SoLID GEM Detectors in US

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SoLID Collaboration Meeting @ JLab, 08/26/2016

Outline

- ✓ Design Optimization
- ✓ U-V strips readout design
- ✓ Large GEMs for PRad in Hall B

UNIVERSITY of VIRGINIA

Requirements for SoLID GEM Trackers

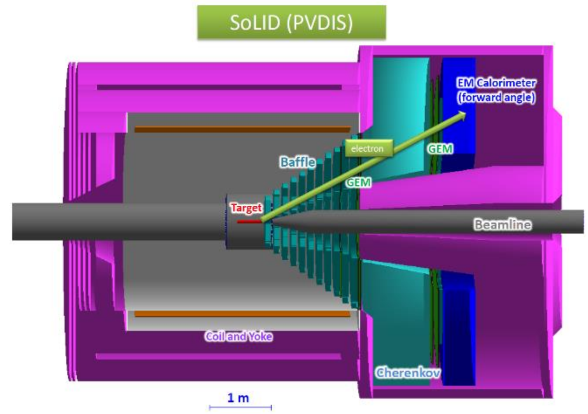
Tracking requirements for PVDIS

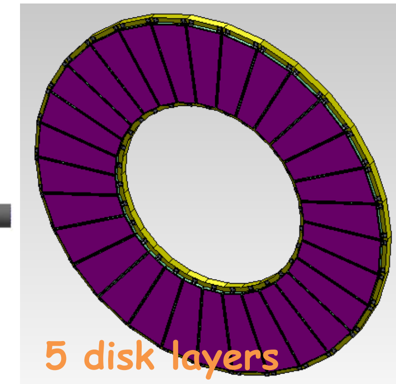
- Luminosity ~ $10^{39}/cm^2/s$
- Rate: from 100 kHz/cm^2 to 600 kHz/cm^2 (with baffles) from GEANT4 estimation
- Spatial Resolution: ~ 100 µm (σ) in azimuthal direction
- Total area: ~37 m2 total area
- Need radiation and magnetic field tolerant

Large area GEM challenges

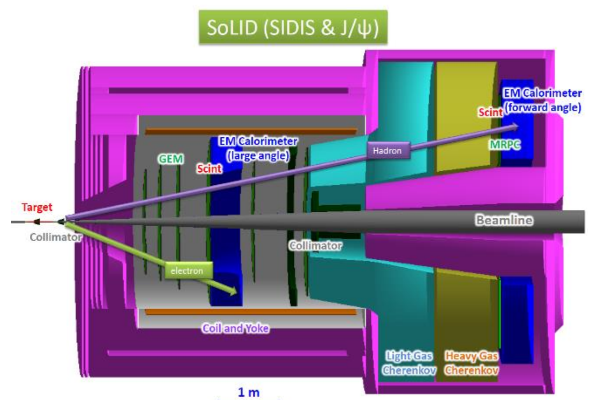
- Larger SoLID GEM modules as large as 113 cm × 55 cm
  - ✓ Single Mask technique allows large GEMs (200 × 55 cm^2)
  - ✓ Similar size as GEMs for PRad Exp. (in Hall B 06/2016)
- The remaining challenge is large production capacity:
  - ✓ Large volume GEM production for LHC upgrade (CMS, ALICE, TOTEM)
  - ✓ Will require almost 100 % of CERN production capacity
  - ✓ Currently work going on for large GEM production capabilities in China and in the US.

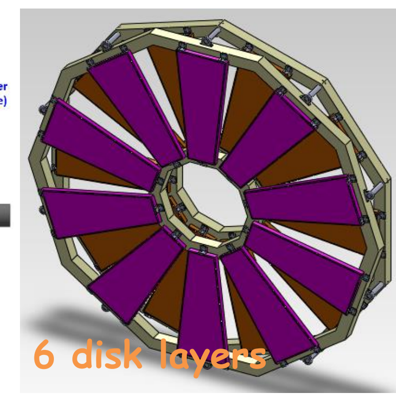
PVDIS





SIDIS

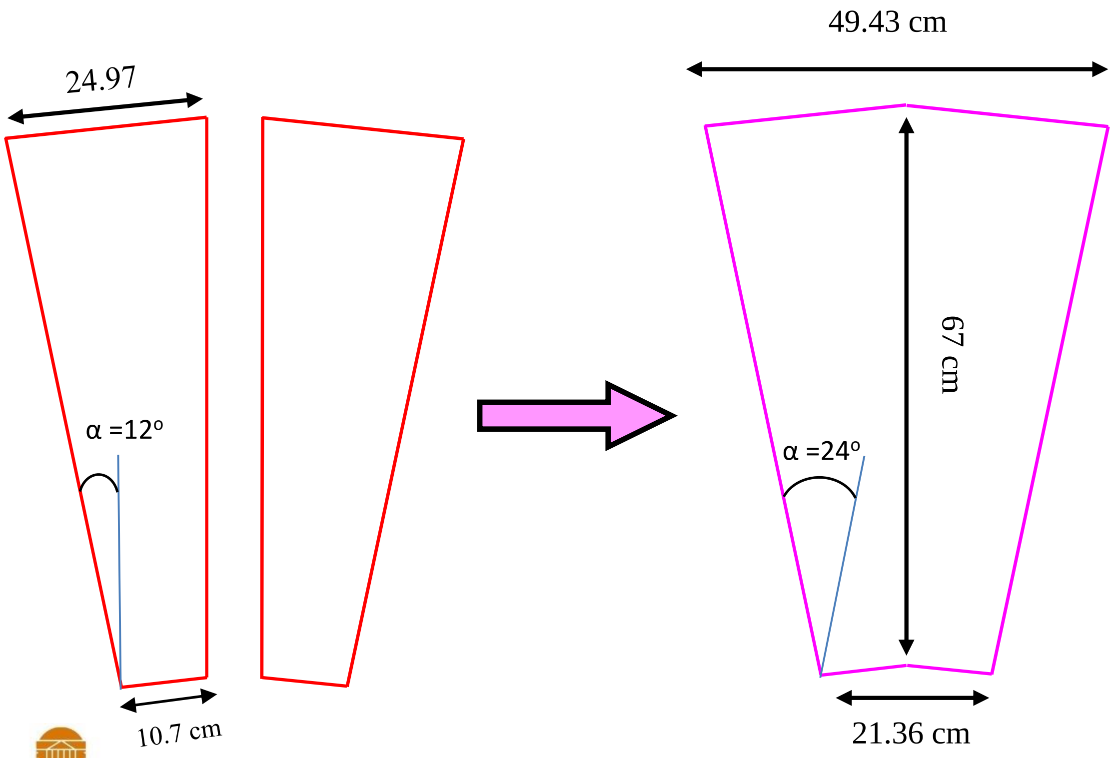


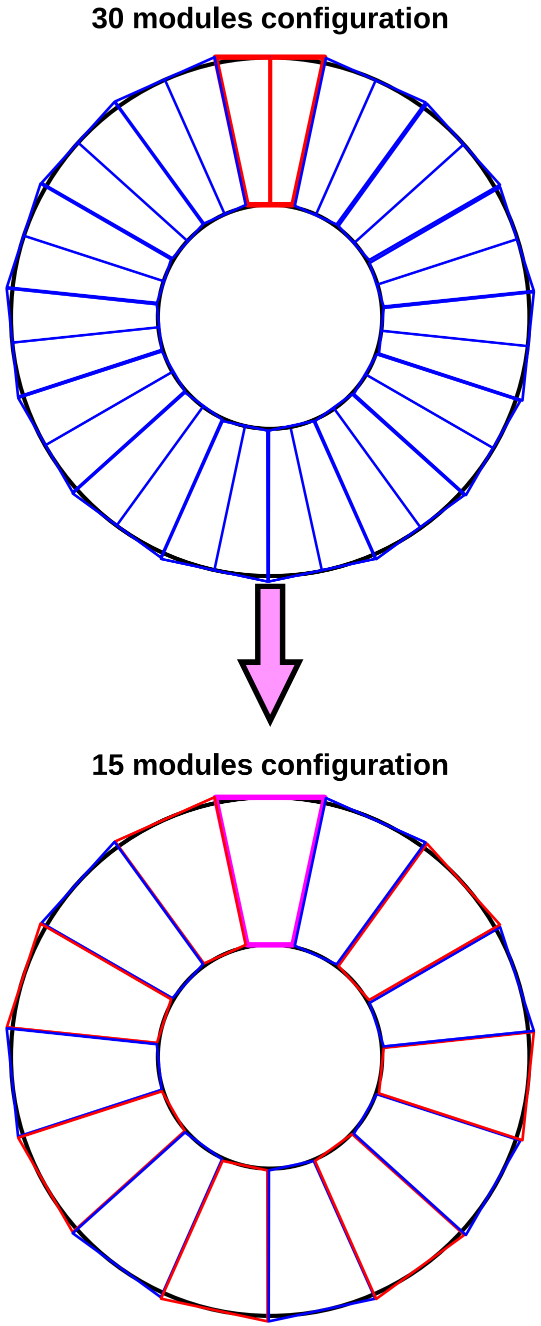


Large number of readout channels; but cost of electronics going down – cost per channel for the RD51 SRS APV-25 based readout is ~ $3.00 + U/V stereo angle 2D readout reduce the channel count while maintaining a very good spatial resolution

