Status of the PRad Experiment
(E12-11-106)

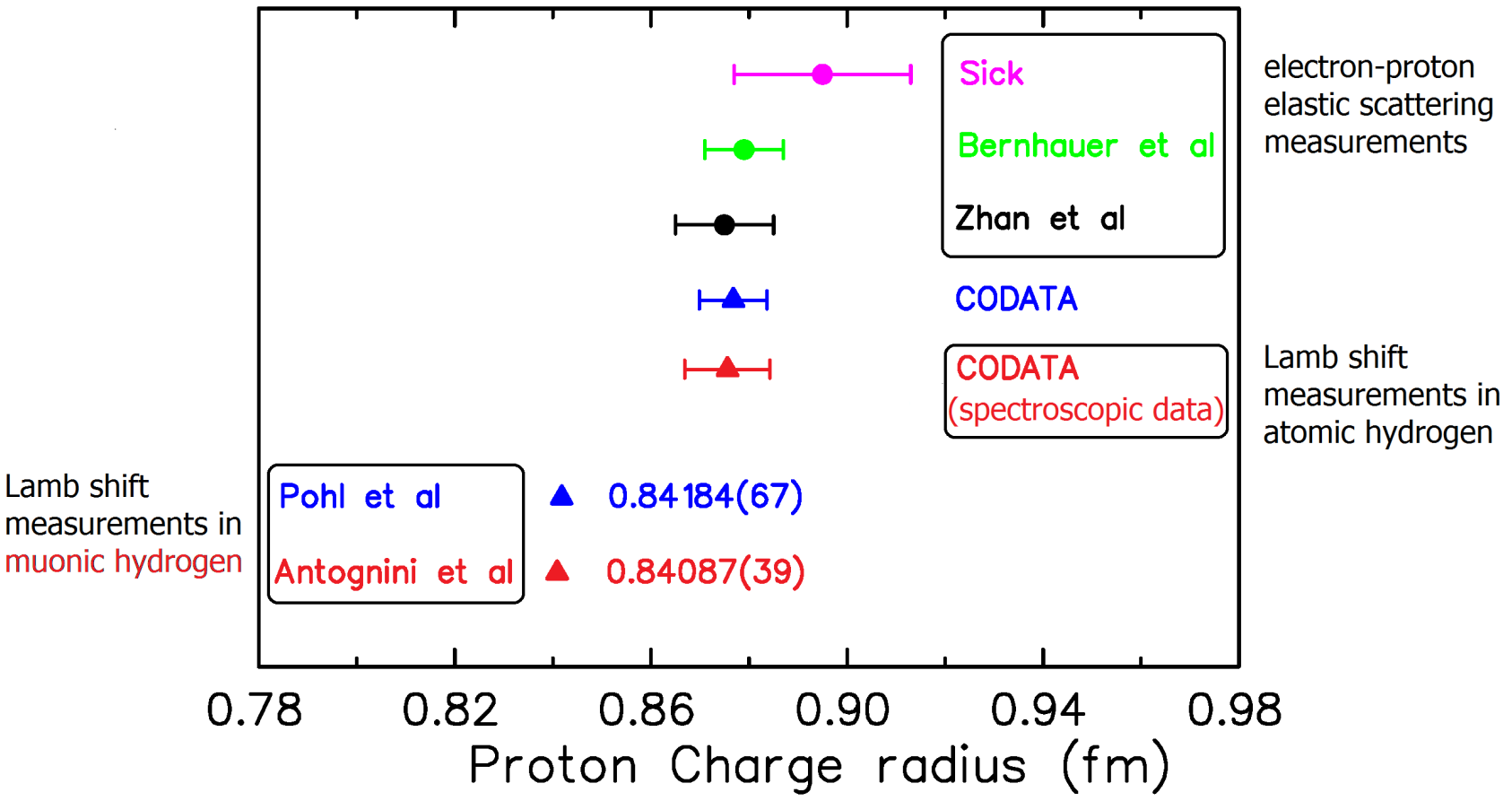
A. Gasparian
NC A&T State University

for the PRad collaboration

Outline

- PRad Physics goals
- Experimental setup
- Current status
- Summary

The Proton Charge Radius Puzzle

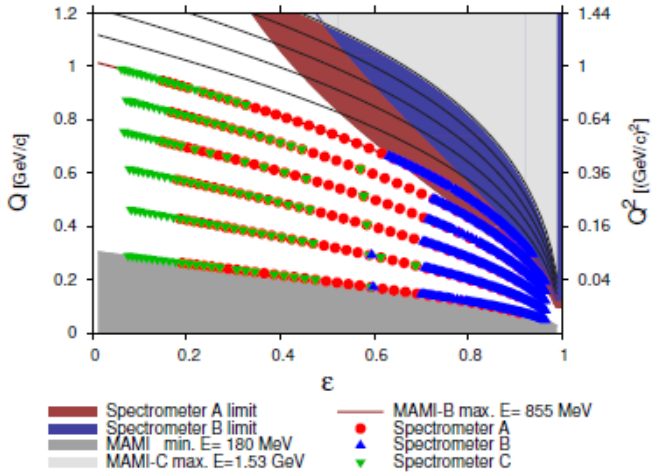


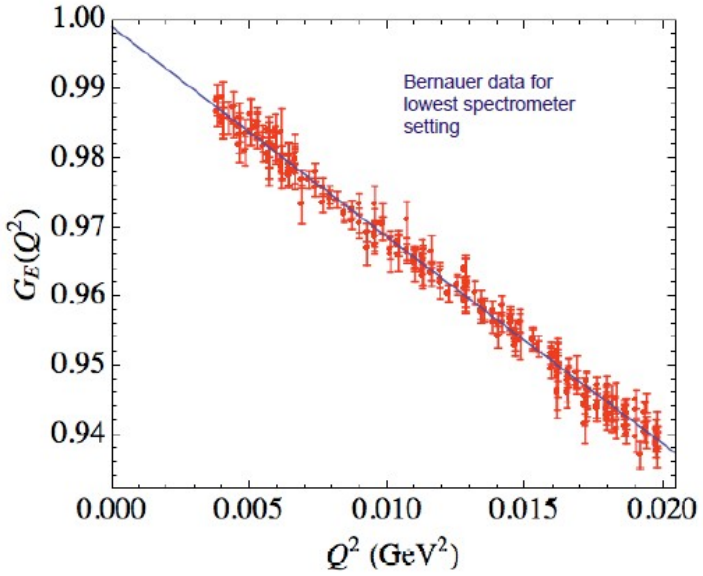
- **New high precision experiments are needed to solve this 7σ discrepancy**

An Example: Recent Mainz ep-Experiment (2010)

Three spectrometer facility of the A1 collaboration:

J. Bernauer, PRL 105,242001, 2010





- ✓ Q^2 = [0.004 – 1.0] (GeV/c)^2 range
- ✓ Large amount of overlapping data sets (~1400)
- ✓ Statistical error ≤ 0.2%
- ✓ Luminosity monitoring with spectrometer
- ✓ Additional beam current measurements

$$r_p = 0.879(5)_{stat}(4)_{sys}(2)_{mod}(4)_{group}$$

- ✓ Confirms the previous results from *ep*→*ep* scattering;
- ✓ Consistent with CODATA06 value: (r_p=0.8768(69) fm)

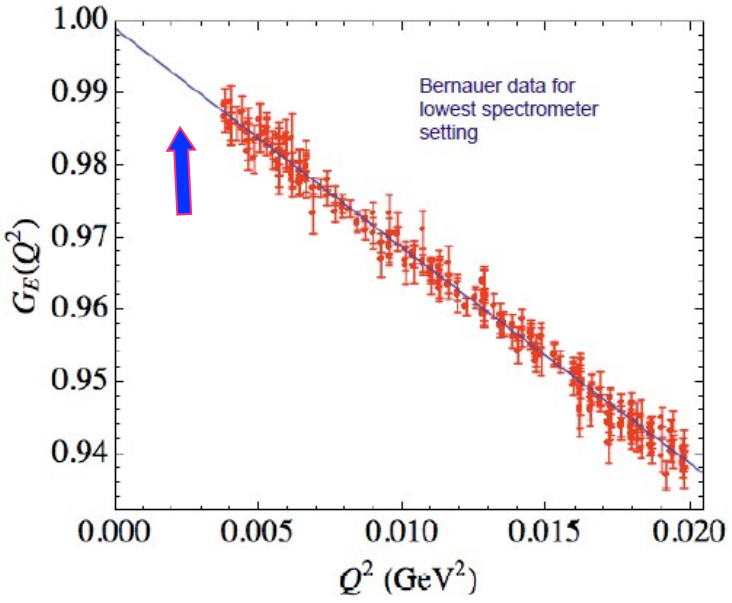
The PRad Experiment (E12-11-106)

- Experimental goals:
  - reach very low Q^2 range (~ 10 times less than the Mainz experiment)
  - reach sub-percent precision in r_p extraction

- Suggested solutions:
  1) Non-magnetic-spectrometer method:
     use high resolution high acceptance crystal calorimeter
     - reach smaller scattering angles: ($\Theta = 0.7^0 - 3.8^0$)
       ($Q^2 = 2\times10^{-4} - 8\times10^{-2}$) GeV/$c^2$
       → essentially, model independent r_p extraction

  2) Simultaneous detection of $ee \rightarrow ee$ Moller scattering
     - (best known control of systematics)

  3) Use high density windowless H2 gas flow target:
     - beam background fully under control with high quality CEBAF beam
     - minimize experimental background



