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

A. Gasparian
NC A&T State University

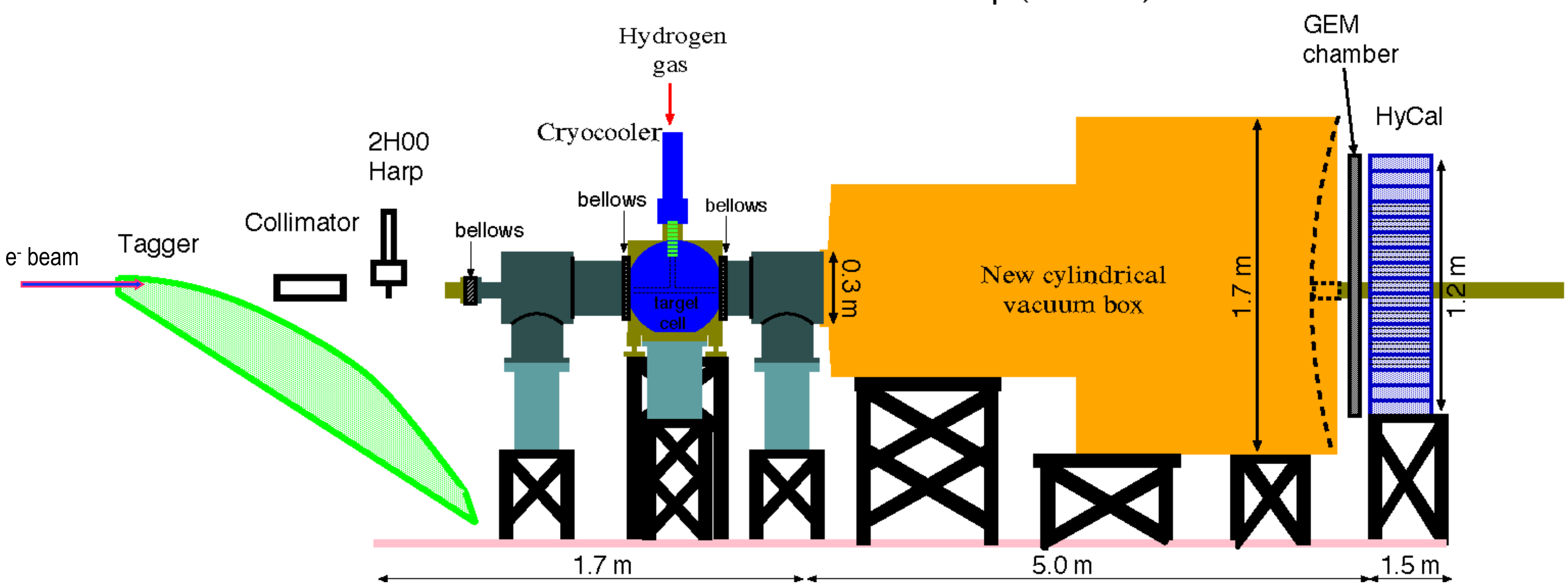
### Outline

- 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.

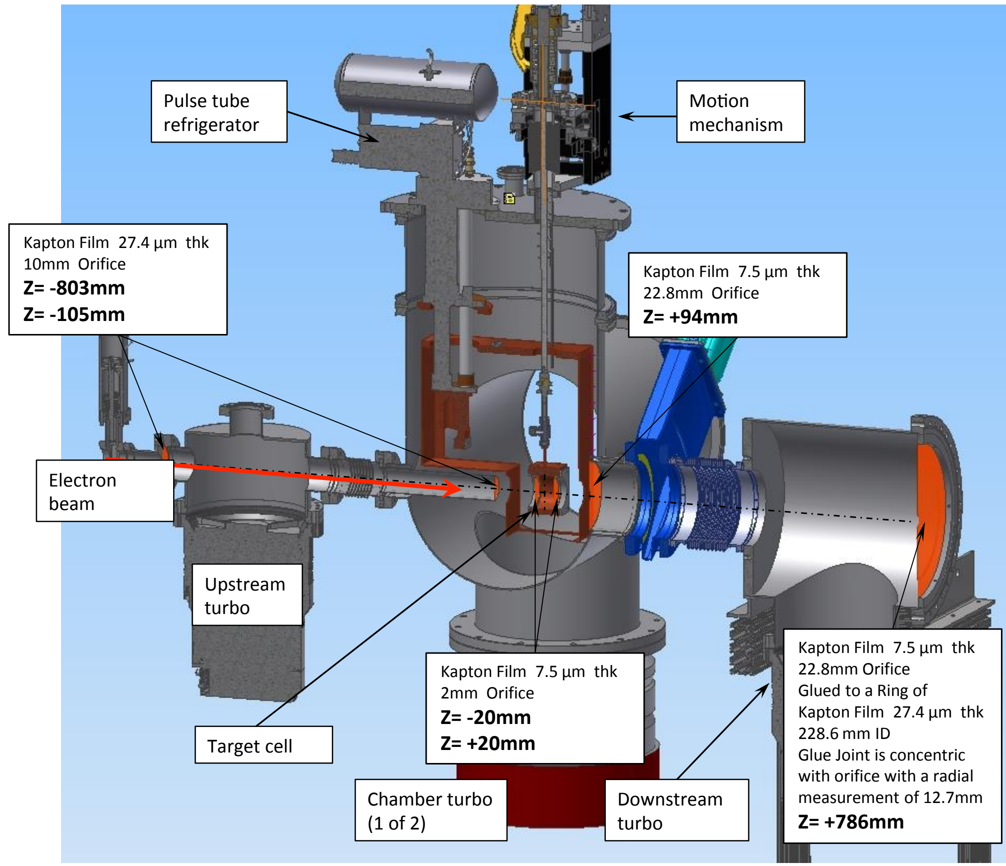
- Two solid target foils:
  - *1 µm carbon*
  - *1 µm aluminum*

