Scientific Programme

The Scientific Programme will consist on Plenary Sessions plus Parallel Sessions organised in six Working Groups:

WG1: Structure Functions and Parton Densities
WG2: Small-x, Diffraction and Vector Mesons
WG3: Electroweak Physics and Beyond the Standard Model
WG4: QCD with Heavy Flavours and Hadronic Final States
WG5: Spin and 3D Structure
WG6: Future Experiments

International Advisory Committee

Halina Abramowicz (Tel Aviv)
Barbara Badelek (Warsaw)
Olaf Behnke (DESY)
Ties Behnke (DESY)
Sergio Bertolucci (INFN)
Ian Brock (Bonn)
Allen Caldwell (MPI Munich)
Amanda Cooper-Sarkar (Oxford)
John Dainton (Lancaster)
Dmitri Denisov (BNL)
Abhay Deshpande (Stony Brook)
Cristinel Diaconu (Marseille)
Eckhard Elsen (DESY)
Rolf Ent (JLAB)
Joel Feltesse (Saclay)
Stefano Forte (Milano)
Elisabetta Gallo (DESY)
Haiyan Gao (BNL)
Robert Klanner (Hamburg)
Max Klein (Liverpool)
Aharon Levy (Tel Aviv, Co-Chair)
Bob McKeown (JLAB)
Joachim Mnich (CERN)
Rosario Nania (Bologna)
Paul Newman (Birmingham, Co-Chair)
Fred Olness (SMU Dallas)
Marta Ruspa (INFN/Torino)
Juan Terrón (Madrid)
Robert Thorne (UCL London)
Katsuo Tokushuku (KEK)
Matthew Wing (DESY / UCL London)
Yuji Yamazaki (Kobe)

Local and Program Committee

Tolga Altinoluk (NCBJ Warsaw)
Néstor Armesto (Santiago de Compostela, Chair)
Patricia Conde (IST/LIP)
Leticia Cunqueiro (École Polytechnique)
Pasquale Di Nezza (INFN Frascati)
Elena Ferreiro (Santiago de Compostela)
Abraham Gallas (Santiago de Compostela)
Pier Paolo Giardino (Santiago de Compostela)
Claire Gwenlan (Oxford)
José Guilherme Milhano (IST/LIP)
Hannu Paukkunen (Jyväskyla)
Carlos Salgado (Santiago de Compostela)
Christian Schwanenberger (DESY/Hamburg)
Bin Wu (Santiago de Compostela)

indico.cern.ch/e/dis2022
dis2022@igfae.usc.es

Sponsored by Brookhaven National Laboratory BNL, Deutsches Elektronen-Synchrotron DESY, the European Organization for Nuclear Research CERN, and Thomas Jefferson National Accelerator Facility JLab

EXCELENCIA MARÍA DE MAEZTU
Xacobeo 21·22
Fondo Europeo de Desenvolvemento Rexional "Unha maneira de facer Europa"
UNIÓN EUROPEA
XUNTA DE GALICIA

Measurement of W^+/W^- cross-section ratios in pp collisions at STAR

Jae D. Nam

Temple University,

for the STAR collaboration

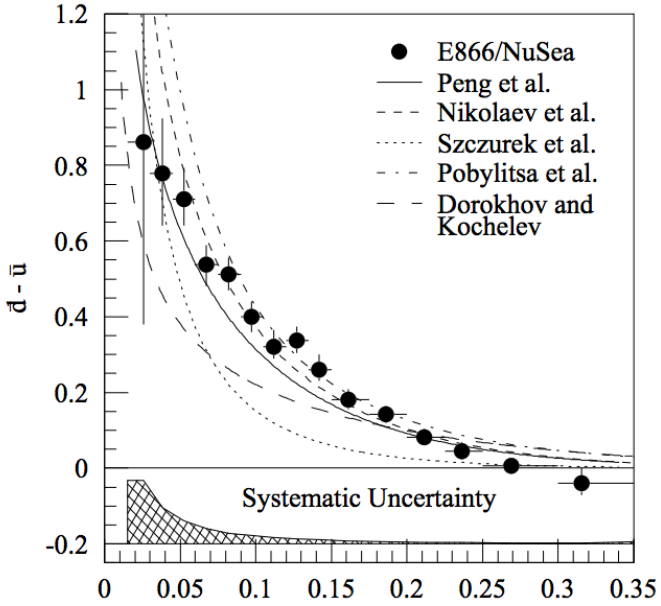
Supported in part by:

