Paper Preview:

Measurements of W^+/W^- cross-section ratio in pp Collisions at RHIC

Jae Nam, Matt Posik, Bernd Surrow

Temple Univ.

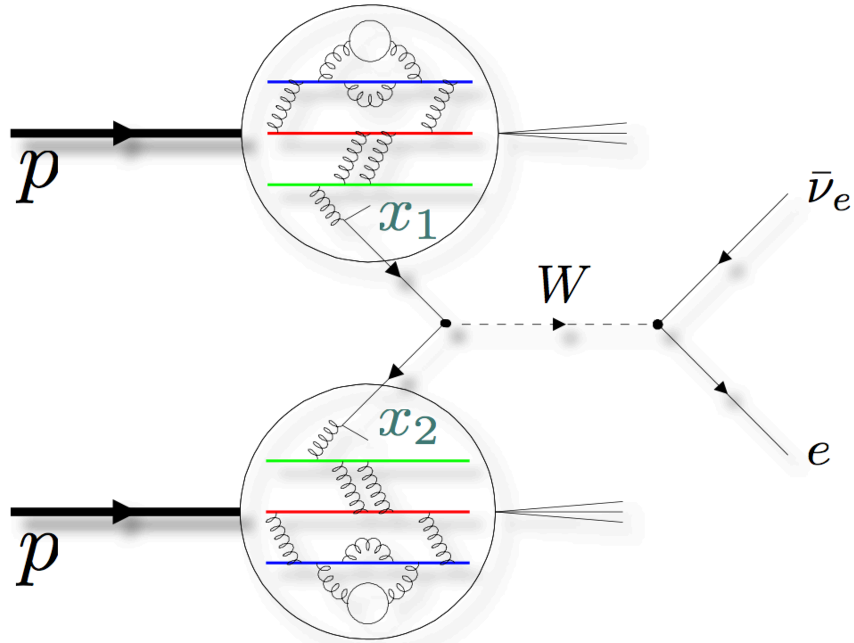
General Information

- **Title**: Measurements of W^+/W^- cross-section ratio in pp collisions at RHIC
- **Target Journal**: PRD
- **PA**: Jae Nam, Matt Posik, Bernd Surrow
- **Webpage**: link
- **Analysis Note**: link
- **Paper draft**: link
- **Previous Publications**:
    - Z cross section and AN, PLB 854 (2024) 138715
    - Unpol W/Z cross section + ratio, PRD 103 (2021) 1, 012001
    - W-AL, PRD 99 (2019) 5, 051102
    - W/Z-AN, PRL 116 (2016) 13, 132301

Motivation

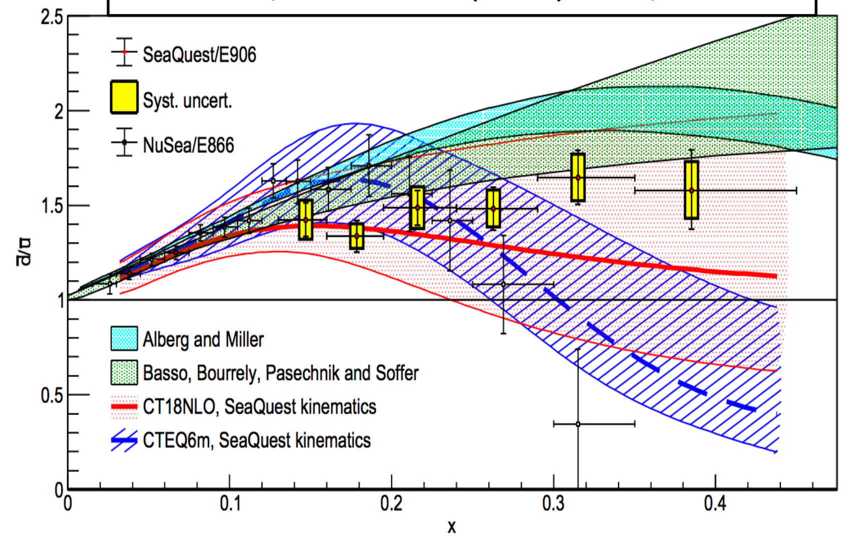
- W ($W \to e\nu$) in pp at LO
  - $d\sigma^{W+} \propto u(x_1)\bar{d}(x_2) + u(x_2)\bar{d}(x_1)$
  - $d\sigma^{W-} \propto \bar{u}(x_1)d(x_2) + \bar{u}(x_2)d(x_1)$

$$\boxed{\rightarrow R_W = \frac{\sigma^{W+}}{\sigma^{W-}} \sim \frac{u(x_1)\bar{d}(x_2) + u(x_2)\bar{d}(x_1)}{\bar{u}(x_1)d(x_2) + \bar{u}(x_2)d(x_2)}}$$



- Sensitive to non-perturbative SU(2) $\bar{d}/\bar{u}$ asymmetry
- Momentum scale set by the W mass, complementary to fixed-target experiments
- Provides robustness test of STAR W/Z reconstruction scheme
- Key features of $W \to e\nu$ in pp
  - High p_T electron.
  - Large imbalance in p_T due to missing ν.

SeaQuest, Nature 590 (2021) 7847, 561-565

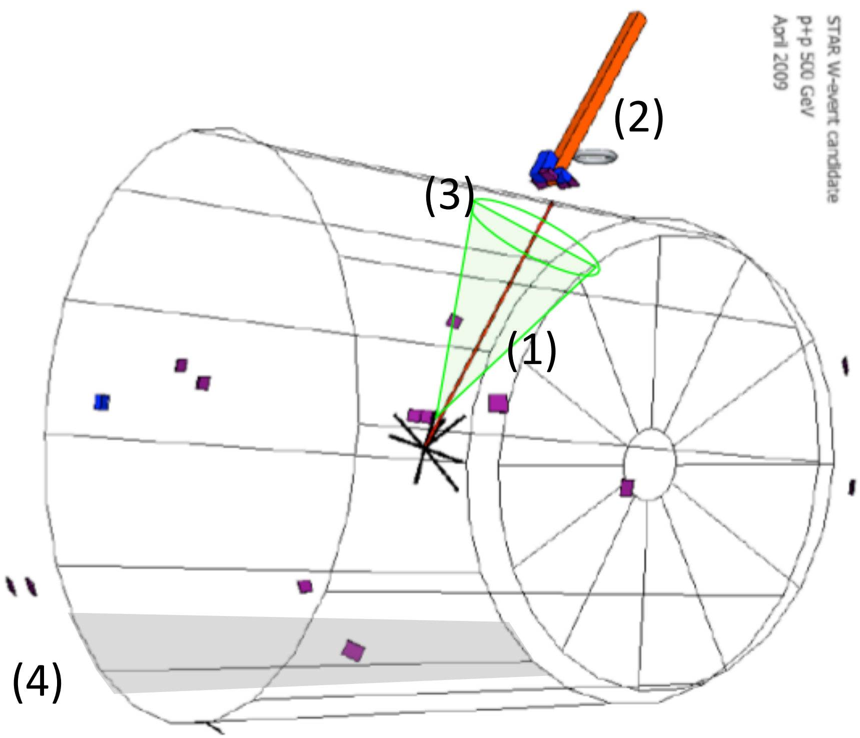


Data & MC

- Data: STAR Run 2017 $pp\ \sqrt{s} = 510\ GeV$
- Trigger set: pp500_production_2017
- Production tag: P20ic
- Trigger: L2BW || L2EW
- Run list: /star/u/jaenam/W2017/lists/runnumber.list (2691 runs, $340\ pb^{-1} \pm 5\%$)
  - 2.6% correction based on Xiaoxuan's luminosity study (link)
  - $352\ pb^{-1}$ (Jamie's table) $-2.6\% = 343\ pb^{-1}$; reporting as $340\ pb^{-1}$)
  - Same has been done for previous (Run 11-13) results, when combining
- TPC Sec 20 masked out
- Simulation: Request ID 20201502 (link)
  - Pythia 6, CTEQ5L,
    STAR Tune based on Perugia 2012

Event Reconstruction

Event Display of typical W event



1) A high momentum track is identified ($p_T > 10$ GeV; we expect $p_{T,e} \sim 40\ GeV$)

2) Energy cluster is formed (2×2 towers, each covering 0.05×0.05 in $\eta \times \phi$; cluster: 0.1×0.1)

3) Isolation requirement ($E_T^{2\times2}/E_T^{\Delta R<0.7} \sim 1$, $E_T^{2\times2}/E_T^{4\times4} \sim 1$)

4) Backward (neutrino direction) energy flow requirement ($E_T^{\Delta\phi\sim\pi} < 11$ GeV)

5) Energy imbalance (signed-$p_{T,bal}$) ($\hat{p}_{T,e} \cdot \left(\vec{p}_{T,e} + \sum \vec{p}_{T,jet}\right) > 16$ GeV)

Selection cuts

*same as PRD 103 (2021) 1, 012001

<table>
<tr><th></th><th>Barrel ($-1 < \eta < 1$)</th><th>Endcap ($1 < \eta < 1.5$)</th></tr>
<tr><td>Trigger</td><td>L2BW</td><td>L2EW</td></tr>
<tr><td rowspan="2">Vertex</td><td colspan="2">Rank > 0</td></tr>
<tr><td colspan="2">$|Z_{vtx}| < 100\ cm$</td></tr>
<tr><td rowspan="5">Track</td><td>$p_T > 10\ GeV$</td><td>$p_T > 7\ GeV$</td></tr>
<tr><td>$N_{hit} > 15$</td><td>$N_{hit} > 5$</td></tr>
<tr><td colspan="2">$N_{hit}/N_{pos} > 0.51$</td></tr>
<tr><td>$R_{TPC,in} < 90\ cm$</td><td>$R_{TPC,in} < 120\ cm$</td></tr>
<tr><td>$R_{TPC,out} > 160\ cm$</td><td>$R_{TPC,out} > 70\ cm$</td></tr>
<tr><td rowspan="3">Cluster</td><td>$\Delta R_{trk,cls} < 7\ cm$</td><td>$\Delta R_{trk,cls} < 10\ cm$</td></tr>
<tr><td colspan="2">$E_T^{2\times2} > 16\ GeV$</td></tr>
<tr><td></td><td>$N_{ESMD} > 20$</td></tr>
<tr><td rowspan="3">Isolation</td><td>$E_T^{2\times2}/E_T^{2\times2} > 0.96$</td><td>$E_T^{2\times2}/E_T^{2\times2} > 0.97$</td></tr>
<tr><td>$E_T^{2\times2}/E_T^{\Delta R<0.7} > 0.82$</td><td>$E_T^{2\times2}/E_T^{\Delta R<0.7} > 0.88$</td></tr>
<tr><td></td><td>$R_{ESMD}^{7\times7/41\times41} > 0.6$</td></tr>
<tr><td rowspan="4">W Selection</td><td>signed-$p_{T,bal} > 16\ GeV$</td><td>signed-$p_{T,bal} > 20\ GeV$</td></tr>
<tr><td>$E_T^{\Delta\phi\sim\pi} < 11\ GeV$</td><td></td></tr>
<tr><td>$|Q\times E_T p_T| < 3.0$</td><td>$|Q\times E_T p_T| < 2.5$</td></tr>
<tr><td colspan="2">$25\ GeV < E_{T,e}(\equiv E_T^{2\times2}) < 50\ GeV$</td></tr>
</table>

Abstract

We report measurements of inclusive $pp \to W^{\pm}X$ production cross sections via the leptonic decay channel $W \to e\nu$ and their ratio in unpolarized pp collisions at a center-of-mass energy of $\sqrt{s} = 510$ GeV. The measurements were performed within the fiducial region defined by the charged-lepton pseudorapidity $-1 < \eta_e < 1.5$, and transverse energy 25 GeV $< E_{\mathrm{T},e} <$ 50 GeV. The cross-section ratio, $\sigma(pp \to W^{+}X)/\sigma(pp \to W^{-}X)$ and differential cross sections, $\mathcal{B}(W \to e\nu) \cdot d\sigma(pp \to W^{\pm}X)/d\eta_e$, are sensitive to the unpolarized sea quark ratio, $\bar{d}/\bar{u}$, and are measured as a function of the leptonic pseudorapidity within the studied region. The results are based on pp collision data collected with the STAR detector at RHIC in 2017, which correspond to an integrated luminosity of 340 pb^{-1}, and found to be consistent with previous STAR publications. Perturbative predictions at next-to-next-to-leading order (NNLO) accuracy, based on the FEWZ 3.1 simulation framework, and NNLO predictions supplemented with q_{T} resummation up to next-to-next-to-next-to-leading logarithmic terms (NNLO+N^{3}LL), based on the ResBos2 framework, with the latest global fit results are compared to the combined STAR data with an integrated luminosity of 680 pb^{-1}. While the predicted cross-section ratio describes the data well, the predictions for the differential cross sections overestimate the measurements by approximately 2σ.

Abstract

We report measurements of inclusive $pp \to W^{\pm}X$ production cross sections via the leptonic decay channel $W \to e\nu$ and their ratio in unpolarized pp collisions at a center-of-mass energy of $\sqrt{s} = 510$ GeV. The measurements were performed within the fiducial region defined by the charged-lepton pseudorapidity $-1 < \eta_e < 1.5$, and transverse energy 25 GeV $< E_{T,e} <$ 50 GeV. The cross-section ratio, $\sigma(pp \to W^+X)/\sigma(pp \to W^-X)$ and differential cross sections, $\mathcal{B}(W \to e\nu) \cdot d\sigma(pp \to W^{\pm}X)/d\eta_e$, are sensitive to the unpolarized sea quark ratio, $\bar{d}/\bar{u}$, and are measured as a function of the leptonic pseudorapidity within the studied region. The results are based on pp collision data collected with the STAR detector at RHIC in 2017, which correspond to an integrated luminosity of 340 pb^{-1}, and found to be consistent with previous STAR publications. Perturbative predictions at next-to-next-to-leading order (NNLO) accuracy, based on the FEWZ 3.1 simulation framework, and NNLO predictions supplemented with q_T resummation up to next-to-next-to-next-to-leading logarithmic terms (NNLO+N^{3}LL), based on the ResBos2 framework, with the latest global fit results are compared to the combined STAR data with an integrated luminosity of 680 pb^{-1}. While the predicted cross-section ratio describes the data well, the predictions for the differential cross sections overestimate the measurements by approximately 2σ.

This is also the case for unpol. W/Z Run 2011-13
Run 17 Z pub. under investigation

Close communication with PAs (Pavel Nadolsky, et al.)
For this presentation, **FEWZ** framework is used (w/o NLL)

Fig 1: Signal + BG description

*captions in the backup slides

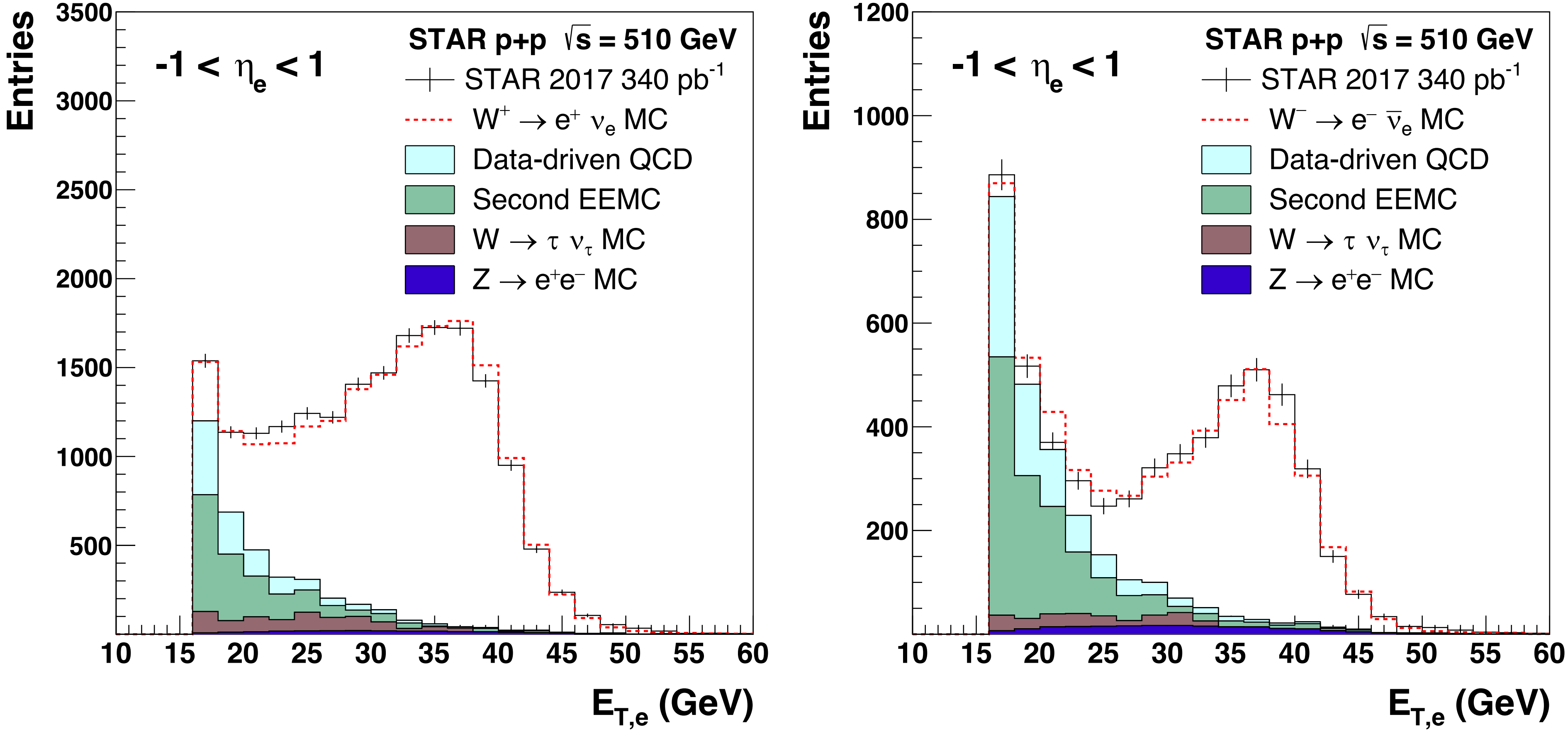
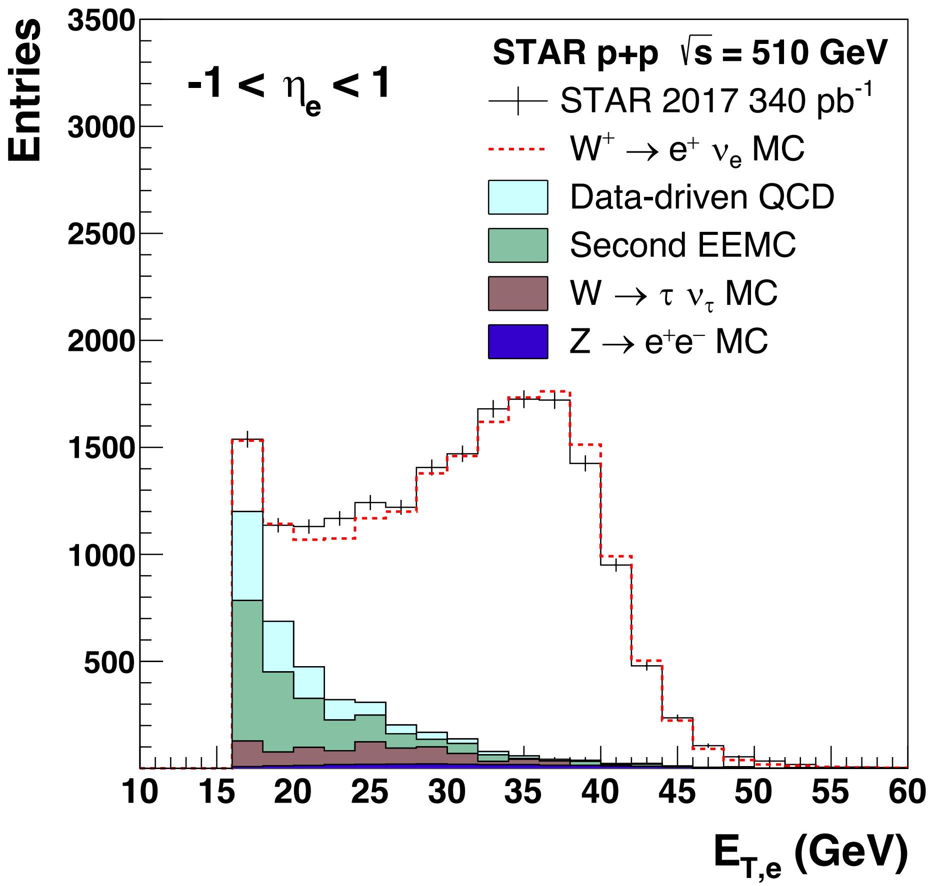


