# 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

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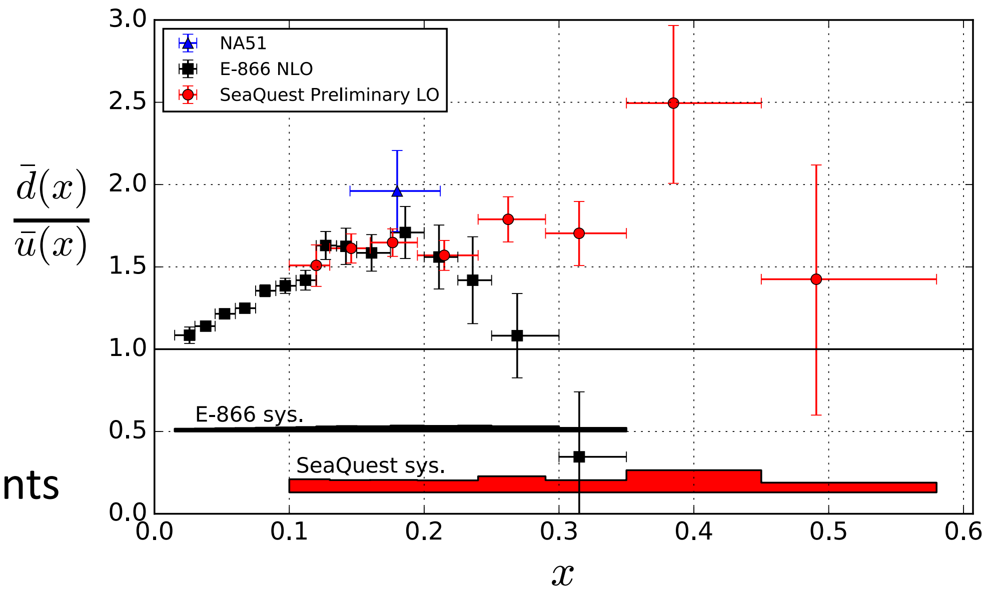
# Motivation

- 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.

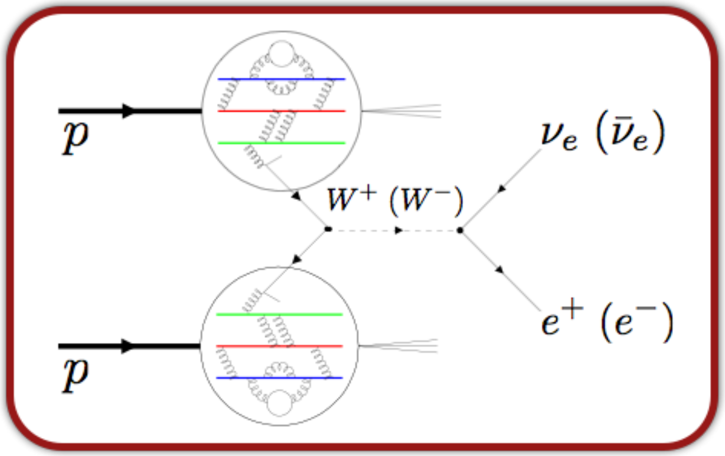
B. Kerns et al. (SeaQuest Collaboration), APS April Meeting 2016.

- 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**.
  - This will allow for different **systematic effects** and also serve as a **cross check** of our understanding of the physics.

# W Boson Production Through p+p Collisions




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

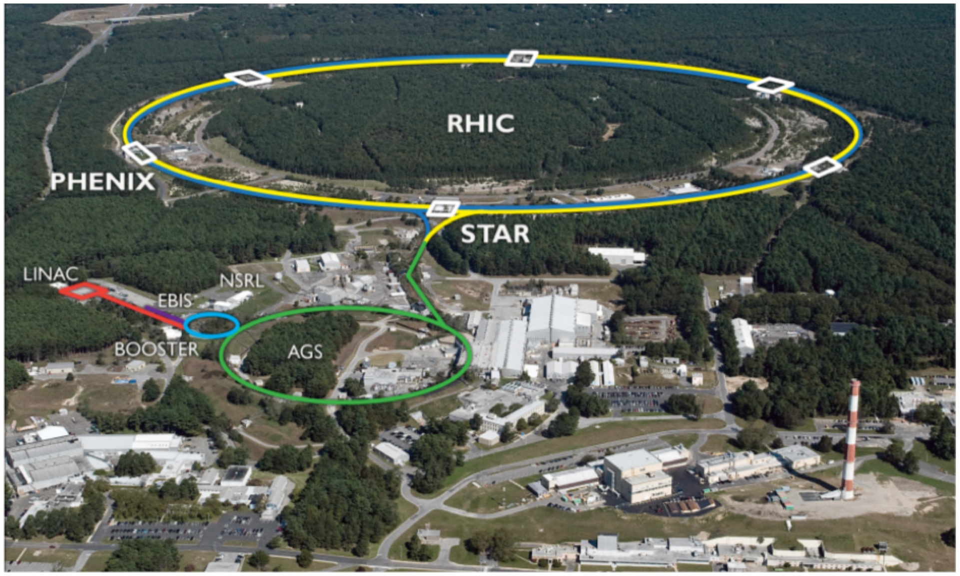
- The **charged W cross section ratio**
  - is proportional (at LO) to the $\bar{d}/\bar{u}$ ratio
  - can be used to **constrain** the **sea quark distributions**

