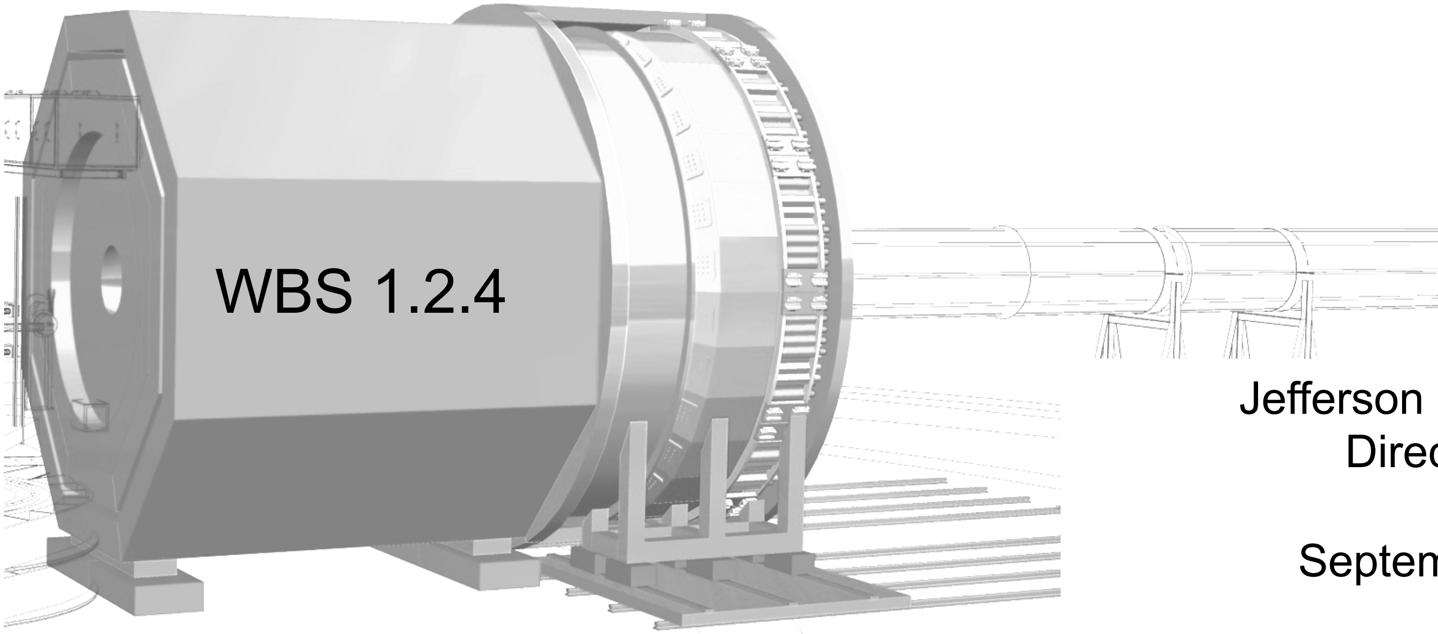
Gas Electron Multiplier (GEM) Tracker



Jefferson Lab SoLID Project
Director's Review

September 9-11, 2019

SOLENOIDAL LARGE INTENSITY DEVICE

Nilanga Liyanage

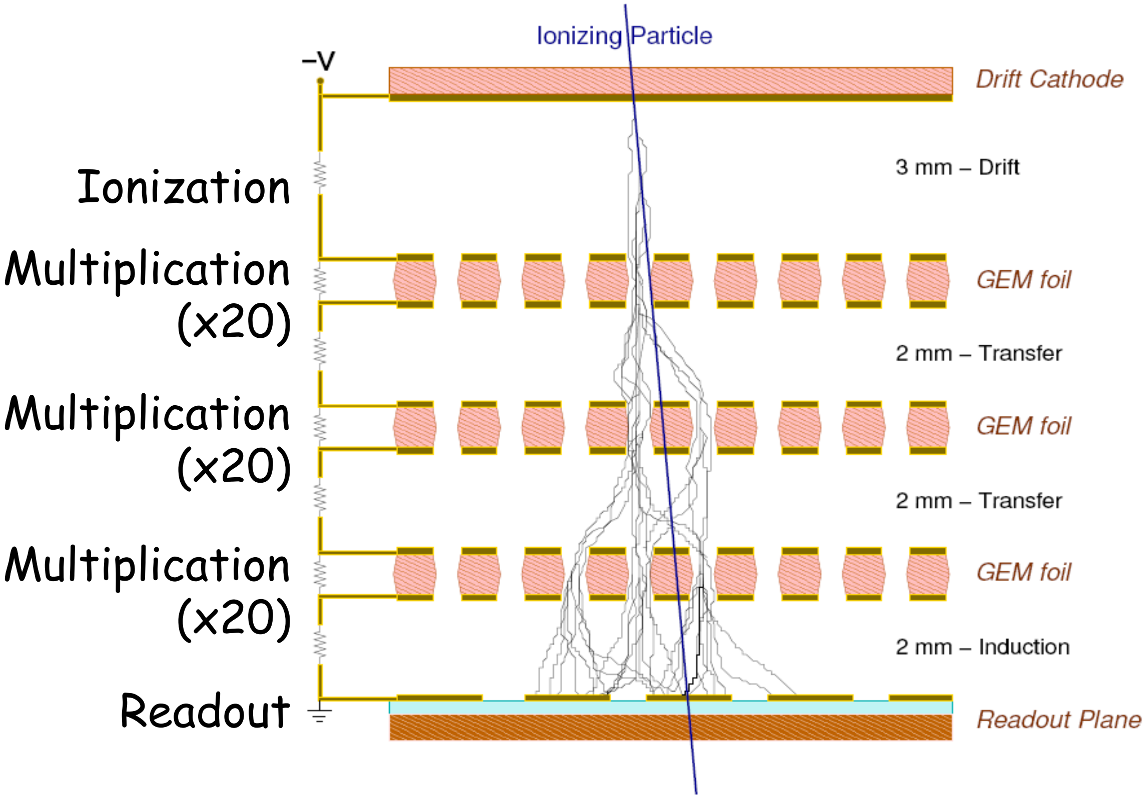
SoLID GEM Group
University of Virginia

Outline

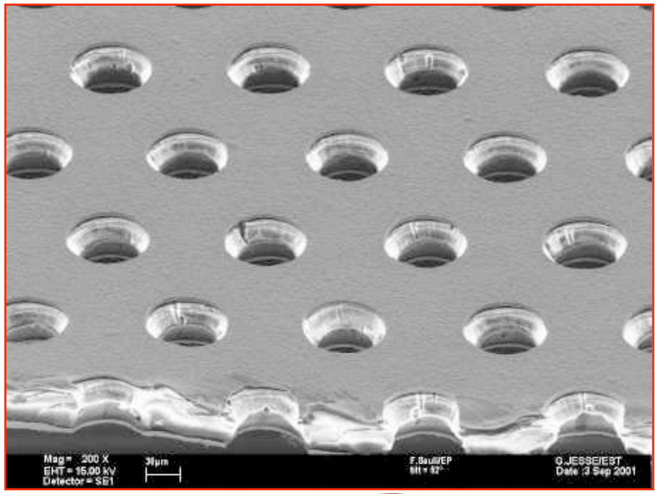
1. Why GEMs for SoLID ?
2. Requirements and Design
3. Technical Risks
4. Cost and Duration and basis
5. EH&S Considerations
6. Addressing Previous Director's Review Recommendations

Why GEMs

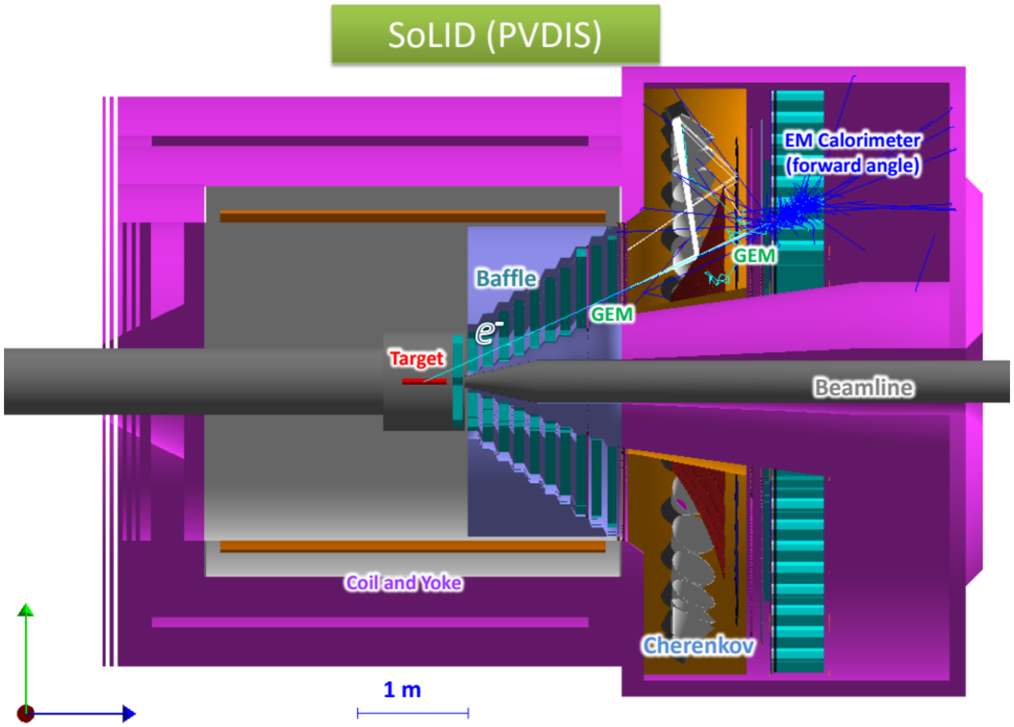
- SoLID concept leads to need for high rate trackers with good position resolution.
- GEMs: cost effective for high resolution tracking under high rates over large areas.
  - Rate capabilities higher than many MHz/cm^2
  - High position resolution (< 75 μm)
  - Ability to cover very large areas (10s – 100s of m^2) at modest cost.
  - Low thickness (~ 0.5% radiation length)
- Used for many experiments around the world: COMPASS, CMS upgrade, ALICE TPC, pRad, SBS etc.

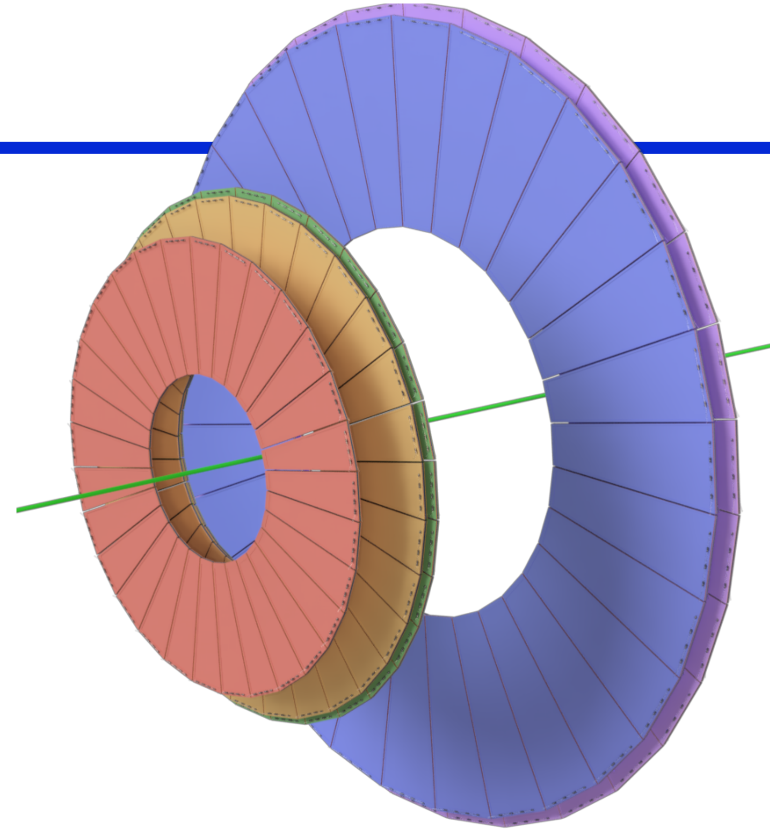


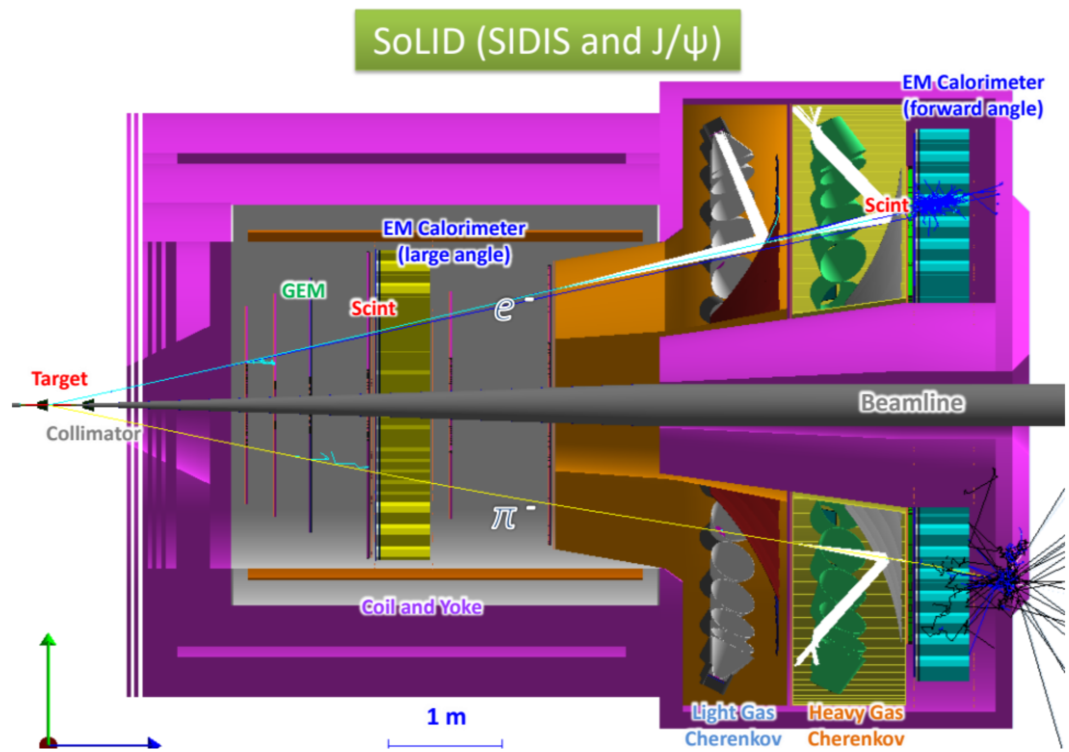
GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch

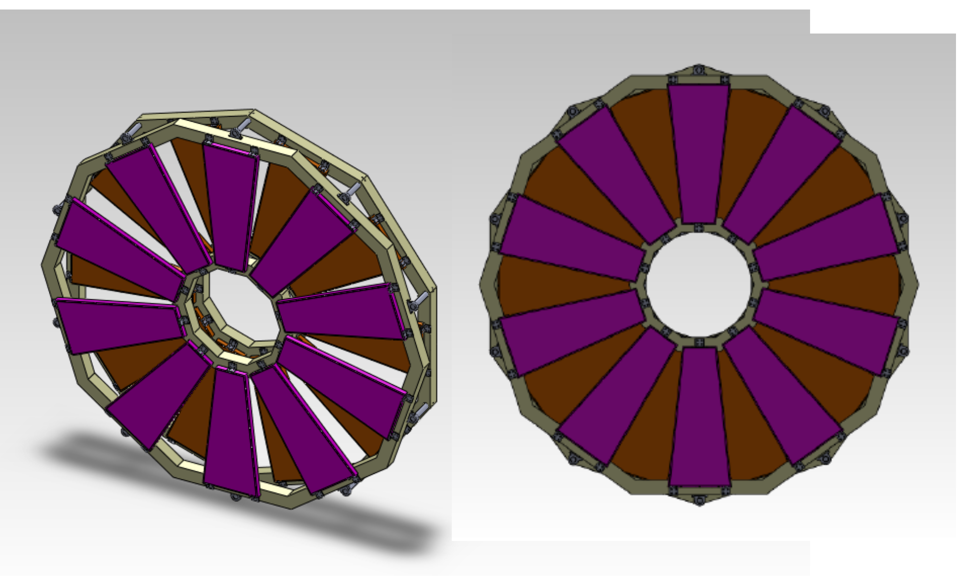


GEM Overview





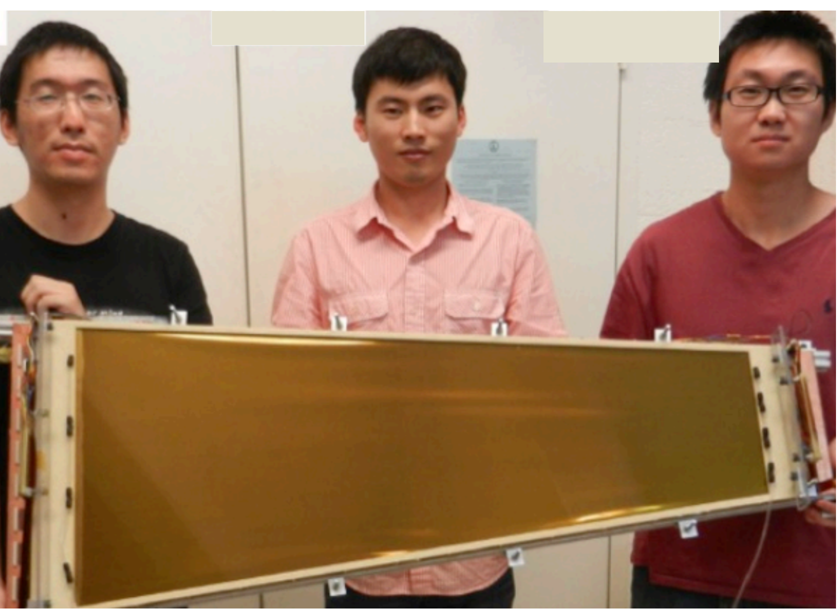


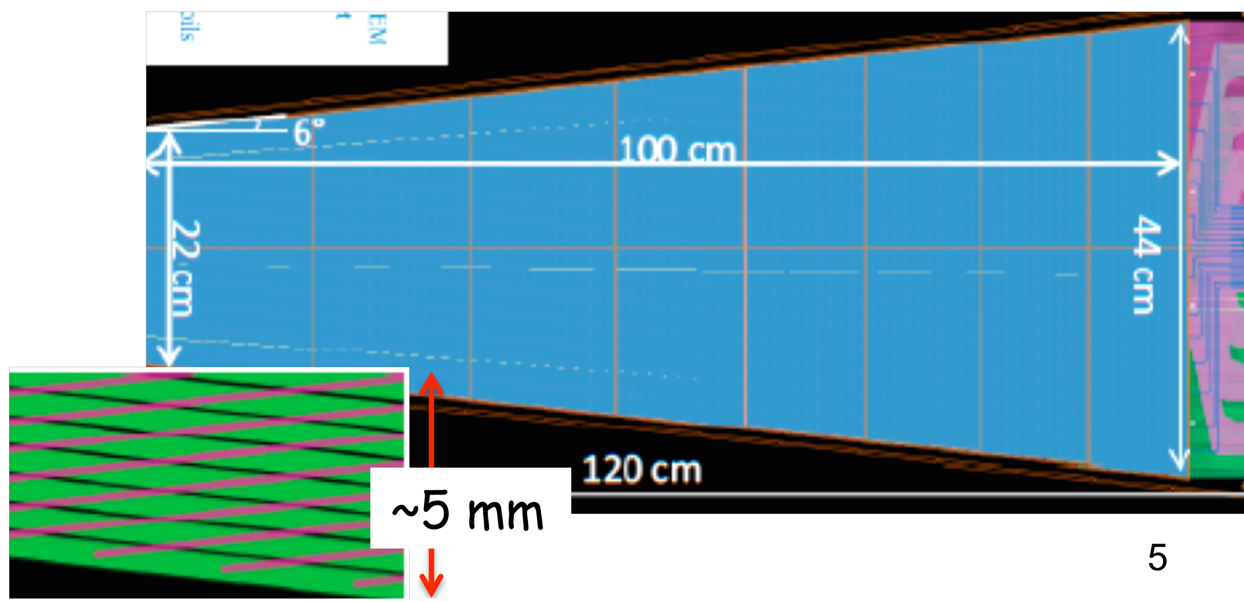


GEM Requirements: for all experiments

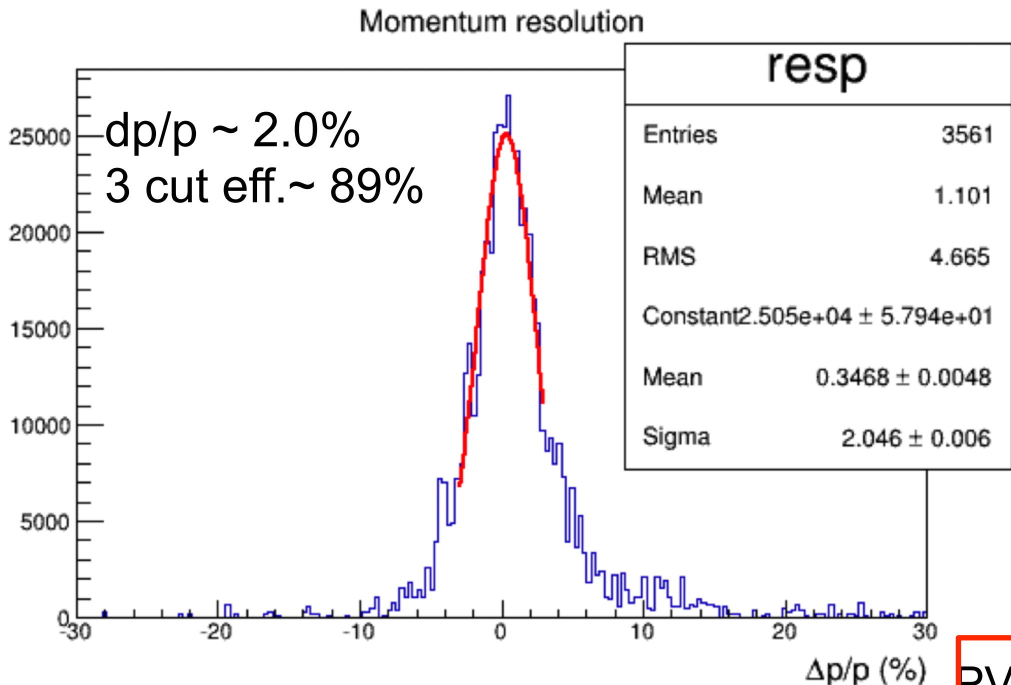
- ❑ Good position resolution
  - ❑ 100 μm (1 mm) in azimuthal (radial) direction.
    - ➢ 2D U-V readout with 12-degree stereo angle between strips
    - ➢ 400 μm (600 μm) strip pitch for layers 1-3 (5-6)
- ❑ 92 % overall GEM-module efficiency.
- ❑ modules with a trapezoidal geometry, with 12^o angular width
- ❑ All readout electronics located at the outer edge: Given radiation exposure map.
- ❑ Side frames need to be very narrow: minimize material thickness in active area (especially for SIDIS, J/Ψ)

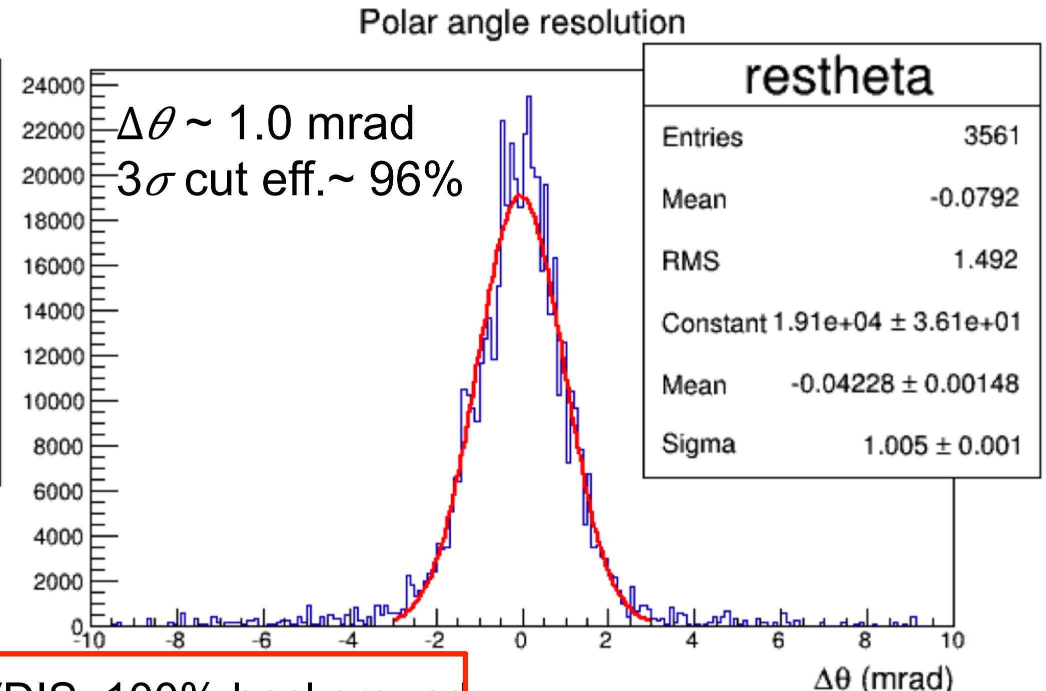
All requirements follow from tracking and neutron/radiation dose simulation to meet SoLID conditions.



