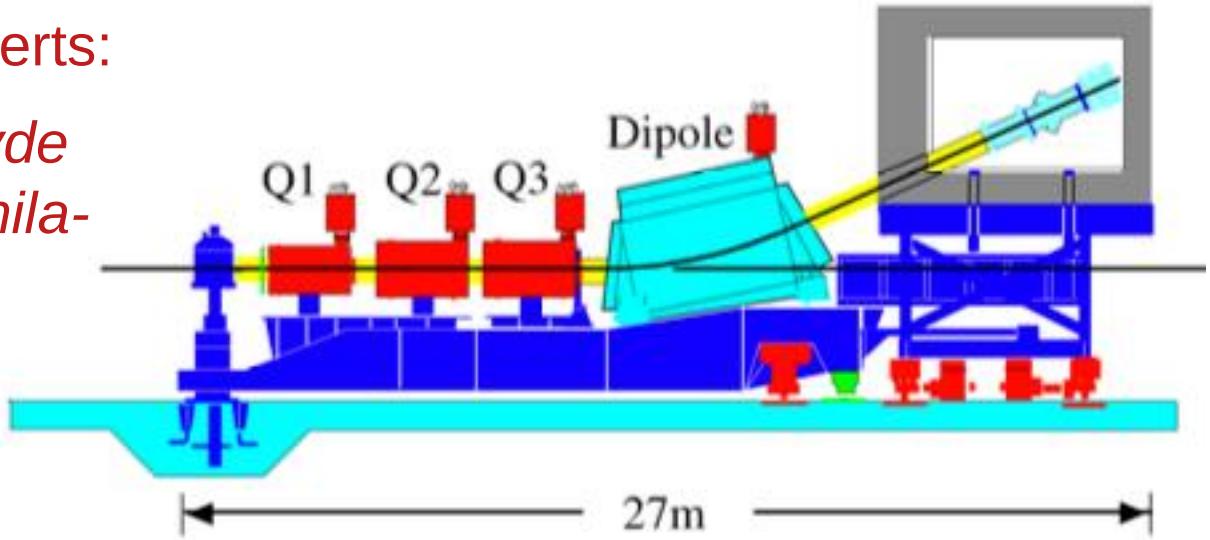
NPS Optics Optimization at High Momentum: Milestones and Next Steps

Thank you to the spokespersons and experts:

Tanja Horn, Charles Hyde Mark Jones, Holly Szumila-Vance



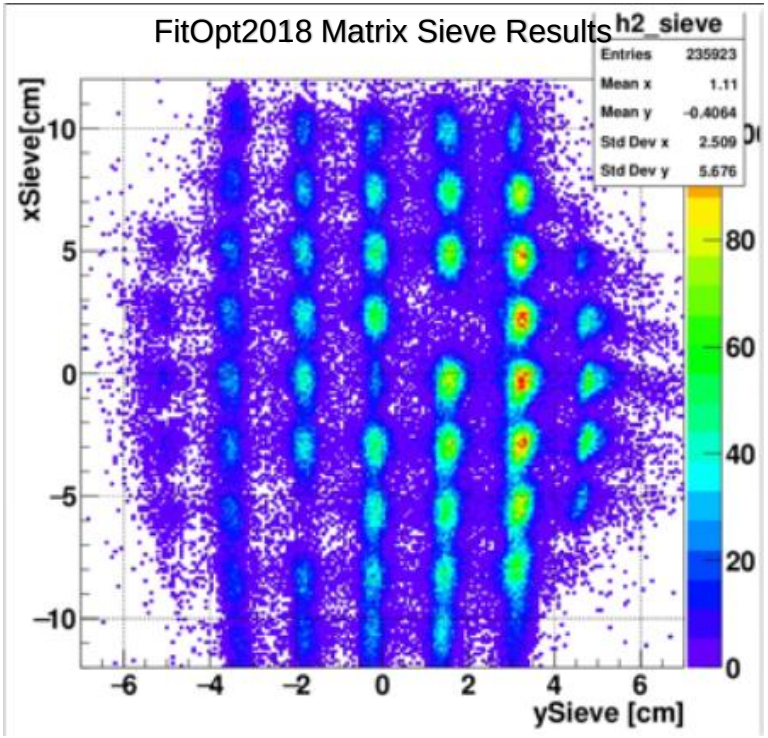
Christine Ploen, Joshua Crafts

Monday, May 5, 2025

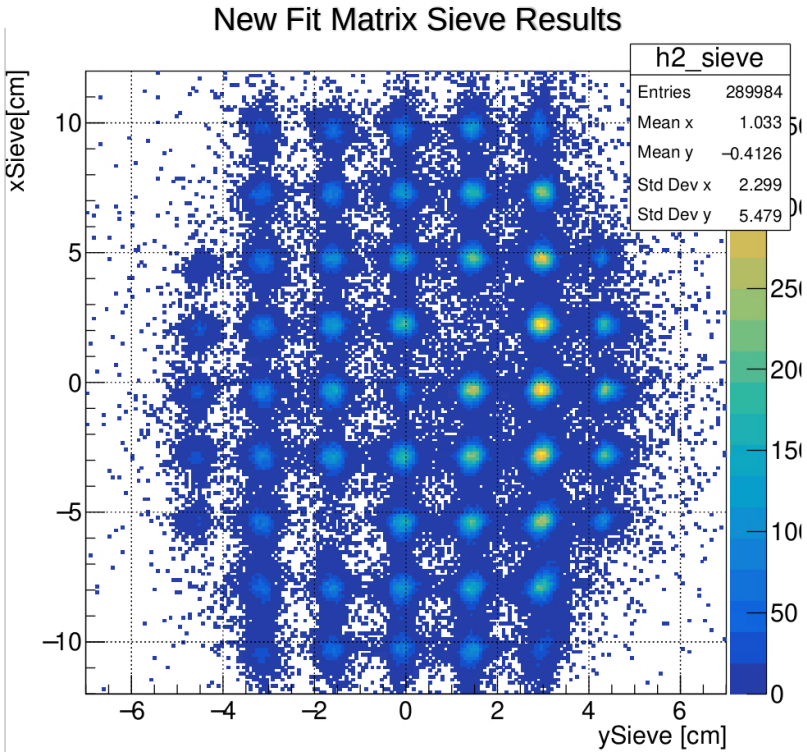
Motivation: Saturation in HMS Dipole

- At high momentum, HMS dipole saturation causes nonlinearities and the low-momentum transport matrix does not accurately reconstruct the physics variables, requiring precision tuning of matrix elements for angular and delta components.

