


Calcium Radius Experiment (CREX)

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(On behalf of the CREX collaboration)

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Introduction

CREX At a Glance

- High-precision Measurement of neutron skin of ^{48}Ca using parity violating electron scattering.
- Beam Energy ~ 2.2 GeV
  Beam Current ~ 150 uA
  Average Q^2 ~ 0.0297 GeV^2
  Target ~ 90% ^{48}Ca
  Lab Scattering Angle ~ 5 degrees
- Informs ab initio models and poorly constrained iso-vector terms in nuclear DFT

Coulomb Distortions
And Radiative
Corrections

Asymmetry
Q^2 and acceptance

Weak form Factor

Account for
spin-orbit
currents

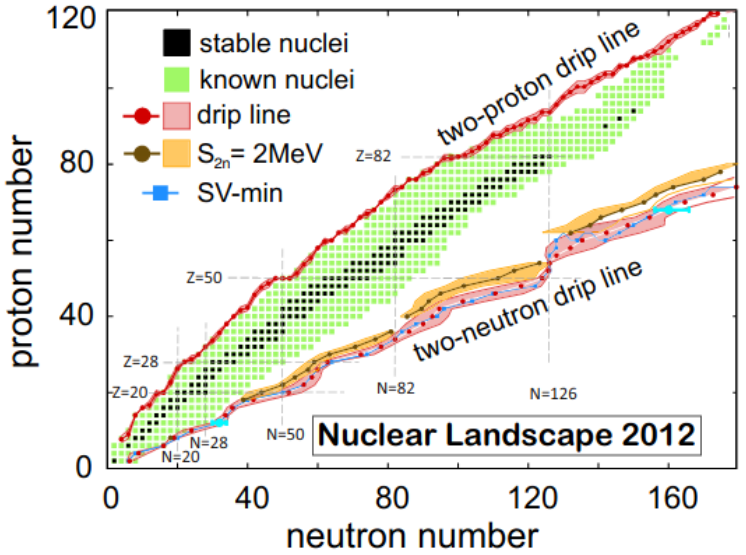
Assumption about
surface thickness of
weak charge density

Neutron Skin

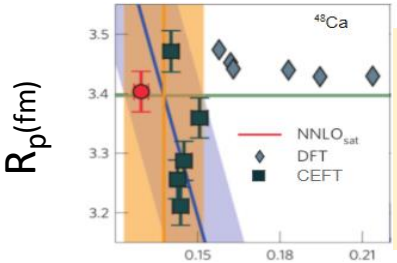
Weak skin

Poorly understood nuclear landscape and forces at play

The limits of the nuclear landscape, J. Erler, N. Birge, M. Kortelainen, W. Nazarewicz, E. Olsen, A.M. Perhac, M. Stoitsov, Nature (2012)

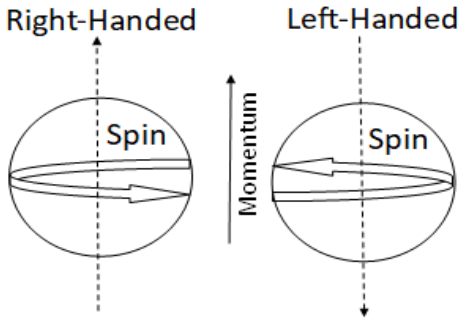


- A map of all possible nuclei with bounds set by the driplines.
- Ab initio calculations – Low to medium mass
- Density functional theory - Large mass region and neutron stars



^{48}Ca
At Junction
Neutron-rich
Doubly Magic
Natural
abundance

Nature Physics
12, 186 (2016)



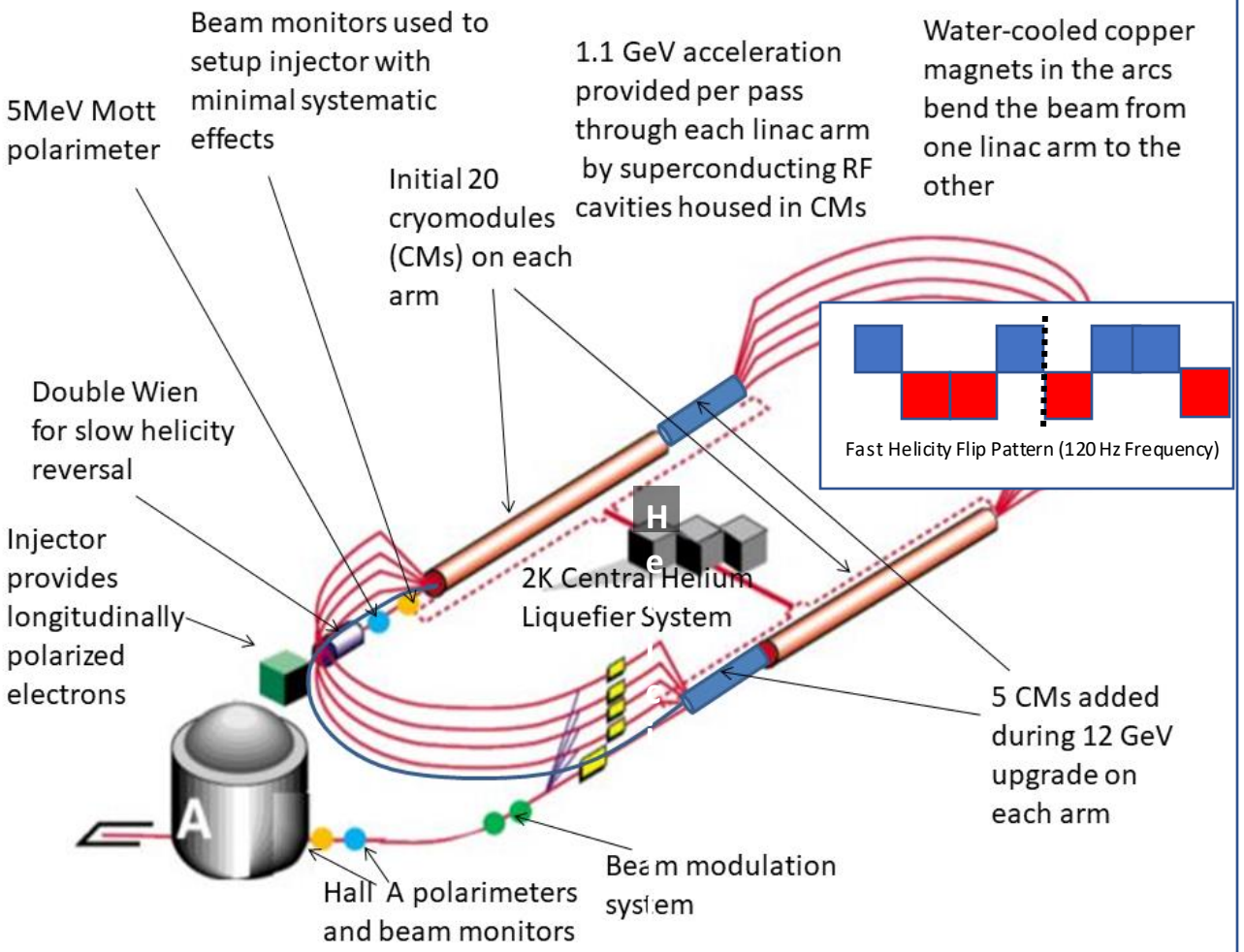
Opposite helicities
Created based on source image from D. J. Griffiths. Introduction to elementary particles. Wiley, New York, 1987.

