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

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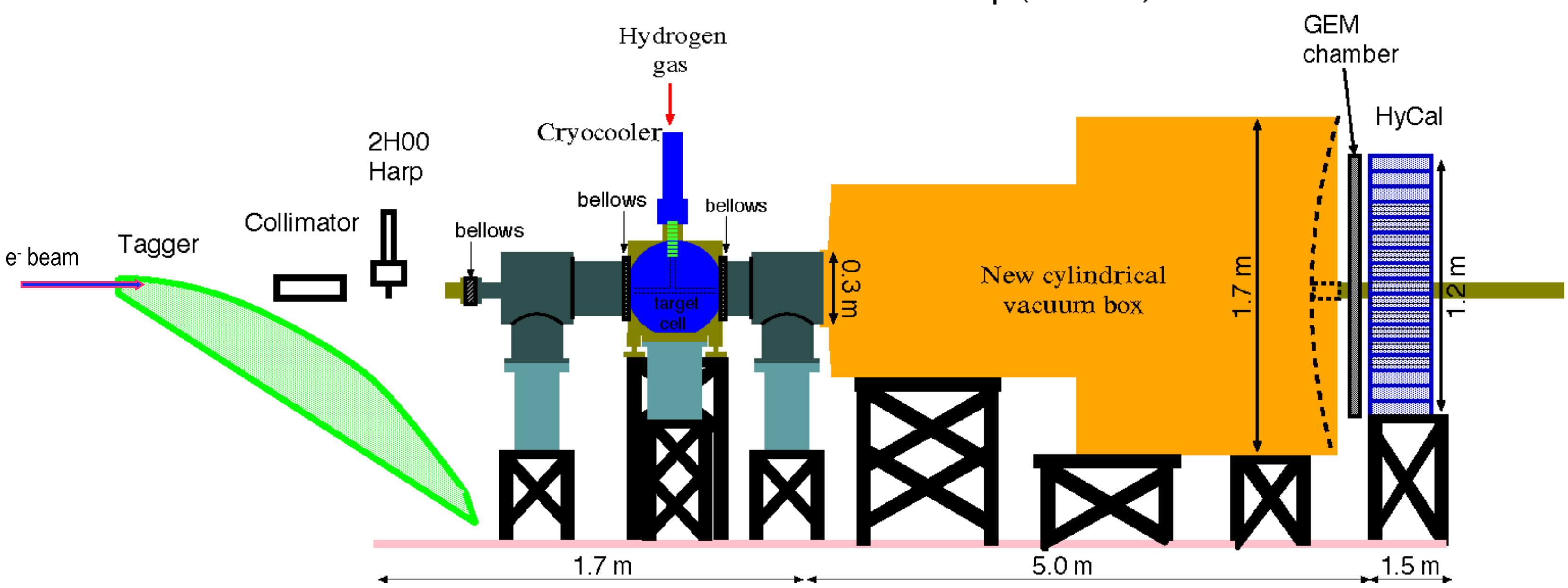
Outline

- Experimental apparatus, current status
- Installation plan
- Draft run plan
- Summary

PRad Experimental Setup

- 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

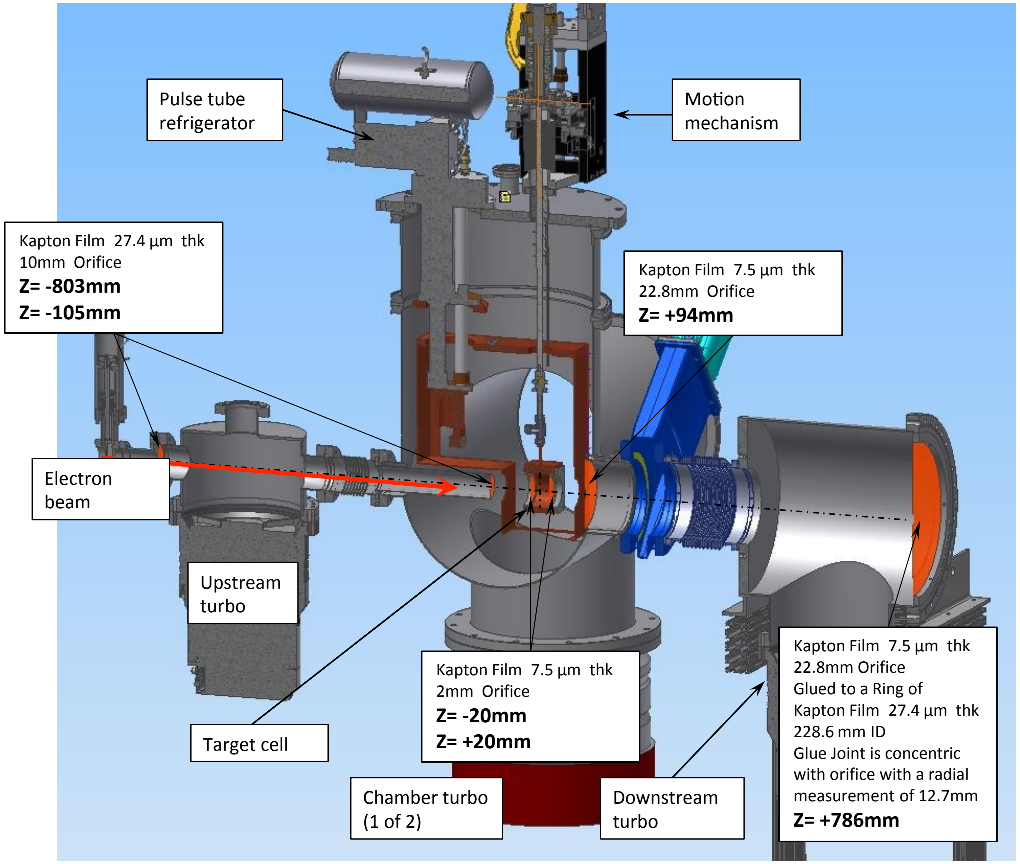
PRad Setup (Side View)



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 ±10 μm accuracy.

- Two solid target foils:
  - *1 μm carbon*
  - *1 μm aluminum*

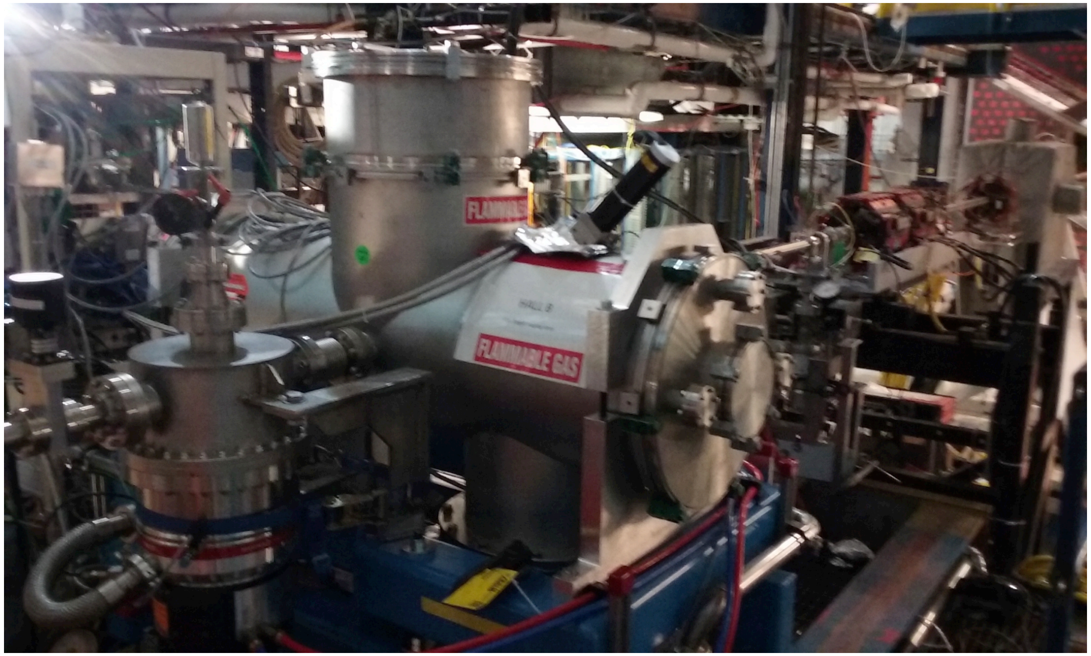


Goal parameters	
Length:	4 cm
Temperature:	25 K
Pressure:	0.6 torr
Thickness:	1×10^{18} H/cm^2

Secondary goal:
Reduce H_2 background gas!

