Status of GEM-US @ UVa

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SoLID Collaboration Meeting @ JLab

05/15/2015

Outline

- GEM trackers for SoLID
- GEM R&D program @ UVa
- Plans on SoLID-GEM specific R&D

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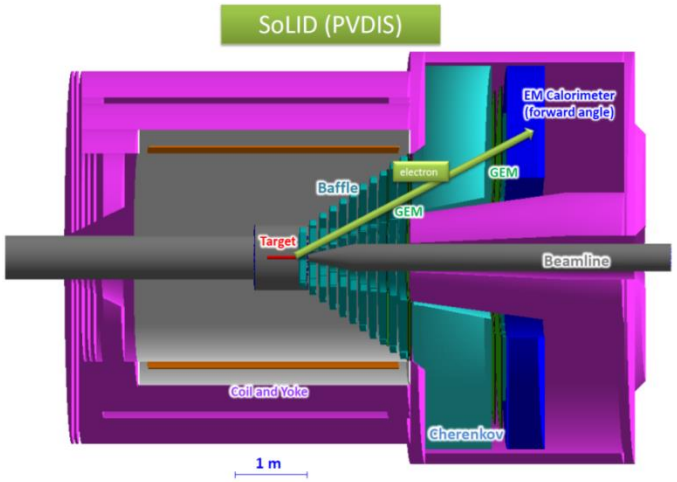
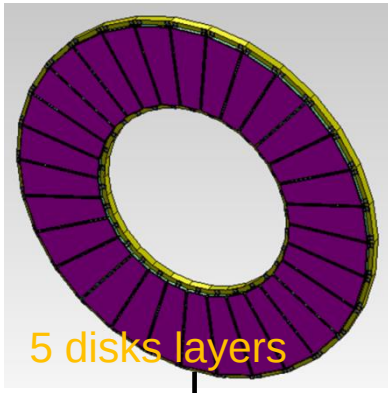
SoLID GEM Trackers: PVDIS and SIDIS configuration

Tracking requirements for PVDIS

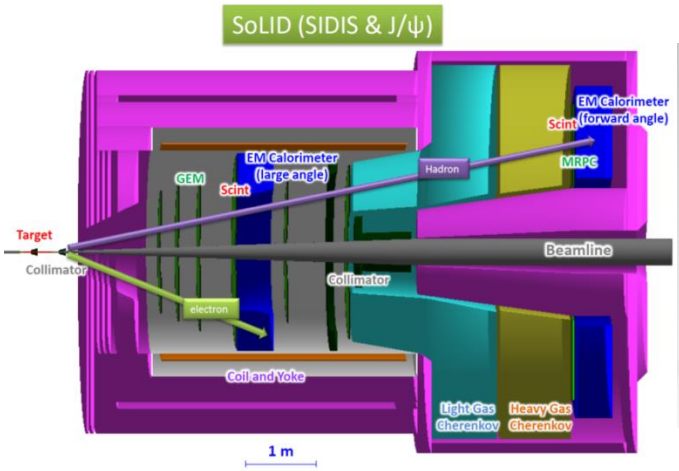
- Rate: from 100 kHz/cm^2 to 600 kHz/cm^2 (with baffles) from GEANT4 estimation
- Spatial Resolution: ~0.1 mm (σ) in azimuthal direction
- Total area: ~37 m^2 total area (30 sectors × 5 planes, each sector covering 12 degree)
- Need to be radiation and magnetic field tolerant

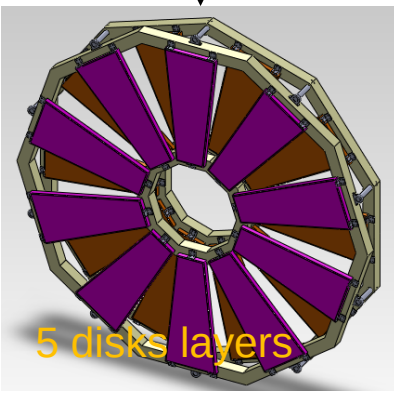


PVDIS



SIDIS





Idea

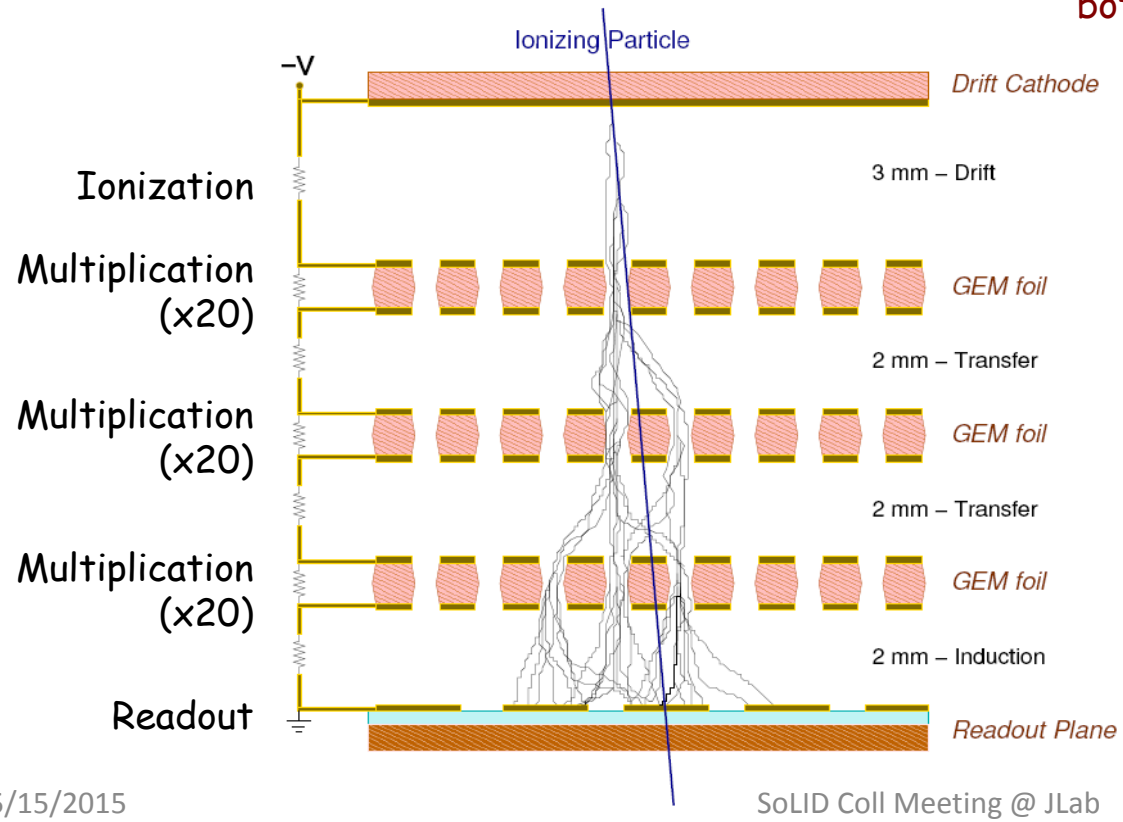
- GEM Modules shared by SIDIS and PVDIS configuration

But

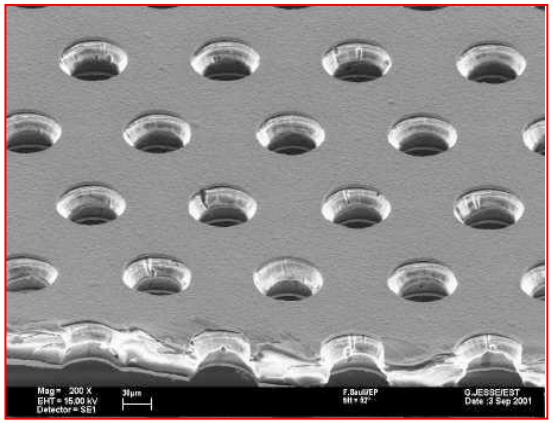
- We have to evaluate how much we can use the same modules for both configurations

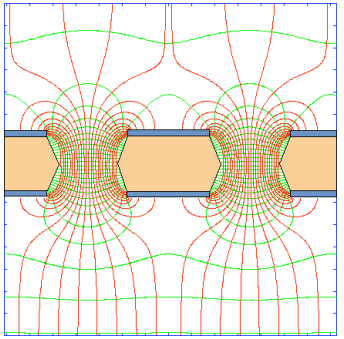
Large area GEMs for SoLID

- Rate capabilities higher than many MHz/cm^2
- High position resolution (< 75 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, STAR FGT, Prototypes for CMS upgrade, SBS etc.



GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch





Strong electrostatic field in the GEM holes

Large GEM chamber challenges for SoLID

- SoLID needs GEM modules as large at 113 $\times$ 55 cm^2.
- The biggest challenge used to be the non-availability of large area GEM foils.
- Not a problem anymore: CERN shop can produce 200 $\times$ 55 cm^2 now.
  - Previously limited by double mask technique for etching: hard to the two masks accurately: Max area was limited to ~ 45 $\times$ 45 cm^2
  - New Single Mask technique allows to make large GEM foils
  - UVa is building largest GEM chamber (120 $\times$ 55 cm^2) for pRad in Hall B
- One problem may be the production capacity of the CERN shop: especially if a LHC related large GEM project gets underway.
- Currently ongoing work for large GEM production capabilities in China and in the US.

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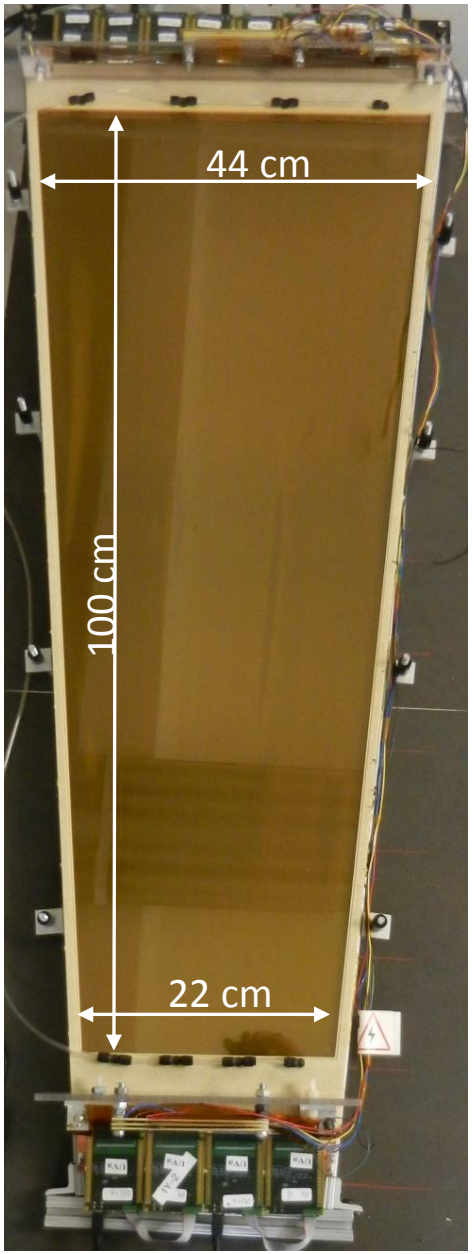
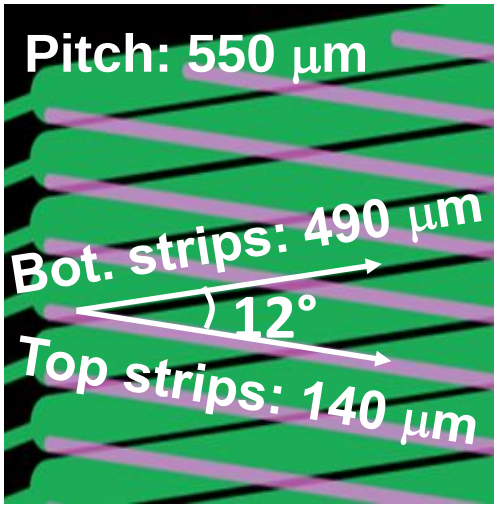
- GEM R&D program @ UVa
- Plans on SoLID-GEM specific R&D

R&D for EIC / SoLID Large GEM: Design of EIC-FT-GEM proto I

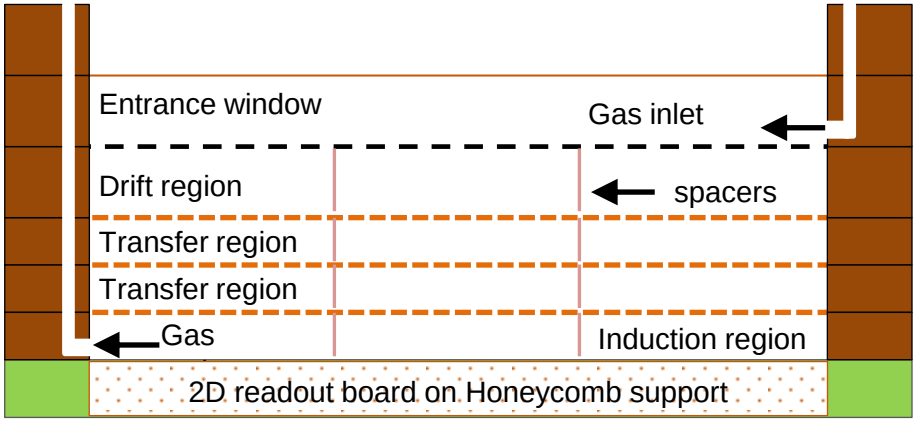
- **Key characteristics**
- Largest 2D GEM detector ever built: 100 cm × (44 cm – 22 cm)
- Low mass and small dead area full disk chamber
  - Narrow edge GEM frame support and honeycomb for the readout
  - All electronics on inner and outer radius side of the chamber
- Fine strips 2-d small stereo angle u/v readout on flexible board
  - Good position resolution and low capacitance noise



