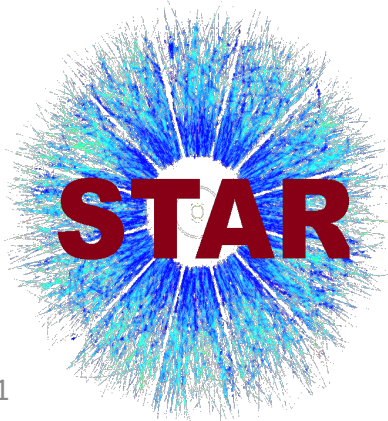
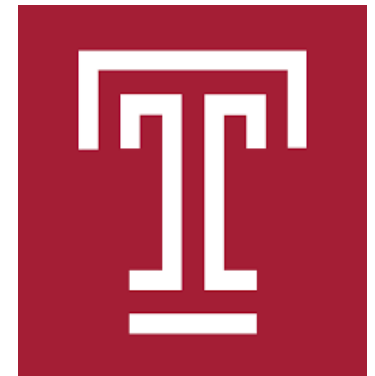


Measurement of W and Z/γ^* cross sections and their ratios in pp collisions at STAR



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Temple University,
for the STAR collaboration



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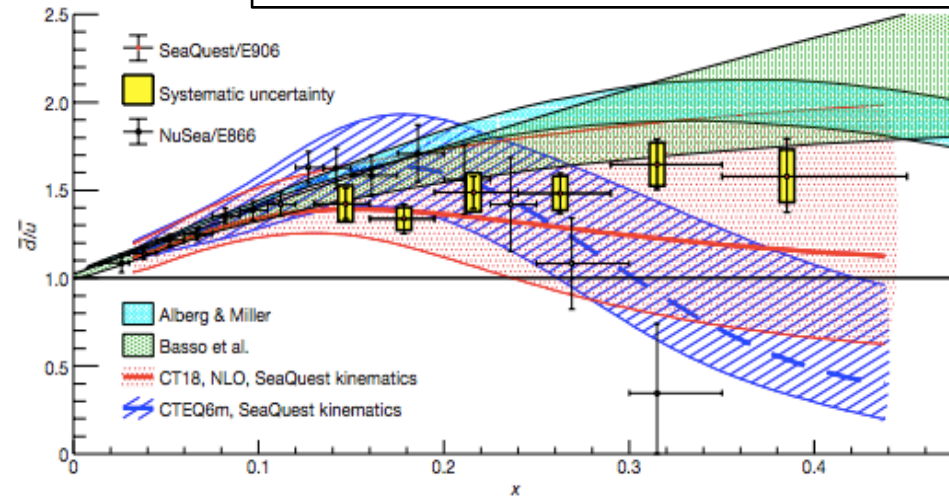
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Motivation

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

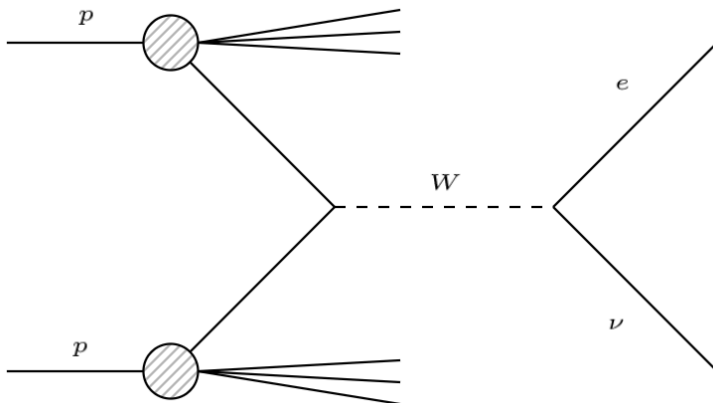


- Unpolarized sea quark ratio \bar{d}/\bar{u}

- Predominantly measured via Drell-Yan
- Conflict between measurements around the valence region.
- STAR kinematics at the mid-rapidity ($|\eta| < 1$) is sensitive to the region $0.1 < x < 0.3$ at $Q^2 = M_W^2$.
- Can be further stretched to $0.06 < x < 0.4$ with Endcap EM Calorimeter (EEMC).

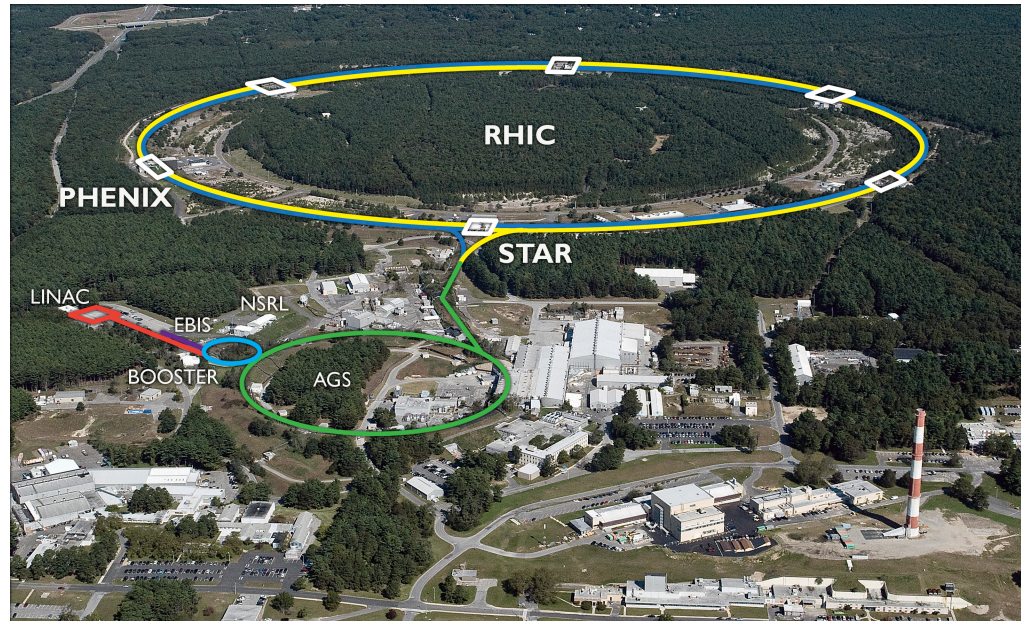
- W production at STAR/RHIC

- LO production sensitive to \bar{d} (W^+) and \bar{u} (W^-).
- Large momentum scale, $Q^2 = M_W^2$.
- Missing p_T due to final state ν .
- Isolated high p_T electron.
- The cross-section ratio $\sigma_{W^+}/\sigma_{W^-}$ can be used to probe \bar{d}/\bar{u} ;



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

Relativistic Heavy Ion Collider (RHIC)



- RHIC is the world's first polarized pp collider.
- $L \approx 700 \text{ pb}^{-1}$ of pp collision data with sufficiently high Q^2 for W production.
 - Measurement with $\sim 350 \text{ pb}^{-1}$ of data has been published.
 - The remaining $\sim 350 \text{ pb}^{-1}$ has been granted preliminary release.

