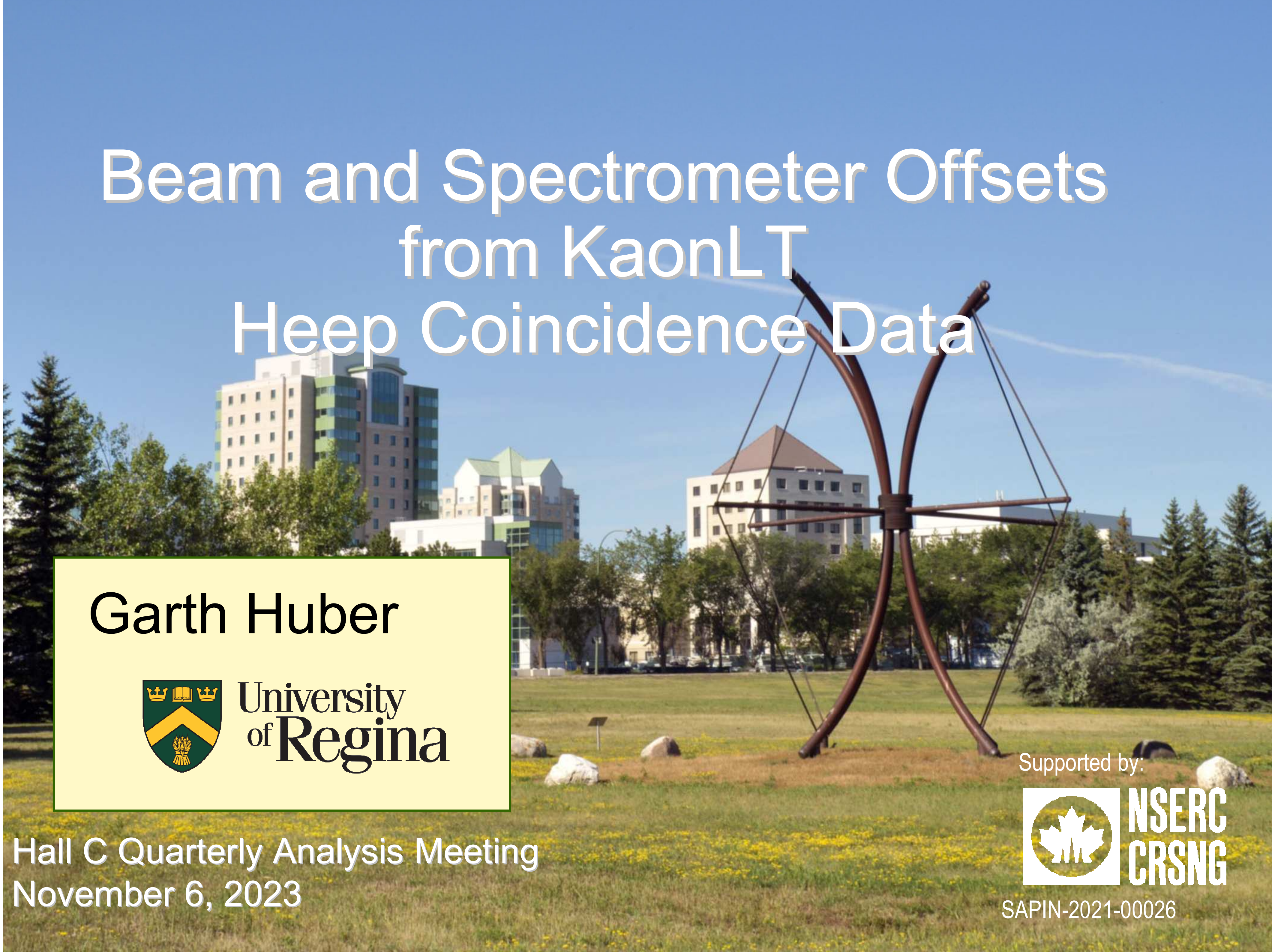

Beam and Spectrometer Offsets from KaonLT Heep Coincidence Data

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KaonLT Heep Coincidences

- ^{1}H(e,e'p) measurements are OVER–CONSTRAINED
- This information can be used to provide accurate calibrations of spectrometer angles, spectrometer momenta, and beam energies

- **OFFSET** = difference between the measured value (e.g. spectrometer floor angle, or Arc energy beam energy) and corrected value from Heep Coincidence data

- **KaonLT acquired 5 sets of HeeP Coincidence Data:**
  - 3834.9 MeV HMS=38.605°, –2.026 SHMS=29.31°, +2.583
  - 4932.0 MeV HMS=27.15°, –3.124 SHMS=33.50°, +2.583
  - 6190.1 MeV HMS=27.27°, –3.571 SHMS=28.56°, +3.486
  - 8208.9 MeV SHMS=23.99°, –4.672 HMS=25.28°, +4.371
  - 10585.4 MeV HMS=18.845°, –6.590 SHMS=26.147°, +4.840

- **PionLT Part 1 (Summer 2019) acquired 3 lower energy sets:**
  - 2750.0 MeV HMS=37.10°, –1.729 SHMS=37.10o, +1.729
  - 3660.2 MeV HMS=35.65°, –2.114 SHMS=32.40°, +2.300
  - 4559.7 MeV HMS=33.05°, –2.553 SHMS=29.90°, +2.792

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In–Plane Offsets

- $^1H(e,e'p)$ reaction is inherently coplanar
  - Well understood kinematics can be used to calculate derivatives of missing energy and missing momentum components with respect to electron and proton scattering angles and momenta, needed for determining offsets

Example: 6.1901 GeV θe'=27.27°				
	dW	**dEm**	**dPm∥**	**dPm⊥**
dE	3.56	6.19	5.44	2.95
dθe'	-10.87	0	2.95	-2.01
dPe'	-6.21	-3.57	-2.01	-2.95
dθp	0	0	0	3.43
dPp	0	-3.31	-3.43	0

