Performances of the SRS during the PRad experiment

Kondo Gnanvo

University of Virginia, Charlottesville, VA

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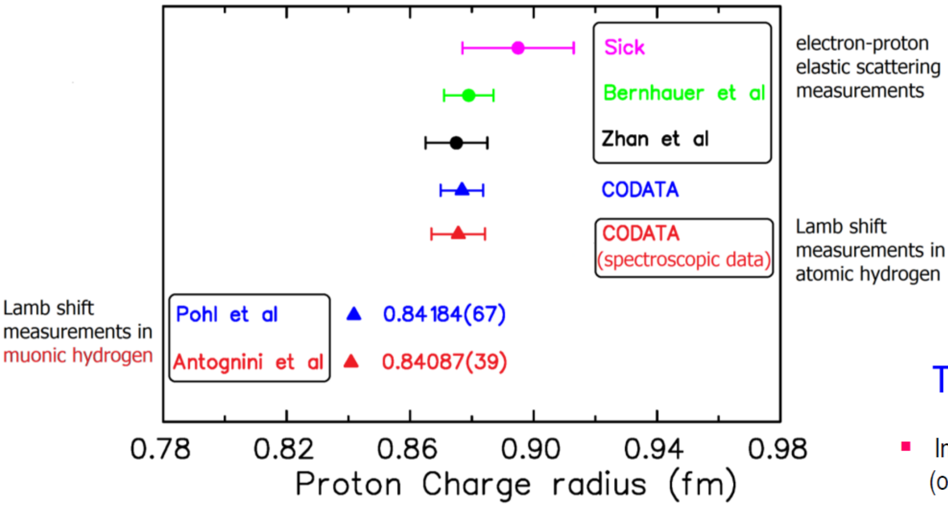
Outline

- ✓ Upgrade of SRS firmware
- ✓ SRS configuration for PRad run
- ✓ Performances of the readout

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

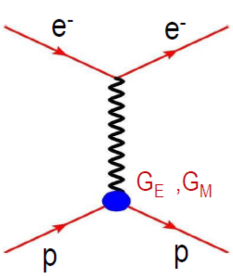
- Non Magnetic spectrometer
- High resolution and high acceptance calorimeter ⇨ low scattering angle [0.7° - 3.8°]
- Simultaneous detection of ee → ee (Moller Scattering) ⇨ minimize systematics
- High density windowless H_2 gas ⇨ minimze background
- clean CEBAF electron beam (1.1 GeV & 2.2 GeV) ⇨ minimze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

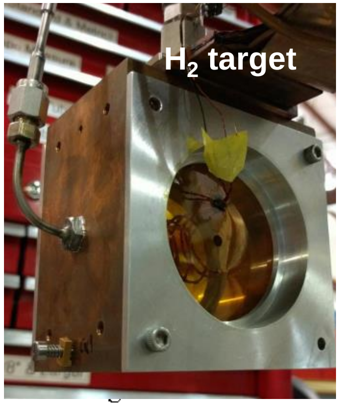
Target specs:

Cell: 30 μm thick Kapton, length 4 cm

- diameter 8 cm with 2 mm diameter holes for the beam to pass through
- Cell pressure 0.5 torr

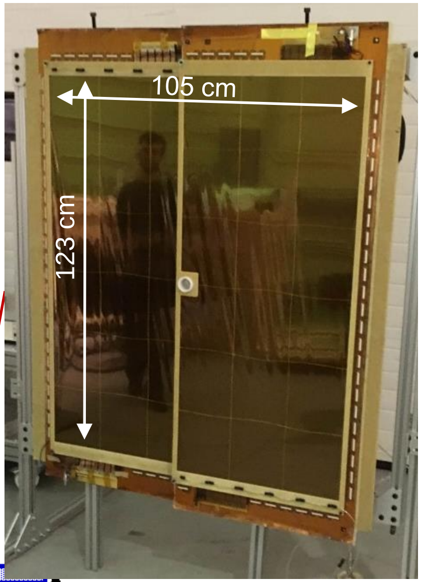
Target: H_2 input gas temp. 19.5 K

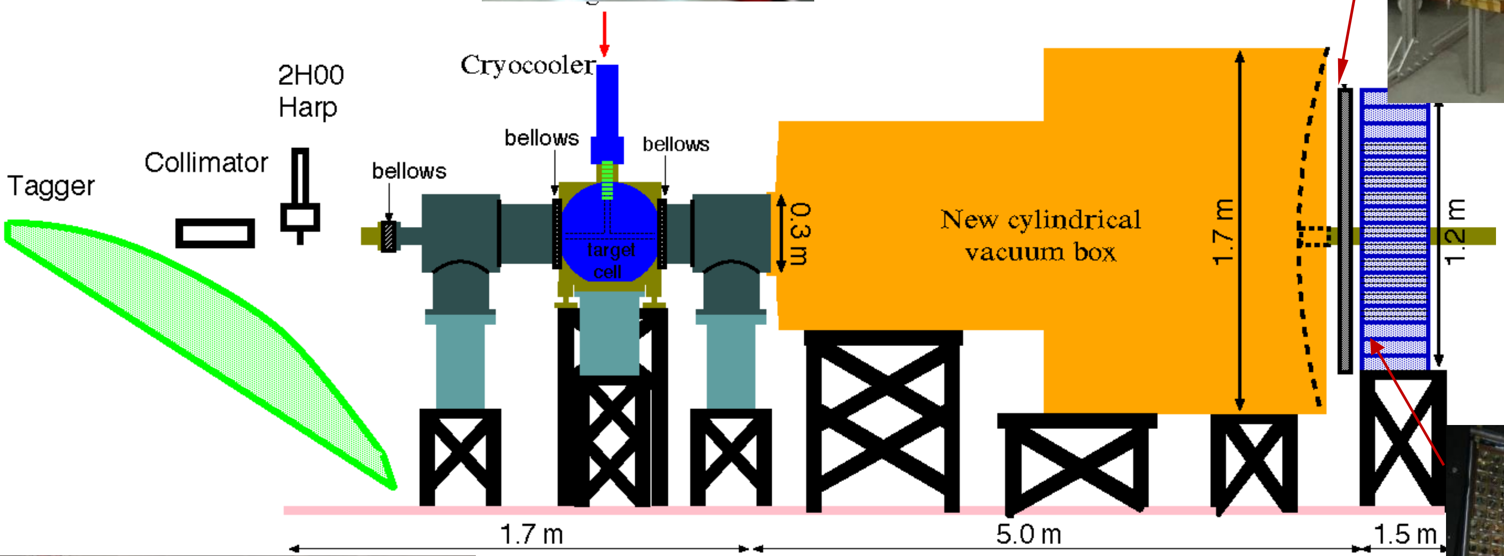
- thickness 2×10^{18} **(atoms)** / cm^2
- density 2.75×10^{17} **(molecules)** / cm^3
- Vacuum in target chamber ~5×10^{-3} torr



