Update on PRad GEMs, Readout Electronics & DAQ

Kondo Gnanvo

EIC Weekly Meeting, 2016

Outline

- ✓ PRad GEMs update
- ✓ Upgrade of SRS electronics
- ✓ Integration into JLab DAQ system
- ✓ Cosmic tests in EEL

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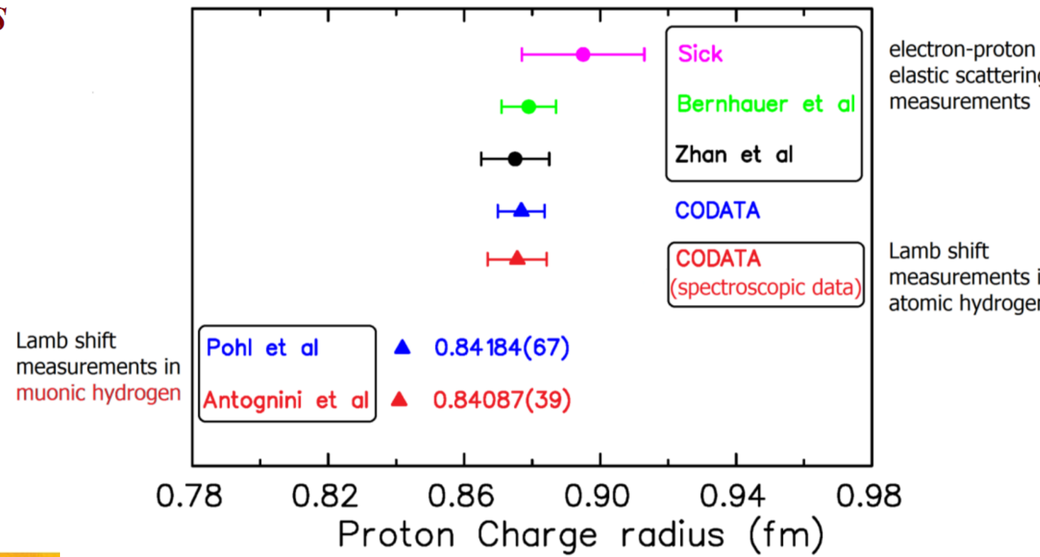
The Proton Charge Radius Puzzle

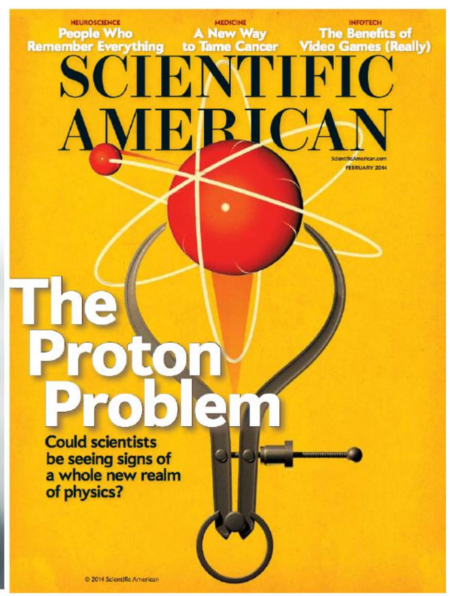
Methods for measuring proton charge radius

- Electron-proton elastic scattering to determine electric form factor (Nuclear Physics)

$$\sqrt{< r^2 >} = \sqrt{-6 \frac{dF(\vec{q})}{dq^2})|_{q^2=0}}$$

- Spectroscopy (Atomic physics)
  - Hydrogen Lamb shift
  - Muonic Hydrogen Lamb shift





- **7σ** discrepancy between the atomic hydrogen Lamb shift and muonic hydrogen Lamb shift
- New Experiments:
  - Atomic spectroscopy
  - Muon spectroscopy (PSI)
  - Muon – proton scattering (MUSE, PSI)
  - Electron - Proton scattering with different schematics (JLab, Mainz)

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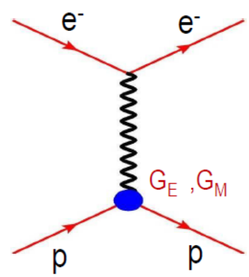
The PRad Experiment @ JLab: ep → ep Scattering

The Proton Charge Radius from $ep \rightarrow ep$ Scattering Experiments

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

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

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



- Structure less proton:

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

- 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:

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

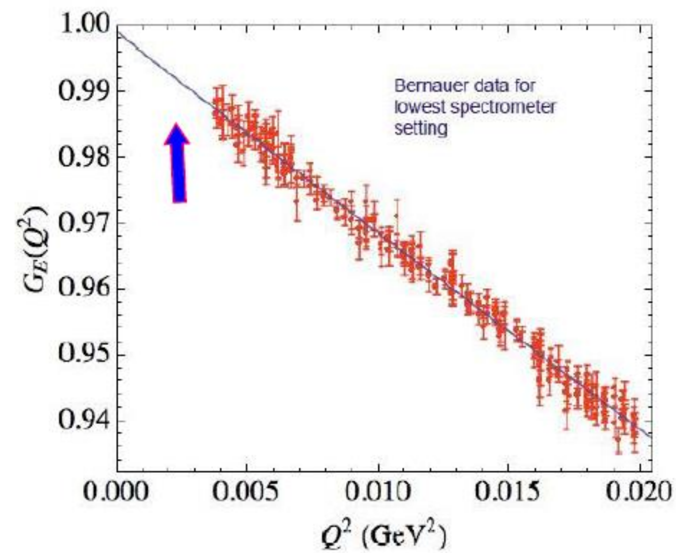
- Definition of the Proton Radius: (r.m.s. charge radius given by the slope)