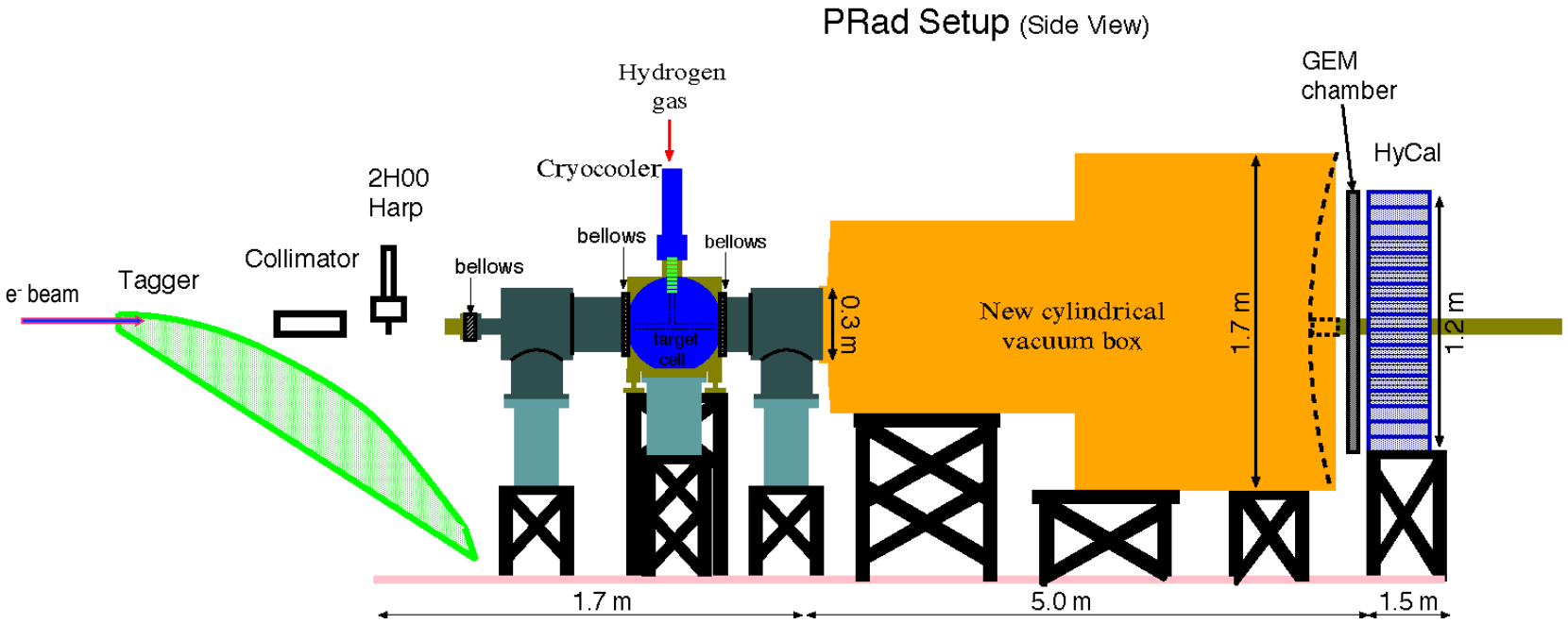
Mainz low Q^2 data set

- Two beam energies: E_0 = 1.1 GeV and 2.2 GeV to increase Q^2 range: ($2\times10^{-4} - 8\times10^{-2}$) GeV/$c^2$
- Will reach sub-percent precision in r_p extraction (0.6% total)
- Approved by PAC39 (June, 2012) with high "A" scientific rating

PRad Experimental Setup (schematics)

- Main detectors and elements:
  - windowless H_2 gas flow target
  - PrimEx HyCal calorimeter
  - vacuum box with one thin window at HyCal end
  - X,Y – GEM detector on front of HyCal

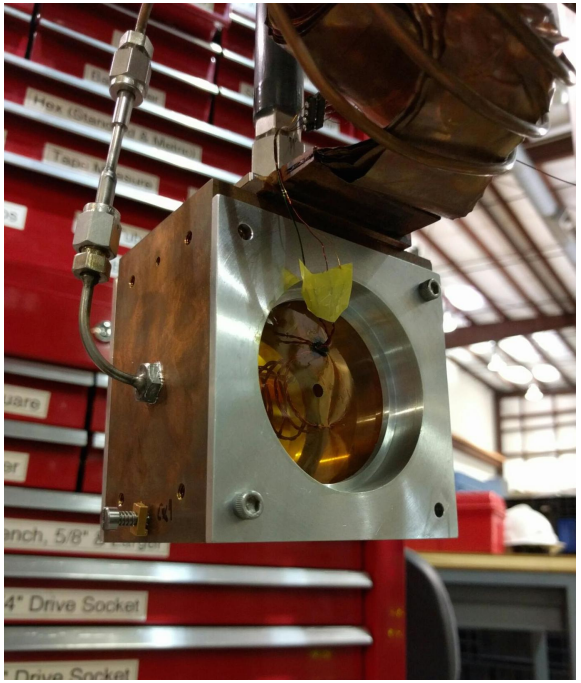
- Beam line equipment:
  - standard beam line elements (0.1 – 10 nA)
  - photon tagger for HyCal calibration
  - collimator box (6.4 mm collimator for photon beam, 12.7 mm for e^- beam halo “clean-up”)
  - Harp 2H00
  - pipe connecting Vacuum Window through HyCal

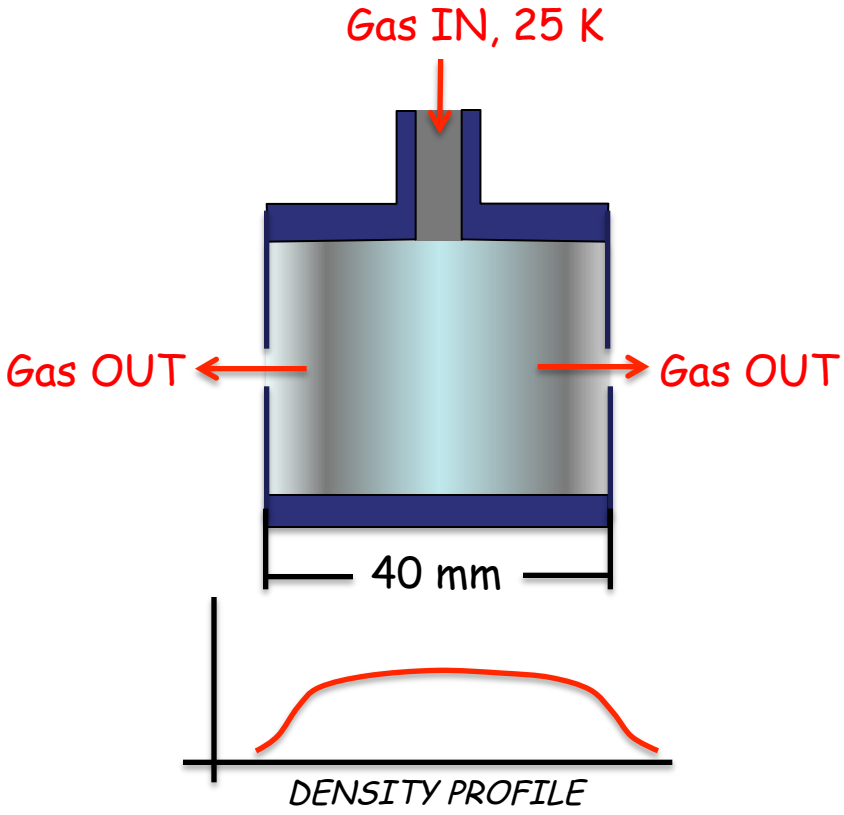


Windowless H_2 Gas Flow Target

A windowless gas target of cryogenically cooled hydrogen

- Target cell is 40 mm long copper, attached to cryocooler via heat strap
- Cell covers are 7.5 μm kapton with 2 mm beam orifices
- Two solid target foils: *1 μm carbon*
  1 μm aluminum





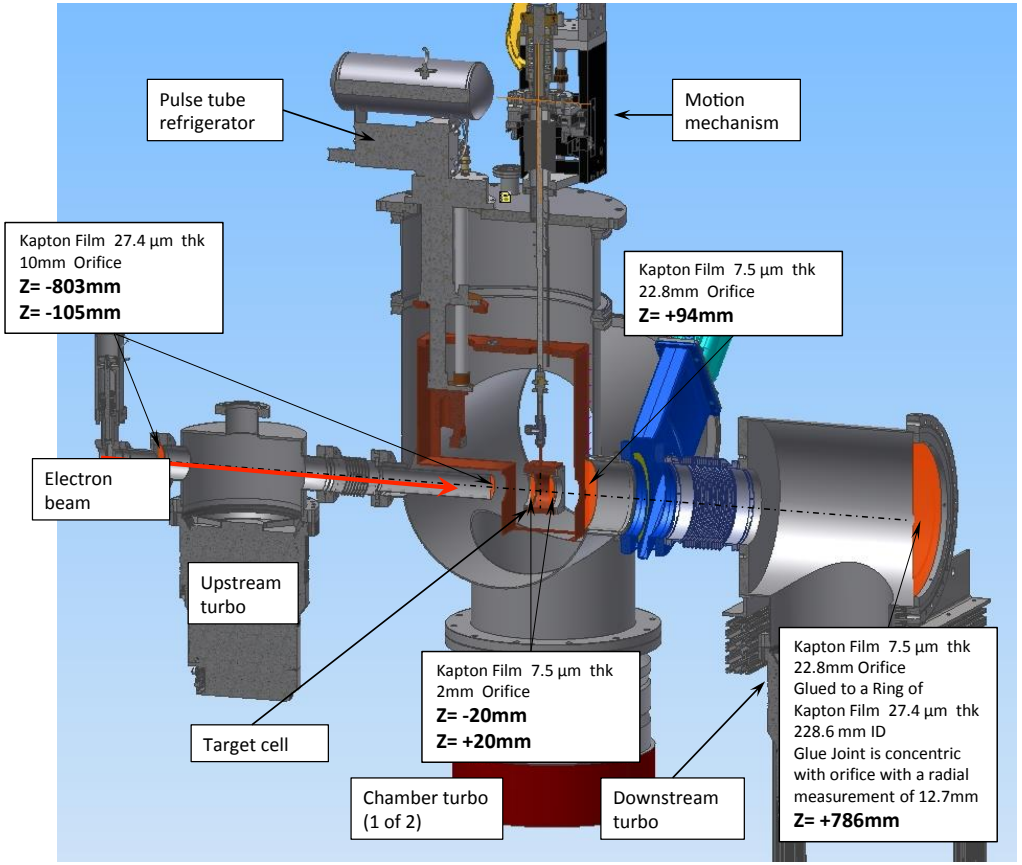
Windowless H_2 Gas Flow Target

- Target chamber is differentially pumped with four high speed turbos.
- Kapton orifices up- and downstream from the cell reduce the beam line vacuum.
- A four-axis motion mechanism positions the target cell, with approximately ±10 μm accuracy.

