Constraining the Sea Quark Distributions Through $W^{\pm}$ Cross Section Ratio Measurements at STAR

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Motivation

- Unpolarized $\bar{d}/\bar{u}$ distribution can be probed via Drell-Yan production.

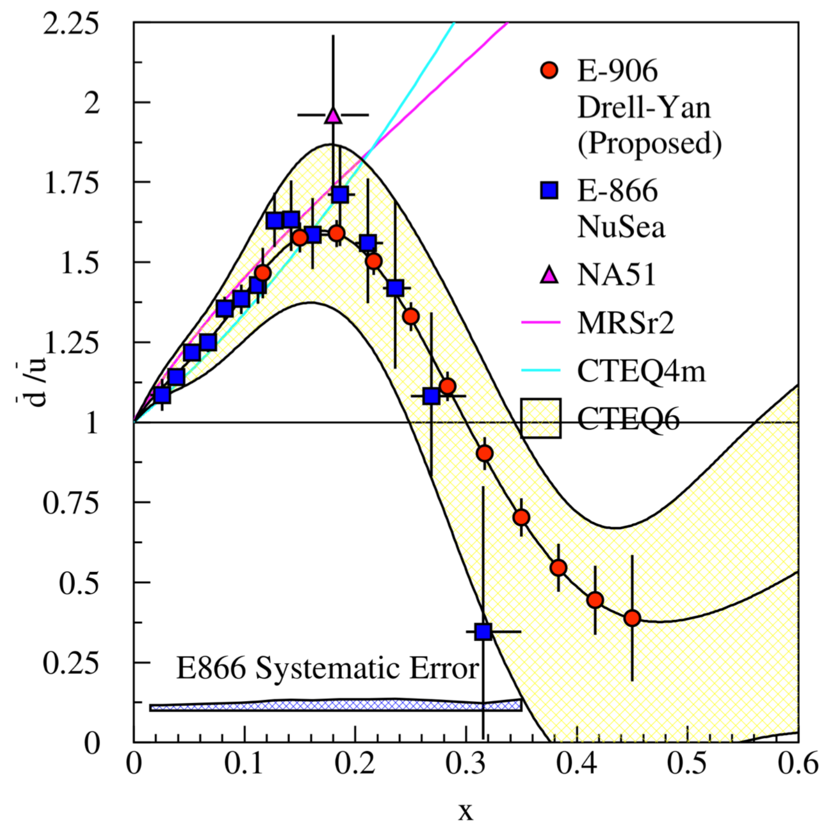
- **E-866** suggests a trend where the $\bar{d}/\bar{u}$ ratio appears to be decreasing at large-x.

- The **SeaQuest (E-906)** will probe the sea quark distribution using Drell-Yan at **higher x** and **lower Q^2** than **E-866**.

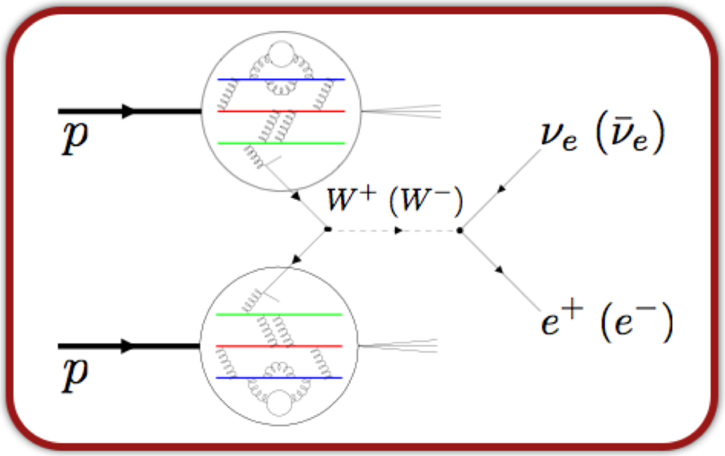
- More **direct** and **indirect** data are needed at **high-x** to help **constrain** the sea quark distributions.

- New measurements from different experiments can provide data at different **Q^2** and from different **scattering processes**.
  - This will allow for understanding different **systematic effects** and also serve as a **cross check** of our understanding of the physics.

J. Phys. Conf. Ser. 295 (2011) 012163



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
  - $u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$
  - $d + \bar{u} \rightarrow W^- \rightarrow e^- + \bar{\nu}$

- 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**

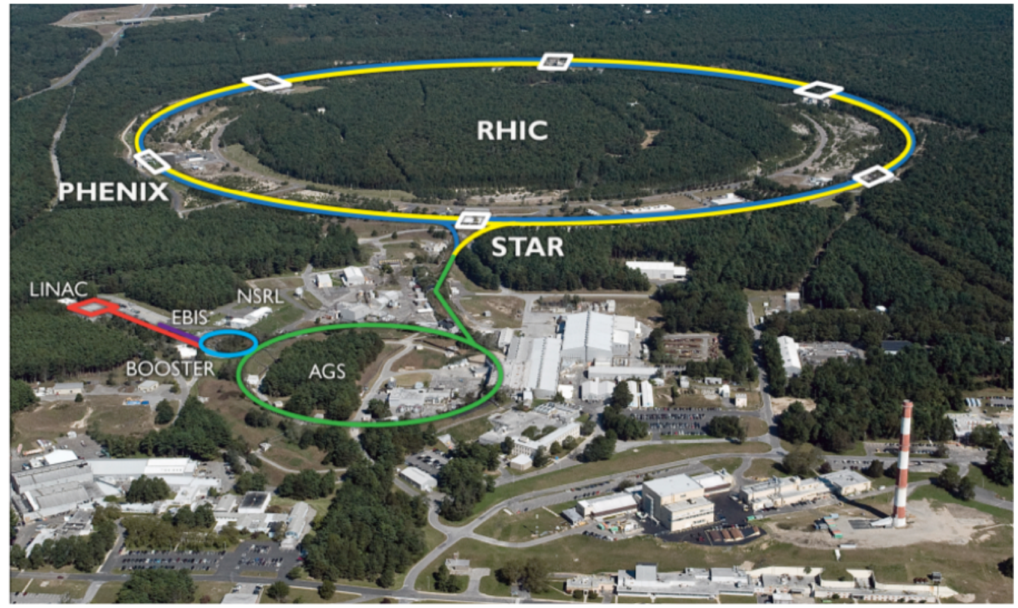
$$\frac{\sigma_{W^+}}{\sigma_{W^-}} \approx \frac{u(x_1)\,\bar{d}(x_2) + u(x_2)\bar{d}(x_1)}{d(x_1)\bar{u}(x_2) + d(x_2)\bar{u}(x_1)}$$

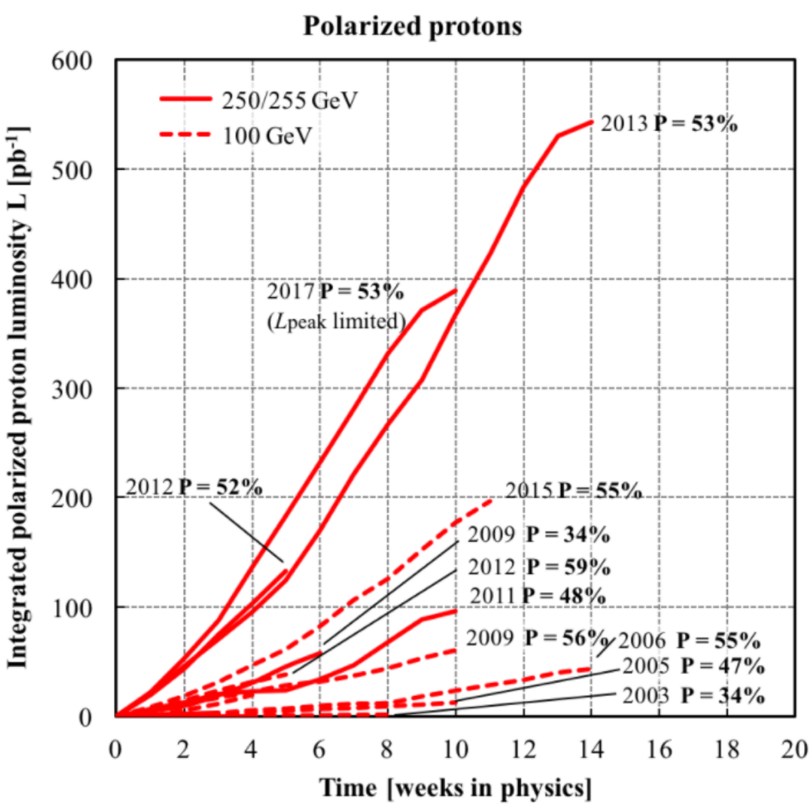
$$\frac{\sigma_{W^+}}{\sigma_{W^-}} = \left(\frac{N_O^+ - N_B^+}{N_O^- - N_B^-}\right)\left(\frac{\epsilon^-}{\epsilon^+}\right)$$

- +/- 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

Relativistic Heavy Ion Collider

- **RHIC** is the world's first polarized hadron collider
- Over the past several years luminosity at **RHIC** has **steadily increased**





p+p production runs

Run	$\sqrt{s}$ (GeV)	Sampled Luminosity (pb^{-1})
9	500	10
11	500	25
12	510	75
13	510	250
17	510	350