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

A. Gasparian CLAS col. meeting, 2015

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



Mainz low Q^2 data set

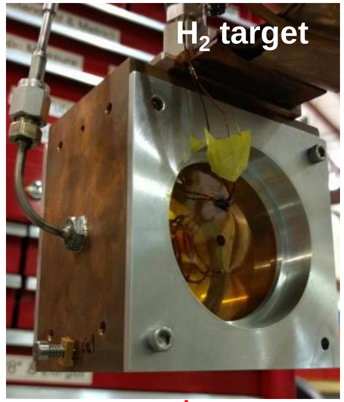
Specifications for PRad Experiment

- 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 and 2.2 GeV) ⇨ minimze background

The PRad Experimental Setup in Hall B

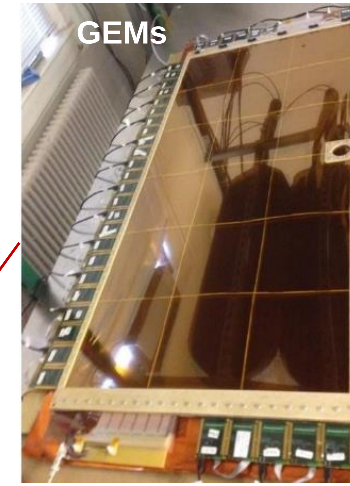
Target specs:

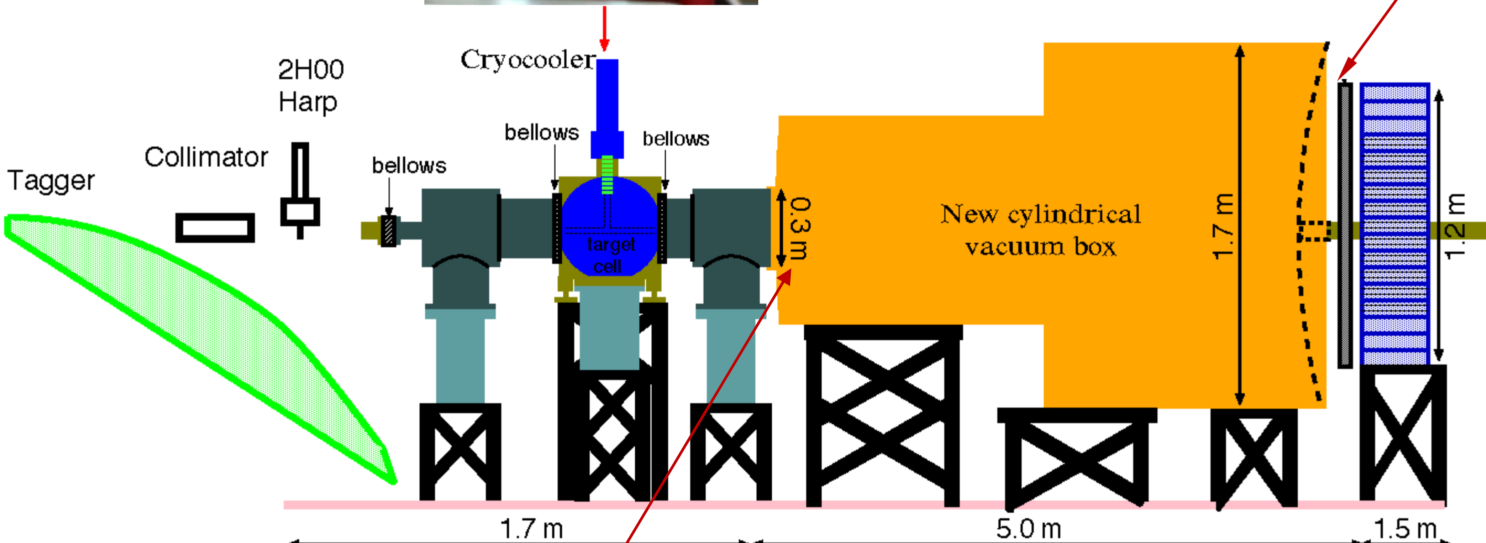
- *cell length 4.0 cm*
- *cell diameter 8.0 mm*
- *cell material 30 μm Kapton*
- *input gas temp. 25 K*
- *target thickness 1x10^{18} H/cm^2*
- *average density 2.5x10^{17} H/cm^3*
- *Cell pressure 0.6 torr*
- *Vacuum in target chamber ~5x10^{-3} torr*



GEMs:

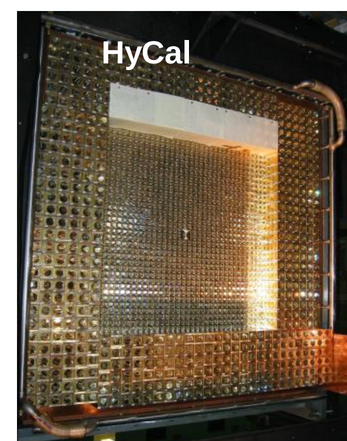
- *factor of >10 improvements in coordinate resolutions*
- *similar improvements in Q2 resolution (very important)*
- *unbiased coordinate reconstruction (including transition region)*
- *increase Q2 range by including Pb-glass part*