Parity Violating Electron Scattering

- Scatter longitudinally polarized electron beam from nuclei in unpolarized target nuclei elastically and measure parity-violating asymmetry
- Relatively clean method to study nuclear structure in terms of theoretical uncertainties compared to strong probe measurements.

$$A_{pv} = \frac{d\sigma/d\Omega_+ - d\sigma/d\Omega_-}{d\sigma/d\Omega_+ + d\sigma/d\Omega_-} \approx \frac{G_F Q^2 |Q_W|}{4\pi\alpha\sqrt{2}Z} \frac{F_W(Q^2)}{F_{ch}(Q^2)}$$

Facility and Apparatus



Continuous Electron Beam Accelerator Facility

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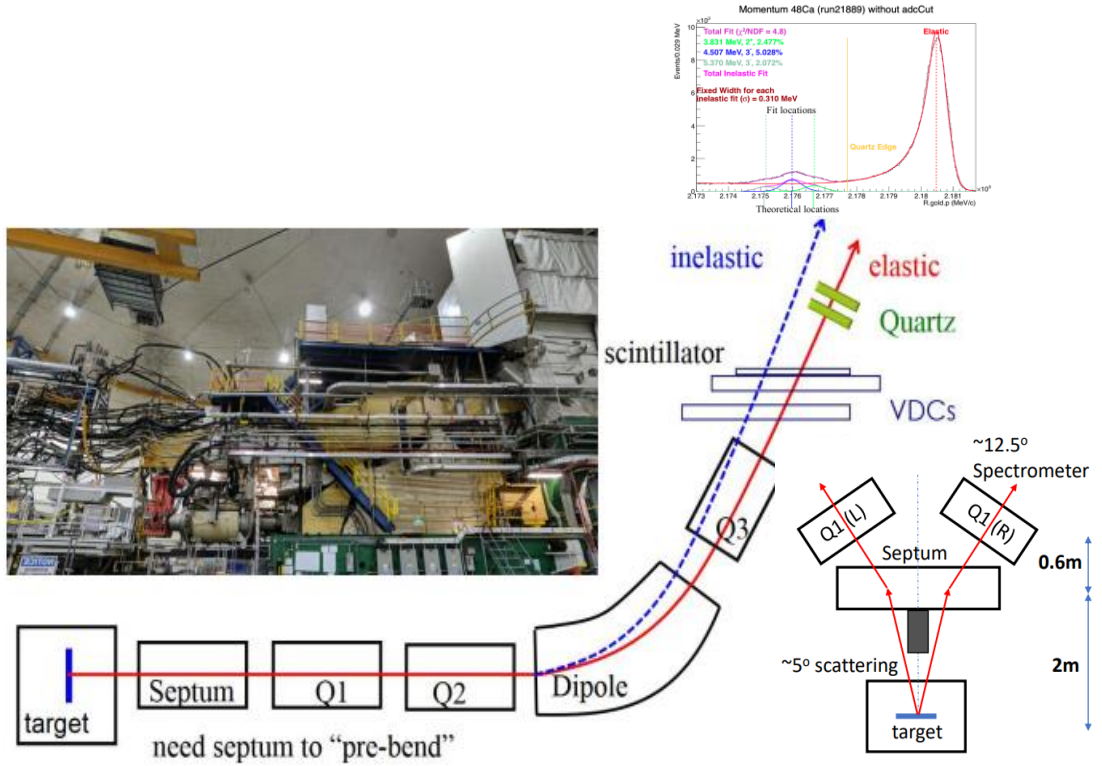


CREX schematic

Reprinted with the full permission from C. Gal. New precision measurements of the neutral weak form factor of 208Pb. In 2020 Fall Meeting of the APS Division of Nuclear Physics. American Physical Society, Oct. 2020. https://prex.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=473.

Analysis

Measure raw asymmetry from charge-normalized detector yields

Apply helicity-correlated beam property corrections to get corrected asymmetry

Apply background and polarization corrections. Account for acceptance.

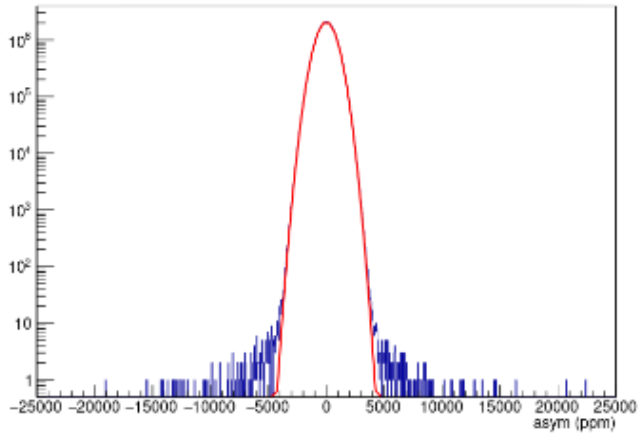
Add in blinding factor

Corrections	Absolute[ppb]	Relative[%]
Polarization	382 +/- 13	14.4 +/- 0.5
Beam Asymmetry	68 +/- 7	2.5 +/- 0.3
Charge Correction	112 +/- 1	4.2 +/- 0.0
^{40}Ca impurities	10 +/- 9	0.4 +/- 0.3
3.831 MeV (2^+) inelastic	-35 +/- 19	-1.3 +/- 0.7
4.507 MeV (3^-) inelastic	-0.3 +/- 10	0 +/- 0.4
5.370 MeV (3^-) inelastic	-1.5 +/- 4	-0.1 +/- 0.1
Transverse asymmetry	0 +/- 13	0 +/- 0.5
Spectrometer Re-scattering	0 +/- 0.5	0 +/- 0.0
Detector Non-linearity	0 +/- 6.7	0 +/- 0.2
Acceptance	0 +/- 24	0 +/- 0.9

