PREX-II

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NSKINS-2016, MITP

What We Learned in PREX-I

What Worked:

New Septum
We now know how to tune it to optimize FOM

A_T false asymmetry
A_T is small (<1 ppm Pb, <10 ppm C)
and $\mathrm{A}_{\mathrm{false}}$ will be small if P_T is minimized

HRS Tune
We have a tune and good first-guess optics matrix for a tune optimized for the small detectors

Fast Helicity Flipping
We know how to control false asymmetries and monitor performance

Lead Target
Survival > 1 wk, 15 C

Injector Spin Manipulation
Second Wein and solenoid are calibrated and used for helicity reversal. Important cancellation for systematic beam asymmetries from the polarized source.

New Detectors
Suitable energy resolution achieved for 1 GeV electrons. <5% precision loss.

Polarimetry at low energy
Moller at 1.3%, Integrating Compton at 1.2%

Beam Modulation System
Fast beam kicks cancel low frequency noise and improve precision of beam position corrections

Ready for PREX-II, after resolving:
- Target Vacuum system
- Radiation Damage in Hall

PREX/CREX Summary

PREX-2: 25+10 days, 3% stat, 0.06 fm
CREX: 35+10 days, 2% stat, 0.02fm

Achieved

PREX-I
E=1.1 GeV, 5°
A=0.6 ppm

Charge Normalization	0.2%
Beam Asymmetries	1.1%
Detector Non-linearity	1.2%
Transverse Asym	0.2%
Polarization	1.3%
Target Backing	0.4%
Inelastic Contribution	<0.1%
Effective Q^2	0.5%
Total Systematic	2.1%
Total Statistical	9%

PREX-II
E=1.1 GeV, 5°
A=0.6 ppm

Charge Normalization	0.1%
Beam Asymmetries	1.1%
Detector Non-linearity	1.0%
Transverse Asym	0.2%
Polarization	1.1%
Target Backing	0.4%
Inelastic Contribution	<0.1%
Effective Q^2	0.4%
Total Systematic	2%
Total Statistical	3%

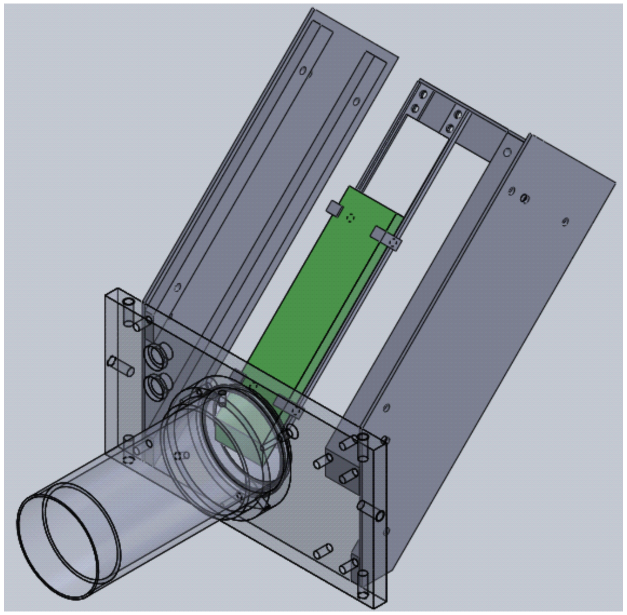
CREX
E=2.2 GeV, 4°
A = 2 ppm

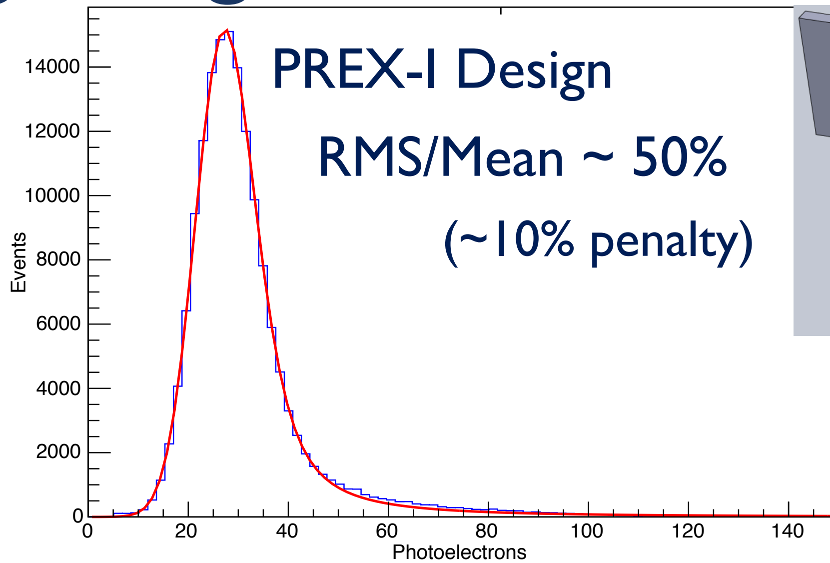
Charge Normalization	0.1%
Beam Asymmetries	0.3%
Detector Non-linearity	0.3%
Transverse Asym	0.1%
Polarization	0.8%
Target Contamination	0.2%
Inelastic Contribution	0.2%
Effective Q^2	0.8%
Total Systematic	1.2%
Total Statistical	2%

Conservative estimates: experience suggests these can be better

Integrating Detectors

- *Thin fused silica: optimize RMS*
  - *thick: higher photo-electron yield*
  - *thin: smaller RMS degradation*

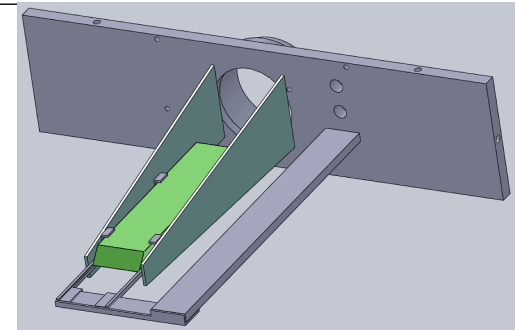




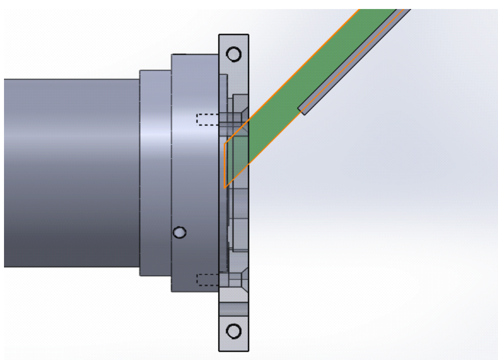
PREX-I Design

RMS/Mean ~ 50%

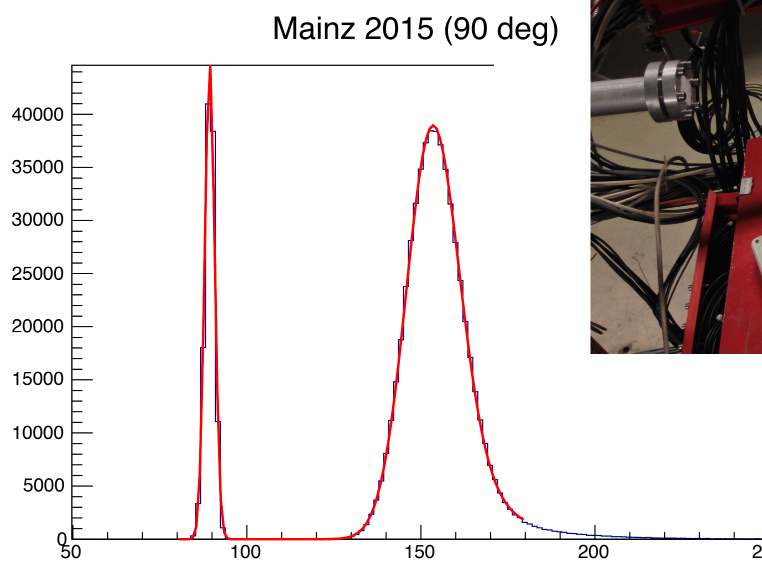
(~10% penalty)

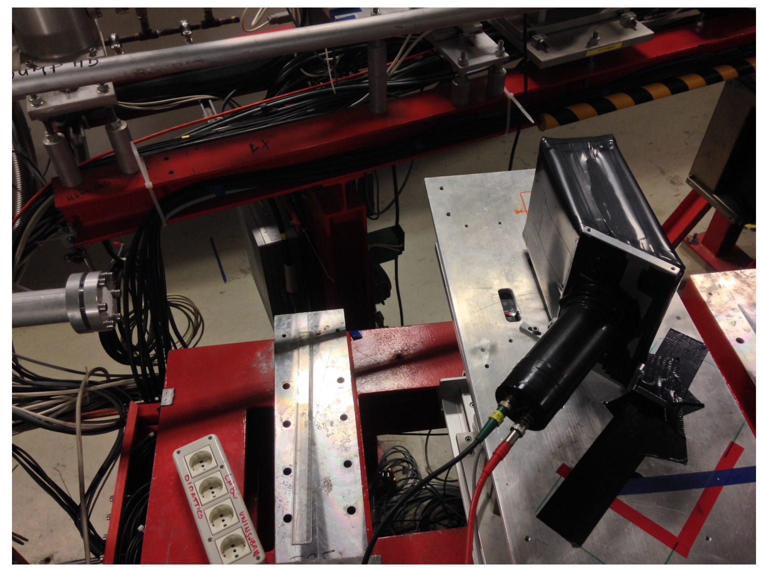


New PREX-II Design



Also under development: improved instrumentation to test linearity





RMS/Mean ~ 18%

(<2% penalty)

Helicty Correlated Beam Asymmetries

$$A_{corr} = A_{det} - A_Q + \alpha \Delta_{\mathbf{E}} + \Sigma \beta_i \Delta \mathbf{x}_{\mathbf{i}}$$

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Uniformity of circular polarization: components, alignment techniques, diagnostics

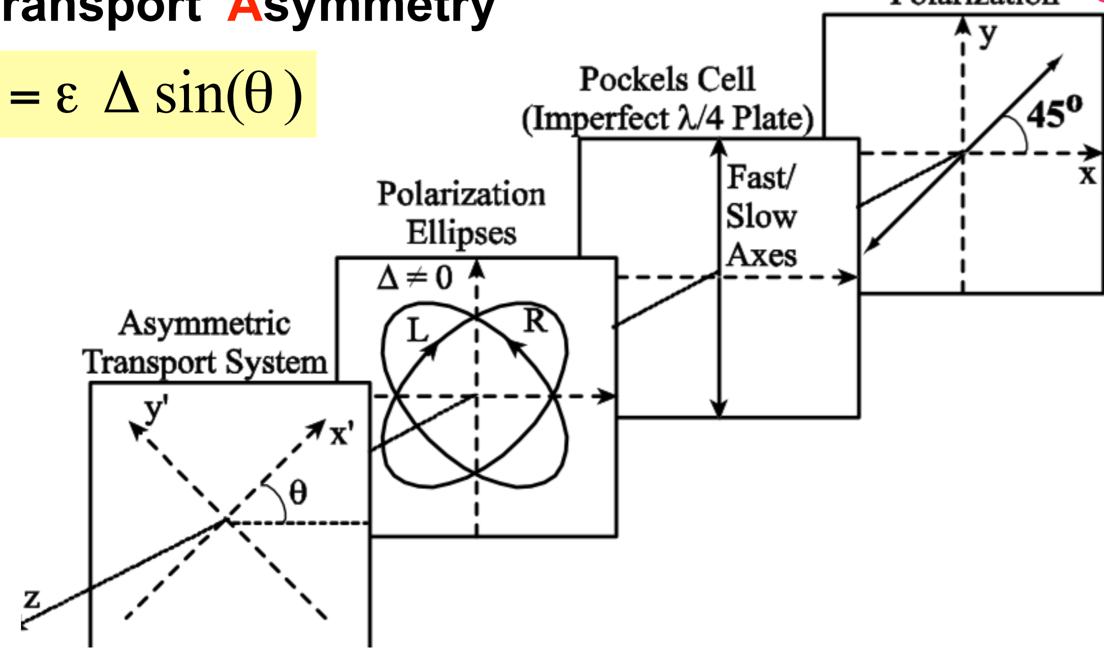
Laser at Polarized Source

PITA: Polarization Induced Transport Asymmetry

Intensity Asymmetry $A_I = \varepsilon\ \Delta \sin(\theta)$

where $\varepsilon = \dfrac{T_x - T_y}{T_x + T_y}$

Quantum Efficiency Asymmetry



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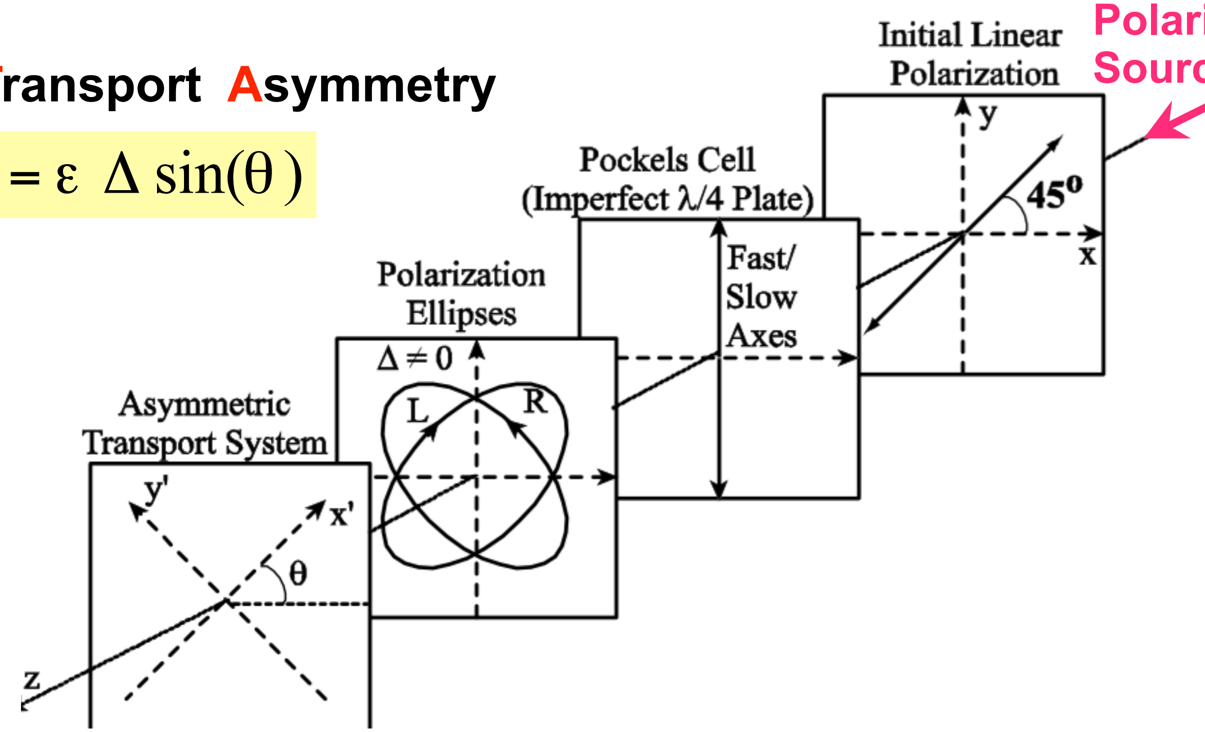
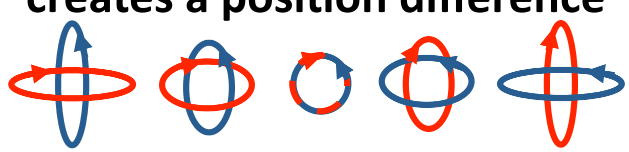
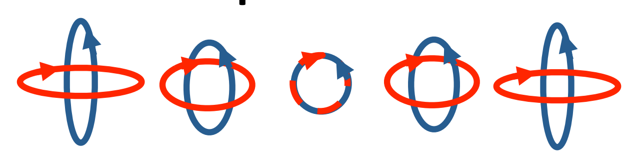