- Derivatives computed by a FORTRAN kinematics program by Jochen Volmer and Henk Blok, 1999 March 26
  - Derivative units: 0.1% for momenta, 1 mrad for angles
  - Heepcheck.f

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Example Shifts in Heep Coin Data

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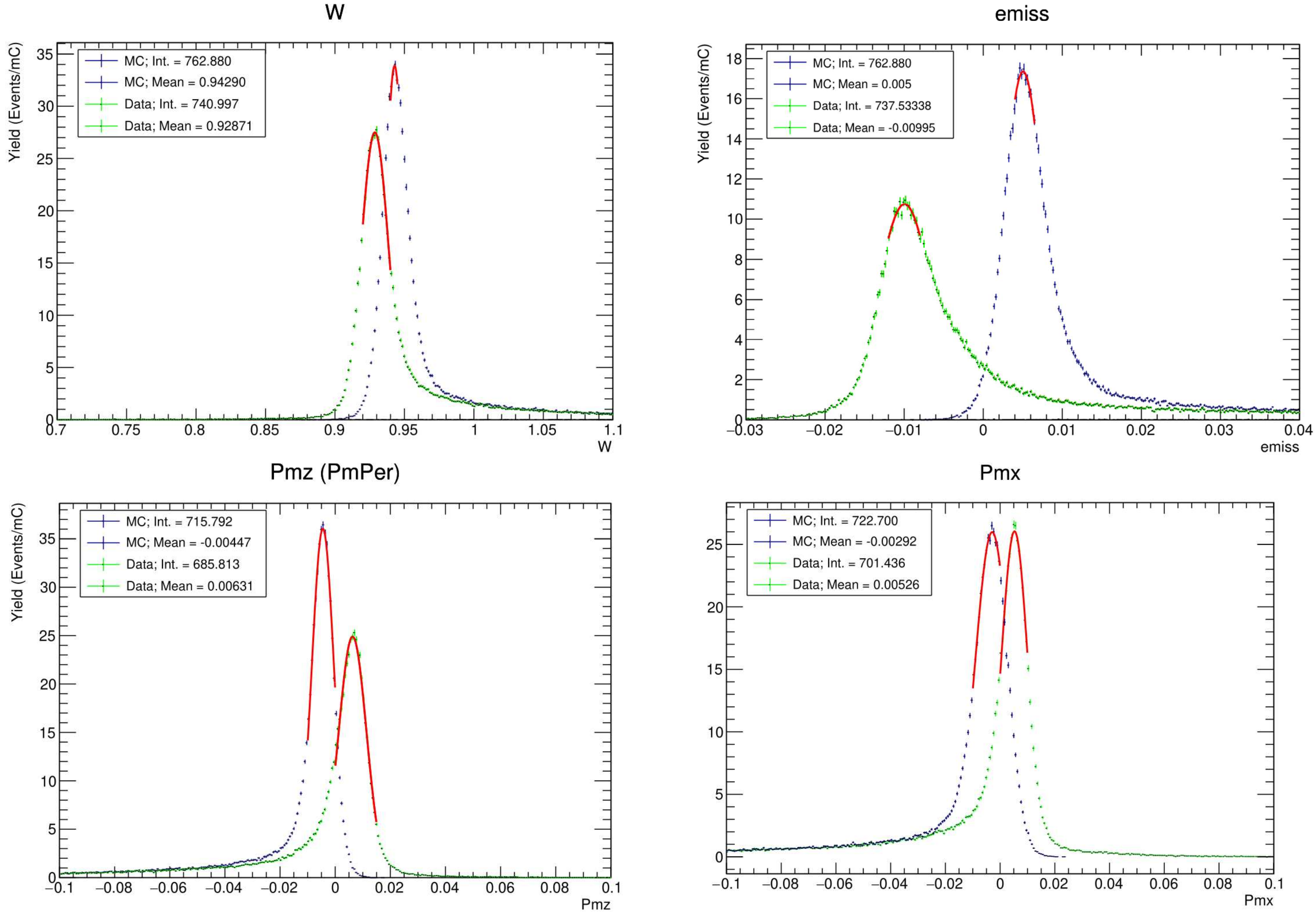

Plots by Vijay Kumar: 4559.7 MeV HMS=33.05°, –2.553 SHMS=29.90°, +2.792

Example Offset Calculation

- Use the mean to characterize each W, EM, PMZ, PMX distribution
- Convert differences between SIMC and Data to units of 0.1% for momenta, 1 mrad for angles

$$W_{shift} = \frac{\left(W_{SIMC} - W_{Data}\right)}{0.9383} \times 1000$$

- Choose set of possible offsets: dE, dθe', dPe', dθp, dPp
- Calculate change in each distribution if offset is applied

$$dW = W_{shift} + \left(\frac{\partial W}{\partial E}\right) dE + \left(\frac{\partial W}{\partial \theta_{e'}}\right) d\,\theta_{e'} + \left(\frac{\partial W}{\partial P_{e'}}\right) dP_{e'} + \left(\frac{\partial W}{\partial \theta_p}\right) d\,\theta_p + \left(\frac{\partial W}{\partial P_p}\right) dP_p$$

- And similar for EM, PMZ, PMX
- Compare new SIMC and Data differences and iterate
- Actual analysis offset signs have to be treated with care