Design optimization for PVDIS disk layers

- From 30 GEM modules per layer to 15 modules Ok for the first 3 smallest layers
- Maintains the symmetry for the individual module trigger scheme of PVDIS
- This example below is based on the dimensions of PVDIS layer 1

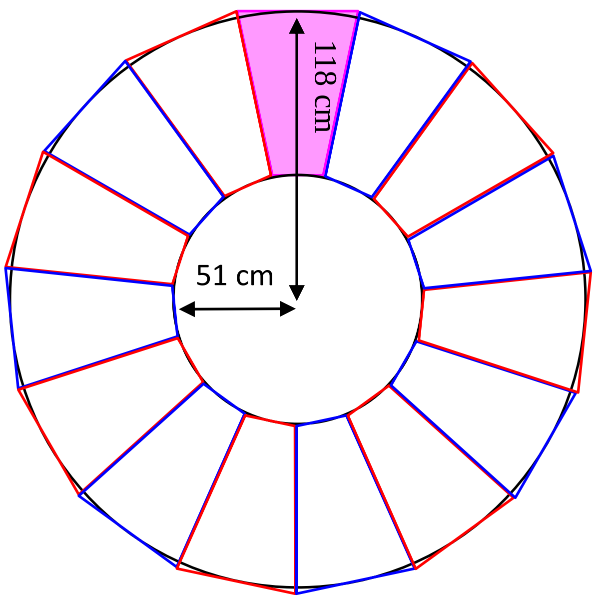




Design optimization for PVDIS disk layers

Dimensions for all 5 layers for PVDIS

PVDIS Layer	Z (cm)	R_in (cm)	R_out (cm)	L (cm)	# module / layer	W_in (cm)	W_out (cm)
1	157.5	51	118	67	15	21.363	49.43
2	185.5	62	136	74	15	25.97	56.97
3	190	65	140	75	15	27.23	58.65
4	306	111	221	110	30	23.25	46.29
5	315	115	228	113	30	24.1	47.75



PVDIS layer 1

First 3 layers for PVDIS made of 15 modules

- Width of raw Kapton material (61 cm) is limiting factor
  - ⇨ module max size up to 59 cm possible (including frames)
  - ⇨ Max active area 57 cm possible
- 105 modules in total needed is for PVDIS

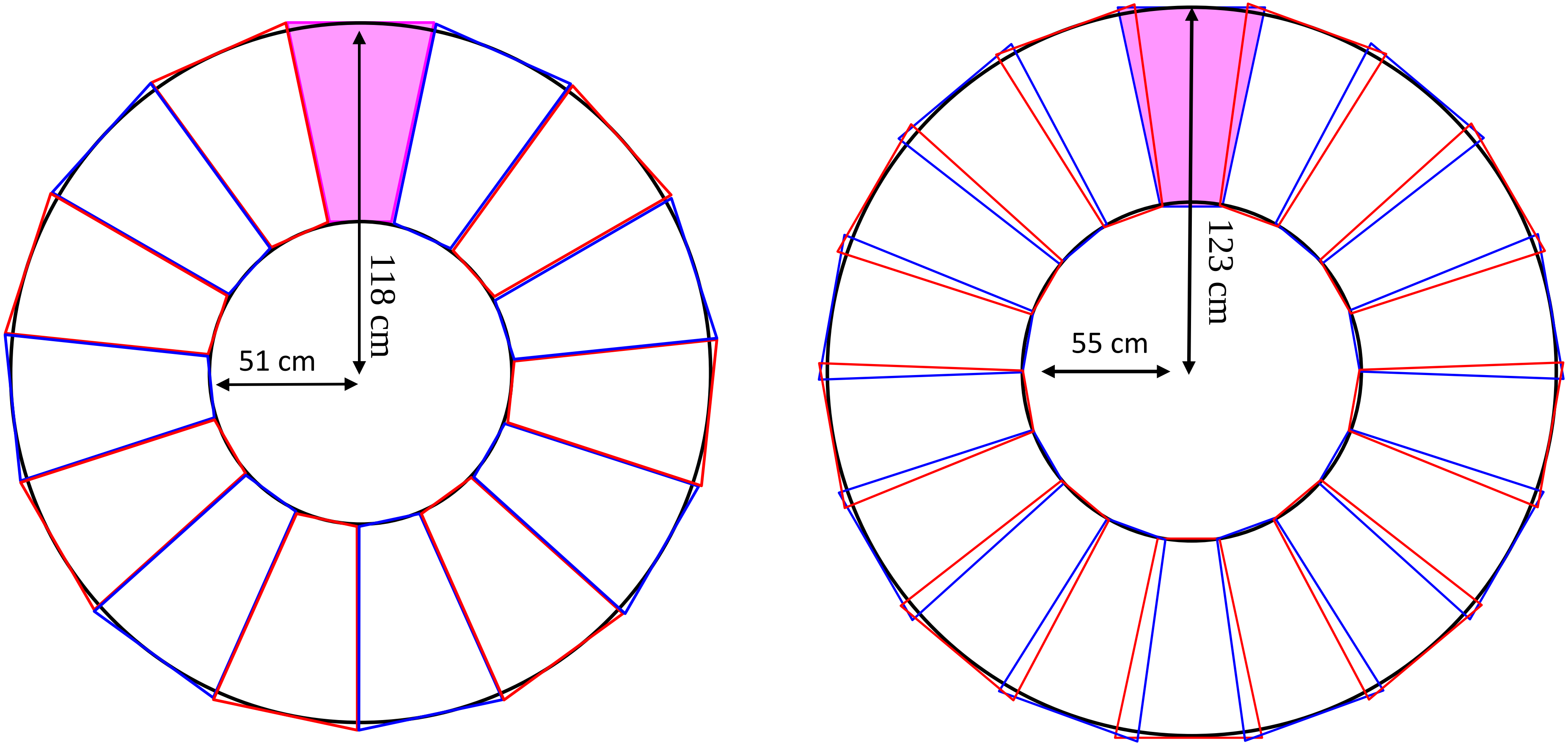
Re-use of PVDIS GEM modules in SIDIS Configuration

- Assuming less constraints on the max size of the SIDIS layers
  - We can use PVDIS modules to instrument 5 layers in SIDIS configuration (PVDIS dimensions in parenthesis)
  - Red color means adjustment need to be done on SIDIS layers
- 105 modules in total needed is for PVDIS

Layer	Z (cm)	R_in (cm)	R_out (cm)	L (cm)	# module / layer
1	-175	36	87	51	10 SIDIS modules
2	-150	21	98	77 (75)	12 of PVDIS layer 3
3	-119	25	112	87 (110)	18 of PVDIS layer 5
4	-68	32	135	102 (113)	20 of PVDIS layer 5
5	5	42	100	58 (74)	15 of PVDIS layer 2
6	92	55	123	68 (67)	18 of PVDIS layer 1