Target Status

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



Work Schedule:

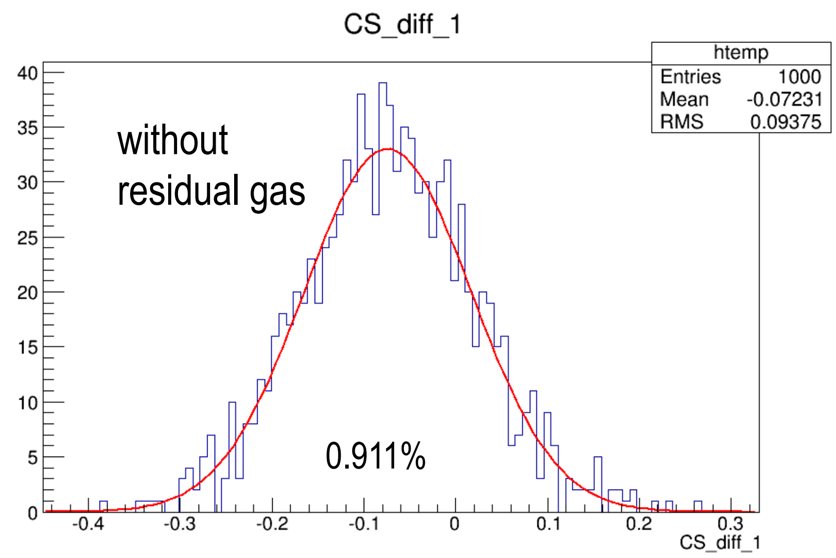
- March 28 – April 7: Install target cell, beam line orifices, perform H_2 tests
- April 8 – 10: Beam Commissioning
- mid May – mid June: PRad data taking time

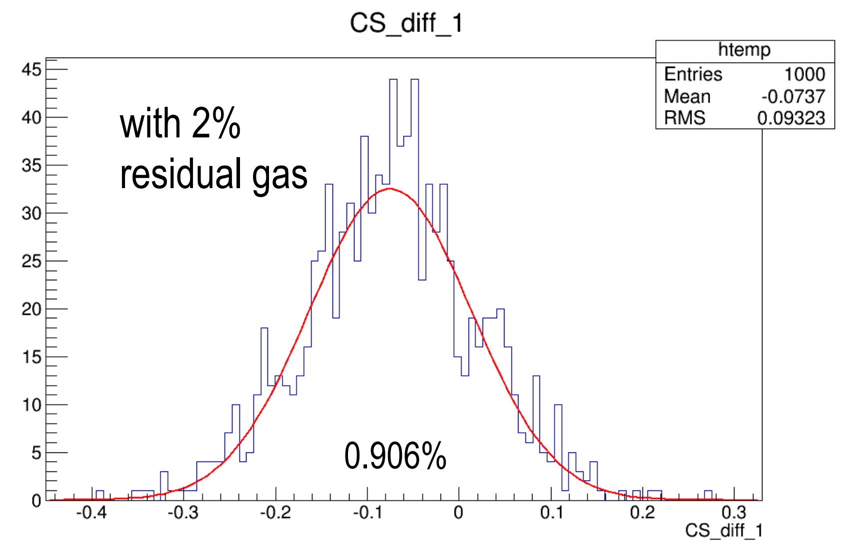
✓ **Target is ready for the experiment (Thanks to Target Group).**

Residual Beam Line Gas Effect (ERR Rec. #5.1)

- Monte Carlo simulations performed with:
  - ✓ 2% of target gas distributed in [-30, +30] cm Z-interval;
  - ✓ Events are reconstructed from the target;
  - ✓ Each case is run 1000 times.

Provided by Chao Peng





Relative differences between the extracted and input cross sections:
σ's considered as the systematic uncertainties

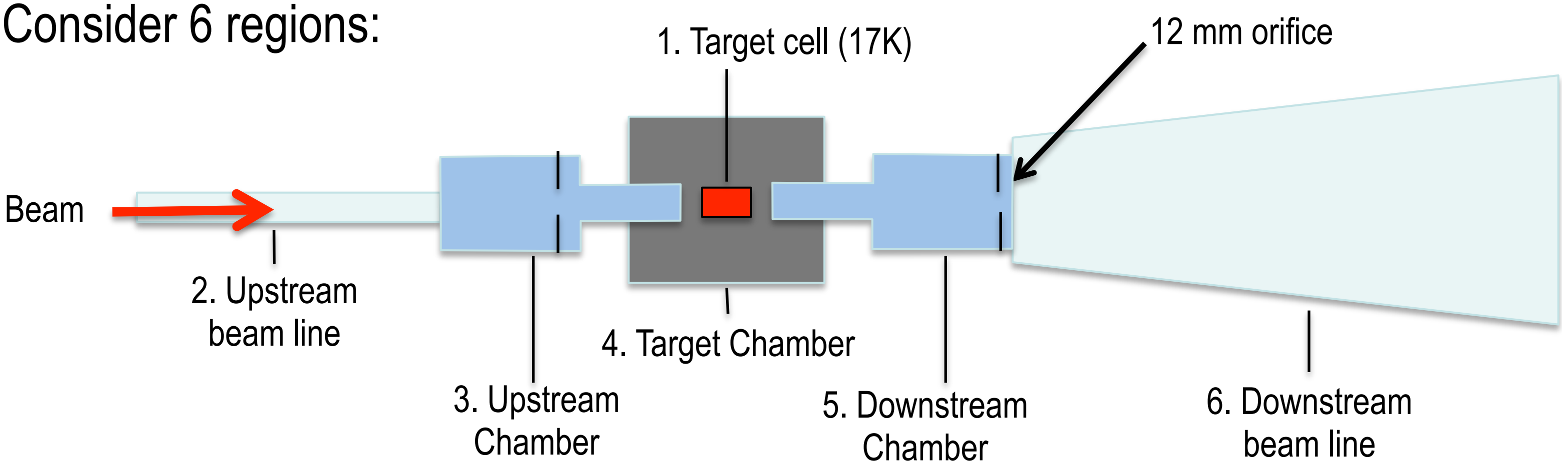
✓ Effect of residual gas shown to be negligible.

