GEM Detectors for SoLID

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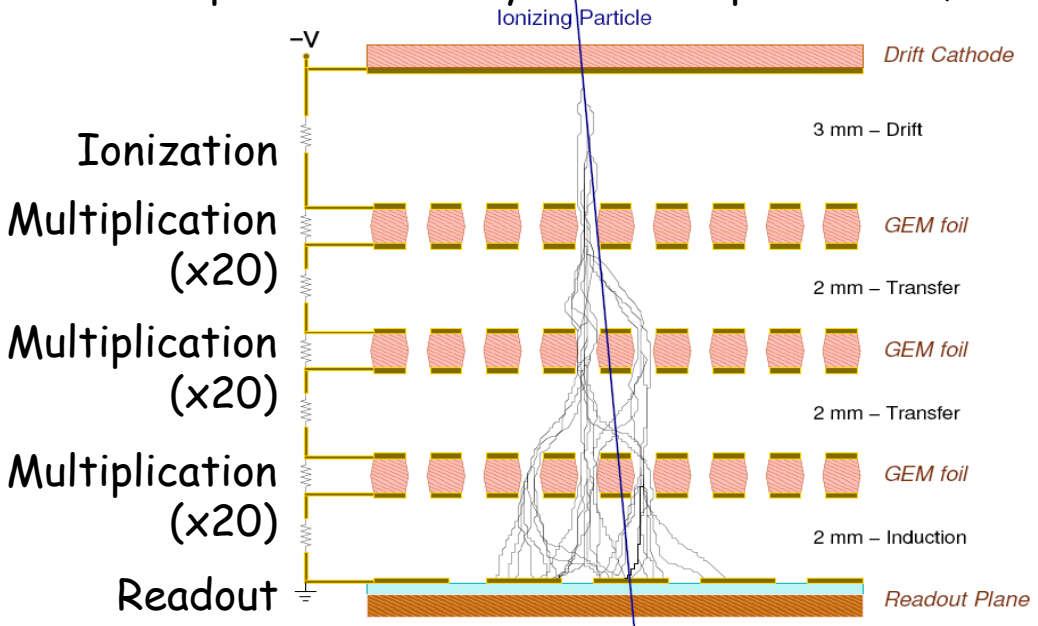
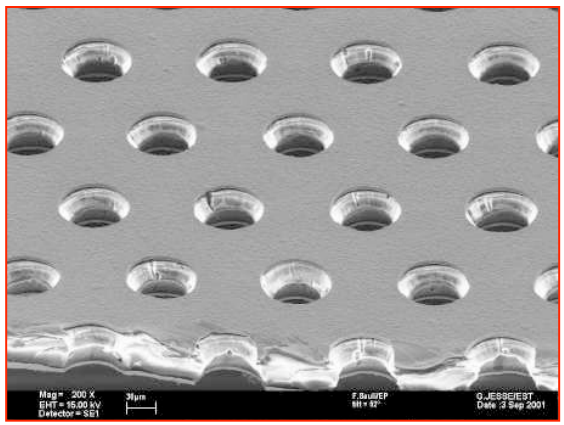
Why GEMs ?

- SoLID concept leads to high rate in trackers: and requires good resolution.
- 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 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, ALICE TPC, pRad etc.
- And planed for many future experiments:, CMS upgrade, SoLID, Moller, P2 @ Mainz