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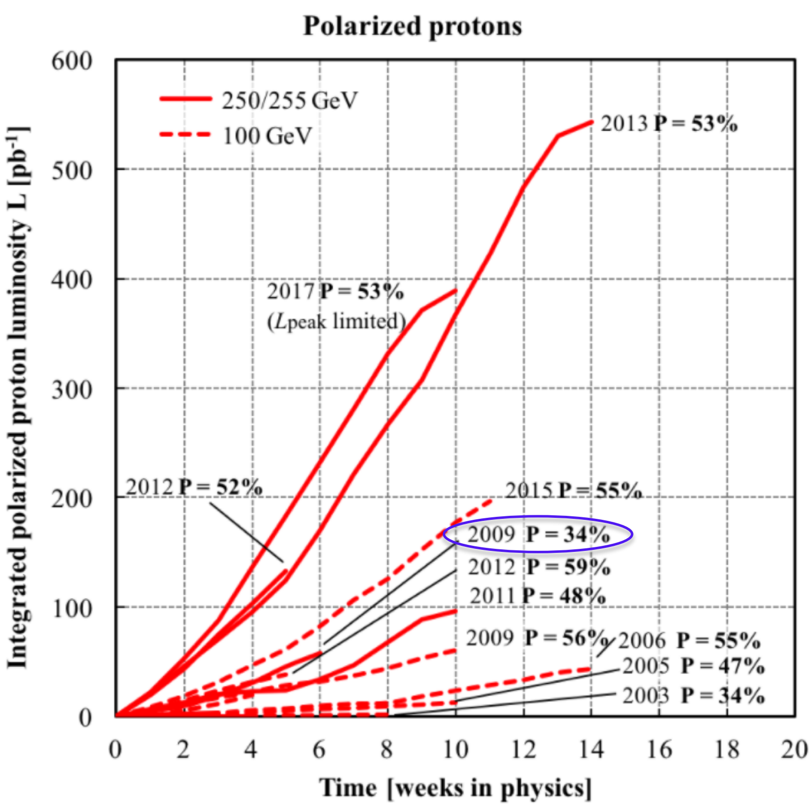

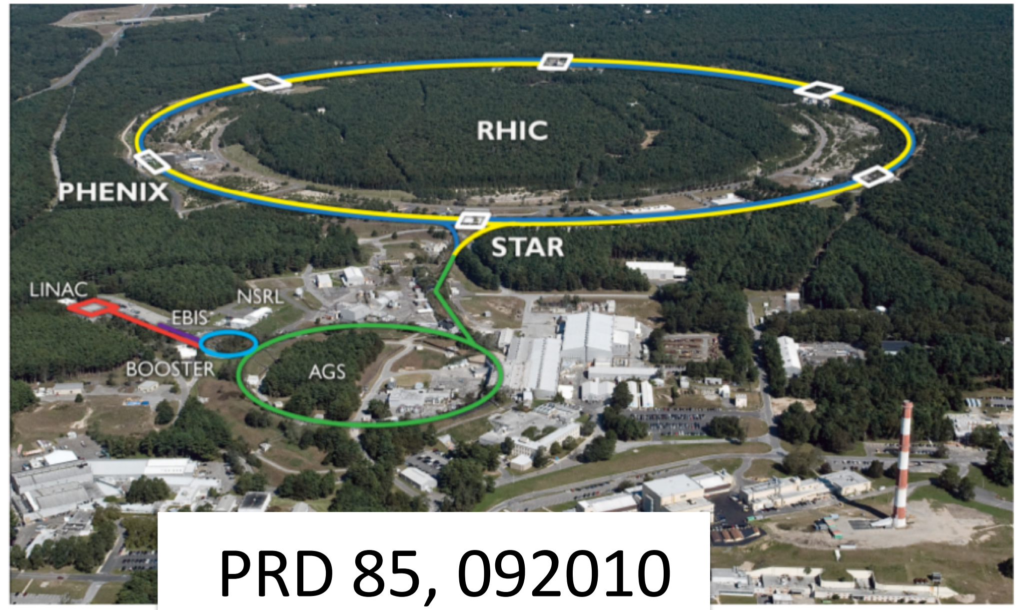

PRD 85, 092010

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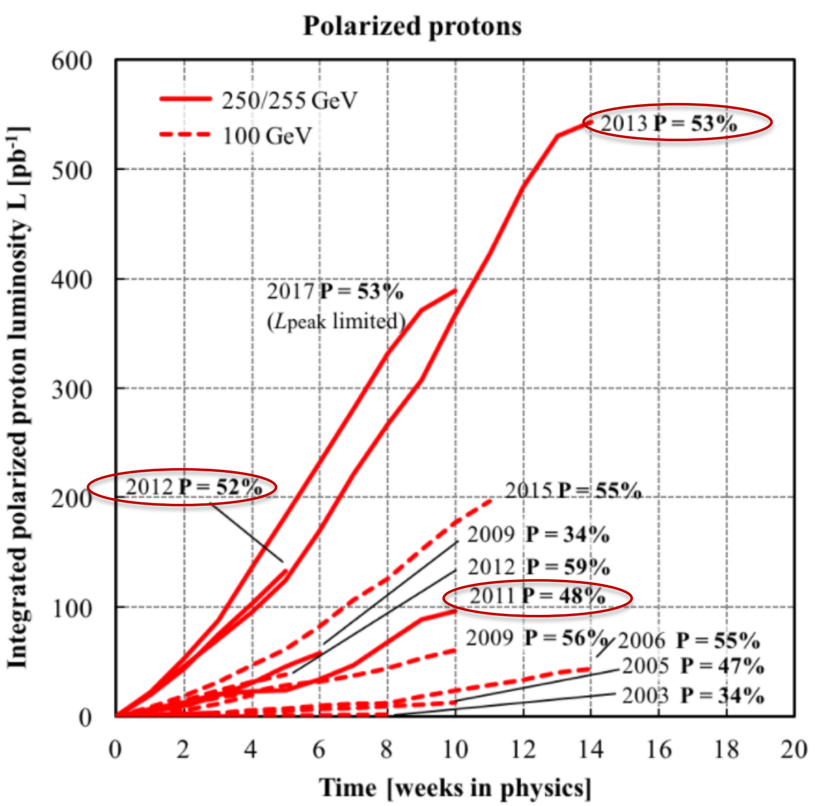

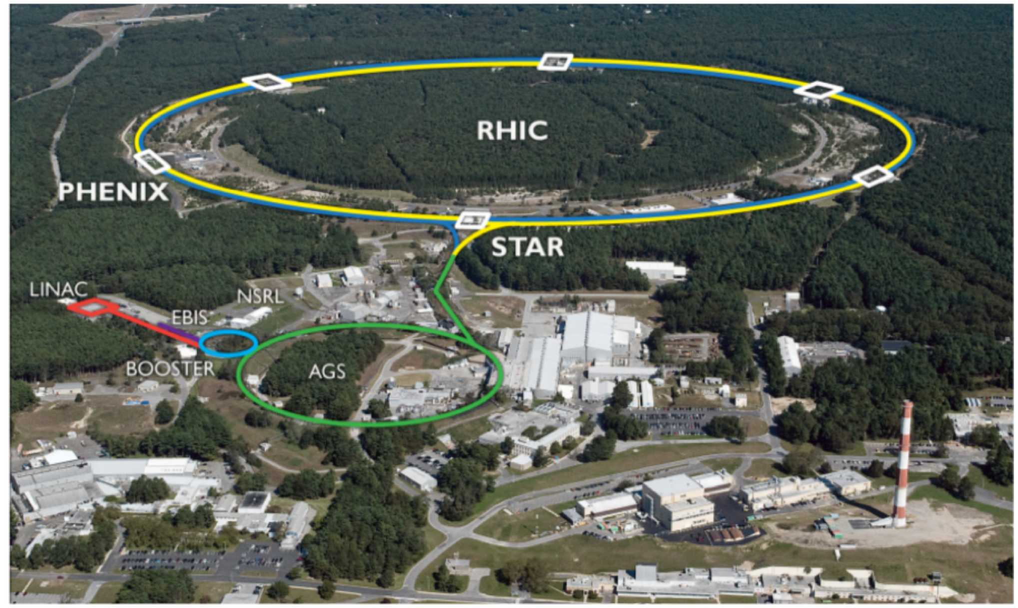

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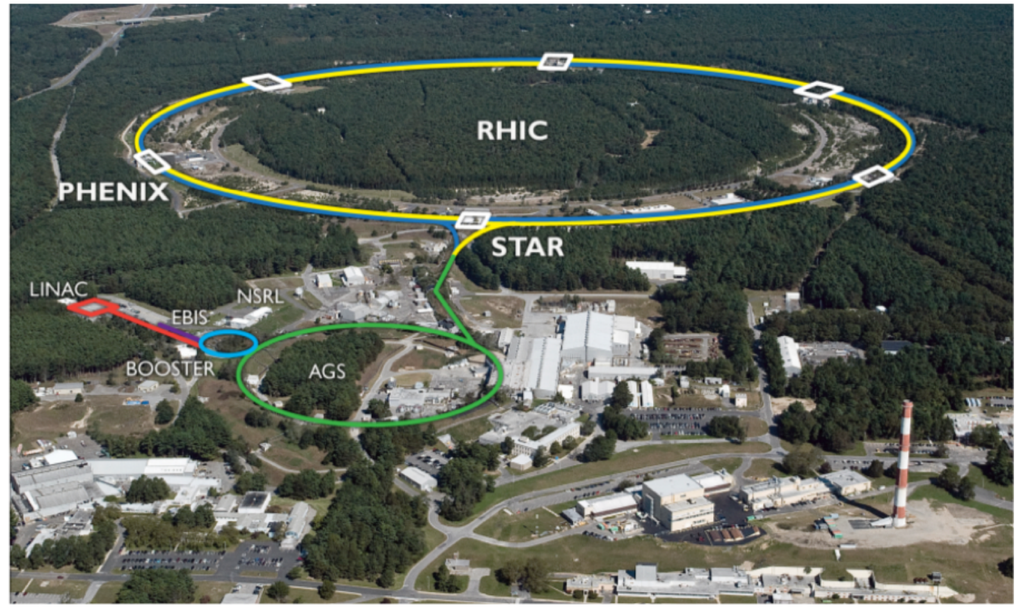