<u>Goal parameters</u>

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

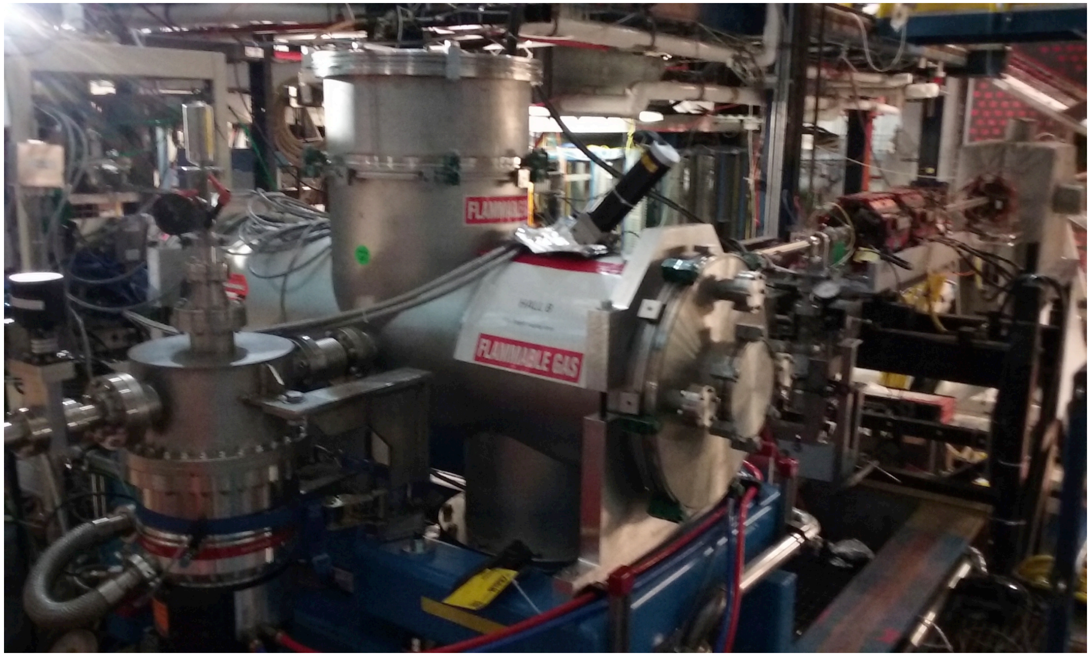
*<u>Secondary goal:</u>*

*Reduce $H_2$ background*



# 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:**

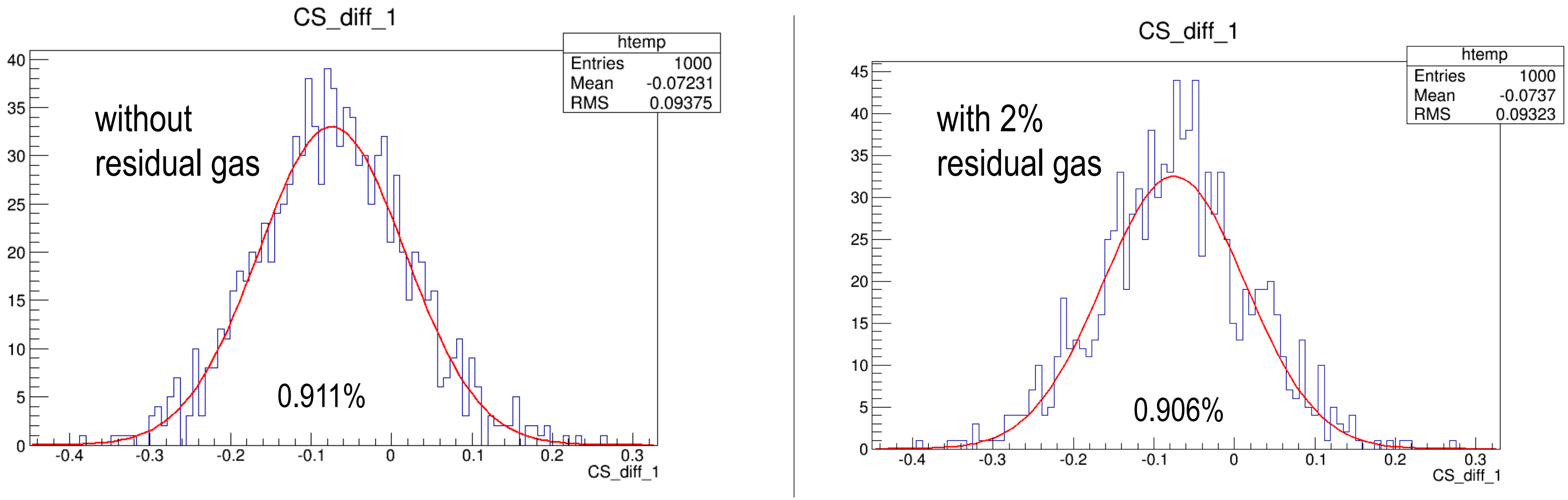
- March 28 – April 7: Install target cell, beam line orifices, perform H2 tests
- April 8 – 10: Beam Commissioning
- mid May – mid June: Prad data taking time

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

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

- Monte Carlo simulation is performed with:
  - ✓ 2% of target gas distributed in [-30, +30] cm area;
  - ✓ 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

