SoLID GEM Detectors in US

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Outline

- ✓ Overview of SoLID GEM Trackers
- ✓ Design Optimization
- ✓ Large Area GEMs for PRad in Hall B
- ✓ Integration of APV25 readout in CODA

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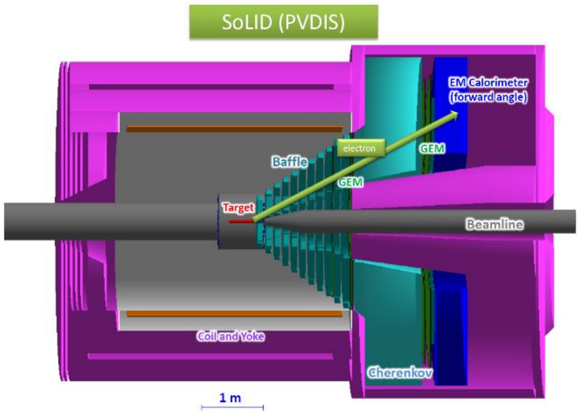
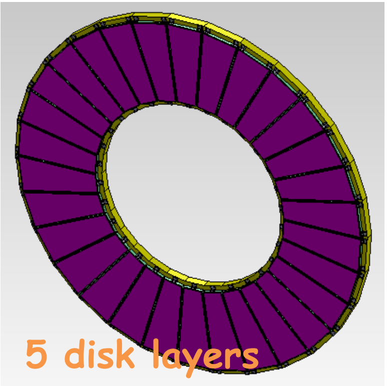
Overview of SoLID GEM Trackers

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 (30 sectors × 5 planes, each sector covering 12 degree)
- Need radiation and magnetic field tolerant

PVDIS

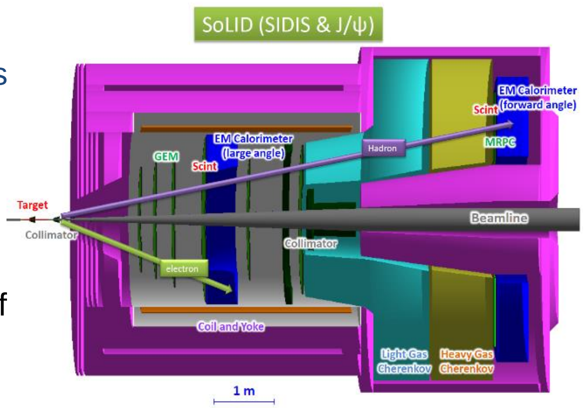




Large area GEM challenges

- Larger SoLID GEM modules as large as 113 cm × 55 cm
  - ✓ New Single Mask technique allows to make GEM foils as large as 200 cm × 55 cm
- The remaining challenge is large production capacity:
  - ✓ If all LHC related large GEM project (CMS, ALICE, TOTEM) gets underway, this will require almost 100 % of CERN production capacity
  - ✓ Currently work going on for large GEM production capabilities in China and in the US.

SIDIS



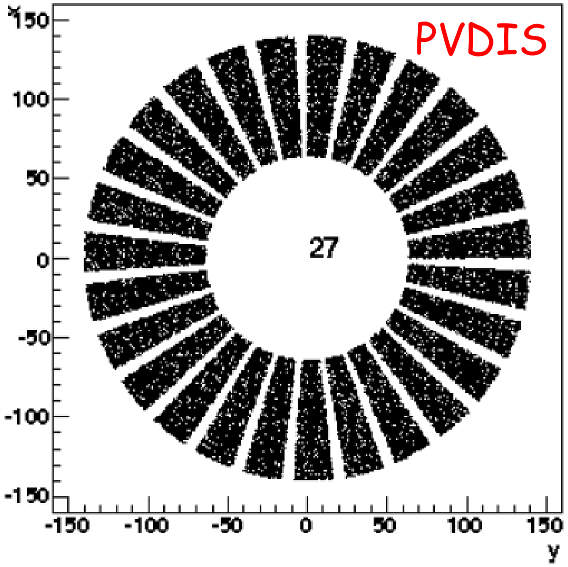
Large number of readout channels; but cost of electronics going down – cost per channel for the RD51 SRS APV-25 based readout is ~ \$3.00 + U/V stereo angle 2D readout reduce the channel count while maintaining a very good spatial resolution

Overview of SoLID GEM Trackers: PVDIS Configuration

- Instrument five locations with GEMs ⇨ 30 GEM modules at each location

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

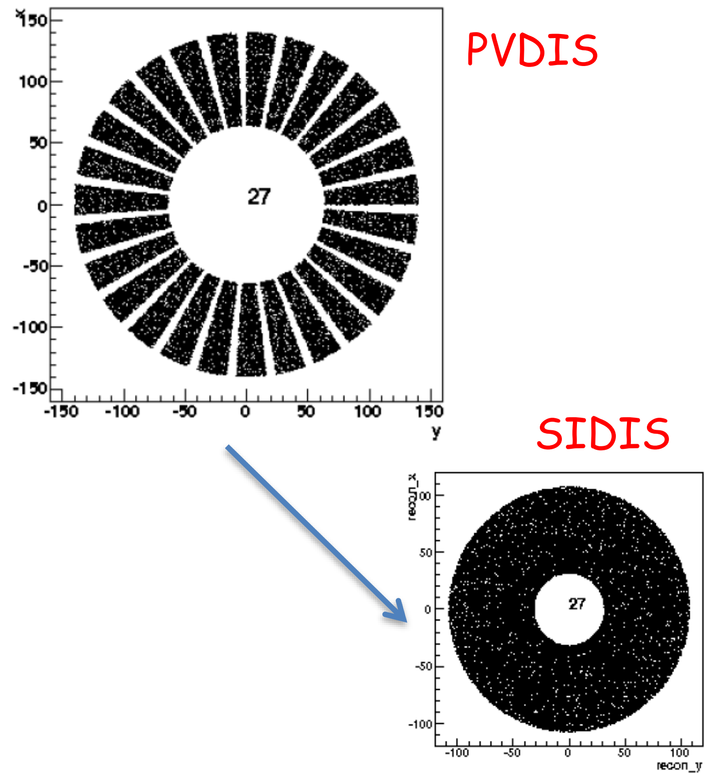
- Largest GEM module size required: 113 cm x 55 cm
- about the size of PRad GEM chambers currently in Hall B
- With ~5% spares, we will need about 170 k readout channels.



