# Novel Resistive-Plate WELL sampling element for (S)DHCAL

Project supported by the RD51 collaboration @ CERN

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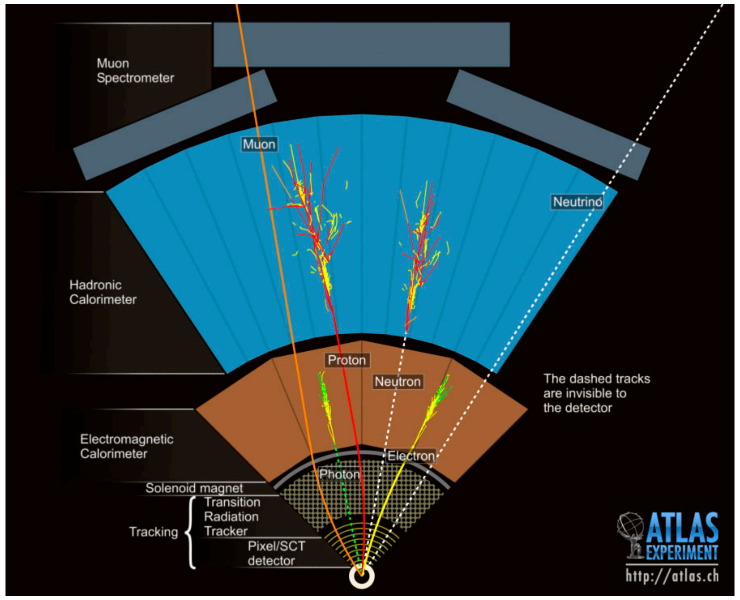
# Traditional Calorimetry



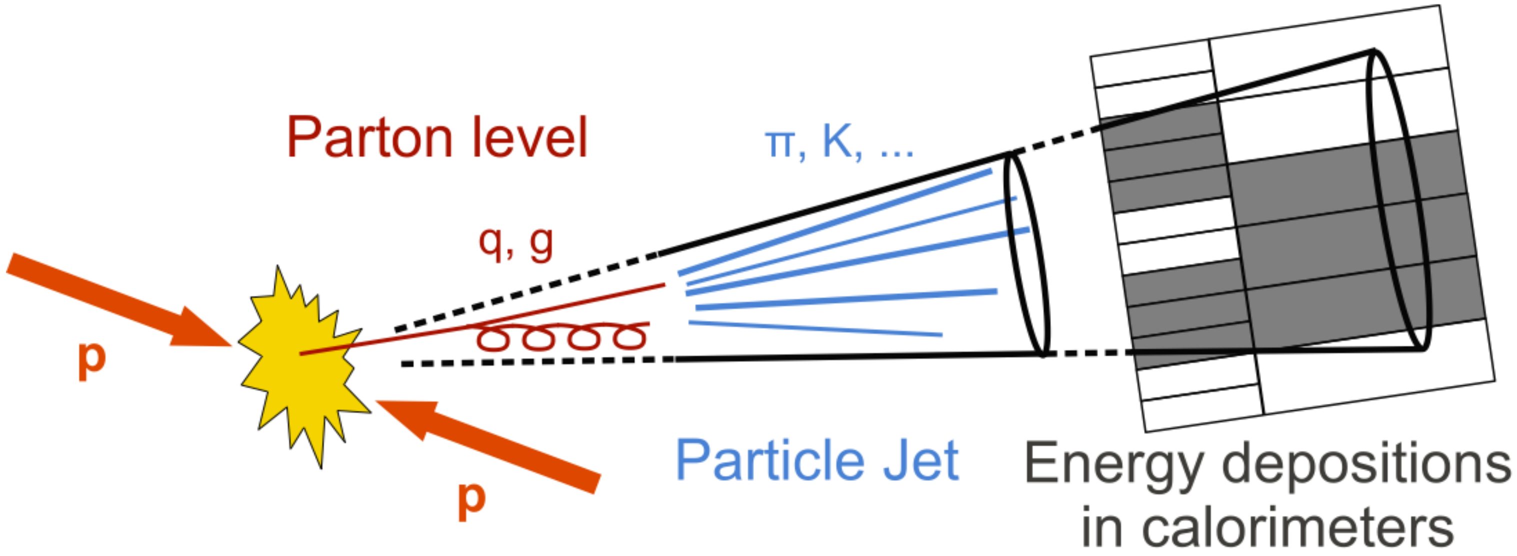

### Particle reconstruction and Identification

- Typical multi-purpose experiments are designed in an onion shape: tracker ⇒ ECal ⇒ HCal ⇒ muon system
- Unique signature for each of the stable particles
  - Enables reconstruction and identification of isolated particles
  - e/$\gamma$ absorbed in the ECal (EM showers)
  - n/p/$\pi$/k absorbed in the HCal (Hadronic showers)

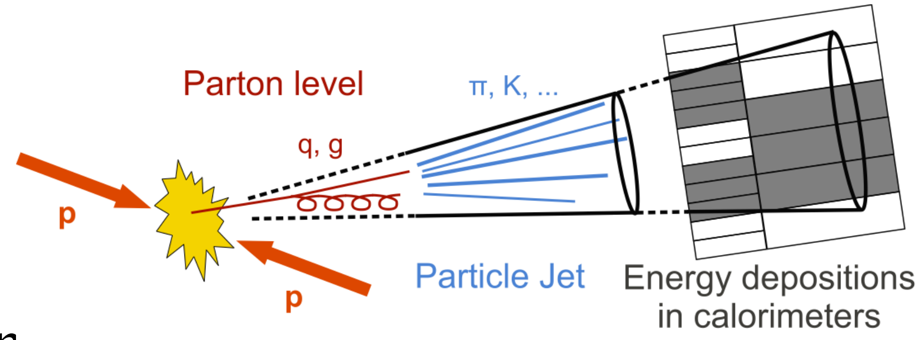
### Jet reconstruction

- Jet - bunch of collimated non-isolated particles (originating from the same colored particle)
- Individual particles / showers can’t be resolved in the calorimeters
  - Reconstructed as single objects - jets

CMS



# Traditional Calorimetry



CMS

Jet energy resolution

- Typical calorimeters are non-compensating
  - Respond differently to the EM and hadronic components of the shower ⇒ calibration is very limited
- Large fluctuations in the fraction of the EM and Hadronic components
- Large jet-by-jet energy deposition fluctuations
- Large fluctuations in the fraction of the 'invisible energy' - deposited energy not contributing to the measured signal

⇒ The energy resolution of traditional HCals is intrinsically limited

- ~70% of the jet energy is carried by hadrons
  ⇒ Strong dependency on the HCal
  ⇒ Poor jet energy resolution
  ⇒ Prevent doing precision measurements with hadronic final states ⇒ needs to be improved

- The target jet energy resolution is $\frac{\sigma_E}{E} = \frac{30\,\%}{\sqrt{E}}$ ⇒ 3% for 100 GeV hadrons

Two possible solutions

- Develop compensating calorimeters ⇒ calibration becomes possible ⇒ highly non trivial
- Reduce the dependency on the HCal ⇒ Particle flow calorimeters

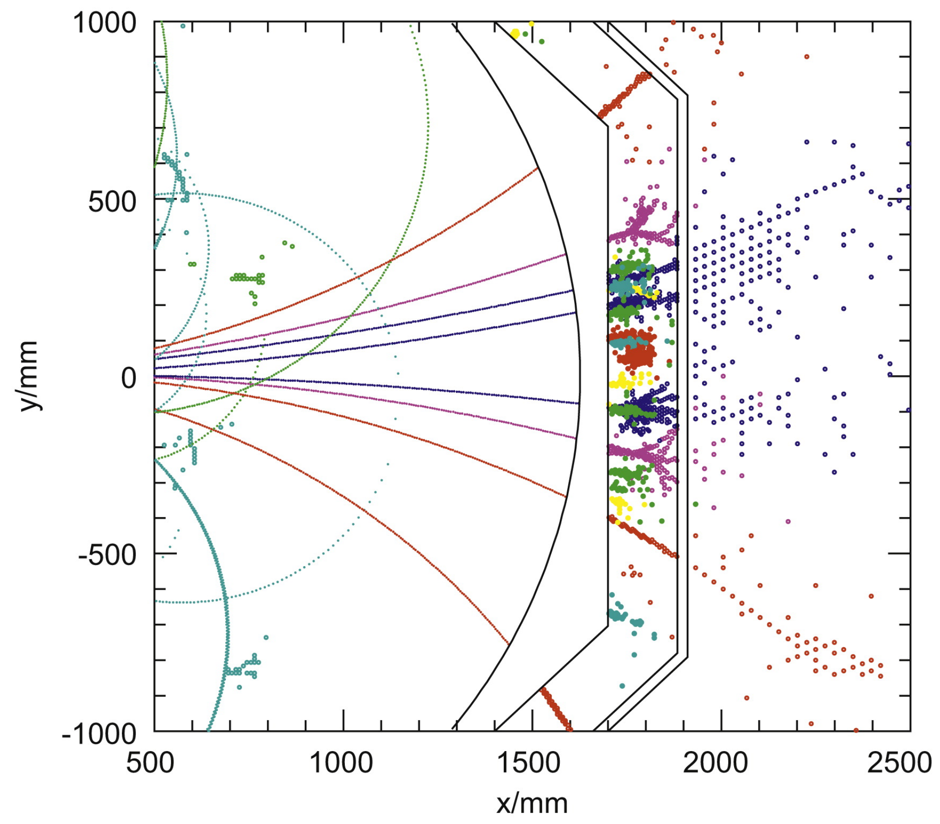
# Particle flow calorimeters

Reduce the dependency on the HCal

- Only 10% of the jet energy is carried by neutral hadrons
- 90% of the jet energy can be measured precisely in the other subsystems
  - Charge hadrons - in the tracker
  - Electrons - in the ECal, tracker or both
  - photons - in the ECal

⇒ Need to be able to resolve the individual particles in a jet

Sefkow et.al. arXiv:1507.05893




HCal requirements

- High granularity to minimize the confusion terms
  - Energy depositions that can be associated to more than one particle

⇒ Many (hundred of thousand) readout channels

- Located inside the magnetic field for better separation of charged from neutral particles
- The best possible measurement of neutral hadron energy

⇒ Controlled response

Several solutions

- Developed and studied by the CALICE collaboration
- Analog HCal - worse granularity with more accurate single-particle energy measurement
- (Semi) Digital HCal - better granularity with less accurate single-particle energy measurement

# (Semi) Digital HCal - (S)DHCAL

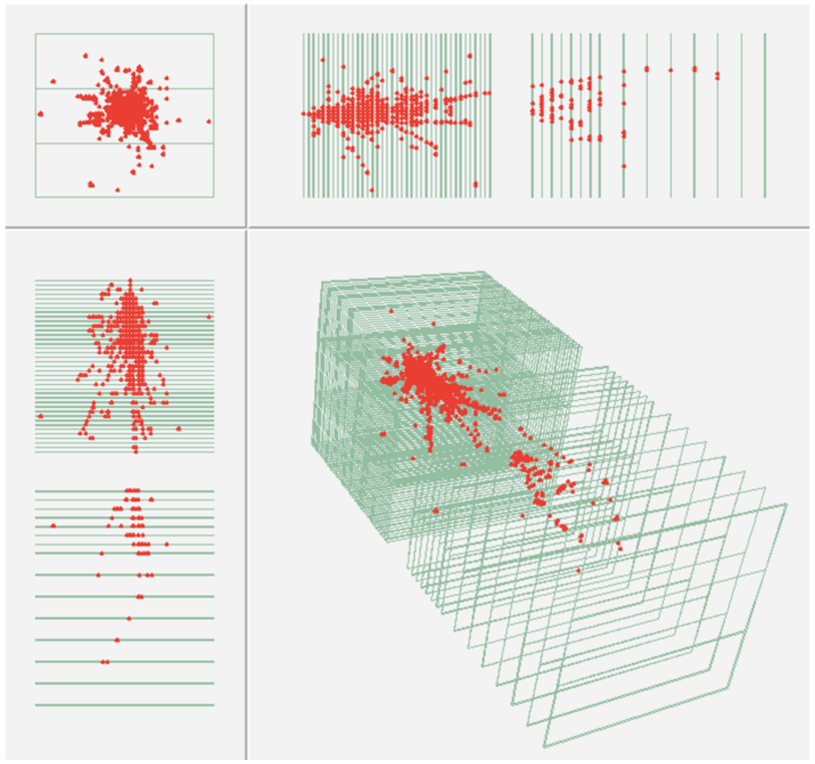
Linear Collider Collaboration

Sampling calorimeter - baseline requirements

- (Semi) Digital readout
- 1 $cm^2$ granularity
- 40-50 layers of sampling element with absorbers in between
- As thin as possible (to minimize cost of the magnet system)

Underline assumption

- Number of fired hits in the shower is proportional to the incoming particle energy
- Non-linear effects - when more than a single track fragment hit the same readout pad
  - If pads are not small 'enough'
  - At large energies when the shower is collimated
  - At the center of the shower where most of the EM energy is deposited
- Can be mitigated
  - With software calibration
  - With semi-digital readout; Two/Three thresholds rather than one



CLIC

# Sampling elements for (S)DHCAL

Underline assumption

- Number of fired hits in the shower is proportional to the incoming particle energy

