Overview of the PRad Experimental Setup
(E12-11-106)

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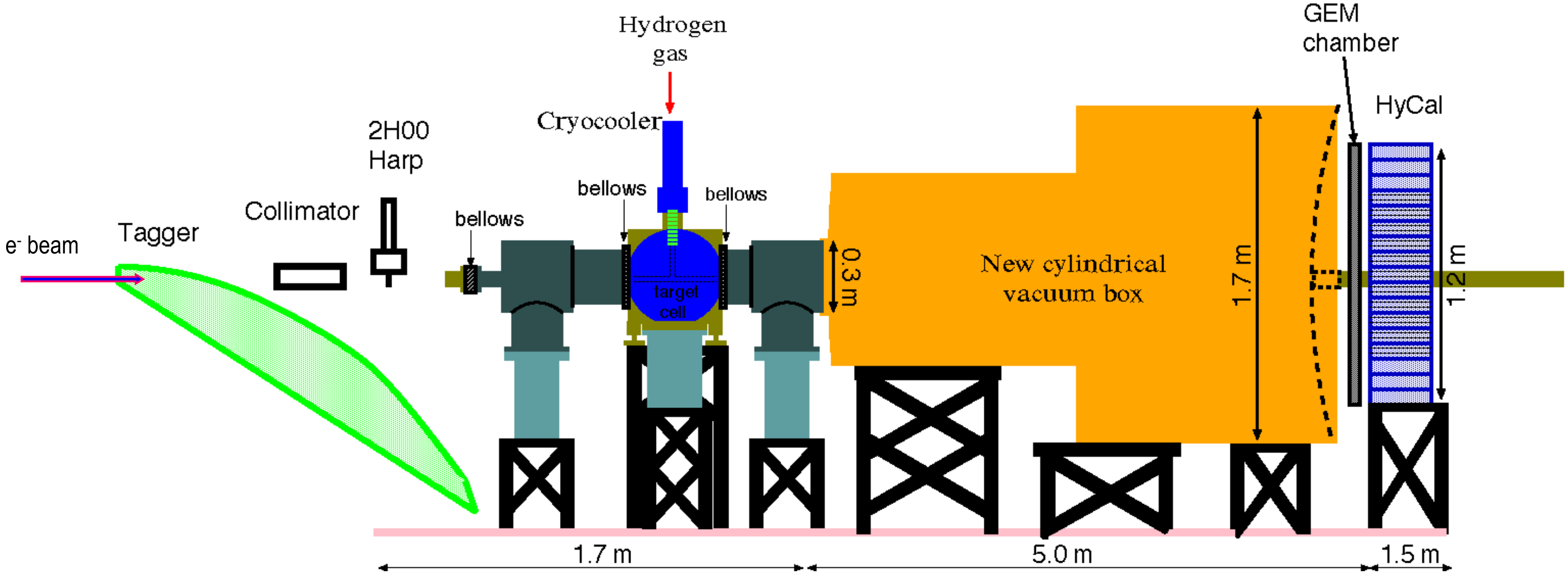
Outline

- PRad experimental setup
- Current status of the apparatus (short)
- Required beam parameters
- Detector alignments
- Draft run plan
- Manpower
- Summary

PRad Experimental Setup

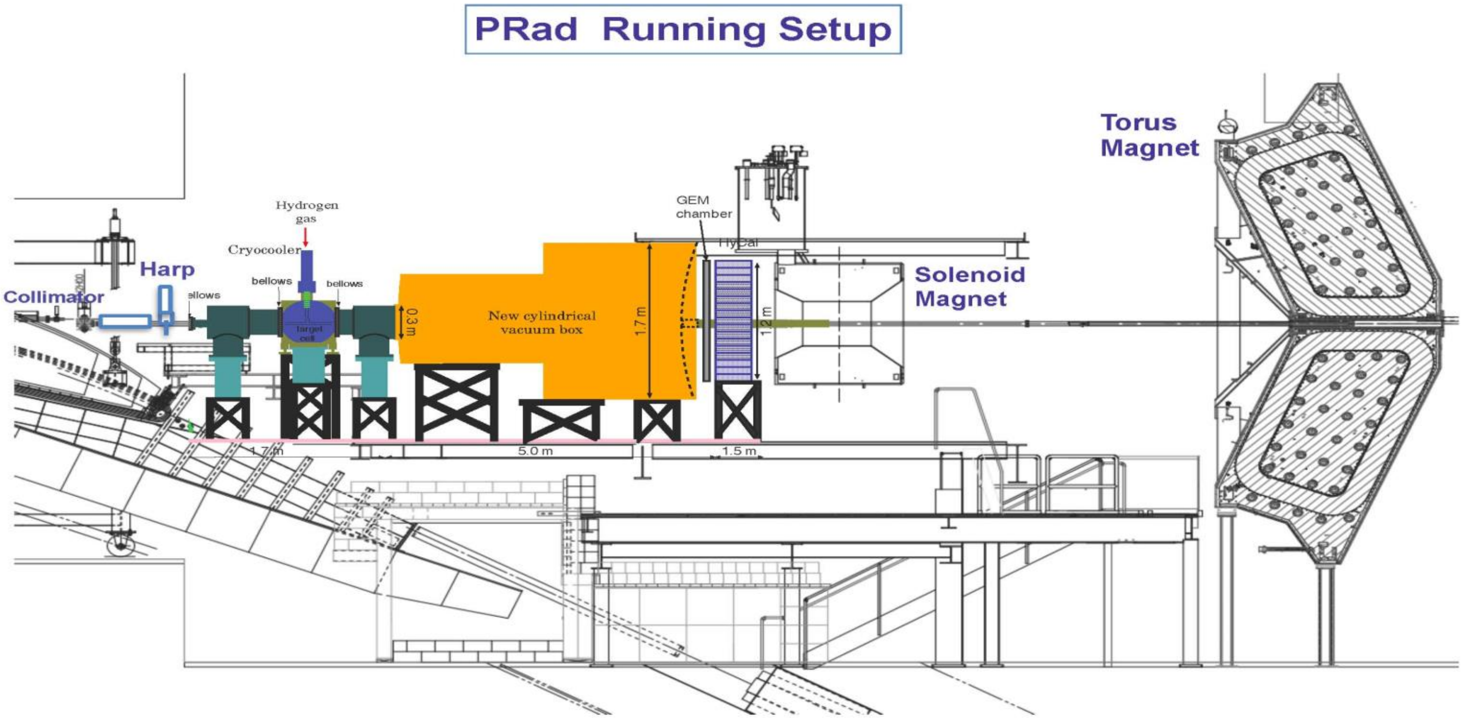
- Main detectors and elements:
  - windowless H_2 gas flow target
  - PrimEx HyCal calorimeter
  - vacuum box with one thin window at HyCal end
  - X,Y – GEM detector in front of HyCal
- Beam line equipment:
  - standard beam line elements (0.1 – 10 nA)
  - photon tagger for HyCal calibration
  - collimator 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)



PRad Running Configuration in Hall B (suggested)

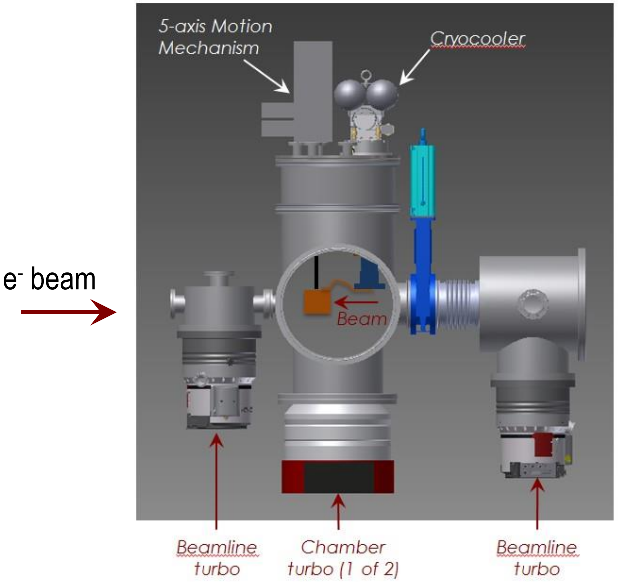
- Footprint of PRad setup: ~ 8.2 x 1.7 m^2
- Installation in parallel with CLAS12 work/assembly in Hall B
- Engineering and Physics runs during evenings/nights and over weekends



