A high performance tracker in the forward angle experiments

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Outline

- High rate tracking needs for forward angle experiments.
- Tracking at very high rates: Pixel Sensors – HV - MAPS
- MPGD technology for high rate tracking.
- GEM detectors for forward angle experiments.
- Future possibilities.

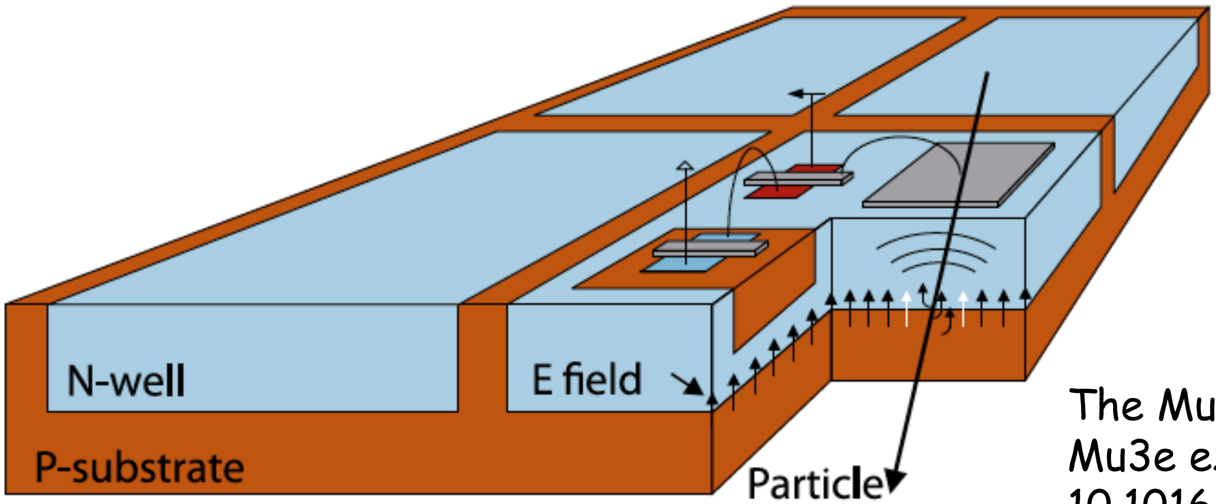
Tracking needs for forward angle experiments

- High rates kHz to MHz per cm^2
- Good spatial Resolution: ~0.1 mm
- Old wire-chamber technology can't deliver.
- Two possible solutions
  - Pixel detectors like HV-MAPS promise:
    - ultra high rates,
    - very good resolution
    - affordability.
    - Very thin
  - Micro-Pattern Gas Detectors (MPGD) provide:
    - Mature technology
    - high rates
    - Good resolution
    - Highly affordable

High Voltage Monolithic Active Pixel Sensors (HV-MAPS)

Ivan Perić (I.Perić, P. Fischer et al., NIM A 582 (2007) 876)

- Use a high voltage commercial process (automotive industry)
- Small active region, fast charge collection via drift
- Readout electronics directly built on pixel



- MuPix chip developed for Mu3e exp. at PSI
- Large area detector planed for P2 @ MESA

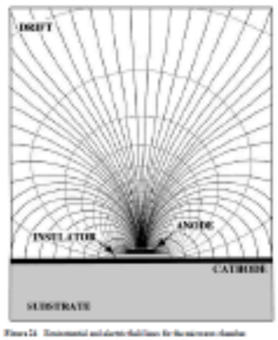
The MuPix system-on-chip for the Mu3e experiment: http://dx.doi.org/10.1016/j.nima.2016.06.095

- Resolutions < 38 μm: limited by pixel size
- 50 μm thin full system chip with sensor and full readout
- 0.1% radiation length
- Ultra fast: 100s of MHz/cm^2
- Still in development stage

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



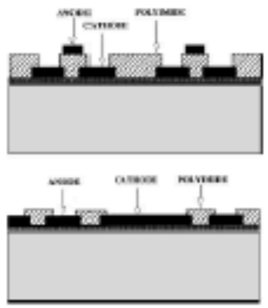


Figure 25 Two variants of small-gap chambers, using thick polyimide ridges to prevent the onset of discharges.

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

Micro Gap Wire Chamber

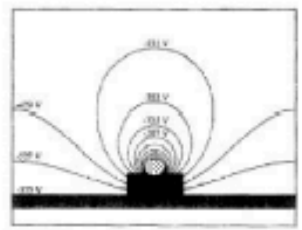
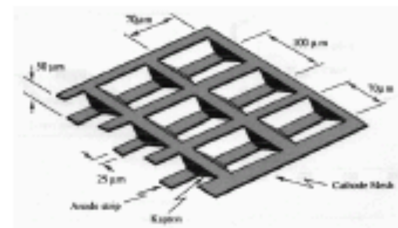


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997].

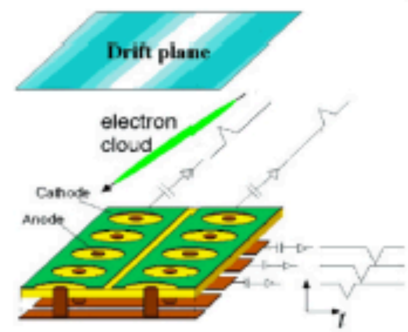
E. Christophel et al, Nucl. Instr. and Meth, vol 398 (1997) 195

Micro Wire Chamber



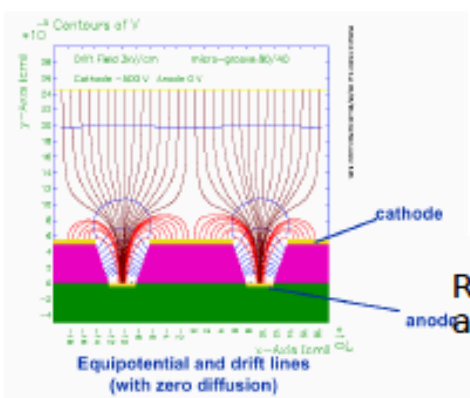
B. Adeva et al., Nucl. Instr. And Meth. A435 (1999) 402

μPIC



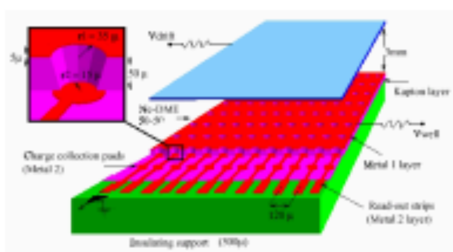
Ochi et al NIMA 471 (2001) 264

MicroGroove



R. Bellazzini et al Nucl. Instr.

MicroWELL



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

MicroDot

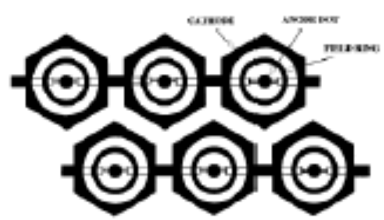
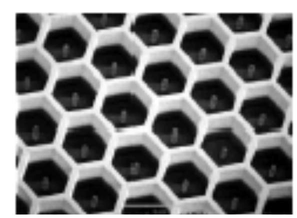


Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

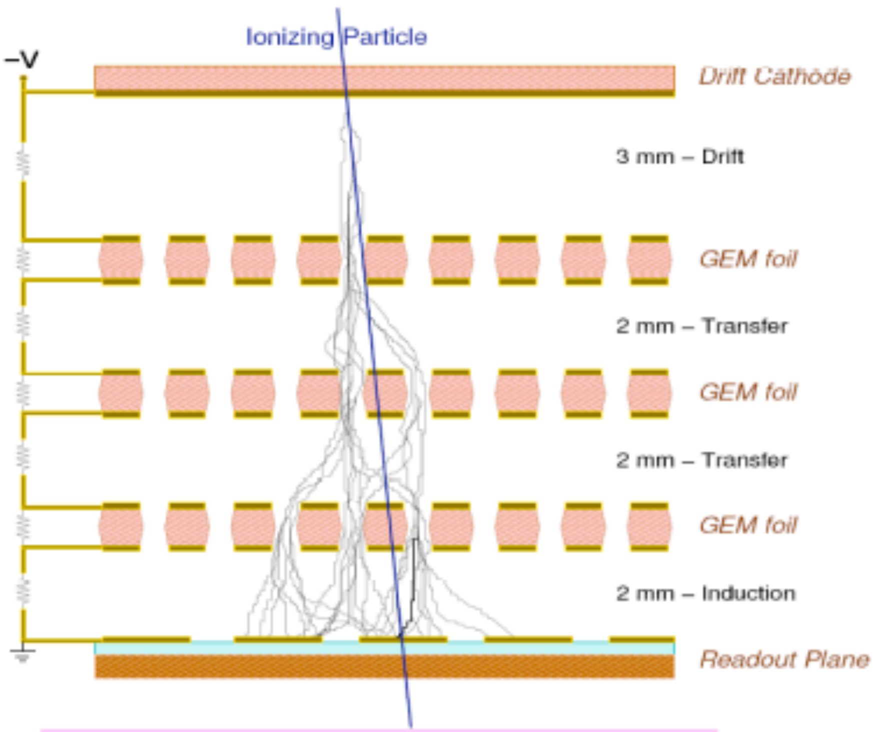
MicroPin



Micro-Pattern Gas Detectors (MPGD)