Requirements for DHCAL

- High detection efficiency
- Low pad multiplicity - one pad fire per track

! To the best of our knowledge - no real studies characterized the performance of a particle flow algorithm as a function of these two parameters

Requirements for SDHCAL

- High detection efficiency
- Low pad multiplicity - one pad fire per track
- Proportional response - pulse height proportional to the energy deposition

# Technologies considered

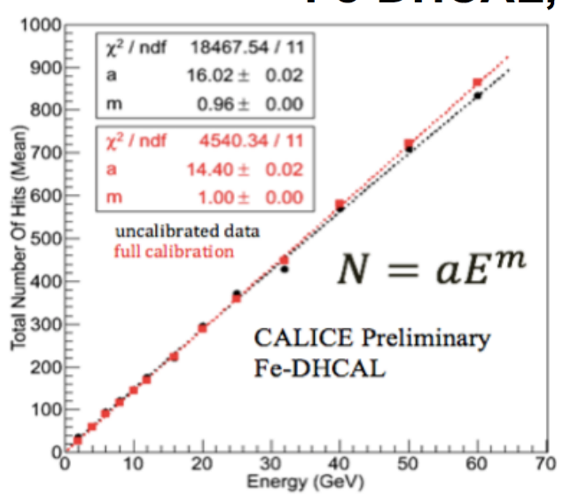
## Baseline technology - Glass RPC

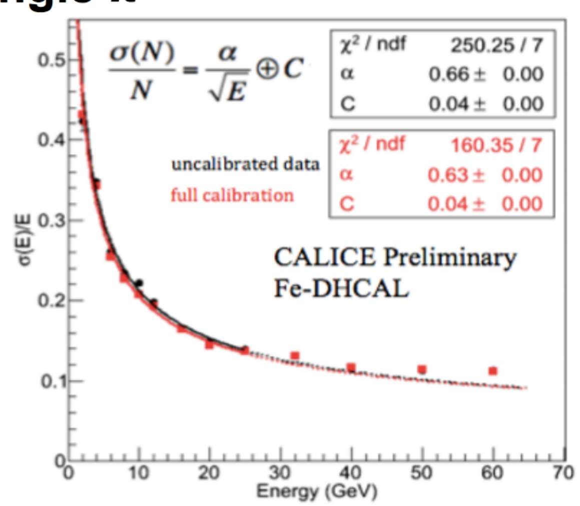
- By far the most studied solution
- Full prototype: 48 layers 1 $m^2$
- Iron and  Tungsten
- Operated in DHCAL and SDHCAL modes

Calice collaboration arxiv:1901.08818

From Jianbei Liu @ IAS HEP2019

**Fe-DHCAL, single $\pi$**

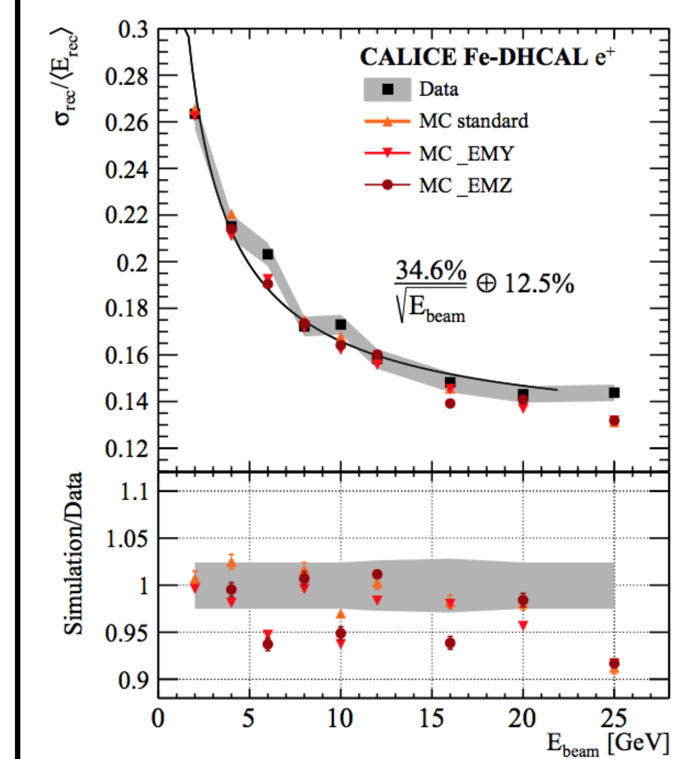



MIP:  efficiency ($\varepsilon$) ~ 96%, pad multiplicity ($\mu$) ~ 1.6

Calibration

$$H_{calibrated} = \sum_{i=RPC_0}^{RPC_n} \frac{\varepsilon_0 \mu_0}{\varepsilon_i \mu_i} H_i$$




See also Bilki et.al arxiv:1404.0041

$$\frac{\sigma_E}{E} = \frac{30\,\%}{\sqrt{E}}$$

## Possible alternative - Micro-Pattern-Gaseous-Detector (MPGD)

- Triple GEMs - 1 $m^2$ prototype were built
- Micromegas - 1 $m^2$ prototype were built, 6 were embedded in a Glass RPC prototype
- Resistive Plate WELL - this talk..

# Why consider other alternatives

RPC Vs. MPGD - potentially benefit from one or more of the following

- Lower pad multiplicity for better efficiency
- Better rate capabilities
  - Relevant also for instantaneous high rates within a single shower
- Closed geometry vs open one
- Proportional response (SDHCAL)
- Environmental friendly gaseous

| Technology | pad multiplicty | efficiency % | Reference |
|---|---|---|---|
| Glass RPC | 1.5-2 | 90-95 | J. Repond, in TIPP 2011 Conf. Chicago **4**, (2011) |
| MM | 1.1 | 98 | C. Adloff et al., *Recent results of Micromegas sDHCAL with a new readout chip*, (2012) |
| Resistive MM | ~1.1 | 95* | M. Chefdeville, et al., *PoS*, SISSA, (2014) 54 |
| GEM | 1.3 | 95 | J. Yu, et.al., *Phys. Procedia* **37**, Elsevier, (2012) 591 |
| RPWELL | 1.2 | 98* | S. Bressler, et.al., *J. Instrum.* **11**, (2016) P01005 |

*smaller area

- Academic interest
  - Life is like a box of chocolate - you never know what you gonna get …

# The Resistive Plate WELL (RPWELL)

- Single sided THick Gaseous Electron Multiplier (THGEM)
- Coupled to segmented readout through material of high bulk resistivity $(10^{8}-10^{10}\ \Omega cm)$
  - Combining MPGD and RPC concepts
- Discharge free operation at high gain $(10^{4}-10^{7})$ depending on the primary ionization
- Moderate rate capabilities

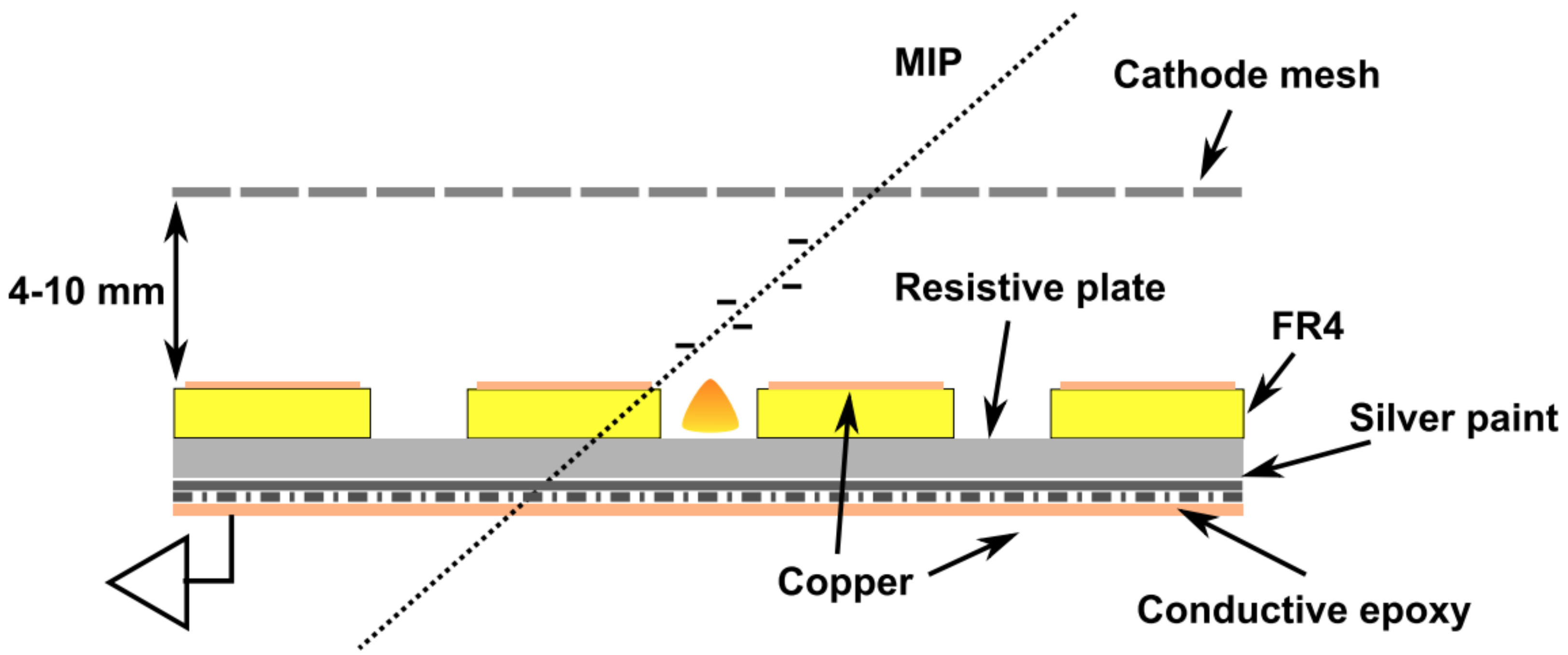



**Figure 1**. The Resistive-Plate WELL (RPWELL) configuration with a resistive anode and a readout electrode. The WELL, a single-faced THGEM, is coupled to a copper anode via a resistive plate. Charges are collected from the copper anode. In some experiments the WELL was directly coupled to the metal anode.

A. Rubin et.al. arxiv:1308.6152

# RPWELL for (S)DHCAL

In beam studies with $10 \times 10$ and $30 \times 30$ $cm^2$ detector prototypes

- In Ar- and Ne-based gaseous mixtures
- 150 GeV muon and pion beams at the CERN/SPS beam line
- APV25/SRS analog readout electronics
- RD51 MM-based tracker

- Internal thickness ~6 mm excluding readout electronics
  - Driven by 5 mm drift gap
- Modular structure
- Segmented electrodes
- Geometry not optimized - large dead regions due to support structure

