GEM Detectors for SoLID

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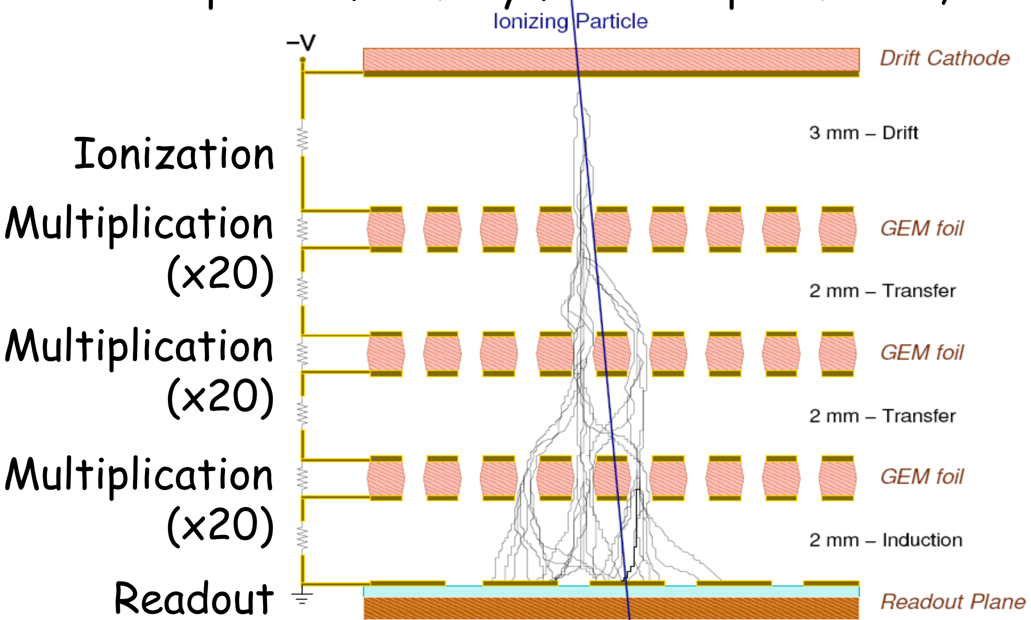
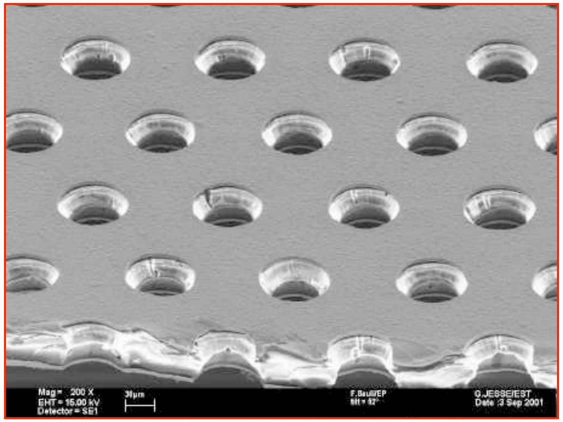
Why GEMs ?

- 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.

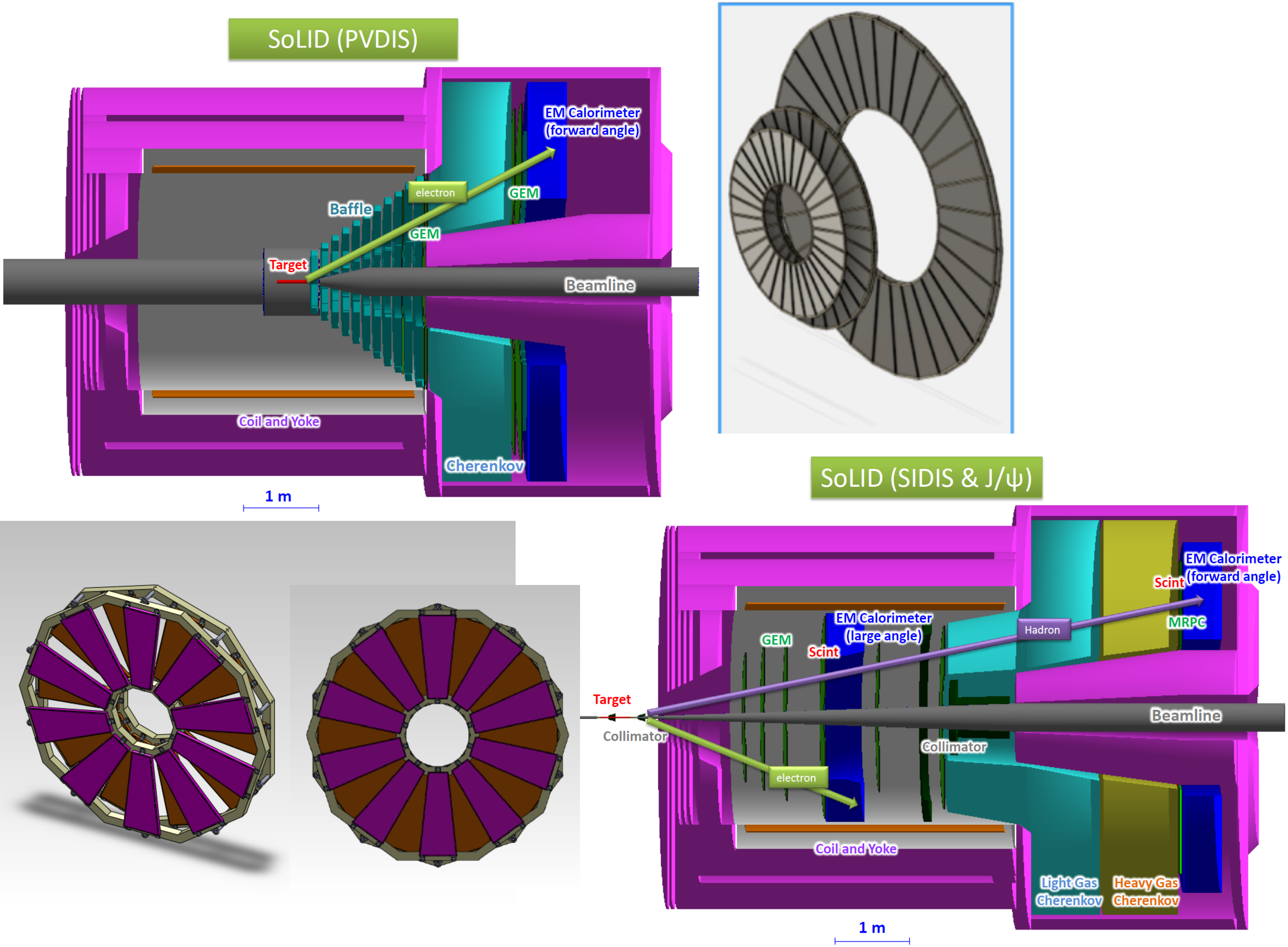
  - Rate capabilities higher than many MHz/cm^2
  - High position resolution (< 75 μm)
  - Ability to cover very large areas (10s – 100s of m^2) at modest cost.
  - Low thickness (~ 0.5% radiation length)
  - Already Used for many experiments around the world: COMPASS, Bonus, KLOE, TOTEM, STAR FGT, ALICE 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)
EM Calorimeter
(forward angle)
electron
GEM
Baffle
GEM
Target
Beamline
Coil and Yoke
Cherenkov
1 m
SoLID (SIDIS & J/ψ)
EM Calorimeter
(forward angle)
Scint
EM Calorimeter
(large angle)
Hadron
MRPC
GEM
Scint
Target
Collimator
Beamline
Collimator
electron
Coil and Yoke
Light Gas
Cherenkov
Heavy Gas
Cherenkov
1 m