December Helium Tests

Provided by Ch. Keith

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

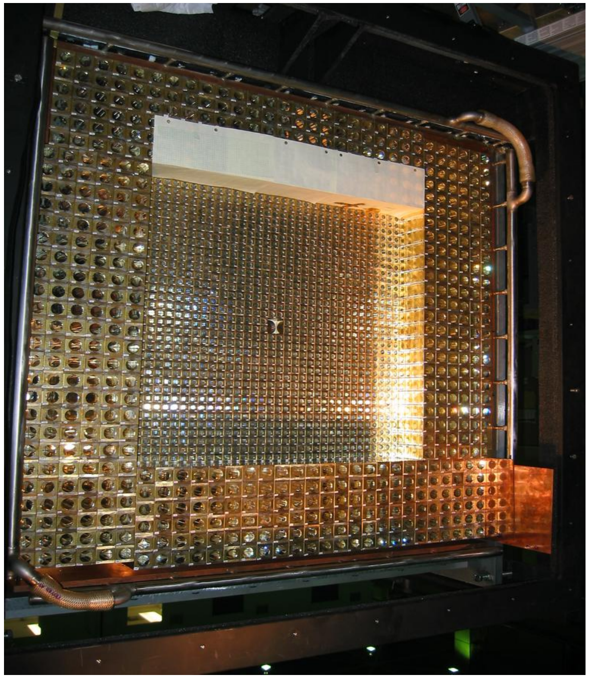
Dec. 2015 tests with HELIUM

Background gas reduced to approx. 0.2% of cell thickness

* Measured ** estimated

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)



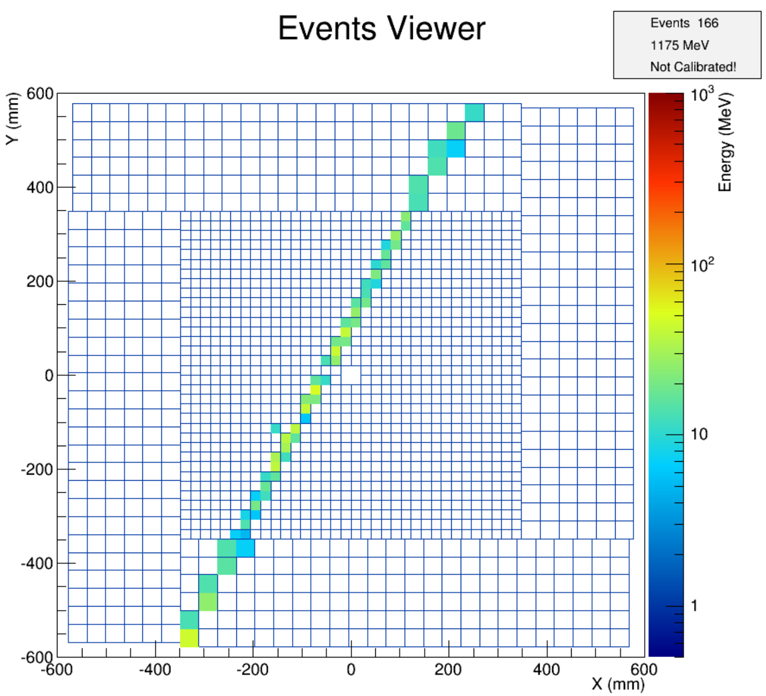
- Moved back to Hall B in June, 2014:

  (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

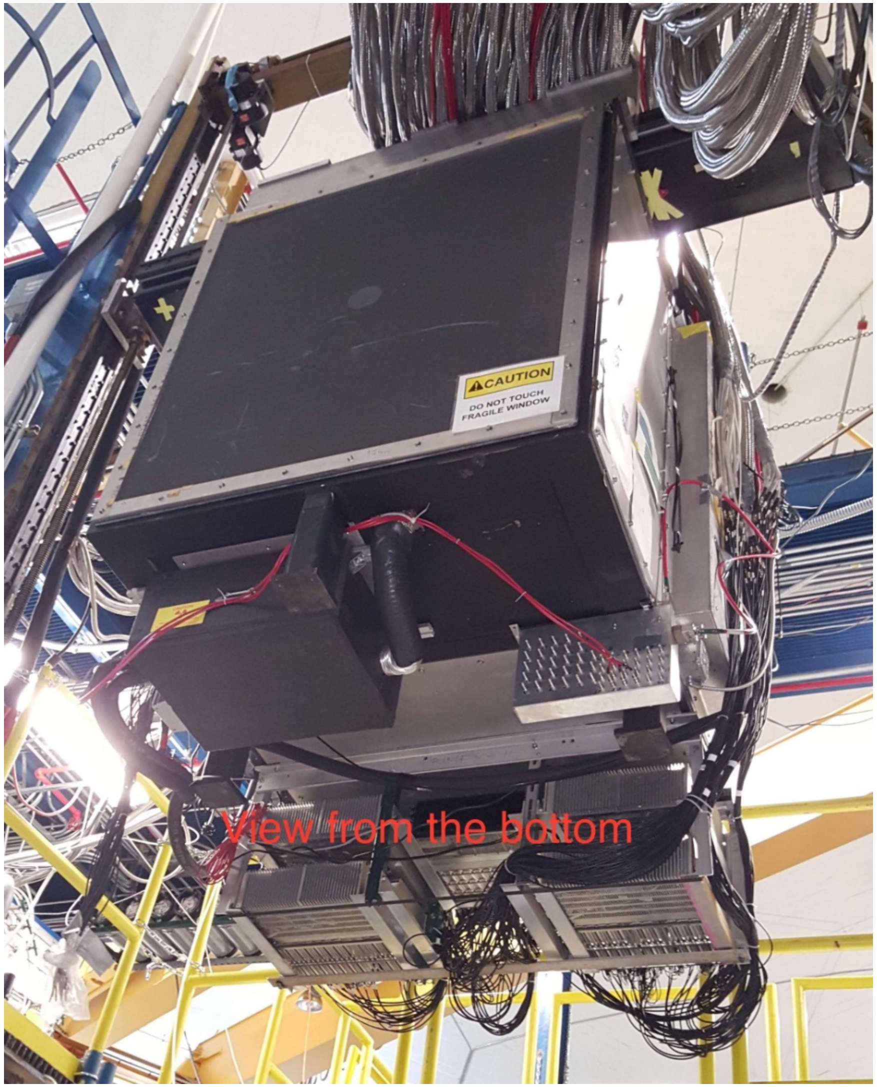
HyCal Current Status

- HyCal is currently up in Transporter, taking cosmic data



Cosmic event in HyCal

✓ **HyCal is ready for the experiment.**



HyCal in Hall B beam line (Oct, 2015)

GEM Chambers

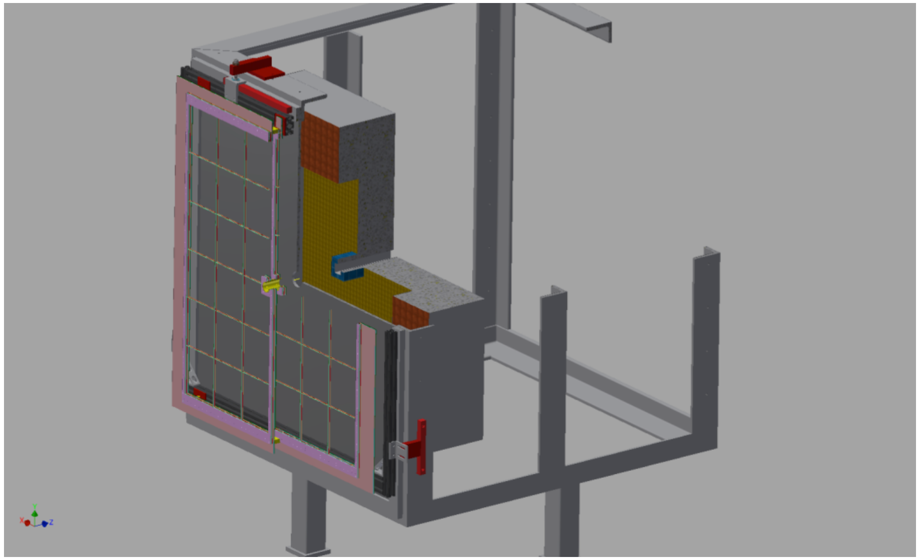
- Tasks for GEM:
  - factor of >10 improvements in coordinate resolutions
  - similar improvements in Q^2 resolution (very important)
  - unbiased coordinate reconstruction (including transition region)
  - increase Q^2 range by including Pb-glass part