Overview of SoLID GEM Trackers: SIDIS Configuration

- Six locations instrumented with GEM trackers:
- Original idea: Re-arrange PVDIS module in SIDIS configuration

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



- However, GEM module length L is set by the inner and outer radius of the disk layer: L= R_out – R_in
- A SIDIS and PVDIS layers can used the same GEM modules only if L is the same, unless there is a tolerance δL on the layer GEM dimensions (for SIDIS) given the module size of a PVDIS GEM module
  - $L_{SIDIS} = L_{PVDIS} + \delta L$

Design optimization: Can we use the same modules in both PVDIS & SIDIS layers?

Assuming different level of tolerance δL on SIDIS GEM modules:

- δL = 1 cm ⇨ only GEM module #3 used for **PVDIS layer #1** can be reused for **SIDIS layer #6**
- δL = 5 cm ⇨ only GEM modules #3 and #5 **used for PVDIS layer #1 & #3** can be re-used for **SIDIS layer #6 & #2**
- δL = 12 cm ⇨ all 5 PVDIS GEM modules can be re-used in SIDIS Configuration

Experiment	module Id	Layer Id	R_in (cm)	R_out (cm)	Length [R_out - R_in] (cm)	Z (cm)
SIDIS	1	1	36	87	51	-175
SIDIS	2	5	42	100	58	5
PVDIS	3	1	51	118	67	157.5
SIDIS	3	6	55	123	68	92
PVDIS	4	2	62	136	74	185.5
PVDIS	5	3	65	140	75	190
SIDIS	5	2	21	98	77	-150
SIDIS	6	3	25	112	87	-119
SIDIS	7	4	32	135	103	-68
PVDIS	8	4	111	221	110	306
PVDIS	9	5	115	228	113	315

- Basically, we can not use the same modules in both PVDIS and SIDIS configuration if we want to keep from the currents dimensions (R_out – R_in) fixed ⇨ 9 GEM modules design (different size and UV angle) (for both SIDIS and PVDIS
- But **(from Zhiwen)** it looks like we can play with outer radius of SIDIS layers and in that case, the number of modules can be limited to 6

Design optimization: Do we need 30 modules / layers?

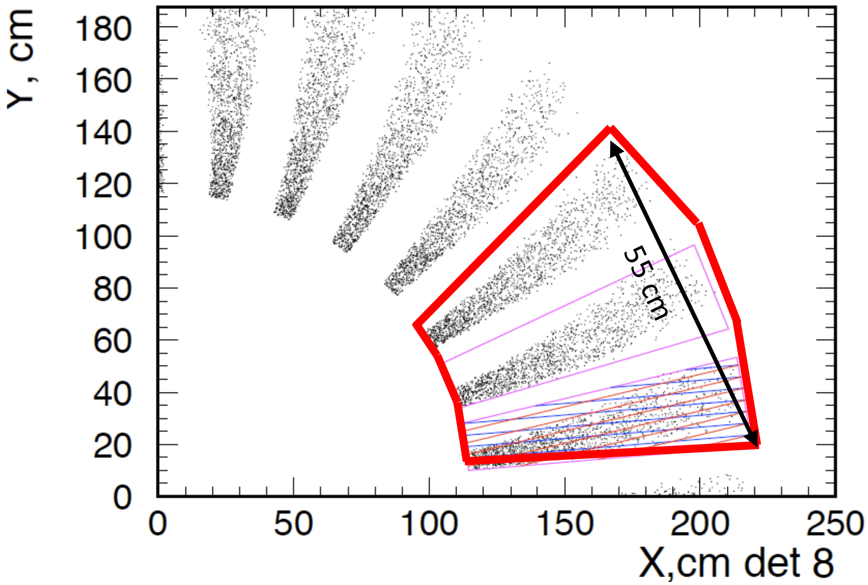
Large GEM modules:

- All GEM modules with a width of ~ 55 cm ⇨ Current limitation imposed by raw material (width of the roll ~ 61 cm)
- we can limit the number of modules in each layer ⇨ Cost saving in materials & labor
- Optimize dead-to-active area ratio ⇨ Reduced constraints on the GEM frames widths

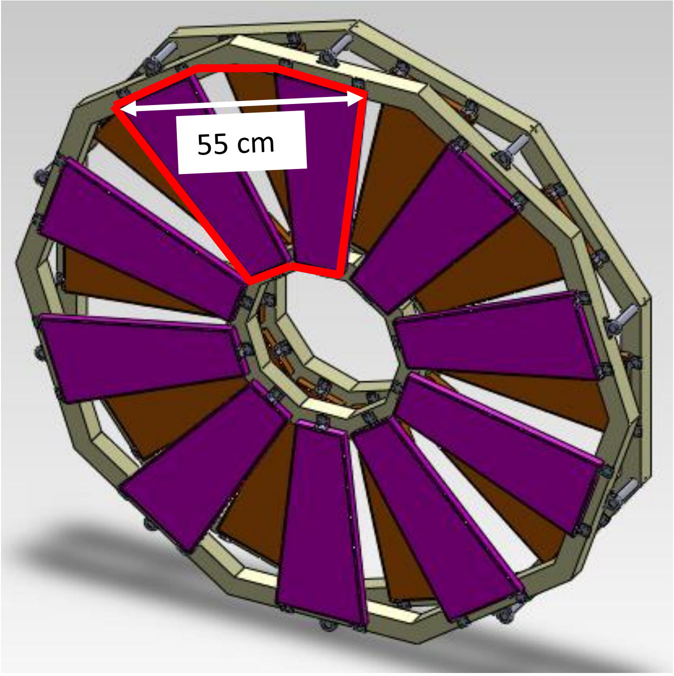
Performances of the readout strips

- With the U/V stereo angle strips readout ⇨ spatial resolution or occupancy do not depend of the detector width
- We can arrange to have HV sector on the foils

Example of PVDIS layer



Example of SIDIS layer



Design optimization: Do we need 30 modules / layers?