If on average linear polarization = 0, that doesn't mean that it is everywhere zero

A non-zero 1st moment creates a position difference



A non-zero 2nd moment creates a spot-size difference



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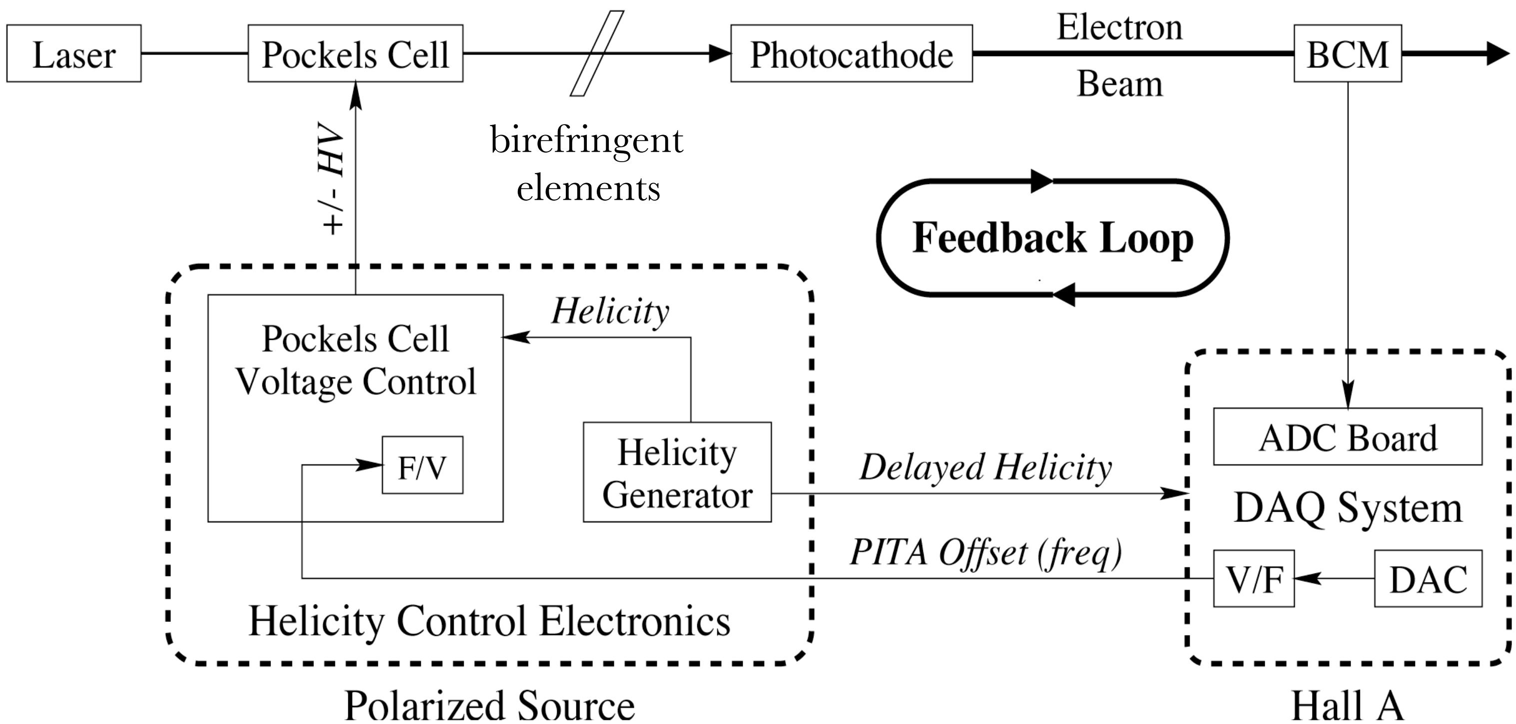

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- *Precision beam position monitoring*
- *Active calibration of detector slopes*

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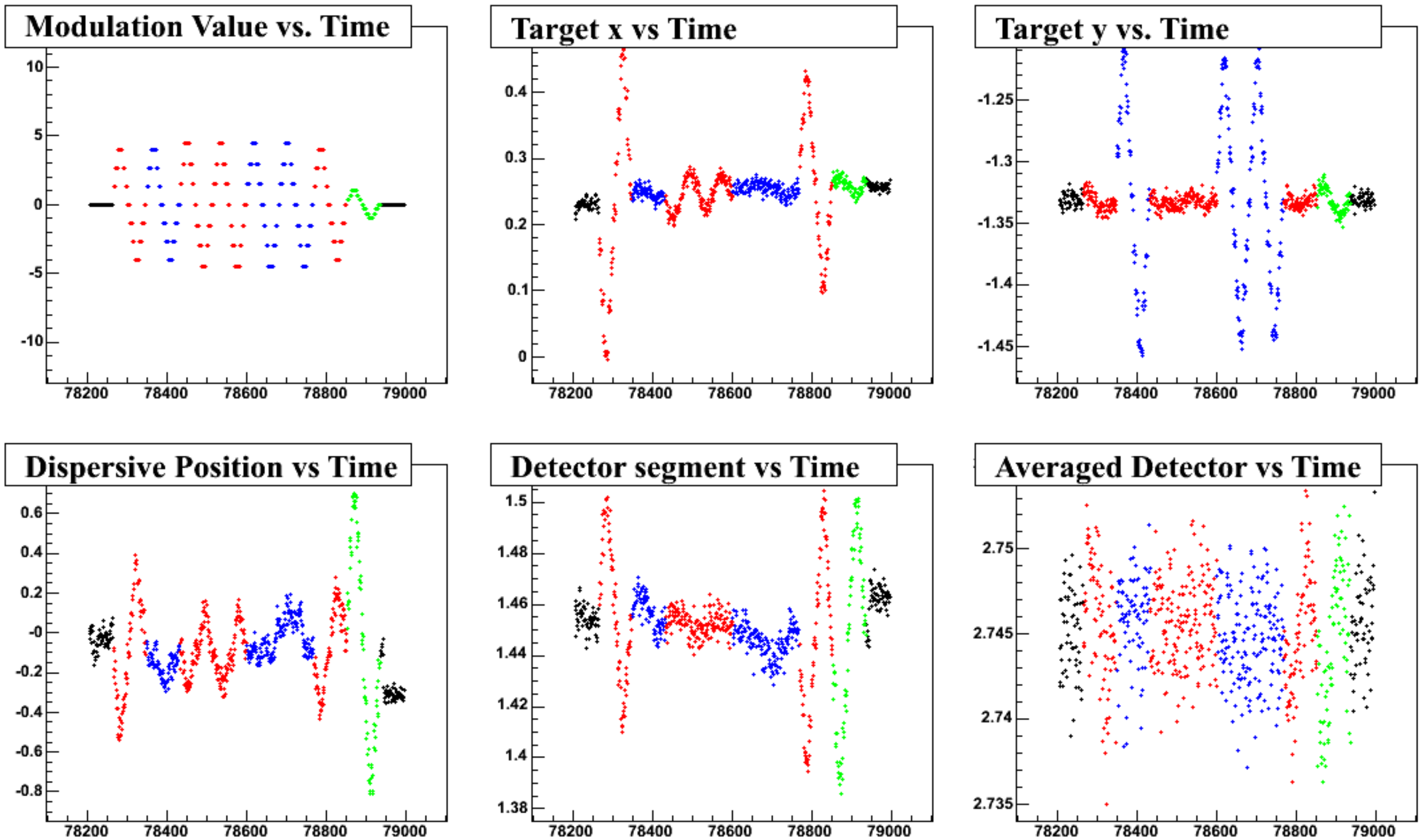
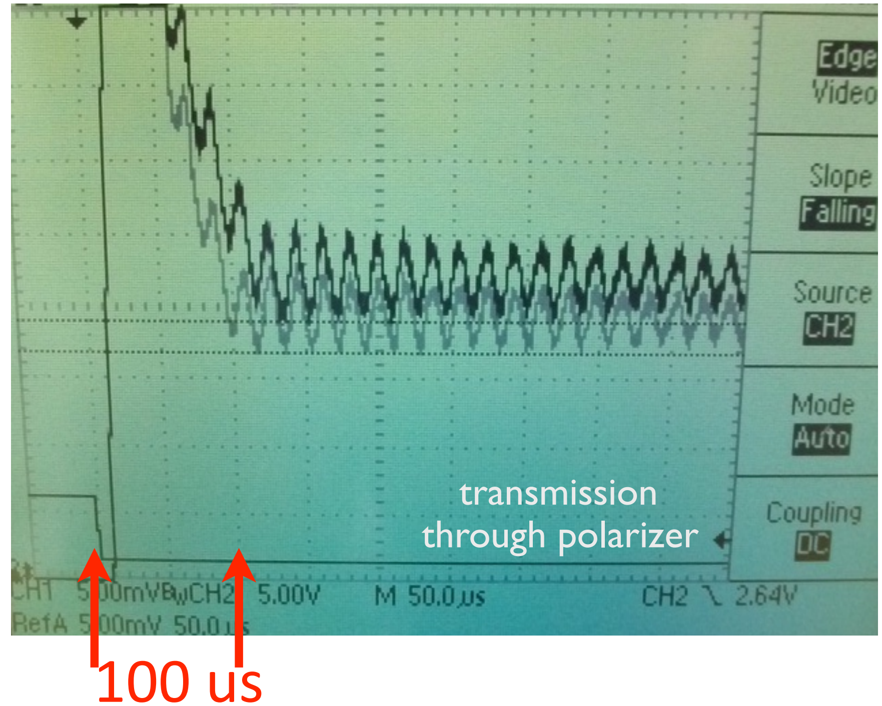
PREX-I used improved beam modulation system



Fast Reversal Asymmetry

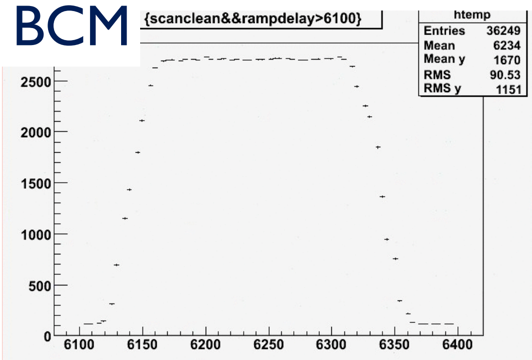
PREX-I had a problem with excessive Pockels cell reversal time

- Slower than expected transition (slightly over 100 μs)
- ringing (out to very long timescales, ~18 μs period)
- **asymmetric transition**

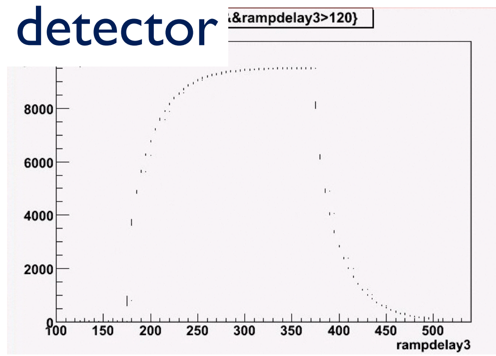


Bandwidth for BCM and Detector didn't match

BCM



detector



Electron beam test:
direct test of beam monitor (and detector) time constants
- 100 microsecond pulse
- short integrate gate with flexible delay

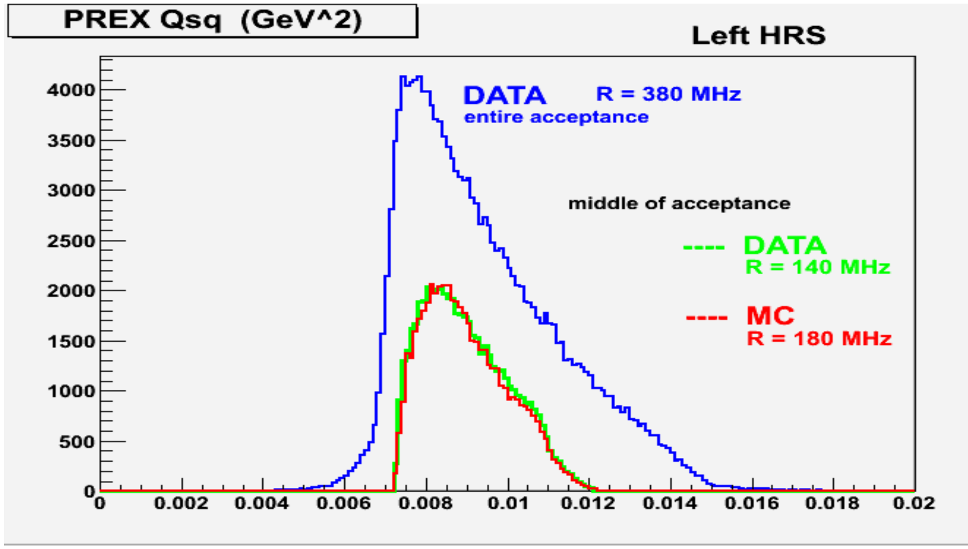
Together = False Asymmetry!

- Improved PC transition to ~80us, symmetric
- Increased gate period (~500 us)
- Improved detector response time to match BCM

Optics Calibration

4-momentum transfer $Q^2 = 4EE'\sin^2\frac{\theta}{2}$

Q² distribution obtained by low rate runs; trigger on quartz pulse-height



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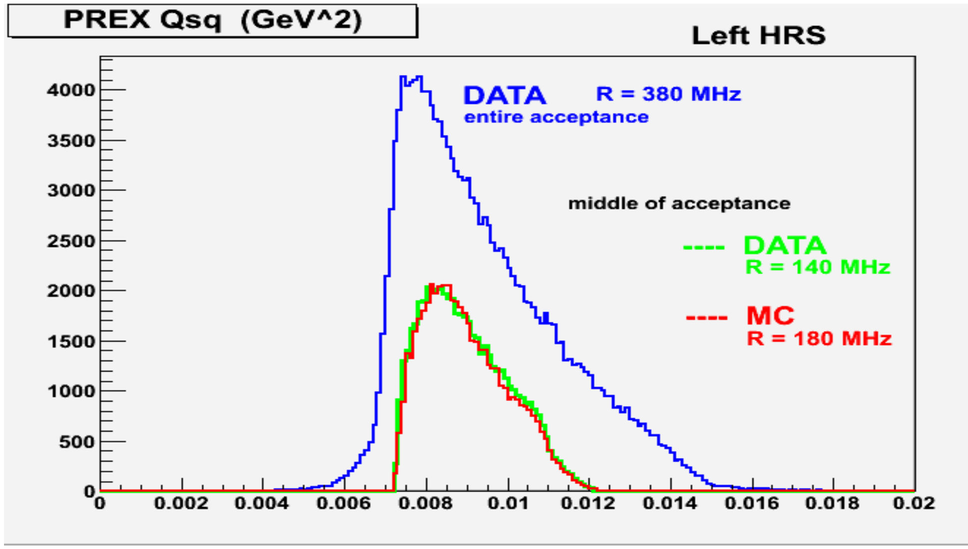
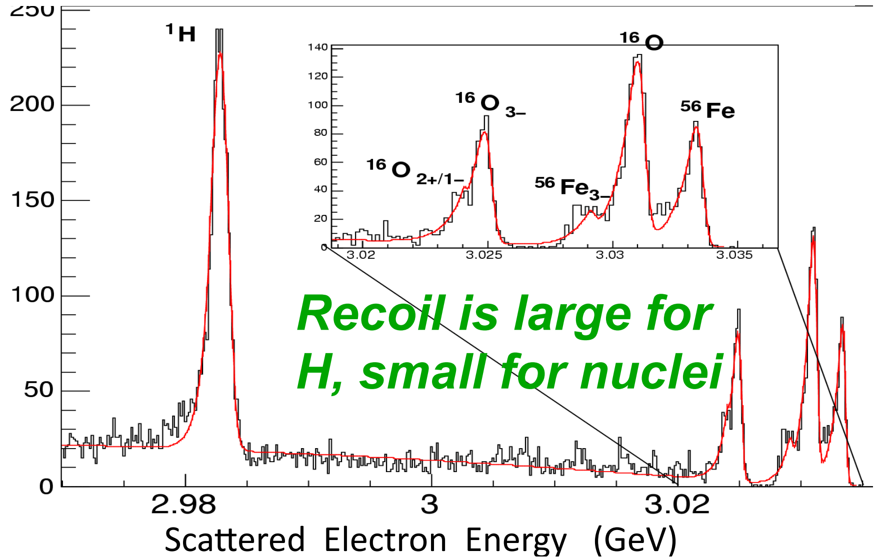
E: calibrated dipole field in arc
E': scattering reconstruction
scattering angle: survey ~ 1 mr



