W^+/W^- cross-section ratio with STAR Run 2017

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Recap

FEWZ study by MSHT

3. Predictions

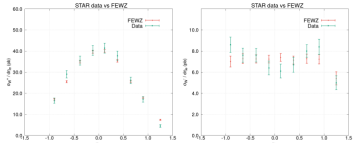
FEWZ predictions

- Thanks for screenshots of input cards for FEWZ...
- We are ≈ able to reproduce your theoretical predictions.
- Total:

Note ≈ 35% reduction from 0 jet cut.

Channel	Data	FEWZ total (0jet cut)	FEWZ total (no 0jet cut)
Z	$3.0 \pm 0.2^{\text{stat}} \pm 0.0^{\text{sys}} \pm 0.3^{\text{eff}}$	2.64 ± 0.01	3.57 ± 0.01
W^+	$64.3 \pm 0.7^{\text{stat}} \pm 0.9^{\text{sys}} \pm 3.4^{\text{eff}}$	67.1 ± 0.1	92.4 ± 0.1
W^-	$17.3 \pm 0.5^{\text{sys}} \pm 0.4^{\text{stat}} \pm 0.9^{\text{eff}}$	19.8 ± 0.1	27.0 ± 0.1

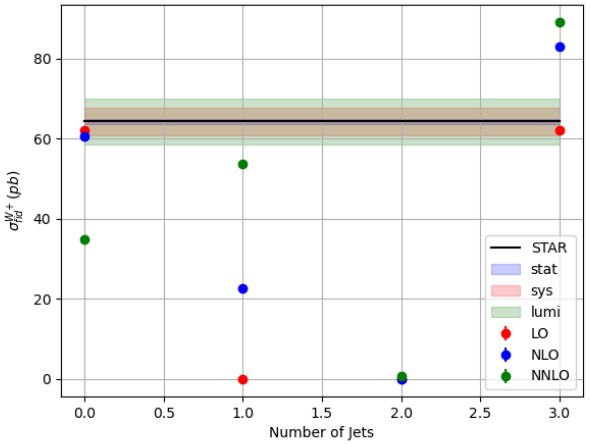
- Applying 0 jet cut makes large difference, is it rigorous/justified?
- Differential:



Can't show for Z as don't know binning? Only bin averages given.

Thomas Cridge | STAR | 19th August 2022 | 5 / 7

Matt's follow-up study



Anastasiou et al., PRD 69 (2004) 094008

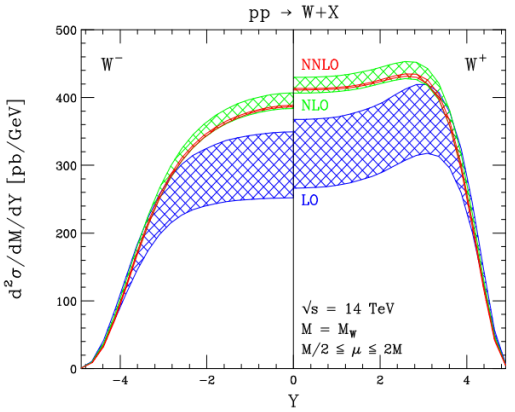
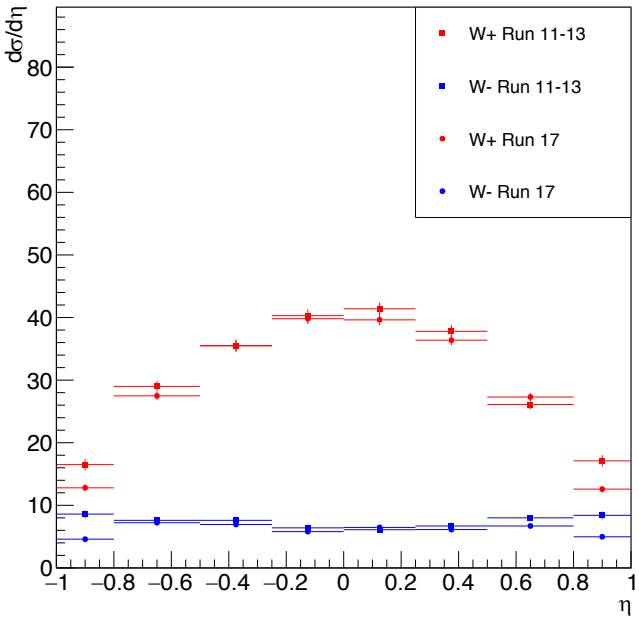


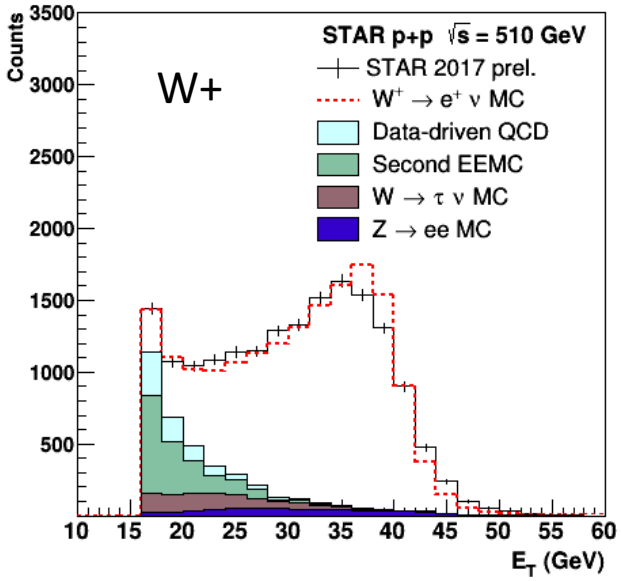
Figure 13: The CMS rapidity distributions for production of an on-shell W^- boson (left) and on-shell W^+ boson (right) at the LHC, at LO, NLO, and NNLO, for the MRST PDF sets. Each distribution is symmetric in Y; we only show half the rapidity range in each case. The bands indicate the common variation of the renormalization and factorization scales in the range $M_W/2 \leq \mu \leq 2M_W$.

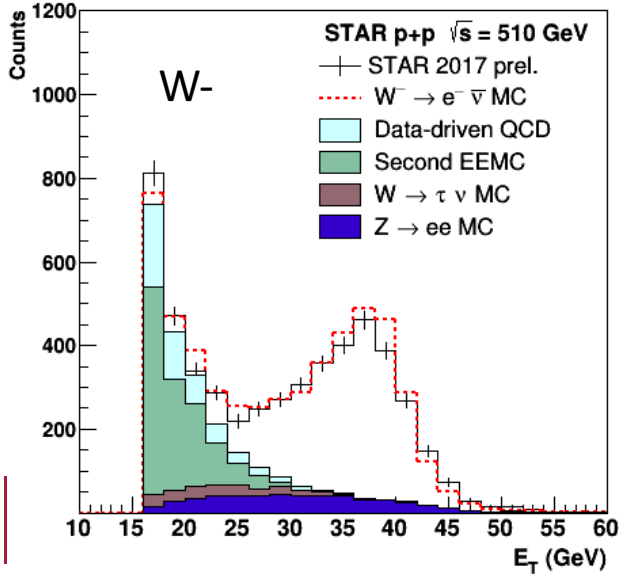
Run 17 W cross section



- STAR publication based on Run 2011-2013 is well described by FEWZ NLO calculation **without** including jet production process $p + p \rightarrow W + jet$
- Issue raised by MSHT (T. Cridge et al.) on justification of "no-jet" cut (without this cut, cross section differs by ~30% for $W^{\pm}$ and Z)
- De Florian and Vogelsang found ~30% contribution from higher order correction indeed possible at STAR kinematics
- STAR Run 2011-2013 publication is not just a one-off case, STAR Run 2017 data also consistent with publication.