Major change in plans since last meeting

- Separated into baseline equipment and enhancements
  - Baseline:
    - Only GEM layers 1, 3, 4,5 for SIDIS: built by the UVa group
    - Reuse electronics from SBS and TDIS
  - Enhancements
    - GEM layers 2 (and 6 ?): Funded and Built by the Chinese collaboration
    - New electronics for these two layers and to replenish others

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

➡ 105 k channels
Needed for baseline

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
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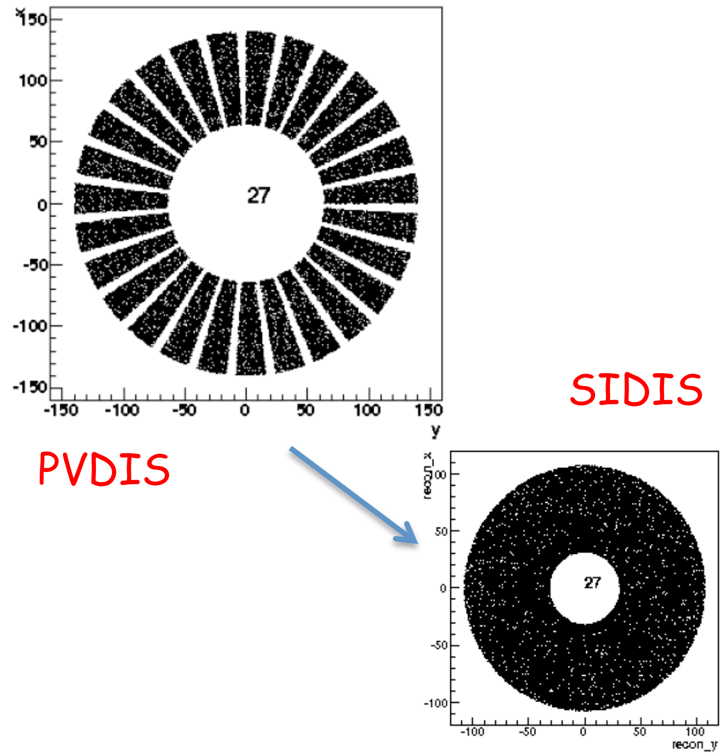


- More than enough electronic channels from PVDIS setup.
- The two configurations will work well with no need for new GEM or electronics fabrication.

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

Largest GEM module size required: 113 cm x (21-44) cm

With ~5% spares, we will need about 170 k readout channels.

- Large number of readout channels; but cost of electronics going down – cost per channel for the RD51 SRS APV-25 based readout is ~ $ 3.00 + R&D expenses to optimize electronics for SoLID needs.

"PVDIS" GEM baseline configuration

- We can cover the 4 baseline SIDIS layers with layers 1, 3 and 4 of PVDIS.

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

- Need 90 modules of 3 sizes ~ 70 cm, ~80 cm, ~110 cm.
- With 10% spares for each size => 99 modules total over 4 years.
- Well within the capabilities of the UVa group.
  - Built 48 large modules for SBS.
  - @ ~ 20 production modules per year.
  - could double to rate with the person-power requested for SoLID

Baseline Plan for electronics

- Need 105 k channels + 10% spares ~ 115 k chan.
- Reuse from SBS (APV-25) and TDIS (SAMPA)
- SBS will have a total of ~ 155 k of APV-25 (115 k chans. owned by Jlab (from UVa) ~ 40 k owned by INFN).
  - Assuming that we can get these all and ~ 66% survival rate after SBS run, we will have ~ 102 k of APV electronics for SoLID
- TDIS will have 27.5 chan. of SAMPA.
  - Assuming 66% survival: will have 18.k k chans. for SoLID.
  - Sufficient for base line.
  - **Warning: SAMPA is not rad-hard**
- No electronics funding in the baseline plane: only 0.5 FTE-year at Jlab for reconfiguring the old electronics for SoLID.
- Also assume reusing all upstream electronics modules (SSPs etc, transducers); but these will be obsolete by then and will require replacing.

Ongoing work carried out by Kondo supported by EIC R&D.

- A new EIC prototype GEM with many new features successfully developed.
  - Moving all readout connections to the outer edge of the circle:
  - successfully demonstrated with small prototype, now implemented in full size module.

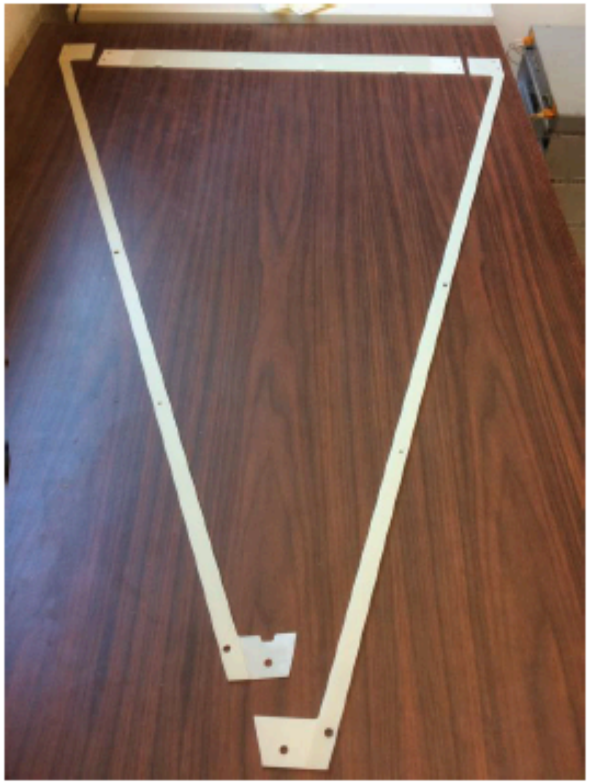
  - Composite frames: will reduce cost for SoLID

- beam tested at Fermilab last summer
- uRwell prototype
- Planning for a 1 k channel VMM based SRS test stand

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

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

Going to the test beam at Fermilab FTBF in two weeks from now

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

Common GEM foil design:

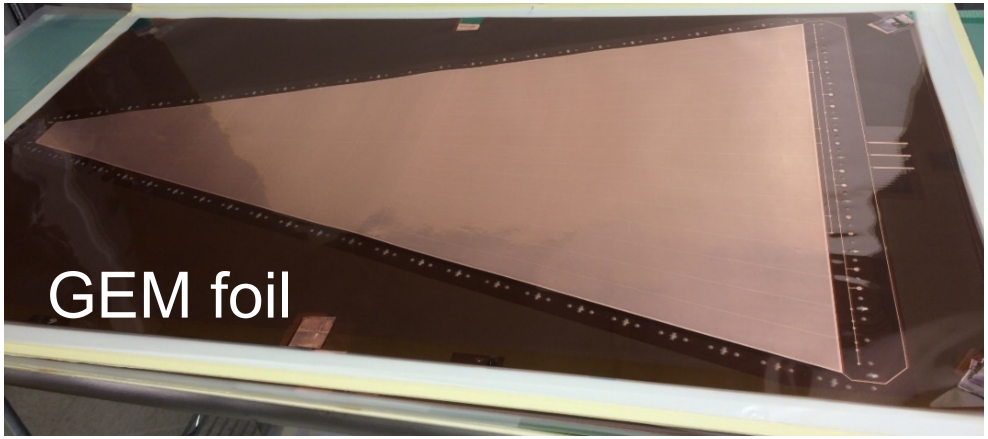
- (Univ. of Virginia, Florida Tech, and Temple U.)
- All connections (HV, gas flow structure and FE cards) are made on outer radius end.