Distance: 2H00 wire harp to Solenoid support frame ~13.7 m

Windowless H_2 Gas Flow Target

- Target proposal specs:
  - cell length — 4.0 cm
  - cell diameter — 8.0 (50.) 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 — 6.0 torr
  - Vacuum in target chamber — $5x10^{-3}$ torr

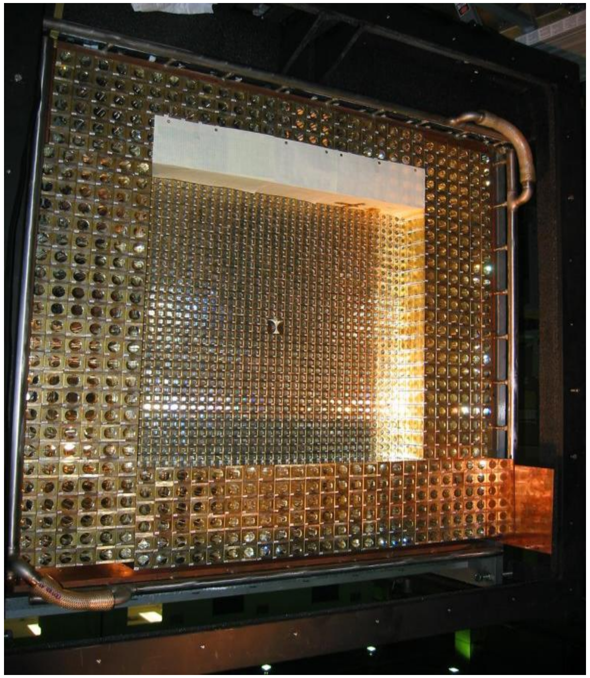


- NSF MRI award in 2012 (#PHY-1229153) to develop and construct this target (~0.4M)
- Full system test is currently underway (Nov. 2015)
- Target survey in EEL in Dec. 2015
- Target will be ready for installation in January, 2016 (estimated time: 10 days)

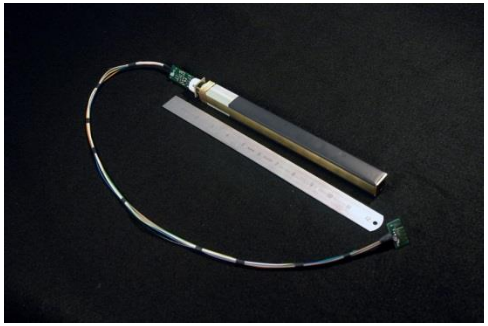
(Talk "Target: parameters, …" by Chris Keith)

Electromagnetic Calorimeter (PrimEx HyCal)

- Combination of $PbWO_4$ and Pb-glass detectors (118 x 118 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 (3.82 x 3.82 x 45.0 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)



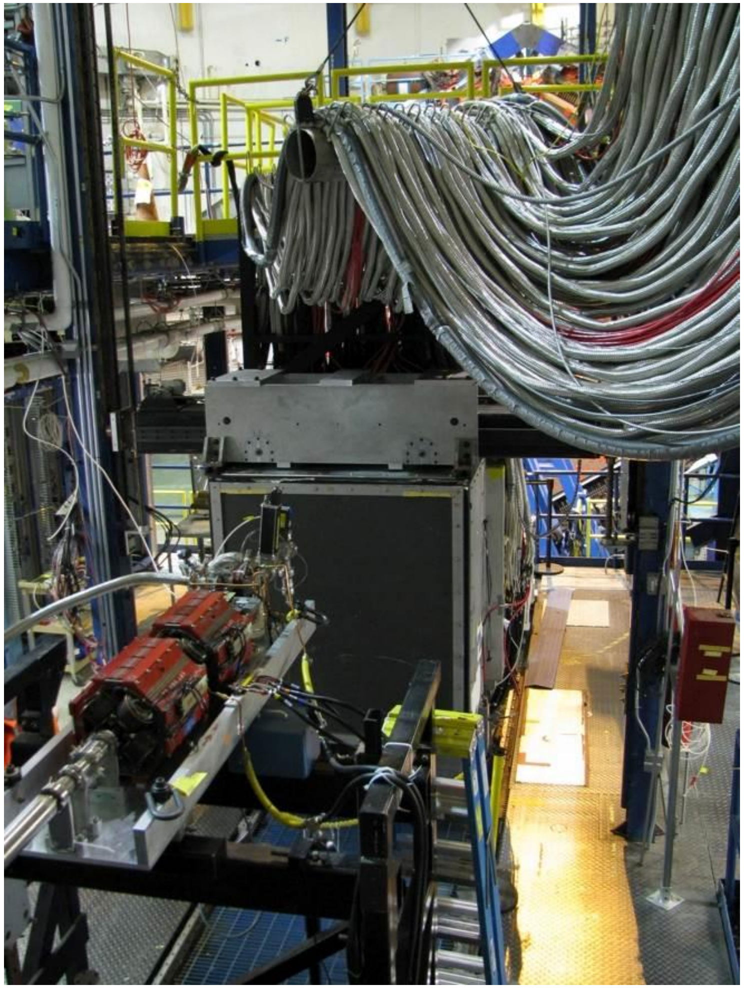
- Resolutions:
  - for $PbWO_4$ shower detectors:
    - ✓ energy: $\sigma/E = 2.6\ \%/\sqrt{E}$
    - ✓ position: $\sigma_{xy} = 2.5\ \text{mm}/\sqrt{E}$
  - for Pb-glass shower detectors factor of ~2.5 worse



HyCal Current Operational Status

- 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

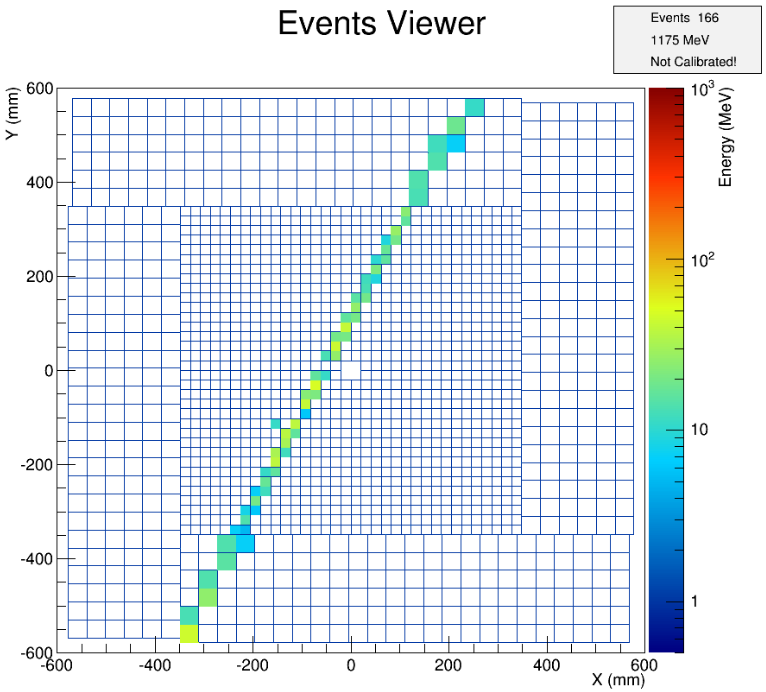
✓ **HyCal is fully repaired and taking cosmics data**



HyCal in Hall B beam line (Nov., 2014)

HyCal Current Status

- HyCal is currently up in Transporter for cosmic ray tests



Cosmic event in HyCal

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

HyCal in Hall B beam line (Oct, 2015)

