Update on the Large GEMs for PRad Experiment in Hall B

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Outline

- ✓ PRad GEMs & Readout Electronics
- ✓ Preliminary results from the experiment run

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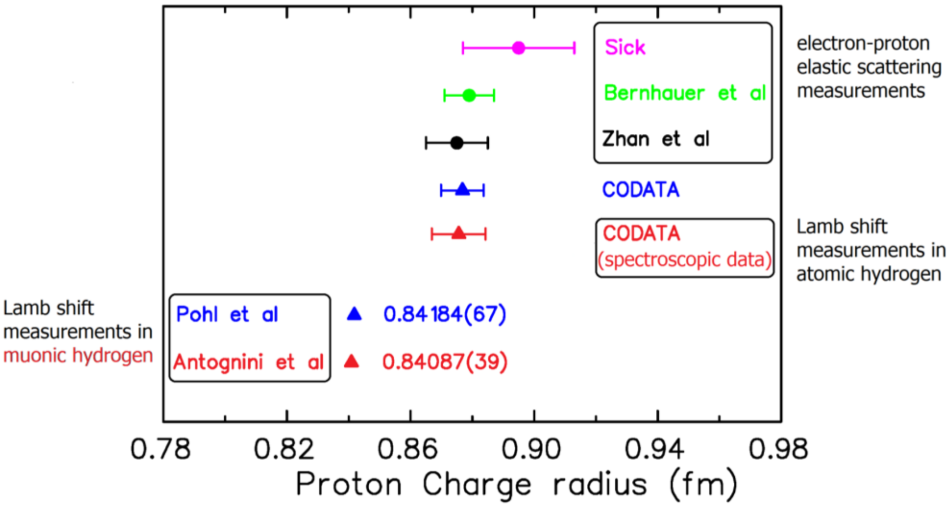
The PRad Experiment @ JLab: ep → ep Scattering

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 $\langle r_p^2\rangle$ extraction

Specifications for PRad Experiment

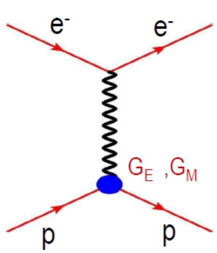
- Non Magnetic spectrometer
- High resolution and high acceptance calorimeter ⇨ low scattering angle [0.7° - 3.8°]
- Simultaneous detection of ee → ee (Moller Scattering) ⇨ minimize systematics
- High density windowless H_2 gas target ⇨ minimze background
- clean CEBAF electron beam (1.1 GeV & 2.2 GeV)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

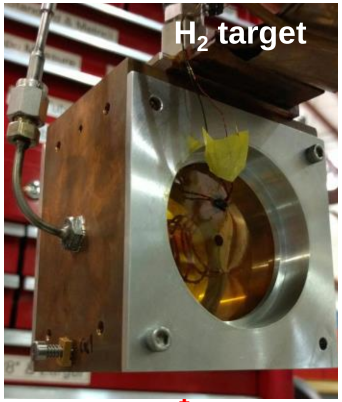
$$\langle r^2\rangle = -6 \left.\frac{dG_E^p(Q^2)}{dQ^2}\right|_{Q^2=0}$$

A. Gasparian CLAS col. meeting, 2015

The PRad Experimental Setup in Hall B

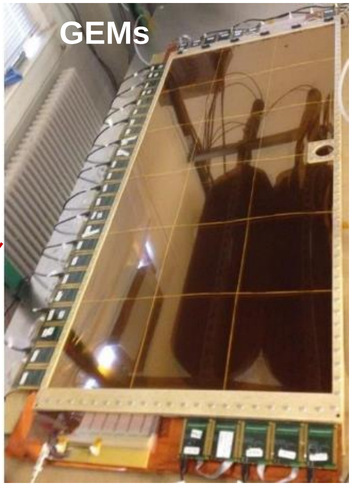
Target specs:

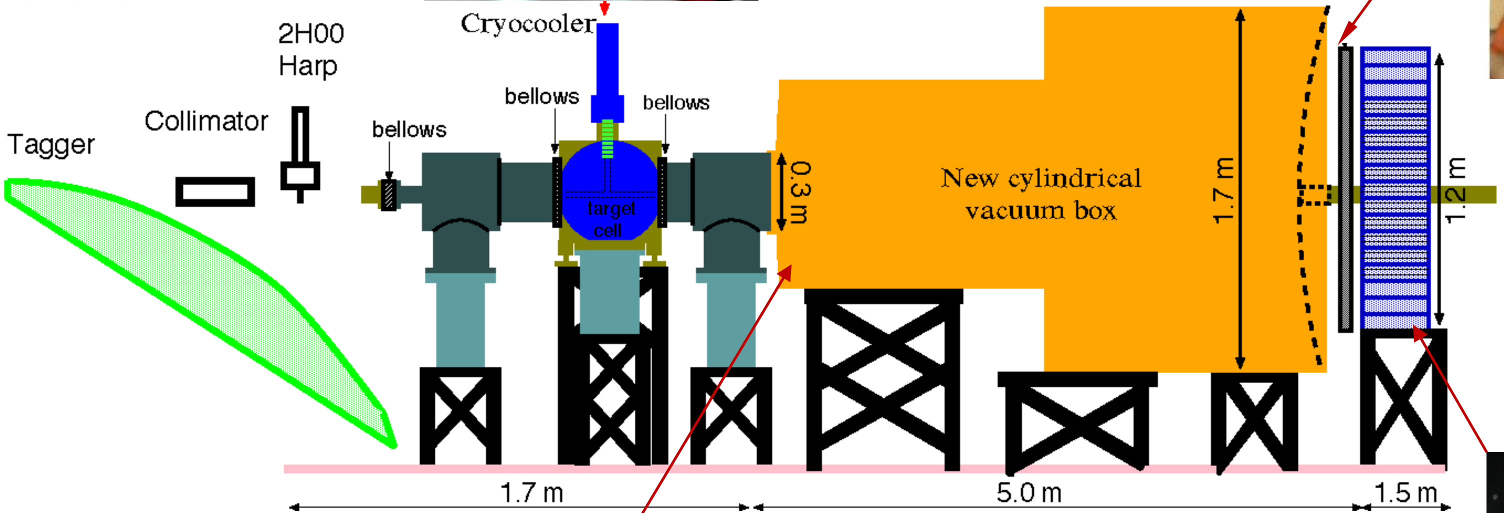
- cell length / diameter 4 / 8 cm
- cell material 30 μm Kapton
- input gas temp. 25 K
- target thickness $1x10^{18}$ H/cm^2
- average density $2.5x10^{17}$ H/cm^3
- Cell pressure 0.6 torr
- Vacuum in target chamber ~$5x10^{-3}$ torr

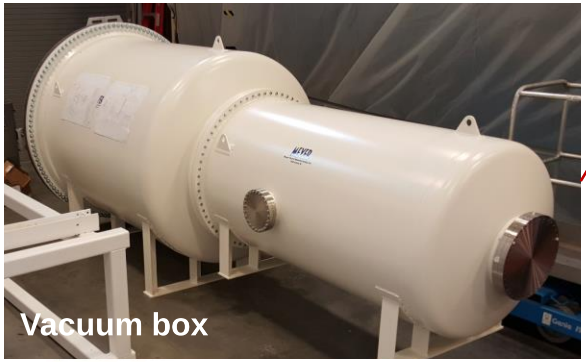


GEMs:

- factor of >10 improvements in coordinate resolutions, similar improvements for Q^2
- unbiased coordinate reconstruction (transition region), increase Q^2 range by including Pb-glass

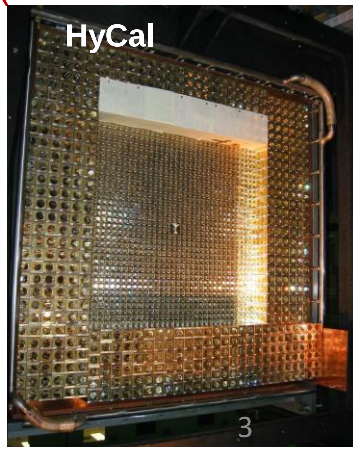






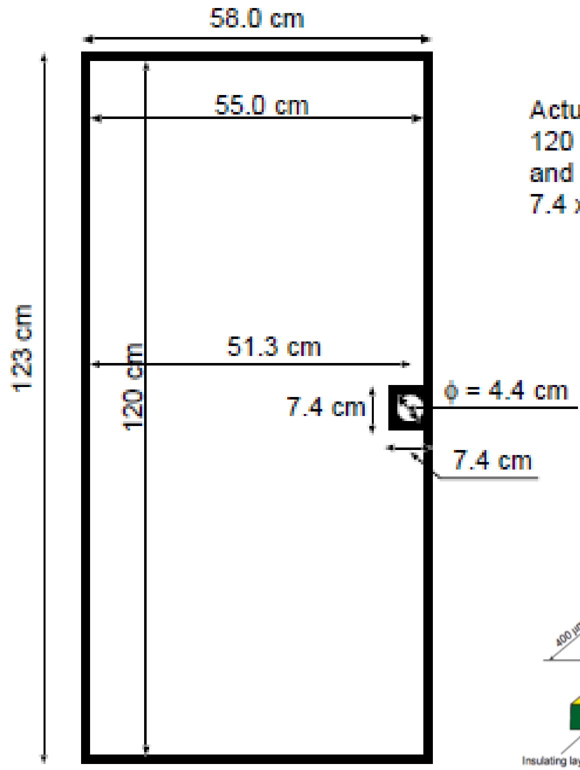
HyCal specs:

- 34 x 34 matrix of 2.05 x 2.05 x 18 cm^3 PbWO4
- 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, $\sigma/E = 2.6\ \%/\sqrt{E}$, $\sigma_{xy} = 2.5\ \text{mm}/\sqrt{E}$
- Resolution for Pb-glass shower factor of ~2.5 worse



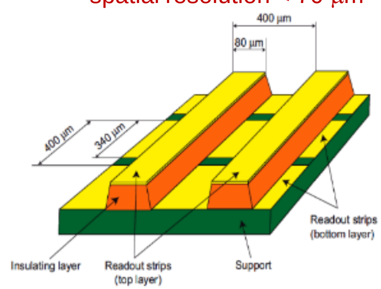
PRad GEMs: Design & Specifications

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

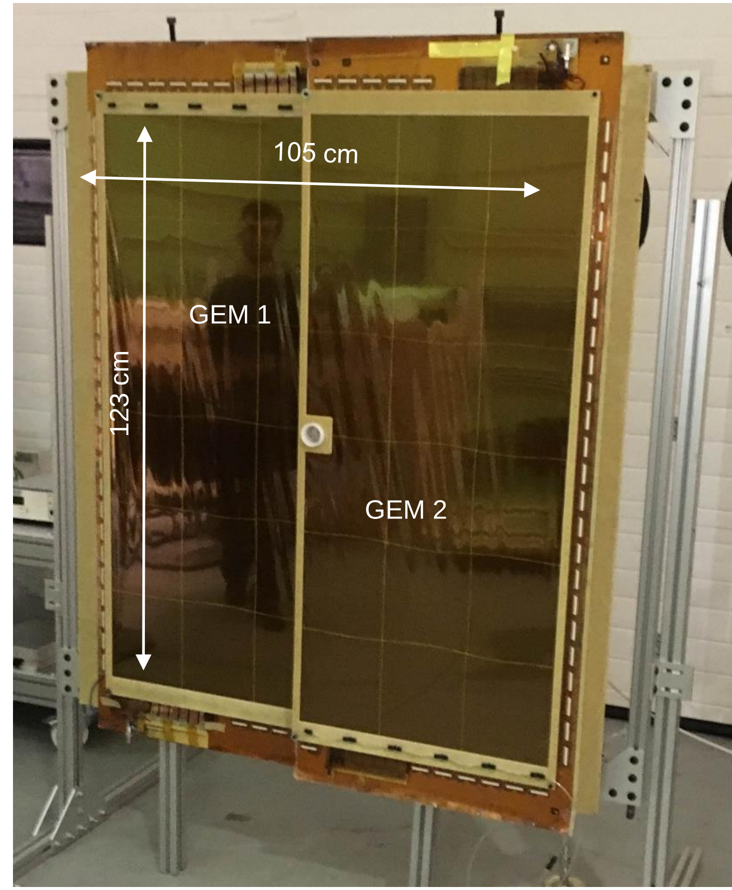


Actual sensitive area:
120 x 102.6 cm^2
and actual non-sensitive area:
7.4 x 7.4 cm^2

2D strips readout
spatial resolution < 70 μm



Two modules mounted on the holding frame Prad GEM configuration before the cosmic run in EEL (March 2016)



- Largest GEM module ever built in the world
  - Each module is twice the size of SBS Back Tracker GEMs (123 cm x 55 cm)
- Two modules overlap in the for the alignment of the beam pipe hole
- COMPASS-like strip readout (1.3 m long strips in the vertical direction ⇨ capacitance noise still OK

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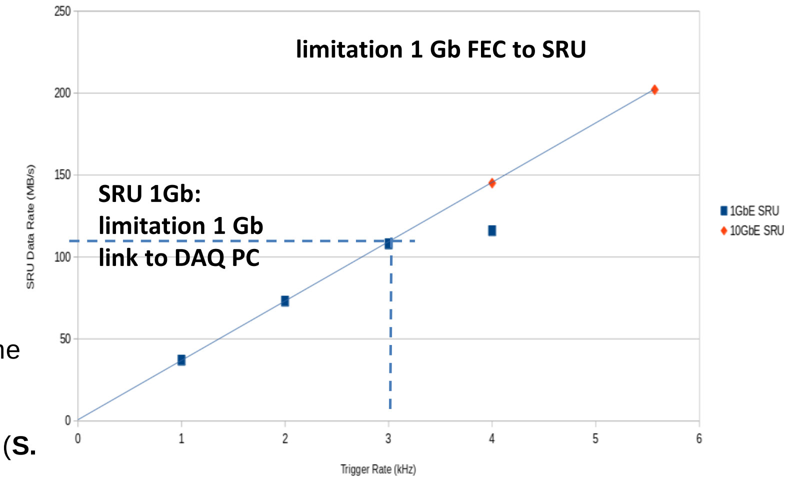
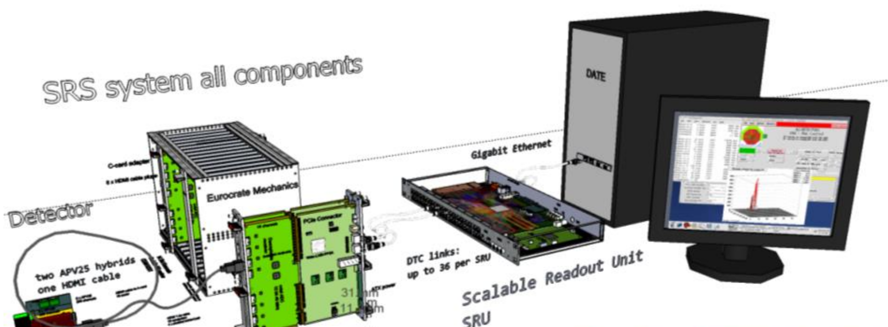
Upgrade of APV25-SRS Electronics for PRad GEMs

