GEM chambers for SoLID

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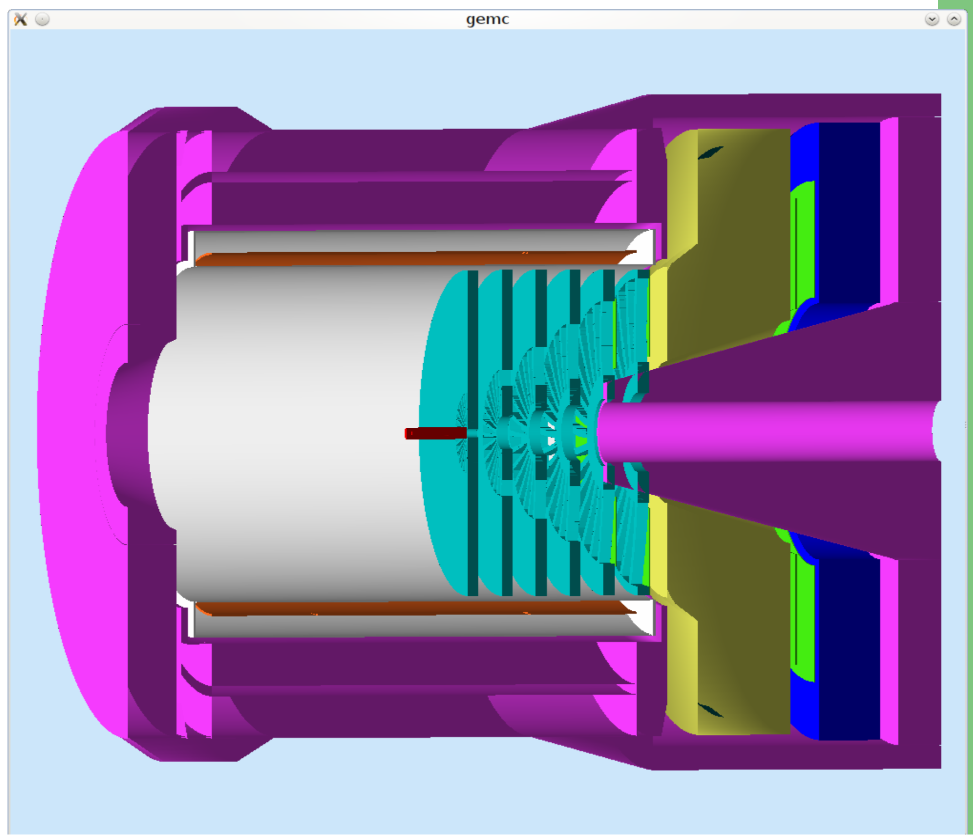
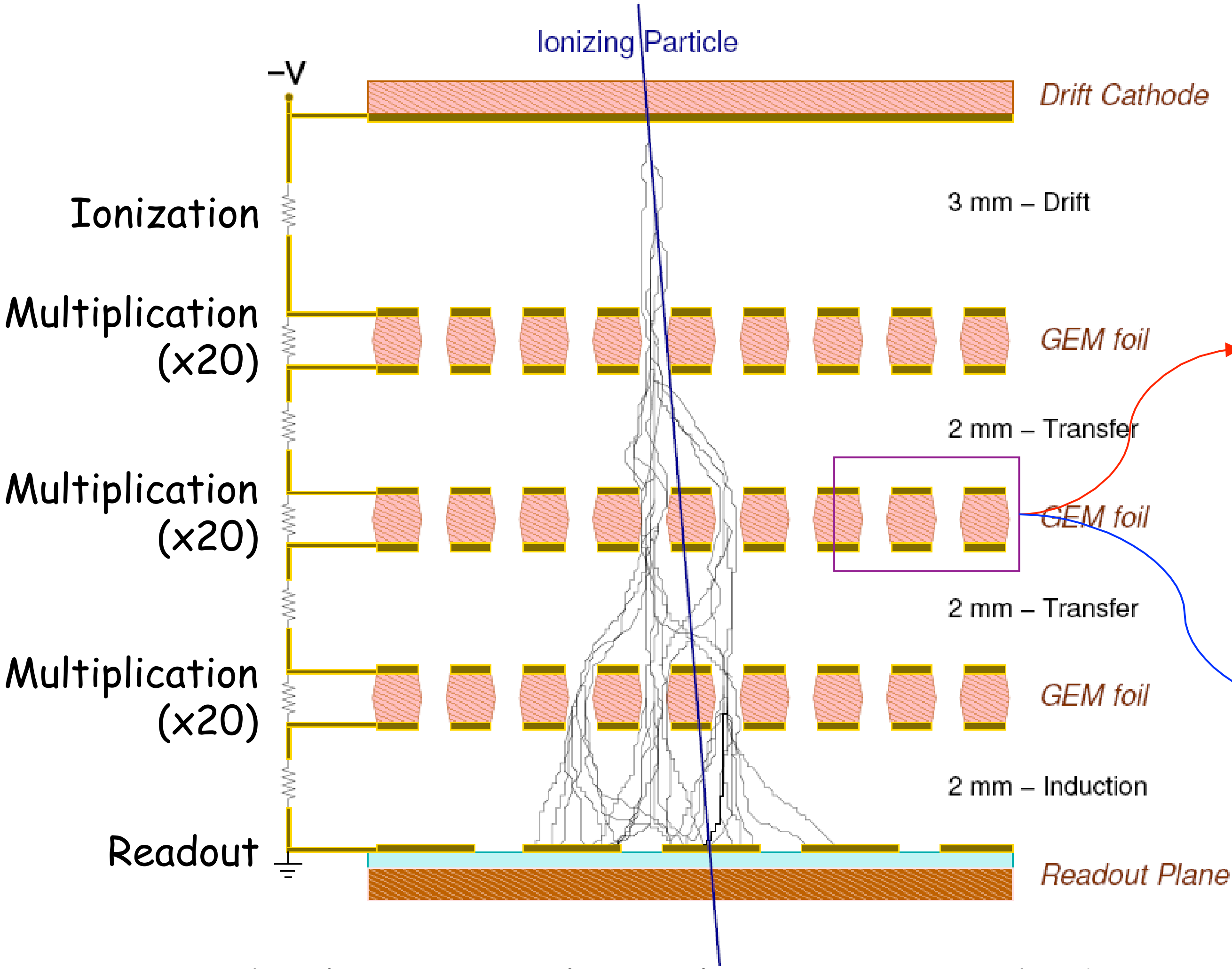
Tracking needs for SoLID (PVDIS)

- Rate: from 100 kHz to 600 kHz (with baffles), GEANT4 estimation
- Spatial Resolution: ~0.2 mm (sigma)
- Total area: ~37 m^2 total area (30 sectors x 5 planes, each sector covering 12 degree)
- Need to be radiation and magnetic field tolerant

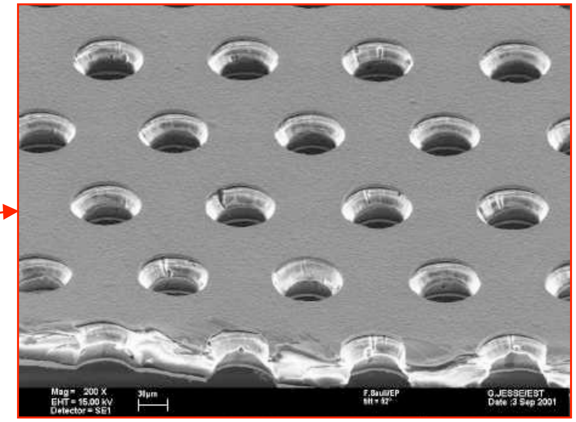
Lumi = 10^{39} /cm^2/s

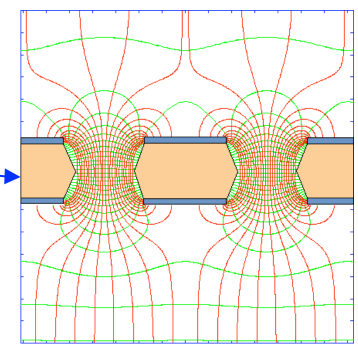


GEM working principle



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

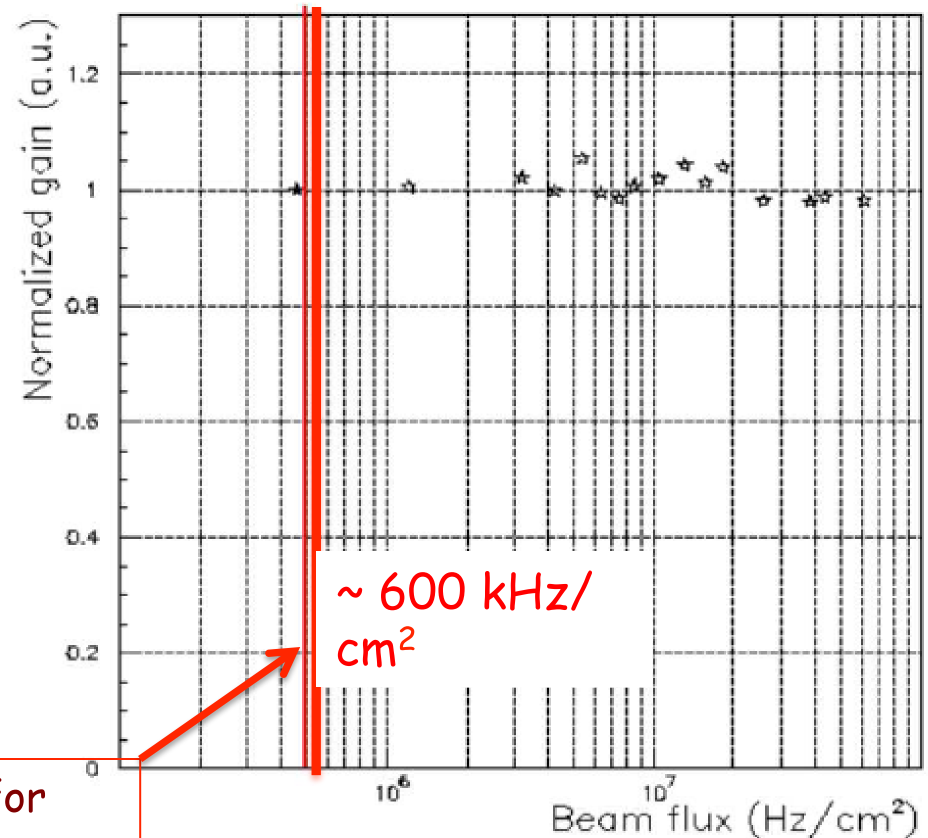
Recent technology: F. Sauli, Nucl. Instrum. Methods A386(1997)531

- COMPASS: A tracker of twenty two 31 cm x 31 cm GEM chambers successfully operated for years
- Rates as high as 2.5 MHz/cm^2

GEM Rate capability

- Multiplication stages shielded from each other: much reduced feed back
- Slow moving positive ions localized to holes, away from the induction region
- Most of the created electrons contribute to signal: can operate at low gains

Much higher rates compared to wire chambers: ~ 50 MHz/cm^2



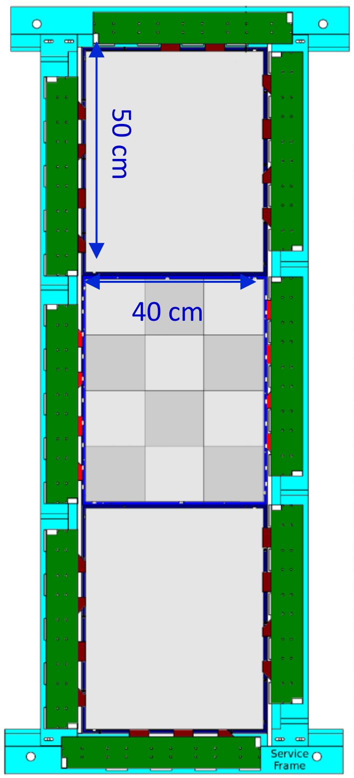
Maximum rate expected for SoLID GEM trackers

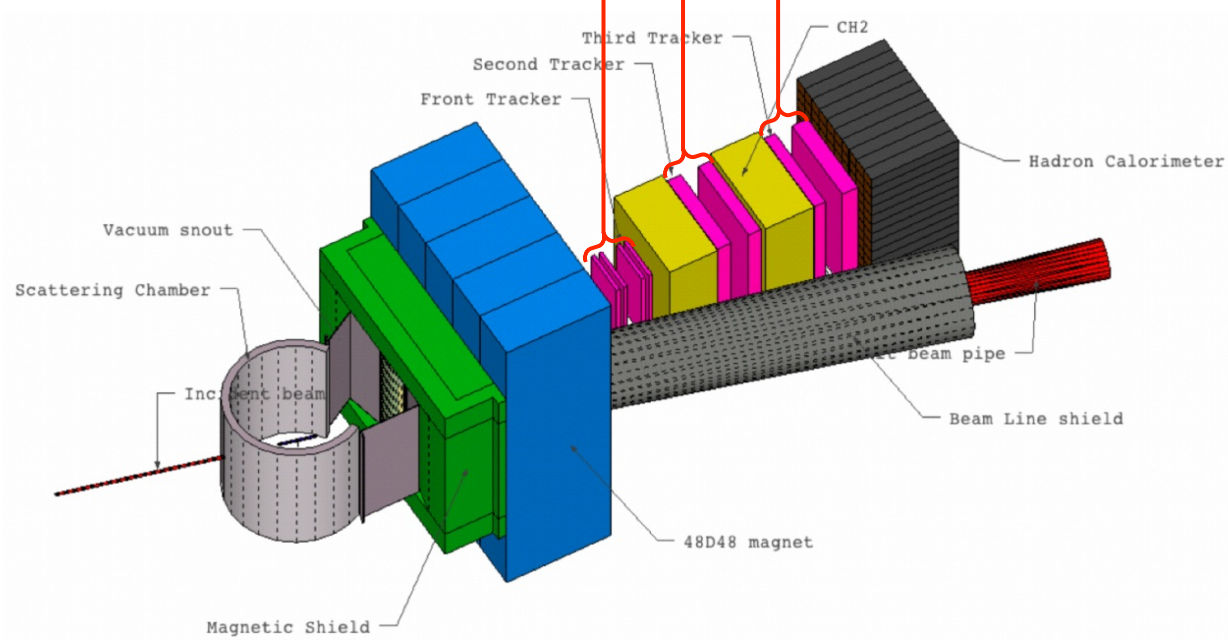
Triple GEM
Poli Lener, PhD Thesis - Rome 2005