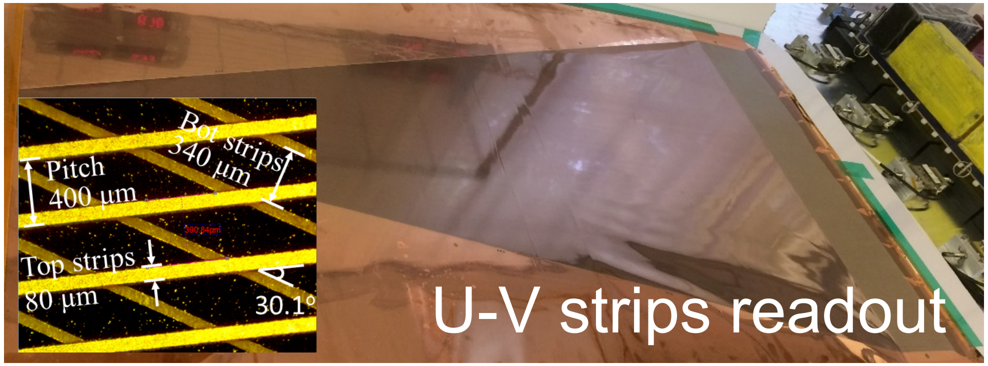
2D U-V strips readout (R/O)

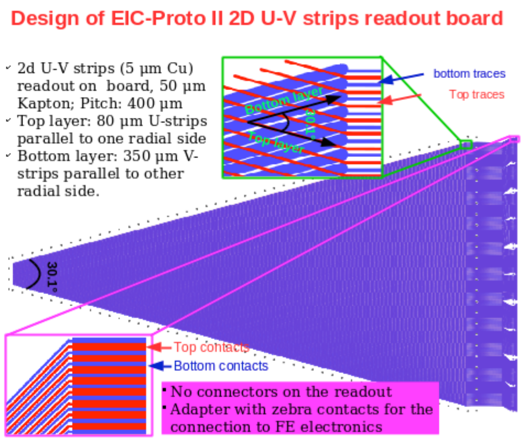
- Spatial resolution improvement
- All readout electronics on outer radius end.
- No connectors or metallized vias on R/O