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

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

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

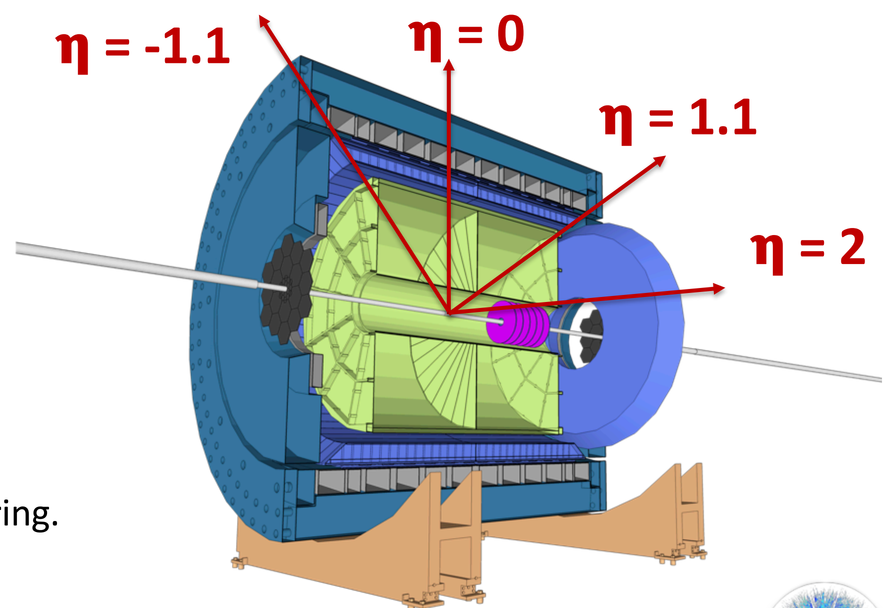
# Solenoidal Tracker At RHIC




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

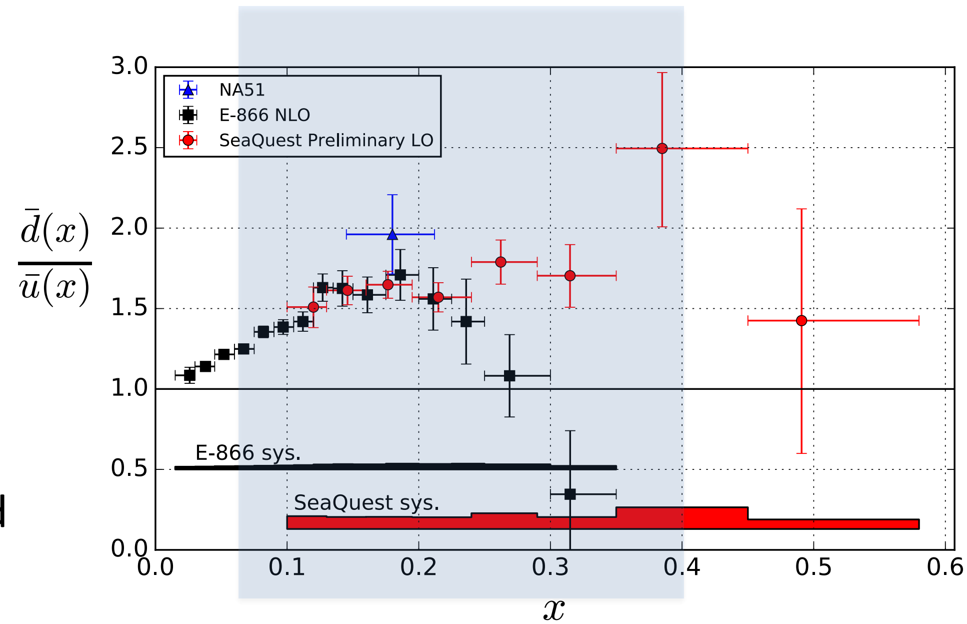
| Year | Luminosity ($pb^{-1}$) |
|---|---|
| 2011 | 25 |
| 2012 | 75 |
| 2013 | 250 |
| 2017 | 350 |
| **Combined** | **700** |

- **Calorimetry system** with $2\pi$ 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
  - $x = M_W/\sqrt{s} = 5.7\times10^{-3}$ ($x_1 \approx x_2$)
- In STAR the **EEMC** could be used to obtain a more forward $\eta$-bin (**$1.1 < \eta < 2$**) which would extend the x reach of STAR
  - $0.06 < x < 0.4$ for $-2 < \eta < 2$