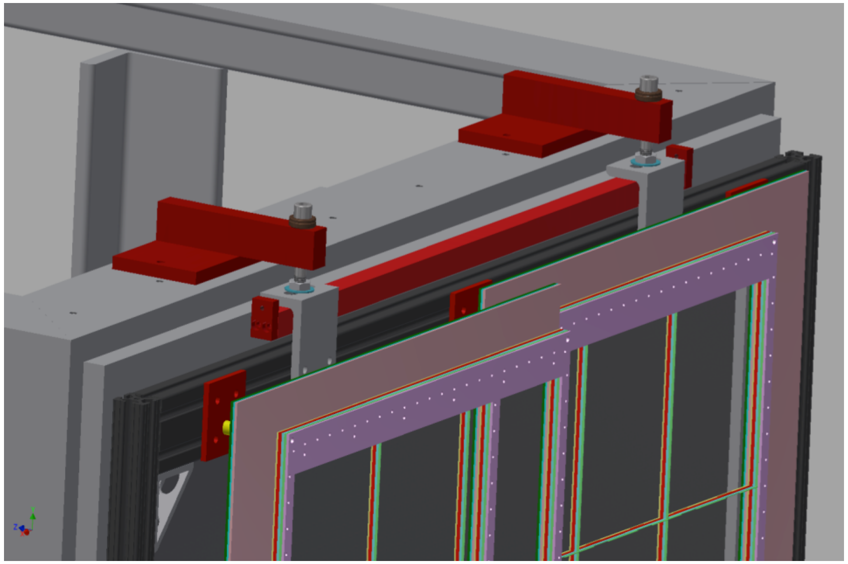
- Designed and built at UVa
- Both GEMs are in EEL at JLab
- Cosmic ray tests are in progress

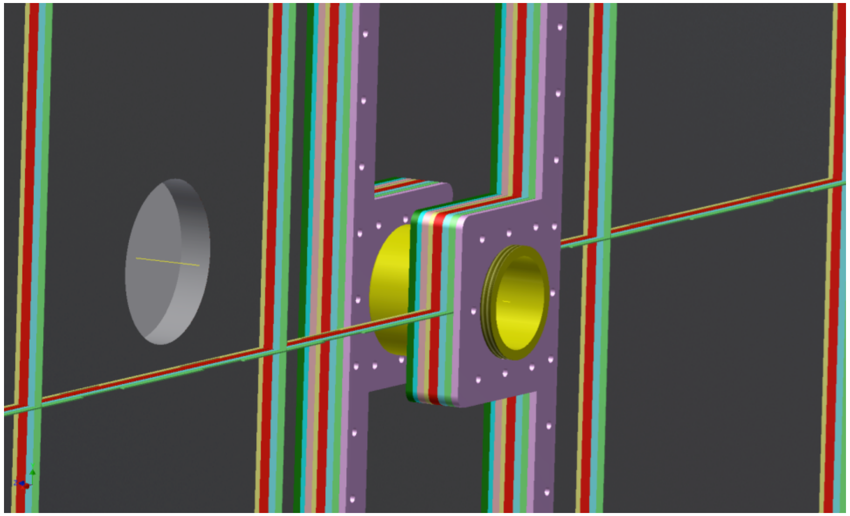
- Talk by Kondo Gnanvo

GEM chambers in EEL at JLab, March 2016

GEM Mount on HyCal







- GEM chambers will be held on light aluminum frames attached to the HyCal frame
- Preassembled in EEL building
- Ready for nstallation in March, 2016

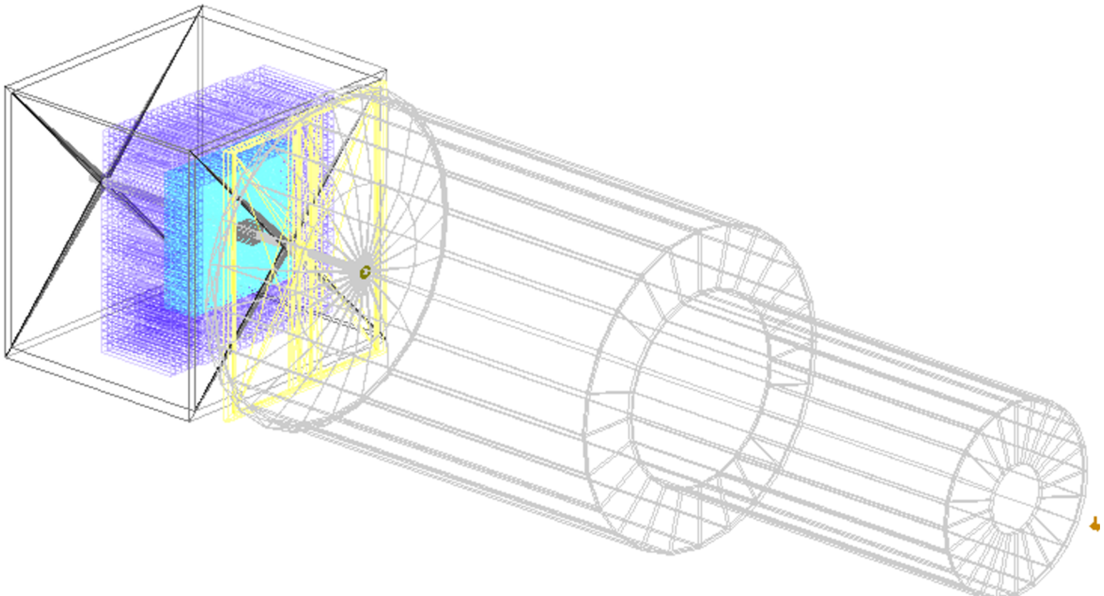
- Talk by Kondo Gnanvo

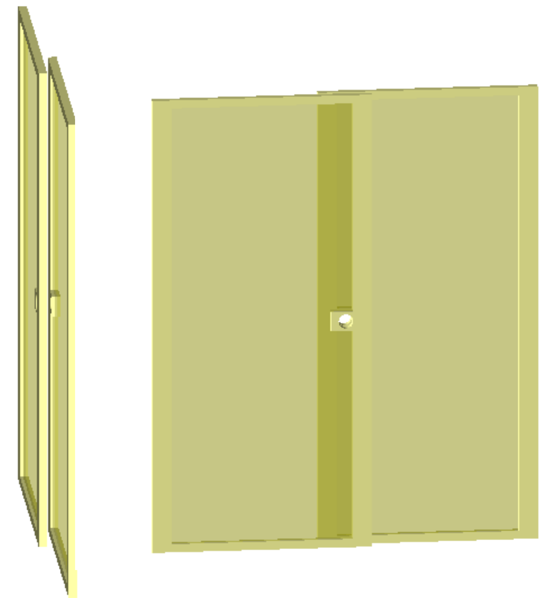
Requirements to GEMs (ERR Rec. #7.2)

- PRad requirements for the GEM:
  - position resolution: 0.1 mm
  - detection efficiency: ~95 % ± 0.1% — will be measured with cosmic rays and during the beam calibration runs
  - Uniformity of detection efficiency: with ± 0.1% accuracy — will be measured with cosmic rays and during the beam calibration runs
  - Minimum material in HyCal acceptance — the effect is estimated by Monte Carlo simulations

GEM Monte Carlo Simulations (ERR Rec. #7.2)