Fig 1: Signal + BG description

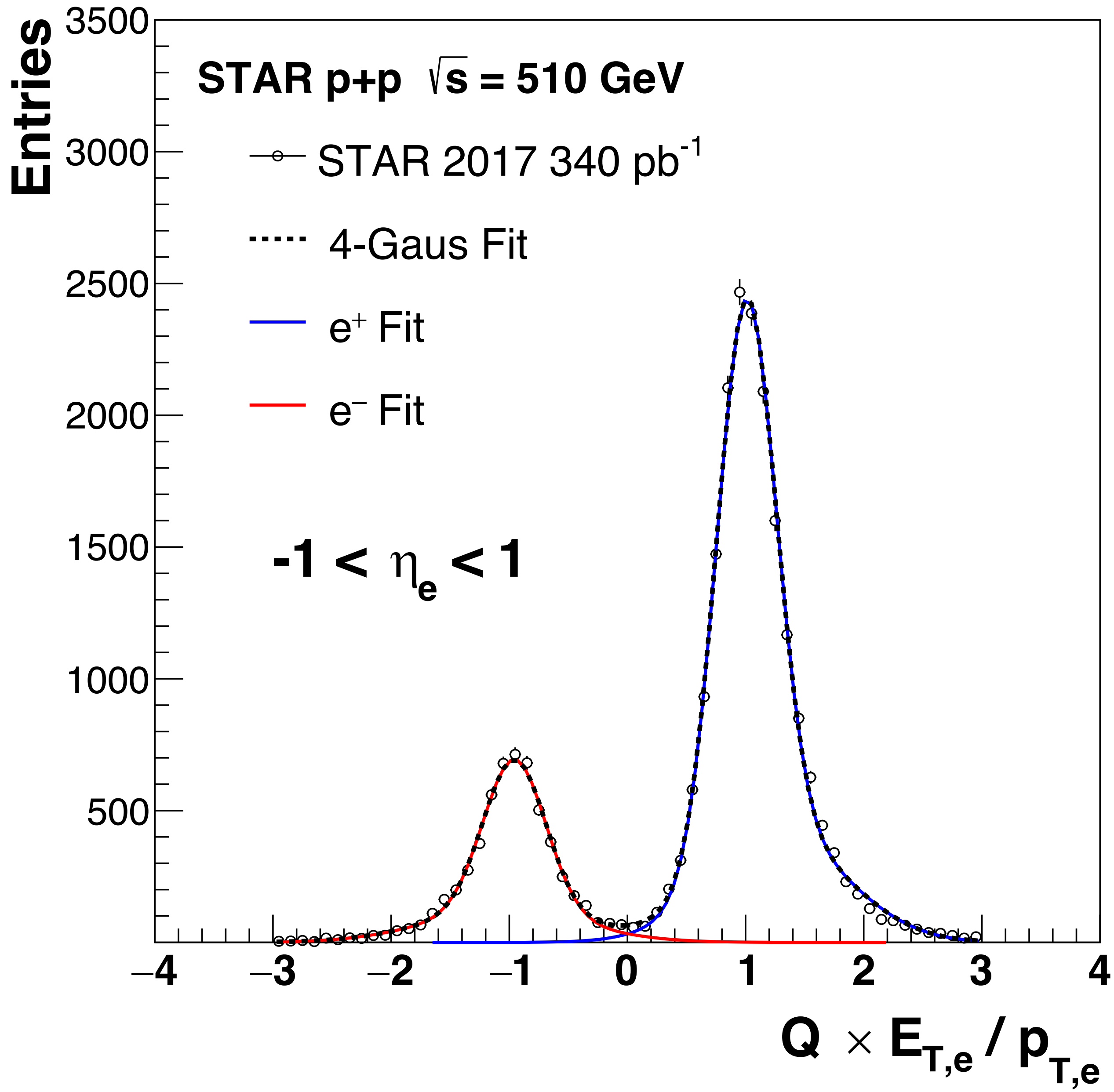


$$N_{sig}^{data} = N_{sel}^{data} - \sum N_{bg,i}$$

Remaining background

- $Z \to e^+e^-$
  - with one electron outside STAR acceptance
  - Indistinguishable experimentally → Estimated based on MC
- $W \to \tau$
  - $\tau \to e$ decay within STAR volume
  - Same as $Z \to e^+e^-$ (MC-based)
- QCD processes (dijets)
  - One jet in dijet events outside STAR acceptance
  - Data-driven method (signed-$p_{T,bal}$ < threshold)
  - Using existing EEMC ($-2 < \eta < -1$)
  - Systematic uncertainty for data-driven QCD background selection and normalization

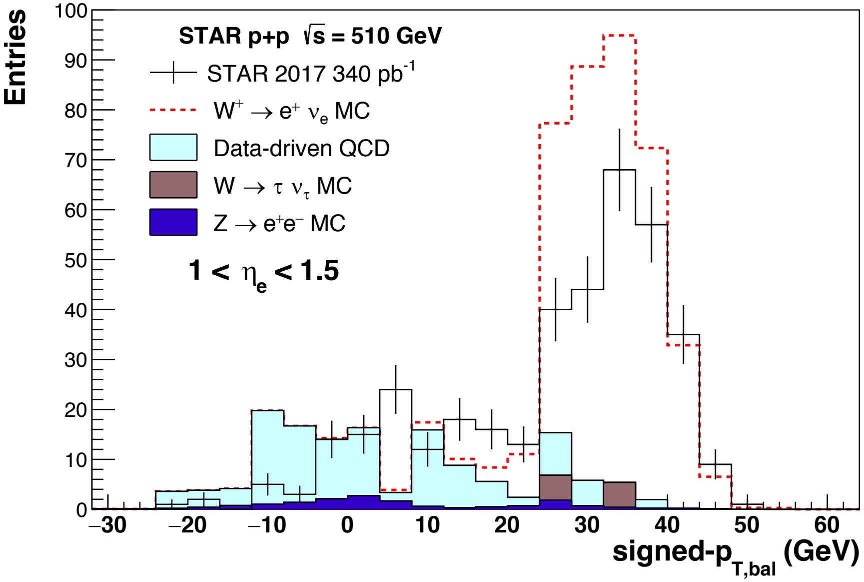
Fig 2: Charge Mis-ID (Barrel, Comb)

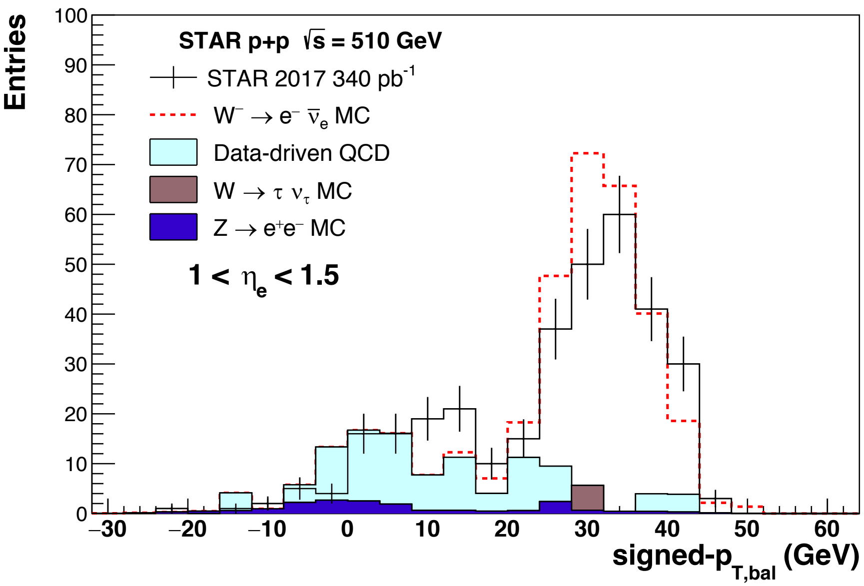


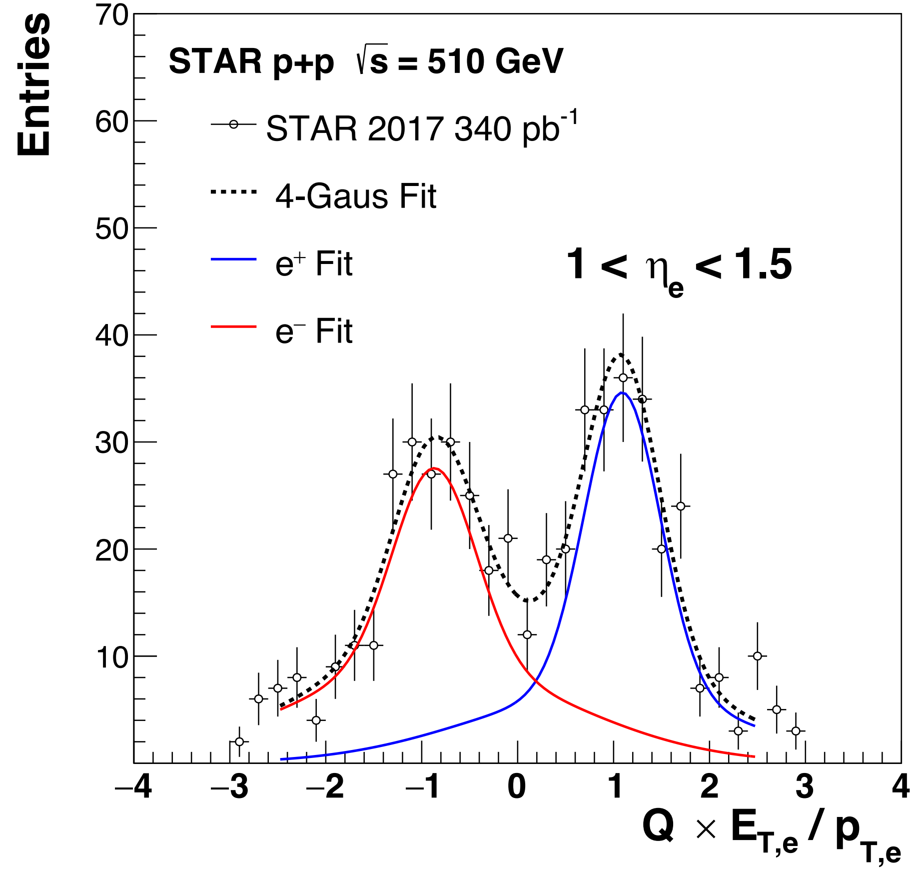
- Charge mis-ID correction based on 4-Gaus fit of $Q \times E_T / p_T$
- 2-Gaus for each sign to describe signal and background
- $c_q^+ = \frac{N^{2Gaus+}}{N_{q>0}^{4Gaus}}$

$$\boxed{N_{sig,cor}^{data} = c_q \times N_{sig}^{data}}$$

Fig 3: Signal + Charge (Endcap)







- MC overestimates W+, also seen in previous publication
- Systematics for data-driven QCD (same as barrel) and charge correction

Fig 4: Efficiency

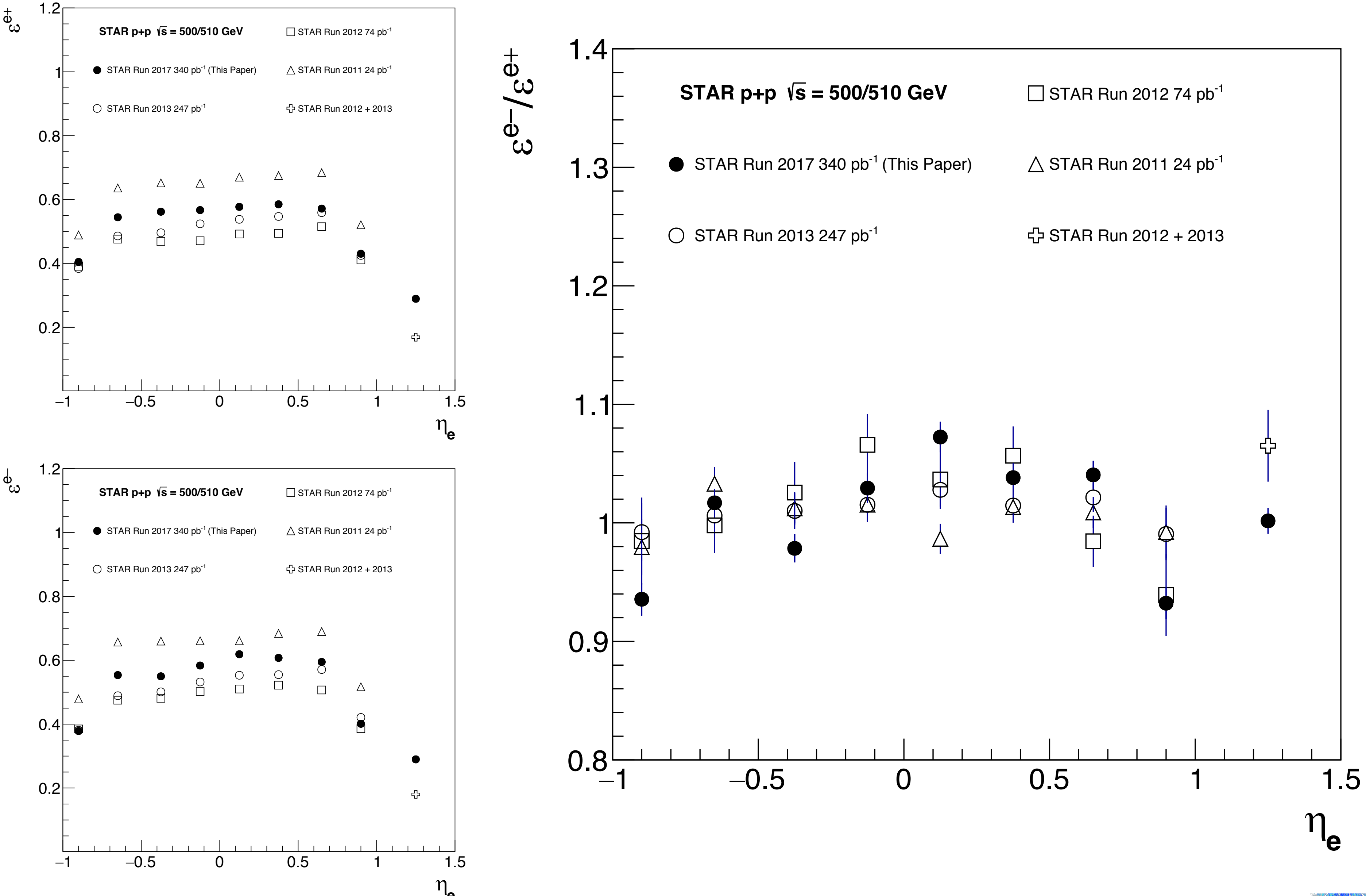
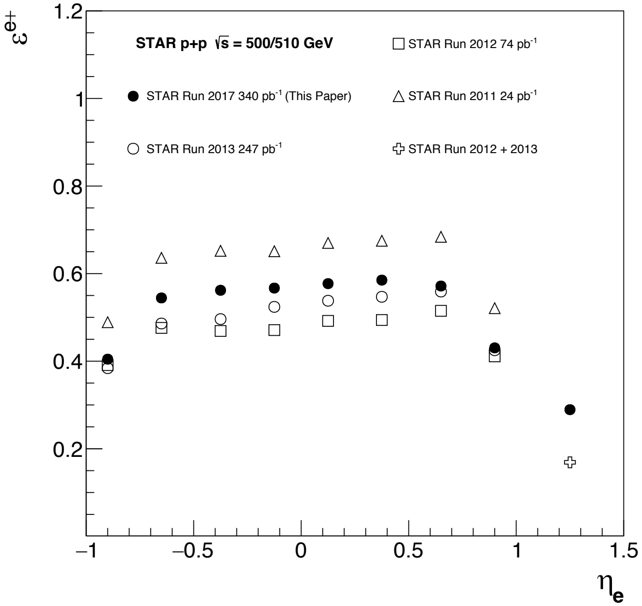
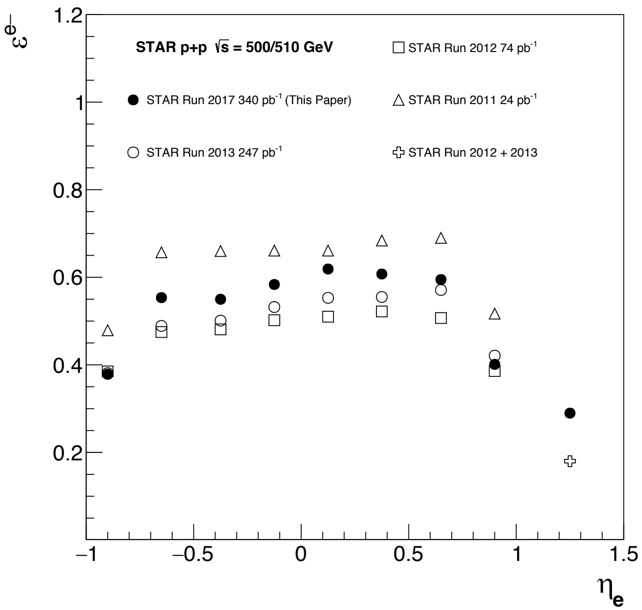


Fig 4: Efficiency

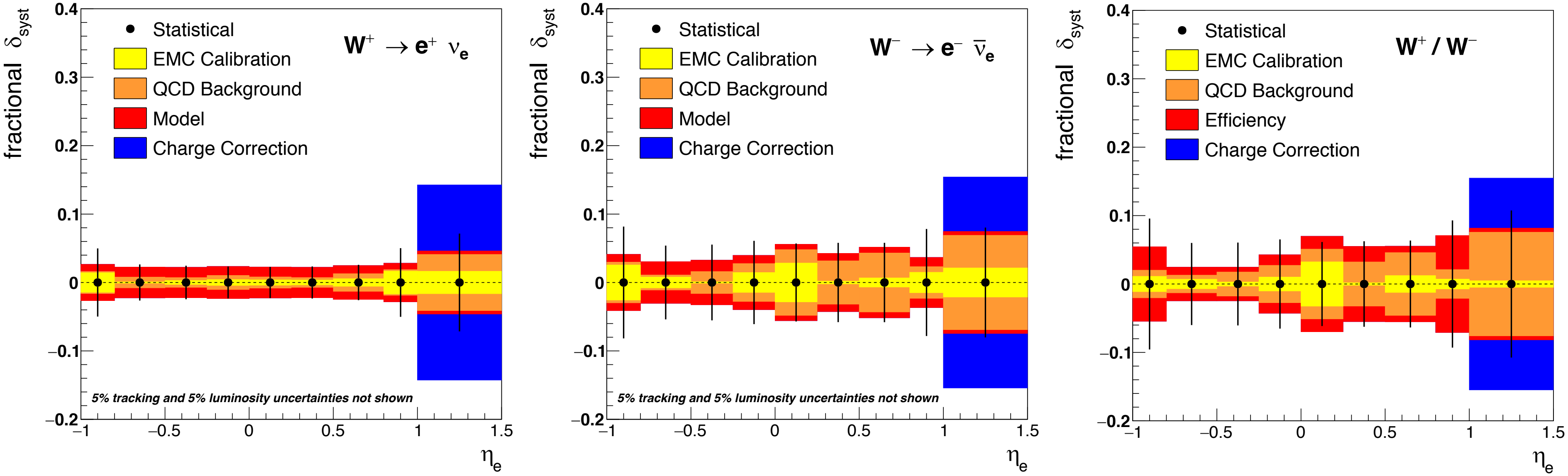




- Run 2011
  - Low material budget
  - Low instantaneous luminosity
- Run 2012 & 2013
  - High material budget (HFT, FGT, support)
  - High instantaneous luminosity
  - STI track algo Run 11, 12 vs STICA Run 13
- Run 2017
  - Low material budget
  - High instantaneous luminosity
  - STICA algo
- Asymmetric in η_e due to TPC Sec 20
  - Sec 20 issue addressed in Run 18 (→ Run 22)