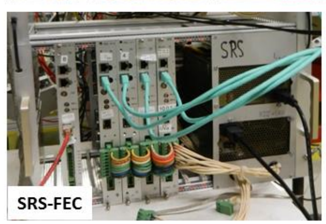
- **Hardware:**
  - 72 SRS-APV FE cards (36 per GEMs) ⇨ total of 9184 channels to read out
  - 8 SRS-ADC / SRS-FECs with 9 APVs cards each, 3 time samples
  - 2 SRS-SRUs to collected the data from the FECs
  - 2 CODA PC with TIpcie: Interface the SRS electronics into JLab DAQ (CODA)
- **Firmware**
  - Upgrade of the Link SRU to DAQ to 10 Gb,
  - FEC firmware upgraded to handle buffering trigger and busy mechanism
  - The upgrades allow the SRS to perform at a rate of 5kHz with less than 15% dead time
- **Software**
  - Integration of the SRS into CODA and implementation of the online zero suppression (**S. Boiarinov, JLab & X. Bai, UVa**)
  - Development of online Monitoring for the GEM data (**Weihzi Xiong, Duke U.**)

SRS-SRU firmware upgrade: 10 Gb link implemented

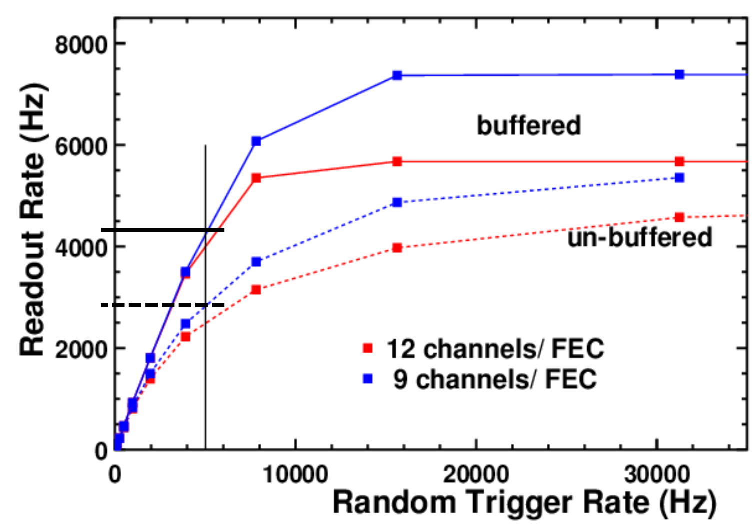


B. Moffit, B. Raydo,
DAQ & Fast Electronics Groups @ JLab





SRS-FEC firmware upgrade: Trigger buffering



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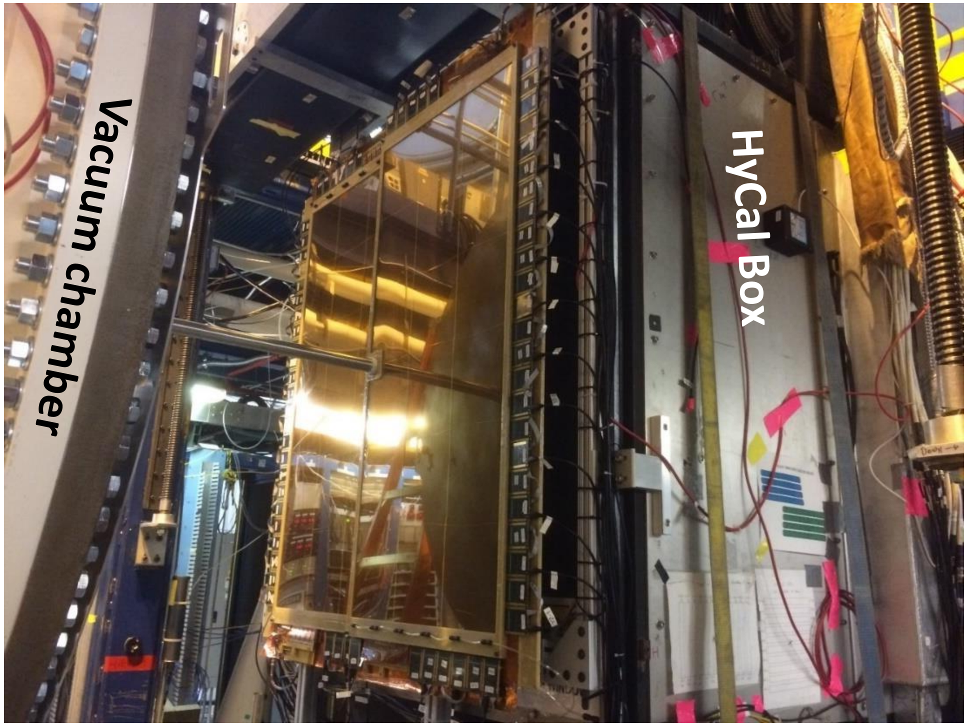
Installation on the PRad Expriment in Hall B



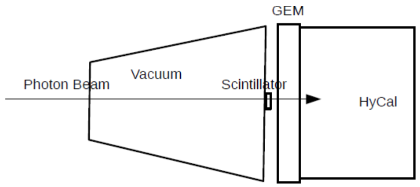
SRS crates underneath HyCal Box

Calibration run: Efficiency of the GEMs

(Xinzhan's preliminary analysis)

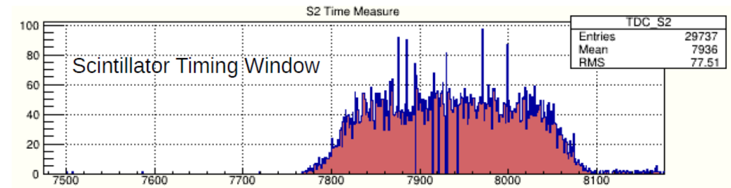
- Dedicated time for GEM efficiency measurement during HyCal calibration run
- Small portion of the photons from the photon tagger converts into e- in the small scintillators just in front of the GEMs
- Trigger from the scintillator, Scan several spot on both chambers
- Offline matching of the timing in the scintillator and the HyCal hits to clean up the events in GEMs
- efficiency > 95 % measured at different spots on each of the two GEMs
    - efficiency drops a few % when beam spots hits the spacer
- More data still need to be analyzed

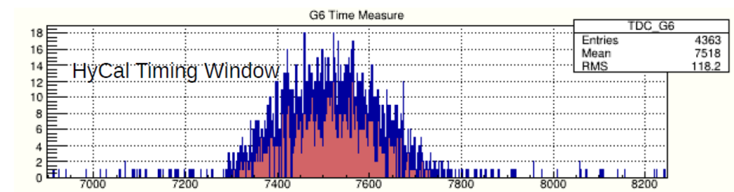
$Efficiency = N\_gem / N\_tot$



N_gem: hits on GEM
N_tot: hits on both scintillator and HyCal.

