PREX-2/CREX: Overview

Ye Tian

Syracuse University
For the Prex/CRex Collaboration

07/16/2020

PREX

Kent Paschke *	UVa
Krishna Kumar	Stony Brook University
Robert Michaels	Jefferson Lab
Paul Souder	Syracuse University
Guido Urcioli	INFN Rome

* contact persons

J. Mammei, J. Birchall, M. Gericke, R. Mahurin, W.T.H. van Oers, S. Page
University of Manitoba

S. Riordan, P. Decowski, K. Kumar, T. Kutz, J. Wexler
University of Massachusetts, Amherst

K. Paschke, G.D. Cates, M. Dalton, D. Keller, X. Zheng
University of Virginia

P.A. Souder, R. Beminiwattha, R. Holmes
Syracuse University

R. Michaels, K. Allada, J. Benesch, A. Camsonne, J.P. Chen, D. Gaskell,
J. Gomez, O. Hansen, D.W. Higinbotham, C.E. Keppel, J. LeRose, B. Moffit
S. Nanda, P. Solvignon-Slifer, B. Wojtsekhowski, J. Zhang
Thomas Jefferson National Accelerator Facility

Konrad Aniol
California State University, Los Angeles

G.B. Franklin, B. Quinn
Carnegie Mellon Univerisity

D. Watts, L. Zana
The University of Edinburgh

P. Markowitz
Florida International University

CREX

Dustin McNulty *	Idaho State University
Robert Michaels	Jefferson Lab
Kent Paschke	UVa
Paul Souder	Syracuse Univeristy
Juliette Mammei	Manitoba University
Silviu Covrig	Jefferson Lab
Seamus Riordan	Argonne National Lab

P. Gueye
Hampton University

E. Cisbani, A. del Dotto, S. Frullani, F. Garibaldi
INFN Roma gruppo collegato Sanità
and Italian National Institute of Health, Rome, Italy

M. Capogni
INFN Roma gruppo collegato Sanità
and ENEA Casaccia, Rome, Italy

V. Bellini, A. Giusa, F. Mammoliti, G. Russo, M.L. Sperduto, C.M. Sute
INFN - Sezione di Catania

D. McNulty, P. Cole, T. Forest, M. Khandaker
Idaho State University

C.J. Horowitz
Indiana University

M. Mihovilovič, S. Širca
Jožef Stefan Institute and University of Ljubljana, Slovenia

A. Glamazdin
Kharkov Institute of Physics and Technology

T. Holmstrom
Longwood University

S. Kowalski, R. Silwal, V. Sulkosky
Massachusetts Institute of Technology

M. Shabestari
Mississippi State University

S.K. Phillips
University of New Hampshire

E. Korkmaz
University of Nortern British Columbia

P. King, J. Roche, B. Waidyawansa
Ohio University

C.E. Hyde
Old Dominion University

F. Meddi, G.M. Urciuoli
Sapienza University of Rome and INFN - Sezione di Roma

A. Blomberg, Z.-E. Meziani, N. Sparveris
Temple University

M. Pitt
Viriginia Polytechnic Institute and State University

D. Armstrong, J.C. Cornejo, W. Deconinck, J.F. Dowd, V. Gray, and J. Magee
College of William and Mary

D. Androic
University of Zagreb

PVES as Clean Probe for Neutron Distributions

$$\sigma \approx \left| \gamma + Z^0 \right|^2$$

Longitudinally polarized e⁻ unpolarized target

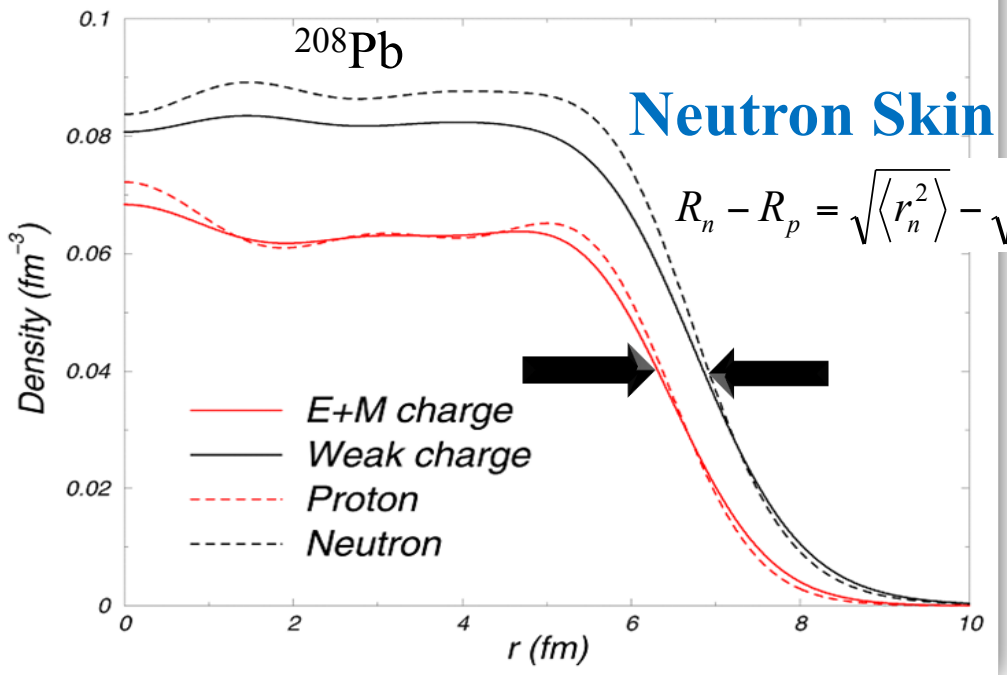
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim 10^{-4} \times Q^2 \sim 10^{-6}$$

$$A_{PV}^{BA} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}} \left[\underbrace{1 - 4\sin^2\theta_W}_{\sim 0} - \frac{F_N(Q^2)}{F_P(Q^2)} \right]$$

$$F_{N,p}(Q^2) = \frac{1}{4\pi} \int d^3r \; j_0(qr) \; \rho_{N,p}(r)$$

Nuclear theory predicts neutron skin on heavy nuclei

C. J. Horowitz



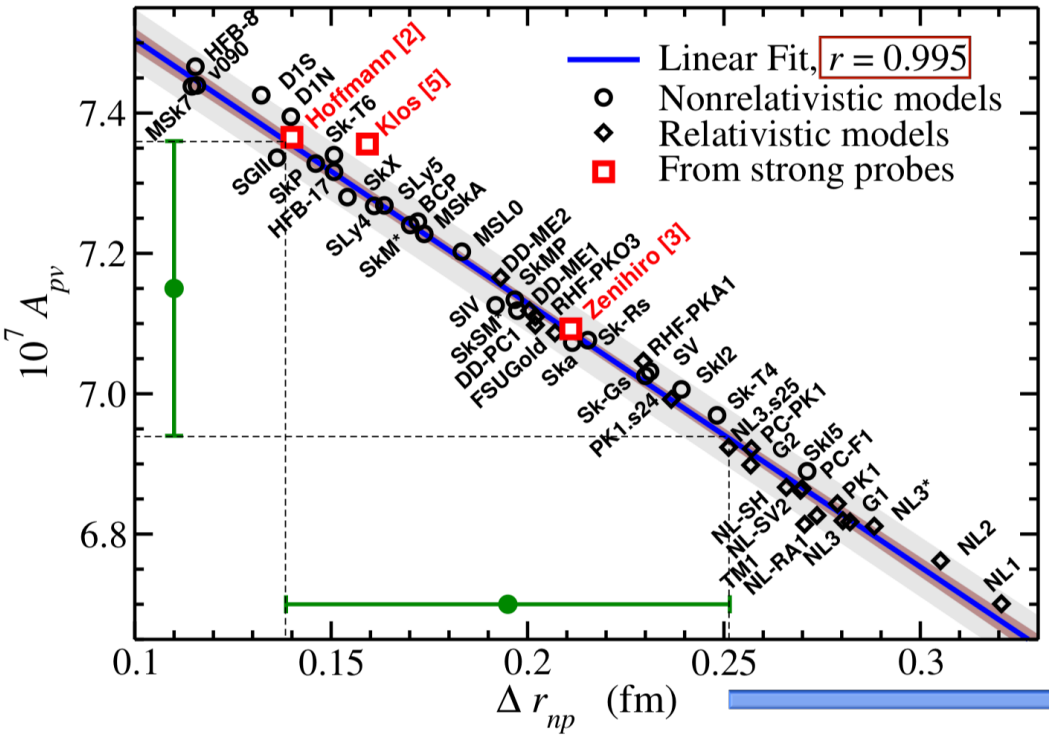
- Hadron scatterings--- model dependent interpretation, large and uncontrolled theoretical systematic uncertainties
- Parity-violating electron scattering--- a clean measurement of neutron distribution.

Weak Interaction: Sees the Neutrons

Charge	proton	neutron
Electric	1	0
Weak	0.08	1

spin-0 nucleus

Neutron Skin Measured by A_{PV}



Mean-Field predictions shows a high linear relation between ^{208}Pb A_{PV} and the neutron skin over existing nuclear structure models

$$R_n - R_p = \sqrt{\langle r_n^2 \rangle} - \sqrt{\langle r_p^2 \rangle}$$

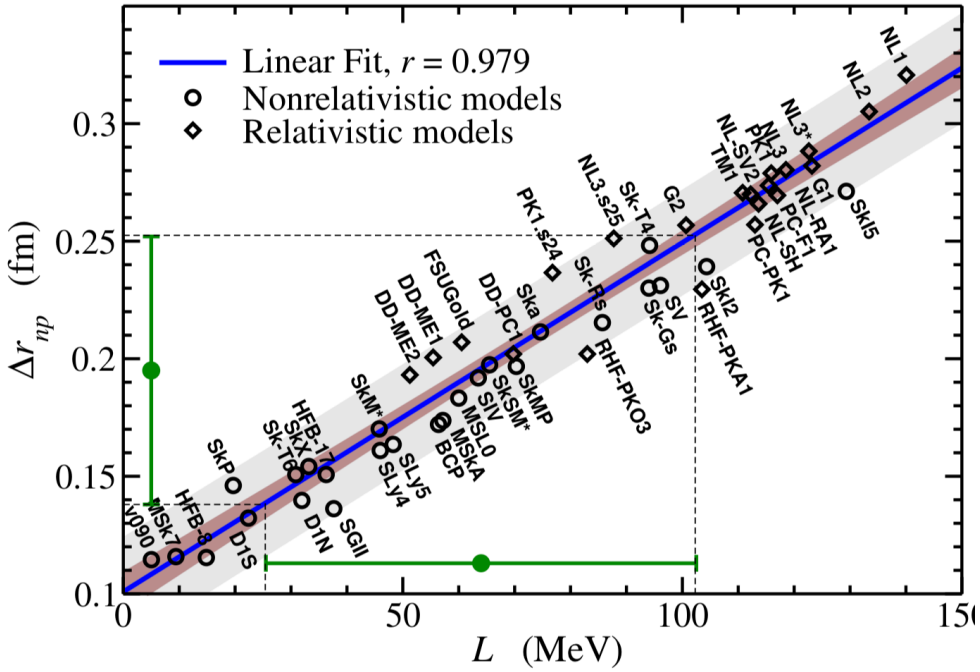
X. Roca-Maza (et al.) PRL 106 (2011) 252501

A_{pv} in PVES provides a clean probe of the neutron distribution

- **PREX-2: A_{PV} to 3% from ^{208}Pb -> R_n to 0.06 fm**
- **CREX: A_{PV} to 2.4% from ^{48}Ca -> R_n to 0.02 fm**

Neutron Skin and Symmetry Energy

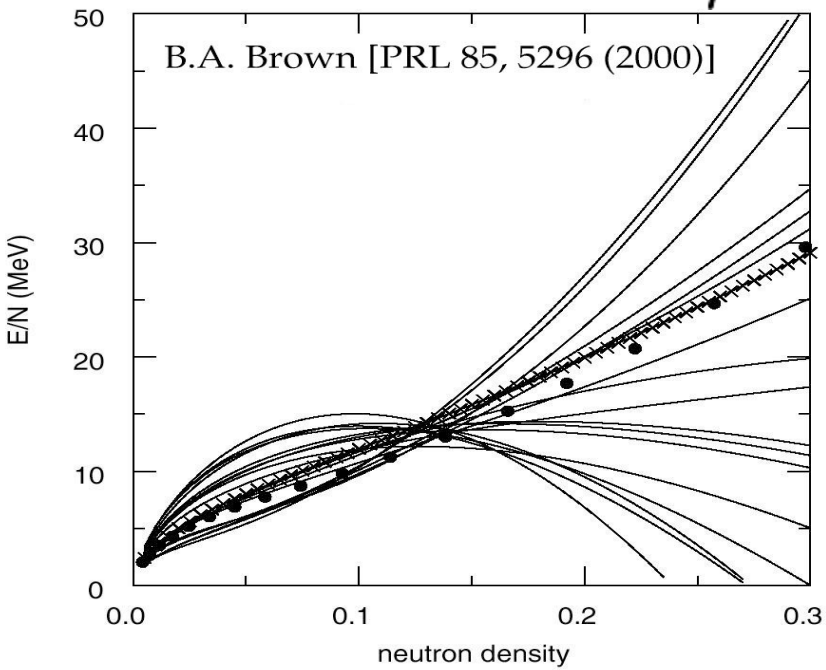
Mean-Field predictions show a clear correlation between neutron skin of a heavy nucleus and the density slope of the symmetry energy.