Goal parameters

Length:	4 cm
Temperature:	25 K
Pressure:	0.6 torr
Thickness:	1 x 10^{18}

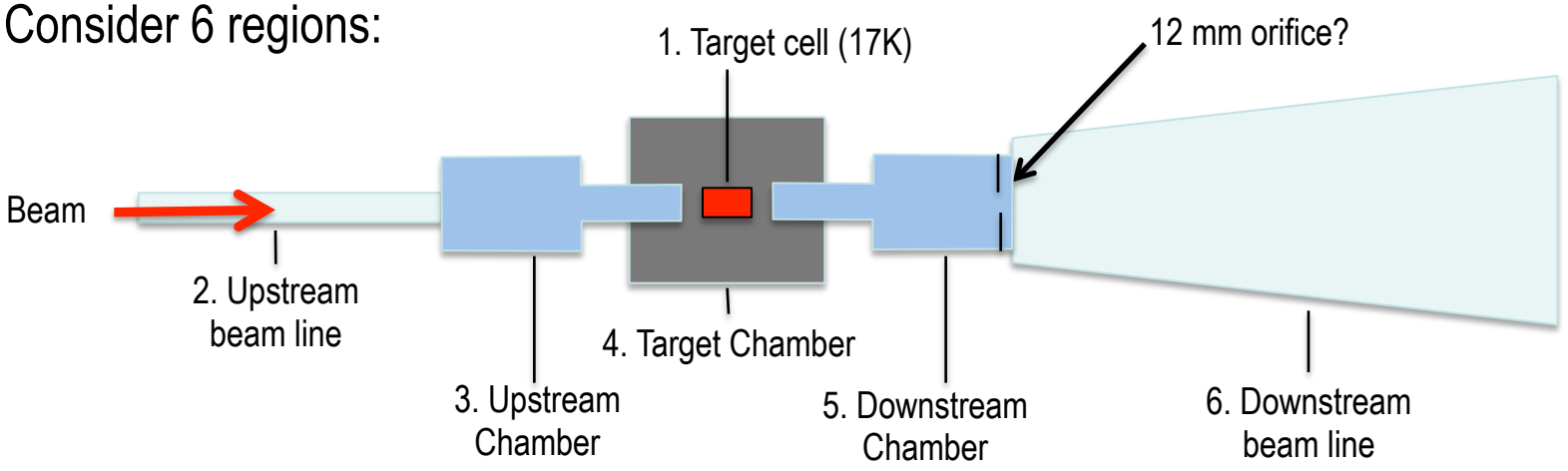
Secondary goal:
Reduce H_2 background



December Helium Tests

Estimate of target background gas

Consider 6 regions:



Region	Length (cm)	Pressure (torr)	Thickness (cm^{-2})	Percent of total
1	4*	(		99.8
2	300**	1		.01
3	71*	6.		.01
4	14*	1.		.03
5	71*	3		.04
6	400**	1		.02

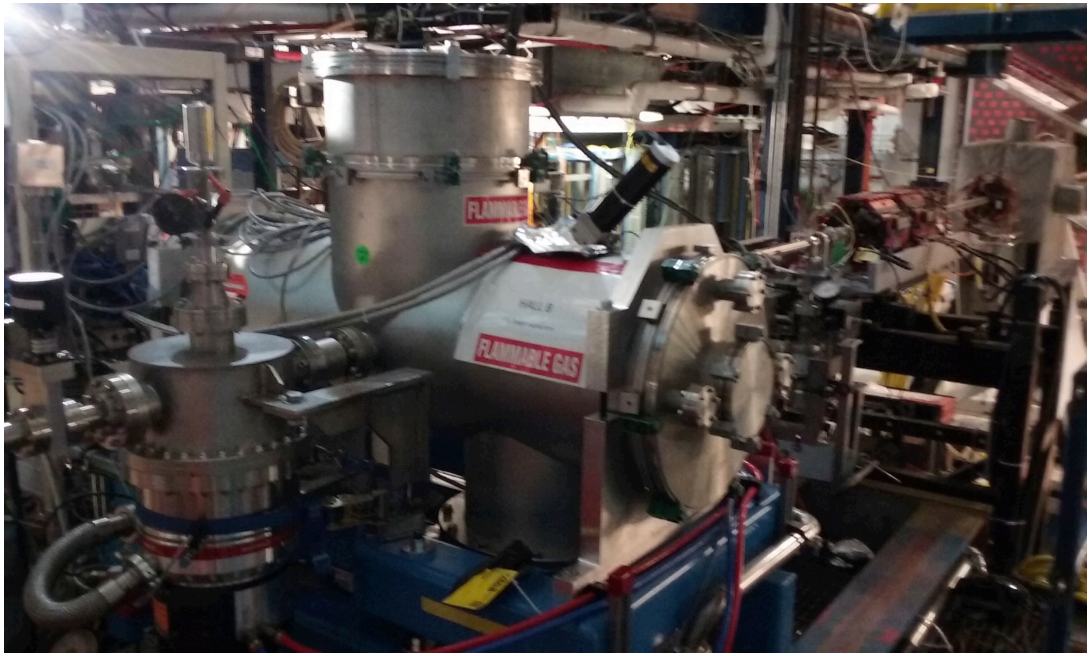
Dec. 2015 tests with HELIUM

Background gas reduced to approx. 0.2% of cell thickness

* Measured ** estimated

Target Status

- Target chamber, pumps, electronics, and all ancillary equipment are installed in Hall B
- Target cell fiducilized in EEL, solid target foils on hand



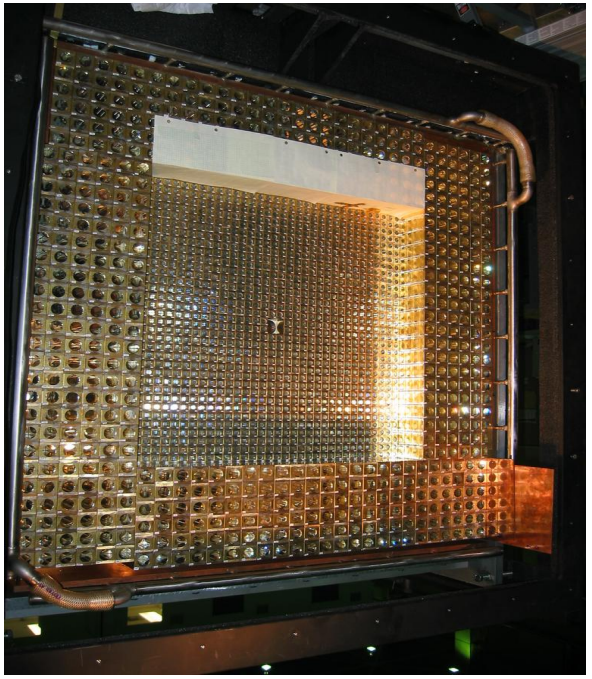
Work Schedule:

- May 14 – April 7: Install target cell, beam line orifices, perform H2 tests
- April 8 – 10: Commissioning
- May 1 – 28: PRad beam time

✓ **Target is ready for the experiment (Thanks to Target Group).**

Electromagnetic Calorimeter (PrimEx HyCal)

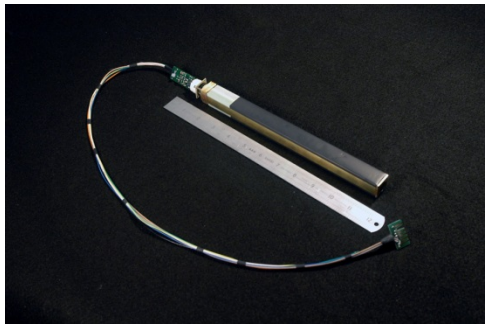
- Combination of $PbWO_4$ and Pb-glass detectors (118x118 cm^2)
- 34 x 34 matrix of 2.05 x 2.05 x 18 cm^3 $PbWO_4$ shower detectors
- 576 Pb-glass shower detectors (3.82x3.82x45.0 cm^3)
- 2 x 2 $PbWO_4$ modules removed in middle for beam passage
- 5.5 m from H_2 target (~0.5 sr acceptance)



- Moved back to Hall B in June, 2014:

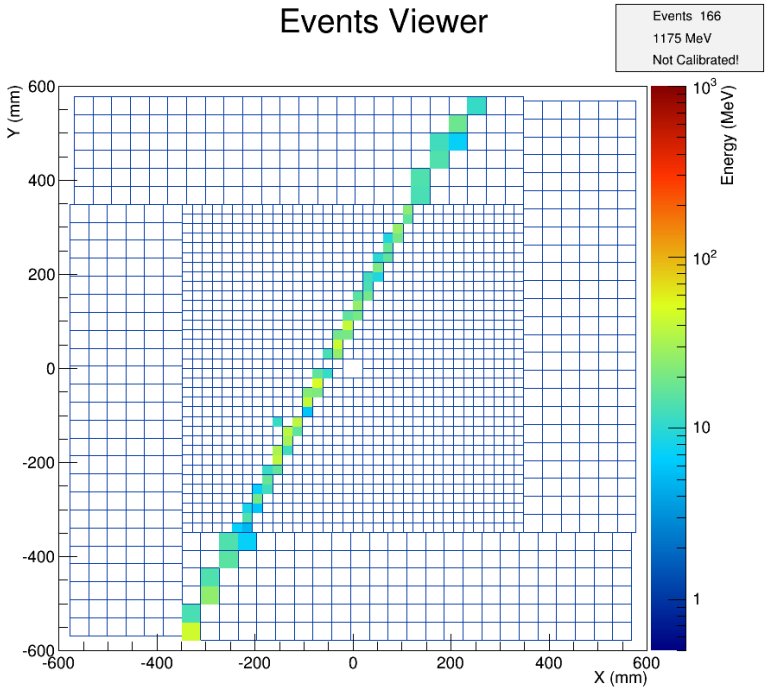
  (thanks to Technical Group (D. Tilles and All)

