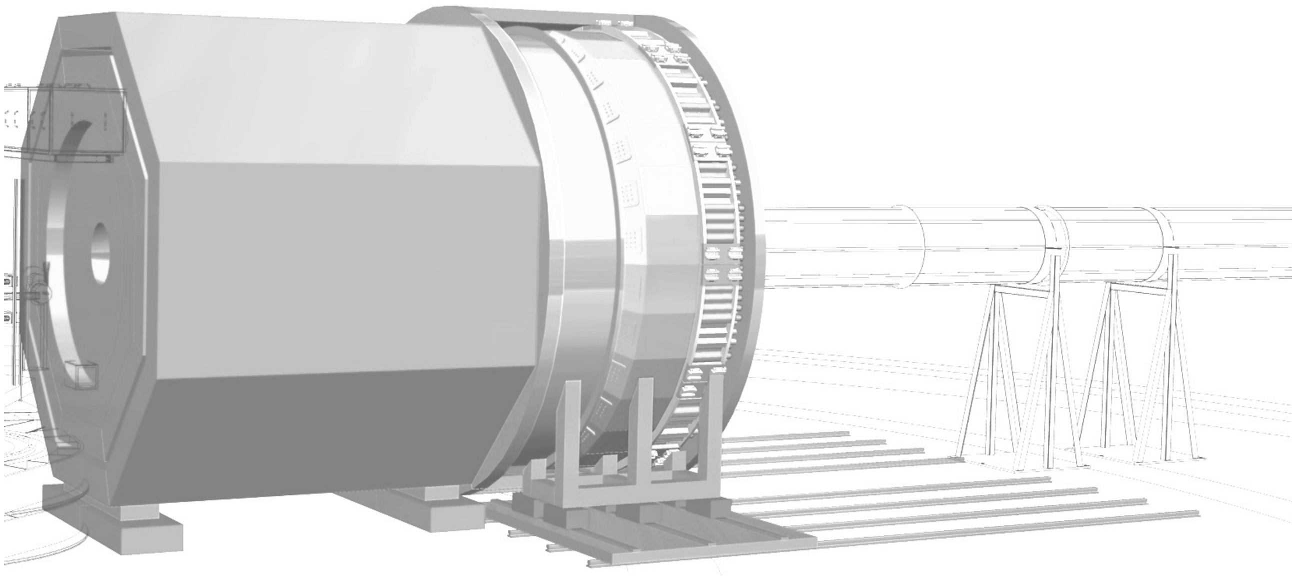
Gas Electron Multiplier (GEM) Tracker

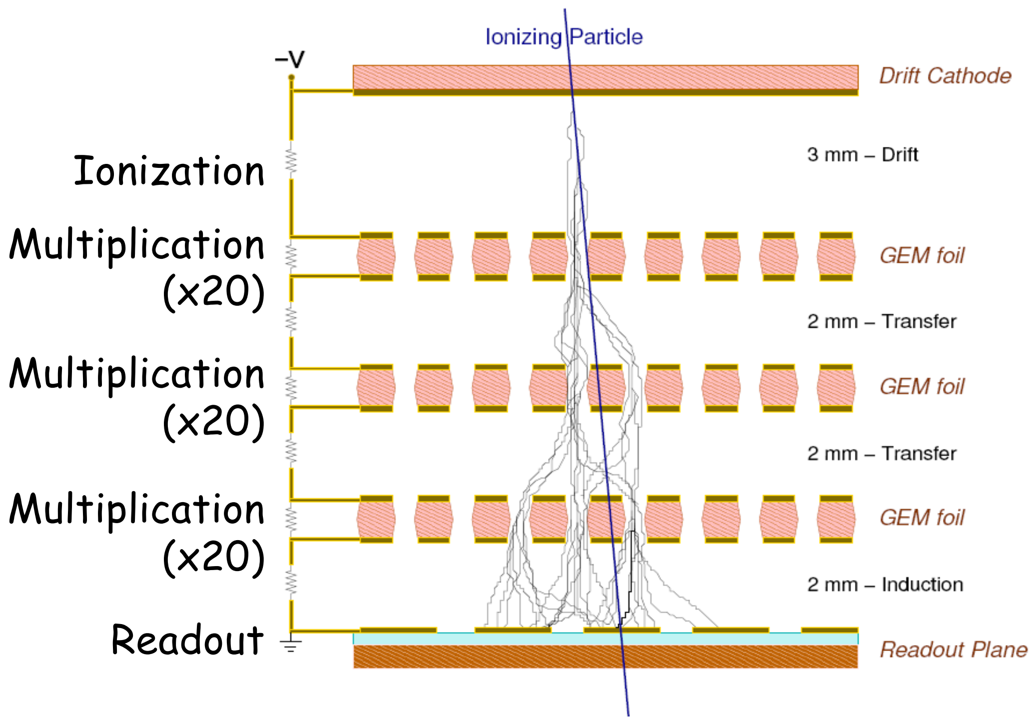


Nilanga Liyanage

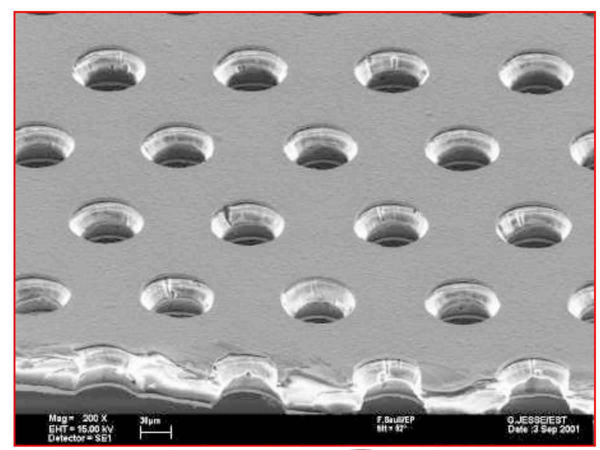
SoLID GEM Group
University of Virginia

GEM: The main tracking option so far: why ?

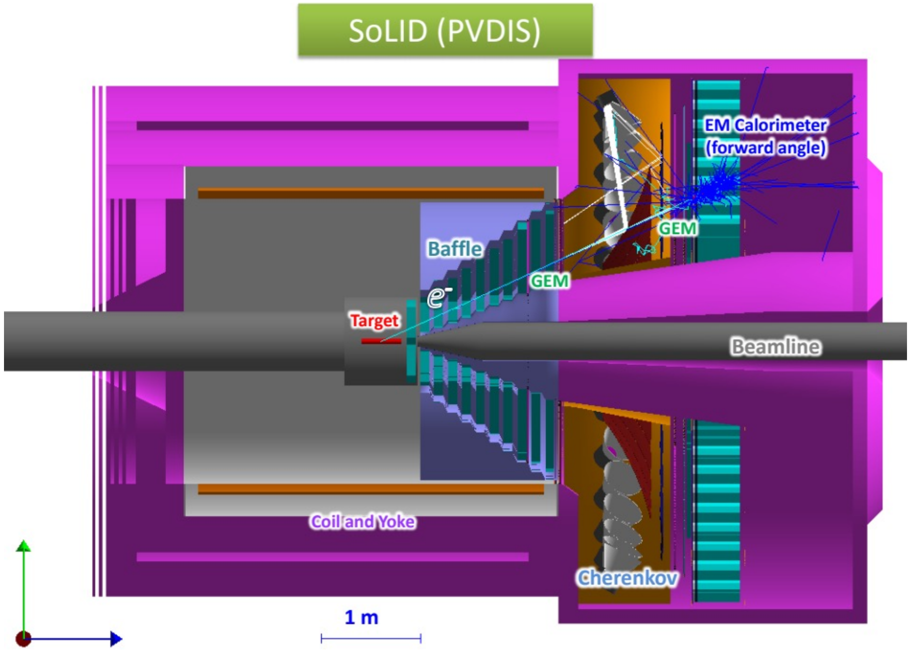
- SoLID concept leads to need for high rate trackers with good position resolution.
- GEMs: cost effective for high resolution tracking under high rates over large areas.
    - Rate capabilities higher than many MHz/cm^2
    - High position resolution (< 75 μm)
    - Ability to cover very large areas (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.

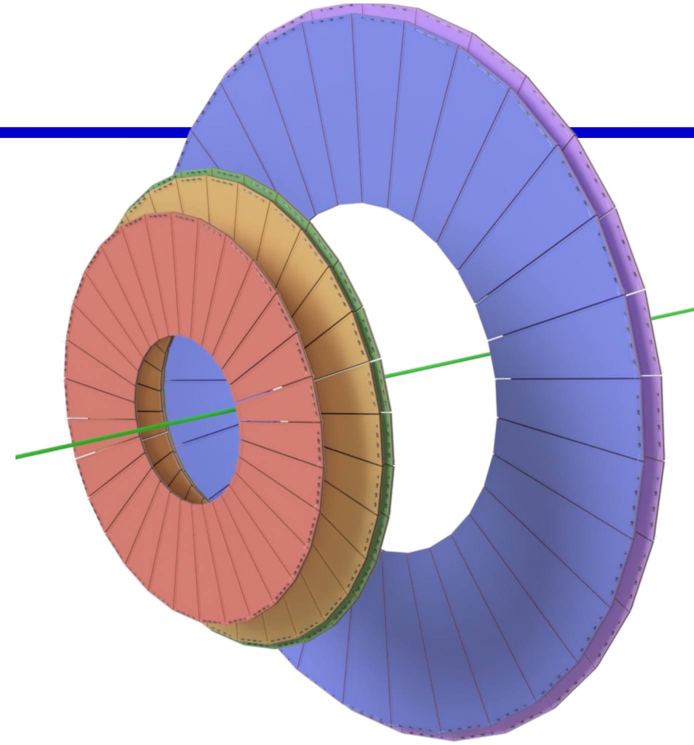


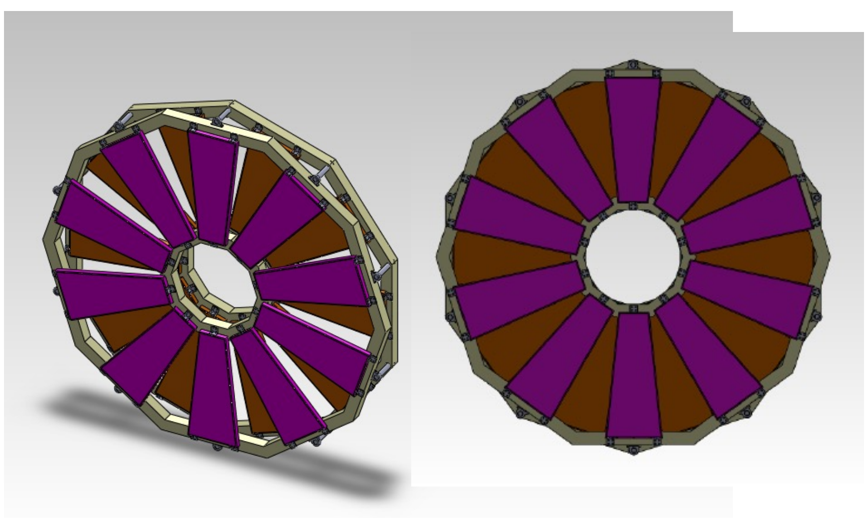
GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch

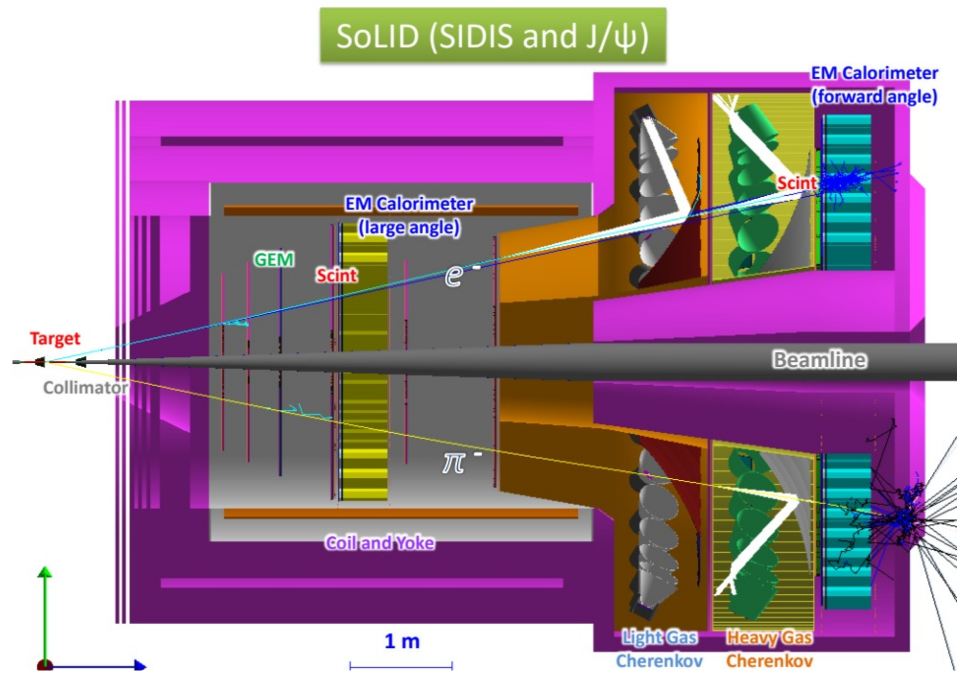


GEM Overview





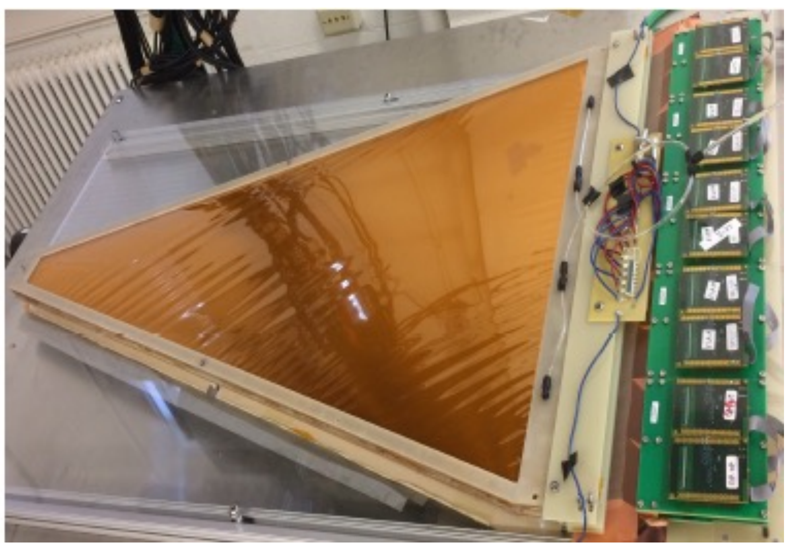




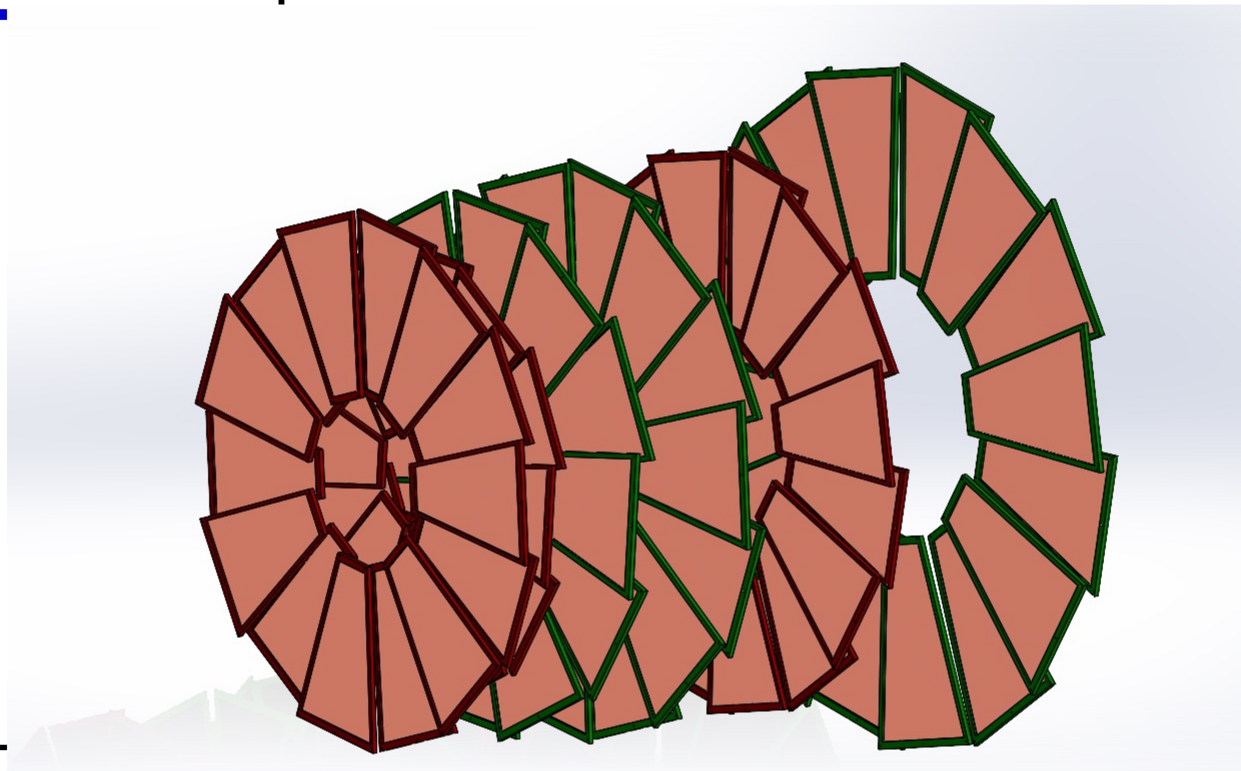
GEM Requirements: for all experiments

- ❑ Good position resolution
  - ❑ 100 µm (1 mm) in azimuthal (radial) direction.
    - ➢ 2D U-V readout with 12-degree or 24-degree stereo angle between strips
    - ➢ 400 µm (600 µm) strip pitch for layers 1-3 (5-6)
    - ➢ The high occupancy at layer #1: split each readout strip into two channels
    - ➢ Total number of channels ~ 215 k (with 15% spares)
- ❑ 92 % overall GEM-module efficiency.
- ❑ modules with a trapezoidal geometry
- ❑ 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.



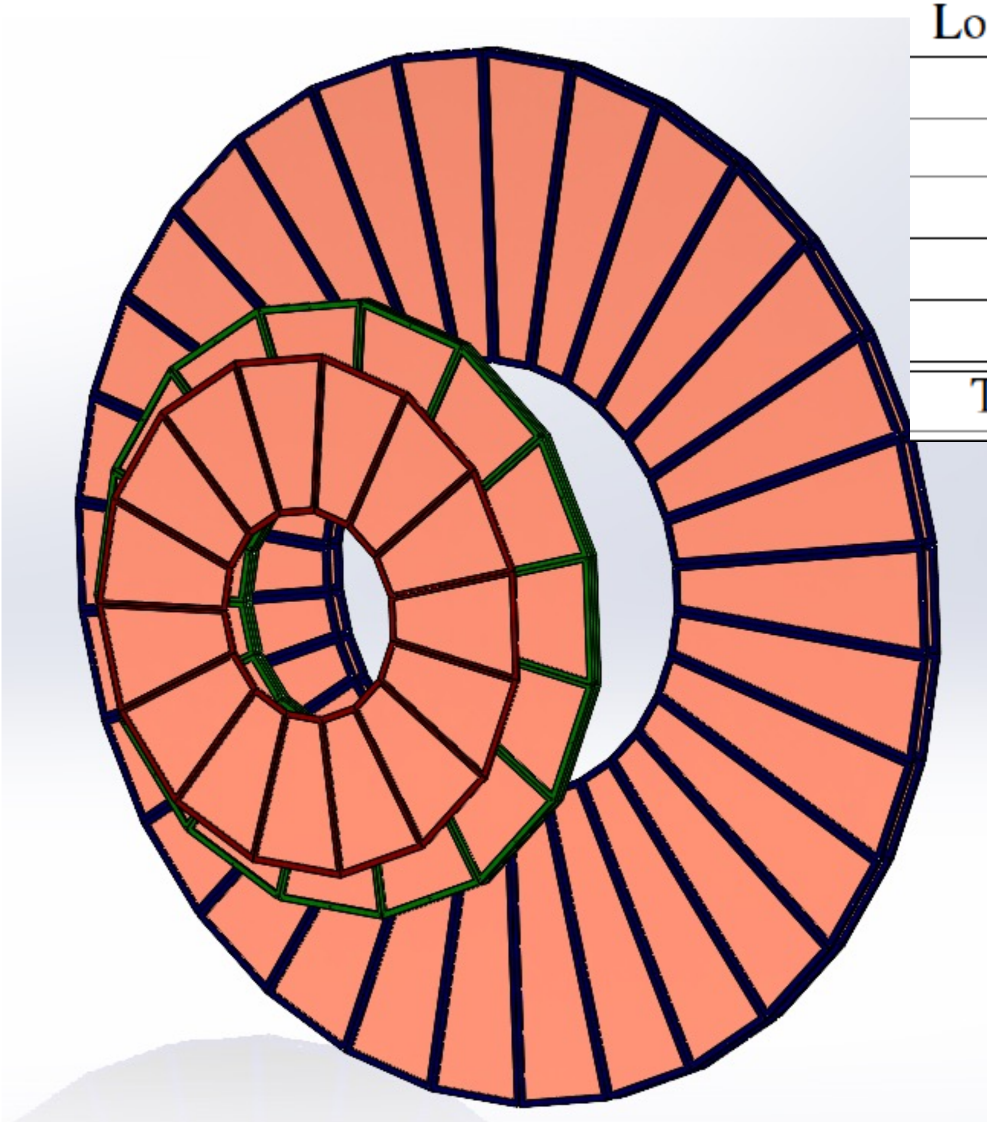
GEM configuration – Under optimization for SIDIS



Plane	Z (cm)	R_I (cm)	R_O (cm)	Length (cm)
1	-175	36	87	51
2	-150	21	98	77
3	-119	25	112	87
4	-68	32	135	103
5	5	42	100	58
6	92	55	123	68

Total active area ~ 21 m^2

GEM configuration – New few slides show the work post-doc Asar Ahmed did to see how many SIDIS GEMs could be used for PVDIS



Location	Z (cm)	R_{min} (cm)	R_{max} (cm)
1	157.5	51	118
2	185.5	62	136
3	190	65	140
4	306	111	221
5	315	115	228
Total			

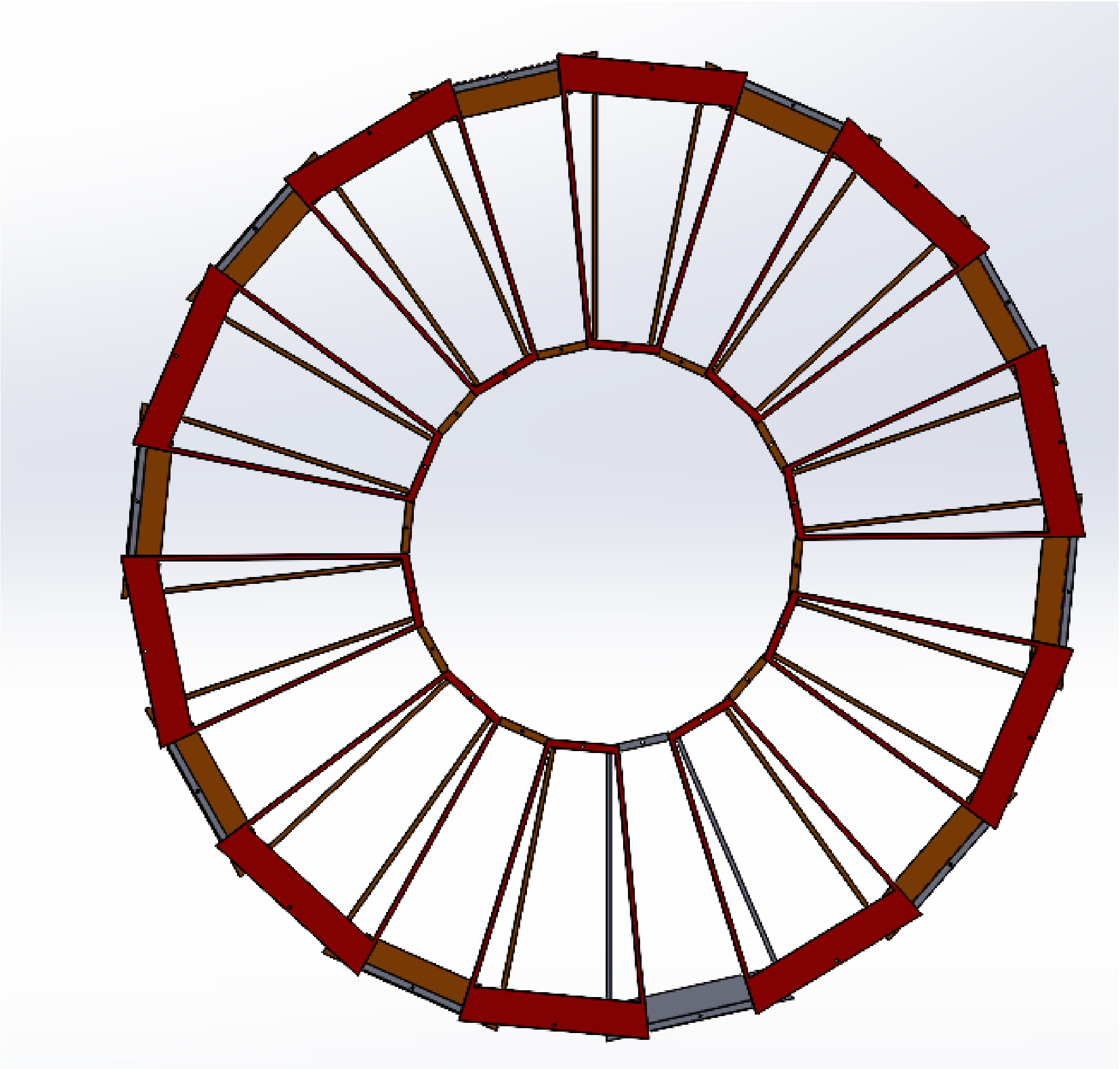
Total active area ~ 37 m^2

SIDIS arrangement

- SIDIS: Layer 6

Z (cm)	Rmin	Rmax	Length
92	55	123	68

- Same module from PVDIS is used to arrange for SIDIS
- At least 19.25 chambers are required to cover 2π
- 20 chambers are used to make an arrangement.
- Active are overlapping.
- Arrangement is fully supporting outer and inner radius requirements



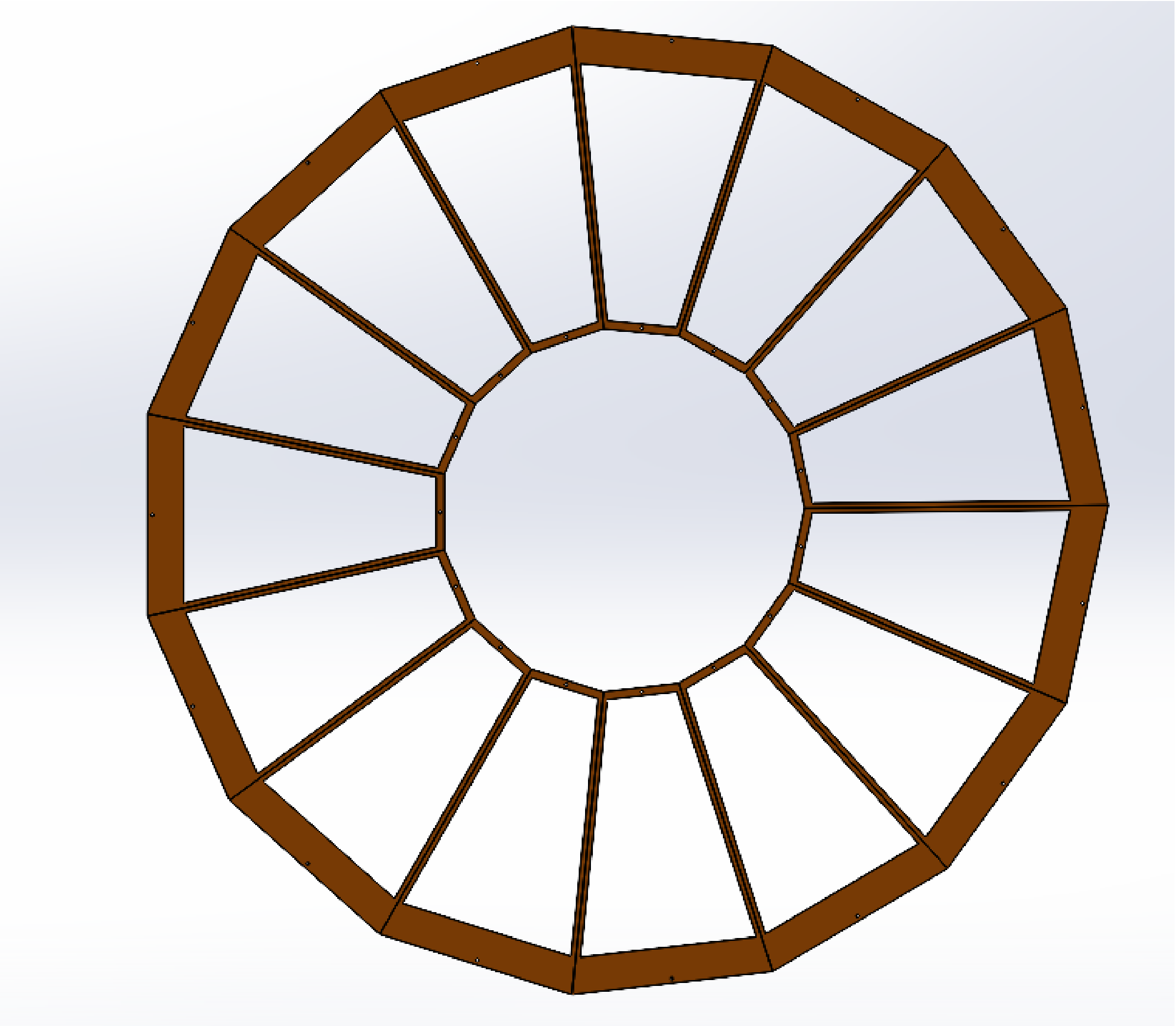
Asar Ahmed

PVDIS

- PVDIS: Layer 1

Z (cm)	Rmin	Rmax	Length	Angle
157.5	50	118	68	24

- Total chamber: 15
    - No overlapping of frames
    - Frames will be behind baffle
    - PVDIS active area per chamber: 2160.6cm^2
    - Total SIDIS requirement for layer 6: 38006.56 cm^2
    - Effective active area for SIDIS chamber: 1974.3 cm^2
    - Total chambers needed for SIDIS: 19.25



