Constraining the Sea Quark Distributions Through W Cross-Section Ratios Measured in pp Collisions at STAR

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TEMPLE UNIVERSITY

STAR

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Motivation

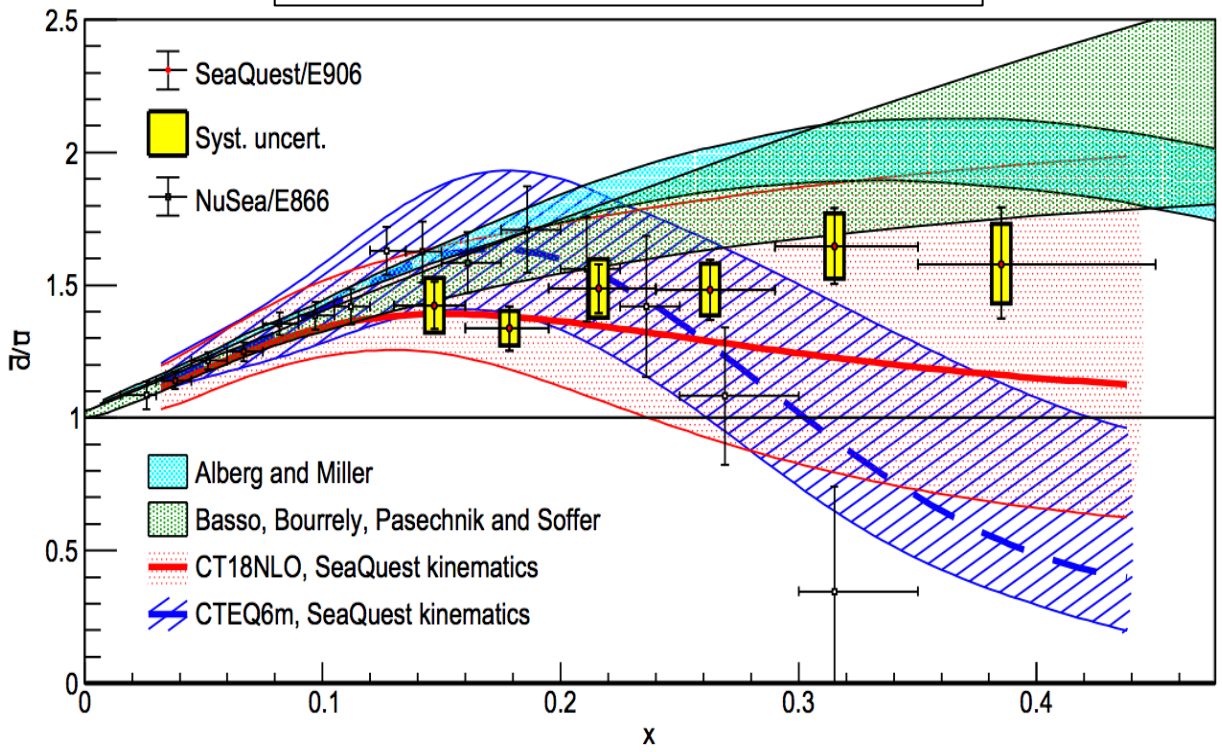
Proton Sea Quark Asymmetry

- Quarks in the proton sea are perturbatively generated via gluon splitting.
  - ➢ Asymmetries between sea quarks is a non-perturbative phenomenon.

Observed $\bar{d}/\bar{u}$ Asymmetry

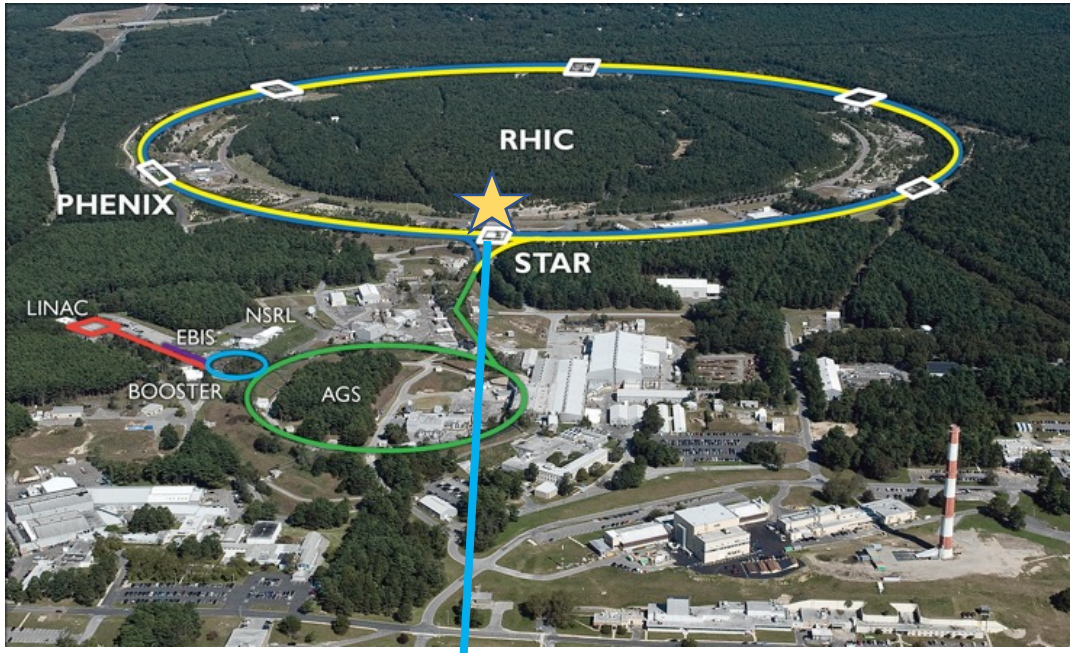
- The anti-quark ratio $\bar{d}$ / $\bar{u}$ is typically measured in Drell-Yan type experiments.
- Measurements of this ratio seem to suggest different large x behavior.
- W measurements at RHIC may be able to provide additional insight.