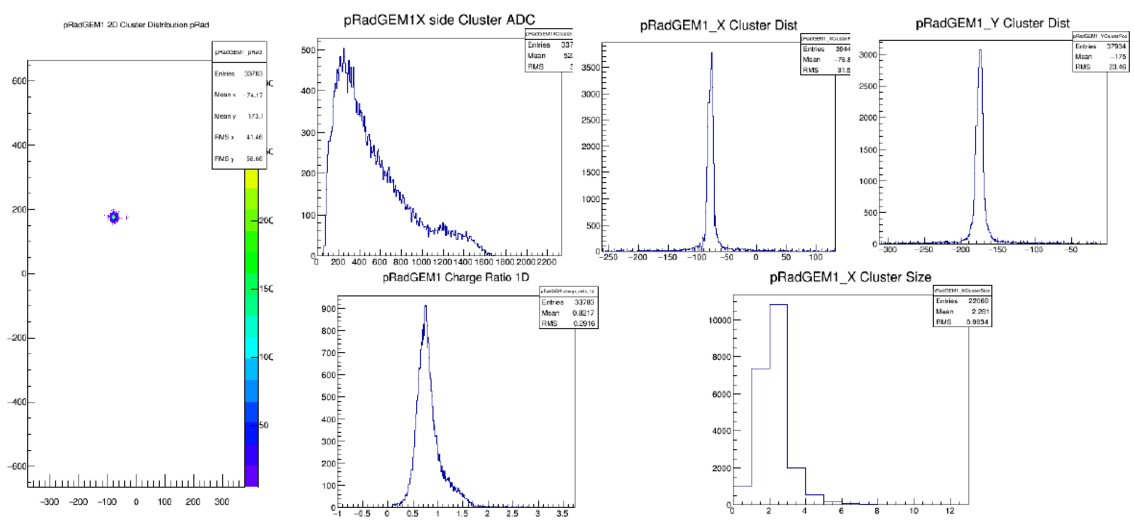
Use Timing Cut to select hits from Scintillator and HyCal.

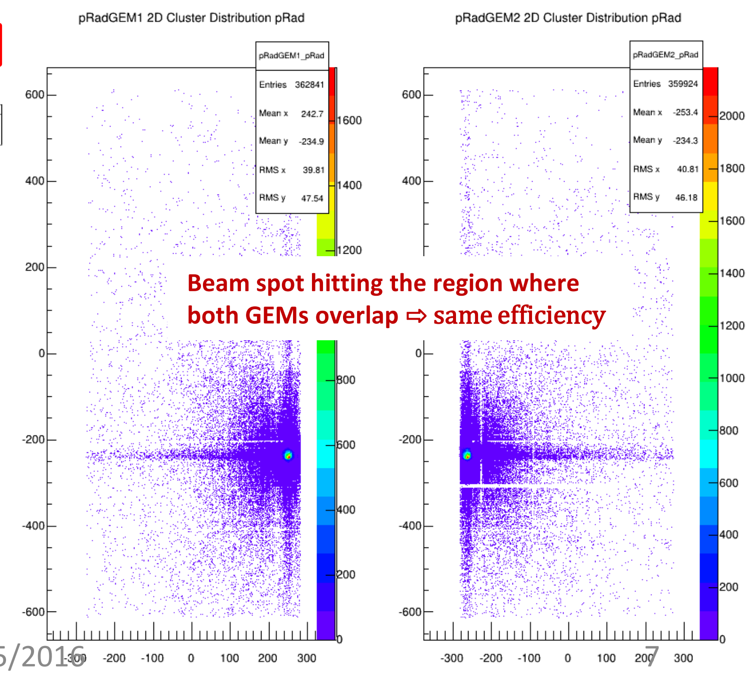




In Match with HyCal Position: W274

Total Events	After-cut events	GEM Events	Scin. Timing cut	HyCal Timing cut	Efficiency / Statistical Error
240819	22069	21069	7800 - 8100	7150 - 7550	95.5% / 0.66%





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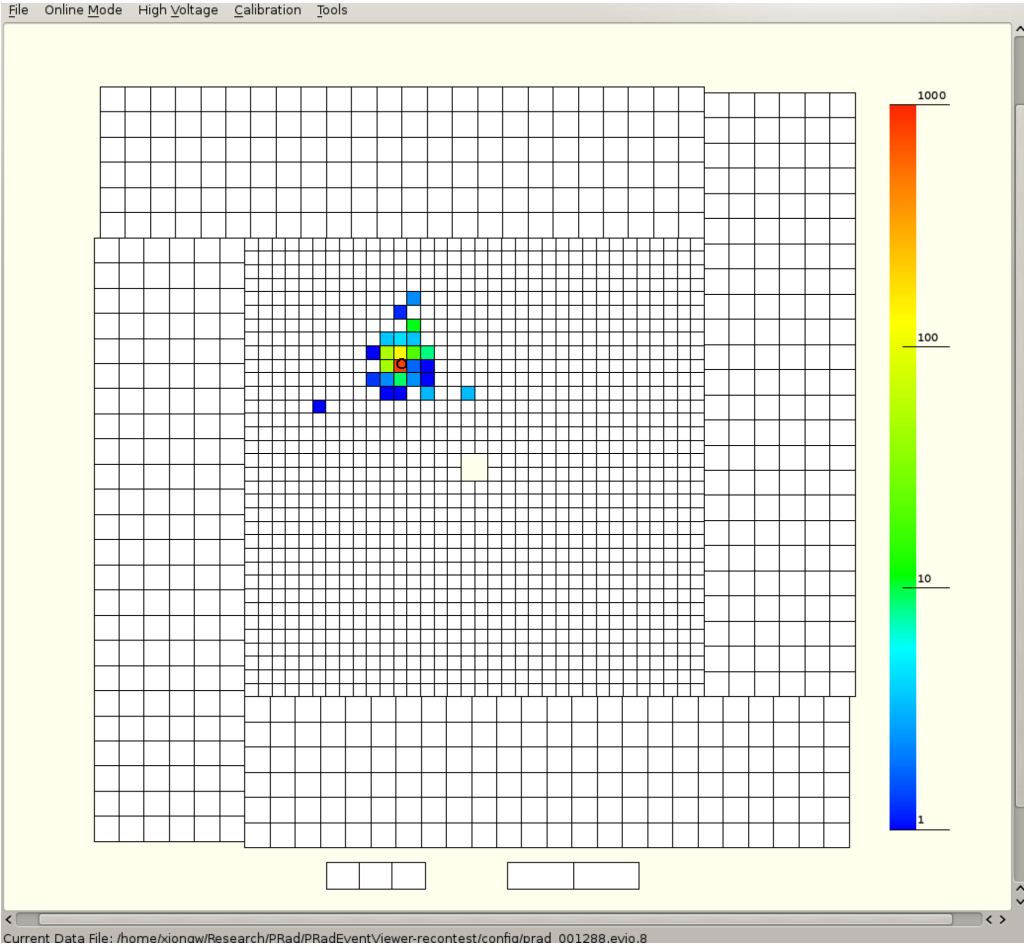
PRad production run program