U.S. DEPARTMENT OF ENERGY

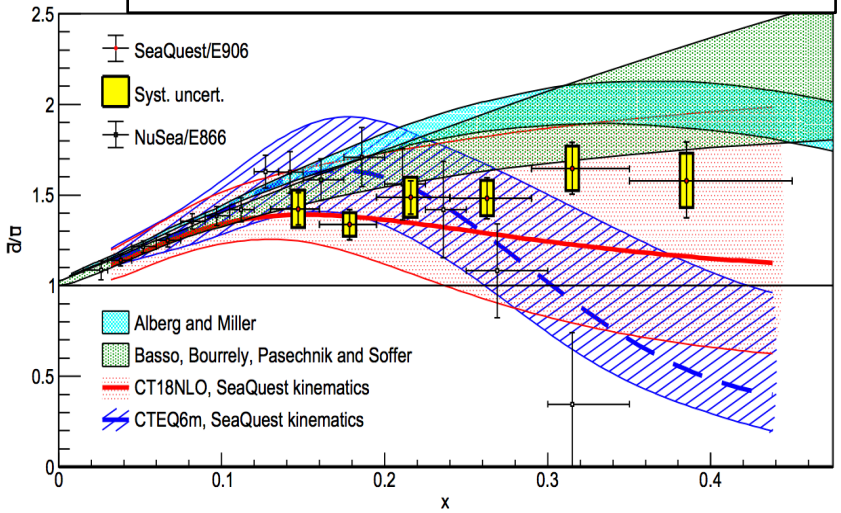
Office of Science

$\bar{d}/\bar{u}$ asymmetry

NuSea, Phys.Rev.D 64 (2001) 052002

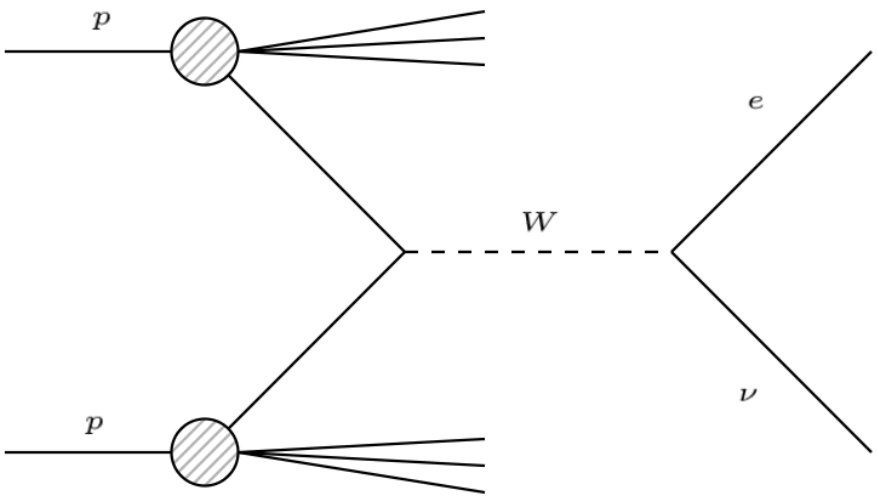


SeaQuest, Nature 590 (2021) 7847, 561-565



- While the valence quark (d, u) structure of the proton is well determined, the anti-quark counter part $(\bar{d}, \bar{u})$ is much less constrained.
- Non-diminishing asymmetry between the anti-quarks in the proton sea $\bar{d}, \bar{u}$ is a purely non-perturbative phenomenon.
- The anti-quark ratio $\bar{d}/\bar{u}$ is typically measured in Drell-Yan type experiments.
- Inconsistencies among these measurements have been found, especially in the proton momentum fraction range $x > 0.3$.
- Independent investigations with different physics processes are desired.

W boson production in pp collisions



- At leading order, the cross-section ratio between W^+ and W^- productions, R_W, is sensitive to the $\bar{d}/\bar{u}$ asymmetry as follows:

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

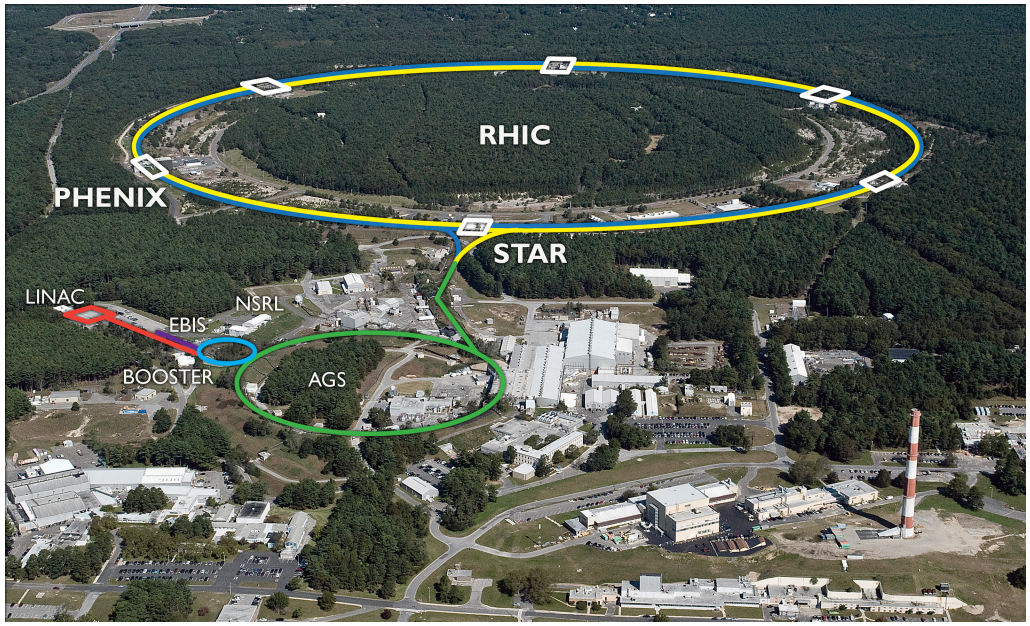
- The large mass of the W boson sets the momentum scale of the process, $Q^2 \approx M_W^2$.

$$\frac{d\sigma(W \to e\nu)}{dp_{T,e}^2} \propto \frac{2(1 \pm \cos\theta)}{\hat{s}\cos\theta}$$

- $p_{T,e} = p_e \sin\theta$
- $\hat{s} = E_e + E_\nu \approx M_W$
- $\cos\theta = \sqrt{1 - \frac{4p_{T,e}^2}{\hat{s}}}$

- At STAR, the leptonic decay of the W boson, $W \to e\nu$, can be observed.
  - Large imbalance in energy deposited in the calorimeter due to the neutrino.
  - The momentum spectrum of the electron has a resonance peak around half mass of W boson, often referred to as the Jacobian peak.

Relativistic Heavy Ion Collider (RHIC)



- RHIC is the world's first polarized pp collider.
- $L \approx 700 + 400\ pb^{-1}$ of pp collision data with sufficiently high Q^2 for W production.
  - Measurement with ~$350\ pb^{-1}$ of data has been published.
  - The remaining ~$350\ pb^{-1}$ has been granted preliminary release.
  - Another dataset with ~$400\ pb^{-1}$ has been taken in 2022.

Run	$\sqrt{s}\ (GeV)$	$L\ (pb^{-1})$
2009	500	10
2011	500	25
2012	510	75
2013	510	250
2017	510	350
2022	510	400 (estimate)