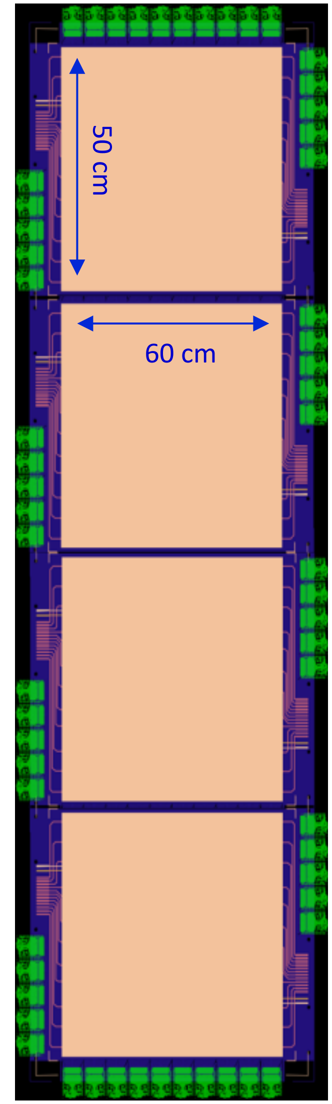
GEM Trackers for SBS

- 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

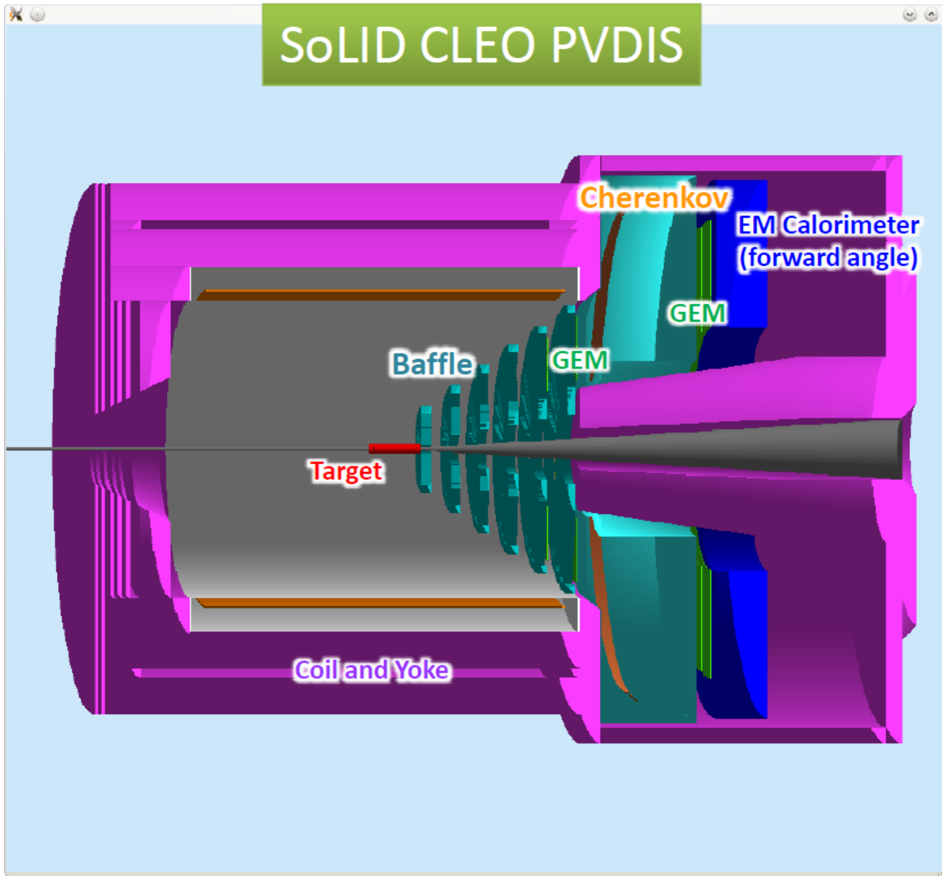


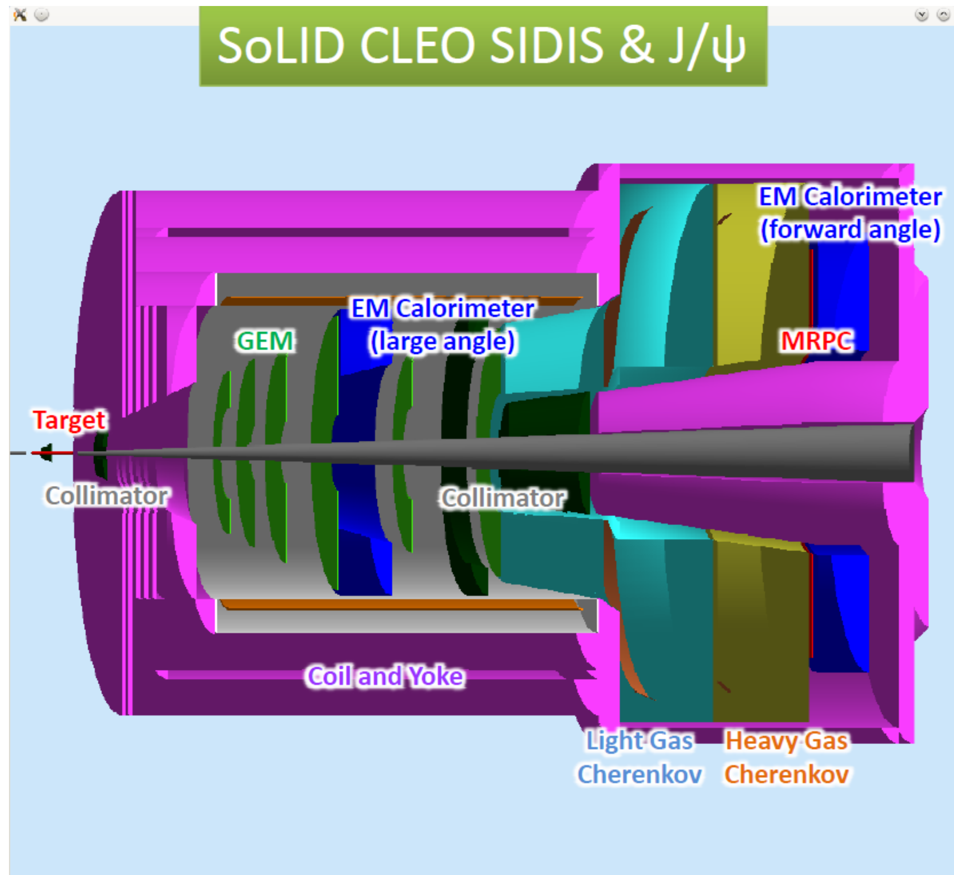




Proton arm layout for GEp (5) experiment

Total Area ~ 16 m^2


SoLID CLEO PVDIS
Cherenkov
EM Calorimeter
(forward angle)
GEM
Baffle
GEM
Target
Coil and Yoke


SoLID CLEO SIDIS & J/ψ
EM Calorimeter
(forward angle)
EM Calorimeter
(large angle)
GEM
MRPC
Target
Collimator
Collimator
Coil and Yoke
Light Gas
Cherenkov
Heavy Gas
Cherenkov

PVDIS GEM configuration

- Instrument locations 1,2,3,4, and 5 GEM:
- 30 GEM modules at each location: each module with a 12-degree angular width.

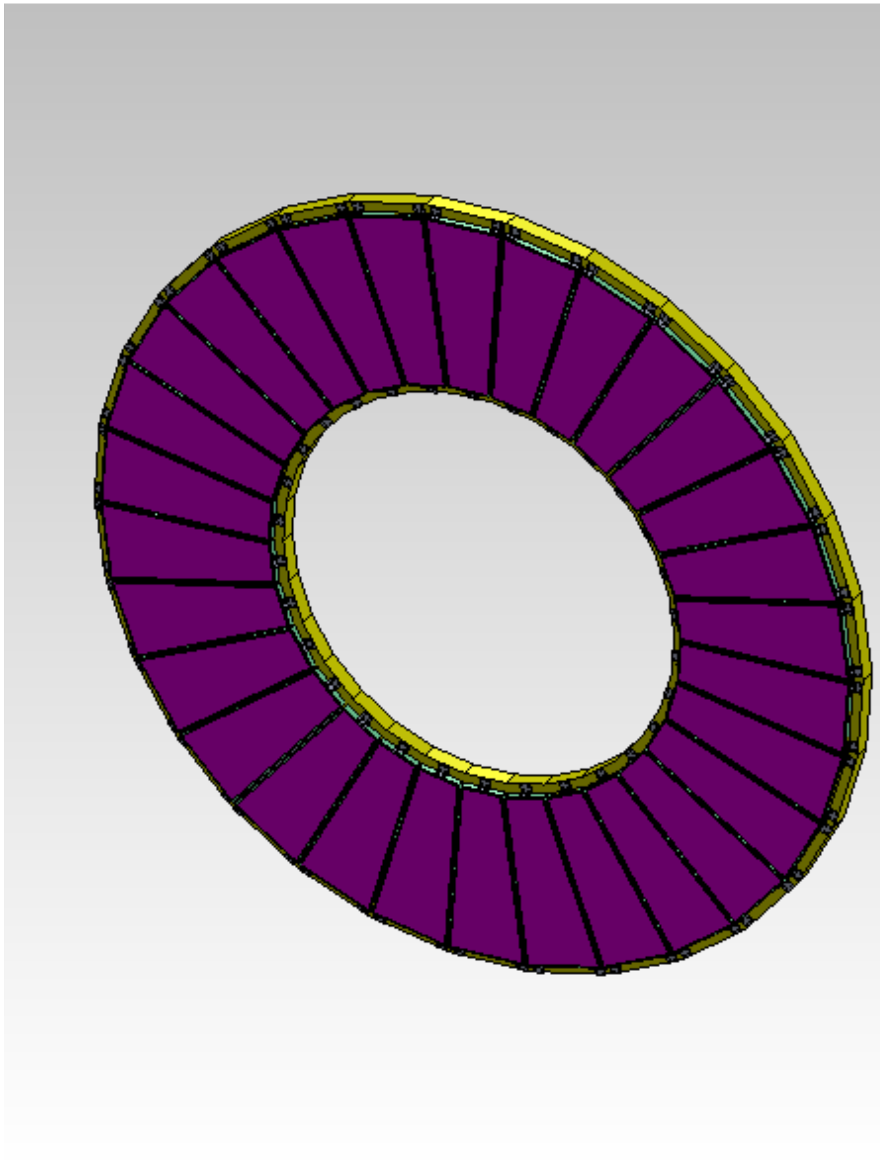
Location	Z (cm)	R_{min} (cm)	R_{max} (cm)	Surface (m^2)	# chan
1	157.5	51	118	3.6	24 k
2	185.5	62	136	4.6	30 k
3	190	65	140	4.8	36 k
4	306	111	221	11.5	35 k
5	315	115	228	12.2	38 k
Total				$\approx$ 36.6	$\approx$ 164 k

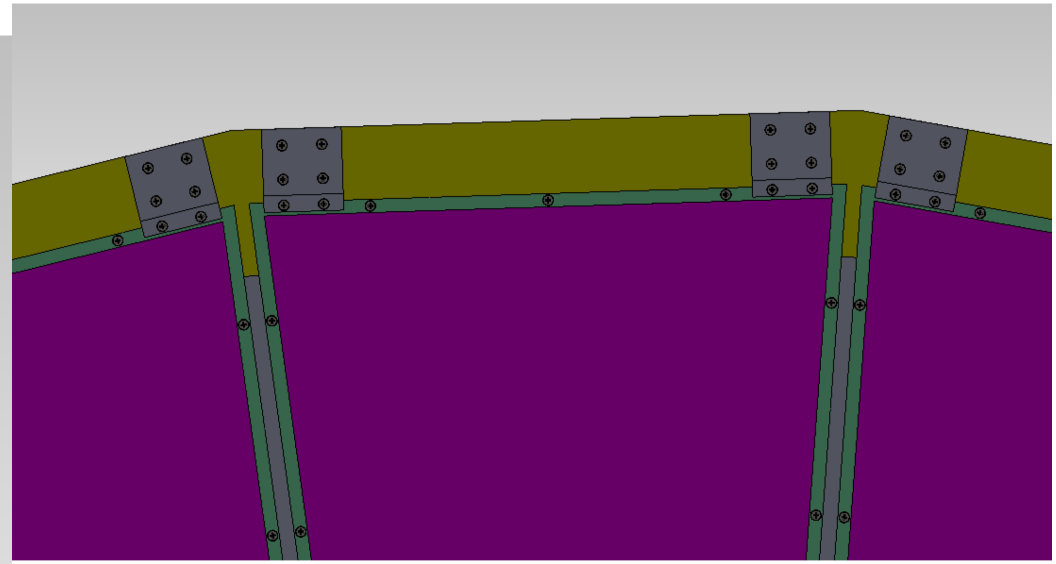
Largest GEM module size required: 113 cm x (21-44) cm

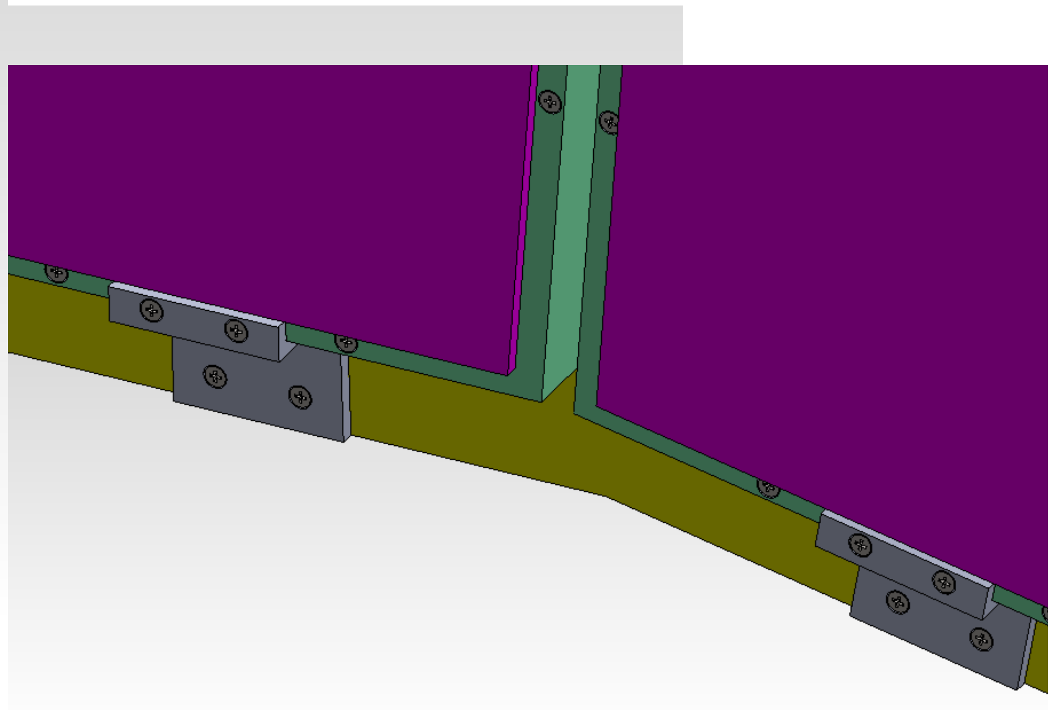
With ~5% spares, we will need about 170 k readout channels.

