Cross section measurements of kinematically reconstructed weak bosons in unpolarized *p+p* collisions at STAR

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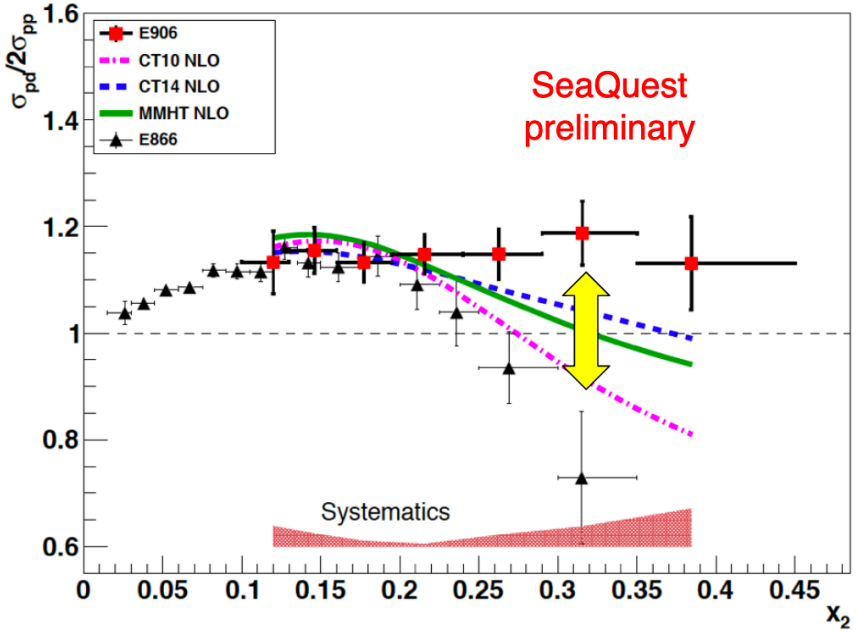
Motivation: quark flavor ratio in PDFs

- Unpolarized d-bar/u-bar in PDFs can be probed via Drell-Yan
- **E-866** suggests a trend where the dbar/ubar ratio appears to be decreasing at large-x.
- The **preliminary SeaQuest** trend appears to level out at **higher x**.
- **Unpolarized W cross-section charge-ratios** are also **sensitive** to **quark/anti-quark** distributions.

LO: $$\frac{\sigma(W^+)}{\sigma(W^-)} = \frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$



- **LHC coverage:** ~$10^{-3} < x < 10^{-1}$

$$\langle x_{1,2} \rangle = \frac{M_W}{\sqrt{s}} e^{-\eta_l/2}$$

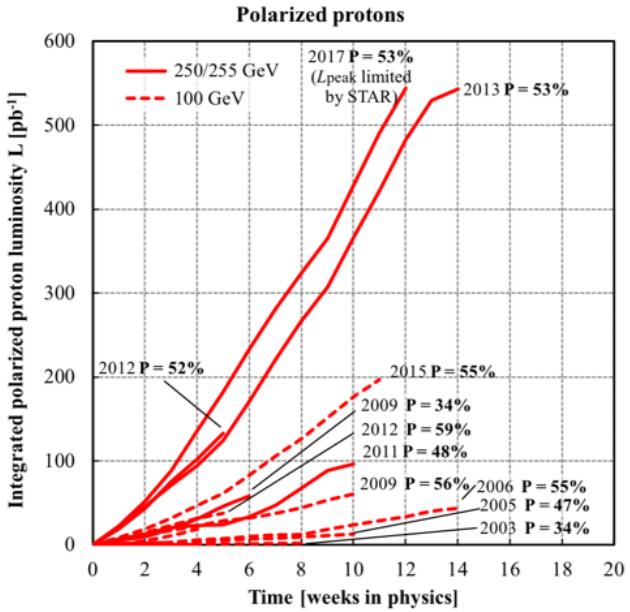
- **STAR coverage:**
  - **Mid-rapidity** $-1 < \eta < 1$ (**TPC +BEMC**) : $0.1 < x < 0.3$
  - **Forward EEMC** $1.1 < \eta < 2$: $0.06 < x < 0.4$

