High Precision $W^{\pm}$ Measurements in ATLAS

Data Analysis for Transverse Momentum Measurements at 13 TeV

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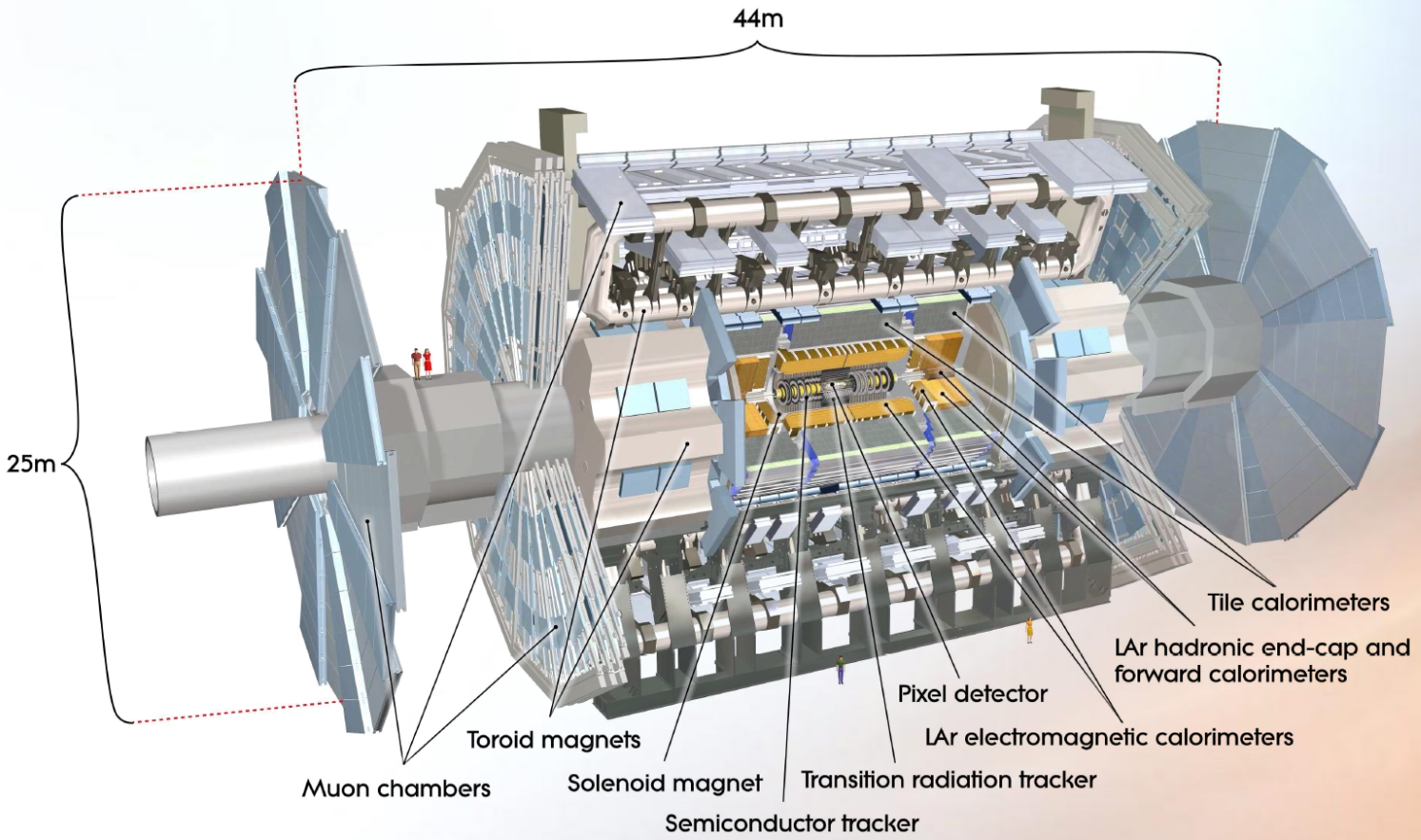
Overview

- About ATLAS
- Research project goals
- Data, analysis, and results
- Project outcome
- Future goals

ATLAS

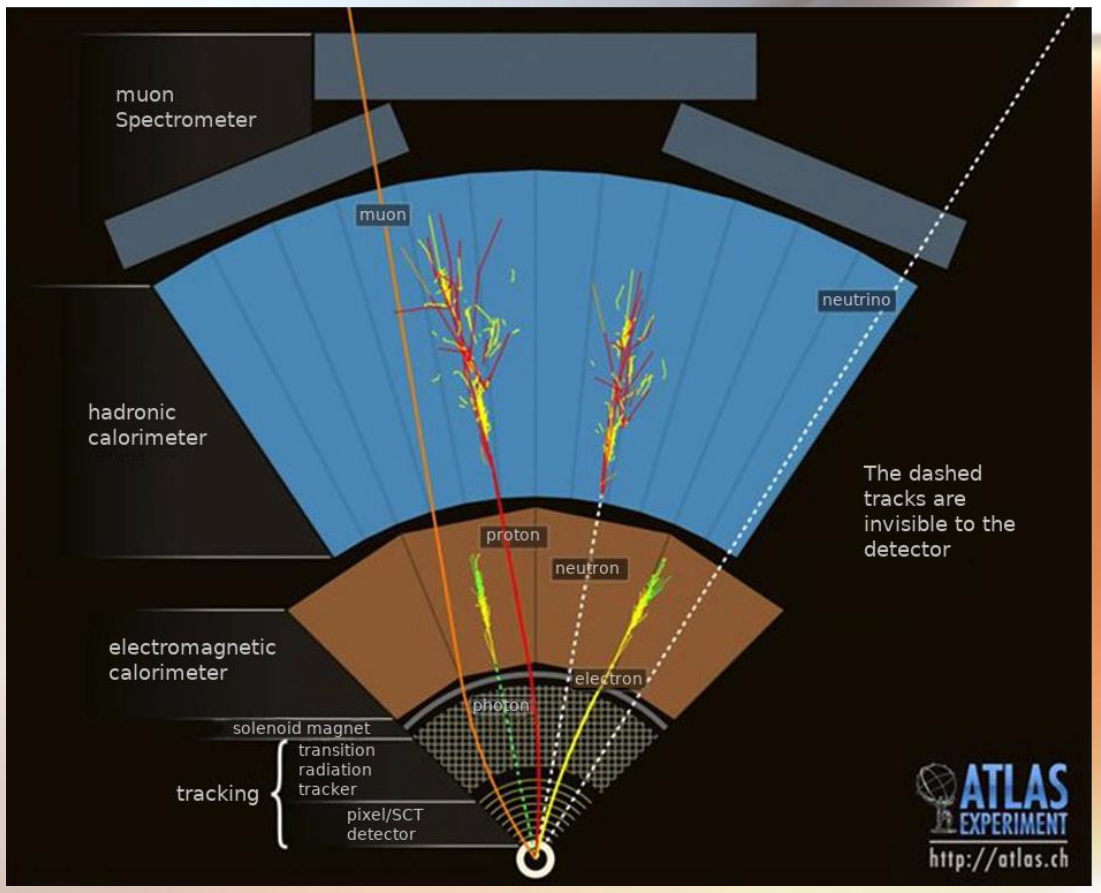

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

ATLAS

- 7,000 tonne detector for particle collisions
- Located at CERN in Geneva, Switzerland
- On the LHC track
  - Mutually anit-parallel proton beams are collided
  - Data is analyzed
- Construction
  - Four types of detectors
  - Magnetic Solenoid