- Good news: 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 configuration



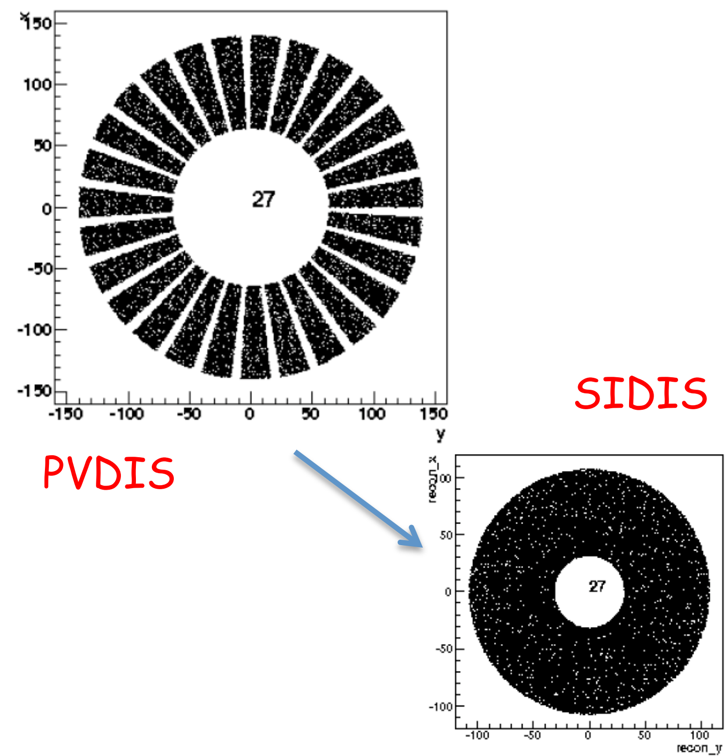




SIDIS GEM configuration

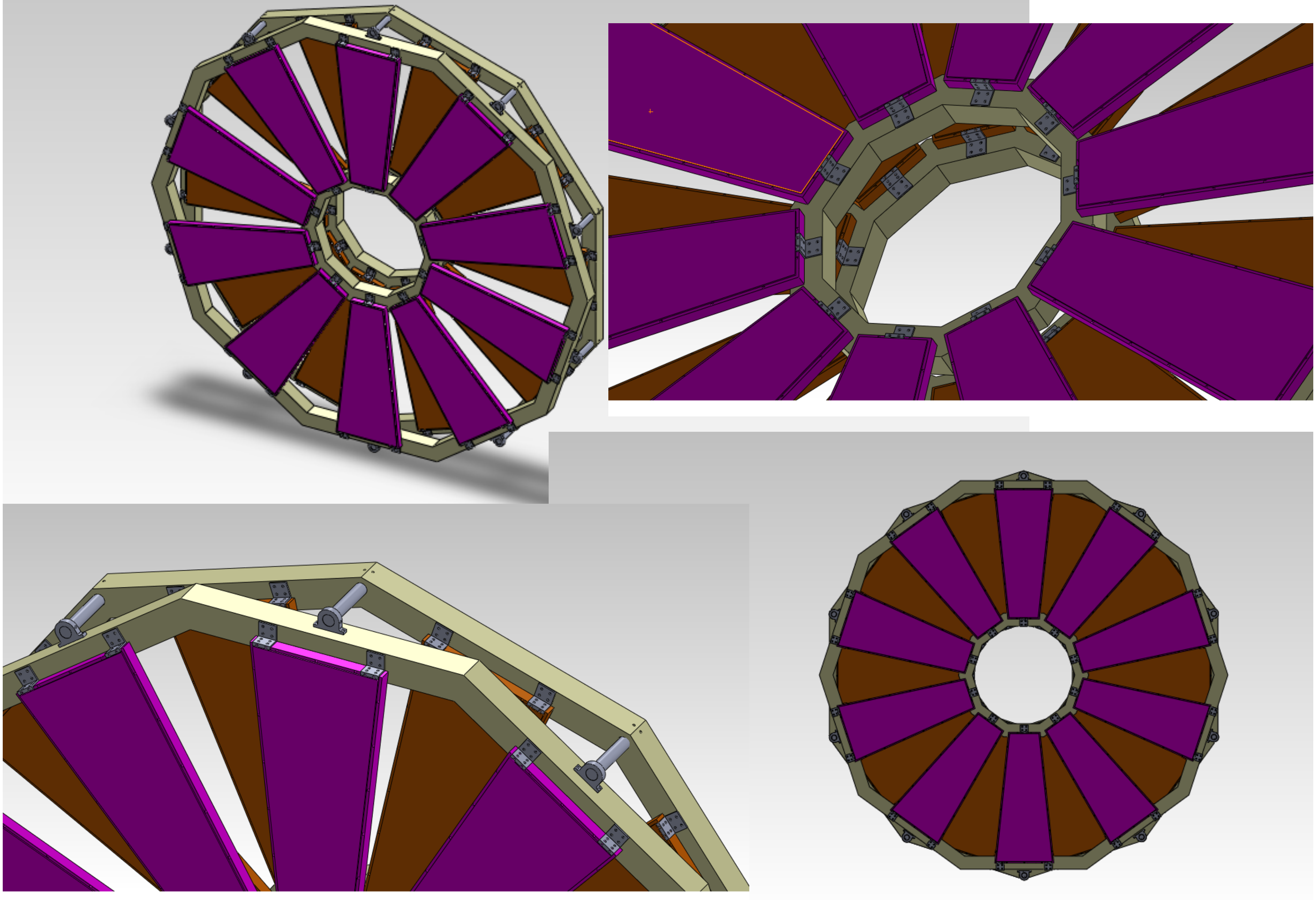
- Six locations instrumented with GEM:
- PVDIS GEM modules can be re-arranged to make all chamber layers for SIDIS. – move the PVDIS modules closer to the axis so that they are next to each other

Plane	Z (cm)	R_I (cm)	R_O (cm)	Active area	# of channels
1	197	46	76	1.1	24 k
2	250	28	93	2.5	30 k
3	290	31	107	3.3	33 k
4	352	39	135	5.2	28 k
5	435	49	95	2.1	20 k
6	592	67	127	3.7	26 k
total:				~18	~ 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.

SIDIS GEM configuration



large area GEM chamber challenges

- SoLID needs GEM modules as large at 100 cm x 40 cm.
- The biggest challenge used to be the non-availability of large area GEM foils.
- Not a problem anymore: CERN shop can make foils as large as 200 cm x 55 cm now.

  •Previously limited by double mask technique for etching: hard to the two masks accurately: Max area was limited to ~ 45 cm x 45 cm

  •. New Single Mask technique allows to make GEM foils as large as 200 cm x 50 cm

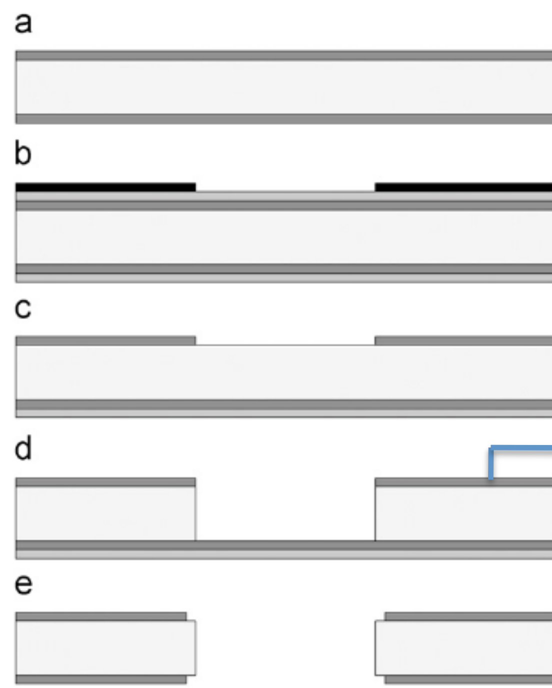
- One problem may be the production capacity of the CERN shop: especially if a LHC related large GEM project gets underway.
- Currently work going on to develop large GEM production capabilities in China.

Major recent development at CERN PCB shop towards large GEM foils

• Base material only ~ 45 cm wide roll.

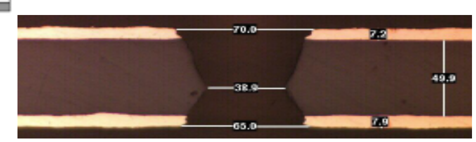
• Used a double mask technique for etching: hard to the two masks accurately: Max area limited to ~ 45 cm x 45 cm previously.

Double Mask



Bias top surface to – w.r.t chemical bath

Single Mask



Single Mask technique allows to make GEM foils as large as 200 cm x 50 cm

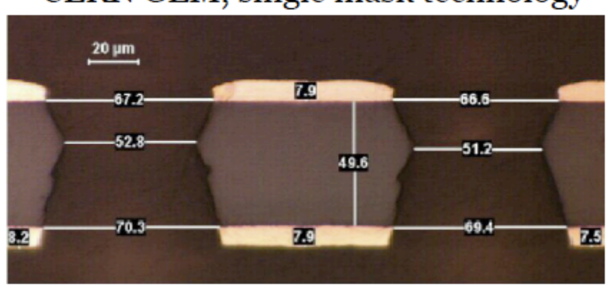
Industrial Production of GEMs

• Many anticipated users of GEMs in the near future; CERN shop can't keep up.

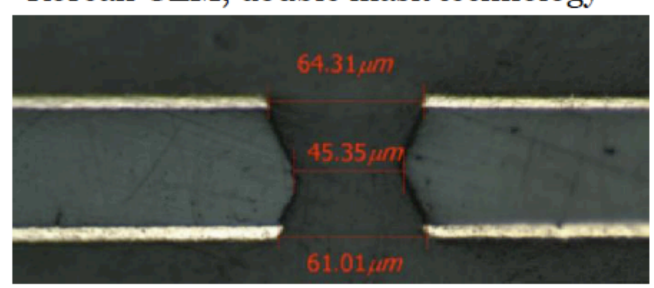
• Several Industrial production around the world starting with CERN technology transfer:

- TechEtch, Plymouth, MA, USA : GEM foils up to ~ 40 cm; produced all foils for STAR FGT: currently a proposal led by Bernd Surrow to get TechEtch to do large area single mask GEMs
- NewFlex Technology, South Korea: produced the tested foils up to 10 x 10 cm2; plans for large production up to 1 m foils.
- TechTra in Poland
- India
- China

