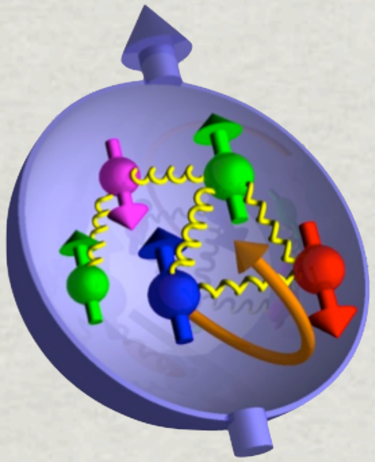
The STAR W Program at RHIC

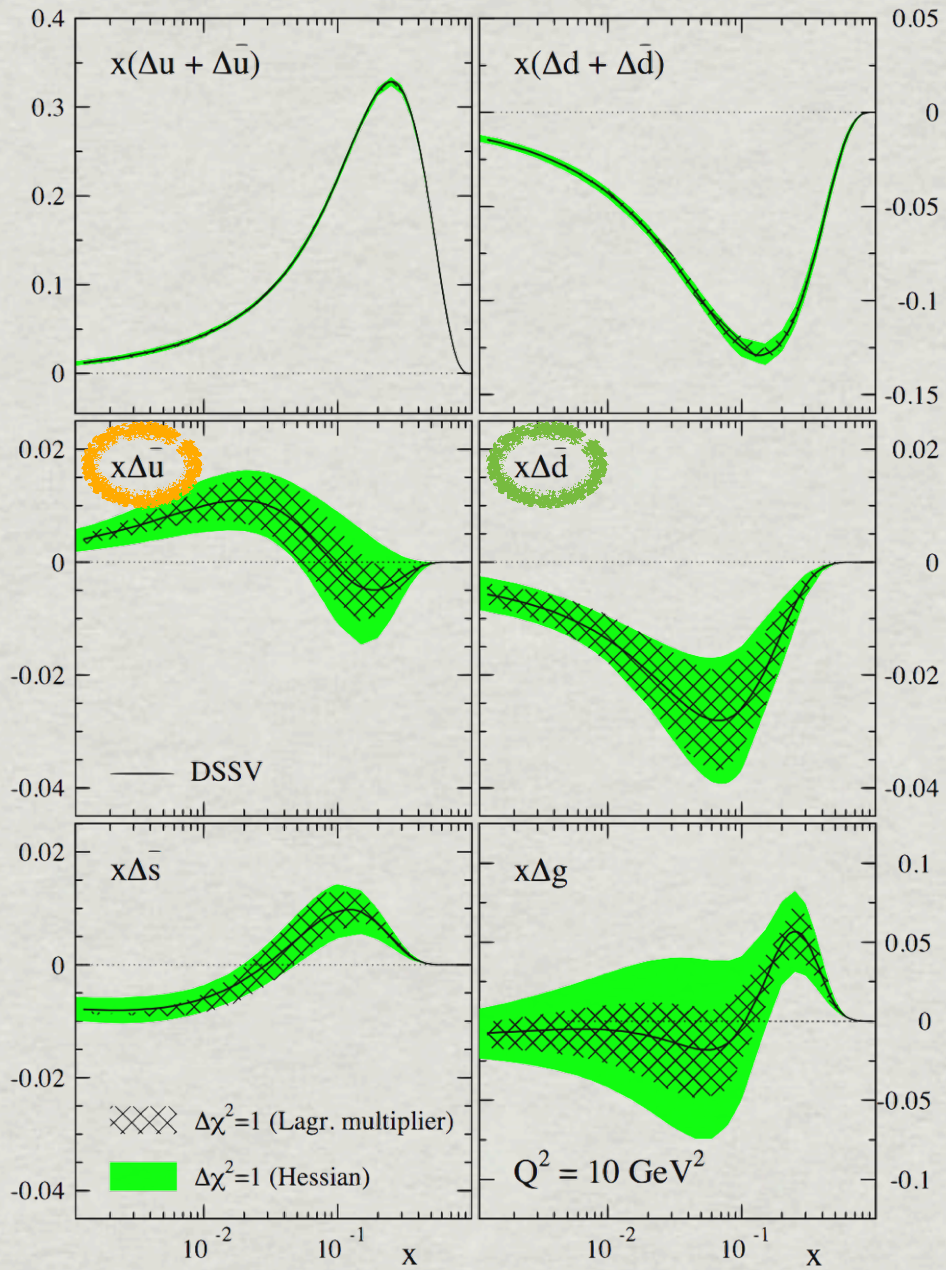
Justin Stevens for the STAR Collaboration

QCD-N' 2012

Proton Spin Puzzle



DSSV Global Analysis



PRD **80**, 034030 (2009)

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

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

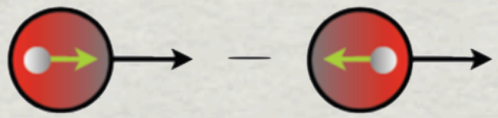
Integral of quark polarization is well measured in DIS to be ~30%, some info on decomposition from SIDIS but sea not well constrained

$$\Delta G = \int \Delta g\left(x\right) dx$$

First experimental evidence of non-zero Δg from 2009 RHIC data (previous two talks)