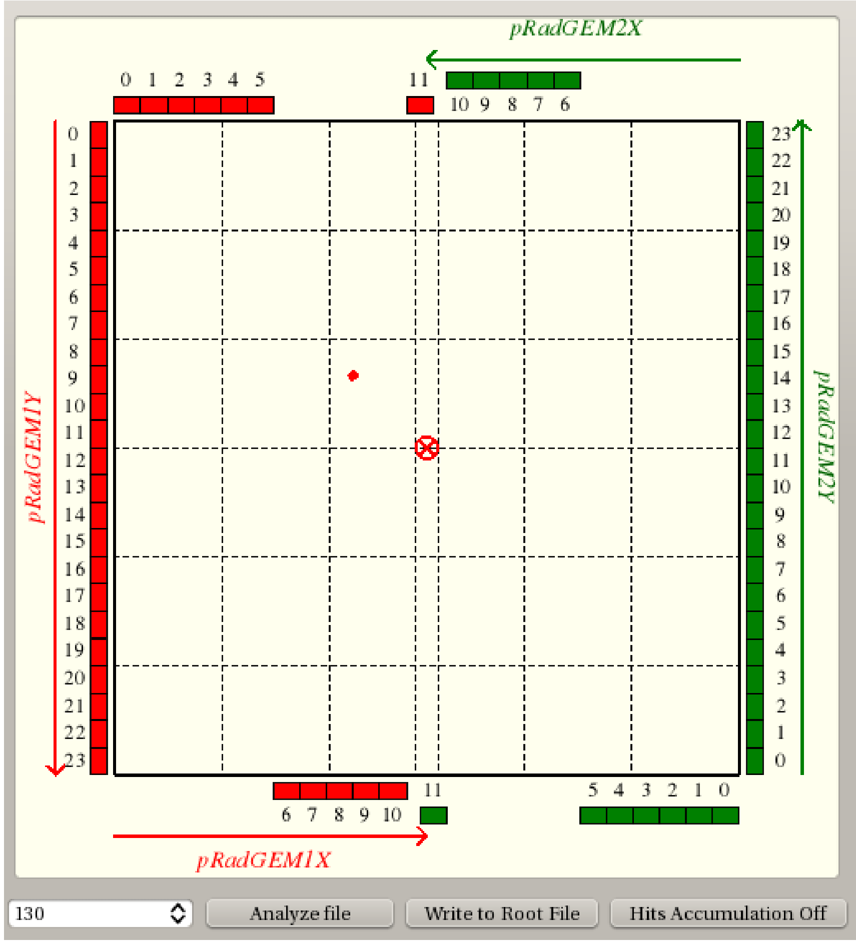
- DAQ Performances
  - With a 1.1 GeV beam @ 15 nA trigger rate ~ 3.8kHz and 87% live-time.
  - Successfully tested the online zero suppression during calibration run phase
  - Data rate ~400 MB/sec without APV data online zero suppression (production run)
    - However, the trigger rate not affected by APV25 raw data size and we have enough disk space ⇨ so production runs are without online zero suppression
- Reached production goal for 1.1 GeV beam on Hydrogen.
  - Over 500M events collected, about 25-30% are background and over 50M events with empty target.
  - GEM chambers with the SRS electronics ran flawlessly
- Just start the production run at 2.2 GeV (Until June 21st)

