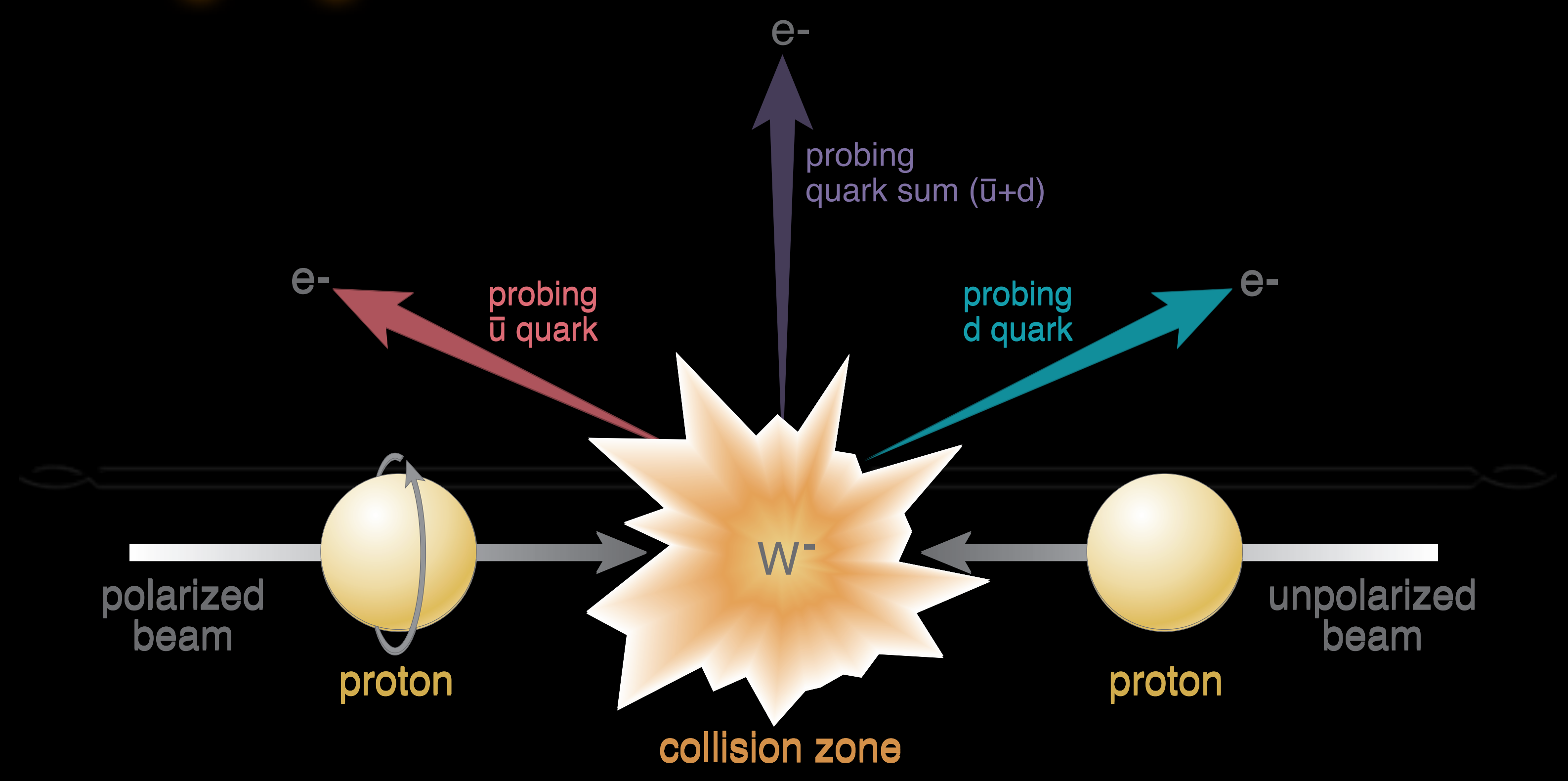
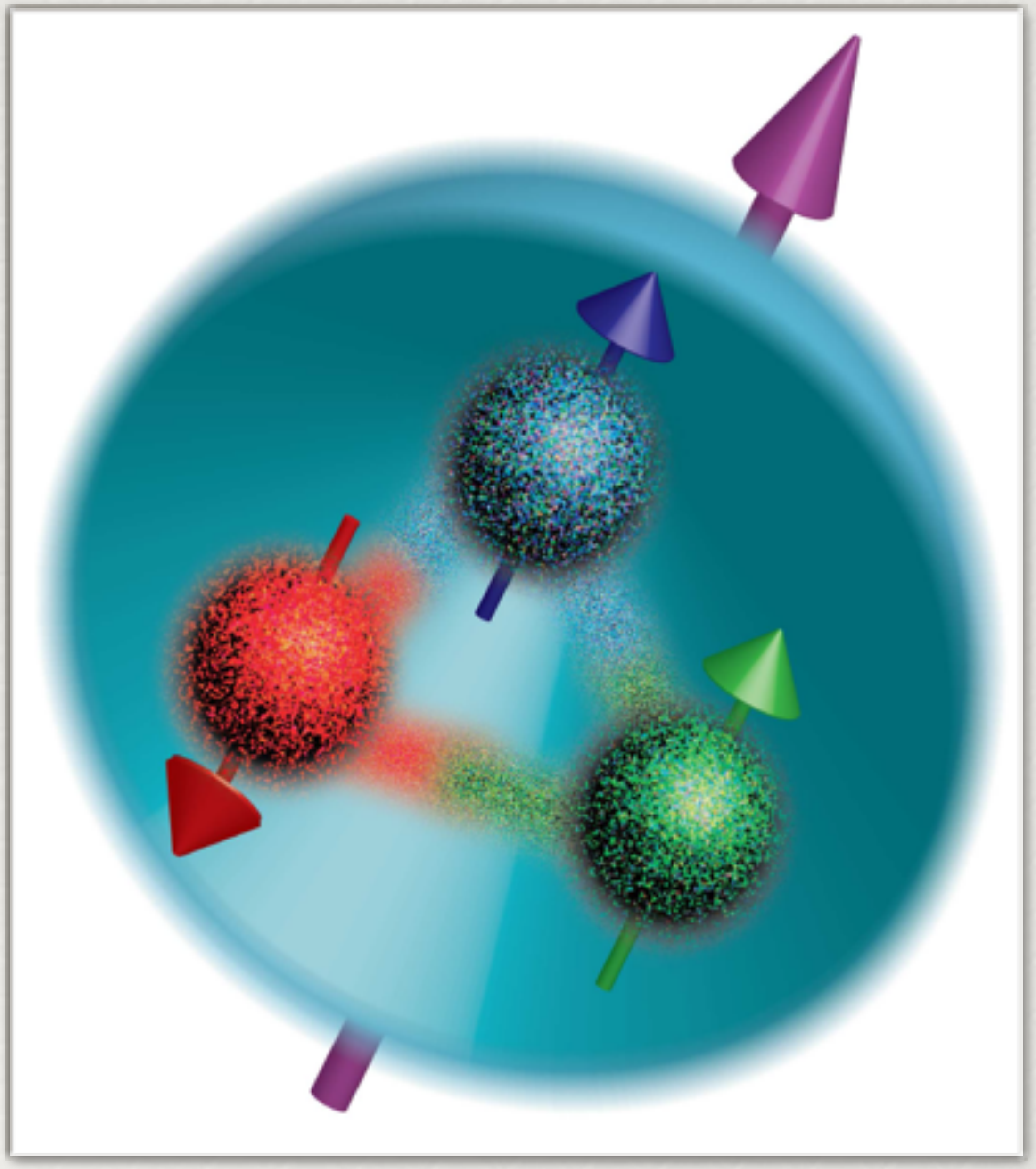
# Measurement of longitudinal single-spin asymmetries for $W^{+/-}$ boson production in polarized p+p collision at $s=\sqrt{510}$ at RHIC



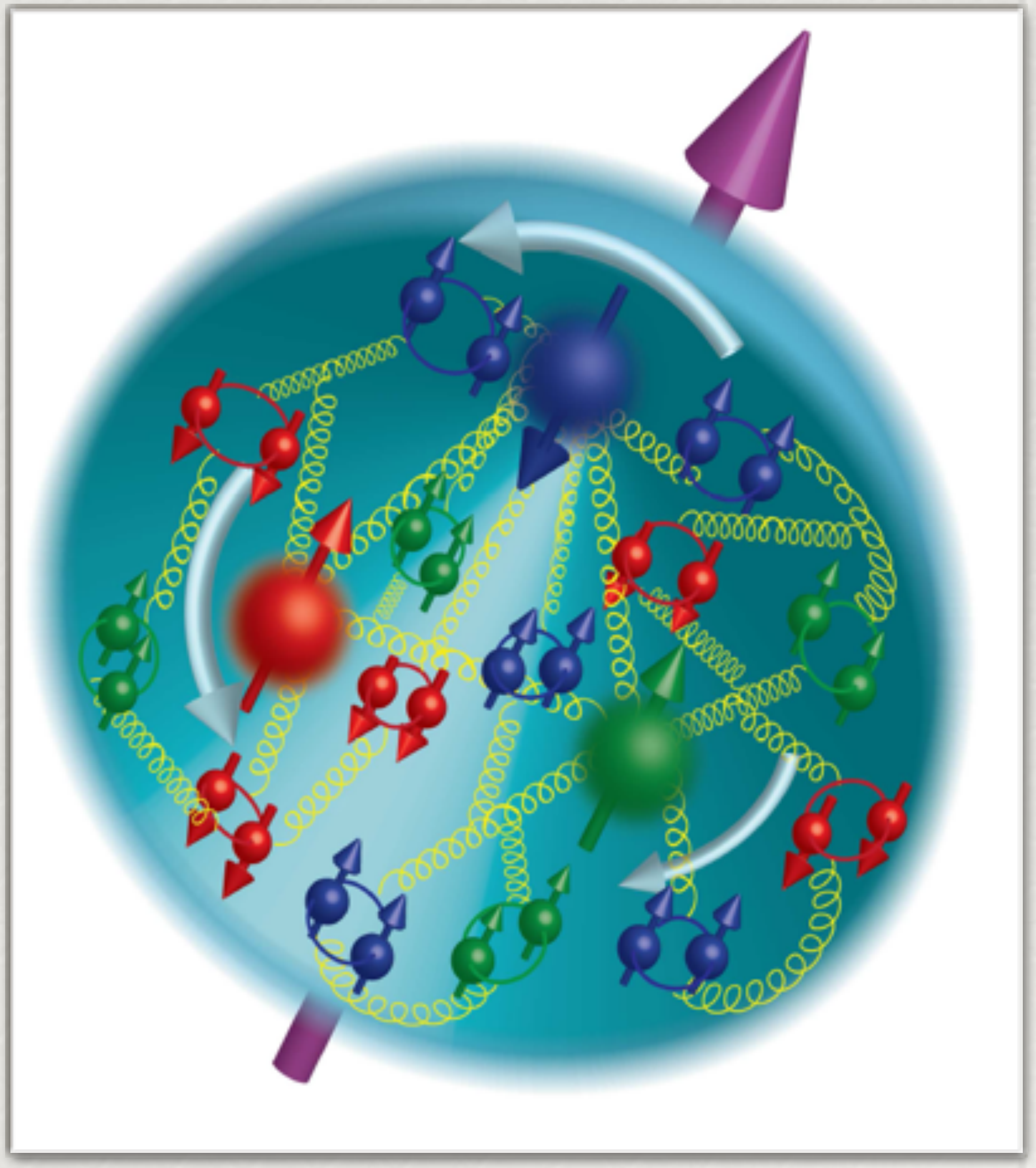


**Devika Gunarathne**
**(for the STAR collaboration)**
**Temple University**

# Proton's Spin Evolution



Valance Quarks



Sea Quarks and Gluons

# Anti Quarks Polarization

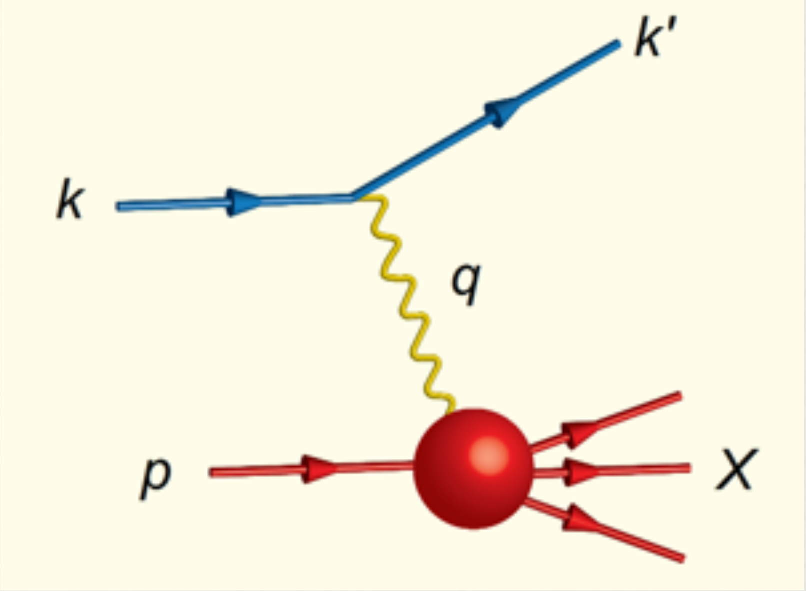
**Spin sum rule for longitudinally Polarized proton :**

