Calcium Radius EXperiment (CREX)

Analysis Update

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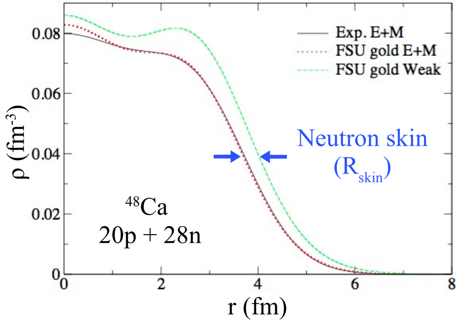
(On behalf of CREX Collaboration)

Outline

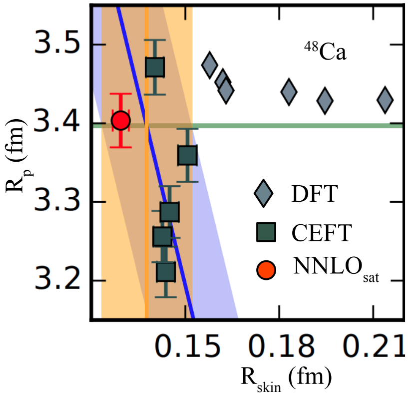
- Introduction
- The experiment
- Recent analysis updates
- Summary

What are we looking for?

PRC **92**, 014313 (2015)



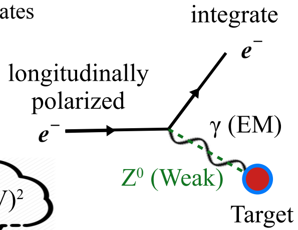
Nature Physics 12, 186 -190 (2016)



- *Ab initio* calculations smaller R_{skin} than DFT estimations
- Different DFT models are not in close agreement with each other
- CREX provides exp. data point crosschecking these theories

Parity-Violating Electron Scattering (PVeS)

- Elastic scattering of longitudinally polarized electrons from unpolarized (isotopically pure) targets
- Asymmetry of the detected rates between the beam's opposite helicity states



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \quad \text{where} \quad \sigma \sim \left|\mathcal{M}_\gamma + \mathcal{M}_{Z^0}\right|^2$$

$$A_{PV} \approx \frac{2\,\mathcal{M}_\gamma (\mathcal{M}_{Z^0})^*}{|\mathcal{M}_\gamma|^2}$$

0.031 (GeV)^2

(91 GeV)^2

For $Q^2 \ll (M_{Z^0})^2$

~10^{-5}

$$A_{PV} \approx \frac{G_F Q^2 |Q_W|}{4\pi\alpha\sqrt{2}Z} \frac{F_W(Q^2)}{F_{ch}(Q^2)} \sim \left\{ \frac{10^{-4} Q^2}{(GeV/c)^2} \right\}$$

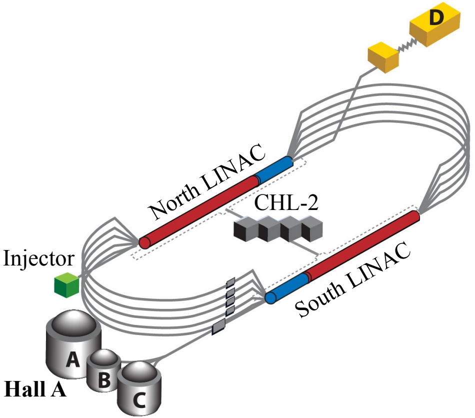
$$|\mathcal{M}_{Z^0}| \sim \frac{1}{(M_{Z^0})^2} \quad \text{and} \quad |\mathcal{M}_\gamma| \sim \frac{1}{Q^2}$$

Tiny asymmetry (A_{PV})