  - Cabling system with infrastructure reassembled
  - Trigger, analog and HV electronics are reinstalled
  - Cooling system is operational
  - LMS checked and repaired
  - All individual detectors checked and repaired
  - DAQ is operational (HyCal readout part)
  - Transporter is reinstalled/repaired and operational



HyCal Current Status

- HyCal is currently up in Transporter, taking cosmic data



Cosmic event in HyCal

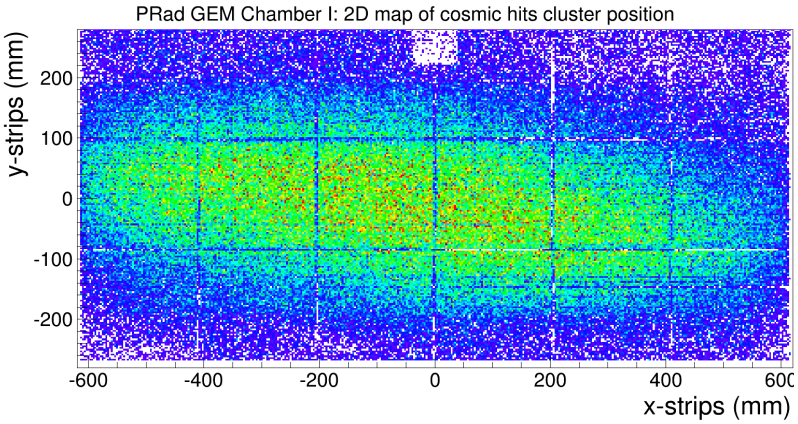
✓ **HyCal is fully repaired and ready for the experiment.**

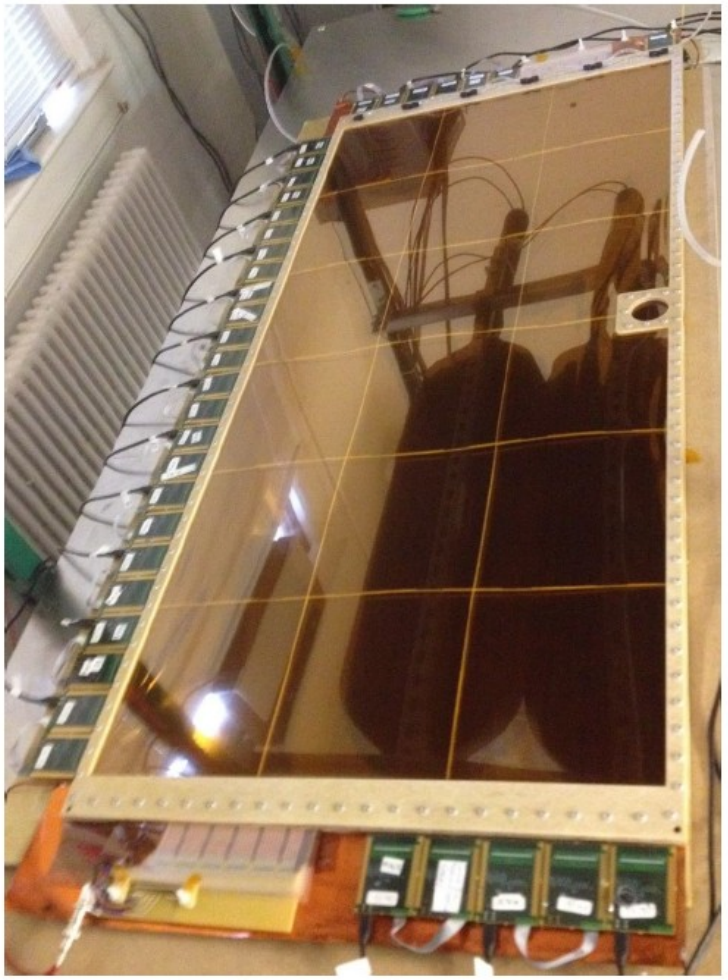
HyCal in Hall B beam line (Oct, 2015)

GEM Chambers

- Tasks for GEM:
  - factor of >10 improvements in coordinate resolutions
  - similar improvements in Q^2 resolution (very important)
  - unbiased coordinate reconstruction (including transition region)
  - increase Q^2 range by including Pb-glass part

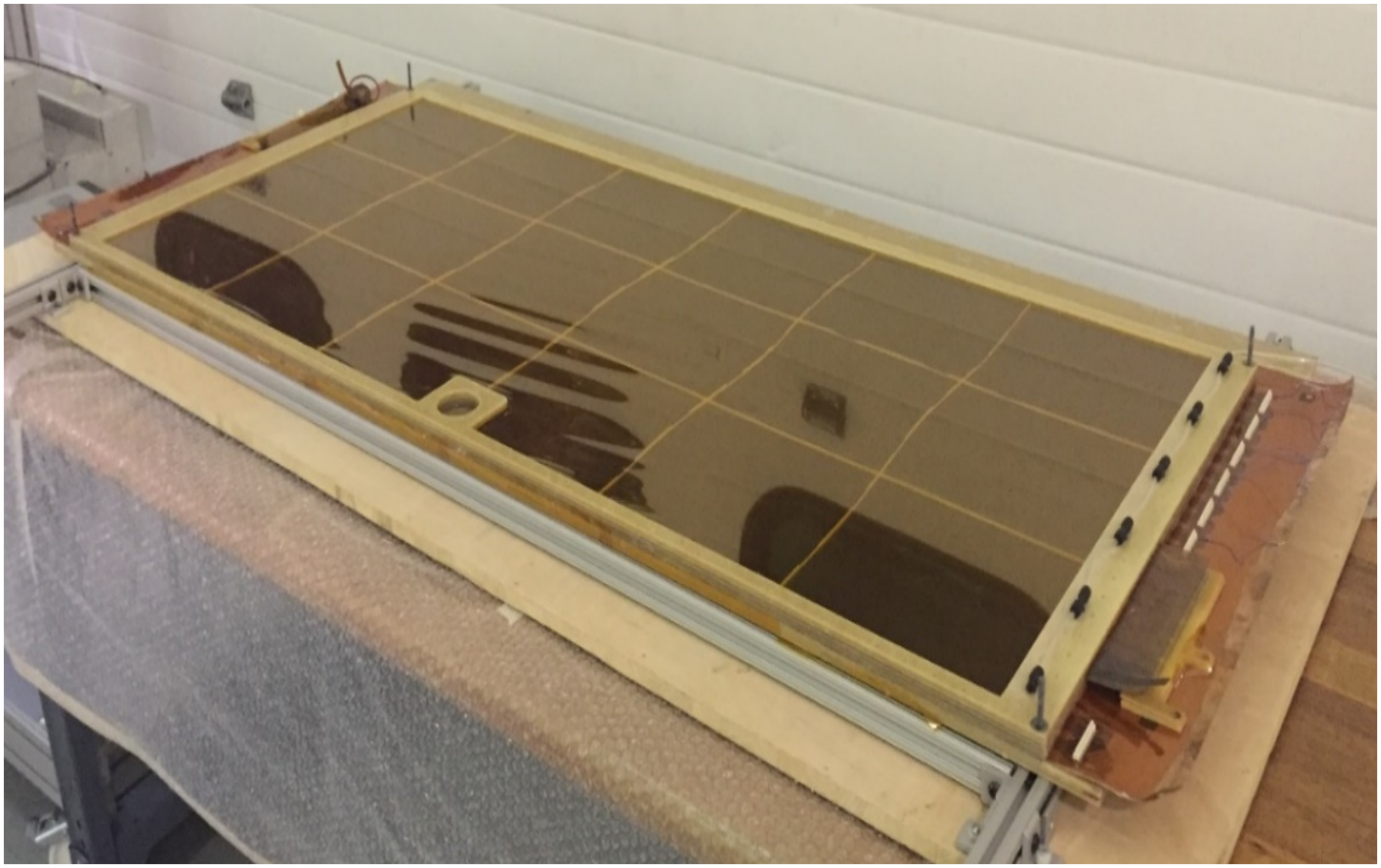
- Designed and built at UVa
- 1st GEM chamber (GEM-II) is completed in Sep. 2015
- Cosmic tests are done at UVa, moved to JLab





GEM chambers at UVa, Aug. 2015

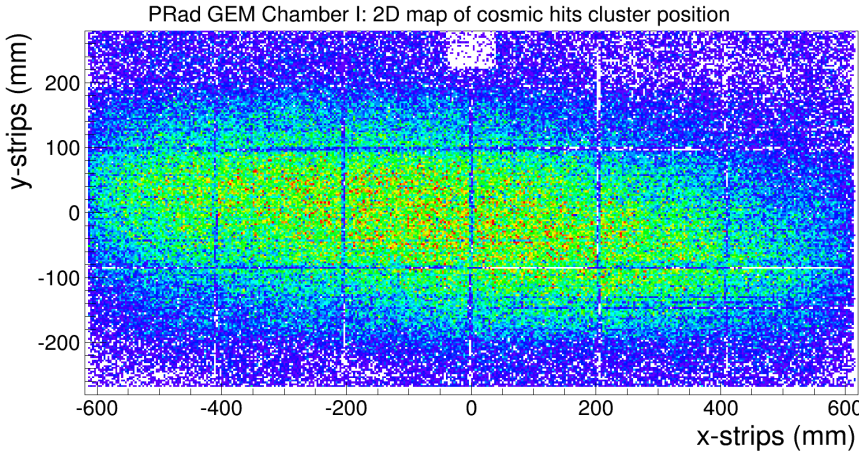
GEM-II in EEL at JLab

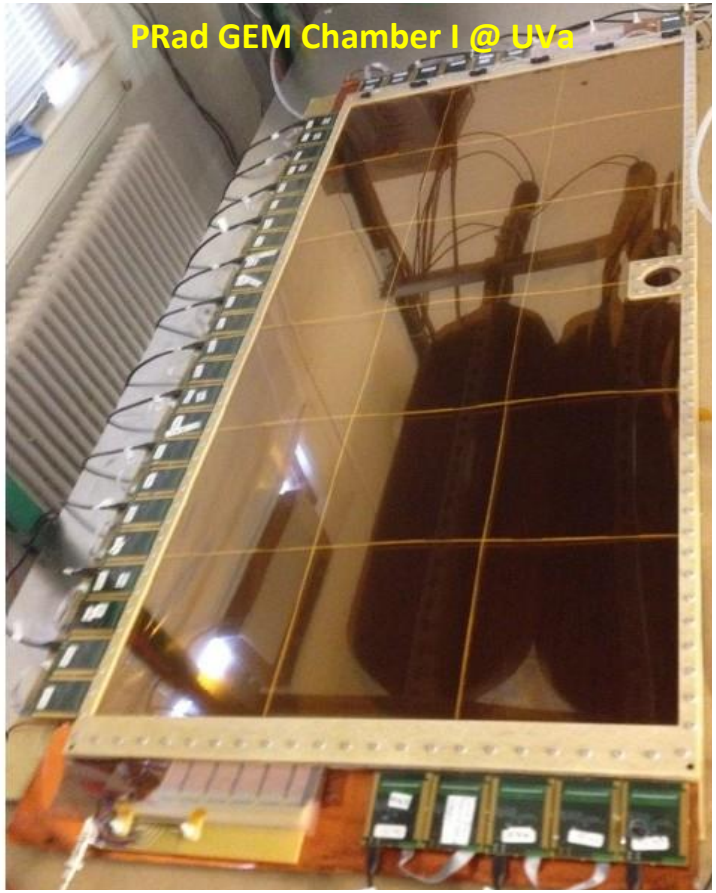


- Cosmic test setup in EEL for tests and characterization of the chambers before migration to Hall B