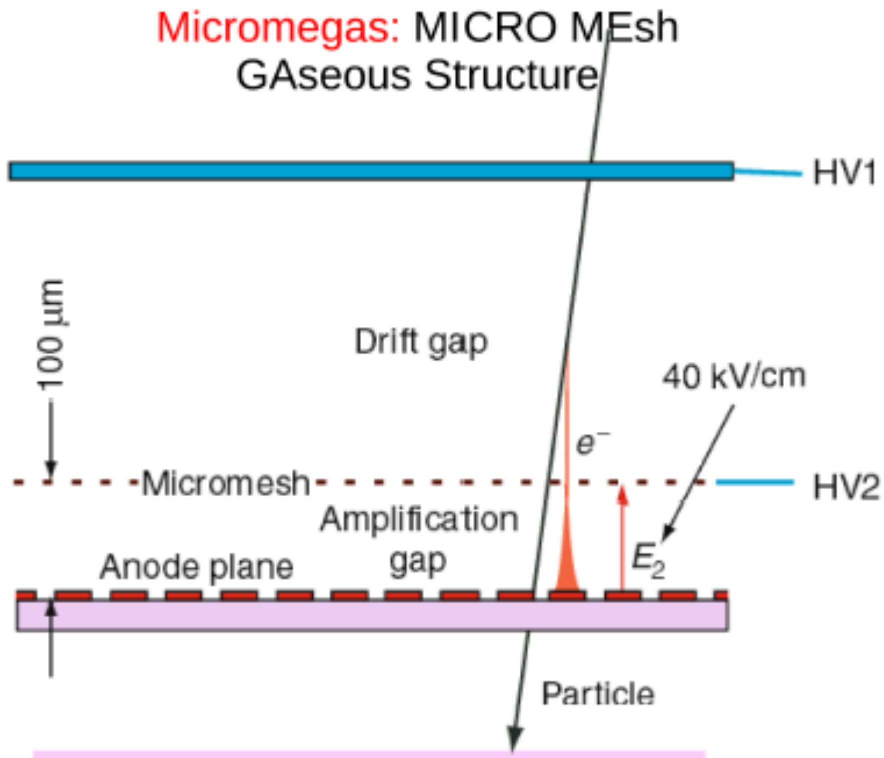
Two MPGD Technologies stood out

GEM: Gas Electron Multipliers



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

Micromegas: MICRO MEsh GAseous Structure

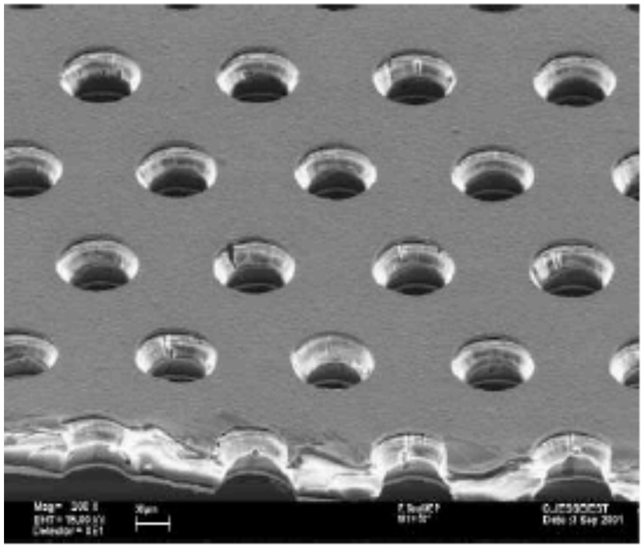


Y. Giomataris, Nucl.Instr. and Meth. A419 (1998) 239

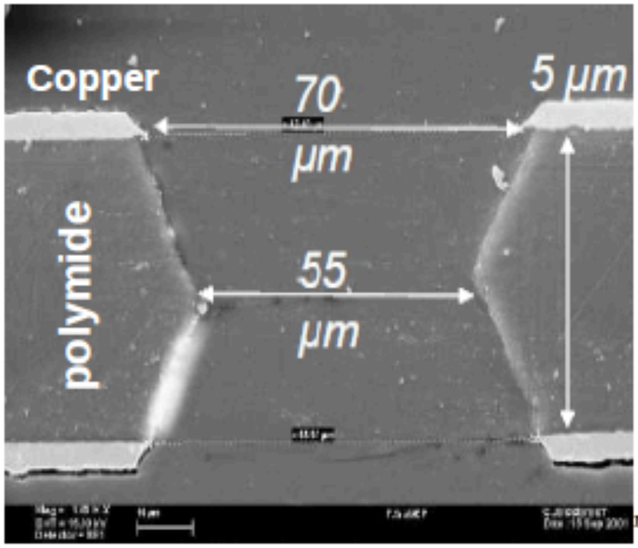
GEM foil: Electron amplification device

- 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

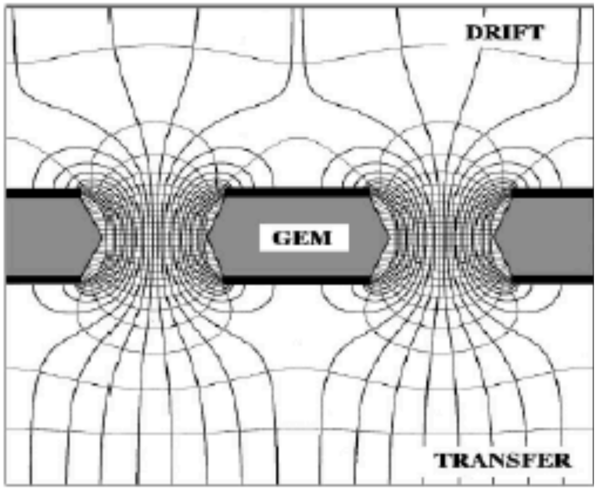


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

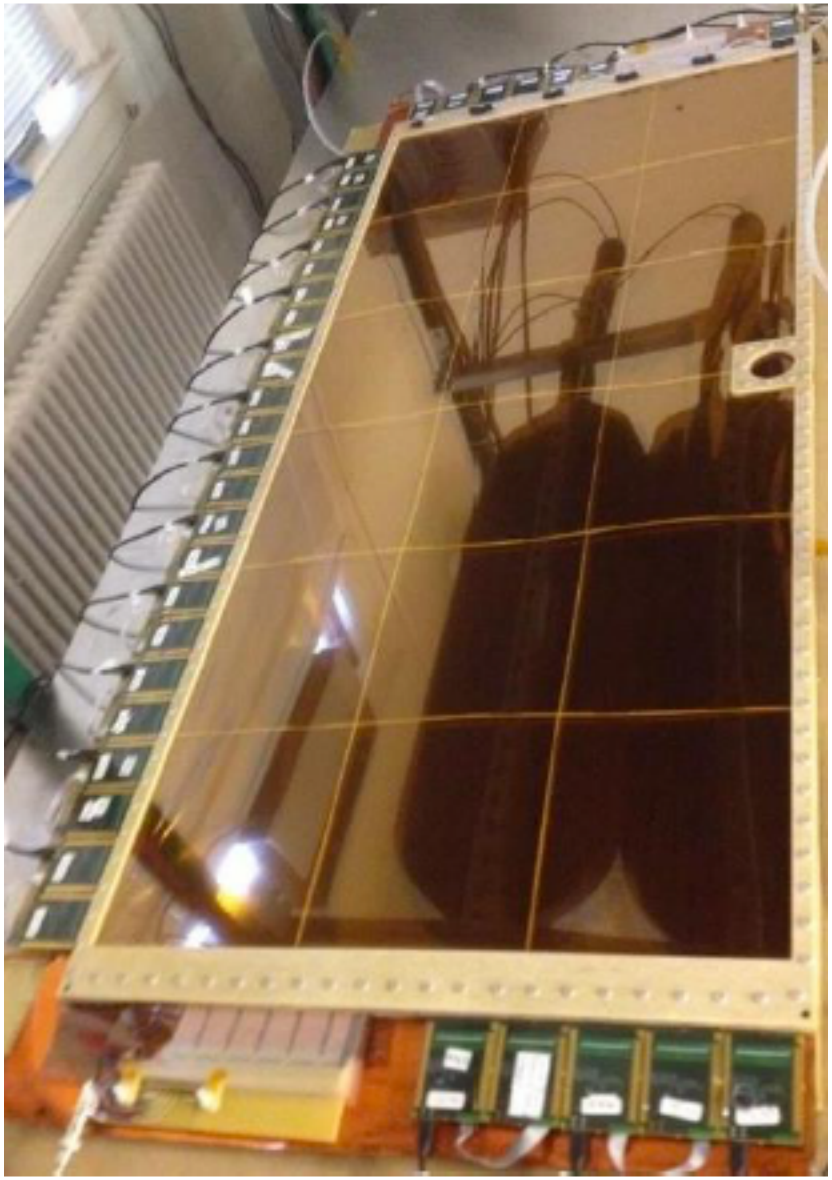
UNIQUE FEATURE

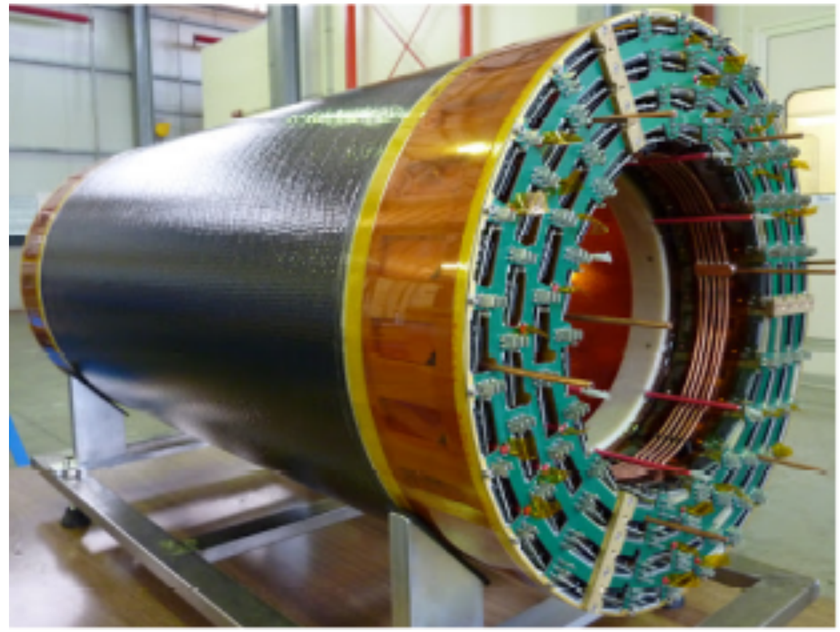
Charge amplification is decoupled from the charge collection ⇨ *Multi-stage amplification*

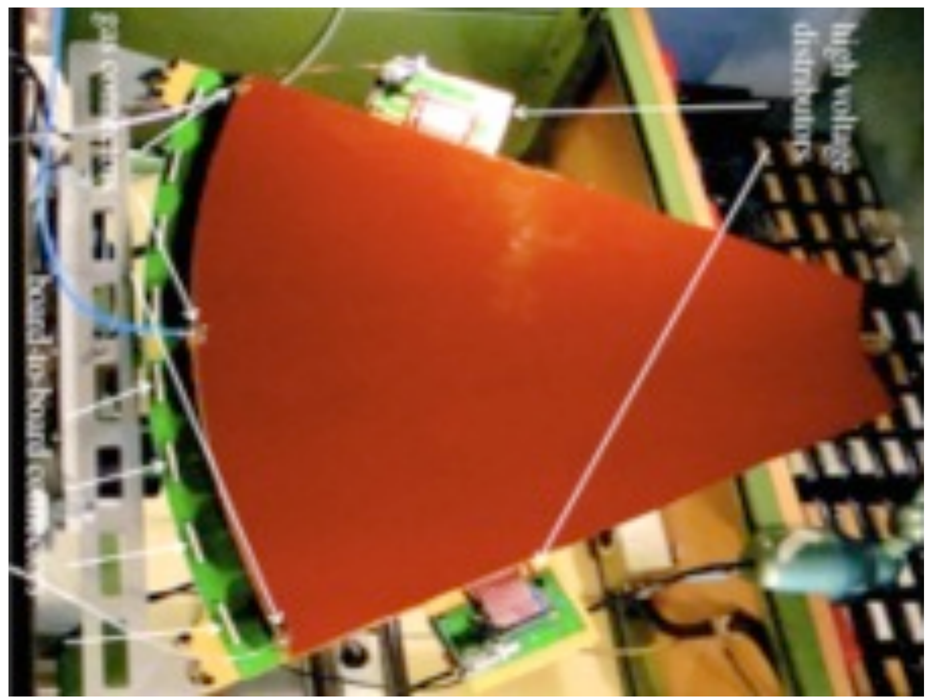
Why GEMs ?

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

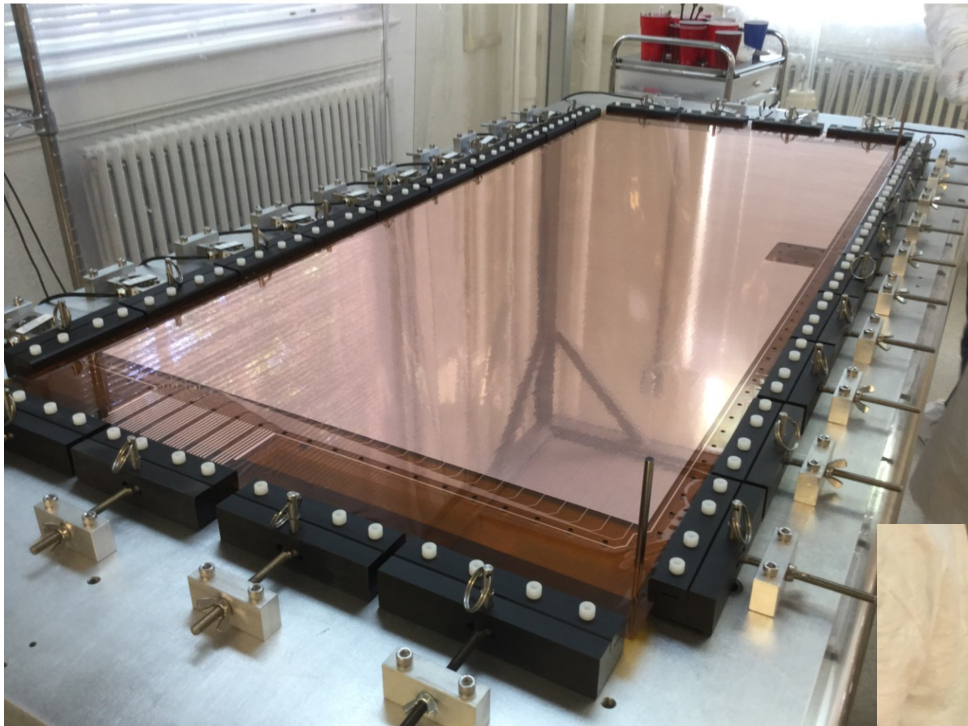
- Rate capabilities higher than many 100s of MHz/cm^2
- High position resolution (< 70 μm)
- Ability to cover very large areas (10s – 100s of m^2) at modest cost.
- Low thickness (~ 0.5% radiation length)
- Already Used for many experiments around the world: COMPASS, Bonus, KLOE, TOTEM, Prototypes for CMS upgrade, 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.
- Need to come up with creative solutions.