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Global Offset Philosophy

- One could try to find a set of spectrometer and beam energy offsets which work perfectly for each Heep Coincidence setting in isolation
- However, the KaonLT Physics data [p(e,e'K^+)Λ/Σ, p(e,e'π^+)n/Δ, p(e,e'ω)p] are taken at somewhat different kinematics (smaller SHMS angle, larger SHMS–HMS momentum difference) than the Heep coincidence data
- This makes it difficult to know if the offsets determined from Heep data are applicable to the Physics data
- Our approach is to find a set of "global offsets" for multiple Heep settings, so they may be applicable also to Physics data
- Since each Arc energy measurement is independent, only the beam energy offset is allowed to vary within the Arc measurement uncertainty, with spectrometer angle and momentum offsets common across multiple energies
- Unfortunately, this leads to compromises in the level of agreement between what is measured and expected

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Global Offsets

- It was not possible to find a set of offsets that work well for all 8 beam energies.
- Obtained several different sets of offsets, which are generally similar

all 8 energies: 2.7, 3.7, 3.8, 4.6, 4.9, 6.2, 8.2, 10.6				
dE	**dθe'**	**dPe'**	**dθp**	**dPp**
0.017–0.07%	+0.4mr	+0.07%	+1.8mr	0%

5 lowest energies: 2.7, 3.7, 3.8, 4.6, 4.9.				
dE	**dθe'**	**dPe'**	**dθp**	**dPp**
0.0–0.07%	+1.4mr	+0.06%	+1.7mr	+0.4%

3 low PionLT: 2.7, 3.7, 4.6				
dE	**dθe'**	**dPe'**	**dθp**	**dPp**
0.0–0.07%	+1.2mr	+0.15%	+2.8mr	0%

2 lowest KaonLT: 3.8, 4.9				
dE	**dθe'**	**dPe'**	**dθp**	**dPp**
0.02–0.07%	+0.5mr	+0.145%	+2.45mr	0%

3 highest KaonLT: 6.2, 8.2, 10.6				
dE	**dθe'**	**dPe'**	**dθp**	**dPp**
0.04–0.06%	+1.0mr	0%	+0.8mr	+1.2%

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Results with In–Plane Offsets Applied

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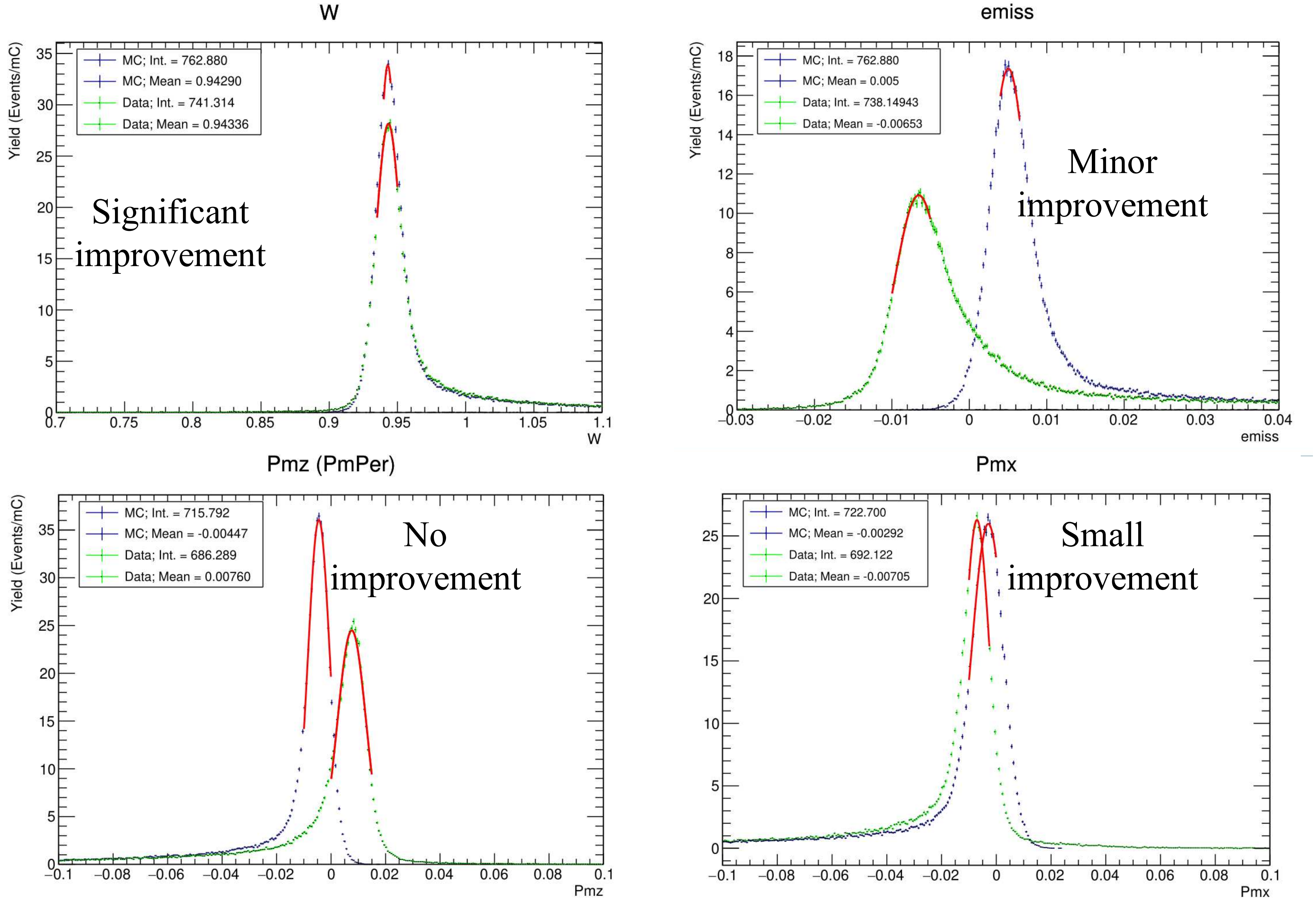

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 Plots by Vijay Kumar: 4.6GeV Heep dE=0.045% dθe'=+1.2mr dPe'=0.15% dθp=+2.8mr