Below: Effects of using low momentum matrix elements on high momentum data



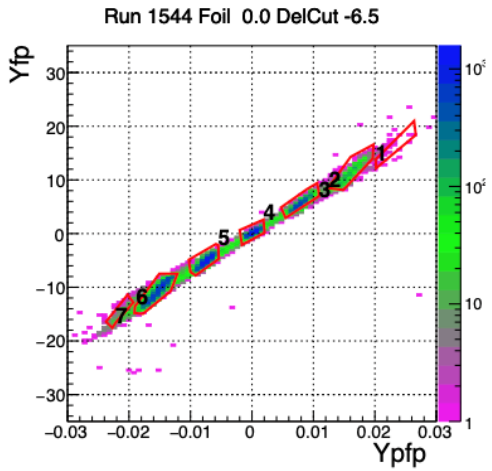
Below: Same data, optimized (angular) matrix!

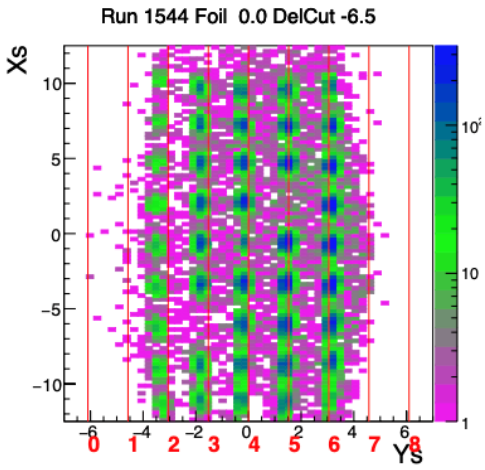


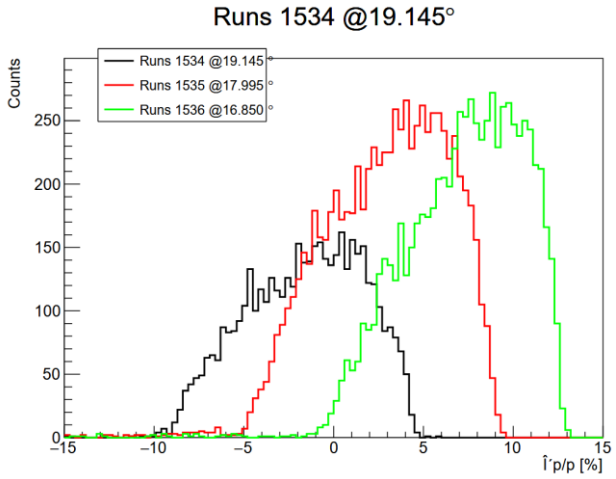
OPTIMIZATION

Two complementary optimization branches:

- Angular :
  - Data: Sieve slit on extended carbon foils
  - Method:
    - Select sieve holes
    - Reconstruct physics variables with 6th-order polynomials
    - Optimize coefficients using SVD
- Delta :
  - Data: Elastic delta-scans on LH2 (vary angle)
  - Method:
    - Get missing mass (Mp) from simulation
    - Reconstruct delta via SVD
    - Relies on completion of angular optimization



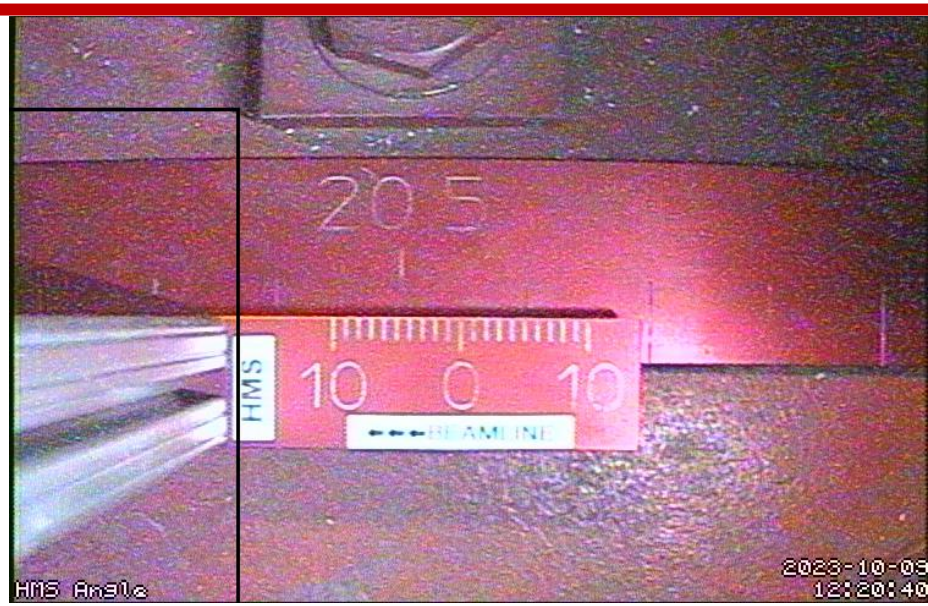




Jefferson Lab

Prerequisites for Delta: Angular Optimization

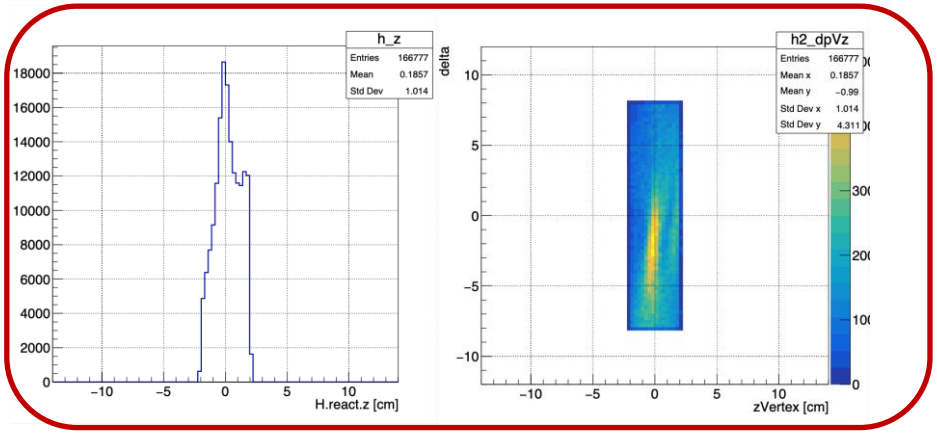
- ✓ Angular optimization completed at specific HMS momenta and implemented in delta scan replays
- ✓ HMS detector angles verified (via camera image) and implemented in replay and optimization code