X. Roca-Maza (et al.) PRL 106 (2011) 252501

- Symmetry energy (S): Variation of binding energy as n/p changes.
- Slope of symmetry energy at saturation density

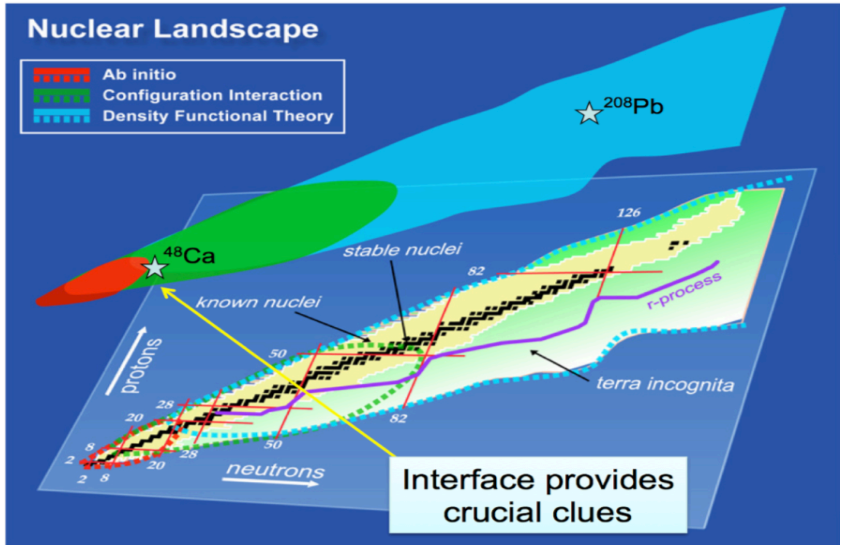
$$L \propto \frac{\partial S(\rho)}{\partial \rho}\Big|_{\rho_0}$$

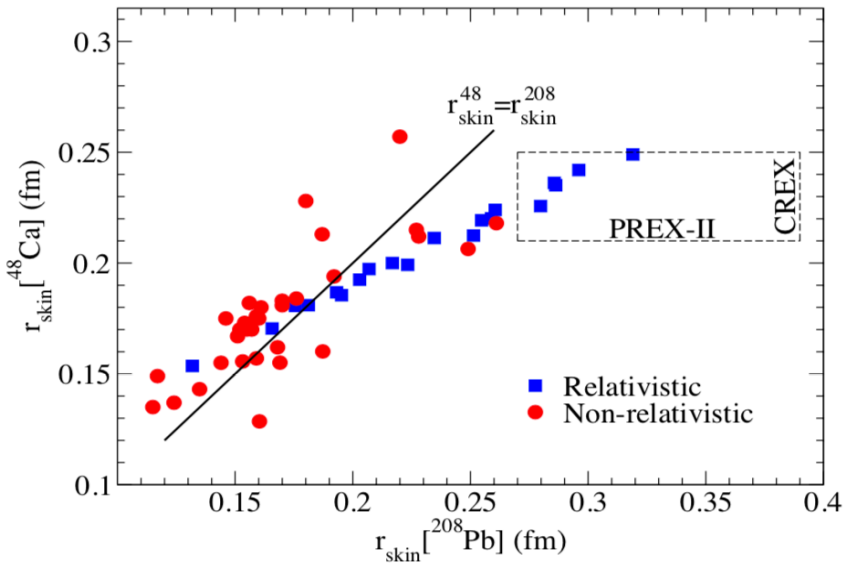


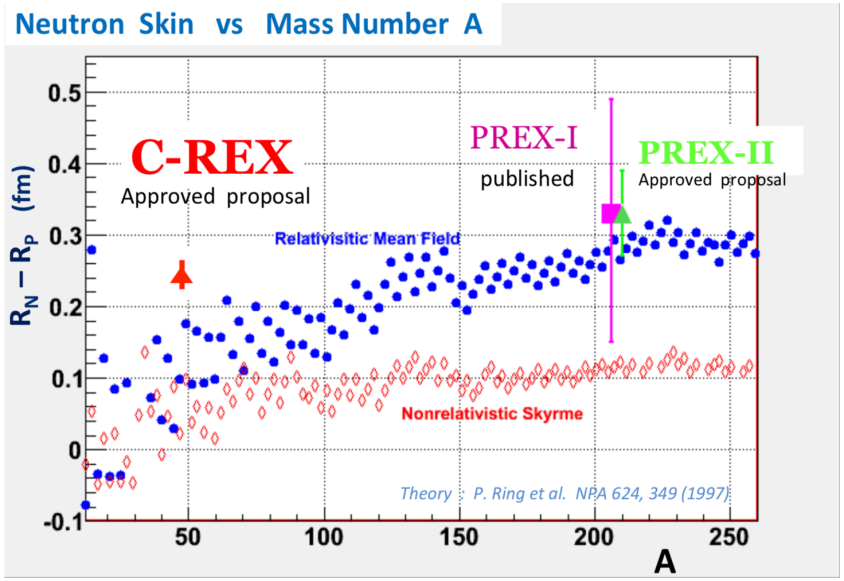
Neutron skin thickness is highly sensitive to the pressure of pure neutron matter: the greater the pressure, the thicker the skin as neutrons are pushed out against surface tension.

PREX and CREX

- ^{208}Pb can be well-described by the nuclear density functional theory (DFT)
- The ^{48}Ca nucleus provide a key information for bridging DFT and ab initio approaches (based on nucleon-nucleon and three nucleon forces)
- R^{208}_n and R^{48}_n are expected to be correlated, but the correlation depends on the correctness of the models
- Measure both R^{208}_n and R^{48}_n – test nuclear structure models over a large range of A





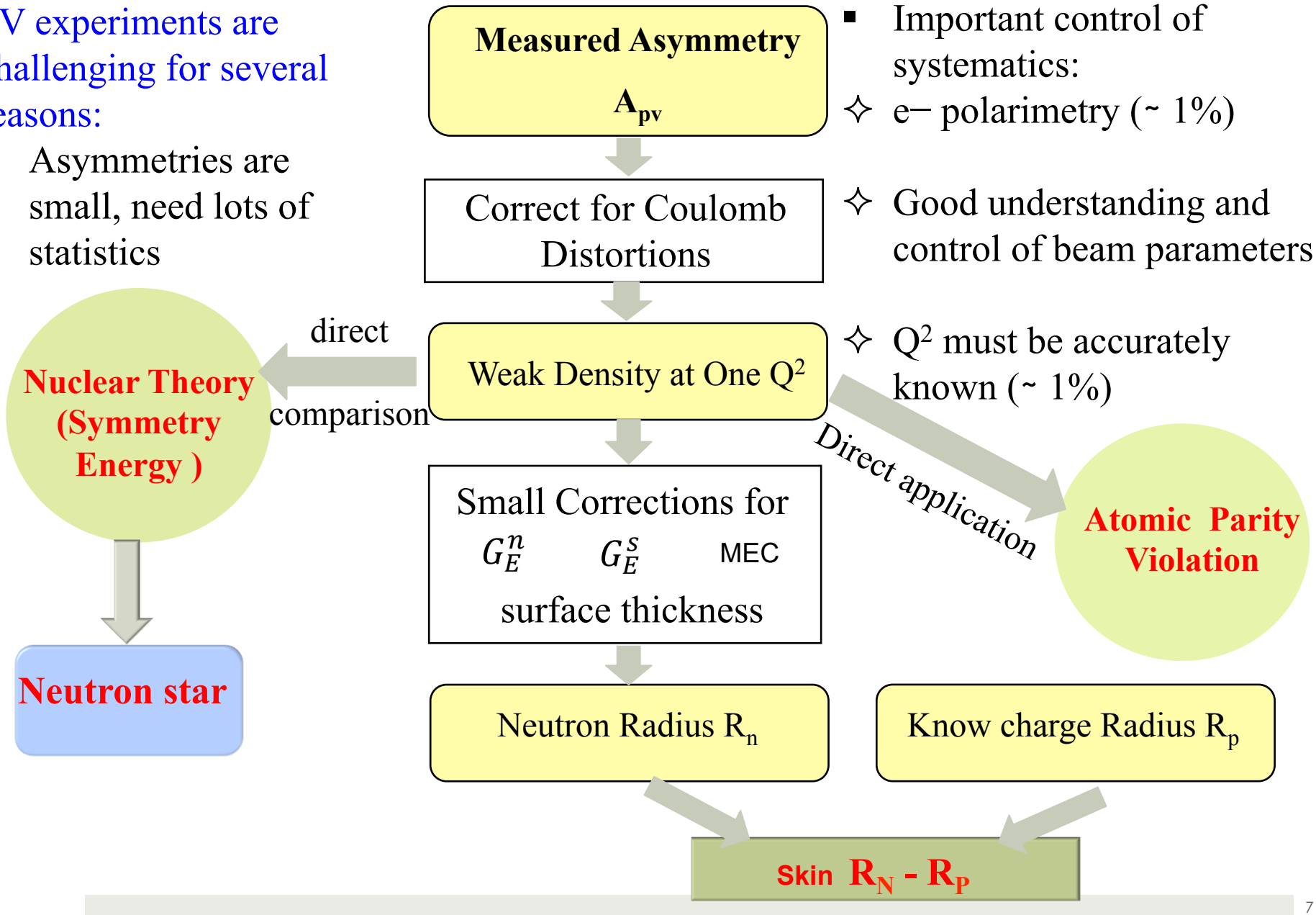


Theory from P. Ring et al. Nucl. Phys. A 624 (1997) 349

Physics Outputs

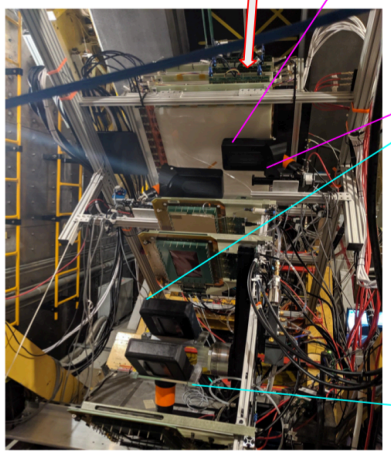
PV experiments are challenging for several reasons:

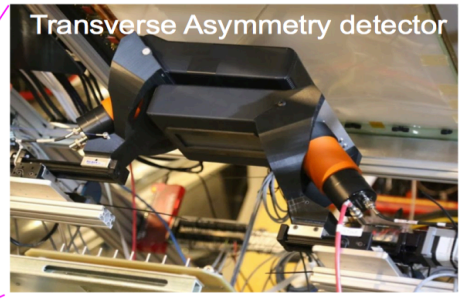
- Asymmetries are small, need lots of statistics

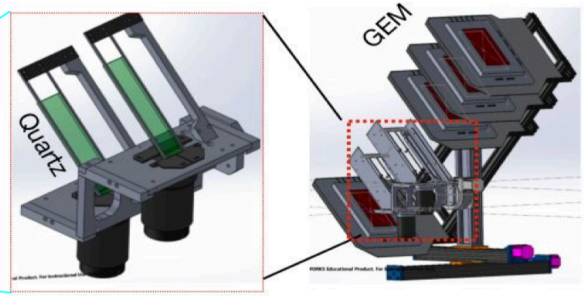


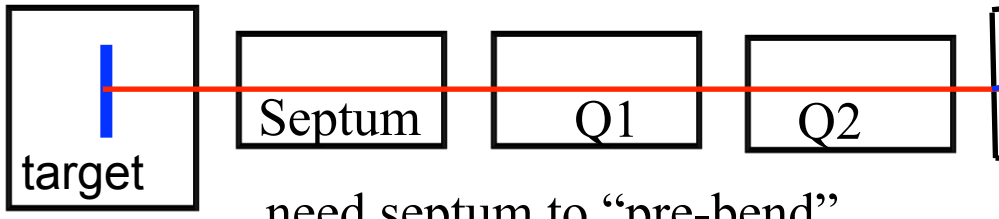
- Important control of systematics:
  - ✧ e– polarimetry (~ 1%)
  - ✧ Good understanding and control of beam parameters
  - ✧ Q^2 must be accurately known (~ 1%)

Hall A High Resolution Spectrometers

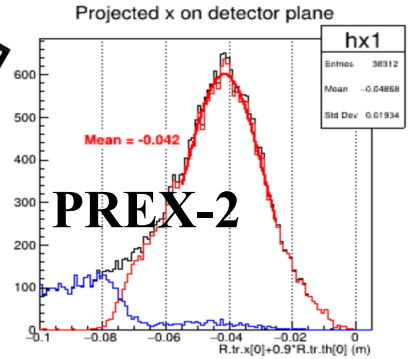


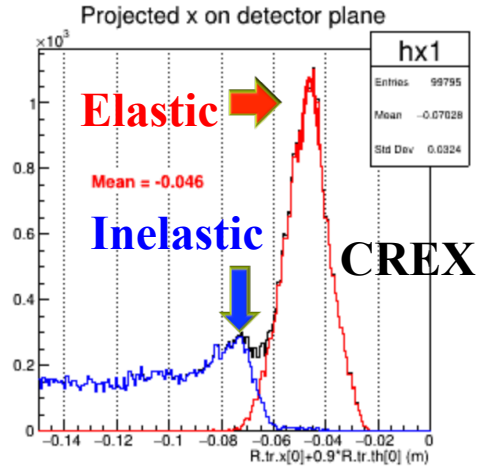


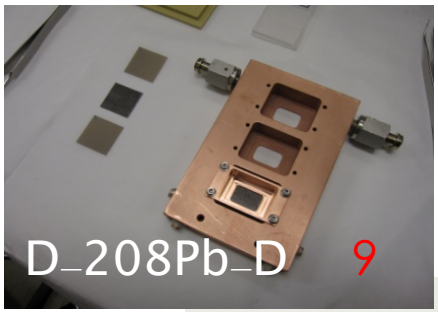




need septum to "pre-bend"



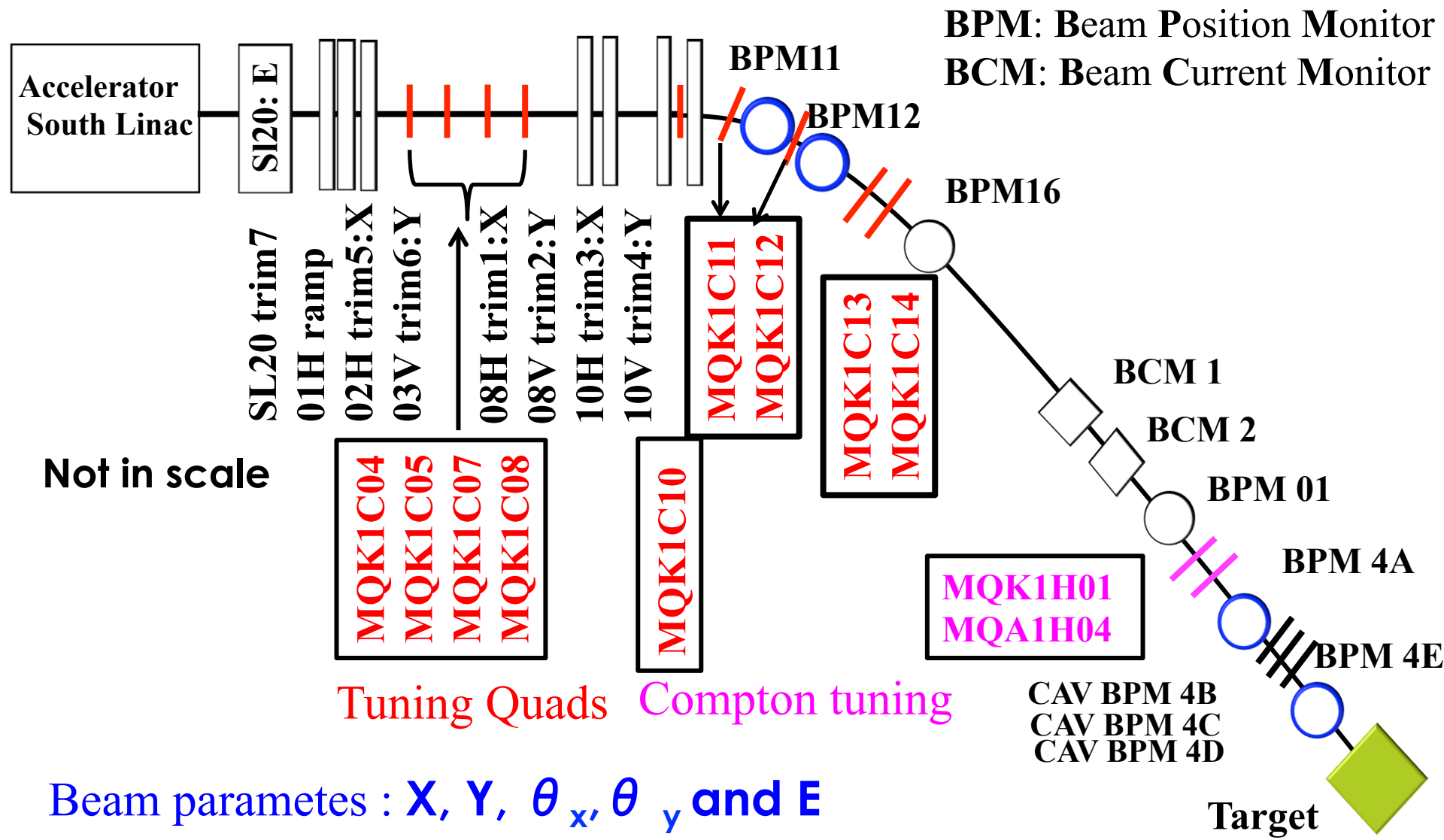




PREX-2:
0.95 GeV e- beam, 70uA
0.5 mm thick ^{208} Pb target
5^{o} scattered electrons

CREX:
2.1 GeV e- beam, 150uA
0.5 mm thick ^{48}Ca target
5^{o} scattered electrons

Hall A Beam Monitors and Beam Modulation Coils



Beam parametes : **X, Y, θ_x, θ_y and E**

Asymmetry Correction

$$A_{meas} = \frac{D_R/I_R - D_L/I_L}{D_R/I_R + D_L/I_L}$$

- $D_{R(L)}$ are integrated detector responses, $I_{R(L)}$ are the beam current monitor response

$$A_{corr} = A_{meas} - \sum_{i=1}^{N} B_i \Delta x_i - A_{FT}$$

Caryn's talk

- Regression: based on nature beam fluctuations and minimizing the χ^2 of a given fit.
- Beam Modulation: involves deliberately perturbing the beam in a slow and non-helicity-correlated way and measuring the detector rate response.

$$A_{sig} = \frac{A_{corr} - A_{bkg} f_{bkg}}{f_{sig}}$$

- ^{12}C contamination
- Events from the 1 st excited state of ^{208}Pb.
- Inelastically scattered events rescattered into the acceptance of the quartz detectors.