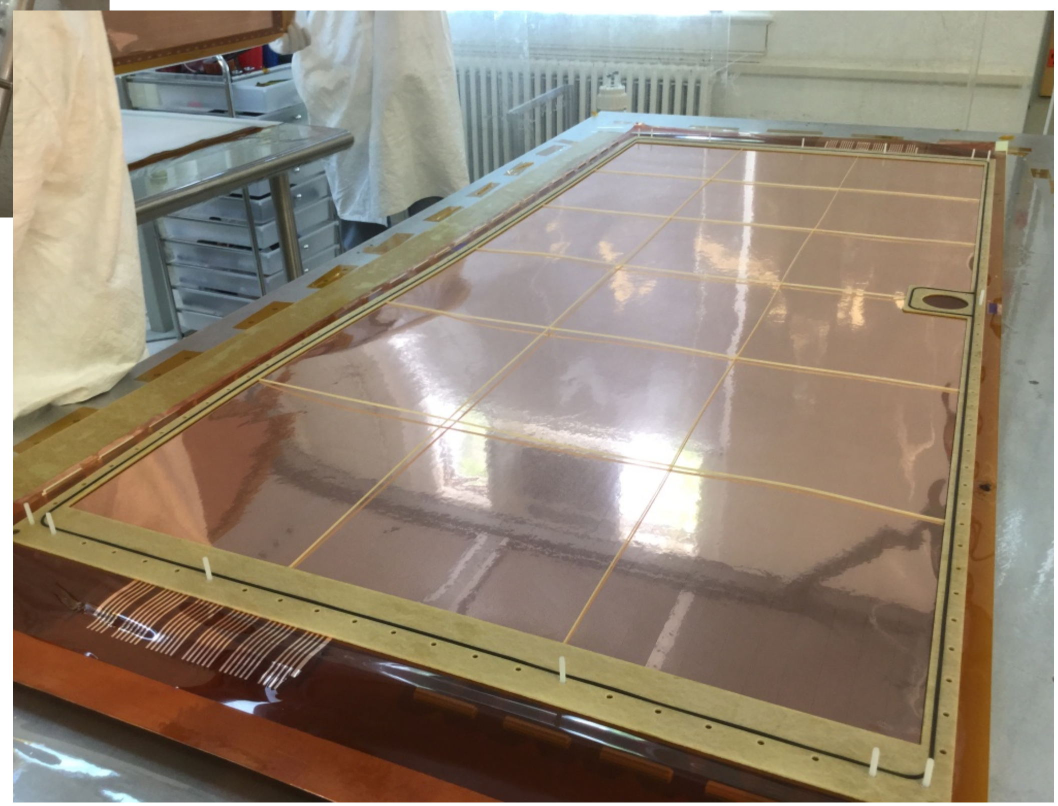




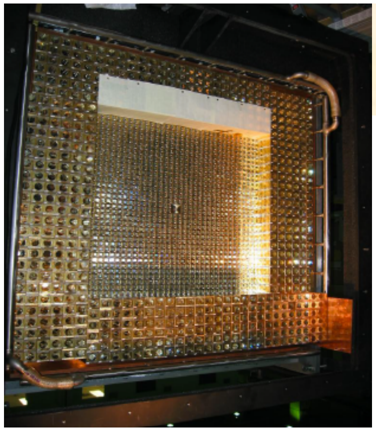

high voltage distribution

Recent developments: now very large areas possible

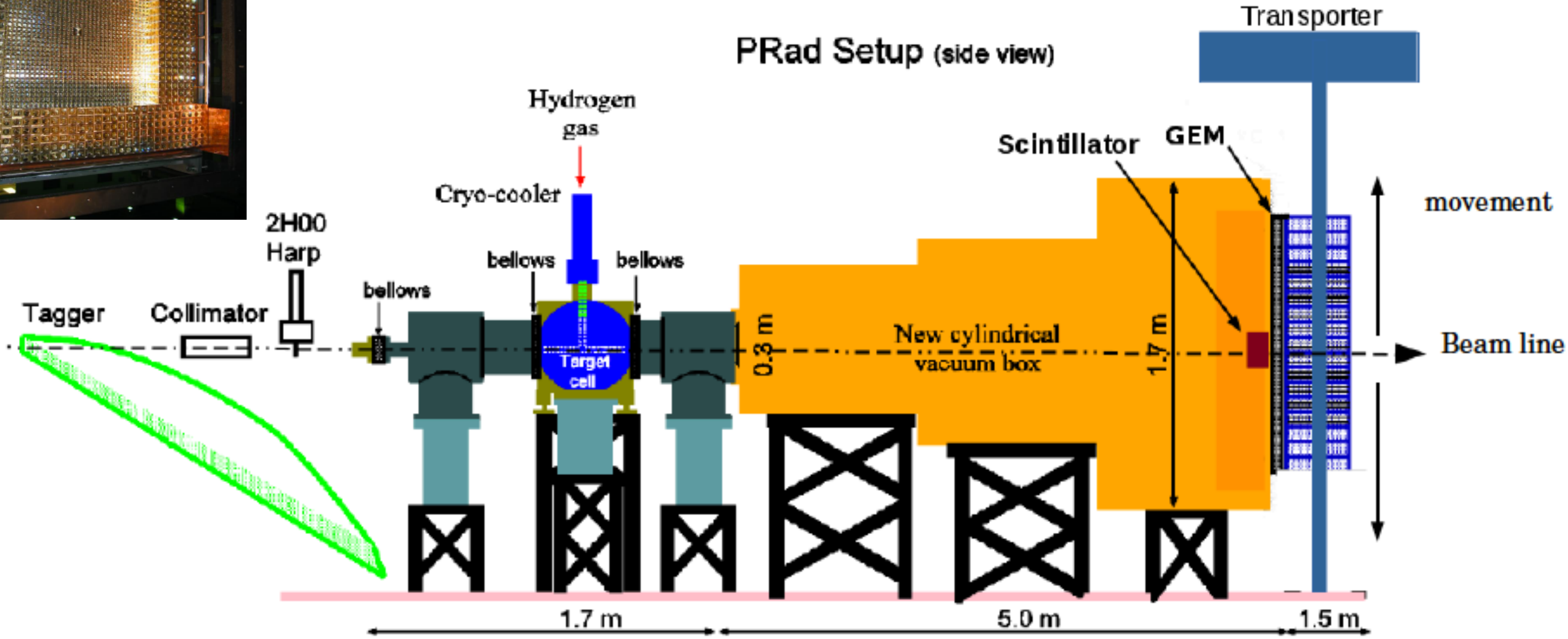




123 cm x 55 cm active area
GEM detectors for pRad experiment
during construction at UVa



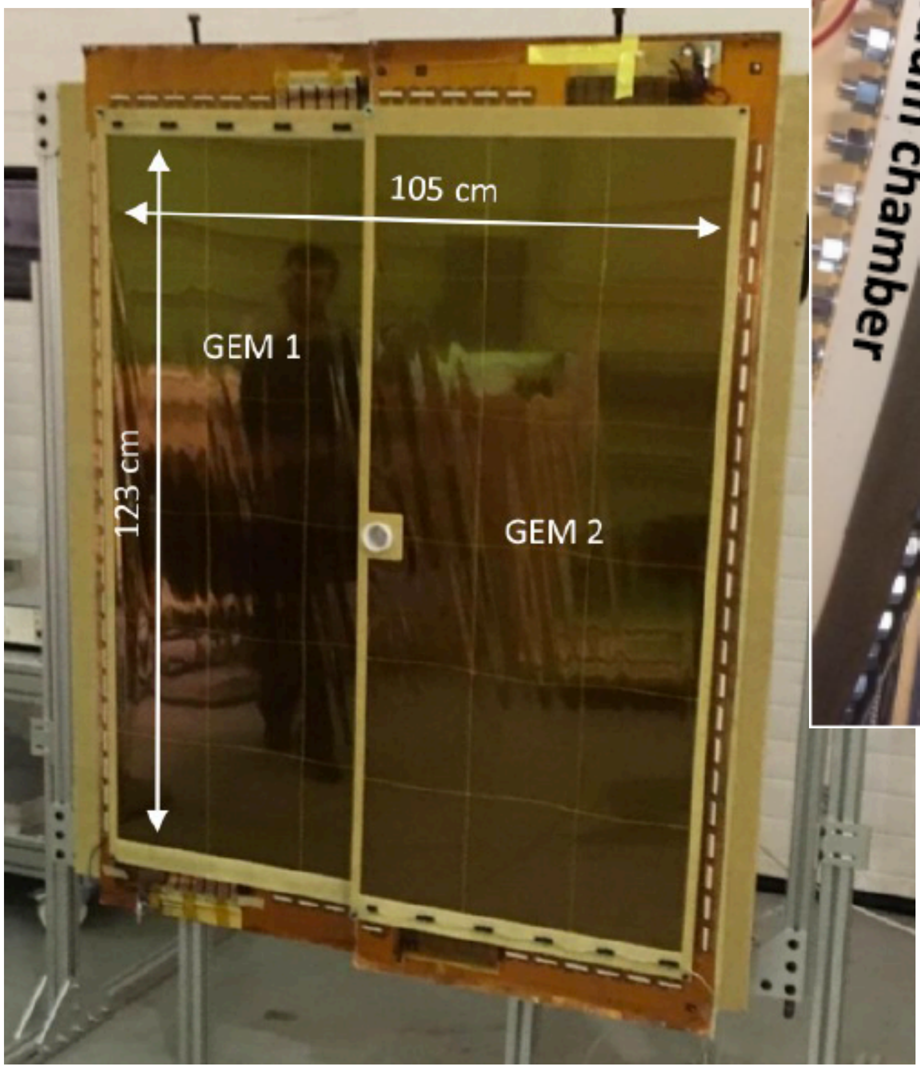
pRad Setup

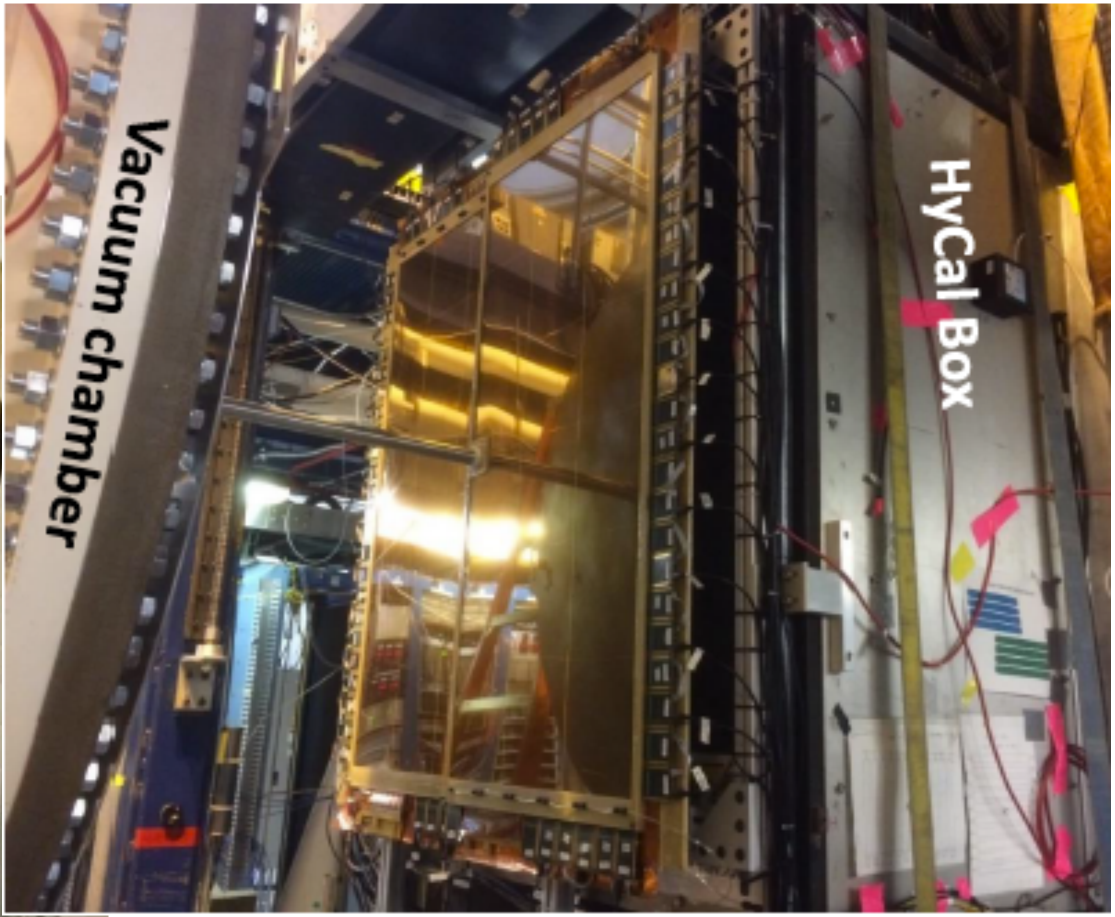


- Non-magnetic and calorimetric method with GEM detectors, aiming at an unprecedented low Q^2 region, $Q^2 = 2\times10^{-4} - 1\times10^{-1}\ (\text{GeV}/c)^2$ with sub-percent precision
- Simultaneous measurement of e-p elastic scat. and Møller processes

- Beam currents up to 100 nA.
- But very thin gas flow target.
- Rate in GEM detectors ~ 100 Hz/cm^2

