Applications of Detectors based on THGEM-like Configurations

PURBA BHATTACHARYA

Department of Physics, School of Basic and Applied Science
Adamas University

Standard Model of particle physics (SM) describes the elementary particles and their interactions.

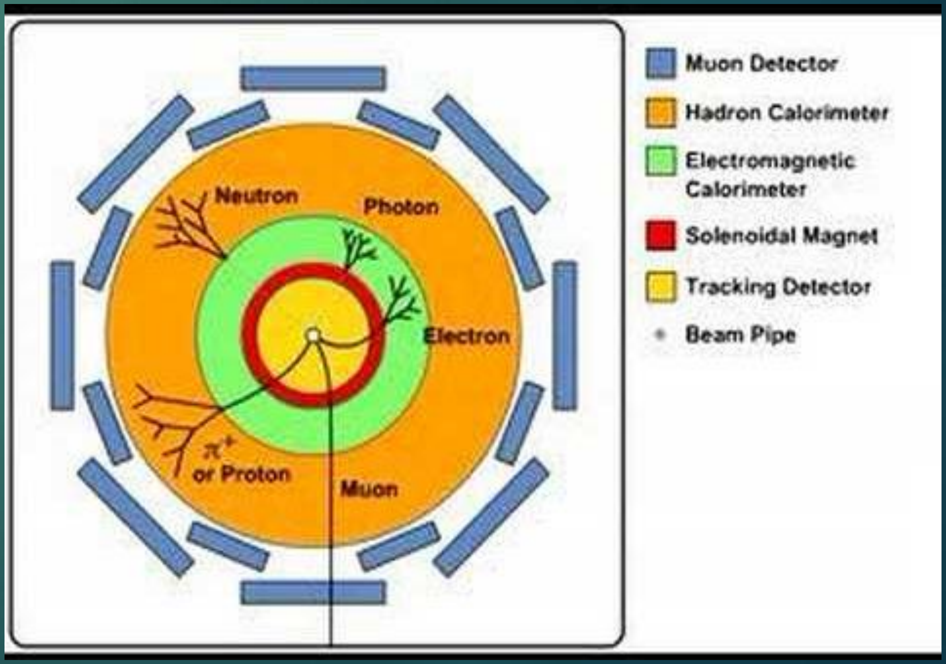
Experimental High-Energy Particle Physics

The physicists tool: The accelerator

LHC: the world largest accelerator, both in energy and size

Colliding Beams: During a colliding-beam experiment, the particles radiate in all directions, so the detector is spherical or, more commonly, cylindrical.

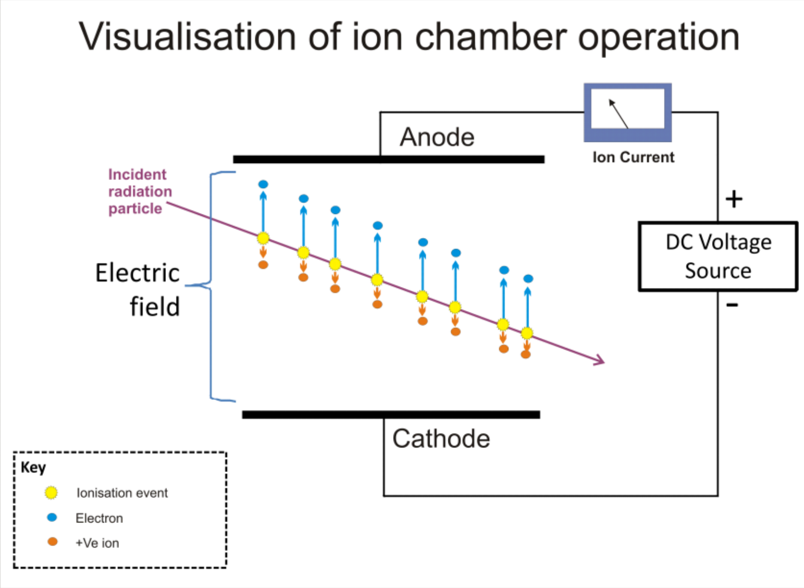
- Charged particles, like electron and protons are detected both in the tracking chamber and the calorimeter. Muon also leaves track in tracking chamber and is detected in Muon detector
- Neutral particles, like neutrons and photons, are not detectable in the tracking chamber; Photons are detected by the electromagnetic calorimeter, while neutrons are evidenced by the energy they deposit in the hadron calorimeter.
- Each particle type has its own "signature" in the detector. For example, if a physicist detects a particle **only** in the electromagnetic calorimeter, then he is fairly certain that he observed a photon.



Detection and measurement of different type of particles – development of different types of detectors

Ionization Detectors

Detectors that depend on ionization of the media and its registration
Gas / Liquid Detectors: Electron - Ion pairs
Solid State Detectors: Electron – Hole pairs
They can both be used as Tracking detectors in which you need to know the position to varied degrees of precision.



Visualisation of ion chamber operation

1908: FIRST WIRE COUNTER

1928: GEIGER COUNTER

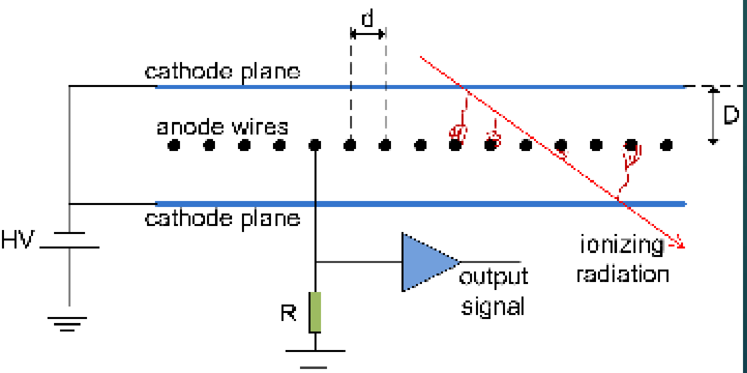
1968: MULTIWIRE PROPORTIONAL CHAMBER

(G. Charpak Nobel Prize in 1992)

Gas Detectors – Oldest and widely used radiation detectors

A particle passing through a gas-filled counter will ionize the gas along its path. The applied voltage V between the electrodes will sweep the positive and negative charges toward the respective electrodes causing a charge Q to be induced on readout electrodes.

Multi Wire Proportional Counter (MWPC)

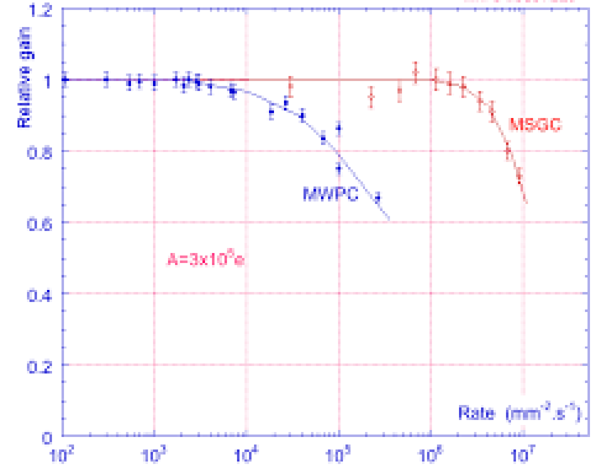


Disadvantages: ***Rate capability limited by space charge defined by the time of evacuation of positive ions***

Micro-Pattern Gaseous Detectors – Fundamental Innovation

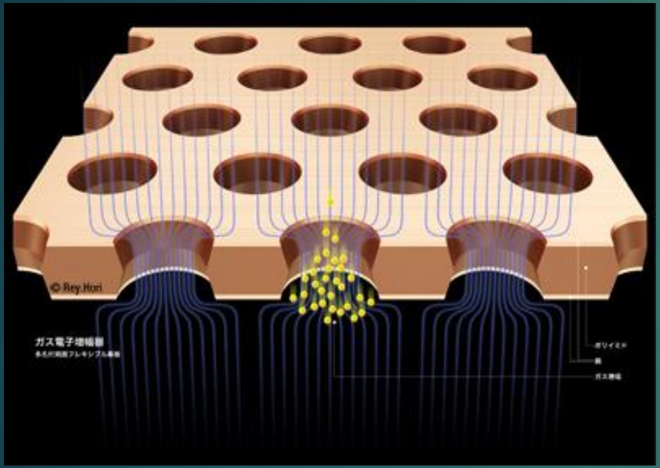
PCB Technology

- ❖ Photolithography
- ❖ Etching
- ❖ Coating
- ❖ Doping
- ❖ Wafer Post processing



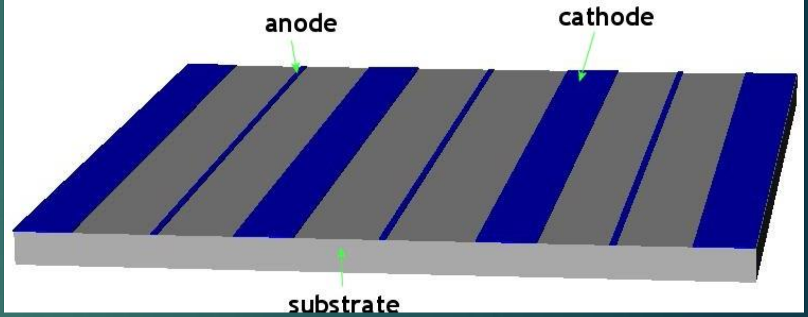
Applications

- ❖ High energy physics
- ❖ Low energy nuclear physics
- ❖ High resolution tracking device
- ❖ Astroparticle physics
- ❖ Rare event detection
- ❖ Medical Imaging