- This is a quick estimation of how many modules are needed for each layer for both PVDIS and SIDIS with the assumption that layer #3 and #5 are common for PVDIS and SIDIS ⇨ **151 GEM modules needed for all 9 GEM designs**

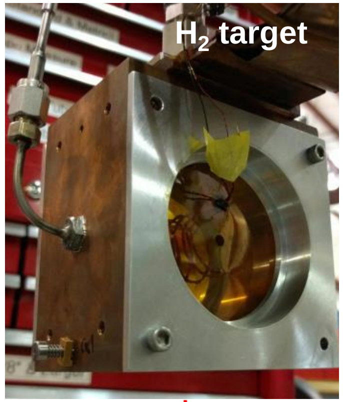
module Id	Experiment	Layer Id	Z (cm)	R_in (cm)	R_out (cm)	L = R_out - R_in (cm)	# modules / layer
1	SIDIS	1	-175	36	87	51	10
2	SIDIS	5	5	42	100	58	12
3	PVDIS	1	157.5	51	118	67	0
3	SIDIS	6	92	55	123	68	15
4	PVDIS	2	185.5	62	136	74	16
5	PVDIS	3	190	65	140	75	16
5	SIDIS	2	-150	21	98	77	0
6	SIDIS	3	-119	25	112	87	13
7	SIDIS	4	-68	32	135	103	16
8	PVDIS	4	306	111	221	110	26
9	PVDIS	5	315	115	228	113	27
TOTAL							151

Large Area GEMs for PRad Experiment in Hall B @JLab

The PRad Experimental Setup in Hall B

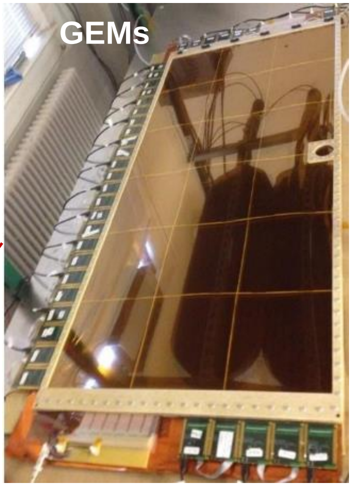
Target specs:

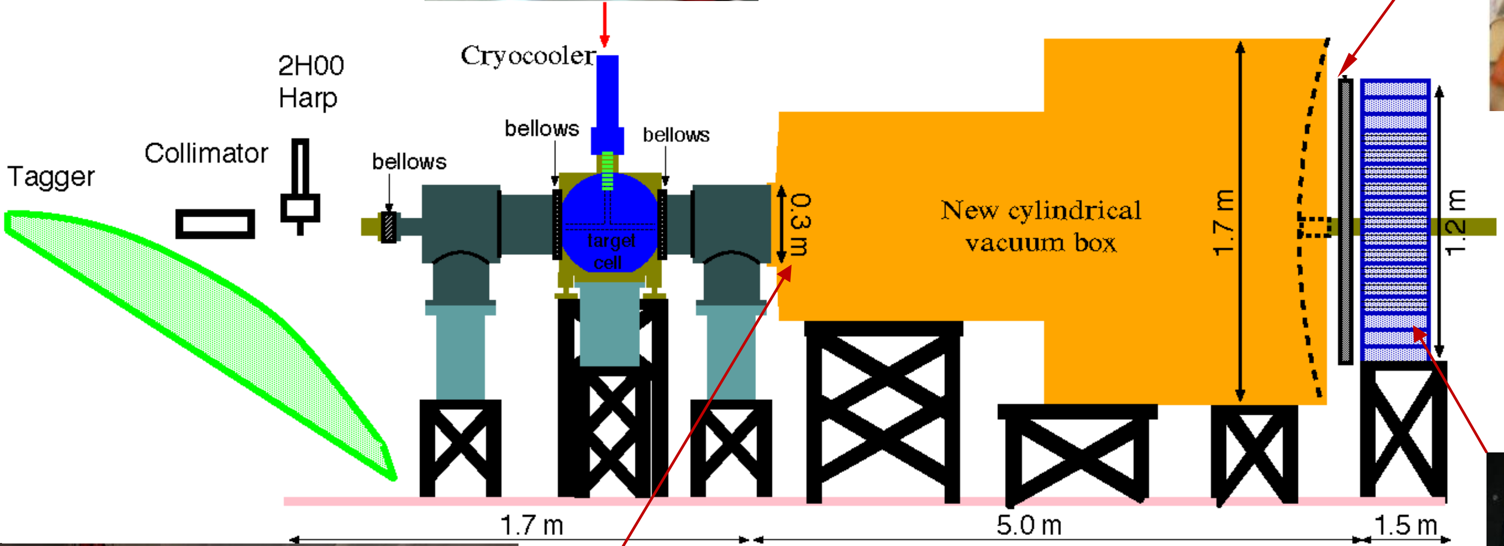
- *cell length 4.0 cm*
- *cell diameter 8.0 mm*
- *cell material 30 μm Kapton*
- *input gas temp. 25 K*
- *target thickness 1x10^{18} H/cm^2*
- *average density 2.5x10^{17} H/cm^3*
- *Cell pressure 0.6 torr*
- *Vacuum in target chamber ~5x10^{-3} torr*



GEMs:

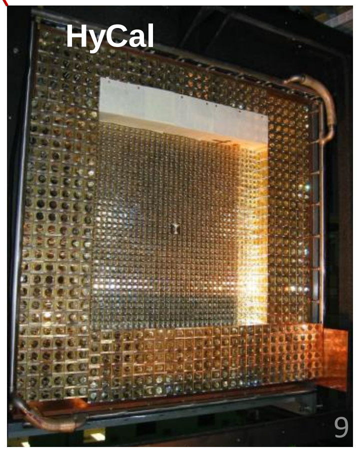
- *factor of >10 improvements in coordinate resolutions*
- *similar improvements in Q2 resolution (very important)*
- *unbiased coordinate reconstruction (including transition region)*
- *increase Q2 range by including Pb-glass part*





