Introduction.

Motivation and goals:
Many if not all detectors in LHC experiments need to monitor their environmental parameters, like temperature and humidity. Monitoring of environmental parameters is the most common task for a DCS (Detector Control System). Application requirements in many cases seem to be rather similar, so the use of common solutions for the entire end-to-end path, from sensors up to a SCADA application, is beneficial for all experiments.

In order to minimize the overall system design, setup and maintenance costs, a standard industrial control approaches and commercially available products should be used as wide as possible. However, a typical LHC experiment's DCS application brings its specific challenges:

- extremely high channel counts per system (hundreds and thousands of sensors);
- radiation and magnetic field environments.

This leads to a situation, when readily available industrial approaches fail to be directly applied by the reasons of technical feasibility and/or total system cost. One can see the two alternatives in solving this problem: either to develop a specific home-made solution, which answers the above mentioned challenges, or to customize the most suitable commercial solutions, possibly extending them with some home-made developed parts.

There are several industrial control solutions, which can be considered in this context; also, developments at CERN and in LHC experiments are known, which attack the problem. Thus, the primary goal of the sub-project is to analyze potentially applicable solutions for their technical feasibility and implementation cost. Resulting estimates would then be presented to DCS developers, to help them in making a choice for their specific DCS applications.

The sub-project main tasks are:

- define a list of (temperature monitoring) solutions which seem commonly applicable.
- study those solutions and select several candidates for more detailed evaluation in the laboratory setup; come out with 2 - 3 tested solutions.
- make cost estimates for the entire path "sensor - SCADA application".
- make estimates for system scalability, performance, fault tolerance, configuration and maintenance.
- Implement one of the candidate solutions in a prototype DCS application

The time scale, resources and manpower:
The duration of the sub-project was 6 months: February - July, 2001. Resources of the CERN IT-CO group were using (PVSS SCADA system, computers, front-end data acquisition equipment, fieldbus communication equipment, sensors, cables, etc.). Two people were constantly busy in the sub-project, with the total manpower of 1.6 FTE.

Sub-project workflows:
The work on the sub-project has been organized in two parallel workflows:
- Search for applicable solutions; collecting, sorting and analyzing information.
- Evaluation of selected solutions with a small scale but fully functional implementation (vertical slice).

In the last 1.5 months a third workflow has been created and then maintained:
- CMS/ECAL M0 testbench application for temperature measurements.
Because of limited time and resources, not all applicable solutions were evaluated on the vertical slice. In the next chapters, containing technical consideration and cost estimates, non-tested solutions are considered basing on collected information and using the experience obtained with implemented and evaluated solutions. While the primary focus was on studying the data acquisition equipment layer and its interfacing to PVSS, some basic information about sensors and analog signal cabling has also been collected and used in the cost estimates.

Report structuring:
In the next chapters the following topics are considered:
• the list of solutions to be studied;
• vertical slice -- layout and work items;
• solutions study -- technical matters;
• solutions study -- cost estimates;
• summary comments.

A prototype DCS application (temperature measurements with ELMB on CMS/ECAL M0 testbench) is not considered here; it is described in a separate report.

The list of solutions under consideration.

1. "Beckhoff Pt100".
   Based on a commercial product: Beckhoff fieldbus station. The station is equipped with data acquisition (DAQ) modules, which directly support Pt100/Pt1000 sensors. Several stations can be connected to a PC with a Profibus, CANopen or Ethernet fieldbus connection. PVSS interfacing is provided with a standard OPC connection, using a commercial OPC server product.

2. "Beckhoff 20mA + transducer-MUX".
   This is an enhancement of the solution above, using a home-made developed transducer-multiplexer module for sensor signal conditioning. Supported sensors are NTC thermistors (10K/100K). Fieldbus and OPC connections are the same.

3. "ELMB".
   Based on ELMB module, developed in ATLAS experiment. ELMB directly supports Pt100/Pt1000 sensors and NTC thermistors; it also provides CANopen fieldbus connection to a PC. PVSS interfacing is via a standard OPC connection, using a home-made OPC server.

4. "PC instrumentation card".
   Based on a commercial product, so-called "PC instrumentation card", which is extended with home-made developed external multiplexer modules. Supported sensors are NTC thermistors (10K/100K). No fieldbus is needed, as the card is installed directly in a PC. PVSS interfacing can be done with an OPC connection, using a SLIC OPC server; a SLIC based application for the card should be developed.

5. "PC instrumentation card + transducer-MUX".
   This is an enhancement of the solution 4 above; it uses transducer-multiplexer modules (see solution 2) for signal conditioning. Supported sensors are NTC thermistors (10K/100K). PVSS interfacing is the same as in solution 4.

6. "Keithley 2700/2750 data acquisition system".
   Based on a commercial product, Keithley 2700/2750 data acquisition system, which directly supports both Pt100/Pt1000 sensors and NTC thermistors. Connection to a PC is via IEEE-488 (GPIB) bus or RS-232. PVSS interfacing can be done with an OPC connection, using a SLIC OPC server; a SLIC based application for the Keithley 2700/2750 instrument should be developed.

7. "TempScan/1100".
   Based on a commercial product, high speed multichannel instrument TempScan/1100, which directly supports RTD (Pt100/Pt1000) sensors. Connection to a PC is via IEEE-488 (GPIB) bus or RS-232. PVSS interfacing is provided with a standard OPC connection, using a commercial OPC server product.
8. "GESPACK Pt100".
Based on a commercial product, GESPAC GESSCD-1137 microcontroller board (G64 form factor). The board supports 32 analog inputs and a WorldFIP fieldbus connection; extension board exists to support Pt100 sensors.

From the list above, solutions 1 - 7 are considered in details in the following chapters; solutions 1 - 3 were evaluated on the vertical slice.
Solution 8 has not yet been studied in details; it is actually a CERN development [RB_1], intended for use in the LHC control system, which is now to be manufactured and supported by GESPAC. It looks somewhat similar to ELMB solution, in that the board is foreseen to work in radiation areas. For the moment, no OPC servers supporting the board (via WorldFIP) are known. Also, the board pricing is not yet available. Solution has to be reviewed after some time, to find about its possible improvements (OPC connection) and pricing.
The vertical slice: layout and work items.

The vertical slice was initially configured for a "Beckhoff Pt100" solution. Further on, the configuration has been extended with two more solutions: "Beckhoff 20mA + Transducer-MUX" and "ELMB". The final layout is shown below:

The vertical slice work items include:

"Beckhoff Pt100":
Installing all equipments and software. Configuring firmware and software:

- Beckhoff fieldbus station: KL3202 Pt100 modules and BK3000 bus coupler.
- Applicom Profibus card/driver and OPC server.
- PVSS OPC client and PVSS database manager (datapoints mapping to OPC items).
- DCOM remote communication (used by OPC).

Connecting sensors (3x Pt100, 2x Pt1000). Creating a simple PVSS application to monitor temperatures.

"Beckhoff 20mA + Transducer-MUX":
Installing additional modules to the fieldbus station (KL3022 4..20mA analog input and KL2124 4-bit digital output module). Configuring the KL3022 module and extending the OPC server configuration with new OPC items. Connecting T-MUX prototype module and sensors (4x NTC thermistors).
Creating a new instrumentation application under PVSS (DataLogger) to record data and visualize them with gnuplot utility (see example outputs below). Testing and calibrating the T-MUX module, using temperatures from KL3202 Pt100 modules as a reference.

"ELMB":
Installing and configuring ELMB, CANopen OPC server (ATLAS) and NI-CAN fieldbus card/driver. Extending PVSS database with ELMB datapoints, extending DataLogger application to work with ELMB. Connecting sensors (2x Pt100, 2x NTC thermistors 10K). Studying ELMB’s modes of operation, calibrating NTC channels, developing an adapter for NTC thermistors 100K.

Series of measurements were started to test stability of DAQ modules and study signal degradation in long cable sections (~100m), using different types of cables and connectors. However, this work was not completed. Some of these measurements will be performed on the CMS/ECAL M0 testbench with a prototype DCS application.
Temperature monitoring solutions – technical features.

A single DCS application layout is used when considering all solutions in this chapter (see on the figure below): sensors are placed inside a sub-detector; individual (relatively short) cables connect sensors to patch panels, located possibly outside the sub-detector but inside the overall detector. These patch panels are connected with multiconductor cables to the next patch panels, outside the overall detector. At this point, sensor signals are either processed with radiation tolerant electronics, or further transmitted with trunk cables (over a distance of about 100 m) to the electronics room. There, all non-radiation hard electronics and computers are located. Such layout seems to be more or less typical for the most of foreseen applications (some concrete applications may have a slightly different one, though); its primary purpose is to provide a single base for a comparison of different solutions. Each solution falls into one of the two categories (shown below as variants of the layout): data acquisition equipments are located either in the electronics room or near the detector.

Note on sensors:
Two types of sensors are selected for consideration: RTD Pt100/Pt1000 and NTC thermistors (10K/100K from Betherm or from Fenwal Electronics). Both are known as radiation tolerant devices and have been tested for LHC experiments requirements.

Note on PCs:
For now, a PC seems to be an ultimate choice for a DCS data acquisition computer node. It is assumed here, that such a PC runs WindowsNT/2K or Linux. Windows NT/2K is required by all commercial OPC products. Linux may be used in more specific cases when connecting a non-standard equipment and/or there are no such products readily available.
Solution 1 -- “Beckhoff Pt100”.
Solution is based on a standard industrial controls scheme, from sensors up to an OPC server, using only commercial products. It has been implemented (in a small scale configuration) and evaluated in the vertical slice sub-project.

General layout:

![Diagram of general layout](image)

Sensors are connected with analog signal cables to data acquisition (DAQ) modules, which are stacked in a “fieldbus station”. DAQ modules provide sensor excitation and convert raw analog signal to digital data. Station controller (“bus coupler”) reads data from DAQ modules and sends them via fieldbus to a PC, which is equipped with a fieldbus card and a software driver. The PC (WinNT/2K) also runs an OPC server, which takes data from the fieldbus and makes them available to PVSS, via a standard OPC connection. PVSS OPC client may run either locally or on a separate PC.

Radiation and magnetic field tolerance:
Fieldbus station is not a radiation and magnetic field tolerant equipment; it can not be located in a detector area and thus should be installed in an electronics room. Only sensors and (partially) analog signal cables are in the detector area.

**DAQ module:** Beckhoff KL3202 [BK_1].

Equivalent modules from other manufacturers are available.

Module features are:
- low resistance (Pt100/Pt1000) sensors support; 3-wire or 2-wire sensor connection.
- 2 sensor channels per module.
- resistance to temperature conversion with internal microcontroller; 12-bit output value with a selectable resolution of 1/10 °C or 1/16 °C.
  - measuring error is ±1°C at the full Pt100 range [-200°C .. +850°C].
- measured resistance range is 10 Ohm – 1.2 KOhm (or 10 Ohm – 5.0 Kohm)
  - with a resolution of 1/16 Ohm (internal resolution is 1/255 Ohm).
- typical measurement/transformation time is 250 ms
- diagnostics and configuration via bus coupler.

**Supported sensors:** Pt100/Pt1000.

Thermistors can not be used with KL3202 (or equivalent) module; see solution 2, which has a similar layout but uses a different DAQ module to support thermistors.
**Analog signal cabling:**

Each sensor has an individual raw analog signal path of a considerable length (about 100 m or more). In a typical application, this path will include several cable sections of different type and joint/transition points with patch panels and connectors:

- individual cables from sensors (3 - 5 m) are collected inside the detector with several patch panels;
- multiconductor cables (10 – 20 m) connect those points with the next level patch panels outside the detector;
- from there, long multiconductor cable sections (~ 100 m) are laid to the electronics room;
- in the electronics room, patch panels, located near fieldbus stations, provide a transition again to individual cables which are connected to DAQ modules’ inputs.

Because of long and sectional analog signal path, which has no any transducers, a special care should be taken to avoid compromising measurements with potentially considerable errors. High quality (and shielded) analog signal cables and connectors may be required.

**Fieldbus connection:**

A fieldbus connection can be any of industry standard Profibus, CANopen and Ethernet. Profibus has been taken for the vertical slice implementation; this has defined a choice for a station’s controller and PC resident fieldbus hardware and software. An equivalent configuration can be built using other fieldbus, and with equivalent products from other manufacturers.

A fieldbus cabling is relatively short as it is layed inside the electronics room; its length can be just of several meters in a configuration with a single or a few fieldbus stations (small to medium scale systems).

A fieldbus end-node is a DIN-rail mountable Beckhoff fieldbus station [BK_1]. It includes a programmable station controller (bus coupler), digital/analog I/O modules and a termination module. All modules are stacked together and electrically connected with an internal bus, through which the bus coupler controls and powers slave I/O modules. Bus coupler provides reading/writing data from/to modules and exchanging data via fieldbus; also, configuration, monitoring and diagnostics of all station’s modules. Bus couplers are available for Profibus (Beckhoff BK3000), CANopen (Beckhoff BK5120), Ethernet (Beckhoff BK9000) and other fieldbus connections; all I/O modules are fieldbus independent.