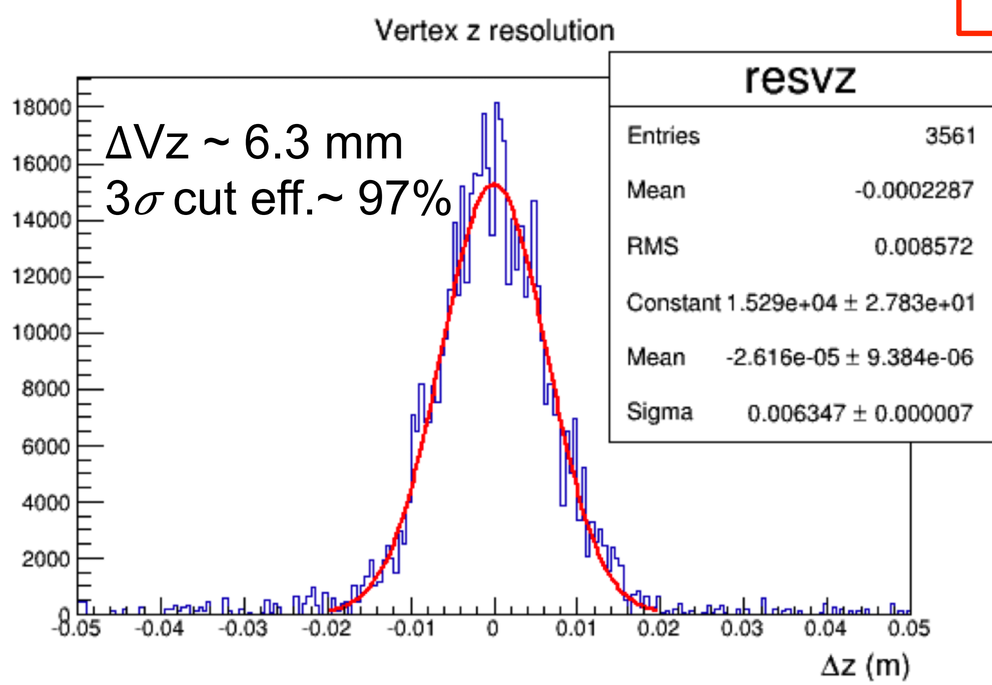


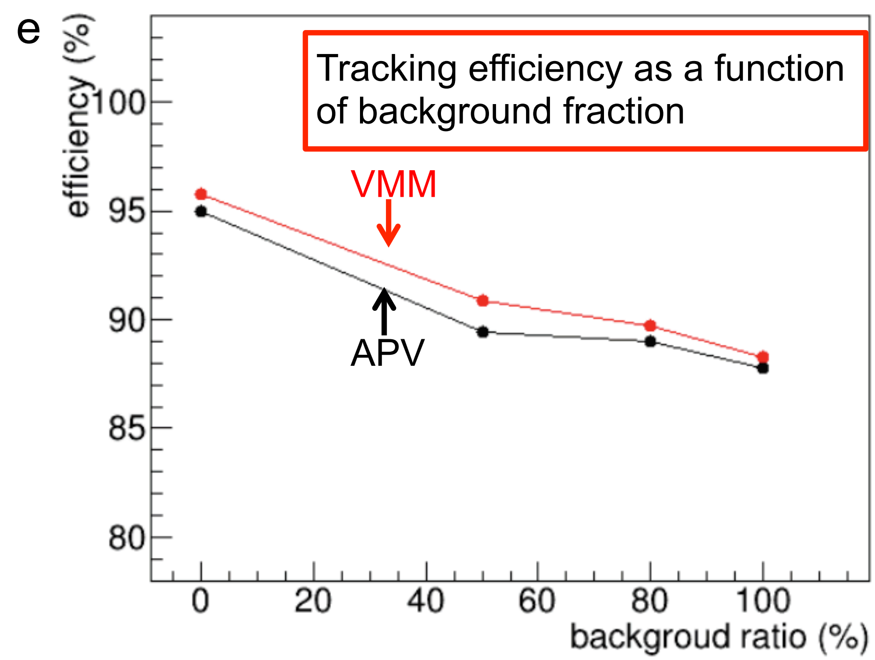
Tracking simulation results under those specs





PVDIS, 100% background case, with VMM





GEM Requirements and Design: PVDIS

- High rate operation up to localized hit rates of approximately 1 MHz/cm^2.
- Instrument 5 locations with GEMs:
  - 30 GEM modules a location: each module with a 12-degree angular width.

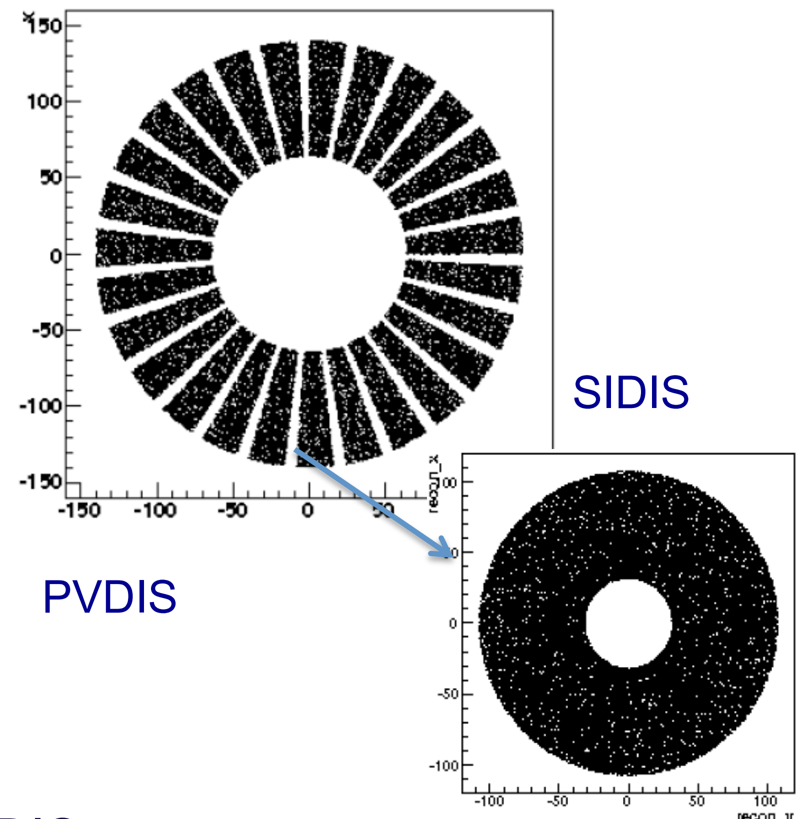
Location	Z (cm)	R_{min} (cm)	R_{max} (cm)	Surface (m^2)	# chan
1	157.5	51	118	3.6	24 k
2	185.5	62	136	4.6	30 k
3	190	65	140	4.8	36 k
4	306	111	221	11.5	35 k
5	315	115	228	12.2	38 k
Total				$\approx$ 36.6	$\approx$ 164 k

- The high occupancy at layer #1: may require splitting each readout strip into two channels: this will add another 12 k channels
- So, total number of channels needed could be : ~ 176 k
- With ~ 15% spares (to account for losses during production etc.) need to plan for 200 k readout channels
- Lot of data at high occupancy; but we can have multiple parallel DAQs

GEM Requirements and Design: SIDIS

- ❑ Compared to PVDIS, rates a bit lower: 0.15 MHz/cm^2.
- ❑ But need to read the whole layer based on a single trigger: no sectors here: no possibility to have many parallel DAQs.
  - ➢ bandwidth could be an issue: but ways to handle it.
- ❑ Instrument 6 locations with GEMs:

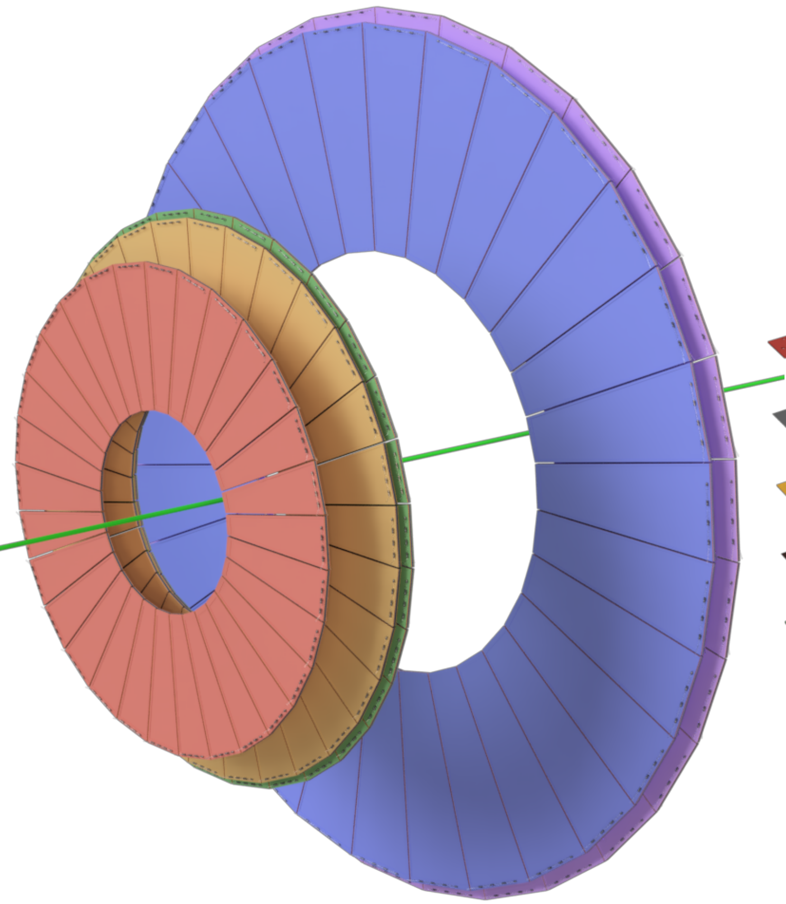
Plane	Z (cm)	R_I (cm)	R_O (cm)	Active area (m^2)	# of channels
1	-175	36	87	2.0	24 k
2	-150	21	98	2.9	30 k
3	-119	25	112	3.7	33 k
4	-68	32	135	5.4	28 k
5	5	42	100	2.6	20 k
6	92	55	123	3.8	26 k
total:				~20.4	~ 161 k



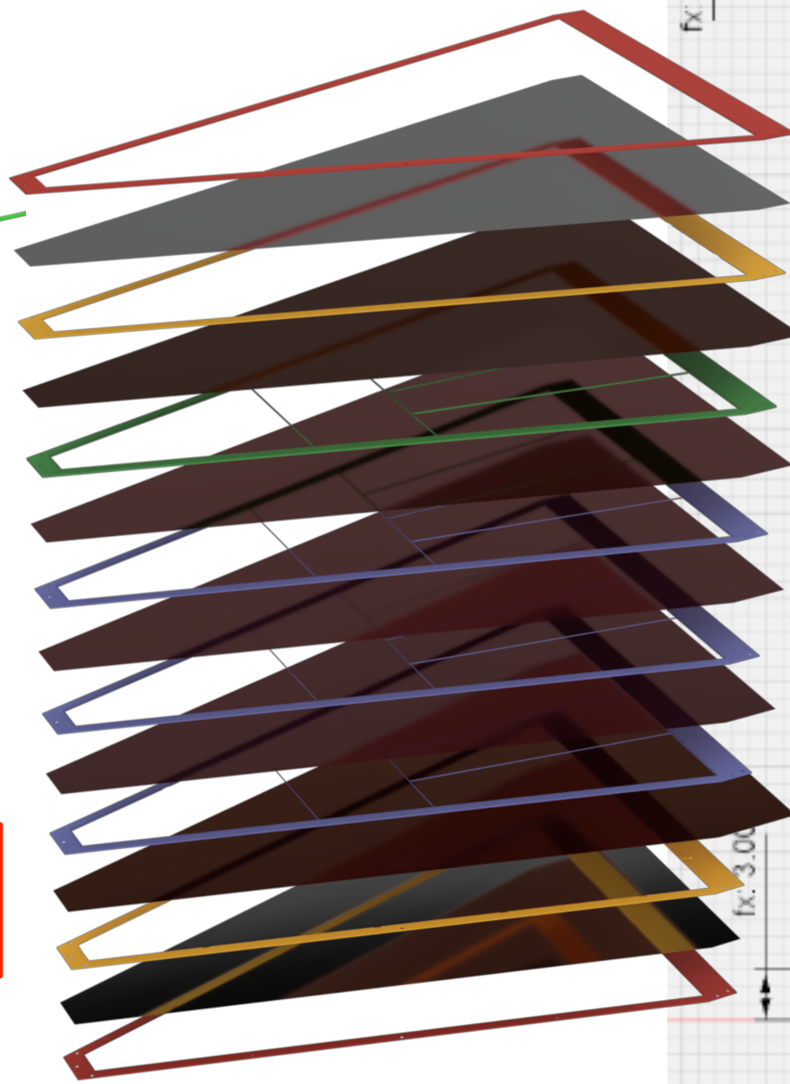
➢ More than enough electronic channels from PVDIS setup.

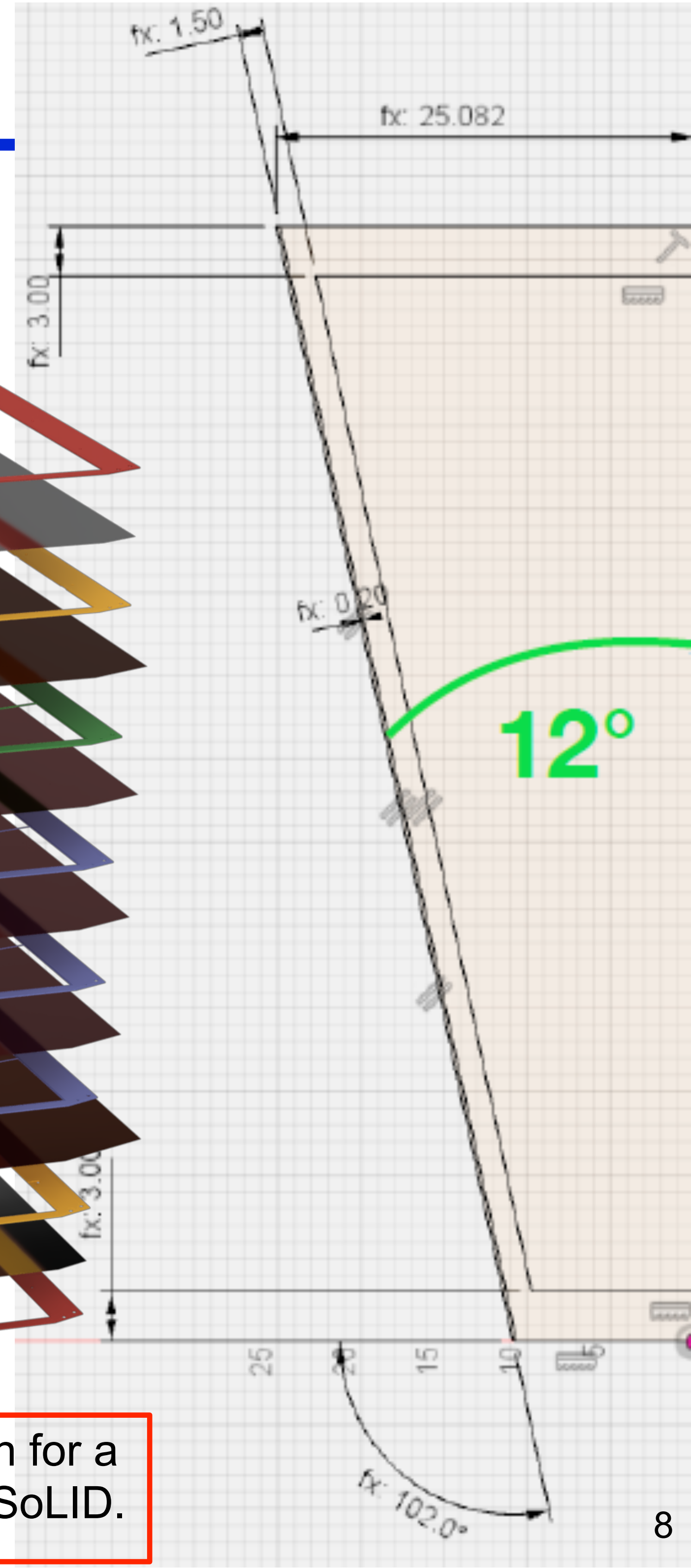
➢ The two configurations will work well with no need for new GEM or electronics fabrication.

GEM Requirements and Design



PVDIS GEM tracker arrangement

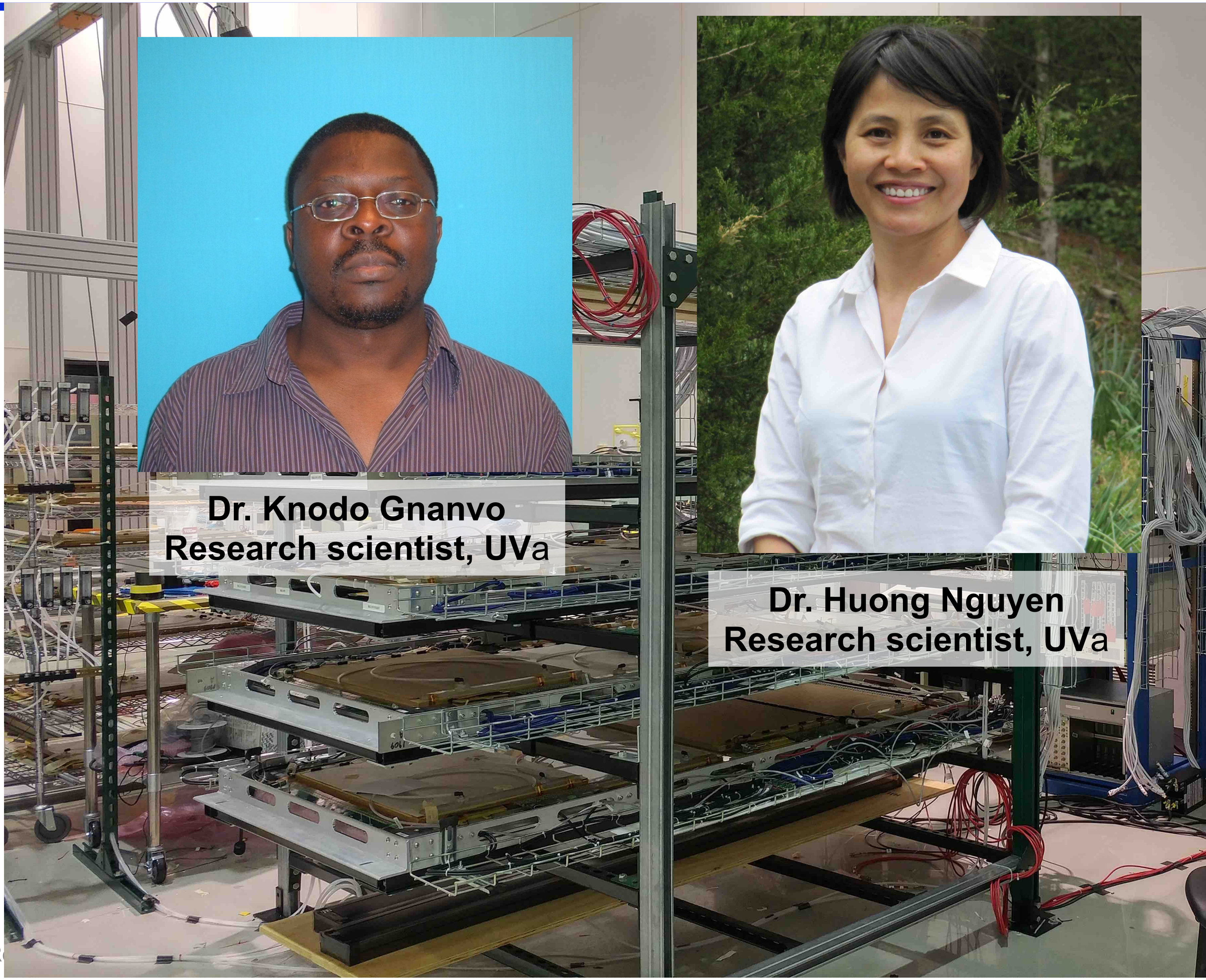




CNC-ready CAD design for a single GEM module for SoLID.

