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

Salvatore Fazio (BNL) on behalf of

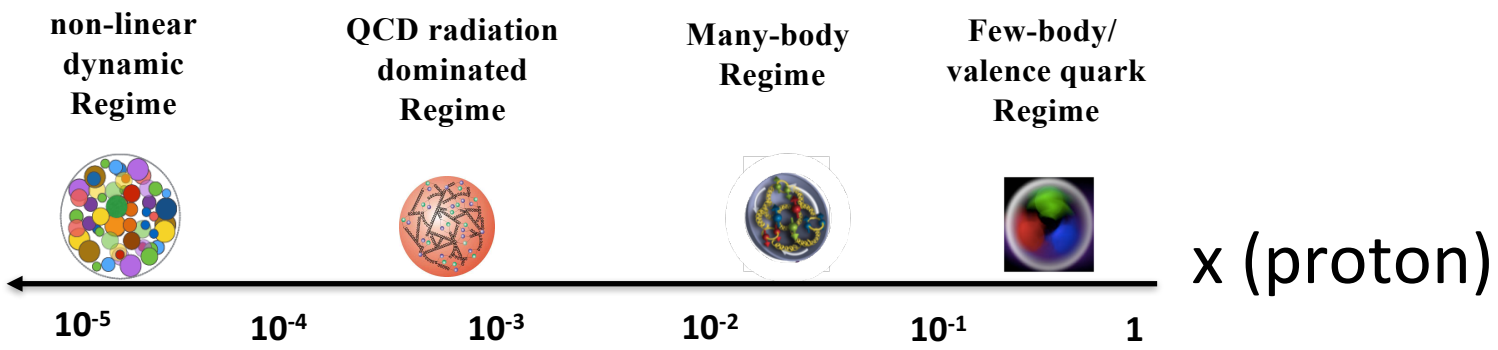
Matthew Posik (Temple University)

STAR Collaboration

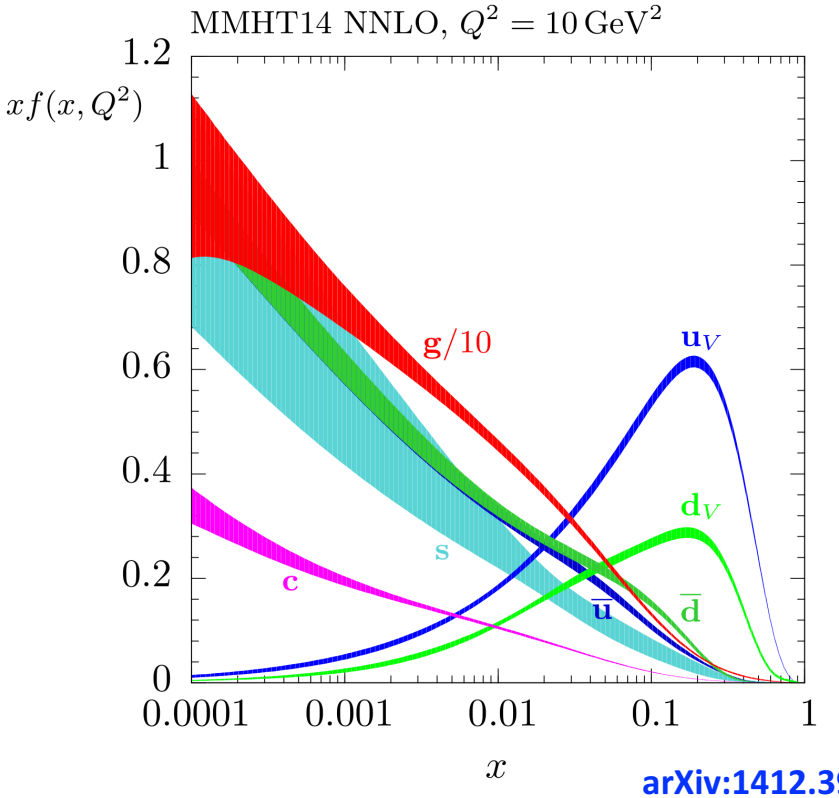
DIS 2017
University of Birmingham
April 3-7 2017

TEMPLE UNIVERSITY®

Motivation



- **Parton Distribution Functions** (PDFs) probe the internal structure of the proton.
- The **x-dependence** of these PDFs allow you to distinguish between the **intrinsic properties** of the proton and **QCD radiation**.
- Several global analyses (CT14, MMHT14, BS15, etc.) have extracted PDFs using various data and functional fit assumptions.



