Measurement of $W^{\pm}$ cross section ratio in pp collisions at STAR

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for the STAR collaboration

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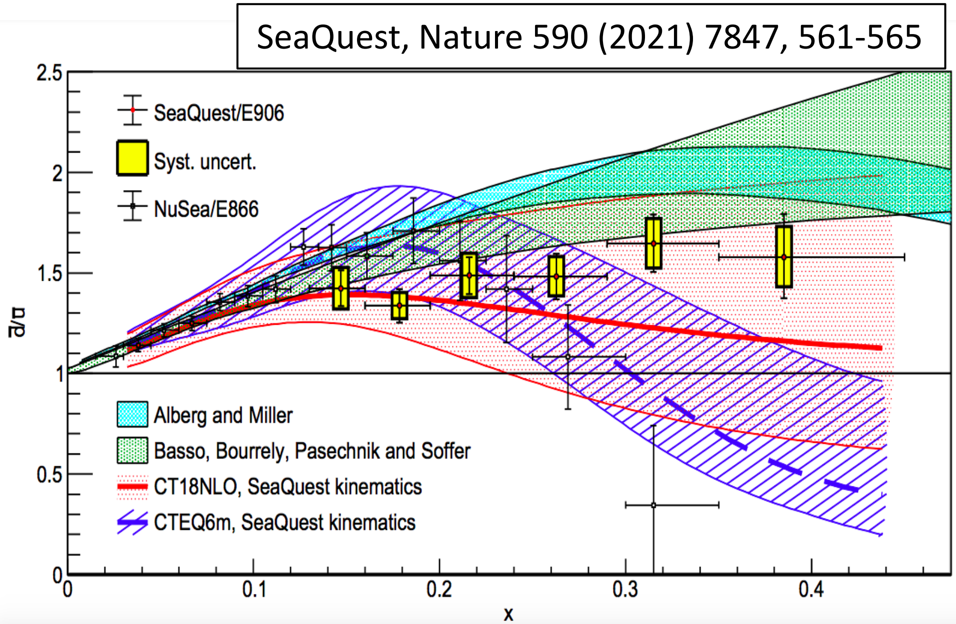
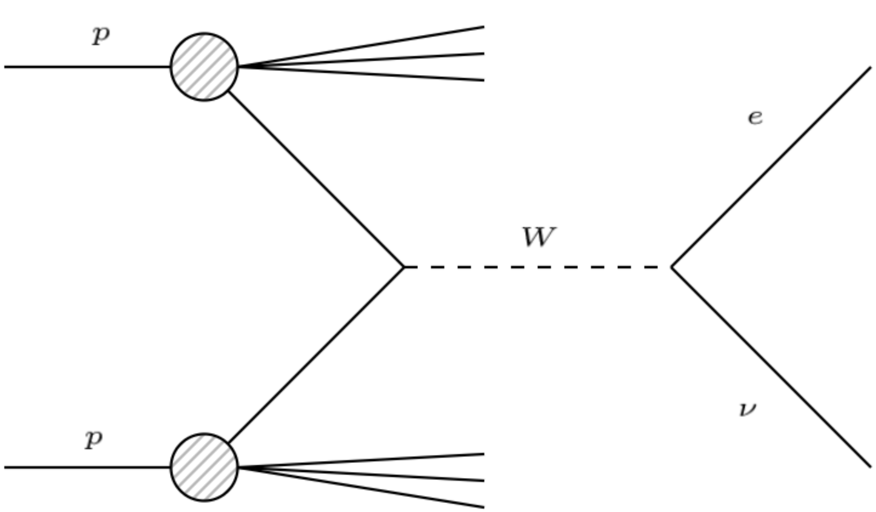
Motivation



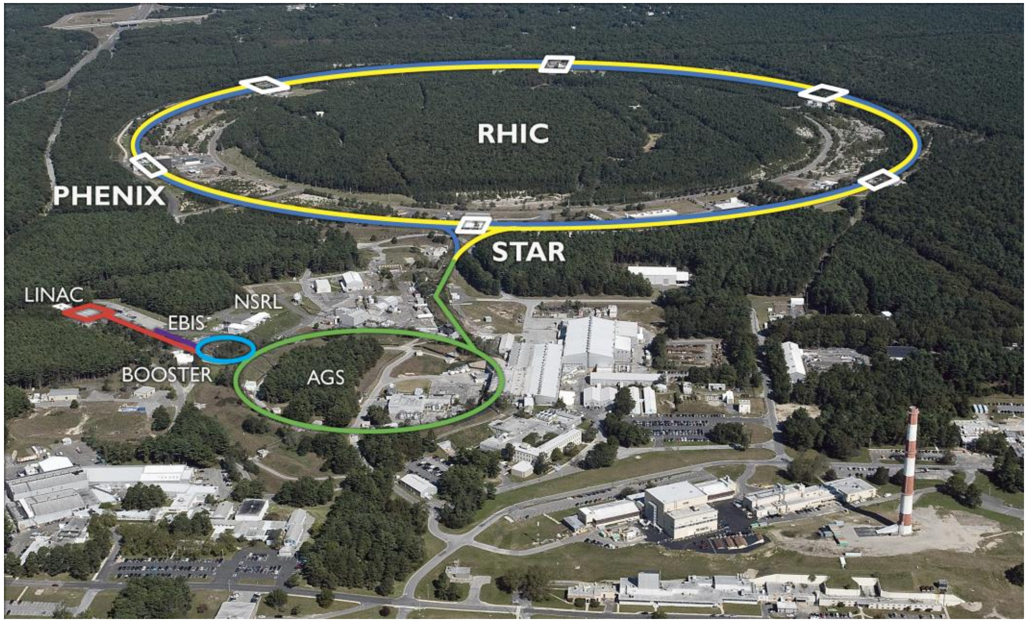


- The $\bar{d}/\bar{u}$ flavor asymmetry
  - Predominantly measured via Drell-Yan.
  - Tension between measurements around the valence region.
- W production at STAR/RHIC
  - LO production sensitive to $\bar{d}$ (W^+) and $\bar{u}$ (W^-).
  - The cross-section ratio $\sigma_{W^+}/\sigma_{W^-}$ can be used to probe $\bar{d}/\bar{u}$;

$$R_W = \frac{\sigma_{W^+}}{\sigma_{W^-}} \approx \frac{u(x_1)\,\bar{d}(x_2) + u(x_2)\,\bar{d}(x_1)}{\bar{u}(x_1)\,d(x_2) + \bar{u}(x_2)\,d(x_1)}$$

  - Naturally provides a large momentum scale, $Q^2 \approx M_W^2$.
  - Sensitive to $\bar{d}/\bar{u}$ in the region $0.1 < x < 0.3$ in the STAR mid-rapidity ($|\eta| < 1$).
  - Can be further stretched to $0.06 < x < 0.4$ with Endcap EM Calorimeter (EEMC).
  - Characteristically produces final state ν.
  - Isolated high p_T electron.

Relativistic Heavy Ion Collider (RHIC)



- RHIC is the world's first polarized pp collider.
- $L \approx 700\ pb^{-1}$ of pp collision data with sufficiently high collision energy for W production.
  - Measurement with ~350 pb^{-1} of data has been published.
  - The remaining $\sim 350\ pb^{-1}$ has been granted preliminary release.