At the PC side, which is a fieldbus master, a bundled package from Applicom [AP_1] has been used; it includes a Profibus card/driver and an OPC server. Also included are a simple OPC client, configuration and diagnostics utilities. Windows NT is required to run the software (all other equivalent products also require WinNT/2K).

**Power supply aspects:**

A fieldbus station is powered via its bus coupler from an external 24V power supply; bus coupler provides power distribution up to 1.75 A to I/O modules via station’s internal “K-bus”. KL3202 modules are powered from that bus and do not require any additional (specific) voltages; typical module’s consumption is 60mA. In large configurations (> 15 I/O modules in a single station), a dedicated K-bus power feed module can provide additional 2A from a second (external) 24V power supply. DIN-rail mountable commercial 24V power supply products are readily available.

PC fieldbus card is powered directly from PC. No other (specific) power supplies are needed.

**PVSS interfacing:** OPC connection, using an Applicom OPC server.

Applicom OPC server provides regular polling of pre-configured fieldbus stations with a programmable time interval. Acquired data are maintained as separate OPC items, one per channel. No internal data conversion is performed, OPC item values are exactly ones taken from DAQ modules. OPC item groups with standard features are supported. PVSS OPC client has been successfully tested with that OPC server; client may run on the same or a remote computer. Several OPC servers can be connected to a single PVSS client, either locally or remotely. Applicom OPC server has been tested to run in parallel (on the same computer) with other OPC server/fieldbus products.

OPC server is typically configured to run in asynchronous client update mode: data are sent to client on value change (only changed values are sent). Thus, datapoints in a PVSS database are effectively updated with the fieldbus polling interval, providing that their values are changed.
Data arriving to PVSS are formatted as 16-bit integers. Normally, DAQ modules are pre-configured for resistance to
temperature conversion, so data values are in 1/10 °C or 1/16 °C increments.
ICOP framework provides an “analog input device” datapoint, which can be used to store data from a single channel; a
simple conversion (with a datapoint function) is needed to present data in a floating point format (x.x °C).

OPC server provides also status/diagnostics information about the card and fieldbus stations (needs to be configured).
DAQ module status information can be sent with each data value as additional status byte (needs to be configured); use
of this feature will slightly complicate the data processing in PVSS. Data are then formatted as 3-byte words, and a
(simple) PVSS script is needed to decode measured value and the module status byte.

**Configuration procedures:**

System I/O configuration procedures include several separate steps, in the following sequence:

- Fieldbus station - with a proprietary software (Beckhoff):
  - DAQ module configuration (sensor type, conversion parameters, filtering mode, data format);
  - Bus coupler configuration (bus address, I/O module types, data transmission mode and frame format).
- PC fieldbus hardware/software - with a proprietary software (Applicom):
  - PC fieldbus card/driver configuration (data transmission mode, I/O ports, bus monitoring);
  - OPC server configuration (fieldbus I/O items to OPC items mapping, refresh rates, etc.).
- PVSS OPC client (and database) configuration - with a proprietary software (ETM).

At the fieldbus station level, configuration settings are stored in a non-volatile memory of the bus coupler and DAQ
modules, so those settings are preserved during power shutdowns. PC resident software also saves and automatically
restores its settings on restart.

Because of the ultimate use of proprietary software from different vendors, there is no direct possibility to integrate
(and automate) configuration procedures using a single tool and a central database. Certain manual efforts are also
needed to maintain consistency of the entire system configuration when adding channels or replacing hardware mod-
ules.

**Fault tolerance, troubleshooting and maintenance:**

In the detector area, only sensors and the first sections of analog signal cables are located. Problems, related to those
parts (broken sensor, short-circuit or wire breakage), may result in a long term or a permanent loss of measuring chan-
nels, as replacement may not be feasible. This equally concerns to all solutions and thus will not be further repeated.
One might consider duplicating sensors to minimize possible waste.

Problems at the DAQ module and fieldbus station level can be solved relatively easy, as this equipment is located in the
electronics room and is accessible at any time. Station’s stackable design enables fast replacement of a broken module
(I/O module as well as a bus coupler); however, this requires temporary powering-off the entire station. Providing that
a new module is pre-configured with proper settings in its non-volatile memory, such operation may take just a few
minutes, including re-connection of cables.

DAQ module and fieldbus station have the following features, which make easier their troubleshooting and mainte-
nance:

- A single broken DAQ module "costs" only 2 lost sensor channels.
- Spring type input connectors provide easy, fast and reliable connection.
- DAQ module inputs are protected from short-circuit and wire breakage.
- All I/O modules are galvanically decoupled from the station's internal bus; fieldbus transceiver is galvanically
decoupled from the rest of bus coupler's circuitry.
- Bus coupler and I/O modules are constantly watching their own and one another's health. All detected problems
  are communicated to a fieldbus master (PC) and locally visualized with indicator LEDs. OPC server and PVSS
  should be accordingly configured to acquire status/diagnostics information.
- Powering off a single station results in a minimal or no disturbance of other fieldbus nodes operation.
- Station is intended for industrial controls (protection class IP20; environmental parameters are 0 - 55°C and max
  95% RH). Normally, it does not require forced cooling (no fans are used or needed).
Problems with a fieldbus cabling and PC resident fieldbus card/software can be diagnosed with provided (proprietary) software utilities. Replacing a broken cable section may take several minutes; this does not require powering off of any fieldbus nodes. Replacing a PC card requires more time, as one needs to orderly shutdown and then restart all running software. The card/driver should be re-configured before restarting of the rest of the software (OPC server, PVSS OPC client).

Using UPS (Uninterruptable Power Supply) may help to protect PC's and fieldbus stations' power supplies from possible (transient) power mains problems.

Normally, all the equipment does not require any specific regular maintenance; the most probable reason for intervention into system's operation is PC software (hardware) upgrade or reconfiguration. DAQ modules can be periodically tested and calibrated during long detector shutdowns, or otherwise, in normal operation, temporarily reconnecting their inputs (channel by channel) to a calibrating equipment.

**Measurement performance:**

A measuring device, KL3202 module, provides a reasonably good resolution (1/16 °C) and a high precision (total measuring error is ±1°C for a full range of more than 1000°C). It supports several analog filtering modes and has galvanic isolation from the rest of a fieldbus station. However, in this application, precision measurements (e.g. with accuracy ~0.1°C in a range of about 10°C) may have significant difficulties because of long and sectional analog signal paths. The two main error sources have to be considered: lead resistance mismatch and noise induced in long cable paths.

Module supports a 3-wire sensor connection scheme to compensate lead resistance; such compensation technique is quite sensitive to the quality of wiring. In a typical fieldbus based industrial application, analog signal path is relatively short and normally has a single cable section (no intermediate joints/connectors). High quality (and rather expensive) analog signal cables are used. In a LHC experiment application, DAQ modules are located far from the point of measurements and there are several cable sections in the analog signal path. Also, the large volume of cabling dictates the use of relatively inexpensive cables (standard twisted pair telephone/data cables). All this may compromise lead resistance compensation of 3-wire connection scheme because of lead resistance mismatch (variations in wire lengths and properties, variations in joint resistances). A 4-wire connection scheme seems more appropriate for such application, however, it is not popular in a fieldbus based measuring equipment.

Several analog filters are selectable in KL3202 module to decrease noise effects. Using of shielded cables/connectors and proper grounding may also help. In addition to (or instead of) analog filtering, one can use digital filtering and averaging techniques, implemented in software. This can be done at the PVSS level, but at the cost of increased raw data traffic and computing load. The better approach is considered in the next section (solution 2); it is based on an intermediate "soft-PLC" component between the OPC server and PVSS.

The speed of measurement (in terms of PVSS database updates with temperature values) is primarily defined by the measurement and conversion time in KL3202 module; this time can be from 65 to 500 ms, depending on the selected filtering mode. The time expenses for data transfer from a fieldbus station to a PC are small comparing to the figures above; these can be roughly estimated as follows:

- reading data (inside the station) from a single KL3202 module requires ~0.2 ms.
- a maximum size station contains about 50 modules = 100 channels; this corresponds to 200 bytes of data. These 200 bytes can be sent in a single Profibus frame (max frame size is 244 bytes); this requires ~2.5 ms on 1.5 Mbit Profibus.
- Thus, 100 channels can be read and the data sent in 0.2 x 50 + 2.5 = 12.5 ms. This does not include run-time expenses in software driver and OPC server; so, one should add several more milliseconds. Then, rough estimate would be about 20 ms.

For the fastest KL3202 module operation mode (65 ms), OPC server may have the fieldbus scanning interval of about 100 ms; for the slowest mode (500 ms) the interval should be slightly more than 500 ms, e.g. 520 ms. Typically, the OPC server is configured to send data to PVSS on a value change (subscription mechanism); only changed values are sent (packed in blocks for transmission efficiency). As the data transfer time (even for all 100 values) from OPC server to PVSS database is much less than 100 ms, the fieldbus scanning period need not be further extended and the PVSS database refresh frequency can be about 10 Hz in the fastest KL3202 module operation mode.
Increasing number of channels by a factor of 2-5 (adding more fieldbus stations) may only slightly impact that figure, due to a relatively high bandwidth of the entire data path (DAQ module à fieldbus à OPC à network à PVSS) and the fact that data arriving to PVSS are already temperatures (the most of other solutions require complex data conversion). Thus, the speed of measurement of a medium scale system (< 1000 channels) can easily be about or even better than one temperature point per second, for each channel.

**System scalability:**

A Beckhoff fieldbus station based system is easily scalable in small channel increments:
- a single DAQ module provides 2 sensor channels;
- a single station may have about 50 modules installed (100 channels);
- a single fieldbus line may have up to 100 stations (with repeaters for more than 32 stations).

With 30 stations per bus and just a single bus per PC, one may have as much as 30 x 100 = 3000 channels per PC. Considering larger configurations does not seem practical, as the cost of 30 fully equipped stations is about 400 KCHF (see the chapter on cost estimates).

**Solution 2 -- "Beckhoff 20mA + transducer-MUX".**

Solution is similar to a previous one, as it is also based on a Beckhoff fieldbus station and DAQ modules. It implements a standard industrial approach, using a transducer to provide sensor signal conditioning. However, transducer is specially designed (in-house) to work in a presence of radiation and magnetic field. Solution has been implemented with a prototype transducer and evaluated in the vertical slice sub-project.

**General layout:**

Sensors are connected to a transducer/multiplexer (T-MUX) module, which provides sensor excitation and conversion of a raw signal to an industry standard 4..20mA signal, suitable for transmission over long distances. This (conditioned) signal is transmitted to DAQ modules, stacked in a "fieldbus station", which provide analog-to-digital conversion. The further data path layout is essentially the same as in solution 1.
T-MUX module also provides multiplexing of several input channels, in order to minimize the number of required DAQ modules and the volume of analog cabling. To control T-MUX multiplexers, an additional control path is required; it includes a control distribution (CD) module, a digital output module in the fieldbus station and a piece of software. This software also provides data demultiplexing before the delivery to a final destination in a PVSS database.

**Radiation and magnetic field tolerance:**

T-MUX and CD modules are designed to work in a presence of radiation and magnetic field. Impact of SEU (single event upset) effects is minimal, as no microcontrollers and memories are used.

**DAQ module:** Beckhoff KL3022 / KL3112.

Module features are:
- 4..20 / 0..20 mA differential analog signal input; 2 channels per module.
- 12-bit / 16-bit resolution; measuring error (total measuring range) is ±0.3% of the full scale value.
- conversion time ~2 ms / 140 ms with 50 Hz filter.
- diagnostics and configuration via bus coupler.

**Transducer/multiplexer (T-MUX):**

T-MUX module is designed for use with NTC thermistors (100K or 10K). Functionally, it is a conventional signal transducer, such devices are widely used in industrial applications, where a weak sensor signal needs to be conditioned for transmitting over a long distance. Its main difference is that it is designed for radiation environments; the second feature is multiplexing several input signals to a single (analog) output. The output signal is an industry standard 4.20 mA current signal; there exists a number of different types of data acquisition equipments which support this signal standard.

T-MUX is based on an instrumentation amplifier and also contains 4..20 mA converter/transmitter, precision voltage source for sensor excitation and input multiplexer for 64 channels. Optional linearizing of raw thermistor signal, to minimize errors in the application temperature range, can be provided with a calibrated resistor network. An onboard voltage regulator powers the circuitry from an external (remote) power supply. All components are selected from radiation hardened products rated to 20 - 300 Krad. In the prototype implementation, a single 8-channel module, made from non-radiation hard components, has been tested (developed by A.Koulemzine, IHEP).

A simple digital output module, installed in the fieldbus station, has been used to control the multiplexer. This module, in turn, is controlled by a PVSS script, in order to provide synchronized read-out of data from a DAQ module and data demultiplexing/conversion. (Using PVSS for data demultiplexing and conversion should, however, be avoided in real applications because of considerable additional load on PVSS).

For the final implementation, other control solution can be proposed (see on the figure above): a single control module is installed in a fieldbus station (e.g. KL6021 RS-422/485 communication module); under software control, this module sends a "command" to a remote CD module. The latter distributes the command to a number of T-MUX modules. A single command is used to put all multiplexers into the same state; thus, all T-MUX modules synchronously select equally numbered channels for measurement. As a result, the entire channel space is scanned in a fixed number of steps (here, 64).