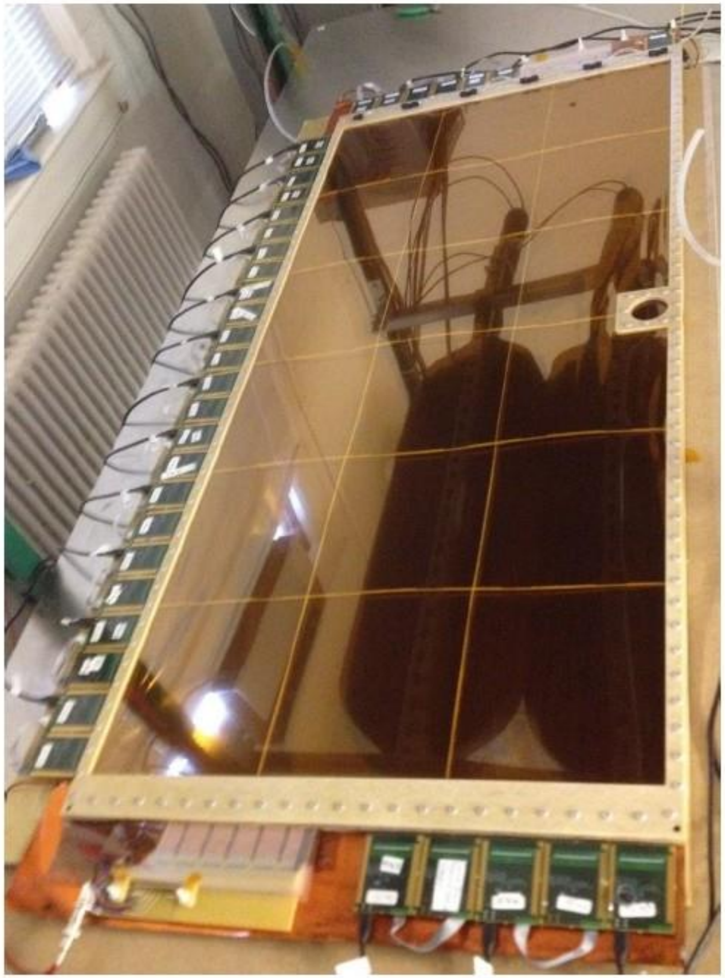
GEM Chambers

- 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 at UVa
- 1st GEM chamber is completed in Sep. 2015, cosmic tests are underway (UVa)
- 2nd chamber started this week (Nov. 2015, UVa)
- GEM DAQ is ported into CODA (MSU/UVa)
- Delivery to JLab: Jan. 2016

- GEM will be ready for installation in Feb. 2016

(Talk "GEM and DAQ integration" by Kondo Gnanvo)



GEM #1 at UVa, Aug. 2015

Vacuum Box

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

- Remaining work:
  - stands for vacuum box:
    - ✓ engineering design completed, submitted to procurement
    - ✓ ready by Jan. 2016

- Ready for installation: Jan., 2016

(Talk "Engineering aspects" by Bob Miller)

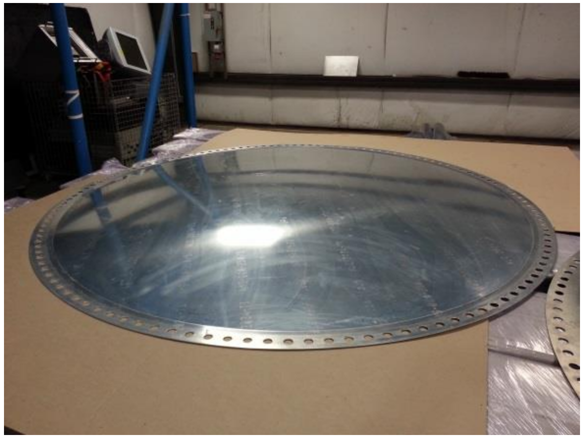
Smaller chamber at JLab

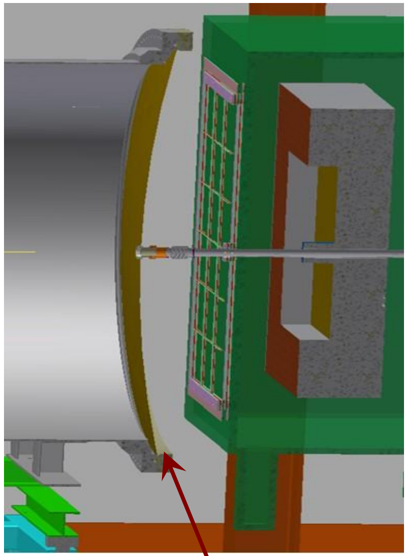
Larger chamber at shop

Larger chamber at JLab

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
- Vacuum tests are done
- Remaining work:
  - connection to the vacuum pipe
  - ✓ engineering design in progress
  - ✓ ready by Feb. 2016



