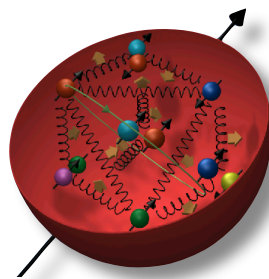


Measurement of the
 longitudinal spin asymmetries for weak boson
 production in polarized proton-proton collisions at
 $\sqrt{s} = 510\text{GeV}$ at RHIC

Bernd Surrow



(On behalf of the STAR Collaboration)



DOE NP contract: DE-SC0013405

Bernd Surrow

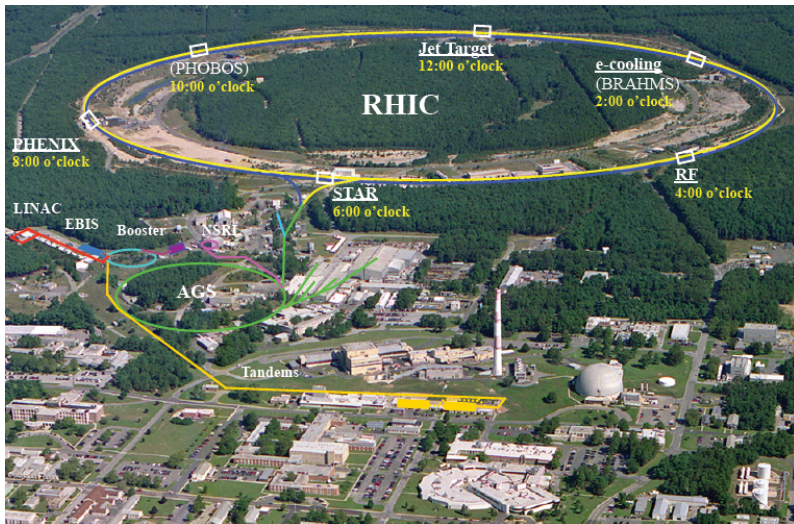
DNP 2019

Fall Meeting of the Division of Nuclear Physics of the
 American Physical Society



DNP 2019 - Fall Meeting of the APS Division of Nuclear Physics
 Arlington, VA, October 14-17, 2019

Outline



Measurement of:

W^\pm single / double spin asymmetry A_L / A_{LL}

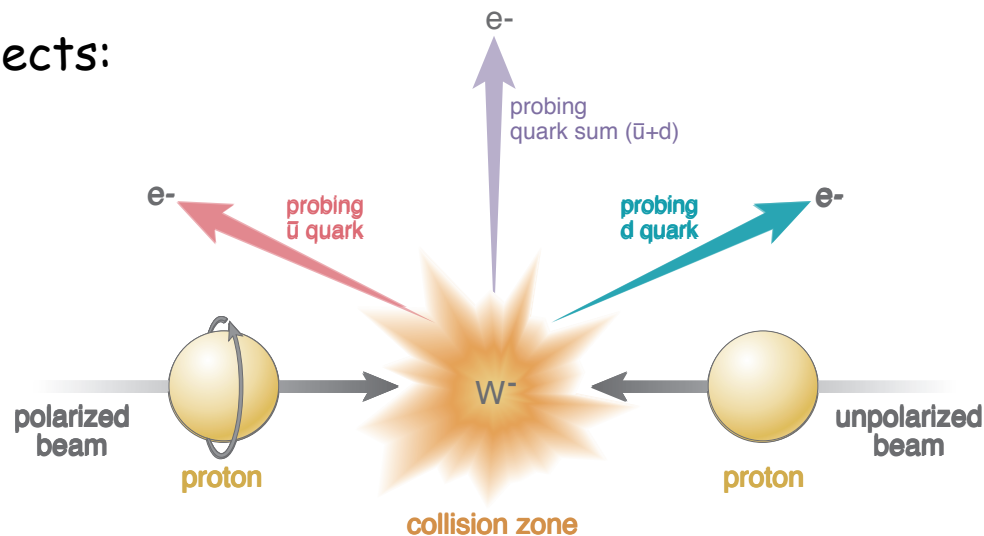
Z^0 single asymmetry A_L

○ Analysis details

○ Results

Experimental aspects: RHIC / STAR

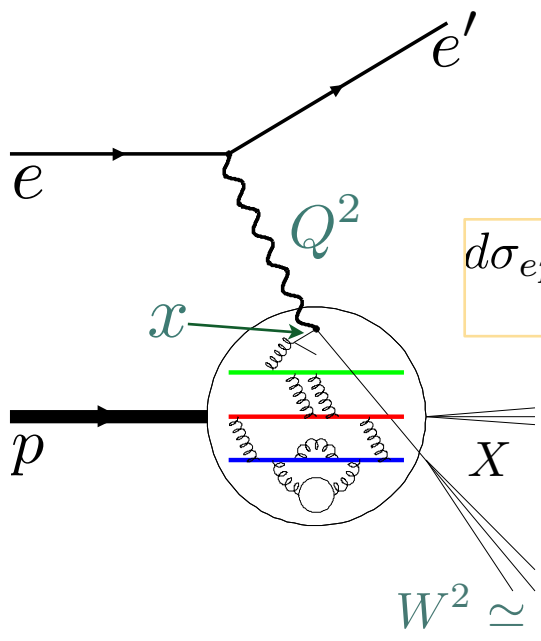
Theoretical foundation



Summary and Outlook

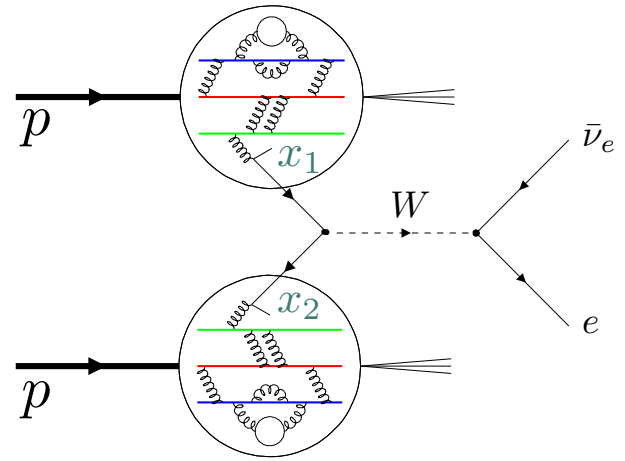
Theoretical foundation

□ How do we probe the structure and dynamics of matter in ep vs. pp scattering?



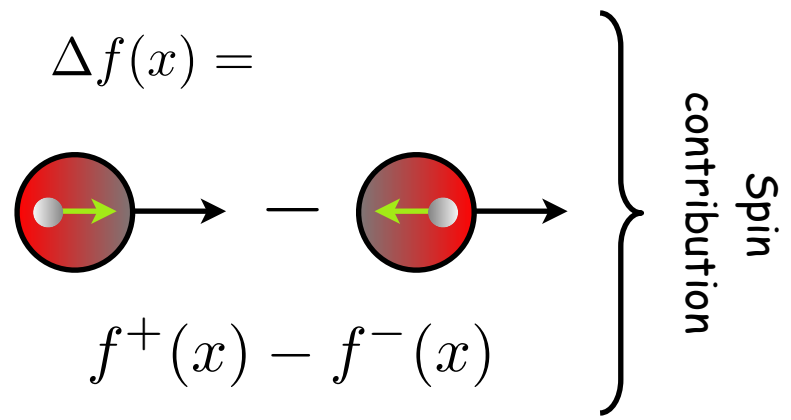
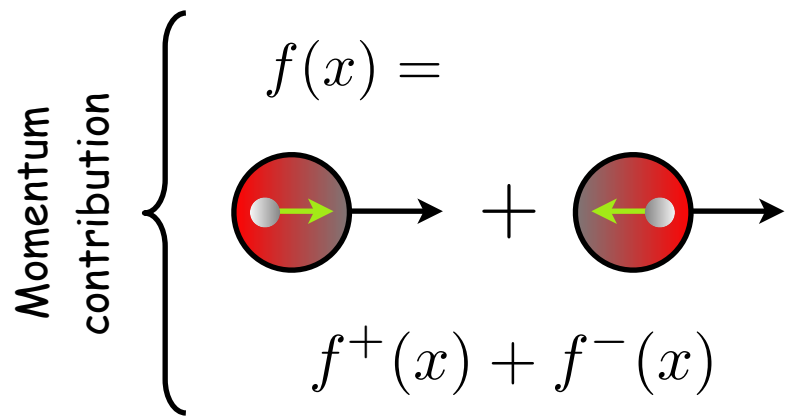
$$d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x)$$