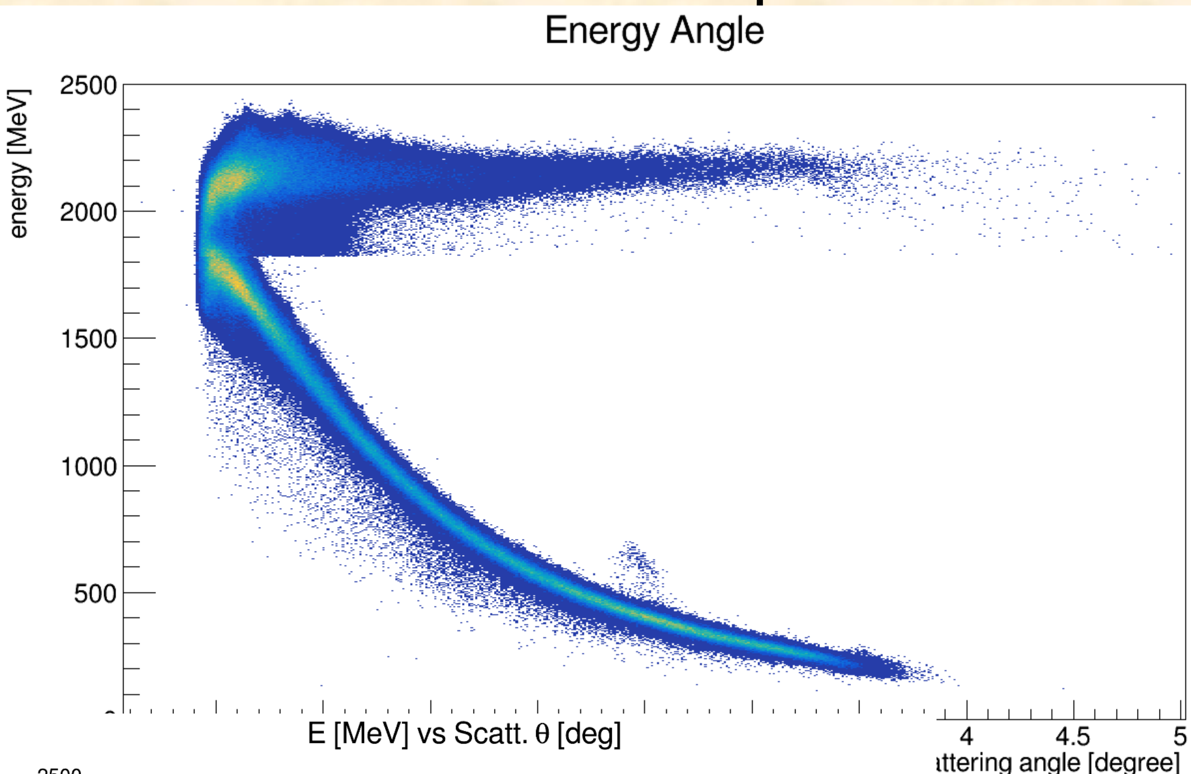
pRad GEMs

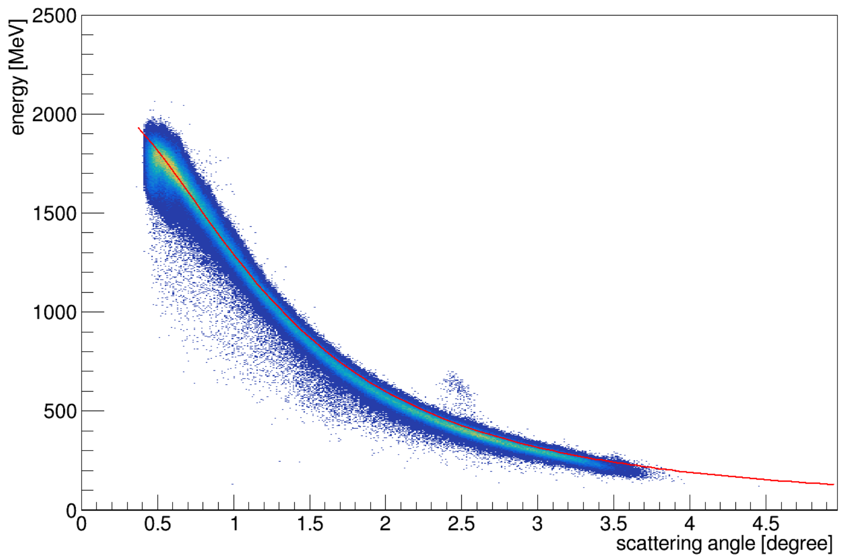


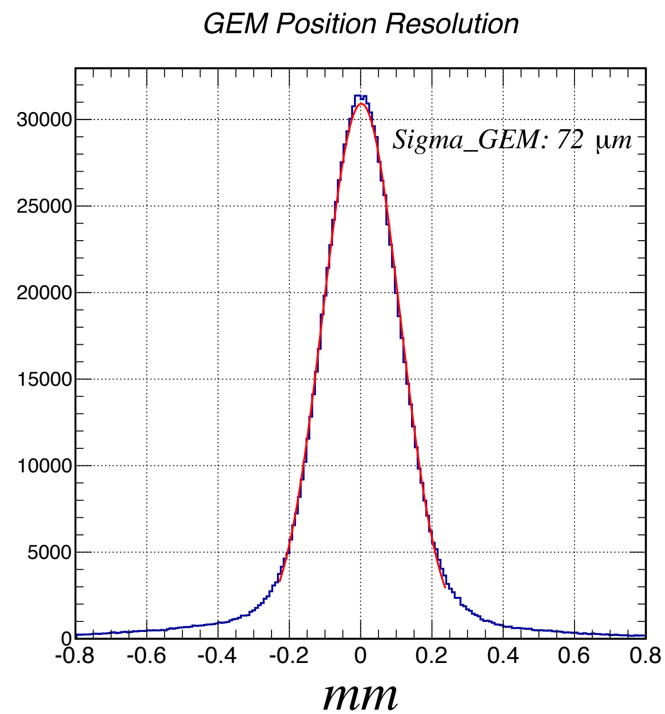


The Largest GEM chambers ever built.

pRad GEMs

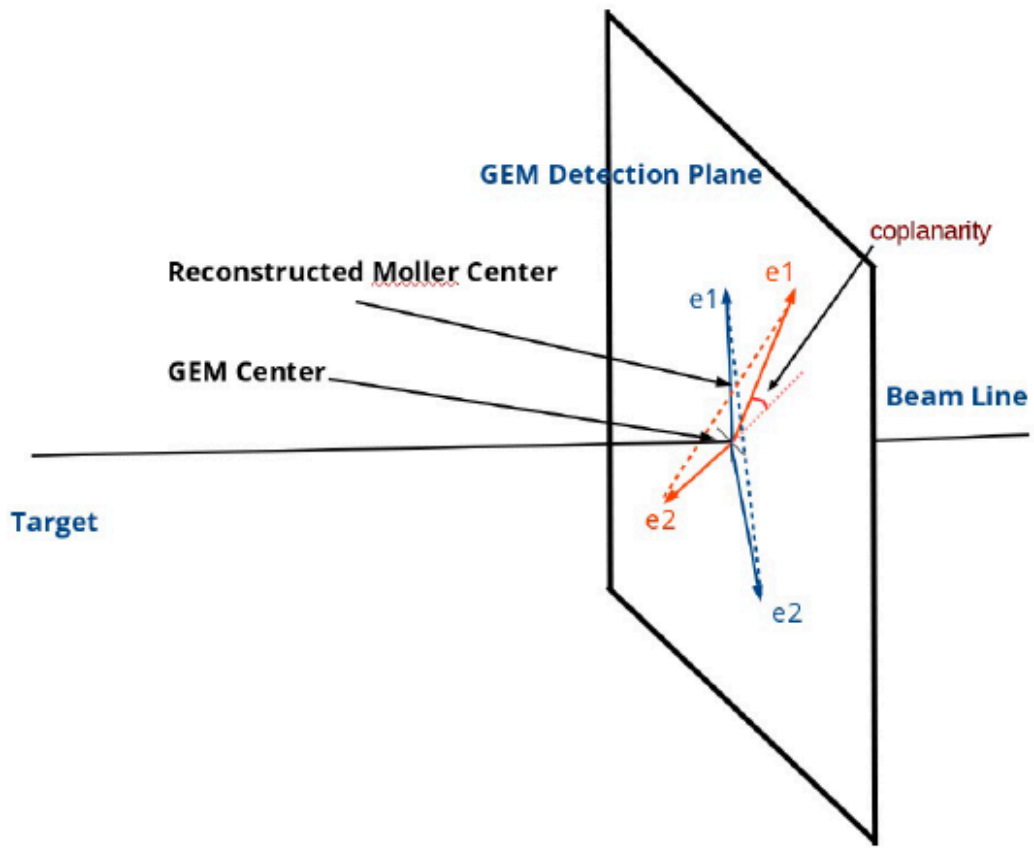

Energy Angle
energy [MeV]
2500
2000
1500
1000
500
E [MeV] vs Scatt. θ [deg]
4
4.5
5
ttering angle [degree]


energy [MeV]
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
scattering angle [degree]

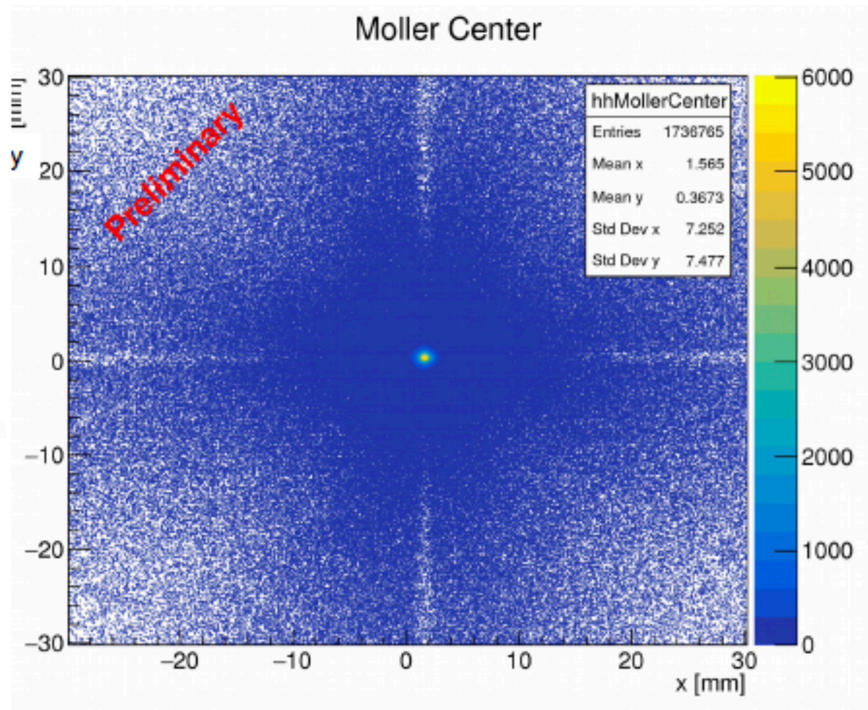

GEM Position Resolution
Sigma_GEM: 72 μm
30000
25000
20000
15000
10000
5000
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
mm