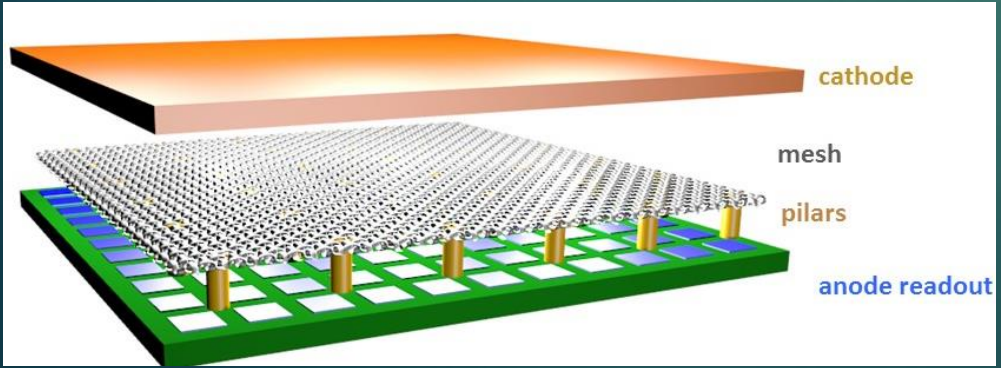


GEM

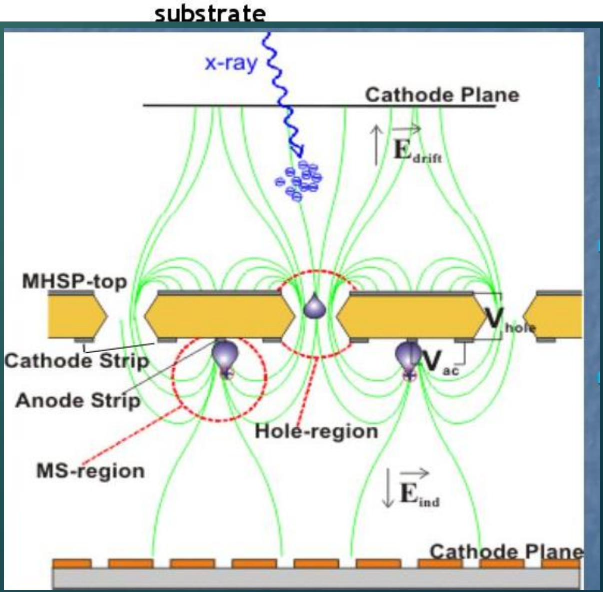
MSGC



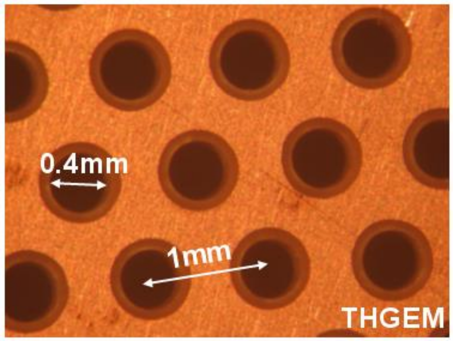
Micromegas



MHSP



Thick Gas Electron Multiplier (THGEM)

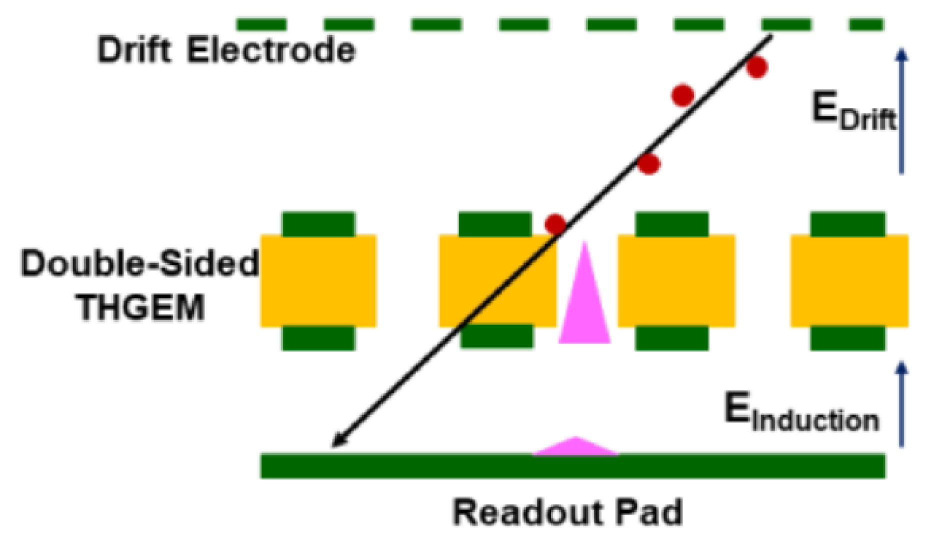


Thickness 0.5-1mm

SIMPLE, ROBUST, LARGE-AREA
Printed-circuit technology*

*** production:**
- **CERN PCB workshop**
- **Print Electronics, Israel**

Effective single-electron detection
Few-ns time resolution
Sub-mm position resolution
>$\mathbf{MHz/mm^2}$ rate capability
Broad pressure range: 1mbar - few bar



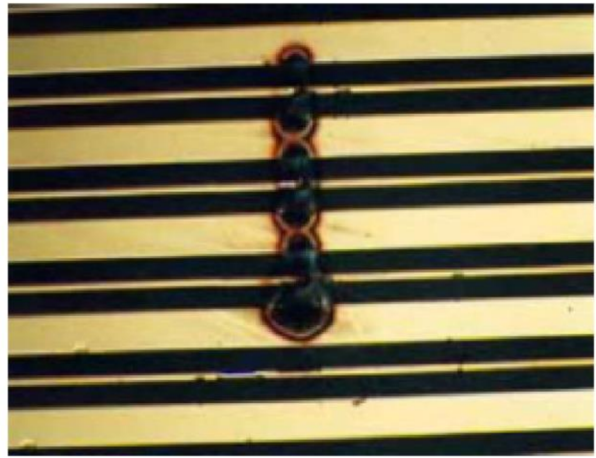
Applications requiring cost-effective large area detectors with moderate spatial resolution

- Digital Hadronic Calorimeter – DHCAL
- Dark Matter Search
- Low energy nuclear physics
- Muon tomography, volcanology and many more

Stability – The Challenge of discharges

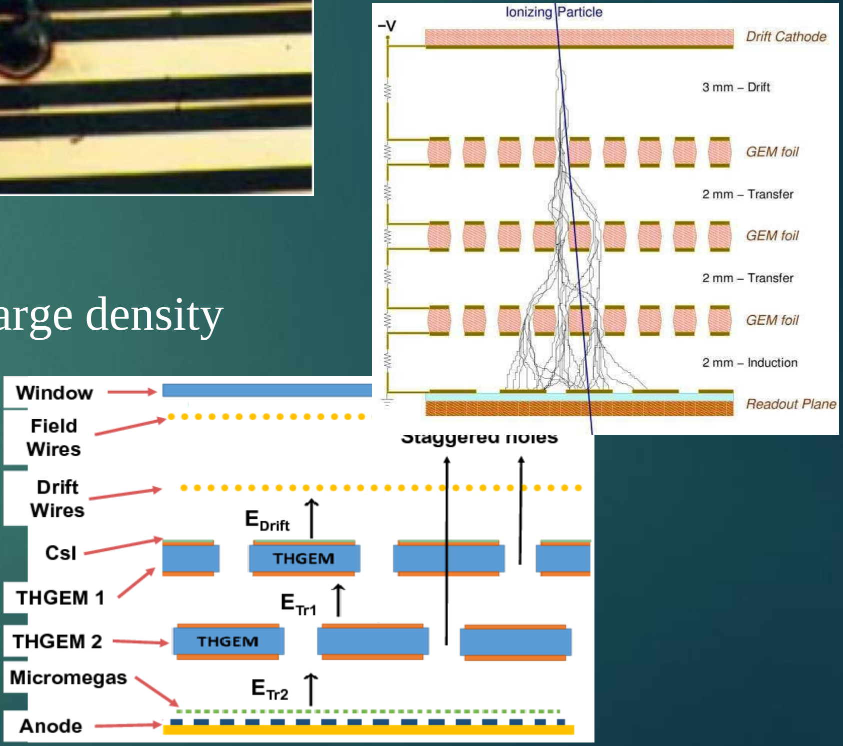
- Known problem in gaseous detectors
- Several reasons
  - Local defects in production
    ⇒ Strong local fields
    ⇒ Spontaneous emissions
  - Raether limit
    ⇒ Spontaneous breakdown of the gas when the charge density reaches certain limit which depends on the field
    ⇒ In MPGD ~10^7-10^8 electrons

- Results in long dead times
- Can destroy the detector
- Can destroy the readout electronics



Solution I – cascade detectors

❖ Smaller field in each stage
❖ Charge spread between several holes smaller → charge density
❖ Far from the discharge regime
❖ Advantage in blocking ion backflow

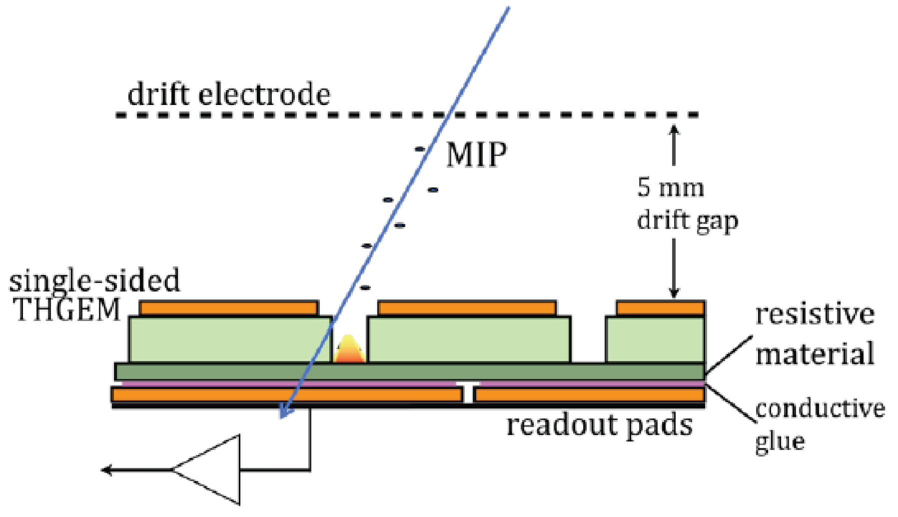


Solution II – resistive configurations

❖ Create self-quenching mechanism
❖ Delay the charge evacuation and force local field reduction
❖ Several attempts

The Resistive Plate WELL (RPWELL): A Robust Single Element Detector

- WELL Structure for electron multiplication
- Coupled to segmented readout through material of high bulk resistivity ($10^9 - 10^{12}\ \Omega\ cm$)
- Quenching of the occasional discharges
- Discharge-free operation at high gain depending on the primary ionization ($10^4 - 10^7$)
- Moderate rate capability (~10^4 Hz/cm^2)



Studied and tested extensively – main fronts

2013 JINST 8 P11004
2016 JINST 11 P01005
2016 JINST 11 P09013
NIM A 845 (2017) 262
2017 JINST 12 P10017
2017 JINST 12 P09036
2019 JINST 14 P10014

