COLD DETECTOR “ENVIRONMENTAL” ISSUES-MONITORING & CONTROL

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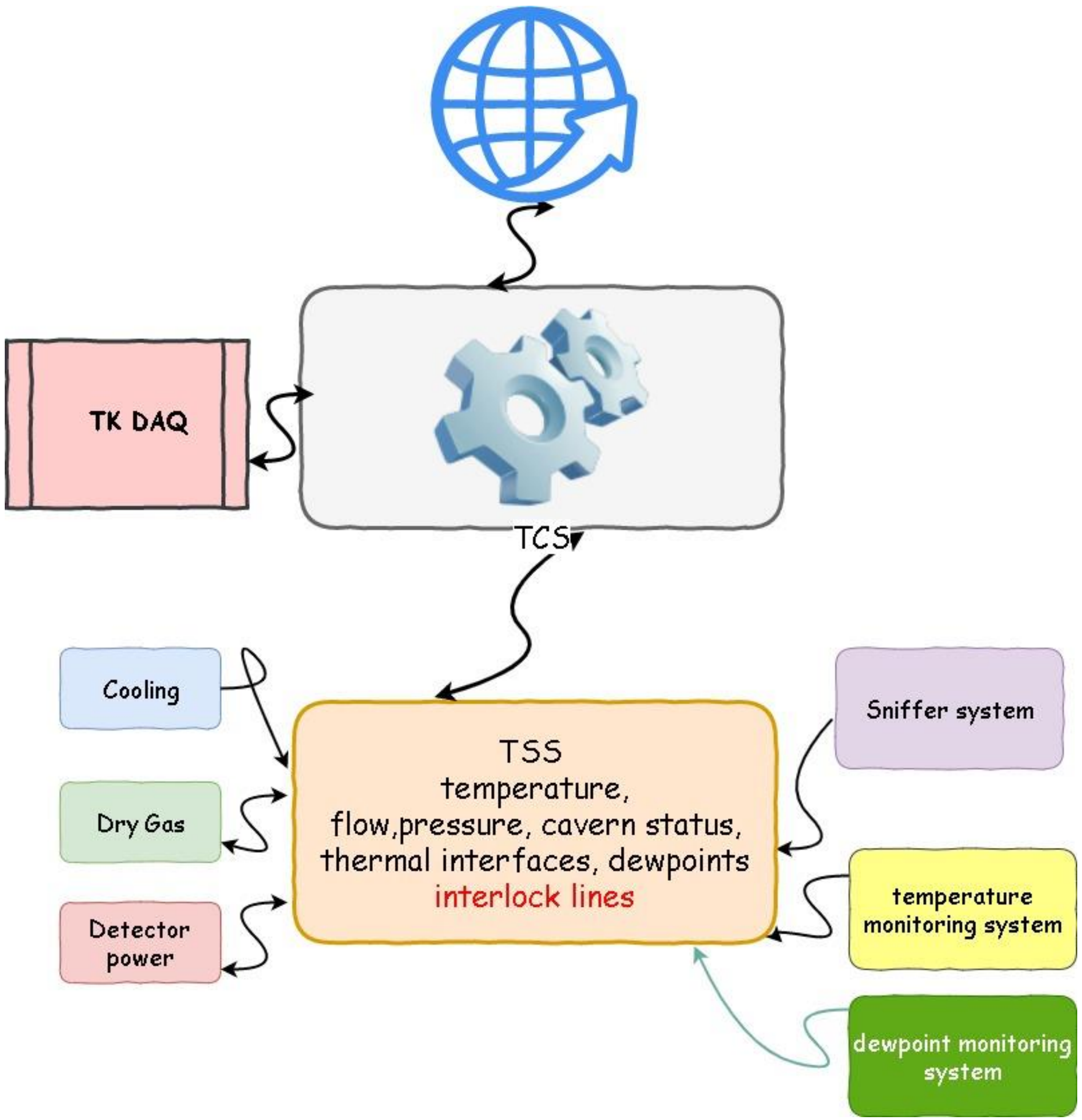
1. DSS/DCS; their role in detector and detector integration. Projected role in Ph II.
2. Environmental parameters (identification, operation/testing, sensor issues).
3. Existing solutions to environmental issues in the context of DSS/DCS.
4. Timetable for possible deliverables, status of tests, foreseeable problems.

* till 30/12/2020

1. DSS/DCS; their role in detector and detector integration. Projected role in Ph II.

DSS and DCS (“T”SS and “T”CS) are the two systems that
ensure the safe existence of the Tracker during any phase of its life (operation, shutdown or modification periods) – TSS-
and its operation as a scientific instrument –TCS-.
It is therefore essential :

- to select a qualified TSS platform and engage in connecting <u>all</u> systems and parameters that affect the Tracker safety to it. This is done, CERN-wise, having picked up an industry standard (“PLC”), a very robust, discless computer that has built in many control processes and provides automatically conditioning to all industrial standard sensors. PLCs are COTS-at a cost!
- to select an equally qualified TCS platform keeping in mind that TSS communicates via TCS but exists autonomously. Many more systems communicate via TCS which combines all to build an interface between the user and the instrument (Tracker). All subdetector DCS systems together build the CMS DCS; the operation panel of the detector. The CMS (LHC-wise) SCADA system is “PVSS-WinCC OA”, also an industry standard. The Tracker has developed many of the necessary software SCADA components to be re-used by cold detectors.
- Both TSS and TCS should be operational at CMS before the Tracker Ph II installation and at integration sites.


TK DAQ
TCS
Cooling
Dry Gas
Detector power
TSS
temperature,
flow,pressure, cavern status,
thermal interfaces, dewpoints
interlock lines
Sniffer system
temperature monitoring system
dewpoint monitoring system

2. Environmental parameters (identification, operation/testing, sensor issues)..

The most important environmental parameter in a Si-based detector is temperature; it depends on the "environment" (cooling system) as well as on the operating status of the detector. The Ph II Tracker will be equipped with thousands of temperature sensors read via the DAQ on a stream that will be almost always available. This is also the case of the current Tracker (DCU). Much less numerous but hardwired temperature sensors always available are necessary for DSS but not only.

These **temperature sensors** should be radiation tolerant, adapted to the detector conditions and integrable to DSS. They must be small (<mm), COTS and require no calibration. In the current TSS systems we have both commercially available thermistors and RTD sensors.

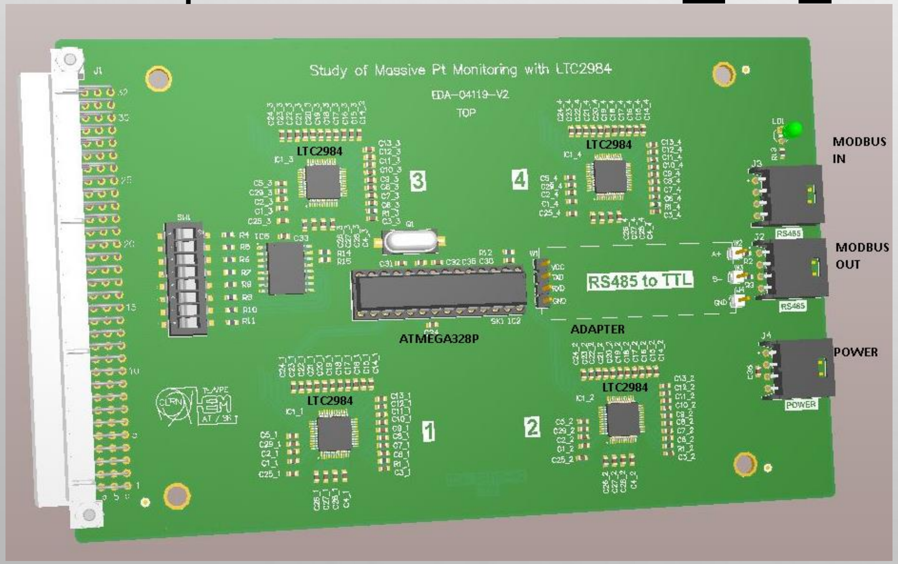
The lessons we have learned from the current Tracker:

1. RTDs are a perfect solution; they require no calibration and have shown no degradation.
2. Four-wire connections guarantee correct measurement at any wire length (thickness of wire irrelevant).
3. For the Tracker, it makes sense to have the sensor wires in the powering cables. A few dedicated cables will always be needed.
4. Not all the hardwired temperature sensors need to be on DSS systems. Just next to them and available on DCS.