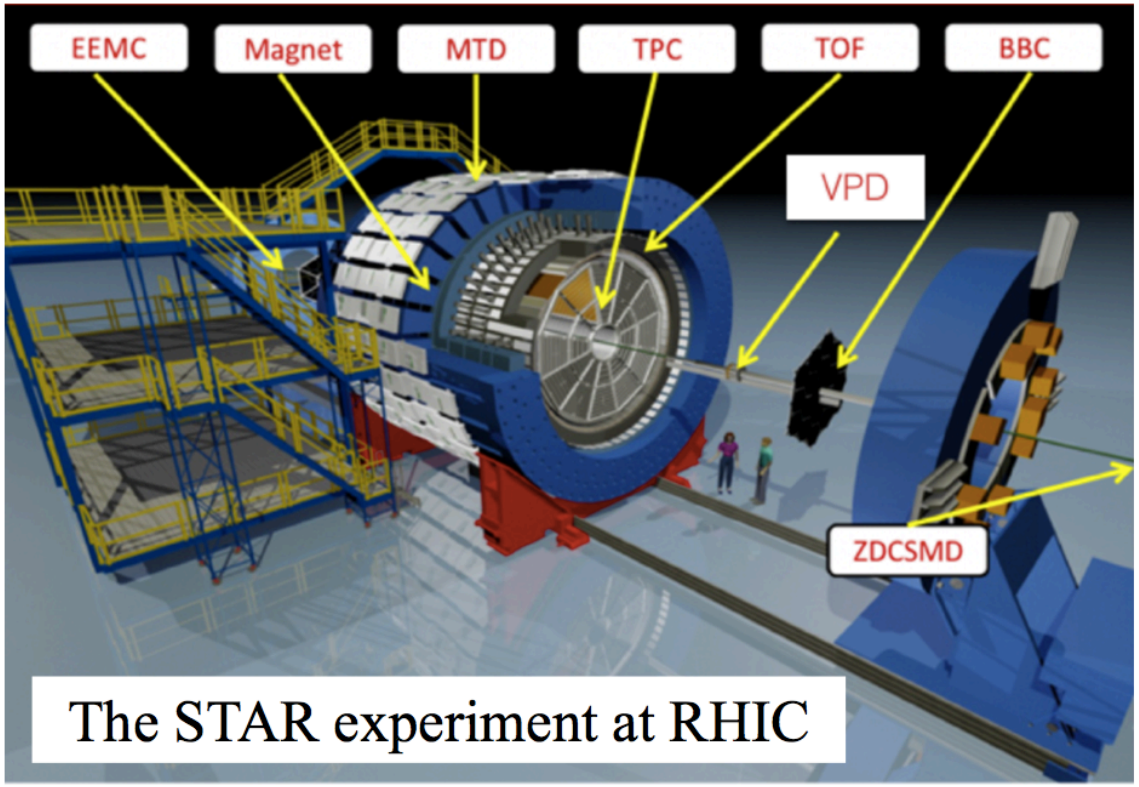
→ STAR, PRD 85, 092010

→ STAR, PRD 103, 012001

→ STAR preliminary (this talk)

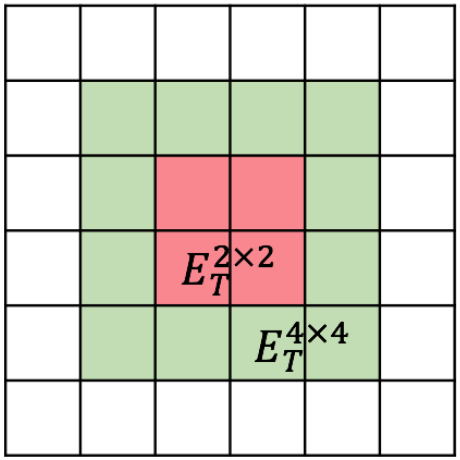
Solenoid Tracker At RHIC (STAR)

- For measurements of W bosons, it is important to achieve near 4π detector acceptance.
- Time Projection Chamber(TPC)
  - Provides tracking & PID
  - Acceptance of $|\eta| < 1.3$
- Electro-Magnetic Calorimenter
  - Barrel (BEMC): $|\eta| < 1$
  - Endcap (EEMC): $1 < \eta < 2$
- Luminosity monitoring & Vertexing
  - Beam-Beam Counter (BBC)
  - Zero Degree Counter (ZDC)
  - Vertex Position Detector (VPD)

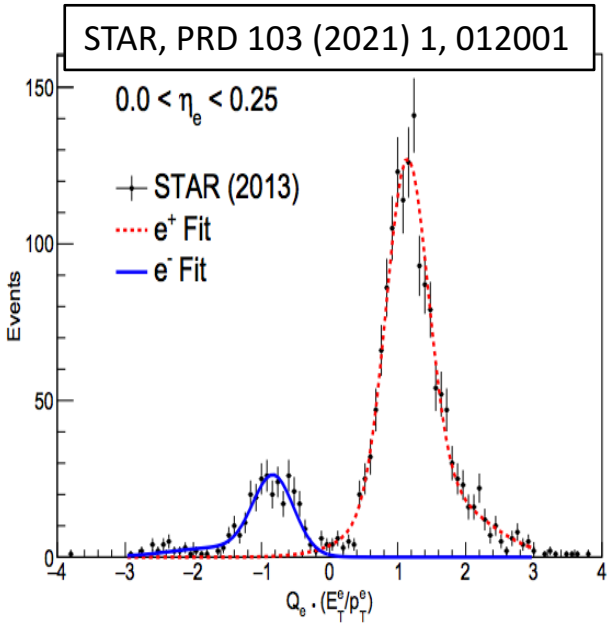


- The W bosons detected in the combined TPC + BEMC (barrel region) arise from a kinematic region of $0.1 < x < 0.3$.
- EEMC provides coverage in the intermediate region $1 < \eta < 2$, extending the kinematic reach to $0.06 < x < 0.4$.