GEMs:

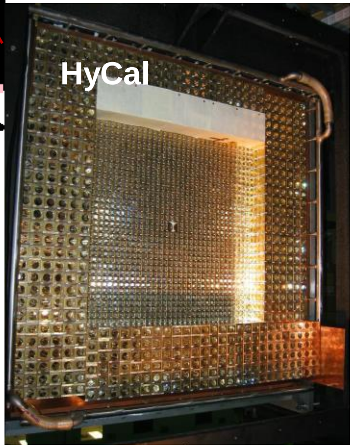
- factor of >10 improvements in coordinate resolutions, similar improvements for Q^2
- unbiased coordinate reconstruction (transition region), increase Q^2 range by including Pb-glass





HyCal specs:

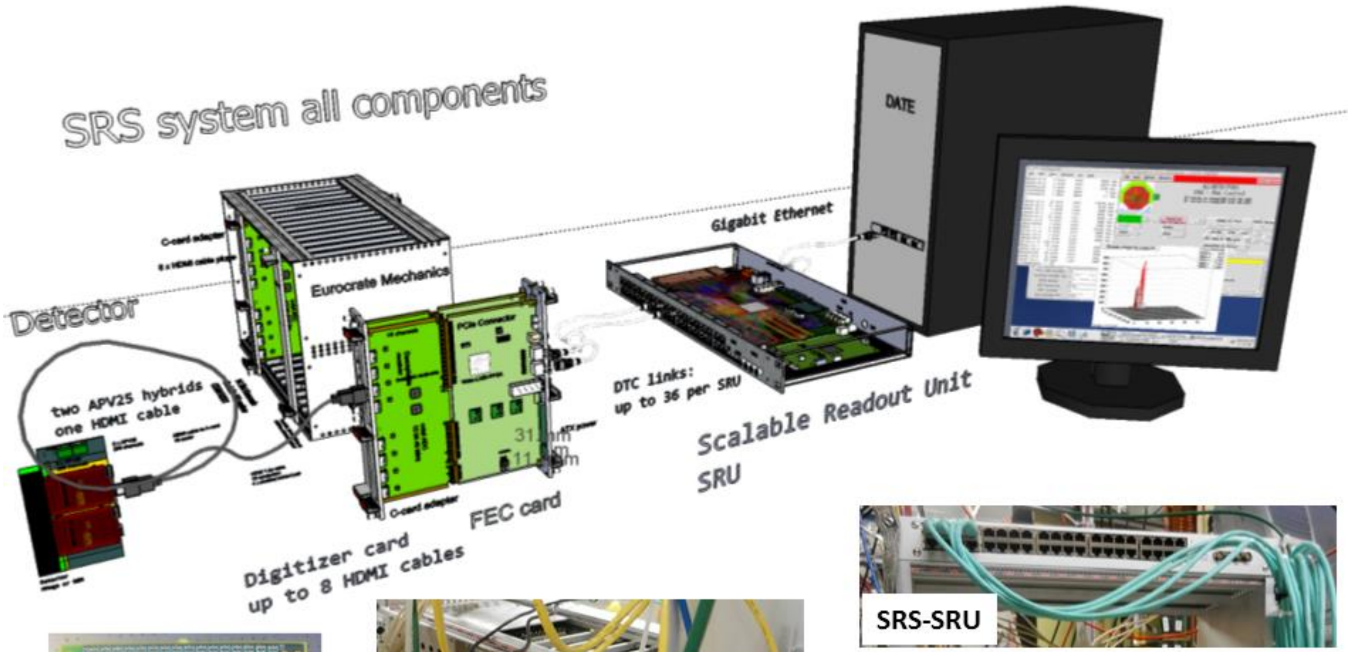
- 34 x 34 matrix of 2.05 x 2.05 x 18 cm^3 PbWO4
- 576 Pb-glass shower detectors (3.82x3.82x45.0 cm^3)
- 5.5 m from H_2 target (~0.5 sr acceptance)
- Resolutions for PbWO4, $\sigma/E = 2.6\ \%/\sqrt{E}$, $\sigma_{xy} = 2.5\ \text{mm}/\sqrt{E}$
- Resolution for Pb-glass shower factor of ~2.5 worse

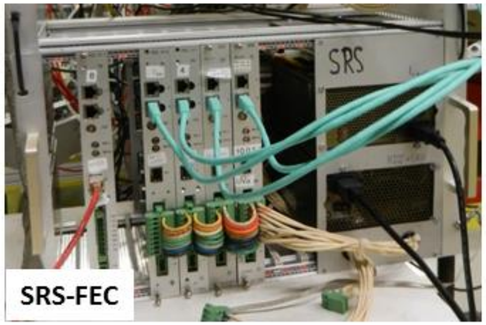


APV25-SRS for PRad GEMs: Challenges @ 5kHz trigger rate

Need for each PRad GEM chambers ⇨ **reading out 4.6 K Channels @ trigger peak rate at 5 kHz**

- One SRS crate with 4 ADC / FECs, 9 APVs and 1 SRU to send the data to the DAQ PC, 3 AP25 time samples
- Integration of the SRS electronics into JLab DAQ (CODA software) required
- Necessary firmware upgrades needed to achieve the data rate of 5 kHz