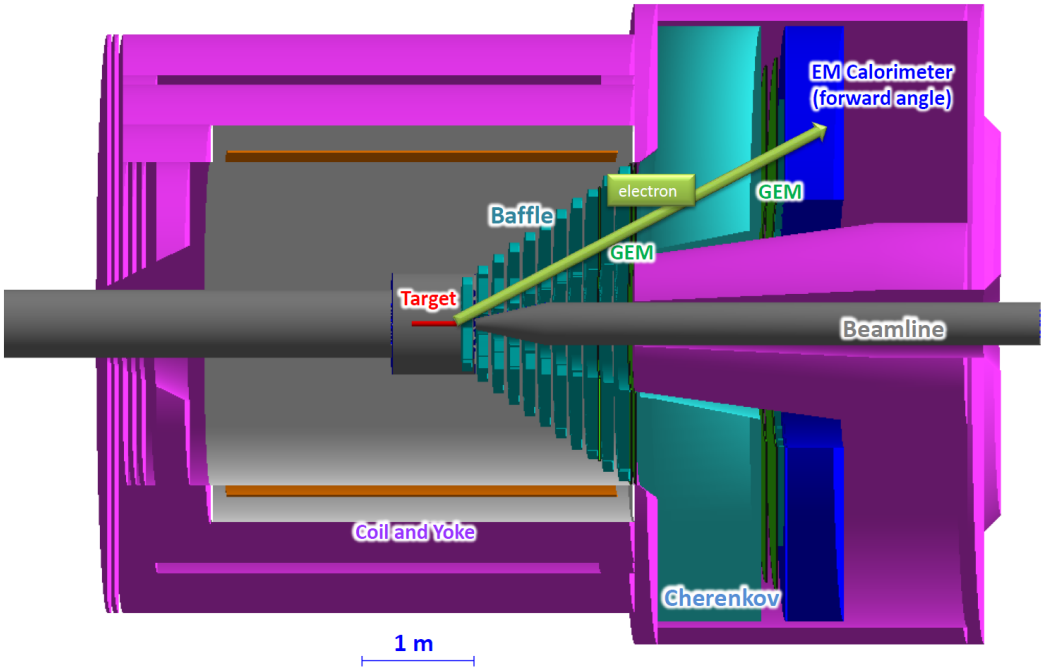


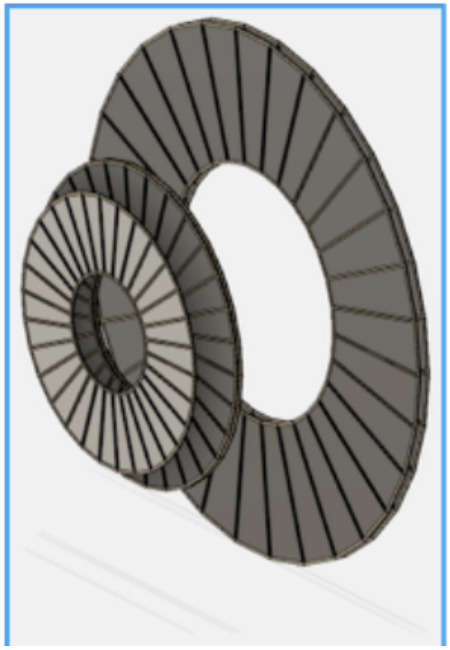
GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch

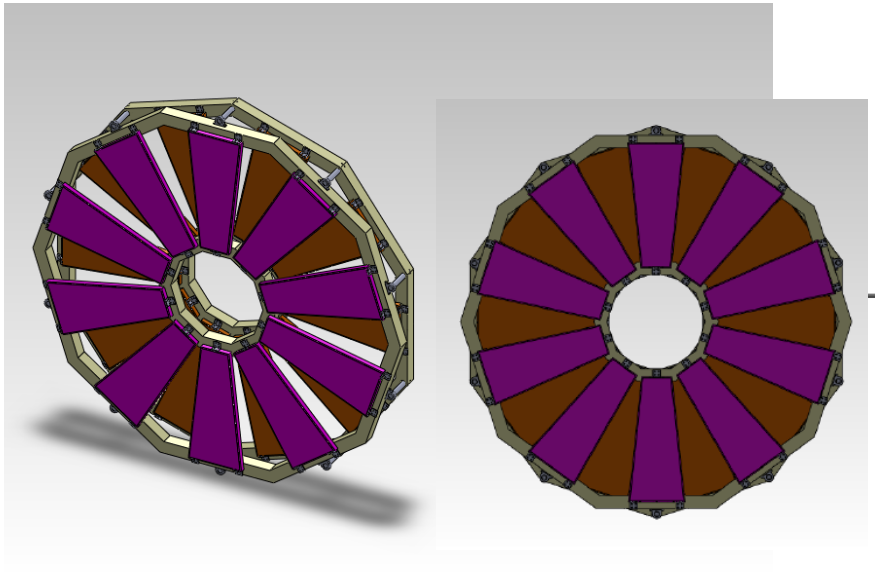


Novel technology: F. Sauli, Nucl. Instrum. Methods A386(1997)531

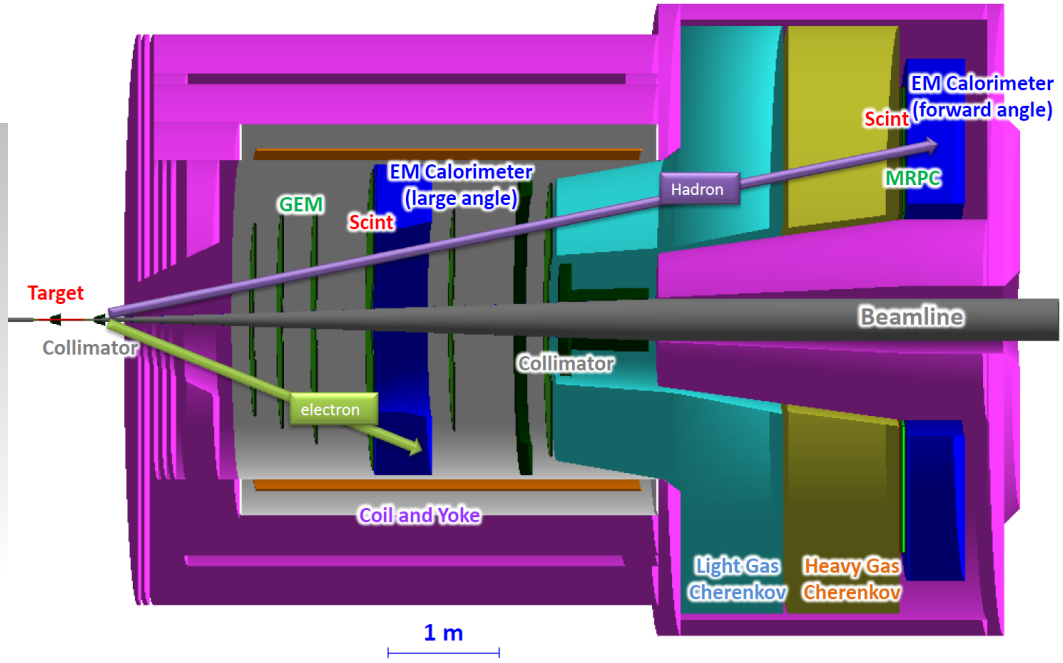
SoLID (PVDIS)







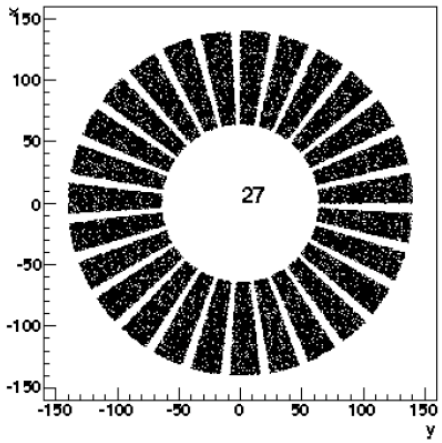
SoLID (SIDIS & J/ψ)



SIDIS GEM full configuration

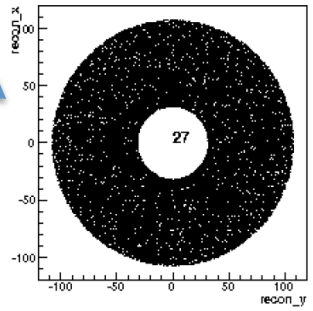
- Six locations instrumented with GEM:
- PVDIS GEM modules can be re-arranged to make all chamber layers for SIDIS. – move the PVDIS modules closer to the axis so that they are overlapping with each other

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



PVDIS

SIDIS



- More than enough electronic channels from PVDIS setup.
- The two configurations will work well with no need for new GEM or electronics fabrication.

PVDIS GEM full configuration

- Instrument five locations with GEMs:
- 30 GEM modules at each 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

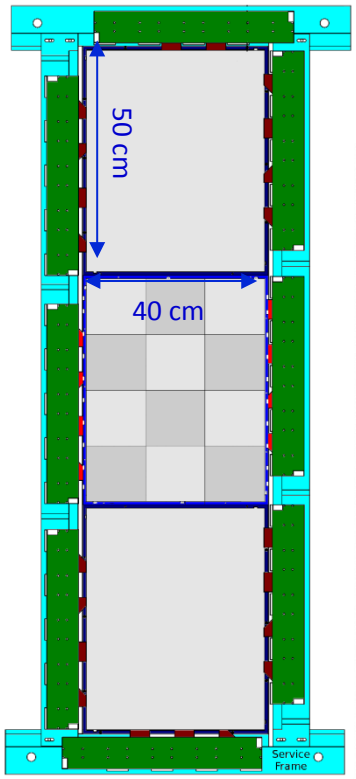
- The high occupancy at location 1 will require splitting each readout strip into two channels: this will add another 12 k channels
- Total number of channels needed: ~ 176 k
- With ~ 15% spares (to account for losses during production etc.) need to plan for