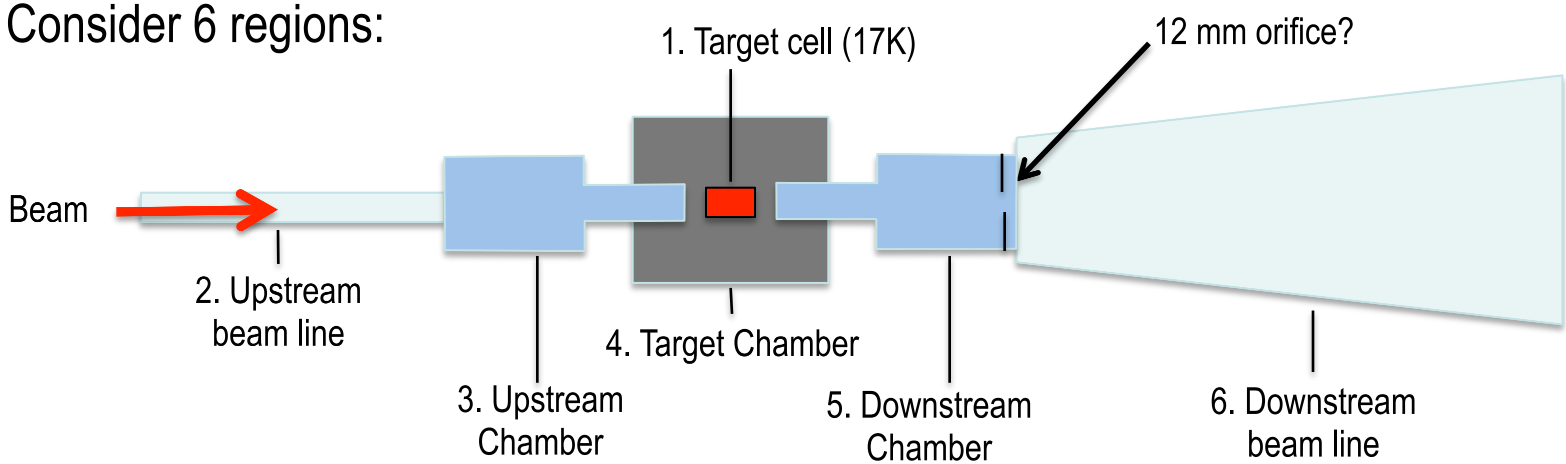
✓ Effect of the residual gas shown to be negligible.

# 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 |

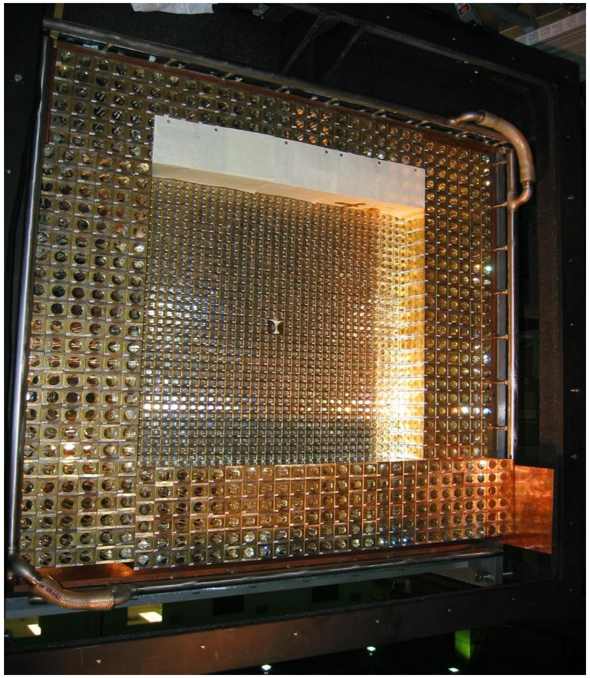
<u>Dec. 2015 tests with HELIUM</u>

Background gas reduced to approx. 0.2% of cell thickness

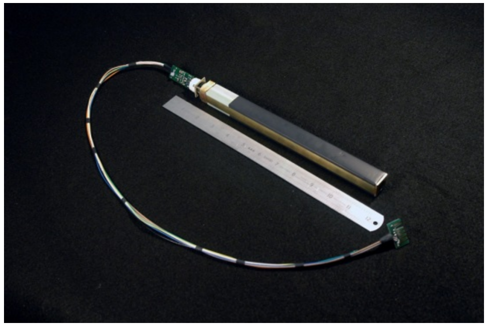
* Measured ** estimated

# 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)

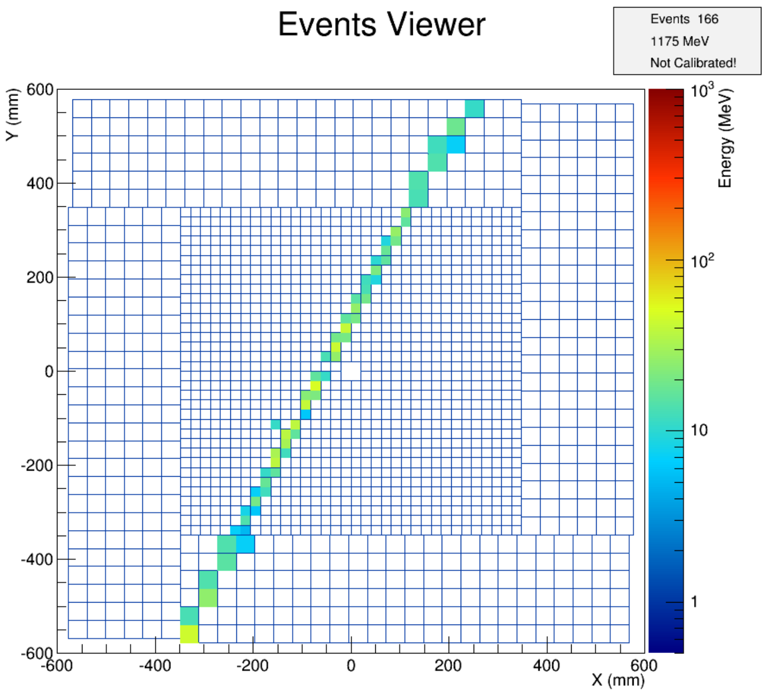


- Moved back to Hall B in June, 2014:
  (thanks to Technical Group (D. Tilles and All)
  - Cabling system with infrastructure reassembled
  - Trigger, analog and HV electronics are reinstalled
  - Cooling system is operational
  - LMS checked and repaired
  - All individual detectors checked and repaired
  - DAQ is operational (HyCal readout part)
  - Transporter is reinstalled/repaired and operational