Update (7.Dec.01):
During a RADWG Day workshop [RADWG_1], a radiation tolerant ASIC named RBFE (Resistance Bridge Front End) has been presented. The RBFE is designed to work with semiconductor behavior temperature sensors. It contains current sources, voltage reference, analog switches and a differential amplifier - that is, the most of components needed for T-MUX module. It cost estimate is 25 - 30 CHF per unit; this makes it a very promising alternative to above mentioned commercial rad-hard components. The possibility to use RBFE in the T-MUX design shall be studied soon.

**Supported sensors:** NTC thermistors (100K/10K).
**Analog signal cabling:**

There are two analog signal paths: "sensor - transducer" and "transducer -- DAQ module". This differs from solution 1 in two important aspects:
- sensor signal path is relatively short; only conditioned signal (4..20 mA), immune to interference, is transmitted over a long distance. Conventional (relatively inexpensive) twisted pair cables can be used.
- conditioned signal path is multiplexed; thus, the total volume of cabling is considerably reduced.

**Fieldbus connection:**

Fieldbus stations and cabling are the same as in solution 1, except that different DAQ modules are used and an additional (digital output or communication) module is needed to provide T-MUX multiplexers control.

PC hosted components (a fieldbus card/driver and an OPC server) may also be taken the same; but a slightly different solution seems more preferable - see "PVSS interfacing" below.

**Power supply aspects:**

In addition to a fieldbus station (see solution 1), T-MUX and CD modules need to be separately powered. A 10-15V unregulated (remote) power supply can be used.

**PVSS interfacing:**

OPC connection, using an Applicom OPC server or a Beckhoff TwinCAT.

Scenario 1: Exactly the same software as in solution 1 is used (Applicom OPC server, PVSS OPC client). PVSS script provides control of T-MUX multiplexers and data demultiplexing. This scheme was tested in the vertical slice prototype implementation. It is proven as the one which inefficiently uses PVSS resources and so should be avoided.

Scenario 2: Control of multiplexers and data demultiplexing is provided with an intermediate software component, so-called "soft-PLC" (a programmable software "device" emulating a PLC), which is logically positioned between a fieldbus driver and an OPC server. Such functionality is offered by e.g. Beckhoff TwinCAT product, which includes an OPC server, soft-PLC component and fieldbus drivers [BK_2]. One more function of the soft-PLC layer is data conversion: raw data contain values of current, measured by the DAQ module; this current is converted to resistance and then to temperature. Thus, PVSS gets data as temperatures, like in solution 1. Soft-PLC can also be used for digital filtering and averaging.

Update (7.Dec.01):
Scenario 3: Applicom Profibus card has an onboard CPU, which can run so-called "satellite tasks" in parallel with fieldbus I/O operations. This functionality might be used for multiplexers control and for data demultiplexing. Resistance to temperature conversion generally requires considerable computing resources, so it would hardly be effectively done with the onboard CPU - however, one can use lookup tables to avoid complex calculations. This approach is proprietary, and it is less powerful (in terms of computing resources) than the one using a Soft-PLC above, but it can be found less expensive as it does not require additional products (i.e. soft-PLC).

**Configuration procedures:** see solution 1 (soft-PLC will just add one more step).

**Fault tolerance, troubleshooting and maintenance:**

Two types of equipment are located in the detector area (T-MUX and CD modules). Replacement of those modules is possible only during non-beam periods.

Transient faults (e.g. SEU produced) may lead to an incorrect selection of channels for a single read-out operation (a single scan step). The "cost" of such fault depends on the type of affected module:
- T-MUX module -- a single reading is invalid.
- CD module -- all attached T-MUX modules will get invalid selection command; all data from a single scan step is invalid.
"Invalid data" means that instead of expected channel_X another cnannel, channel_Z, will actually be selected for measure-ment; the measured value of Z will then be placed in the datapoint for X. If this value belongs to the "normal" range of X, the effect is invisible; otherwise the value can be interpreted as noise (and possibly filtered out). Thus, the total effect is equivalent to some noise increase; however, as such events are very infrequent they can not really impact the noise level.

See solution 1 for a discussion concerning a fieldbus station and PC resident components.

**Measurement performance:**

Although not fully tested on the vertical slice, precision of measurements should be considerably better than of solution 1, providing that measurement path is properly pre-calibrated. NTC thermistors provide much bigger response (3-6% resistance change per 1°C temperature change) than Pt100 sensors; such signal is much easier to separate from noise. Also, due to their high resistance, no lead resistance compensation scheme is required (so, a 2-wire sensor connection is used). Thermistor nonlinearity is processed in software, using Steinhart-Hart equation which accurately models \( T = f(R) \). But additionally, raw signal can be linearized with a calibrated resistor network. Noise effects are much less due to a relatively short raw signal path and the use of a transducer for signal conditioning.

The speed of measurement is mostly defined by the choosen PVSS interfacing scheme (whether a soft-PLC is used or not). Without the soft-PLC, a PVSS script has to do its work: set up multiplexers, make a delay to guarantee correct data delivery to "front-end" (multiplexed) datapoints, then calculate temperatures from raw ADC counts and store them in final destination datapoints (with demultiplexing). Such a loop may have a considerable period, which is roughly proportional to the number of channels (because of relatively complex calculations). The use of soft-PLC will eliminate this extra load from PVSS; figures like ones in the solution 1 or even better can be expected.

**System scalability:**

A system is scalable in 64-channel increments:

- T-MUX module 64 channels;
- DAQ module 2 x 64 = 128 channels;
- a single (fully equipped) fieldbus station 50 x 128 = 6400 channels.

Since a single Profibus line may connect about 30 stations (100 with repeaters), the number of channels per a single PC will actually be defined by its computing performance and system fault tolerance factors.

**Solution 3 -- "ELMB".**

Solution is based on a general purpose ELMB module, developed in ATLAS experiment [ELMB_1]. It has been imple-mented (in a small scale configuration) and evaluated in the vertical slice sub-project.

**General layout:**

![Diagram](image-url)
Sensors are connected to ELMB module, which provides sensor excitation and analog-to-digital conversion for 64 analog input channels; both Pt100 sensors and NTC thermistors are supported. The module also provides direct connection to a CANopen fieldbus; thus, it is functionally equivalent to a fieldbus station (see solutions 1,2). At the PC side, fieldbus connection is provided using a commercial fieldbus card/driver and a home-made OPC server.

**Radiation and magnetic field tolerance:**

ELMB is specially designed to work in a presence of radiation and magnetic field; it has been successfully tested with radiation doses, corresponding to the expected ones during its lifetime. However, the module contains microcontrollers and memories, which are generally susceptible to SEU (single event upset) effects; special measures are needed to provide recovery from SEU produced transient faults. The latest results of ELMB testing in radiation environments can be found at the ATLAS DCS site [ELMB_2].

**DAQ module:** ELMB.

ELMB is a small card, to be embedded in an application specific equipment. What is called here “ELMB module”, actually is a standalone carrier board with a single plugged-on ELMB card, placed in a DIN-rail mountable plastic cover box. The carrier board (or "motherboard") powers ELMB card and hosts all external world connectors: analog input, digital I/O, CANbus and power.

ELMB is a general purpose card designed for monitoring and control in ATLAS experiment environment. Here, only features relevant to temperature monitoring application are considered. Detailed information is available at the ELMB site [ELMB_1].

ELMB features are:

- 64 analog channels per module.
- each analog channel has a differential signal input, which can be customized for different types of measurements (with so-called "signal adapters"). Both Pt100 sensors and NTC-10K thermistors are readily supported; NTC-100K thermistors need an adapter to be developed.
- programmable ADC provides several measuring ranges, from 25mV to 5V;
- conversion rate can be selected in a range 1.8 to 60 Hz;
- output: 16-bit integer (signed or unsigned) with a full scale resolution.
- internal microcontroller provides programmable measurement sequence and fieldbus communication. An auxiliary (second) controller constantly watches the system operation; it initiates a restart or requests for a complete firmware download via fieldbus, when an operation fault is detected.
- diagnostics and configuration via fieldbus.

**Supported sensors:** Pt100/Pt1000, NTC thermistors (10K/100K).

**Analog signal cabling:**

Analog signal path is relatively short (< 30 m). Individual sensor cables are collected with a patch panel, which provides transition to a 16-pairs twisted pair cable (ELMB carrier board has 4 analog input connectors, each providing 16x 2-wire channels). That cable connects to a second patch panel, where transition is made to a short 34-wire flat cable (2x16 are used), connected to ELMB module.

**Fieldbus connection:** CANopen

The use of CAN fieldbus is defined by ELMB design. ELMB uses CANopen communication protocols; however, commercially available software products (OPC servers) do not support the device profile implemented in ELMB for sending analog data. A custom OPC server has been developed in ATLAS (V.Filimonov, PNPI), which has been successfully tested to work with PVSS OPC client. For a low level fieldbus communication, the server requires a NI-CAN PC card and a driver from National Instruments [NI_1].

ELMB is typically configured to work in a synchronized loop mode: having received a SYNC message from a fieldbus master (OPC server), it enters the measurement cycle, sequentially reading input channels and sending measured data.
(one CAN frame per channel). Scanning frequency is configurable (typically 2-30 Hz). Having completed the scan, ELMB waits for the next SYNC message.

When several ELMB modules are on the same bus, all these will be synchronized with a single SYNC message and will start their measurement loop cycles, concurrently using the bus. The next SYNC should not be sent until all ELMB nodes have completed their cycles. Thus, SYNC period is defined by the ELMB scanning rate, fieldbus transmission rate (typically 125 Kbaud), and the number of ELMB nodes on the bus.

**Power supply aspects:**

ELMB module requires 3 voltages (2 x 9V, 6V) to separately power analog circuitry, microcontrollers and CAN transceiver (the latter can be powered via fieldbus cable). Thus, an external (remote) power supply is needed; a single unit may support several ELMB modules, due to a very small ELMB power consumption.

Update (7 Dec. 01): See the latest note "ELMB Full Branch Test: Behaviour and Performance" [ELMB_4].

**PVSS interfacing:**

OPC connection, using an ATLAS OPC server.

Neither ELMB nor the OPC server do not provide any internal data conversion; thus, data arriving to PVSS are raw ADC counts and should be converted to temperatures. A PVSS ELMB library has been developed in ATLAS (F. Varela,) which provides that conversion, as well as PVSS datapoints definition. The library also supports ELMB configuration, diagnostic and management functions; it is compatible with the JCOP PVSS framework.

**Configuration procedures:**

ELMB module can be pre-configured (number of channels, measuring range and rate, etc.) from PVSS, using the above mentioned ELMB library tools. Settings are stored in modules' non-volatile memory and preserved between power shutdowns.

OPC server is dynamically configured (on its start) with a plain text file; this file can also be produced in PVSS. In the next library version this file will be used to automatically generate ELMB relevant datapoints in a PVSS database.

Therefore, practically all configuration procedures can be integrated in PVSS; the only exception is a PC fieldbus card/driver (from National Instruments), which requires a simple but proprietary configuration utility. Fortunately, the card/driver settings are preserved between PC restarts, so this configuration utility is typically used very infrequently.

**Fault tolerance, troubleshooting and maintenance:**

The crucial element is ELMB module, located in the detector area. Replacing is possible only during non-beam periods.

SEU effects may lead to different hardware/software faults, which result in corrupted data values, invalid CAN frames, improper scanning sequence, etc. In some situations, no actions are needed (a single transient fault), while others require a reset or a complete reload of the ELMB software, or the entire CAN branch reset. A watchdog function, implemented with a separate microcontroller resident on the ELMB card, may help to detect some failures and recover from them by a restart or even software reload. However, a dedicated agent is needed at the PVSS level (or below it) to monitor ELMBs and deal with ELMB failures.

Update (7 Dec. 01): Detailed information about testing ELMB for SEU/SEL effects can be found in [ELMB_3].

**Measurement performance:**

ELMB's ADC enables high precision measurements. However, raw signal is transmitted directly to ADC input; no entry analog filtering is provided. In noisy environments shielded cables and digital filtering techniques (implemented in software) may be helpful.

The speed of measurement is primarily defined by the two factors: ELMB channel scanning rate (typically 2-30 Hz), and software expenses for data conversion (ADC counts to temperatures), which currently is done with PVSS datapoint
functions. CANbus bandwith should also be considered if the bus rate is less than the default one of 125 Kbaud; also, if the number of ELMB nodes is greater than 15.

With the default 3.76 Hz setting for the scanning rate, complete 64-channel cycle requires about 17 seconds. The corresponding SYNC interval (see "Fieldbus connection" above) can be selected equal to 20 seconds. This gives 3 readings per minute per channel; conversion time for 64 readings per 20 seconds is negligible (even if done by PVSS), so there is no need to extend the SYNC interval. Then, the result is 3 temperature points per minute per channel (for a single ELMB system). Adding several more ELMB nodes will not decrease that figure, until the moment when conversions become "visible". CANbus bandwith may not be considered in this example (at 125 Kbaud, bus is able to transmit more than 500 frames per second, and each ELMB provides a load of less than 4 frames/sec).