STAR W Measurement





- At the reconstruction-level, **Pythia** describes **data** (STAR Run 11-13, 17) well (MC scaled to data lumi, $L_{MC} = L_{data}$)
- Cross section extracted by

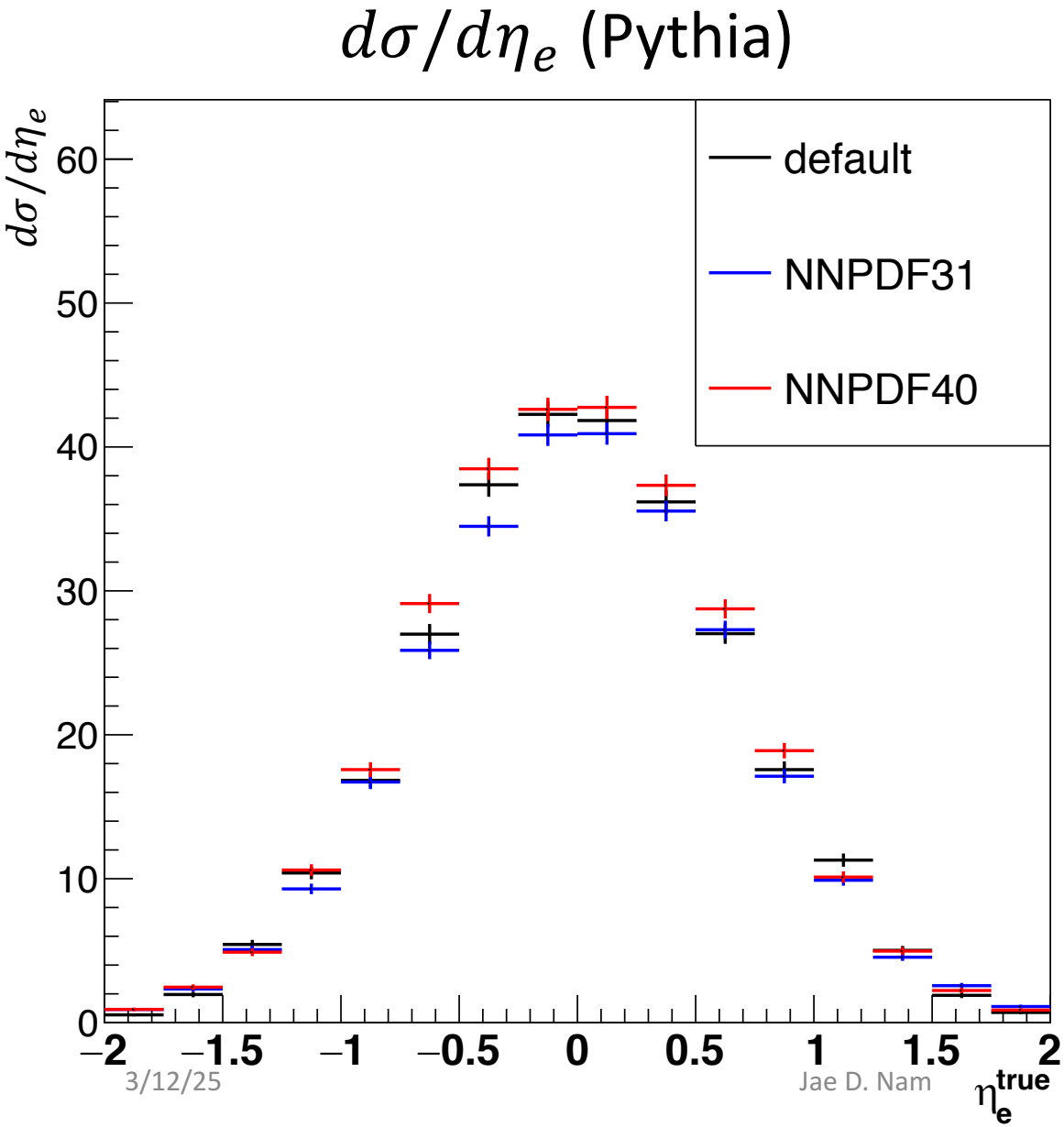
$$\sigma_{data} = \frac{N_{data}}{L_{data}} = \frac{1}{L_{data}} \times \frac{N_{MC}}{M_{MC}} \times M_{data}$$

  - M = Number of reconstructed events
  - N = Number of true events

- $M_{MC} \sim M_{data}$,

$$\sigma_{data} \sim \frac{N_{MC}\ (= \sigma_{MC} \times L_{MC})}{L_{data}} = \sigma_{MC}$$

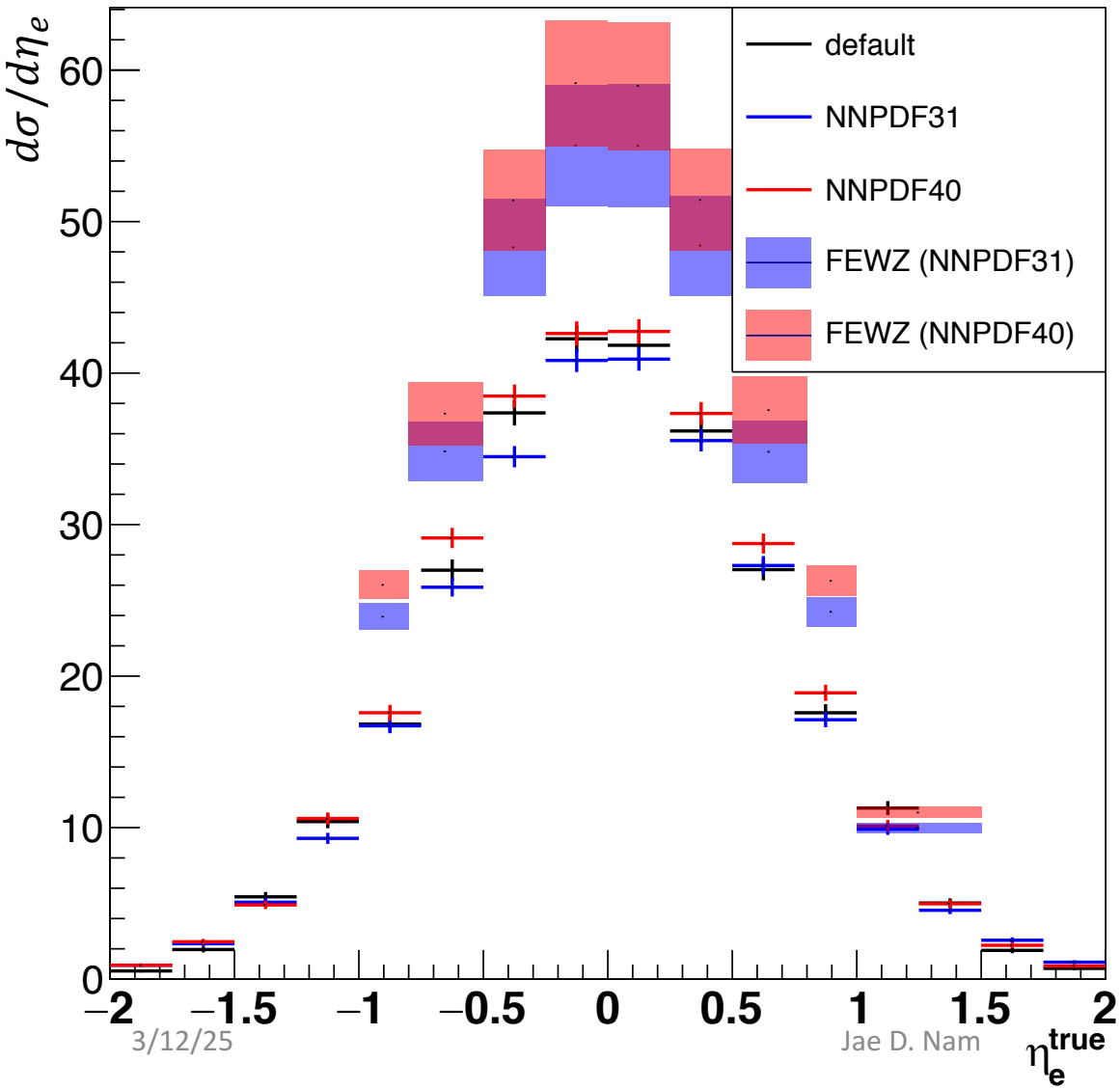
Comparison Pythia6 + PDFsets (W+)