* if there is a choice

3. Existing solutions to environmental issues in the context of DSS/DCS.

During Ph I too many temperature sensors have been included in the TSS system (~300/subsystem). TSS has been used as a secure temperature monitoring hardware platform. The TSS hardware should include input channels only if the channels are part of the interlock logic. In Ph II a certain number of temperature sensors will enter in the interlock logic (TSS) but all hardwired temperature sensors will be readily available for connection to TSS if needed while on permanent monitoring on TCS. 134 temperature sensors will monitor critical spots for the TSS interlocks (preparing a TSS system with 180 temperature inputs). The rest of hardwired temperature sensors is 1020. Some will come on dedicated cables (Tracker services), but mostly on wires in the power cables. Signal extraction and grouping of these sensors is not discussed here. For those sensors and, more generally for the efficient massive monitoring of RTD sensors at reasonable price, we developed a system with less than 10% cost of the TSS channel in value and space. We call this the <u>M</u>ulti<u>T</u>emperature<u>R</u>eadout<u>S</u>ystem (MTRS).



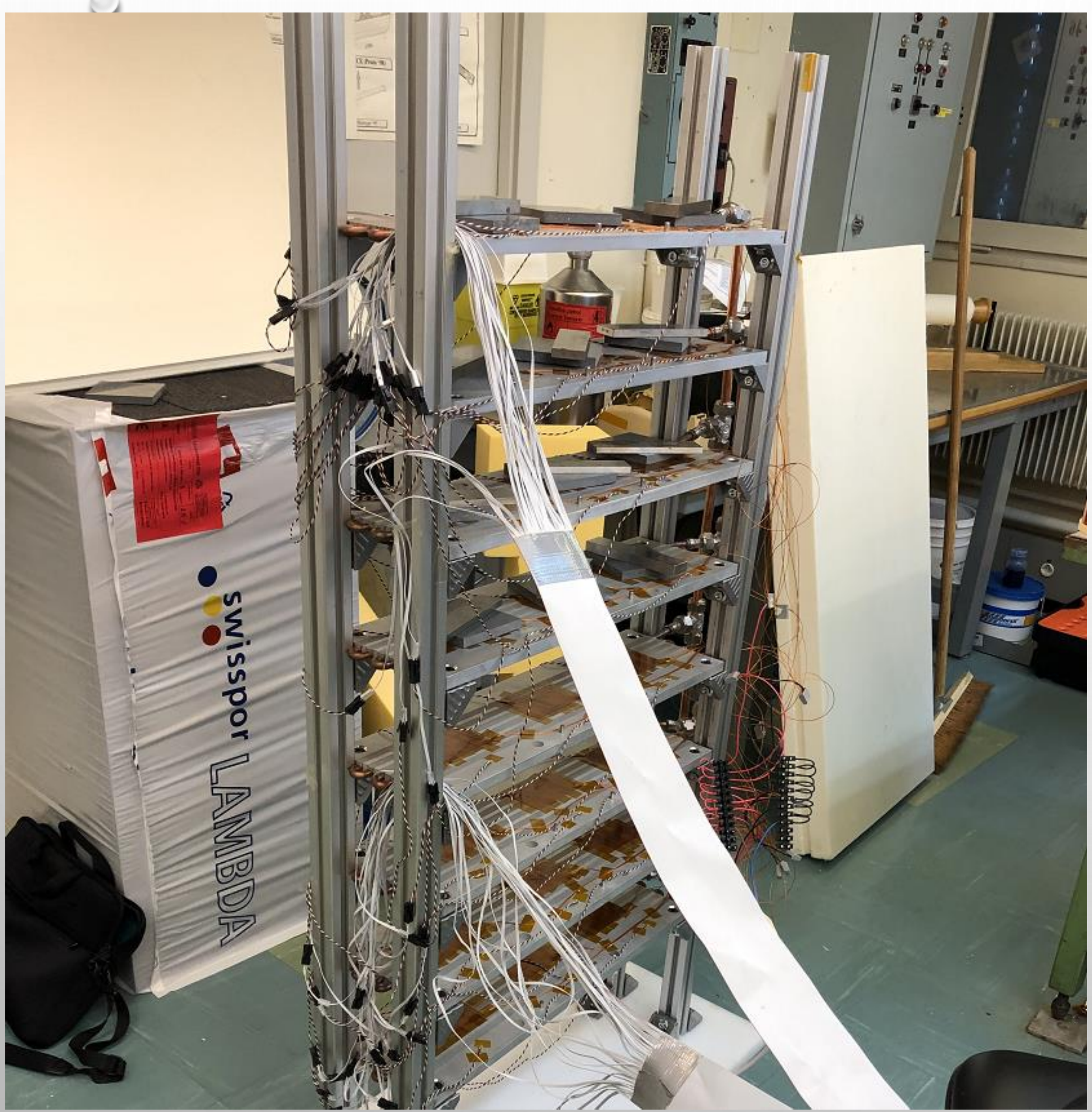
We developed this on the following principles:

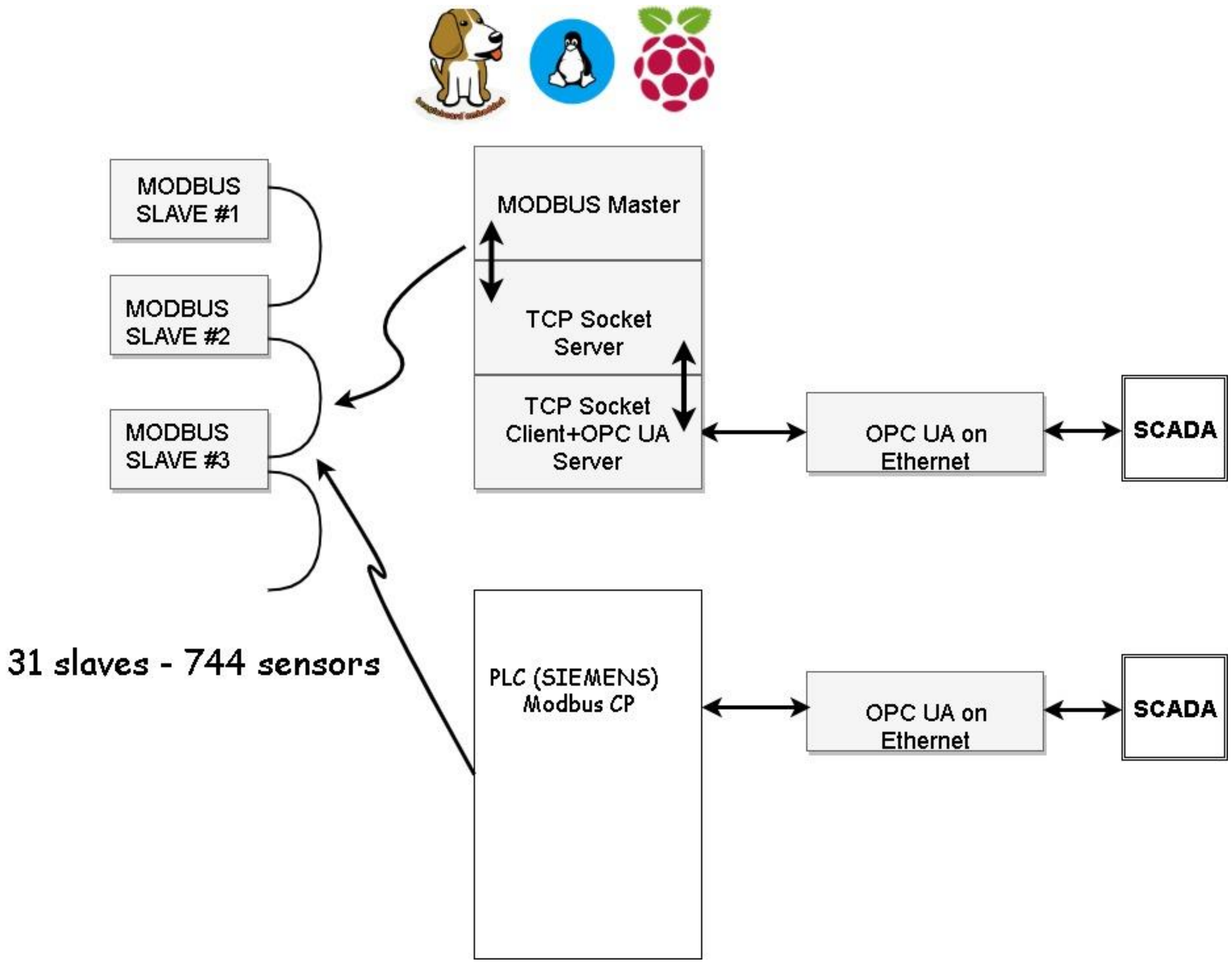
- Accepting all 4- and 3- wire RTD (1K and 0.1K)
- NO multiplexing
- Accessible <u>via OPC UA</u>, via <u>TCP/IP sockets</u> AND <u>directly integrable in the PLC CP</u>