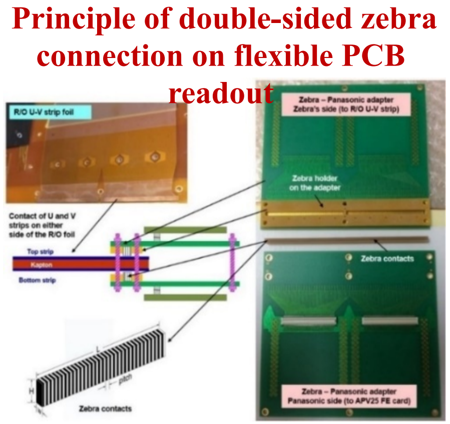
Double-sided zebra connection

- 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

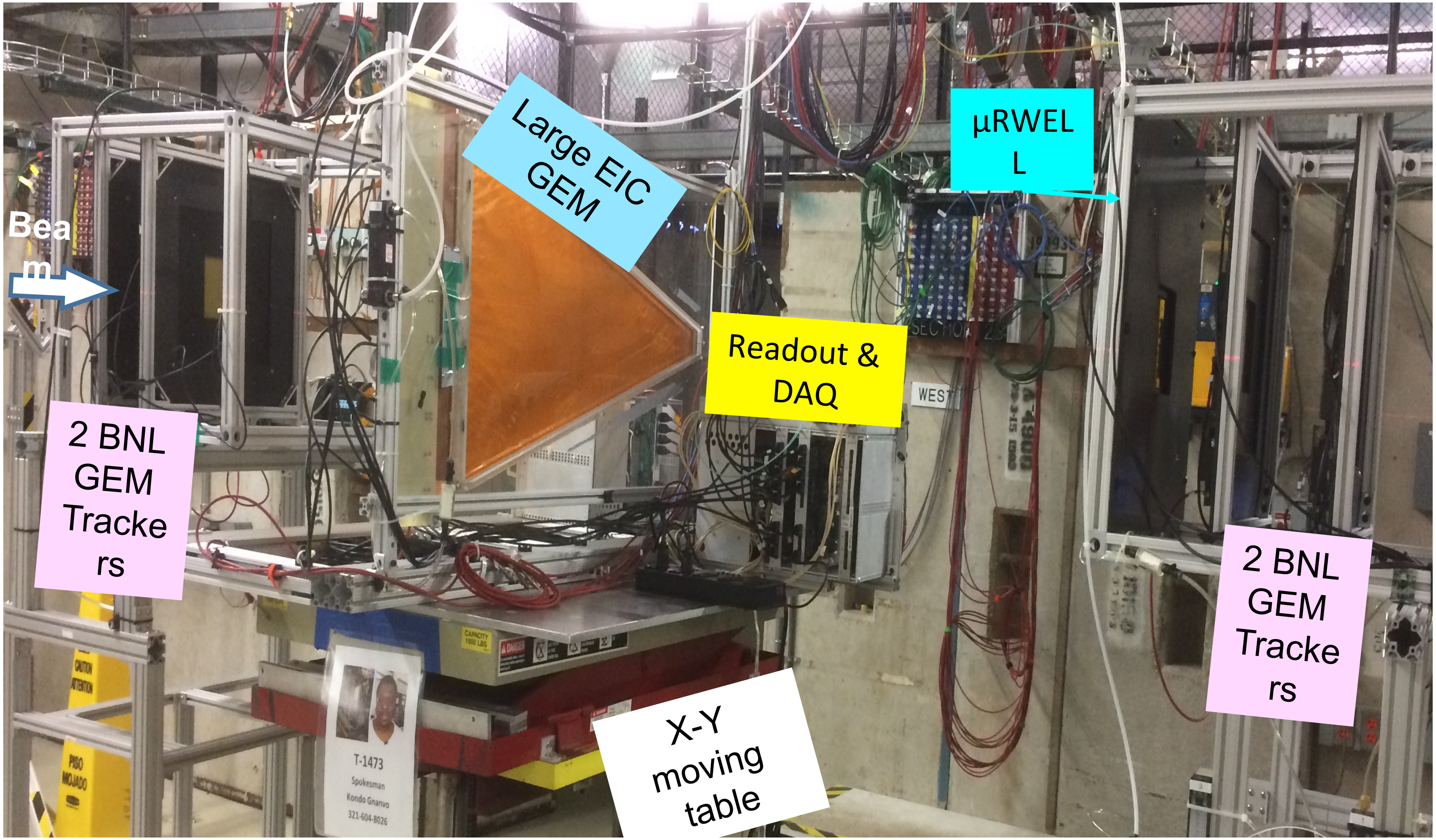


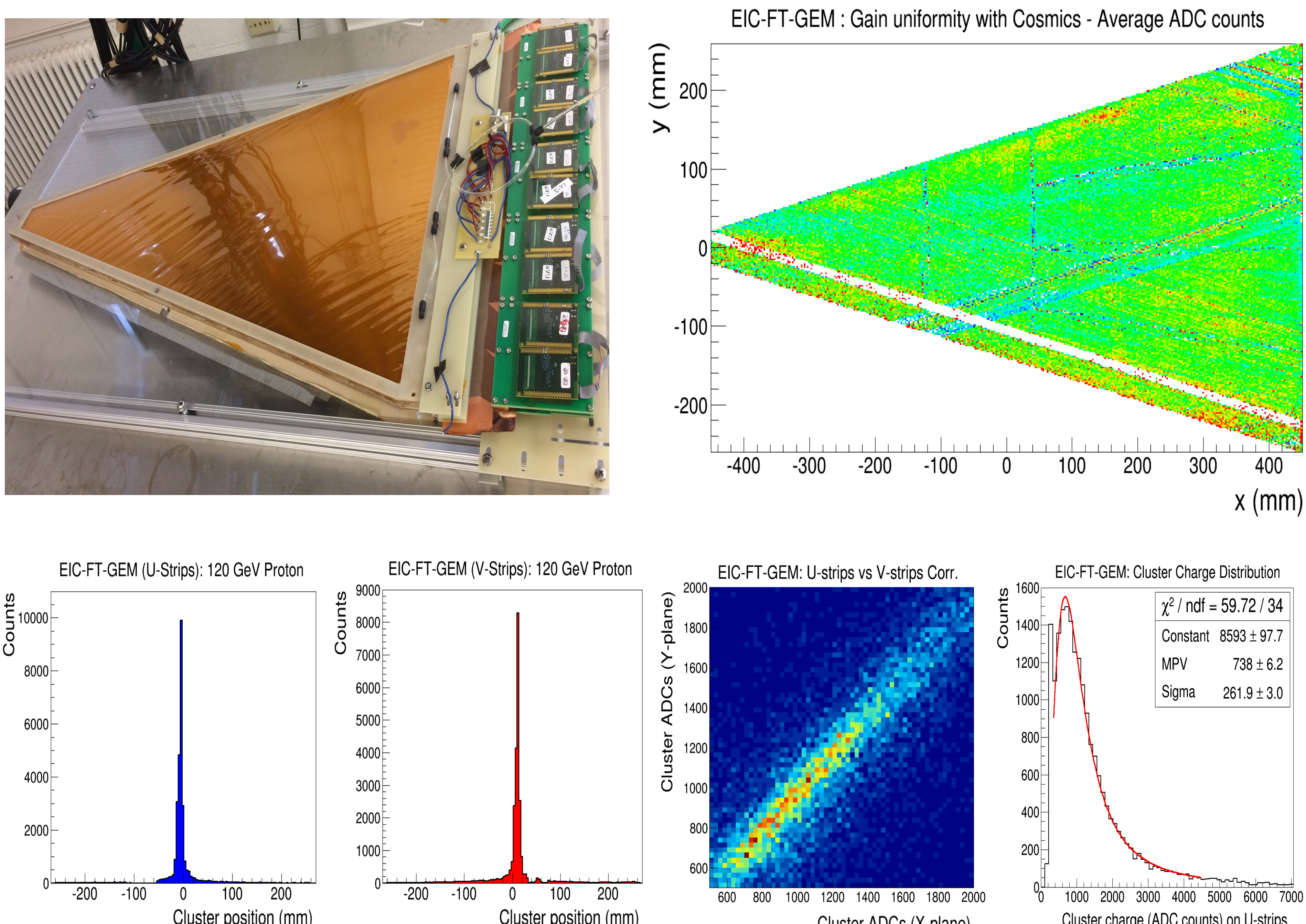






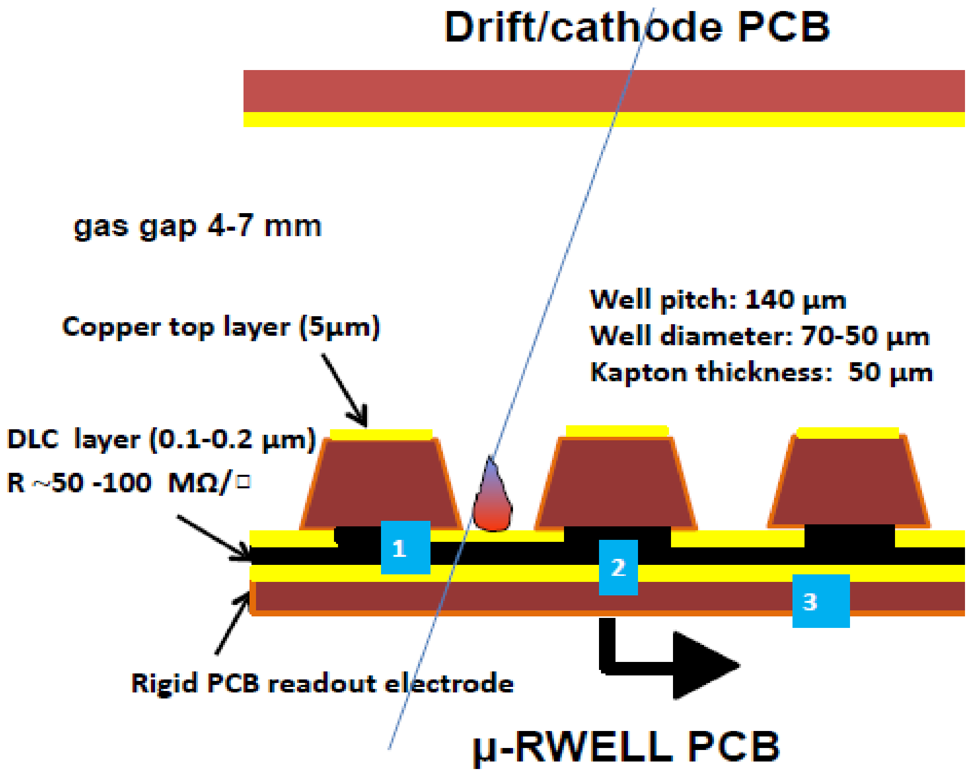
Large GEM Setup in MT6.2b Area at the FTBF (June-July 2018)

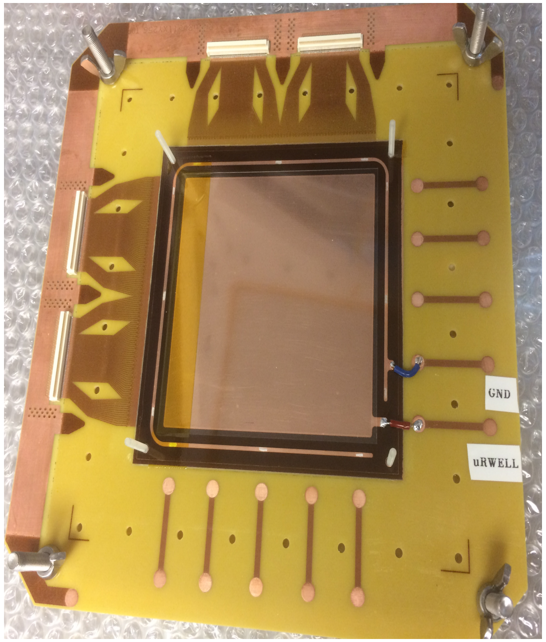


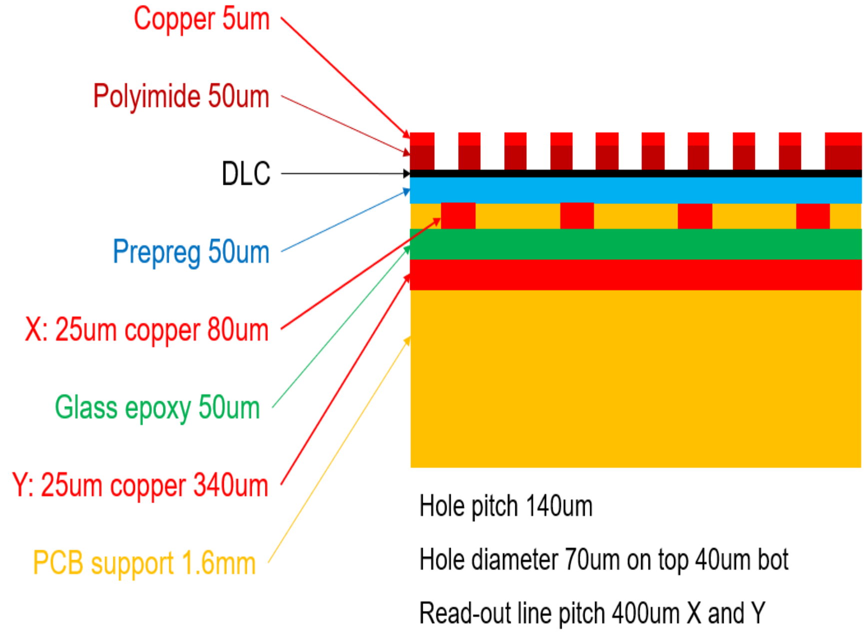

EIC-FT-GEM : Gain uniformity with Cosmics - Average ADC counts
y (mm)
x (mm)
EIC-FT-GEM (U-Strips): 120 GeV Proton
Counts
Cluster position (mm)
EIC-FT-GEM (V-Strips): 120 GeV Proton
Counts
Cluster position (mm)
EIC-FT-GEM: U-strips vs V-strips Corr.
Cluster ADCs (Y-plane)
Cluster ADCs (X-plane)
EIC-FT-GEM: Cluster Charge Distribution
Counts
χ² / ndf = 59.72 / 34
Constant 8593 ± 97.7
MPV 738 ± 6.2
Sigma 261.9 ± 3.0
Cluster charge (ADC counts) on U-strips