Provided by Chao Peng

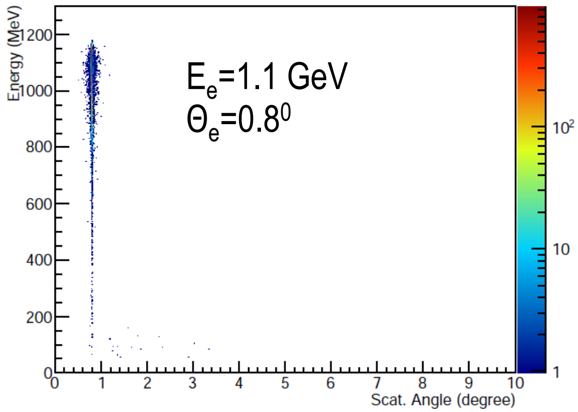


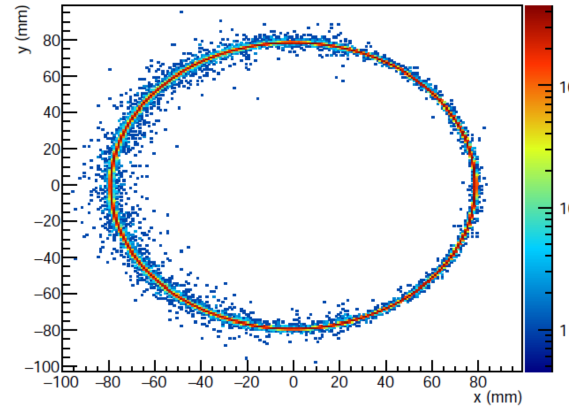


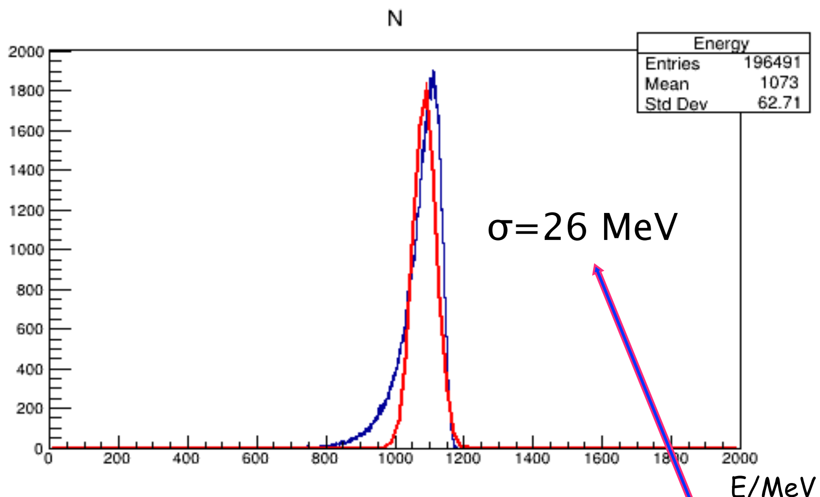
Side view   Front view

- GEANT code includes detailed information about frames

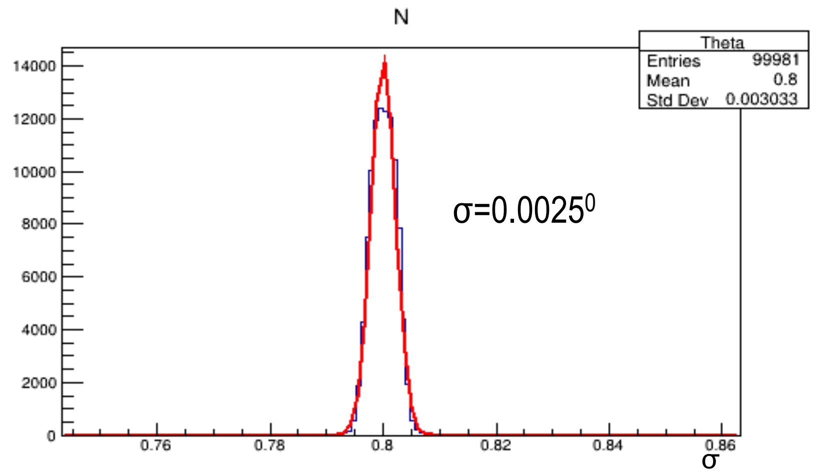
GEM Monte Carlo Simulations (cont'd)







HyCal + GEM energy reconstruction



HyCal + GEM angular reconstruction

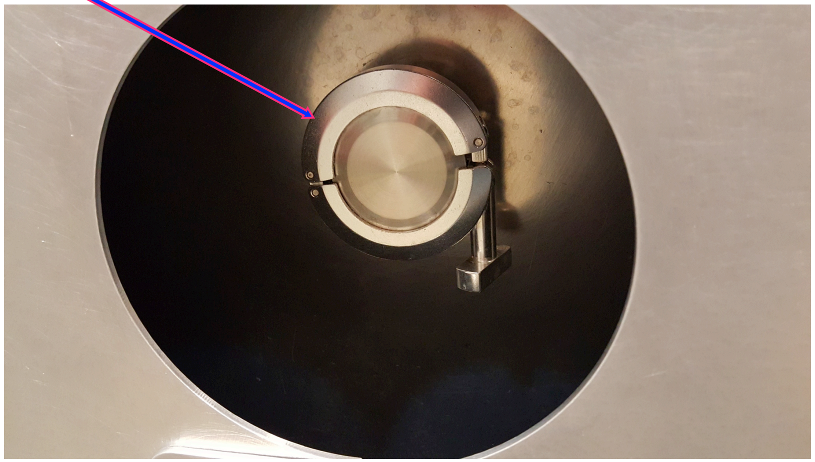
σ(with HyCal only) = 25 MeV

- GEM: critical improvement in angular resolutions, without much change in energy resolutions

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)

- The beam pipe connection adapter



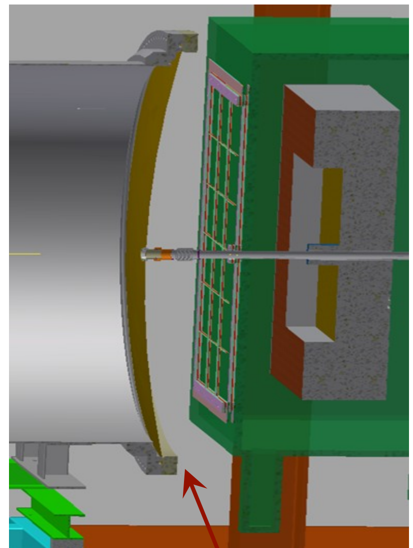
- Assembled and vacuum tested at Jlab
- Vacuum window is installed
- Hydrostatically tested up to 30 psi
- ✓ see https://wiki.jlab.org/pcrewiki/index.php/PRad_Experiment_Readiness_Review

- Vacuum box with window and stands is Ready for installation in March, 2016 (estimated time 2 days)

Vacuum Window

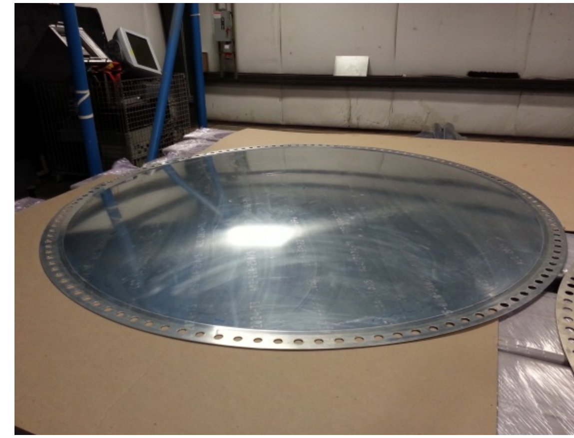
- Thin Al-window on Vacuum Box at the HyCal end
  - thickness: ~2 mm
  - diameter : 1.7 m
  - connected to the beam vacuum pipe in center
- Design and construction done at JLab