Run	$\sqrt{s}\ (GeV)$	$L\ (pb^{-1})$
2009	500	10
2011	500	25
2012	510	75
2013	510	250
2017	510	350

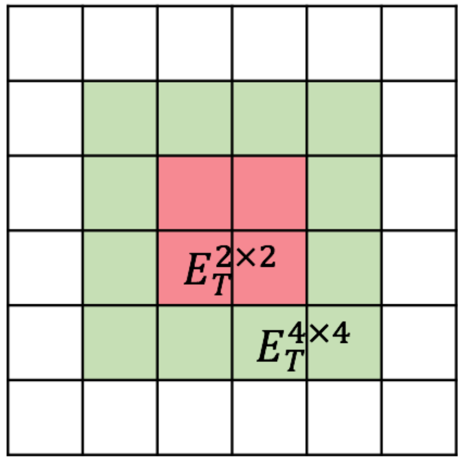
STAR, PRD 85, 092010

STAR, PRD 103, 012001

STAR preliminary

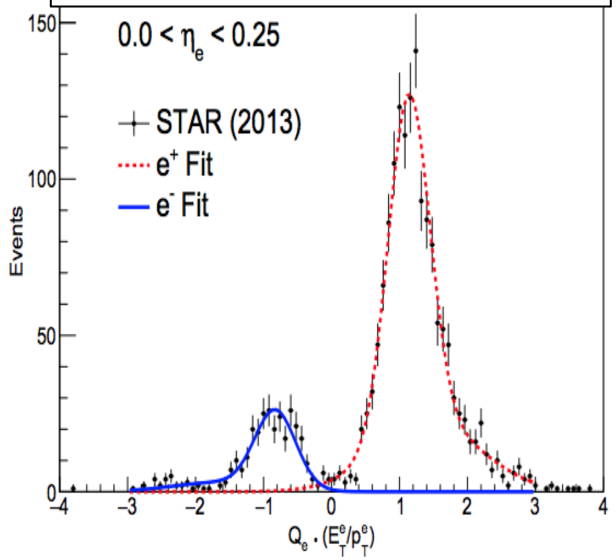
This talk

W selection



TPC track extrapolated to BEMC tower grid

STAR, PRD 103 (2021) 1, 012001



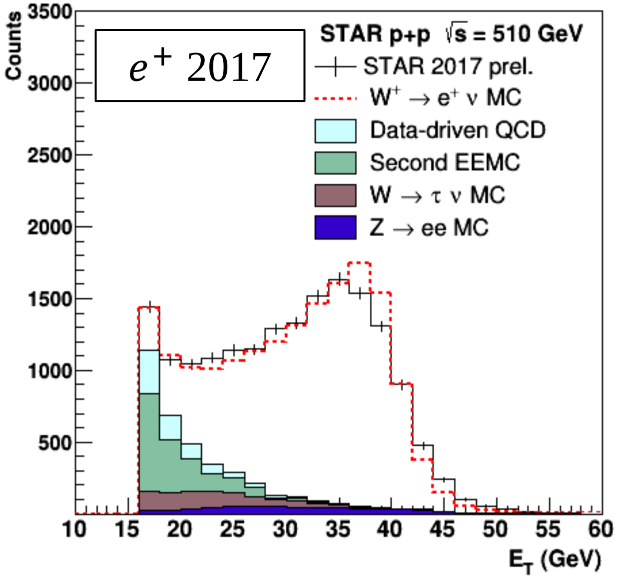
- Event level selection
  - High $\vec{p}_T^{bal}$ $(= \vec{p}_T^{e} + \Sigma \vec{p}_T^{recoil})$ event
  - Isolated electron $(E_T^{2\times2}/E_T^{4\times4})$ with high p_T
  - No energy in the opposite cone.
  - Charge separation from TPC + EMC $(Q_e \times E_T/p_T)$.
- W tagging methods
  - Lepton-tagging
    - Indirect, but smaller systematic uncertainty.
  - W reconstruction with MC
    - The missing neutrino momentum is reconstructed via;

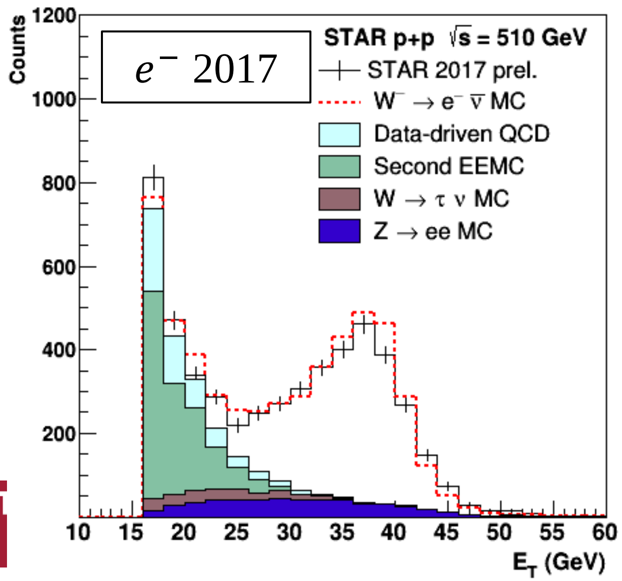
$$\vec{p}_T^{\nu} = -\vec{p}_T^{bal}$$

$$M_W^2 = (E_e + E_\nu)^2 - (\vec{p}_e + \vec{p}_\nu)^2$$

    - Correction for unmeasured tracks and clusters based on MC study.

Background contributions





- Electroweak $(N_{Z\rightarrow ee},\ N_{W\rightarrow \tau\nu})$
  - Z decays with one unidentified electron
  - Leptonic decay of τ^W
  - Estimated with MC
- Second EEMC (N_{EEMC})
  - Accounts for missing backward coverage $(-2 < \eta < -1)$
  - Estimated by mirroring the effect of existing EEMC $(1 < \eta < 2)$
- Data-driven QCD (N_{QCD})
  - Remaining background contributions that pass the selection processes.
  - Distribution obtained by using events that do not pass the $p_{T,bal}$ cut.

