Constraining the Sea Quark Distributions Through W and Z Cross Sections and Cross-Section Ratio Measurements at STAR

Matthew Posik
Temple University
for the STAR Collaboration

DNP 2020 Meeting
New Orleans, LA
Oct. 29 - Nov. 1, 2020

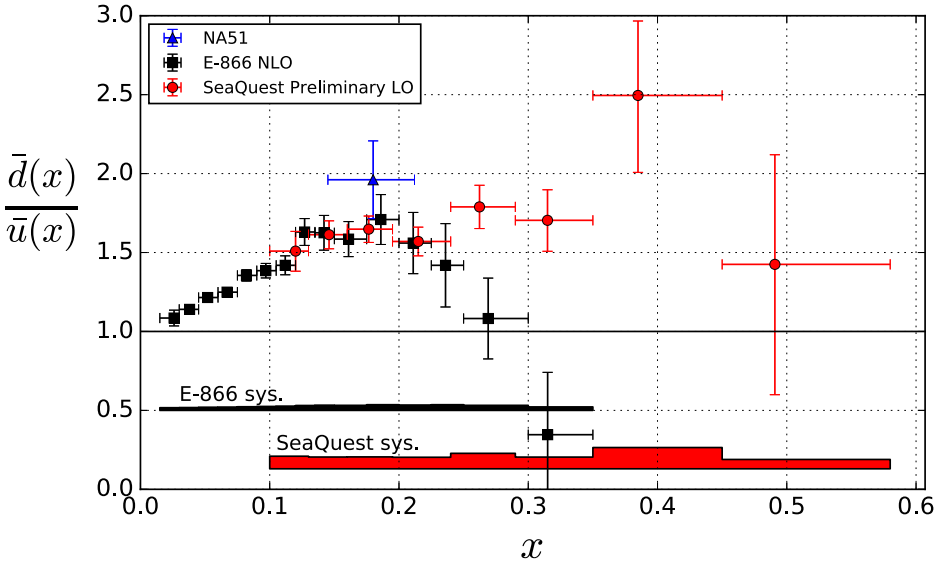
Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science
DOE NP contract: DE-SC0013405

TEMPLE UNIVERSITY

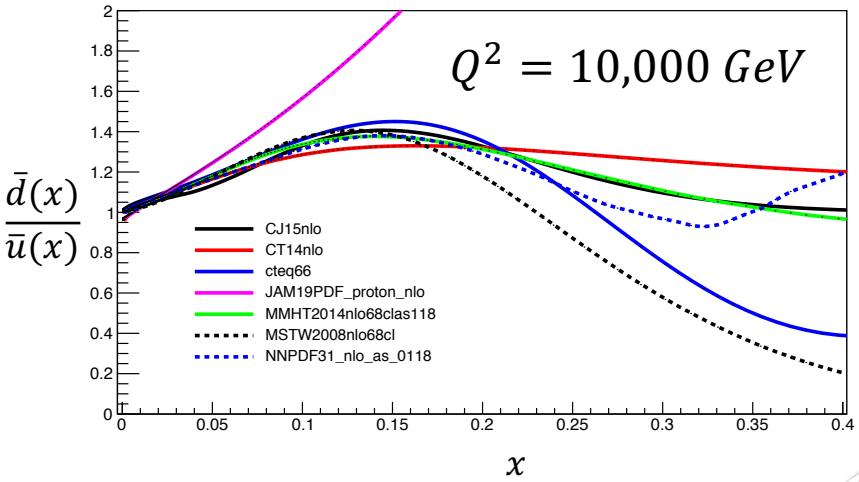
Motivation

- Unpolarized $\bar{d}/\bar{u}$ distribution can be probed via Drell-Yan production.
- **E-866** suggests a trend where the $\bar{d}/\bar{u}$ ratio appears to be decreasing at large-x.
- The **preliminary SeaQuest** trend appears to level out at **higher x**. However preliminary data have large error bars at large-x. Still awaiting full statistical sample.
- More **direct** and **indirect** data are needed at **high-x** to help **constrain** the sea quark distributions.
- New measurements from different experiments can provide data at different **Q^2** and from different **scattering processes**.

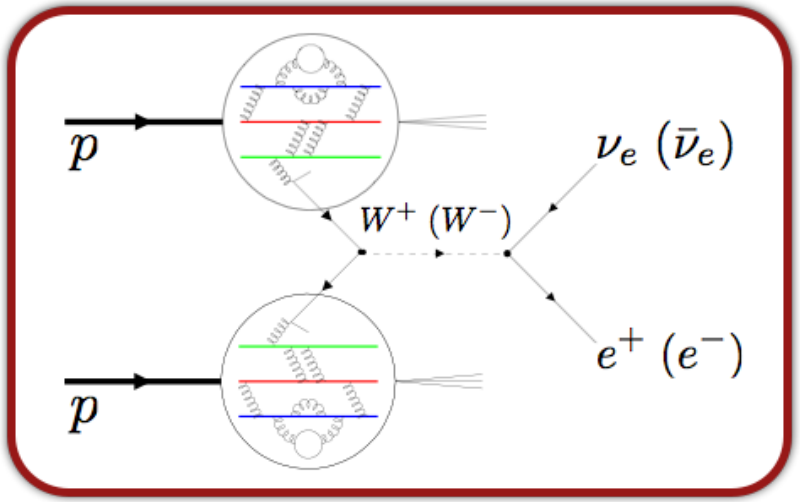
B. Kerns et al. (SeaQuest Collaboration), APS April Meeting 2016.