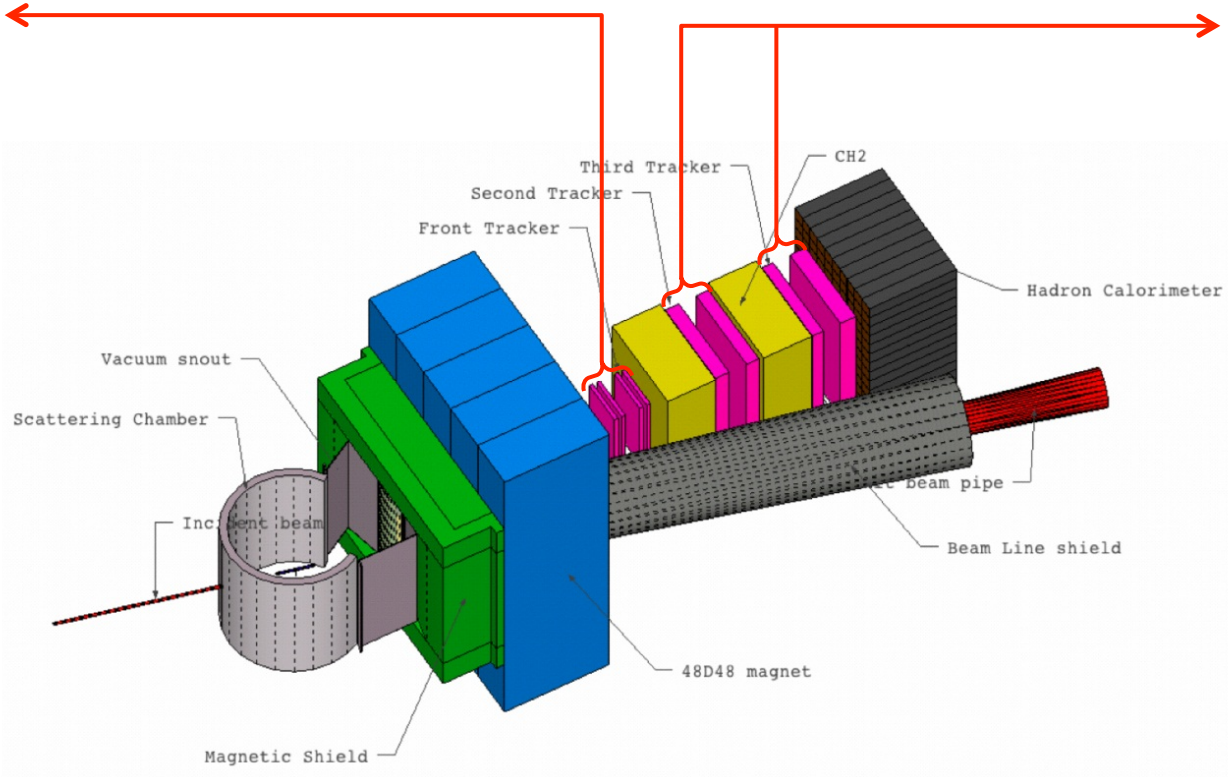
200 k channels

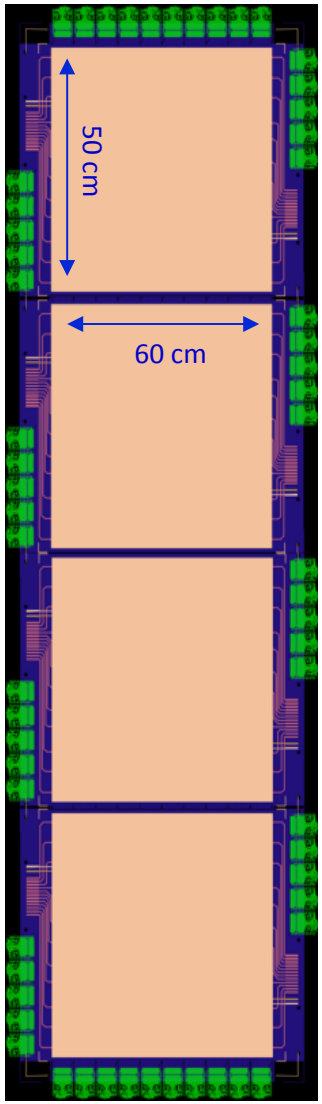
GEM plans for SoLID based on recent work for SBS

- Front Tracker:
- 6 GEM Layers (150 × 40 cm^2)
- Each layer = 3 GEM modules (50 × 40 cm^2)
- R&D and Production by INFN Roma, Catania

- Back Tracker
- 11 GEM Layers (200 × 60 cm^2)
- Each Layer = 4 GEM modules (50 × 60 cm^2)
- R&D and Production @ University of Virginia







Proton arm layout for GEp (5) experiment

Total Area ~ 16 m^2

SBS GEM Production at UVa is complete:

- Completed building 49 modules (plan was to build 48) and tested.
- 46 tested modules and all work per specs.
- GEM foils and readouts from CERN: GEM frames from Resarm in Belgium
- All 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.