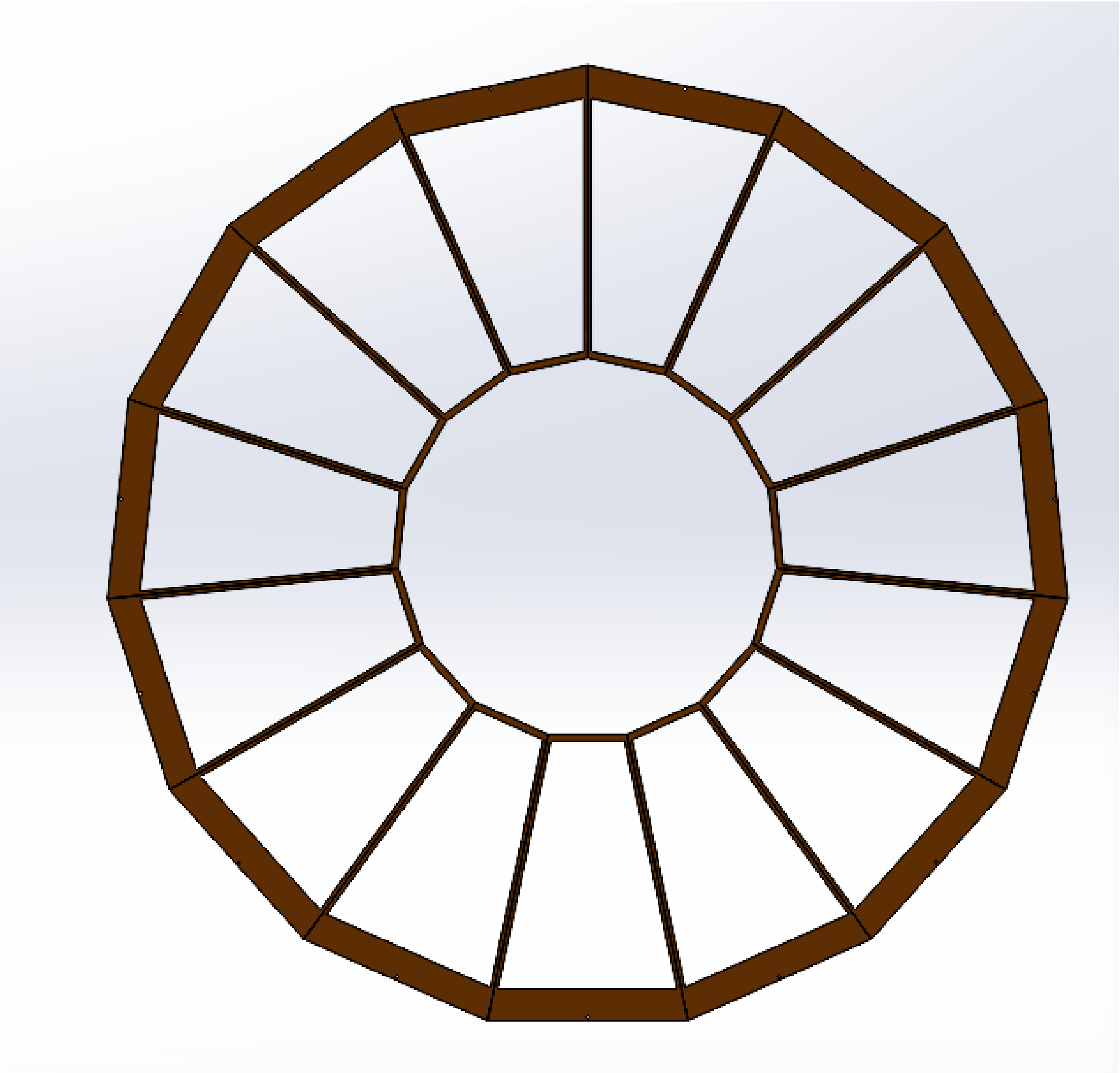
Asar Ahmed

PVDIS Layer 2

Layer	Z (cm)	Rmin	Rmax	Length
2	185.5	61	140	**79**

Total chamber: 15

- No overlapping of frames
- Frames will be behind baffle
- PVDIS active area per chamber: $3018.3cm^2$
- Total SIDIS requirement for layer 2: $28771.8\ cm^2$
- Effective active area for SIDIS chamber: $2826\ cm^2$
- Total chambers needed for SIDIS L2: 10.18



Asar Ahmed

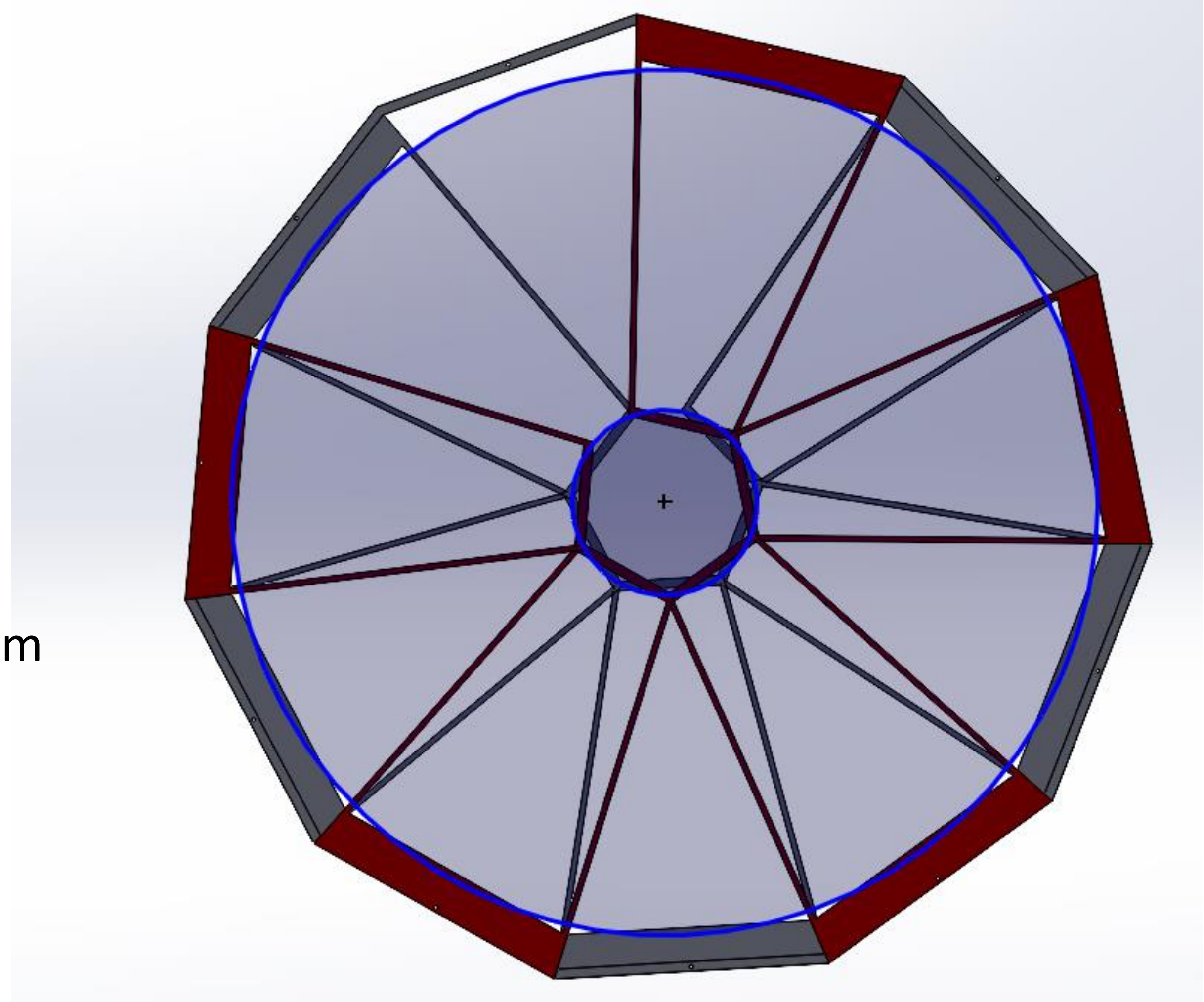
PVDIS L2 -> SIDIS L2 arrangement

Z	Rmin	Rmax	Length
-150	21	98	**77**

- Same module from PVDIS L2 is used to arrange for SIDIS L2
- At least 10.18 chambers are required to cover 2π
- **11** chambers are used to make an arrangement.

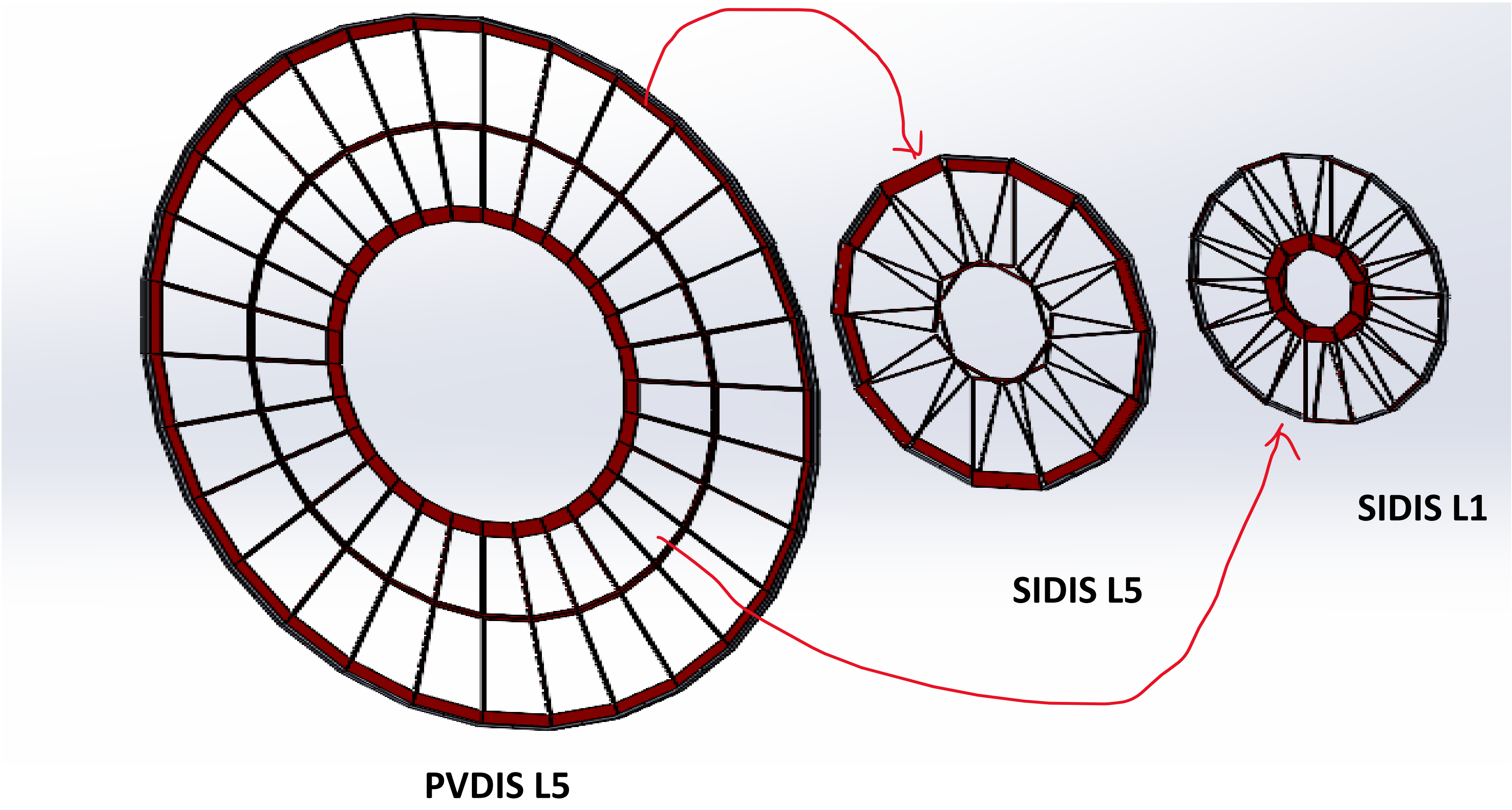
➢ Active area fall between Rmin: 21 cm and Rmax: 98cm
➢ Inner region is crowded with frame