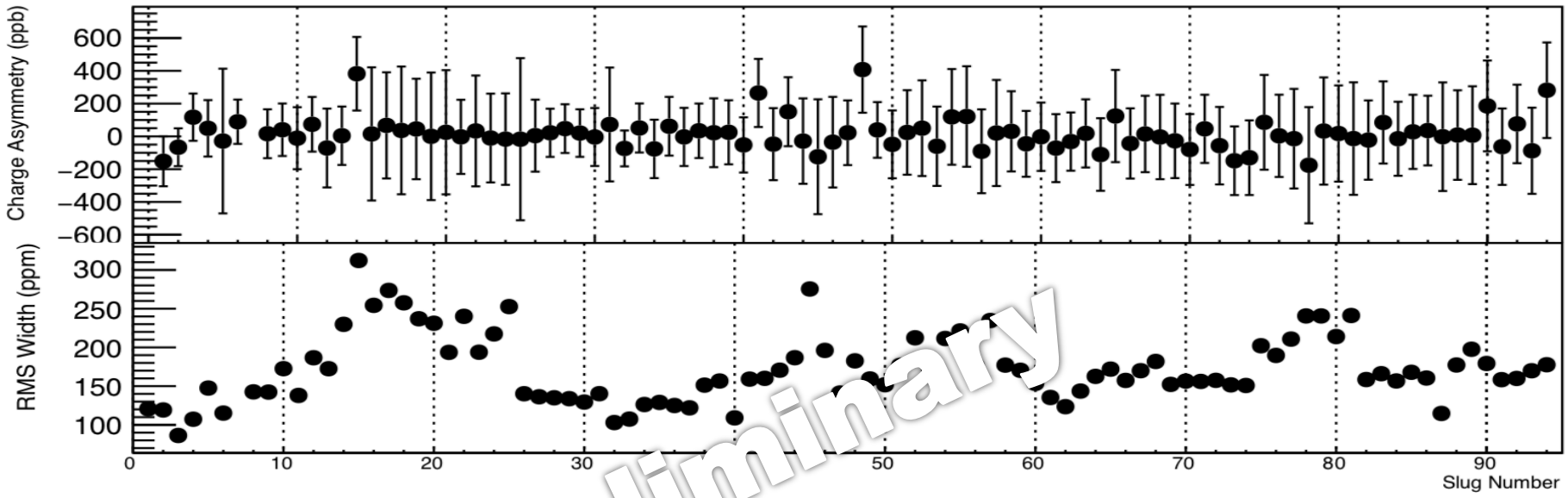
$$A_{PV} = \frac{A_{sig}}{P_{beam}}$$

Longitudinal beam polarization

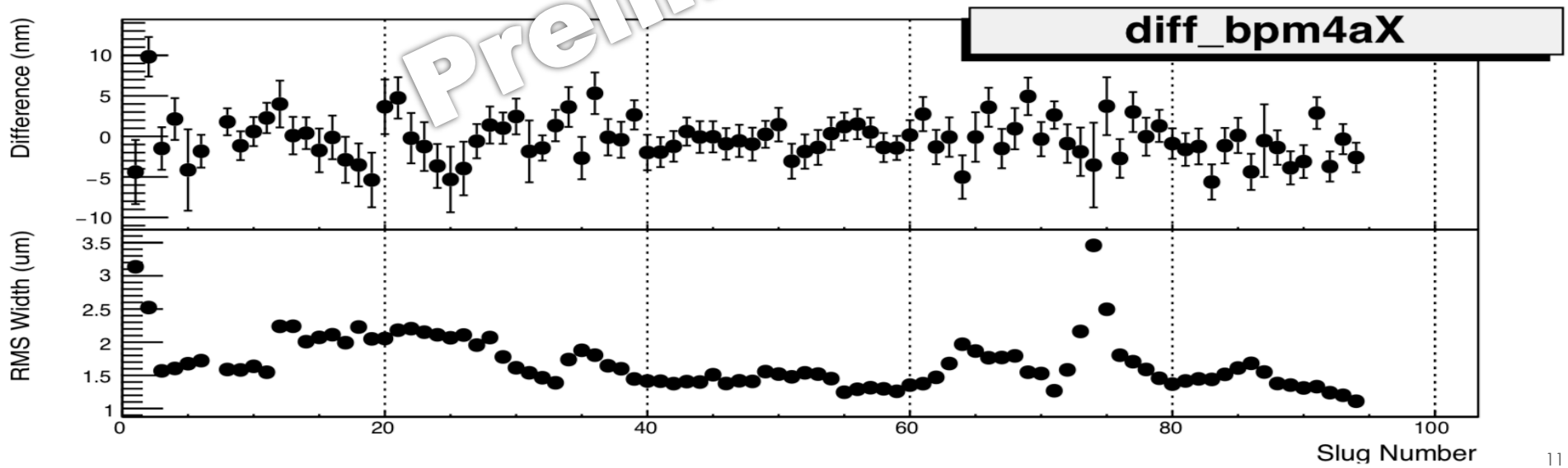
- Moller Polarimeter
- Compton Polarimeter

PREX-2 Beam Quality

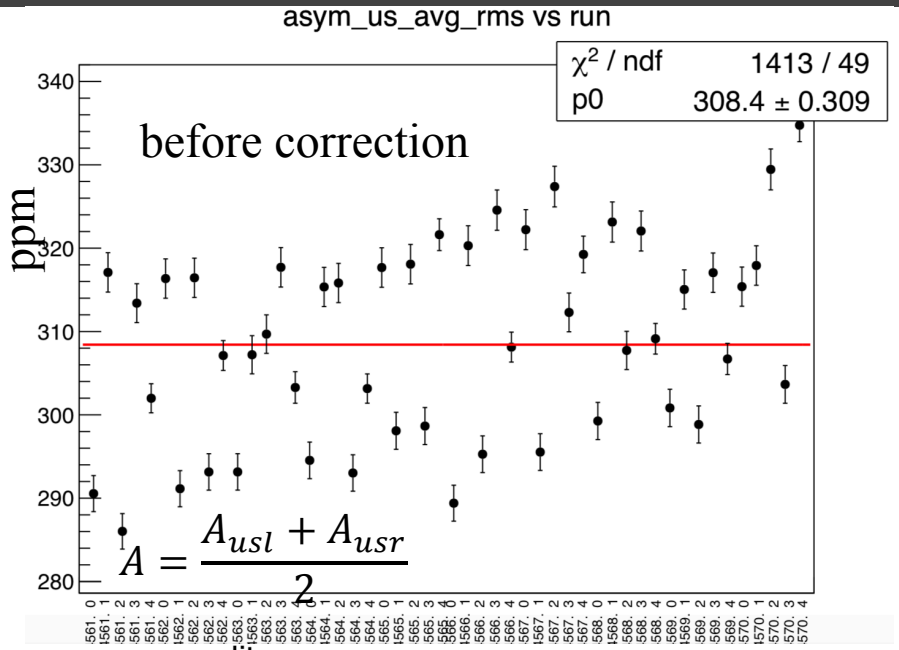
Charge Asymmetries: weighted average A_Q = 26.23 ppb

