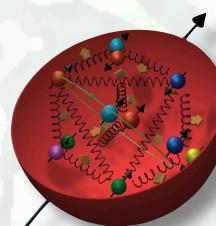


Measurement of W^\pm single-spin asymmetry A_L and W^\pm cross-section ratio $R_W = \sigma_{W^+} / \sigma_{W^-}$ in polarized p+p collisions at 510GeV at STAR

Devika Gunarathne & Bernd Surrow



(On behalf of the STAR Collaboration)



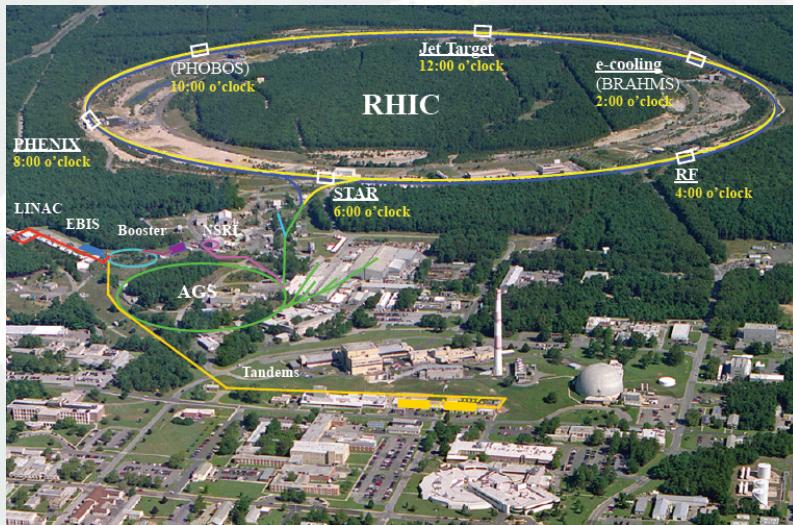
DOE NP contract: DE-SC0013405



XXIV International Workshop on DIS and Related Subjects - DIS2016
Hamburg, Germany, April 11-15, 2016

Bernd Surrow

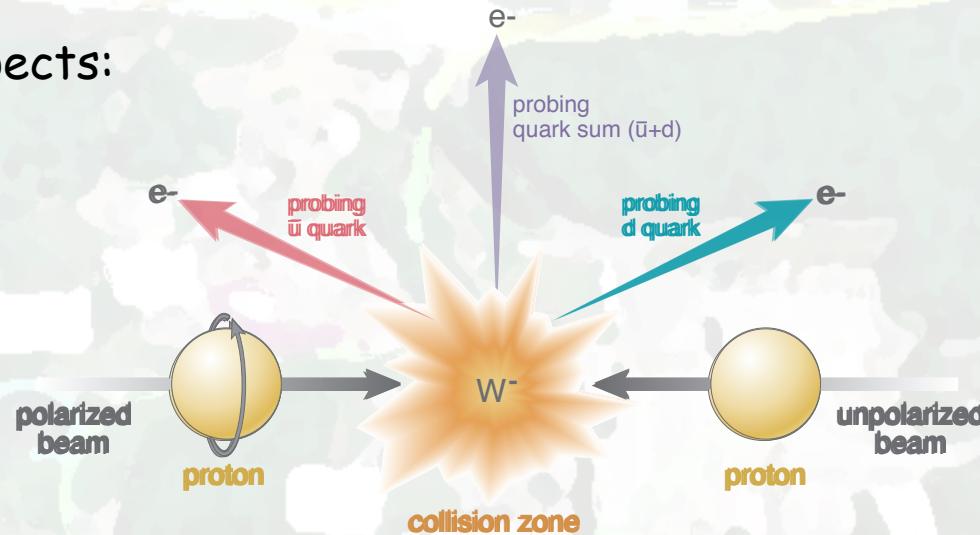
Outline



- Experimental aspects:
RHIC / STAR

- Theoretical
foundation

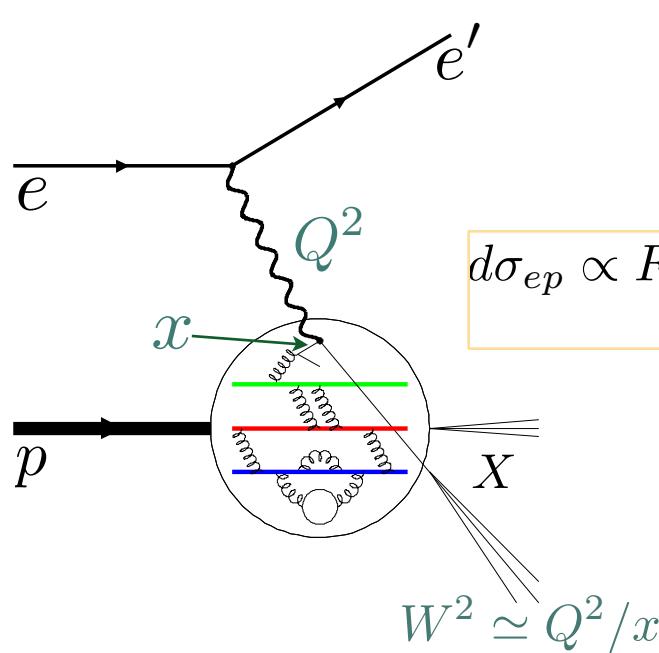
- Results / Status
 - Reconstruction
 - Asymmetry results and status
 - Cross-section ratio results and status



- Summary
and
Outlook

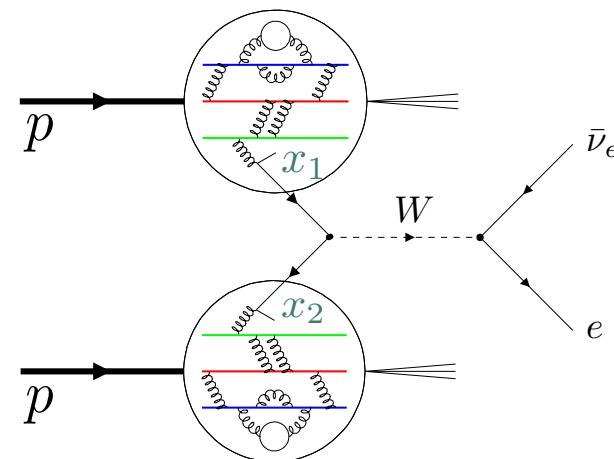
Theoretical foundation

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



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

Universality



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

Factorization

Momentum distribution

$$\left\{ \begin{array}{l} f(x) = \\ \quad \text{Diagram: } \text{Two red circles with a white dot, one arrow right, one arrow left.} \\ \quad f^+(x) + f^-(x) \end{array} \right.$$

Helicity distribution

$$\left\{ \begin{array}{l} \Delta f(x) = \\ \quad \text{Diagram: } \text{Two red circles with a white dot, one arrow right, one arrow left.} \\ \quad f^+(x) - f^-(x) \end{array} \right.$$

Theoretical foundation

- Explore proton spin structure using high-energy polarized p+p collisions: Helicity

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

- Longitudinal single-spin asymmetry A_L

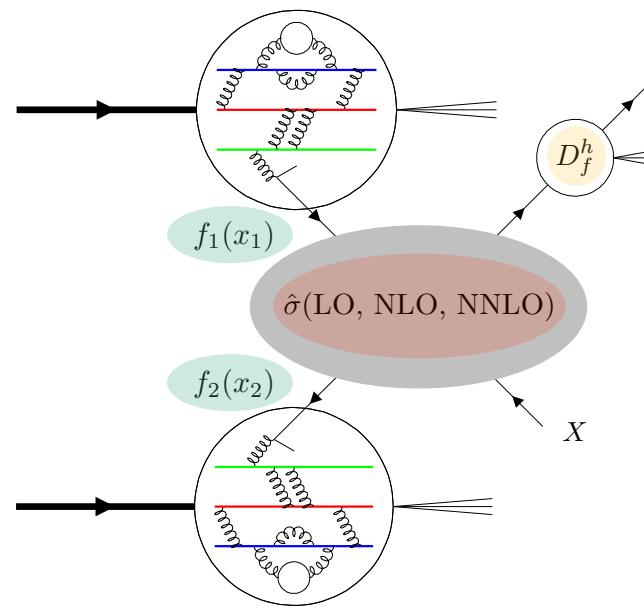
$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- Parity (Spatial inversion) violating for W production!

- Observable: Gluon polarization (Jet/Hadron production)

- Double longitudinal single-spin asymmetry A_{LL}

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$



long-range short-range long-range

$$\Delta f_1 \quad \Delta f_2$$

$$a_{LL} = \frac{\Delta \sigma_h}{\sigma_h}$$

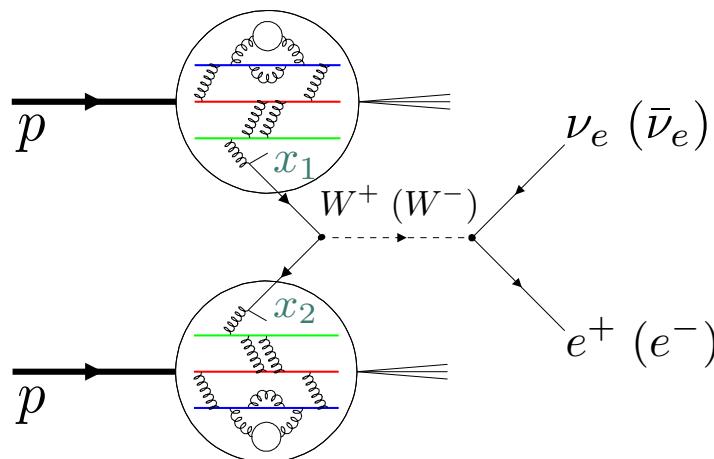
Input

$$\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h$$

$$f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$

Theoretical foundation

□ Probing the quark flavor structure: W boson production (1)



$$y_l = y_W + \underbrace{\frac{1}{2} \ln \frac{1 + \cos \theta^*}{1 - \cos \theta^*}}_{y_l^*}$$