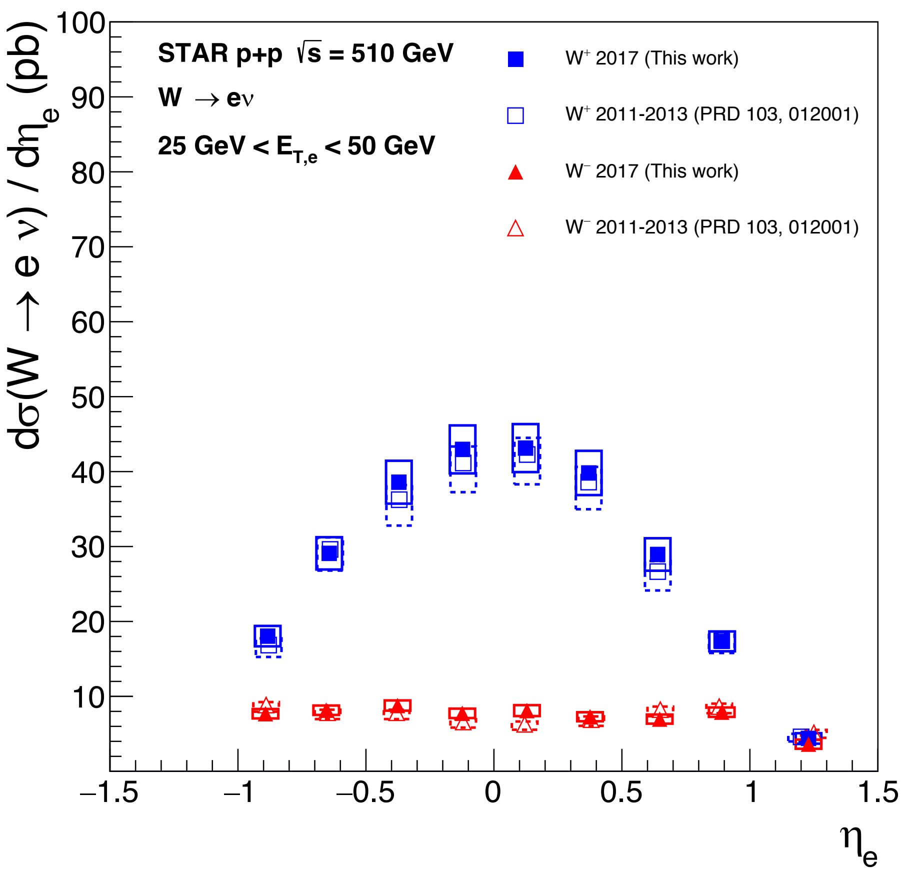
$$\boxed{\left(\frac{d\sigma}{d\eta}\right)_i = \frac{1}{\epsilon_i}\frac{N_{sig,cor,i}}{\delta\eta_{e,i}L}}$$

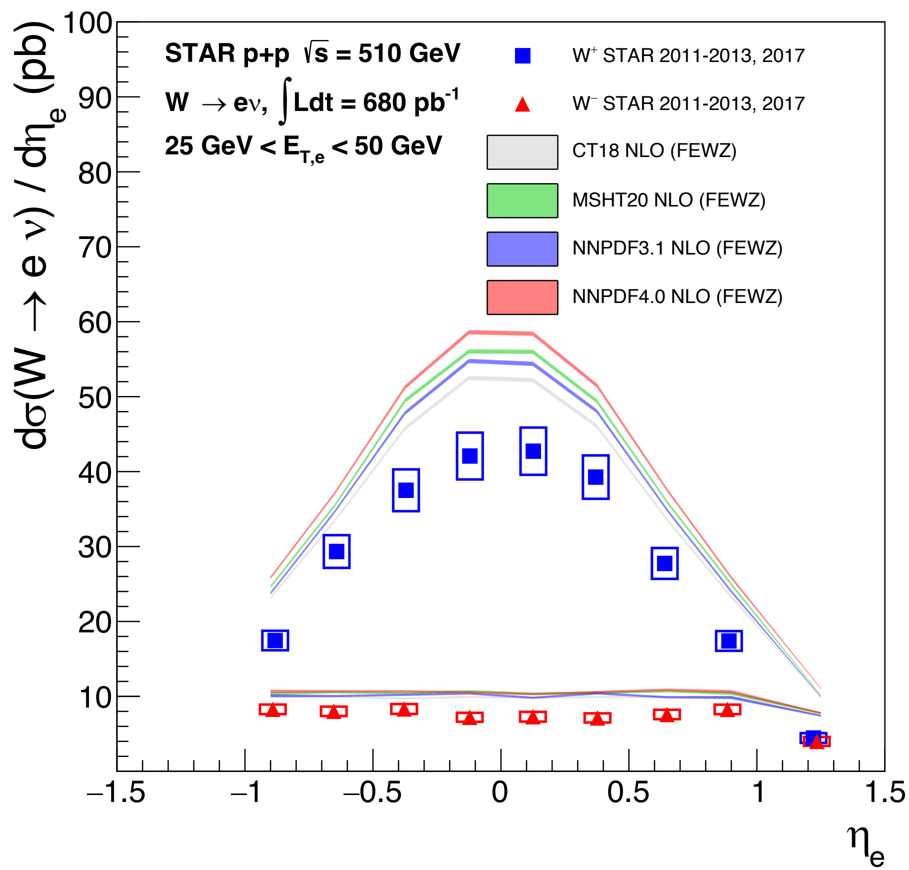
Fig 5: Systematics



- EMC Calibration
  - BEMC/EEMC gains varied by reported uncertainties in calibration
- QCD Background
  - Data-driven QCD background identification and normalization
- Charge Correction (Endcap only)
  - Fit function and range
- Model
  - Mis-estimated $E_T^{\Delta R<0.7}$, $E_T^{\Delta\phi\sim\pi}$, and signed-$p_{T,bal}$ selection efficiency
  - $\sim$2.5% correction and 2.5% uncertainty
- Efficiency (ratio only): deviation from 1
- Luminosity (cross section only) $\sim$5%
- Tracking (cross section only) $\sim$5%

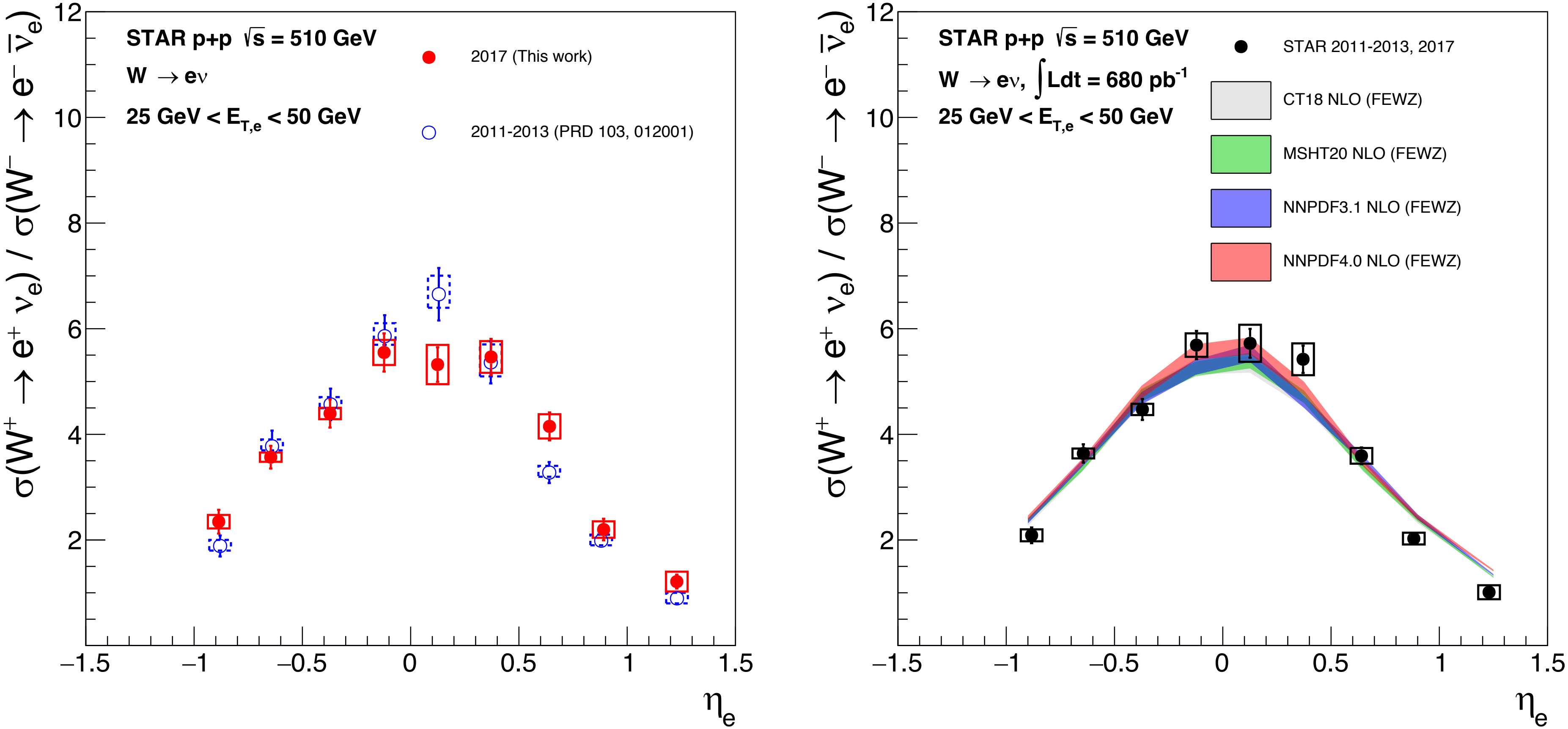
Fig 6 Cross Section





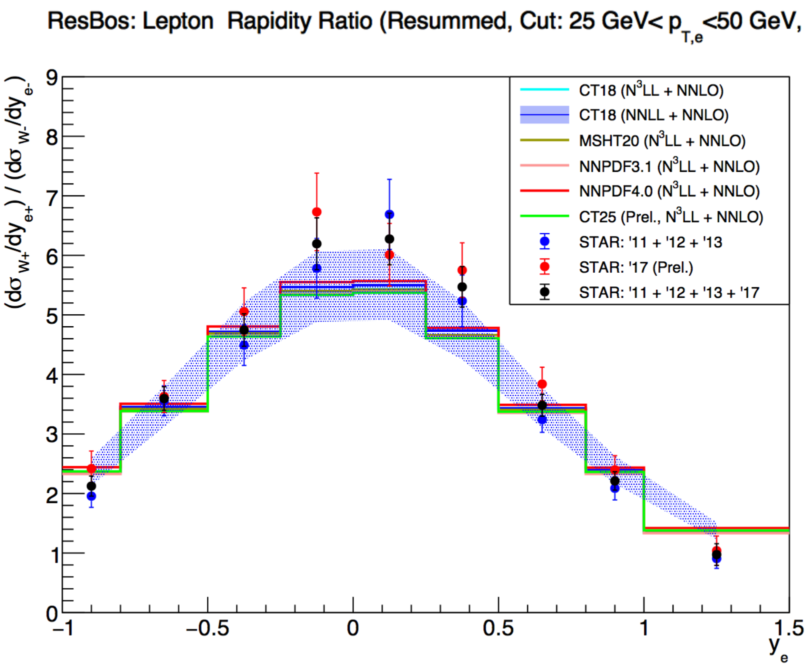
- ~3% shift between Run 17 and previous datasets based on χ^2 minimization
- Systematic effects with strong bin-wise correlation
  - Luminosity (5%, strongly correlated btw datasets)
  - Tracking (5%, different detector conditions, changes in tracking algo, etc.)
- 30% scale mismatch between STAR and pQCD
  - ~10% uncertainty in data, spread btw. PDF sets
- Currently using FEWZ calculation
  - ResBos2 calculation in agreement with FEWZ
  - PDF dependence WIP

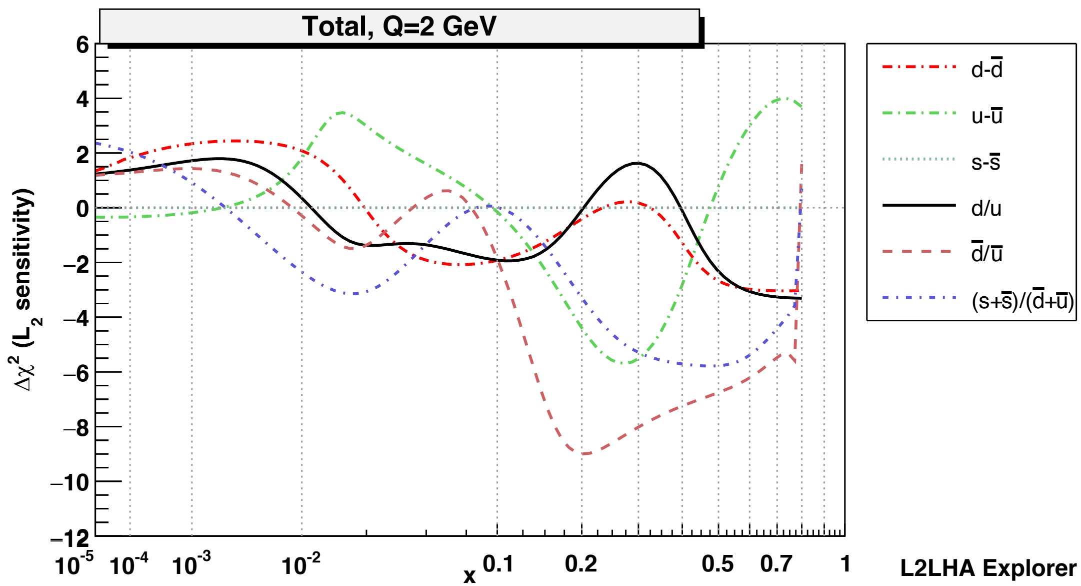
Fig 7: Cross Section Ratio



- Run 17 result consistent previous STAR publication;
  $p > 0.05$ based on T test, t value $= 1.22$ with NDF $= 9 - 1 \rightarrow$ p value $= 0.26$
- Modest improvement (expected) from fitting SeaQuest data
  ($\chi^2 = 16.1 \rightarrow 14.9$ with NNPDF3.1 → 4.0 from FEWZ)

Publication Strategy





Publication from Pavel, et al. (< 3 months)
- Discussions on (W) DY pp
- (N3LL to STAR prediction)
- (Impact of STAR W+/W-)

STAR publication (arXiv submission > 3mo)
- Run 17 + Run 11-13
- Comparisons of Resbos, FEWZ, Pythia

CT25/26 global fit (End of 2025)
- Impact of STAR data (prel or final, depending on the timeline)

Citation for prediction, impact study

Input data

11 Conclusion

The $W^{\pm} \to e\nu$ cross sections and their ratio have been measured with RHIC pp $\sqrt{s} = 510$ GeV collision data collected at STAR in 2017, corresponding to an integrated luminosity of 340 pb^{-1}. The measurements were performed as a function of the leptonic pseudorapidity η_e within the kinematic region defined by the leptonic transverse energy 25 GeV $< E_{T,e} <$ 50 GeV. The resulting cross sections and ratio are consistent with previous STAR publications. These measurements provide independent constraints for the non-perturbative SU(2) $\bar{d}/\bar{u}$ asymmetry at a higher momentum scale ($\sim M_W$), complementary to existing pp/pd Drell-Yan data, and a low-$\sqrt{s}$ and high-x (~ 0.2) reference for LHC W/Z programs.

Perturbative calculations at NNLO+N^{3}LL accuracy with latest PDF sets implemented in the ResBos2 framework [PLACEHOLDER] have been compared to the data. The prediction with the NNPDF4.0 PDF set [28] that includes the latest SeaQuest data [4] in the global fit shows an improvement over the previous NNPDF3.1 PDF set [29] in describing the W^+/W^- cross-section ratio observed at STAR. However, all calculations overestimate the differential cross sections $d\sigma(W^{\pm} \to e\nu)/d\eta_e$ throughout the studied η_e range.

Back up (Captions)

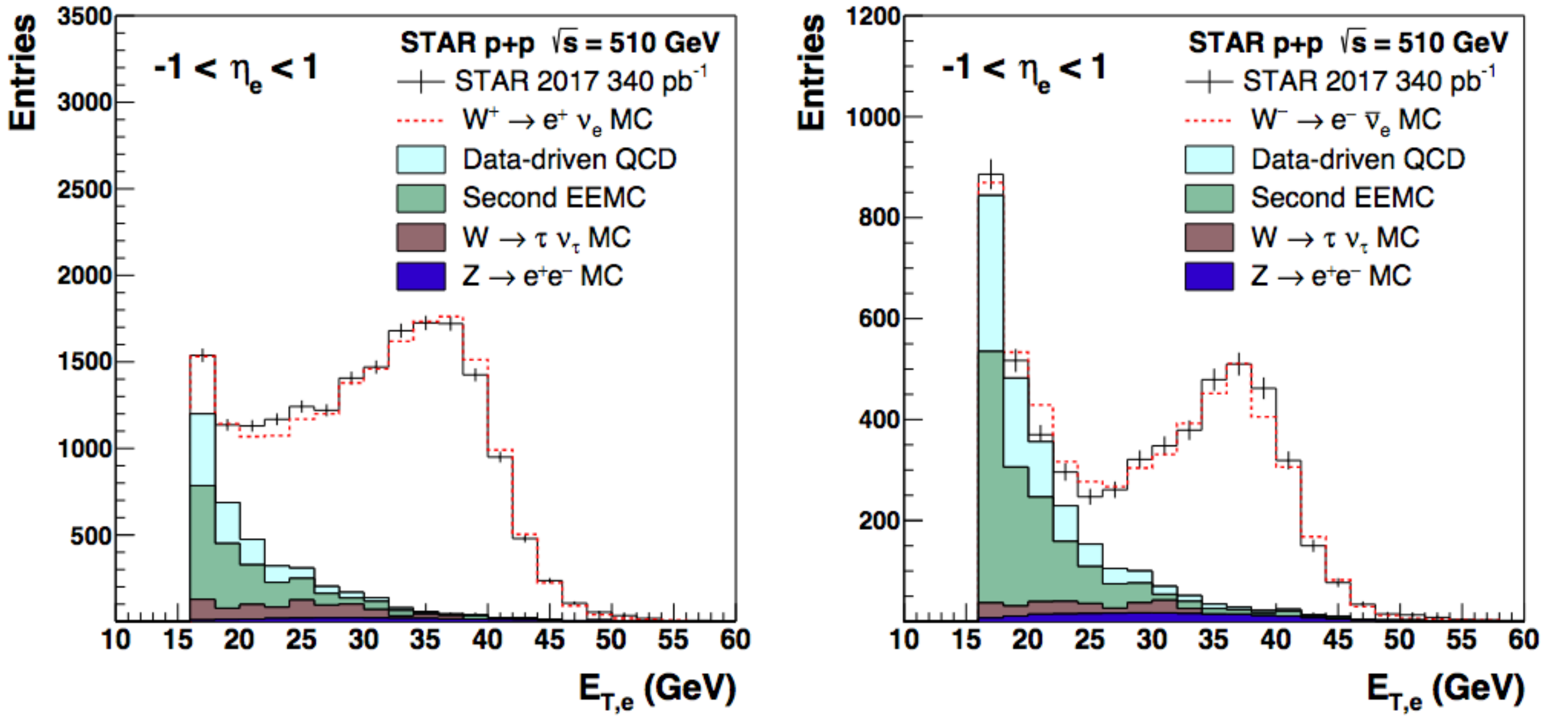


Figure 1: The Jacobian peak after event selection for W^+ (left) and W^- (right) candidates in the barrel ($-1 < \eta_e < 1$) region. The black lines represent the STAR 2017 data after event selection. The vertical and horizontal lines represent the statistical uncertainty and the bin width, respectively. The remaining $Z \rightarrow e^+e^-$, $W \rightarrow \tau\nu$, second EEMC, and data-driven QCD background contributions are highlighted in violet, pink, green, and cyan, respectively. The dotted lines in red represent the signal from MC simulation combined with the remaining background estimates.