CERN GEM, single mask technology



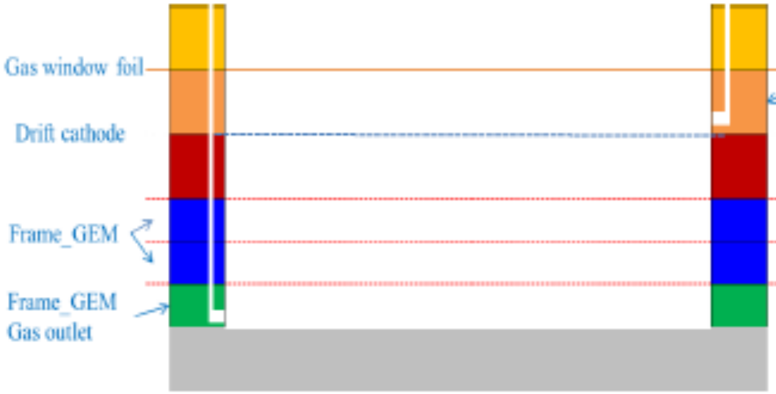
Korean GEM, double mask technology

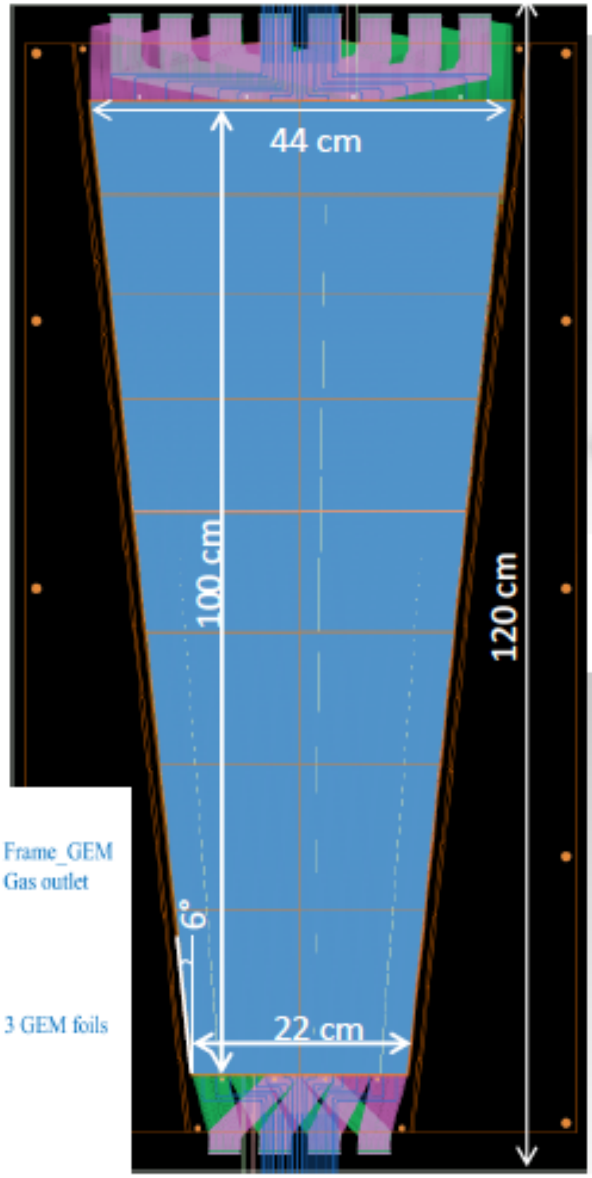


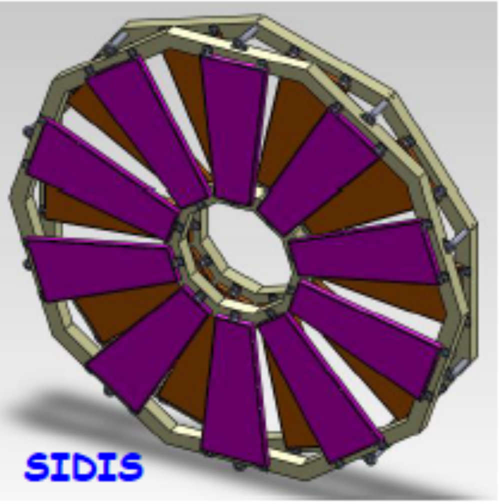
Large Area GEM prototype approaching SoLID dimensions

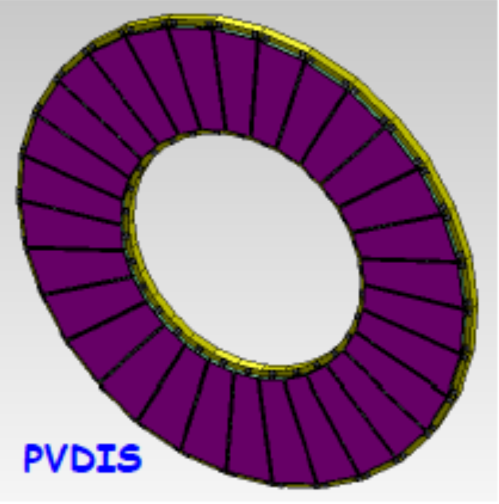
Common R&D for various projects

- Funded by BNL R&D program for EIC Tracking R&D
- Chamber similar in size to CMS high Eta Muon Upgrade
- Design in collaboration with the GEM team at CERN (January 2013)
- Chamber built in September 2013



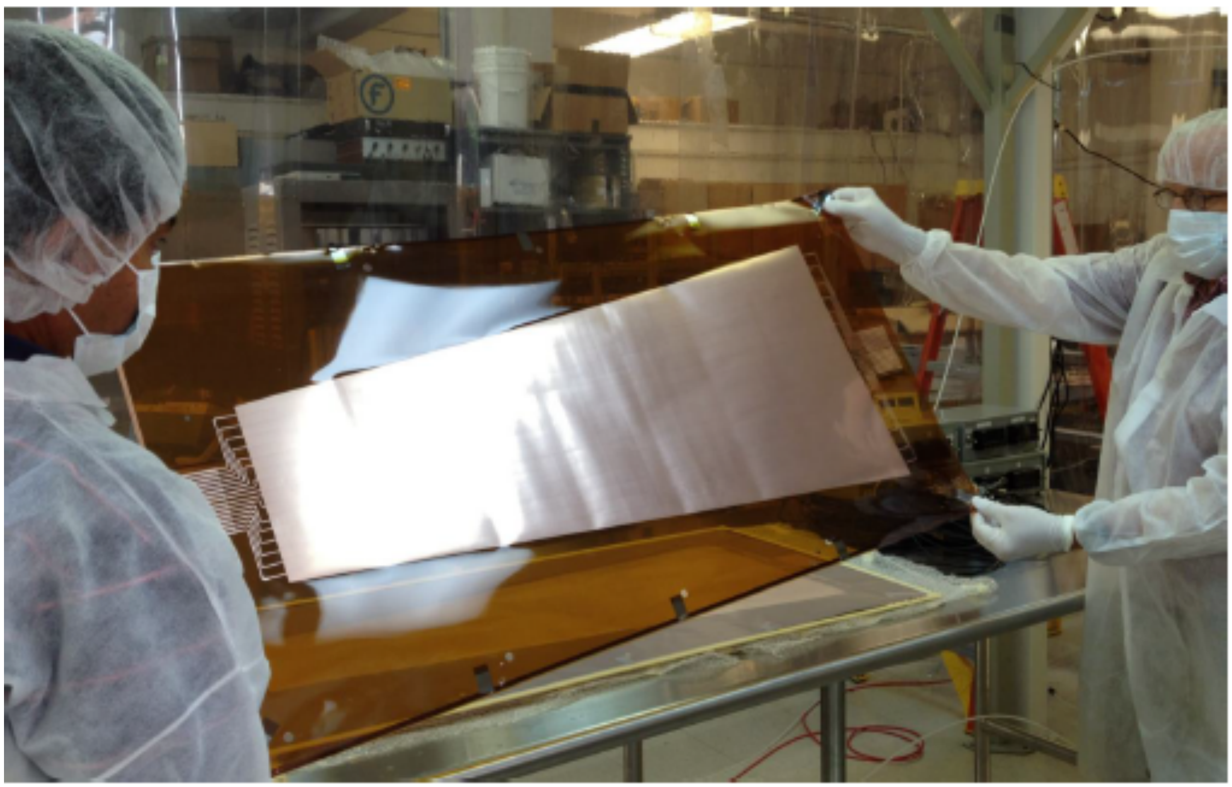


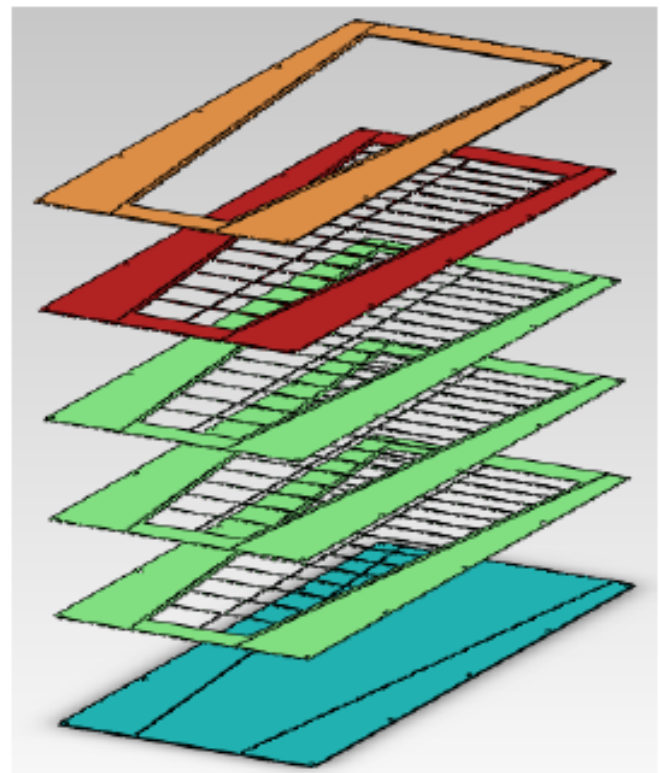




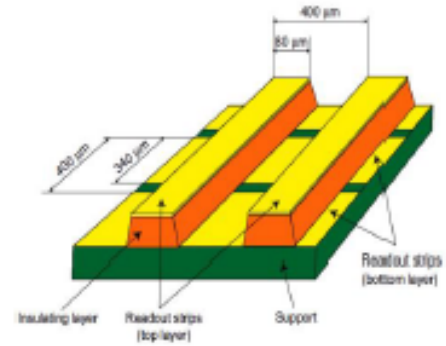
GEM foils and frames

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

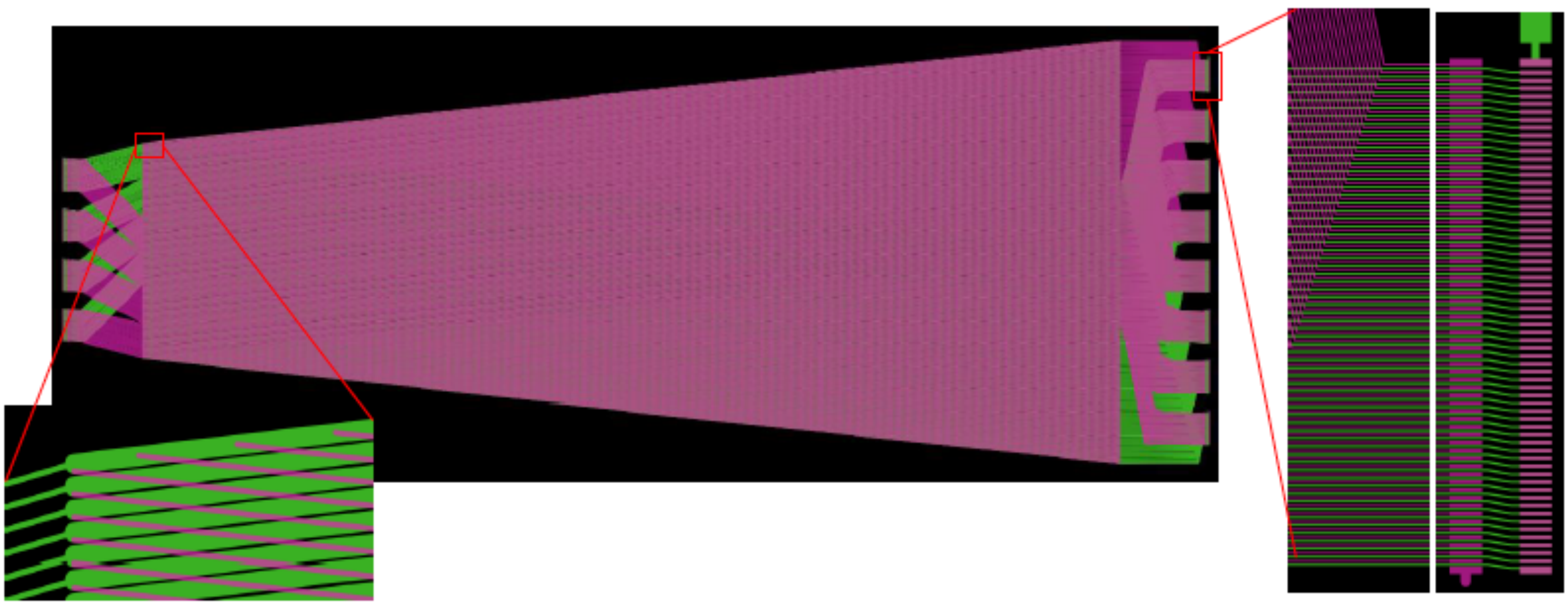




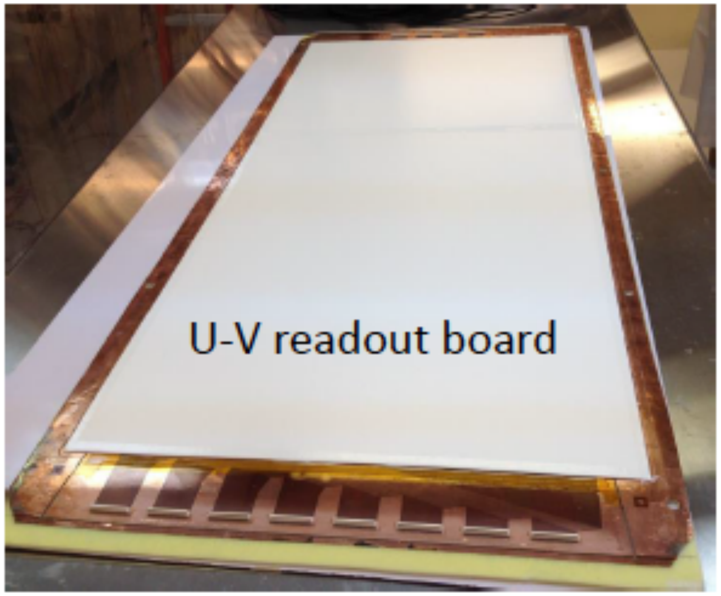
2D stereo-angle (U/V) flexible readout board