PDFs



W Boson Production Through p+p Collisions



- **W bosons** are **sensitive** to **quark/anti-quark** distributions. They can be accessed via the leptonic decay channels in **proton + proton** collisions
  - $u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$
  - $d + \bar{u} \rightarrow W^- \rightarrow e^- + \bar{\nu}$

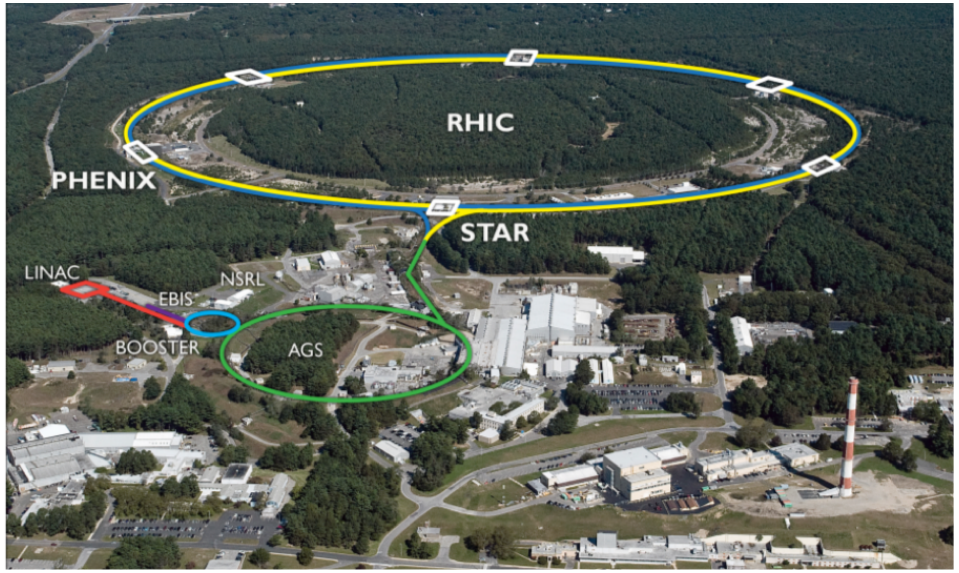
- The **charged W cross section ratio**
  - is proportional (at LO) to the $\bar{d}/\bar{u}$ ratio
  - can be used to **constrain** the **sea quark distributions**

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

$$\frac{\sigma_{W^+}}{\sigma_{W^-}} = \left(\frac{N_O^+ - N_B^+}{N_O^- - N_B^-}\right)\left(\frac{\epsilon^-}{\epsilon^+}\right)$$

- +/- is positron/electron from W leptonic decay
- N_O is number of observed W events
- N_B is number of background events
- ϵ is the W detection efficiency

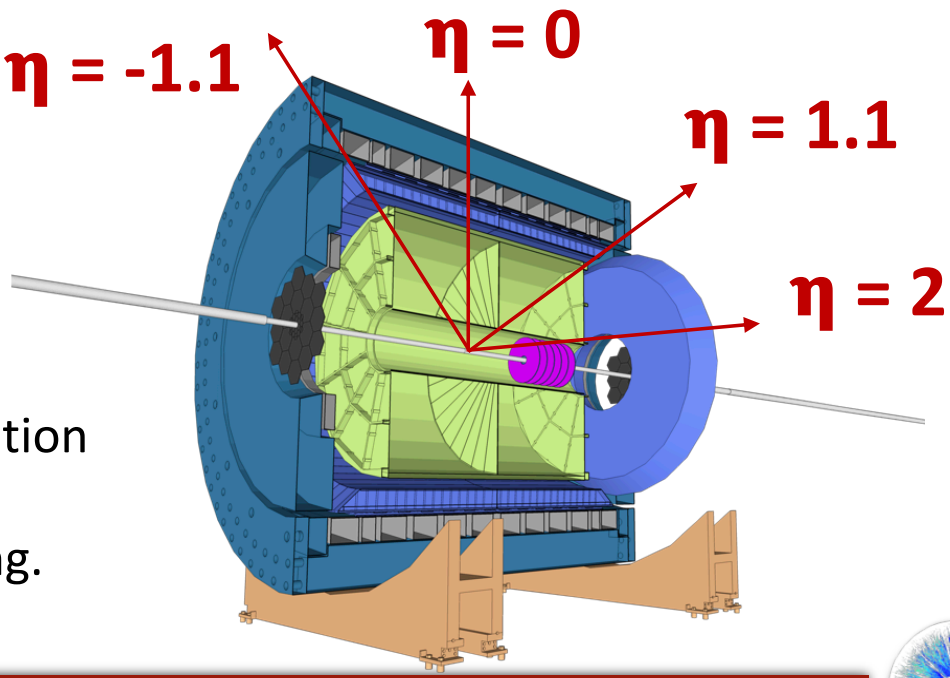
Solenoidal Tracker At RHIC



p+p production runs at $\sqrt{s}$ = 500/510 GeV

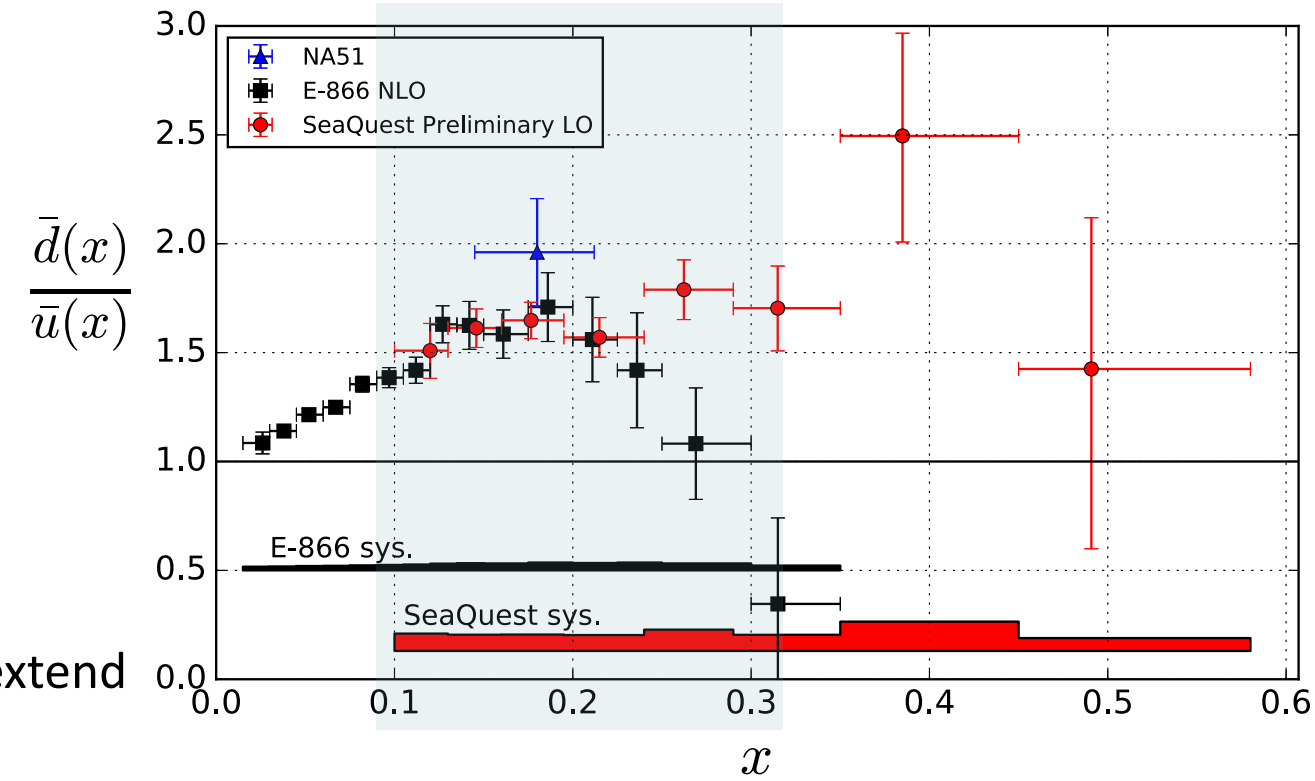
Year	Luminosity (pb^{-1})
2011	25
2012	75
2013	250
2017	350
Combined	**700**