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

All readout connections to the outer edge of the circle:

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

Common GEM foil design:

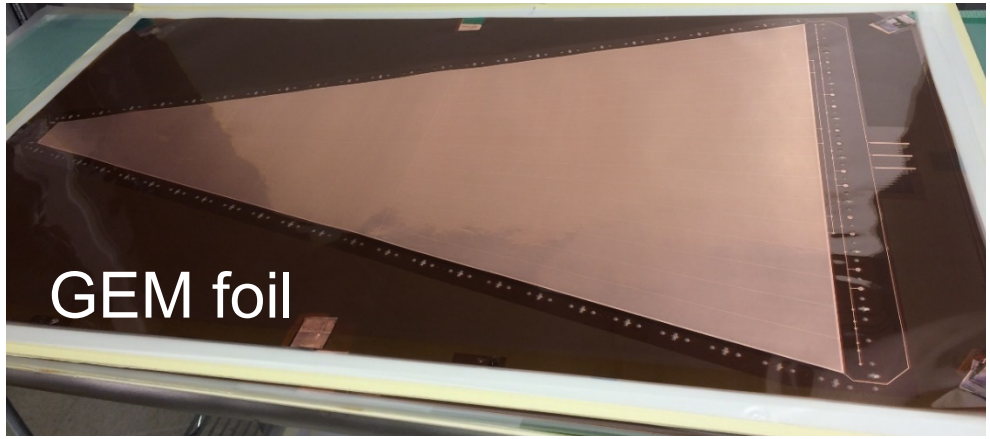
- (Univ. of Virginia, Florida Tech, and Temple U.)
- All connections (HV, gas flow structure and FE cards) are made on outer radius end.

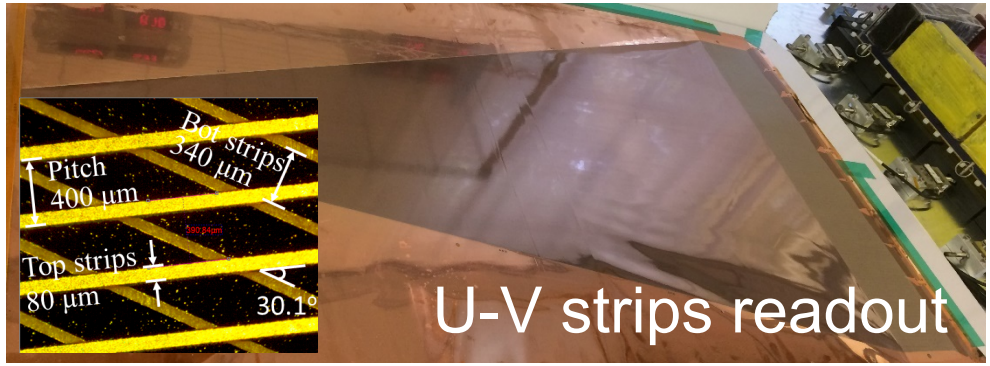
2D U-V strips readout (R/O)