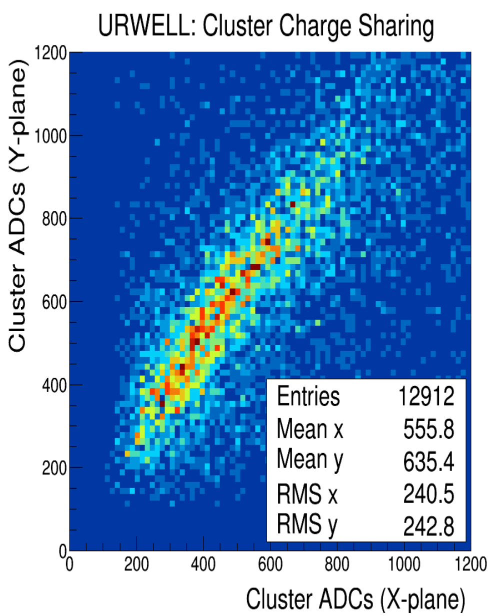
Ongoing work carried out by Kondo supported by EIC R&D.

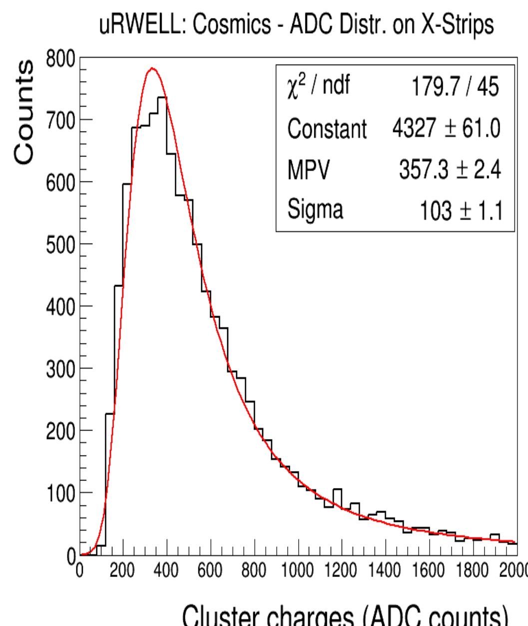
- Development of μ-RWELL detectors:
  - combines GEM and readout together
  - much lower cost
  - can work up to ~ 100 kHz/cm^2.

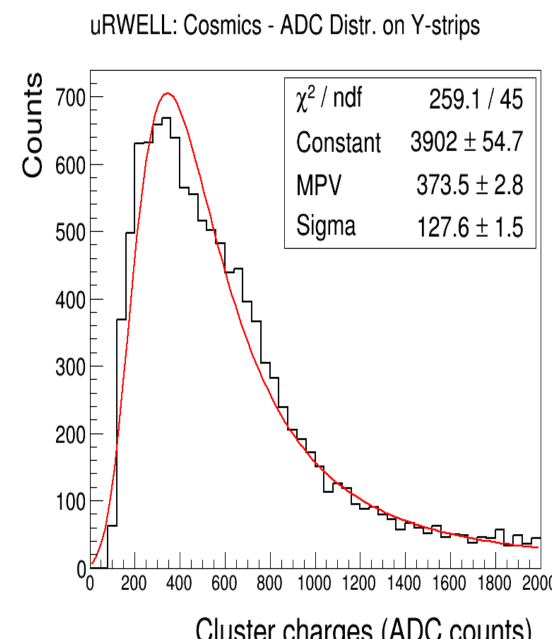



GND
uRWELL

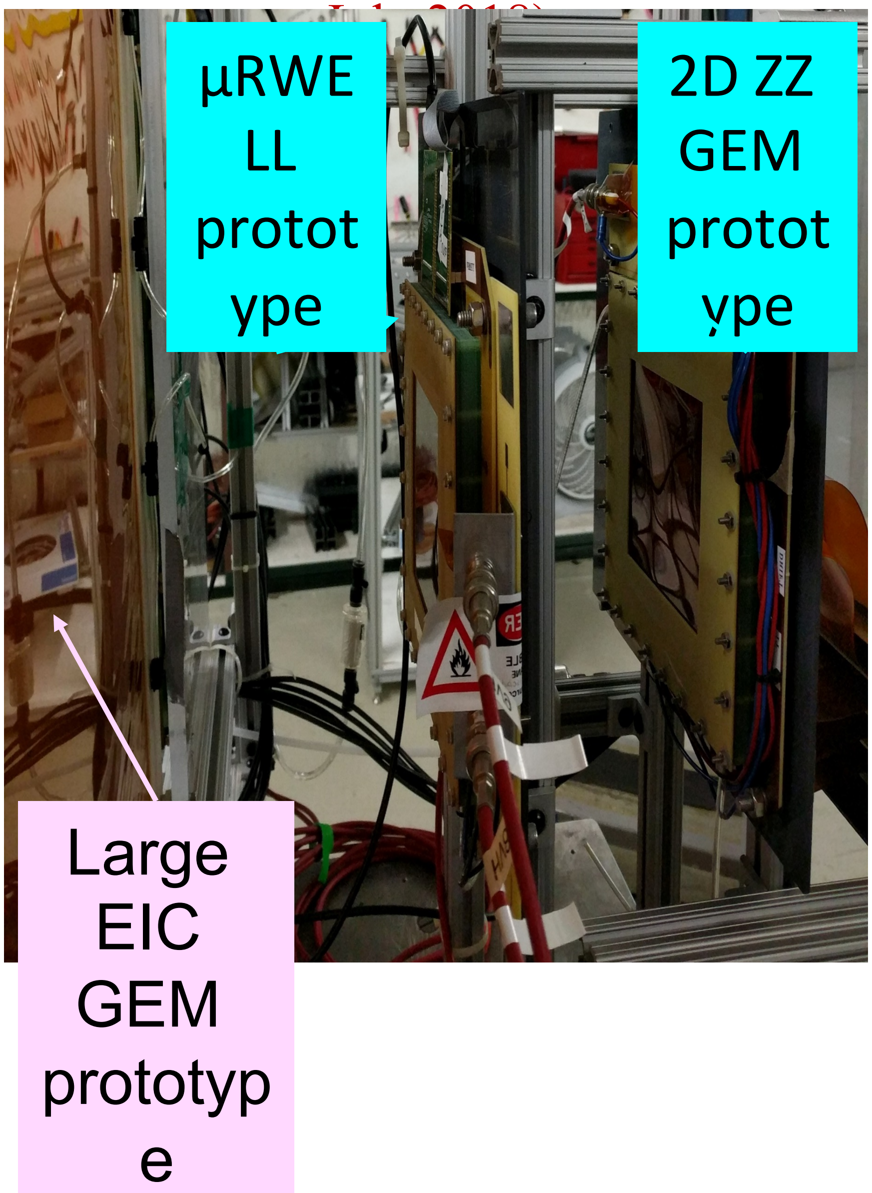

Copper 5um
Polyimide 50um
DLC
Prepreg 50um
X: 25um copper 80um
Glass epoxy 50um
Y: 25um copper 340um
PCB support 1.6mm
Hole pitch 140um
Hole diameter 70um on top 40um bot
Read-out line pitch 400um X and Y