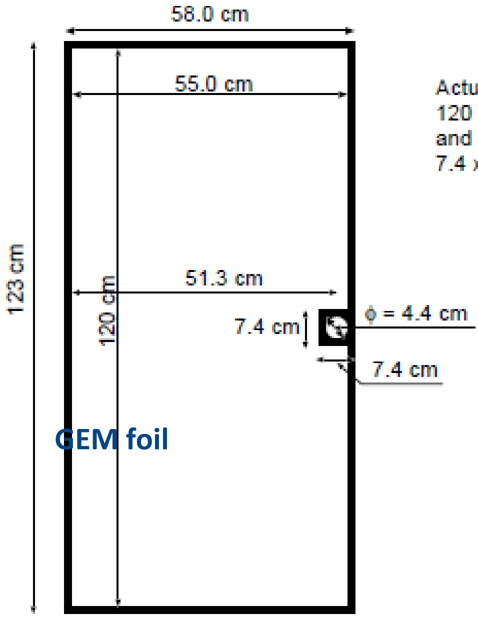
HyCal specs:

- *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: $\sigma/E = 2.6\,\%/\sqrt{E}$, $\sigma_{xy} = 2.5\ \mathrm{mm}/\sqrt{E}$*
- *Resolution for Pb-glass shower detectors factor of ~2.5 worse*



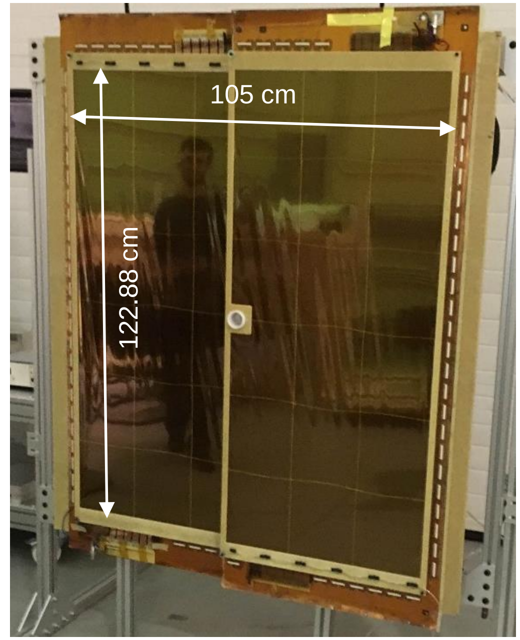
Large Area PRad GEMs: Requirements & Design

Desired Sensitive area: 116.4 x 116.4 cm^2
central hole: diameter 4.4 cm, including the frame max allowed
maximum allowable non-sensitive region 7.8 x 7.8 cm^2

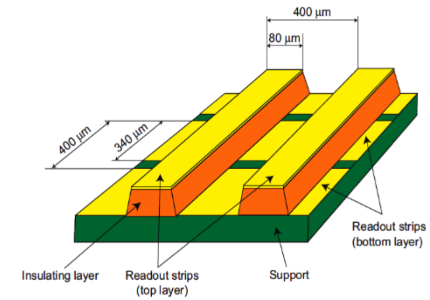


Actual sensitive area:
120 x 102.6 cm^2
and actual non-sensitive area:
7.4 x 7.4 cm^2