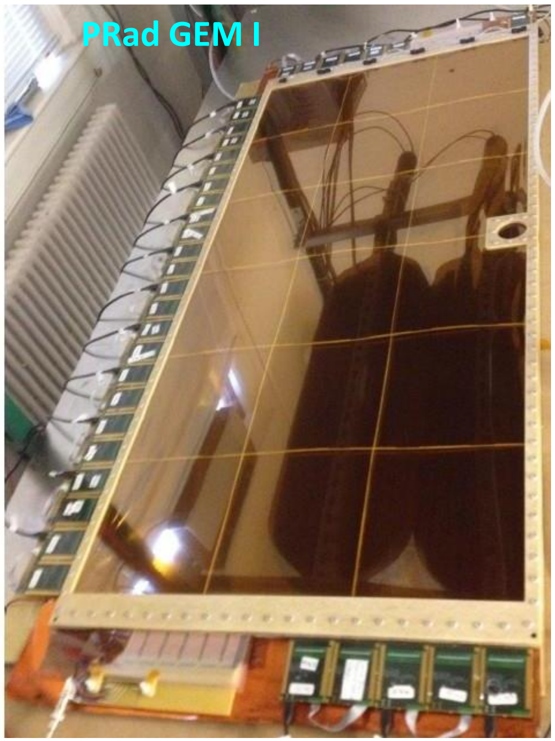


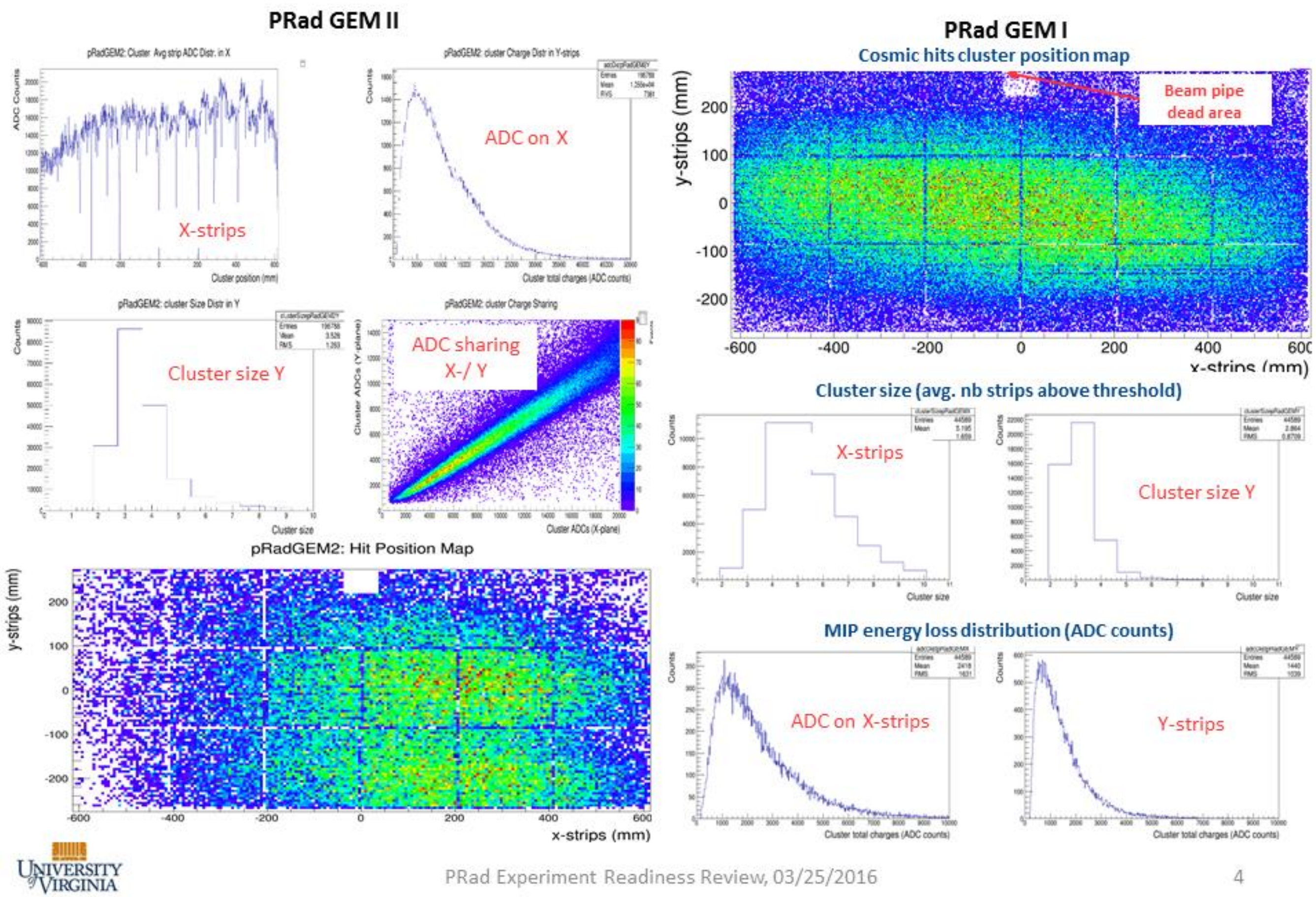
HyCal specs:

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



PRad GEMs: Assembly and cosmic tests @ UVa

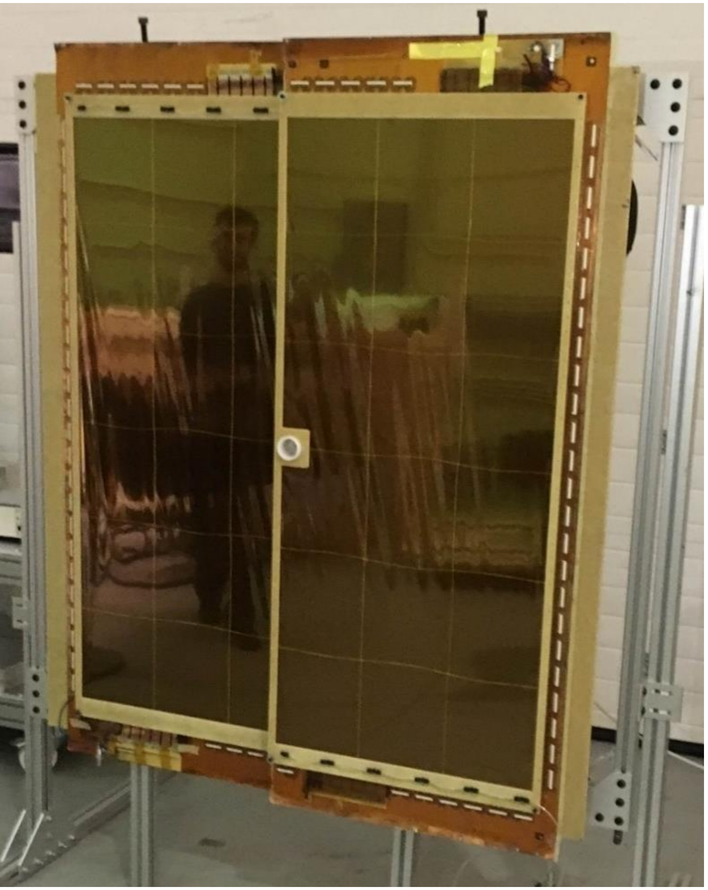




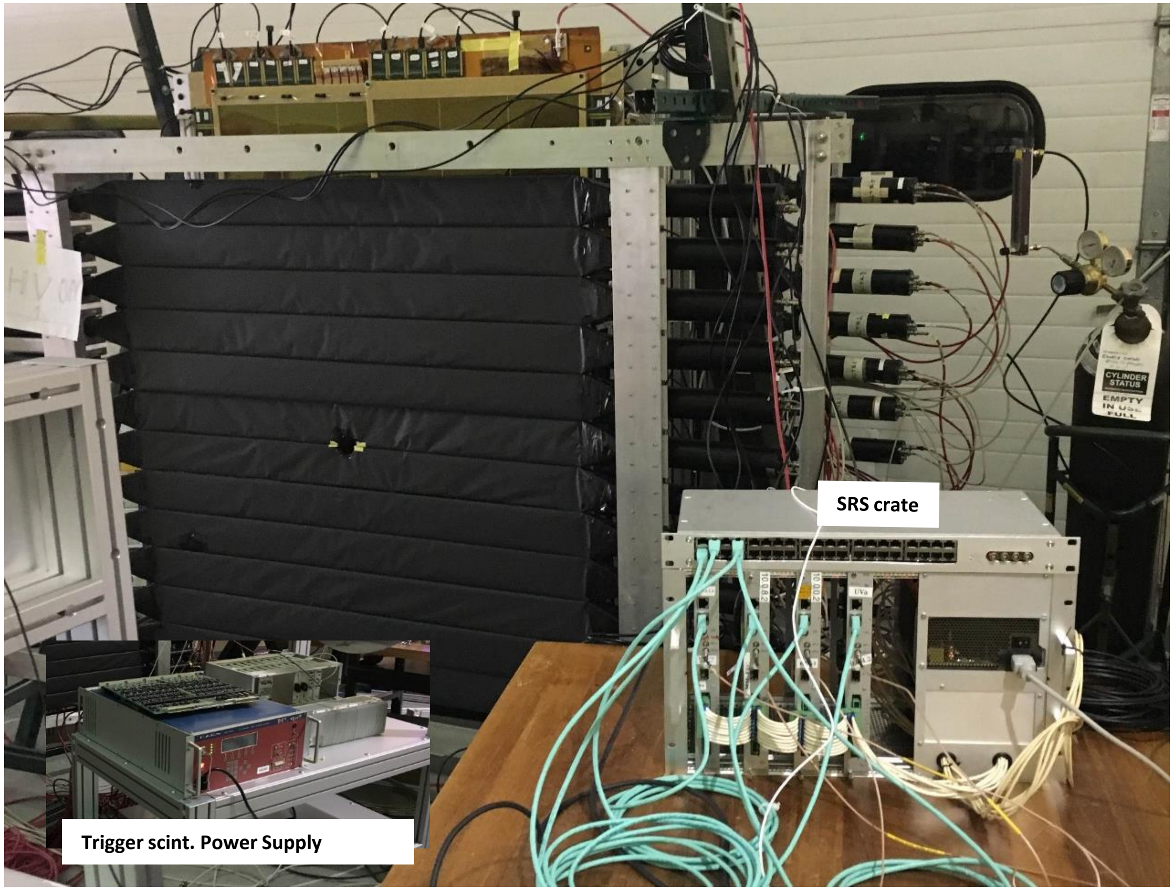
- Both chambers were completed in February
- Cosmic test performed on check all sectors active
- Basic characterization of the performances are evaluated

PRad GEMs @ JLab

Mounted on aluminum support frames



cosmic setup



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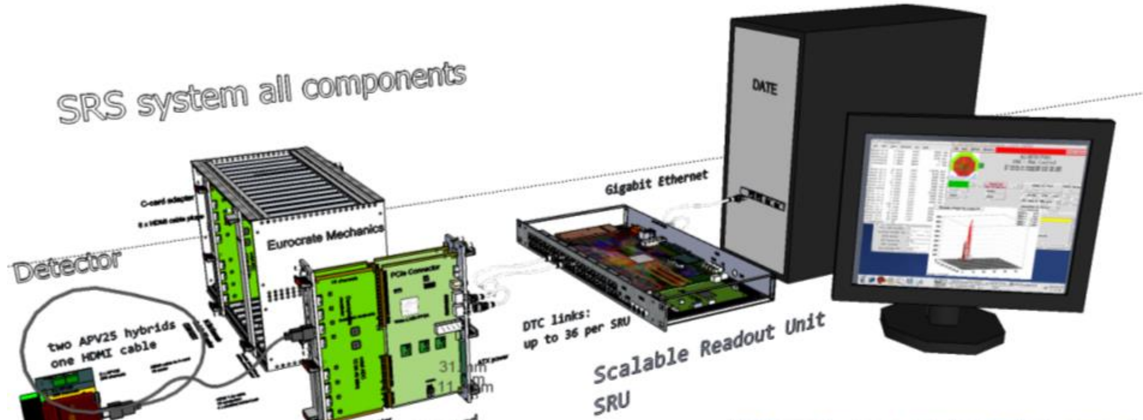
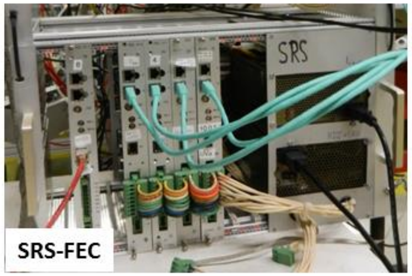
- ✓ Upgrade of SRS electronics
- ✓ Integration into JLab DAQ system
- ✓ Cosmic tests in EEL

Upgrade of SRS Electronics: 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

Upgrade of SRS Electronics: 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 is expected to be reduced by ~ more than a factor 100 to just a couple MB/s