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

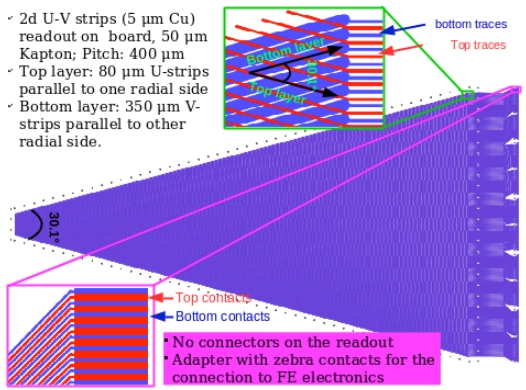
Double-sided zebra connection

- 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

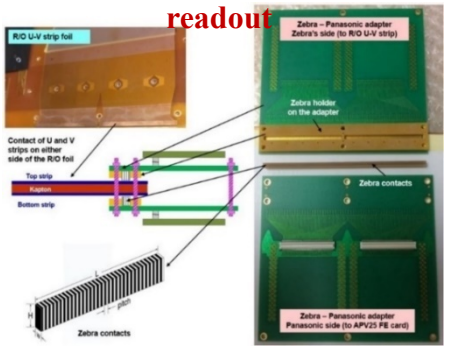




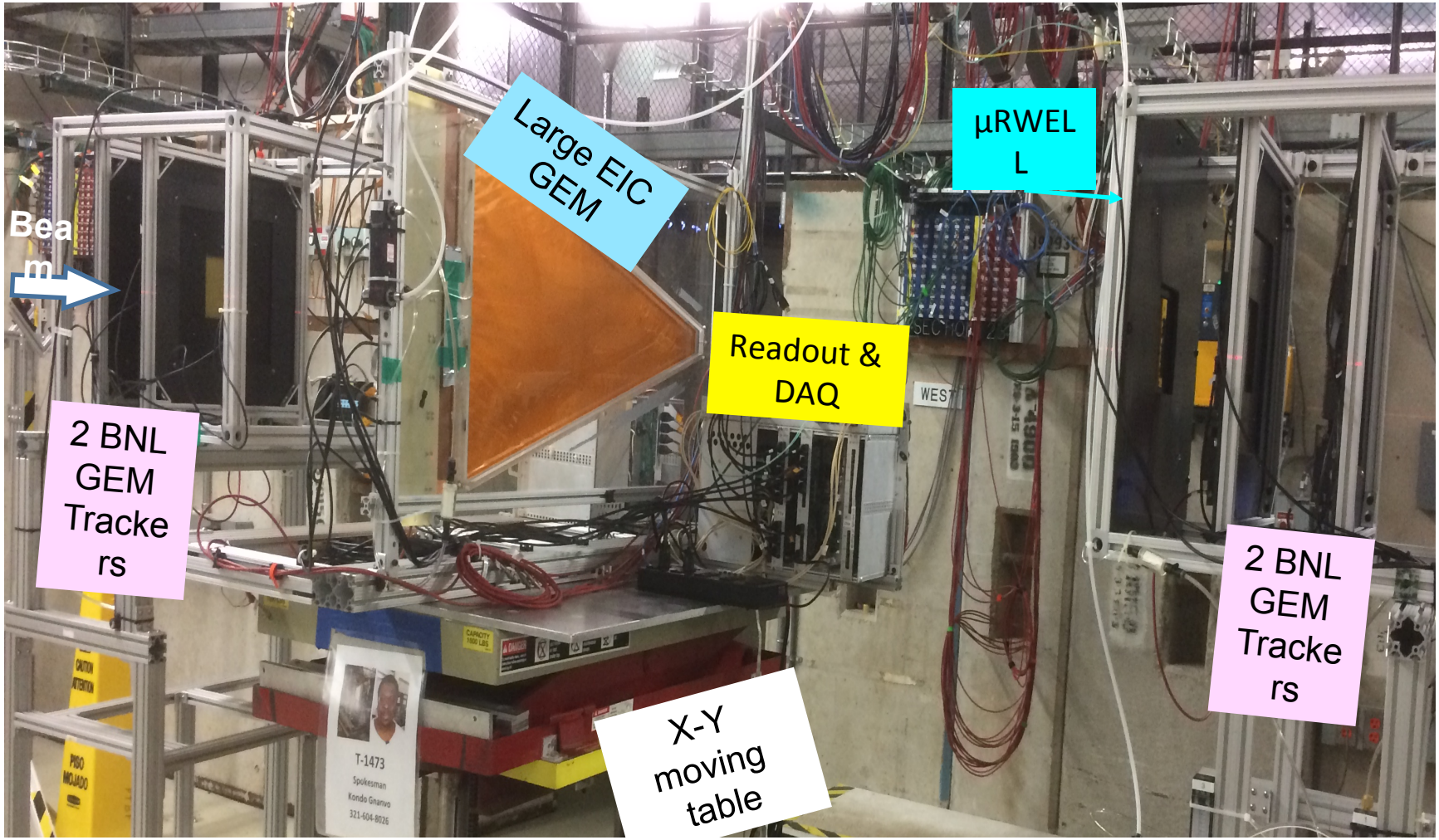
Design of EIC-Proto II 2D U-V strips readout board