Re-use of PVDIS GEM modules in SIDIS Configuration

From PVDIS layer 1 (15 modules) ⇨ **to SIDIS layer 6 (18 modules)**

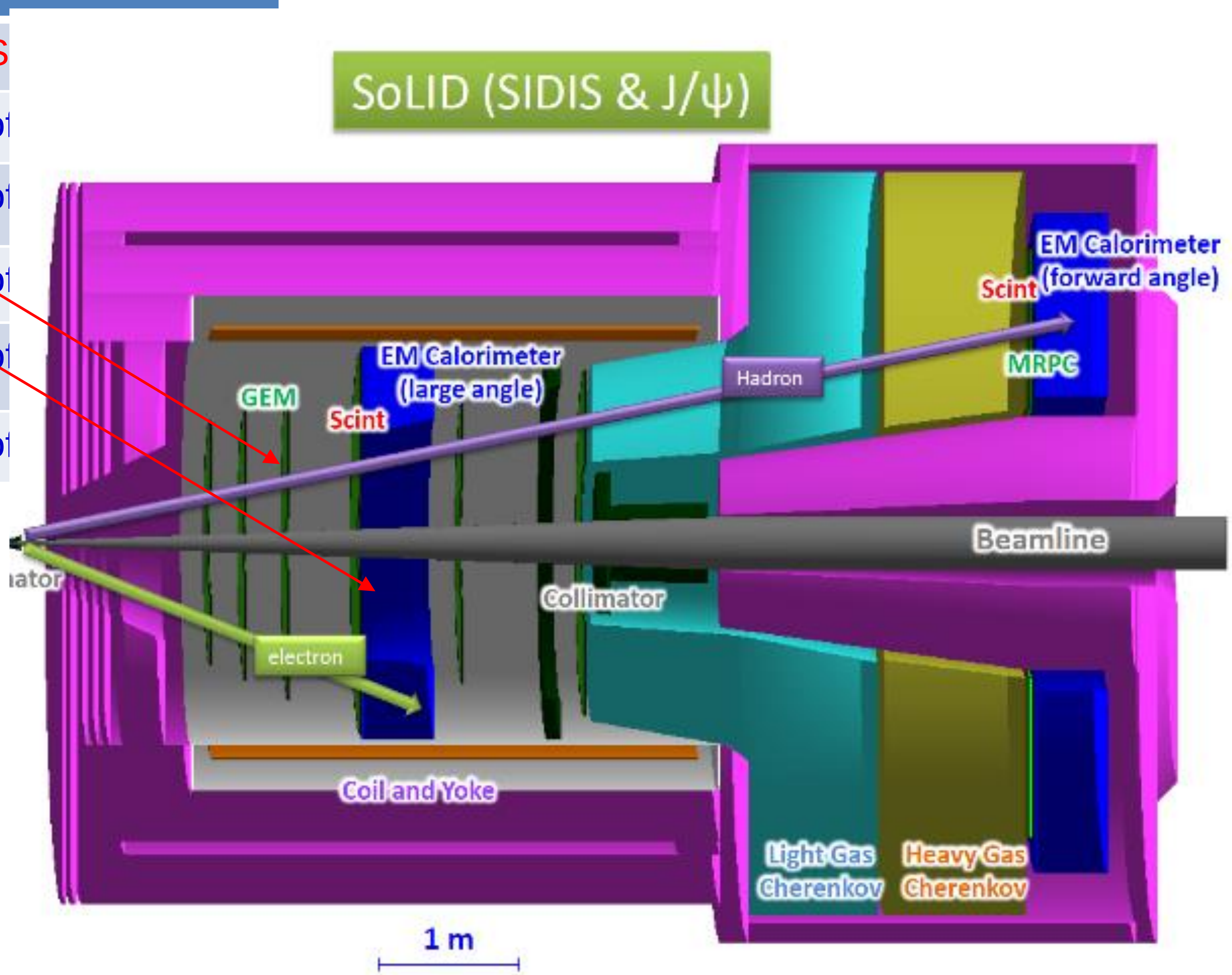


- Works well for these 2 layers with limited sacrifice to the original design ⇨ minimum overlap with 18 modules (Scale is conserved), More modules will give more overlap
- With 10 new additional modules for SIDIS layer 1 and 18 PVDIS modules needed for SIDIS layer 6, **a total of 120 GEM modules will be enough for both SIDIS and PVDIS**

Design optimization for PVDIS disk layers

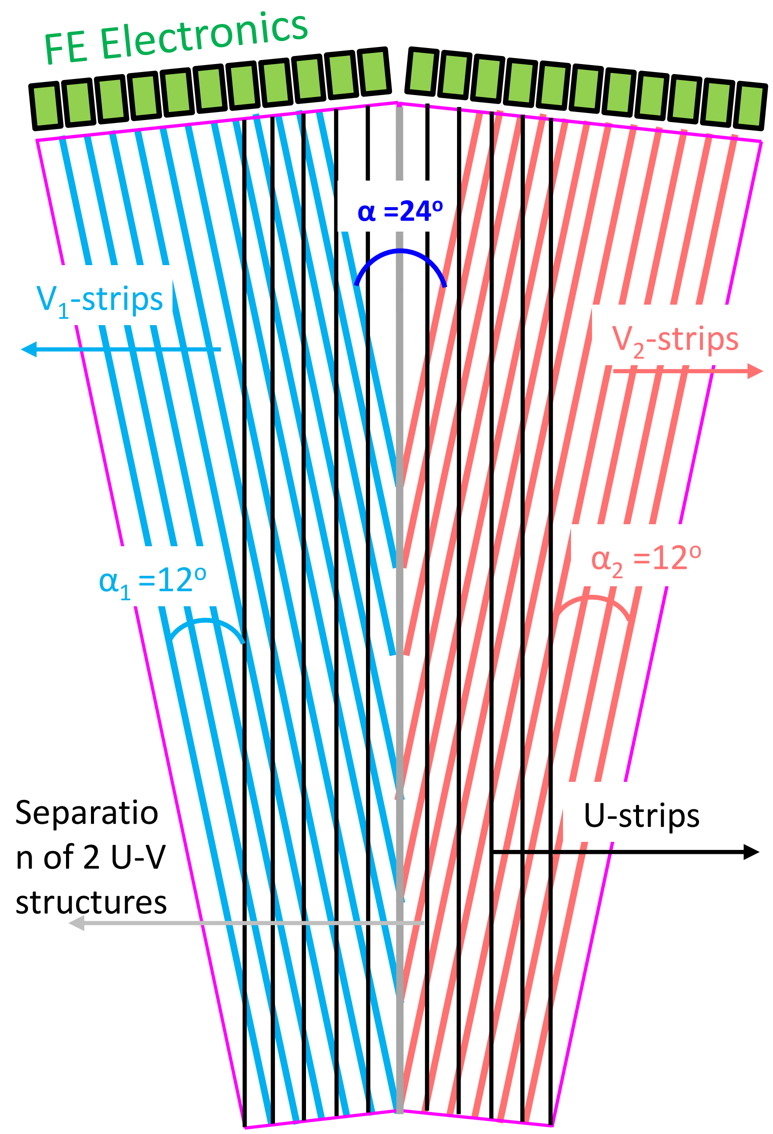
SIDIS layers needed serious adjustments

Layer	Z (cm)	L (cm)	# modules
1	-175	51	10 S
2	-150	77? (75)	12 of
3	-119	87 (110)	18 of
4	-68	102 (113)	20 of
5	5	58 (74)	15 of
6	92	68 (67)	18 of



Double structure U-V strips readout design

- The double structure to keep trigger scheme of the original design
  - U-strips vertical strips, 2 sets of V-strips V_1 and V_2 at opposite angle at ∓ 12 degree w.r.t to U-strips
- Two sets of V-strips separated in the center by 200 µm wide dead strip
- Will be manufactured on a flexible Kapton foil with 2D strips a la COMPASS with 400 µm pitch
- All readout electronics connection on outer radius side of the boards
- Other strips geometry are also being under investigations to address tracking concerns in high rate environment
  - 2D Azimuthal / radial strips in lower part (near to inner radius)
  - Segmented U-V strips or a combination of both



Flexible U-V strips readout board (EIC FT design)

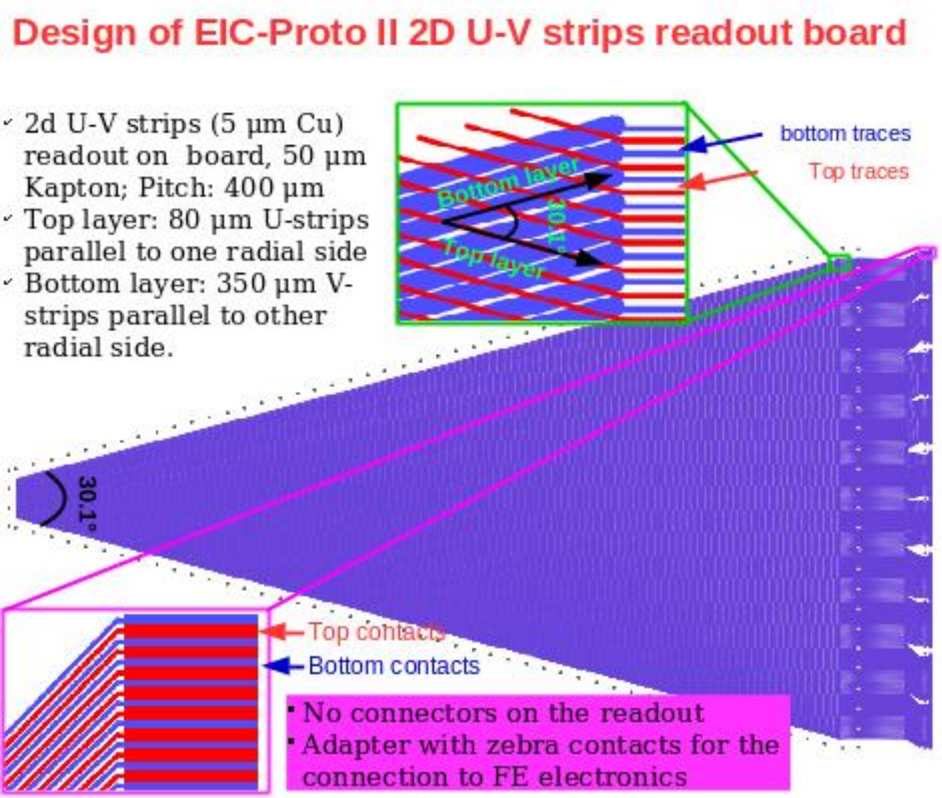
SoLID GEM U-V strips readout board based on the design developed for EIC forward tracking R&D