Arrangement is fully supporting outer and inner radius requirements



Asar Ahmed

PVDIS L5->SIDIS L1 & L5



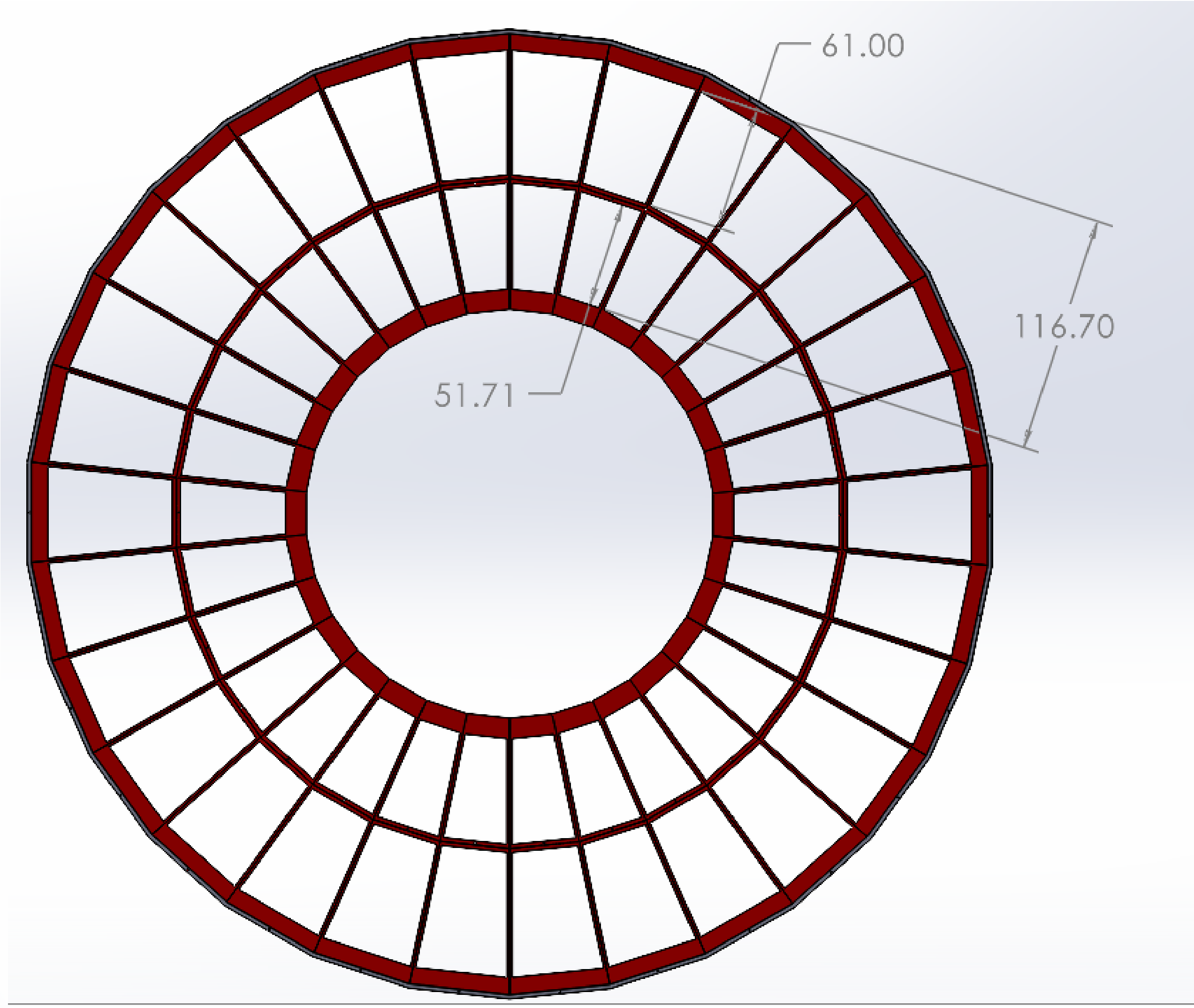
Asar Ahmed

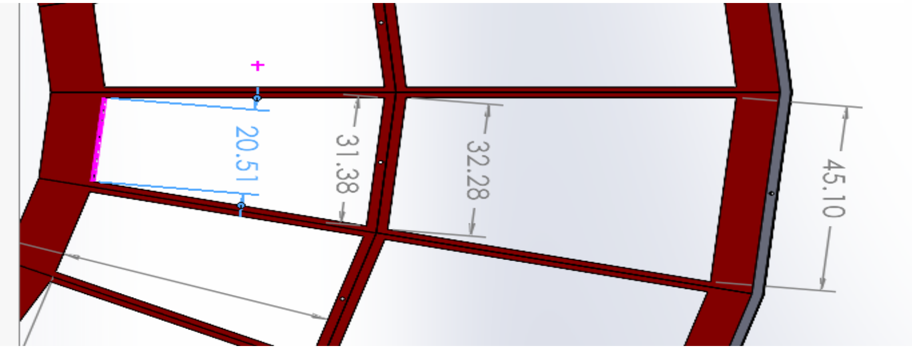
PVDIS Layer 5:

Z	Rmin	Rmax	Length
315	110	228	**118**

Total chamber: 30 (12^o)

- No overlapping of frames
- Divided full length into two
  - Inner chamber (L:51.7, OE: 31.38, IE: 20.51)
  - Outer chamber (L 61.00, OE: 45.10, IE: 32.28) in cm.
- Doing so, same chambers can be used in SIDIS L1 & L5





Asar Ahmed

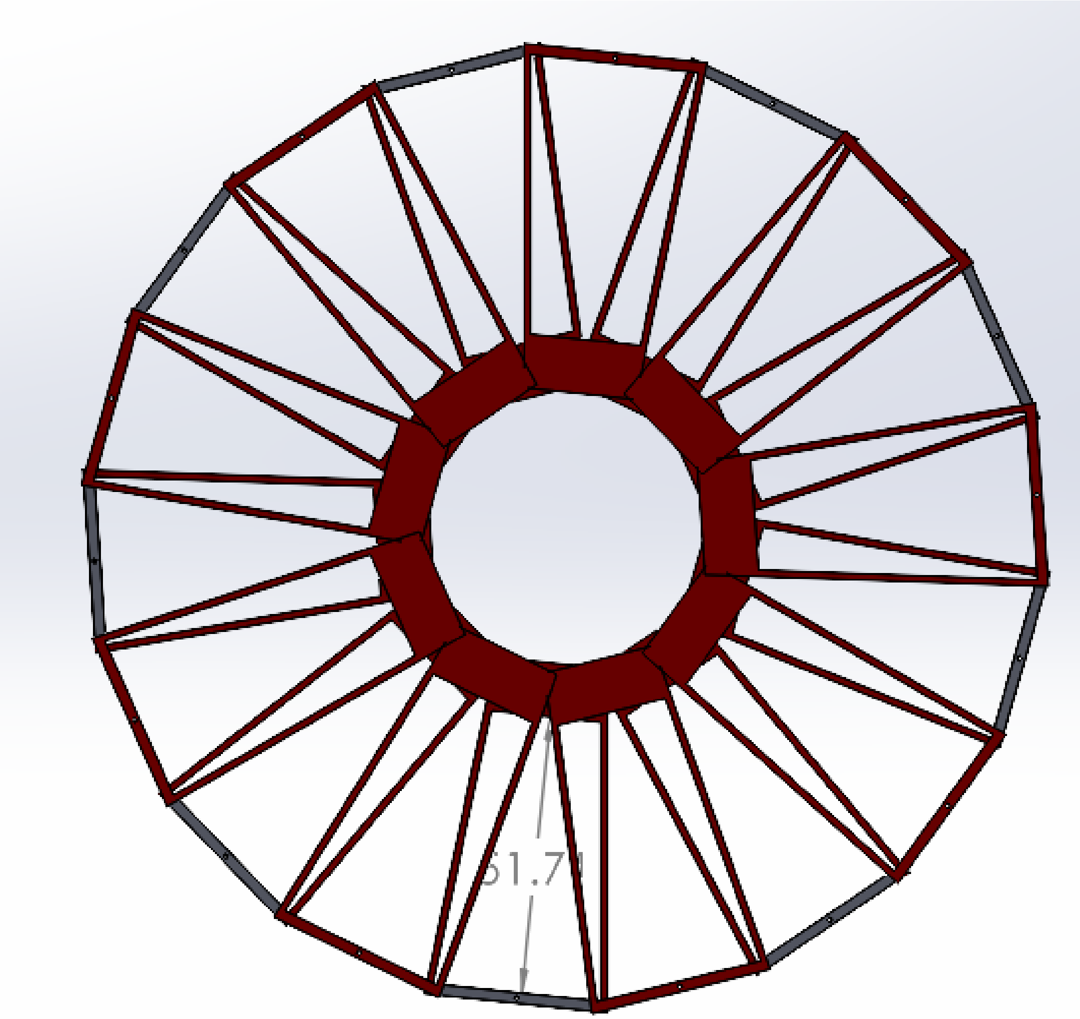
PVDIS L5 inner -> SIDIS L1 arrangement

SIDIS Z	Rmin	Rmax	Length
-175	36	87	**51**

- Same module from PVDIS L5 (inner) is used to arrange for SIDIS L1
- 18/30 chambers from PVDIS L5 (inner) are used to cover 2π

➢ This arrangement requires all the electronics and cabling towards beam pipe.

Arrangement is fully supporting outer and inner radius requirements



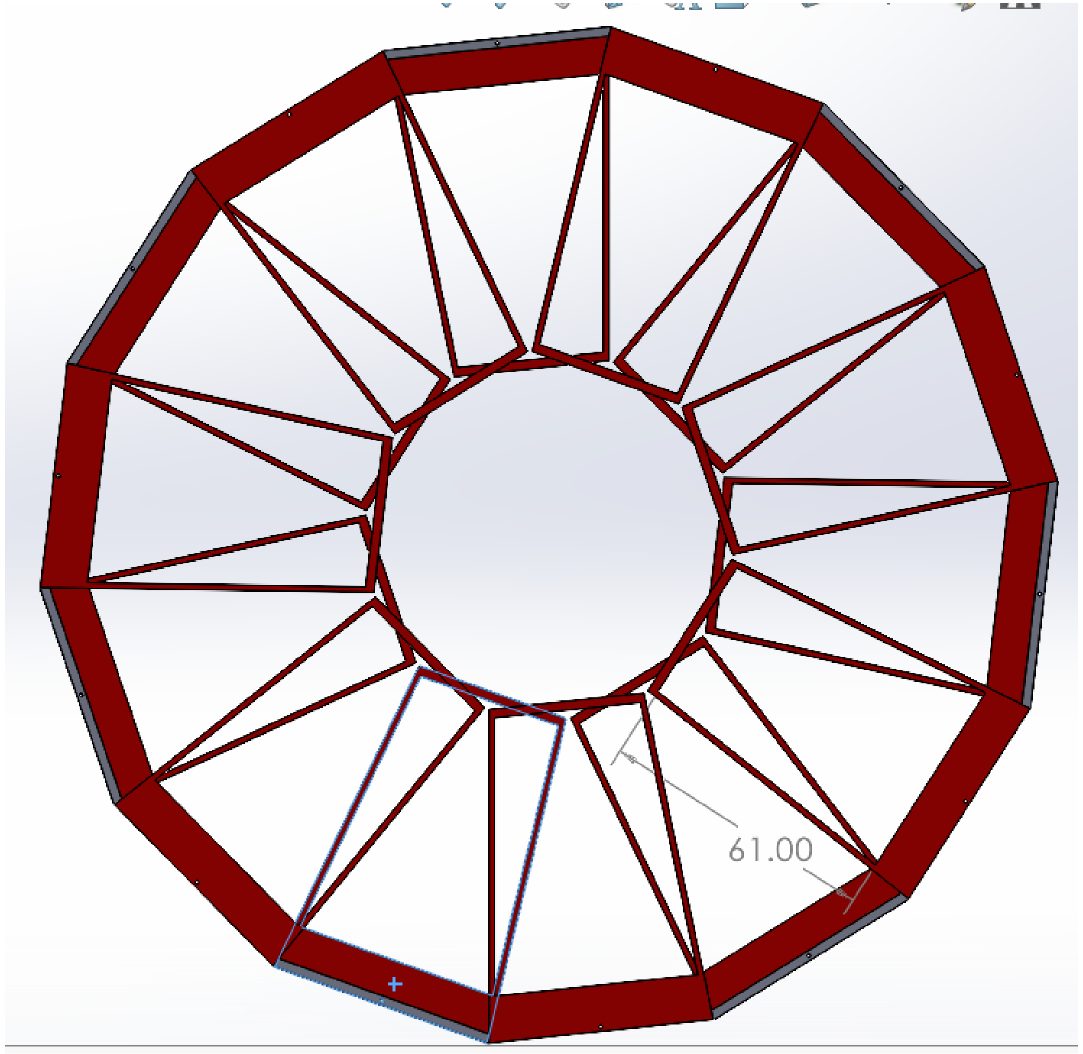
Asar Ahmed

PVDIS L5 outer -> SIDIS L5 arrangement

SIDIS Z	Rmin	Rmax	Length
5	42	100	**58**

- Same module from PVDIS L5 (outer) is used to arrange for SIDIS L5
- 14/30 chambers from PVDIS L5 (outer) are used to cover 2π
- Detector active area is 3cm longer then required length.

