GEM Detector Future prospects and potential uses in Hall A/C

Nilanga Liyanage

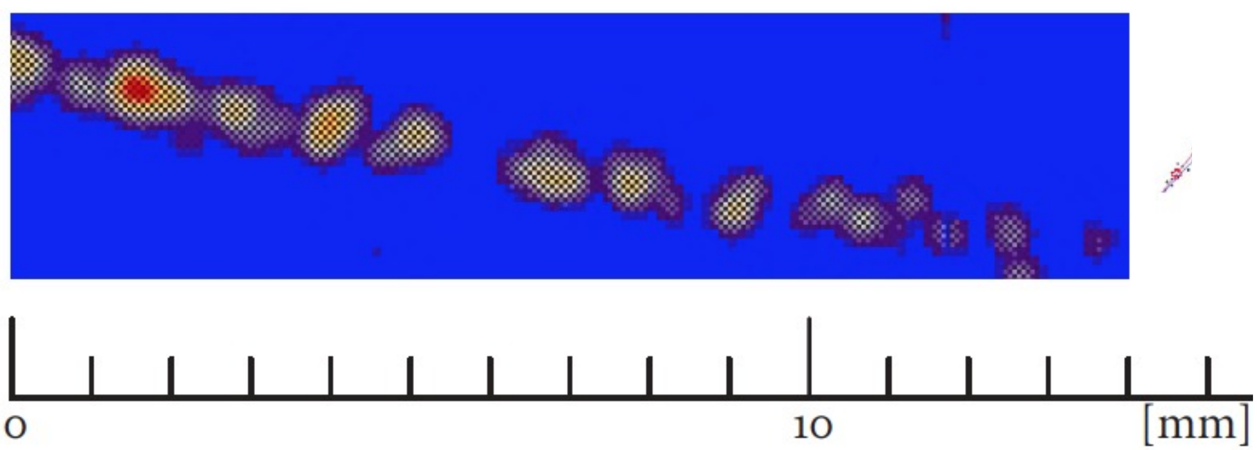
University of Virginia

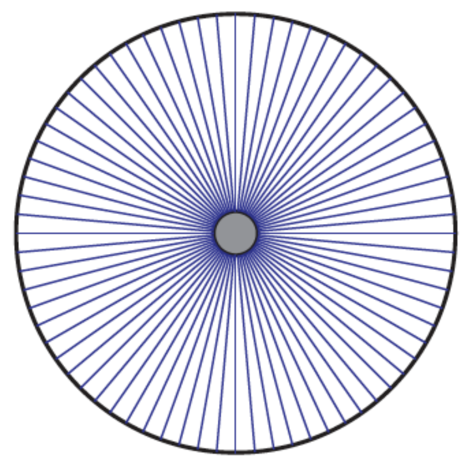
Tracking needs for Hall A/C experiments

- Some of the highest luminosity experiments ever: now and in the future with large acceptance, open spectrometers
  - Rates approaching MHz/cm^2
  - Need to cover large areas.
  - Need to tolerate high radiation doses.
  - require good spatial Resolution: ~0.1 mm
- wire-chamber technology can’t deliver.
- Given the areas involved silicon is not cost effective in most cases
- Micro-Pattern Gas Detectors (MPGD) such as GEMs provide attractive solutions.

Gaseous Detectors

- Predate nuclear physics: invented by Hans Geiger in 1908 (Rutherford, Geiger, Marsden gold foil experiment 1911)
- Essential features:
  - Ionization/drift region: high energy particles creates a trail of electron-ion pairs in an inter gas (reduces recombination)
  - ~ 1-2 Primary ionizations per mm (at 1 atm), energetic electrons created; ionize more nearby atoms: ionization clusters.
  - ~ 27 eV needed per ionization in Argon
  - Electrons drift towards anode (v ~ few cm per μs), ions drift to cathode at speeds thousand times slower.
  - Region of strong electric field (>~ 10 kV/cm/atm): electrons gain sufficient energy between two collisions to cause ionization:
    - Avalanche Multiplication.





Gaseous Detectors

- Avalanche increases exponentially:

$$dN = N\alpha ds.$$

$$\frac{N}{N_0} = \exp \int_a^b \alpha ds.$$

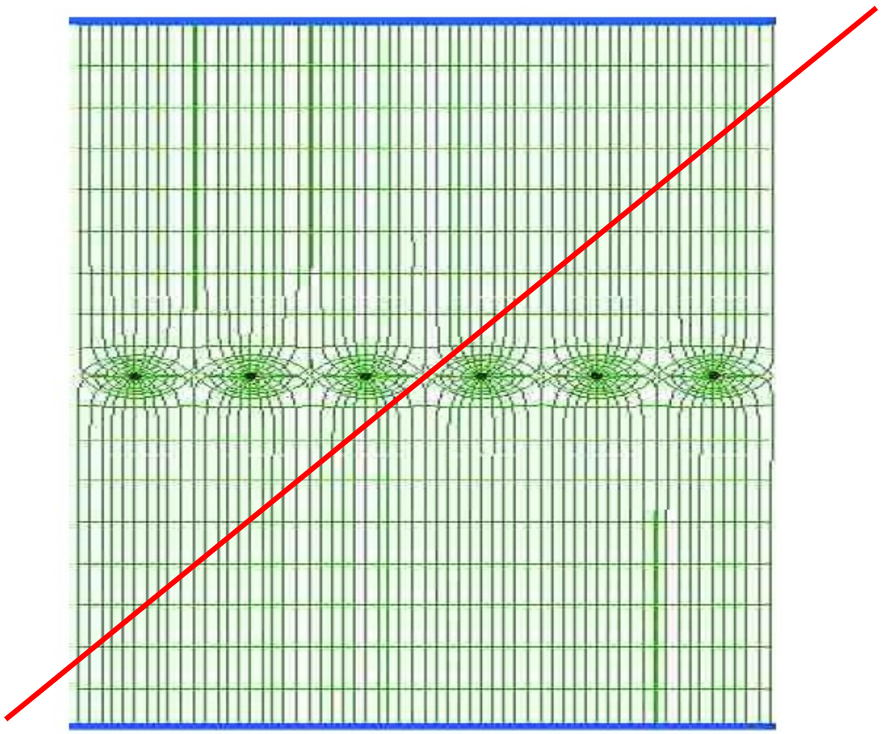
α is the first Townsend coefficient: depends on E, gas composition and density. a and b are the boundaries of the region where E is sufficiently strong.

- Gas gain for a wire chamber could be ~ 10^5-10^6.
- Photons created in avalanche could cause after-pulses away from the primary track: unstable behavior and loss of resolution.
- A quencher, a molecular gas with high photo-absorption coefficient: ex, CO_2, hydrocarbon gases.

4

Gaseous Detectors: wire chambers

- Wire chamber Has been the work-horse of nuclear and particle physics.
  - highly efficient (> 99%)
  - cost effective
  - low mass
  - Rad-hard
  - could cover very large areas
  - good position resolution (~ 100- 200 μm for a MWDC)



5

Issues with wire chambers

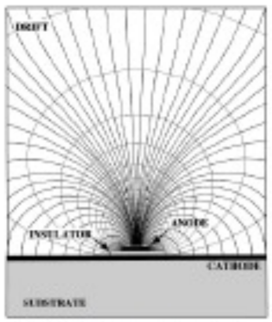
- Slow drift of ions back to the cathode causes space-charge issues that limit the rate ($< \sim 10^5/cm^2$, more commonly $< 10^4/cm^2$).
- High gain around sense wires contribute to high noise, unstable behavior.
- secondary avalanches.
- Ionization clusters limit position resolution
- Plasmas formed during avalanche formation in the strong E field cause aging
- Long electron drifts: susceptible to magnetic field effects.

6

Micro-Pattern Gas Detectors (MPGD)

Solution to MWPC rate limitation: *Fast evacuation of the ions ⇨ Combine Micro structure technology with gas amplification ⇨ Birth of the MPGDs*

Micro Gap Chambers



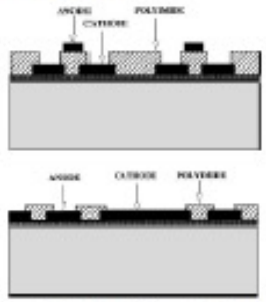


Figure 25 Two variants of small-gap chambers, using thick polyimide ridges to prevent the onset of discharges.

Angelini F, et al. Nucl. Instrum. Methods A335:69 (1993)

Micro Gap Wire Chamber

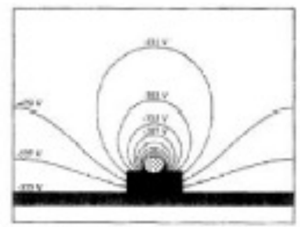
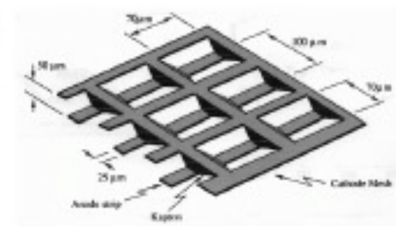


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997].

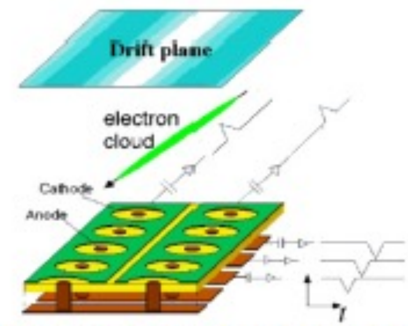
E. Christophel et al, Nucl. Instr. and Meth, vol 398 (1997) 195

Micro Wire Chamber



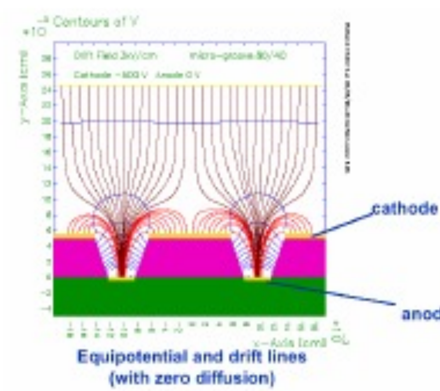
B. Adeva et al., Nucl. Instr. And Meth. A435 (1999) 402

µPIC



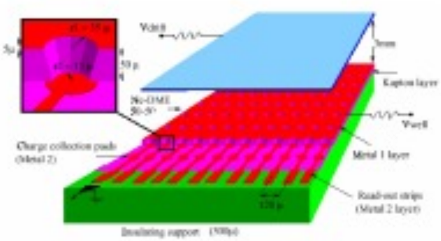
Ochi et al NIMA 471 (2001) 264

MicroGroove



R. Bellazzini et al Nucl. Instr. and Meth. A424(1999)444

MicroWELL



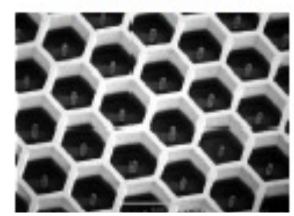
R. Bellazziniet al Nucl. Instr. and Meth. A423(1999)125

MicroDot

Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

Biagi SF, Jones TJ. Nucl. Instrm.