APV25-SRS for PRad GEMs: Challenges @ 5kHz trigger rate

- Data from APV25 data to FEC cards:
    - 3 time samples: readout mode is about 100 kHz (10 μs), no problem for PRad GEMs readout
- Data from FEC to SRU:
    - 1Gb Ethernet (125 MB/s), data transfered through UDP
    - Rate capability 80 MB/s: 800 Mbps line speed × 80% (for 8b10b line encoding overhead).
    - 3 time samples mode: the APV25 data size per event is ~ 1 kB ⇨ transfer rate @ 5 kHz = 5 MB/s
    - Fixed trigger rate: the data transfer is ~ 60 MB/s with 12 APV25/ FECs (45 MB/s for with 9 APV25)
    - ✓ **Firmware upgrade (done) for random trigger rate**: Implementation of trigger buffering
- Data from SRU to GEM DAQ PC:
    - Default SRU implementation: 1Gb Ethernet (125 MB/s), data transfered through UDP
    - First bottleneck to address: SRU data from 36 APV25 ⇨ minimal transfer rate @ 5 kHz = 180 MB/s
    - ✓ **Firmware upgrade (done):** Implementation of 10 Gb optical link to the GEM DAQ PC
- Data from GEM DAQ PC to PRad DAQ PC:
    - Data are sent from GEM DAQ PC to the PRad DAQ computer via JLab network ⇨ GEM DAQ PC has the TIpcie interface
    - Limited bandwidth to send the data to PRad DAQ PC and write them into disk (APV25 data size @ 5kHz = ~ 400 MB/s)
        - **Zero suppression** is done in GEM DAQ PC before the transfer of the data to PRad DAQ PC
        - APV25 data size reduced by ~ more than a factor 100 to **just a couple MB/s**

Upgrade of SRU Firmware: 10 Gb Optical link

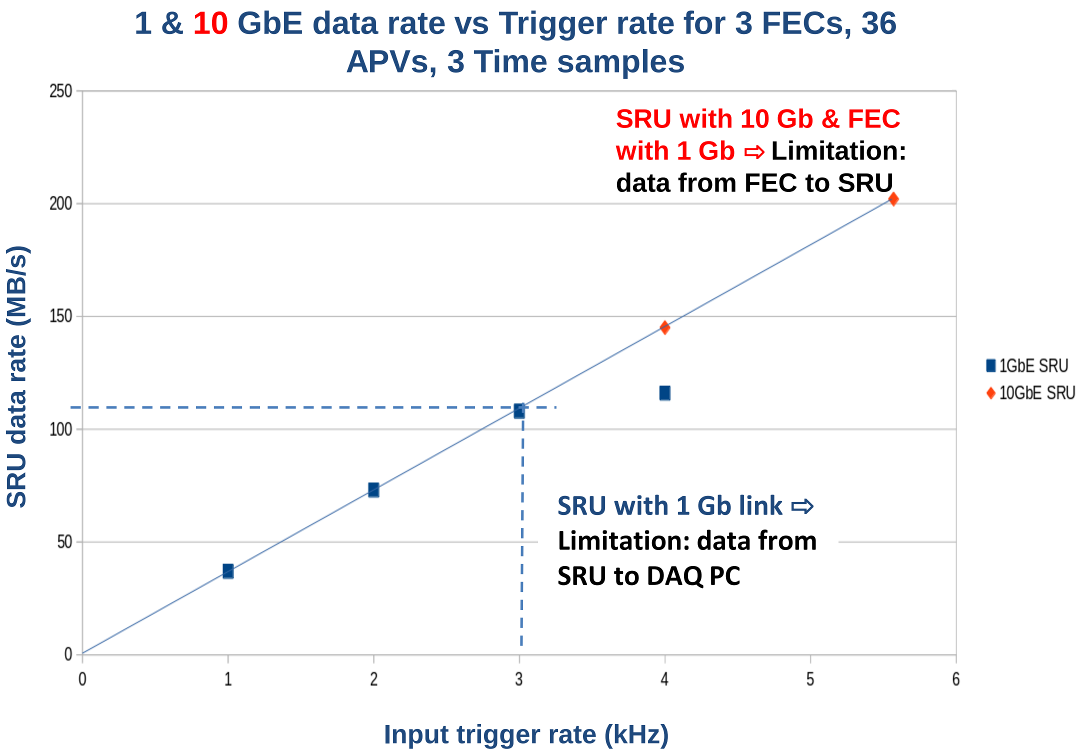
(JLab DAQ & Fast Electronics Groups)

Upgrade the existing 1Gb SRU firmware from RD51 CERN

- Standard SRU firmware developped for the APV25 electronics with 1Gb Ethernet link
- **10 Gb Optical link firmware** previously developped at CERN was available **but** not compatible with standard firmware
- Merging the two firmware and testing with the APV25 electronics by JLab Fast electronics group

Test Setup

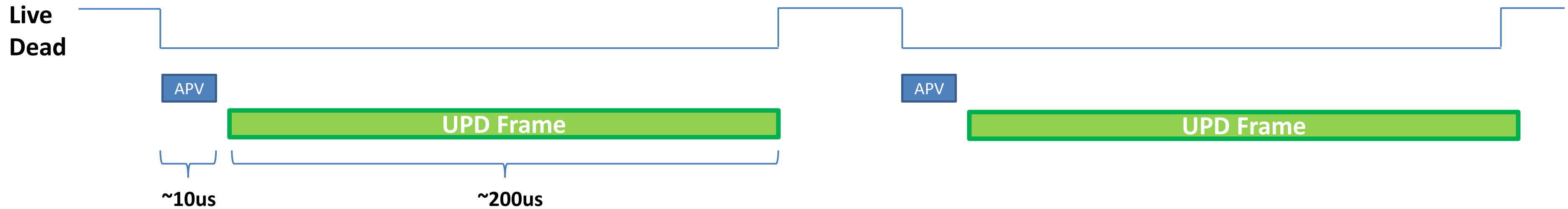
- 36 SRS-APV25 hybrids, connected to 3 FECs (event size 38.5 kB), calibration pulse with internal trigger @ 3 time samples (3TS)
- Rate tests with 1Gb Copper link and upgraded 10 Gb Optical fiber link
- 1Gb SRU: Saturation at ~3.2 kHz (max expected rate before saturation **~ 3.3 kHz)**
- 10Gb SRU: linear data transfet speed up **to 5.5 kHz ⇨ saturation** expected beyond 6 kHz (FEC data to SRU @ 80 MB/s)