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Upgrade of SRS Electronics: 10 GbE link implementation (SRU firmware)

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

Existing SRU firmware from RD51 CERN

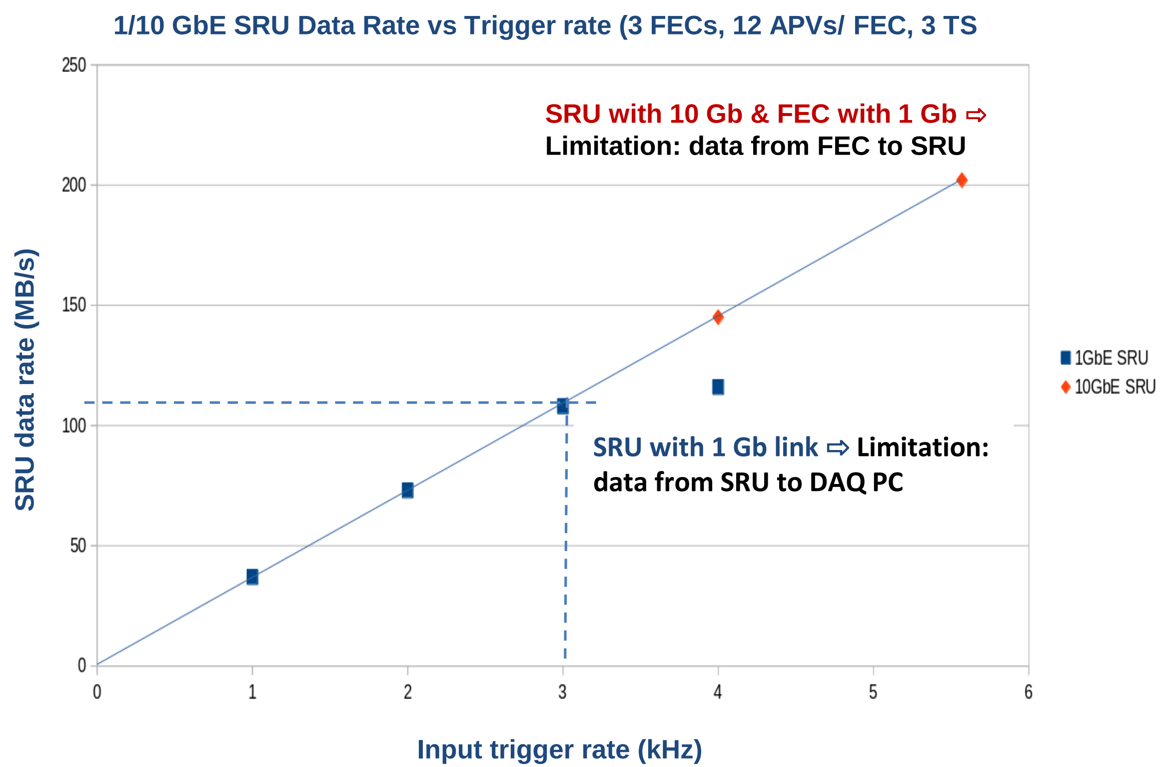
- Standard SRU firmware developped for the APV25 electronics with 1Gb Ethernet link
- 10 Gb Optical link firmware previously developped at CERN was available but not compatible with standard firmware

Upgrade of APV25-compatible 10 Gb SRU firmware (Ben Raydo)

- Merging the two firmware and testing with the APV25 electronics

Test Setup

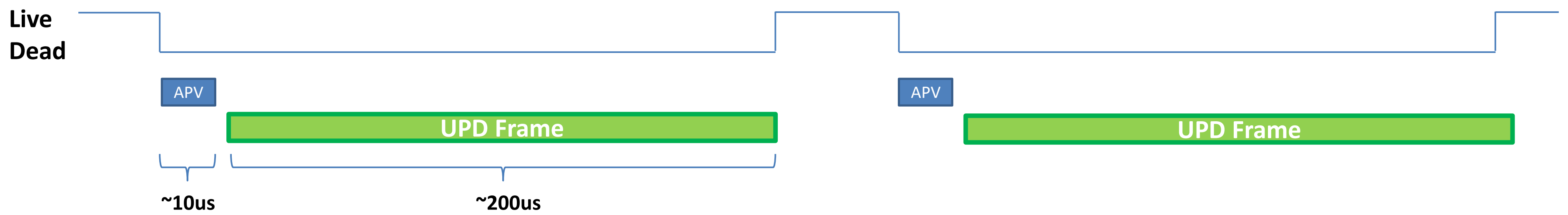
- 36 SRS-APV25 hybrids, connected to 3 FECs (event size 38.5 kB), calibration pulse with internal trigger @ 3 time samples (3TS)
- Rate tests with 1Gb Copper link and upgraded 10 Gb Optical fiber link
- 1Gb SRU: Saturation at ~3.2 kHz (max expected rate before saturation ~ 3.3 kHz)
- 10Gb SRU: linear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



Upgrade of SRS Electronics: Trigger Buffering (FEC firmware)

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

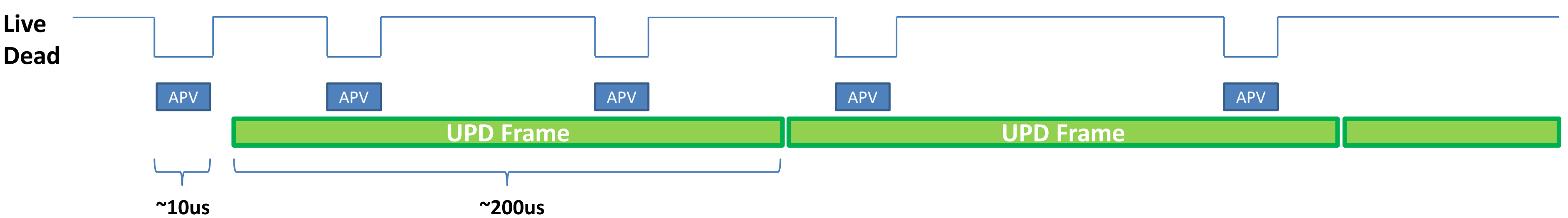
Non-buffered trigger FEC firmware (original):



- Dead/busy while APV sends triggered data **and dead/busy while UDP 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):



- **UDP processing of APV data is "de-coupled" from APV sending data**
- Dead/busy while APV sends triggered data, **no longer dead/busy while UDP packets are sent**
- When buffers, holding captured APV for UDP processing in FPGA become full, 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.