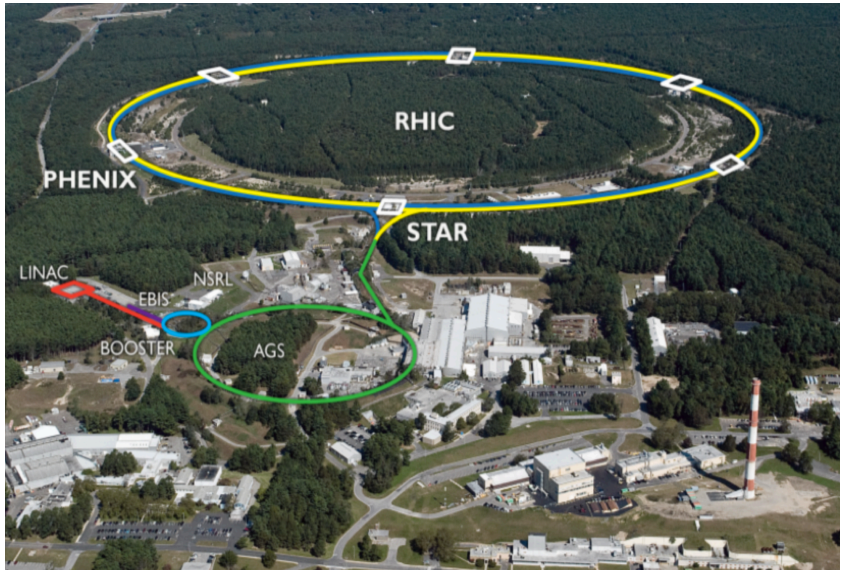
- Differential cross sections of weak bosons are key inputs in global fits of **unpolarized TMDs**
  - STAR constrains large x

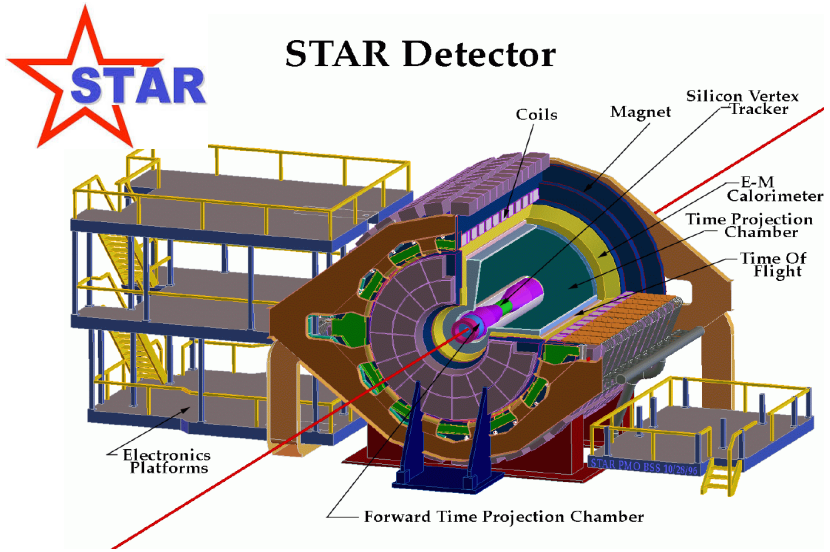
RHIC and the STAR experiment

Beams: √s= 510 GeV *p+p*; 50-60% polarization

- **RHIC** is the world's first and only polarized hadron collider
- Its top energy is enough to produce weak bosons







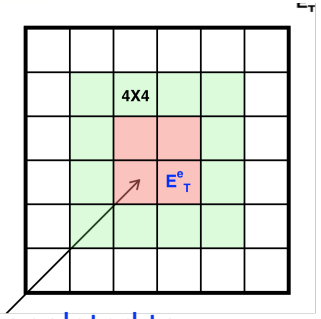
Rich weak boson program @ STAR

- 2009 W A_L (PRL)
- 2009 W/Z Cross Section (PRD)
- 2011+2012 W A_L (PRL)
- 2011 W/Z A_N (PRL)
- 2013 W A_L (PRD-Rapid Com.)
- **And counting…** (being analyzed)
  - 2017 double our sample!

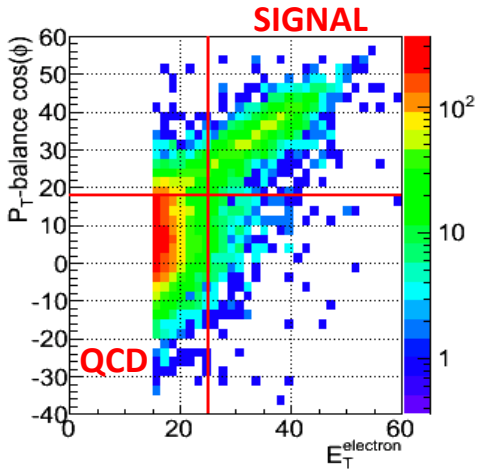
How do we select $W^{\pm}$ bosons?