e$^-$ beam



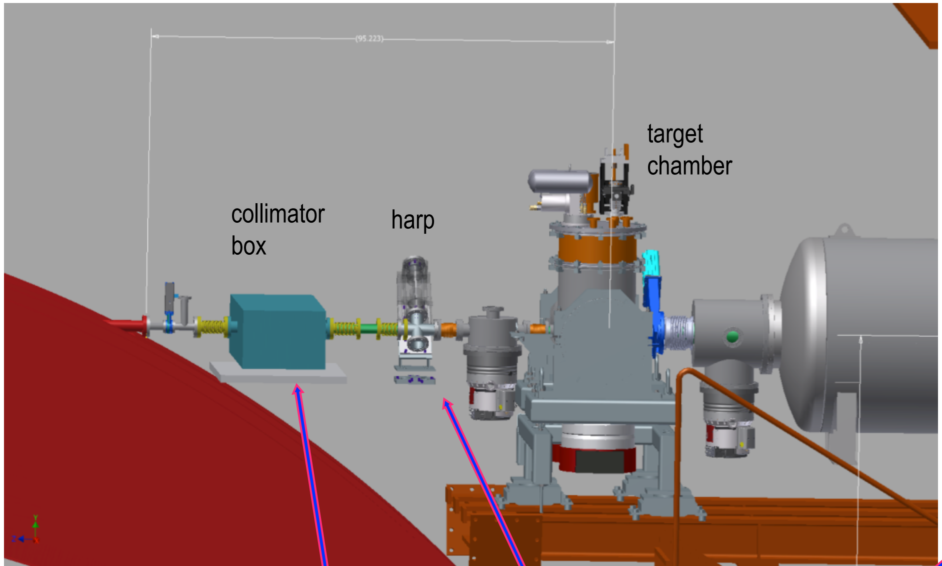
Vacuum Window

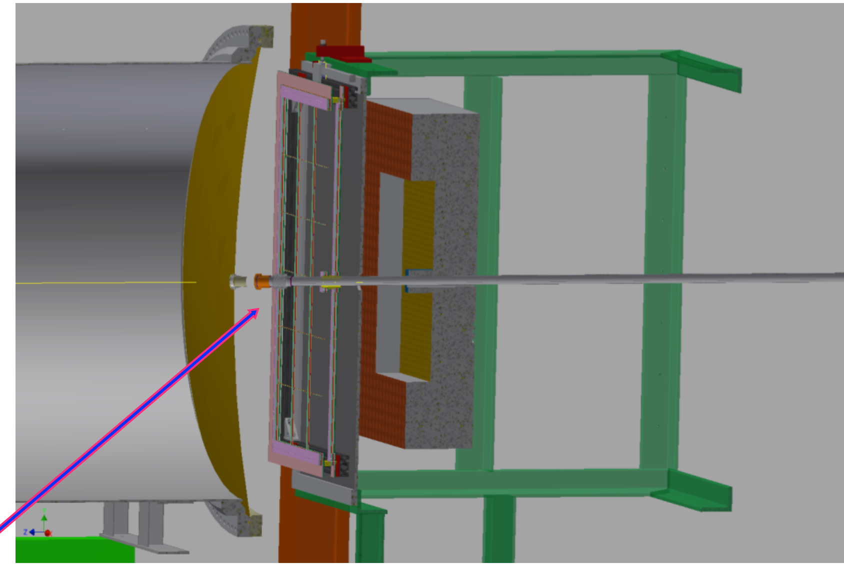
- Vacuum tests are done in March, 2016 (hydrostatically tested up to 30 psi)
- Vacuum Window is already installed on the Vacuum box.

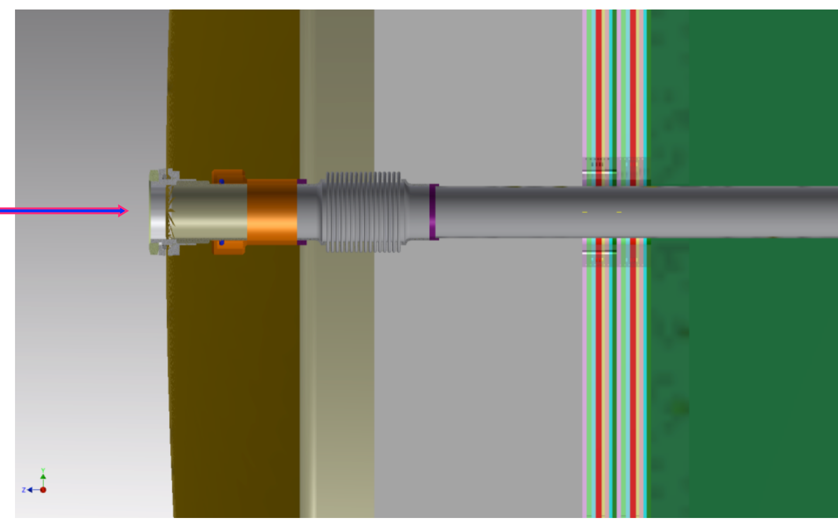


Preparation of the Vacuum Window at JLab

Beam Line Elements







- collimator box is installed
- harp 2H00 will be installed in March/April
- all vacuum pipes are at JLab

- Beam line elements ready for installation:
  March 2016
- Beam line change from HPS to PRad: ~ 10 days

DAQ Status (including GEM)

- Recent tests demonstrated < 15% dead-time for random trigger rates of 5 kHz (especial thanks to Fast Electronics and DAQ groups)

- Talk by Kondo Gnanvo.

Required Beam Parameters

- Tagged Photon Beam for the setup calibration:
  - No special requirements for the tagged photon beam
    - ✓ E_e = 2.2 GeV, I_e = 70 pA – 1 nA
    - ✓ σ_x, σ_y = ~ 100 μm at the Tagger

- Requirements for Electron Beam:
  - very typical for Hall B with a better "beam halo"

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

* for R > 3 mm from the beam center

PRad Commissioning and Data Taking Run Plan

1) Photon Beam Tuning (~1 day):

- HyCal with GEM on Transporter and off the beam line;
- Target cell off the beam line;
- Tagger radiator off, collimator off;
- Tagger magnet on.

a) establish a good electron beam (E_e = 2.2 GeV, I_e = 5 nA) on the tagger dump;
b) take electron harp scans 2C21A and 2C24A,
check the position, widths and peak to tails ratio;
c) study beam halo by setting the harp wire in the tail region and ramping beam current up to 100 nA;
d) lower beam current to 0.1 nA
e) insert radiator 10^{-5} r. l.;
f) check tagger counter scalars;
g) setup MOR logic for calibration (gain equalizing) trigger T5 only;

PRad Run Plan: Formation of Trigger and Checkout

2) HyCal Gain Equalizing and Trigger Checkout (1.5 days):

a) establish HyCal temperature to T=16^o and keep it stable;
b) collimator in, 6 mm;
c) target cell off the beam;
d) HyCal is in “Bottom Right” position;
e) establish a good timing with HyCal readout;
f) adjust trigger delay if necessary;
g) set the gain value: E=2 GeV to ADC=4000 channel;
h) start the gain equalizing process: scan to each module’s center, show the anode and dynode ADC distributions on computer screen, by changing the HV set anode ADC=4000 channel (with ~ 5% precision), save the HV, ADC and anode/dynode ratio;
i) repeat for all HyCal modules (~10 hours).

PRad Run Plan: GEM Calibration

3) GEM Beam Calibration **(1.5 days, look for possibilities to combine with the item #2):**

- 1”x1“l scintillator counters are installed in the beam line just after the Vacuum box.

a) collimator with smallest diameter in (2.7 mm);
b) insert thin ~ 1 μm ^{12}C target in the beam;
c) insert radiator 10^{-5} r. l.;
d) ask for photon beam with lowest intensity (I_e = 70 pA);

e) adjust the timing of the scintillator detectors vs. tagger;
f) scan the GEM with HyCal with a predefined step size both on X and Y-axis, store the data from GEM, HyCal and trigger scintillator detectors;
g) measure the GEM’s detection efficiency vs. position (uniformity).