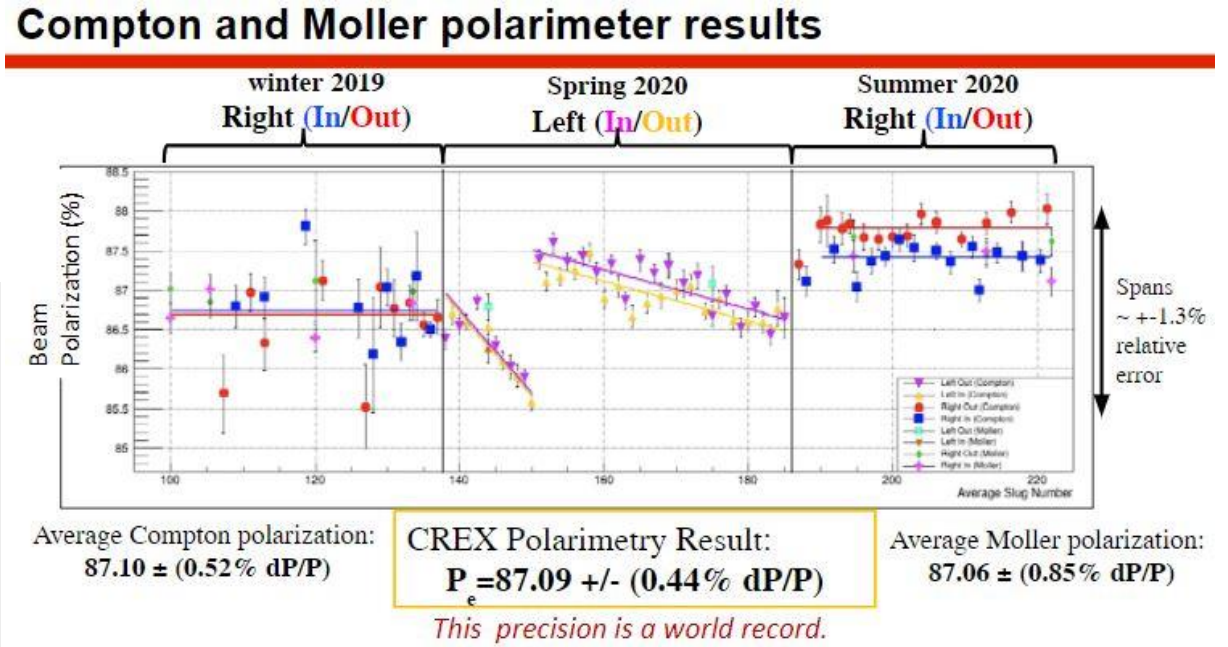
Final Result: A_{PV} = 2658.6 ± 106.07 (stat) ± 39.51 (syst) ppb
Total Uncertainty (Systematic+Statistical) ~ 4.3%

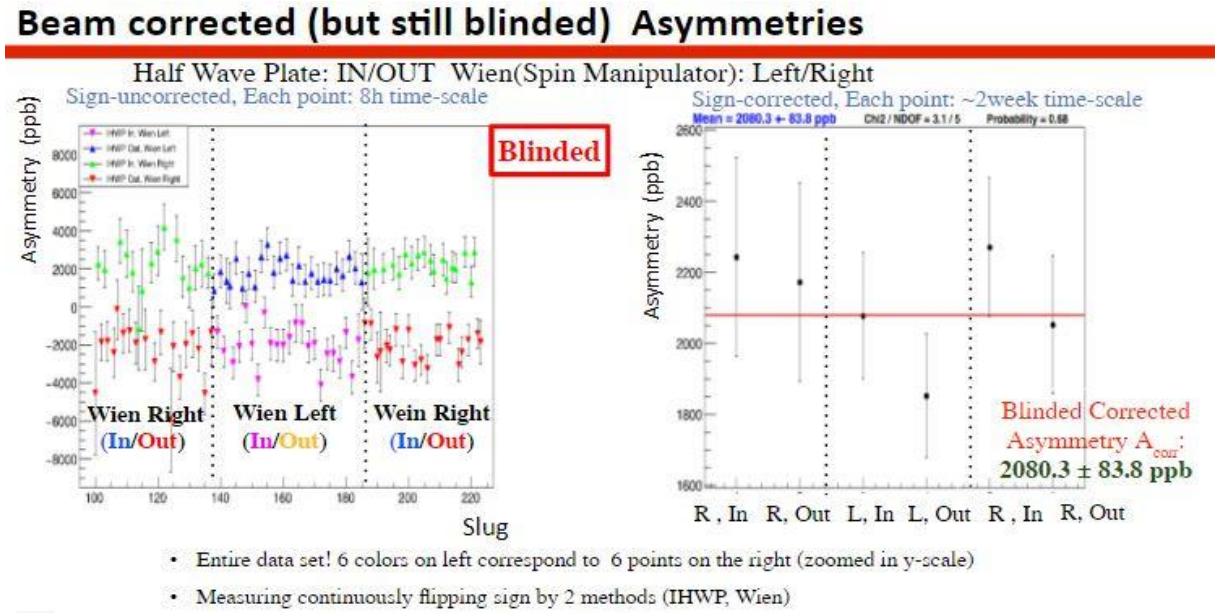
Key Achievements

- Best precision on polarization measurement till date.
- Three independent techniques used for beam corrections (Regression, dithering and lagrange multiplier) that agree across 3-parts of the data set.
- Corrected asymmetry across different timescales demonstrate good statistical behavior and consistency.



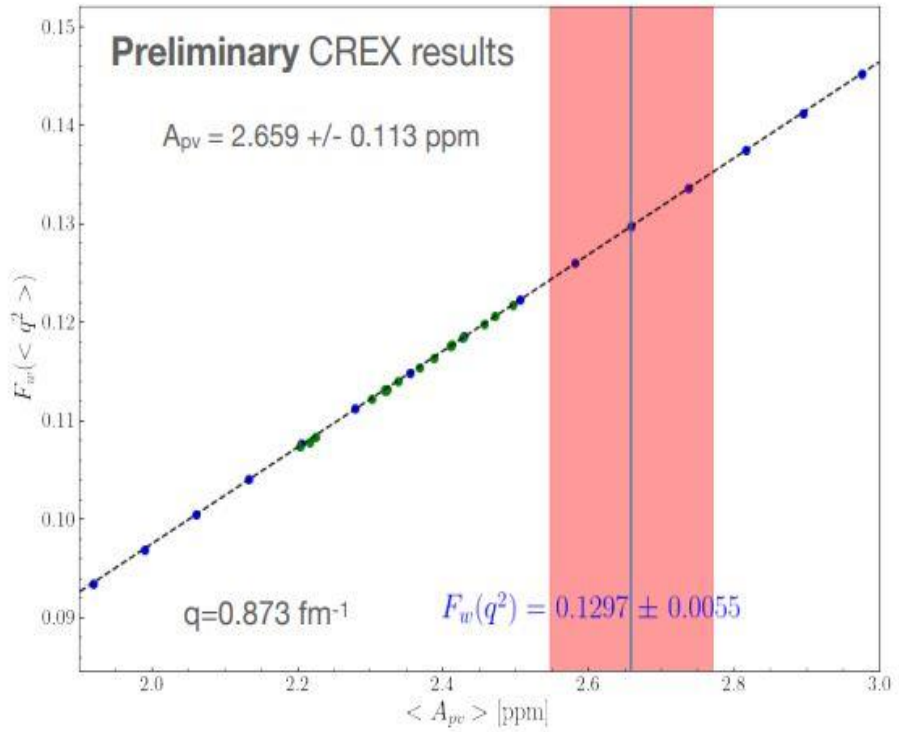
Distribution of multiplet level asymmetries