Run	\sqrt{s} (GeV)	L (pb^{-1})
2009	500	10
2011	500	25
2012	510	75
2013	510	250
2017	510	350

STAR, PRD 85, 092010

STAR, PRD 103, 012001

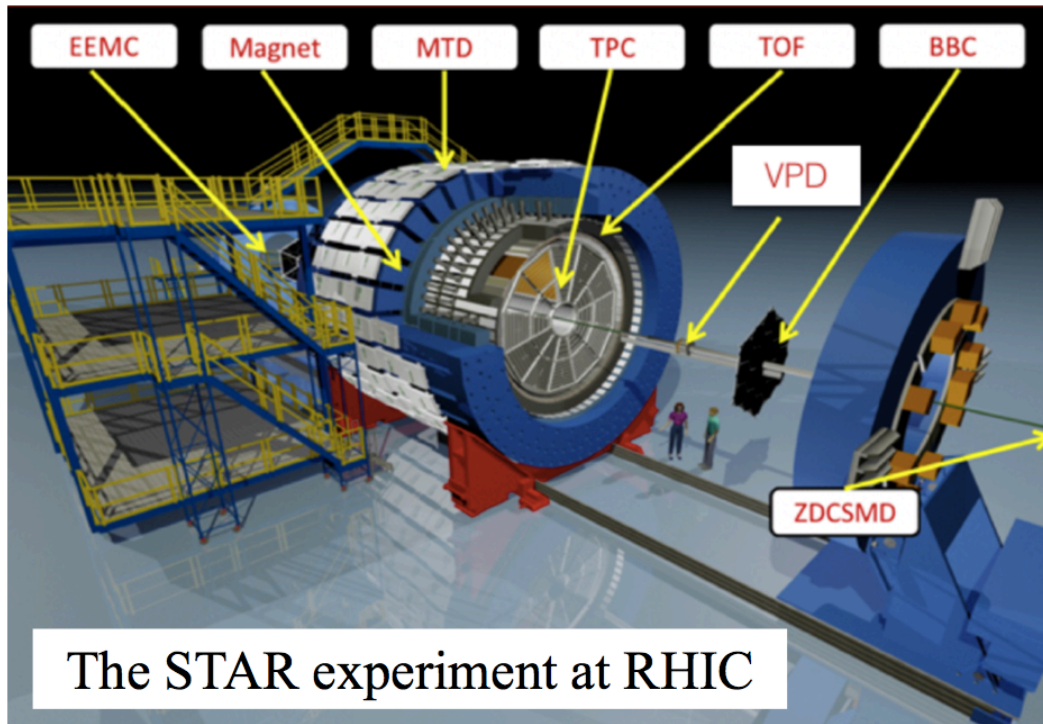
STAR preliminary

This talk



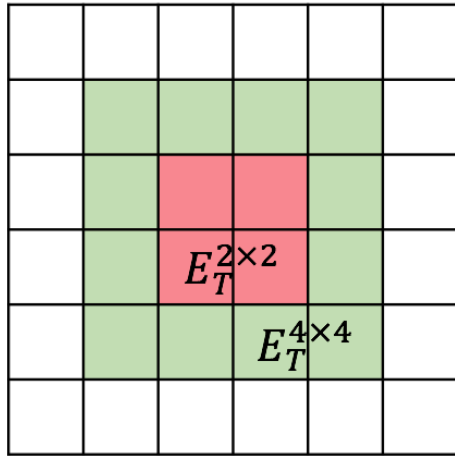
Solenoid Tracker At RHIC (STAR)

- For measurements of W bosons, it is important to achieve near 4π detector acceptance.

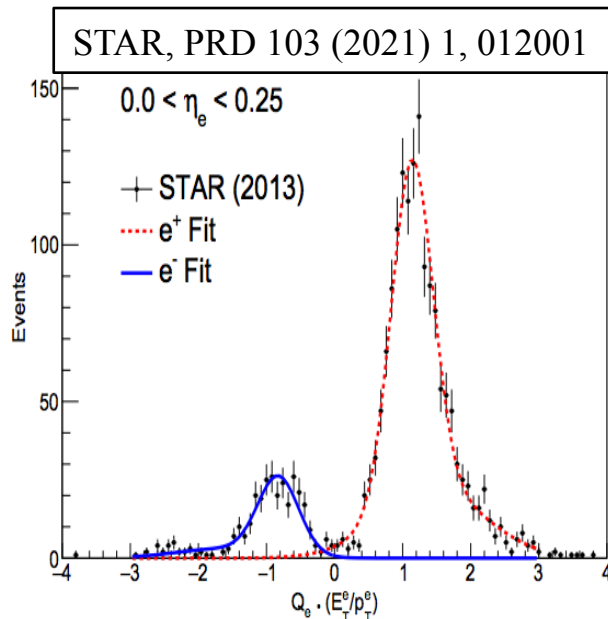


- Time Projection Chamber (TPC)
 - Provides tracking & PID
 - Acceptance of $|\eta| < 1.3$
 - 2π coverage in ϕ
- Electro-Magnetic Calorimeter
 - Barrel (BEMC): $|\eta| < 1$
 - Endcap (EEMC): $1 < \eta < 2$
 - 2π coverage in ϕ
- Luminosity monitoring & Vertexing
 - Beam-Beam Counter (BBC)
 - Zero Degree Counter (ZDC)
 - Vertex Position Detector (VPD)

W reconstruction



TPC track extrapolated to
BEMC tower grid



- Selection

- High \vec{p}_T^{bal} ($= \vec{p}_T^e + \Sigma \vec{p}_T^{recoil}$) event
- Isolated electron ($E_T^{2 \times 2} / E_T^{4 \times 4}$) with high p_T
- No energy in the opposite cone.
- Charge separation from TPC + EMC ($Q_e \times E_T / p_T$).