$$< S_p > = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

Jeff and Monahar, 1990

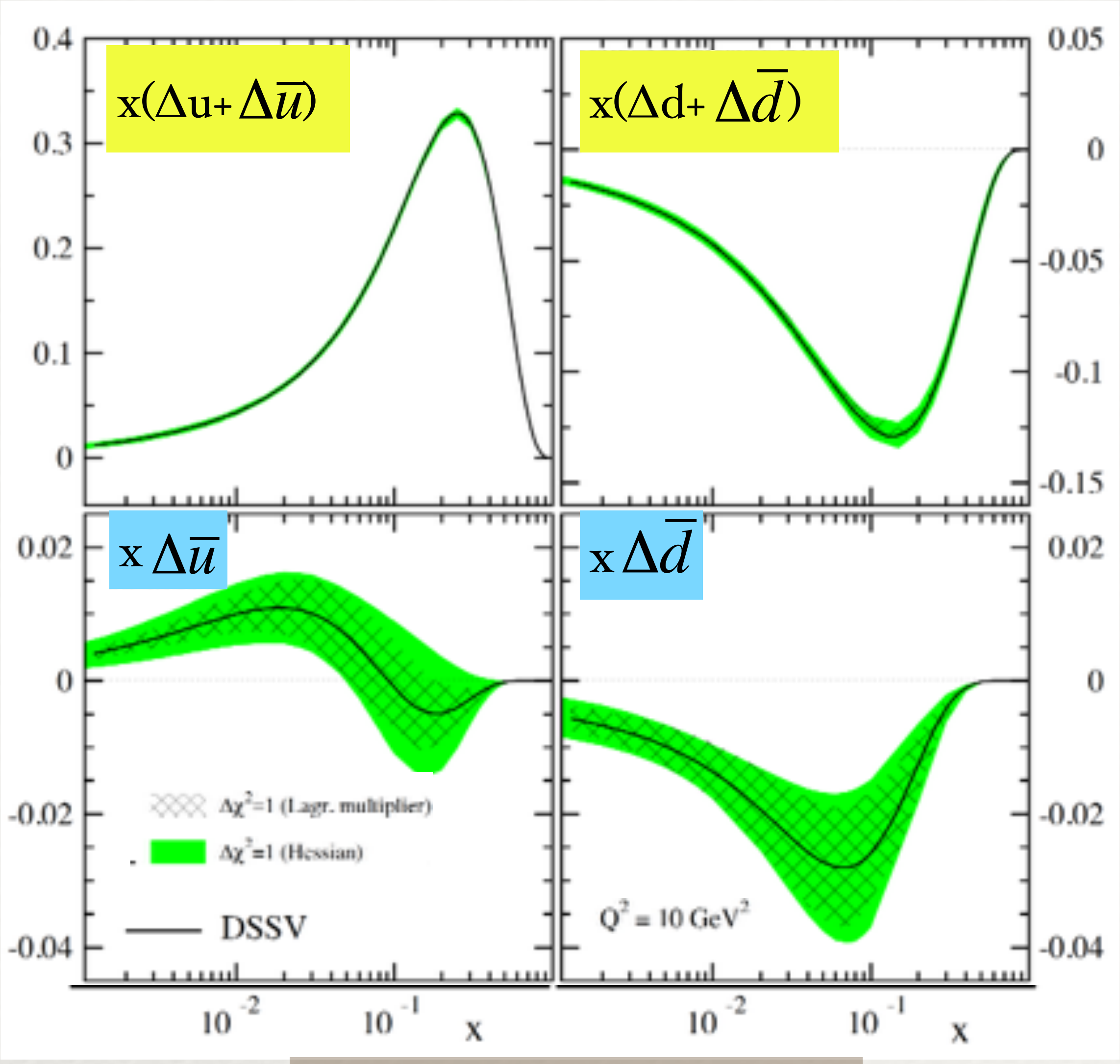
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s})dx$$

**DIS:**




**Polarized parton distribution functions (pPDF) :**

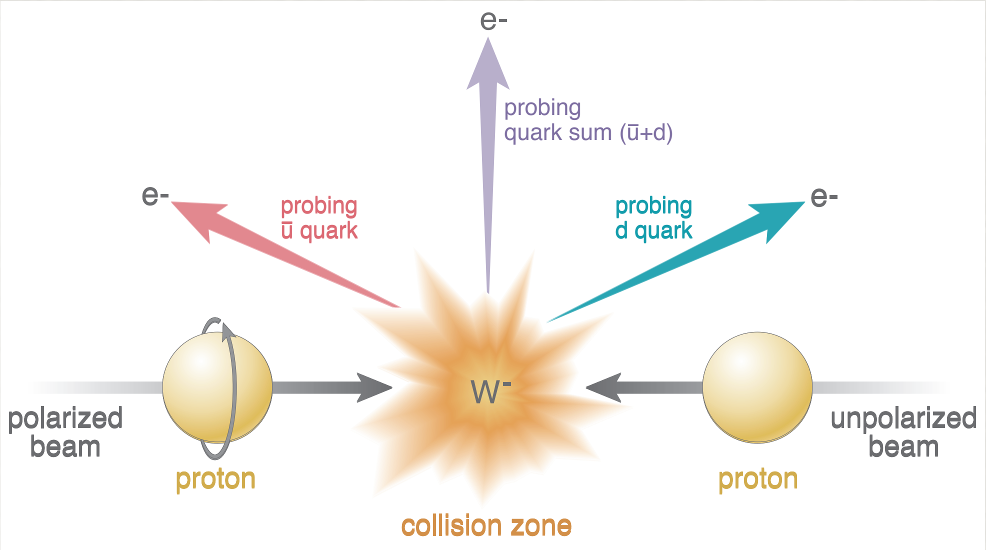
$$\Delta f(x,Q^2) \equiv f^+(x,Q^2) - f^-(x,Q^2)$$




PRD 80, 034030 (2009)

# W-Bosons Production

$u + \bar{d} \rightarrow W^{+} \rightarrow e^{+} + \nu$




$\bar{u} + d \rightarrow W^{-} \rightarrow e^{-} + \bar{\nu}$

- Maximal **Violation of Parity** leads to perfect **spin separation**
- **Direct coupling** to the **quark** and **antiquark** of interest
- **Higher** resolution scale **(Q²)** 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 ($\eta_e$)**

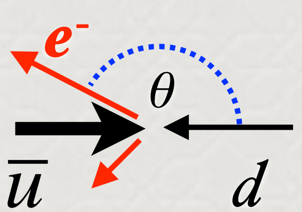
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

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

$$\eta <<< 0 \rightarrow x_1 << x_2, \theta \rightarrow \pi$$

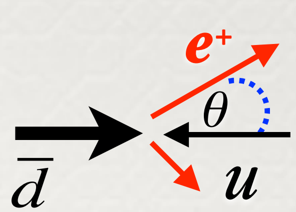
$$\eta >>> 0 \rightarrow x_1 >> x_2, \theta \rightarrow 0$$

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

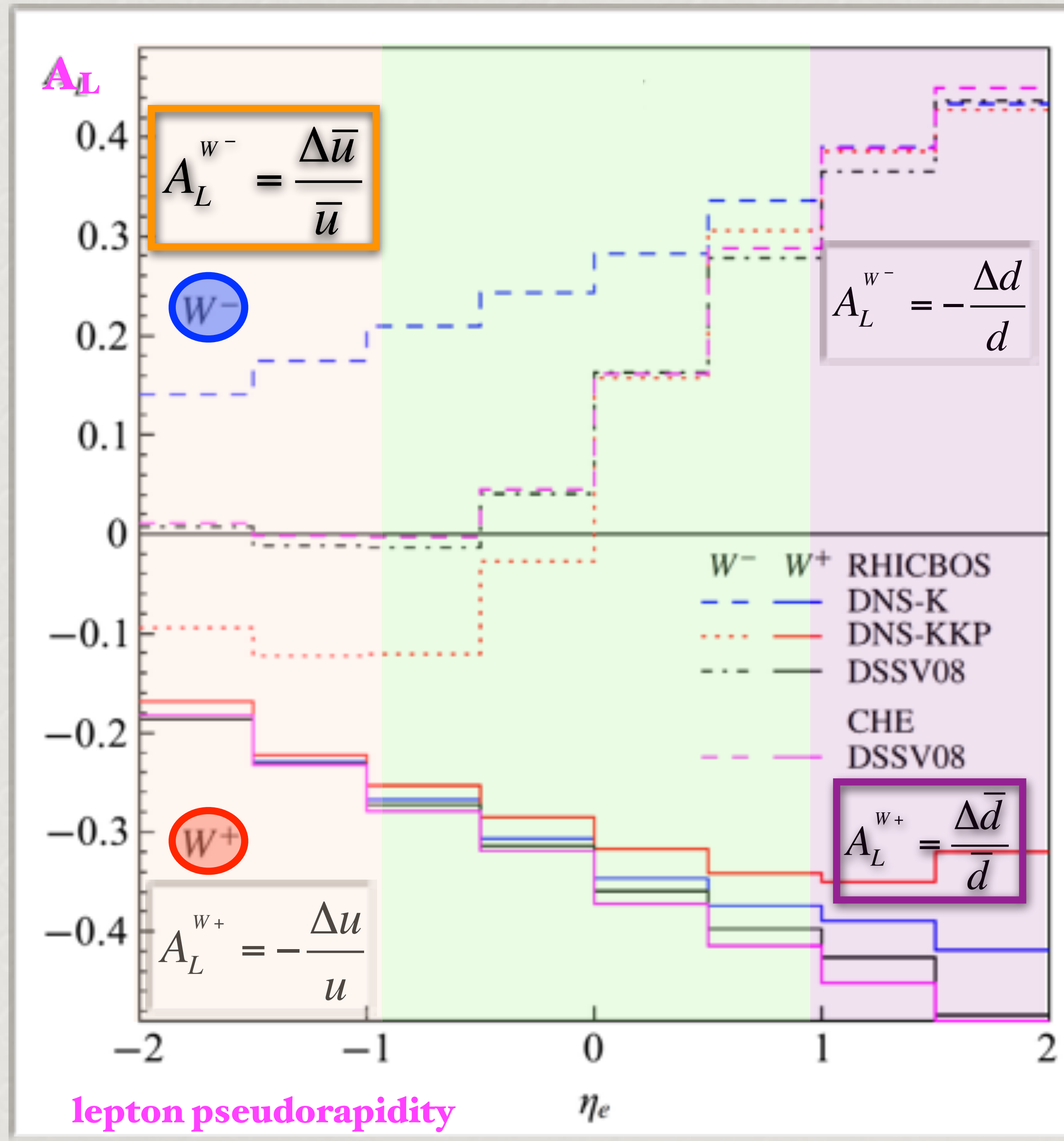



backward e⁻ → parallel to W⁻ : $\frac{\Delta\bar{u}}{\bar{u}}$

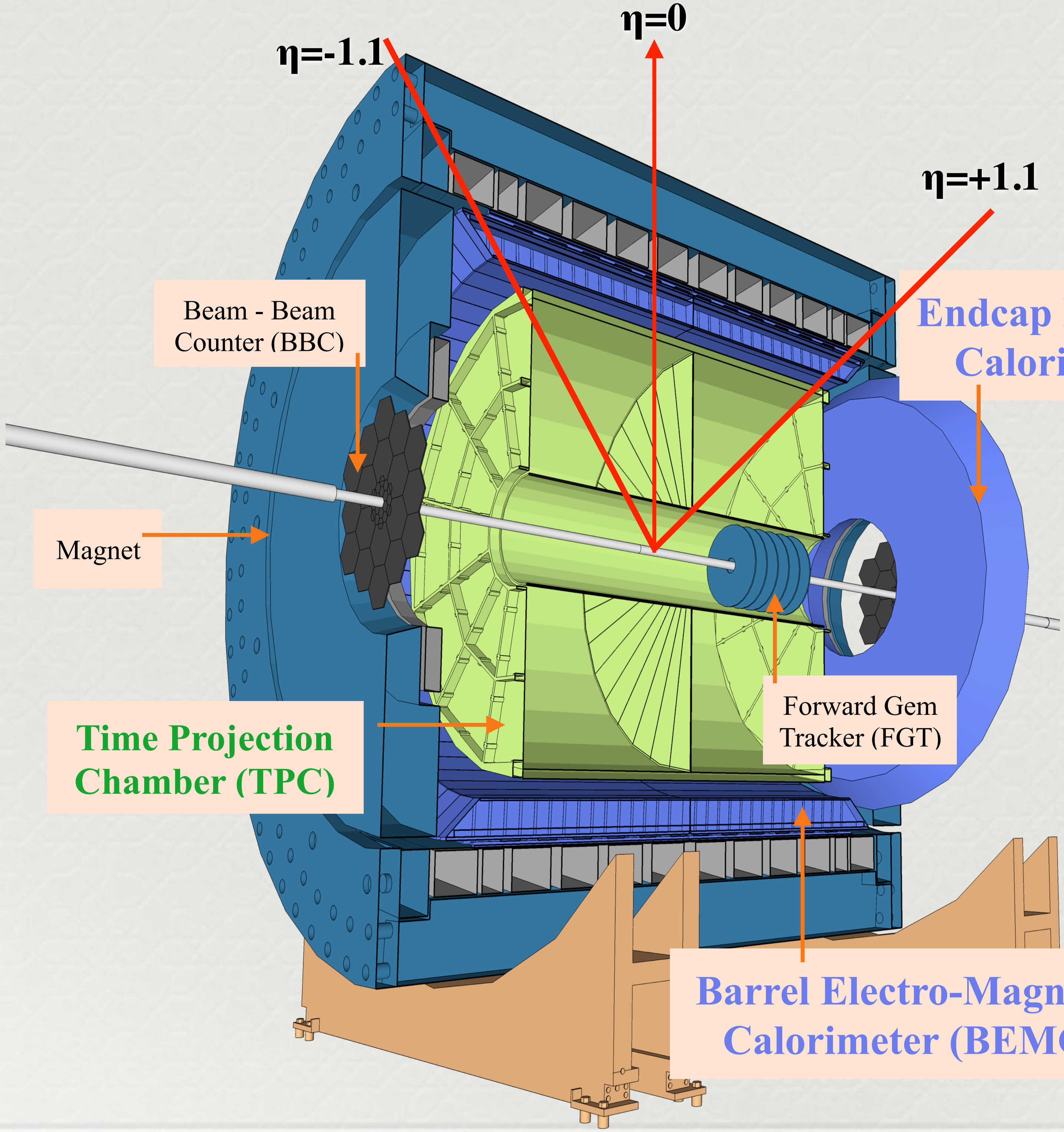
$$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$




forward e⁺ → anti parallel to W⁺ : $\frac{\Delta\bar{d}}{\bar{d}}$



# STAR Detector




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

TPC: Charge particle tracking

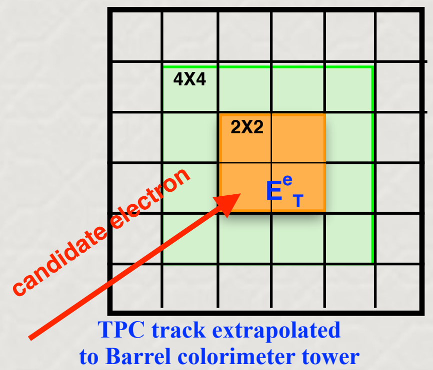
BEMC, EEMC: Energy measurement

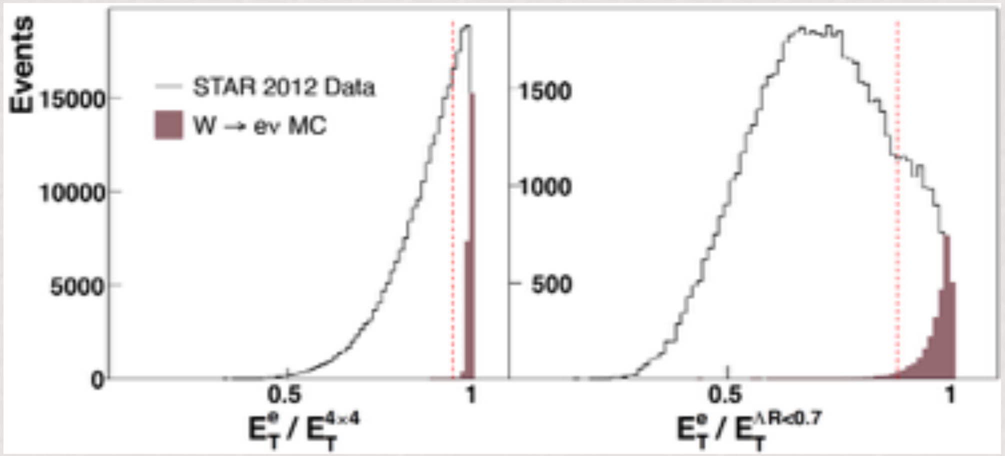
| | |
|---|---|
| **TPC** | **: $-1.3 < \eta < +1.3$** |
| **BEMC** | **: $-1.0 < \eta < +1.0$** |
| **EEMC** | **: $+1.1 < \eta < +2.0$** |

