CALORIMETRY SESSION SUMMARY OF POSTERS

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[1]STOCKHOLM UNIVERSITY, [2]UNIVERSITY OF TOKYO

15TH PISA MEETING ON ADVANCED DETECTORS

ISOLA D'ELBA – MAY 2022

Part I (Christophe)

20 Posters

LHC & HL-LHC Calorimeters (6)

- Engineering challenges in mechanics and electronics in the world's first particle-flow calorimeter at a hadron collider: The CMS High-Granularity Calorimeter
- Design and characterisation of a fully functional FoCal-E prototype in ALICE
- ATLAS LAr Calorimeter Commissioning for LHC Run-3
- Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC
- Time calibration, monitoring and performance of the ATLAS Tile Calorimeter in Run 2
- Long term aging test of the new PMTs for the HL-LHC ATLAS hadron calorimeter upgrade

Particle reconstruction (2)

- Performance studies of single-particles uncertainties and Local Hadron Calibration for Particle-Flow jets in ATLAS
- Deep learning techniques for energy clustering in the CMS electromagnetic calorimeter

Future calorimeters (4)

- Noble Liquid Calorimetry for a Future FCC-ee Experiment
- CRILIN: a semi-homogeneus Crystal Calorimeter for a future Muon Collider
- Highly granular scintillator-strip electromagnetic calorimeter for future Higgs factories
- Test beam results and future R&D of the fibre-sampling Dual-Readout Calorimeter

Part II (Toshiyuki)

Calorimetry for intensity frontier (precision physics)

- The Engineering of the Mu2e Calorimeter
- An automated QC station for the final calibration of the Mu2e Calorimeter SIPMs
- Design, assembly and operation of a scintillator based Cosmic ray tagger with SiPM readout
- Commissioning of Liquid Xenon Gamma-Ray Detector for MEG II Experiment
- A liquid hydrogen target to fully characterize the new MEGII liquid xenon calorimeter
- Towards large calorimeters based on Lanthanum Bromide or LYSO crystals coupled to silicon photomultipliers: A first direct comparison for future precision physics

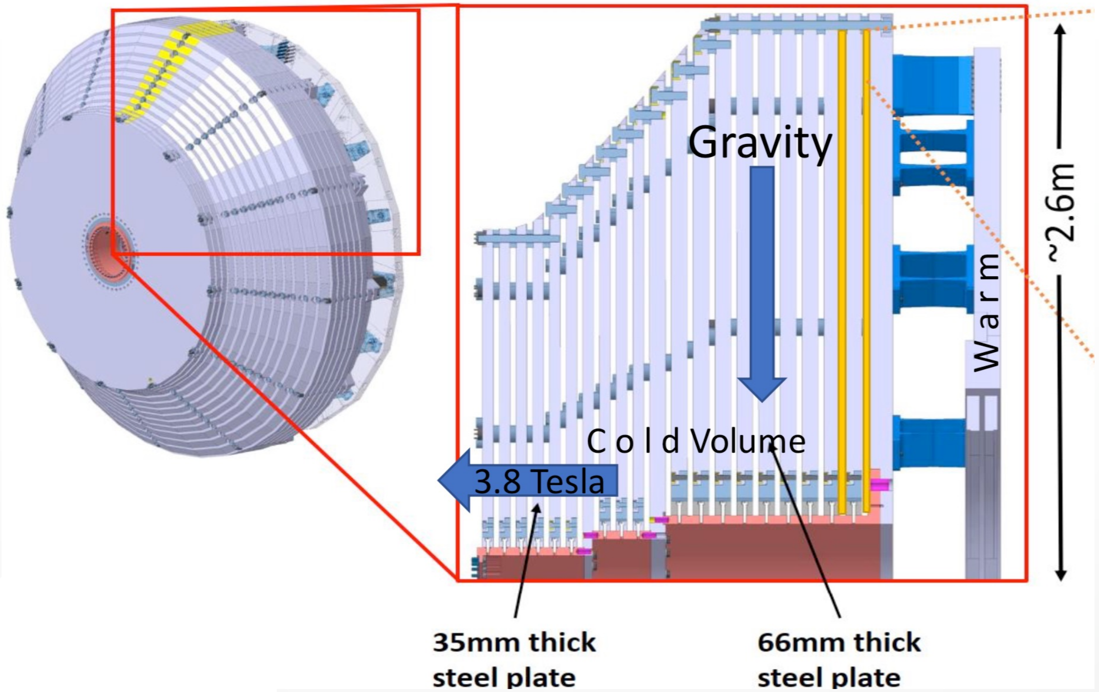
Other calorimetry applications

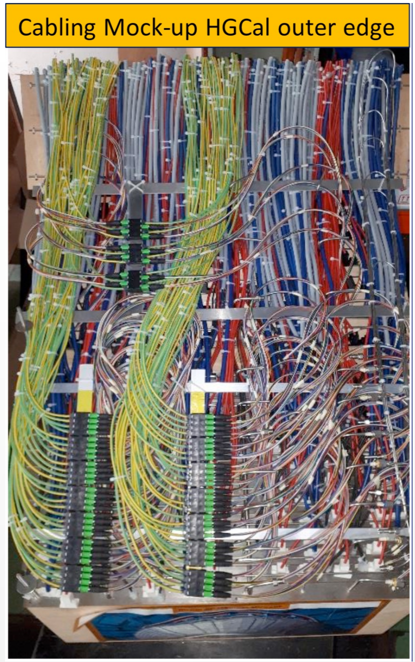
- Looking for Cherenkov light in liquid Xenon with LoLX
- Study of SiPMs for calorimetry application

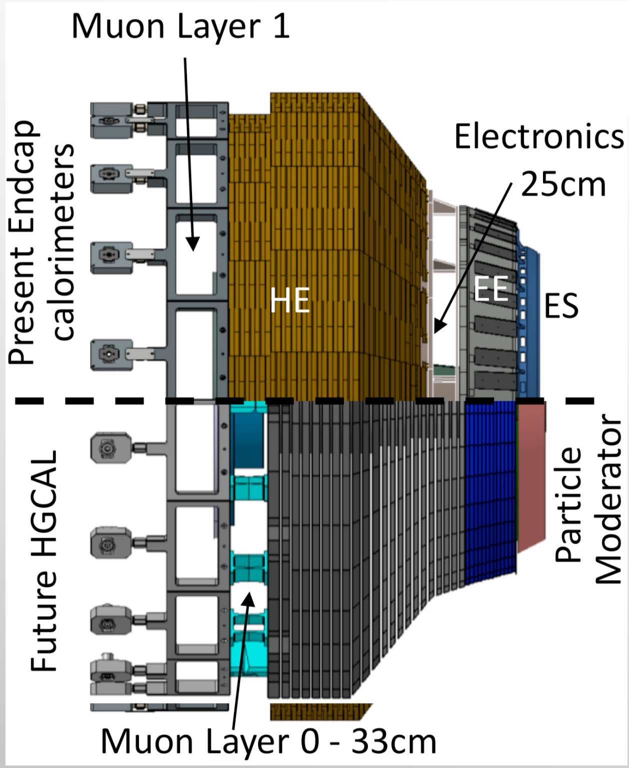
LHC & HL-LHC CALORIMETERS

THE CMS HIGH-GRANULARITY CALORIMETER (HL-LHC)

Hubert Gerwig
(CERN)





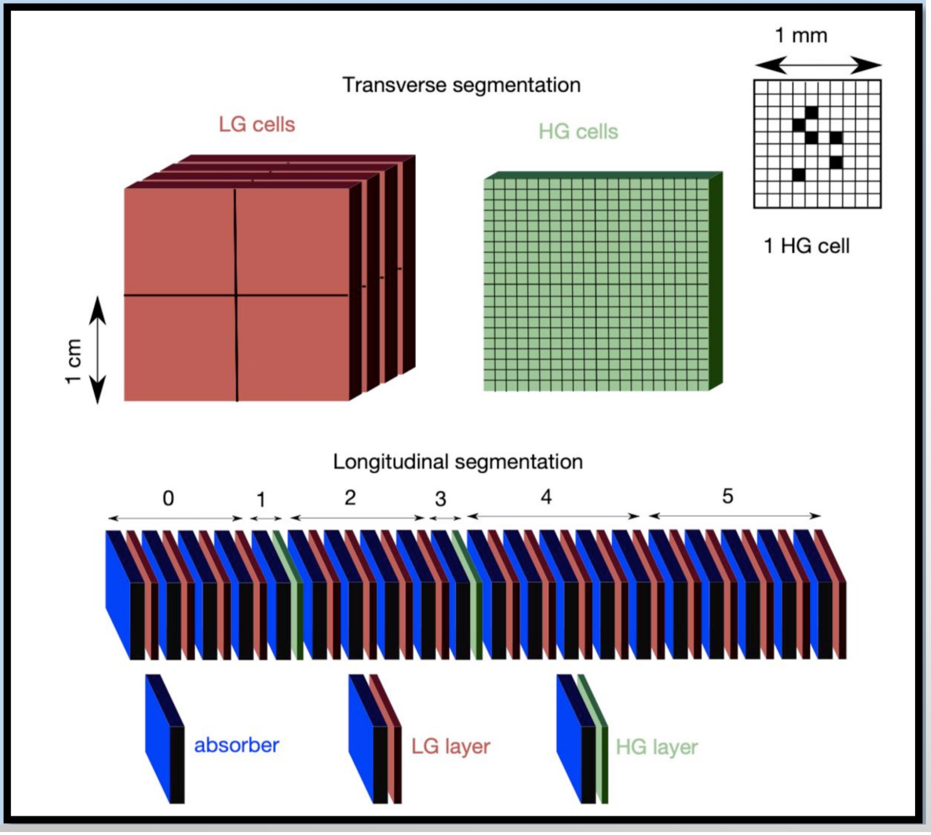


- Replace current CMS endcap calos with **High Granularity Calorimeter for HL-LHC**
- **HL-LHC radiation environment:** 10^{16} neq/cm^2 and doses up to 1.5 MGy
- **Silicon sensors** (high radiation regions) + **scintillating tiles & direct SiPM readout** (low radiation)
- **Operate at -30°C** to **mitigate radiation, challenging given 125kW/endcap** dissipated energy
- **Very compact design** electronics to **free up space for one more muon layer.**
- ASICs, boards, services etc. are integrated into each layer
- **ΔT of 50°C** on back Titanium support structure
- **Production status:** absorbers in production, copper cooling plates new machines installed from production. Silicon and scintillator models prototyped and tested in beam.
- **Full-scale module production is due to start next year**

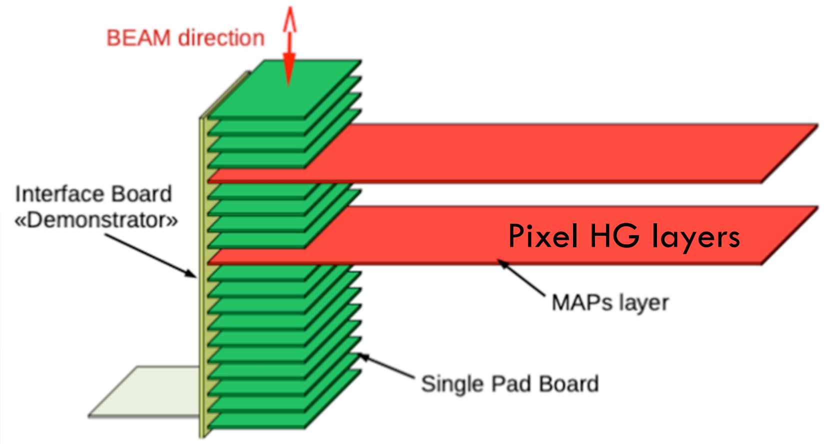
Design and characterisation of a fully functional FoCal-E prototype in ALICE

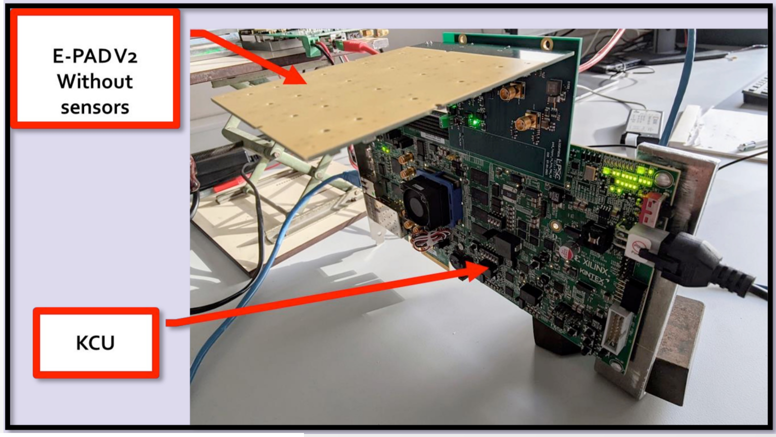
Abderrahmane GHIMOUZ (University of Tsukuba)

- **FoCal is a forward calorimeter** that extends the scope of ALICE (run >2028). FoCal-E is the EM part of FoCal.
- Adds new and unique capabilities to investigate Parton Distribution Functions in **unexplored regime of small-x parton structure down to x ~ 10^{-6}** and low momentum transfer Q ~ 4 GeV/c, **via prompt photon production**
- **Requires excellent γ/π^0 separation:** Capability to reconstruct π^0 decays at forward rapidity and up to p_T ~ 20GeV

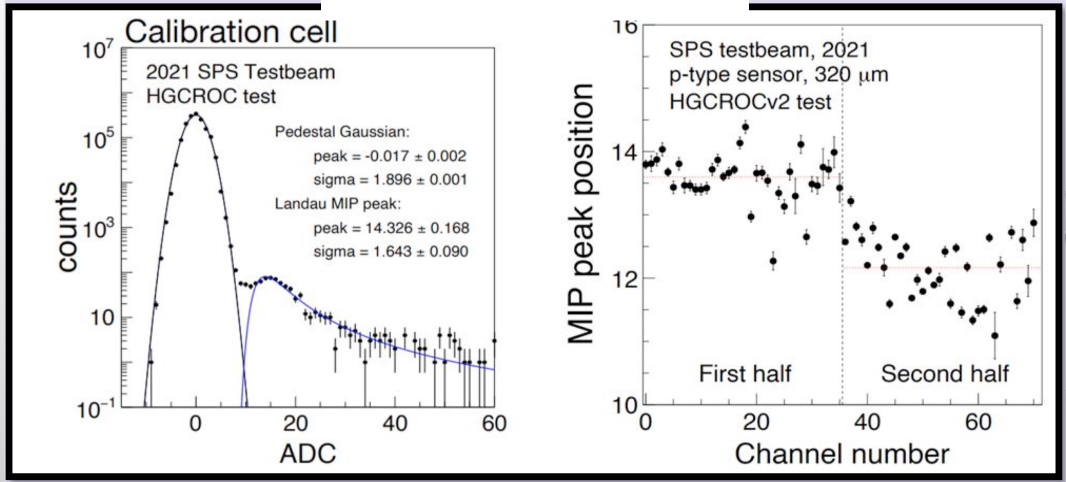


High (30x30 µm^2) & low granularity (1x1 cm^2) silicon sensors



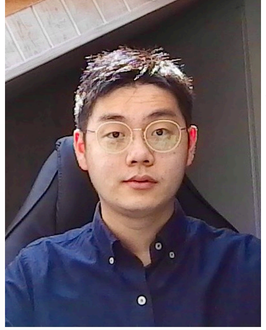


testbeam SPS 2021



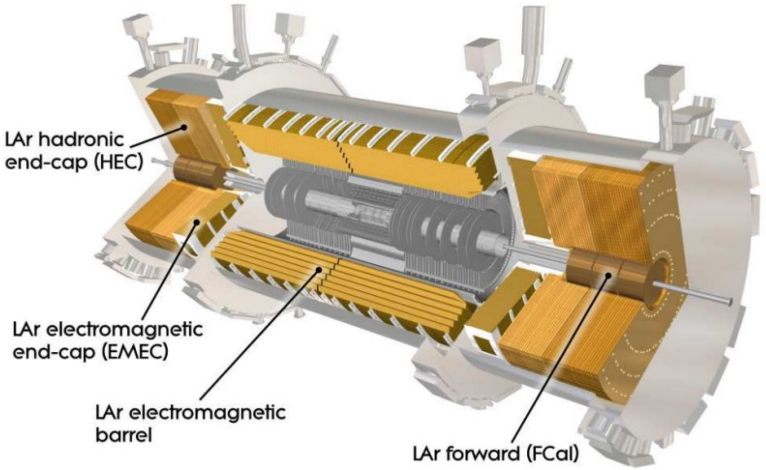
Full demonstrator, including aggregator board to be tested in beam June 2022

ATLAS LAr Calorimeter Commissioning for LHC Run-3



Tingyu Zhang
(University of Tokyo)

- The ATLAS Liquid Argon (LAr) Calorimeter
  - LAr calorimeter provides input of Level-1 triggers and precise measurement of e, γ, jets and missing E_T.
- Phase-I upgrade program for the upcoming LHC Run-3 operation
  - Trigger path upgrade - a new finer granularity scheme called “**Super Cells**”
  - Improves efficiency on EM objects with suppressing jets and pileup contributions under Run-3 high luminosity of $\mathcal{L} = 3\times10^{34}\ \mathrm{cm}^2\mathrm{s}^{-1}$, $\sqrt{s} = 13.6$ TeV.
  - Calibration runs and pilot runs to validate new readout system.
  - Installation & commissioning going well, **ready for Run-3** data taking! ✓