With the 30Hz scan rate setting, complete 64-channel cycle requires about 2.1 seconds; the corresponding SYNC interval can be selected equal to 2.5 seconds. About 15 ELMB nodes, each providing a load of 30 frames/sec, may work without bus overload. However, PVSS should now calculate 15x64=960 conversions each 2.5 seconds, which probably is not a realistic figure. So, the SYNC interval should be extended to allow PVSS to do something else in addition to raw data conversions. In general, such massive and complex calculations should be moved from PVSS to the underlying layers:
A soft-PLC (see solution 2) can be considered as a data conversion engine for medium to large scale systems, especially, if they require high measurement speed (e.g. because of the use of digital filtering).
Another possible approach is to implement this functionality in a dedicated OPC server, e.g. extending the one currently developed in ATLAS.

Update (7.Dec.01): See the latest note "ELMB Full Branch Test: Behaviour and Performance" [ELMB_4].

System scalability:

A single ELMB module supports 64 channels (NTC thermistors) or 32 channels (Pt100 sensors).
A single CANbus may have about 30 ELMB nodes.
A fieldbus card/driver (from National Instruments) supports 2 buses; the ATLAS OPC server also does. Thus, a single PC can service as much as:
   2 x 30 x 64 = 3840 channels (NTC thermistors) or
   2 x 30 x 32 = 1920 channels (Pt100 sensors).

Update (7.Dec.01): See the latest note "ELMB Full Branch Test: Behaviour and Performance" [ELMB_4].

Solution 4 -- "PC instrumentation card".

Solution is based on the use of a commercial product, a PC instrumentation card. The use of PC instrumentation cards (for a slightly different DCS application) has been proposed and prototyped by W.Lustermann (ETHZ) [WL_1]. Because of limited time and resources, this solution has not been implemented in the vertical slice sub-project; it is considered here, basing on available information.

General layout:
The layout is similar to the one of the solution 1: there is a long raw analog signal path (> 100 m). However, no fieldbus is used; DAQ module (i.e. instrumentation card) is installed directly in a PC. The instrumentation card is extended with external modules (boards), which provide sensor excitation and input channel multiplexing. No commercial OPC servers, able to support instrumentation cards, are known for the moment. PVSS interfacing can be done with a SLIC software package [SLIC_1], which provides an OPC connection.

**Radiation and magnetic field tolerance:** No electronics in the detector area; see solution 1.

**DAQ module:** PC instrumentation card + extension boards.

A PC instrumentation card is a commercially available general purpose measuring device. It’s a standard size PC card, installable in the PC’s system box, like any other I/O PC card; it provides several analog inputs and an onboard ADC to convert measured signals to digital data. A big and mature market of such products exists. Here, products from National Instruments are taken as a reference example (NI-6023E, NI-6034E) [NI_2], but similar (and often less expensive) products are available from many other manufacturers.

Card features are:
- 8 input channels (differential) or 16 channels (single ended).
- input range: ±0.05 to ±10 V.
- 12-bit / 16-bit resolution (NI-6023E / NI-6034E).
- 200 KHz sampling rate.
- 8 digital I/O lines (5 V/TTL); two 24-bit counter timers.

NI-DAQ software library, supplied with the card, provides access to the card from a user application (e.g. a SLIC based application). The library includes also functions for configuring measurements, calibrating a card and data processing.

The card itself does not provide sensor excitation; this should be done with a home-made extension module. Such module may also feature additional channel multiplexing; the multiplexer can be controlled from the instrumentation card, using digital I/O lines. Here, it is assumed that a single extension module is connected to each of card’s 8 input channels; the module provides 64 multiplexed channels. Thus, the total extended card capacity is 8 x 64 = 512 channels.

**Supported sensors:** NTC 100K/10K.

**Analog signal cabling:**

Analog cabling is much the same as in solution 1, except that the 2-wire sensor connection is used.

**Fieldbus connection:** Not applicable.

**Power supply aspects:**

Instrumentation card is powered from the PC. Extension modules require a (single) separate power supply.

**PVSS interfacing:** OPC connection, using a SLIC OPC server.

In the SLIC framework, a specific application should be developed to support the following functions:
- multiplexer control and synchronized data acquisition and demultiplexing;
- conversion of raw data (ADC counts or voltages) to resistance values and then to temperatures.

This same application may also support digital filtering and averaging of raw data.

PVSS interfacing is provided with an OPC server, which is a part of SLIC.
Configuration procedures:

Instrumentation card is configured by the SLIC application (using NI-DAQ library); the application and the OPC server, in turn, can be auto-configured with a plain text file to be read on the server start. That configuration file can be prepared with a PVSS script. Thus, all configuration procedures can be integrated at the PVSS level.

Fault tolerance, troubleshooting and maintenance:

All data acquisition equipments are located either inside or close to the PC; they are easily accessible for troubleshooting and possible replacement.

Measurement performance:

NI-6034E instrumentation card provides precision measurements; it contains instrumentation amplifier in a signal processing chain and includes a special circuitry for auto-calibration. High sampling rate (200 KHz) enables to apply digital filtering and averaging to raw data.

The use of high resistivity thermistors avoids the problem of lead resistance compensation. Thus, only noise effects should be considered; these can be minimized with digital filtering and averaging.

The speed of measurement is defined by a data sampling rate (200 KHz), size of averaged sample sequence and computing resources, available for calculations. Sample sequence size is typically 100 values, but may be increased, if e.g. median filtering is to be applied before averaging.

Measuring loop (in the SLIC application) may look like:

- set up external multiplexers.
- acquire 100 values for each of 8 card's channel (about 4 ms).
- calculate averages of 100 values for 8 channels.
- calculate resistances from ADC voltages; then temperatures from resistances (for 8 channels).
- repeat the loop above 64 times for complete channel scan cycle.
- make data available to PVSS (actually, to the SLIC OPC server).

Such cycle may take several seconds, depending on the computing power available.

System scalability:

Instrumentation card has an internal multiplexer for 8 channels. Each channel is again multiplexed (by 64) with an extension module. Thus, an extended card can provide as much as 512 channels.

Adding more cards to a PC depends on available computing power and required speed of measurement (see above).

Solution 5 -- "PC instrumentation card + transducer-MUX".

This is an enhancement of the (previous) solution 4, using transducer-multiplexer modules from solution 2. It has not been implemented in the vertical slice sub-project and is considered here, basing on available information.

General layout:
The layout is a mixture of the ones of solutions 2 and 4. Transducers (T-MUX modules, see solution 2) are used to provide raw signal conditioning; conditioned 4..20mA signal is then transmitted over a long distance and converted to voltage with external modules-converters. The voltage is measured with an instrumentation card (see solution 4). Control of T-MUX modules (actually, of their multiplexers) is provided via the card, using its 8 digital I/O lines. OPC connection (SLIC OPC server) is used for PVSS interfacing.

**Radiation and magnetic field tolerance:** see solution 2.

**DAQ module:**

PC instrumentation card + extension boards.

Transducer is taken from the solution 2.

PC instrumentation card is the same as in the solution 4.

Extension module (home-made) is different: it provides 4..20mA signal conversion to voltage to be measured by the instrumentation card. No more multiplexing is needed at this layer: 8 extension modules are connected to 8 card input channels, servicing 8 T-MUX modules.

**Supported sensors:** NTC 100K/10K

**Analog signal cabling:** Analog cabling is much the same as in the solution 2.

**Fieldbus connection:** Not applicable.

**Power supply aspects:**

Instrumentation card is powered from the PC; its extension modules requires a separate power supply. T-MUX modules require their own (remote) power supply.

**PVSS interfacing:** OPC connection, using a SLIC OPC server.

A SLIC application is practically the same as in the solution 4; the only difference is that multiplexers are now in T-MUX modules.

**Configuration procedures:** see solution 4.

**Fault tolerance, troubleshooting and maintenance:** see solutions 2 and 4.

**Measurement performance:**

Quality of measurements should be better than (or at least equal to) that of solution 4. The speed of measurement is the same as for the solution 4.

**System scalability:**

A single extended card can support as much as 8 x 64 = 512 channels.
Solution 6 -- "Keithley 2700/2750 data acquisition system".

This solution has been proposed by W.Lustermann (ETHZ). It has not been implemented in the vertical slice sub-project and is considered here, basing only on available information.

**General layout:**

The layout is quite similar to the one of solutions 1 and 4, it has a long raw signal path (> 100 m). No fieldbus is used; DAQ module functionality is provided with Keithley 2700/2750 data acquisition system, which is connected to a PC with IEEE-488 (GPIB) or RS-232 connection. Since there are no commercial OPC servers, able to support Keithley 2700/2750 device, the easiest way to provide PVSS interfacing is the use of a SLIC framework which includes an OPC server.

**Radiation and magnetic field tolerance:** No electronics in the detector area; see solution 1.

**DAQ module:** Keithley 2700/2750.

Keithley 2700 and 2750 [KT_1] are very high precision multimeters, extendable with different plug-in modules, which convert them to a powerful data acquisition systems. For this application, 7702 plug-in multiplexer modules can be taken, which provide capacity of 40 analog channels per module.

Device features are:
- K2700: 80 input channels (differential) - with 2x 40-channel plug-in modules.
- K2750: 200 input channels (differential) - with 5x 40-channel plug-in modules.
- Measuring of current, voltage, resistance, temperature with 22-bit resolution.
- Direct support of Pt100/Pt1000 sensors and NTC thermistors (2.5K - 10K);
- 0.01°C temperature resolution.
- ~300 Hz data sampling rate.
- PC connection via IEEE-488 (GPIB) or RS232.

Channel scan interval is programmable; the scan also can be triggered by a GPIB command, external signal or a condition on a particular channel (analog trigger). The instrument can be programmed to provide alarms when any pre-set limits (individual per channel) are breached.

**Supported sensors:** Pt100/Pt1000, NTC thermistors 2.5 - 10K.

**Analog signal cabling:** Analog cabling is much the same as in solution 1.

**Fieldbus connection:** Not applicable.

**Power supply aspects:** Keithley 2700/2750 is powered from AC mains (220V).

**PVSS interfacing:** OPC connection, using a SLIC OPC server.
A specific SLIC based application should be developed to support a connection to Keithley 2700/2750.

**Configuration procedures:**

Keithley 2700/2750 is configured by the SLIC application; the application and the SLIC OPC server, in turn, can be configured from files produced in PVSS. Thus, all configuration procedures can be integrated at the PVSS level.

**Fault tolerance, troubleshooting and maintenance:**

All data acquisition equipments are located close to the PC; they are easily accessible for troubleshooting and possible replacement.

A pluggable multiplexer module (Keithley 7702) contains electro-mechanical relays to switch input analog signals; those components provide electrical channel isolation, but have a limited guaranteed life time (see below). K2700/K2750 supports internal logging of relay switch cycles; this information should be used for device maintenance.

7702 multiplexer module contact life (typical):
- $10^5$ operations at max signal level (300 volt, 500mA; 10VA).
- $10^8$ operations cold switching.

**Measurement performance:**

Keithley 2700/2750 provides much higher quality of measurements comparing to any other of considered solutions. It provides sample averaging or advanced digital filtering, power line cycle integration, internal autozeroing and other features to reduce noise and increase the effective resolution.

The device is well suited for applications, which require high precision measurements and have a moderate channel count.

The speed of measurement is primarily defined by a data sampling rate (~300 Hz). Since acquired data are already converted to temperatures, no additional data conversion is needed in the SLIC application or PVSS. Figures of about 1 temperature point per second per channel can be expected for a 200-channel system.

**System scalability:**

Keithley 2700 and 2750 are both scalable by 40 channels (K-7702 multiplexer module). Maximum configurations are:
- **Keithley 2700:**
  - 80 channels (2-wire connection, 10K thermistors);
  - 40 channels (4-wire connection, Pt100/Pt100).
- **Keithley 2750:**
  - 200 channels (2-wire connection, 10K thermistors);
  - 100 channels (4-wire connection, Pt100/Pt100);

For a higher channel count system, one can consider several Keithley 2700/2750 devices attached (via IEEE-488) to a single PC.
Solution 7 -- "TempScan/1100".

Solution is based on a commercial product TempScan/1100; it has not been implemented in the vertical slice sub-project and is considered here, basing only on available information.

General layout:

The layout is quite similar to the one of solutions 1, 4, 6; it has a long raw signal path (> 100 m). No fieldbus is used; DAQ module functionality is provided with TempScan/1100 instrument, which is connected to a PC with IEEE-488 (GPIB) or RS-232. PVSS interfacing is via standard OPC connection; ScanServer software includes an OPC server.

Radiation and magnetic field tolerance: No electronics in the detector area; see solution 1.

DAQ module: TempScan/1100.

TempScan/1100 from IOtech [TS_1] is a modular multichannel high speed temperature and/or voltage measurement instrument. Its basic configuration includes the main unit (device itself) with a single slot for a so-called "scanning module"; further expansion is provided with expansion chassis (each for 2 or 10 modules).