# Mid-rapidity ($|\eta_e| < 1$) W Selection

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

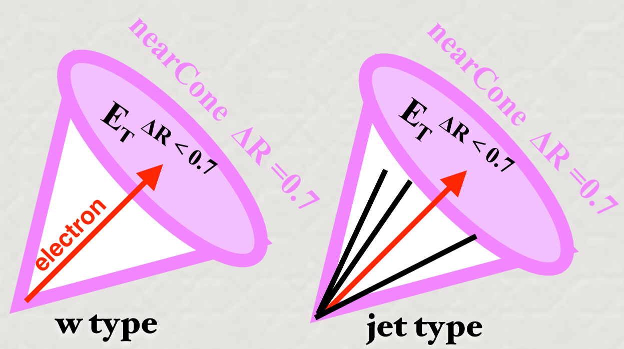
  $E^e_T \,/\, E_T^{4X4} \quad > 0.95$

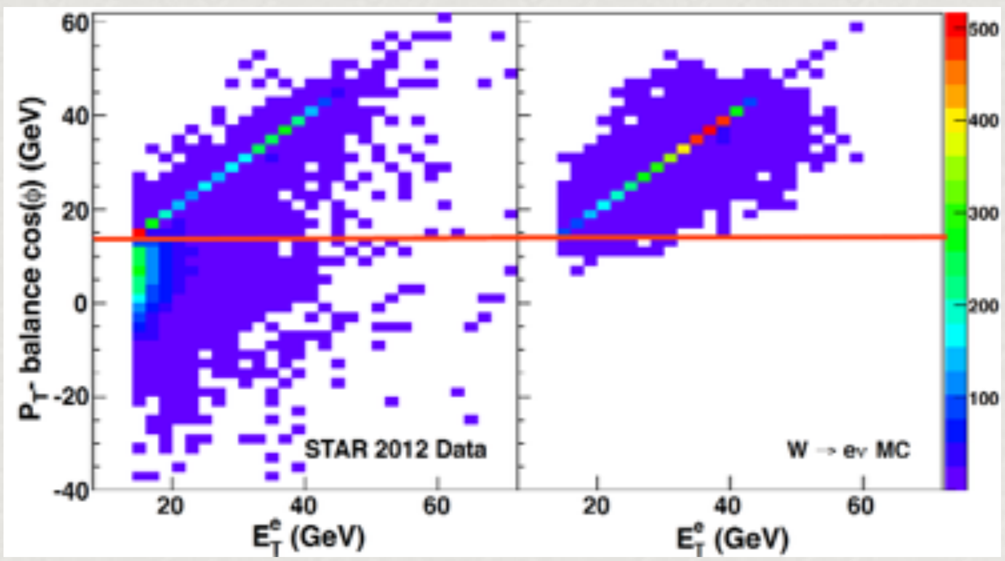



- **Isolate from QCD di-jet type event**

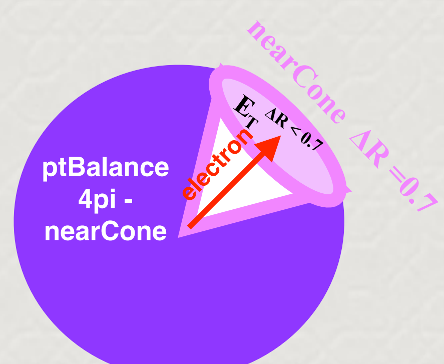
  $E^e_T \,/\, E_T^{\Delta R < 0.7} \quad > 0.88$



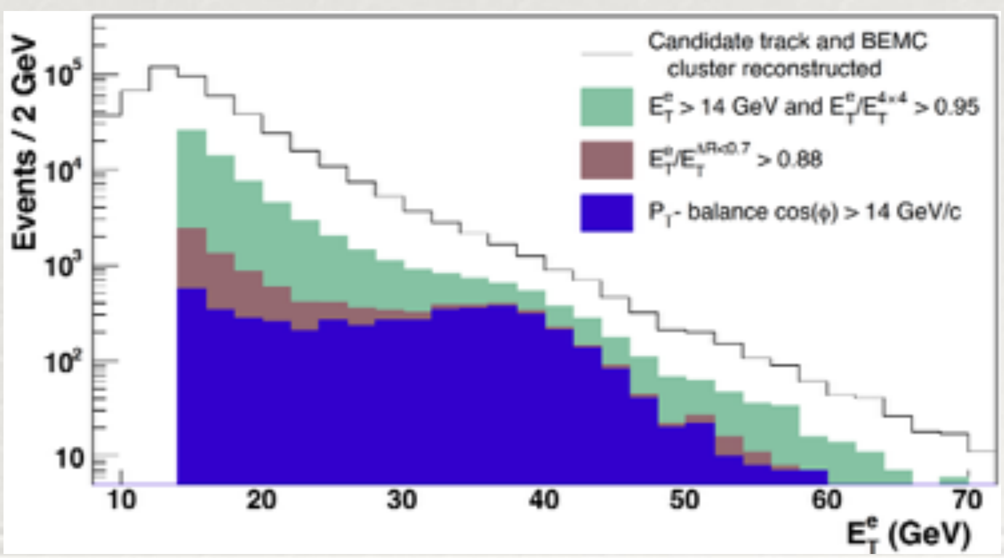




- **Use Larger imbalance of transverse momentum**

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

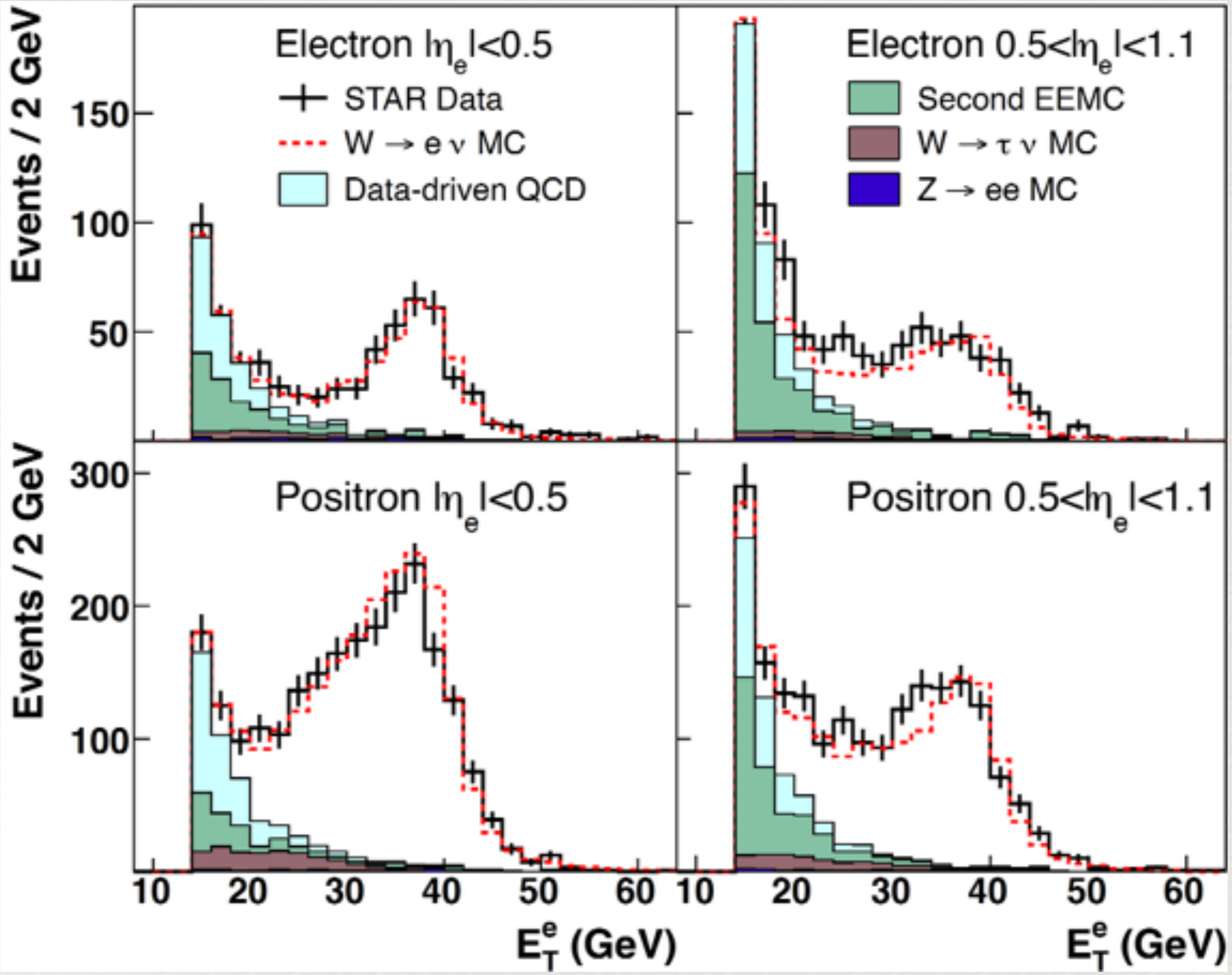



Transverse plane views




- **e+ and e- Charge sign Separation**

# Mid-rapidity Background Estimation




PRL 113,72301 (2014)

✤Electroweak BG

✳ $W \to \tau\nu$ : Embedding MC

✳ $Z \to e^{+}+e^{-}$ : Embedding MC

✤ Data driven QCD

✤Second Endcap

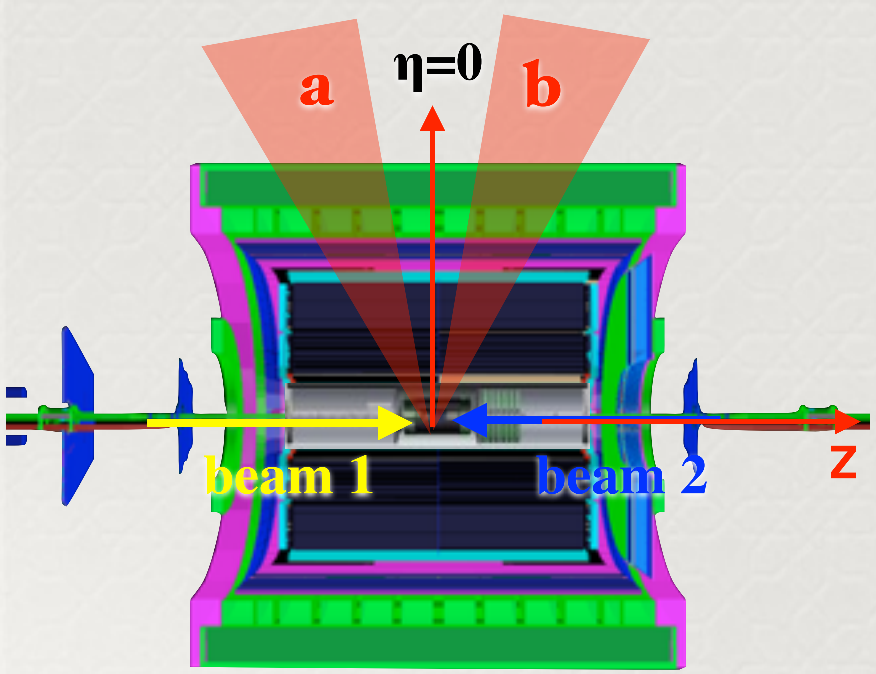
Forward rapidity ($1<\eta_e<1.4$ ) W selection use similar technique as mid rapidity and Background Estimation improve using additional Endcap Shower Maximum Detector (ESMD)

# 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

$$L = \Pi_i^4 p(M_i^a \mid \mu_i^a) p(M_i^b \mid \mu_i^b) g(\beta^a) g(\beta^b)$$




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

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

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

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

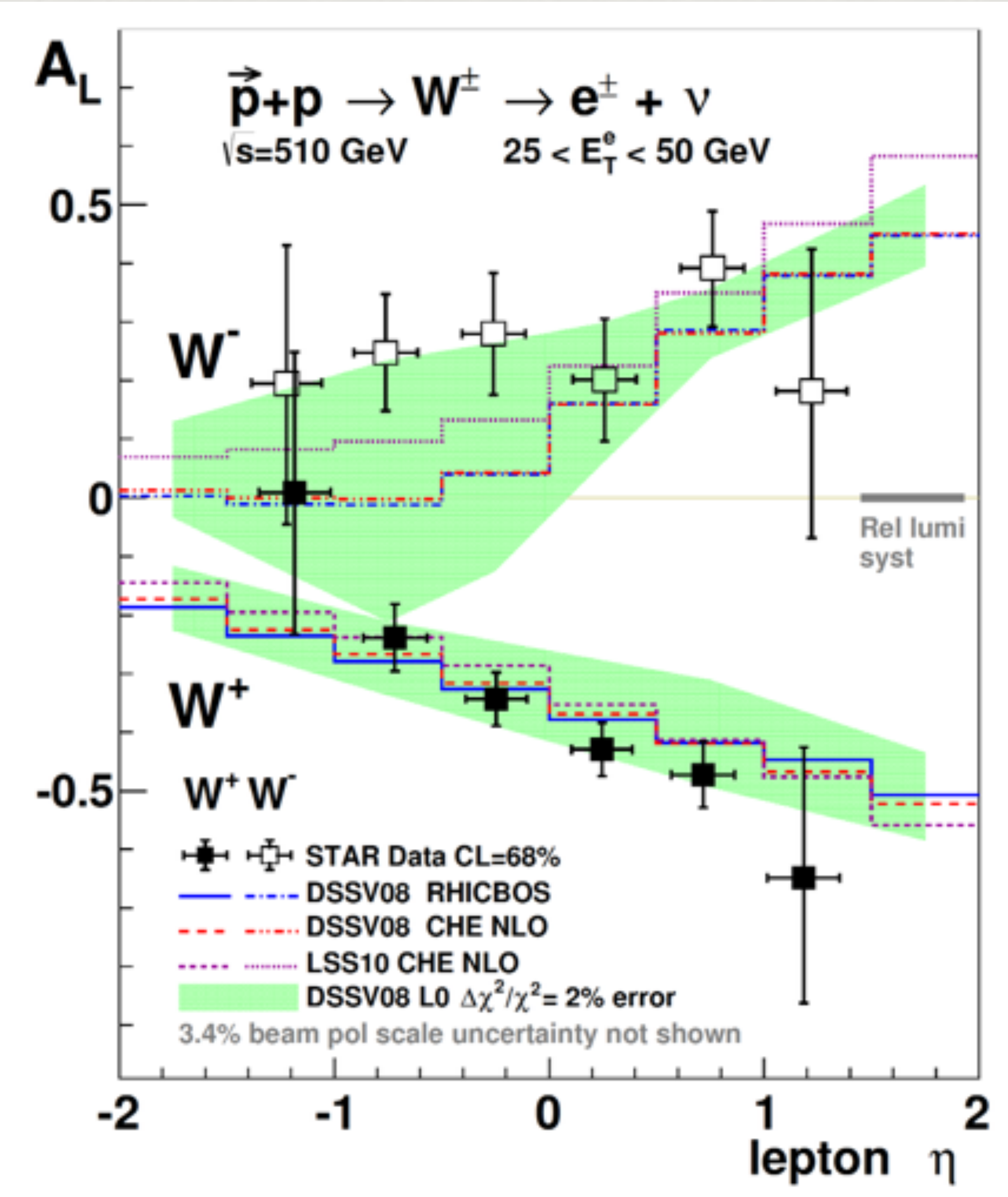
$$\mu_{--}^a = I_{--} N(1 - P_1 \beta A_L^{+\eta_e} - P_2 \beta A_L^{-\eta_e} + P_1 P_2 \beta A_{LL}$$