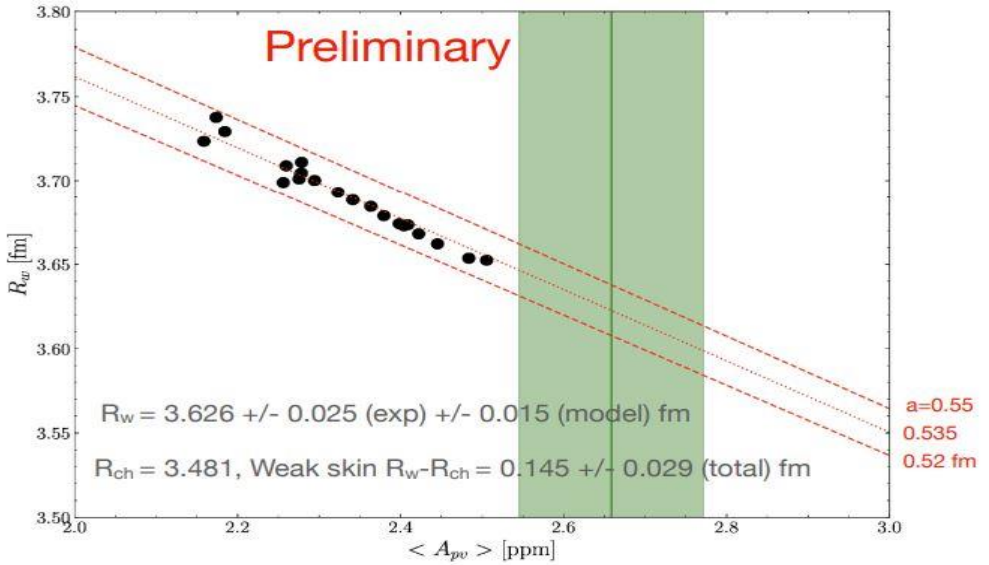
Source: Chandan Ghosh, UMass Amherst

Preliminary Interpretations

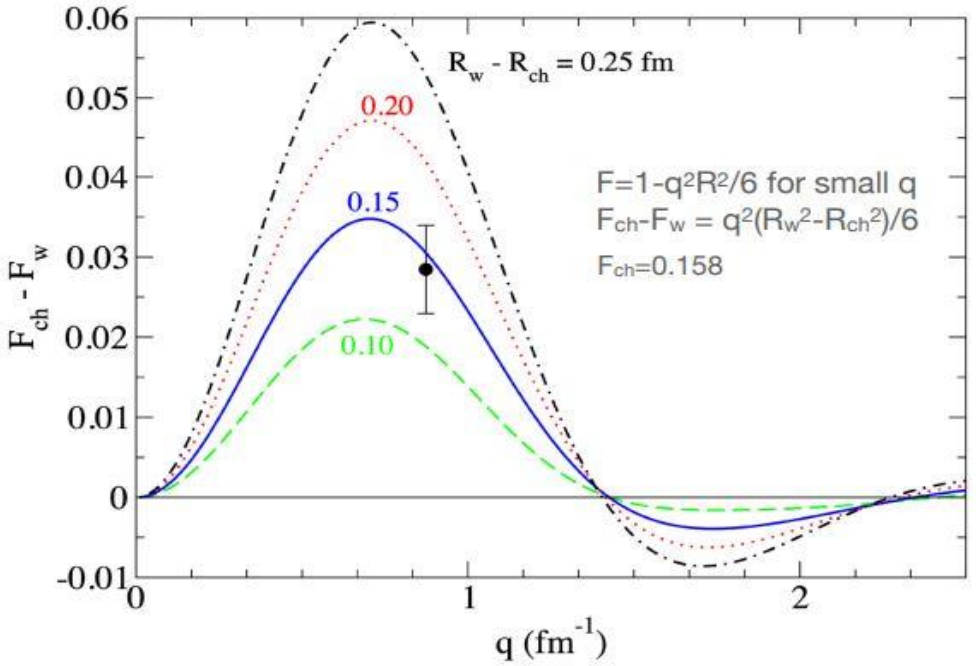


Determination of weak form factor

Source: C. Horowitz, Indiana University



Determination of weak skin



CREX supports models that predict thin weak skin

Conclusion and Future Outlook

CREX Results

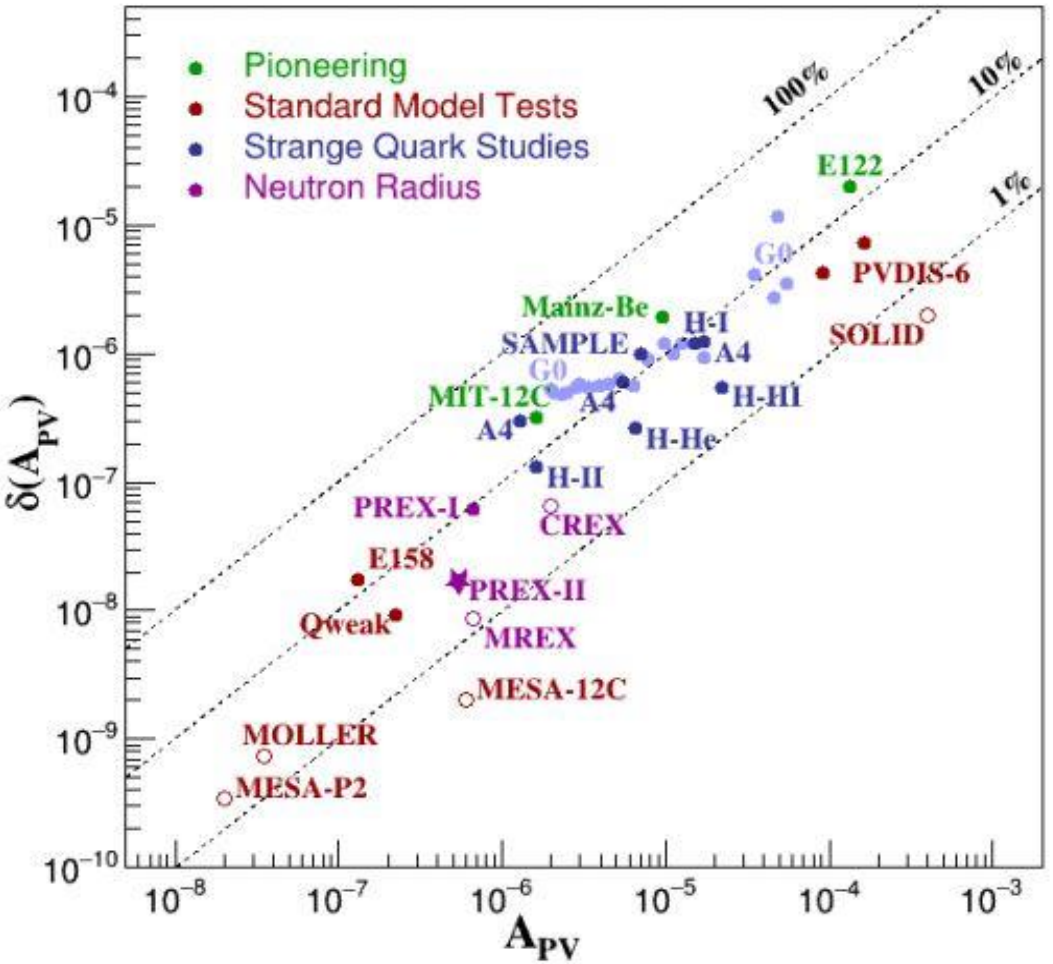
- A_{PV} = 2658.6 ± 106.07 (stat) ± 39.51 (syst) ppb
- F_W ~ 0.1297 ± 0.0055 (Preliminary)
- ΔR_{Wskin} ~ ± 0.029 fm (Preliminary)

With additional future measurements at MREX, the model dependence from surface thickness assumption can be reduced.