W tagging in the barrel region

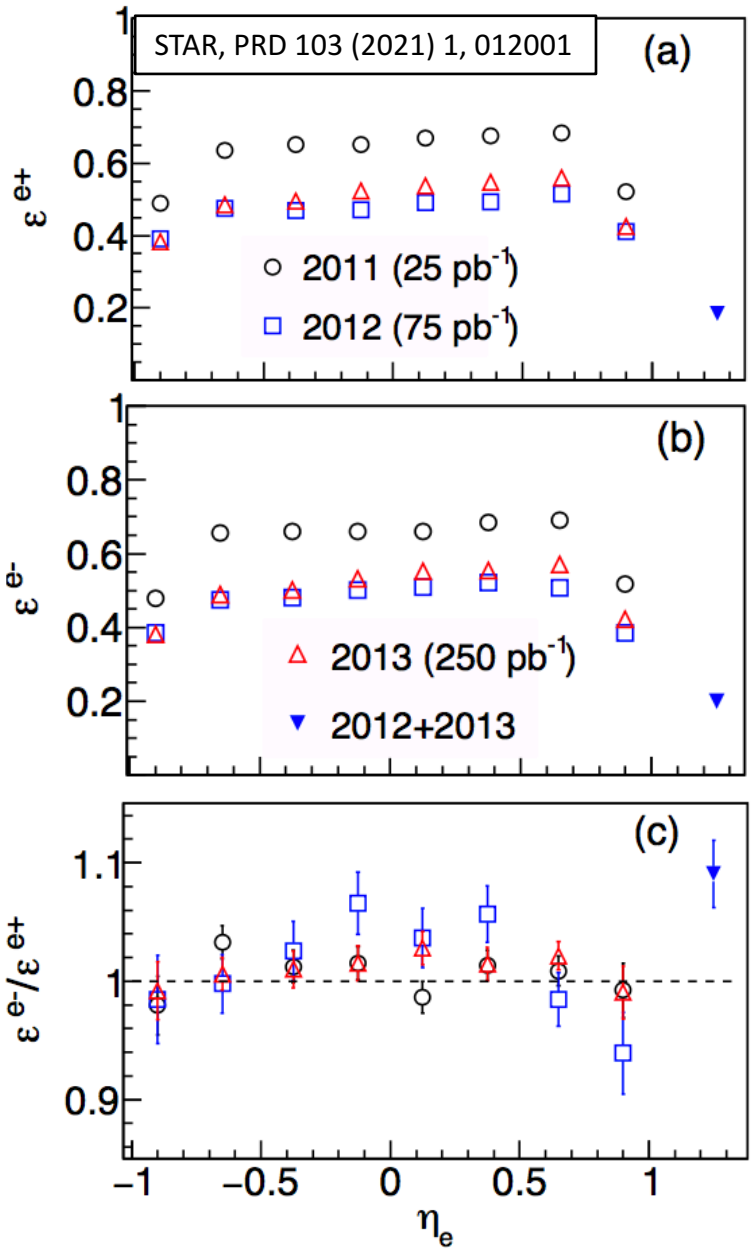


TPC track extrapolated to BEMC tower grid



- W bosons that undergo the leptonic decay process, $W \rightarrow e\nu$, are tagged.
- Imbalance in p_T due to the missing neutrino. High $\vec{p}_{T,bal}$ $(= \vec{p}_{T,e} + \Sigma\vec{p}_{T,recoil})$ events are selected.
- Unlike hadrons, electrons deposit their energy in a highly concentrated region in the EMC. This isolated electron energy deposit is quantified with $E_T^{2\times2}/E_T^{4\times4}$.
- Charge separation from TPC + EMC ($Q_e \times E_T/p_T$).
- Indirect, but smaller systematic uncertainty than full W kinematic reconstruction.

Analysis strategy



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

$$\sigma_{W^+}/\sigma_{W^-} = \frac{N^+_{obs}}{\epsilon^+ \int Ldt} \Big/ \frac{N^-_{obs}}{\epsilon^- \int Ldt}$$

$$= \frac{\epsilon^-}{\epsilon^+} \cdot \frac{N^+_{sig} - N^+_{bg}}{N^-_{sig} - N^-_{bg}}$$

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

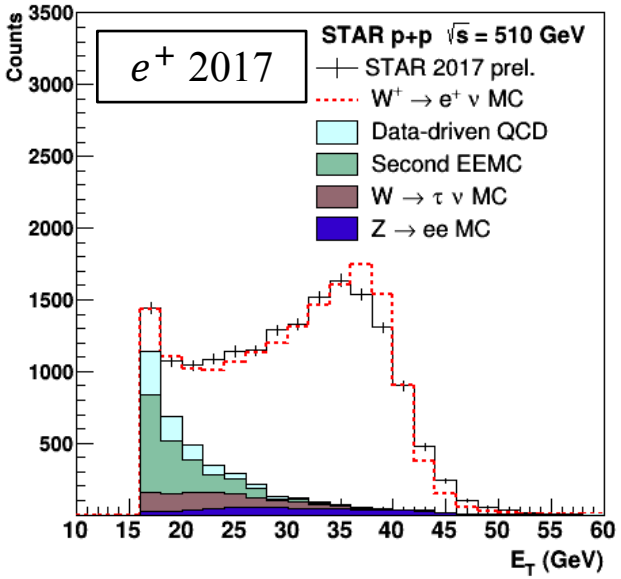
$$\epsilon = \epsilon_{trigger} \times \epsilon_{vertex} \times \epsilon_{tracking} \times \epsilon_{tagging}$$

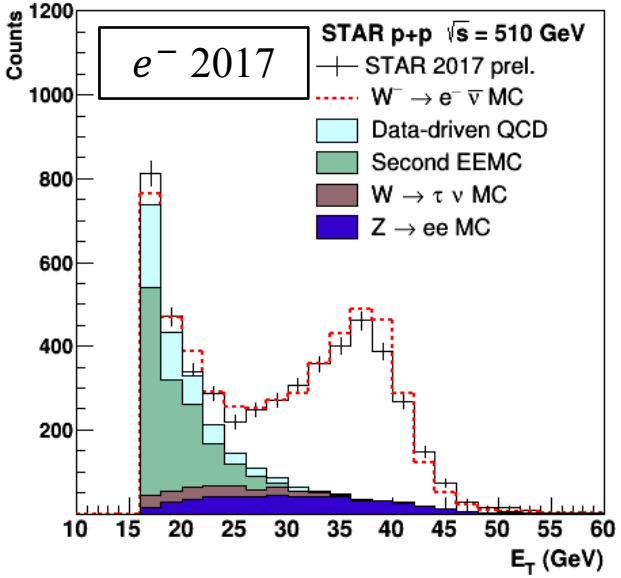
  - MC study suggests that the efficiency ratio ϵ^-/ϵ^+ is consistent with unity and the deviation from unity is taken as a source of systematic uncertainty.