- W tagging methods

- Lepton-tagging
 - Indirect, but smaller systematic uncertainty.
- W reconstruction with MC (prel.)
 - The missing neutrino momentum is reconstructed via;

$$\vec{p}_T^\nu = -\vec{p}_T^{bal}$$

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

- Correction for non-measured tracks and clusters based on MC study.

W^+ / W^- cross-section ratio

- In the W cross-section ratio measurement, the expression of the ratio reduces to:

$$\sigma_{W^+} / \sigma_{W^-} = \frac{N_{obs}^+}{\epsilon^+ \int L dt} / \frac{N_{obs}^-}{\epsilon^- \int L dt} = \frac{\epsilon^-}{\epsilon^+} \cdot \frac{N_{sig}^+ - N_{bg}^+}{N_{sig}^- - N_{bg}^-}$$

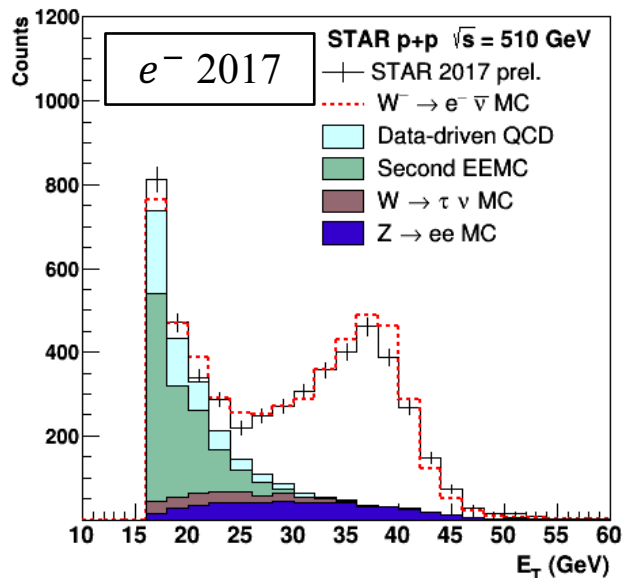
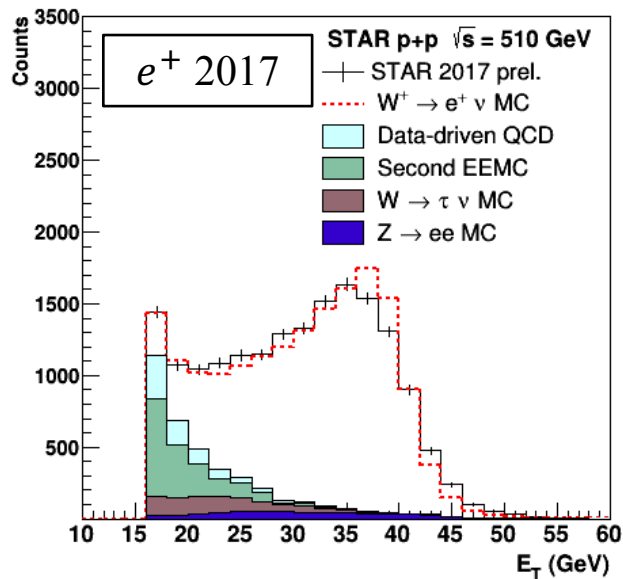
- where ϵ represents the product of the efficiencies of our selection process.

$$\epsilon = \epsilon_{trigger} \times \epsilon_{vertex} \times \epsilon_{tracking} \times \epsilon_{tagging}$$

- MC study suggests that the efficiency ratio ϵ^- / ϵ^+ is consistent with unity.
- N_{bg} represents the sum of all remaining background contributions.

$$N_{bg} = N_{W \rightarrow \tau \nu} + N_{Z \rightarrow ee} + N_{QCD} + N_{EEMC}$$

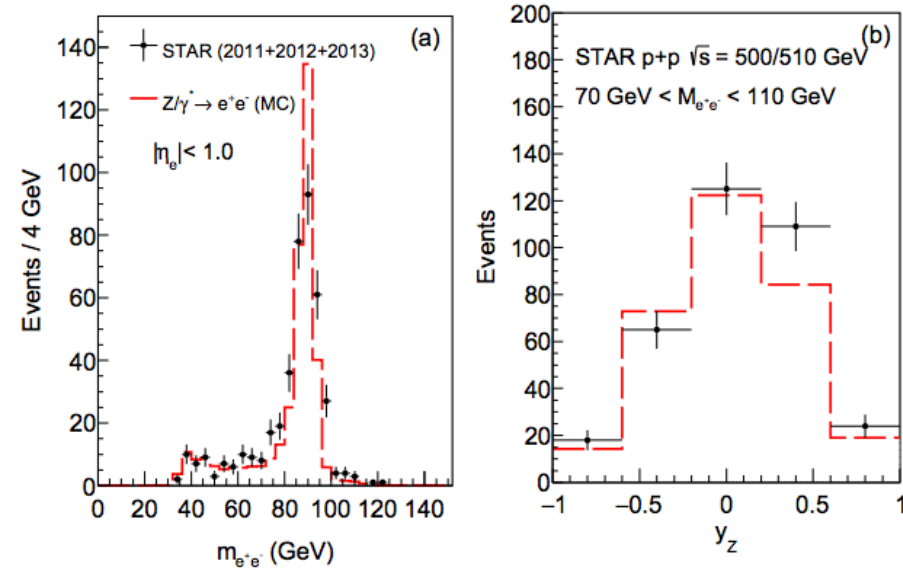
Background



- Electroweak ($N_{Z \rightarrow ee}$, $N_{W \rightarrow \tau \nu}$)
 - Z decays with one unidentified electron
 - Leptonic decay of τ^W
 - Estimated with MC (Pythia)
- Second EEMC (N_{EEMC})
 - Accounts for missing backward coverage ($-2 < \eta < -1$)
 - Estimated by mirroring the effect of existing EEMC ($1 < \eta < 2$)
- Data-driven QCD (N_{QCD})
 - Remaining background contribution that passes the selection process.
 - Distribution obtained by using events that do not pass the $p_{T,bal}$.