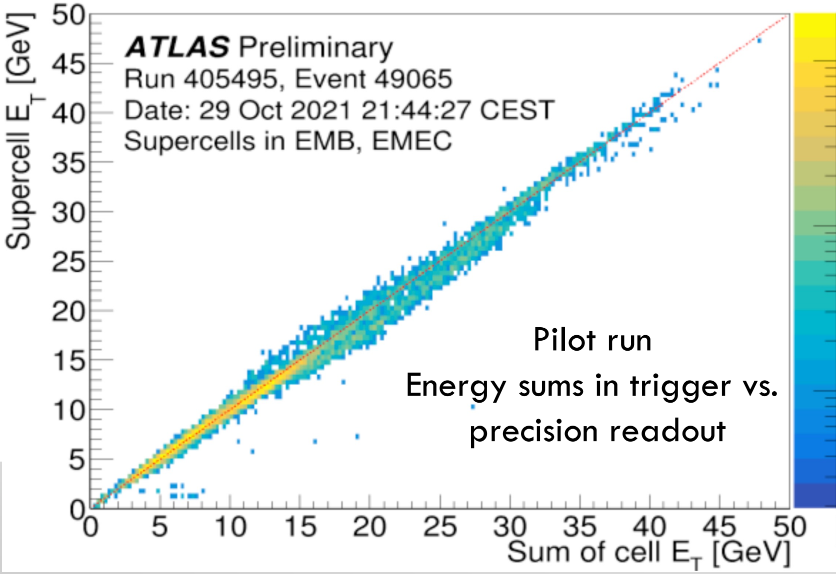
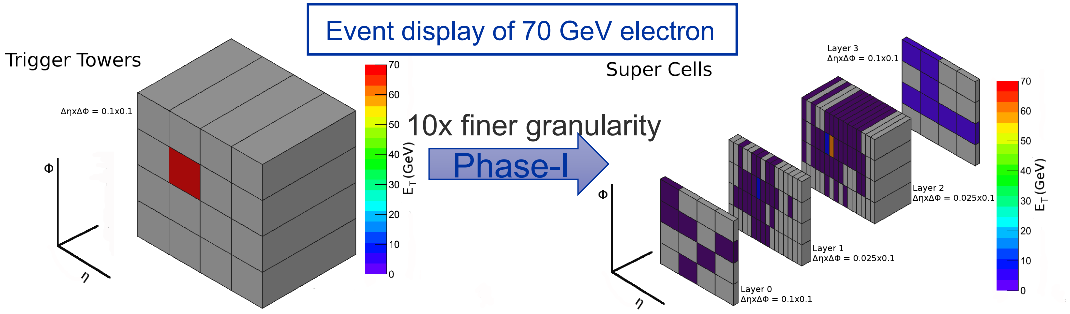
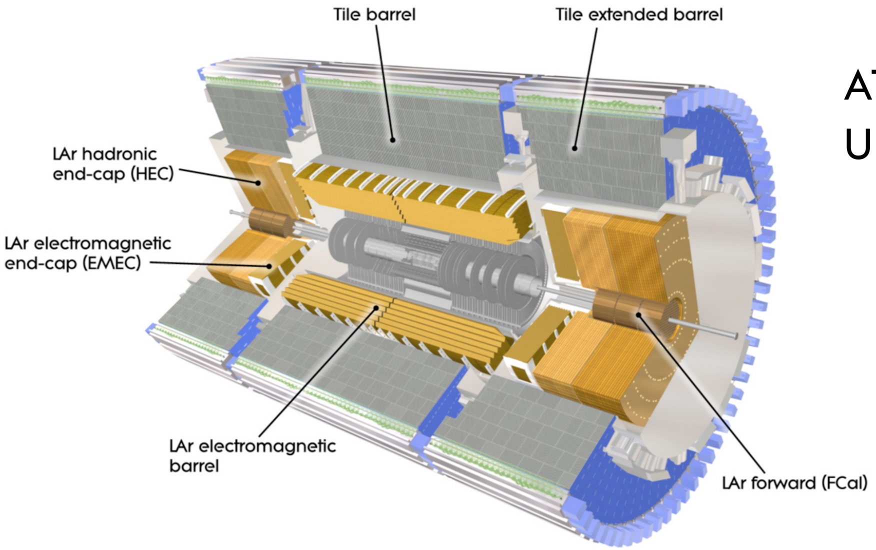


Fig 3



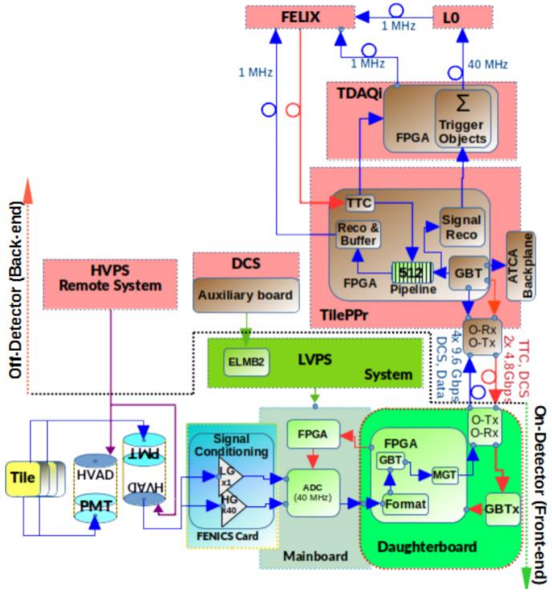
Upgrade of ATLAS Hadronic Tile Calorimeter for HL-LHC

Antonio Jesus Gomez Delegido
(Valencia and CSIC)



ATLAS Tile Calorimeter: central region hadron calorimeter.
Up to 3 TeV per cells.

- At the HL-LHC, **instantaneous luminosity** will be **increased** by a factor ~7.
- ATLAS Tile Calorimeter will need **new electronics** to meet the requirements of a **1 MHz** fully digital **trigger**, **higher radiation** dose and ensure a good **performance** under a **high pile-up** level.
- TileCal upgrade program has undergone extensive R&D and test beam studies.
- Ongoing **developments** and **recent results** are discussed in the poster.

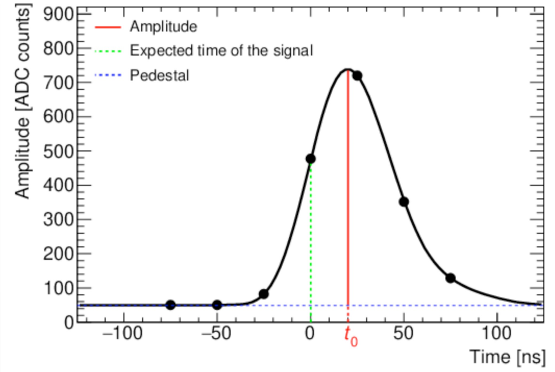


Antonio Jesús Gómez Delegido on behalf of the ATLAS Tile Calorimeter system

ATLAS EXPERIMENT
VNIVERSITAT DE VALÈNCIA
IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

TIME CALIBRATION, MONITORING AND PERFORMANCE OF ATLAS TILE CALORIMETER IN RUN 2

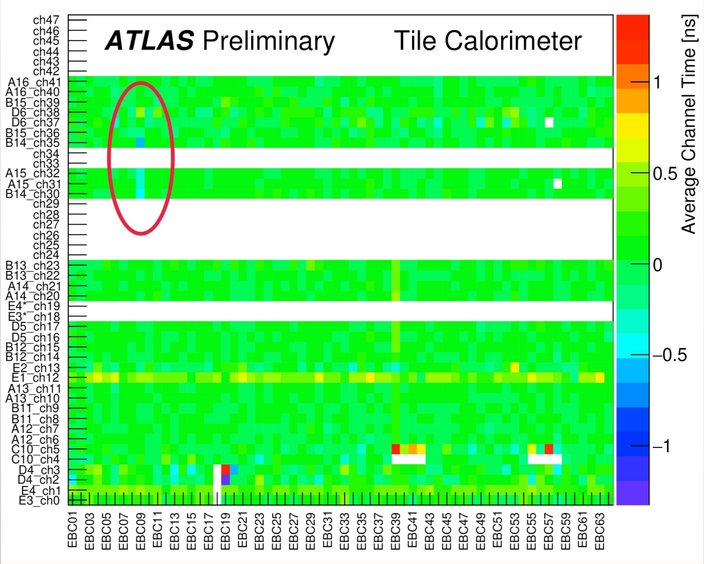
Kristina Mihule
(Charles University)



Signal sampling at 40 MHz. Precise and fast (trigger) energy reconstruction (Up to 3 TeV per cells) requires pulse position to be known and stable in time.

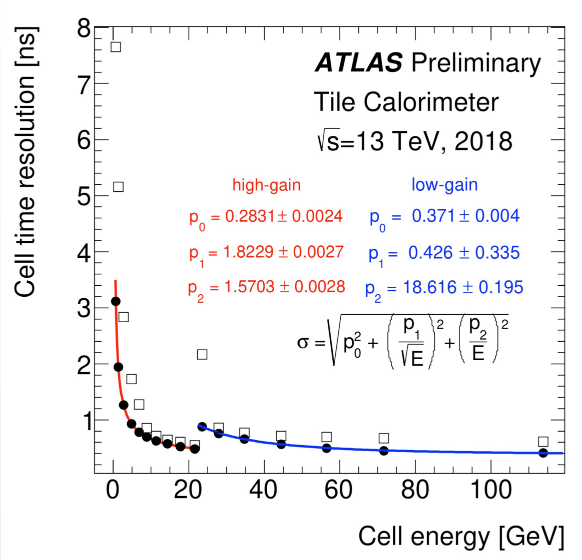
→ The time calibration is performed with multiple methods and redundantly monitored.

Monotoring of timing quality

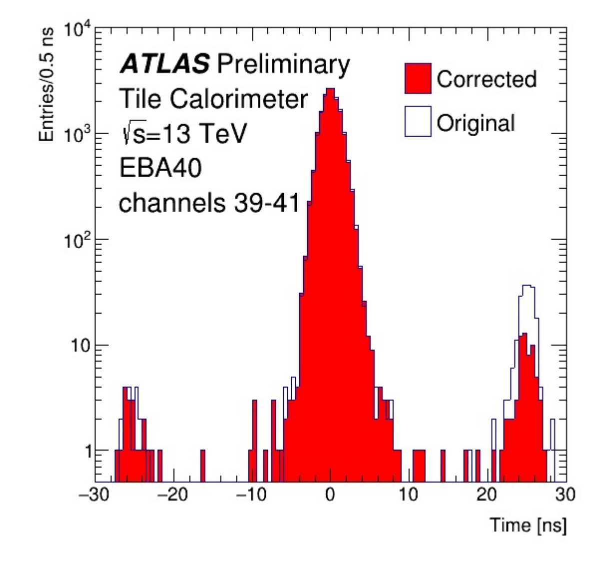


Very few outliers, sources of mistiming in general traced down to the electronics.

Cell time resolution



Cell time can also be used to remove non-collision background

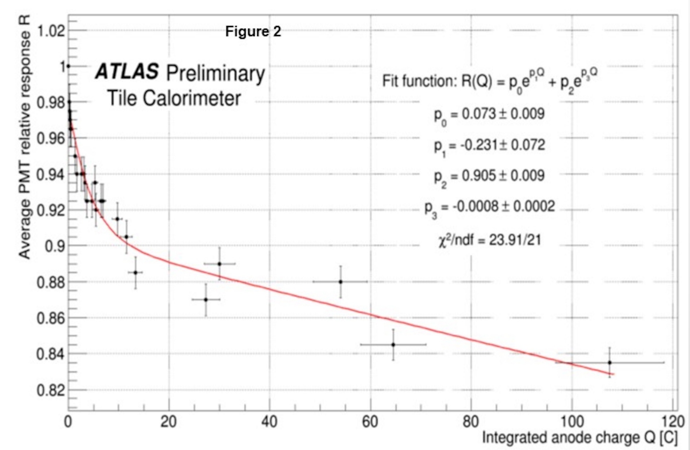


Giorgio Chiarelli
INFN Pisa

LONG TERM AGING TEST OF THE NEW PMTS FOR THE HL-LHC ATLAS HADRONIC TILE CALORIMETER UPGRADE

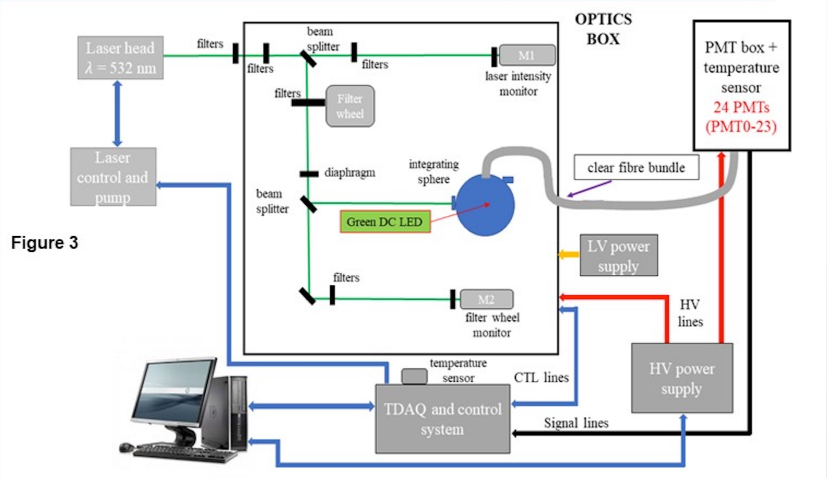
ATLAS Hadron Tile Calorimeter employs 10,000 PMTs used since the beginning of LHC. Need to understand the long term aging of the PMTs and feasibility to keep these PMTs until the end of HL-LHC.

The evolution of the current PMT R7877 response over the integrated charge has been determined with ATLAS data.

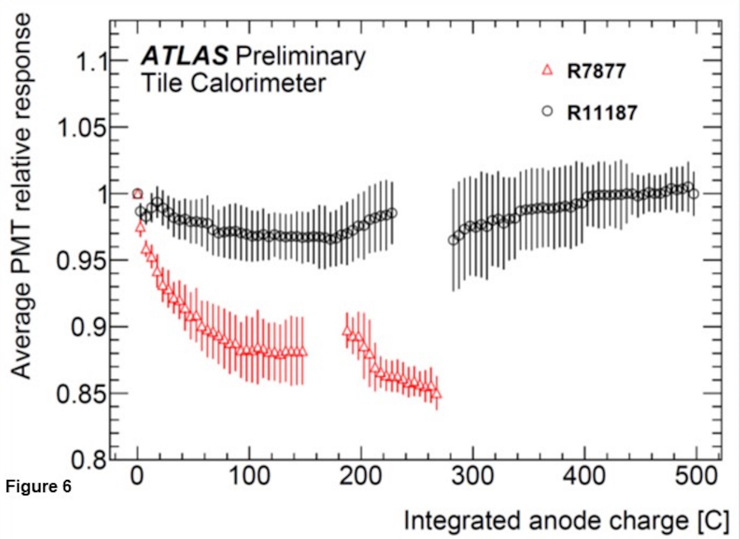


Model indicates that the 8% most exposed PMTs will reach unacceptable losses and need to be replaced.

A precision teststand was developed in Pisa for long term studies of aging of new PMT R11187 Hamamatsu model considered for HL-LHC upgrade



Hamamatsu PMT R11187 have now been tested to ~500C and all but one shows excellent performance.



PARTICLE RECONSTRUCTION

Polina Simkina
(CEA)

DEEP LEARNING TECHNIQUES FOR ENERGY CLUSTERING IN THE CMS EM CALORIMETER

Rechits → Clusters → SuperClusters

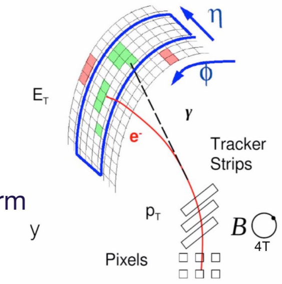
Rechits: **Reconstructed energy deposits** in the PbWO4 crystals of the calorimeter (rechits) left by particles.

Clusters: Rechits are gathered together around the crystal with highest deposited energy to form **clusters**.

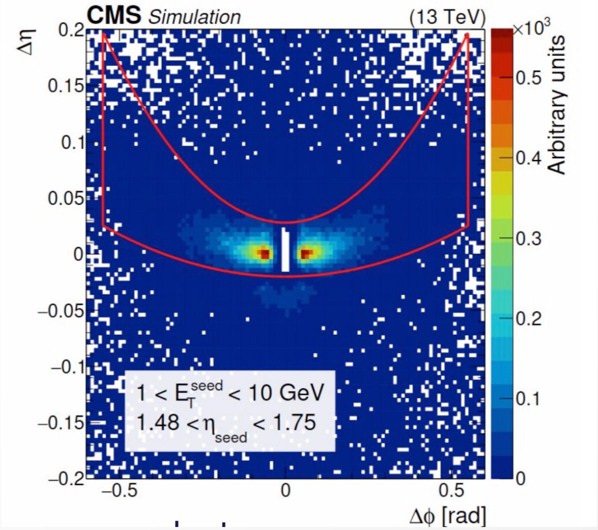
Each cluster represents a **single particle**.
➔ Or several overlapping particles.

SuperClusters: Due to bremsstrahlung and photon conversion before the ECAL, the individual clusters have to be combined together to form a **SuperCluster**.

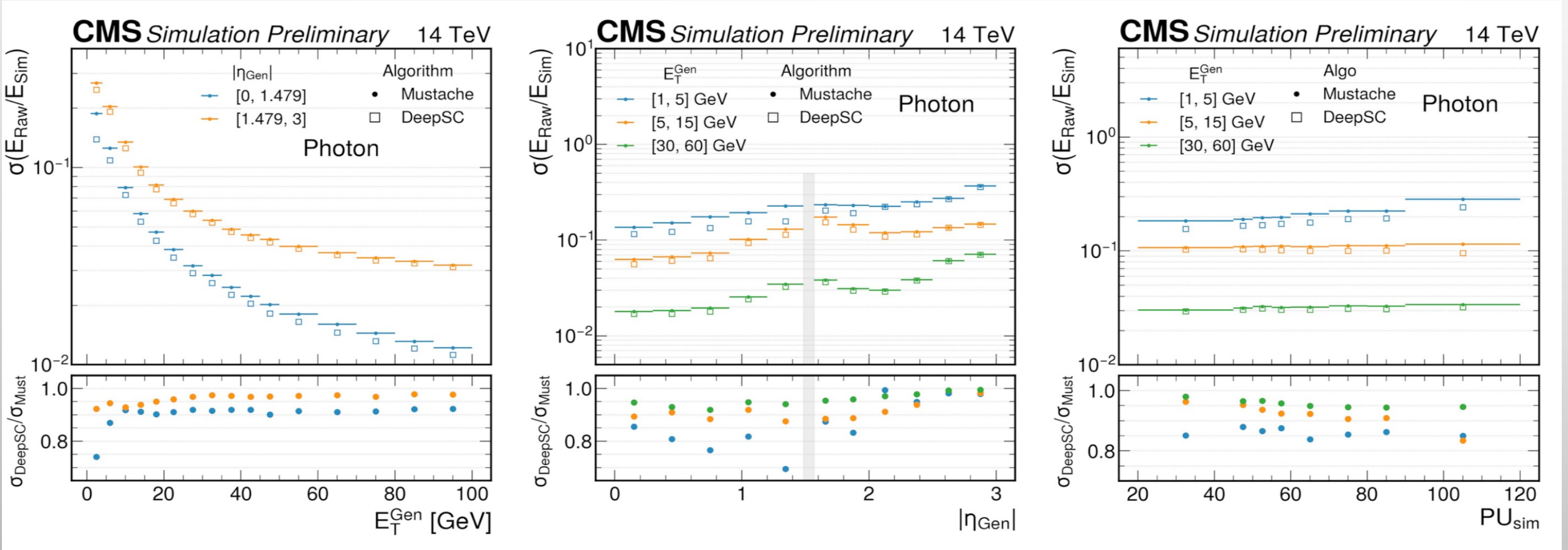
The energy of the initial particle can be reconstructed from the SuperCluster.