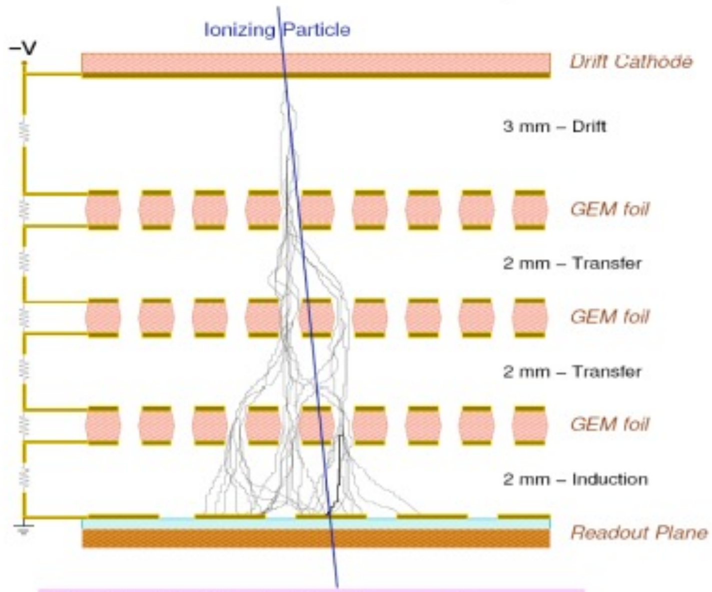
MicroPin



Micro-Pattern Gas Detectors (MPGD)

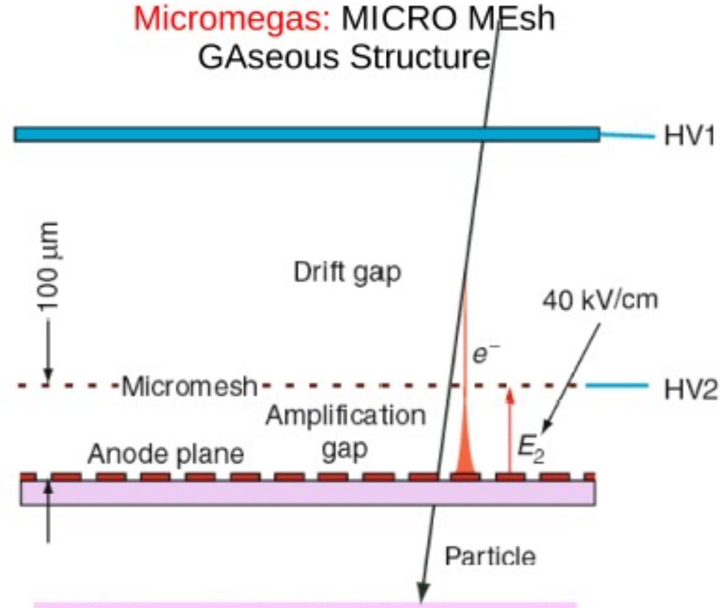
Two MPGD Technologies stood out

GEM: Gas Electron Multipliers



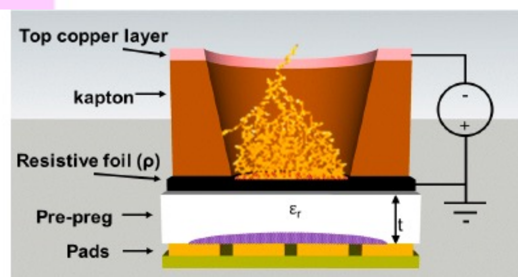
F. Sauli, Nucl. Instr. and Meth. A386(1997)531

Micromegas: MICRO MEsh GAseous Structure



Y. Giomataris, Nucl.Instr. and Meth. A419 (1998) 239

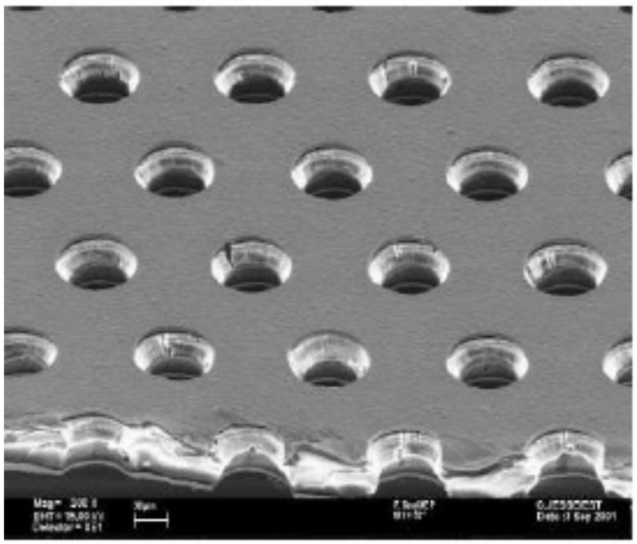
And starting around 2014: μ-Rwell



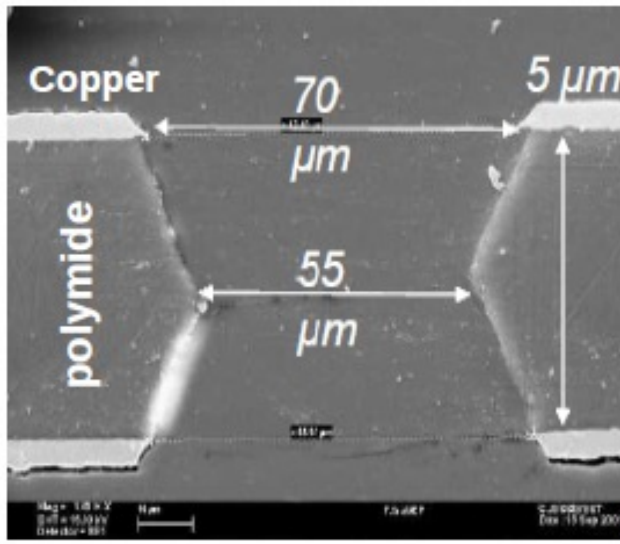
GEM foil: Electron amplification device

- Thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm^2
- Voltage of ~ 350 V across the Cu electrode creates a strong field in the hole leading to amplification
- The ionization pattern is preserved by design with the electric field focusing the charges inside the holes

GEM foil



GEM hole parameters



E Field pattern

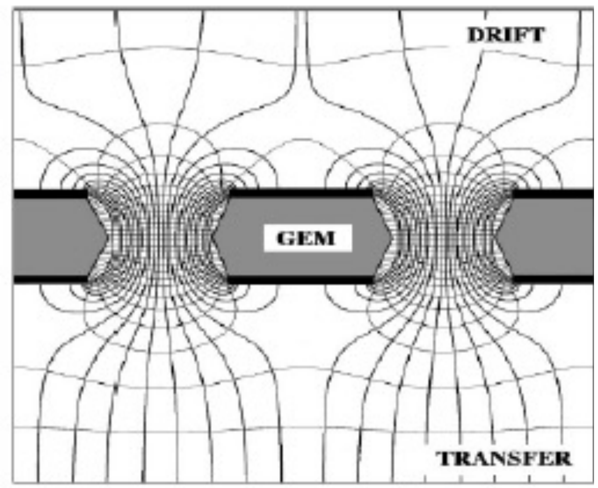


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

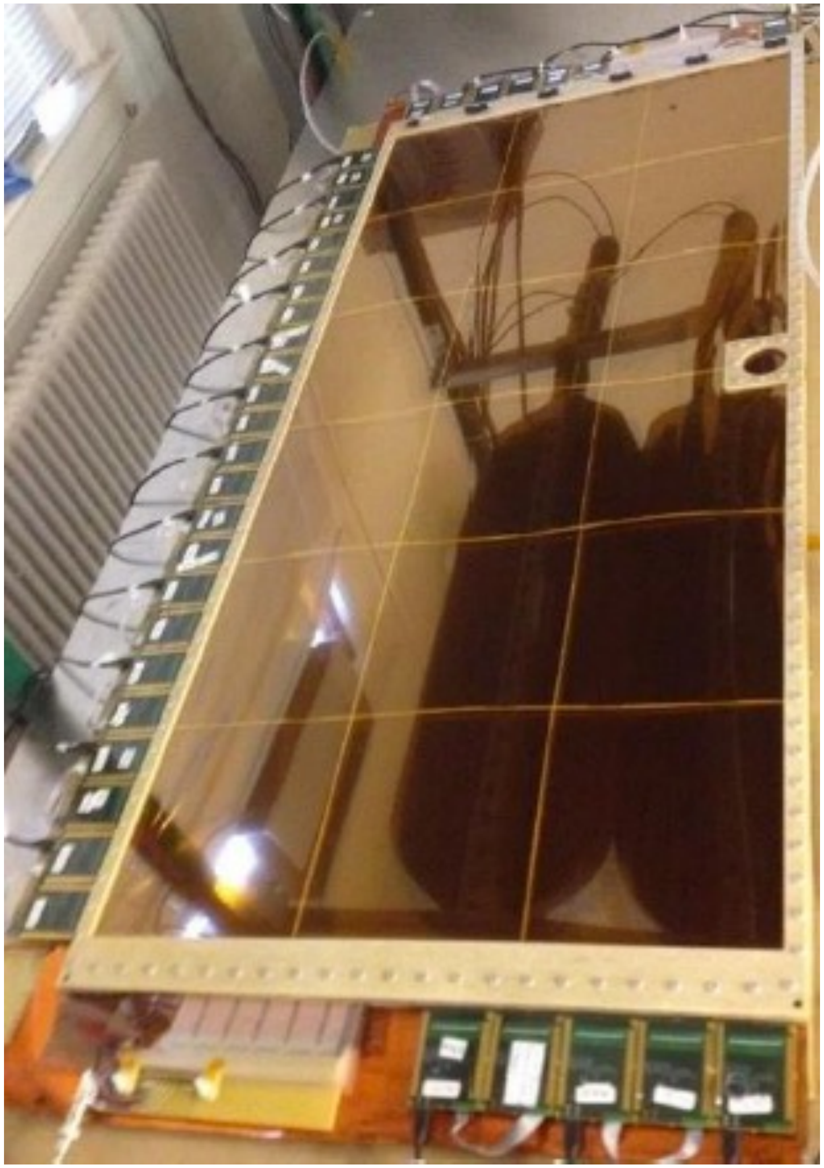
UNIQUE FEATURE

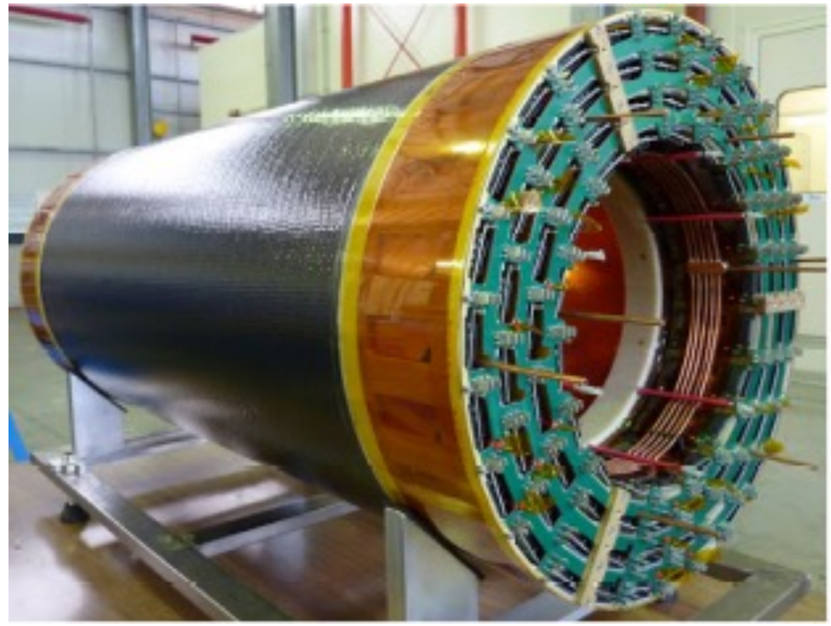
Charge amplification is decoupled from the charge collection ⇨ *Multi-stage amplification*