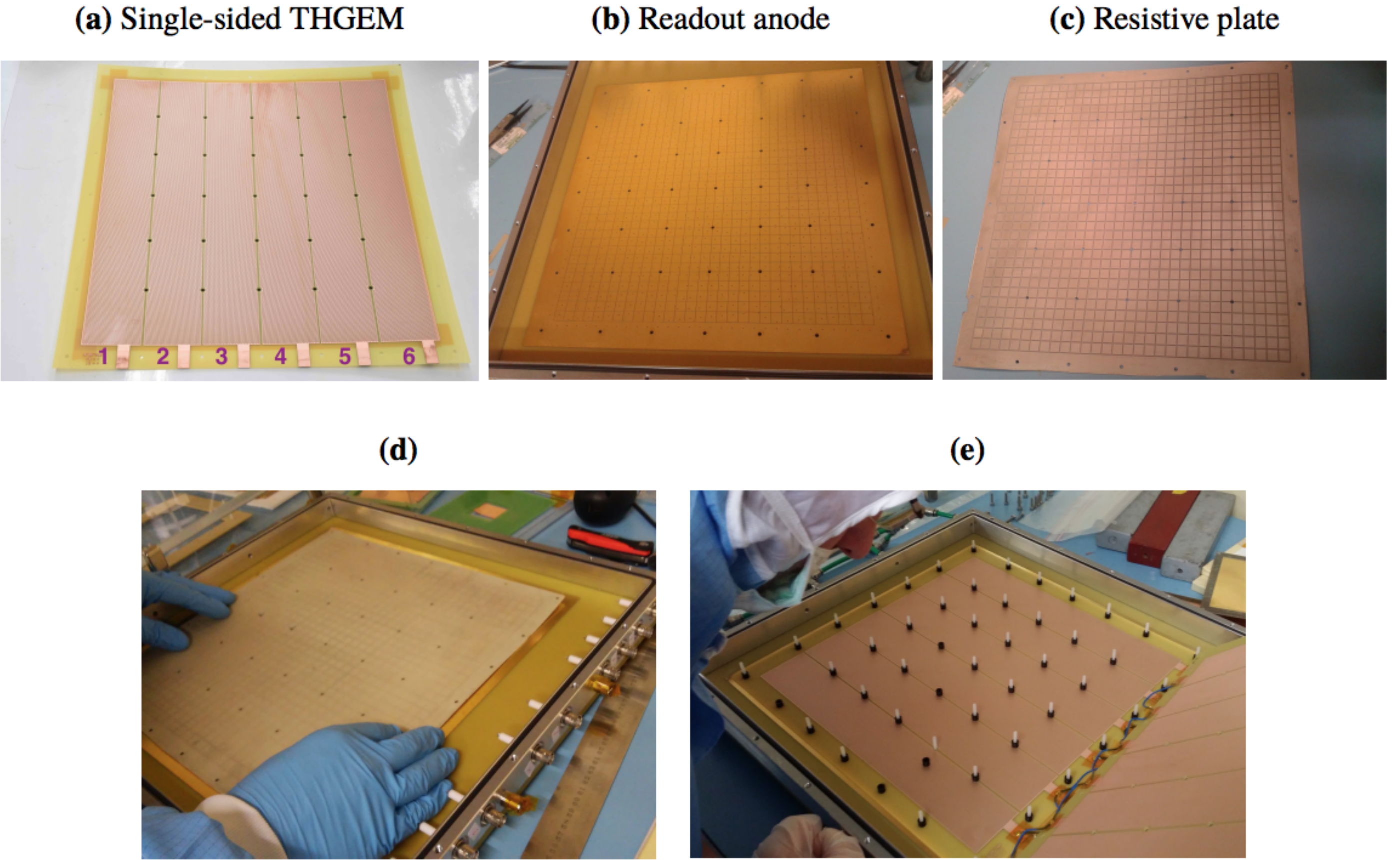


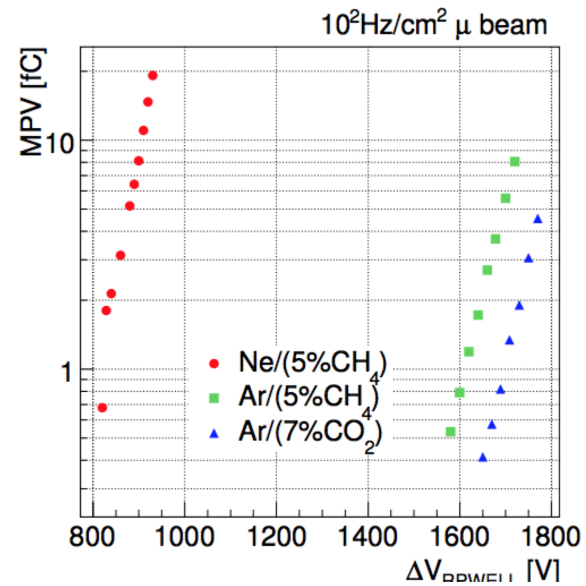

**Figure 2.** Detector prototype parts: (a)–(c). (d) Assembling the resistive plate (c) on top of the readout anode (b), using conductive tape. (e) The open detector with all its elements (except the vessel cover): the anode and resistive plate (not visible); the THGEM electrode, with the support nylon pins (white) and Delrin® spacers (black); the cathode (lifted on the right side); the aluminium vessel.

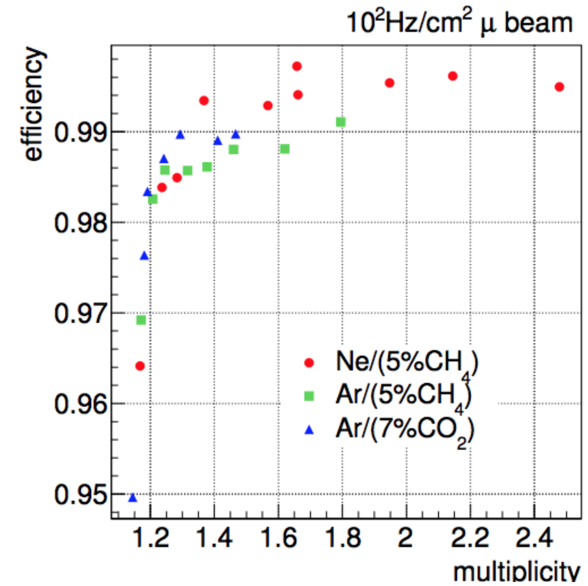
L. Moleri et al 2016 JINST 11 P09013

# RPWELL for (S)DHCAL

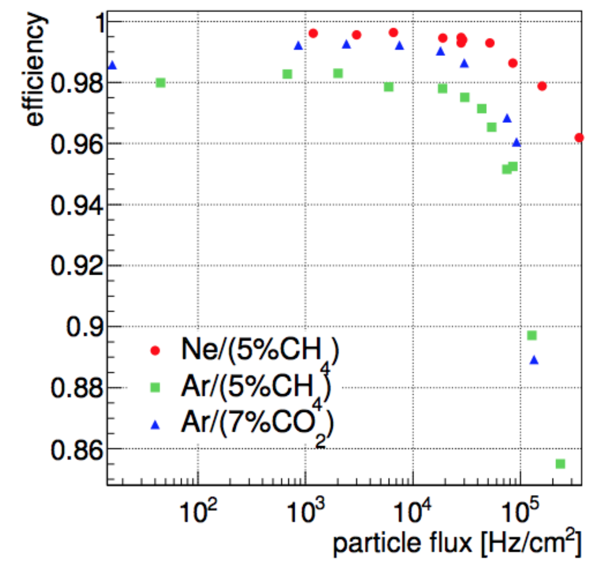
Main results $30 \times 30\ cm^2$

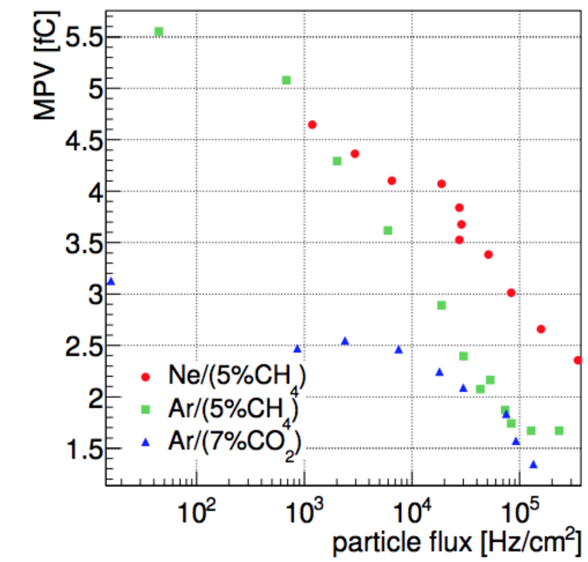
- 1.2 average pad multiplicity at 98% detection efficiency
- Discharge free operation also under high intense pion beam
- Uniform response
- Moderate rate capabilities



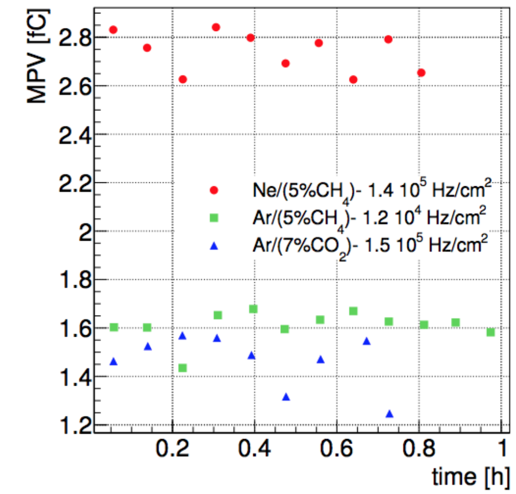




- Measurements conducted with APV25/SRS analog readout




- Discharges close to the support spokes (no discharges with $10 \times 10\ cm^2$ proto)
  - $\Rightarrow$ lead to significant design modifications
  - $\Rightarrow$ No support structure
  - $\Rightarrow$ Gluing the electrode to the resistive plate



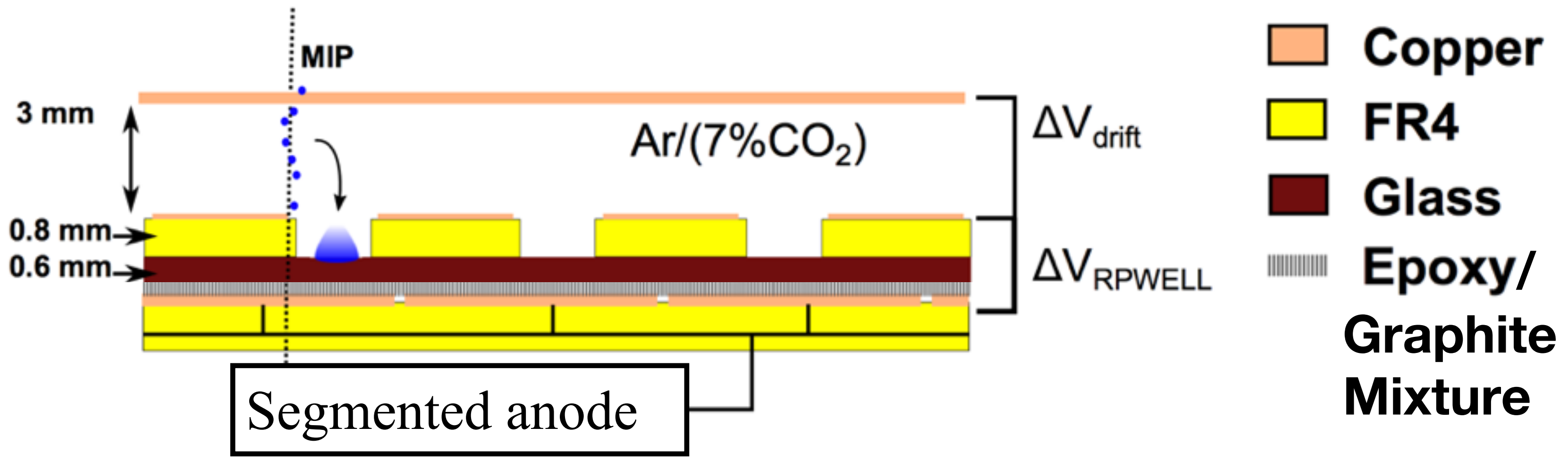
# $50 \times 50\ cm^2$ RPWELL prototypes

Design

- Non modular (glued rather than screwed)
- No support structure - minimal dead region
  - Achieved after several iterations
- 3 mm drift gap (for operation with Ar-based gaseous mixture)

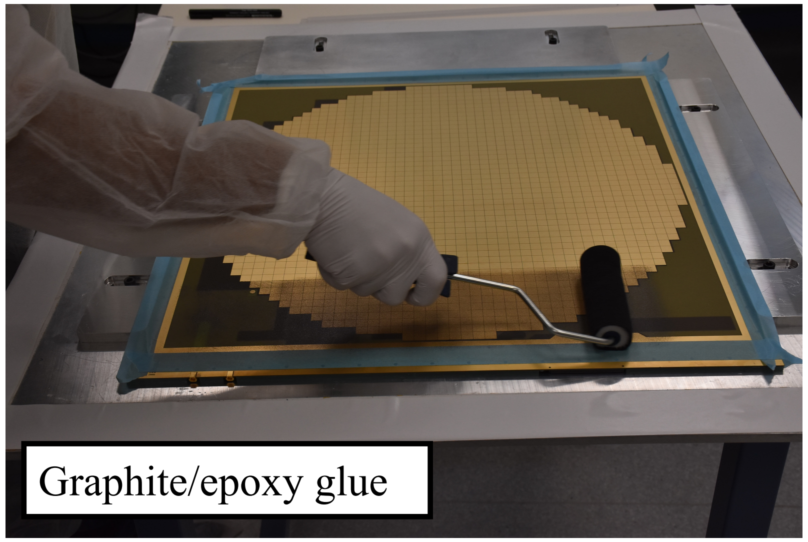
First (S)DHCAL prototype

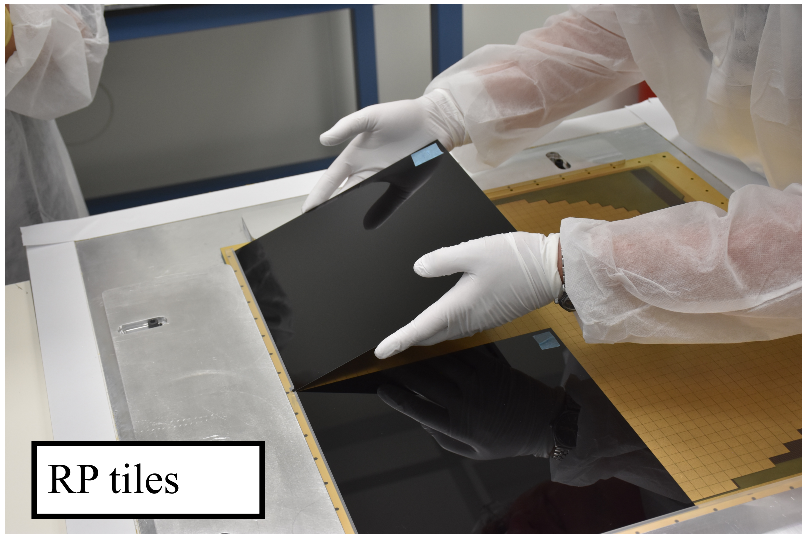
- With (S)DHCAL electronics based on the MICROROC chip
  - Developed within CALICE by the Omega group
- With 1 $cm^2$ pad readout
- Silicate glass resistive plate ($\sim 10^{10}\ \Omega cm$)
- Resistive plate/anode coupling through graphite-epoxy layer ($M\Omega$)