Z reconstruction

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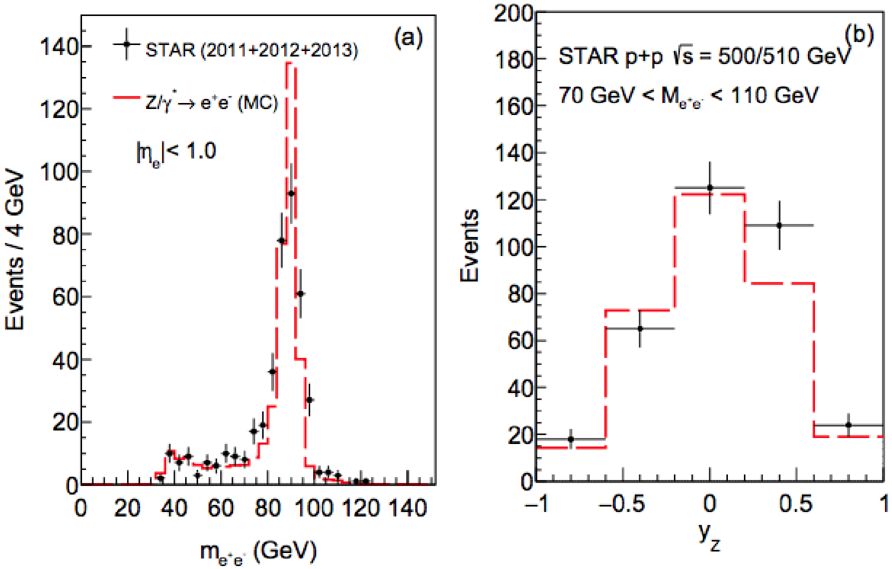
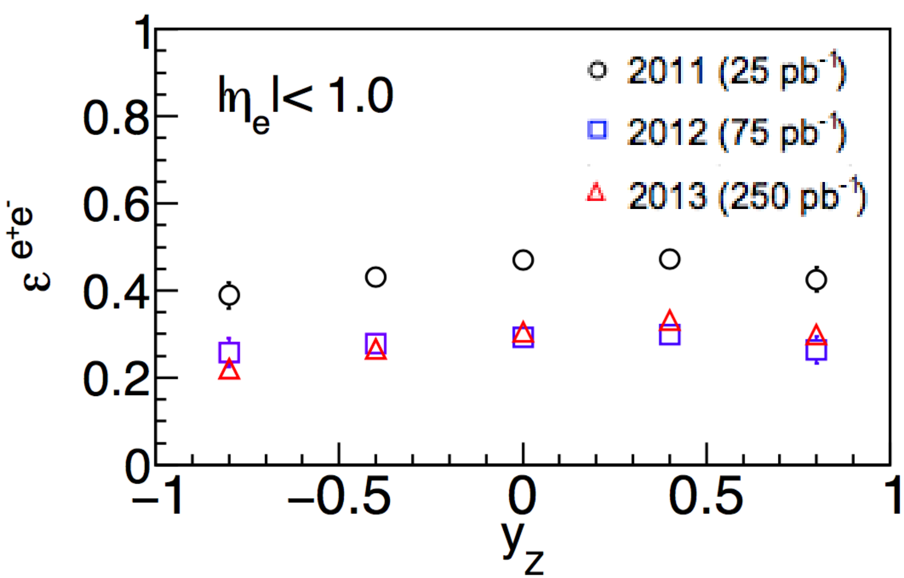


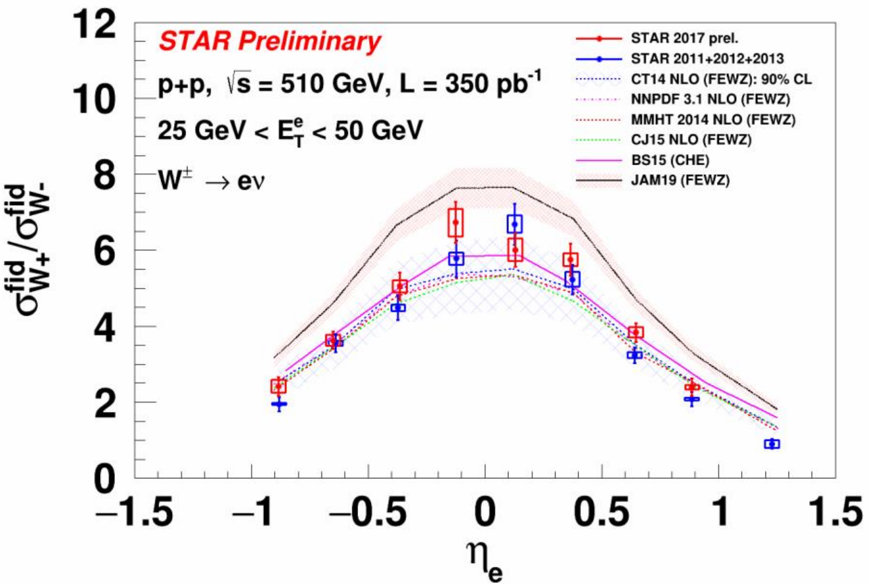


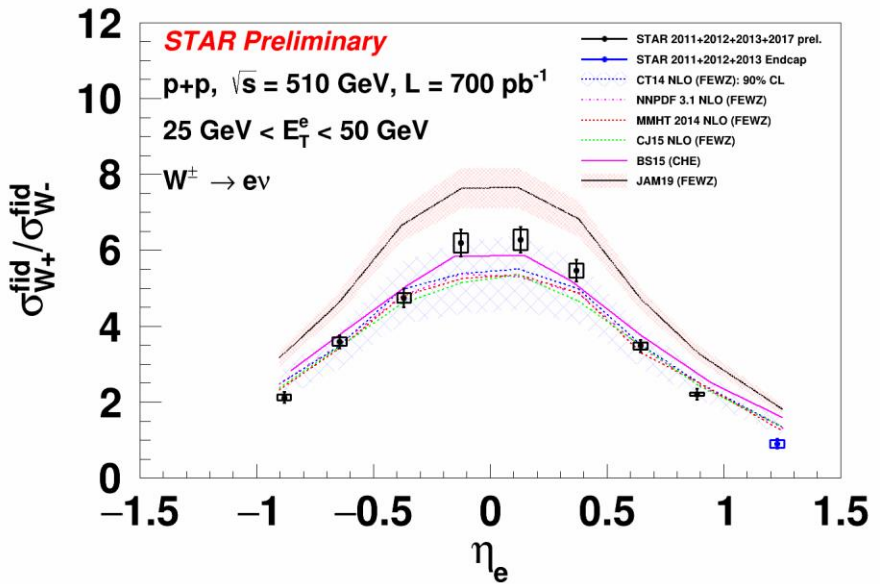
- The leptonic decay of Z boson can be observed at STAR

$$pp \to Z/\gamma^* \to e^+e^-$$

- Z candidates are selected by tagging two isolated electrons with opposite charges.
  - Clean identification of Z candidates.
- M_Z can be reconstructed and used to fine-tune the BEMC calibration.
- Efficiencies estimated with Pythia and GEANT.

Results: W^+/W^- (lepton-tagging)