It makes use of the recent (~5yrs) technological “explosion” in anything that has to do with sensing and sensor conditioning. We have designed a Eurocard 3U sized monitoring card based on the LTC2984 chip that conditions and monitors up to 24 RTD (4 or 3-wire) (EDMS EDA-04119-V2).The card format means that a 3U crate can house 744 temperature sensors. The same for the TSS system would be more than 60 U…(~2 LHC racks)

The card can be used in three ways (after all TCS is “just” software):

- As a standalone object(24 RTD sensors) data in text (xls) files on one’s pc.
- As a group of up to 31 cards (744 RTD sensors) connecting via almost any type of processor (Raspberry pie, Beaglebone etc.) via a classical TCP/IP socket system.
- With the above multiplicity via an OPC server running on almost any processor and connecting to the CMS SCADA or any SCADA system.
- Integrated to PLC– based DSS systems and connecting through those to the CMS SCADA system (PVSS). This means that the monitored values could be directly integrated in the PLC logic.


swisspor
LAMBDA


MODBUS SLAVE #1
MODBUS SLAVE #2
MODBUS SLAVE #3
31 slaves - 744 sensors
MODBUS Master
TCP Socket Server
TCP Socket Client+OPC UA Server
OPC UA on Ethernet
SCADA
PLC (SIEMENS) Modbus CP
OPC UA on Ethernet
SCADA

Where are we currently with the project:

- Twelve cards have been produced; the card is a standard card that can be produced (outsourced) by the CERN PCB lab. Material at hand for another hundred.
- We are looking into a front panel and supports in the 3U Eurocrate. The "mechanics" will also be something we buy.
- The software has been developed by P.G.Verdini, H. Tekis. We are starting a collaboration with the St. Joseph University in Lebanon (school of computer engineering) for further standardization. Code repository exists.
- We will be able to provide one (two?) types of cables allowing the connection of 24 RTD sensors. These cables can be ordered at CEGELEC, St.Genis (they produce them regularly).
- We are still collecting data for the next card production (targeting the Tracker, HGCAL, and the timing layer) where we would like to drop the cost to 5CHF /channel. The integration facilities will be even stronger consumers, all this must be organized
- Next step for us is designing and building the TCS and TSS(temperature monitoring systems) for the Tracker/TIF, and in collaboration with the HGCAL and Timing layer DSS teams, their respective DSS and temperature DCS. We expect to have the Tracker/MTD TIF one by the end of the year if the appropriate budget exists.

Other environmental parameters; dewpoint, Oxygen, CO2…

Dewpoint is the second most important parameter to monitor in cold detectors (and their services); however, even the simplest dewpoint or rel. humidity sensors (and therefore the preferred ones for a device like the future cold detectors) cannot be made from a slab of metal (..RTDs) we have two approaches to the problem :

1. Extracting gas from spots to be monitored inside the detector (currently 26). This means (long, ~120m) piping, pumping and running an "industrial" dewpoint monitoring sensor per line (also flow/pressure measurements); that is gas analysis racks
2. Have humidity sensors inside the detector; this means "consumer electronics" sensors, small (mm), radiation tolerant and capable of being conditioned and read out over long (~120m) wires. The Tracker has tried before and failed because the sensors were not "engineered" enough (HMX). A similar, yet different, approach is going to be presented by Amar. This sensor is important for services and where the cold detector consists of closed volumes where the "local" dewpoint measurement is important.
3. In Ph II we are/will be having another system like (1); only much more extended and optimized –the smoke/O_2 sniffer system – should we try to kill two(three, four) birds with one stone? The "idea" is to use indispensable smoke detection piping for more than smoke detection.


FESTO
2.11
3.11


VAISALA
XANA-9117/4
PT 9116
9115
PT 9114

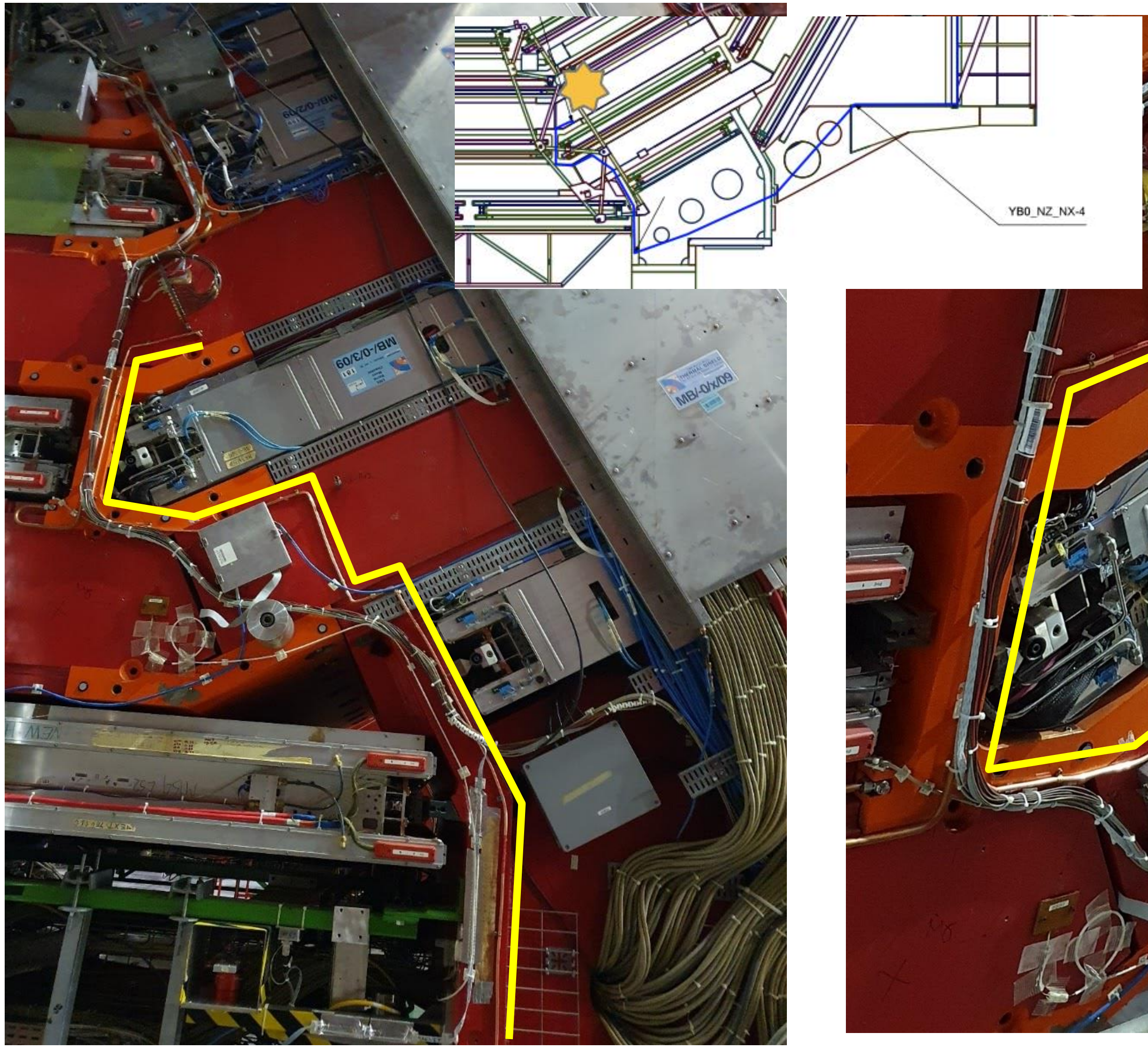
<u>Safety</u>:Roberto Perruzza -<u>Sensing, monitoring and control system:</u> Andromachi Tsirou ,Piero Giorgio Verdini (INFN Pisa), Andreas Sochopoulos , Andrzej Stanislaw Nagi -<u>Integration and routing</u>: Andrea Gaddi, Ali Karaki, May Alali CERN

