CREX Polarimetry

2022 Hall A Winter Collaboration Meeting

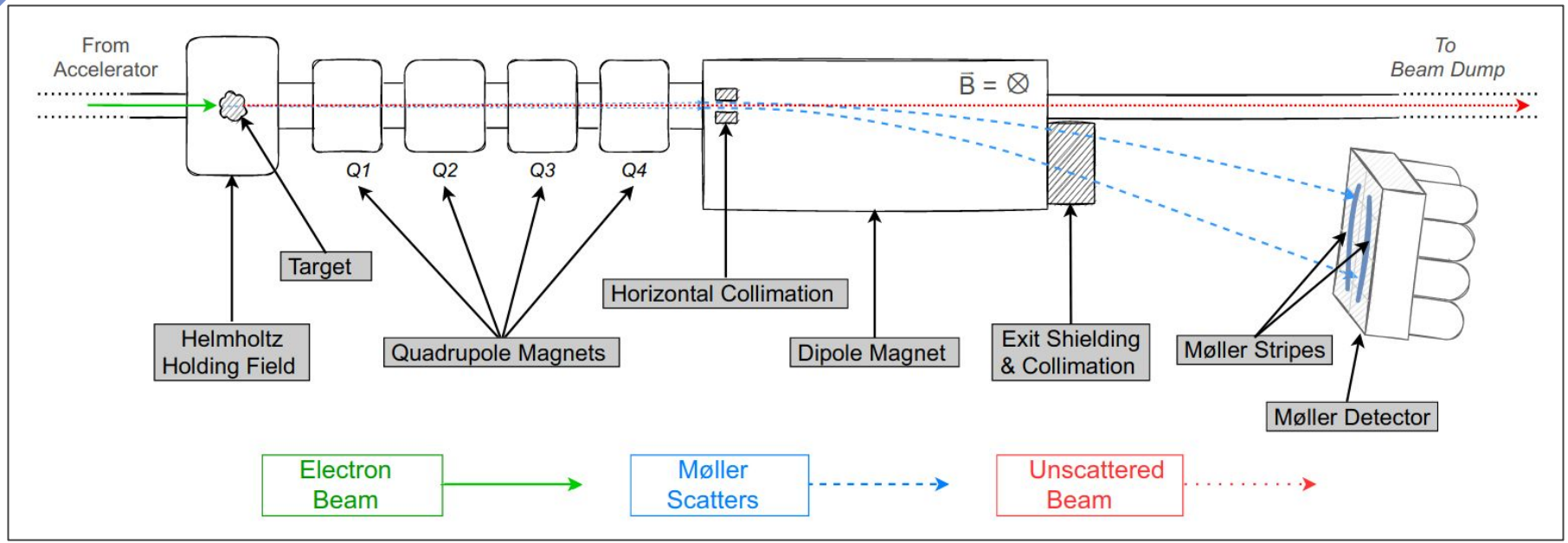
Eric King
On behalf of the CREX Møller and Compton Polarimetry Working Groups

TEMPLE UNIVERSITY

Jefferson Lab

Polarimeters

Hall A Møller Polarimeter



- Beam scatters off polarized foil.
- Mollers are steered by quadrupoles into dipole.
- Dipole bends events to detector situated below the beamline.

Hall A Møller Polarimeter

Polarized Cross section

Unpolarized Cross-section

Analyzing Powers

$$\frac{d\sigma^M}{d\Omega} = \frac{d\sigma_0^M}{d\Omega}\left(1 + \sum P_{beam,i} P_{targ,j} A_{ij}\right)$$

Utilizes Møller scattering (elastic ee)

Measures large ~5% QED asymmetry for polarized scatters

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Brute Force Setup

$P_{targ} \parallel P_{beam}$

$$A_{zz} = -\frac{\sin^2\theta^*(7+\cos^2\theta^*)}{(3+\cos^2\theta^*)^2} \approx -\frac{7}{9}$$

Around 90° COM scatters

Hall A Møller Polarimeter

Polarized Cross section

Unpolarized Cross-section

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Around 90° COM scatters

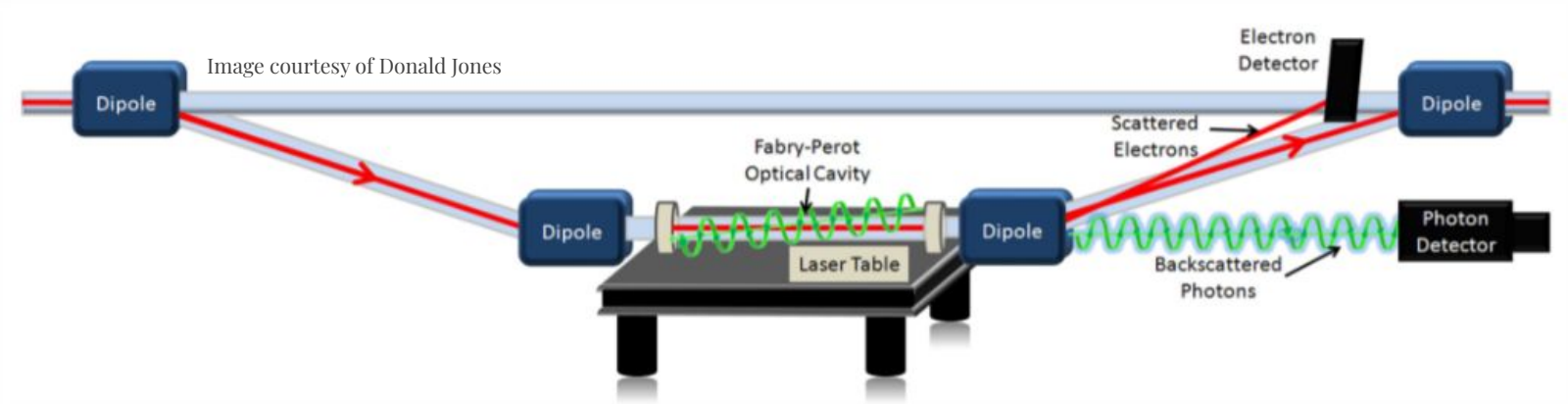
Measured asymmetry

Target polarization known

Computed analyzing power

$$\frac{\frac{d\sigma}{d\Omega}_a - \frac{d\sigma}{d\Omega}_b}{\frac{d\sigma}{d\Omega}_a + \frac{d\sigma}{d\Omega}_b} = A_{meas} = P_{beam} P_{targ} \langle A_{zz} \rangle$$