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Upgrade of SRS Electronics: Source code changes

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

APV25 chip has a 4096 deep sample buffer. When capturing a few time samples (e.g. 3), only a small fraction of the buffer is used. The new firmware makes use of the available buffer to optimize the rate capability of the system

Old firmware (standard from CERN)

- The firmware performs the following steps sequentially:
  1. receive a trigger and capture the APV25 data
  2. wait for the data to be fully processed by the UDP processor
  3. Then is ready to accept another trigger.

New firmware (upgrade @ JLab)

- circularly writes multiple events along with trigger header information in the existing buffer.
- A new FIFO is added to provide a pointer into the circular buffer to the UPD packet processor.
- The new firmware performs the following steps in parallel:
  1. Receive a trigger, capture APV25 data and is ready to accept another trigger [~ 25 μs]
  2. Check trigger FIFO and build UPD packets independently from step #1 [~ 200 μs]
  3. Check circular buffer and assert BUSY if no more events can be accepted.
- Trigger processing dead time ~ 25 microseconds with up to 10 triggers can be buffered
- BUSY output (NIM Out): Busy Feedback to Trigger Supervisor ⇨ allows for more efficient trigger acceptance without assumptions of FEC processing dead time.
- As a test example, without buffering, we needed up to 70kHz input rate to readout near 5kHz ⇨ dead-time close to 100%. With buffering enabled the input rate could be slightly over 5kHz to readout near 5kHz ⇨ dead-time just a few percent.

Upgrade of SRS Electronics: Tests of trigger buffering

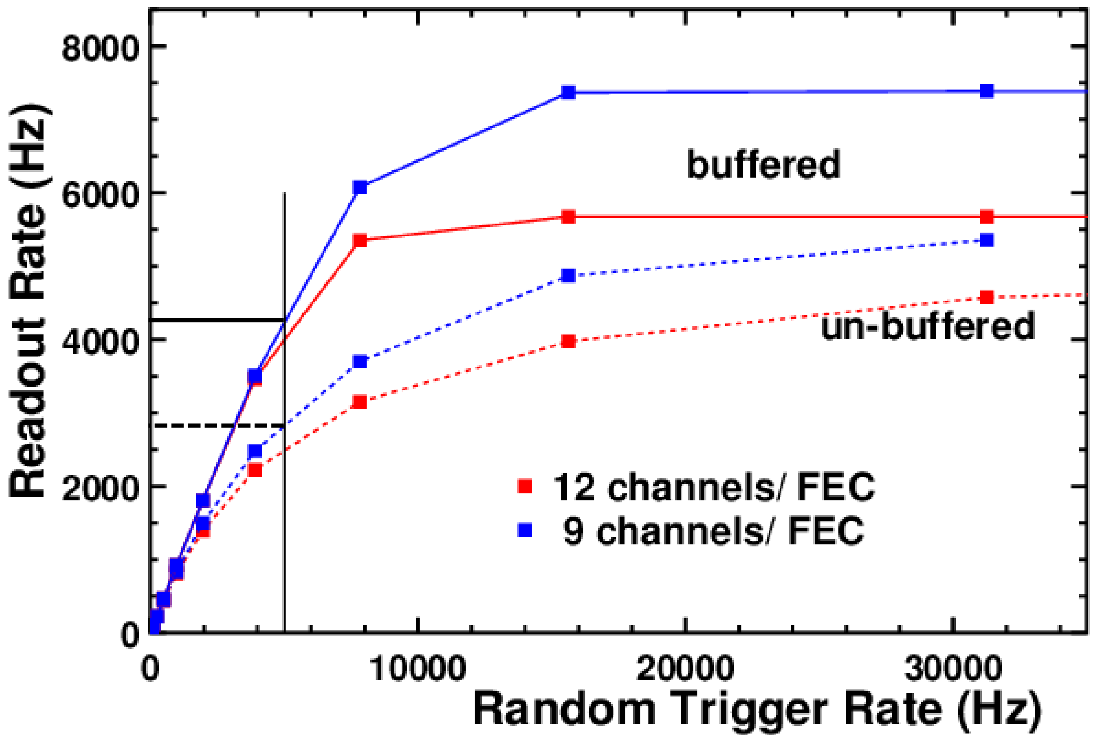
(B. Moffit, JLab DAQ group - B. Raydo, JLab Fast Electronics Group)