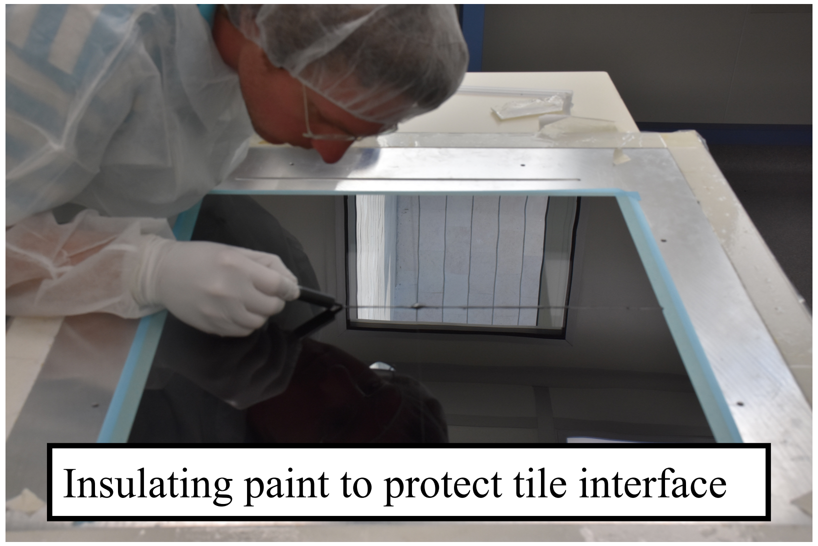


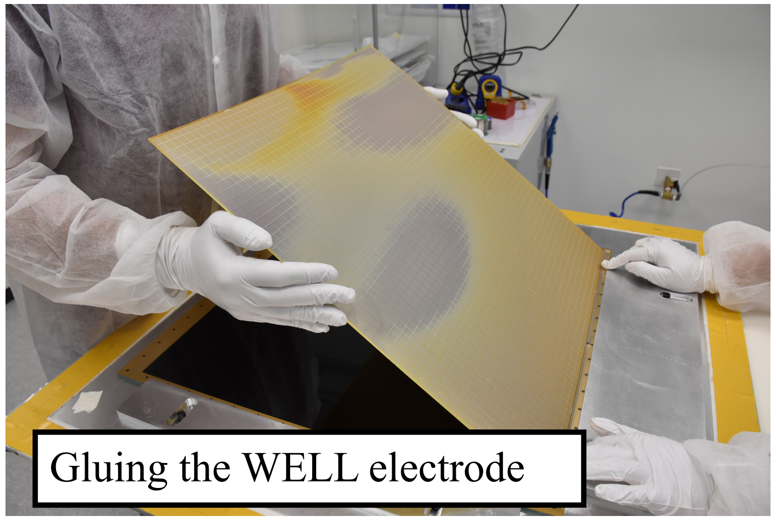
# $50 \times 50\ cm^2$ RPWELL prototypes

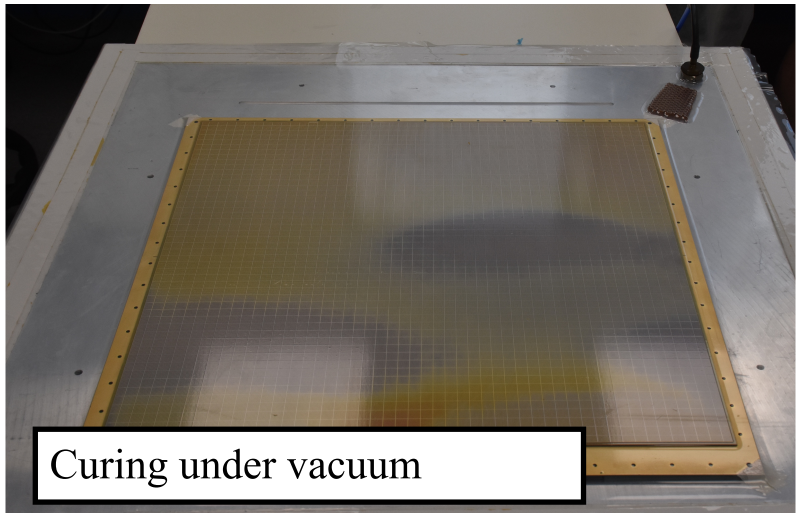
## Assembly

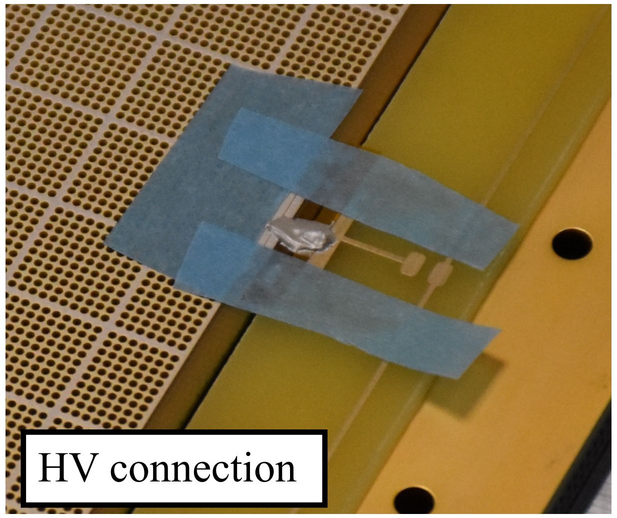

Graphite/epoxy glue


RP tiles

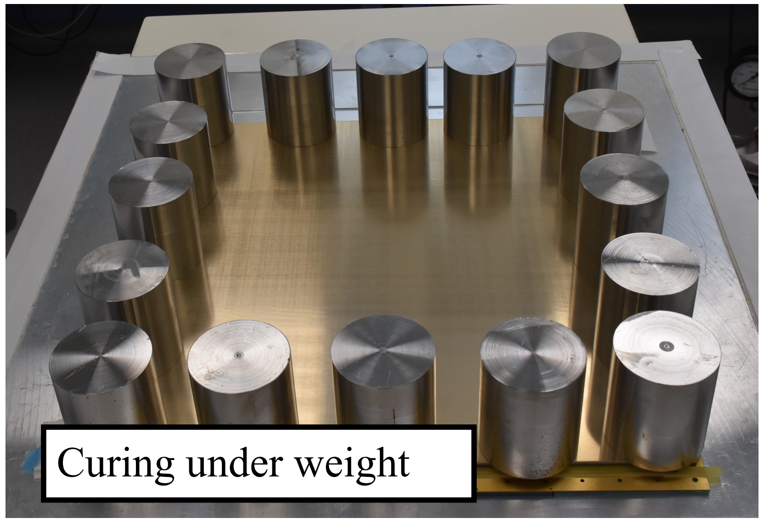

Insulating paint to protect tile interface


Gluing the WELL electrode


Curing under vacuum


HV connection

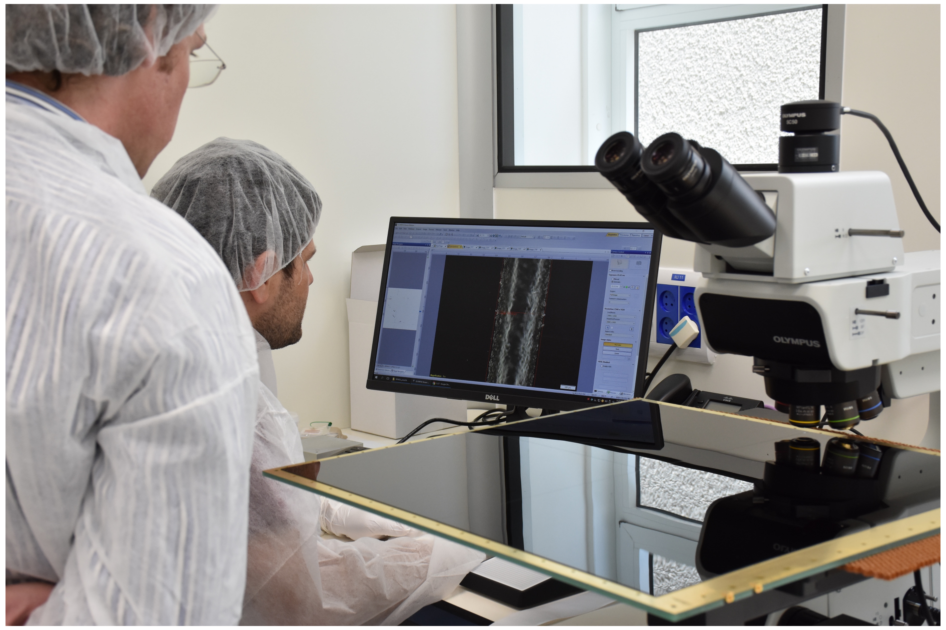

Cathode gluing


Curing under weight

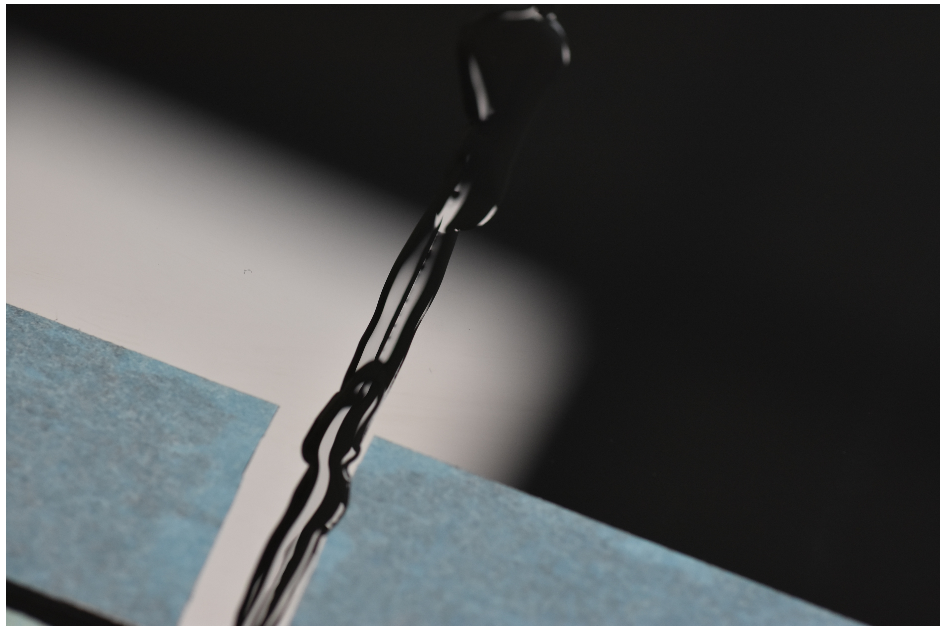
# $50 \times 50\ cm^2$ RPWELL prototypes

QA/QC

- Careful selection of components
  - Uniform electrode thickness - **first prototype had 20% thickness variations**
    ⇒ large gain/efficiency variations
    ⇒ Poor performance and instabilities
  - Uniform (thickness) and precise (cutting) glass tiles



- Inspection under microscope to validate interface coating
  - The interface between the glass tiles is potentially an open path between the top WELL electrode and the anode
  - In the future there is a need for larger area tiles



- Leak current measurements
  - Before and after any gluing step

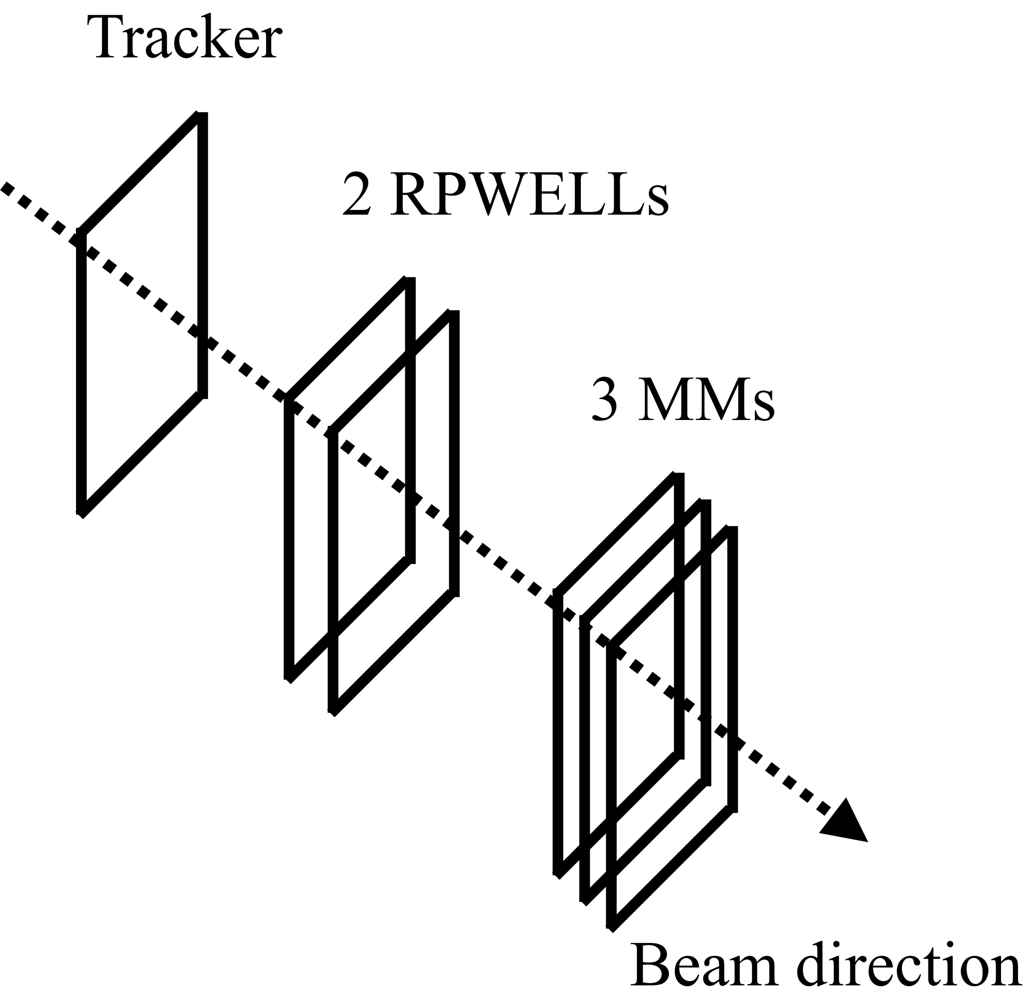
# $50 \times 50\ cm^2$ RPWELL prototypes