pRad GEMs

Geometry Calibration



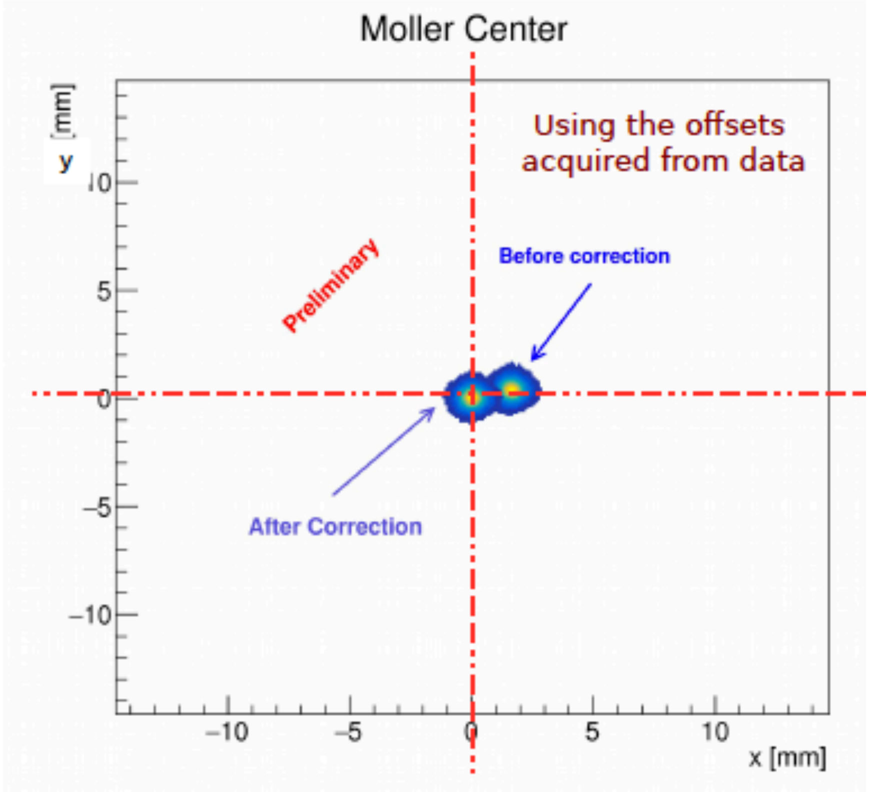
Moller Geometry

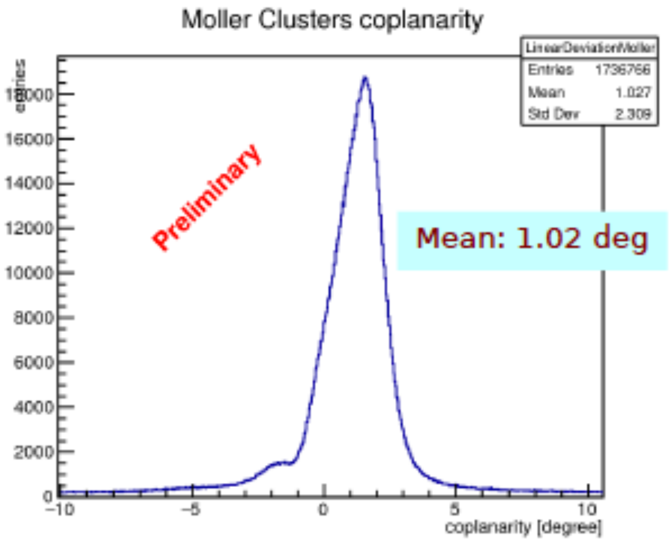


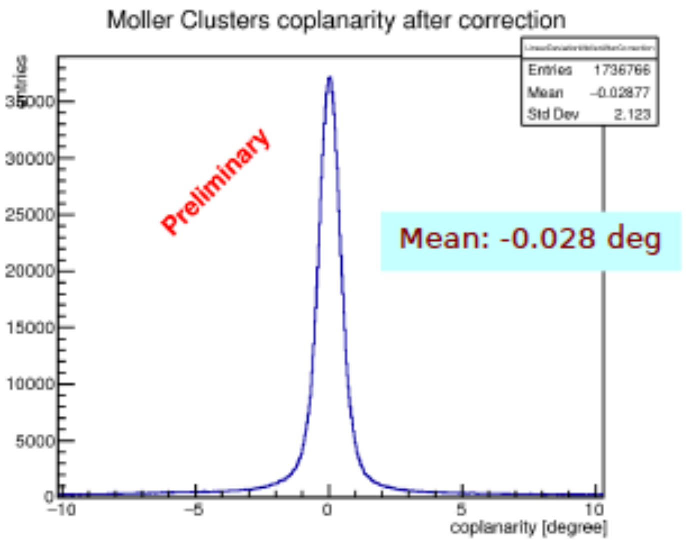
Reconstructed Moller Center

Geometry Calibration

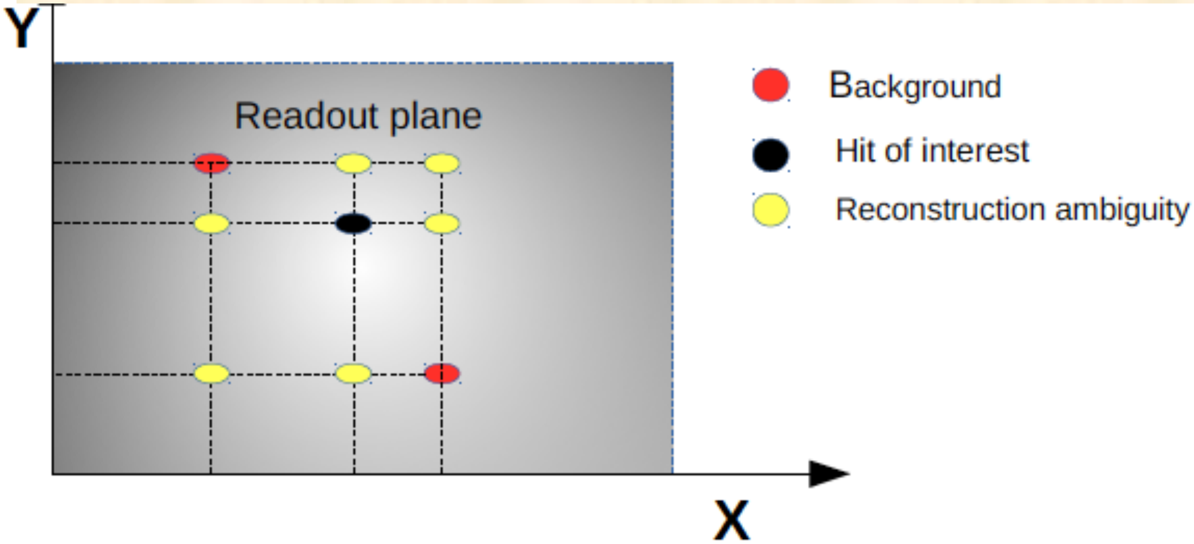
Moller center shifts
with offset correction.







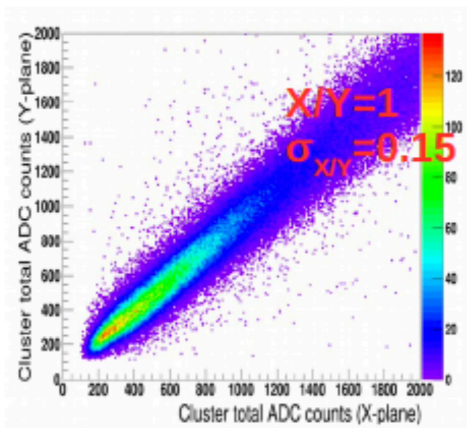
One main issue with long strips is the x and y matching issue



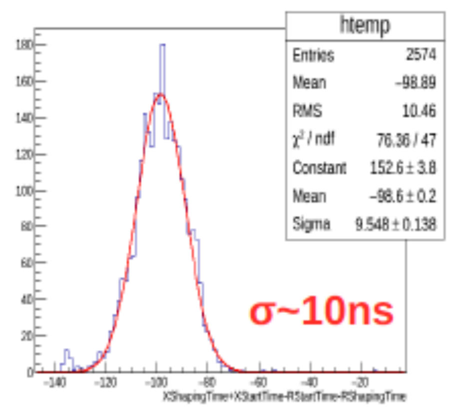
Solution

Do cuts according to characteristics of GEM

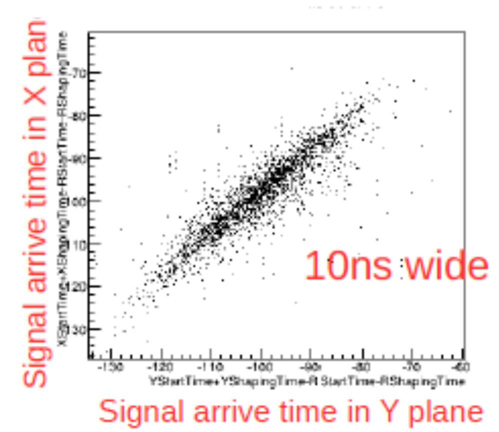
Good Time resolution



Charge correlation between X and Y plane

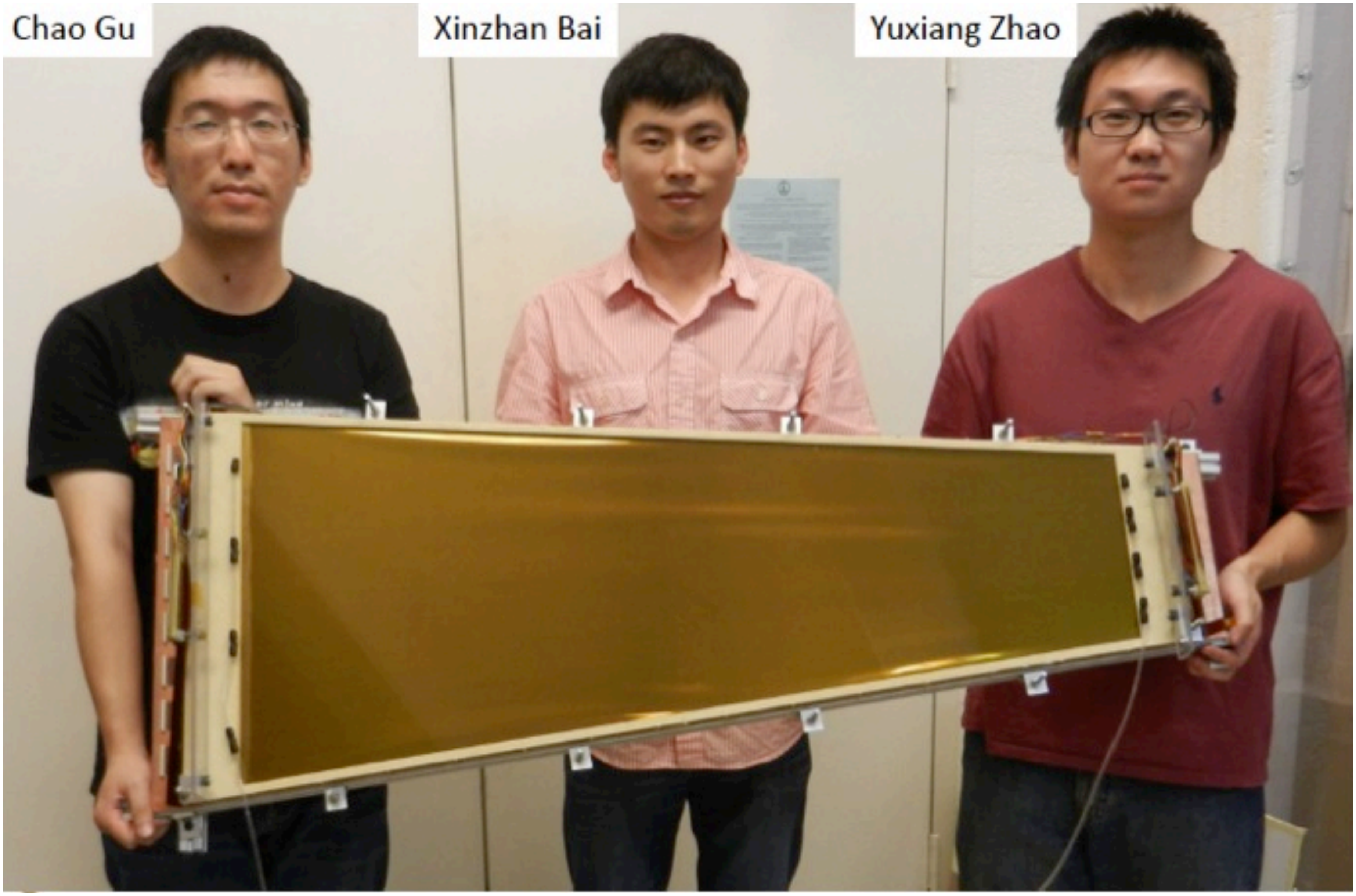


Time resolution(after DAQ clock phase correction, from fit)

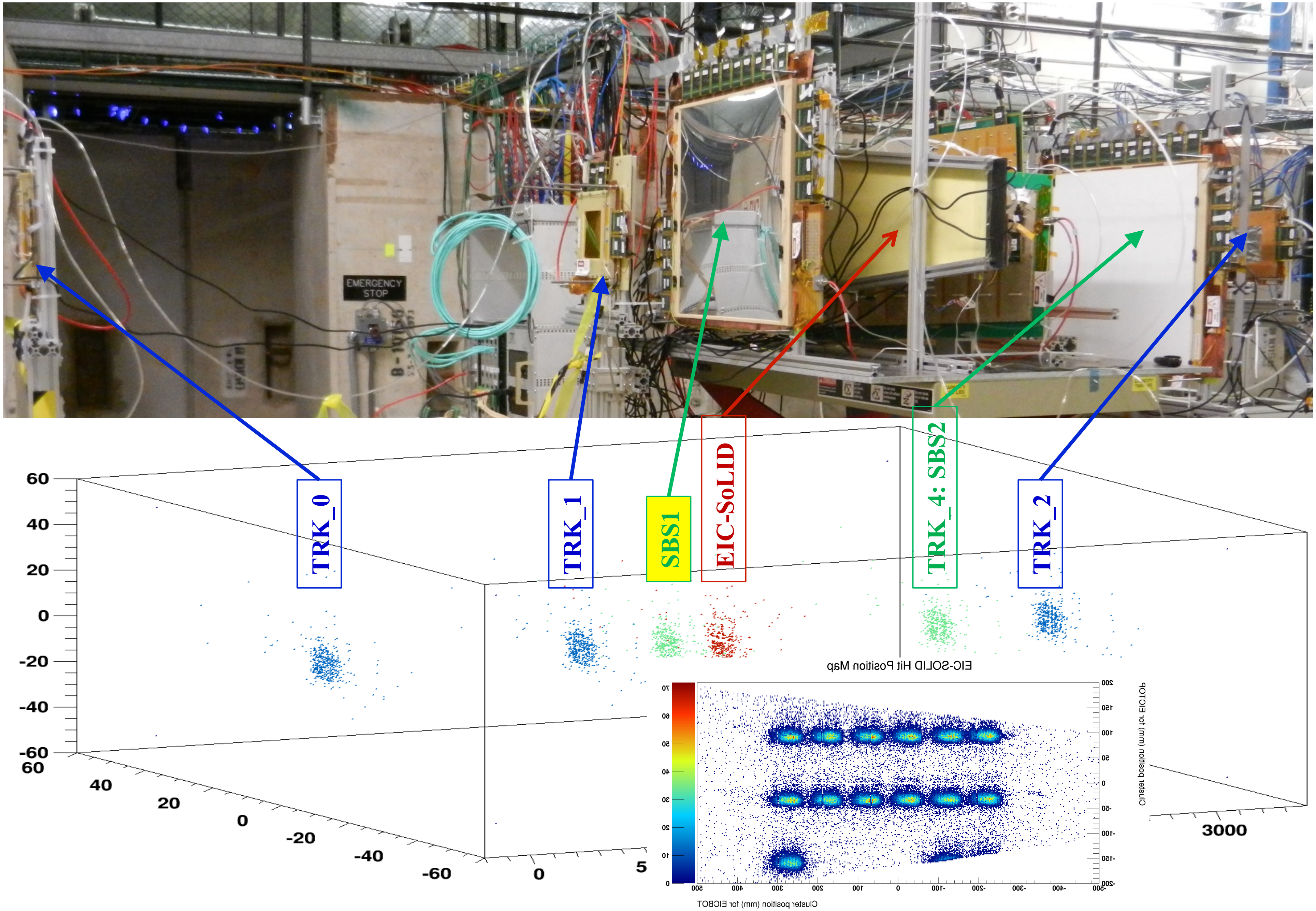


Timing correlation between X and Y plane

SoLID-EIC GEM prototype



Large Size GEMs in MT6-2B @ FTBF (Fermilab)