- ❑ Characterization
- ❑ Attempt to understand the physics processes governing its response
- ❑ Scaling up – transition from small to large area
- ❑ Readout element in potential applications @ RT (DHCAL)
- ❑ Gaseous Photomultipliers (GPM): UV-photon recording
- ❑ Cryo-RPWELL charge multipliers in dual-phase noble-gas detectors: investigating possible enhancement of current gain limitations of LEM detectors

Motivation: Digital Hadron Calorimeter

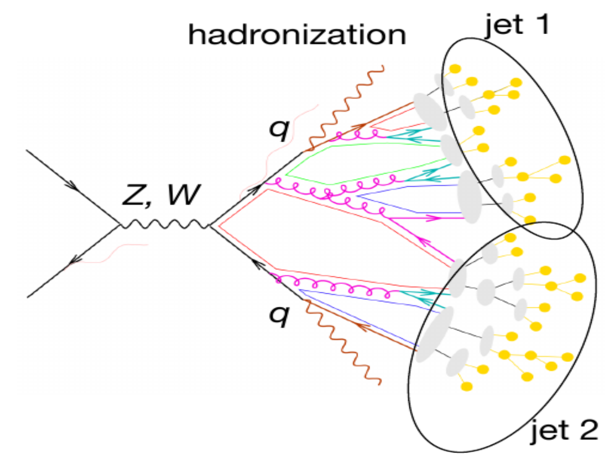
- Many Scenarios of BSM physics involve hadronic-decay channels
- Precision measurements in future colliders require precise **hadron jet reconstruction**
- Distinguishing between W and Z bosons reconstructed in multi-jet final states on the basis of their invariant mass

Design criterion for future calorimeters:

Z/W separation in the hadronic decay mode

☐ a jet-energy resolution <30/√E

☐ σ/E=3% for 100 GeV jets



Proposed approach: highly granular / particle flow / sampling calorimeters

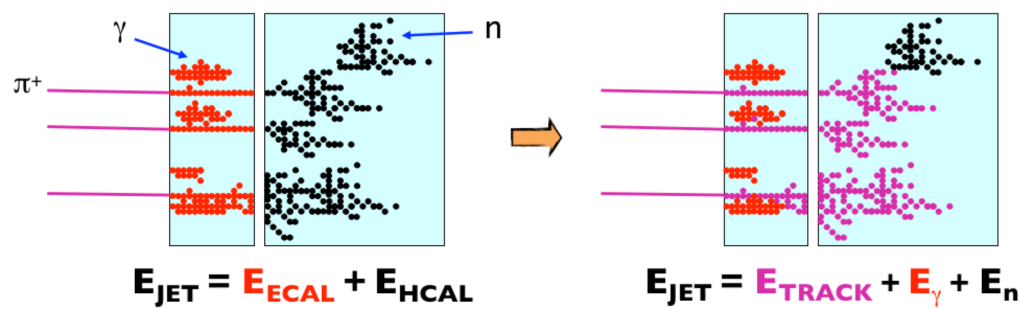
Traditional calorimetric approach: jet-energy is measured as a whole – 70% of the energy is measured in HCAL with $\frac{\sigma_E}{E} \approx 60\%/\sqrt{E(GeV)}$

Particle flow calorimetry – individual particles are reconstructed and measured separately

☐ Charged particle measured in tracker

☐ Photons in ECAL

☐ Neutral Hadrons only in HCAL – Only 10% of jet energy from HCAL



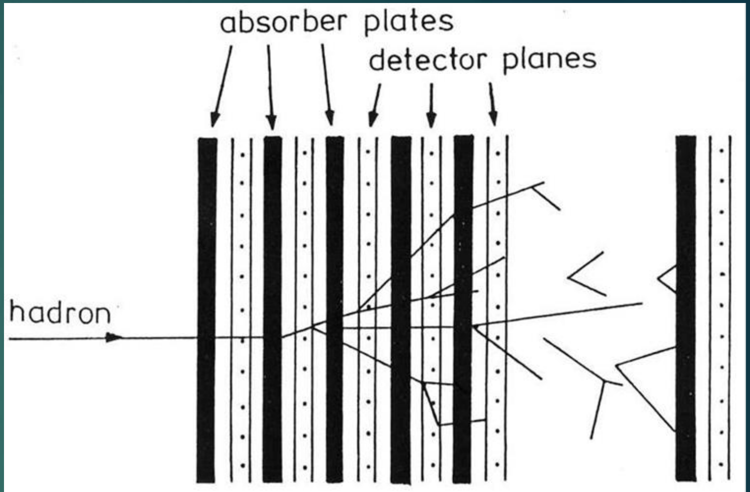
$E_{JET} = E_{ECAL} + E_{HCAL}$

$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

Sampling calorimeter consists of alternating layers of absorber planes and readout elements which samples the deposited energy

Digital Hadron Calorimeter (DHCAL) – one bit readout

- Cheap readout -> allow high granularity (1 cm^2) - > strong imaging capabilities
- The number of hit is proportional to the deposited energy
  - Saturation at high energy (high cluster density)



Foreseen (S)DHCAL systems require 40-50 layers of thin sampling elements for few thousands of m^2 area coverage. Total channel number 10^7 – 10^8.

***Physics requirements*:**

- High detection efficiency
- Low pad multiplicity
- Moderate rate capability
- Stability over wide dynamic range

***Technical requirements*:**

- Total thickness ~8 mm including readout electronics
- Cost-effectiveness
- Ease of production

Gaseous Detector Technologies are suitable to fulfil these requirements

- But they must be discharge free

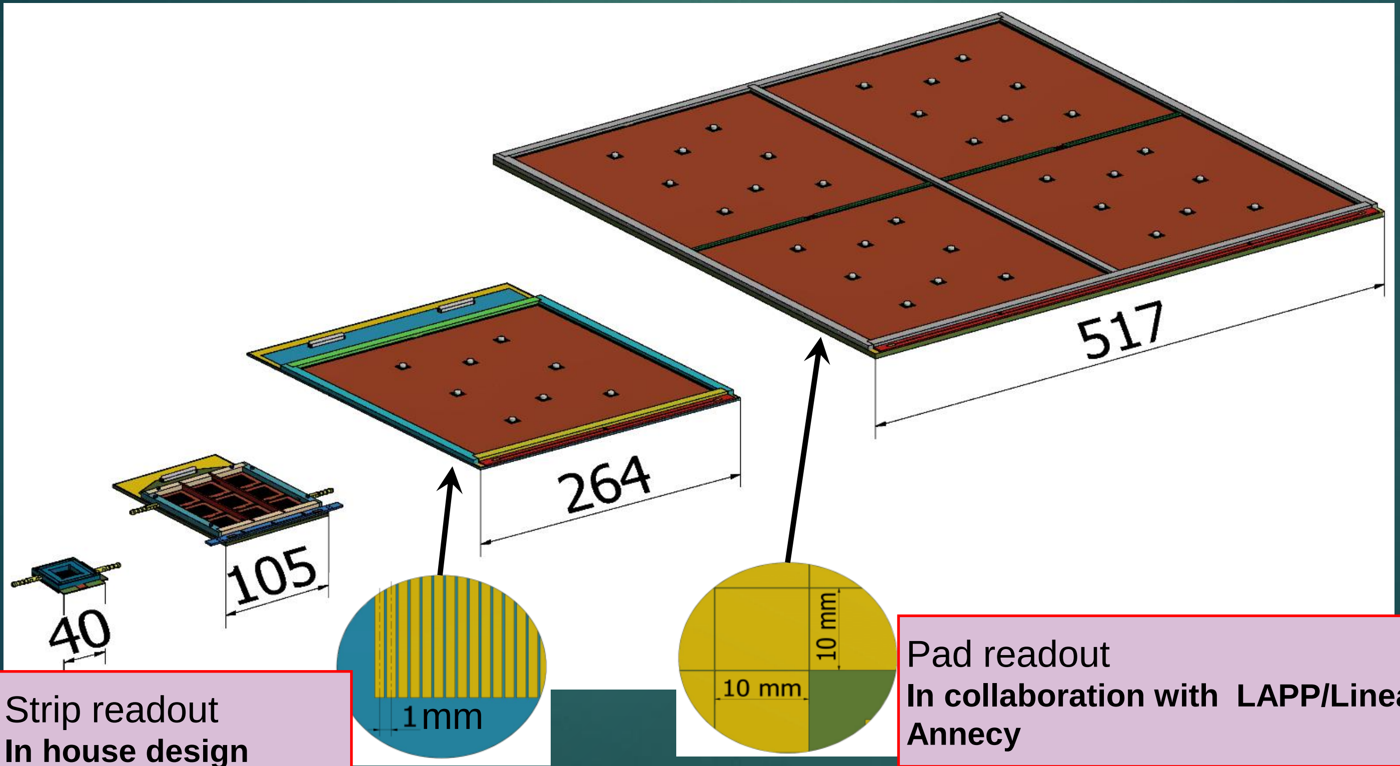
Suggested technologies for sampling elements for DHCAL:

Resistive Plate Chambers (RPC)
Resistive-MICROMEGAS
Double GEM

RPWELL??