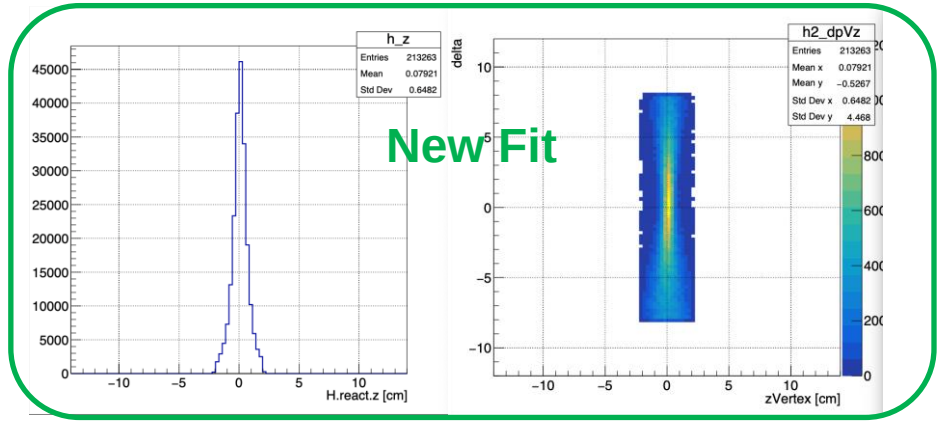


Kinematic (old name)	Central P	Student	Angle 1 Sieve	Angle 2 Sieve	Angular Optimization
x50_2	-6.667	Christine	C 0.5% +/- 8cm	C 0.5% +/- 8cm +/- 3cm	✓ Matrix Elements
x36_3	-6.117	Josh	C 0.5% +/- 8cm	C 0.5% +/- 8cm +/- 3cm	✓ Matrix Elements
x60_3	-5.878	Christine	C 0.5% +/- 8cm	C 0.5% +/- 8cm +/- 3cm	✓ Matrix Elements

Prerequisites for Delta: Angular Optimization

Coeff2018





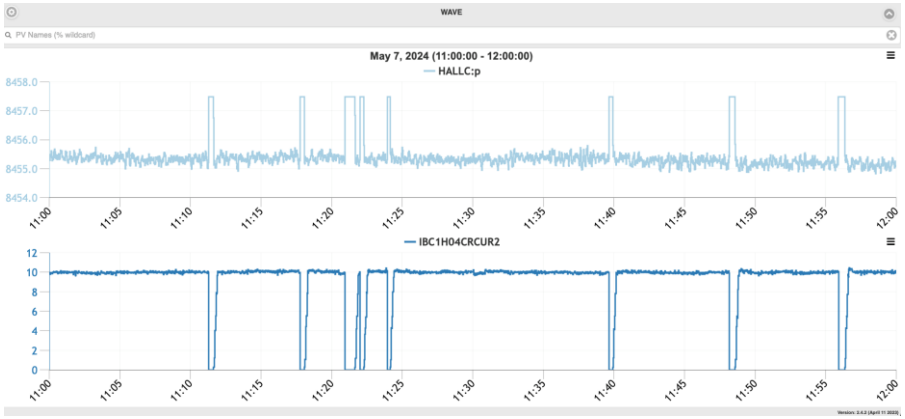
-6.667 GeV/c, Run 1544:

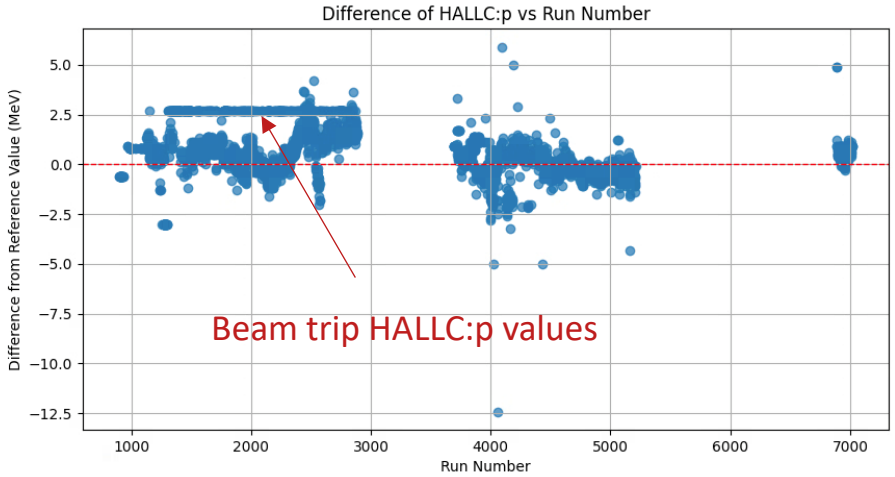
Z vertex resolution much improved!

Milestones

- ✓ Graphical cuts around sieve holes from optics runs at various HMS angles for all high momenta
- ✓ Polynomial fit to 6th order using SVD, iterative refinement
- ✓ Histograms and sieve hole data replays as quality checks
- ✓ Git commit of angular matrices and zero-order offsets for replay (Pass1 and onward)
- ➢ Future opportunity - rerun software using exact beam position (H.react.x) instead of the average, and exact location of carbon foil targets