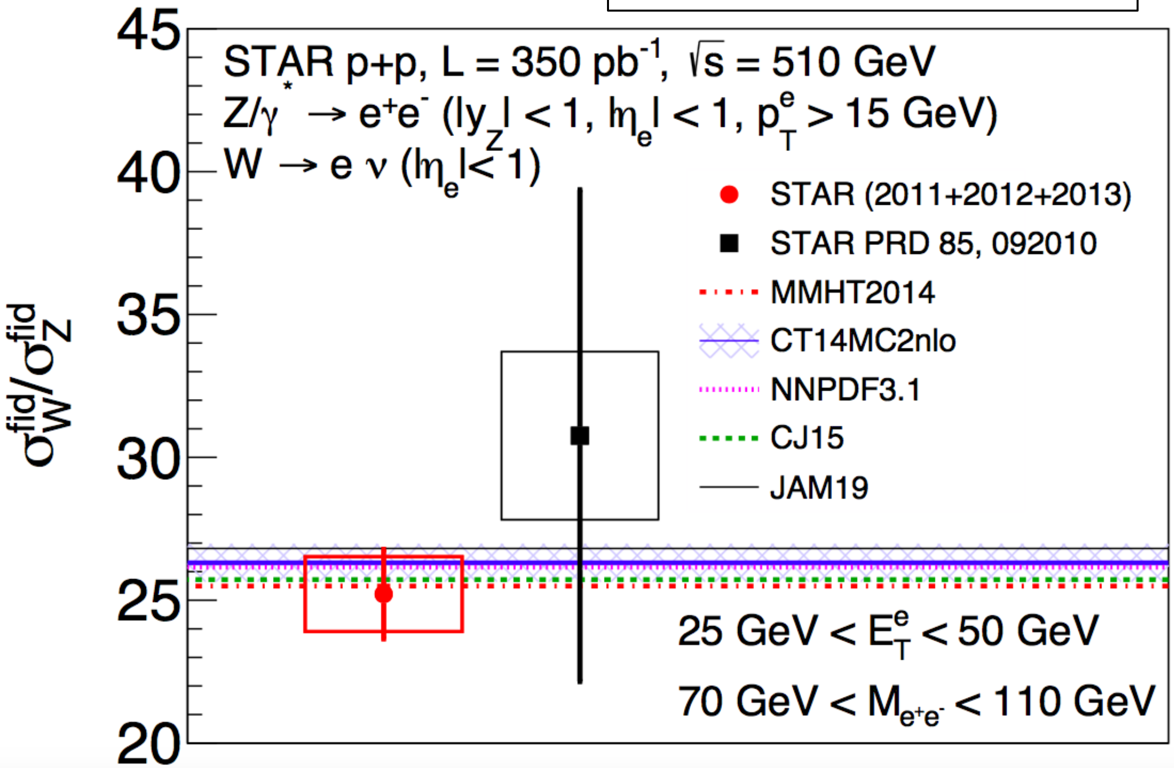




- W^+/W^- cross-section ratio measurement with STAR 2011-2013 data has been published [PRD 103 (2021) 1, 012001].
- Preliminary measurement with STAR 2017 data
  - Only the barrel region, $|\eta| < 1$ (Endcap study in progress).
  - Systematic uncertainty driven by BEMC gain correction.
  - Doubles the statistics of the published result $(L \approx 700\ pb^{-1})$.
  - Overall good agreement with the current PDF distributions.

Results: W/Z cross-section ratio

STAR, PRD 103 (2021) 1, 012001



- W/Z cross-section ratio

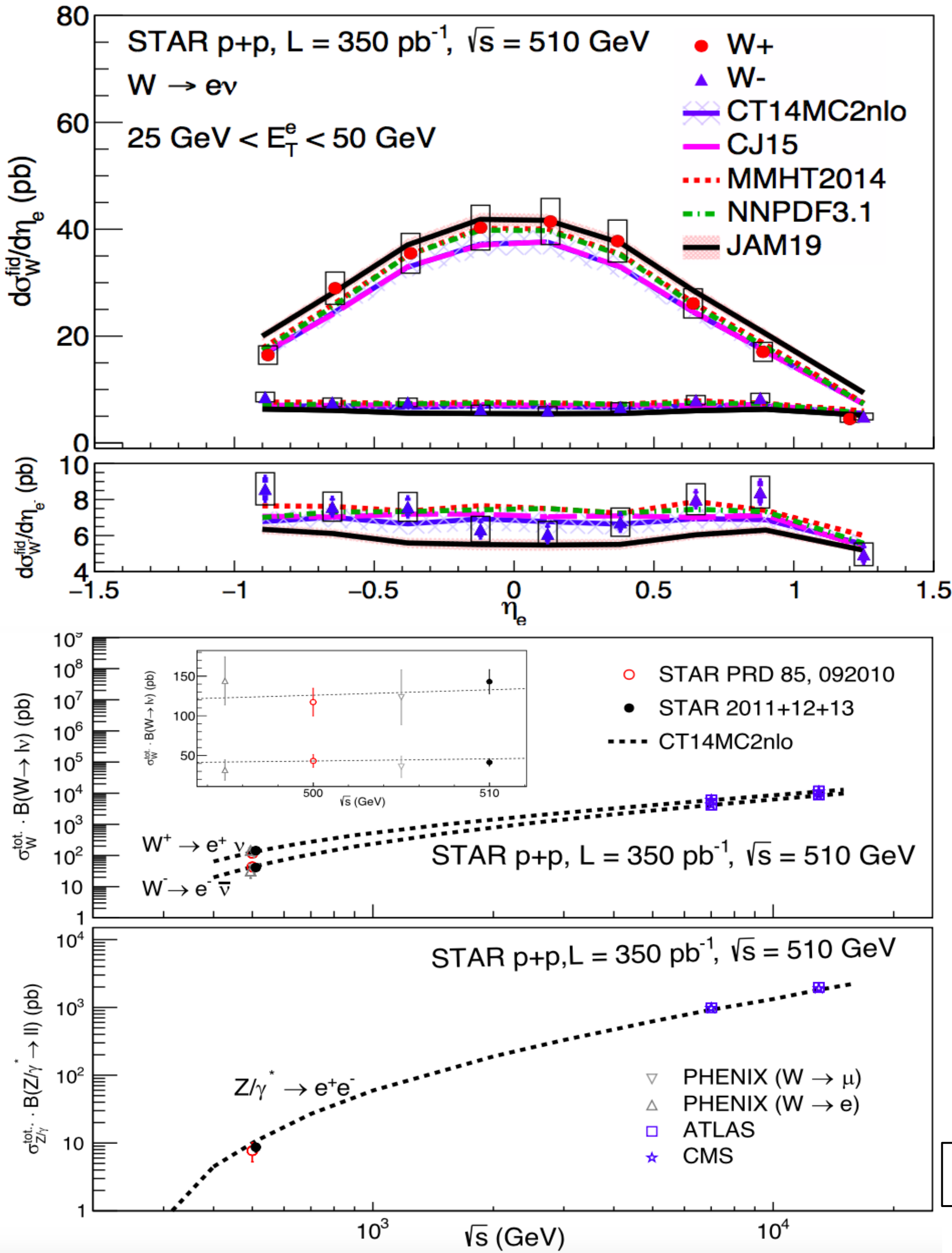
$$\frac{\sigma_W}{\sigma_Z} = \frac{\epsilon_Z}{\epsilon_W}\frac{N_{sig}^W - N_{bg}^W}{N_{sig}^Z}$$

  - Where $W = W^+ + W^-$.

- Consistent with STAR 2009 result and FEWZ calculations.

- Further constraints to PDFs, s and $\bar{s}$, in particular.

Results: Absolute cross sections



- Measurement of the total cross sections.

$$\sigma_{W/Z}^{fid} = \frac{N_{sig} - N_{bg}}{\epsilon \int Ldt}$$

$$\sigma_{W/Z}^{tot} = \sigma_{W/Z}^{fid} / A_{W/Z}$$

- Acceptance correction onto 2011 sample ($\sqrt{s} = 500\ GeV$) to match 2012 and 2013 samples ($\sqrt{s} = 510\ GeV$) by using FEWZ [PRD 86 (2012) 094034].