Experience and Expertise for SoLID GEM from SBS

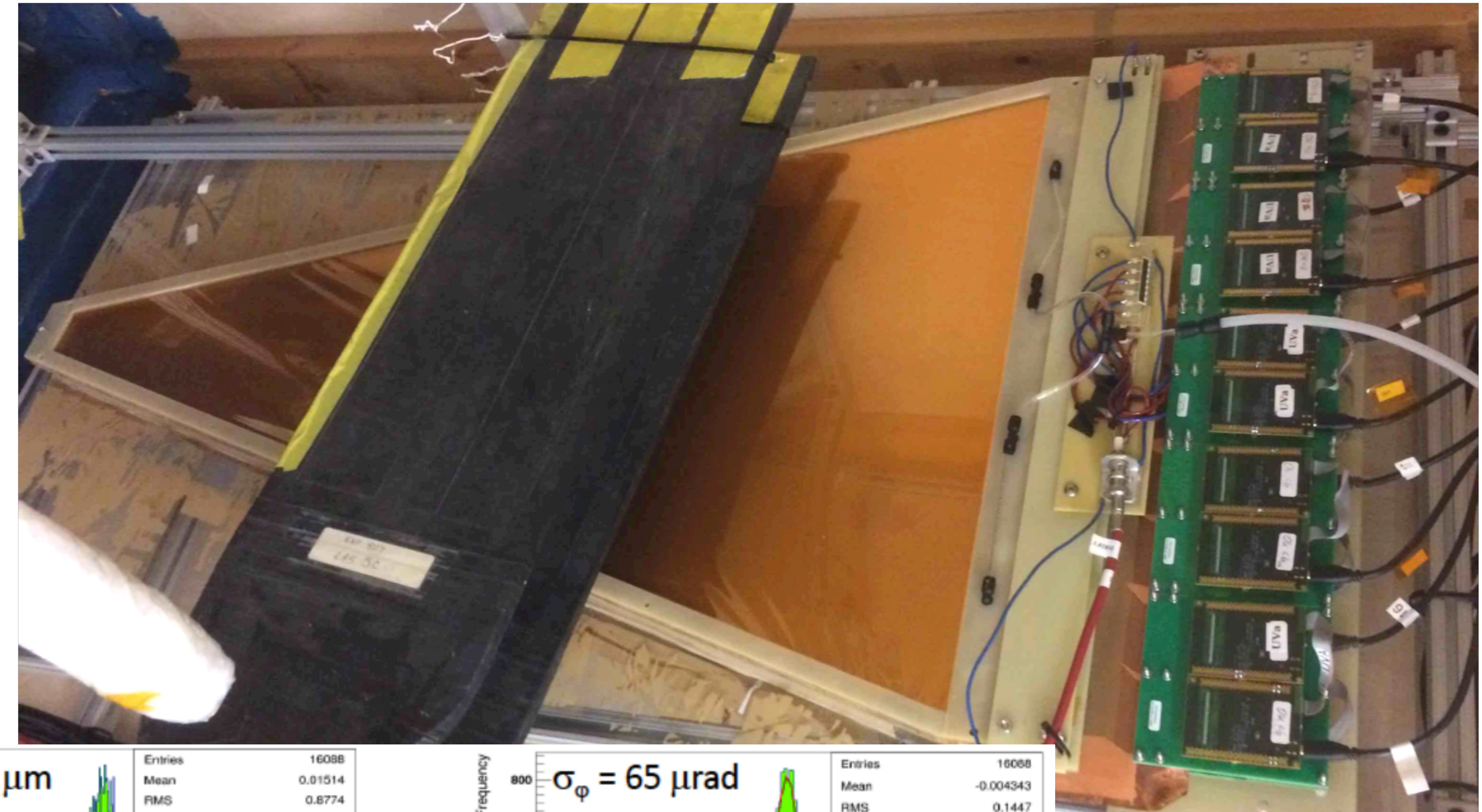
The true GEM experts at UVa

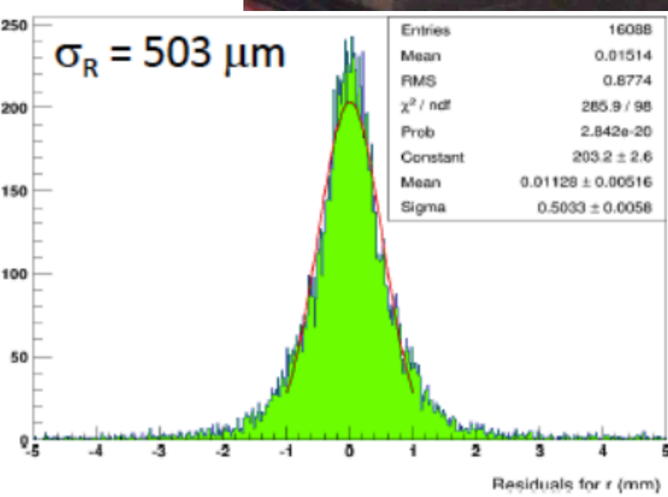


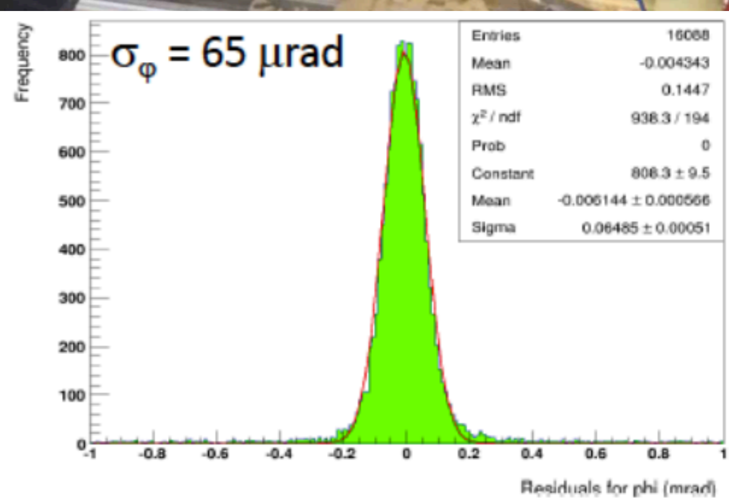
SBS GEM Production at UVa is complete:

- ❑ Completed building 50 modules (original plan was to build 40).
- ❑ 48 have been tested; 46/48 (96%) modules work per specs.
- ❑ GEM foils and readouts from CERN: GEM frames from Resarm in Belgium.
- ❑ All QA, cleaning, glueing and assembly done in clean-room at UVa.
- ❑ Foils from CERN very high quality; over 90% yield; mostly on-time delivery.
- ❑ Foil QA at every step extremely important.
- ❑ Production design and prototyping process takes at least about 1 year.
- ❑ The GEM foil ordering process has a long lead time, need at least ~ 1 year to get started.
- ❑ In production mode: ~ 2 modules per month.
- ❑ Could be increased to two parallel assembly lines, yielding ~ 4 modules/ month.
- ❑ If needed, easy to double the clean room space and go to 3 or 4 production lines (up to 8 modules per month)
    - ❑ only about $ 40 k for doubling the size of the cleanroom.

Experience for SoLID geometry and size GEMs gained from two EIC GEM prototypes







All readout connections to the outer edge of the circle

Plan for electronics

- Need 200 k chan.
- The plan has been to use AVP-25 electronics.
  - Used for SBS
  - Already developed.
  - Lot of expertise at Jlab
  - Cheap
  - Unfortunately APV-25 chip is now extinct.
- Reuse APV-25 electronics from SBS :
  - SBS has a total of ~ 160 k of APV-25 (120 k chans. owned by Jlab (from UVa) ~ 40 k owned by INFN).
  - Assuming that at least ~ 66% survival rate after SBS run, we will have ~ 105 k of APV electronics for SoLID
- Need another ~ 100 k channels: need to find a suitable readout chip for these
- VMM3 from BNL/ATLAS is a good choice: but need to develop direct mode readout.
  - Assume $ 75 k for pre-R&D work
  - Assume $ 200 k engineering design and development of readout system
  - $ 4/chan for fabrication costs.

Technical Risks

- On-time availability of GEM foils: low risk based on past experience
  - Since this is a very large order of GEM foils, and since CERN has been the only supplier of GEM foils of this size, there is the risk of delays in GEM foil availability.
  - Mitigation strategies:
    - Place the orders for the whole need well in advance (at least 1 year or more) to allow CERN GEM workshop to plan production and delivery.
    - Now there are several companies around the world working with CERN on large GEM foils: need to engage them early and evaluate their foils.
    - This model (setup with Rolf Ent's help) worked well for the SBS project: ~ 150 good GEM foils, delivered more or less on time (was never an issue to hold up module production)
    - Working with its associated companies, CERN GEM workshop is now completing a very large foil order for CMS upgrade project. This shows that with advanced planning and early coordination with CERN, risks could be minimized.

- Not a show-stopper

Technical Risks

- ❑ Suitability of VMM electronics for high rate operation needed for SoLID ?
- ➢ medium risk based on available evidence from other labs:
  - ❑ The standard operating mode of VMM looks too slow for SoLID conditions
  - ❑ Mitigation strategies:
    - ❑ The direct readout mode of VMM appears to work as needed. Evaluate and characterize the chip in this mode as part of pre R&D. If SoLID rate needs are not met, look for alternate solutions.

- ❑ Given the high rates, especially at the first layer, the strip occupancy could be simply too high to yield good tracks.
- ➢ medium risk based on simulations and realistic modeling
  - ❑ Mitigation strategies:
    - ❑ SBS running will provide a huge amount of data, at rates similar to what is expected for SoLID GEMs, starting next year: use this data to fine tune the simulations and tracking for SoLID.
    - ❑ If the improved simulations show the need, split each readout strip in first layer (and may be in the second) into two channels each. will provide a large improvement in tracking performance for a very modest increase in in the cost (just a few tens of k$ if we plan ahead, but impossible to do if not)

Technical Risks

No show stoppers as far as we can see, based on recent lab experience on a similar project, as long as we plan ahead, and also assume we do the needed pre-R&D

Cost and basis - I

Activity Name	Costed Labor (PW)	Contrib Labor (PW)	Total Labor (PW)	Labor Cost ($K)	Procurement Cost ($K)	Total Cost ($K)
GEM	**632.00**	**40.00**	**672.00**	**$1,605.28**	**$2,194.00**	**$3,799.28**
GEM Modules	**484.00**	**0.00**	**484.00**	**$1,229.36**	**$1,464.00**	**$2,693.36**
GEM foils			0.00	$0.00	$620.00	$620.00
GEM readout planes			0.00	$0.00	$464.00	$464.00
GEM cathode foils			0.00	$0.00	$100.00	$100.00
GEM module frames			0.00	$0.00	$230.00	$230.00
GEM module supplies			0.00	$0.00	$40.00	$40.00
GEM module tooling			0.00	$0.00	$10.00	$10.00
GEM module assembly	484.00		484.00	$1,229.36		$1,229.36

- Main items: materials for 150 GEM modules.
  - 450 GEM foils from CERN shop.
  - 150 2-D readout boards from CERN shop
  - 150 GEM frame sets from Resarm
  - Technician manpower for GEM assembly: ~ 12 FTYE.

- All estimates based on recent lab experience from SBS GEM module production.

Cost and basis - II

Activity Name	Costed Labor (PW)	Contrib Labor (PW)	Total Labor (PW)	Labor Cost ($K)	Procurement Cost ($K)	Total Cost ($K)
GEM Readout	**0.00**	**0.00**	**0.00**	**$0.00**	**$430.00**	**$430.00**
VMM electronics channels			0.00	$0.00	$400.00	$400.00
VMM electronics cables			0.00	$0.00	$30.00	$30.00
GEM high voltage	**0.00**	**0.00**	**0.00**	**$0.00**	**$80.00**	**$80.00**
HV power supplies			0.00	$0.00	$70.00	$70.00
HV power cabling			0.00	$0.00	$10.00	$10.00
GEM gas system	**0.00**	**0.00**	**0.00**	**$0.00**	**$30.00**	**$30.00**
GEM Gas plumbing			0.00	$0.00	$30.00	$30.00
GEM mechanical support	**16.00**	**0.00**	**16.00**	**$40.64**	**$90.00**	**$130.64**
GEM mechanical support wheels	16.00		16.00	$40.64	$90.00	$130.64
Transport and travel			0.00	$0.00	$100.00	$100.00
Installation and Testing	132.00		132.00	$335.28		$335.28
Management		40.00	40.00	$0.00		$0.00

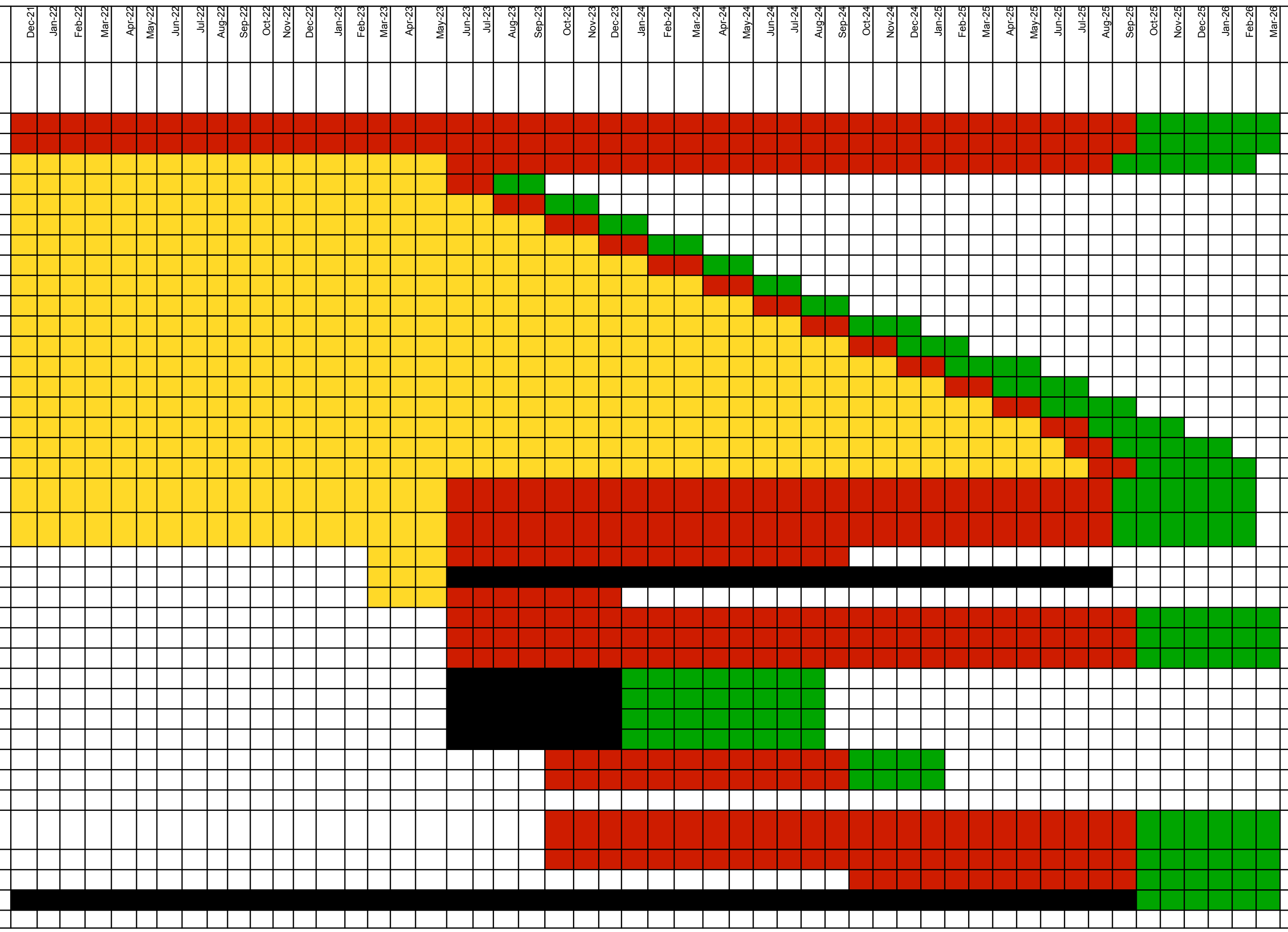
- All estimates based on recent lab experience from SBS GEM module production.

Duration and basis - engineering design and prototyping

	Task	FY21				FY22			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1.1.4	**GEM Design and Prototyping**								
1.1.4.1	**GEM Module design**								
1.1.4.1.1	GEM Module component design and prototyping								
1.1.4.1.1.1	GEM Module component design for level 1 prototypes								
1.1.4.1.1.2	GEM Module component procument for level 1 prototypes								
1.1.4.1.1.3	GEM Module level 1 prototype fabrication and testing								
1.1.4.1.1.4	GEM Module component design for level 2 prototypes								
1.1.4.1.1.5	GEM Module component procument for level 2 prototypes								
1.1.4.1.1.6	GEM Module level 2 prototype fabrication and testing								
1.1.4.1.1.6	GEM Module final engineering design								
1.1.4.1.2	GEM fabrication tooling design and prototyping								
1.1.4.1.1.1	GEM fabrication tooling: level 1 design and fabrication								
1.1.4.1.1.2	GEM fabrication tooling: level 2 design and fabrication								
1.1.4.1.1.3	GEM fabrication tooling: final engineering design								
1.1.4.2	**GEM Readout design**								
1.1.4.2.1	VMM electronics level 1 prototype design, fabrirication								
1.1.4.2.2	VMM electronics level 1 prototype testing								
1.1.4.2.3	VMM electronics level 2 prototype design, fabrirication								
1.1.4.2.4	VMM electronics level 2 prototype testing								
1.1.4.2.5	VMM electronics final engineering design								
1.1.4.5	**GEM mechanical support design**								
1.1.4.5.1	GEM mechanical support wheels design								
1.1.4.5.2	GEM mechanical support cable support design								
1.1.4.5.3	GEM mechanical support: 1 sector prototype fabrication								
1.1.4.5.4	GEM mechanical support final engineering design								
1.1.4.6	Transport and travel								
1.1.4.8	Management								

Duration and basis - Fabrication

	Item	total labor (PW)	Start Date	Finish Date	duration (WKS)	comments
1.2.4	GEM	680	10/1/21	10/1/25	130.00	Long lead time items
1.2.4.1	**GEM Modules**	484	10/1/21	10/1/25	130.00	Long lead time items
1.2.4.1.1	GEM foils	0	10/1/21	8/1/23		Long lead time item
1.2.4.1.1.1	GEM foils order #1	0	10/1/21	8/1/23		Long lead time item
1.2.4.1.1.2	GEM foils order #2		10/1/21	10/1/23		Long lead time item
1.2.4.1.1.3	GEM foils order #3		10/1/21	12/1/23		Long lead time item
1.2.4.1.1.4	GEM foils order #4		10/1/21	2/1/24		Long lead time item
1.2.4.1.1.5	GEM foils order #5		10/1/21	4/1/24		Long lead time item
1.2.4.1.1.6	GEM foils order #6		10/1/21	6/1/24		Long lead time item
1.2.4.1.1.7	GEM foils order #7		10/1/21	8/1/24		Long lead time item
1.2.4.1.1.8	GEM foils order #8		10/1/21	10/1/24		Long lead time item
1.2.4.1.1.9	GEM foils order #9		10/1/21	12/1/24		Long lead time item
1.2.4.1.1.10	GEM foils order #10		10/1/21	2/1/25		Long lead time item
1.2.4.1.1.11	GEM foils order #11		10/1/21	4/1/25		Long lead time item
1.2.4.1.1.12	GEM foils order #12		10/1/21	6/1/25		Long lead time item
1.2.4.1.1.13	GEM foils order #13		10/1/21	8/1/25		Long lead time item
1.2.4.1.1.14	GEM foils order #14		10/1/21	9/1/25		Long lead time item
1.2.4.1.1.15	GEM foils order #15		10/1/21	10/1/25		Long lead time item
1.2.4.1.2	GEM readout planes	0	10/1/21	10/1/25		same order fractions as GEM foils
1.2.4.1.3	GEM cathode foils	0	10/1/21	10/1/25		same order fractions as GEM foils
1.2.4.1.4	GEM module frames	0	3/1/23	10/1/24		Long lead time item
1.2.4.1.5	GEM module supplies	0	3/1/23	10/1/25		Long lead time item
1.2.4.1.6	GEM module tooling	0	6/1/23	1/1/24		
1.2.4.1.7	GEM module assembly	484	6/1/23	10/1/25		
1.2.4.2	**GEM Readout**	0	6/1/23	10/1/25		
1.2.4.2.1	VMM electronics channels	0	6/1/23	10/1/25		
1.2.4.2.2	VMM electronics cables	0	6/1/23	1/1/24		
1.2.4.3	**GEM high voltage**	0	6/1/23	1/1/24		
1.2.4.3.1	HV power supplies	0	6/1/23	1/1/24		
1.2.4.3.2	HV power cabling	0	6/1/23	1/1/24		
1.2.4.4	**GEM gas system**	8	10/1/23	10/1/24		
1.2.4.4.1	GEM Gas plumbing	8	10/1/23	10/1/24		
1.2.4.5	**GEM mechanical support**	16	10/1/23	10/1/25		
1.2.4.5.1	GEM mechanical support wheels	16	10/1/23	10/1/25		
1.2.4.6	Transport and travel	0	10/1/21	10/1/25		
1.2.4.7	Installation and Testing	132	10/1/24	10/1/25		
1.2.4.8	Management	40	10/1/21	10/1/25		



Address Recommendations from Director's Review

#12- Close interaction between the US and Chinese groups in the development of GEM foils to assure good quality control is highly recommended

- NA: Under the current plan for the GEM production at UVa, the GEM foils will be purchased from the CERN GEM-shop and its associated partner companies (in Poland, South Korea etc.), with already established and proven large GEM capabilities.

#13- Investigate the schedule risk when GEM foils are not produced in a timely way and continue to pursue Tech-Etch as a potential supplier for the foils.

- Tech-Etch gave up the development of large area GEM foils and decided not to invest in the single-mask technology needed for the production of these large GEMs; they are unlikely to restart production.
- However, given the recent, positive experience of GEM foil production and delivery from CERN for the SBS GEM project (and even more recent and larger ALICE upgrade and CMS upgrade GEM projects), the schedule risk associated with this will be low (with proper advanced planning, ordering and coordination with CERN)

Address Recommendations from Director's Review

Rui De Oliveira <Rui.de.Oliveira@cern.ch>
Tue 9/10/2019 2:31 AM
Liyanage, Nilanga K (nl8n); Kondo Gnanvo kagnanvo@jlab.org

Dear Nilanga

I'm fine , thank you.

Your time frame fits perfectly with our program. We are starting now a production of 400 Foils for CMS with the same size as your request (1.3m x 50cm active area). In theory we have enough resources to produce this in about 1 year, but this will be too fast for CMS (they do not want to store the GEM for a long period) so we will slow down the production and produce then within 2 years. So your project can start right after CMS.

There is no problem to charge you 50% earlier to prepare the job/buy the base material.

Best regards

Rui

EH&S Considerations

Based on the Lab experience from the SBS GEM construction and testing, the main EH&S considerations for the SoLID GEM project are:

- ❑ Hazardous vapor inhalation during GEM foil gluing and GEM frame varnishing operations using industrial epoxies and varnishes.
  - ❑ These hazards have been carefully investigated and addressed in the Liyanage lab at UVa in full coordination with the University of Virginia EH&S office as a part of the SBS GEM fabrication project. The mitigation strategies recommended/required by UVa EH&S, and all of which have been put in place and evaluated, include:
    - ➢ Application of varnish on GEM frames is carried out inside a fume-hood.
    - ➢ Application of epoxy is carried out under the required ventilation conditions.
    - ➢ Limitations on the number of hours per day spent on the gluing operations.

- ❑ Hazards involved during the soldering of the components on the GEM detectors
  - ❑ The mitigation strategies include:
    - ➢ Reduce the amount of soldering required to be done at UVa as much as possible: for example, all readout connector soldering (making connections for over 10^5 channels for SBS) was carried out at CERN using industrial techniques and ovens before the readout foils are sent to UVa.
    - ➢ All soldering in the lab is carried out using the recommended EH&S procedures.
    - ➢ All large Soldering jobs are carried out by trained technicians and not by graduate or undergraduate students. (well, when we were students, we were not pampered like this, but whatever !)