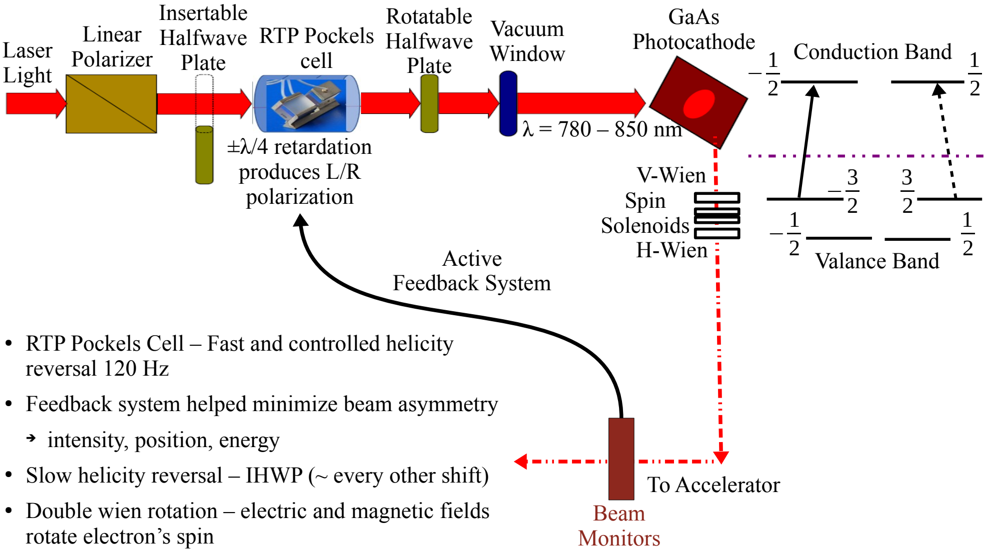
*** Extreme control over systematic uncertainties and background corrections are very important!

CREX Overview

- CREX ran in Hall A from Dec 2019 to Sep 2020
- ~4 months interruption due to pandemic
- Beam energy → ~ 2.181 GeV
- Beam current → ~ 150 uA
- Scattering angle → ~ 5^0
- Q-square → 0.031 $(GeV/c)^2$
- Rate → ~ 28 MHz per arm



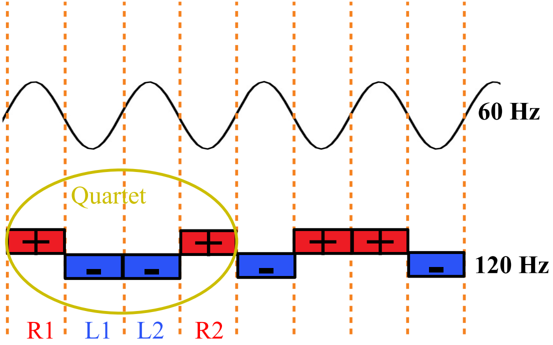
Experimental Components – Polarized Source



- RTP Pockels Cell – Fast and controlled helicity reversal 120 Hz
- Feedback system helped minimize beam asymmetry
  - intensity, position, energy
- Slow helicity reversal – IHWP (~ every other shift)
- Double wien rotation – electric and magnetic fields rotate electron's spin

Integration Technique

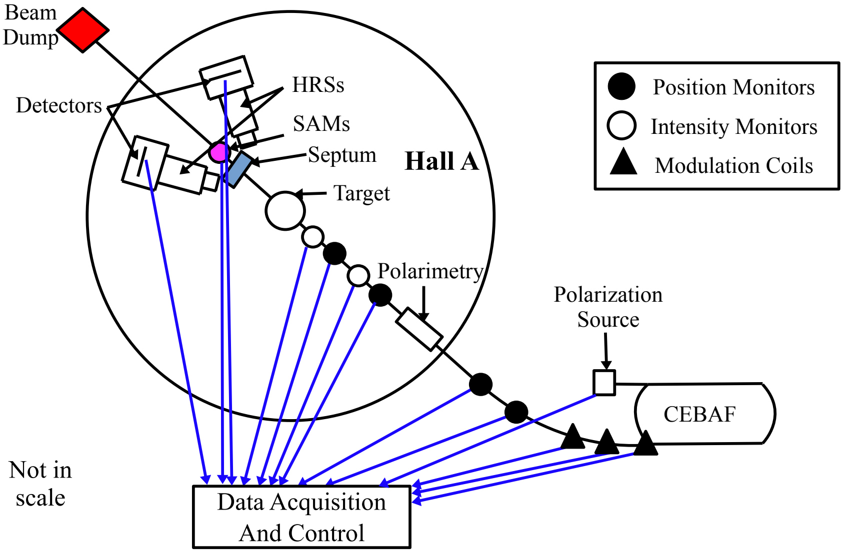
- Very high rates
  - ➔ practically impossible to count individual electrons
  - ➔ DAQ dead-time prevents the individual electron counting
- Integrate detector signal over a helicity window defined by 120 Hz flipping
- Fast helicity reversal cancels noise from:
  - ➔ target density fluctuations
  - ➔ beam current fluctuations
- Pattern combination cancels 60 Hz noise associated with electronics power