Universality



$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$

Factorization



Theoretical foundation

□ Proton spin structure using high-energy polarized p+p collisions - W production

○ Observable: Quark/Anti-quark polarization (W production)

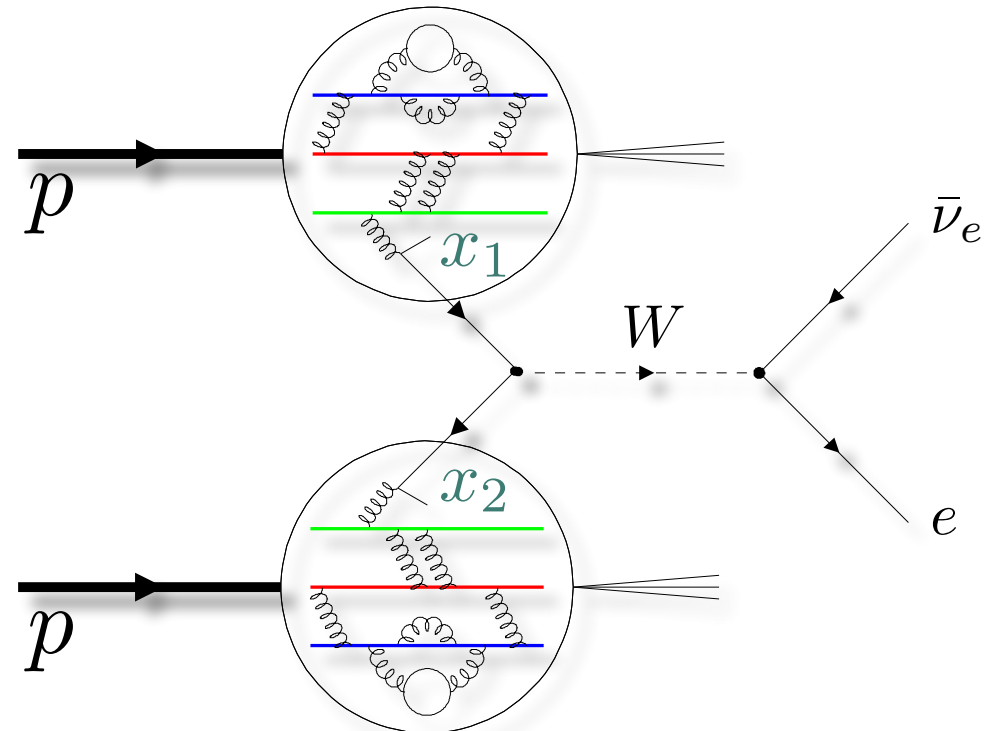
- Longitudinal single-spin asymmetry A_L

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- Parity (Spatial inversion) violating for W production!

○ Features of W boson production probing parton distributions:

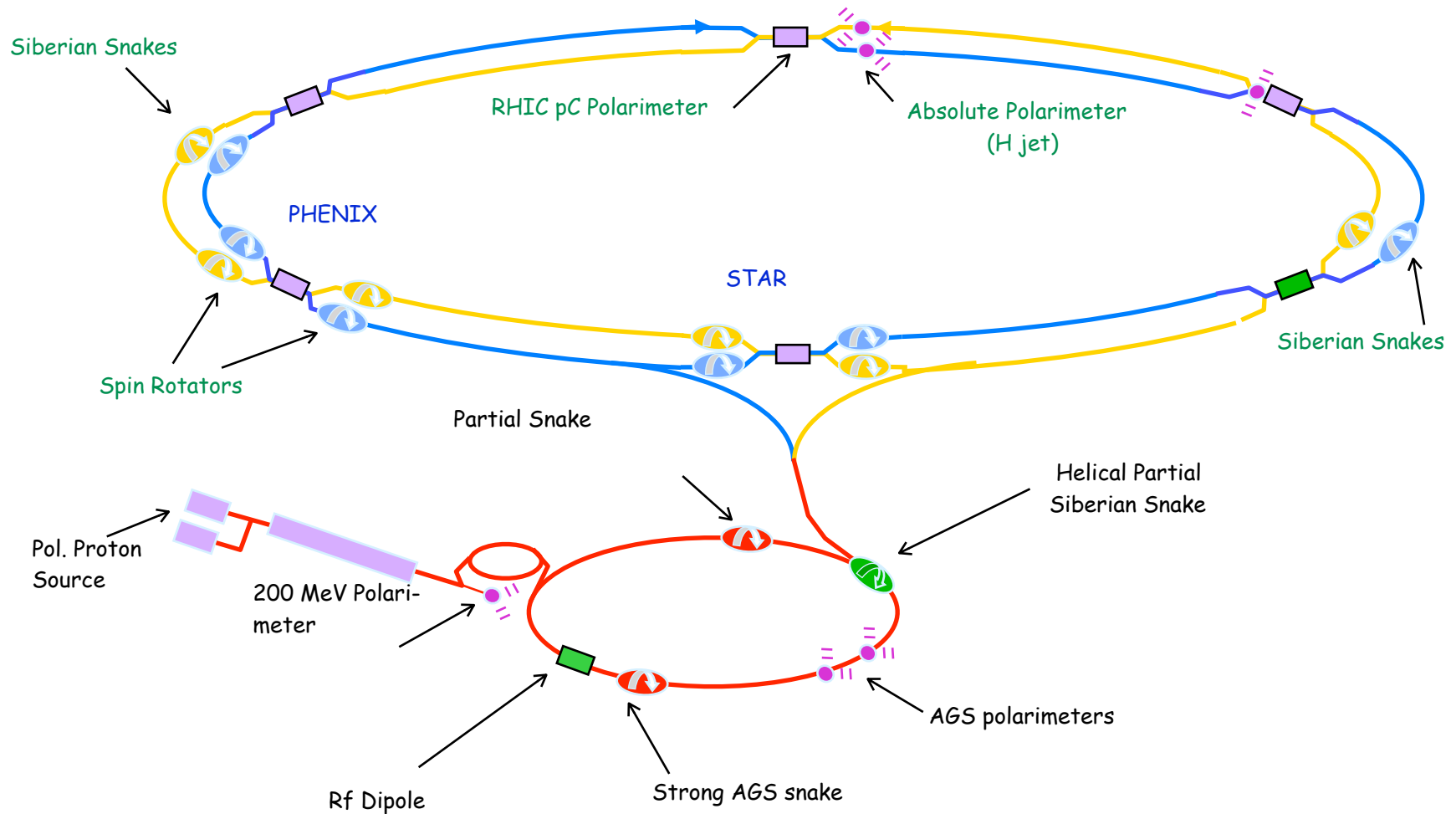
- **Direct sensitivity** to quark (u/d) / anti-quark (ubar/dbar) distributions
- **Large scale defined by W mass** (~80GeV)
- Simple final state of charged leptons: **No dependency on fragmentation functions**



- Polarized and unpolarized partonic cross-sections known at NLO - **W A_L asymmetry results powerful input for global analyses** such as DSSV and NNPDF at NLO level!