CREX is consistent with models predicting thin neutron skin unlike prior sister experiment PREX.

The same models may not be able to explain heavy nuclear region dominated by volume effects and the medium mass region dominated by surface effects. This needs to be confirmed with further theory analysis.

CREX constraint on ab initio calculations still valuable in the medium mass scale.



Currrent and Future Parity Experiments

Reprinted from D. Becker, S. Rahman, · · · , and P2 collaboration. The P2 experiment: A future high-precision measurement of the weak mixing angle at low momentum transfer. Eur. Phys. J. A, 54(11), Nov. 2018. URL https://link.springer.com/article/ 10.1140/epja/i2018-12611-6 and C. Gal. New precision measurements of the neutral weak form factor of 208Pb. In 2020 Fall Meeting of the APS Division of Nuclear Physics. American Physical Society, Oct. 2020. URL https://prex.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=473

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Backup Slides

Thanks to Chandan Ghosh, UMass Amherst

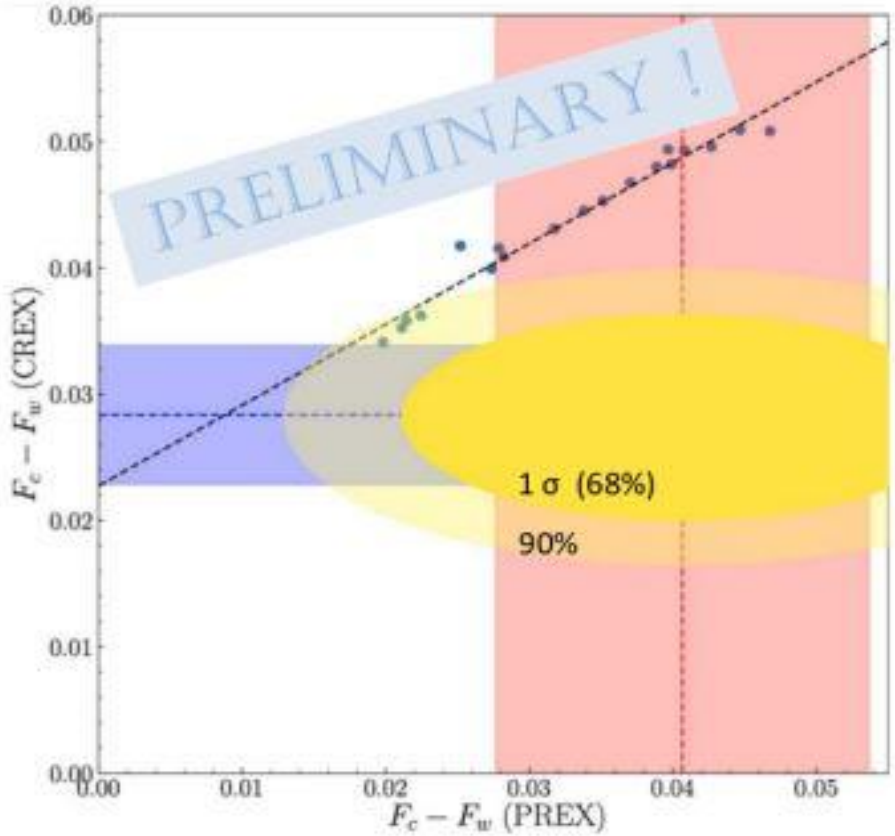
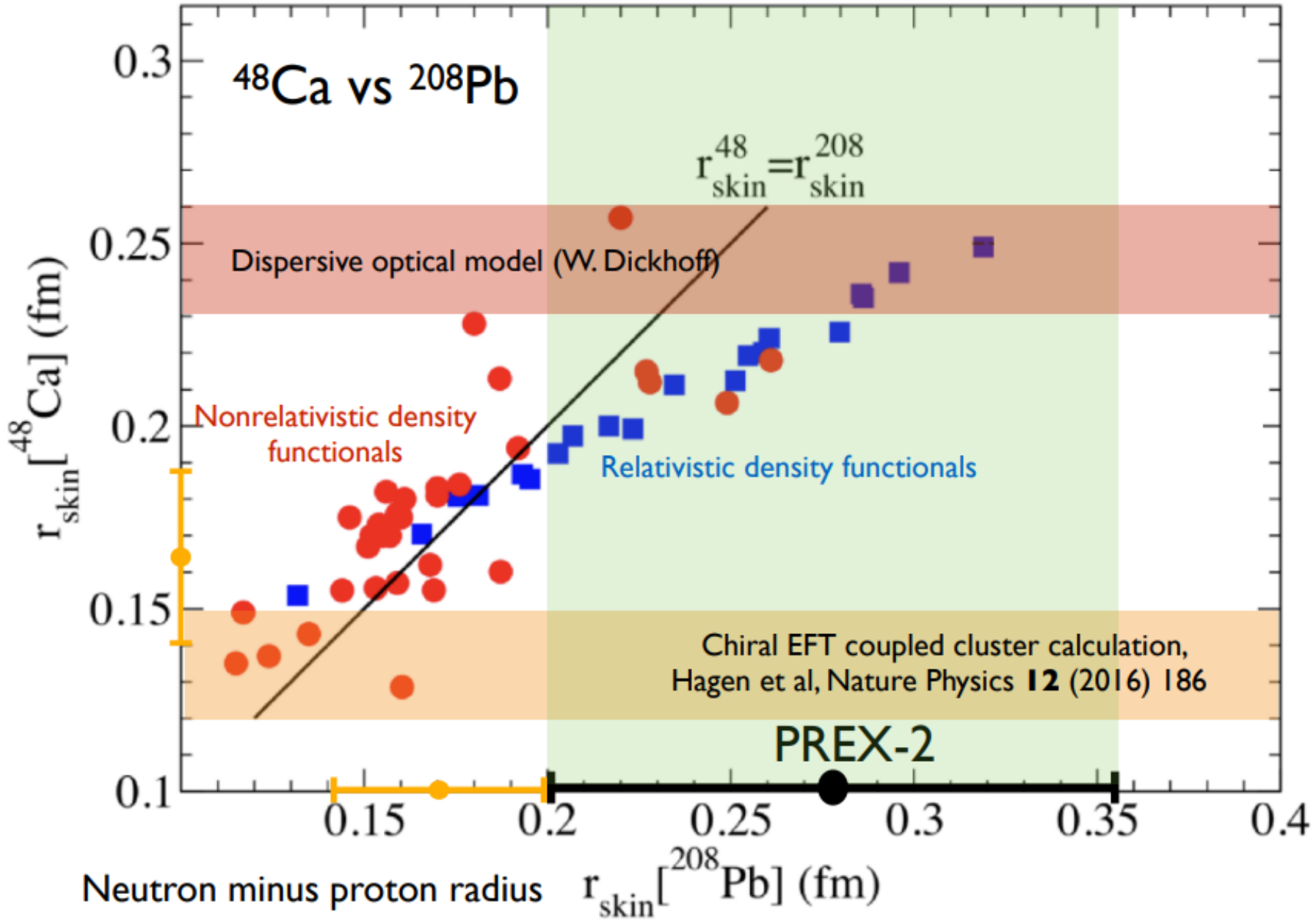
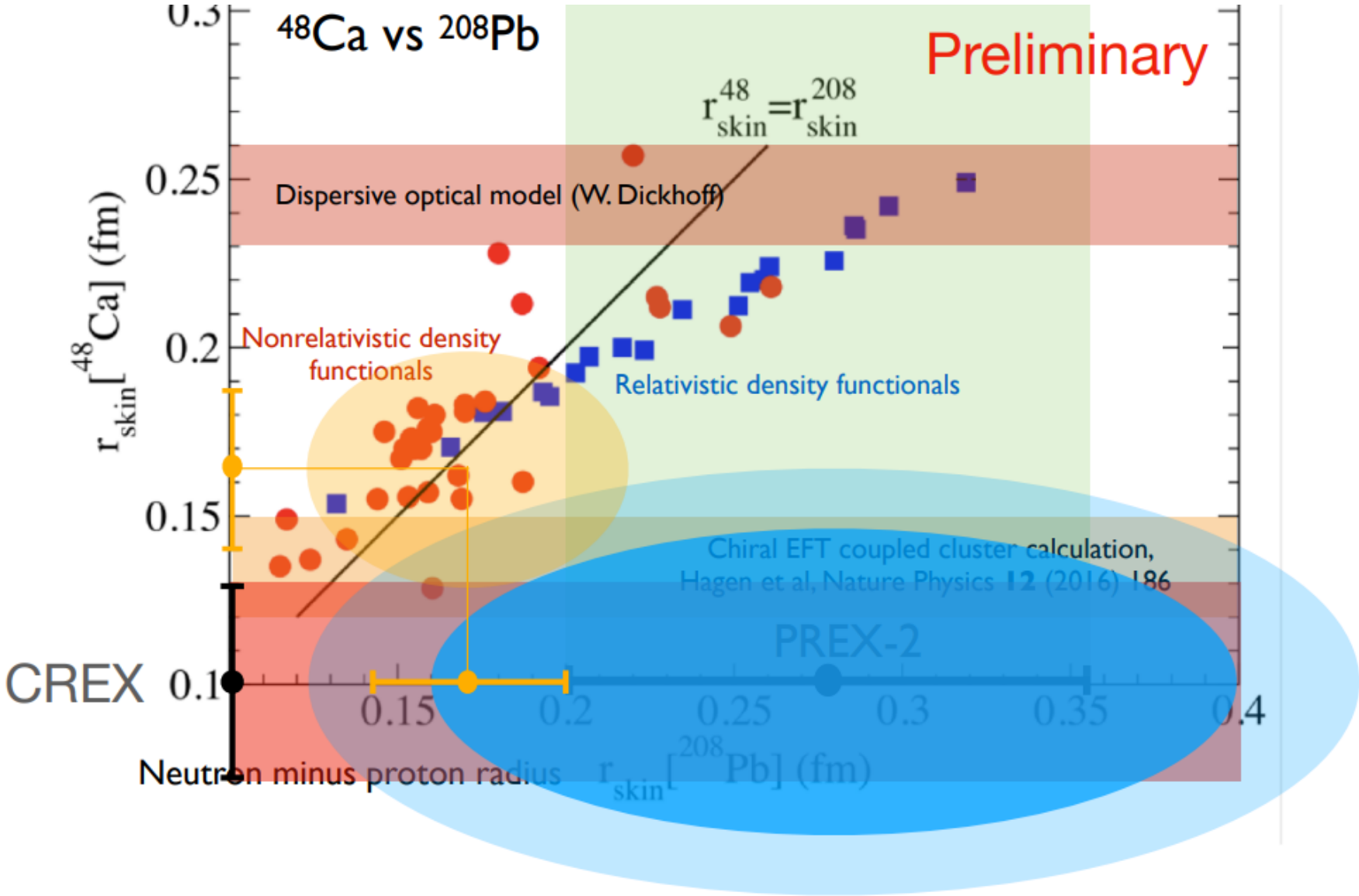