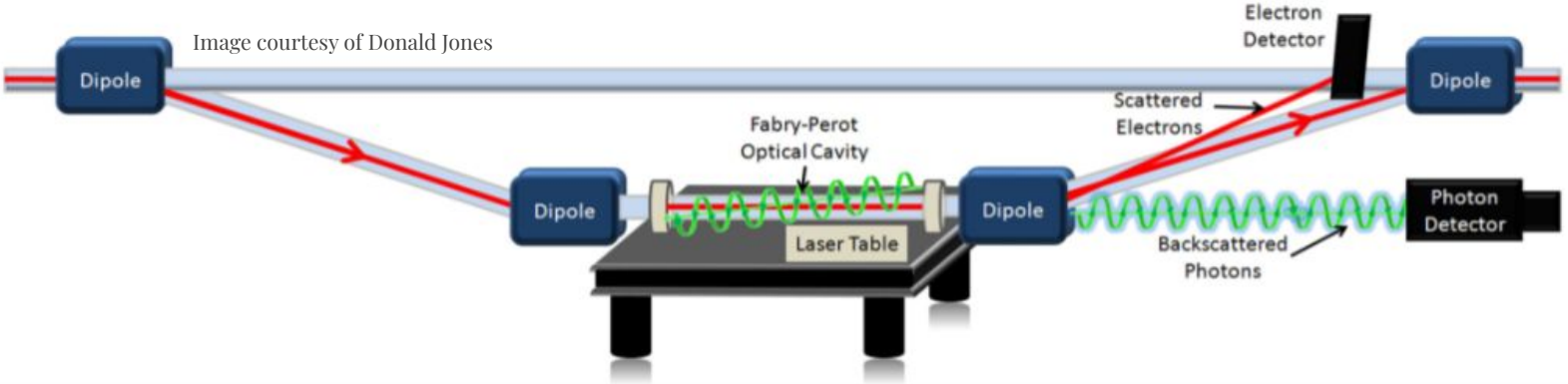
Compton Polarimeter



Takes advantage of the scattering asymmetry of Compton Scattering

- Beam electrons interact with γ in optical cavity.
- Back-scattered photons picked up by photon detector.
- Compton polarimetry allows a non-invasive continuous measurement of beam polarization while experiments are running.

Compton Polarimeter



In order to subtract out backgrounds, laser alternates between on and off phases.

Measured asymmetry

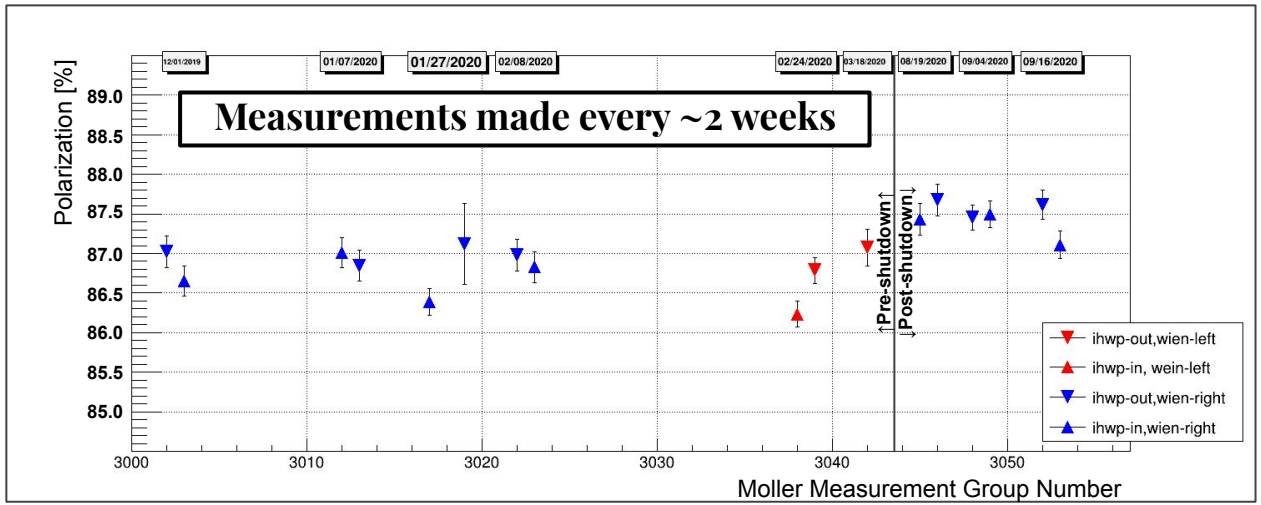
γ are ~circularly polarized

Computed longitudinal analyzing power

$$\langle A_{ON} \rangle - \langle A_{OFF} \rangle = \mathcal{A}_{exp} = P_{beam} P_{\gamma} A_{\mathcal{L}}$$

Polarimetry Results

Møller Measurements During CREX



Data set:	All			Pre-Shutdown			Post-Shutdown		
Møller Mean Pol	87.08%	±	0.06%	86.72%	±	0.08%	87.43%	±	0.08%