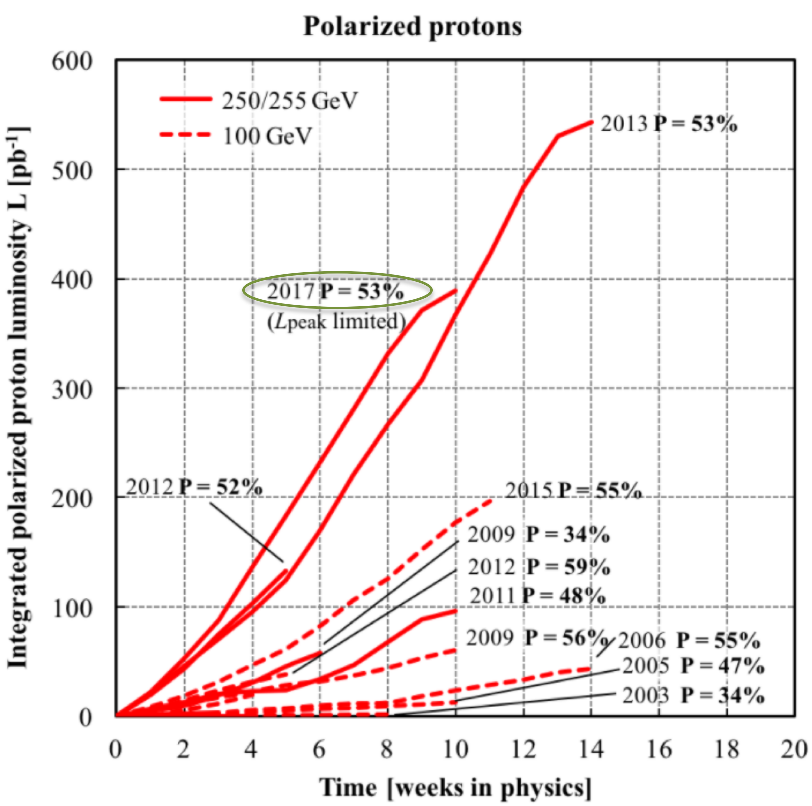

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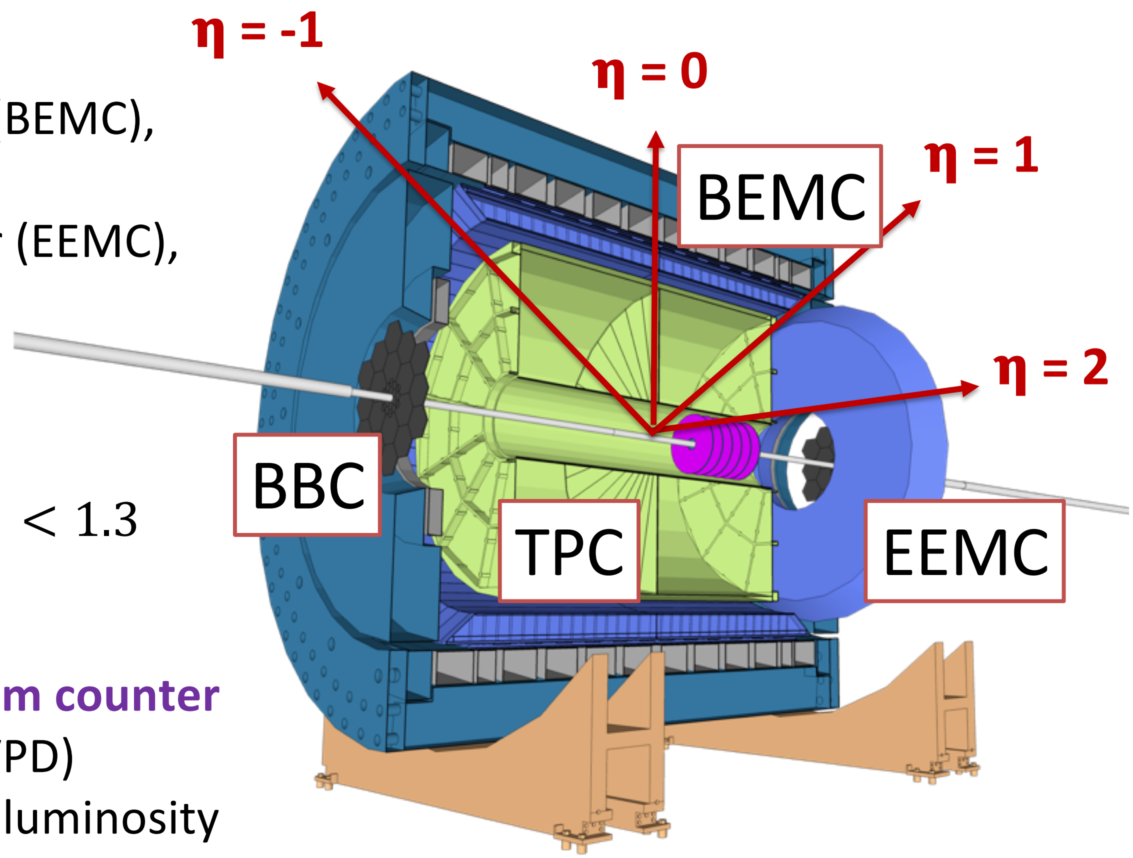
Solenoid Tracker At RHIC

- **Calorimetry system** with 2π coverage
  - Barrel electromagnetic calorimeter (BEMC), $-1 < \eta < 1$
  - Endcap electromagnetic calorimeter (EEMC), $1 < \eta < 2$

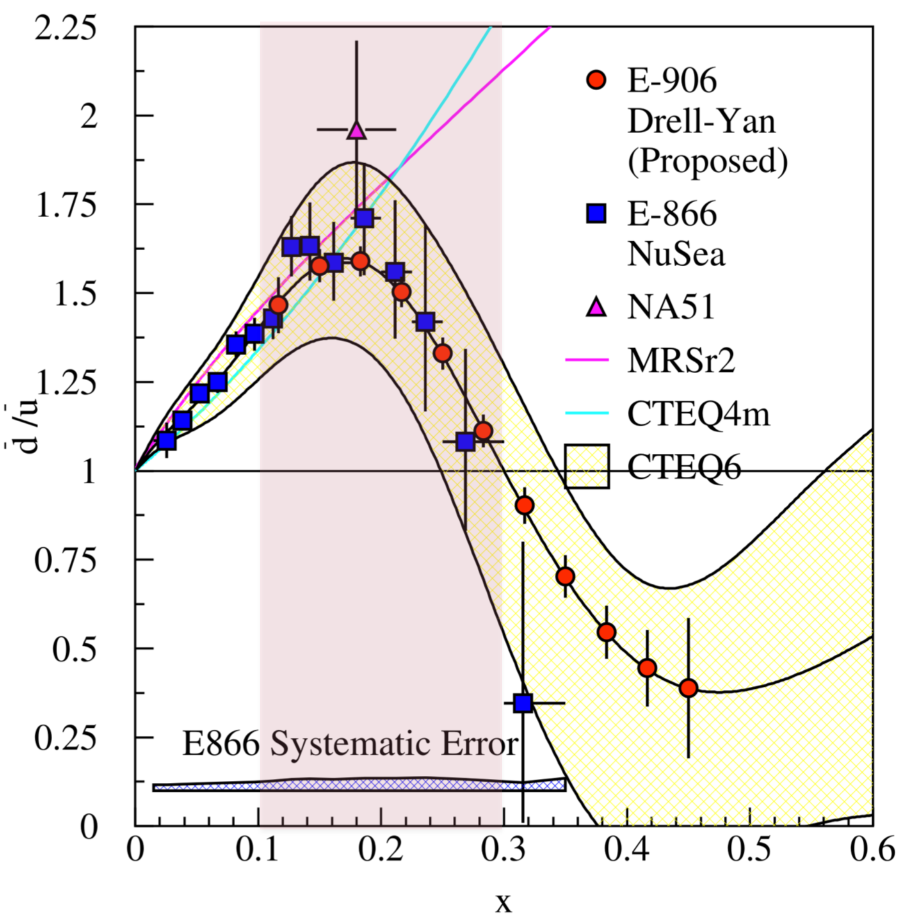
- **Time projection chamber** (TPC)
  - Provides tracking and particle ID $|\eta| < 1.3$

- **Zero degree counter** (ZDC), **beam-beam counter** (BBC), and **vertex position detector** (VPD)
  - Provides minimum bias trigger and luminosity monitors



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
  - $x = M_W/\sqrt{s} = 5.7\times10^{-3}$ ($x_1 \approx x_2$)