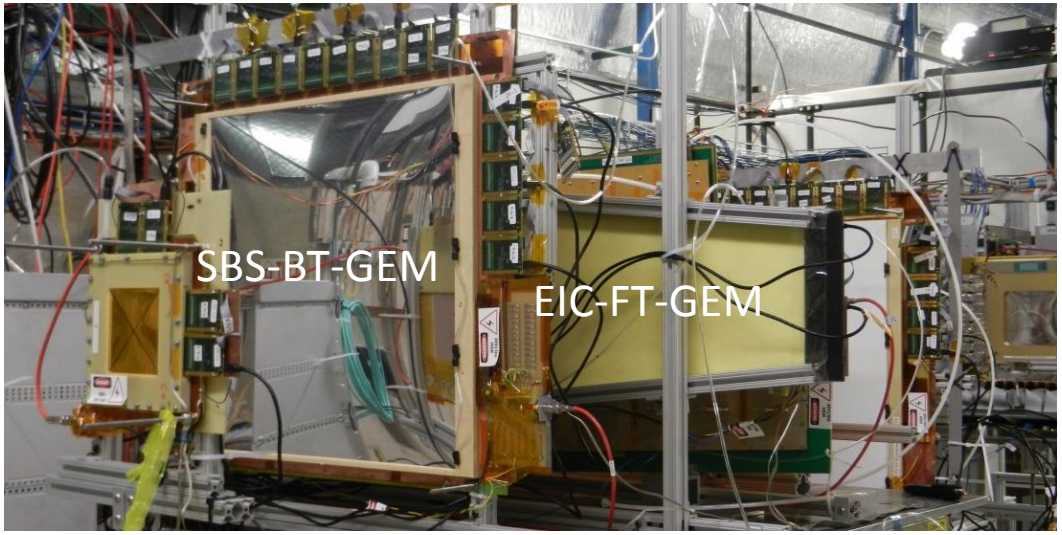
2D u/v readout strips



Cross section of low mass triple GEM



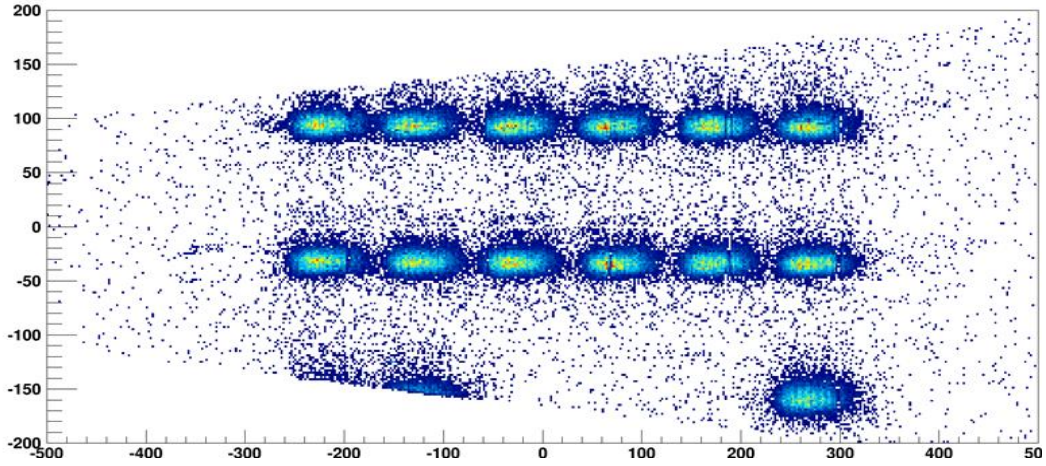
EIC-FT-GEM @ FTBF: Spatial resolution

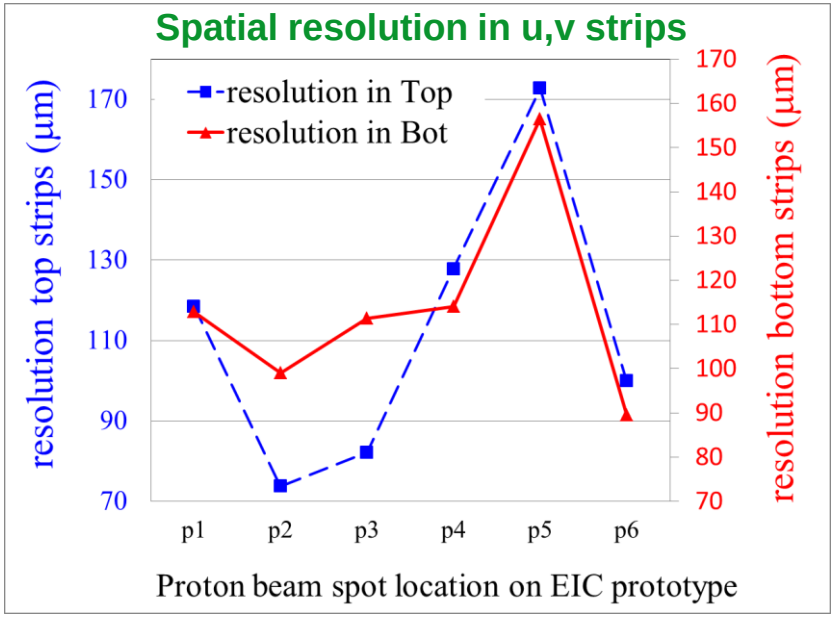


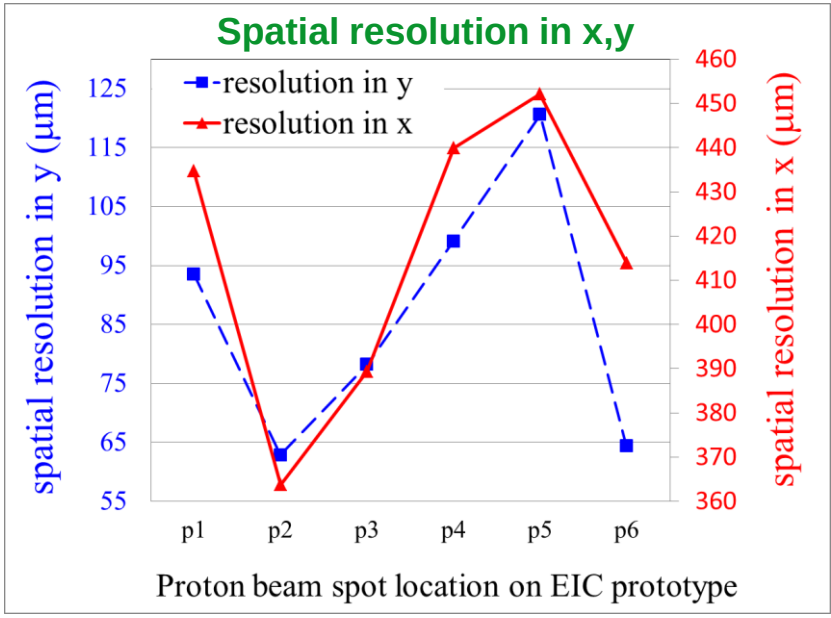
Good spatial resolution

- Better than 130 μm for the top and bottom strips
- Better than 100 μm (in azimuthal) for y and 450 μm for x