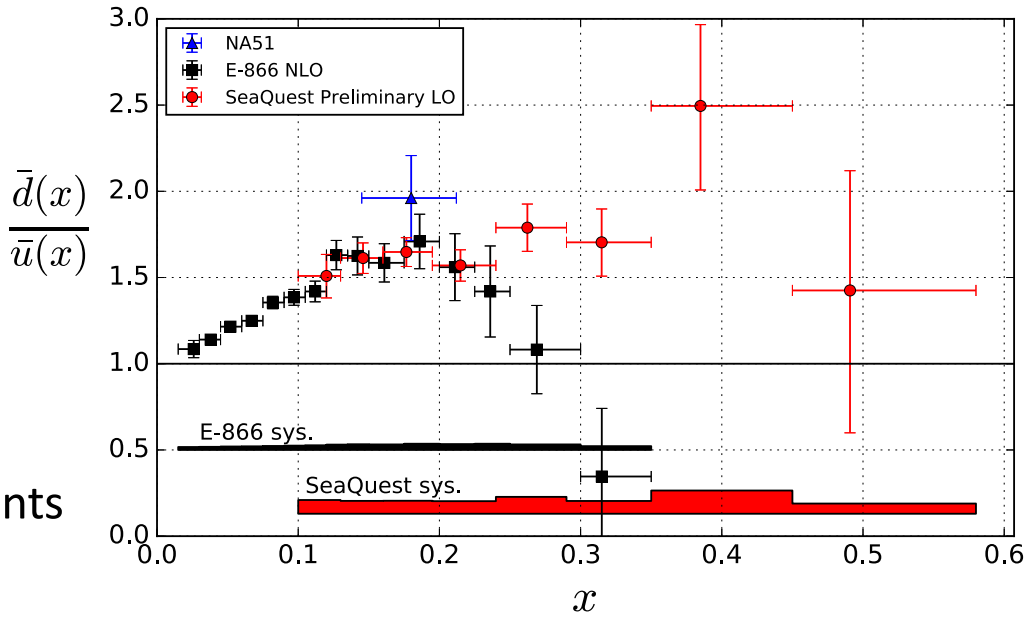
arXiv:1412.3989

Motivation

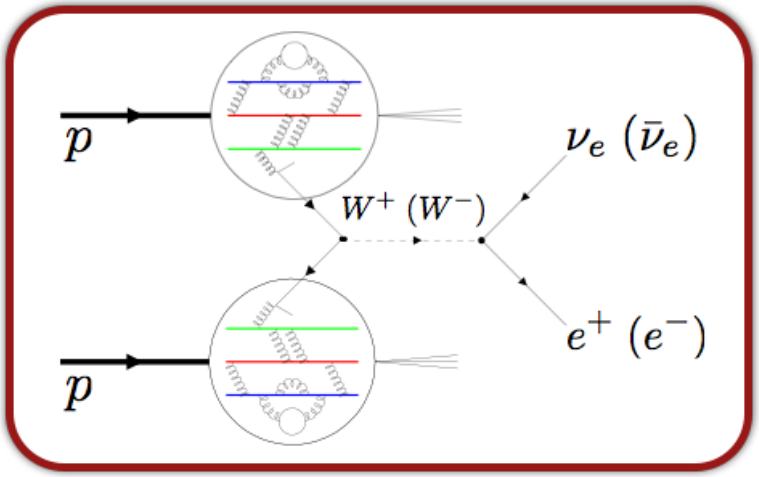
- Unpolarized **dbar/ubar** distribution can be probed via Drell-Yan production.
- **E-866** suggests a trend where the **dbar/ubar** ratio appears to be decreasing at large-x.

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

- The **preliminary SeaQuest** trend appears 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
  - $u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$
  - $d + \bar{u} \rightarrow W^- \rightarrow e^- + \bar{\nu}$

- The **charged W cross-section ratio**
  - is proportional to the **dbar/ubar** ratio
  - can be used to **constrain** the **sea quark distributions**

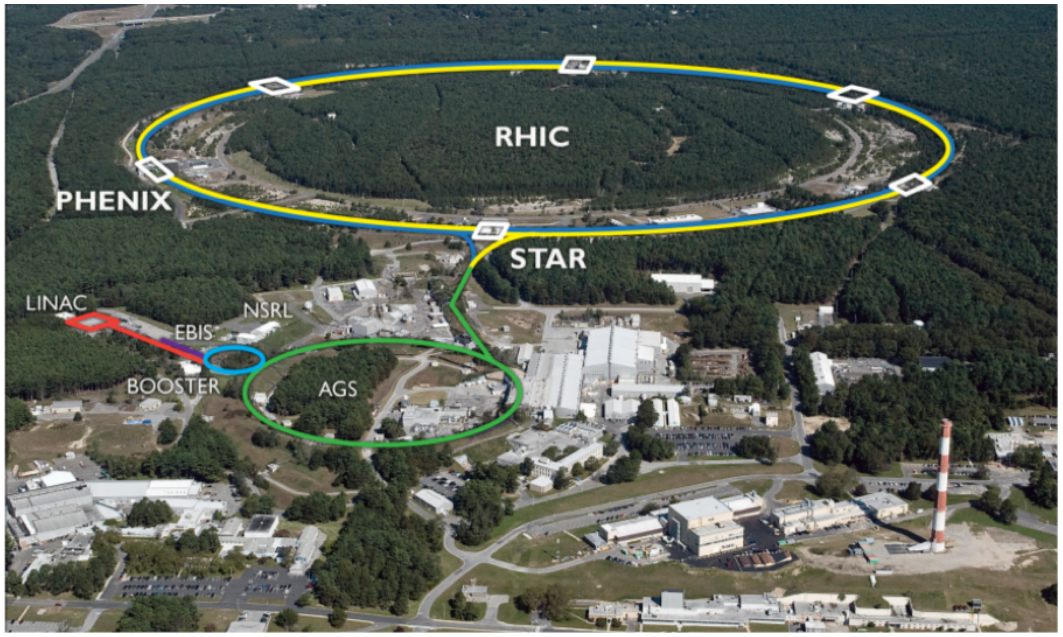
$$\frac{\sigma_{W+}}{\sigma_{W-}} \approx \frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$

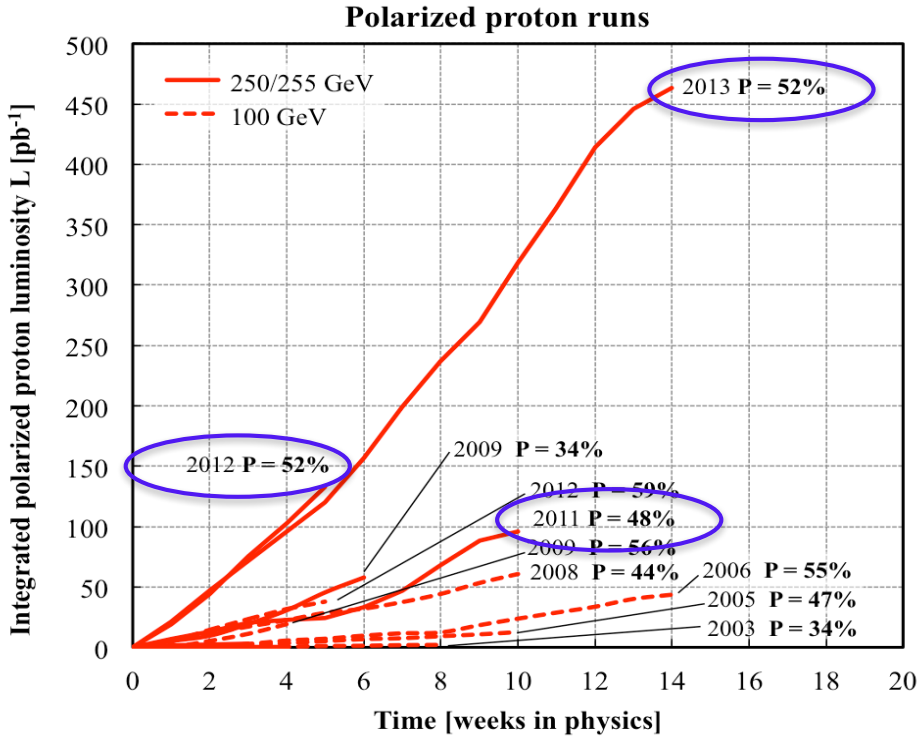
$$\frac{\sigma_{W+}}{\sigma_{W-}} = \left(\frac{N_O^+ - N_B^+}{N_O^- - N_B^-}\right)\left(\frac{\epsilon^-}{\epsilon^+}\right)$$

- +/- 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 measured W efficiency