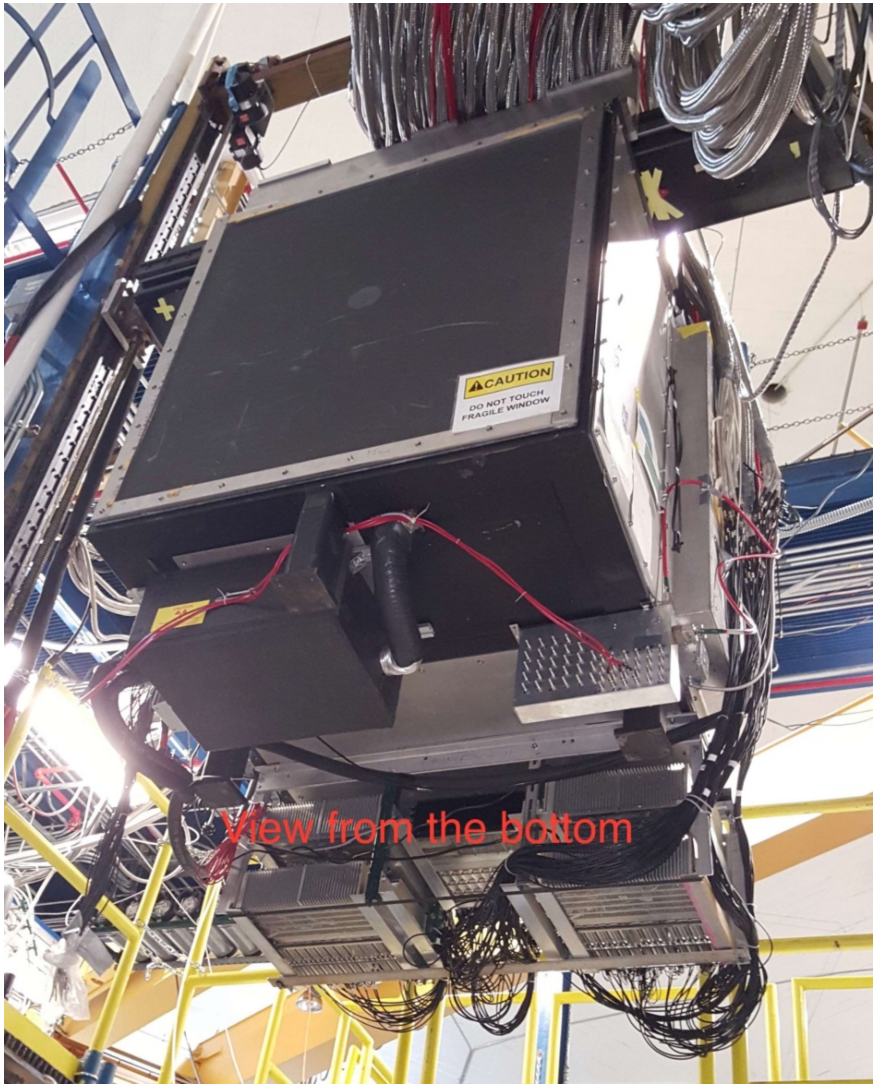
# HyCal Current Status

- 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

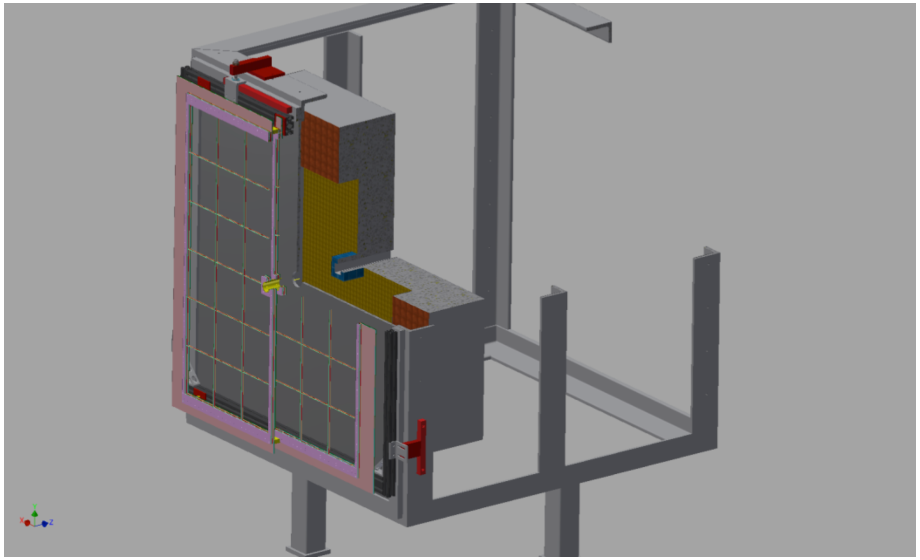
- Tasks for GEM:
  - factor of >10 improvements in coordinate resolutions
  - similar improvements in $Q^2$ resolution (very important)
  - unbiased coordinate reconstruction (including transition region)
  - increase $Q^2$ range by including Pb-glass part

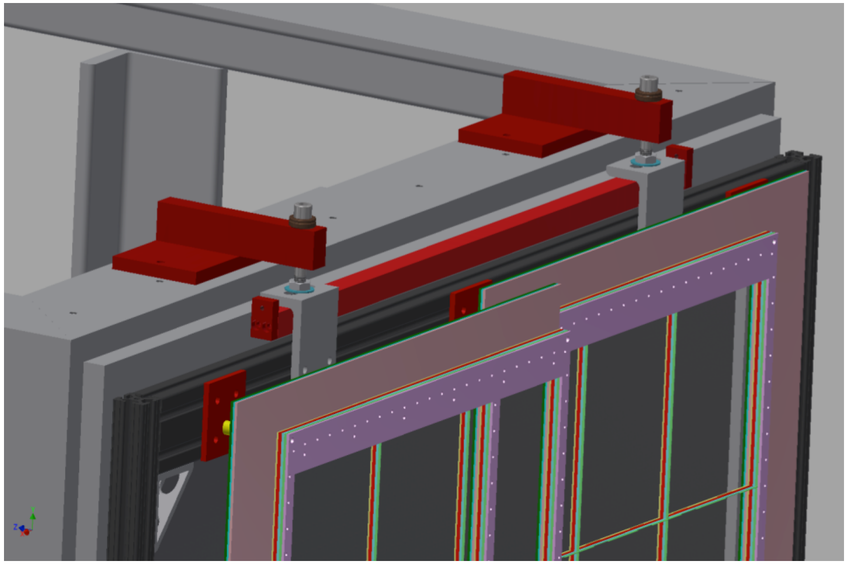
- Designed and built at UVa
- Both GEMs are in EEL at JLab
- Cosmic ray tests are in progress