Prerequisites for Delta: Calibrating Beam E HALLC:p values





Left: HALLC:p readback is an artificial value during beam trips

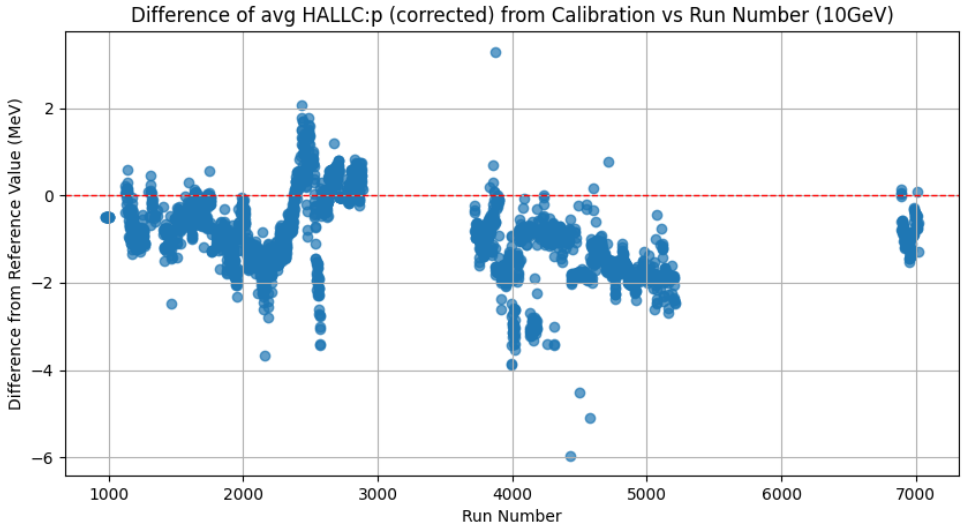
Right: Those incorrect readbacks, when used as the reference HALLC:p value, appear as straight lines. Here, I had plotted the autologged HALLC:p values from the start of run, with no cuts or averaging.

For Reliable Values of HALLC:p

- Use HALLC:p from replay root files *or*
- RCDB/autolog ➡️ get timestamps ➡️ mySampler on cdaq
  - 30 s time slices for each run
- Not all epics readbacks are correct
  - cut 1: HALLC:p > 50 MeV (removes random zeros)
  - cut 2: current > 2 uA (*IBC3H00CRCUR4)* (removes beam trips)

Prerequisites for Delta: Beam Energy Calibration @ 5 Pass

Top Right: Corrected HALLC:p Results:
E_b - HALLC:p_{cor} vs Run
Red line is E_b from beam energy measurement

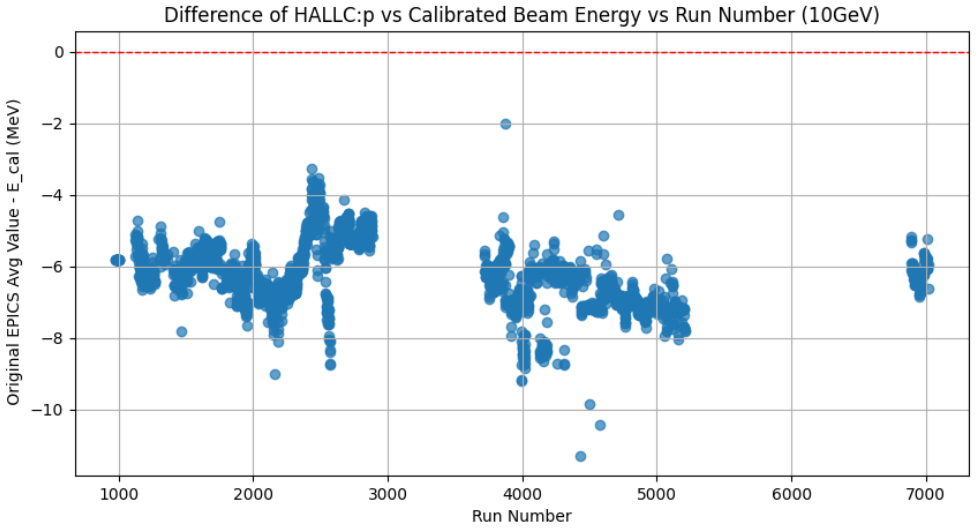


$$\text{HALLC:p}_{cor} = \frac{E_b}{\text{HALLC:p}_0} \cdot \text{HALLC:p}_{avg} - 0.5 \cdot \delta E_{SR}$$

$$= 1.00063 \cdot \text{HALLC:p}_{avg} - 0.5 \cdot 0.0026$$

Scale factor from calibration

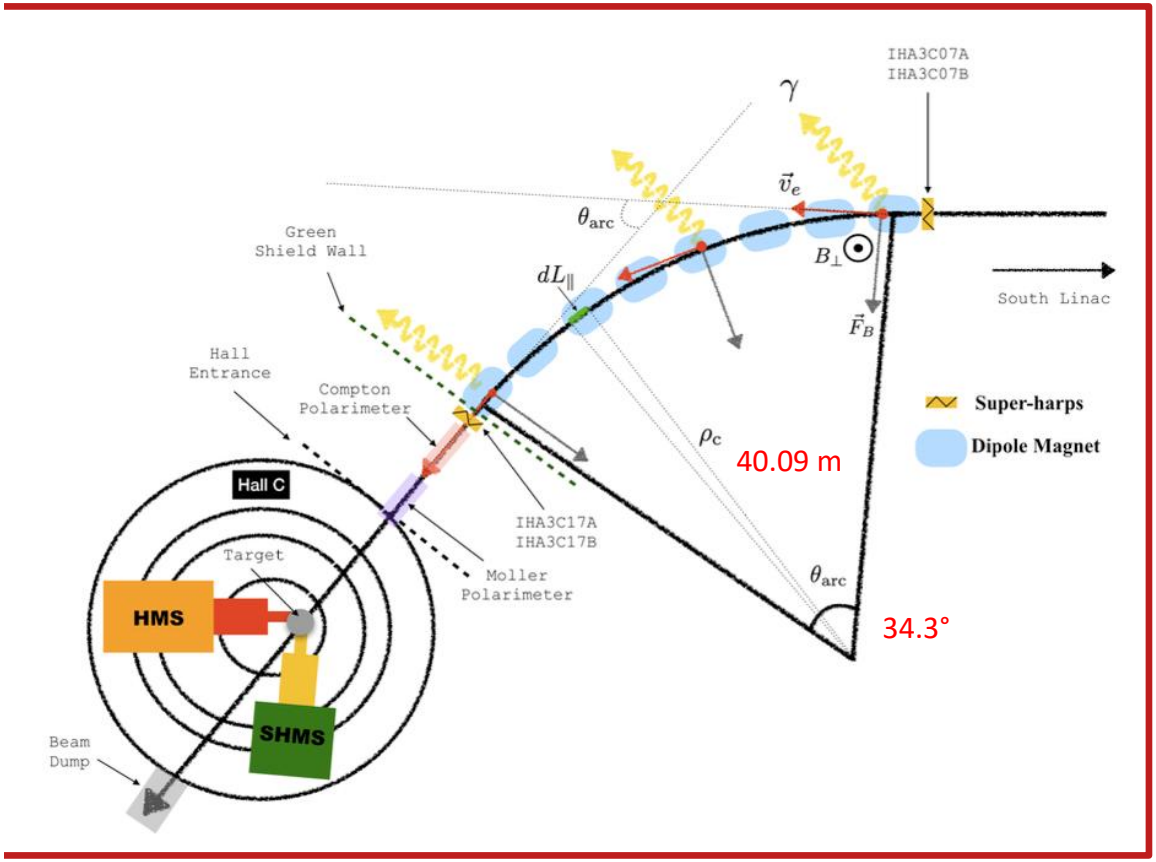
Bottom Right: Uncorrected HALLC:p:
E_b - HALLC:p vs Run
Red line is E_b from beam energy measurement