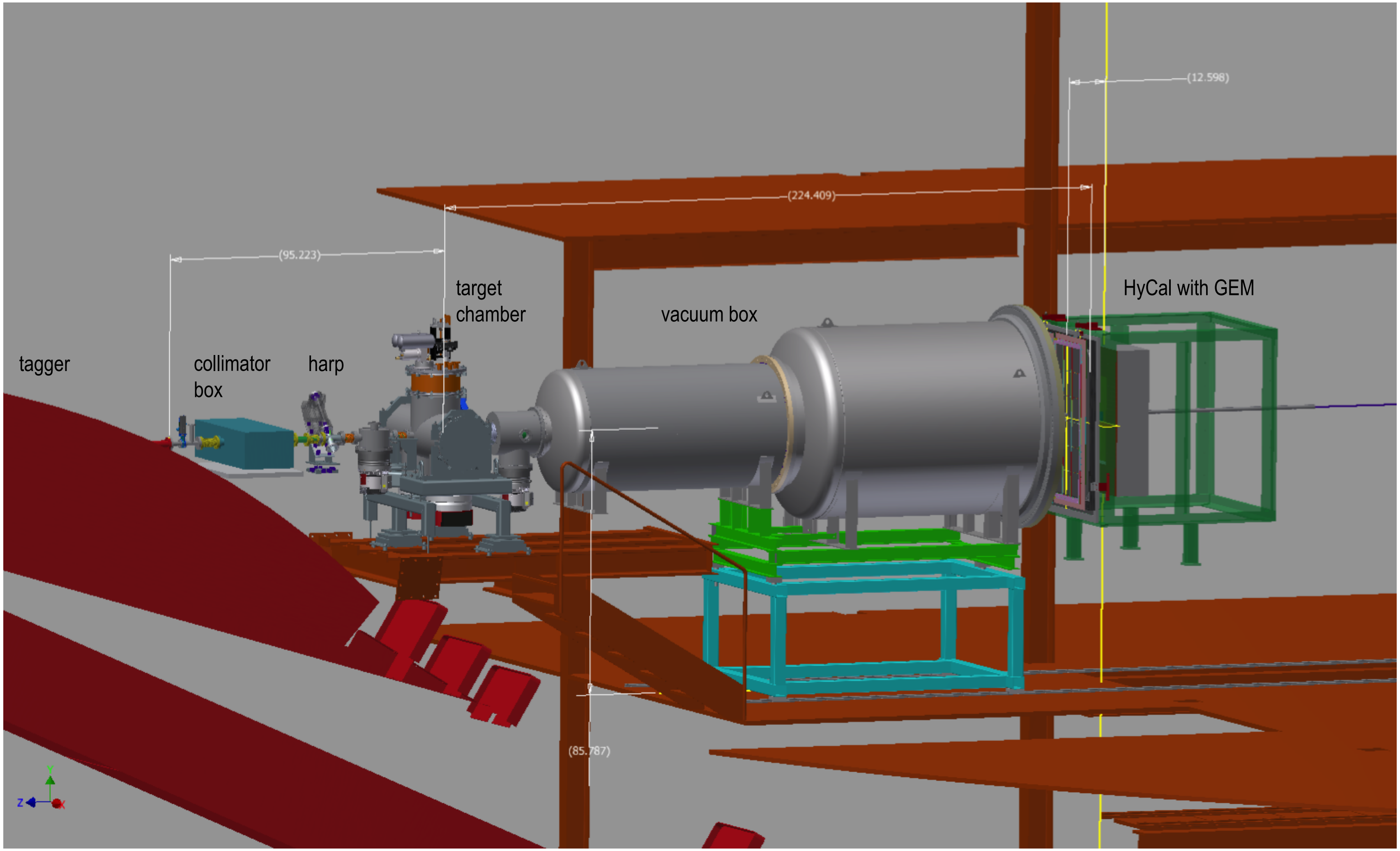


- Vacuum Window will be ready
  for installation: Feb. 2016

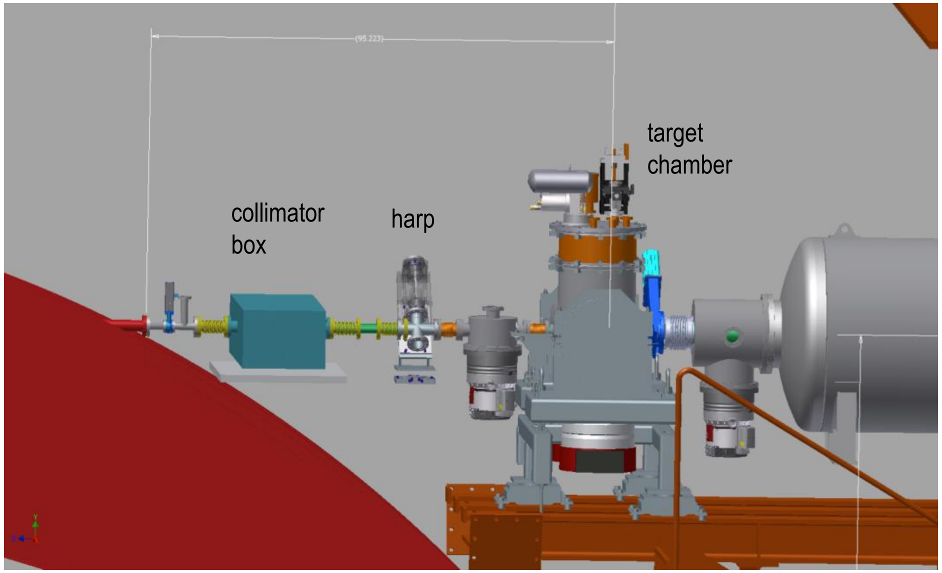
(Talk "Engineering aspects" by
Bob Miller)

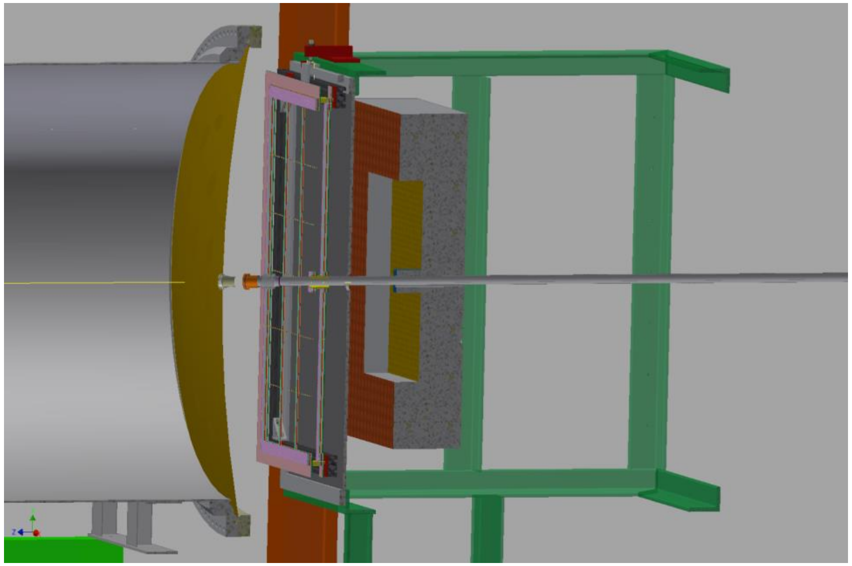
Preparation of the Vacuum Window at JLab

PRad Beam Line



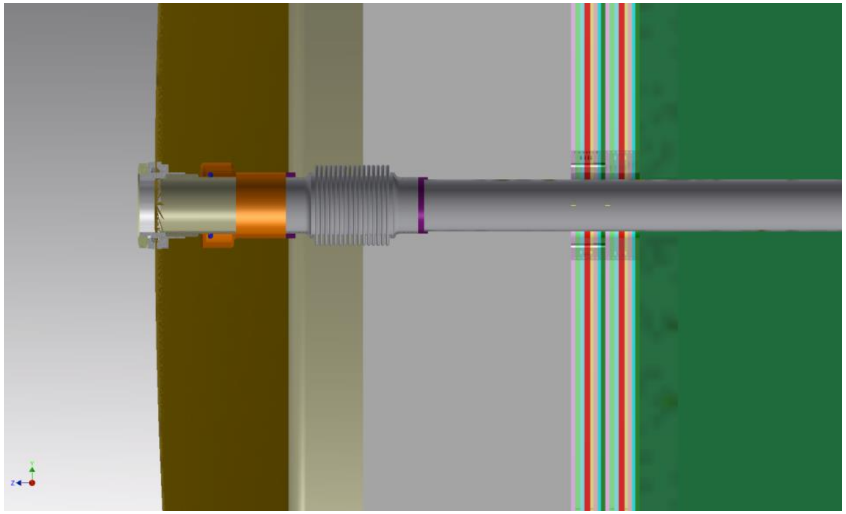
Beam Line Elements



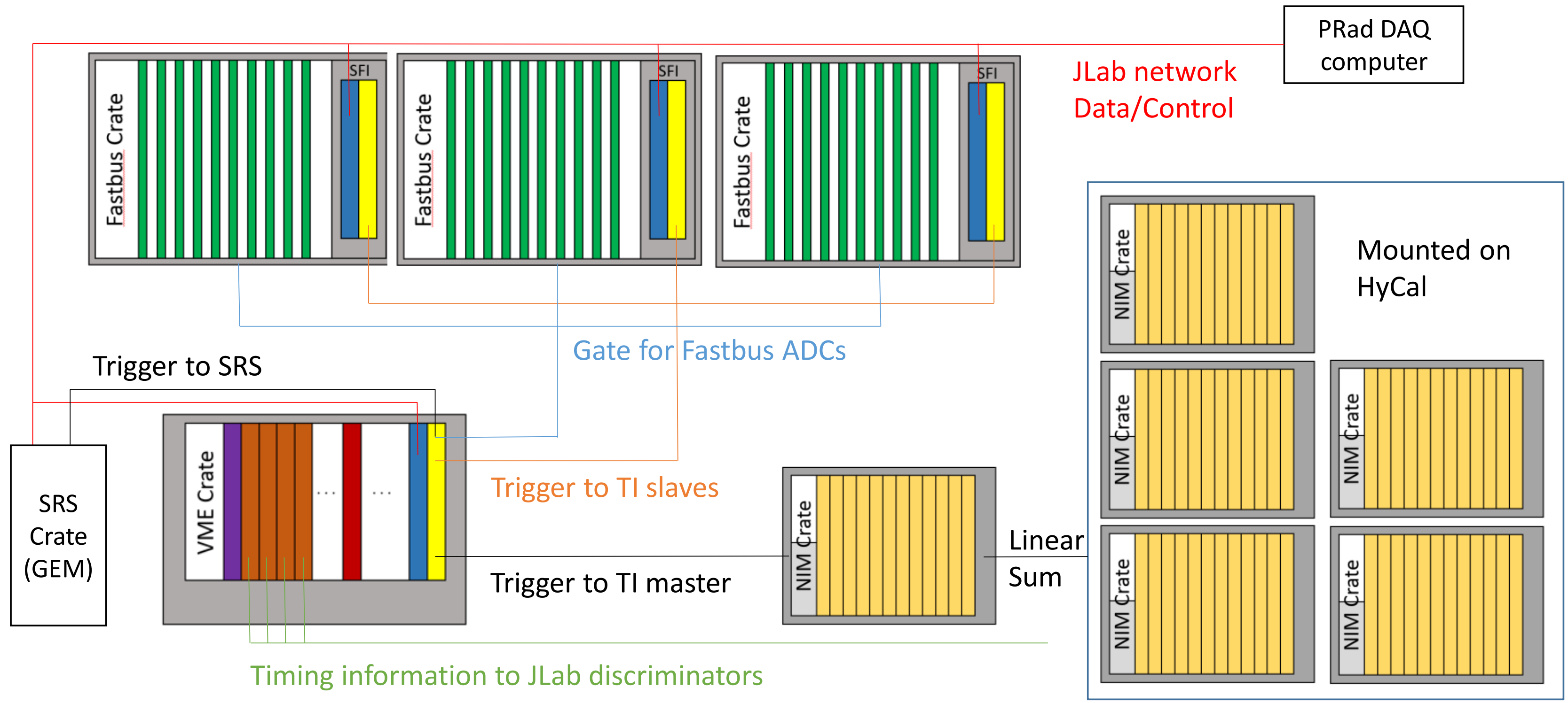


- Remaining work on Beam Line:
  - vacuum box stands (engineering design in progress)
  - beam line from Vacuum Window through HyCal (engineering design in progress)
  - collimator box (installation)
  - Harp 2H00 (installation)
- Beam line ready for installation: Jan 2016

(Talk "Engineering aspects" by Bob Miller)



DAQ and Electronics



- PrimEx FASTBUS-based electronics and UVa linear sum modules for trigger.
- Ready in most parts, taking cosmics data.