Z boson reconstruction

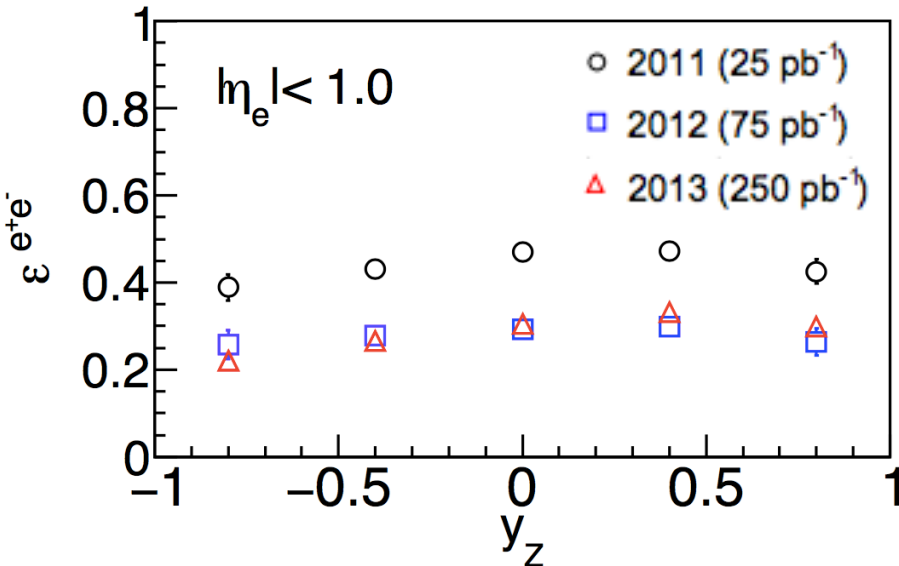
STAR, PRD 103 (2021) 1, 012001



- The leptonic decay of Z boson can be observed at STAR

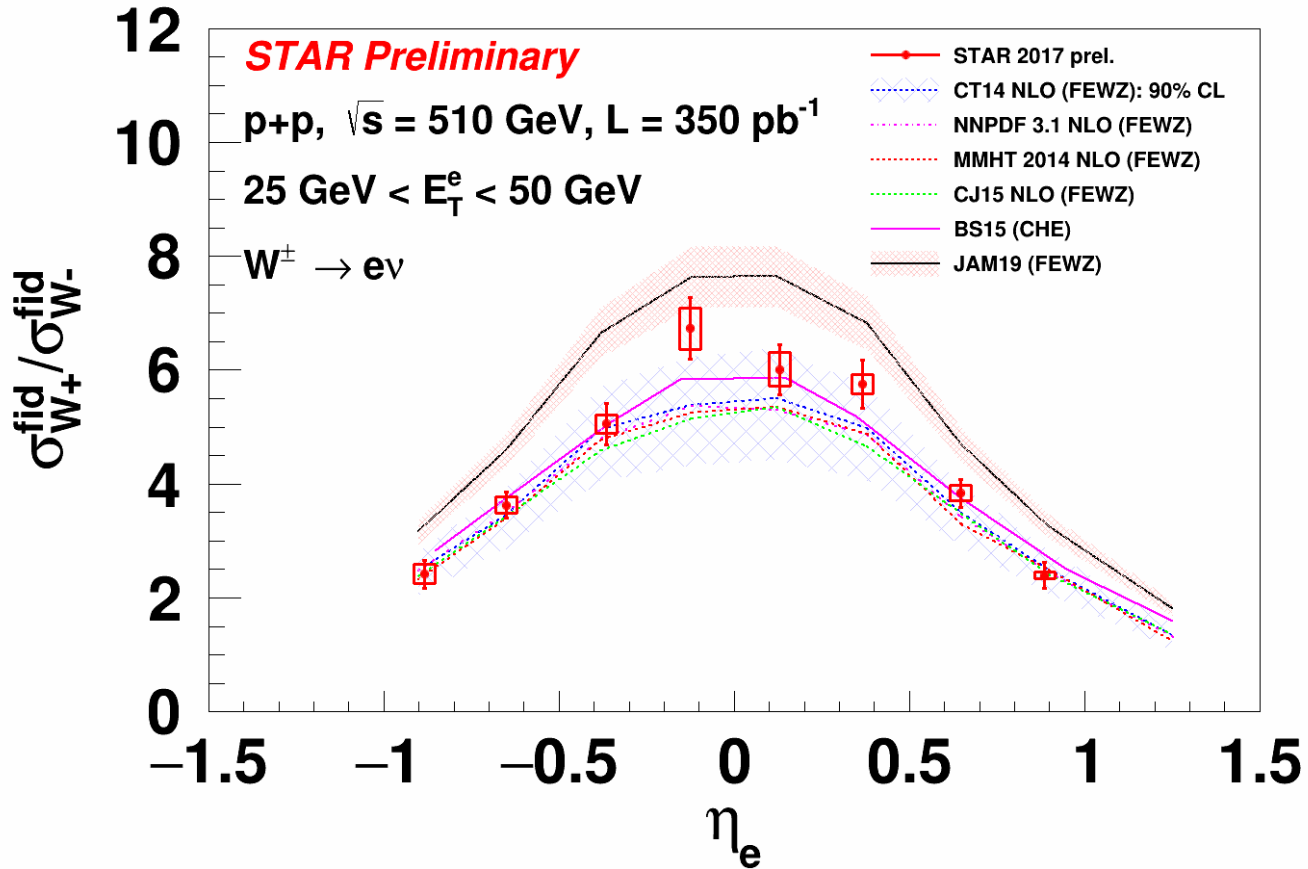
$$pp \rightarrow Z/\gamma^* \rightarrow e^+e^-$$

- Z candidates are selected by tagging two isolated electrons with opposite charges.
 - Provides clean identification of Z candidates.