Prerequisites for Delta: Beam E Synchrotron Subtraction

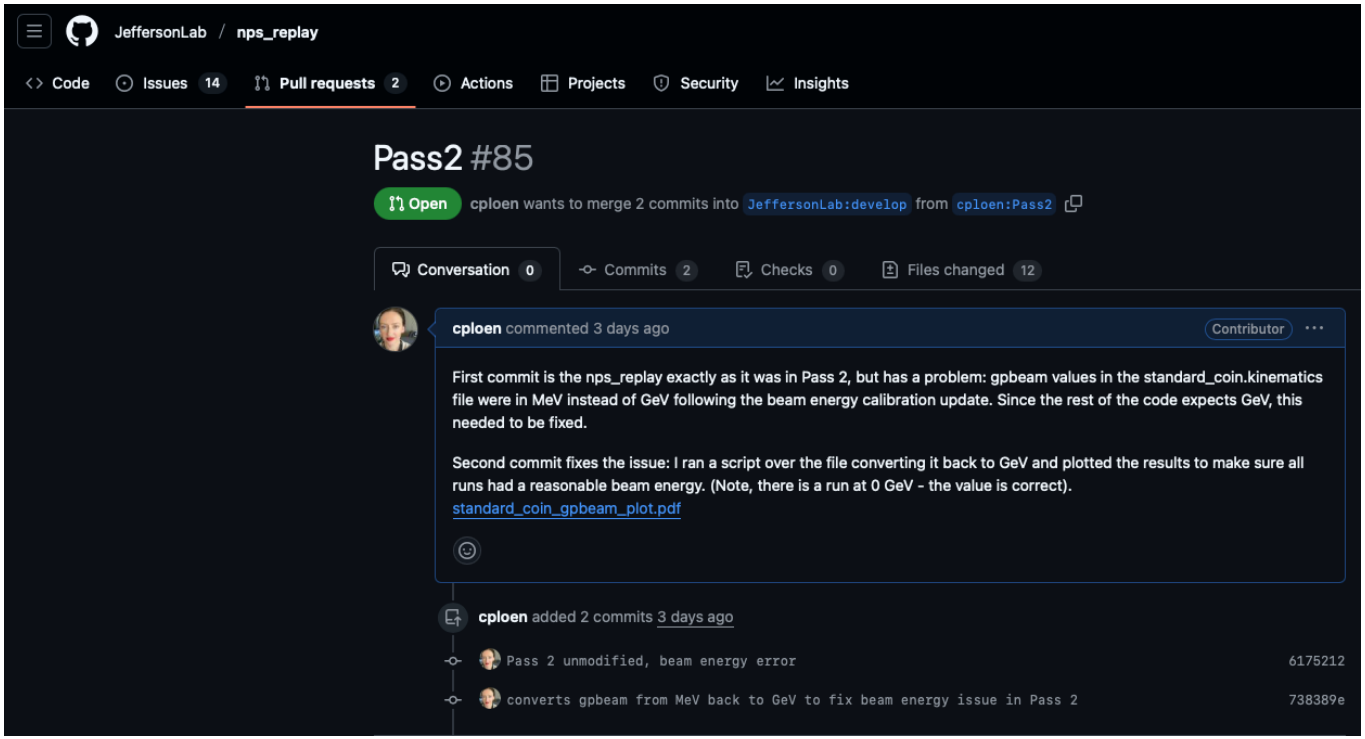
Layout of Hall C Beamline Arc:

- 8 dipoles
  - Effective length = 3m each dipole
  - 8 x 4.2875°/dipole (θ_{arc}) + 3.2°$_{\text{dipole 3C04}}$ = 37.5° net bend
  - Bending radius ρ_{arc} = 40.09 m
- Super harps for beam position before/after dipole chain
- Synchrotron Loss in circular accelerator:
- $\delta E_{SR} = 88.46 \cdot E^4 \cdot \theta_{arc}/(\rho_{arc} \cdot 360°)$
  - 88.46 is a derived empirical constant
  - Formula is for full 360°, scaled by $\theta_{arc}/360°$
  - @ 5 pass:
    - Total SR Loss = 2.6 MeV



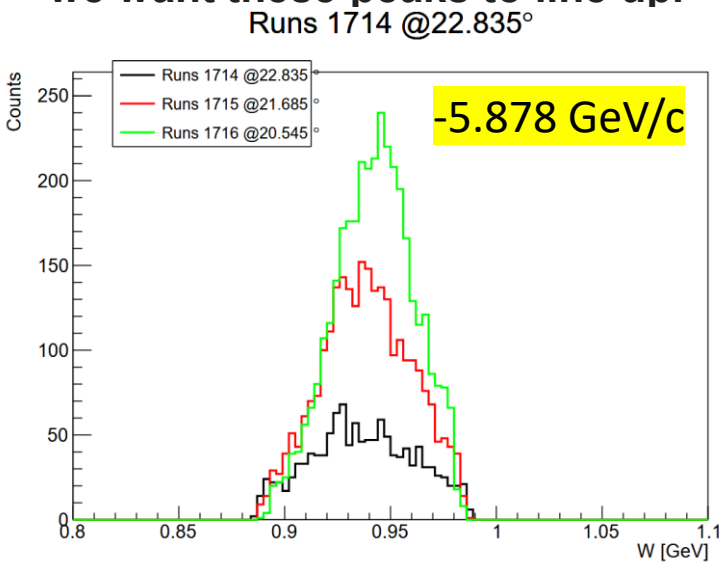
Prerequisites for Delta: Putting it Together