Water cell target

Absolute angle calibration via nuclear recoil variation

$$\frac{\delta E}{E} \approx \frac{\theta^2}{2}\frac{E}{M_A}$$



(3 GeV example - much harder at 1 GeV)

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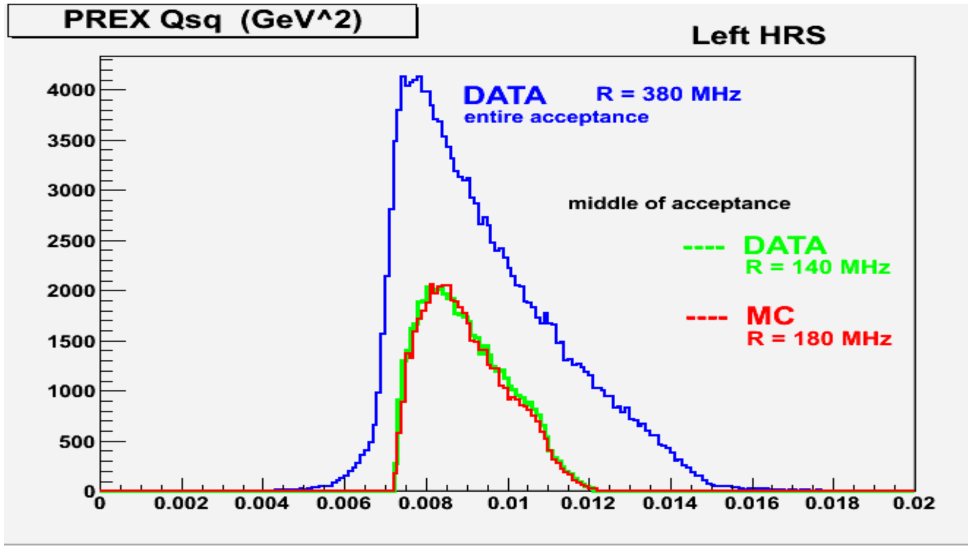

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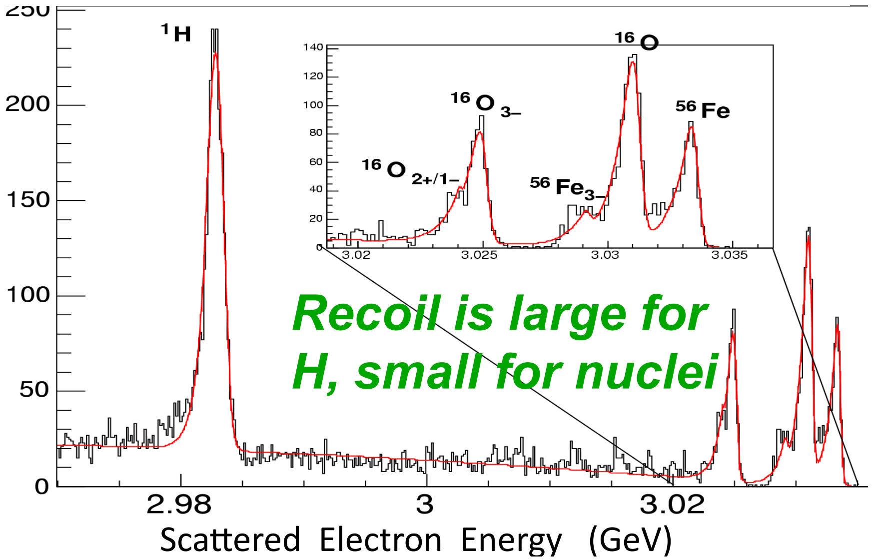


(3 GeV example - much harder at 1 GeV)

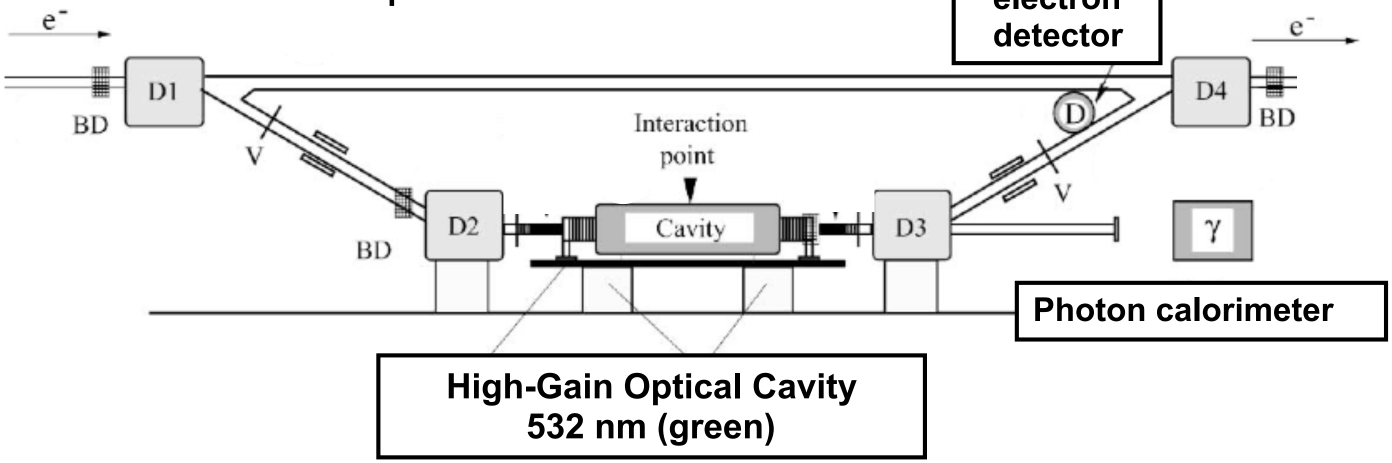
1% absolute calibration on Q² achieved:
δA_{pv} ~ 0.5%

PREX-2 will add:
- GEMs to help eliminate rate-dependent distortion of distribution
- repeatable optics calibrations (separate watercell target mover)

Beam Polarization

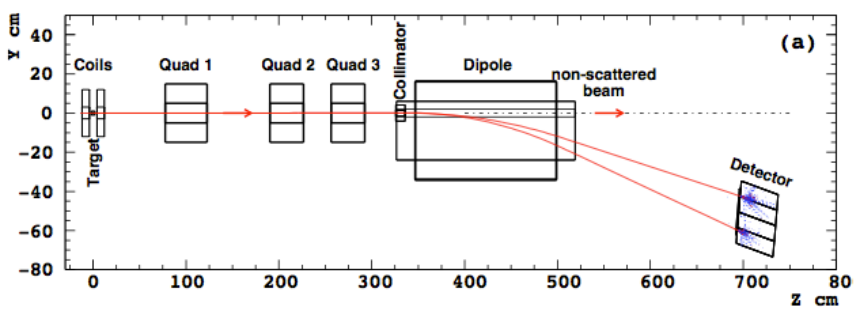
Goal: 1% beam polarimetry

Compton



- continuous measurement
- small asymmetry (~3%) but normalization well controlled
- GSO calorimeter to response low E photons
- laser polarization to 0.2%
- electron arm difficult to use at 1 GeV, possible at 2 GeV

Møller



- Coincidence detection in QQQQD spectrometer
- fast counting DAQ

<u>Pure Iron at High Field</u>

- Magnetized perpendicular to foil
- 3-4 T applied field - magnetization saturated
- Spin polarization, known to 0.25%

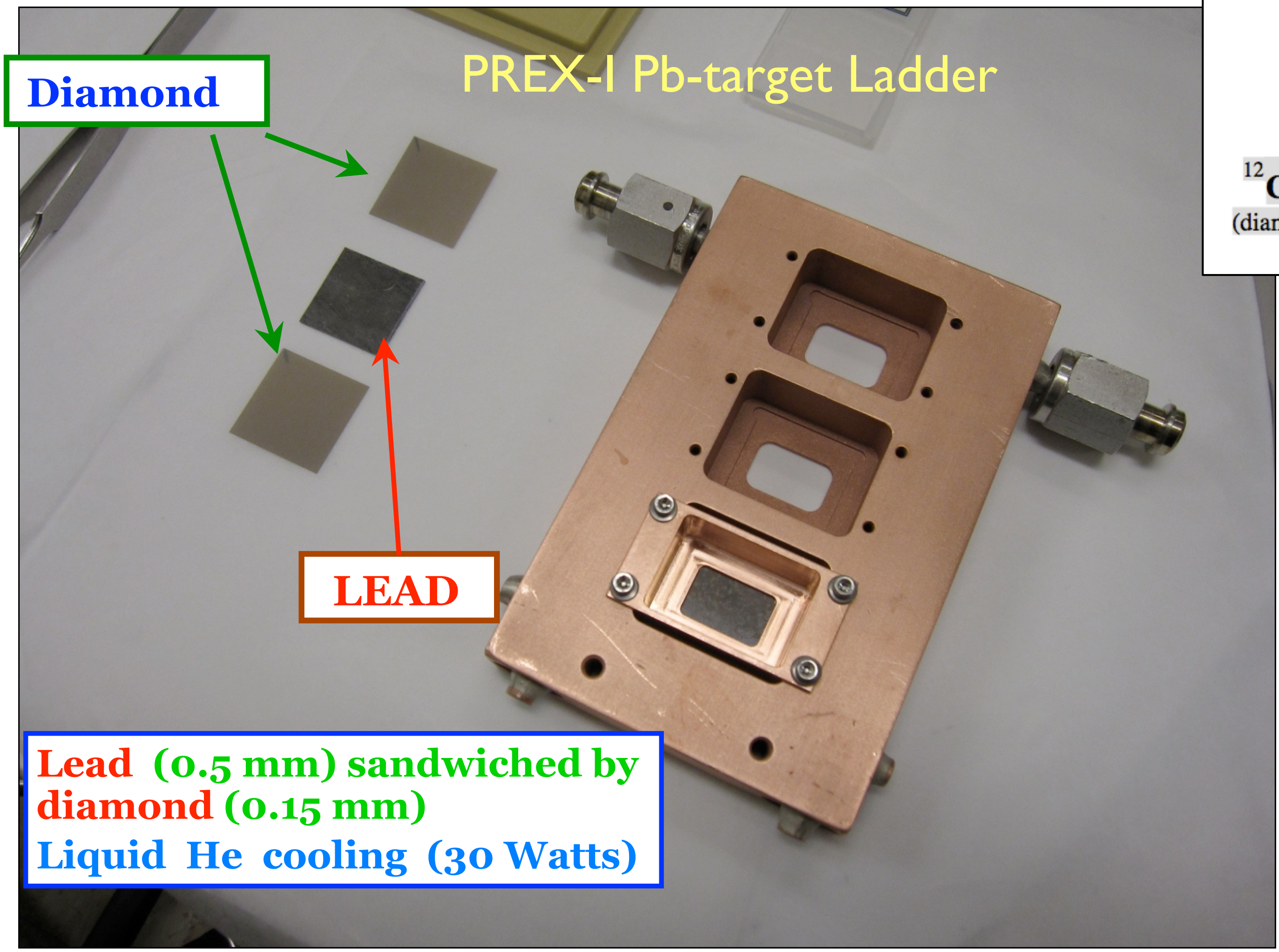
- new high-field solenoid for saturated iron target
- 0.5% precision already claimed on Hall C polarimeter
- Spin polarization can not be independently verified
- Low-E spectrometer optics, distortion by holding field
- Low-current, invasive measurement

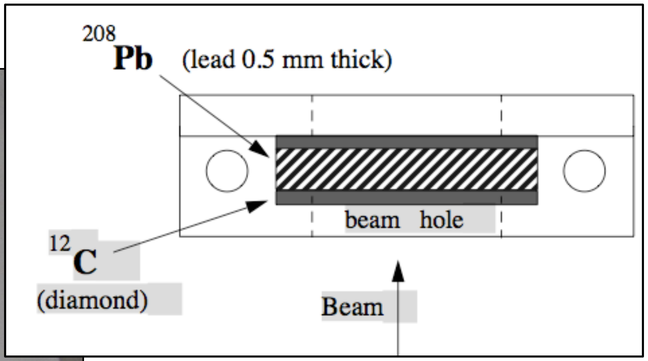
Lead / Diamond Target

Lead has low melting point, and low thermal conductivity

Diamond foils have excellent thermal conductivity

^{12}C is isoscaler, spin-0 (and well-measured) so benign background!

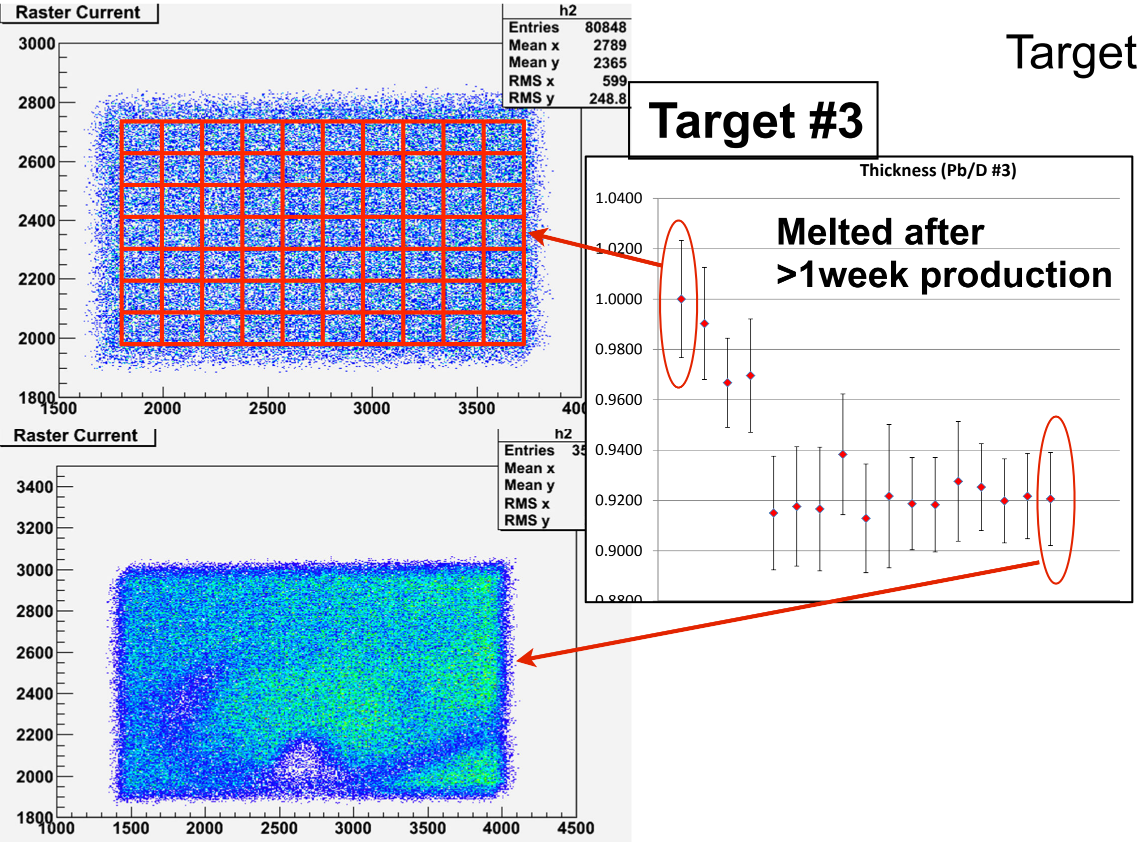




Two questions:
- thermal contact?
- diamond lifetime?