PRad GEM chambers:
2 large modules side by side

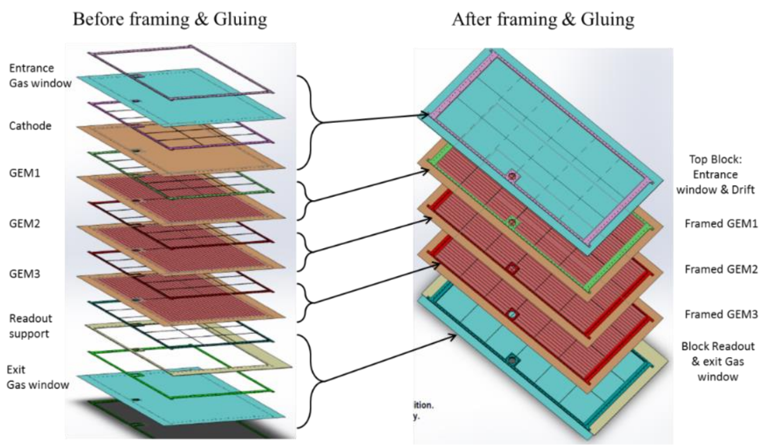


2D strips readout spatial resolution < 70 μm

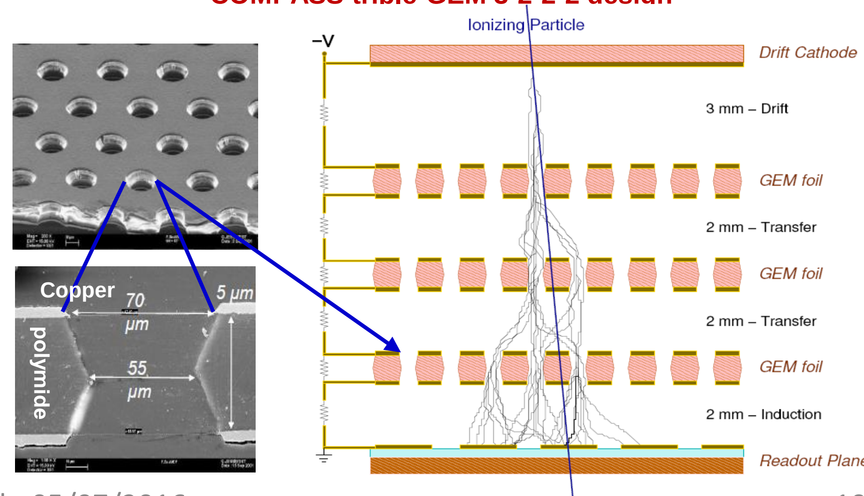


F. Sauli, Nucl. Instr. and Meth. A386(1997)531

Exploded view



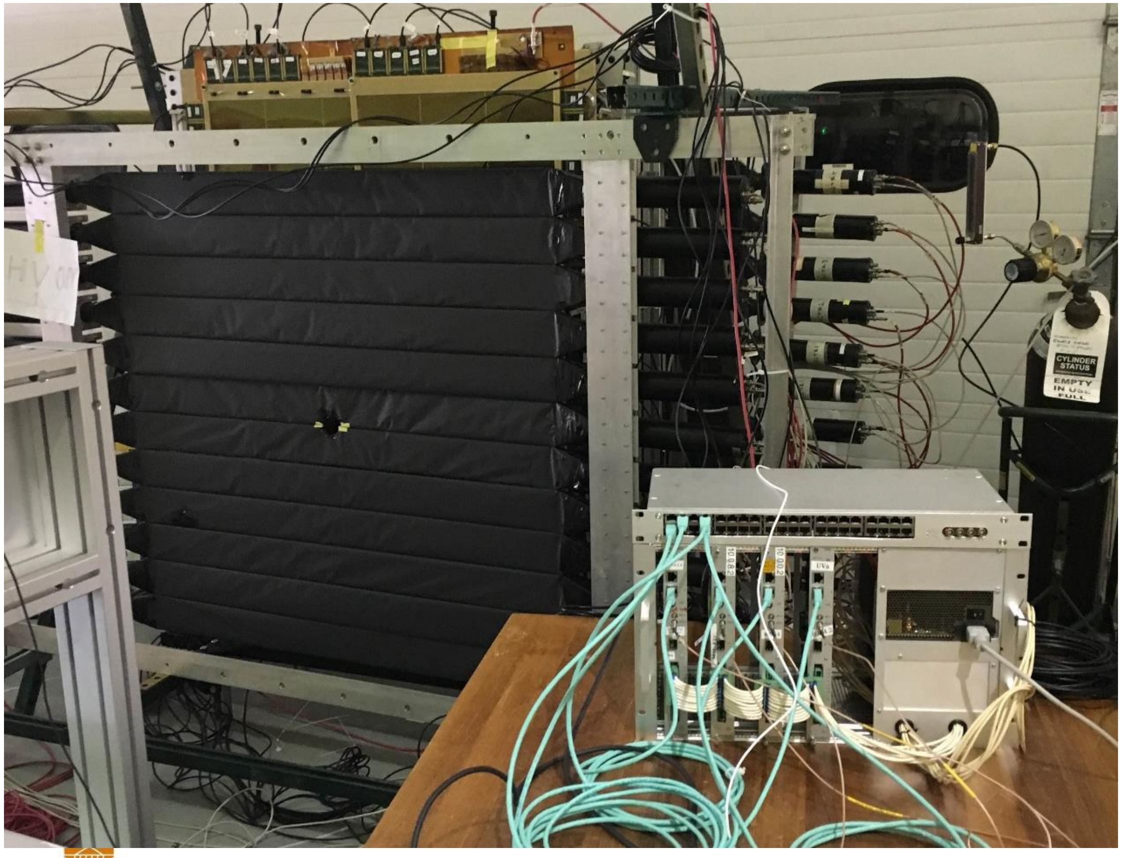
COMPASS triple-GEM 3-2-2-2 design



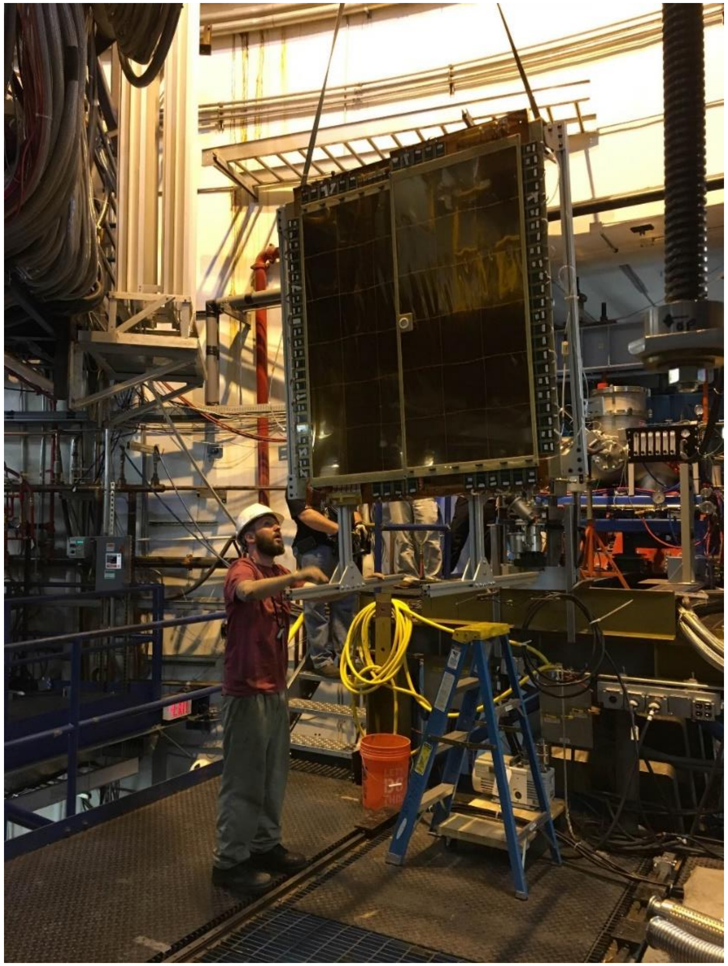
PRad GEMs in Hall B @ JLab

- Two chambers were built at UVa and sent to JLab in February 2016
- we setup a cosmic run with PrimEx Scintillators layers used for trigger of the APV25 SRS
- The chambers are now in Hall B, installed in front of the HyCal
- Installation is ongoing and commissionning to start on May 13