$P_1, P_2$ - 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(β)** - Gaussian probability for estimated dilution background **β**

# STAR 2012+2011 W $A_L$ ($\eta_e$)




PRL 113,72301 (2014)

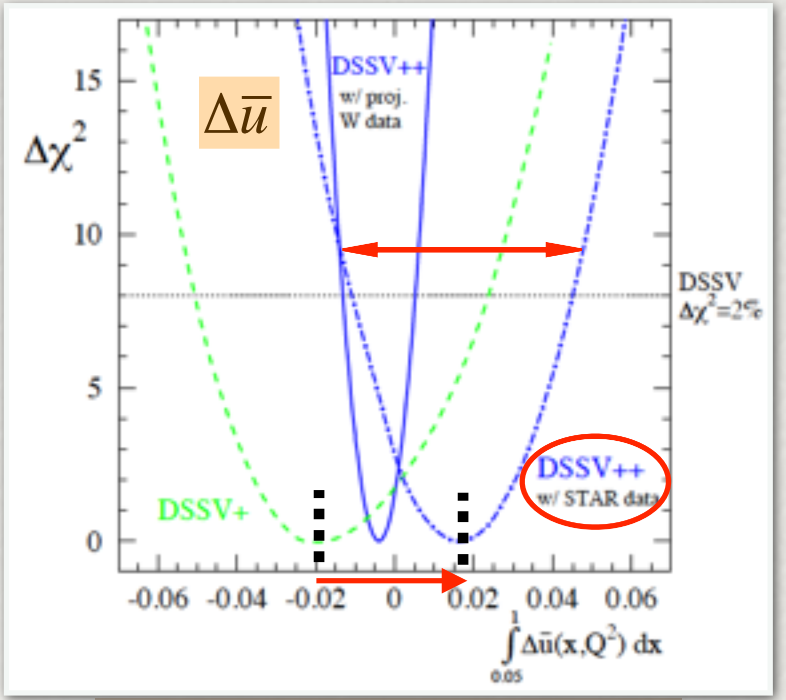
- $A_L(W^-)$ is larger than the DSSV Predictions.
  - The enhancement at $\eta e < 0$, in particular is sensitive to the $\Delta\bar{u}$ polarized antiquark distribution.
- $A_L$ $(W^+)$ is consistent with theoretical predictions using the DSSV polarized PDFs.
- The Systematic uncertainties for AL are well under control for $|\eta e| < 1.4$ .

# Impact on DSSV++ Global Analysis

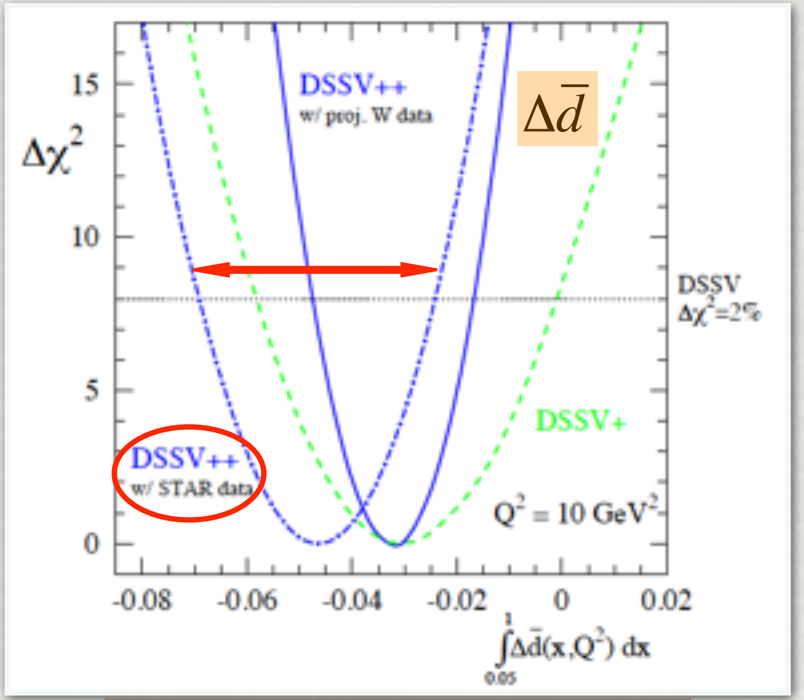
- Preliminary Global analysis (DSSV++) from DSSV group and recent NNPDF includes preliminary STAR 2012 W $A_L$ data.

- Shift in central value for $\Delta\bar{u}$ (negative -> positive) and $\Delta\bar{d}$ due to $A_L$ W from STAR .

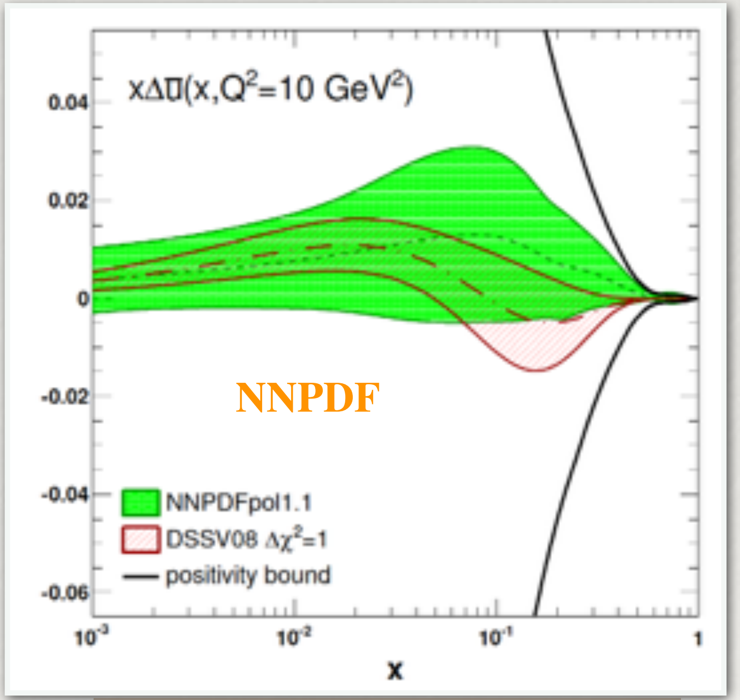
- STAR run 12 W results provide significant constrain on anti u and anti d quark polarization.




arXiv: 1304.0079




arXiv: 1304.0079

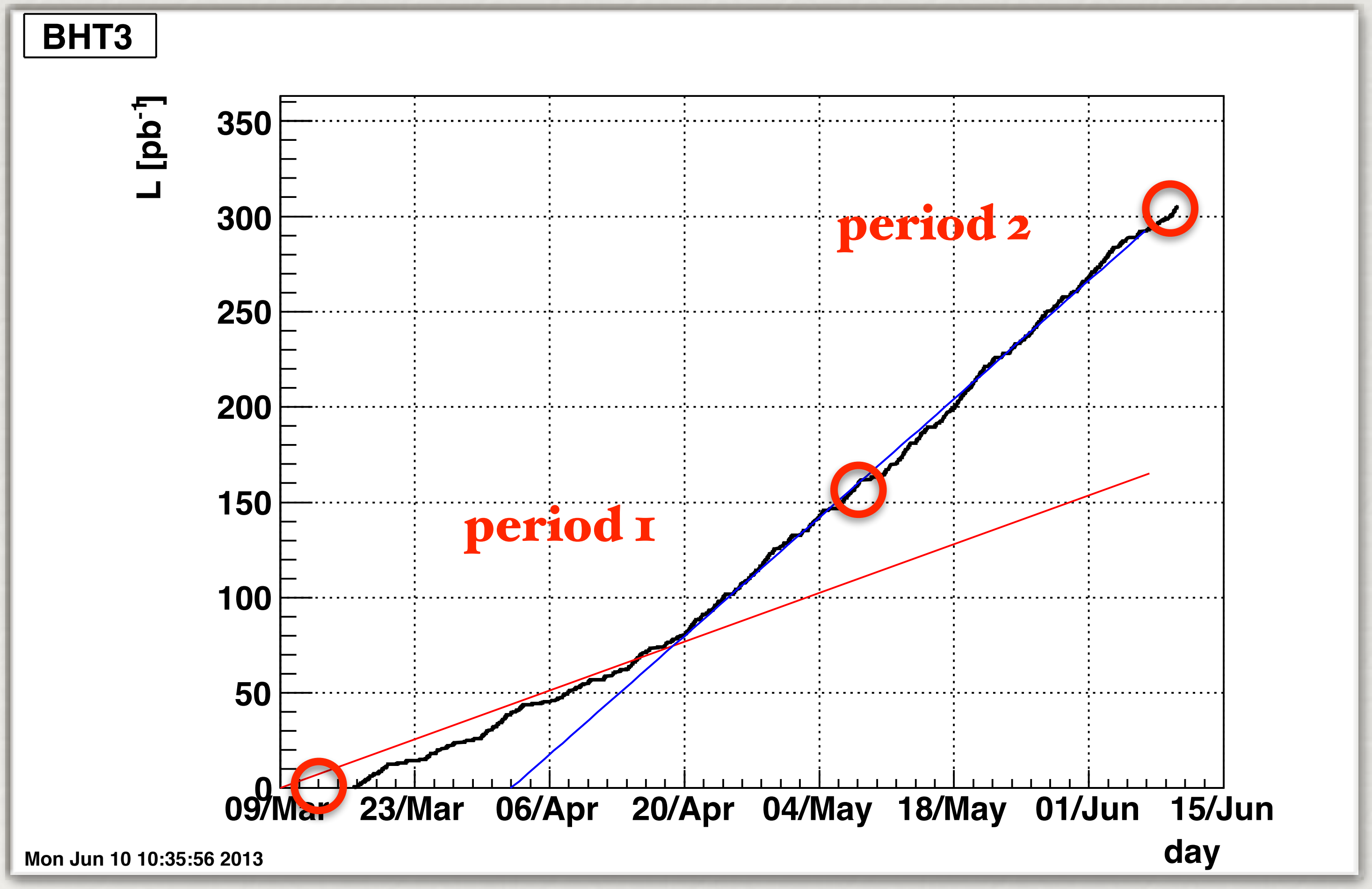



arXiv: 1403.0440

# Run 2013 Analysis Staus

## Run 13 Data Sample

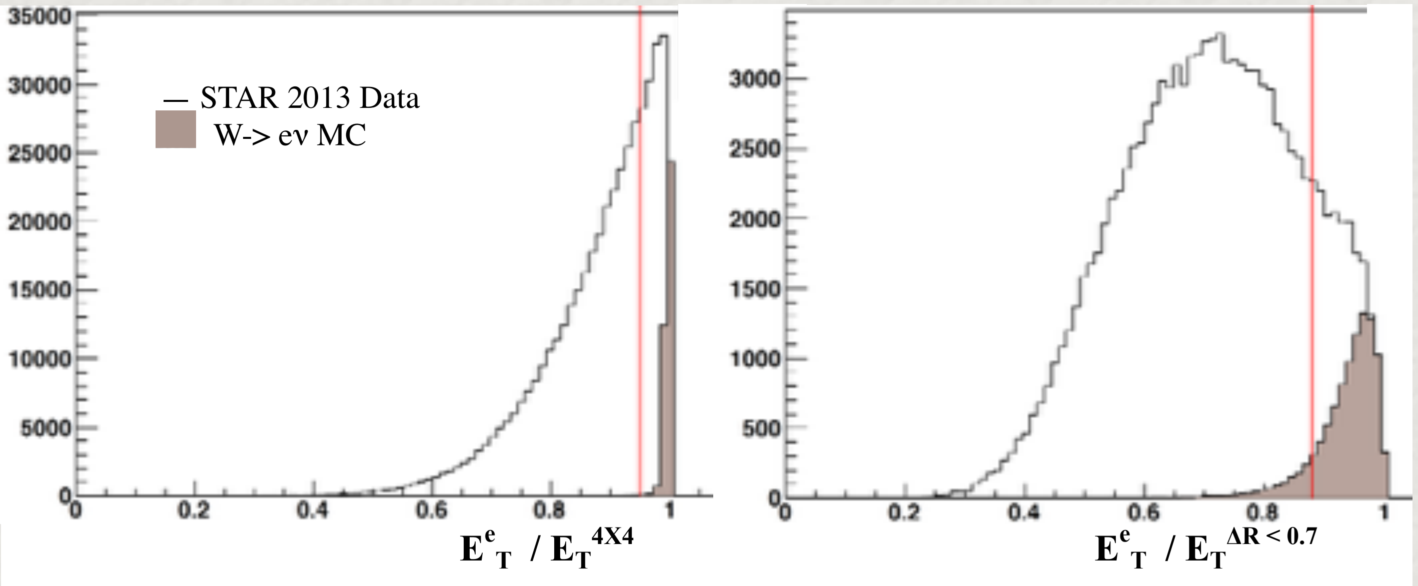
**Barrel EMC triggered Integrated Luminosity**