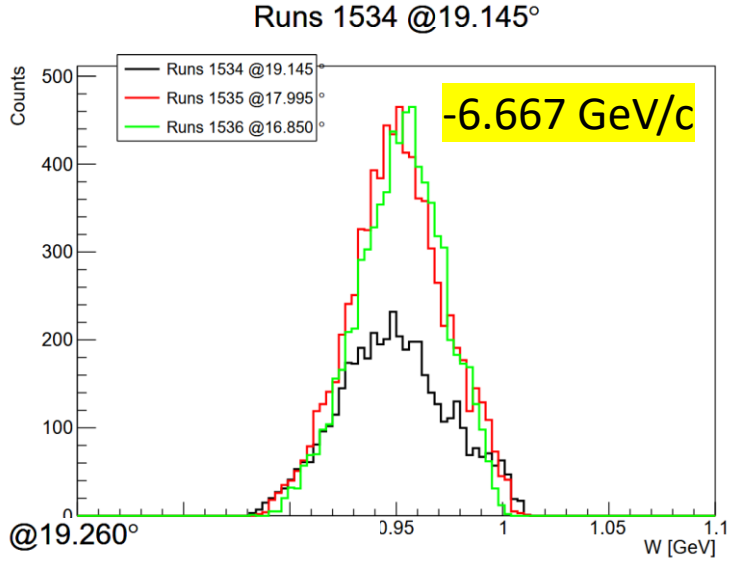
- ✓Update to standard_coin.kinematics & inclusion of relevant EPICS variables
- ✓ Pull request: Pass 2 + Fix
- ✓ Replayed delta scans with optimized matrix, correct Beam E & HMS Angle

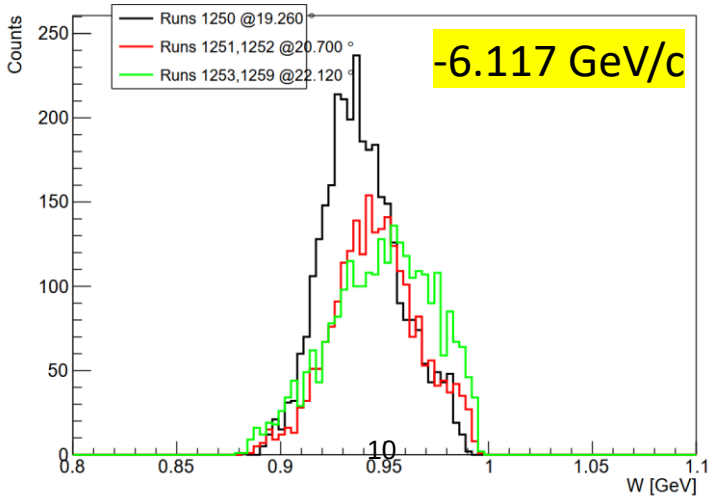


W Before Optimization

- Elastics: $W = M_p$
  - This is the constraint used to calibrate delta
  - **we want these peaks to line up.**