PREX-I used three different diamond thickness,(4.5%-8%)

Target Thickness and Uniformity



Target *uniformity* degraded by beam damage.

Targets with <u>thin</u> diamond backing (4.5 % background) degraded fastest.

<u>Thick</u> diamond (8%) ran well and did not melt at 70 uA.

A larger ladder, with 10 targets, will give PREX-2 a large safety margin

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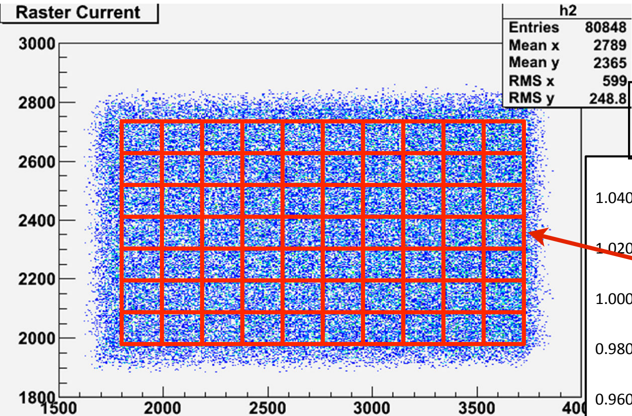

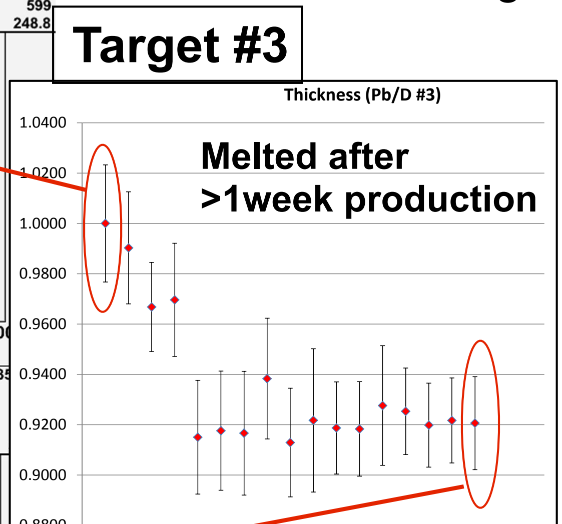

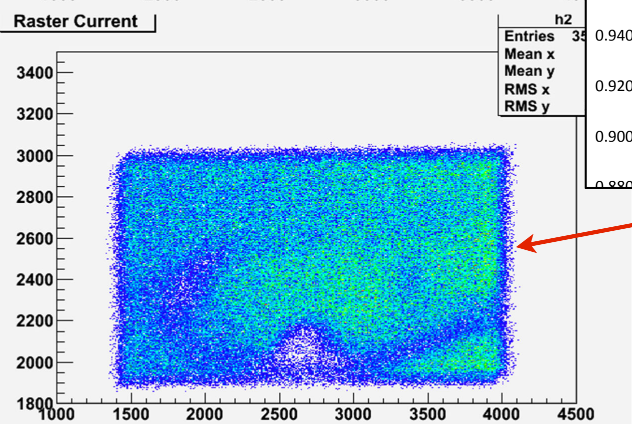

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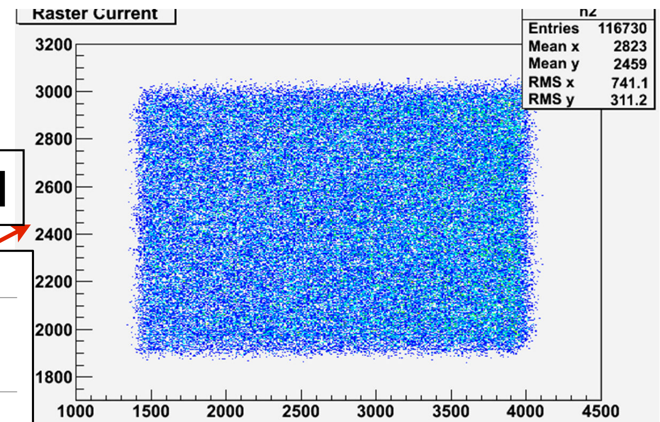

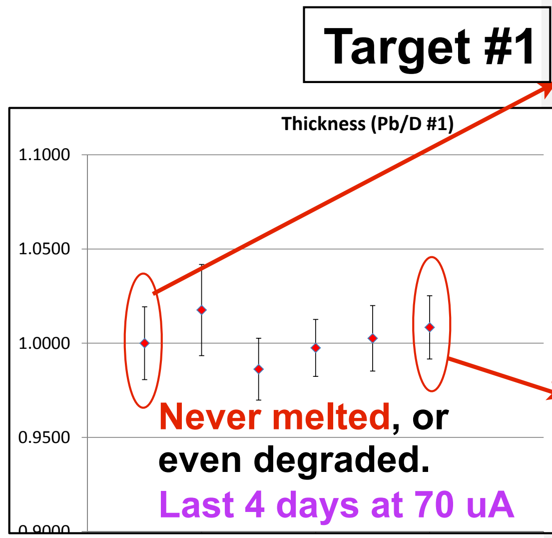

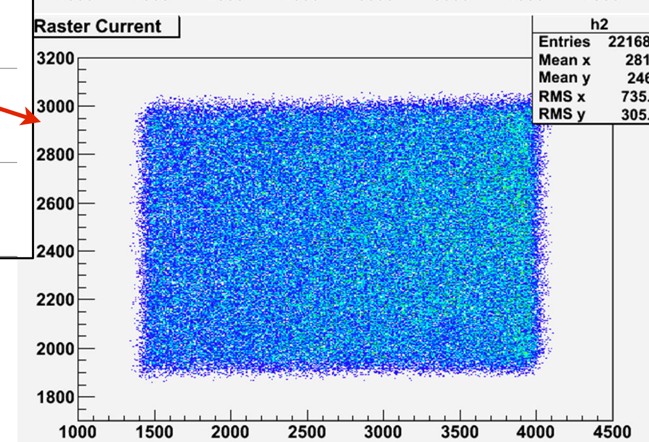

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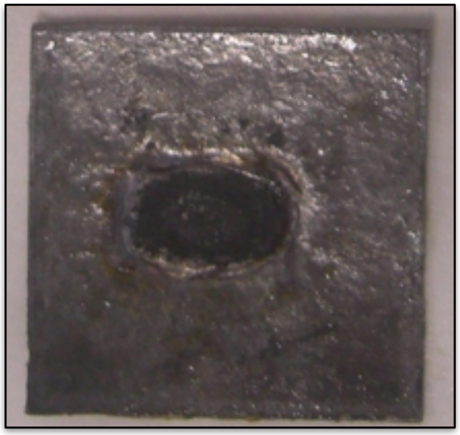
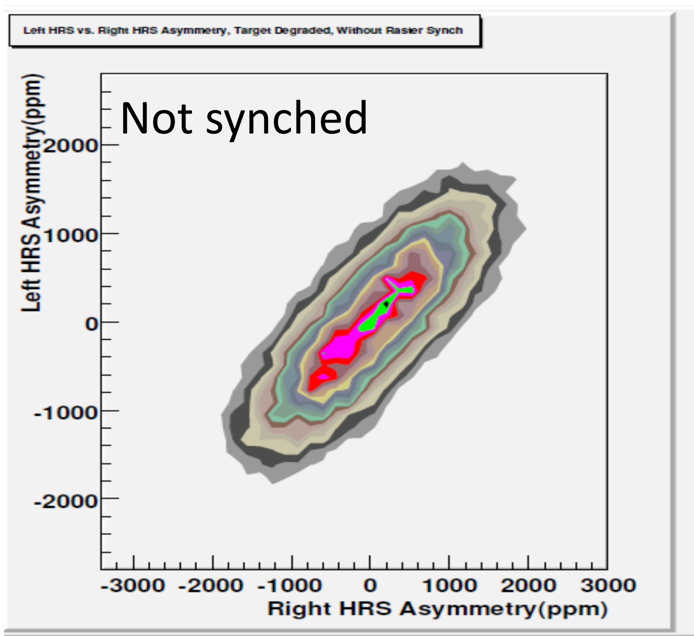
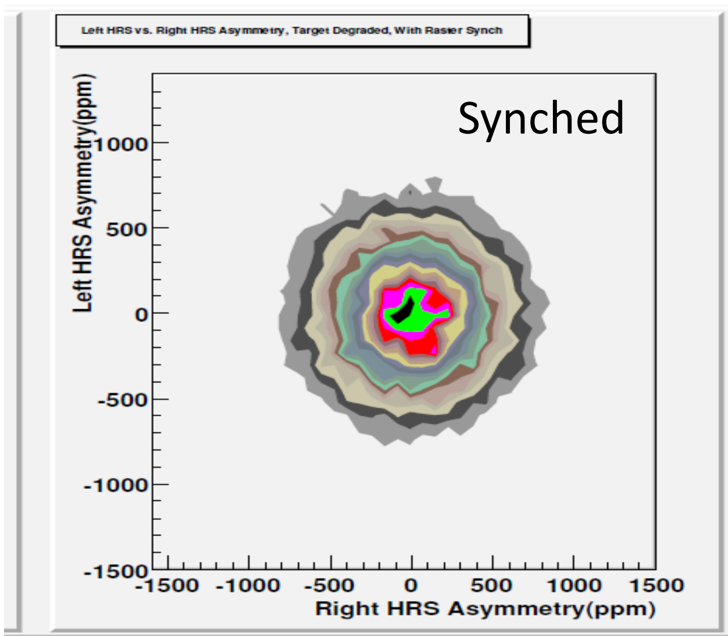
Target Uniformity

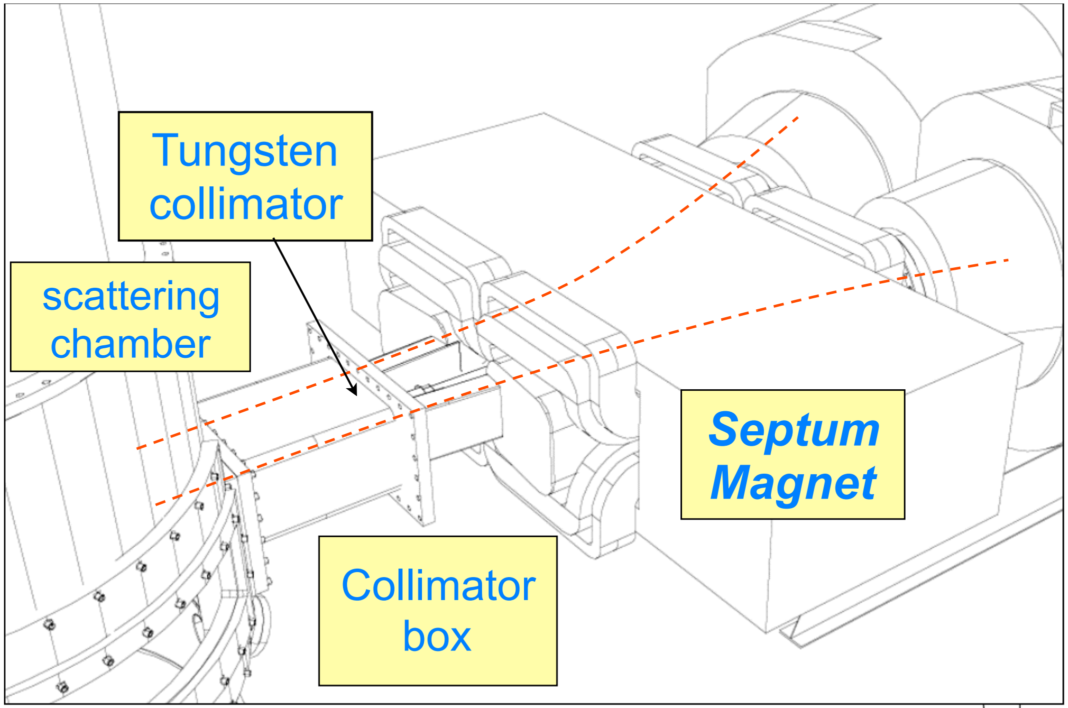
- Target *uniformity* degraded by beam damage.
- Created noise due to (fast) raster, as helicity windows measured over slightly different target regions.
- Width start <200 ppm, grew >300 ppm
- Beat frequency between x/y chosen so that lissajous is periodic at 480 Hz, and synchronized to helicity flip frequency
- With synchronized raster, recovered 200 ppm width







Vacuum Issues



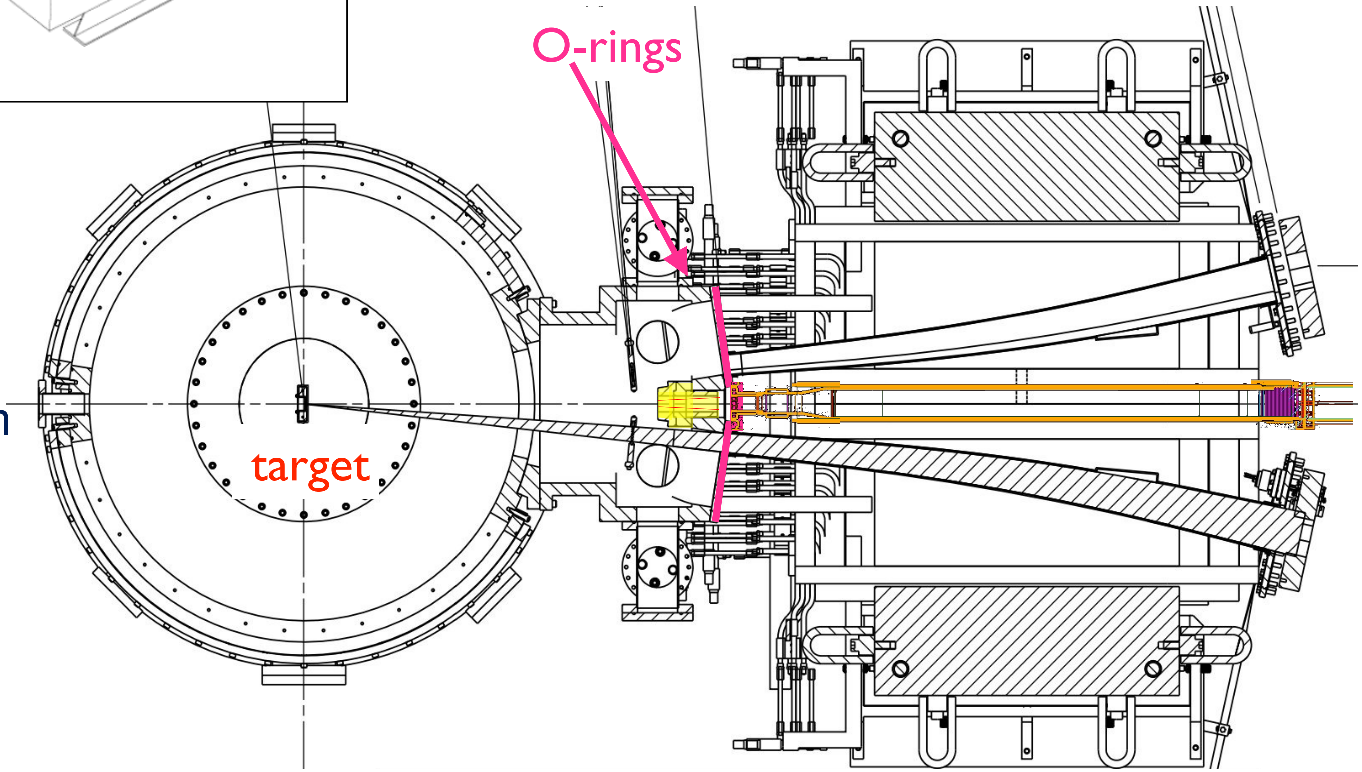
Pb target: 0.6 g/cm^2, 10% R.L.
Beam: 70 μA, 1 GeV