Hadron bean reconstruction from position scan





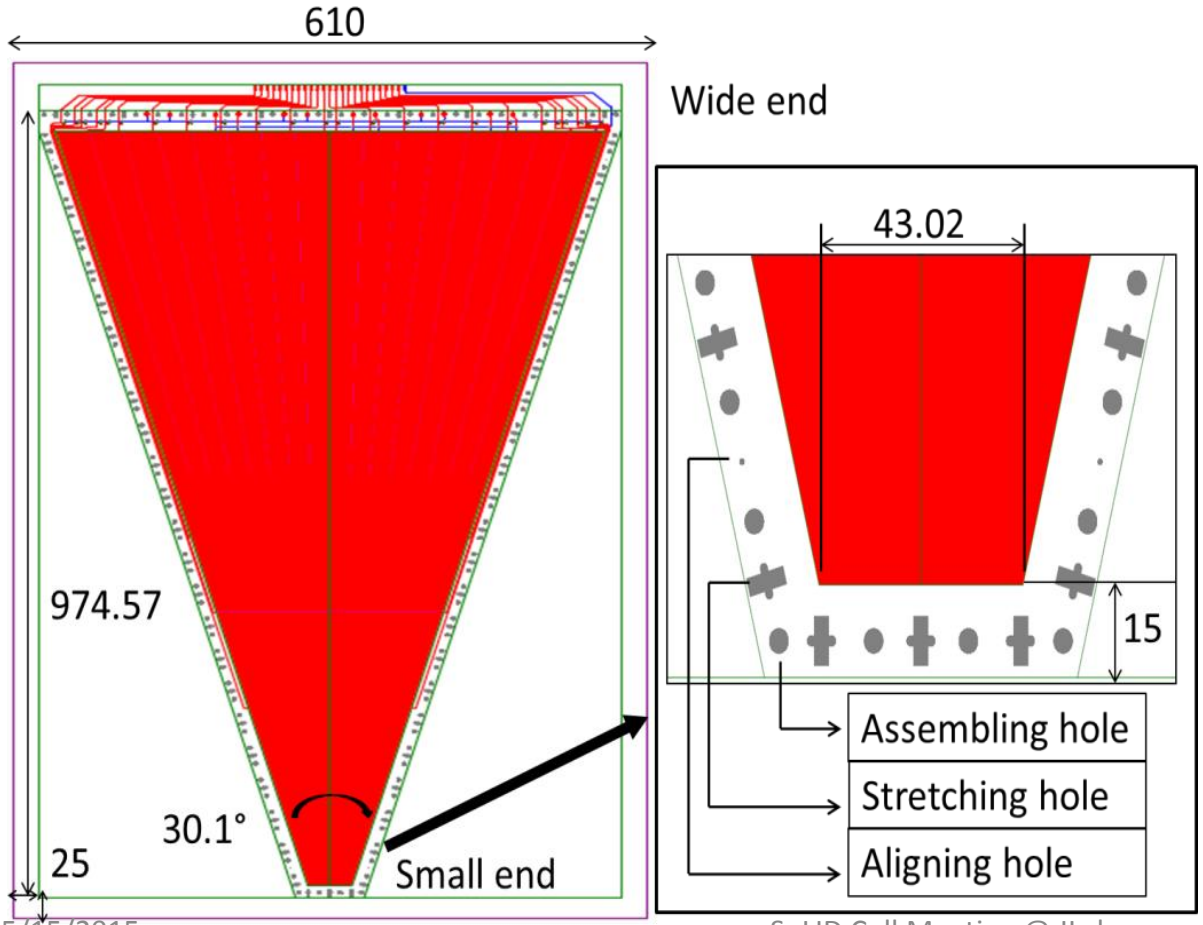


R&D for large GEMs: EIC-FT-GEM prototype II

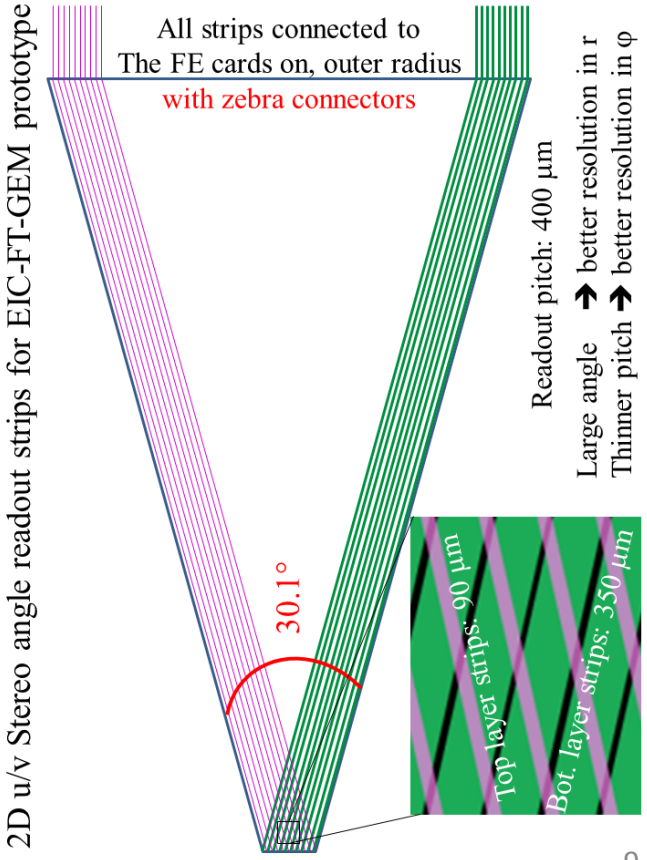
EIC GEM prototype II:

- Common GEM foil design between UVa, Florida Tech (FIT) and Temple Univ. (TU)
- Low mass and light detector, New detector construction technique
- New u/v strips readout design

Common GEM foil UVa, FIT and TU



u/v strips readout board



R&D for large GEMs: New assembly technique for large GEM

Idea:

- GEM foil stretched and glued to support frames
- Individual framed GEM stacked together in the assembled chamber
- O-ring and screws used to close the chamber and ensure the gas tighness

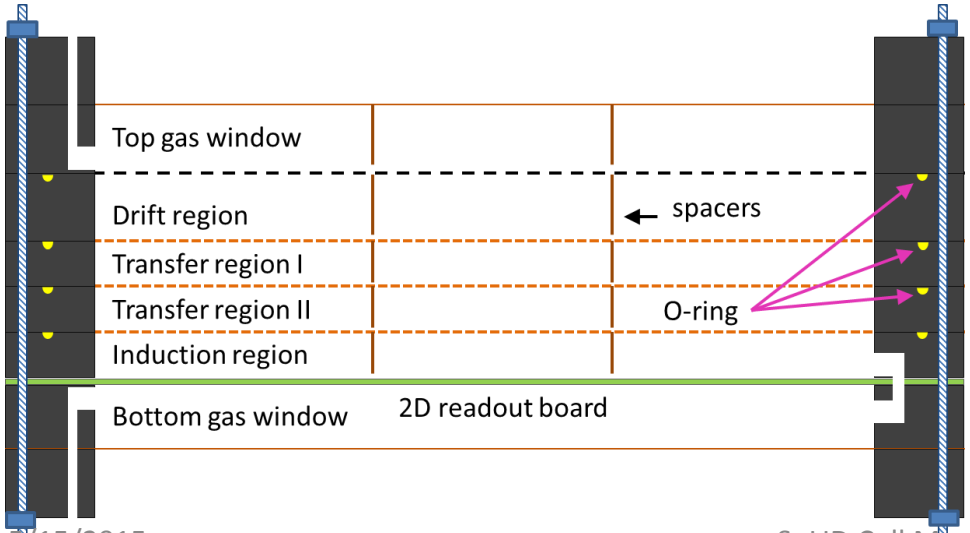
Pros:

- Possibility of easy replacement of GEM foils or readout board after assembly
- Work for light detector: plastic screw and narrow support frames, no rigid support needed
- Idea already being tested on the pRad GEM chamber

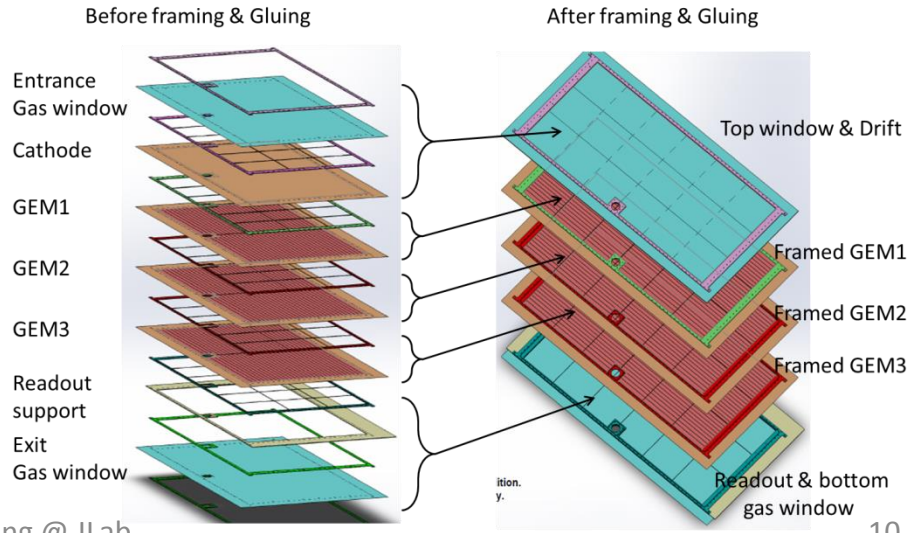
Cons:

- Need to evaluate gas tightness with O-ring + screw system
- Would still need spacers inside the active area