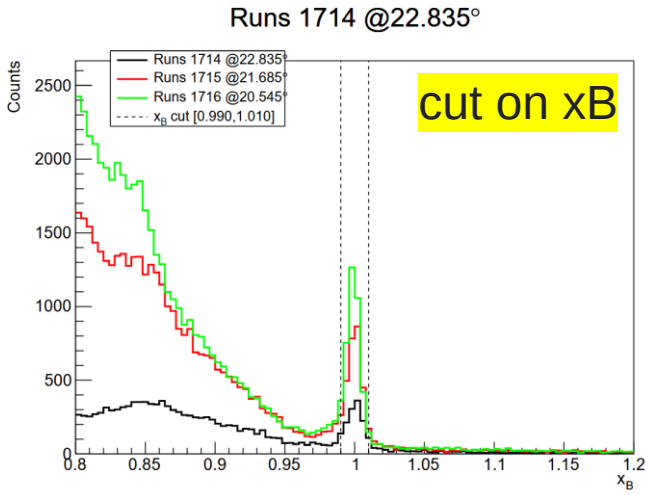


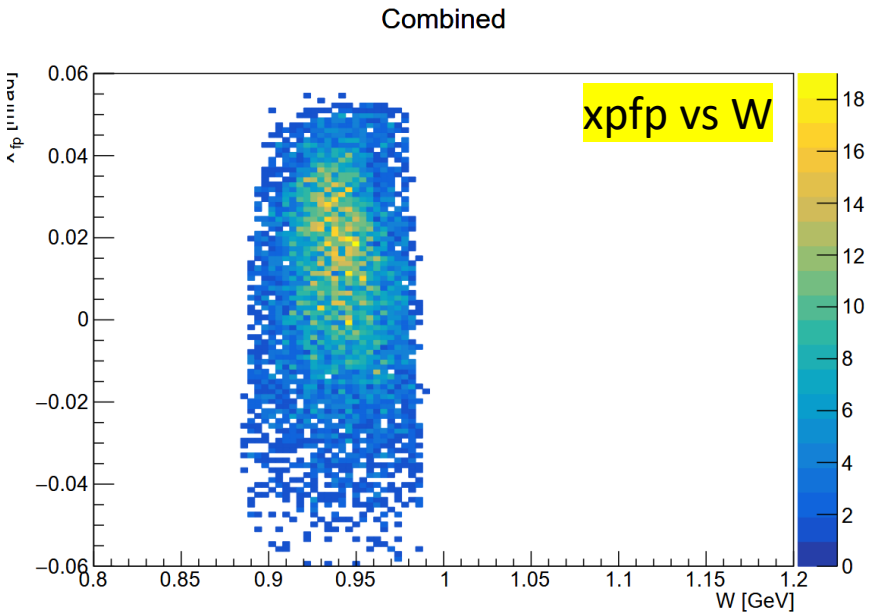


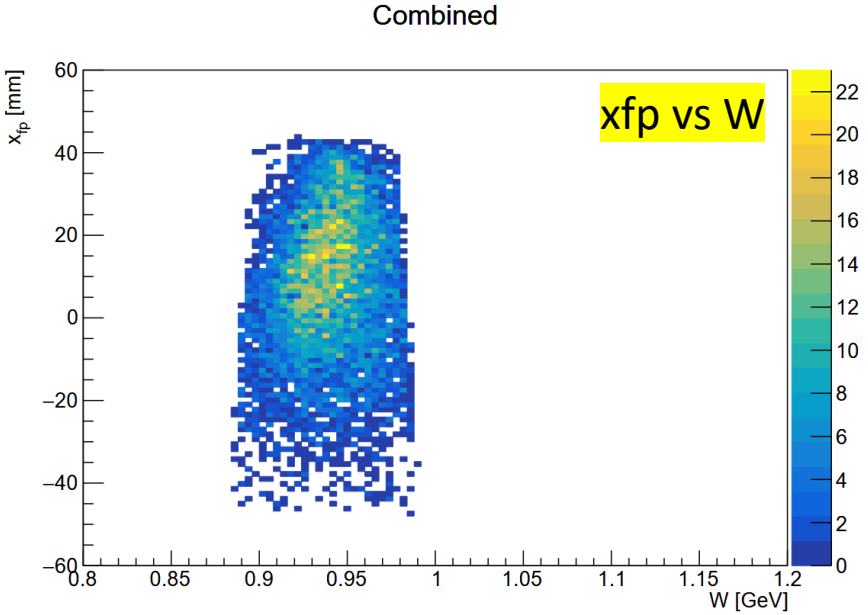
Why is high momentum so good? Inherited delta opt from the -6.59 Ge/c ME (Jacob Murphy's work!)

W vs Focal Plane Variables Before Optimization: -5.878 GeV/c

- xfp, xpfp vs W
  - Some correlation shown, esp in xfp:
    - Should be more or less straight for no correlation.
  - We don't have a lot of events, but enough to optimize .
  - Might need even tighter cut on xB to get rid of all inelastics.

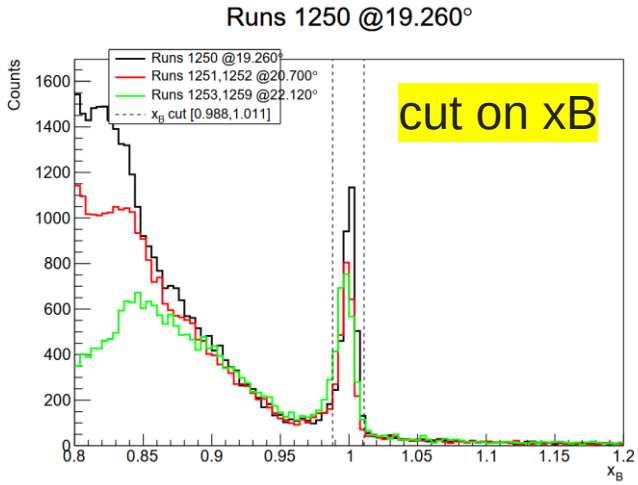


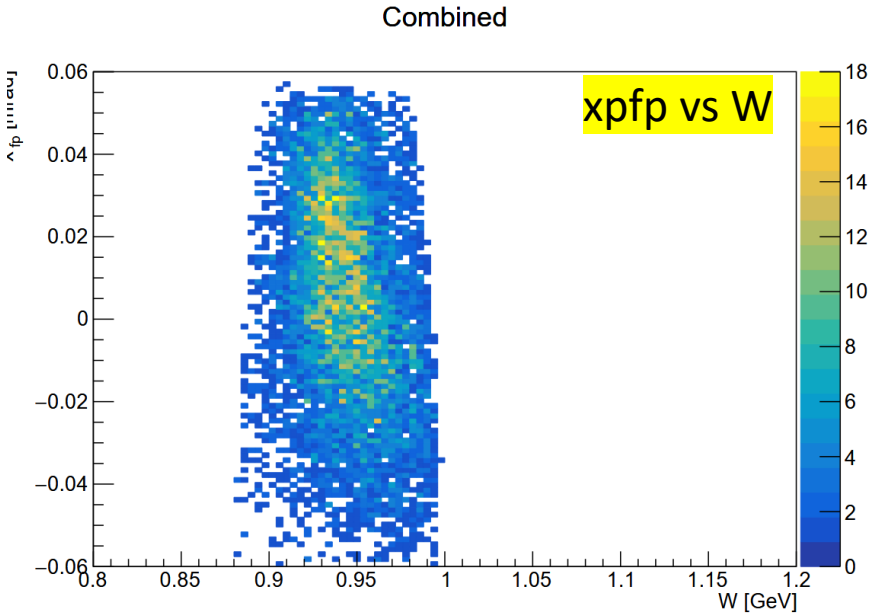


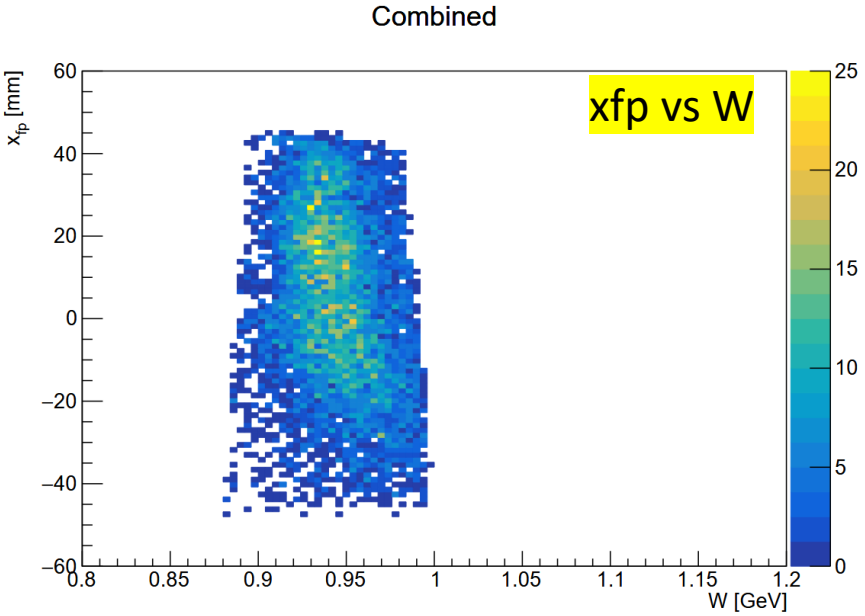


W vs Focal Plane Variables Before Optimization: -6.117 GeV/c

- xfp, xpfp vs W
  - Here we see the curvature a little more clearly.
    - Should be more or less straight for no correlation
  - We have even more events for these runs
  - Might need even tighter cut on xB to get rid of all inelastics.