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

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

Signal/background in the barrel region

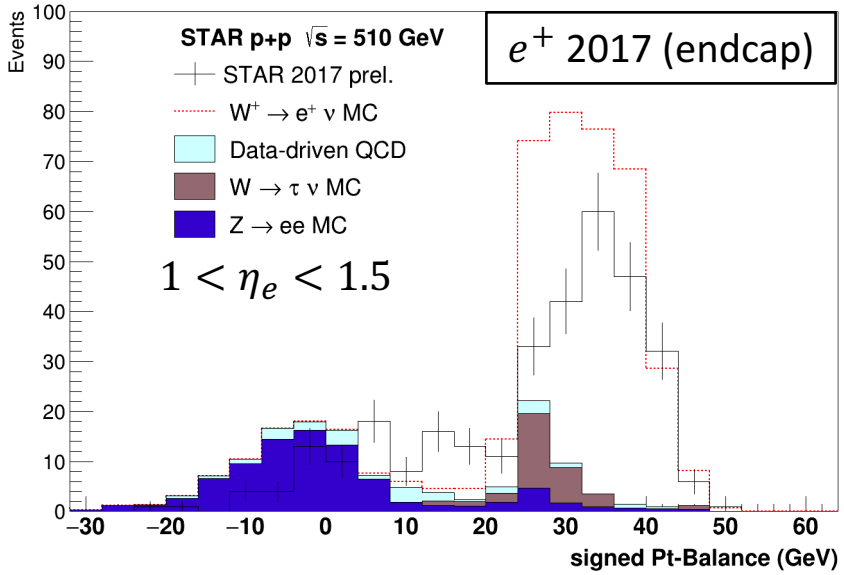


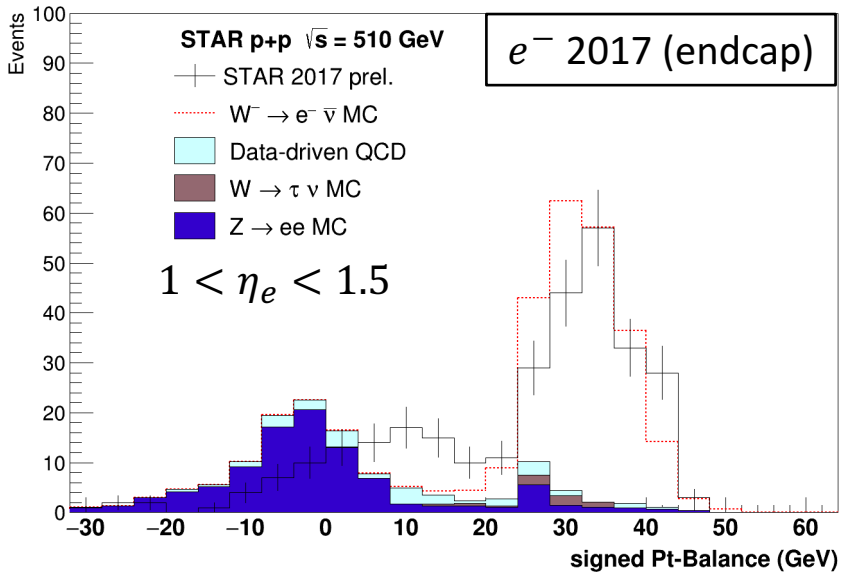


- Electroweak ($N_{Z\rightarrow ee}$, $N_{W\rightarrow \tau\nu}$)
  - Z decays with one unidentified electron
  - Leptonic decay of τ^W
  - Estimated with MC (Pythia)

- QCD background
  - Due to the limited acceptance and kinematic coverage, imbalance in p_T may appear in QCD events.
  - Two methods employed to estimate their contributions:
  - Second EEMC (N_{EEMC})
    - Accounts for missing backward coverage ($-2 < \eta < -1$)
    - Estimated by mirroring the effect of existing EEMC in the forward direction.
  - Data-driven QCD (N_{QCD})
    - Remaining background contribution that passes the selection process.
    - Distribution obtained by using events that do not pass the $p_{T,bal}$.

Endcap measurement

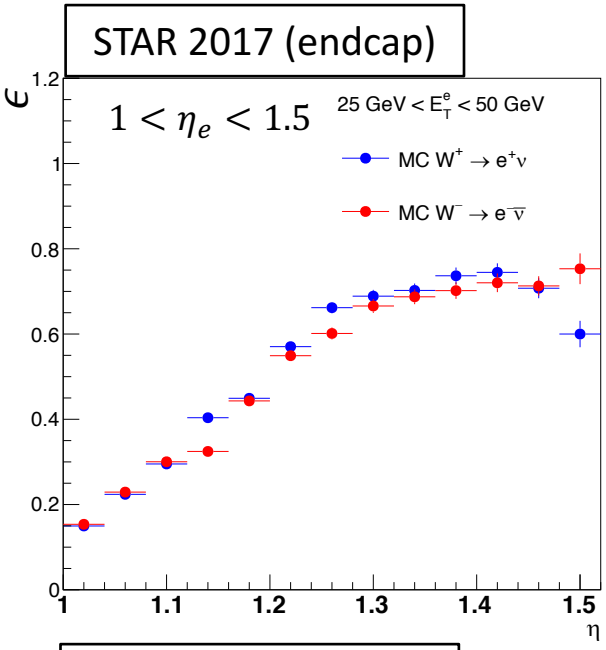


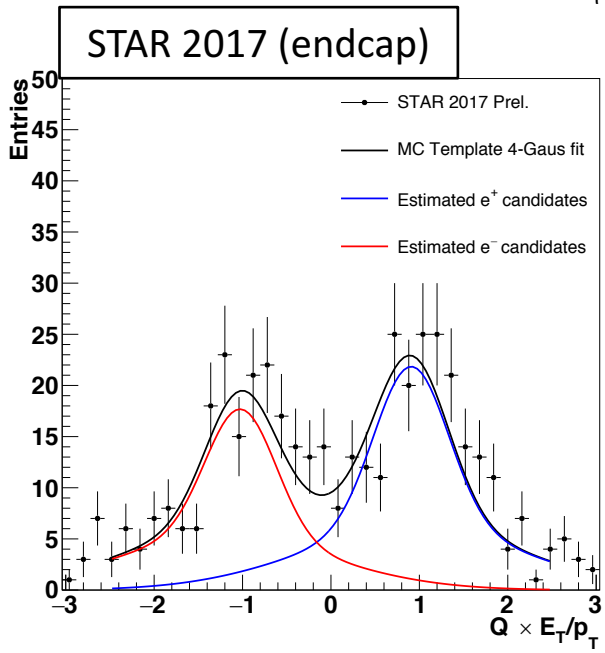


- W tagging method in the endcap region is similar to that for the barrel region.
  - Relaxed tracking requirements.
  - Employ EEMC and its subcomponents instead of BEMC.

- Background description also follows a similar procedure.
  - Simulations are used to estimate electroweak background.
  - Description of QCD background purely relies on data-driven method.