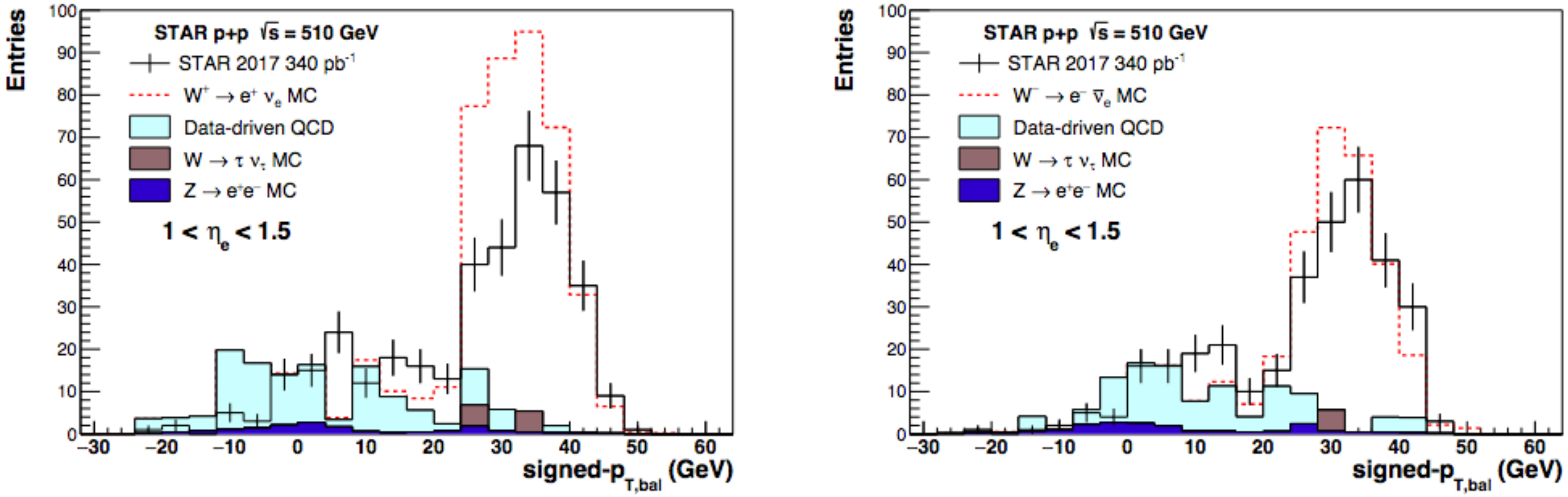


Figure 2: The signed-$p_{\mathrm{T,bal}}$ distributions after event selection for W^+ (left) and W^- (right) candidates in the intermediate pseudorapidity region ($1 < \eta_e < 1.5$). Other details are as in the caption to Fig. 1.

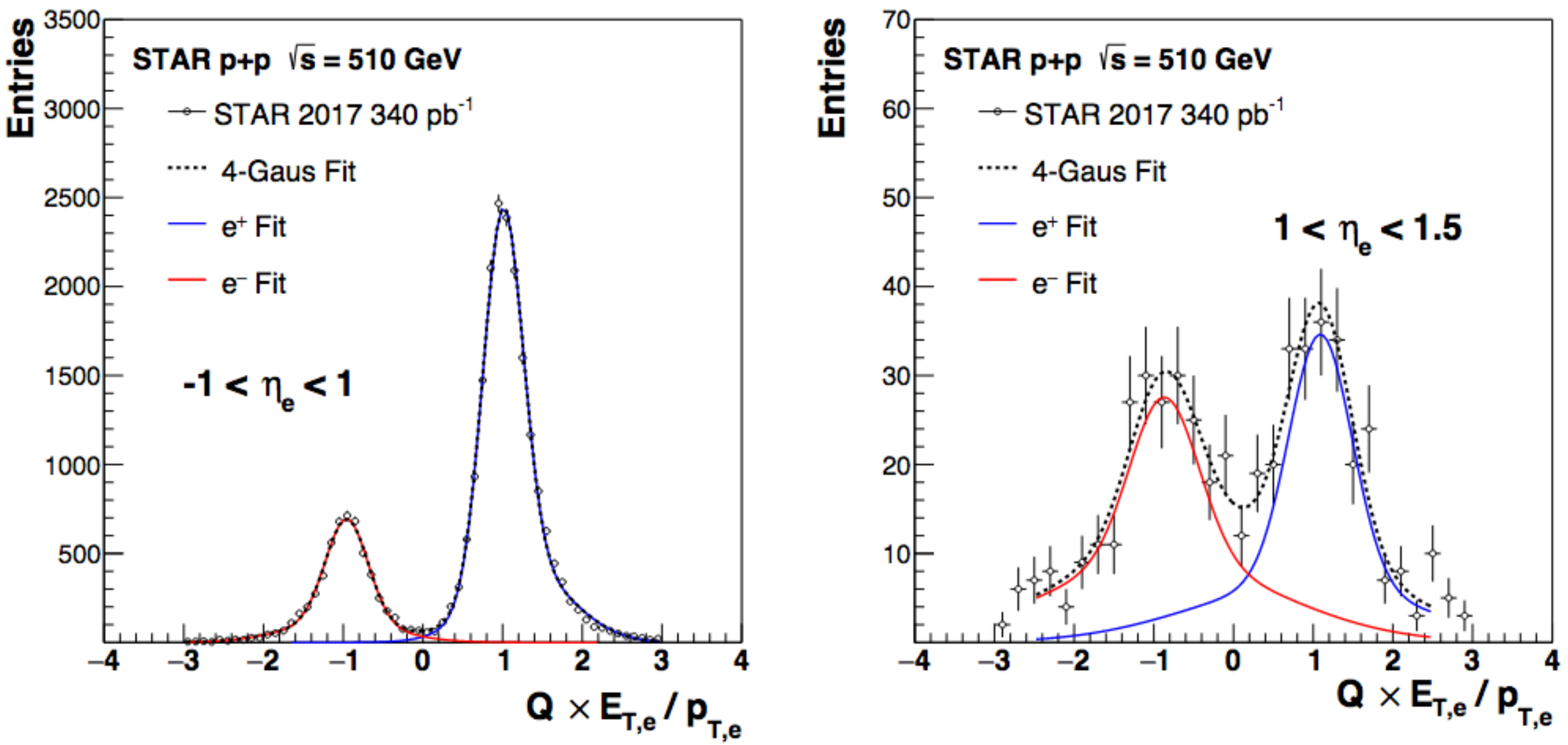


Figure 3: The $Q \times E_{\mathrm{T},e}/p_{\mathrm{T},e}$ distributions for the BEMC (left) and EEMC (right) candidates. The blue and red lines represent the two-Gaussian components for W^+ and W^- candidates, respectively. The dotted lines in black represent the combined four-Gaussian fit results.

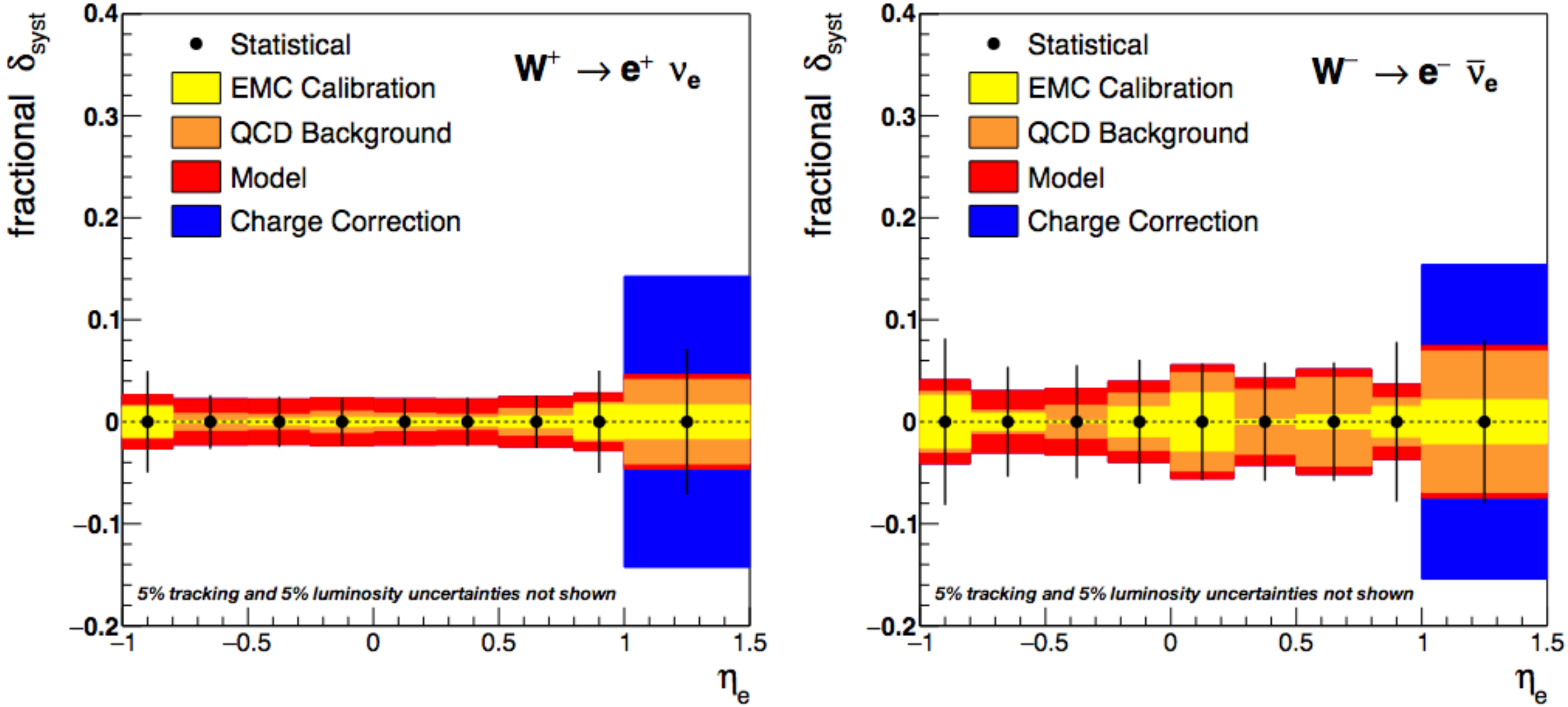


Figure 4: Relative systematic uncertainties in the differential cross sections for W^+ (left) and W^- (right). Statistical uncertainties are drawn in black vertical lines for comparison. Each band represents the addition in quadrature to all of the prior contributions, so that "EMC Calibration" only represents the systematic uncertainty associated with the imperfect resolution of the STAR calorimetry, "QCD Background" represents the "EMC Calibration" uncertainty added in quadrature to the uncertainty associated with the assignment and normalization of the QCD background, and "Model" includes both calorimetry and background uncertainties in addition to the systematic dependence in the assumptions made in Pythia. "Charge Correction" uncertainty was estimated for the endcap ($1 < \eta_e < 1.5$) bin only. The 5 % tracking and luminosity uncertainties are not drawn in these plots.

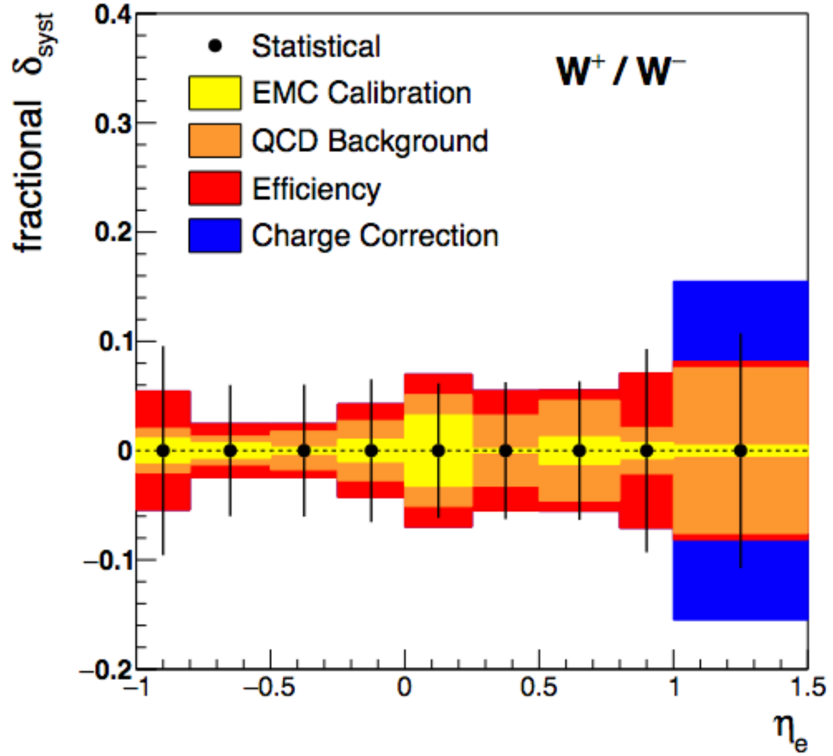


Figure 5: Relative systematic uncertainties in the cross-section ratio. The "Efficiency" uncertainty estimates the uncertainty in the efficiency-ratio calculation and was determined from any deviation from unity. Other details are as in Fig. 8.

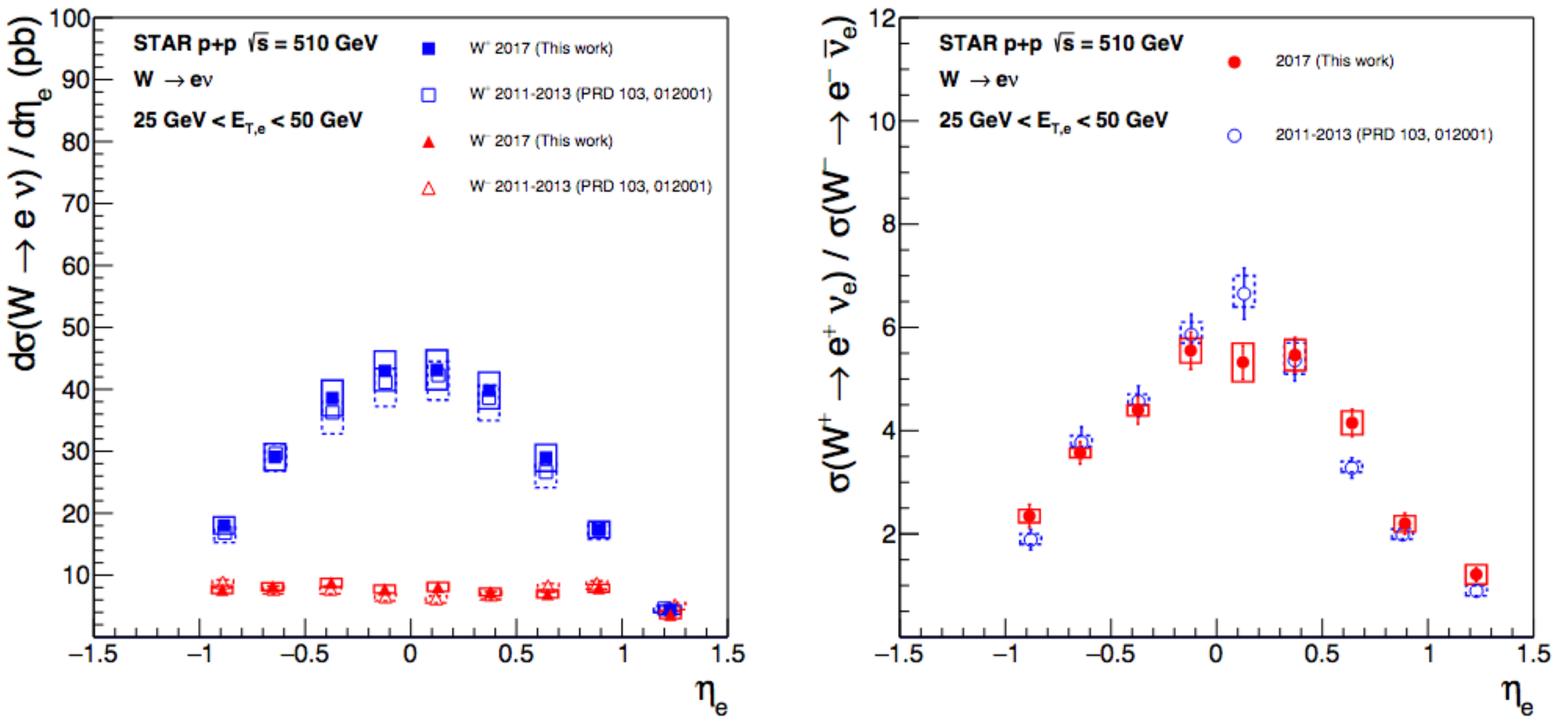


Figure 6: Differential cross sections as a function of the leptonic pseudorapidity η_e for W^+ and W^- (left) and the cross-section ratio (right) from the STAR 2017 dataset in comparison to the STAR 2011-2013 dataset. The solid blue squares and red triangles represent the differential cross sections for W^+ and W^- from the STAR 2017 dataset, respectively. The open blue suqares and red triangles represent the same measurements from the STAR Run 2011-2013 dataset. The solid red circles and open blue circles represent the cross-section ratio measured with STAR Run 2017 and the 2011-2013 datasets, respectively. The boxes represent the systematic uncertainty.

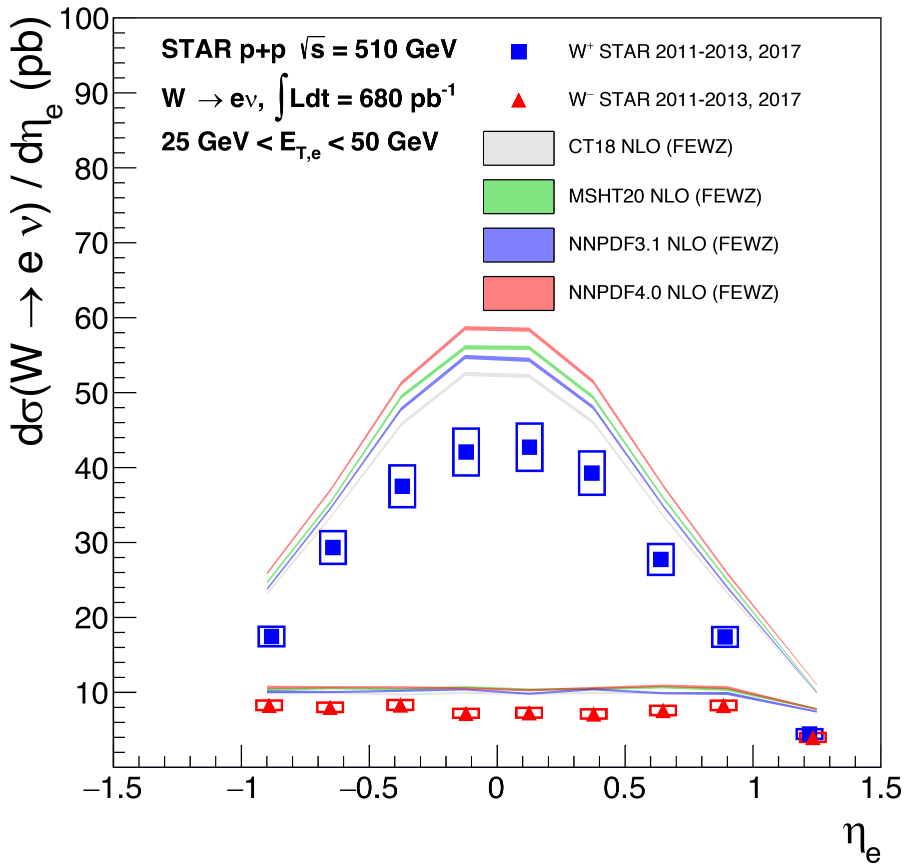


Figure 7: Differential cross sections as a function of the leptonic pseudorapidity η_e for W^+ and W^- from the combined STAR 2011-2013 and 2017 dataset. The gray, green, blue and red bands represent the FEWZ NLO calculations [7] with CT18 NLO [28], MSHT20 NLO [29], NNPDF3.1 NLO [30], and NNPDF4.0 NLO [31] PDF sets, respectively.

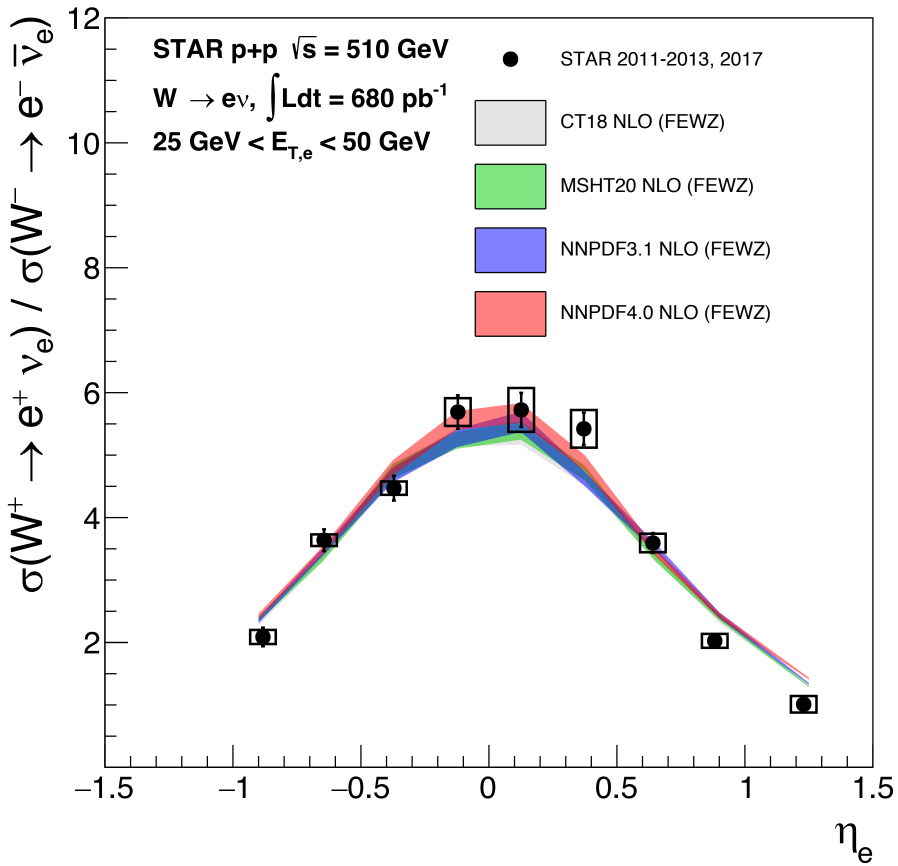


Figure 8: Cross-section ratio as a function of the leptonic pseudorapidity η_e for W^+ and W^- from the combined STAR 2011-2013 and 2017 dataset. The gray, green, blue and red bands represent the FEWZ NLO calculations [7] with CT18 NLO [28], MSHT20 NLO [29], NNPDF3.1 NLO [30], and NNPDF4.0 NLO [31] PDF sets, respectively.