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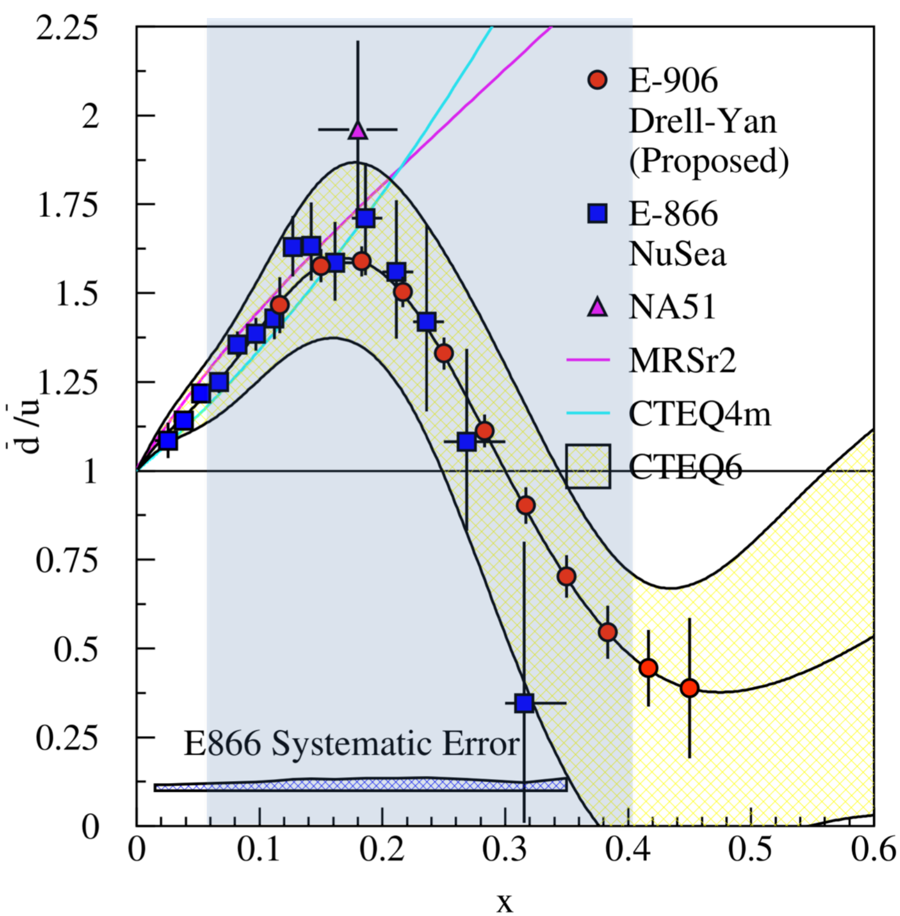
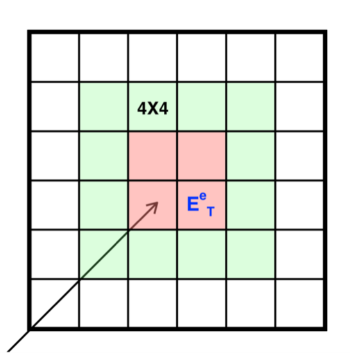
- In STAR the **EEMC** could be used to obtain a more forward η-bin (**$1.1 < \eta < 2$**) which would extend the x reach of STAR
  - $0.06 < x < 0.4$ for $-2 < \eta < 2$

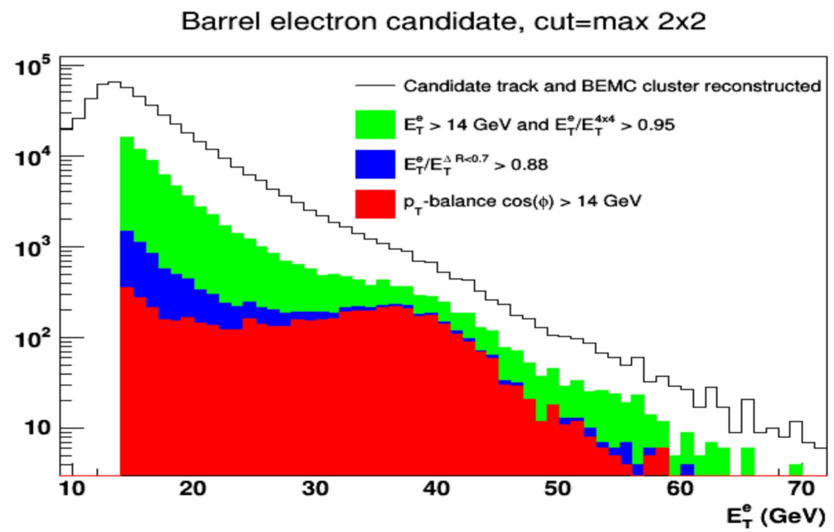


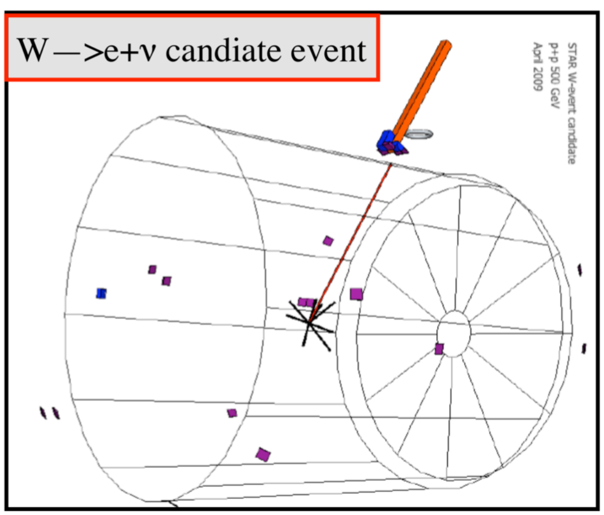
Selecting W Candidates

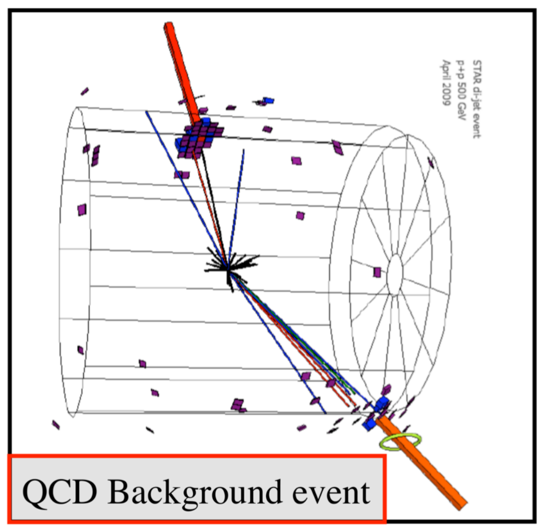
- Mid-rapidity STAR W selection criteria
  - Match p_T > 10 GeV/c track to BEMC cluster
  - Isolation ratio 1 / Isolation ratio 2
  - p_T-balance cut
  - Leads to good charge discrimination