Relativistic Heavy Ion Collider

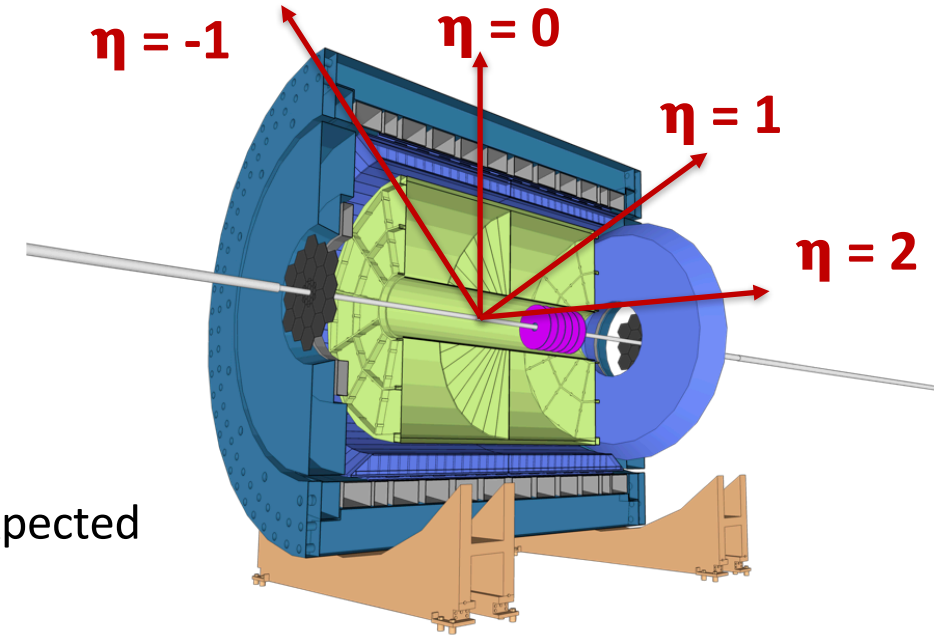
- **RHIC** is the world's first polarized hadron collider
- Over the past several years luminosity at **RHIC** has **steadily increased**





Solenoidal Tracker At RHIC

- **Calorimetry system** with 2π coverage
  - Barrel electromagnetic calorimeter (**BEMC**), $-1 < \eta < 1$
  - Endcap electromagnetic calorimeter (**EEMC**), $1.1 < \eta < 2$
- Time projection chamber (**TPC**), $|\eta| < 1.3$
- The **2017** (transverse p+p √s = 510 GeV) run is expected to deliver ~**400 pb^{-1}** more data

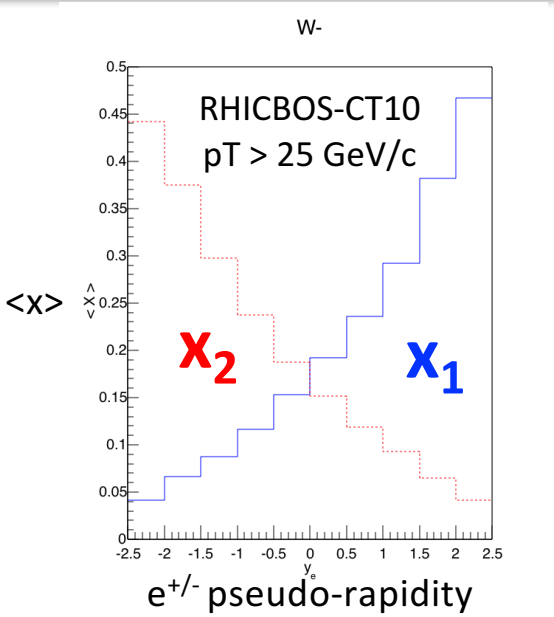


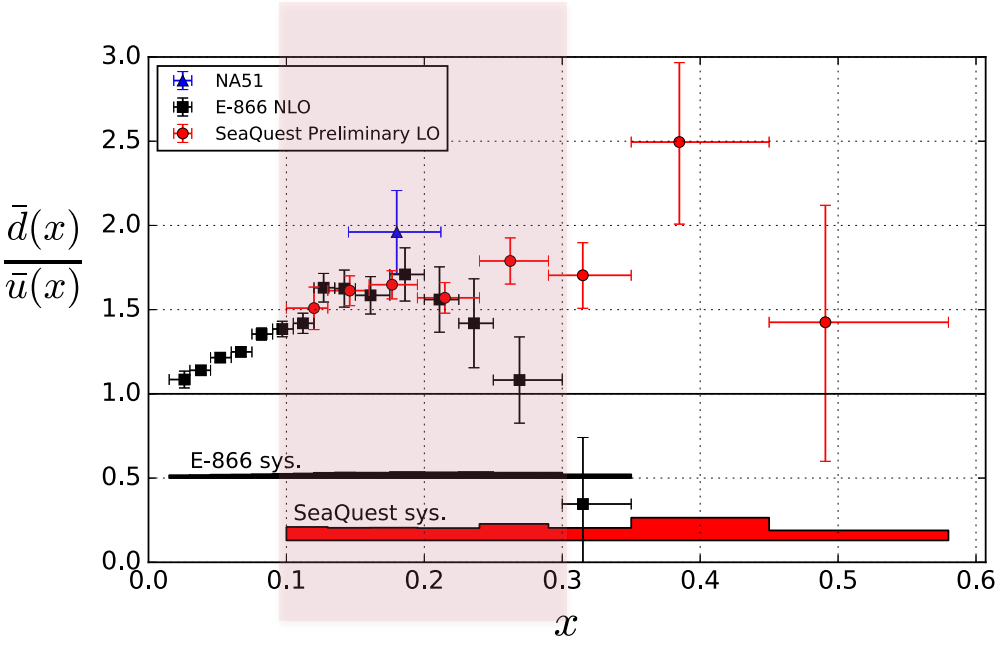
Production runs at **√s = 500/510 GeV**

Year	~Luminosity (pb^{-1})
2011	25 (sampled)
2012	75 (sampled)
2013	250 (sampled)
2017	400 (delivered)
Combined	**750**

STAR Kinematics

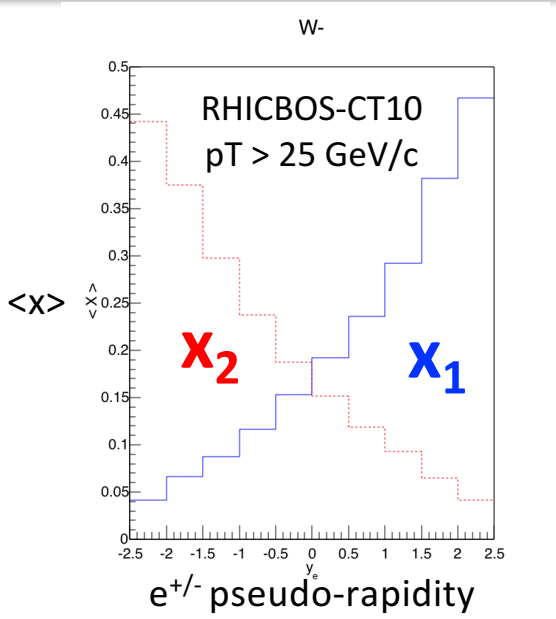
- Approximate kinematic range at STAR **mid-rapidity** (**TPC + BEMC**)
  - $0.1 < x < 0.3$ for $-1 < \eta < 1$
- For collision energies of $\sqrt{s} = 500$ GeV and $\eta = 0$, ($x_1 \approx x_2$)
  - $x = M_W/\sqrt{s} = 0.16$