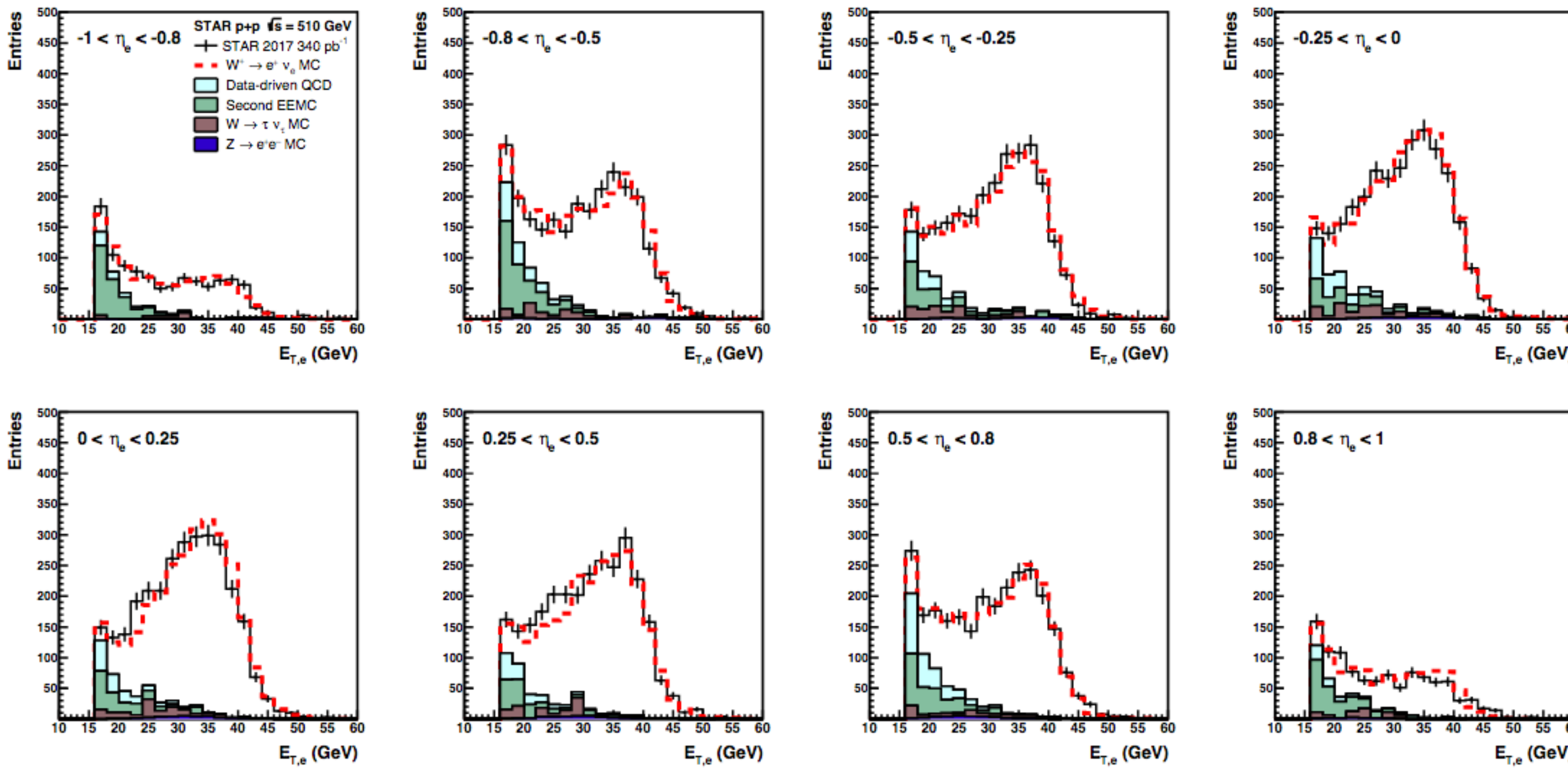


Figure 9: The Jacobian peak after event selection for W^+ candidates in different ranges of η_e. Other details are as in Fig. 1.

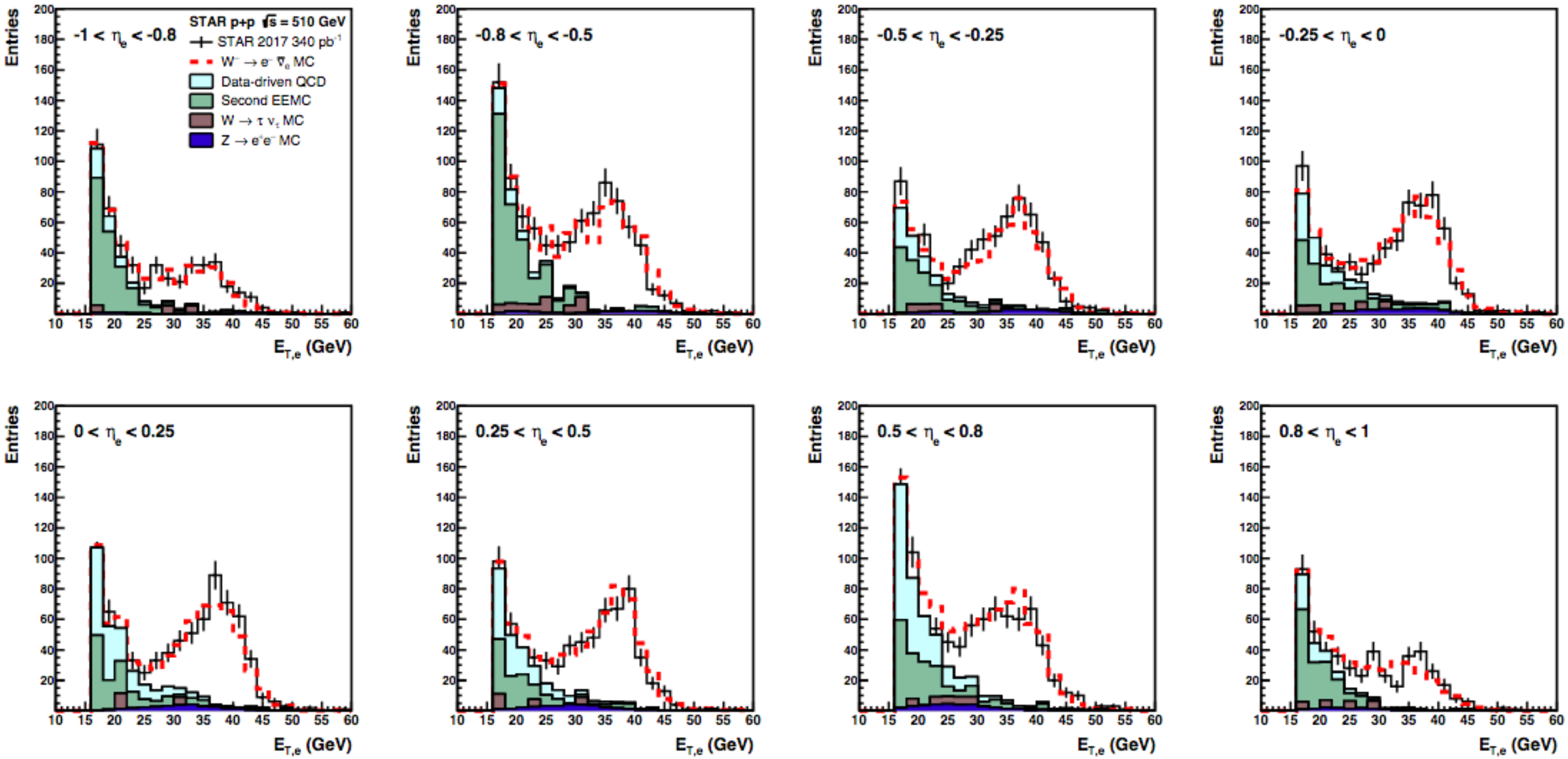


Figure 10: The Jacobian peak after event selection for W^- candidates in different ranges of η_e. Other details are as in Fig. 1.

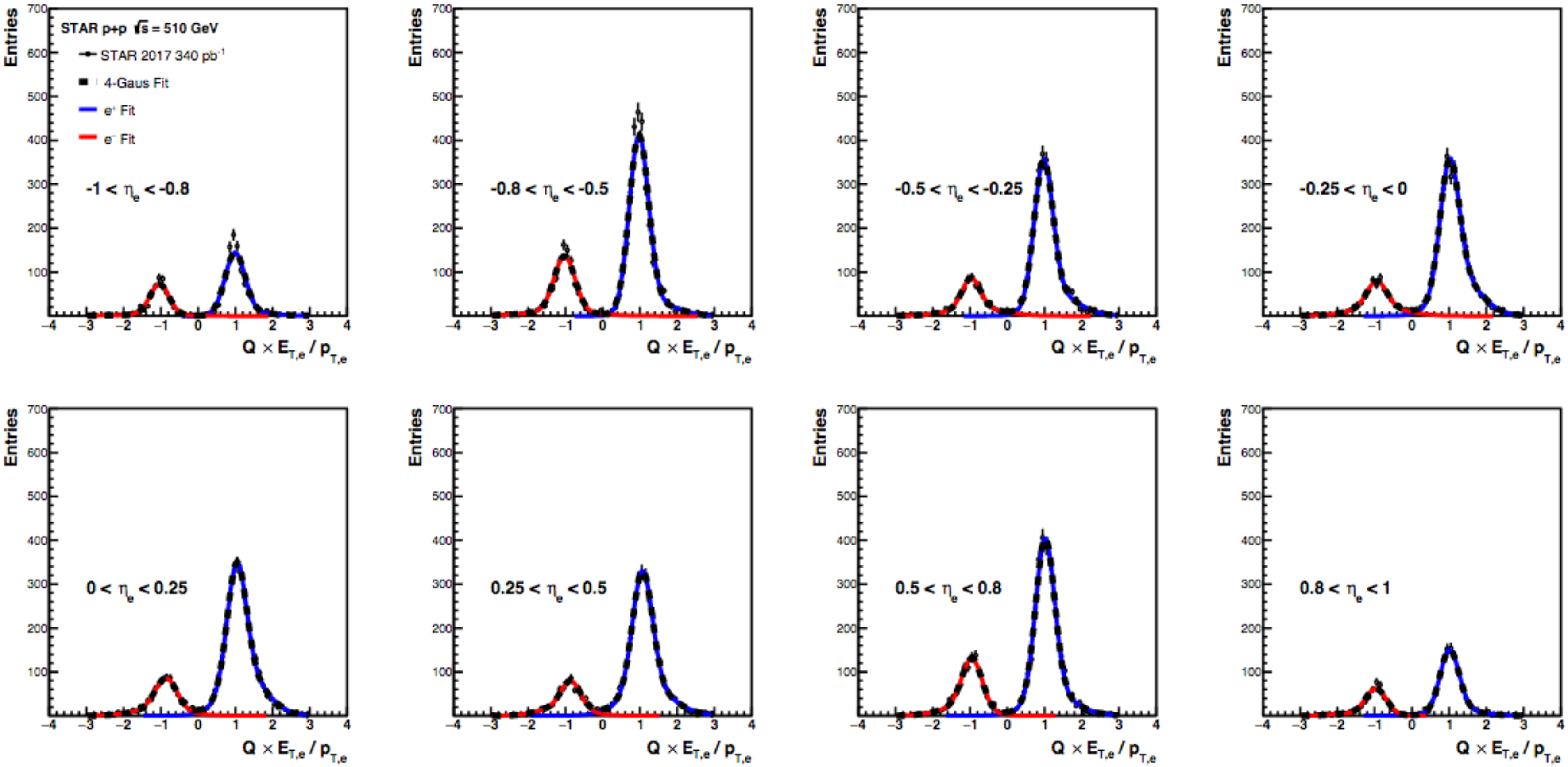
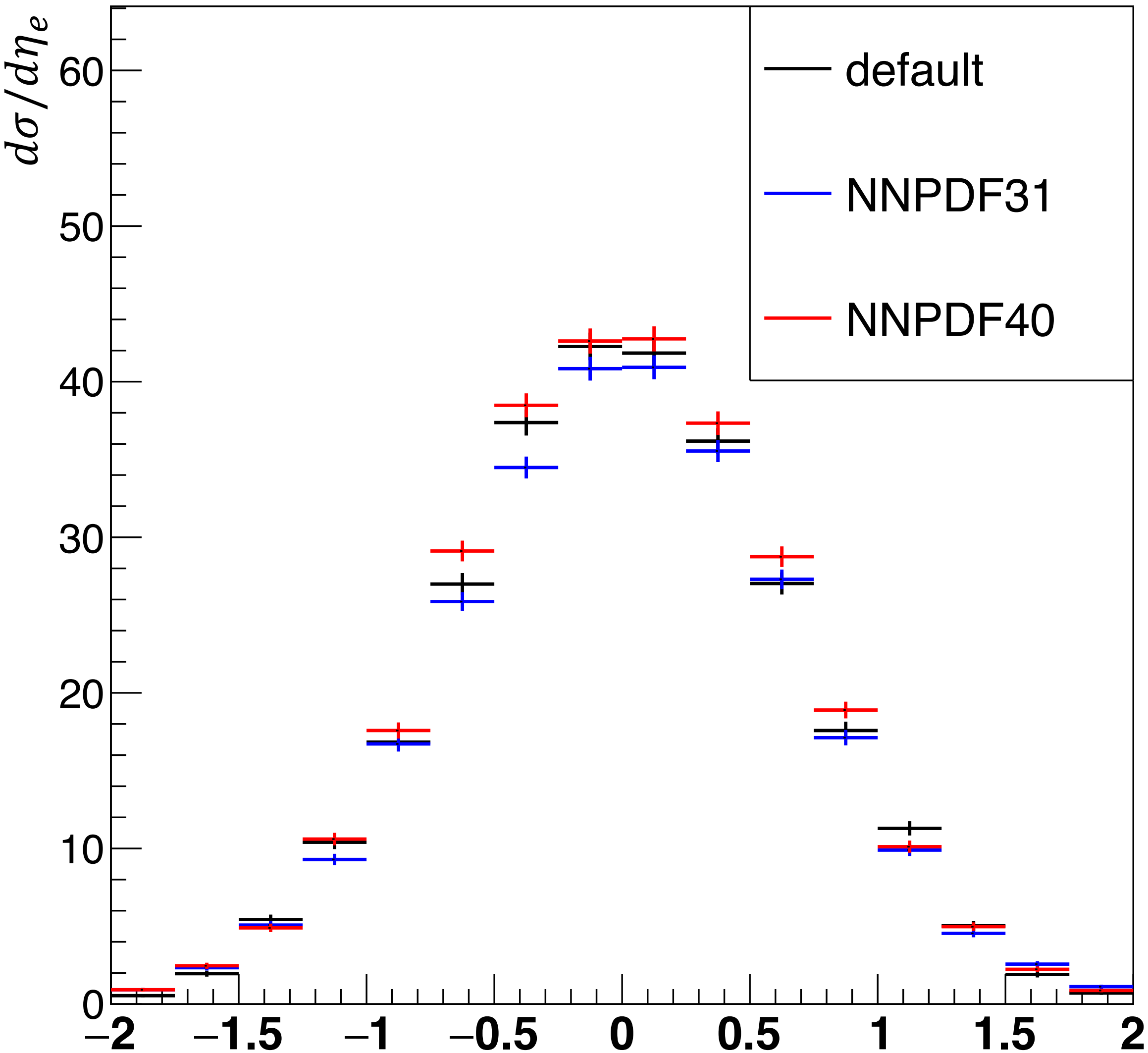


Figure 11: The $Q \times E_{\mathrm{T},e}/p_{\mathrm{T},e}$ distributions for the BEMC candidates in different ranges of η_e. Other details are as in Fig. 3.

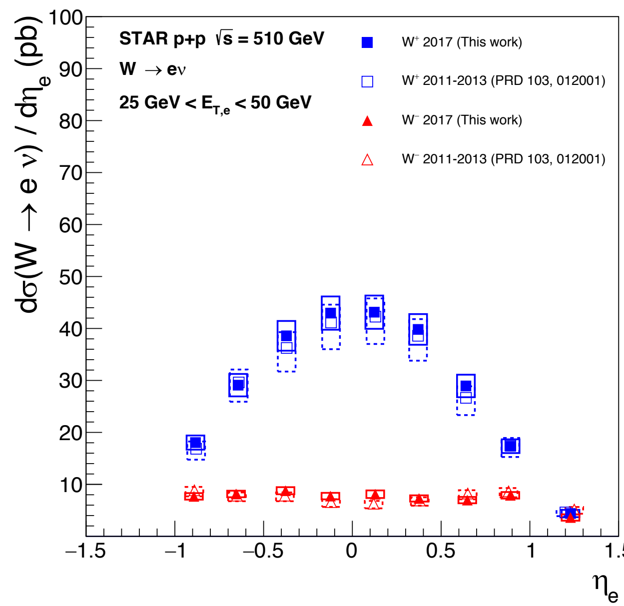
Backup

Comparison Pythia6 + PDFsets (W+)

$d\sigma/d\eta_e$ (Pythia)

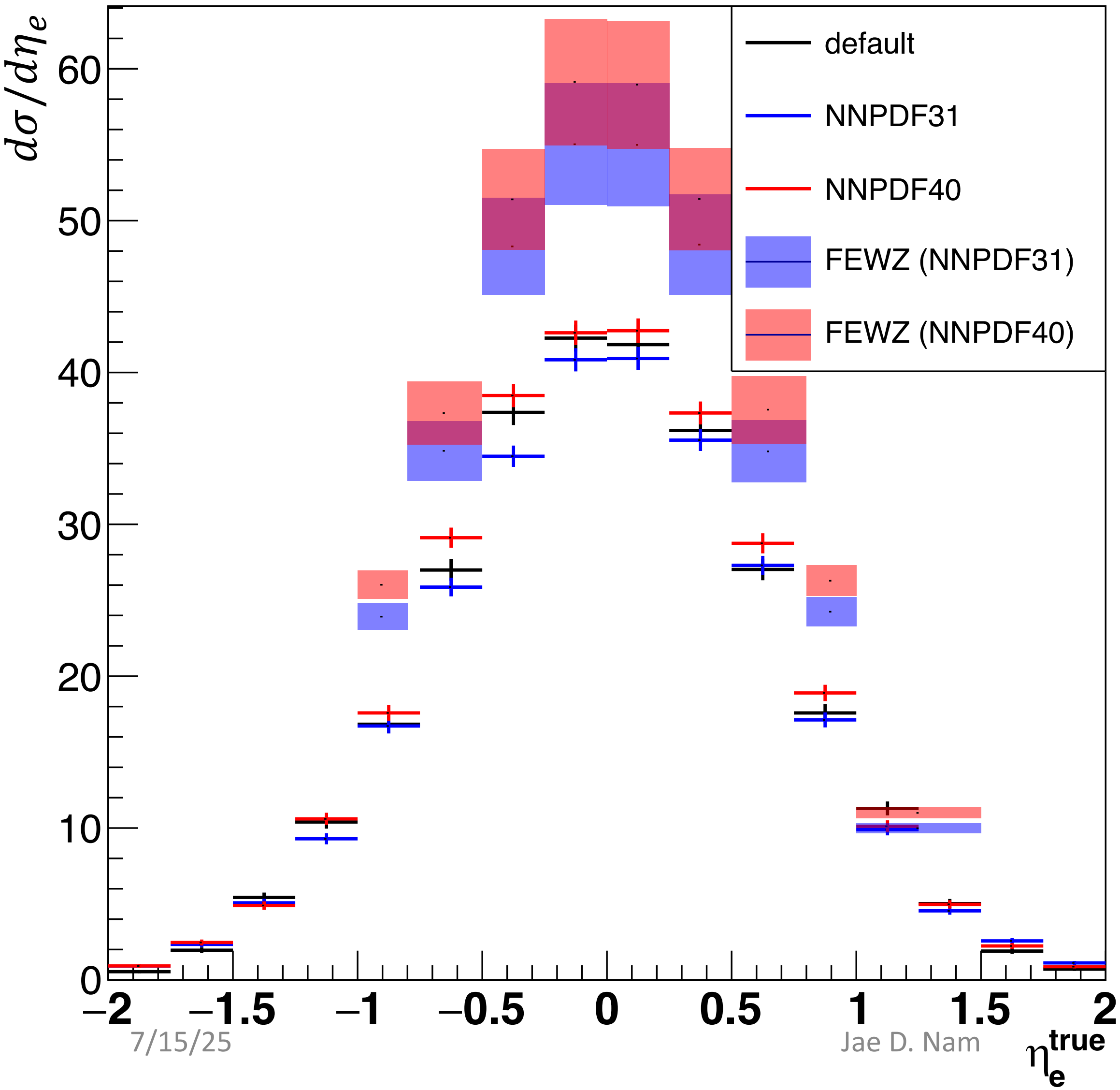


- Comparison of different PDF sets with Pythia 6
- Only looking at W+
- Default = CTEQ5L
- Pythia with different PDFs $<$ 10% from each other