2.7 GeV Heep Before After

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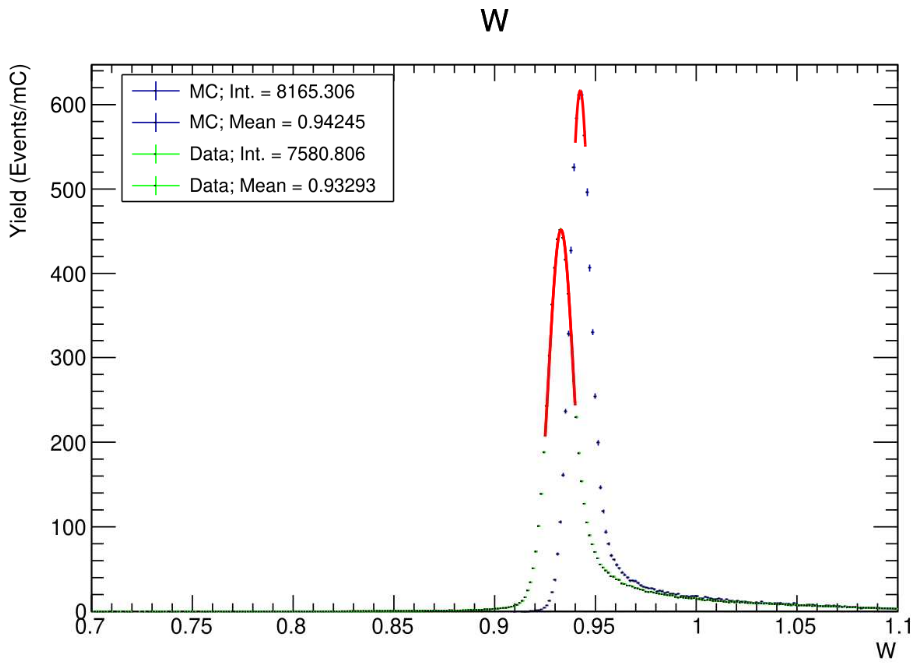