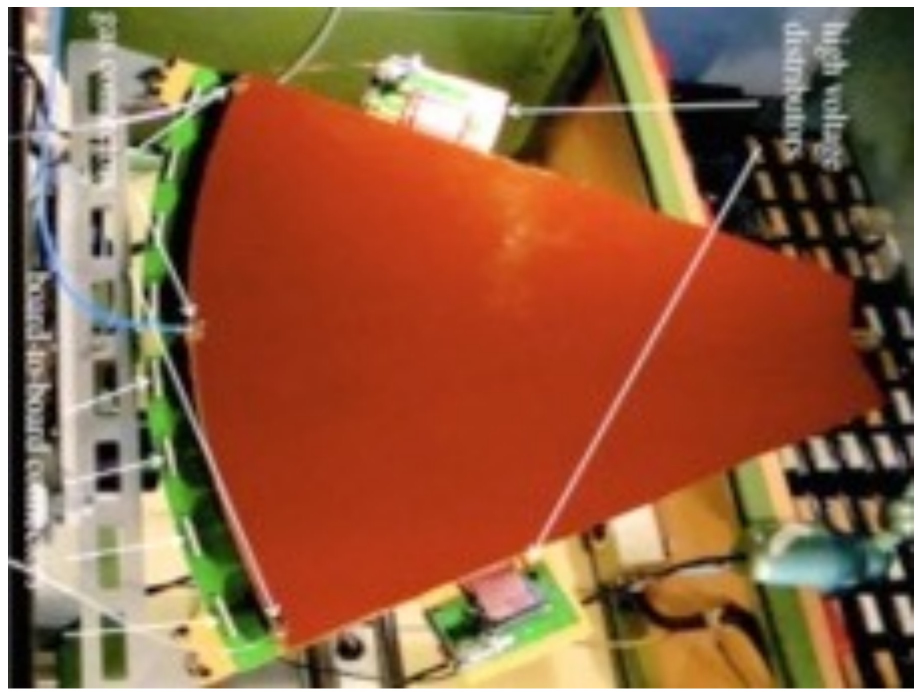
Why GEMs ?

- Gas Electron Multiplier (GEM) detectors provide a cost effective solution for high resolution tracking under high rates over large areas.

- Rate capabilities higher than many 100s of MHz/cm^2
- High position resolution (< 70 mm)
- Ability to cover very large areas (10s – 100s of m^2) at modest cost.
- Low thickness (~ 0.5% radiation length)
- Already Used for many experiments around the world: COMPASS, CMS upgrade, PRad, SBS etc.
- Now come in many sizes and shapes:
- To go to the highest possible rates need a pixel readout.
- With large areas and high resolution needs lead to impossible channel counts
- Strip readouts give good resolution with affordable readout, but lead to very high occupancy and multi-hit ambiguity.
- Large area (~ m^2) strip readout limits to rates to less than ~ 0.5 MHz/cm^2
- Need to come up with creative solutions.

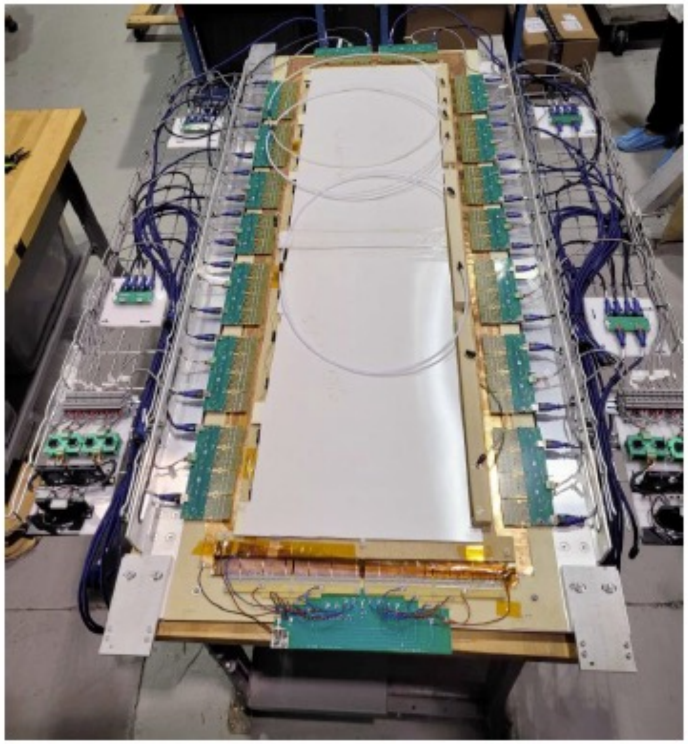





high voltage distribution

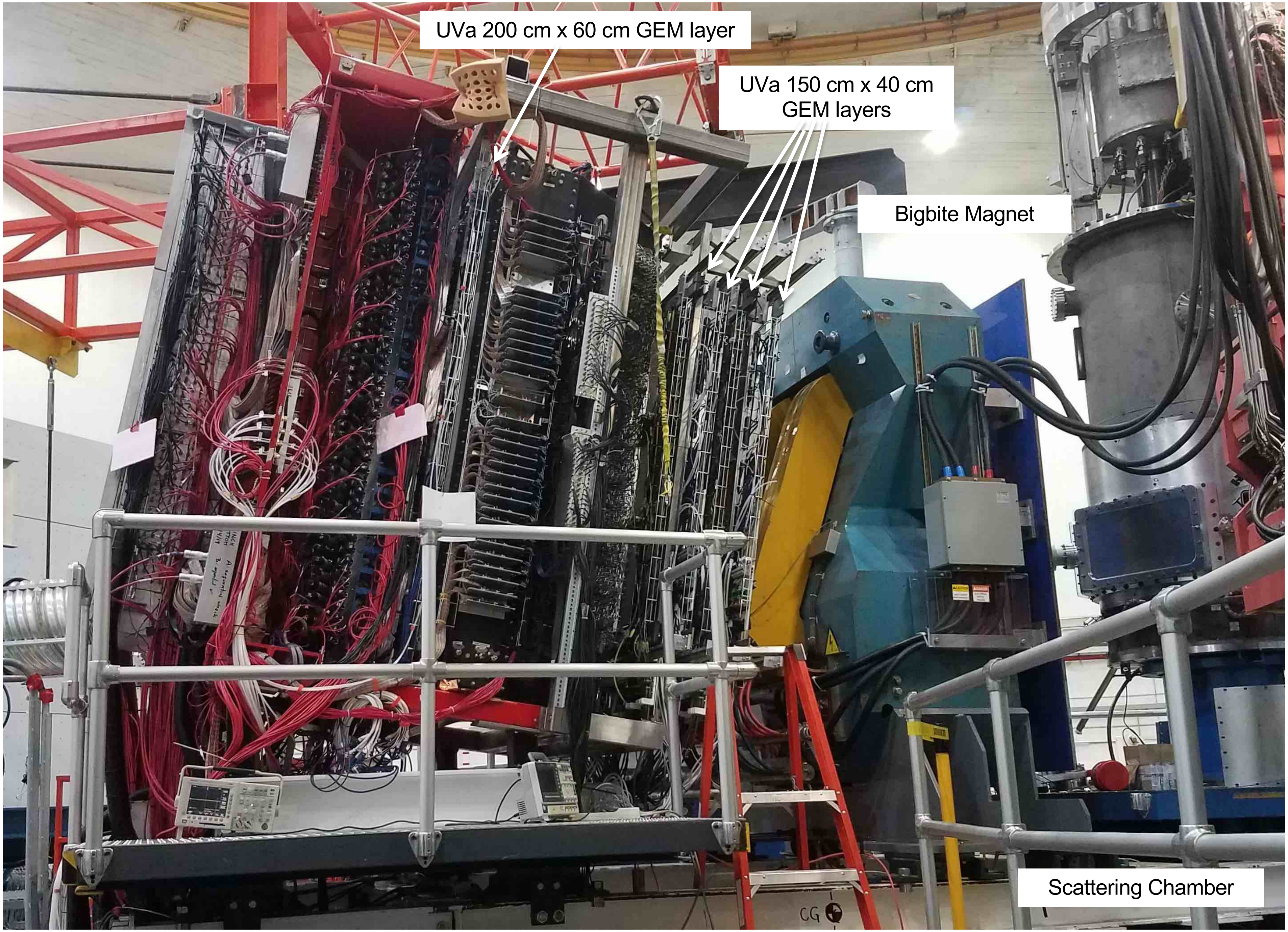
SBS GEM trackers

- 50 cm x 60 cm GEM modules for SBS rear tracker: 48 modules – 36 have been in beam
- 150 cm x 40 cm large GEM modules for SBS front tracker: 6 modules – all in beam