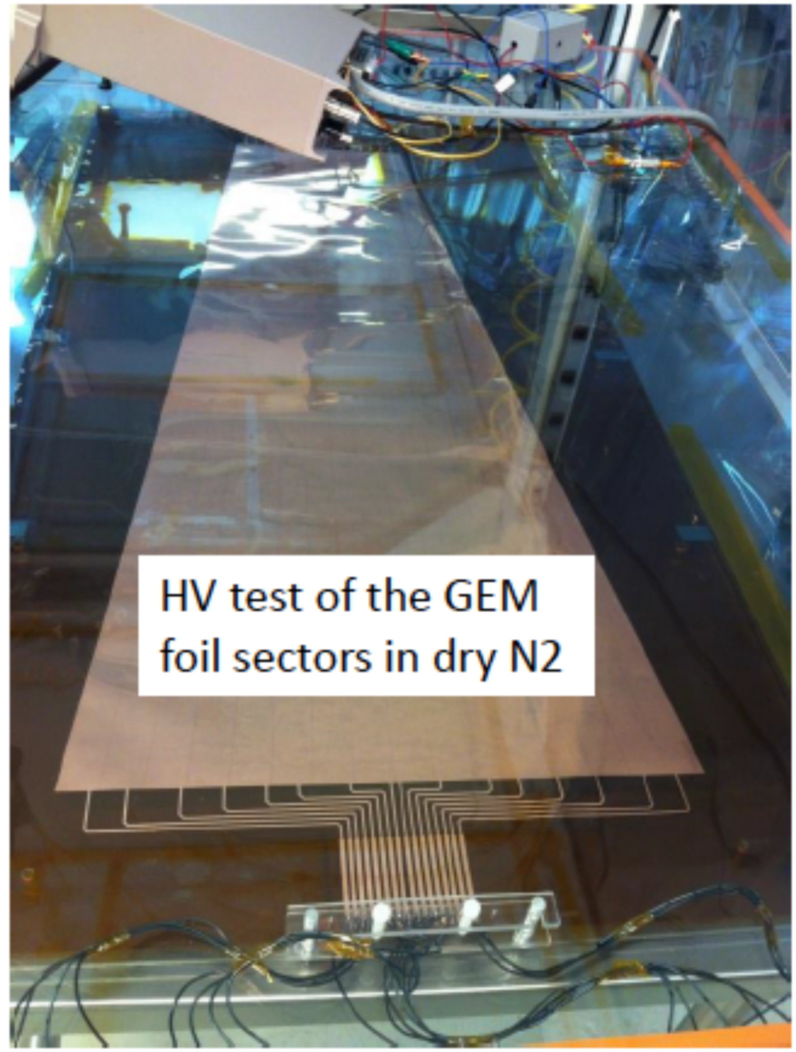


- COMPASS-like 2D stereo angle (12°) U/V readout board
- Pitch = 550 µm, top strips = 140 µm, bottom = 490 µm
- R/O support: 3mm Rohacell foam sandwiched between 100 µm fiberglass
- 12 connectors 8 on the top and 4 bottom part of the r/o board
- 64 strips from top layer and 64 from bottom on each Panasonic connectors



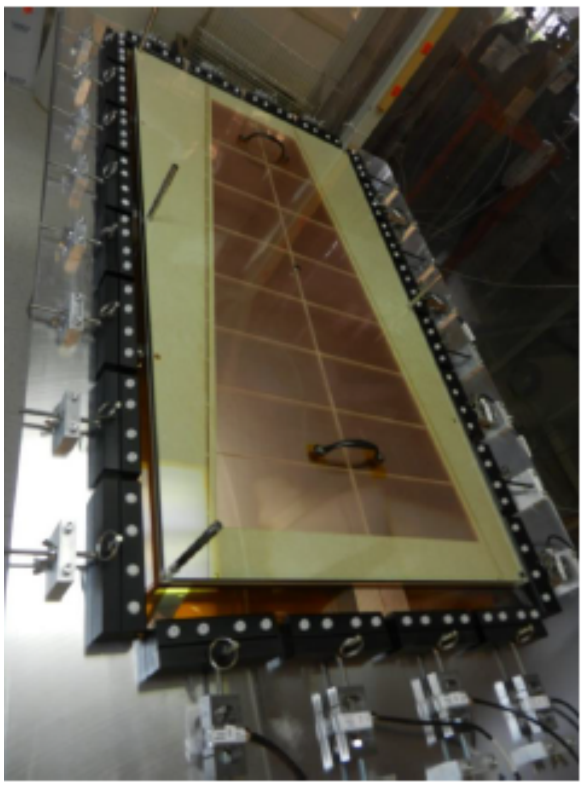
Preparing for the assembly



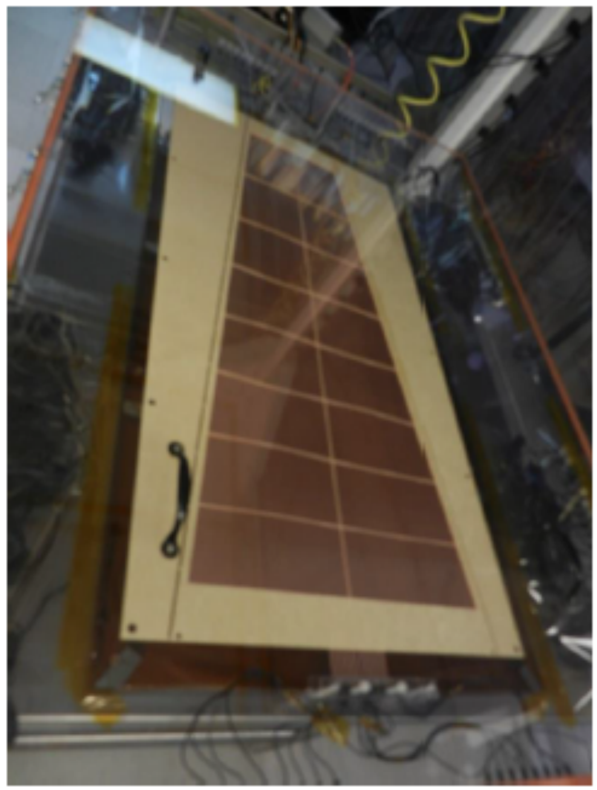


Assembly steps

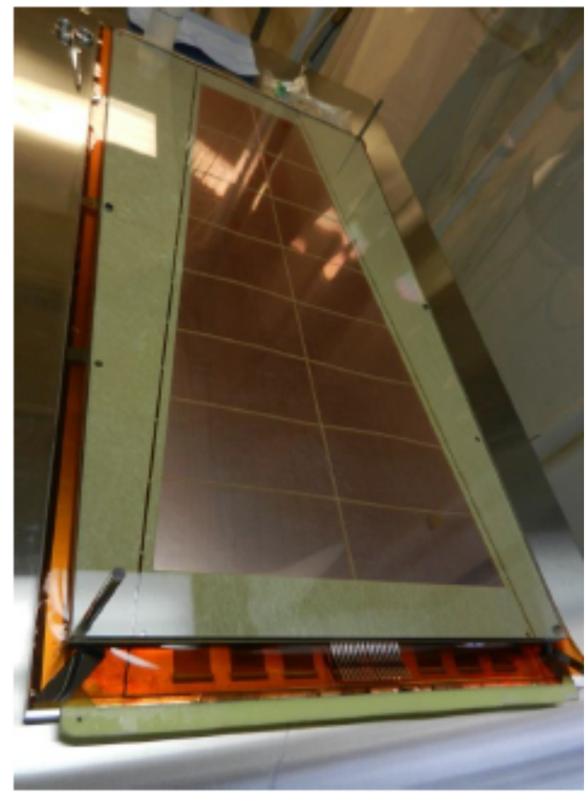
Stretching GEM and gluing the frame



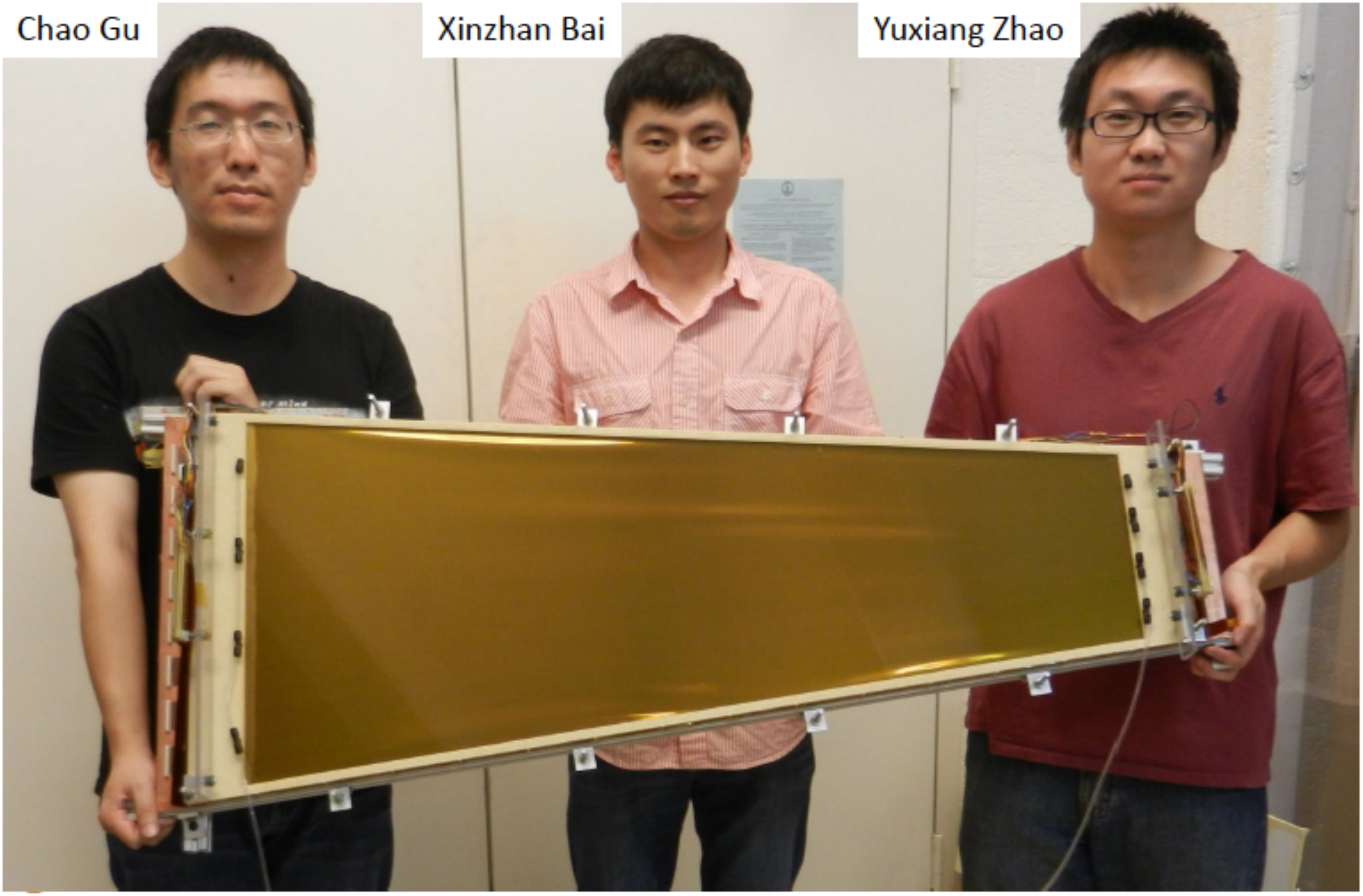
HV test of the framed GEM sectors in dry N2



Gluing the framed GEM onto the readout board



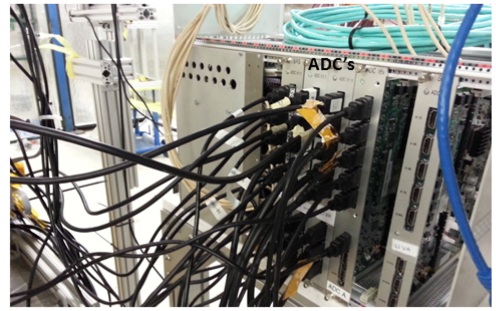
The “real” SoLID-GEM Chinese collaboration

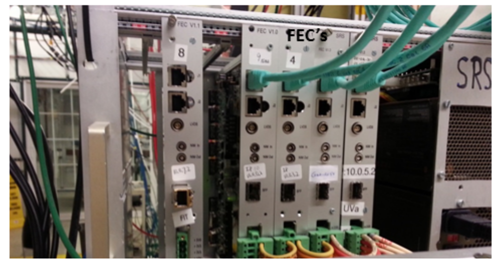


Test Beam @ FNAL (october 2013)

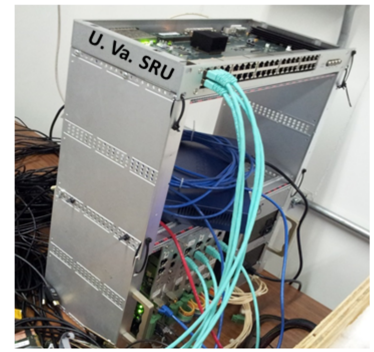
- Successful test beam campaign with SBS 50 ×50 cm^2 prototype alongside the EIC-SoLID GEM prototype
- Data analysis for spatial resolution, gain efficiency, gain uniformity, timing of the APV25 signal …
- FNAL test beam data reveals big issues (timing of the APV25 vs. gas flow, Quality of readout board vs charge sharing …)
- Medium size APV25 electronic tested at moderate trigger rate 400 Hz

