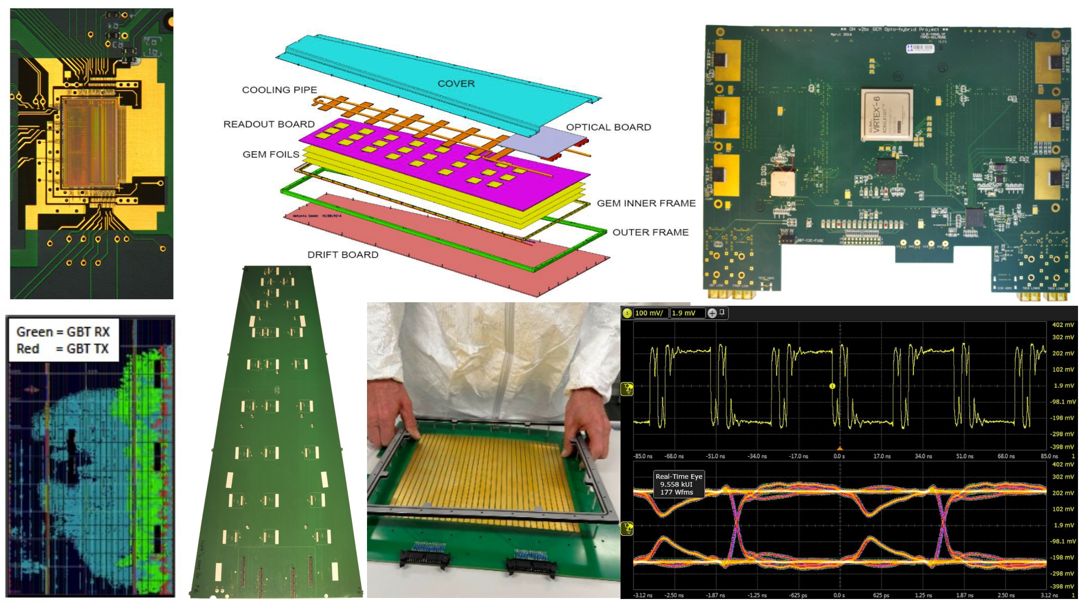
R&D @ IIHE

G. De Lentdecker (ULB)



Introduction

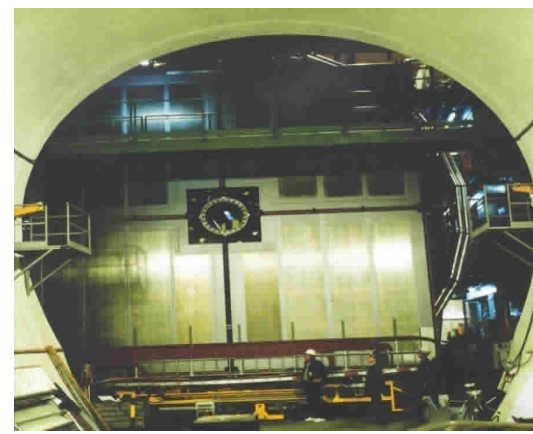
- Today, I extended my talk beyond R&D at collider
  - However you may find some R&D activities in other talks (RNO-G, RET, JUNO, AUGER, etc.)
  - I will not talk about CMS Tracker upgrade activities as you have just seen its dedicated talk ;-)

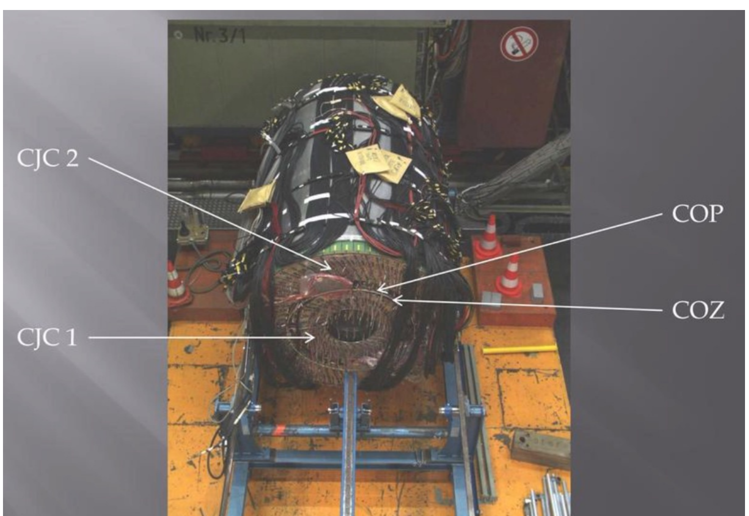
- On a more personal note:
  - All IIHE current projects have started with or from R&D
  - R&D does not always converge into a large scale or a well defined project
  - It is vital for our lab to maintain a significant R&D activity

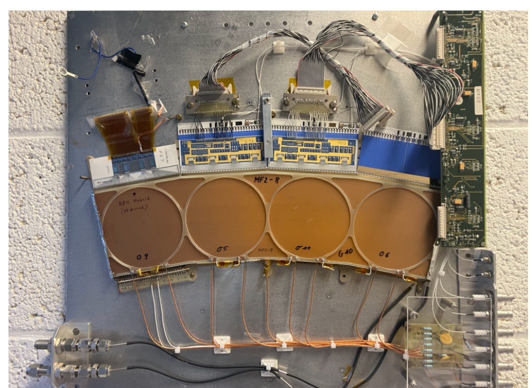
PART I: Gaseous Detector Developments

Gaseous Detectors at IIHE: a long tradition

- IIHE has a long tradition in gaseous detectors
  - (mid-80's) Drift chambers for the Muon system of Delphi
  - (mid-90's) COP (central outer proportional chamber) of H1
  - (End of 90's) MSGC and their variants for CMS Tracker
  - (2000's) Resistive Plate Chambers for CMS
  - (2015) Triple-GEM for CMS

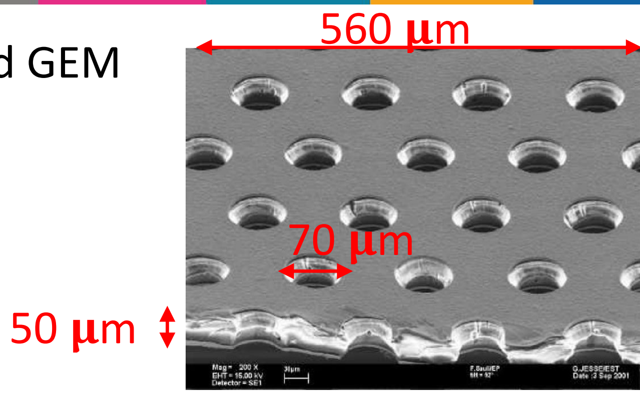


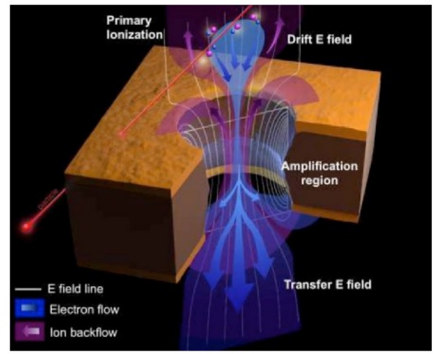


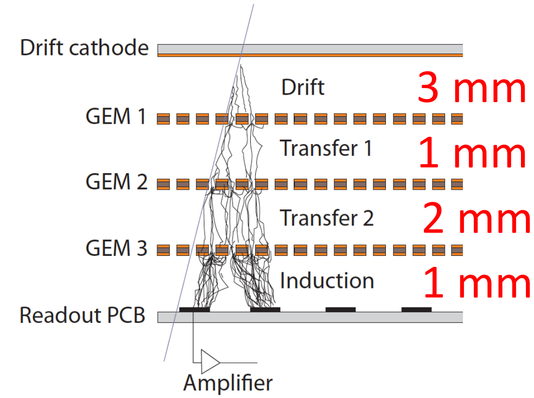


Today's technologies

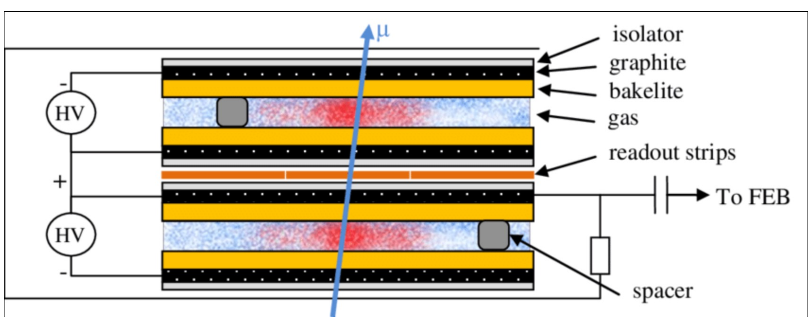
Standard GEM







Double gap RPC (standard, bakelite)



	RPC	Triple-GEM
Spatial resol. (mm)	1.0	0.2
Time resol. (ns)	1.0	10
Rate capability (kHz)	1.0	> 100
GWP gas	>1000	1
production	easy	complex

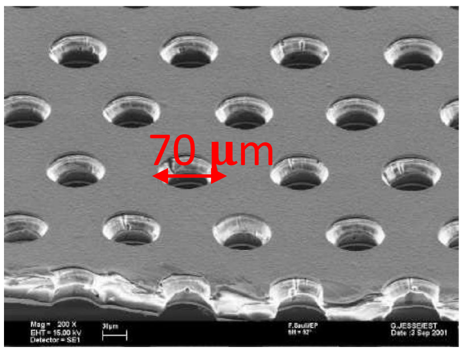
Used in many experiments (mainly for muon systems):
CMS (RPC & GEM)
ATLAS (RPC & MMEGAS)

Next generation technologies

Standard GEM

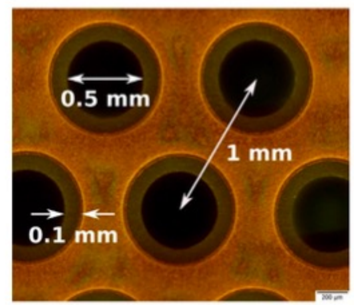
- Thin (50 um) Kapton foil
- Chemical etching to create the holes

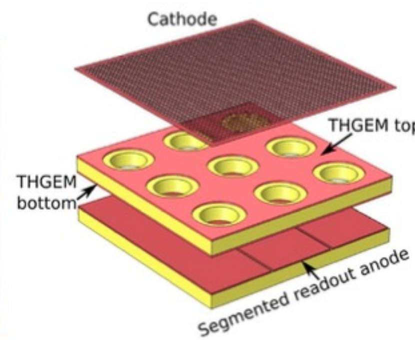
50 µm



Thick GEM (TGEM)