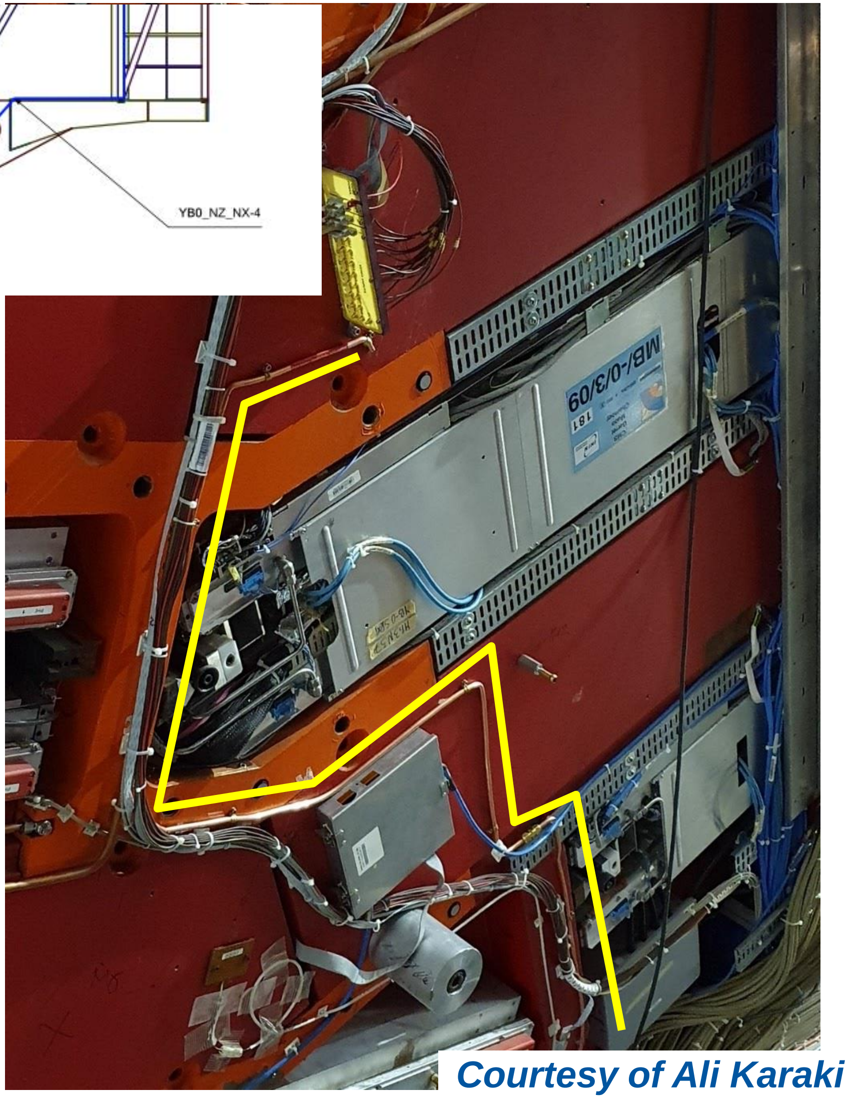
- In the current detector we have a smoke/O_2 sniffing system AND a dewpoint sniffing system. In Ph.II we should combine dewpoint with smoke/O_2/ CO_2 detection into the "Sniffing system".
- The Sniffing system should be one and be an integral part of the detector mechanics up to the first connection rack(s). All components, sensors included should be COTS. Pneumatic multiplexing (~10 lines per valve/pump) should be used for all measurements but dewpoints for cold detectors. Thus the smoke/O_2/CO_2 sensors will exist per pumping station. There has to be an educated compromise on the number of pipes; current requests based on the dewpoint monitoring are for a bit less than 200.

We are working towards defining (measuring) all parameters for this. Piping (in Cu), pumping and pneumatic multiplexing issues are studied. We are testing CO_2 and O_2 sensors (we have experience with the dewpoint ones). Once the parameters fixed, the complete design (and size) of the system will be presented (~1 year from now; this is pressing because USC space has to be claimed). But – a common large system is smaller than more small(er) ones.

- The dewpoint sensors belonging to different subdetectors will be an integral part of their DSS/DCS system.
- Most (70%) of the DCS software is already existing, thanks to the Tracker, Sniffer and central DCS work.
- More engineering presence will be needed when the studies will be finished.

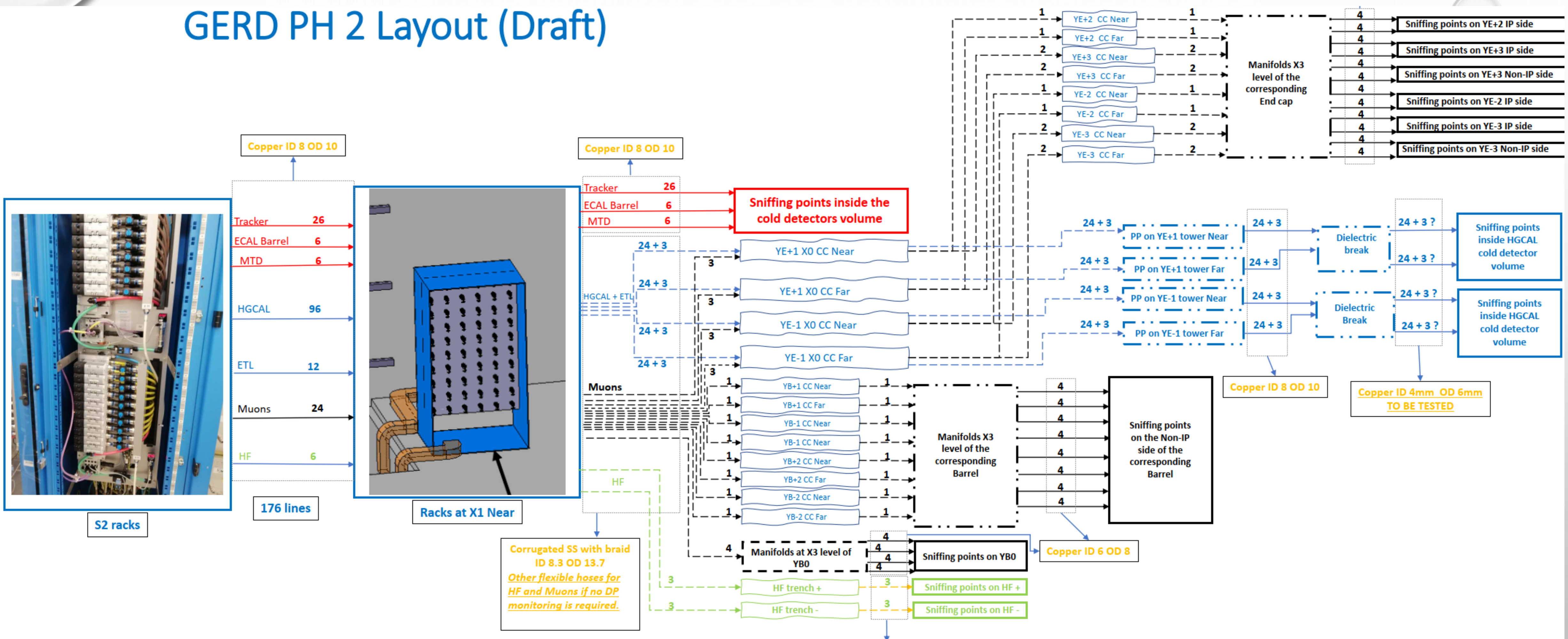
UXC55 (now): Sniffing points





Courtesy of Ali Karaki

GERD PH 2 Layout (Draft)



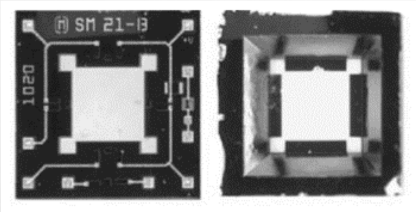
- *YB0 muons lines can remain copper between X1 rack and X3.*
- *Mobile barrels and HF lines can stay in copper until CC entry*

A. Karaki 29/04/2021

Humidity sensor choice

- “consumer electronics” sensors, small (mm), radiation tolerant and capable of being conditioned and read out over long (~120m) wires” BUT ALSO “capable of 5% resolution at (at least) $-30^{0}C$”. We are seeking a sensor whose output will change with irradiation in a way that it can be “described” by an analytical formula for its whole lifetime inside the detector.