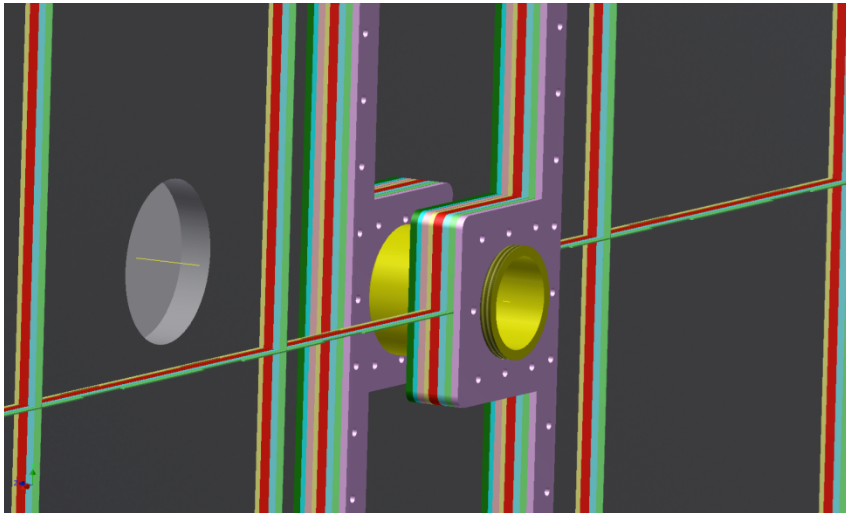
  - Talk by Kondo Gnanvo

GEM chambers in EEL at JLab, March 2016

# GEM Mount on HyCal







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

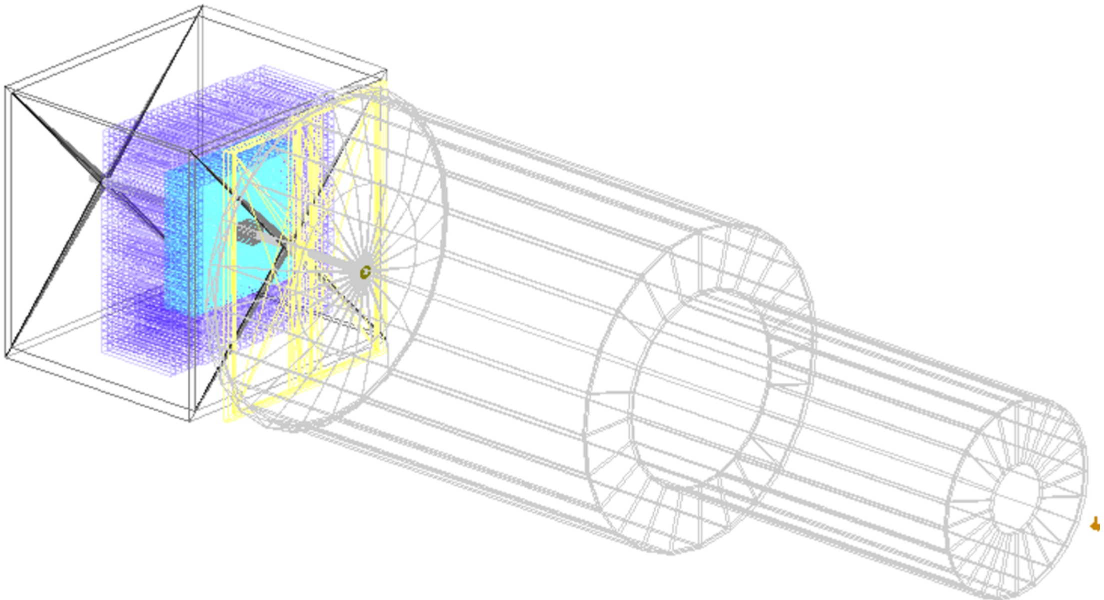
- Talk by Kondo Gnanvo

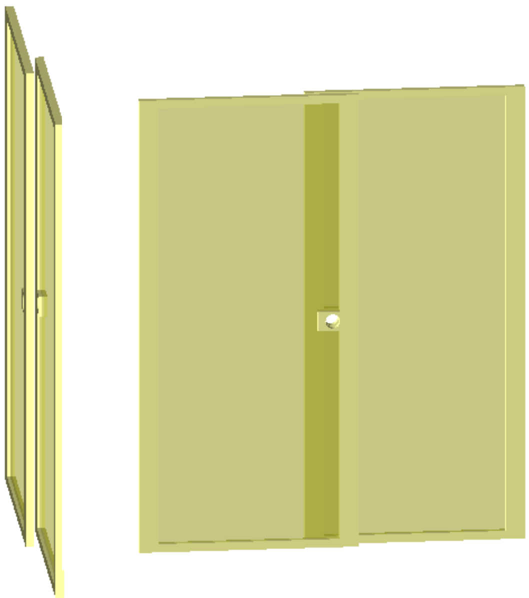
# Requirements to GEMs (ERR Rec. #7.2)

- PRad requirements to GEM chambers:
  - 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