(Talk "DAQ, on-line and off-line software" by Chao Peng)

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	< $(1\times10^{-7})^*$
Divergence	< mrad
Luminosity	~ 10^{28} $cm^{-2}s^{-1}$

* for R > 3 mm from the beam center

(Talk "Beam Commissioning, …" by Arne Freyberger)

Detector Alignements

1) All detectors and beam line elements will be fiducialized before the beam line installation

- ✓ hardware installed fixed survey points (“survey balls”) to define the detector’s specific internal X,Y,Z coordinate axes;
- ✓ engineering survey to define coordinates of the internal detectors, wires, cells, chambers.

2) All detectors and beam line elements will be engineering surveyed after the installation.

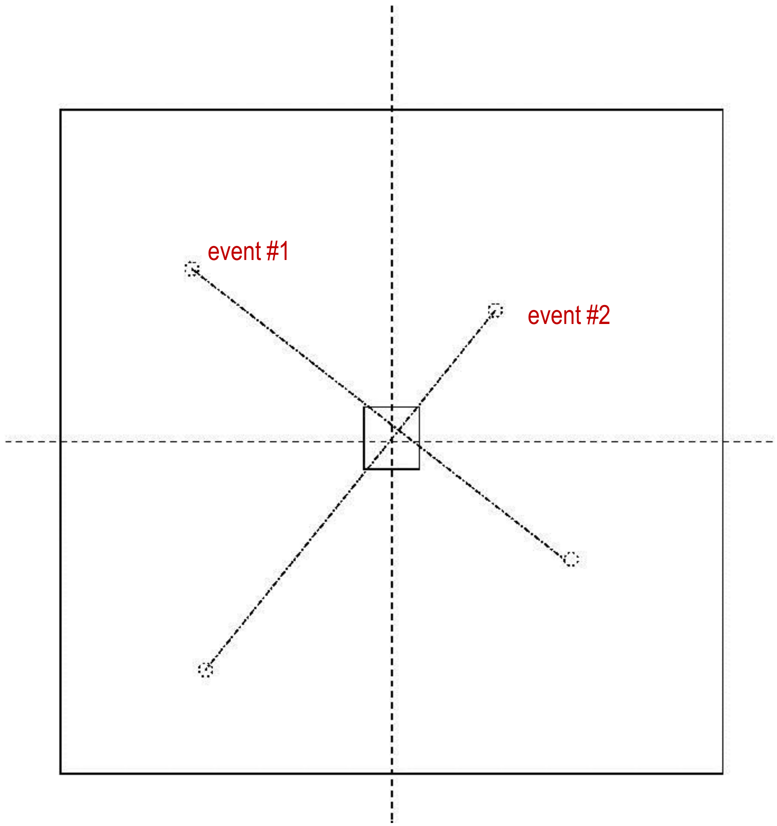
- ✓ to define particular (X,Y,Z) vs. Hall B beam line coordinate system;
- ✓ to position in the beam line.

3) Off-line verification of the detectors position vs. beam by Physics processes.

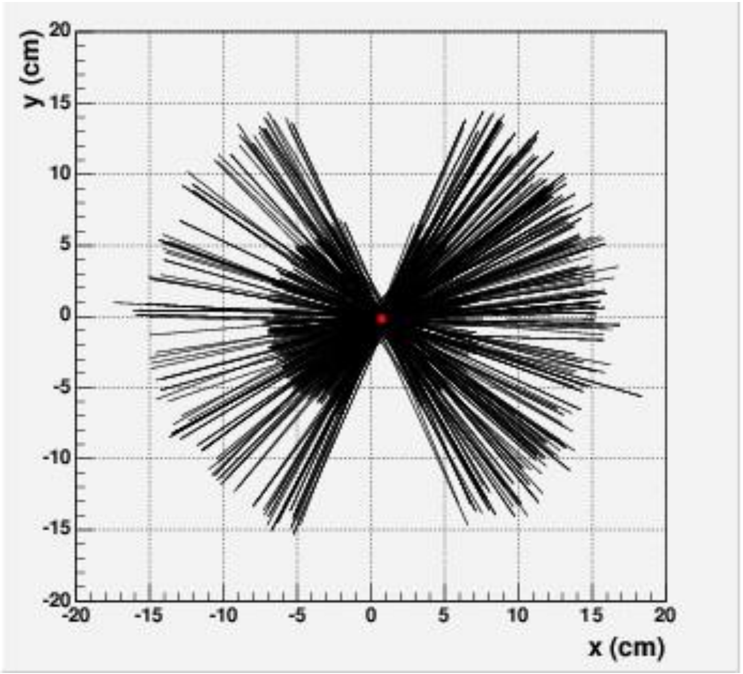
- ✓ use Compton scattered events from GEM calibration with tagged photon beam;
- ✓ use Moeller scattered events from Physics runs.

Survey Verification by Physics Processes

- Using the event co-planarity with the beam for two-body scattering processes:
  - ✓ Compton scattering: $\gamma + e^- \rightarrow \gamma + e^-$
  - ✓ Moeller scattering: $e^- + e^- \rightarrow e^- + e^-$