- **Tag on a high p_T lepton** [$25 < E_T < 50$ GeV]
- **Lepton must be isolated:**
  - $P_T^{\text{el-track}} / (\Sigma[P_T^{\text{tracks}} \text{ in R=0.7 cone}] - E_T^{\text{el-cluster}}) > 82\%$
  - $(E^{2x2} / E^{4x4}) > 96\%$
- **Energy imbalance:** no energy in opposite cone, E<11 GeV
- **Good vertex:** |Z-vertex|<100 cm
- **Identify lepton charge:** (separate W^+ and W^- samples)

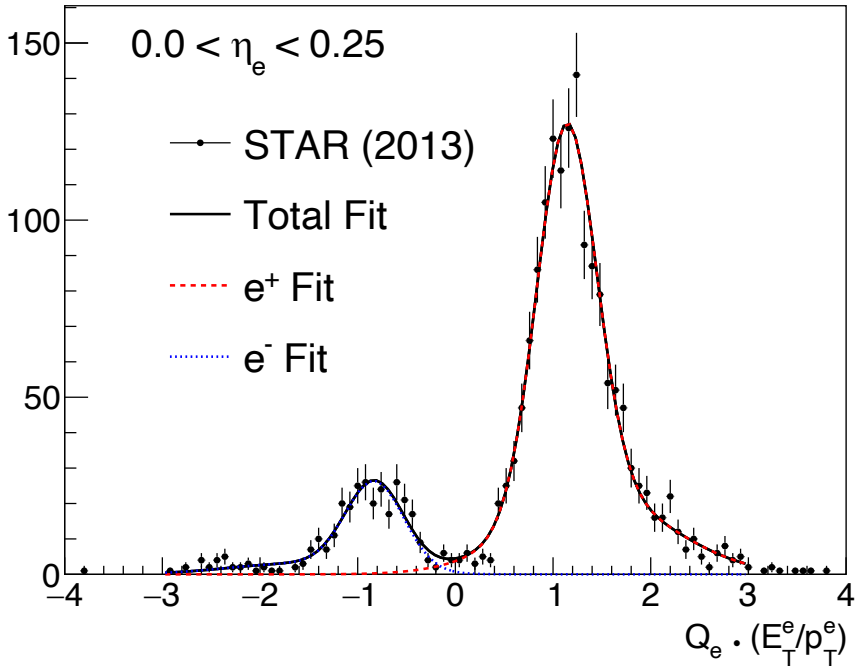
  $0.4 < |\text{Charge (TPC)} \times E_T \text{ (EMC)} / P_T \text{ (TPC)}| < 1.8$
- **Suppress QCD background:** Signed P_T balance > 16 GeV/c



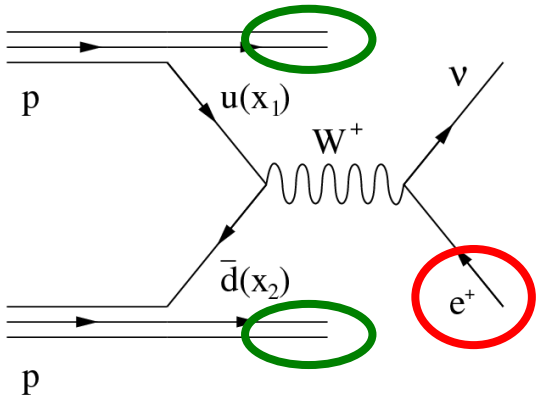
TPC track extrapolated to BEMC tower grid



$$\vec{P}_T^{\,bal} = \vec{P}_T^{\,e} + \sum \vec{P}_T^{\,recoil}$$



How do we reconstruct $W^{\pm}$ bosons?



Ingredients for the analysis

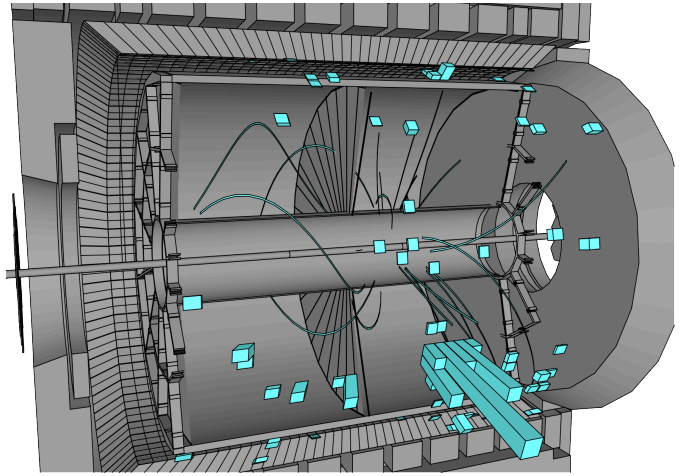
- Isolated electron
- Neutrino (not measured directly)
- Hadronic recoil