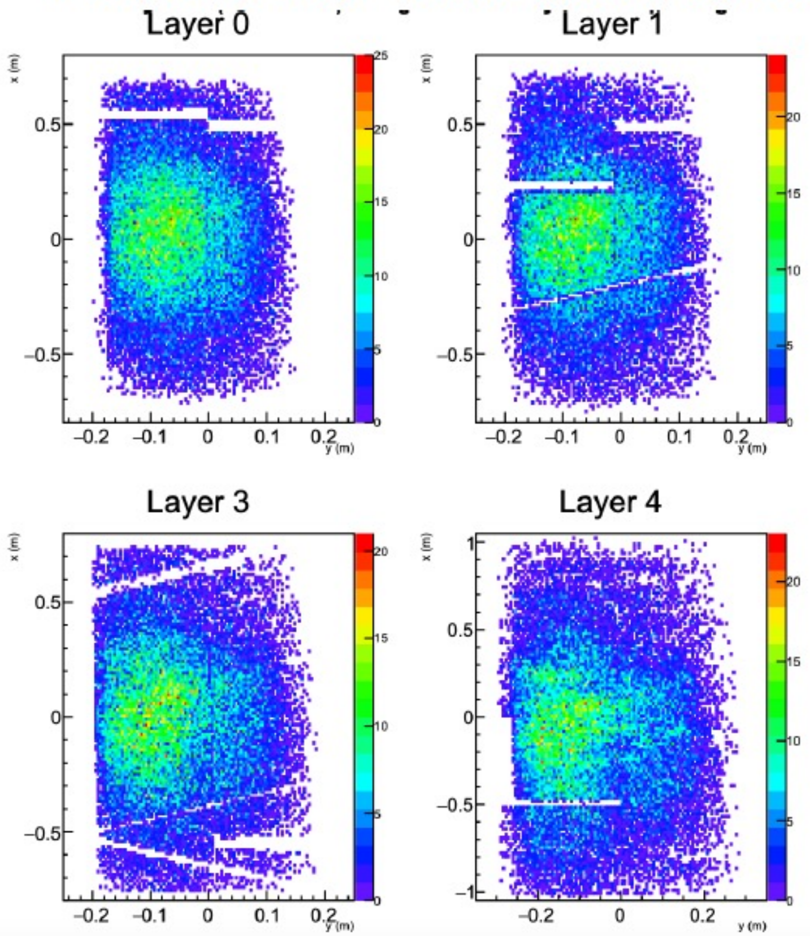


UV (shown)
40 x 150 sq.cm
Single module

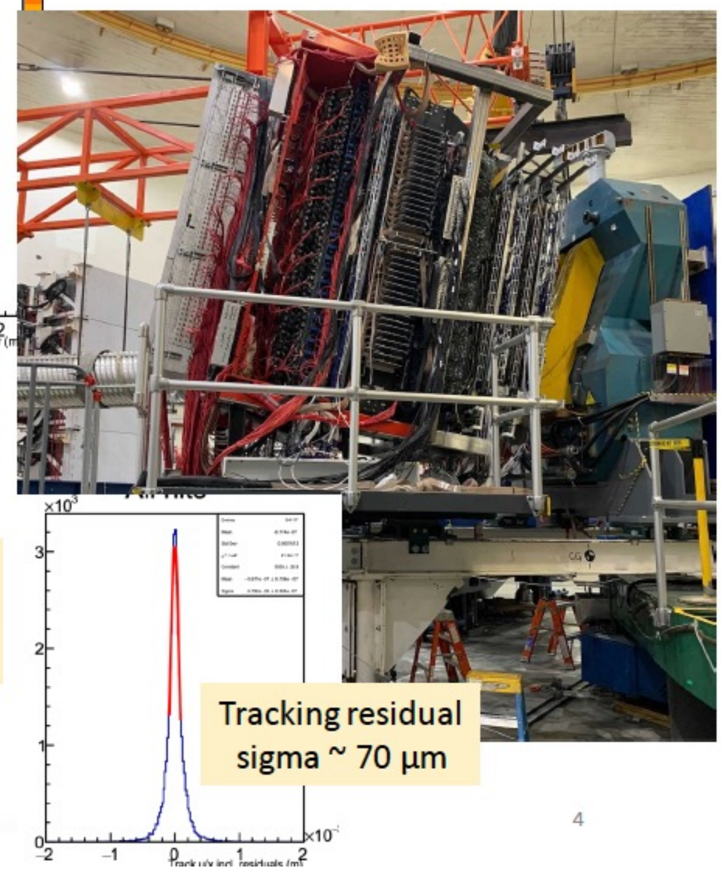
XY (shown)
60 x 200 sq.cm
4 modules


UVa 200 cm x 60 cm GEM layer
UVa 150 cm x 40 cm
GEM layers
Bigbite Magnet
Scattering Chamber

4 UV and 1 XY have been running successfully in BigBite since 2021

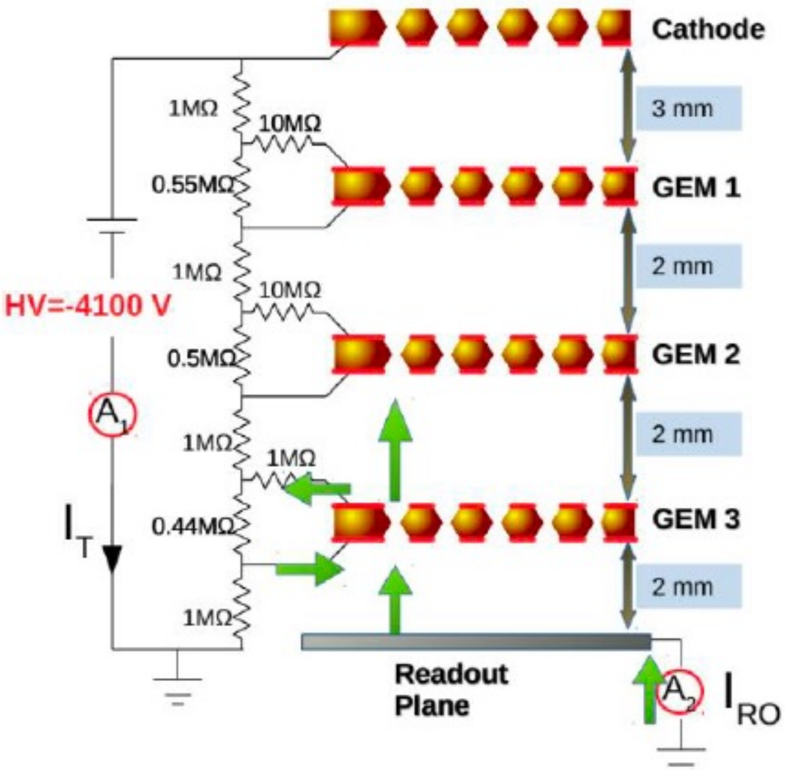


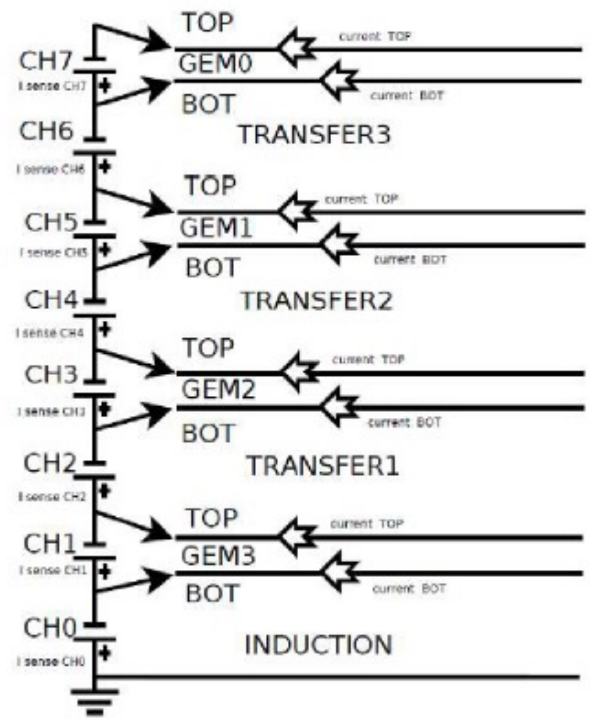
Hit maps with tracking constraints shown per layer



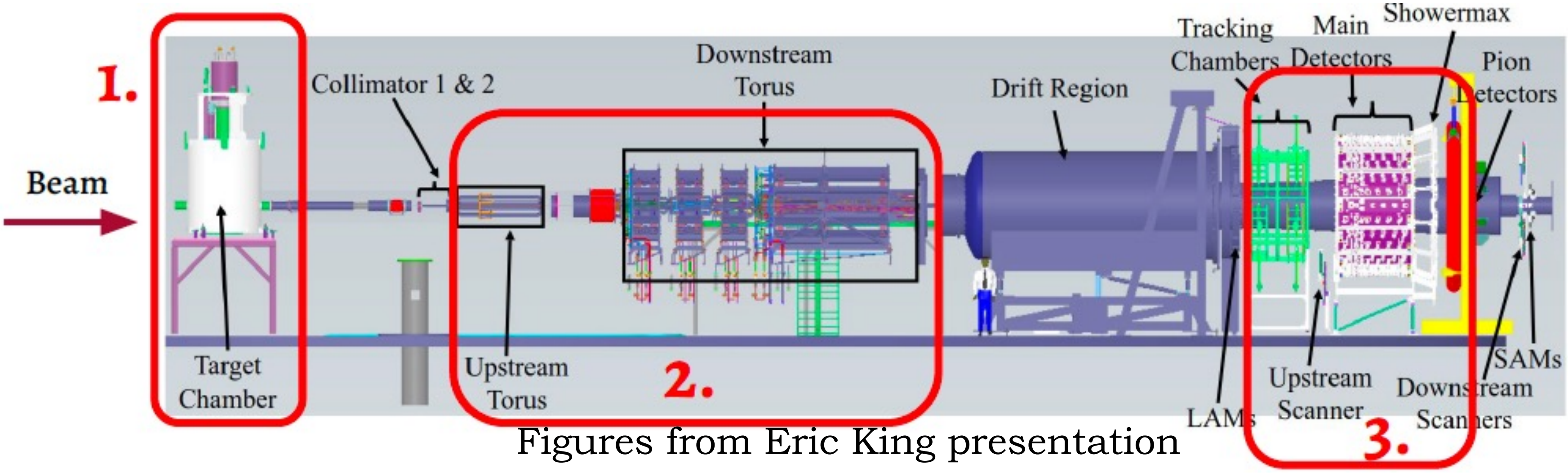
Tracking residual sigma ~ 70 µm

SBS GEM: HV supply issue



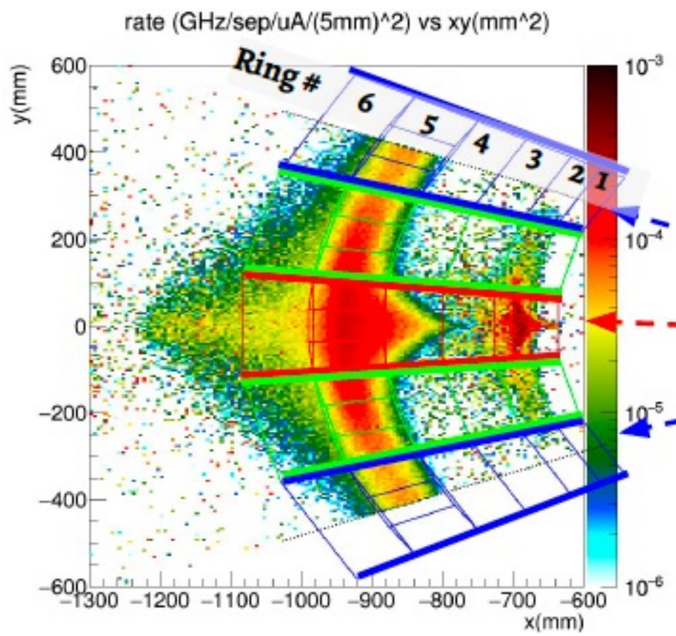


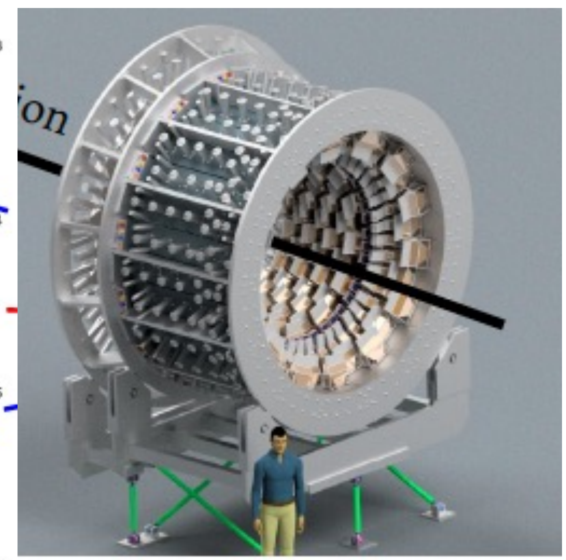
GEMs for MOLLER



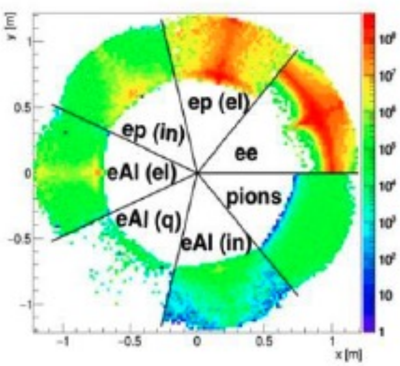
Figures from Eric King presentation

- Precision coordinate detection is needed for calibration of the Setup.
- GEMs: a good choice
- Calibration to be done with ~ 100 nA beam; highest local rates around 100 kHz/cm^2