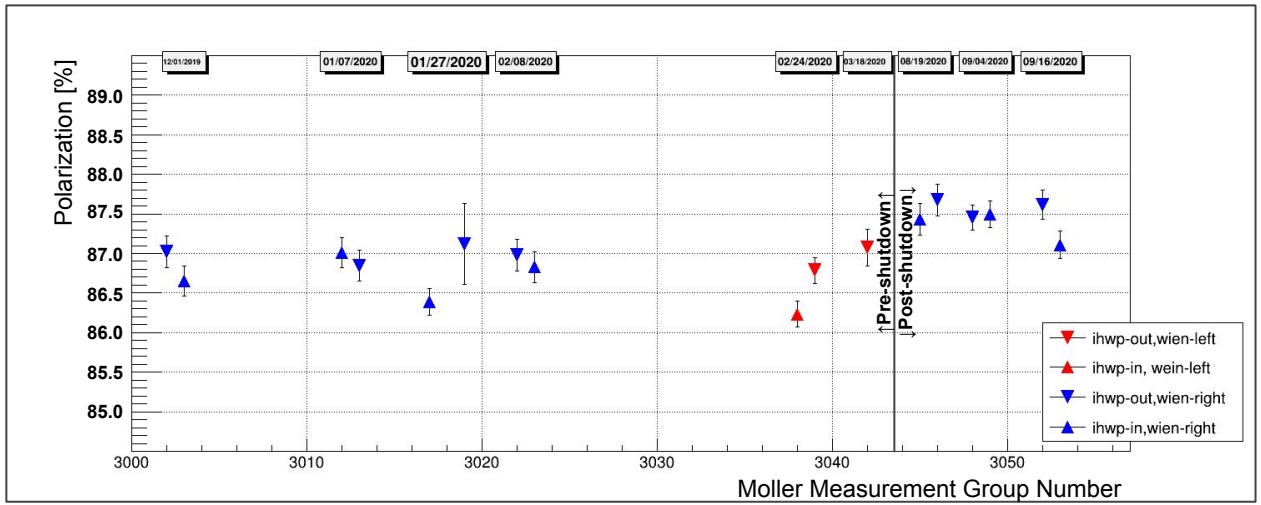
Moller Measurements During CREX

Systematics Table

Source	Value	$\delta P/P$ (%)
A_{zz}	0.75421	0.16
Foil Polarization	0.08005	0.57
Dead Time Correction	0.148%	0.15
Accidental Correction	0.205%	0.04
Charge Normalization	0.029%	0.01
Null Asymmetry (Cu Foil)	0.0%	0.22
PITA Variation	—	0.06
Spin Precession (dP/P)	—	0.04
High Current Extrapolation	—	0.50
Bleed through	—	0.18
Slit Dependence	—	0.10
	Total	**0.85**

Total Møller systematic uncertainty during CREX: **0.85%**

Majority contributors are foil polarization uncertainty and high-current extrapolation uncertainty.



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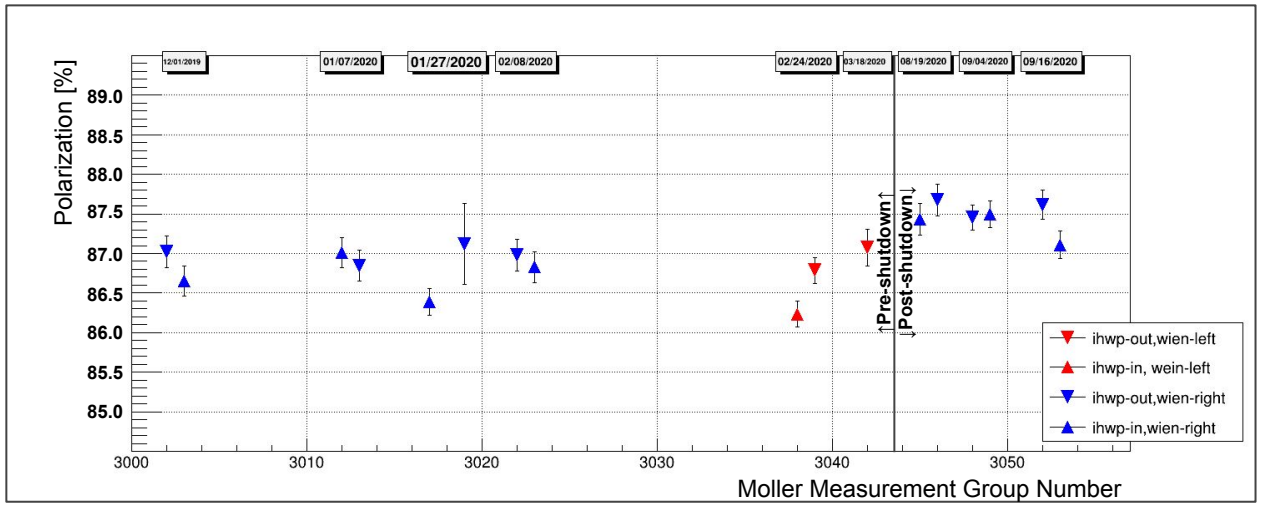

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Møller Mean Pol	87.08% ± 0.06%	86.72% ± 0.08%	87.43% ± 0.08%

➢ **Moller mean polarization over CREX was 87.08% ± 0.06% (stat) ± 0.85% (sys)**

CREX Systematics Comparison to PREX-I

Systematics Table CREX

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Systematics Table PREX-I

Variable	dA / A
Foil Polarization	0.25%
Target Saturation	0.3%
Target Temperature	0.02%
Target-to-target variation	0.5%
Analyzing Power	0.3%
Levchuk Effect	0.5%
Dead time	0.3%
Background	0.3%
Others	0.5%
Total	**1.1%**

0.39%

Data: O. Glamazdin, PREX Collaboration Meeting (2011)

- Quoted CREX "Foil Polarization" systematic: polarization, saturation and temperature corrections. We took a very conservative approach to this but it remains a dominant systematic.

CREX Systematics Comparison to PREX-I

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- [Major Improvement] Levchuk effect: Rolled into our analyzing power systematic.
  - We had an effective method for effectively eliminating this and the total systematic uncertainty for the Levchuk Effect was **0.06%**

CREX Systematics Comparison to PREX-I

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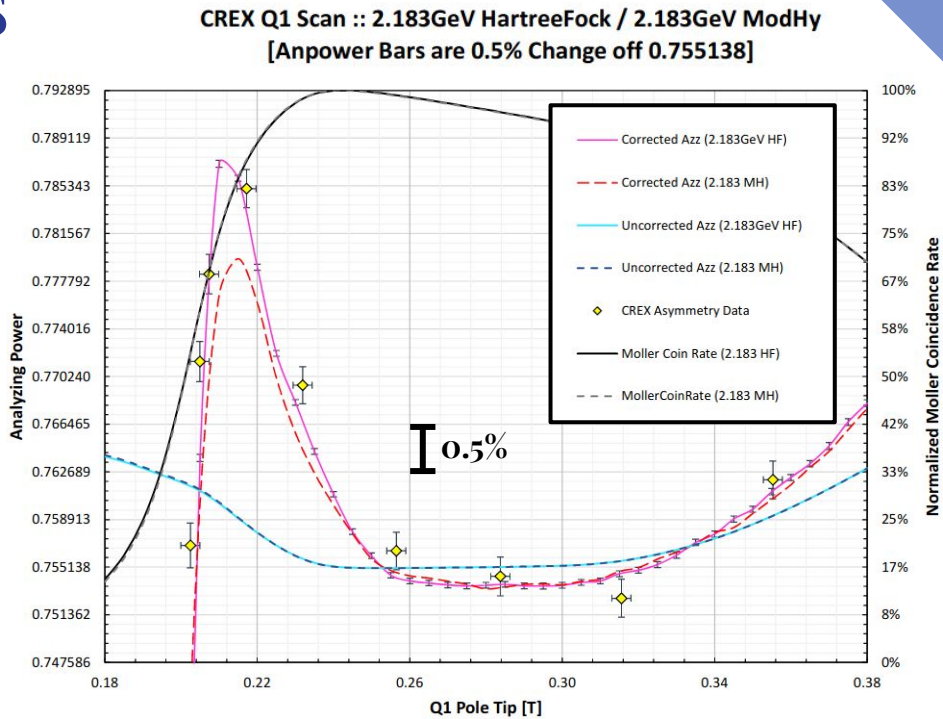
Data: O. Glamazdin, PREX Collaboration Meeting (2011)

- High Current Extrapolation: Experiment runs at ~100 uA and Moller polarimetry is performed at ~1 uA range.
  - Constrained by 2007 Hall C studies to the 0.5% level.
  - Unsure if this was considered in PREX-I systematics.