Backup Slides

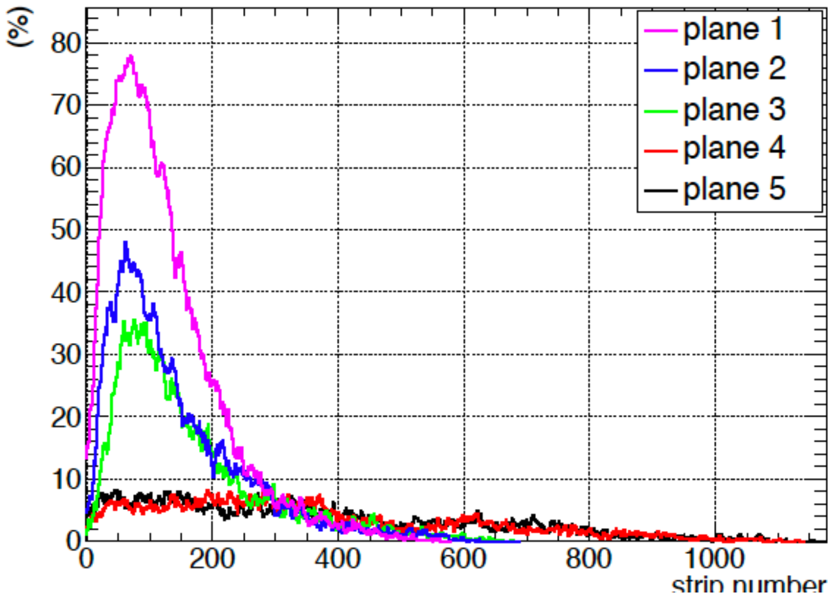
Tracking simulation: Digitization

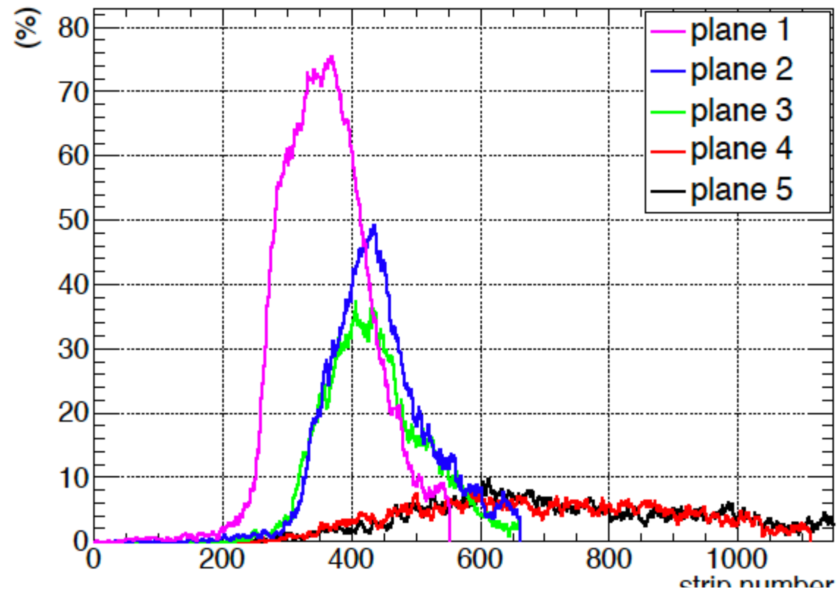
- **Ionization**: Using the hit position, deposited energy, and range of hits from simulation, electron-ion pairs are generated in GEM drift region. The e-ion pairs are distributed randomly within the area the hit covers within the GEM drift region.
- **Amplification and Drift:** The electron signals are amplified while drifting through GEM foils and propagating to the readout plane. Diffusion is also taken into account. The ADC gain is tuned based on.
- **Electronic noise:** Pedestal noise of the same level as real is added into channels. The noise profile variation in time is modeled using measurement of pedestal data from real GEM detectors.
- **Cross talk:** In the APV readout system, a strong hit in a channel always introduces a small detectable image signal in adjacent channels on the readout chip (adjacent channels on the chip are mapped to non-adjacent channels on the detector). This cross-talk effect is seen and measured in the PRad experiment; the size of the cross-talk partner is about 10% of the primary hit. Using the chip-channel-to-readout-channel correspondence, the cross talk signals could be accurately identified and suppressed. In the digitization A cross talk signal is added to corresponding channels for every primary signal in APV

PVDIS Occupancy

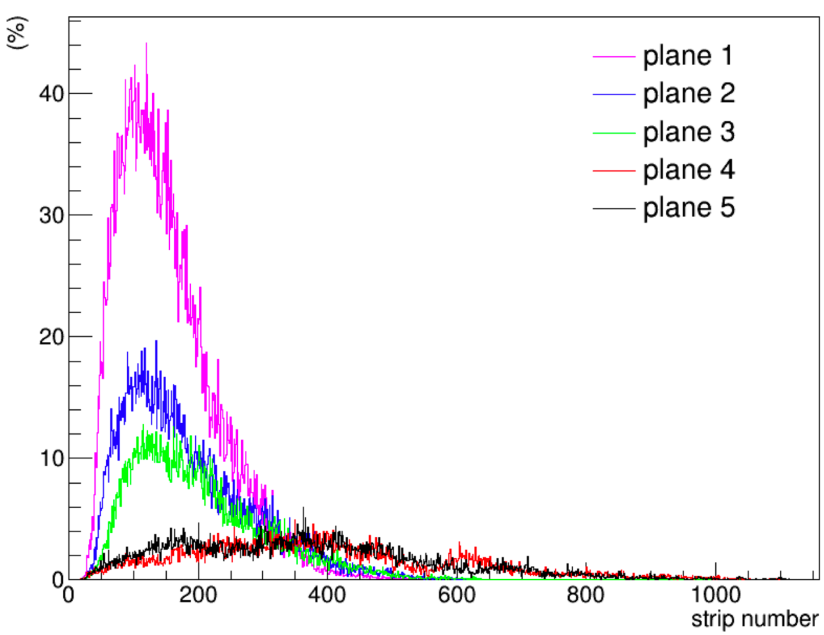
U plane **V plane**

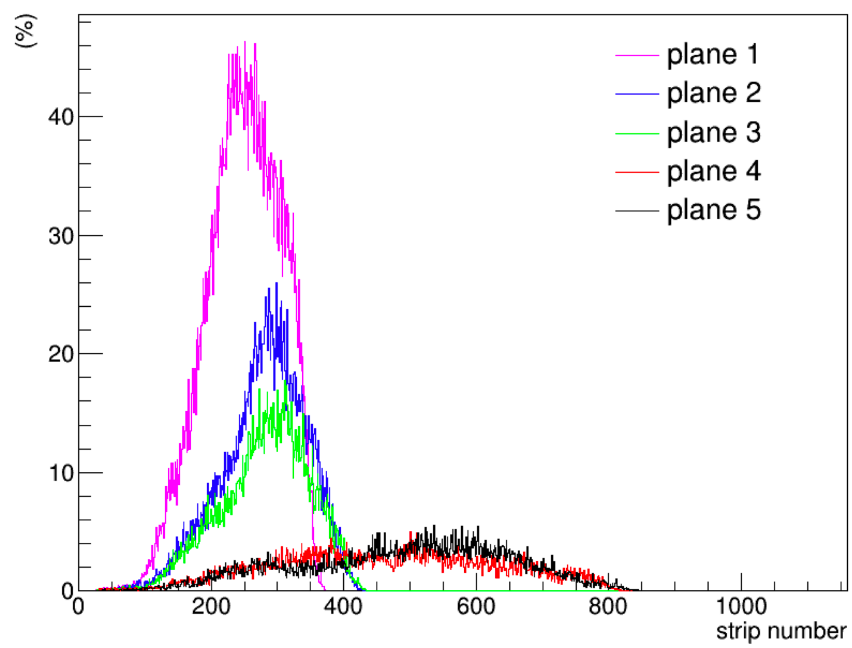
APV25





VMM3





Large & Low-mass Forward Tracker GEM for EIC R&D

Common GEM foil design:

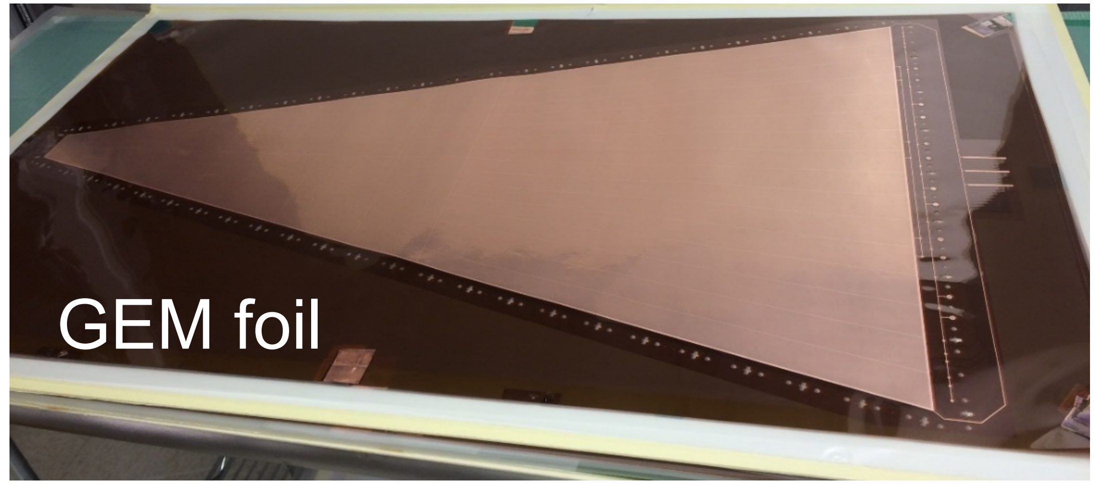
- (Univ. of Virginia, Florida Tech, and Temple U.)
- All connections (HV, gas flow structure and FE cards) are made on outer radius end.

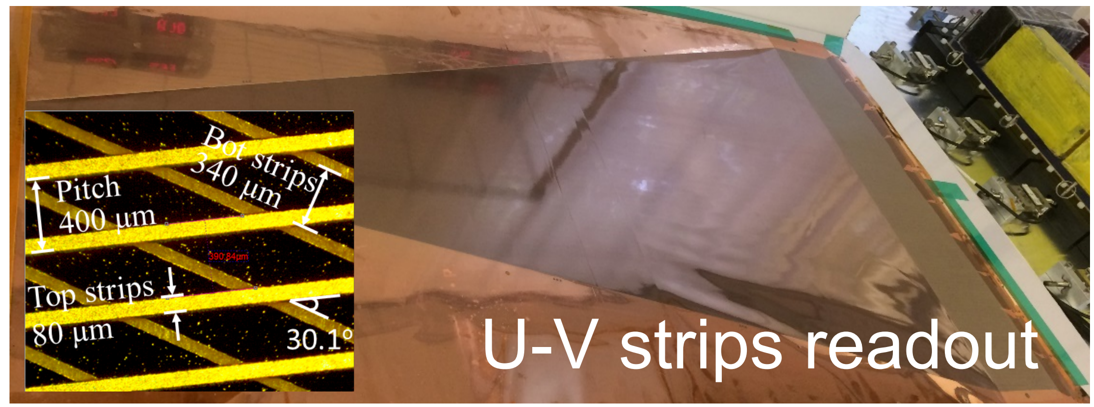
2D U-V strips readout (R/O)

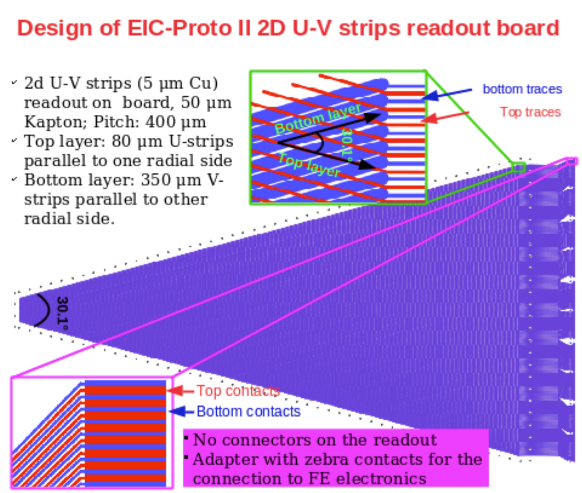
- Spatial resolution improvement
- All readout electronics on outer radius end.
- No connectors or metallized vias on R/O

Double-sided zebra connection

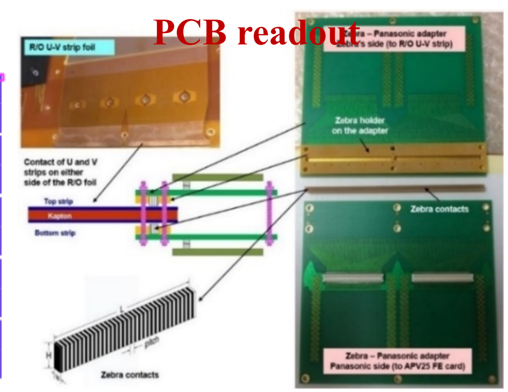
- Large density of electronics channels read out on side of the detector (outer radius)
- No electronics on side or inner radius, no multiple scattering or radiation damage issues
- No connectors or metallized vias on R/O



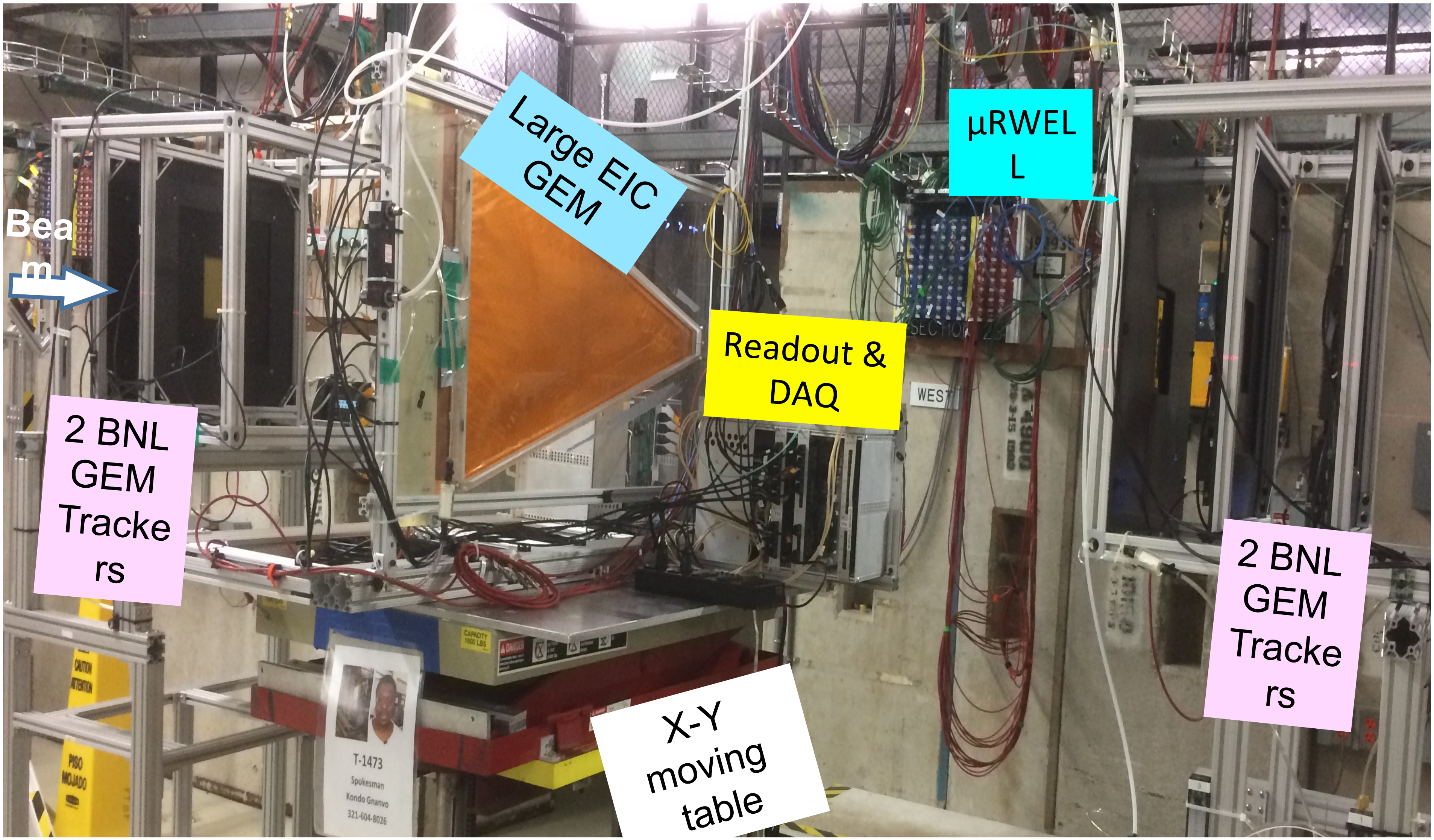


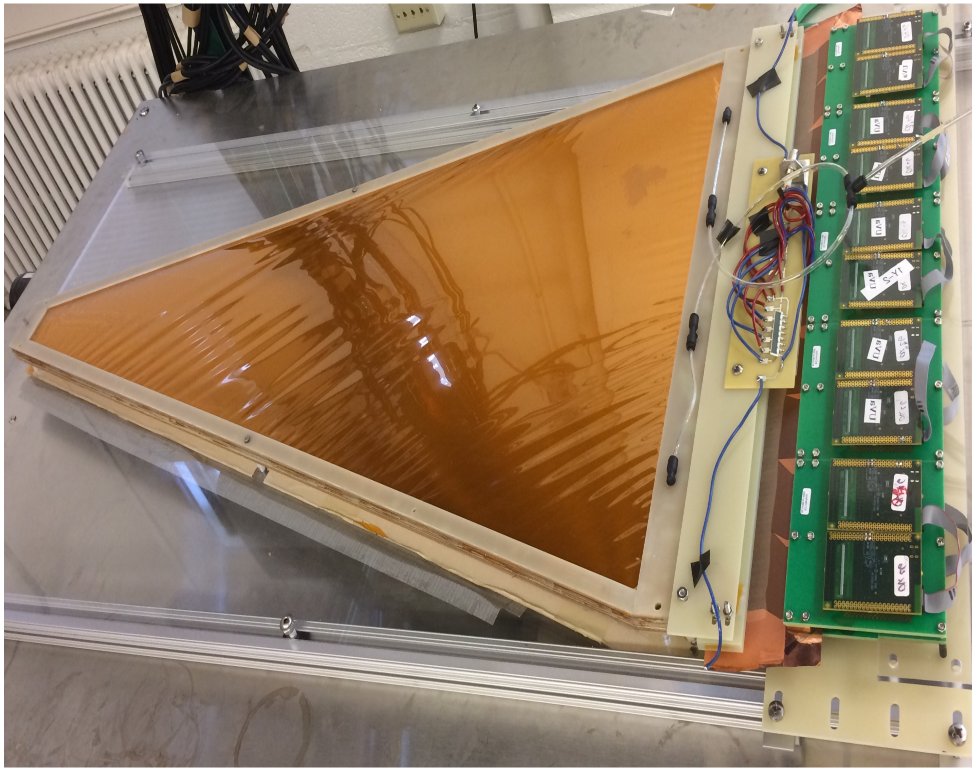


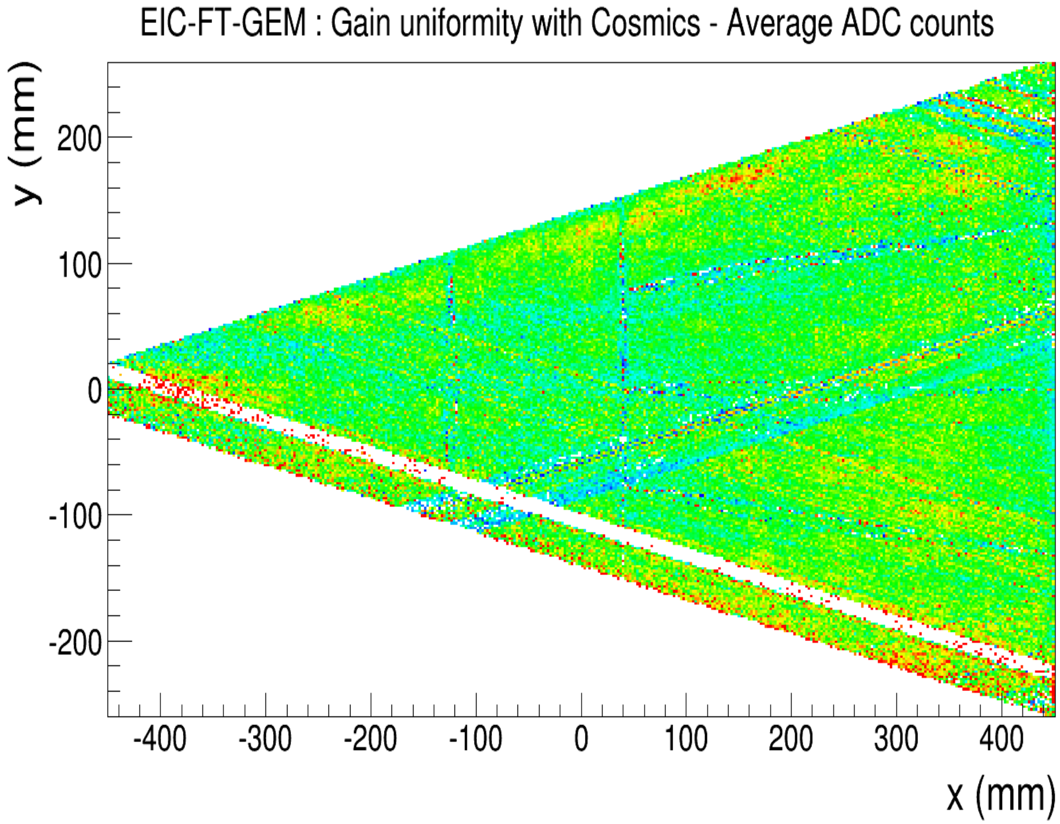
Principle of double-sided zebra connection on flexible PCB readout

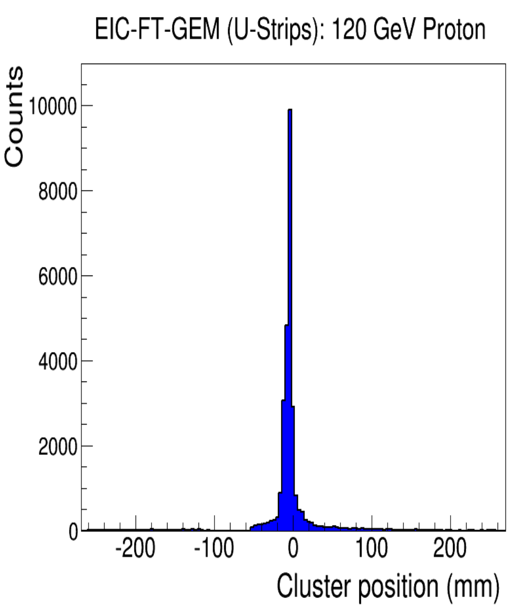


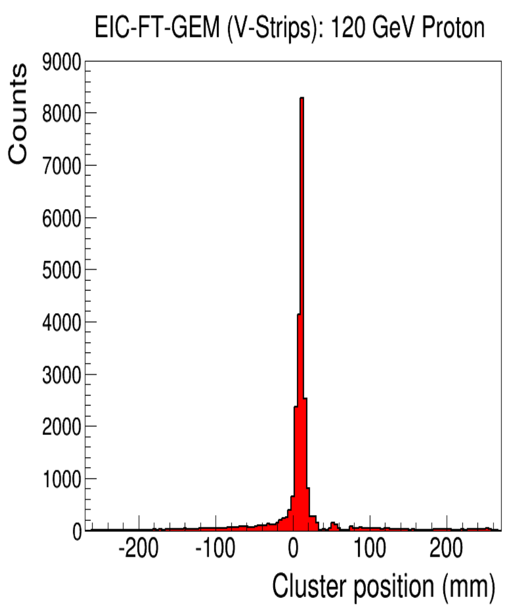
Large GEM Setup in MT6.2b Area at the FTBF (June-July 2018)