FIG. 3. The difference in electromagnetic charge form factor minus the calculated weak charge form factor result from a family of relativistic and non-relativistic DFT models for CREX versus that of PREX. The model calculation for both experiments' results are plotted, and the values consistent with the experimental results are shown in the red (PREX) and blue (CREX) bands. The yellow ellipses show the 1σ and 90% confidence levels of the overlap region for the two experiment results.


^{48}Ca vs ^{208}Pb
$r^{48}_{skin}=r^{208}_{skin}$
Dispersive optical model (W. Dickhoff)
Nonrelativistic density functionals
Relativistic density functionals
Chiral EFT coupled cluster calculation, Hagen et al, Nature Physics **12** (2016) 186
PREX-2
0.3
0.25
0.2
0.15
0.1
0.15
0.2
0.25
0.3
0.35
0.4
$r_{skin}[^{48}Ca]$ (fm)
Neutron minus proton radius $r_{skin}[^{208}Pb]$ (fm)


48Ca vs 208Pb
Preliminary
$r_{skin}^{48} = r_{skin}^{208}$
Dispersive optical model (W. Dickhoff)
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Relativistic density functionals
Chiral EFT coupled cluster calculation, Hagen et al, Nature Physics 12 (2016) 186
PREX-2
CREX
Neutron minus proton radius
$r_{skin}[^{48}Ca]$ (fm)
$r_{skin}[^{208}Pb]$ (fm)
0.3
0.25
0.2
0.15
0.1
0.15
0.2
0.25
0.3
0.35
0.4

PREX/CREX beam time and systematic goal

PREX - 25+10 days, 0.06fm
CREX - 35+10 days, 0.02fm

PREXI

E = 1.06 GeV, 70 uA
A_{pv} = 0.6 ppm;

Charge Normalization	0.2%
Beam Asymmetries	1.1%
Detector nonlinearity	1.2%
Transverse Asym	0.2%
Polarization	1.3%
Inelastic Contribution	<0.1%
Effective Q^2	0.5%
Total	2.1%

PREXII

E = 0.95 GeV, 70 uA
A_{pv} = 0.6 ppm; Rate ~ 2.2 GHz

Charge Normalization	0.1%
Beam Asymmetries	1.1%
Detector nonlinearity	0.5%
Transverse Asym	0.2%
Polarization	1.1%
Inelastic Contribution	<0.1%
Effective Q^2	0.4%
Total	2%