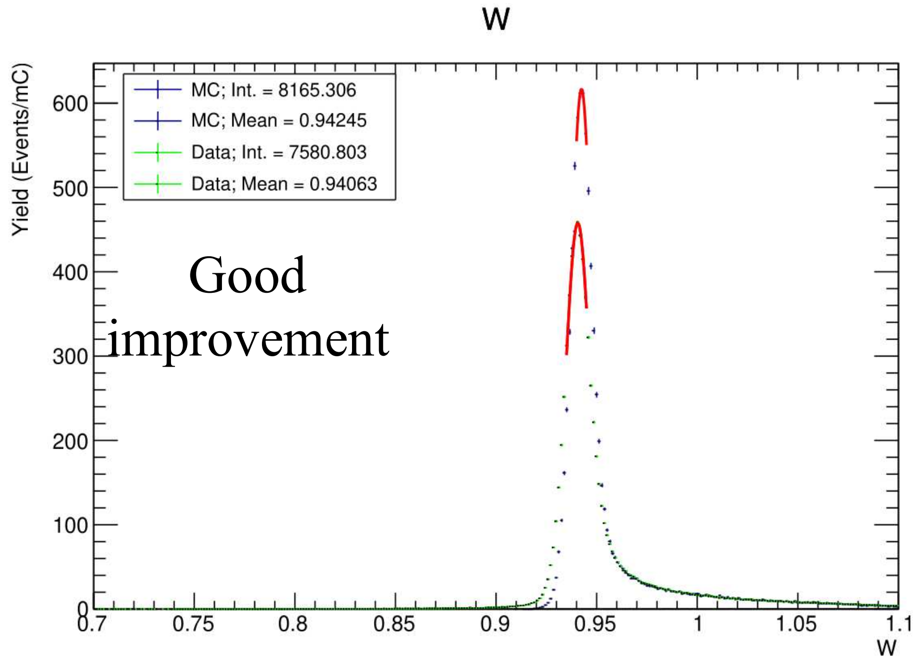
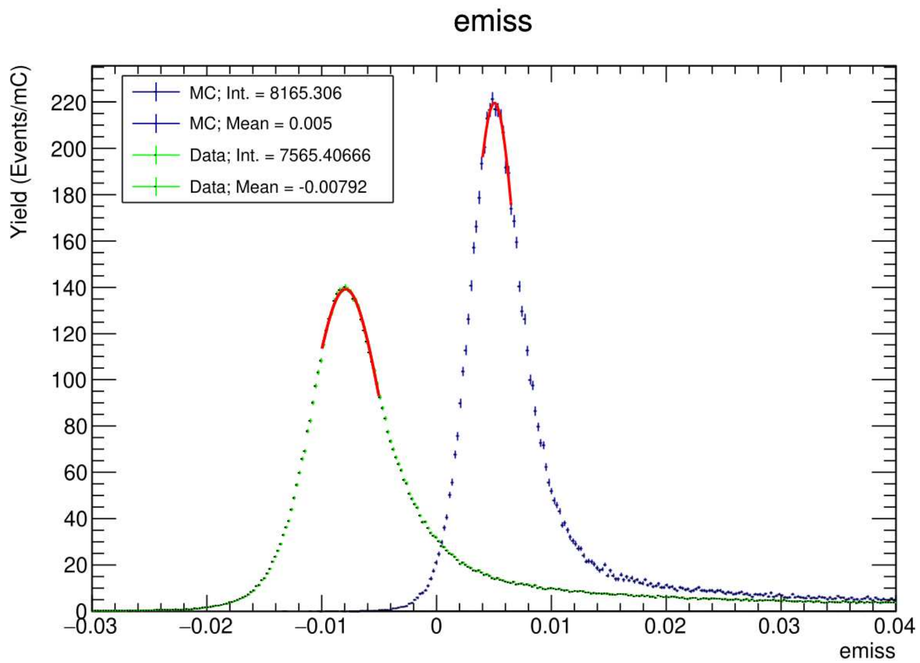
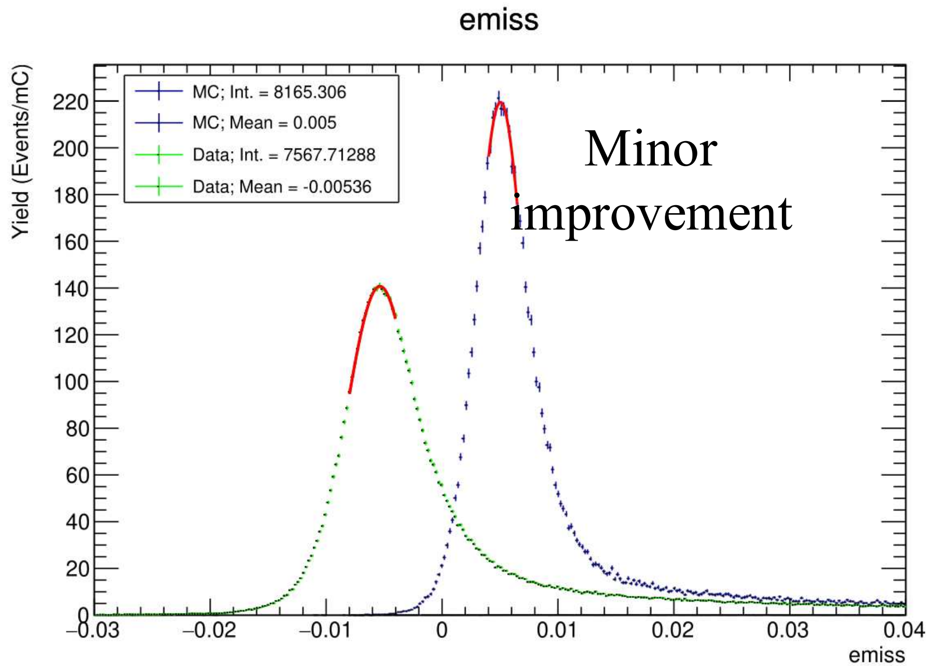