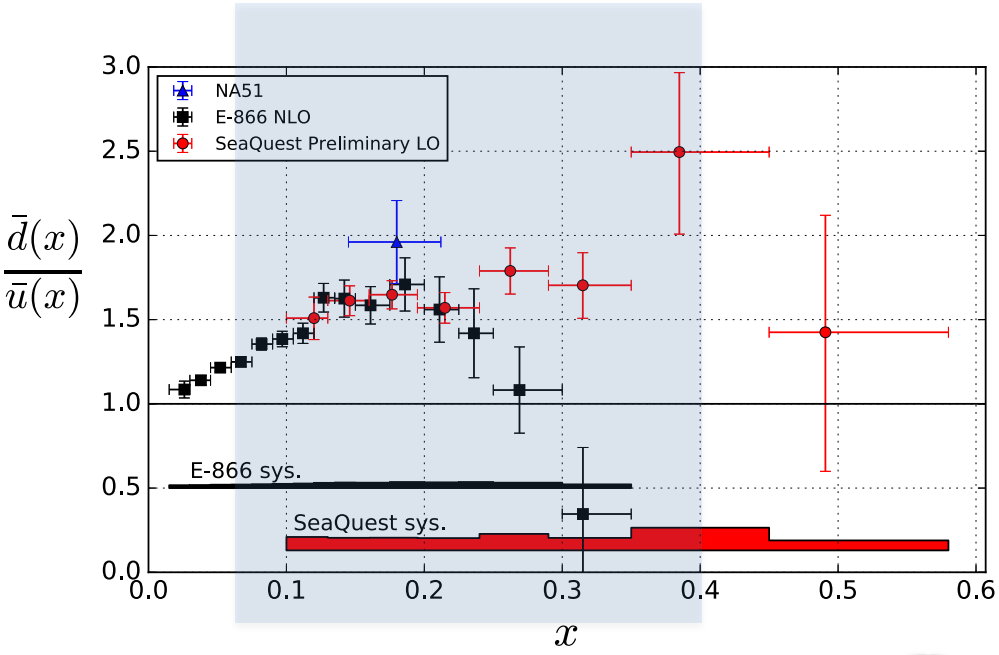




STAR Kinematics

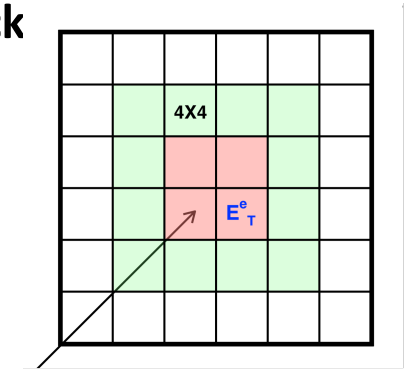
- Approximate kinematic range at STAR **mid-rapidity** (**TPC + BEMC**)
  - $0.1 < x < 0.3$ for $-1 < \eta < 1$
- For collision energies of $\sqrt{s}$ = 500 GeV and $\eta = 0$, ($x_1 \approx x_2$)
  - $x = M_W/\sqrt{s} = 0.16$
- In STAR the **EEMC** could be used to obtain a more forward eta-bin (**$1.1 < \eta < 2$**) which would extend the x reach of STAR
  - $0.06 < x < 0.4$ for $-2 < \eta < 2$
- Analysis of this **forward EEMC** eta-bin is currently underway