Pseudo-random helicity patterns

$$Asym = \frac{\sum_{i=1}^{2} R_i - \sum_{i=1}^{2} L_i}{\sum_{i=1}^{2} R_i + \sum_{i=1}^{2} L_i}$$

Hall A Beamline



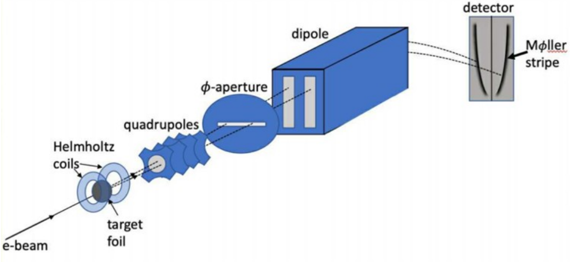
Polarimetry Moller

Moller polarimetry:

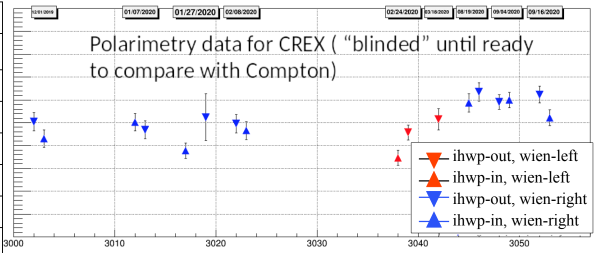
- Low current, invasive measurement
- Moller scattering of beam electrons from a magnetized Fe foil

$$A_{moller} = \langle A_{ZZ} \rangle P_t P_b$$

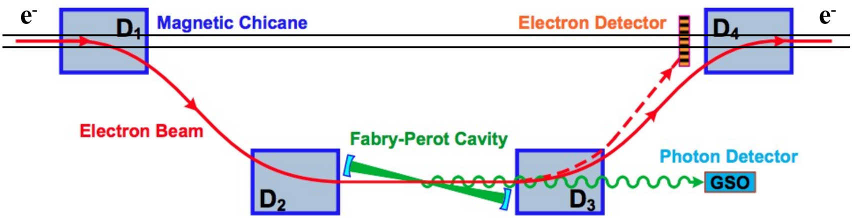
- 3-4 T field gives saturated magnetization perp. to the foil
- Consistent results throughout the run



Source	Error (%)
A_{zz}	0.175
Foil polarization	0.571
Current bleed-through	0.09
Laser polarization	0.07
High current extrapolation	0.51
Other	0.31
Total Systematic	0.85



Polarimetry Compton

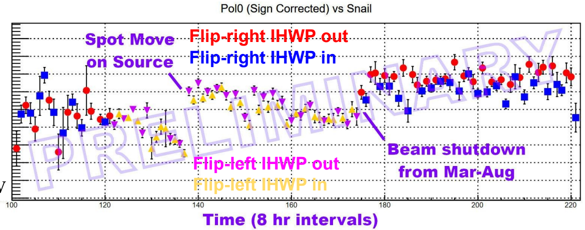


Compton Polarimetry:

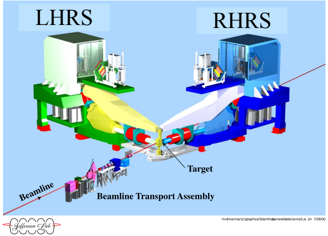
- Non-invasive, *in situ* measurement
- Compton scattering of beam electrons from polarized photons

$$A_{meas} = \langle A_s \rangle P_\gamma P_b$$

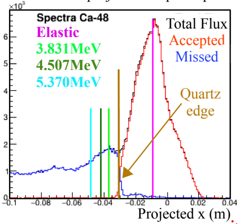
- Systematic error is still under review