- Use traditional Printed Circuit Board (PCB)
- Mechanical drilling

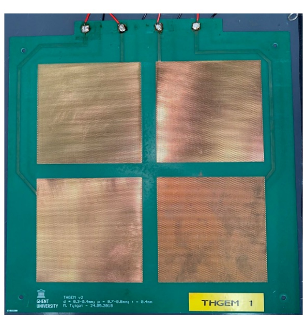


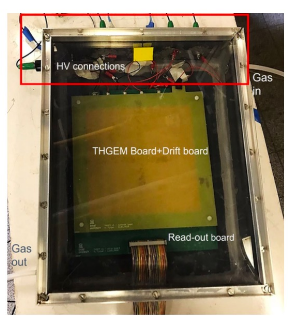


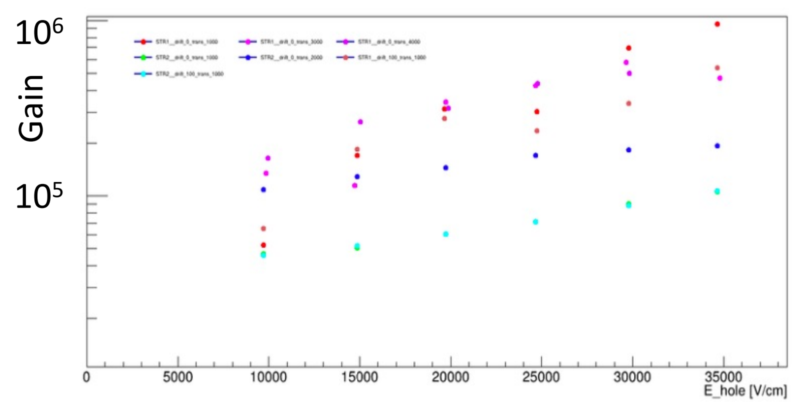
- More robust & easier to assemble

- First tests with multiple GEM patterns (note the high gains)

thickness=0.4mm;
hole diameter=
0.3-0.4mm;
rim size = 0.1mm;
pitch=0.7-0.8mm

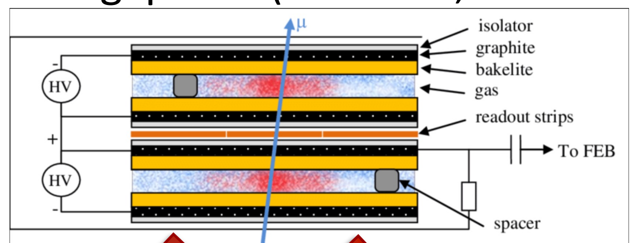




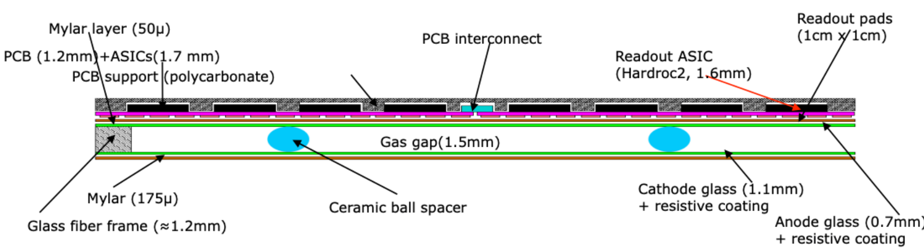


Next generation technologies

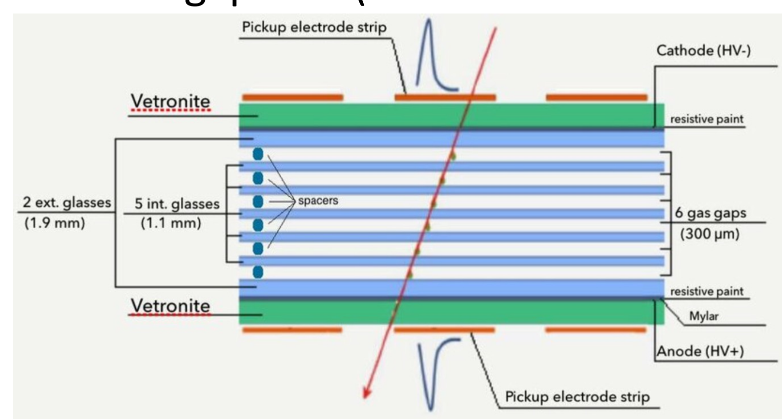
Double gap RPC (standard, bakelite)



glass RPC (gRPC)



multi gap RPC (mRPC



Advantages of gRPC:

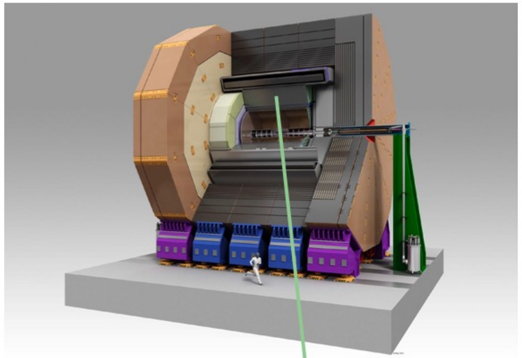
- Excellent surface quality -> no oil needed
- More rigid -> thinner plates
- Higher rate capability (with doped glass)

Advantages of mRPC:

- Better time resolution ~50 ps

PART II: Gaseous Detector Applications

Application #1 : SDHCAL



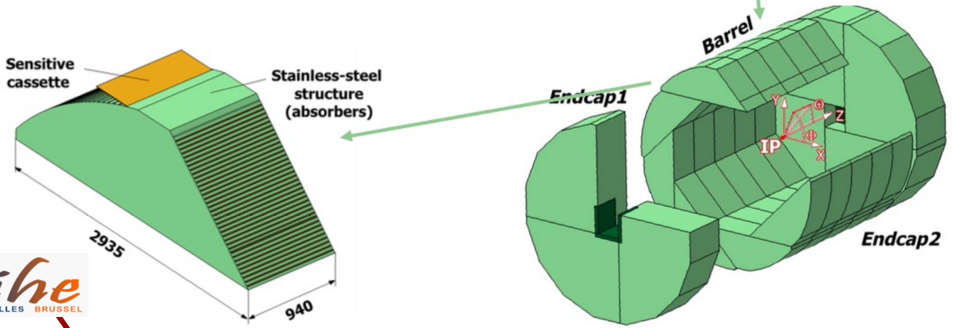
Semi-Digital Hadron CALorimeter

The SDHCAL-GRPC is one of the two **highly-granular HCAL** options **based on PFA**; part of the **International Large Detector (ILD)** baseline detector option originally proposed for **ILC/CEPC**, and now also for **FCCee**

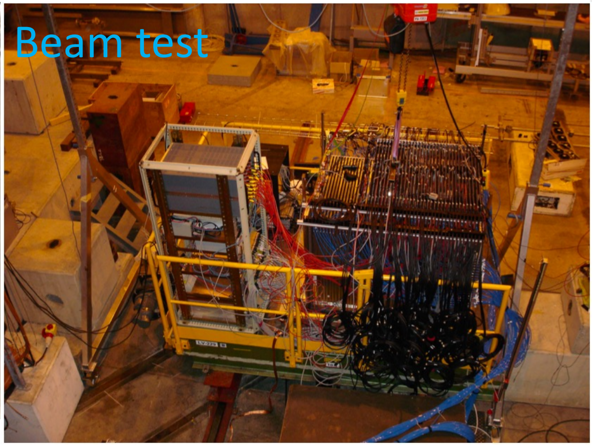
Modules are made of 48 RPC chambers (**$6\lambda_I$**) equipped with **semi-digital, power-pulsed electronics** readout and placed in **self-supporting mechanical** structure that serves as absorber as well

The structure proposed for the SDHCAL:

- very **compact** with negligible dead zones
- eliminates projective cracks
- minimizes barrel / endcap separation (services leaving from the outer radius)

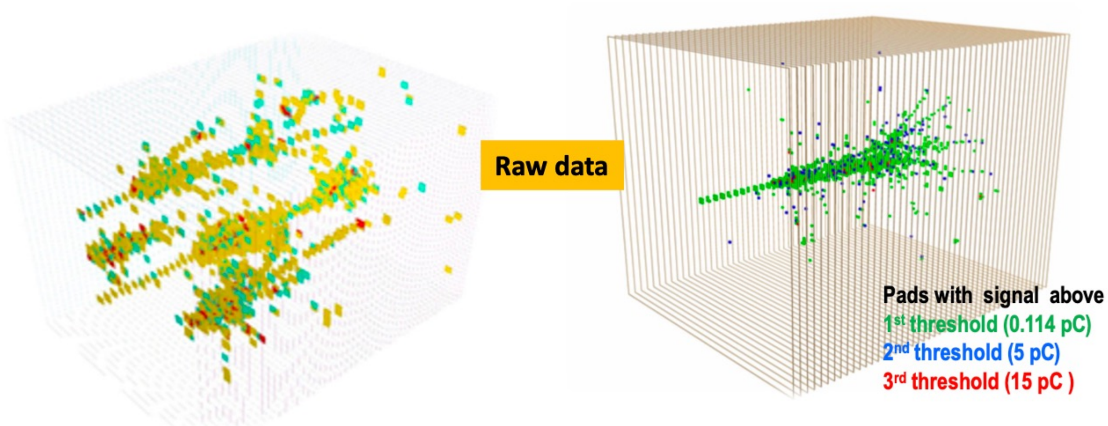


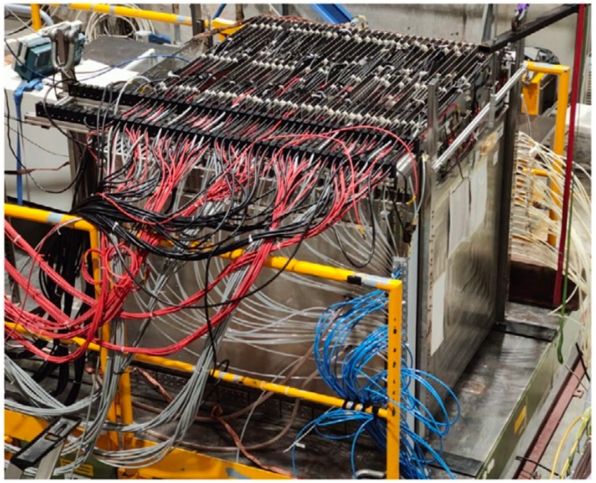
Challenges:
- -Homogeneity for large surfaces
- -Thickness of only few mms
- -Lateral segmentation of 1 cm x 1 cm
- -Services from one side
- -Embedded power-cycled electronics
- -Self-supporting mechanical structure

