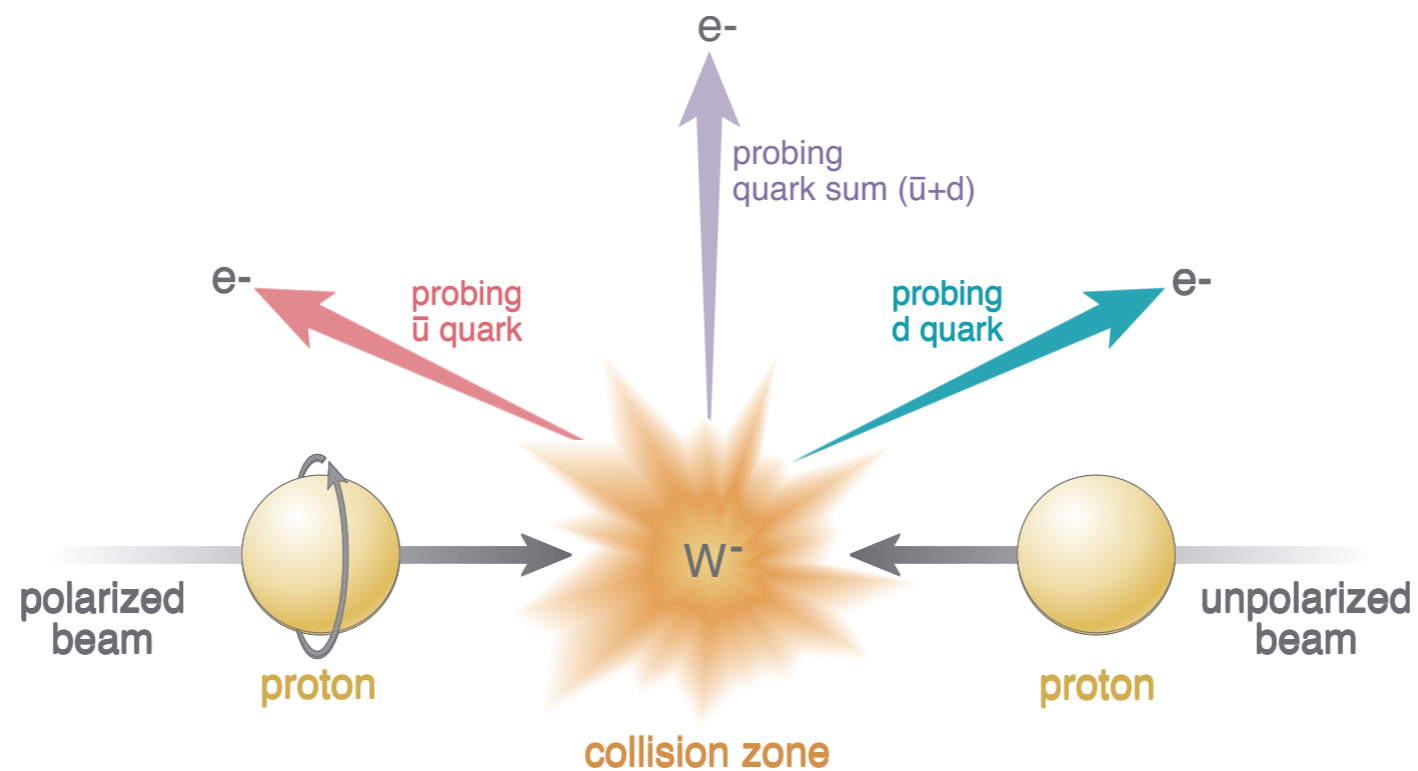


Measurement of longitudinal single-spin asymmetries for W^\pm boson production in polarized p+p collision at $\sqrt{s}=510$ GeV at RHIC

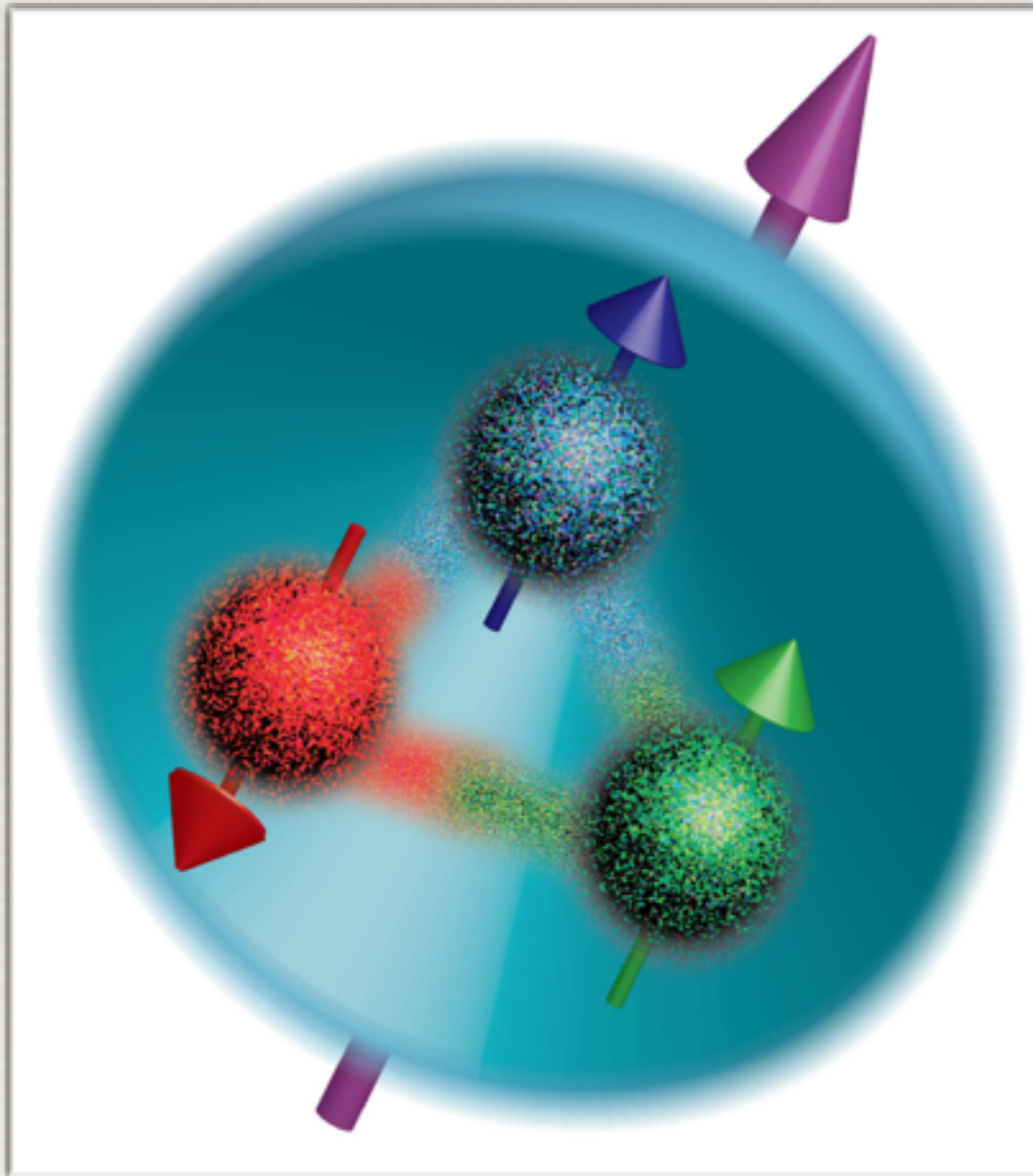


Devika Gunarathne
(for the STAR collaboration)
Temple University

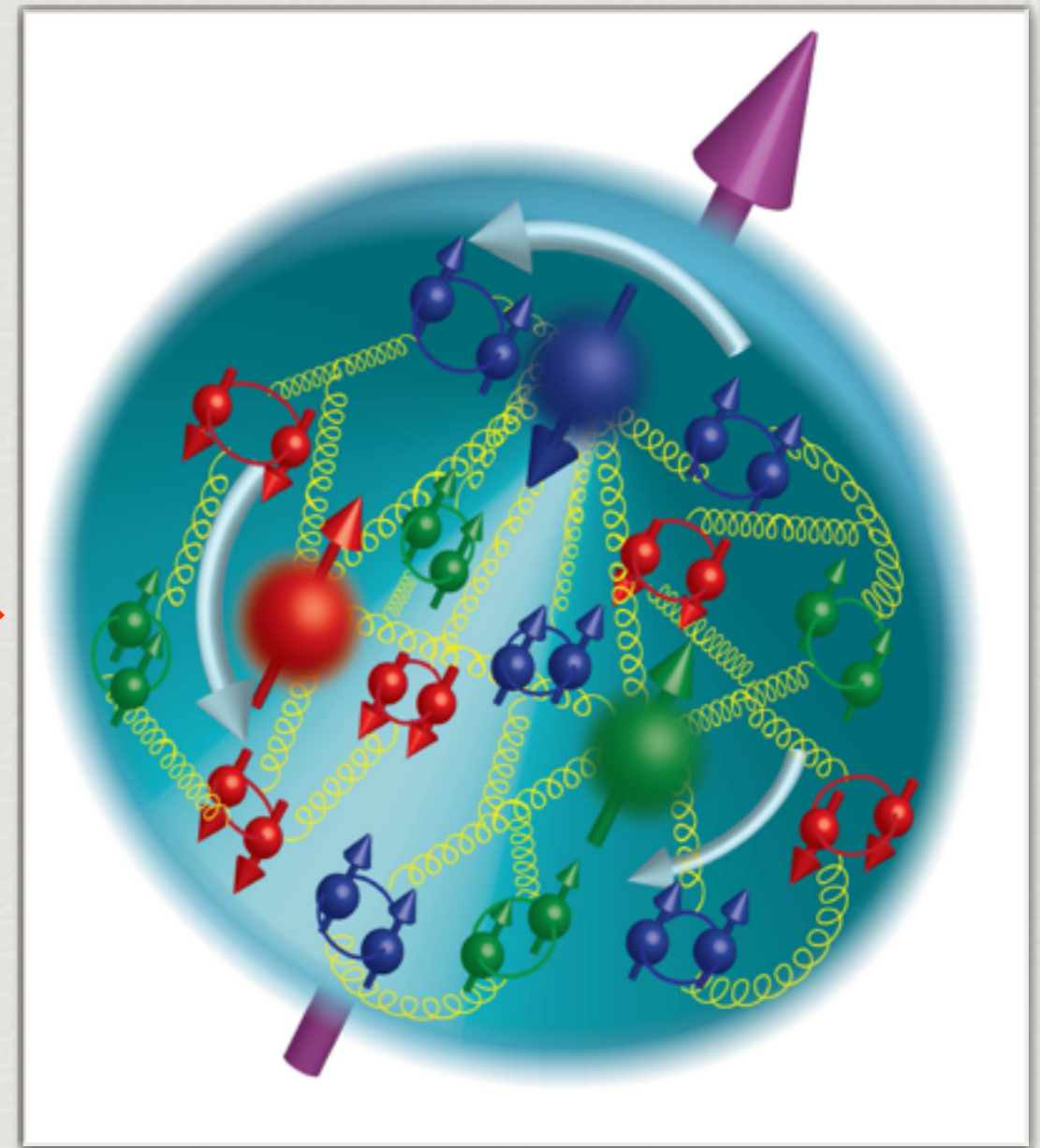
Devika Gunarathne DNP : 7-11, OCT 2014



Proton's Spin Evolution



Valance Quarks



Sea Quarks and Gluons

Anti Quarks Polarization

Spin sum rule for longitudinally Polarized proton :

Polarized parton distribution functions (pPDF) :

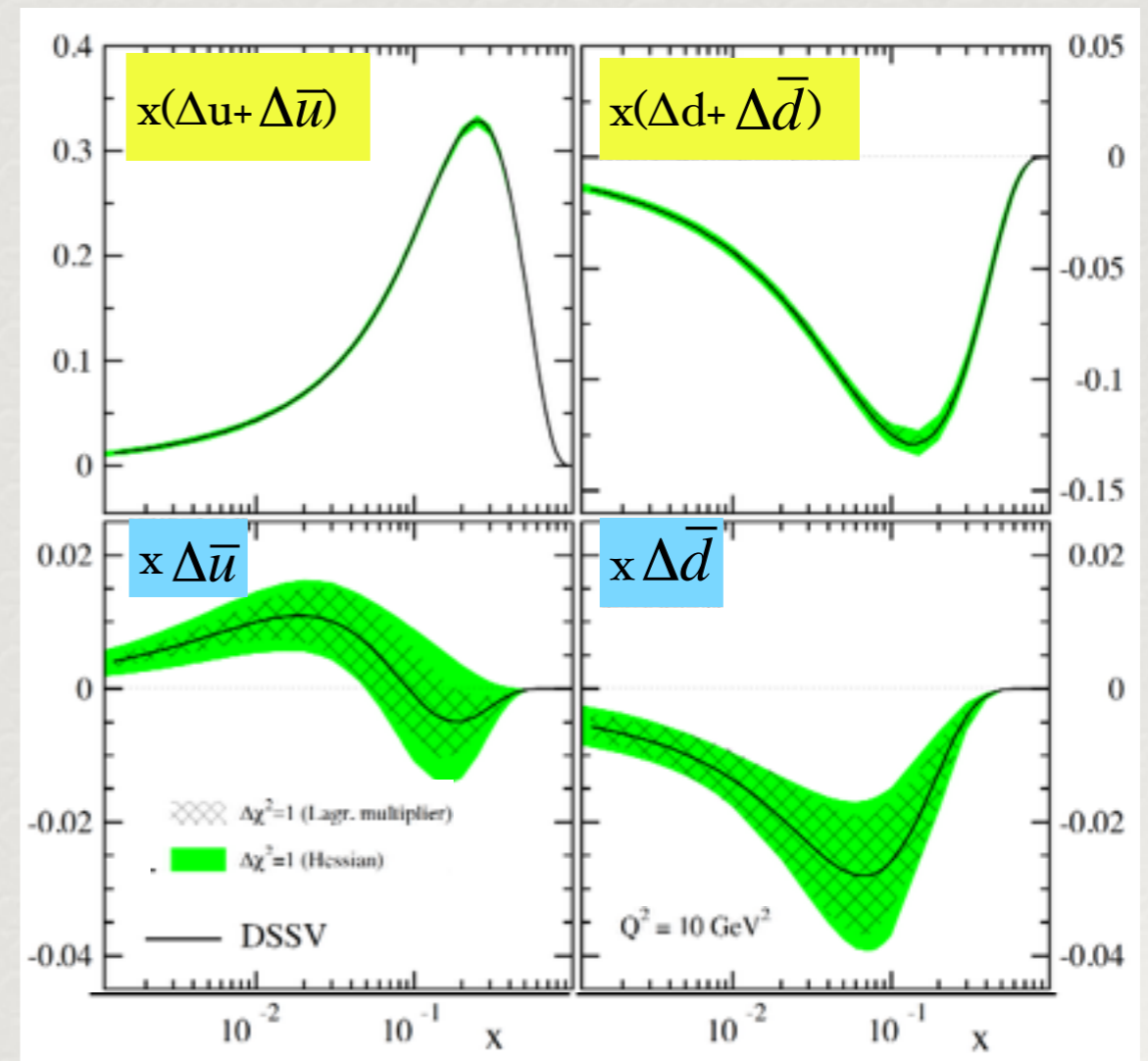
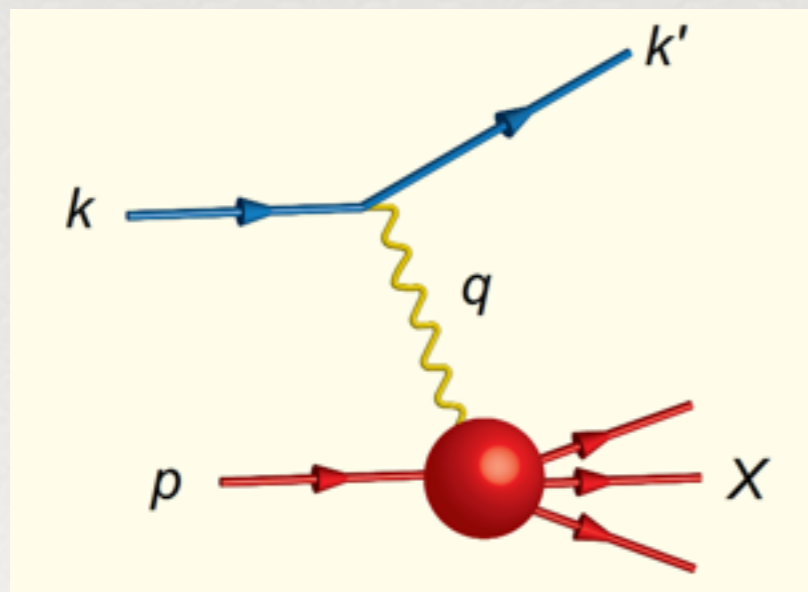
$$\langle S_p \rangle = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L$$