- 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

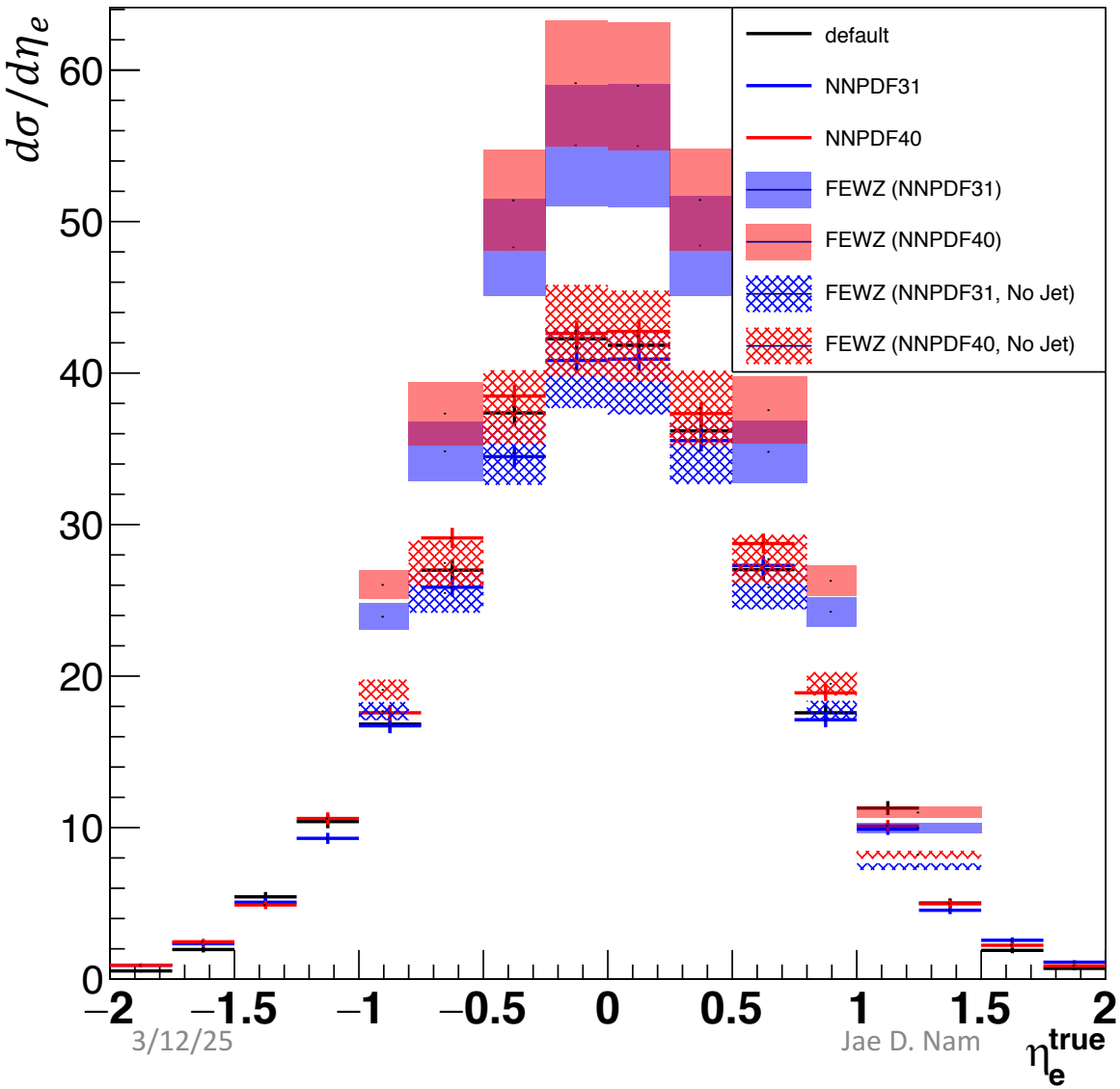
$d\sigma/d\eta_e$ (Pythia, FEWZ NLO)



- 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

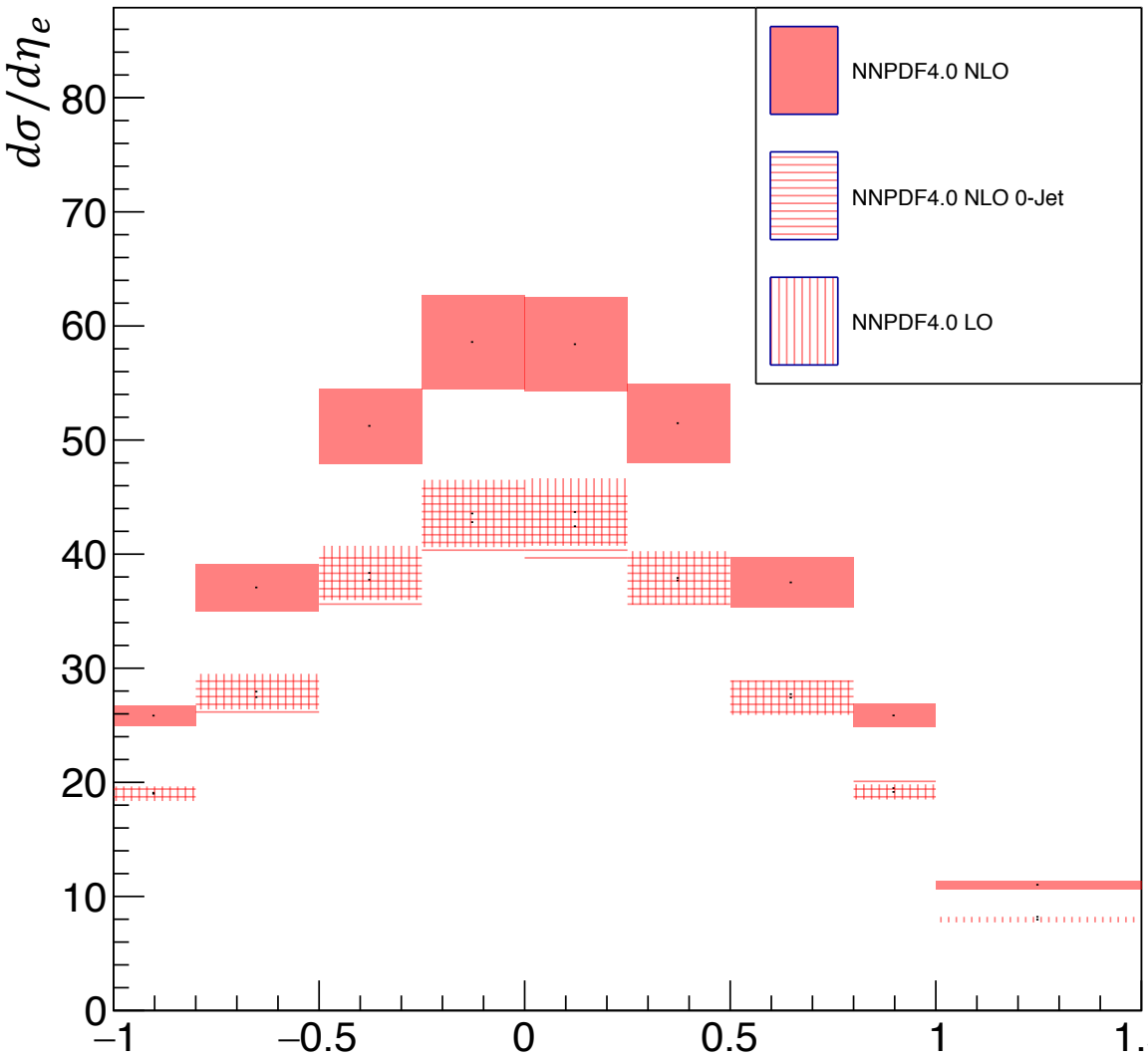
$d\sigma/d\eta_e$ (Pythia, FEWZ NLO)



- 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
- $\sigma_{data} \sim \sigma_{FEWZ,LO}$? Why?