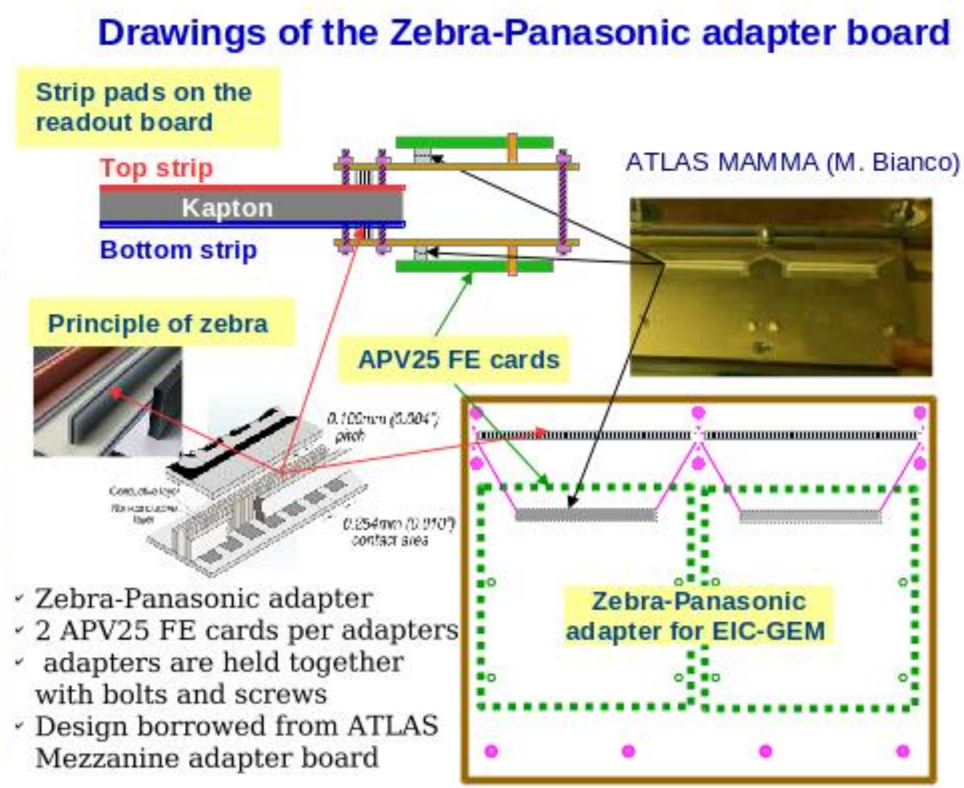
✓ All electrical contacts between the strips and the FE electronics on the outer radius side of the detector

⇨ **zebra connectors** ⇨ no mounted connectors or metallized holes

Zebra-Panasonic adapter board ⇨ to connect to existing APV-SRS Electronics

✓ Final version for an EIC FT trackers ⇨ the zebra strips directly on the FE cards





Electronics for SoLID GEMs

Integration of the SRS Electronics for PRad GEMs *(H. Muller, RD51 @ CERN)*

- Firmware upgrade done at JLab to allow 10 Gb Ethernet fast link data transmission at 5 kHz
- Fully incorporated into JLab CODA system (Online software data reduction developed)
- System with 10 K channels were used during PRad run at a trigger rate of 4.4kHz with 87% live time
- SRS support VMM chips developed by BNL for ATLAS Muon Chambers upgrade

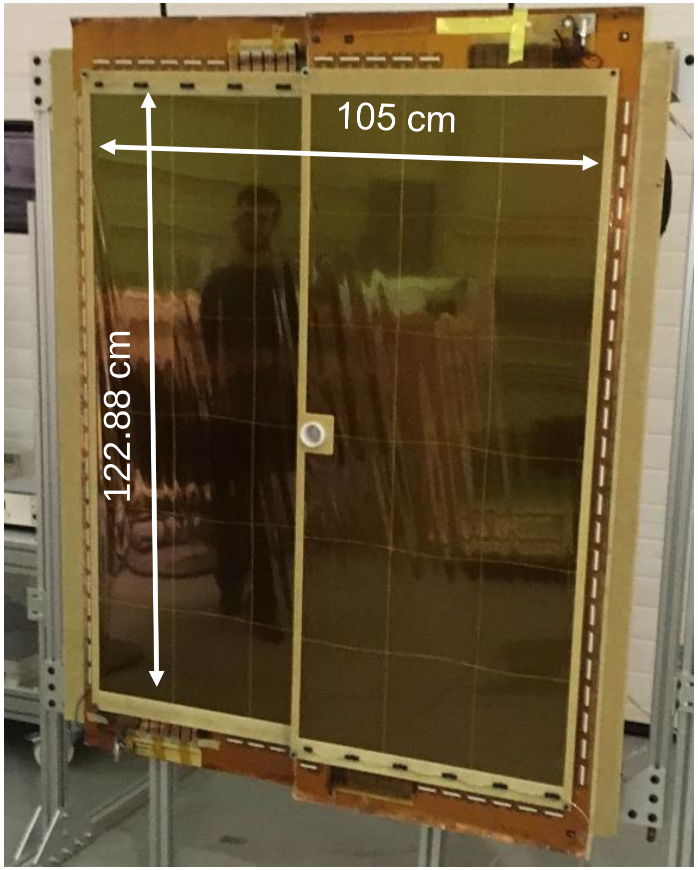
Status of APV25 based MPD Electronics for SBS GEMs *(P. Musico & E, Cisbani INFN Roma, JLab)*

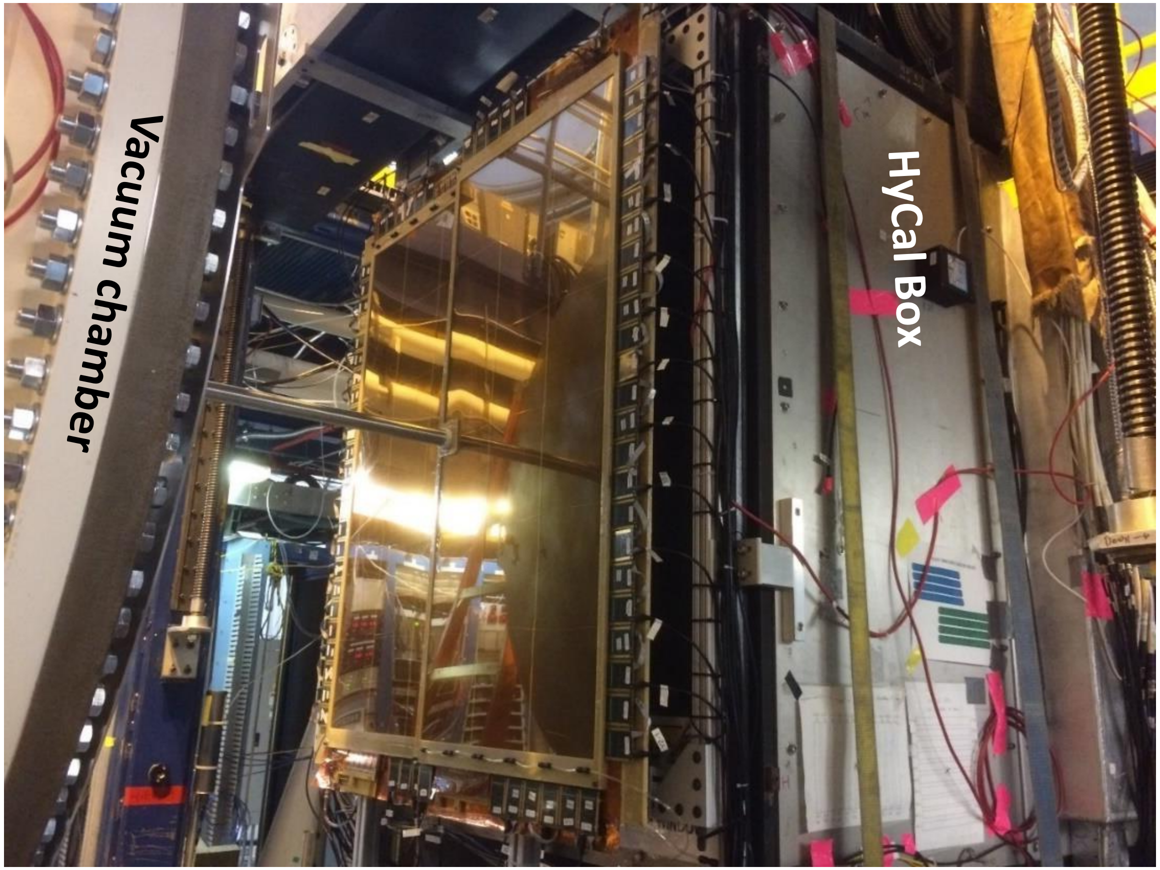
- We are building a system of ~ 160 K channels for SBS now (same number proposed for SoLID)
- Currently being incorporated into JLab CODA system now; with the new fast connections/FPGA level data reductions DAQ at ~ 5 kHz is achievable.
- Even faster bandwidths on the horizon; GEM data speed and volume will not be a bottleneck for SoLID.