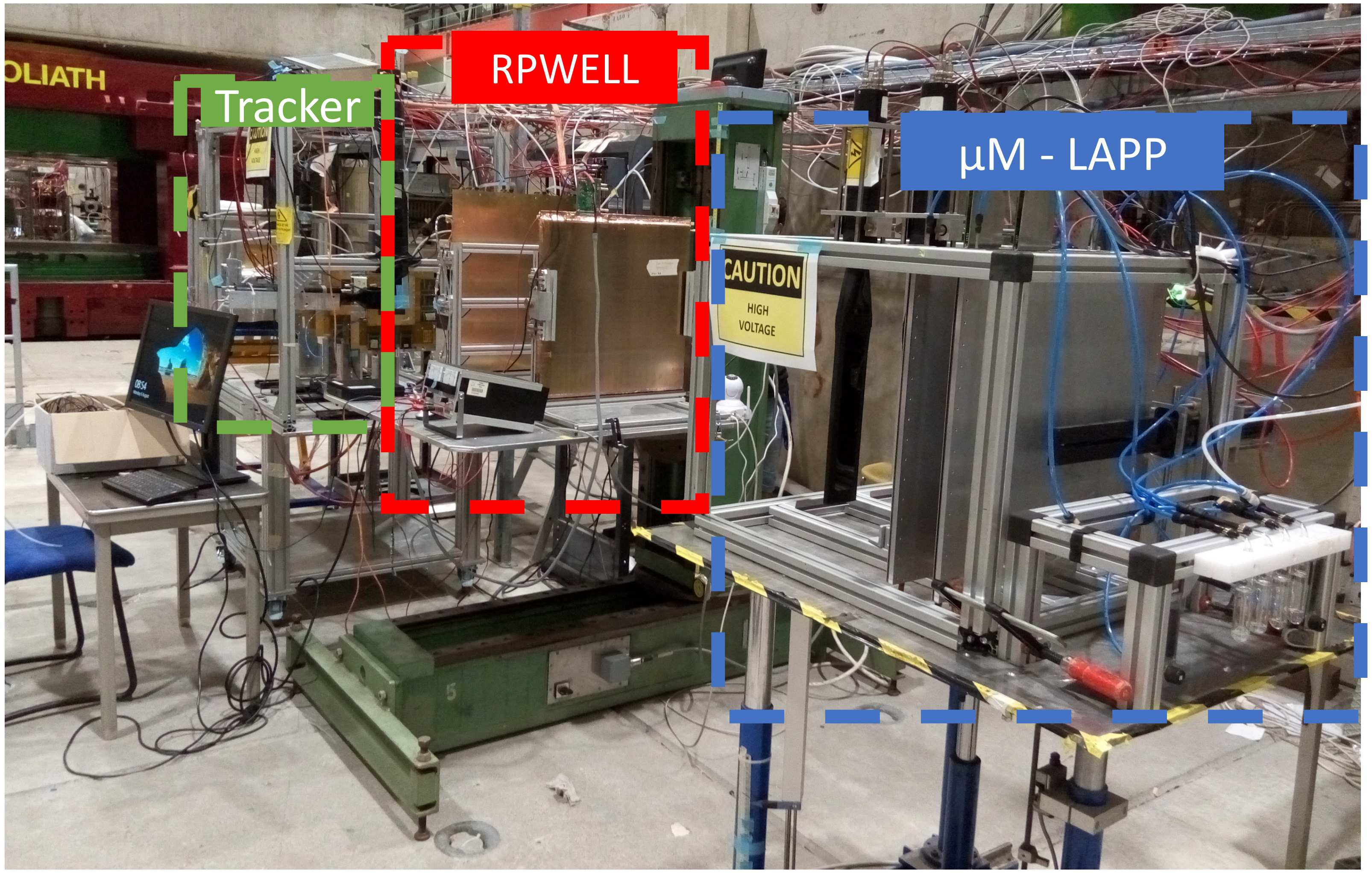
Test beam setup

- Studies conducted at the CERN/SPS beam line with 150 GeV muons
- In setup combining 3 MM detectors and 2 RPWELLs
  - One with MICROROC/ASU digital readout and one with APV25/SRS analog readout
- Ar/7%$CO_2$ gas mixture

Goals

- Validate the new design
- Make sure that the RPWELL can be readout with MICROROC/ASU readout

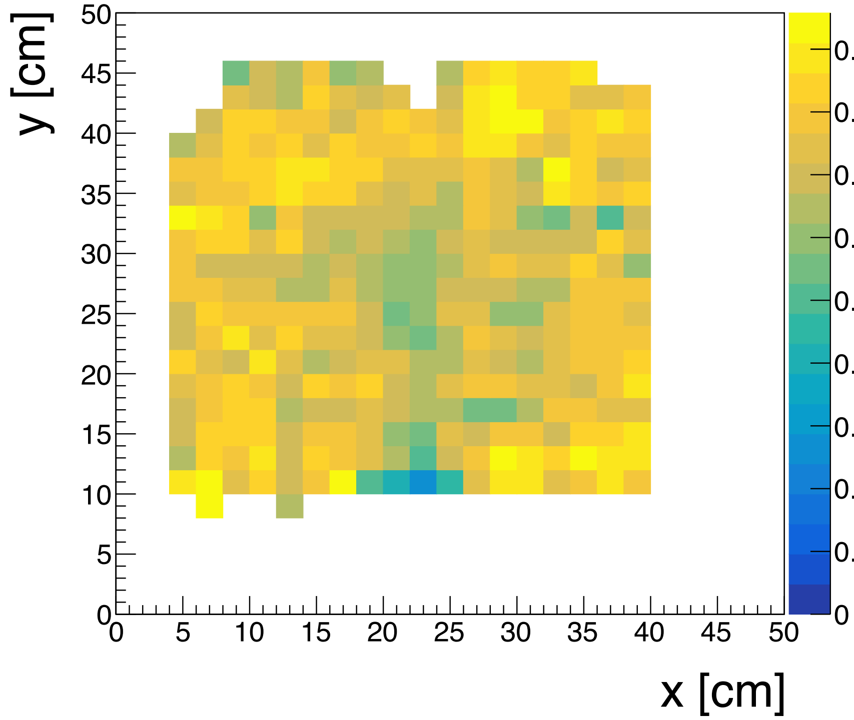


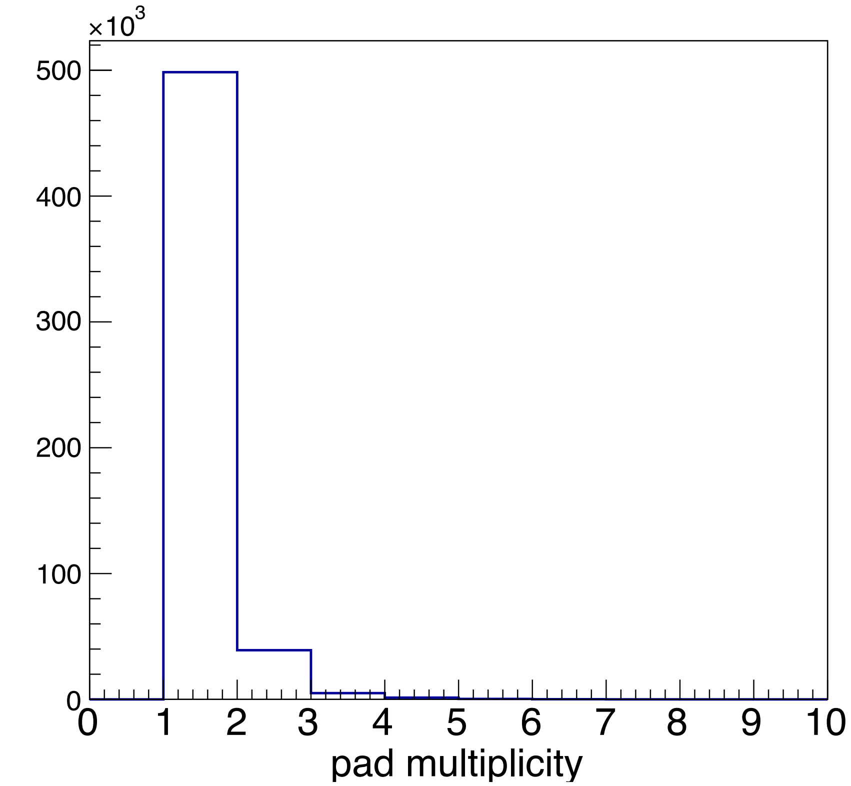



# $50 \times 50\ cm^2$ RPWELL prototypes

Main results
- New design with no support structure works well
- New assembly is feasible
  - Glue does not penetrate the holes
- Large efficiency variations
  - Due to large thickness variations
  - Reaching > 90% in the thiner regions
- Glass tile interfaces are weak point

- The RPWELL couples well with the MICROROC/ ASU semi-digital readout



# The SCREAM project

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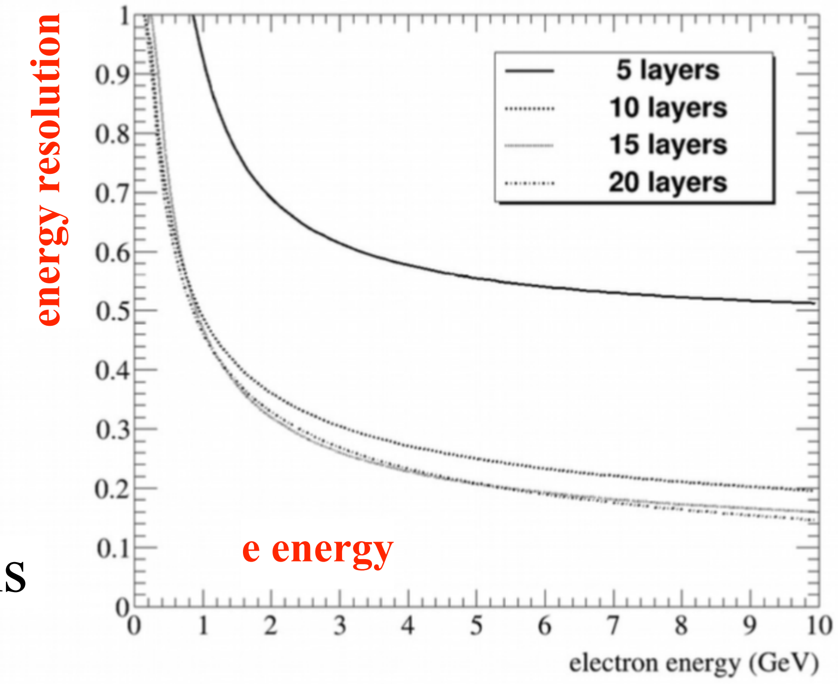
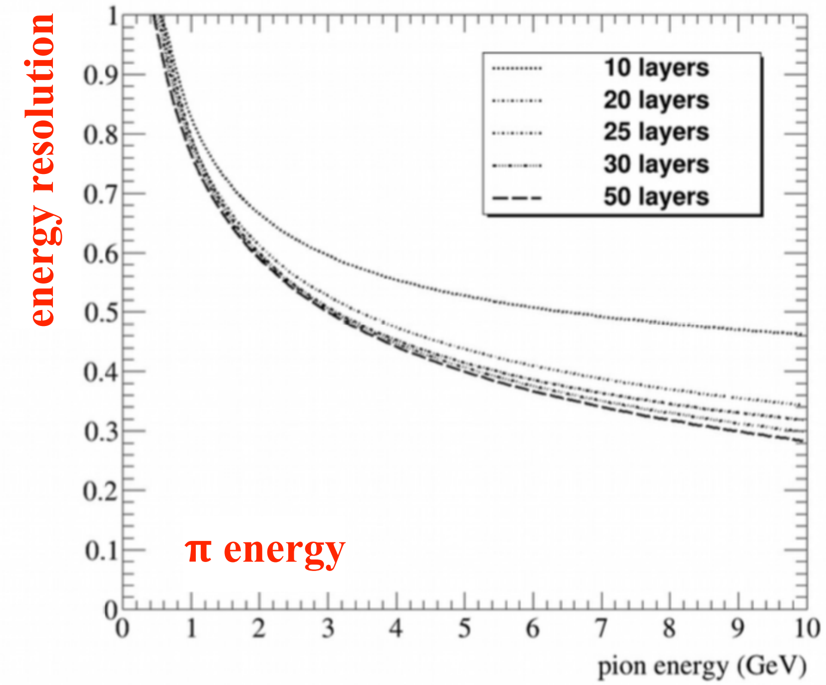
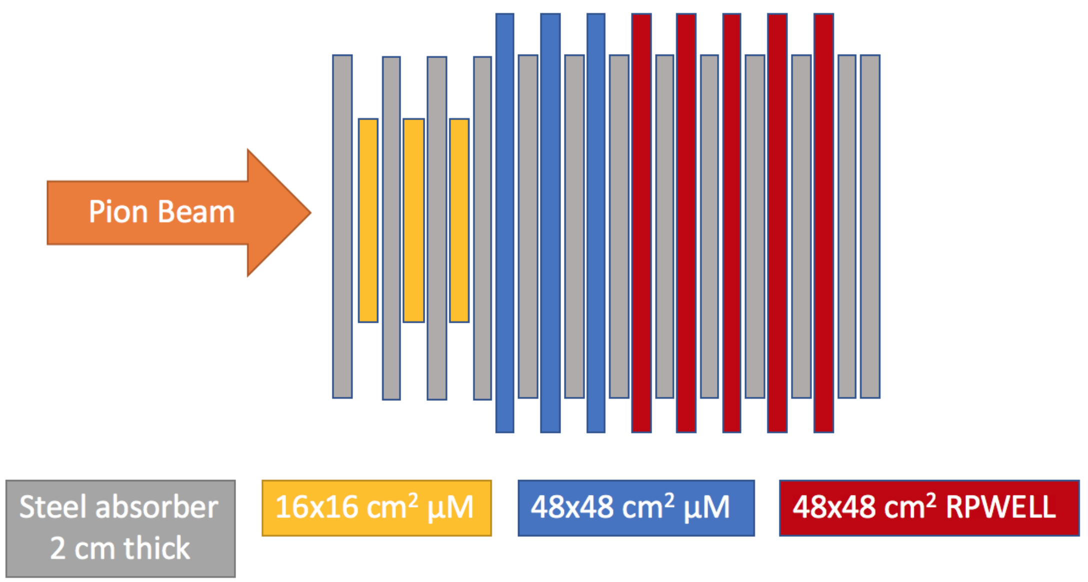
## **S**ampling **C**alorimetry with **RE**sistive **A**node **MPGD**