Arrangement is fully supporting outer and inner radius requirements



Asar Ahmed

Summary

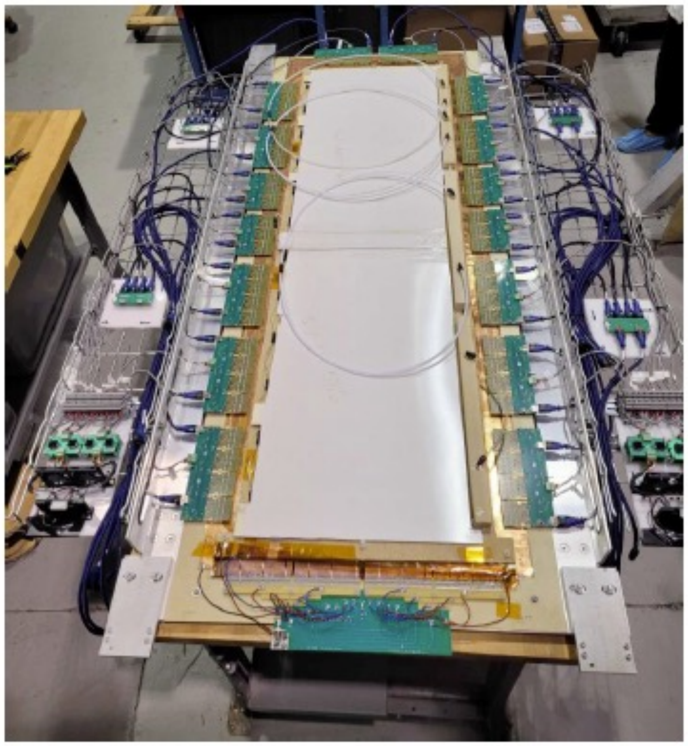
PVDIS Layer No	Chambers required	SIDIS Layer No	Chamber reused	Status
1	15 (24^o)	6	20	-5
2	15 (24^o)	2	11	+4
3	15 (24^o)	3	13	+2
4	30 (12^o)	4	19	+11
5	30 (12^o) shor + 30 (12^o) long	1 5	18 short 14 long	+12 +16

SIDIS			N. Det:	16		Frame Width;	1.25							
Location	**Z**	**Rmin**	**Rmax**	**Length**	**Angle**	**Act Min arc L**	**Act Max arc L**	**T Act ar**	**Act ar/Det**	**Sectors/Foil**	**Frame width**	**AvrLap ar/Frame**	**T ovr region**	**% ovr**
1	-175	36	87	51	22.5	14.13	34.1475	19697.22	1231.0763	12.3107625	1.25	63.75	4080	20.7136
2	-150	21	98	77	22.5	8.2425	38.465	28771.82	1798.2388	17.9823875	1.25	96.25	6160	21.4098
3	-119	25	112	87	22.5	9.8125	43.96	37425.66	2339.1038	23.3910375	1.25	108.75	6960	18.5969
4	-68	32	135	103	22.5	12.56	52.9875	54011.14	3375.6963	33.7569625	1.25	128.75	8240	15.2561
5	5	42	100	58	22.5	16.485	39.25	25861.04	1616.315	16.16315	1.25	72.5	4640	17.942
6	92	55	123	68	22.5	21.5875	48.2775	38006.56	2375.41	23.7541	1.25	85	5440	14.3133
4	-68	32	61	29	22.5	12.56	23.9425	8468.58	529.28625	5.2928625	1.25	36.25	2320	27.3954
4	-68	61	140	79	22.5	23.9425	54.95	49860.06	3116.2538	31.1625375	1.25	98.75	6320	12.6755

PVDIS			N. Det:	15		Frame Width;	1.25							
Layer	Z (cm)	Rmin	Rmax	Length	Angle	Act Min arc L	Act Max arc L	**T Act ar**	**Act ar/Det**	**Sectors/Foil**	**Frame width**	**AvrLap ar/Frame**	**T ovr region**	**% ovr**
1	157.5	50	118	68	24	20.93333333	49.40266667	35871.36	2391.424	23.91424	1.25	85	5100	14.2175
2	185.5	61	140	79	24	25.53866667	58.61333333	49860.06	3324.004	33.24004	1.25	98.75	5925	11.8833
3	190	61	140	79	24	25.53866667	58.61333333	49860.06	3324.004	33.24004	1.25	98.75	5925	11.8833
4	306	110	228	118	12	23.02666667	47.728	125235.76	8349.0507	83.4905067	1.25	147.5	8850	7.06667
5	315	110	228	118	12	23.02666667	47.728	125235.76	8349.0507	83.4905067	1.25	147.5	8850	7.06667

SBS GEM trackers: gaining GEM operation experience under conditions exceeding SoLID requirements

- 50 cm x 60 cm GEM modules for SBS rear tracker: 48 modules –All installed, 36 in beam
- 150 cm x 40 cm large GEM modules for SBS front tracker: 6 modules – all in in beam; two more under construction now



UV (shown)
40 x 150 sq.cm
Single module

XY (shown)
60 x 200 sq.cm
4 modules

Active areas larger than the largest SoLID GEM detectors needed

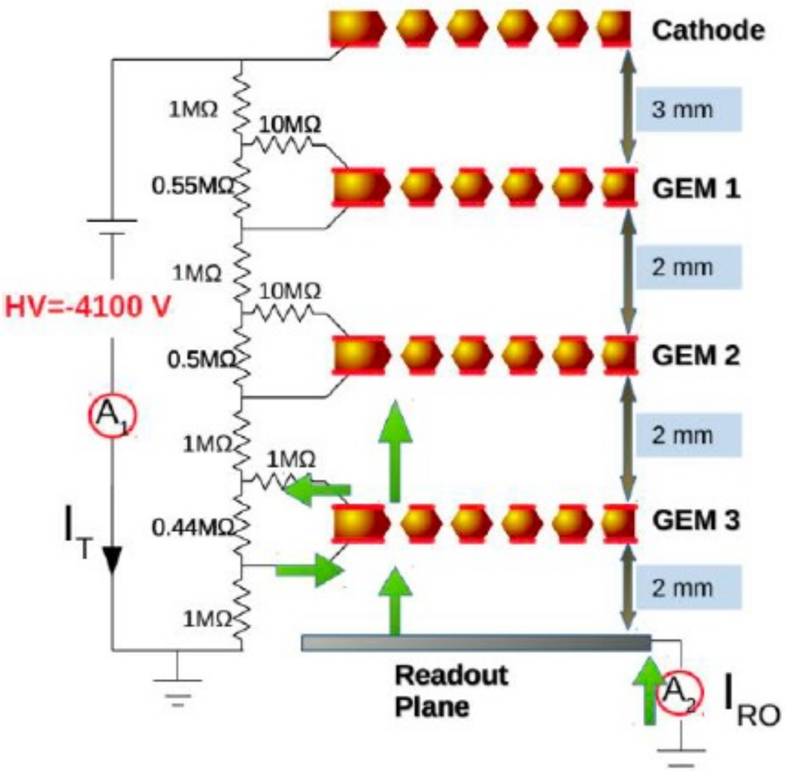
SBS GEM trackers: gaining GEM operation experience under conditions exceeding SoLID requirements

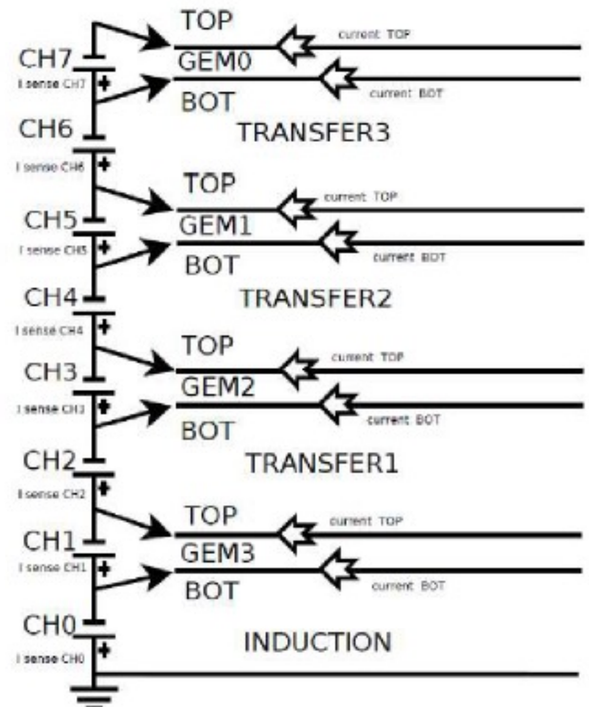
- SBS GEM trackers have been running well for about 18 months months in GMn, nTPE, Gen-II, and GEn-RP experiments.
- In Gen-II: up to 45 uA on 60 cm 3He target: luminosity ~ 5 times higher than proposed SoLID 3He SIDIS run.
- In GMn and GEn-RP: already ran the BB GEM tracker in unprecedented integrated rates (active area x local rate): stable running with 12 uA beam on 15 cm LD2 target: test runs up to 36 uA on LD2: luminosity ~ 3 x $10^{38;}$ within about factor of 3 of SoLID PVDIS.
- In SBS all this without baffles and direct line of sight to target: GEM hit rates and occupancies already achieved in SBS are higher than the worst case predicted for SoLID

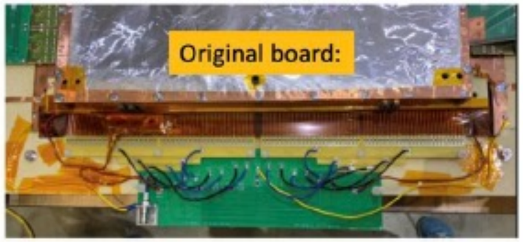
SBS GEM trackers: Important conclusions about long term running under very high exposure conditions

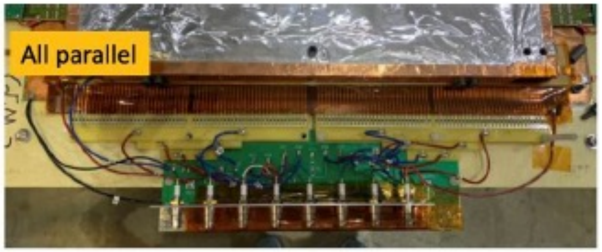
- UVa GEM tracker layers have been working very well:
  - stable operation: not too many HV trips
  - Robust under harsh conditions. So far only 4 out of the 42 detectors in beam had to swapped out due to suspected short in one sector (out of 30 in the detector).
  - No radiation damage observed
  - No detector aging effects observed
  - Noise levels sufficiently low
  - Good gain: signals well above noise
  - Very good resolution: ~ 70 um for tracks perpendicular to detector.
  - Real time firmware zero suppression has been working very well.
  - Data volumes manageable
- Most important lesson: The current drain to detector is too high for the resistive voltage dividers to handle; caused efficiency drop.
- The Good solution with new power supply scheme: tested and demonstrated to work