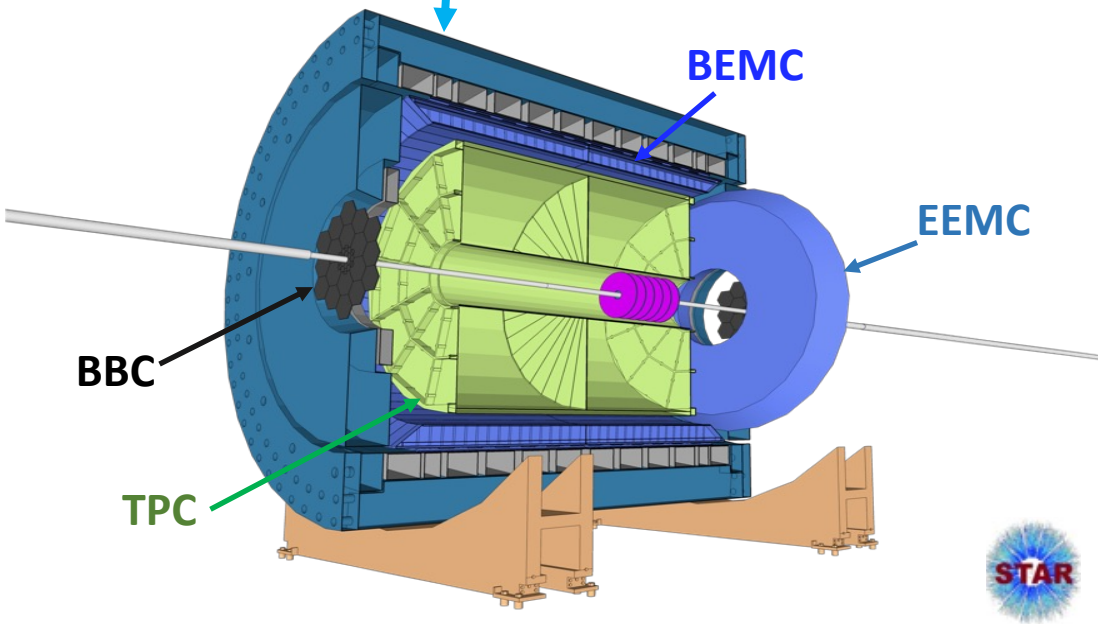
SeaQuest, Nature 590 (2021) 7847, 561-565



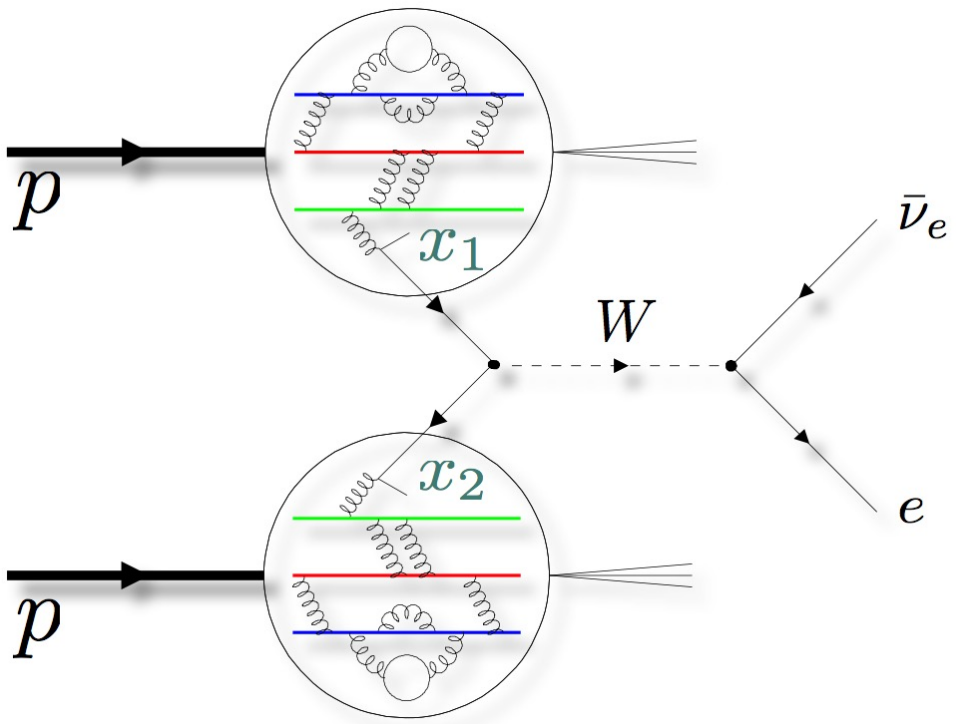
Relativistic Heavy Ion Collider (RHIC) and the Solenoid Tracker At RHIC (STAR)

- 0.5 T solenoid magnet along with time projection chamber (**TPC**), $|\eta| < 1.3$
  - Provides tracking and PID
- Electromagnetic Calorimeter
  - Barrel (**BEMC**), $|\eta| < 1$
  - Endcap (**EEMC**), $1.1 < \eta < 2$
  - Provides energy measurements and aids in particle discrimination
- Zero-degree calorimeter (**ZDC**), beam-beam counter (**BBC**), and vertex position detector (**VPD**)
  - Provide minimum bias trigger and luminosity monitoring





W Production in pp Collisions



- W bosons are sensitive to quark/anti-quark distributions.

  They can be accessed via W leptonic channels.

  - $d\sigma^{W+} \propto u(x_1)\,\bar{d}(x_2) + u(x_2)\,\bar{d}(x_1)$
  - $d\sigma^{W-} \propto d(x_2)\,\bar{u}(x_1) + d(x_1)\,\bar{u}(x_2)$

- The W cross-section is sensitive to the $\bar{d}/\bar{u}$ ratio
- Can be used to constrain the sea quark distribution
  - $R_W = \frac{\sigma^{W+}}{\sigma^{W-}} \sim \frac{u(x_1)\,\bar{d}(x_2)+u(x_2)\,\bar{d}(x_1)}{d(x_2)\,\bar{u}(x_1)+d(x_1)\,\bar{u}(x_2)}$