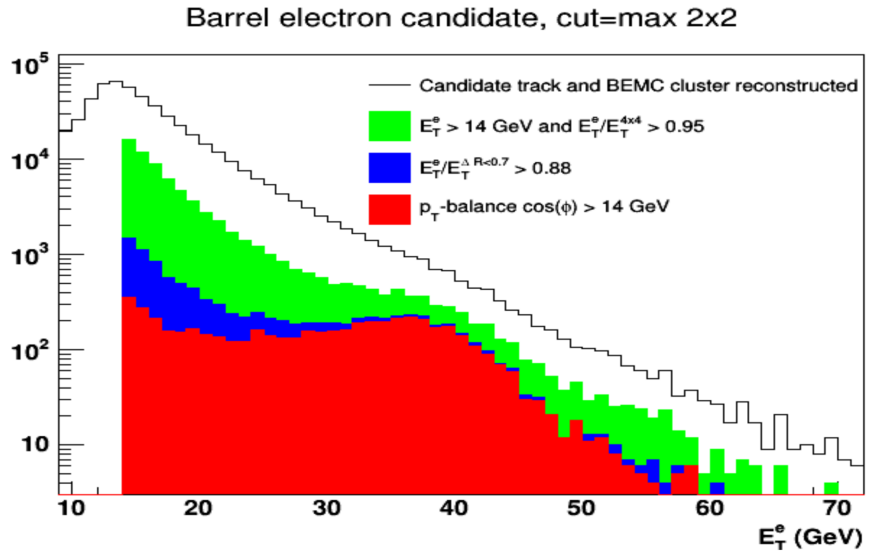


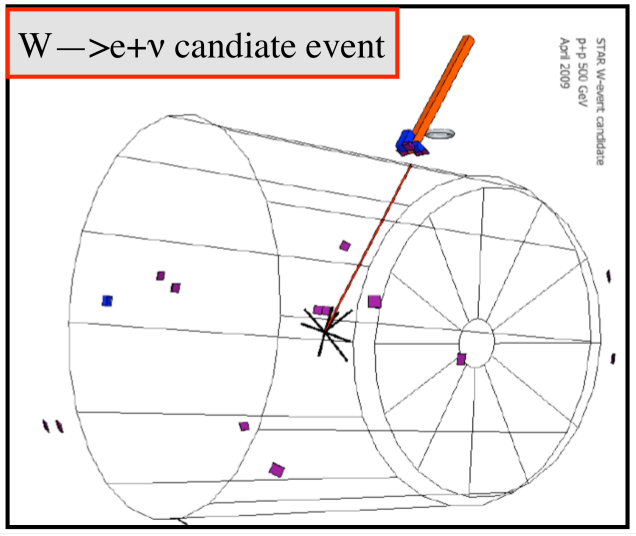
Selecting W Candidates

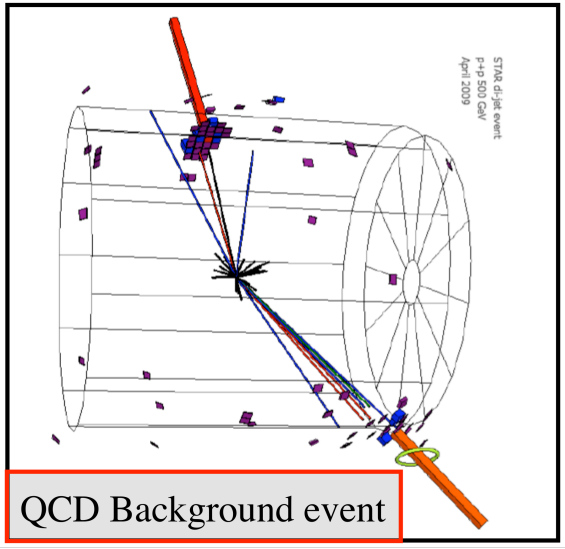
- Mid-rapidity STAR W selection criteria
  - **Match p_T > 10 GeV/c track to BEMC cluster**
  - **Isolation ratio 1 / Isolation ratio 2**
  - **p_T-balance cut**
  - **Leads to good charge discrimination**

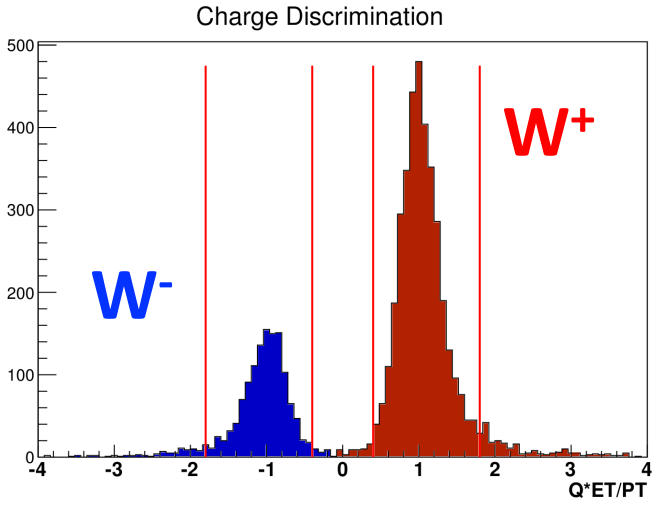


TPC track extrapolated to BEMC tower grid





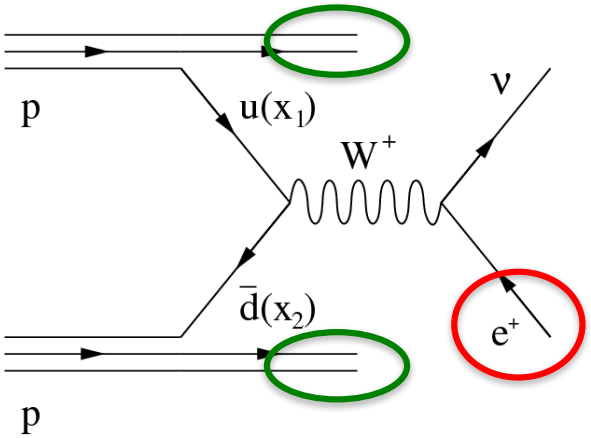




Reconstruction W bosons

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]

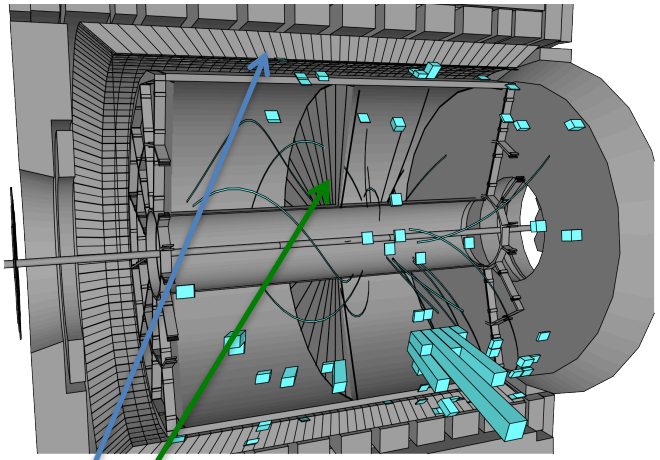
- **Select events with the W-signature (STEP 1)**
  - Isolated high P_T electron
- **Neutrino transverse momentum is reconstructed from missing P_T (Step 2)**

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

- **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

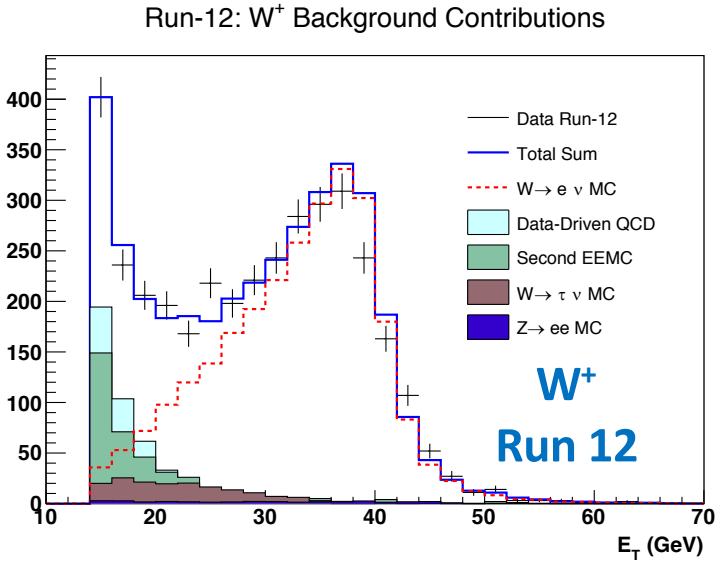


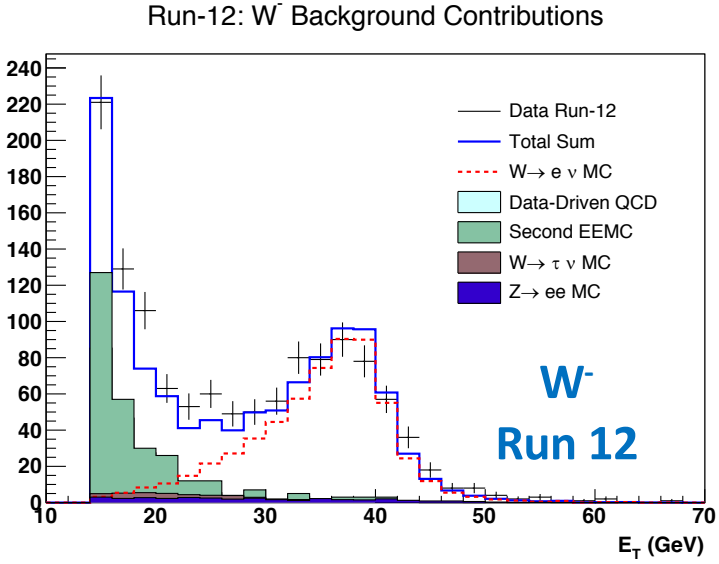
TPC (|η| < 1.4)