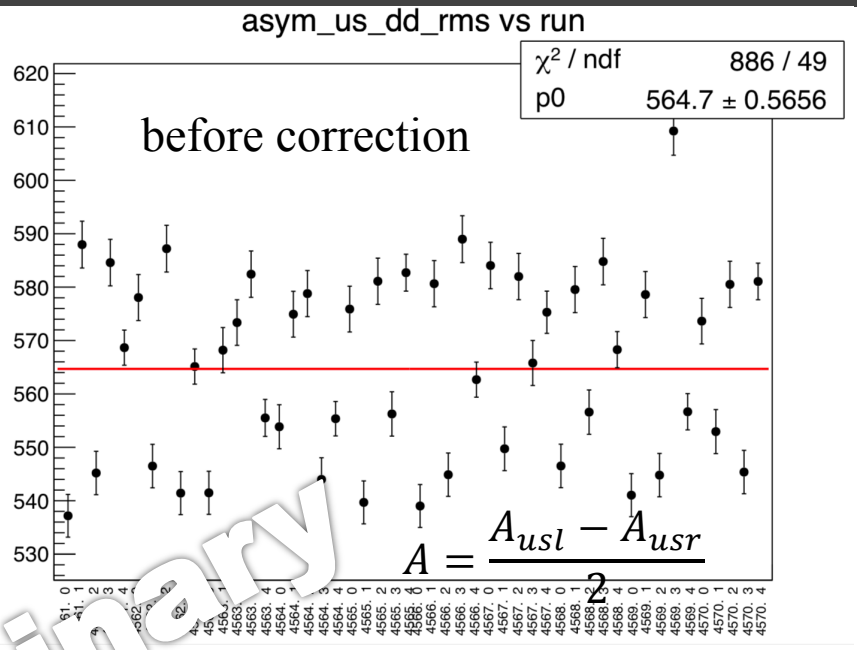


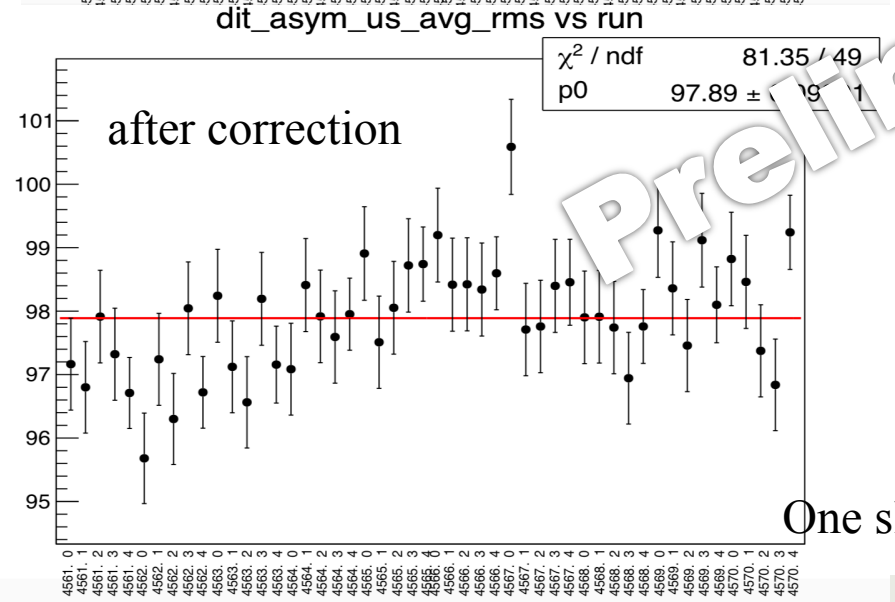
Preliminary

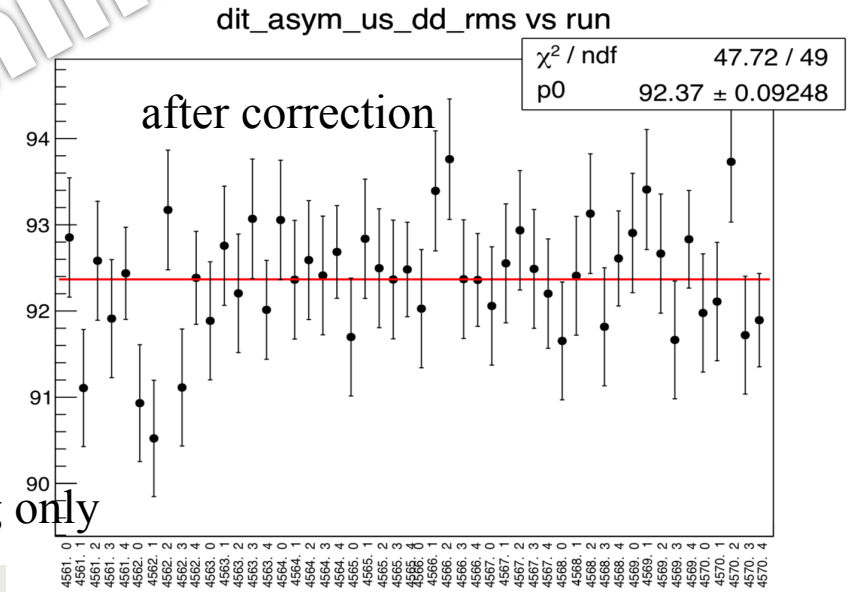


PREX-2 Beam Correction







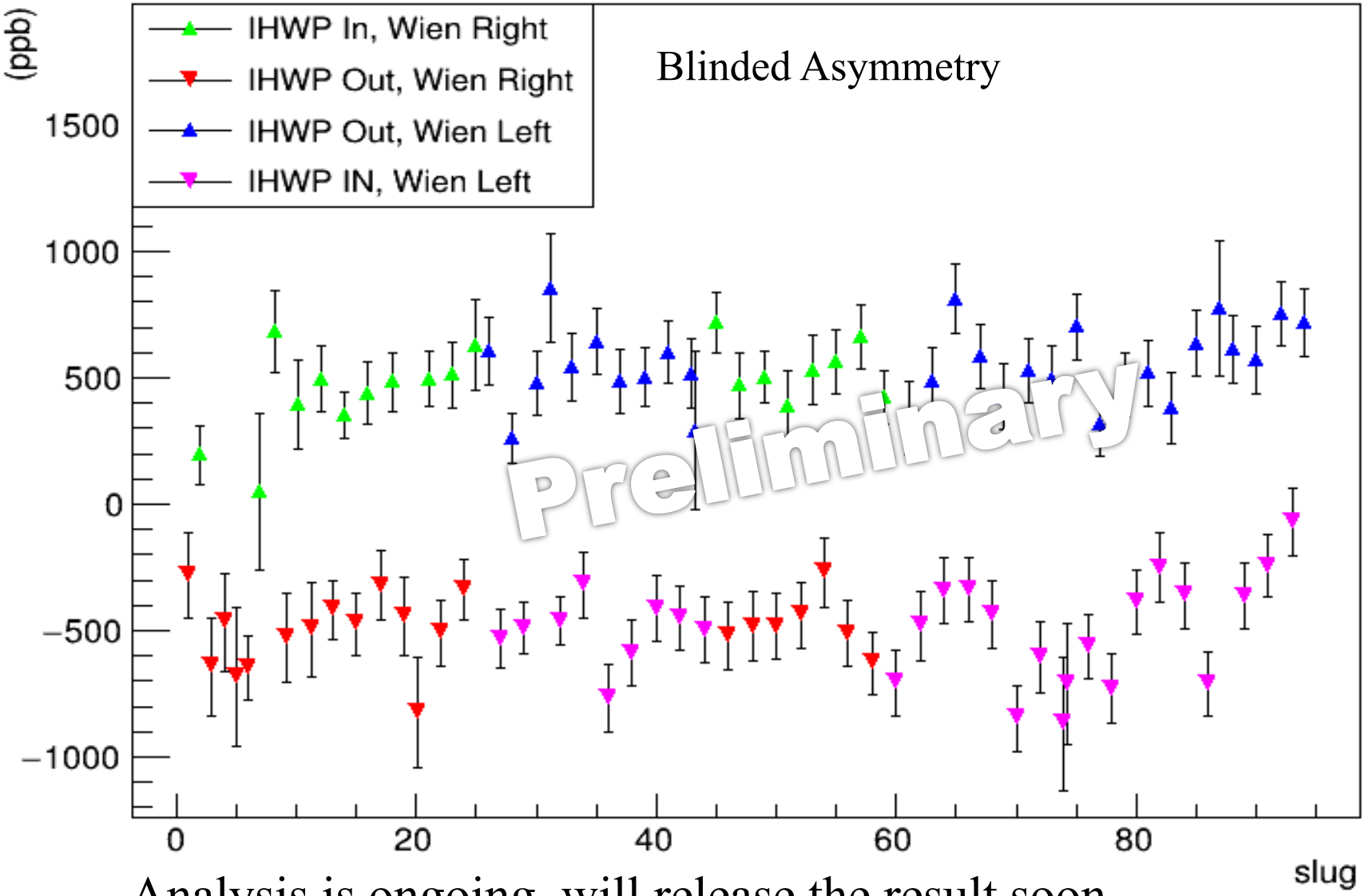


Preliminary

One slug only

PREX-2 Data

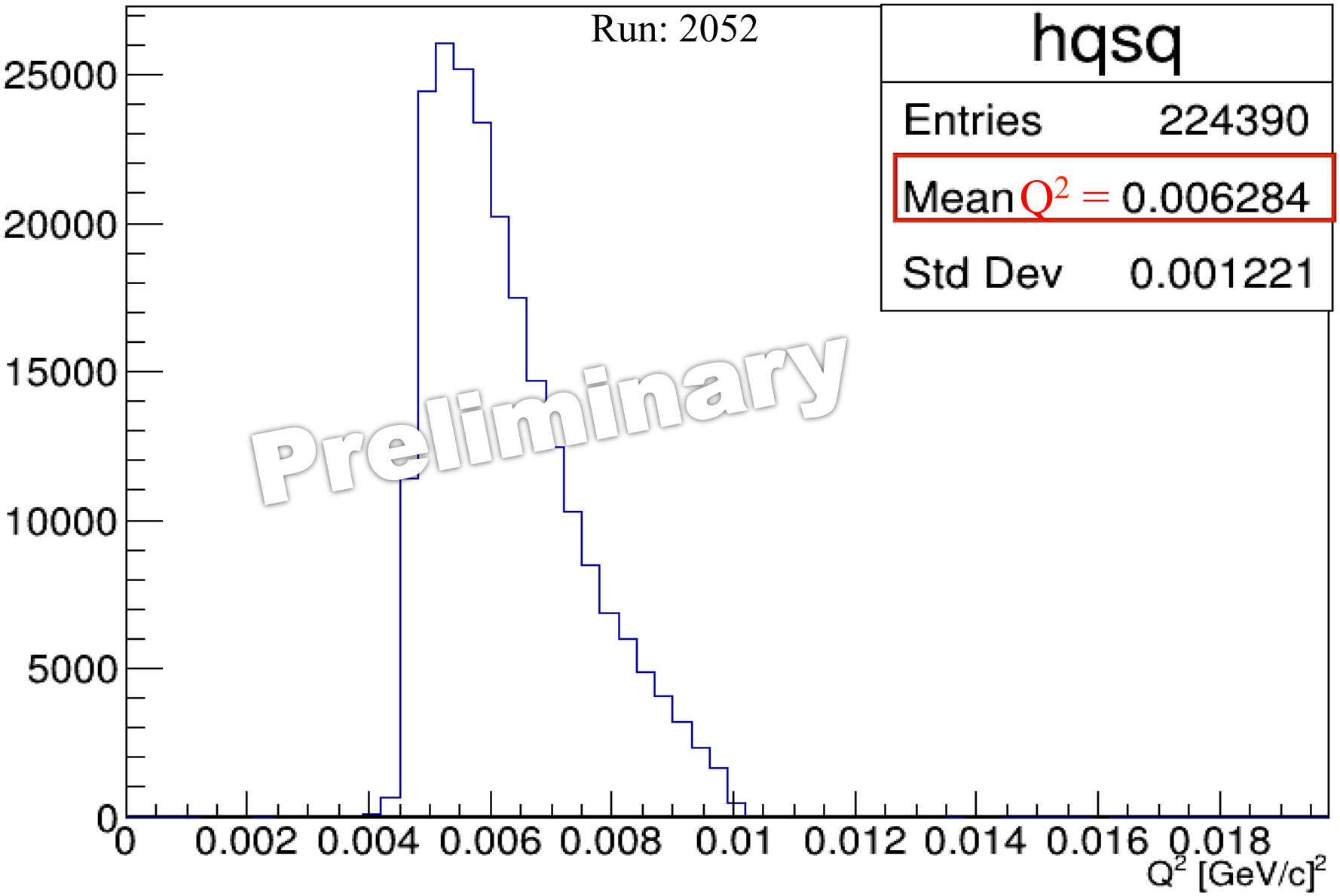
Regression Corrected Asymmetries



Analysis is ongoing, will release the result soon

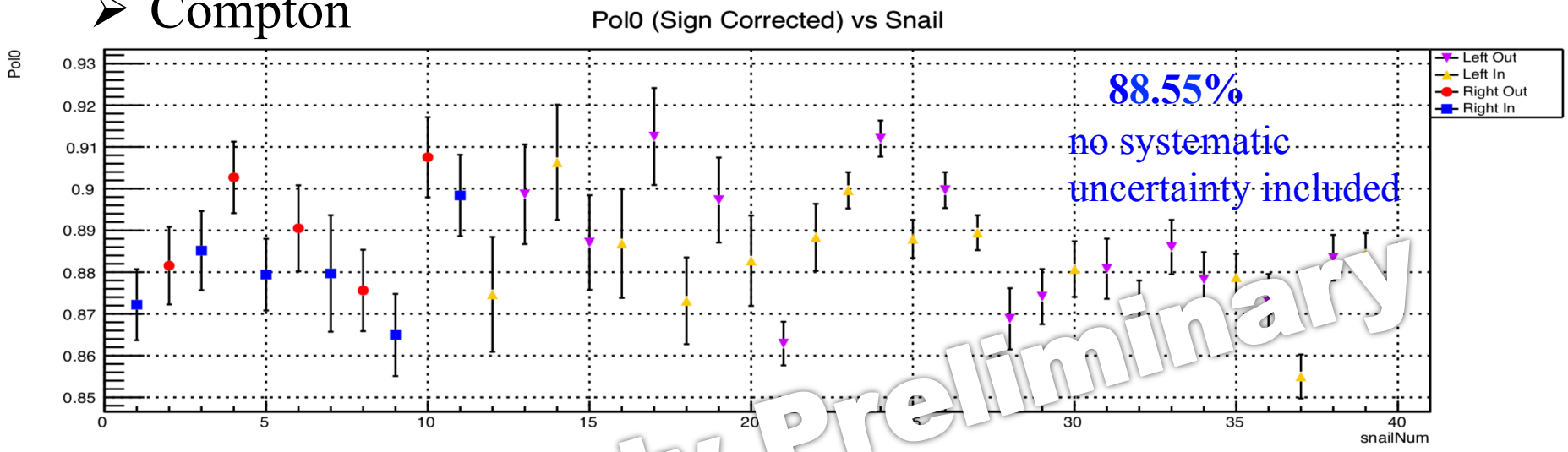
PREX-2 Data

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

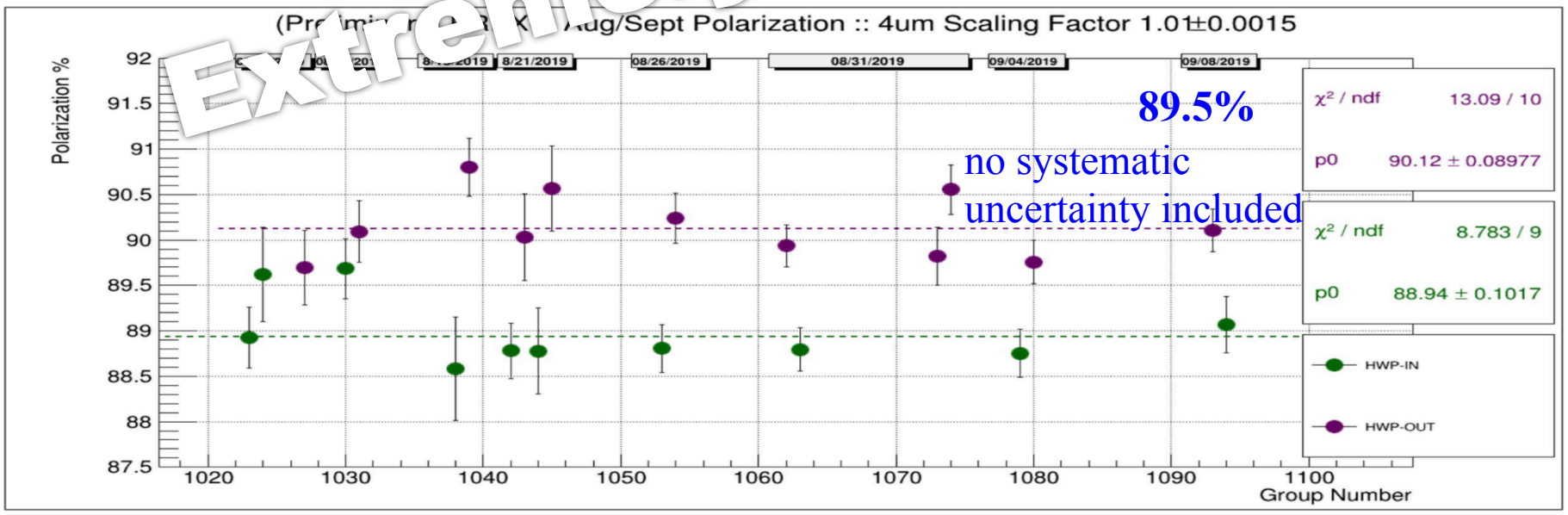