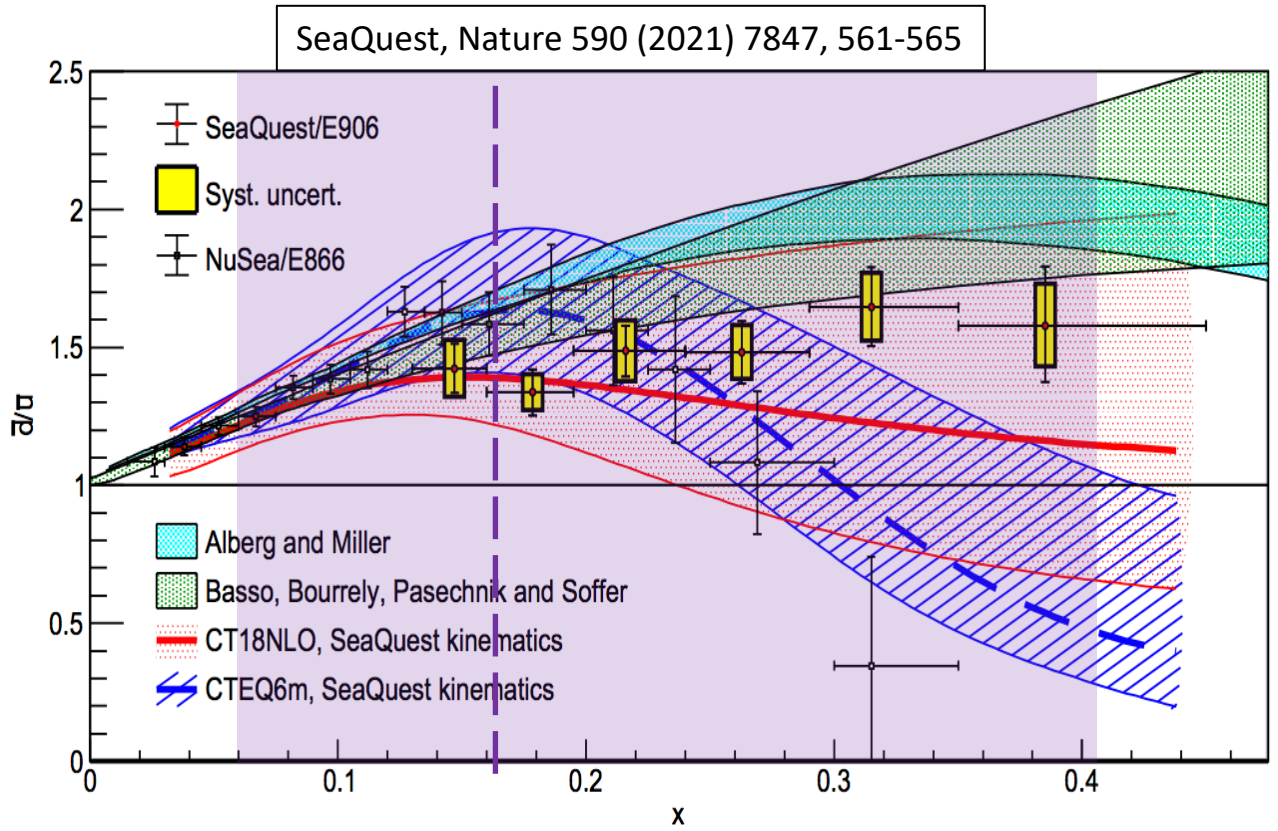
Measureing R_W

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

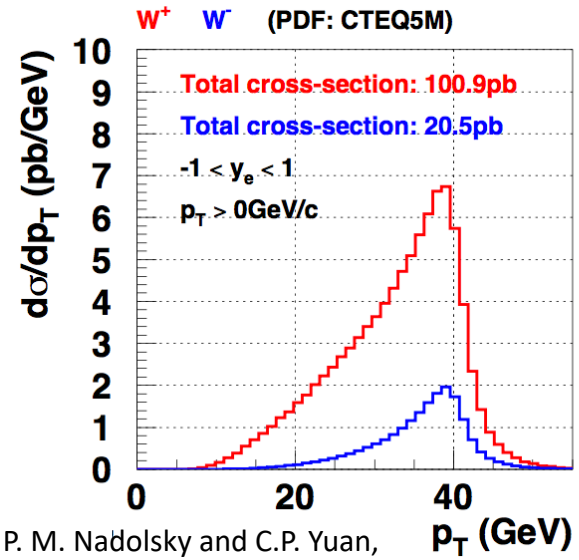
- +/- : denotes charge of lepton from W leptonic decay (positron/electron)
- N_O: number of observed W events
- N_B: number of background events
- ϵ: W efficiency correction

STAR's Kinematic Reach

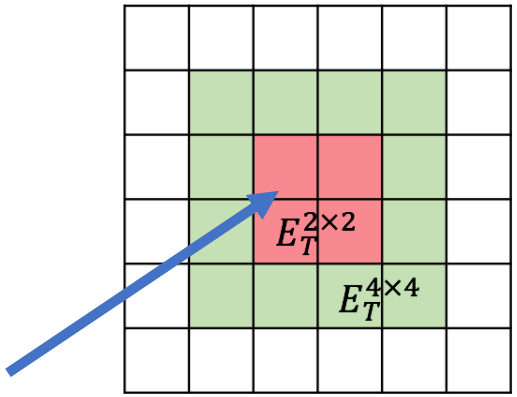
- Approximate STAR kinematic reach: $\sim 0.06 < \ x <\sim 0.4$
  - Good kinematic overlap with past experiments
- At STAR pp collisions with energy of $\sqrt{s} = 510\ GeV$ at $\eta = 0,\ x_1 \approx x_2 \approx 0.16$
- Compliments high energy ($\sqrt{s} = 14\ TeV$) LHC data that probes lower x, at $\eta = 0,\ x_1 \approx x_2 \approx 6{\times}10^{-3}$