SRS + SRU Readout using DATE @ FTBF

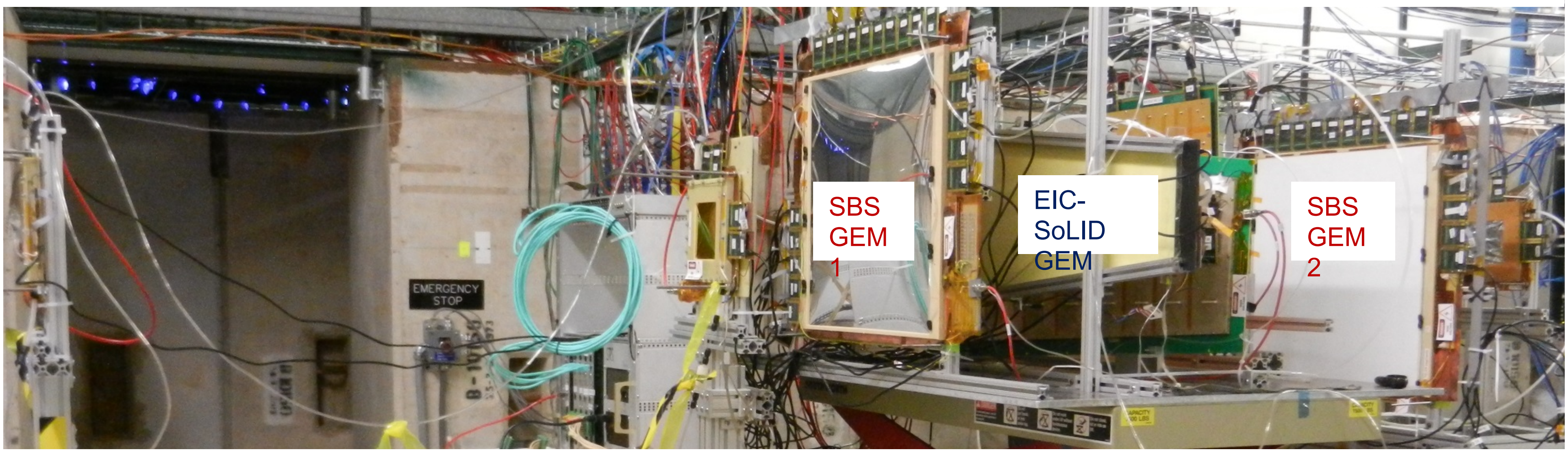




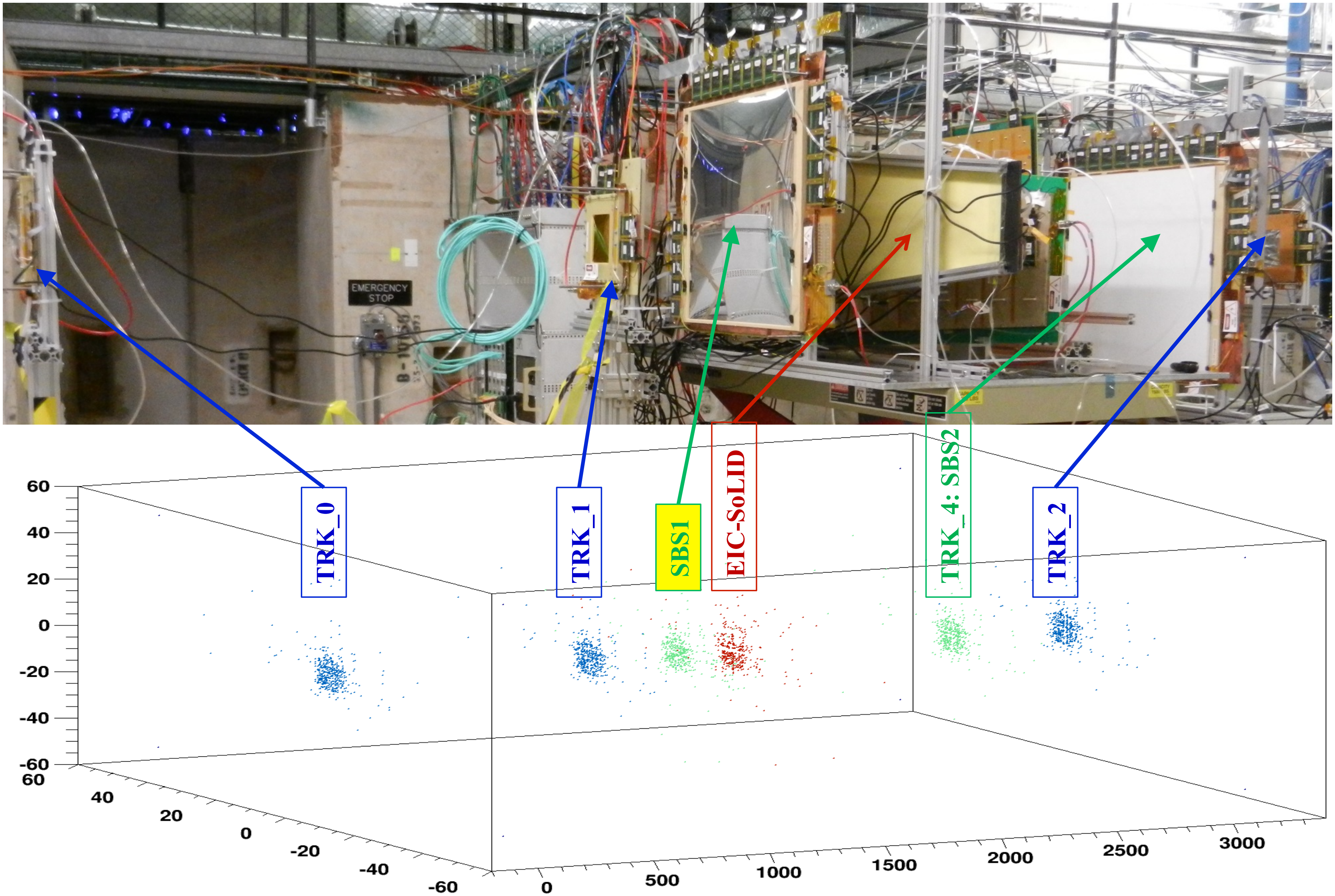
- 64 APV's read out by SRS
- Acquiring data from FECs with an SRU
- Current DAQ rate is ~150 Hz
- Using 6-9 25ns time slices for digitization
- Beam structure: 4s spills, 1min rep. time, 10 - 20k particles/spill
- Trigger: coincidence of 3 scintillators



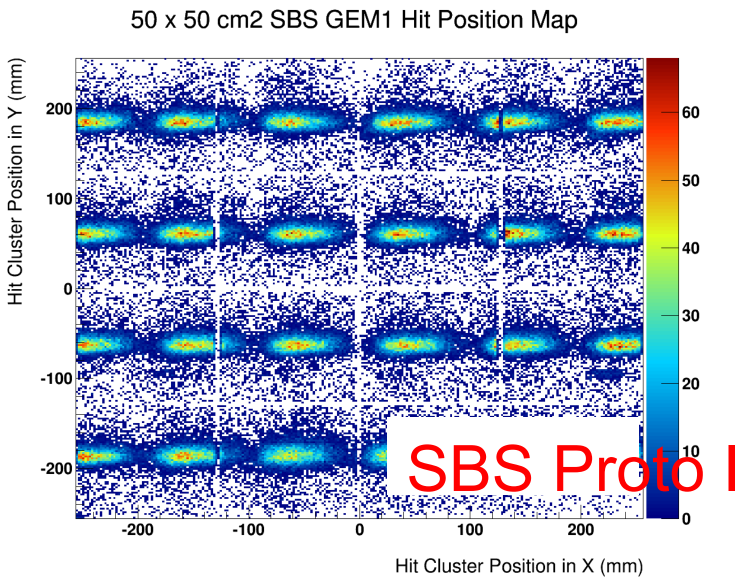
Large GEM Test Beam Setup @ (FNAL) UVa an FIT

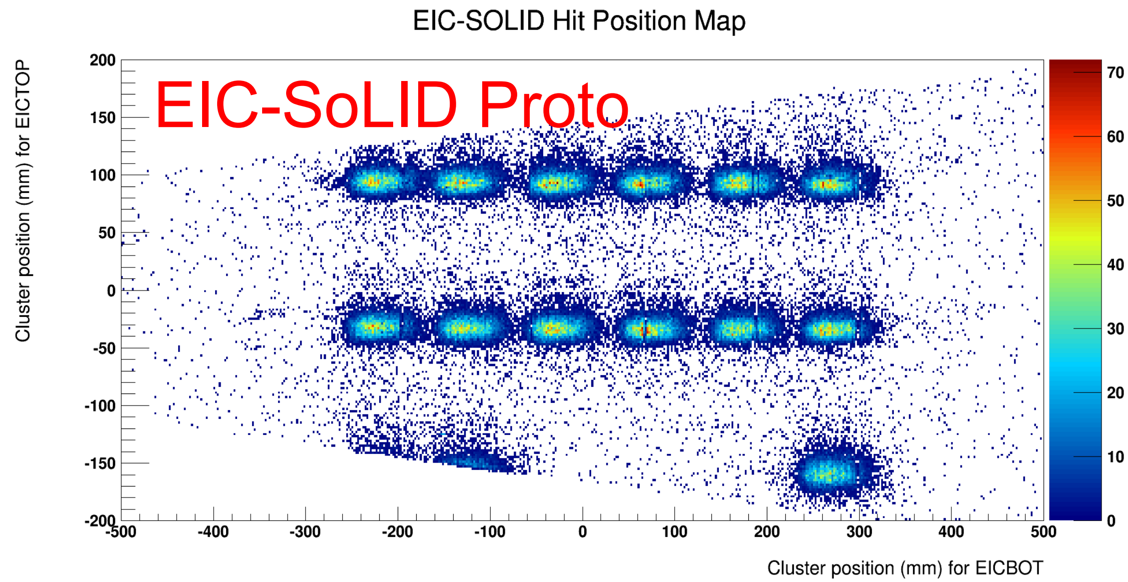


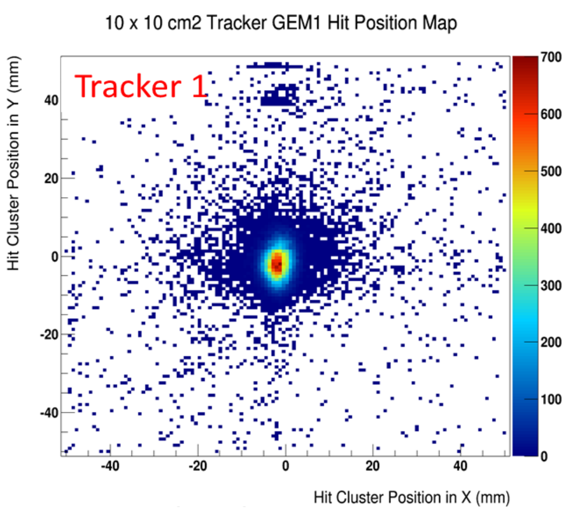
Large Size GEMs in MT6-2B @ FTBF (Fermilab)

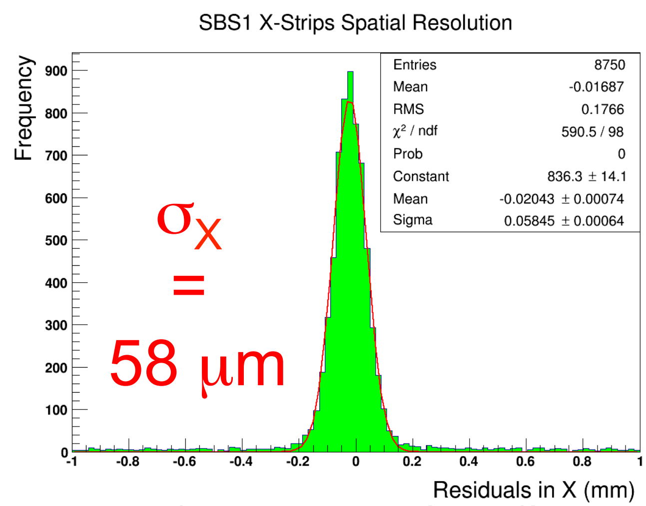


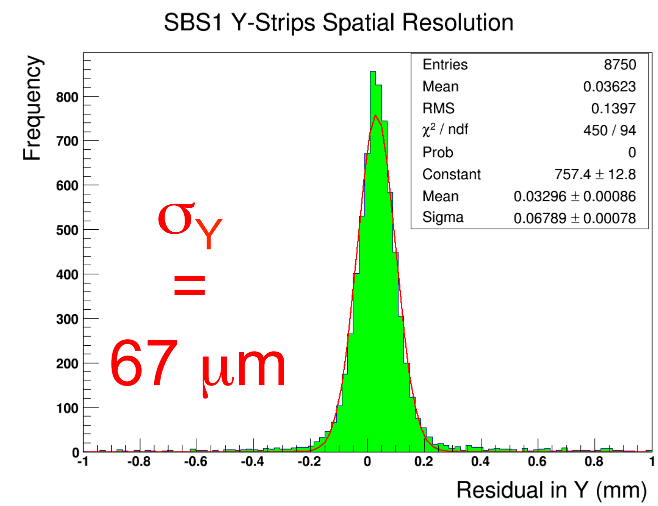
Preliminary Results with Fermilab Test Beam