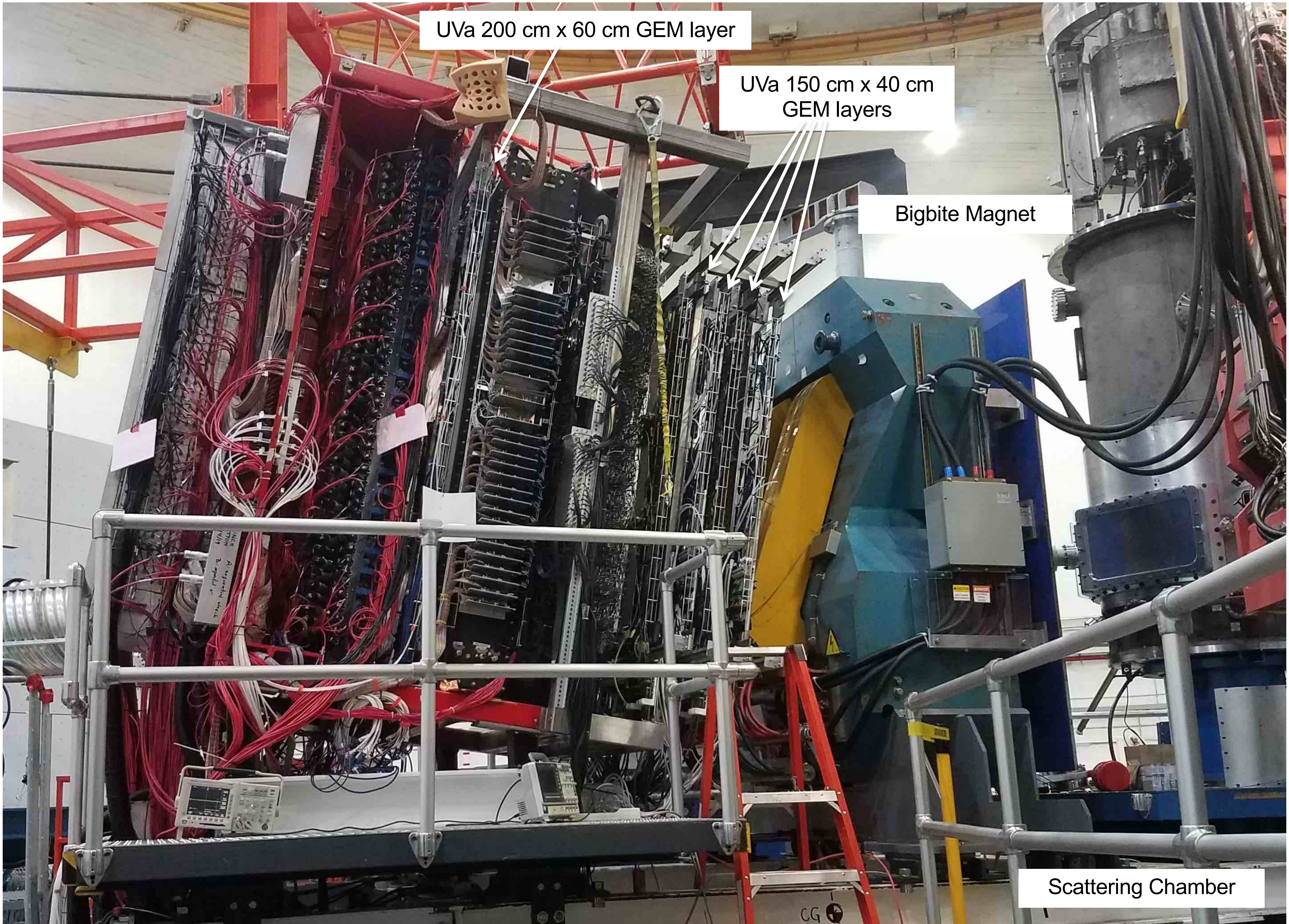
SBS GEM: HV supply issue



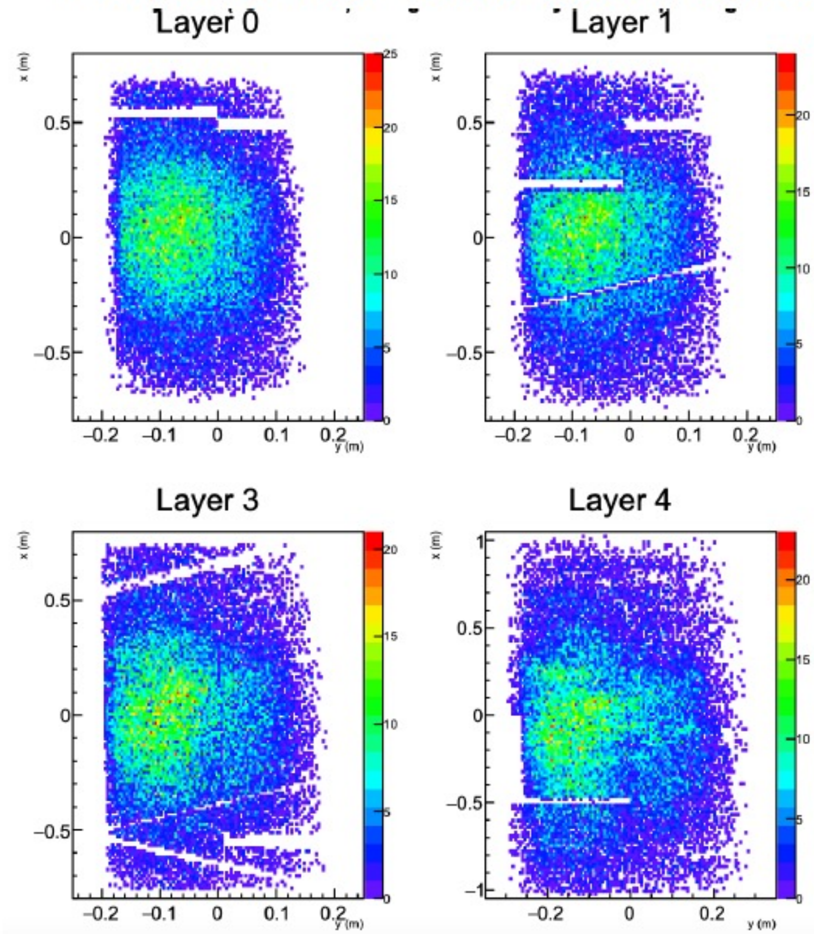




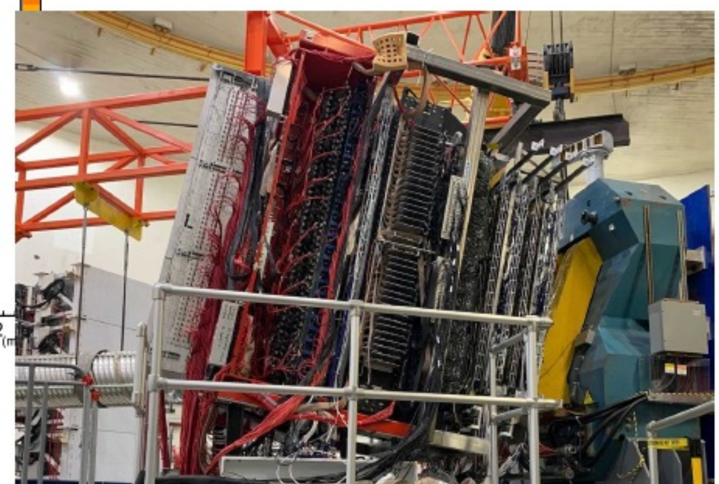


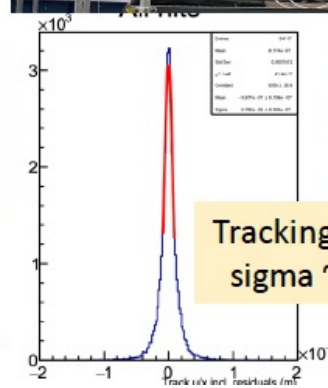

UVa 200 cm x 60 cm GEM layer
UVa 150 cm x 40 cm GEM layers
Bigbite Magnet
Scattering Chamber

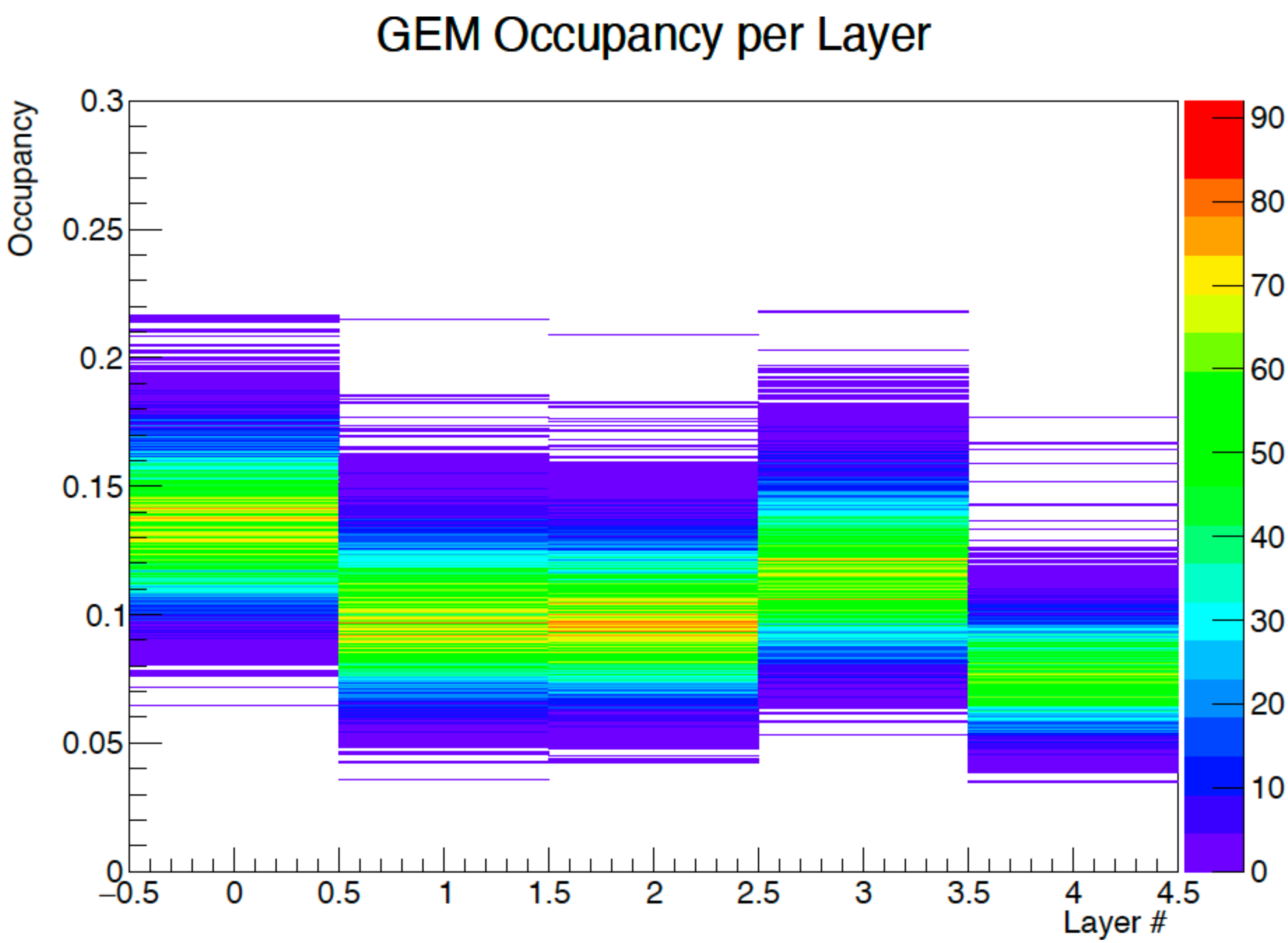
4 UV and 1 XY have been running successfully in BigBite since 2021



Hit maps with tracking constraints shown per layer





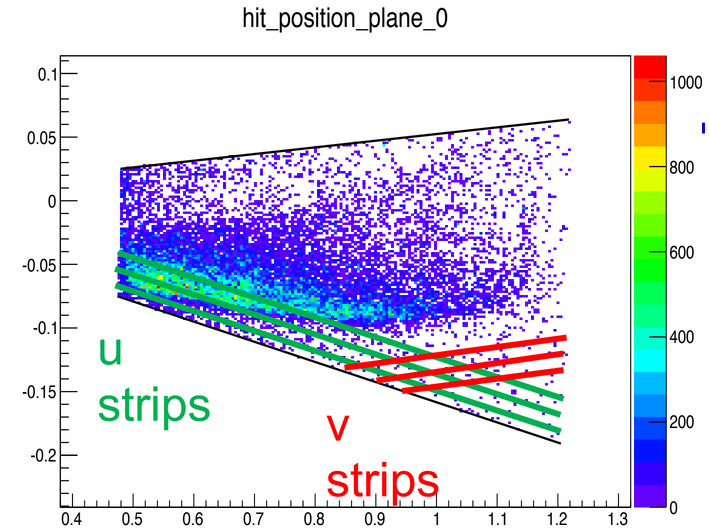


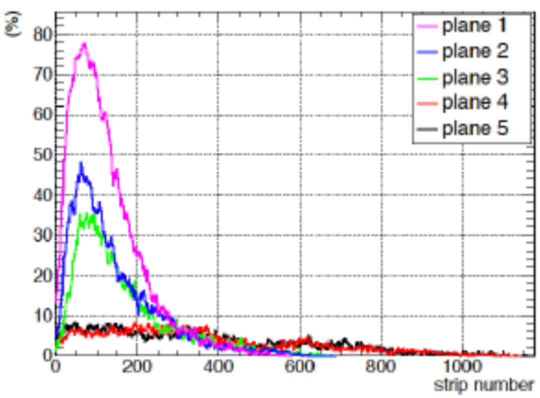
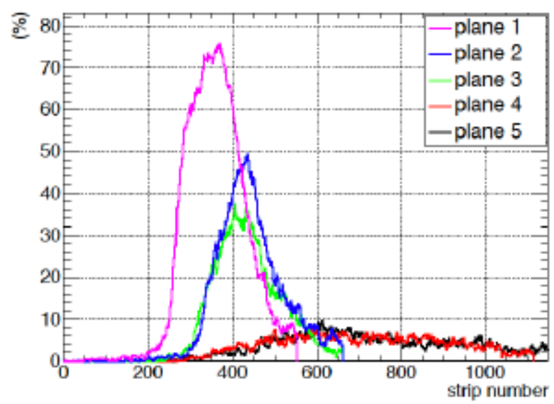
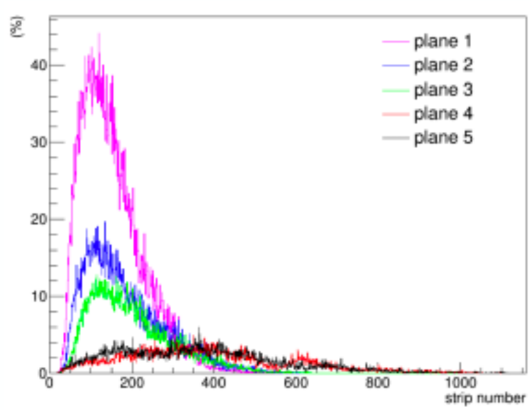
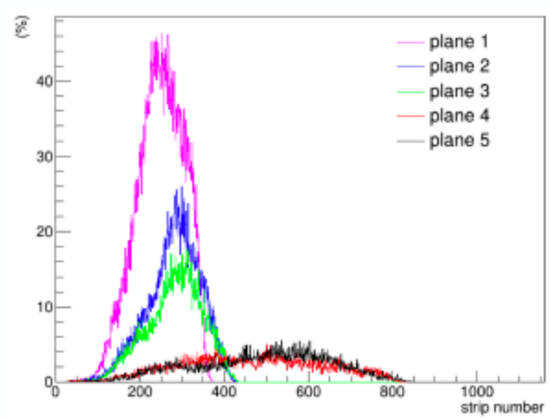
Gen-II run 2551 - 45 uA on polarized 3He target

PVDIS GEM occupancies		
Plane	Total strip number (u+v) per sector	Raw Occupancy (%)
1	1156	4.48
2	1374	2.55
3	1374	2.21
4	2287	0.82
5	2350	0.75

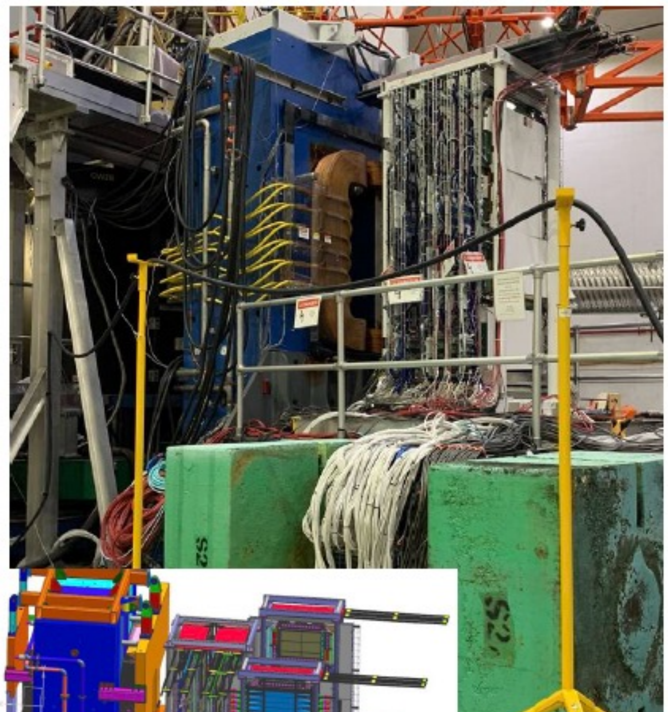
SBS achieved occupancies higher than what is projected for PVDIS and SIDIS

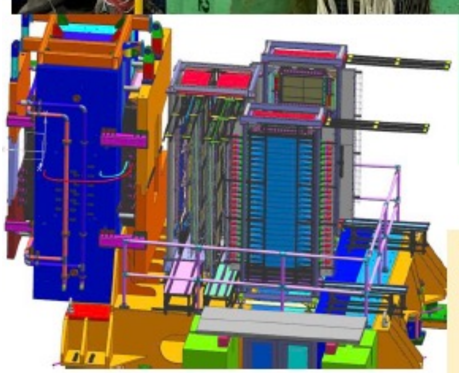
However, we need to be careful – SoLID occupancy is not uniform, hot-spots at small radius