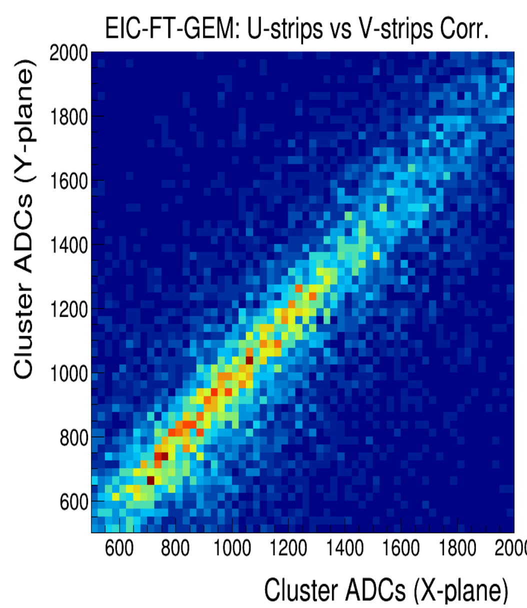


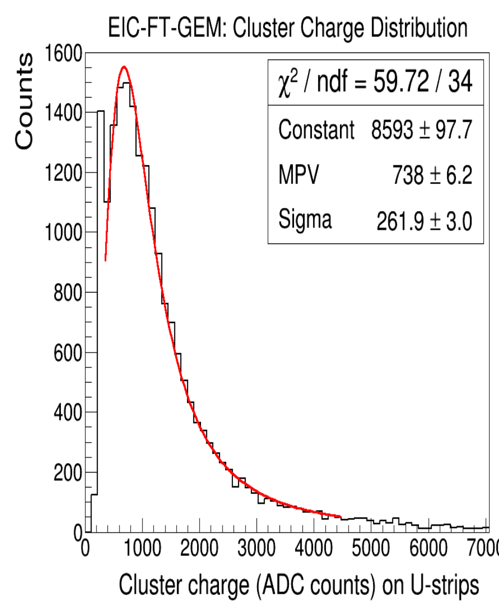



EIC-FT-GEM : Gain uniformity with Cosmics - Average ADC counts
y (mm)
200
100
0
-100
-200
-400 -300 -200 -100 0 100 200 300 400
x (mm)


EIC-FT-GEM (U-Strips): 120 GeV Proton
Counts
10000
8000
6000
4000
2000
0
-200 -100 0 100 200
Cluster position (mm)


EIC-FT-GEM (V-Strips): 120 GeV Proton
Counts
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-200 -100 0 100 200
Cluster position (mm)

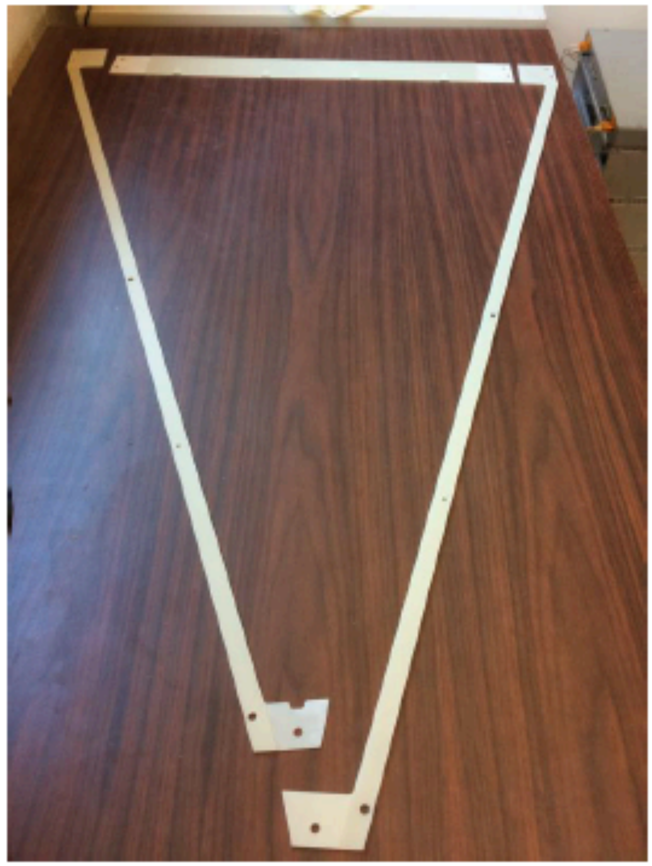

EIC-FT-GEM: U-strips vs V-strips Corr.
Cluster ADCs (Y-plane)
2000
1800
1600
1400
1200
1000
800
600
600 800 1000 1200 1400 1600 1800 2000
Cluster ADCs (X-plane)


EIC-FT-GEM: Cluster Charge Distribution
Counts
1600
1400
1200
1000
800
600
400
200
0
χ^2 / ndf = 59.72 / 34
Constant 8593 ± 97.7
MPV 738 ± 6.2
Sigma 261.9 ± 3.0
0 1000 2000 3000 4000 5000 6000 7000
Cluster charge (ADC counts) on U-strips

EIC Low Cost Frames

Total set of pieces for all 4 frames

Set of 3 pieces for 1 frame



pieces fit together to form a frame

Alternate Chip Options

- VMM3: Developed by BNL for ATLAS
  - Good
    - digital output with on board zero suppression
    - High rates
    - suitable for large detectors,
  - Bad
    - single sample; does not allow pileup correction or time based background rejection

Alternate Chip Options: VMM

SRS
Scalable Readout Syster

APV (ANALOGUE)

APV (250 nm CMOS)

- Pipeline depth: max. 192 clocks
- Trigger latency: max. 3 us
- Noise: < 500 e- intrinsic >750..1400 e- on detector
- dynamic range: 25 fC
- Detector capacity: 18… < 60pf
- ADC ext. 4096/1000 [counts/baseline]
- Gain: fixed CSA gain 100uA/mip, 5 output signal gains (in step of 20%)
- Timing jitter : ½ (1/fc) [+- 12ns]
- Shaping times: 50 ns adjustable to 80 ns
- max readout rate: 7 kHz

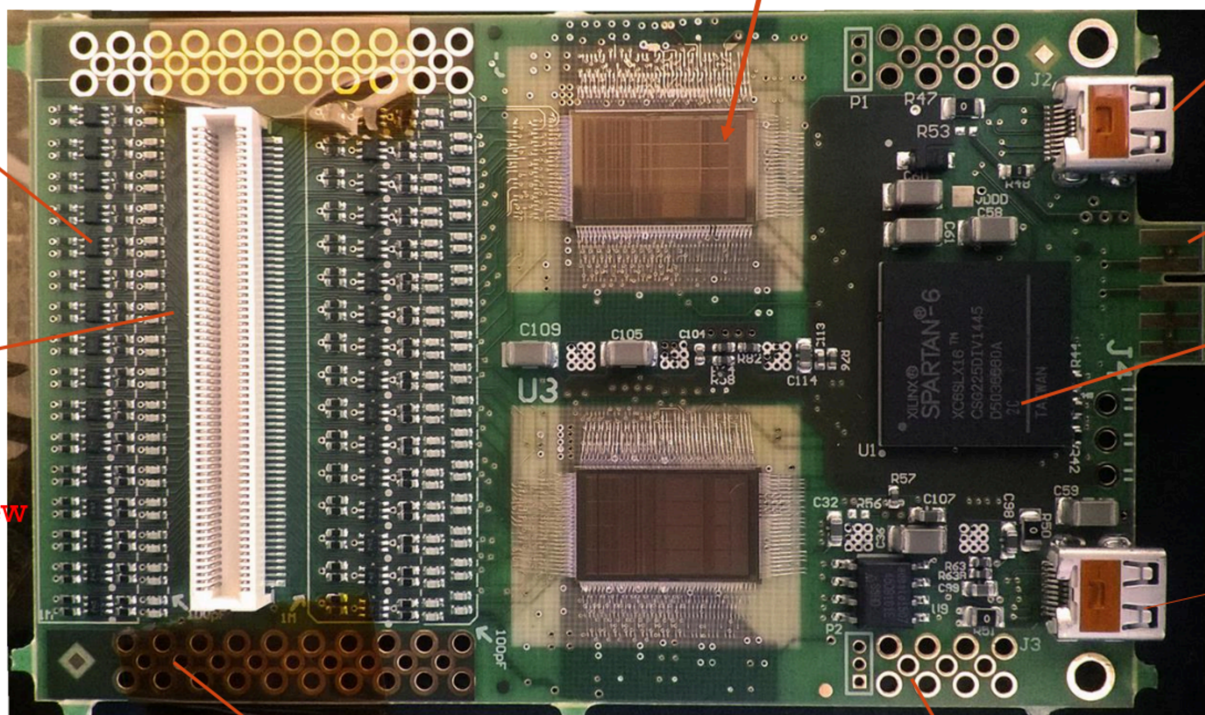
VMM (DIGITAL)

VMM (130nm CMOS)

- Pipeline depth: 64 digital frames (peak)
- Trigger latency: (self triggered) or L0 (12.8us)
- noise : < 400 e- on 10x10 detector reported
- dynamic range: expect >> 25 fC
- Detector capacity: 30pF …. < 1nF
- ADC: embedded, 10 bit
- Gains: 8 CSA gains [0.5..16mV/fC]
- Timing jitter: 20 bit t-stamp, 1ns resolution
- Shaping times: 4 [25… 200ns]
- max readout rates: estimated 4 MHz/ch

Alternate Chip Options: VMM: SRS version

Photo: 2 x wire-bonded VMM2 chips -> new VMM3 board fully routed



AC coupling
&
spark protection

Panasonic 130 pin
connector for MPGDs
Will be replaced by new
140 pin HRS connector

HDMI link 1 DTCCP

JTAG

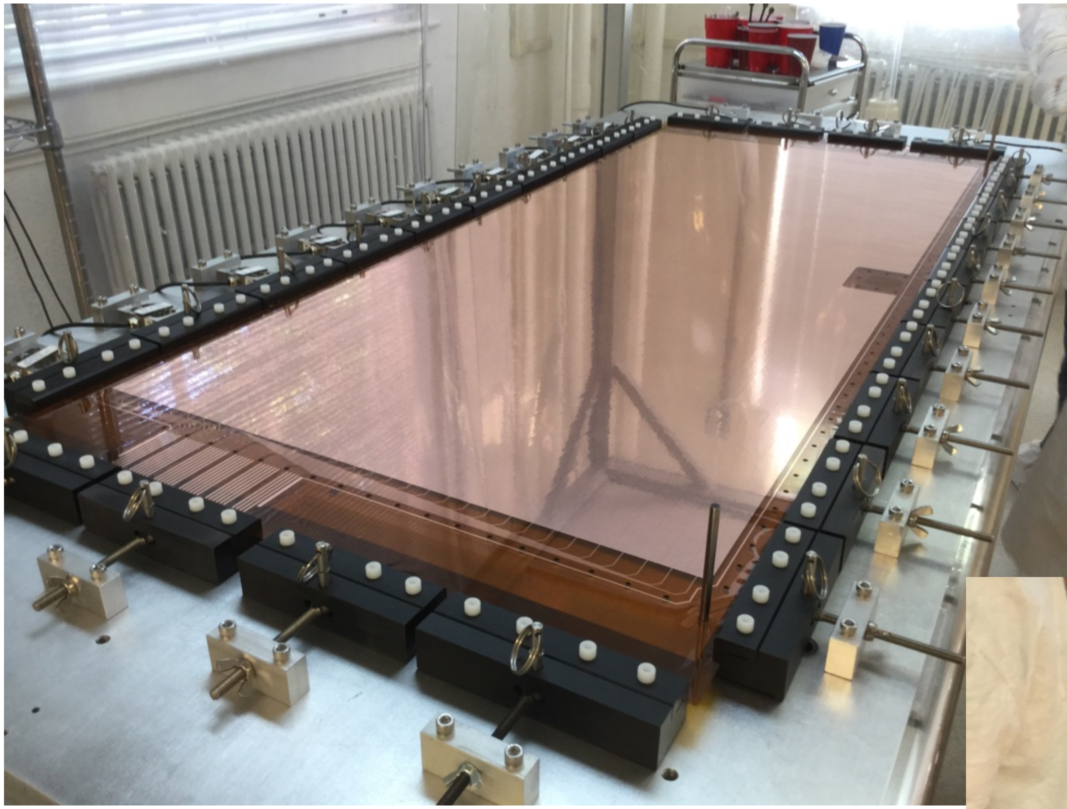
Companion FPGA

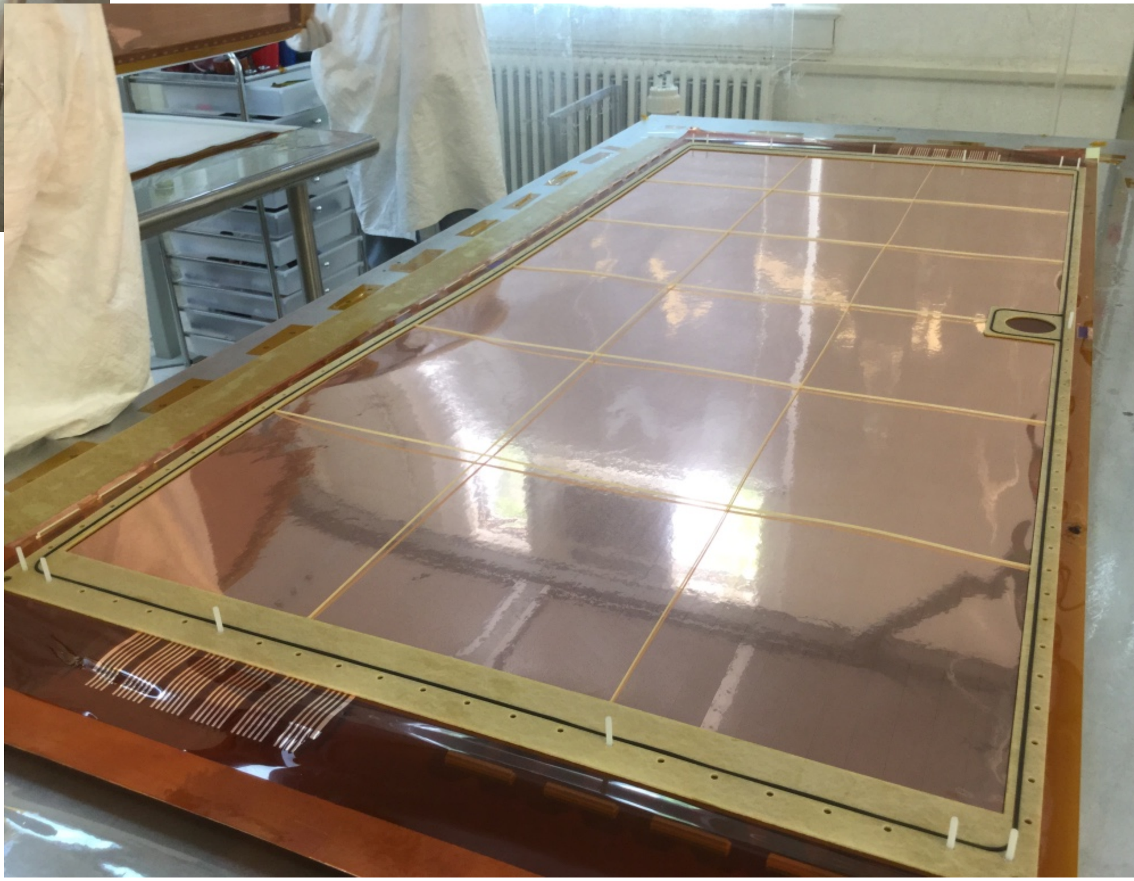
HDMI link 2 DTCCP

Detector GND MMCx

Neighbor-channel via MMCX

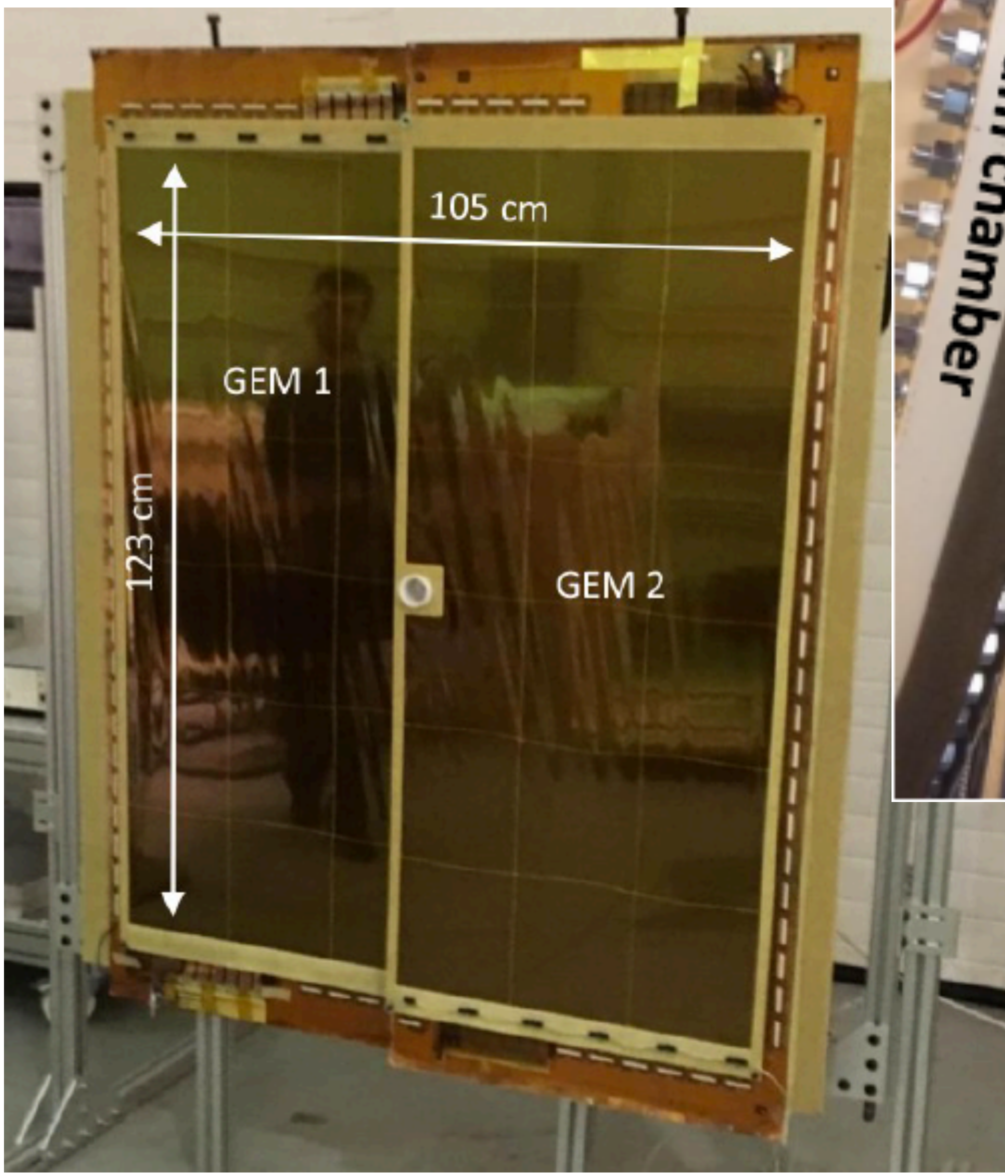
Recent developments: now very large areas possible

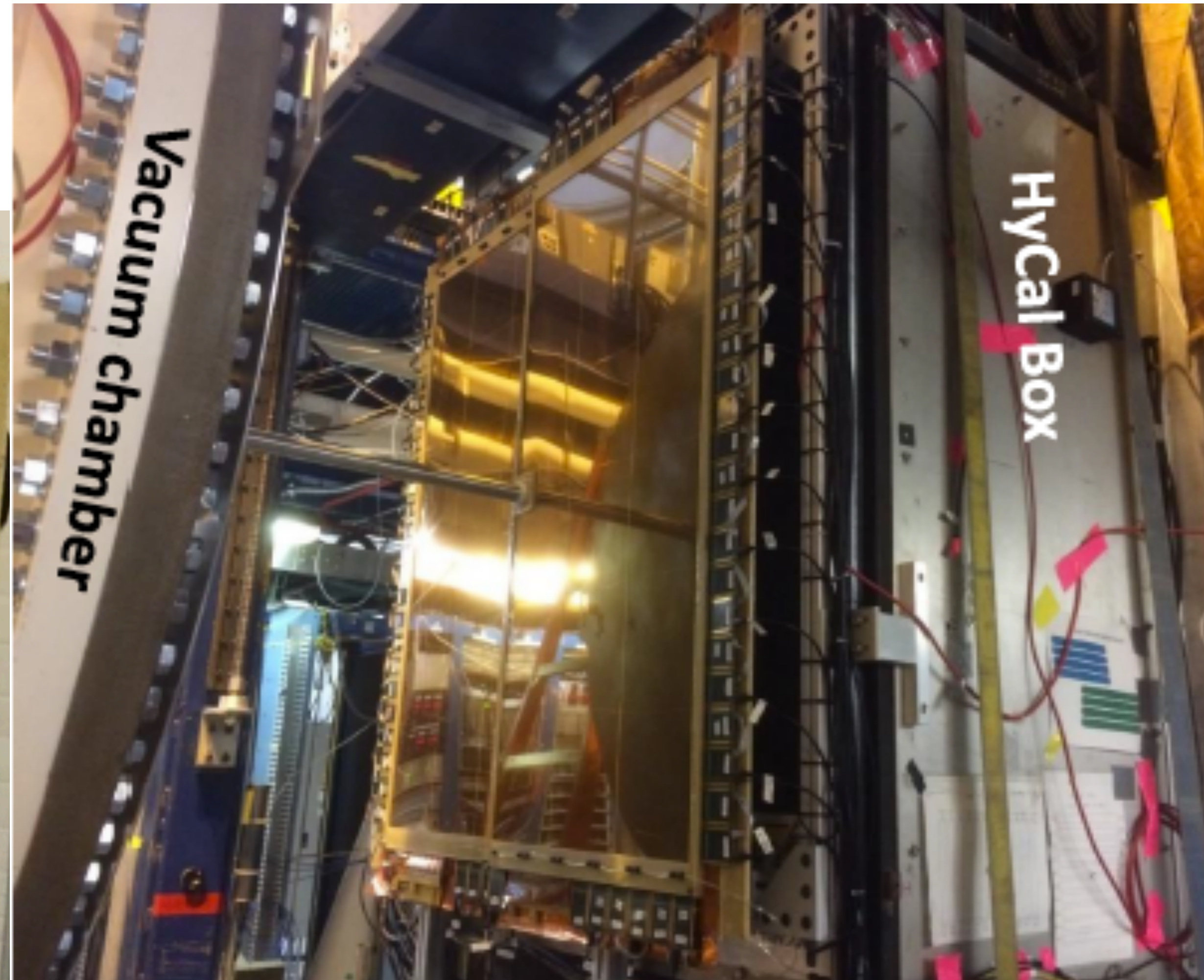




123 cm x 55 cm active area
GEM detectors for pRad experiment
during construction at UVa