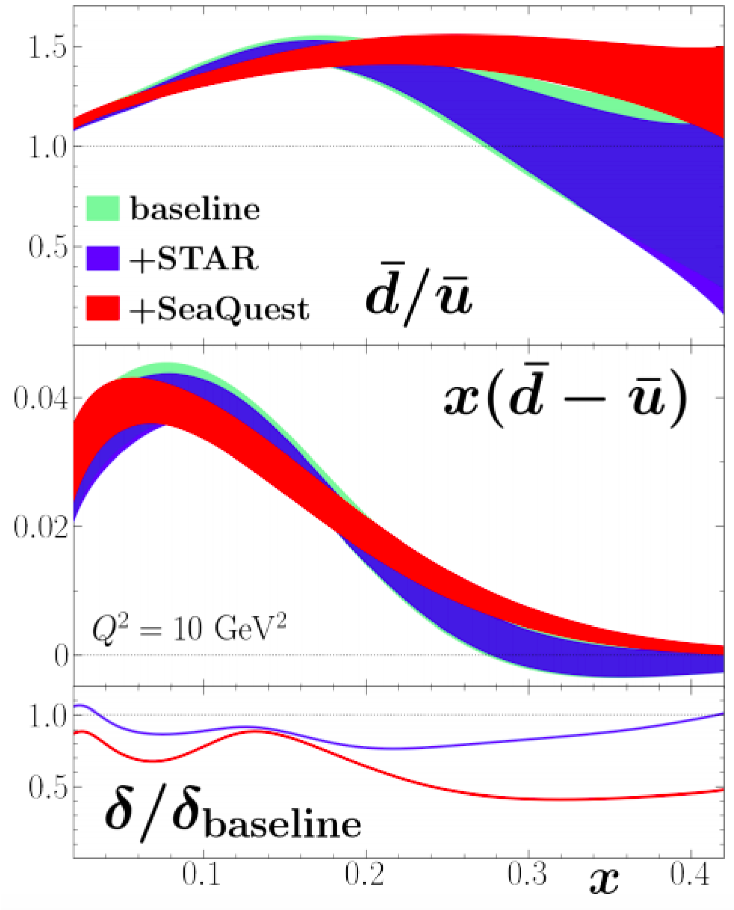
- Agreement between NLO pQCD calculation and experimental results for different bosons over a wide energy range

- Run 2017 result in progress.