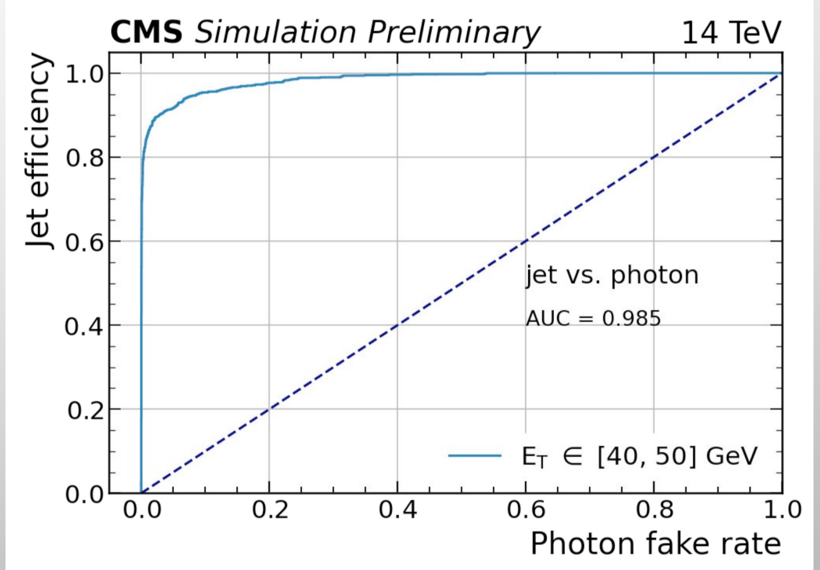
Currently used: Mustache algorithtm



Graph-based Machine Learning algorithm for SuperClustering maintain efficiency, improves noise and PU rejection.



High performance for jet vs. photon discrimination

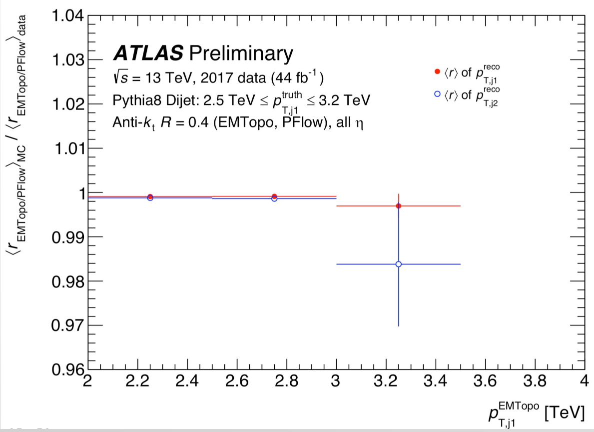


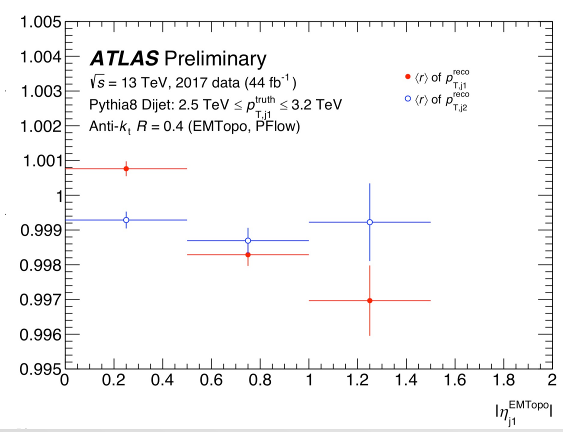
Nina Wenke
(Munich)

SINGLE-PARTICLES UNCERTAINTIES AND LOCAL HADRON CALIBRATION FOR PARTICLE-FLOW JETS IN ATLAS

ATLAS particle flow (PFlow) associates calorimeter clusters to charged hadron tracks (p_T<40 GeV).
Idea: Exploit a better track momentum resolution for low p_T charged particles and **replace calorimeter energy by** the **track measurement**. Subtract the energy of the track from the calorimeter, keep remaining calorimeter cluster energy if significant (neutrals!)

Single particle uncertainties are used to evaluate energy scale uncertainties at p_T>2 TeV. Prove that the same technique can be used for PFlow jets, by studying MC-response/data-response

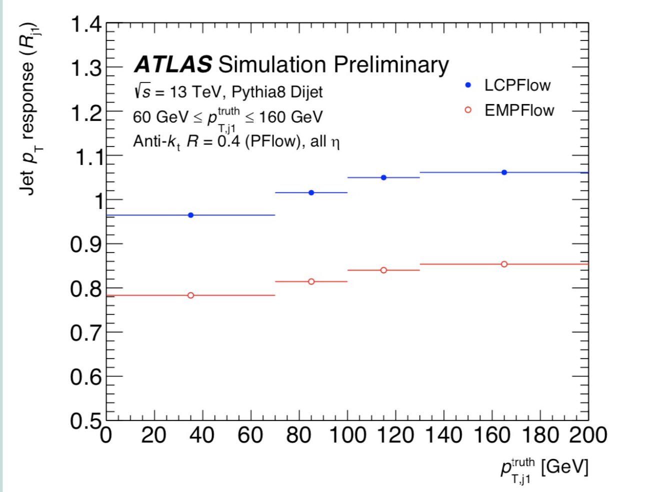


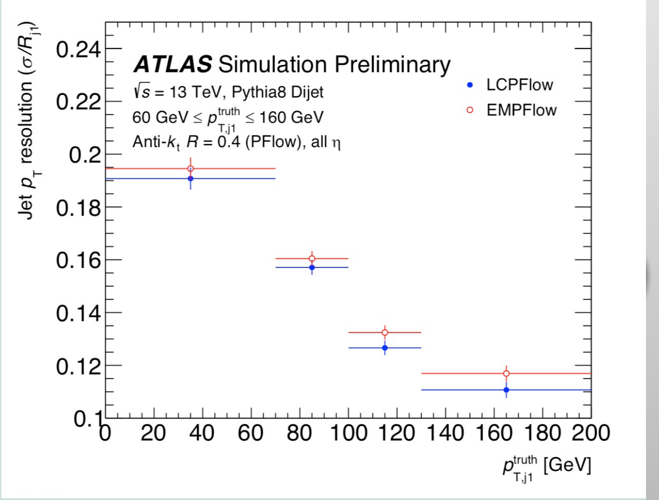


In ATLAS PFlow calorimeter clusters are calibrated at the EM scale: "EMPFlow".

Check the characteristics of each cluster to determine whether it is more like an EM or Hadronic component of the shower => weight the cluster energy correspondingly: **"LC weight".**

New: use LC weighted clusters with PFlow algorithm "LCPFlow".
Brings **jet response closer to one** and **improves the jet energy resolution.**



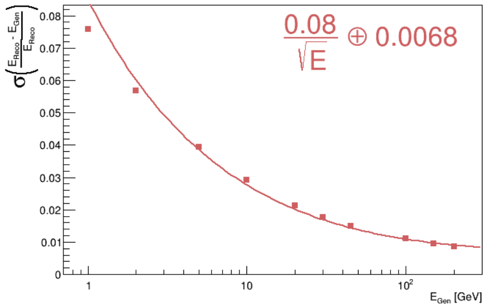


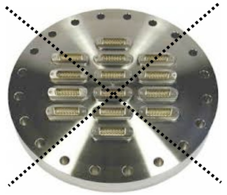
FUTURE CALORIMETERS

Noble Liquid Calorimetry for a Future FCC-ee Experiment

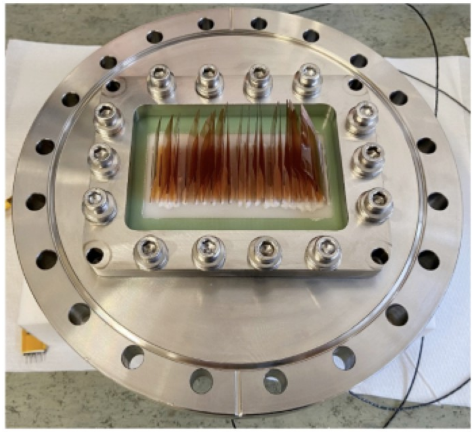
Christophe de la Taille &
François Brieuc
OMEGA Ecole Polytechnique

Very good EM energy resolution

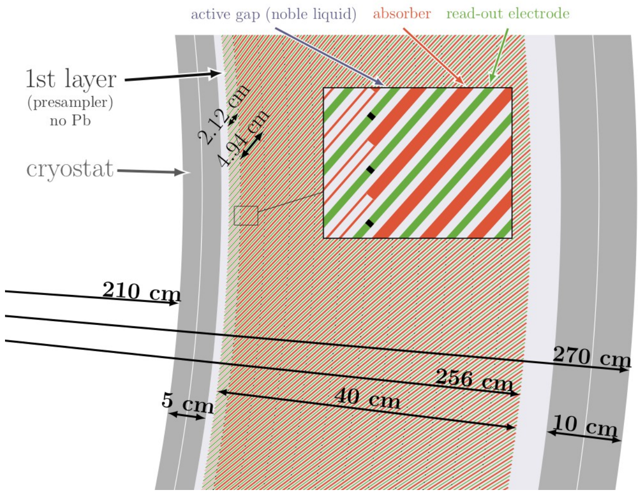




Connector-less feedthroughs to extract the ~ 2 M channels

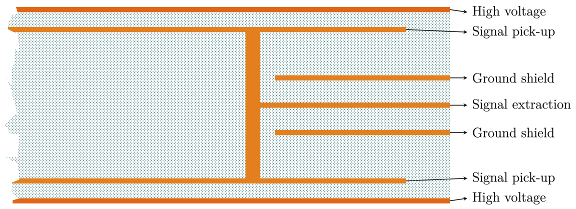


High granularity sampling calorimeter with inclined Pb/W plate geometry and Noble Liquid sensitive gap



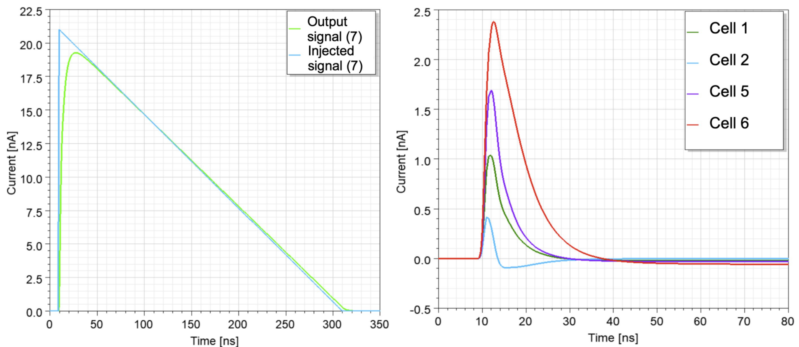
Multi-layer PCB readout electrode

- **12 longitudinal compartments**
- $\Delta\theta$ = 10 mrad (2.5 for the strip layer), $\Delta\Phi$ > 8 mrad, Δr = 3.5 cm



Carbon fibre cryostat to minimize dead material budget

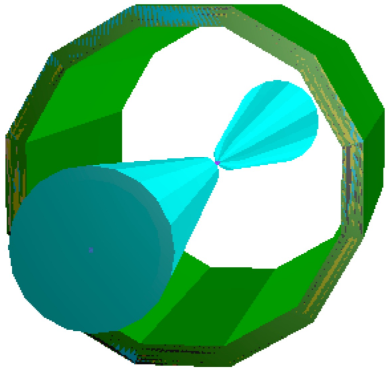
Cross-talk and noise study with FEM tools



- Simulations: MIP S/N > 5 per cell is achievable
- Carbon fiber cryostat:10 times < material than Al.
- High density connector-less feedthroughs
- 8% sampling term in conservative design
- Competitive τ final state categorization

CRILIN: a semi-homogeneus Crystal Calorimeter for a future Muon Collider

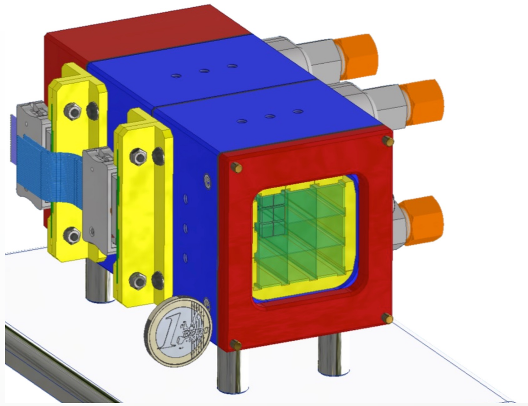
Daniele Paesani
(INFN Frascati)



Muon collider major challenge: **beam-induced background (BIB)** due **to muons decay** and subsequent interactions, characterized by particles with low momentum (~ 1.8 MeV), **displaced origin**, and **asynchronous time of arrival.**

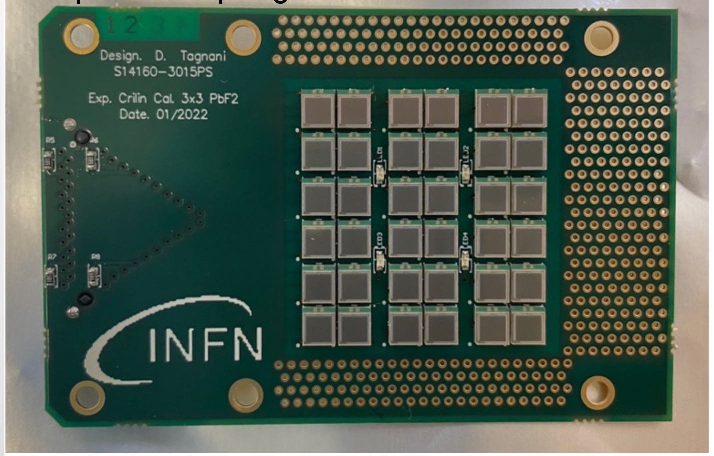
Cherenkov PbF2 crystals with UV- extended SiPM readout.

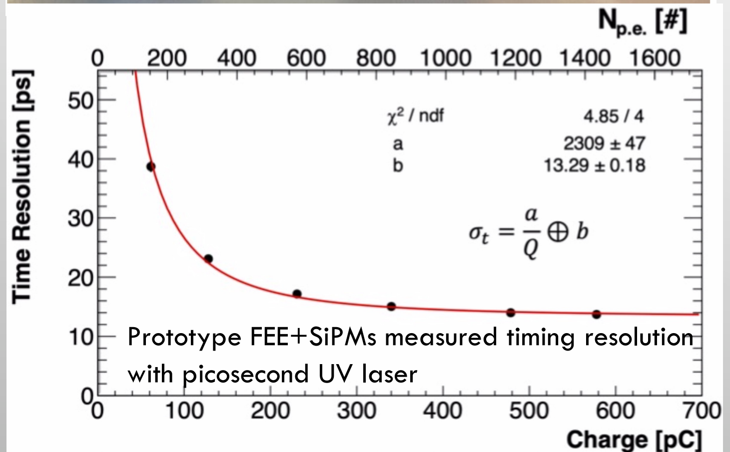
Crilin ECAL barrel design **with 5 layers of 10x10x40 mm³** evaluated for the reconstruction of b-jets from Higgs decays (at $\sqrt{s}$ = 1.5 TeV) against the expected (300 γ/cm2 per BX) BIB using particle-flow methods: good separation is achieved with O(5 GeV) energy deposit per crystal.