Barrel EMCAL (|η| < 1)

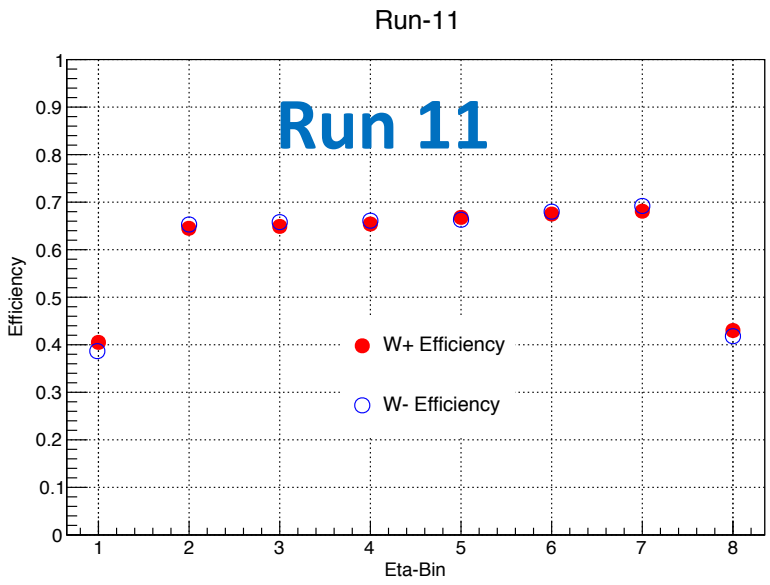
Mid-Rapidity $W^{+/-}$ Backgrounds

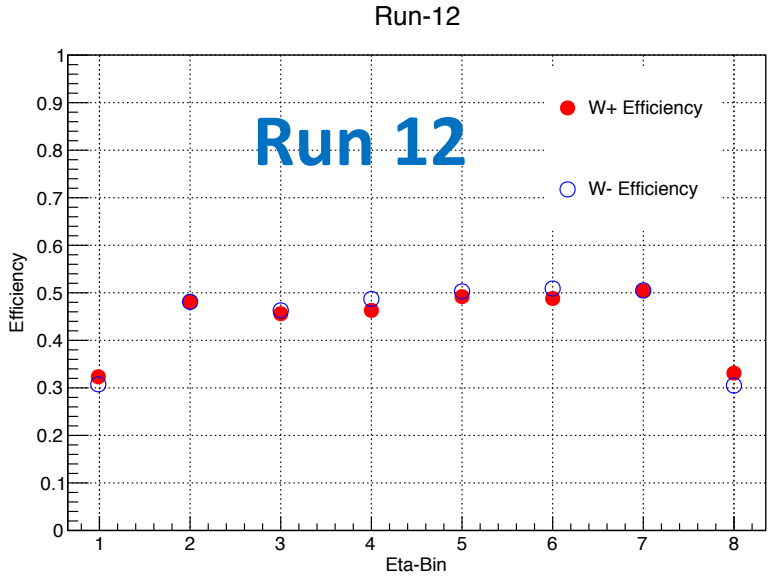
- **Data-driven QCD** backgrounds satisfy $e^{+/-}$ isolation cuts
- **Second EEMC backgrounds** result from backward ("Jet") at non-existing calorimeter coverage for $-2 < \eta < -1.1$
- **Second EEMC backgrounds** are estimated from EEMC located at $1.1 < \eta < 2$
- **Electro-weak background** from Z decay is done with PYTHIA/MC simulations.
- Small background contribution from Z decay.





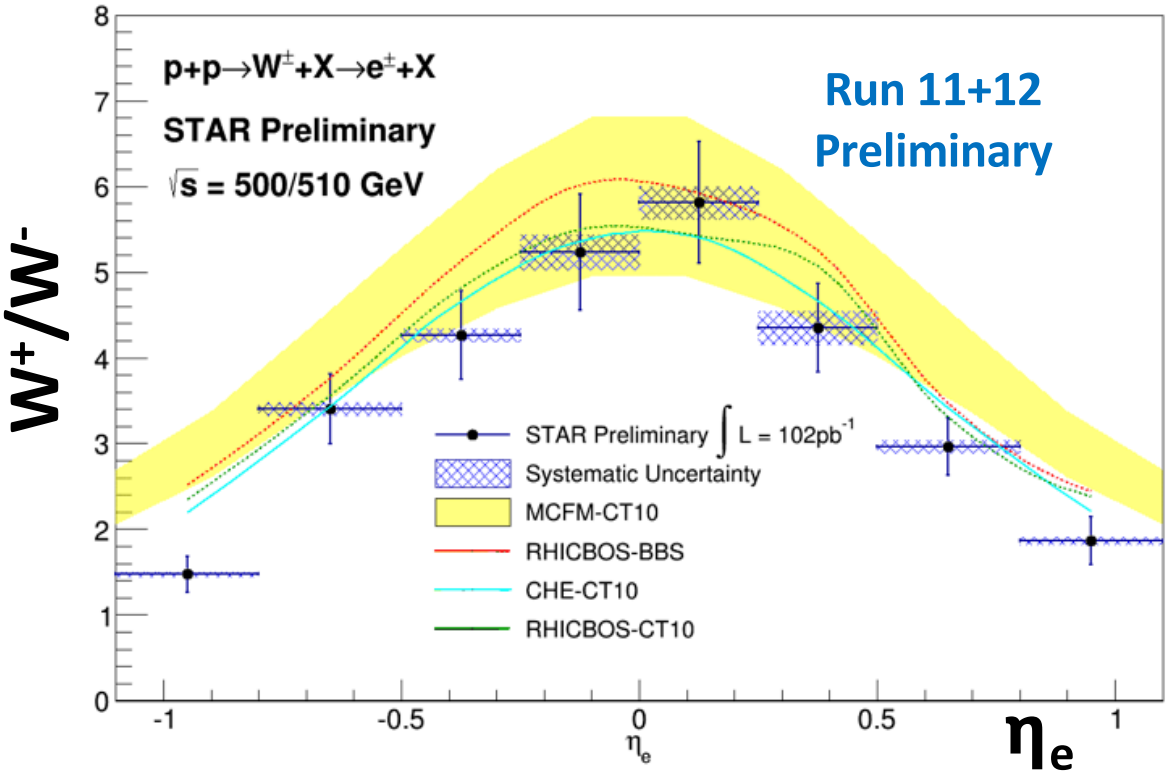
$W^{+/-}$ Efficiencies (Runs 11 and 12)