Jeff and Monahan, 1990

$$\Delta f(x, Q^2) \equiv f^+(x, Q^2) - f^-(x, Q^2)$$

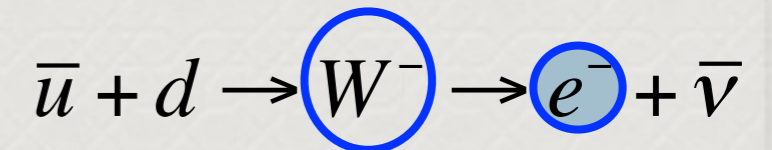
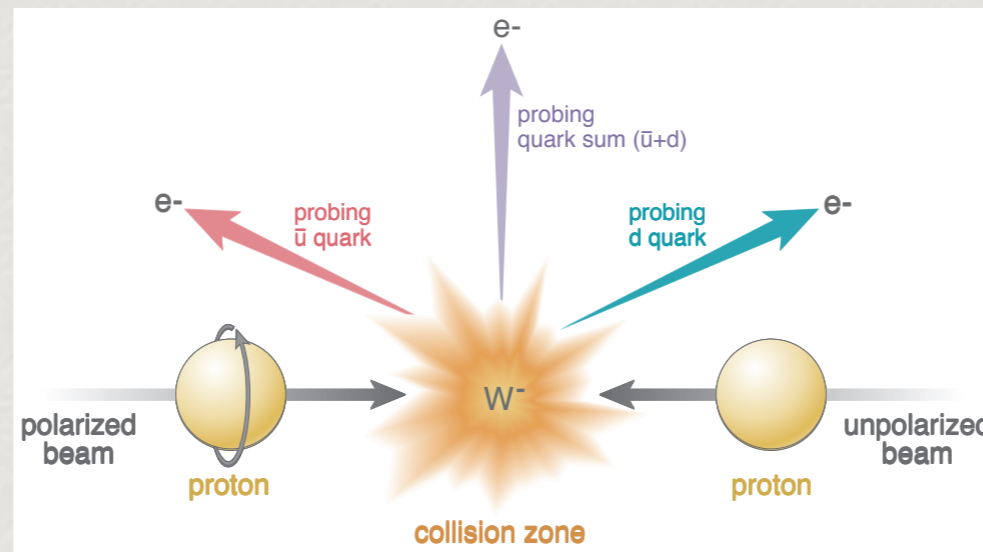
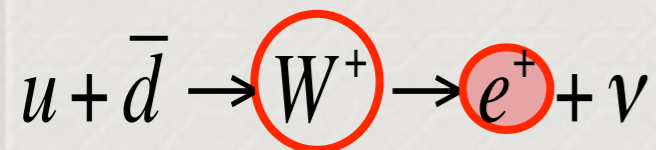
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}) dx$$

DIS:



PRD 80, 034030 (2009)

W-Bosons Production



- ❖ **Maximal Violation of Parity** leads to perfect **spin separation**
- ❖ **Direct coupling to the quark and antiquark of interest**
- ❖ **Higher resolution scale (Q^2)** set by the **W mass**.
- ❖ **Easy detection via the leptonic decay channels**

**Parity violating longitudinal
single spin asymmetry**

$$A_L = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

W A_L : Theoretical Aspects

Higher sensitivity to pPDF if A_L is measured as a function of decay lepton pseudo rapidity (η_e)

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

$$\langle x_{1,2} \rangle \sim \frac{M_W}{\sqrt{s}} e^{\pm\eta_e/2}$$

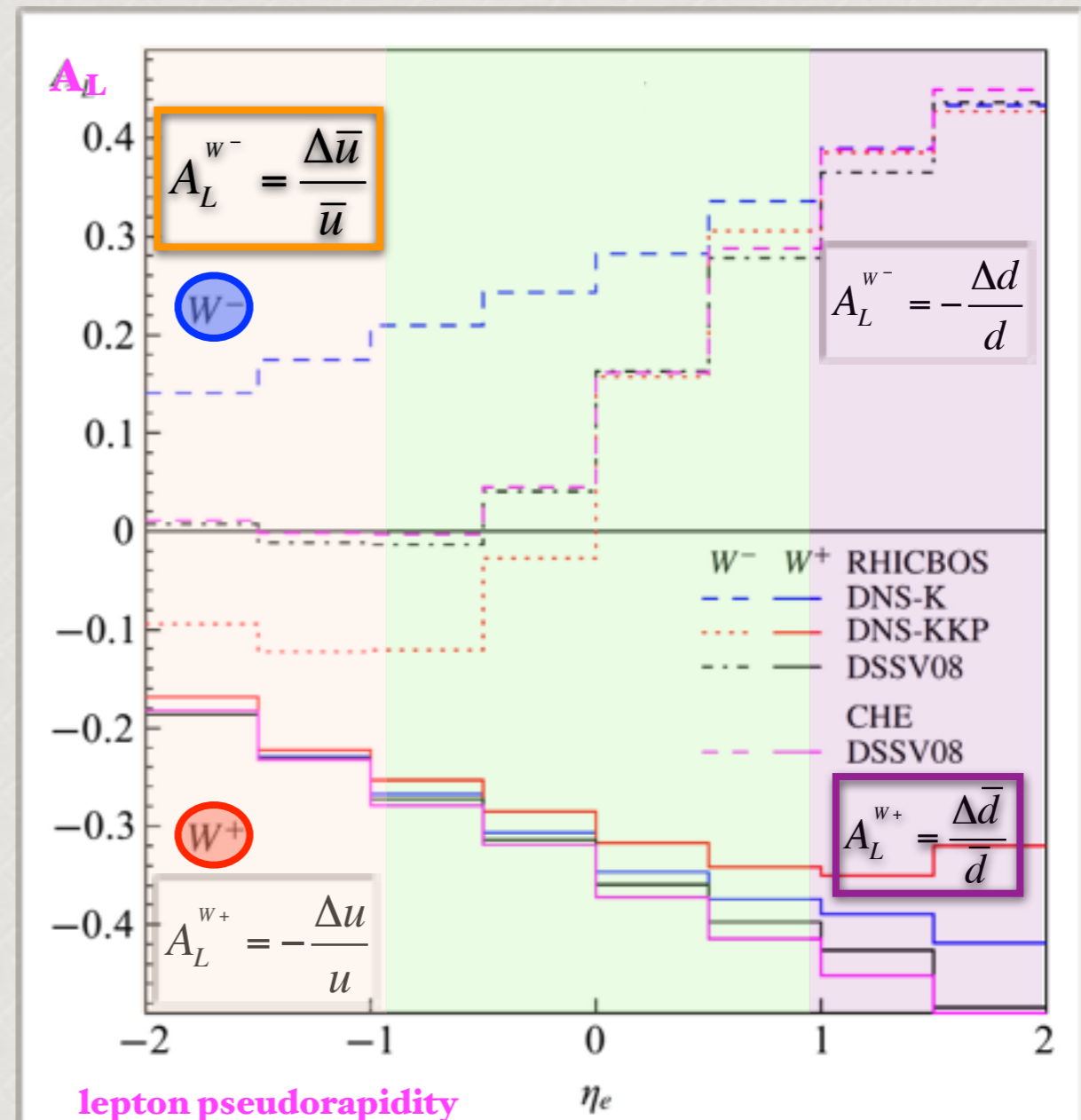
$$\eta \lll 0 \rightarrow x_1 \ll x_2, \theta \rightarrow \pi$$

$$\eta \ggg 0 \rightarrow x_1 \gg x_2, \theta \rightarrow 0$$

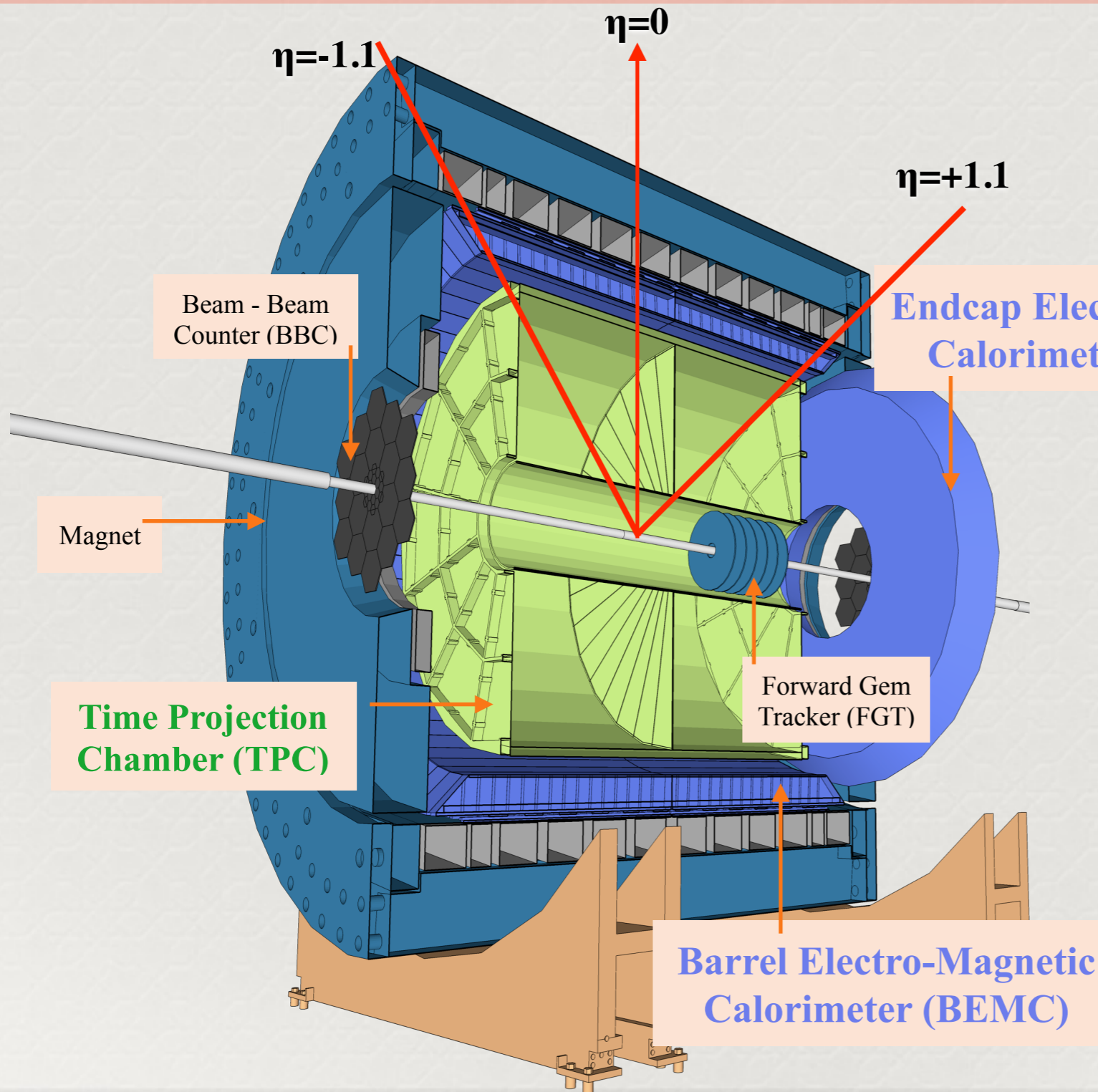
$$A_L^{W^-} \propto \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$



$$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$



STAR Detector



$$\eta = -\ln(\tan(\theta/2))$$

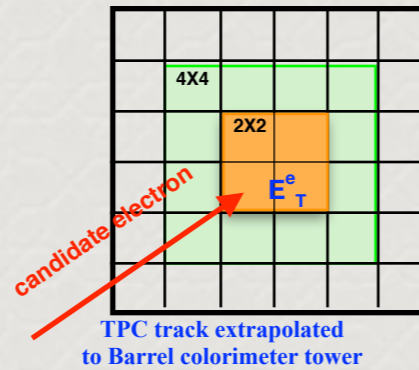
TPC: Charge particle tracking
 BEMC, EEMC: Energy measurement

TPC : $-1.3 < \eta < +1.3$
 BEMC : $-1.0 < \eta < +1.0$
 EEMC : $+1.1 < \eta < +2.0$

Mid-rapidity ($|\eta_{el}| < 1$) W Selection

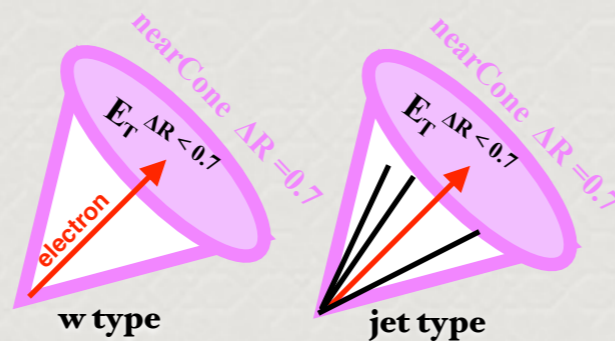
- ❖ Match $P_T > 10$ GeV TPC tracks to EMC cluster