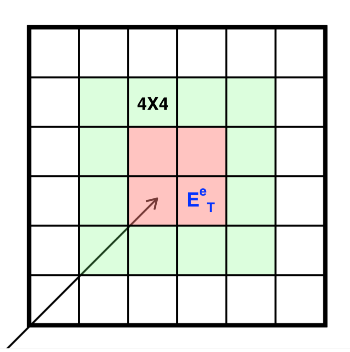




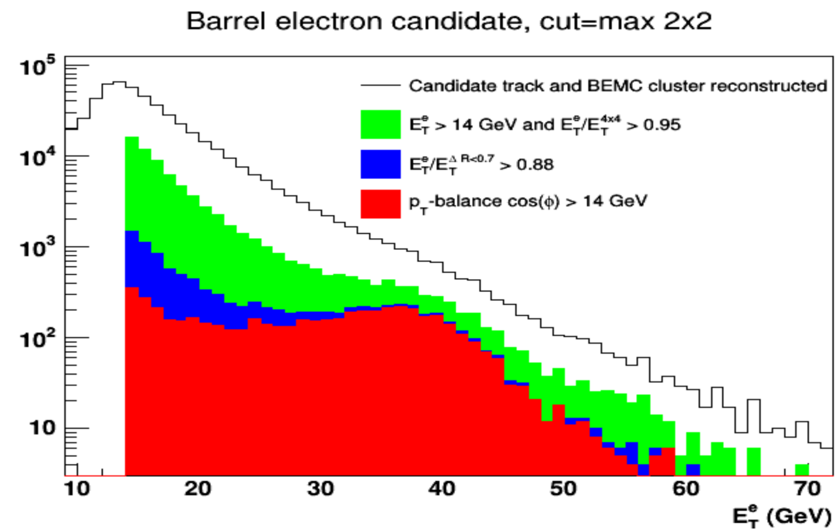

STAR

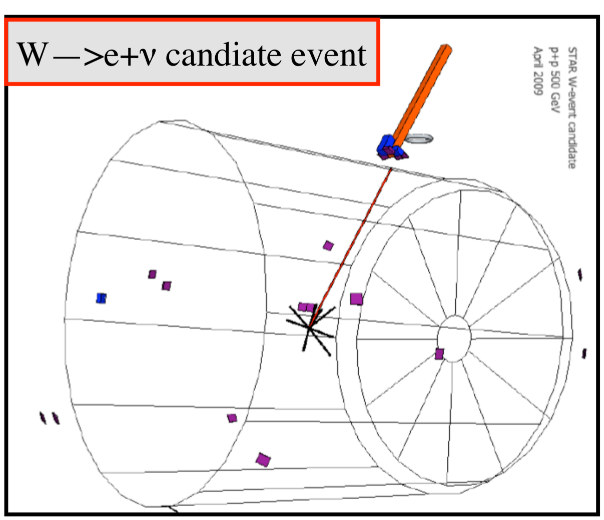
# Selecting W Candidates

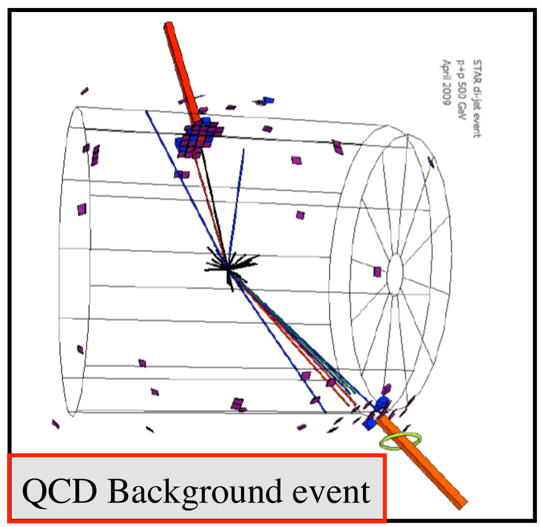
- Mid-rapidity STAR W selection criteria
  - **Match $p_T$ > 10 GeV/c track to BEMC cluster**
  - **Isolation ratio 1 / Isolation ratio 2**
  - **$p_T$-balance cut**
  - **Leads to good charge discrimination**