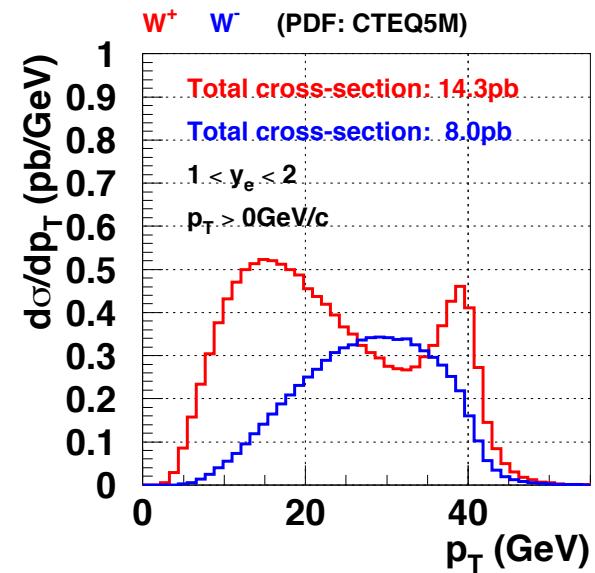
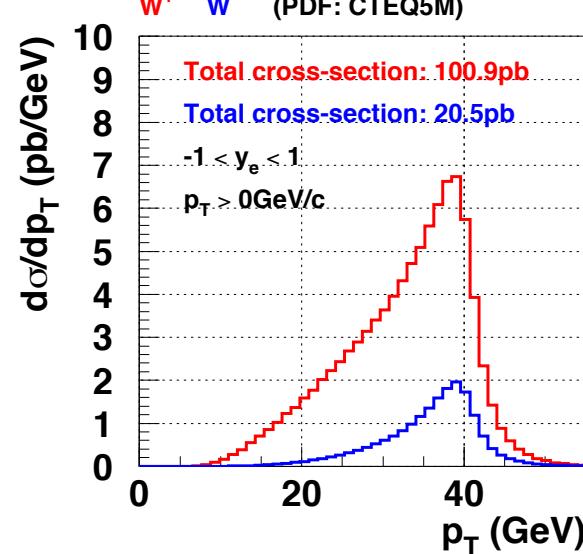
$$p_T = p_T^* = \frac{M_W}{2} \sin \theta^*$$

$$x_1 = \frac{M_W}{\sqrt{s}} e^{y_W}$$

$$x_2 = \frac{M_W}{\sqrt{s}} e^{-y_W}$$

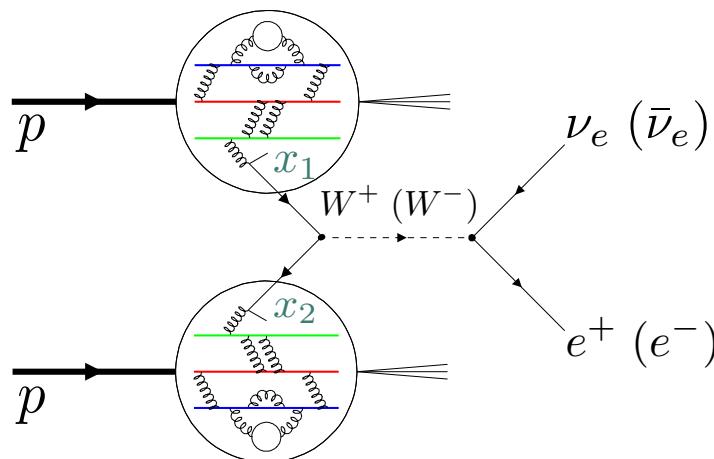
$$\frac{M_W}{\sqrt{s}} = 0.16$$

- Key signature: High p_T lepton
 $(e^-/e^+)(\text{Max. } M_W/2)$ - Selection
of W^+/W^- : Charge sign
discrimination of high p_T
lepton
- Required: Lepton/Hadron
discrimination



Theoretical foundation

□ Probing the quark flavor structure: W boson production (1)



$$y_l = y_W + \underbrace{\frac{1}{2} \ln \frac{1 + \cos \theta^*}{1 - \cos \theta^*}}_{y_l^*}$$

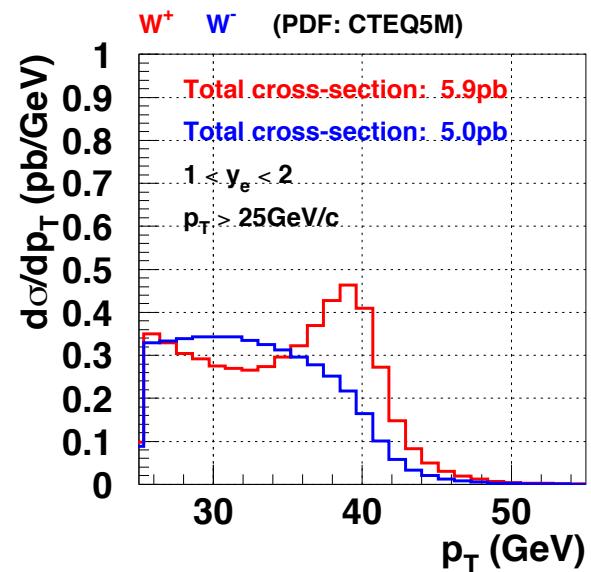
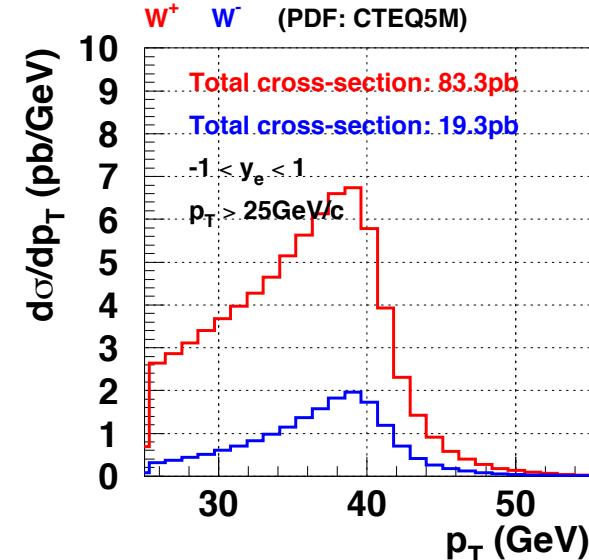
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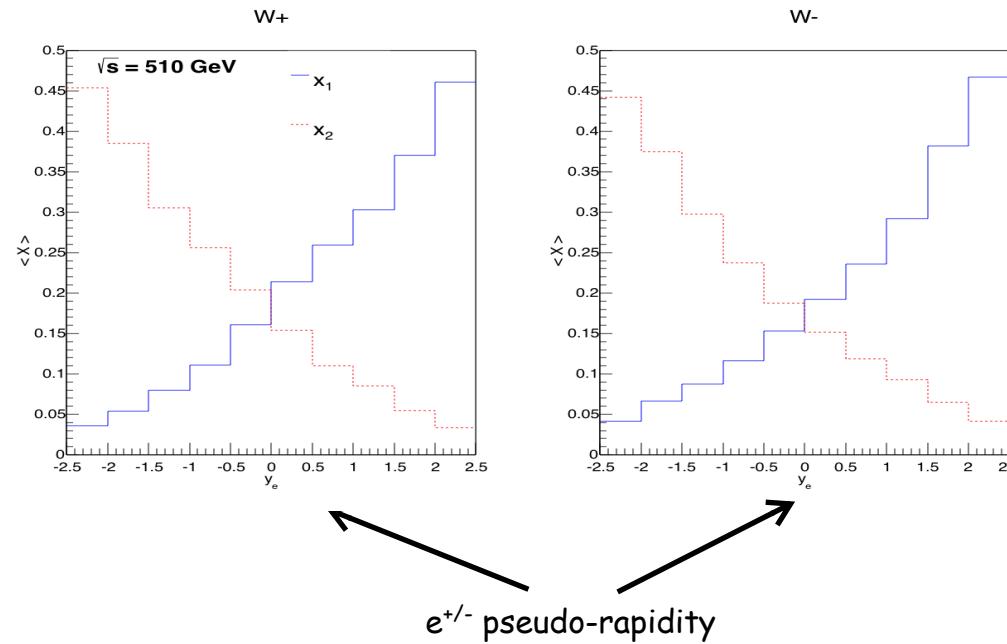
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discrimination

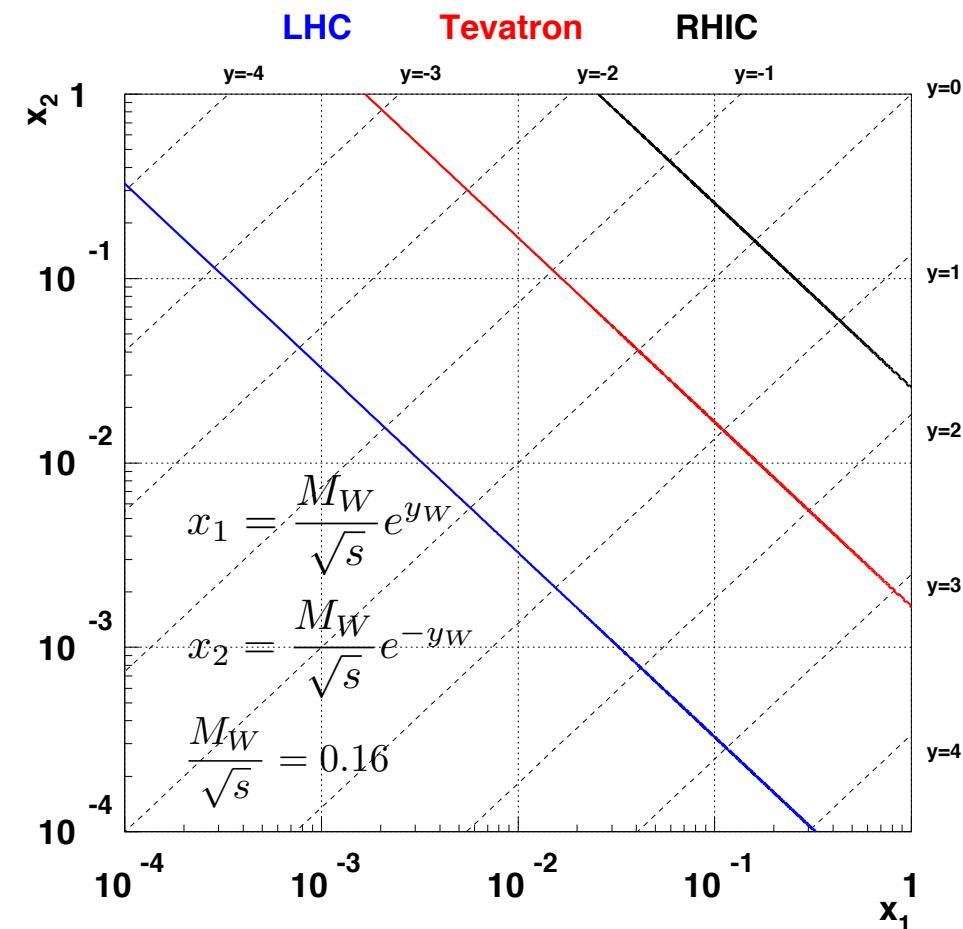


Theoretical foundation

□ Probing the quark flavor structure: W boson production (2)