- **Calorimetry system** with 2π coverage
  - Barrel electromagnetic calorimeter (**BEMC**), $-1 < \eta < 1$
  - Endcap electromagnetic calorimeter (**EEMC**), $1.1 < \eta < 2$
- Time projection chamber (**TPC**), $|\eta| < 1.3$
- Zero degree calorimeter, beam-beam counter and vertex position detector
  - Provide minimum bias trigger and luminosity monitoring.
- The **2017** run will add **350 pb^{-1}** more data



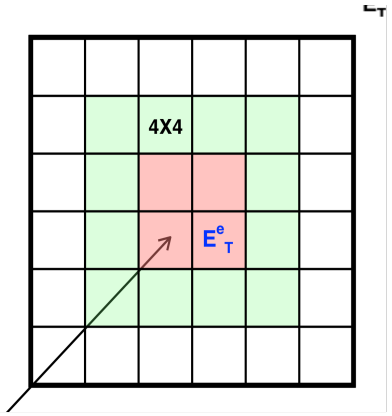
STAR Kinematics

- Approximate kinematic range at STAR **mid-rapidity** (**TPC + BEMC**)
  - $0.1 < x < 0.3$ for $-1 < \eta < 1$
- For collision energies of $\sqrt{s}$ = 500 GeV and $\eta = 0$, ($x_1 \approx x_2$)
  - $x = M_W/\sqrt{s} = 0.16$
- Good complementarity to LHC ($\sqrt{s}$ = 14 TeV) which probes much lower x
  - $x = M_W/\sqrt{s} = 5.7\times10^{-3}$ ($x_1 \approx x_2$)
- The STAR **EEMC** (**$1.1 < \eta < 2$**) can be used to extend the x reach of STAR
  - $0.06 < x < 0.4$ for $-1 < \eta < 2$

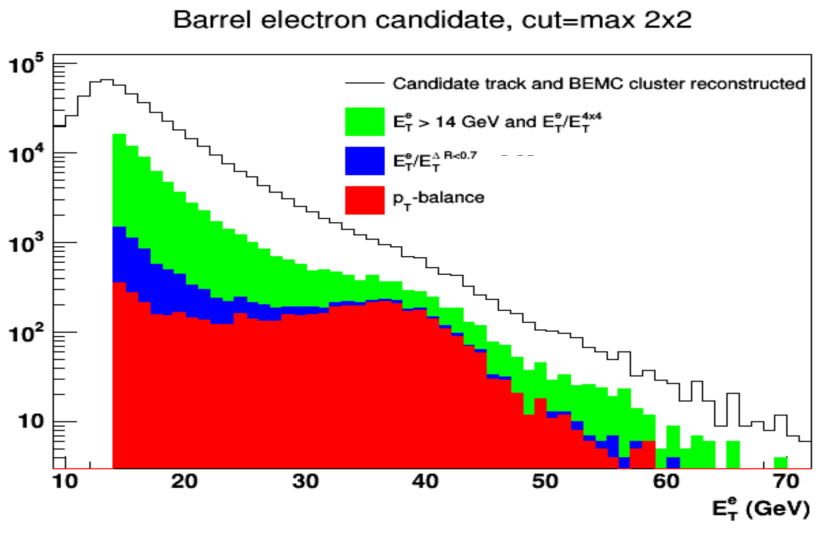


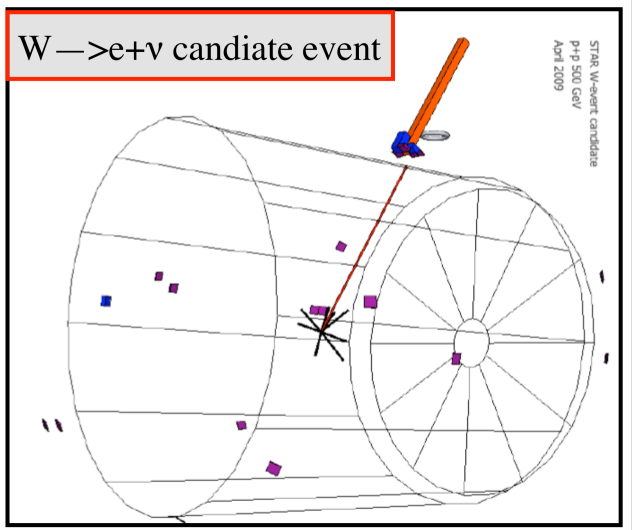
Selecting W Candidates

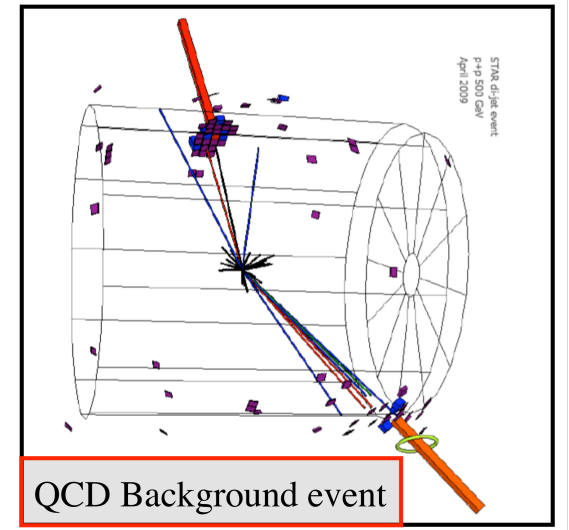
- Mid-rapidity STAR W selection criteria
  - **Match p_T > 10 GeV/c track to BEMC cluster**
  - **Isolation ratio 1: E_T^e/E_T^{4x4} < 0.96**
  - **Isolation ratio 2: E_T^e/E_T^R < 0.82**
  - **p_T - balance > 16 GeV/c**
  - **Leads to good charge discrimination**