PRad Run Plan: HyCal Gain Calibration

4) HyCal Gain Calibration (1.5 days):

a) run HyCal with HV unchanged for ~ 3 hours after the "Gain Equalizing";
b) the beam and the beam line are the same as in "Gain Equalizing";
c) trigger: all T1-T19 tagger counters, DAQ without the "sparsification";
d) start from the "Top Left" position with a continuous motion (~1 min/module) "illuminate" all modules, store the data with HyCal's X,Y positions from EPICS;
e) stop the HyCal motion by the end of each row, make new DAQ run with pedestals and LMS, store the files;
f) run on-line calibration programs for constants, store the data.

5) Configuration change to running configuration with HyCal on the cart, engineering survey (~4 days).

- **Request for Beam Energy Change to E_e = 1.1 GeV (0.5 day)**

PRad Run Plan: Target Commissioning

6) Electron Beam Tuning and Target Commissioning (2 days)

a) target cell off the beam line, no gas flow in the cell and chamber;
b) collimator off;
c) set threshold energy for the HyCal trigger $E \sim 0.5xE_e$;
d) request electron beam (E = 1.1 GeV, I = 1 nA);
e) take harp scans 2C21A, 2C24A and 2H01, check position and widths, establish a good electron beam and fix the beam line parameters;
f) record HyCal trigger rate with no cell and no gas flow take one short file with ADCs;
g) electron beam off; insert the target cell in the beamline, still empty, ask for beam;
h) target cell is empty (no gas flow into the cell and chamber);
i) record HyCal trigger rate, take one short file with ADCs;
j) gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
k) record HyCal trigger rate, take one short file with ADCs;
l) move the cell on X-axis by +/- 3 mm with 0.2 mm steps and take HyCal rate;
m) move the cell on Y-axis by +/-3 mm with 0.2 mm steps and take HyCal rate;
n) change the cell angles and record the HyCal rate, get optimal cell direction;
o) center the cell in beam based on those measurements;
p) no gas flow into the cell and chamber, record HyCal rate;
q) gas flow into the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
r) record HyCal trigger rate, take one short file with ADCs;

PRad Run Plan: Target Commissioning (cont'd)

7) Target Commissioning (cont'd):

a) gas flow into the chamber only (P_{cell} = P_{cham} = 5 mtorr);
b) record HyCal trigger rate, take one short file with ADCs (in-beam residual gas effect);

c) If there is no sizable effect between cell in/out, skip following steps.
d) beam off, 12.7 mm collimator in, target cell in, ask for beam;
e) no gas flow in cell, record HyCal rate;
f) gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr), record HyCal rate;
g) beam off, insert 6.4 (?) mm collimator in, take beam and repeat items (w) and (x);
h) make a decision about the size of the collimator.

PRad Run Plan: Data Taking with E_e = 1.1 GeV

8) Data taking with E_e = 1.1 GeV (5 days)

a) beam intensity: I_e = 10 nA;
b) collimator in (with the diameter defined in 6 (z);
c) HyCal trigger is set, DAQ is ready, all slow control readout is ready;
d) target cell in with maximum density ($2.x10^{17}$ H/cm^3);

e) take data for 2 days, record all information on disk and on tape;
f) no gas in the cell, take data for 0.5 day (empty target run);
g) gas in the cell, run for 2 days (same as in (e));
h) no gas in the cell, take data for 0.5 day (empty target run);

9) Request for Beam Energy Change to E_e = 2.2 GeV (0.5 day)

PRad Run Plan: Data Taking with E_e = 2.2 GeV

10) Data taking with E_e = 2.2 GeV (4 days)

a) intensity: : I_e = 10 nA;
b) collimator in (with the diameter defined in 5 (r);
c) HyCal trigger is set, DAQ is ready, all slow control readout is ready;
d) target cell in with maximum density ($2.x10^{17}$ H/cm^3);

e) take data for 2 days, record all information on disk and on tape;
f) no gas in the cell, take data for 0.5 day (empty target run);
g) gas in the cell, run for 1.0 day (same as in (e);
h) no gas in the cell, take data for 0.5 day (empty target run).

Summary

- PRad experimental setup is developed, constructed and tested.
  It is ready for the experiment.

- We have addressed all Recommendations from the past ERR
  (thank you for your helpful comments and recommendations).

- DAQ is currently ready for the experiment.

- All systems and detectors are currently ready for installation.

- PRad will be ready to run from April, 2016.

- It is highly desirable to have a short test run before the data taking run.

✓ 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

Beam Commissioning Run Plan (April Test Run)

- **Goals:**
  - ✓ Initial test of entire apparatus with an electron beam;
  - ✓ Test of the H_2 gas flow target initial performances in electron beam;
  - ✓ Test of the beam halo effect on the trigger rate;
  - ✓ Check the effect of the “beam halo collimator” on the trigger rate;
  - ✓ Check and setup all timings, check the new DAQ (mostly GEM);
  - ✓ Collect initial data set to test on-line and off-line monitoring codes;
  - ✓ Find out weaknesses of the setup and software to prepare for May run.

- **Experimental setup:**
  - HyCal with GEM off the Transporter on the “Run Cart” in the beam line and surveyed (check with engineering group);
  - Vacuum box installed with the window;
  - Beam line completely assembled;
  - DAQ is ready, trigger is HyCal total sum (analog sum);
  - Target is ready (installation was done in January, 2016).

- **Beam:**
  - Electron beam (E_e = 2.2 GeV, I_e = 1 – 20 nA, focused on the target cell).

Beam Commissioning Run Plan (cont'd)

1) Electron Beam Tuning (~0.5 shift):

- Target cell off the beam line, no gas flow in the chamber;
- Collimator is in the "Beam Block" position;
- Tagger radiator off the beam line;
- Tagger magnet "on".

a) establish a good electron beam (E_e = 2.2 GeV, I_e = 5 nA) on the tagger dump;
b) take electron harp scans 2C21A and 2C24A,
check the position, widths and peak to tails ratio;
c) study beam halo by setting the harp wire in the tail region and ramping beam current up to 100 nA;
d) tagger magnet "off", prepare for an electron beam through the setup.

Commissioning Run Plan (cont'd)

2) Target Commissioning (2 shifts)

a) target cell off the beam line, no gas flow in the cell and chamber;
b) beam collimator in "off" position;
c) set threshold energy for the HyCal trigger to $E \sim 0.5\ E_e$;
d) request electron beam (E = 2.2 GeV, I = 1 nA);
e) take harp scans 2C21A, 2C24A and 2H01, check position and widths, establish a good electron beam and fix the beam line parameters;
f) record HyCal trigger rate with no cell and no gas flow take one short DAQ run (record HyCal and GEM information);
g) electron beam off; insert the target cell in the beamline, still empty, ask for beam;
h) target cell is empty (no gas flow into the cell and chamber);
i) record HyCal trigger rate, take one short DAQ run (record all information);
j) gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
k) record HyCal trigger rate, take one short DAQ run (record all information);
l) move the cell on X-axis by +/- 3 mm with 0.2 mm steps and take HyCal rate;
m) move the cell on Y-axis by +/-3 mm with 0.2 mm steps and take HyCal rate;
n) change the cell angles and record the HyCal rate, get optimal cell direction;
o) center the cell in the beam based on those measurements;
p) no gas flow into the cell and chamber, record HyCal rate;
q) gas flow into the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
r) record HyCal trigger rate, take one short DAQ run (record all information);

Commissioning Run Plan (cont'd)