Proto-1=two 3-by-3 crystals submodules

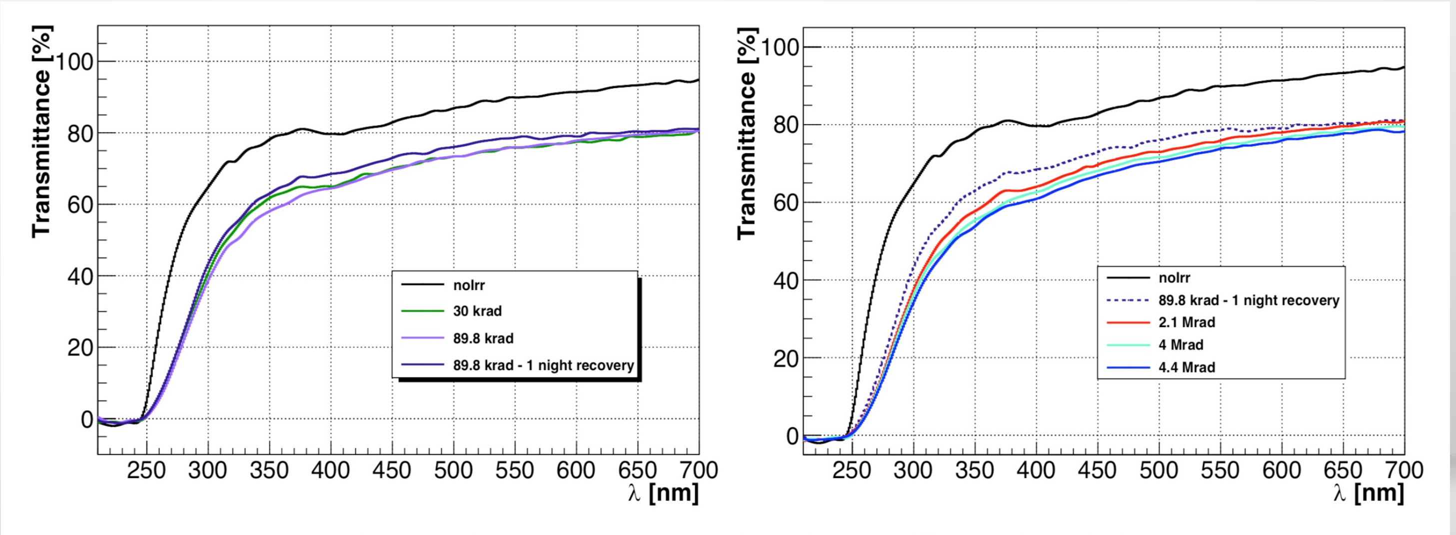
optical coupling to SiPM boards





Prototype FEE+SiPMs measured timing resolution with picosecond UV laser

Radiation effects FLUKA predicts neutron fluence 10^{14} n_{1MeV}/cm^2 and TID 10^{-4} Grad/y
Evaluation of TID effects on PbF2 crystals show 40% degradation at 4 Mrad
NIEL with 14 MeV neutrons up to a 10^{13} n_{1MeV}/cm^2 fluence showed no effect



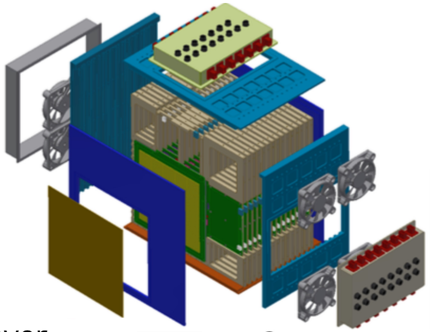
Crystal transmission spectra deterioration at different irradiation steps

Highly granular scintillator-strip electromagnetic calorimeter for future Higgs factories

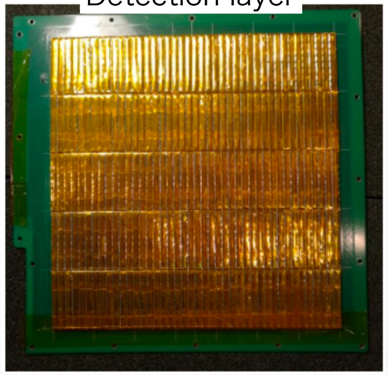
Naoki Tsuji
(University of Tokyo)

Scintillator-strip ECAL (Sc-ECAL)

✓ Highly granular calorimeter for Higgs factories
- Based on scintillator strips readout by SiPM
- Virtual segmentation: 5×5 mm^2 in x-y configuratic



Detection layer



Constructed prototype

Large technological prototype constructed

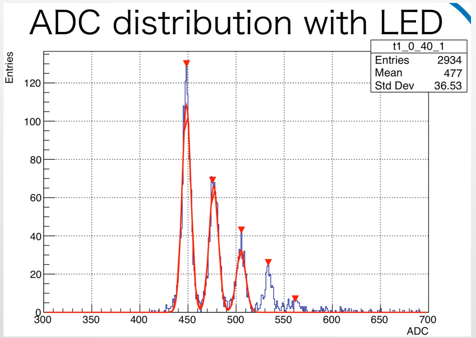
- Use the same technology as foreseen in full scale detector
- Evaluate the performance of Sc-ECAL using **full 30 layers**

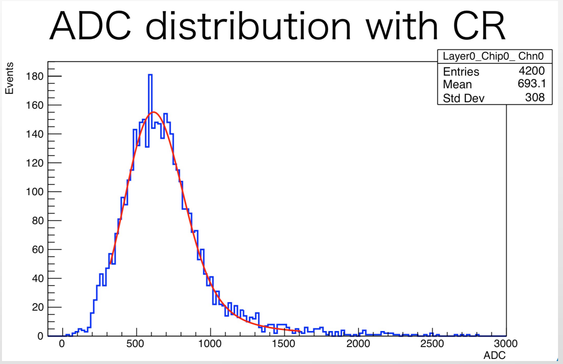
Per-channel calibration succeeded

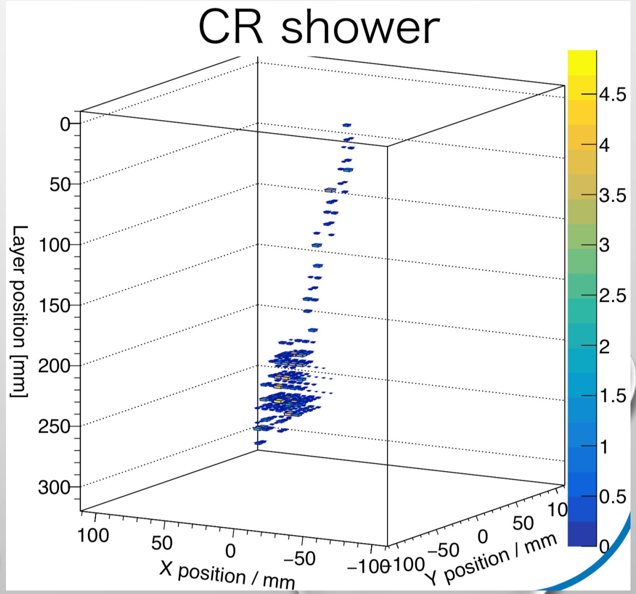
- Gain, MIP, cross-talk …

Calibration with LED

- Single photo-electron gain
- Excellent stability over 1 month







Calibration with cosmic rays

- Good agreement with simulations
- Investigating trend of ADCs per MIP decreasing slowly with time over 3 momnths.

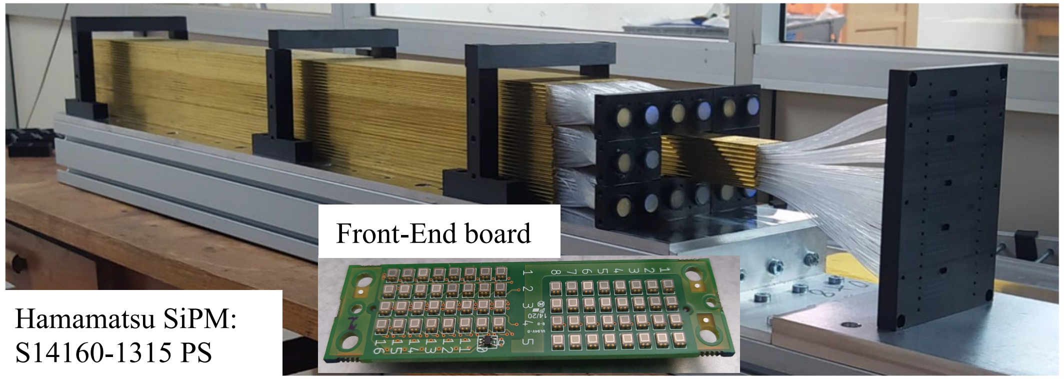
Sc-ECAL is found to be a promising and mature technology for highly granular calorimeter

Test beam results of the fibre-sampling Dual-Readout Calorimeter

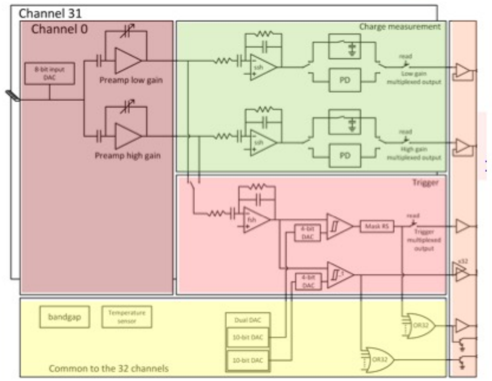
Agnese Giaz
(Milano)

IDEA Dual-Readout Collaboration

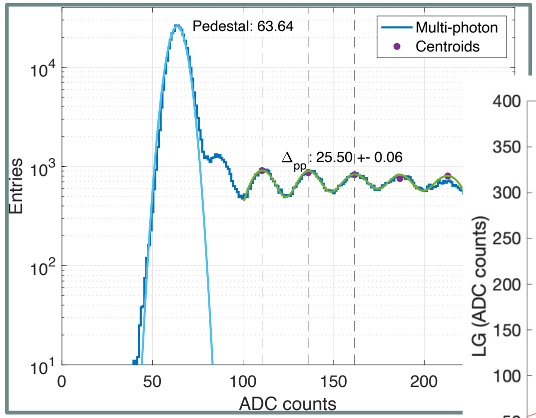
Em size prototype tested @ DESY



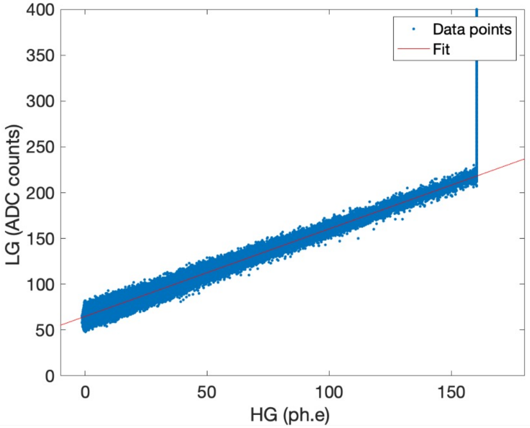
CITIROC 1A: block diagram



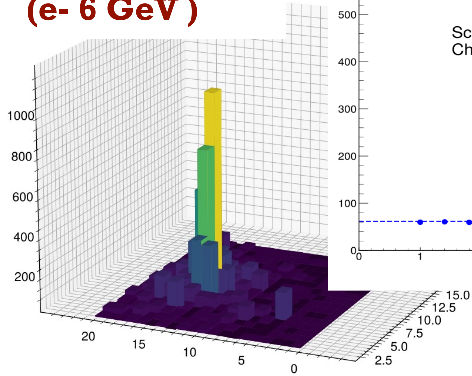
High Gain calibration (ADC/Ph-e)



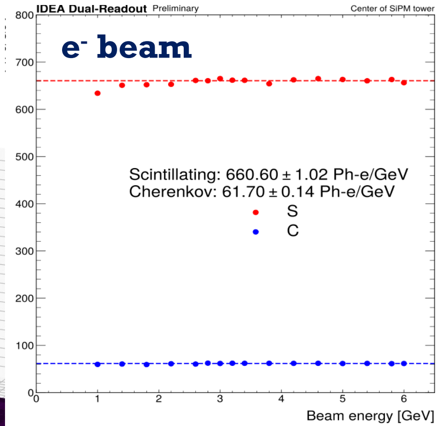
Low Gain calibration (ADC/Ph-e)



Event display (e- 6 GeV)



Linearity



INFN

R. Santoro

Conclusion and future R&D

- The first em size prototype equipped with SiPMs has been tested on beam and the strategy to calibrate the SiPMs was fully qualified
- The design of a scalable solution compliant with the next generation of leptonic colliders is progressing
- The final goal is to assess the hadronic performances using a prototype with hadronic containment

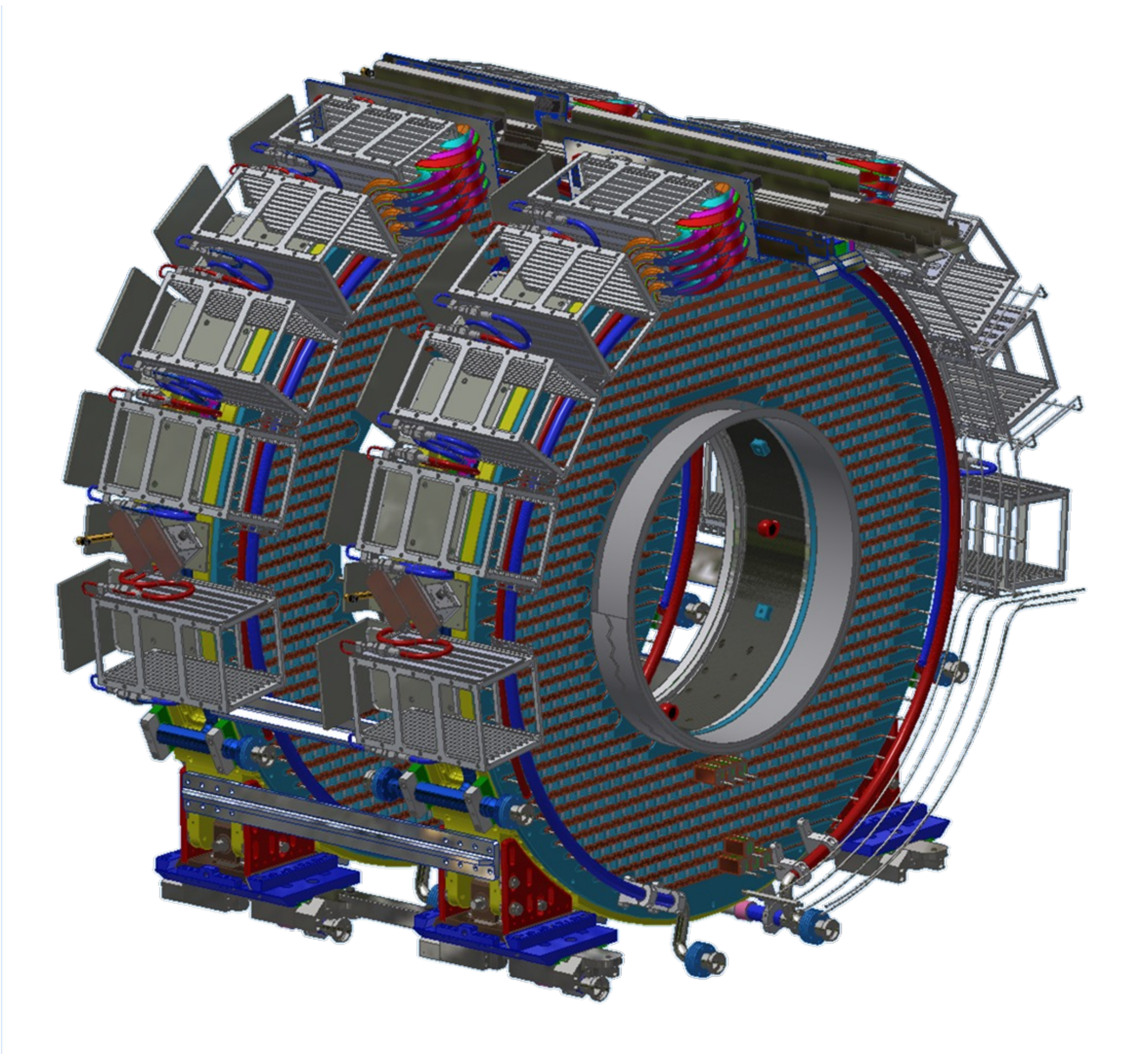
Calorimetry for intensity frontier experiment (precision physics)

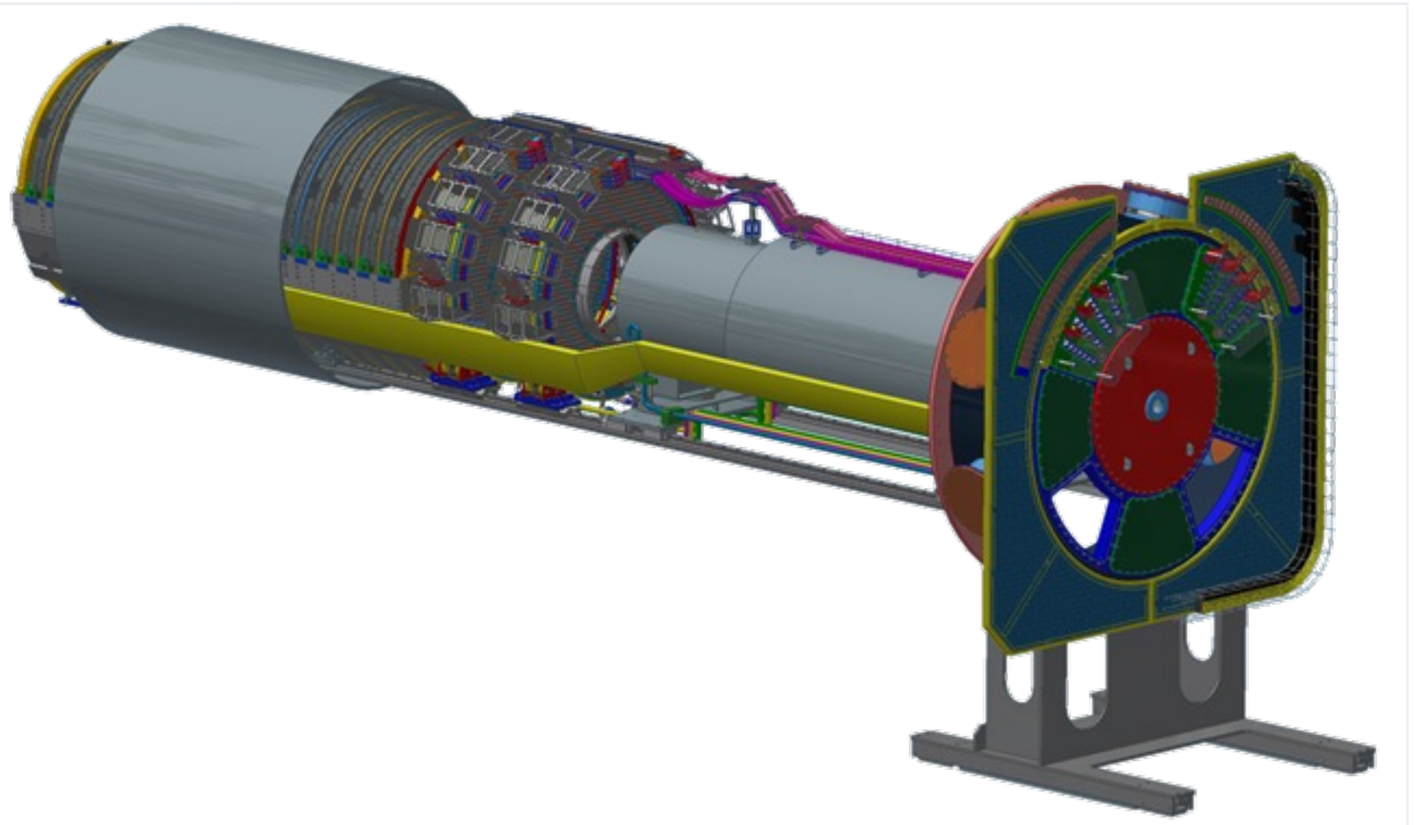
The Engineering of the Mu2e Calorimeter

Abstract

The Mu2e experiment at Fermi National Accelerator Laboratory (Batavia, Illinois, USA) searches for the charged-lepton flavor violating neutrino-less conversion of a negative muon into an electron in the field of an aluminium nucleus. The calorimeter plays an important role to provide excellent particle identification capabilities and an online trigger filter while aiding the track reconstruction capabilities, asking for 10% energy resolution and 500 ps timing resolution for 100 Mev electrons. It consists of two disks, each one made by 674 un-doped CsI crystals, read out by two large area UV-extended SiPMs. In order to match the requirements of reliability, a fast and stable response, high resolution and radiation hardness (100 krad, 10^12 n/cm^2) that are needed to operate inside the evacuated bore of a long solenoid (providing 1 T magnetic field) and in the presence of a really harsh radiation environment, fast and radiation hard analog and digital electronics has been developed. To support these crystals, cool down the SiPMs and support and dissipate the electronics heat power, a sophisticated mechanical and cooling system has been also designed and realized.