Device features are:
- RTD temperature measurements with TempRTD/16B scanning module:
  - 16 channels of 3-wire or 4-wire RTDs.
- Voltage measurements with TempV/32B scanning module:
  - 32 differential channels; programmable ranges ±10V, ±5V, ±1V, ±100mV.
- A/D resolution 16-bit w/ oversampling.
- Accuracy (100 Ohm platinum RTD) ±0.2°C [-100°C .. +630°C]; resolution 0.1°C.
- Programmable scan interval; maximum scan rate 960 channels/sec (60Hz) or 800 chan/sec (50Hz).
- Alarm (or digital) outputs 32 bits (TTL); 8 digital inputs.
- Maximum 3 expansion chassis per a single system (31 module in total).
- PC connection via IEEE-488 (300 KB/sec) or RS232/RS422 (9600 baud).
- Optional Ethernet connection with a Net232 Ethernet interface.

Supported sensors: RTD, Pt100/Pt1000.

Analog signal cabling: Analog cabling is much the same as in solution 1.

Fieldbus connection: Not applicable.

Power supply aspects: TempScan/1100 is powered from AC mains (220V).
**PVSS interfacing:**  
OPC connection, using a ScanServer OPC server.

ScanServer software from IOtech [TS_2] provides a standard OPC server functionality (plus DDE connectivity, with virtually all DDE formats). It supports unlimited number of nodes, i.e. IOtech instruments, connected with IEE-488, RS-232/422 or Ethernet. Measurement rates up to 10 times per second are supported.

In addition to temperature and voltage inputs, ScanServer provides client access to each instrument's eight digital inputs and 32 digital outputs. These digital I/O lines can be used to read external state information or to turn external devices on or off, such as audible or visible alarms.

**Configuration procedures:**

TempScan/1100 is configured with a ScanServer; but the latter has to be configured with a proprietary tool. It is not possible to integrate all configuration procedures under PVSS.

**Fault tolerance, troubleshooting and maintenance:**

All data acquisition equipments are located close to the PC; they are easily accessible for troubleshooting and possible replacement.

**Measurement performance:**

TempScan/1100 is equipped with a high-speed 16-bit A/D converter; its scanning modules provide all required signal conditioning and amplification. The device filters AC line cycle noise by sampling and averaging 16 measurements per line cycle. It uses a technique whereby groups of 16 consecutive channels are scanned during every AC line cycle. This results in maximum measurement rates of 960 channels per second (60 Hz) or 800 channels per second (50 Hz).

The TempScan/1100 offers two programmable scan rates for applications that require acceleration of the measurement rate on a specified event, such as an alarm condition. Upon cessation of the alarm condition, the device resumes sampling at the normal rate. Device can be configured to begin and end data logging on a specified event - such as a TTL signal, temperature level, IEEE GET, alarm condition, or absolute time of day - or upon completion of a specified number of readings.

The speed of measurement at the PVSS level can be about 1 temperature point per second per each of 496 channels (all data, arriving to PVSS, are temperatures).

**System scalability:**

TempScan/1100 is scalable by 1 scanning module (16 channels for TempRTD/16B):

- **Main unit** - 1 module 16 channels (3-wire or 4-wire).
- **Exp.chassis** - 10 modules 160 channels.
- **Fully equipped instrument** - 31 modules 496 channels.

With IEEE-488, several instruments can be connected to a single PC. ScanServer supports unlimited number of nodes (instruments).
Temperature monitoring solutions - cost estimates.

In this chapter, cost estimates for above considered temperature monitoring solutions are presented. Figures are scaled by a number of sensor channels. Presentation format for each solution is: total cost estimate; per channel cost estimate; contribution in percents by system layers/components; estimates by layers and/or components.

In the summary section, which ends this chapter, totals and per channel values for all variants are collected together to make comparison easier.

While certain efforts were put into producing a realistic and cost optimized strategy for each variant, resulting estimates are just indicators. Real applications may have different geographical layouts and cabling schemes; some cost savings are possible for medium to large scale systems (due to better prices) and some additional expenses may result from e.g. custom hardware/software developments (which are not included in the estimates).

Notes (common for all variants):

1). Top layers of a (possibly distributed) SCADA system configuration are not considered here, as they may look quite different in different DCS applications. Only the lower layers of such configuration, which provide the data acquisition functionality, are considered: a PC, running a PVSS OPC (or DIM [DIM_1]) client or at least a remote OPC/DIM server, and all the software and equipments down to and including sensors.

2). Geographical layout assumptions, taken for all variants, are:
   • PC is located in the (radiation safe) electronics room.
   • Sensors are distributed in a sub-detector area; individual signal cables are collected with a patch panel, located in the same area; that transition point is connected with a multiconductor twisted pair cable to a second transition point (again, a patch panel) outside the overall detector. Then, raw signals are either processed in place (with radiation tolerant electronics!), or further transmitted via trunk cables to the electronics room.
   • Distance (in terms of cable length) between sensors and the first patch panel is 5 m.
   • Distance between the first and the second patch panels is 20 m.
   • Distance between the detector area and the electronics room is 100m.

3). Cost estimates are done, using vendor invoices and/or offers for commercial products like PC cards, fieldbus modules, sensors, etc. All cabling items were estimated using pricing information from the CERN stores. In a few cases, when offers were not available at the time of writing, indicative estimates were used (marked with *). Also, some solutions use home-made electronic modules - those items have indicative estimates too.

4). PC layer components, included in the estimates, are:
   • PC itself, including operating system and network connection; indicative estimate is 2000 CHF.
   • Some variants require more than one PC (or more than one PC card) to support high channel count configurations; it is assumed, that enough (up to 4) free PCI slots are then available.
   • OPC server (or equivalent software layer).
   • Fieldbus card(s) and driver(s).
   PVSS license cost is not included as well as any hardware/software maintenance costs.

5). It is assumed, that all patch panels are made using (the same type) DIN-rail mountable WAGO spring connection terminals. Cost estimate is 0.8 CHF per connection.

In real applications, other connector types may be preferred, which are less (or more) expensive. For example, cost estimate for DB25 connector is 0.57 CHF per connection.

6). It is assumed, that "sensors" are just commercially available sensors, and not "probes" or some application specific assemblies. The cost of any probes or custom made assemblies is not included.

Two sensor types are used in the estimates; their per sensor pricing (for small quantities, about 10 pcs):
   • RTD Pt100 (from IST, Switzerland) - 5.60 CHF
   • 10K/100K NTC thermistors (from Betatherm, USA) - 6.50 CHF

7). Manpower and any work related expenses (assembly, mounting, etc.) are not included in the estimates.
Solution 1: "Beckhoff Pt100".

Notes:

1). Sensor types - Pt100/Pt1000 only; 3-wire connection. Cost estimate is 5.6 CHF per sensor. Raw signal delivery distance is about 125 m.

2) Cable pricing (CERN stores):
   - 3x STP -- 0.8 CHF / m (2x pairs are used)
   - 36x STP -- 7.2 CHF / m
   - 72x STP -- 8.6 CHF / m

3). Profibus is used as a fieldbus. Profibus cable -- 1.5 CHF / m
   A bundled package from Applicom is used, including an OPC server and a Profibus card/driver; its cost estimate is 1063 CHF.
   (Other OPC server and fieldbus card/driver products, including CANopen products, could also be used with comparable cost expenses).

4). Beckhoff fieldbus station configuration and cost estimates:
   - 1 -- BK3000bus coupler (Profibus) -- 343 CHF;
   - 1-50 -- KL3202Pt100 analog input modules -- 237 CHF;
   - 1 -- KL9010K-bus termination module -- 14 CHF;
   - 1 -- KL9400K-bus power supply module -- 20 CHF (indicative);
   - 1-4 -- externally mounted 24V/30W power supply -- 140 CHF.
   Cost estimate for a "maximum size" fieldbus station (50 modules = 100 channels): 12,787 CHF

26 7.12.01
Table 1 Cost estimates.

<table>
<thead>
<tr>
<th>No. channels</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost estimate</td>
<td>CHF</td>
<td>4972</td>
<td>6075</td>
<td>12951</td>
<td>21168</td>
<td>92044</td>
<td>180926</td>
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<tr>
<td>Costs per channel</td>
<td>CHF</td>
<td>4972</td>
<td>608</td>
<td>259</td>
<td>212</td>
<td>184</td>
<td>181</td>
</tr>
<tr>
<td>Contribution (percents):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors</td>
<td>%</td>
<td>0.1</td>
<td>0.9</td>
<td>2.2</td>
<td>2.6</td>
<td>3.0</td>
<td>3.1</td>
</tr>
<tr>
<td>Detector area cabling</td>
<td>%</td>
<td>3.1</td>
<td>3.8</td>
<td>6.7</td>
<td>8.2</td>
<td>9.2</td>
<td>9.3</td>
</tr>
<tr>
<td>Trunk cables</td>
<td>%</td>
<td>17.3</td>
<td>14.2</td>
<td>13.3</td>
<td>12.2</td>
<td>13.1</td>
<td>13.3</td>
</tr>
<tr>
<td>Fieldbus stations</td>
<td>%</td>
<td>14.8</td>
<td>28.1</td>
<td>53.0</td>
<td>61.7</td>
<td>71.0</td>
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<tr>
<td>Fieldbus cabling</td>
<td>%</td>
<td>3.1</td>
<td>2.5</td>
<td>1.2</td>
<td>0.7</td>
<td>0.4</td>
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</tr>
<tr>
<td>PC layer components</td>
<td>%</td>
<td>61.6</td>
<td>50.4</td>
<td>23.7</td>
<td>14.5</td>
<td>3.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Estimates by layers/components:

| Sensors (pt100) | CHF | 5.6 | 56 | 280 | 560 | 2800 | 5600 | 28000 |
| Detector area cabling | CHF | 153 | 232 | 872 | 1744 | 8432 | 16864 | 84032 |
| 3x STP, 5m | CHF | 4 | 40 | 200 | 400 | 2000 | 4000 | 20000 |
| Length, m | | 5 | 50 | 250 | 500 | 2500 | 5000 | 25000 |
| WAGO terminals (6/chan) | CHF | 4.8 | 48 | 240 | 480 | 2400 | 4800 | 24000 |
| 36x STP, 20m | CHF | 144 | 144 | 432 | 864 | 4032 | 8064 | 40032 |
| No. pcs (18 ch) | | 1 | 1 | 3 | 6 | 28 | 56 | 278 |
| Length, m | | 20 | 20 | 60 | 120 | 560 | 1120 | 5560 |
| Trunk cables, 72x STP, 100m | CHF | 860 | 860 | 1720 | 2580 | 12040 | 24080 | 119540 |
| No. pcs (36 ch) | | 1 | 1 | 2 | 3 | 14 | 28 | 139 |
| Length, m | | 100 | 100 | 200 | 300 | 1400 | 2600 | 13900 |
| Fieldbus stations | CHF | 737 | 1710 | 6862 | 13067 | 65335 | 130670 | 653350 |
| No. stations | | 1 | 1 | 1 | 1 | 5 | 10 | 50 |
| No. pt100 modules (2 ch) | | 1 | 5 | 25 | 50 | 250 | 500 | 2500 |
| No. 30W pow.supplies | | 1 | 1 | 3 | 4 | 14 | 28 | 139 |
| Fieldbus cabling (Profibus) | CHF | 154 | 154 | 154 | 154 | 374 | 649 | 2849 |
| Cable length, m | | 22 | 22 | 22 | 22 | 30 | 40 | 120 |
| No. connectors | | 2 | 2 | 2 | 2 | 6 | 11 | 51 |
| No. fieldbus lines | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PC layer components | CHF* | 3063 | 3063 | 3063 | 3063 | 3063 | 3063 | 3063 |
| OPC server | CHF | 1063 | 1063 | 1063 | 1063 | 1063 | 1063 | 1063 |
| Profibus card/driver | CHF | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

* - indicative cost estimate
Solution 2: "Beckhoff 20mA + transducer-MUX".

Notes:

1). Sensor types - NTC thermistors (10K, 100K); cost estimate is 6.5 CHF. Raw signal delivery distance is 25 m; conditioned signal delivery distance is 100 m.

2) Cable pricing (CERN stores):
   1x STP -- 1.0 CHF / m
   18x STP -- 5.6 CHF / m (16x pairs are used)
   12x STP -- 5.0 CHF / m (10x pairs are used)

2). Profibus is used as a fieldbus; fieldbus hardware/software configuration is the same as for solution 1 (above), except that a Beckhoff fieldbus station is configured with KL3022 (4..20mA) modules instead of KL3202 (Pt100) ones. KL3022 cost estimate is: 234 CHF.

3). Transducer-MUX module (64 channels) - custom made; indicative cost estimate is: 300 CHF. T-MUX control is provided with a Beckhoff KL6021 communication module and custom made modules.
   Indicative cost estimates: KL6021 -- 120 CHF
   Custom made modules: -- 100 CHF + 100 CHF per 10 T-MUX modules
   Cable (100 m): -- 500 CHF
Table 2  Cost estimates.