- Goal: construct the first MPGD-based sampling calorimeter
  - As an alternative to the RPC baseline technology
- Two technologies
  - RPWELL
  - Resistive MICROMEGAS
- Geometrical requirements
  - $50 \times 50\ cm^2$ is large enough
  - 15 layers are sufficient for full containment of electrons
  - 25 layers are necessary for pions



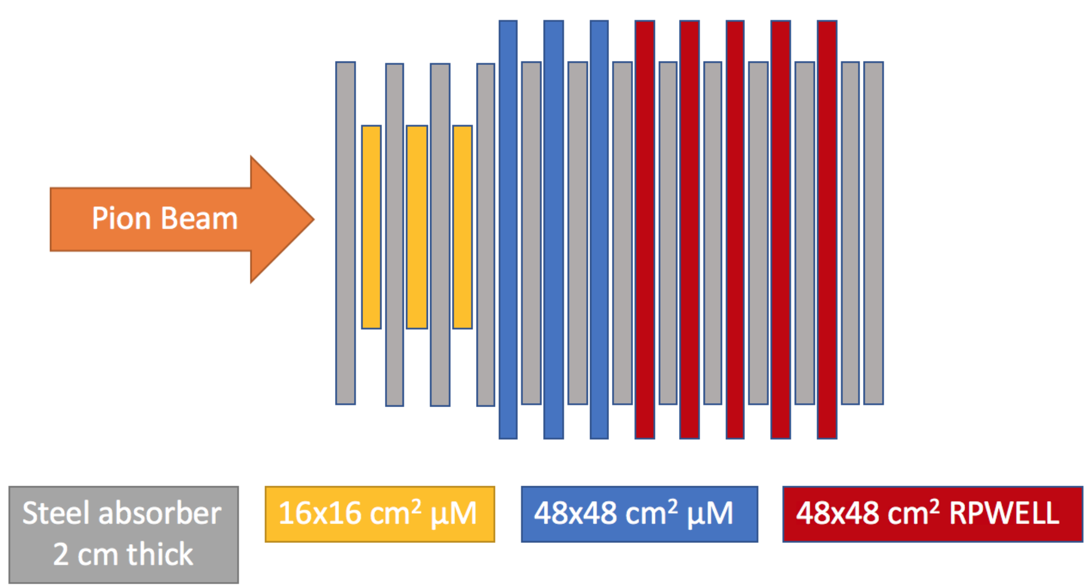

- Geometry - reality
  - 12 layers in total:
    5 $50 \times 50\ cm^2$ RPWELL
    3 $50 \times 50\ cm^2$ Resistive bulk MM
    3+1 $16 \times 16\ cm^2$ Bulk+Resistive Bulk MM
  - 2 cm steel absorbers between the layers
  - Single DAQ system
    - Based on the MICROROC Chip
  - HV mainframe and monitoring provided by RD51

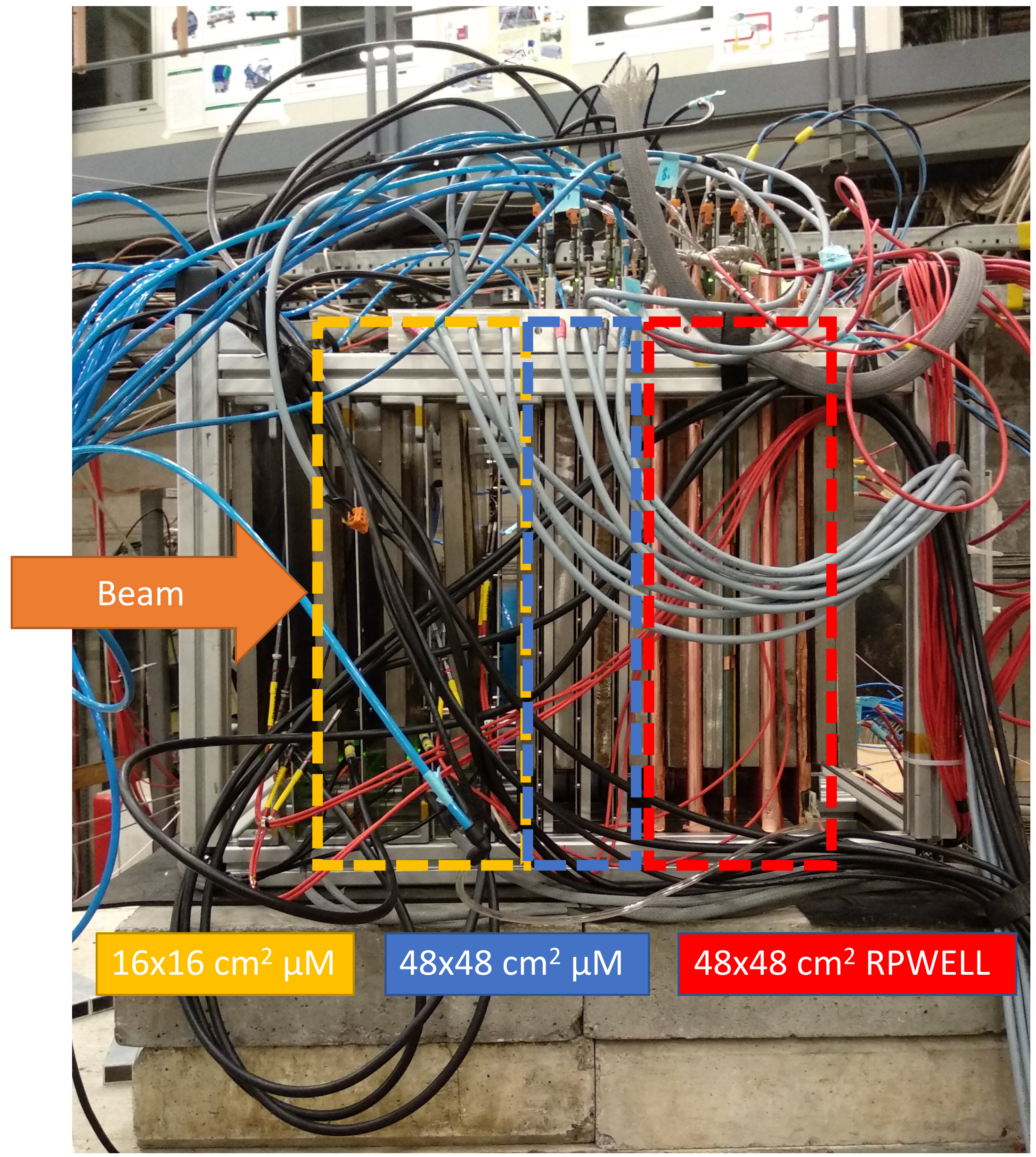


# The SCREAM project

**Sampling Calorimetry with REsistive Anode MPGD**

- Geometry - reality
  - Non uniform layers were excluded
  - Most of the analysis was conducted with 8 layers - 2 RPWELLs
    - Operation voltage 1575 V close to efficiency plateau
- Pion beam 2-6 GeV
- 3 thresholds setup - not optimized
  - DAC0 - 0.8 fC
  - DAC1 - 1.4 fC
  - DAC2 - 3.8 fC