PRad GEMs on cosmic setup in EEL



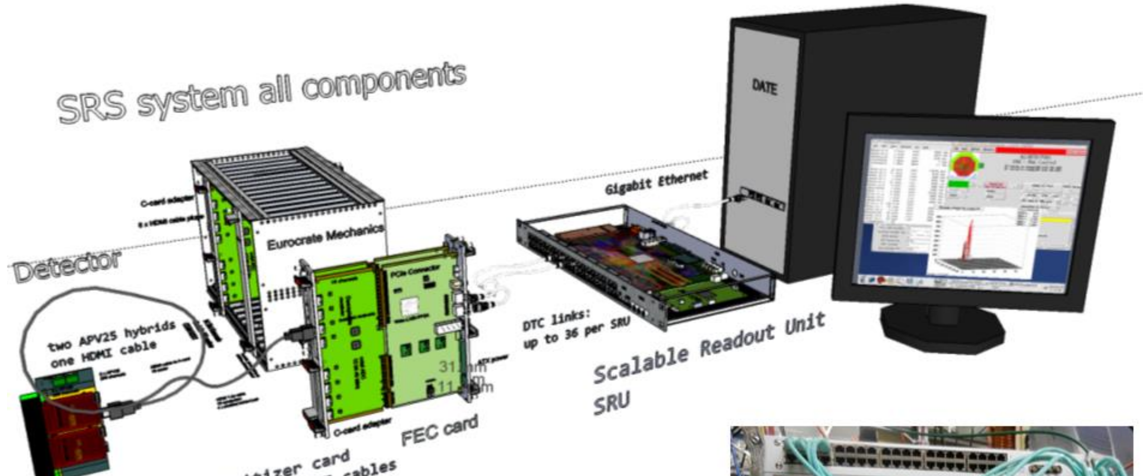
PRad GEMs move to the Hall last week

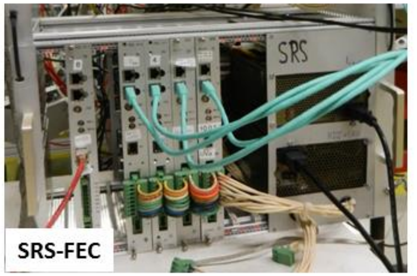


Front-End Electronics for PRad GEMs: The Scalable Readout System (SRS)

Multichannel electronics developed by the RD51 Collaboration for Micro Pattern Gaseous Detectors such as GEMs. It is based on:

- SRS-APV25: Front End cards (hybrids hosting the APV25 chip) mounted on the detector ⇨ send multiplexed data from128 channels to SRS-ADC cards via standard commercial HDMI cables.
- SRS-ADC: card that host the ADC chips, de-multiplex and convert data from up to 16 SRS-APV25 cards into digital format then send them to the SRS-FEC cards
- SRS-FEC: is the FPGA board, handles the clock and trigger synchronization of the SRS-APV hybrid cards, send digitized data from ADC to the SRS-SRU via 1 Gb Ethernet Copper link.
- SRS-SRU: handles communication between multiple (up to 40) SRS-FEC cards and the DAQ computer. It also distributes the clock and trigger synchronization to the SRS-FEC cards and send the data fragment to the DAQ PC through Gb Ethernet.





Need for the PRad GEMs:

- Hardware:
  - 72 SRS-APV FE cards (36 per GEMs) ⇨ total of 9184 channels to read out
  - 8 SRS-ADC / SRS-FECs with 9 APVs cards, 3 time samples
  - 2 SRS-SRUs to collected the data from the FECs transfer to the DAQ PC
  - TIpcie: Interface the SRS electronics into JLab DAQ (CODA)
- Firmware upgrade

SRS Firmware Upgrades

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

SRS-SRU firmware upgrade:

- Standard firmware developped for APV25 had 1Gb Ethernet link
- Upgrade of APV25-compatible 10 Gb SRU firmware (JLab DAQ)

Test setup

- 36 APVs, 3 Time sample, 3 FECs (Event size 38.5 kB)
- APV25 calibration pulse with internal trigger
- Rate tests with standard 1(Gb) and upgraded (10 Gb) firmware
- 1 Gb link (SRU): Saturation @ ~3.2 kHz (Max. rate ~ 3.3 kHz)
- 10 Gb link (SRU): linear data transfer speed up to 5.5 kHz

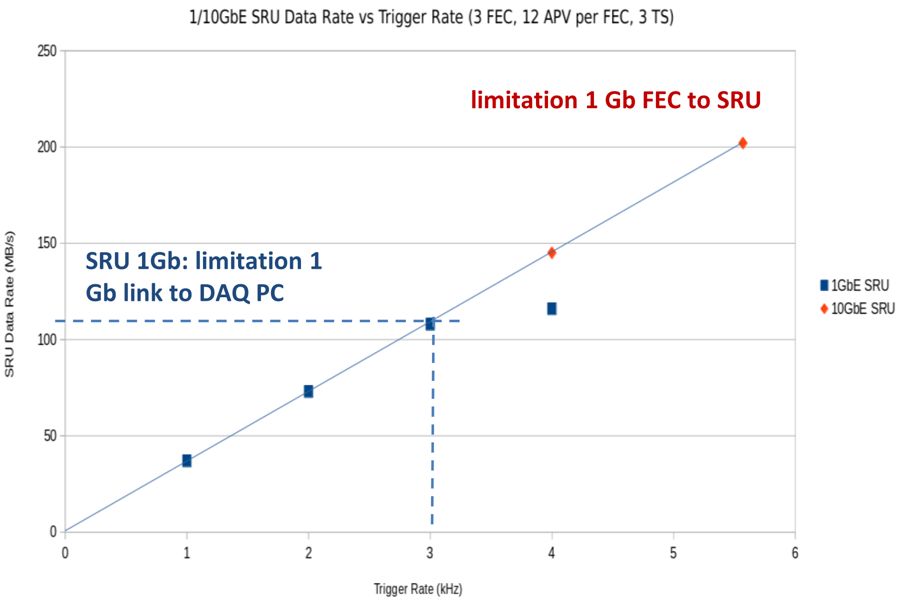
⇨ saturation expected beyond 6 kHz (FEC data to SRU @ 80 MB/s)

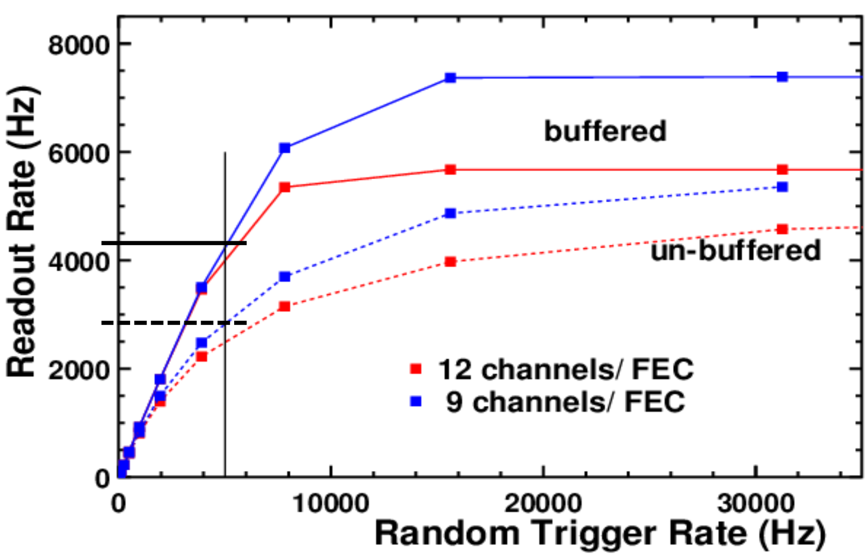
SRS-FEC firmware upgrade:

- Trigger buffering and Busy signal implementation

Test setup for 5 kHz random trigger rate

- 9 / 12 APV25 (ADC channels), on 1 FEC with 3 time samples to the SRU (Expected configuration for PRad)
- Random pulse generator board
- Un-buffered triggers firmware: readout rate of ~2.8 kHz (9 APVs on FEC) ⇨ 44% dead time
- Buffered trigger firmware: readout rate of ~4.25 kHz (9 APVs on FEC) ⇨ 15% dead time, OK for PRad





Integration of SRS into JLab DAQ

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

PCIexpress Trigger Interface (TIpcie)

- **PC / Server Integration into JLab Pipeline DAQ**
- Standard PC Hardware allows for multiple network cards (1G, 10G, Infiniband)
- Fiber Connection (Clock, Trigger, Sync) to Trigger Supervisor
- Runs in Standalone (Master) or Larger-Scale DAQ (Slave).

Software librairies for the slow control

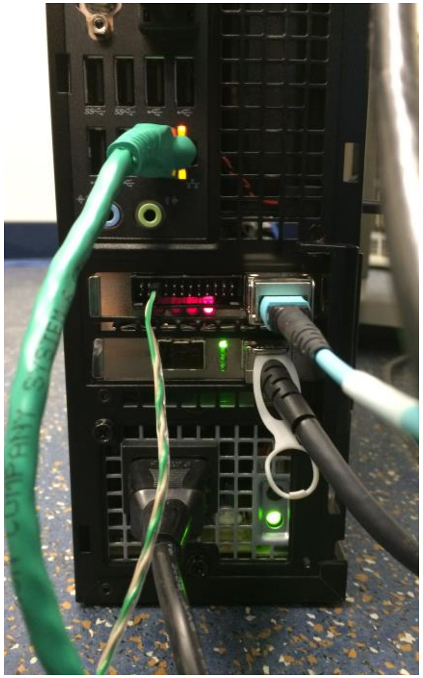
- C Library written to be used with CODA, **but also works standalone (Master mode)**
- Kernel and userspace driver compatible with EL5, EL6 (i386, x86_64)

Interface to the SRS

- APV Data from SRU to the DAQ PC with 10 Gb Ethernet
- SRU trigger from the TIpcie, FECs send BUSY signal to Trigger Supervisor
- DAQ PC multiple cores/threads for data processing ⇨ **online zero suppression for data reduction factor ~200** ⇨ TIPCie to transfer data to main DAQ PC
- Online monitoring of Raw APVdata and GEM hits

Setup test with the Tipcie

- The back side of the DAQ PC shows:
- TIPCIe blue fiber connection to the TS
- Twisted pair connections for triggers.
- The 10 Gb card for data transfer with the links connected (black) to the SRU.



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

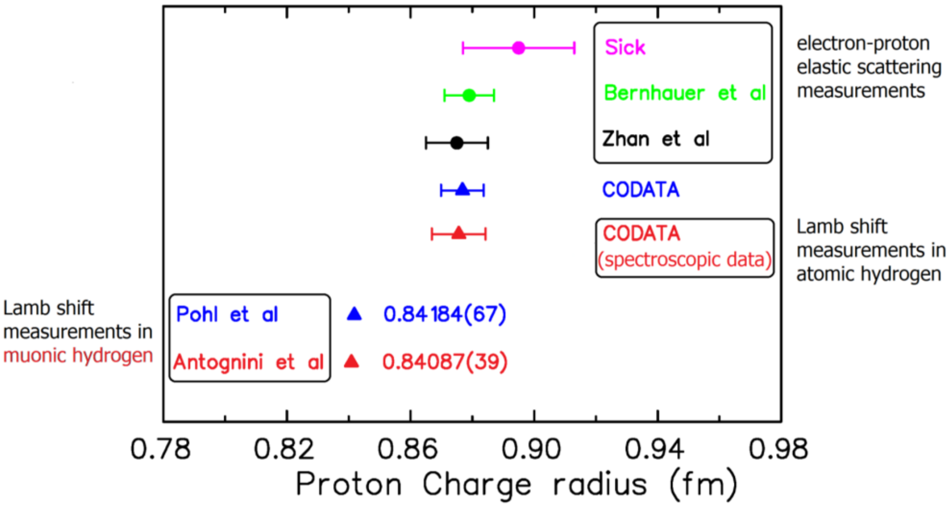
Large GEM activities in US (UVa & Temple U)

- 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

The PRad Experiment @ JLab: ep → ep Scattering

Proton Radius puzzle



Specifications for PRad Experiment

- Non Magnetic spectrometer
- High resolution and high acceptance calorimeter ⇨ low scattering angle [0.7º - 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

PRad Experiment (E12-11-106):

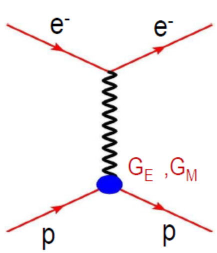
- **High "A" rating (JLab PAC 39, June 2011)**
- Experimental goals:
  - Very low Q^2 (2×10^{-4} to 4×10^{-2})
  - 10 times lower than current data @ Mainz
  - Sub-percent precision in $\langle r_p^2\rangle$ extraction