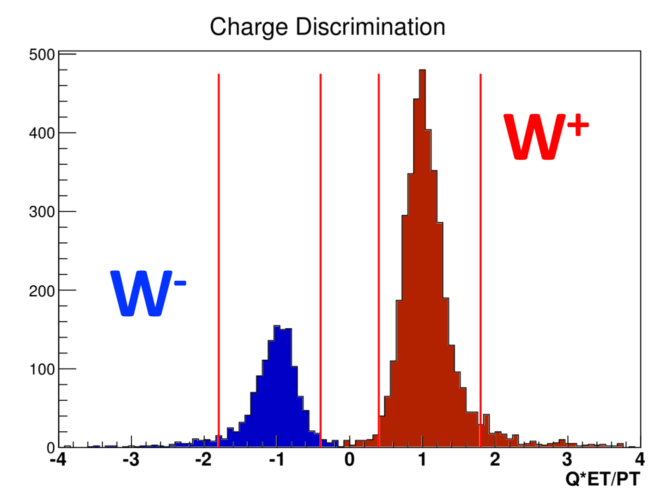



TPC track extrapolated to BEMC tower grid



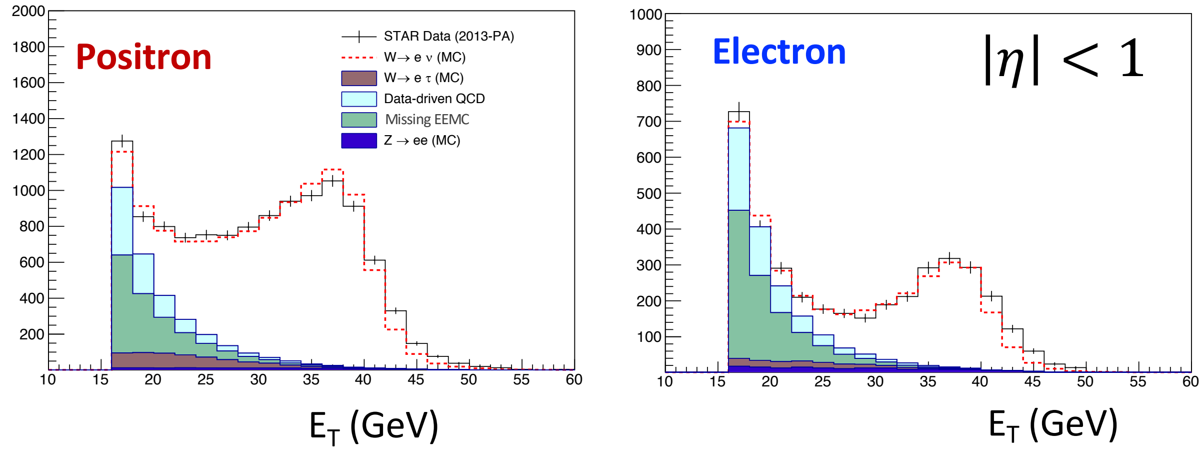



# Backgrounds

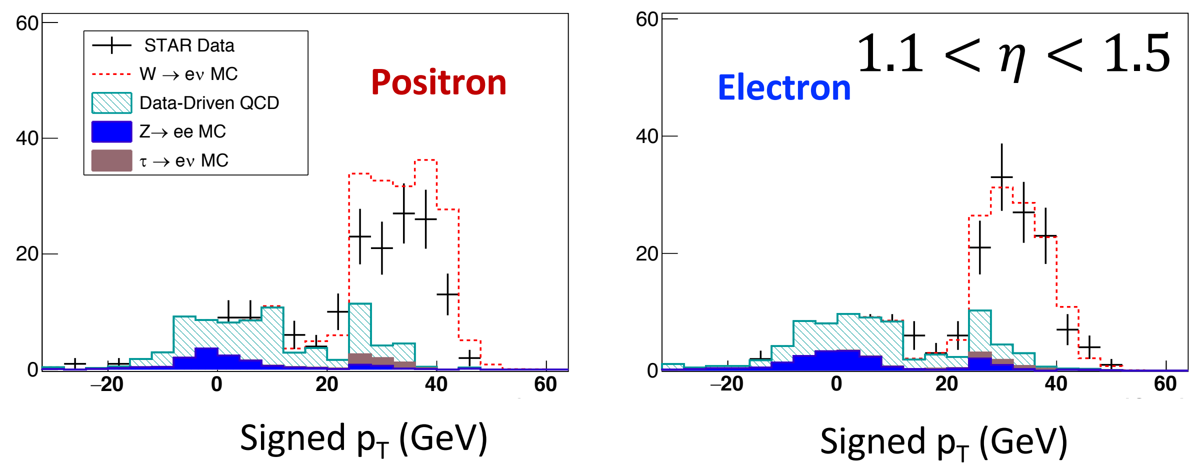
❑ **W+ /W- signal** and **background** distributions

- **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 $\tau$ decays is estimated from PYTHIA/MC simulations.
- Small background contribution from Z and $\tau$ decays.

2013 (BEMC)