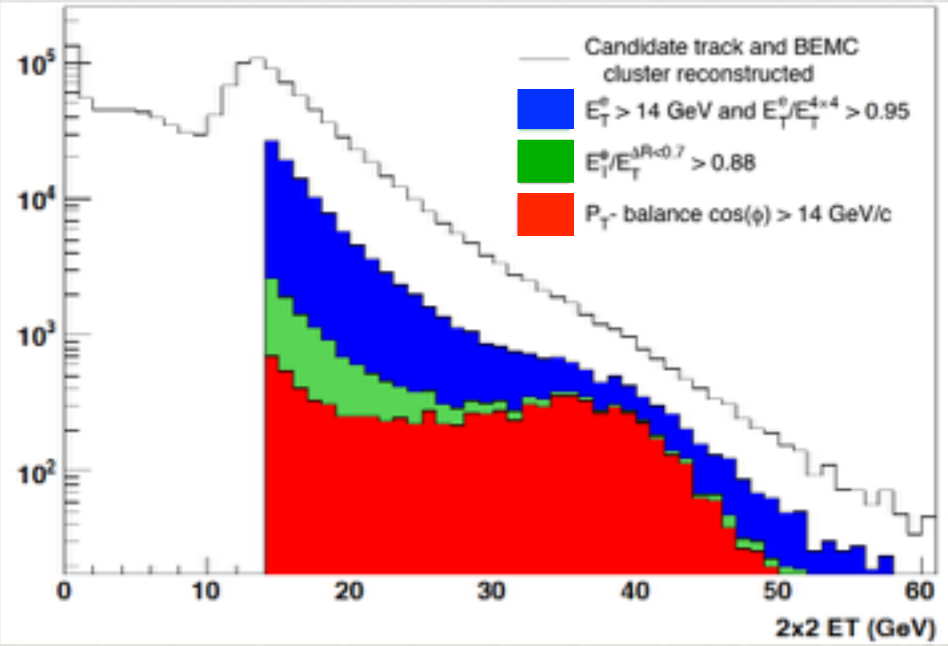

| | L (pb$^{-1}$) | P | $P^2L$ (pb$^{-1}$) |
|---|---|---|---|
| Run 9 | 12 | 0.38 | 1.7 |
| Run 11 | 9.4 | 0.49 | 2.3 |
| Run 12 | 72 | 0.56 | 24 |
| Run 13 | ~300 | 0.54 | ~ |