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



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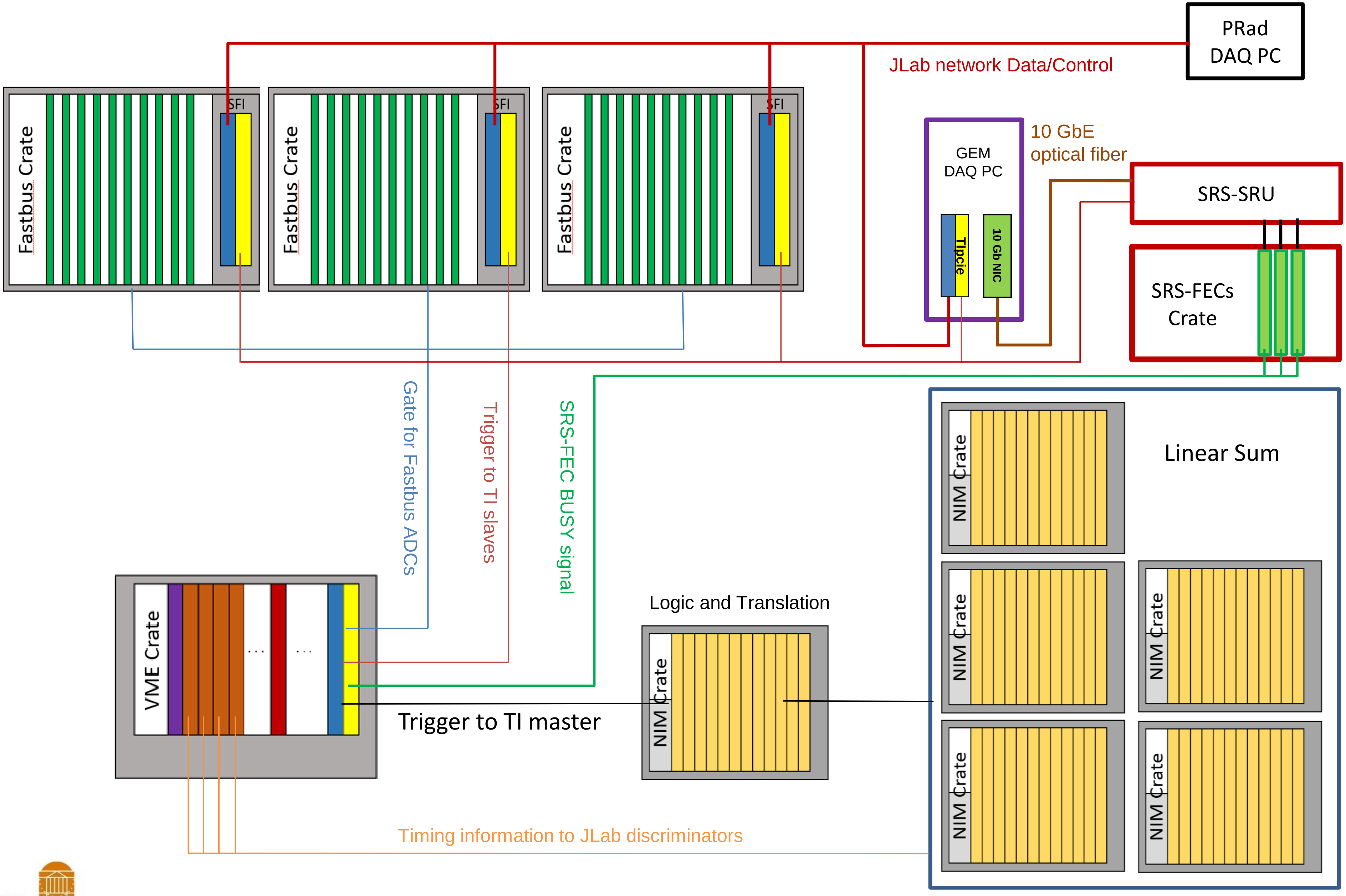
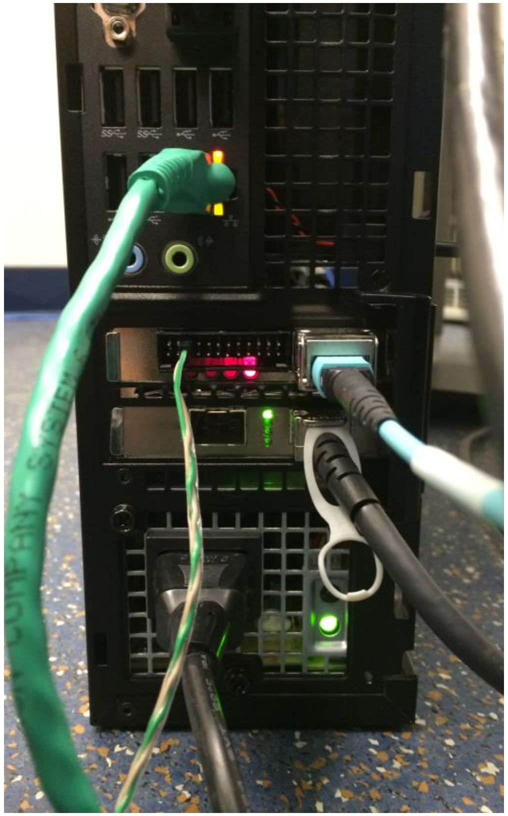
Integration of SRS into JLab DAQ: PRad DAQ Overview



Integration of SRS into JLab DAQ: Hardware

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

- PCIexpress Trigger Interface (TIpcie)
  - Integrate standard desktop or Server PC with PCIe bus into JLab Pipeline DAQ (CODA)
  - Optimal for the use of multiple cores / threads for data processing and data reduction required for PRad GEMs data
  - PC Hardware allows for multiple network cards (1G, 10G, Infiniband)
  - Runs in Standalone (Master) or Larger-Scale DAQ (Slave).
  - Kernel and userspace driver compatible with EL5, EL6 (i386, x86_64)
- Interface to the SRS
  - SRU receive the trigger from the Trigger Supervisor and send BUSY.
  - TIpcie collects data from SRU send to PRad DAQ PC via JLab Network



- Setup of the high rate (5kHz) test with the TIpcie
- The back side of the DAQ PC shows:
  - PCIe TI with the blue fiber connection to the TS
  - The twisted pair connections for triggers.
  - The 10 Gb card for data transfer with the links connected (black) to the SRU.

