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Constraining Sea Quark Distributions Through W and Z Cross Section and Cross Section Ratios Measured at STAR

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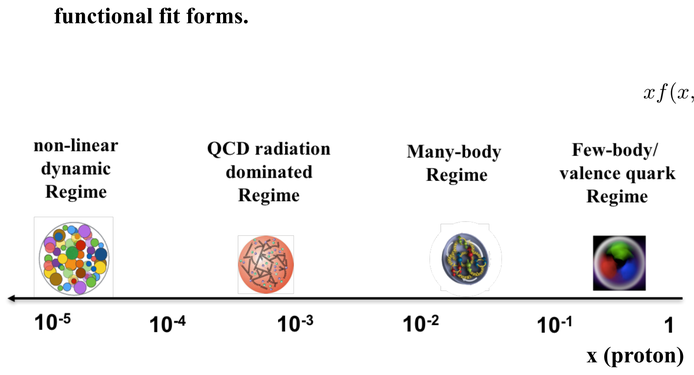
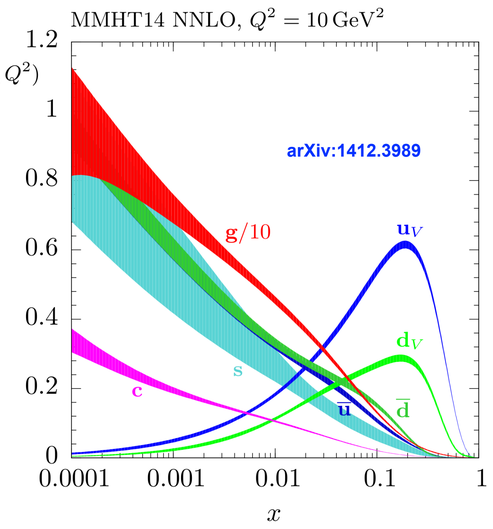
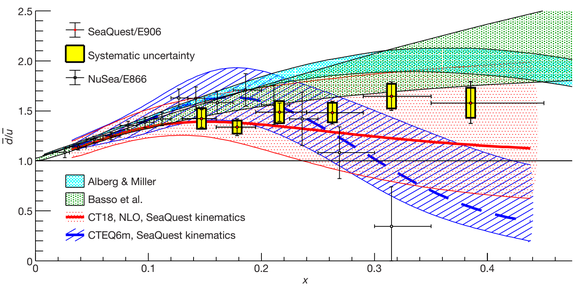
Motivation

- **Parton distribution functions (PDFs) probe the internal structure of the proton. The x-dependence of these PDFs allows one to map the intrinsic and dynamic properties of the proton.**
- **Various global analyses (CT14, MMHT14, BS15, etc.) extract PDFs from data using various data sets and functional fit forms.**





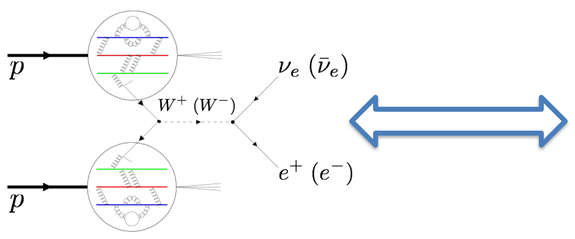


Dove, J., Kerns, B., McClellan, R.E. *et al.* (SeaQuest Collaboration), Nature **590**, 561–565 (2021).

- **The $\bar{d}/\bar{u}$ distribution has been measured by several experiments.**
- **More data are needed at higher x to help constrain the sea quark distributions.**
- **New measurements from different experiments can provide more data at different Q^2 values and scattering processes.**

W/Z Boson Production

- **W/Z bosons are directly sensitive to quark/anti-quark distributions. They can be measured through the W and Z lepton decay channels in proton + proton collisions**
- **W(Z) production probes high Q^2 ($= M_{W^\pm}^2 (M_Z^2)$)**



$$q + \bar{q} \rightarrow Z/\gamma^* \rightarrow e^+ + e^-$$
$$u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu_e$$
$$d + \bar{u} \rightarrow W^- \rightarrow e^- + \bar{\nu}_e$$

- **The W cross section ratio at leading order takes the form:** $\dfrac{\sigma_{W^+}}{\sigma_{W^-}} \approx \dfrac{\bar{d}(x_2)u(x_1) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_2)d(x_1) + \bar{u}(x_1)d(x_2)}$
- **The W and Z fiducial cross sections can be measured experimentally as:**

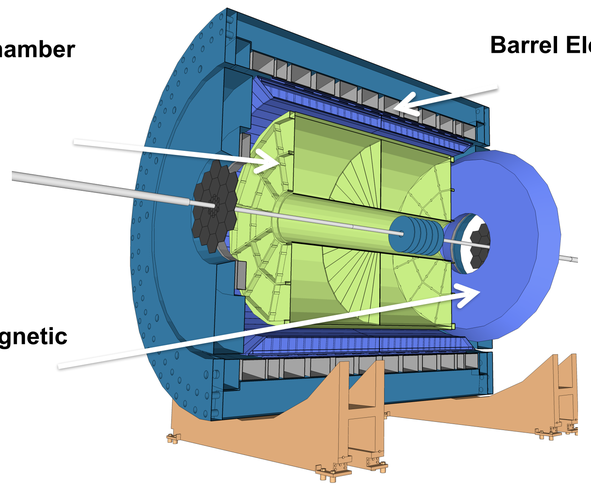
$$\sigma^{fid}_{W^\pm,Z} = \frac{N_O^{W^\pm,Z} - N_B^{W^\pm,Z}}{\mathscr{L} \cdot \epsilon^{W^\pm,Z}}$$