Experimental aspects - RHIC

- The world's first polarized proton-proton collider

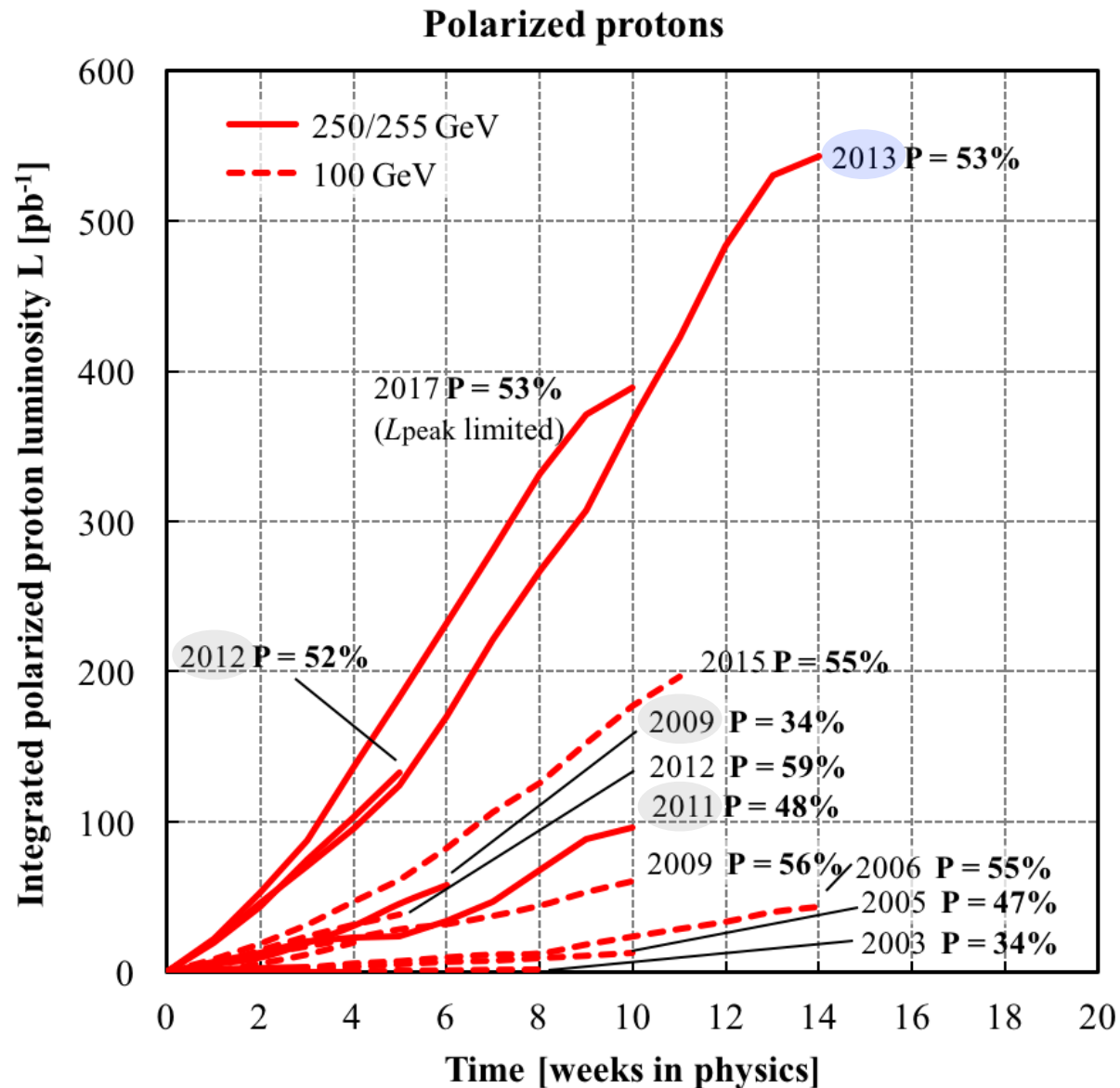


Experimental aspects - RHIC

□ Polarized p-p collisions

- Production runs at $\sqrt{s}=500/510\text{GeV}$ (long. polarization) in 2009, 2011, 2012, 2013: W production (Quark polarization) / Jet and Hadron production (Gluon polarization)

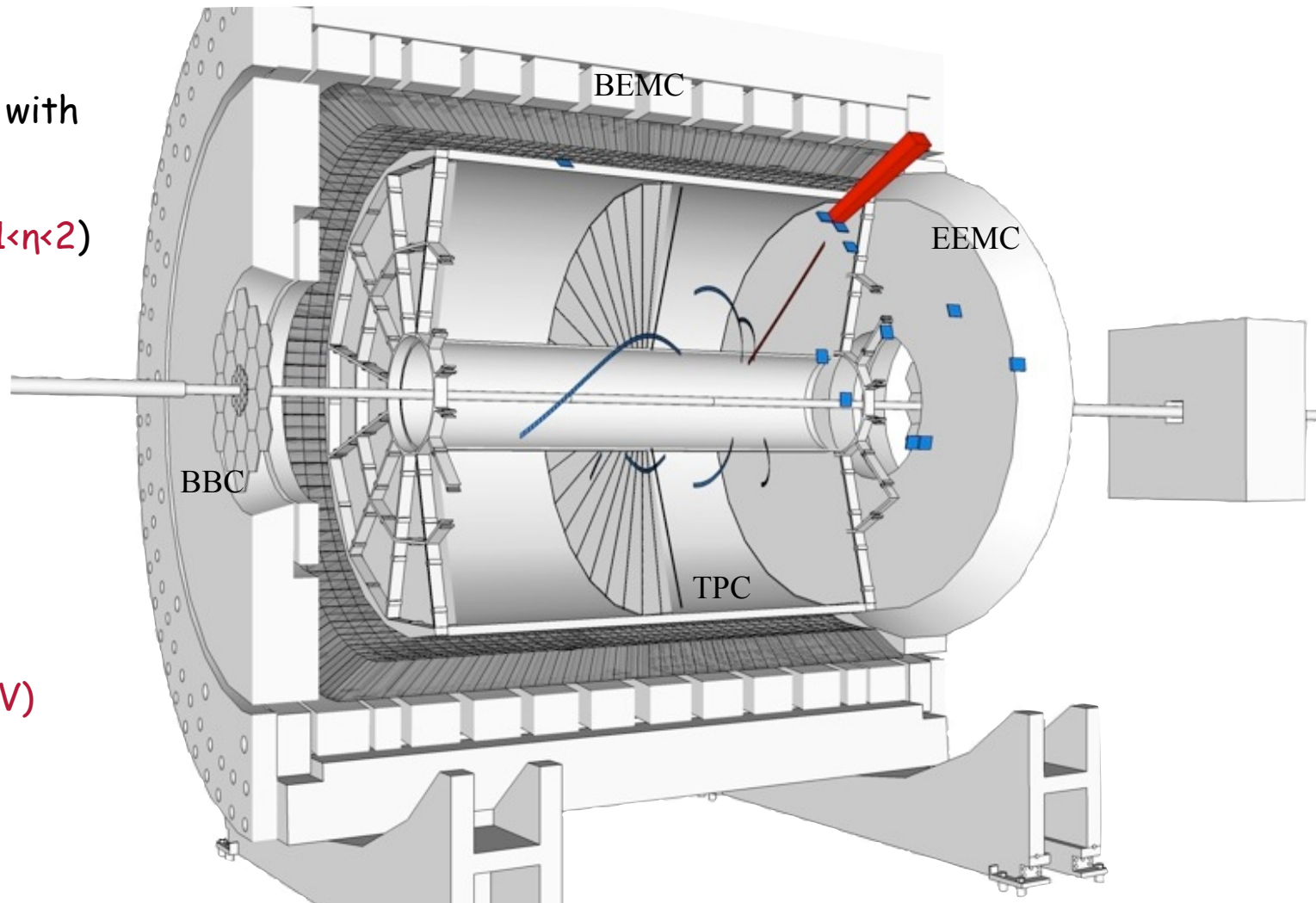
Run	L (pb ⁻¹)	P (%)	FOM (P ² L) (pb ⁻¹)
Run 9	12	0.38	1.7
Run 11	9	0.49	2.2
Run 12	77	0.56	24
Run 13	250	0.56	78