Upgrade of FEC Firmware: Trigger Buffering

(JLab DAQ & Fast Electronics Groups)

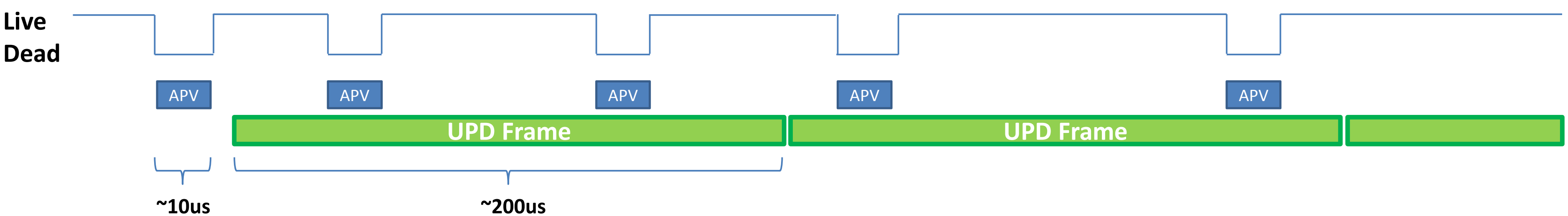
Non-buffered trigger FEC firmware (original):



- 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.

Upgrade of FEC Firmware: Source codes changes

(JLab DAQ & Fast Electronics Groups)

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Old firmware (standard)

- APV chip has a 4096 deep sample buffer. When capturing a few samples (e.g. 3), only a fraction of this buffer is used.
- **The firmware performs the following steps sequentially:**
  1. receive a trigger and capture APV data
  2. wait for the data to be fully processed by the UDP processor
  3. Ready to accept another trigger.

New firmware

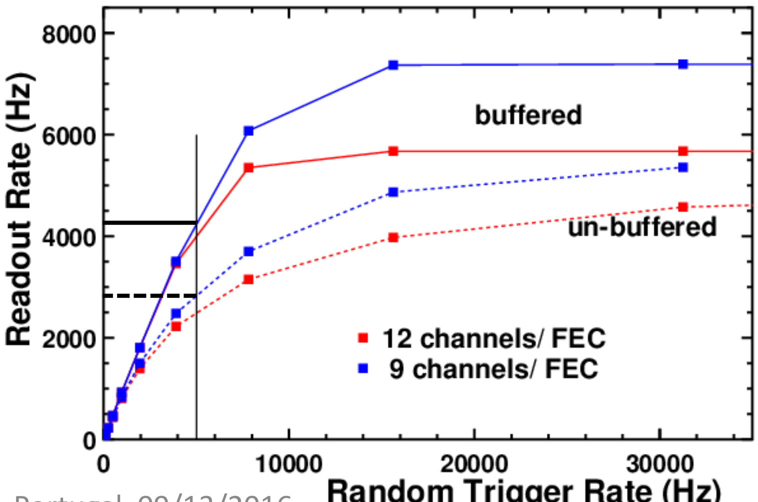
- writes multiple events in the existing buffer circularly. A new FIFO was added that gives a pointer into this buffer (along with other trigger header information) to the UPD packet processor.
- **The new firmware performs the following steps in parallel:**
  1. Receive a trigger, capture APV data, ready to accept another trigger
  2. Check trigger FIFO, build UPD packets
  3. Check circular buffer and send BUSY if no more events can be accepted.
- Trigger processing dead time ~25 μs, up to 10 triggers can be buffered
- BUSY output (NIM Out): Busy Feedback to Trigger Supervisor for more efficient acceptance of triggers without assumptions of FEC processing dead time.
- Without buffering, as a test example, we needed up to 70kHz input rate to readout near 5kHz ⇨ dead-time close to 100%. With buffering enabled the input rate slightly over 5kHz provide 5kHz readout rate ⇨ dead-time ~15% few percent.

Preliminary tests

- 9 / 12 APV25 (ADC channels), on 1 FEC with 3 time samples to the SRU (Expected configuration for PRad)
- Random pulse generator board with both buffered and un-buffered Trigger tested simultaneously
- Additional tests was done with multiple FECs ⇨ for debbugging and troubleshooting
- Cosmic data test setup with the GEM chambers is underway to test the full DAQ with all the changes

Validation @ 5 kHz random trigger rate

- 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



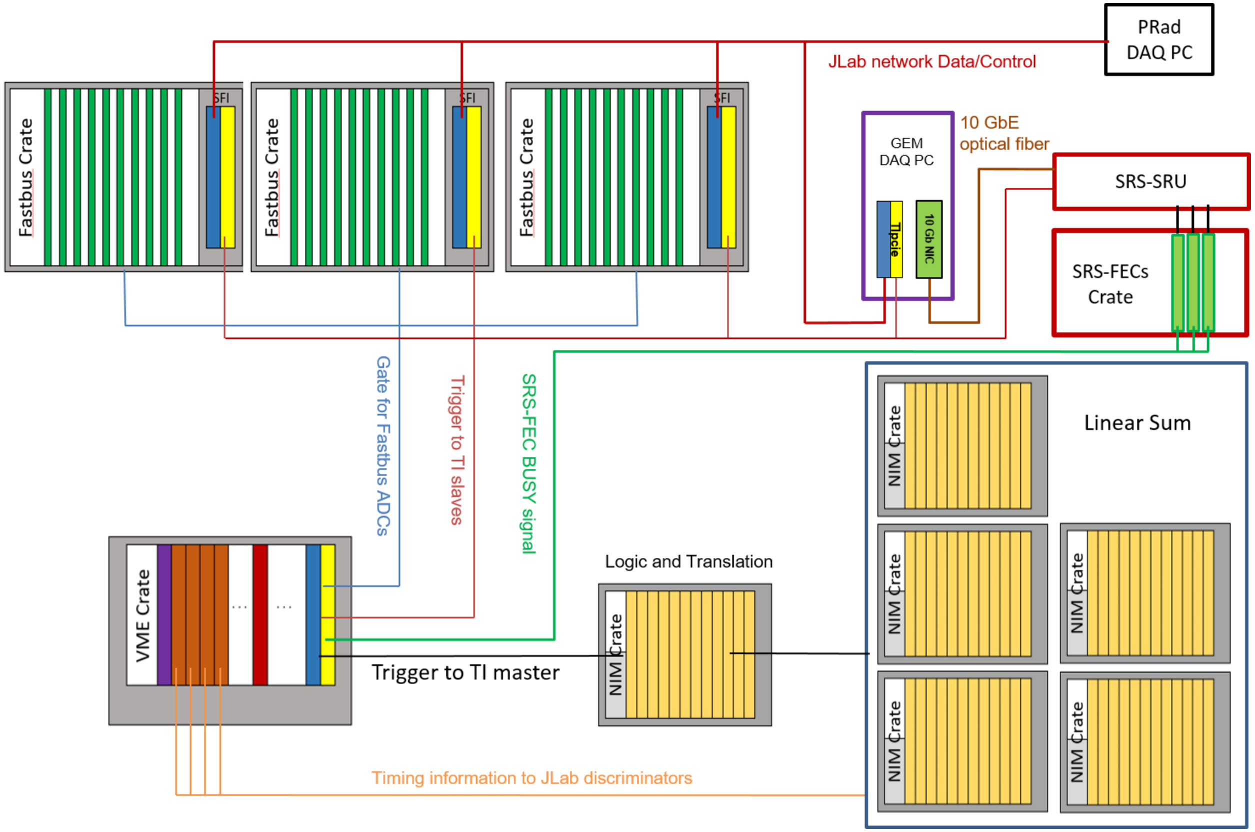
Integration of APV25-SRS into JLab DAQ system (CODA)