Polarized PDF

$\Delta f(x) =$

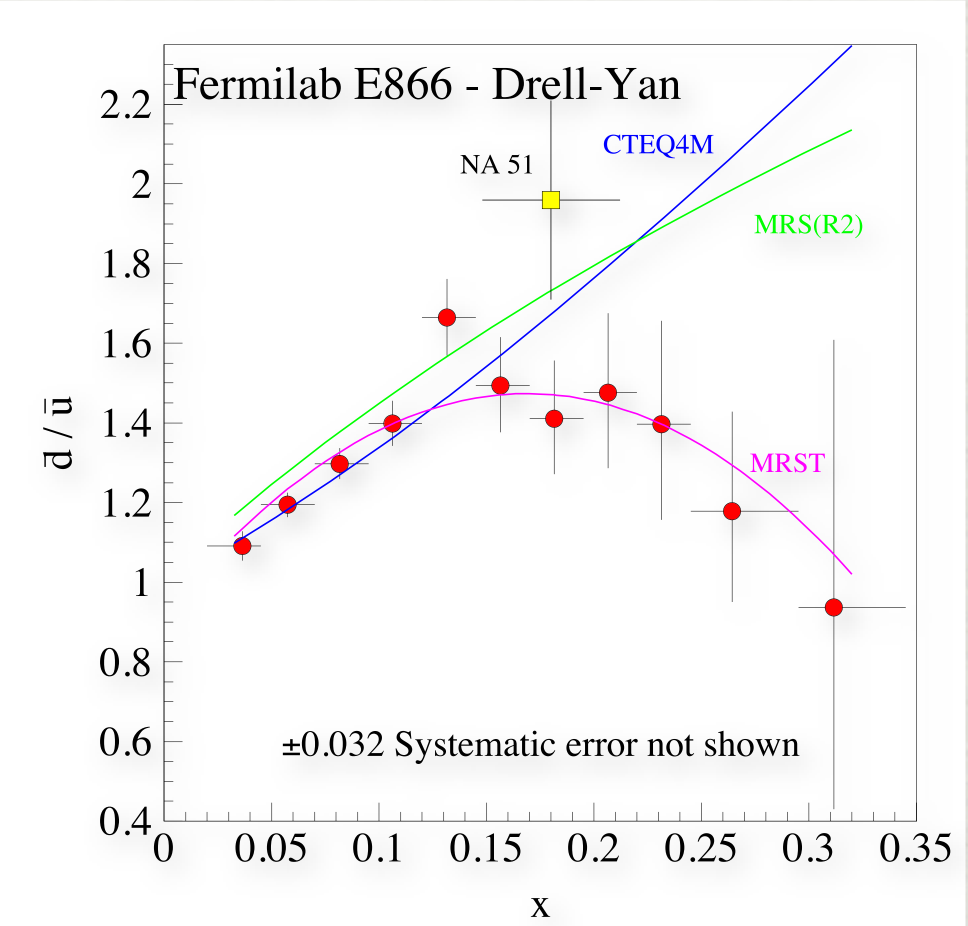


$f^+(x) - f^-(x)$

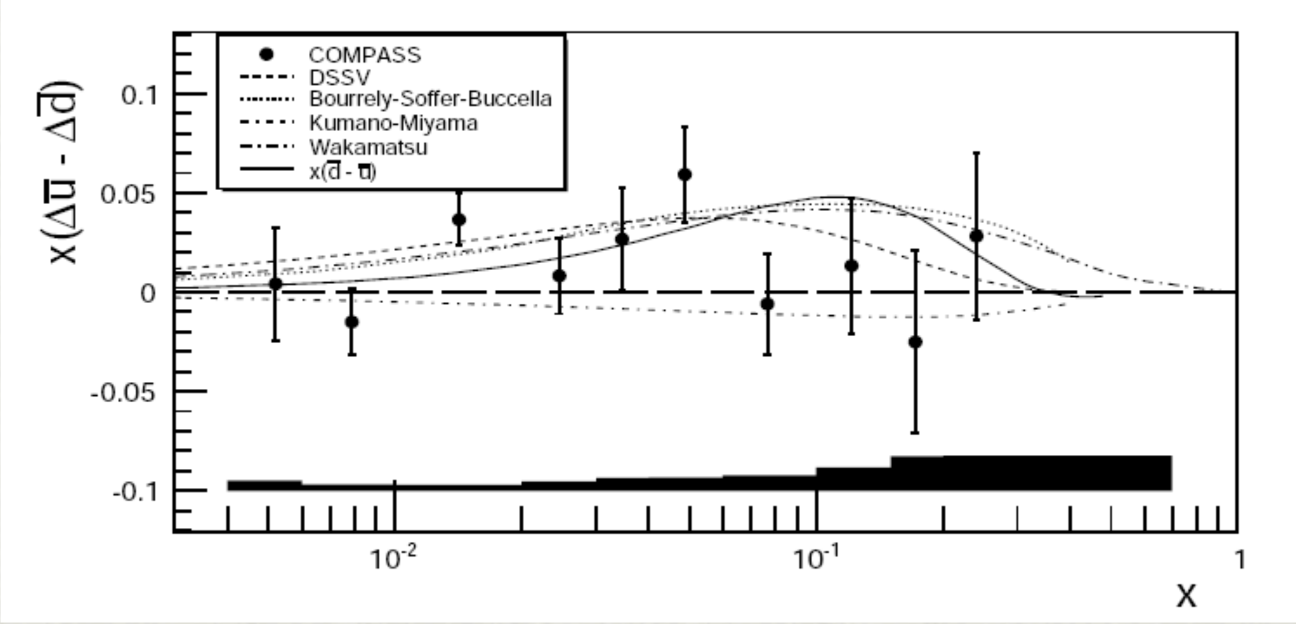
Flavor Asymmetry of the Sea

Unpolarized Flavor Asymmetry:

- Quantitative calculation of Pauli blocking does not explain $\bar{d}/\bar{u}$ ratio
- Non-perturbative processes may be needed in generating the sea
- E866 results are qualitatively consistent with pion cloud models, chiral quark soliton models, instanton models, etc.



PRD **64**, 052002 (2001)

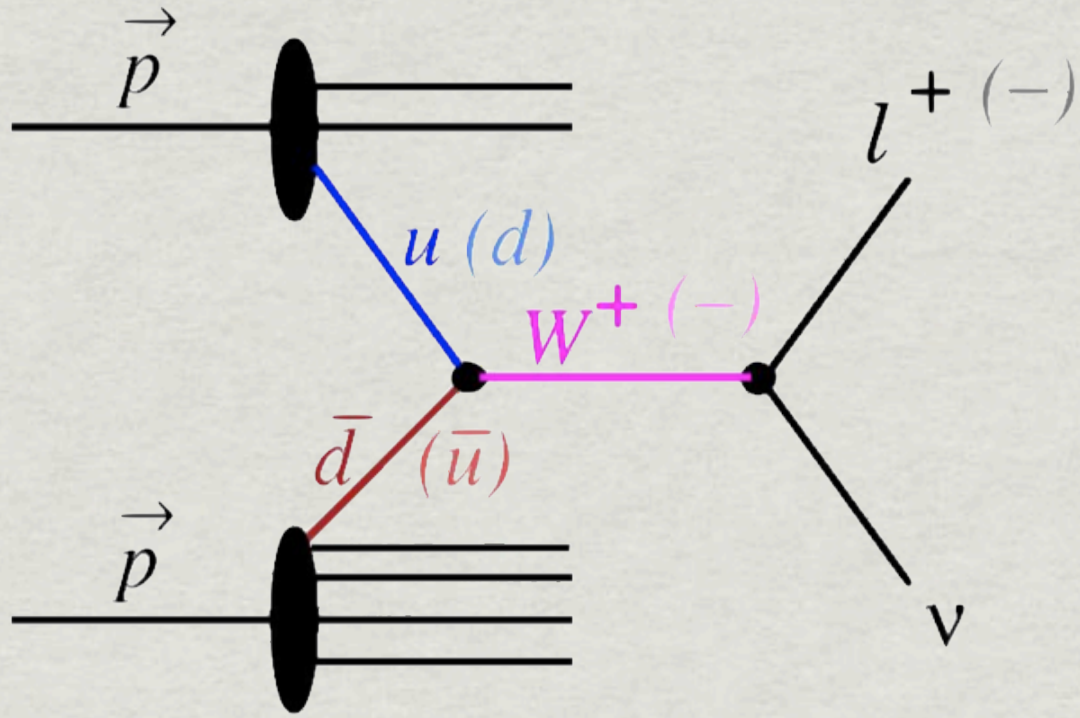


PLB **693**, 227 (2010)

Polarized Flavor Asymmetry:

- Valence u and d distributions are well determined from DIS
- Polarized flavor asymmetry $x(\Delta\bar{u} - \Delta\bar{d})$ could help differentiate models
- SIDIS results depend on FFs

Why Ws?