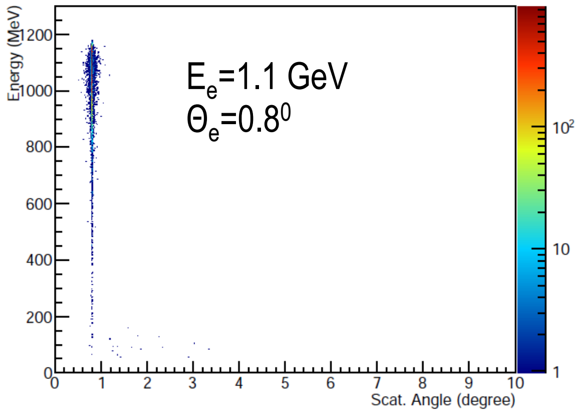


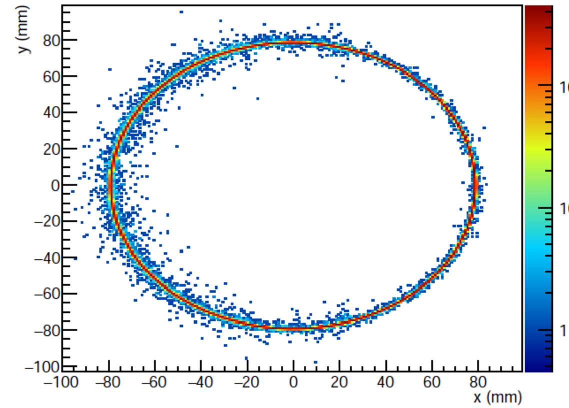
Side view

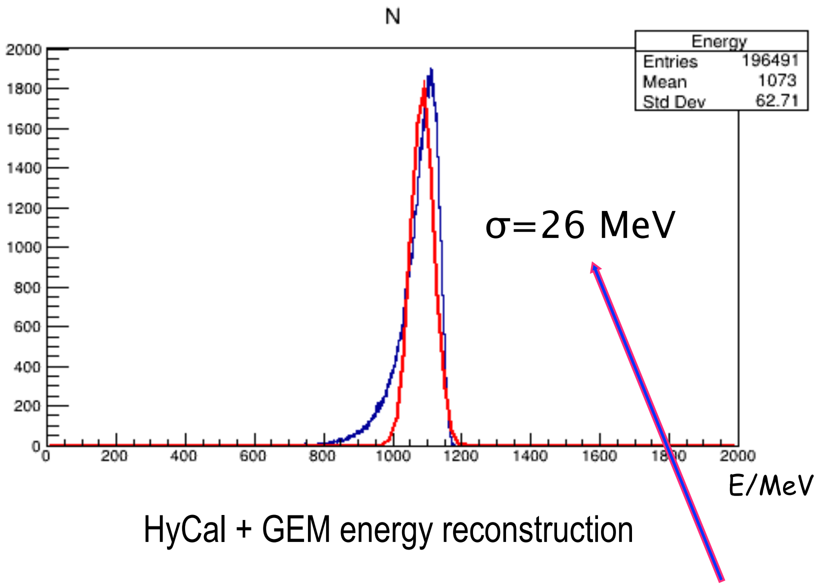
Front view

- GEANT code includes detailed information about frames

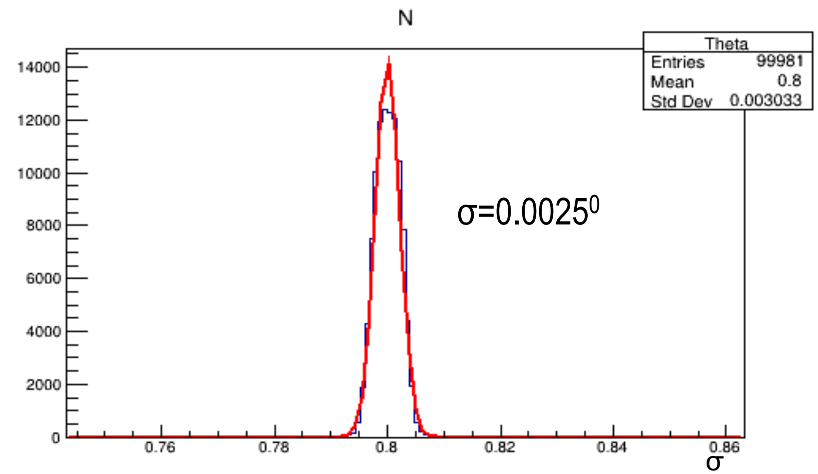
# GEM Monte Carlo Simulations (cont'd)




HyCal + GEM energy reconstruction




HyCal + GEM angular reconstruction

σ(with HyCal only) = 25 MeV

Ch. Peng

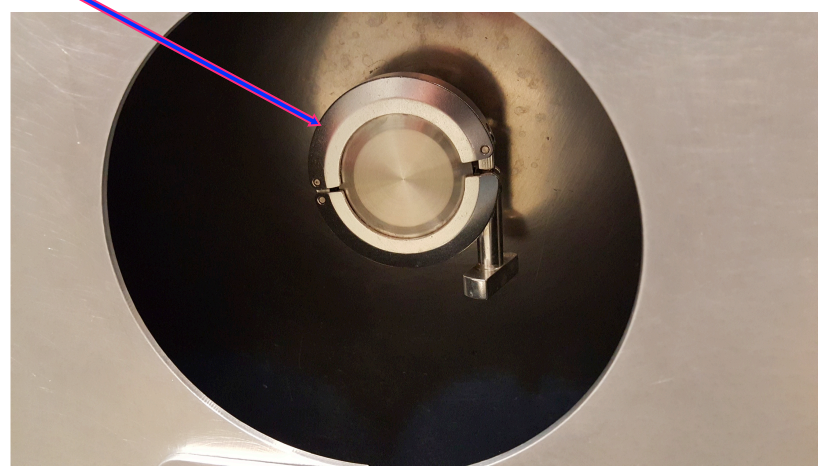
- GEM: critical improvement in angular resolutions, without much change in energy resolutions