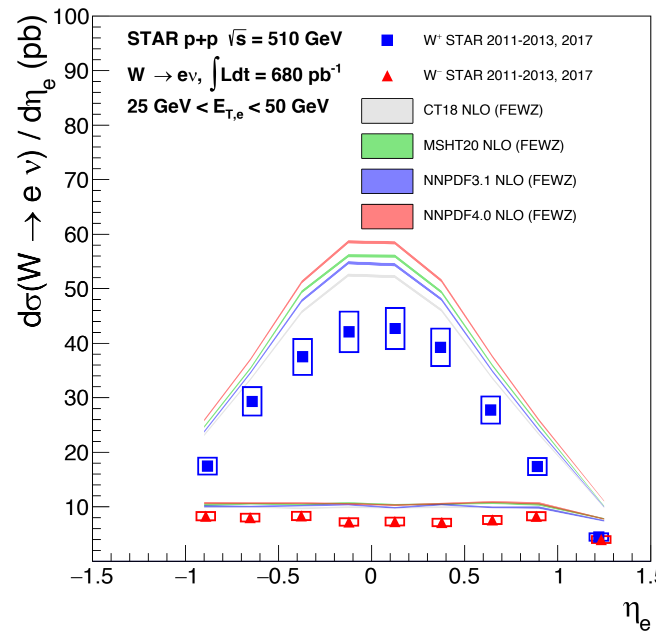


Comparison Pythia6 + FEWZ NLO

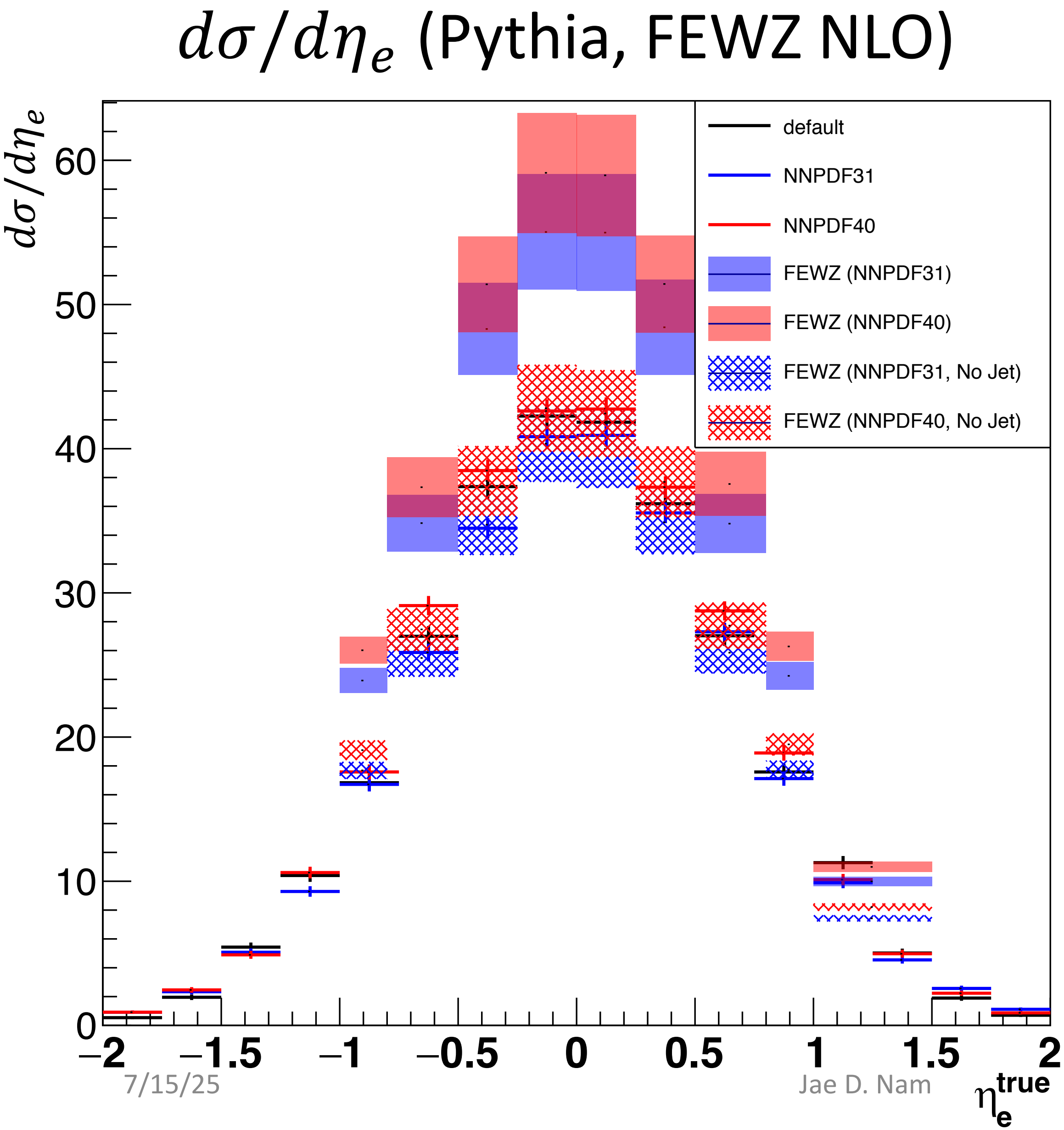
$d\sigma/d\eta_e$ (Pythia, FEWZ NLO)



- Comparison of different PDF sets with Pythia 6 + FEWZ NLO
- FEWZ NLO $= W +$ jet
  *Jet = anti-kT, R = 0.6, min-pT = 3.5 GeV
- Similar PDF dependence with FEWZ NLO
- $\sigma_{FEWZ} > \sigma_{Pythia}$ by 30%



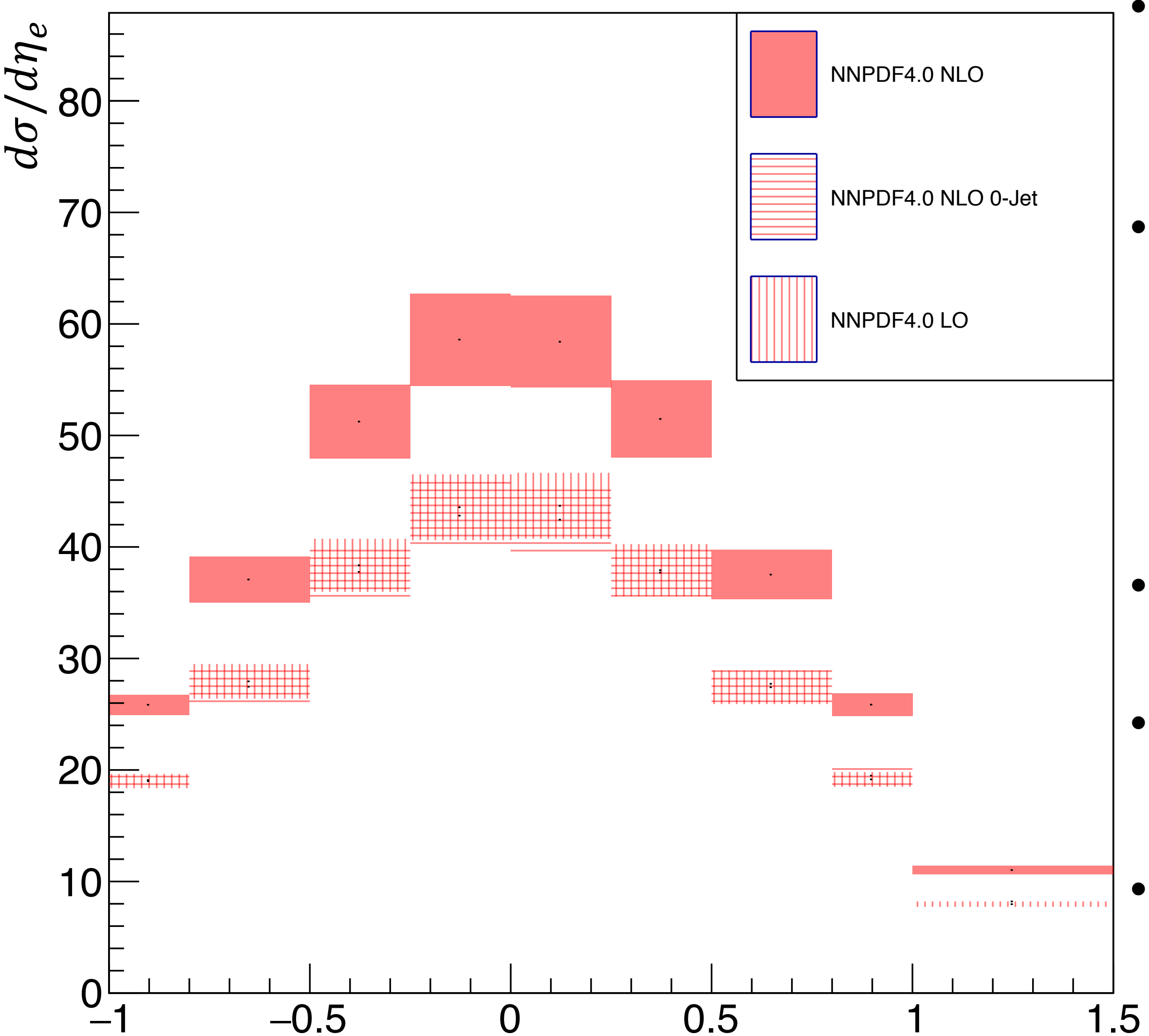
Comparison Pythia6 + FEWZ NLO



- Comparison of different PDF sets with Pythia 6 + FEWZ NLO
- FEWZ NLO $= W +$ jet
  Also shown is NLO with no-jet requirement
  (this is what is compared to data in publication:
  PRD 103 (2021) 1, 012001)
- FEWZ NLO + 0J consistent with Pythia (with STAR data)

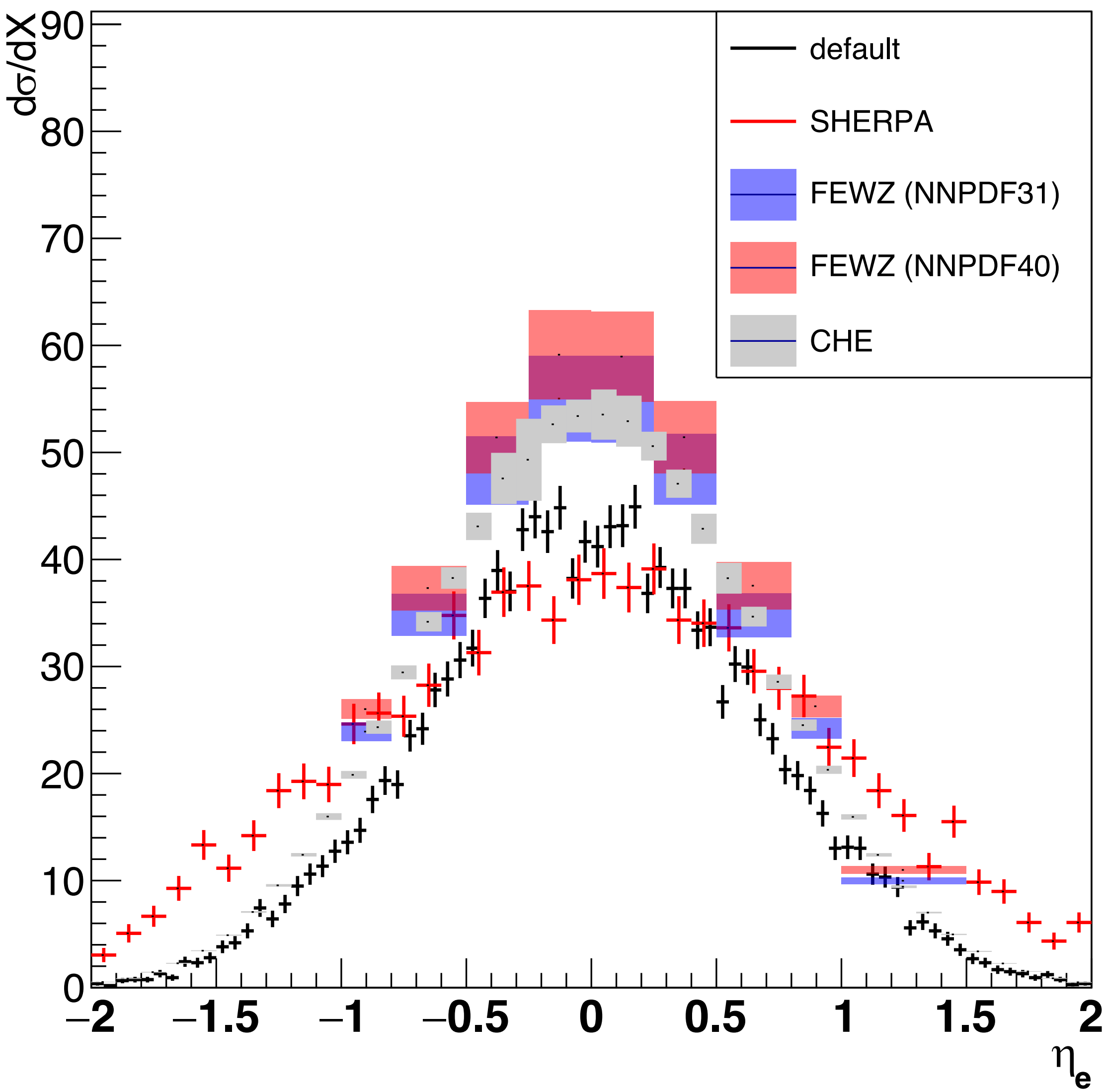
Comparison Pythia6 + FEWZ NLO

$d\sigma/d\eta_e$ (FEWZ NLO v LO)



- Comparison of different PDF sets with Pythia 6 + FEWZ NLO
- FEWZ NLO $= W +$ jet
  Also shown is NLO without jet, and LO prediction
- FEWZ NLO + 0J consistent with Pythia (with STAR data)
- FEWZ NLO + 0J $\sim$ FEWZ LO
- $\sigma_{data} \sim \sigma_{FEWZ,LO}$

LO+PS vs NLO+PS vs NLO vs NNLO



- Default = Pythia 6 w CTEQ5L
- SHERPA = NLO+PS with CT10 (out of the box, default tune)
- CHE = second opinion NLO with MRST2002NLO

Potential source of 30% ($\sim 2\sigma$) mismatch

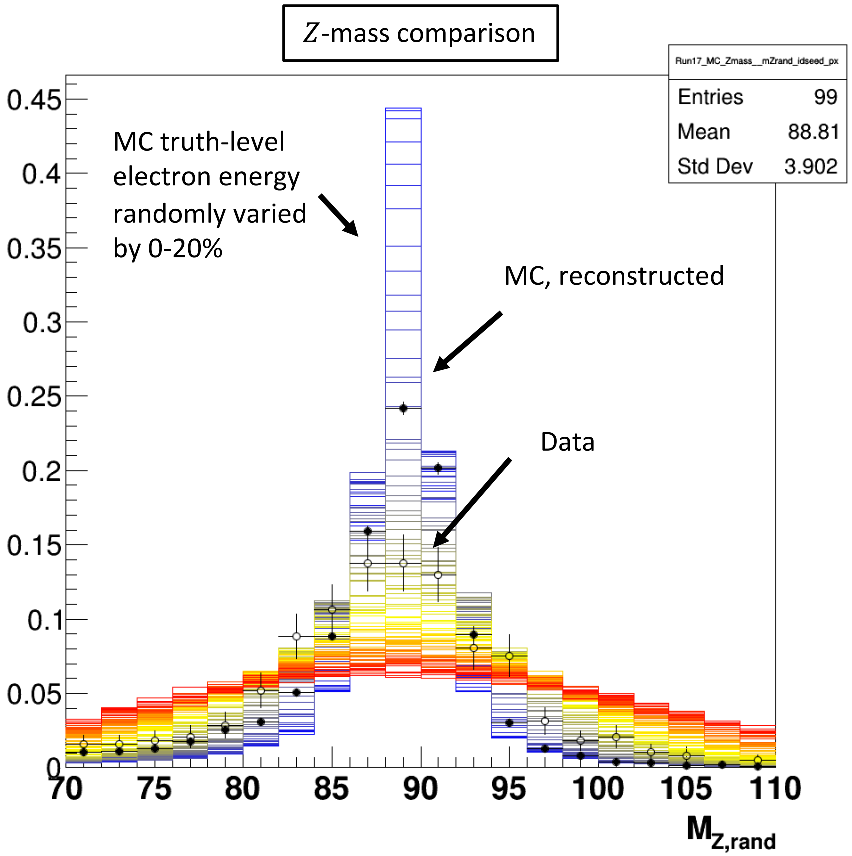
- Detector level
  - Luminosity → 5%, Run 17 Z publication
  - Trigger dead time → $5\sim10\%$ already included in sampled luminosity
  - EMC tower variation
  - QED radiation

  → No significant effect (backup)
  - Tracking → high p_T tracks, should be well simulated (experts)

- Physics level
  - Incorrect estimation of $E_T^{\Delta R<0.7}$ (ETnear), $E_T^{\Delta\phi\sim\pi}$ (ETaway), signed-$p_{T,bal}$ selection efficiency → No significant effect, treated as "Model" uncertainty (backup)

- Conclusion: No evidence for $\sim 30\%$ experimental errors

BEMC Effects

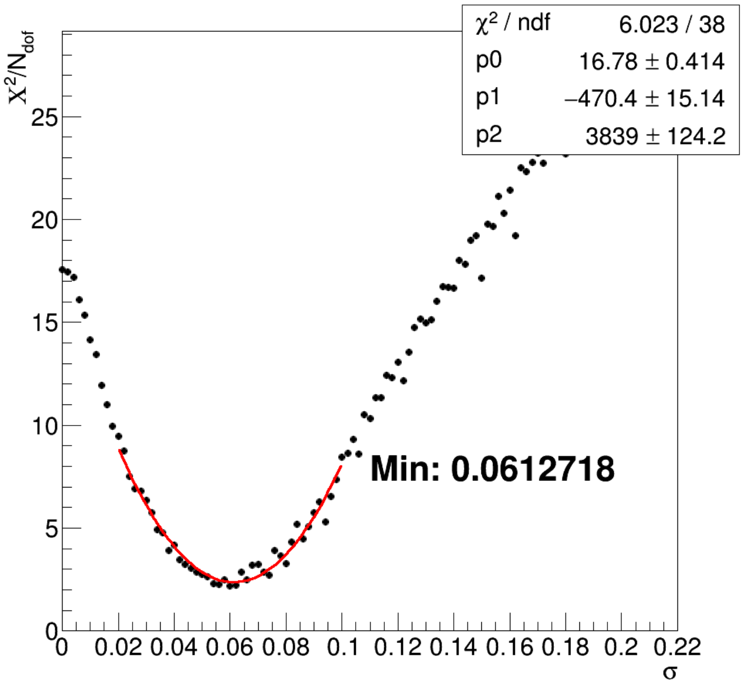


- Systematic uncertainty in the current BEMC calibration accounts for possible change in the mean gain
  - Tower-by-tower variation studied with MIP
  - No uncertainty assigned
- Unlike hadron-/jet-type measurements, lepton measurements might be sensitive to tower-by-tower variation in gain (estimated with MIPs)
- This tower-by-tower variation might not have been simulated properly.