Elastic e-nuclear scattering to moderate angles, so high rate of energetic electrons in the hall

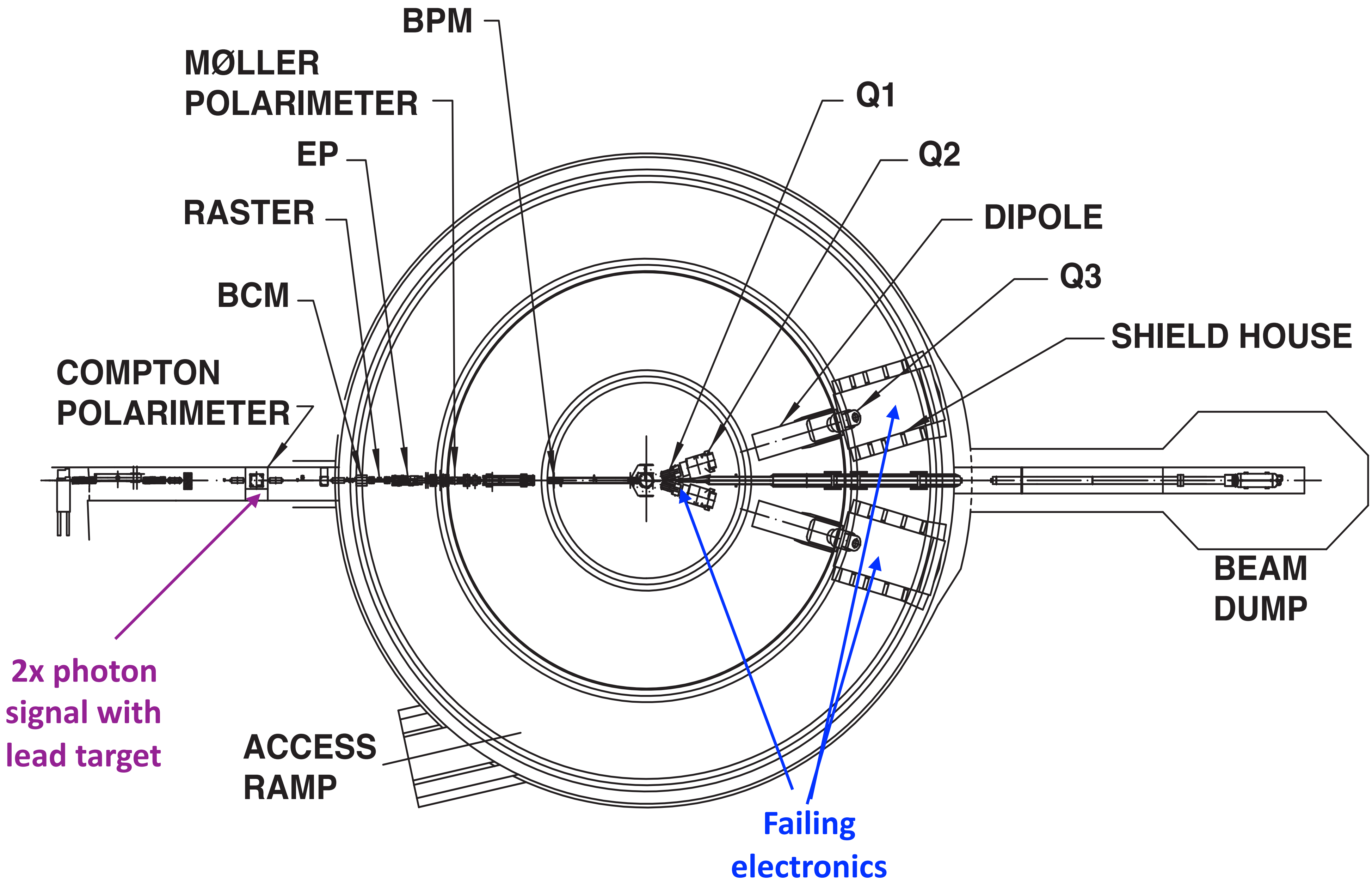
PREX-I had elastomer O-rings at small angles (<1 degree)

Radiation damage cause vacuum leaks, led to premature end of experiment

Solution: all metal seals



PREX-I Radiation Issues



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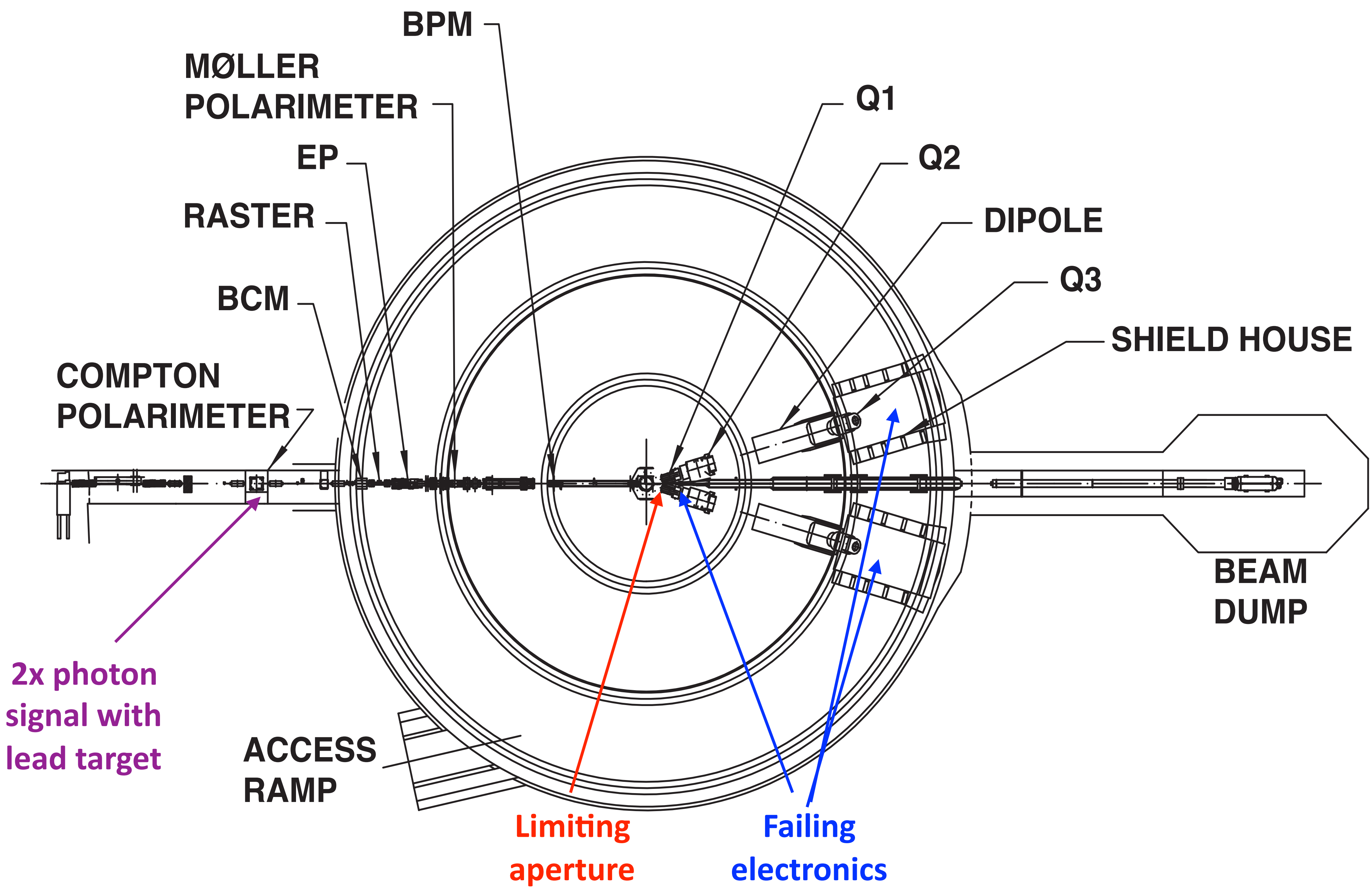
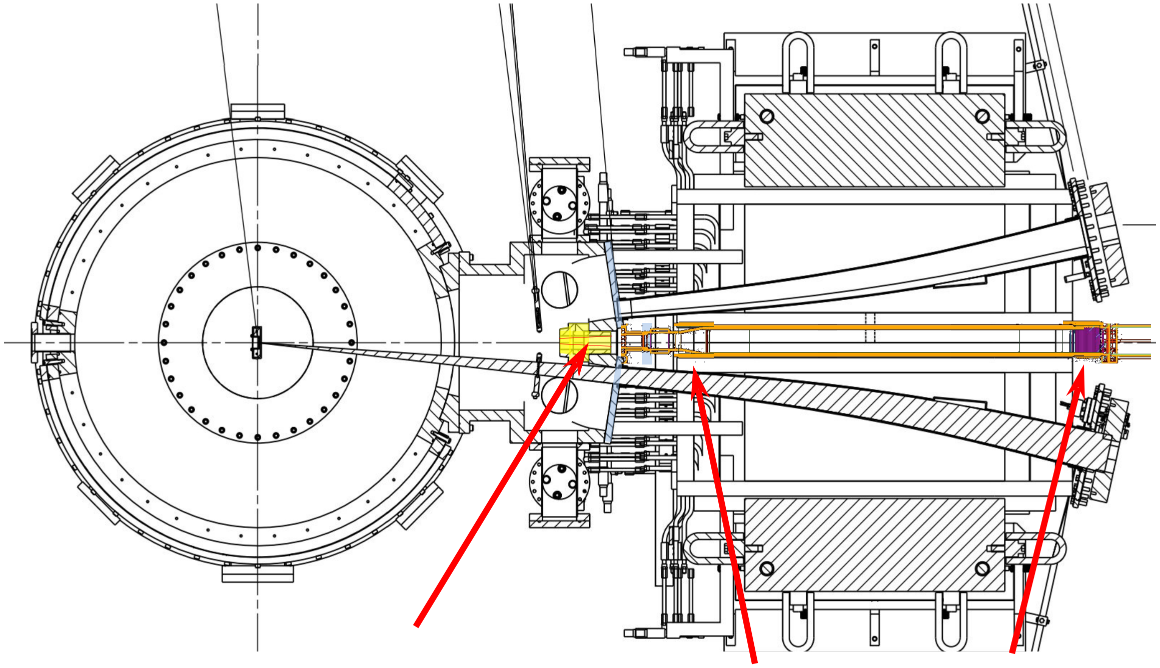


Stopping PREX-I sources of radiation

Neutrons:
- elastics from the thick, high-Z target
- dominantly GDR excitation in the collimator or beampipe
- soft neutron spectrum (<10 MeV)



Plan: Use a single collimator to stop everything that misses the dump. Then shield around that collimator

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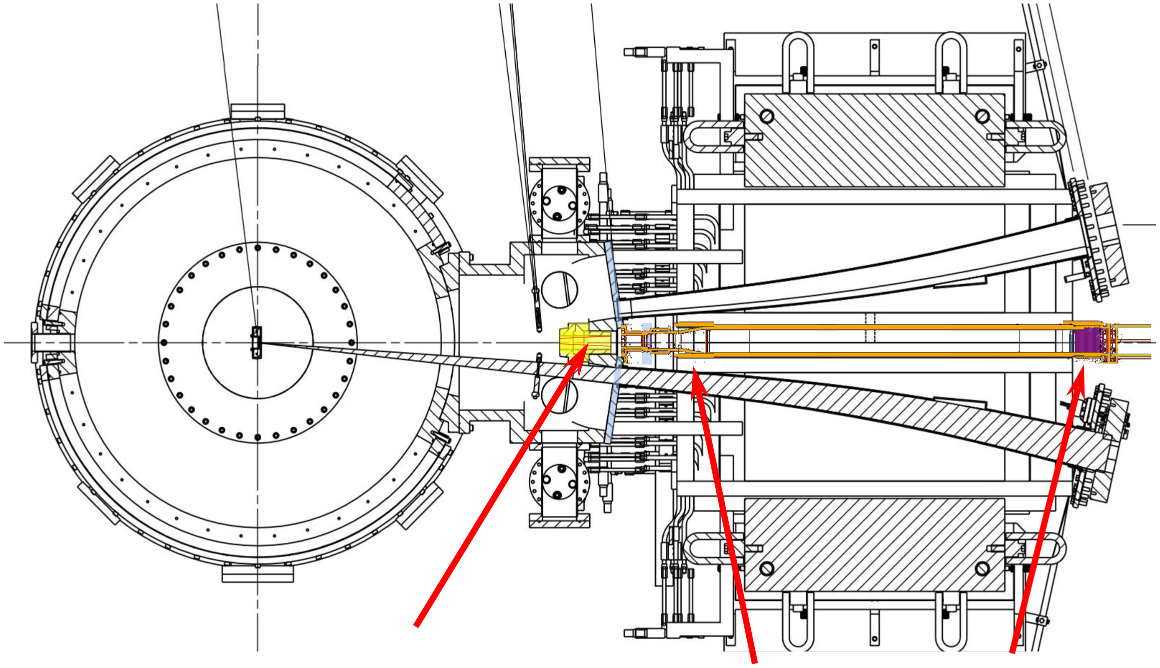

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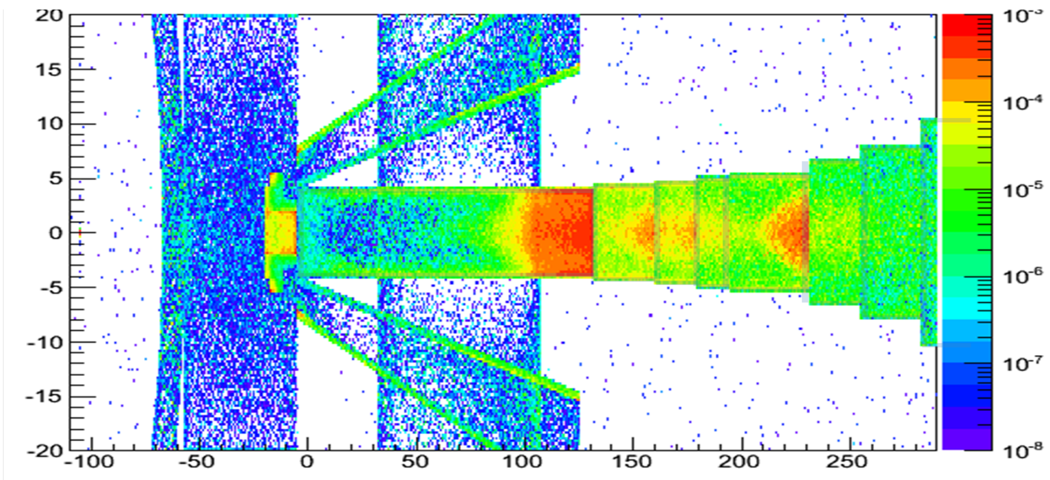
PREX I