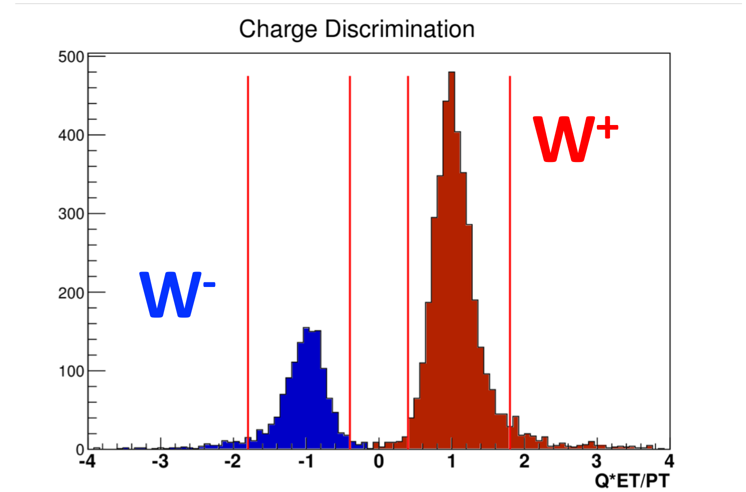


TPC track extrapolated to BEMC tower grid





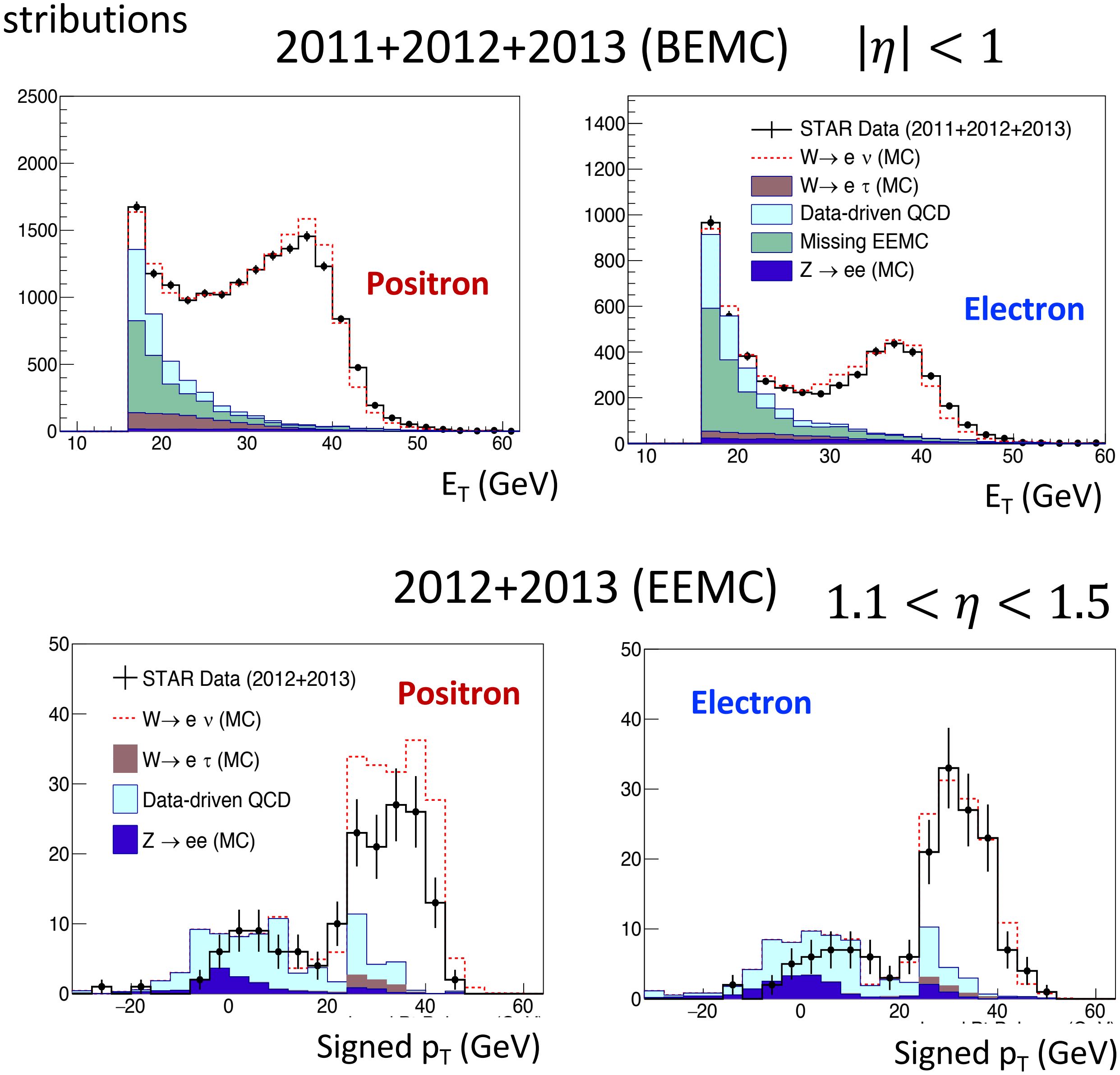




Backgrounds

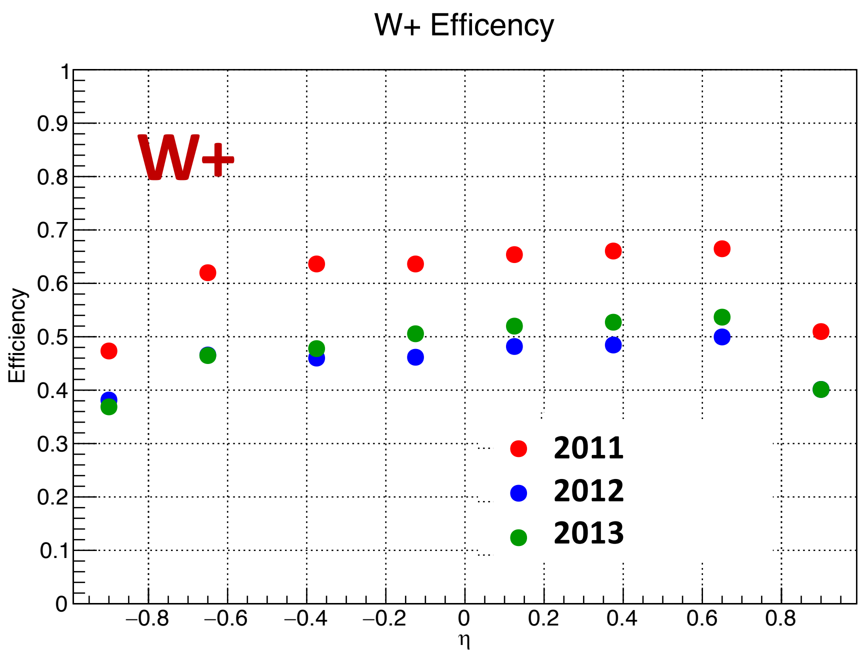
○ **W+ /W- signal** and **background** distributions

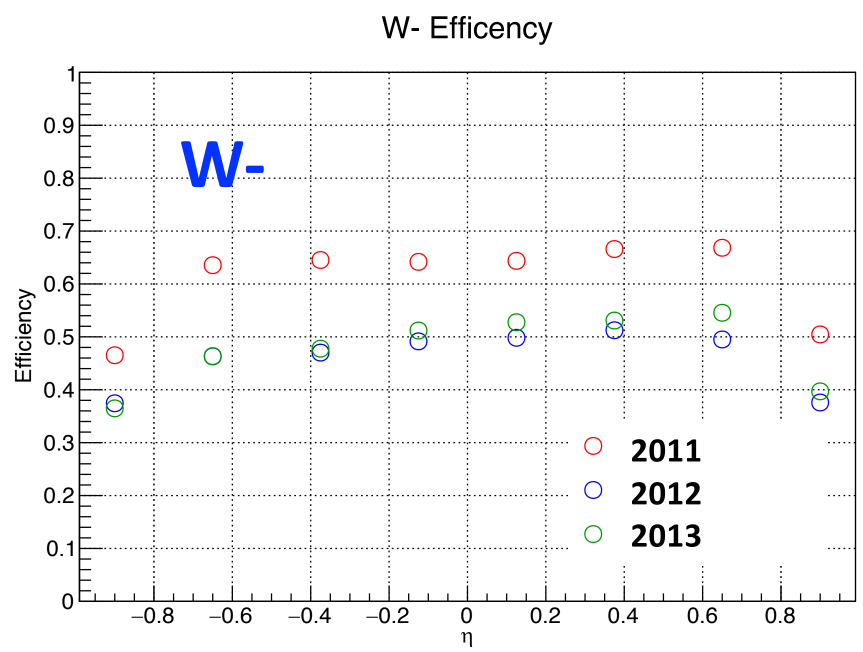
- **Data-driven QCD** background satisfies $e^{+/-}$ isolation cuts
- **Missing EEMC background** results from backward "Jet" at non-existing calorimeter coverage for $-2 < \eta < -1.1$
- **Missing EEMC background** is estimated from EEMC located at $1.1 < \eta < 2$
- **Electro-weak background** from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



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).