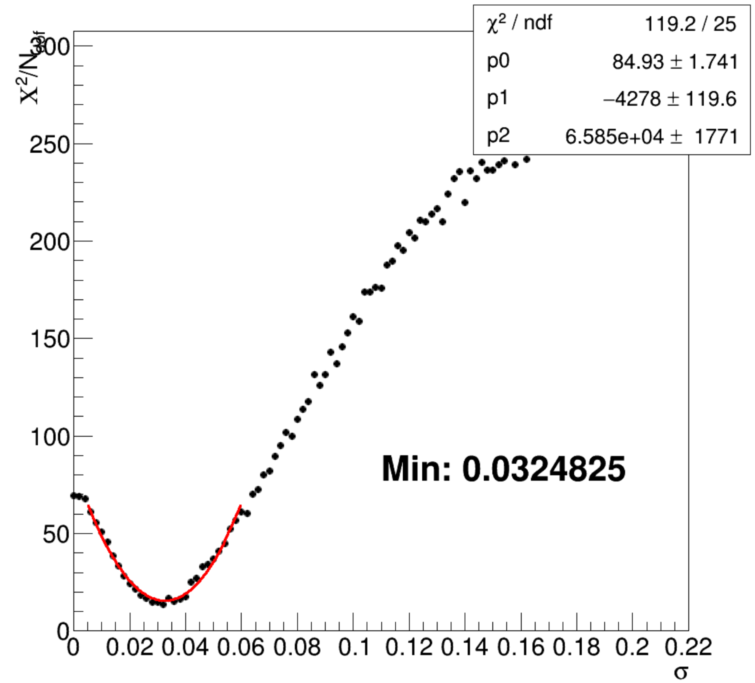
- True electron was projected onto EMC surface with each tower gain was smeared by up to 20% to simulate tower-by-tower gain variation
- Reconstructed Z masses compared to data & MC to identify degree of this variation

Tower-by-tower variation

X^2 test (data)



X^2 test (MC)

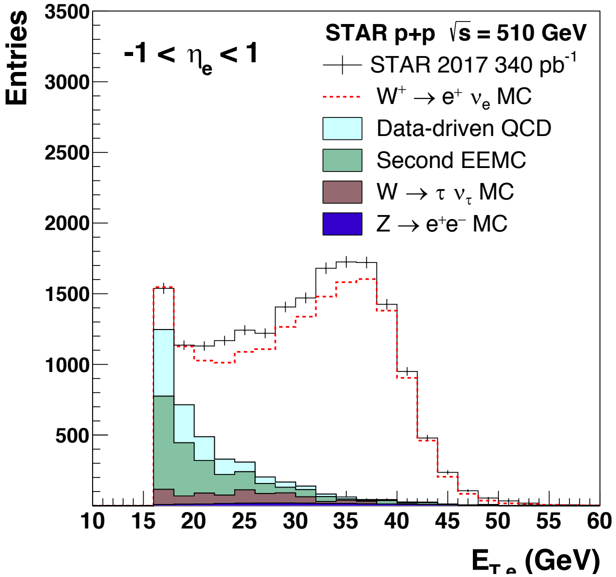


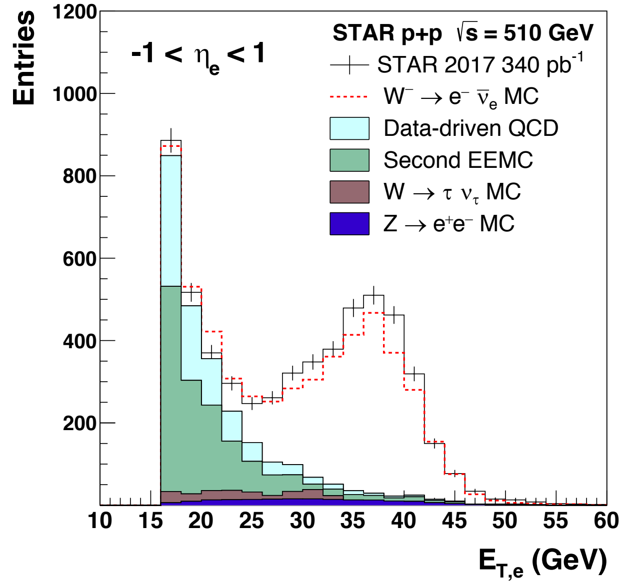
- Tower-by-tower variation extracted from minimum of parabola fit
  - $\sigma_{MC} \sim 3\%$
  - $\sigma_{Data} \sim 6\%$

5% gain smearing introduced to MC

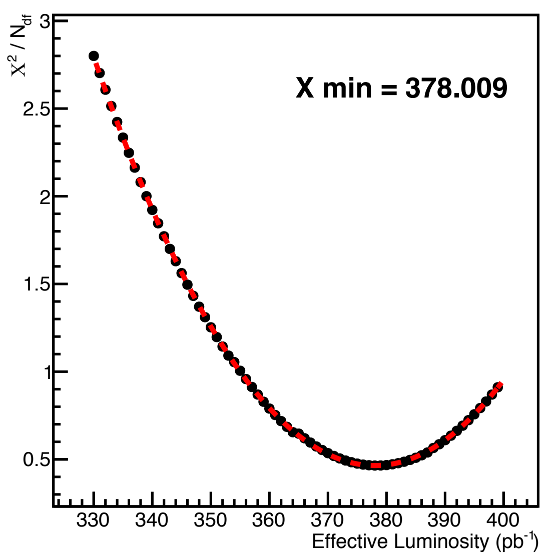
MC Normalization

L = 343 pb-1 (352 pb – 2.6%)

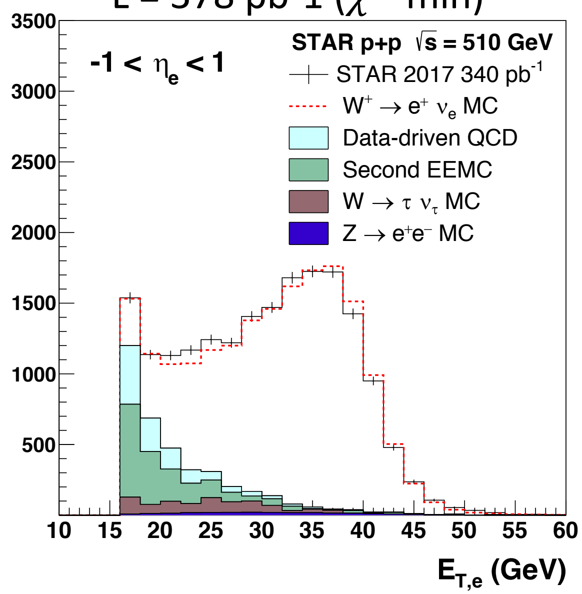




$W^+ + W^-$

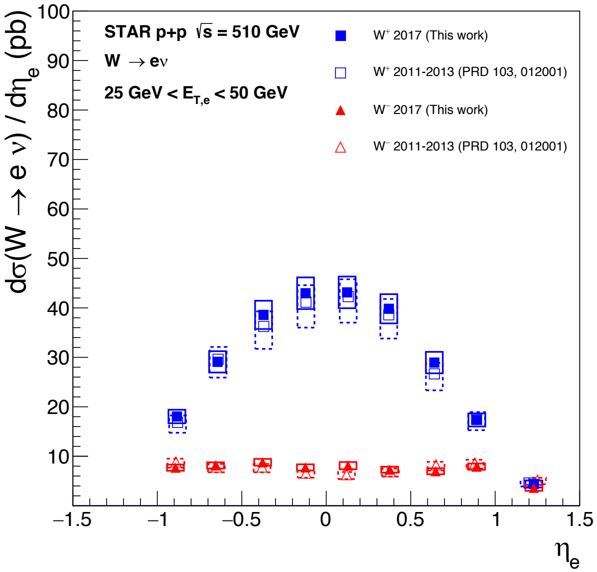


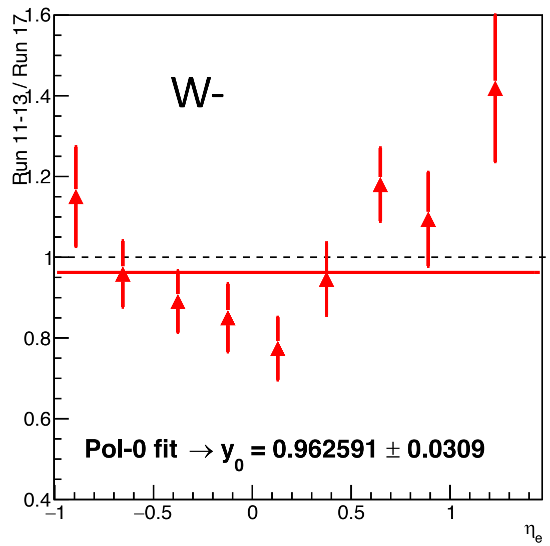
L = 378 pb-1 (χ^2-min)

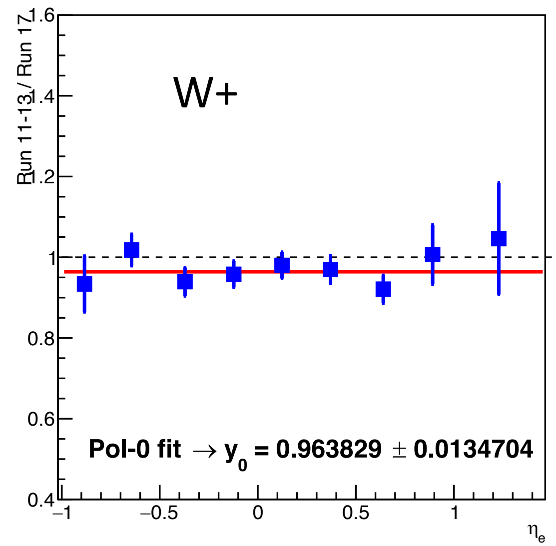


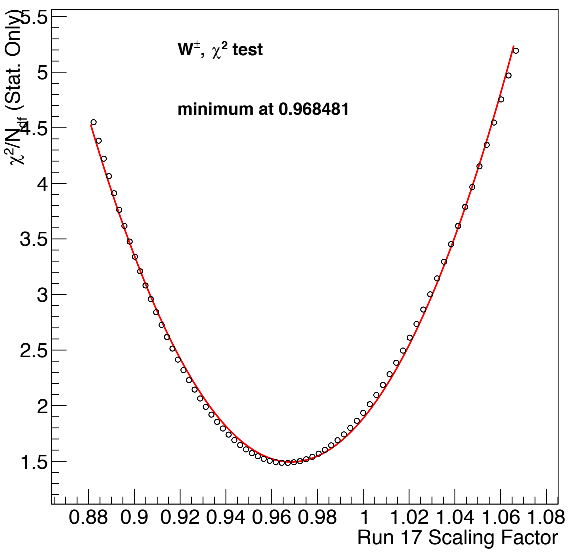
- Luminosity based on Jamie's table 352 pb^{-1}
- Systematic shift between MC and data
- Lumi correction + Changes in analysis details (MC gain smearing, etc.)
- χ^2 test minimzing effective luminosity $= 378\ pb^{-1}$
- Well within (lumi + track) 352 $(\pm 9\% \pm 5\%)\ pb^{-1}$
- Around 1.4σ within 343 $(\pm 5\% \pm 5\%)\ pb^{-1}$
- Dropping claims about "MC normalized to data luminosity"
- Instead, "MC normalization based on χ^2 minimization"

Systematic shift between Run 17 and 11-13



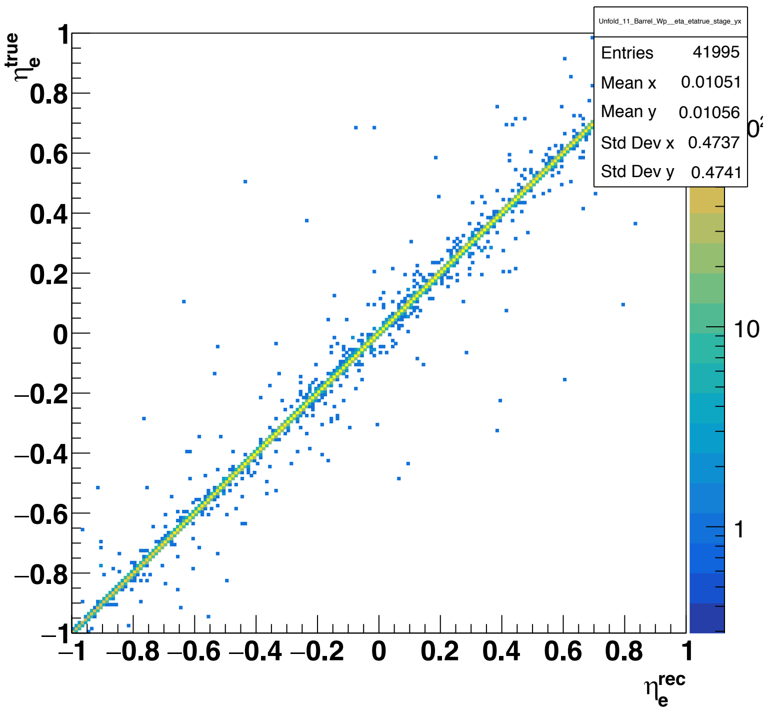


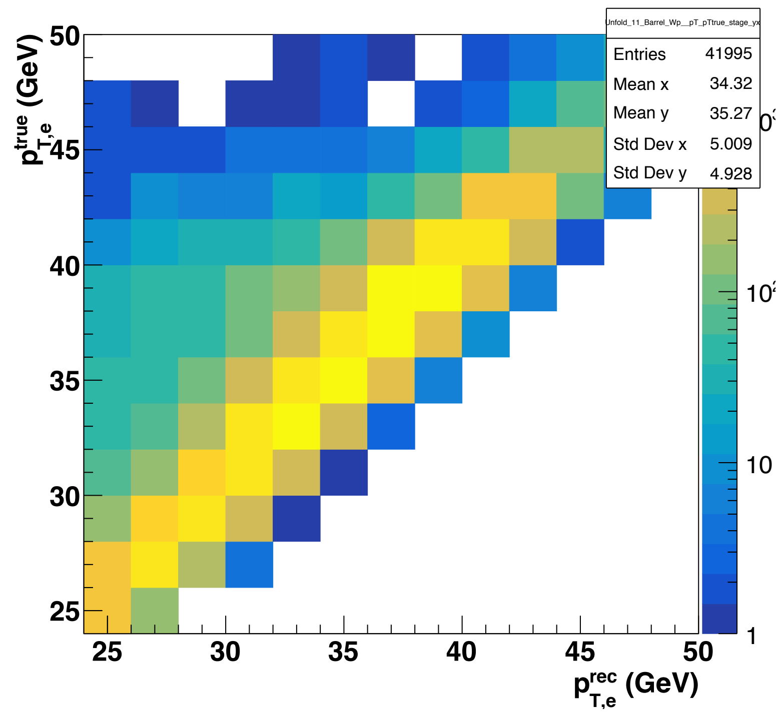




- 2.6% luminosity correction included for both Run 17 and 11-13
- $> 2\sigma$ shift based on pol-0 fit of W+
- χ^2 scan (based on statistical uncertainty) suggests there is 3.2% systematic shift between Run 11-13 and Run 17

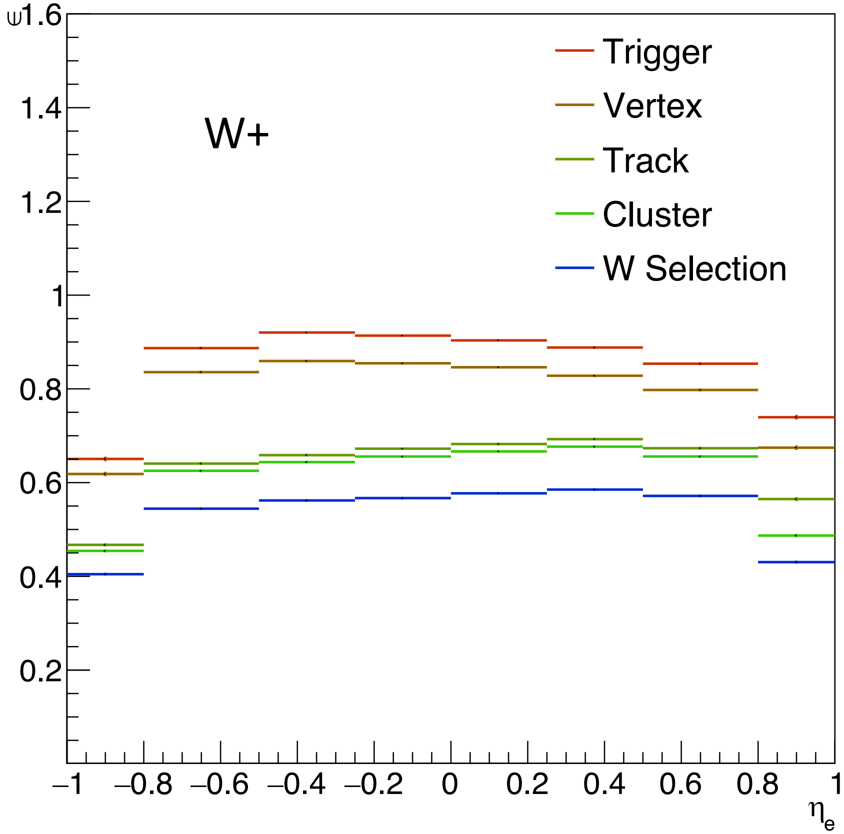
Bin migration correction?

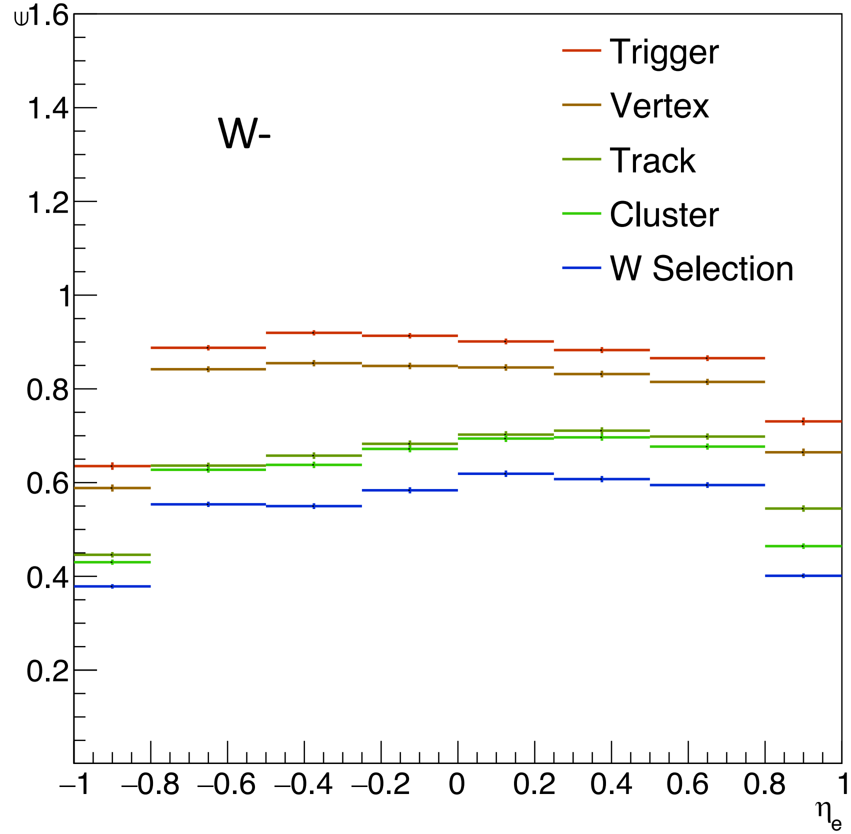




- Good reconstruction of η and E_T
- Binwise correction factor $\sim 0.5\%$
- Ignored; not included in the calculation, and was not considered as systematics