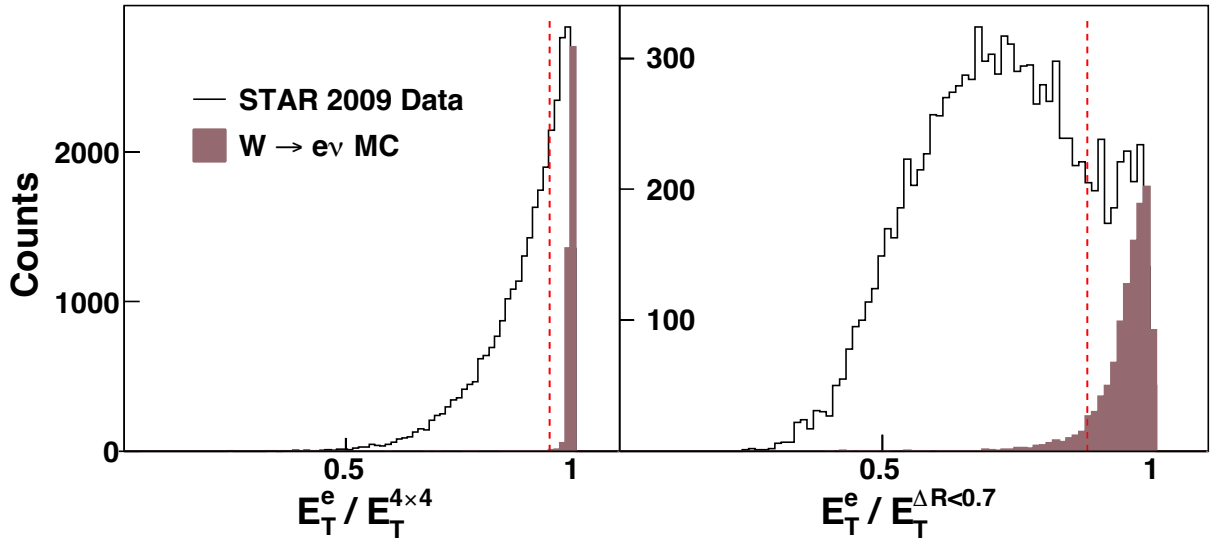
Identifying W Decay Lepton



P. M. Nadolsky and C.P. Yuan, Nucl. Phys. B666 (2003) 31.



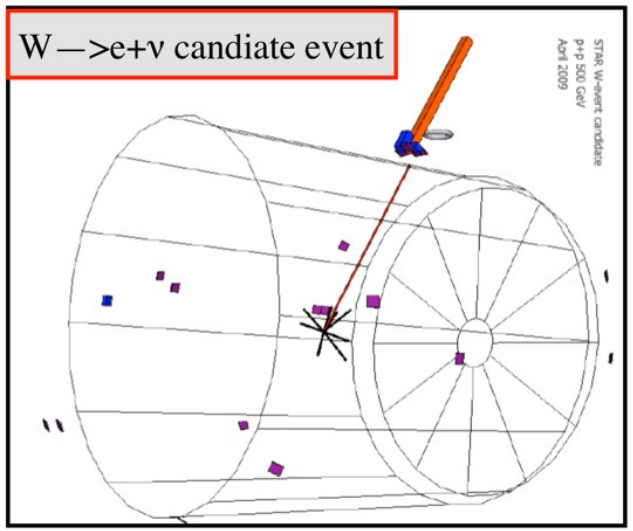
TPC track extrapolated to BEMC tower grid

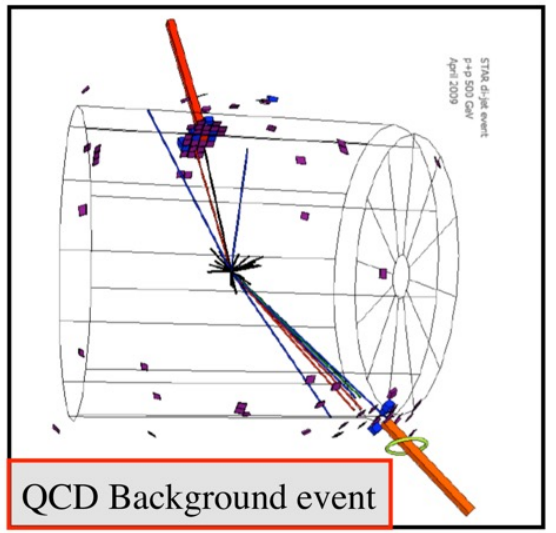


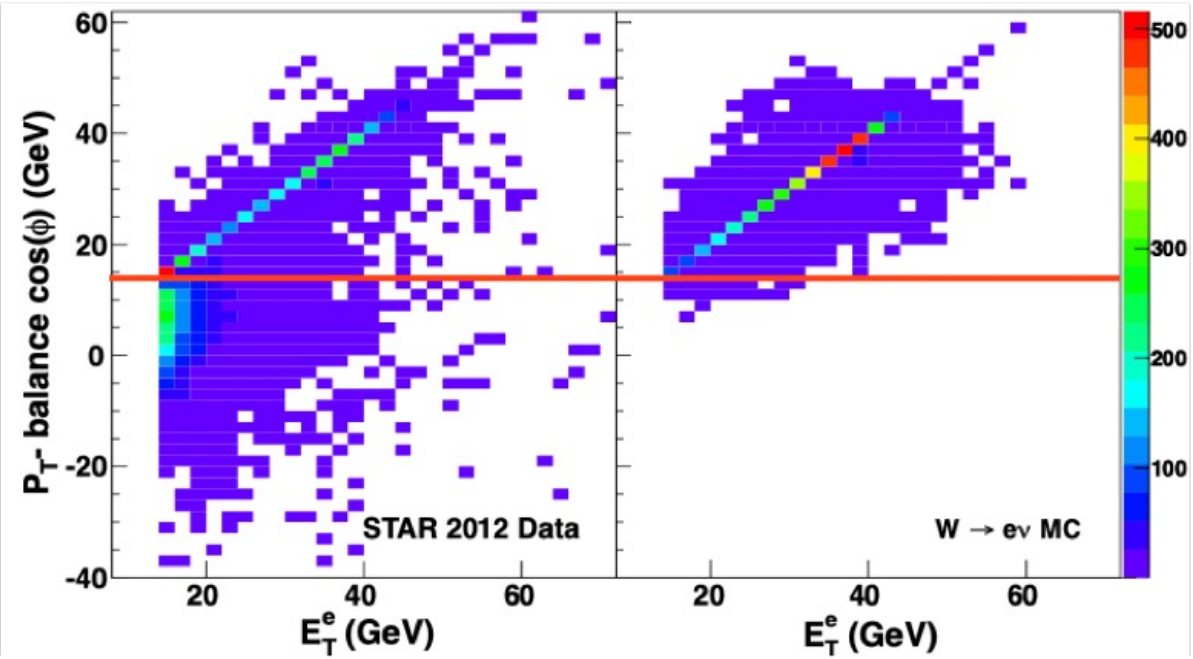
$W \rightarrow e\nu$ Key Signatures

- Decay lepton has large p_T
- Lepton's electromagnetic shower is localized to small cluster
- Large p_T imbalance due to undetected neutrino
- Lepton charge used to determine W charge