Experimental Origins

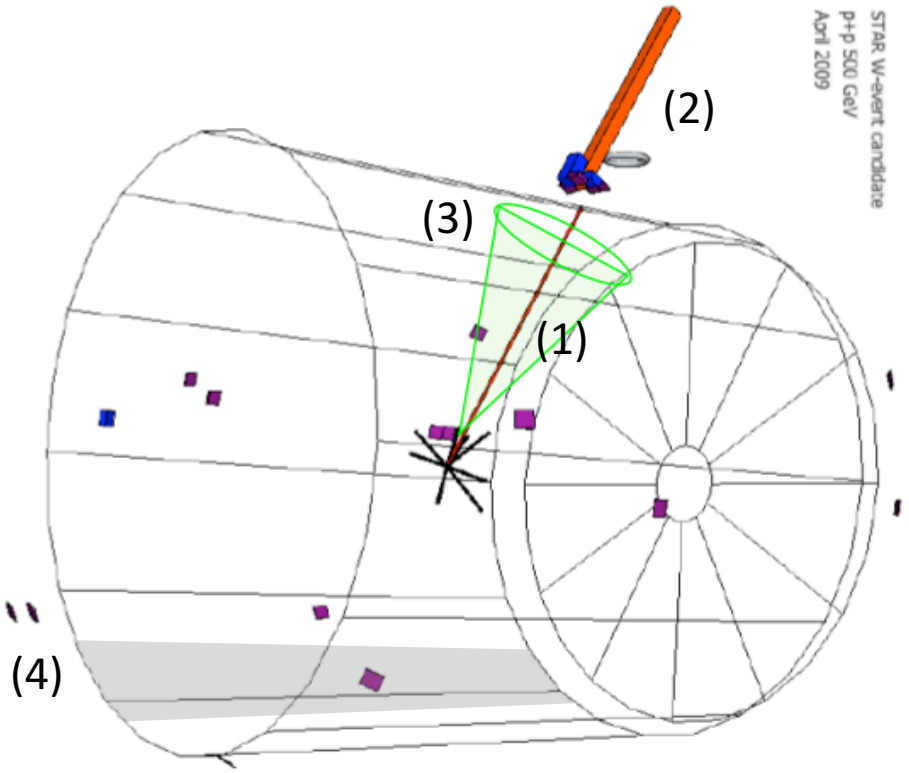
- Few different aspects from the experimental side that could have caused $M_{data} \sim M_{MC} \rightarrow \sigma_{data} \sim \sigma_{FEWZ,LO}$
  - Effects arising from Calorimetry (BEMC)
  - Effects arising from Tracking (TPC)
  - Bremsstralung
  - Coding Error?

No significant effect found

- Event reconstruction removing higher order effect?

Review of Event Reconstruction

Event Display of typical W event



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)

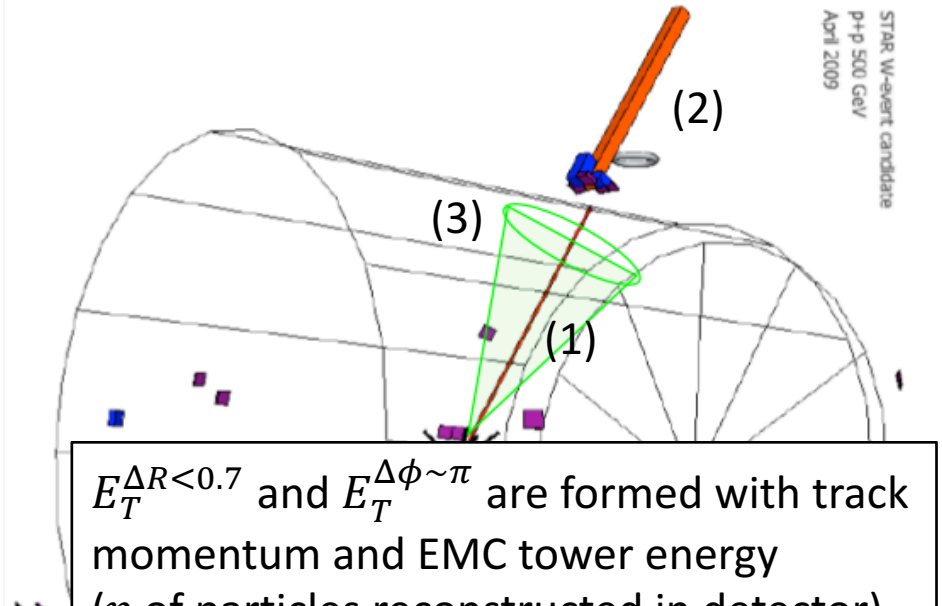
3) Isolation requirement ($E_T^{2\times2}/E_T^{\Delta R<0.7}\sim1$, $E_T^{2\times2}/E_T^{4\times4}\sim1$)

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)

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)

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

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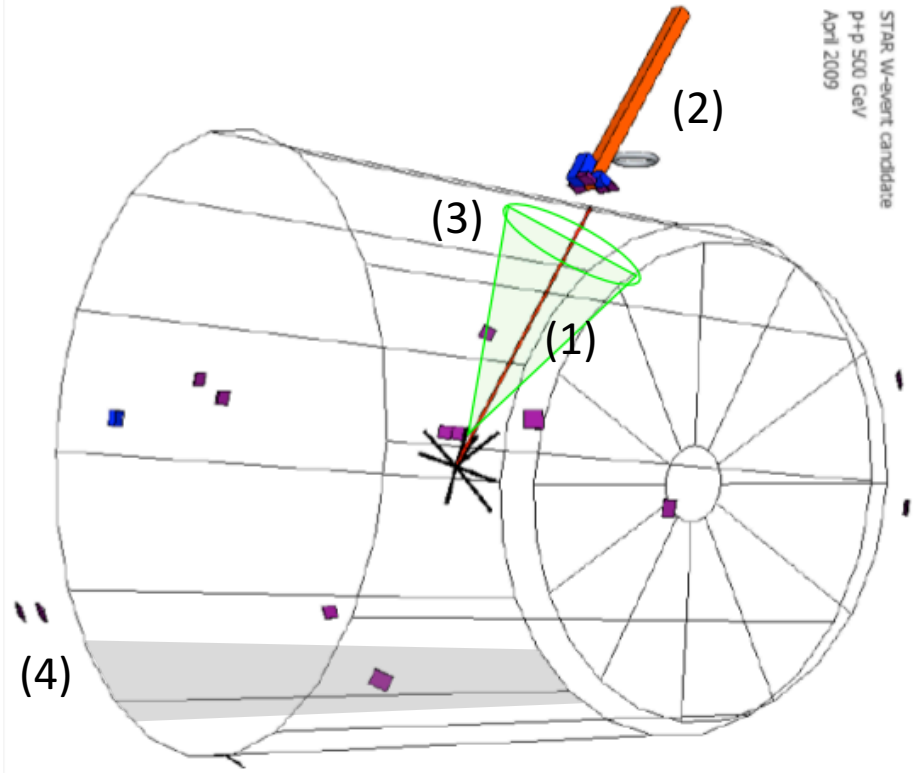
Review of Event Reconstruction