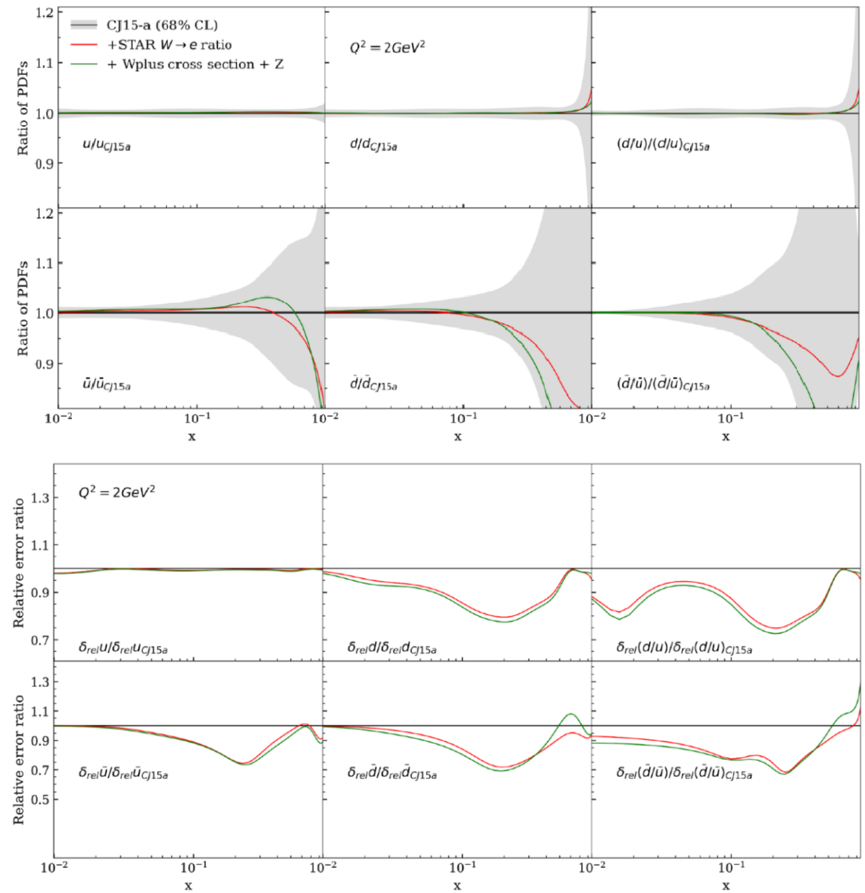
STAR, PRD 103 (2021) 1, 012001

Impact of STAR data

JAM, arXiv:2109.00677

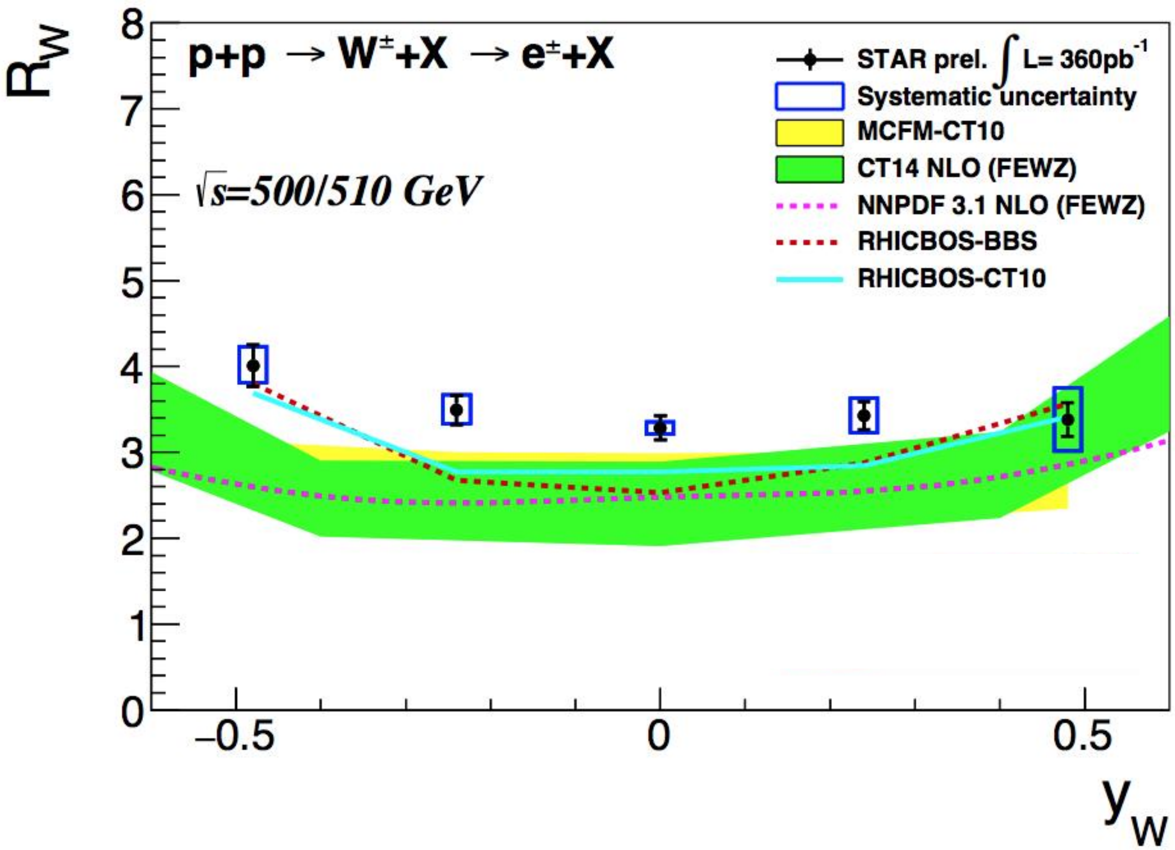


S.Park, DIS2021



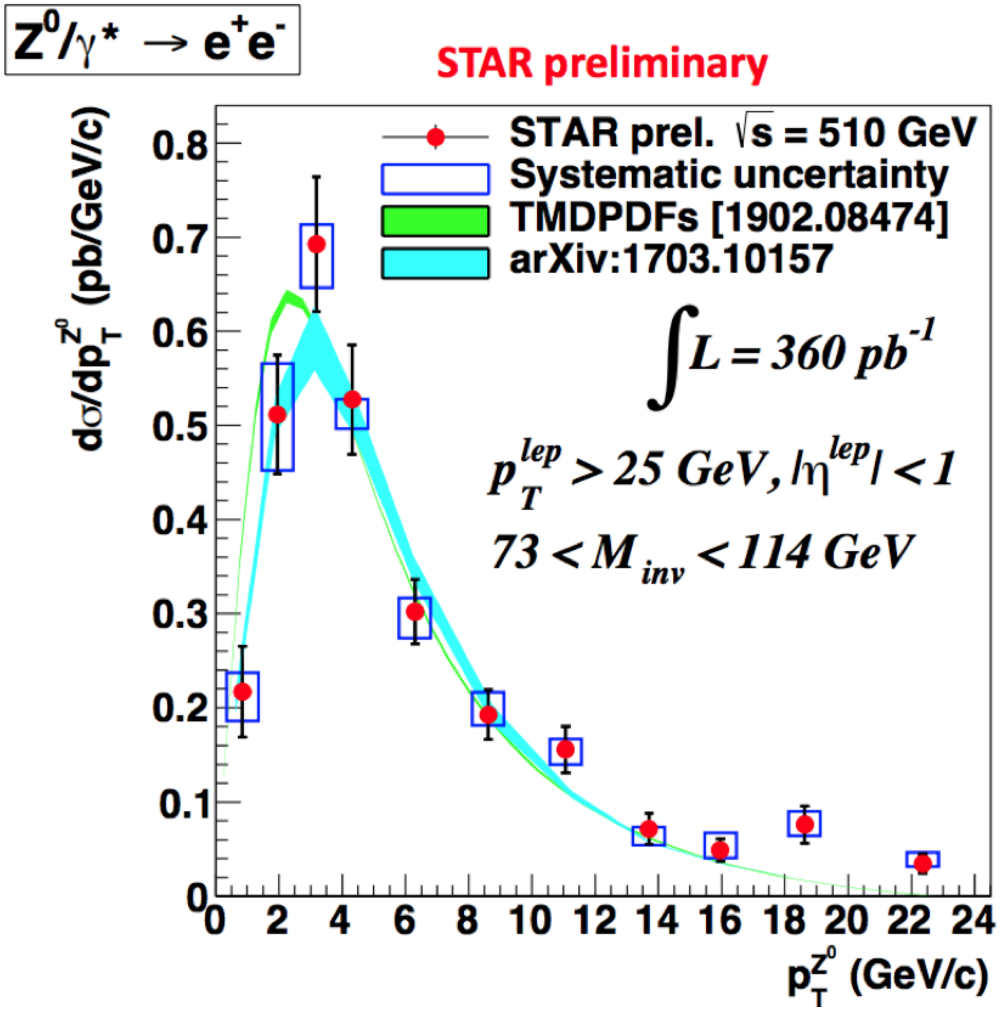
- STAR results have been included in recent global fits.
- STAR data have a significant impact on the sea quark distributions around $x \sim 0.2$.

Results: W^+/W^- (W reconstruction)



- W^+/W^- cross-section ratio with STAR Run 2011+2012+2013 ($L \approx 360pb^{-1}$)
  - Systematics driven by W rapidity reconstruction.
  - Run 17 study in progress

Results: Differential Z cross section



- Preliminary measurement of $d\sigma/dp_T^{Z^0}$.
  - Systematic uncertainty driven by BEMC gain unceratinty.
- Help constrain unpolarized TMDPDFs.
- Theory curves based on recent extractions of TMDPDFs.

Summary

- W^+/W^- cross sections and their ratio have been measured as a function of lepton pseudorapidity η^e with STAR $p+p$ collision data at $\sqrt{s} = 510\ GeV$.
  - Published with the combined dataset (2011+2012+2013, $L \approx 350\ pb^{-1}$).
  - Help constrain the $\bar{d}$ and $\bar{u}$ sea quark PDFs, complementary to DY measurements.
  - In addition, $W^\pm$ and Z absolute cross sections are measured.

- Preliminary release of results using STAR 2017 data.
  - Effectively doubles the statistics of these measurements.
  - Only deals with the cross-section ratio measurement at the barrel region for the moment (endcap + absolute cross section in progress).

- Preliminary results with W reconstruction method.
  - More direct measurement than the lepton-tagging method.
  - Larger systematic uncertainty.

- Preliminary results of differential cross section $d\sigma/dp_T^Z$.
  - Constraints to unpolarized TMDPDFs.

- New theory curves & global fits are out since recent publication
  - Confirms constraining power in the valence region.

Cross-section ratio

- In the W cross-section ratio measurement, the expression of the ratio reduces to:

$$\sigma_{W^+}/\sigma_{W^-} = \frac{N_{obs}^+}{\epsilon^+ \int Ldt} / \frac{N_{obs}^-}{\epsilon^- \int Ldt} = \frac{\epsilon^-}{\epsilon^+} \cdot \frac{N_{sig}^+ - N_{bg}^+}{N_{sig}^- - N_{bg}^-}$$

  - where ϵ represents the product of the efficiencies of our selection process.

$$\epsilon = \epsilon_{trigger} \times \epsilon_{vertex} \times \epsilon_{tracking} \times \epsilon_{tagging}$$

  - MC study suggests that the efficiency ratio ϵ^-/ϵ^+ is consistent with unity.