$$E_T^e / E_T^{4 \times 4} > 0.95$$



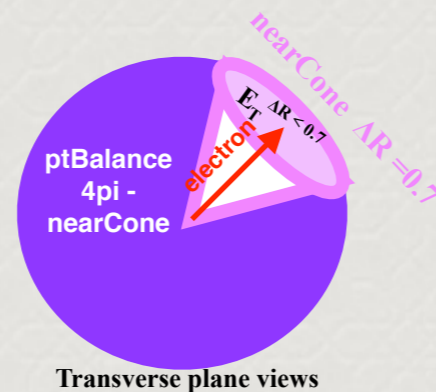
- ❖ Isolate from QCD di-jet type event

$$E_T^e / E_T^{\Delta R < 0.7} > 0.88$$

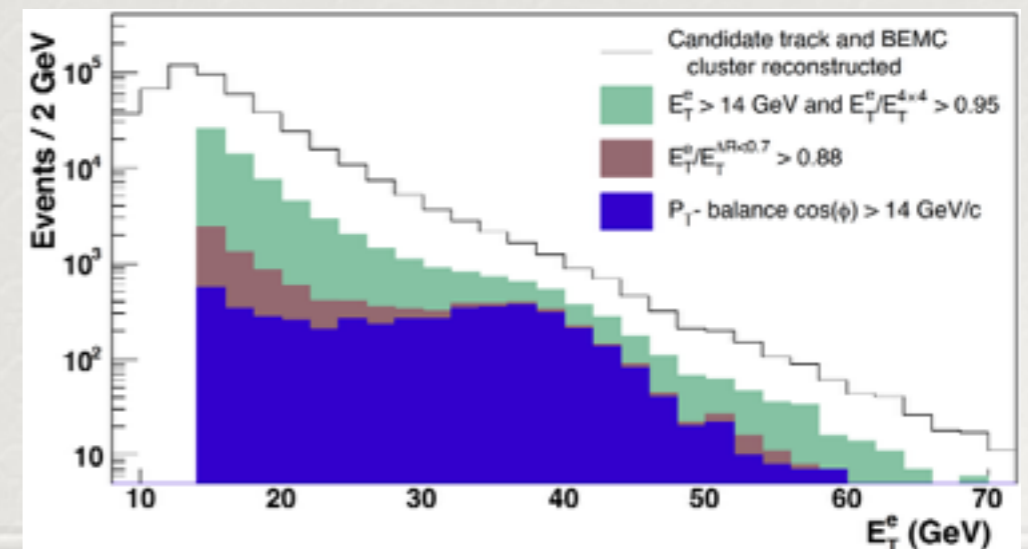
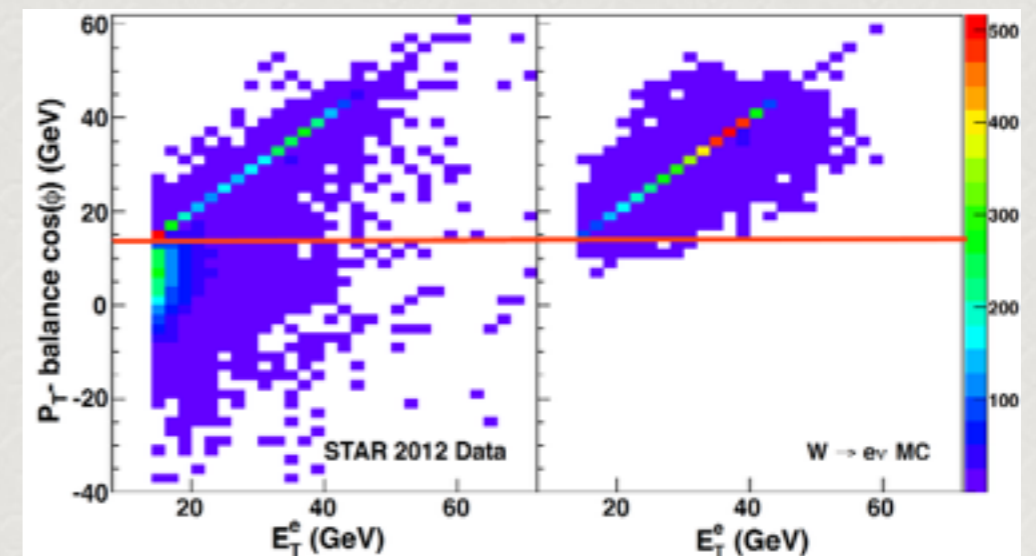
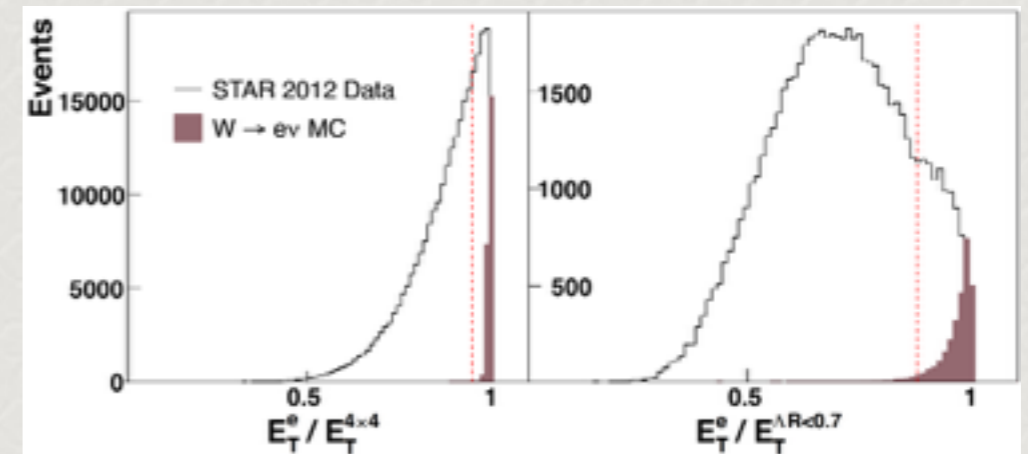


- ❖ Use Larger imbalance of transverse momentum

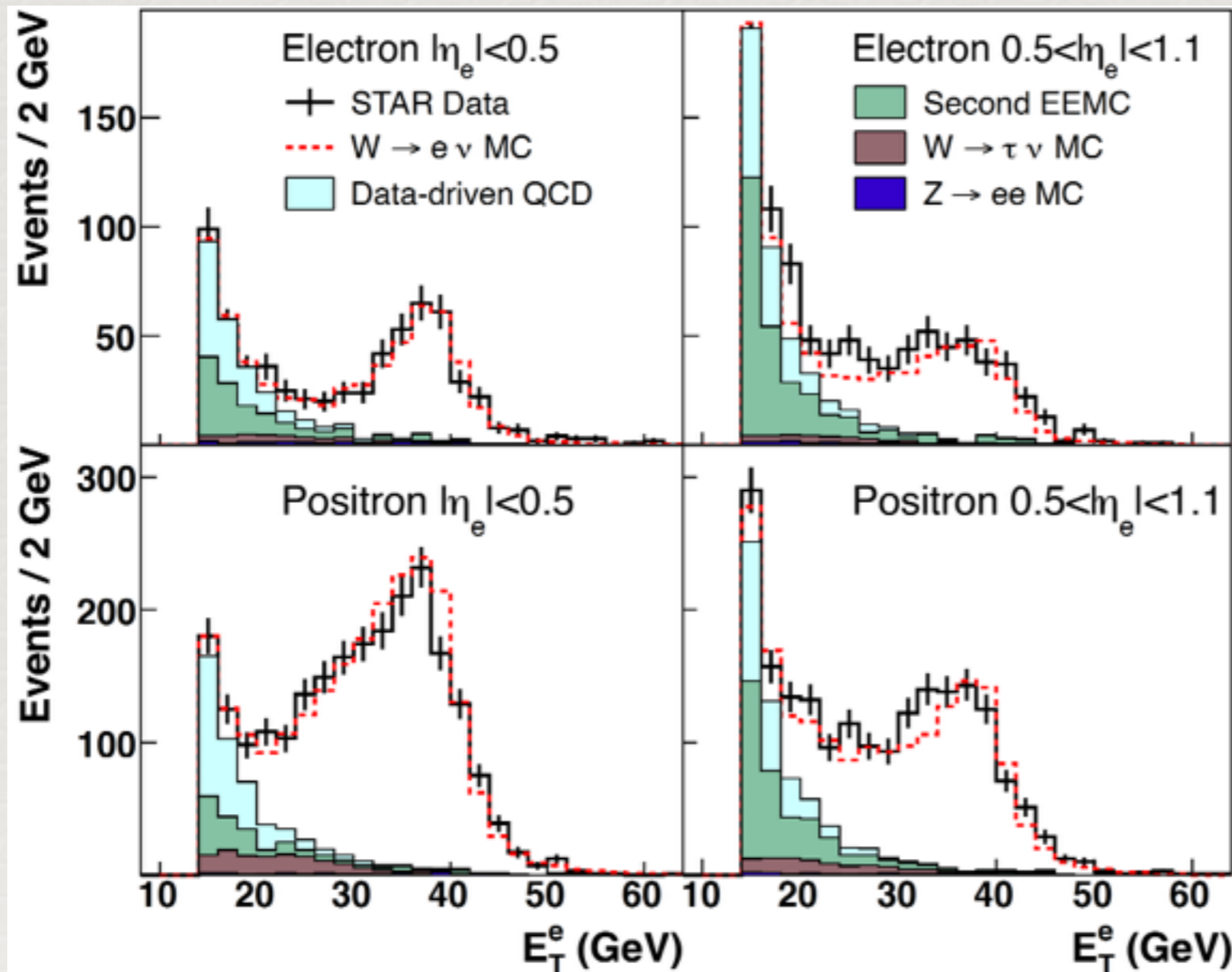
$$\vec{p}_T^{balance} = \vec{p}_T^e + \sum_{\Delta R > 0.7} \vec{p}_T^{jets}$$



- ❖ e+ and e- Charge sign Separation



Mid-rapidity Background Estimation



PRL 113,72301 (2014)

❖ Electroweak BG

* $W \rightarrow \tau \nu$: Embedding MC

* $Z \rightarrow e^+ e^-$: Embedding MC

❖ Data driven QCD

❖ Second Endcap

Forward rapidity ($1 < \eta_e < 1.4$) W selection use similar technique as mid rapidity and Background Estimation improve using additional Endcap Shower Maximum Detector (ESMD)

Extracting Asymmetries using Profile Likelihood Method

- Profile Likelihood method used in extracting Asymmetries from combination of run 2012 and run 2011 data [simple gaussian uncertainties breakdown particularly for small 2011 data sample]
- Define likelihood function for 8 spin-dependent yields from pair of symmetric η region of STAR

$$L = \prod_i^4 p(M_i^a | \mu_i^a) p(M_i^b | \mu_i^b) g(\beta^a) g(\beta^b)$$

$p(M_i | \mu_i)$ - Poisson probability, for measured spin sorted yield M_i in the expected value μ_i given by:

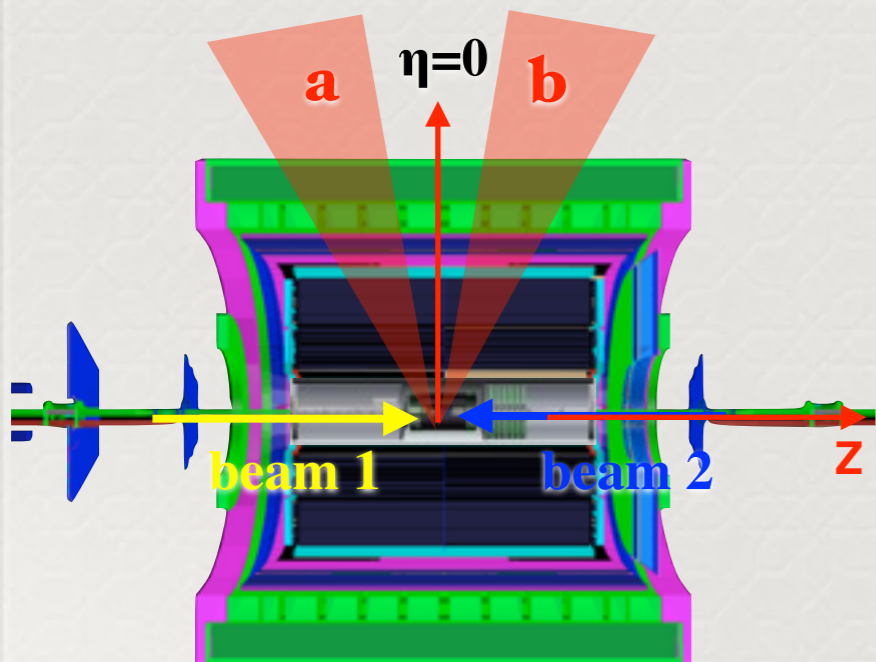
$$\mu_{++}^a = I_{++} N (1 + P_1 \beta A_L^{+\eta_e} + P_2 \beta A_L^{-\eta_e} + P_1 P_2 \beta A_{LL})$$

$$\mu_{+-}^a = I_{+-} N (1 + P_1 \beta A_L^{+\eta_e} - P_2 \beta A_L^{-\eta_e} - P_1 P_2 \beta A_{LL})$$

$$\mu_{-+}^a = I_{-+} N (1 - P_1 \beta A_L^{+\eta_e} + P_2 \beta A_L^{-\eta_e} - P_1 P_2 \beta A_{LL})$$

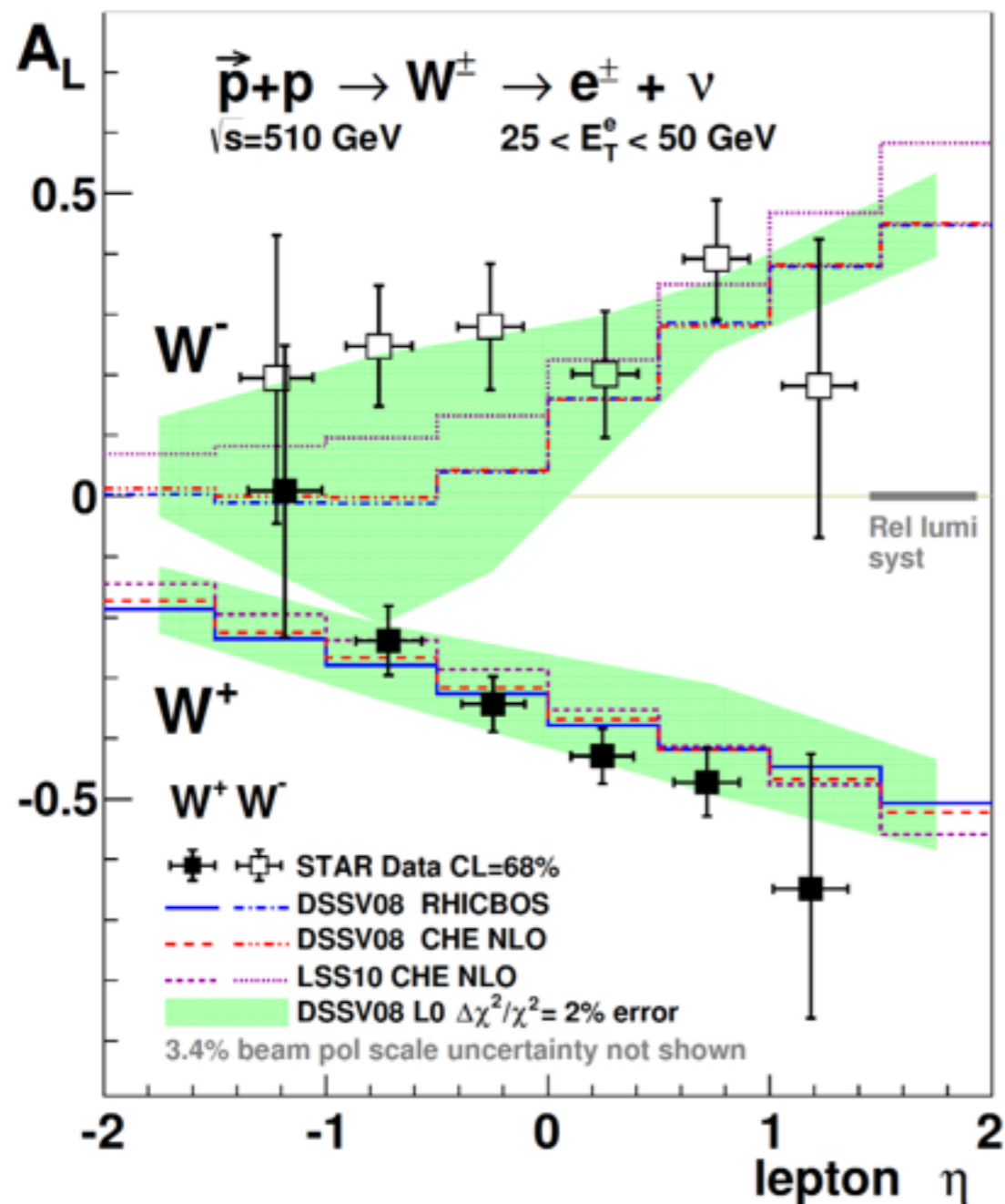
$$\mu_{--}^a = I_{--} N (1 - P_1 \beta A_L^{+\eta_e} - P_2 \beta A_L^{-\eta_e} + P_1 P_2 \beta A_{LL})$$

P_1, P_2 - beam polarization $A_L^{+\eta_e} (A_L^{-\eta_e})$ - single spin asymmetry
 A_{LL} - double spin asymmetry N - spin averaged yield $I_{\pm\pm}$ - relative luminosity



$g(\beta)$ - Gaussian probability for estimated dilution background β

STAR 2012+2011 W A_L (η_e)



PRL 113,72301 (2014)

❖ **A_L(W⁻) is larger** than the DSSV Predictions.