Experimental aspects - STAR

□ Overview

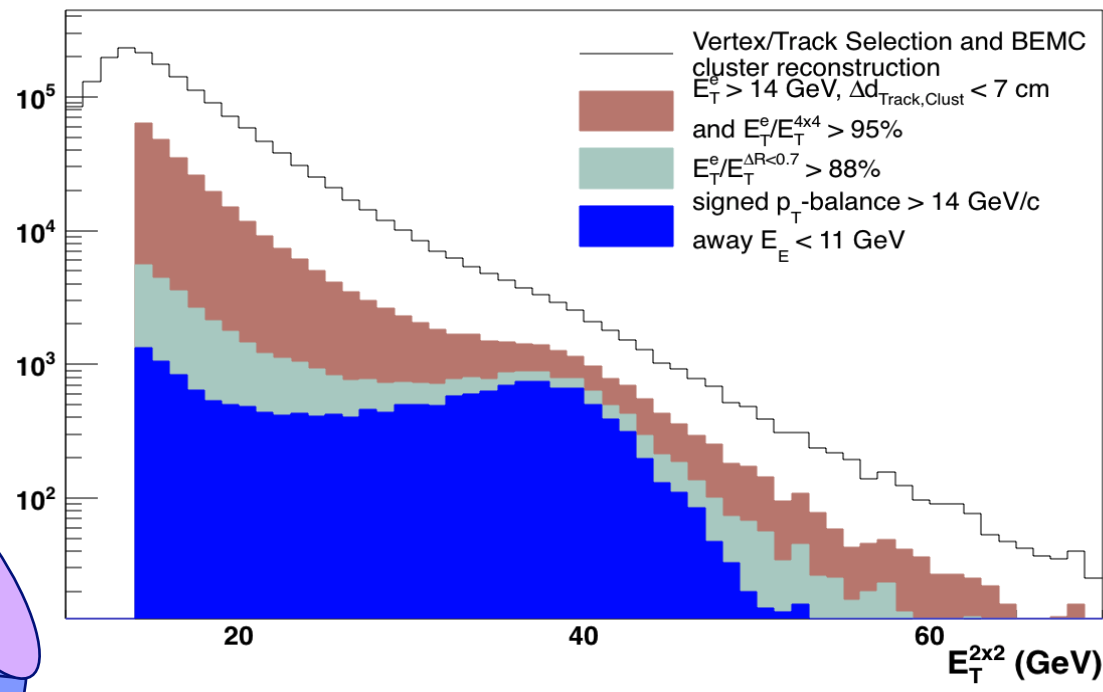
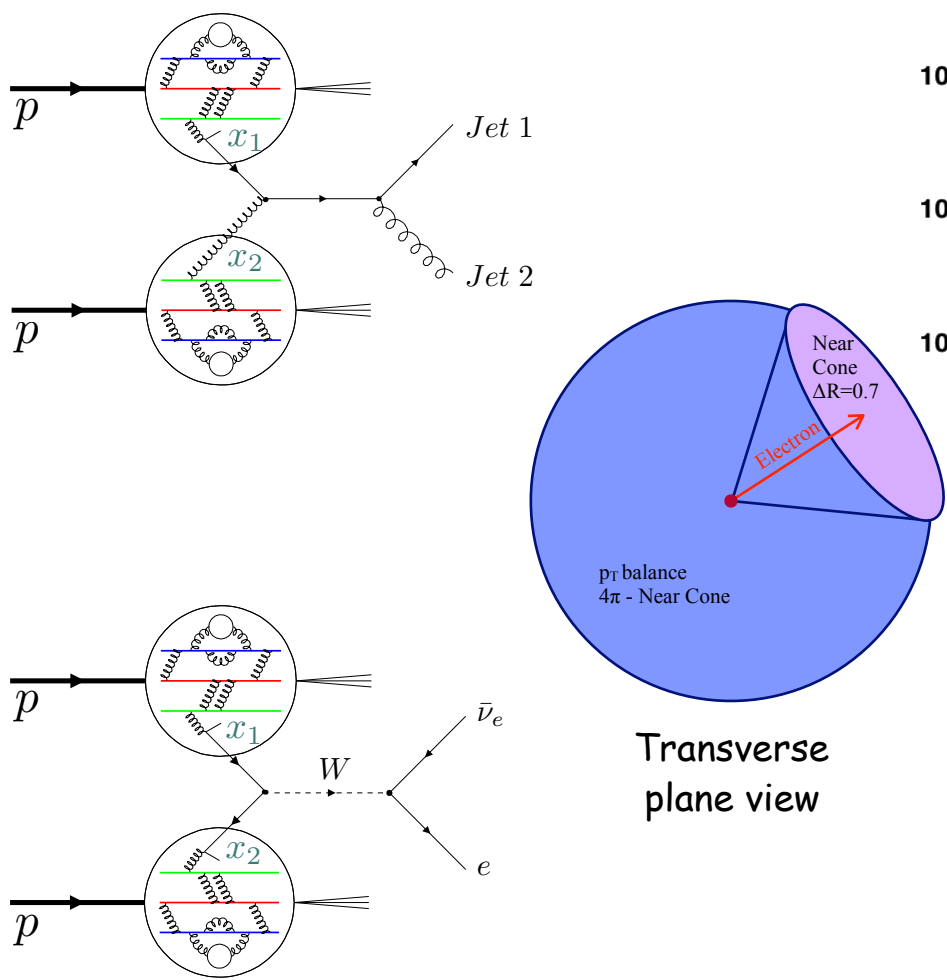
- Calorimetry system with 2π coverage: BEMC ($-1 < \eta < 1$) and EEMC ($1 < \eta < 2$)
- TPC: Tracking and particle ID
- ZDC: Relative luminosity and local polarimetry (500GeV)
- BBC: Relative luminosity and Minimum bias trigger



$$\eta = -\ln \left(\tan \left(\frac{\theta}{2} \right) \right)$$

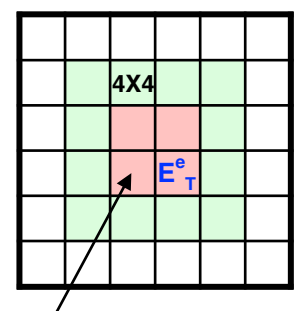
Results / Status - W reconstruction

□ W boson reconstruction at STAR



$$\vec{p}_T^{bal} = \vec{p}_T^e + \sum_{\Delta R > 0.7} \vec{p}_T^{jets}$$

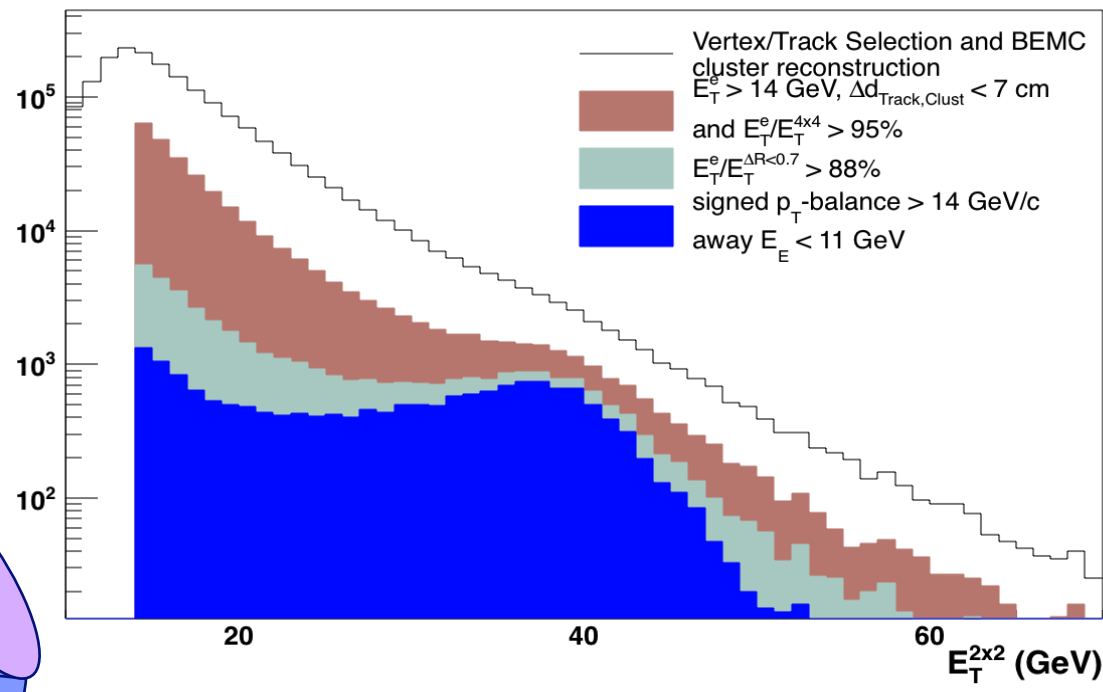
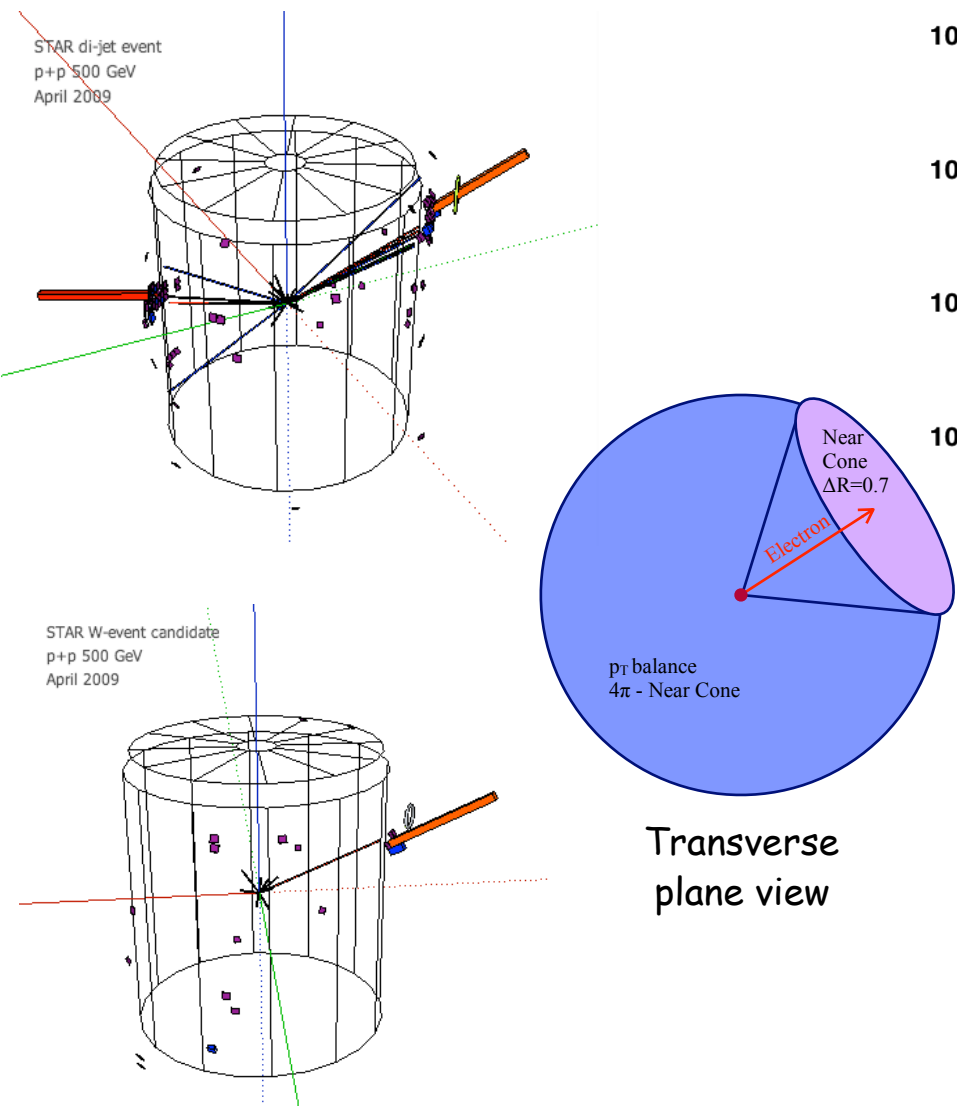
$$P_T\text{-balance } \cos(\phi) = \frac{\vec{p}_T^e \cdot \vec{p}_T^{bal}}{|\vec{p}_T^e|}$$