Origin of photons hitting a “plane” detector downstream of the septum

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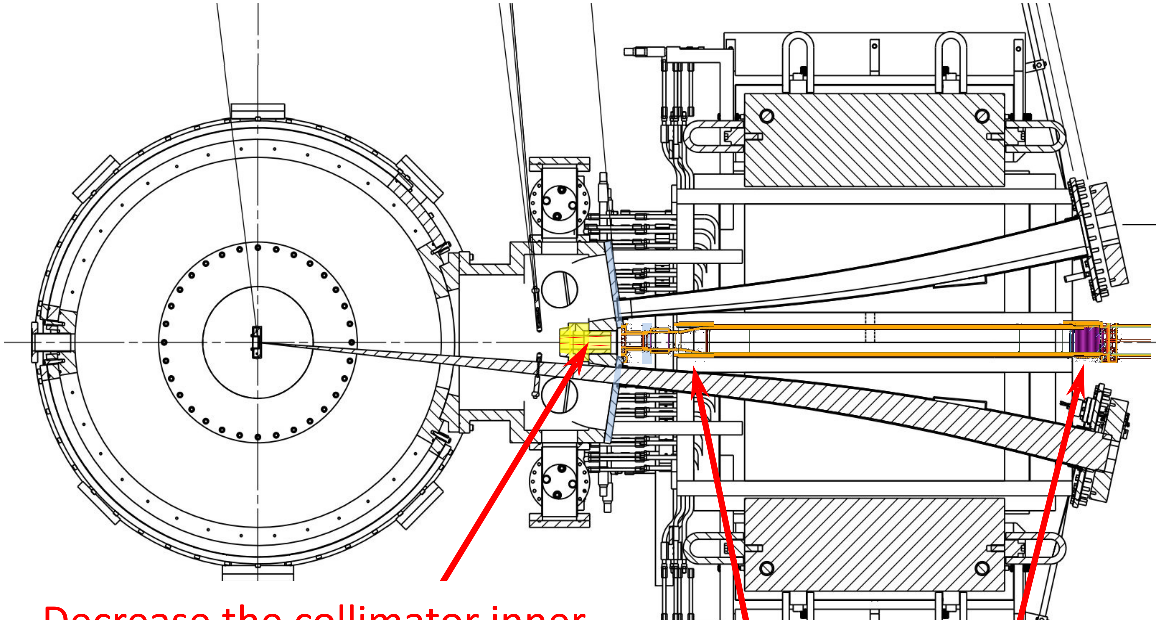
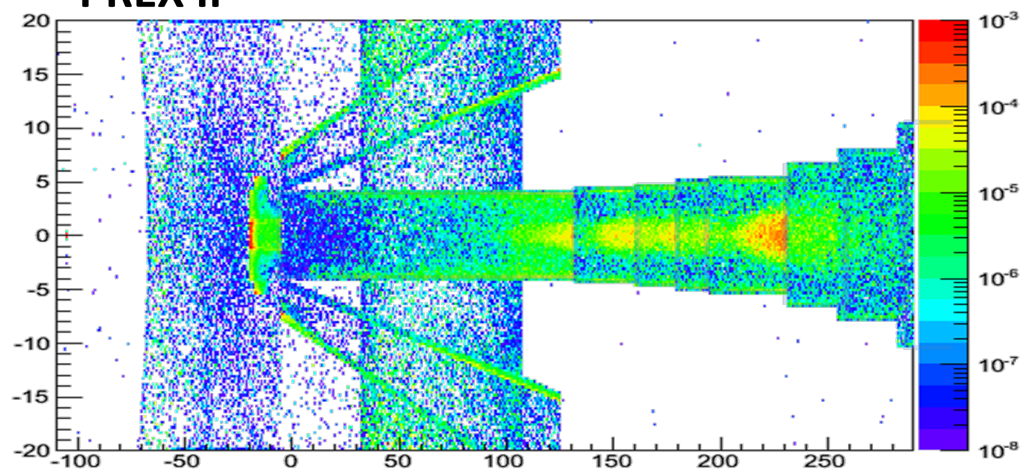


Decrease the collimator inner diameter and water cool it

Extend magnetic shield through septum magnet

PREX II



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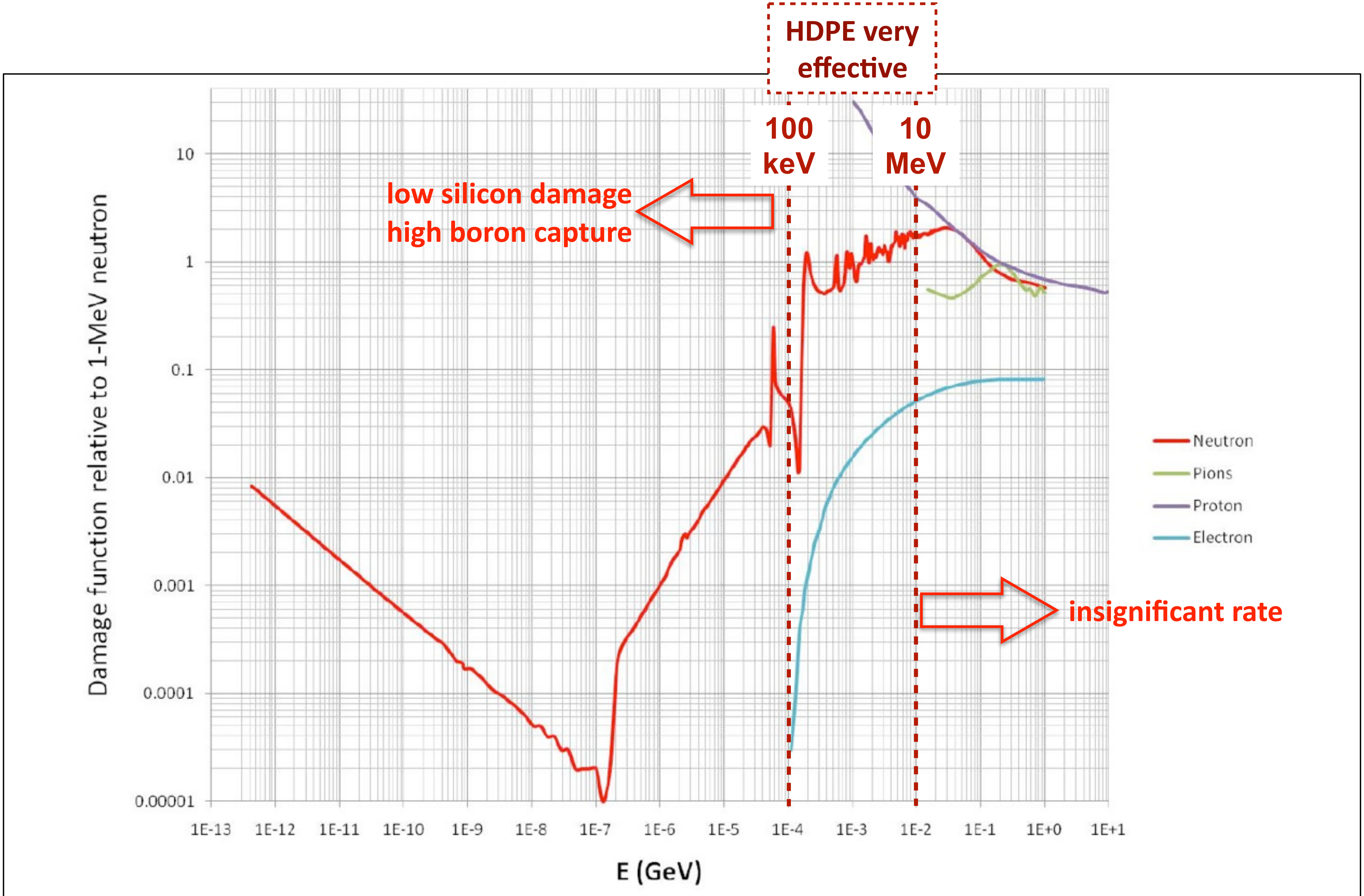
Relative Silicon Damage vs. Neutron Energy

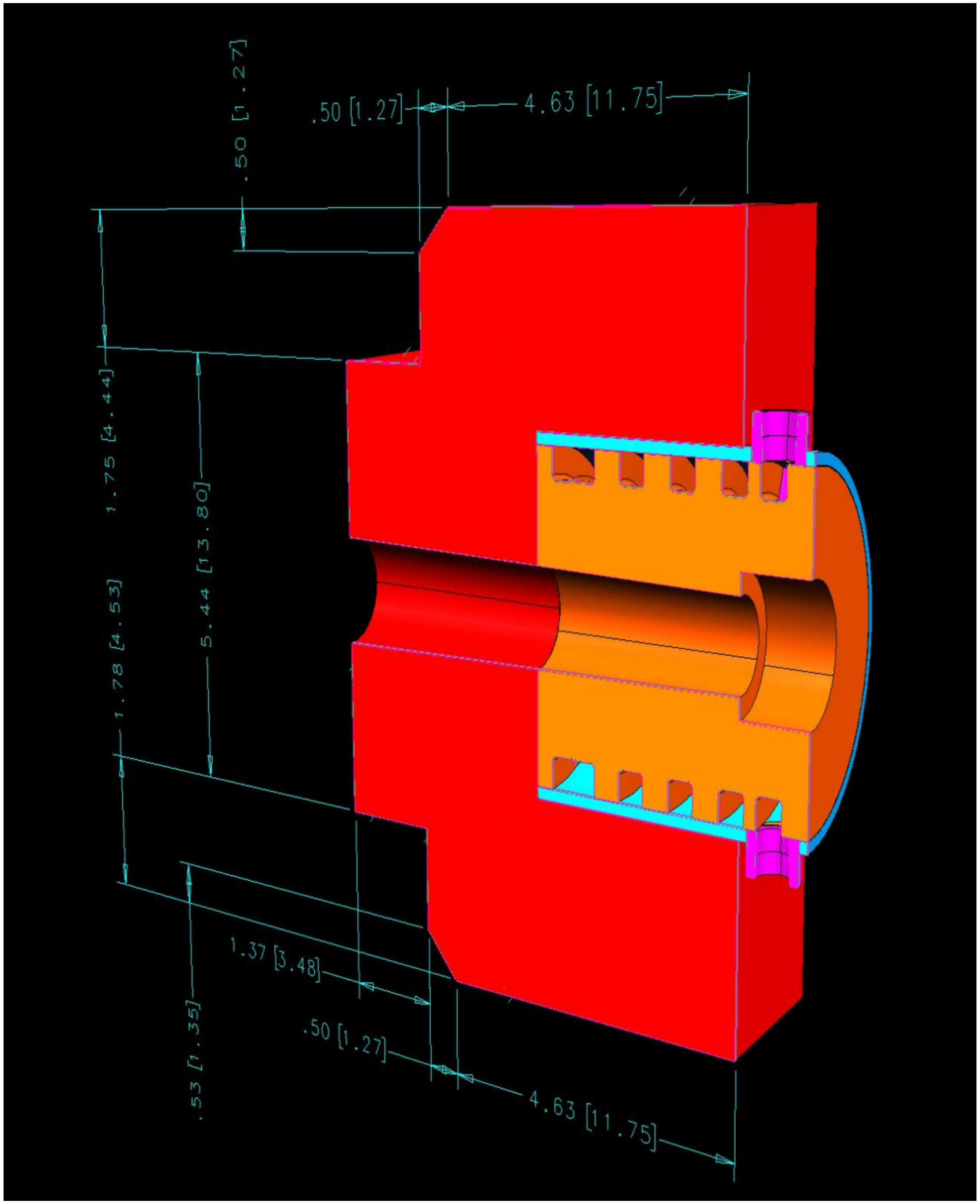


PREX-II collimator

Collimator front face 85cm from target, intercepts electrons >0.78°

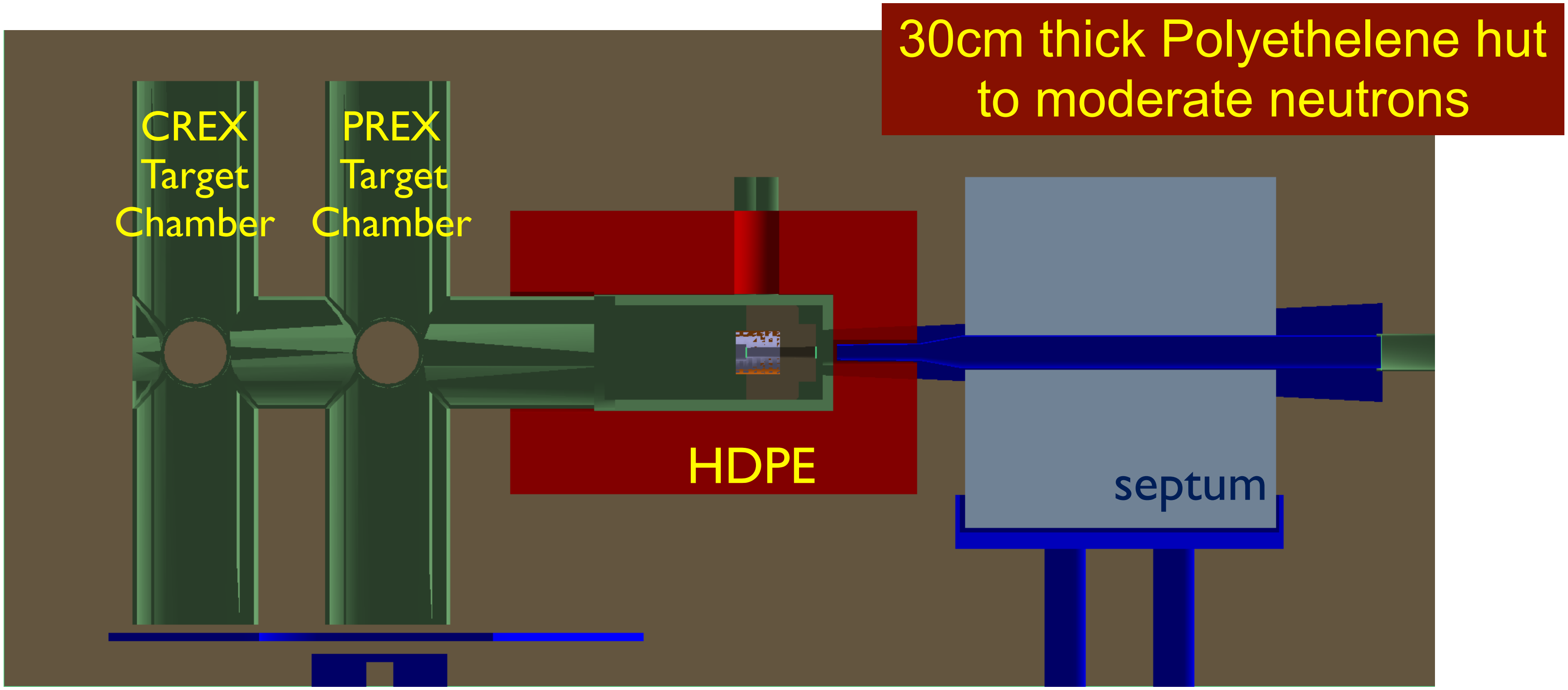
- Inner cylinder 30% Cu-70% W
- Water-cooled slug with Cu sleeve brazed, similar to Qweak collimator
- Outer box Tungsten
- Power deposited: 2.1k@ at 70 μA

PREX-I collimator: >1.27°, ~700W@70 μA, 1850W in Hall



PREX-II: Shielding Strategy

Tungsten collimator down to 0.8° so whatever gets past the **plug** gets to the **dump**



Maximize **solid angle** coverage of collimator by HDPE

Also need improved shielding of septum fringe field at the beampipe

Radiation: similar to HAPPEX-II

"FULL HALL DETECTOR"	PREX-I	PREX-II	PREX-II / PREX-I
Neutron E <0.1MeV	3.4E+10	1.0E+10	29%
Neutron 1 MeV < E < 10 MeV	1.4E+10	1.9E+09	13%
Neutron E>10MeV	2.3E+08	4.4E+07	19%