Cross section of triple GEM with new assembly

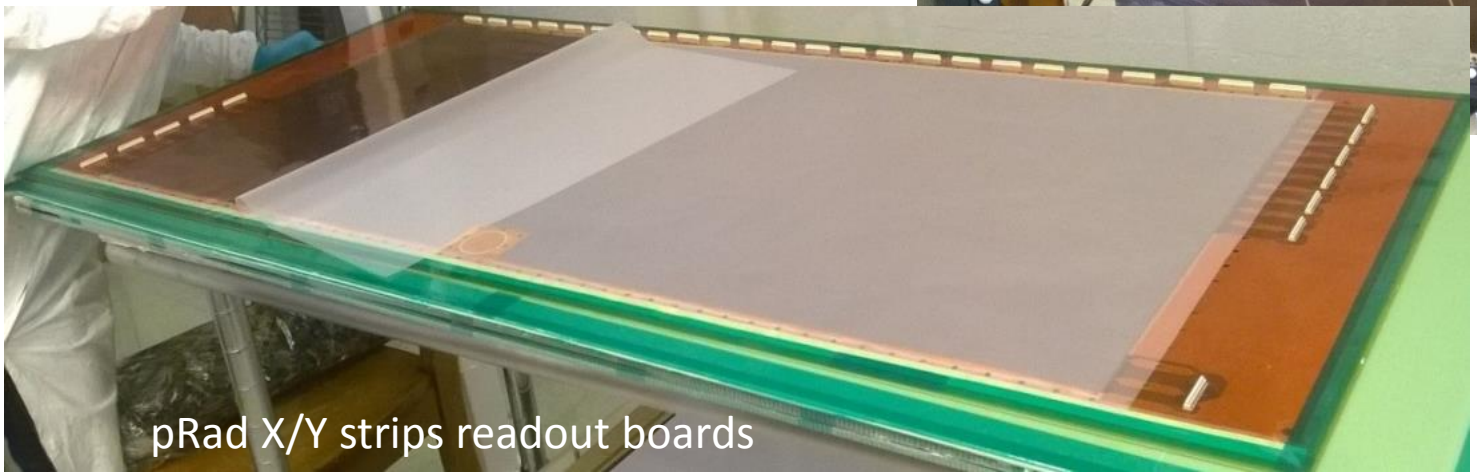


Exploded view of pRad GEM: 100 cm × 55 cm

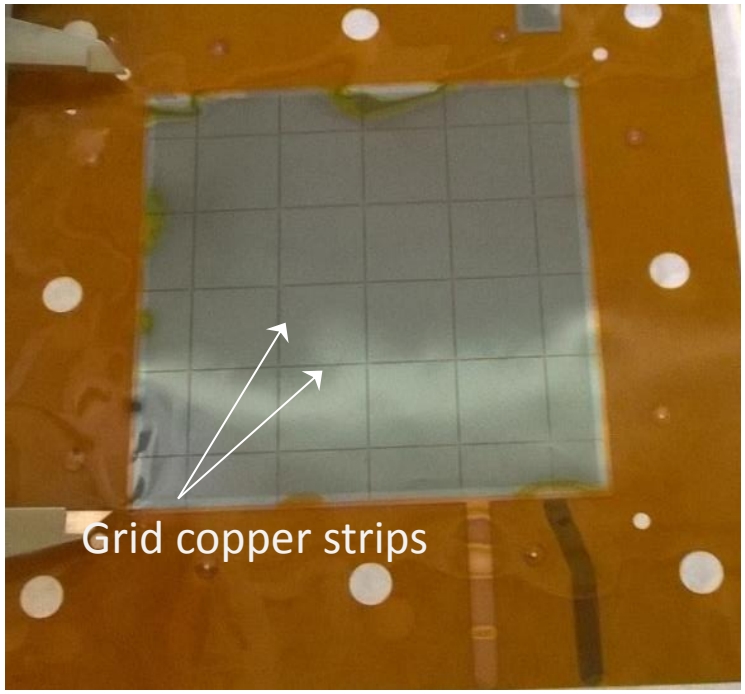


R&D for large GEMs: Assembly of the pRad GEM chamber

New assembly technique used for pRad chambers (See next slide)

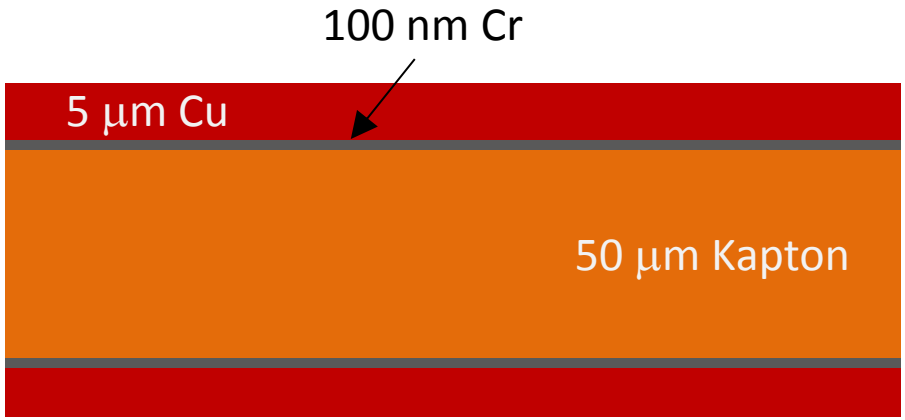


R&D for large GEMs: Copper Free GEM foil

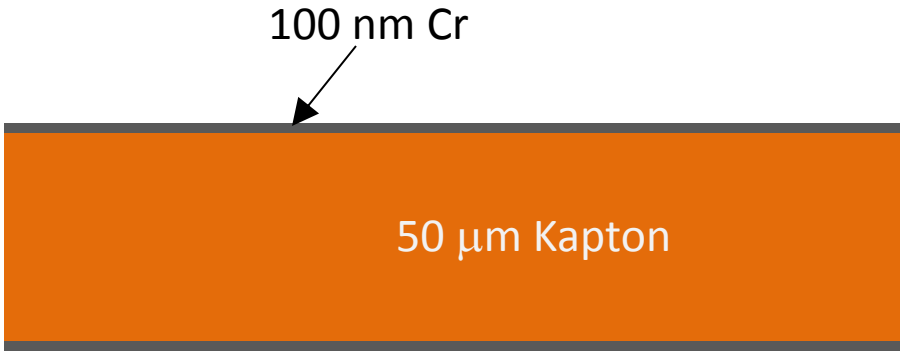


Cu-Free GEM foil

- Standard GEM foil with the copper layer removed
- Copper clad Kapton based material comes with 100 nm Chromium (Cr) layer between Cu and Kapton
- 100 nm Cr layer replace Cu as top and bottom GEM electrode
- Cu-Free GEM Samples from Rui with a grid of Cu strips



Standard GEM foil



Cu-Free GEM foil

R&D for large GEMs: radiation length of Cu-Free GEM

Triple-GEM detector 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
Drift							
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 detector with Cu-Free GEM foil

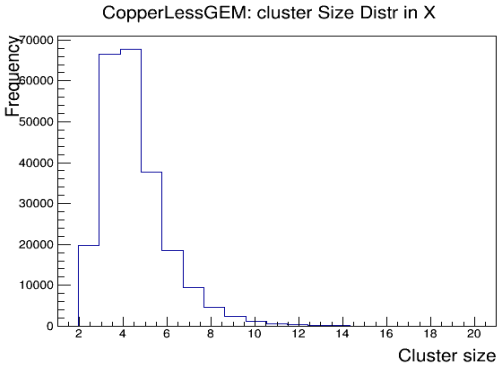
	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	0	8.96	14.3	1	0.0000	0.0000
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	0	8.96	14.3	0.8	0.0000	0.0000
Kapton	3	50	1.42	286	0.8	0.0420	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**

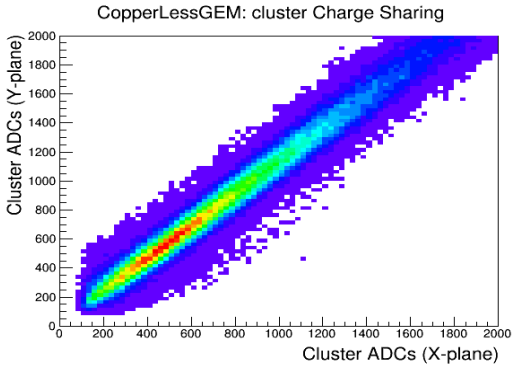
- Based on the data for the SBS-BT-GEM modules
- The contribution of the Cr layer has not been added but is negligible to the first order