Large GEMs for PRad Experiment in Hall B @JLab

Large GEMs in PRad Experiment

2 large GEM chambers side by side ⇨ installation in Hall B beam line in May 2016





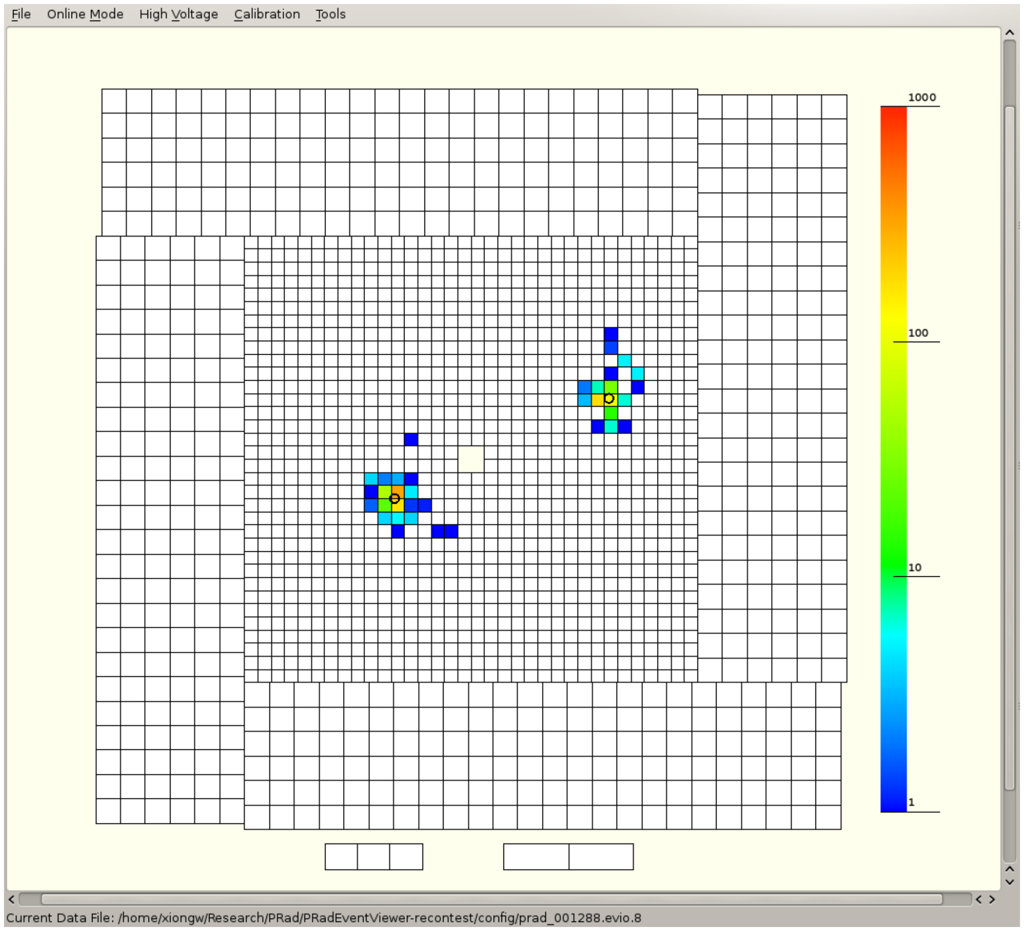
- Each chamber similar in size with the largest SoLID GEM module
- Largest GEM built and ran in experiment

- Production goal for 1.1 and 2.2 GeV beam on Hydrogen @ 15 nA reached with over 1500M events collected
- DAQ Performances: Average trigger rate 4.4 kHz with average DAQ rate ~ 3.8kHz (Full DAQ system)⇨ 87% live-time.

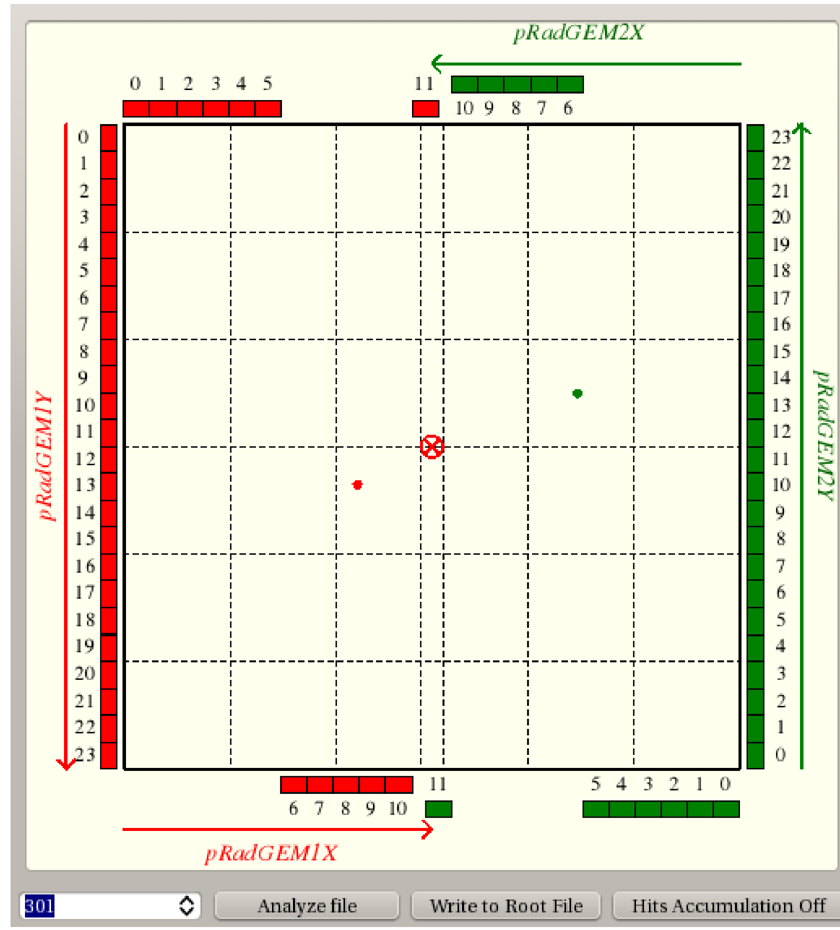
Large GEMs in PRad Experiment

- Data during PRad run (June 2016)
- Double cluster matching between HyCal and GEMs ⇨ Moller (ee →ee) Moller event candidate