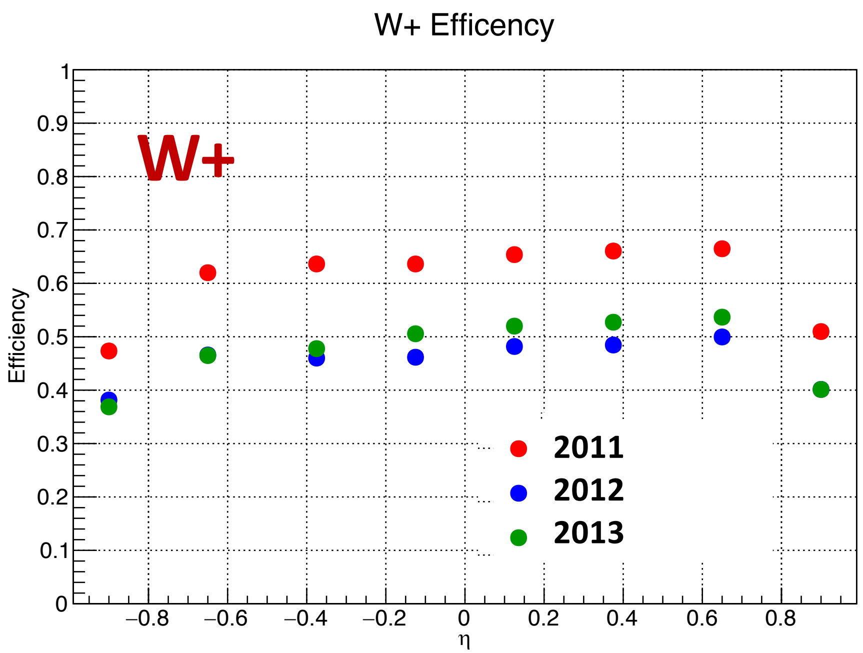


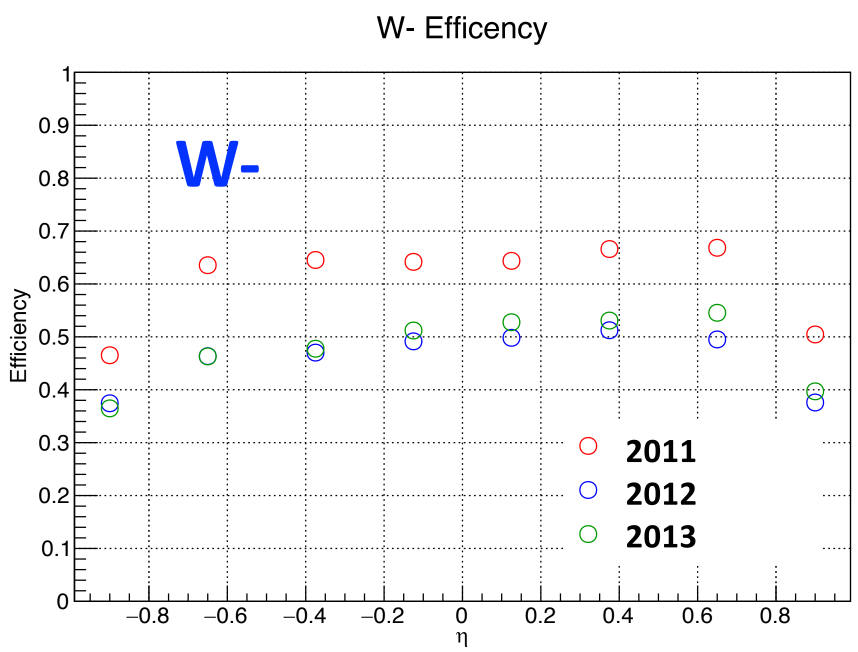

2012+2013 (EEMC)



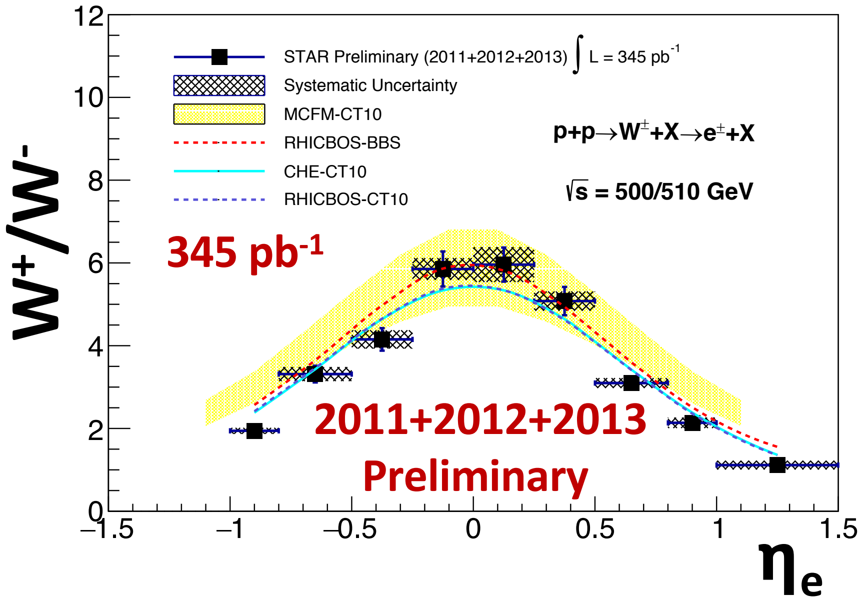
# W Efficiencies

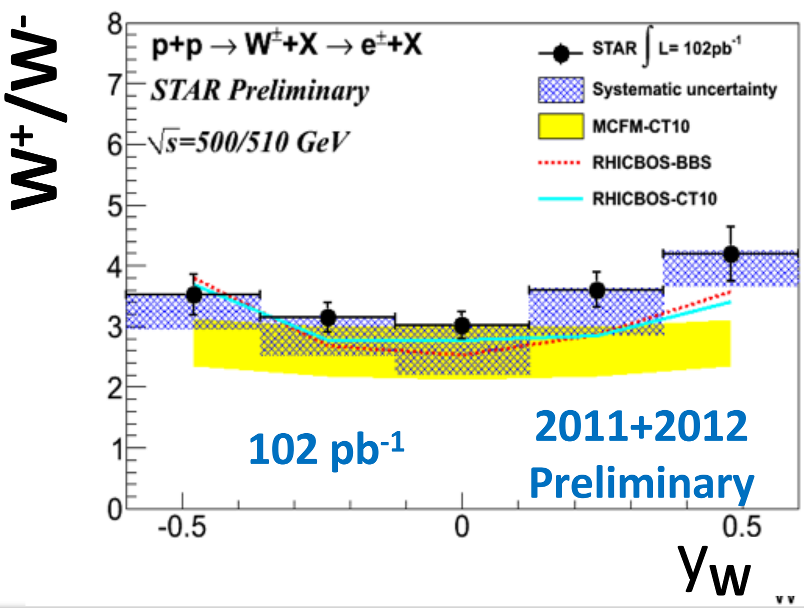
- Efficiencies computed using Pythia and GEANT.
  - **2012** and **2013** efficiencies decrease due to higher instantaneous luminosity, which leads to more pile-up and less efficient track reconstruction.
  - **2013** efficiencies are higher than **2012** due to new tracking algorithm (STICA).