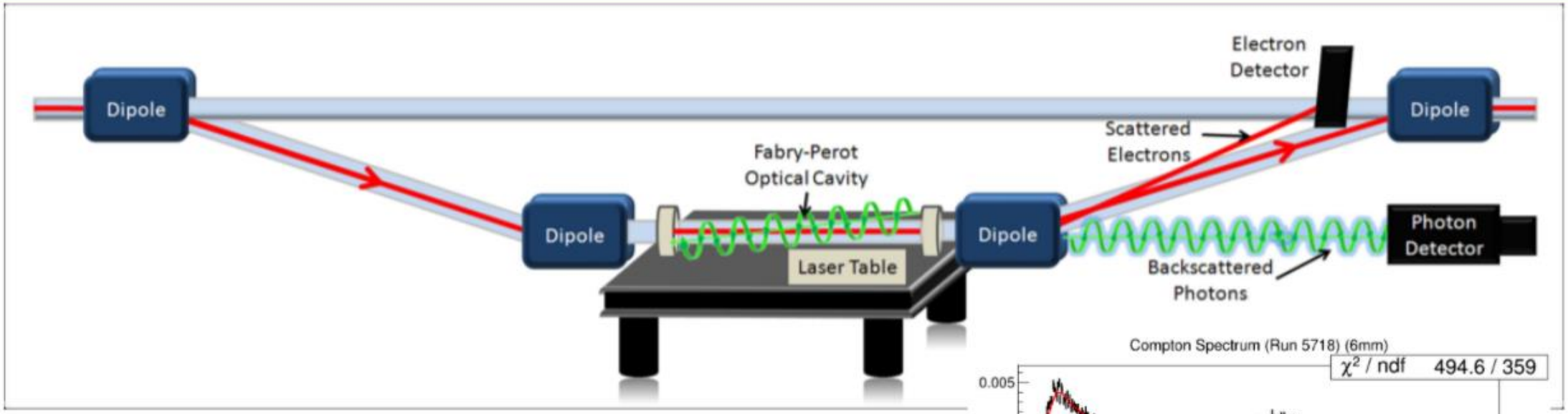
CREX

E = 2.18 GeV, 150 uA
A_{pv} = 2 ppm; Rate ~ 27 MHz

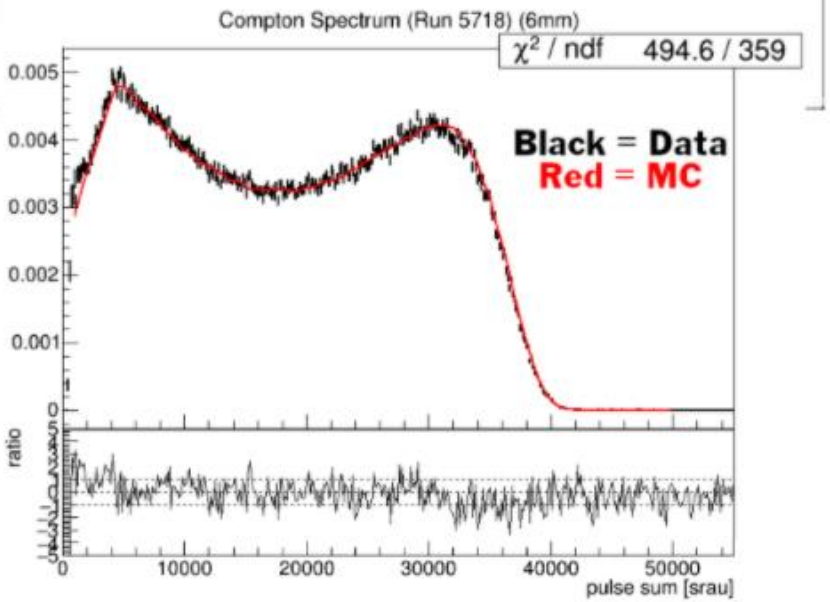
Charge Normalization	0.04%
Beam Asymmetries	0.26%
Detector nonlinearity	0.25%
Transverse Asym	0.48%
Polarization	0.49%
Inelastic Contribution	0.81%
Effective Q^2	0.9%
Total	1.48%

PREXI - Goal achieved - Systematic was under control, limited by statistics

Compton Polarimeter

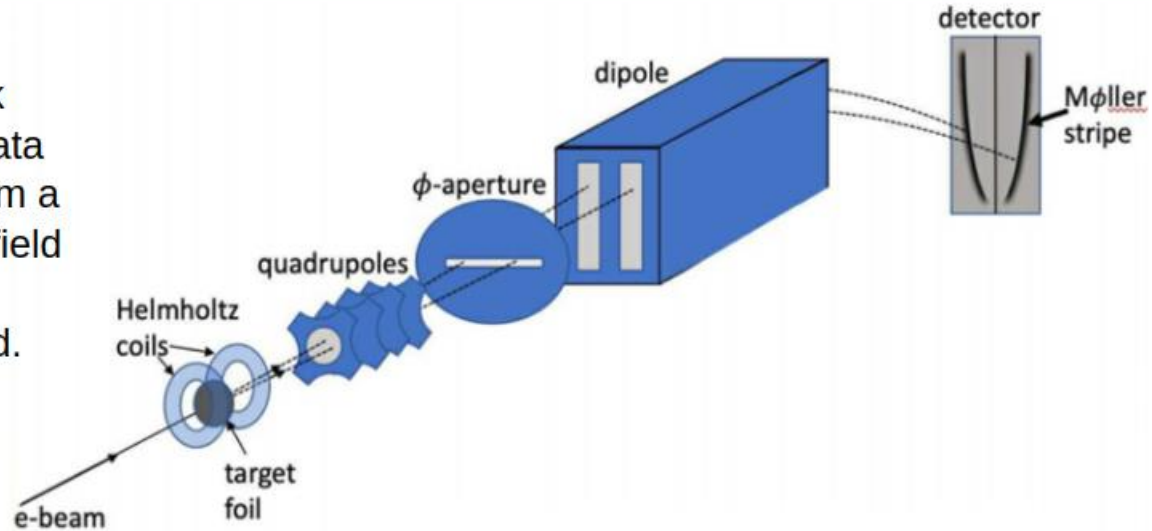


- Continuous, non-invasive measurement
- Polarimeter runs were taken continuously alongside the main detector data
- Utilized integrating technique with photon detector
- Evaluated systematic uncertainty