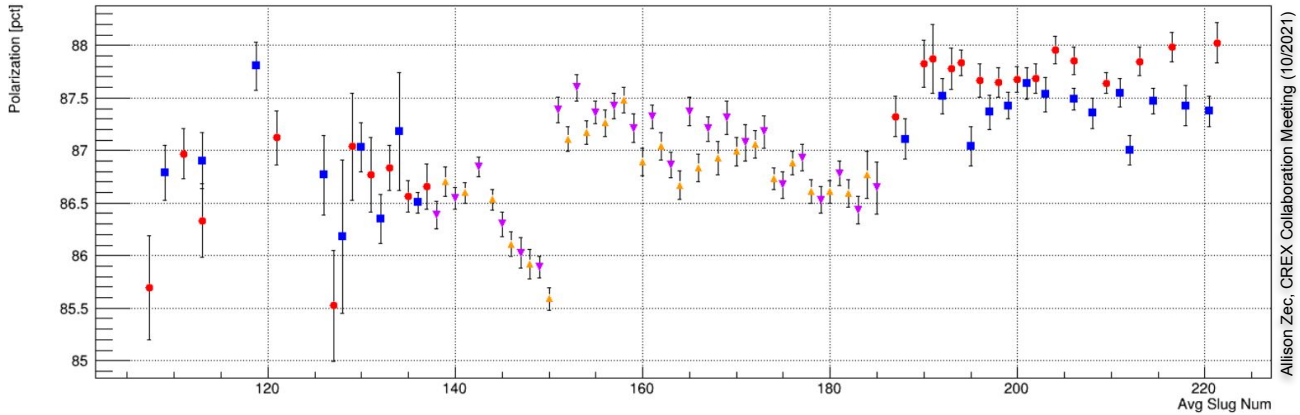
Moller Improvements

- Addition of harp for precision alignment of beam onto foil.
  - This made CREX Møller setups (and measurements) highly reproducible
- Granted systematics study time (image on right) that provided fundamental improvements on understanding our dominant analyzing power correction (Levchuk Effect).



- Modified Hydrogen wavefunctions - - - - - - used for Levchuk Effect are now replaced by Hartree-Fock derived momentum distributions ———.

Compton Results During CREX



- Compton measurements aligned in time with CREX slugs
- Compton polarization average weighted by A_{PV} uncertainty of matching slugs.

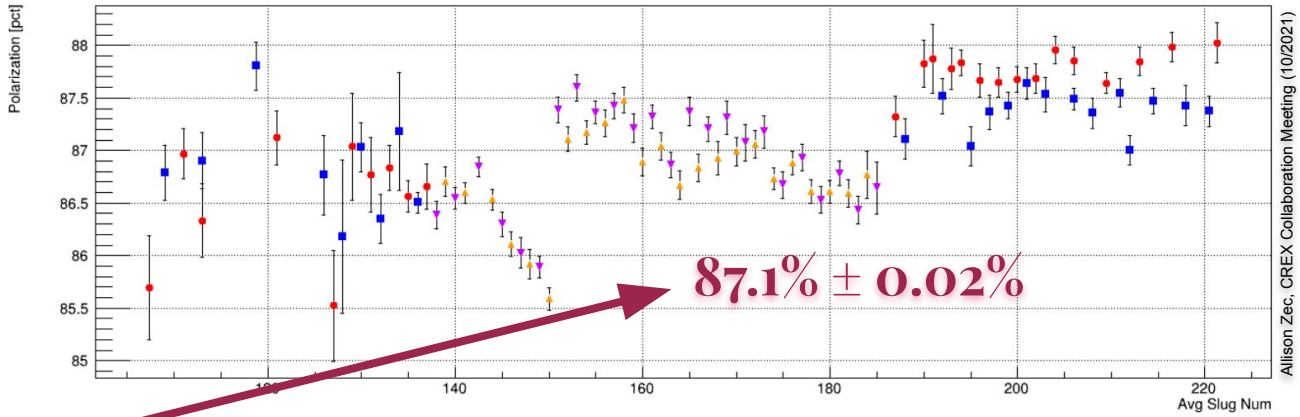
Compton Results During CREX

The Compton team examined multiple averaging models all of which yielded consistent results:

Escargatoire Average
87.118% ± 0.018%

Piecewise Fitting
87.119% ± 0.016%

Mini-Esc. Average
87.104% ± 0.019%



- Compton measurements aligned in time with CREX slugs
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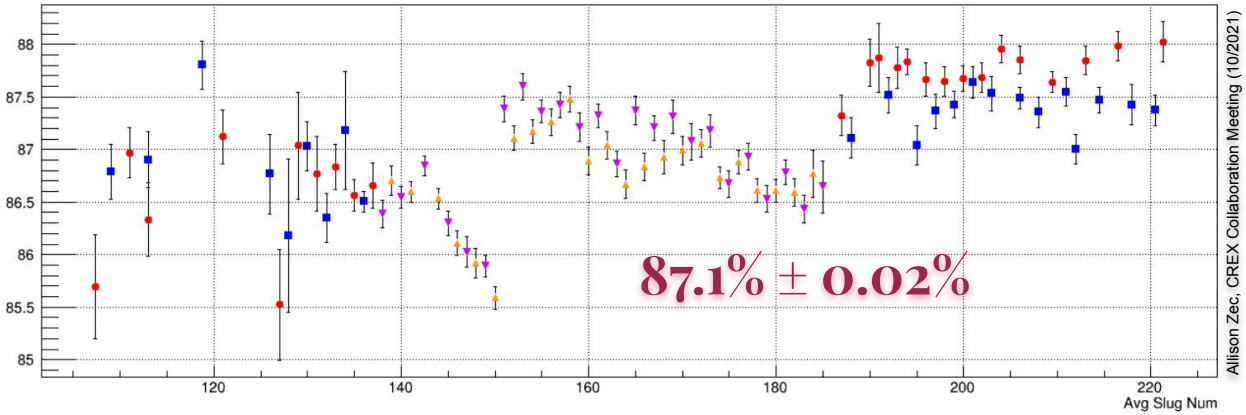
Compton Results During CREX

Compton Systematics Table

Source	Relative Correction	Uncertainty
Collimator	-	0.20%
Laser DOCP	0.29%	0.45%
Gain Shift	-	0.15%
Model	-	0.02%
Beam Energy	0.103%	0.05%
Nonlinearity	-	0.02%
Rad Corr	0.3%	< 0.01%
Statistics	-	0.02%
Total	-	0.52%

Data: Allison Zec, CREX Collaboration Meeting (10/2021)



Total Compton systematic was 0.52%

Driving contributor to Compton systematic is the degree of circular polarization at 0.45%.