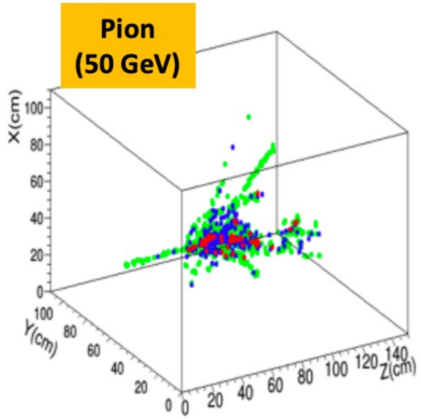


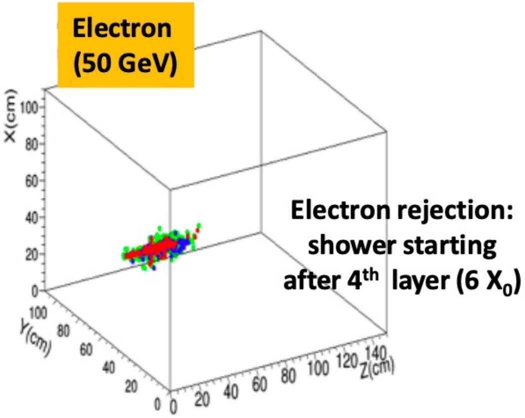
Some results from test beams

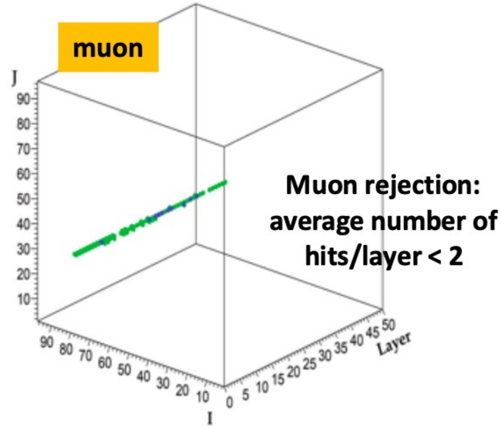
SDHCAL @ CERN Test Beams











New Timing SDHCAL (T-SDHCAL)

Overall performance of PFA algorithms depends on capability to associate calorimeter showers to tracked particles, and on the energy resolution of the calorimeters

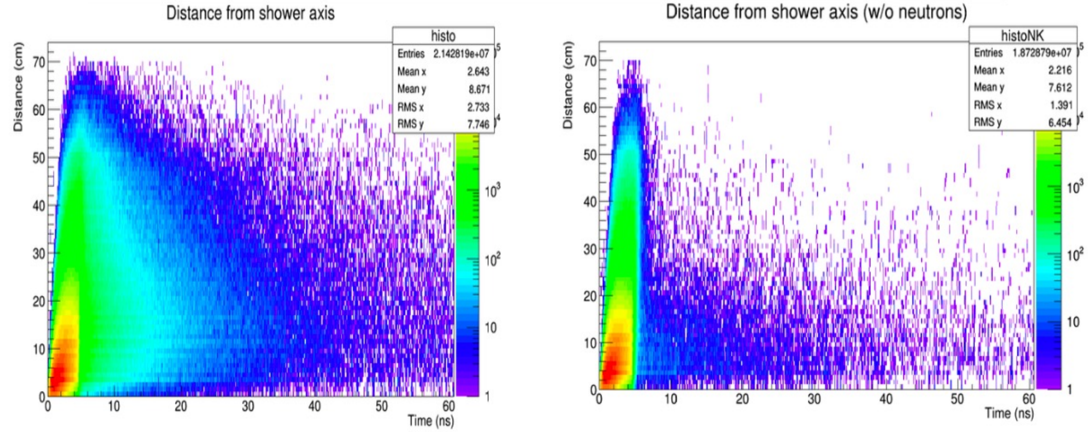
Timing capabilities of the calorimeter systems in collider detectors open up new possibilities in event and object reconstruction (TOF, LLP, shower reconstruction …)

Hadronic showers show a complex time structure, with late components connected to neutron-induced processes

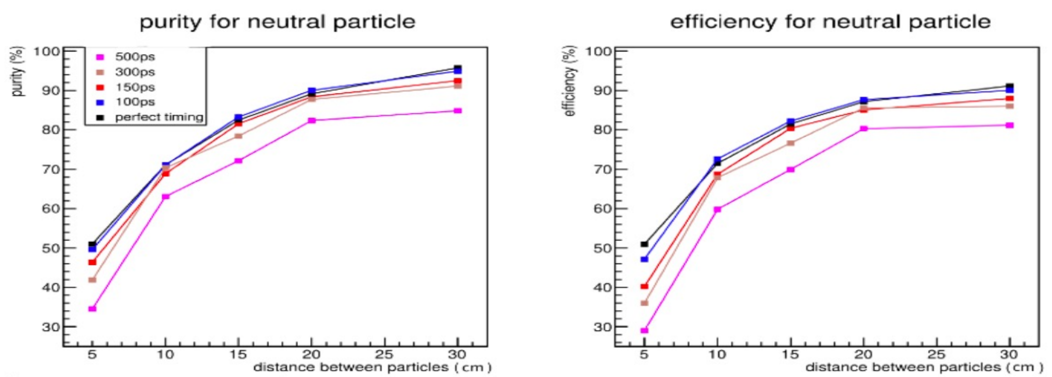
A time resolution on the order of a few 100 ps to 1 ns results in a sharper definition of the shower core

In addition, we found that time information could improve significantly hadronic showers separation at lower distances

Separate delayed neutrons for better energy reconstruction



Separation of close-by showers (e.g. 10 GeV neutral and 30 GeV charged particle)



T-SDHCAL

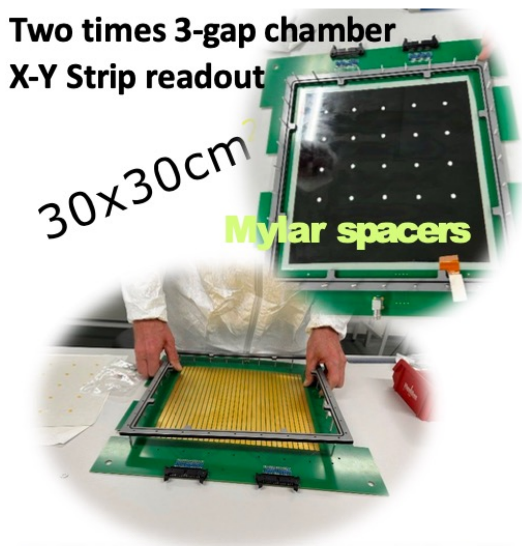
- **Replacing the single-gap RPCs in SDHCAL with MRPCs**
  → Need to study how many gaps are needed to reach 100 ps, taking into account the cost on the cassette thickness.

SDHCAL was first developed for **ILC**, i.e. low rate and power pulsing, and needs to be adapted to cope with future **circular collider** requirements, i.e.

- Continuous readout
- High particle rates

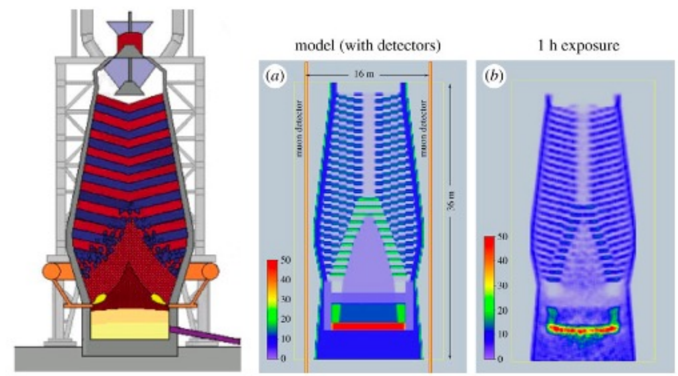
- **Developing a cooling system**
  → The cooling system should not add too much dead zone; could we use it with the present SDHCAL mechanics with limited efforts? Initial studies on this topic done

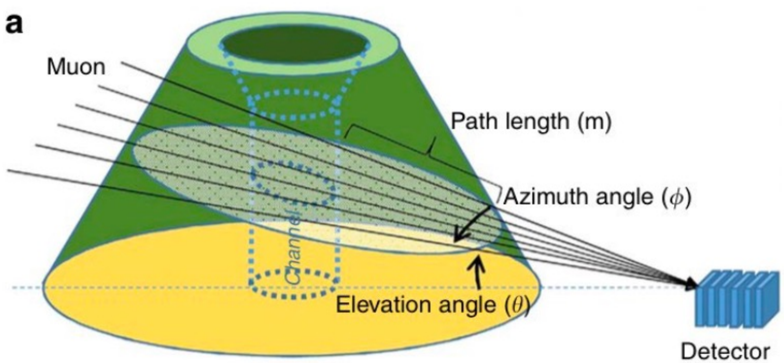
- **Increase rate capability with low resistive materials**
  → low resistivity glass, PEEK doped with Carbon Nanoparticles



Applications #2 : Muon Radiography

Principle: measuring the differential **attenuation of the muon flux as a function of the amount of material crossed along different directions**, allows to determine the density distribution of the interior of a large object





- Requires a muon telescope, i.e. multiple layers of position sensitive muon detectors

- Common detector technologies:
  - Plastic scintillators
  - Nuclear emulsions
  - Gaseous detectors (MWPC, Micromegas, RPC …)

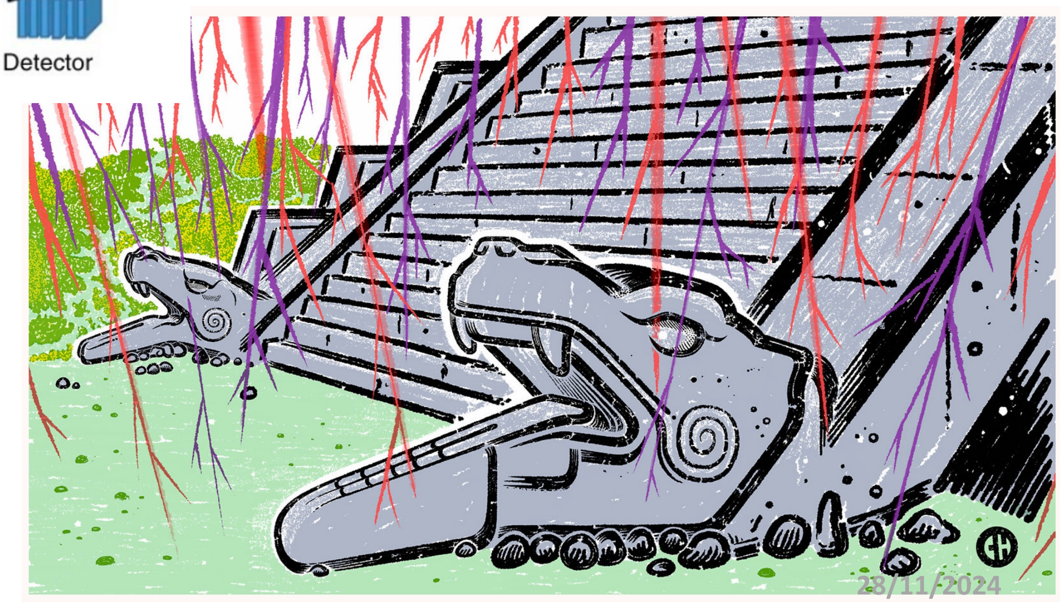
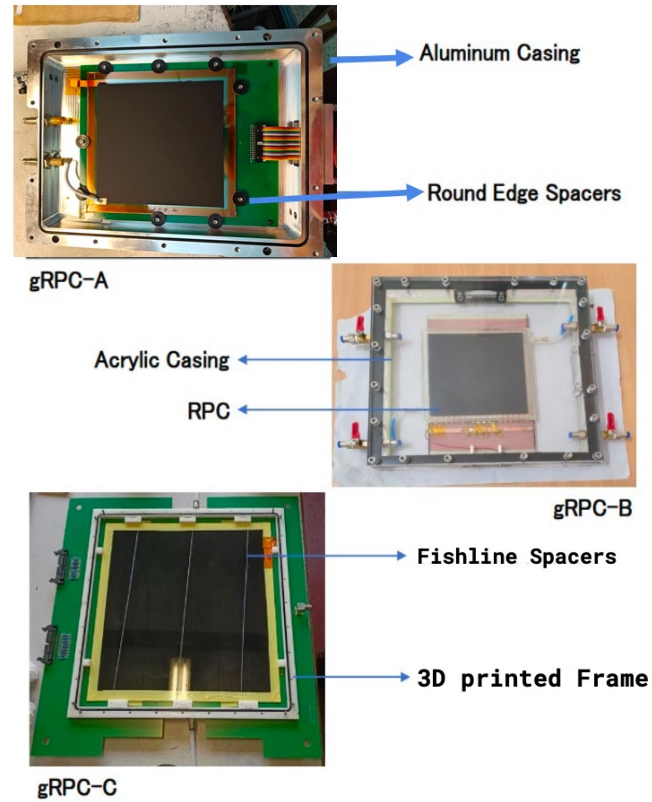


Illustration by Sandbox Studio, Chicago with CHema Skandall

Portable Muoscope Project

Collaboration between **VUB & UCLouvain (Belgium) and NISER (India)** to produce general-purpose telescope for applications in confined/remote environments (geology, archaeology, civil engineering, and industrial safety ...)