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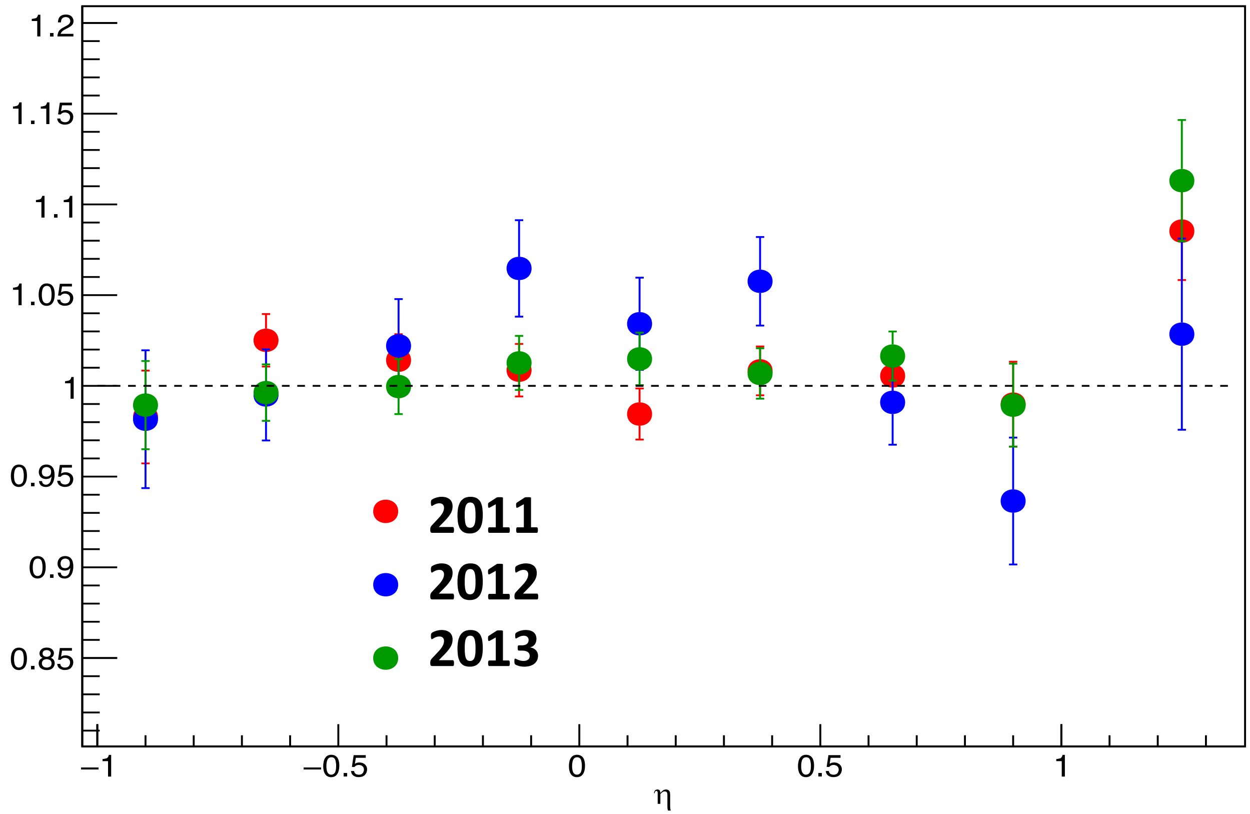
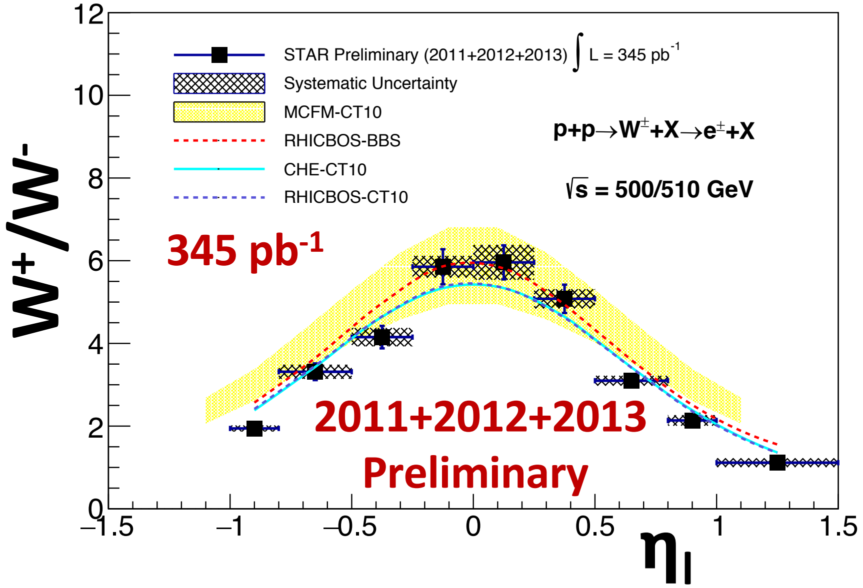
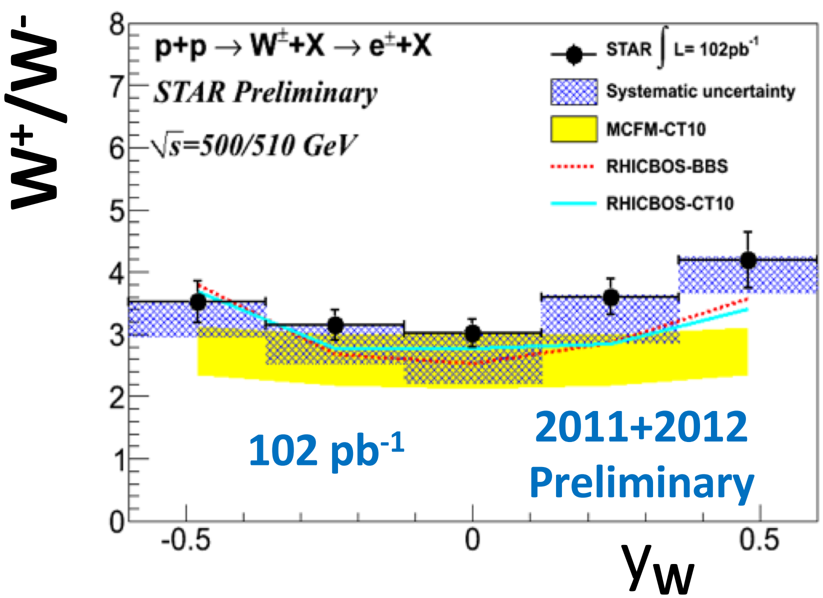
  - Minimal charge dependence leads to small correction to the W cross section ratio.

W-/W+ Efficiency



W Cross Section Ratio



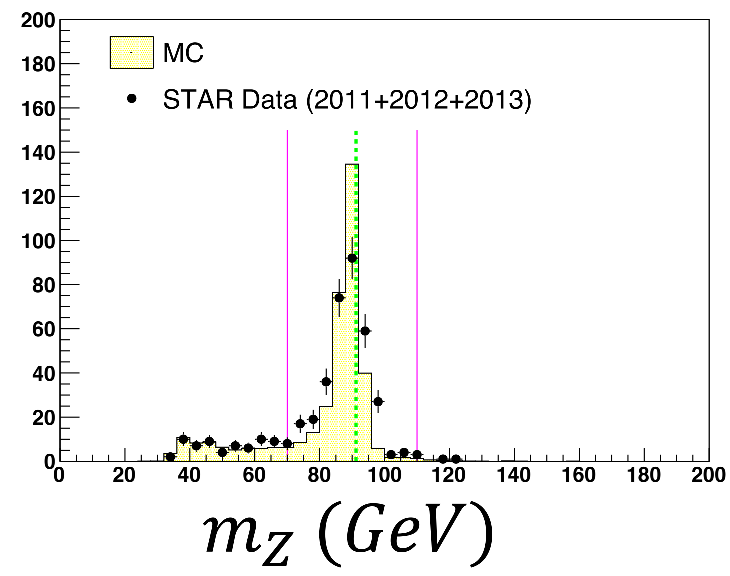


- STAR **2017** W production data is expected to add **350 pb^{-1}** more data.
- Final systematic uncertainties will be reduced for **W cross section ratio** vs. **lepton pseudo-rapidity** compared to preliminary result.
- Impact on PDF distributions currently under investigation.
- The **W boson rapidity** 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**.

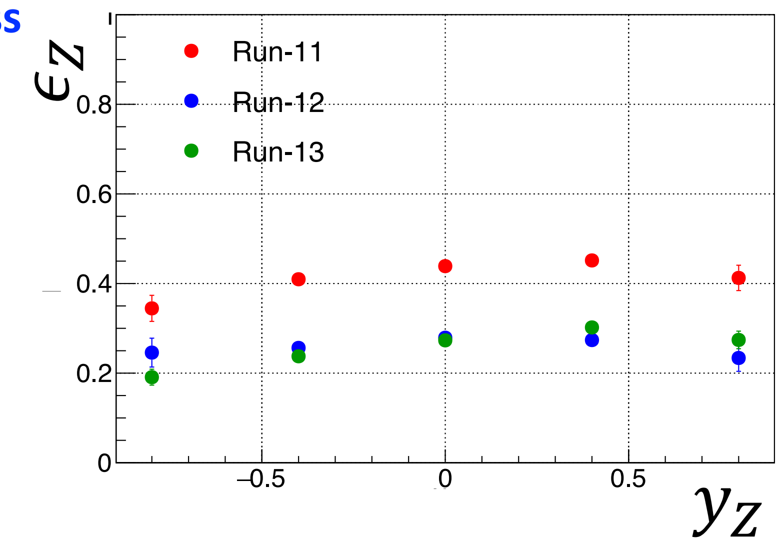
Selecting Z Candidates

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

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

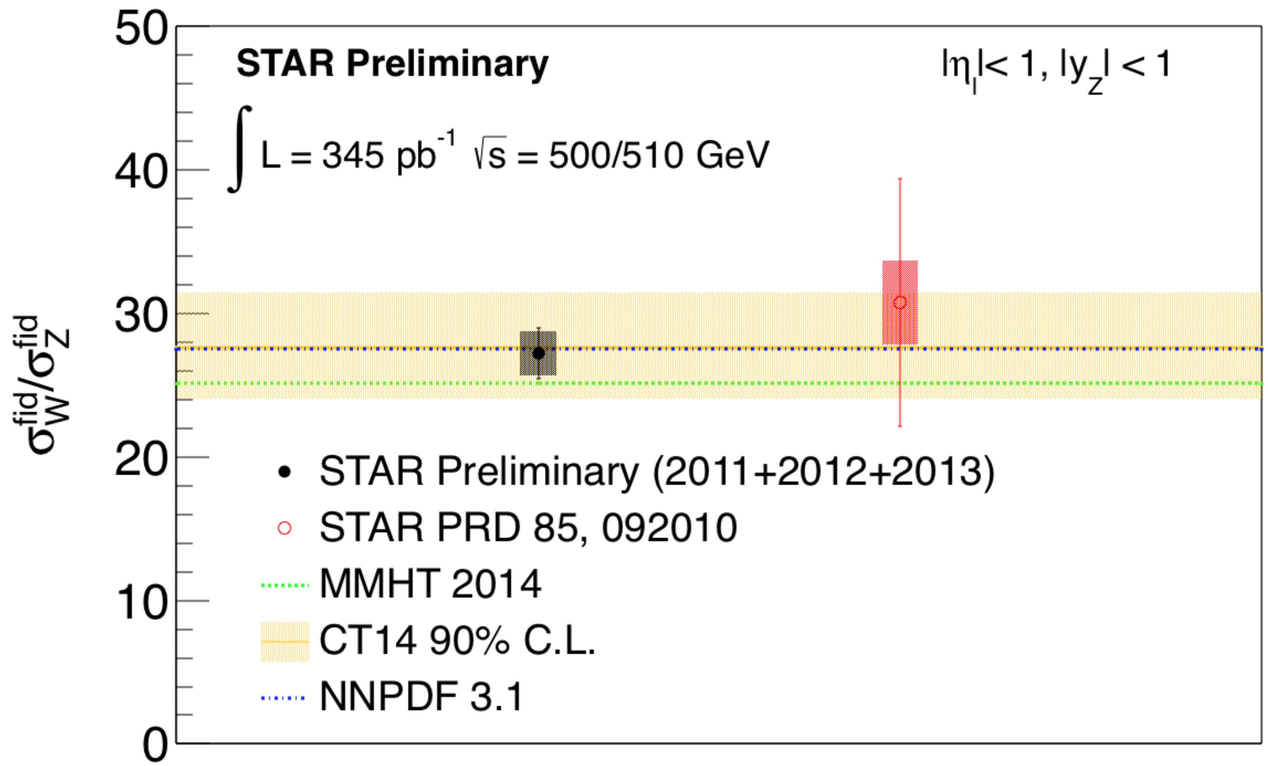


- **Z candidates** are selected by using **isolated $e^{\pm}$ sample** and requiring a pair of isolated $e^{\pm}$ candidates to have **opposite charge**.
  - The invariant mass of each e^+e^- pair can be reconstructed.
  - Final Z candidates selected using an **invariant mass cut of $70\ GeV < m_Z < 110\ GeV$**



- Reconstruction of two charged tracks lead to **cleaner** identification of Z candidates.
- Efficiencies (ϵ_Z) and background are estimated using Pythia and GEANT
  - No background correction applied.