Event Display of typical W event



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

Base

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

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

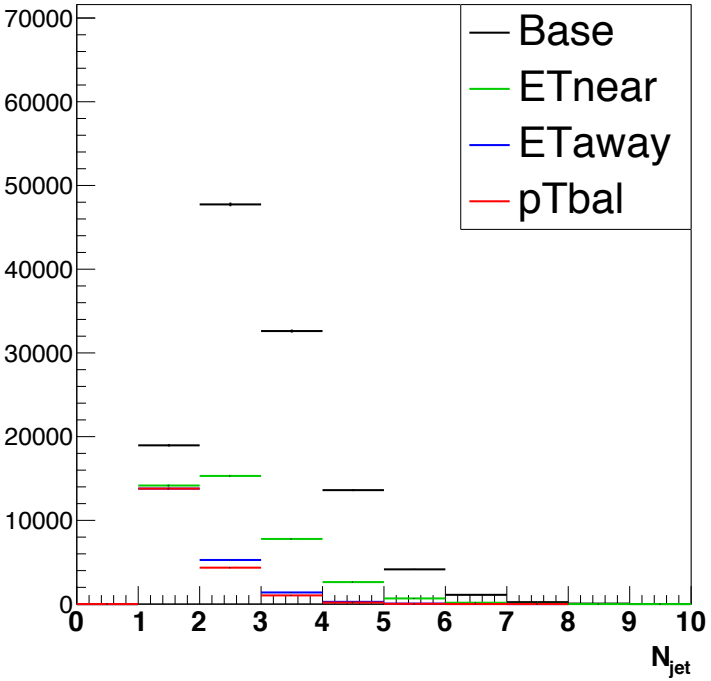
4) ETaway (neutrino direction) energy flow requirement ($E_T^{\Delta\phi\sim\pi} <$ threshold)

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

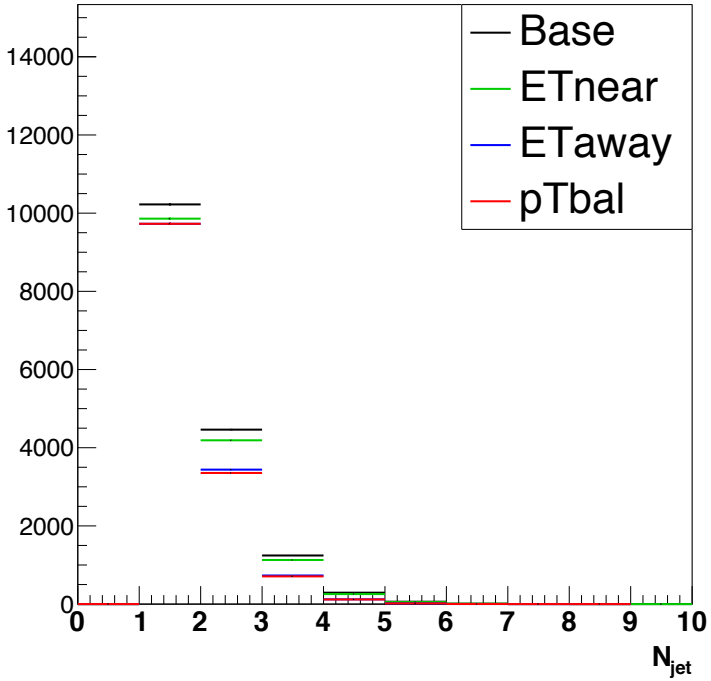
Looking at Jets (W+ only)

StJetFinder, anti-kT, R=0.6, min-pT=3.5 GeV

N_{jet}^{det} (DATA)

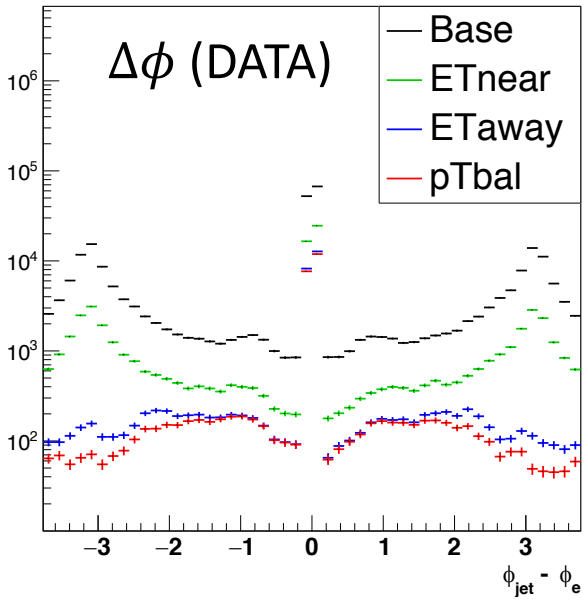


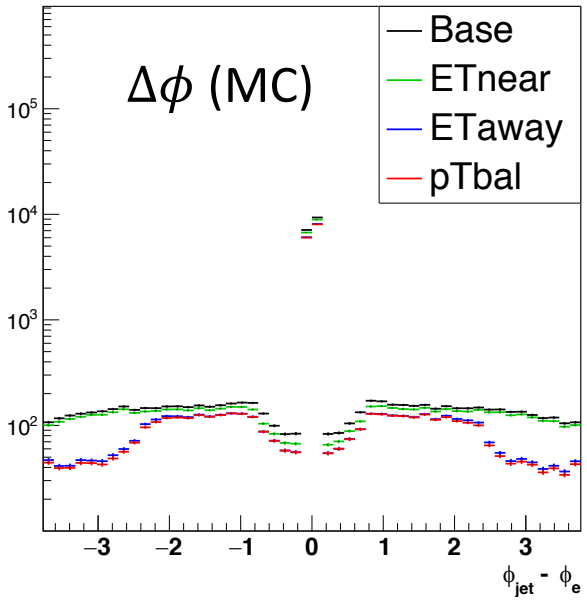
N_{jet}^{det} (MC)

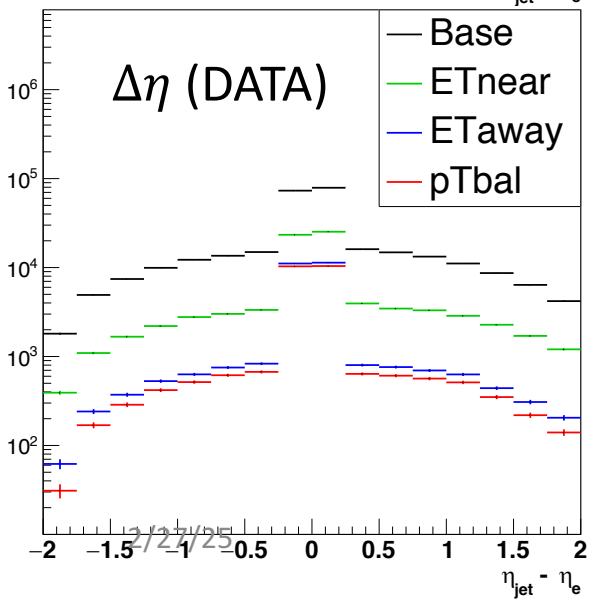


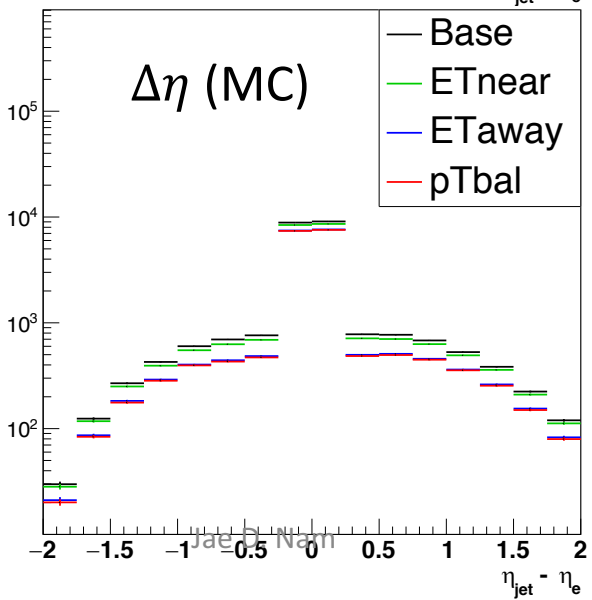
- Most of the MC events are single jet events (containing electron)
- Most of the data events are dijet events (QCD)
- Most of the dijet events in data are removed after ETnear+ETaway cut

Looking at Jets (W+ only)