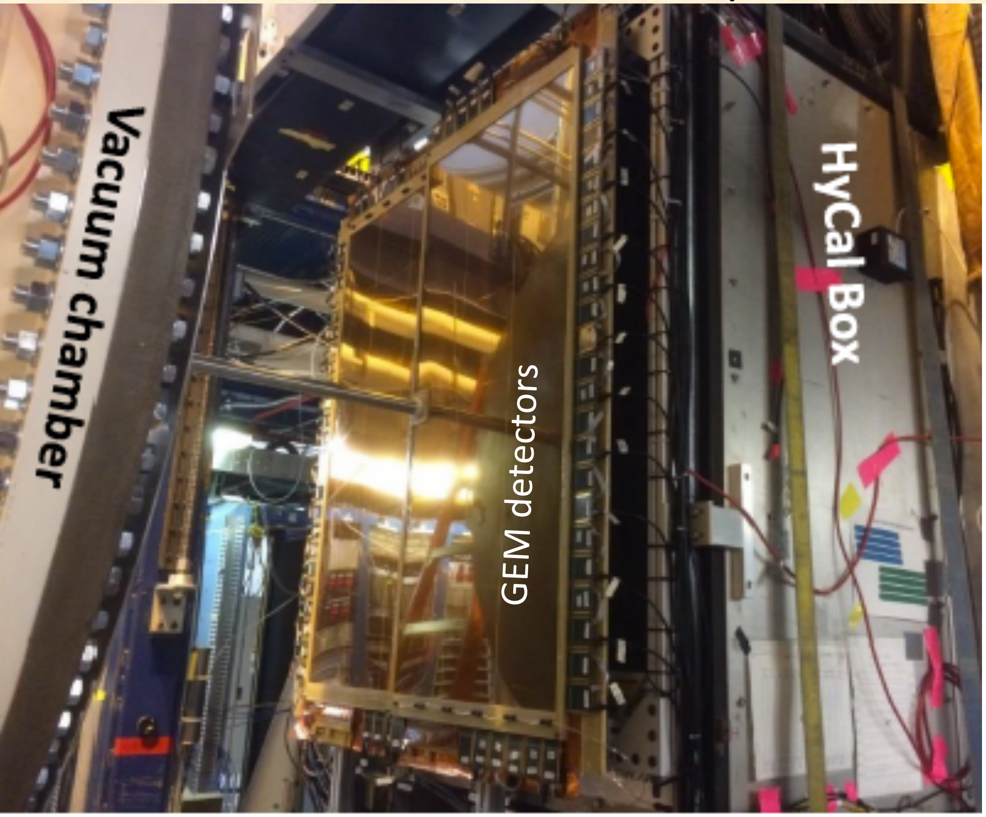
pRad GEMs



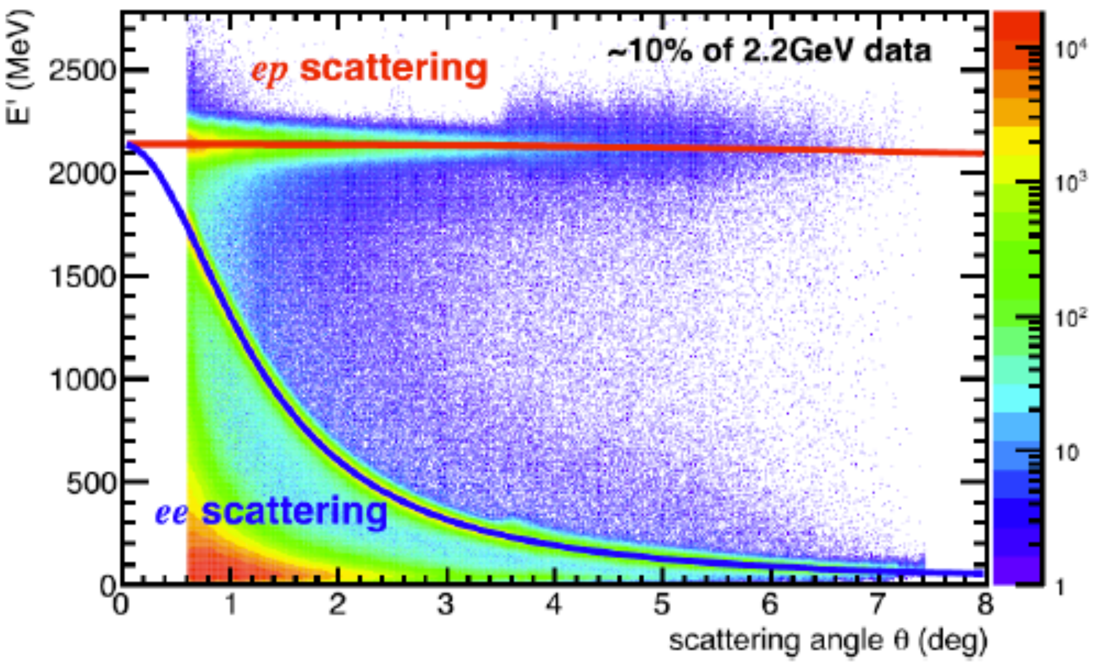


The Largest GEM chambers in the world at that time.

pRad GEMs - Results

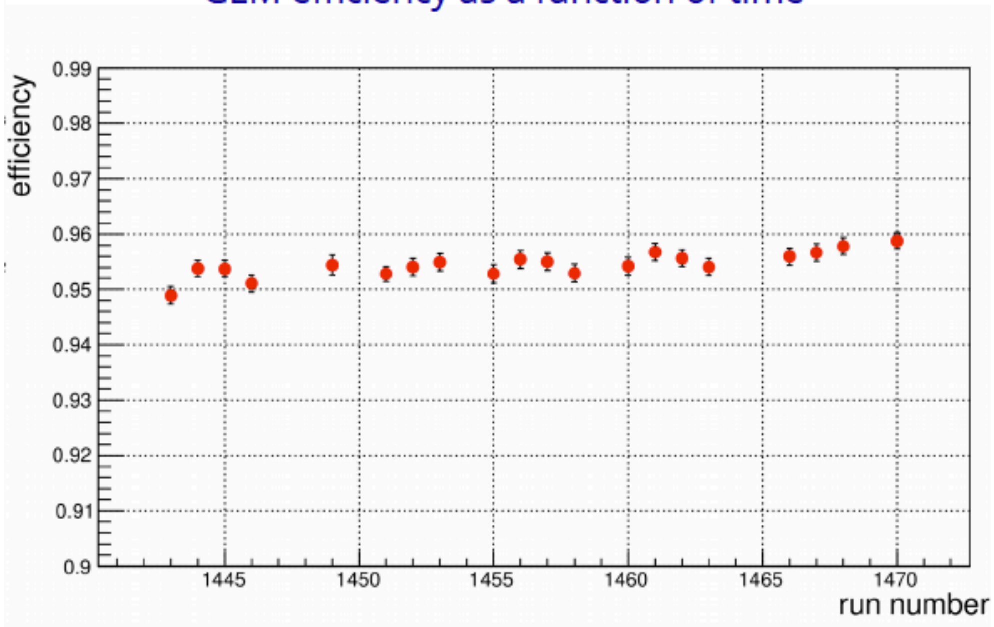


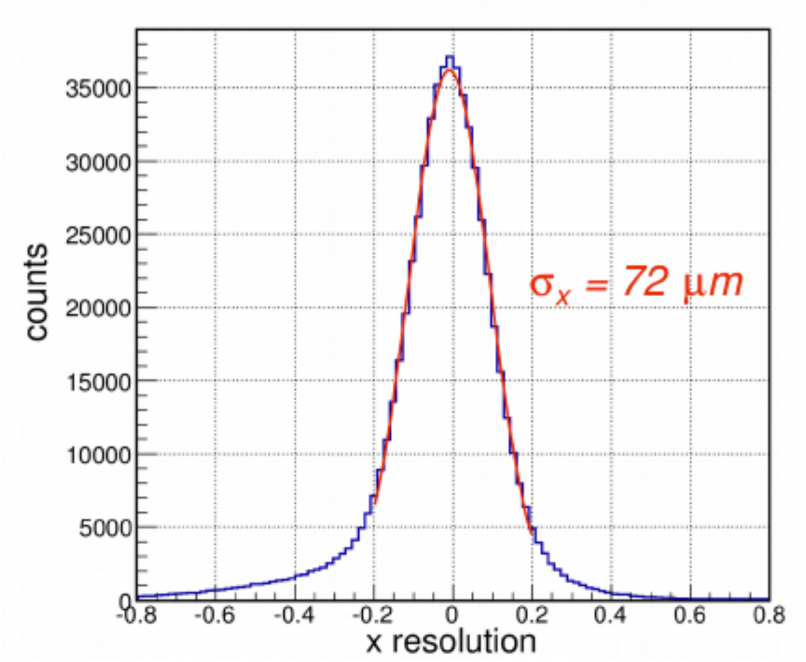
Using coordinates from GEM detectors, and energy from calorimeter.