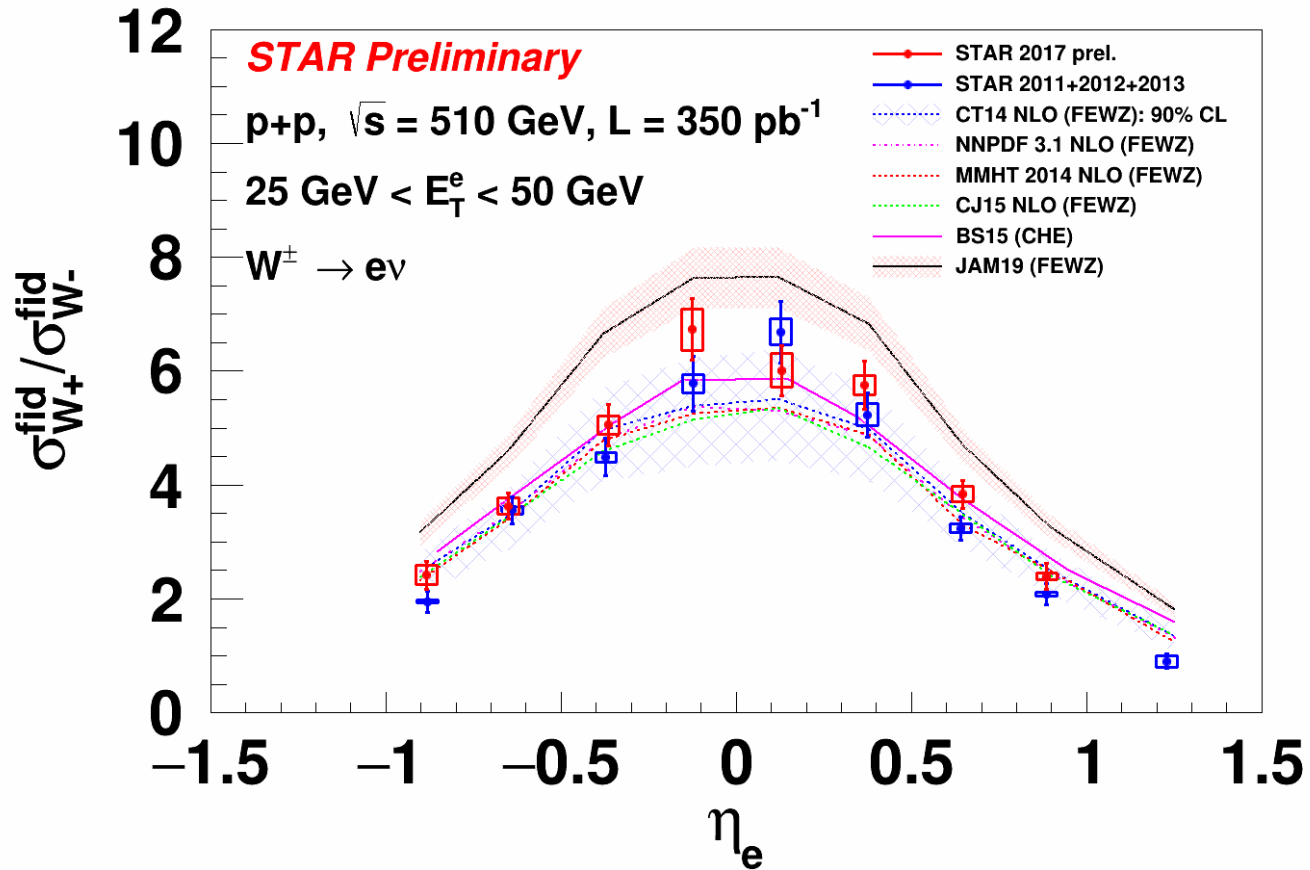
- M_Z can be reconstructed and used to fine-tune the BEMC calibration.
- Efficiencies estimated with Pythia and GEANT.

Results: W^+ / W^- (lepton-tagging)



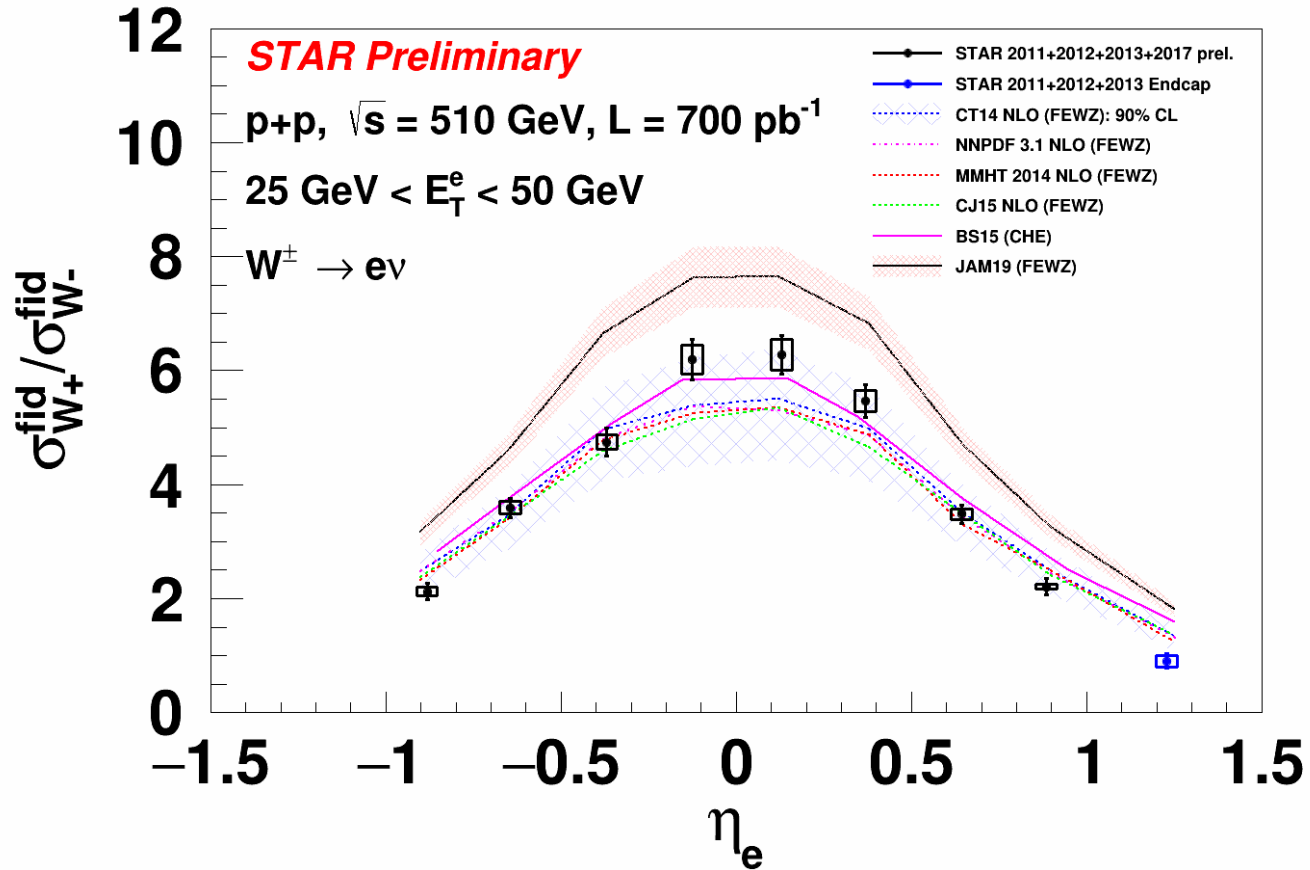
- W^+ / W^- cross-section ratio with STAR 2017 data (prel.)
 - Only the barrel region, $|\eta| < 1$ (Endcap study in progress).