- Resistive (electrical conductivity) humidity sensors



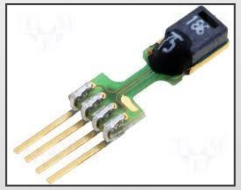
HMX2000

No cable length problem,
Wheatstone bridge type sensor,
ideal, but not engineered enough

- Capacitive humidity sensors

Precon
HS2000

Honeywell
HIH4030



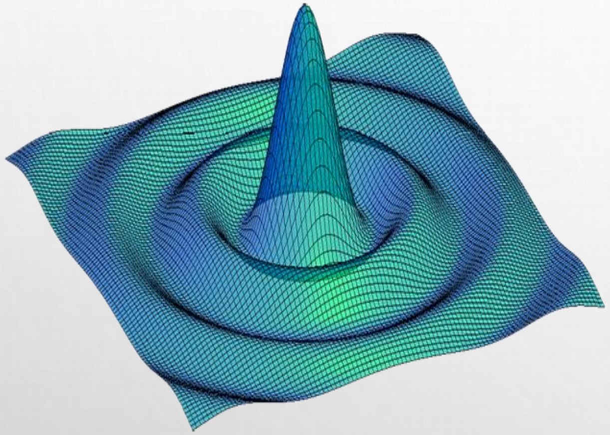
Sensirion
SHT75

Our choice is the “sensor”
of the Sensirion

MK33-W

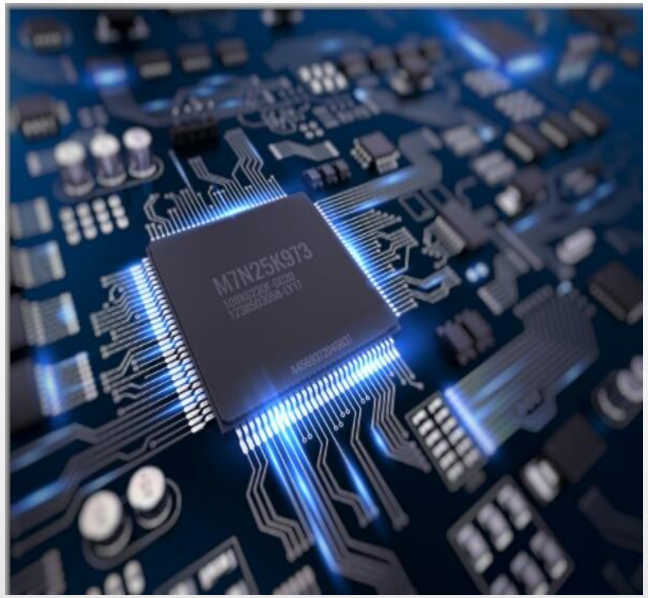
produced by iST Innovative Sensor Technology physical. chemical. biological.

PART I



Characterisation and Modelling of Humidity Sensor

PART II

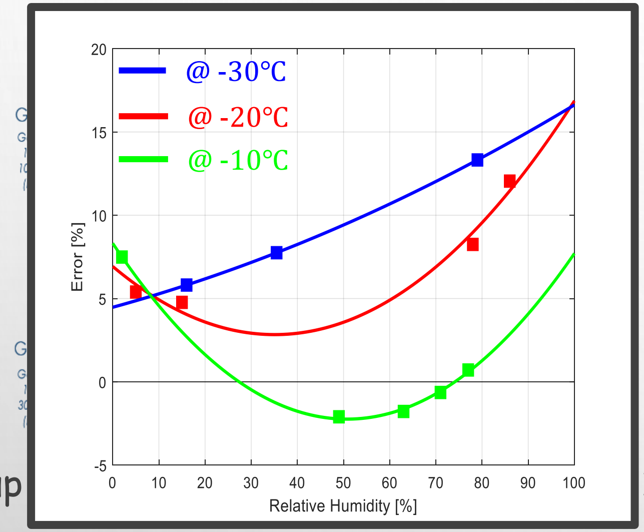


Readout System

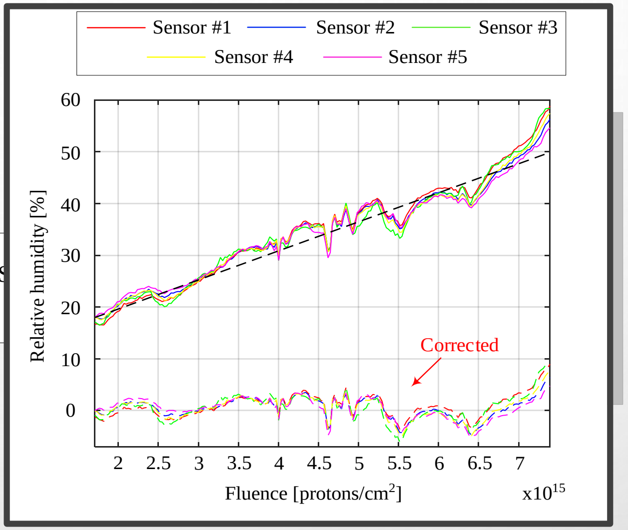
PART III

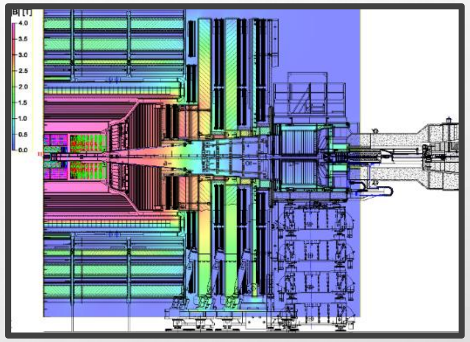
Design of Multi-Sensor System Architecture

Sensor characterisation and modelling



Setup ... 186

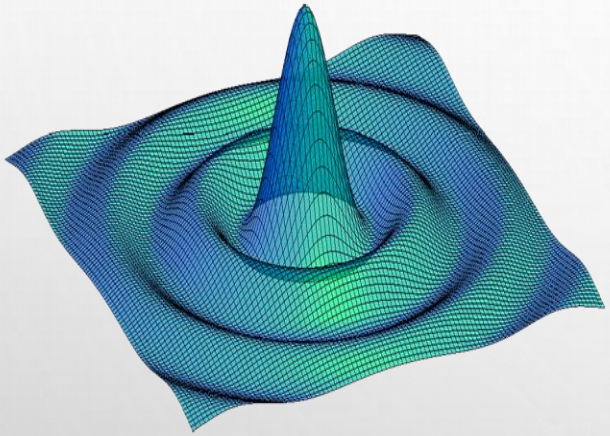




f (C, T) *f* (fluence) *f* ($\vec{B}$)