PREX-2 Beam Polarimetry Measurements

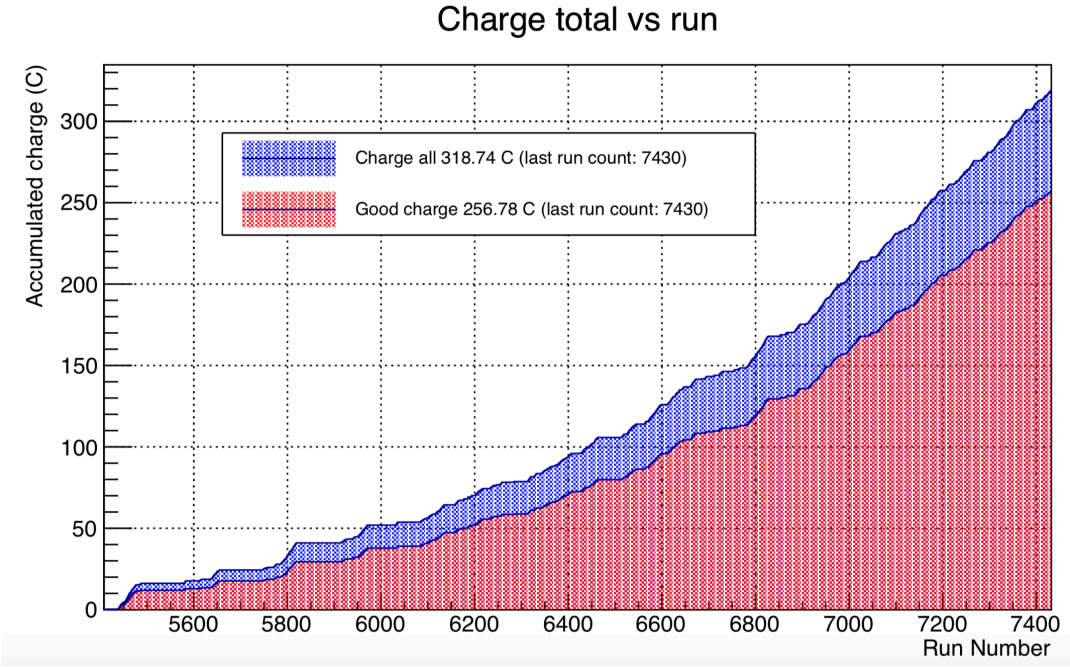
- Compton



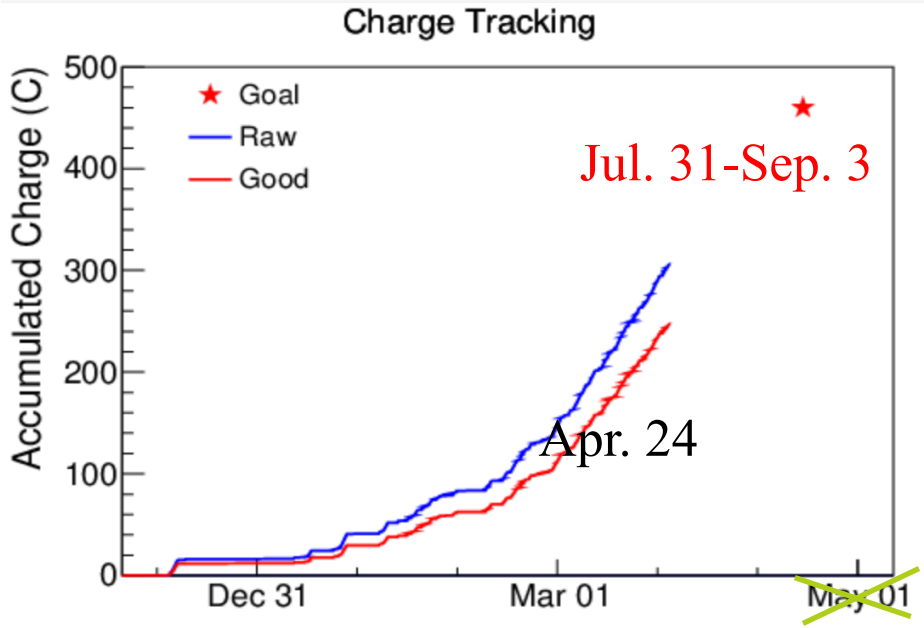
- Moller

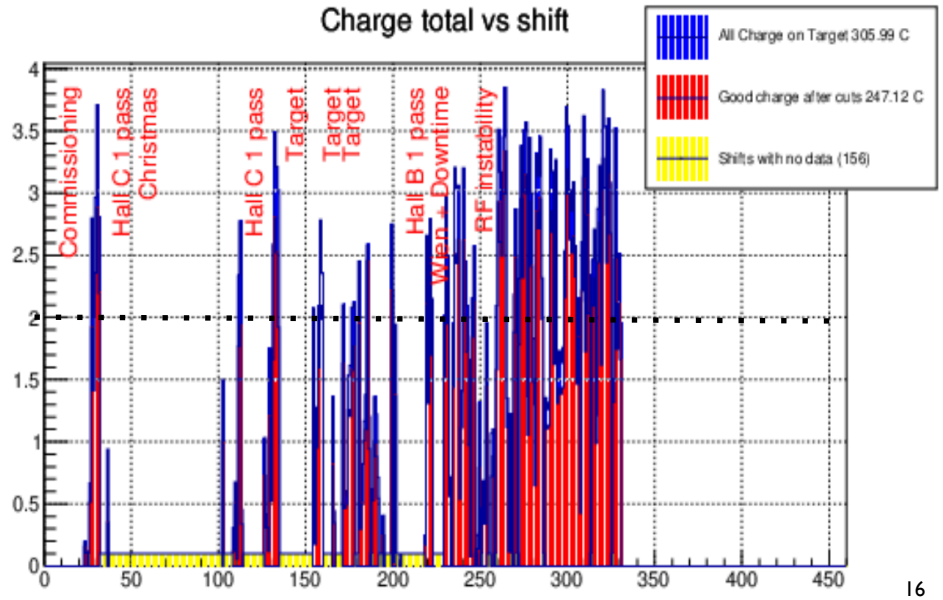


CREX Running



Goal: 453 C
Achieved: 54%
Need: 2C per shift to hit the goal.

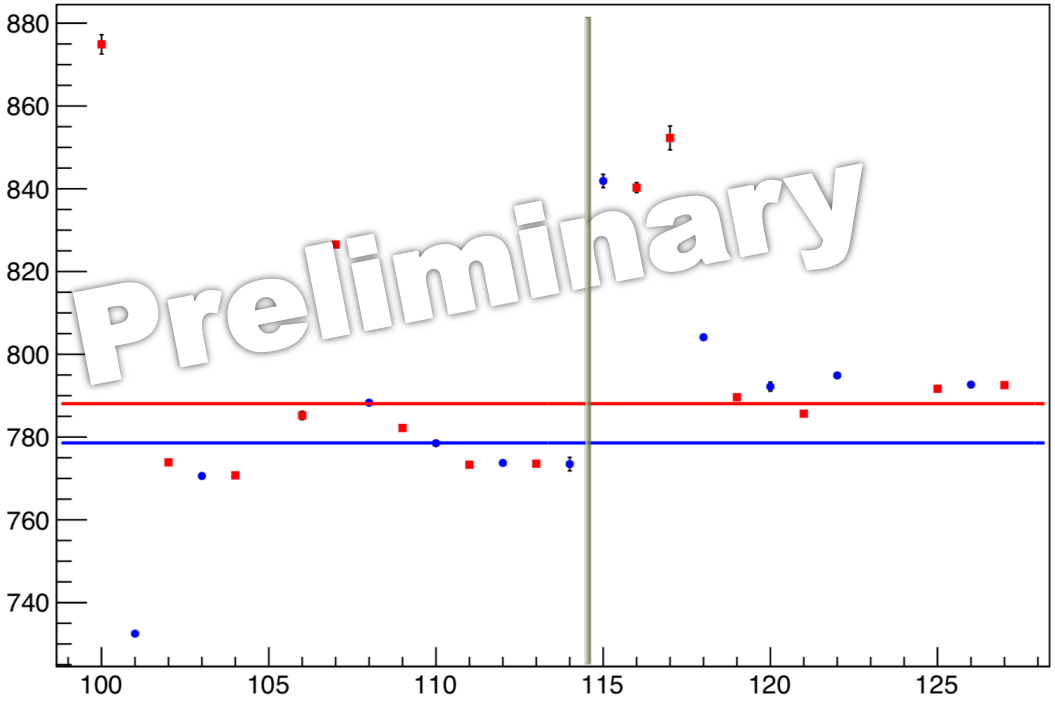


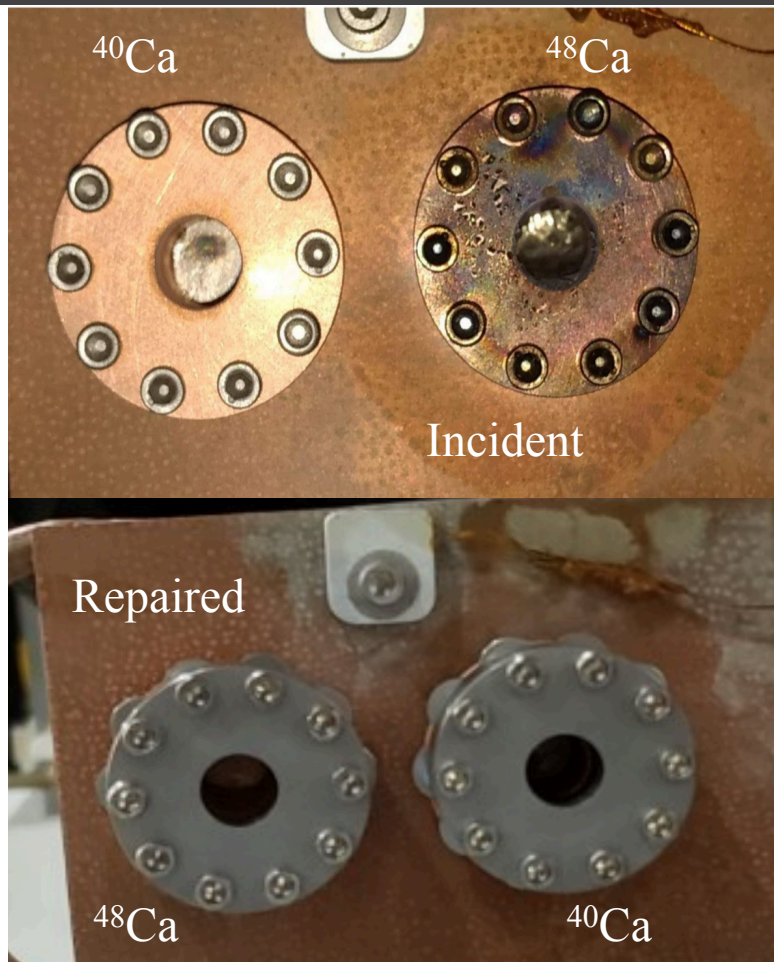


CREX Running

- We had a target accident on Jan 18.
- Thanks to target and radiation group to replace the target quickly and bring us back to production

RMS vs “slug”