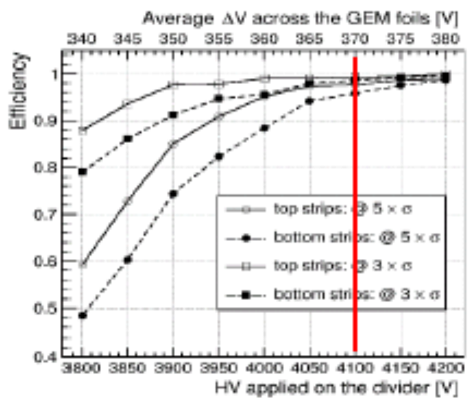


Solid GEM Prototype test results

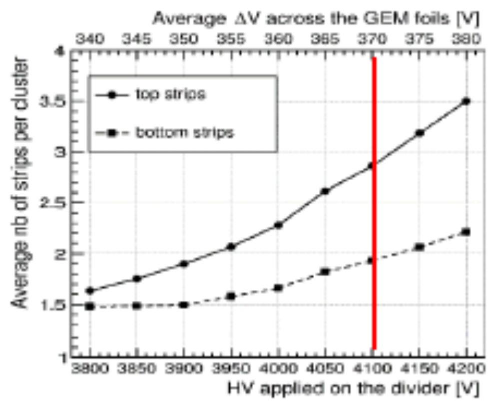
EIC-FT-GEM (SoLID) Prototype I

- Trapezoid shape **1-m long** triple-GEM (3-2-2-2): widths at the inner radius and outer radius equal **to 23 cm and 44 cm** respectively.
- Readout board: flexible 2D U-V strip readouts (COMPASS style) with a **pitch of 550 µm**, top layer (**140 µm, wide U-strips**) run parallel to one radial side of the detector and bottom layer (**490 µm, V-strips**) run parallel to the other side.
- Test beam results published in [NIM A 808 (2016) 83-92]

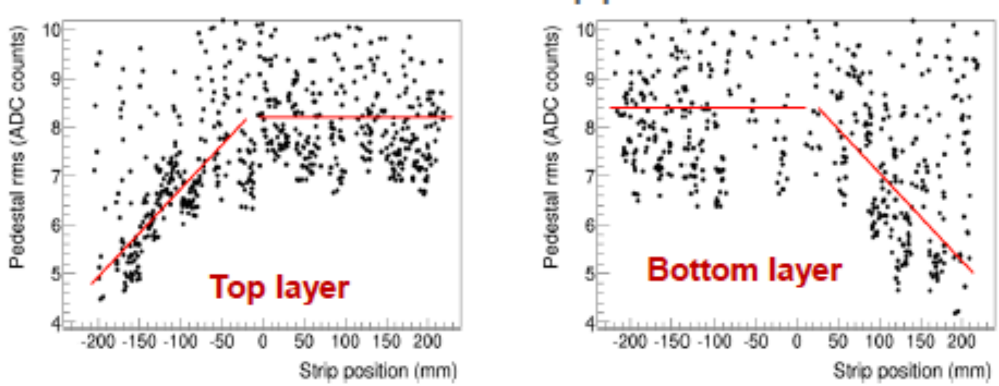
Efficiency vs. HV



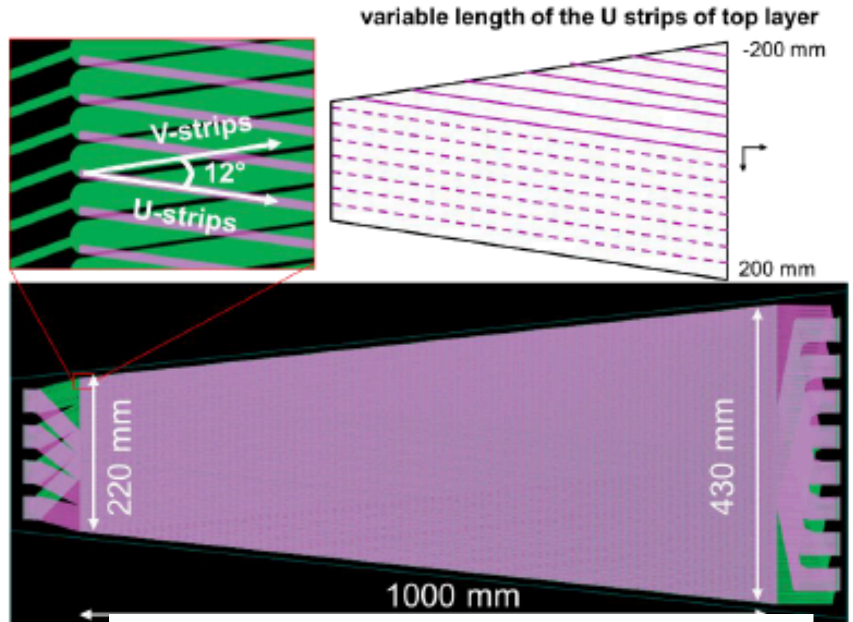
Cluster size vs. HV

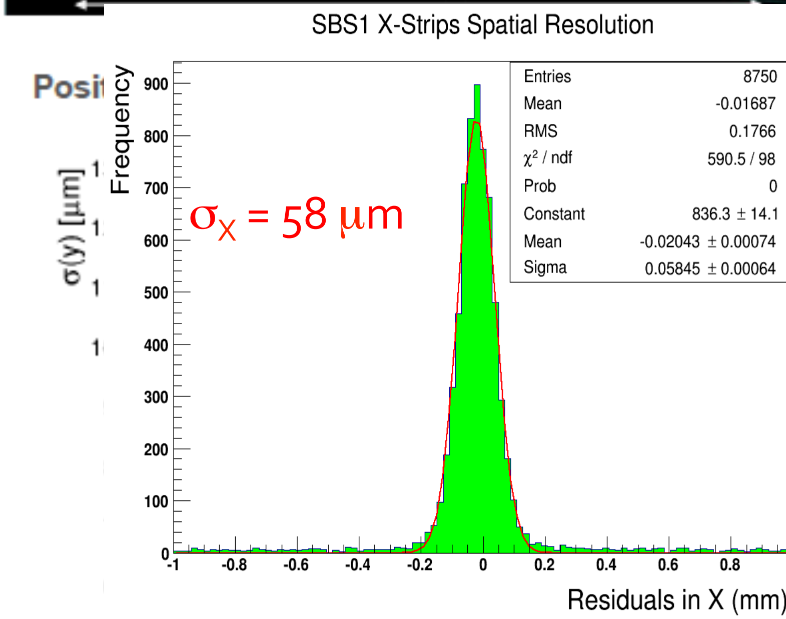


Distribution of the strip pedestal noise



U-V strip Readout of EIC-SoLID GEM Proto I

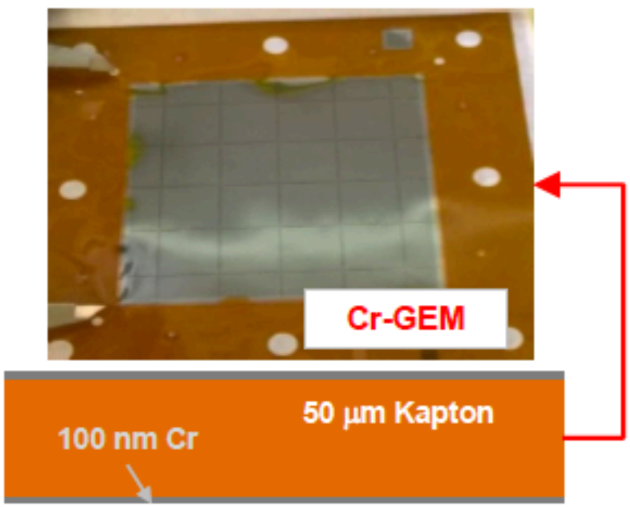




For the future

Low-Mass GEM R&D: Chromium GEM foil (Cr-GEM)

Standard GEM



Triple-GEM with standard GEM foil

	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drit							
Copper	1	5	8.96	14.3	1	0.0350	0.0045
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	5	8.96	14.3	0.8	0.1678	0.0215
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	5	8.96	14.3	0.2	0.0070	0.0009
Copper-350	1	5	8.96	14.3	0.75	0.0262	0.0034
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.471	0.090

Triple-GEM with Cr-GEM foil

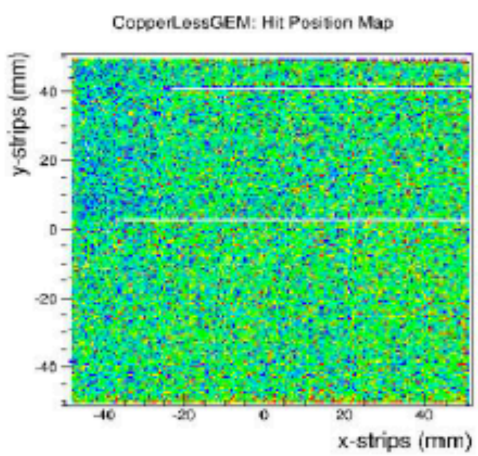
	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drit							
Copper	1	0	8.96	14.3	1	0.0000	0.0000
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	0	8.96	14.3	0.8	0.0000	0.0000
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	0	8.96	14.3	0.2	0.0000	0.0000
Copper-350	1	0	8.96	14.3	0.75	0.0000	0.0000
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.235	0.060

About 50% reduction in the amount of material in a EIC-FT-GEM with Cr-GEM

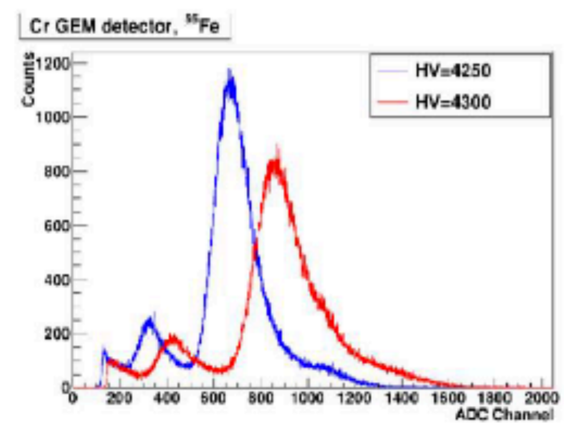
Cr-GEM foil:

- ✓ Copper (Cu) clad raw material comes with 100 nm Chromium (Cr) layer between Cu and Kapton, 5µm Cu layers removed, leave only 100 nm residual Cr layers as electrodes, **Cr-GEM foils provided CERN PCB workshop**
- ✓ Using Cr-GEM foil lead to almost 50% reduction of the material of an SoLID-like light weight **triple-GEM detector**: this is because the material in a lightweight triple-GEM is dominated by the GEM foils & readout board

Response uniformity



ADC Spectrum with Fe55

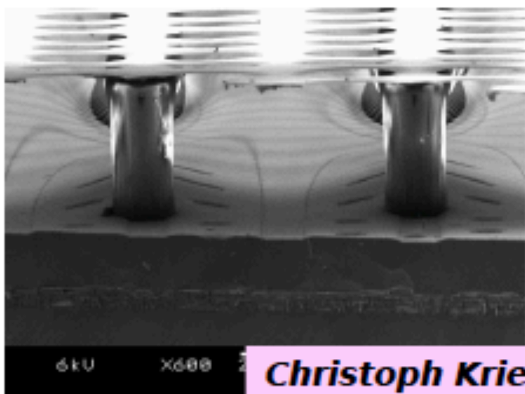


For the future

The newcomers: InGrid + Timepix

Combining:
Gaseous amplification (Micromegas) & Silicon readout (Timepix)