(JLab DAQ & Fast Electronics Groups)

PCIexpress Trigger Interface (TIpcie) ⇨ **PC / Server Integration into JLab DAQ**

- Using multiple cores/threads for data processing / data reduction
- Standard PC Hardware allows for multiple network cards (1G, 10G, Infiniband)
- Fiber Connection (Clock, Trigger, Sync) to Trigger Supervisor (TS)
- Runs in Standalone (Master) or Larger-Scale DAQ (Slave).

Interface to SRS ⇨ **SRU receive trigger from Tipcie, FECs send BUSY to TS**



Software librairies for the slow control

- C Library written to be used with CODA, **but also works standalone**
- Compatibility: REDHAT EL5, EL6 (i386, x86_64)
- Zero suppression algorithm by CODA Event Builder in the DAQ PC

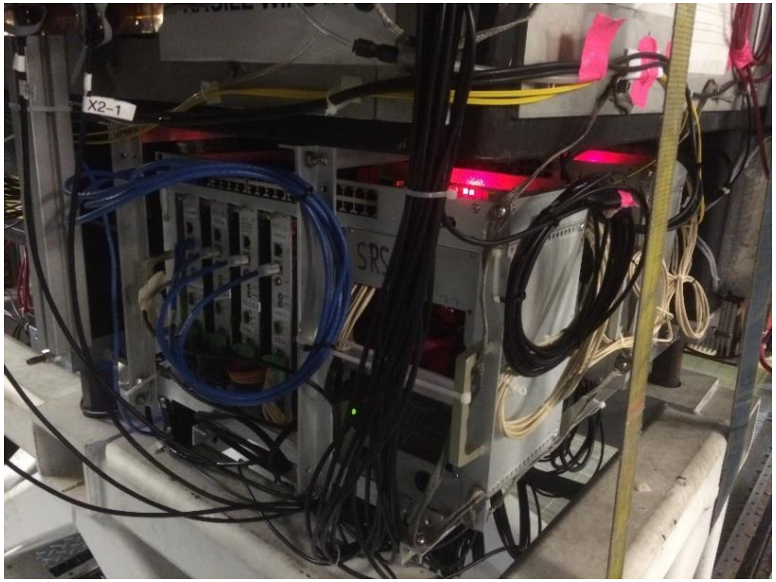
Online monitoring tool

- Raw APV25 data frames as well as hit after zero suppression are available for online monitoring during the life time of PRad run lifetime

GEMs and SRS readout on the beamline in Hall B @ JLab

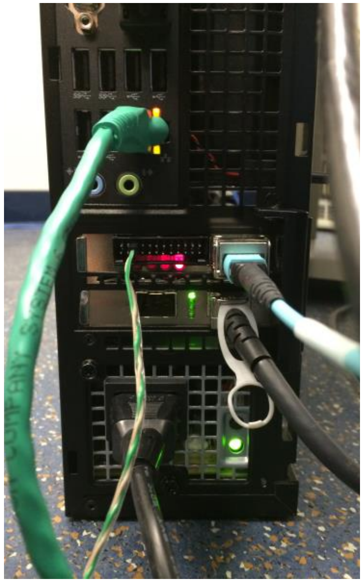
(May – June 2016)

2 SRS-SRU crates underneath the HyCal and GEMs



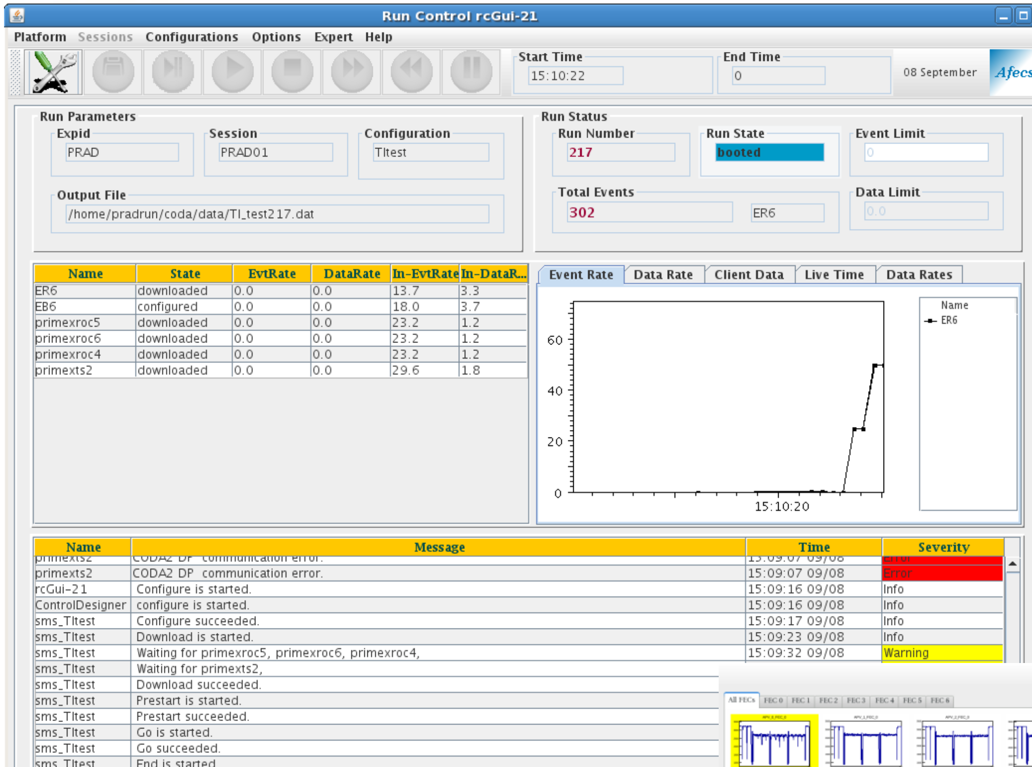
2 PRad GEMs equipped with the APV25-FE cards