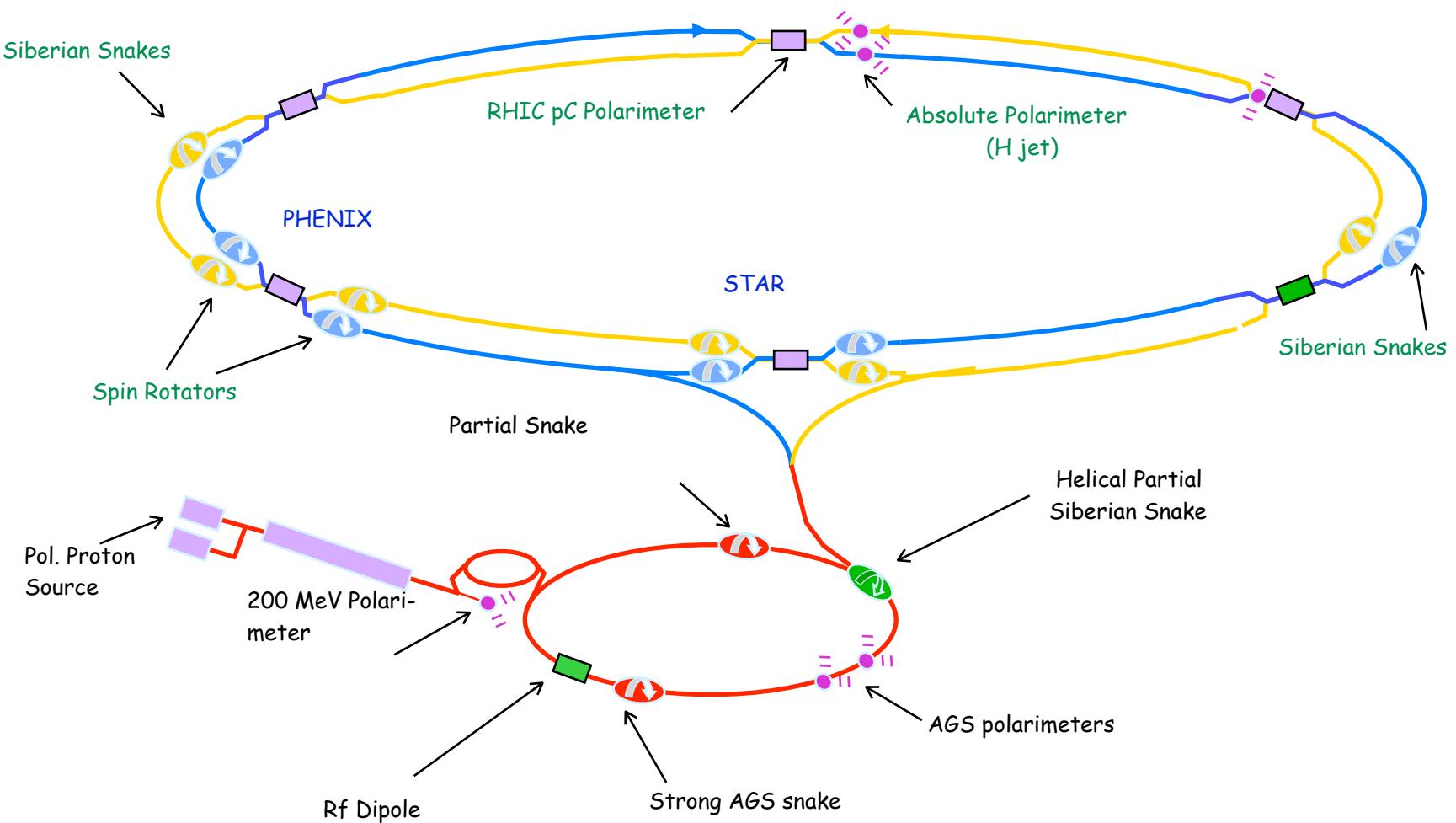


- Approximate kinematic range at RHIC:
 $0.06 < x < 0.4$ for $-2 < \eta < 2$
- Measurement at LHC in high- x range would require very forward measurements



Experimental aspects - RHIC

- The world's first polarized proton-proton collider

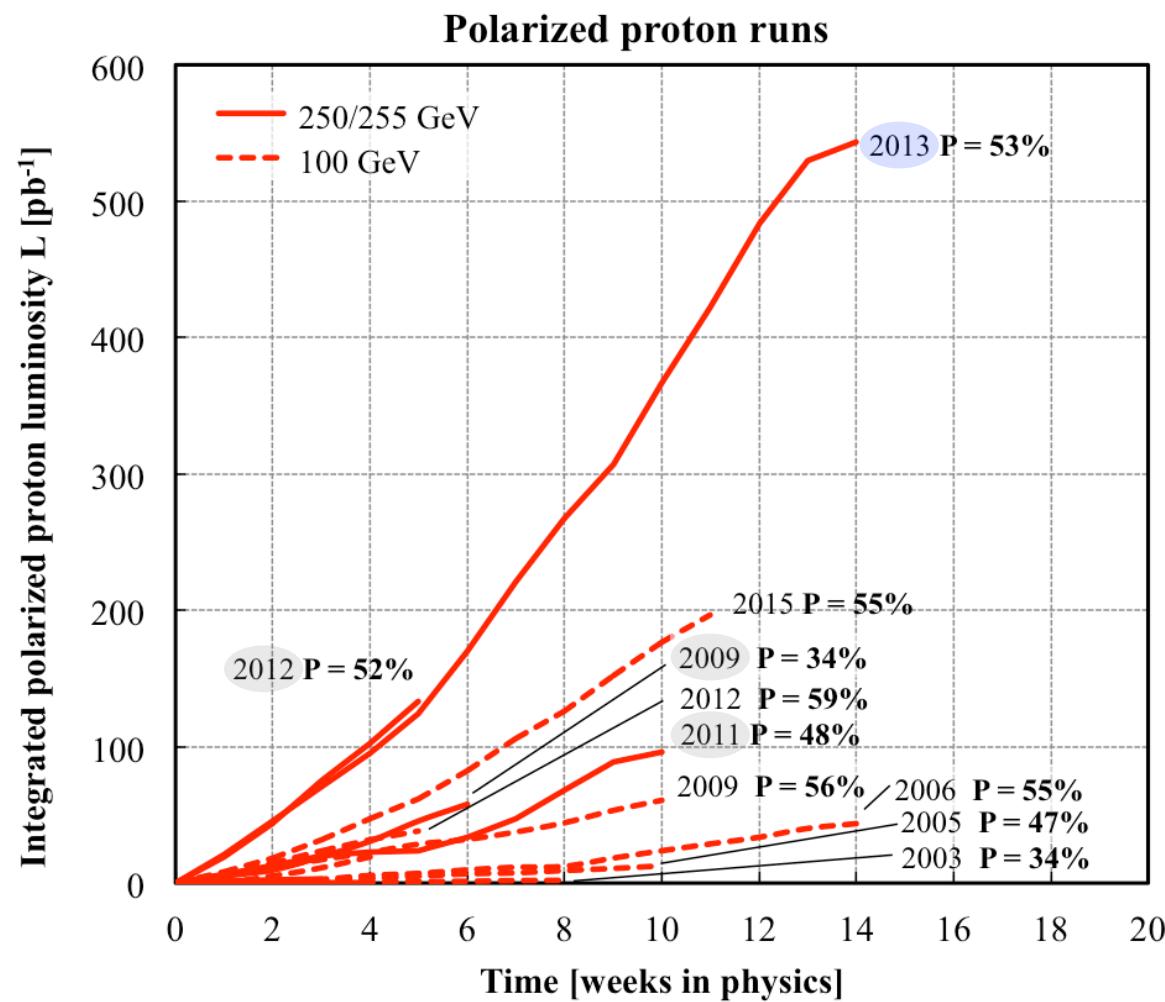


Experimental aspects - RHIC

□ Polarized p-p collisions

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

Run	$L (\text{pb}^{-1})$	P (%)	FOM ($P^2 L$) (pb^{-1})
Run 9	12	0.38	1.7
Run 11	9.4	0.49	2.3
Run 12	72	0.56	24
Run 13	~300	0.54	~87



Experimental aspects - STAR

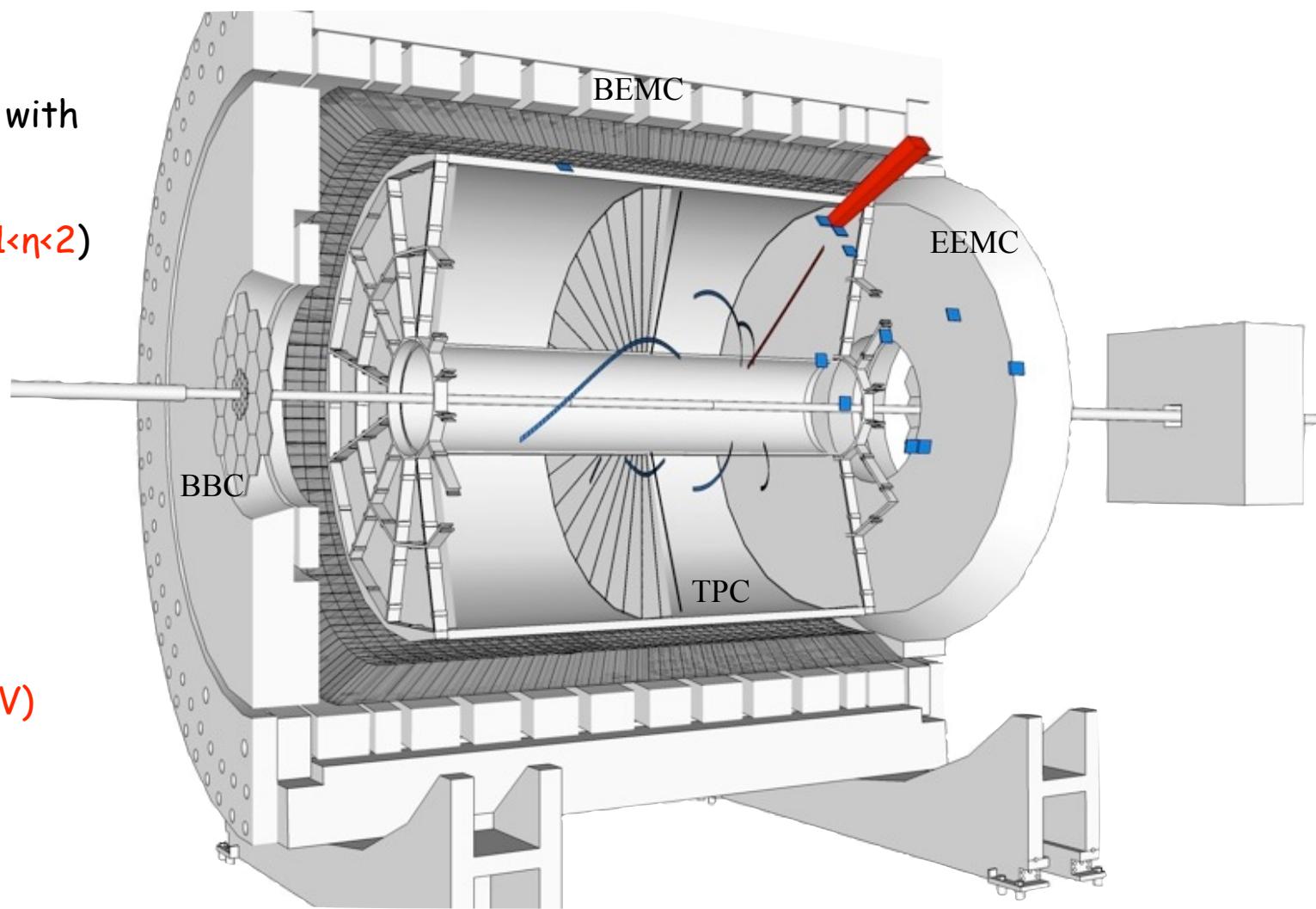
□ Overview

- 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)