Detector Construction

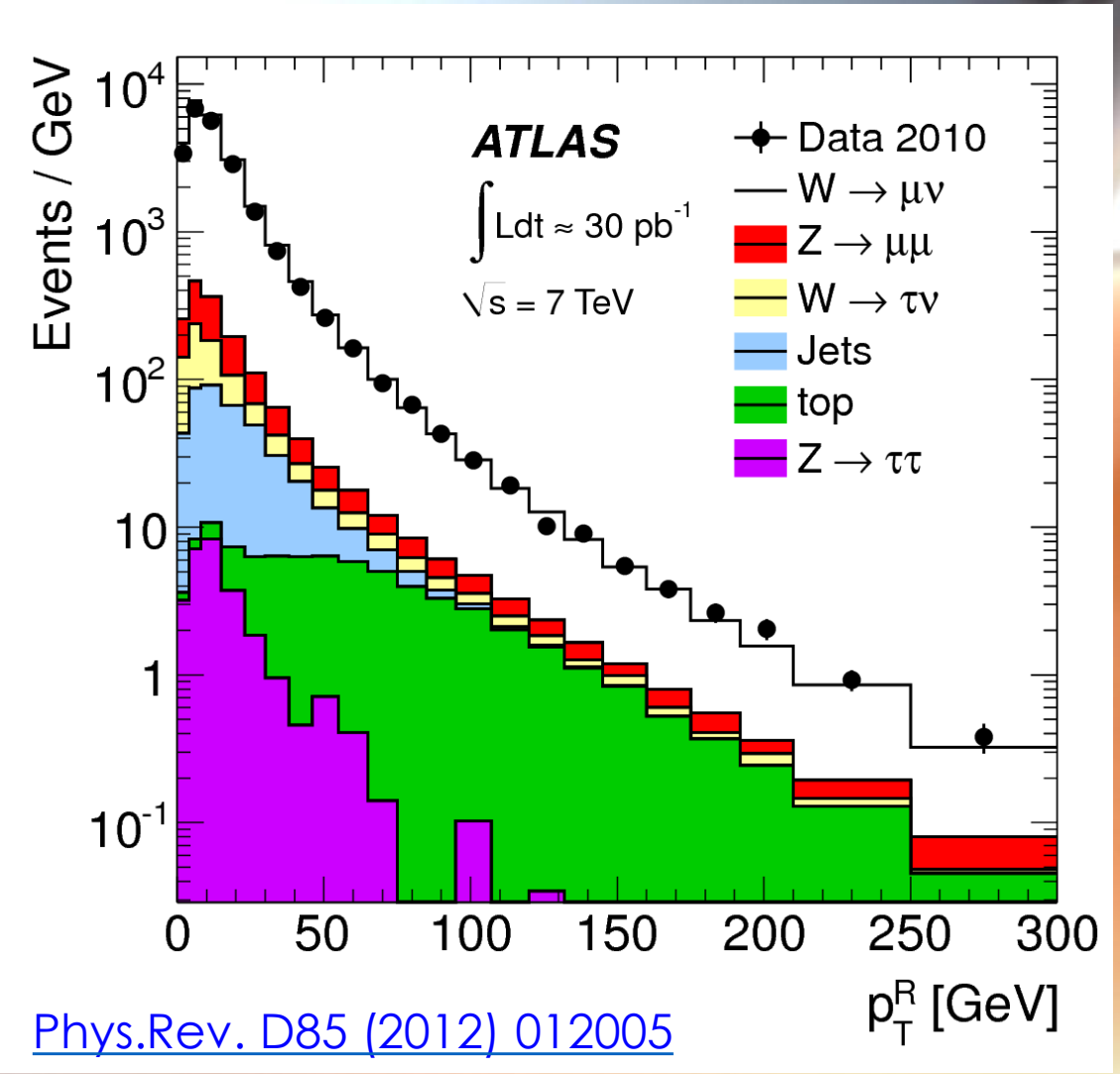
- Inner tracking detectors
  - Pixel detector
    - 80 Million pixels
  - Semiconductor Tracker
    - Silicon microstrip
  - Transition radiation tracker
    - Array of tungsten wires
  - Direction, momentum, and charge
- Solenoid magnet
  - Field parallel to beam
- Calorimeters
  - Absorb particle energy so it can be measured
  - Electromagnetic Calorimeter
    - Electrons, photons
  - Hadronic Calorimeter
    - Protons, neutrons
- Muon spectrometer
  - Gas detectors
  - Measure the pT of the muon particle



Project

Current Measurements of W Mass

- Previous precision
  - Averages of multiple measurements
  - Particle data group average
    - 80385 ± 15 MeV
  - Room for improvement
    - Standard model predicts an uncertainty of 8 MeV
  - Future goals
    - Standard model consistency
    - Expand knowledge beyond standard model



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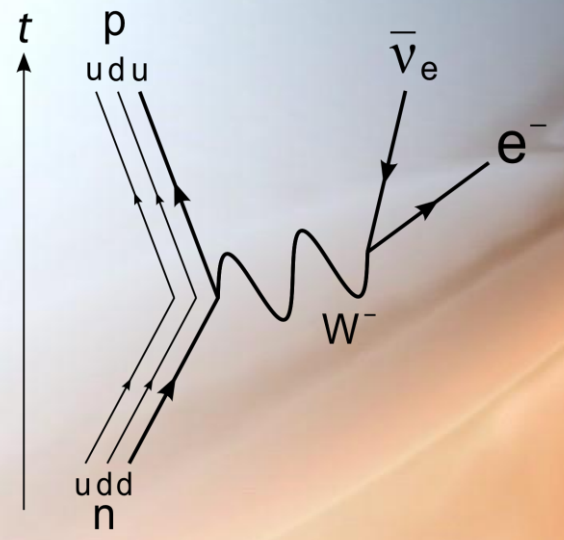
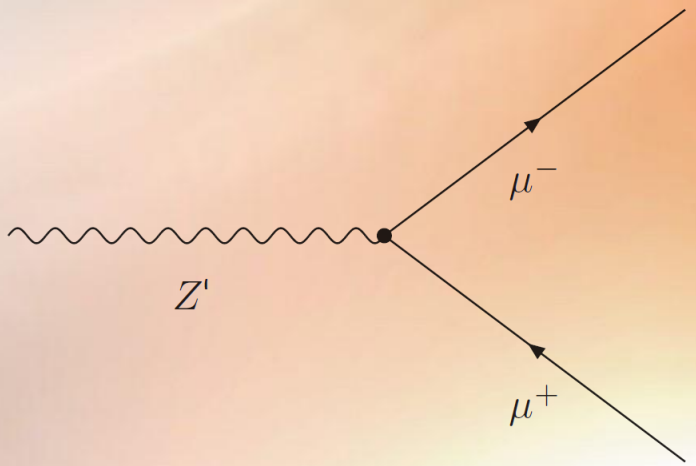
Current W Topology Limitations