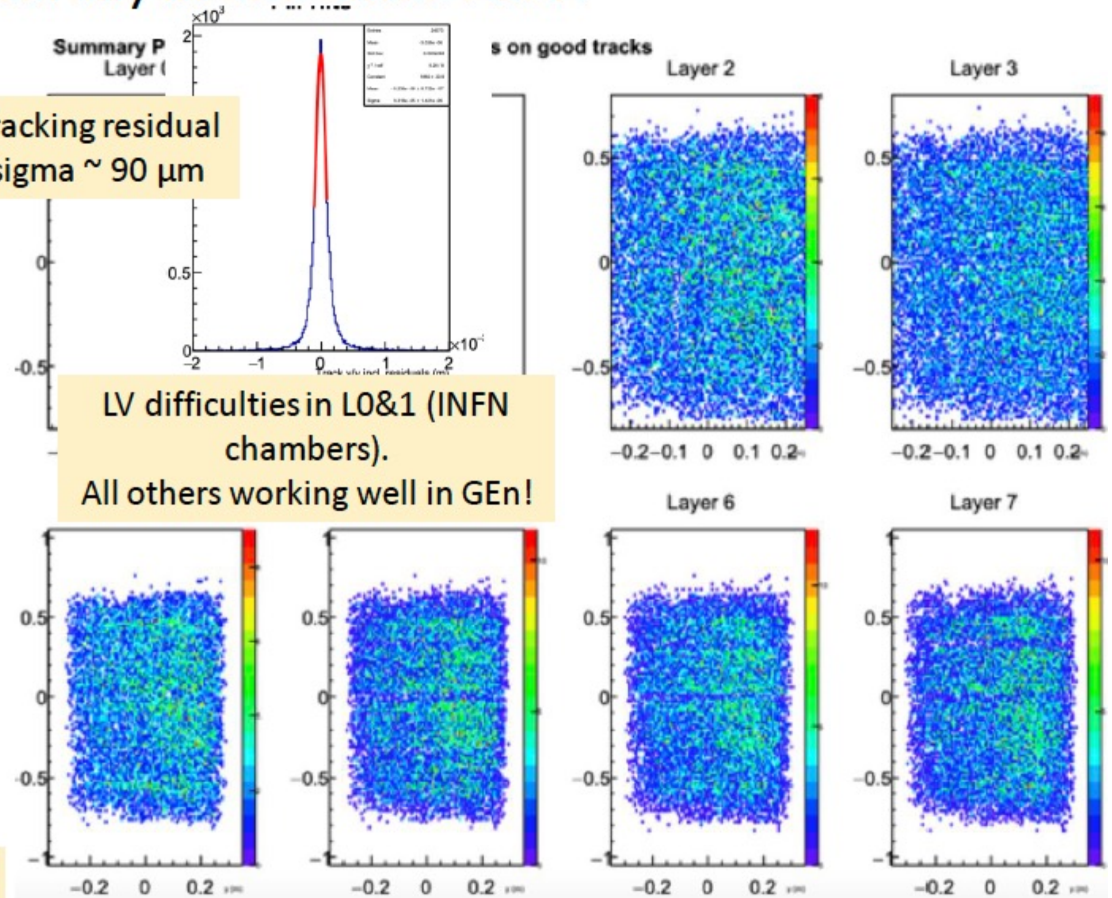
	U plane	V pl
APV25		
VMM3		

6 XY have been running successfully in SBS since 2022





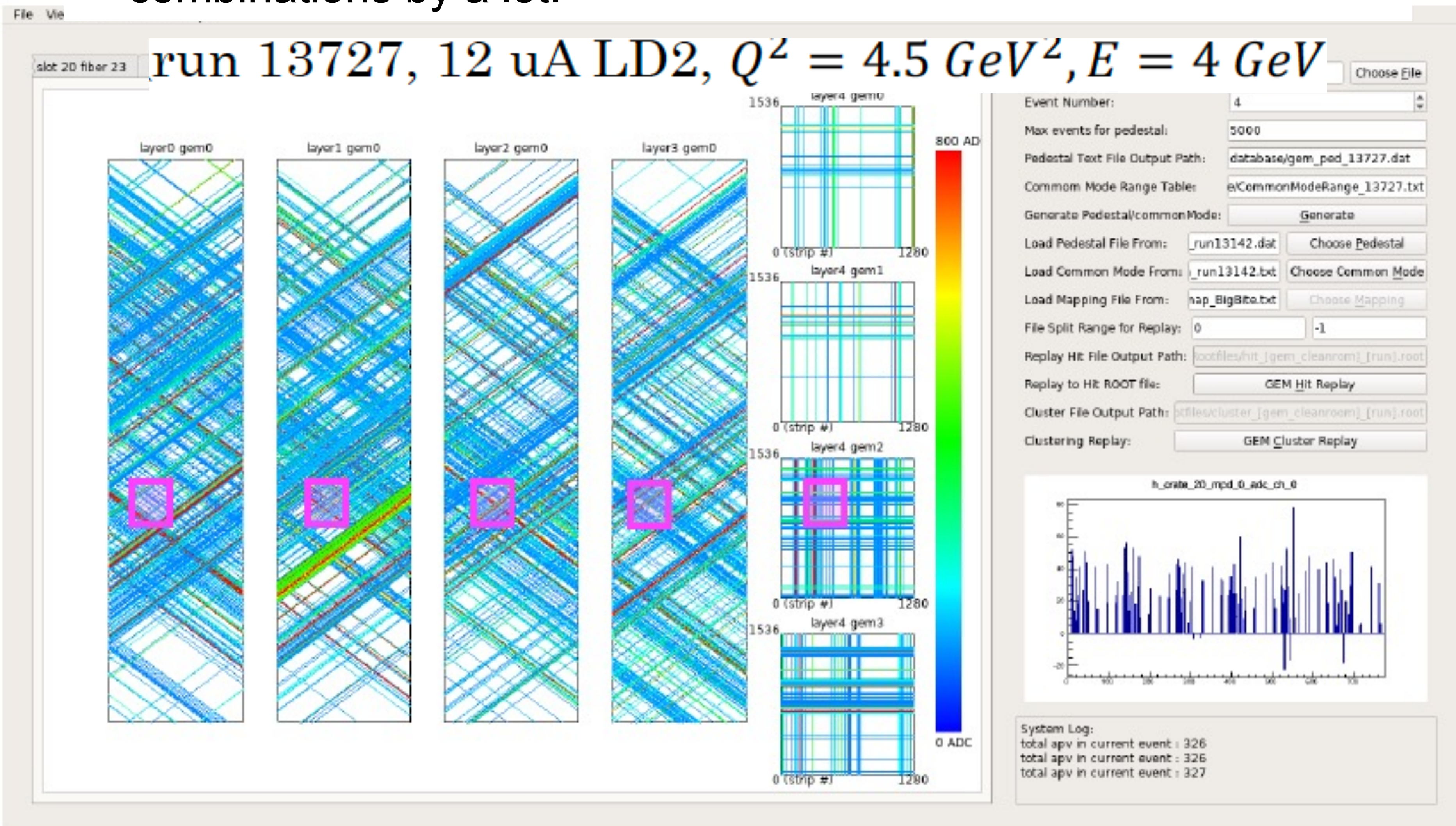
GEn-RP will run with all layers next spring (prior to GEp)



Tracking residual sigma ~ 90 µm

LV difficulties in L0&1 (INFN chambers).
All others working well in GEn!

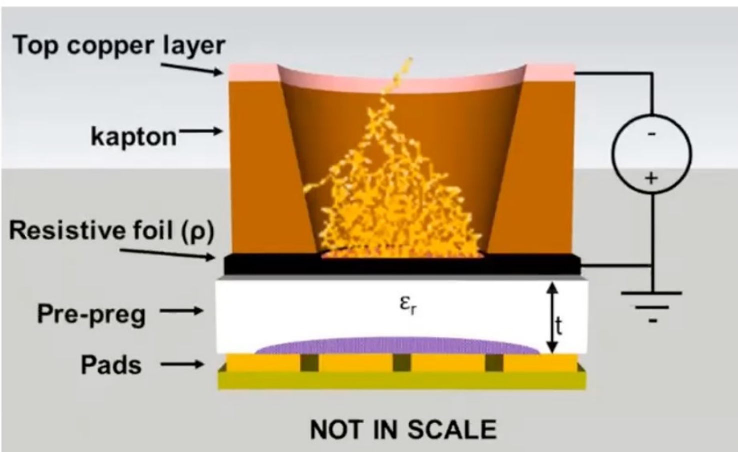
- The biggest challenge: tracking with so many possible combinations at high occupancies.
- New idea we are trying to implement: 2 or 3 pixel chambers with ~ 1x1 cm^2 pixels in addition to strip layers: reduces the combinations by a lot.



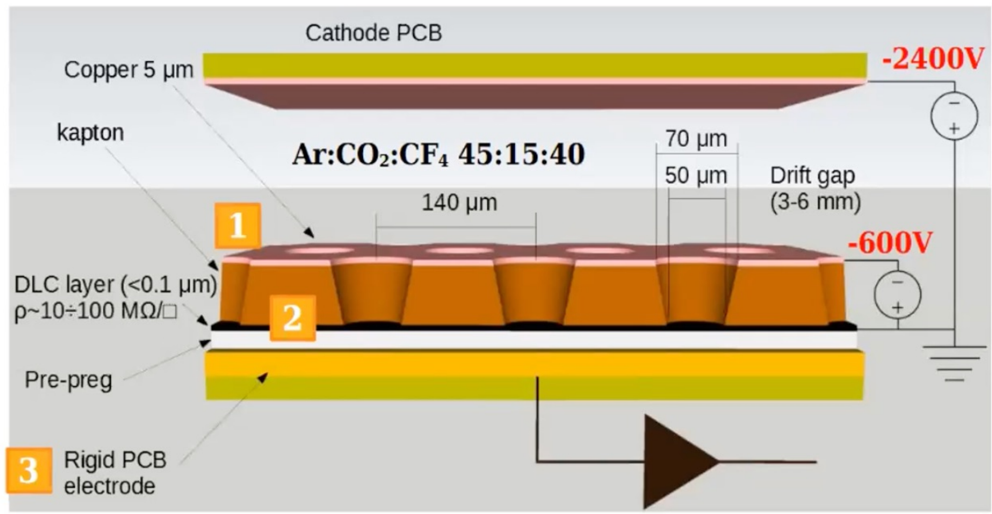
A new possibility for SoLID tracking: u-Rwell. Large area detectors with rate capabilities up to 10 MHz/cm^2 have been developed for LHCb.

The µ-RWELL – Principle of Operation

The µ-RWELL is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements: the µ-RWELL_PCB and the cathode. **The core is the µ-RWELL_PCB**, realized by coupling three different elements:



Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.



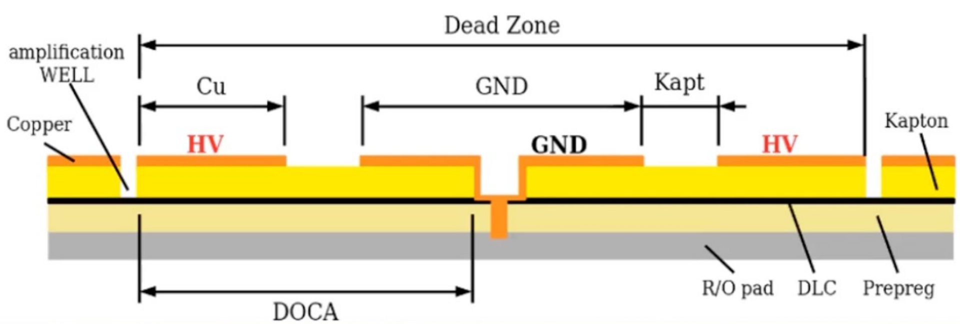
1. a **WELL** patterned kapton foil acting as **amplification stage** (GEM-like)
2. a **resistive DLC layer (Diamond-Like-Carbon)** for discharge suppression with surface resistivity ~ 50÷100 MΩ/□
3. a standard readout PCB

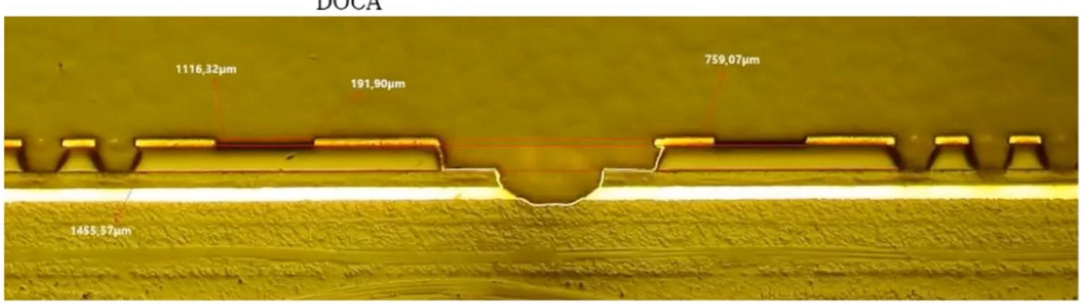
G. Bencivenni et al., 2015 *JINST* **10** P02008

New development by Giovanni Bencivenni's group at Frascatti in collaboration with Rui De Oliveira at CERN

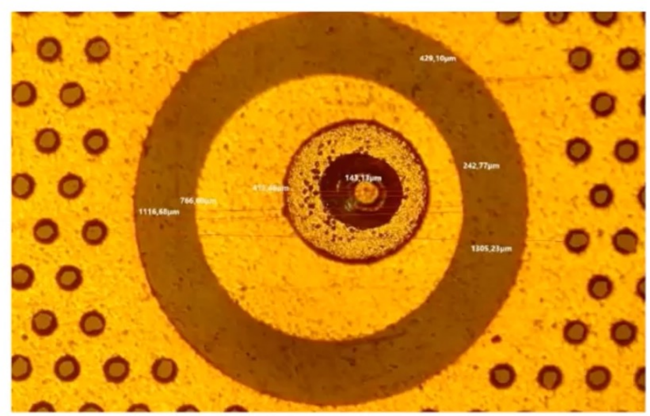
The PEP-dot μ-RWELL

DLC-GND pitch [mm]	Dead Zone [mm]	GND width [mm]	Insulation gap [mm]	DOCA [mm]
9	1.1 (2%)	0.6	0.25	0.7