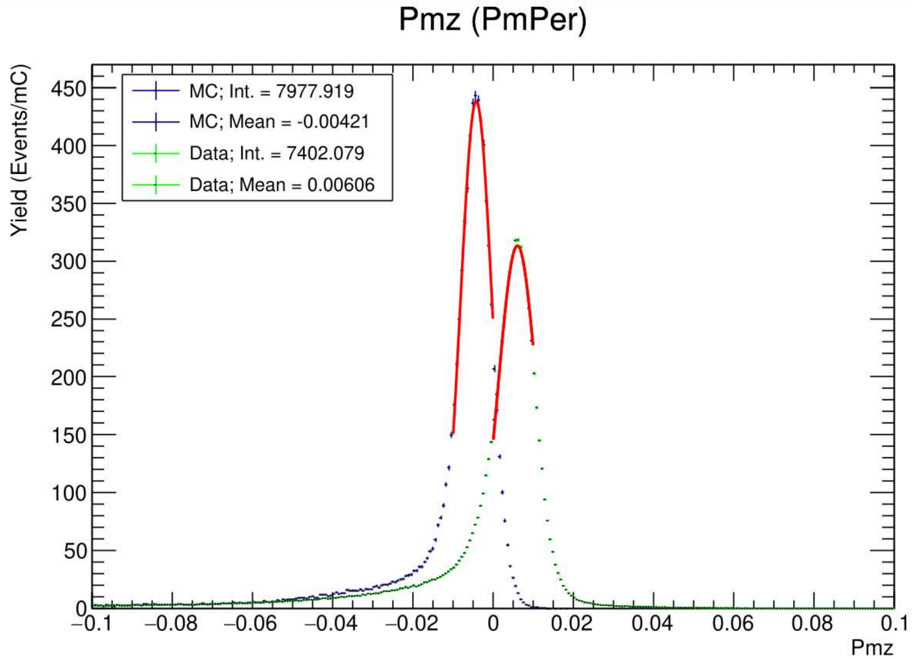


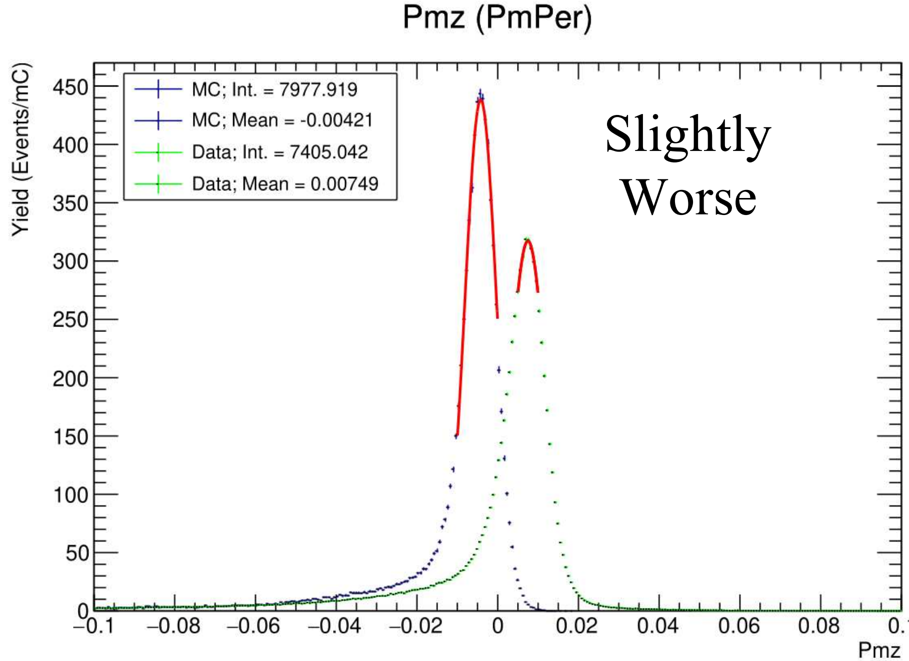


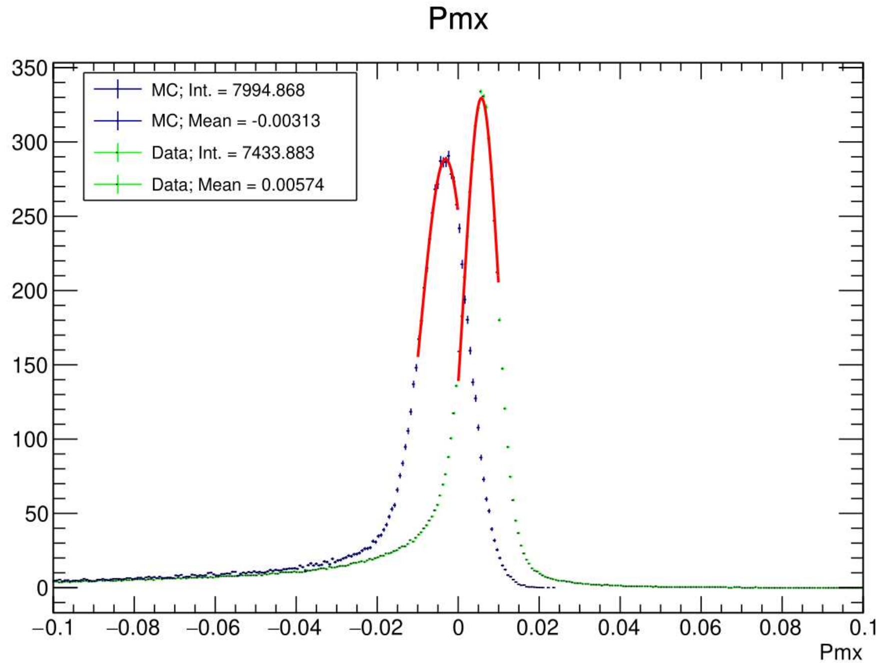


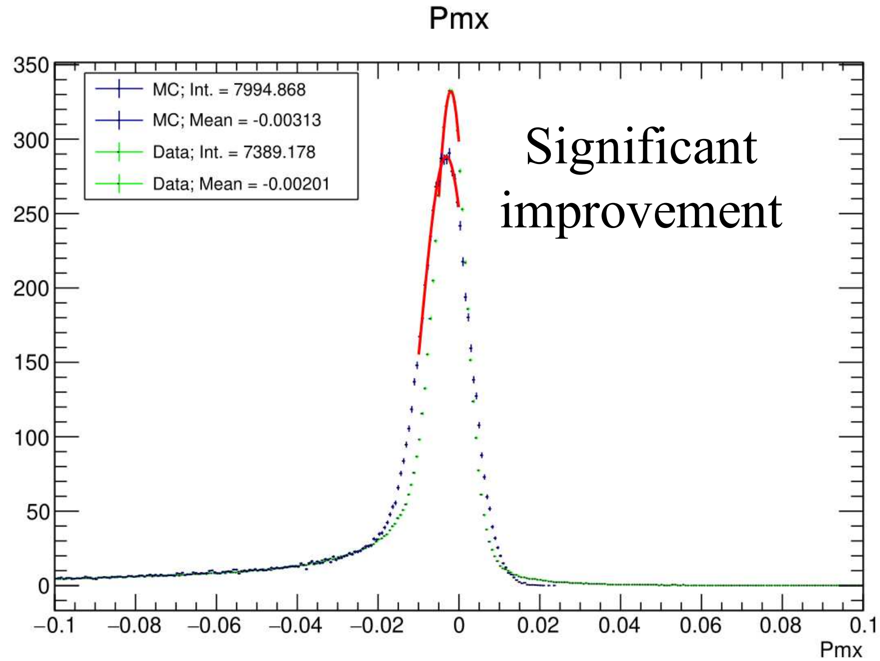
Plots by Vijay Kumar: 2.7GeV Heep dE=0.0% dθe'=+1.2mr dPe'=0.15% dθp=+2.8mr