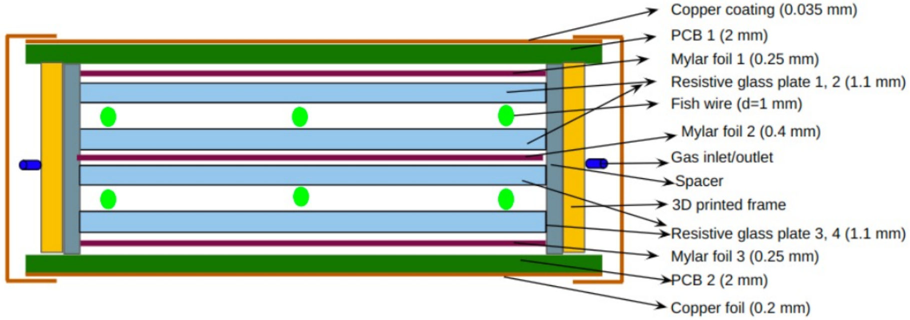
Detector	A	B	C
Institute	UCLouvain	NISER	UGent/VUB
Size	16 × 16 cm^2	16 × 16 cm^2	28 × 28 cm^2
Outer Casing	Aluminum casing	Standalone RPC housed in acrylic casing	Closed with top and bottom PCBs
Readout Strips	16-1D	16 × 16 - 2D	32 × 32 - 2D
Strip Pitch	1 cm	1 cm	0.8 cm
Gas mixture	95.2% Freon, 0.3% SF6, 4.5% isobutane		
Gas Gap	1 mm Single gap	2 mm Single gap	1 mm Double gap
Thickness of Electrodes	1.1 mm	3.0 mm	1.1 mm
Resistive Coating	Serigraphy (~ 4 MΩ/□) and Hand-painted (0.5-1.0 MΩ/□)	Spray gun (~ 1 MΩ/□)	Spray gun (~ 1.5 MΩ/□)
DAQ	NIM + CEAN integrated / custom made and ASIC + FPGA		
Portability	Yes	Yes (Currently operating in gas flow mode)	Yes (Currently operating in gas flow mode)

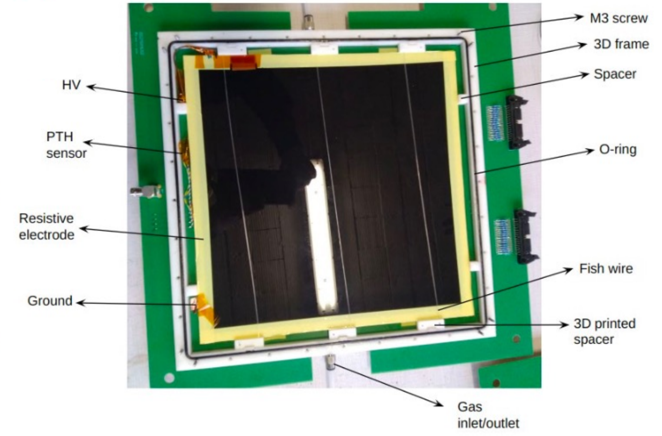


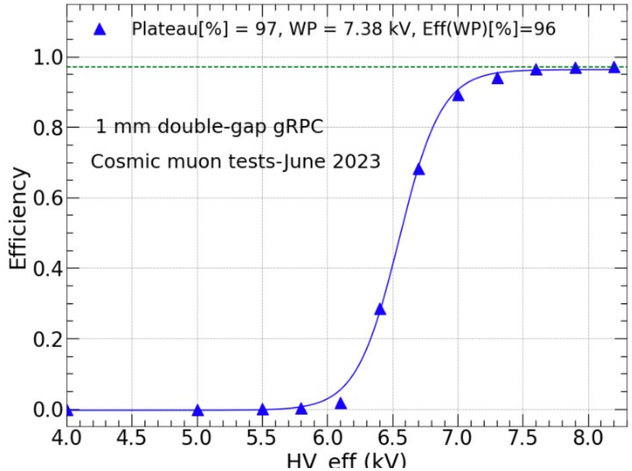
gRPC-based detector design features portability, robustness, autonomous operation, low power consumption, gas tightness, modular geometry ...

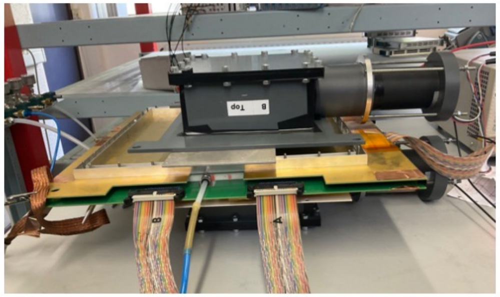
gRPC prototyping

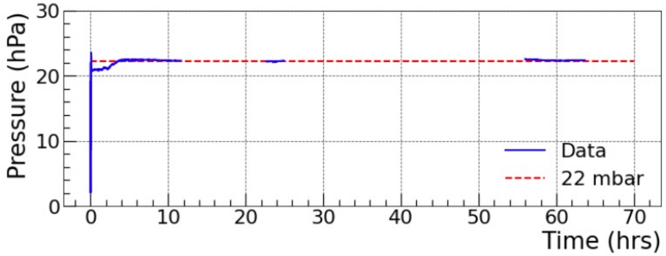
Double-layer 1mm gRPC, leak tight design





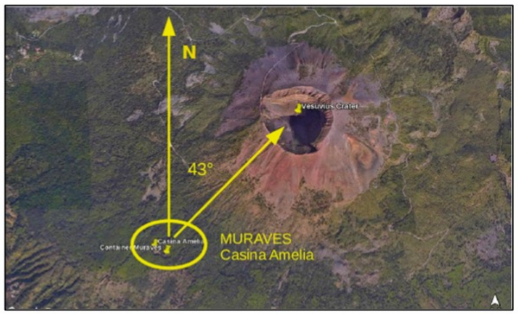






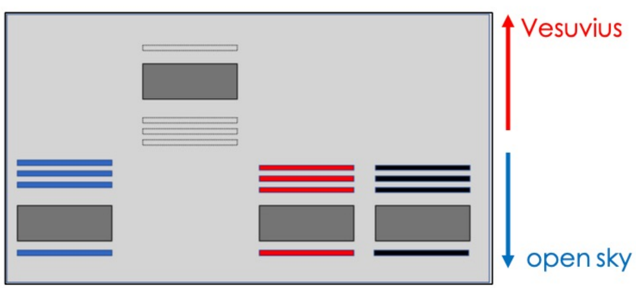
Muon Radiography of Mt Vesuvius (MURAVES)

Muraves @ Mt. Vesuvius



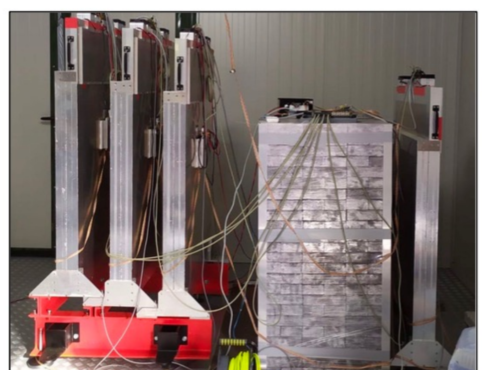
Muraves is located 1500m away from crater and ~640m asl, i.e. slightly below the bottom of the Vesuvius crater

4 concrete platforms inside container, i.e. 3 pointing to Vesuvius and 1 open-sky calibration position



Powered via solar panel system on the container roof connected to array of batteries

muon trackers



Collaboration between **Italy (INGV, INFN Naples & Florence) and Belgium (UCLouvain, VUB)**

3 equal muon trackers ("ROSSO, NERO and BLU") giving a 3m^2 muon telescope

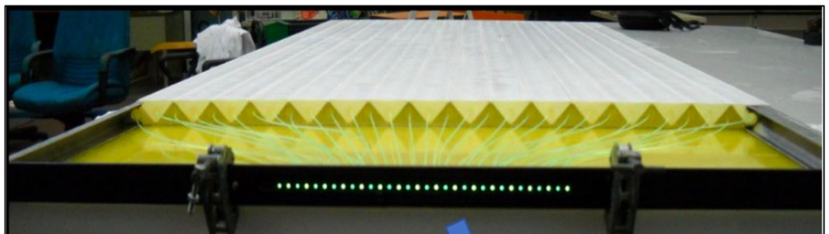
Each tracker has 4 tracking stations of 1m^2 active area, distributed over ~2m, with 60cm of lead in between two downstream stations

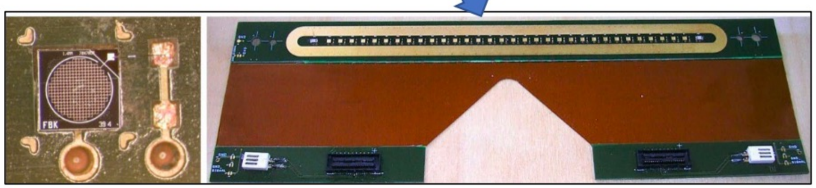
Each station consists of a pair of orthogonal (XY) planes, where each plane made of 2 modules, composed of 32 triangular scintillator bars (produced at Fermilab) each

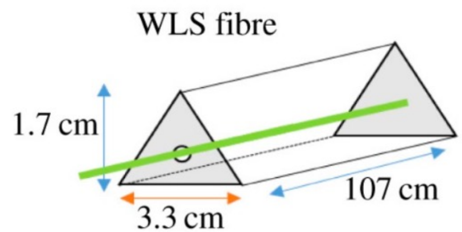
Light collection via 1.2mm WLS fibers (Kuraray) inserted into each strip and coupled to SiPM (Advansid)