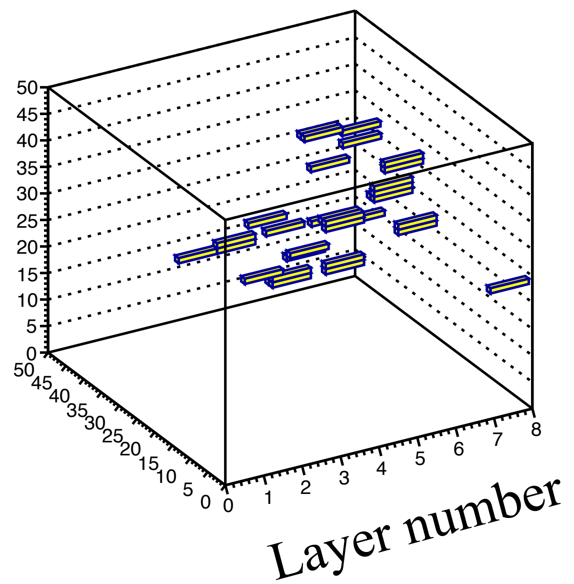



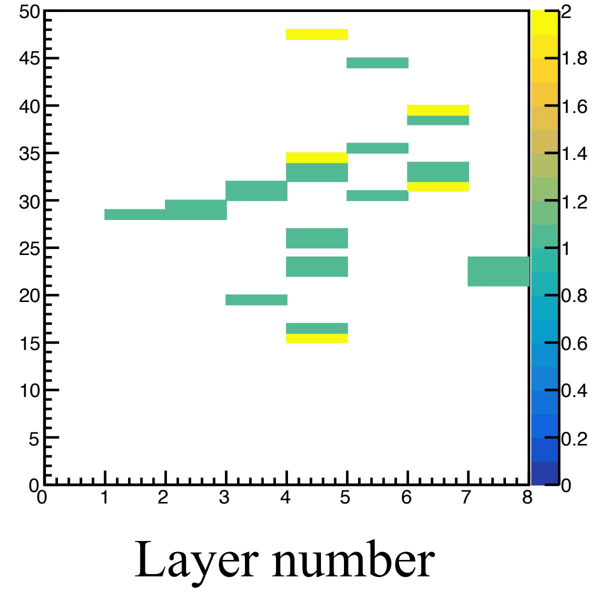
# The SCREAM project

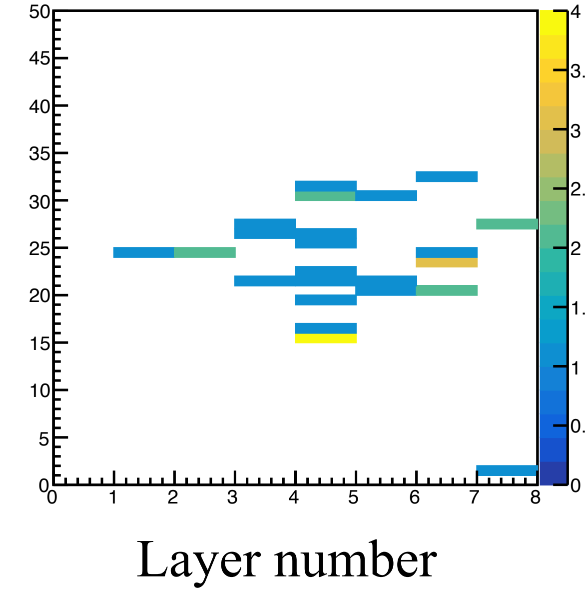
**Event displays**

3D view | Z-X projection | Z-Y projection

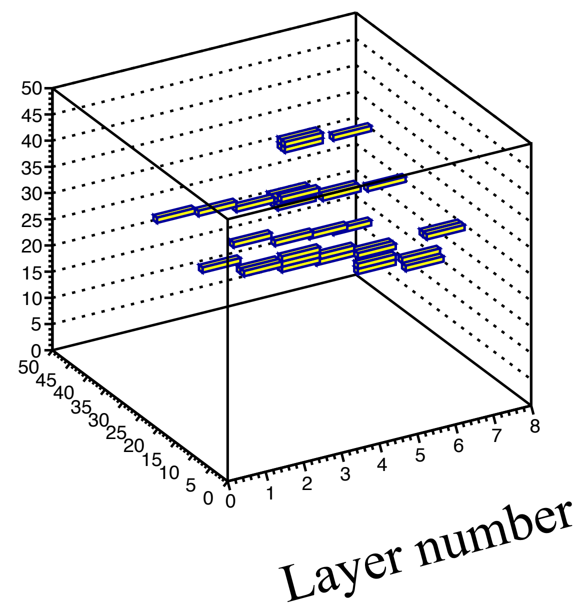
6 GeV pion

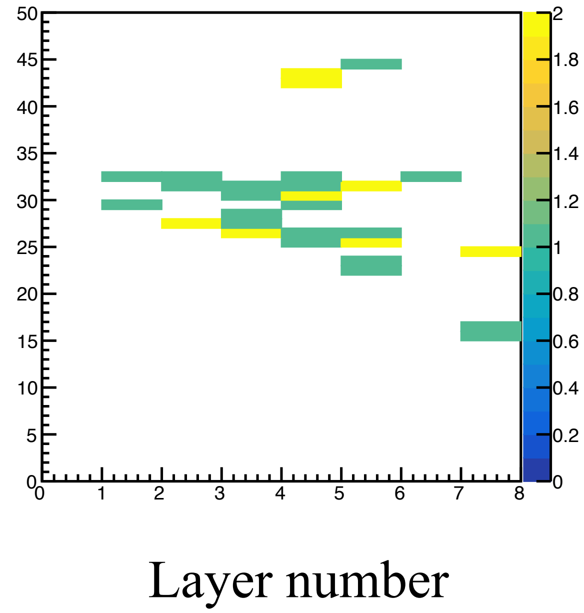


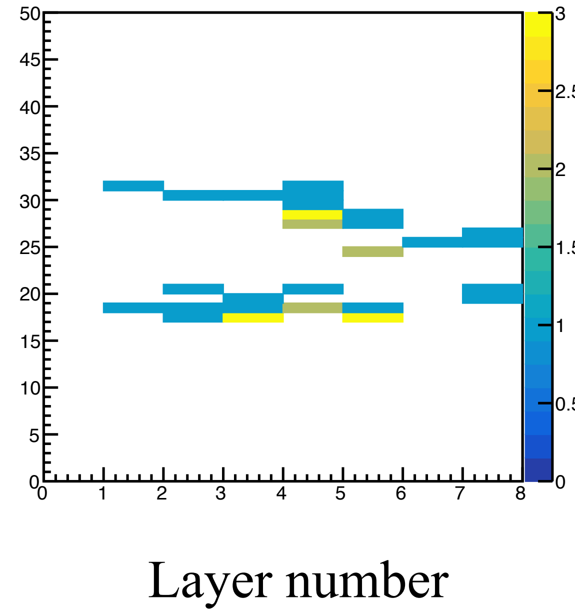




Two 2 GeV pions



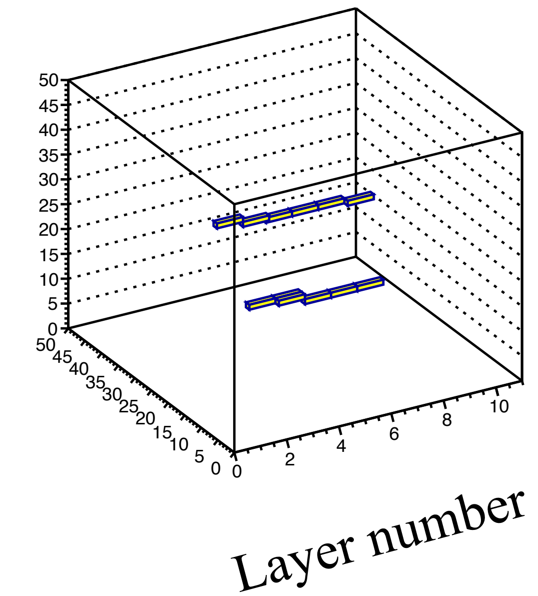



# The SCREAM project

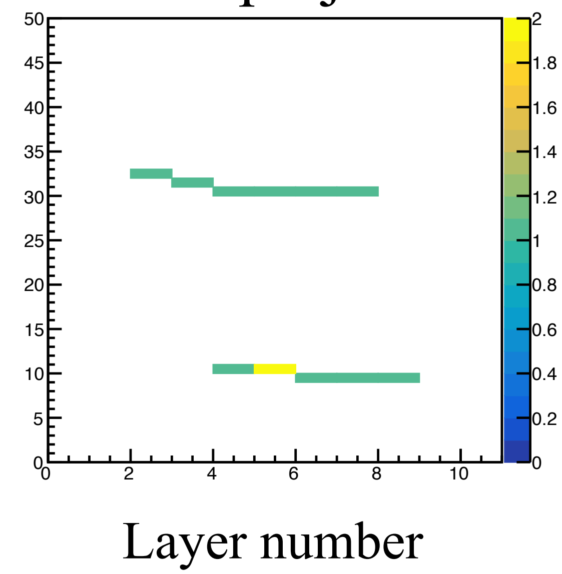
## Event displays

Two MIPs
Bottom one outside of
the small MM acceptance

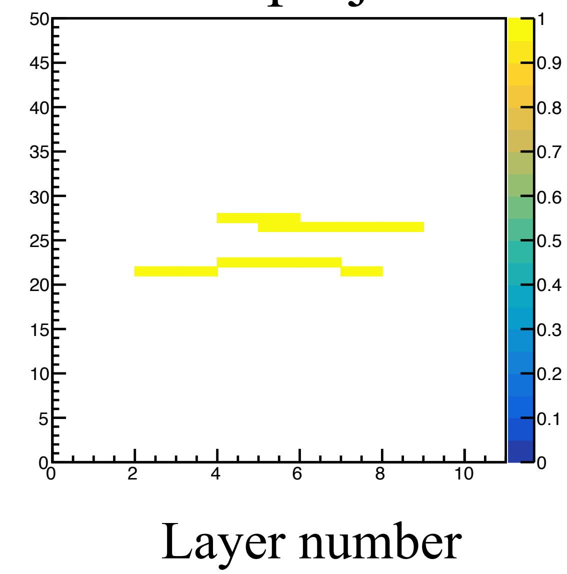
3D view



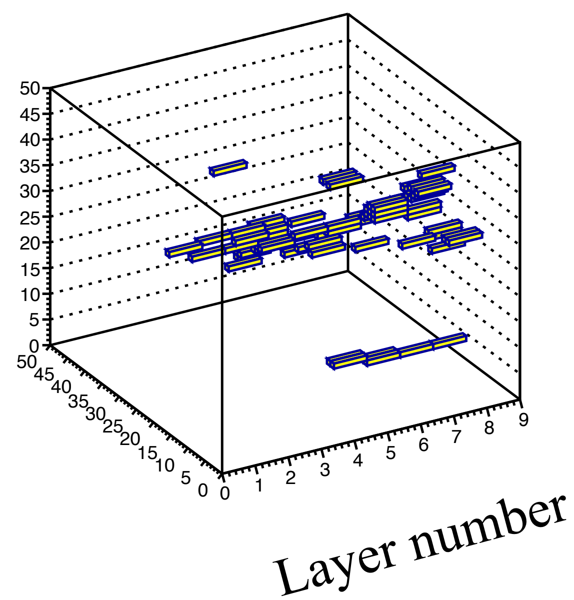

Z-X projection

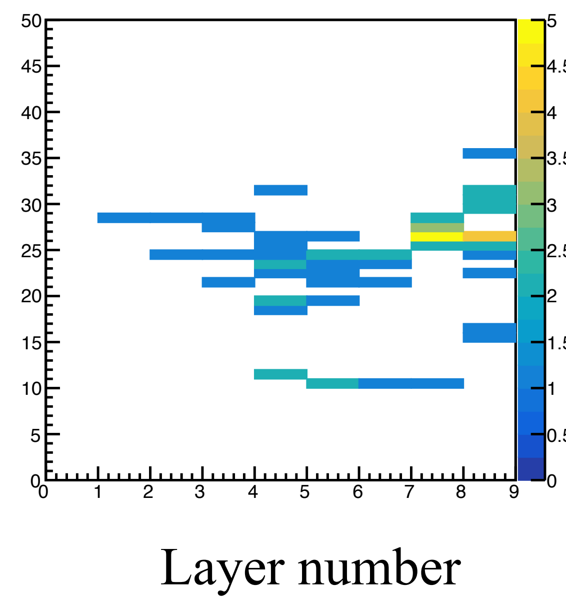


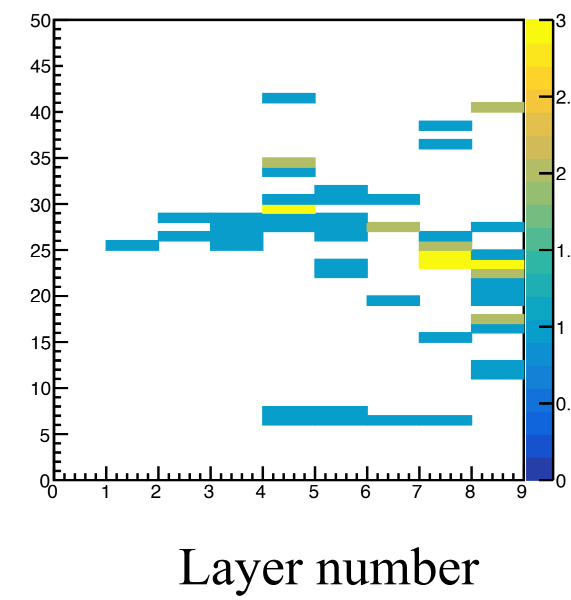

Z-Y projection




MIP and 5 GeV pion



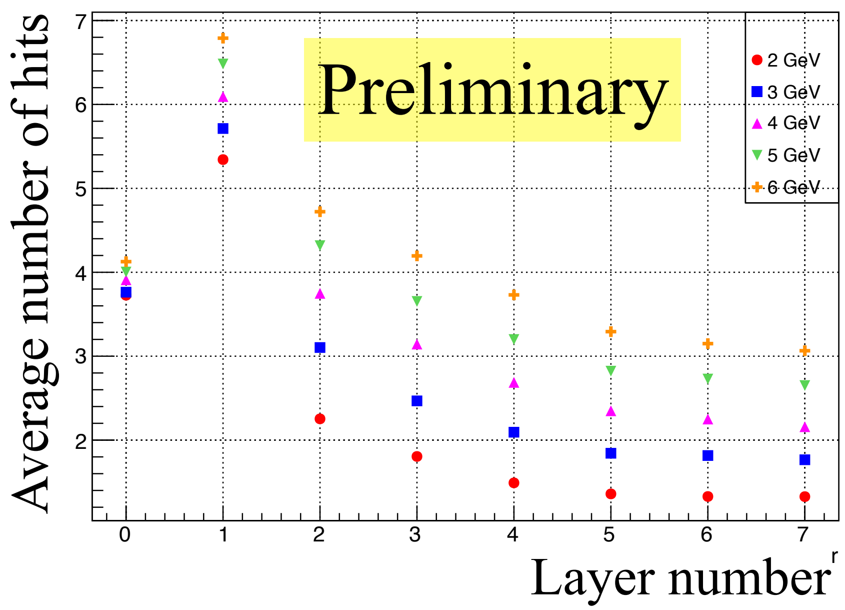



# RPWELL for SDHCAL

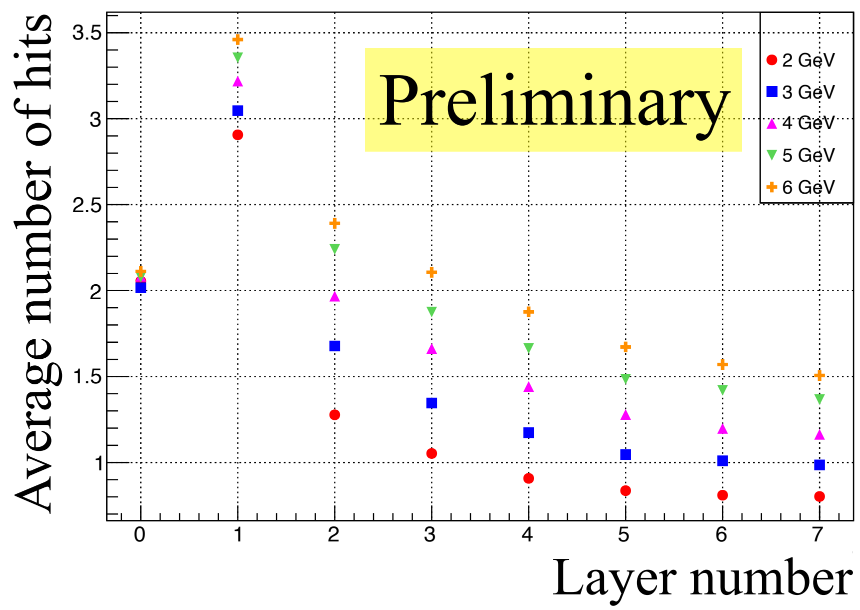
**Looking only at the RPWELL detector (chose the one with 5% thickness variations)**