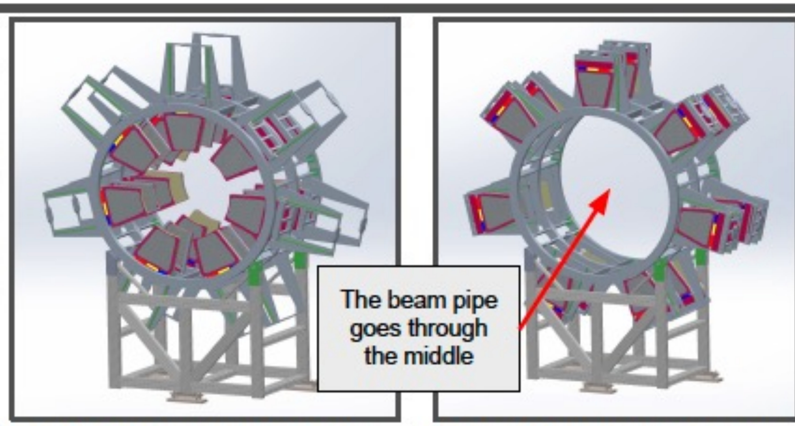




MOLLER GEM design at UVa
Fabrication at UVA and SBU

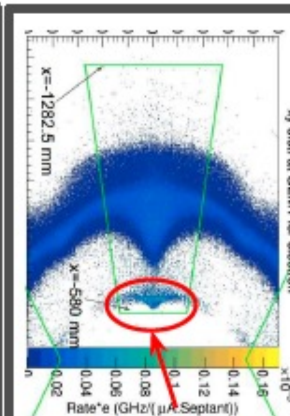


Particles distribution at the Detector Plane



GEM Module Rotator Orientation during Calibration runs

GEM Module Rotator Orientation during Production runs



Events occurring very close to the beam pipe

Geometry of a Single GEM Detector Module

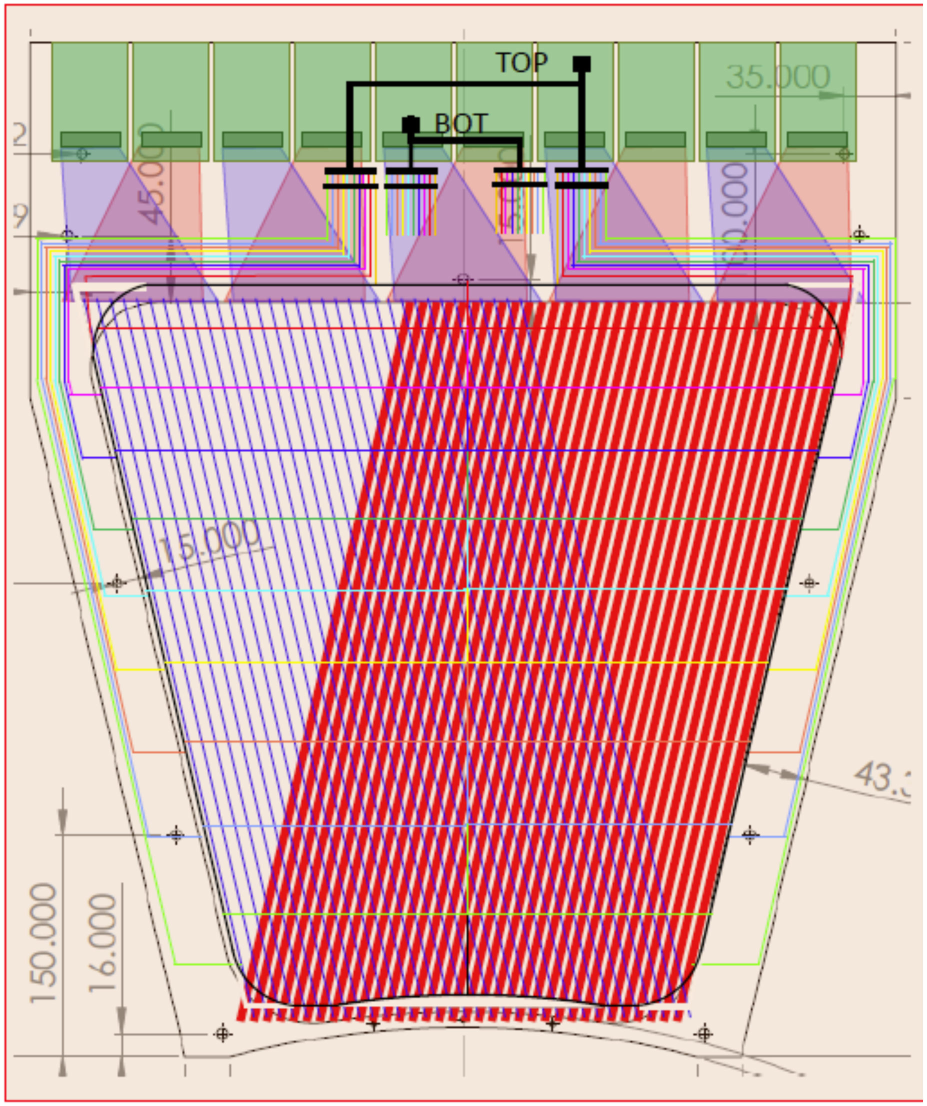
- 4 GEM tracking layers, **7 trapezoidal shaped** detectors at each layer
- Only 50% azimuthal coverage cuts down overall costs
- GEM layers can be rotated around the beam pipe axis
- Pulled out during production runs (as shown above)
- Different geometric requirements for each layer - one single design to match with all 4 layers

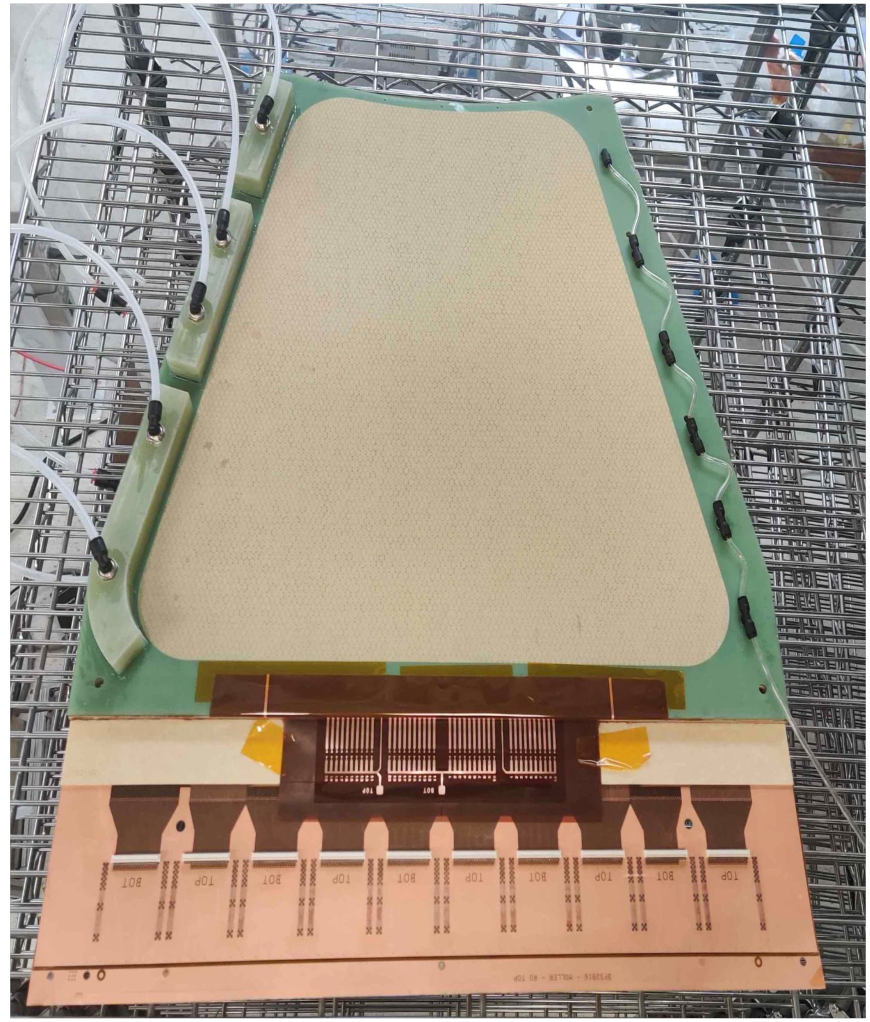
The work at UVa

- **Engineering Design** of GEM tracking detector module
- **Prototyping and Testing** of GEM tracking Modules
- Engineering Design of GEM **Polarimeter**
- **Mass fabrication** of **16** (+2 spares) out of **28** (+4 spares) total tracking detector modules
- **Fabrication** of **2** GEM Polarimeters
- **Commissioning, Operation** and **Data Analysis**

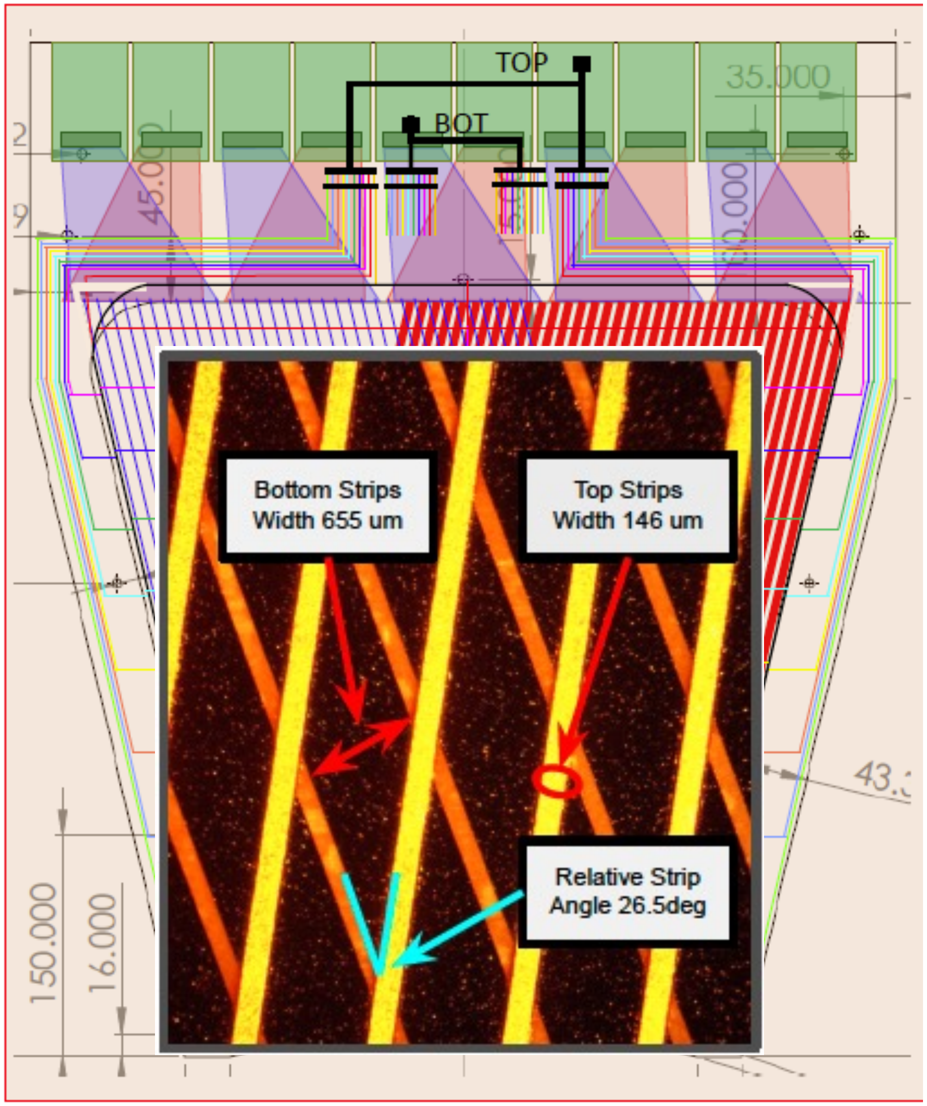
'Rotator' Image courtesy - Chandika Annasiwatt