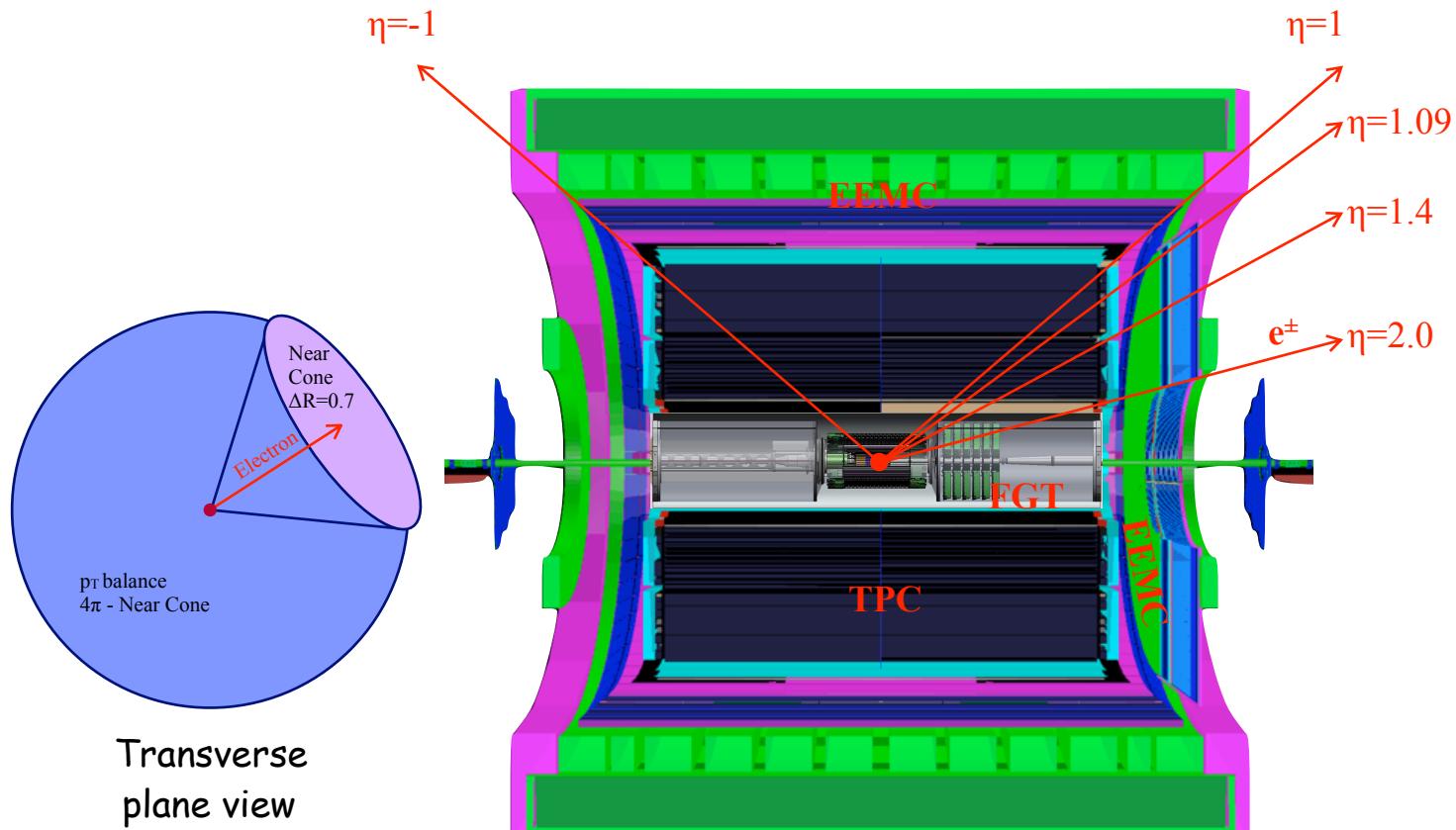
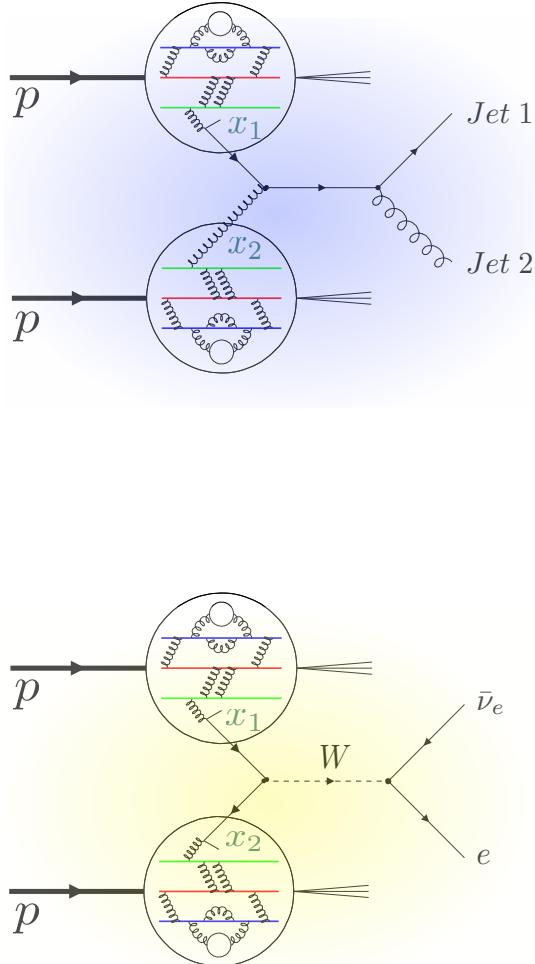
- BBC: Relative luminosity and Minimum bias trigger



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

Results / Status - W reconstruction

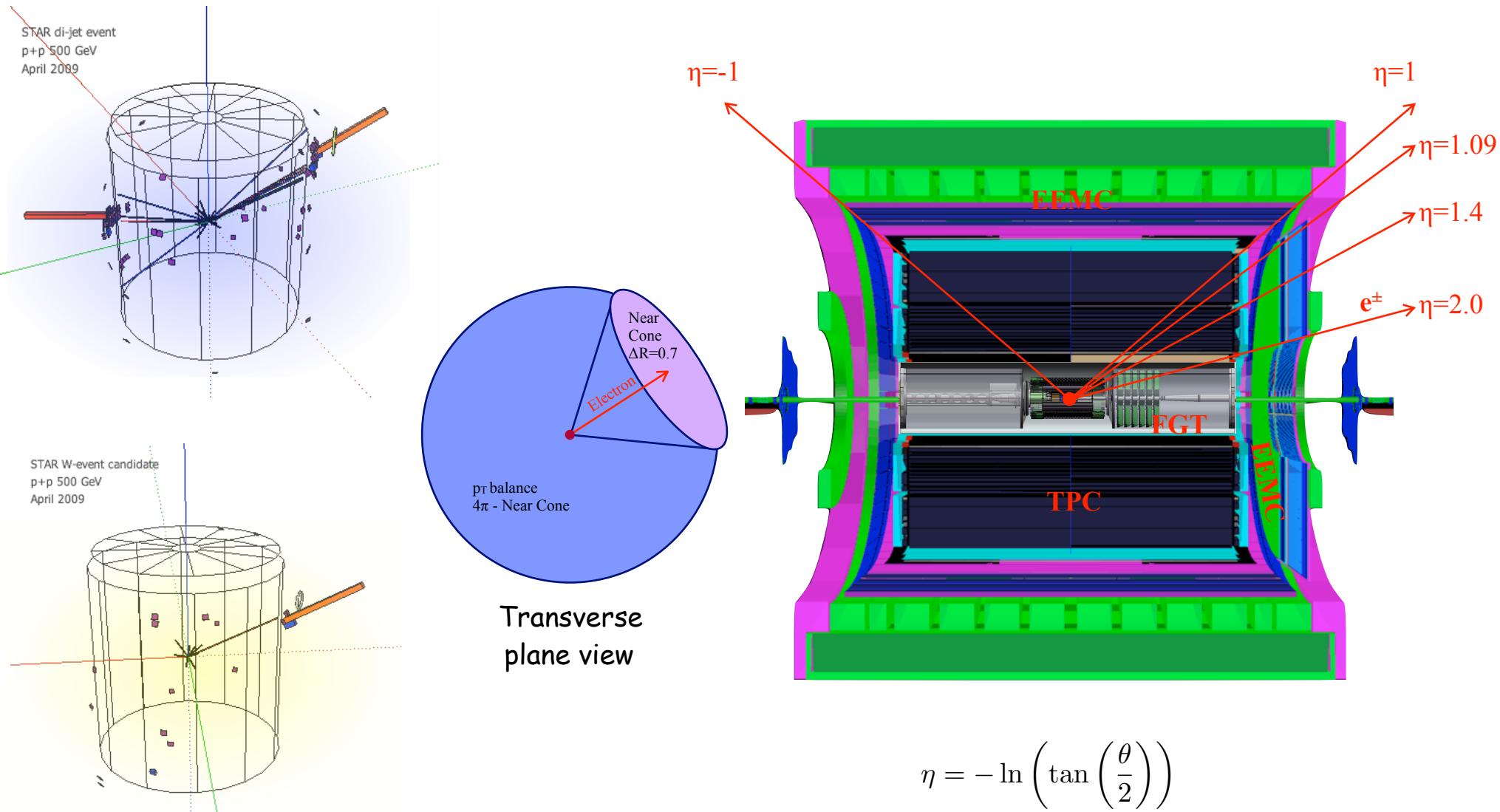
- W boson reconstruction at STAR vs. pseudo-rapidity η