# 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

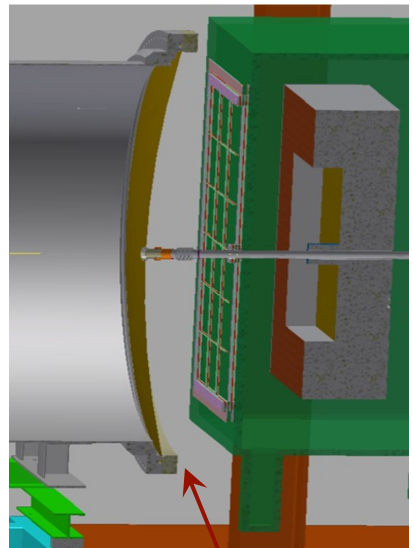
- Assembled and vacuum tested at Jlab
- Vacuum window is installed
- Hydrostatically tested up to 30 psi
- ✓ see https://wiki.jlab.org/pcrewiki/index.php/PRad_Experiment_Readiness_Review



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

# Vacuum Window

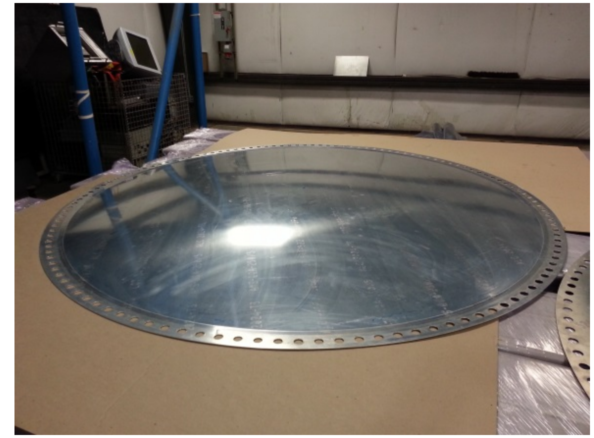
- Thin Al-window on Vacuum Box at the HyCal end
  - thickness: ~2 mm
  - diameter : 1.7 m
  - connected to the beam vacuum pipe in center
- Design and construction done at JLab



e$^-$ beam

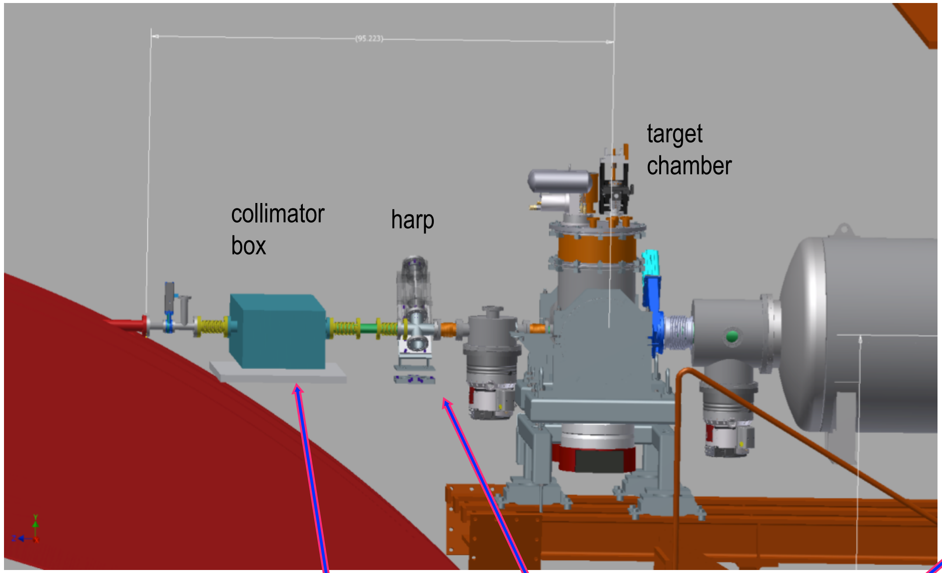
Vacuum Window

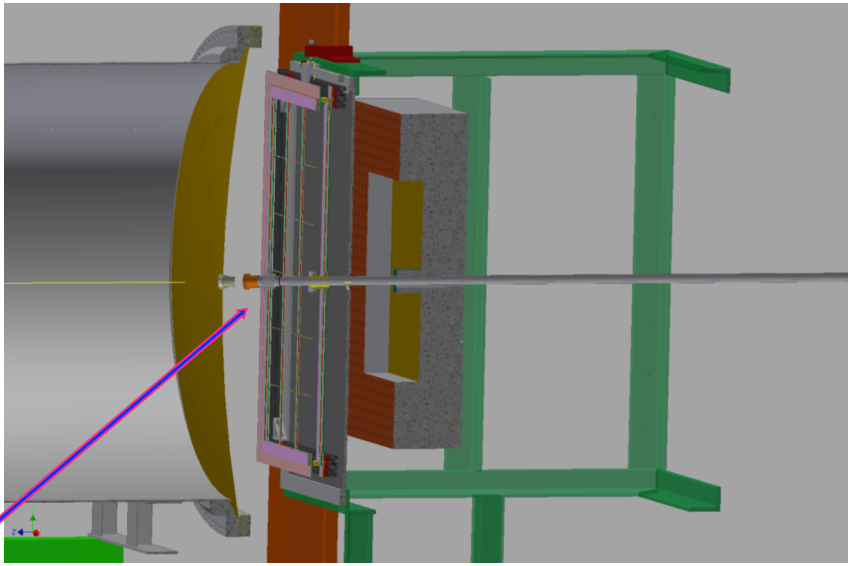
- Vacuum tests are done in March (hydrostatically tested up to 30 psi)
- Vacuum Window is already installed on Vacuum box.