Evolution of RPWELL:

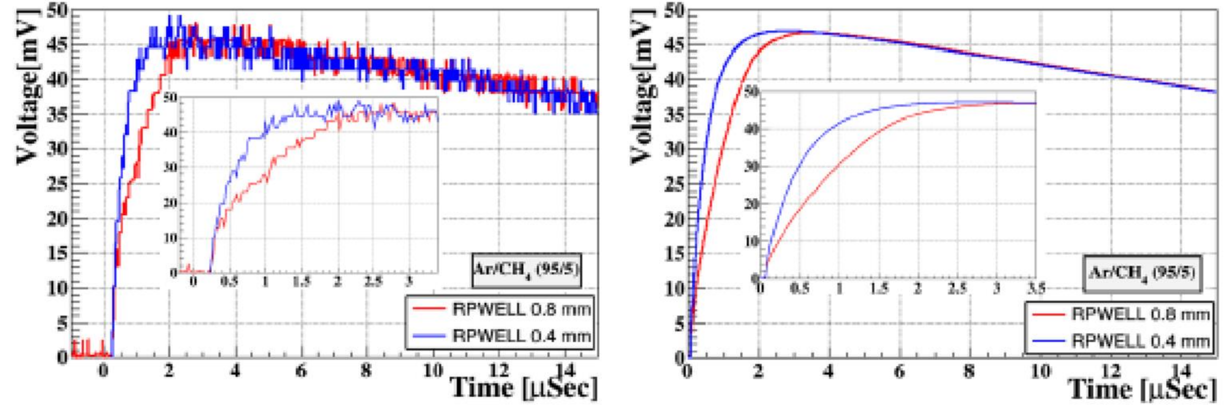
- Different prototypes were built for different purposes.
- They comprised RPs made of different materials: the Semitron ESD225 plastic and a silicate doped-glass.
- Both options gave satisfactory performances but present different technical issues in terms of mechanical properties.
- Basic R&D on small and medium-size detector prototypes was conducted.
- The largest prototype assembled was 500x500 mm^2, demonstrating the scalability of the RPWELL concept to large areas



Strip readout
In house design

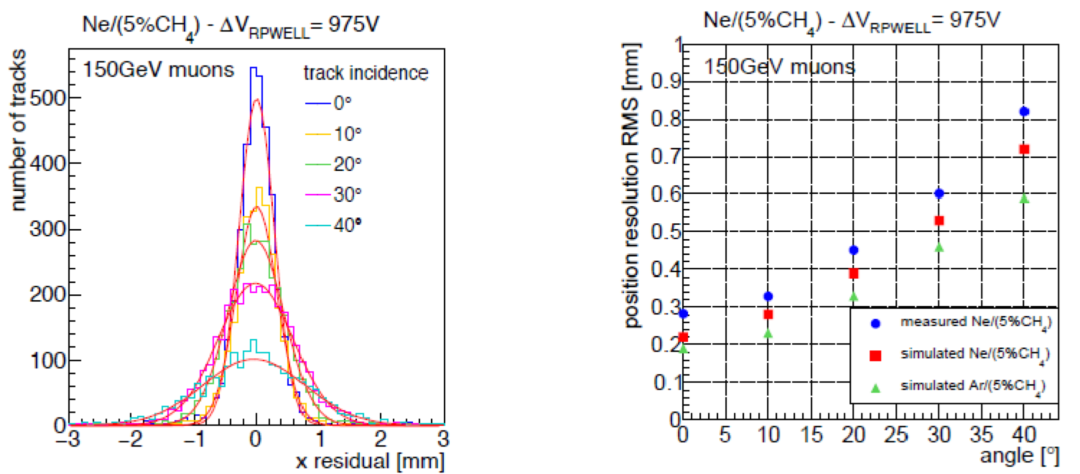
Pad readout
In collaboration with LAPP/Linear Collider group, Annecy

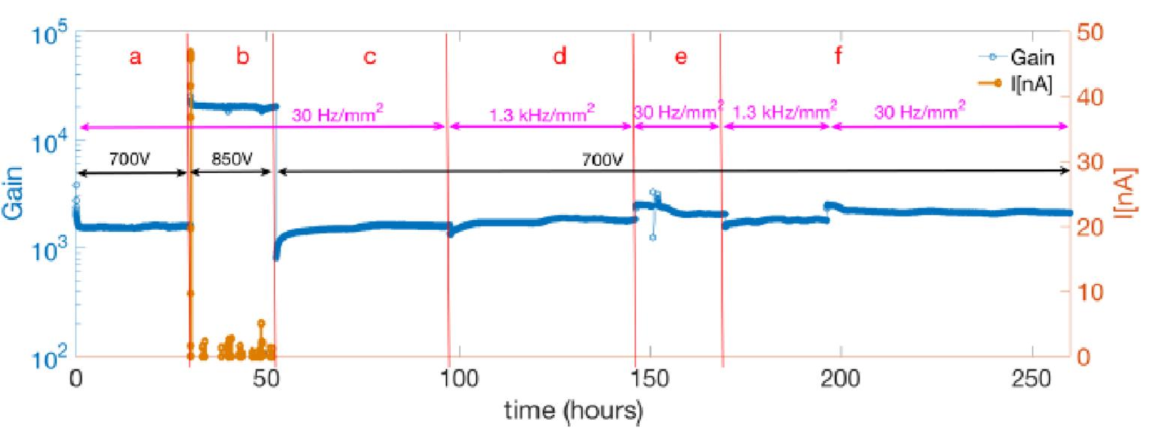
Motivation Characterization and Physics (RPWELL)



Signal Formation
NIMA vol 916 (2019) 125

Position Resolution
JINST vol 12 (2017) P10017



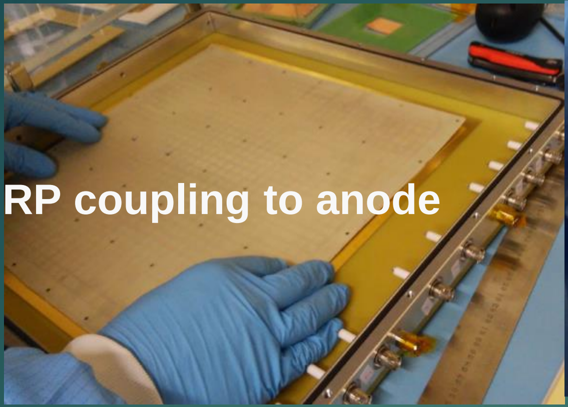


Gain Stabilization
JINST vol 12 (2017) P09036

Still not all is clear
Role of Resistive Layer??

Construction

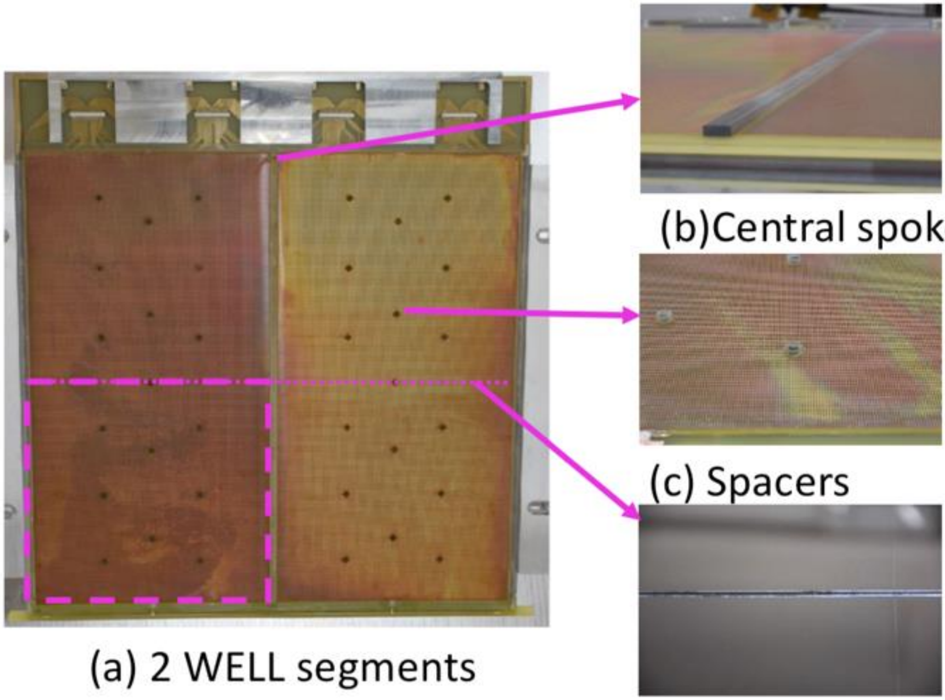
30x30 cm^2 prototype –



RP coupling to anode

Assembled detector before placing cathode

50x50 cm^2 prototype –

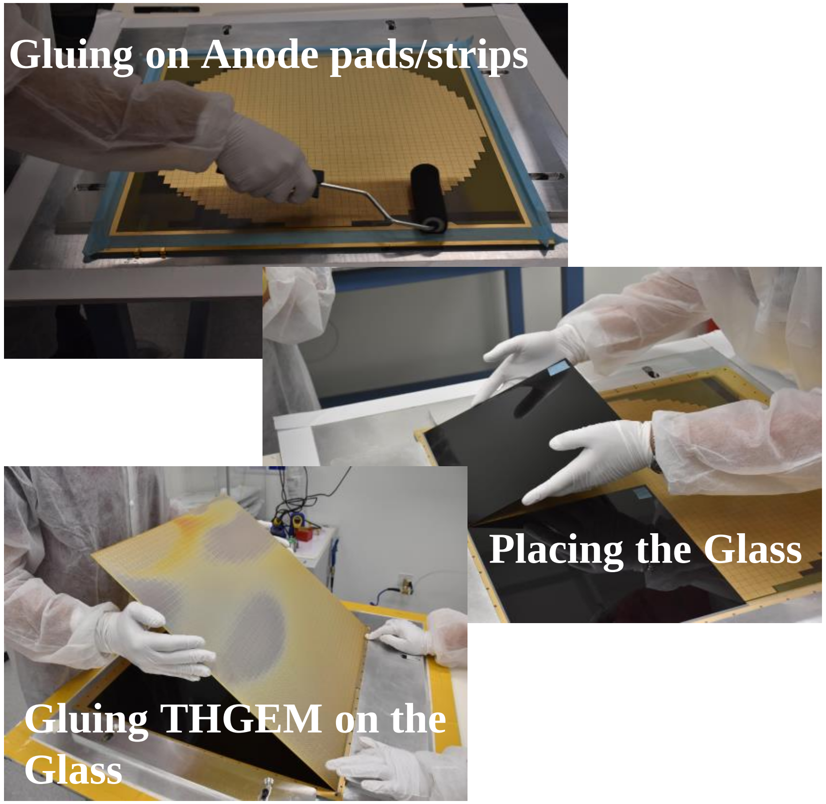


(a) 2 WELL segments

(b)Central spoke

(c) Spacers

(d) Glass tiles

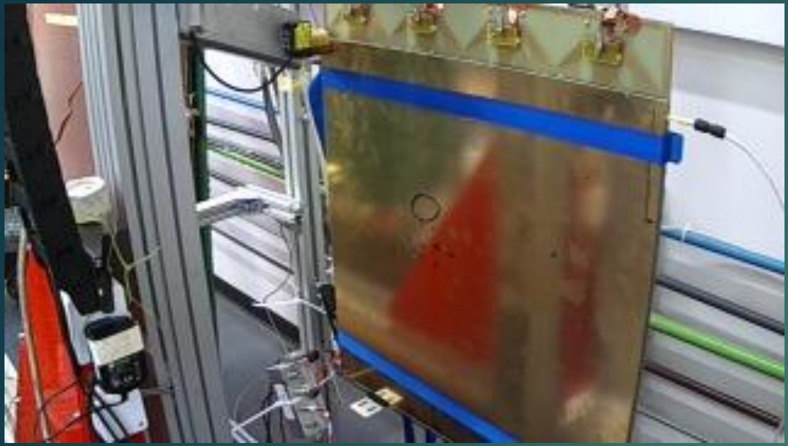


Gluing on Anode pads/strips

Placing the Glass

Gluing THGEM on the Glass

Stability Test: Chamber was installed in a X-Y System:



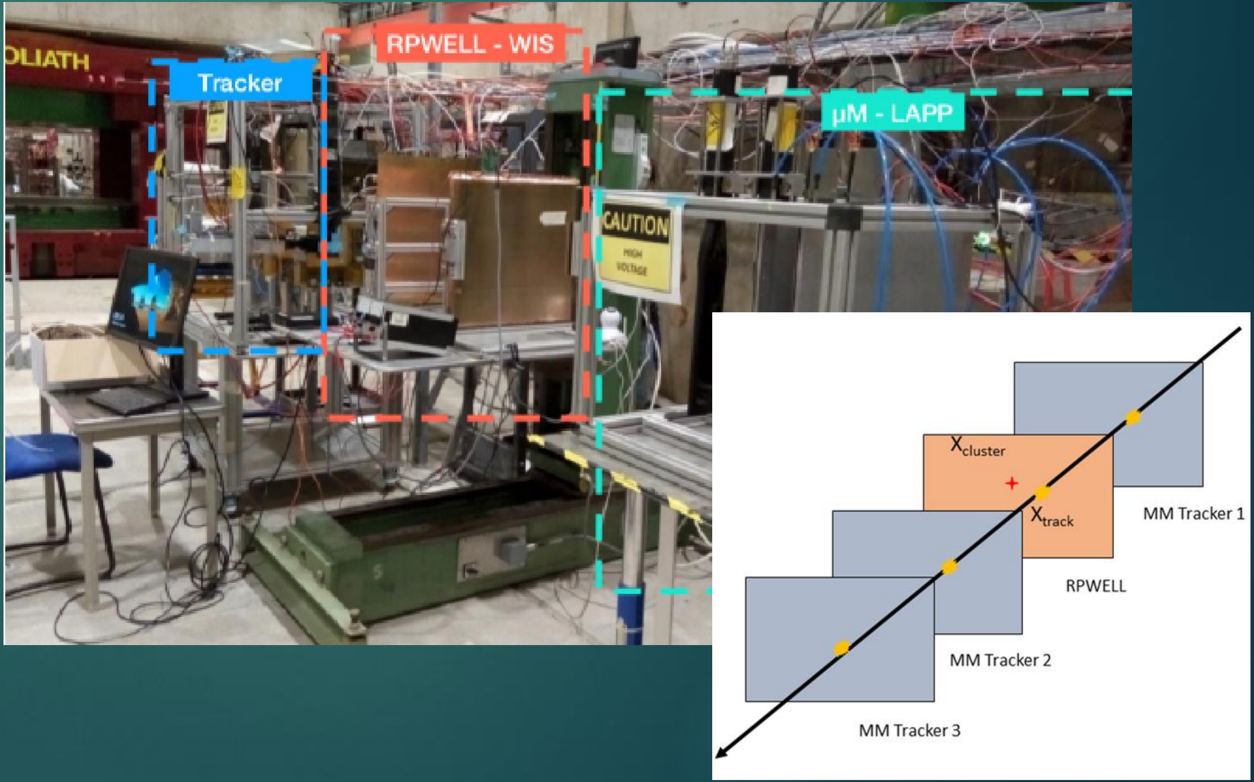
- silver x-ray gun (~22keV photons)
- 30mm diameter collimator
- current measurement from each electrode

- 1-10 nA dark currents
- no discharge observed

Stable operation of a 50x50 cm^2 RPWELL under high irradiation conditions

Testing of Detectors under μ and π Beam

- ➢ Setup in CERN-SPS in July 2017, April 2018, August 2018
- ➢ Four prototypes tested
  - ○ Pad Anode with Semi-Digital Readout
  - ○ Strip Anode with SRS/APV25



Results with 30x30 cm^2 prototype with μ and π beam at CERN-SPS

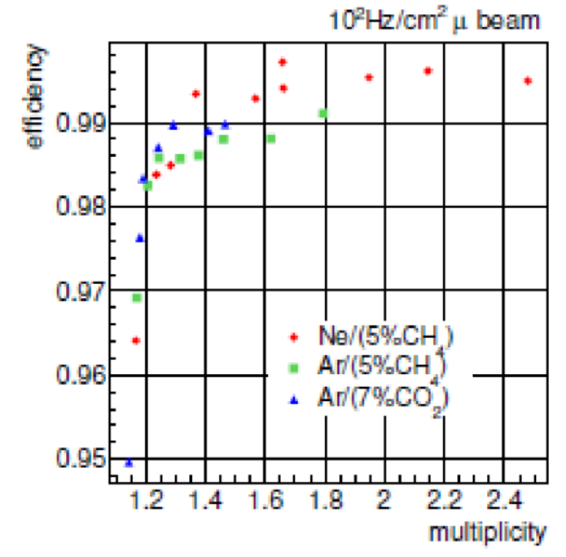
Physics requirements:

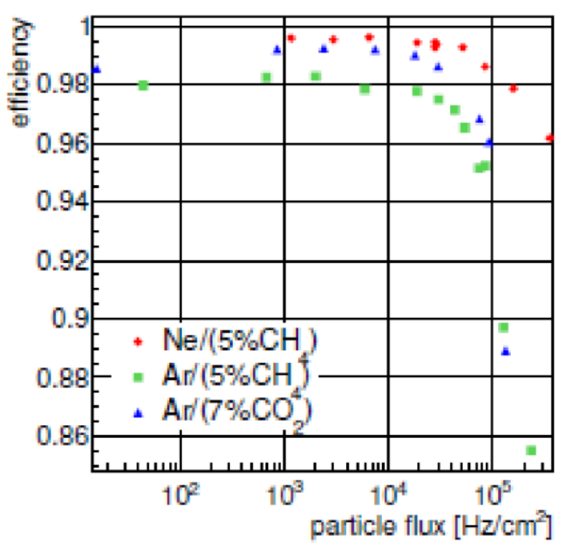
JINST 11 (2016)

- High detection efficiency
- Low pad multiplicity
- Moderate rate capability
- Stability over wide dynamic range

Technical requirements:

- ~6 mm thick excluding readout.
- Cost-effectiveness
- Ease of production

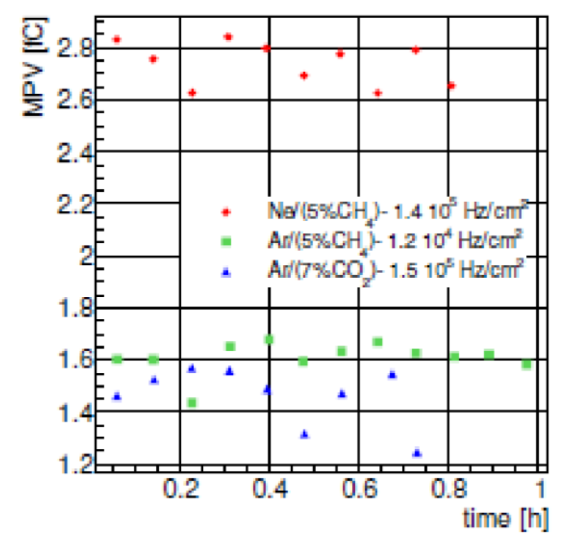




Reached DHCAL requirements with RPWELL

- 98% efficiency
- Multiplicity 1.2
- No efficiency loss up to 10^4 Hz/cm^2
- Achieved for the first-time stable operation in high intensity pion beam – No discharge over 10^8 events

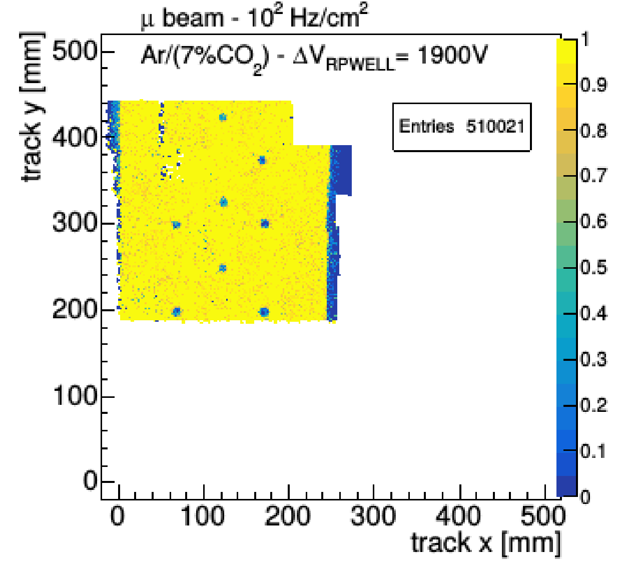
- Total thickness ~ 5 mm without electronics
- Use of argon gas – Low cost, high number of PEs, low diffusion



Meet DHCAL requirement for a single sampling element – Step towards large scale prototype

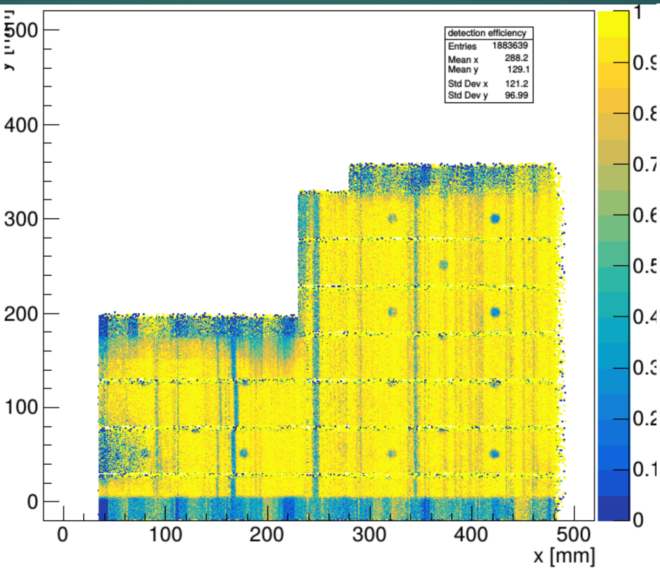
Results with 50x50 cm^2 prototype with μ beam at CERN-SPS
Strips Readout