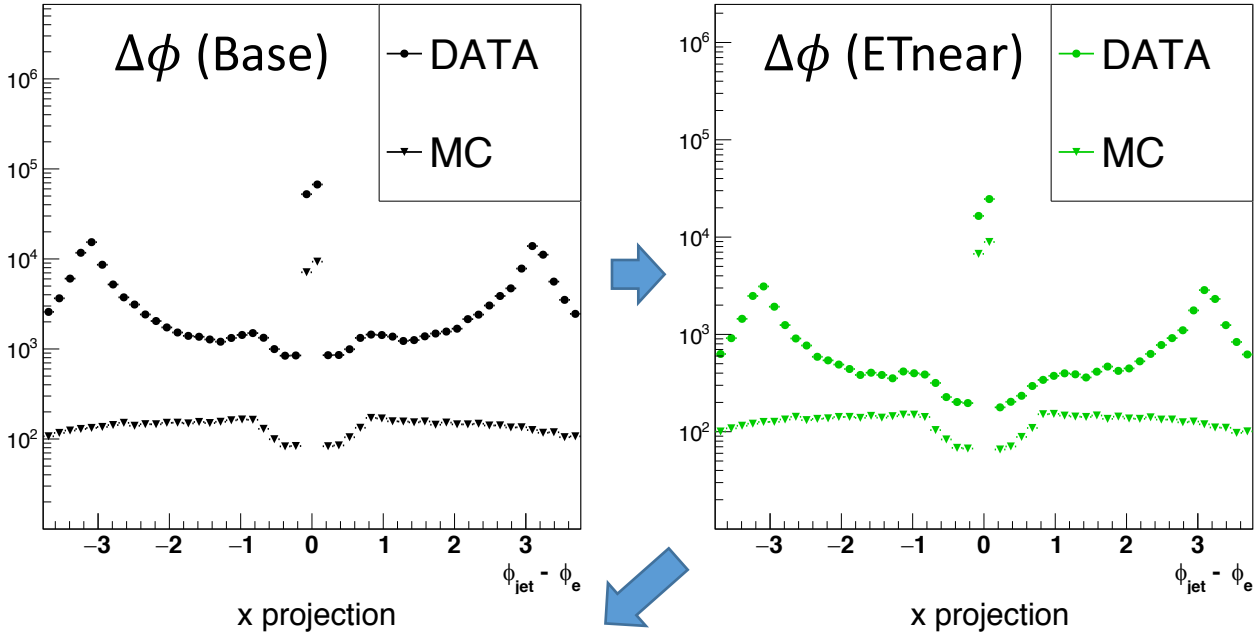






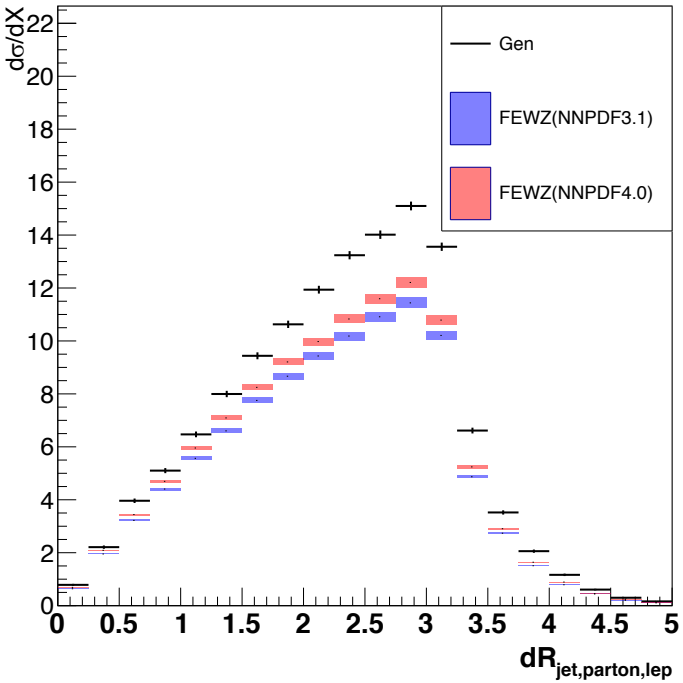
- $\Delta X = X_{\mathrm{jet}} - X_{\mathrm{e,cand}}$
- Most of data events have back-to-back topology between electron and jet
- Most of the events with back-to-back topologies are removed by ETaway cut.

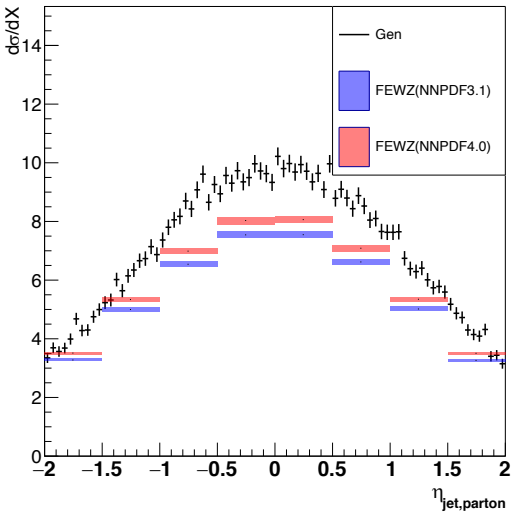
Looking at Jets (W+ only)

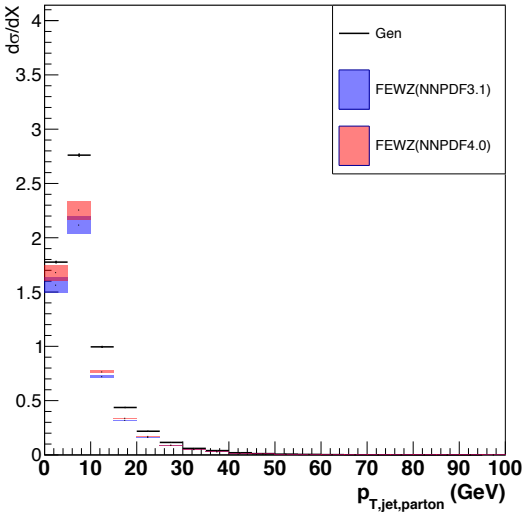


- Most of the events with back-to-back topologies are removed by the ET away cuts.
- This cuts does improve data-MC matching
- How well does Pythia describe jets at the truth level, compared to FEWZ?

Jets: Pythia vs FEWZ NLO







- For Pythia, Parton jet reconstructed
  - Anti-kT, E-scheme, R=0.6
  - pT > 3.5 GeV
  - (same as FEWZ)
  - Electron/Neutrino rejected
  - **Leading jet (highest pT) only**

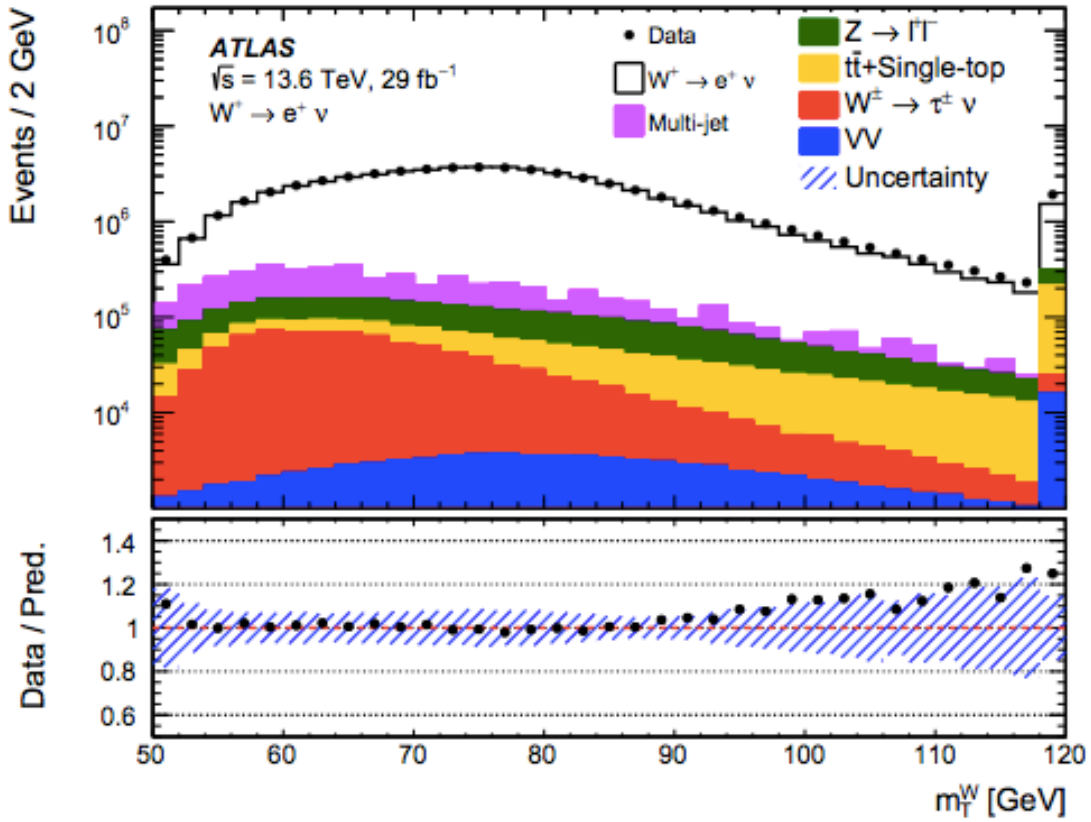
- Only looking at leading jets in Pythia to avoid multiplicity effects
- Pythia overestimates jet associated W events
- Shape is described relatively well