Endcap corrections

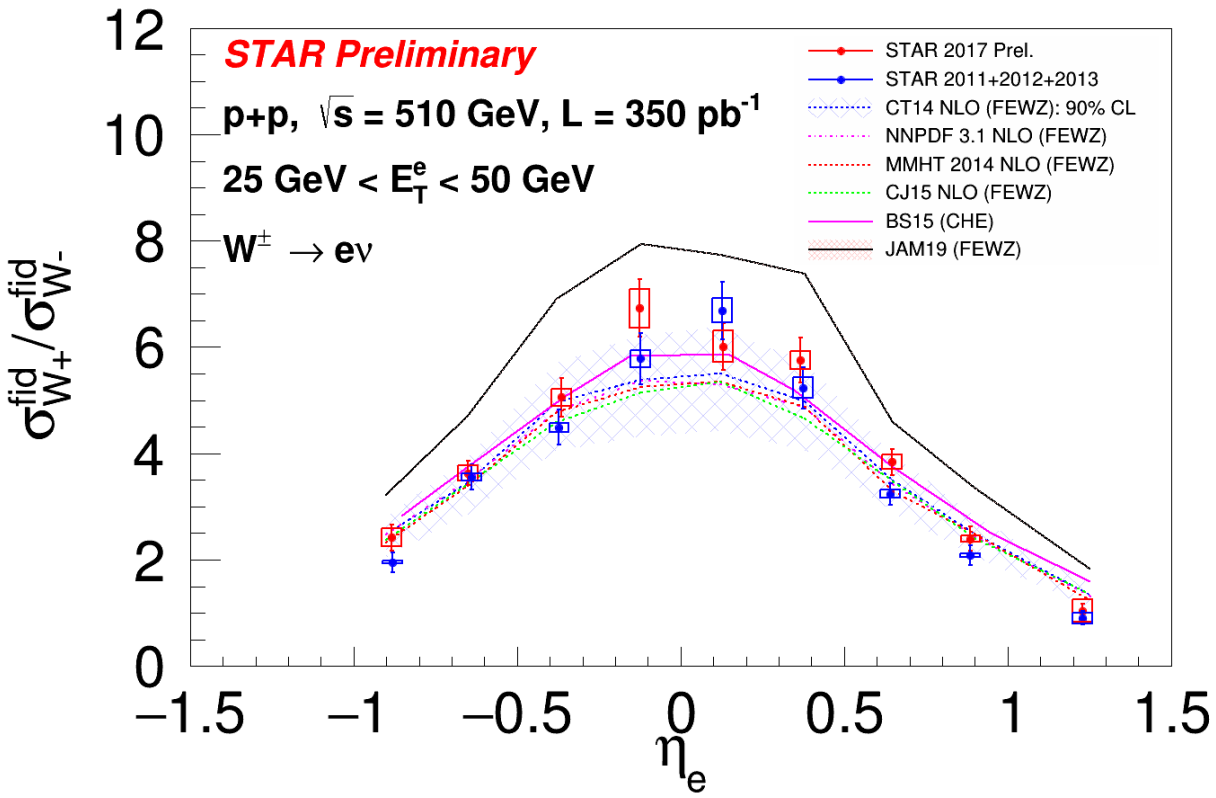




- Efficiency correction
  - Evaluates detector acceptance & efficiency of the selection process.
  - Considers e^W within $25\ GeV < E_T < 50\ GeV$.
  - Reduced efficiency in the lower η region due to detector acceptance effect.
  - The correction factor (ϵ^-/ϵ^+) is consistent with unity.
  - Remaining deviation is taken as a contribution to the systematic uncertainty.

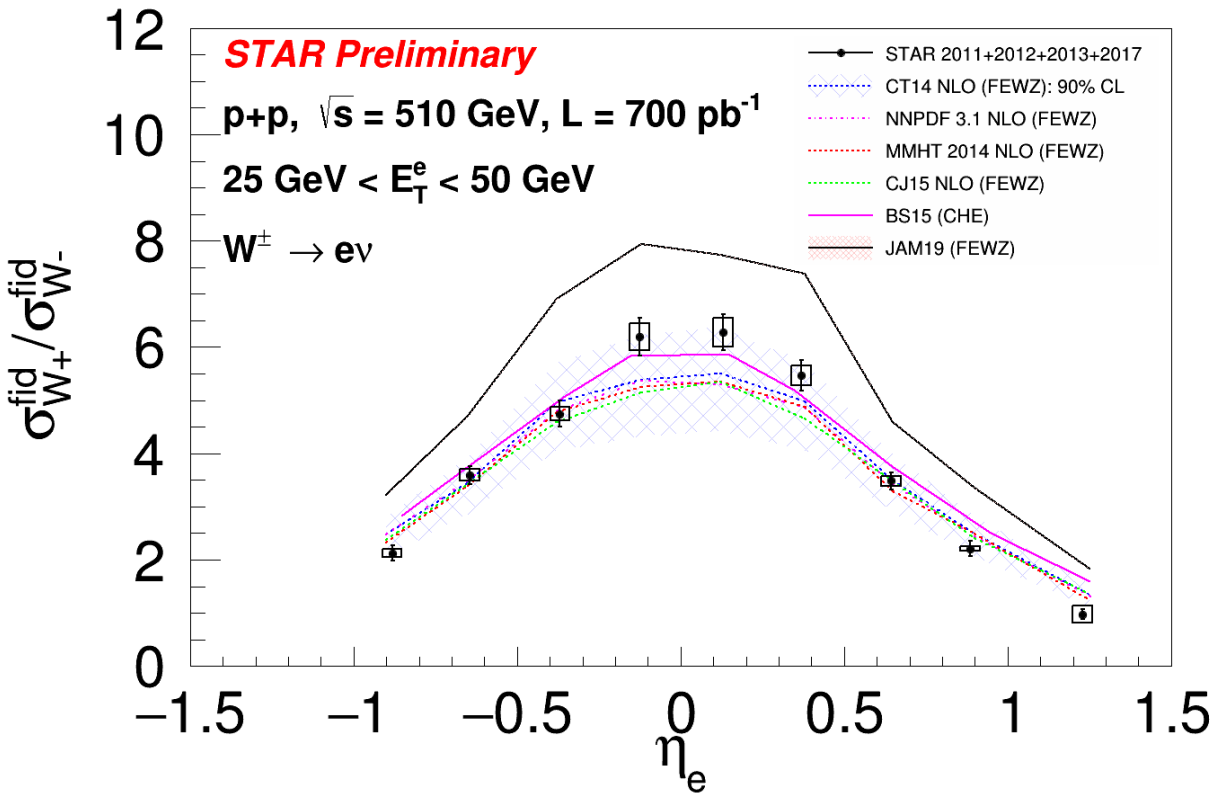
- Charge correction
  - Uses charge ($Q \times E_T/p_T$) distribution to determine the correct-charge ratio.
  - Two different fit methods used.
    - MC template method uses $W \to e\nu$ simulations for baseline description of the charge fit (nominal).
    - Log-likelihood fitting of double-gaussian function to data.
  - Difference between the two results are taken as a contribution to the systematic uncertainty.