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

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

- Ws couple directly to the quarks and antiquarks of interest
- Detect Ws through e+/e- decay channels
- V-A coupling of the weak interaction leads to perfect spin separation

Measure parity-violating single-spin asymmetry:

(Helicity flip in one beam while averaging over the other)

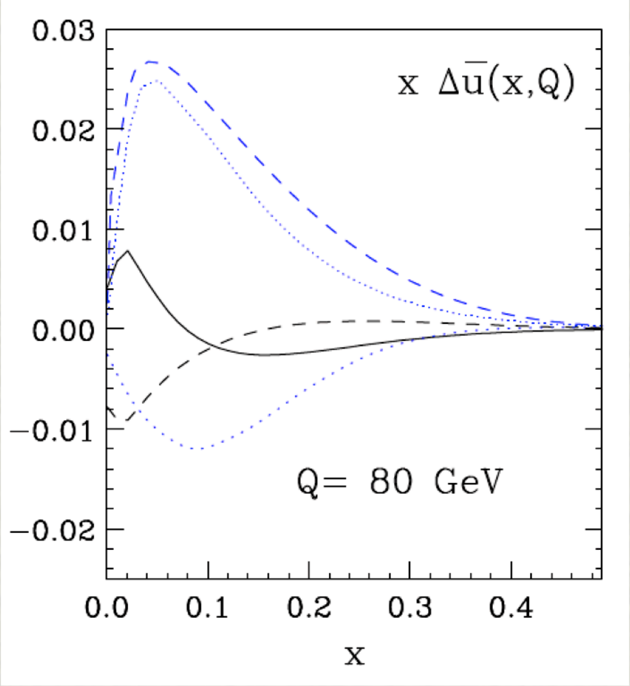
$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

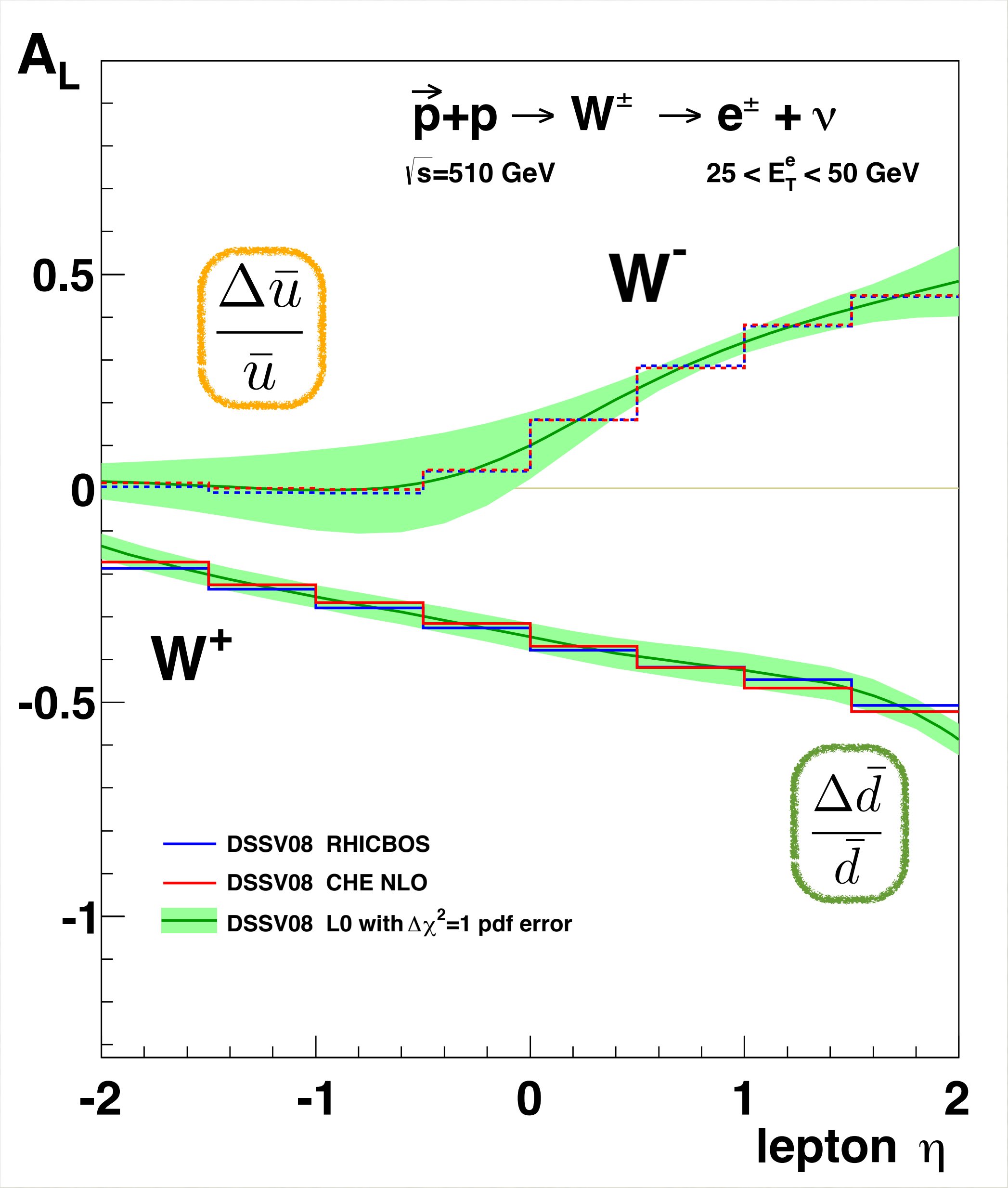
$$A_L^{W-} \propto \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