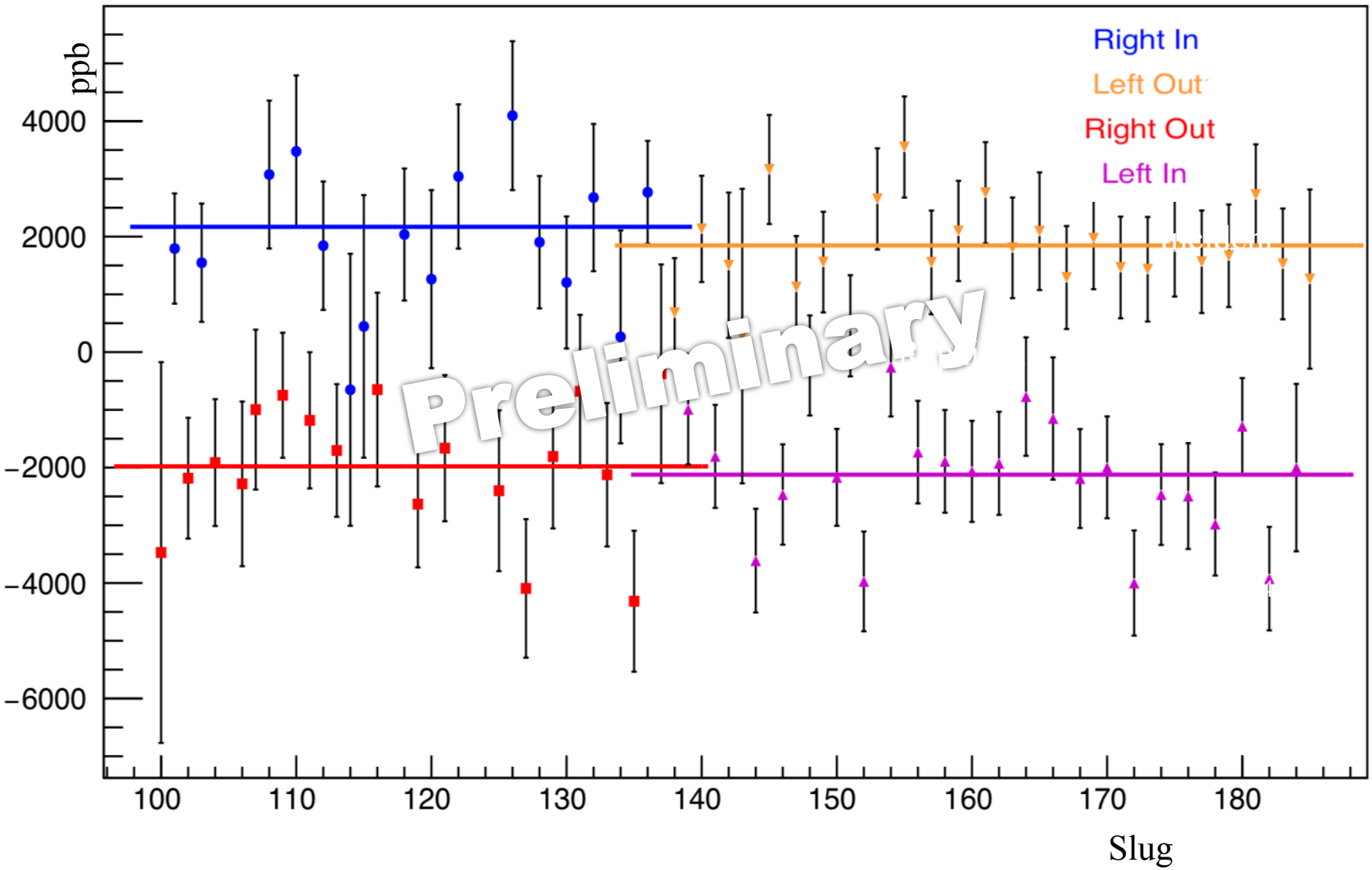




- Collimators (Tungsten, copper nickel) have been installed on both targets upstream