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

Results / Status - W reconstruction

□ W boson reconstruction at STAR vs. pseudo-rapidity η

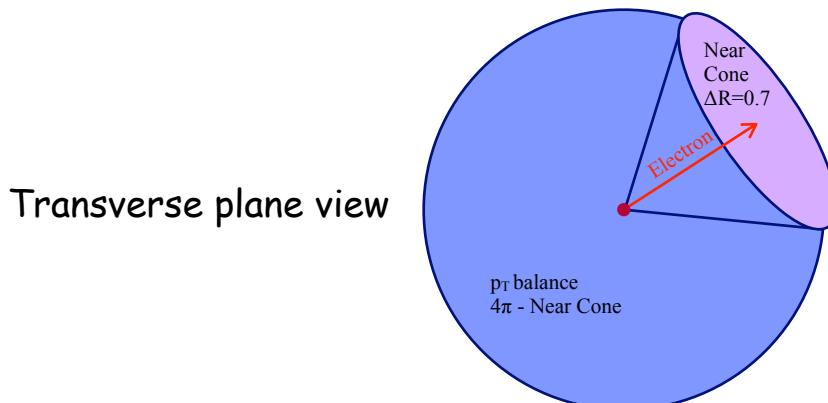


Results / Status - W reconstruction

- Mid-rapidity STAR selection criteria
 - Match $p_T > 10$ GeV track to BEMC cluster
 - Isolation ratio 1 / Isolation ratio 2
 - p_T -balance cut

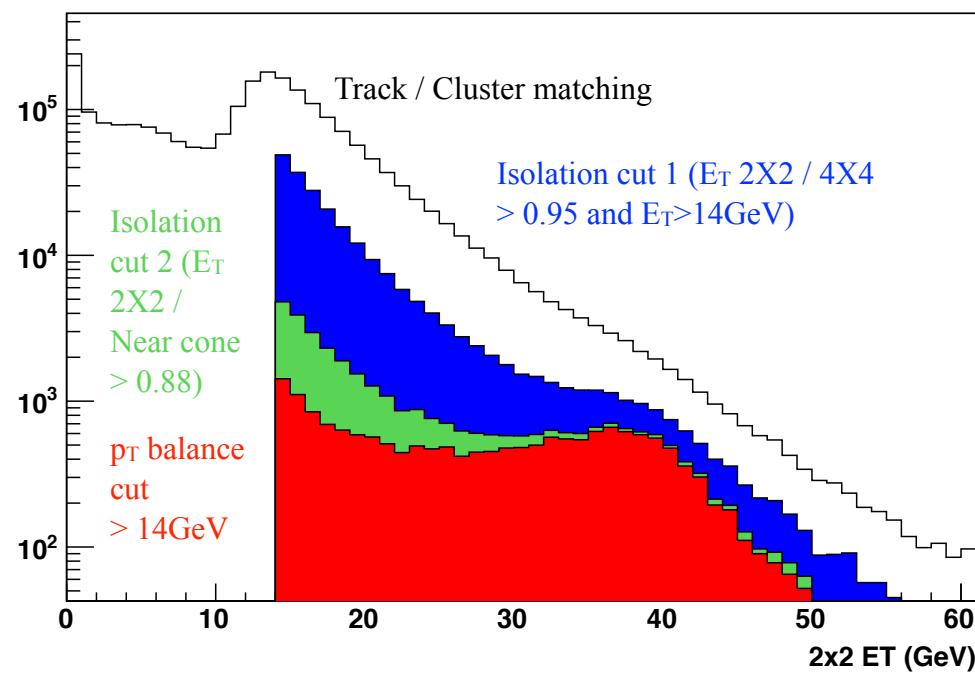
$$\vec{p}_T^{bal} = \vec{p}_T^e + \sum_{\Delta R > 0.7} \vec{p}_T^{jets}$$

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



Barrel electron candidate, cut=max 2x2

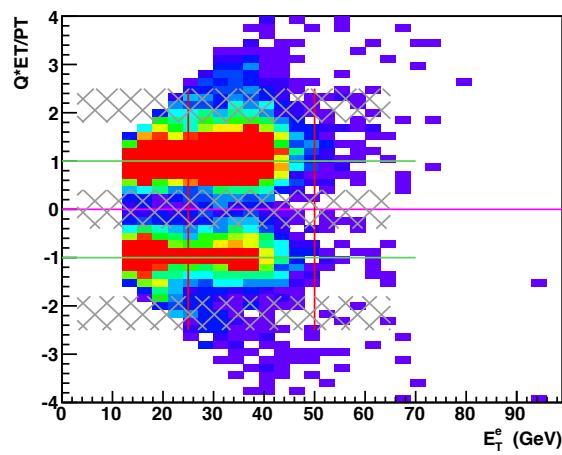
Run 13



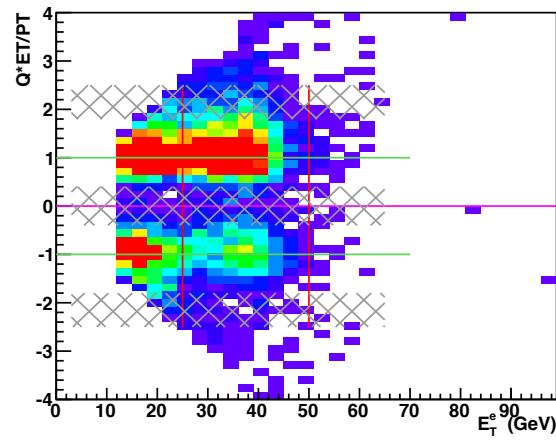
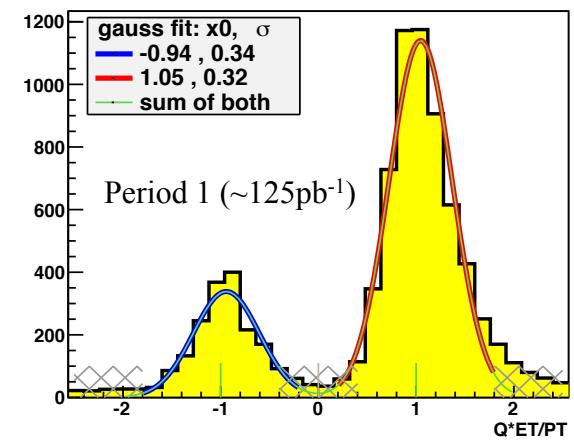
Results / Status - W reconstruction

□ W boson measurement mid-rapidity: Charge-sign separation

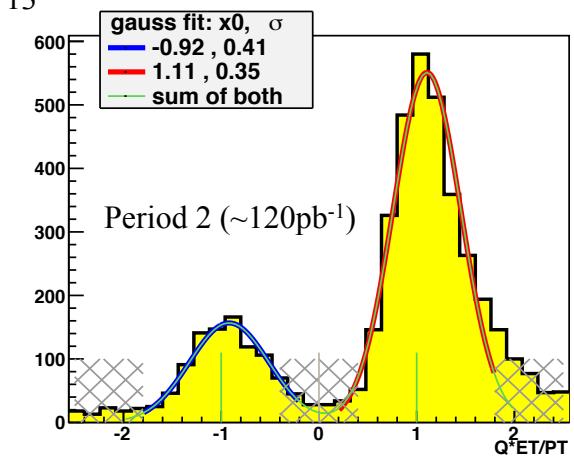
- Charge sign discrimination at mid-rapidity based on TPC
- Challenging environment at high- p_T using TPC in high luminosity / pile-up environment - Careful TPC calibration essential!
- New seed finding algorithm better suited for high pile-up environment / Currently being tested and finalized!



Run 13



Run 13

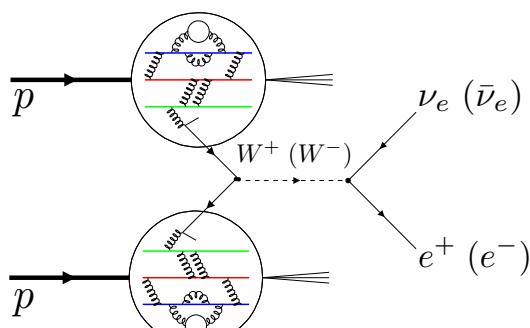
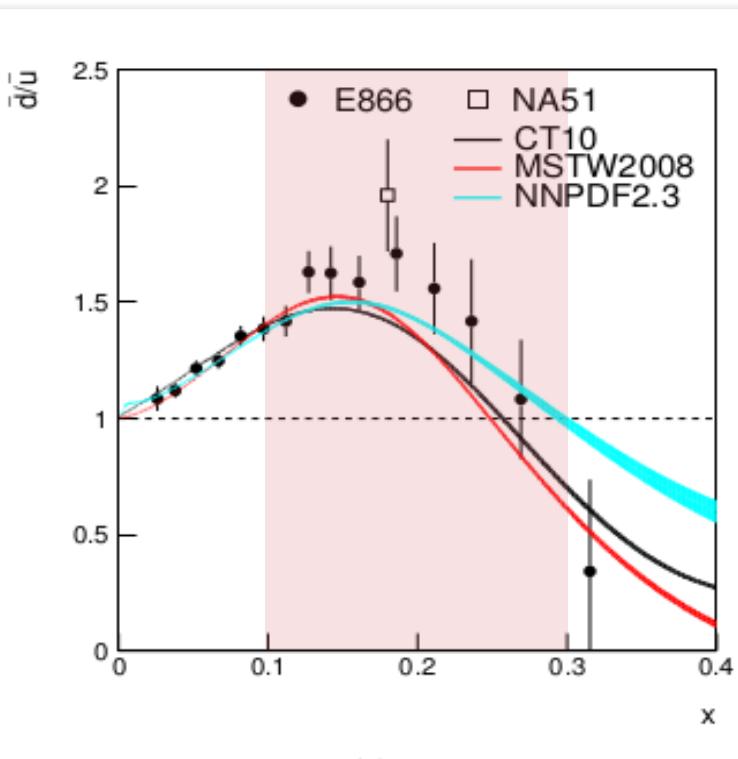


Results / Status - W reconstruction

- Analysis status overview Run 13
 - Calorimetry: BEMC / EEMC
 - BEMC Tower calibration in final stage - Evaluation of systematic uncertainties
 - EEMC Tower calibration in progress
 - Mid-rapidity tracking TPC
 - Main TPC calibration completed
 - Testing new track seed finding algorithm - Improvement of efficiency
 - Forward rapidity tracking FGT
 - Full pedestal / electronics QA and status table completed
 - Cluster analysis and evaluation starting
 - Standalone tracking algorithm available and evaluated incl. MC
 - Outstanding: W event selection and asymmetry analysis