- Current ability to account for all particles precisely
  - Specifically, neutrinos cannot be measured by ATLAS
  - They can, however, be accounted for indirectly
    - Calculate missing energy after reconstruction
      - Increase precision of reconstruction
        - Multiple methods and algorithms
        - Choose best one through analysis

Precision Calibration

- Calibrate detector
  - $W \rightarrow l\nu$
- Candidate for detector calibration: Z boson
- Easy to select
- Clean final state
  - $Z \rightarrow ll$
- Using $\mu\mu^-$



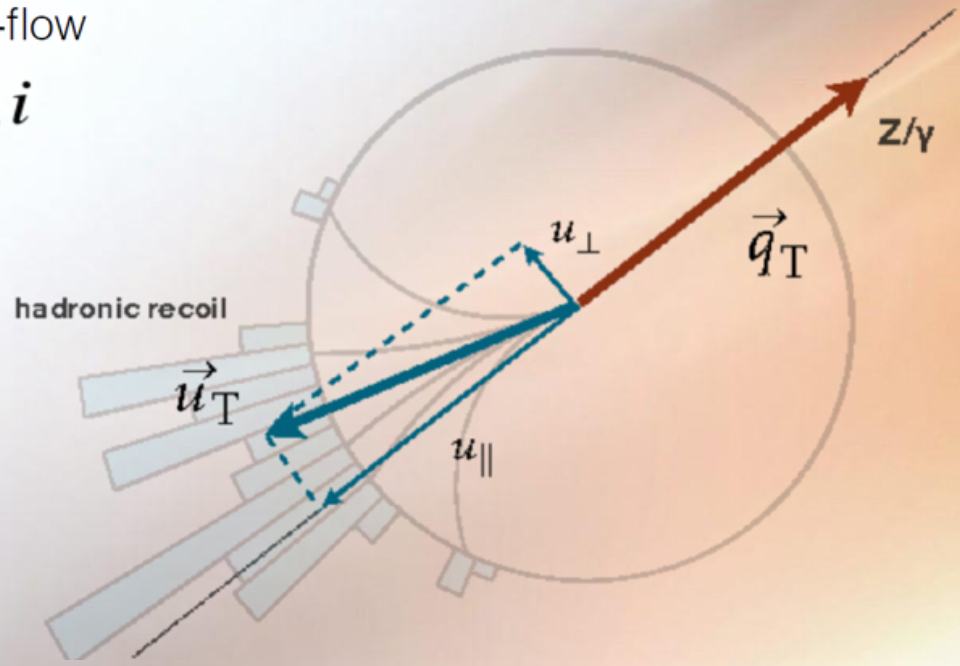


Hadronic Recoil components

- $u^{\perp}$ is a measure of resolution
- $u^{\parallel} + Z_{PT}$ is a measure of scale

Relative Resolution: $\frac{U_{RMS}^{\perp}}{\langle U_T \rangle}$

$$\vec{u}_{\mathrm{T}} = \sum_i \vec{E}_{\mathrm{T},i}^{\text{ p-flow}}$$

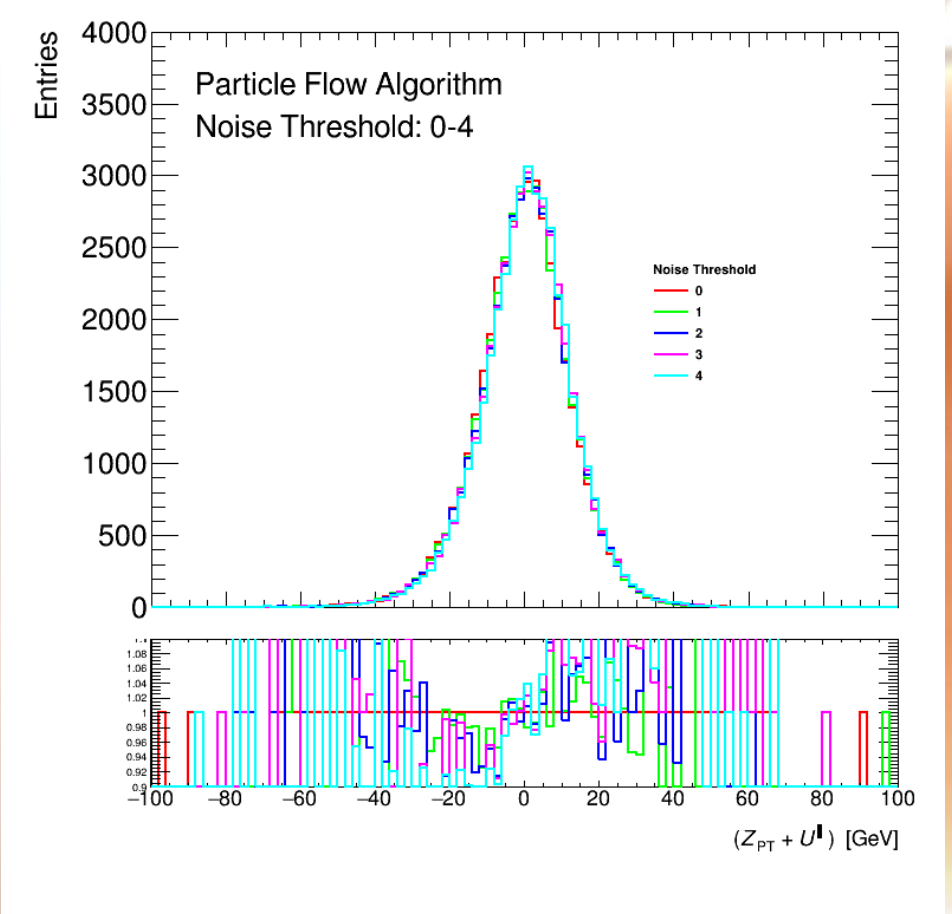


Methodology

- Split scale bias and resolution into bins based on energy level
  - Bins of Z_{PT}
    - 16 energy bins from [0,200]
  - Bins of $\sum E_T$
    - 10 energy bins from [0,1000]
- Two different methods to extract scale bias and resolution
  - Fit: Gaussian fits with ±2σ
  - RMS and Mean: Get these values from the histogram