- Compton measurements aligned in time with CREX slugs
- Compton polarization average weighted by A_{PV} uncertainty of matching slugs.

➢ **Compton mean polarization over CREX was 87.1% ± 0.02% (stat) ± 0.52% (sys)**

Compton Systematics Compared to HAPPEX-III

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Allison Zec, CREX Collaboration Meeting (10/2021)

HAPPEX-III Systematics Table

Systematic Errors	
Laser Polarization	0.80%
Signal Analyzing Power:	
Nonlinearity	0.30%
Energy Uncertainty	0.10%
Collimator Position	0.05%
Analyzing Power Total	**0.33%**
Gain Shift:	
Background Uncertainty	0.31%
Pedestal Uncertainty	0.20%
Gain Shift Total	**0.37%**
Total Uncertainty	0.94%

Data: M. Friend, et al, NIM A676 (2012) 96-105

➢ [Major Improvement] Measurement of the DOCP of the Compton laser.

Compton Systematics Compared to HAPPEX-III

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Gain Shift Total	**0.37%**
Total Uncertainty	0.94%

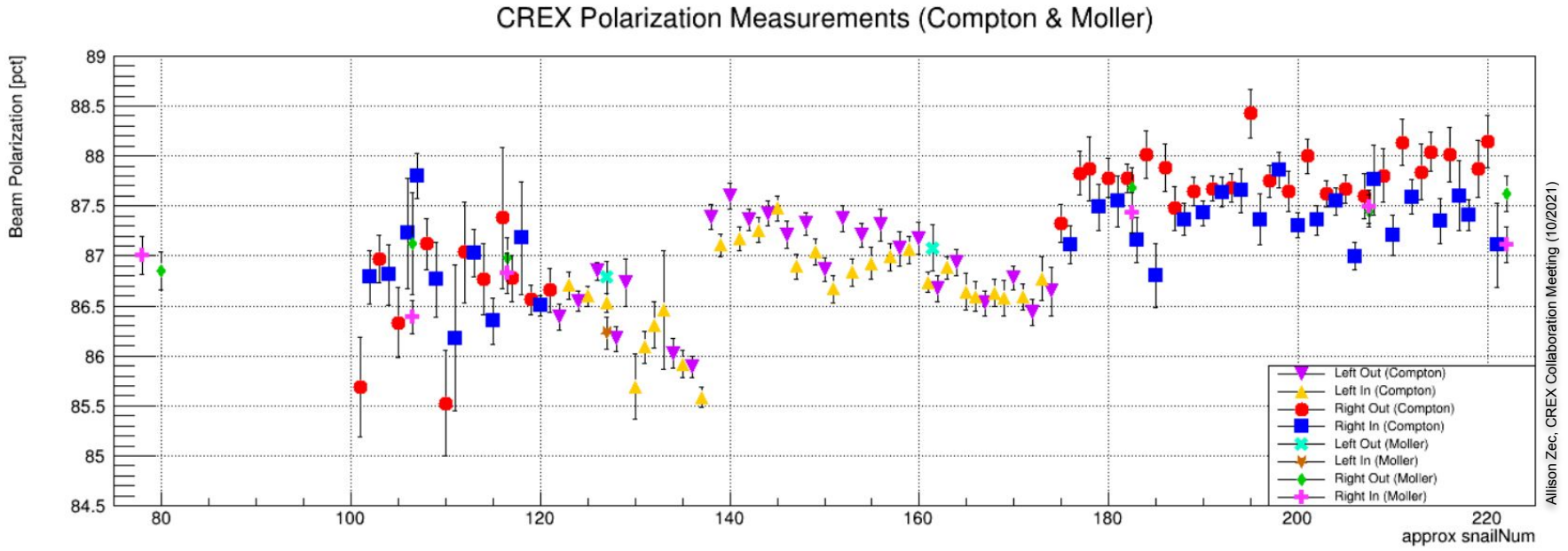
Data: M. Friend, et al, NIM A676 (2012) 96-105

➢ [Major Improvement #2] Better understanding of the photon detector gain shift.

Final CREX Polarization

Moller/Compton Combined Results

Compton and Møller Measurement Overlay



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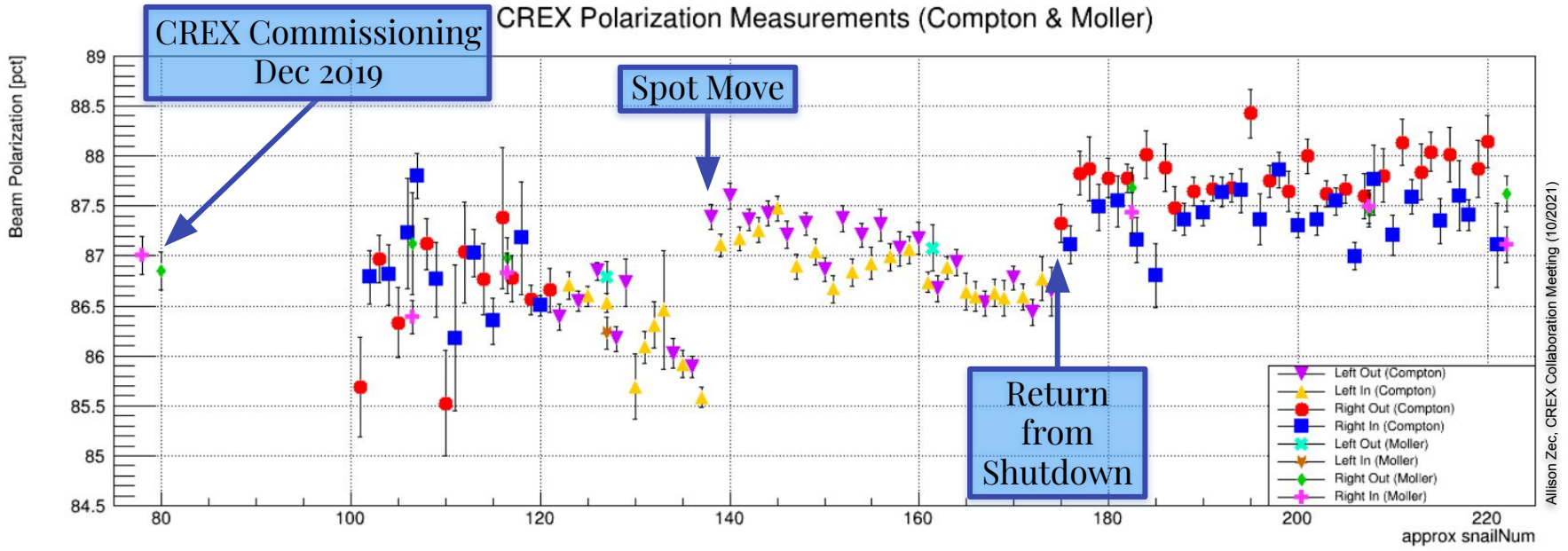