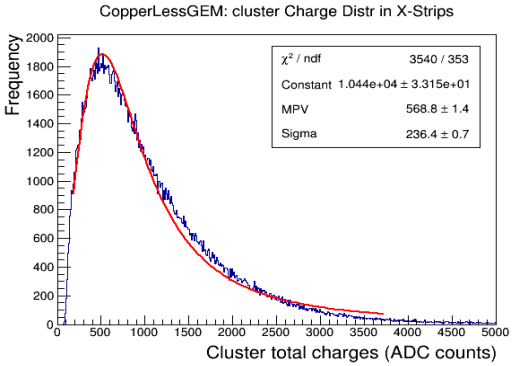
About 50% reduction in the material in a EIC-like chamber with Cu-Free GEM

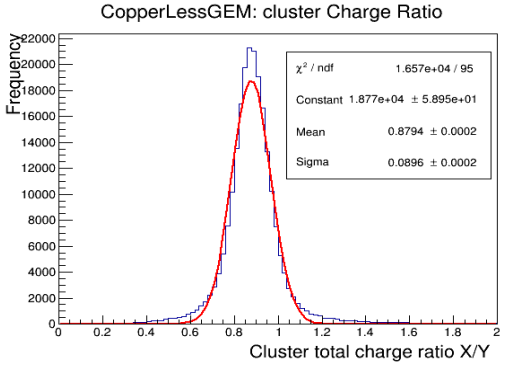
R&D for large GEMs: Preliminary tests of Cu-Free GEM

Tests with Cosmics

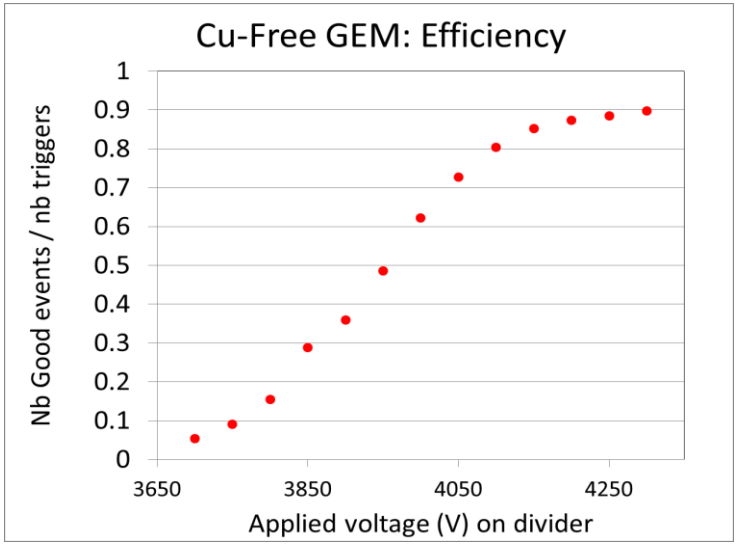


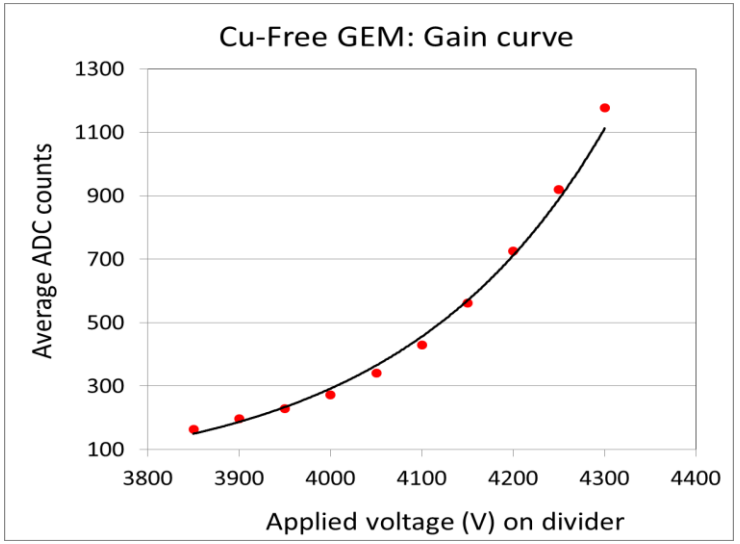






HV scan with Sr90 source





- Good performances of the Cu-free GEM
- Need to study spark rate and ageing of the foil
- High rate and long term performance study will be done with our x-ray source
- Investigate Cu-less COMPASS-like readout board

Outline

- GEM trackers for SoLID
- GEM R&D program @ UVa
- Plans on SoLID-GEM specific R&D

Pre R&D for SoLID GEM Chambers: First year

- Design of the GEM chambers for SoLID
  - CAD design (SolidWorks…) for all different size GEM modules and disks and associated readout boards and electronics and cabling …and full Integration inside SoLID
  - Implement new ideas for a more cost effective GEM support frames design
- Hardware
  - Cu-Free GEMs: High rate, ageing and spark rate capability
  - Readout strips board with zebra connectors
- Resources and timescale
  - Manpower: Undergraduate/graduate student to work on the 3D CAD drawings
  - Timescale: 6 to 12 months
  - Cost estimate for the R&D: 10 k$ (material and manpower)

Pre R&D for SoLID GEM Chambers: Second year

- Build large size prototype of Solid GEM
  - Incorporate the new assembly technique, new UV readout strip board
  - Large area Cu-Free GEM foil
- Test beam effort
  - Need some test beam for resolution studies (readout board, Cu-Free GEM etc …)
  - Probably at FNAL (FTBF) sometimes in Fall 2016
- Resources and timescale
  - Manpower: 1 (under) graduate student to work on the 3D CAD drawings
  - Timescale: 12 months
  - Cost estimate for the R&D: 40 k$ (material and manpower)

Large GEM foils suppliers for SoLID

- CERN
  - Already producing very large beyond 150 × 60 cm^2 ➔ pRad GEM foils size
  - Large volume production for projects outside CERN experiments might be an issue
- China
  - R&D on single mask technique
- Tech Etch (recommendation of the Director' review report)
  - Already active collaboration with EIC Tracking detector R&D for large GEM foils
  - Already producing 50 × 50 cm^2 with single mask technique ➔ limit of the current capability
  - Need support from all future large GEM users to upgrade their equipment for very large foil production (beyond 150 × 60 cm^2) ➔ this is very critical

Summary

- Large GEM R&D already on going at UVa
  - First pre-R&D prototype for EIC / SoLID GEM trackers (successfully tested @ FTBF)
  - Assembly of the largest GEM for pRad experiment is ongoing
- New R&D for on large GEMs
  - New assembly technique and frames design
  - Investigation of copper free GEM foils for low material detector
  - SoLID specific readout strip board
- Pre-R&D
  - Year I: Complete design & drawings of the GEMs for SoLID and small scale R&D projects
  - Year II: Building a full size SoLID GEM prototype and characterization in detector lab and at Test Beam

Backup

Shared GEM modules between SIDS and PVDIS

- Data for SoLID based on CLEOv8 field map, updated in 01/30/2015 on the wiki page
- Modules from 2 layers can be shared between SIDIS and PVDIS with a little bit of imagination
- Modules dimensions based on current maximum GEM foil dimension