<table>
<thead>
<tr>
<th>No. channels</th>
<th>1</th>
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<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
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<td>5959</td>
<td>6819</td>
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<td>32841</td>
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<tr>
<td>Costs per channel</td>
<td>CHF</td>
<td>5841</td>
<td>596</td>
<td>136</td>
<td>81</td>
<td>37</td>
<td>33</td>
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**Contribution (percents):**

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<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
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<td>4.8</td>
<td>8.0</td>
<td>17.4</td>
<td>19.8</td>
<td>22.4</td>
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<td>36.8</td>
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<tr>
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<td>8.6</td>
<td>8.4</td>
<td>7.3</td>
<td>6.2</td>
<td>2.7</td>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
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<td>12.4</td>
<td>10.8</td>
<td>9.1</td>
<td>7.8</td>
<td>7.4</td>
<td>7.3</td>
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<tr>
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<td>3.5</td>
<td>2.9</td>
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<td>5.8</td>
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<td>2.6</td>
<td>2.3</td>
<td>1.9</td>
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<td>51.4</td>
<td>44.9</td>
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Estimates by layers/components:

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<thead>
<tr>
<th>Category</th>
<th>CHF</th>
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<th>CHF</th>
<th>CHF</th>
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</thead>
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<td><strong>Detectors area cabling</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1x STP, 5m</td>
<td>CHF</td>
<td>5</td>
<td>50</td>
<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
<td>25000</td>
</tr>
<tr>
<td>No. pcs (16 ch)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td><strong>Trunk cables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18x STP, 20m</td>
<td>CHF</td>
<td>112</td>
<td>112</td>
<td>448</td>
<td>784</td>
<td>3584</td>
<td>7056</td>
<td>35056</td>
</tr>
<tr>
<td>No. pcs (16 ch)</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>32</td>
<td>63</td>
<td>313</td>
<td></td>
</tr>
<tr>
<td><strong>Fieldbus stations</strong></td>
<td>CHF</td>
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<td>736</td>
<td>736</td>
<td>736</td>
<td>1462</td>
<td>2427</td>
<td>10583</td>
</tr>
<tr>
<td>No. stations</td>
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<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<tr>
<td>No. 20mA modules</td>
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<td><strong>Fieldbus cabling (Profibus)</strong></td>
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<td>154</td>
<td>154</td>
<td>154</td>
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<td>154</td>
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<tr>
<td>Cable length, m</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
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</tr>
<tr>
<td>No. connectors</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>No. fieldbus lines</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>PC layer components</strong></td>
<td>CHF</td>
<td>3063</td>
<td>3063</td>
<td>3063</td>
<td>3063</td>
<td>3063</td>
<td>3063</td>
<td>3063</td>
</tr>
<tr>
<td>PC hw/sw</td>
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<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
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<td>1063</td>
<td>1063</td>
<td>1063</td>
<td>1063</td>
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</tr>
<tr>
<td>Profibus card/driver</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* -- indicative cost estimate
Solution 3: ELMB.

Notes:

1) Sensor types - Pt100/Pt1000 and NTC thermistors (10K/100K). Thermistors are taken for estimates. Raw signal delivery distance is about 25 m (ELMB modules are located outside the overall detector, but in the detector area).

2) Cable pricing (CERN stores):
   - 1x STP - 1.0 CHF / m
   - 18x STP - 5.6 CHF / m (16x pairs are used)
   - CANbus cable - 2.0 CHF / m

3) CANopen is used as a fieldbus; this is defined by ELMB design. An ATLAS developed CANopen OPC server and NI-CAN card/driver from National Instruments are used. There are no other choices to support ELMB for the moment. NI-CAN card/driver cost estimate is 1356 CHF.

4) ELMB module is a carrier board (so-called "motherboard") with a plastic cover box, DIN-rail mountable and ELMB card, plugged onto the carrier board. Carrier board provides signal and power connections. ELMB module cost estimate is: 150 (carrier) + 250 (ELMB) = 400 CHF
   A single power supply can be used to power several (10) ELMB modules. Cost estimate is 200 CHF.
Table 3 Cost estimates.

<table>
<thead>
<tr>
<th>No. channels</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
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<td>CHF</td>
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<td>4495</td>
<td>5419</td>
<td>6937</td>
<td>18304</td>
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<tr>
<td>Costs per channel</td>
<td>CHF</td>
<td>4362</td>
<td>449</td>
<td>108</td>
<td>69</td>
<td>37</td>
<td>33</td>
</tr>
<tr>
<td><strong>Contribution (percents):</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors</td>
<td>%</td>
<td>0.1</td>
<td>1.4</td>
<td>6.0</td>
<td>9.4</td>
<td>17.8</td>
<td>19.8</td>
</tr>
<tr>
<td>Detector area cabling</td>
<td>%</td>
<td>2.8</td>
<td>4.3</td>
<td>15.8</td>
<td>23.1</td>
<td>42.0</td>
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</tr>
<tr>
<td>ELMB modules</td>
<td>%</td>
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<td>14.0</td>
<td>11.6</td>
<td>15.3</td>
<td>19.8</td>
<td>22.1</td>
</tr>
<tr>
<td>Fieldbus cabling</td>
<td>%</td>
<td>5.7</td>
<td>5.6</td>
<td>4.6</td>
<td>3.9</td>
<td>2.1</td>
<td>1.6</td>
</tr>
<tr>
<td>PC layer components</td>
<td>%</td>
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<td>74.7</td>
<td>61.9</td>
<td>48.4</td>
<td>18.3</td>
<td>10.2</td>
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</table>

Estimates by layers/components:

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<th>6.5</th>
<th>65</th>
<th>325</th>
<th>650</th>
<th>3250</th>
<th>6500</th>
<th>32500</th>
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<td>194</td>
<td>858</td>
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<td>7684</td>
<td>15256</td>
<td>76056</td>
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<td>1x STP, 5m</td>
<td>CHF</td>
<td>5</td>
<td>50</td>
<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
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<td>Length, m</td>
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<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
<td>25000</td>
</tr>
<tr>
<td>WAGO terminals (4-chan)</td>
<td>CHF</td>
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<td>32</td>
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<td>320</td>
<td>1600</td>
<td>3200</td>
<td>16000</td>
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<td>18x STP, 20m</td>
<td>CHF</td>
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<td>112</td>
<td>448</td>
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<td>3584</td>
<td>7056</td>
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<td>No. pcs</td>
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<td>4</td>
<td>7</td>
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<td>Length, m</td>
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<td>630</td>
<td>1058</td>
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<td>16</td>
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<td>2</td>
<td>8</td>
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<td>Flat cables + connectors</td>
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<td>30</td>
<td>30</td>
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<td>1</td>
<td>3</td>
</tr>
<tr>
<td>PC layer components</td>
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<td>3356</td>
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<td>3356</td>
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</tr>
<tr>
<td>CAN card/driver (NI-CAN)</td>
<td>CHF</td>
<td>1356</td>
<td>1356</td>
<td>1356</td>
<td>1356</td>
<td>1356</td>
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<td>2712</td>
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</tbody>
</table>

* - indicative cost estimate
Solution 4: "PC instrumentation card".

Notes:

1). Sensor types - NTC thermistors (10K, 100K). Raw signal delivery distance is about 125 m.

2) Cable pricing (CERN stores):
   1x STP -- 1.0 CHF / m
   18x STP -- 5.6 CHF / m (16x pairs are used)
   72x STP -- 8.6 CHF / m (64x pairs are used)

3). No fieldbus is used; PC instrumentation card (NI 6023E/ NI 6034E) is a measurement device, it is extended with a custom made external modules which provide sensor excitation and raw signal multiplexing. Price estimates:
   NI 6023E (8 channels, differential; 12-bit) -- 1165 CHF
   NI 6034E (8 channels, differential; 16-bit) -- 1600 CHF
   External MUX board (64 channels) -- 350 CHF (indicative estimate)
   Power supply 5V/1.25A -- 100 CHF

Configuration:
Max 4 instrumentation cards per PC;
Max 8 external MUX boards per instrumentation card (+ 1 power supply);
Max 64 sensor channels per MUX board.
All MUX boards are controlled from their master instrumentation card, using digital I/O (8 lines).

4). PVSS interfacing (custom development) can be done using SLIC/OPC.
Table 4 Cost estimates.

<table>
<thead>
<tr>
<th>No. channels</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost estimate</td>
<td>CHF 5037</td>
<td>5169</td>
<td>6093</td>
<td>8374</td>
<td>24314</td>
<td>46516</td>
<td>227146</td>
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<tr>
<td>Costs per channel</td>
<td>CHF 5037</td>
<td>517</td>
<td>122</td>
<td>84</td>
<td>49</td>
<td>47</td>
<td>45</td>
</tr>
</tbody>
</table>

**Contribution (percents):**

- **Sensors** % 0.1 1.3 5.3 7.8 13.4 14.0 14.3
- **Detector area cabling** % 2.4 3.8 14.1 19.2 31.6 32.8 33.5
- **Trunk cables** % 17.1 16.6 14.1 20.5 28.3 29.6 29.9
- **PC layer components** % 71.5 69.6 59.1 43.0 14.8 11.2 9.7
- **External MUX boards** % 8.9 8.7 7.4 9.6 11.9 12.5 12.6

**Estimates by layers/components:**

- **Sensors (Betatherm 10K/100K)** CHF 6.5 65 325 650 3250 6500 32500
- **Detector area cabling** CHF 120.2 194 858 1604 7684 15256 76056
  - 1x STP, 5m CHF 5 50 250 500 2500 5000 25000
  - Length, m 5 50 250 500 2500 5000 25000
  - WAGO terminals (4/ch) CHF 3.2 32 160 320 1600 3200 16000
  - 18x STP, 20m CHF 112 112 448 784 3584 7056 35056
    - No. pcs (16 ch) 1 1 4 7 32 63 313
    - Length, m 20 20 80 140 640 1260 6260
- **Trunk cables, 72x STP, 100m** CHF 860 860 880 1720 6880 13760 67940
  - No. pcs (64 ch) 1 1 1 1 2 8 16 79
  - Length, m 100 100 100 200 800 1600 7900
- **PC layer components** CHF** 3600 3600 3600 3600 3600 5200 22000
    - No. PCs (4 cards) 1 1 1 1 1 1 3
- **SLIC OPC server / SLIC app** CHF 0 0 0 0 0 0 0
  - No. cards (8 boards) 1 1 1 1 1 1 10
- **External MUX boards (custom)** CHF** 450 450 450 800 2900 5800 28650
  - No. boards (64 chan) 1 1 1 2 8 16 79
  - No. power supplies 1 1 1 1 1 1 10

* -- indicative cost estimate
Solution 5: "Transducer-MUX + PC instrumentation card".

Notes:

1). Sensor types - NTC thermistors (10K, 100K).
   Raw signal delivery distance is 25 m; conditioned signal delivery distance is 100 m.

2) Cable pricing (CERN stores):
   1x STP  --  1.0 CHF / m
   18x STP  --  5.6 CHF / m (16x pairs are used)
   12x STP  --  5.0 CHF / m (8x pairs are used)

3). This is a mixture of solutions 2 and 4 (see above). Transducer-MUX module is used for raw signal conditioning and PC instrumentation card is used for data acquisition and T-MUX controls.

Each instrumentation card is extended with a custom made current-voltage converter module, which also translates T-MUX control signals from instrumentation card. Indicative cost estimate for converter module is 200 CHF.

4). PVSS interfacing (custom development) can be done using SLIC/OPC
Table 5  Cost estimates.