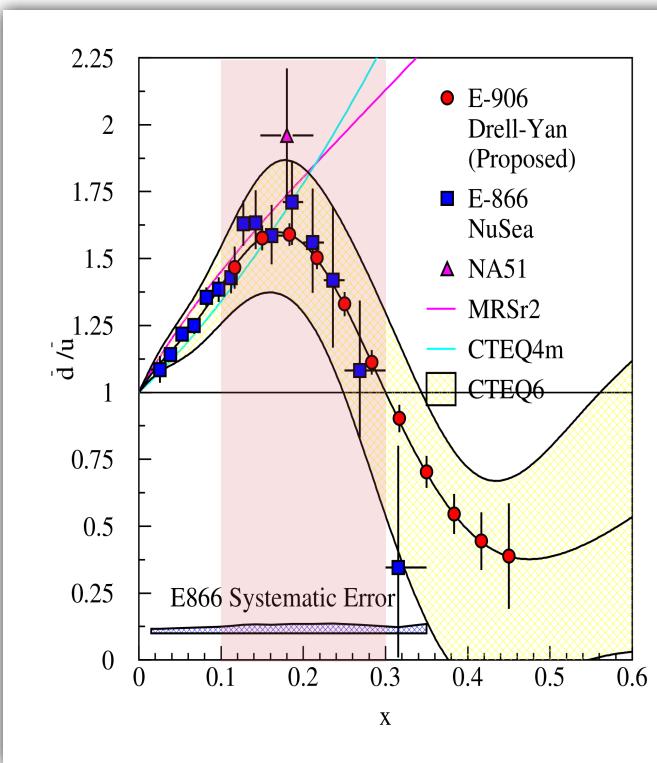
Results / Status - q / qbar related studies

- STAR: Probing dbar / ubar ratio: QCD sea



$$R_W = \frac{\sigma_{W^+}}{\sigma_{W^-}} =$$

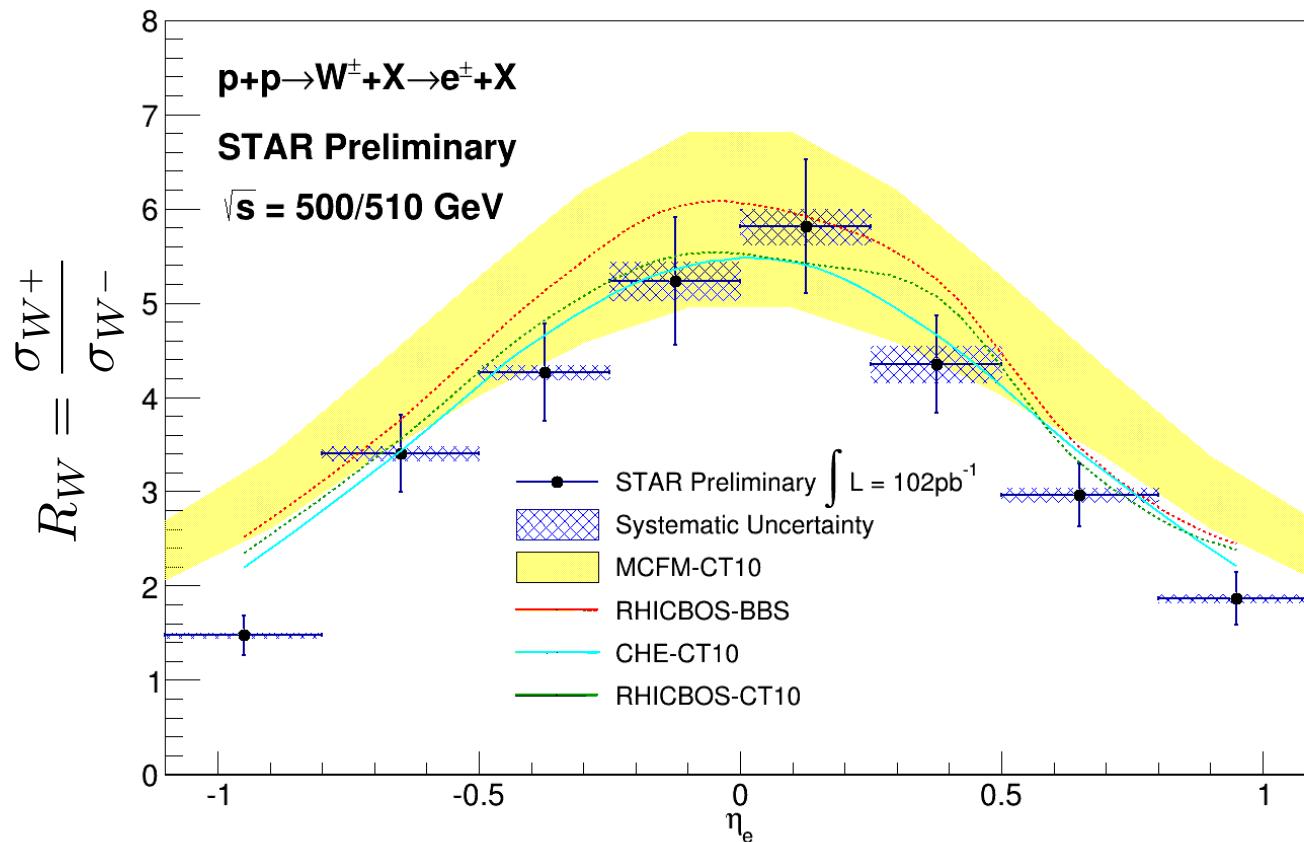
$$\frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$



- STAR coverage at mid-rapidity: $0.1 < x < 0.3$ for $-1 < \eta < 1$
- Constraints on global fitting for dbar/ubar through W production at higher Q^2 compared E906
- Independent cross-check of Drell-Yan data

Results / Status - q / qbar related studies

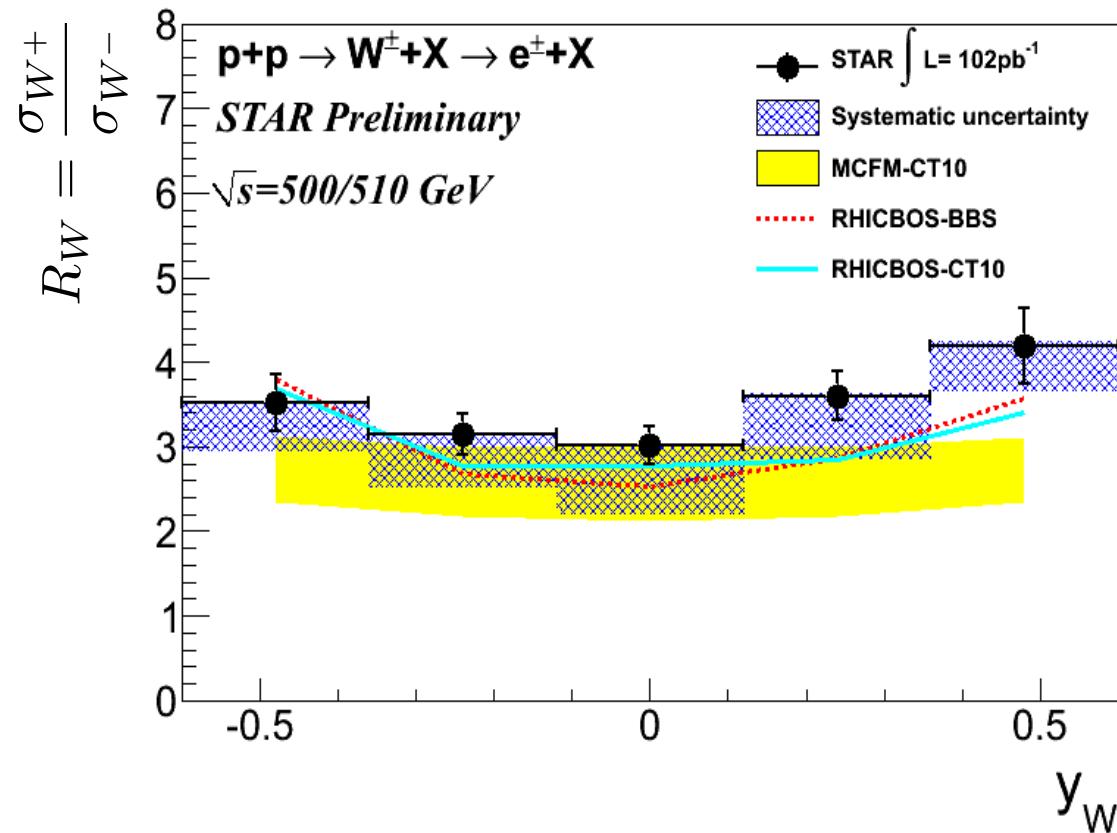
□ STAR: W cross-section ratio measurements



- Run 11 + Run 12 preliminary result: $\sim 100 \text{ pb}^{-1}$
- Run 13 data sample with $\sim 300 \text{ pb}^{-1}$ will provide important improvement on precision
- Planned Run 17 data sample of $\sim 400 \text{ pb}^{-1}$

Results / Status - q / qbar related studies

- STAR: W cross-section ratio measurements

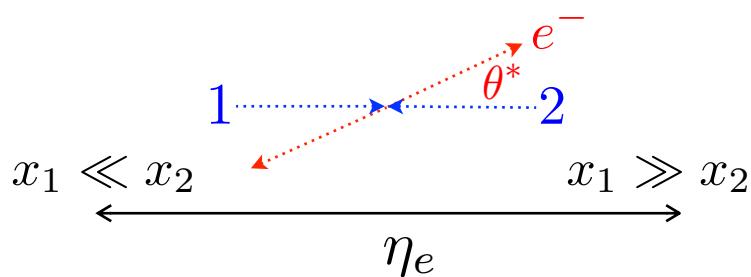


- W boson kinematics can be determined by reconstructing the W kinematics via its recoil
- Combination of data/MC simulations allows W boson rapidity reconstruction
- Critical for transverse single-spin asymmetry result of W production probing Sivers sign change