Results: W^+ / W^- (lepton-tagging)



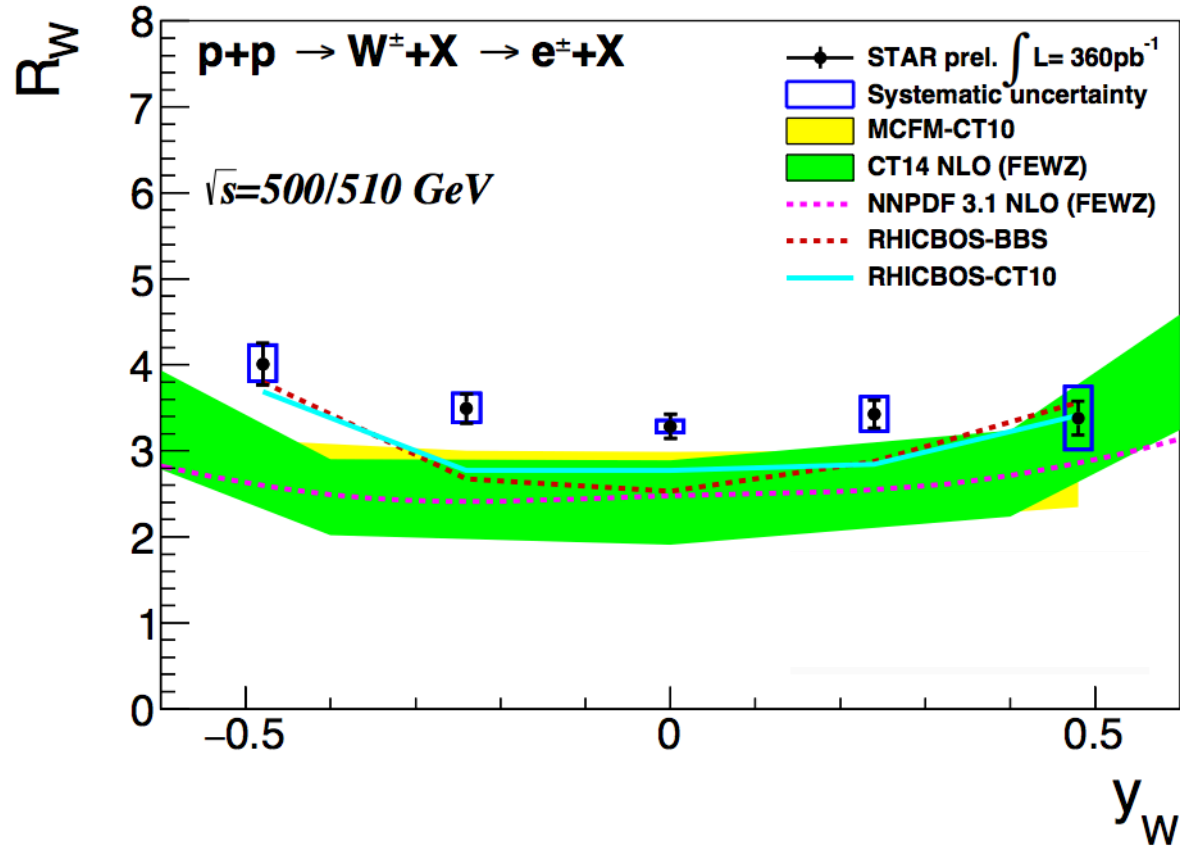
- Measurement with STAR 2011-2013 data has been published [PRD 103 (2021) 1, 012001].
 - The systematic uncertainty of Run 2017 measurement driven by BEMC gain calibration.

Results: W^+ / W^- (lepton-tagging)



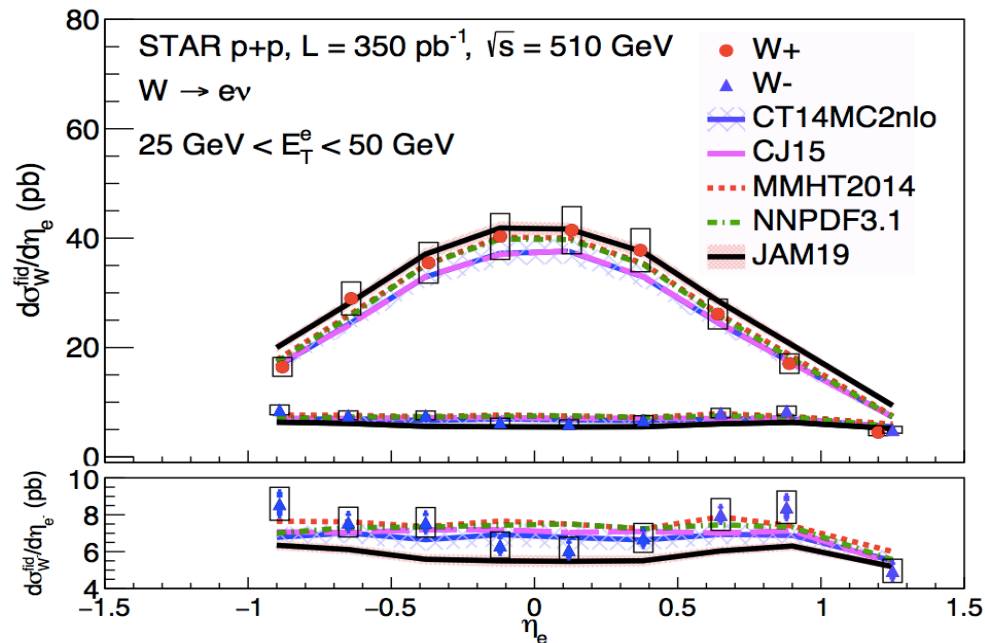
- Combined dataset
 - Doubles the statistics of the published result ($L \approx 700 \text{ pb}^{-1}$).
 - Overall good agreement with the current PDF distributions.