HyCal



GEMs

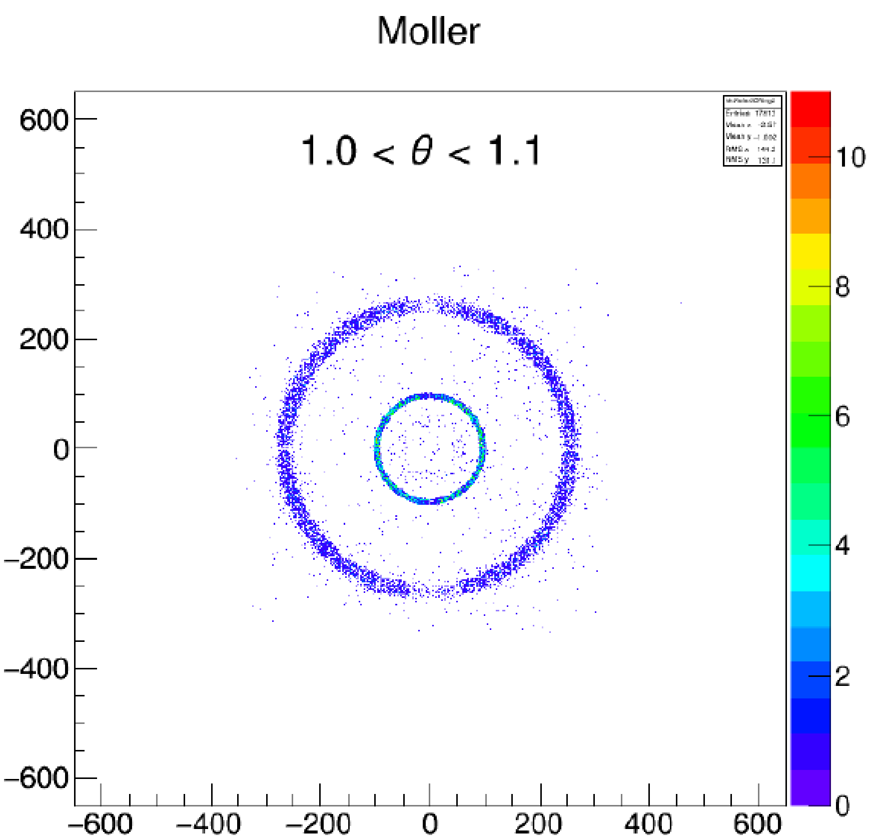


Large GEMs in PRad Experiment

Some preliminary results

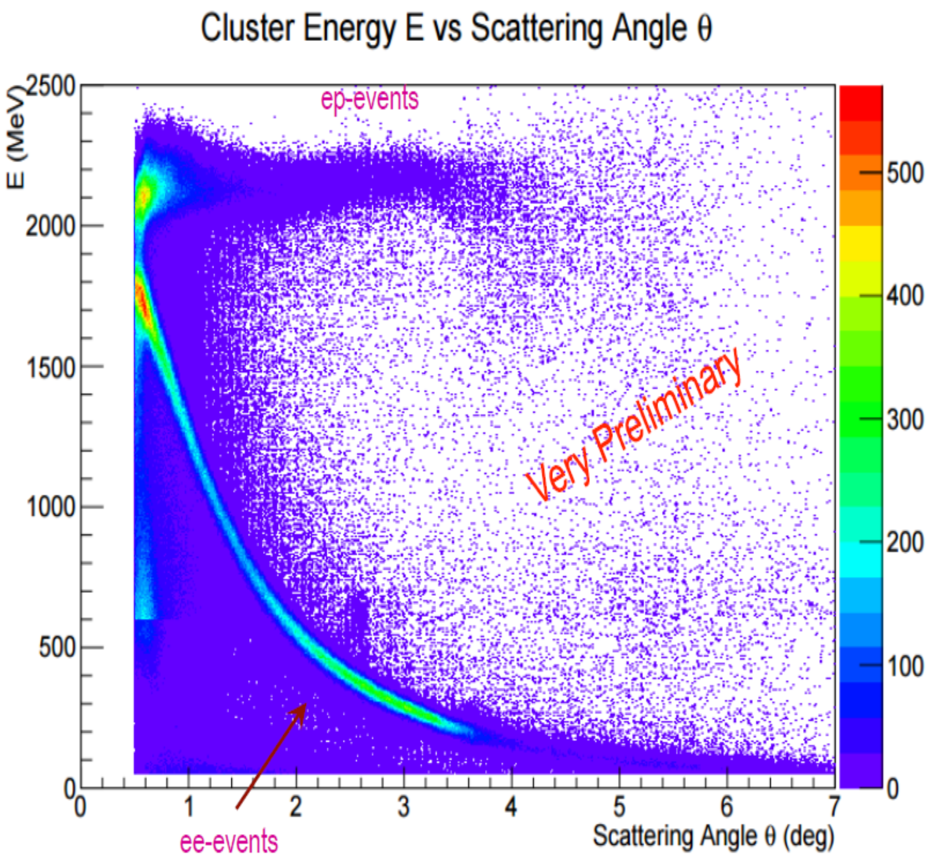
2D Reconstruction of Moller (ee)

with cut on opening angle



2D distribution of cluster energy (HyCal) vs

scattering angle (GEMs) with 2.2 GeV beam



GEM Efficiency From Production Run

Efficiency from ep(suspected) events:
Requirement:
1) HyCal one cluster (preliminary, will change to after match one cluster left)
2) cluster energy > beam_energy - 5 sigma
2) match with GEM
Efficiency = number of clusters after match / number of clusters before match

Efficiency from moller(suspected) events:
Requirement:
1) HyCal two cluster (preliminary)
2) two cluster total energy > beam_energy - 5 sigma
2) match with GEM
Efficiency = number of clusters after match / number of clusters before match

Using quantity of clusters, instead of number of events.

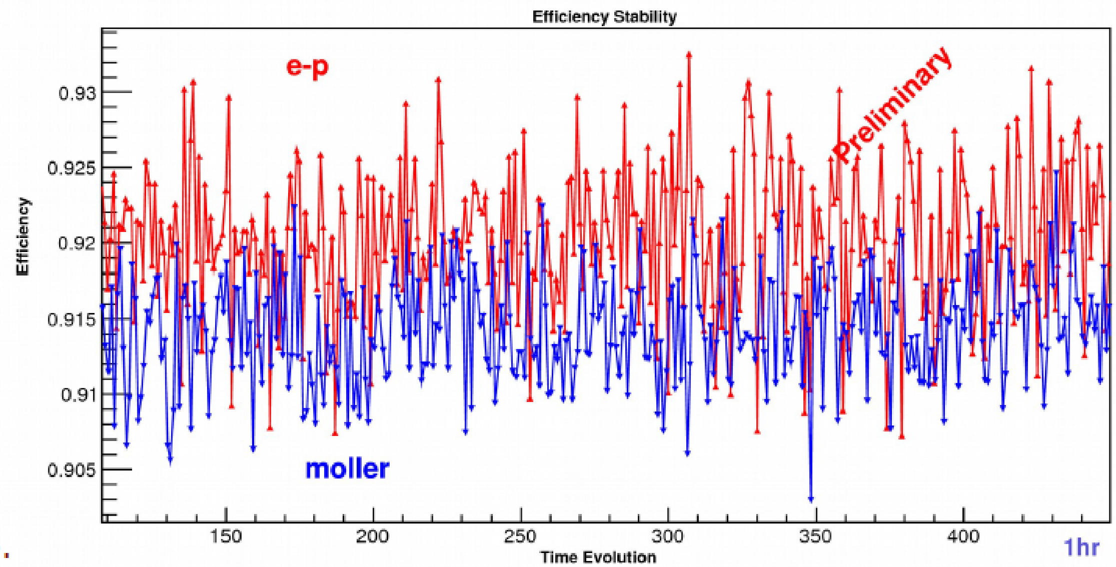
Relative to HyCal

Efficiency Results:

E-p: 92.0% +/- 0.03%
Moller: 91.4% +/- 0.03%

Covering nearly the whole
Active area of GEMs!!!
spacer, dead area, ...

Results Preliminary:
According to design, HyCal has a
Larger acceptance at smaller angle.



Summary / Outlook

SoLID GEM-US program for a two years pre-R&D

- Optimized & finalize the design of GEM modules for all SoLID configuration
  - Design ideas to improve performance and lower production cost
- Setup a program to start testing and characterization of Chinese GEM foils
- Investigate needs and option for SoLID GEM readout electronics
- Study the currently available candidate such as BNL VMM or Saclay DREAM chip

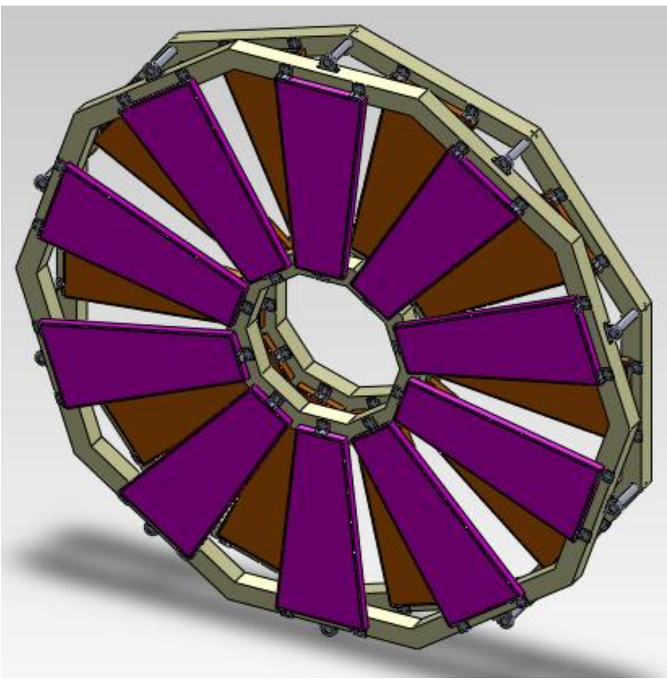
Large GEM activities in US (UVa & Temple U)