2.7 GeV Heep Before After









Plots by Vijay Kumar: 2.7GeV Heep dE=0.0% dθe’=+1.2mr dPe’=0.15% dθp=+2.8mr

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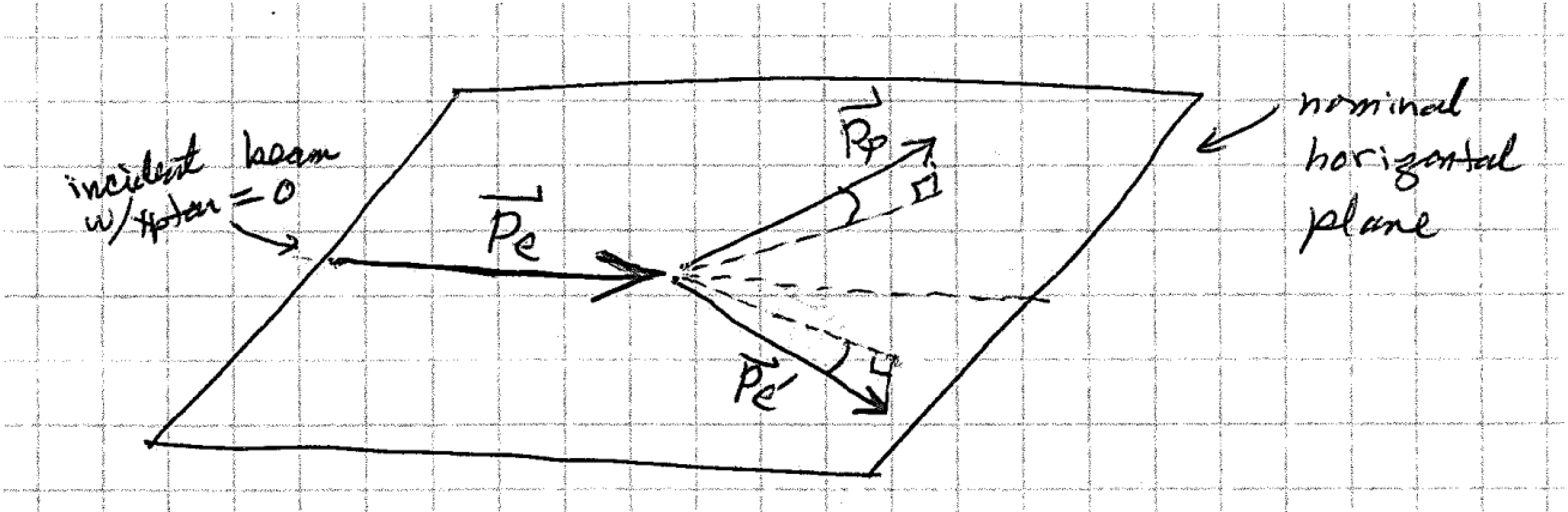
Out–of–Plane (OOP) Offsets

- Use the constraint PMY=0 with correct offsets to determine out–of–plane offsets
  - ^{1}H(e,e'p) reaction is coplanar, so in–plane kinematics provide no guidance, and Heepcheck program can't be used
- Simplifying Assumptions:
  - During KaonLT the beam was well centered on target (xptar<0.002) so ignore the xptar correction for now
  - OOP angles are small, so sinθ≈θ



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OOP offsets from PMY data

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Experimentally, we have:

$$PMY = 0 - P_{e'} \sin \phi_{e'} - P_p \sin \phi_p$$

We desire offsets such that:

$$0 = 0 - P_{e'} \sin(\phi_{e'} + \phi_{HMS}) - P_p \sin(\phi_p + \phi_{SHMS})$$

Use $\sin \phi \approx \phi$

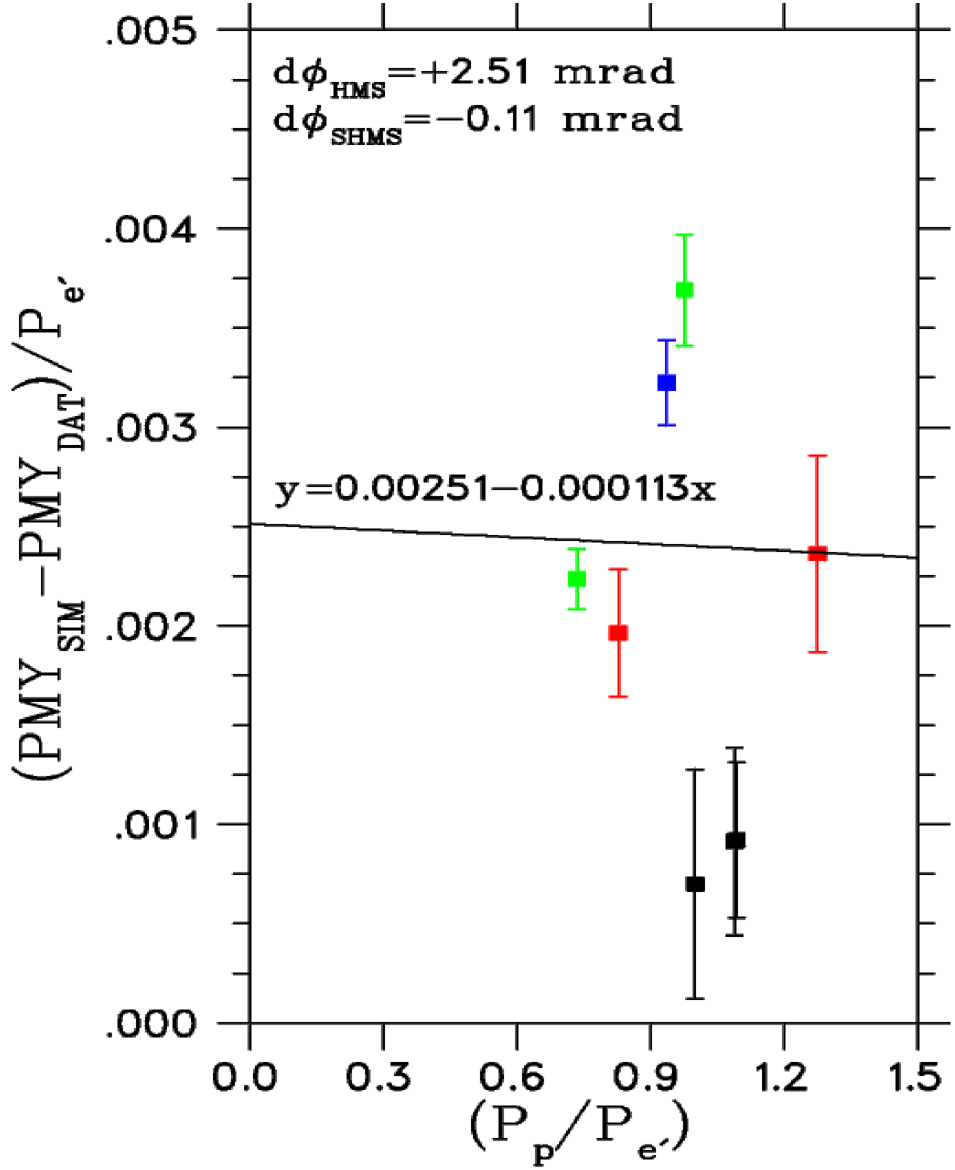
$$1: \quad PMY = -P_{e'} \phi_{e'} - P_p \phi_p$$

$$2: \quad 0 = -P_{e'} (\phi_{e'} + \phi_{HMS}) - P_p (\phi_p + \phi_{SHMS})$$

Subtract $1-2$: $PMY = P_{e'} \phi_{HMS} - P_p \phi_{SHMS}$

Plot: $\left(\frac{PMY}{P_{e'}}\right) = \phi_{HMS} + \left(\frac{P_p}{P_{e'}}\right) \phi_{SHMS}$

This is still a work in progress. Approximate correlation with beam energy indicates analysis incomplete.