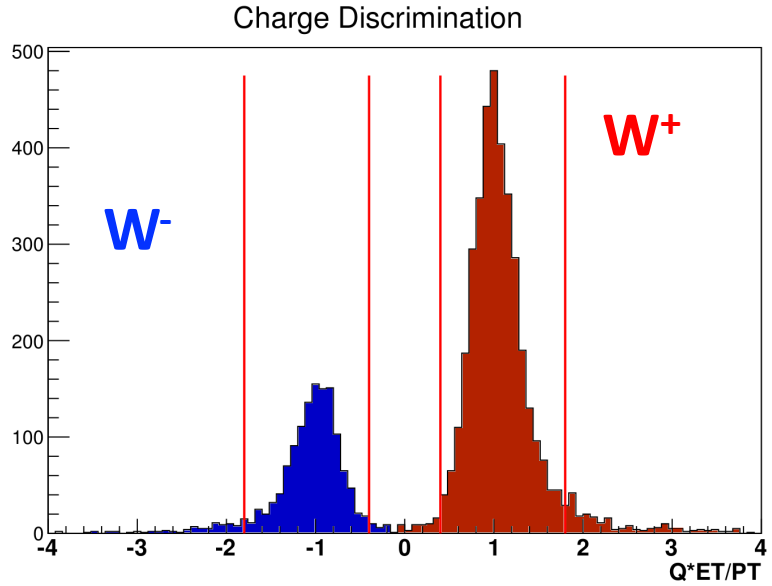


TPC track extrapolated to BEMC tower grid





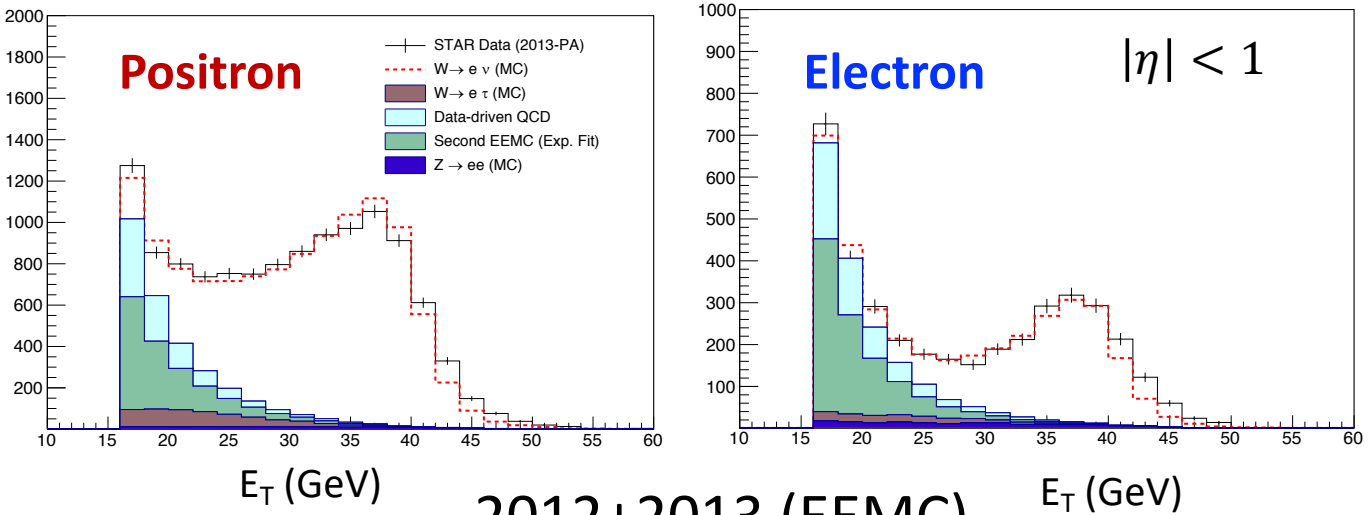




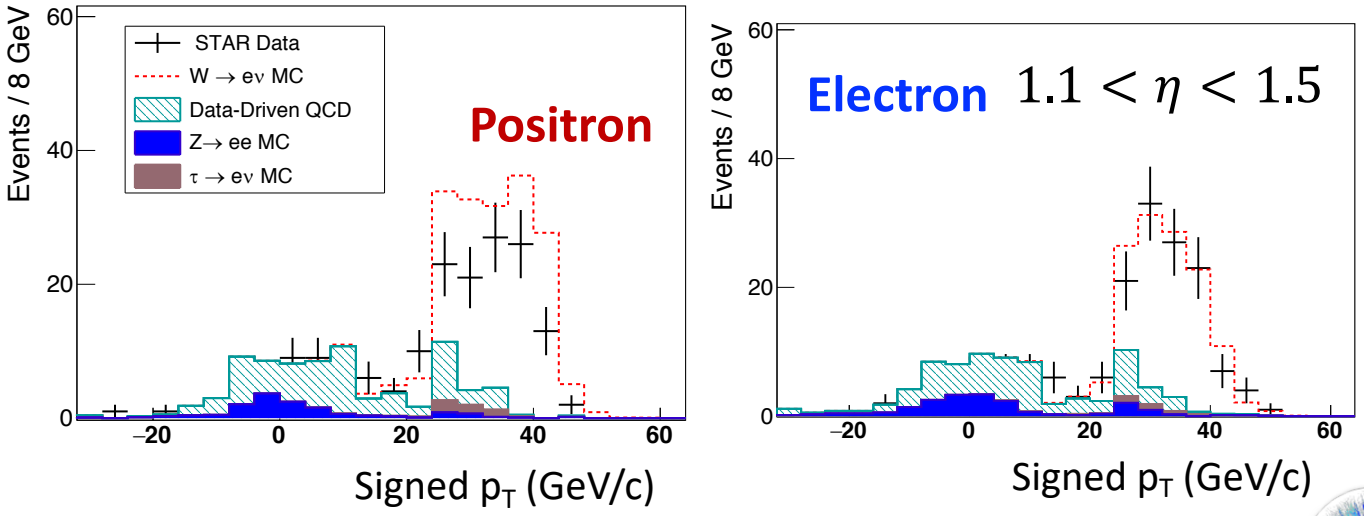
W Backgrounds

- **Data-driven QCD** background satisfies $e^{+/-}$ isolation cuts
- **Missing EEMC background** results from backward "Jet" at non-existing calorimeter coverage for $-2 < \eta < -1.1$
- **Missing EEMC background** is estimated from EEMC located at $1.1 < \eta < 2$
- **Electro-weak background** from Z and τ decays is estimated from PYTHIA/MC simulations.
  - Small background contribution from Z and τ decays.