<table>
<thead>
<tr>
<th>No. channels</th>
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<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
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<tbody>
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<td>5586</td>
<td>6446</td>
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<td>Costs per channel</td>
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<td>5468</td>
<td>559</td>
<td>129</td>
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<td>33</td>
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<tr>
<td>Contribution (percents):</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Sensors</td>
<td>%</td>
<td>0.1</td>
<td>1.2</td>
<td>5.0</td>
<td>8.4</td>
<td>18.5</td>
<td>19.7</td>
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<tr>
<td>Detector area cabling</td>
<td>%</td>
<td>2.2</td>
<td>3.2</td>
<td>12.1</td>
<td>18.7</td>
<td>39.1</td>
<td>41.4</td>
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<tr>
<td>T-MUX modules</td>
<td>%</td>
<td>17.2</td>
<td>16.9</td>
<td>14.6</td>
<td>16.1</td>
<td>17.4</td>
<td>18.6</td>
</tr>
<tr>
<td>Trunk cables</td>
<td>%</td>
<td>9.1</td>
<td>9.0</td>
<td>7.8</td>
<td>6.5</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Converter boards</td>
<td>%</td>
<td>5.5</td>
<td>5.4</td>
<td>4.7</td>
<td>3.9</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>PC layer components</td>
<td>%</td>
<td>65.8</td>
<td>64.5</td>
<td>55.9</td>
<td>46.5</td>
<td>20.5</td>
<td>15.8</td>
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</table>

Estimates by layers/components:

<table>
<thead>
<tr>
<th>Sensors (Betatherm 10K/100K)</th>
<th>CHF</th>
<th>6.5</th>
<th>65</th>
<th>325</th>
<th>650</th>
<th>3250</th>
<th>6500</th>
<th>32500</th>
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</thead>
<tbody>
<tr>
<td>Detector area cabling</td>
<td>CHF*</td>
<td>118.6</td>
<td>178</td>
<td>778</td>
<td>1444</td>
<td>6884</td>
<td>13656</td>
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<td>1x STP, 5m</td>
<td>CHF</td>
<td>5</td>
<td>50</td>
<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
<td>25000</td>
</tr>
<tr>
<td>length, m</td>
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<td>5</td>
<td>50</td>
<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
<td>25000</td>
</tr>
<tr>
<td>WAGO terminals (2/channel)</td>
<td>CHF</td>
<td>1.6</td>
<td>16</td>
<td>80</td>
<td>160</td>
<td>800</td>
<td>1600</td>
<td>8000</td>
</tr>
<tr>
<td>18x STP, 20m</td>
<td>CHF</td>
<td>112</td>
<td>112</td>
<td>448</td>
<td>784</td>
<td>3584</td>
<td>7056</td>
<td>35056</td>
</tr>
<tr>
<td>No. pcs (16)</td>
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<td>1</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>32</td>
<td>63</td>
<td>313</td>
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<tr>
<td>length, m</td>
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<td>20</td>
<td>80</td>
<td>140</td>
<td>640</td>
<td>1260</td>
<td>6260</td>
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<tr>
<td>T-MUX modules</td>
<td>CHF*</td>
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<td>942.6</td>
<td>942.6</td>
<td>1245.2</td>
<td>3060.8</td>
<td>6121.6</td>
<td>30025</td>
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<tr>
<td>No. T-MUX modules (64)</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>79</td>
</tr>
<tr>
<td>No. 24V/30W pow.sup.</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>T-MUX controls (cable)</td>
<td>CHF*</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>5.2</td>
<td>20.8</td>
<td>41.6</td>
<td>205.4</td>
</tr>
<tr>
<td>WAGO term. (2/T-MUX)</td>
<td>CHF</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>3.2</td>
<td>12.8</td>
<td>25.6</td>
<td>126.4</td>
</tr>
<tr>
<td>1x STP, 1m</td>
<td>CHF</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>79</td>
</tr>
<tr>
<td>Trunk cables, 12x STP, 100m</td>
<td>CHF</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>1000</td>
<td>5000</td>
</tr>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>200</td>
<td>1000</td>
</tr>
<tr>
<td>PC layer components</td>
<td>CHF*</td>
<td>3600</td>
<td>3600</td>
<td>3600</td>
<td>3600</td>
<td>3600</td>
<td>5200</td>
<td>22000</td>
</tr>
<tr>
<td>No. PCs (4 cards)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>SLIC OPC server / SLIC app.</td>
<td>CHF</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>NI 6034 card/driver</td>
<td>CHF</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>3200</td>
<td>16000</td>
</tr>
<tr>
<td>No. cards (1 board)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Converter boards (custom)</td>
<td>CHF*</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>500</td>
<td>2300</td>
</tr>
<tr>
<td>No. boards (8)</td>
<td></td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>No. power supplies</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

* -- indicative cost estimate
Solution 6: "Keithley 2700/2750 data acquisition system".

Notes:
1). Sensor types - NTC thermistors (10K). Also supported: Pt100/Pt1000. Raw signal delivery distance is about 125 m.

2) Cable pricing (CERN stores):
- 1x STP -- 1.0 CHF / m
- 12x STP -- 5.0 CHF / m (10x pairs are used)
- 72x STP -- 8.6 CHF / m (40x pairs are used)

3). No fieldbus is used. Keithley 2700/2750 is a measurement device; it also provides sensor excitation and raw signal multiplexing (for max 80/200 channels); it is connected to PC via IEEE-488 GPIB standard interface (several devices can be connected to the same bus). For cost estimates, K-2700 is taken for systems with 1 - 80 channels, and K-2750 for systems with more than 80 channels. Indicative price estimates:
- K-2700 main unit -- 3000 CHF
- K-2750 main unit -- 5000 CHF
- K-77xx plug-in module (40 ch) -- 1500 CHF

4). PVSS interfacing (custom development) can be done using SLIC/OPC.
Table 6  Cost estimates.

<table>
<thead>
<tr>
<th>No. channels</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost estimate</td>
<td>CHF</td>
<td>8359</td>
<td>8491</td>
<td>11923</td>
<td>17602</td>
<td>61922</td>
<td>113600</td>
</tr>
<tr>
<td>Costs per channel</td>
<td>CHF</td>
<td>8359</td>
<td>849</td>
<td>238</td>
<td>176</td>
<td>124</td>
<td>114</td>
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<table>
<thead>
<tr>
<th>Contribution (percents):</th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>%</td>
<td>0.1</td>
<td>0.8</td>
<td>2.7</td>
<td>3.7</td>
<td>5.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Detector area cabling</td>
<td>%</td>
<td>1.3</td>
<td>2.1</td>
<td>7.6</td>
<td>10.3</td>
<td>14.7</td>
<td>16.0</td>
</tr>
<tr>
<td>Trunk cables</td>
<td>%</td>
<td>10.3</td>
<td>10.1</td>
<td>14.4</td>
<td>14.7</td>
<td>18.1</td>
<td>18.9</td>
</tr>
<tr>
<td>Keithley 2700/2750</td>
<td>%</td>
<td>54.8</td>
<td>54.0</td>
<td>51.7</td>
<td>55.4</td>
<td>57.5</td>
<td>56.9</td>
</tr>
<tr>
<td>PC layer components</td>
<td>%</td>
<td>33.5</td>
<td>33.0</td>
<td>23.5</td>
<td>15.9</td>
<td>4.5</td>
<td>2.5</td>
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</table>

Estimates by layers/components:

<table>
<thead>
<tr>
<th>Sensors (Betatherm 10K/100K)</th>
<th>CHF</th>
<th>6.5</th>
<th>65</th>
<th>325</th>
<th>650</th>
<th>3250</th>
<th>6500</th>
<th>32500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector area cabling</td>
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<td>108.2</td>
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<td>910</td>
<td>1820</td>
<td>9100</td>
<td>18200</td>
<td>91000</td>
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<tr>
<td>1x STP, 5m</td>
<td>CHF</td>
<td>5</td>
<td>50</td>
<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
<td>25000</td>
</tr>
<tr>
<td>Length, m</td>
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<td>250</td>
<td>500</td>
<td>2500</td>
<td>5000</td>
<td>25000</td>
<td></td>
</tr>
<tr>
<td>WAGO terminals (4/ch)</td>
<td>CHF</td>
<td>3.2</td>
<td>32</td>
<td>160</td>
<td>320</td>
<td>1600</td>
<td>3200</td>
<td>16000</td>
</tr>
<tr>
<td>12x STP, 20m</td>
<td>CHF</td>
<td>100</td>
<td>100</td>
<td>500</td>
<td>1000</td>
<td>5000</td>
<td>10000</td>
<td>50000</td>
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<td>10</td>
<td>50</td>
<td>100</td>
<td>500</td>
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</tr>
<tr>
<td>Length, m</td>
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<td>20</td>
<td>100</td>
<td>200</td>
<td>1000</td>
<td>2000</td>
<td>10000</td>
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</tr>
<tr>
<td>Trunk cables, 72x STP, 100m</td>
<td>CHF</td>
<td>860</td>
<td>860</td>
<td>1720</td>
<td>2580</td>
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<td>3</td>
<td>13</td>
<td>25</td>
<td>125</td>
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<td>Length, m</td>
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<td>100</td>
<td>200</td>
<td>300</td>
<td>1300</td>
<td>2500</td>
<td>12500</td>
<td></td>
</tr>
<tr>
<td>Keithley 2700/2750</td>
<td>CHF*</td>
<td>4584</td>
<td>4584</td>
<td>6168</td>
<td>9752</td>
<td>35592</td>
<td>64600</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>13</td>
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<td>125</td>
<td></td>
</tr>
<tr>
<td>No. patch panels (40 ch)</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>13</td>
<td>25</td>
<td>125</td>
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</tr>
<tr>
<td>PC layer components</td>
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<td>2800</td>
<td>2800</td>
<td>2800</td>
<td>2800</td>
<td>2800</td>
<td>2800</td>
<td>11200</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SLIC OPC server /SLIC app</td>
<td>CHF</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>GPIB card/driver</td>
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<td>800</td>
<td>800</td>
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<td>800</td>
<td>800</td>
<td>3200</td>
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</tr>
</tbody>
</table>

* -- indicative cost estimate
Solution 7: "TempScan/1100".

Notes:
1). Sensor types - Pt100/Pt1000. Raw signal delivery distance is about 125 m.

2) Cable pricing (CERN stores):
   3x STP -- 0.8 CHF / m (2x pairs are used)
   36x STP -- 7.2 CHF / m (32x pairs are used)
   72x STP -- 8.6 CHF / m (64x pairs are used)

3). No fieldbus is used. Measurement device is TempScan/1100; it provides sensor excitation and raw signal multiplexing for max 496 channels; it is connected to a PC via IEEE-488 GPIB (several devices can be connected to the same bus). PVSS interfacing is via OPC connection (ScanServer OPC server).

Cost estimates:
TempScan/1100 main unit -- 3619 CHF
TempRTD/16B scanning module -- 1270 CHF
Exp/11a expansion chassis -- 6394 CHF
Personal488/PCI IEEE-488 card -- $495 ~ 840 CHF (indicative price)
ScanServer™ software -- $995 ~ 1690 CHF (indicative price)
<table>
<thead>
<tr>
<th>No. channels</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>496</th>
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<tr>
<td>Total cost estimate</td>
<td>CHF</td>
<td>10541</td>
<td>10685</td>
<td>22924</td>
<td>29891</td>
<td>94499</td>
<td>183506</td>
</tr>
<tr>
<td>Costs per channel</td>
<td>CHF</td>
<td>10541</td>
<td>1069</td>
<td>458</td>
<td>299</td>
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<td>185</td>
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**Contribution (percents):**

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>0.1</th>
<th>0.5</th>
<th>1.2</th>
<th>1.9</th>
<th>2.9</th>
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<tr>
<td>Detector area cabling</td>
<td></td>
<td>1.5</td>
<td>2.3</td>
<td>4.8</td>
<td>6.9</td>
<td>10.2</td>
<td>10.5</td>
<td>10.6</td>
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<tr>
<td>Trunk cables</td>
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<td>8.2</td>
<td>8.0</td>
<td>7.5</td>
<td>11.5</td>
<td>14.6</td>
<td>14.5</td>
<td>14.7</td>
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<tr>
<td>TempScan/1100</td>
<td></td>
<td>47.4</td>
<td>46.7</td>
<td>66.7</td>
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<td>67.5</td>
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<td>PC layer components</td>
<td></td>
<td>43.0</td>
<td>42.4</td>
<td>19.8</td>
<td>15.2</td>
<td>4.8</td>
<td>2.5</td>
<td>1.0</td>
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**Estimates by layers/components:**

<table>
<thead>
<tr>
<th>Sensors (Pt100)</th>
<th>CHF</th>
<th>5.6</th>
<th>56</th>
<th>280</th>
<th>560</th>
<th>2778</th>
<th>5555</th>
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<tr>
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<td>248</td>
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**3x STP, 5m**

<table>
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<tr>
<th>No. pcs (16 ch)</th>
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<th>4</th>
<th>40</th>
<th>200</th>
<th>400</th>
<th>1984</th>
<th>3968</th>
<th>19840</th>
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<tbody>
<tr>
<td>Length, m</td>
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<td>5</td>
<td>50</td>
<td>250</td>
<td>500</td>
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<td>4960</td>
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**WAGO terminals (8/chan)**

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<thead>
<tr>
<th>CHF</th>
<th>6.4</th>
<th>64</th>
<th>320</th>
<th>640</th>
<th>3174.4</th>
<th>6348.8</th>
<th>31744</th>
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**36x STP, 20m**

<table>
<thead>
<tr>
<th>No. pcs (32 ch)</th>
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<th>144</th>
<th>144</th>
<th>576</th>
<th>1008</th>
<th>4464</th>
<th>8928</th>
<th>44640</th>
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<tbody>
<tr>
<td>Length, m</td>
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<td>20</td>
<td>20</td>
<td>80</td>
<td>140</td>
<td>620</td>
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<td>6200</td>
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**Trunk cables, 72x STP, 100m**

<table>
<thead>
<tr>
<th>CHF</th>
<th>860</th>
<th>860</th>
<th>1720</th>
<th>3440</th>
<th>13760</th>
<th>26660</th>
<th>133300</th>
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**TempScan/1100**

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<tr>
<th>No. main units</th>
<th>1</th>
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<th>1</th>
<th>1</th>
<th>1</th>
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<td>No. expansion chassis</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>30</td>
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<tr>
<td>No. Temp. modules (16 ch)</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>31</td>
<td>62</td>
<td>310</td>
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**PC layer components**

<table>
<thead>
<tr>
<th>CHF*</th>
<th>4530</th>
<th>4530</th>
<th>4530</th>
<th>4530</th>
<th>4530</th>
<th>4530</th>
<th>9060</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. PCs</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>OPC server (ScanServer)</td>
<td>CHF*</td>
<td>1690</td>
<td>1690</td>
<td>1690</td>
<td>1690</td>
<td>1690</td>
<td>1690</td>
</tr>
<tr>
<td>GPIB card/driver</td>
<td>CHF*</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
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<tr>
<td>No. GPIB cards</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>2</td>
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* -- indicative cost estimate
Summary estimates.