- Characterize the RPWELL response as a function of the shower depth
- Observed leakage at the higher energies

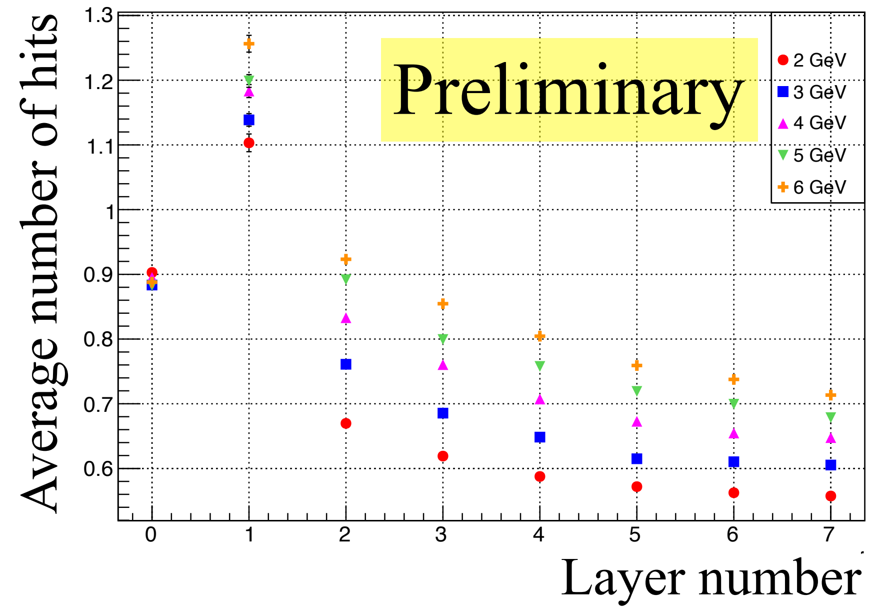
DAC0 - 0.8 fC



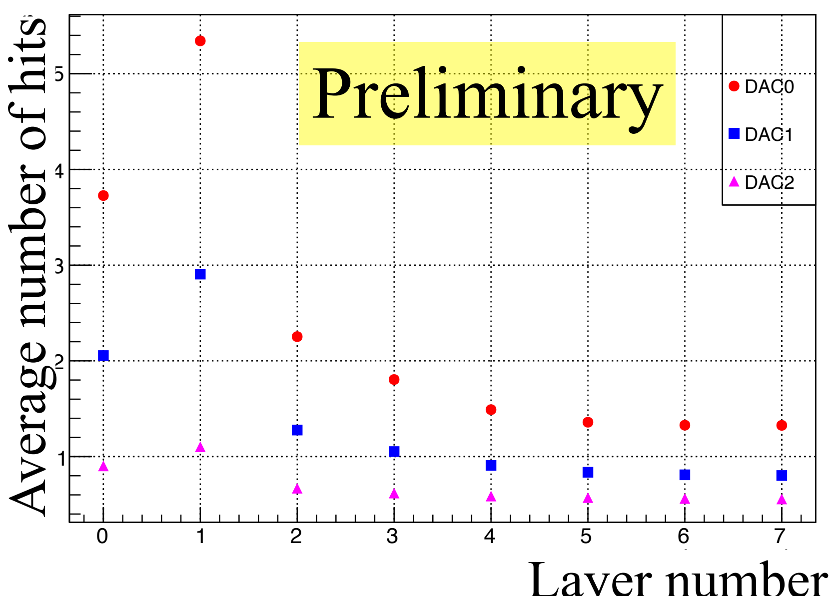

DAC1 - 1.4 fC



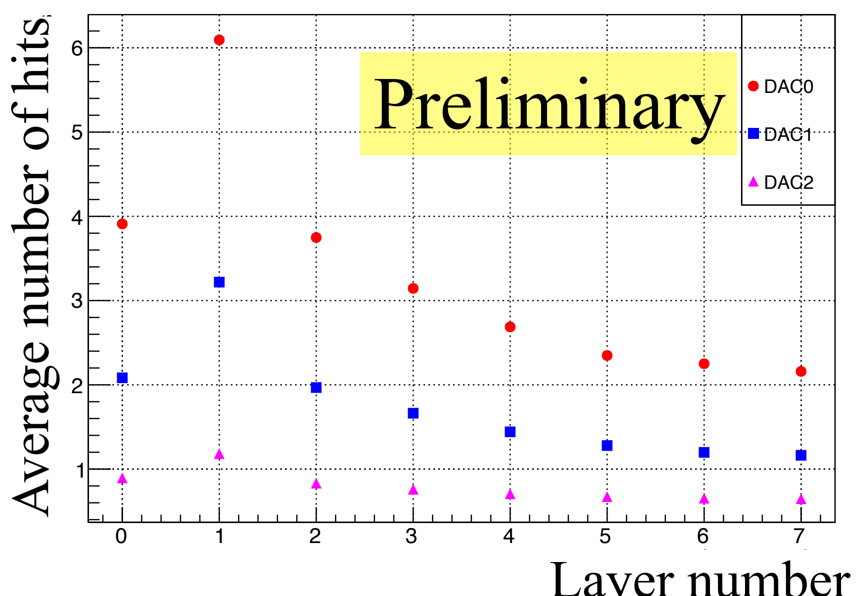

DAC2 - 3.8 fC



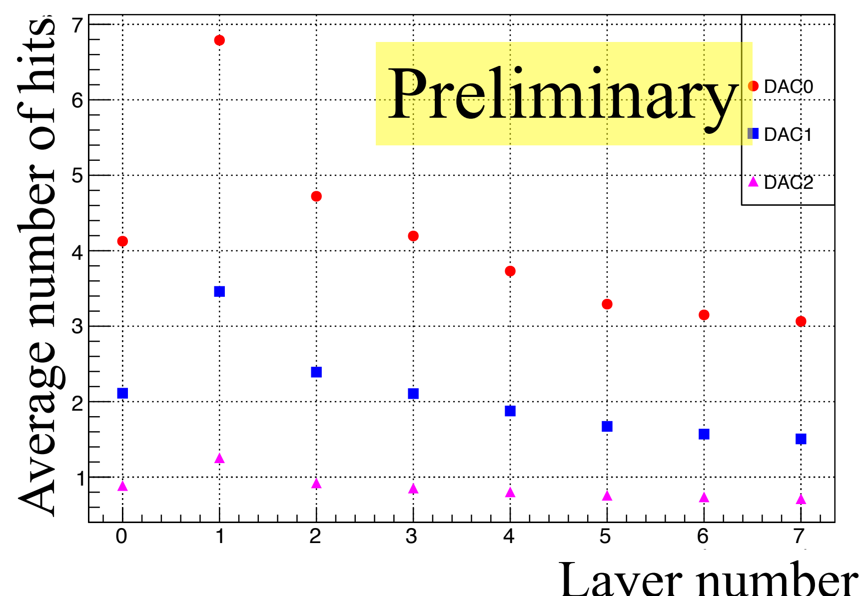

2 GeV




4 GeV



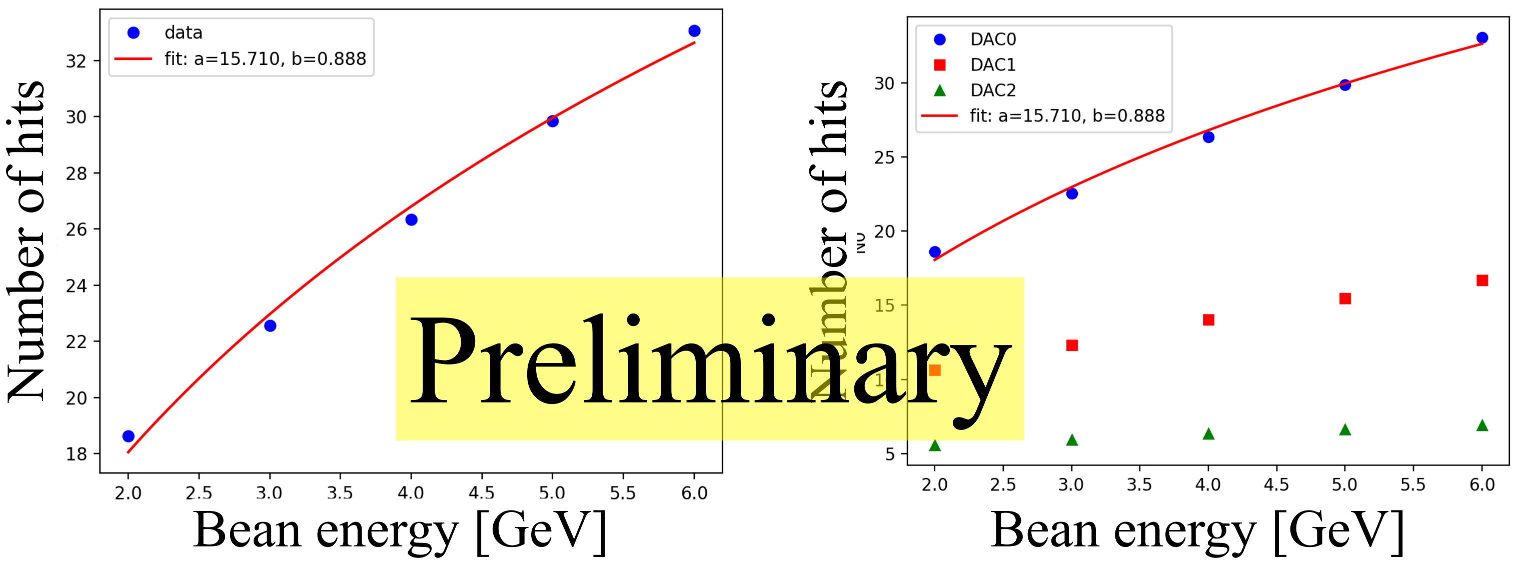

6 GeV



# RPWELL for SDHCAL

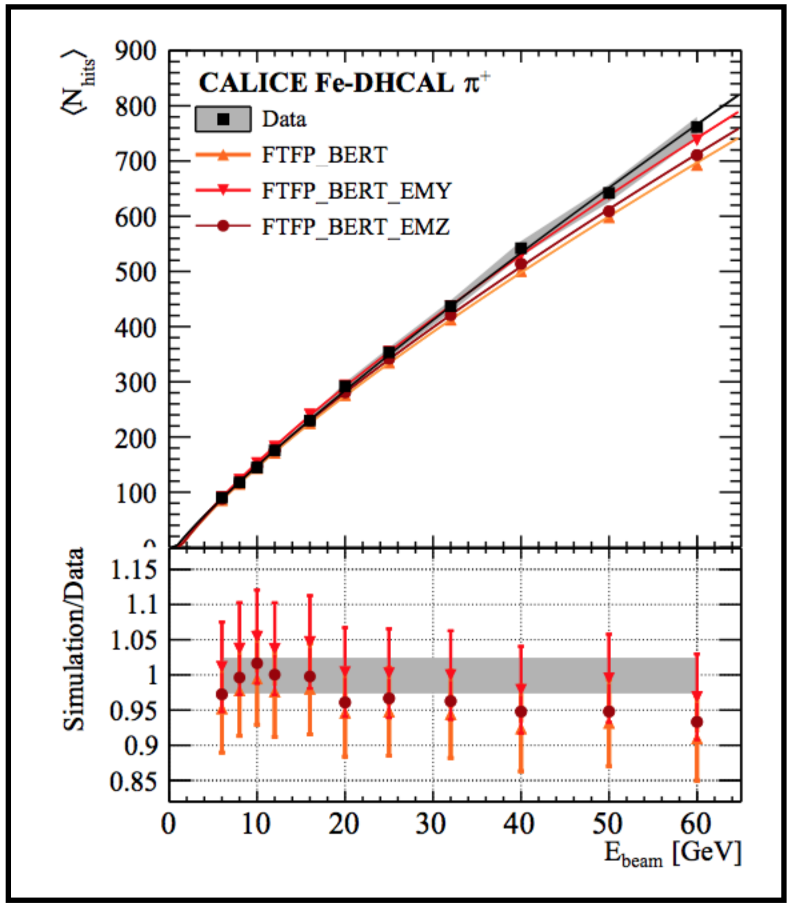
**First look at 'virtual' response**

- Number of hits vs incoming particle energy
  - Deduced from measurement with single layer
- Expecting significant leakage hence significant deviation from linearity




- To be compared e.g. to CALICE results

Calice collaboration arxiv:1901.08818



# RPWELL for SDHCAL

**Next steps - many things to do**

- Conclude the current analysis
  - Expected energy resolution with full RPWELL-SDHCAL
  - Understand the number of hits distribution
  - Compare to MC simulation
  - Look at the performance under different irradiation conditions
- Based on analysis results
  - Optimize detector design, assembly and testing procedures
- Measurements in cosmic test bench
  - Individual layers efficiency and multiplicity
  - Layer uniformity

- Compare results to MM and GlassRPC

# Summary

- SDHCAL is seriously considered as a solution to all future accelerator experiments
- GlassRPC-based SDHCAL performs nicely
- MPGD-based SDHCAL could outperform so worth being developed and studied
- RPWELL is a potential candidate