PionLT Part 1: 2.8, 3.7, 4.6
KaonLT Low: 3.8, 4.9
KaonLT: 6.2, 10.6
KaonLT: 8.2 (HMS ↔ SHMS)

Alternate OOP method

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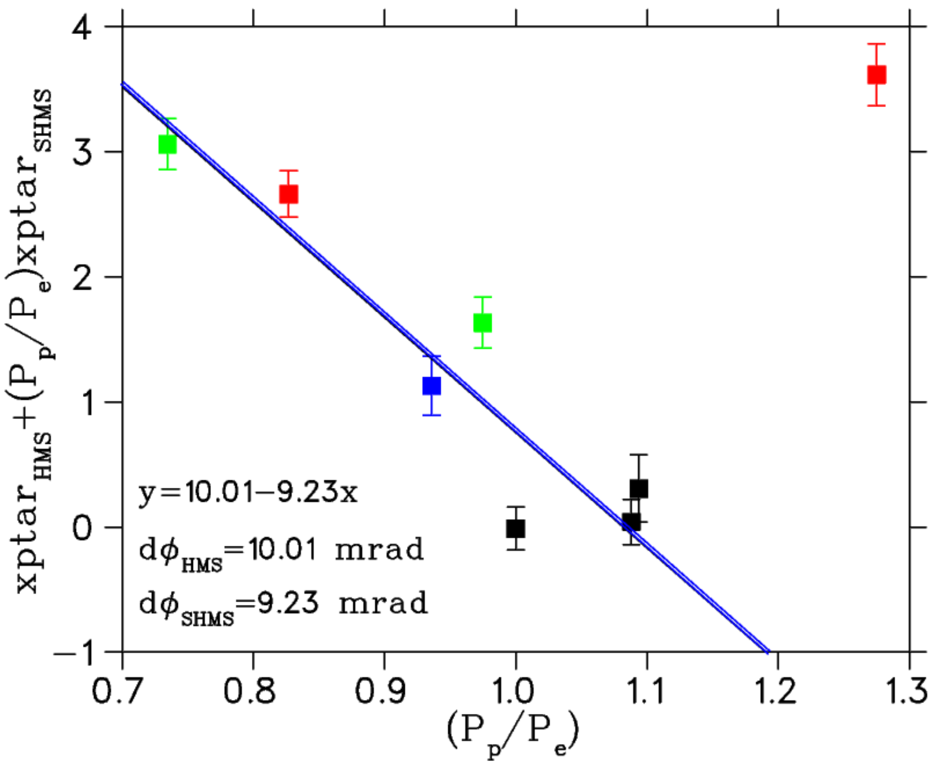
- Fπ–2 Analysis used Heep Coincidence xptar distributions instead of PMY data
- Obtained offsets seem unphysically large, and one data point is a significant outlier

In the F_π-2 analysis HMS and SOS x'_{tar} offsets were separated by looking at the out-of-plane momentum difference. Since the vertical beam position significantly influences the reconstruction of x'_{tar} (see section 3.2.1), any offset in the beam position has to be taken into account in this method. The relation between HMS and SOS out-of-plane angles can then be written,

$$x'_{SOS} - \left(0.43 - 1.14\frac{P_p}{P_e}\right)\cdot D_b + \frac{P_p}{P_e}x'_{HMS} = 0 \qquad (3.10)$$

where P_e and P_p are the electron and proton momentum given by the spectrometer central momentum and D_b is the vertical offset of the beam in mm. x'_{HMS} and x'_{SOS} are the reconstructed out-of-plane angles. The values 1.14 mrad/mm and 0.43 mrad/mm are the first order HMS and SOS expansion coefficients denoting the effect of the vertical beam position on x'_{tar}. For each setting the vertical beam position

Tanja Horn PhD Thesis (2006) p.105



PionLT Part 1: 2.8, 3.7, 4.6

KaonLT Low: 3.8, 4.9

KaonLT: 6.2, 10.6

KaonLT: 8.2 (HMS ↔ SHMS)

KaonLT Heep Offsets Summary

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- **In–Plane Offsets:**
  - Global solutions for different beam energy sets are generally similar, but none work uniformly well for all beam energies
  - Will use 3 different sets of offsets for:
    - PionLT Part 1 (2.8, 3.7, 4.6)
    - KaonLT Low Energy (3.8, 4.9)
    - KaonLT High Energy (6.2, 8.2, 10.6)
  - Have not found strong evidence of needing special $P_{e'}$ offset for 10.6 GeV Heep setting with P_{HMS}= –6.59 GeV/c
  - This is more demanding situation than Fπ–2, with 3 beam energies (3.8, 4.7, 5.2 GeV), and global offsets were found
- **Out–Of–Plane Offsets:**
  - Method from Fπ–2 analysis gives $d\Phi_{HMS}$= +10.0mr, $d\Phi_{SHMS}$= +9.2mr
  - PMY method (in progress) gives $d\Phi_{HMS}$= +2.5mr, $d\Phi_{SHMS}$= –0.1mr
- **Suggestions Welcome!**

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