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)**
  - Non-measured recoil particles accounted for via MC correction
- **Neutrino's longitudinal momentum is reconstructed from the decay kinematics (Step 3)**

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



STAR acceptance

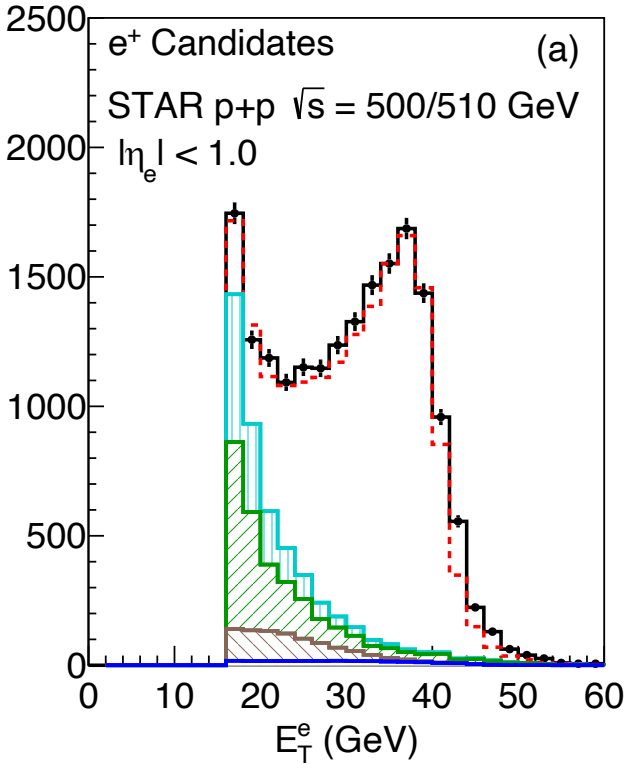
TPC + EMCAL

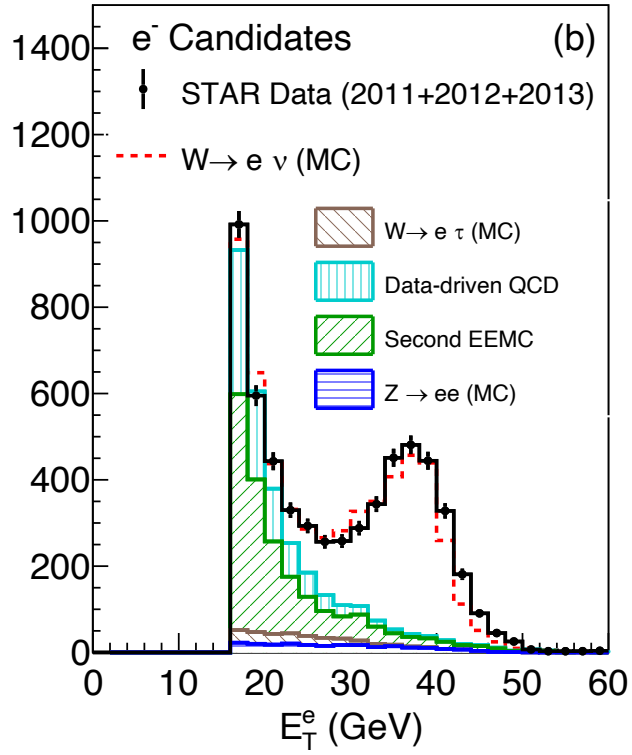
$|\eta| < 1$

Backgrounds to W ± boson selection

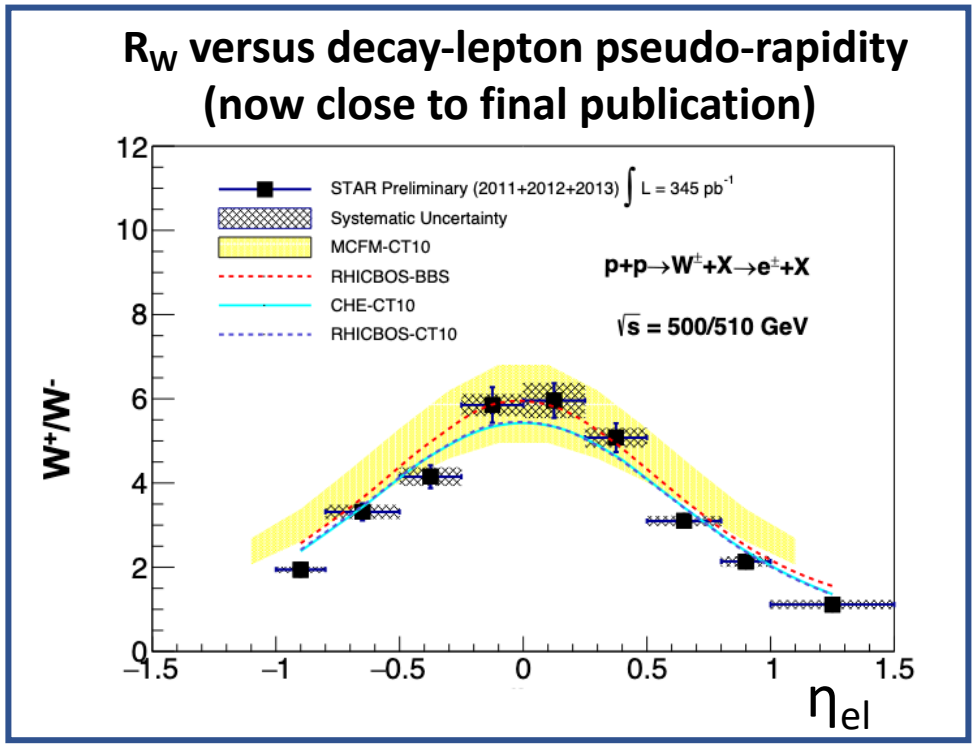
- **QCD background** (data-driven)
  - Satisfies $e^{\pm}$ isolation cuts