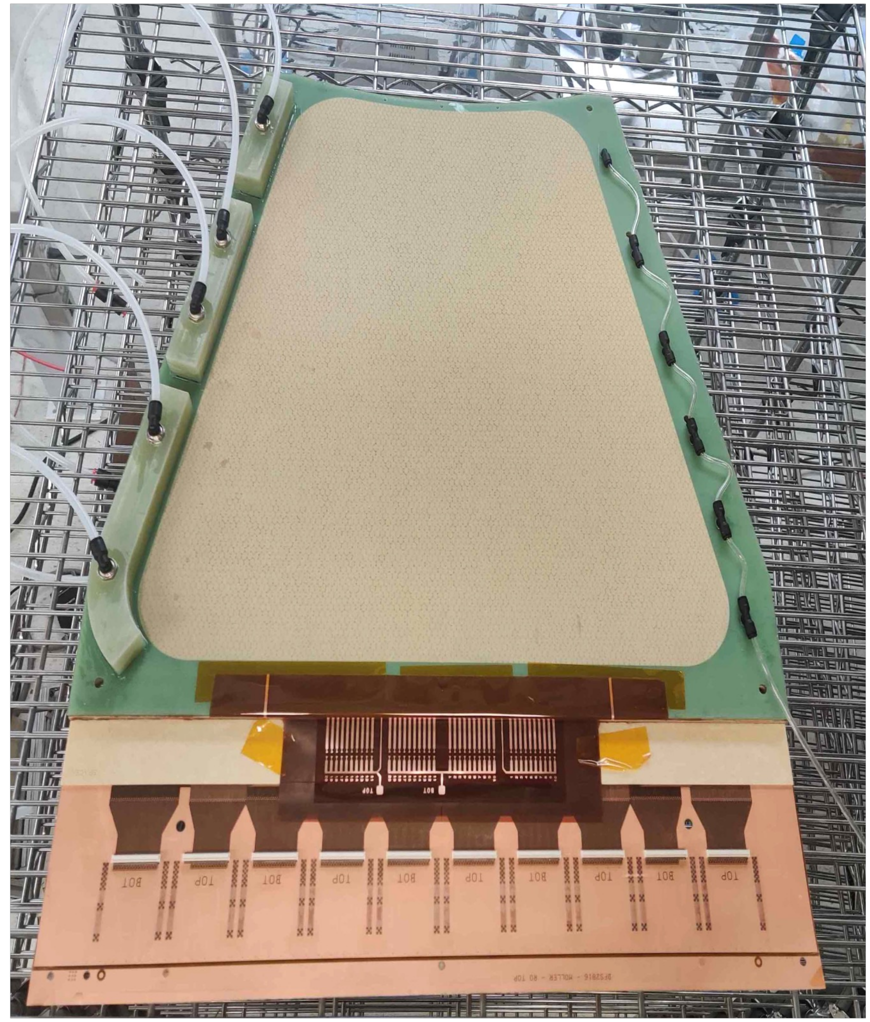
GEMs for MOLLER





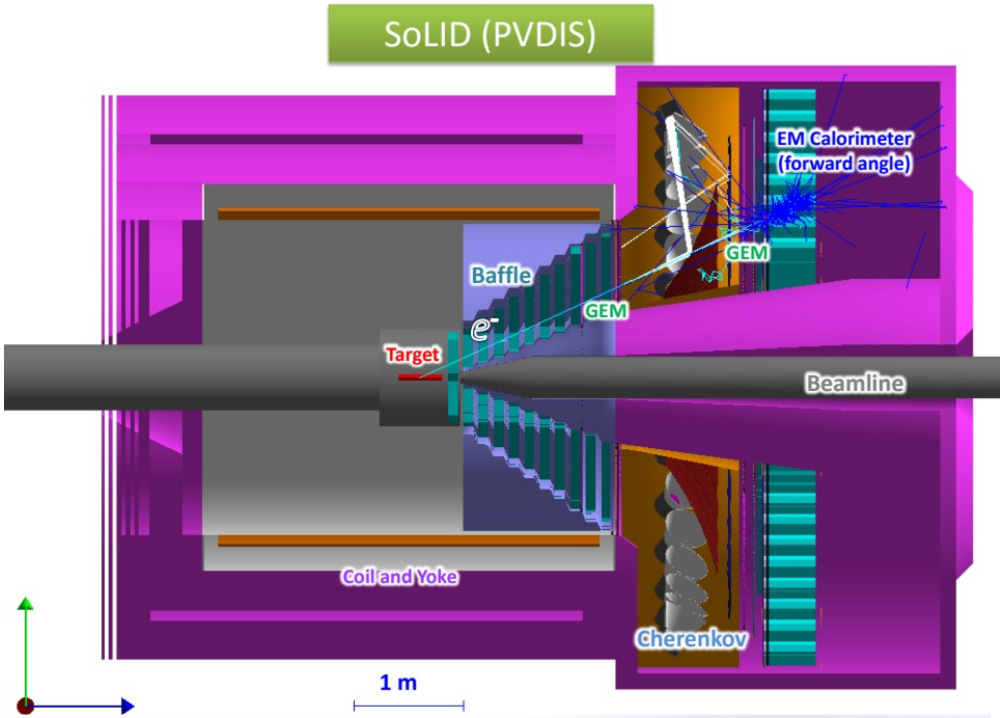
GEMs for MOLLER



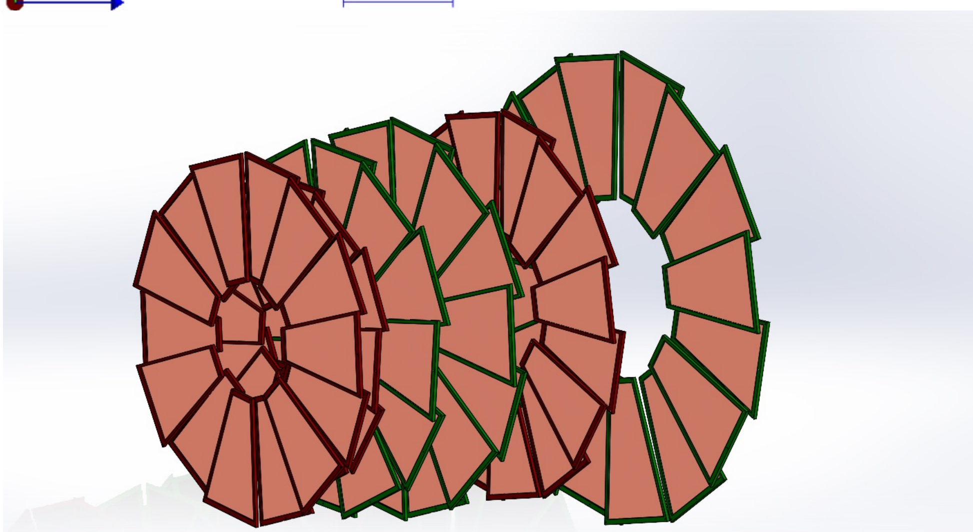


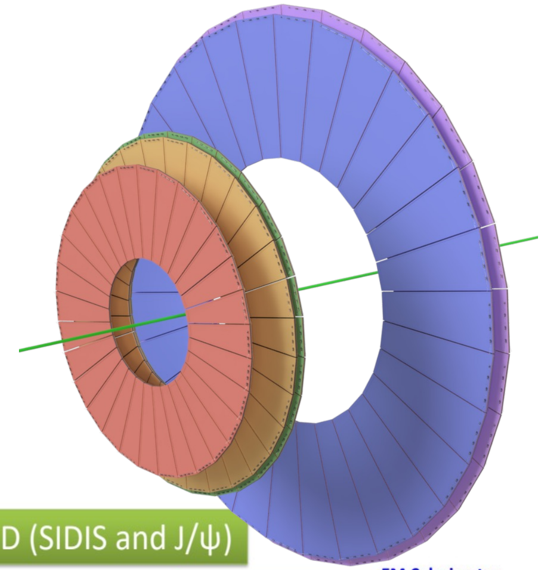
- Both UVA and SBU teams have built and tested the prototype and first production modules.
- Major production run expected starting this September.