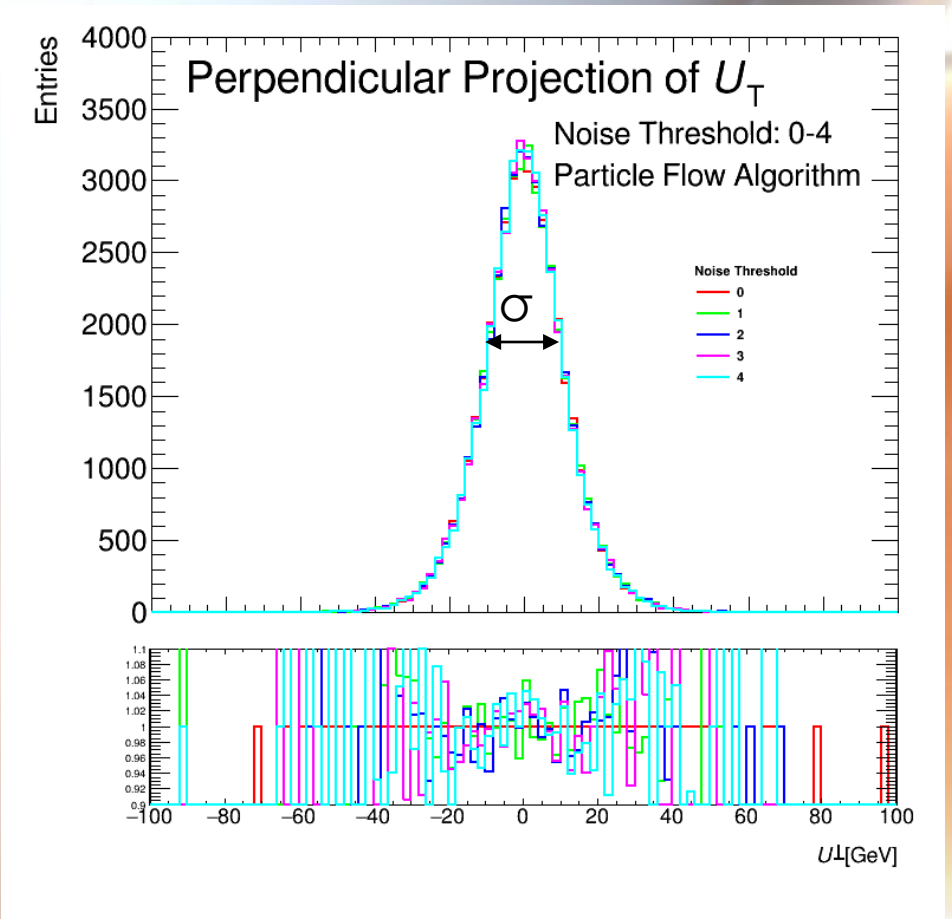
Scale Comparison

- Add Z_{PT} & $u^{\parallel}$ together
  - Mean value should be zero
  - Mean value is not zero
    - Need beter H-recoil reconstruction through calibration
- Next steps
  - Create gaussian fits to these distributions
  - Compare mean value