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

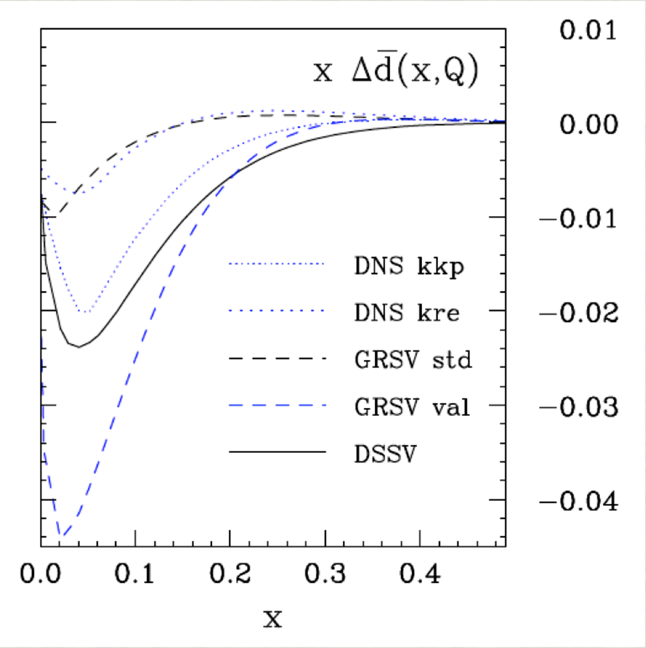
Expectations for W A_L

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





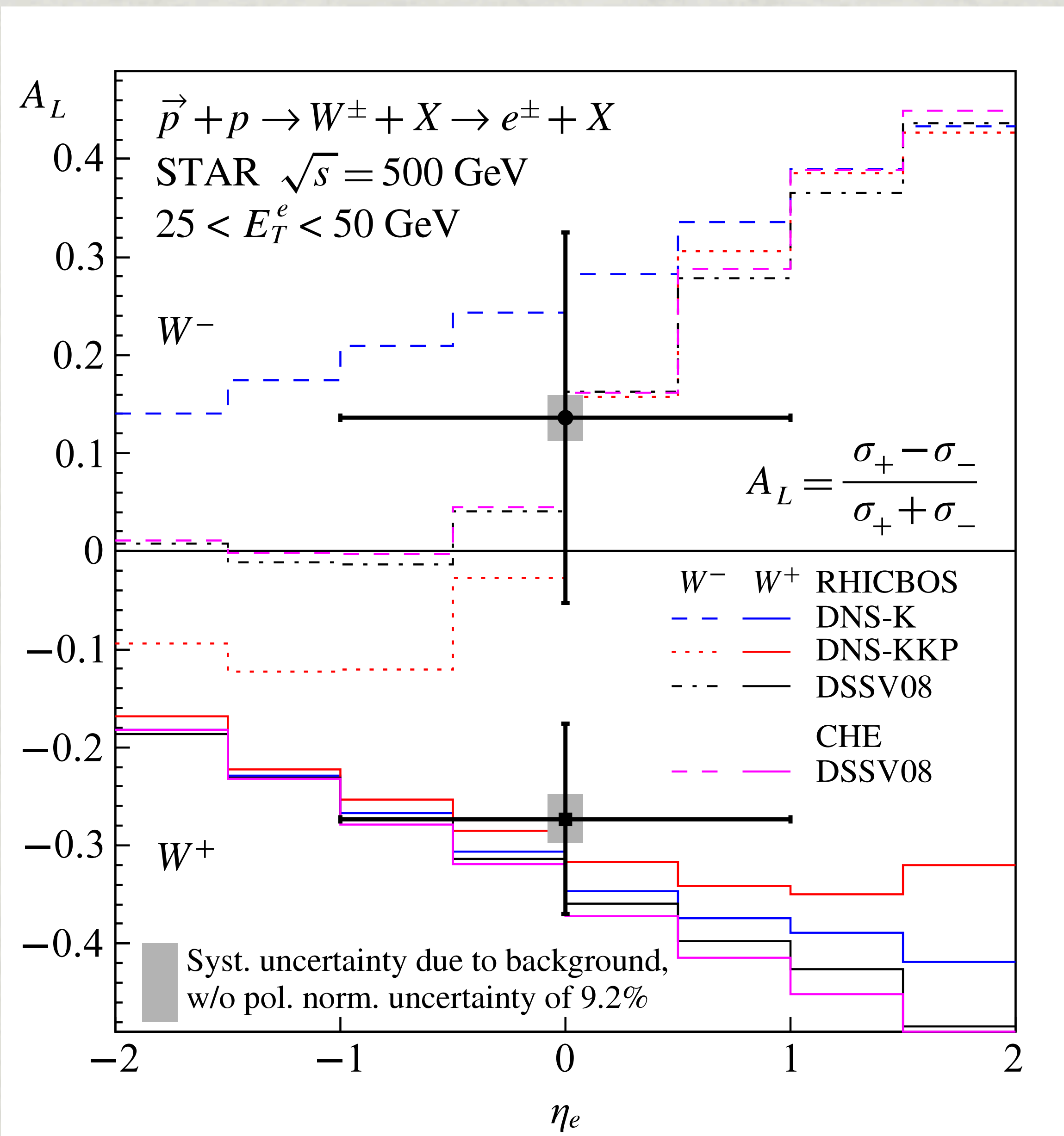
- Large parity-violating asymmetries expected
- Simplified interpretation at forward and backward rapidity



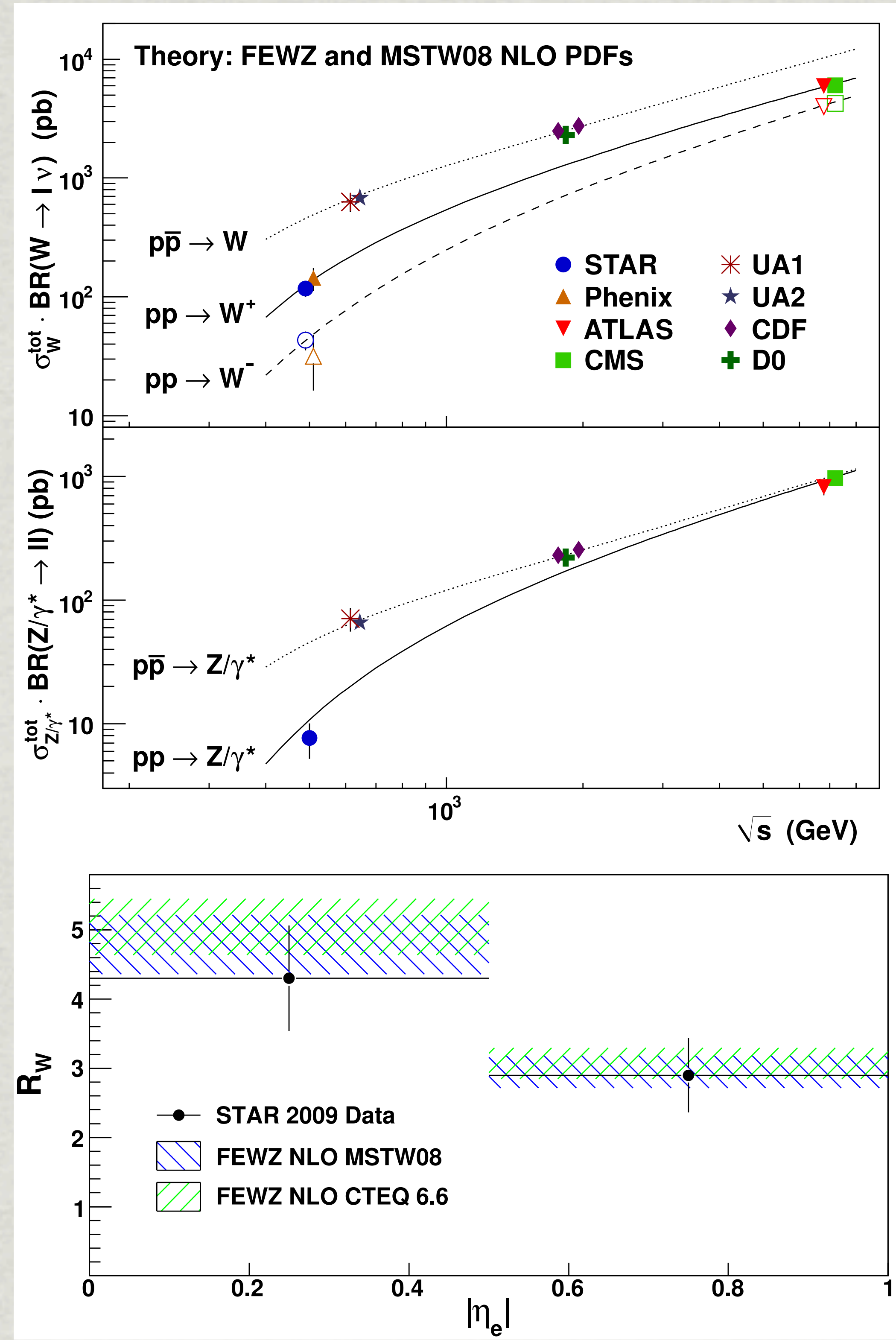
- DSSV $\Delta\chi^2 = 1$ band underestimates the theoretical uncertainty (and Lagrange multiplier estimates for a $\Delta\chi^2/\chi^2$ = 2% error are in progress)

STAR 2009 W Measurements

Very successful first 500 GeV physics run!