Results



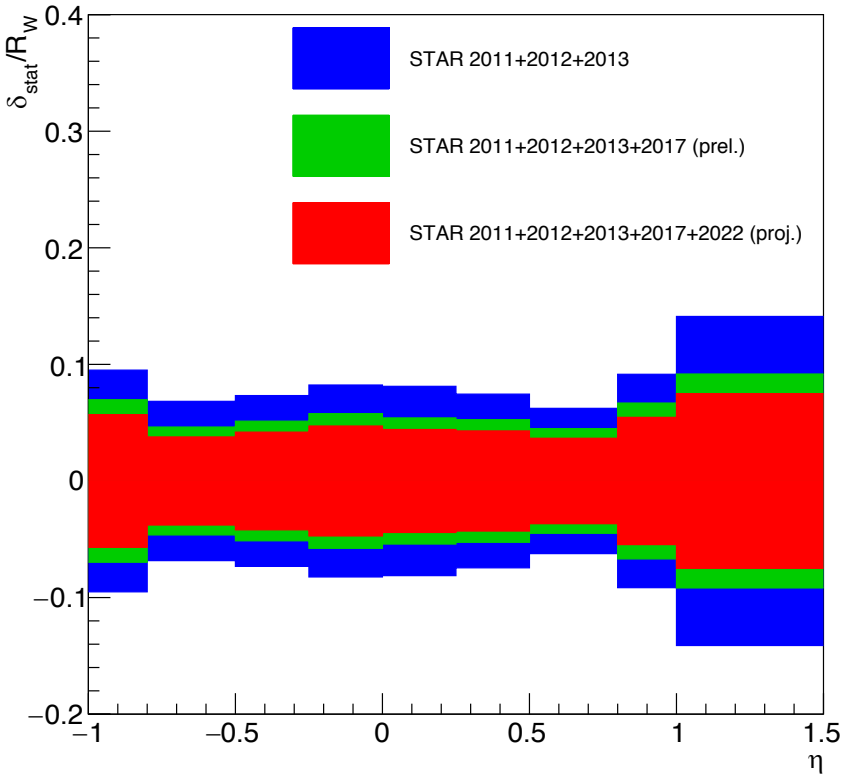
- Measurement with STAR 2011-2013 data set has been published (PRD 103 (2021) 1, 012001).
- Additional data set taken in 2017 has been analyzed and is in preliminary release.
- These measurements are consistent with each other within their uncertainties.

Results (continued)



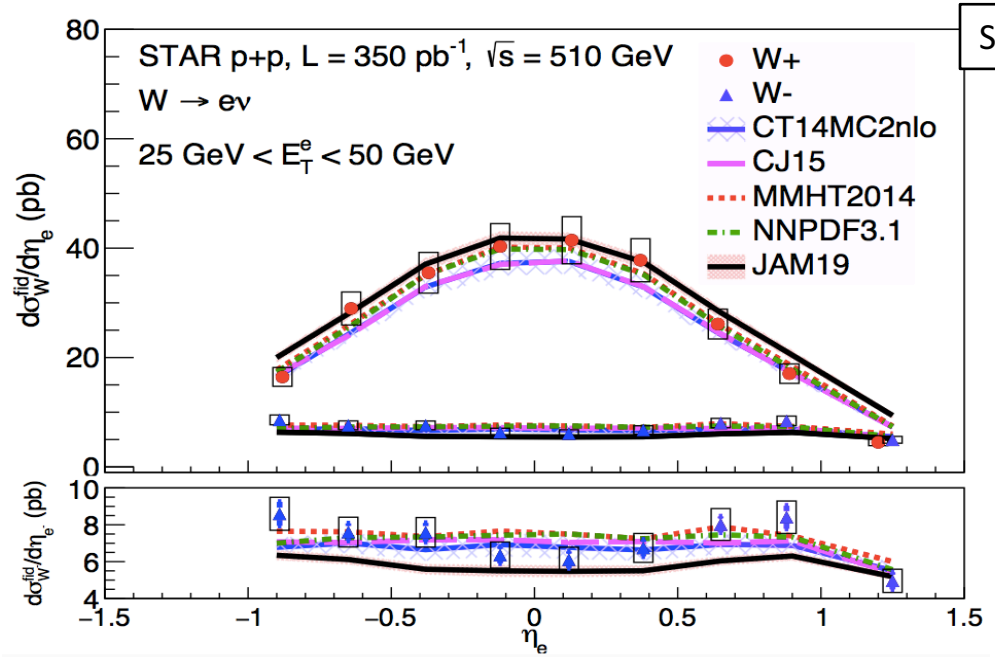
- Shown here is the result from the combined STAR 2011-2013 + 2017 data set.
  - Represents combined statistics of $L \approx 700\, pb^{-1}$.
  - Overall good agreement with the current PDF distributions.

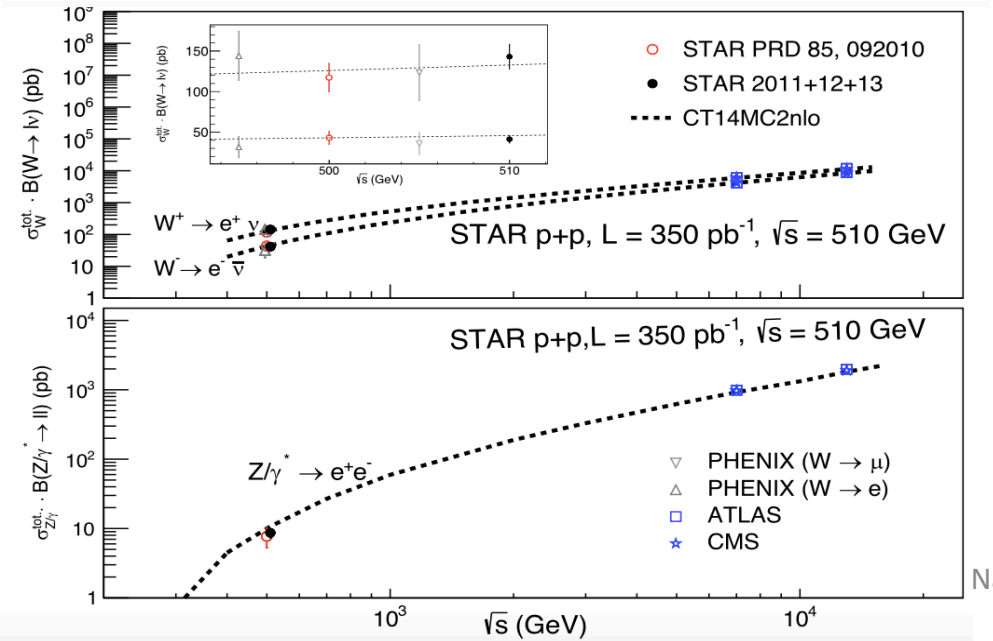
Results (projection)



- Projection for STAR 2022 data set
  - Combined statistics $\sim 1\ fb^{-1}$
  - Pushes the measurement to the systematic limit.
  - Concludes $500/510\ GeV\ pp$ program at STAR

Absolute cross sections





STAR, PRD 103 (2021) 1, 012001

- Measurement of the total cross sections.