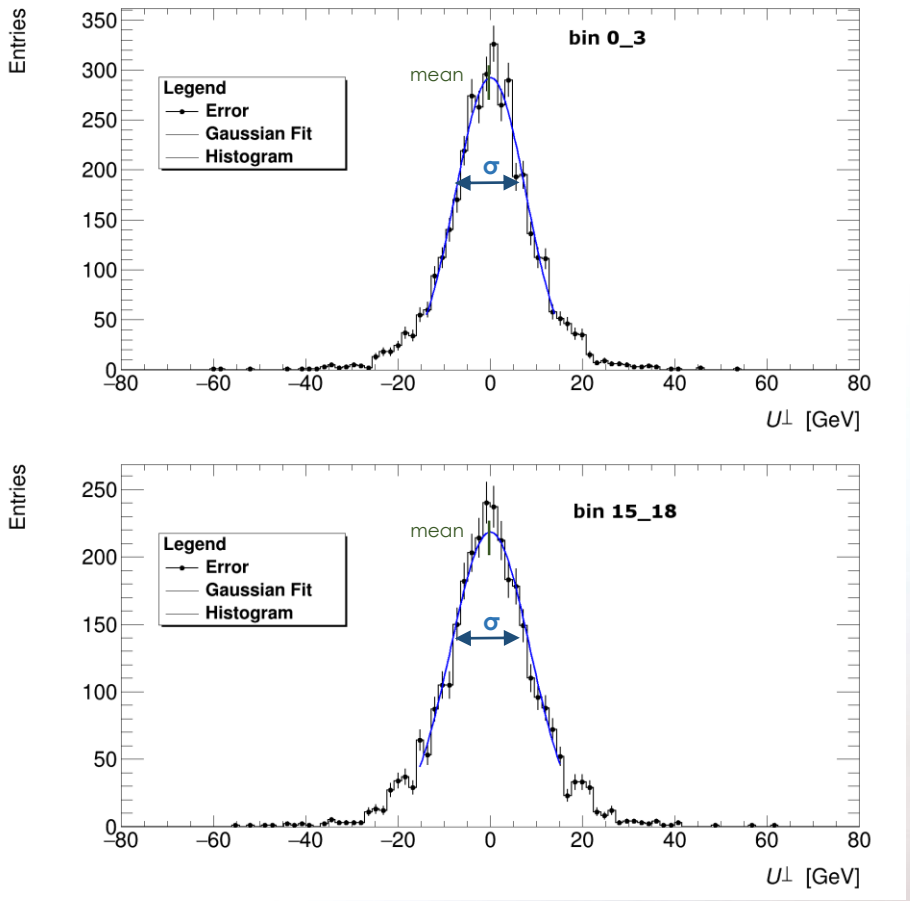


Resolution Comparison

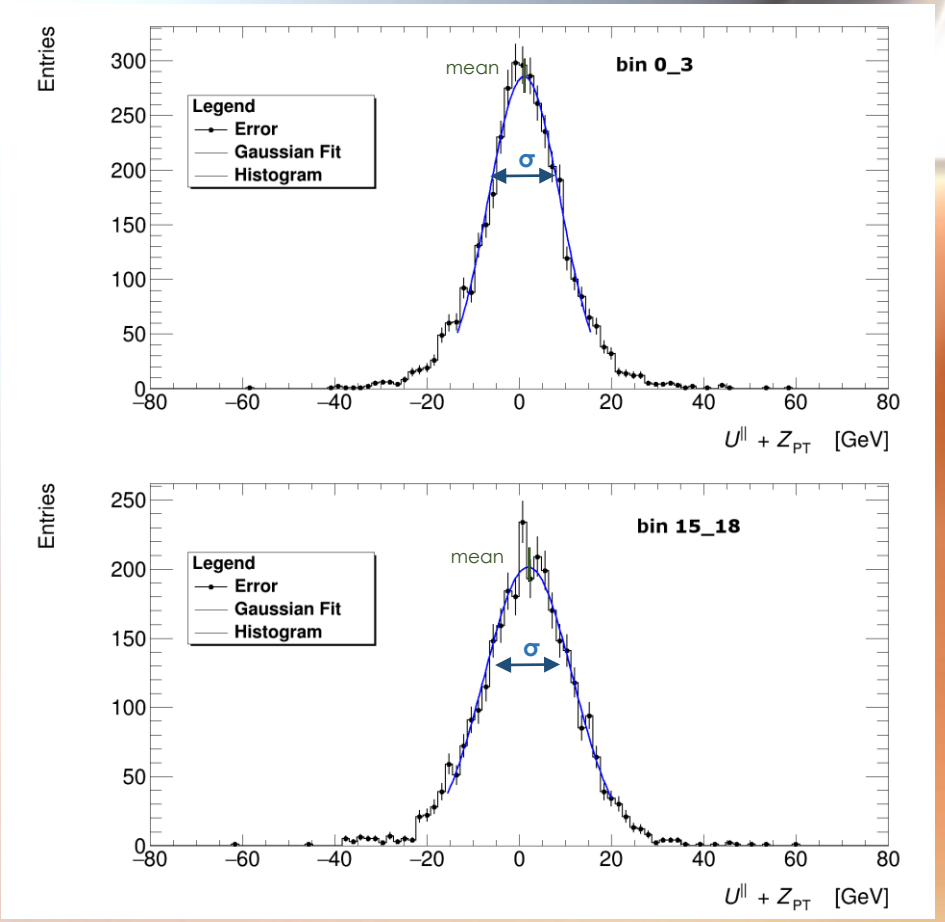
- Using $u^{\perp}$
  - Spread of distribution gives resolution of measurements
  - Smaller standard deviation means better resolution
    - Achieved through detector calibration
- Next steps
  - Create gaussian fits to these distributions
  - Compare RMS and σ



Gaussian Fits



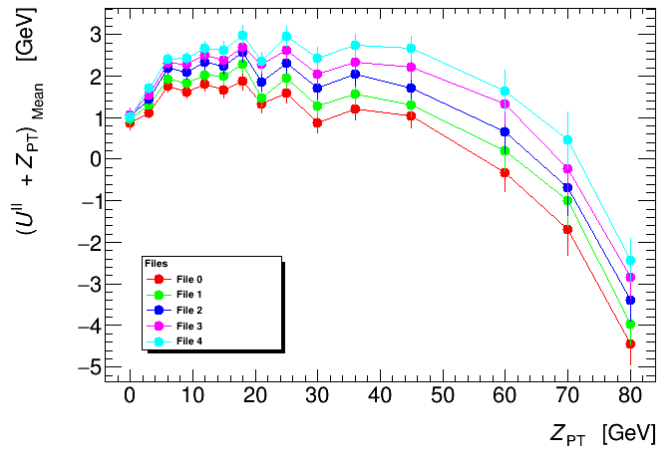
Gaussian fits for resolution: low energy bin (top) and medium energy bin (bottom)

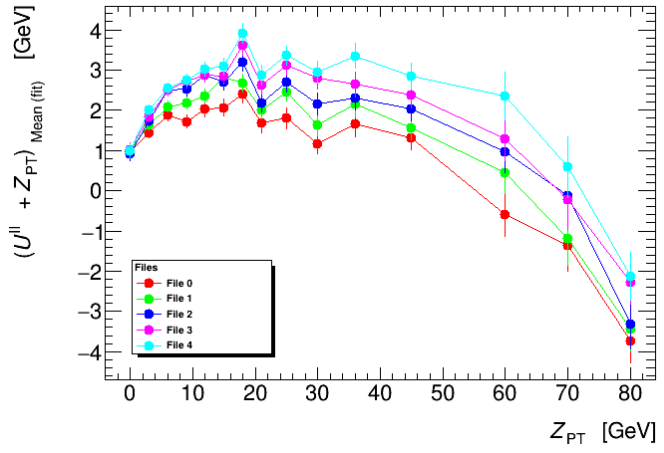


Gaussian fits for scale: low energy bin (top) and medium energy bin (bottom)

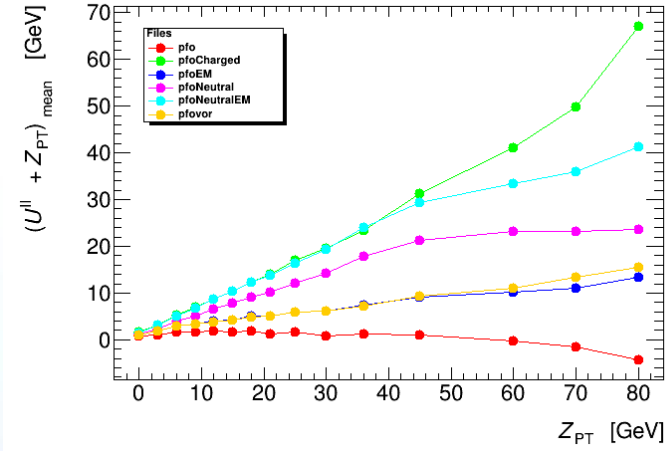
Histogram vs. Fit

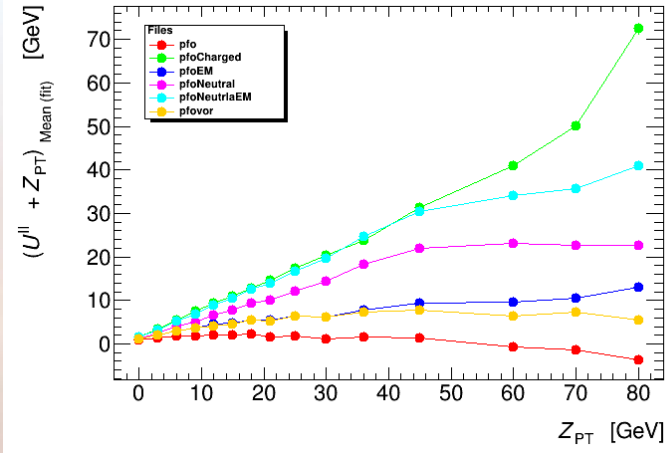
- Top: scale bias mean value vs. energy bin
- Bottom: scale bias mean value from Gaussian fit vs. energy bin