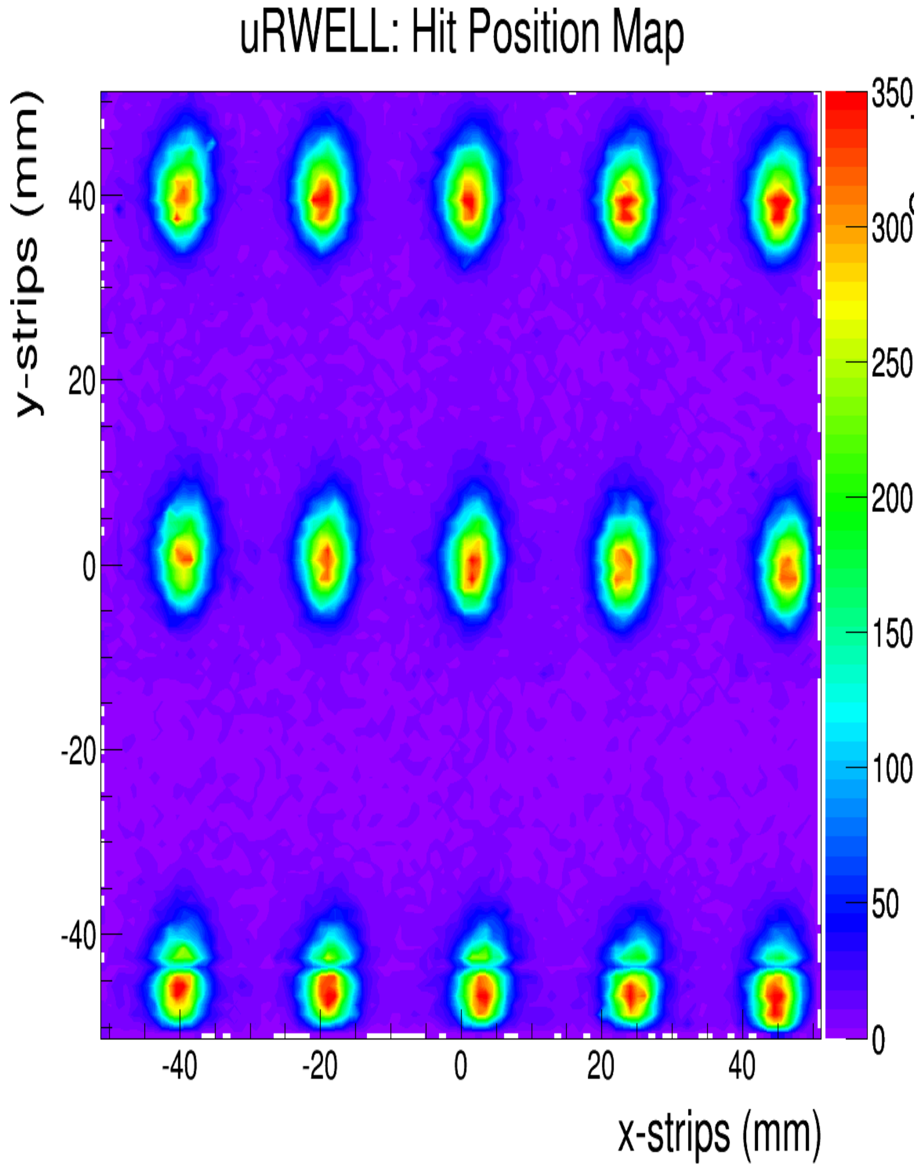

URWELL: Cluster Charge Sharing
Cluster ADCs (Y-plane)
Cluster ADCs (X-plane)
Entries 12912
Mean x 555.8
Mean y 635.4
RMS x 240.5
RMS y 242.8

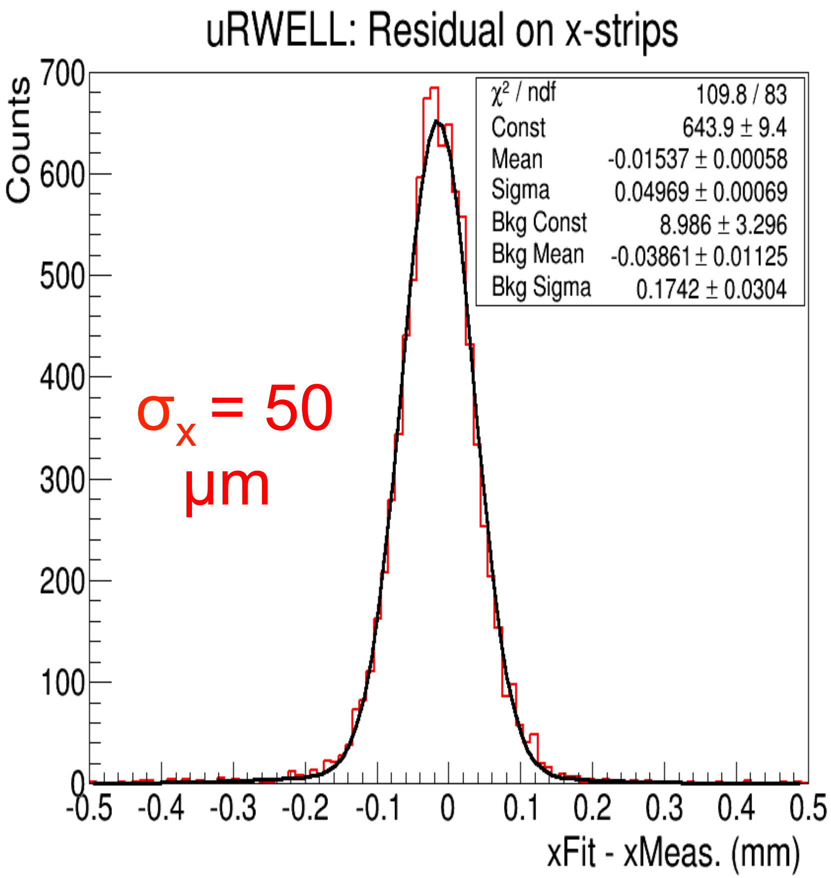

uRWELL: Cosmics - ADC Distr. on X-Strips
Counts
Cluster charges (ADC counts)
χ^2 / ndf 179.7 / 45
Constant 4327 ± 61.0
MPV 357.3 ± 2.4
Sigma 103 ± 1.1