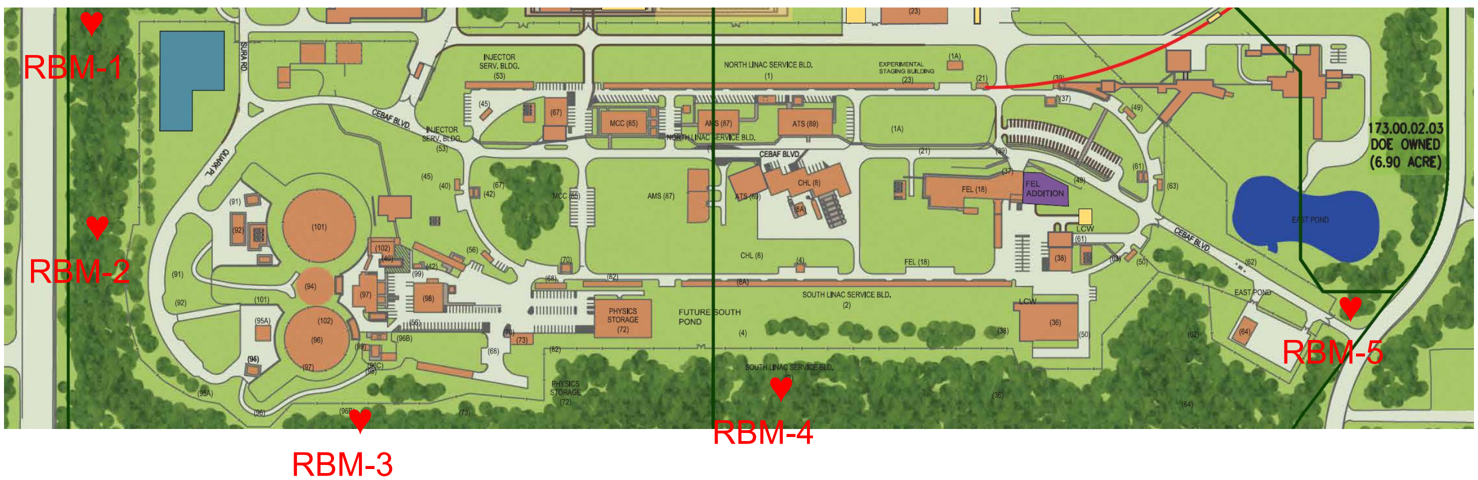
Overall, dangerous neutron flux is down by order of magnitude

At HRS power supplies, flux density is similar to HAPPEX-II

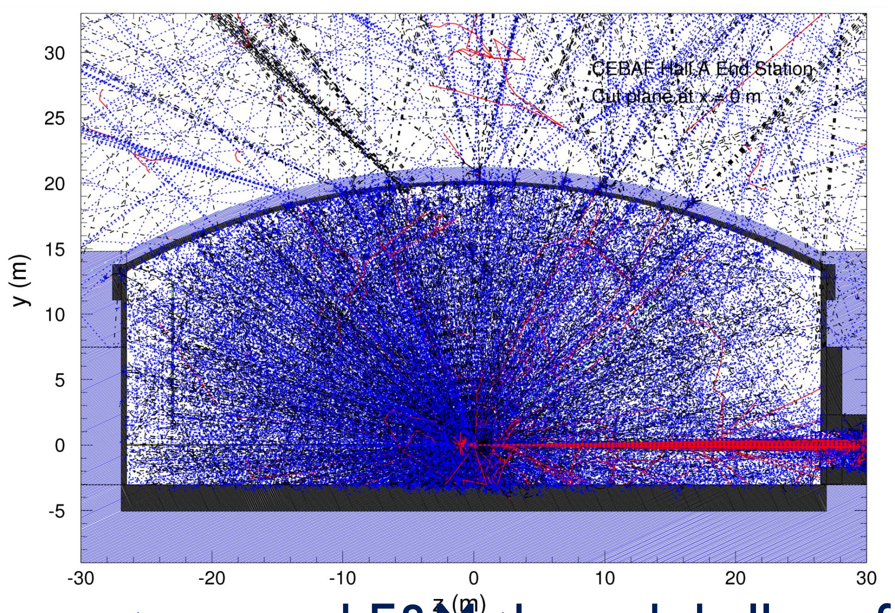
HRS Power Supplies	PREX-II	PREX-I	HAPPEX-II	PREX-II / HAPPEX-II
EM E > 10 MeV	2.5E+07	2.8E+08	2.5E+07	100%
Neutron 1 MeV < E < 10 MeV	1.8E+06	8.9E+06	1.4E+06	130%

Site Boundary

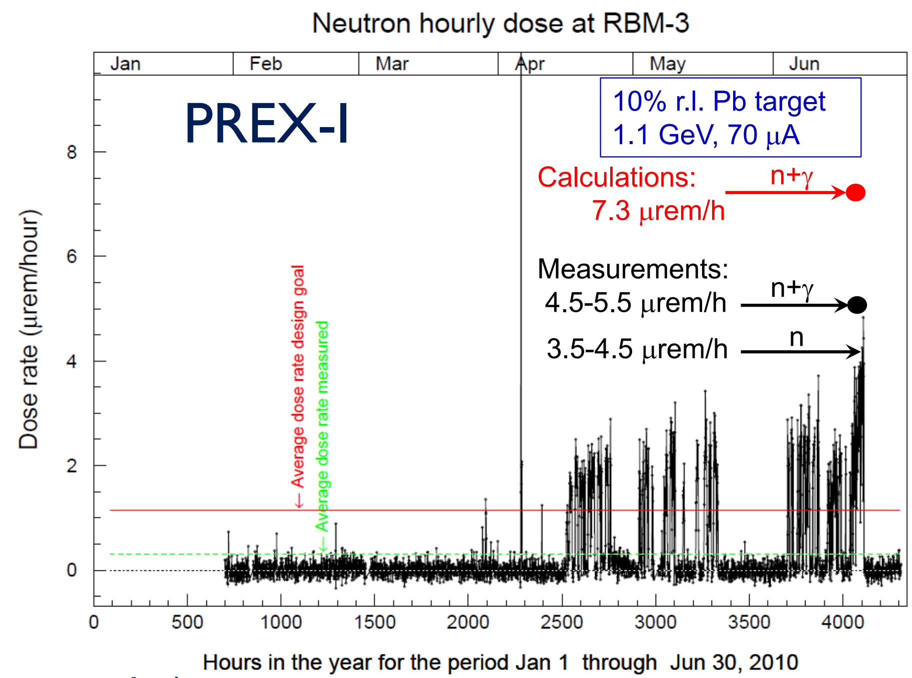
CEBAF Area Map



Estimate: PREX-2 will exceed JLab administrative limits by 50%



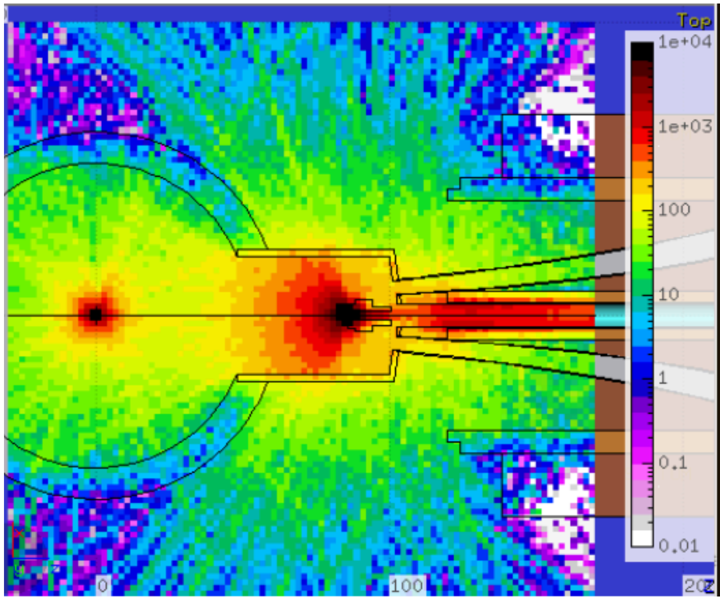
neutrons and E&M through hall roof

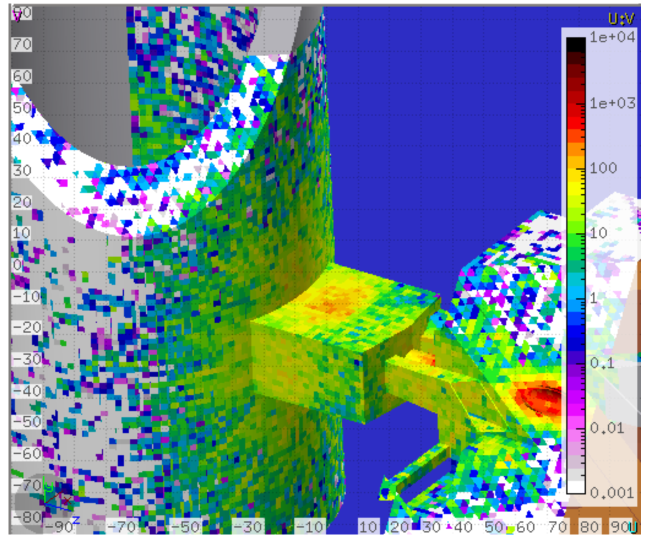


(Pavel Degtiarenko)

Activation

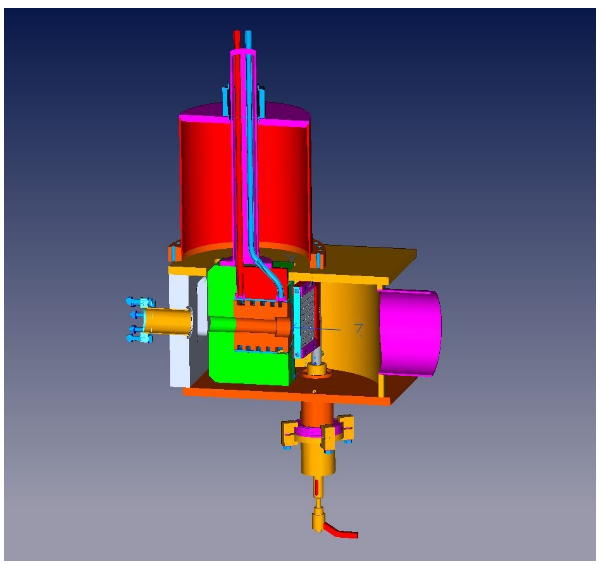
Simulation to guide de-installation planning (Lorenzo Zana)

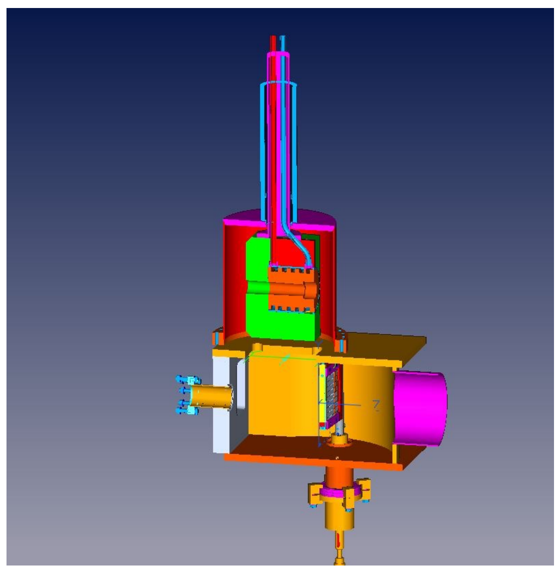




Sieve Box + collimator
(1 month decay, 28 days at 70 uA)

Design to minimize exposure in de-installation





Shielded housing for collimator:
- hot bore is covered
- quick removal

Schedule

Startup after the upgrade has been difficult to produce physics

- various maintenance, hardware issues
- cryogenic plant problems
- some challenges with the new C100 cavities

The order of experiments remains the same, but until recently nothing was completed

Next opening, expected to be Spring 2018.

- Requires a fast installation, over winter break.
- One possibility low-energy experiments sometimes run alone in summer

Readiness Review, June 1-2

- design concept
- may require follow-up reviews

snippet from slide (M.Poelker @ APS)

- PREx-II and its cousin, CREx, have requirements similar to QWeak-I. CEBAF can support these experiments without modification.

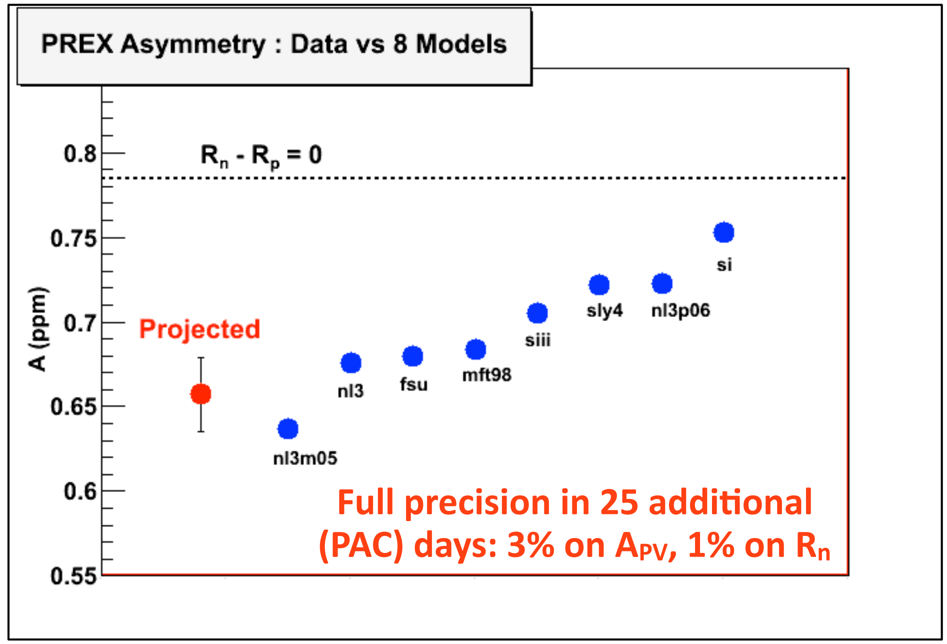
Summary

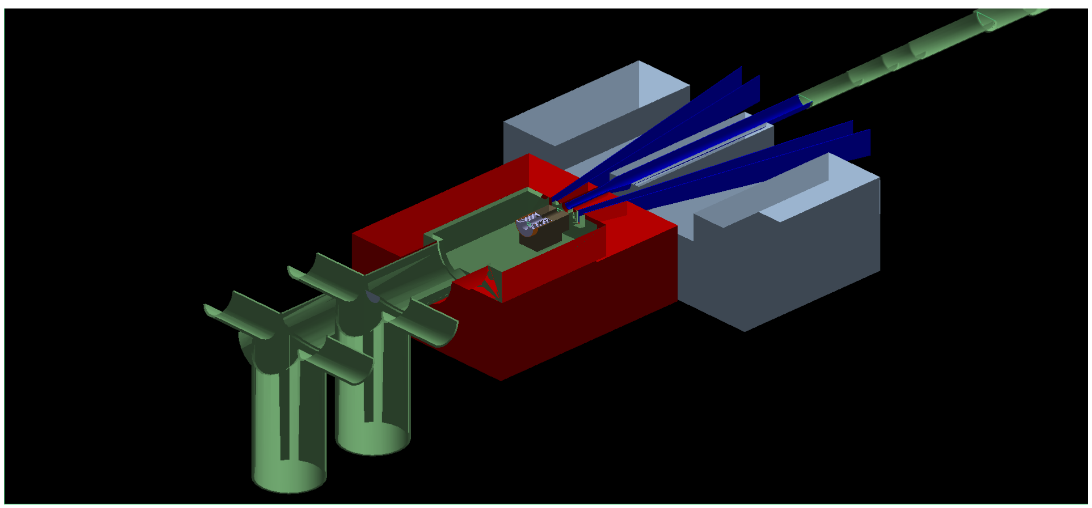
Neutron skin studies at JLab will provide a crucial benchmark for the understanding of nuclear structure