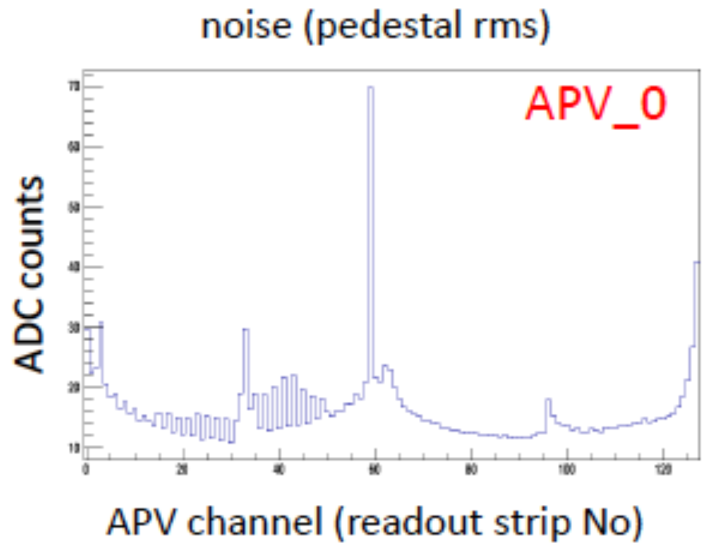




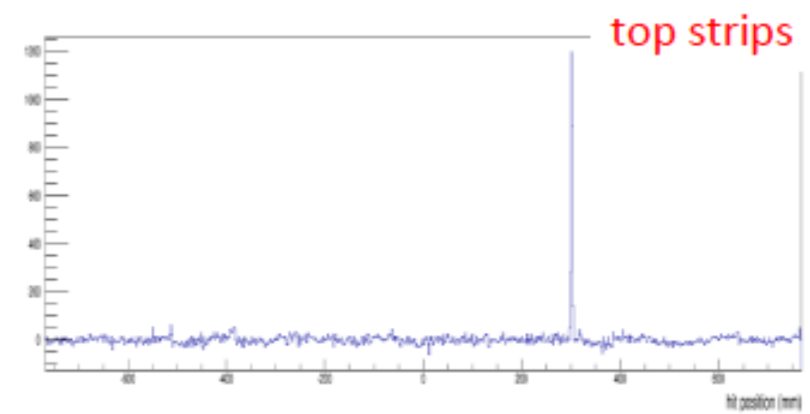


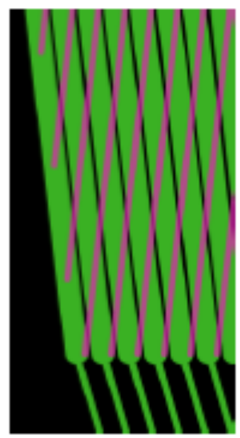


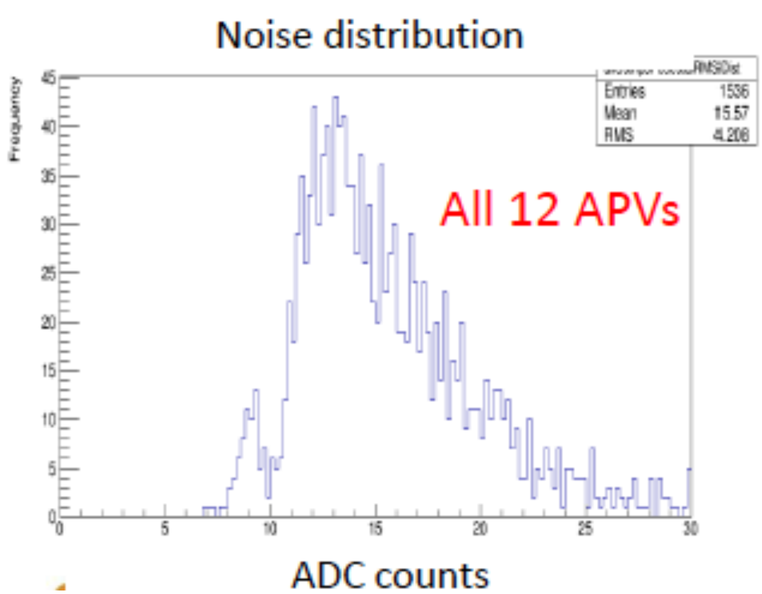
Preliminary results: EIC-SoLID readout strip capacitance noise

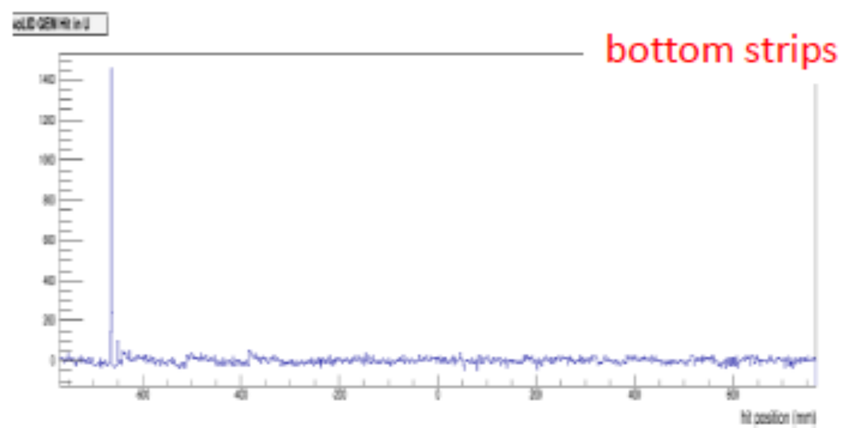


- Pedestal noise distribution over all 1536 strips (768 narrow top strips and 768 wider bottom strips)
- Strips of different lengths (U/V strips on trapezoidal readout)
- Average pedestal RMS noise 16 ADC counts, maximum 30 ADC counts

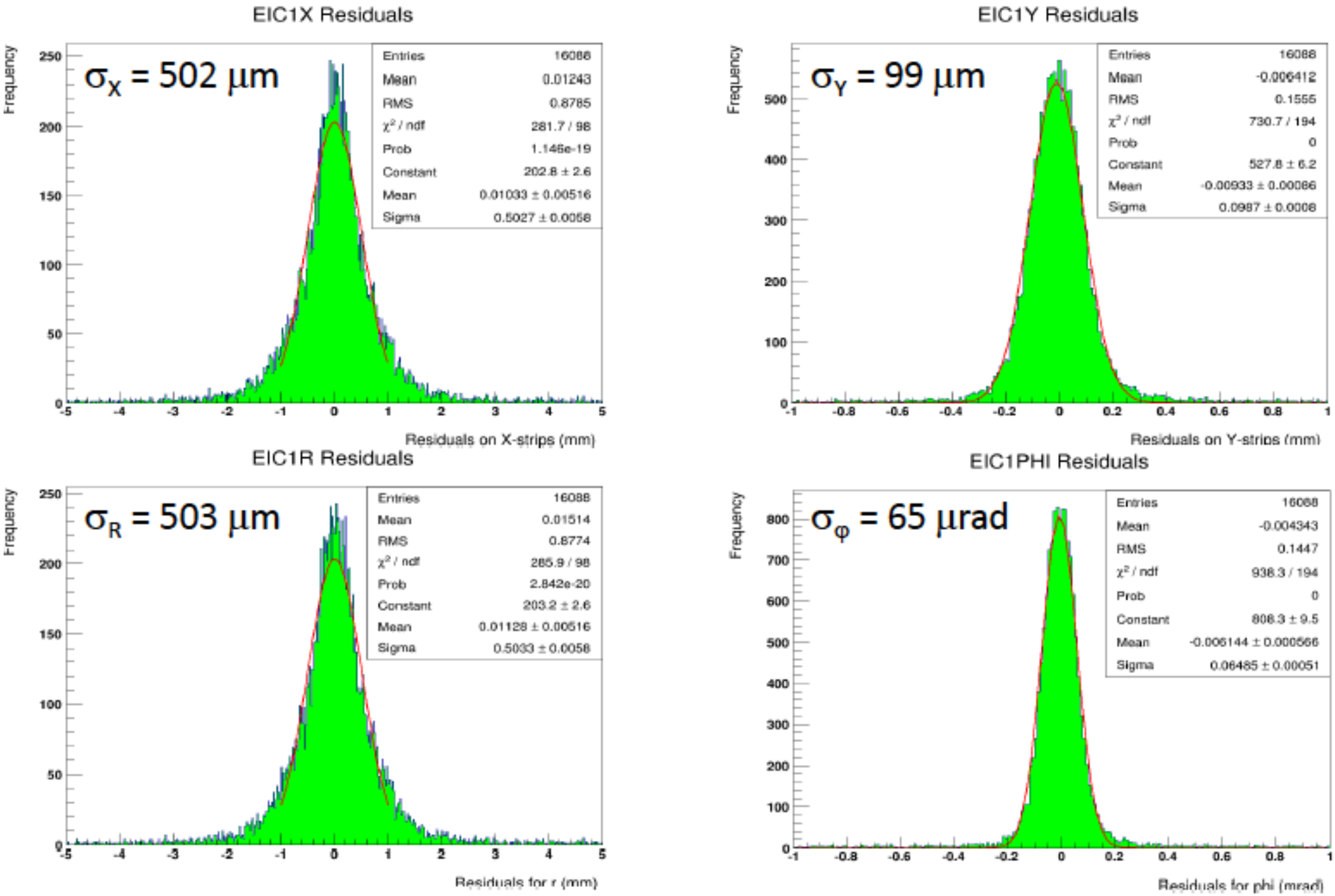






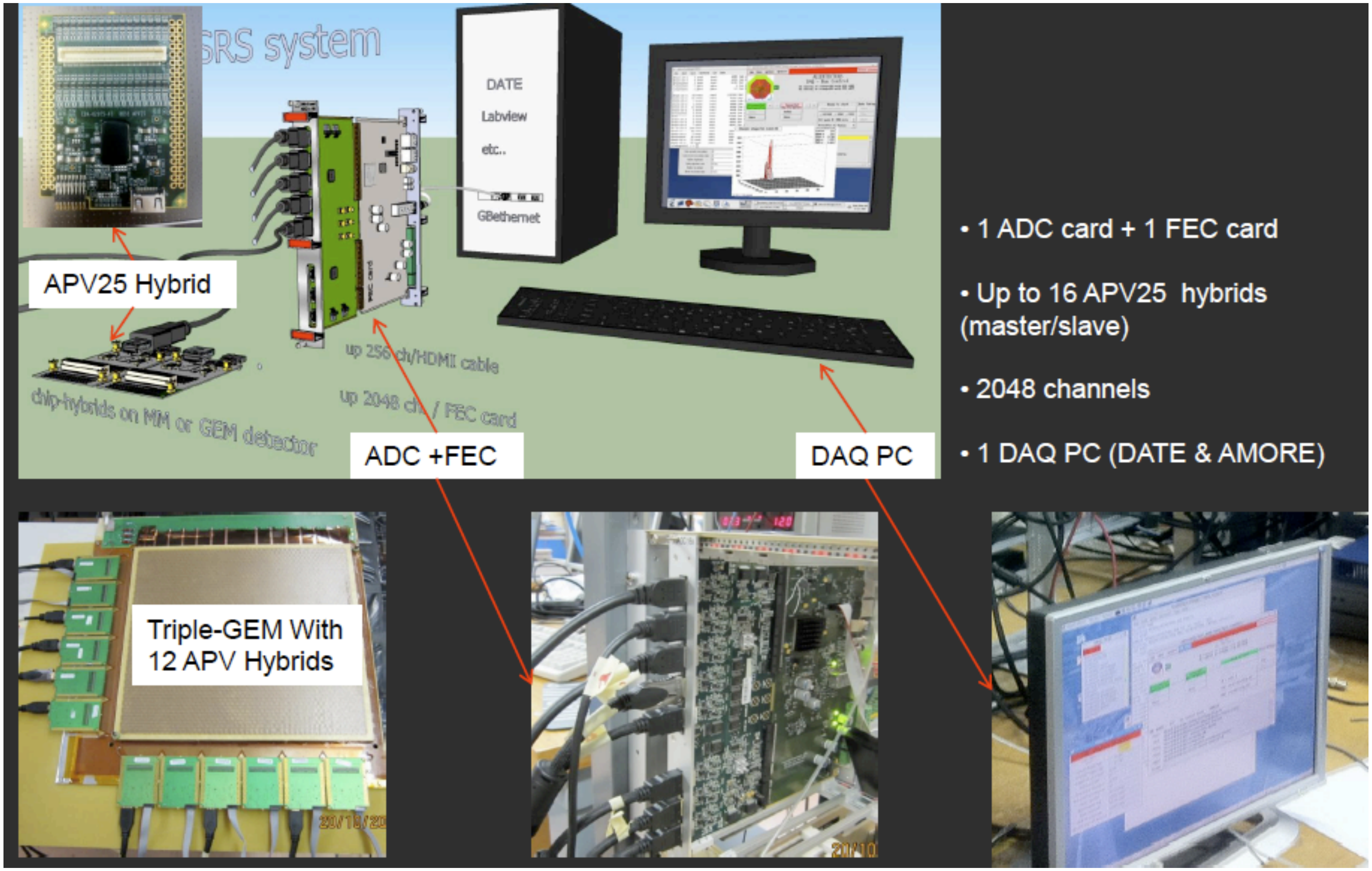


Resolution in x, y, r and φ @ P1



GEM chamber electronics

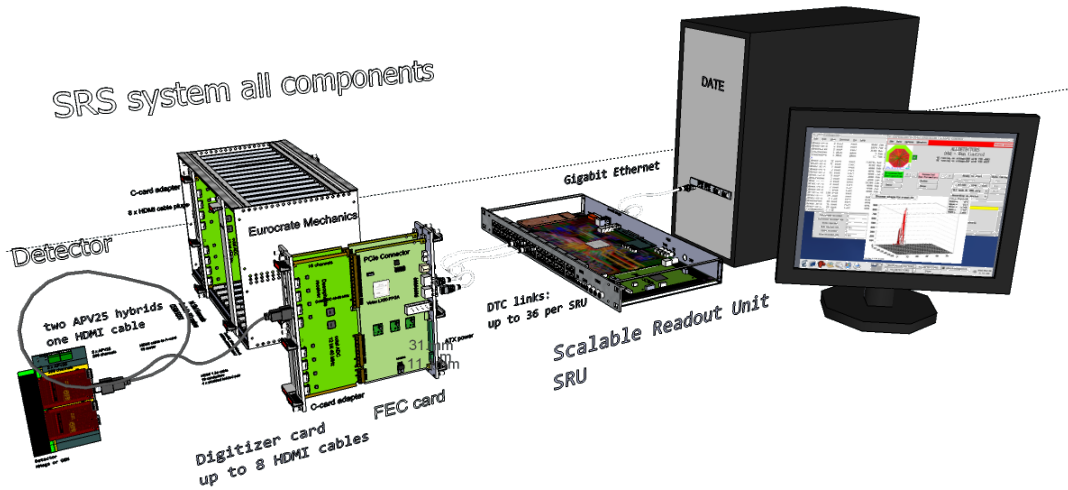
- The RD-51 Scalable Readout System provides a low-cost, common platform that can accommodate different readout chips.
- Currently tested with APV25-S1 chip.
- The cost is < $ 4 /chan.