Total costs

<table>
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<th>No. channels</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
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<tbody>
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<td>Total cost estimates</td>
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<tr>
<td>1 Beckhoff pt100</td>
<td>4972</td>
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<td>12951</td>
<td>21168</td>
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<tr>
<td>2 Beckhoff 20mA + T-MUX</td>
<td>5841</td>
<td>5959</td>
<td>6819</td>
<td>8114</td>
<td>18694</td>
<td>32841</td>
<td>144901</td>
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<tr>
<td>3 ELMB</td>
<td>4362</td>
<td>4495</td>
<td>5419</td>
<td>6937</td>
<td>18304</td>
<td>32908</td>
<td>150933</td>
</tr>
<tr>
<td>4 PC instrum.card</td>
<td>5037</td>
<td>5169</td>
<td>6093</td>
<td>8374</td>
<td>24314</td>
<td>46516</td>
<td>227146</td>
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<tr>
<td>5 T-MUX + PC instr.card</td>
<td>5468</td>
<td>5586</td>
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<tr>
<td>6 Keithley 2700/2750</td>
<td>8359</td>
<td>8491</td>
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<tr>
<td>7 TempScan/1100</td>
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Per channel costs

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<th>50</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
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<tbody>
<tr>
<td>Per channel costs</td>
<td>CHF</td>
<td></td>
<td></td>
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<tr>
<td>1 Beckhoff pt100</td>
<td>4972</td>
<td>608</td>
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<td>212</td>
<td>184</td>
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<td>178</td>
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<tr>
<td>2 Beckhoff 20mA + T-MUX</td>
<td>5841</td>
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<td>136</td>
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<td>37</td>
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<td>29</td>
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<td>3 ELMB</td>
<td>4362</td>
<td>449</td>
<td>108</td>
<td>69</td>
<td>37</td>
<td>33</td>
<td>30</td>
</tr>
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<td>4 PC instrum.card</td>
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<td>122</td>
<td>84</td>
<td>49</td>
<td>47</td>
<td>45</td>
</tr>
<tr>
<td>5 T-MUX + PC instr.card</td>
<td>5468</td>
<td>559</td>
<td>129</td>
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<td>35</td>
<td>33</td>
<td>32</td>
</tr>
<tr>
<td>6 Keithley 2700/2750</td>
<td>8359</td>
<td>849</td>
<td>238</td>
<td>176</td>
<td>124</td>
<td>114</td>
<td>113</td>
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<tr>
<td>7 TempScan/1100</td>
<td>10541</td>
<td>1069</td>
<td>458</td>
<td>299</td>
<td>191</td>
<td>185</td>
<td>182</td>
</tr>
</tbody>
</table>
Summary comments.

A brief summary of the two preceding chapters, containing technical considerations and costs estimates, can be formulated as follows:

**Solution 1** ("Beckhoff Pt100") has been taken as a reference when considering other alternatives. It is a standard, readily available solution, based on well established commercial products. It provides easy PVSS interfacing, using a standard OPC connection, and it is scalable to considerable channel counts in small increments. However, this solution has serious disadvantages:

- High total system cost, mainly because of expensive DAQ modules (but also of a big volume of analog signal cabling). This is one of the most expensive solutions.
- Possible measurement accuracy problems because of long raw analog signal path (and a 3-wire Pt100 sensor connection scheme).

**Solution 2** ("Beckhoff 20mA + transducer-MUX") is an enhancement of the solution 1 in the both above mentioned aspects:

- Channel multiplexing provides considerable savings on DAQ modules and analog cables;
- Signal conditioning (and the use of thermistors) provides higher measurement accuracy.

This solution seems to be technically adequate and is one of the less expensive. It is scalable to very high channel counts and has a standard OPC connection to PVSS. Its only disadvantage is that a T-MUX module has to be finally developed and tested; then produced in series and further supported.

**Solution 3** ("ELMB") is technically adequate and is the most cost efficient for channel counts up to 1000 (thereafter solution 2 looks equally and even slightly more efficient). It is scalable to considerable channel counts and has a standard OPC connection to PVSS (with a home-made OPC server). Also, ELMB is a general purpose card, able to measure voltages and currents; it provides also several digital I/O lines and optional DAC. In a DCS, it can be used as a flexible "standard" monitoring and control node.

**Solution 4** ("PC instrumentation card") can be considered as a considerably less expensive alternative to the solution 1. However, it requires an external module to be developed. Other disadvantages are long raw analog signal path and a large volume of cabling (like in solution 1). Also, PVSS interfacing requires specific software (a SLIC application) to be developed.

**Solution 5** ("PC instrumentation card + transducer-MUX") is an enhancement of the solution 4, providing signal conditioning and savings on analog cables. Cost efficiency is close to the one of solutions 2 and 3. Disadvantages are several home-made developments: a T-MUX module, a card extension module, a SLIC application.

**Solution 6** ("Keithley 2700/2750 data acquisition system") is similar to the solution 1 but less expensive and can provide the better accuracy (using NTC thermistors or 4-wire Pt100). However, it is still much more expensive than solutions 2,3,5. It also requires home-made developments: a SLIC application.

**Solution 7** ("TempScan/1100") also looks similar to the solution 1, but is more expensive; it is the most expensive solution. It does not require home-made developments, providing a standard OPC connection to PVSS.

Basing on the cost estimates, solutions 2,3,5 are the most cost effective ones. From them, only solution 3 ("ELMB") is readily available, providing that ELMB is fully supported CERN-wide; two others require home-made developments. All three solutions have electronic modules in the detector area (ELMB or T-MUX). This provides significant savings on analog signal cables; also, the better measurement accuracy can be expected. However, the overall system fault tolerance becomes lower, as broken modules can not be replaced immediately; the result is long term loss of measurement channels. One can consider either some degree of sensor duplication, or a limited use of expensive "safe" solutions (like 6 or 1) in addition to low cost "unsafe" ones.

Transient faults (e.g. SEU produced) have a negligible effect for solutions 2,5, which use T-MUX; ELMB may have to be restarted or even reloaded with firmware (both options are provided with ELMB internal watchdog controller, but not yet supported by PVSS).

The two tables below summarize solutions' features and cost estimates.
## Temperature monitoring solutions comparison

<table>
<thead>
<tr>
<th>Solution</th>
<th>Supported sensors</th>
<th>Measurement accuracy</th>
<th>Raw analog signal path</th>
<th>Electronics in the detector area</th>
<th>PVSS interfacing</th>
<th>Home-made developments</th>
<th>Max No. channels per a PC</th>
<th>Total system cost</th>
<th>Availability</th>
<th>Est.time to develop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Beckhoff Pt100</td>
<td>Pt100/Pl1000</td>
<td>moderate</td>
<td>&gt; 100 m</td>
<td>no</td>
<td>OPC, commercial</td>
<td>no</td>
<td>&gt; 3000</td>
<td>very high</td>
<td>now</td>
<td>6-12 months</td>
</tr>
<tr>
<td>2 Beckhoff 4..20mA + T-MUX</td>
<td>NTC 10K/100K</td>
<td>moderate to good</td>
<td>&lt; 30 m</td>
<td>yes, T-MUX</td>
<td>OPC, commercial</td>
<td>T-MUX</td>
<td>&gt; 10,000</td>
<td>low</td>
<td>N/A</td>
<td>6-12 months</td>
</tr>
<tr>
<td>3 ELMB</td>
<td>Pt100/Pl1000 NTC 10K/100K</td>
<td>good to very good</td>
<td>&lt; 30 m</td>
<td>yes, ELMB</td>
<td>OPC, home-made</td>
<td>ELMB, OPC server</td>
<td>~3000 ~1900</td>
<td>low</td>
<td>now</td>
<td>now</td>
</tr>
<tr>
<td>4 PC Instrumentation card</td>
<td>NTC 10K/100K</td>
<td>moderate to good</td>
<td>&gt; 100 m</td>
<td>no</td>
<td>SLIC/OPC, SLIC app., home-made</td>
<td>Ext. module, SLIC app.</td>
<td>512 to ~1500</td>
<td>moderate</td>
<td>N/A</td>
<td>6-12 months</td>
</tr>
<tr>
<td>5 Instrument card + T-MUX</td>
<td>NTC 10K/100K</td>
<td>good</td>
<td>&lt; 30 m</td>
<td>yes, T-MUX</td>
<td>SLIC/OPC, SLIC app., home-made</td>
<td>Ext. module, T-MUX, SLIC app.</td>
<td>512 to ~1500</td>
<td>low</td>
<td>N/A</td>
<td>6-12 months</td>
</tr>
<tr>
<td>6 Keithley 2700/2750</td>
<td>NTC 10K/100K</td>
<td>moderate to good</td>
<td>&gt; 100 m</td>
<td>no</td>
<td>SLIC/OPC, SLIC app., home-made</td>
<td>SLIC app.</td>
<td>200 to 1000</td>
<td>high</td>
<td>N/A</td>
<td>2-5 months</td>
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<tr>
<td>7 TempScan</td>
<td>Pt100/Pl1000</td>
<td>moderate</td>
<td>&gt; 100 m</td>
<td>no</td>
<td>OPC, commercial</td>
<td>no</td>
<td>~496 to ~2500</td>
<td>very high</td>
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### Total cost estimates, KCHF

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<th>100</th>
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<td>6</td>
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<td>21</td>
<td>92</td>
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<td>891</td>
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<td>6</td>
<td>7</td>
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<td>5</td>
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<td>18</td>
<td>33</td>
<td>151</td>
</tr>
<tr>
<td>4 PC Instrumentation card</td>
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<td>8</td>
<td>24</td>
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<td>5 PC Instrumentation card + T-MUX</td>
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<td>6 Keithley 2700/2750</td>
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Acknowledgements.

Many people contributed in different ways to the sub-project. Author would like to thank members of the IT-CO group, where the sub-project was hosted: S.Olofsson, who with his energy and optimism has multiplied his official 0.6 FTE, allocated to the sub-project, by several times and put much efforts in the setting up the vertical slice equipments and making them interoperable; J-P.Puget for help with configuring commercial fieldbus/OPC products; J.Rochez and M.Merkel for their expertise and giving to loan measuring/control tools; H.Milcent for consulting on the first releases of the JCOP PVSS framework software. Special thanks to C.Nebout for organizing an office workplace, installing Windows, and help in solving numerous everyday problems.

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Also, to W.Lustermann for multiple consultations and advices, and help in organizing of calibration procedures.

Many thanks to R.Barillere and W.Salter, who periodically reviewed the project status; they made a number of valuable comments and suggestions, and helped to solve various organizational problems.

Still many people are not yet mentioned… Heart thanks to all of them.

Update (7.Dec.01): D.Myers, W.Salter, R.Barillere and W.Funk have read and commented the first draft -- most updates marked “7.Dec.01” are done basing on their comments.

References:

[AP_1] Applicom OPC server- see www.applicom-int.com

[BK_1] Beckhoff "bus terminal" products - see www.beckhoff.com (Fieldbus components > Bus terminal)

[BK_2] Beckhoff TwinCAT software - see www.beckhoff.com (TwinCAT)

[DIM_1] DIM -- see at http://delonline.cern.ch/d$onl/communications/dim/doc/www/welcome.html

[ELMB_1] ELMB home page:

[ELMB_2] ELMB radiation tests:- see http://atlasinfo.cern.ch/ATLAS/GROUPS/DAQTRIG/DCS/iwn.html

Single event effect test of the Embedded Local Monitor Box. ATLAS DCS-IWN12
- see http://atlasinfo.cern.ch/ATLAS/GROUPS/DAQTRIG/DCS/iwn.html

[ELMB_4] F.Varela Rodriguez, J.Cook, V.Filimonov, B.Hallgren
ELMB Full Branch Test: Behaviour and Performance. ATLAS DCS-IWN13
- see http://atlasinfo.cern.ch/ATLAS/GROUPS/DAQTRIG/DCS/iwn.html

[KT_1] Keithley 2700/2750 - see www.keithley.com

[NI_1] NICAN card/driver- see www.ni.com
Products & Services > Industrial Networks > CAN > PCI CAN Solutions > PCI-CAN/2

[NI_2] NI-6023E, NI-6034E cards - see www.ni.com
Products & Services > Measurement Hardware > Multifunction DAQ > Low Cost E-Series DAQ devices > NI 603xE > PCI-6034E

see also ADAC 5501 card at www.adac.com

[RADWG_1] RBFE ASICM.A.Rodriguez Ruiz et.al.
Radiation tolerant instrumentation for the LHC cryogenic system.
[RB_1] Please, contact Raymond Brun (LHC/IAS) for more details.

[SLIC_1] SLIC framework- see http://itcofe.web.cern.ch/itcofe/Projects/SLiC/welcome.html


[TS_2] ScanServer- see http://www.iotech.com/catalog/software/scanserver.html

- see http://itcowww.cern.ch/DCS-CMS/dcs-day-presentations/CMSDays2000/DCS.pdf