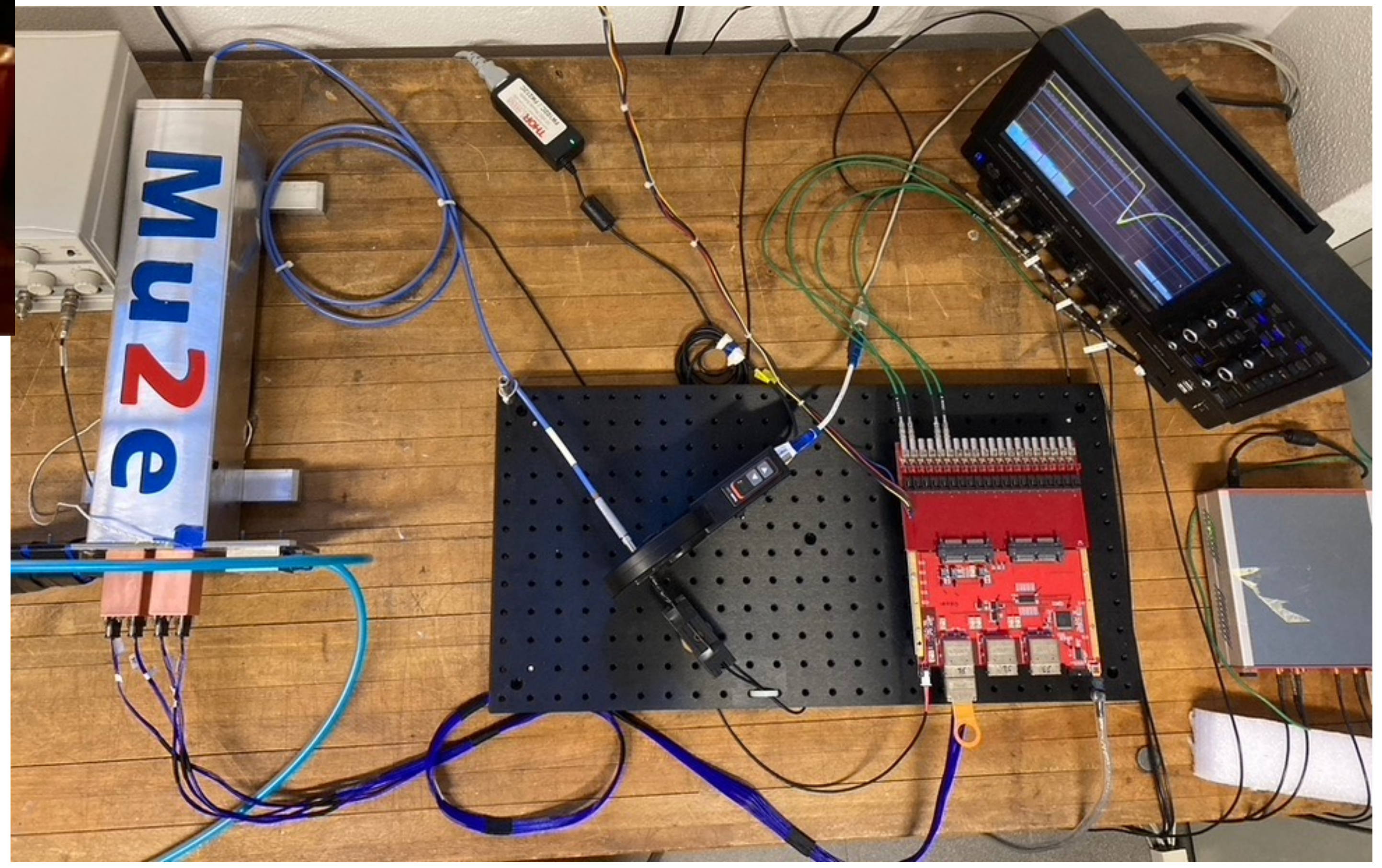
We describe the mechanical details, design and performances along with the assembly status of all the calorimeter components and its integration in the Mu2e Experiment.





An automated QC station for the calibration of the Mu2e Calorimeter Readout Units

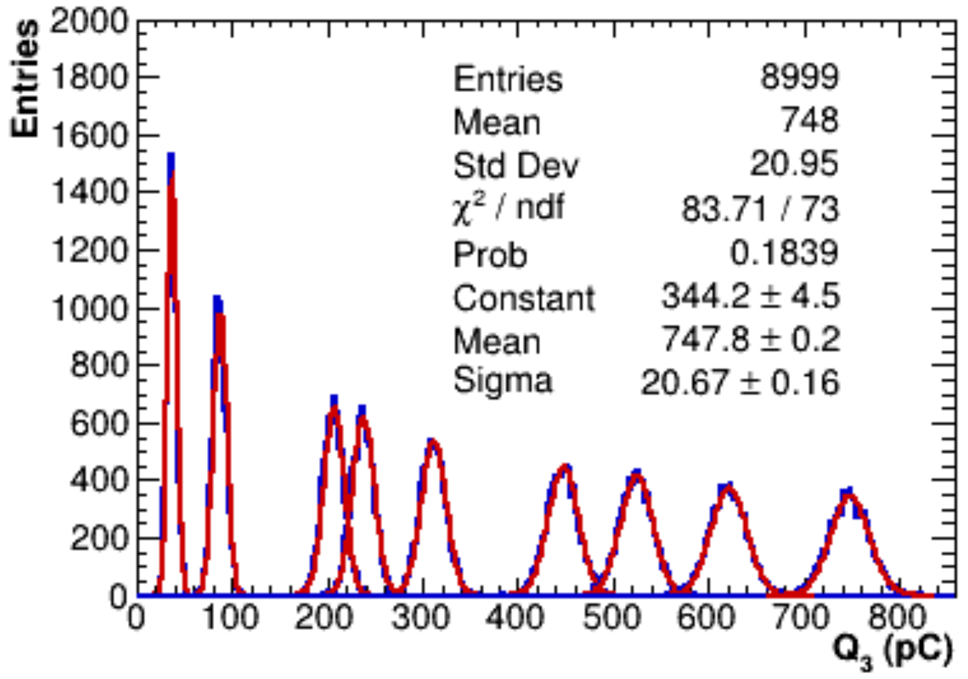
Elisa Sanzani on behalf of the Mu2e Calorimeter group



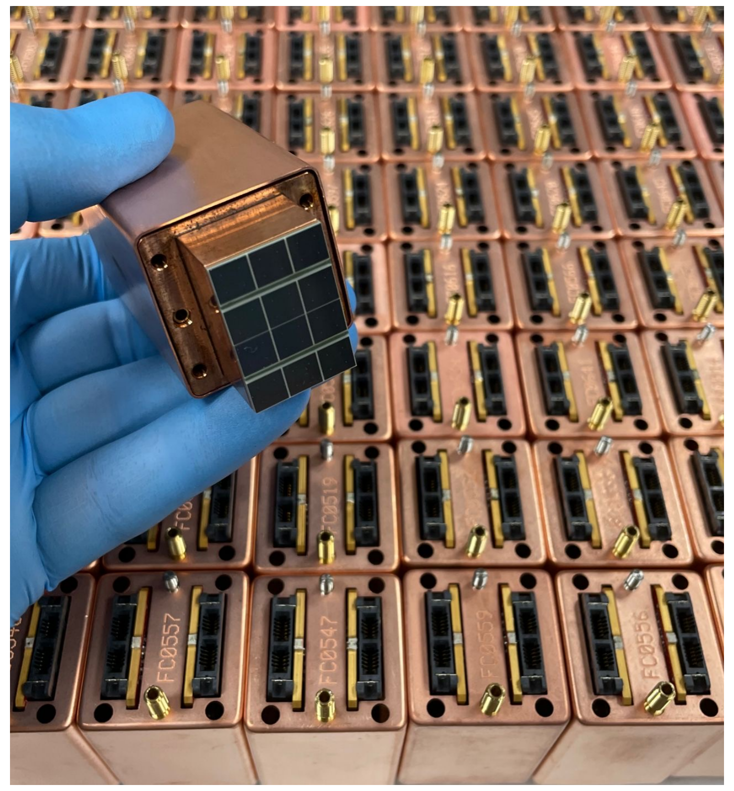
<u>Mu2e CsI Crystal Calorimeter Readout Unit (ROU)</u>:
Two 2x3 SiPM matrices, two Front End Electronics boards, copper holder and Faraday cage

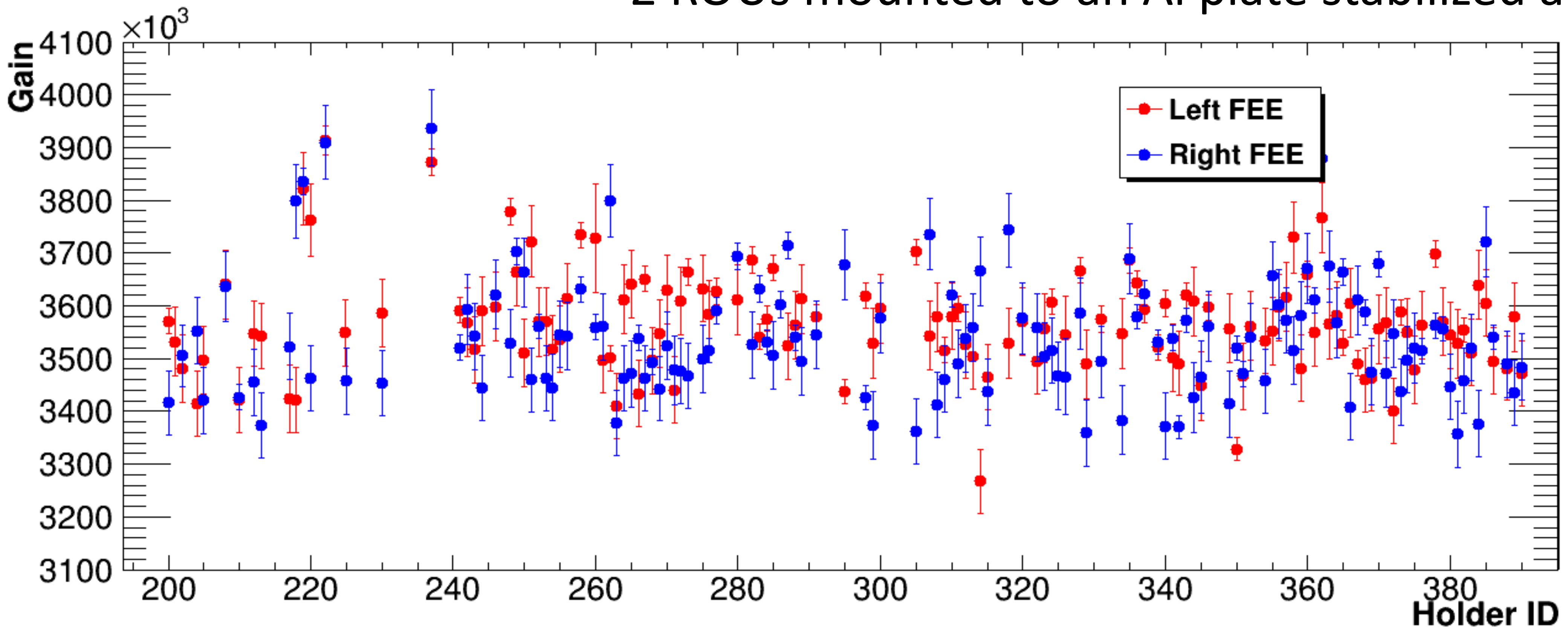
⇨ <u>Characterization of the ROUs with the **QC Station**</u>

⇨ Study of SiPMs Gain, Photon Detection Efficiency and charge at different light intensities and bias voltages



- ✓ 420 nm Blu LED
- ✓ 9 position filter wheel to attenuate the light intensity
- ✓ Sandblasted glass layers to diffuse light, in a box to ensure light tightness
- ✓ 2 ROUs mounted to an Al plate stabilized at 25 °C





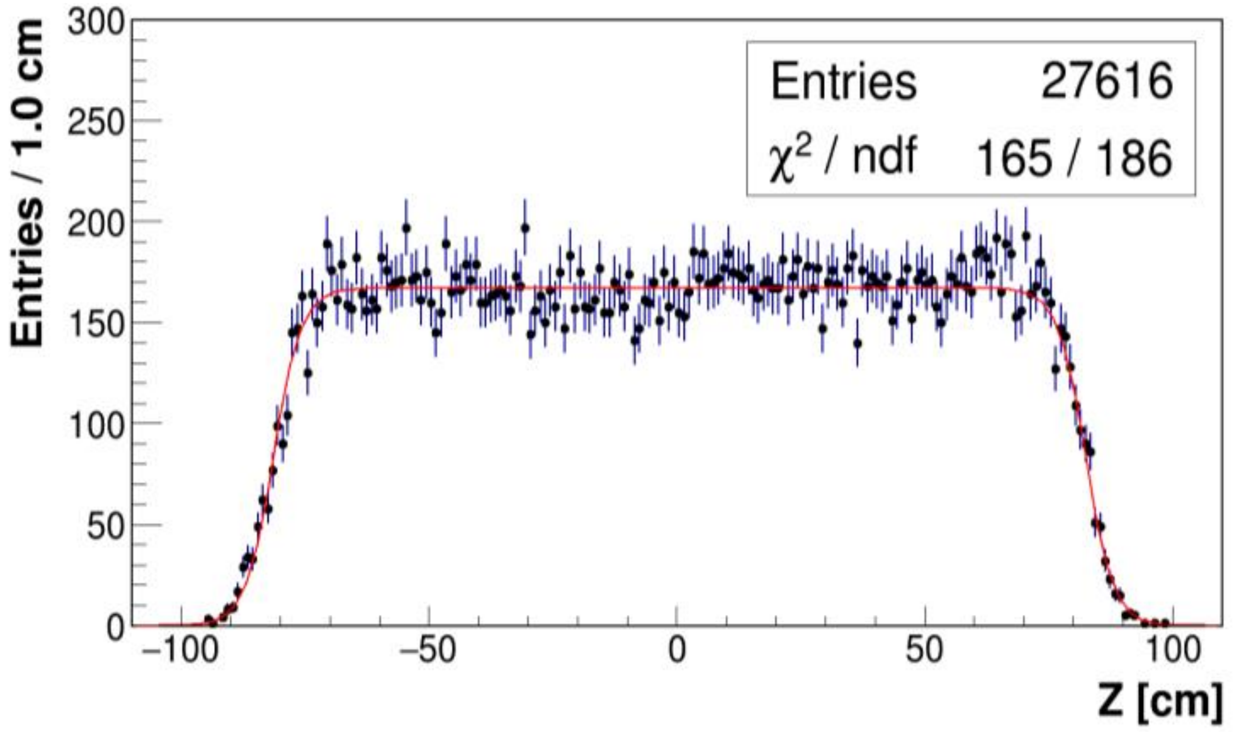
- ✓ Gain spread 2.5%
- ✓ Reproducibility 2%
- ✓ Mean gain $3.6 \cdot 10^6$
- ✓ Full characterization of the ROUs

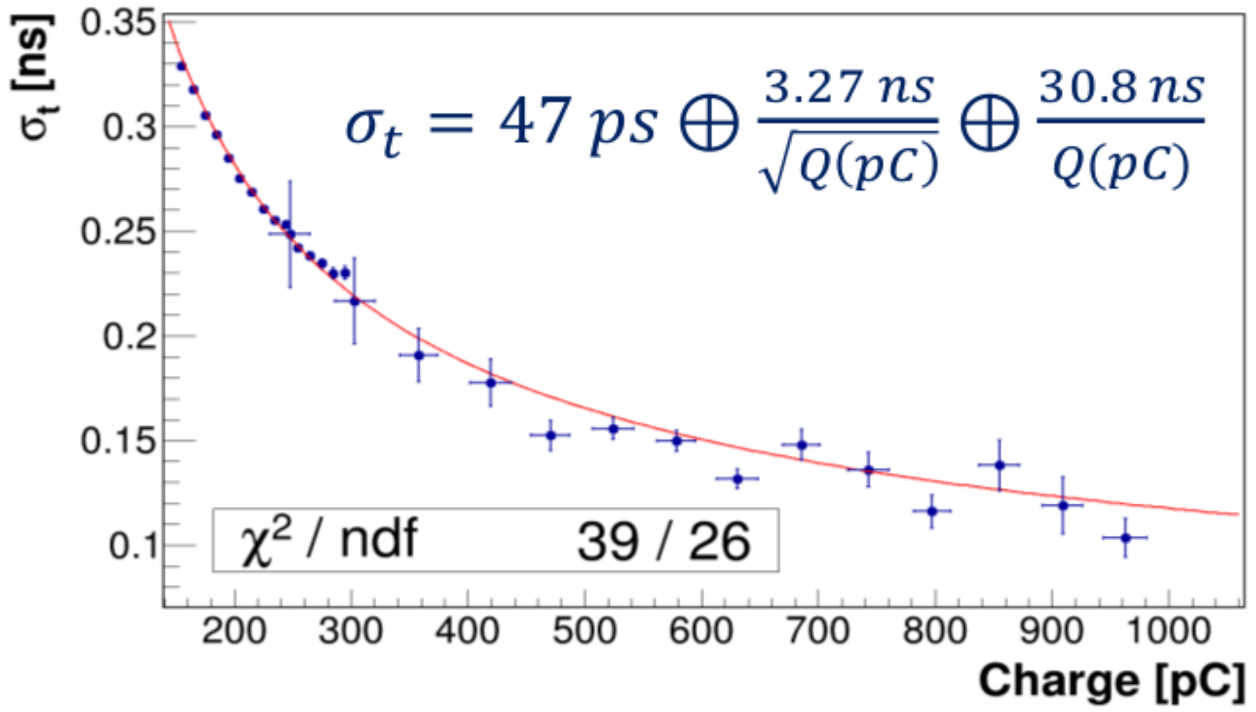
⇨ Complete knowledge of the ROU response during operations