- +/- is positron/electron from W leptonic decay
- N_O is number of observed W (Z) events
- N_B is number of background events
- ϵ is the measured W (Z) efficiency
- $\mathscr{L}$ is the total luminosity

The STAR Detector and Data

Sub Detectors

- **The W and Z cross sections were measured in the mid-rapidity region making use of three major sub detectors:**
  - **The TPC and solenoid magnet were used for particle tracking**
  - **Particle energy was measured using the BEMC / EEMC / QCD background estimates and corrections made use of the BEMC / EEMC**

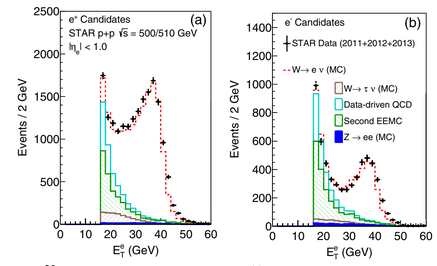


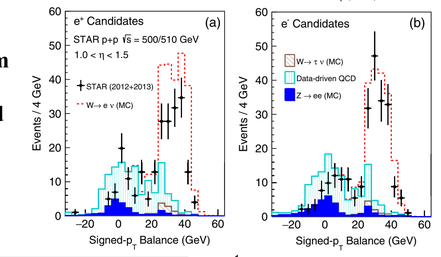
Data Sets

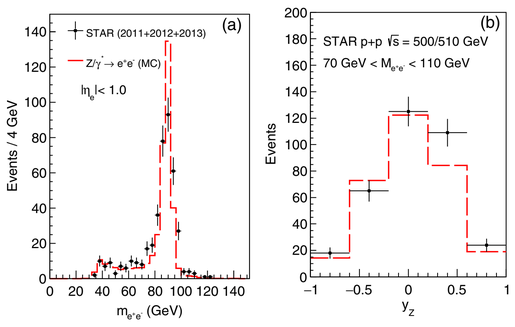
- **W and Z cross sections were measured during STAR p+p 2011, 2012, and 2013 running**
- **Protons were collided at center of mass energies of 500 and 510 GeV**
- **Data totaling about 345 pb-1 from years 2011, 2012, and 2013 have now been published**
- **Proton-proton data at 510 GeV was also taken in 2017. This data set is in the later analysis stages, and will contribute an additional 350 pb-1 / Publication is in preparation**
- **Additional data set in 2022 at 510 GeV will contribute an additional 400 pb-1**

Backgrounds and Efficiencies

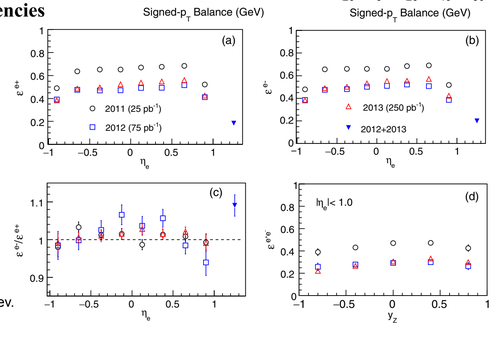
- **Data-driven QCD background satisfies $e^\pm$ isolation cuts**
- **Missing EEMC background results from backward jet at non-existing calorimeter coverage for $-2 < \eta < -1.1$ and is estimated from instrumented EEMC located at $1.1 < \eta < 2$**
- **Electroweak background from Z decay is estimated from PYTHIA/MC simulations**
- **The reconstruction of two oppositely charged, isolated, high E_T tracks from Z decay candidates results in much cleaner distribution where background correction is negligible**
- **W and Z efficiencies are computed using PYTHIA and MC**







Efficiencies



Adam, J. *et al.* (STAR Collaboration), Phys. Rev. D **103,** 012001 (2021).