GEM-I Chamber

- Second GEM chamber (GEM-I) is built and tested with cosmic rays at UVa

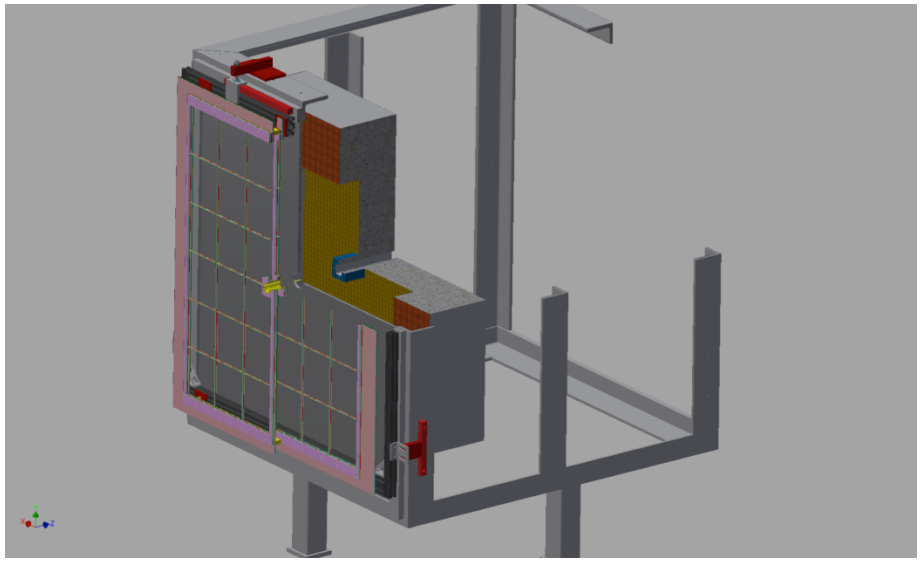


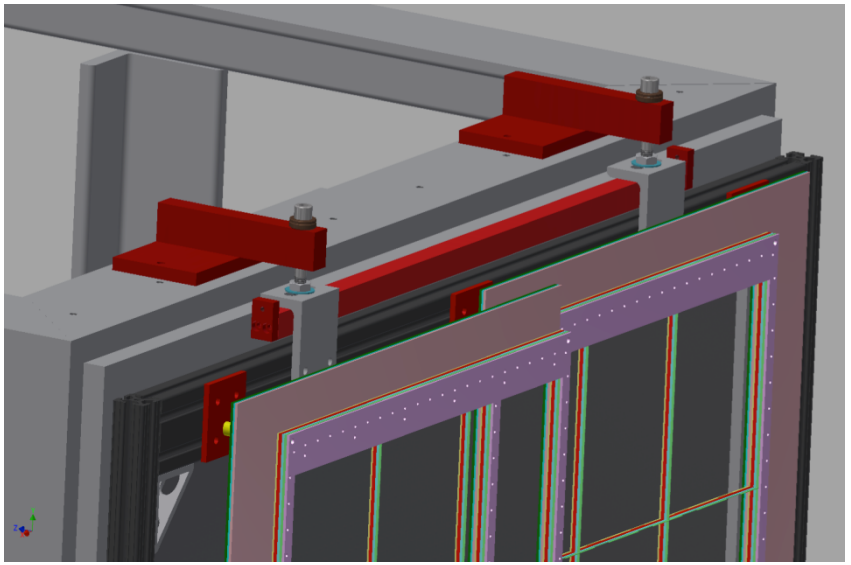


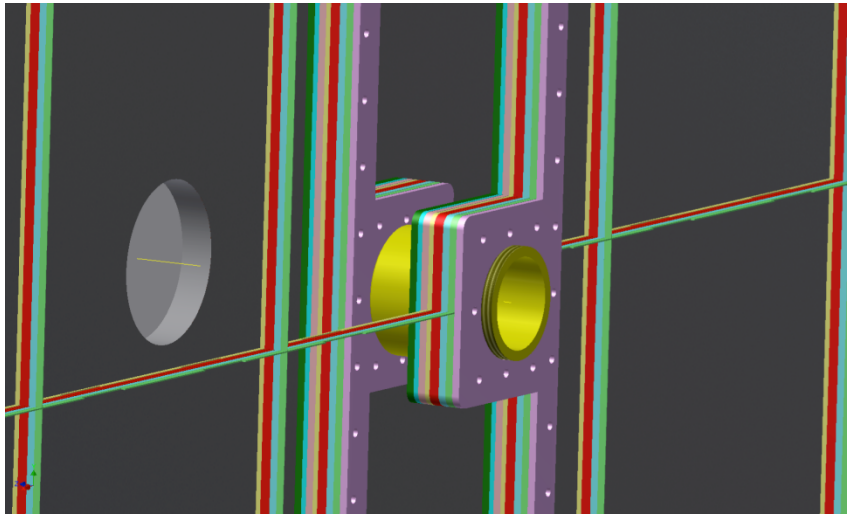
GEM-I at UVa, January. 2016

- GEM-I will be transported to Jlab on Monday
- GEM chambers will be ready for installation on March 15, 2016

GEM Mount on HyCal



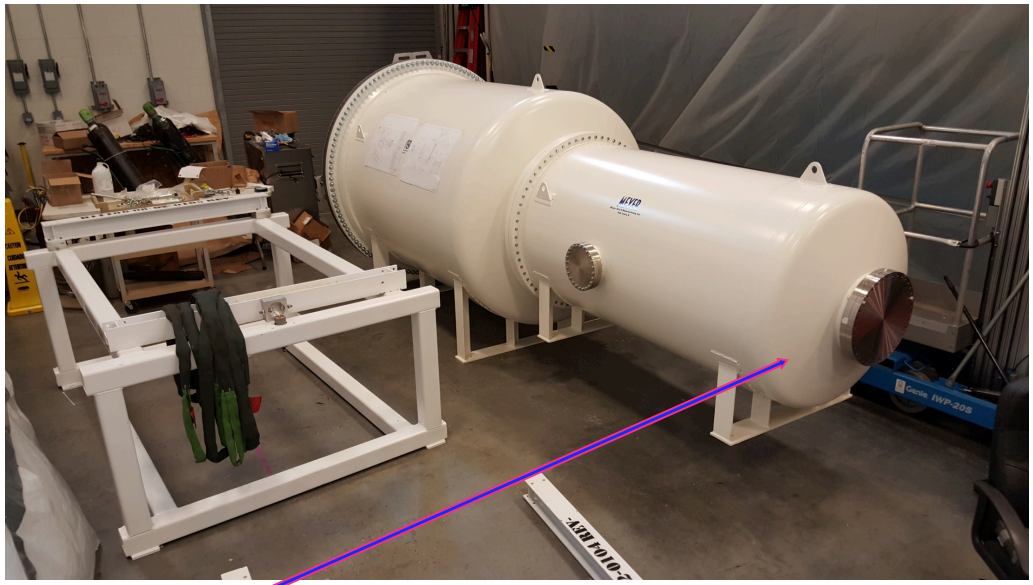




- GEM chambers will be held on a light aluminum frames attached to the HyCal frame
- Preassembled in EEL building
- Ready for the installation in March

Vacuum Box

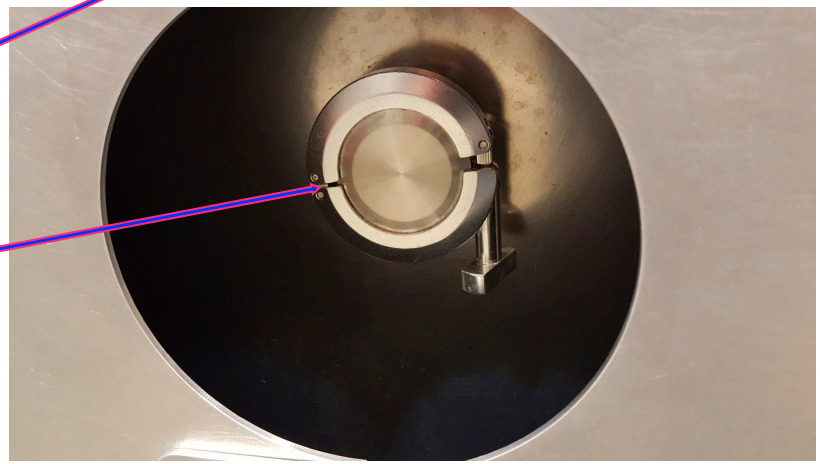
- Engineering design is done by Duke/Jlab
- Construction is done (March 2015)
- Tested with window by vendor (March 2015)
- Delivered to JLab (March 2015)