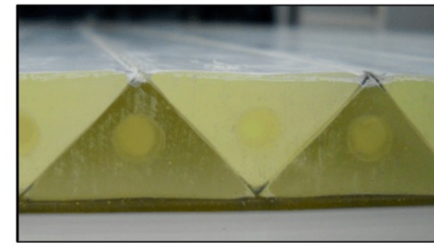
MURAVES

Muraves Muon Trackers

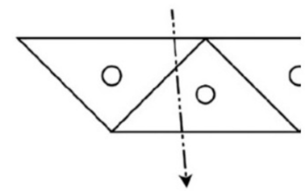








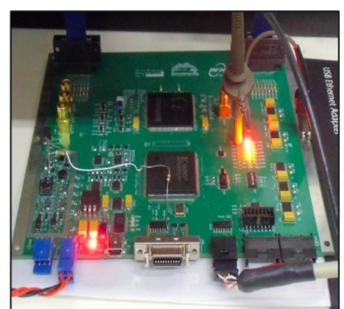
Triangular section of scintillators yields improved spatial resolution (~3mm): muon hit position is computed as an energy weighted mean



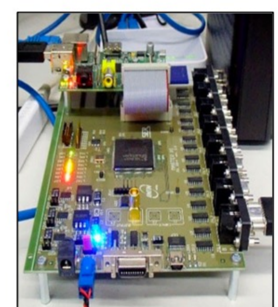
SiPMs are glued in groups of 32 to a custom flex PCB hybrid, which provides biasing of the SiPMs, amplification, discrimination and ADC conversion of the signals, and hosts T&H sensors

Every hybrid is read out by 1 SLAVE EASIROC based FEE board

16 FEE boards of one tracker are read out by 1 MASTER board (equipped with a Raspberry Pi) which controls the trigger logic and data-acquisition



...



Scintillator Imaging Detector for Egyptian Pyramids

The ScIDEP Project

VUB VRIJE UNIVERSITEIT BRUSSEL

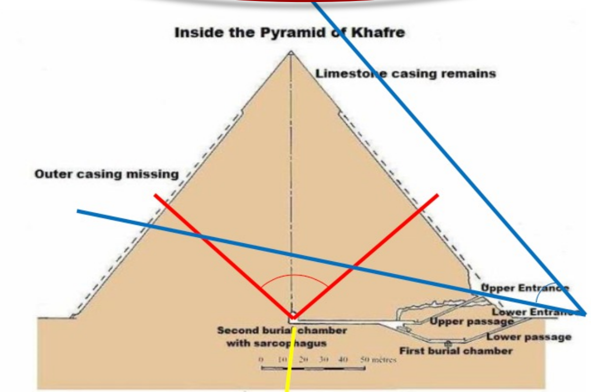
iihe BRUXELLES BRUSSEL

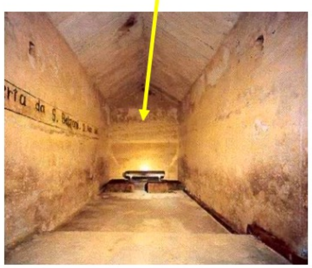
Egypt-Japan University of Science and Technology

Pacific Northwest NATIONAL LABORATORY

IFIN-HH

- ❑ Collaborators from Belgium (VUB), Egypt, USA and Romania; targeting the Pyramid of Khafre (since 2020)



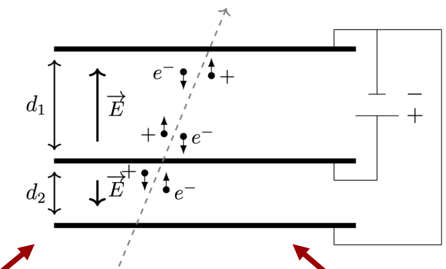


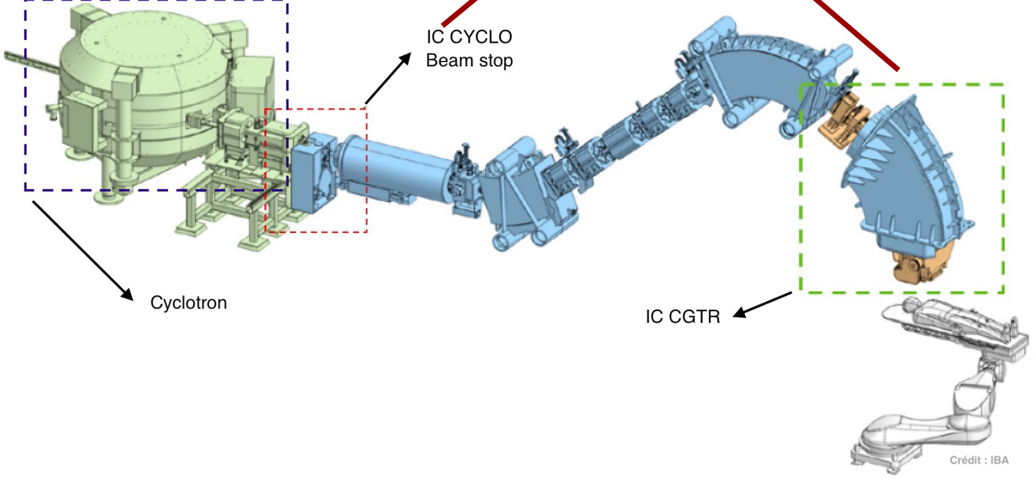
ScIDEP

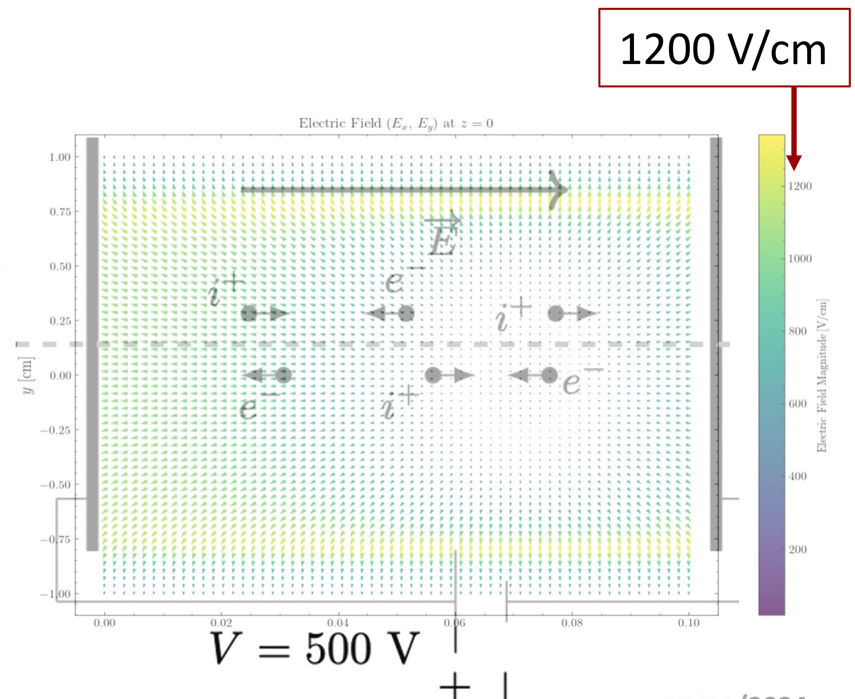
- ❑ Options to install a muon telescope inside burial chamber, i.e., only slightly off-center from the central axis of the pyramid (stable temperature of 20°C inside), and outside of pyramid → 3D imaging
- ❑ Note, no gaseous detectors allowed inside pyramid (tbc …)
- ❑ ScIDEP is developing two scintillator-based muon telescopes:
  - Detector 1: detector stations with plain scintillator plates, inspired by an existing borehole detector concept
  - Detector 2: detector stations with scintillator bars

Application #3: Dose monitoring for Protontherapy

230 MeV proton beam intercepted by Ionization Chambers (IC);
In FLASH proton-therapy, up to 100 pC / pulse
-> released charge is so high that there is Space Charge Screening effect





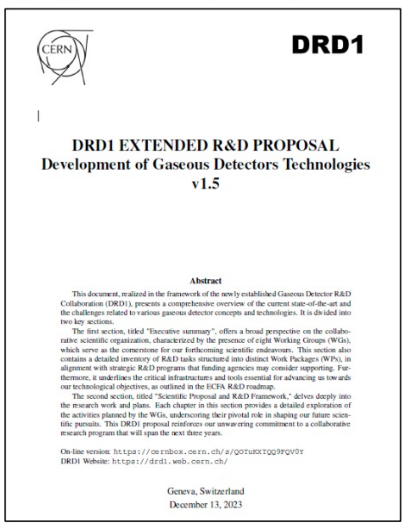


To close this chapter…

Most of the R&D activities presented so far
are included in the ECFA Detector R&D Roadmap

- Initial period 2024-2026; collaboration and management have been implemented in 2024; MoU to be signed soon
- **DRD1 signed by UCL** (E. Cortina, A. Giammanco), **ULB** (G. de Lentdecker), and **VUB** (M. Tytgat); **DRD6 by VUB** (M. Tytgat)
- VUB in DRD1 Management: M. Tytgat (co-convenor WG1; DRD1 MB member)
- DRD1: https://drd1.web.cern.ch/; https://indico.cern.ch/category/17385/
- DRD6: https://indico.cern.ch/category/17390/

https://cds.cern.ch/record/2885937



DRD1

DRD1 EXTENDED R&D PROPOSAL
Development of Gaseous Detectors Technologies
v1.5

Abstract

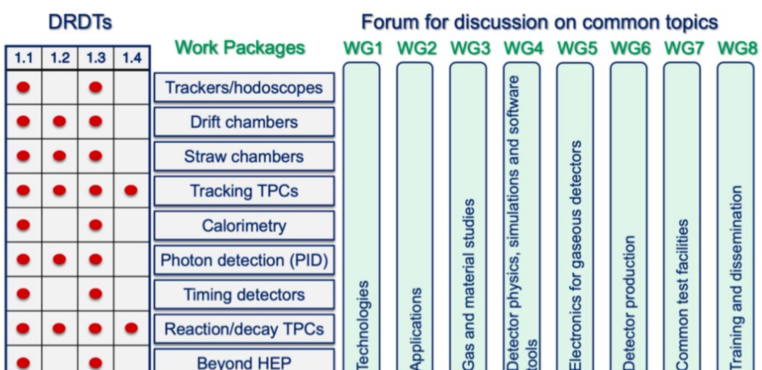
This document, realized in the framework of the newly established Gaseous Detector R&D Collaboration (DRD1), presents a comprehensive overview of the current state-of-the-art and the challenges related to various gaseous detector concepts and technologies. It is divided into two key sections.

The first section, titled "Executive summary", offers a broad perspective on the collaborative scientific organization, characterized by the presence of eight Working Groups (WGs), which serve as the cornerstone for our forthcoming scientific endeavours. This section also contains a detailed inventory of R&D tasks structured into distinct Work Packages (WPs), in alignment with strategic R&D programs that funding agencies may consider supporting. Furthermore, it underlines the critical infrastructures and tools essential for advancing us towards our technological objectives, as outlined in the ECFA R&D roadmap.