1.1 GeV Production run: Online event matching between GEM and HyCal

HyCal



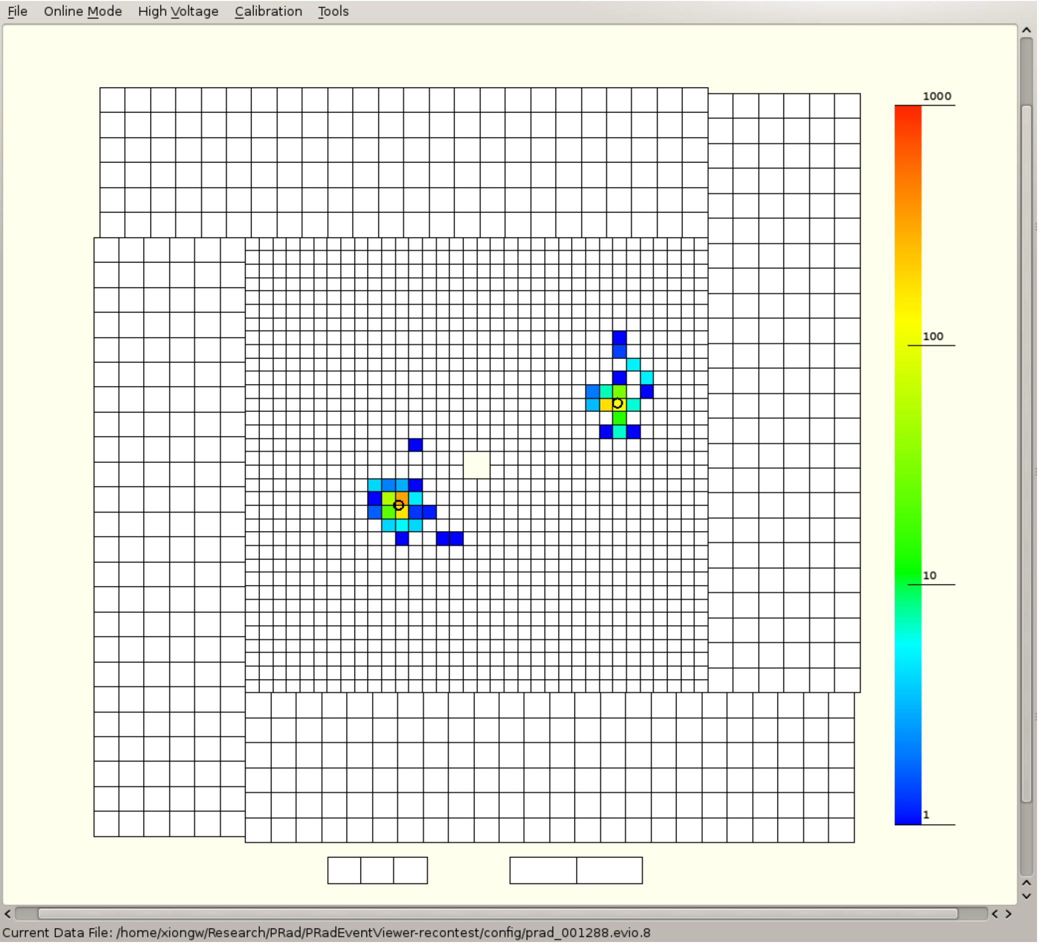
GEMs



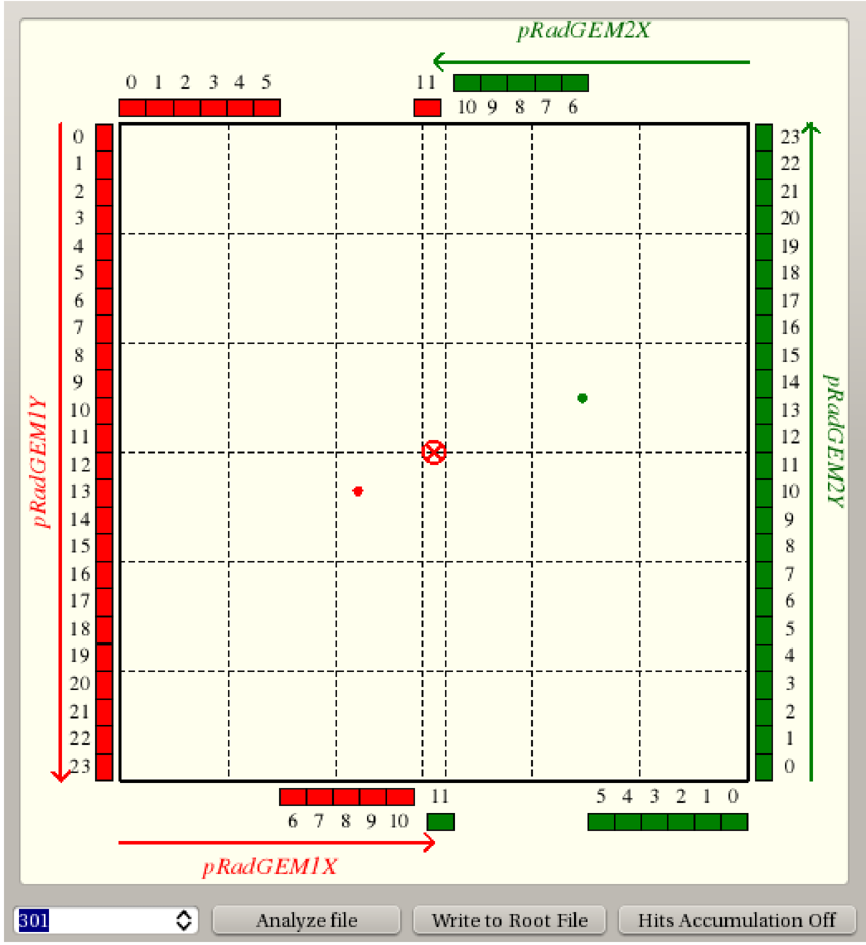
An e-p elastic scattering event

1.1 GeV Production run: Online event matching between GEM and HyCal

HyCal



GEMs

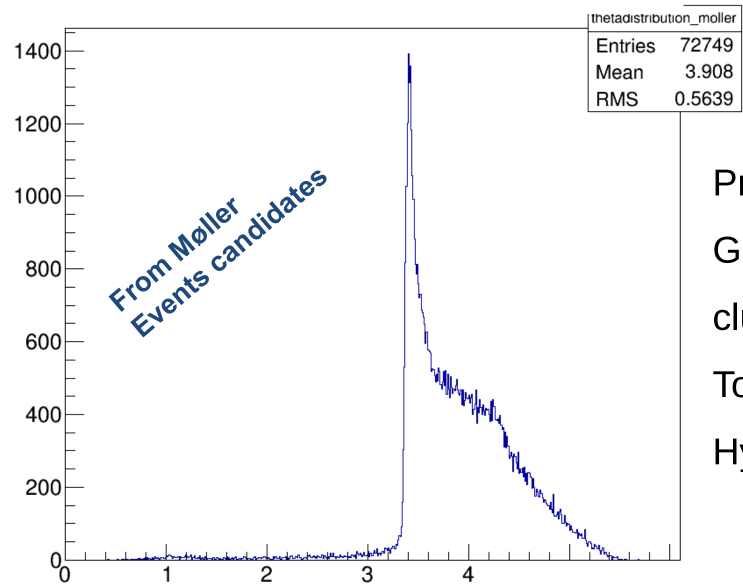


An e-e Møller event

Preliminary results from 1.1 GeV Production run

(Xinzhan's preliminary analysis)

θ distribution of double cluster events

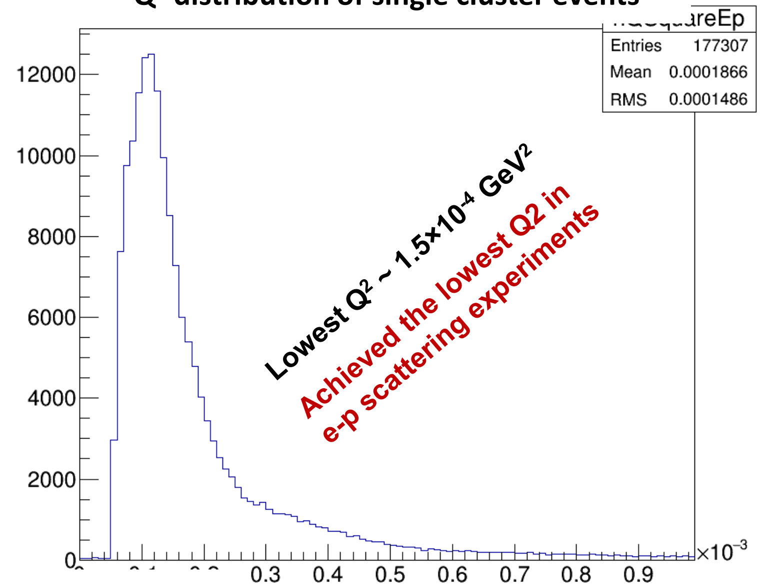


Møller opening angle θ (deg)

Preliminary matching of GEM hits with HyCal clusters ($PbWO_4$ only)

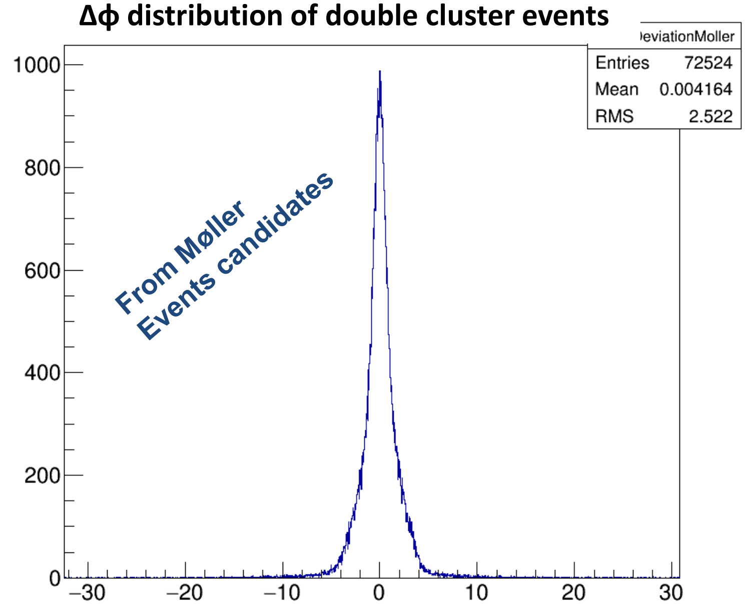
Total cluster energy in HyCal > 700 MeV

Q^2 distribution of single cluster events

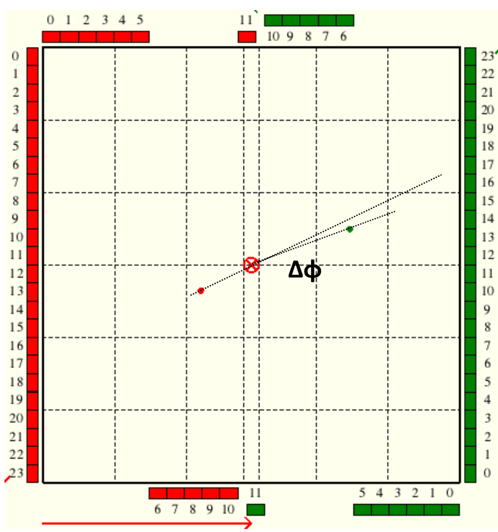


Q^2 (GeV^2)

Δϕ distribution of double cluster events



Møller coplanarity angle Δϕ (deg)