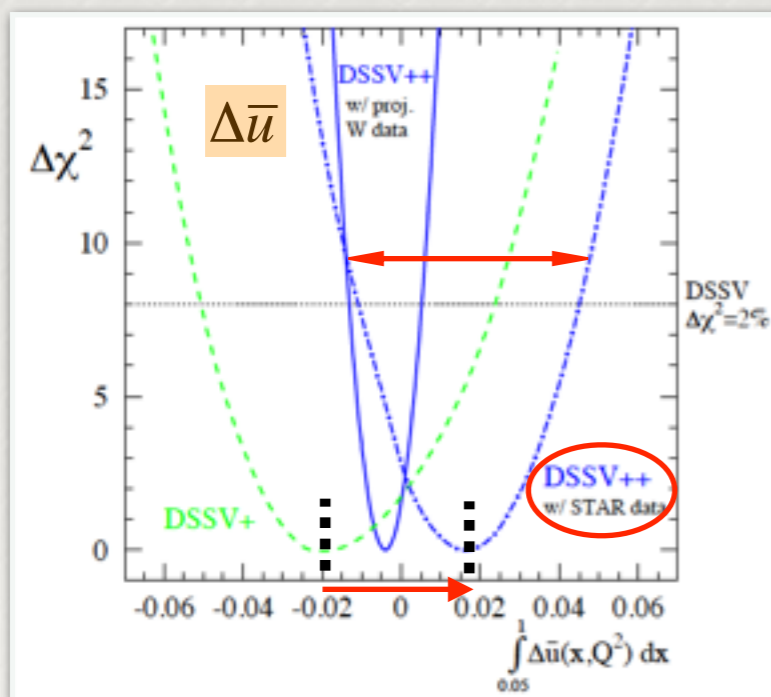
❖ The enhancement at **η_e < 0**, in particular is sensitive to the $\Delta\bar{u}$ polarized **antiquark distribution**.

❖ **A_L (W⁺) is consistent** with **theoretical predictions** using the DSSV polarized PDFs.

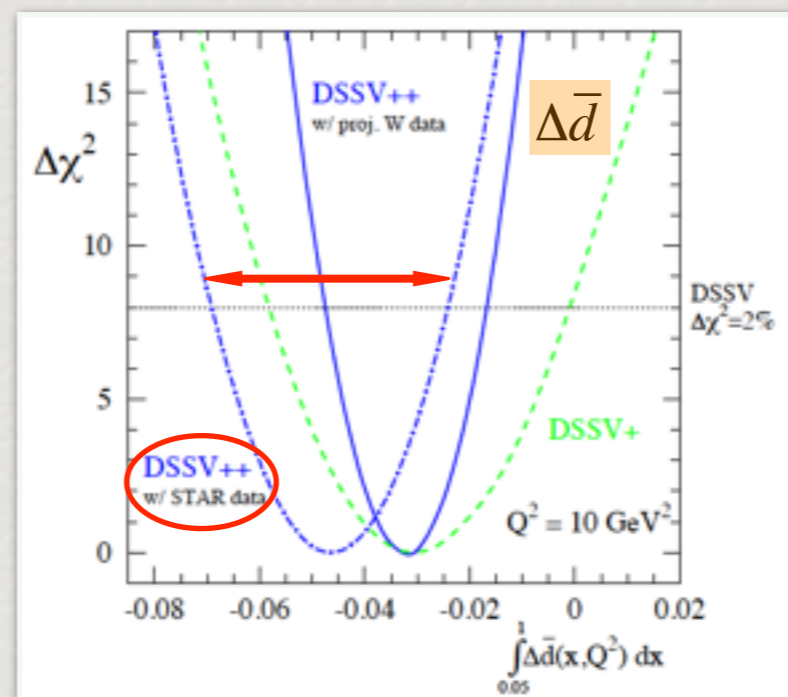
❖ The Systematic **uncertainties** for A_L are well **under control** for **|η_e| < 1.4** .

Impact on DSSV++ Global Analysis

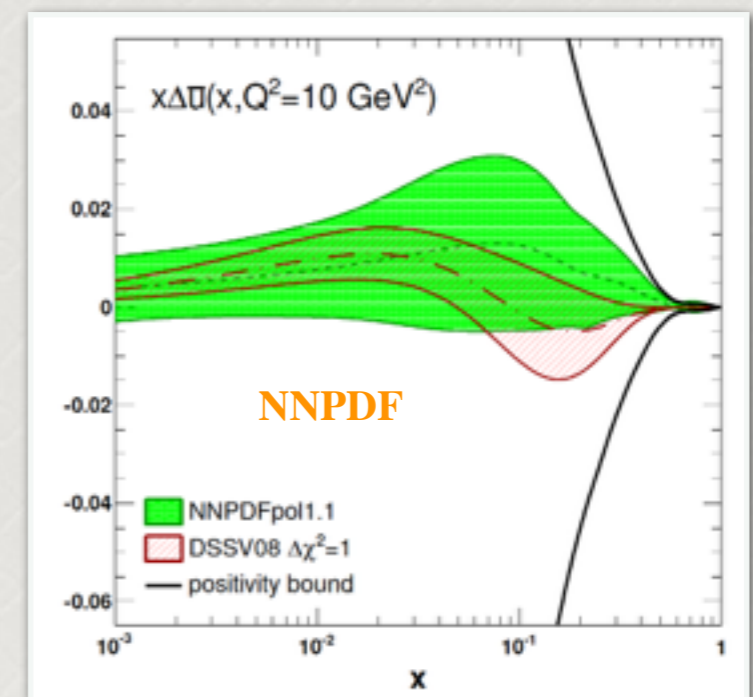
- ❖ Preliminary Global analysis (DSSV++) from DSSV group and recent **NNPDF** includes preliminary STAR 2012 W_{A_L} data.
- ❖ **Shift** in central value for $\Delta\bar{u}$ (negative \rightarrow positive) and $\Delta\bar{d}$ due to $A_L W$ from STAR .
- ❖ STAR run 12 W results provide significant constrain on anti u and anti d quark polarization.



arXiv: 1304.0079



arXiv: 1304.0079

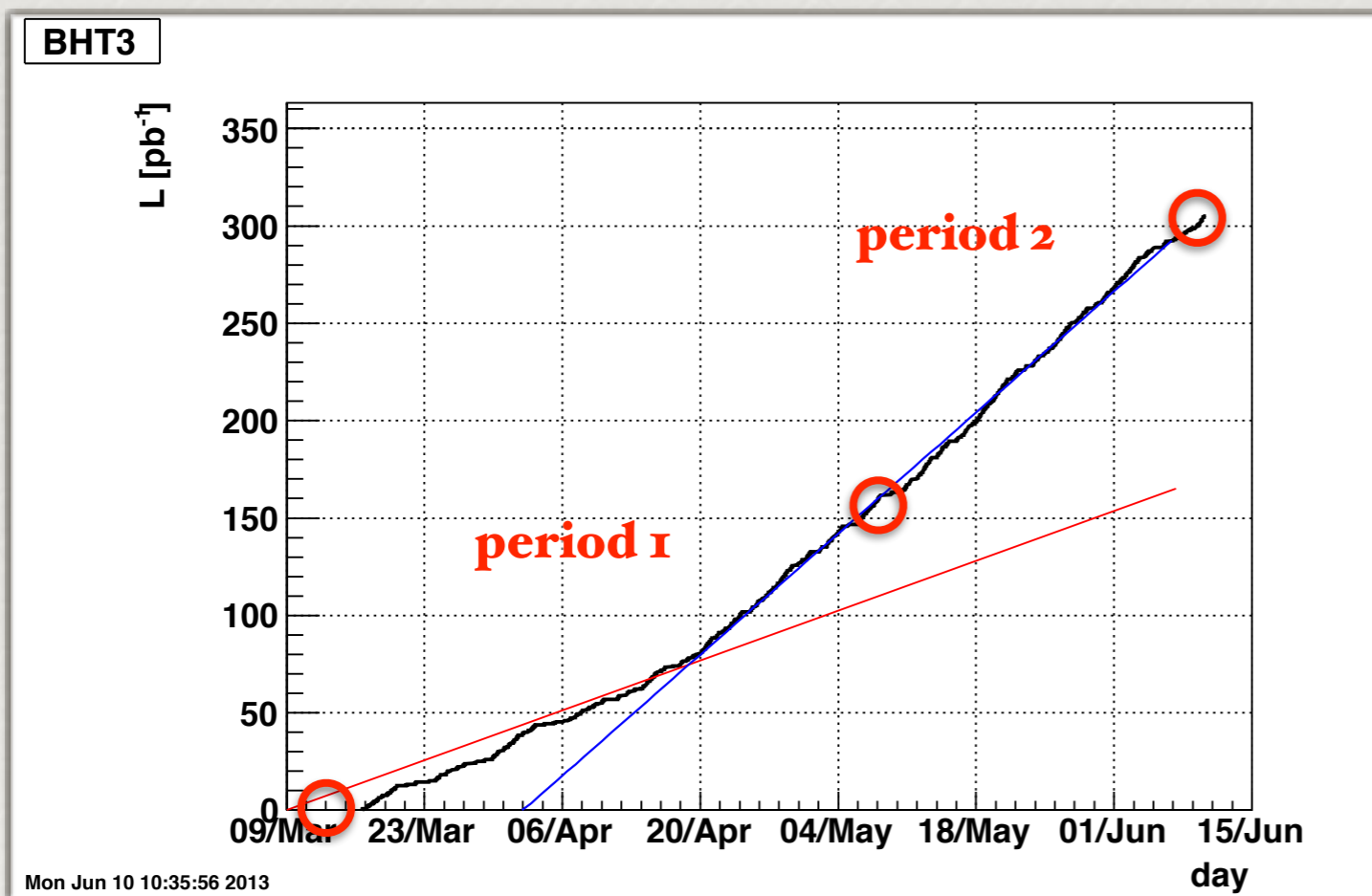


arXiv: 1403.0440

Run 2013 Analysis Status

Run 13 Data Sample

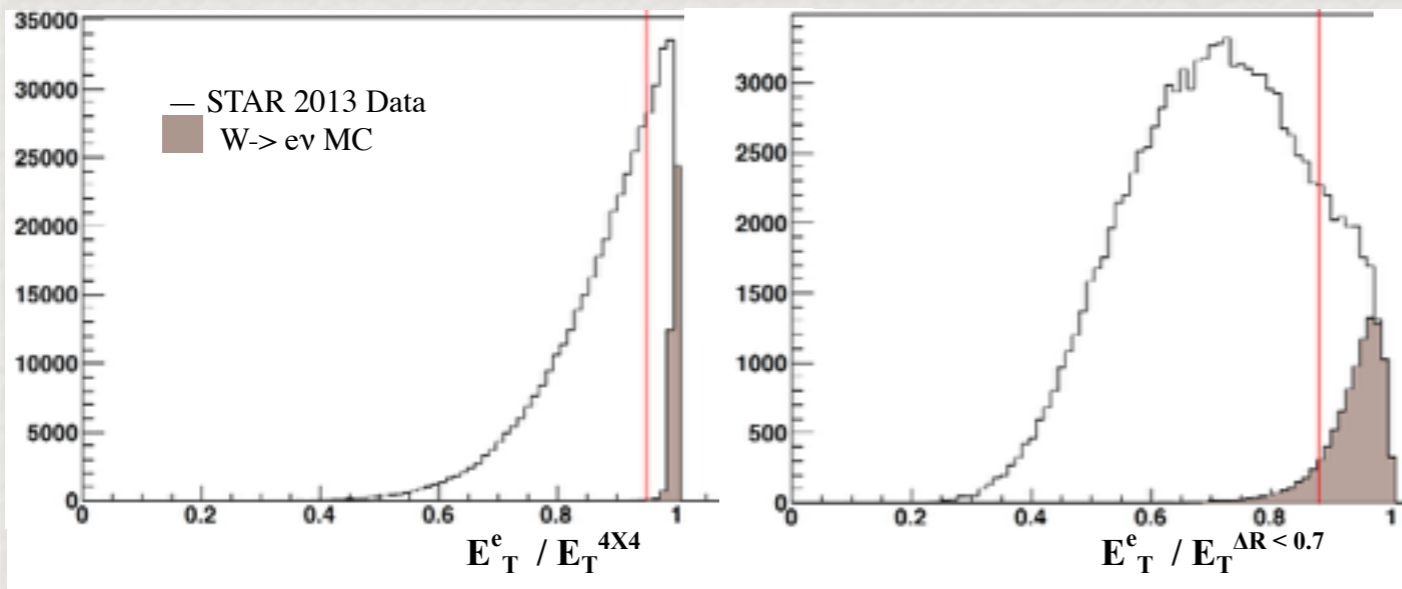
Barrel EMC triggered Integrated Luminosity



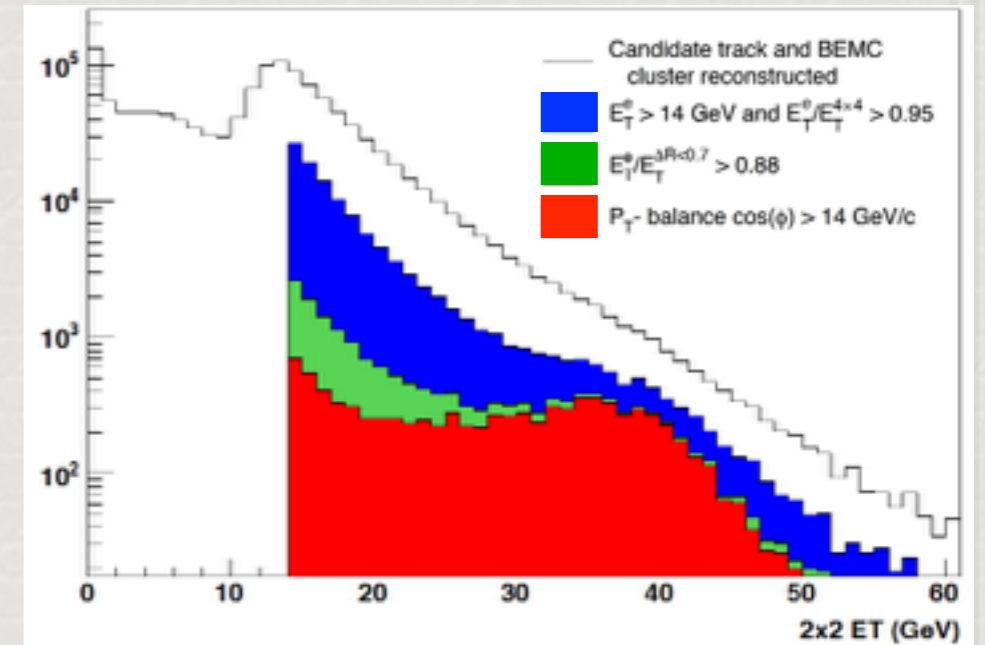
	L (pb ⁻¹)	P	P ² L (pb ⁻¹)
Run 9	12	0.38	1.7
Run 11	9.4	0.49	2.3
Run 12	72	0.56	24
Run 13	~300	0.54	~