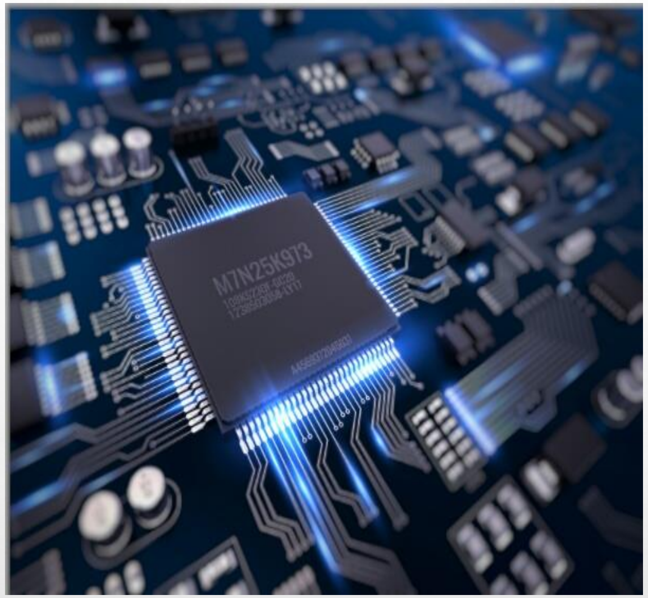
$$\boxed{\%RH = f\,(C, T, \text{fluence}, B)}$$

PART I



Characterisation and Modelling of Humidity Sensor

PART II

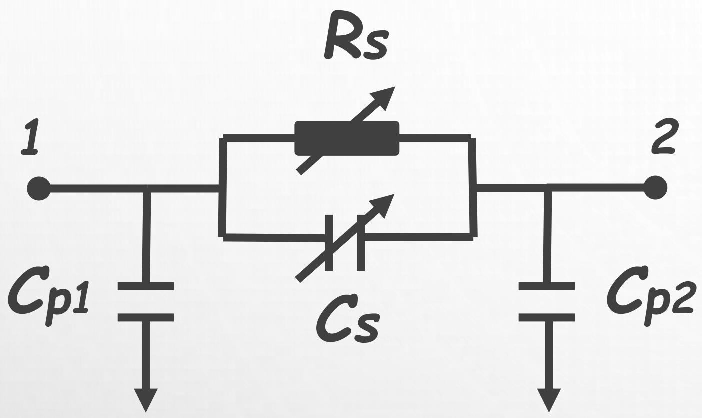


Readout System

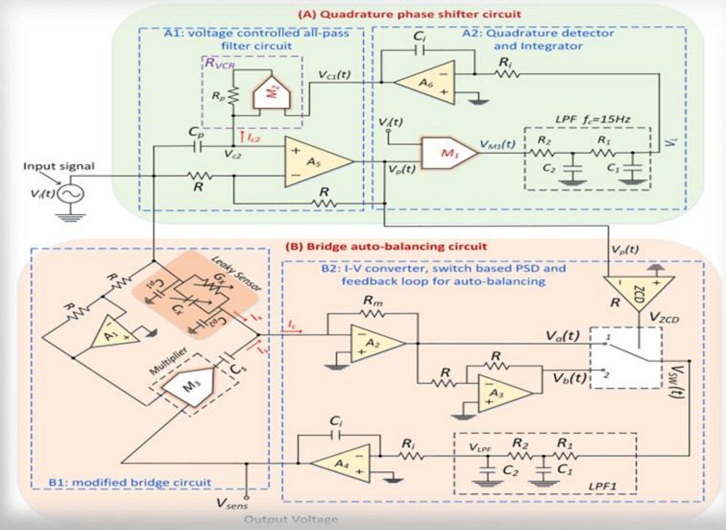
PART III

Design of Multi-Sensor System Architecture

Electrical Equivalent Circuit



Cs – sensing capacitor
Rs – dielectric loss
Cp1 , ***Cp2*** – stray capacitances due to sensor leads



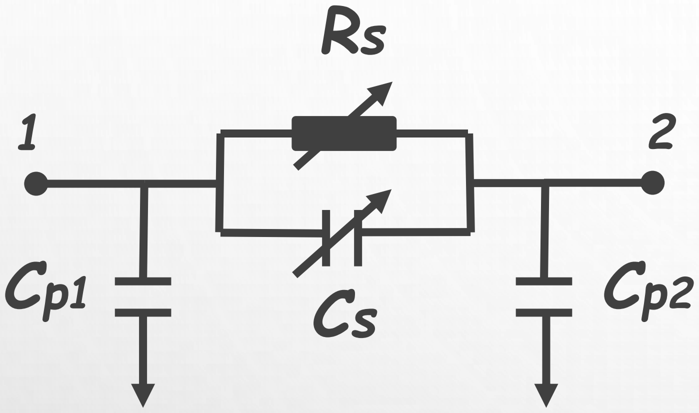
Part A: Quadrature phase shifter circuit

- To generate a phase-shifted output signal

Part B: Auto-balancing bridge circuit

- Separation of the capacitive components by demodulating the bridge output

Electrical Equivalent Circuit



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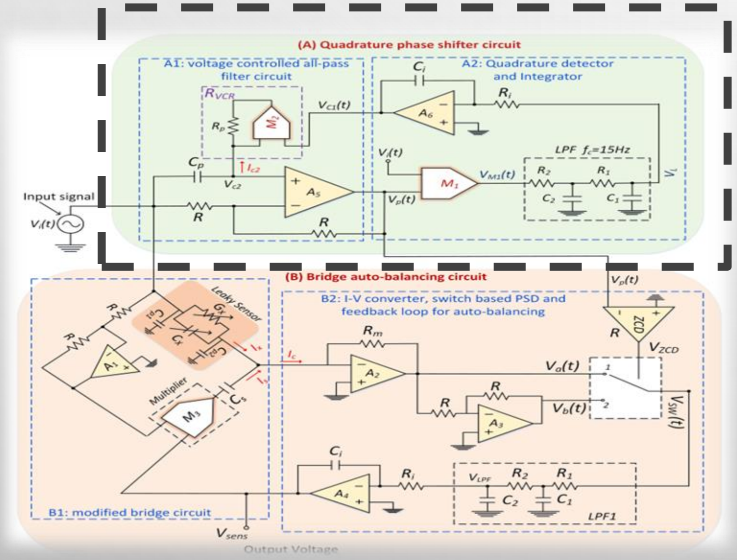

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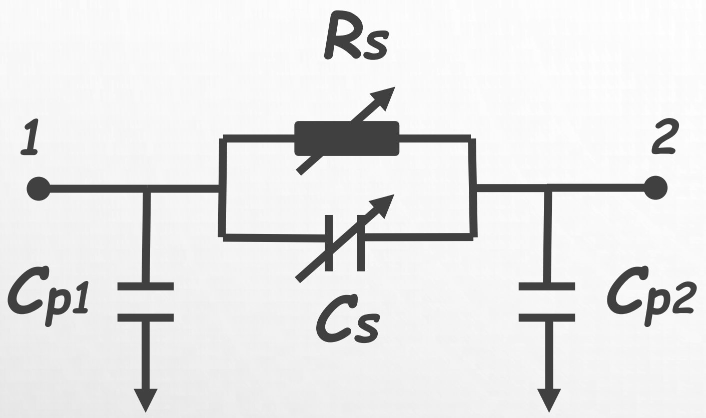
Electrical Equivalent Circuit



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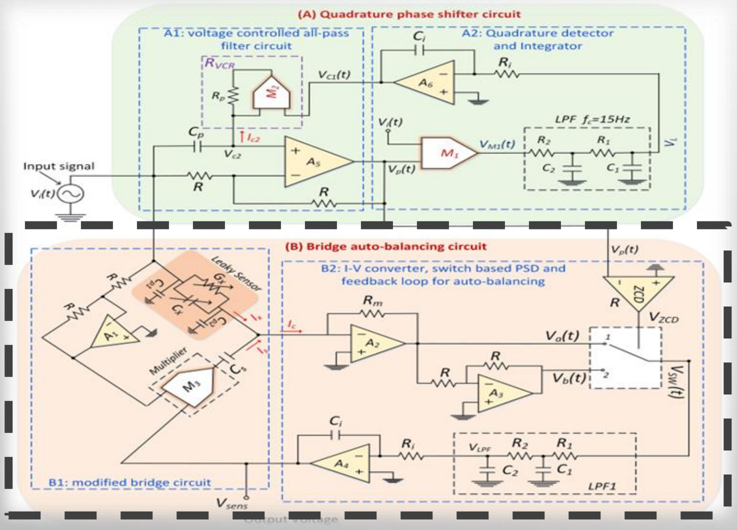