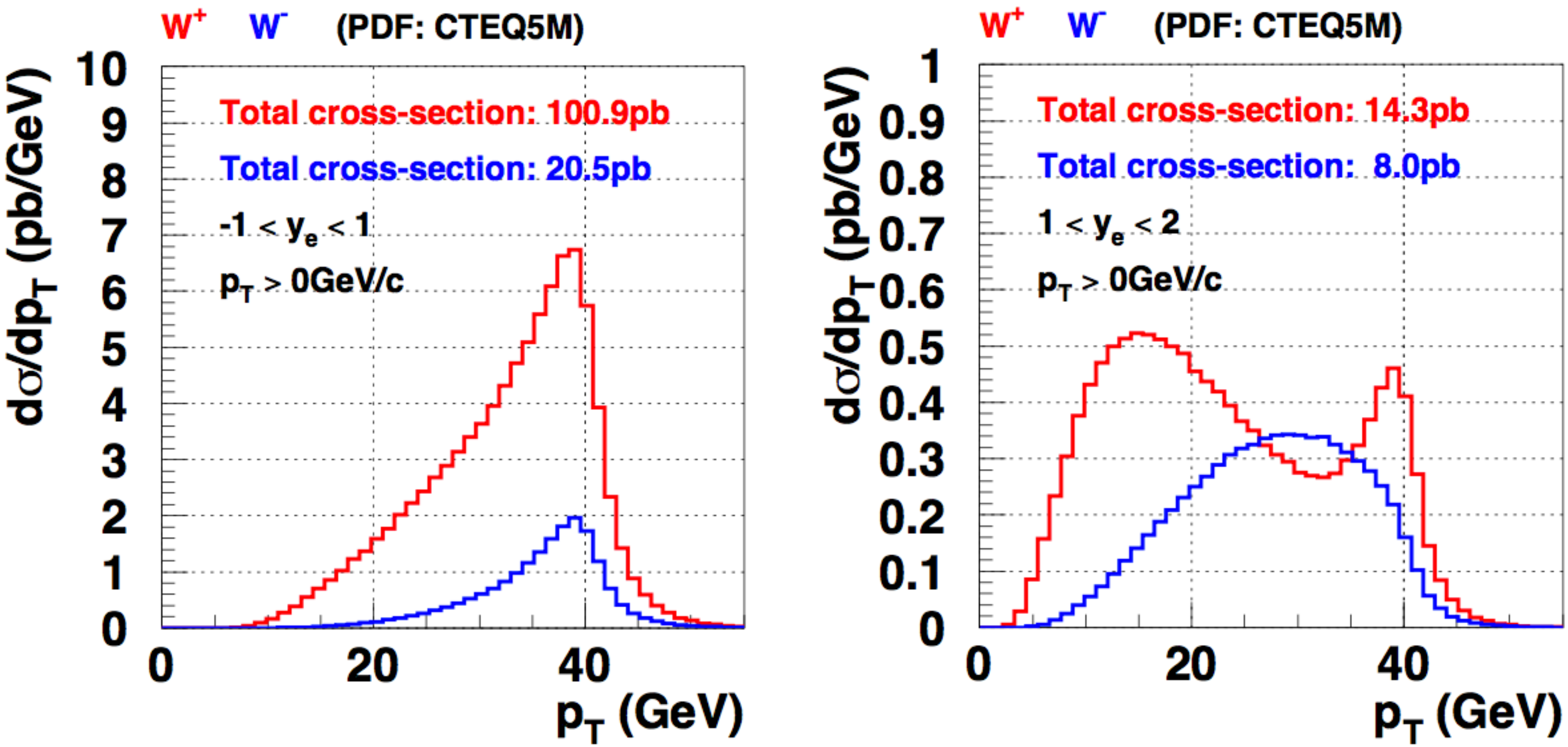
Efficiency breakdown





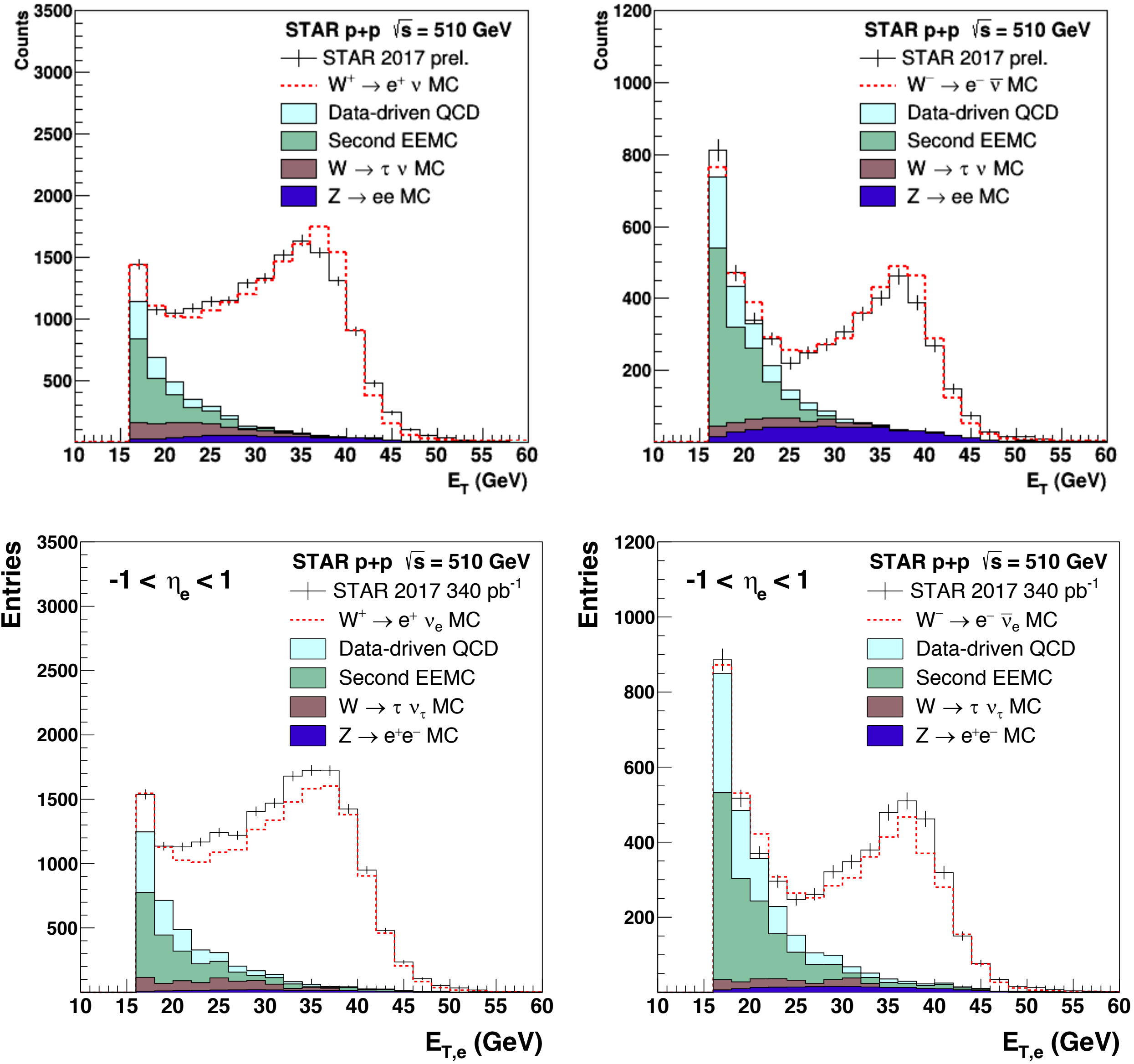
Why not one value for certain syst.?

P. M. Nadolsky and C.P. Yuan, Nucl.Phys. B666 (2003) 31.



- The shape of Jacobian peak, and thus EMC/Efficiency systematics, should depend on η_e

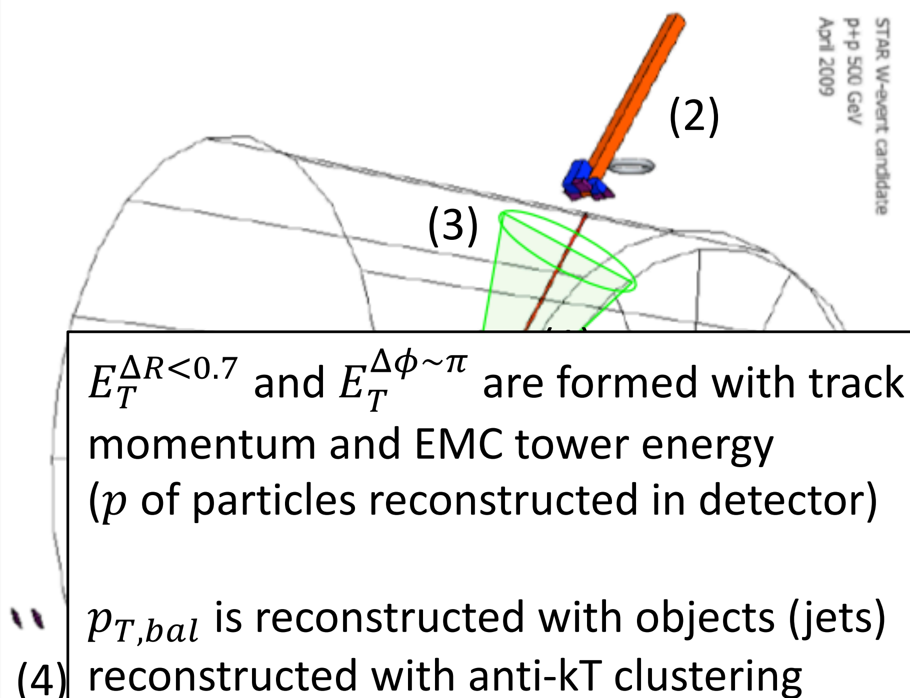
Comparison to Preliminary



- Top: Preliminary
  - MC normalized to $352\ pb^{-1}$
- Bottom: Publication
  - MC normalized to $343\ pb^{-1}$
  - Includes MC gain smearing of 5%
  - Software-level inconsistency corrections (analysis note)

Review of Event Reconstruction

Event Display of typical W event



$E_T^{\Delta R<0.7}$ and $E_T^{\Delta\phi\sim\pi}$ are formed with track momentum and EMC tower energy
(p of particles reconstructed in detector)

$p_{T,bal}$ is reconstructed with objects (jets) reconstructed with anti-kT clustering algorithm
(E-scheme, $R = 0.6$, min-p_T =3.5 GeV)

Relevant studies in:
https://drupal.star.bnl.gov/STAR/system/files/userfiles/6368/Nam_20250326(1).pdf
https://drupal.star.bnl.gov/STAR/system/files/userfiles/6368/Nam_20250409.pdf
https://drupal.star.bnl.gov/STAR/system/files/userfiles/6368/Nam_20250423(1).pdf
https://drupal.star.bnl.gov/STAR/system/files/userfiles/6368/Nam_20250604.pdf

1) A high momentum track is identified ($p >$ threshold)

2) Energy cluster is formed (2×2 towers, each covering 0.05×0.05 in $\eta\times\phi$; cluster: 0.1×0.1)

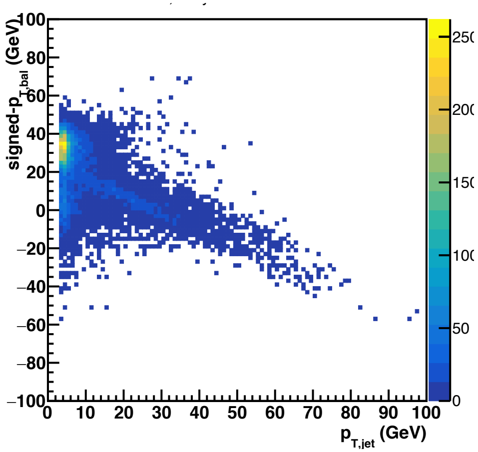
3) Isolation requirement ($E_T^{2\times2}/E_T^{\Delta R<0.7}\sim1$, $E_T^{2\times2}/E_T^{4\times4}\sim1$)

4) Backward (neutrino direction) energy flow requirement ($E_T^{\Delta\phi\sim\pi}<$ threshold)

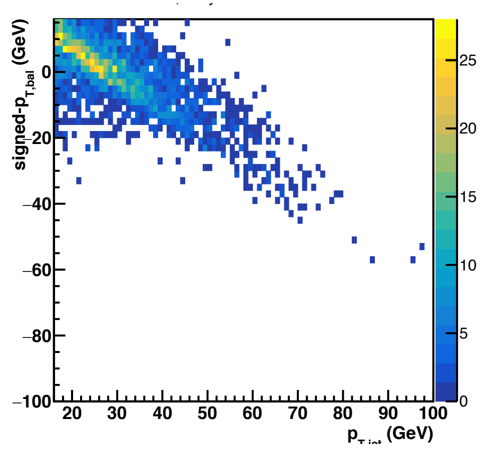
5) Energy imbalance ($p_{T,bal}$) ($\hat{p}_{T,e}\cdot\sum[\vec{E}_T$ and $\vec{p}_T] >$ threshold)

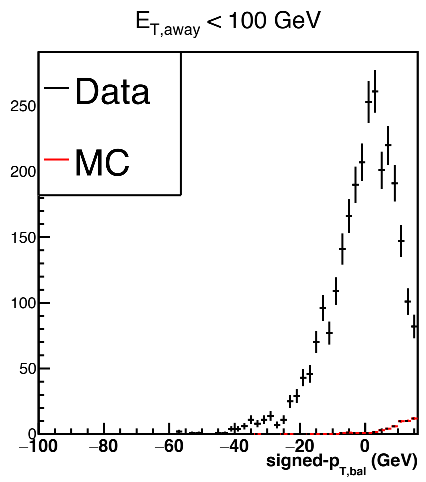
Signed-$p_{T,bal}$ and Jet p_T (W+)

Data W+

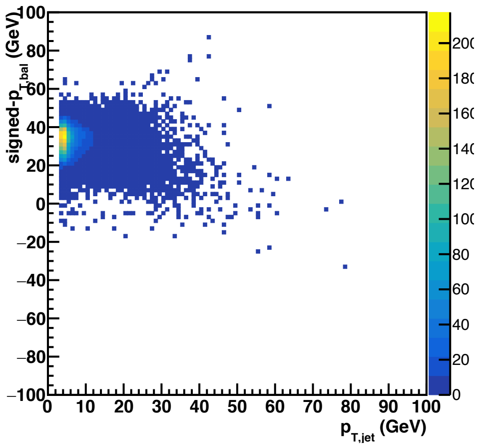


Data W+ (Zoomed in)

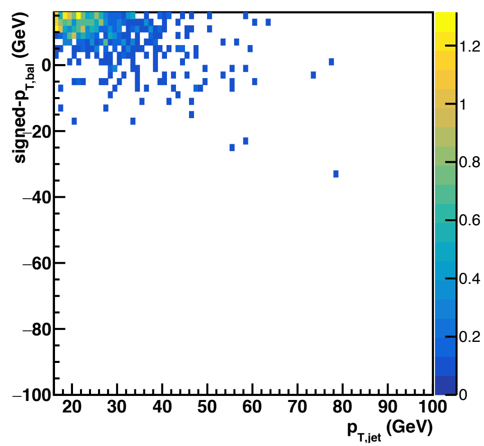


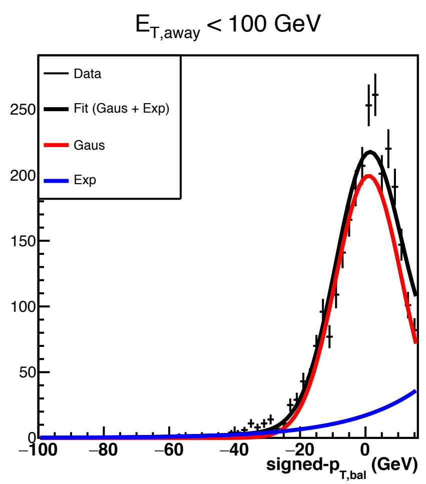


MC W+



MC W+ (Zoomed in)

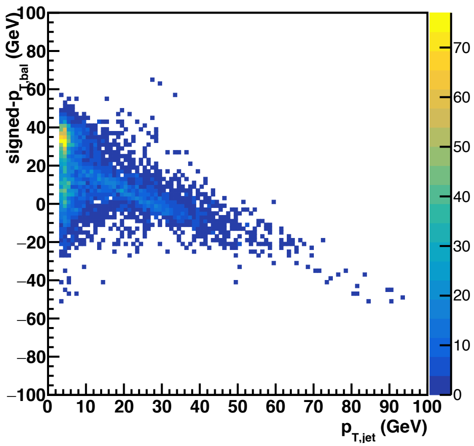




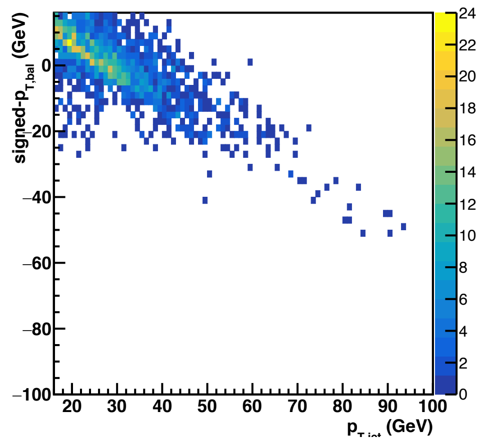
- Asymmetric contribution can be as large as ~5% of signal

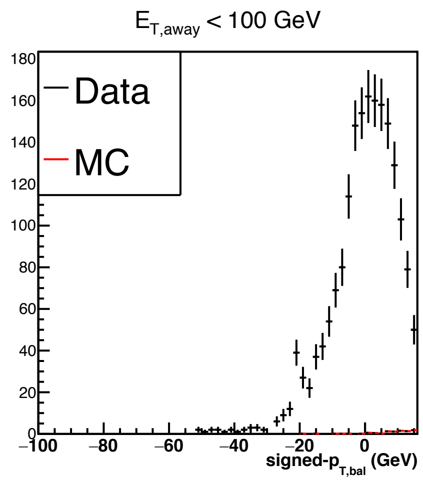
Signed-$p_{T,bal}$ and Jet p_T (W-)

Data W-

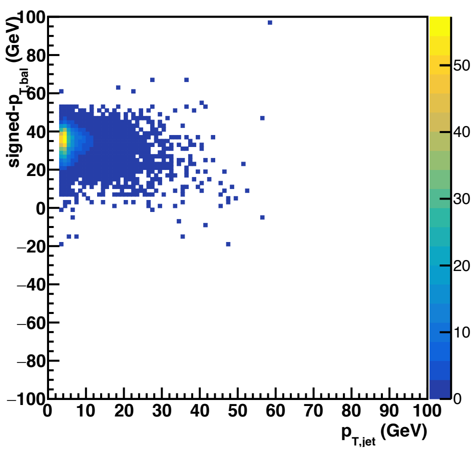


Data W- (Zoomed in)

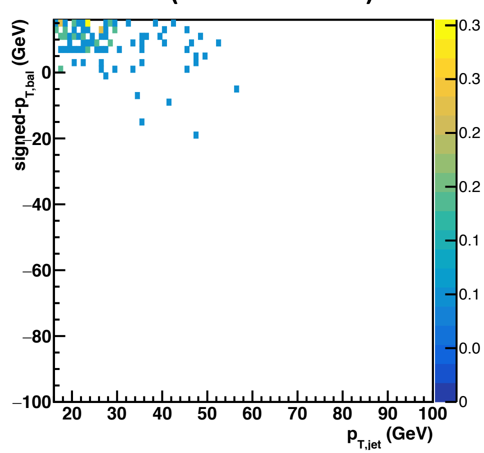


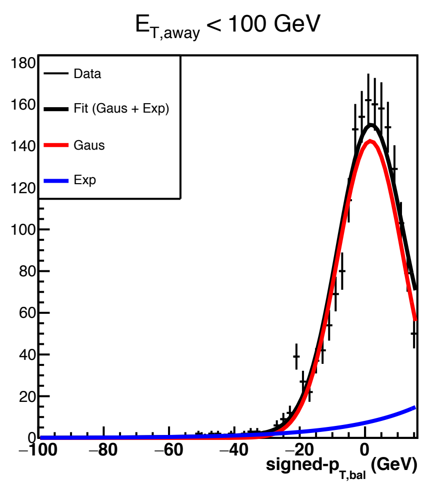


MC W-



MC W- (Zoomed in)





- Similar observation with W-
  (Asymmetric contribution can be as large as ~5% of signal)

Summary of Model Uncertainty

- Mock W study with new QCD jet definition suggests **no significant** mis-estimation of signed-$p_{T,bal}$ cut
- Similar study was repeated with W data and found that the mis-estimation effect can **only be as large as** $\sim\mathbf{5}\%$

→ No significant contribution from signed-$p_{T,bal}$ and $E_{T,away}$

- The following lines will be added In the text,
  - Emission of soft and hard gluons simulated with LO+PS models, such as Pythia, is subject to uncertainties originating from the underlying assumptions behind parton showering algorithms, and cannot be trusted entirely.
  - The resulting misdescription of soft and hard QCD radiation may appear as an incorrect estimation of the reconstruction efficiency in equation (X).
  - The inefficiency of the selection criteria that rely on activities within a large area of the detector, such as $\boldsymbol{E_T^{\Delta R<0.7}}$ and $\boldsymbol{E_T^{\Delta\phi\sim\pi}}$, and the description of reconstructed jets, such as **signed-$\boldsymbol{p_{T,bal}}$**, have been re-evaluated using reconstructed W and Z samples from data without these requirements.
  - The impact of the mis-estimation of the reconstruction efficiency to the overall cross section was found to be less than 5% and taken as a **systematic uncertainty**.