Results: W^+ / W^- (W recon.)



- W^+ / W^- cross-section ratio with STAR Run 2011+2012+2013 ($L \approx 360 \text{ pb}^{-1}$)
 - Systematics driven by W rapidity reconstruction.
 - Run 17 study in progress

Results: Absolute cross sections

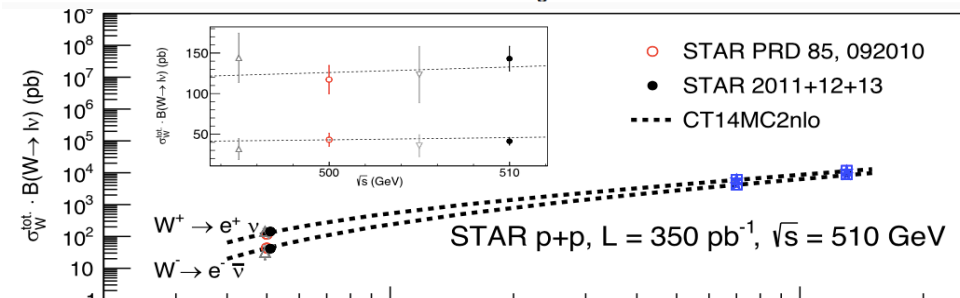


- Measurement of the total cross sections.

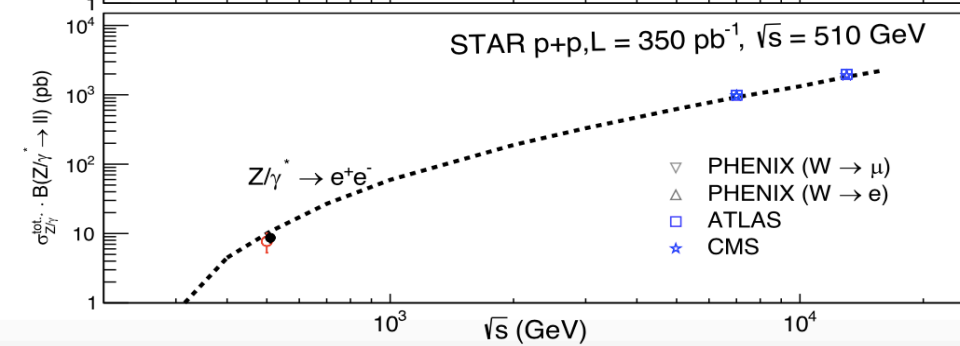
$$\sigma_{W/Z}^{fid} = \frac{N_{sig} - N_{bg}}{\epsilon \int L dt}$$

$$\sigma_{W/Z}^{tot} = \sigma_{W/Z}^{fid} / A_{W/Z}$$

- Acceptance correction onto 2011 sample ($\sqrt{s} = 500 \text{ GeV}$) to match 2012 and 2013 samples ($\sqrt{s} = 510 \text{ GeV}$) by using FEWZ [PRD 86 (2012) 094034].



- Consistent with world pp data trend and theory.

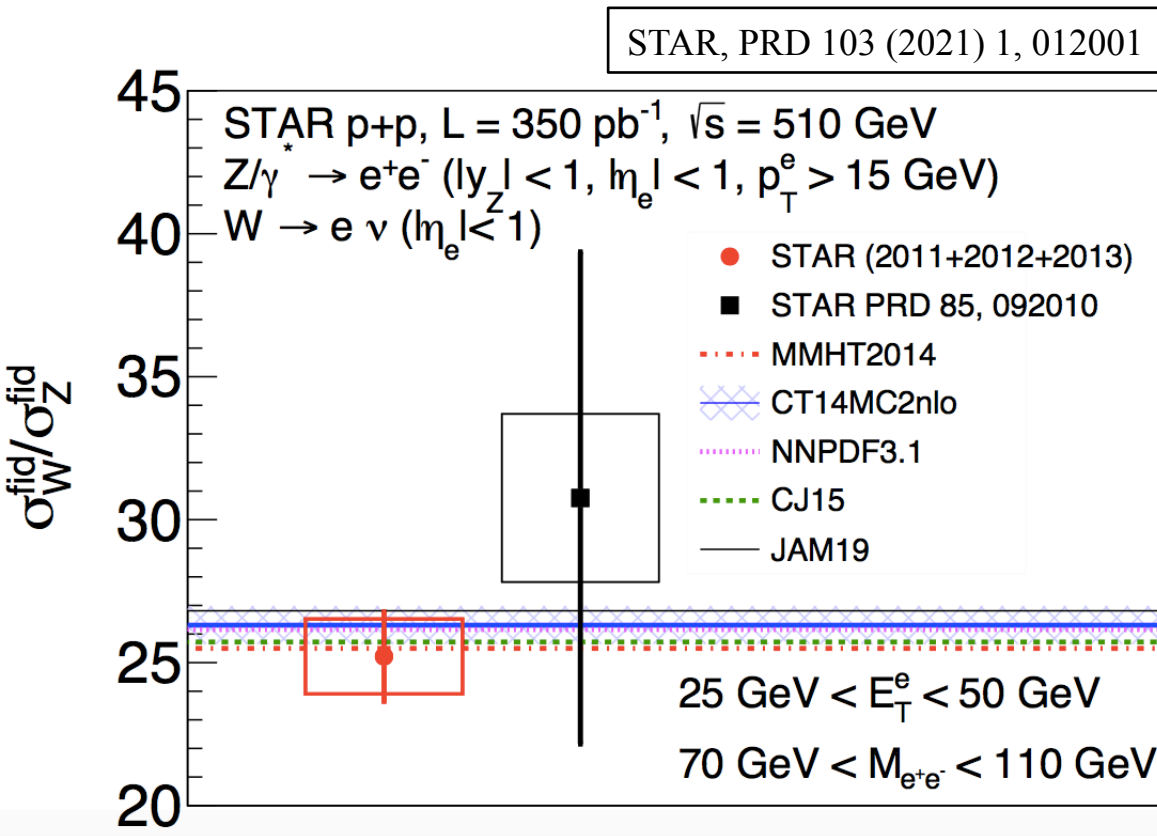


- Run 2017 result in progress.