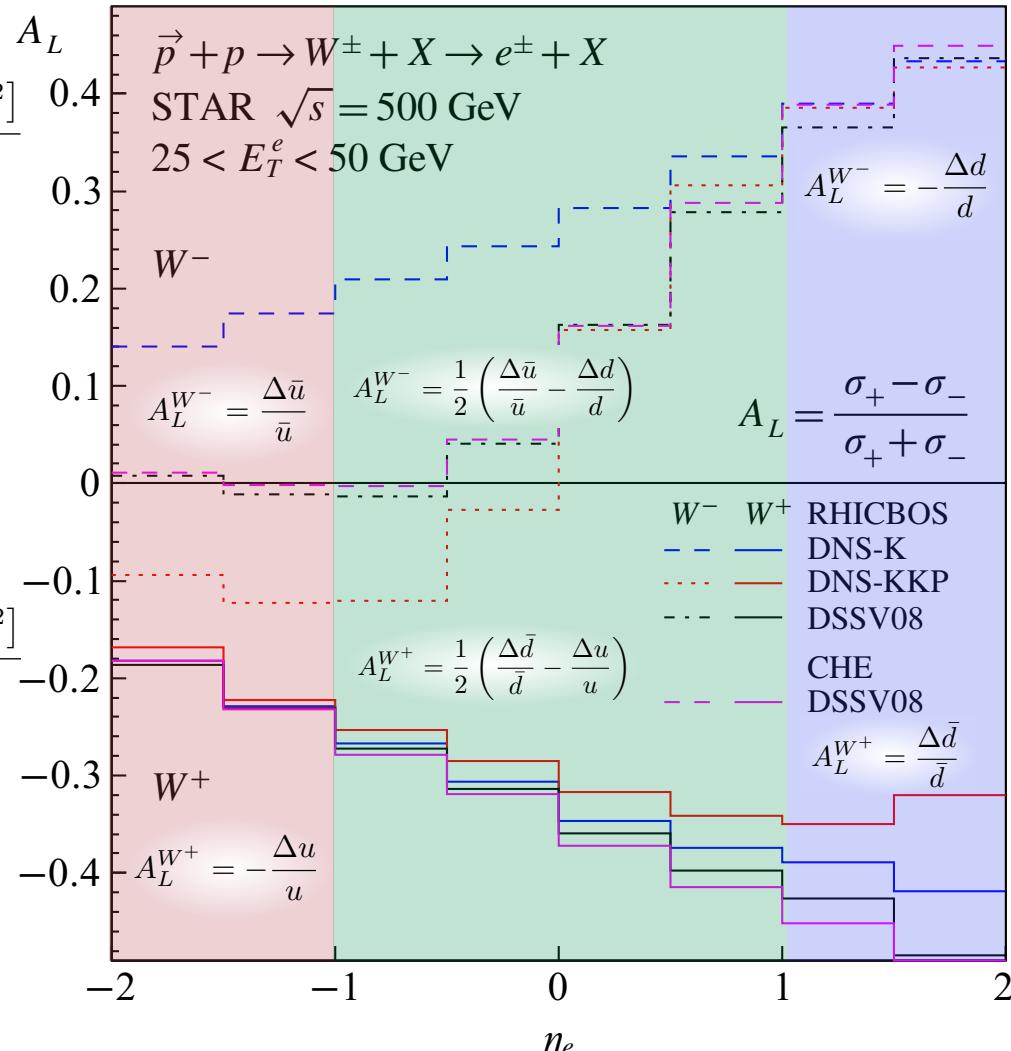
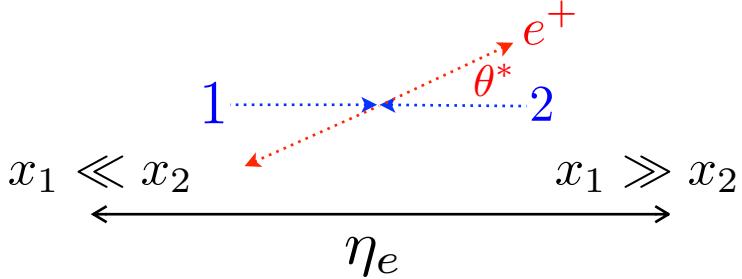
Results / Status - q / qbar related studies

□ RHIC Probing the quark flavor structure using W boson production

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



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

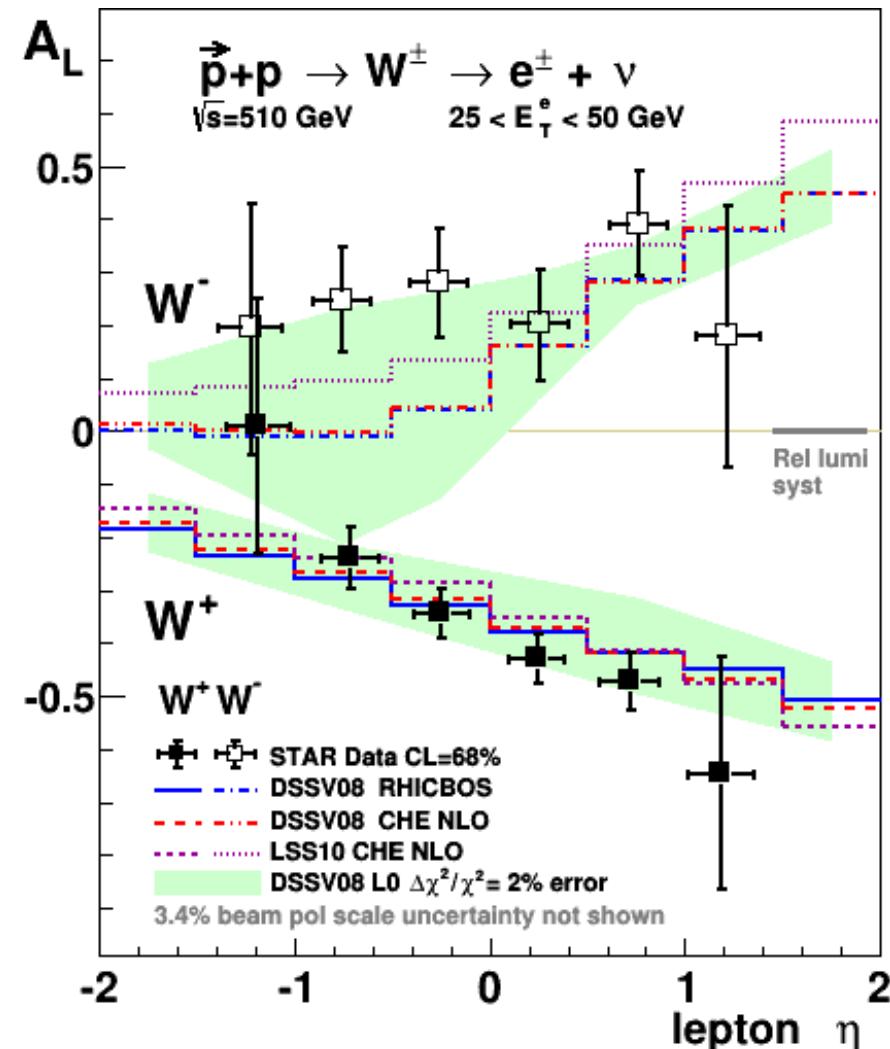


Results / Status - q / \bar{q} related studies

□ STAR: $W A_L$ results / projections

- Measured asymmetries constrain anti-quark polarizations: Larger asymmetry for W^- suggest large anti-u quark polarization!
- Critical: Measurement of W^+ and W^- asymmetries as a function η_e
- Extension of backward / forward η_e acceptance enhances sensitivity to anti-u / anti-d quark polarization
- ⇒ STAR Forward GEM Tracker ($1 < |\eta_e| < 2$)

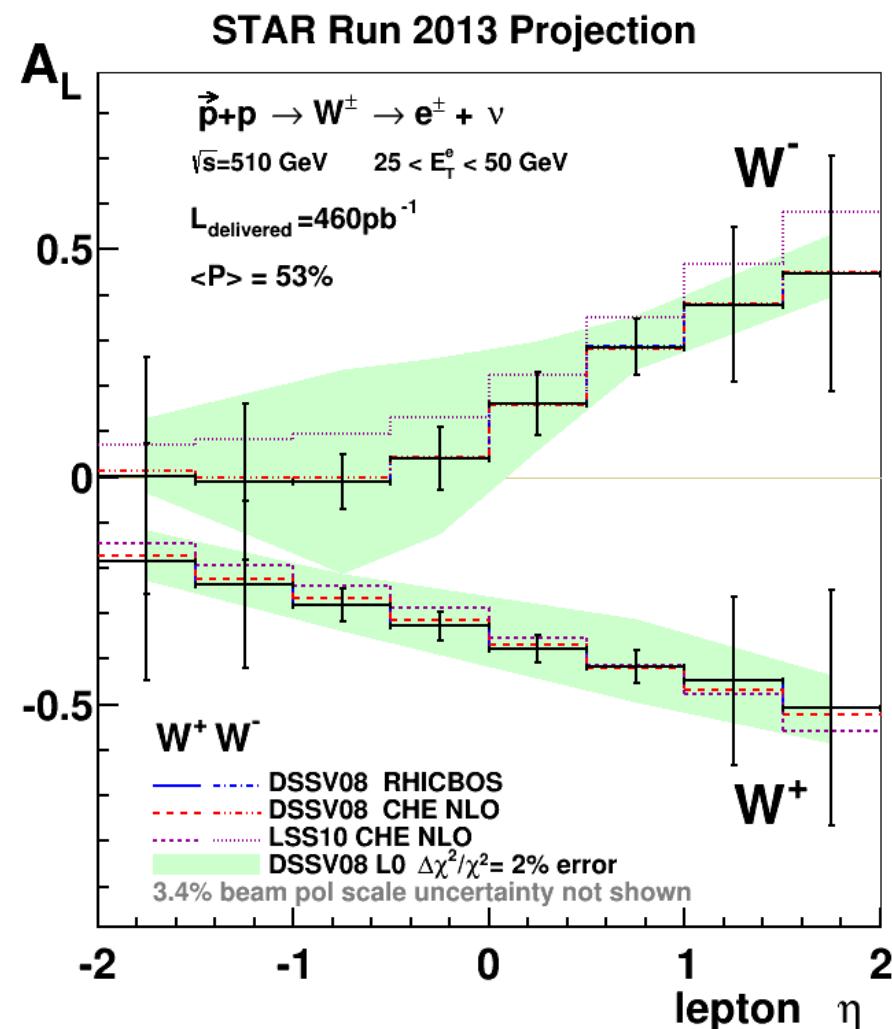
Run 2011+2012



L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 113 (2014) 72301.