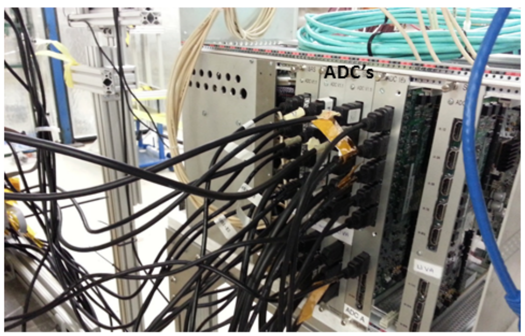
Experience with APV25-SRS @ UVa

SRS with the SRU

- Small size (2k channels) in use in the detector lab at UVa lab the last 3 years
- Successful run with medium size (8k channels) SRS during test beam at FNAL and JLab
- But current system not designed for real experiment-environment like the SBS GEMs



SRS + SRU Readout using DATE @ FTBF



- 64 APV's read out by SRS
- Acquiring data from FECs with an SRU
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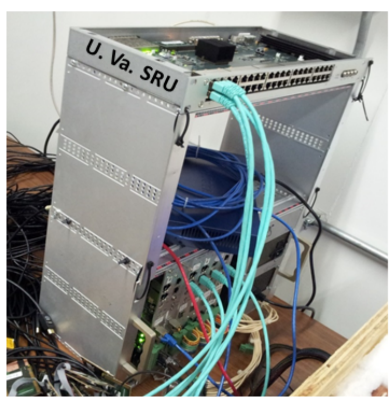
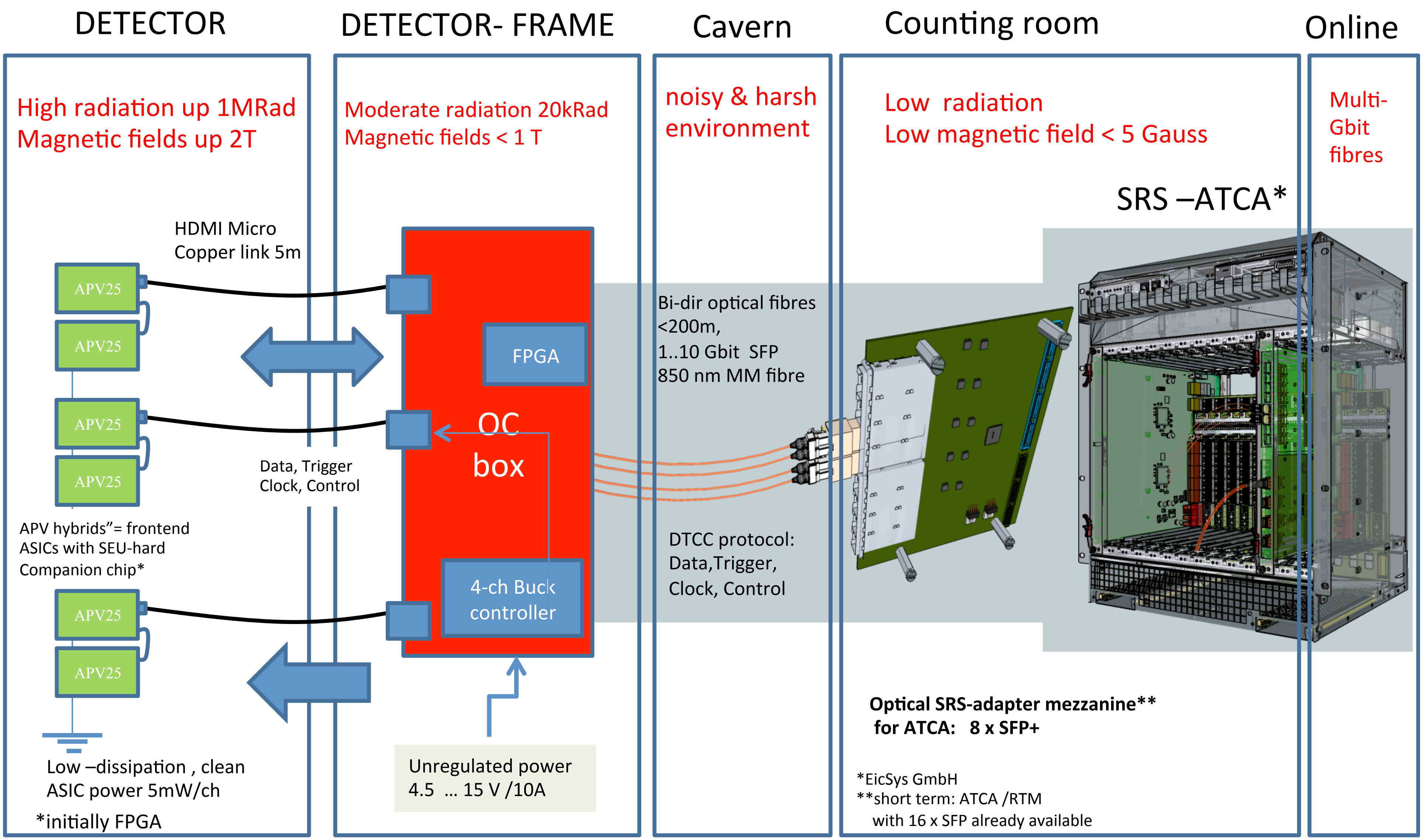


Shortcomings of the current APV25-SRS

- APV25 hybrids are not rad hard compliant
- HDMI cables length is a limitation for a system that need to be at some distance from the detector area
- Limitation on acquisition rate: 5 khz expected for SBS GEp5 experiment
- Safety concerned and crate certification issues raised for operation in environment like JLab

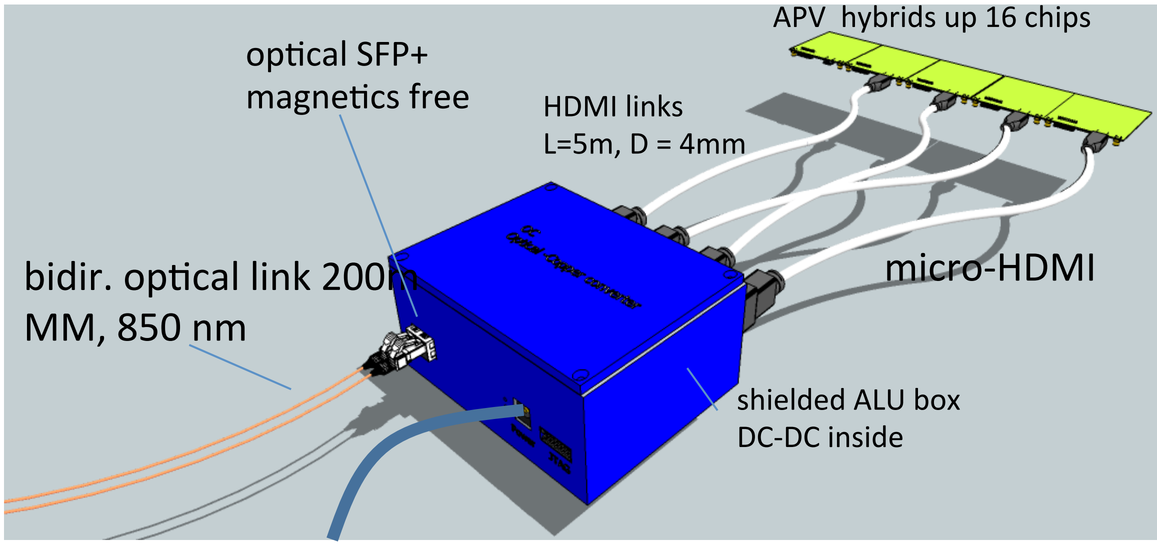
ATCA-SRS architecture

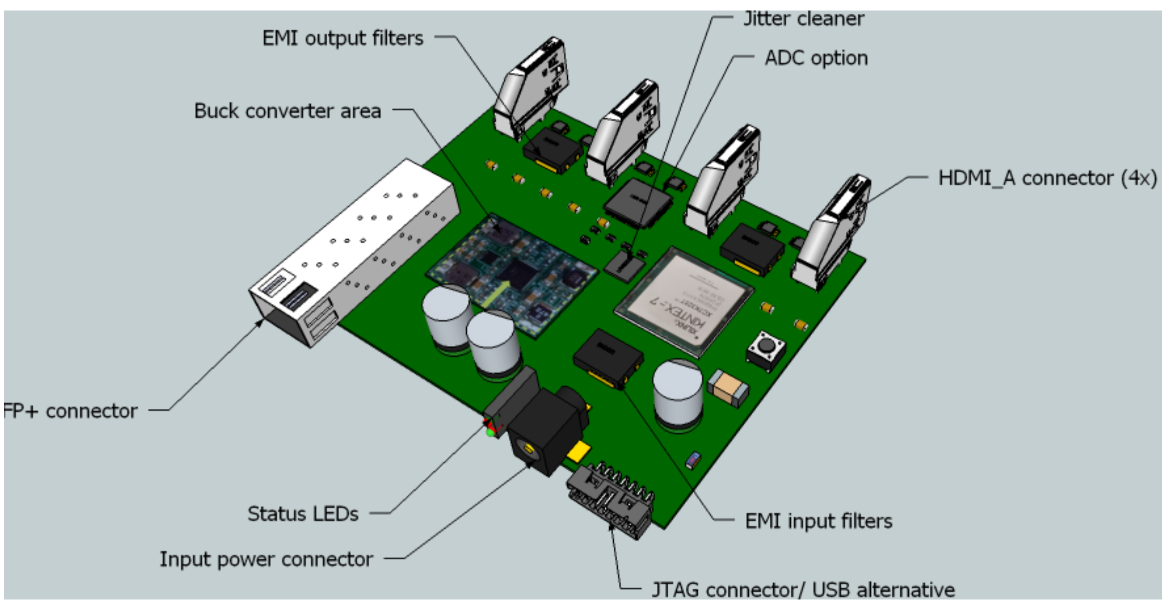


Upgrades needed for SRS

- Optical to Copper Box with ADC option
  - Link from OC directly to the RTM
  - Skip digital mezzanine adapter board
- APV-hybrid with radiation tolerant capability
  - Remove the voltage regulator
  - hybrids powered from OC boxes through HDMI
- New development must be compatible with the ATCA version
  - High density readout and high rate capability
  - certified ATCA crate, safety concerns need to be addressed

Optical to Copper (OC) Box (with ADC option for APV25)



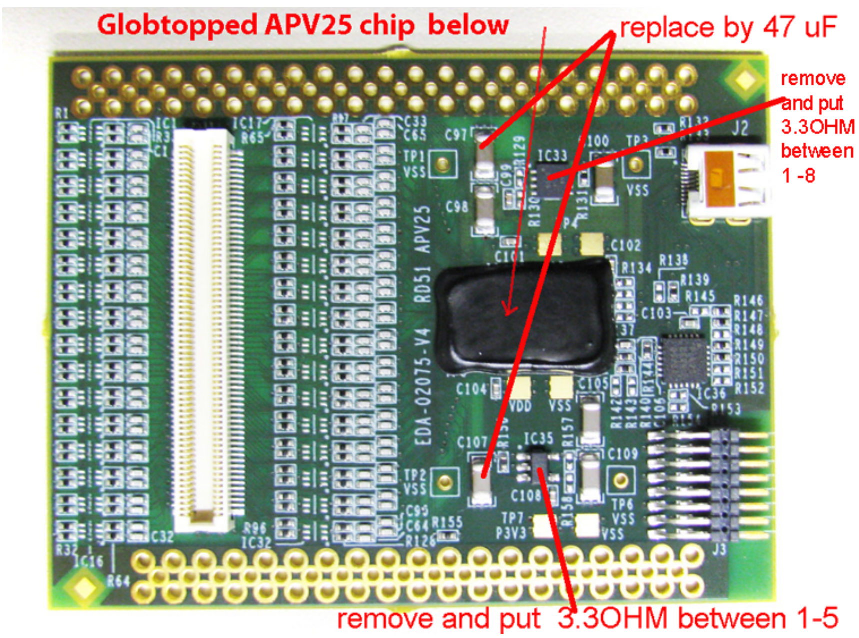


1 optical link (up 200m) ➔ SRS multiplexed DTCC protocol :
1 fiber = 4 x copper = 1k ch.

- Initial development by RD51 is a digital OC for BNL VMM chip
- Key feature of interest for SBS is an "analog" OC box with the ADCs chip on the board
- The OC box will also provide the power to the APV25 hybrids
- RD51 and EicSys (ATCA manufacturer) to work together for an ATCA version of the analog OC

Radiation tolerant APV25-SRS hybrids v5

- APV25 chip are specified for rad hard operation up to O (10 MRad), but the linear voltage regulators (LDO) on the hybrids for local power conversion will most likely fail at integrated radiation levels
- Ongoing study the feasibility of an LDO-free APV25 hybrid revision (v5) for remote powering via the readout cables. Such a scheme eliminates local voltage regulators from the hybrids.



Current status of the development

- APV25 without the voltage regulators and external powering system was tested earlier this year
- Powering scheme of the VMM chip via OC box is understood now (supported by ATLAS NSW group)
- Same scheme for the analog OC for APV hybrids
- Likely 2 versions of APV25-SRS v5 to be available:
  - a.) voltage regulators for standard SRS user,
  - b.) voltages via the HDMI for OC box users
- Support from SBS will be needed

cost estimate

Item	Number	Unit Cost ($)	Cost ($)
tooling	5	10,000	50,000
Modules 1,2,3(foil Length 75cm)			
GEM foils	270	1,103	357,210
Drift Foils	90	525	56,700
Readout Boards	90	1,890	204,120
Honeycomb	90	473	51,030
Panasonic connectors	1080	3	4,082
Assembly of connectors	1080	20	25,515
Chamber frame sets (RESARM)	90	2,000	216,000
Modules 4,5(foil length 115cm)			
GEM foils	180	1,890	408,240
Drift Foils	60	788	56,700
Readout Boards	60	3,150	226,800
Honeycomb	60	735	52,920
Panasonic connectors	900	3	3,402
Assembly of connectors	900	20	21,263
Chamber frame sets (RESARM)	60	2,000	144,000
For all modules			
Chamber supplies	5	10,000	50,000
Gas system plumbing	5	10,000	50,000
HV distribution	5	10,000	50,000
HV power mainframes	2	7,000	14,000
8-channel HV modules	20	3,500	70,000
HV cabling	150	100	16,500
Readout electronics			
SRS APV-25 Channels	170000	4	816,000
Equipment total			*2,944,482*
Technician (FTE years)	16	100,000	1,600,000
Graduate Students (FTE years)	6	50,000	300,000
Manpower total			*1,900,000*
Travel costs (to CERN and Jlab)	1	150,000	*150,000*
Grand Total for Production			**4,994,482**
design R&D and prototyping			
Prototype electronic systems	10000	5	50,000
Material for 5 prototypes	5	20,000	100,000
Research Scientist	2	125,000	250,000
R&D total			**400,000**
Grand Total for the project			**5,394,482**