# W Cross Section Ratio



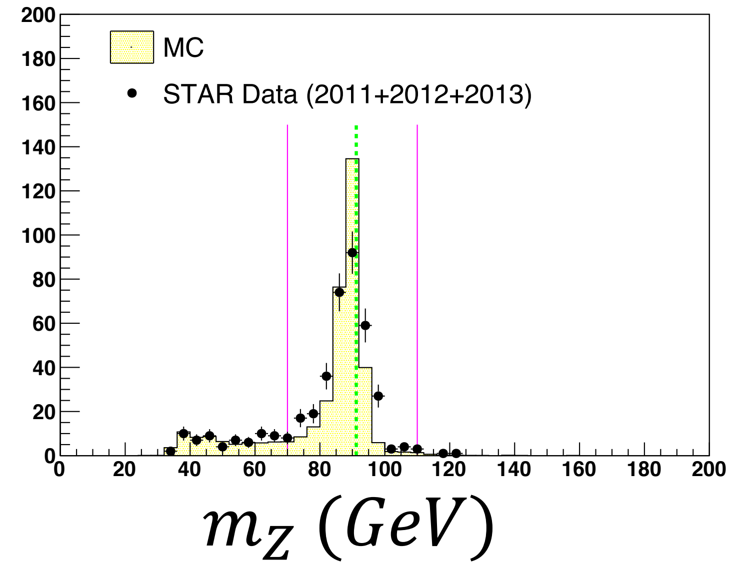

- STAR **2017** W production data is expected to add **350 pb$^{-1}$** more data.
- Final systematic uncertainties will be reduced for **W cross section ratio** vs. **lepton pseudo-rapidity** compared to preliminary result.
- The **W boson rapidity** can now also be reconstructed at STAR via its recoil (used for 2011 transverse single-spin asymmetry measurement, **Phys.Rev.Lett. 116 (2016)**).
- Work is ongoing to improve the systematic uncertainty associated with the reconstructed **W boson rapidity**.