2.2 GeV beam

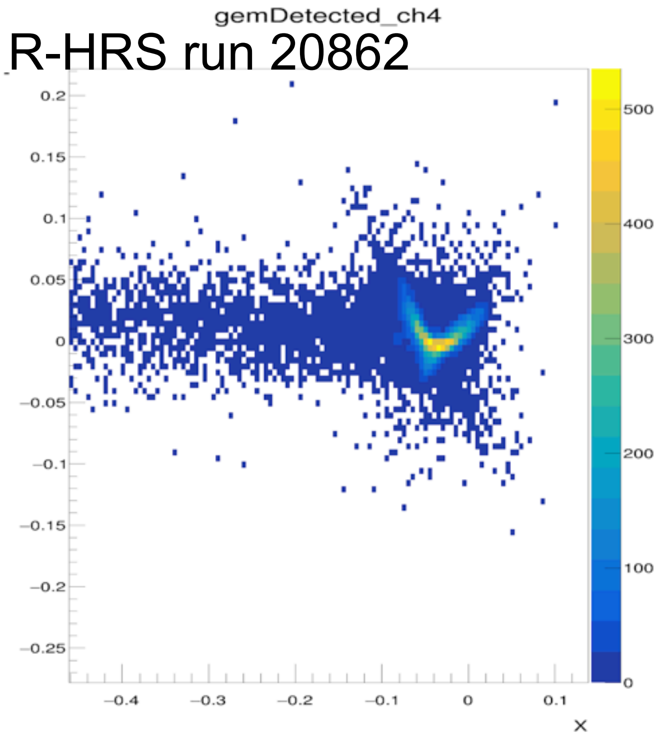
GEM efficiency as a function of time

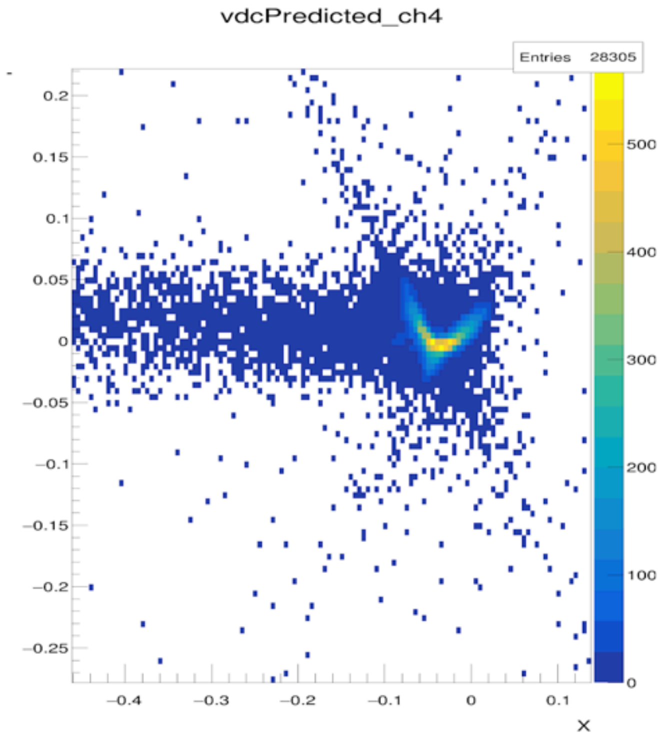


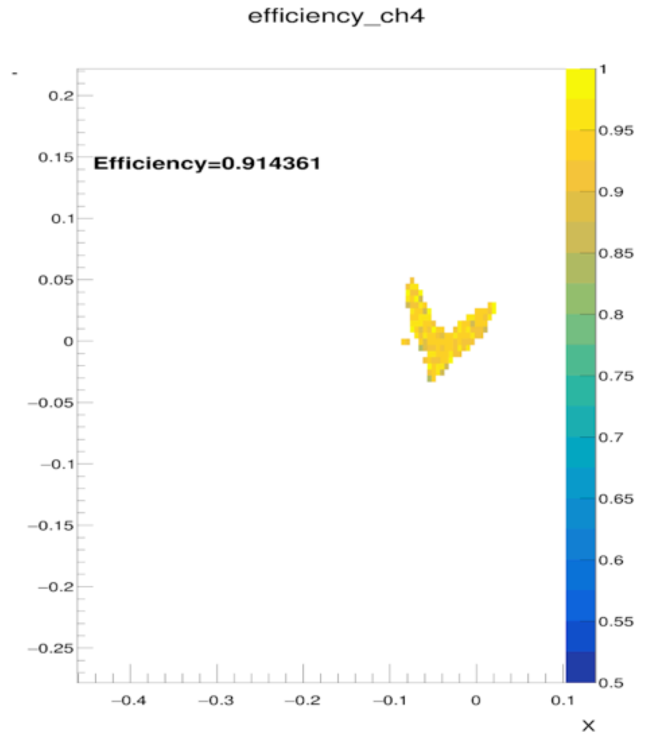


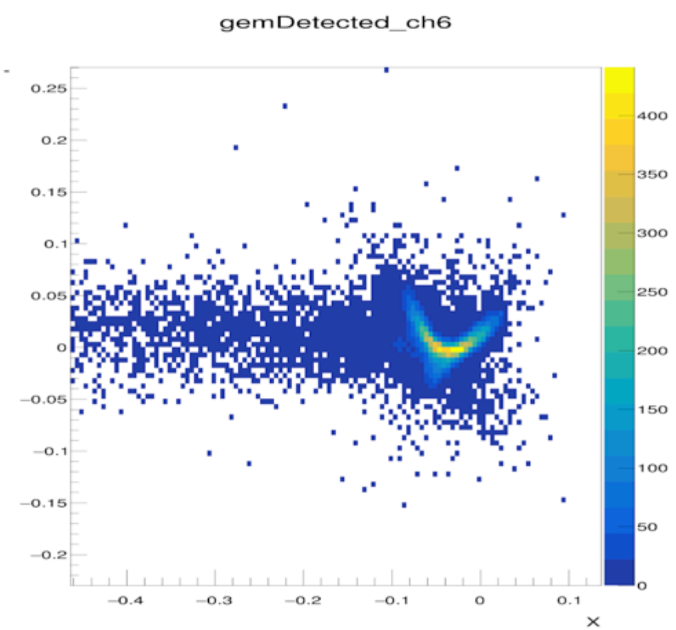
SBS GEMs in PREX experiment

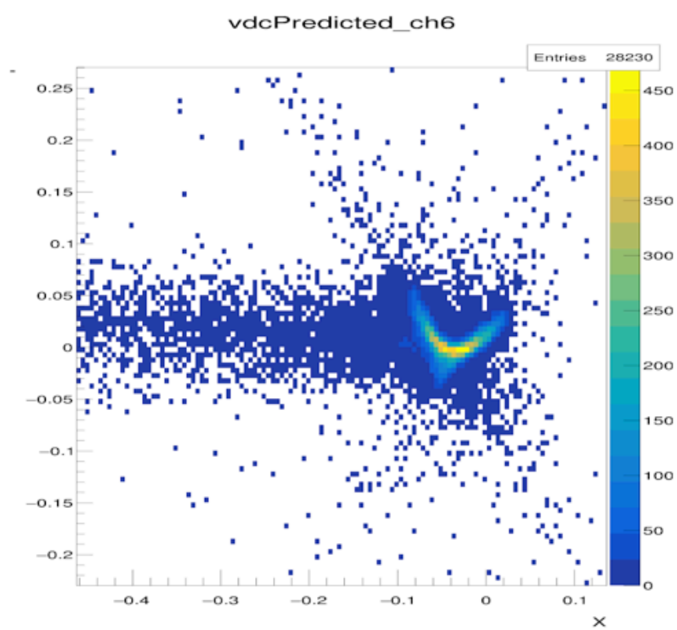
R-HRS run 20862

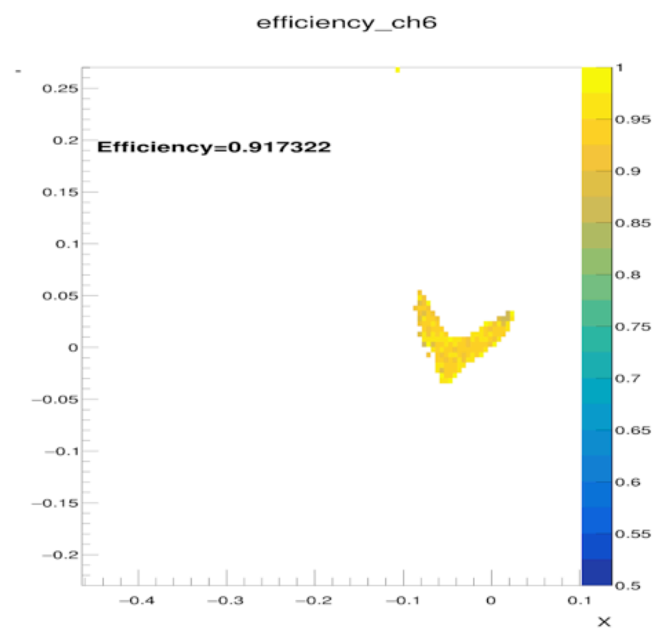






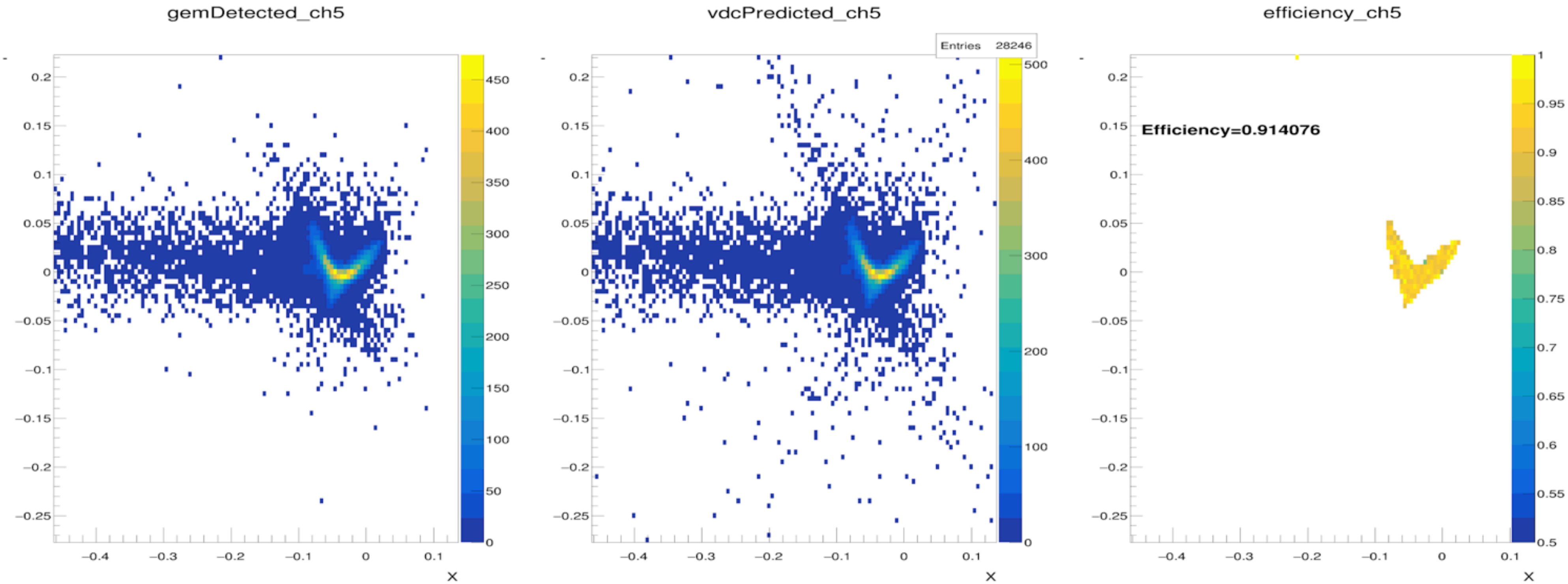


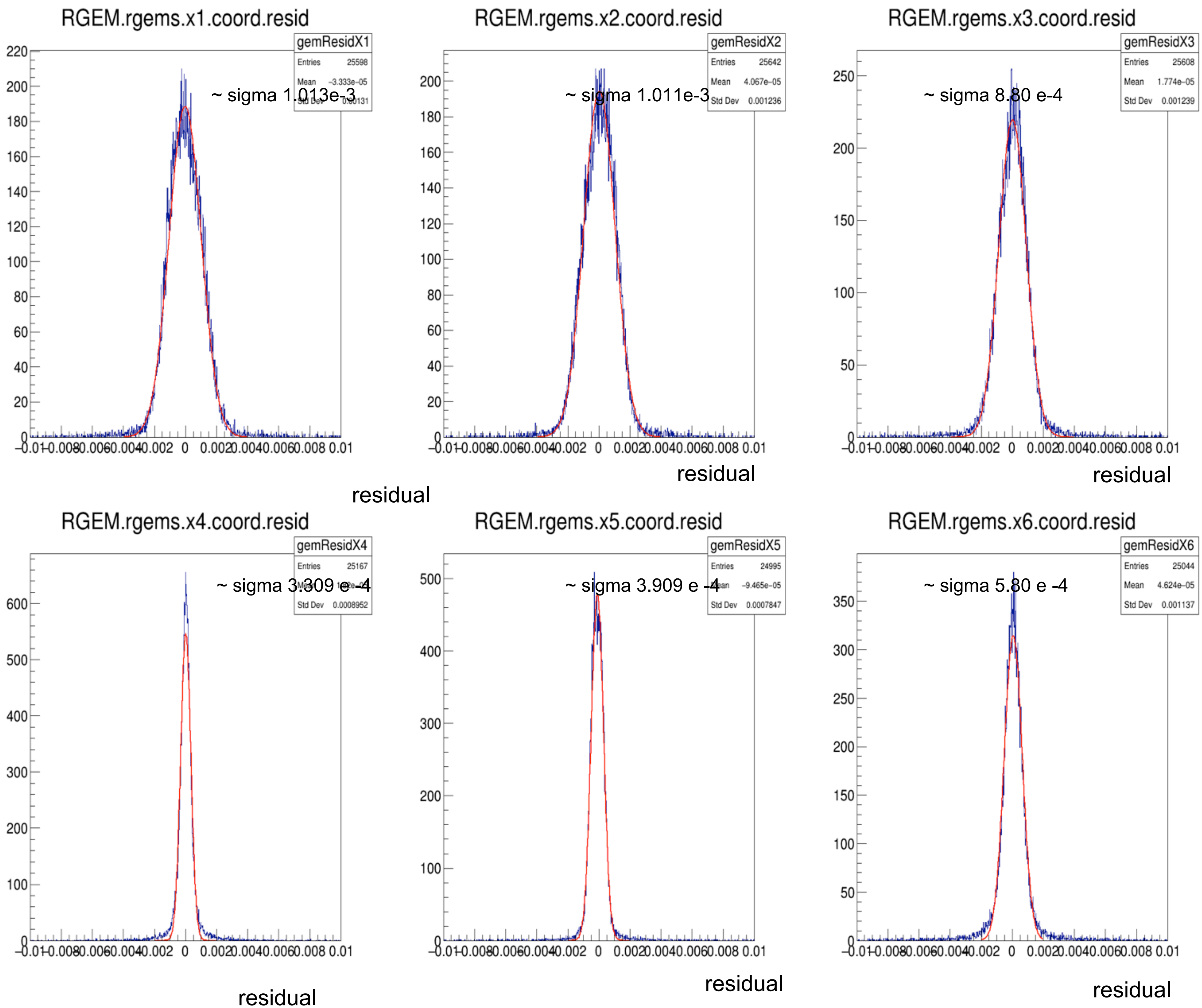


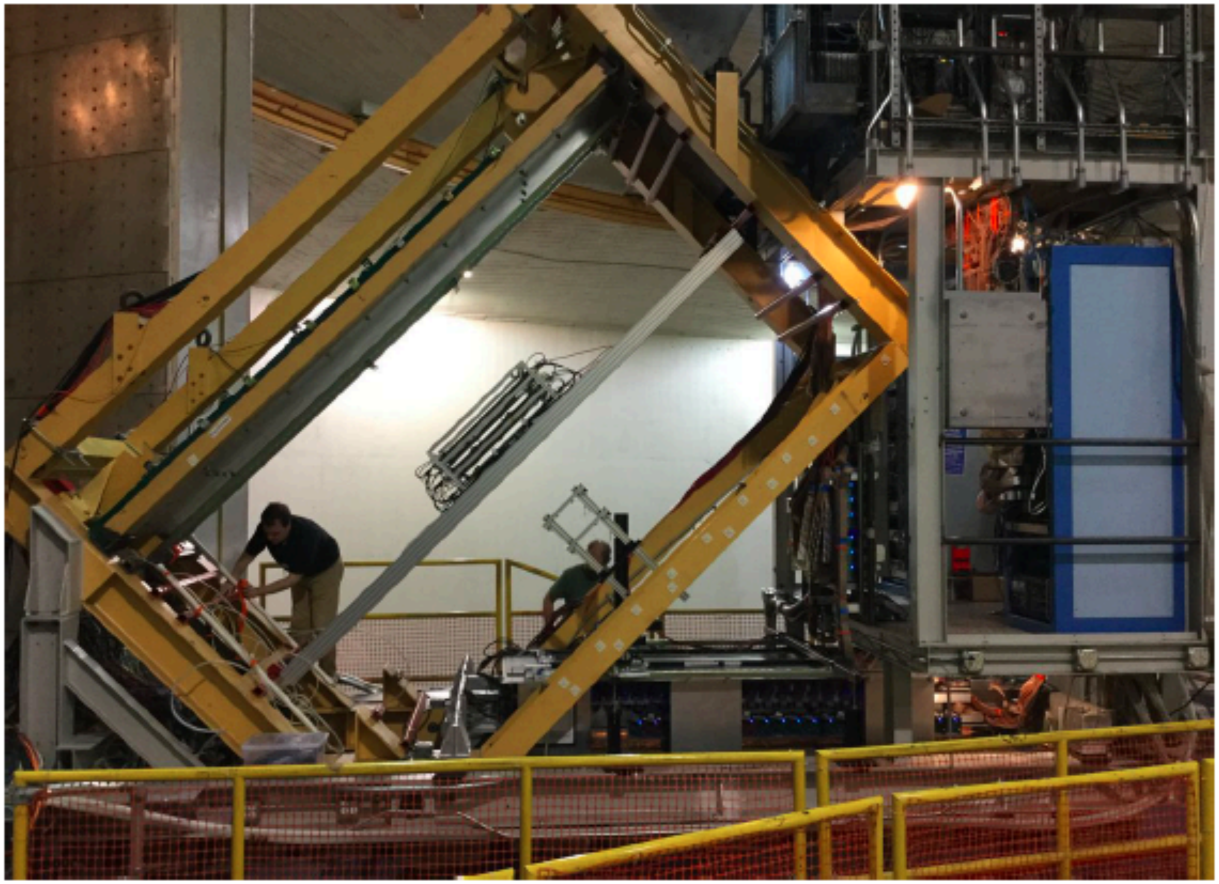


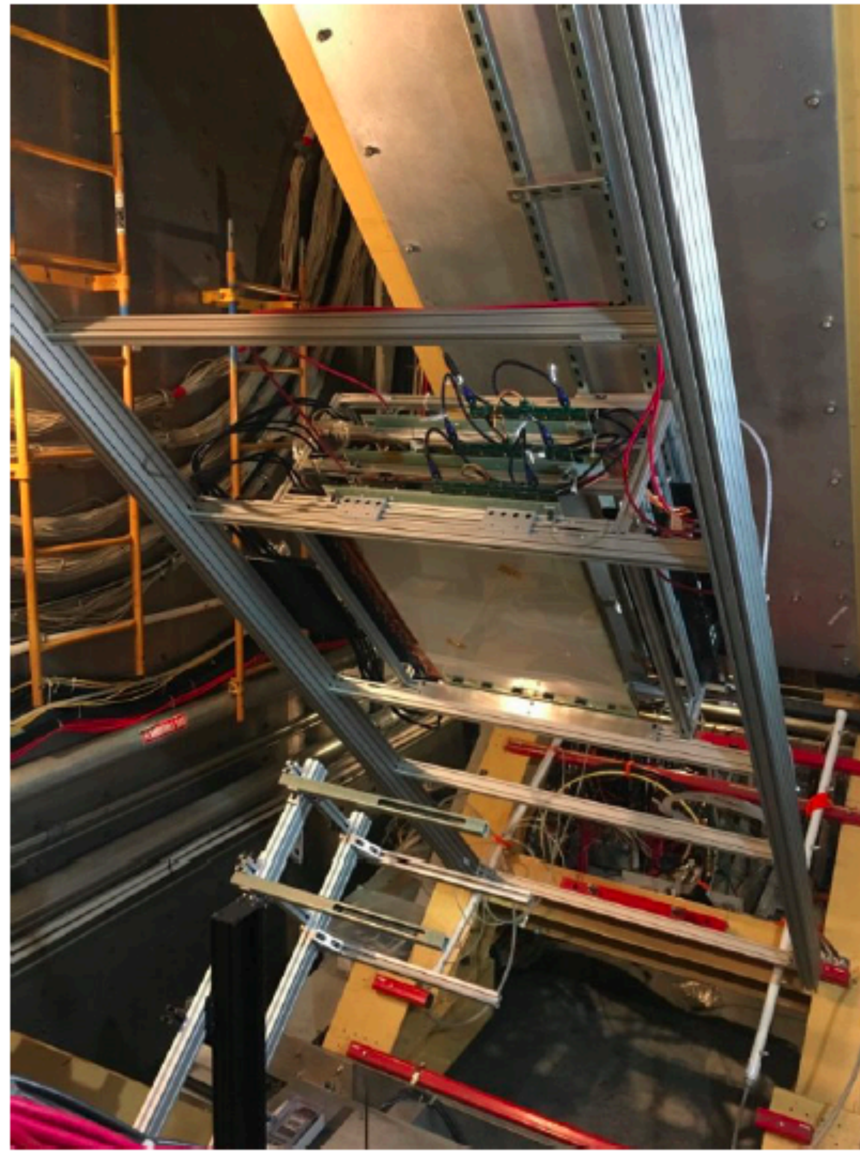
R-HRS run 20862

R-HRS run 20862

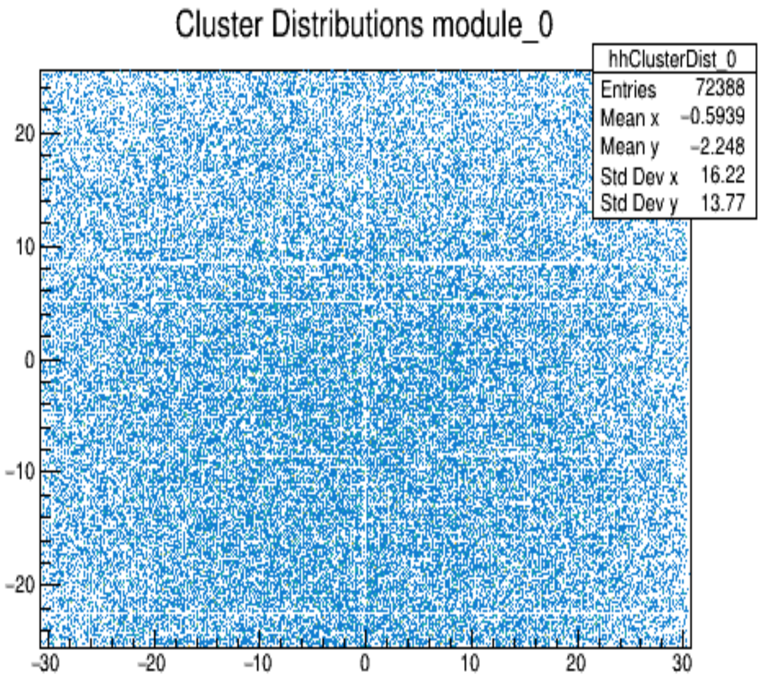



RGEM.rgems.x1.coord.resid
gemResidX1
Entries 25598
Mean -3.333e-05
~ sigma 1.013e-3
residual
RGEM.rgems.x2.coord.resid
gemResidX2
Entries 25642
Mean 4.067e-05
Std Dev 0.001236
~ sigma 1.011e-3
residual
RGEM.rgems.x3.coord.resid
gemResidX3
Entries 25608
Mean 1.774e-05
Std Dev 0.001239
~ sigma 8.80 e-4
residual
RGEM.rgems.x4.coord.resid
gemResidX4
Entries 25167
Std Dev 0.0008952
~ sigma 3.309 e-4
residual
RGEM.rgems.x5.coord.resid
gemResidX5
Entries 24995
-9.465e-05
Std Dev 0.0007847
~ sigma 3.909 e -4
residual
RGEM.rgems.x6.coord.resid
gemResidX6
Entries 25044
Mean 4.624e-05
Std Dev 0.001137
~ sigma 5.80 e -4
residual