Summary

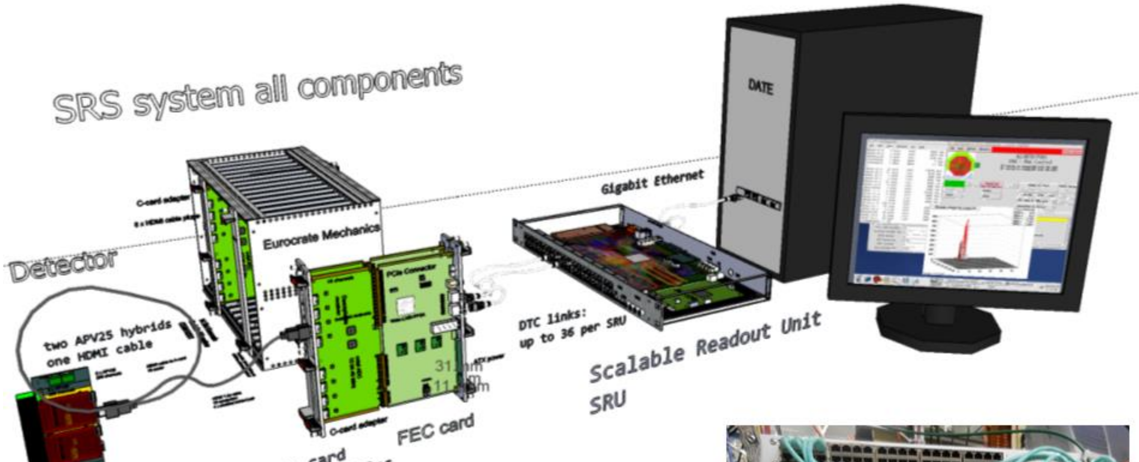
- The PRad Experiment runs
    - Experiment has been successfully running for about 4 weeks
    - Over 600M events collected (with about 25-30% background) for the 1.1 GeV run
    - 2.2 GeV run just started and expect to run until June 21st
- Large PRad GEM chambers have been performing well
    - Two chambers performing at ~ 95% efficiency in the beam
    - Upgrade done on the APV25-based SRS electronics validated with the 1.1 GeV beam run
    - Trigger rate of the full DAQ (SRS and Fast bus crates) stable at 3.8 kHz with 87% live time
    - Preliminary results from analysis show expected performances of the GEMs will be met

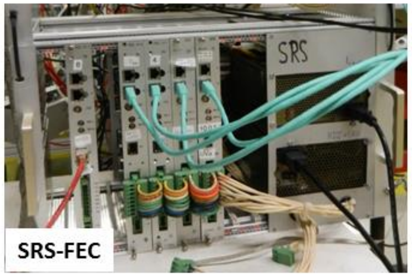
Back Up

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.





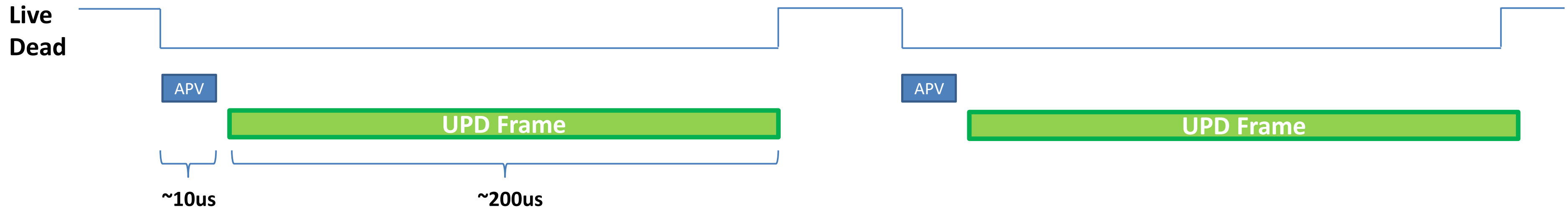
Need for the PRad GEMs:

- 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-FEC Firmware Upgrade: Trigger Buffering

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

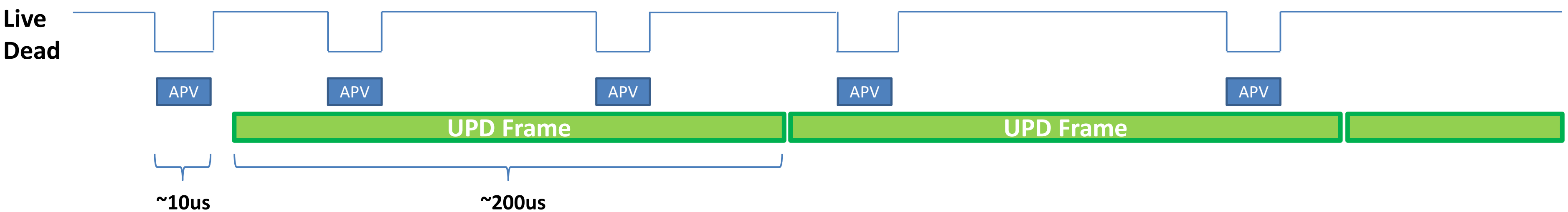
Non-buffered trigger FEC firmware (original):



- 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

(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).

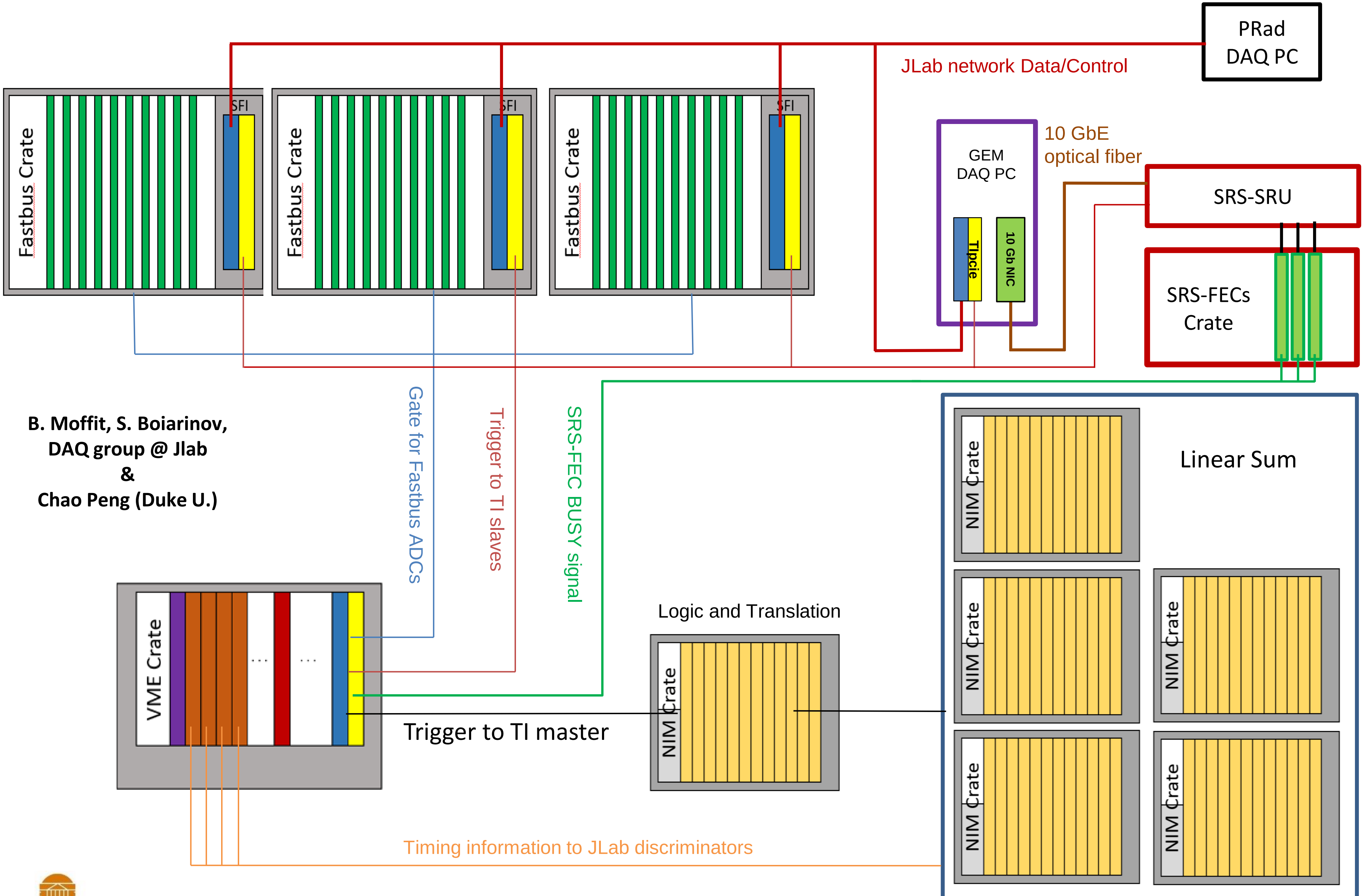
Software librairies for the slow control