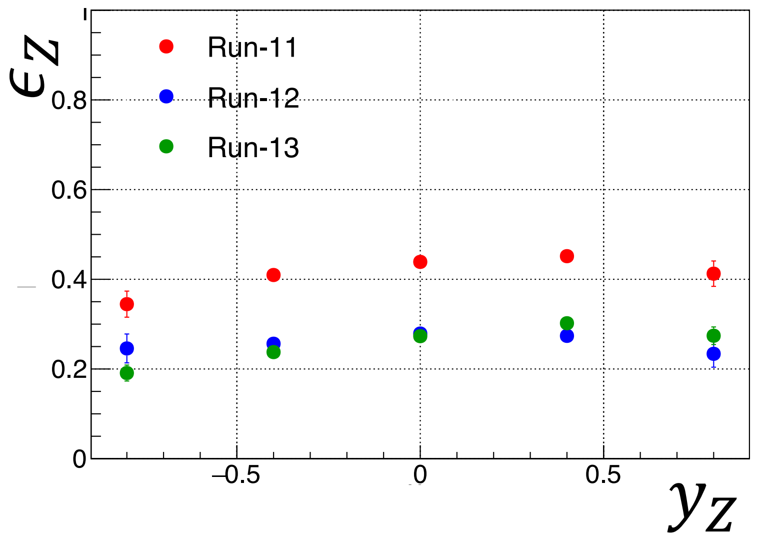
# Selecting Z Candidates

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

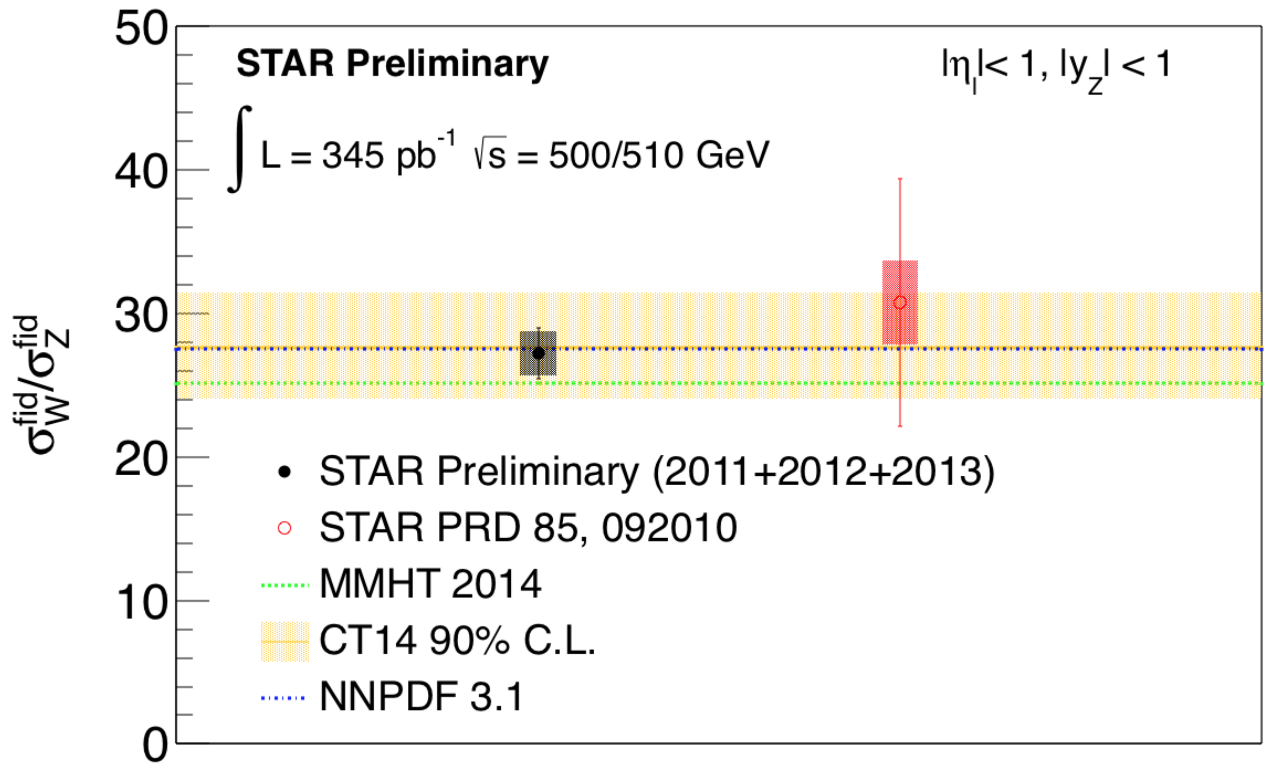
$$p + p \rightarrow \frac{Z}{\gamma^*} \rightarrow e^+ + e^- + X$$

- **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 $70\ GeV < m_Z < 110\ GeV$**
- Reconstruction of two charged tracks lead to **cleaner** identification of Z candidates.
- Efficiencies ($\epsilon_Z$) and background are estimated using Pythia and GEANT
  - No background correction applied.