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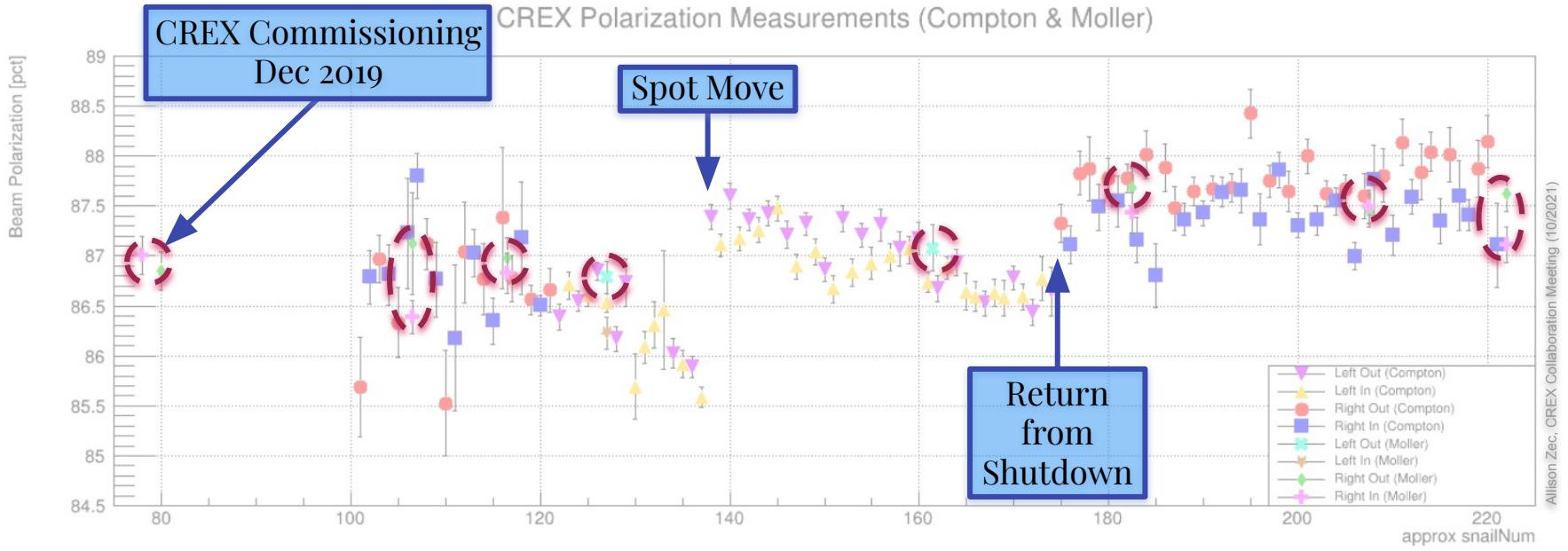
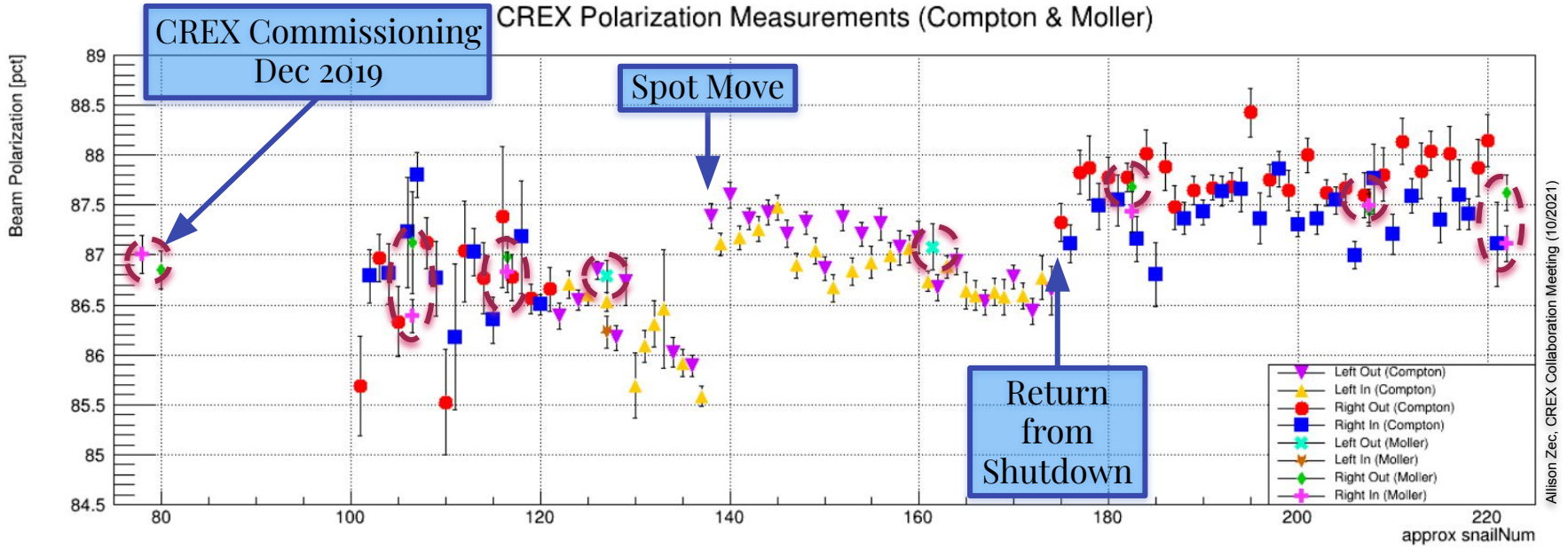


I've made an attempt to highlight the less-frequent Moller measurements among the Comptons