Scale Bias : COMPARING differnet reconstruction parameter for the same recoil algorithm

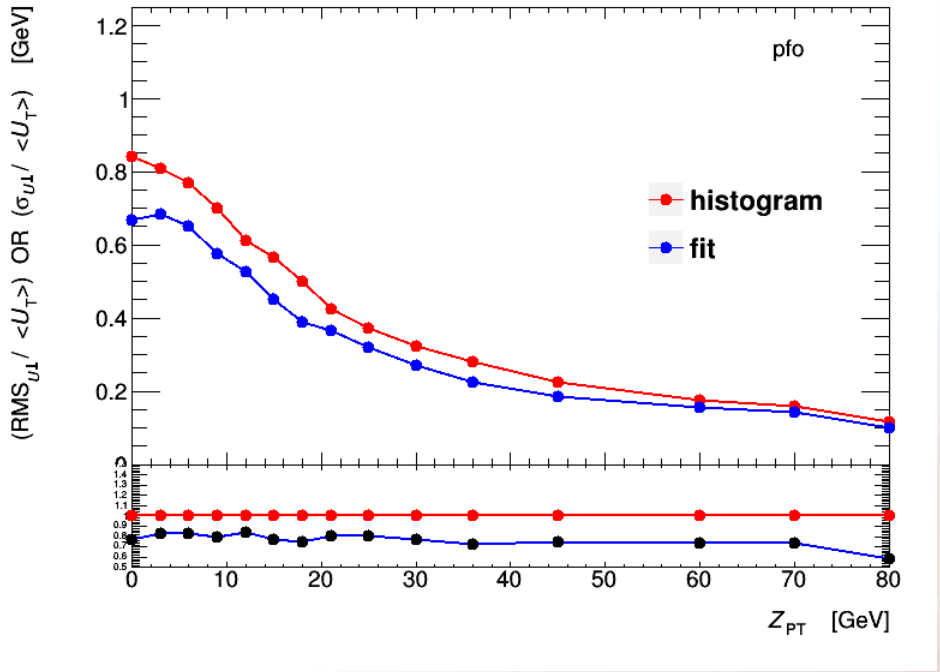


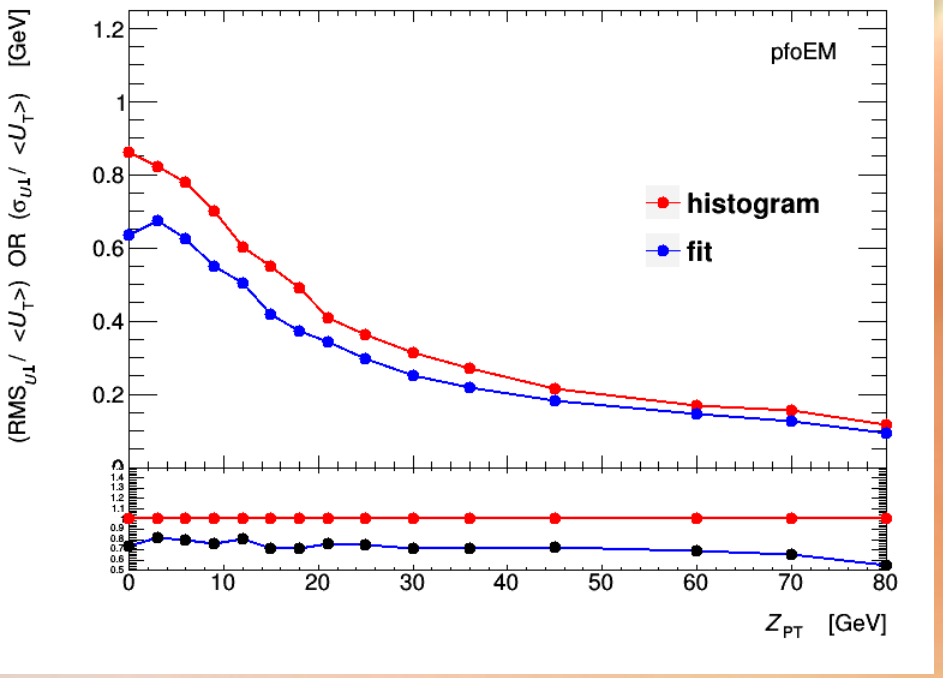


Scale Bias: COMPARING differnet recoil algorithm

P-flow vs. P-flowEM

Relative Resolution





Standard pfo fit values are slightly higher than other algorithms throughout.

pfoEM fit values are slightly lower, and within 20-30% of histogram values at low energy.