W/Z Cross Section Ratio

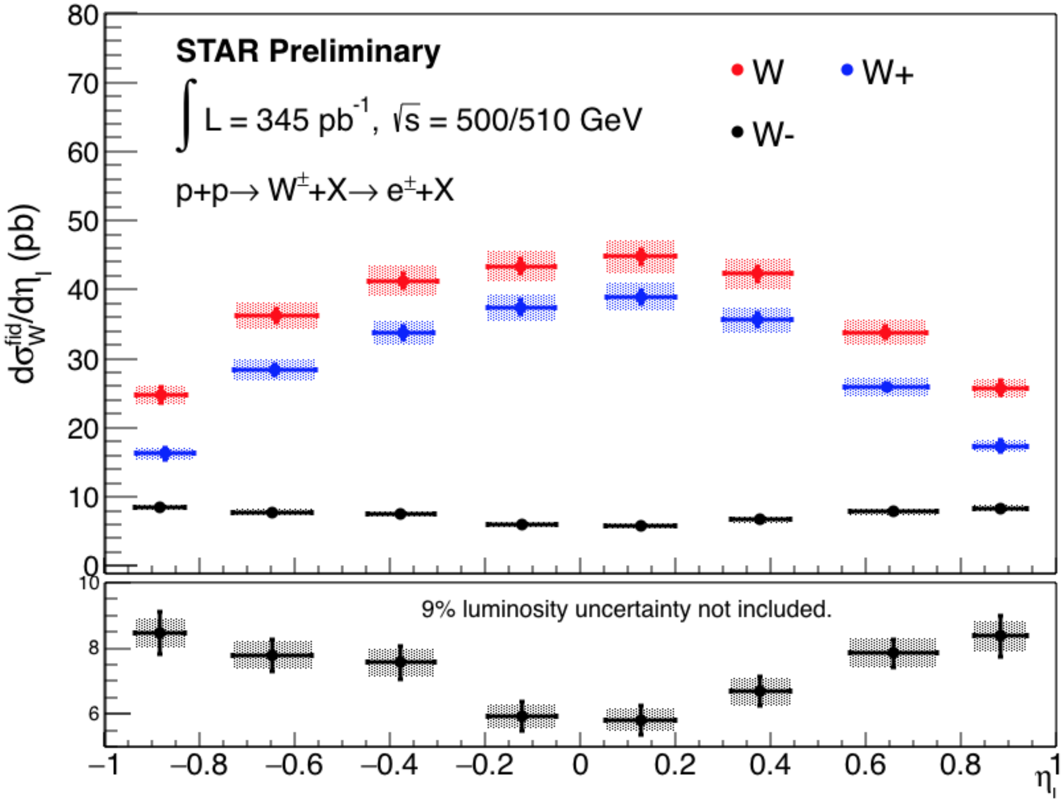


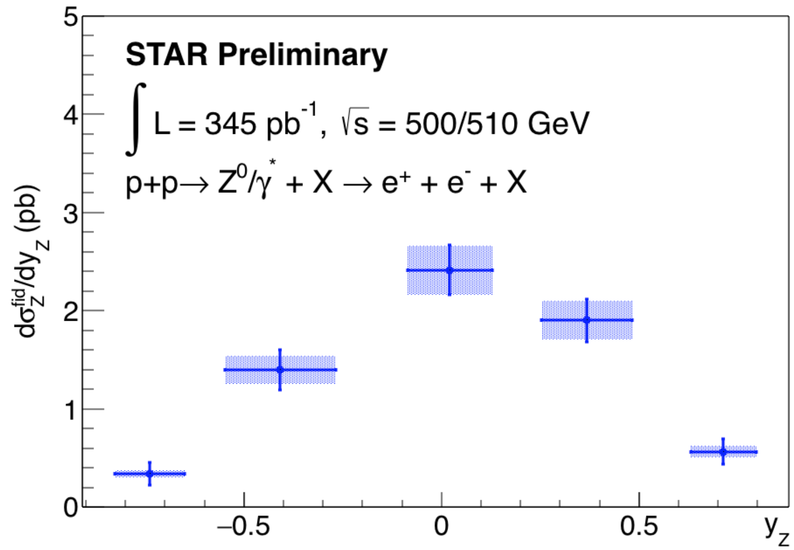
- Can be used to measure the **W/Z cross section ratio**

$$\frac{\sigma_W^{fid}}{\sigma_Z^{fid}} = \frac{N_O^W - N_B^W}{N_Z^O} \cdot \frac{\epsilon_Z}{\epsilon_W}$$, 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** to PDFs.

Differential Cross Sections





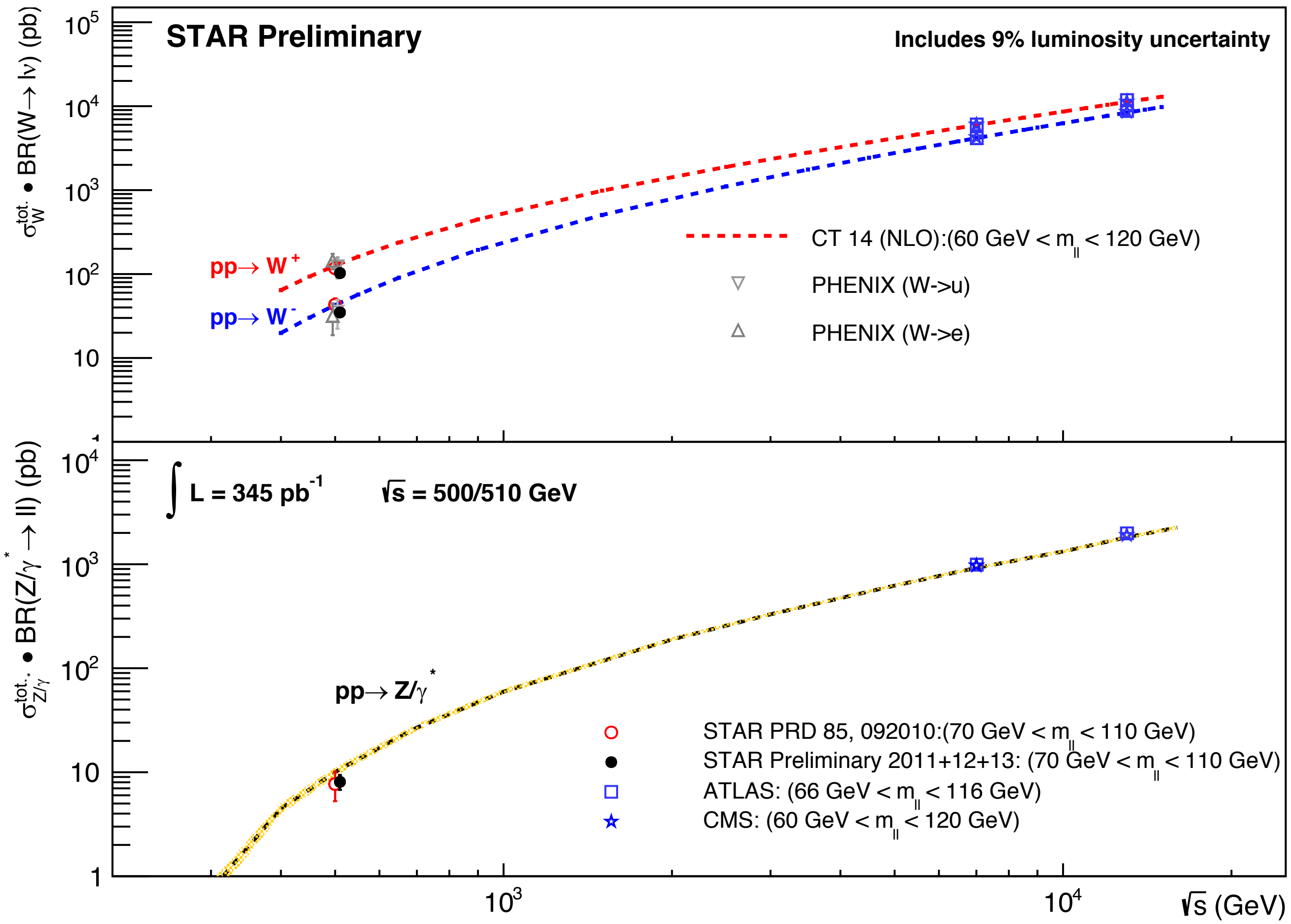
- Including the luminosity (L) information, one can also measure the **differential cross sections**