MOLLER polarimeter

- Low current invasive measurements - Took fewer runs to cross-check with Compton data
- MOLLER -scattering of beam electrons from a magnetized Fe foil using a 3-4T magnetic field
- No significant fluctuation of measured polarization is observed over the run period.
- **Statistics: <0.25% per measurement**
- **Systematic: 0.85% relative uncertainty**



$$A_{beam} = A_{zz}\, P_{Fe\ foil}\, P_{beam}$$

measured — from simulation — from theory assuming saturation — extracted

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

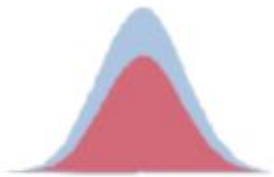
Source

Polarized Source: Precision and Systematic Uncertainty

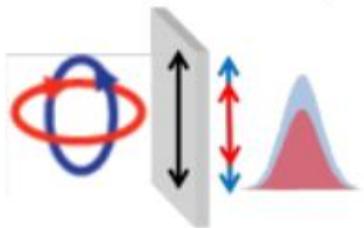
Any change in the polarized beam, correlated to helicity reversal, can be a potential source for a false asymmetry

$$A_{raw} = A_{det} - A_Q + \alpha\Delta_E + \Sigma\beta_i\Delta x_i$$

Intensity Asymmetry

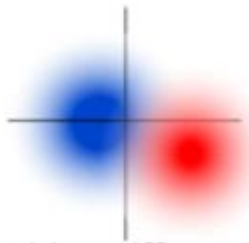


Intensity Asymmetry from Laser Polarization Asymmetry

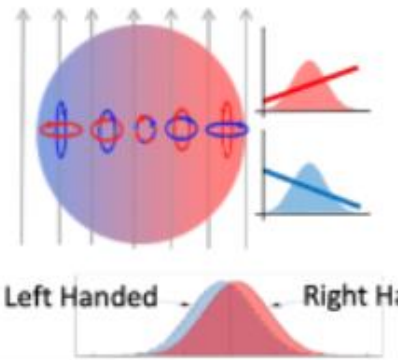


Polarizing element (i.e. photocathode)

Position Difference

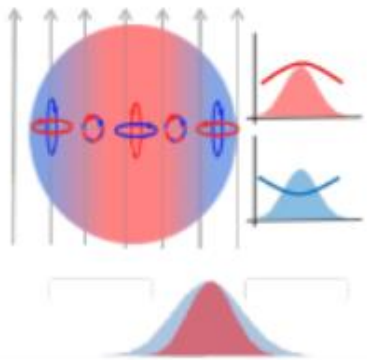


Position Difference from Polarization Gradient

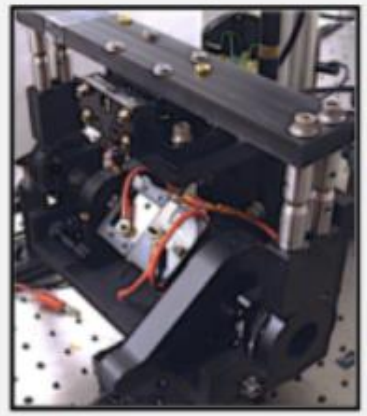


Spot-size *Asymmetry*

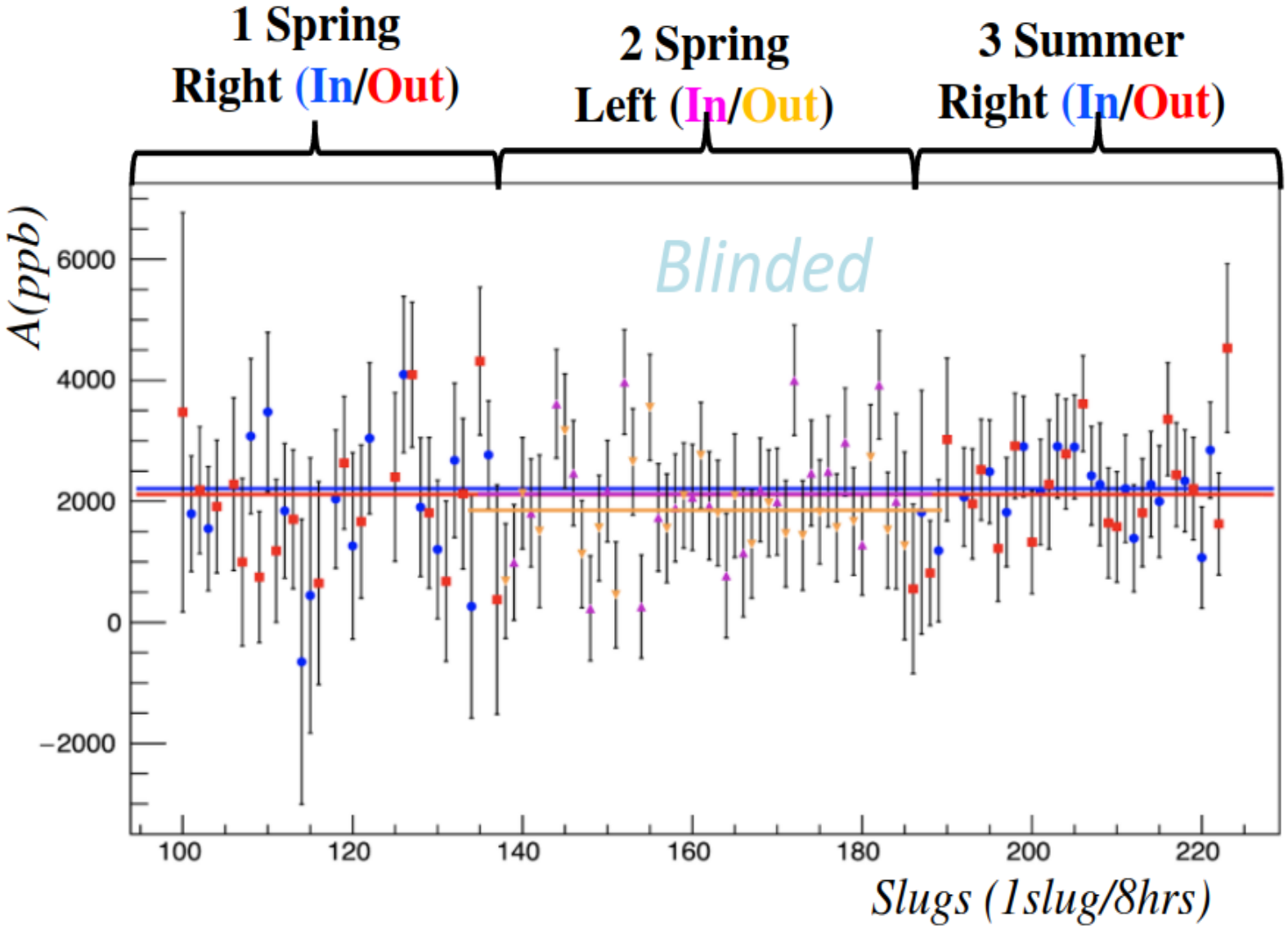
Spot-size Asymmetries from 2nd moment Polarization Gradient



new UVa RTP cell (MOLLER R&D)



Blinded Asymmetries



Data Divided Into 3 Parts

- Part 1: Wien Right Spring 2020 (started Dec 2019)
- Part 2: Wien Left Spring 2020
- Part 3: Wien Right Summer 2020 (ended Sept 2020)

Statistical Test

X^2 / dof = 95.2/120

Probability 95%

Data Overview: Corrected Asymmetry

Final result averaging over all IHWP and 3 Part Wien flip configurations

1: ~Right (In/Out)
2: ~Left (In/Out)
3: =Right (In/Out)

Lagrange corrected main detector asymmetry results

(ppb)	Main det Asym	Weight	Stat Error	Correction
1	2157.68	15.65%	211.77	-179.65
2	1992.07	47.48%	121.58	51.89
3	2160.94	36.88%	137.95	154.37
Net	**2080.26**		±83.77	Net = 53.45 ± 5.44

Blinded Corrected Asymmetry A_{corr}:
2080.3 ± 83.8 ppb