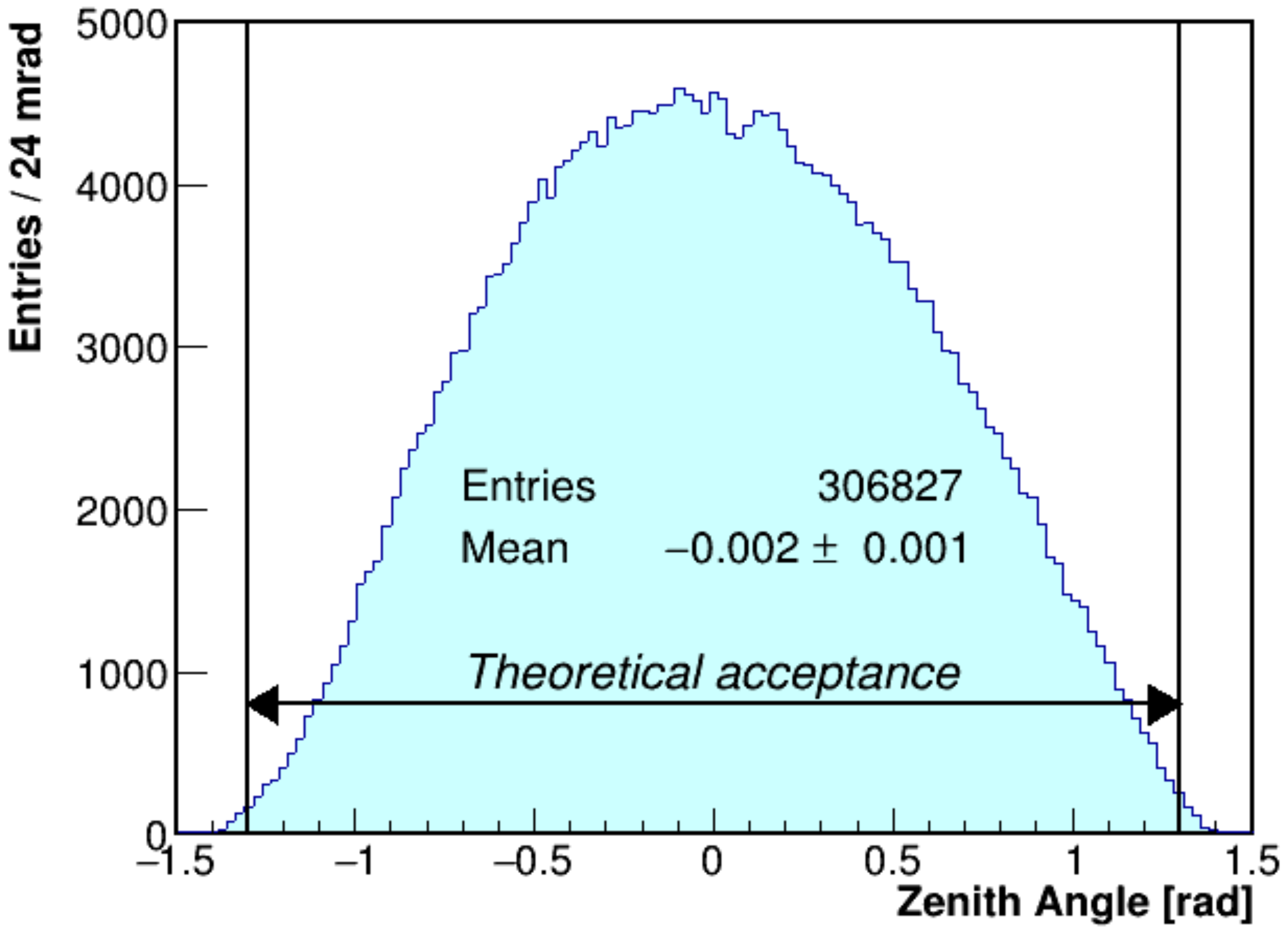
R. Gargiulo on behalf of the Mu2e Calorimeter group - INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 54, 00054 Frascati, Italy

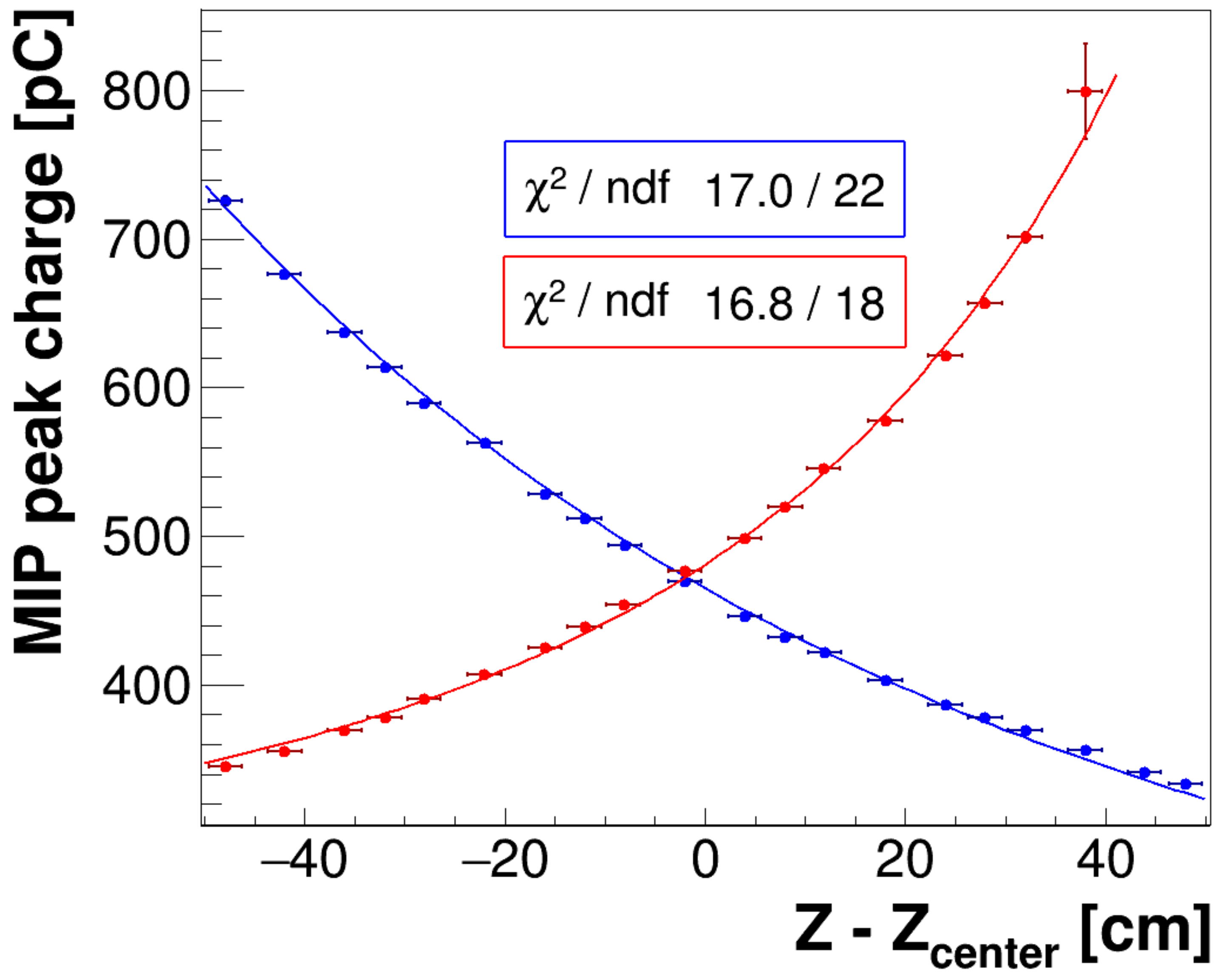
Design, assembly and operation of a scintillator based Cosmic Ray Tagger with SiPM readout

- Cosmic Ray Tagger developed for the calibration of the Mu2e Calorimeter
- Two layers of 8 (160x1.5x2.5) cm^3 EJ-200 scintillating bars, with 3.8 m Bulk Attenuation Length
- Dual-side readout based on 16 custom UV-extended large area SiPMs
- 3D tracking with time-of-arrival position reconstruction (1.6 cm σ_Z with a 14cm/ns v_p)
- 160 ps time resolution on single readout side at the cosmic ray peak
- Good zenith angle reconstruction and flat hit position profile

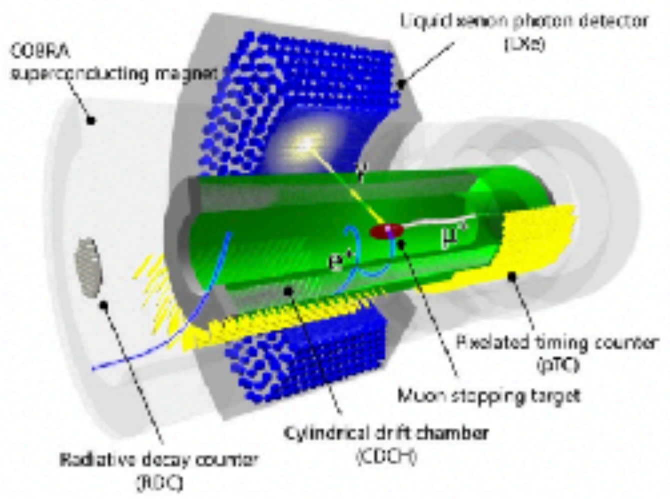








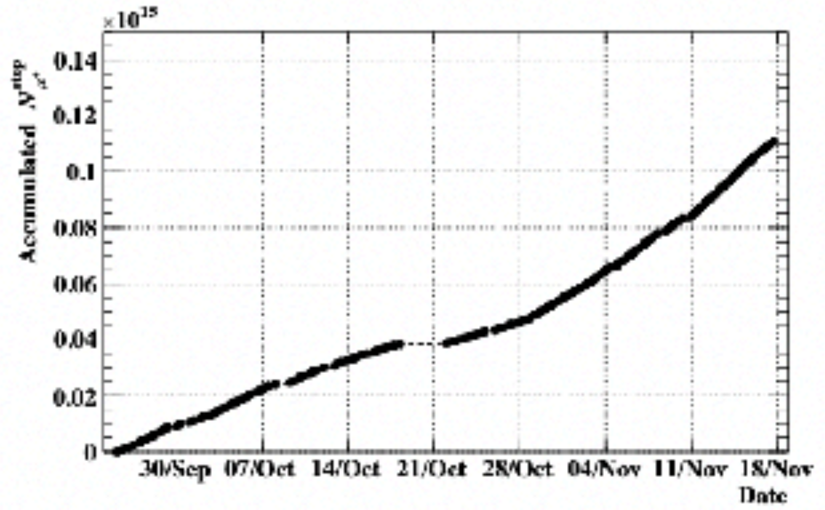
Commissioning of Liquid Xenon Gamma-Ray Detector for MEG II Experiment



Ayaka Matsushita, S.Ban, F.Ikeda, T.Iwamoto, S.Kobayashi, T.Mori, R.Onda,
W.Ootani, A.Oya, Y.Uchiyama, K.Yamamoto, T.Yonemoto, K.Yoshida
The University of Tokyo

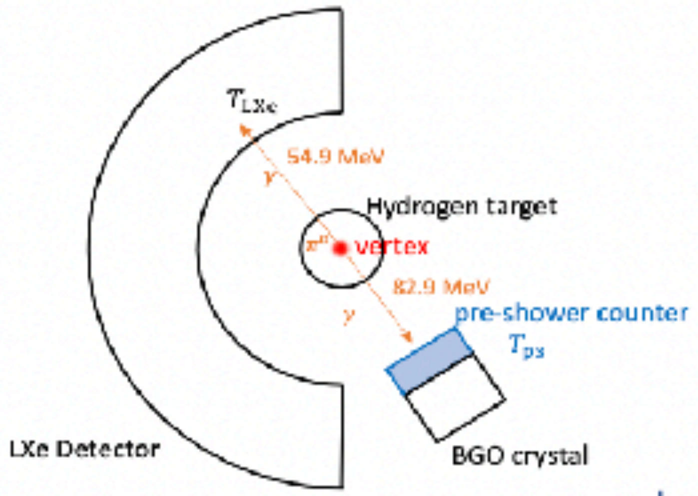
Start of Physics Data Taking

- The full electronics were installed in 2021.
- All kinds of the required calibration data were taken.
  →Physics data taking started.
- The energy scale is monitored stably with sensor calibration.
- MPPC PDE decrease has an impact for energy scale, but it can be recovered by annealing.
- Trigger for $\mu \to e\gamma$ is fired correctly.
- Physics data was taken in 2021 in some beam intensities, and analysis is ongoing.



Accumulated number of muon stopped on target

Timing Resolution Evaluation



absolute timing resolution

$$\sigma_{abs} = \sigma\left(T_{LXe} - T_{ps} - T_{TOF}\right) \ominus \sigma_{ps} \ominus \sigma_{vertex}$$

intrinsic timing resolution

$$\sigma_{int} = \sigma(T_{PM,even} - T_{PM,odd})/2$$

	Measured	MC
σ_{abs} [ps]	85.4	57.3
σ_{int} [ps]	37.8	38.4

To be investigated

(Preliminary result)

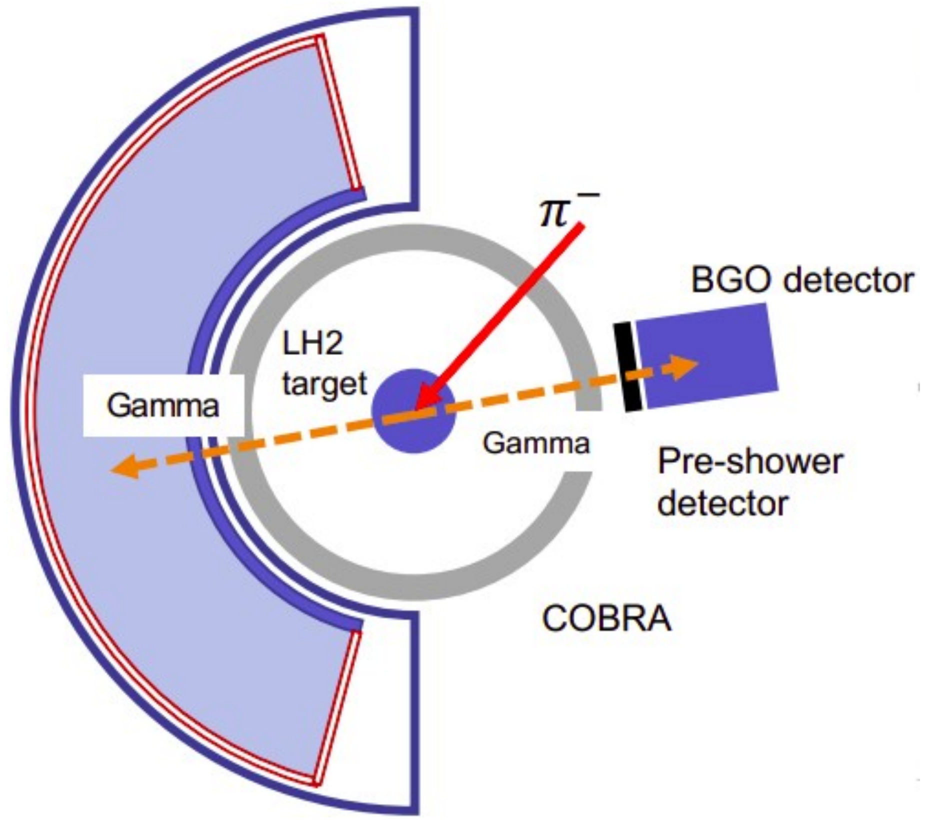
- The cause of the difference between the measured resolution and the result of MC should be investigated.
- Timing reconstruction and calibration method should be improved.

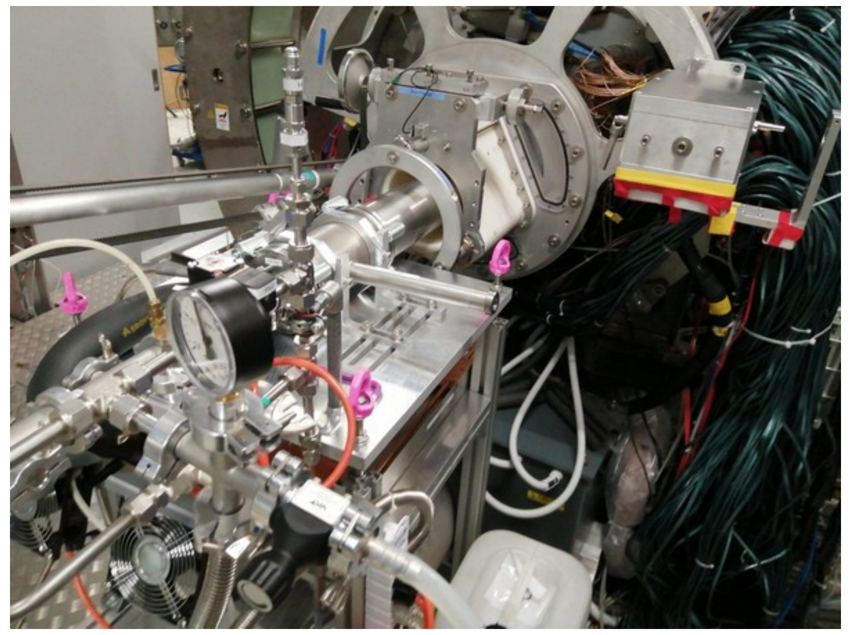
Liquid xenon gamma-ray detector is ready for the long-term physics data taking, and the detector performance and stability will be improved furthermore.