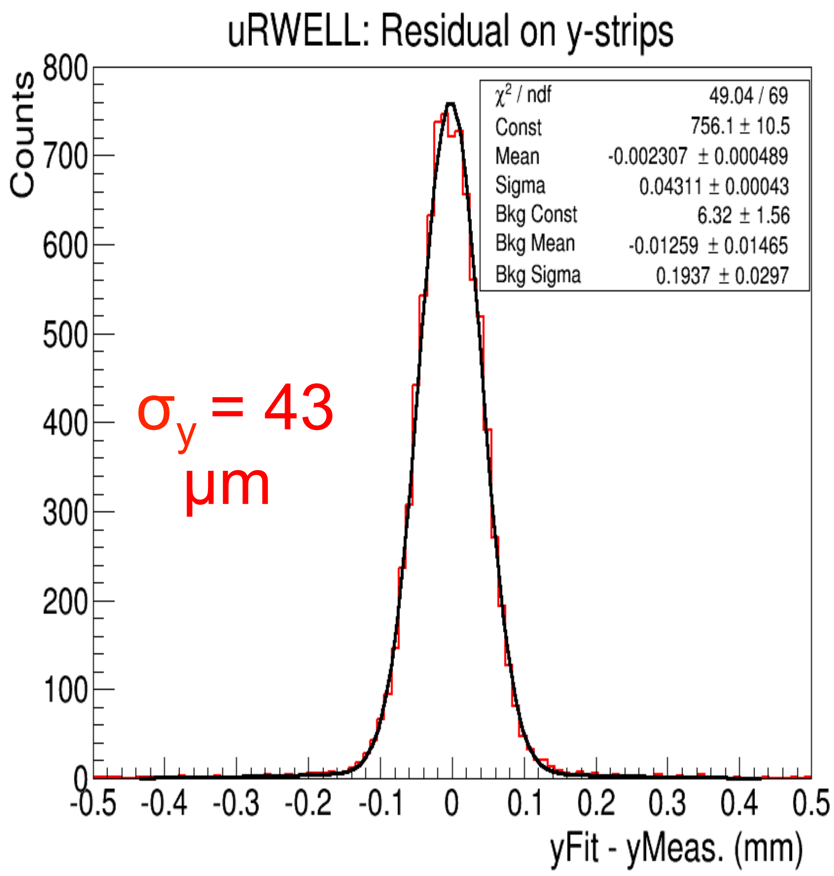

uRWELL: Cosmics - ADC Distr. on Y-strips
Counts
Cluster charges (ADC counts)
χ^2 / ndf 259.1 / 45
Constant 3902 ± 54.7
MPV 373.5 ± 2.8
Sigma 127.6 ± 1.5

Small Prototypes Setup (FTBF June-July 2018)





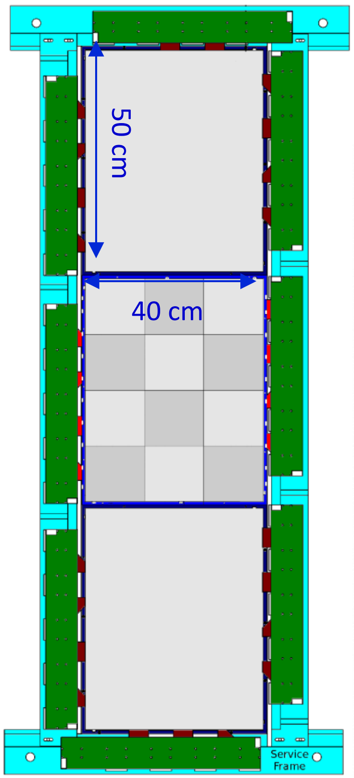

uRWELL: Residual on x-strips
Counts
χ^2 / ndf 109.8 / 83
Const 643.9 ± 9.4
Mean -0.01537 ± 0.00058
Sigma 0.04969 ± 0.00069
Bkg Const 8.986 ± 3.296
Bkg Mean -0.03861 ± 0.01125
Bkg Sigma 0.1742 ± 0.0304
σ_x = 50 µm
xFit - xMeas. (mm)

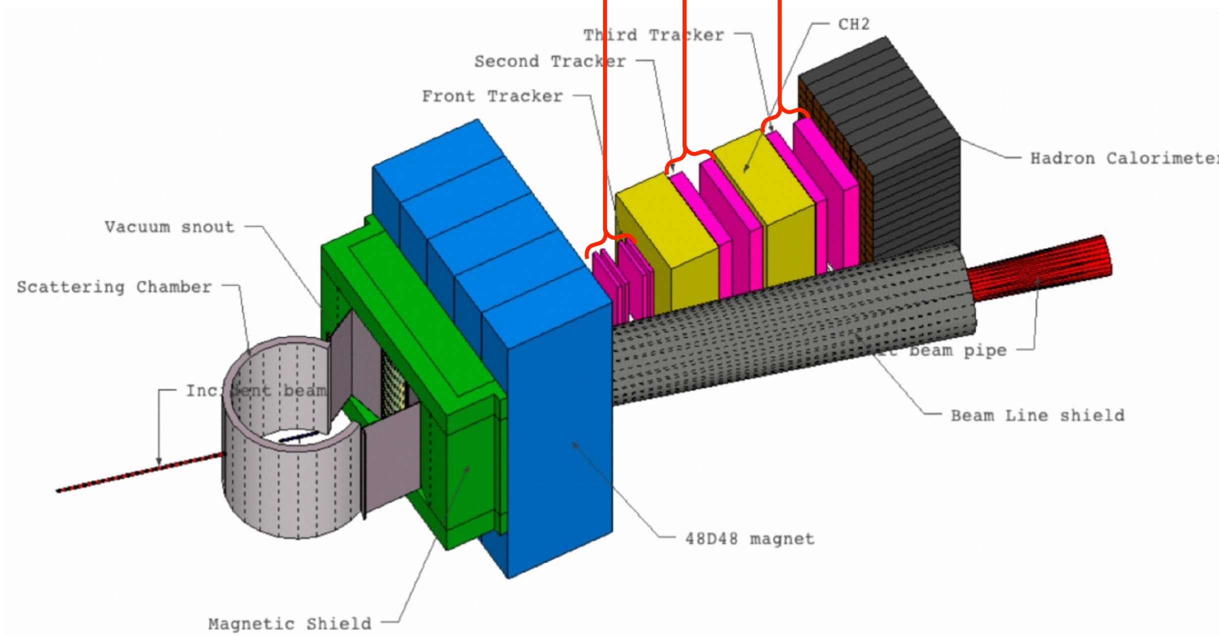

uRWELL: Residual on y-strips
Counts
χ^2 / ndf 49.04 / 69
Const 756.1 ± 10.5
Mean -0.002307 ± 0.000489
Sigma 0.04311 ± 0.00043
Bkg Const 6.32 ± 1.56
Bkg Mean -0.01259 ± 0.01465
Bkg Sigma 0.1937 ± 0.0297
σ_y = 43 µm
yFit - yMeas. (mm)

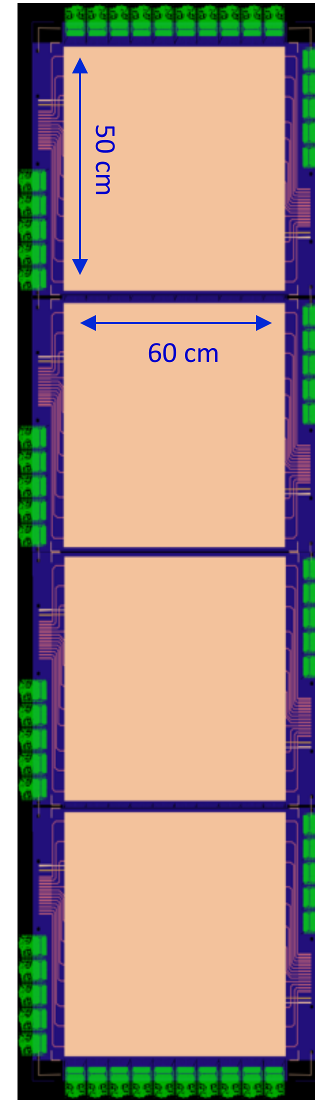
GEM Trackers for SBS

- 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
- 10 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