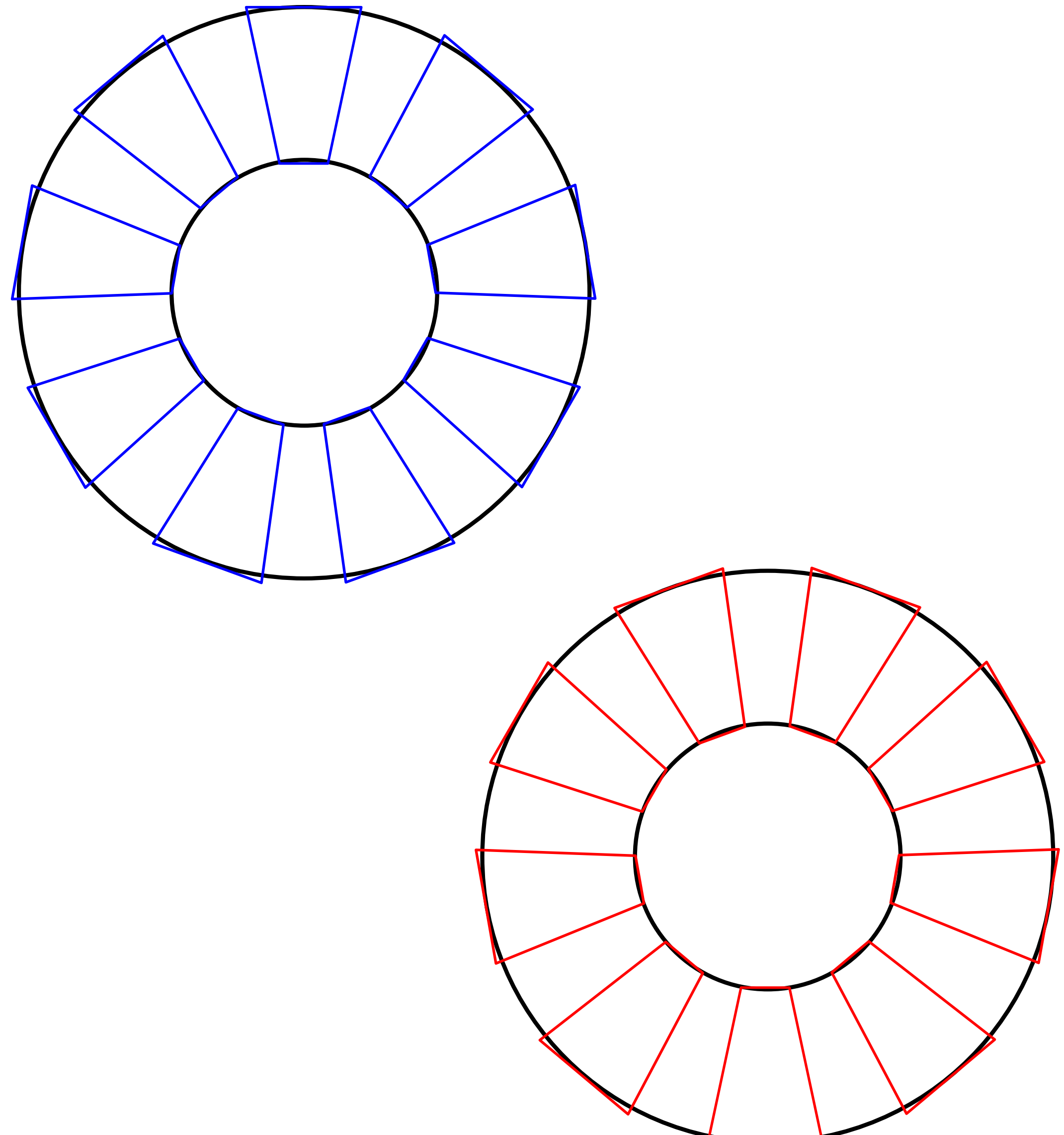
- Production of Large Area GEM trackers for the SBS in Hall A and PRad in Hall B
  - PRad GEM largest GEM detector built. Size comparable to largest SoLID GEM module
- Ongoing intensive GEM R&D for the EIC forward tracking
- Progress in the integration of the APV25 readout electronics into JLab CODA DAQ
  - Development for both SRS and MPD readout systems

Back Up

Design optimization for SIDIS disk layers

Two disks layer SIDIS configuration to allow overlap Allow overlap in

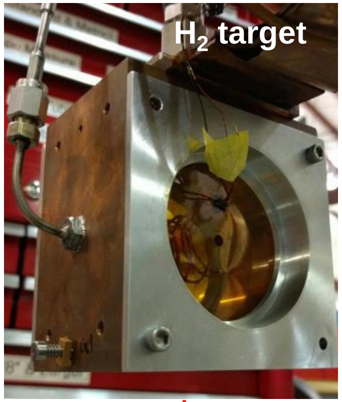




The PRad Experimental Setup in Hall B

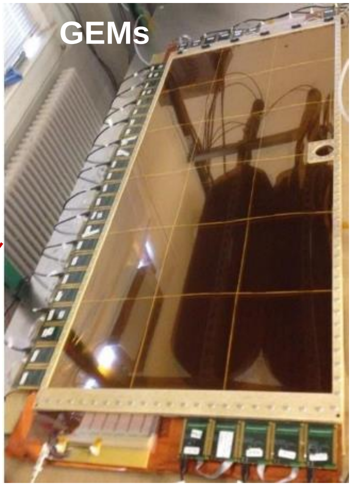
Target specs:

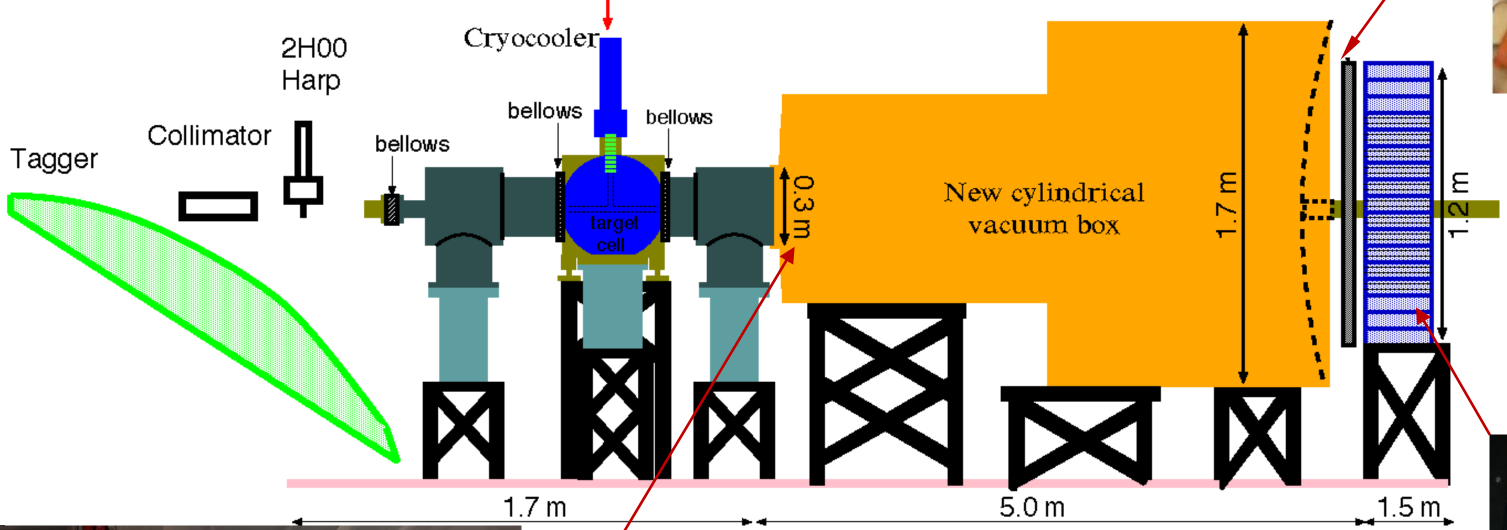
- *cell length 4.0 cm*
- *cell diameter 8.0 mm*
- *cell material 30 μm Kapton*
- *input gas temp. 25 K*
- *target thickness 1×10^{18} H/cm^2*
- *average density 2.5×10^{17} H/cm^3*
- *Cell pressure 0.6 torr*
- *Vacuum in target chamber ~5×10^{-3} torr*