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

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

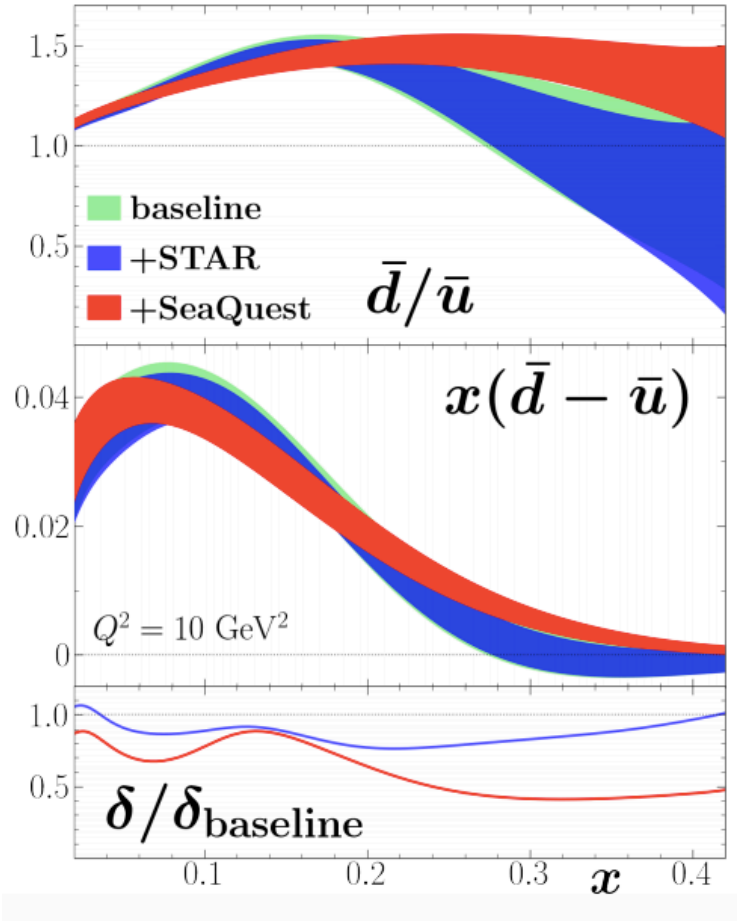
  - Acceptance correction on 2011 sample ($\sqrt{s} = 500\ GeV$) to match 2012 and 2013 samples ($\sqrt{s} = 510\ GeV$) by using FEWZ [PRD 86 (2012) 094034].

- Z reconstruction
  - The leptonically decaying $Z \to e^+e^-$ bosons are tagged by looking for electron-positron pairs.
  - Additional selection process based on the reconstructed mass M_Z to reject $\gamma^* \to e^+e^-$ processes.

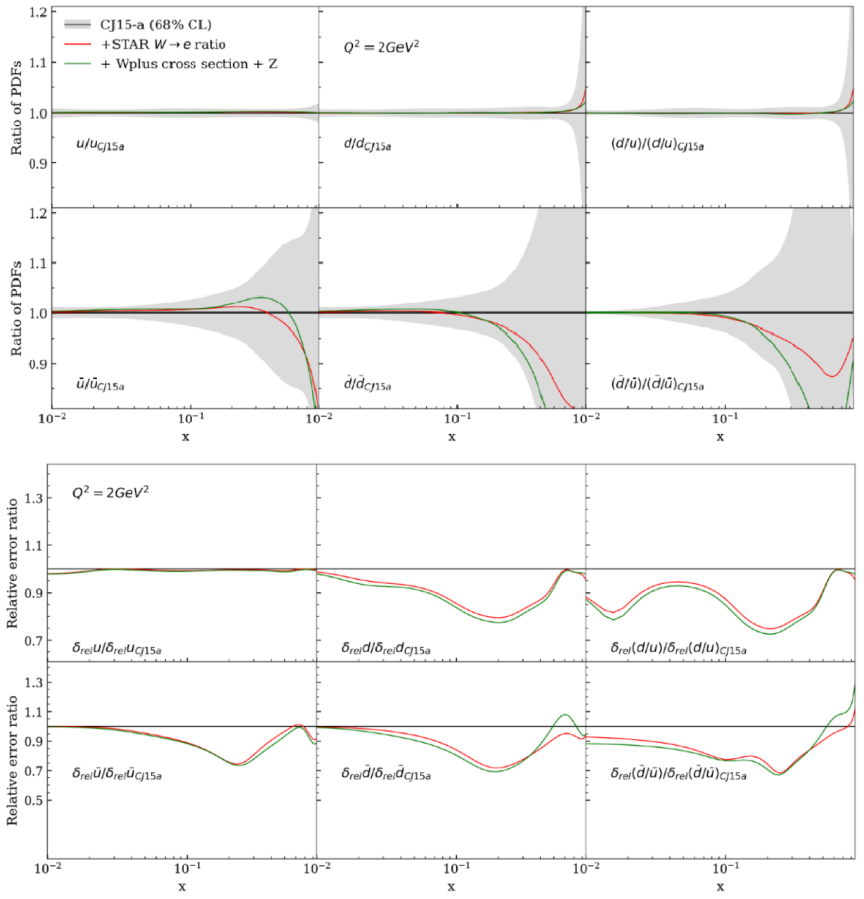
- Results with STAR 2017 in progress.

PDF impacts

C. Coccuza, arXiv:2109.00677



S.Park, DIS2021



- Recent publication (STAR 2011+2012+2013) has been included in recent global fits.
- STAR data have a decent amount of impact on the sea quark distributions around $x \sim 0.2$.

Summary/Outlook

- Summary
  - W^+/W^- cross-section ratio has been measured with STAR pp ($\sqrt{s} = 500/510\ GeV$) data sets.
    - Probes the $\bar{d}/\bar{u}$ sea quark ratio in the proton, complementary to Drell-Yan measurements.
    - STAR 2011+2012+2013 ($L \approx 350\ pb^{-1}$) results have been published.
    - STAR 2017 ($L \approx 350\ pb^{-1}$) results in preliminary release.
    - The result based on the combined data set is consistent with current PDFs.
  - In addition, W and Z absolute cross sections have been measured.
    - Measurement with STAR 2017 data set in progress.
  - New global fit analyses since the recent STAR publication.
    - Confirms the constraining power in the valence region.

- Outlook
  - The measurement of STAR 2017 data is being finalized for publication.
  - Upon inclusion of STAR 2022 data set that adds another $L \approx 400\ pb^{-1}$, the measurement will be pushed to the systematic limit ($\delta_{syst} < 5\%$).