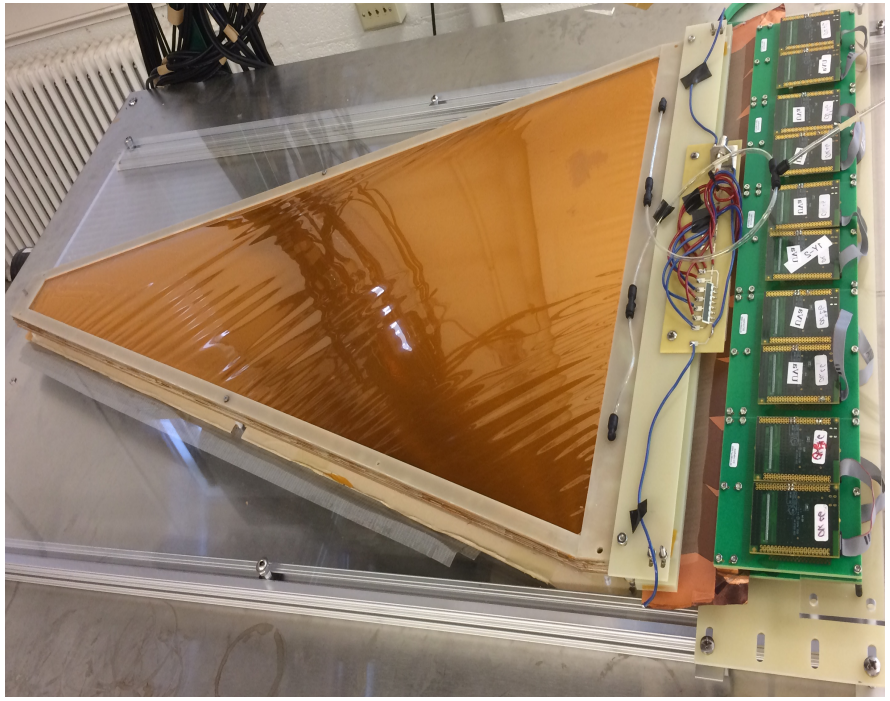


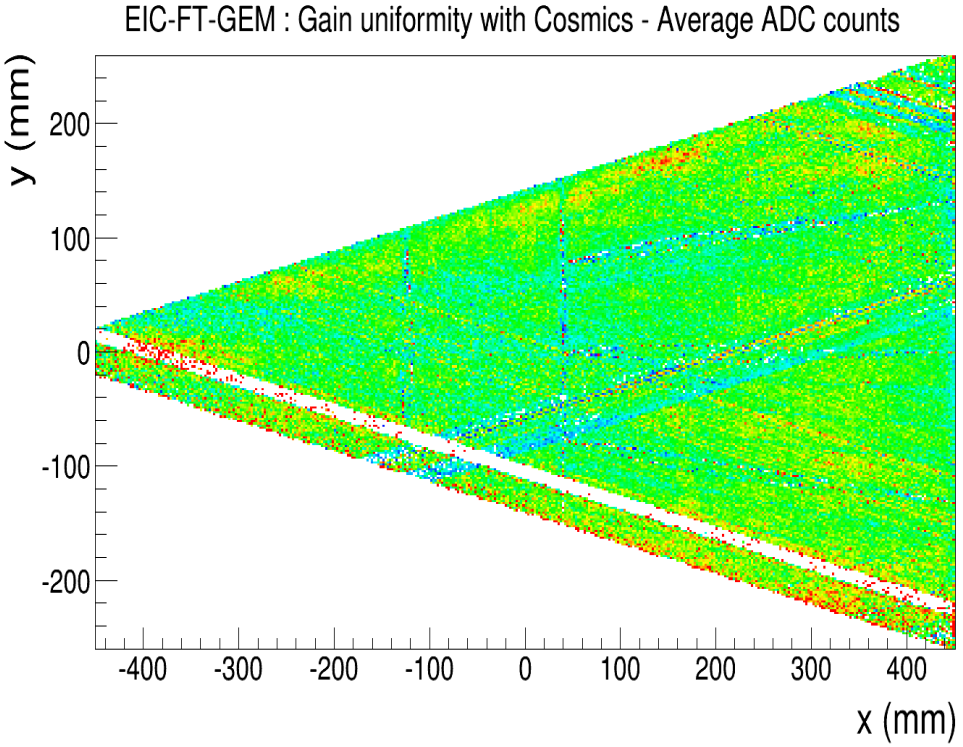
Principle of double-sided zebra connection on flexible PCB readout