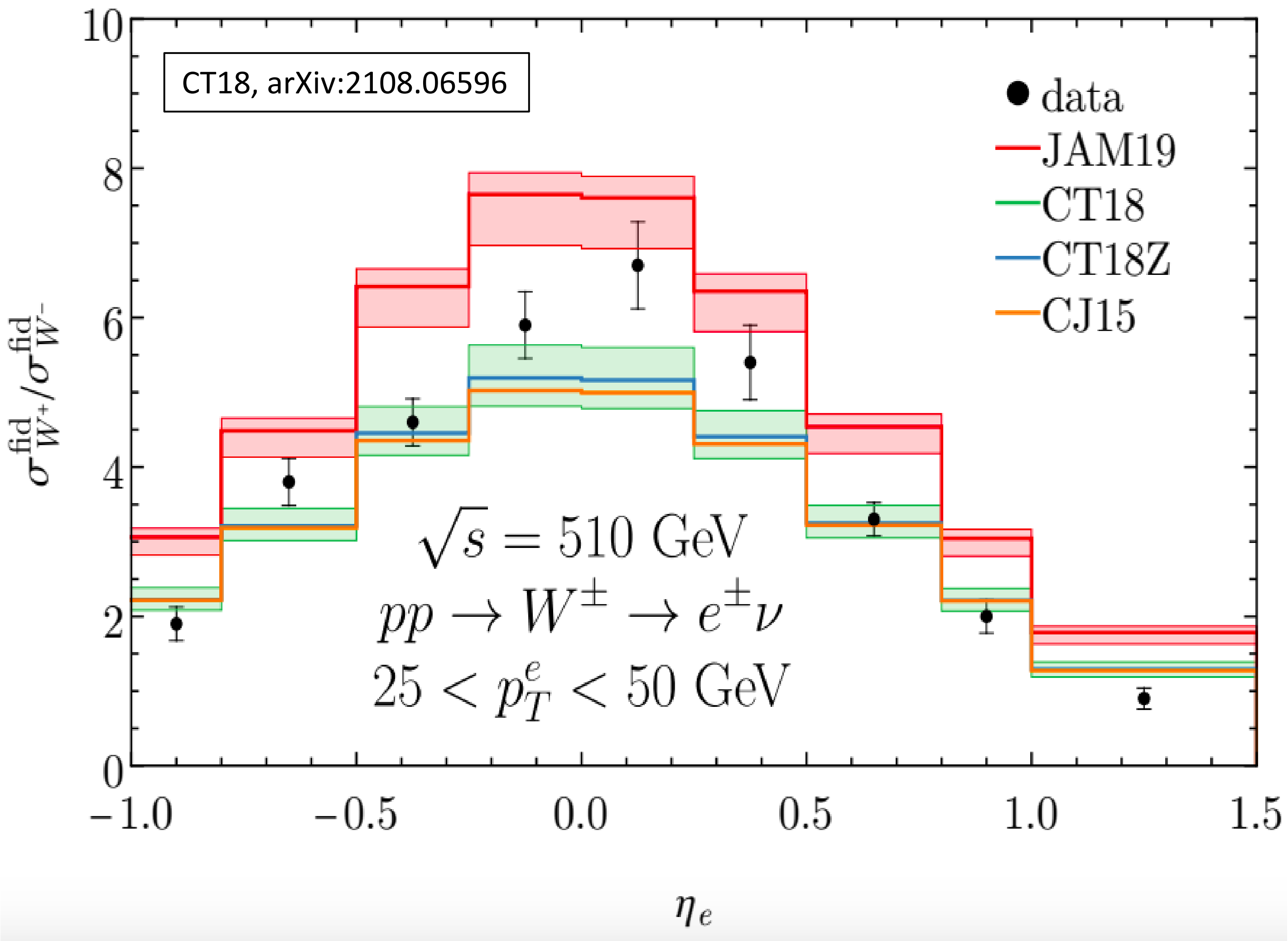
  - N_{bg} represents the sum of all remaining background contributions.

$$N_{bg} = N_{W\to\tau\nu} + N_{Z\to ee} + N_{QCD} + N_{EEMC}$$

Systematic uncertainties

- Charge dependence $\delta_{\Delta\epsilon}$
  - Remaining charge dependence obtained by taking the difference between $\epsilon^{\pm}$.
- BEMC calibration δ_{BEMC}
  - Due to imperfect BEMC calibration, obtained by taking the variation in the efficiency ratio while varying BEMC gain by the calibration unceratinty.
- Background description δ_{QCD}^{bg}
  - The uncertainty associated with the QCD background description in terms of its shape and normalization has been tested by varying $p_{T,bal}$ cut and the normalization window.
- Missing jet in QCD dijet δ_{QCD}^{dijet}
  - Dijet events are neglected when one of the two jets is outside the detector acceptance region.
  - A Pythia study was done to estimate the effect.
- (Run 2017 prel. only) BEMC gain correction $\delta_{BEMC,cor}$
  - The gain values of BEMC at STAR have been fine-tuned by reconstructing the mass of Z boson.
  - A larger BEMC correction has been observed STAR Run 2017 sample.
  - This effect has been estimated by taking the difference between the nominal sample and a test sample without the correction.

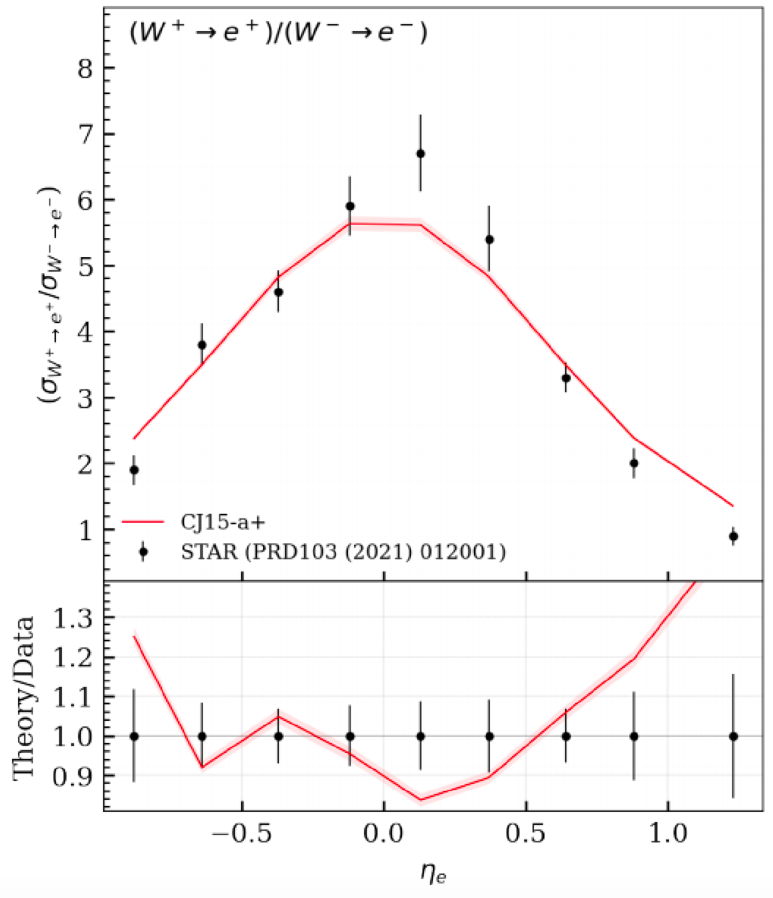
New theory curves & impact (CT18)



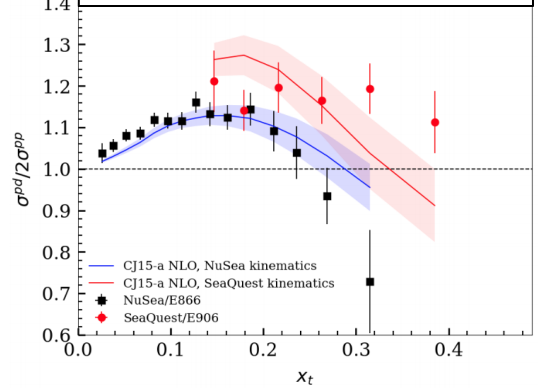
- Good overall shape matching
- Mismatch in the central ($0 < \eta_e < 0.5$) and forward ($\eta_e > 1$) regions.
  - Better matching expected once STAR Run 2017 data set is included

New theory curves & impact (CJ)