PRL **106,** 062002 (2011)

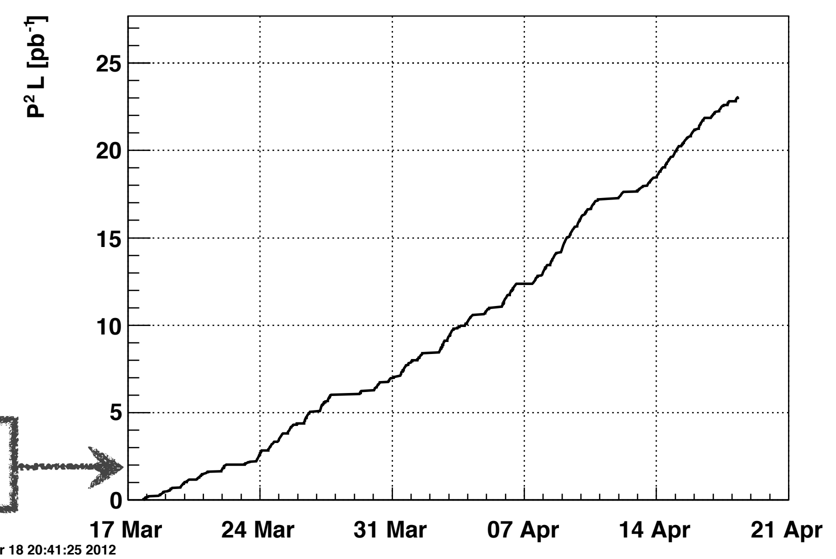


PRD **85,** 92010 (2012)

NEW!