→ Questions

- (albeit some scaling factor) LO+PS jet describes NLO jet very well
  → Where is the ~30% shift coming from?
  → What do other people do?

LHC Measurements

ATLAS, PLB 854 (2024) 138725



- ATLAS $W \rightarrow e\nu$ reconstruction method similar to STAR
- E_T^{near} cut with variable cone size
- Without E_T^{away} cut

- Chooses a specific m_T^W region
- MC prediction based on NLO+PS models, SHERPA and POWHEG+Pythia8
- NLO+PS models describe LHC data very well

SHERPA

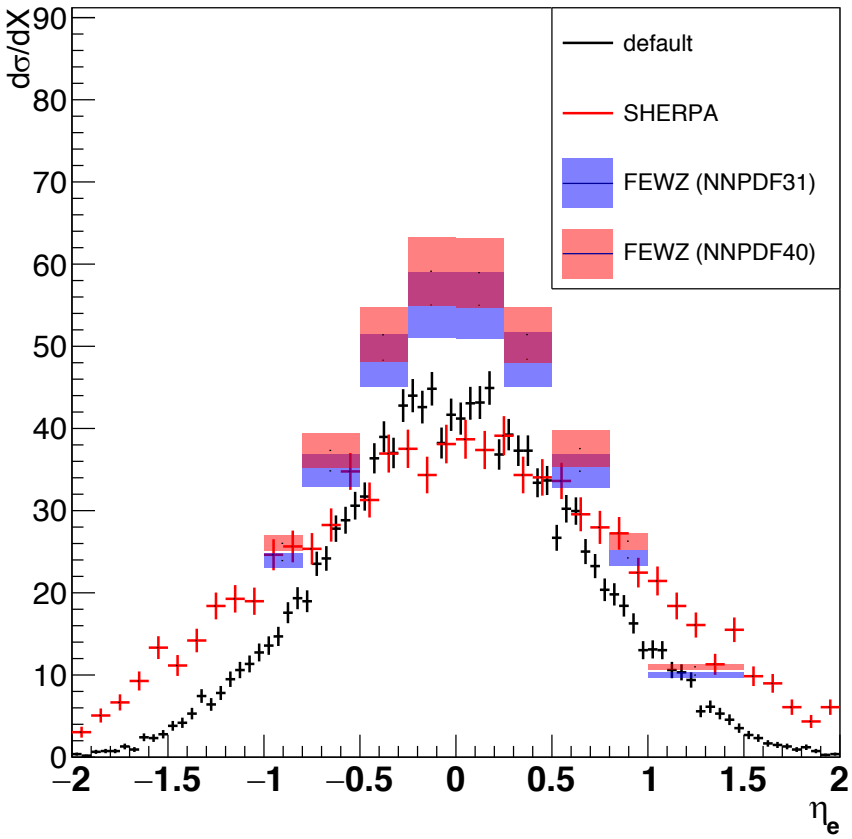
- SHERPA 2.2.16 NLO+PS event generator
  - https://sherpa.hepforge.org/doc/SHERPA-MC-2.2.16.html
  - Uses MEPS@NLO jet merging technique
  - Matrix elements computed by BlackHat
  - LHC W+jets prediction from BlackHat+SHERPA: https://arxiv.org/pdf/1005.3728

- Test sample generated using the same tune as the SHERPA's W+jets study (CT10 PDF set)

- Key Parameters
  - $N_{jet} = 4$
  - $L_{jet} = 2,3,4$
  - $Q_{cut} = 20\ GeV$
    "jet merging scale"
    Qcut dependence needs to be checked

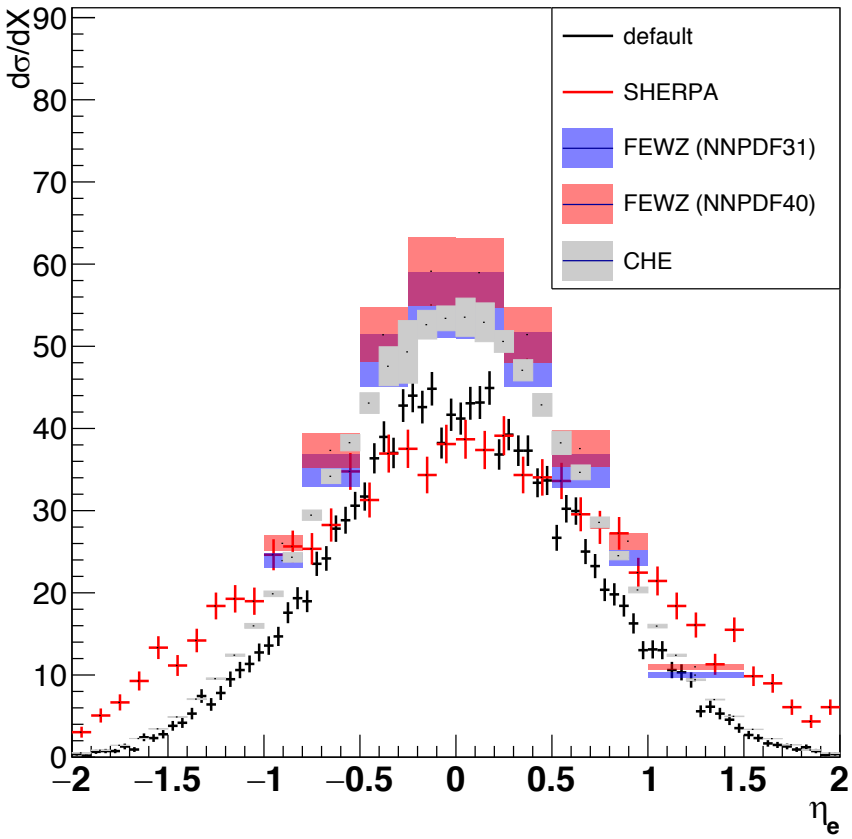
$p + p \rightarrow e^+ + \nu$ at NLO
$p + p \rightarrow e^+ + \nu + j$ at NLO
$p + p \rightarrow e^+ + \nu + j + j$ at NLO
$p + p \rightarrow e^+ + \nu + j + j + j$ at LO
$p + p \rightarrow e^+ + \nu + j + j + j + j$ at LO