TPC track extrapolated to Barrel calorimeter tower grid

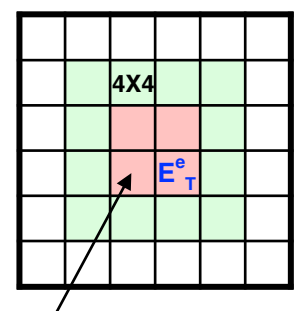
Results / Status - W reconstruction

W boson reconstruction at STAR



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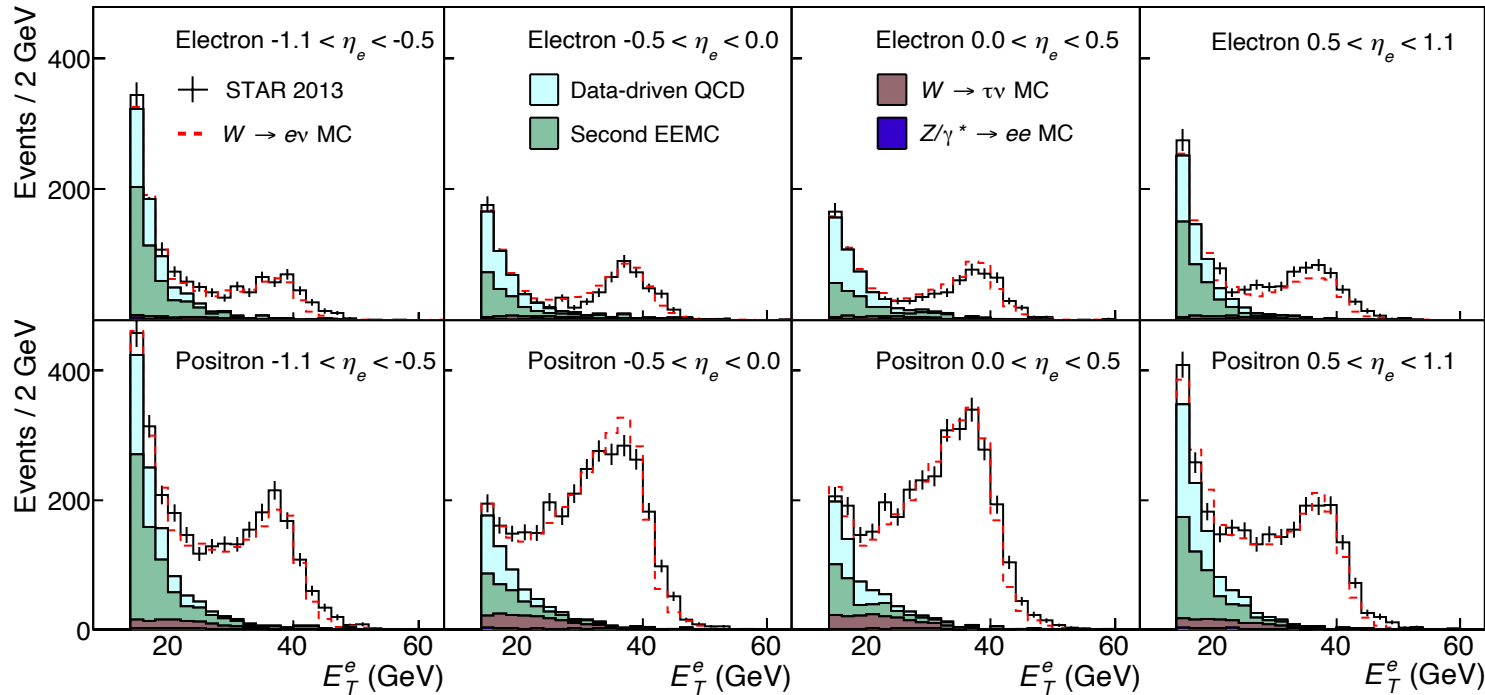
$$P_T\text{-balance } \cos(\phi) = \frac{\vec{p}_T^e \cdot \vec{p}_T^{bal}}{|\vec{p}_T^e|}$$



TPC track extrapolated to Barrel calorimeter tower grid

Results / Status - W reconstruction

Mid-rapidity W^+ / W^- signal distributions / Background determination



STAR E_T distributions for W^-/W^+ candidate events well described by $W \rightarrow e + \nu$ (W - e decay) signal events and data-driven QCD background estimation plus electro-weak background events in four mid-rapidity η bins

QCD background:

J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.

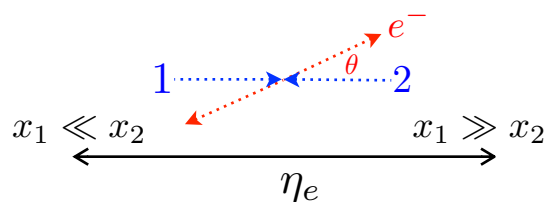
- Data-driven QCD background estimate: Background which satisfy e^\pm candidate isolation cuts
- Second EEMC QCD background estimate: Background ("Jet") at non-existing calorimetric coverage for $-2 < \eta < 1.1$ based on instrumented calorimetric coverage with STAR EEMC for $1.1 < \eta < 2$

Electro-Weak background: $Z \rightarrow e^+ + e^-$ (Z decay) and $W \rightarrow \tau + \nu$ (W -Tau decay) / PYTHIA-MC estimation!