Run13 Mid-rapidity W Selection

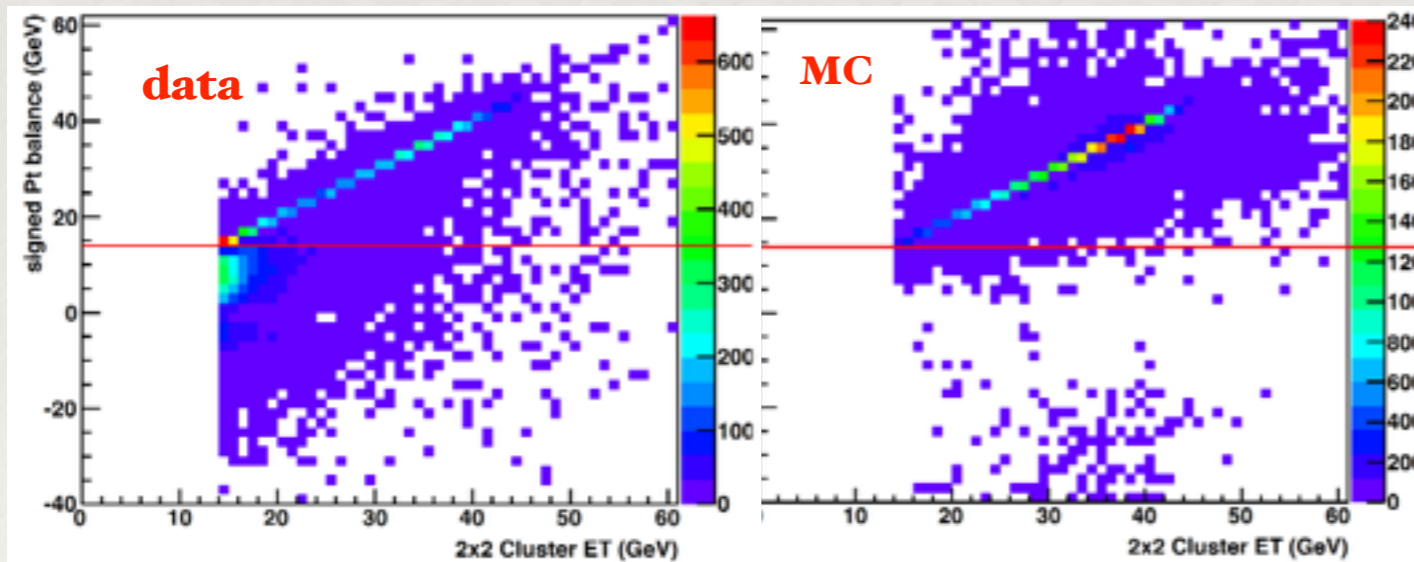
e^+, e^- Isolation



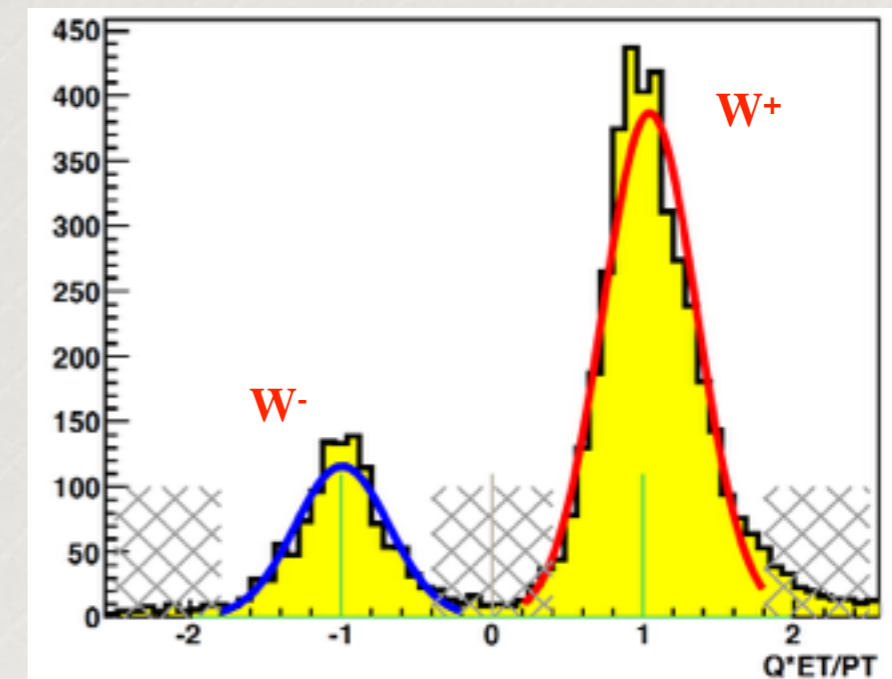
E_T distribution compare to Selection Cuts



Sign- P_T balance

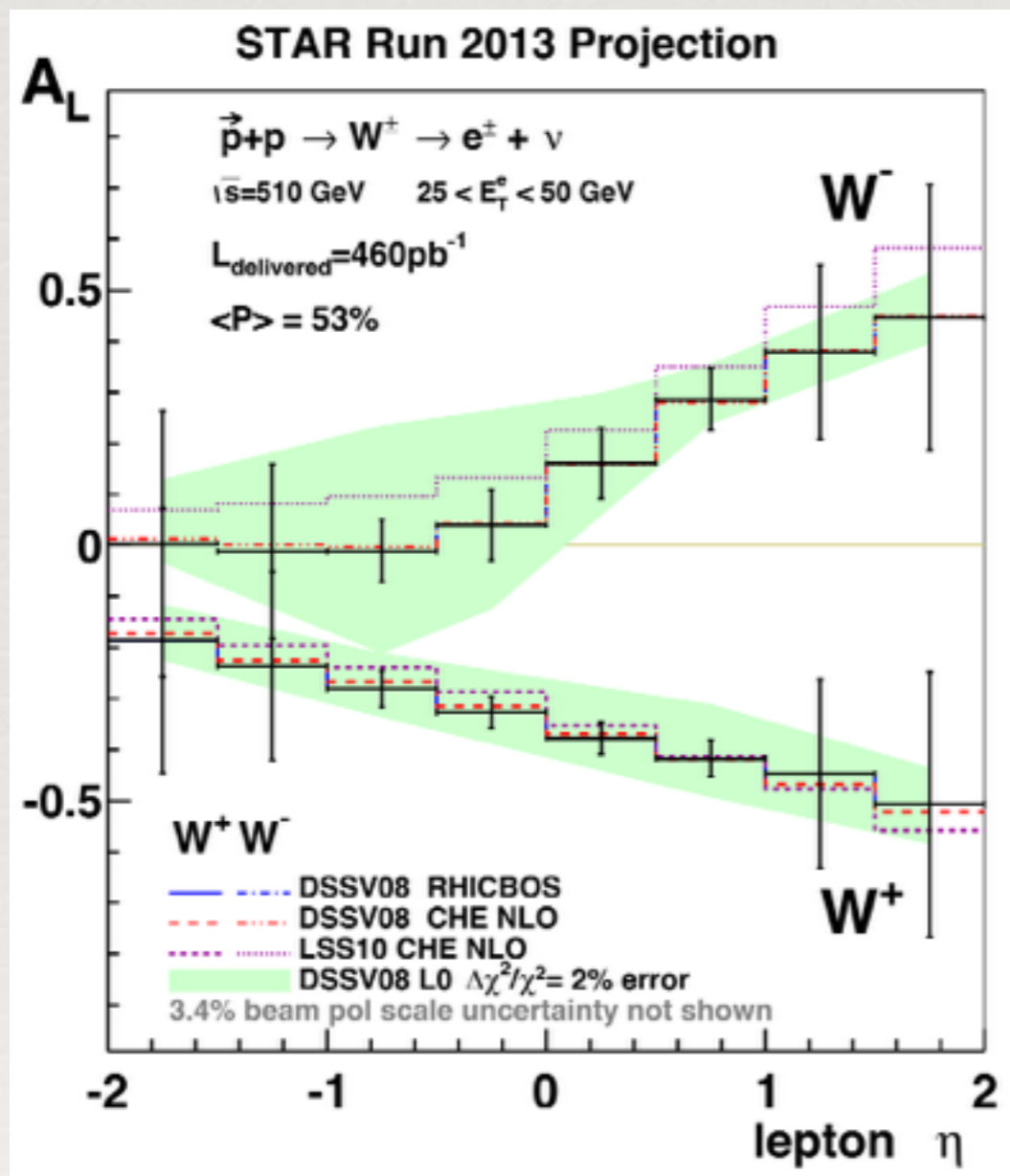


Charge-sign Separation



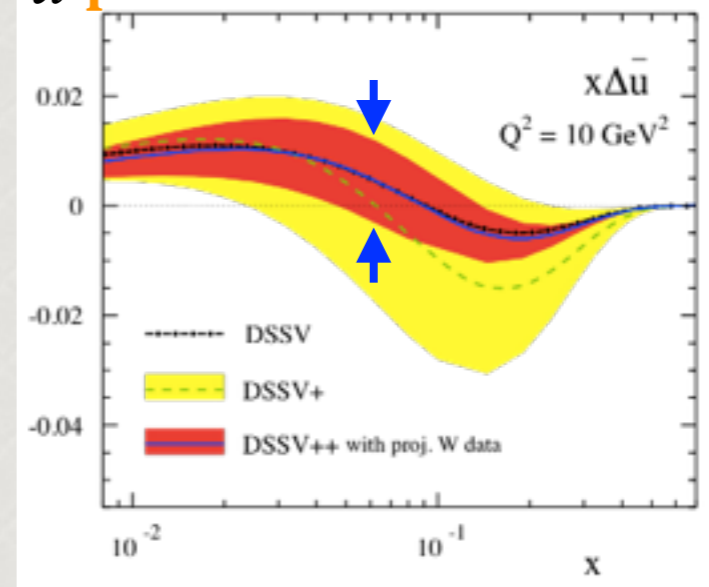
STAR Run 13 W Projections

W A_L

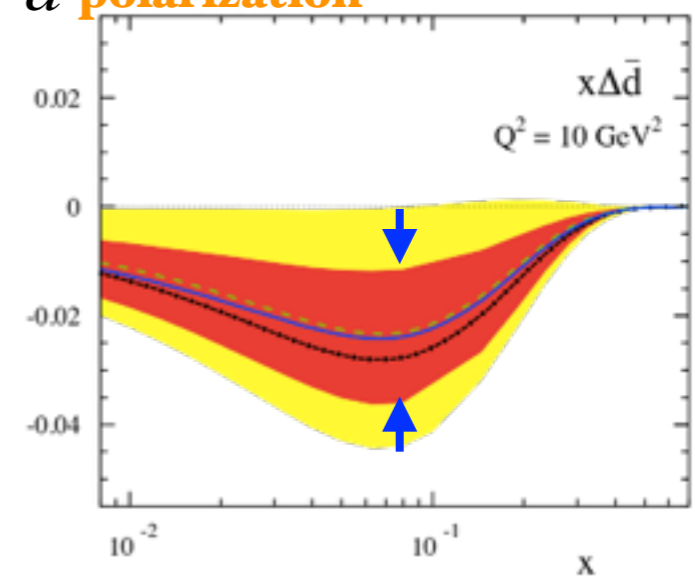


Impact on antiquark polarization

\bar{u} polarization



\bar{d} polarization



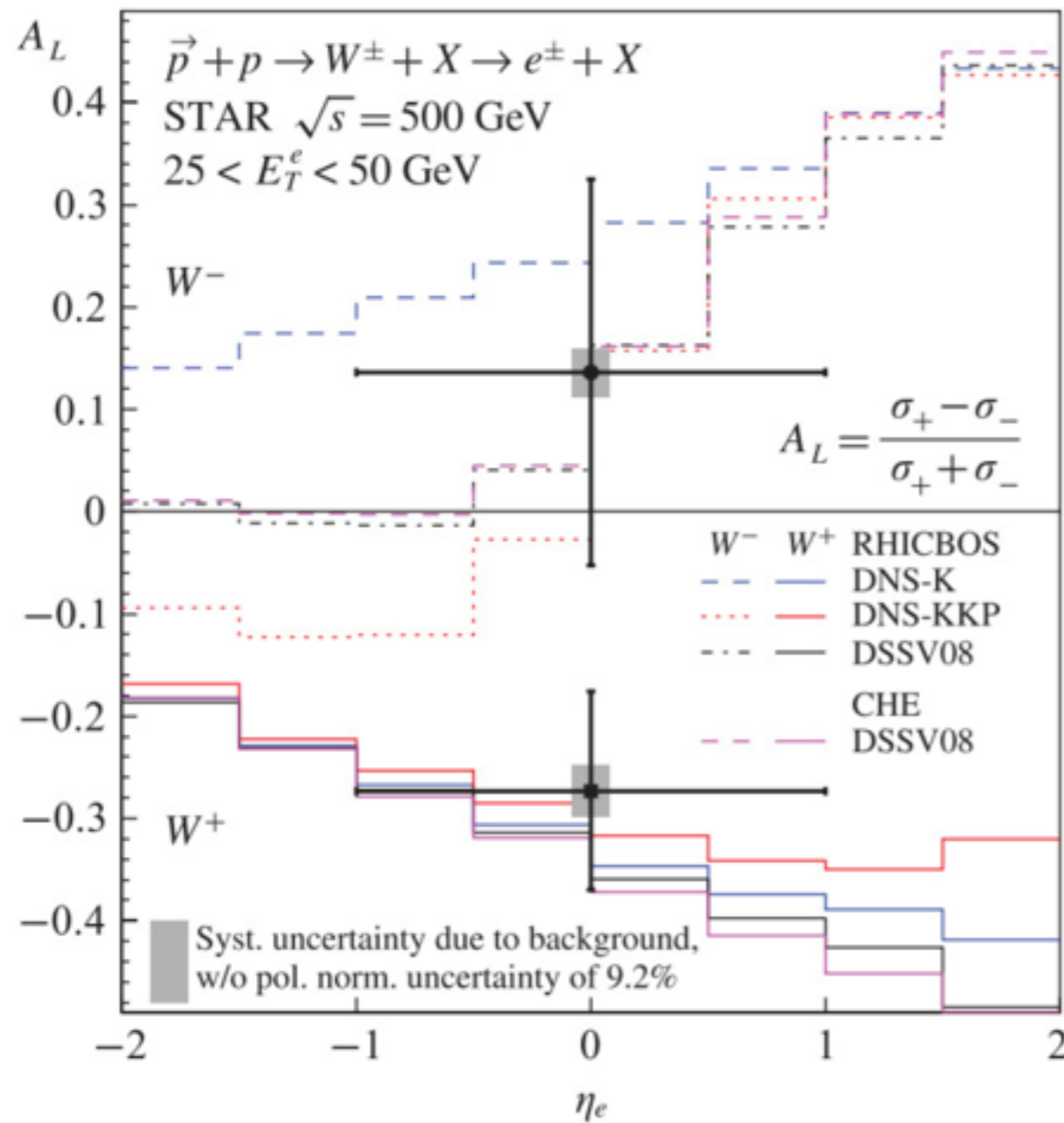
arXiv: 1304.0079

Summary / Outlook

- ◆ *The Production of W Bosons in polarized p+p collisions provides a new means to study the spin and flavor asymmetries of the proton sea quark distributions*
- ◆ *STAR has measured the parity violating single-spin asymmetry A_L for $|\eta_e| < 1.4$ from 2012 data, providing the first detailed look at the asymmetry's η_e dependence.*
- ◆ *STAR run 12 W AL results provide significant constrain on anti u and anti d quark polarization.*
- ◆ *Half of the data from Larger statistics of run 2013 (more than 4 times larger than run 2012) is in the final state of analysis and second half is being started to analyze.*
- ◆ *Projected results from run 13 data shows comparable reduction of uncertainty.*