Back end of the DAQ PC



Online monitoring SRS readout during PRad run

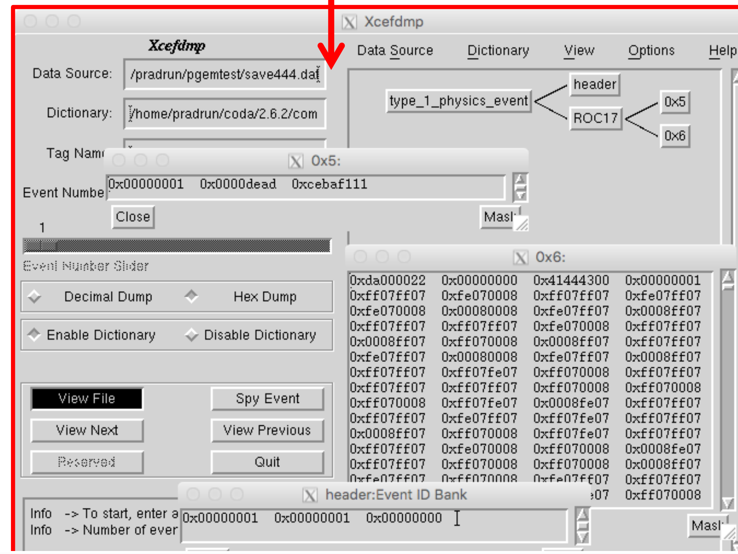
(May – June 2016)

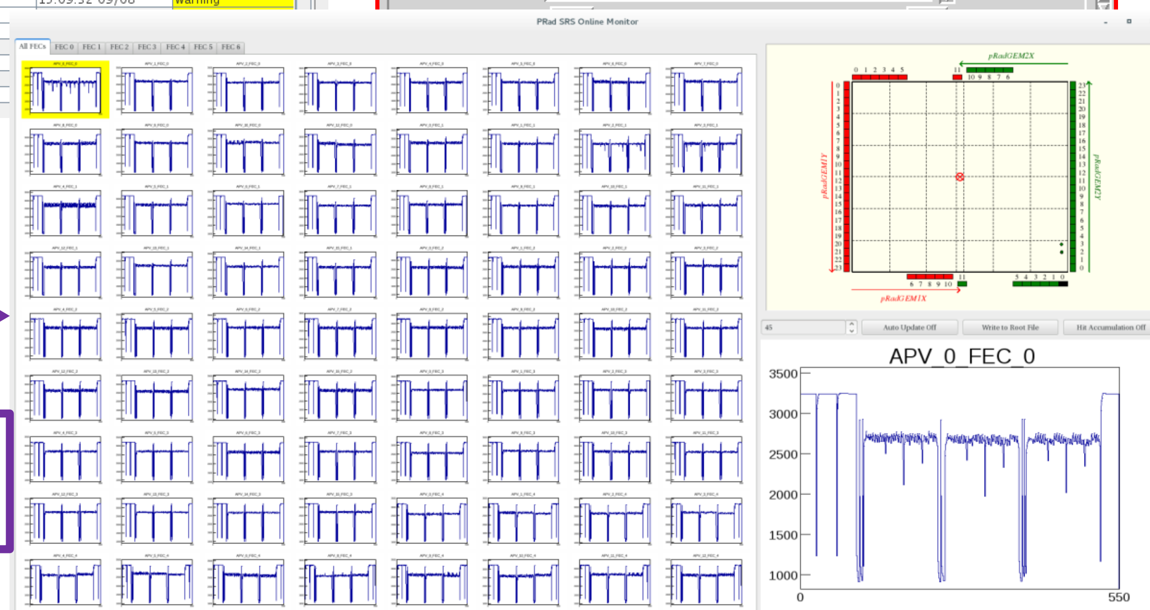


Name	State	EvtRate	DataRate	In-EvtRate	In-DataR...
ER6	downloaded	0.0	0.0	13.7	3.3
EB6	configured	0.0	0.0	18.0	3.7
primexroc5	downloaded	0.0	0.0	23.2	1.2
primexroc6	downloaded	0.0	0.0	23.2	1.2
primexroc4	downloaded	0.0	0.0	23.2	1.2
primexts2	downloaded	0.0	0.0	29.6	1.8

Name	Message	Time	Severity
primexts2	CODA2 DP communication error.	15:09:07 09/08	Error
rcGui-21	Configure is started.	15:09:16 09/08	Info
ControlDesigner	configure is started.	15:09:16 09/08	Info
sms_TItest	Configure succeeded.	15:09:17 09/08	Info
sms_TItest	Download is started.	15:09:23 09/08	Info
sms_TItest	Waiting for primexroc5, primexroc6, primexroc4,	15:09:32 09/08	Warning
sms_TItest	Waiting for primexts2,		
sms_TItest	Download succeeded.		
sms_TItest	Prestart is started.		
sms_TItest	Prestart succeeded.		
sms_TItest	Go is started.		
sms_TItest	Go succeeded.		
sms_TItest	End is started.		