Exp.	layer	R in	R out	Length	Nb of Modules	Outer Width	Inner Width	Z
SIDIS	1	45	80	35	10	55	28.28	-175
PVDIS	1	56	108	52	13	55	27.07	157.5
SIDIS	5	46	98	52	12	55	24.09	5
PVDIS	3	67	129	62	15	55	28.07	190
SIDIS	6	58	122	64	14	55	26.04	92
SIDIS	2	26	96	70	11	55	14.86	-150
SIDIS	3	30	107.5	77.5	13	55	14.5	-119
PVDIS	2	59	143	84	17	55	21.81	185.5
SIDIS	4	37	135	98	16	55	14.53	-68
PVDIS	4	113	215	102	25	55	28.4	306
PVDIS	5	117	222	105	26	55	28.28	315
TOTAL					**172**			
TOTAL with shared modules					**149**			

Shared modules

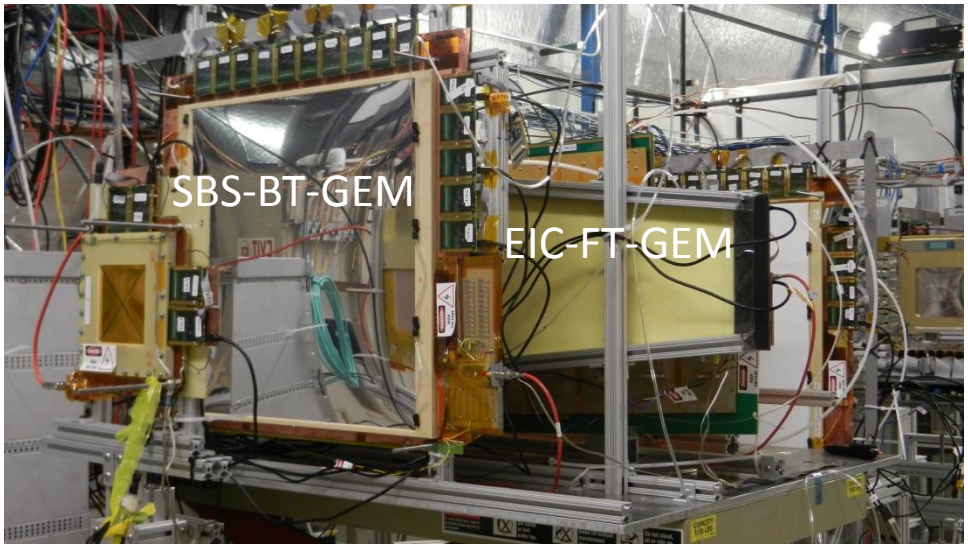
Shared modules

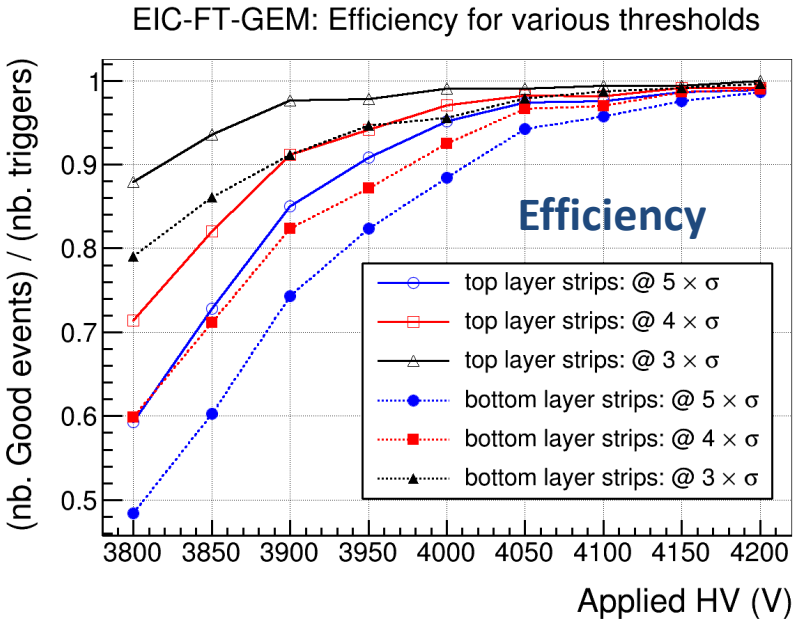
SBS-BT-GEM: Production

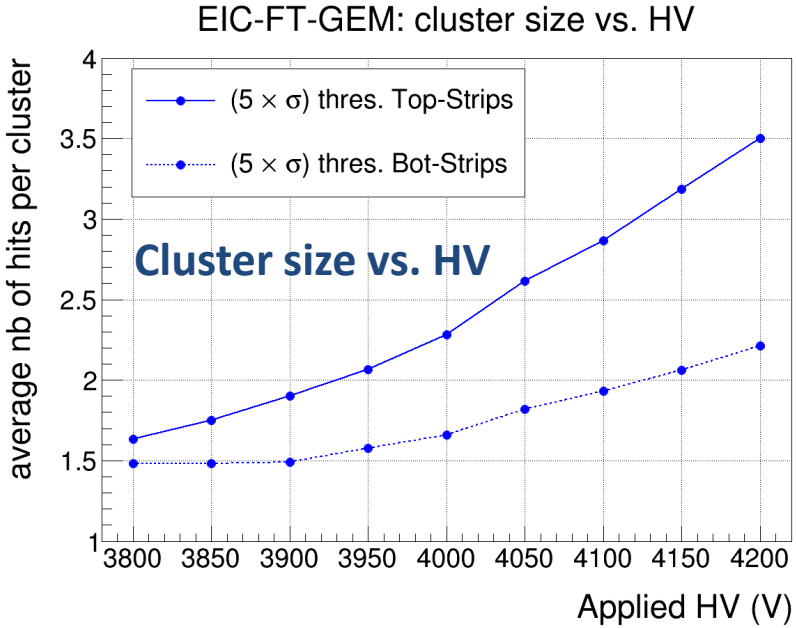
Production of the SBS-BT-GEM Modules

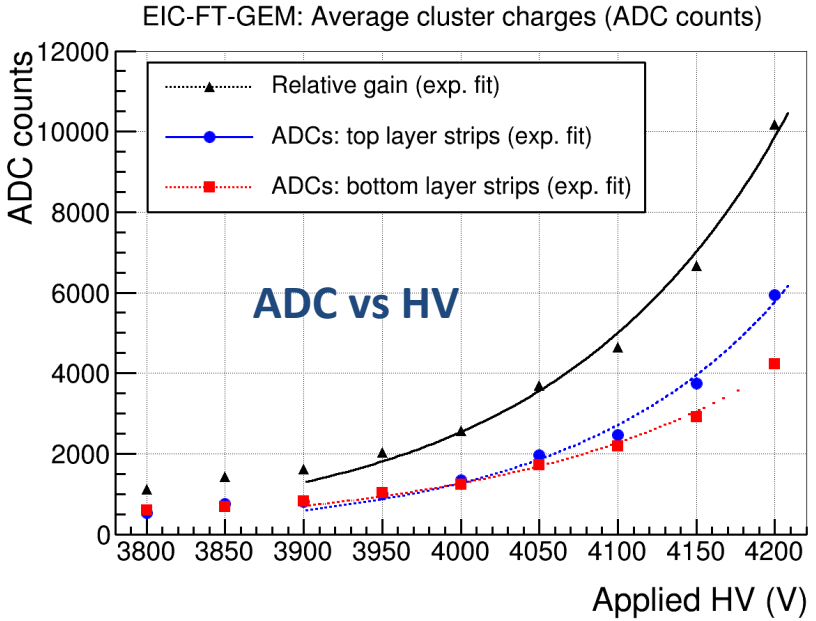
- 40 modules to be built by July 2017
- 13 modules already built as of May 09, 2015
- successfully passes the ultimate test with cosmics
  - 2 HV sector out of 1170 (13 × 3 × 30) was shorted and disabled
- Last 1 modules just out of the clean room and will be tested in the coming days
- Construction rate of 2 SBS modules / month