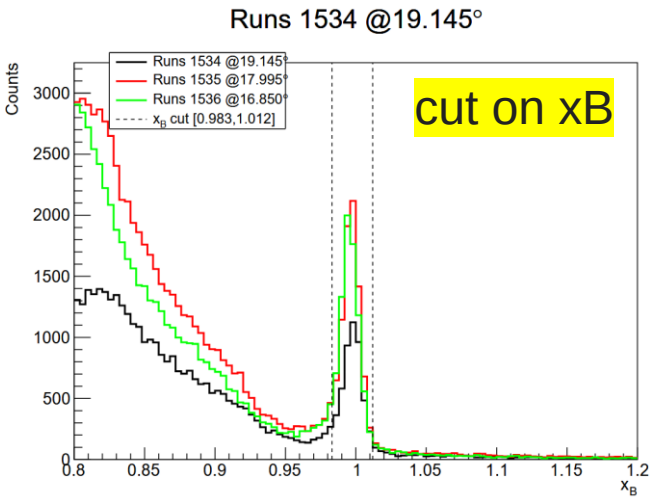


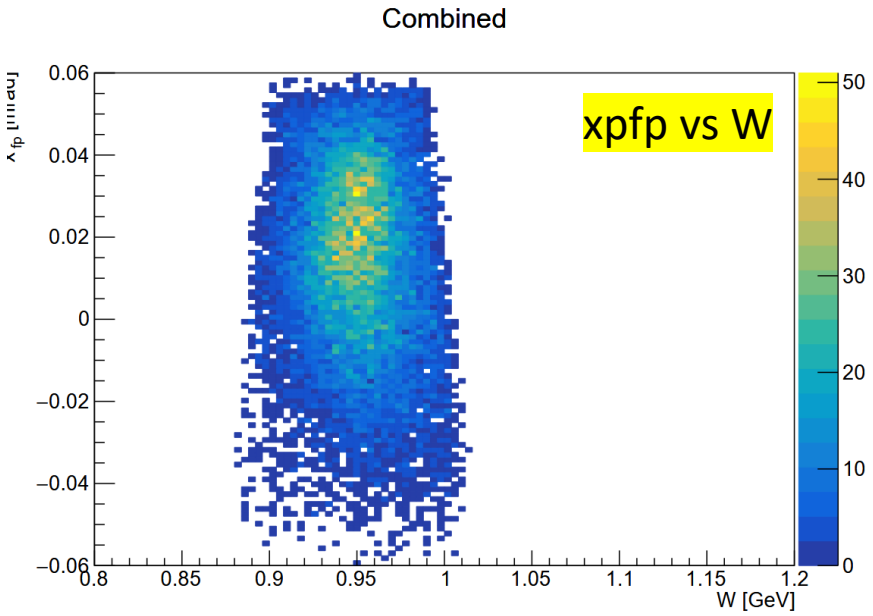


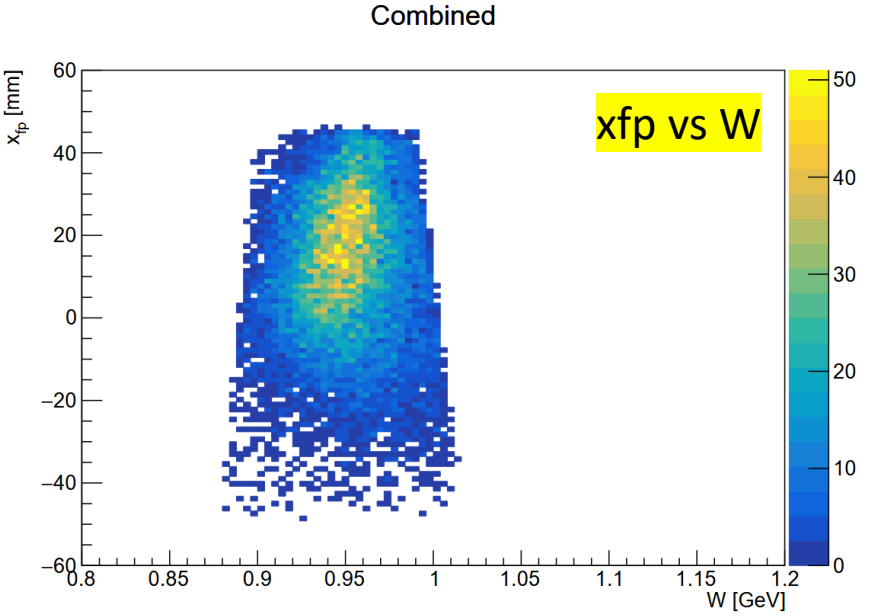


W vs Focal Plane Variables Before Optimization: -6.667 GeV/c

- xfp, xpfp vs W
  - Here we see some curvature in *xfp*.
    - Should be more or less straight for no correlation
  - We have the most events for these runs!
  - Might need even tighter cut on xB to get rid of all inelastics.







Next Steps: SIMC Fit for M_p, SVD, and Analysis

- SIMC: simulation and fit M_p from tight cut on elastic peak
- replay without 0 order offsets
- SVD fit results for delta-reconstruction
  - Coefficient behavior (compare to previous)
  - W vs. Physics Variables After Optimization
  - Fine tuning out remaining discrepancies, full replay test, GitHub PR with fully updated matrix elements and offsets
- Validation against data: reconstructed M_p agreement across HMS angle, plots of focal plane variables

Thank You!

Extras: Beam Energy Calibration Workflow Overview

1. Obtain an average *HALLC:p* value for each run (no beam trip values or error readbacks).
2. Calculate $HALLC{:}p/BeamE_{cal}$ with good value from time of calibration.
3. Scale the *HALLC:p* values with this factor.
4. Subtract synchrotron loss.
5. Update `standard_coin.kinematics` and submit `nps_replay` pull request.

Extras: Delta Optimization Workflow Overview

1. Obtain optimized coefficients for xptar, yptar, ytar physics variables via sieve slit/carbon foil data analysis (SVD)
2. Determine HMS Theta from camera and implement in nps_replay.
3. Calibrated and implement precise beam energy in nps_replay.
4. Replay delta scan runs without offsets (contained in hms_flags file).
5. Simulate elastics with simc to obtain W
6. Use simc results, tight cuts on xB to obtain new delta coefficients via SVD
7. Check plots, especially alignment of W