- 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 reduction factor ~ x200**
- Online monitoring of Raw APVdata and GEM hits

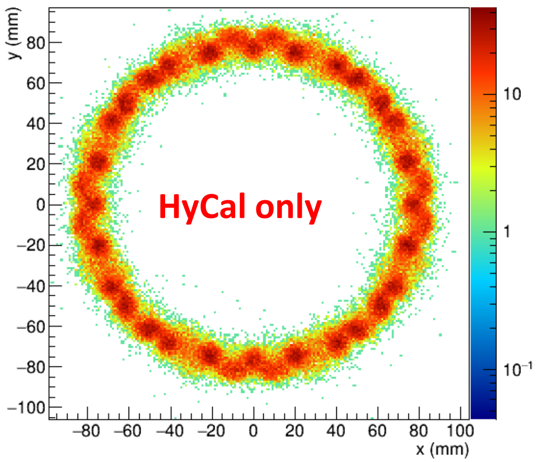
Integration of SRS into JLab DAQ: PRad DAQ Overview



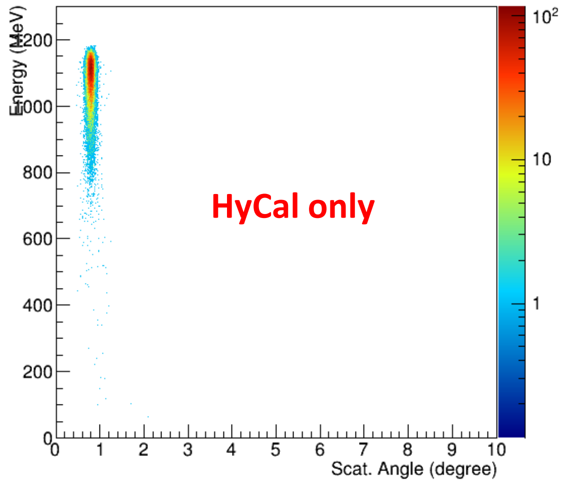
B. Moffit, S. Boiarinov,
DAQ group @ Jlab
&
Chao Peng (Duke U.)

Monte Carlo Simulation: Impact of GEMs on the performances

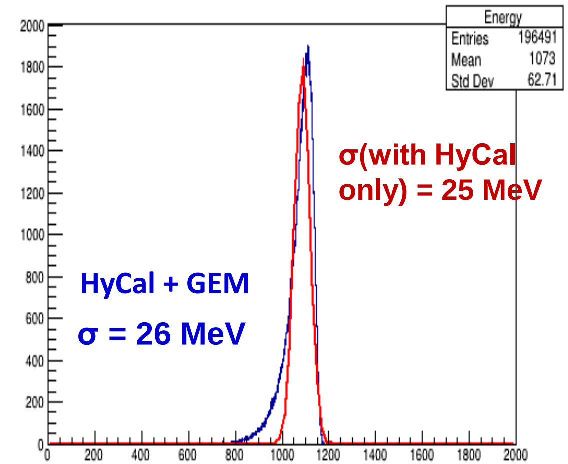
Reconstructed theta ring (0.8 degree)

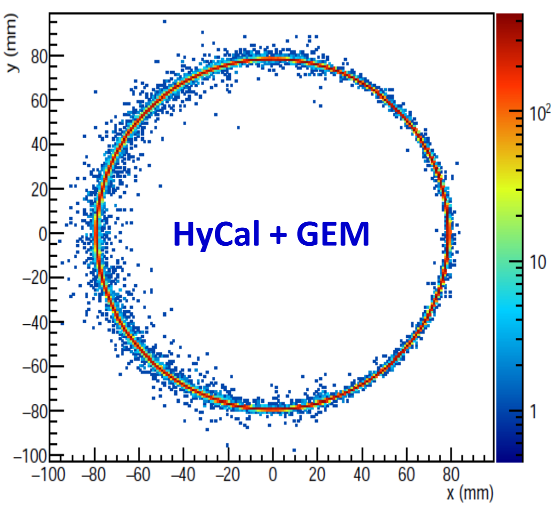


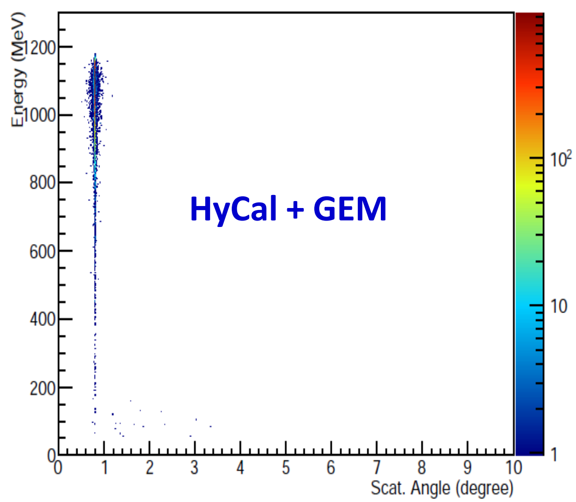
Energy vs. angle, reconstructed hits



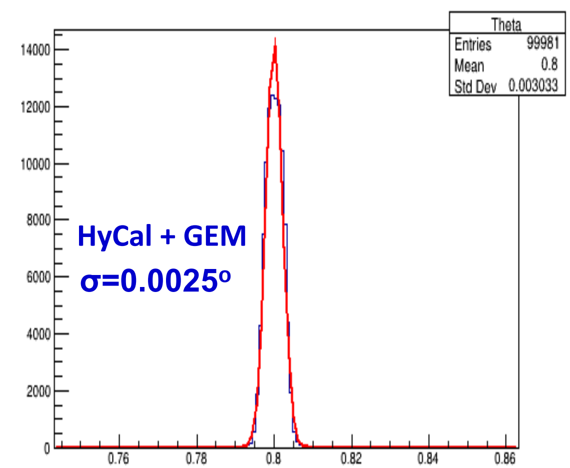
Energy reconstruction







angle reconstruction



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