Many experimental questions have been answered in the first run

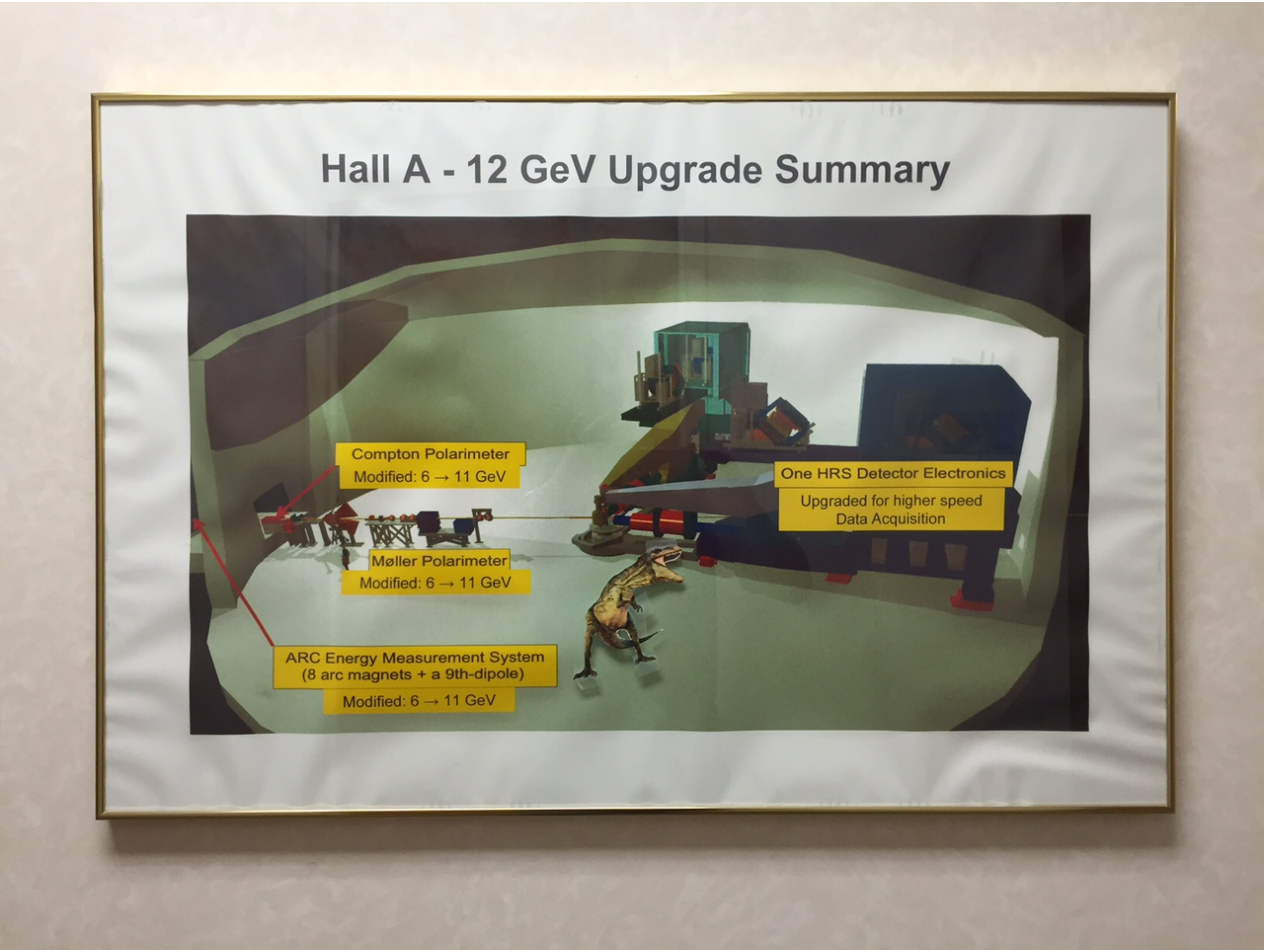
- Lead sandwich target
- Precision polarimetry at 1 GeV
- HRS optics optimization
- Source performance
- Detectors
- Beam Corrections
- Transverse Asymmetry

Primary technical issues for a full run have been addressed



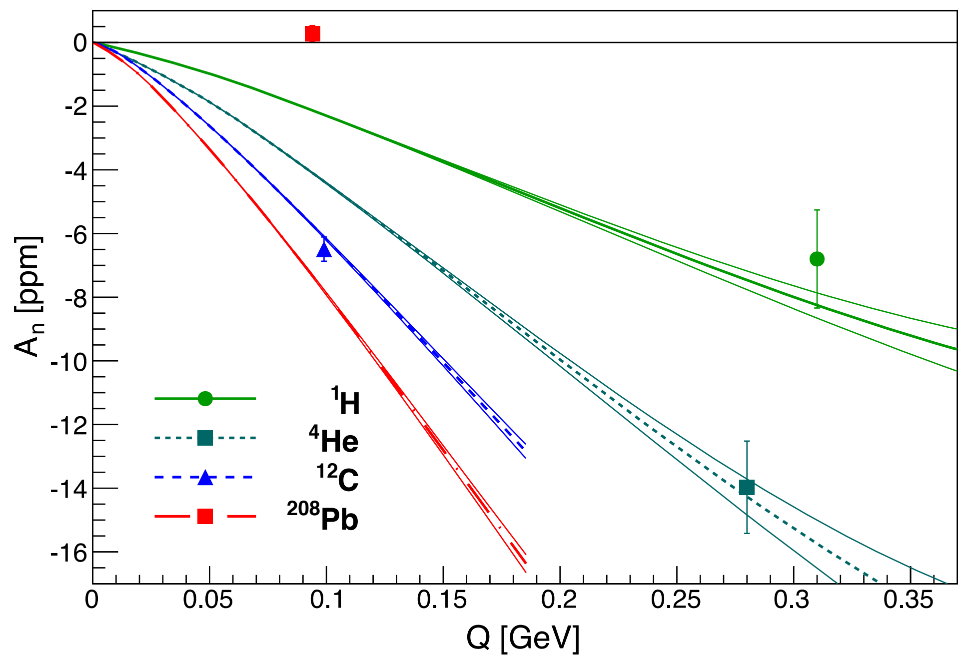


Accelerator upgrade is nearly (officially) complete, physics has returned to JLab, and the lab is moving forward with Spring 2018 now considered likely


Hall A - 12 GeV Upgrade Summary
Compton Polarimeter
Modified: 6 → 11 GeV
One HRS Detector Electronics
Upgraded for higher speed
Data Acquisition
Møller Polarimeter
Modified: 6 → 11 GeV
ARC Energy Measurement System
(8 arc magnets + a 9th-dipole)
Modified: 6 → 11 GeV

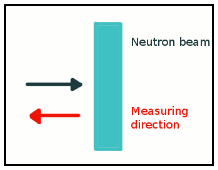
Transverse Asymmetry

- Asymmetries are highly suppressed, few ppm for $Q^2 \sim 10^{-2}\ \mathrm{GeV}^2$



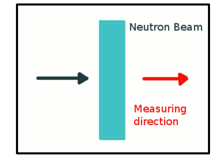
- Dispersion calculations: agreement with low Z nuclei
- ^{208}Pb is significantly off - Coulomb distortions?

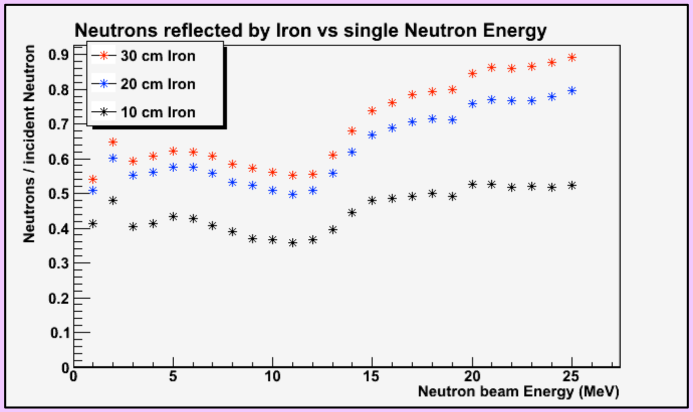
How Neutrons Behave



Reflection

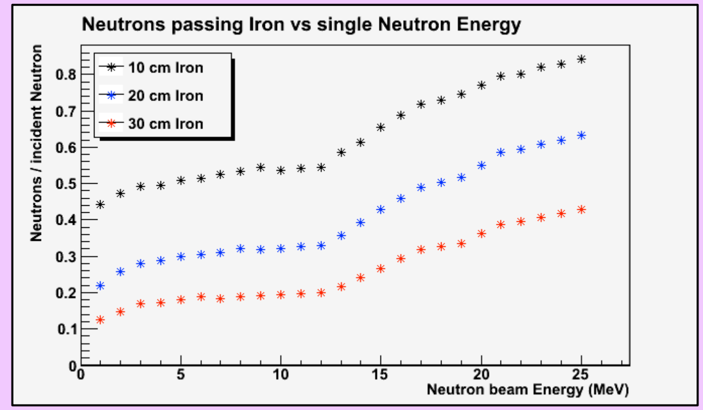
Transmission

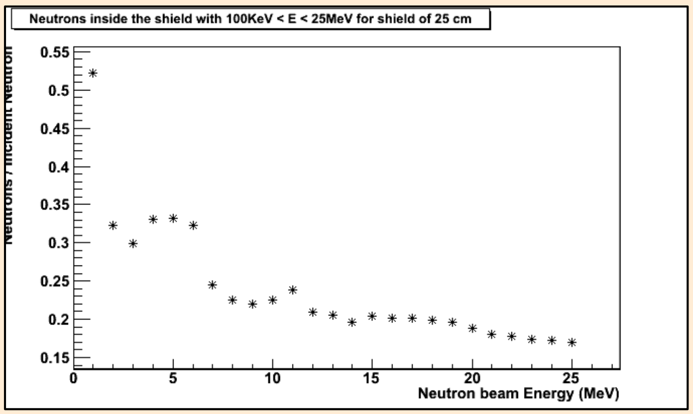




Iron

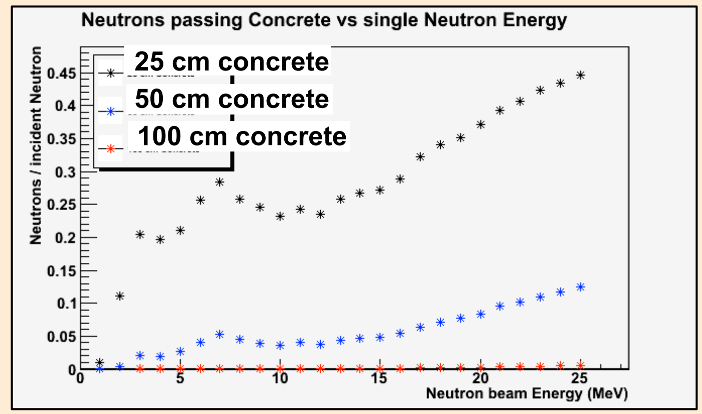
high reflection, not efficient at stopping

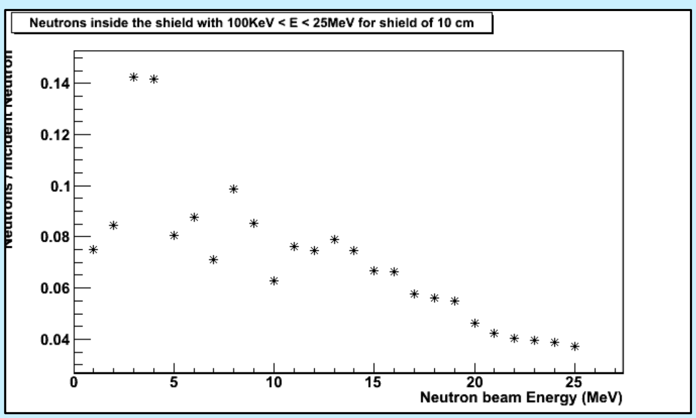




Concrete

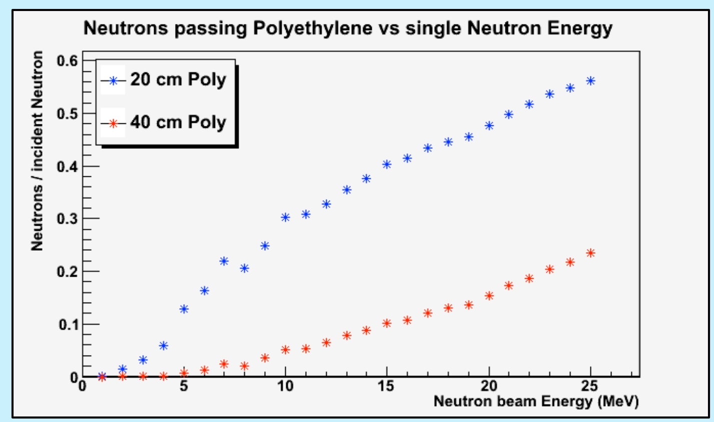
30% reflection, 0.5m to block





HD Polyethylene

low reflection, 30cm blocks well

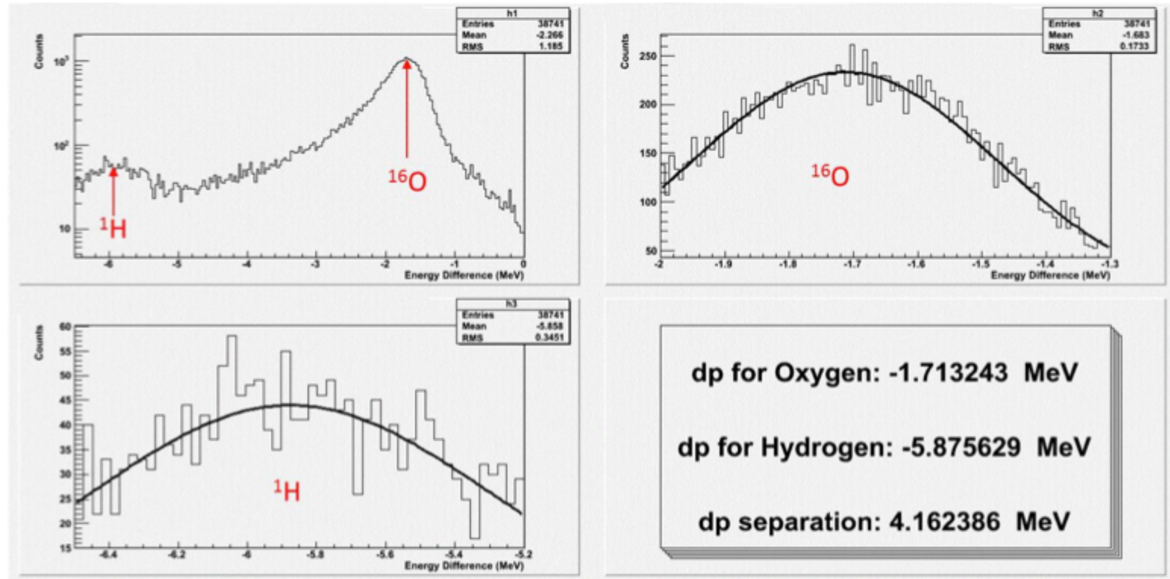


Optics

Pointing Calibration

- **Water Cell**
  - 1% relative measurement of Q^2
  - **H peak on O radiative tail**

Separate target mover for repeated measurement



GEMs / High-rate tracking

reuse previous mounting concept? chambers, readout…

Spectrometer Optics Configuration

Non-standard optics. Previous PREX optics, but need simulation / analysis ability to tweak