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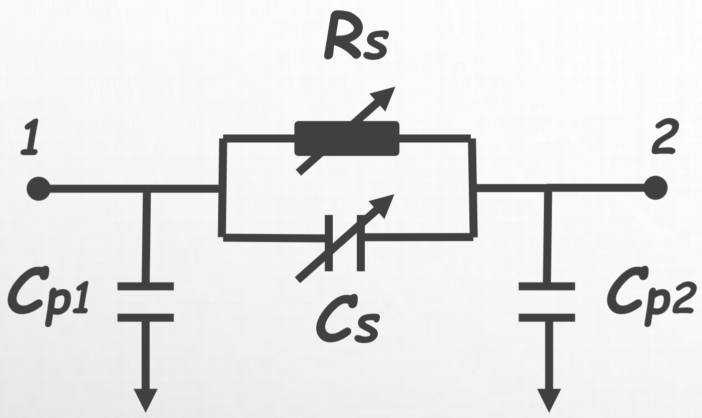
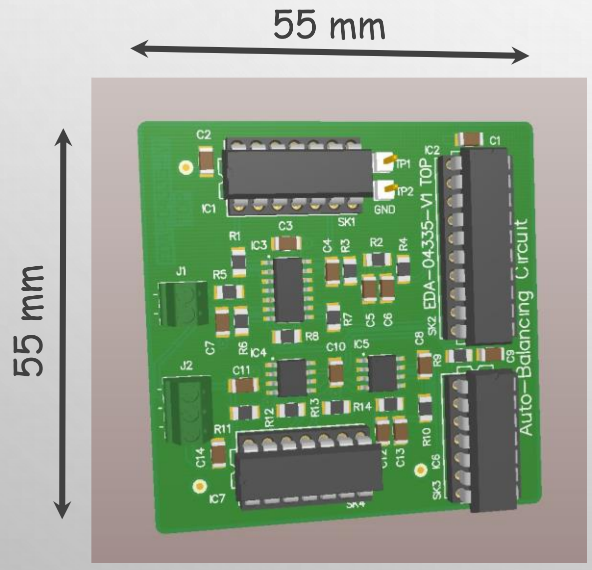
Electrical Equivalent Circuit



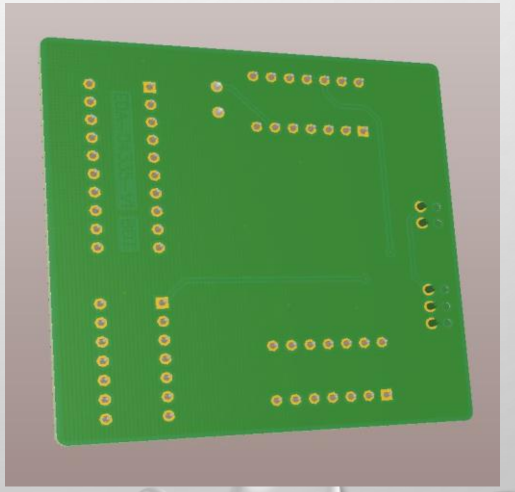
C_s – sensing capacitor

R_s – dielectric loss

C_{p1}, C_{p2} – stray capacitances due to sensor leads



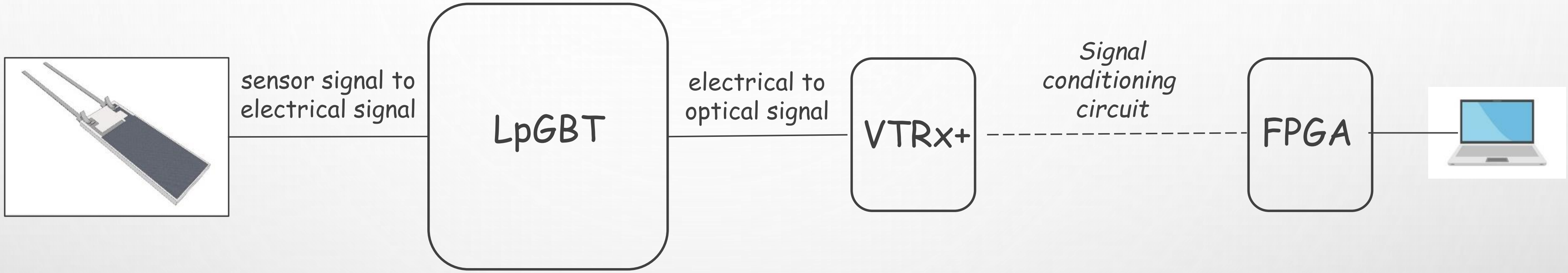
Top side



Bottom side

Sensor readout

One option:



<u>From sensor datasheet</u>

Measurement frequency: 1 kHz to 100 kHz (recommended 10 kHz)

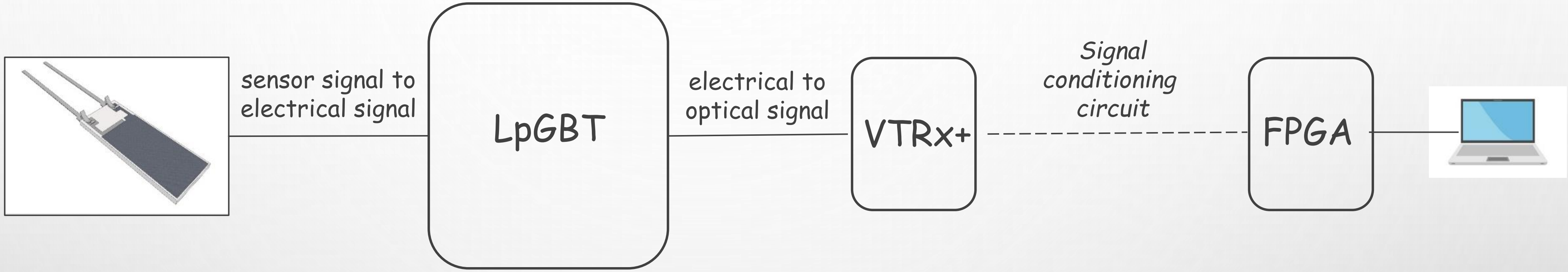
BUT ... LpGBT lowest frequency ~ 40 MHz ☹

Designing circuit between sensor and LpGBT chip ?

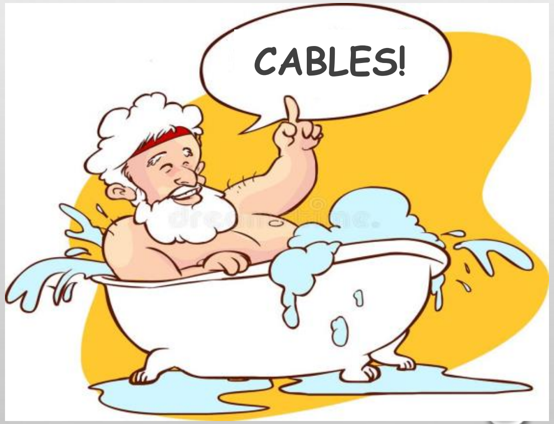
- *Still in testing phase*
- *Not accessible to everyone for testing*

Sensor readout

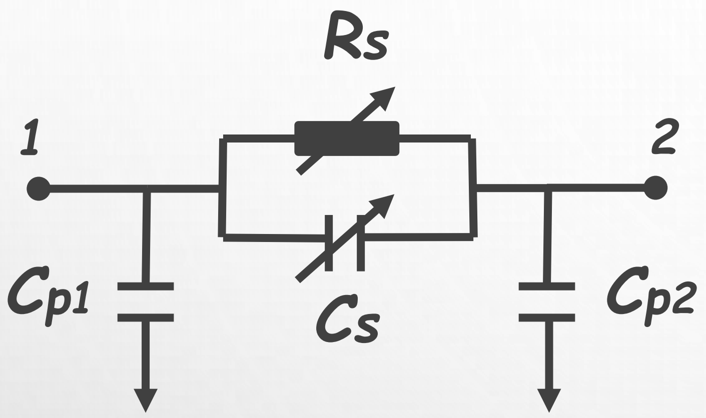
One option:



Another option:



Electrical Equivalent Circuit



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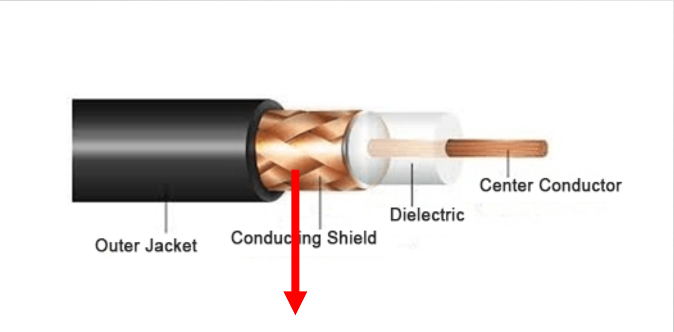
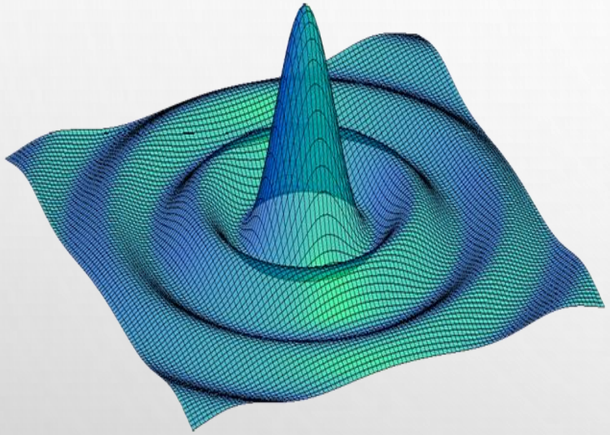


up to 500 pF

- Sensor capacitance: 300 ± 40 pF
(at 30 %RH and at 23℃)

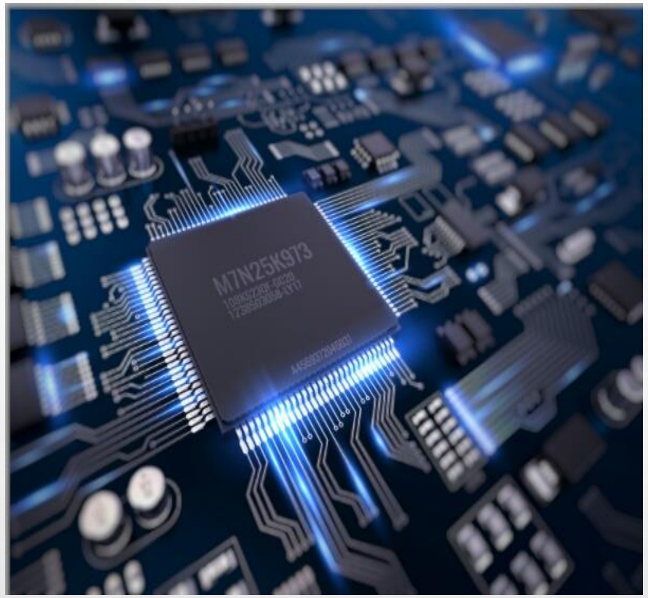
- Capacitance of coax cable: 100 pF/m

PART I



Characterisation and Modelling of Humidity Sensor

PART II



Readout System

PART III

Design of Multi-Sensor System Architecture

Multi-Sensor Array System

Tracker:
Temperature: **-30** ℃
Fluence: $2 \cdot 10^{16}\ to\ 1 \cdot 10^{17}\ n_{eq}/cm^2$

1. Designing system architecture

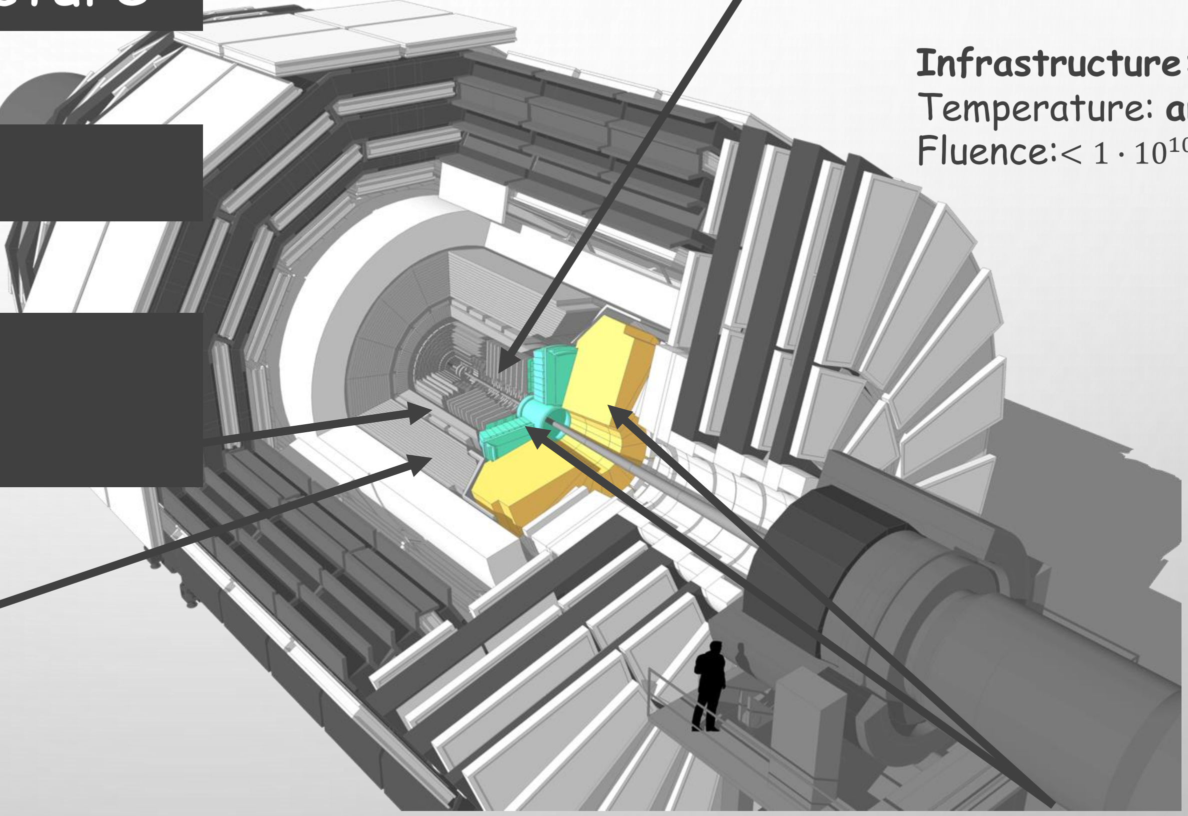
- More sensors

Infrastructure:
Temperature: **ambient** ℃
Fluence: $< 1 \cdot 10^{10}\ n_{eq}/cm^2$

2. Establishing the model

- RH = *f* (model#1, d)

3. Validating system for different subdetectors



ECAL:
Temperature: **10** ℃
Fluence: $2 \cdot 10^{15}\ to\ 2 \cdot 10^{16}\ n_{eq}/cm^2$

HCAL:
Temperature: **23** ℃
Fluence: $2 \cdot 10^{13}\ to\ 2 \cdot 10^{15}\ n_{eq}/cm^2$

HGCAL:
Temperature: **-30** ℃
Fluence: $1 \cdot 10^{13}\ to\ 2 \cdot 10^{16}\ n_{eq}/cm^2$

Milestones and Conclusions

- MTRS Realistic estimate of temperature monitoring boards needs (final detector and integration centers) in order to launch larger scale production (end 2021 and 2022? Better wait for electronics components market to stabilize). The Tracker DSS system design and construction for the TIF tests (shared with BTL) and for the final P5 system will start as soon as the environmental sensor cabling is clarified.
- The “sniffer system” tests will be concluded by April 2022. At the same time, pipe-counting and integration issues will be settled. A design of the proposed system will follow, to be released by the end of 2022.
- The dewpoint sensor/readout

✓ Equipping the IRRAD facility (in the next months, even with prototypes), two sensors required (they have our very prototype version)

✓ Put whatever else we have in the HGCAL cassette mockup to function together with the Sensirion SHT30 or 31- studies to finish by the end of the summer.

✓ Prepare to the test on magnetic field

✓ Prepare for the final irradiation.

✓ Rework the readout circuit (EDA-04335-V1-2) optimizing parameters and achieving a higher number of channels in a 3U Eurocrate format.