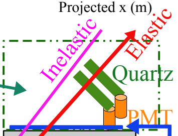
HRSs and Acceptance Collimators

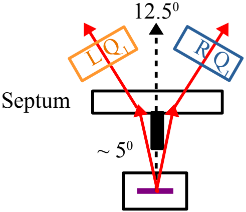


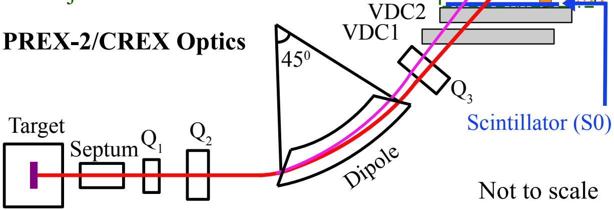
VDC tracks projected to quartz plane



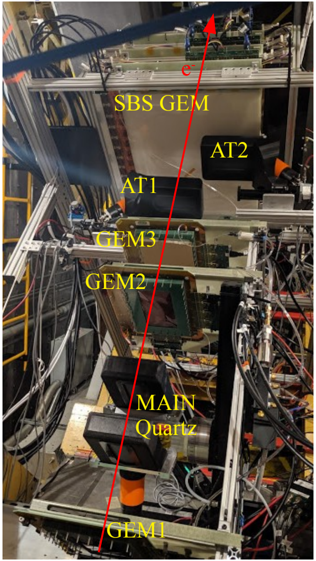
Good hardware momentum resolution and precise detector alignment helped geometrically reject inelastic events

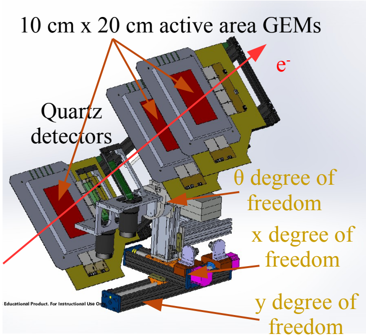


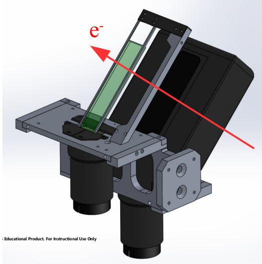




Experimental Components – Focal Plane Detectors







Quartz dimension:
16 cm × 3.5 cm × 0.5 cm

- Integrating detectors use rad-hard, Spectrosil 2000 fused-silica
- Downstream quartz always connected in counting mode for efficient alignment check
- Non-linearity of detector response was tested on the bench and with beam during the experiment
- GEMs, used during PREX-2 – could handle orders of magnitude higher rates (~MHz/cm^2) than VDCs (10 kHz/cm^2)

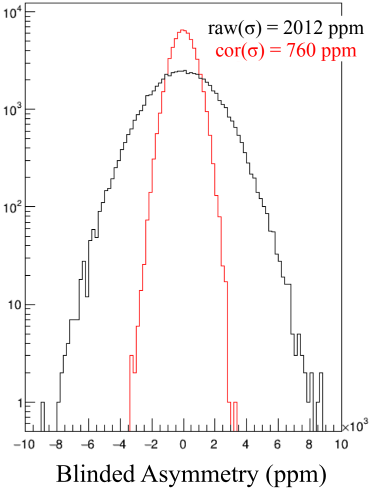
Beam Fluctuation Correction

- Beam jitter noise can be several times greater than counting statistics
- One of the major sources of systematic error
- Detector asymmetry (A_{det}) needs proper correction for beam fluctuations

$$A_{cor} = A_{det} - A_q - \underbrace{\left(\Sigma_i \alpha_i \Delta M_i + \alpha_E A_E \right)}_{(A_{false})}$$

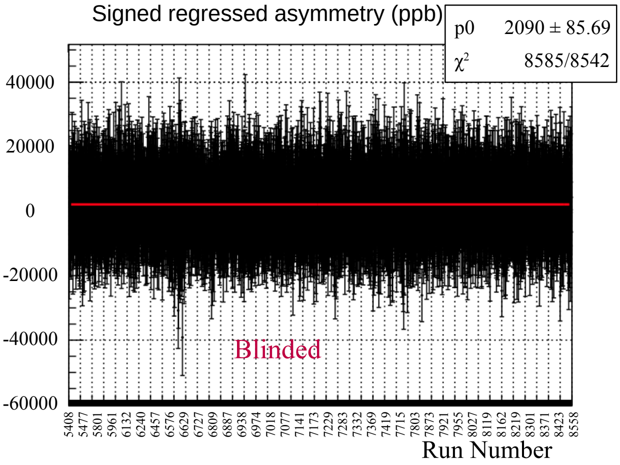
- Beam intensity asymmetry (A_q) controlled using A_q feedback system
- Multiple techniques to calibrated correction slopes (α_i):
  - Linear (multivariate) regression → uses natural beam motion
  - Beam modulation → uses artificial/driven beam motion
  - Lagrange multiplier → hybrid of regression and beam modulation

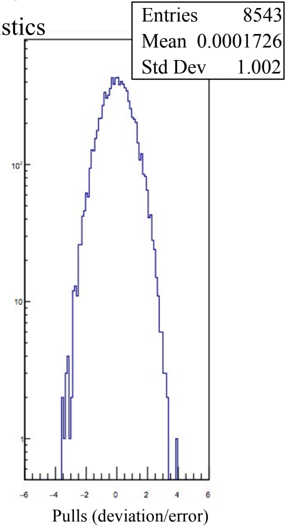
A typical production run



Average Over Entire CREX (Blinded)