3) Target Commissioning with the Beam Collimators (~0.5 shift)

a) electron beam off;
b) 12.7 mm beam collimator in;
c) target cell is empty (no gas flow into the cell and chamber);
d) request electron beam (E = 2.2 GeV, I = 1 nA);
e) record HyCal trigger rate, take one short DAQ run;
f) electron beam off;
g) target cell is still off, gas flow in the chamber (P_{cham} = 5 mtorr);
h) request for beam;
i) record HyCal trigger rate, take one short DAQ run (record all information);
j) electron beam off;
k) Insert target cell in, gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
l) request for beam;
m) record HyCal trigger rate, take one short DAQ run (record all information);
n) no gas flow in the cell and in the chamber;
o) record HyCal trigger rate, take one short DAQ run (record all information);
p) electron beam off;

Commissioning Run Plan (cont'd)

4) Target Commissioning with the Beam Collimator (~0.5 shift)

a) electron beam off;
b) 6.8 mm beam collimator in;
c) target cell is empty (no gas flow into the cell and chamber);
d) request electron beam (E = 2.2 GeV, I = 1 nA);
e) record HyCal trigger rate, take one short DAQ run;
f) electron beam off;
g) target cell is still off, gas flow in the chamber (P_{cham} = 5 mtorr);
h) request for beam;
i) record HyCal trigger rate, take one short DAQ run (record all information);
j) electron beam off;
k) Insert target cell in, gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
l) request for beam;
m) record HyCal trigger rate, take one short DAQ run (record all information);
n) no gas flow in the cell and in the chamber;
o) record HyCal trigger rate, take one short DAQ run (record all information);
p) electron beam off;

Commissioning Run Plan (cont'd)

5) Target Commissioning with the Beam Collimator (~0.5 shift)

a) electron beam off;
b) 2.7 mm beam collimator in;
c) target cell is empty (no gas flow into the cell and chamber);
d) request electron beam (E = 2.2 GeV, I = 1 nA);
e) record HyCal trigger rate, take one short DAQ run;
f) electron beam off;
g) target cell is still off, gas flow in the chamber (P_{cham} = 5 mtorr);
h) request for beam;
i) record HyCal trigger rate, take one short DAQ run (record all information);
j) electron beam off;
k) Insert target cell in, gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
l) request for beam;
m) record HyCal trigger rate, take one short DAQ run (record all information);
n) no gas flow in the cell and in the chamber;
o) record HyCal trigger rate, take one short DAQ run (record all information);
p) electron beam off;

Commissioning Run Plan (cont'd)

6) Test Runs with Different Beam Intensities and Trigger Thresholds (~2 shifts)

(Runs with I_e = 5 nA)

a) electron beam off;
b) insert the optimized beam collimator;
c) insert target cell in, gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
d) request electron beam (E = 2.2 GeV, I = 5 nA);
e) set HyCal trigger to lowest level: E ~ 0.1 E_e ;
f) record HyCal trigger rate, take one full DAQ run;
g) no gas flow in the target (empty target run);
h) record HyCal trigger rate, take one full DAQ run;
i) set HyCal trigger to : E ~ 0.3 E_e ;
j) record HyCal trigger rate, take one full DAQ run;
k) gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
l) record HyCal trigger rate, take one full DAQ run;
m) set HyCal trigger to : E ~ 0.5 E_e ;
n) record HyCal trigger rate, take one full DAQ run;
o) no gas flow in the target (empty target run);
p) record HyCal trigger rate, take one full DAQ run;
q) set HyCal trigger to : E ~ 0.8 E_e ;
r) record HyCal trigger rate, take one full DAQ run;
s) gas flow in the cell (P_{cell} = 6 torr, P_{cham} = 5 mtorr);
t) record HyCal trigger rate, take one full DAQ run;

Commissioning Run Plan (cont'd)

7) Test Runs with Different Beam Intensities and Trigger Thresholds (~1 shift)

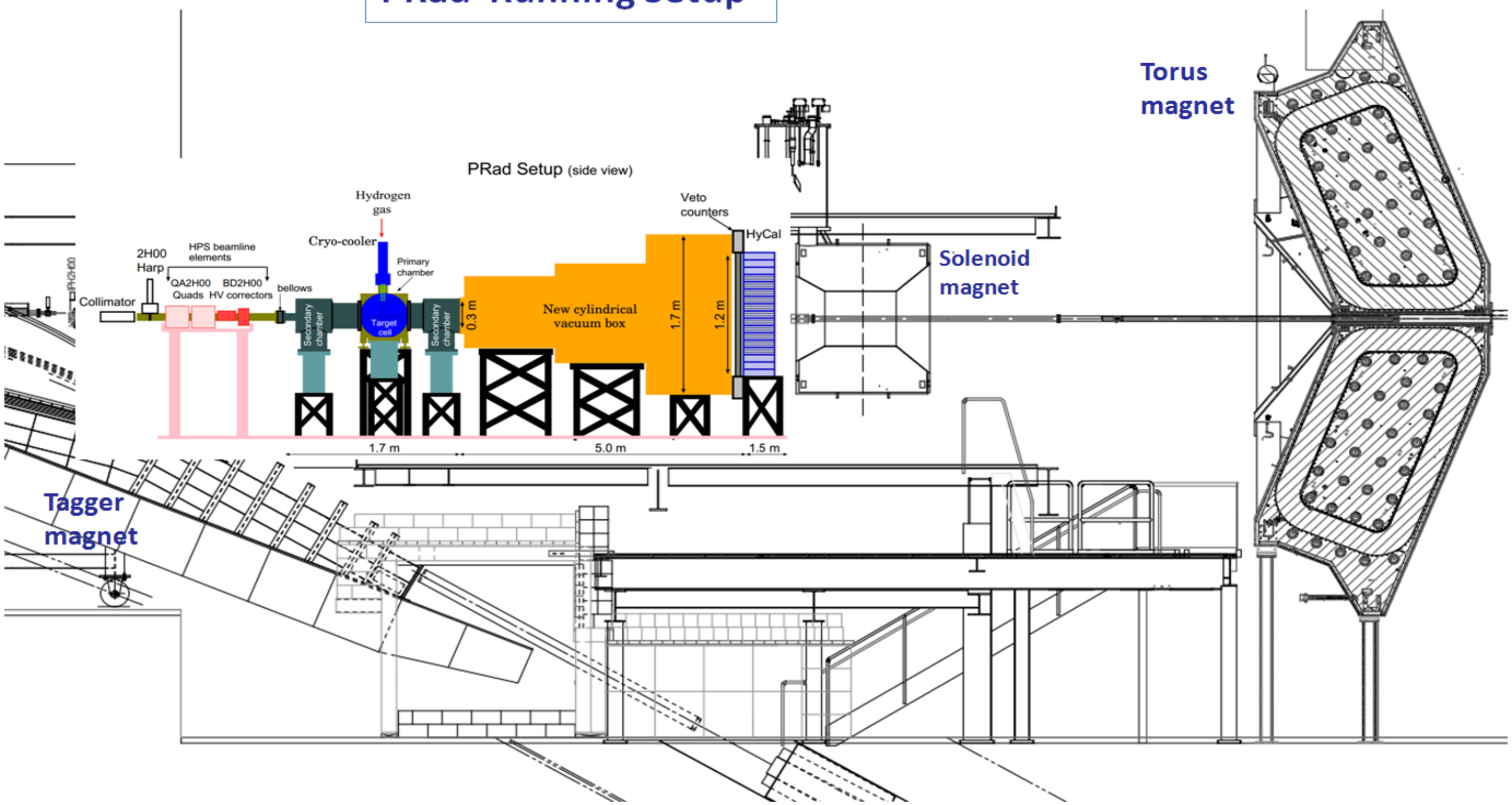
(Runs with I_e =10 nA)

a) Repeat all steps in part (4) for E = 2.2 GeV, I_e = 10 nA)

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

PRad Running Setup



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