Pressing



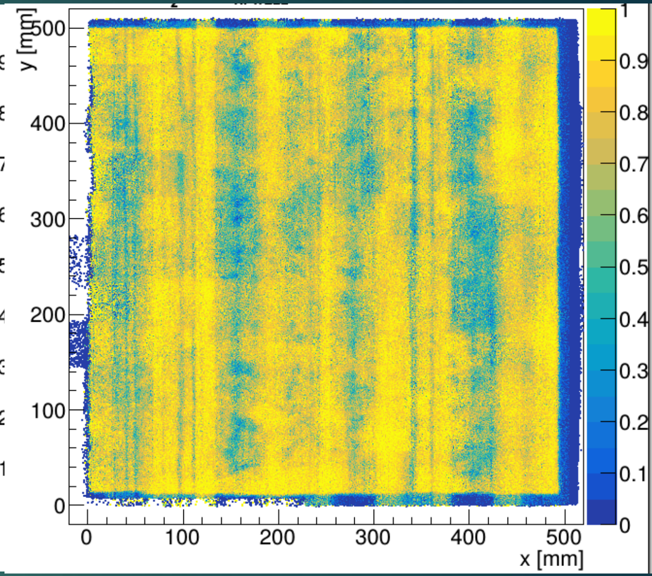
July 2017

Gluing: 1st Attempt



April 2018

Gluing: 2nd Attempt



August 2018

- ☐ July 2017 – THGEM pressed to the glass tiles with spacers and buttons, no gluing
- ☐ April 2018 – First attempt to glue the THGEM to the glass tiles
- ☐ August 2018 – Second gluing attempt

Results with 50x50 cm^2 prototype with μ beam at CERN-SPS
Pad Readout

RPWELL was placed after 3 MM chambers

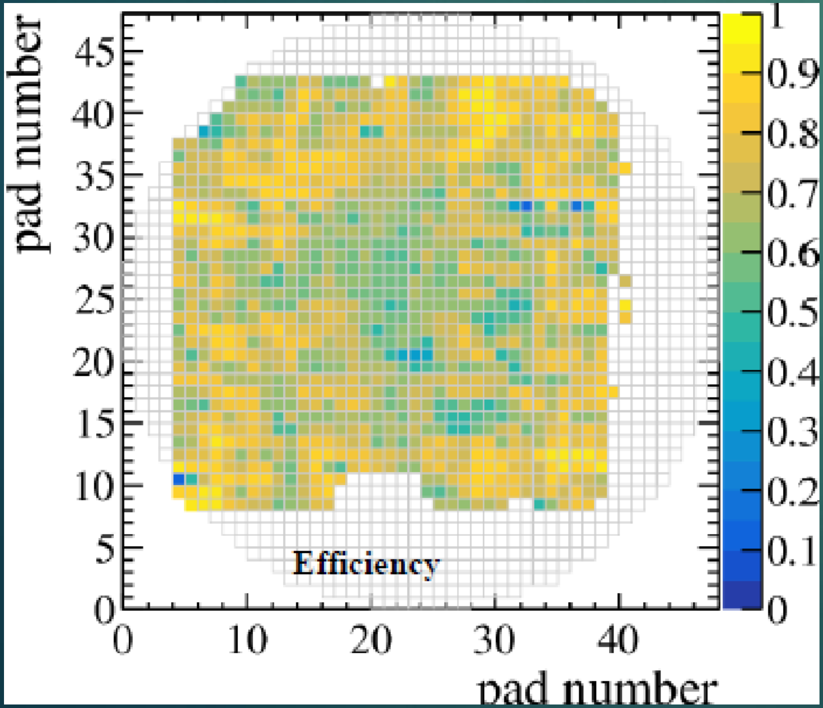
Reconstruction of Muon track from hits in all 3 MM

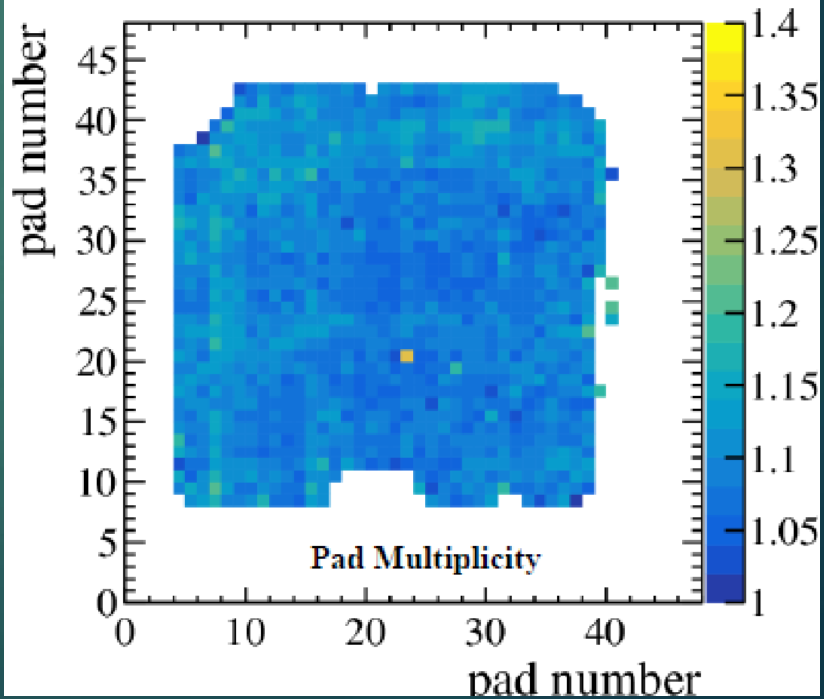
Extrapolation of Muon interaction with RPWELL

Efficient hit – close enough to Muon intersection

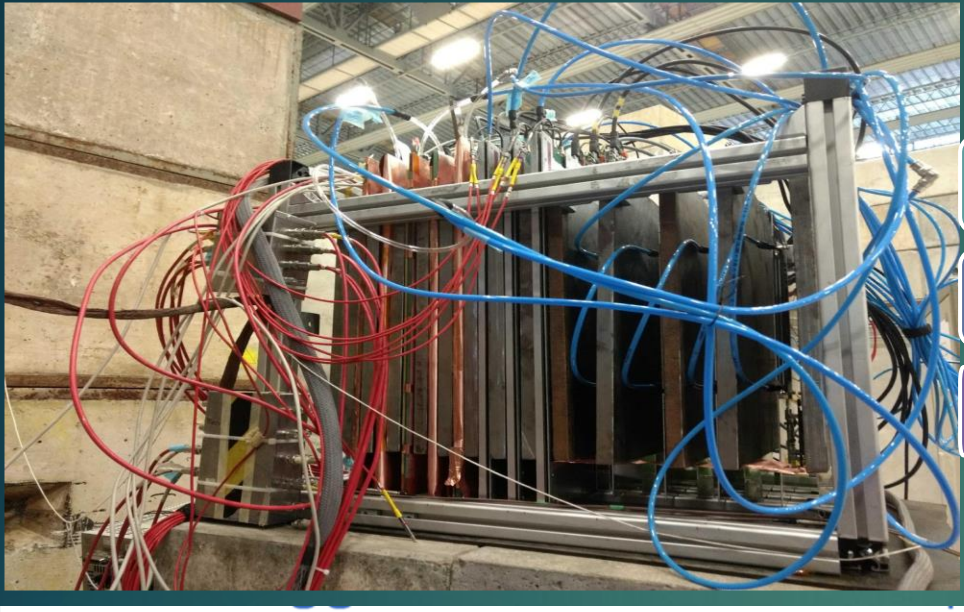
Achievement:

- ✓ Whole detector area is operational
- ✓ ~ 95% efficiency, 1.1 pad multiplicity
- ✓ Stable operation under high irradiation condition
- ✓ Non uniformity: most probably related to 20 – 25% thickness variation in electrode