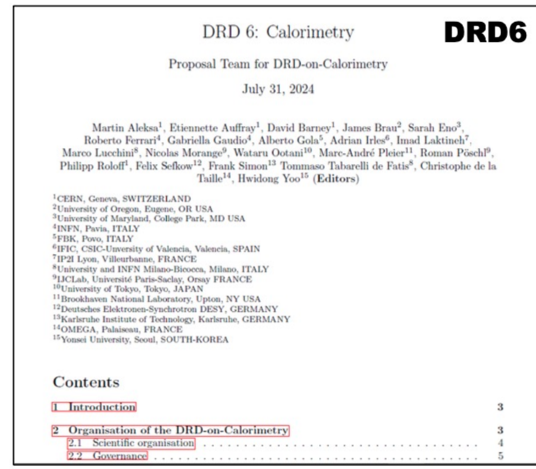
The second section, titled "Scientific Proposal and R&D Framework," delves deeply into the research work and plans. Each chapter in this section provides a detailed exploration of the activities planned by the WGs, underscoring their pivotal role in shaping our future scientific pursuits. This DRD1 proposal reinforces our unwavering commitment to a collaborative research program that will span the next three years.

On-line version: https://cernbox.cern.ch/s/QOTuKXTQQ9FQV0Y
DRD1 Website: https://drd1.web.cern.ch/

Geneva, Switzerland
December 13, 2023



https://cds.cern.ch/record/2886494



DRD 6: Calorimetry

DRD6

Proposal Team for DRD-on-Calorimetry

July 31, 2024

Martin Aleksa[1], Etiennette Auffray[1], David Barney[1], James Brau[2], Sarah Eno[3], Roberto Ferrari[4], Gabriella Gaudio[4], Alberto Gola[5], Adrian Irles[6], Imad Laktineh[7], Marco Lucchini[8], Nicolas Morange[9], Wataru Ootani[10], Marc-André Pleier[11], Roman Pöschl[9], Philipp Roloff[1], Felix Sefkow[12], Frank Simon[13] Tommaso Tabarelli de Fatis[8], Christophe de la Taille[14], Hwidong Yoo[15] (**Editors**)

[1]CERN, Geneva, SWITZERLAND
[2]University of Oregon, Eugene, OR USA
[3]University of Maryland, College Park, MD USA
[4]INFN, Pavia, ITALY
[5]FBK, Povo, ITALY
[6]IFIC, CSIC-Unversity of Valencia, Valencia, SPAIN
[7]IP2I Lyon, Villeurbanne, FRANCE
[8]University and INFN Milano-Bicocca, Milano, ITALY
[9]IJCLab, Université Paris-Saclay, Orsay FRANCE
[10]University of Tokyo, Tokyo, JAPAN
[11]Brookhaven National Laboratory, Upton, NY USA
[12]Deutsches Elektronen-Synchrotron DESY, GERMANY
[13]Karlsruhe Institute of Technology, Karlsruhe, GERMANY
[14]OMEGA, Palaiseau, FRANCE
[15]Yonsei University, Seoul, SOUTH-KOREA

Contents

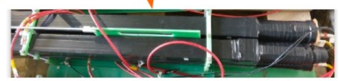
- WP1 - Sandwich calorimeters with fully embedded electronics
- WP2 - Liquified Noble Gas Calorimeters
- WP3 - Optical calorimeters
- WP4 - Electronics and readout

PART III: Other developments

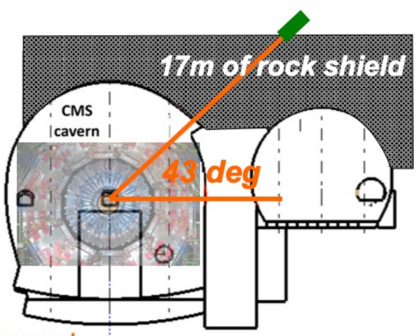
Search for low (milli-) charged particles (Dark Matter particles)

1st component: bar detector

- 1 bar = 60cm x 5cm x 5cm plastic scintillator + PMT
  - pointing to CMS



- look for tiny energy deposits, 4 in a row
  - sensitive down to Q ~ 10^{-3} e !
- 4x4x4 bars taking Run3 data stably
  - data analysis ongoing



100m underground

2nd component: slab detector

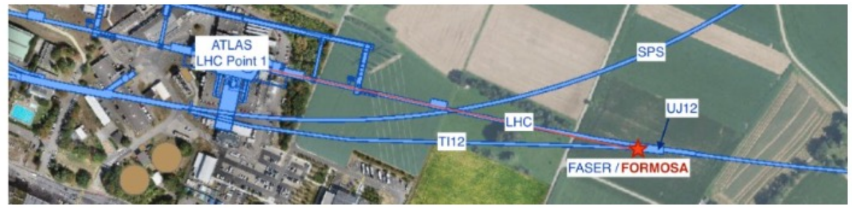
- 4 layers of 2m² surface, but only 5cm thick
- finalized Summer '24, commissioning ongoing
- joint project with IceCube (Juanan):

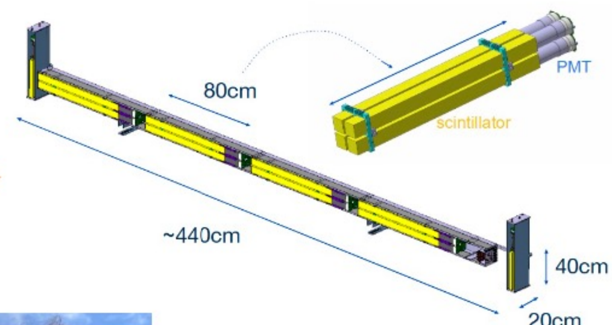
  search for low-charge particles produced in atmosphere, crossing the earth

100m underground

Same principle, different location

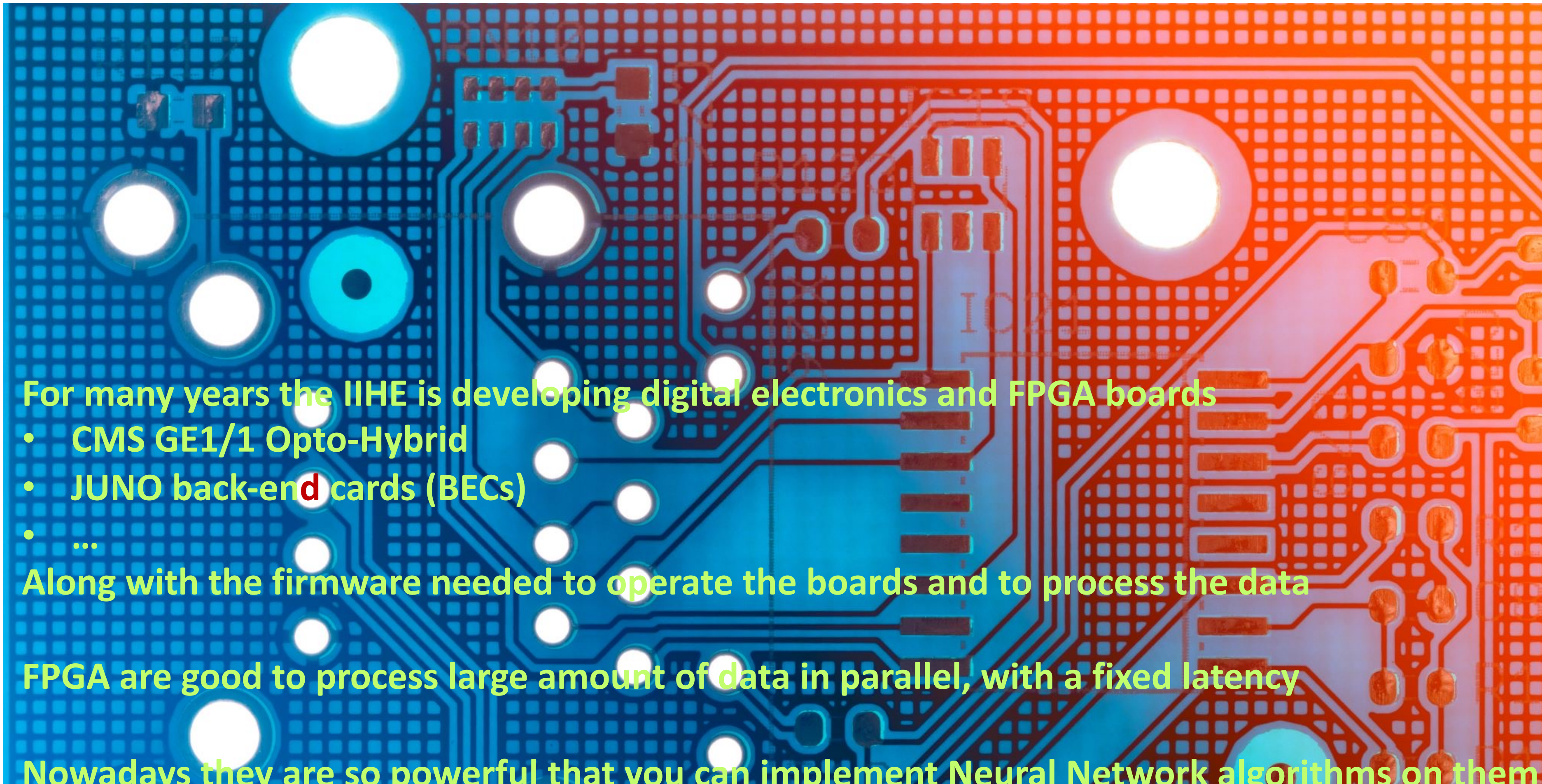
- 480m forward direction from ATLAS
  - behind FASER
  - 100m of rock shielding
- much higher signal rate
- different, large background:
  - muons → easy veto
  - interactions in nearby LHC magnets





- initial collaboration formed Summer '24
  - aiming for FPF (or other future location)
- demonstrator took data in '24
  - data being analyzed
- upgrade intervention in Winter '25


Digital electronics



For many years the IIHE is developing digital electronics and FPGA boards

- CMS GE1/1 Opto-Hybrid
- JUNO back-end cards (BECs)
- …

Along with the firmware needed to operate the boards and to process the data

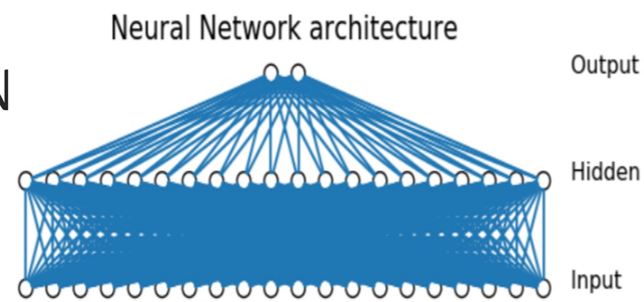
FPGA are good to process large amount of data in parallel, with a fixed latency

Nowadays they are so powerful that you can implement Neural Network algorithms on them

JUNO L1 Trigger

- Neural Network as alternative to the more traditional trigger algorithm based on “Nbr. Of Hits” threshold or “vertex finding”