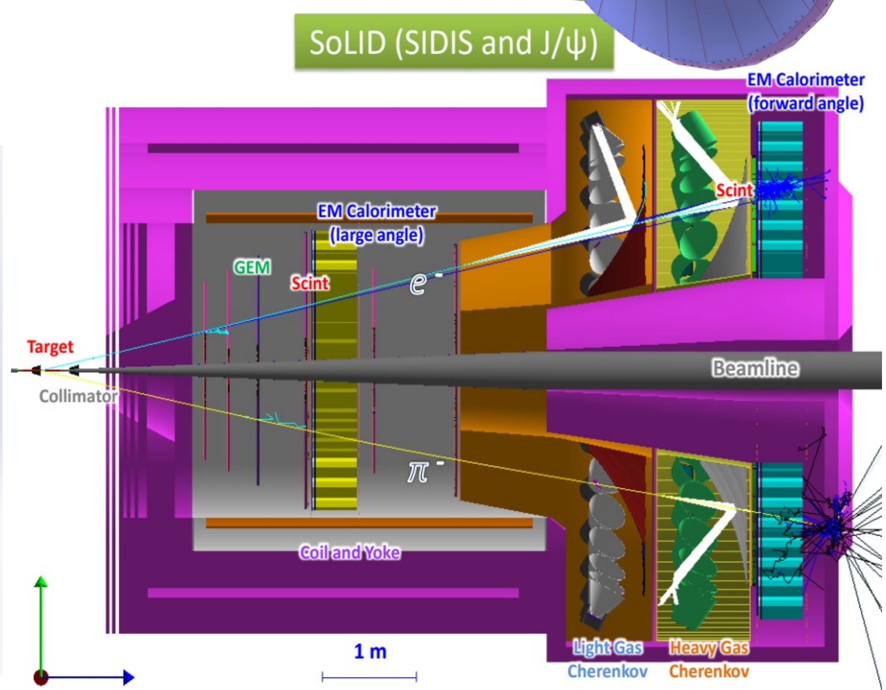
GEMs for SoLID



- U-V readout: similar to MOLLER

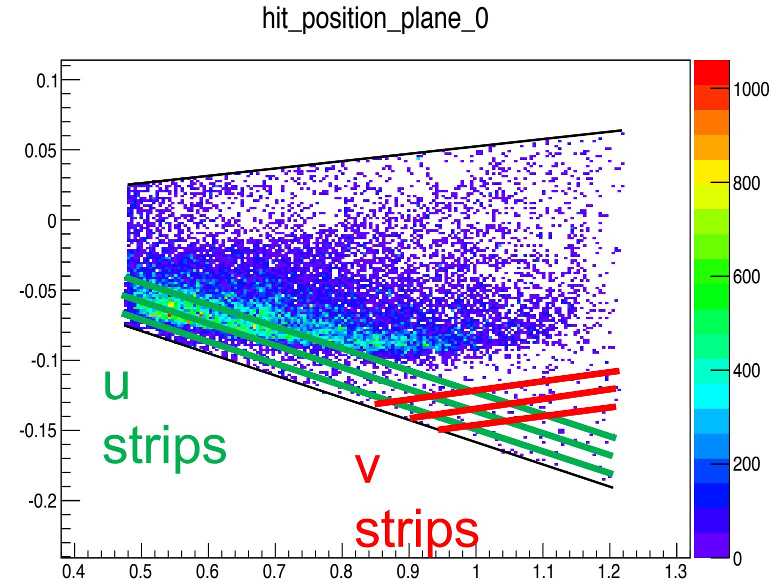






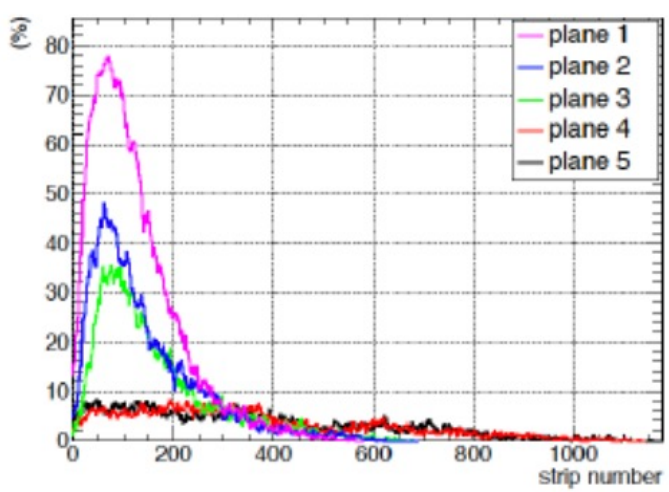
GEMs for SoLID

- SoLID requires a large collection of GEMs: about 40 m^2 in the PVDIS configuration: ~2.5 more than SBS
- High rates: similar to current rates on SBS GEMs.
- New challenge: Very high occupancies locally.
  - Segment the strips in very high occupancy areas
  - Choice of electronics becomes critical

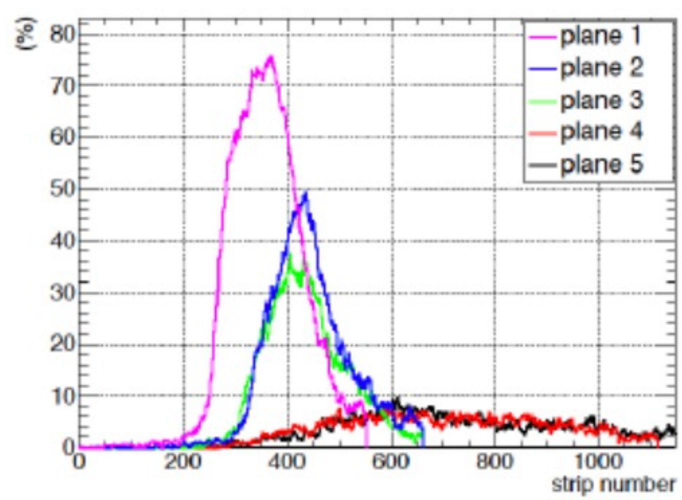


APV25

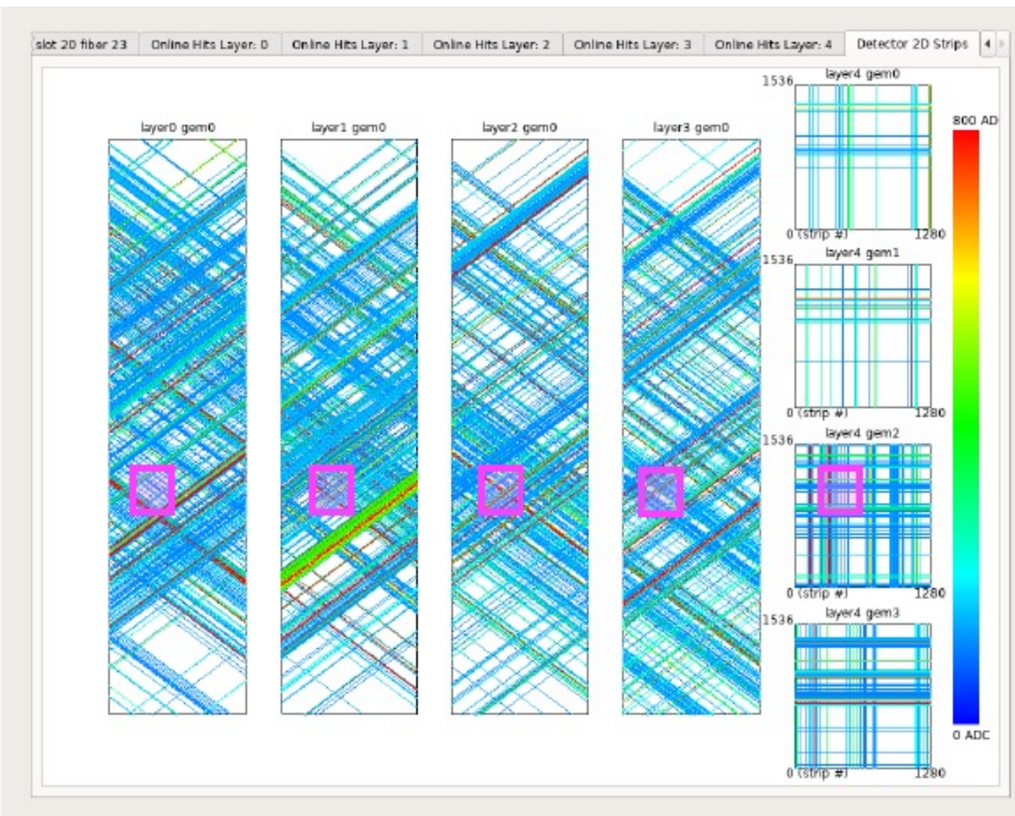
U plane



V plane



- Common challenge for SBS, SoLID and other high rate experiments in the future: tracking with many possible combinations at high occupancies.
- A possible solution: 2 or 3 pixel readout detectors with ~ 1x1 cm^2 pixels in addition to strip layers.
- Catchment area for a 1 cm^2 pixel ~ 6 times smaller than for a 50 cm strip: much lower occupancy
- Requiring .AND. between a pixel layers mostly eliminates random background.
- Clean tracks identified with coarse resolution: strip layers take over for precise tracking.



The 1 cm2 pixel is a good compromise size: the number of pixels ~ number of strips for a SBS or SoLID size large detector.

Exciting new development in MPGE: μ-Rwell (Bencivenni ~ 2014)

Conventional μwell: high probability of electrical breakdown

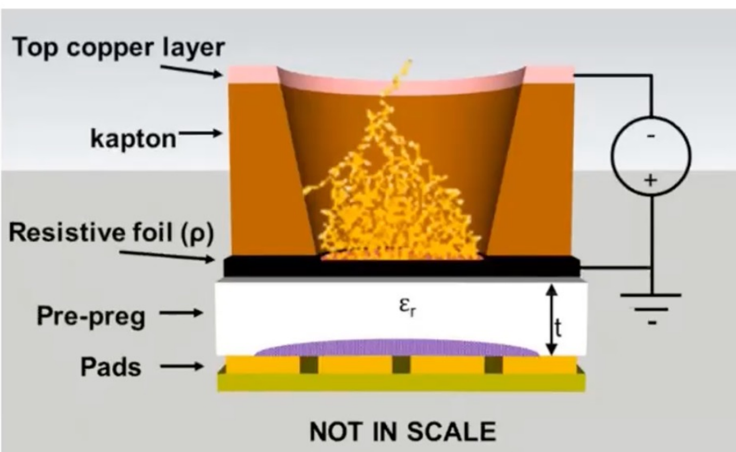
Major step forward by Bencivenni: add a resistive layer: cuts down the breakdown significantly

One limitation for Halls A/C applications: max rate was limited to ~ 100 kHz/cm^2

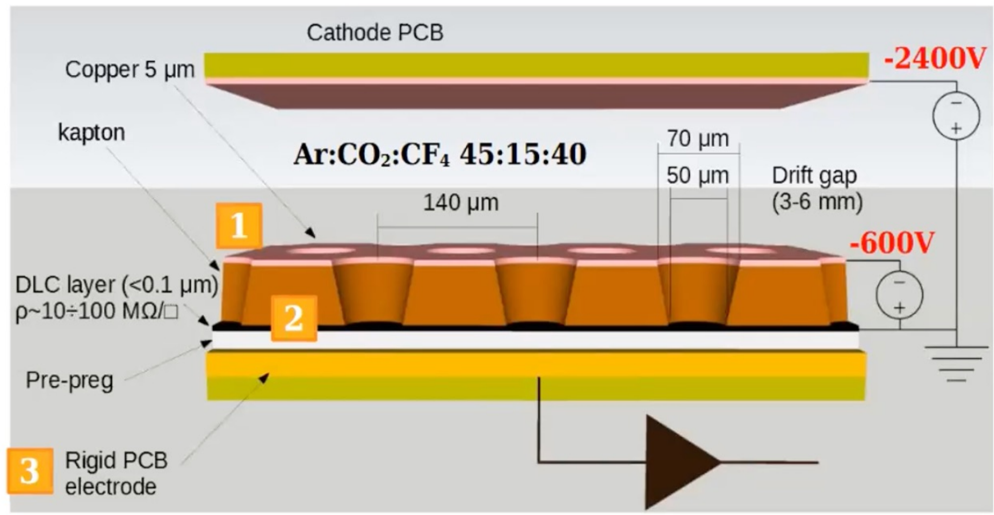
The μ-RWELL – Principle of Operation

Slide from Dr. Bencivenni

The μ-RWELL is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements: the μ-RWELL_PCB and the cathode. **The core is the μ-RWELL_PCB**, realized by coupling three different elements:



Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.