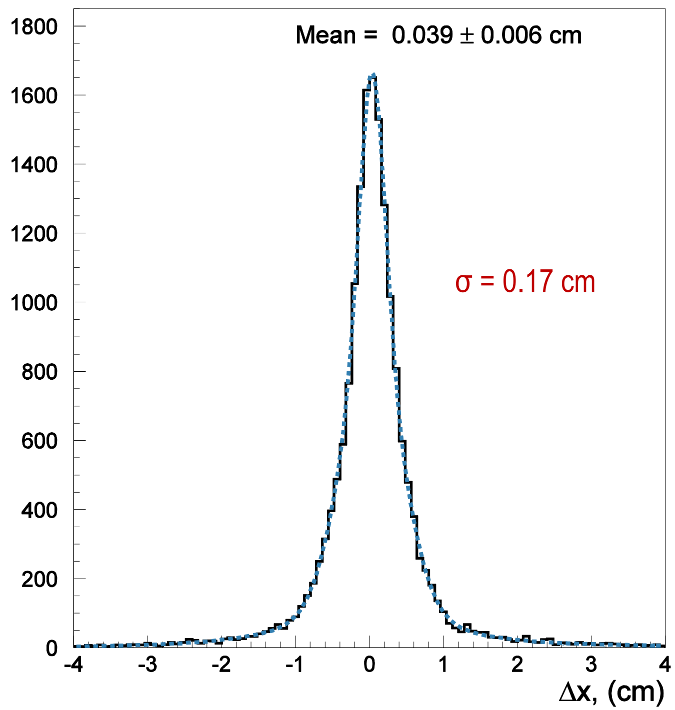


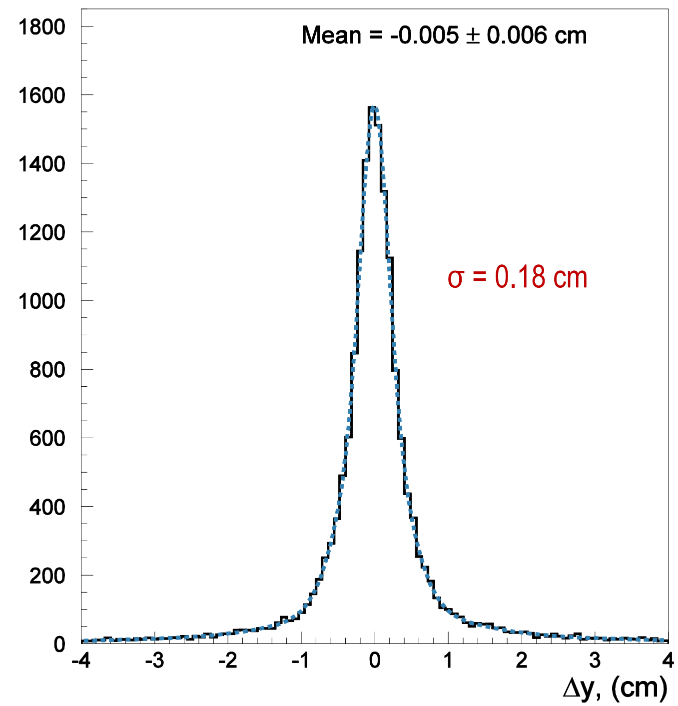
Compton events from PrimEx-I
By Y. Prok, PrimEx Note #33



Survey Verification by Physics Processes (cont'd)

- Compton events reconstructed from PrimEx-I data:
  - ✓ Beam center can be identified with 0.08 mm uncertainty;
  - ✓ GEM will allow a factor of 10 better precision.





Target Survey and Alignment

- Target fiducialization is scheduled for Dec., 2015
- Engineering survey and positioning will be required after installation,
  precision: 0.1 mm

(Talk “Target: parameters, …” by Chris Keith)

HyCal Survey and Alignment

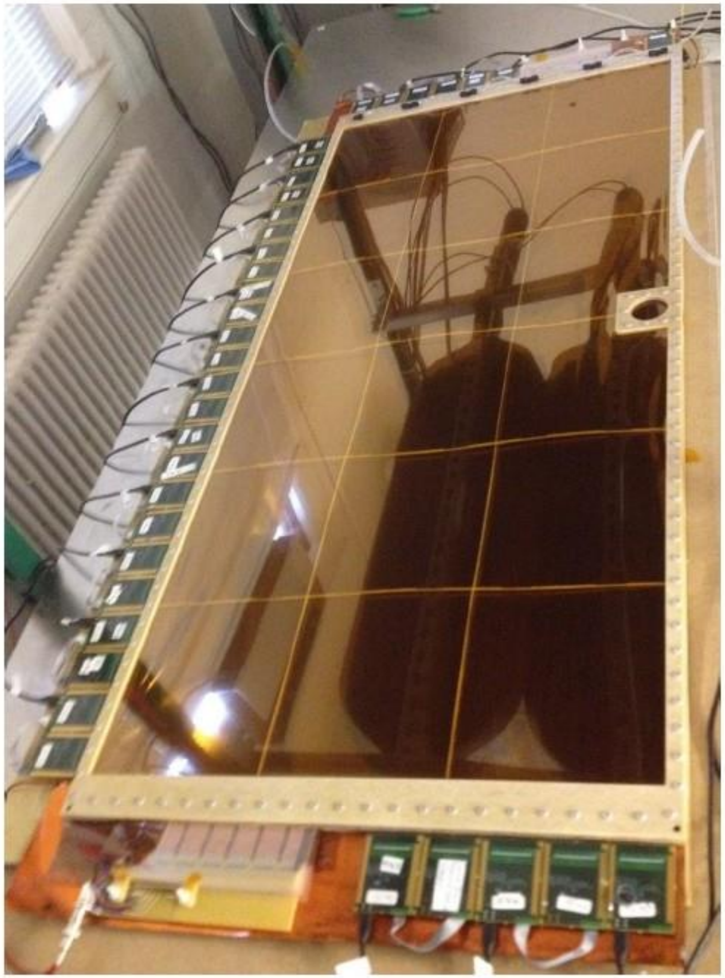
- HyCal is already fiducialized for PrimEx experiments:
  - ✓ "survey points" are hard-welded on the frame;
  - ✓ engineering survey of crystals is done;
  - ✓ data are saved.

- In-beam engineering survey and positioning will be required when HyCal is on "Run Cart",
  precision: 0.1 mm

GEM Survey and Alignment

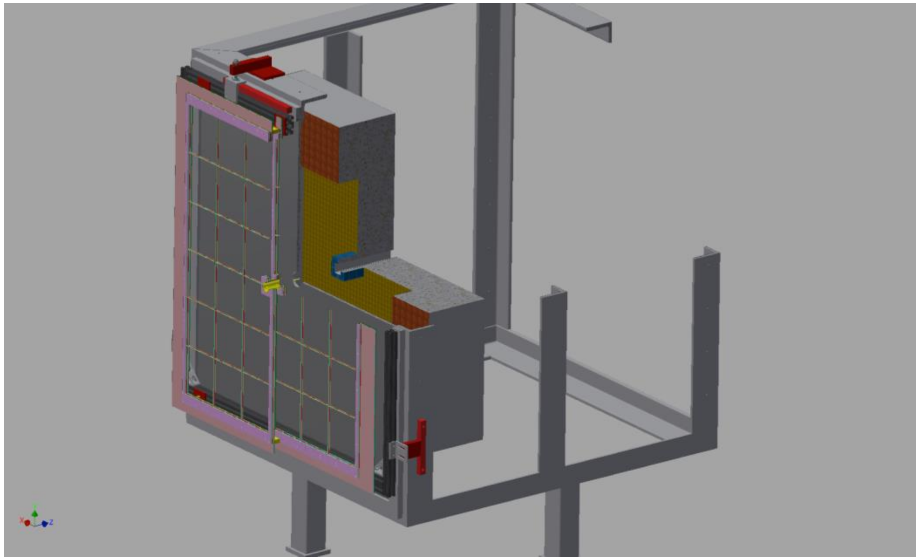
- Fiducialization of GEM chambers is tentatively scheduled for Jan., 2016

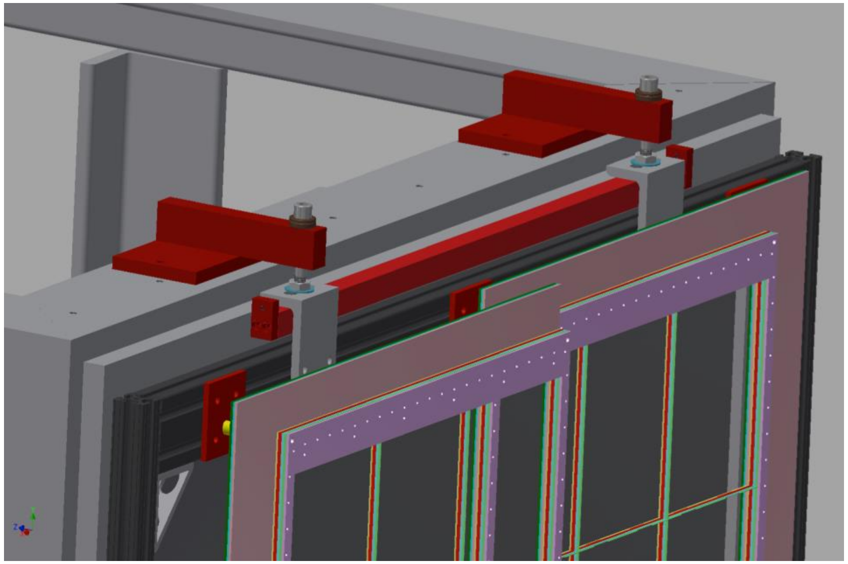
- Engineering survey and positioning will be required after GEM installation on HyCal.
  (precision: 0.1 mm)
  Tentatively scheduled for Jan. 2016



(Talk "GEM and DAQ integration" by Kondo Gnanvo)