- Preassembled at JLab
- Ready for installation: March, 2016

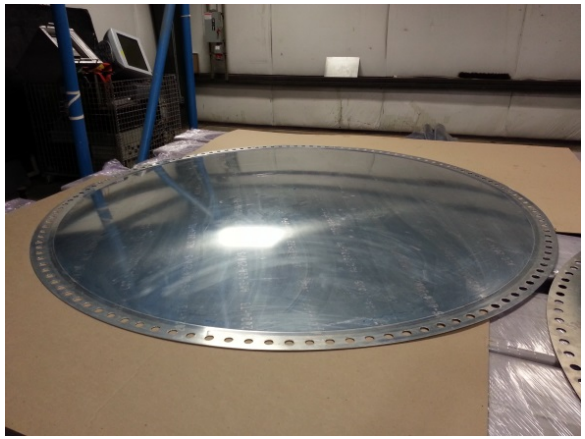
(estimated time 2 days)

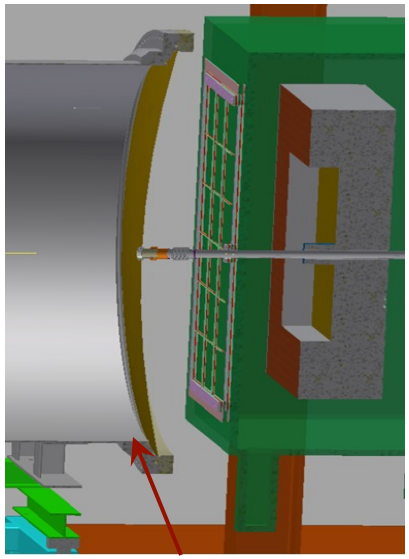
- The beam pipe connection adapter



Vacuum Window

- Thin Al-window on Vacuum Box at the HyCal end
  - thickness: ~2 mm
  - diameter : 1.7 m
  - connected to the beam vacuum pipe in center
- Design and construction done
- Final vacuum tests are done in last week
- Remaining work:
  - connection to the vacuum pipe
  - ✓ ready by March 2016



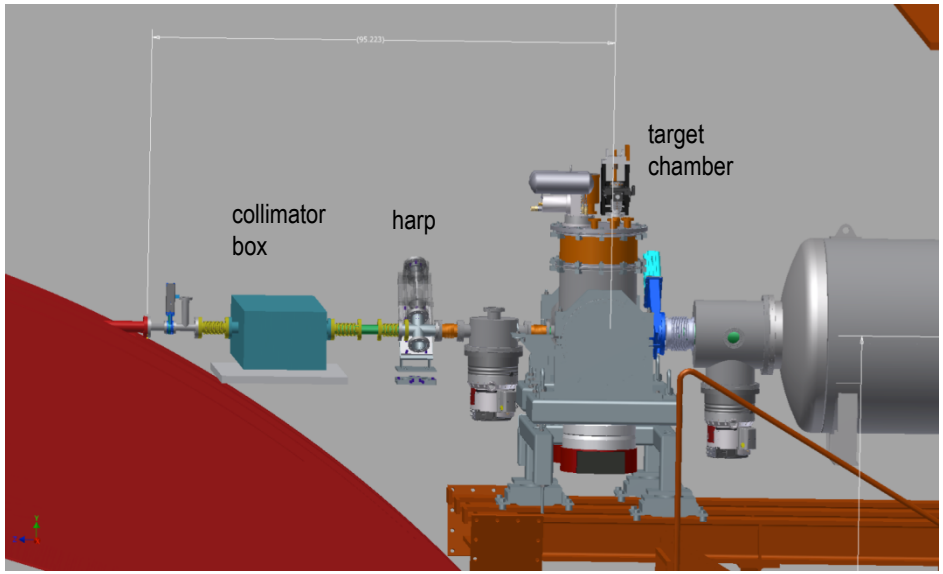


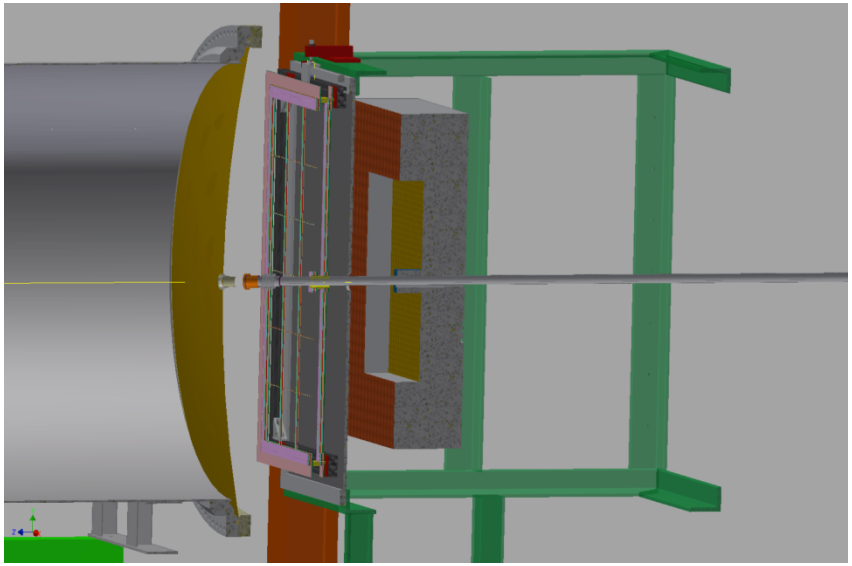
Vacuum Window

Preparation of the Vacuum Window at JLab

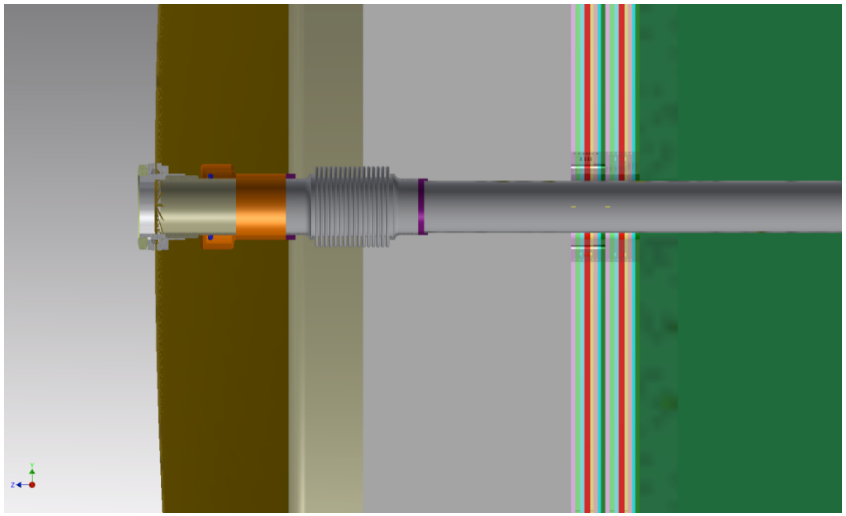
- Vacuum Window will be ready for installation in March, 2016 (estimated time: 2 days)

Beam Line Elements

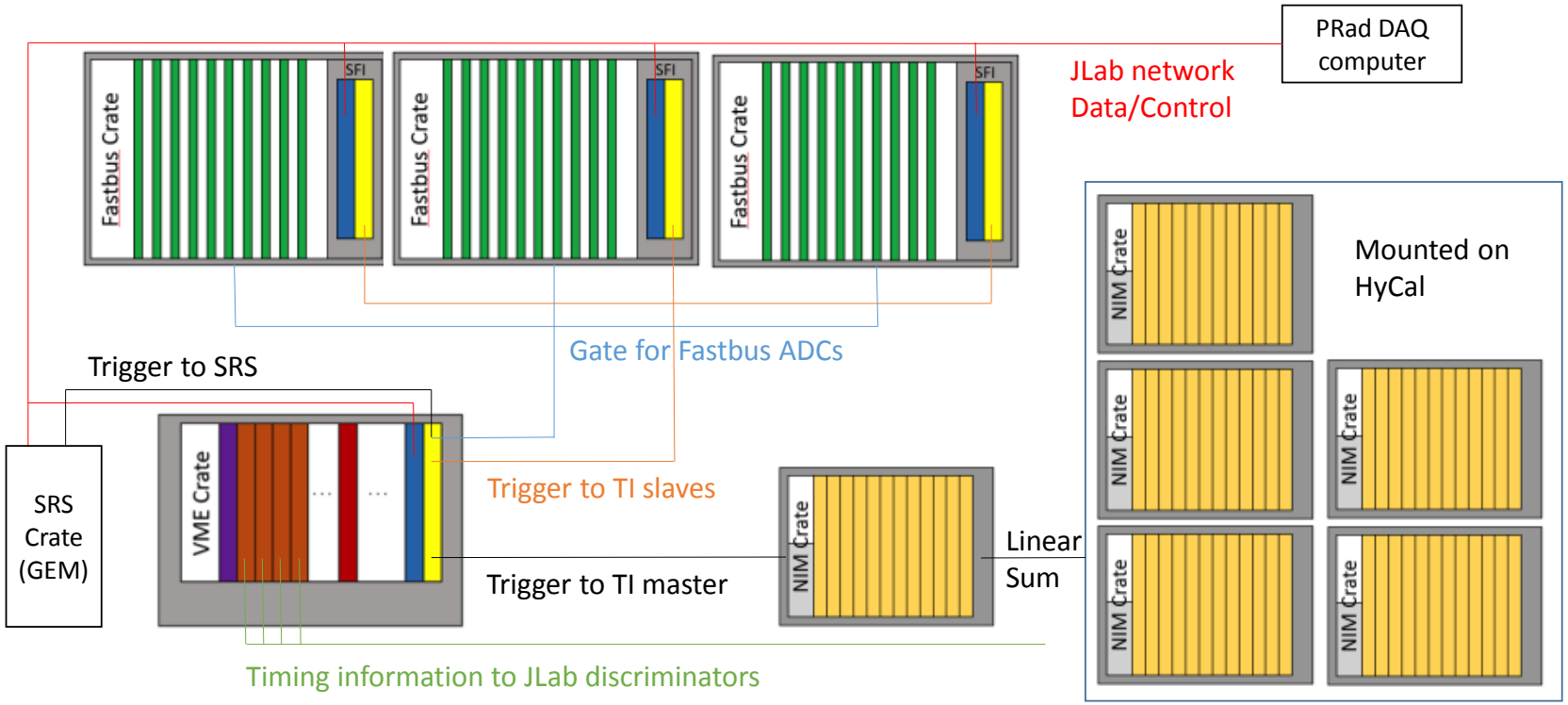




- Remaining work on Beam Line:
  - beam line from Vacuum Window through HyCal (parts are ordered)
  - collimator box is installed
  - Harp 2H00 will be installed in March
- Beam line ready for installation: March 2016
- Beam line change from HPS to PRad: ~ 10 days