A liquid hydrogen target to fully characterize the new MEG II liquid xenon calorimeter

The poster is organized as follows:

- Short introduction on MEG and the Charge EXchange process
- Description of the LH2 target and its functioning
- Description of the LH2 circuit
- Few infos on the sensors used and the control during operation
- How the LXe resolutions are obtained (Analysis still ongoing)





Bastiano Vitali, bastiano.vitali@gmail.com

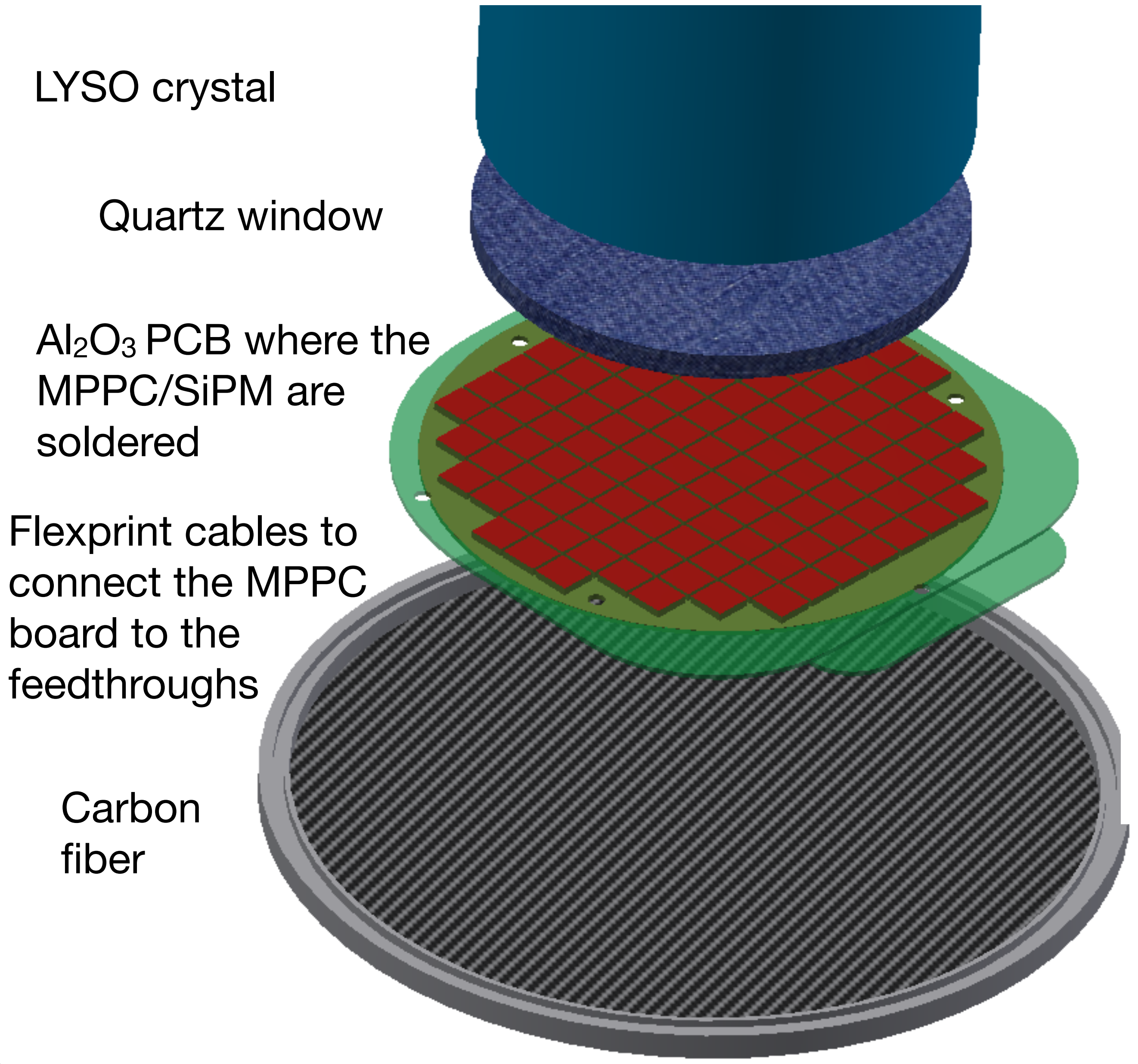
Towards large calorimeters based on Lanthanum Bromide or LYSO crystals coupled to silicon photomultipliers: A first direct comparison for future precision physics

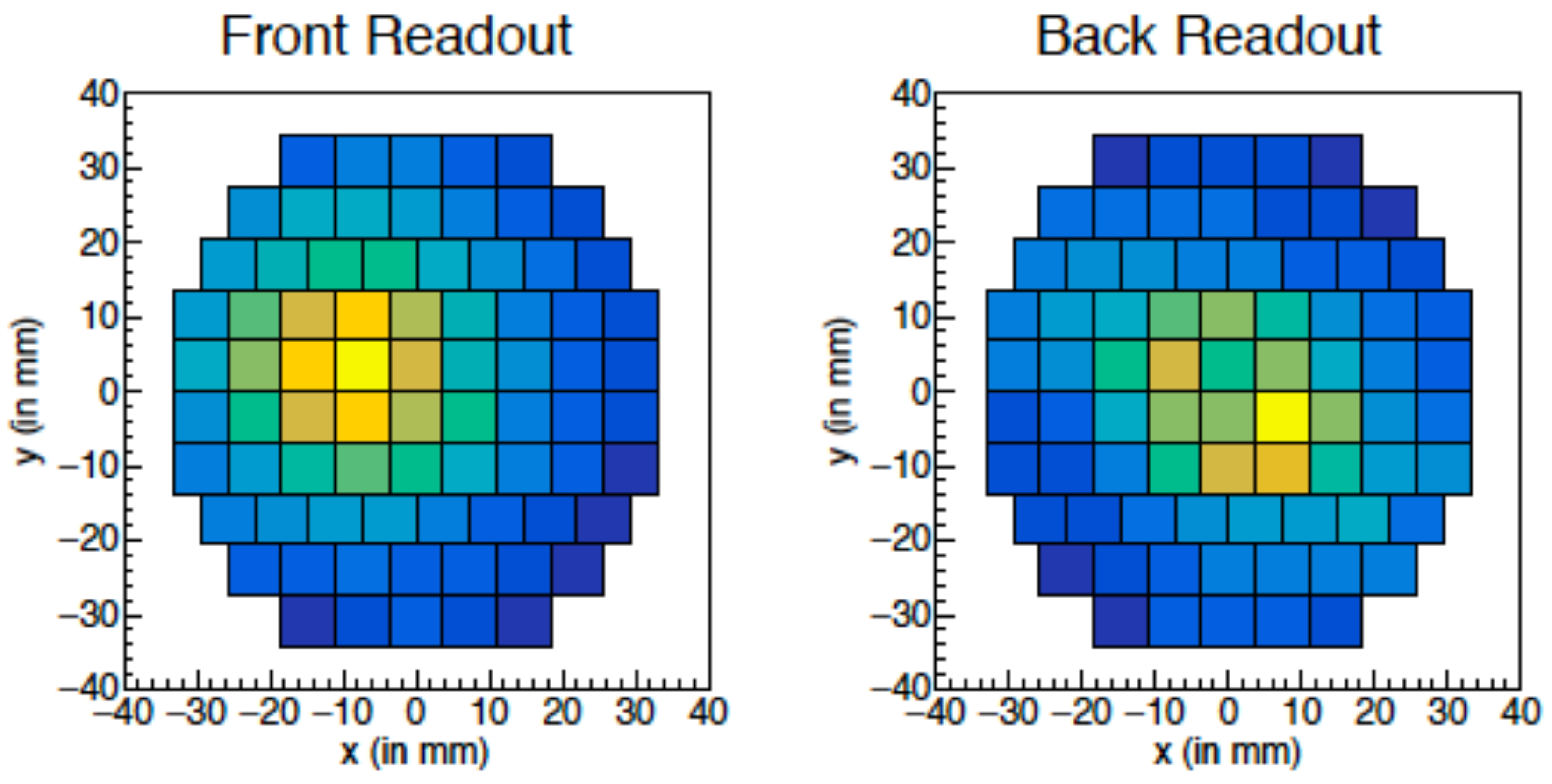
A.M. Baldini[1], H. Benmansour[123], F. Cei[12], M. Chiappini[1], G. Chiarello[1], G. Dal Maso[23], M. Francesconi[12], L. Galli[1], M. Grassi[1], U.Greuter[3], A. Gurgone[125], L. Kuenzi[3], D. Nicolò[12], **A. Papa[123]**, S. Ritt[3], P. Schwendimann[36], G. Signorelli[1], A. Venturini[12], B. Vitali[17]

(1) Istituto Nazionale Fisica Nucleare, sez. Pisa (IT), (2) Dipartimento di Fisica Università di Pisa (IT), (3) Paul Scherrer Institute (Villigen, CH), (4) ETH Zurich (CH), (5) now at Dipartimento di Fisica Università di Pavia (IT), (6) now at Washington University (US, MO), (7) Dipartimento di Fisica Università degli studi di Roma “La Sapienza”

- **Goal: Detect photons with energy O(50) MeV with ultra-precise time resolution and supreme energy resolution at the Intensity Frontiers**
- LYSO or LaBr(Ce) big crystals
- Photosensor: MPPC/SiPM for a front and back readout
- Use granularity for geometrical reconstruction
- MC simulations based on GEANT4 and including the photosensors and the electronics. Reconstruction algorithm based on waveform analysis

The first large prototype is under construction (D = 7 cm and L = 16 cm)



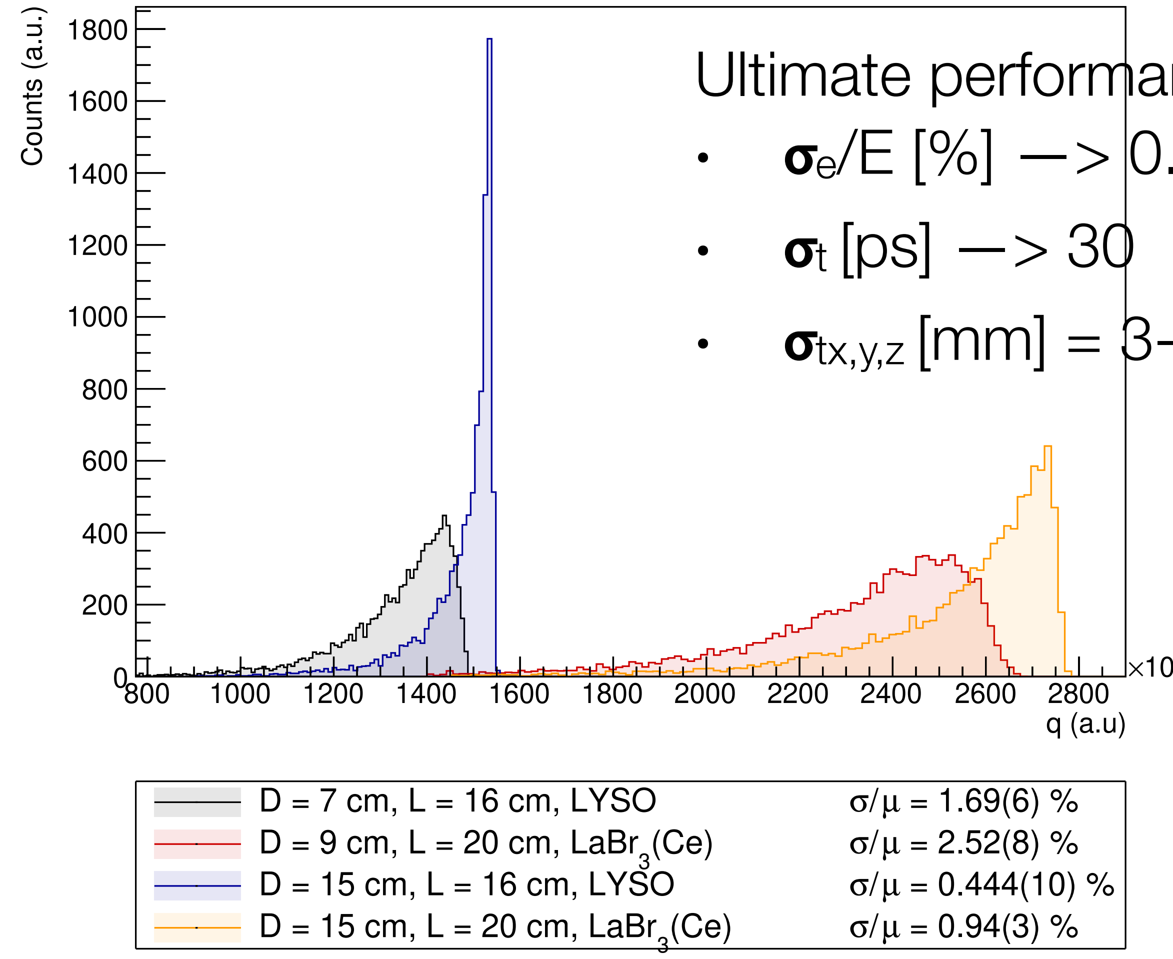


(a) Hit in Central Region: $(x, y) = (-10\,\text{mm}, 3\,\text{mm})$

Expected performances:

- σ_e/E [%] = 1.7(1)
- σ_t [ps] = 35(1)
- $\sigma_{x,y,z}$ [mm] = 3-5

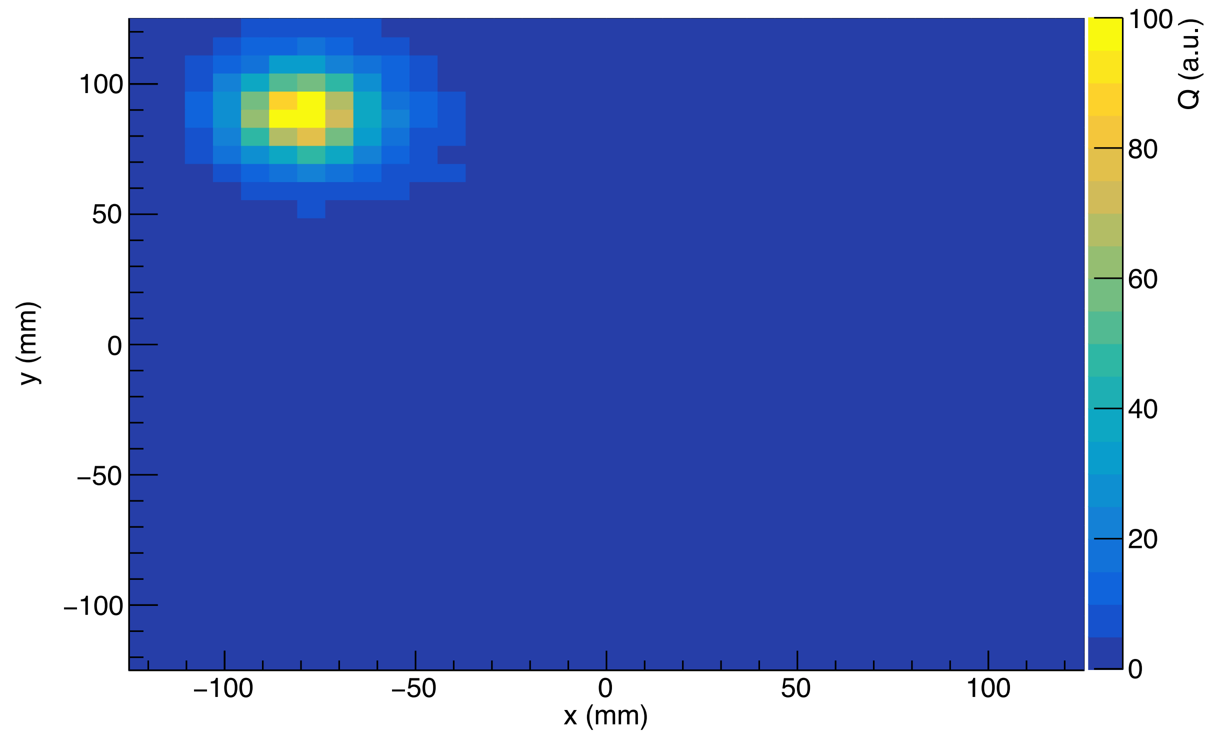
Energy Resolution at O (50 MeV)



Ultimate performances

- σ_e/E [%] —> 0.3-0.4
- σ_t [ps] —> 30
- $\sigma_{x,y,z}$ [mm] = 3-5

Photons detected per SiPM on the inner surface of an ultimate big crystal



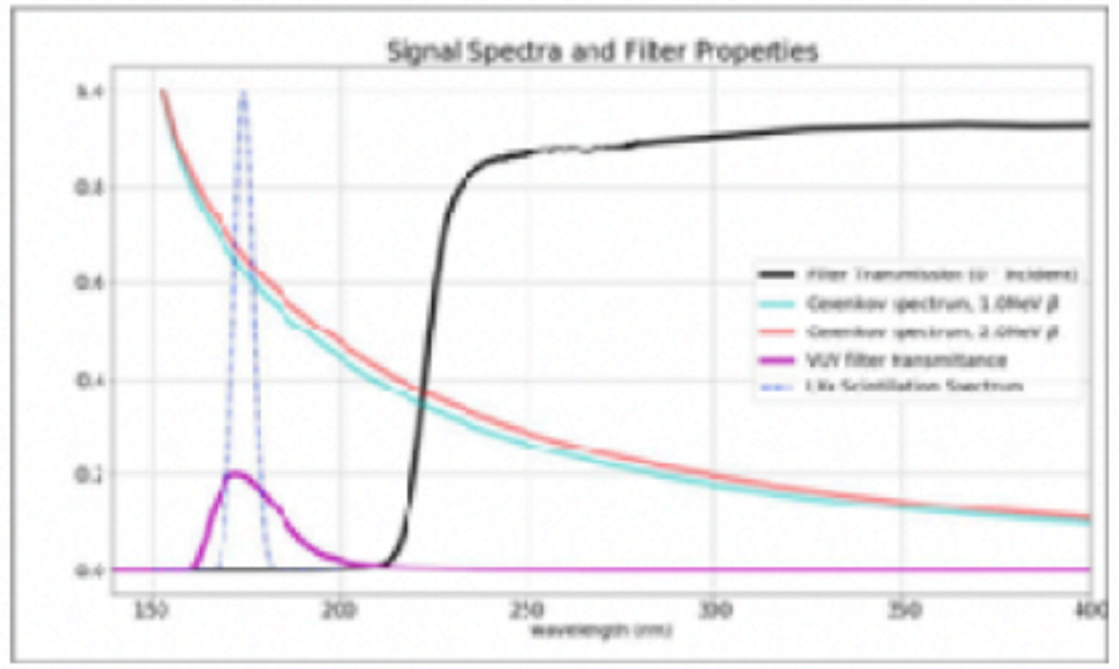
Contact: angela.papa@unipi.it, angela.papa@pi.infn.it, angela.papa@psi.ch