# Run13 Mid-rapidity W Selection

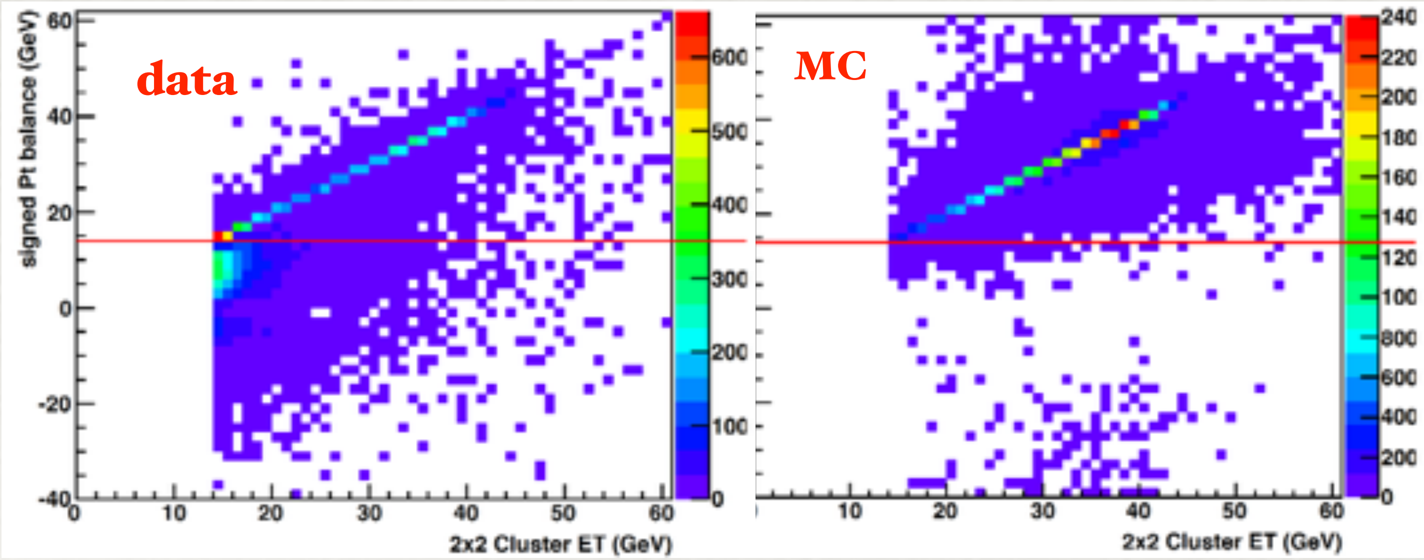
## $e^+$ ,$e^-$ Isolation



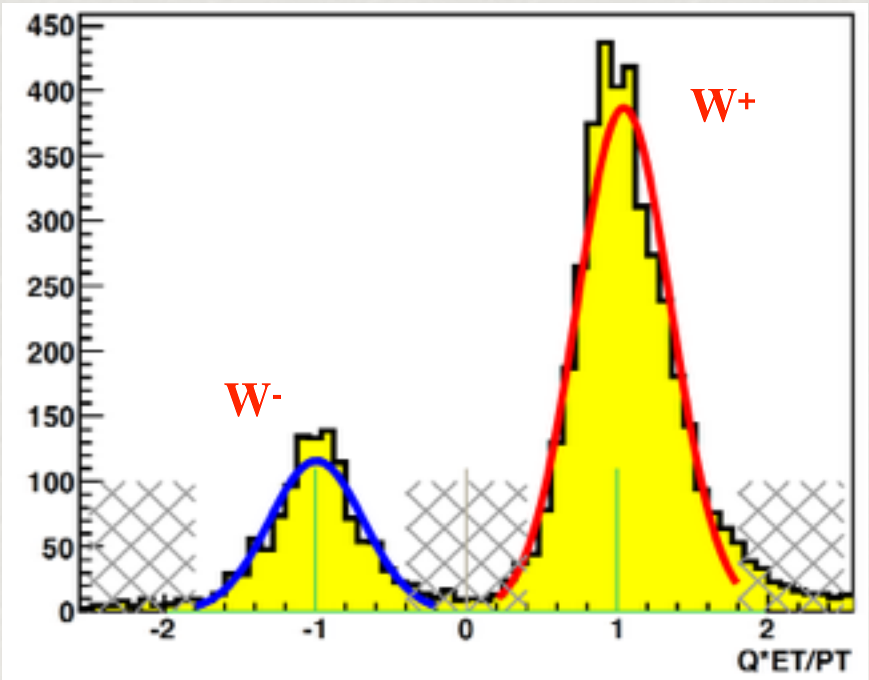

## $E_T$ distribution compare to Selection Cuts




## Sign-$P_T$ balance

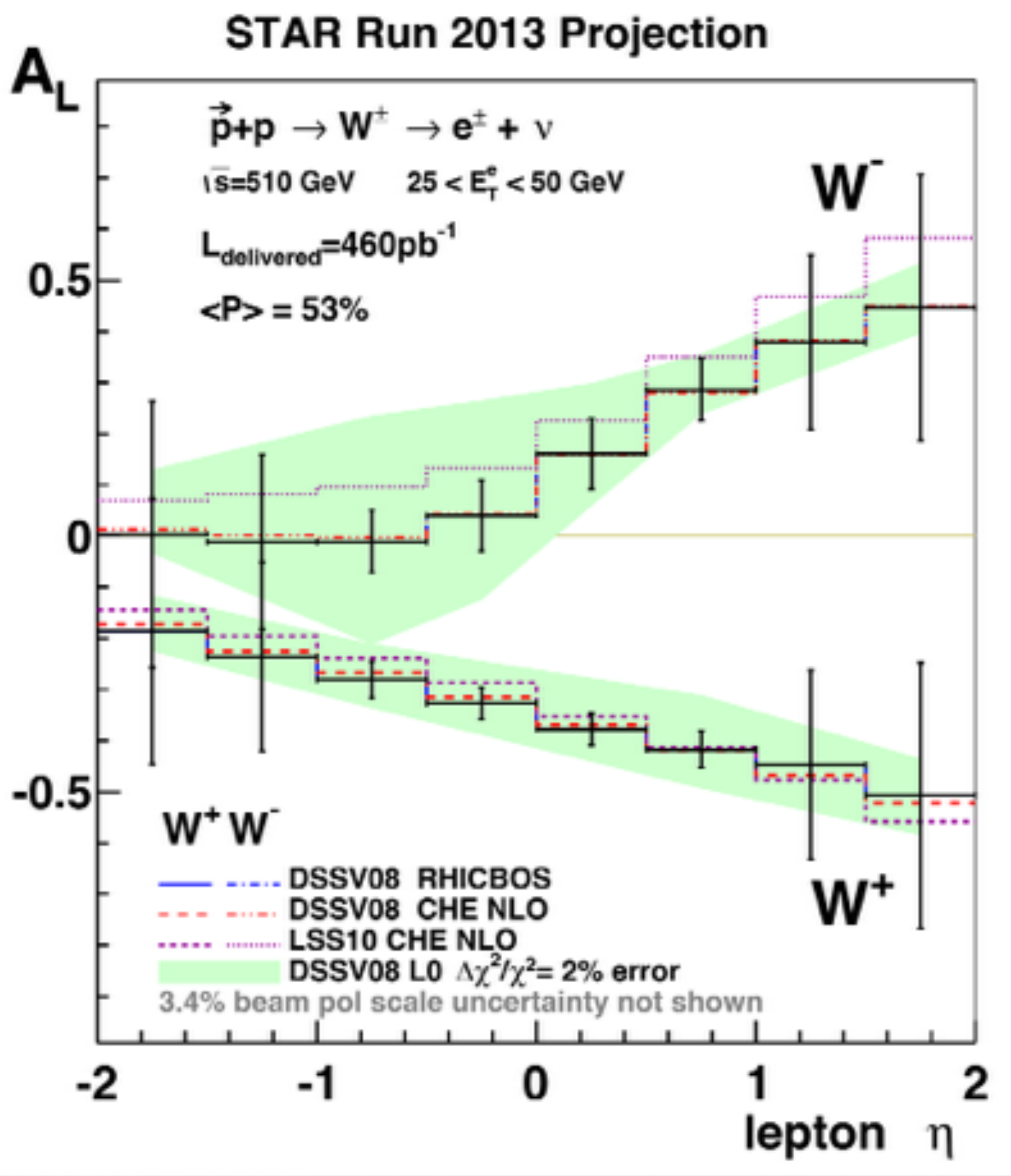



## Charge-sign Separation



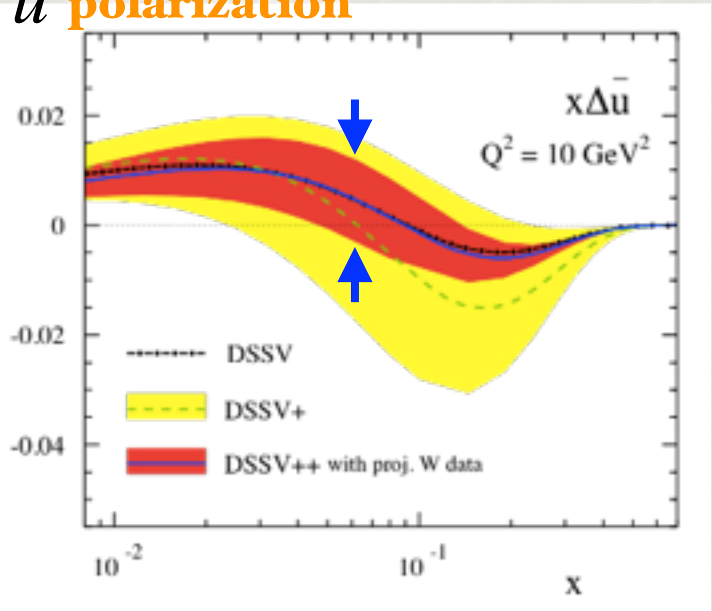
# STAR Run 13 W Projections

- **W $A_L$**

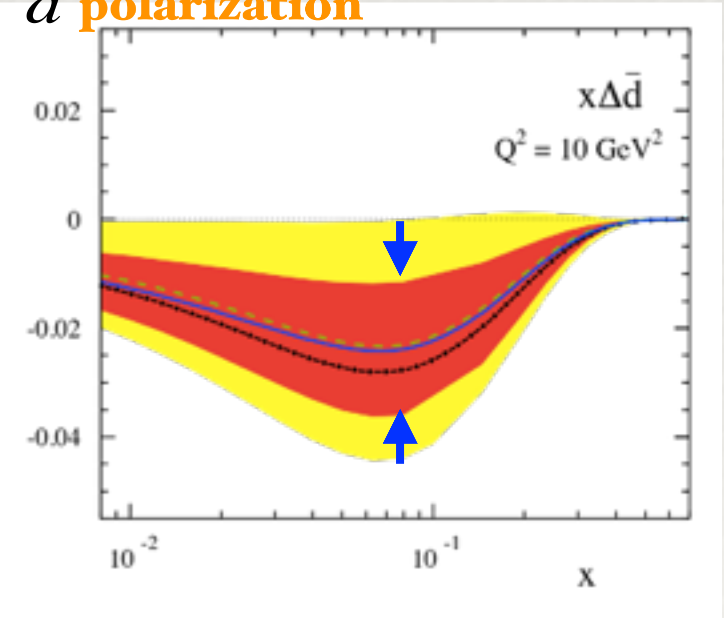



- **Impact on antiquark polarization**

$\bar{u}$ polarization




$\bar{d}$ polarization



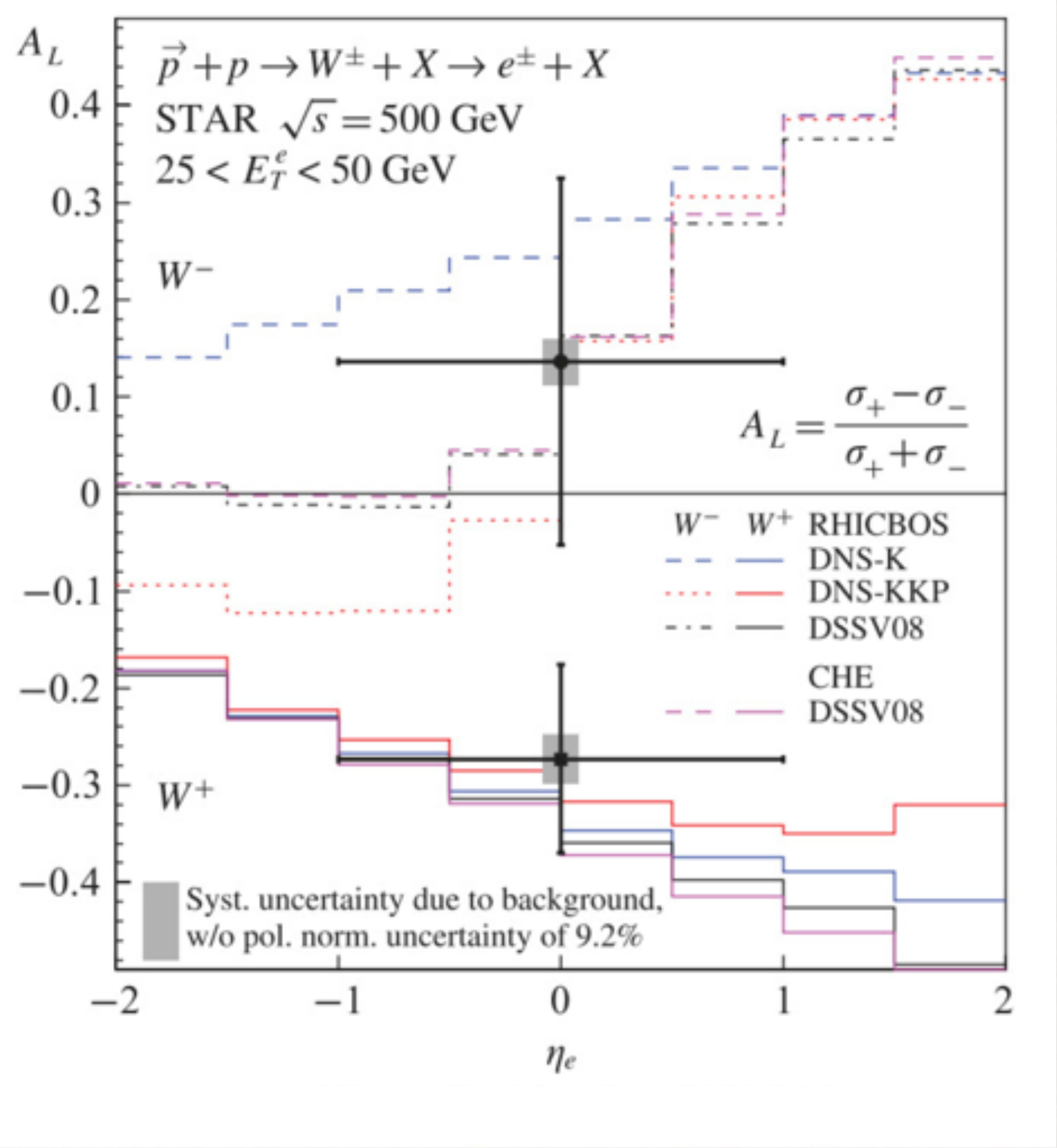

arXiv: 1304.0079

# 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 $\eta_e$ dependance.*
- *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

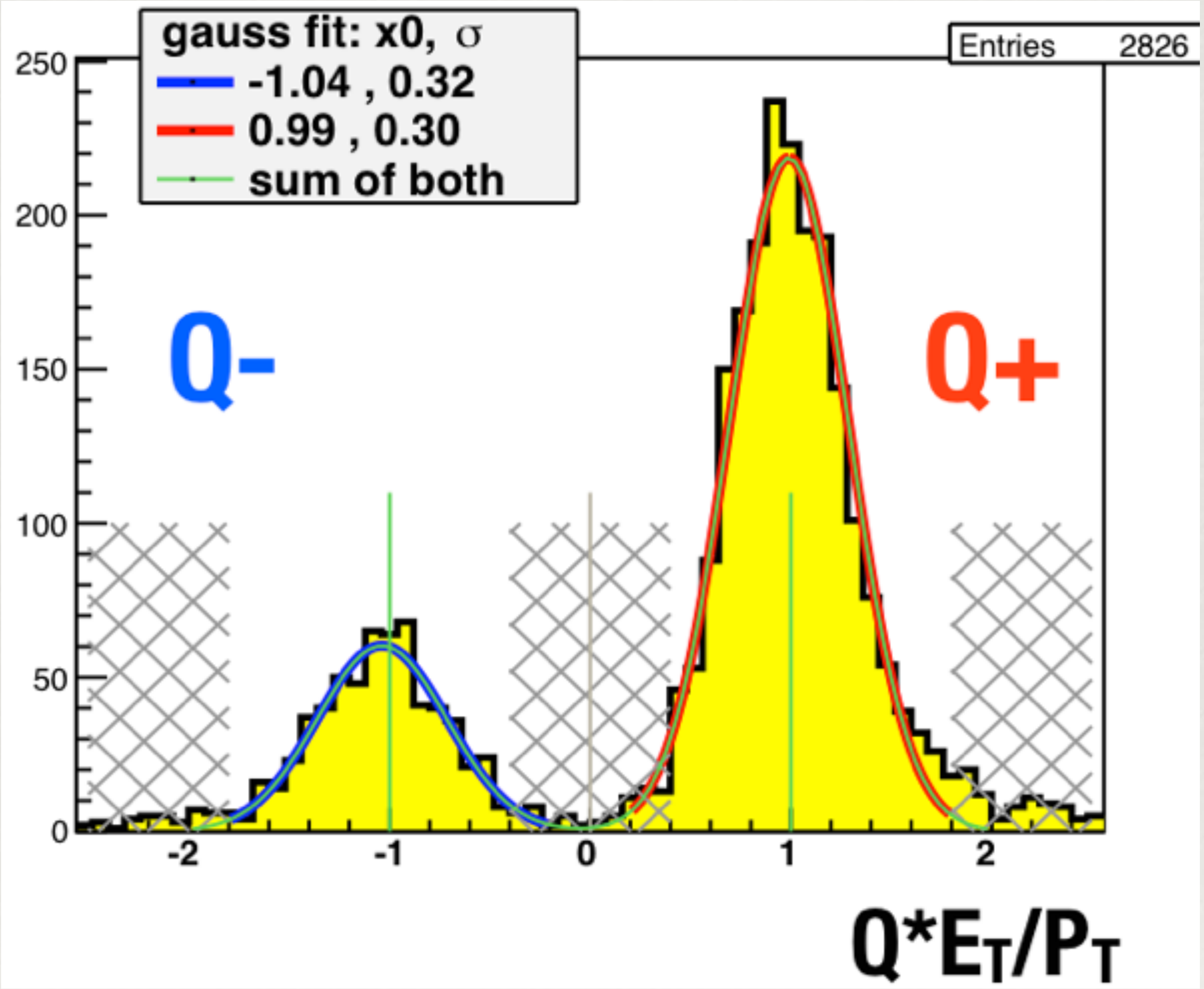
# STAR 2009 W Results



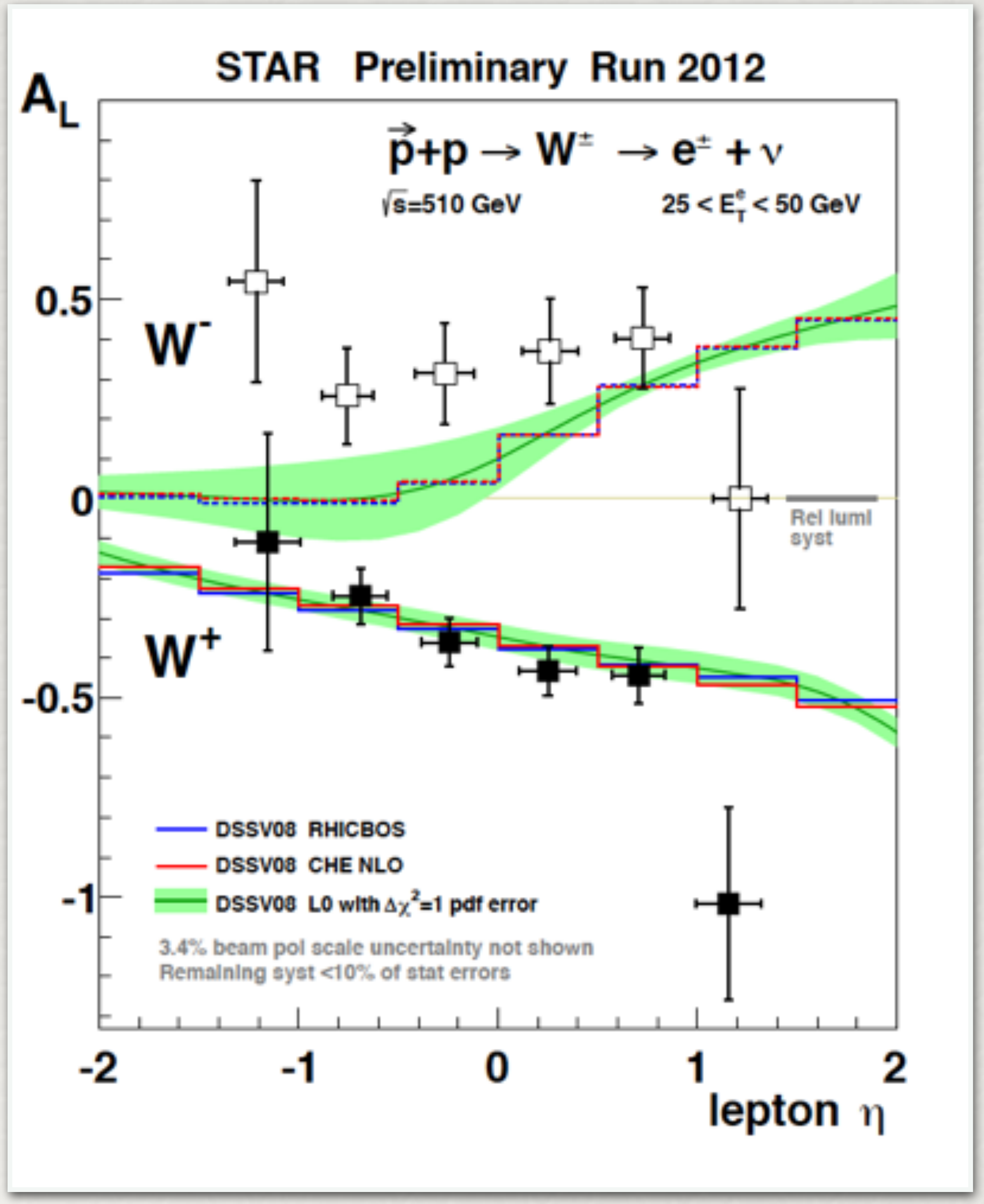

PRL 106, 062002 (2011)