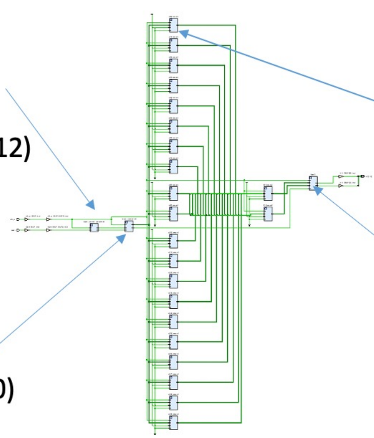
- Implemented a 20 x 20 x 2 NN



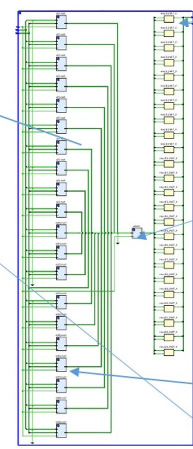
Activation functions
- *Relu* function : $\sigma(z) = \max(0, z)$
- *Softmax* function : $\sigma(z) = \frac{e^{\beta z_k}}{\sum_i e^{\beta z_i}}$

Bram for parameter loading (462×12)

Bram for input(500×160)

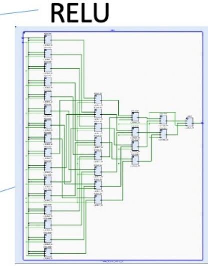


Top

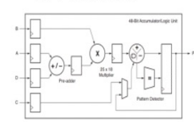


1 neuron

RELU



32 adder



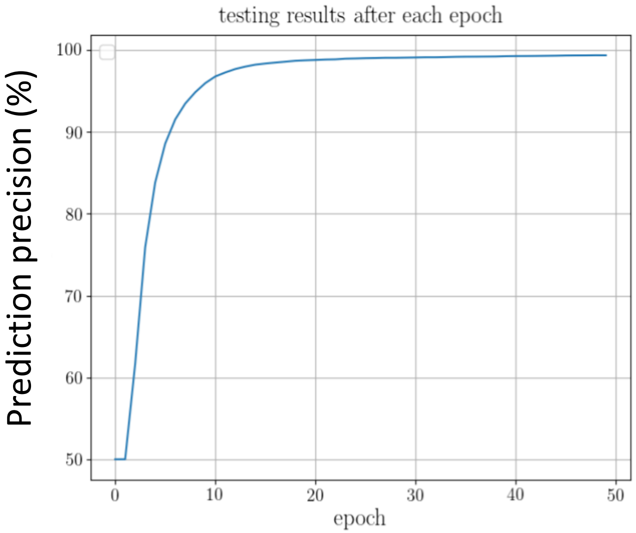
25×18 multiplier

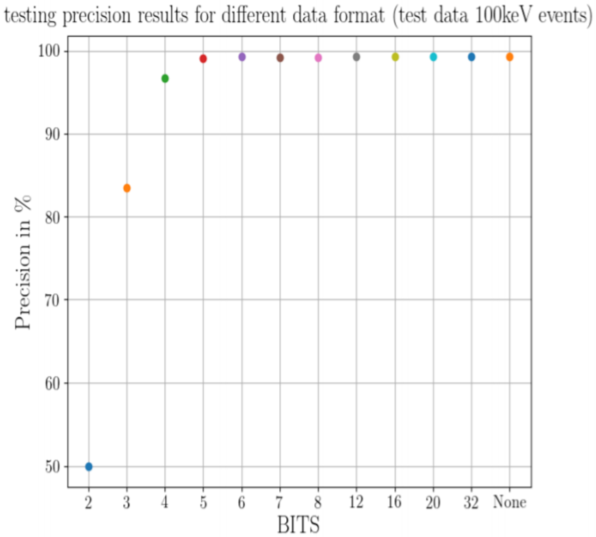
Output function
For cut setting at 0.5, no softmax is needed

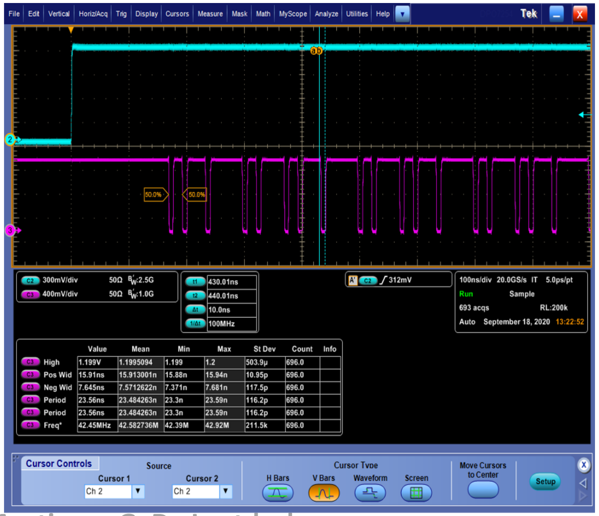
Requirements:
Latency <600ns
Jitter < 16ns
Data refresh rate > 62.5MHz

Name	Slice LUTs (203800)	Slice Registers (407600)	Slice (50950)	LUT as Logic (203800)	LUT Flip Flop Pairs (203800)	Block RAM Tile (445)	DSPs (840)	Bonded IOB (500)	BUFGCTRL (32)
top	16262	26214	7412	16262	13659	2.5	440	4	2
top	7.98%	6.43%	14.55%	7.98%	6.70%	0.56%	52.38%	0.80%	6.25%

Some results



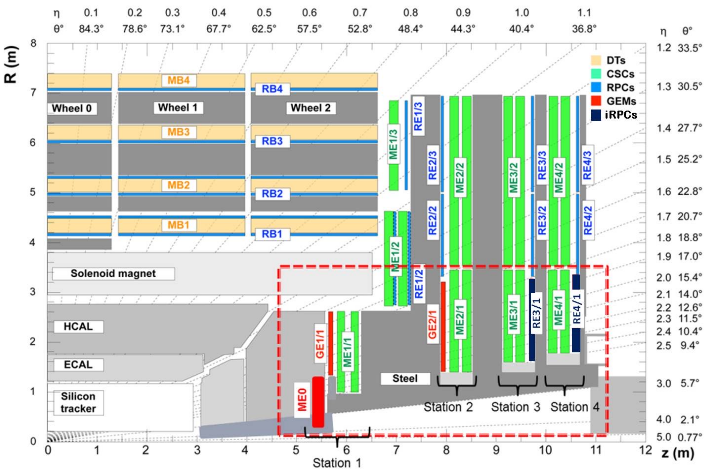




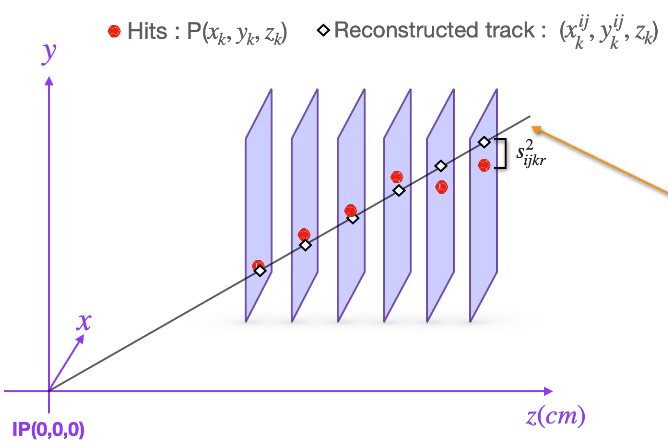
Latency < 600ns

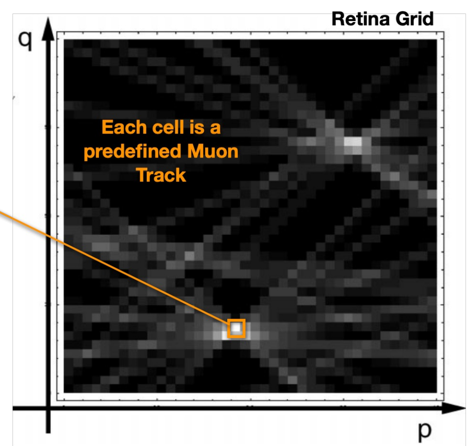
Jitter < 1 ns

CMS ME0 Trigger: Retina algorithm



- Inspired from visual mechanism in mammals.
  - Highly parallelized -> suitable for FPGA
  - Robust to background hits
  - CMS GEM ME0 geometry perfectly suitable