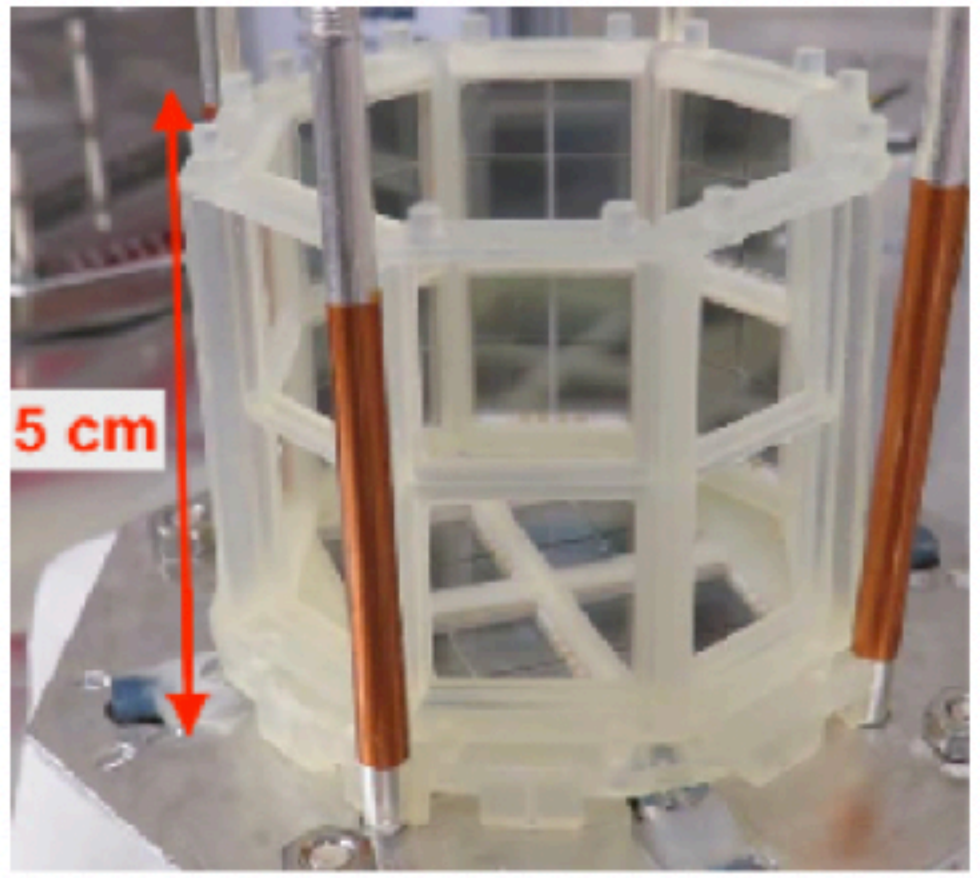
Other calorimetry applications

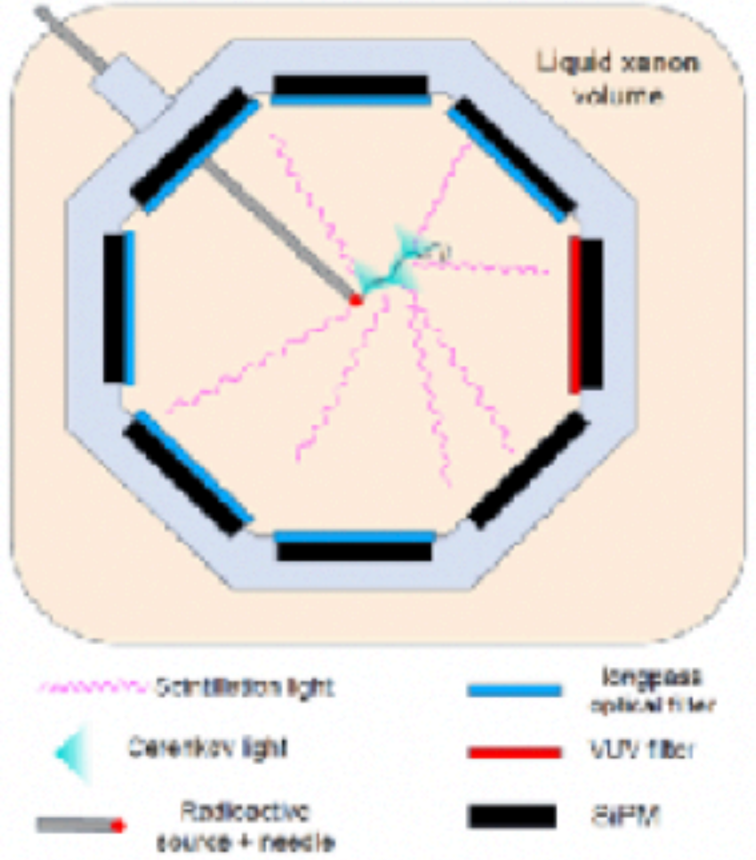
Looking for Cherenkov light in liquid Xenon with LoLX

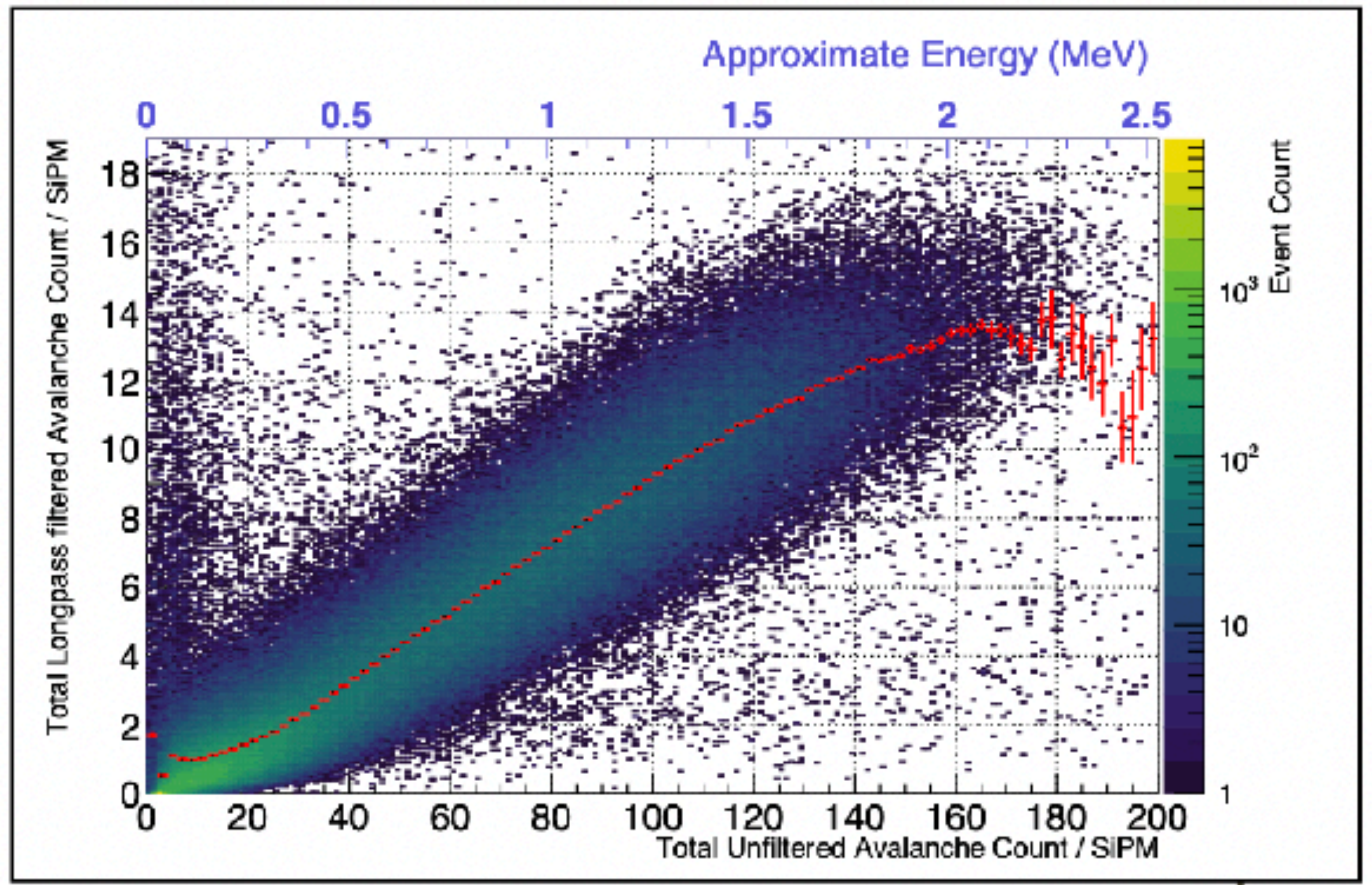
S. Al Kharusi[a], T. Brunner[a], C. Chambers[a], B. Chana[b], A. de St. Croix[c], E. Egan[a], M. Francesconi[d], D. Gallacher[a], L. Galli[d], P. Giampa, J. Lefebvre[e], P. Margetak[c], J. Martí[c], M. Patel[c], B. Rebeiro[a], F. Retière[c], L. Rudolf[a], G. Signorelli[d], S. Stracka[d], M.-A. Tétrault[e], S. Viel[b], L. Xie[c]

- We want to disentangle scintillation light and Cherenkov radiation in liquid xenon
  - different spectrum, different timing
  - can be used for background rejection in, e.g., neutrino-less double-beta decay of Xe (es. nEXO)
  - LoLX is fully submerged in a LXe volume and uses 96 SiPMs to measure LXe scintillation and Cherenkov radiation from a ^{90}Sr source needle.
- Filters in front of SiPMs help disentangling the different spectra
  - 22 longpass λ>220 for Cherenkov
  - 1 + 1 with no filter (scintillation ~ 178 nm)
- Preliminary results show that there is an excess of non-scintillation light maybe due to fluorescence in the 3D printed cage material
- Plans to repeat with aluminum cage and refined DAQ, including waveform digitizing for timing characteristics.









Study of SiPMs for calorimetry applications

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ABSTRACT The possible use of SiPM arrays for calorimetry applications is object of investigation. A piece of a lead-scintillating-fiber calorimeter is read by conventional photo-multiplier tubes (PMTs) at one edge and by SiPMs at the other one. Here the experimental set-up and the different couplings of light-guides with SiPMs are reported. Some preliminary results, as light yield and efficiency for SiPMs, compared to PMTs performance, are presented.

Introduction

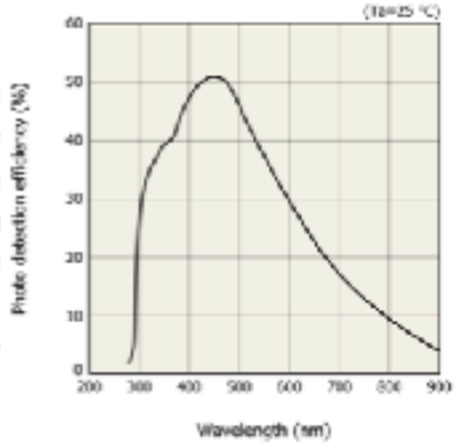
SiPMs, Silicon Photo-Multipliers or Multi-Pixel Photon Counters (MPPCs) **have potentiality and specific advantages for the calorimetry studies**[1]:

- unlike the PMTs, SiPMs are insensitive to magnetic fields
- SiPMs operate at low voltage, then high voltage power supplies are not necessary, with convenience in compactness and cost,
- the SiPM photodetection range is compatible with the typical wavelength-shifted light in the scintillating fibers.

This study is aimed to evaluate the compatibility of SiPM readout of an electromagnetic calorimeter, and the possible capability of SiPMs to allow improvements in efficiency and time resolution, over standard PMT readout.

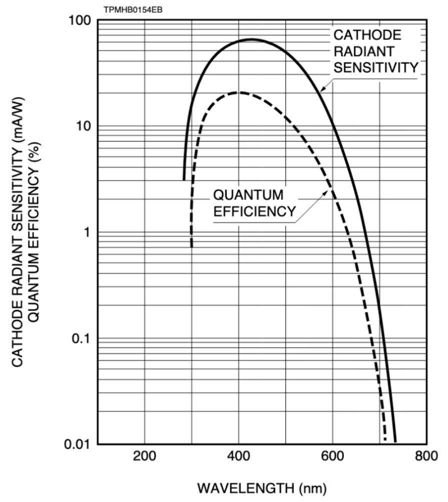
The SiPMs

We use Hamamatsu S14161 series [2], with 16 (4×4) and 64 (8×8) channels. The SiPM arrays are characterized by a small dead space in the photosensitive area, a gain $\sim 10^6$, a **maximum PhotoDetection Efficiency** **PDE_{MAX} = 50%** at the **wavelength λ_{MAX} = 450 nm.**
The λ_{MAX} value is close to the wavelength peak of the scintillating fibers in the calorimeter.



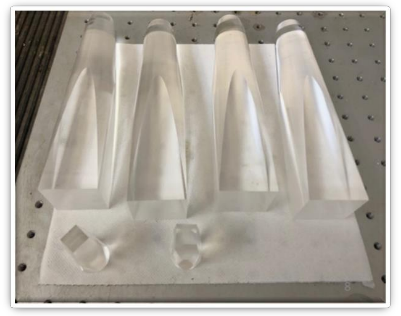
Serial N.	N. Of channels	Effective photosen. area/ch.	Pixel pitch (μm)	N. Of pixel/ch.	Package type	Window refractive index
S14161-3050hd-04 S14161-3050hd-08	16 (4×4) 64 (8×8)	3.0×3.0 mm² 3.0×3.0 mm²	50	3531	Surface mount type	1.57

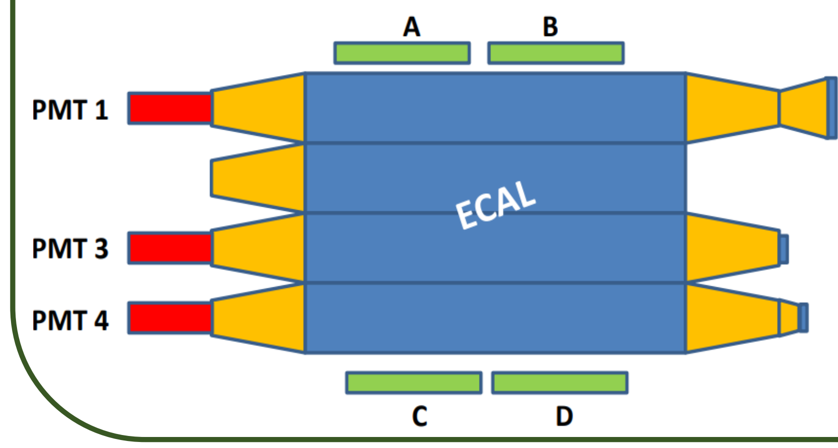
The experimental set-up



PMT quantum efficiency vs wavelength

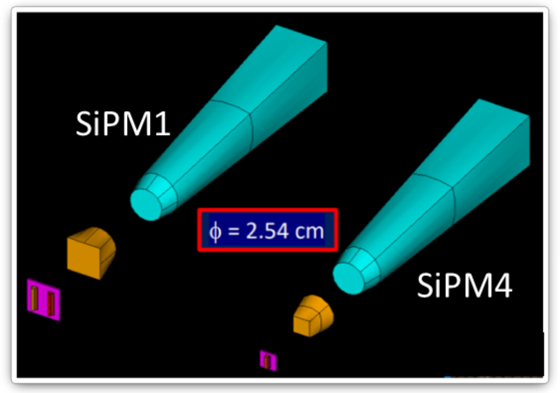
A dedicated experimental set-up has been realized with a slice of a sampling calorimeter (ECAL), made of lead and scintillating fibers. The fibers emit in the blue region with wavelength peak $\lambda_p \sim 460$ nm.
The calorimeter is segmented in squared section modules of size 4.3× 4.3 cm², characterized by the same features and performances of the KLOE electromagnetic calorimeter [3]. On one side the ECAL modules are read by Hamamatsu-R5946 PMTs connected through light-guides. Similar light-guides are used to connect SiPMs at the other side, employing different configuration of adapters.
For the SiPMs readout, we used a desktop front-end unit, CAEN DT5202, housing Weeroc Citiroc-1A chips.


Light guides



The different couplings under test:

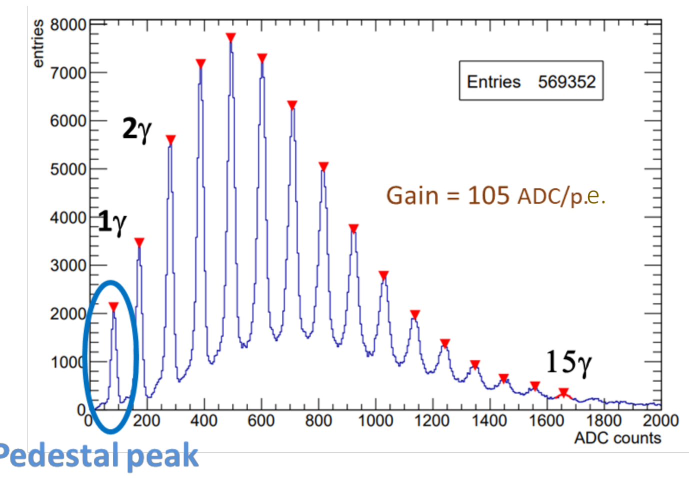
SiPM1) 8x8 channels SiPM coupled by a large adapter to the light-guide,
SiPM2) directly coupling of the SiPM to the ECAL,
SIPM3) 4x4 channels SiPM coupled to the light-guide, without the adapter,
SIPM4) 4x4 channels SiPM coupled by a small adapter to the light-guide.




Adapter to the light-guide

Calibration of light yield

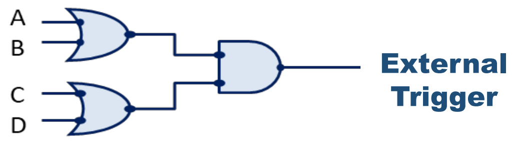
The SiPM charge is readout as ADC. **Each SiPM channel is calibrated separately** by low-voltage (V_{BIAS}) regulation, looking at the self-trigger rate. The SiPMs show stability in energy conversion and the photon spectrum is obtained as in figure.



From the ADC values of the peaks we get the formula to convert the ADC signal in the number of photoelectrons

$$N_\gamma = 0.0094\ \text{ADC} - 0.65$$

Efficiency measurements



The SiPM efficiency has been studied using cosmic rays. The trigger is provided by an external system of 4 scintillators (surface ~ 2 x 12 cm²). During the SiPM data acquisition also the PMTs efficiency is measured. Some preliminary results are presented here (see table). The trigger rate of the "finger" scintillators is a few mHz and the statistics should be improved.

PRELIMINARY RESULTS

ECAL	PMT efficiency (%)	SiPM efficiency (%)
module 3	90.1 ±2.1 3	90.1 ± 2.1
module 4	88.4 ±2.5	89.6 ± 2.5

Next steps

SIPM efficiency with improved statistics.

The front-end unit provides the **pre-amplified signal readout from the SiPM single channel**.
It could be used for measurements **of time resolution** compared with the PMTs (~200 ps).

References

[1] S. Gundacker, A. Heering, *Phys. Med. Biol.* **65** (2020) 17TR01
[2] https: // www. hamamatsu.com/ eu/ en/product/ optical-sensors/ mppc/ mppc-array/ S14161-3050HS-08. html
[3] M. Adinolfi et al., *NIM A* 482 (2002) 364

15th Pisa Meeting on advanced detectors, La Biodola Isola d'Elba 22-28 May 2022

Summary

- Higher granularity, better timing resolution, radiation tolerance, and the readout electronics are essential for higher luminosity to ensure good performance.

- Calorimetry plays a central role not only for the collider experiments but also for the intensity frontier experiments.