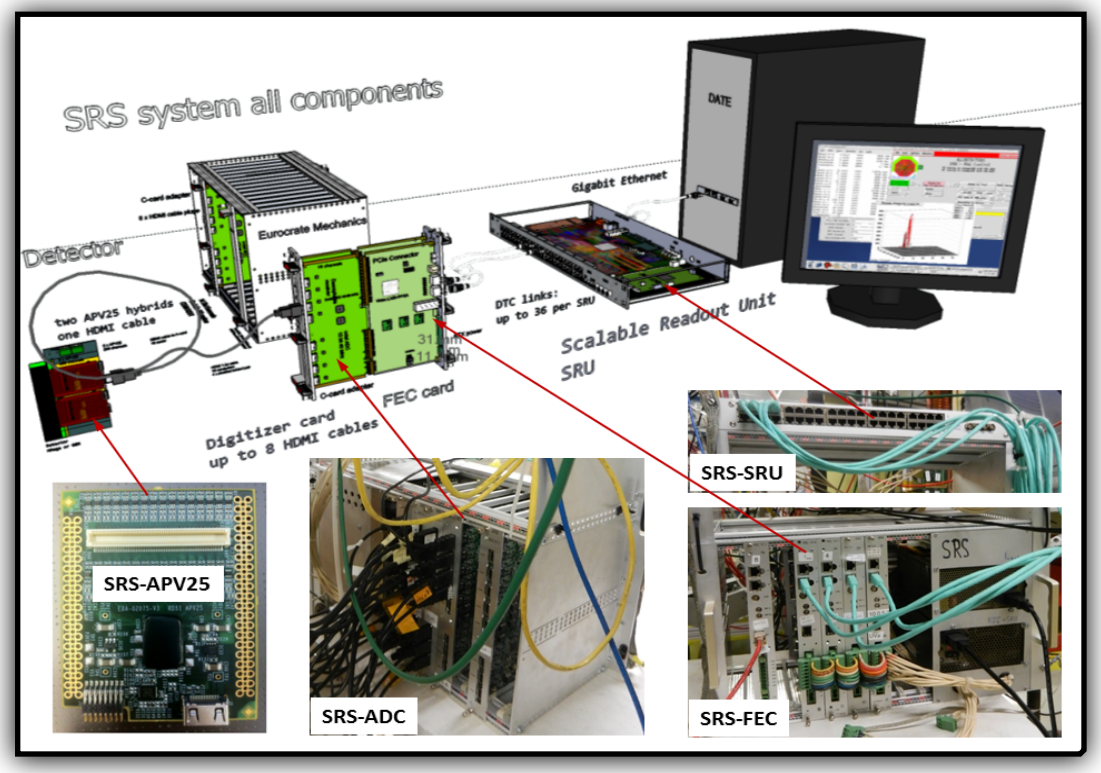


DAQ and Electronics



- PrimEx FASTBUS-based electronics and UVa linear sum modules for trigger
- Ready, taking cosmic data

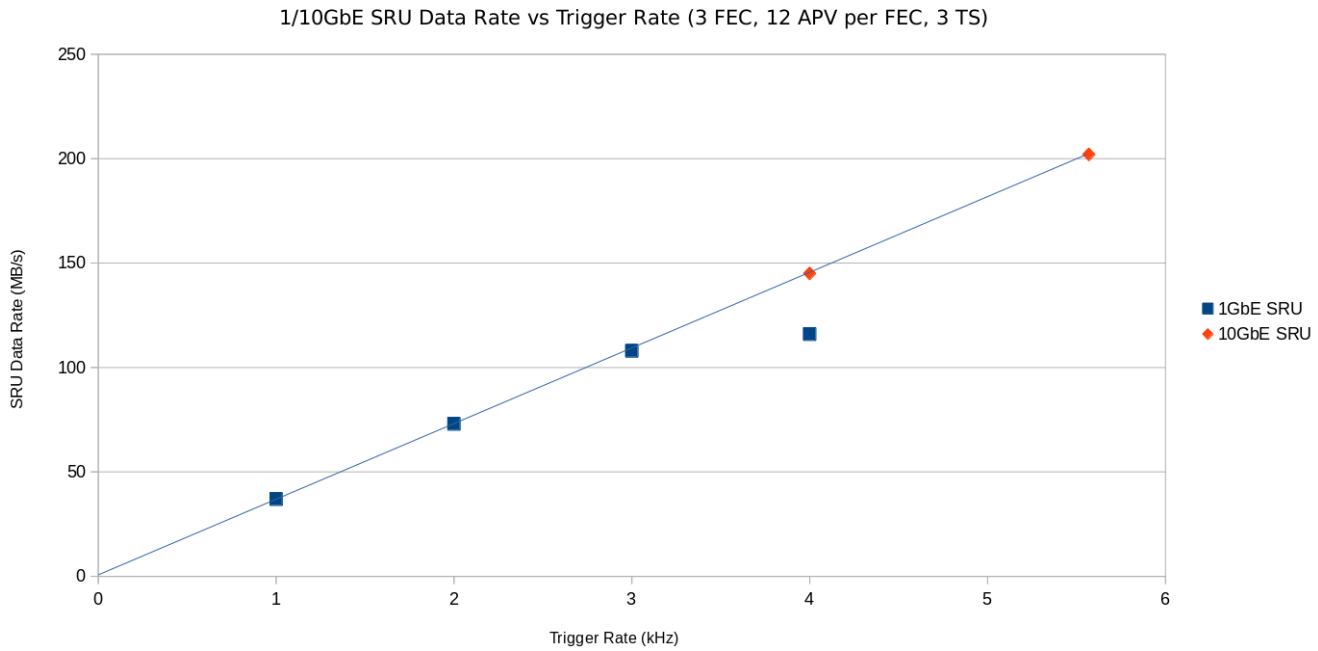
The GEM DAQ System



- Uses the Scalable Readout System (SRS) developed by CERN
- SRS-APV25 hybrid cards mounted on GEM detector, each card reads 128 channels
- Data is digitized using the SRS-ADC unit and controlled by a SRS-Front End Card (FEC).
- Each ADC and FEC combo can handle 16 SRS-APV cards (PRad will use a total of 72 APV cards with 9/12 cards handled by each FEC).
- A Scalable Readout Unit (SRU) communicates with the FEC cards, PRad will use 6/8 FEC cards.
- The SRU is read out using CODA.

Recent Upgrades to the GEM DAQ

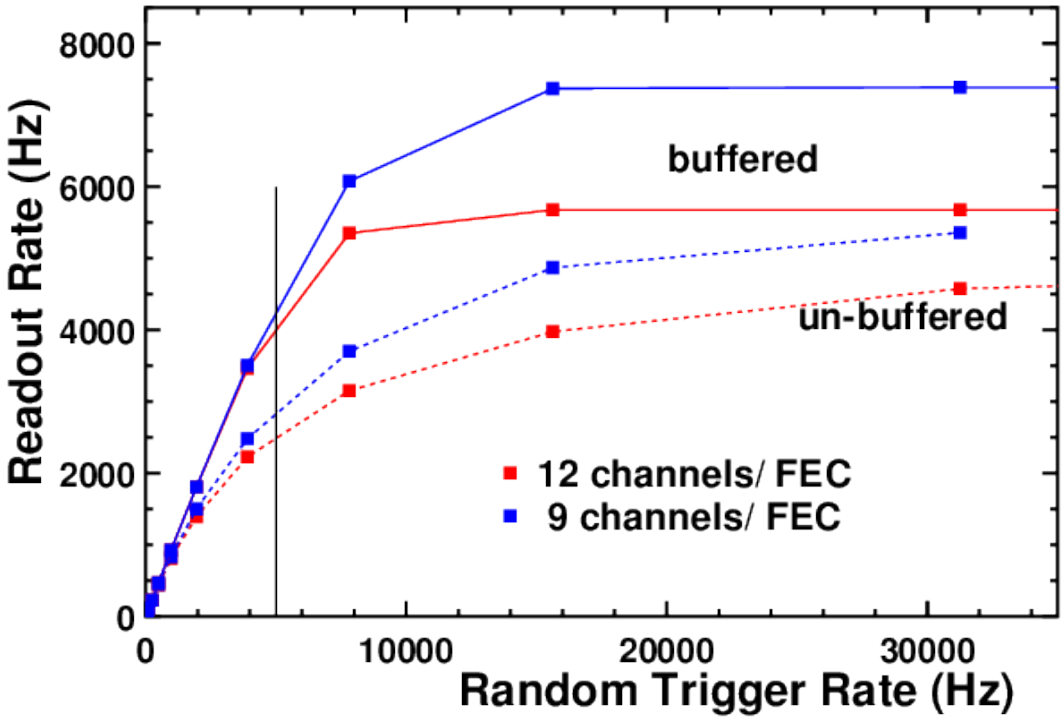
- Implemented by the JLab Fast Electronics and DAQ groups
- The SRS firmware was upgraded to handle a 10 Gb/s fiber based link (originally used a 1 Gb/s copper link)



- Tests indicated that the bottleneck with the 1 Gb/s link has been removed with the 10Gb/s link

Recent Upgrades to the GEM DAQ

- The JLab PCI Express based Trigger Interface card is used to integrate the SRS readout with CODA.
- New drivers were recently released by the JLab DAQ group.
- The SRS firmware was upgraded to allow buffering (firmware upgrades by the JLab Fast Electronics group)



- Tests demonstrate < 15% dead-time for random trigger rates of 5 kHz (Thanks to Fast Electronics and DAQ groups)

PRad Collaboration Institutional List

- Currently 16 collaborating universities and institutions

  Jefferson Laboratory
  NC A&T State University
  Duke University
  Idaho State University
  Mississippi State University
  Norfolk State University
  University of Virginia
  Argonne National Laboratory
  University of North Carolina at Wilmington
  University of Kentucky
  Hampton University
  College of William & Mary
  Tsinghua University, China
  Old Dominion University
  ITEP, Moscow, Russia
  Budker Institute of Nuclear Physics , Novosibirsk, Russia

- Open for new collaborators and institutional groups !!!