Small DHCAL Prototype for testing under π beam



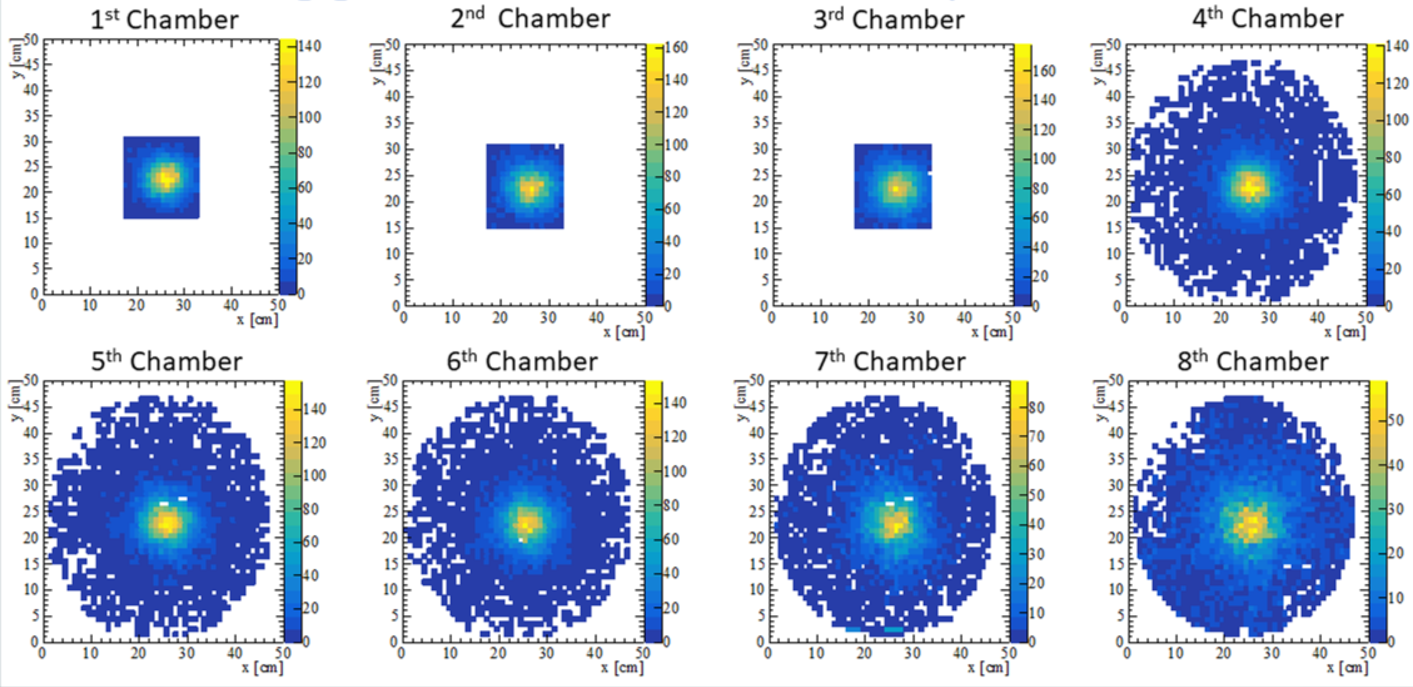
- Setup in CERN-PS in November 2018

Source pion-beam (2-6 GeV/c) – CERN/PS/T10

Single DAQ system – based on MICROROC chip

8 layers

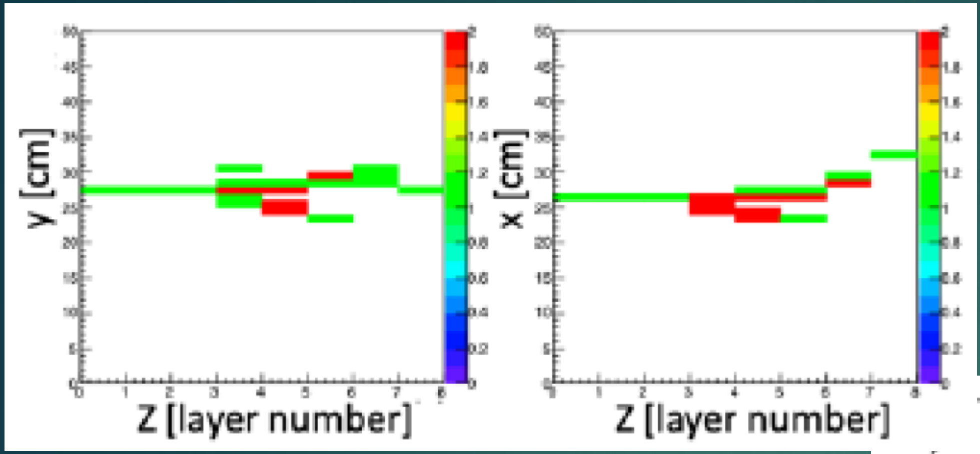
- 2 cm Steel absorbers between layers
- $\lambda_{int} = 20$ cm: 45% chance of shower inside setup



Sampling elements:

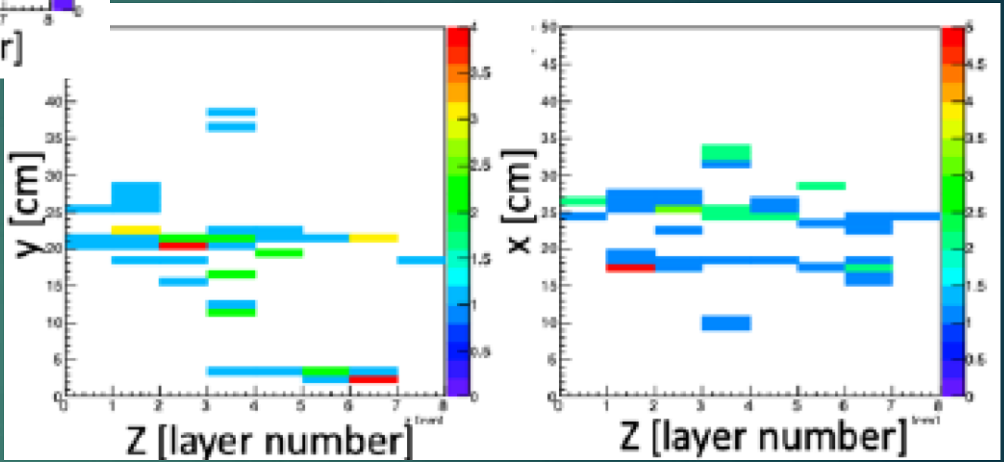
- 2+1 16x16 cm^2 bulk + resistive bulk µM
- 3 48x48 cm^2 resistive bulk µM
- 2 48x48 cm^2 RPWELL

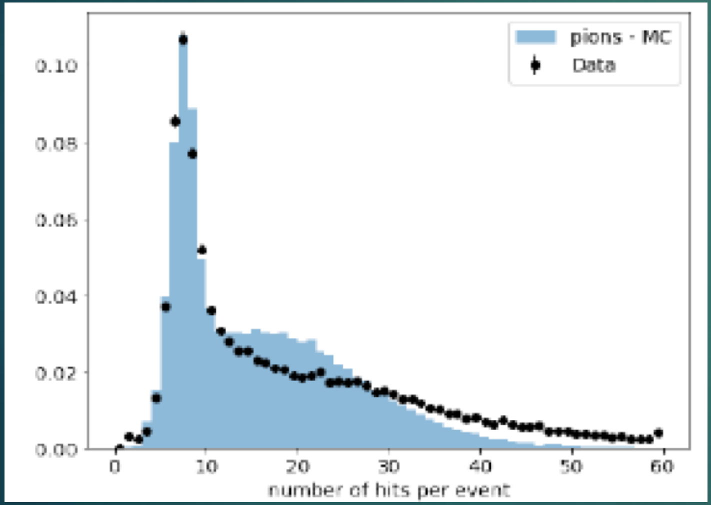
NIM A 958 (2020)
J. Phys. Conf. Ser. 1498 (2020)



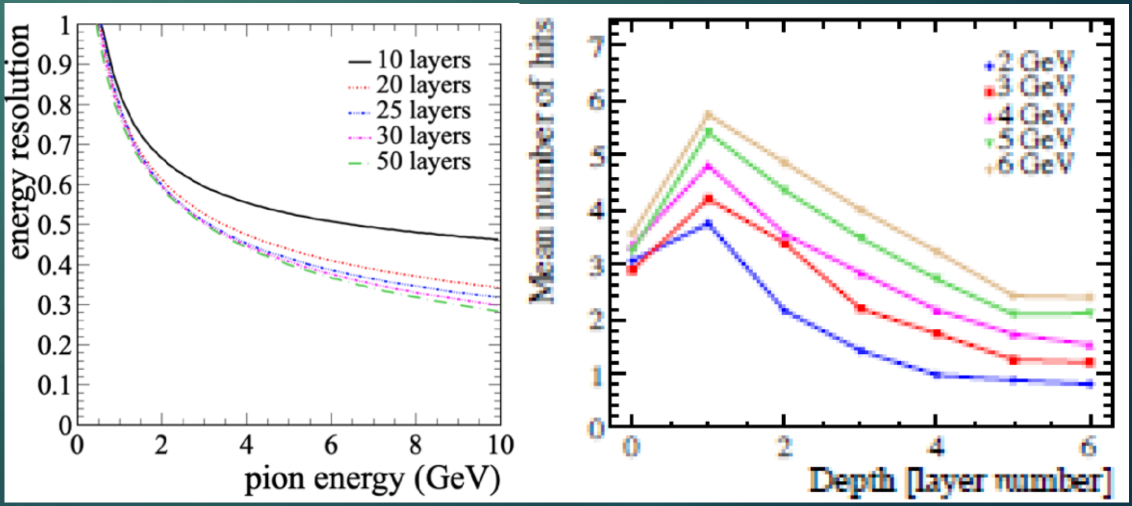
Shower that starts before prototype (Rejected Events)

4 GeV pion shower recorded with protype (Selected Events)





- ✓ Distribution of number of hits per event for 5 GeV pion beam
- ✓ Small depth -> poor shower confinement -> no linear relation

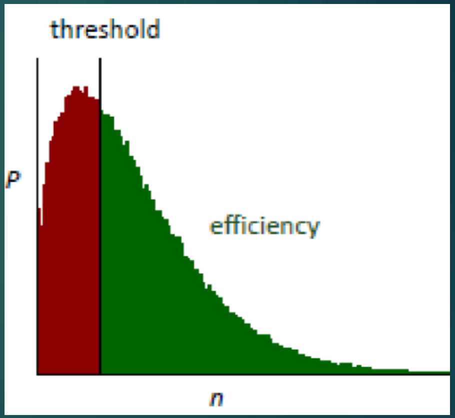


Motivation: Detection of Single Photon

R. Bellazzini et al., NIM A 581 (2007) 246 → GEM
R. Chechik et al., *NIM A 505 (2005) 35 → THGEM*
A. Breskin et al., NIM A 639 (2011) 117 → THGEM
T. Zerguerras et al; *NIM A 608 (2009) 397 → Micromegas*
T. Zerguerras et al; *NIM A 772 (2015) 76 → Micromegas*
S. Dalla Torre et al., NIM A 936 (2019) 416 → Micromegas+ THGEM
S. Dalla Torre et al., J. Phys.: Conf. Ser. 1498 (2020) 012007 → *Micromegas+ THGEM*

- ➢ Avalanche fluctuation: Two probability distributions
  - ❑ Exponential (Furry distribution)
  - ❑ Polya (Generalisation proposed by Byrne) $P(N_e) = \frac{(1+\theta)^{(1+\theta)}}{\Gamma(1+\theta)}\left(\frac{N_e}{\bar{N}_e}\right)^{\theta} exp\left[-(1+\theta)\frac{N_e}{\bar{N}_e}\right]$

Polya parameter θ is related to the relative gain variance $f = \frac{1}{1+\theta}$