1. **a WELL** patterned kapton foil acting as **amplification stage** (GEM-like)
2. a **resistive DLC layer (Diamond-Like-Carbon)** for discharge suppression with surface resistivity ~ 50÷100 MΩ/□
3. a standard readout PCB

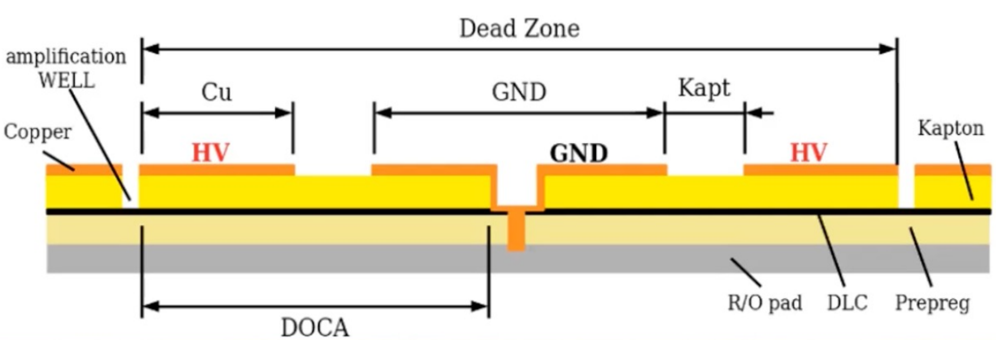
G. Bencivenni et al., 2015 *JINST* **10** P02008

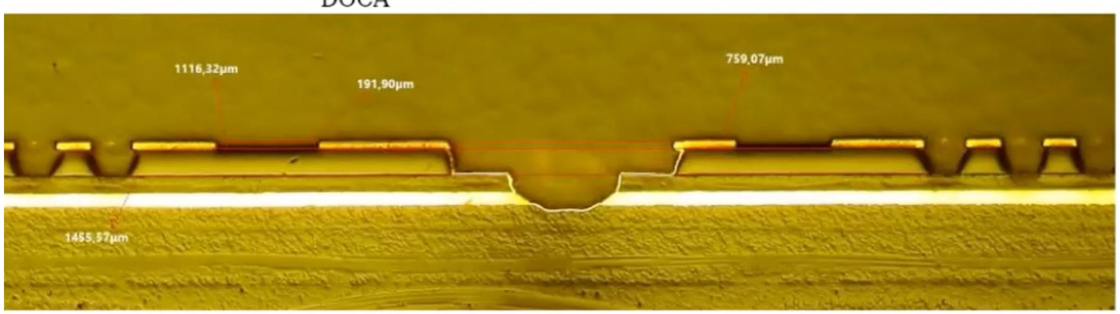
Very recent (2023) New development by Bencivenni group at Frascati in collaboration with Rui De Oliveira at CERN:

PEP-dot μ-Rwell: capable of rates over 10 MHz/cm^2

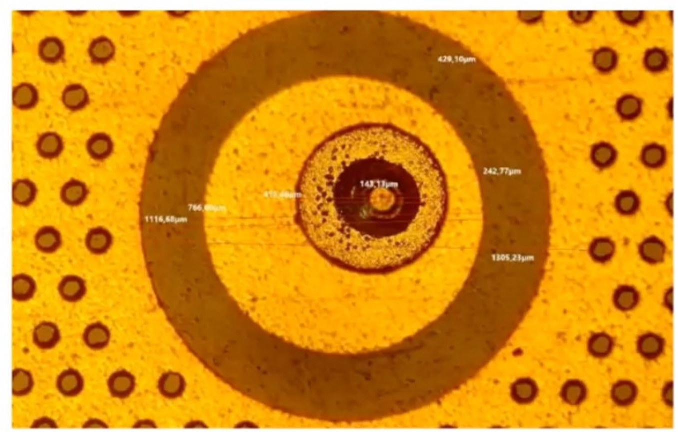
The PEP-dot μ-RWELL

DLC-GND pitch [mm]	Dead Zone [mm]	GND width [mm]	Insulation gap [mm]	DOCA [mm]
9	1.1 (2%)	0.6	0.25	0.7



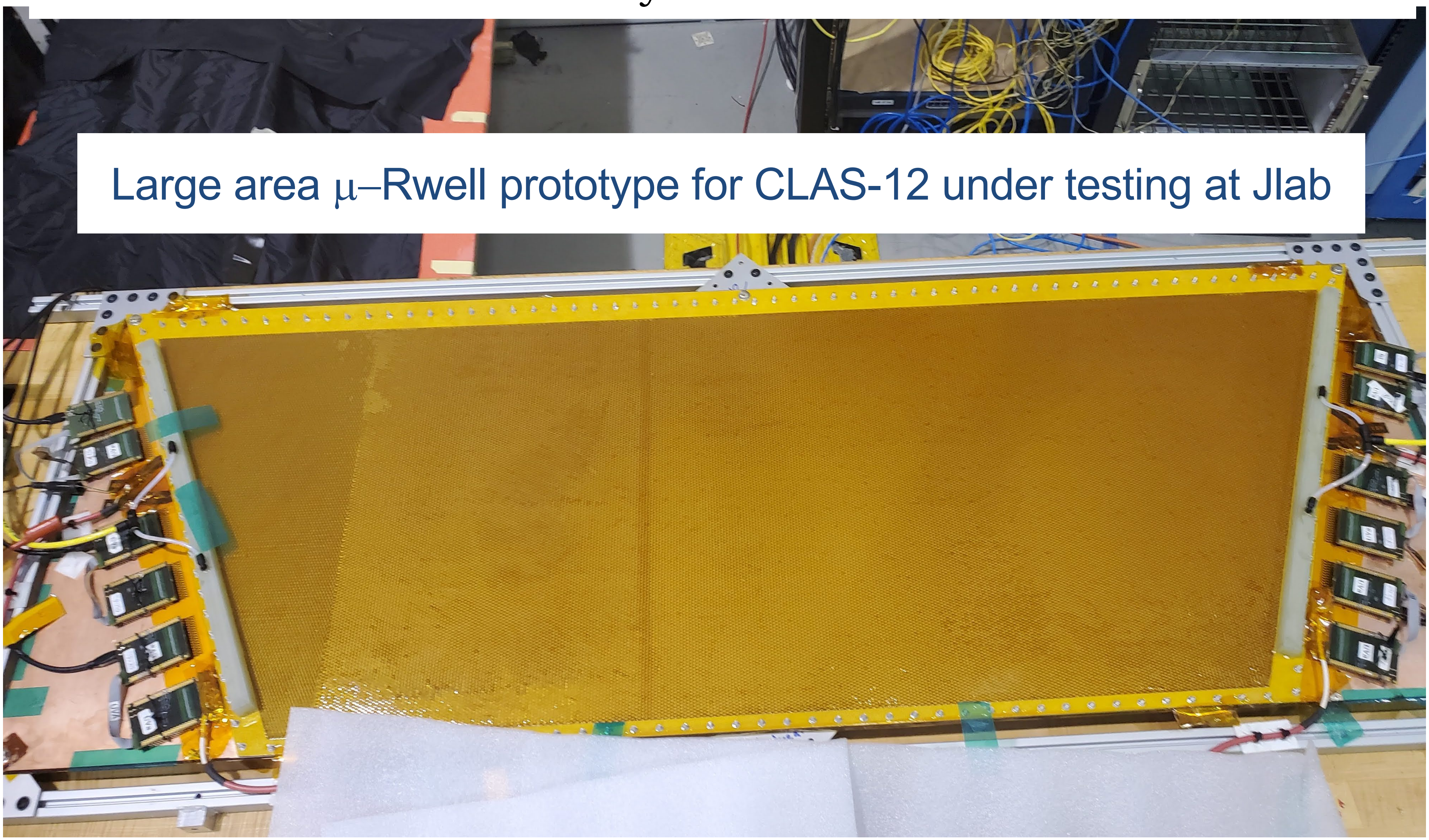


- The most recent high rate layout
  - **P**atterning-**E**tching-**P**lating
- The DLC ground connection is established by creating **metalized vias from the top Cu layer through the DLC**, down to the pad-readout of the PCB
- The dead zone is ~2%



One challenge still remains:

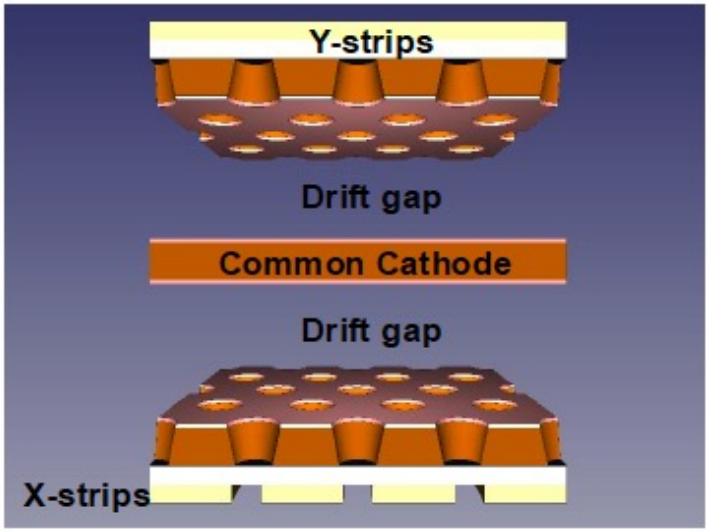
- M-Rwell: single amplification stage: gain ~ 1/5 of a GEM.
- Enough charge for 1D readout: ideal for pixels or 1D strips
- But not enough for 2D strip readout:
  - leads to low efficiency.



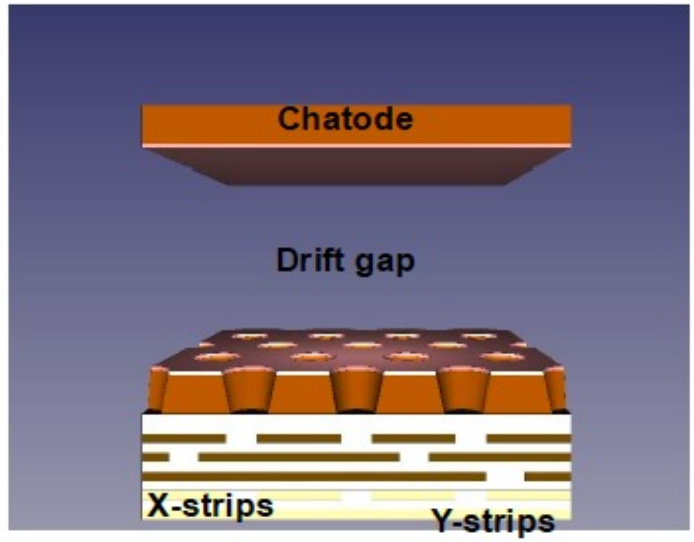
Large area μ–Rwell prototype for CLAS-12 under testing at Jlab

Getting to m-Rwell with 2D readout

N.2 u-RWELLs 1D (2⊗1D)

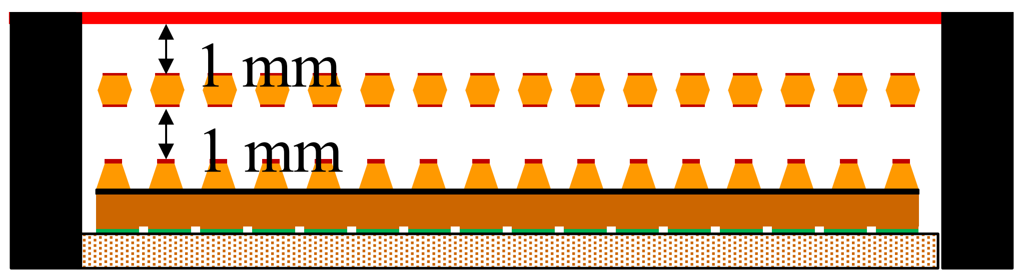


u-RWELL - Capacitive Sharing r/out



Or Boosting the gain by adding a GEM pre-amplification layer:

(from K. Gnanvo)



Summary

- SBS run demonstrates that high rate GEM tracking over large areas is feasible.
- High rate μ-Rwell offers exciting possibilities.
- Need continued work in readout electronics to match the high rate demands
- New MPGD center at Jlab: exciting R&D. Looking forward to a bright MPGD future at Jlab.