2013 (BEMC)

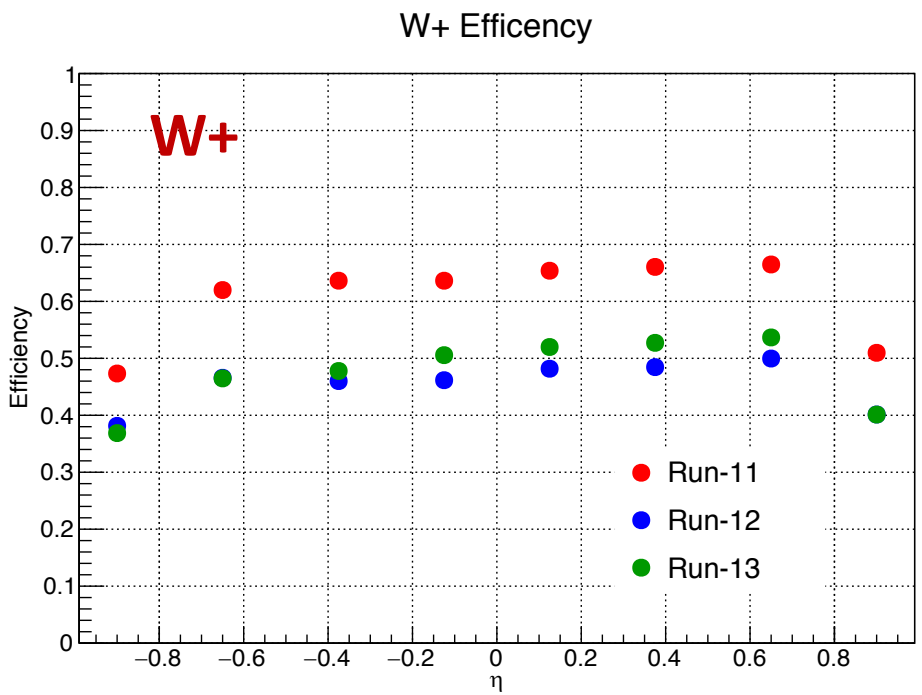


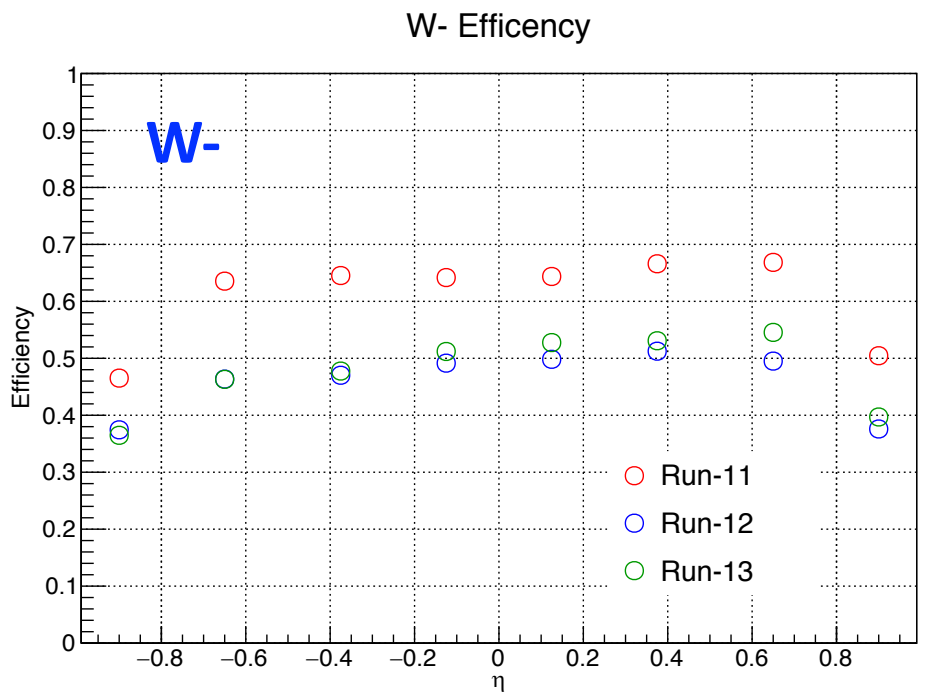
2012+2013 (EEMC)