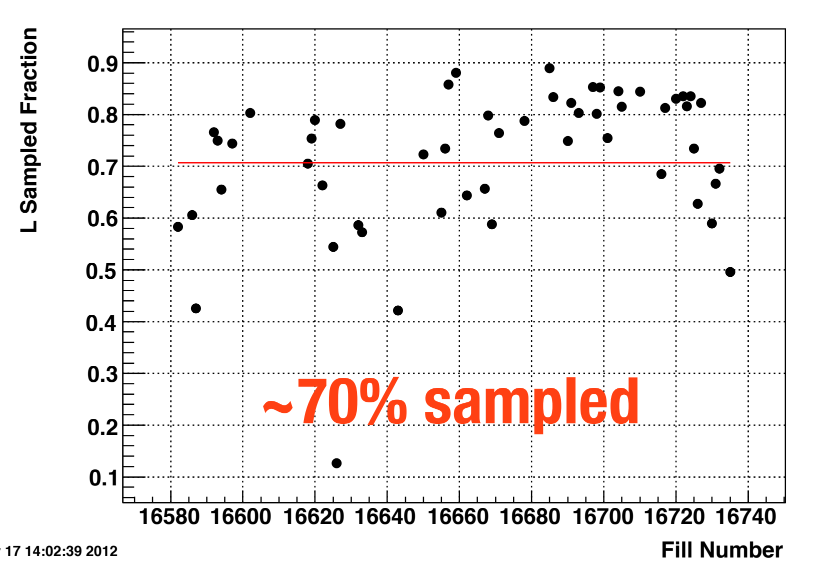
2012 STAR Dataset

W Trigger FOM = P^2L



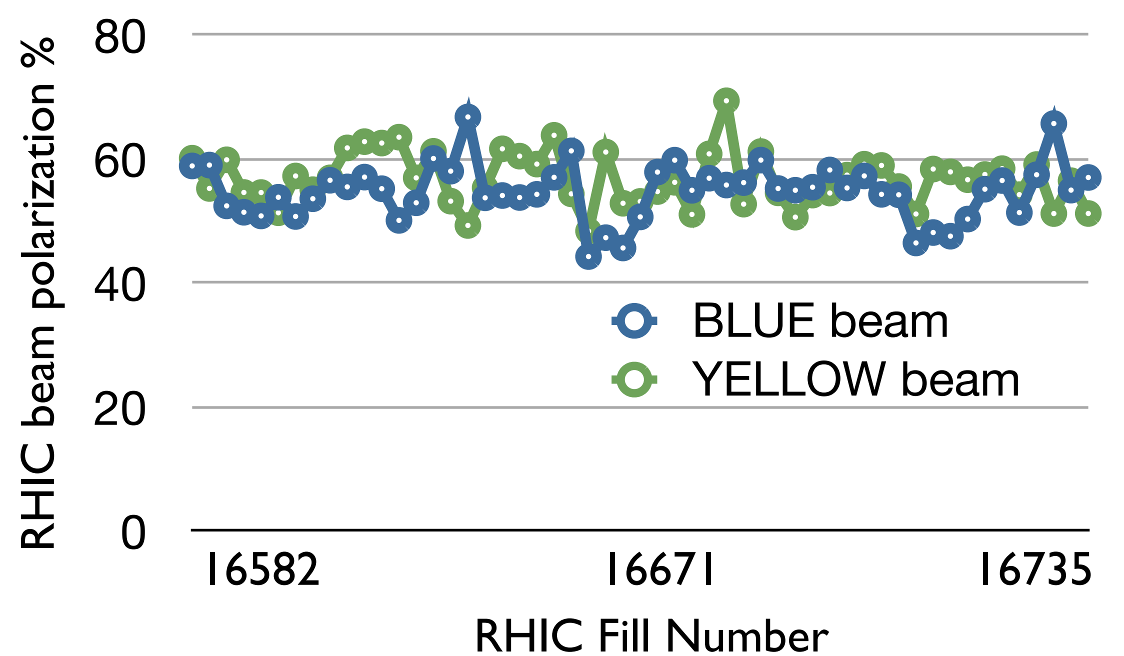
Run 9 FOM

Lumi Sampled Fraction



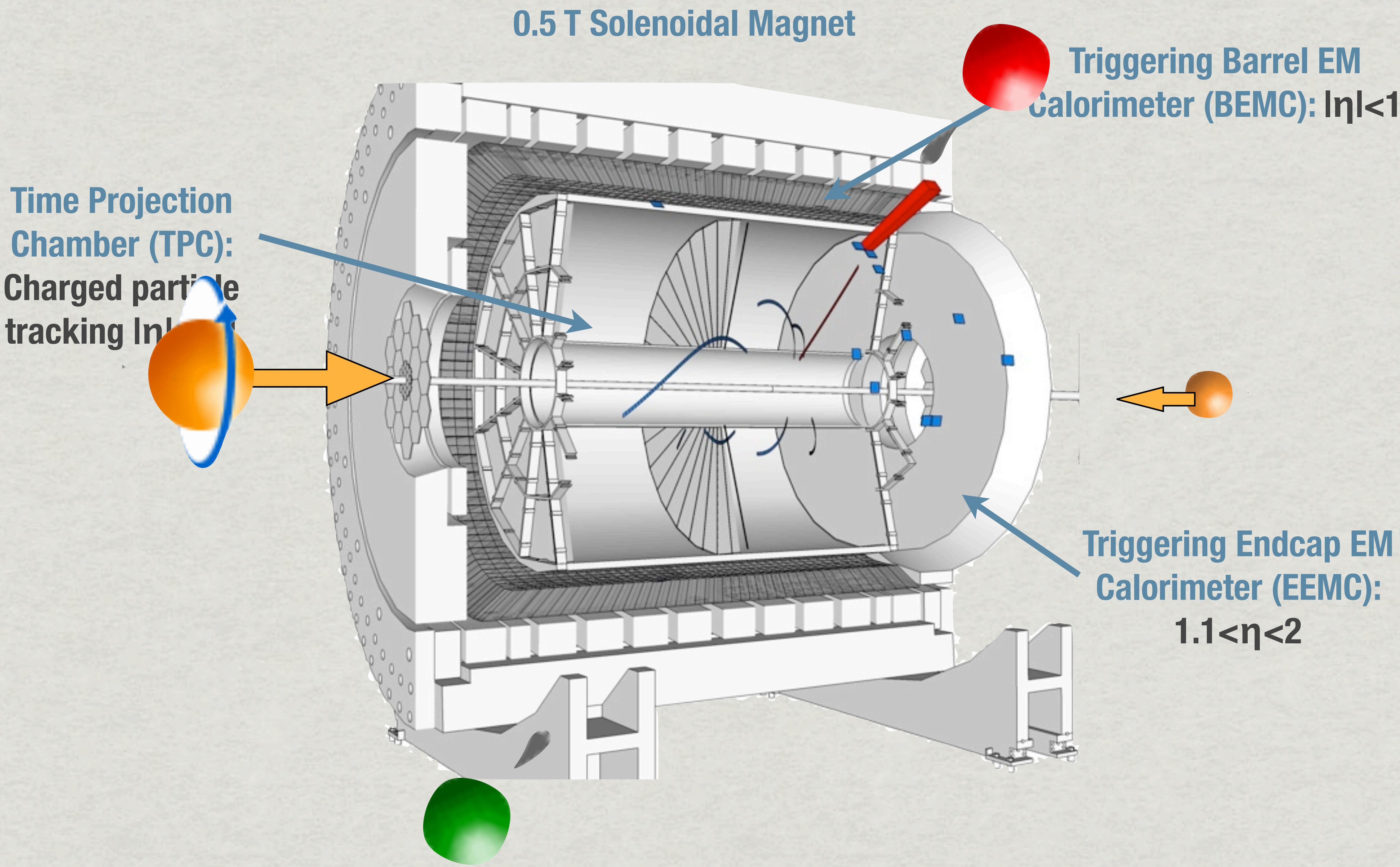
	L (pb^{-1})	P	P^2L (pb^{-1})
Run 9	12	0.40	1.9
Run 12	72	0.56	22.6

Note: For Run 12 expect ~10% more statistics with final calibrations

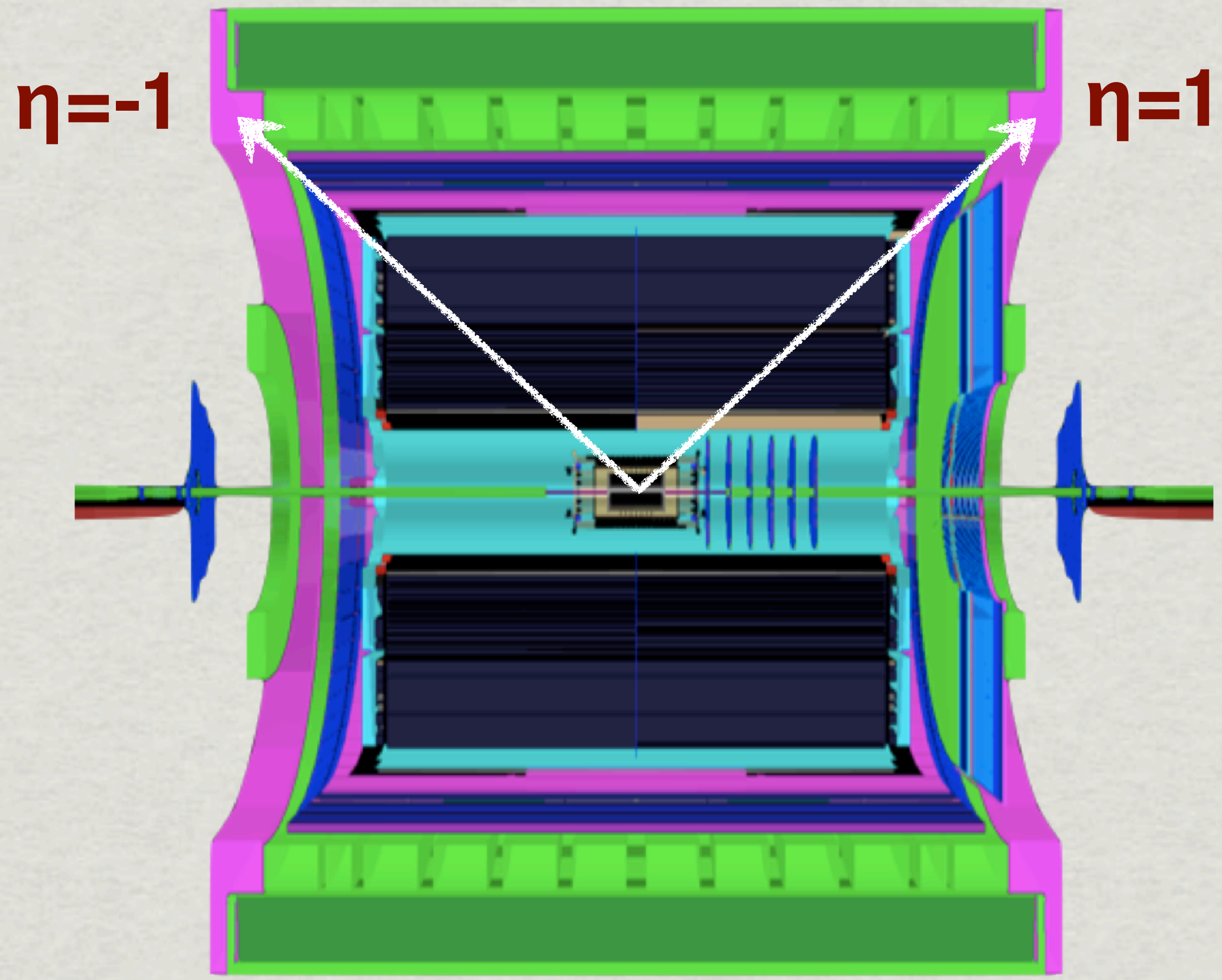


Excellent RHIC and STAR performance. Thanks!