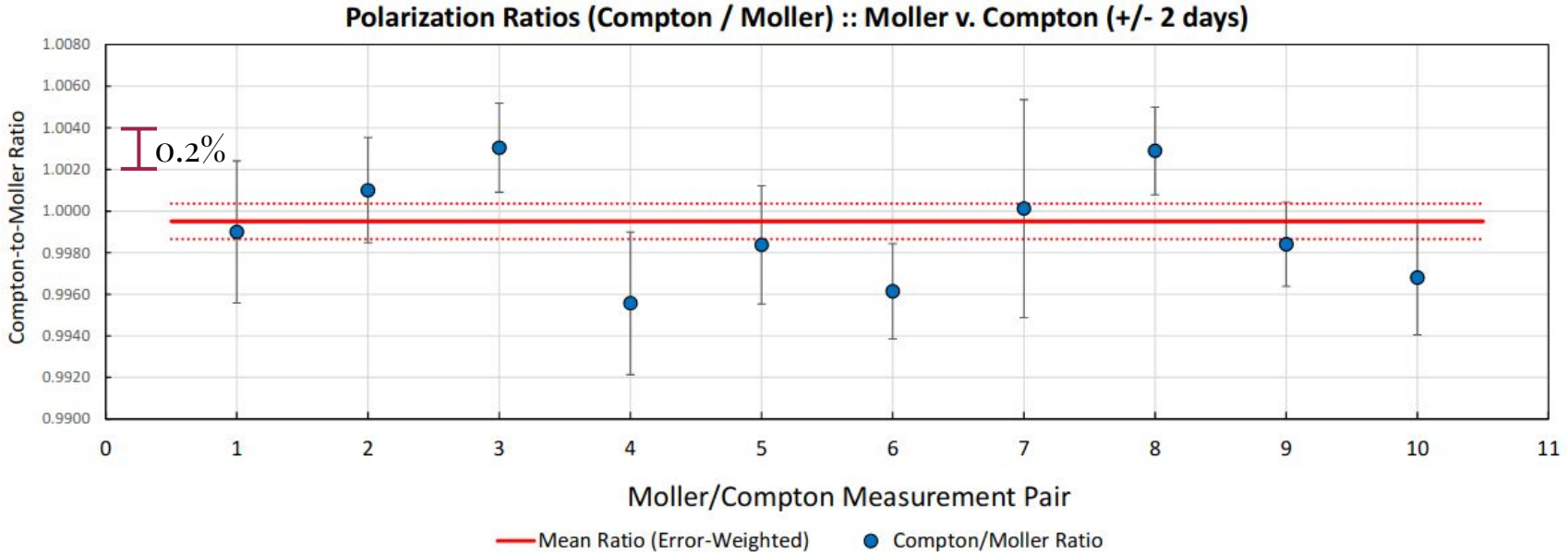
Compton and Møller Measurement Overlay



➢ Møller and Compton measurements were consistent throughout the CREX experiment.

I've made an attempt to highlight the less-frequent Moller measurements among the Comptons

Comparison of Compton & Møller Polarization Measurements



- Møller measurements were compared to Compton measurements taken within roughly ± 48 hours.
- The mean Compton/Møller ratio was **0.9995 ± 0.0008**

  Ratio consistent with 1 at the ~0.1% level.

Final Combined Result for CREX

CREX Running Moller Result		CREX Running Compton Result
$\mathcal{P}_e=(87.1\pm0.85)\%$	+	$\mathcal{P}_e=(87.1\pm0.52)\%$

- Sub 1% precision measurement from Moller.
- This is a JLab tie for 'best' for a Møller measurement (between Hall A and C Møller polarimeters).
    - This is a marked improvement for the Hall A polarimeter.
- Highest precision for any experiment performed at JLab.
- Compton measurement at 0.5% is an *apparent* record breaker.
    - There's no knowledge of any experiment claiming better precision.

Final Combined Result for CREX

CREX Running Moller Result

$\mathcal{P}_e = (87.1 \pm 0.85)\%$

+

CREX Running Compton Result

$\mathcal{P}_e = (87.1 \pm 0.52)\%$

CREX Compton+Moller Combined Result

$\mathcal{P}_e = (87.1 \pm 0.44)\%$

We have a combined **0.44%** high-precision polarimetry measurement!

- Substantial systematic uncertainty improvements
  - Compton: In high-precision territory 0.52%.
  - Møller: Improvements over previous measurements; current systematics are likely overly-convservative.
  - Major step towards future PV experimental requirements.
- Two independent measurements utilizing different physical processes

Combined 0.44%

THE TWO MEASUREMENTS AGREE !!!

CREX Polarimetry Teams

Møller:

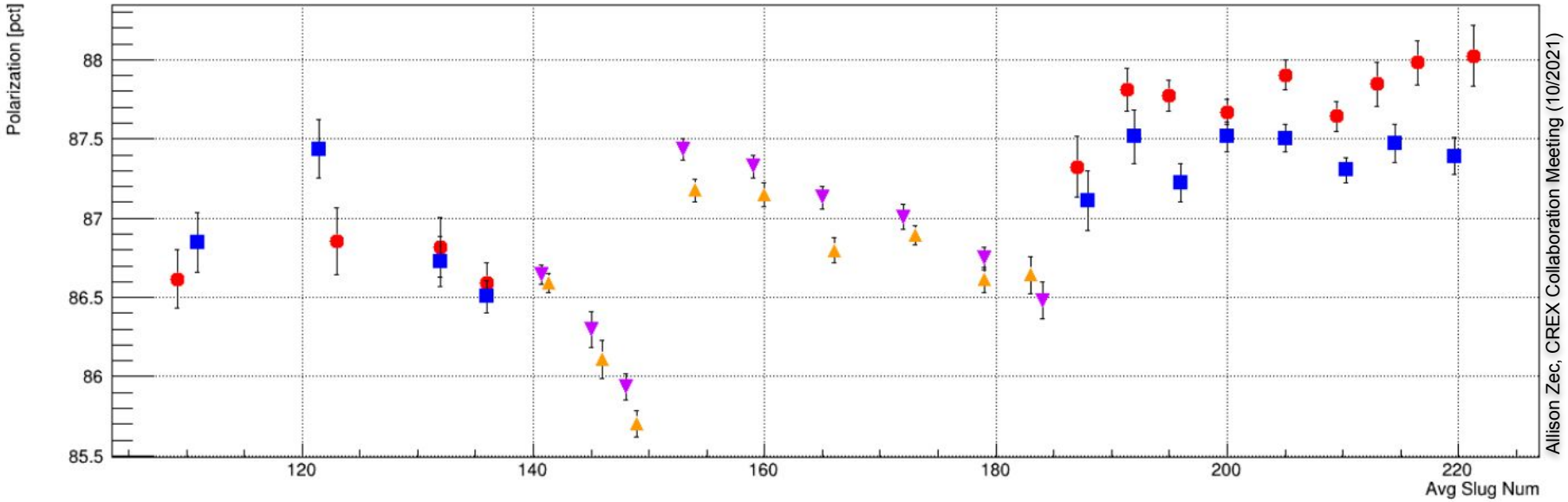
Eric King; Paul Souder; Donald Jones; Bill Henry; Jim Napolitano; Simona Malace; Dave Gaskell; and Kent Paschke.