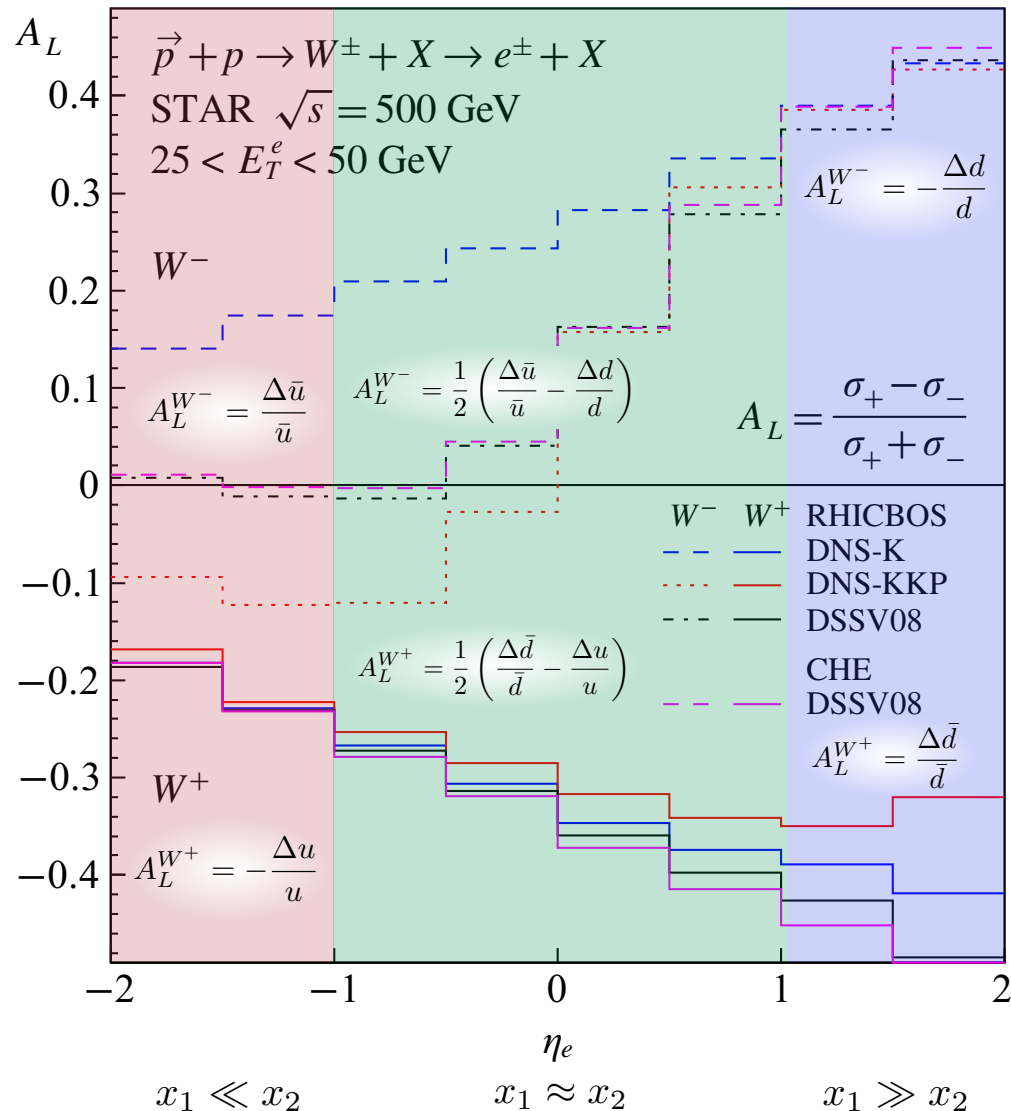
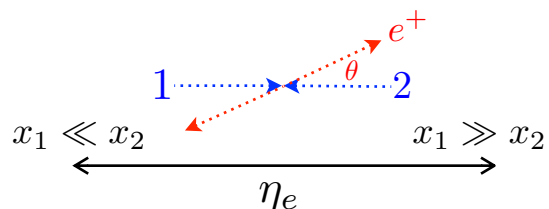
Results / Status - Δq / Δq_{bar} related studies

- RHIC Probing the quark flavor structure using W boson production

$$A_L^{e^-} \approx \frac{\int_{\otimes(x_1, x_2)} [\Delta \bar{u}(x_1) d(x_2) (1 - \cos \theta)^2 - \Delta d(x_1) \bar{u}(x_2) (1 + \cos \theta)^2]}{\int_{\otimes(x_1, x_2)} [\bar{u}(x_1) d(x_2) (1 - \cos \theta)^2 + d(x_1) \bar{u}(x_2) (1 + \cos \theta)^2]}$$



$$A_L^{e^+} \approx \frac{\int_{\otimes(x_1, x_2)} [\Delta \bar{d}(x_1) u(x_2) (1 + \cos \theta)^2 - \Delta u(x_1) \bar{d}(x_2) (1 - \cos \theta)^2]}{\int_{\otimes(x_1, x_2)} [\bar{d}(x_1) u(x_2) (1 + \cos \theta)^2 + u(x_1) \bar{d}(x_2) (1 - \cos \theta)^2]}$$



$\sqrt{s} = 500$ GeV

Results / Status - Δq / Δq_{bar} related studies

□ $W A_L$ measurements at STAR 2013 and 2011+2012 and PHENIX

○ STAR 2013 $W A_L$ results is the most precise

measurement of $W A_L$ up to date.

○ STAR 2013 $W A_L$ results consistent with published

2011+2012 results

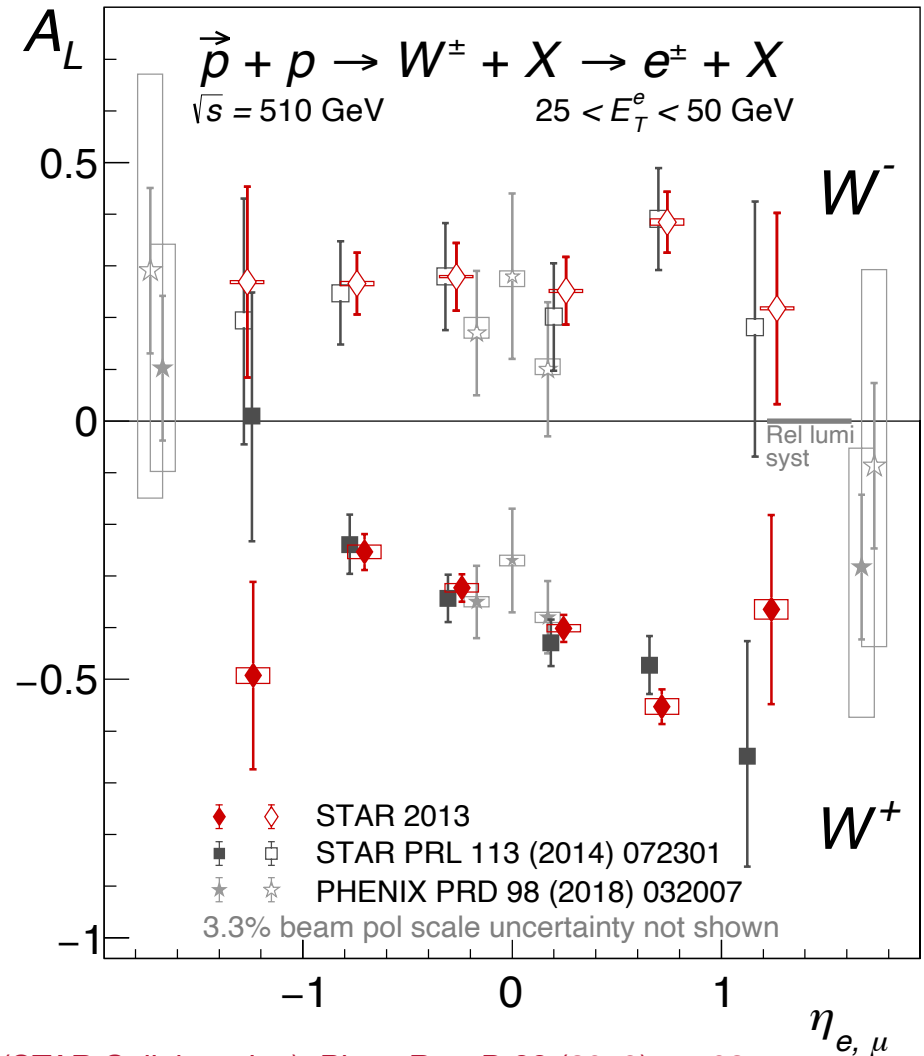
○ Statistical uncertainties (Dominant uncertainties)

were reduced by 40-50% compared to published

2011+2012 results / Similar systematic uncertainties.