W Events

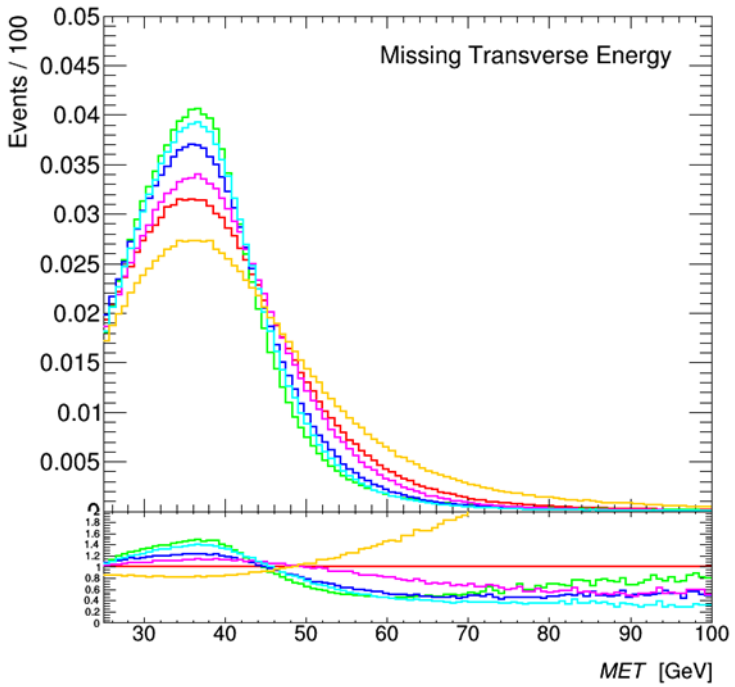
Calibration Procedure

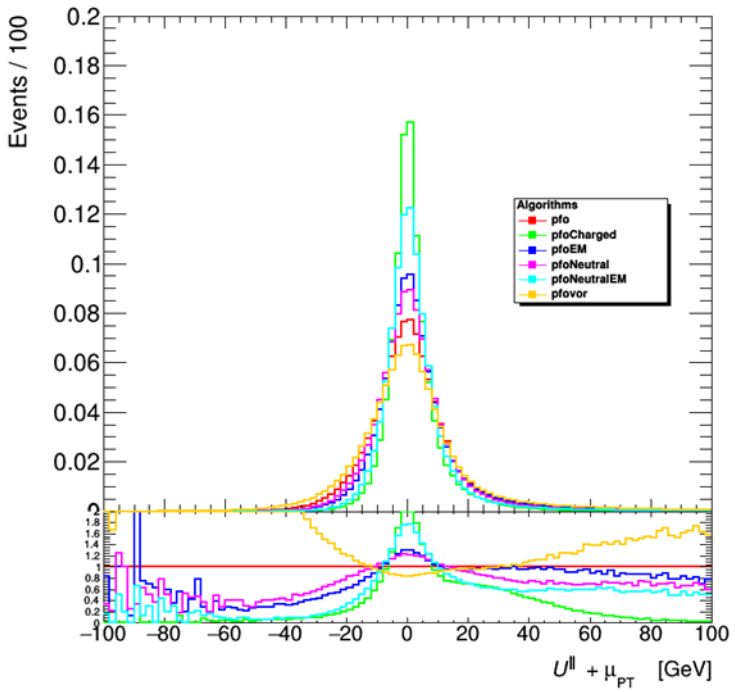
- W-boson: different decay from Z-boson
  - Can no longer use just hadronic recoil to calibrate
  - Neutrino must be accounted for by missing energy
- U_T -- H-recoil retrieved from the tree
- MET -- Addition of H-recoil vector and muon vector
- $U^{\perp}$ -- H-recoil projected perpendicular to muon vector
- $U^{\parallel}$ -- H- recoil projected parallel to muon vector
- W_{mT} -- Calculated using $\sqrt{2 \cdot P_T{}_{\vec{\mu}} \cdot P_T{}_{\overrightarrow{MET}} \cdot \left(1 - \cos\left(\Delta\phi_{\vec{\mu},\, \overrightarrow{MET}}\right)\right)}$