Compton:

Allison Zec; Dave Gaskell; Amali Premithilake; Juan Carlos Cornejo; Kent Paschke; Ciprian Gal; Caryn Palatchi; and Mark Dalton.

Backup Slides

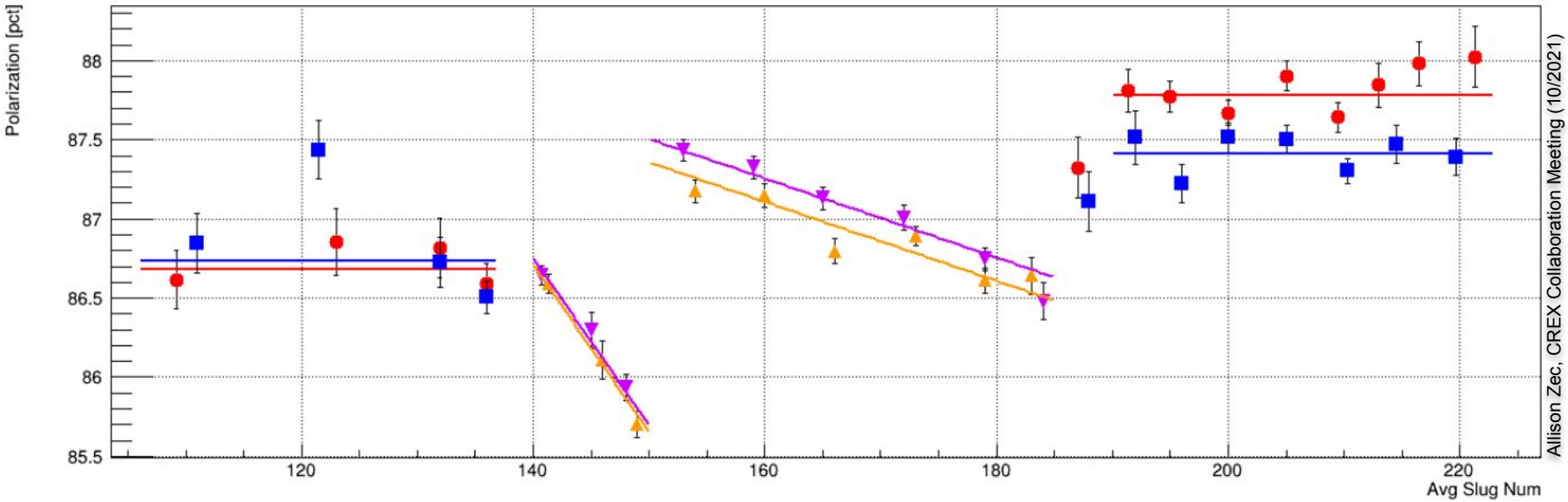
Compton Polarization Averaging [Method 1]



- Grouped Compton measurements which are aligned in time with CREX slugs.
- Groupings then weighted by error of corresponding A_{PV} measurement.
- Average calculated polarization:

  (87.118 ± 0.018 (stat))%

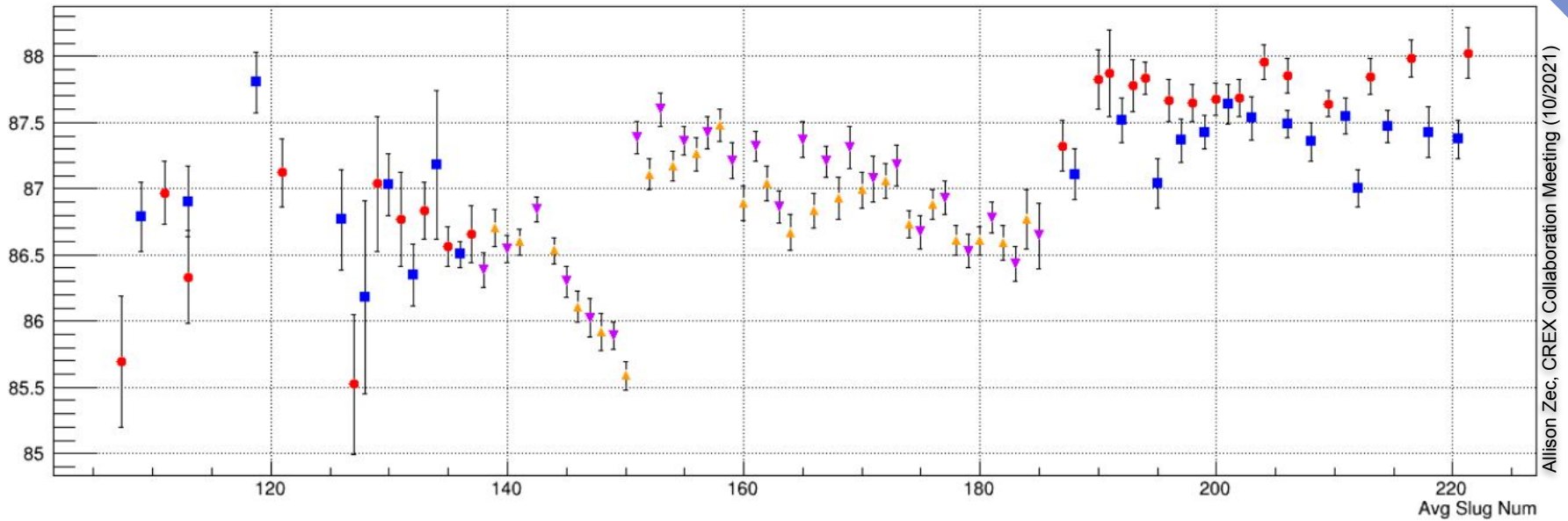
Compton Polarization Averaging [Method 2]



- Grouped Compton measurements which are aligned in time with CREX slugs.
- Groupings then weighted by error of corresponding A_{PV} measurement.
- Average calculated polarization:

  (87.119 ± 0.016 (stat))%

Compton Polarization Averaging [Method 3]



- Compton measurements grouped IFF they overlapped with CREX slugs.
- Averages derived from fit evaluations and uncertainties come from fit parameters.
- Average calculated polarization:

  (87.104 ± 0.019 (stat))%