W Efficiencies

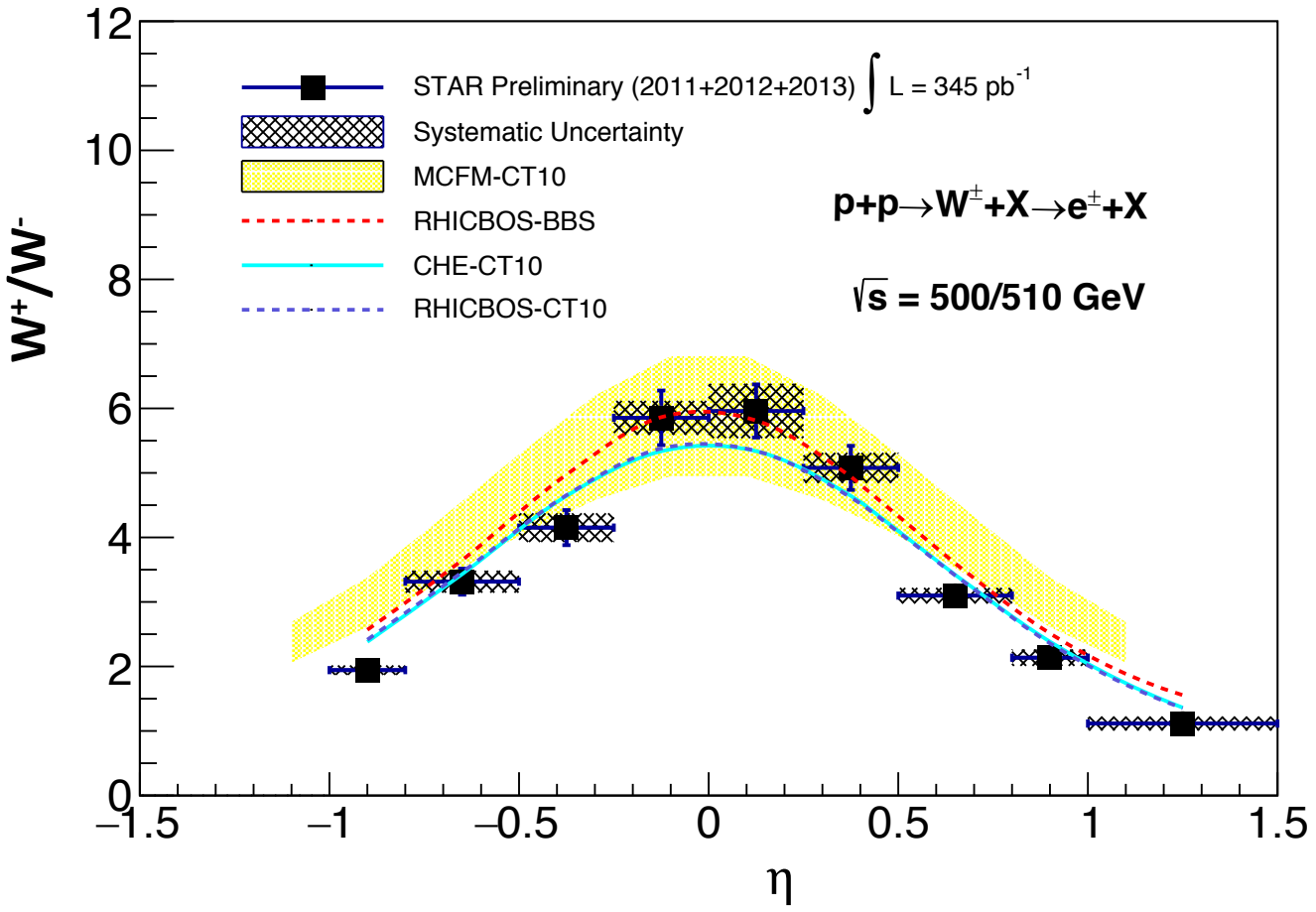
- Efficiencies computed using Pythia and GEANT.
  - **2012** and **2013** efficiencies decrease due to higher instantaneous luminosity, which leads to more pile-up and less efficient track reconstruction.
  - **2013** efficiencies are higher than **2012** due to new tracking algorithm (STICA).





W Cross-Section Ratio

- Final systematic uncertainties will be reduced for **W cross-section ratio** vs. **lepton pseudo-rapidity** compared to preliminary result.
  - Paper to be submitted very soon!
- STAR **2017** W production data is expected to add **350 pb^{-1}** more data.
- The **W boson rapidity** can now also be reconstructed at STAR via its recoil
  - See presentation by Salvatore Fazio: Hadrons: Spin Asymmetries, 10/30 9:45 AM

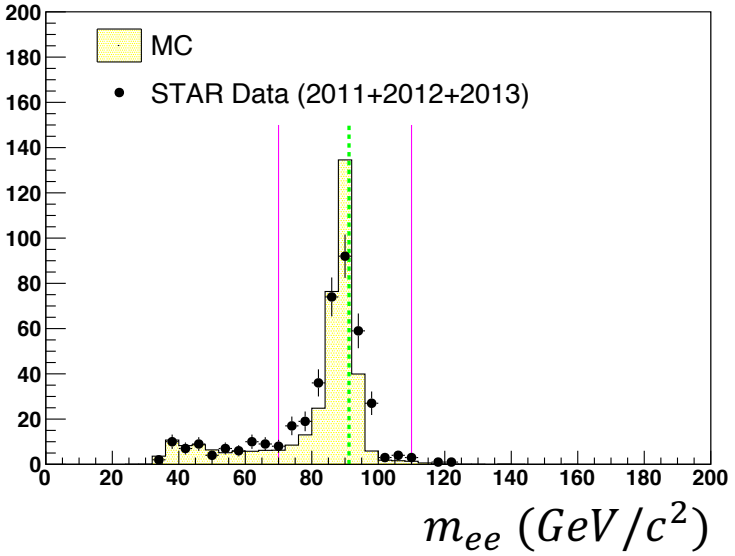


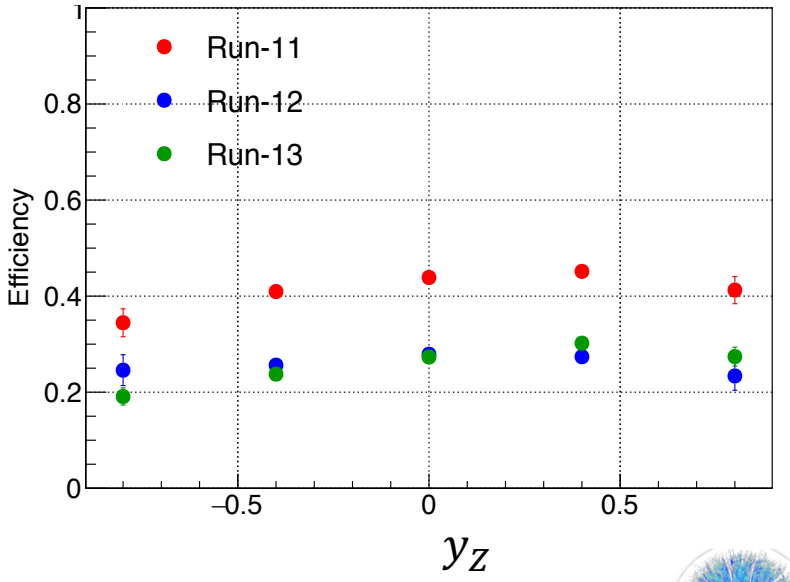
Selecting Z Candidates

- STAR is able to reconstruct **Z boson** candidates via their **leptonic decays**

$$p + p \rightarrow Z/\gamma^* \rightarrow e^+ + e^-$$

- **Z candidates** are selected by using **isolated $e^{\pm}$ sample** and requiring a pair of isolated $e^{\pm}$ candidates to have **opposite charge**.
  - The invariant mass of each e^+e^- pair can be reconstructed.
  - Final Z candidates selected using an **invariant mass cut of $70\ GeV/c^2 < m_{ee} < 110\ GeV/c^2$**
- Reconstruction of two charged tracks lead to **cleaner** identification of Z candidates than W candidates.
- Efficiencies (ϵ_Z) and background are estimated using Pythia and GEANT