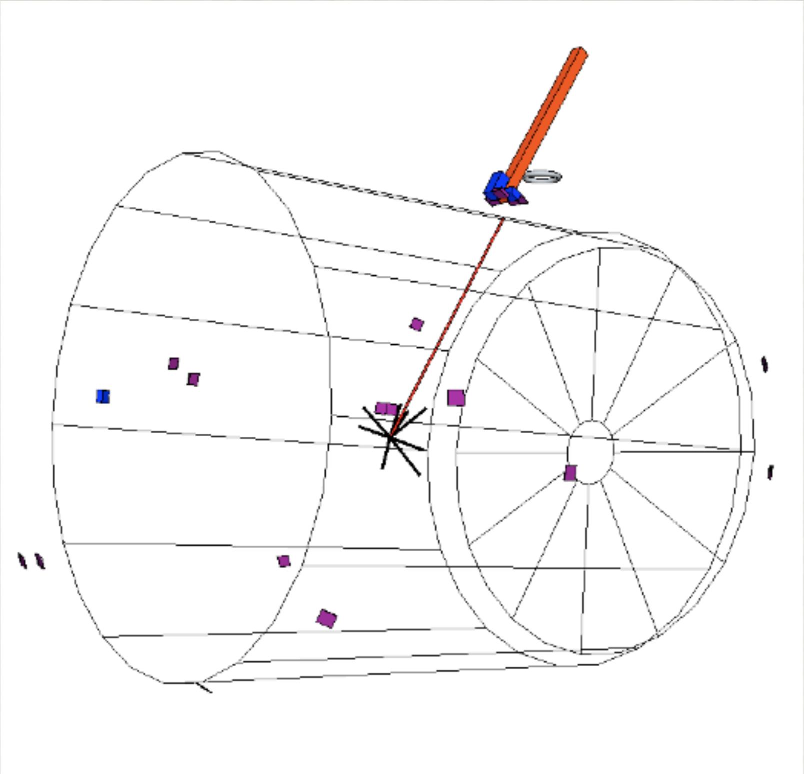
STAR Detector Overview



Mid-Rapidity Ws at STAR



What do W decays look like?

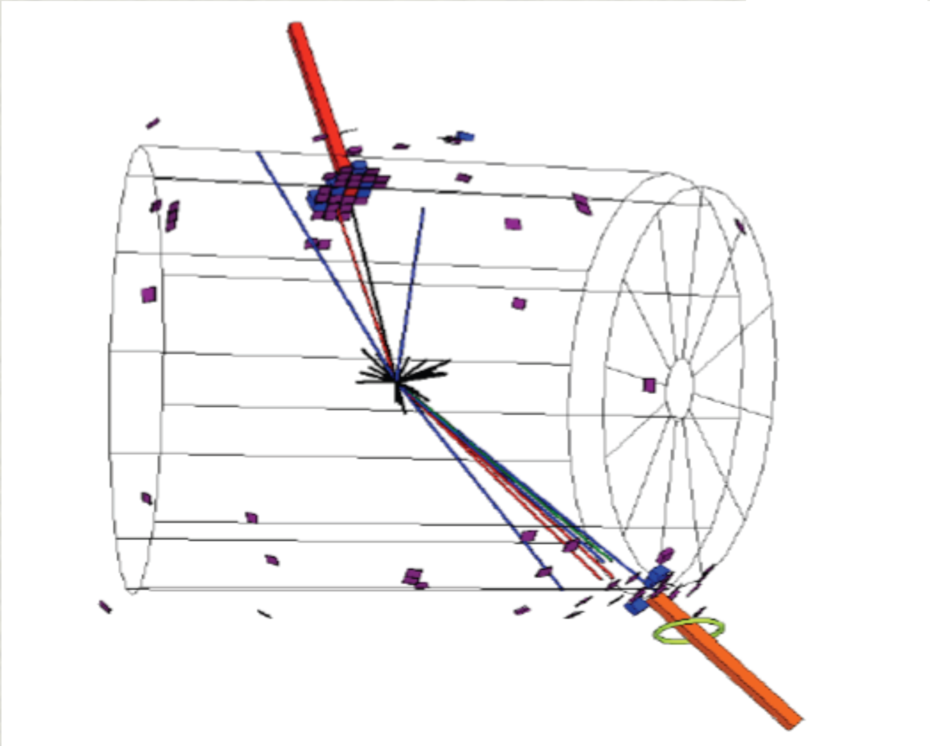


W → e + ν Candidate Event

- Isolated track pointed to isolated EM cluster in calorimeter
- Large "missing energy" opposite the electron candidate