- Blinded asymmetry after beam fluctuation correction using regression
- Noisy data points around run 6629 are single arm runs → low statistics





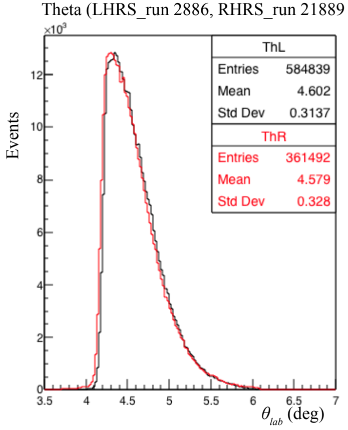
Q^2 Measurements

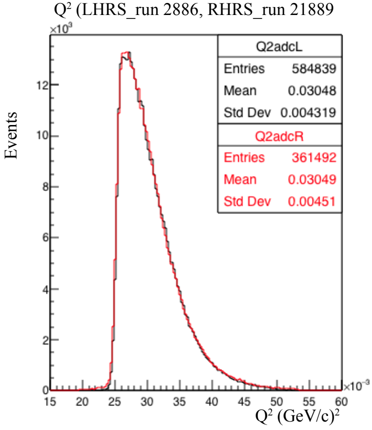
$Q^2 = 2EE'(1 - \cos\theta)$

E, E' = Energy before, after scattering

θ = Scattering angle

- Similar Q^2 values for both HRSs
- Measurements were performed periodically
- Consistent measurement throughout the runs





Summary

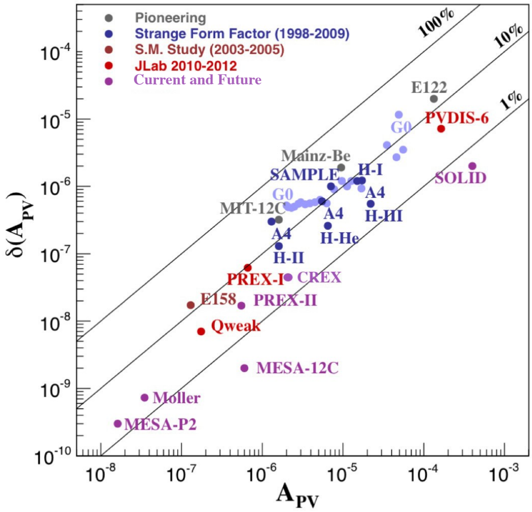
- CREX successfully completed data taking
- Asymmetry and beam correction analysis is near complete
- Polarimetry measurement is near complete
- Inelastic background analysis is close to complete
- Planning to unblind in the Fall DNP meeting
- Publication will be out in a few months after unblinding

Backup

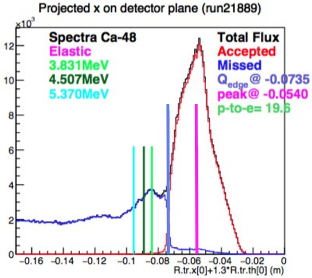
PVeS – Now a Precision Tool

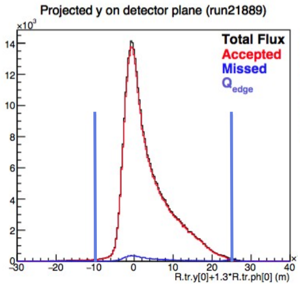
- E122 – 1st PVeS exp. (late 70's) at SLAC
- JLab program launched in 90's
- E158 – measured PV in Møller scattering at SLAC (2007)
- Significant improvement in experimental components over time:
  - ➔ photocathodes
  - ➔ polarimetry
  - ➔ cryotargets
  - ➔ beam stability to nanometer level
  - ➔ low noise electronics
  - ➔ radiation-hard detectors

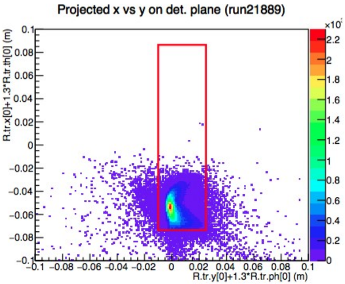
Summary of PVeS Experiments



Experimental Components – Detector Alignment







Measurement at a Single Q^2