Tagging Leptonic W Decays







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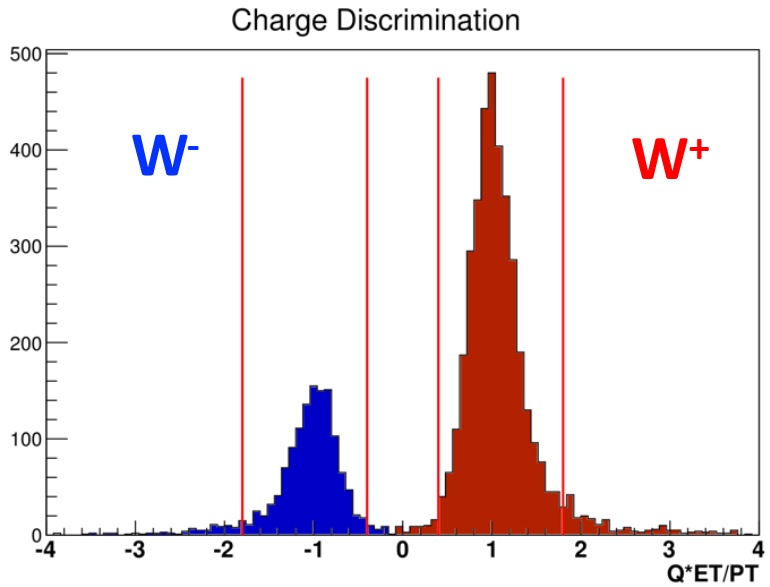
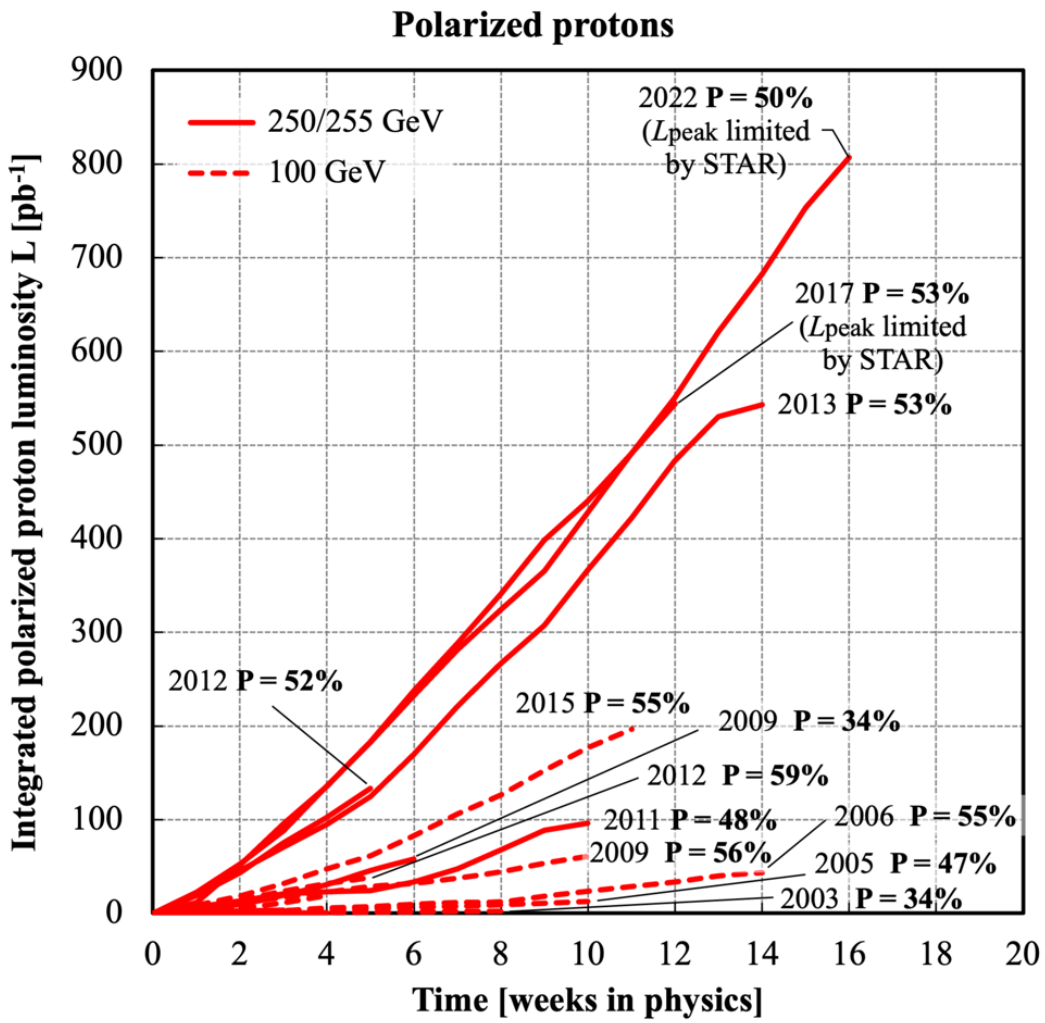