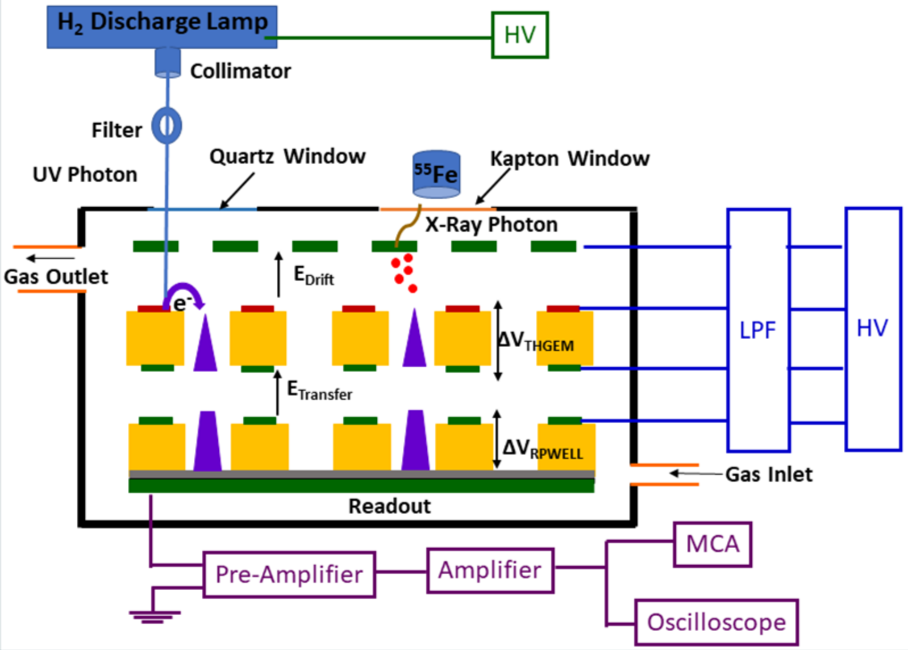
The shape of the avalanche size distribution important for detection performance
– contribution to energy resolution
– detection efficiency

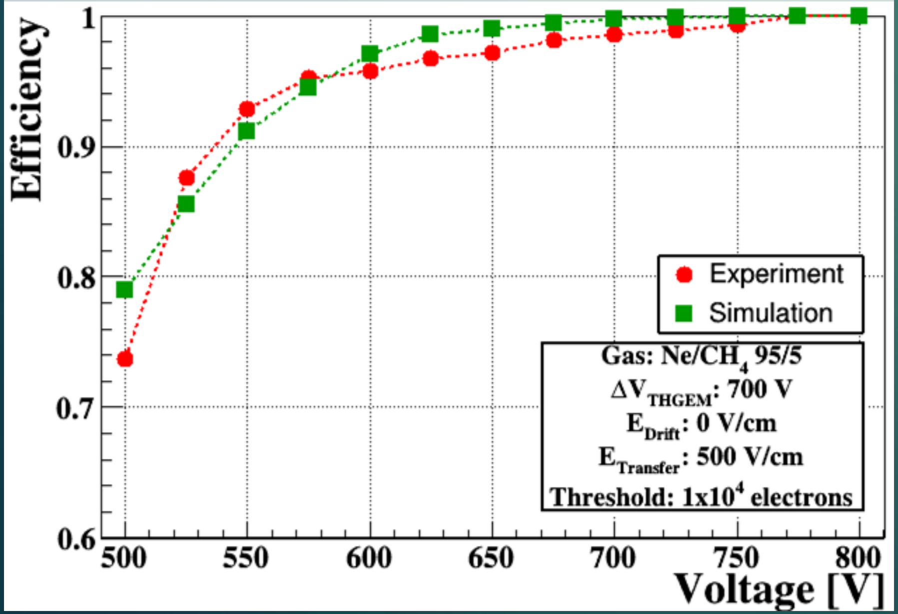
Present study

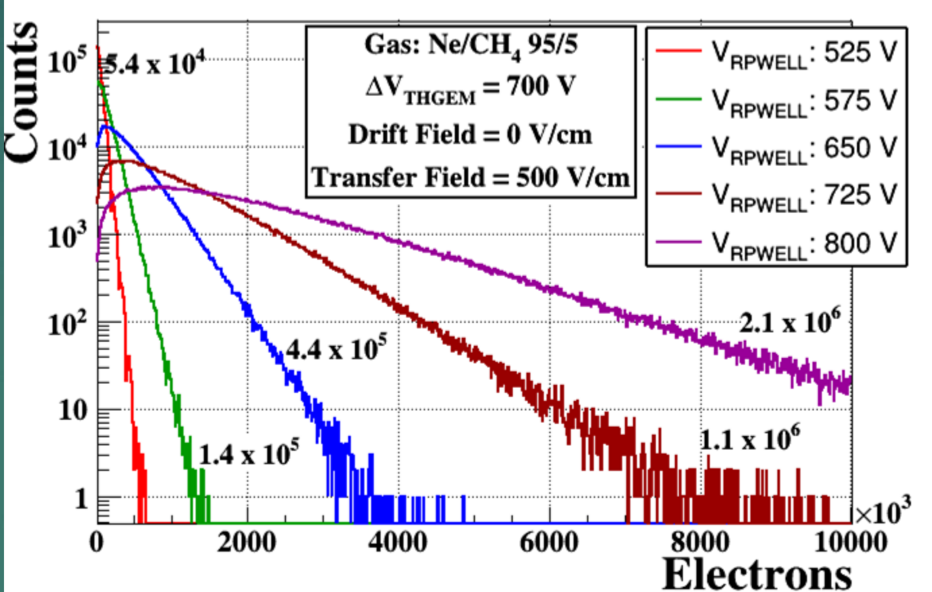
- ❑Investigation of the possibility of detecting **single-UV photons in RPWELL-based** detectors
- ❑Understanding the underlying physics process of Polya distribution → the effect of the inelastic (including excitation) and ionization collision on avalanche size distribution

RPWELL–based 2-stage UV-photon detector using CsI as PhotoCathode

Experimental set up







Single Electron Spectrum Evolution

- Maximal gain for single electron spectra is ~ 2×10^6 under stable operating condition
- X-Rays: maximal gain ~ 4×10^5, θ ~ 0.25, > 91% efficiency with an electron threshold of 10^4 or less (85% efficiency for exponential distribution)

JINST vol 16 (2021) P02018

Particle Detector Group from Weizmann Institute of Science

Application of Gas Detectors in detection of fission fragment (Presently Involved in this Project)

Study of Survival of Nuclear Shell Effect → Key for Super Heavy Elements

A gas detector based on Parallel Plate Avalanche Chamber (PRAC) and Multi Wire Proportional Counter (MWPC) proved to be effective in heavy ion induced fission studies at low energies

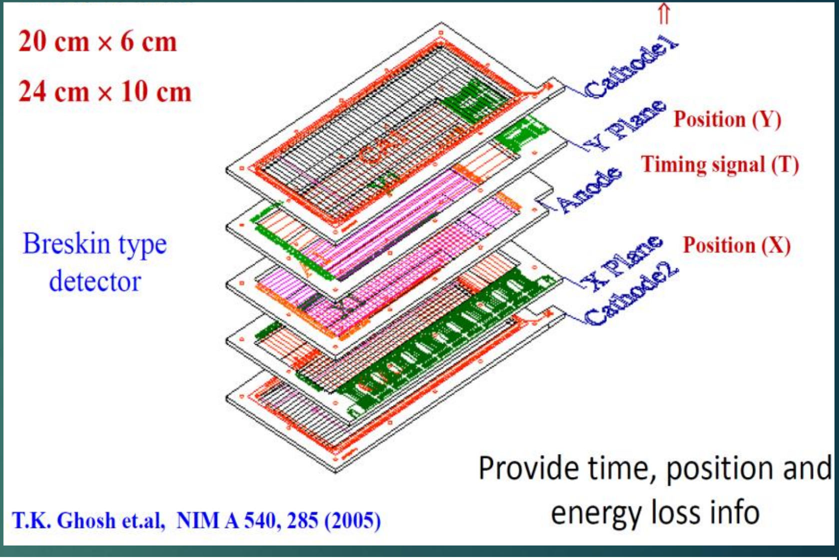
Fragile Anode Wire is not suitable

Replace MWPC by MPGDs

The goal of the proposed research project will be to develop a ***low-pressure gaseous detector for the detection of charged particles and fission fragments***.

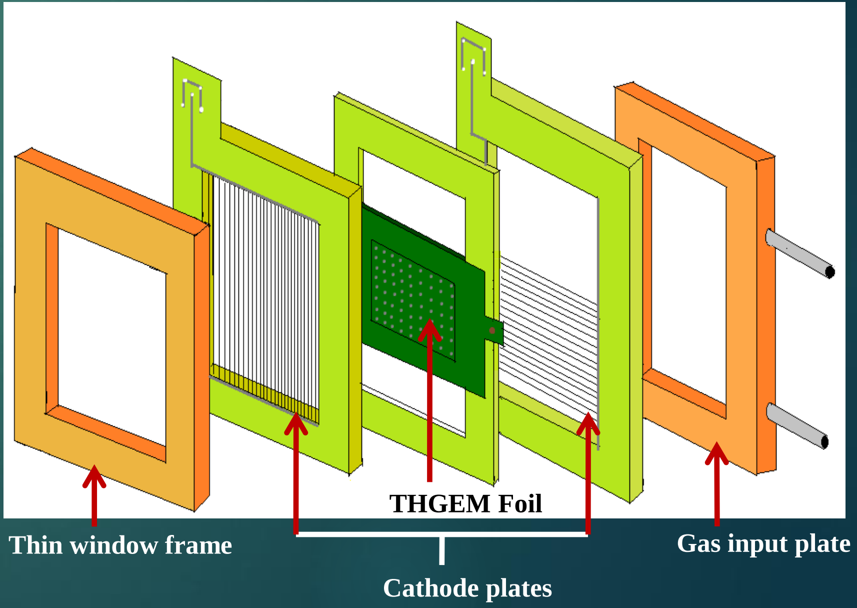
This will be first ever study of fission dynamics using a low-pressure MPGD-based detector which will in turn be helpful to resolve the mystery of shell effect of heavy elements.

Apart from fundamental interest to study the dynamics of heavy ion nuclear reactions, these studies may guide us to find out the right kind of target and projectile combination for the synthesis of super heavy elements.



Provide time, position and energy loss info

T.K. Ghosh et.al, NIM A 540, 285 (2005)



Please attend the talk of Dr. Tilak Ghosh and Mr. Arijit Sen

Summary:

- Develop a large-area, robust, thick detector concept, suitable as sampling element for the future Hadron Calorimeter requiring particle imaging at moderate, sub-mm spatial resolution over a large area.

- Novel Resistive-Plate Well (RPWELL) concept was developed at Weizmann Institute.

- Systematic investigations - both in the laboratory, and with muon and high-rate pion beams at the CERN-Super Proton-Synchrotron (SPS) → RPWELL became a competitive technology, compared to other candidate sampling elements for Digital Hadron Calorimeter (DHCAL).

- RPWELL detector concepts → possible solution for other applications such single photon detection etc.

- The field of gas detector is in constant movement forwards

- R&D effort yield large variety of ideas and solutions

- The community is active and ready to stand up to any future challenge

THANK YOU
For Your Kind Attention