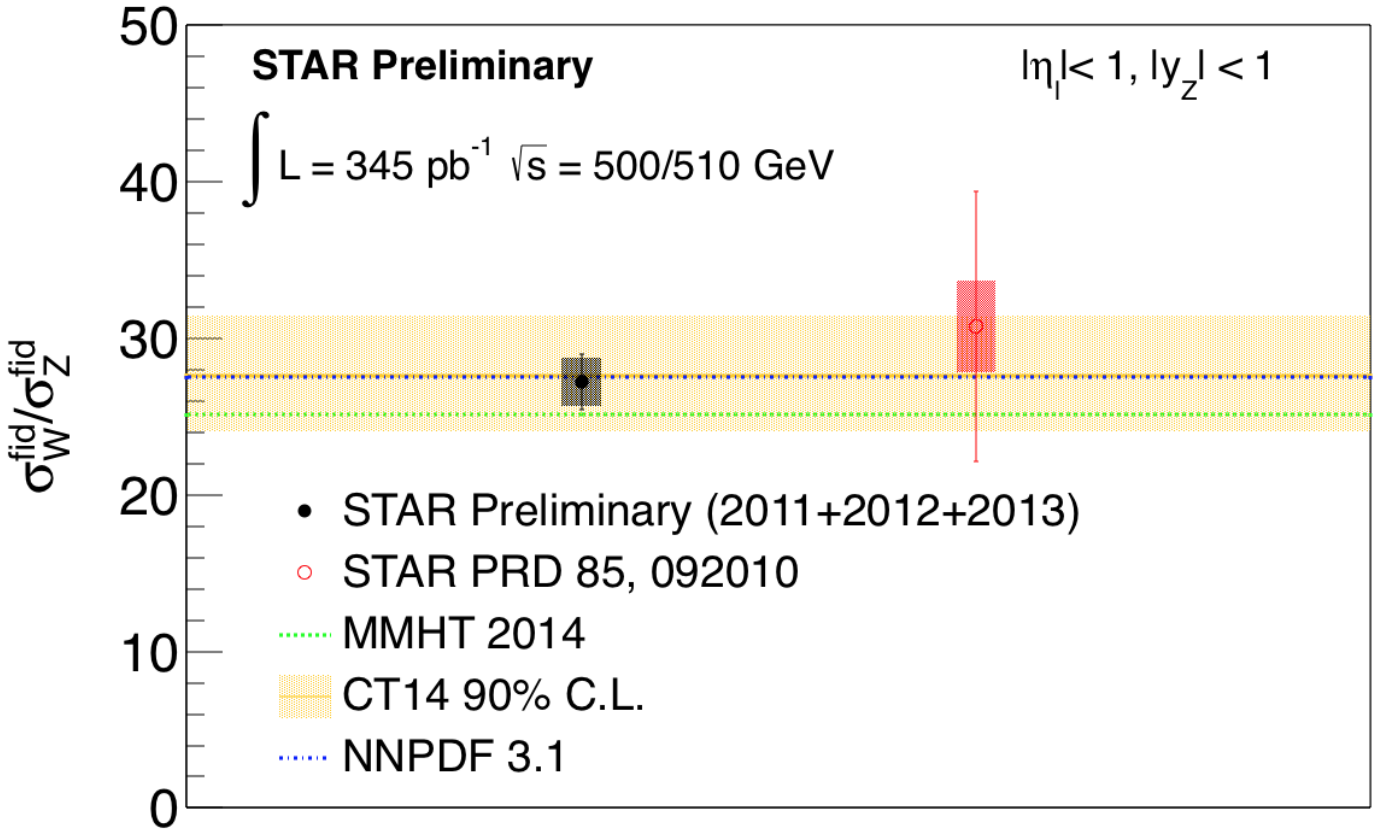


W/Z Cross-Section Ratio

- **W/Z cross-section ratio** measured as

$$\frac{\sigma_W^{fid}}{\sigma_Z^{fid}} = \frac{N_O^W - N_B^W}{N_Z^O} \cdot \frac{\epsilon_Z}{\epsilon_W}$$, where W is the total W $(W^+ + W^-)$

- **W/Z cross-section ratio** in great agreement with various PDF sets (computed with FEWZ).
  - FEWZ is a theory framework for W/Z production
- **Consistent** with previous STAR result based on 2009 data.
- Will help provide **further constraints** on PDFs.