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

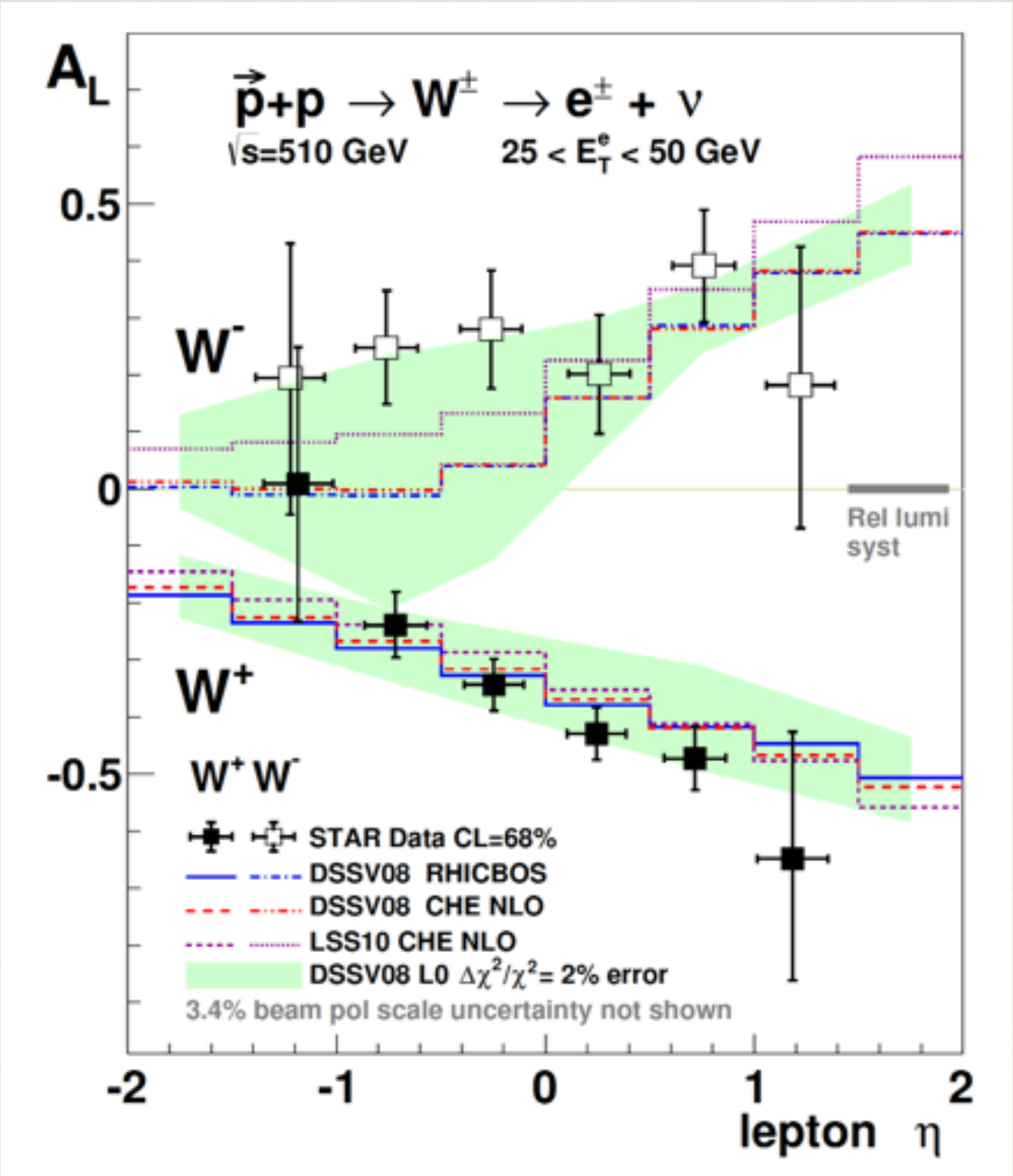
# Mid-Rapidity charge sign separation



# Run 12 Preliminary results compare to Final

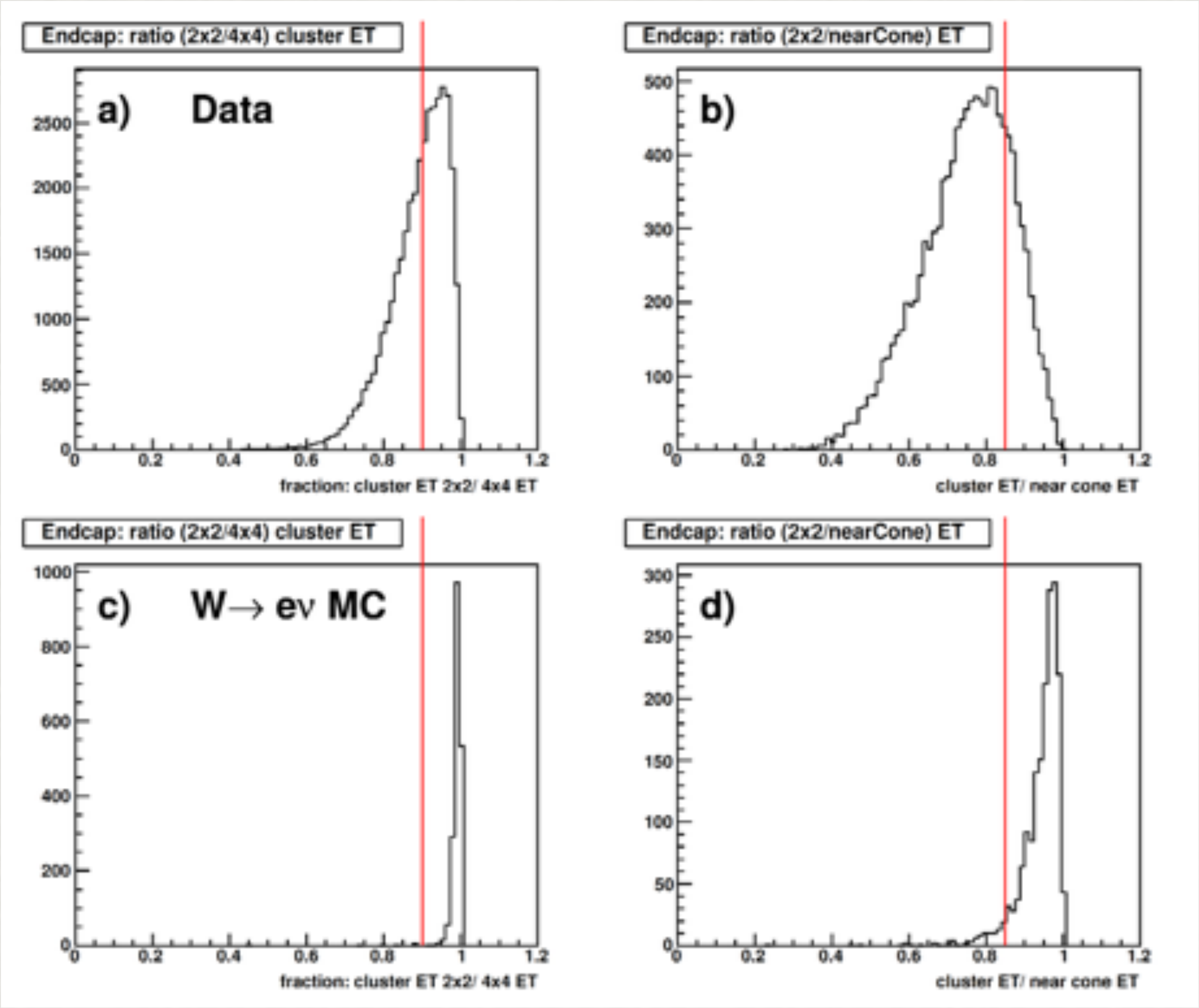


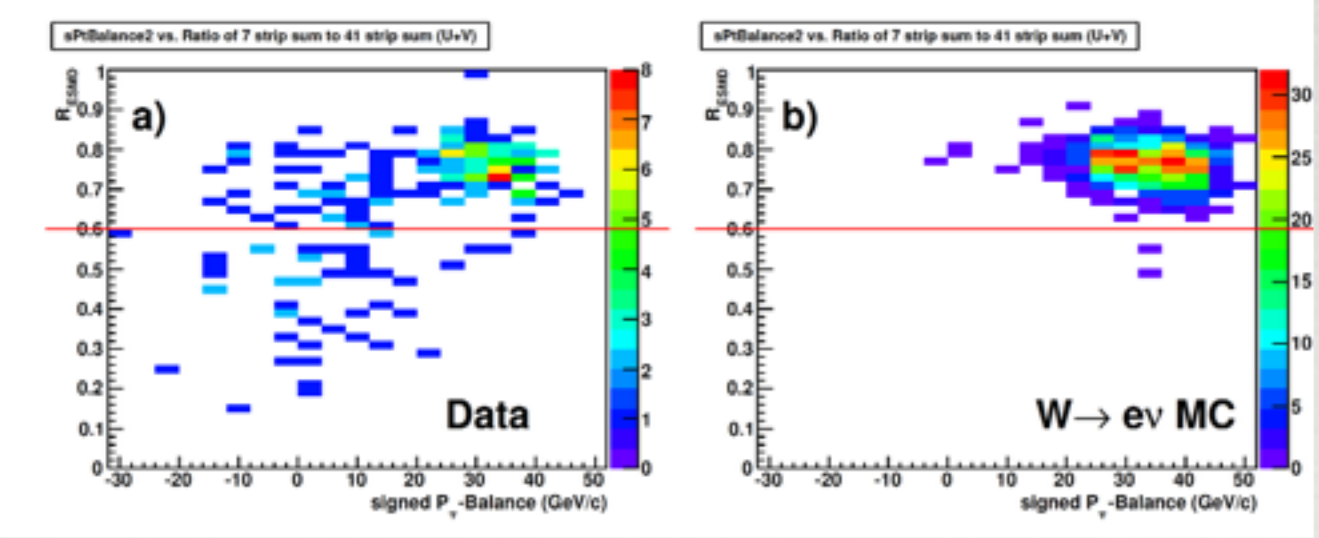

STAR FINAL Run 2012+2011



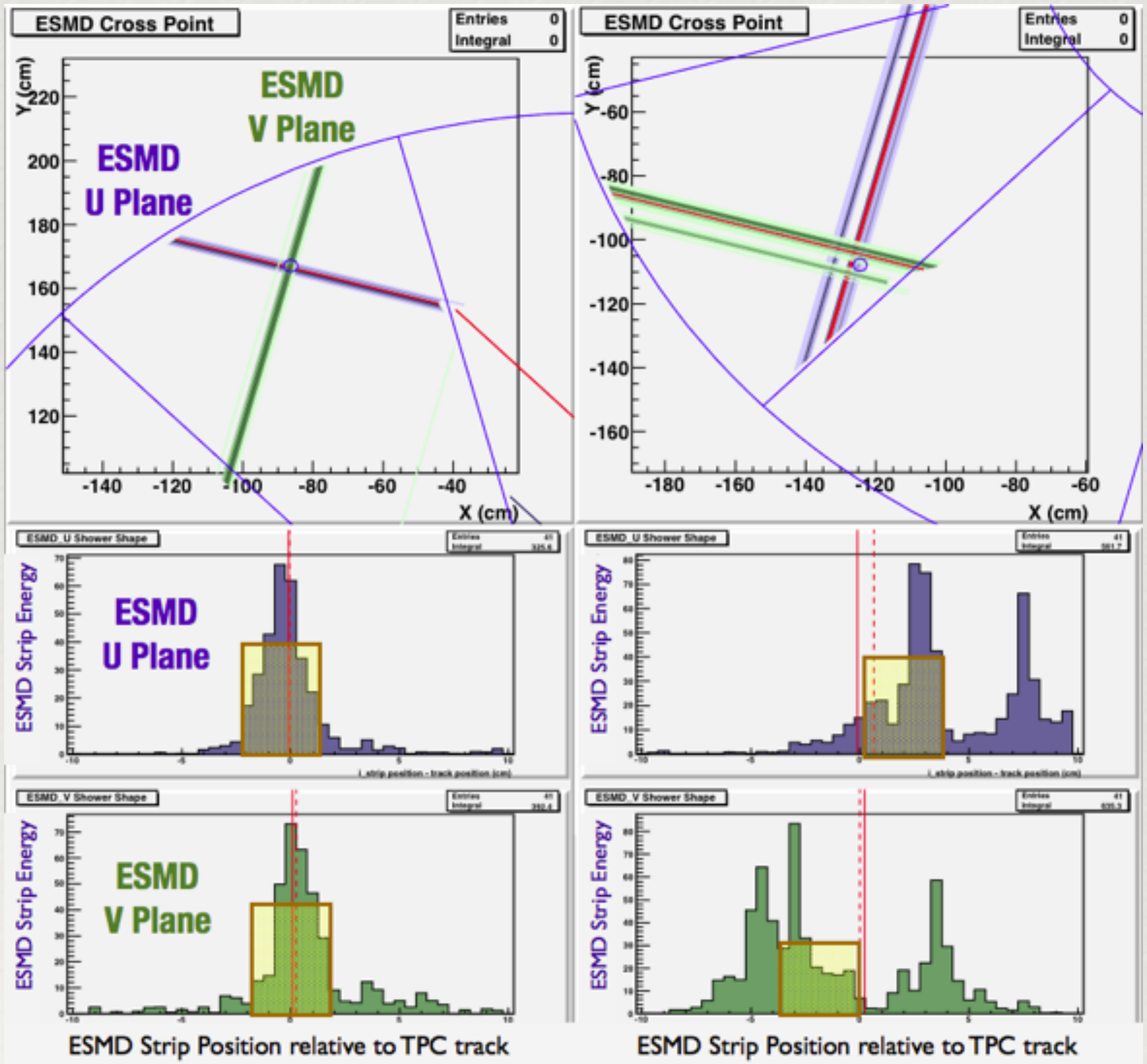

PRL 113,72301 (2014)

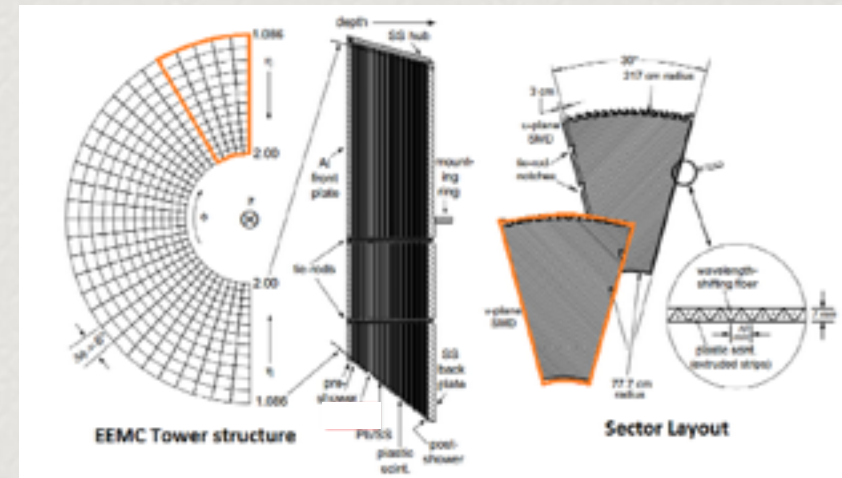
# Endcap W Selection



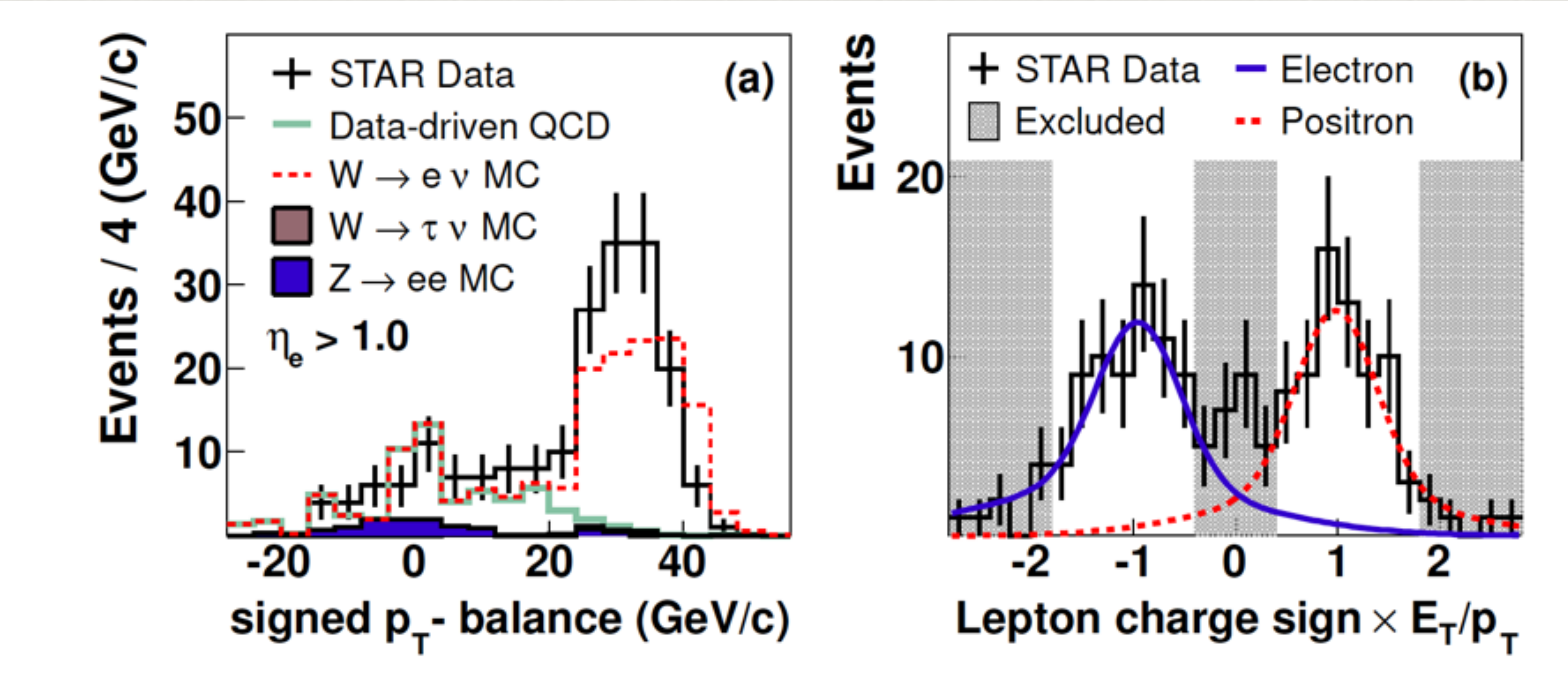
# ESMD CUTS




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

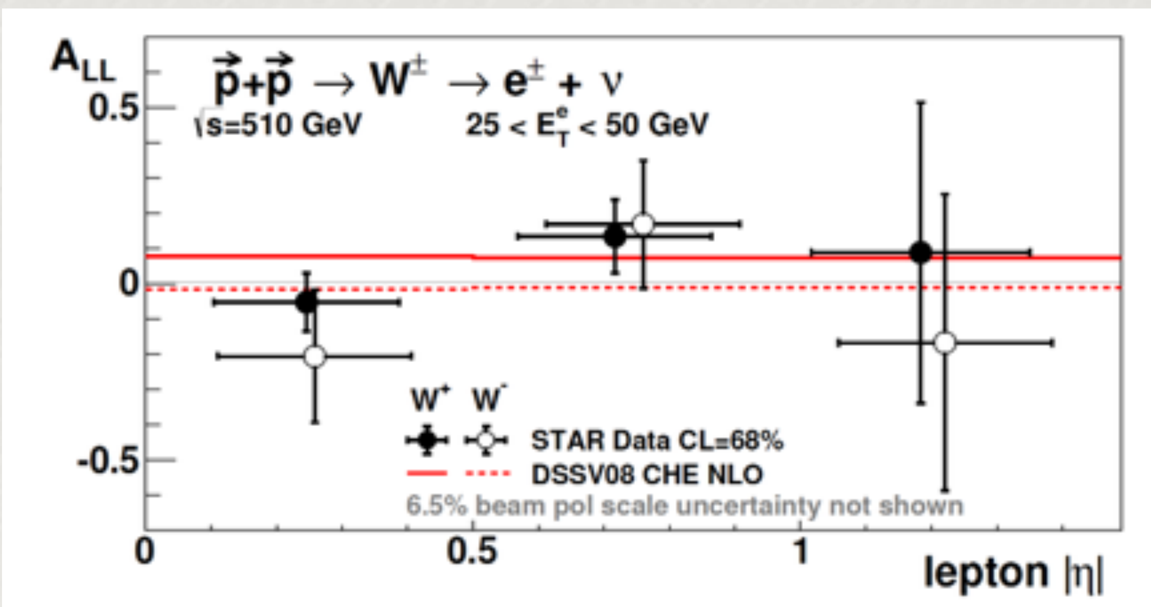
# Forward Rapidity Background Estimation and charge sign separation