GEMs:

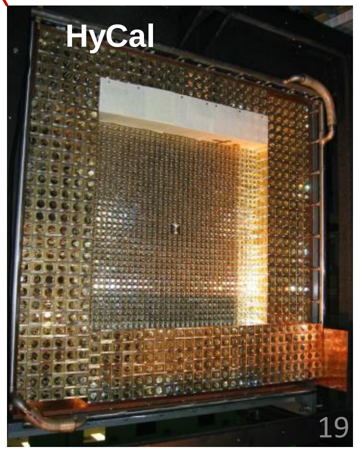
- *factor of >10 improvements in coordinate resolutions*
- *similar improvements in Q2 resolution (very important)*
- *unbiased coordinate reconstruction (including transition region)*
- *increase Q2 range by including Pb-glass part*





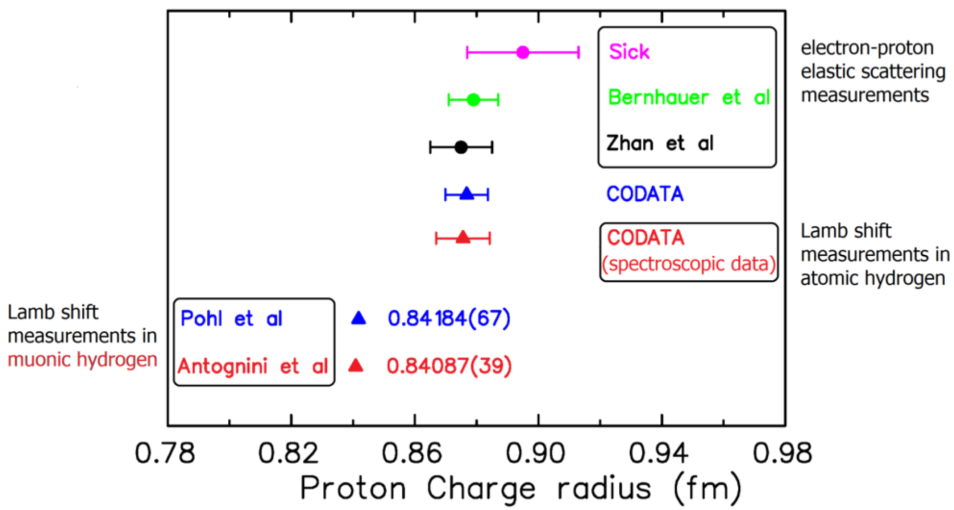
HyCal specs:

- *34 x 34 matrix of 2.05 x 2.05 x 18 cm^3 PbWO4 shower detectors*
- *576 Pb-glass shower detectors (3.82x3.82x45.0 cm^3)*
- *5.5 m from H_2 target (~0.5 sr acceptance)*
- *Resolutions for PbWO4 shower: $\sigma/E = 2.6\,\%/\sqrt{E}$, $\sigma_{xy} = 2.5\ \text{mm}/\sqrt{E}$*
- *Resolution for Pb-glass shower detectors factor of ~2.5 worse*



The PRad Experiment @ JLab: ep → ep Scattering

Proton Radius puzzle



PRad Experiment (E12-11-106):

- **High “A” rating (JLab PAC 39, June 2011)**
- Experimental goals:
  - Very low Q^2 (2×10^{-4} to 4×10^{-2})
  - 10 times lower than current data @ Mainz
  - Sub-percent precision in $<r_p^2>$ extraction

Specifications for PRad Experiment

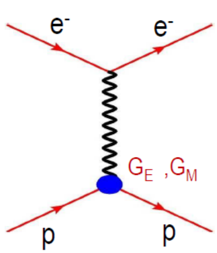
- Non Magnetic spectrometer
- High resolution and high acceptance calorimeter ⇨ low scattering angle [0.7° - 3.8°]
- Simultaneous detection of ee → ee (Moller Scattering) ⇨ minimize systematics
- High density windowless H_2 gas target ⇨ minimze background
- clean CEBAF electron beam (1.1 GeV & 2.2 GeV) ⇨ minimze background

The Proton Charge Radius from *ep* → *ep* Scattering Experiments

- In the limit of first Born approximation the elastic *ep* scattering (one photon exchange):

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^{p\,2}(Q^2) + \frac{\tau}{\varepsilon} G_M^{p\,2}(Q^2)\right)$$

$$Q^2 = 4EE'\sin^2\frac{\theta}{2} \qquad \tau = \frac{Q^2}{4M_p^2} \qquad \varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$



- Structure less proton:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} = \frac{\alpha^2\left[1-\beta^2\sin^2\frac{\theta}{2}\right]}{4k^2\sin^4\frac{\theta}{2}}$$

- G_E and G_M were extracted using Rosenbluth separation (or at extremely low Q^2 the G_M can be ignored, like in the PRad experiment)
- The Taylor expansion at low Q^2:

$$G_E^p(Q^2) = 1 - \frac{Q^2}{6}\langle r^2\rangle + \frac{Q^4}{120}\langle r^4\rangle + \ldots$$

- Definition of the Proton Radius: (r.m.s. charge radius given by the slope)

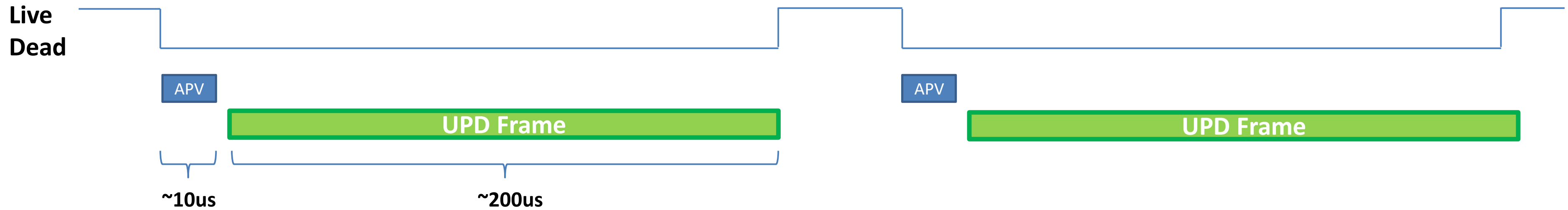
$$\langle r^2\rangle = -6\left.\frac{dG_E^p(Q^2)}{dQ^2}\right|_{Q^2=0}$$

A. Gasparian   CLAS col. meeting, 2015

SRS-FEC Firmware Upgrade: Trigger Buffering

(B. Moffit, JLab DAQ group - B. Raydo, JLab Fast Electronics Group)

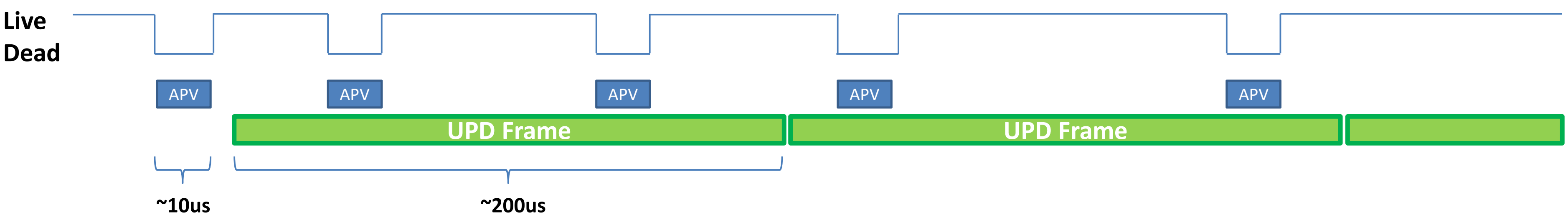
Non-buffered trigger FEC firmware (original):



- Dead/busy while APV sends triggered data **and dead/busy while UPD packets are sent**
- For fixed trigger rate, the dead time is basically determined by the UDP data processing (~200 μs)
- For random trigger: the mechanism is inefficient

  ⇨ no use of live time with low trigger burst but high trigger burst mean data loss because of dead time

Buffered trigger FEC firmware (new):



- Dead/busy while APV sends triggered data, **no longer dead/busy while UPD packets are sent**
- **UDP processing of APV data is “de-correlated” from APV sending data**
- When buffers in FPGA (holding captured APV for UDP processing) become full, then the FEC create necessary dead/busy time.
- For random trigger, @ high trigger burst, APV data are stocked in buffer and UDP packet is formed during the low trigger burst
- Dead/busy time while APV sends data can be eliminated to improve live time, but requires significant changes to FEC firmware.