Backup

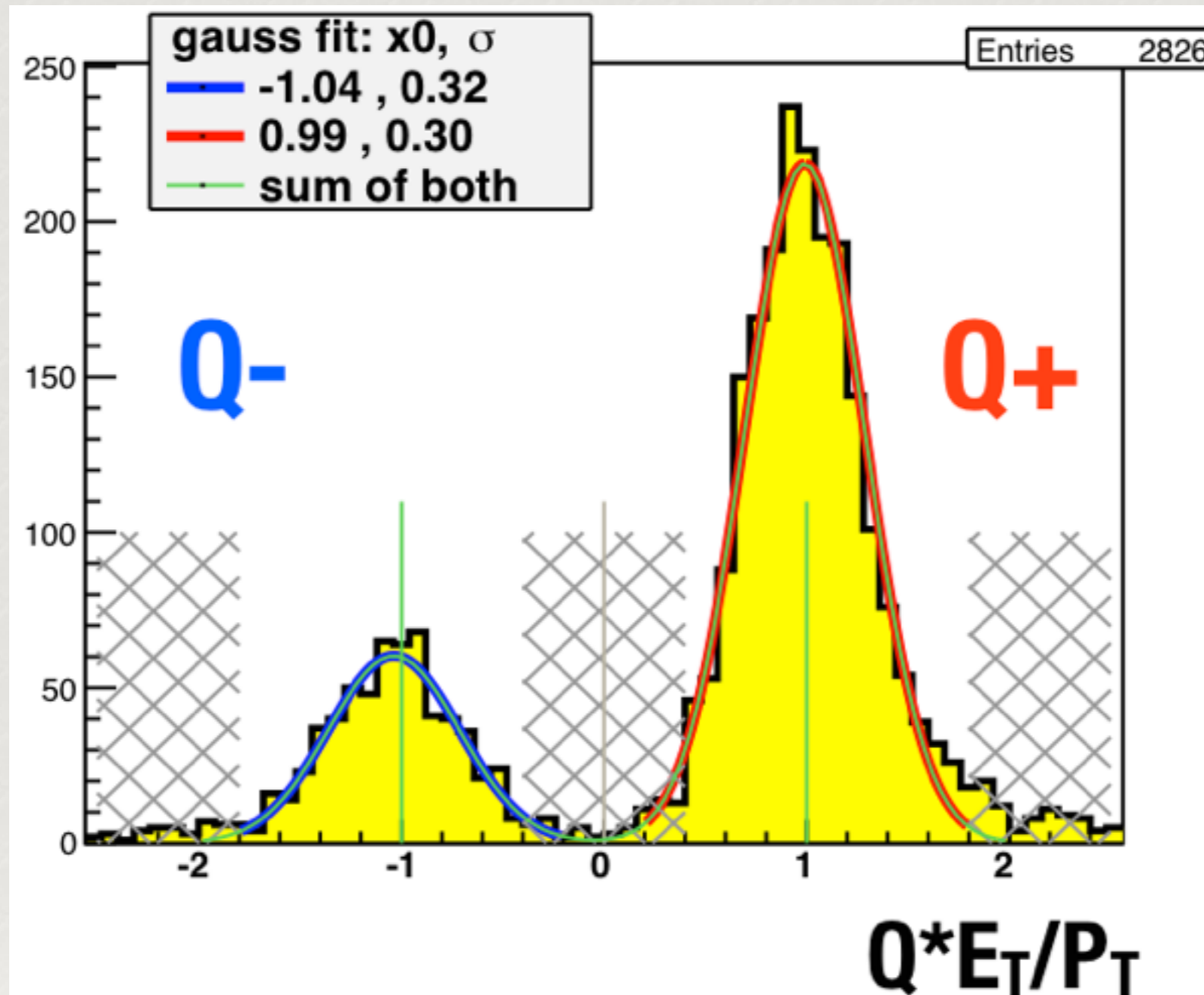
STAR 2009 W Results



STAR pp500 Longitudinal		
Run	L (pb^{-1})	$W^+(W^-)$ raw yield
2009	12	462 (192)
2011	9	342 (103)
2012	77	2417 (734)

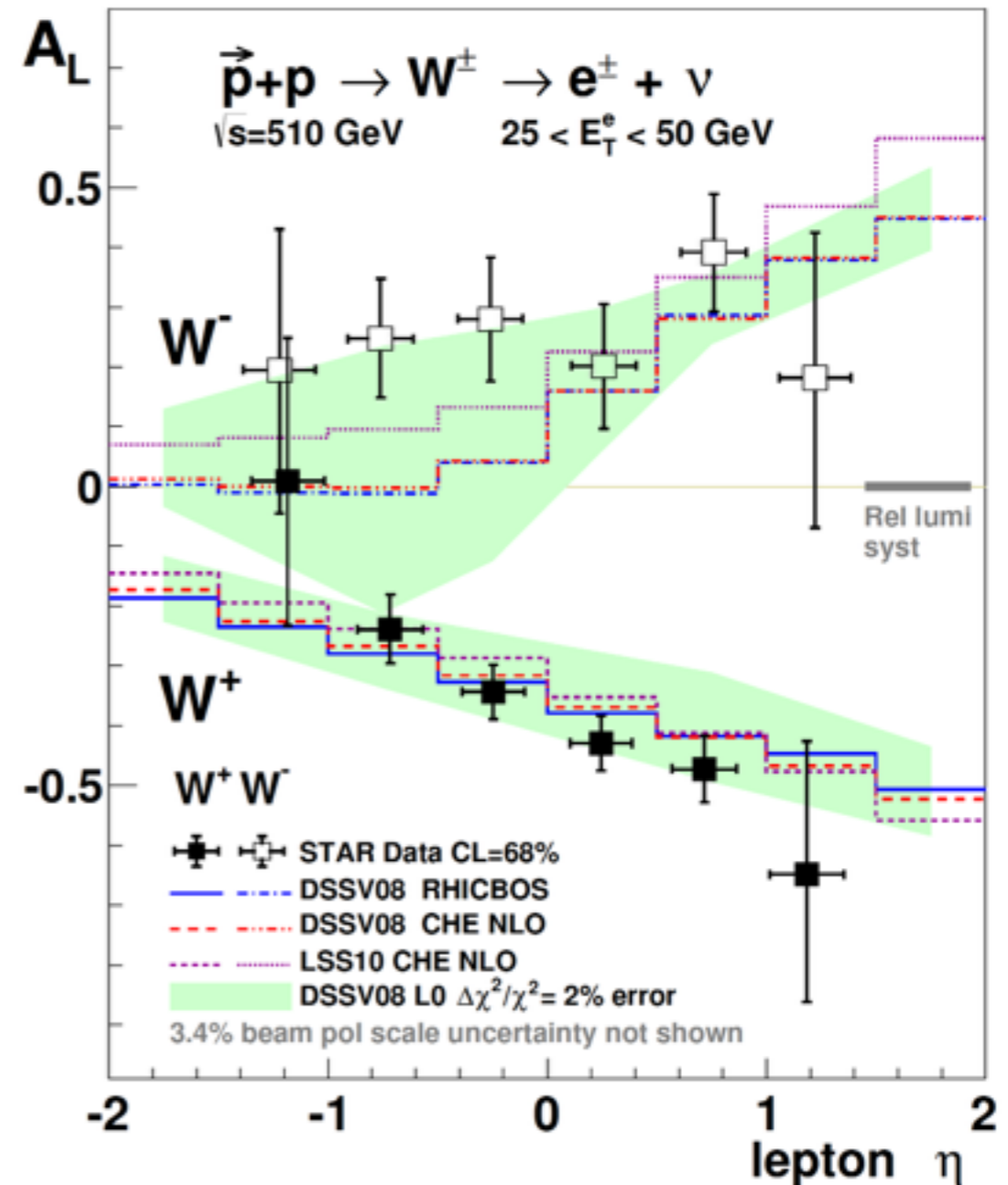
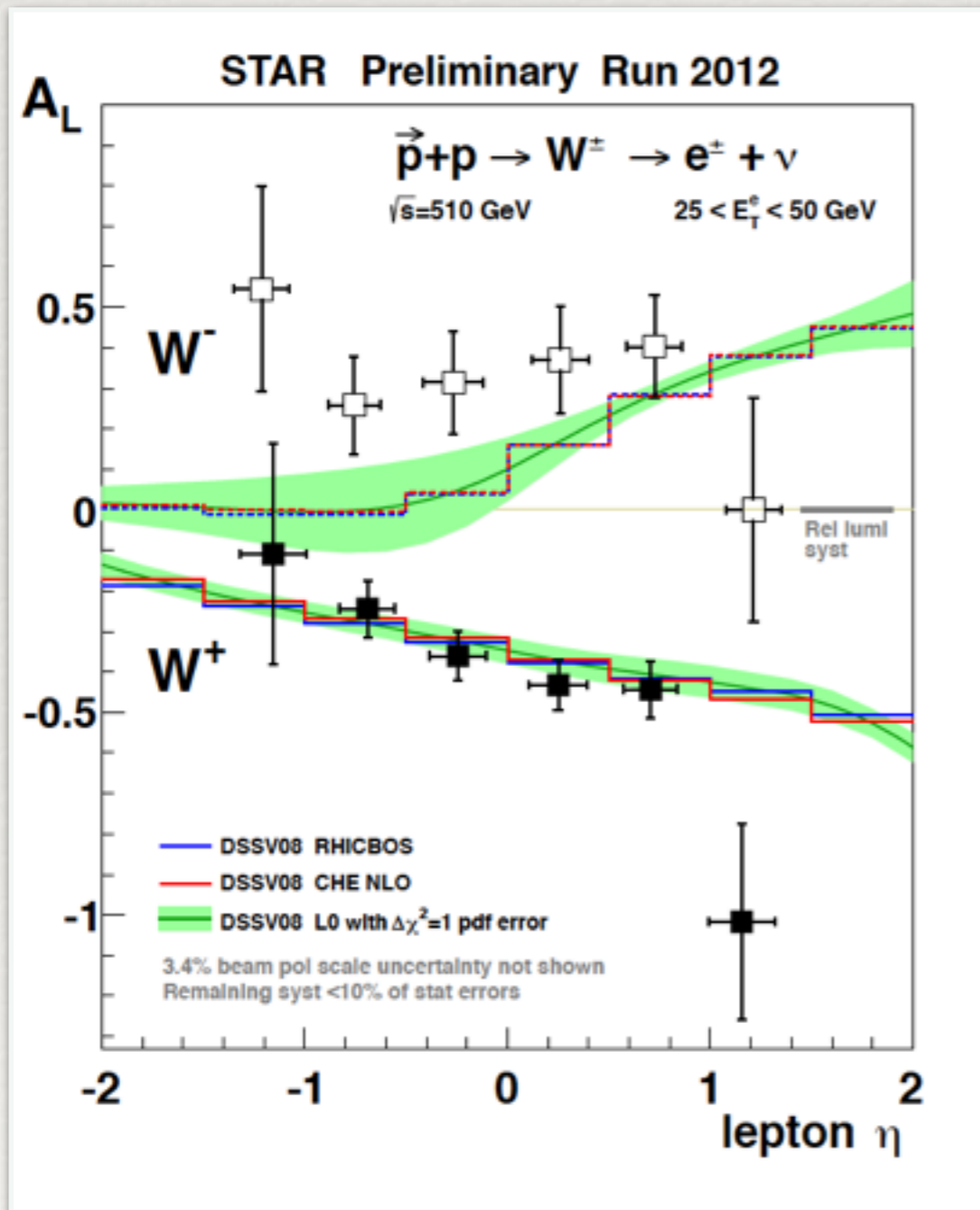
PRL 106, 062002 (2011)

Mid-Rapidity charge sign separation



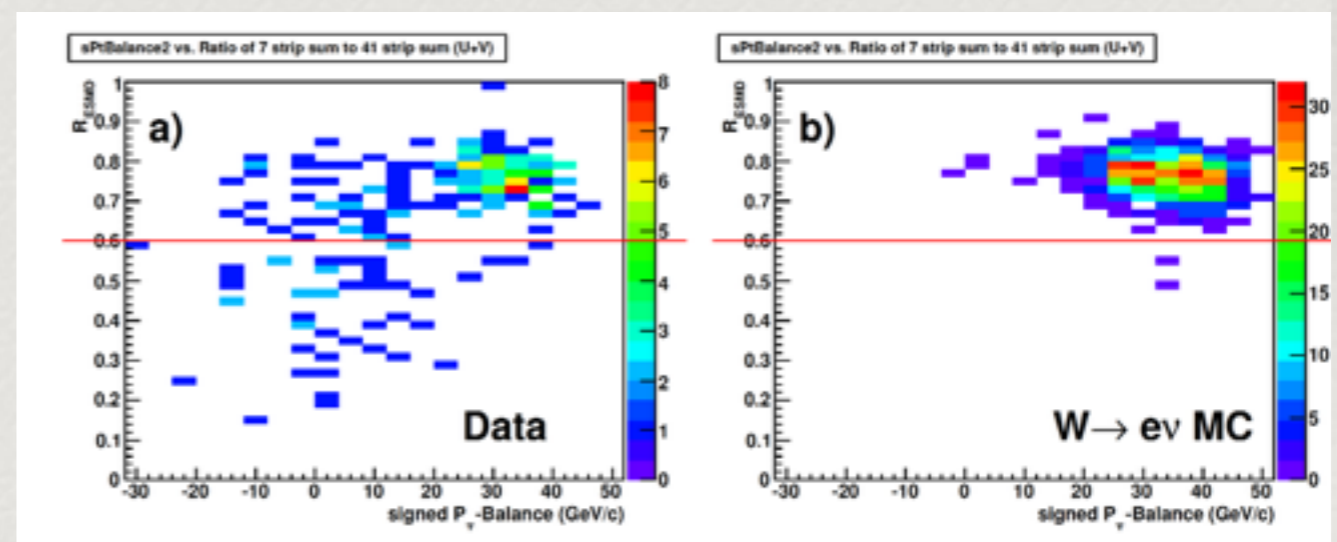
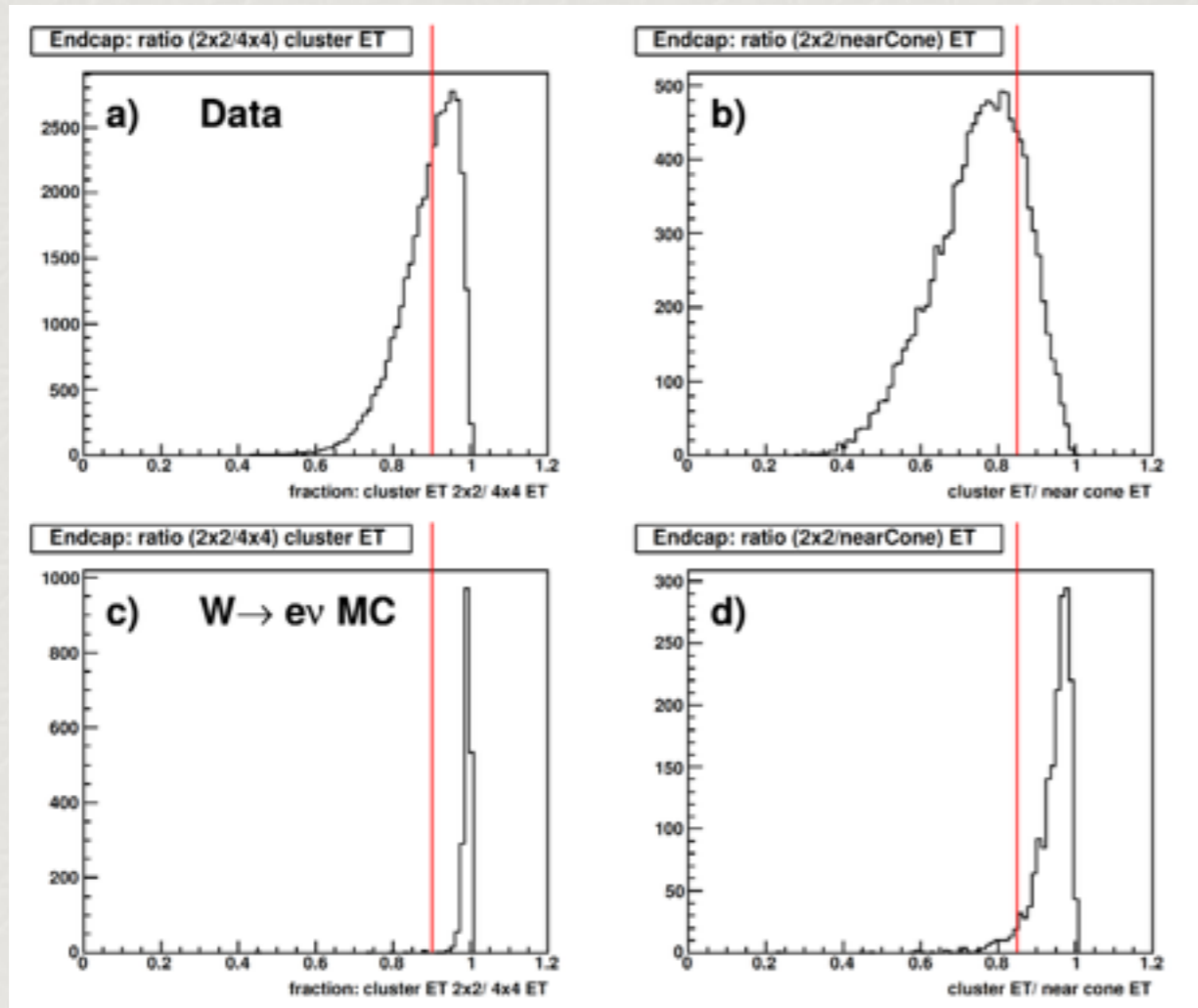
Run 12 Preliminary results compare to Final