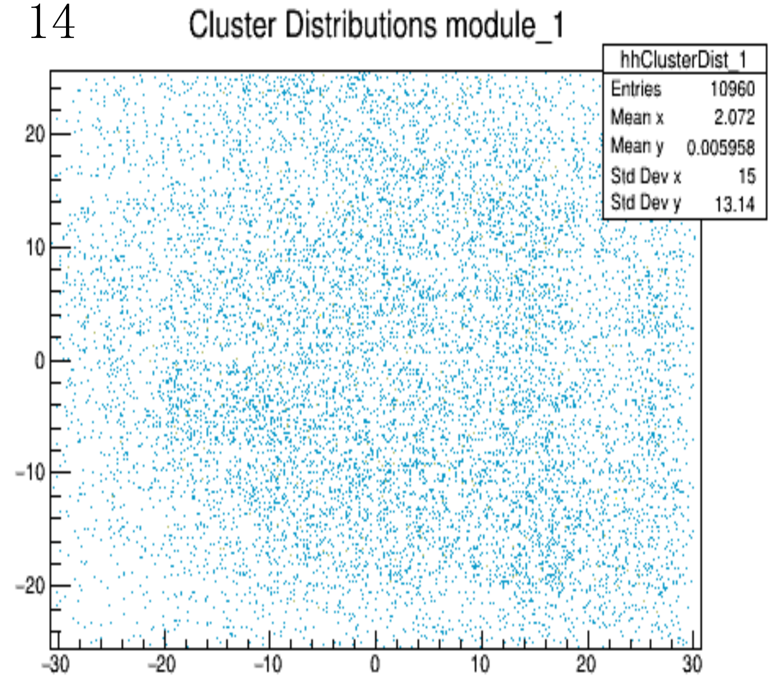




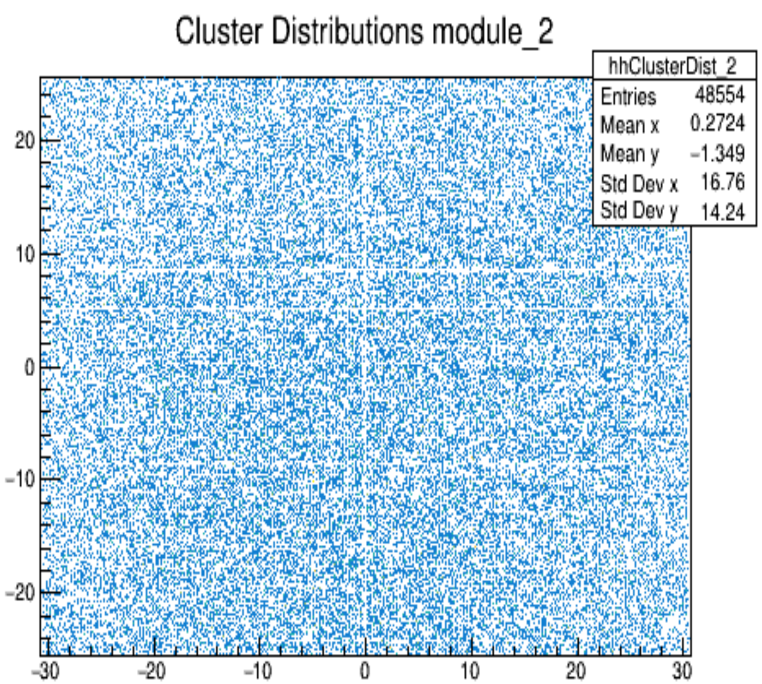
SBS28



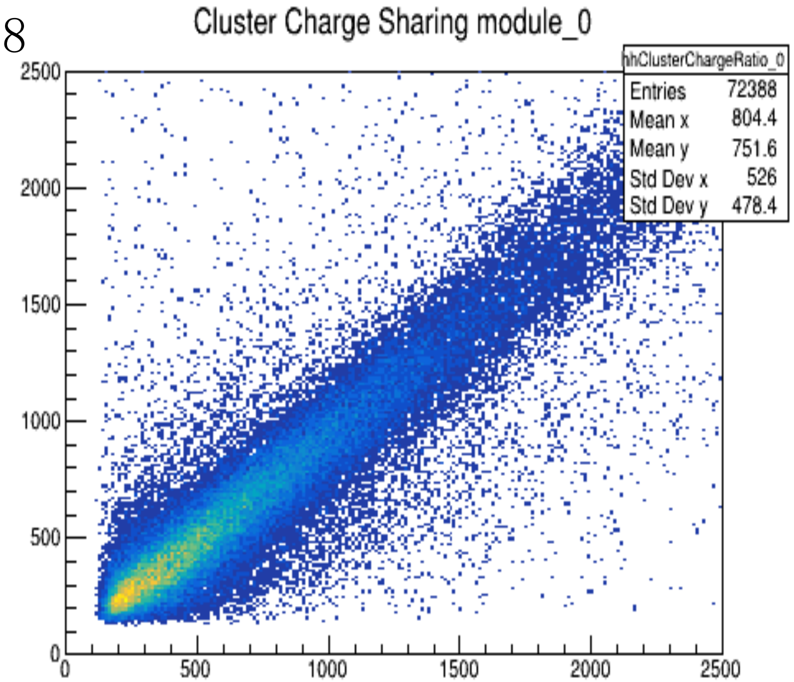
SBS 14



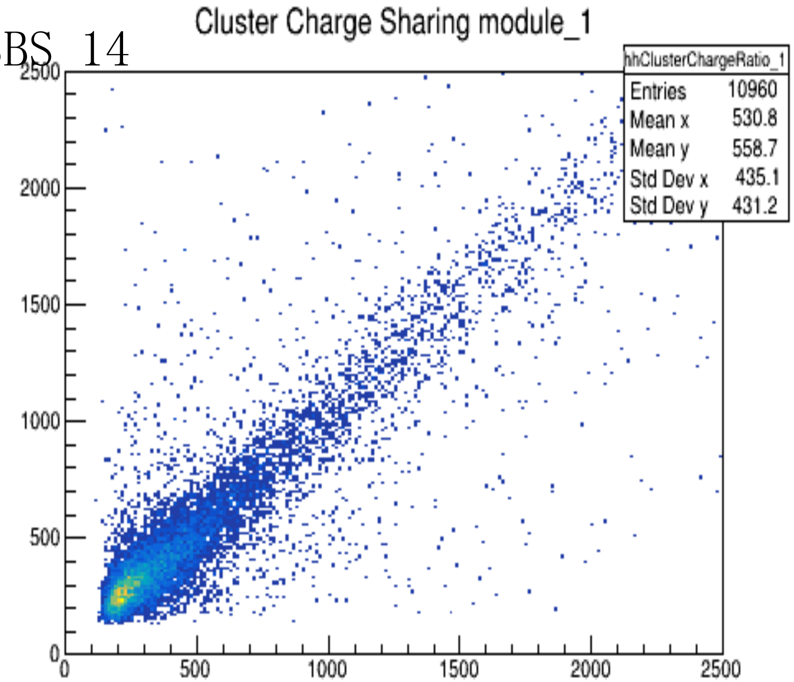
SBS26



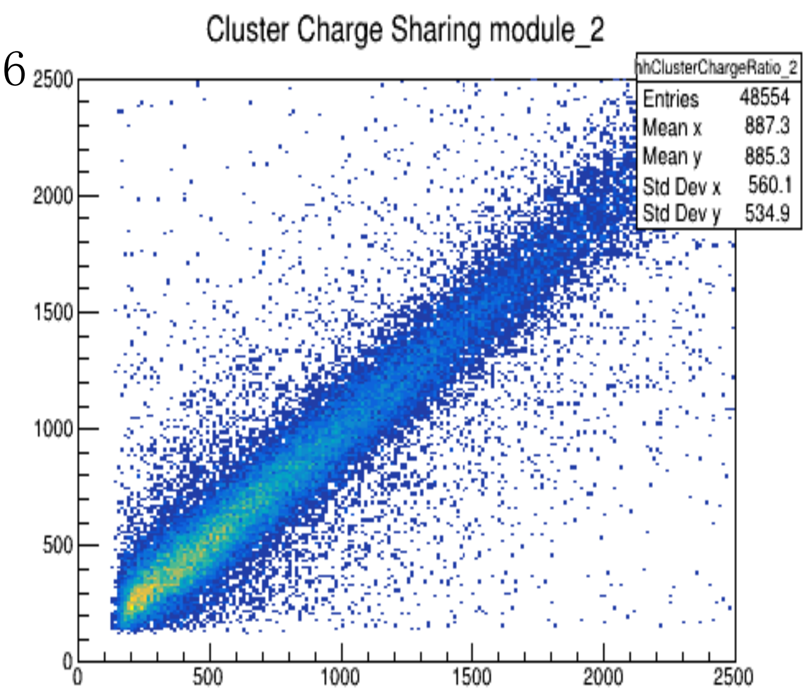
SBS28



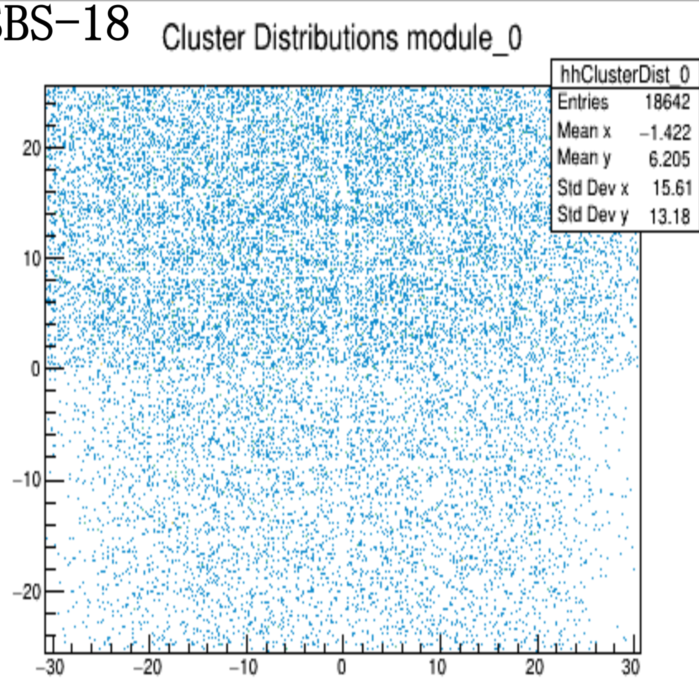
SBS_14



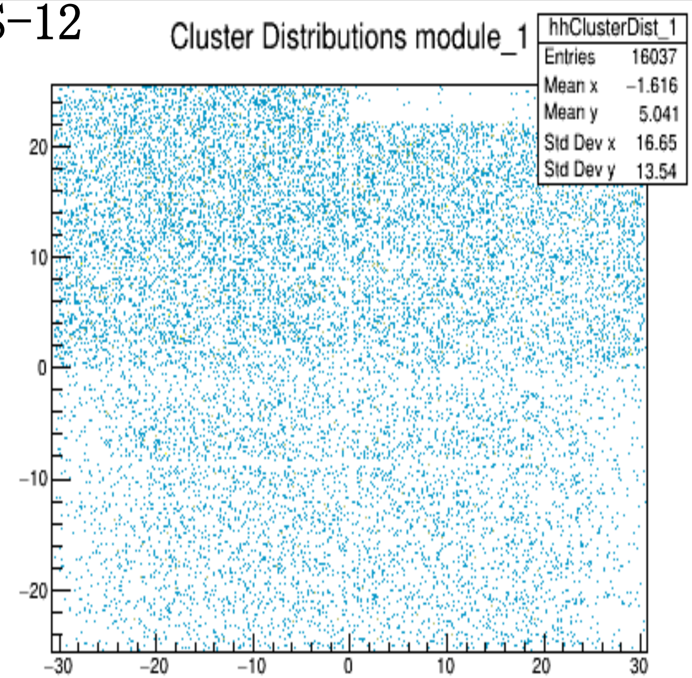
SBS26



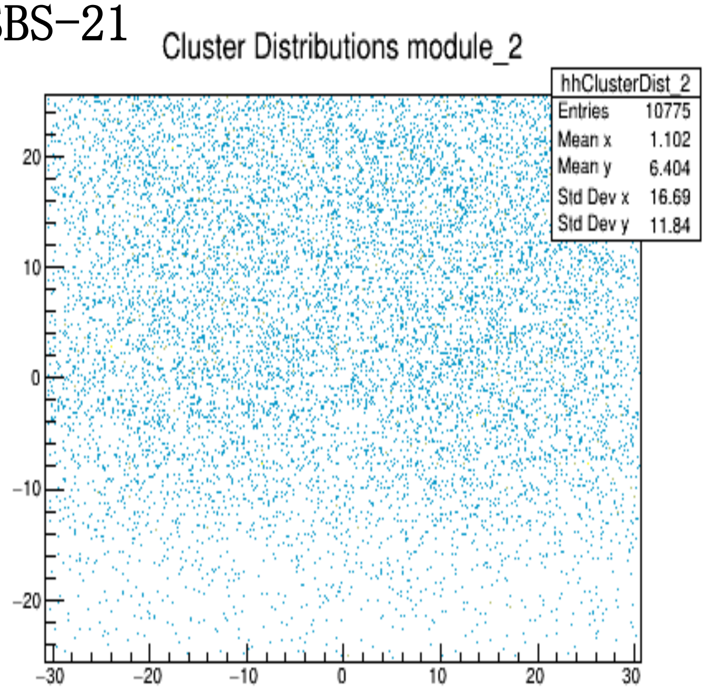
SBS−18



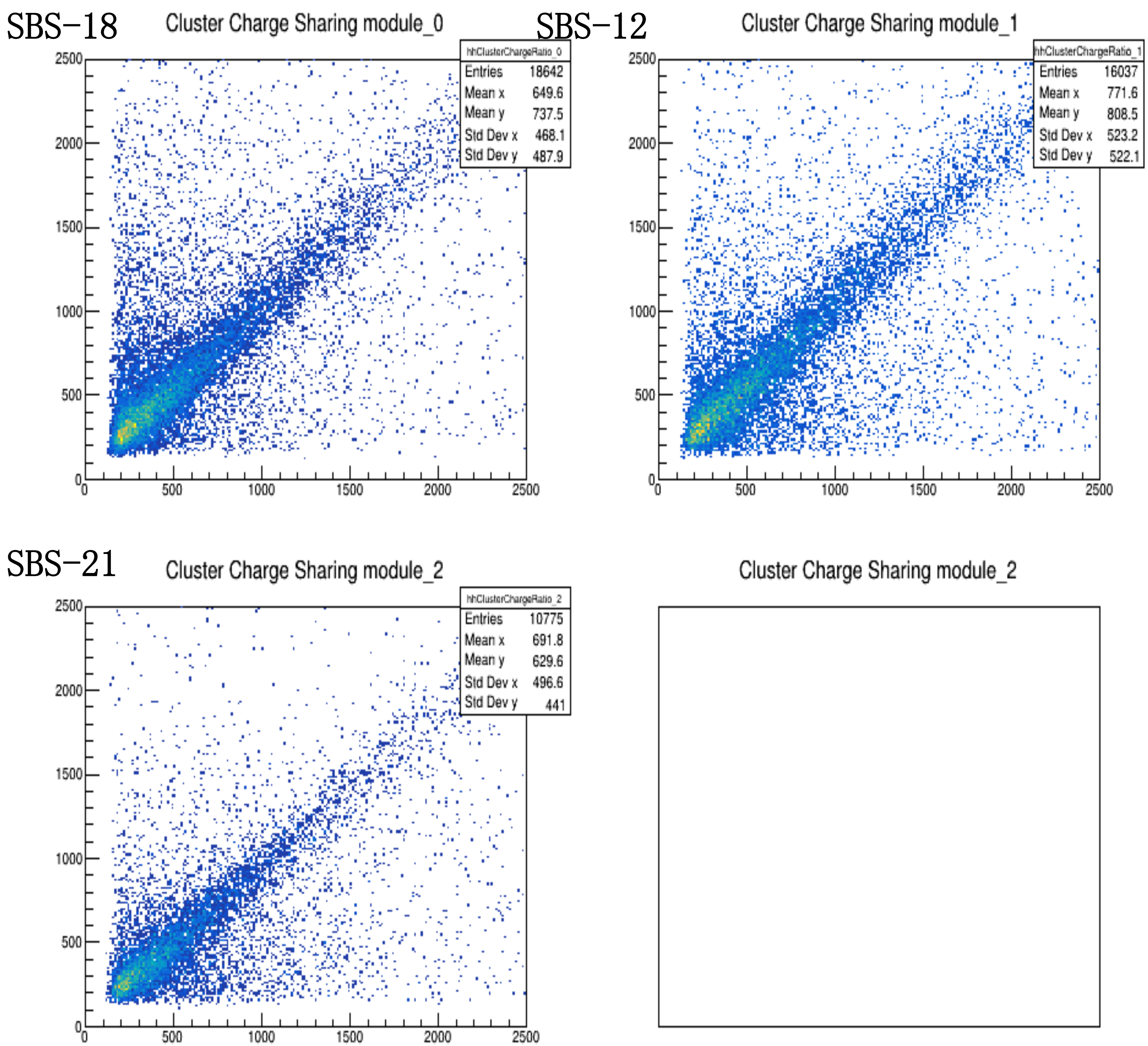
SBS−12



SBS−21

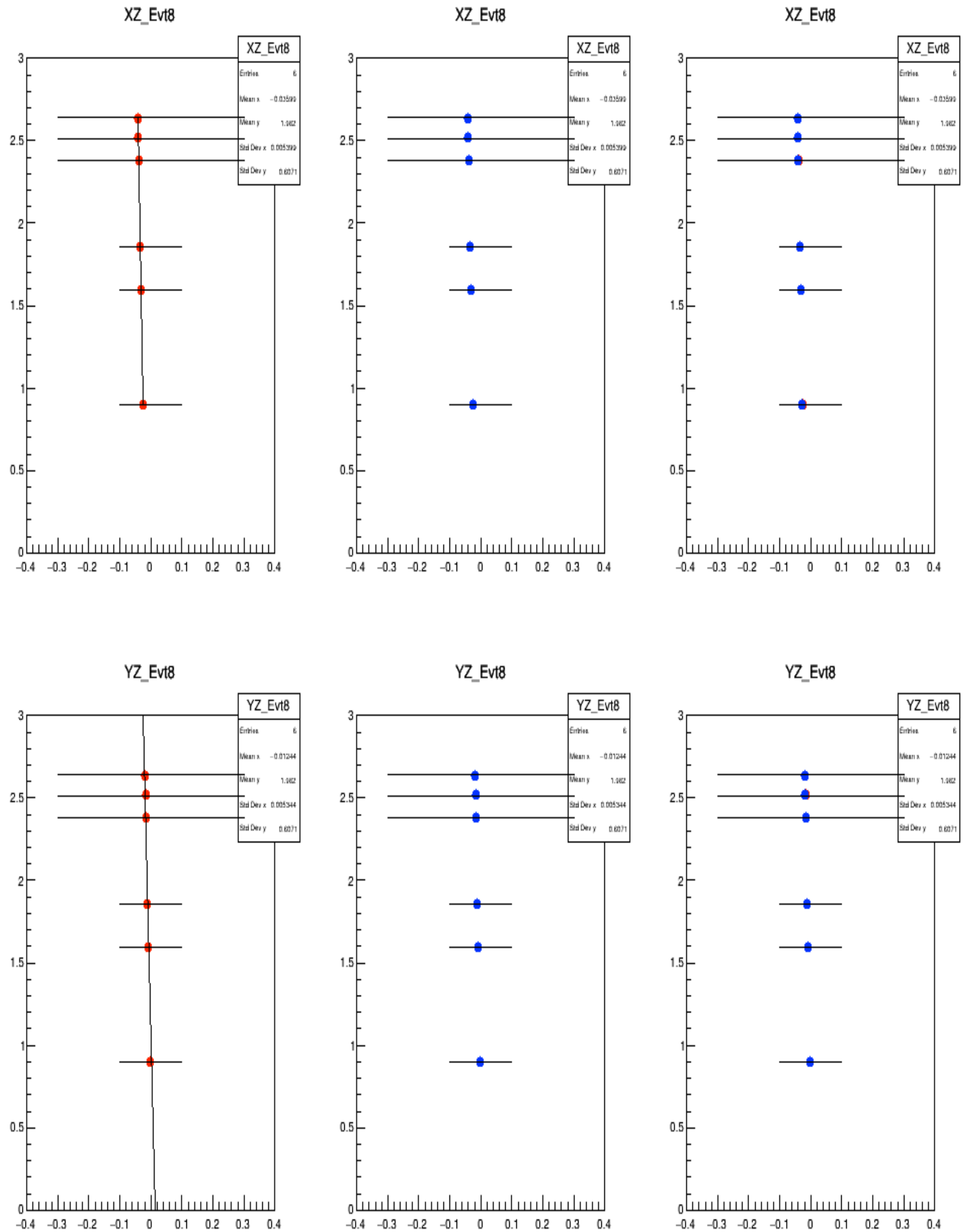


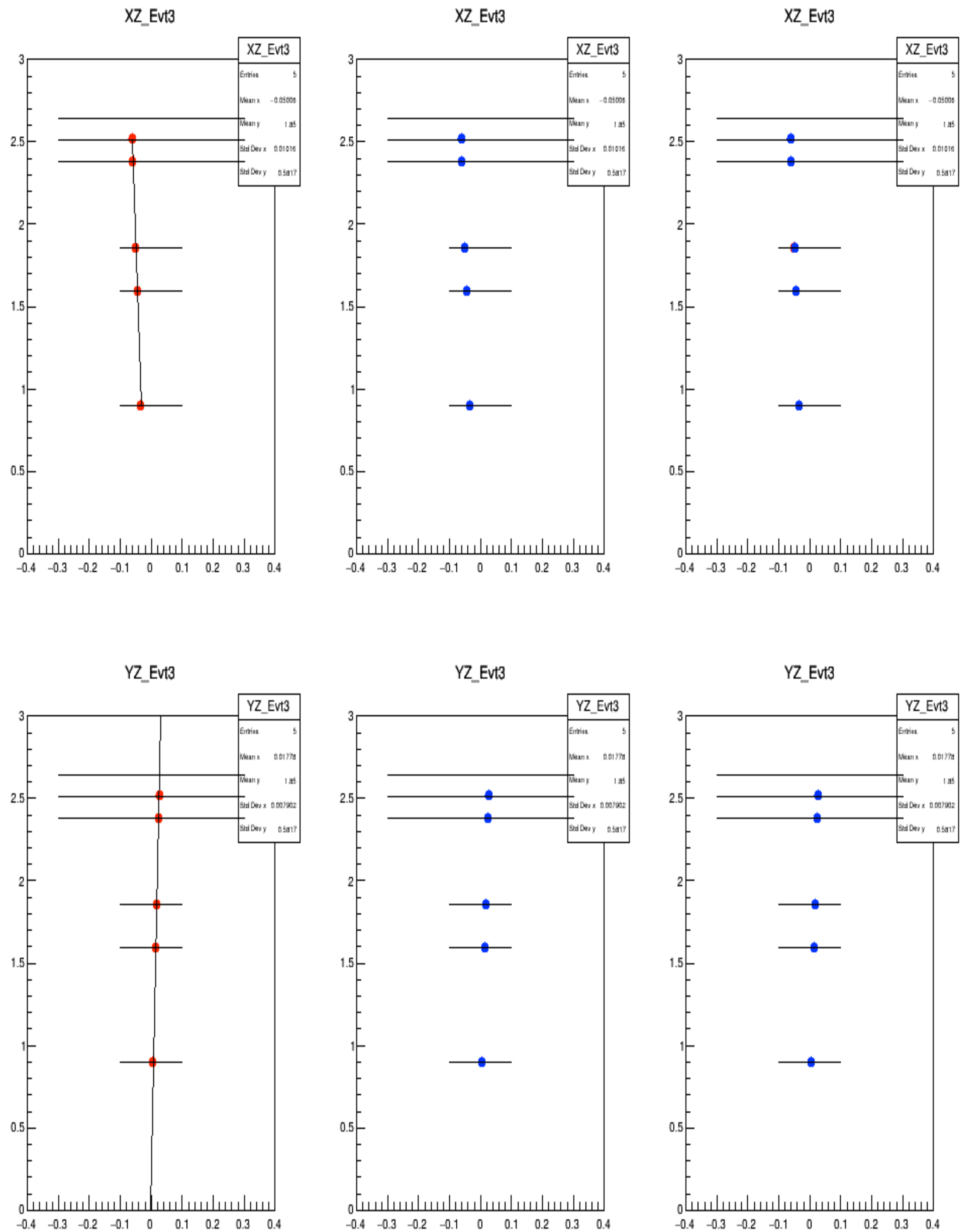
Ar−CO2 : 75:25
HV : 3900 and 3950


SBS−18
Cluster Charge Sharing module_0
hhClusterChargeRatio_0
Entries 18642
Mean x 649.6
Mean y 737.5
Std Dev x 468.1
Std Dev y 487.9
SBS−12
Cluster Charge Sharing module_1
hhClusterChargeRatio_1
Entries 16037
Mean x 771.6
Mean y 808.5
Std Dev x 523.2
Std Dev y 522.1
SBS−21
Cluster Charge Sharing module_2
hhClusterChargeRatio_2
Entries 10775
Mean x 691.8
Mean y 629.6
Std Dev x 496.6
Std Dev y 441
Cluster Charge Sharing module_2
0
500
1000
1500
2000
2500

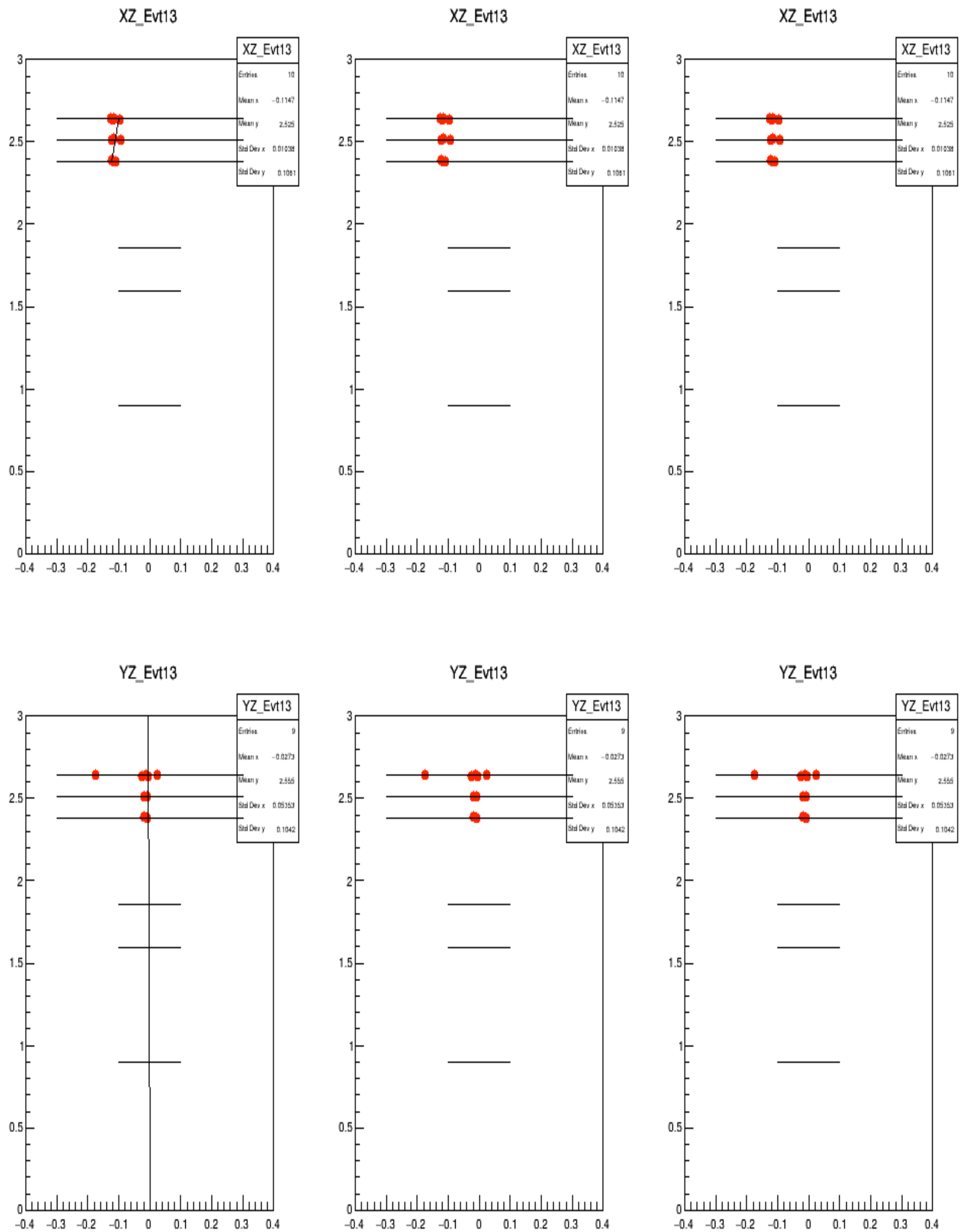
backups

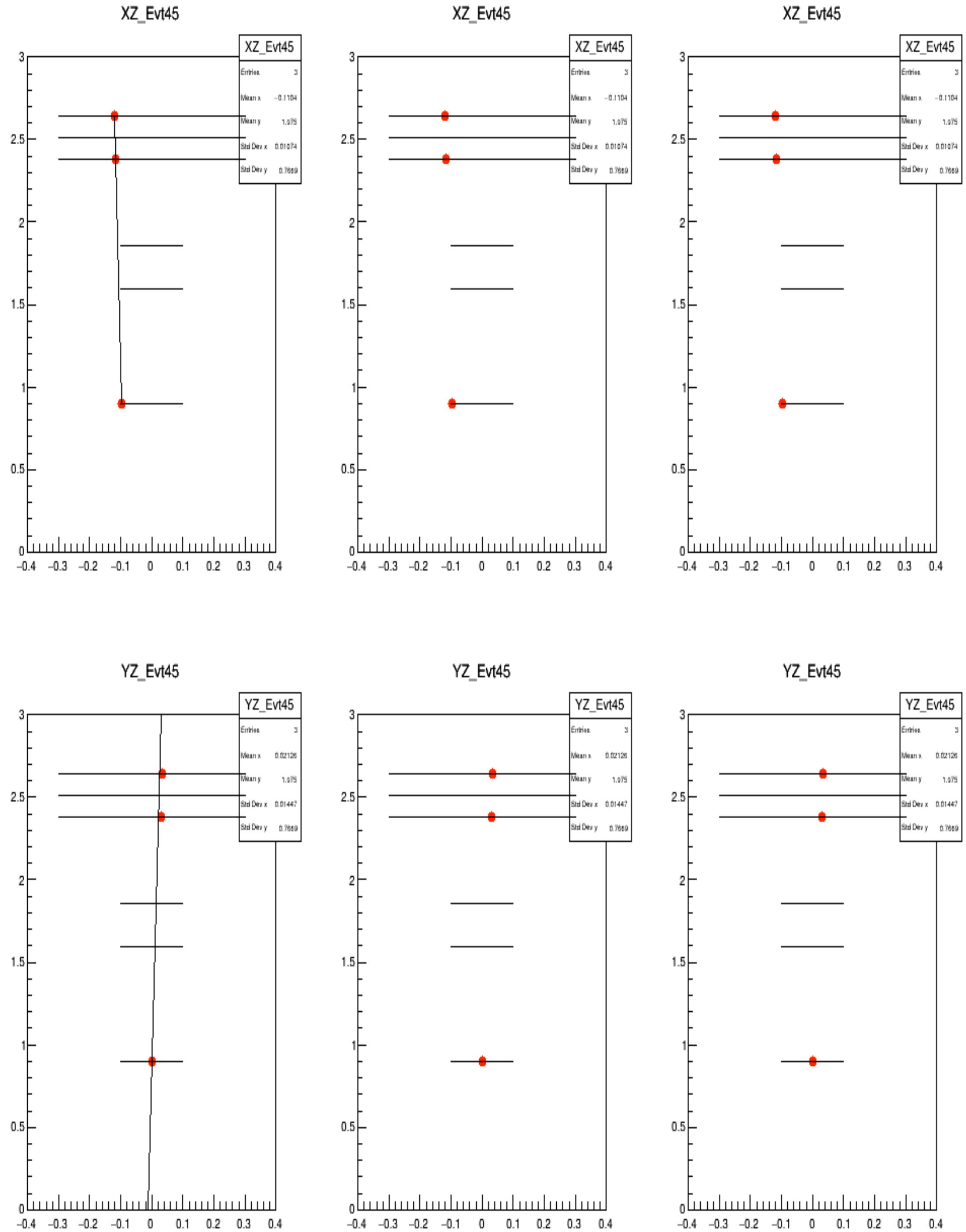
TreeSearch works fine if 5 or 6 GEM detec

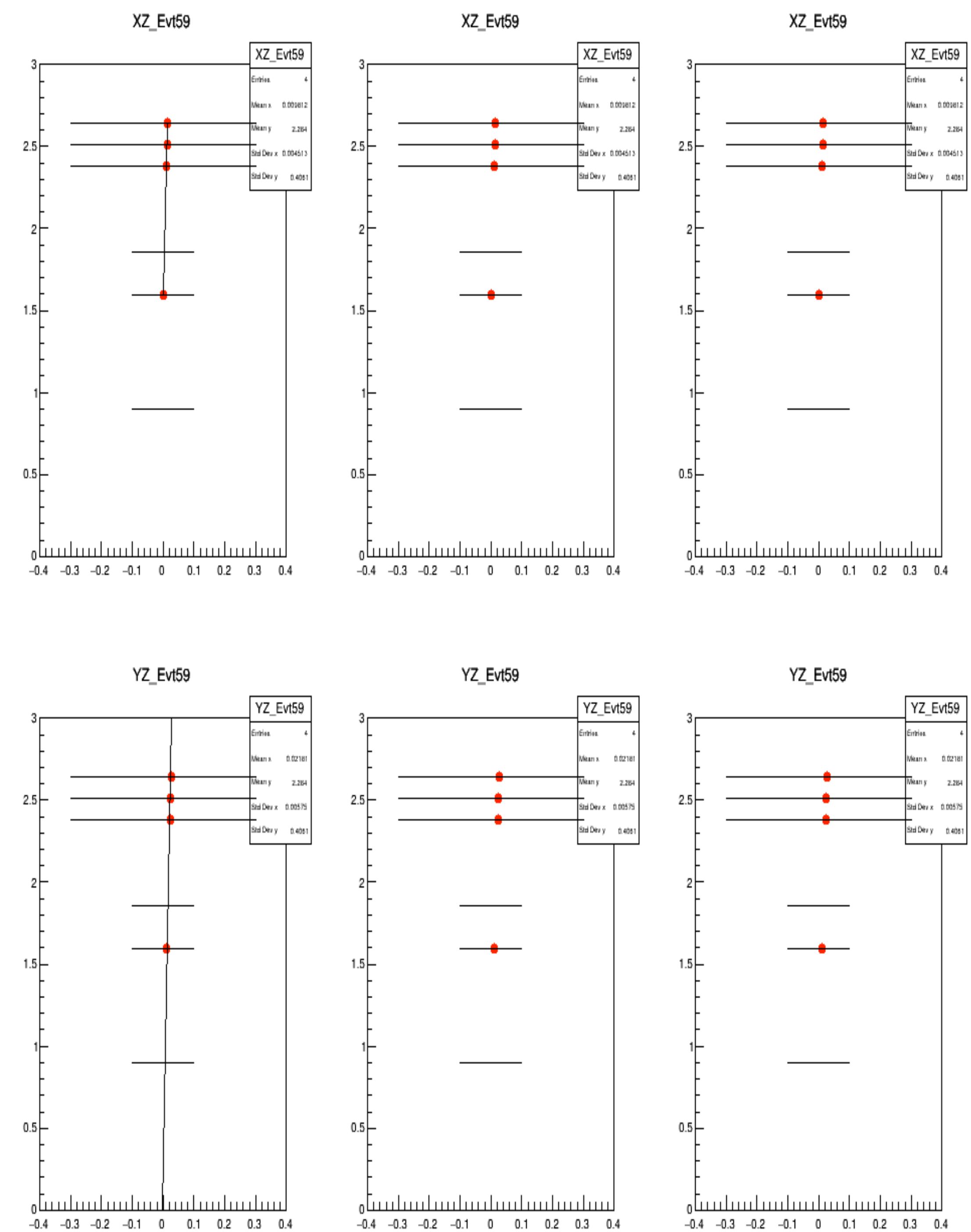



XZ_Evt3
XZ_Evt3
Entries 5
Mean x −0.05006
Mean y 1.85
Std Dev x 0.01016
Std Dev y 0.5817
XZ_Evt3
XZ_Evt3
Entries 5
Mean x −0.05006
Mean y 1.85
Std Dev x 0.01016
Std Dev y 0.5817
XZ_Evt3
XZ_Evt3
Entries 5
Mean x −0.05006
Mean y 1.85
Std Dev x 0.01016
Std Dev y 0.5817
YZ_Evt3
YZ_Evt3
Entries 5
Mean x 0.01778
Mean y 1.85
Std Dev x 0.007902
Std Dev y 0.5817
YZ_Evt3
YZ_Evt3
Entries 5
Mean x 0.01778
Mean y 1.85
Std Dev x 0.007902
Std Dev y 0.5817
YZ_Evt3
YZ_Evt3
Entries 5
Mean x 0.01778
Mean y 1.85
Std Dev x 0.007902
Std Dev y 0.5817

fail to get the track when
4 or less plane have hit




XZ_Evt45
XZ_Evt45
Entries 3
Mean x −0.1104
Mean y 1.975
Std Dev x 0.01074
Std Dev y 0.7669
YZ_Evt45
YZ_Evt45
Entries 3
Mean x 0.02126
Mean y 1.975
Std Dev x 0.01447
Std Dev y 0.7669



XZ_Evt59
XZ_Evt59
Entries 4
Mean x
Mean y 2.284
Std Dev x 0.004513
Std Dev y 0.4081
XZ_Evt59
XZ_Evt59
Entries 4
Mean x
Mean y 2.284
Std Dev x 0.004513
Std Dev y 0.4081
XZ_Evt59
XZ_Evt59
Entries 4
Mean x
Mean y 2.284
Std Dev x 0.004513
Std Dev y 0.4081
YZ_Evt59
YZ_Evt59
Entries 4
Mean x 0.02181
Mean y 2.284
Std Dev x 0.00575
Std Dev y 0.4081
YZ_Evt59
YZ_Evt59
Entries 4
Mean x 0.02181
Mean y 2.284
Std Dev x 0.00575
Std Dev y 0.4081
YZ_Evt59
YZ_Evt59
Entries 4
Mean x 0.02181
Mean y 2.284
Std Dev x 0.00575
Std Dev y 0.4081