Integration of SRS into JLab DAQ: Software development

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

Software librairies for the slow control (B. Moffit)

- C Library written to be used with CODA, **but also works standalone**
- Compatibility: REDHAT EL5, EL6 (i386, x86_64)
- Uses calls to routines for the configuration and readout
  - instead of using system calls to external programs/scripts
  - Still has the capability of reading in the original configuration text files.
  - More ‘human’ readable, Parameters can be input in any base (hexadecimal, decimal)
- Allows for iterating over several FEC with similar configuration

✓ Done and under test with the cosmic test run

Online monitoring (Xinzhan and Weizhi)

- Before zero suppression (not implemented at the firmware level)
  - Raw APV25 data frames are available for online monitoring during the life time of PRad run
  - During initalisation of all APV25 after DAQ reboot
  - ✓ Done and under test with the cosmic test run
- Zero suppression at software level by CODA Event Builder in the DAQ PC
  - Monitoring of hits and clusterization algorithm for real time characterisation of the GEMs
  - Hits and cluster data will be passed to the CODA Event Recorder to be written into disk
  - ✓ Under development

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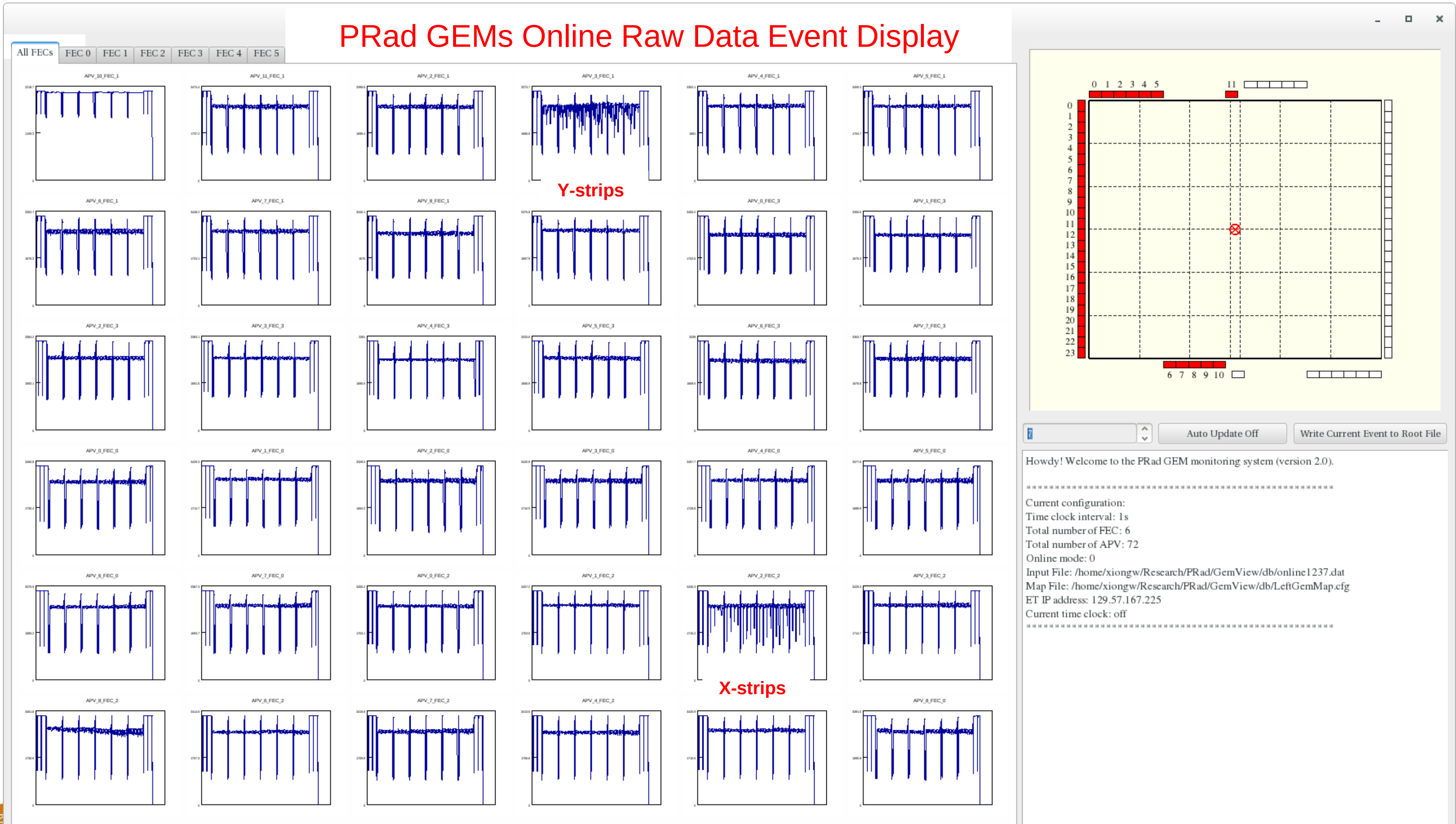
Cosmic Tests: Preliminary data

(Xinzhan and Weizhi)

✓ At last we are seeing cosmic data signal with the GEM chambers

- Ongoing tuning of trigger signal and APV25 data latency for optimization of the setting
- Plan to monitor the stability of the DAQ in the cosmic setup for a few days
- Will after move to the full DAQ system to read out all two chambers and take data for several days for efficiency study



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Summary

- Two large PRad GEM chambers built at Uva
  - Preliminary cosmic data test conducted at UVa to test basic performances
  - Delivered to JLab in Februrary and mounted on the support frames in the cosmic setup
- APV25-based SRS is the readout electronics for the Prad GEMs
  - Readout System is based on the SRS electronics developped by the RD51 coll. @ CERN
  - Challenge is to read out 9216 electronic channels (detector strips) @ 5 khz trigger rate
- Firmware upgrade to allow high rate capability
  - SRU firmware: implementation of 10 Gb optical link for the data transfer from the SRU to the DAQ PC
  - FEC firmware: Implementation of the buffering trigger ⇨ allow 5 kHz trigger rate with limited dead time
- Integration of the SRS into JLab DAQ system
  - JLab custom board TIpcie for the trigger interface between SRS and Prad DAQ system
  - Development of the TIpcie libraries and slow control routines, online monitoring software
- Cosmics setup of the GEM chambers with SRS readout / DAQ
  - First real data from the GEM with the full DAQ chain
  - Test of the DAQ / readout and preliminary study of the chamber detection efficiency
- Goals and plans or the coming weeks before the installation in Hall B
  - Implementation the zero suppression algorithm for online data reduction
  - More tests and checks of the performances of the DAQ and GEM chambers with cosmic setting

Back Up