○ Results consistent with published PHENIX mid-

rapidity measurements.



J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.

Results / Status - Δq / Δq_{bar} related studies

□ $W A_L$ measurements: Combination of 2011+2012+2013

- STAR 2013 $W A_L$ results is the most precise

measurement of $W A_L$ up to date.

- STAR 2013 $W A_L$ results consistent with published

2011+2012 results

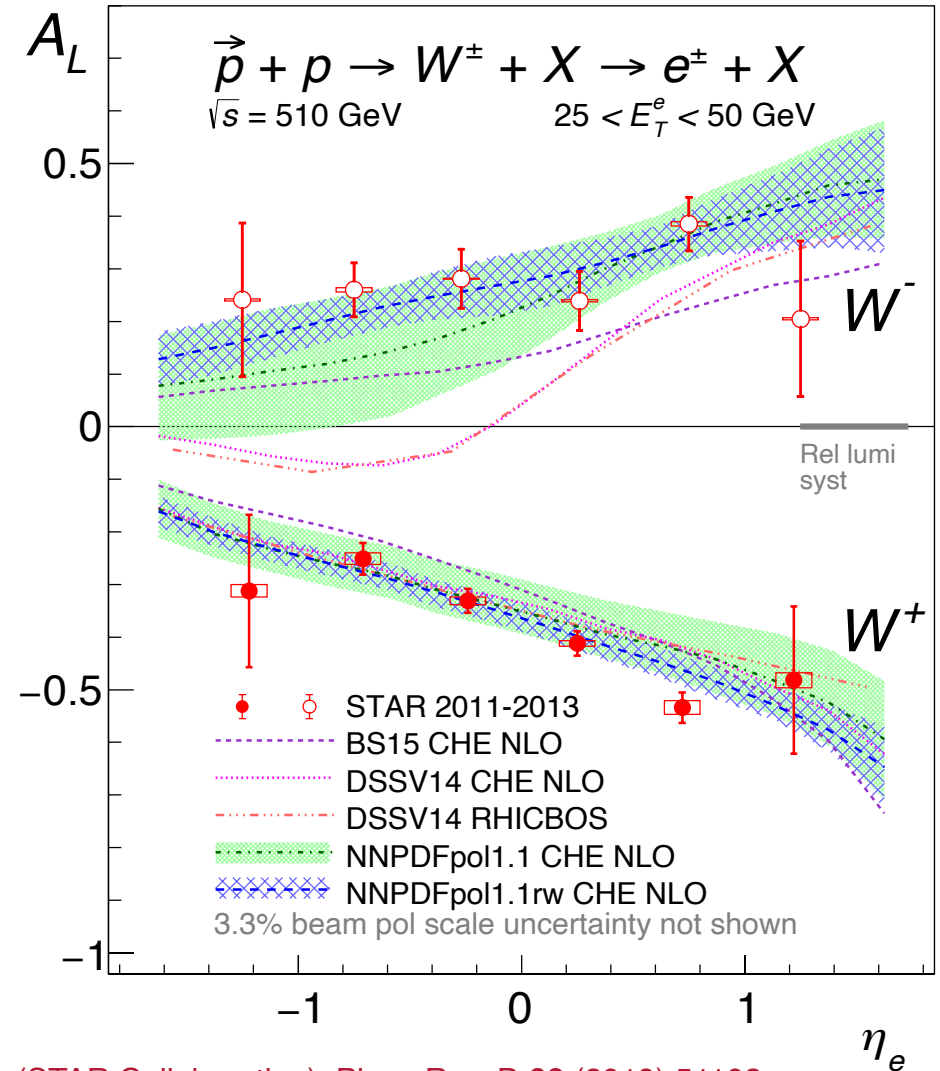
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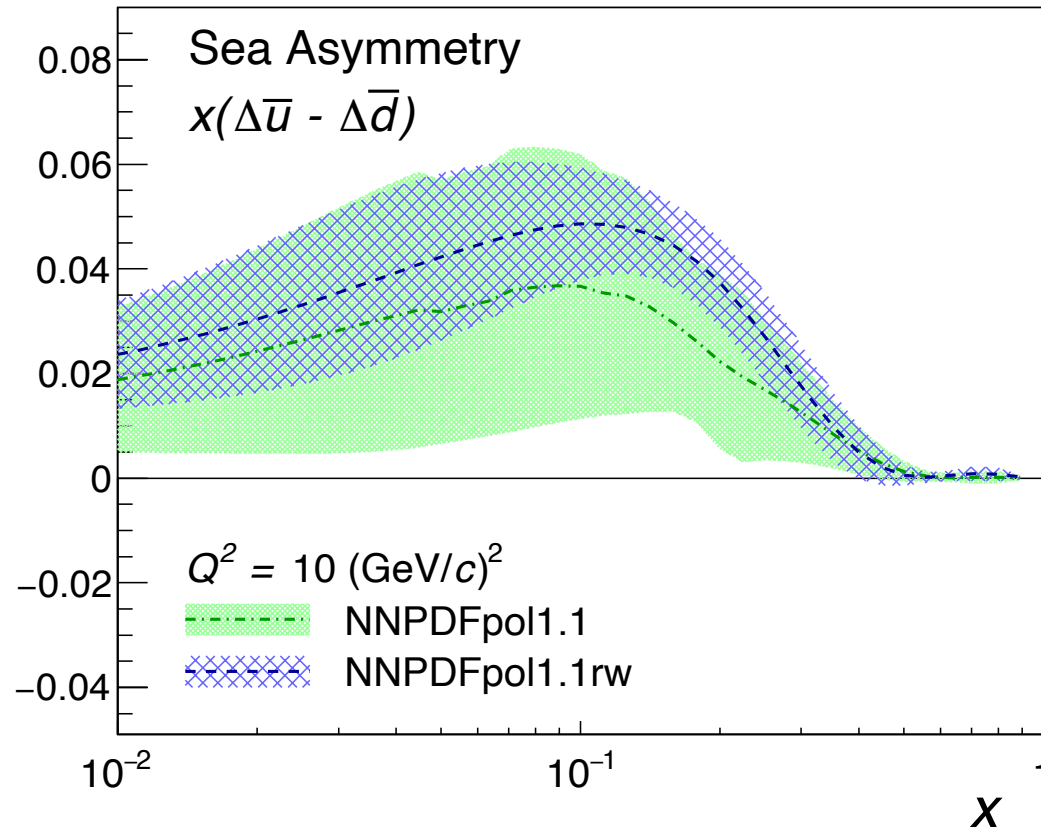
rapidity measurements.



J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.

Results / Status - $\Delta q / \Delta q_{\text{bar}}$ related studies

- Impact of STAR $W A_L$ measurements on $\Delta \bar{u}$ and $\Delta \bar{d}$:



J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.

- Significant constraint for $\Delta \bar{u}$ and $\Delta \bar{d}$: $\Delta \bar{u} > \Delta \bar{d}$ at intermediate Bjorken- x ($M_W/\sqrt{s} \simeq 0.16$)
- Polarized flavor asymmetry $\Delta \bar{u} - \Delta \bar{d}$ of similar size, but opposite sign compared to unpolarized asymmetry $\bar{u} - \bar{d}$