  - Estimated by reversing Sign-p_T balance cut
- **Missing EEMC background**
  - Arises from a backward jet exiting STAR through the uninstrumented endcap ($-2 < \eta < -1.1$)
  - Estimated from instrumented EEMC at $1.1 < \eta < 2$
- **Electroweak background**
  - Results from $Z^0 \rightarrow e^+e^-$ and $W \rightarrow \tau\nu \rightarrow eX$ decays
  - Estimated from PYTHIA/MC simulations
  - Overall contribution is small
- **Backgrounds are subtracted from samples**

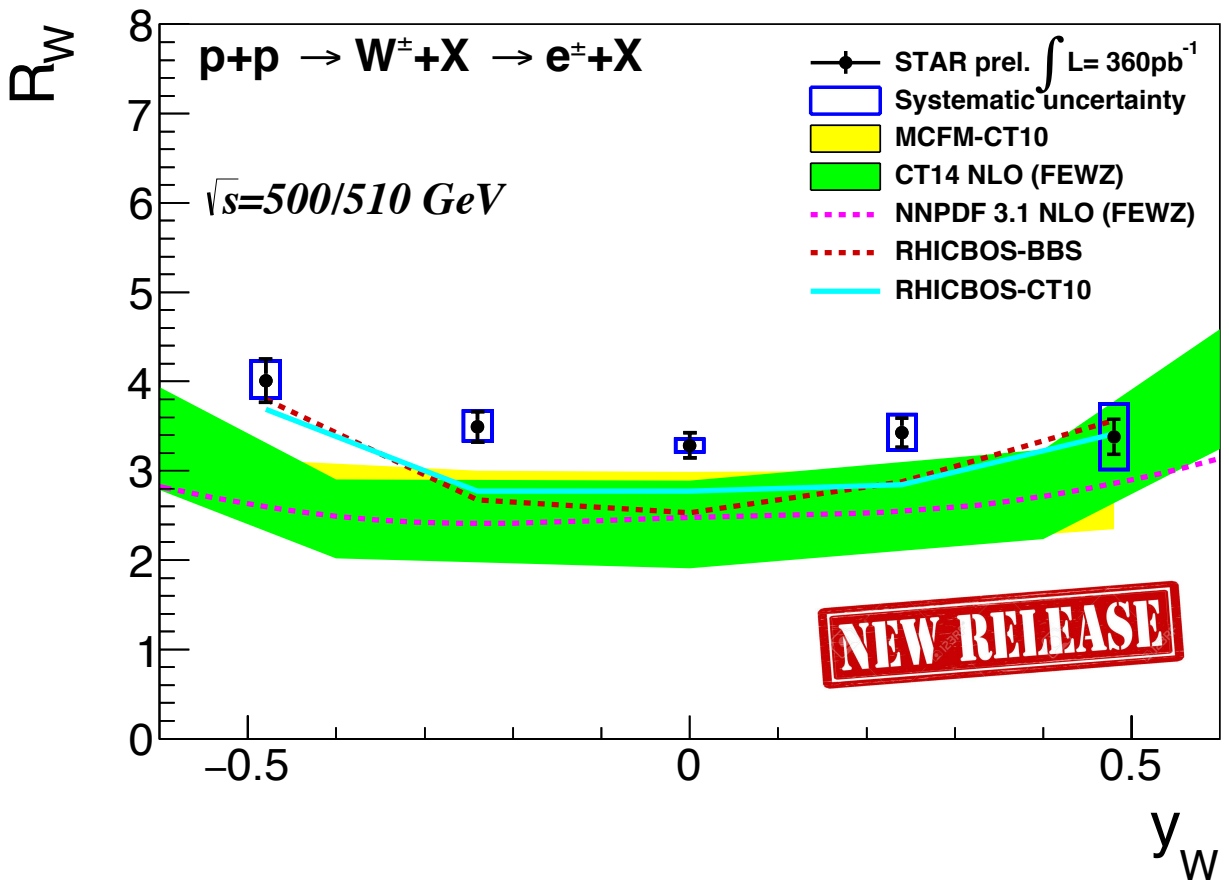
($|\eta| < 1$)