Results: Cross Section Ratios

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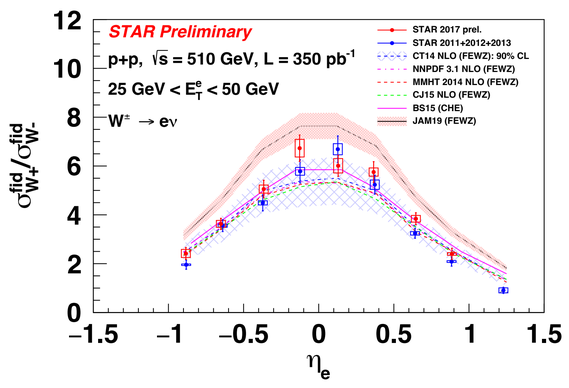

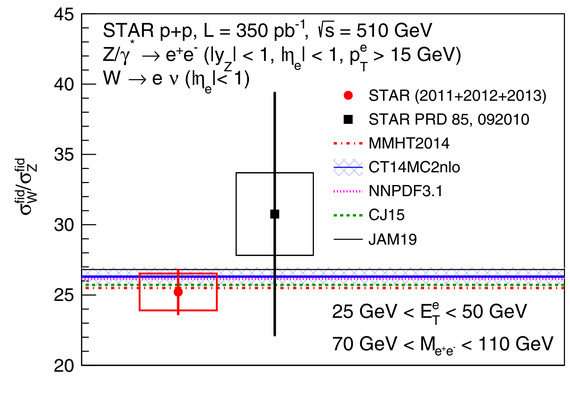

- **W^+/W^- and W/Z cross section ratios can be included into global PDF analyses to reduce current PDF uncertainties**
- **The different cross section ratios have different quark and anti-quark sensitivities**

Results: Cross Sections

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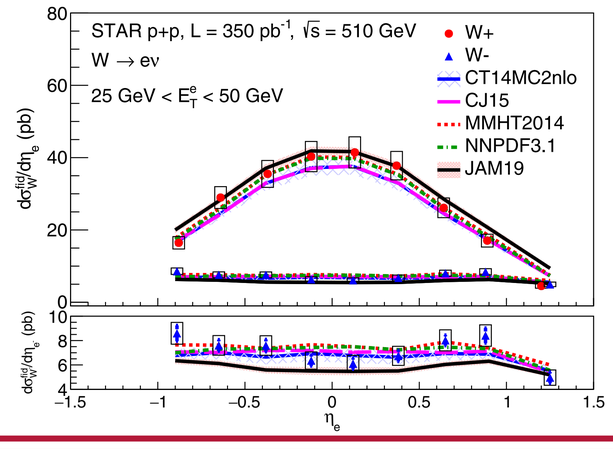
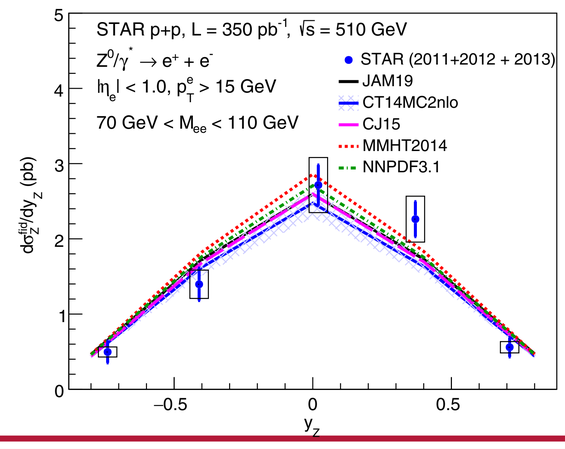
- **Differential W and Z cross sections can also help to constrain PDFs, as they are also sensitive to quark and anti-quark distributions**



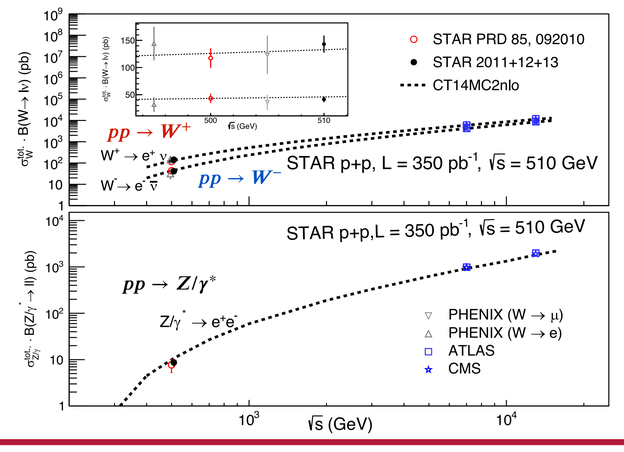


Results: Total Cross Sections

Adam, J. *et al.* (STAR Collaboration), Phys. Rev. D **103,** 012001 (2021).

- **STAR kinematic acceptance needs to be accounted for to compute total W and Z cross section**
- **Kinematic acceptance factor, A, was computed using FEWZ cross section code**
- **Total cross sections are then given as:**

$$\sigma^{tot}_{W^\pm,Z} = \frac{\sigma^{fid}_{W^\pm,Z}}{A_{W^\pm,Z}}$$



Summary and Projections

- **The STAR W cross section ratio measurements covers an interesting kinematic range ($0.06 \lesssim x \lesssim 0.4$)**
- **Fits to the STAR W and Z cross section data will help to constrain the sea quark PDFs and could help better understand the sea quark distributions**
- **Published W and Z cross sections using combined 2011, 2012, and 2013 data sets have been measured as a function of electron pseudo-rapidity. This accounts for about 345 pb-1**
- **The 2017 (2022) data have delivered 350 (400) pb-1 and will further improve the W and Z cross section measurements**