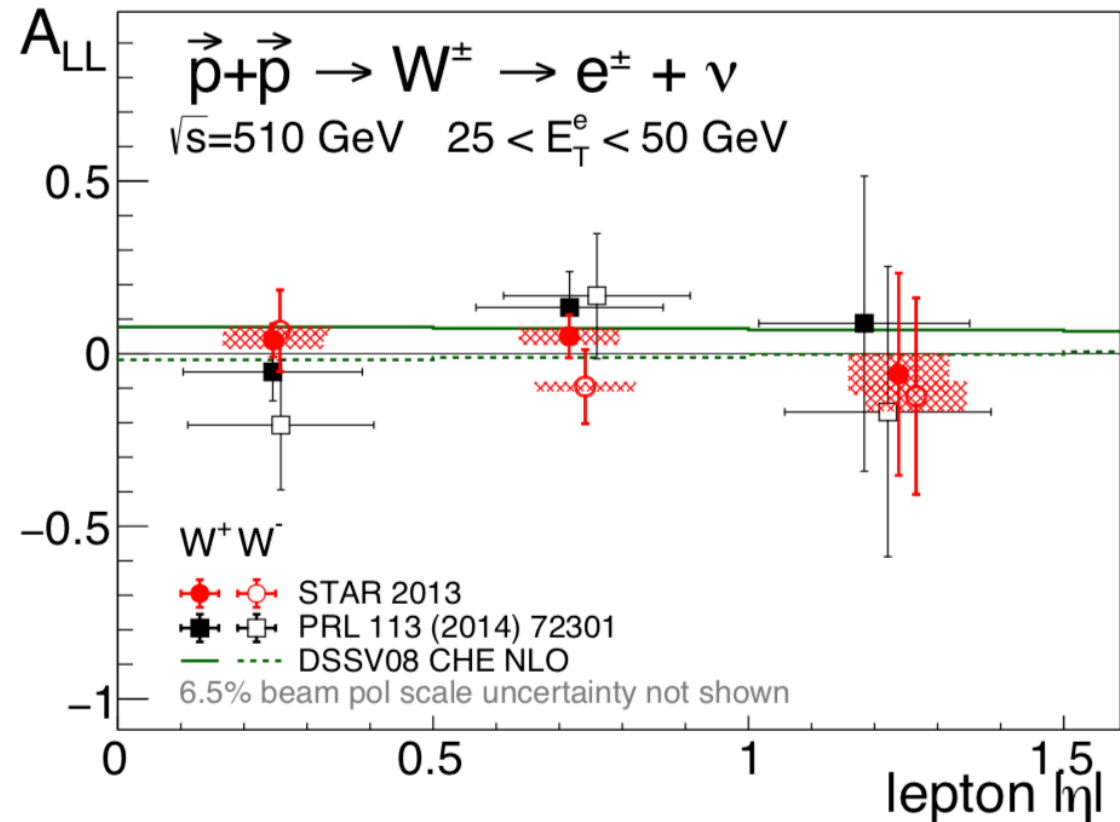
Results / Status - $\Delta q / \Delta q_{\text{bar}}$ related studies

□ $W A_{LL}$ measurements

- New published measurement of longitudinal double-spin asymmetry A_{LL} based on STAR 2013 results compared to 2011+2012 results
- Results are consistent within uncertainties as a function of leptonic rapidity
- Probe W^+/W^- initial light quark polarized flavor combinations:

$$A_{LL}^{W^+} \propto \frac{\Delta u}{u} \frac{\Delta \bar{d}}{\bar{d}} \quad \text{and} \quad A_{LL}^{W^-} \propto \frac{\Delta d}{d} \frac{\Delta \bar{u}}{\bar{u}}$$

J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.



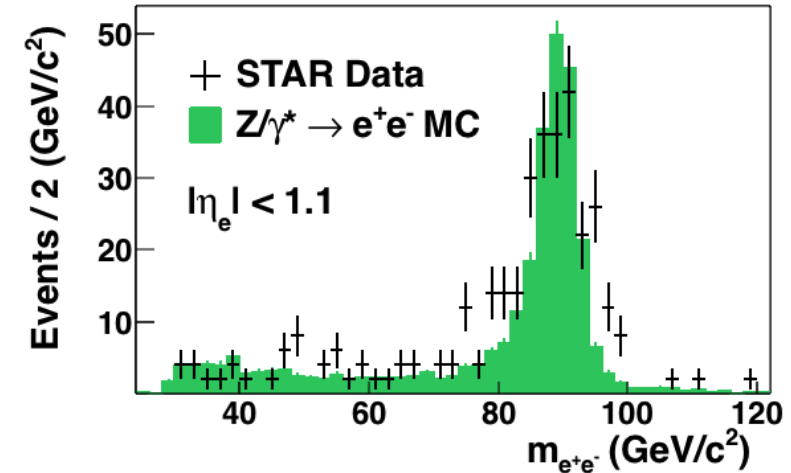
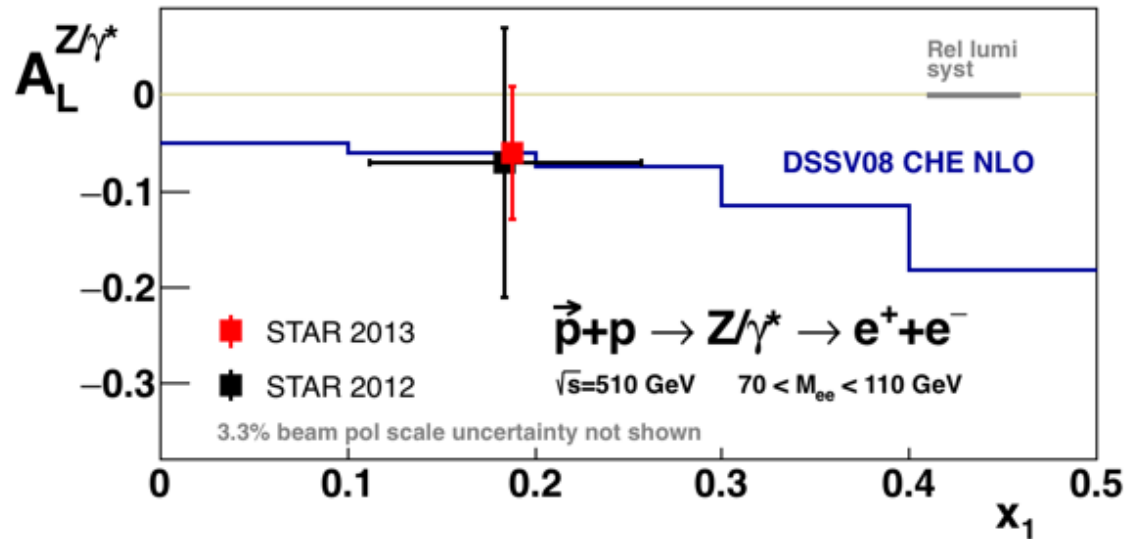
- Positivity constraints involving A_L and A_{LL} :

$$1 \pm A_{LL}^{W^\pm}(y_W) > \left| A_L^{W^\pm}(y_W) \pm A_L^{W^\pm}(-y_W) \right|$$

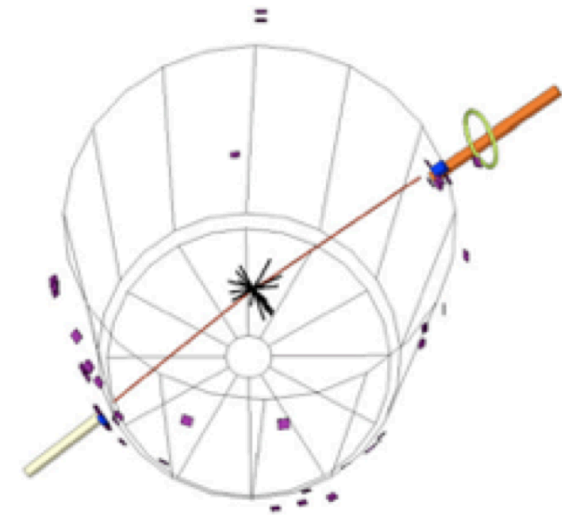
Z.Kang and J.Soffer, Phys. Rev. **D83** (2011) 114020.

Results / Status - Z^0 reconstruction

□ Z boson



- Z^0/γ^* full reconstruction of $Z/\gamma^* \rightarrow e^+ + e^-$
- A_L is sensitive to the combination of light quark flavor polarizations: $u, \bar{u}, d,$ and \bar{d}



J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.

Summary / Outlook

□ Summary

- Mid-rapidity: Published W asymmetry (results suggest large anti- u quark polarization along with broken QCD sea.
- New published result of STAR 2013 W A_L is the most precise measurement to date: Further constrain anti-quark helicity distributions
- New STAR 2013 W A_L results consistent with published STAR 2011+2012 results and published PHENIX mid-rapidity results

J. Adam et al. (STAR Collaboration), Phys. Rev. D **99** (2019) 51102.



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Science

DOE NP contract: DE-SC0013405

□ Outlook

- Long 510GeV run in 2017 (Run 17) at transverse spin polarization of about 350pb^{-1} : W A_N / Unpol. QCD sea
- Unpolarized program for Run 17: Cross-section ratio measurements of W^+/W^- Unpolarized $d\bar{b}ar$ / $u\bar{b}ar$ probe
- Exciting long-term polarized pp/pA program beyond 2020 requiring forward detector upgrade (NSF grant)