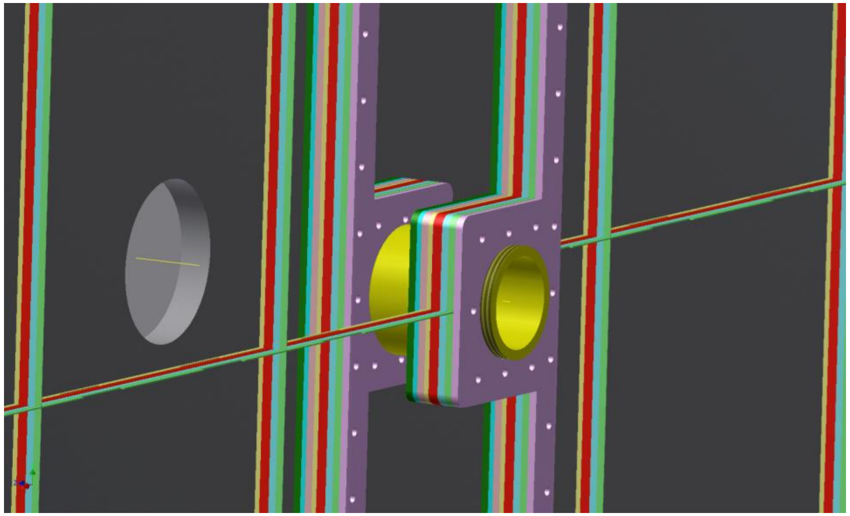
GEM Mount on HyCal and Survey





- GEM frame will be hard mounted on HyCal and surveyed vs. HyCal coordinate axes (precision: 0.1 mm)

(Talk “GEM and DAQ integration” by Kondo Gnanvo)



PRad Beam Commissioning and Run Plan
(draft)

PRad Run 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 out, collimator out;
- 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 peack to tails ratio;
a) study beam halo by setting the harp wire in the tail region and ramping beam current up to 100 nA;
b) lower beam current to 0.1 nA
c) insert radiator 10^{-5} r. l.;
d) check tagger counter scalers;
e) 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, 6mm;
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 (~6 hours).

PRad Run Plan: GEM Calibration

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

a) collimator with smallest diameter in (2.7 mm);
b) insert thin ~ 1% r. l. CH_2 target in the beam;
c) insert 1”x1” small scintillator counter in the beam just after the Vacuum Box;
d) insert radiator 10^{-5} r. l.;
e) ask for photon beam with lowest intensity (I_e = 70 pA);

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

PRad Run Plan: HyCal Gain Calibration

4) **HyCal Gain Calibration (1.5 days)**:

   a) run the 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 (4 days)**

   (Talk "Coexistence, Schedule, …" by Eugene Pasyuk)

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 = 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 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)

6) Target Commissioning (cont'd):

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

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

PRad Run Plan: Data Taking with E_e = 2.2 GeV

7) Data taking with E_e = 2.2 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);

8) Change Beam Energy to E_e = 1.1 GeV (0.5 day)

PRad Run Plan: Data Taking with E_e = 1.1 GeV

9) Data taking with E_e = 1.1 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).

Manpower: PRad Collaboration Institutional List

- Currently 16 collaborating universities and institutions

  NC A&T State University
  Duke University
  Idaho State University
  Mississippi State University
  Jefferson Laboratory
  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

Collaboration Manpower: (from Leading Institutions)

Institution	Senior Researcher	Postdoc	Graduate student	Others (for shifts)
Duke Univ.	H. Gao (40%)	1 FTE* (50%)	1 FTE	2 postdocs for shifts 5 grad students for shifts
Mississippi State Univ.	D. Dutta (50%)	1 postdoc (50%) located at Jlab	1 FTE 3 for shifts	2 faculty for shifts 3 grad, students for shifts
Idaho State Univ.	M. Khandaker (50%)			
NC A&T SU	A. Gasparian (75%)		0.5 FTE (1 M.S. degree)	1 Visiting Scientist (5 months)
Argonne				1 faculty for shifts (25%) 2 postdocs for shifts (50%)
Hampton U.				2 postdocs for shifts (25%) 2 grad, students for shifts
ITEP Moscow				1 visiting scientist (50%)
TOTAL	2.2 FTE	1.0 FTE	2.5 FTE	6 postdocs (~ 40%) 10 grad students (50%) 1 visiting Scientist (50%)

Summary

- PRad experimental setup, in most part, is developed, constructed and ready for the experiment:
  - ✓ few remaining engineering work on beam line elements;
  - ✓ construction and cosmic tests of GEM-2

- The experimental setup will be ready for installation by Feb. 2016.

- PRad will be ready for any “opportunistic” run for this spring.

✓ 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

Buck 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)

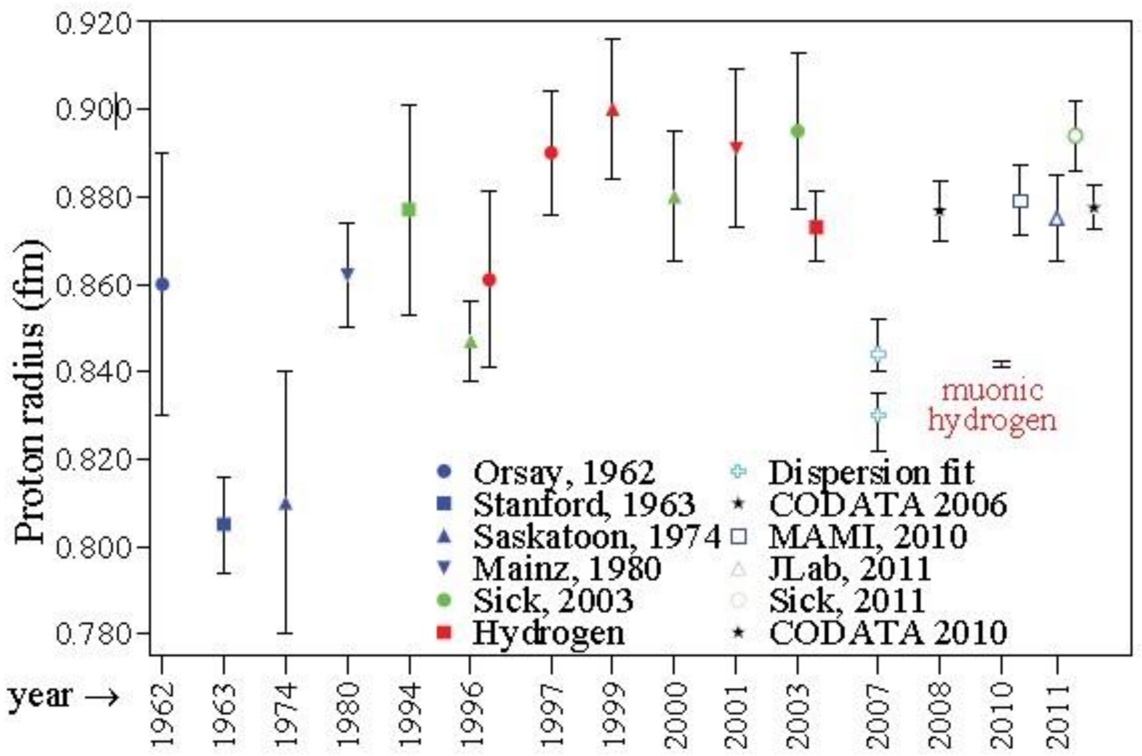
- Simultaneous detection of two processes:
  - *ep* → *ep*
  - *ee* → *ee* Moller scattering
- and windowless H_2 gas target