$\sigma(W^+)/\sigma(W^-)$ versus boson's rapidity





STAR preliminary results:

- Combine RHIC run 11-12-13 ~**360 pb^{-1}**
- Cross section charge ratio measured vs. both the decay lepton and the boson's kinematics
- Systematics in novel R_W vs. y_W release are driven by boson's rapidity reconstruction

How do we select Z^0 bosons?

Main selection criteria

$$pp \rightarrow Z^0 \rightarrow e^+e^-$$

- **Tag on two high p_T leptons** [p_T > 25 GeV/c]
- Leptons must have **opposite charge**
- **Leptons both coming from same vertex:** |Z-vertex|<100 cm
- **Suppress backgrounds:** M_{INV} about ± 20% from nominal Z^0 mass
  - 70 < m_{e+e-} < 110 GeV/c^2

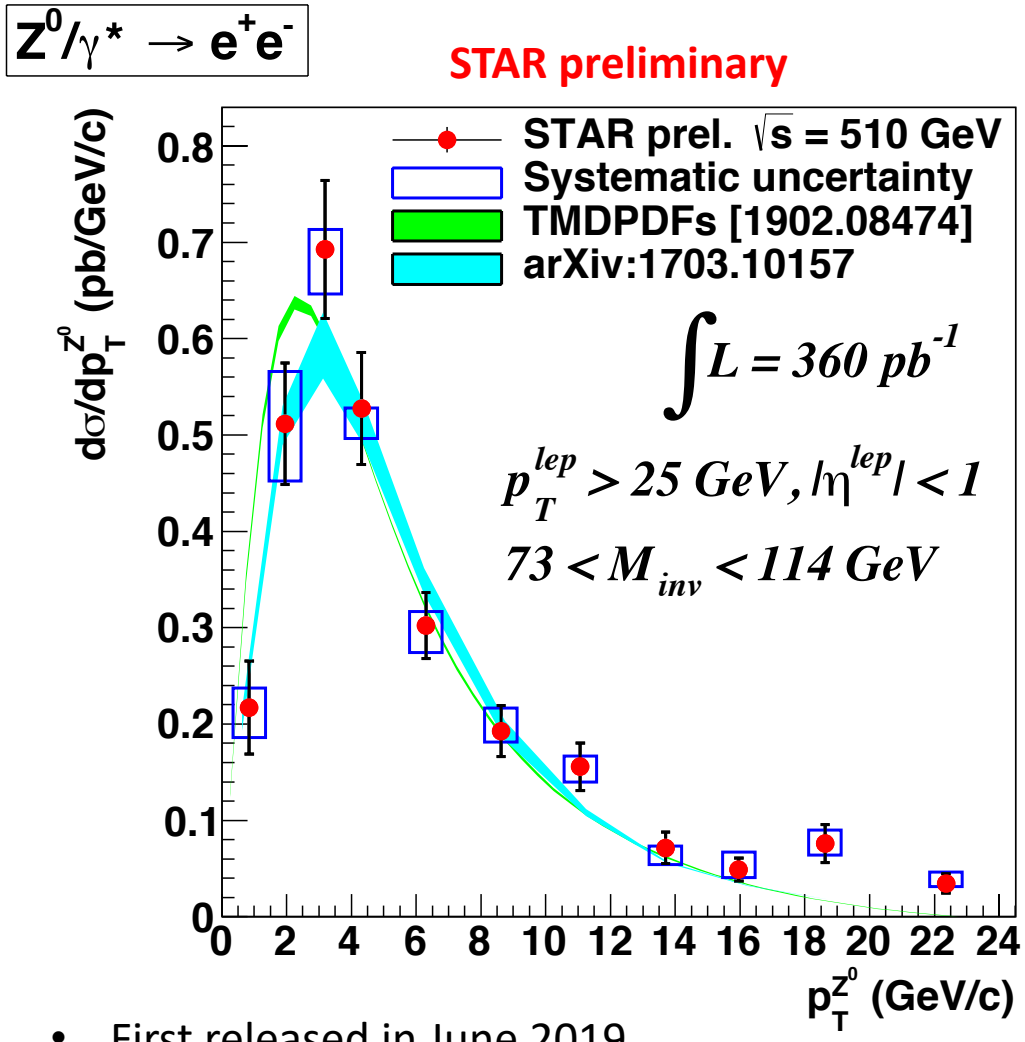
❖ **Clean experimental reconstruction of decay leptons**