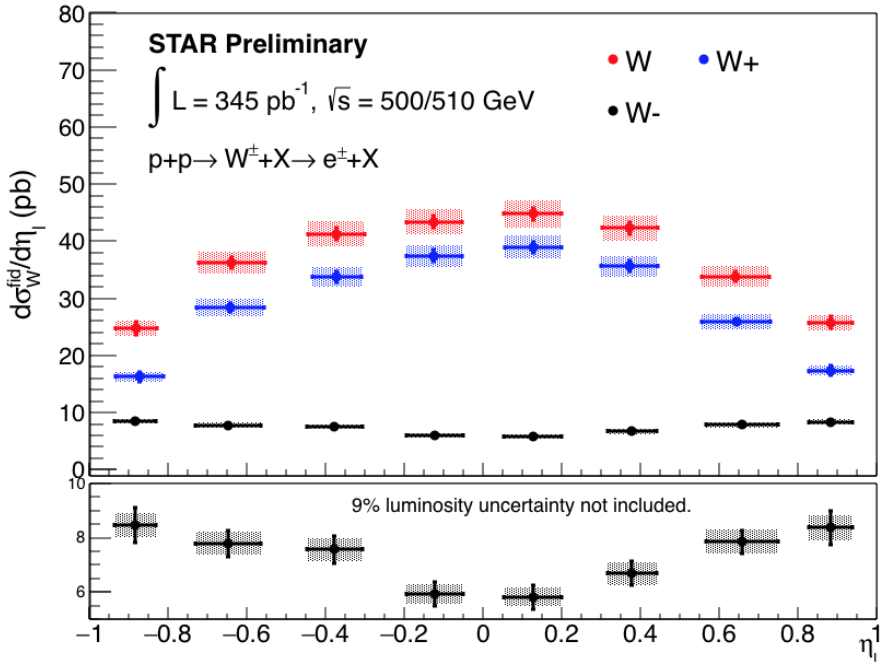
W and Z Differential Cross Sections

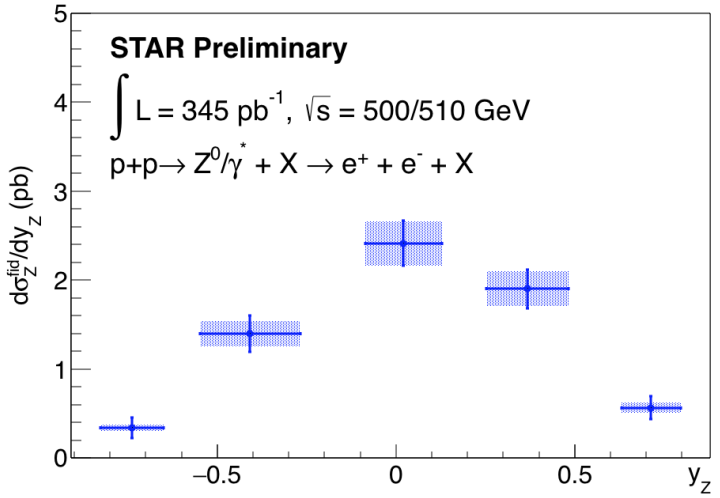
- Including the luminosity (L) information, one can also measure the **differential cross sections**

$$\frac{d\sigma^{fid}}{d\eta} = \frac{(N_O - N_B)}{L \cdot \epsilon}$$

- Work is currently being done to obtain the W and Z differential cross sections as a function of the respective boson's p_T.

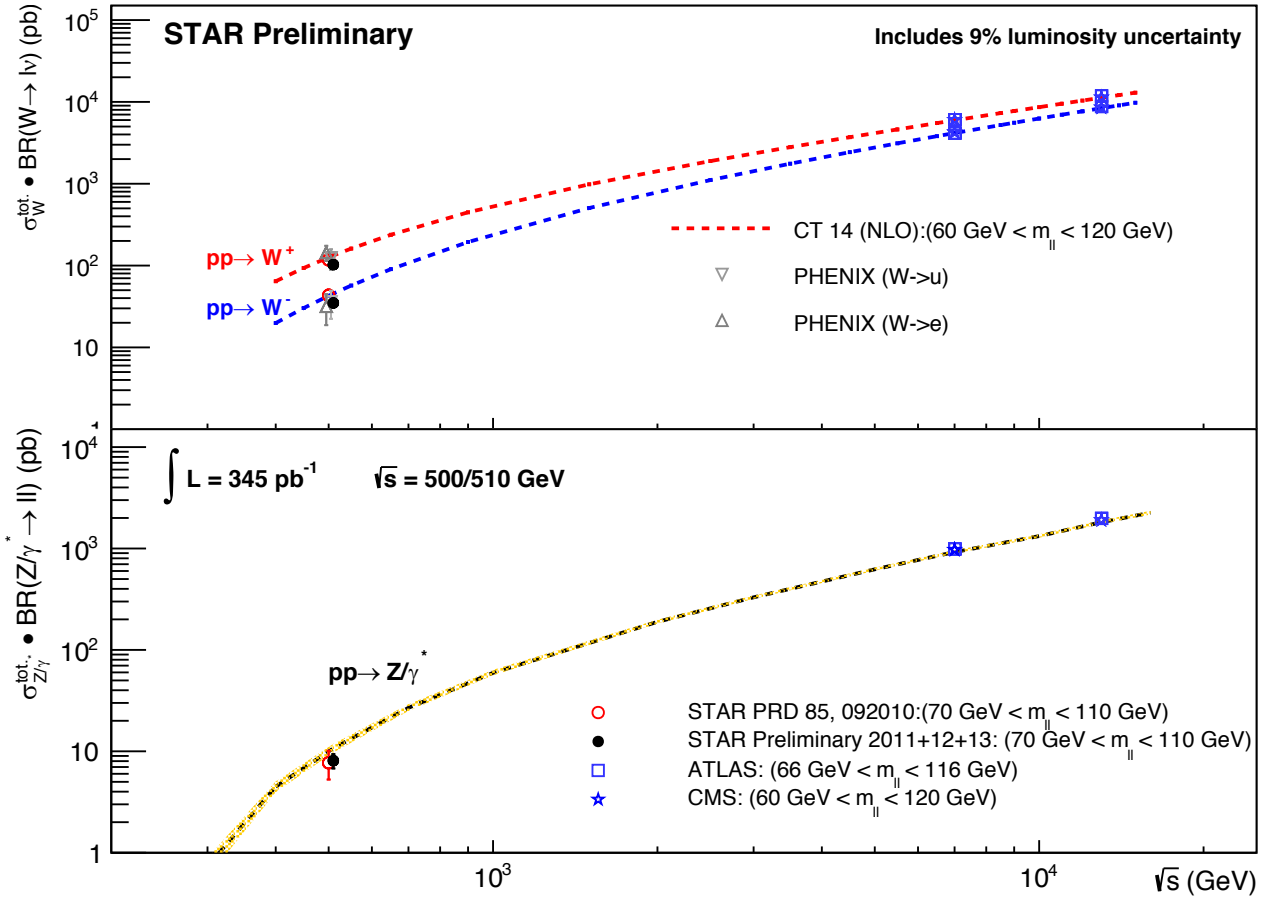
  - See presentation by Salvatore Fazio:
    Hadrons: Spin Asymmetries, 10/30 9:45 AM





Total Cross Sections

- The **total cross sections** can be computed from the measured **fiducial cross sections** by correcting for STAR acceptance.
- **Acceptance correction** computed using **FEWZ**
- Preliminary results are consistent with world $p + p$ data and theory.
- **STAR** data are **complementary** to **LHC** data



Summary

- **STAR** measured **$W^{+/-}$ cross-section ratio**
  - A **complementary** measurement to **SeaQuest** and **E-866** and **LHC**
  - Will help to further **constrain** the **sea quark PDFs**
- **W/Z cross-section ratio**
  - A **complementary** measurement to **LHC**
  - Will help to **constrain PDFs**
- Preliminary W and Z **differential** and **total cross sections** were also presented
- Paper draft now at final STAR collaboration review stage
- Ongoing analysis from STAR
  - **2017** W and Z production data will **double** the statistics of the STAR cross section and cross-section ratio measurements.
  - Measuring W and Z differential cross sections vs. boson kinematics (p_T and y)