RHIC pp Data Collection Overview

Delivered Luminosity

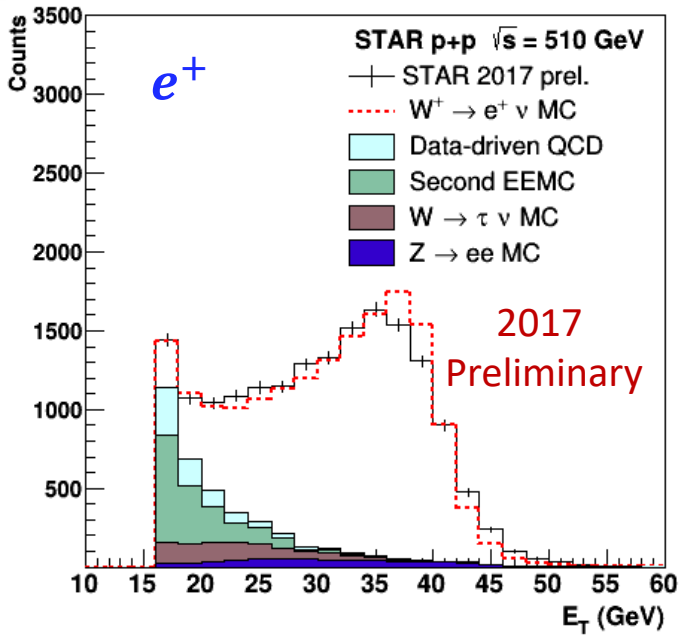


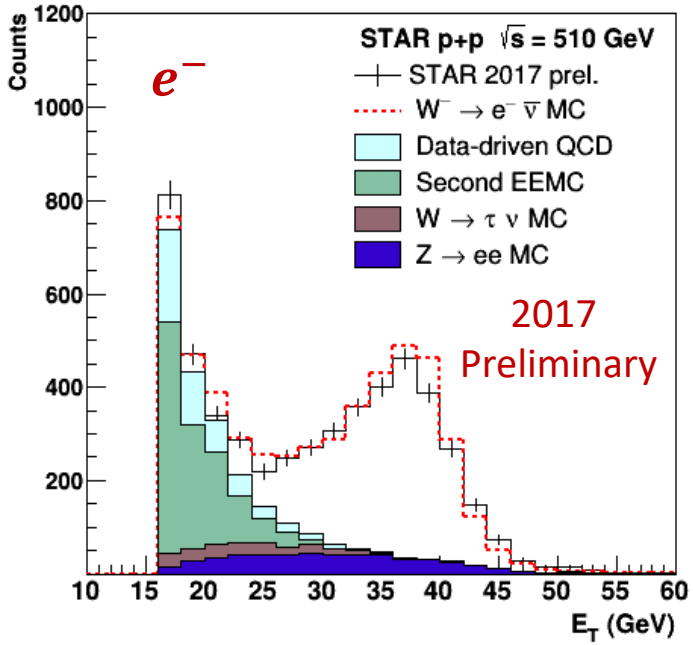
Sampled Luminosity

Year	$\sqrt{s}$ (GeV)	L (pb^{-1})	Measurement Status
2009	500	10	STAR, PRD 85 092010
2011	500	25	STAR, PRD 103,012001
2012	510	75	
2013	510	250	
2017	510	350	Preliminary
2022	510	450	Recently completed data taking

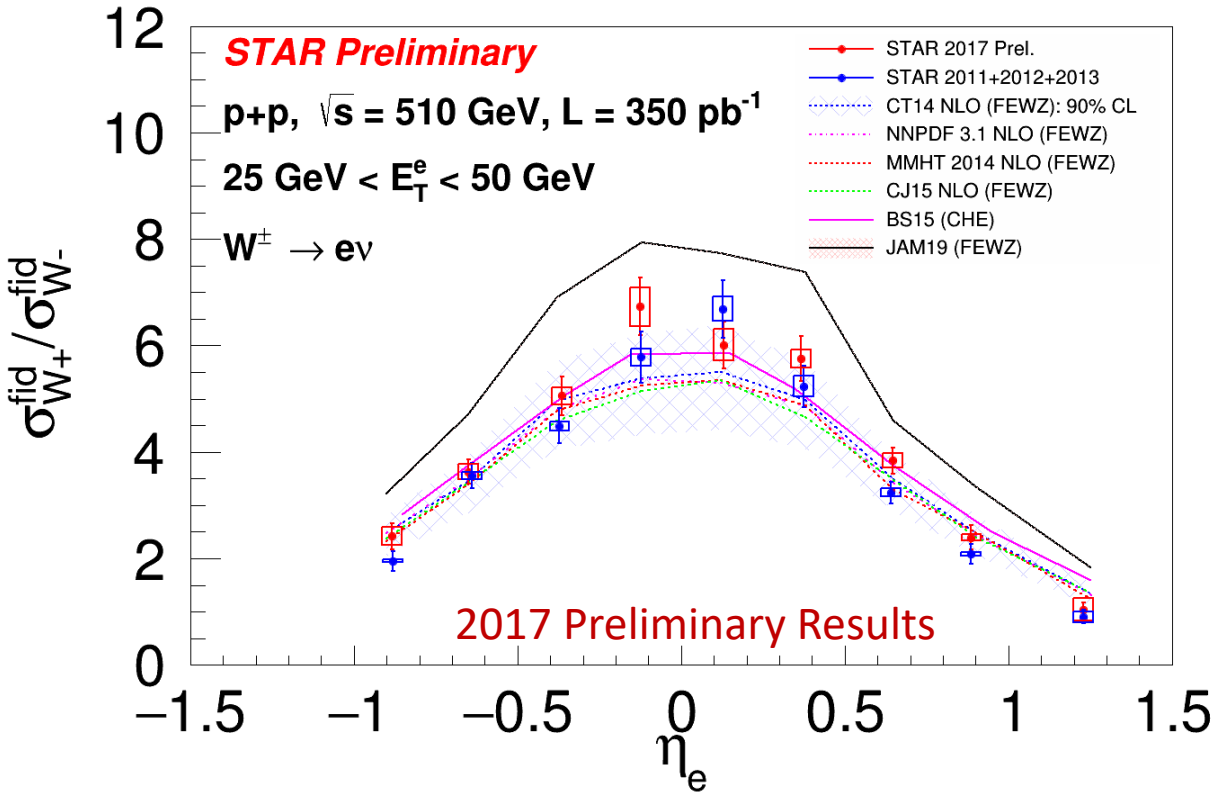
Backgrounds in the Barrel

- **Electroweak background** from $Z \rightarrow e^+e^-$ with one unidentified lepton and $W \rightarrow \tau\nu$ decays corrected with PYTHIA/MC simulations.
- **QCD background**
  - Due to limited acceptance and kinematic coverage, imbalance in p_T could appear in QCD events.
  - Two methods employed to estimate their contributions:
  - **Second EEMC**
    - Accounts for missing backward coverage $(-2 < \eta < -1)$
    - Estimated from EEMC in the forward direction
  - **Data-driven QCD**
    - Remaining background contribution that passes selection cuts.
    - Distribution obtained by using events that do not pass the p_T imbalance cut