❖ **Negligible background found**

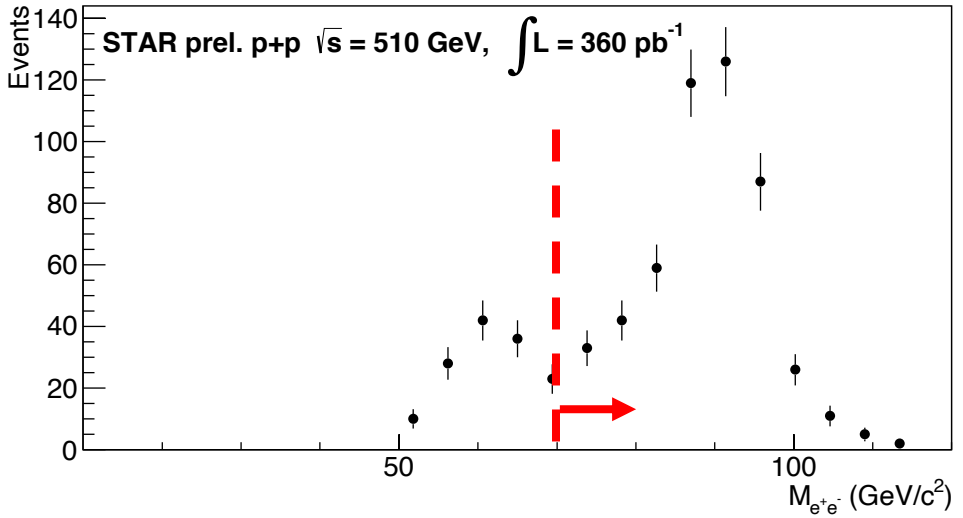
❖ **Cross section much lower than for the W production!**

❖ **Selection efficiency also slightly lower than the Ws → two high-p_T leptons in final state**

$d\sigma/dp_T^Z$



- First released in June 2019
- Now updated with a new theory band (cyan)



- Overall uncertainty on luminosity (8.5%) not shown on the plot
- Systematics evaluated by
  - varying p_T^{lep} and M_Z cuts according to resolution
  - varying EMCal calibration gains by ± 4% (conservative value)
- Dominant systematics come from BEMC calibration gains
- Theory curves based on recent extractions of TMDPDFs