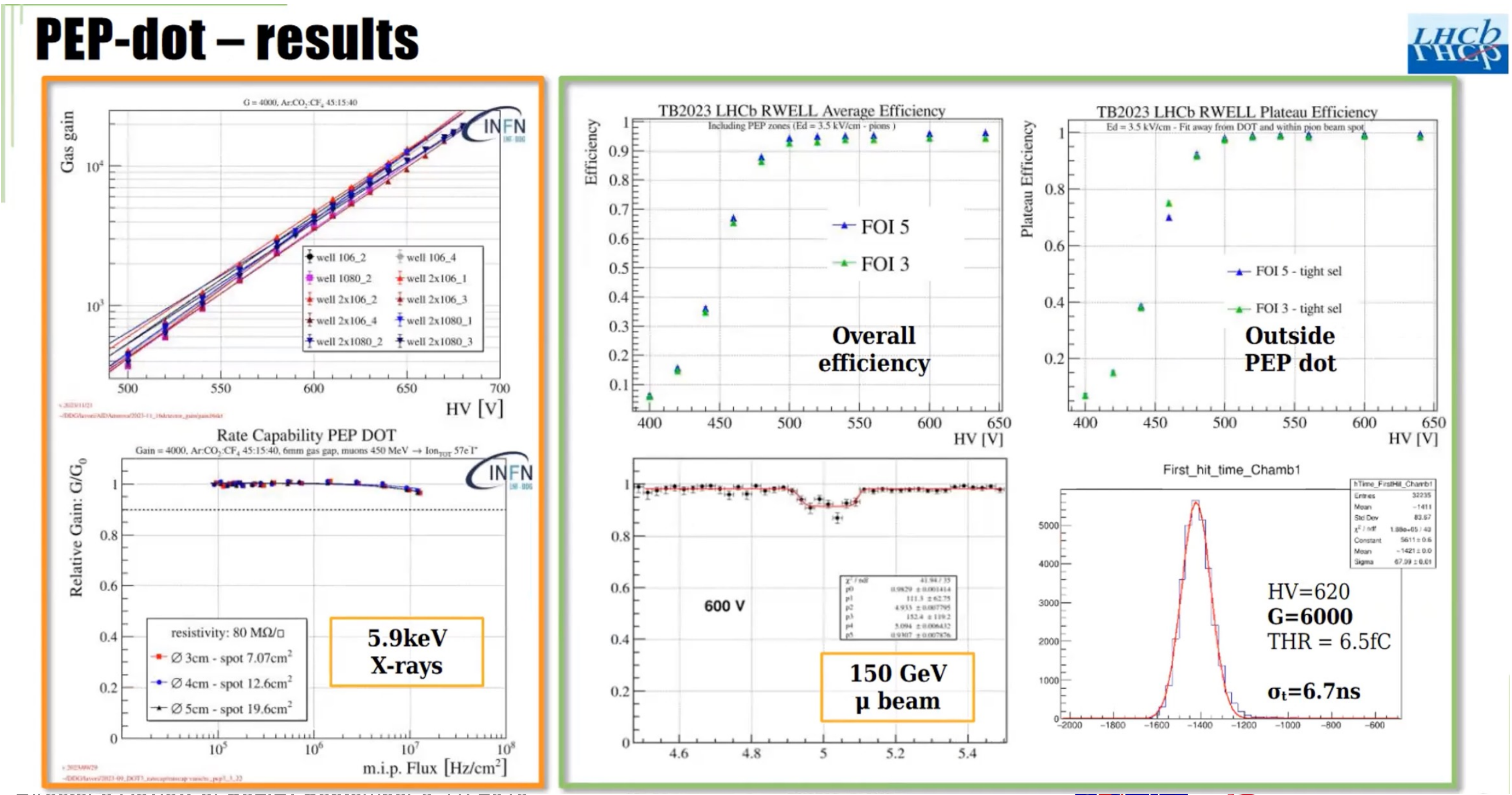




- The most recent high rate layout
  - **P**atterning-**E**tching-**P**lating
- The DLC ground connection is established by creating **metalized vias from the top Cu layer through the DLC**, down to the pad-readout of the PCB
- The dead zone is ~2%



- Excellent efficiency and stable operation up to 10 MHz/cm^2 for 1D readout pixel or strip chambers
- 2D strip readout is a challenge due to relatively low gain.
- A good solution is two 1D strip chambers next to each other.



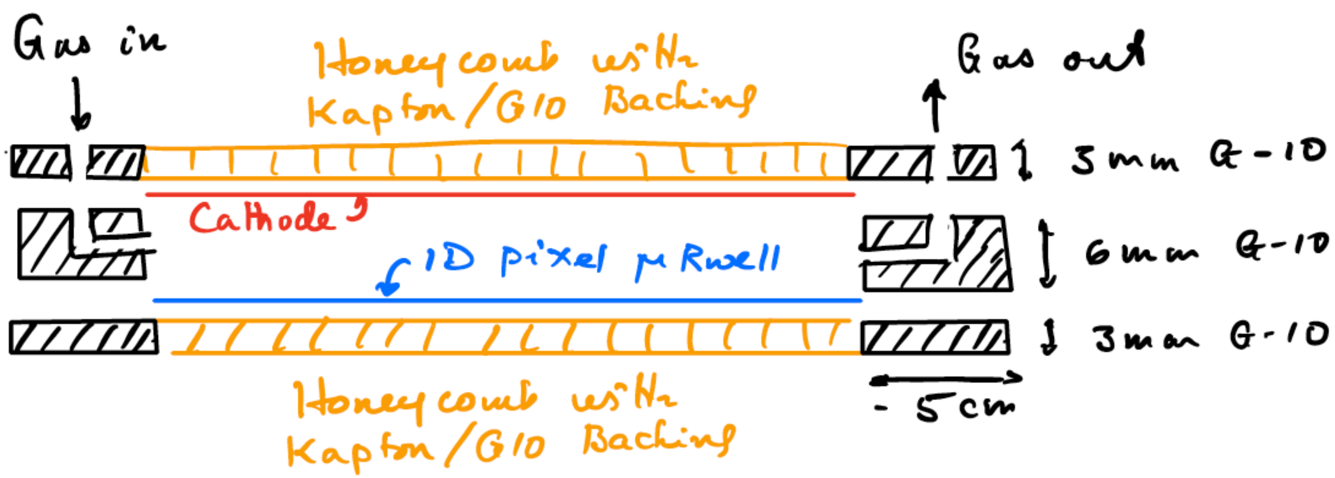
• Gianni Bencevinni's group at Frascati has shown that the improved uRwell could operate at hit rates up to 10 MHz/cm^2; my colleague Huong Nguyen has visited his lab and formed collaborative connections with his group; Dr. Bencevinni has graciously agreed to collaborate with us on this new development aimed at SoLID.

•Having three pixel chambers separated by some distance and requiring .AND. between hits on all 3 can clean up most of the random hits and select mostly the high energy tracks.

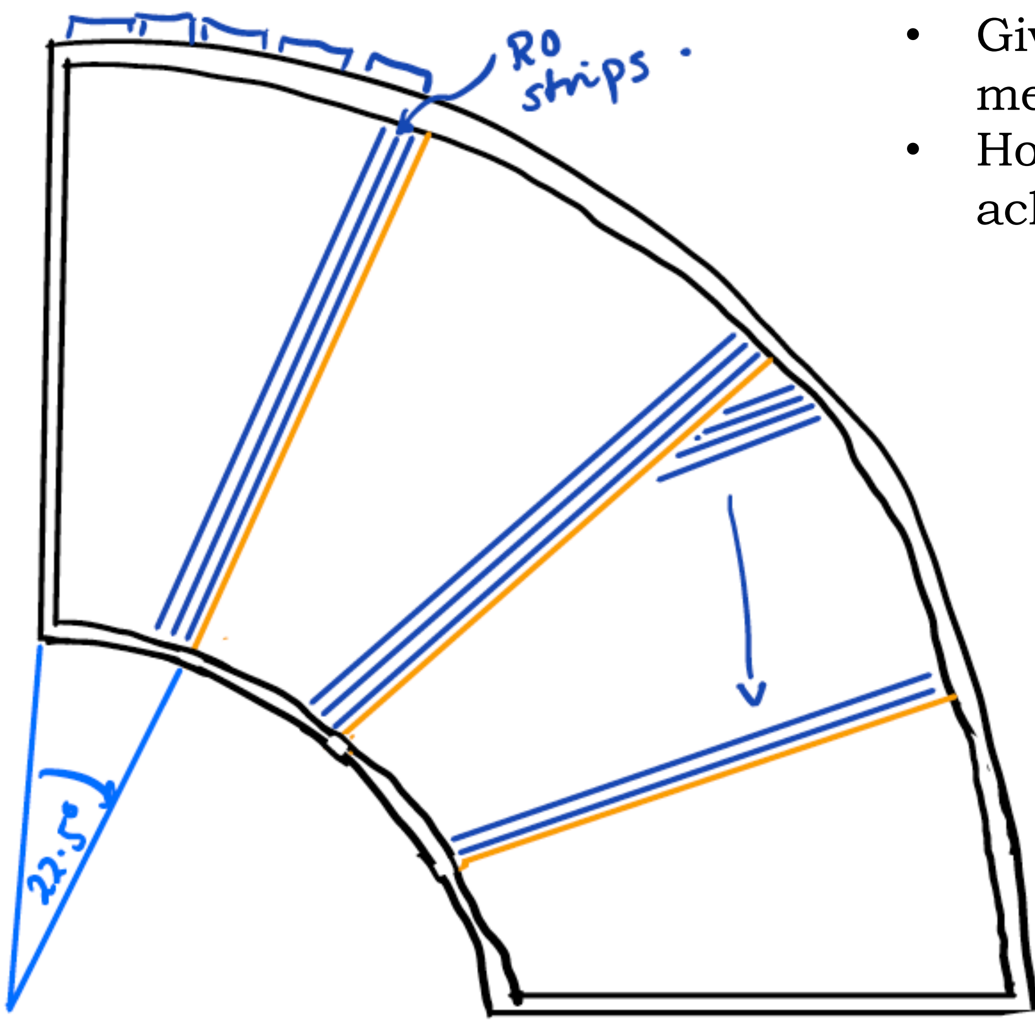
•Given the catchment area for these pixels, the occupancy level would be about 1/6th of that of any proposed UV chamber; so in the worst case the occupancy would be around 10%; and the .AND. condition would lower this down to about 10^{-3}

•All this would ensure that we have a pretty narrow (about a factor of 100 smaller in area than right now), very clean search area for hits on the strip chambers.

•Plus the detector construction becomes much simpler compared to GEMs

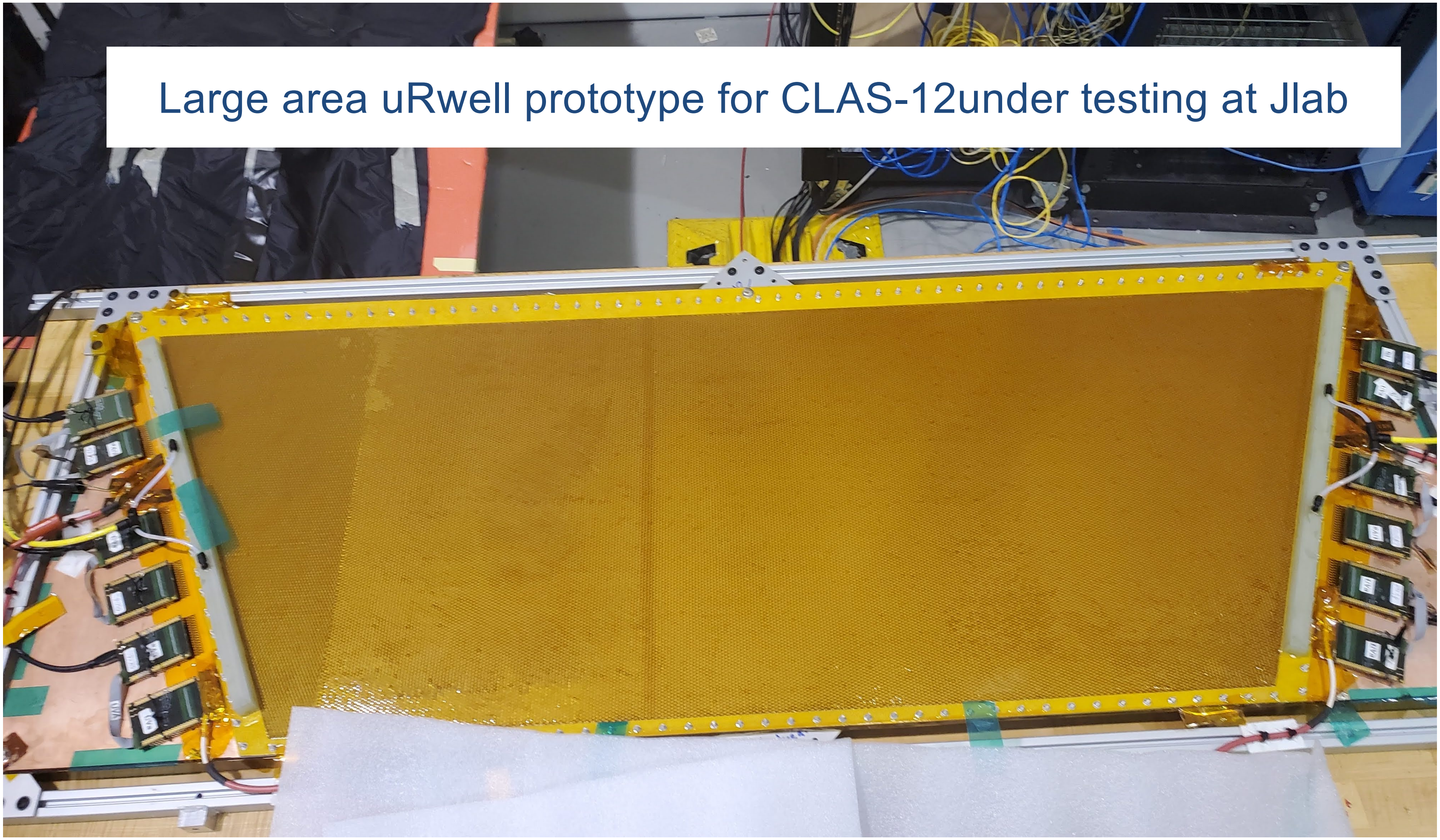


- One idea is to build each wheel with four 90-degree chambers
- Each chamber by gluing some number of 1D u-Rwell layers side by side
- Largest chambers will be ~ 1 m^2 , with outer arc lengths ~ 2 m



- Given the large area, need to study mechanical stability of the gap.
- How thin can we make the gap to achieve good resolution

Large area uRwell prototype for CLAS-12under testing at Jlab



The detector works well and highly stable; the reason efficiency is ~ 70% due to charge being divided between the U and V strips. We propose to use the proven high efficiency single layer readout

Pre R&D needs if early funding is available

- GEMs: Design and prototype two or three of required sizes, test and characterize with new electronics.
- Optimize engineering design: GEM foil stress, holding frame thickness, gas flow optimization etc.
- μ-Rwell: Design, optimize and build mechanical prototypes to evaluate the large surface area designs.
- Build and characterize a μ-Rwell side-by-side mosaic detector with 2 or 3 trapezoidal slices.
- Participate in the μ-Rwell development and fabrication work at Frascati and CERN.

Summary

- SBS run demonstrates that ambitious goals of SoLID tracking could be achievable with GEMs.
- However, adding a couple of pixel layers could enhance tracking significantly: needs evaluation with simulations
- High rate μ-Rwell is an exciting new possibility.
- Has the potential to lower the cost and reduce fabrication complexity.
- Pre-R&D is needed to evaluate