Micromegas grid



Timepix

Christoph Krieger
RD51 Week
CERN,06/19/2014

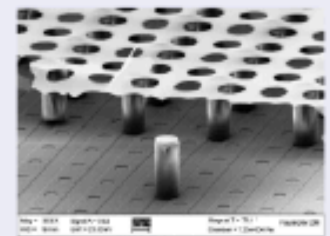
Integrated Micromegas – InGrid

Chefdeville et al - Nucl. Inst. Meth. A 556(2006), p 490

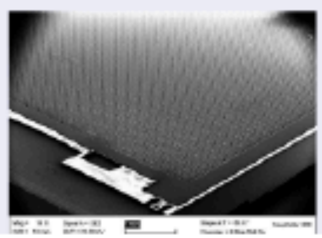
Micromegas on top of Timepix ASIC

- Fabrication by means of photolitho-graphic postprocessing
- Very good alignment of grid and pixels
- Each avalanche is collected on one pixel
- Detection of single electrons possible

InGrid - SEM



Timepix + InGrid



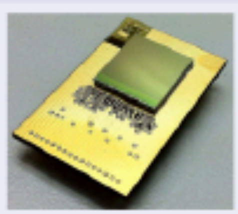
Production of InGrids

- Single and few chip processing: NIKHEF / Mesa+ (Twente)
- Wafer processing ($\sim$ 100 chips at once): in cooperation with IZM Berlin

Facts about the Timepix ASIC

- 256×256 pixels, $55 \times 55\,\mu\mathrm{m}^2$ pitch
- $1.4 \times 1.4\,\mathrm{cm}^2$ active area
- Charge sensitive amplifier and discriminator in each pixel, $90\,e$ ENC
- Two modes: **Charge** or **Time**

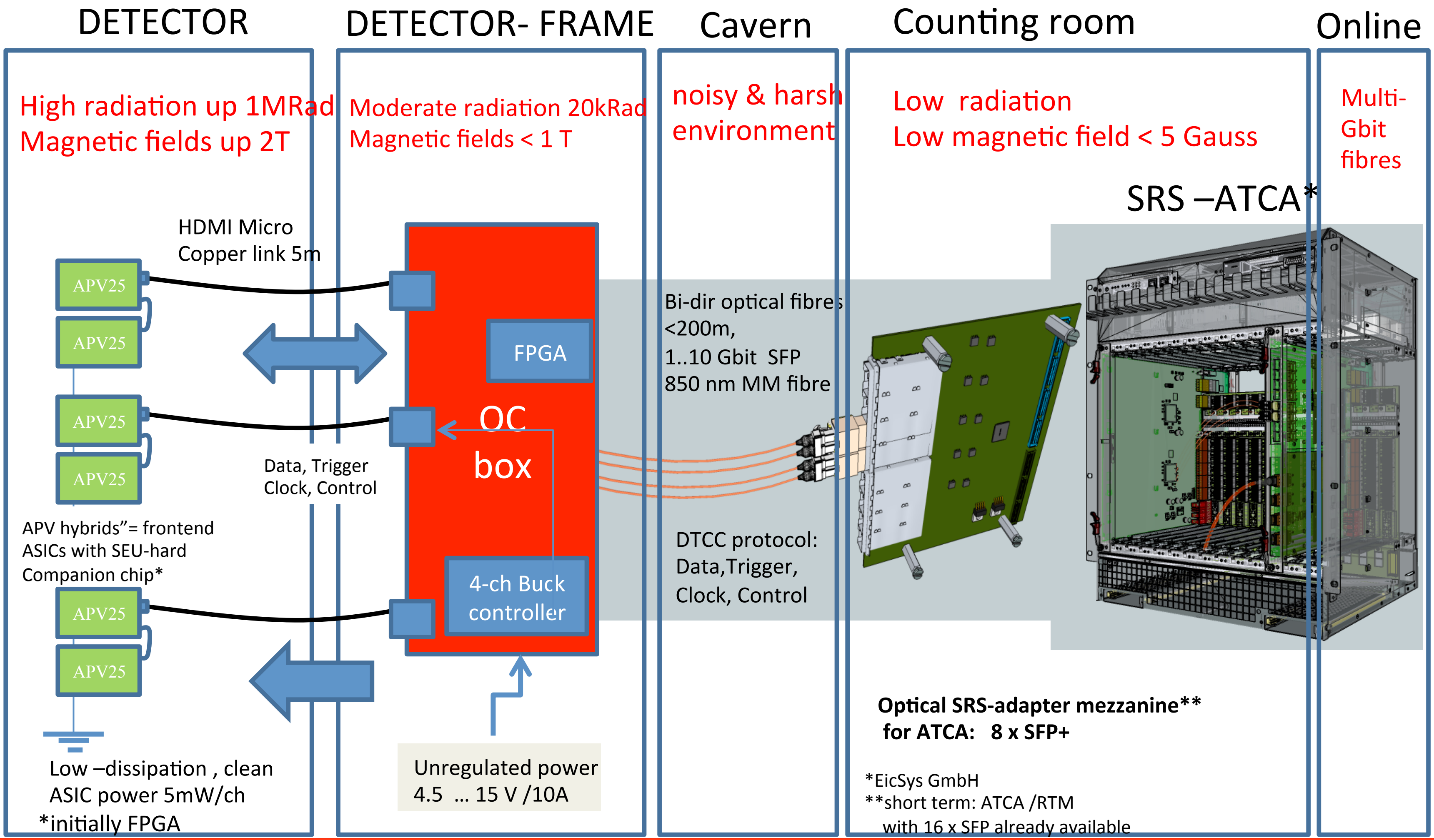
Carrier board



Energy Resolution

- Resolutions down to $\sigma_E/E \approx 3.85\,\%$ at 5.9 keV were observed in Ar/iC$_4$H$_{10}$ 90/10 at optimized settings (Energy determined from pixel counting)
- In Ar/iC$_4$H$_{10}$ 97.7/2.3 resolutions down to $\sigma_E/E \approx 5.33\,\%$ at 5.9 keV are possible

GEM readout



- Currently installing a 120 k chan. APV 25 system (based on an INFN designed system) for SBS.
- Plan to read at ~ 5 kHz with Jlab CODA
- Large amounts of data: need to address bandwidth and data writing limitations.
- Online zero suppression/background suppression at FPGA level.

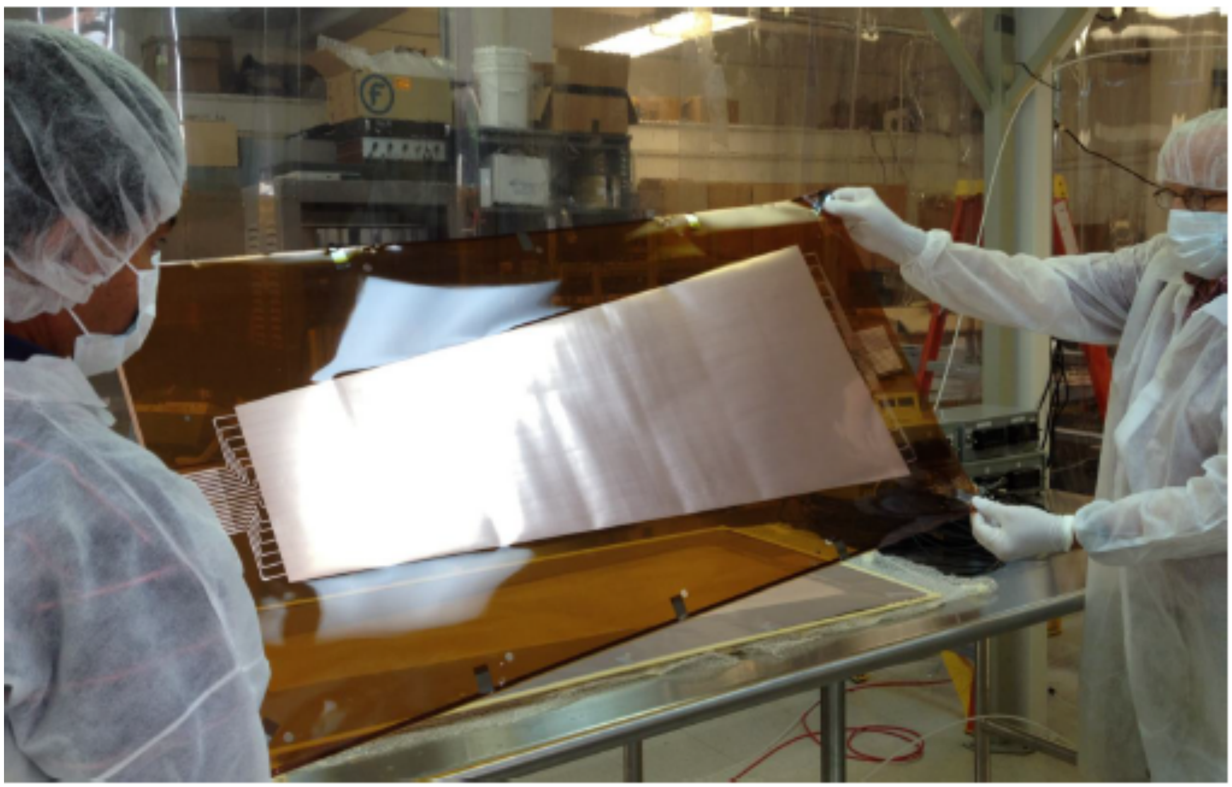
Conclusion

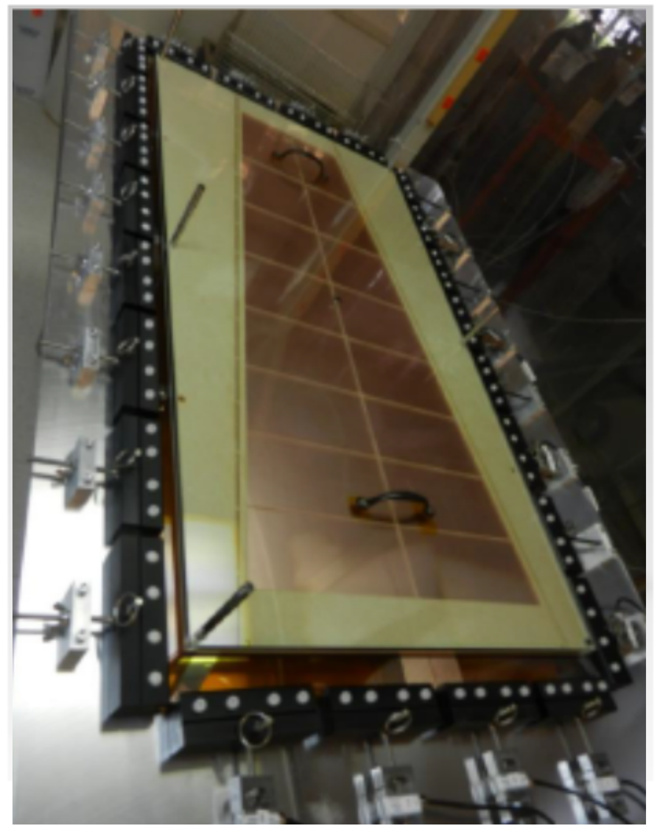
- The large area GEM detector + high granularity calorimeter provided a powerful combination for forward tracking in pRad.
- Experiments requiring tracks will need 2-3 layers of GEMs.
- Calorimeter + 2-3 layers of GEMs + pixel detector in front will allow forward experiments at very high rates.