- **2012** running had lower $W^{+/-}$ efficiencies due to **higher luminosity** running.
- This leads to **more pile-up** in the TPC, which resulted in **less efficient** track reconstruction.
- **Minimal charge dependence** leads to small contribution to the charged W cross-section ratio

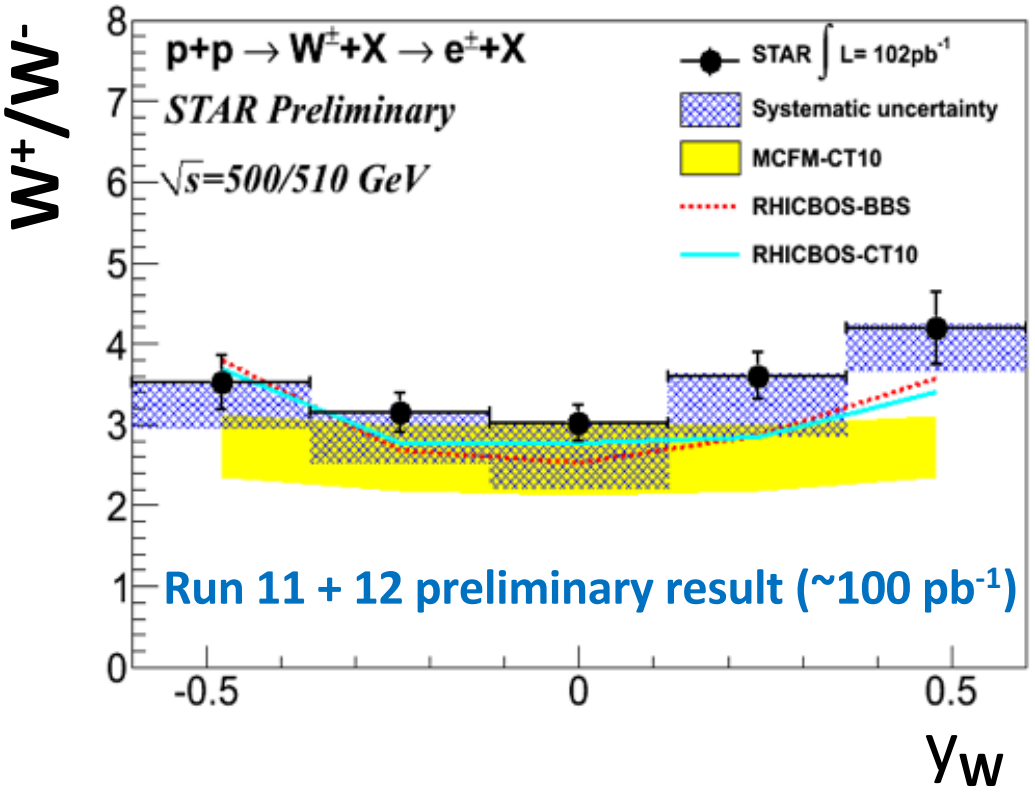
Charged W Cross Section Ratios



Run 11 + 12 preliminary result (~100 pb^{-1})

- **Charge W cross-section ratio** vs. **lepton pseudo-rapidity** precision is dominated by statistics.
- **Run 13** should add another **~ 250 pb^{-1}** of data
- While **Run 17** is projected to deliver **~400 pb^{-1}**

Charged W Cross Section Ratios

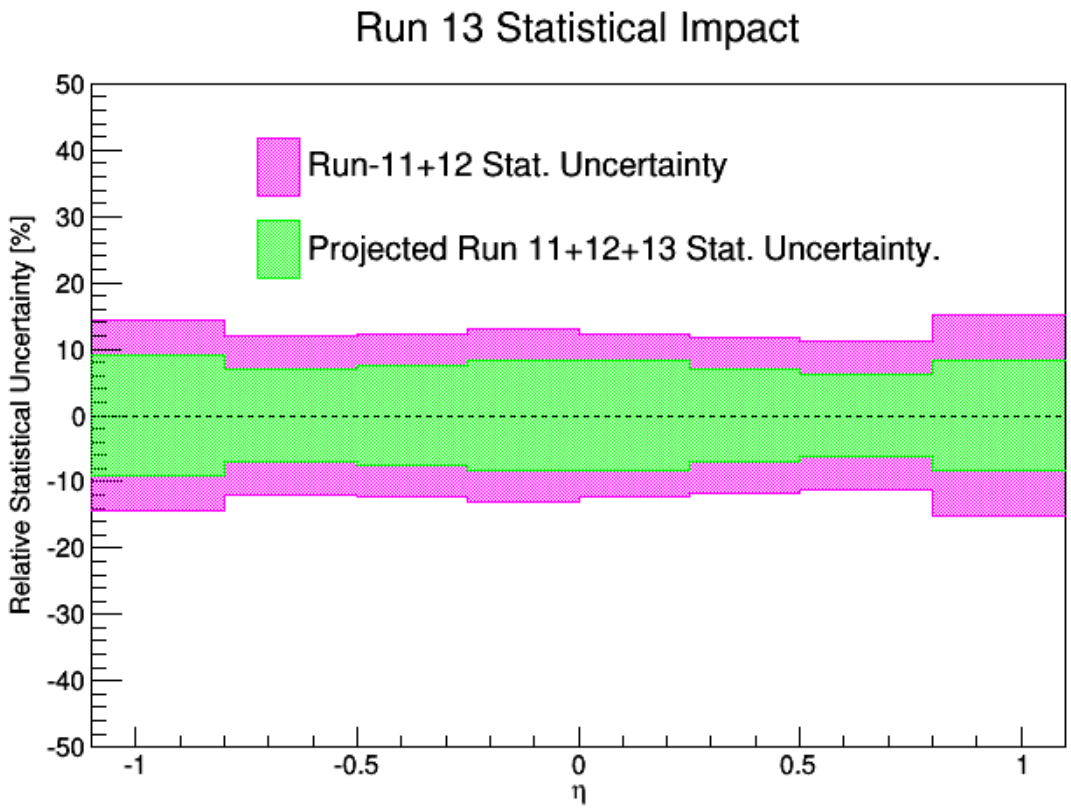


- The **W boson rapidity** can now also be reconstructed at STAR via its recoil. (Needed for run 11 transverse single-spin asymmetry measurement, **Phys.Rev.Lett. 116 (2016)**)

- Work is ongoing to improve the systematic uncertainty associated with the reconstructed **W boson rapidity**.