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Results: W/Z cross-section ratio



- W/Z cross-section ratio

$$\frac{\sigma_W}{\sigma_Z} = \frac{\epsilon_Z}{\epsilon_W} \frac{N_{sig}^W - N_{bg}^W}{N_{sig}^Z}$$

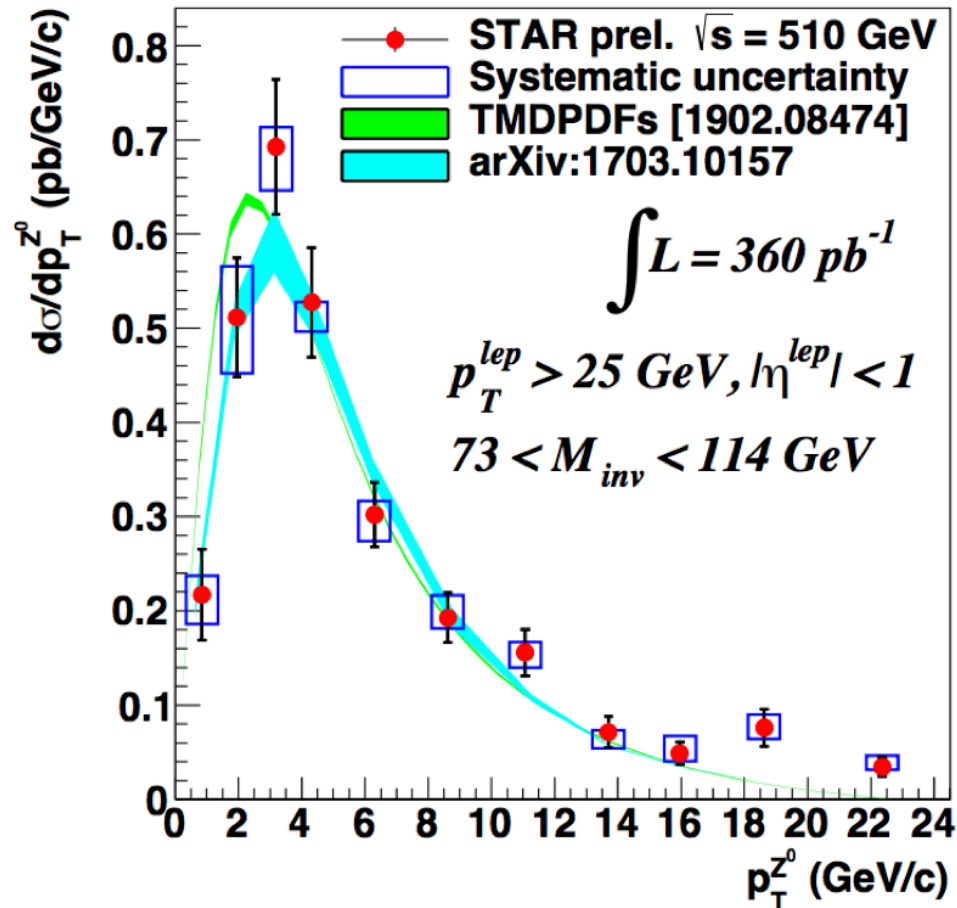
- Where $W = W^+ + W^-$.

- Consistent with STAR 2009 result and FEWZ calculations.
- Further constraints to PDFs (strangeness).

Results: Differential Z cross section

$Z^0/\gamma^* \rightarrow e^+e^-$

STAR preliminary



- Preliminary measurement of $d\sigma/dp_T^{Z^0}$.
 - Systematic uncertainty driven by BEMC gain uncertainty.
- Help constrain unpolarized TMDPDFs.
- Theory curves based on recent extractions of TMDPDFs.



Summary

- W^+ / W^- cross sections and their ratio have been measured as a function of lepton pseudorapidity η^e with STAR $p + p$ collision data at $\sqrt{s} = 510 \text{ GeV}$.
 - Published with the combined dataset (2011+2012+2013, $L \approx 350 \text{ pb}^{-1}$).
 - Help constrain the \bar{d} and \bar{u} sea quark PDFs (complementary to DY).
 - In addition, W/Z ratio measured.
 - Low- \sqrt{s} and high- x measurement complementary to LHC measurements.
- Preliminary release of results using STAR 2017 data.
 - Effectively doubles the statistics of these measurements.
 - Only deals with the cross-section ratio measurement at the barrel region for the moment (endcap + absolute cross section in progress).
- Preliminary results on W reconstruction.
 - More direct measurement than the lepton-tagging method.
 - Larger systematic uncertainty.
- Preliminary measurement of differential Z cross section.
 - Constraints to unpolarized TMDPDFs.



Backup



Systematic uncertainties

- Charge dependence $\delta_{\Delta\epsilon}$
 - Remaining charge dependence obtained by taking the difference between ϵ^\pm .
- BEMC calibration δ_{BEMC}
 - Due to imperfect BEMC calibration, obtained by taking the variation in the efficiency ratio while varying BEMC gain by the calibration uncertainty.
- Background description δ_{QCD}^{bg}
 - The uncertainty associated with the QCD background description in terms of its shape and normalization has been tested by varying $p_{T,bal}$ cut and the normalization window.
- Missing jet in QCD dijet δ_{QCD}^{dijet}
 - Dijet events are neglected when one of the two jets is outside the detector acceptance region.
 - A Pythia study was done to estimate the effect.
- (Run 2017 prel. only) BEMC gain correction $\delta_{BEMC,cor}$
 - The gain values of BEMC at STAR have been fine-tuned by reconstructing the mass of Z boson.
 - A larger BEMC correction has been observed STAR Run 2017 sample.
 - This effect has been estimated by taking the difference between the nominal sample and a test sample without the correction.