  - 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%

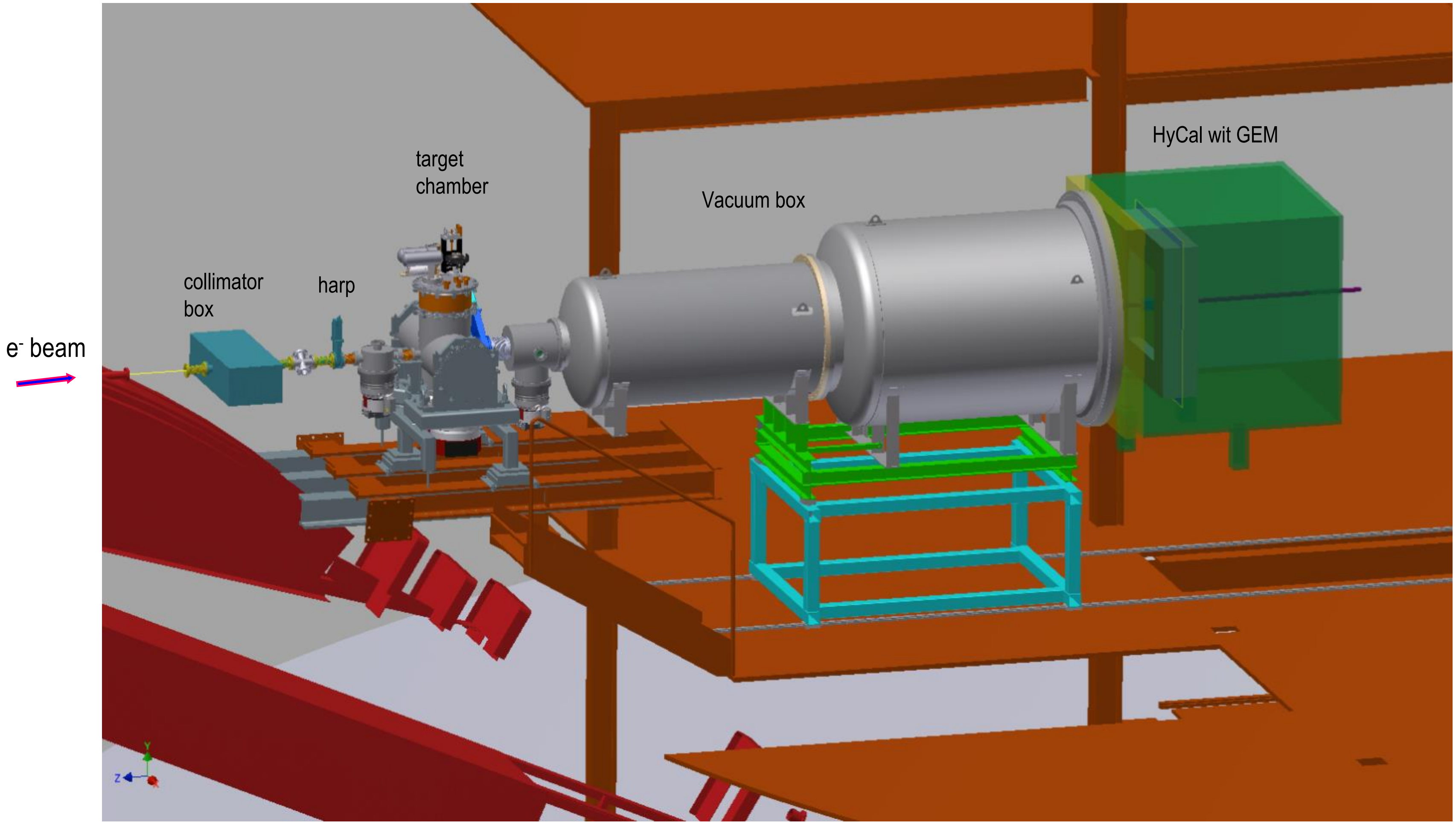
- Estimated error budget (added quadratically)

Proton Radius Extracted From e-p Scattering Experiments

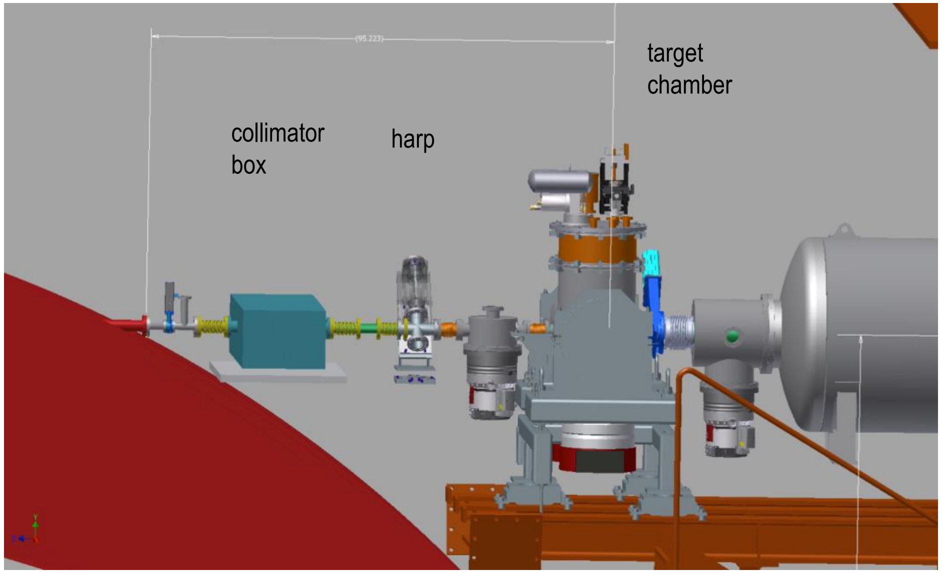


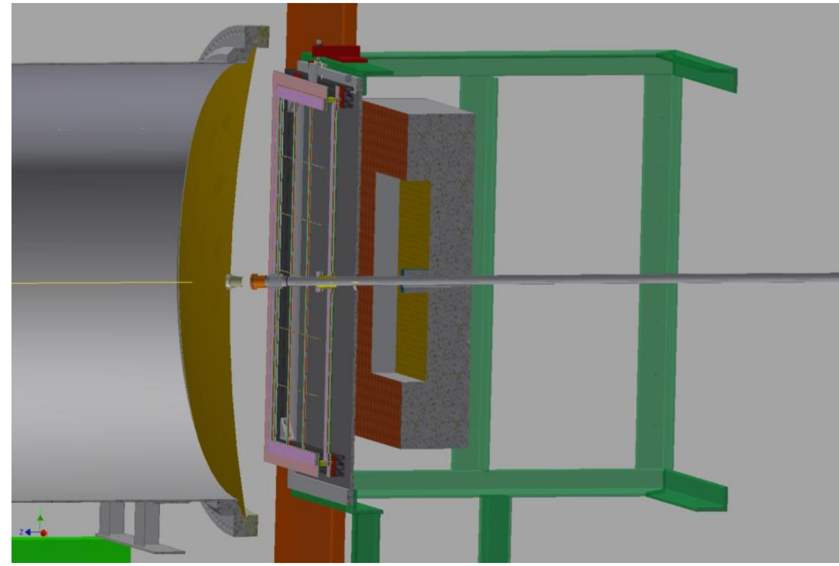
- More different analysis results than actual experiments
- Started with: $r_p \approx$ 0.81 fm in 1963
- Reached to: $r_p \approx$ 0.88 fm by 2011

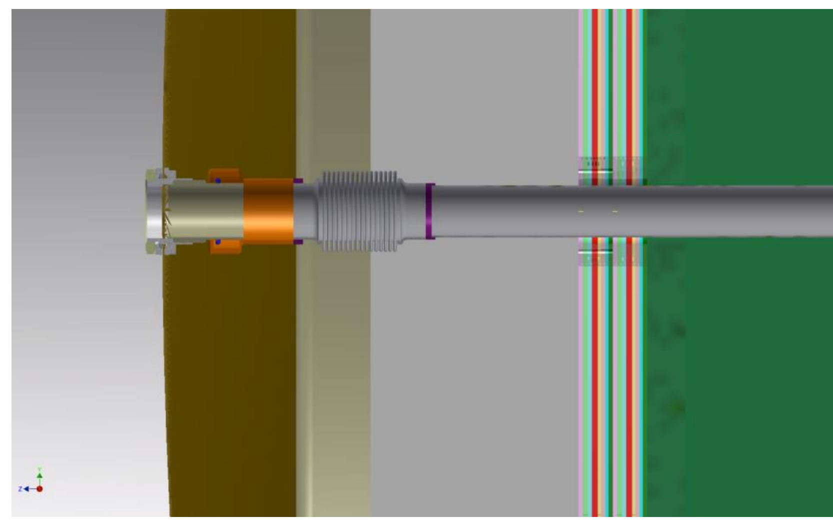
PRad Experimental Setup (3D view)



Beam Line Elements: Survey and Alignment (including Vacuum Box)







(Talks "Engineering aspects" by Bob Miller, and by Eugene Pasyuk)