EIC-FT-GEM @ FTBF: Performances

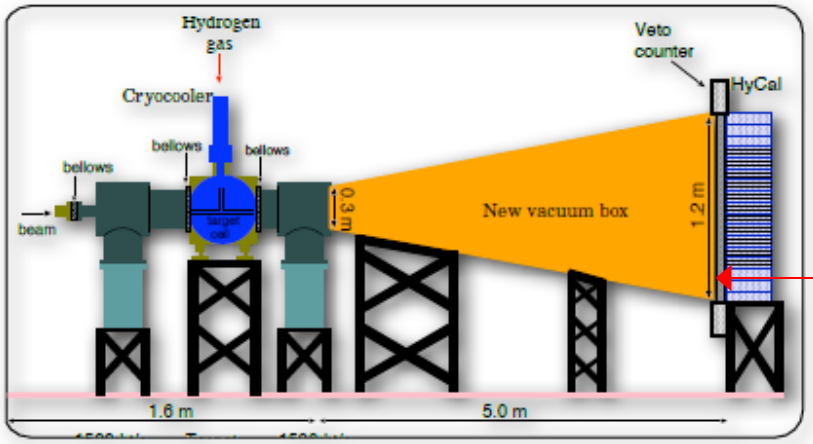








pRad GEM: Proton Radius Experiment pRad @ JLab



Spokesperson: A. Gasparian,
Co-spokespersons: M. Khandaker, H. Gao and D. Dutta

The PRad experiment in JLab Hall-B

Approved with A rating

- High resolution, Hybrid calorimeter (Magnetic Spectrometer Free)
- Windowless H_2 gas flow target
- Simultaneous detection of elastic and Moller electrons
- Vacuum box, one thin window
- Q^2 range of $2x10^{-4} – 2.0x10^{-2}$ GeV^2 (lower than all previous electron scattering expts.) (using a 1.1 and 2.2 GeV electron beam)

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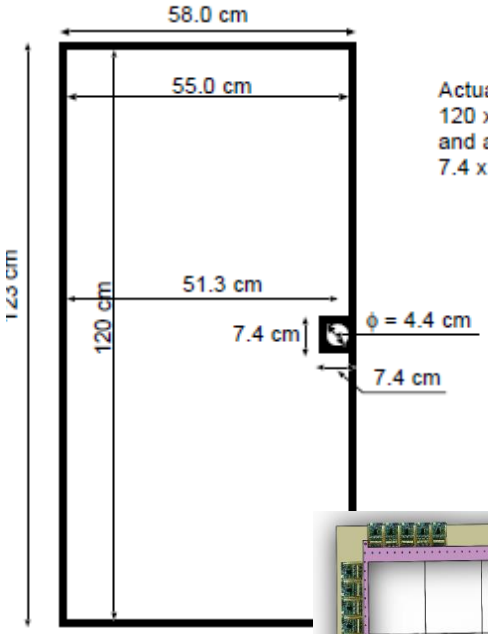
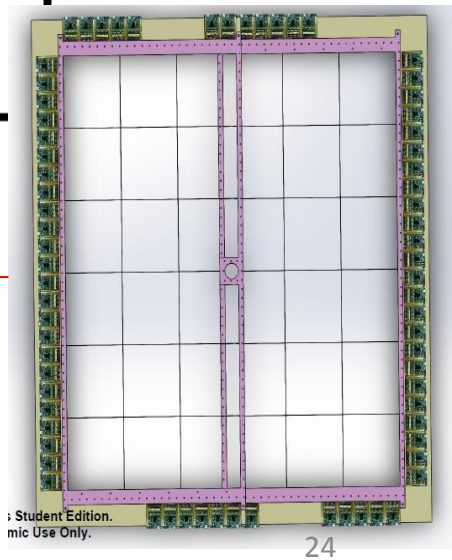
Slide from D. Dutta, PasSpin, Ji'nan, China, Oct. 30, 2013

GEM chambers: X-Y veto counter

ed Sensitive area: 116.4 x 116.4 cm^2
al hole: diameter 4.4 cm, including the frame max allowed
num allowable non-sensitive region 7.8 x 7.8 cm^2

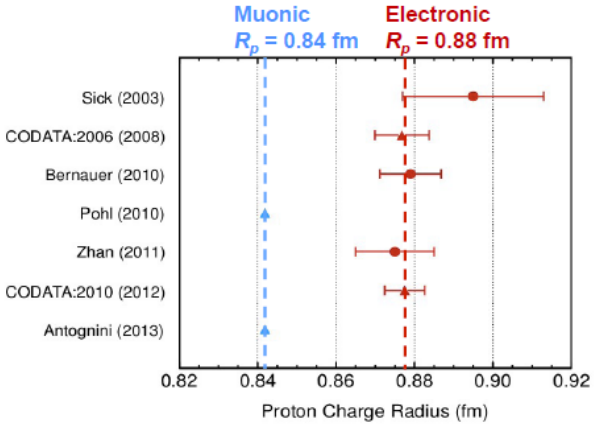




Proton Radius Experiment pRad @ JLab

The proton radius puzzle

- >7σ discrepancy between **muonic** and **electronic** measurements
- High-profile articles in Nature, NYTimes, etc.
- Puzzle unresolved, possibly New Physics



▲ Spectroscopy
● Scattering

R_p = 0.84184(67) fm
R_p = 0.875(10) fm
R_p = 0.8775(51) fm
R_p = 0.84087(39) fm

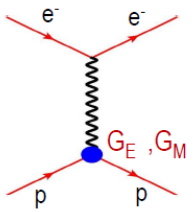
es from M. Kohl
N2013, Paphos, Cyprus 2013

Proton charge radius: ep elastic scattering

- First Born approximation (one photon exchange):

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^{p\,2}(Q^2) + \frac{\tau}{\varepsilon} G_M^{p\,2}(Q^2)\right)$$

$$Q^2 = 4EE'\sin^2\frac{\theta}{2} \qquad \tau = \frac{Q^2}{4M_p^2} \qquad \varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$



- Structureless proton:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} = \frac{\alpha^2\left[1-\beta^2\sin^2\frac{\theta}{2}\right]}{4k^2\sin^4\frac{\theta}{2}}$$

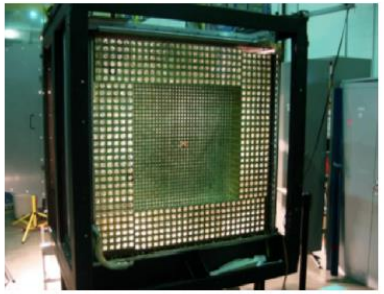
- G_E and G_M from Rosenbluth separation
  Can ignore G_M at extremely low Q^2, (assumed in PRad)
- Taylor expansion at low Q^2:

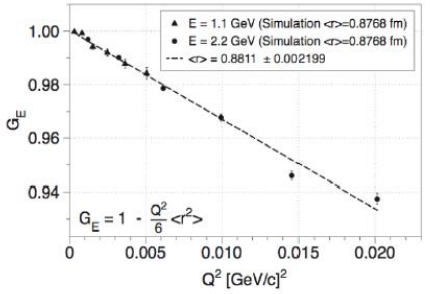
$$G_E^p(Q^2) = 1 - \frac{Q^2}{6}\langle r^2\rangle + \frac{Q^4}{120}\langle r^4\rangle + \ldots$$

- Definition of the Proton Radius:
  rms charge radius from slope of G_E

$$\langle r^2\rangle = -6\frac{dG_E^p(Q^2)}{dQ^2}\bigg|_{Q^2=0}$$

The PRad proton radius proposal (JLAB)





- Low intensity beam in Hall B @ Jlab into windowless gas target
- Scattered ep and Moller electrons into HYCAL at 0°
- Lower Q^2 than Mainz. Very forward angle, insensitive to 2γ, G_M
- Conditionally approved by PAC38 (Aug 2011): ``Testing of this result is among the most timely and important measurements in physics.''
- Approved by PAC39 (June 2012), graded "A"