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

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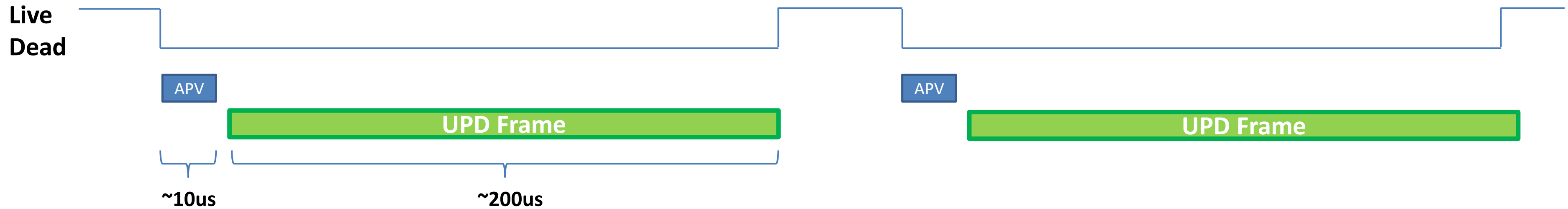
SRS-FEC Firmware Upgrade: Trigger Buffering

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

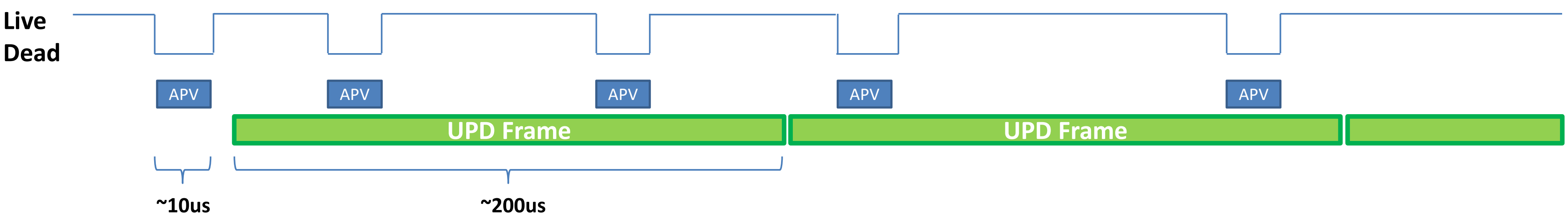
Non-buffered trigger FEC firmware (original):



- 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

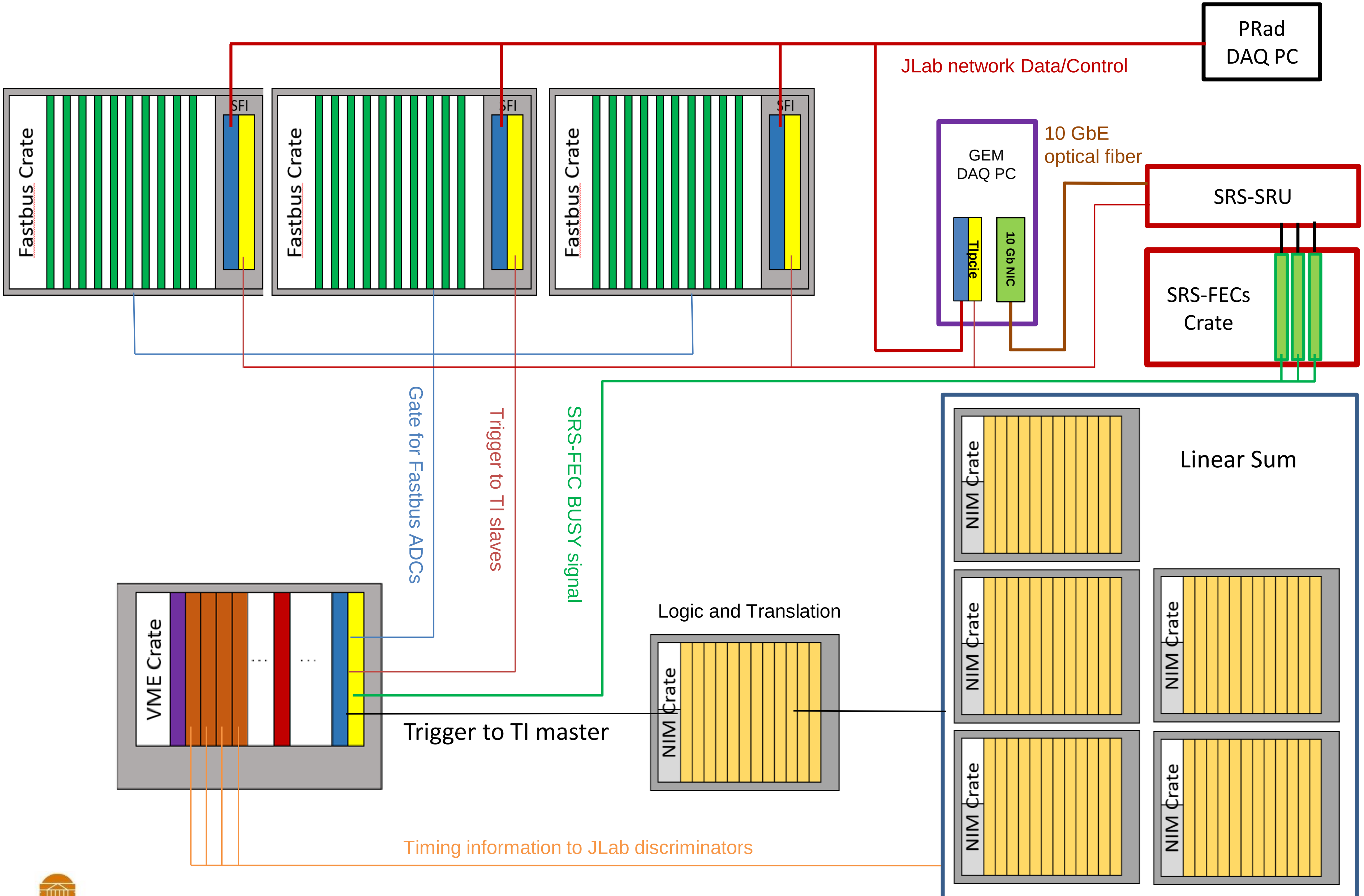
  ⇨ no use of live time with low trigger burst but high trigger burst mean data loss because of dead time

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.

Integration of SRS into JLab DAQ: PRad DAQ Overview



University of Virginia