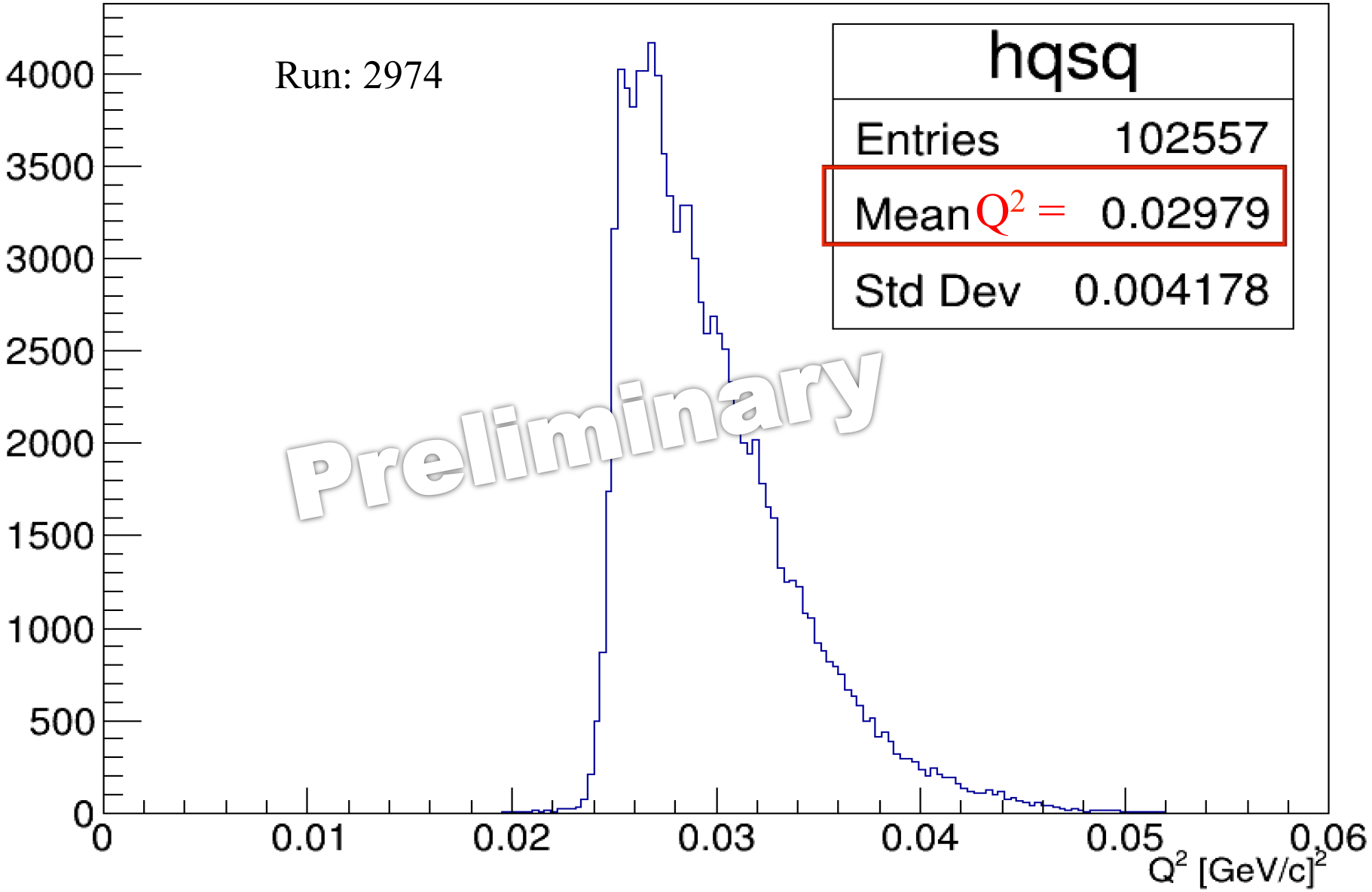
CREX Data

Regression Corrected Asymmetries



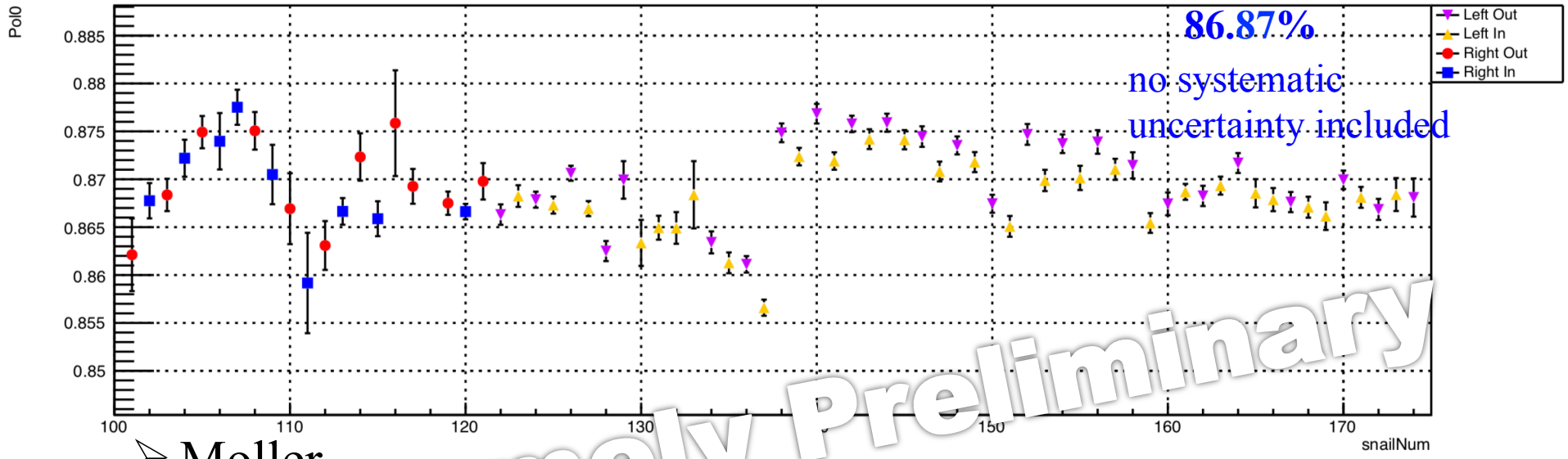
CREX Data

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

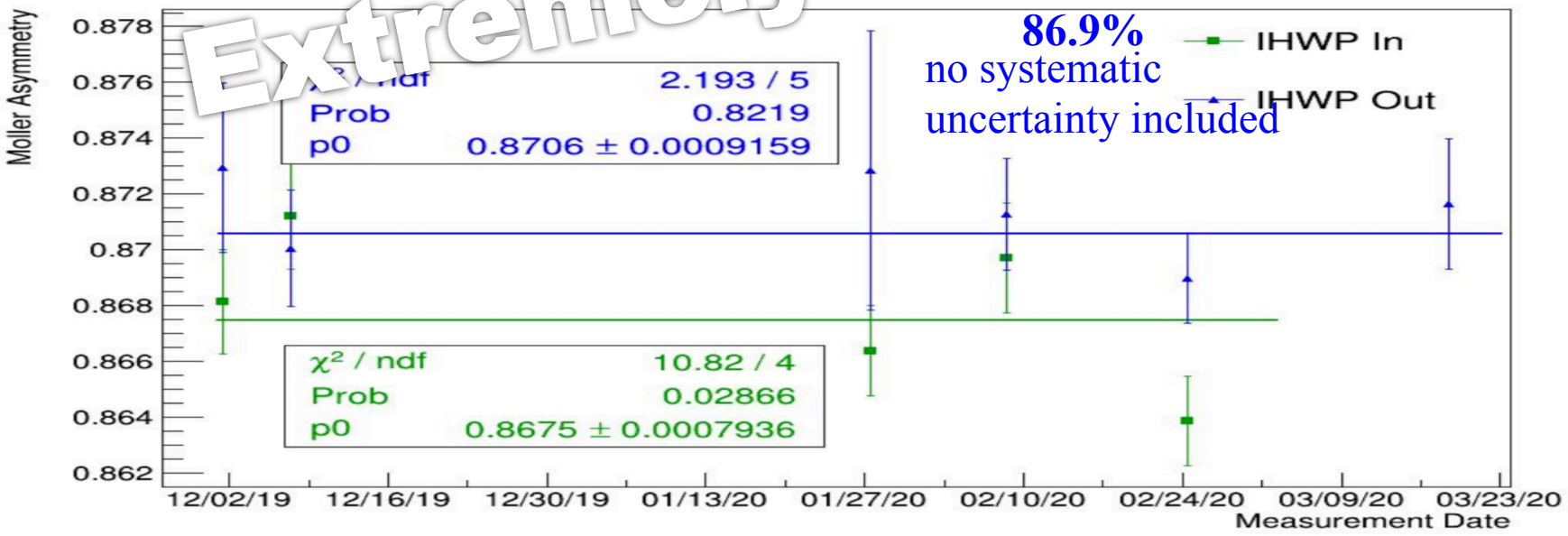


CREX Beam Polarimetry Measurements

- Compton



- Moller

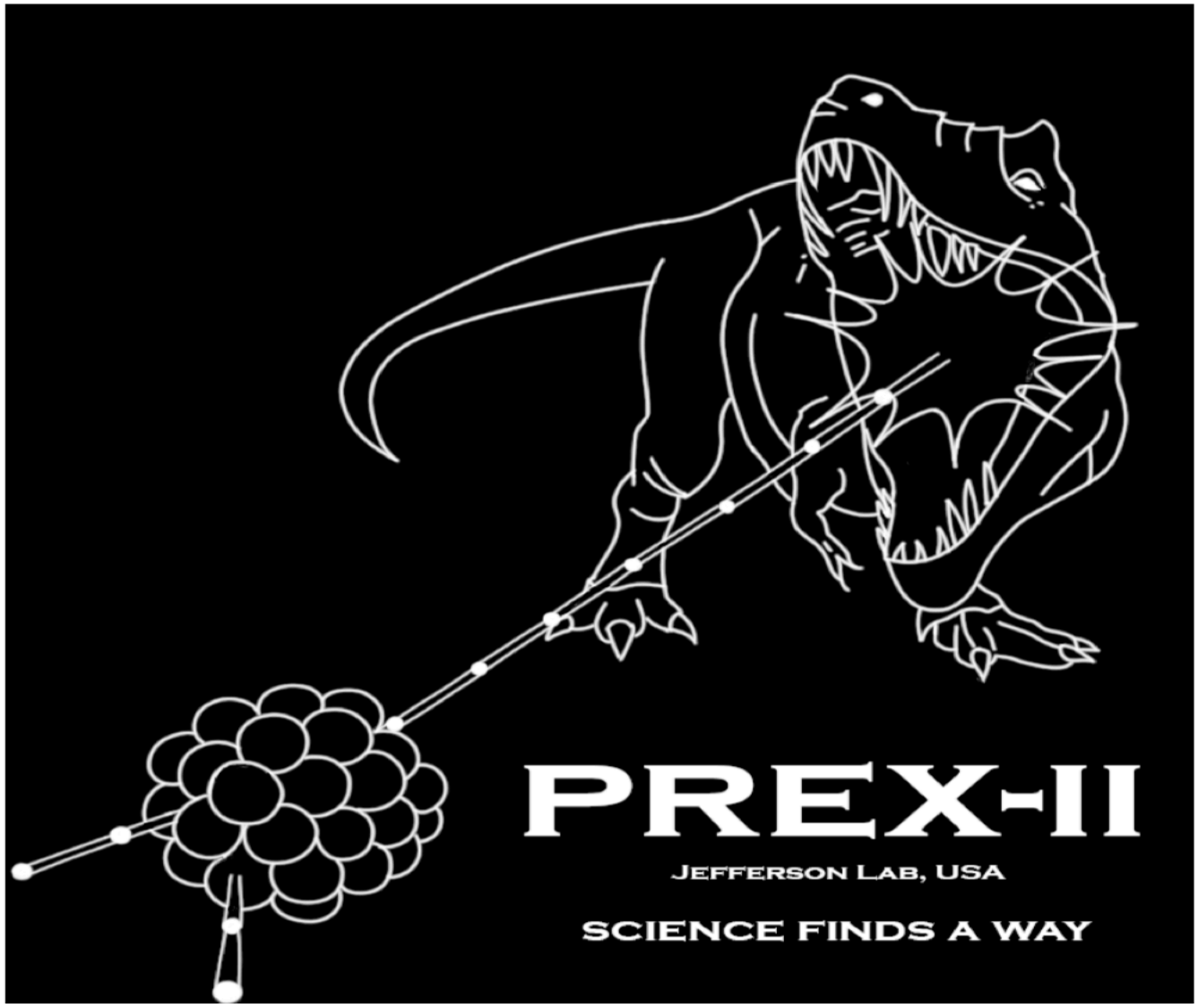


Extremely Preliminary

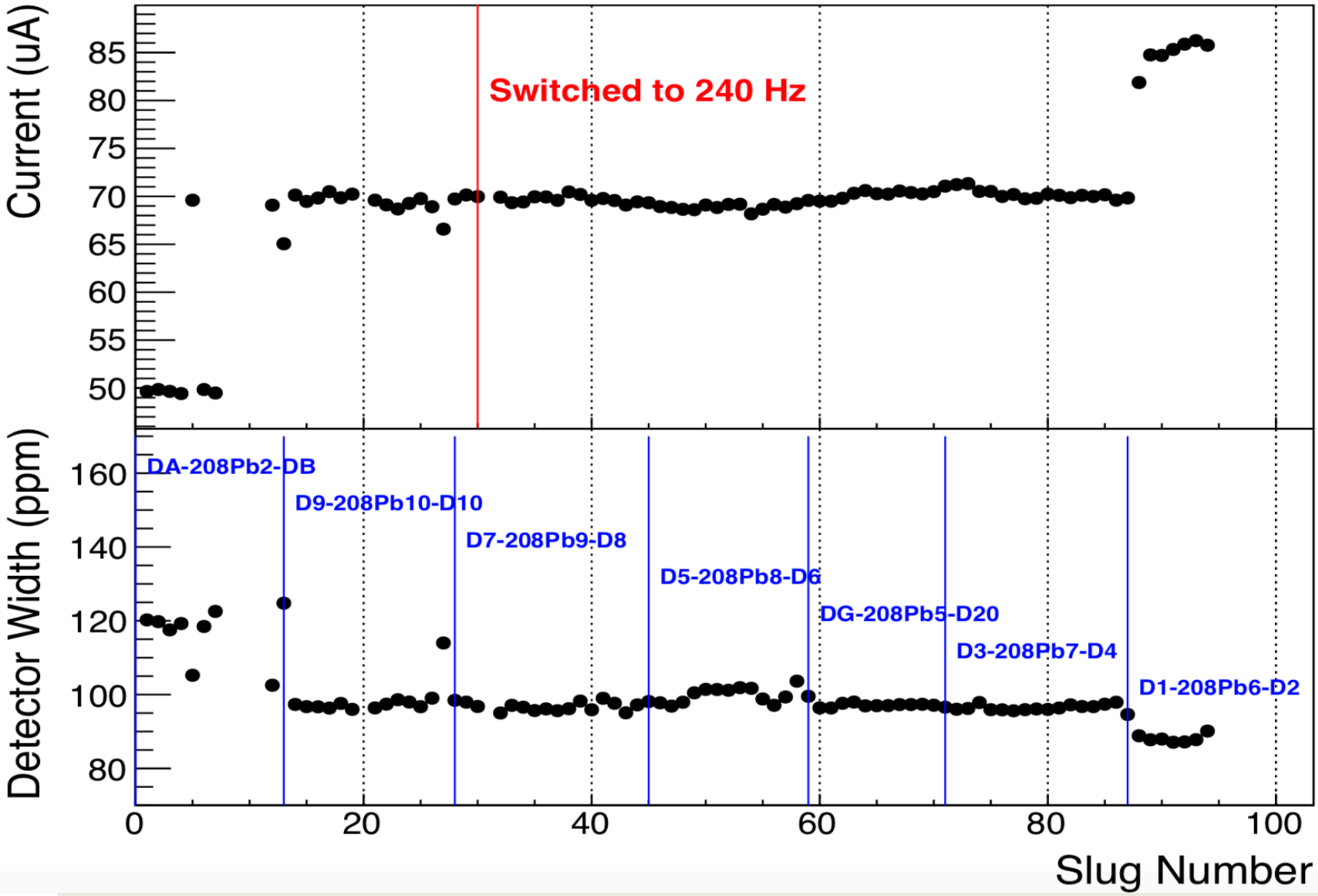
Summary

- PREX/CREX - fundamental nuclear physics with many applications.
- We are working on data analysis- aiming PREX-2 results in fall APS 2020 meeting (Oct. 2020)
- CREX will be resumed on July 31

Thank you !

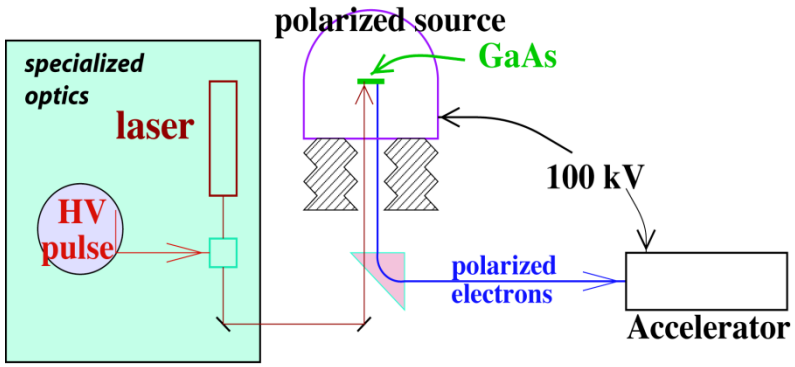


PREX-2 Data


Current (uA)
85
80
75
70
65
60
55
50
Switched to 240 Hz
Detector Width (ppm)
160
140
120
100
80
DA-208Pb2-DB
D9-208Pb10-D10
D7-208Pb9-D8
D5-208Pb8-D6
DG-208Pb5-D20
D3-208Pb7-D4
D1-208Pb6-D2
0
20
40
60
80
100
Slug Number

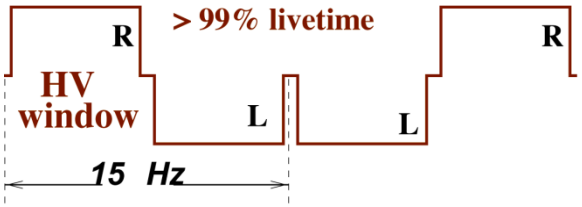
Parity Experiment Method

(integrating mode)



rapid, random, helicity flipping

Rapid, Random Helicity Flips



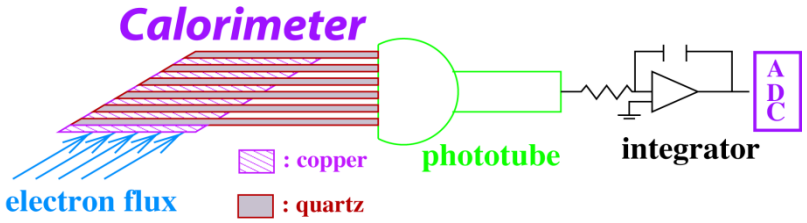
Measure flux F for each window

$$A_{\text{window pair}} = \frac{F_R - F_L}{F_R + F_L}$$

Flux Integration Technique:

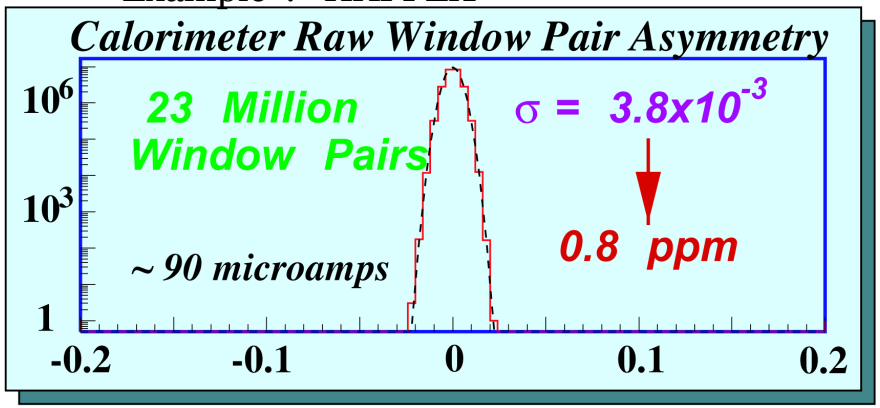
C-REX : 140 MHz

PREX: 500 MHz



Signal Average N Windows Pairs: $A \pm \frac{\sigma(A)}{\sqrt{N_{\text{windows}}}}$

Example : HAPPEX



No non-gaussian tails to +/- 5σ

Borrowed from *Robert Michaels*

PREX/CREX Experiments

PREX-2: 3% stat, 0.06 fm
CREX: 4% stat, 0.02fm

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%**

Achieved, published
statistics limited result,
systematics well under control

PREX-II
E=1.1 GeV, 5°
A=0.6 ppm
70 μA, 25+10 days

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%**

*Experience suggests that leading systematic errors can be improved beyond proposal

CREX
E=1.9 GeV, 5°
A = 2.3 ppm
150 μA, 35 + 10 days

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	**2.4%**