STAR FINAL Run 2012+2011

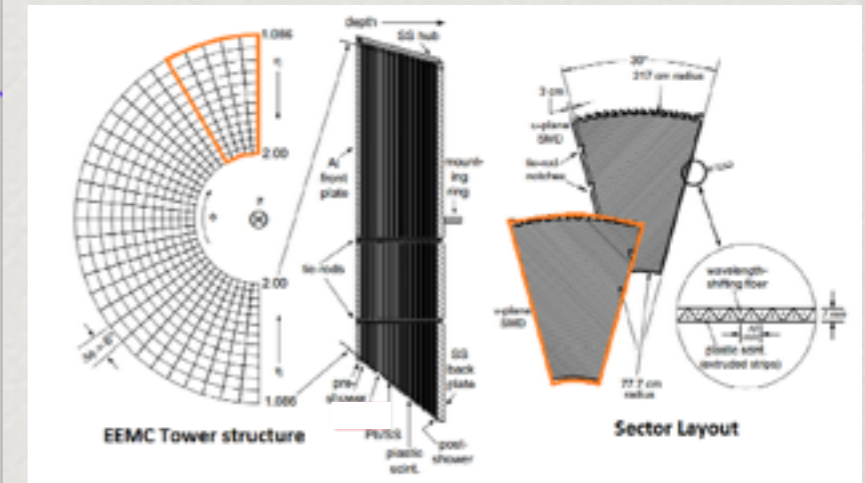
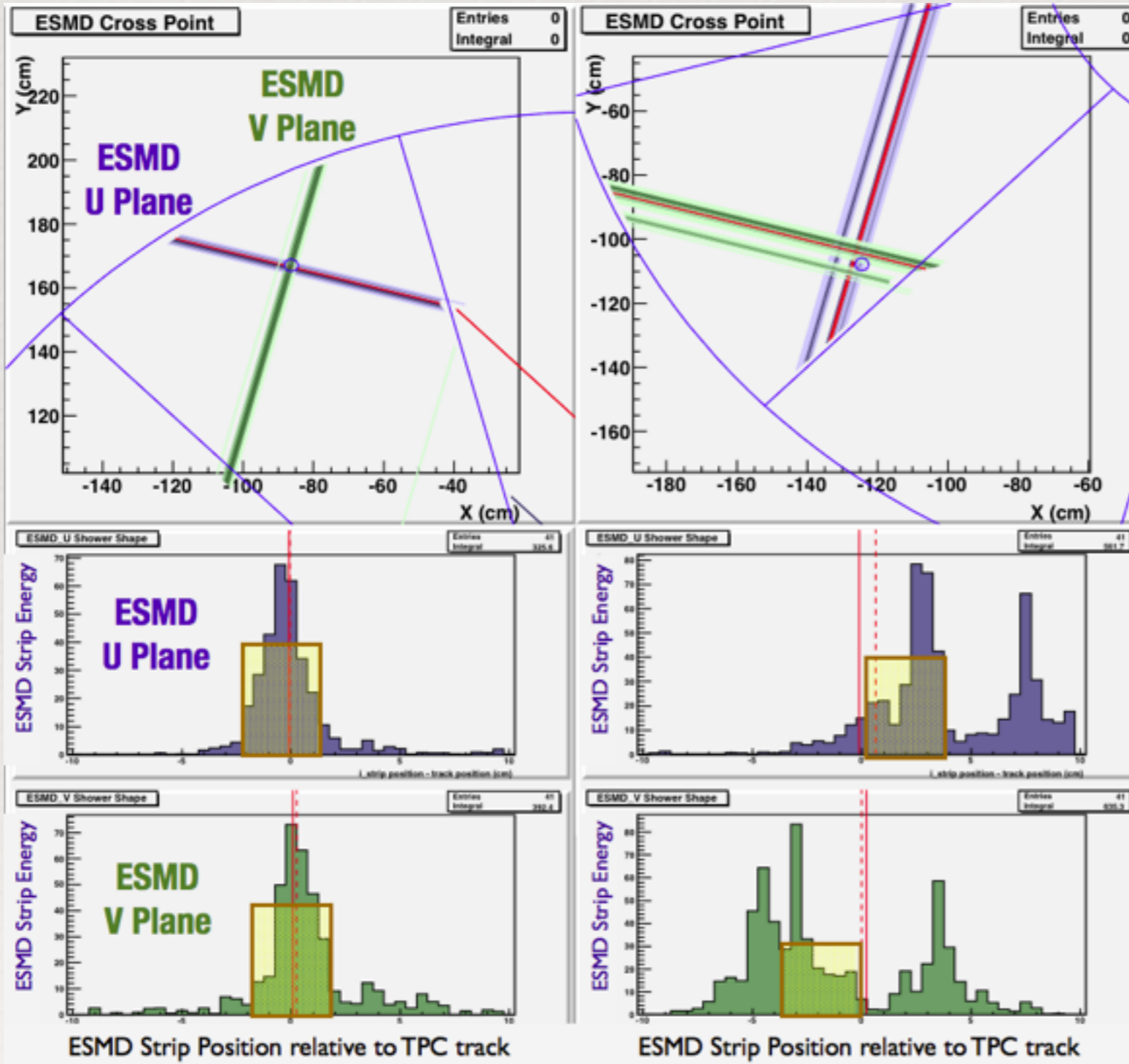


PRL 113,72301 (2014)

Endcap W Selection

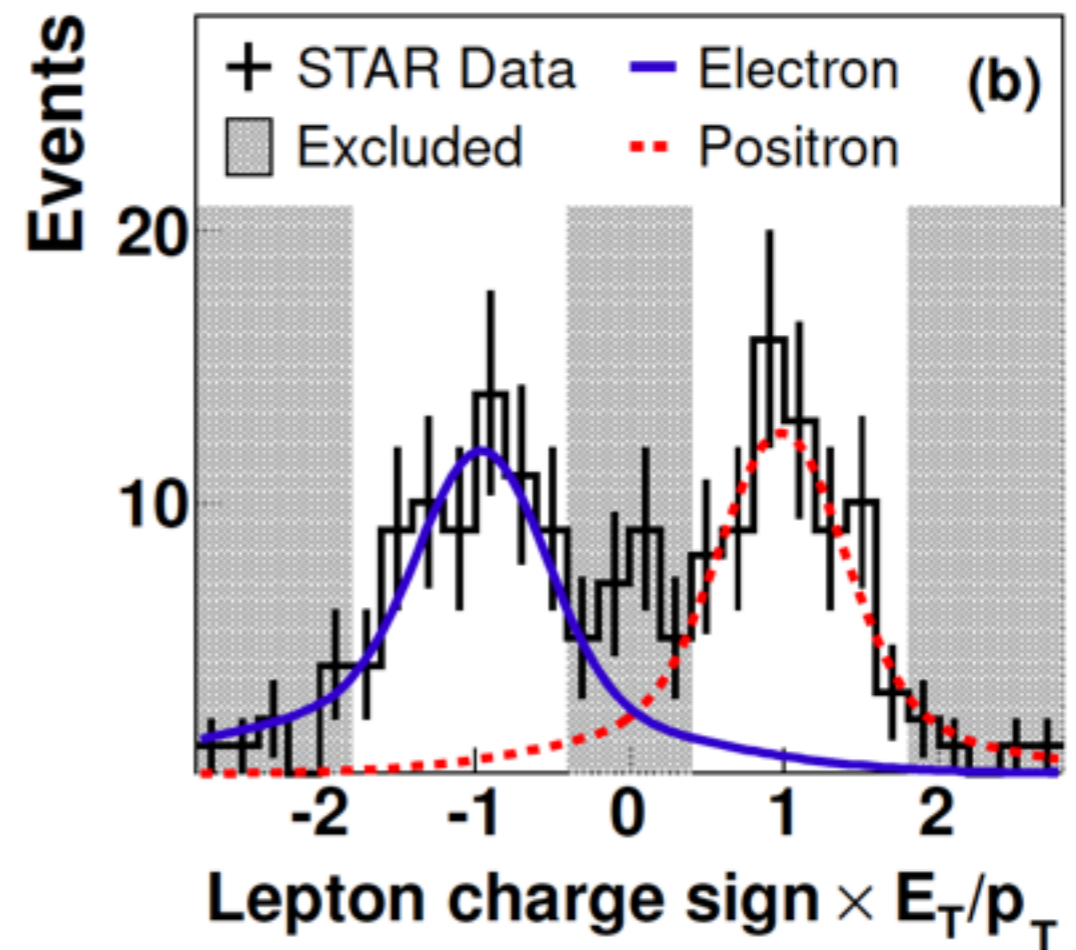
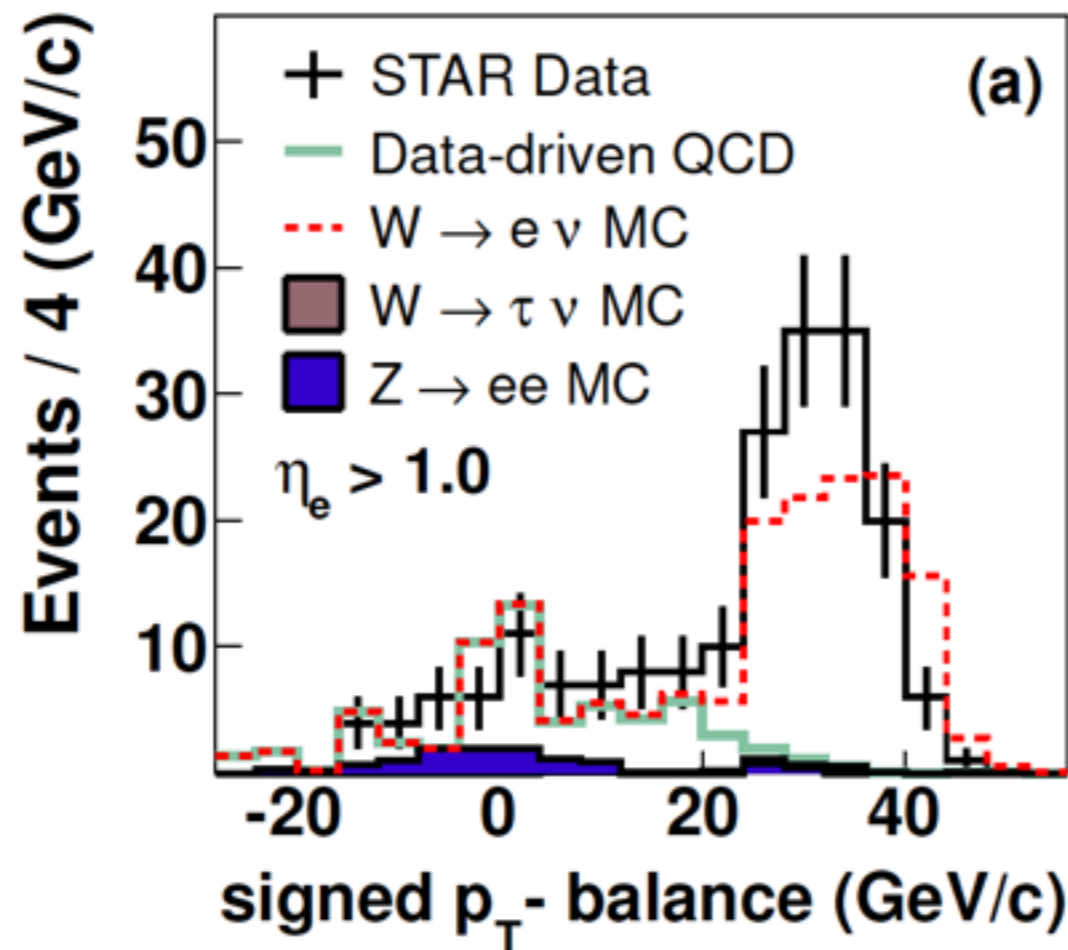


ESMD CUTS



$$R_{ESMD} = \frac{\sum_{i=-3}^{+3} E_i^U + E_i^V}{\sum_{i=-20}^{+20} E_i^U + E_i^V}$$

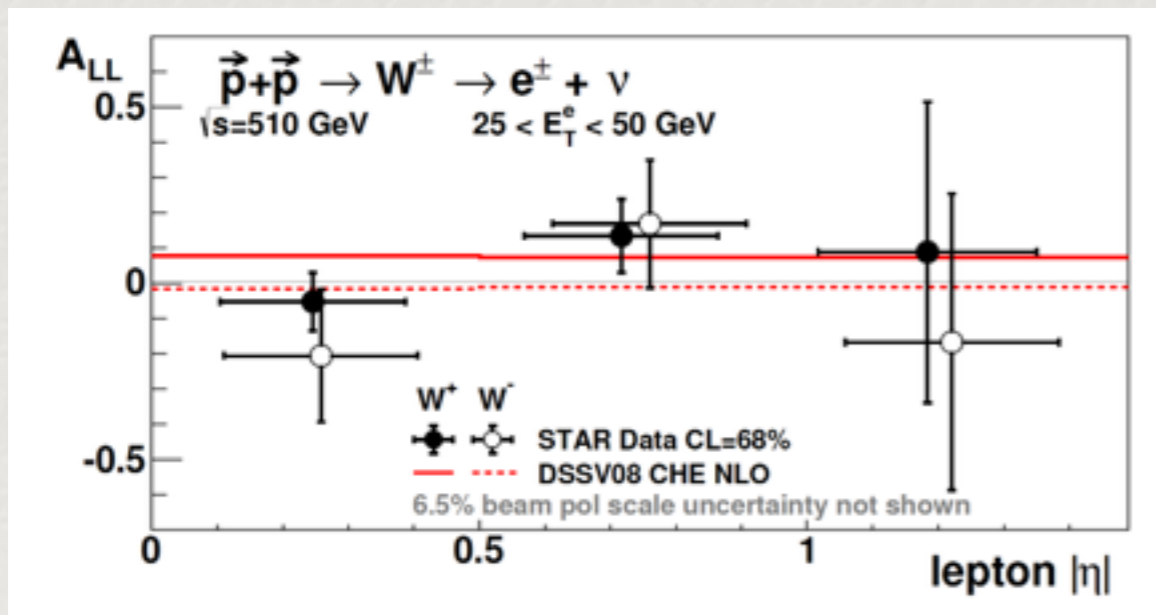
Forward Rapidity Background Estimation and charge sign separation