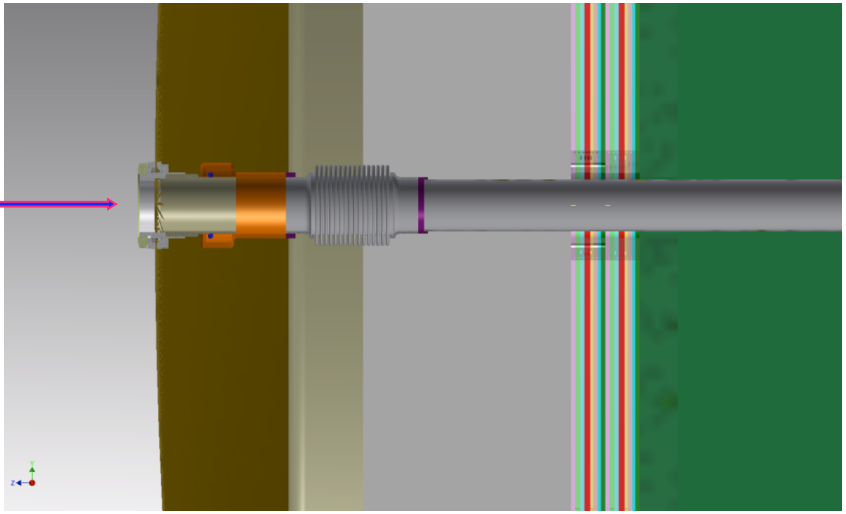


Preparation of the Vacuum Window at JLab

# 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
    - ✓ $\sigma_x$, $\sigma_y$ = ~ 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 |
| $\sigma_x$, $\sigma_y$ | ~ 100 μm |
| Position stability | ~ 100 μm |
| Beam halo | < $(1\times10^{-7})^*$ |
| Divergence | < 1 mrad |
| Luminosity | ~ $10^{28}$ $cm^{-2}s^{-1}$ |

* for R > 3 mm from the beam center

# Beam Commissioning Run Plan (April Test Run)

- **Goals:**
  - ✓ Initial test of entire apparatus with an electron beam;
  - ✓ Test of the H2 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 is 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 Data Taking Run Plan (May-June)

- See the "Back Up" section of this presentation

# 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 on March 28, 2016

- PRad is ready for the April test run and data taking run in May, 2016


✓ 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

# PRad Run Data Taking Plan (Tagger and Photon Beam)

## 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 $\mu$m $^{12}C$ 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 +/- 2 mm with 0.2 mm steps and take HyCal rate;
m) move the cell on Y-axis by +/-2 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

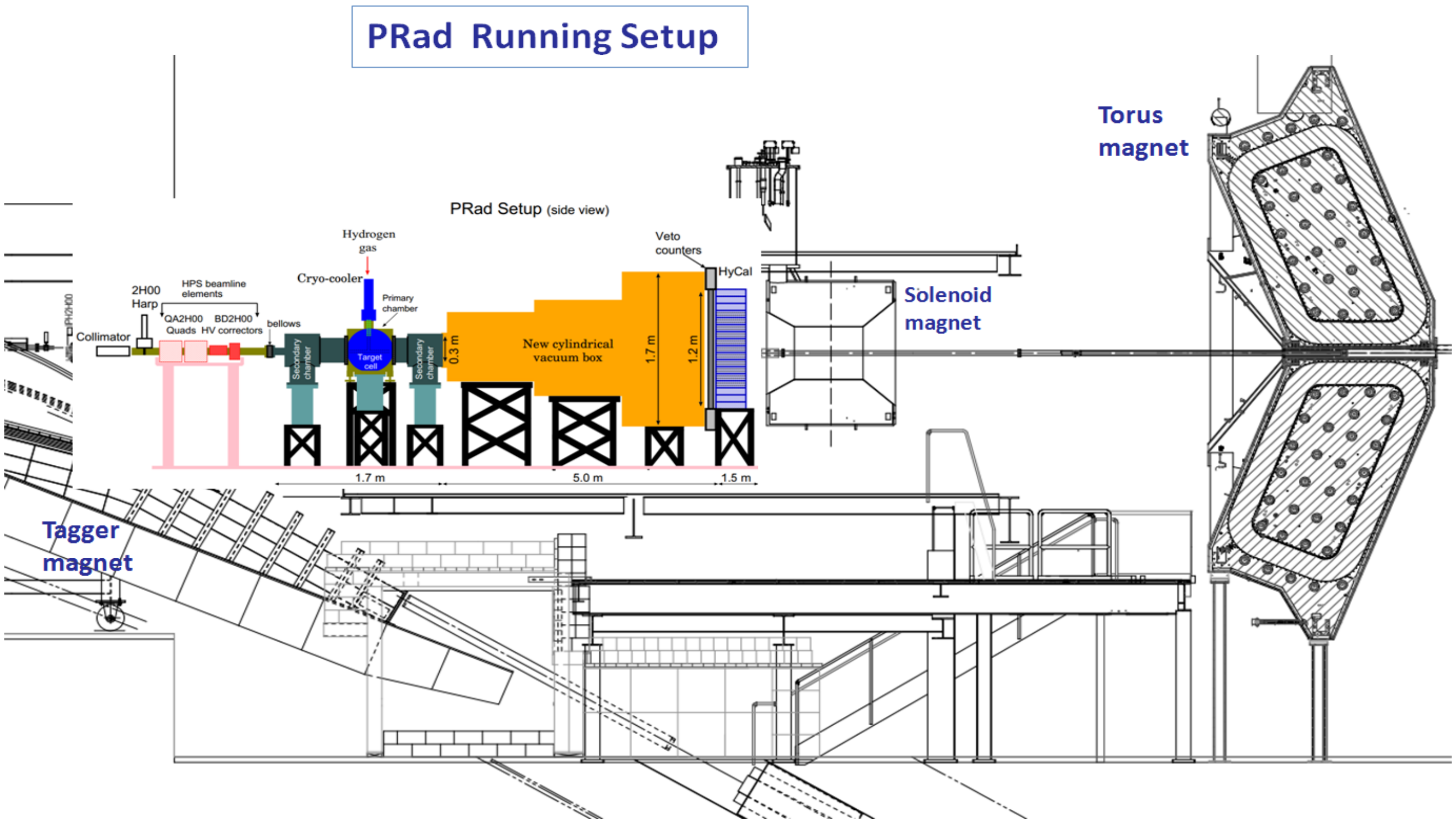
**10) Data taking with $E_e$ = 2.2 GeV (4 days)**

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).

# 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