SRS Data Frame.





A typical CODA (2.6.2) event viewed with "xcefdmp" utility showing SRS data bank with other information.

Online monitoring of APV25 raw data frames

Experimental data collected during PRad run

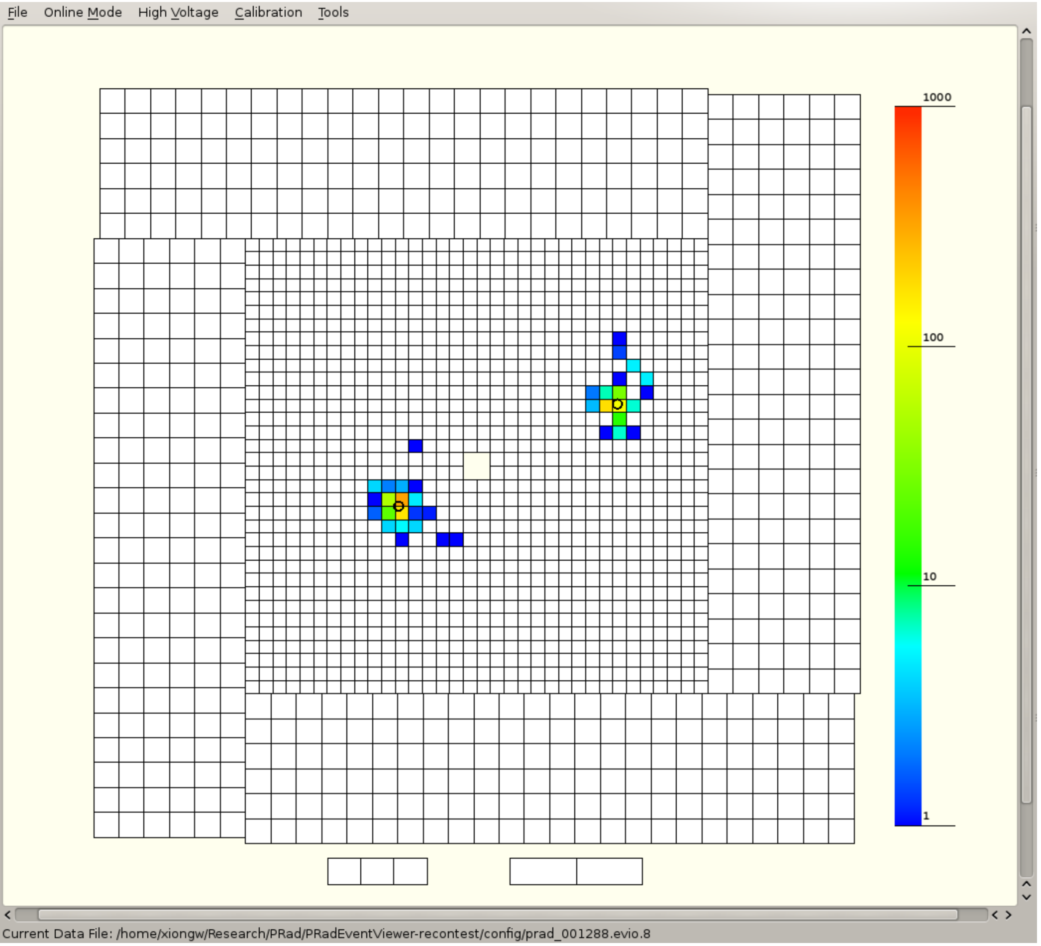
(May – June 2016)

- E_e = 1.1 GeV beam:
  - 4.2 mC (target density: 2x10^{18} H atoms/cm^2)
  - **604 M** events with target;
  - **53 M** events with "empty" target;
  - **25 M** events with ^{12}C target for calibration.
- E_e = 2.2 GeV beam:
  - 14.3 mC (target density: 2x10^{18} H atoms/cm^2)
  - **756 M** events with target;
  - **38 M** events with "empty" target;
  - **10.5 M** events with ^{12}C target for calibration.

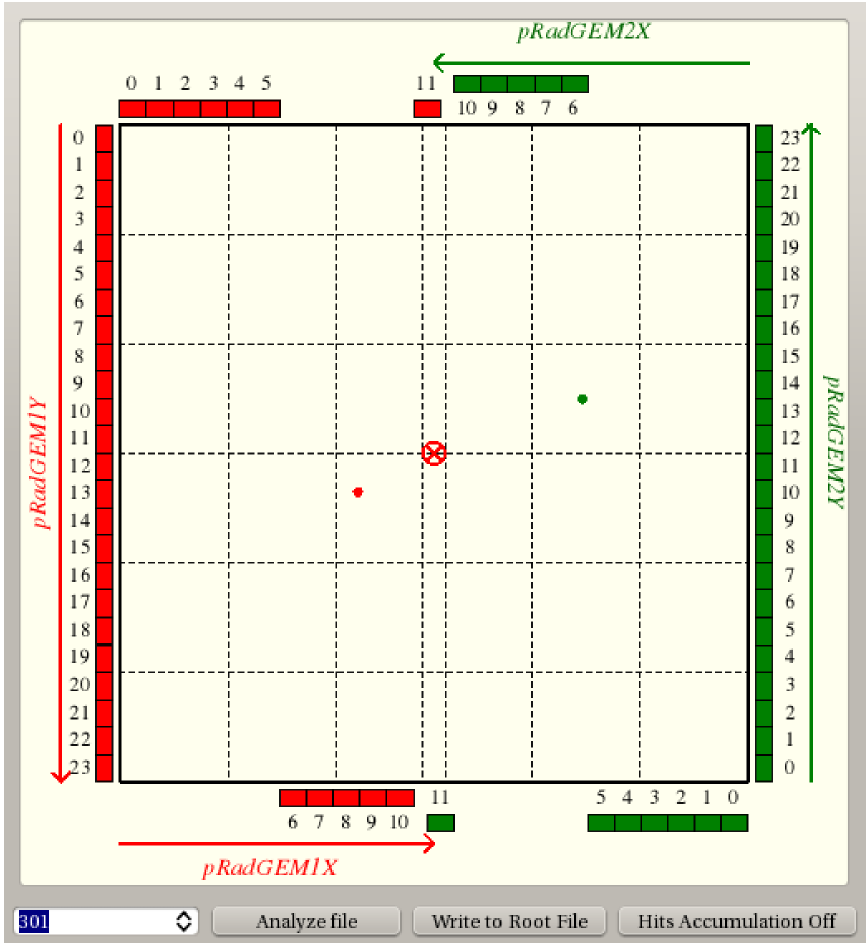
- DAQ Performances
  - Average trigger rate **4.4 kHz** with average DAQ rate ~ 3.8kHz (Full DAQ system)⇨ 87% live-time.
  - The online zero suppression was tested during calibration run phase
  - Data rate ~600 MB / sec without **APV data online zero suppression** (production run)
  - However, the trigger rate not affected by APV25 raw data size and we had enough disk space ⇨ so **production runs are without online zero** suppression
  - Smooth and stable performance of the SRS readout during the 6 weeks long PRad run