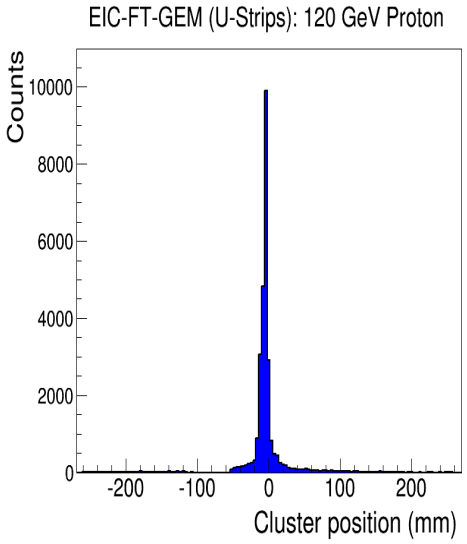


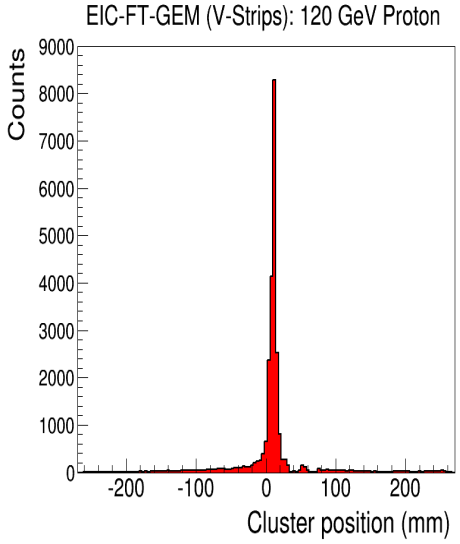
Large GEM Setup in MT6.2b Area at the FTBF (June-July 2018)

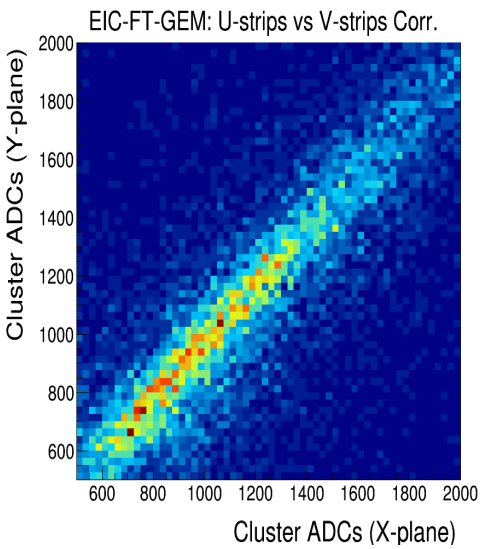


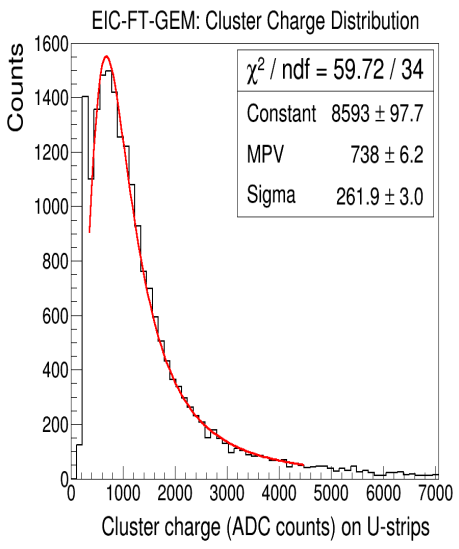



EIC-FT-GEM : Gain uniformity with Cosmics - Average ADC counts
y (mm)
200
100
0
-100
-200
-400
-300
-200
-100
0
100
200
300
400
x (mm)


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
χ² / 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

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
- SAMPA chip is not rad-hard: will not work for SoLID
- VMM is a good choice: but need to develop direct mode readout.
  - Assume $ 75 k for pre-R&D work
  - Assume $ 200 engineering design and development of readout system
  - $ 4/chan for fabrication costs.

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
  - The direct readout mode (with fast ~ 200 ns reset time) may work well for SoLID.
  - Only 6-bit ADC in this mode.
  - Need to understand and evaluate the VMM chip for SoLID with pre-R&D work
  - Important to get a collaborator to take over the project.

Alternate Chip Options: VMM

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)

SRS
Scalable Readout System

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

Budget Estimates

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.

Budget Estimates

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.

Risks and Mitigation strategies

- On time availability of GEM foils.
  - 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:
  - Please the orders for the whole need well in advance (at least 1 year or more) to allow CERN shop to plan the 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.

- All Working with these companies, CERN shop is now completing a very large foil order for CMS upgrade project. This shows that advanced planning and early coordination with CERN, risks could be minimized.

Risks and Mitigation strategies

- The fabrication timeline may be too ambitious for one group to complete on time.
  - Based on SBS experience, it seems that the UVa group could build up to about 40-50 modules/year, but a more conservative and safe goal would be about 35-40 per year. This will require longer than anticipated in the plan.

  - Mitigation strategies:
    - Work with partner institutions with GEM experience to distribute the production to more locations. Work with these institutions from prototyping stage to build readiness.
    - Work with groups at Temple U and Hampton U.

Risks and Mitigation strategies

- Suitability of VMM electronics for high rate operation needed for SoLID ?
  - 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.

Alternate Chip Options: VMM: SRS version