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

- Work is currently being done in hopes of reducing the two dominant systematic uncertainties
  - Tracking efficiency: 5% for W's (10% for Z's)
  - Luminosity: 9%

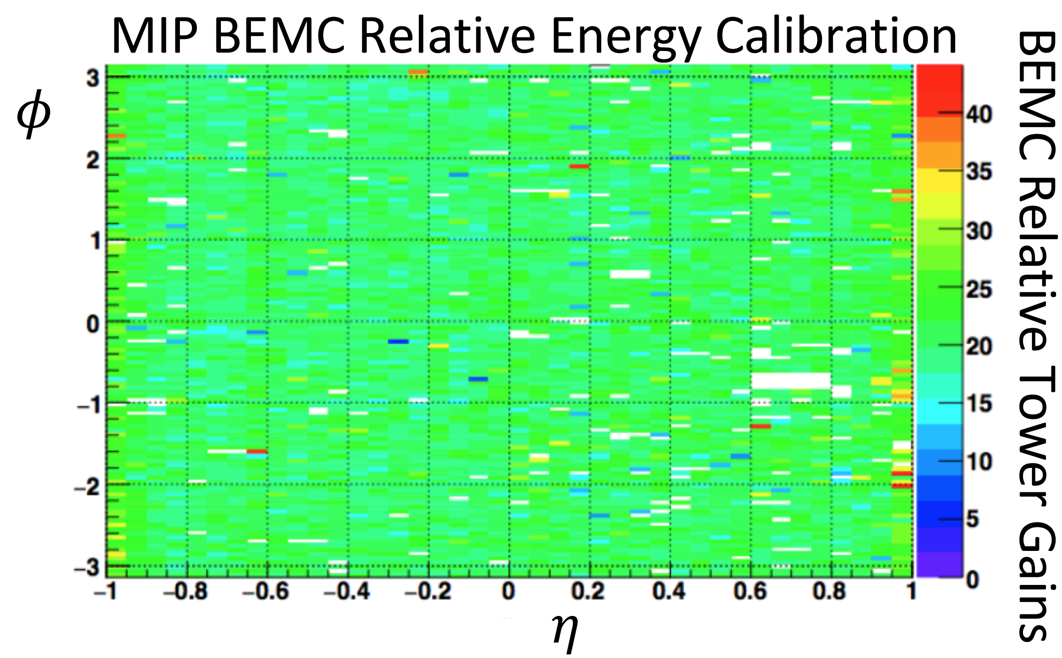
Total Cross Sections

- 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 2017 Analysis Update

- STAR 2017 $p^{\uparrow} + p$ data set collected 350 pb^{-1}
  - Sivers function (via W,Z A_N)
  - Drell-Yan
  - W/Z cross sections and cross section ratios
- W and Z production data calibration, QA, and analysis is underway
- Offline **BEMC calibration** is now wrapping up
  - Initial tower QA has been done
  - Relative tower calibration completed using MIPs
  - Absolute energy calibration underway using electron E/p

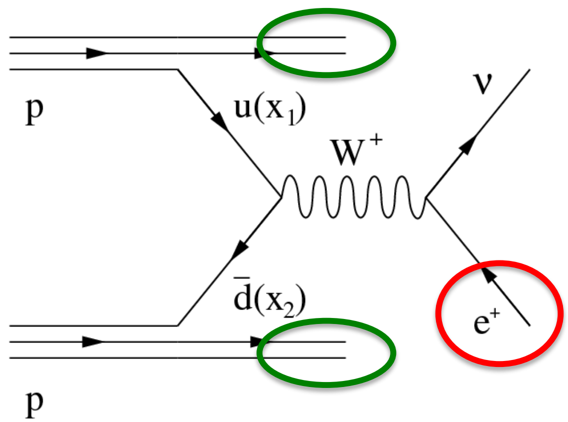


Summary

- **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
- On going analysis from STAR **2017** W and Z production data will **double** the statistics of the STAR preliminary cross section and cross section ratio measurements.

Reconstruction W bosons

First developed at STAR for run 11 transverse single-spin asymmetry measurement of W bosons
Phys.Rev.Lett. 116 (2016)



Ingredients for the analysis
- Isolated electron
- neutrino (not measured directly)
- Hadronic recoil

W boson momentum reconstruction technique well tested at FermiLab and LHC
[CDF: PRD 70, 032004 (2004); ATLAS: JHEP 1012 (2010) 060]

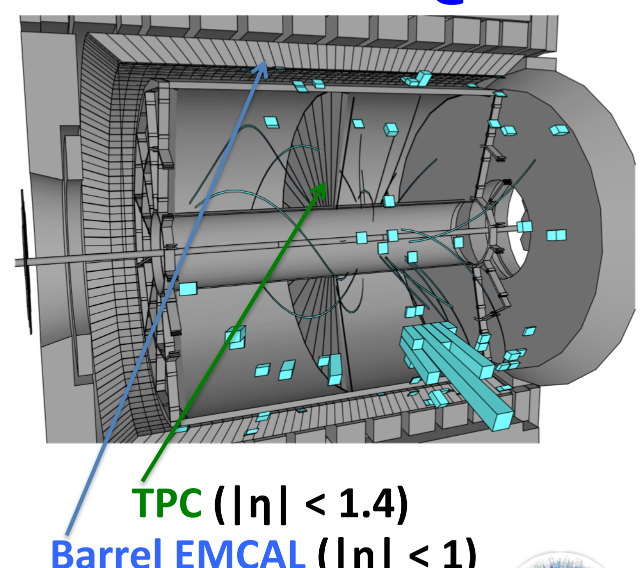
- ❑ **Select events with the W-signature (STEP 1)**
  - ➢ Isolated high P_T electron
- ❑ **Neutrino transverse momentum is reconstructed from missing P_T (Step 2)**

$$\vec{P}_T^{\nu} \approx - \sum_{i \in \substack{tracks \\ clusters}} \vec{P}_T^{i}$$

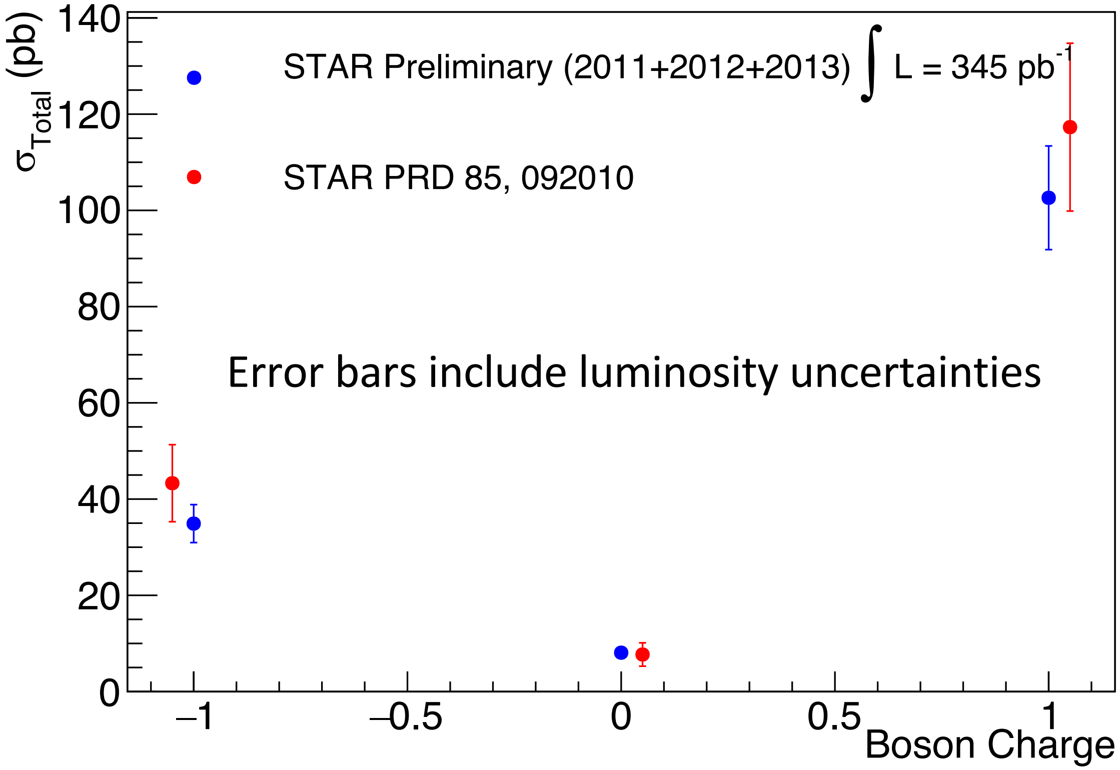
- ❑ **Neutrino's longitudinal momentum is reconstructed from the decay kinematics (Step 3)**

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

The STAR detector @ RHIC



Total Cross Sections: STAR 2009 Comparison



- Measurements consistent between published cross sections based on STAR 2009 data set and new preliminary results based on STAR 2011,2012, and 2013 data sets.
- Error bars include luminosity uncertainties
  - 2009: 13%
  - STAR Preliminary (2011+2012+2013): 9%