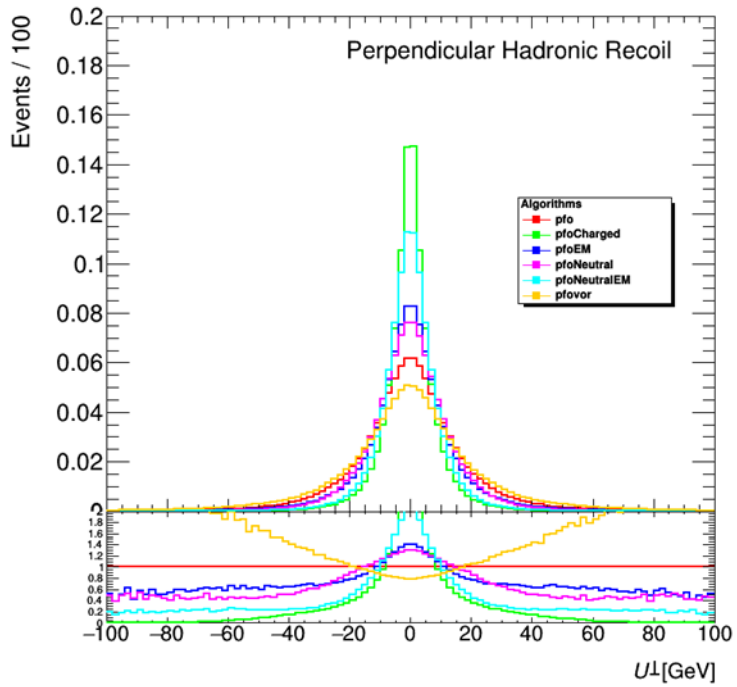
$\underline{MET}$

$\underline{U^{\parallel} + \mu_{PT}}$

$\underline{U^{\perp}}$

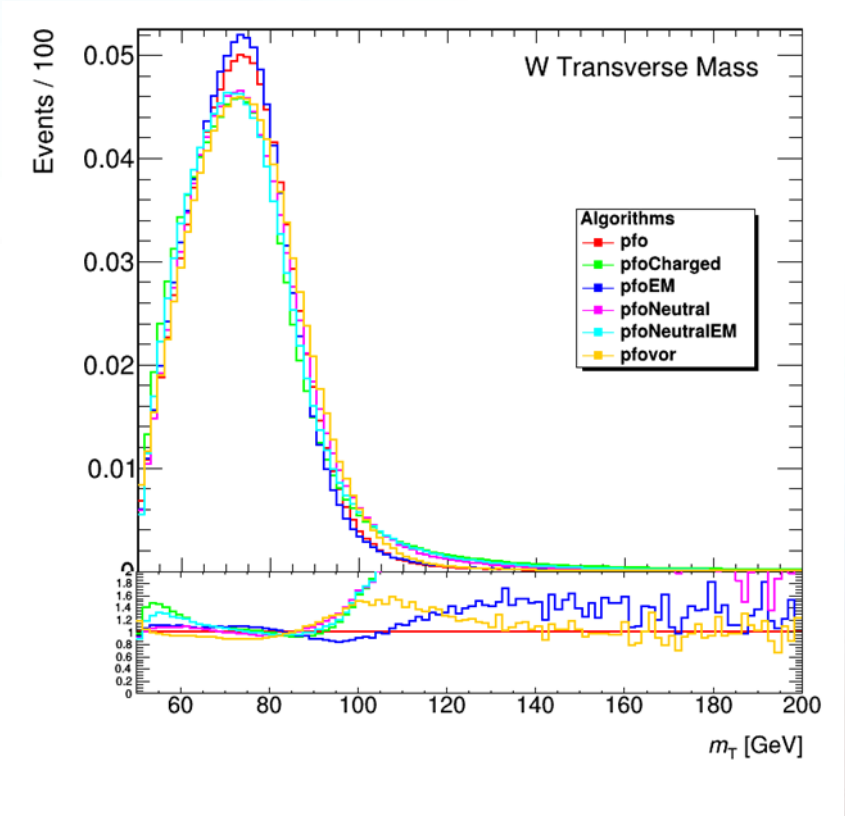






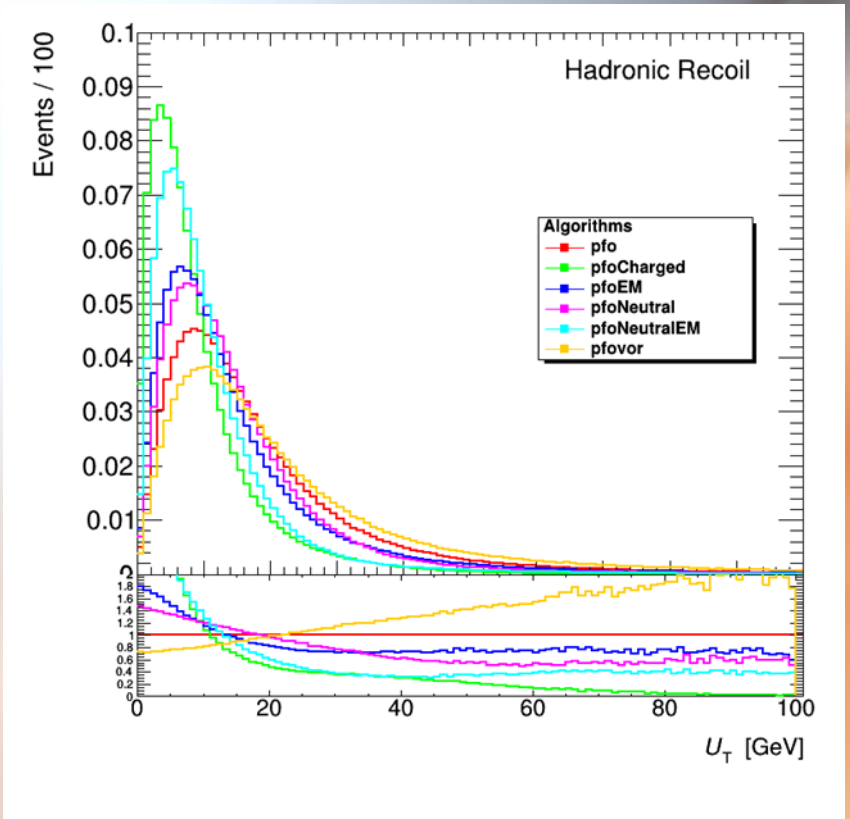
pfoCharged gives the best results in these plots – drastically so in the $U^{\parallel}$ distribution

W_{mT}



Here pfoEM gives the best W mass distribution

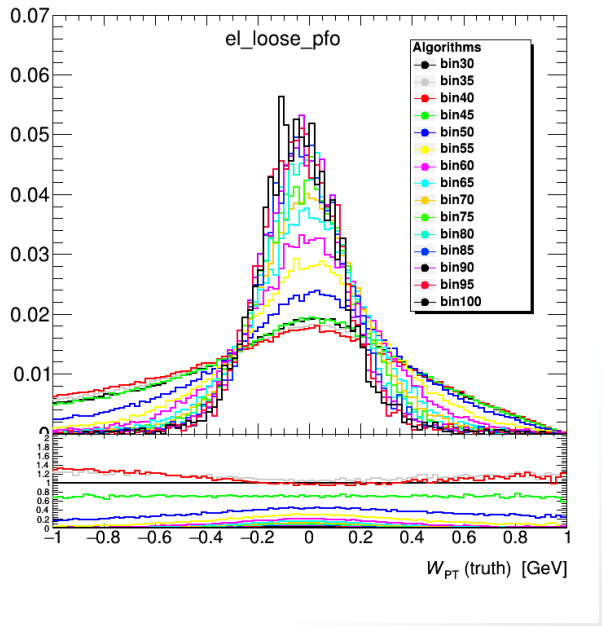
U_T

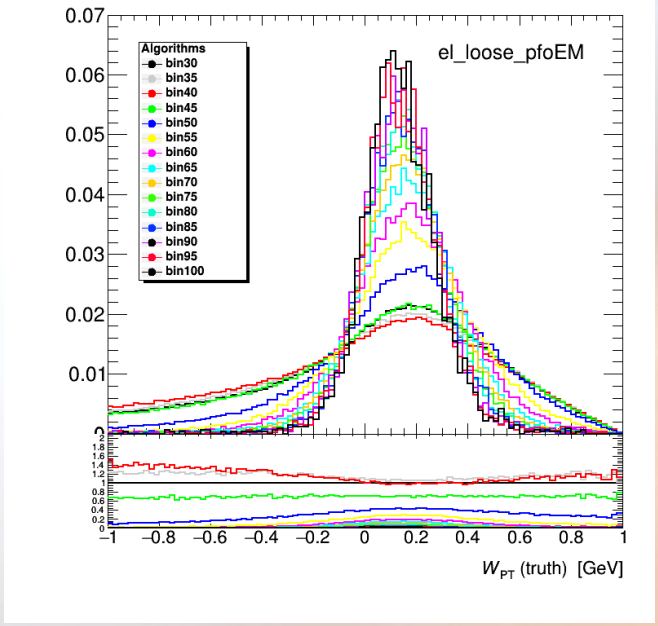


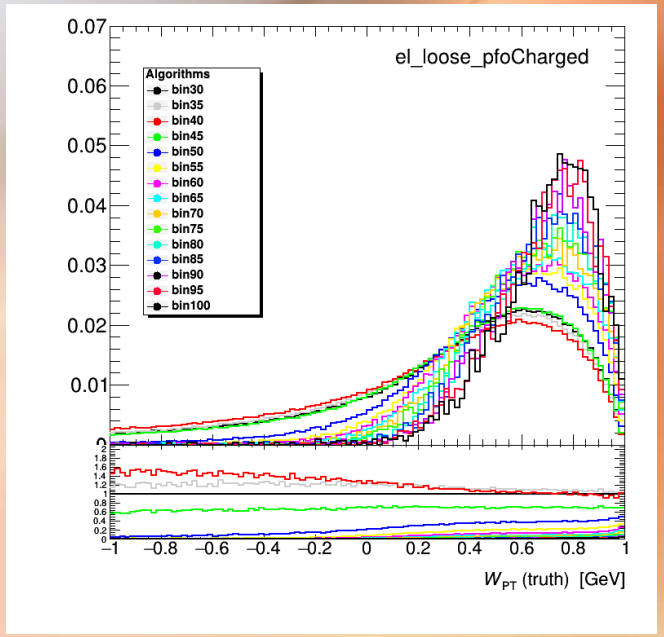
Once again pfoCharged has the highest, most narrow peak

W Truth Transverse Momentum

$$\frac{(W_{PT})_{Truth} - U_T(recoil)}{(W_{PT})_{Truth}}$$







Summary

- Use $Z \rightarrow \mu\mu^{-}$ events to see best reconstruction algorithm
- Compare $W \rightarrow \mu\nu$ events to see best reconstruction algorithm
- Look for mutual consistencies in success
  - Found ~20%-30% bias in relative resolution RMS and Gaussian fits
    - $U^{\parallel}$ & $U^{\perp}$ Projections
- Choose best suited algorithm for detector calibration
  - Previous plots show that pfoEM has the best:
    - Relative resolution
    - Transverse W mass

What I Have Learned

- A large amount of particle physics
- Detector physics and operation
- Data analysis
- Coding and implementation
- Problem solving
- I have great interest in this field of study

Acknowledgements

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COPENHAGEN

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SPECIAL GUEST
MEGADETH
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ROYA
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/LP/DIGITAL

Questions?

References

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