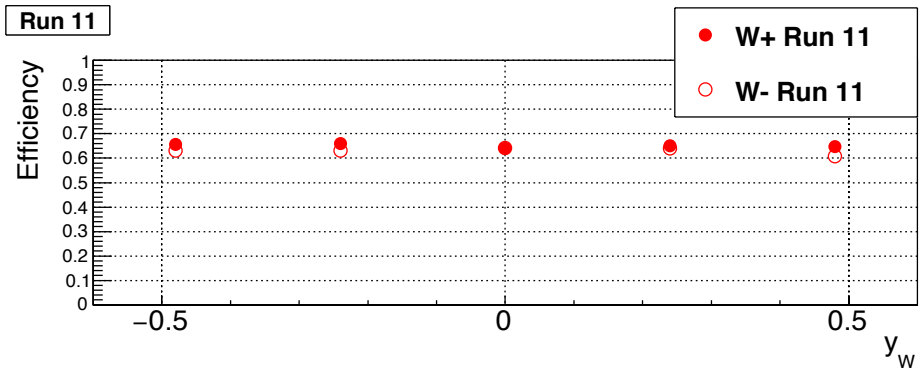
Conclusions

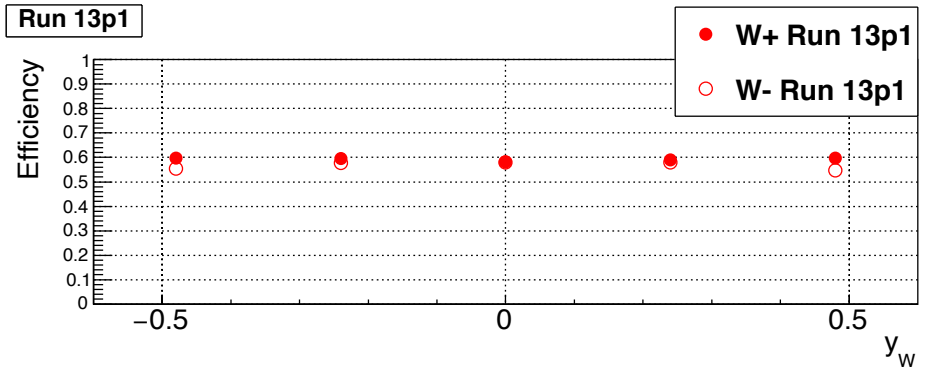
- **STAR has a rich program in measuring unpolarized cross sections of weak bosons**
  - W+/W- data constrain d-bar/u-bar at x>~0.1-0.3 where current uncertainties are large
  - Differential cross section constrains global fits of unpolarized TMDs at larger x than LHC
  - Preliminary results of $\sigma(W^+)/\sigma(W^-)$ versus boson's rapidity including RHIC run13 have been shown for the first time at this venue
- **STAR preliminaries are based on RHIC run 11+12+13, corresponding to ~360 pb^{-1}**
  - **Run 17 will double the sample!**
    - Calibration of run17 data has been completed and reproduction of embedded MC is starting

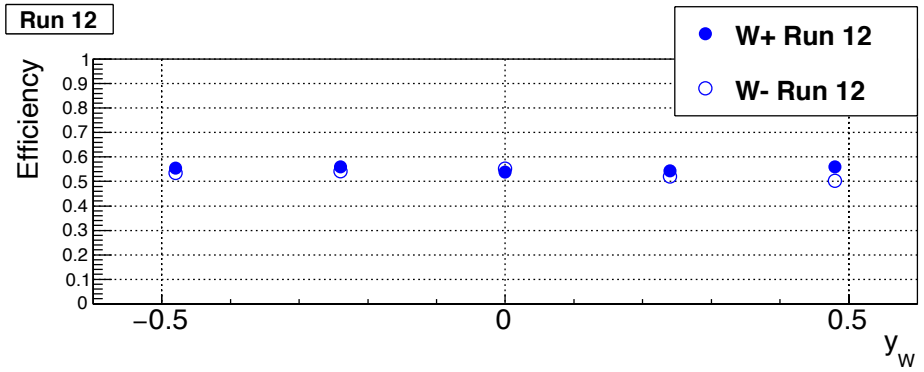

BACKUP

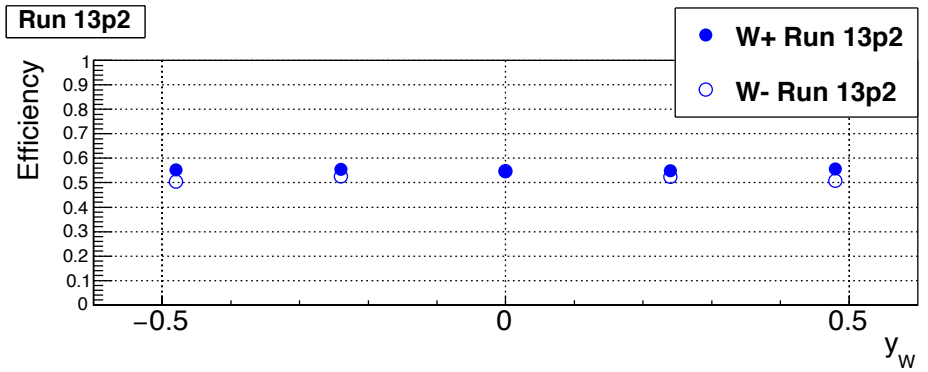
Efficiency of selecting $W^{\pm}$

- **Computed from Pythia+GEANT simulations:** Eff. = [#evt. Reco. trigger&selection]/[#evt. Gen. in acceptance]
- **2012-2013 efficiency is lower due to higher instantaneous luminosity**
  - ➢ Results in more pile-up and less efficient track reconstruction
- **New tracking algorithm was implemented for 2013 data production**
  - ➢ 2013 efficiency higher overall than 2012
- **Very small dependence on boson's charge** → small correction to W+/W- ratios









Efficiency of selecting Z^0

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  - Results in more pile-up and less efficient track reconstruction
- **New tracking algorithm was implemented for 2013 data production**
  - 2013 efficiency higher overall than 2012
- **Efficiency is lower than for Ws → two final state leptons**