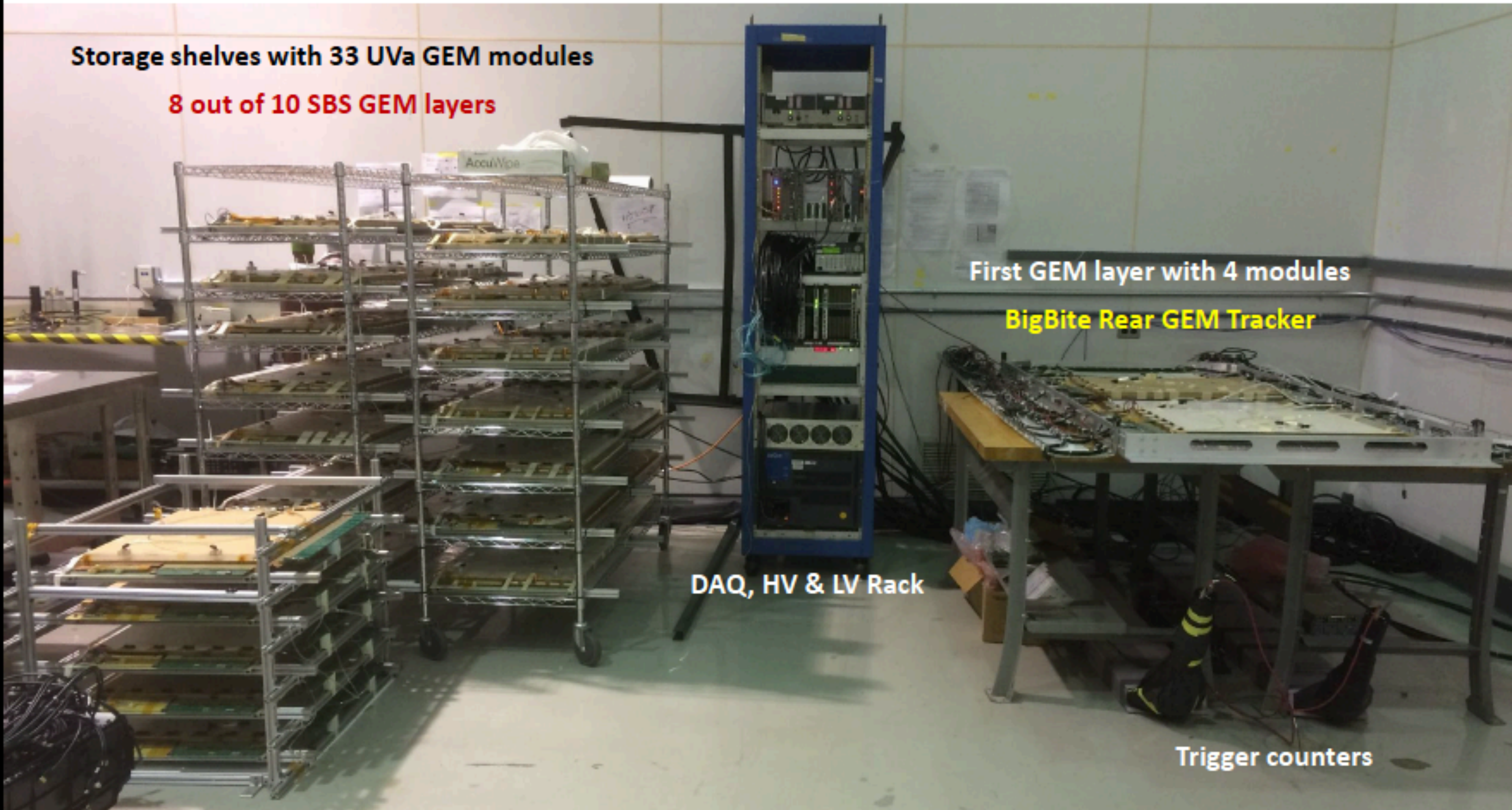
SBS GEM Production complete

- Completed building 48 modules (plan was to build 40) and tested.
- 46 tested modules and all work per specs.
- Foils from CERN very high quality; over 90% yield; mostly on-time delivery.
- Foil QA at every step extremely important.

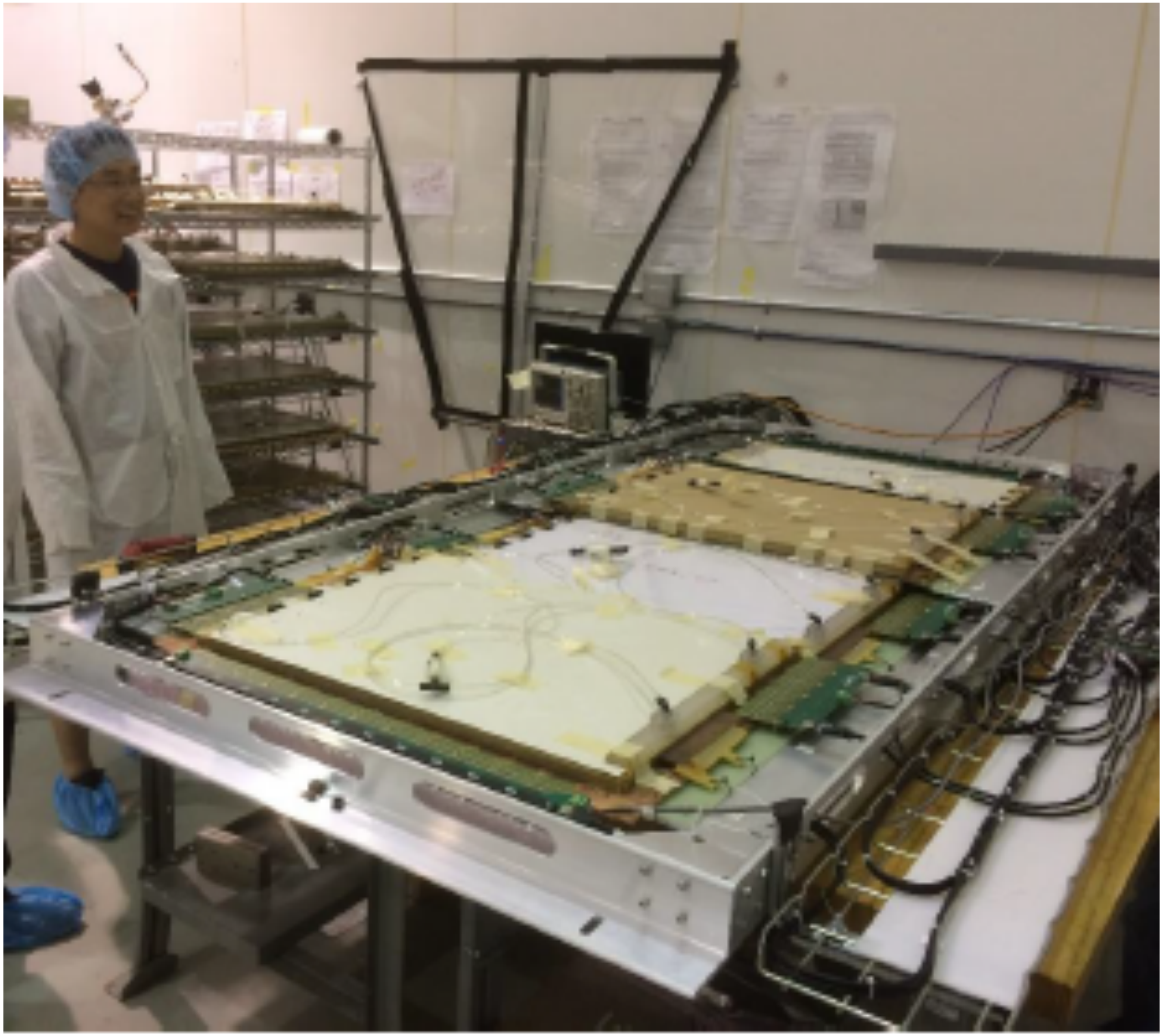
Ongoing work for SBS GEMs

- Installation of GEM modules into layers now
- Installation and testing of all electronics.
- Working with DAQ group to implement hardware level data reduction.
    - common mode correction
    - pedestal subtraction
    - zero suppression
    - filter out background not correlated with trigger time.
- Working on GEM background suppression and tracking for GMn experiment conditions (rates ~ 100 kHz/cm2)

Status of UVa GEMs for SBS (EEL Clean Room 124)



- 37 Modules for 9 SBS GEM layers already in store at JLab (EEL Clean Room 124)
- Additional 7 modules (+ spares) for 2 remaining layers to be shipped to JLab in the coming weeks (~November 2018)
- 2 INFN SBS GEM layers to be assembled / tested in Testlab CL after 4 INFN BB GEMs installed in BB in TED (Summer 2019)



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

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

Alternate Chip Options: VMM: SRS version