Summary

- *"Proton radius puzzle"* is still unsolved after 5 years
- PRad is uniquely designed to address this *puzzle*

- The experimental setup is ready for the final installation in March 2016

- First Readiness Review was done on November 12, 2015
- Final Readiness Review is scheduled for March 25, 2016
- PRad is currently scheduled to run in April and May of 2016

  ✓ open for new collaborators and institutional groups !!!

✓ PRad is supported in part by NSF MRI award #PHY-1229153
✓ my research work is supported in part by NSF awards: PHY-1506388 and PHY-0855543

Back up slides

Estimated Errors

- Extraction of proton charge radius was always limited by systematics and fitting uncertainties

- High rates will provide good statistical errors (~0.2% for all Q^2 bins)

- Simultaneous detection of two processes:
  - $ep \rightarrow ep$
  - $ee \rightarrow ee$ Moller scattering
- and windowless H_2 gas target

  - will significantly reduce major systematic errors typical for all previous *ep*-scattering experiments

Contributions	Estimated Error (%)
Statistical error	0.2
Acceptance (including Q^2 determination)	0.4
Detection efficiency	0.1
Radiative corrections	0.3
Background and PID	0.1
Fitting error	0.2
Total Error	0.6%

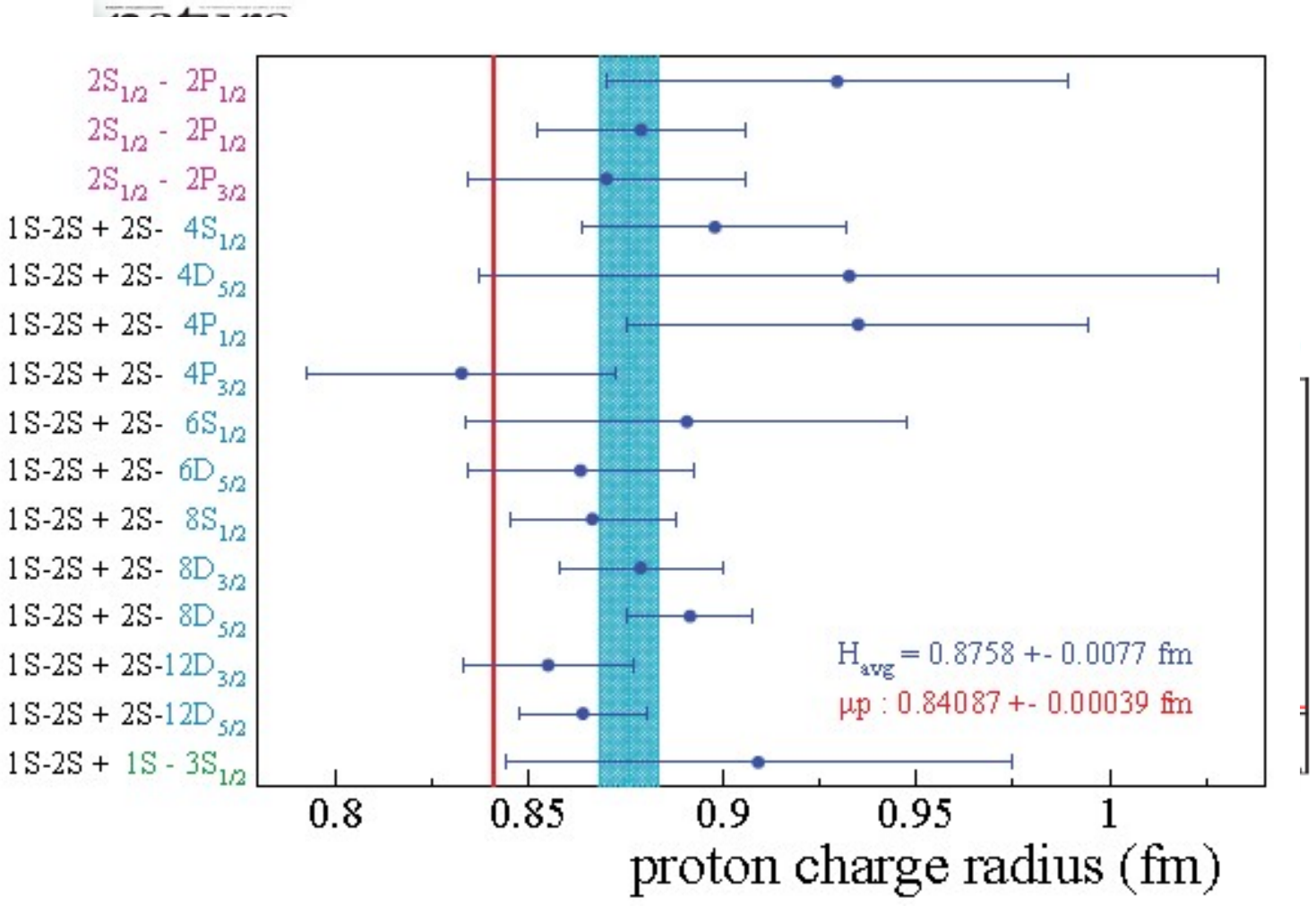
- Estimated error budget (added quadratically)

Beam Quality Requirements

Quality	Value
Energy	1.1 and 2.2 GeV
Beam current	0.1 – 10 nA
Luminosity	~ 10^{28} $cm^{-2}s^{-1}$
σ_x, σ_y	~ 100 μm
Position stability	~ 100 μm
Beam halo	< $(1x10^{-7})^*$
Divergence	< mrad
Emittance (ε_x, ε_y)	$8x10^{-10}$ m-rad

* for R > 3 mm from the beam center

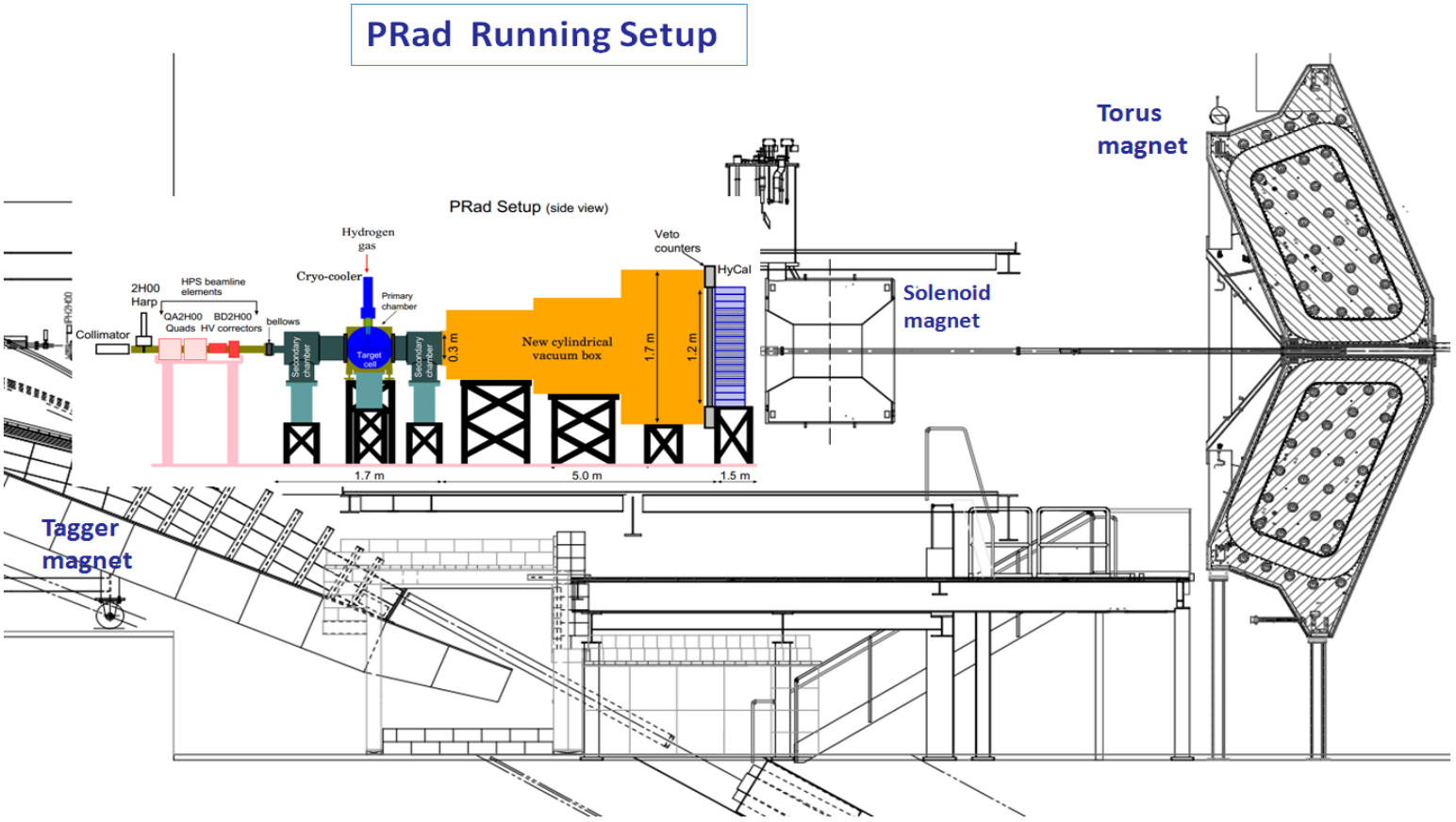
New Results from Muonic Hydrogen Experiments (2010, 2013)



- r_p = 0.84184(67) fm ➡ Unprecedented less than 0.1% precision
- Different from most of previous experimental results and analyses

PRad Running Configuration in Hall B (suggested)

- Footprint of PRad setup: ~ 8.2 x 1.7 m^2
- Installation in parallel with CLAS12 work/assembly in Hall B
- Engineering and Physics runs during evenings/nights and over weekends



Distance between the HPS Quads' girder and the center of the Hall is ~10.5 m