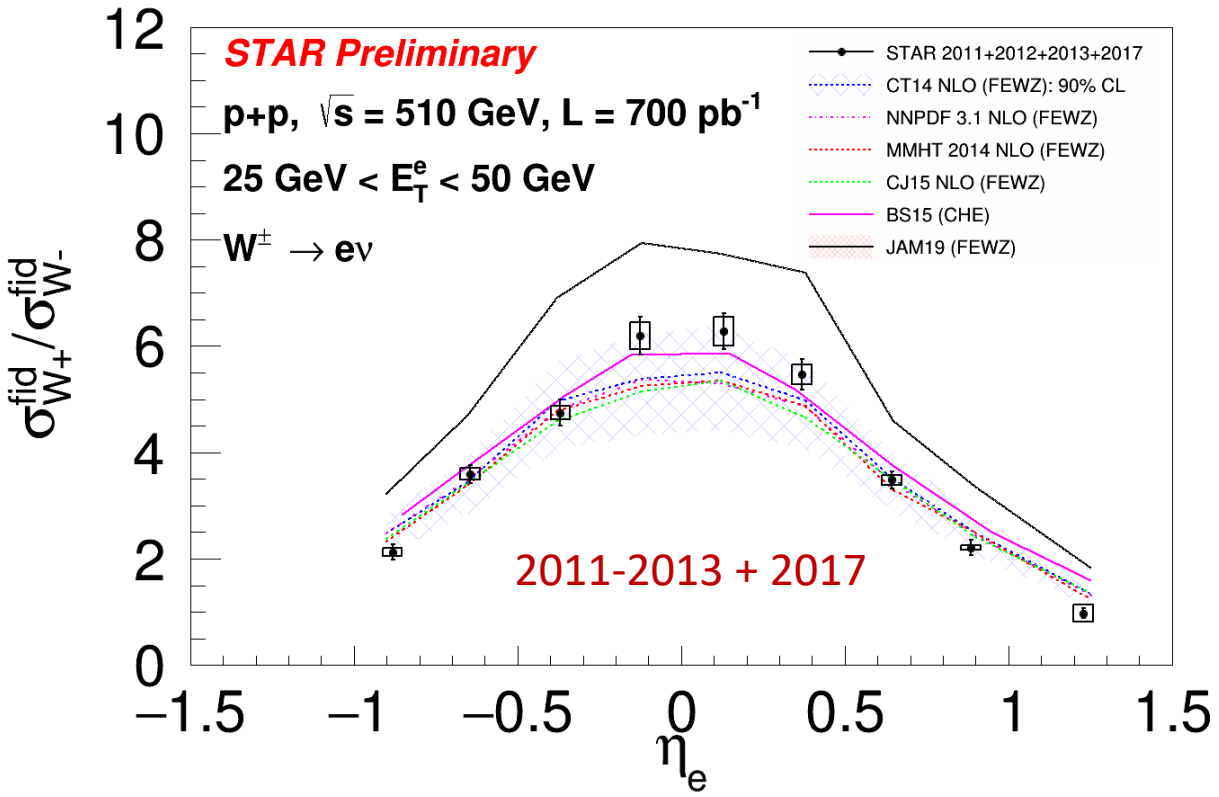


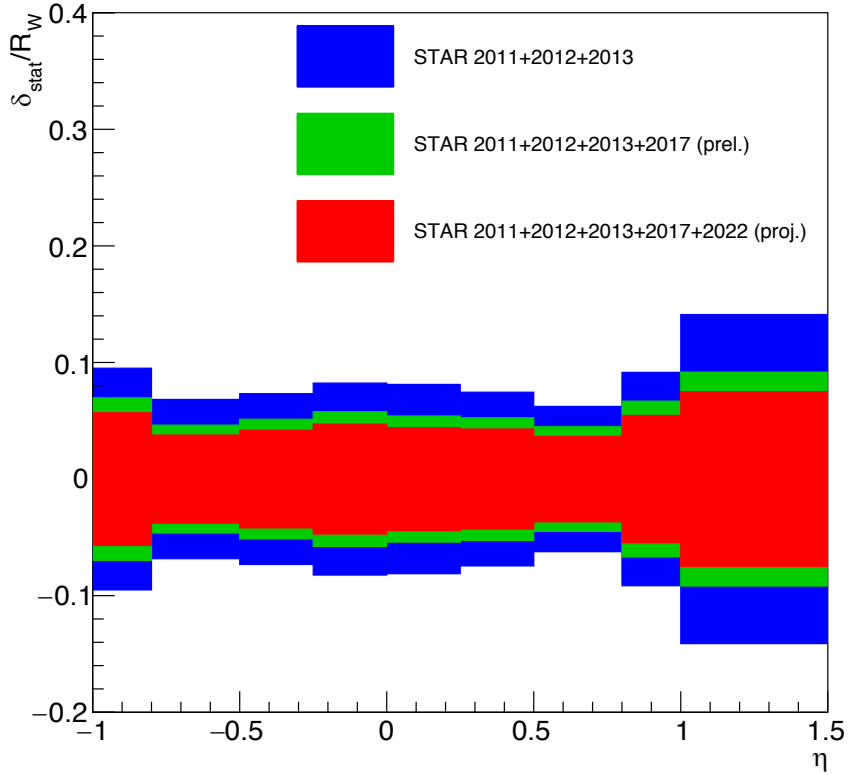
2017 Preliminary W+/W- Results



- Measurement with STAR 2011-2013 data set has been published: PRD 103 (2021), 1, 012001.
- Results from 2017 data set has been released as preliminary.