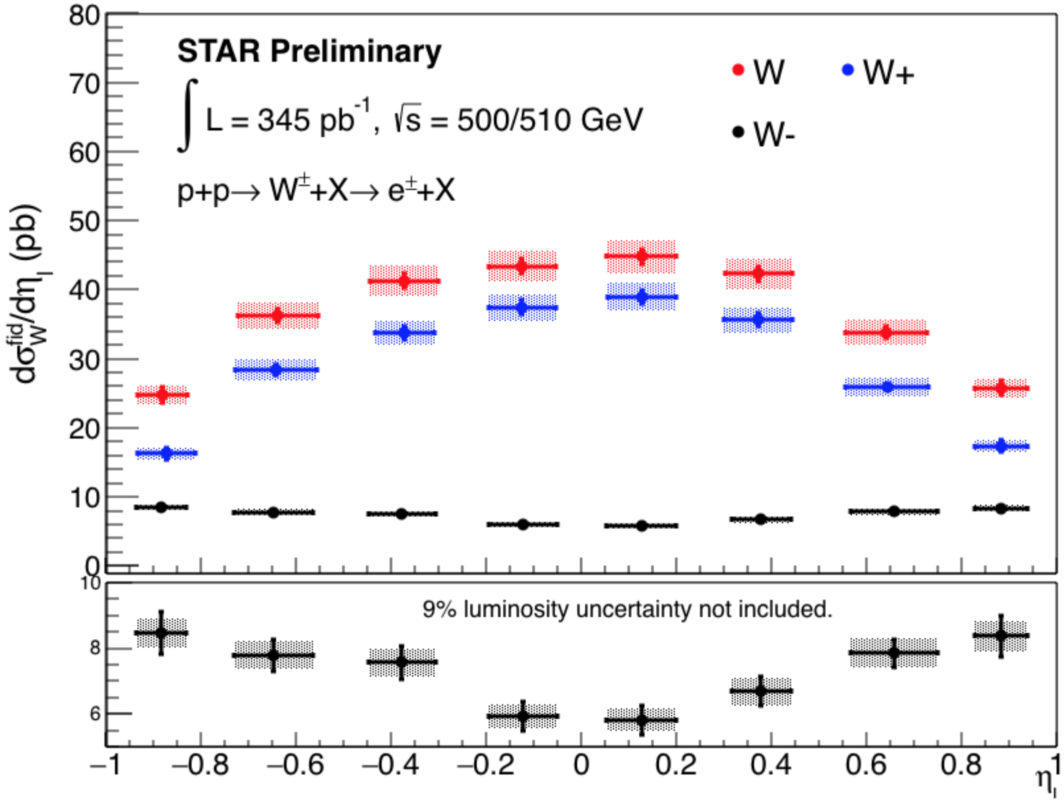
# W/Z Cross Section Ratio

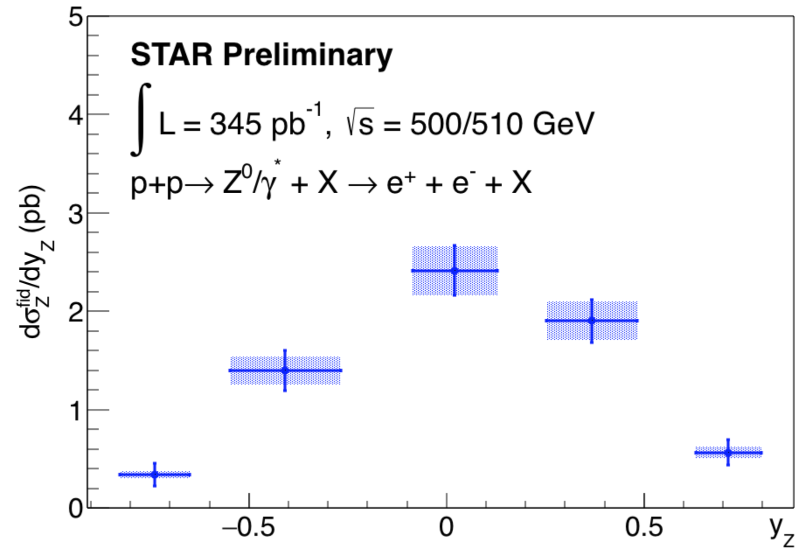



- **W/Z cross section ratio** measured as

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

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



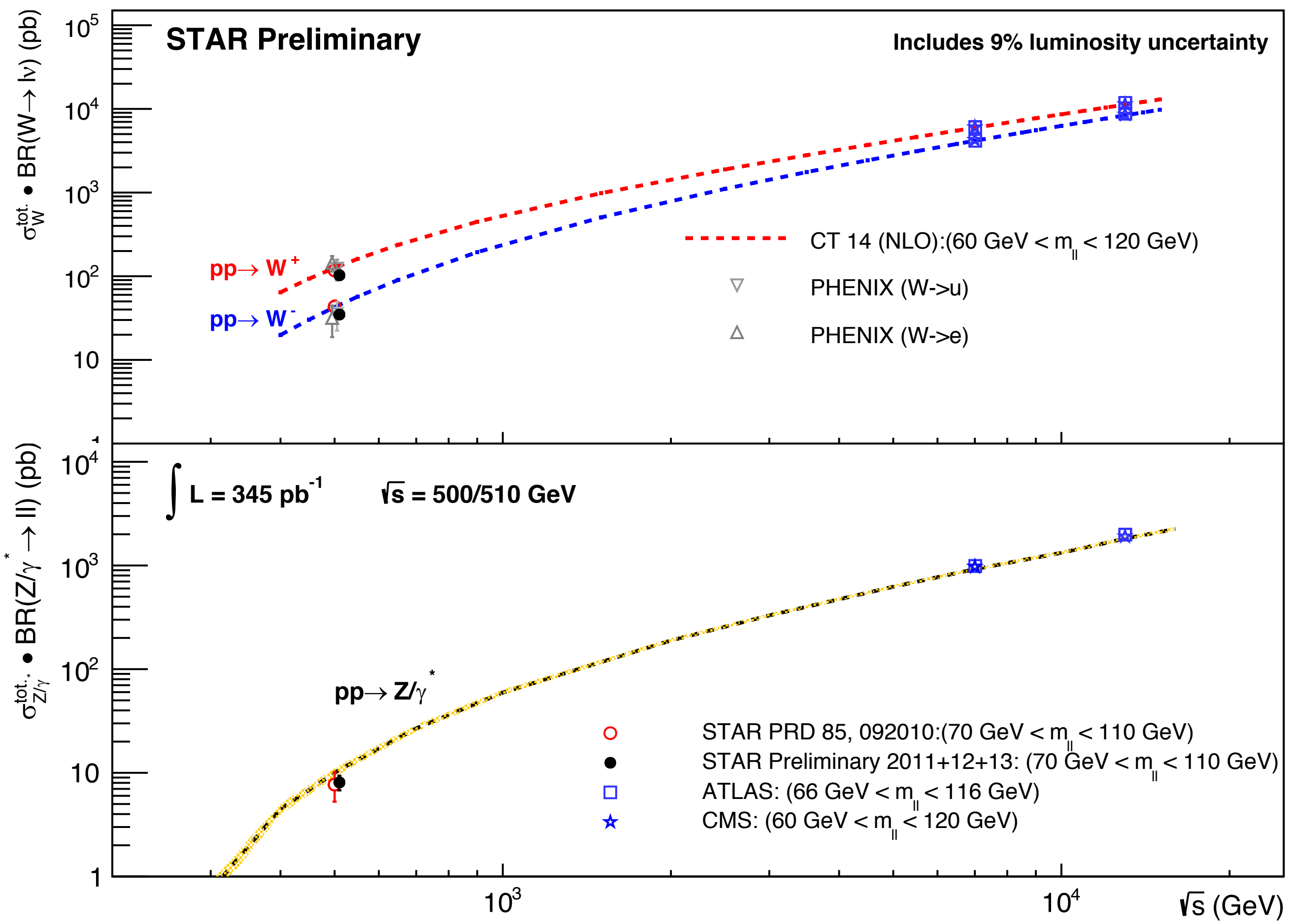

- Including the luminosity ($L$) information, one can also measure the **differential cross sections**

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

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

# 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**
- Impact of cross section ratios on the PDF distributions currently under analysis
- Preliminary W and Z **differential** and **total cross sections** were also presented
- 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 $y$)