Pythia vs FEWZ vs SHERPA



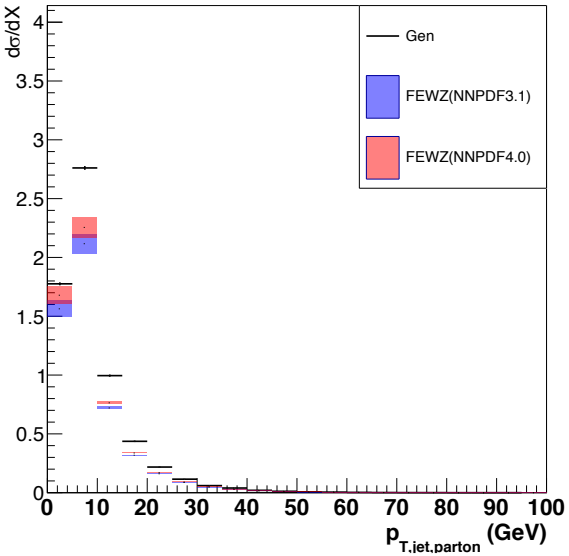
- Integrated cross section from SHERPA agrees with FEWZ NLO
- The shape does not describe Pythia/FEWZ → Proper tuning needed

Pythia vs FEWZ vs SHERPA vs CHE

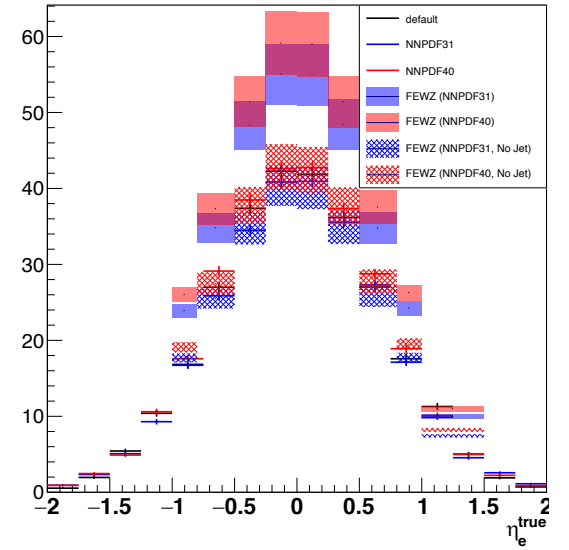


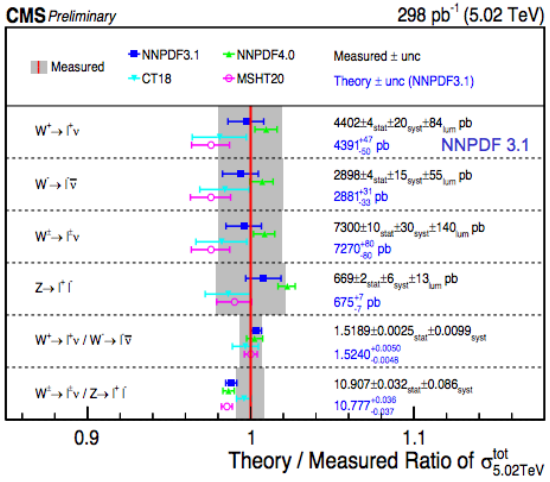
- 2nd opinion from CHE (NLO calculator)
- CHE with MRST2002NLO PDF set agrees well with FEWZ, given that the two currently use different PDF sets

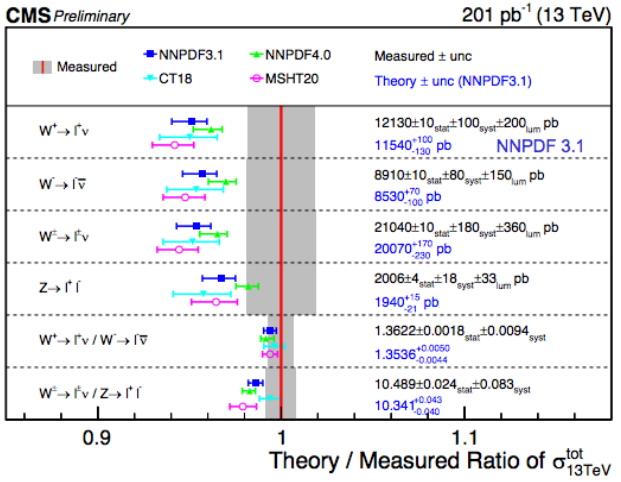
Questions



- Performance of pQCD describing DY with very soft jets, $p_T > 3.5\ GeV$?
- Performance of pQCD in this scale? (describes LHC within 5%)
- What is the nature of $\sigma^{Pythia} \sim \sigma^{pQCD,LO}$?
- Can we trust Pythia with ETnear, Etaway (+ pTbal with rather soft jets)?

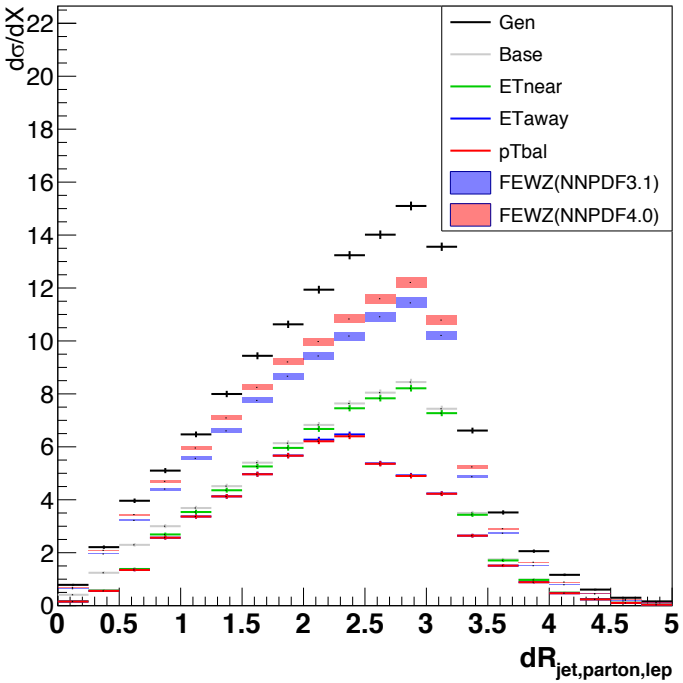


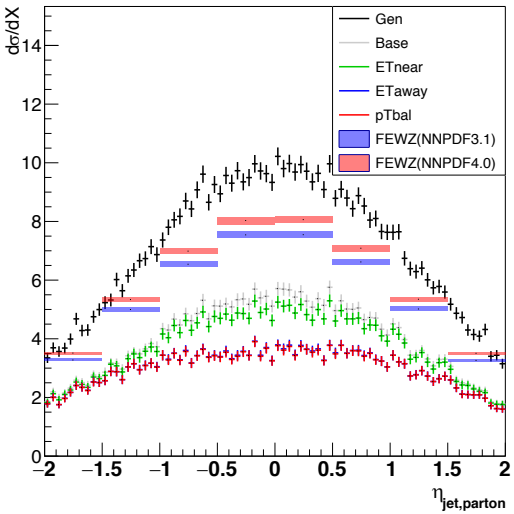


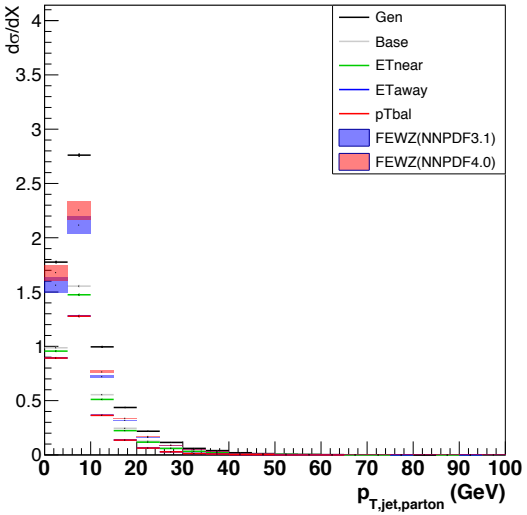


Backup

Pythia vs FEWZ NLO







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  - pT > 3.5 GeV
  - (same as FEWZ)
  - Electron/Neutrino rejected
  - **Leading jet (highest pT) only**

- There are some depression around $dR \sim \pi$, but these do survive and should be accounted for by the efficiency correction

- Conclusion:
  It's not easy to estimate the fraction of higher-order contributions that get cut out by our selection method.