Backup

GEM foils and frames

- The foil is divided into 32 HV sectors of roughly 100 cm2 with
- The V applied on the 16 sectors from the top and 16 from the bottom
- Frames with 300 μm spacers, 8 mm width on the side and 60 mm width on top and bottom
- Extra frame material with alignment holes for the assembly, production by RESARM (Belgium)

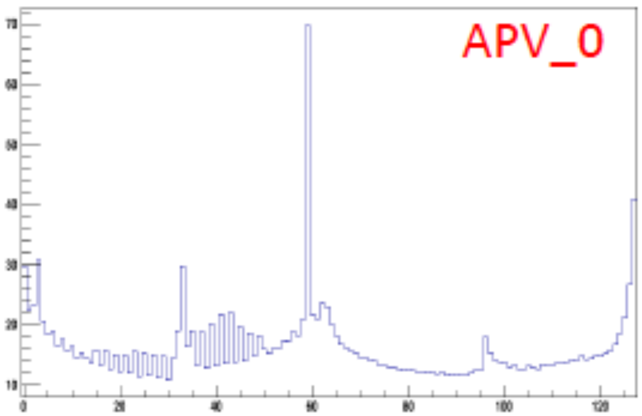




Preliminary results: EIC-SoLID readout strip capacitance noise

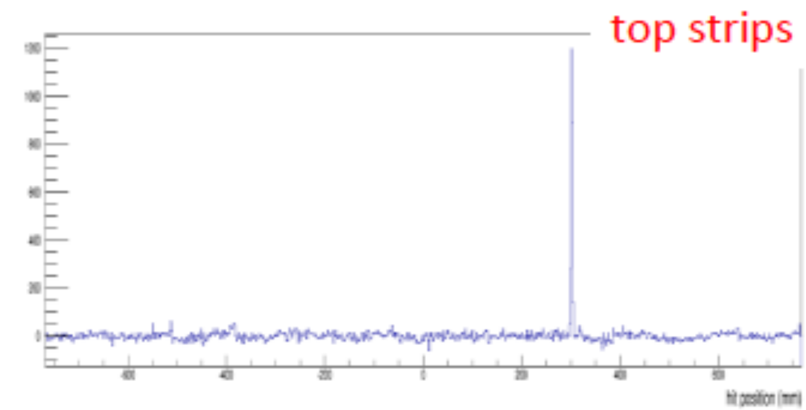
noise (pedestal rms)

ADC counts

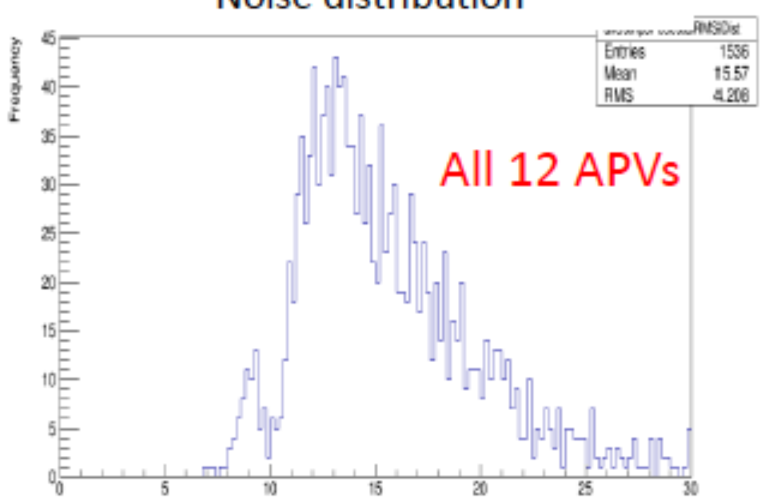


APV channel (readout strip No)

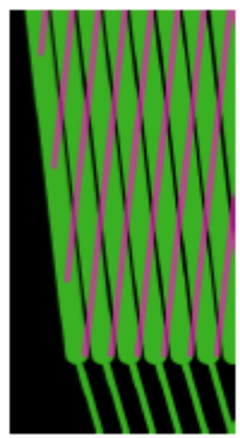
- Pedestal noise distribution over all 1536 strips (768 narrow top strips and 768 wider bottom strips)
- Strips of different lengths (U/V strips on trapezoidal readout)
- Average pedestal RMS noise 16 ADC counts, maximum 30 ADC counts

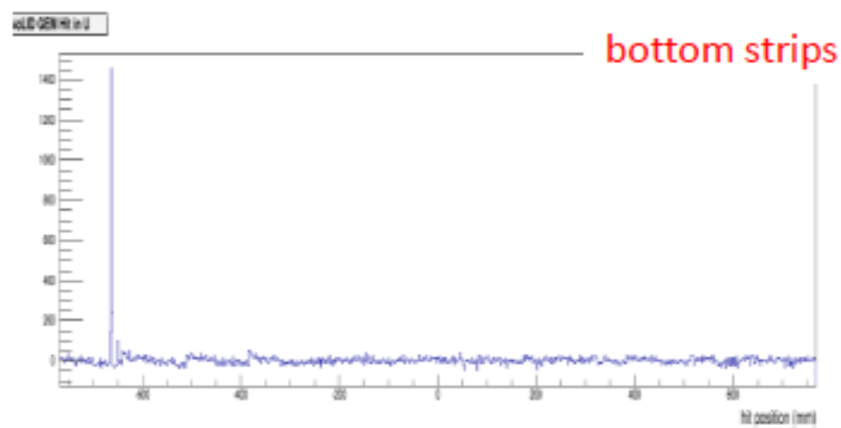


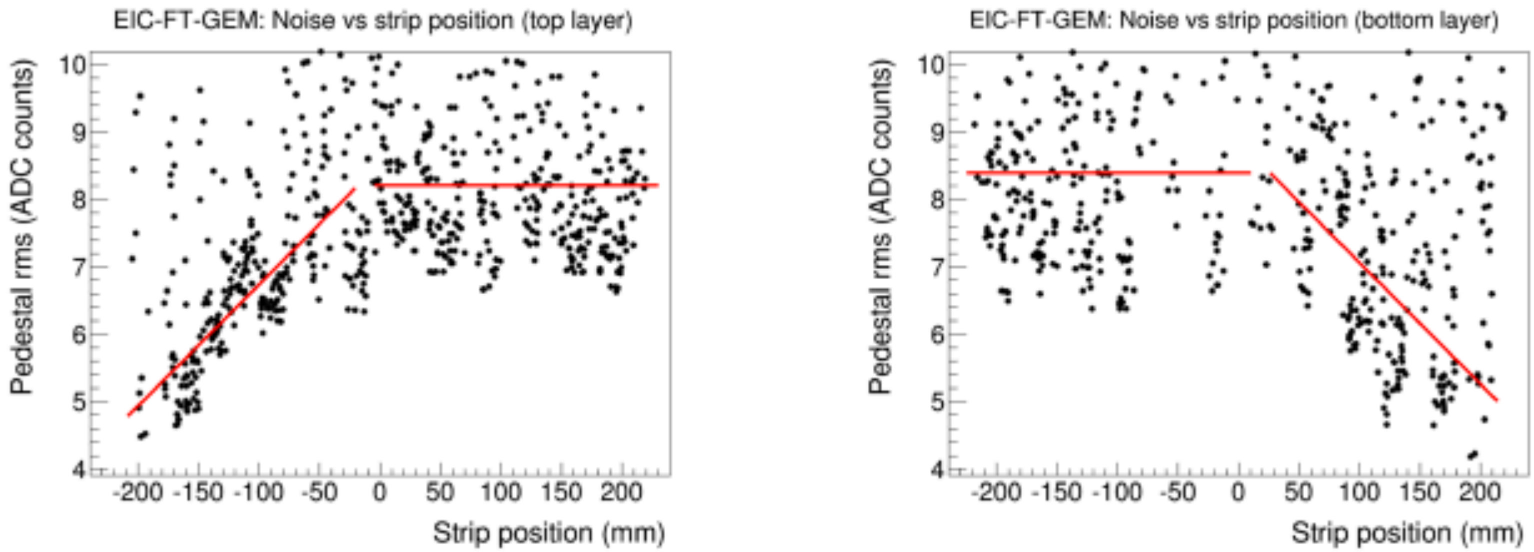
Noise distribution



ADC counts

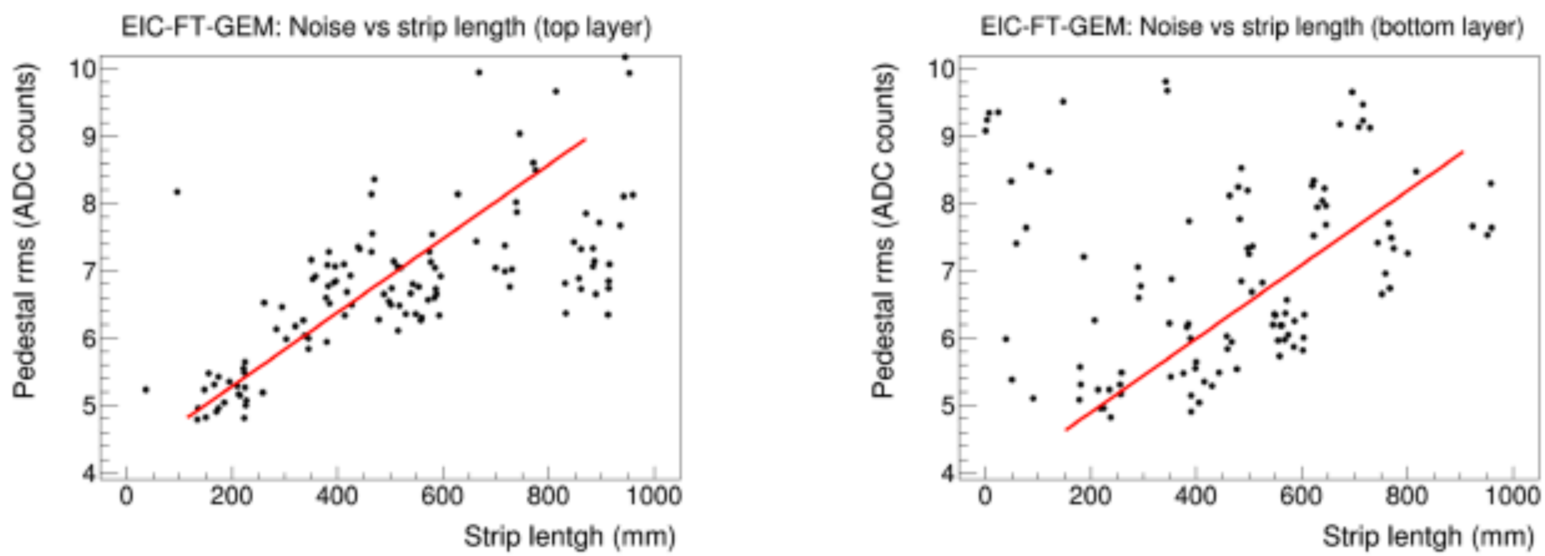






(a) top layer　　**(b)** bottom layer

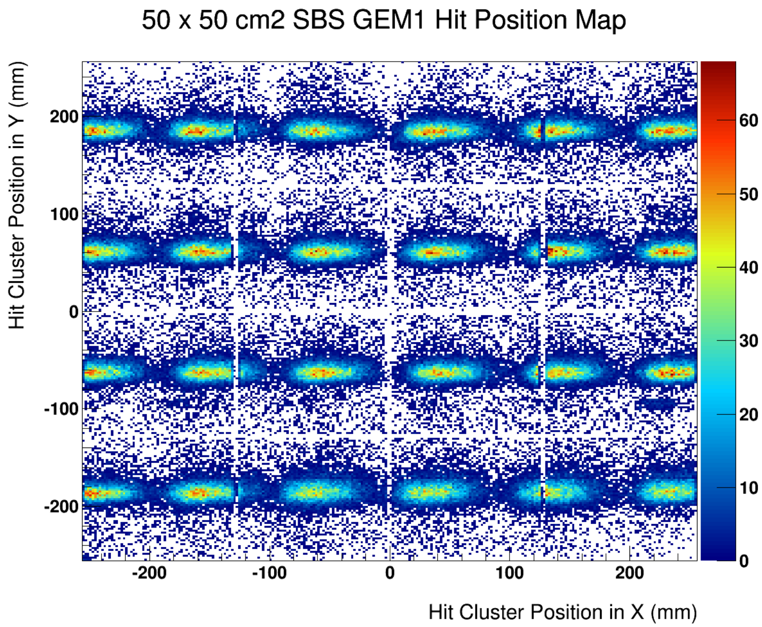
Figure 6: rms of the pedestal (noise level) vs. strip position on the outer radius side of the chamber

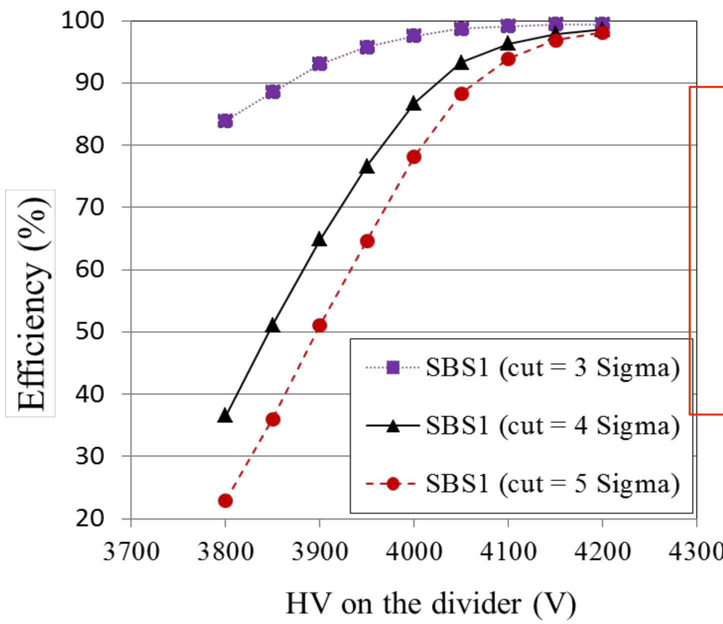


(a) top layer　　**(b)** bottom layer

Prototype test beam results

Data with beam scan covering the active area of the GEM module. (average particle rate ~ 10 kHz/cm^2)





Results published in NIM-A (arXiv: 1409.5393)