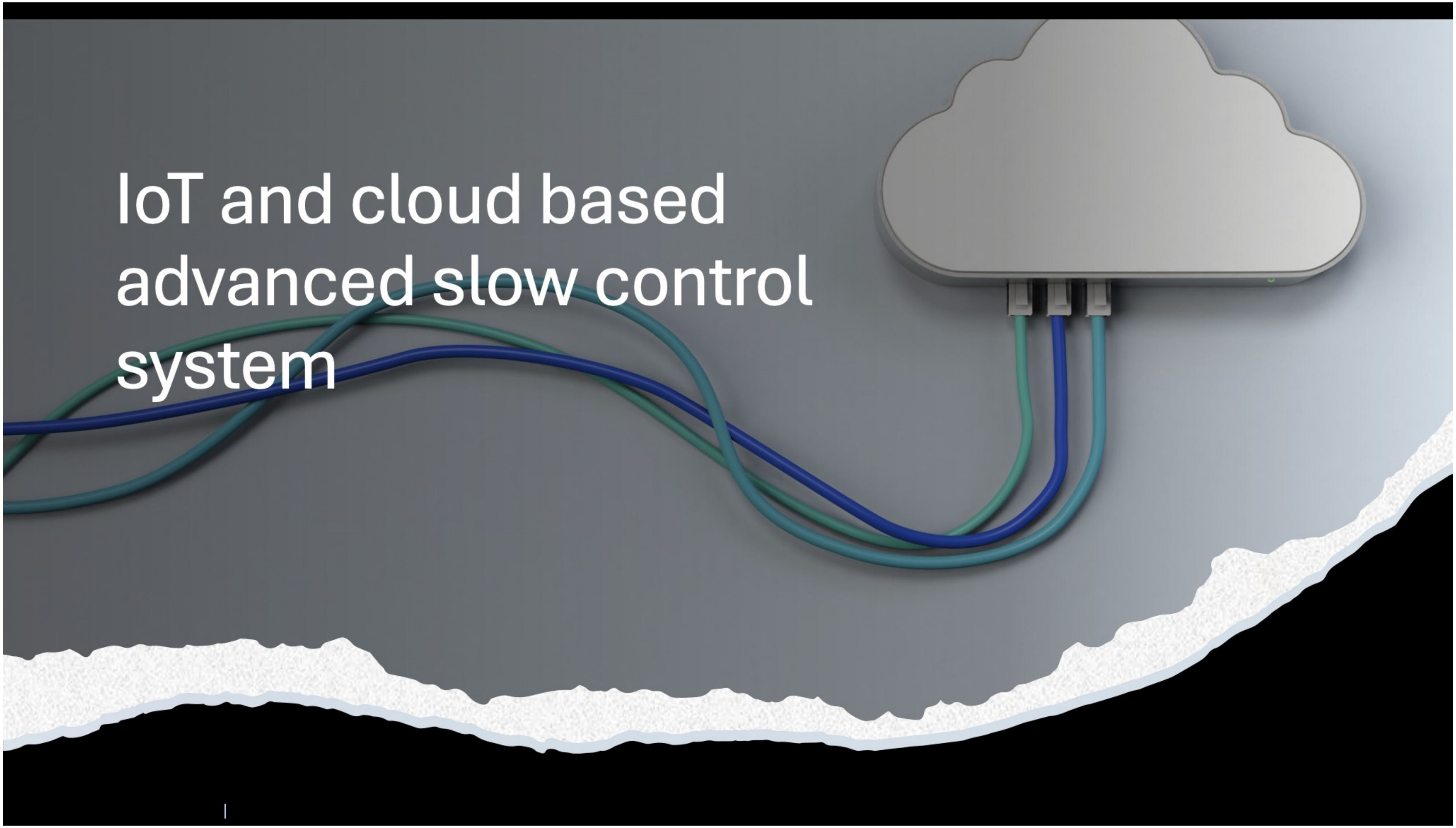


$$R_{ij} = \sum_{k,r} \exp\left(-\frac{s_{ijkr}^2}{2\sigma^2}\right)$$

→ $s_{ijkr} = x_r^{(k)} - y_k(p_i, q_j)$

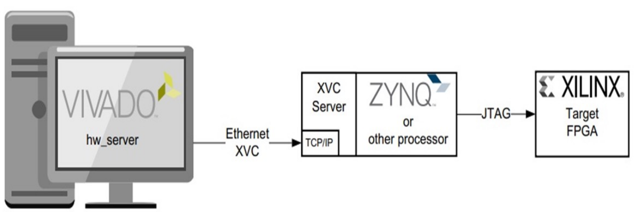
→ Width of response function

slow control system



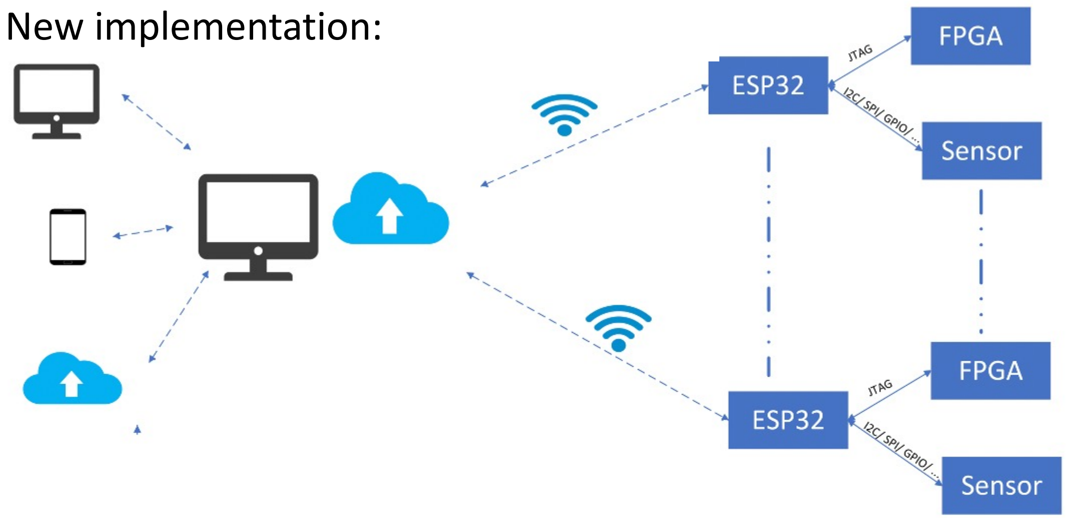
Empowering FPGA debugging with ESP32 & IoT

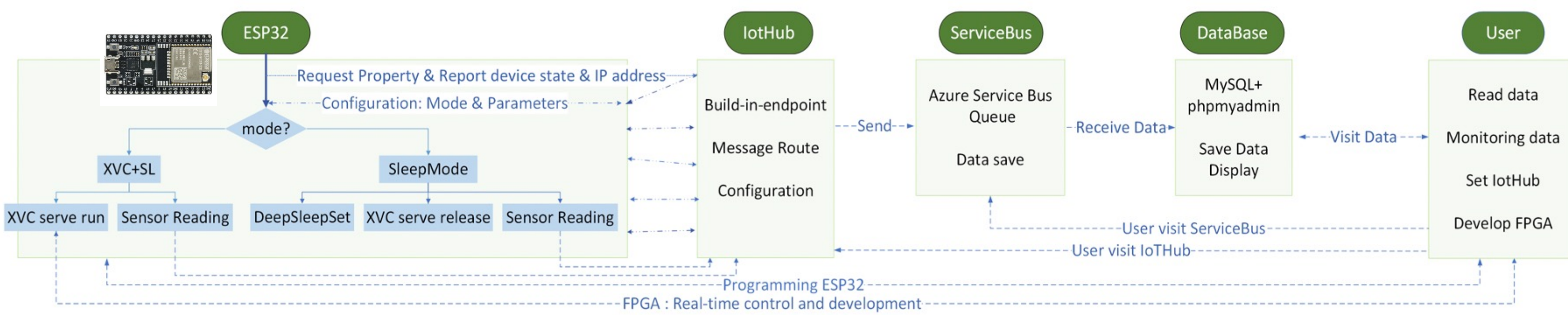
Current implementation:



- Rely on JTAG programmer at early stages
- Remote configuration and slow control at later stages
  - -> use large amount of FPGA resources
  - -> typically not available at the beginning of the developments

New implementation:





ESP32: microprocessor IoT device

XVC: TCP/IP-based Protocol; acts like JTAG

IoTHub: security-enhanced communication hub

ServiceBus: store messages until receiver is ready

And its implementation

Test Setup & Real-Time Debugging and Environment Monitoring & Data Management

- Test Setup: ESP32 with a sensor DTH11 is connected to a Kintex 7 FPGA through JTAG interface and is powered by the JTAG's VREF.
- Real-Time Debugging with XVC server.
- Environment Monitoring by distributing sensor data through Azure IoTHub and service bus queue.

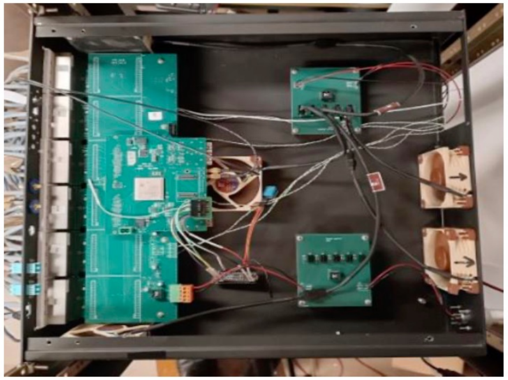


Fig: Setup for ESP32+Sensor+FPGA

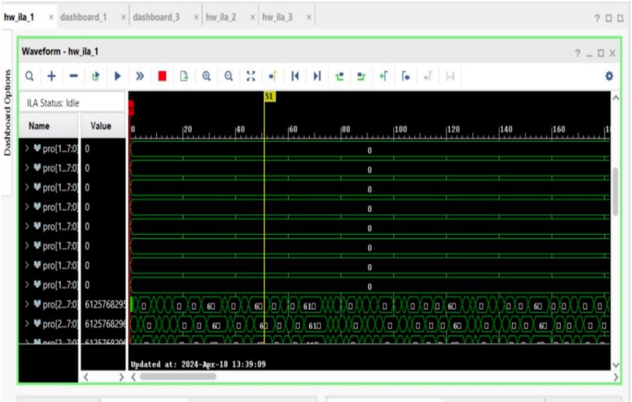


Fig: Interface for FPGA debug

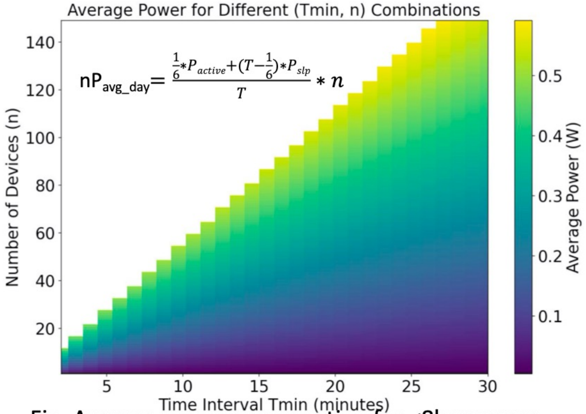


Fig: Average power consumption for <8k message

- Data Management and Quality Assurance:
  - Data from service bus queue is systematically written into a local database.
  - Successfully monitoring data during 42.8 hours continuous test period. There are 27 message loss, resulting in a data loss rate of 0.53%.
- Power consumption:
  - ESP32 works in XVC mode and sensor monitoring mode, in the latter mode, ESP32 switches periodically between normal operation and deepsleep.
  - The power with XVC run is 0.7W, the power for normal operation is 0.5W, the power with deepsleep is less than 1mW.
- Extra features:
  - Simultaneous Debugging of Multiple FPGAs.
  - Monitoring I2C sensors located on FPGA card via slighly modified JTAG connector pinout.

Conclusions

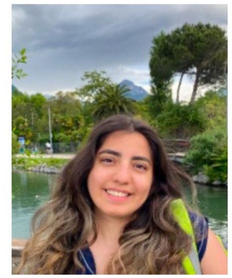
- The IIHE has a vibrant R&D program
  - Reminder: only a part was showed in this talk
- Very promising for the future
- Still, we have to continuously remind its importance to our FA’s & authorities

Who’s who

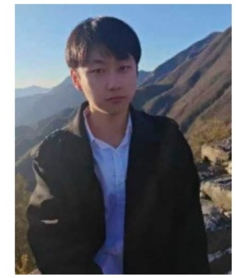
Michael Tytgat

Yifan Yang

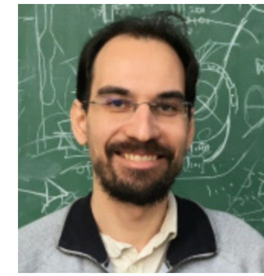
Yanwen Hong
(CMS GEM, MURAVES, THGEMs)



Donya Ahmadi
(CMS RPC, mRPC, Portable muoscope)



Zhe “Kevin” Wang
(ScIDEP)



Yannick Allard

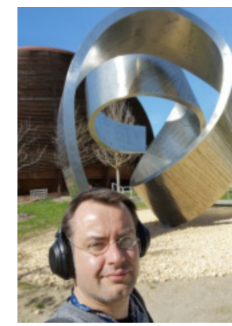
GDL

Pierre Gerard
(p-therapy)

Yuqi Bai
(THGEMs)

Dora Geeraerts
(ScIDEP)

Liesbeth Jacops
(MURAVES)



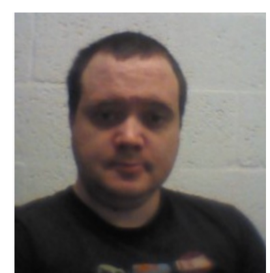
Pierre Dewulf

Steven Lowette

Indrani Jayam
(p-therapy)

Isabelle De Bruyn
(CMS GEM)

Tiepolo Wybow
(Milliqan)



Benoit Denegre

Michael Korntheuer

And many more…