Preliminary W+/W- Results

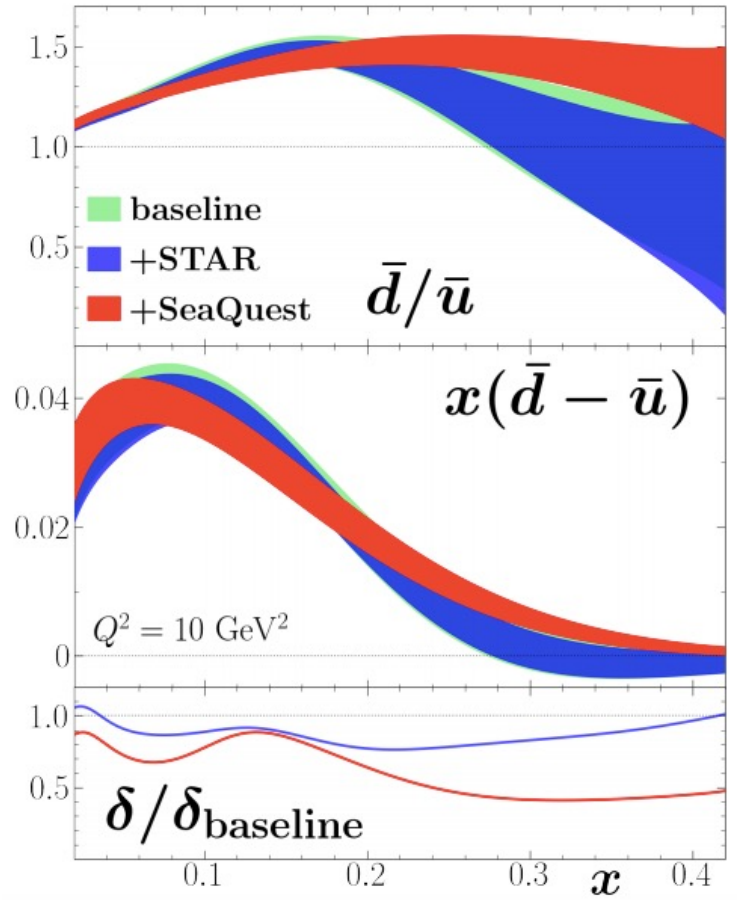




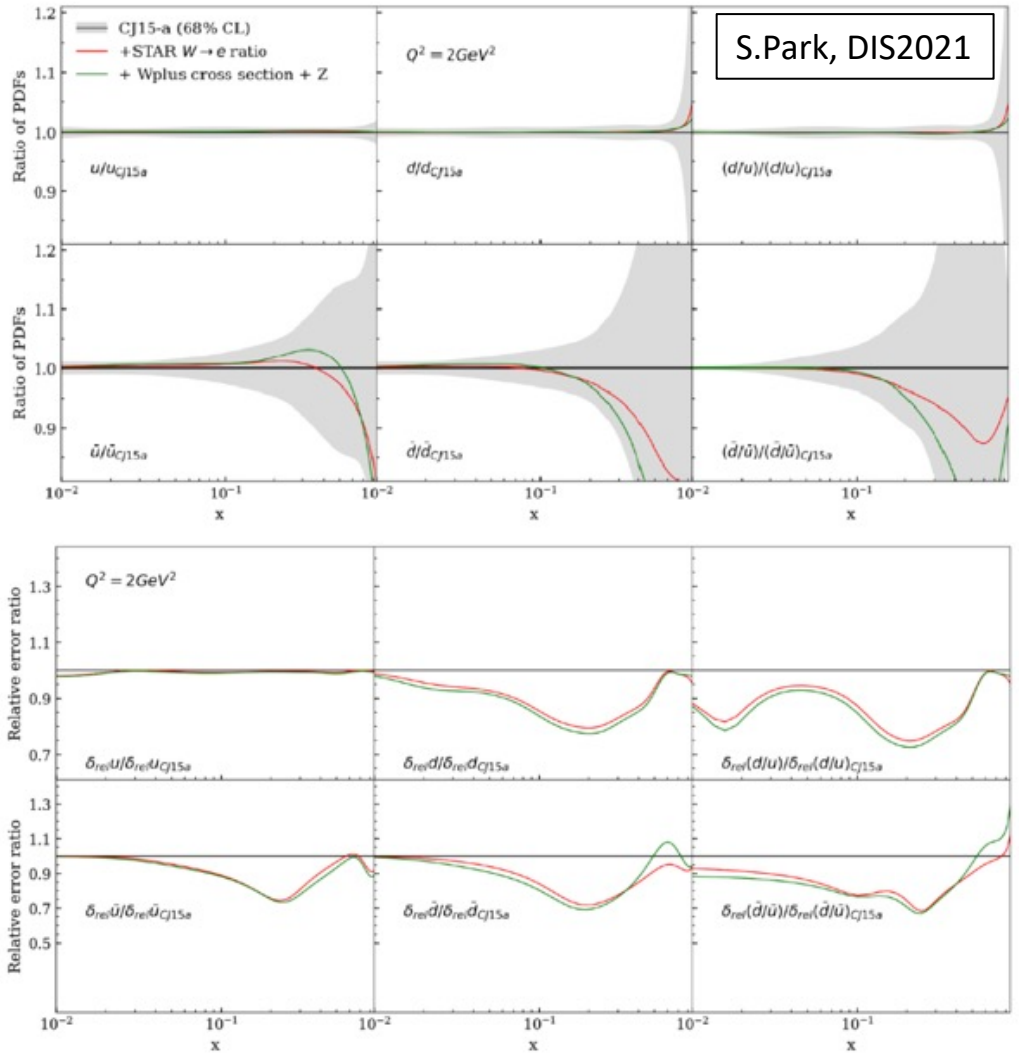
- Combined 2011-2013 + 2017 data sets total $\approx 700\ pb^{-1}$
- Combining the recent 2022 run with measurements from 2011-2013 + 2017 will yield $\sim 1.15\ fb^{-1}$
- The 2022 run concludes STAR's W and 500-510 GeV pp program

PDF Impacts

JAM, PRD 104 (2021) 7, 074031



S.Park, DIS2021



- Recent publication (PRD 103,012001, STAR 2011+2012+2013) has been included in recent global fits.
- STAR data have a moderate impact on the sea quark distributions around $x \sim 0.2$.

Summary

- The W+/W- cross section ratios have been measured at STAR in $\sqrt{s} = 500 - 510\ GeV$ pp collisions
  - Probe $\bar{d}$ / $\bar{u}$ asymmetry in the proton sea
  - The measurement is complimentary to Drell-Yan and LHC measurements
  - Provides moderate improvement to $\bar{d}$ / $\bar{u}$ and other quark distributions in the valence region