STAR Run 13 Statistical Impact

- **Run 13** will **significantly improve** the statistical precision of the STAR measured **W+/W- cross section ratio**.



- Further improvement is expected from **Run 17** p+p 510 GeV run, which is expected to deliver **~ 400 pb^{-1}**.

Run 13 Analysis Update

- Over the past year or so, the run 13 data set has had some updates/calibrations implemented.

  1) **Run 13** recently switched over to a new **tracking algorithm** which resulted in

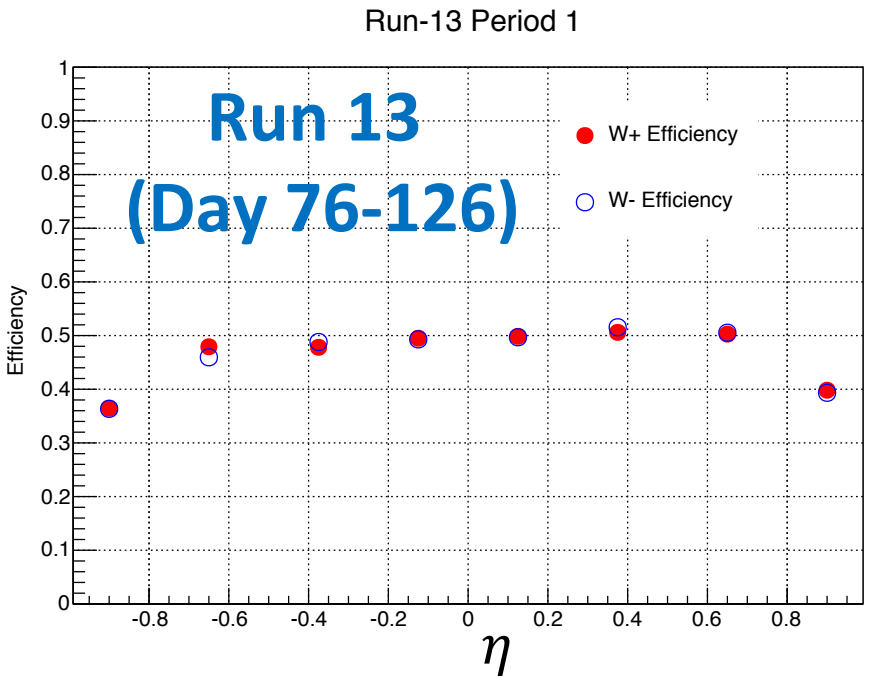
     - Higher track reconstruction efficiency at large luminosity
     - W+ and W- efficiencies for **run 13** show **similar behavior** as those measured in run 12

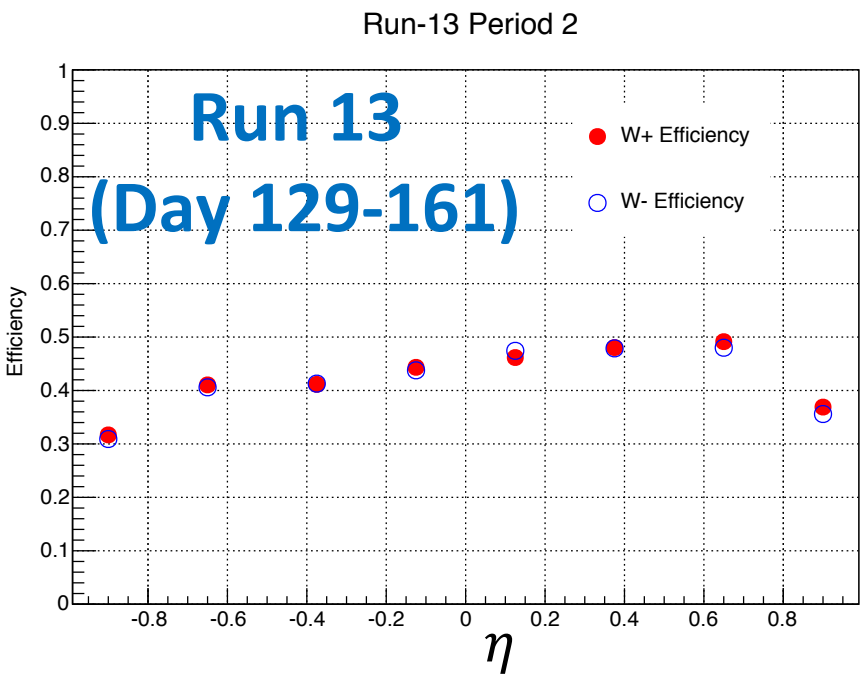
  2) The **BEMC** was calibrated using **run 13 p+p 510 GeV** data and is now applied to the ongoing **run 13** analysis (used in STAR 2013 W A_L Prelim. Results shown at INPC and SPIN 2016).

- These analysis updates were included in the STAR 2013 mid-rapidity W A_L preliminary result first shown at INPC and SPIN 2016.

- **Preliminary W A_L results in the forward region** will be shown at this conference during the talk on **Wed. 17:00 in the WG6** session!

$W^{+/-}$ Efficiencies (Run 13)





- W+ and W- efficiencies for **run 13** show **similar behavior** as those measured in run 12
  - Average efficiency ~ 50%
  - Small to negligible difference between W+ and W- efficiency
- Efficiency **dip** seen days 129-161 is due to **insertion of a new sub detector** (HFT).

Summary

- **STAR** measured **cross-section ratio** using W production
  - A **complimentary** measurement to **SeaQuest** and **E-866**
  - Should help further **constrain** the **sea quark PDFs**
- **Preliminary results** of measured cross-section ratios using **Run 11 and 12** data sets have been released as a function of **lepton pseudo-rapidity** and **W boson rapidity**
- **Run 13** analysis now takes advantage of recently implemented
  - Barrel electromagnetic calorimeter calibration
  - Tracking algorithm
- **Run 13** data set **(~250 pb^{-1}**)to be included into the cross-section ratio measurement soon
- More **forward eta-bin (1.1 – 2.0)** looking to be added to the cross section ratio via the electromagnetic endcap
- Long 510 GeV **run in 2017** at transverse spin polarization is expected to deliver **400 pb^{-1}** which should further **improve** the charged W cross-section ratio precision.