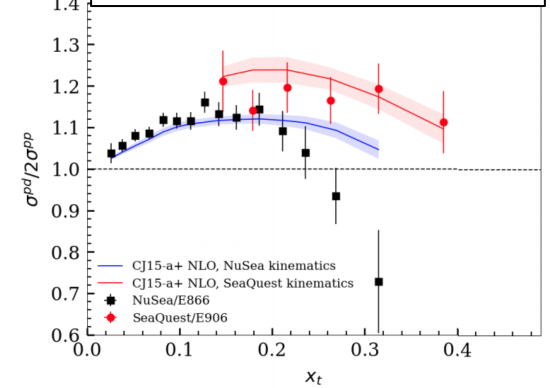
CJ, arXiv:2108.05786

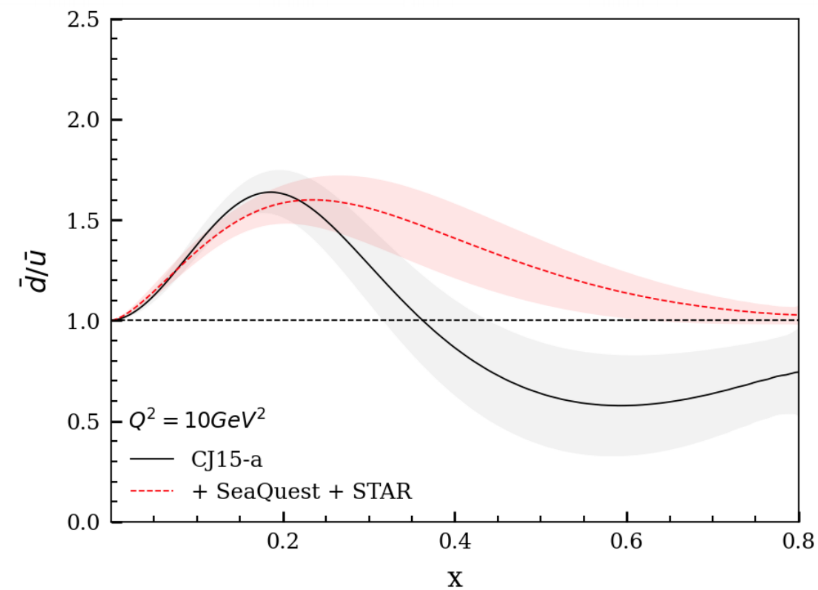


Before STAR & SeaQuest



After STAR & SeaQuest

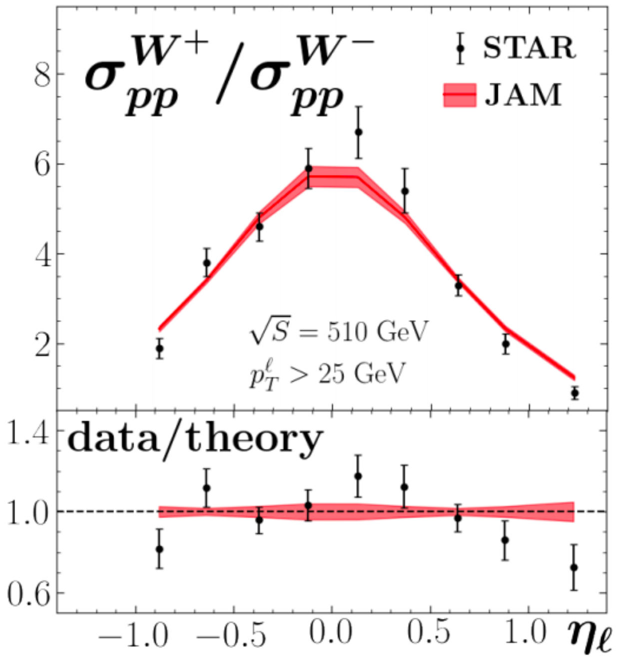


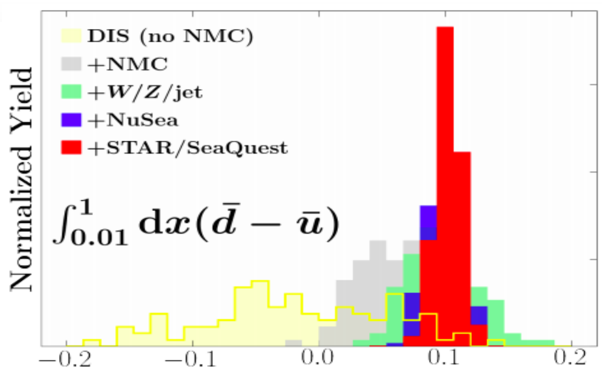


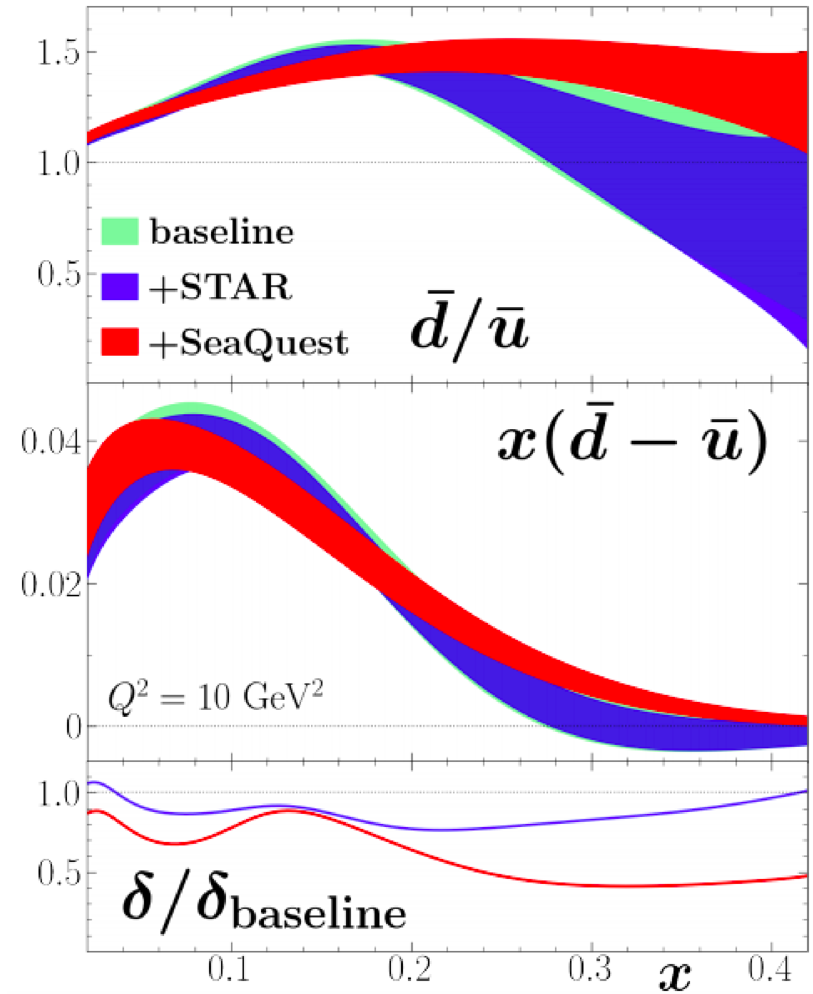
- Significant improvement in uncertainty when including STAR + SeaQuest.
- $\bar{d}/\bar{u}$ now above 1 throughout all x.

New theory curves & impact (JAM)

JAM, arXiv:2109.00677







- Significant constraining power around valence region ($x \sim 0.2$).
- Not much decisiveness in the shape.