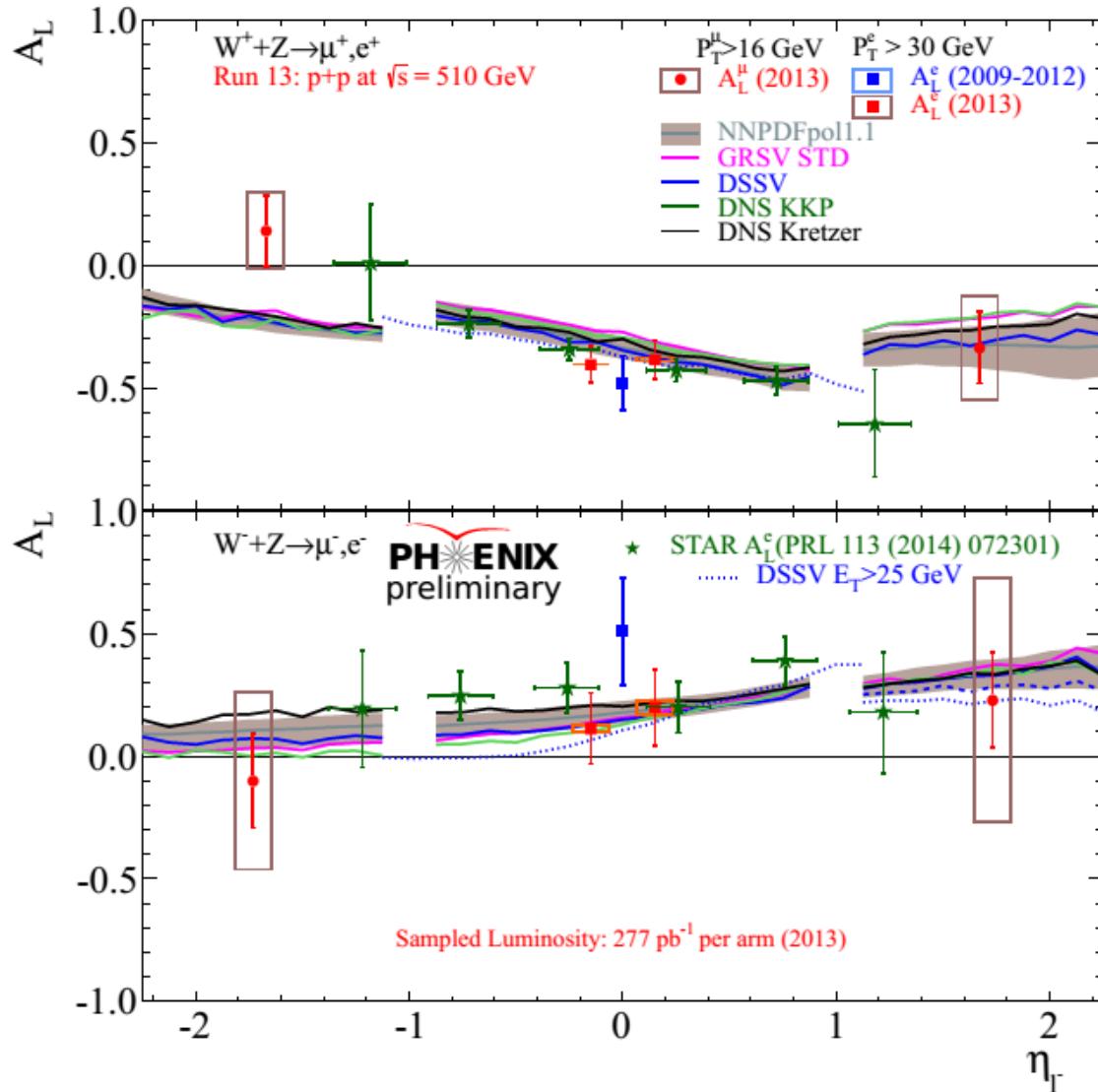
Results / Status - q / \bar{q} related studies

- STAR: $W A_L$ results / projections
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Results / Status - q / qbar related studies

- PHENIX: W A_L mid-rapidity and forward rapidity results



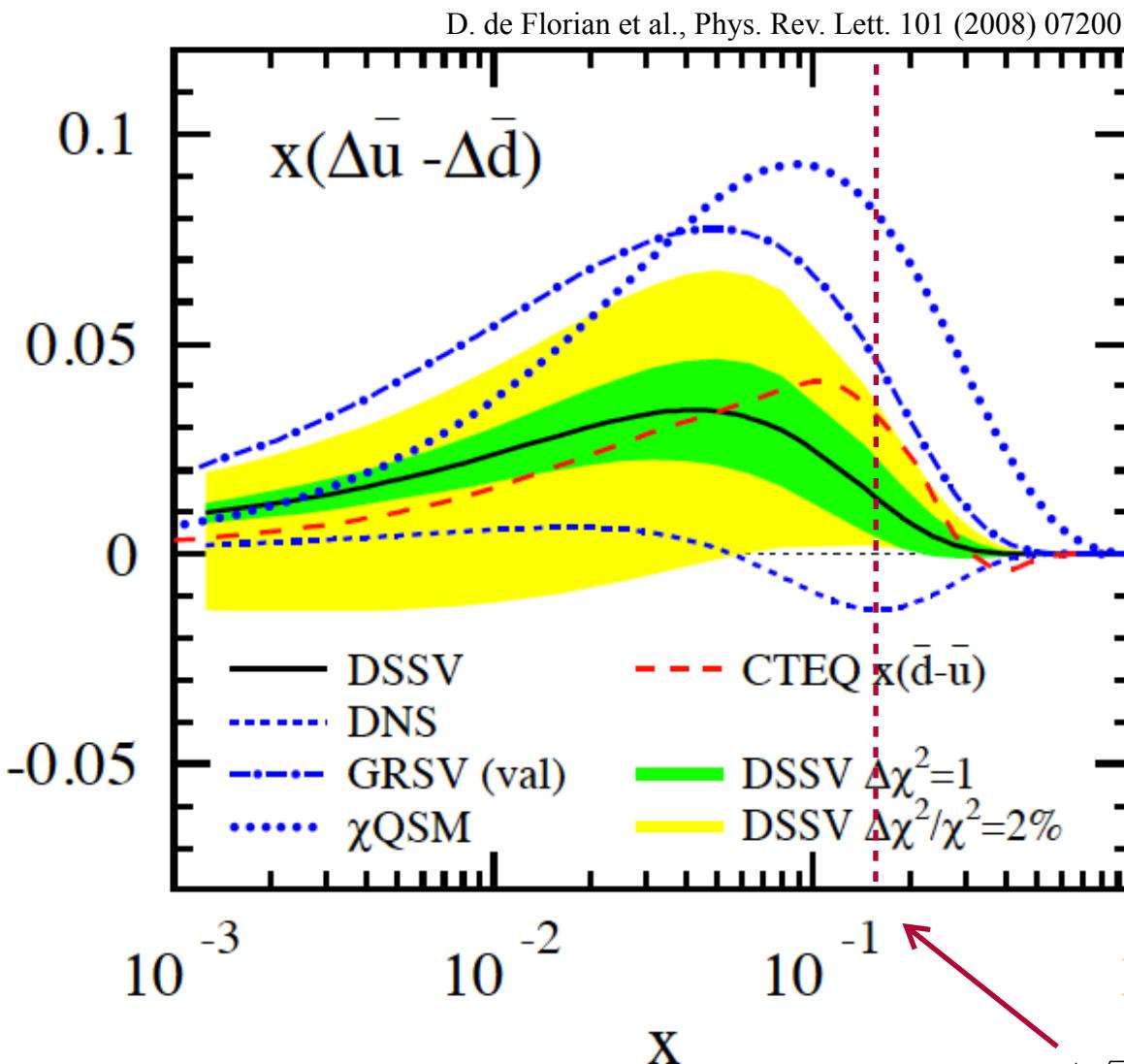
- Compilation of PHENIX Run

13 forward rapidity and mid-rapidity results together
with STAR mid-rapidity results

PHENIX Mid-rapidity: A. Adare et al. (PHENIX Collaboration), Phys.Rev. D93 (2016) 051103.

Results / Status - q / \bar{q} related studies

DSSV global fit result



- From recent DSSV++ result incl. STAR A_L data:

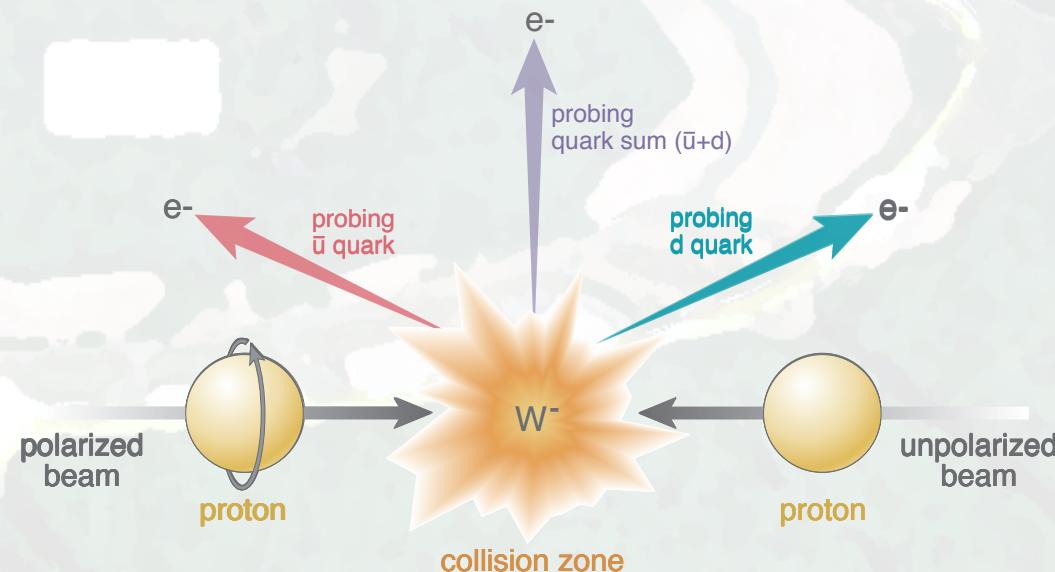
$$\int_{0.05}^1 \Delta\bar{u}(x, Q^2) dx \approx 0.02$$

$$\int_{0.05}^1 \Delta\bar{d}(x, Q^2) dx \approx -0.05$$

Summary / Outlook

□ W boson program

- Mid-rapidity (Run 11/12): Published W asymmetry
results suggest large anti-u quark polarization
along with broken QCD sea
- New prelim. result of cross-section ratio
measurement (Run 11/12): Strong physics case of
unpolarized dbar/ubar probe using W production
complementary to SeaQuest
- Run 13: Completion of TPC tracking for mid-
rapidity analyses and in particular FGT calibration
/ tracking for forward analysis required



□ Future

- Long 510GeV run in 2017 (Run 17) at transverse spin polarization of about 400pb⁻¹: Focus on W A_N
- Unpolarized program for Run 17: Cross-section ratio measurements of W⁺/W⁻ Unpolarized dbar / ubar probe