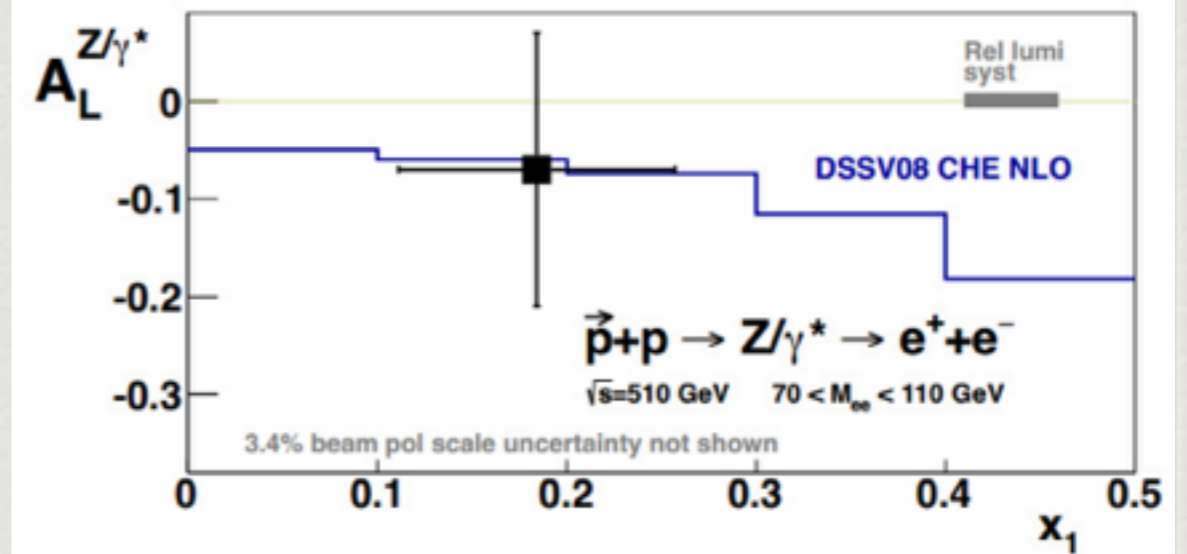
PRL 113,72301 (2014)

Run 12 ALL and Z AL results

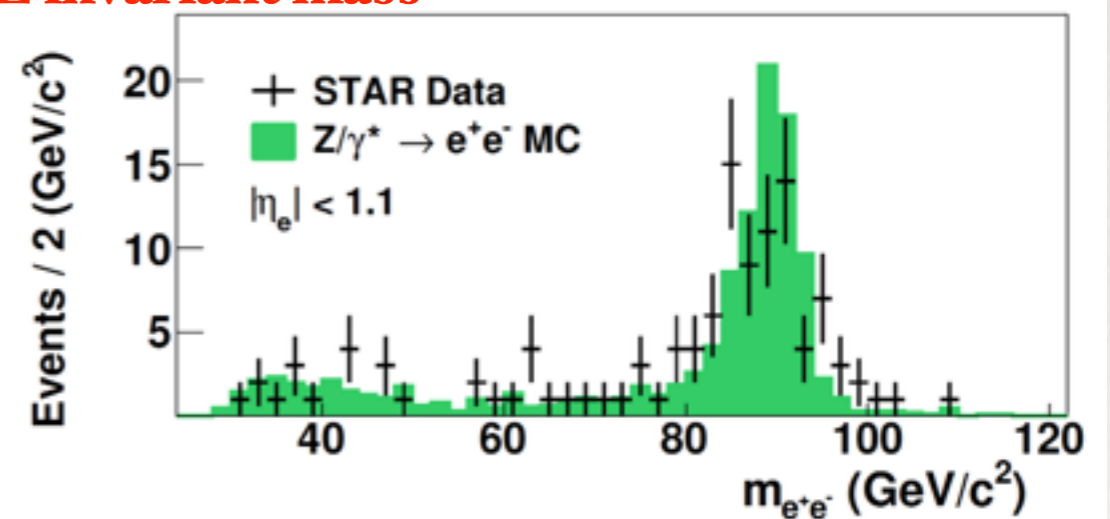
$$A_{LL} = \frac{(\sigma^{++} + \sigma^{--}) - (\sigma^{+-} + \sigma^{-+})}{(\sigma^{++} + \sigma^{--}) + (\sigma^{+-} + \sigma^{-+})}$$



PRL 113,72301 (2014)



Z invariant mass



PRL 113,72301 (2014)

W production: more details

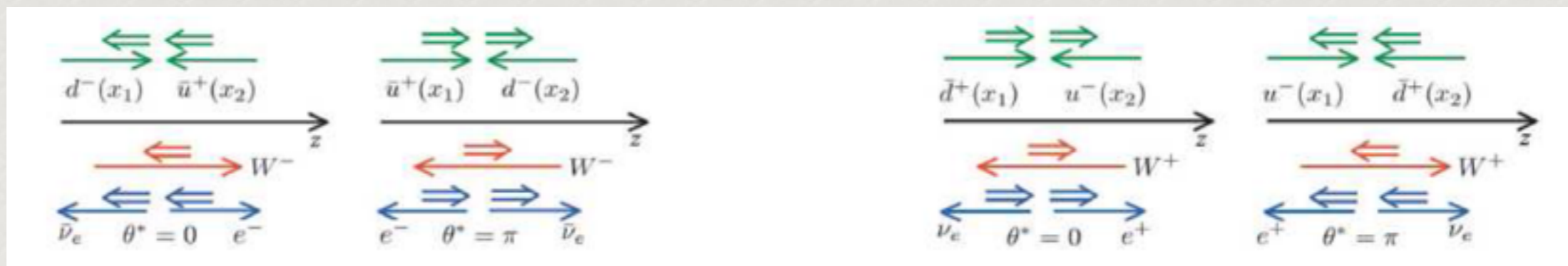
Helicity structure can see in the differential cross section of W

$$\frac{d\sigma_{W^+}}{d\cos\theta} \propto \bar{d}(x_1)u(x_2)(1 + \cos\theta)^2 + u(x_1)\bar{d}(x_2)(1 - \cos\theta)^2$$

$$\frac{d\sigma_{W^-}}{d\cos\theta} \propto \bar{u}(x_1)d(x_2)(1 - \cos\theta)^2 + d(x_1)\bar{u}(x_2)(1 + \cos\theta)^2,$$

W tends to boost direction of the valance quark traveling

Helicity structure of the interaction causes lepton to emit parallel (antiparallel) to W-(W+)



higher (lower) x parton in the collision is most likely quark (antiquark) . And quark is very likely to come from valance region

W longitudinal momentum

e decay kinametics in lab frame related to W boost direction

$$p_{L,W} = \frac{\sqrt{s}}{2} (x_1 - x_2)$$

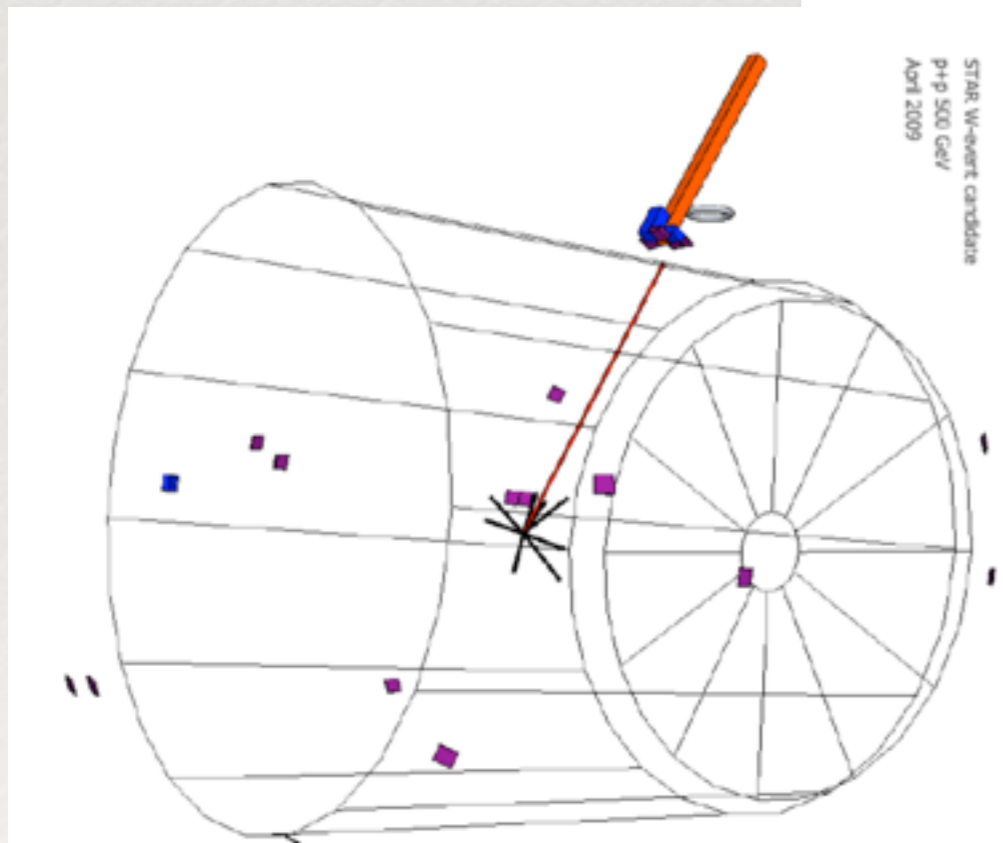
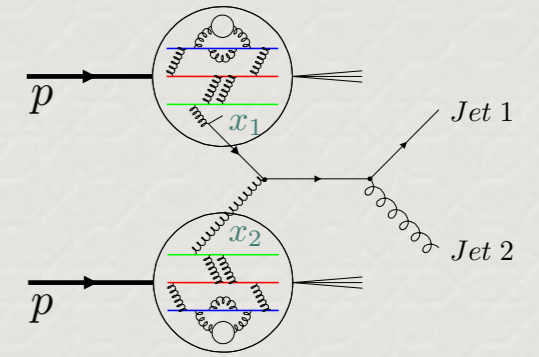
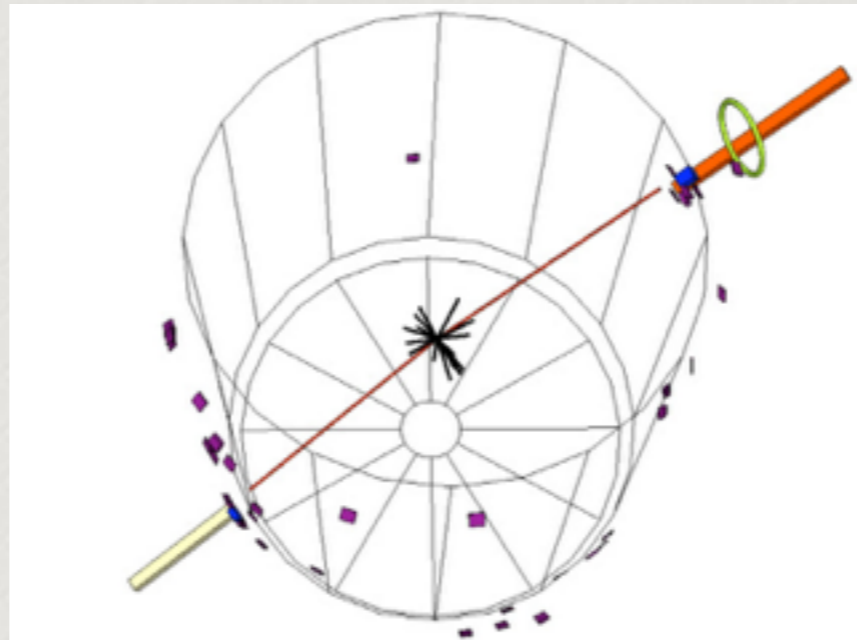
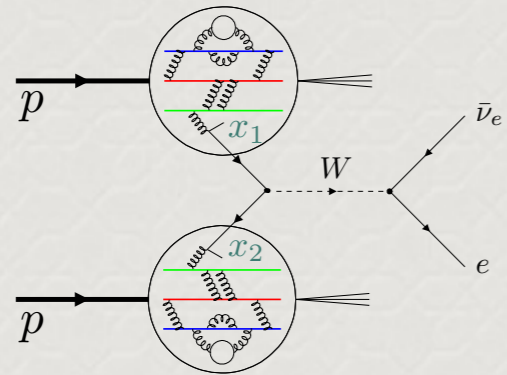
$$p_{L,e}^{lab} = \frac{1}{\gamma} p_{L,e}^* + \beta E_e^{lab},$$

$$p_{L,e}^* = \cos\theta \cdot M_W/2$$

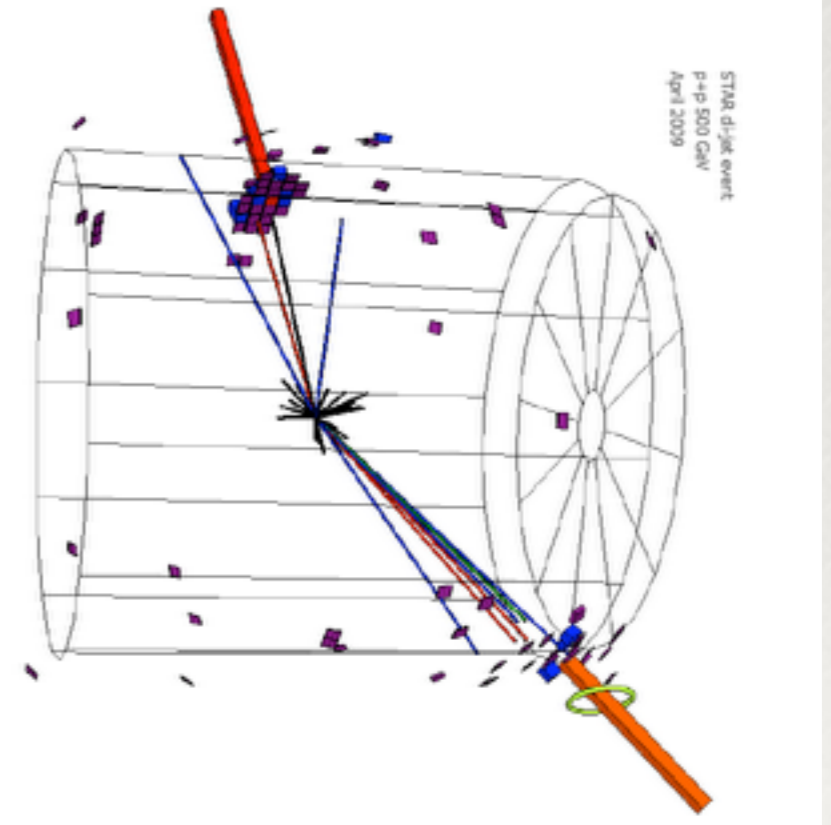
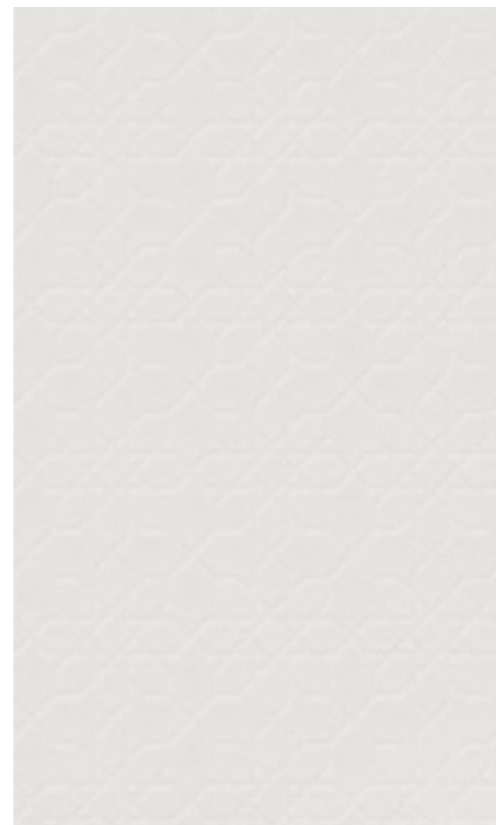
$$(p_T^e = \sin\theta \cdot M_W/2).$$

W, di-Jet and Z type events

simulated Z-ee event



simulated W->e event



simulated di-jet event

Unpolarized BG β and systematic uncertainties