Online Event monitoring with 1.1 GeV beam

HyCal



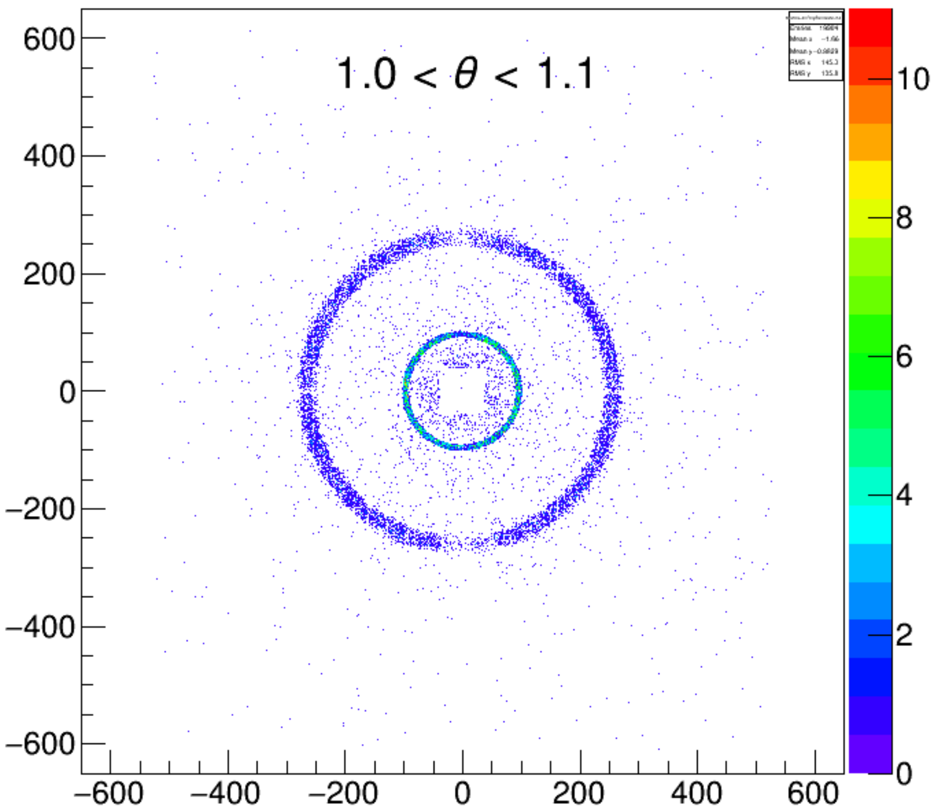
GEMs



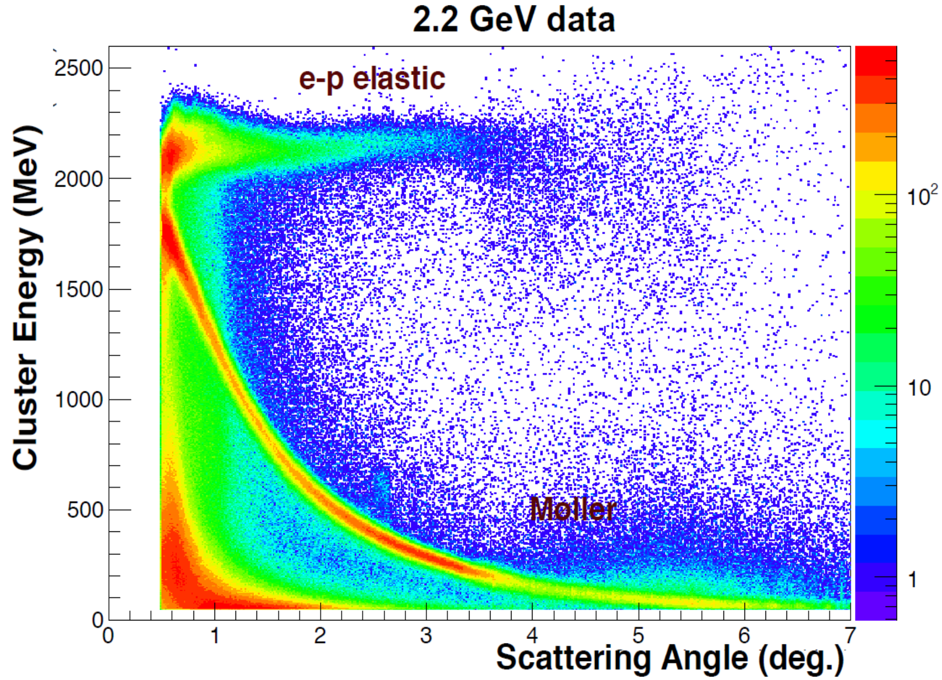
An e-e Møller event matching between HyCal and GEMs

Some very preliminary results

2 clusters



The X−Y distribution of the two Møller scattered electrons on the GEMs the angular range of $1 < \theta < 1.1$ degree



Angle measurement by GEMs and energy by HyCal

Summary

- The APV25-SRS has been adopted to readout electronics of PRad GEMs
- SRS Firmware have been upgraded to read out > 9k channels at 5 kHz trigger rate
- Integration of the APV25-SRS into JLab DAQ system (CODA) was successfully done
- Smooth and stable performance of the APV25-SRS readout during the PRad run
  - 1.4 billions events at an average trigger rate of 4.4 kHz and 87% live time