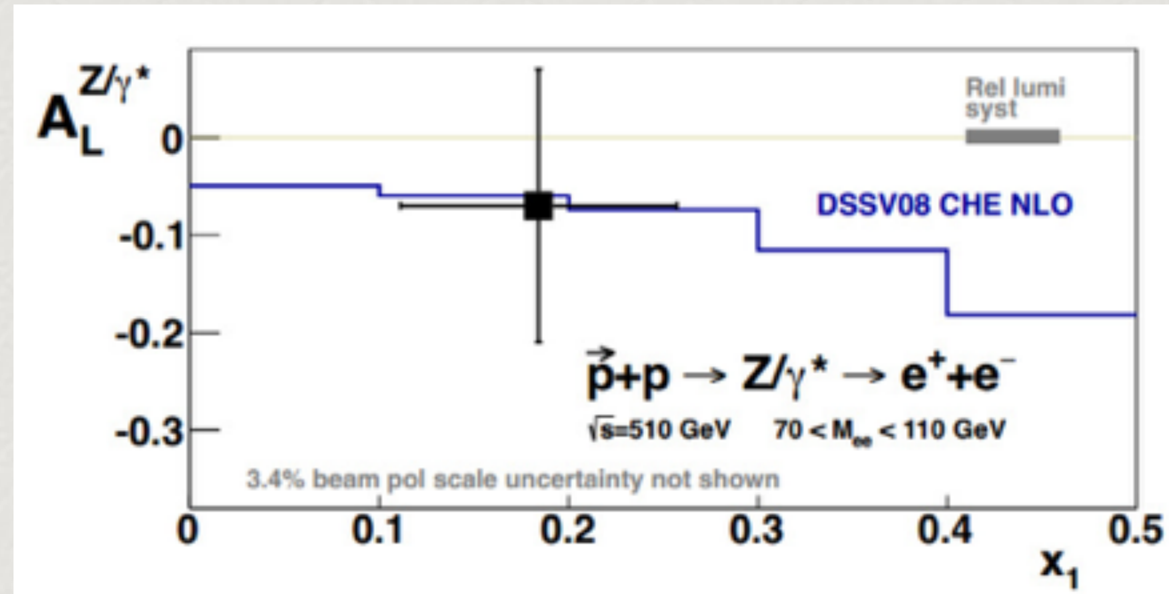

PRL 113,72301 (2014)

# Run 12 ALL and Z AL results

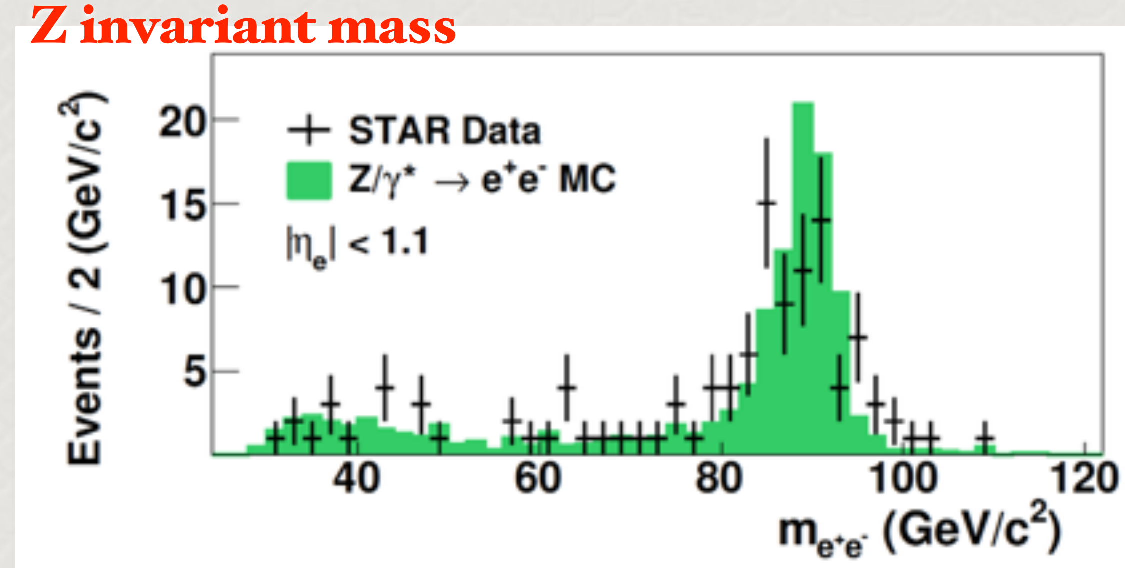
$$A_{LL} = \frac{(\sigma^{++}+\sigma^{--})-(\sigma^{+-}+\sigma^{-+})}{(\sigma^{++}+\sigma^{--})+(\sigma^{+-}+\sigma^{-+})}$$




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

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

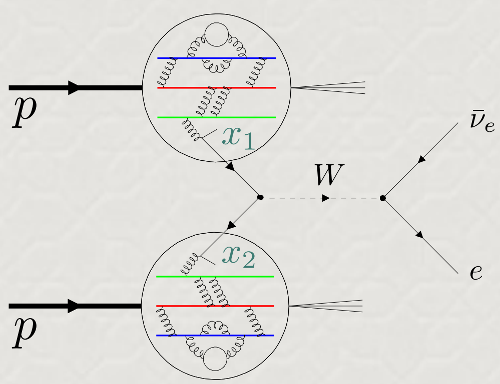
e decay kinematics in lab frame related to W boost direction

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

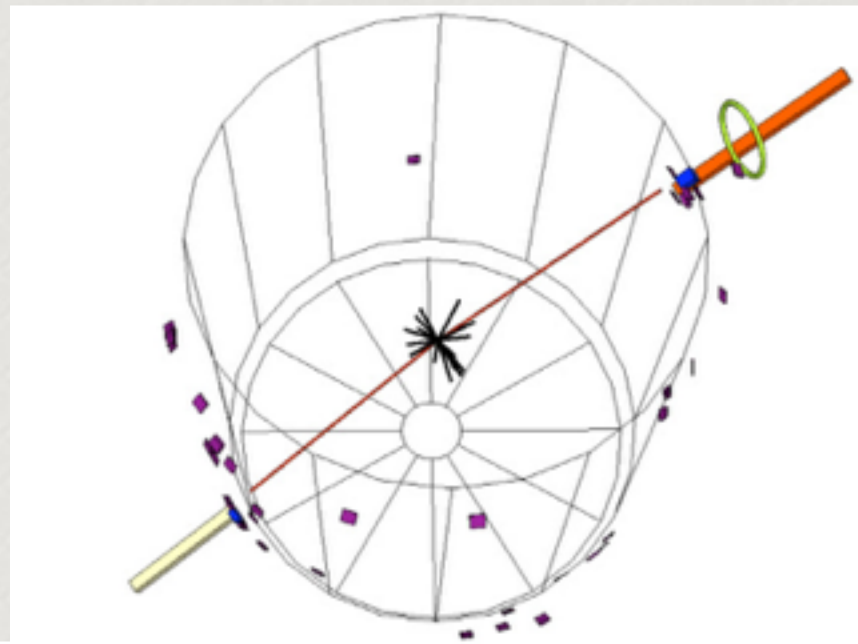
$$p_{L,e}^{*} = \cos\theta \cdot M_W/2$$

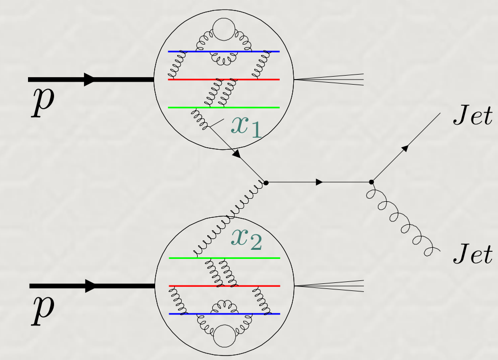
$$(p_T^e = \sin\theta \cdot M_W/2).$$

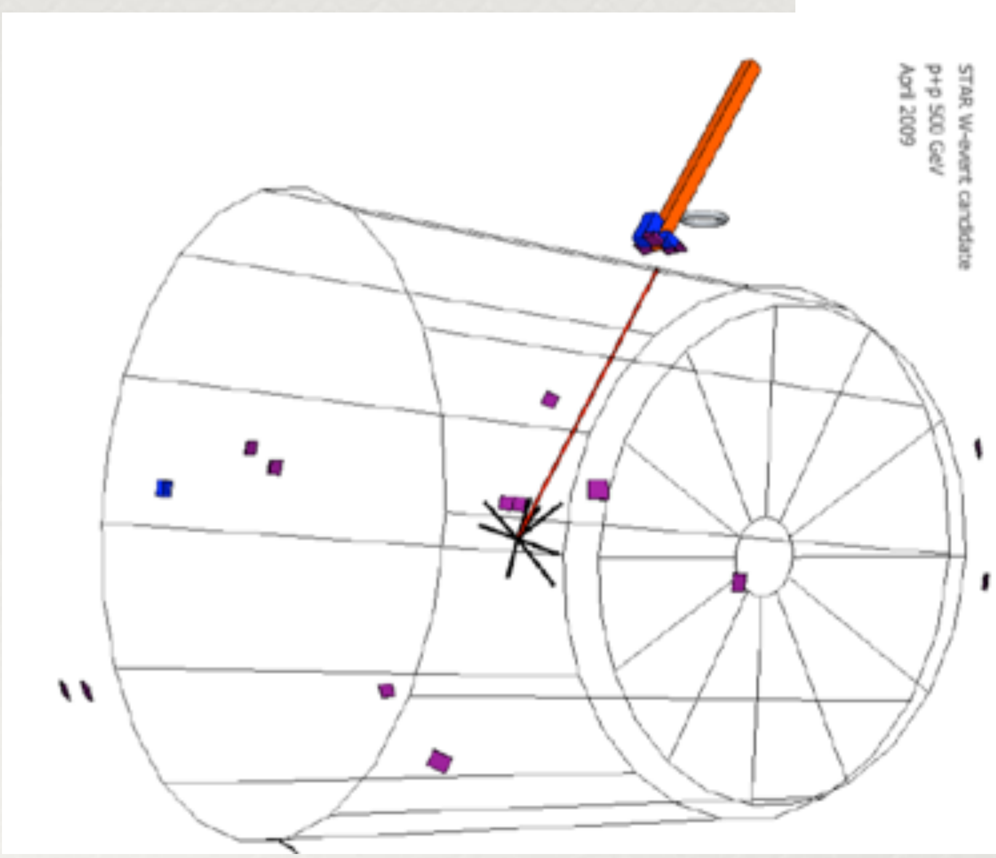
# W , di-Jet and Z type events



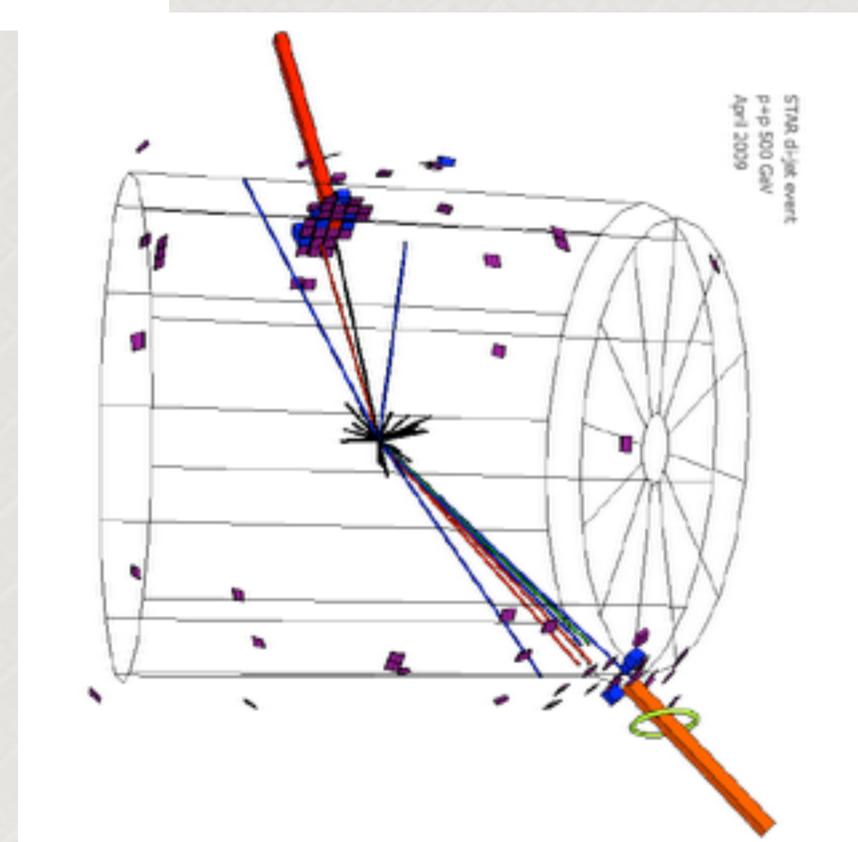

**simulated Z-ee event**






**simulated W->e event**




**simulated di-jet event**

# Unpolarized BG β and systematic uncertainties