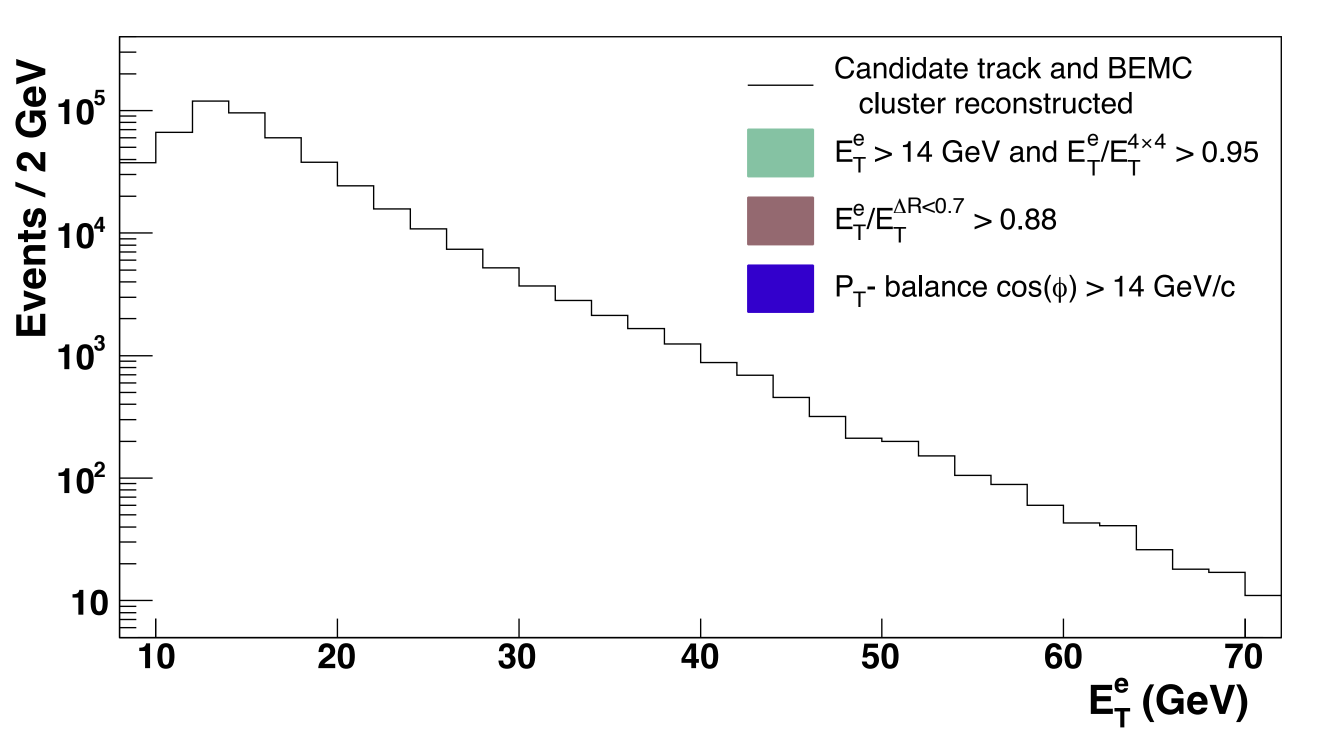
Di-jet Background Event

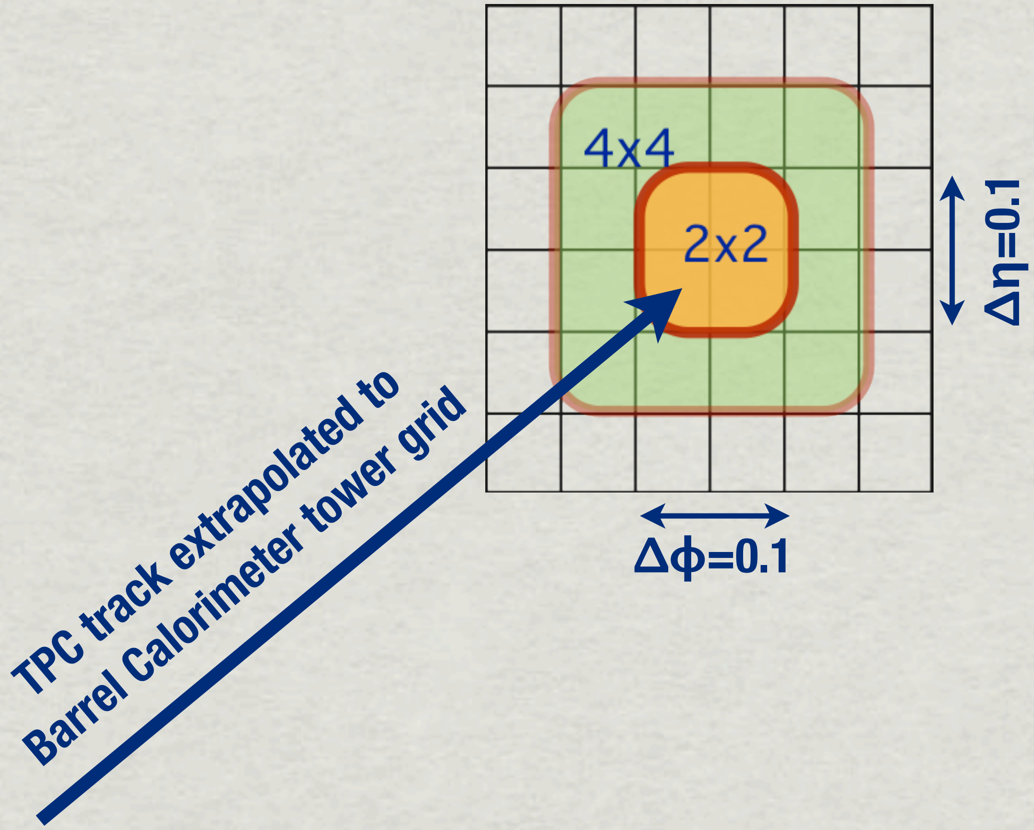
- Several tracks pointing to EM energy deposit in several towers
- Vector p_T sum is balanced by opposite jet, "missing energy" is small



How do we find Ws?

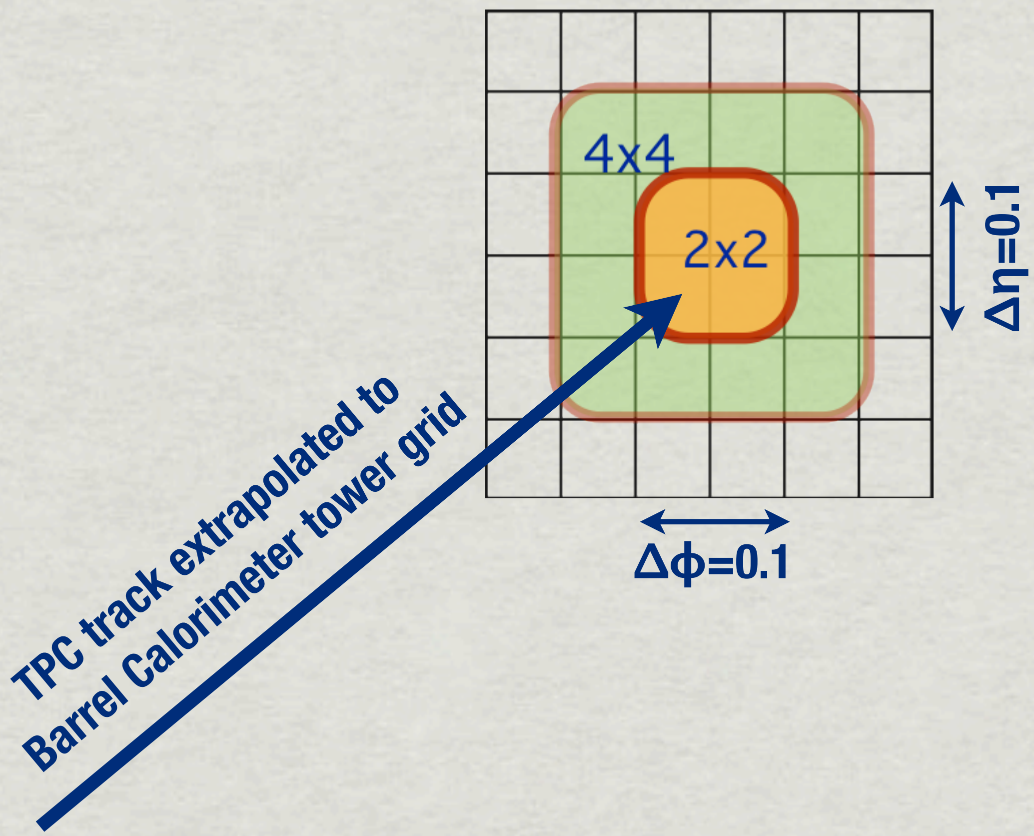
- Match $p_T > 10$ GeV track to BEMC cluster

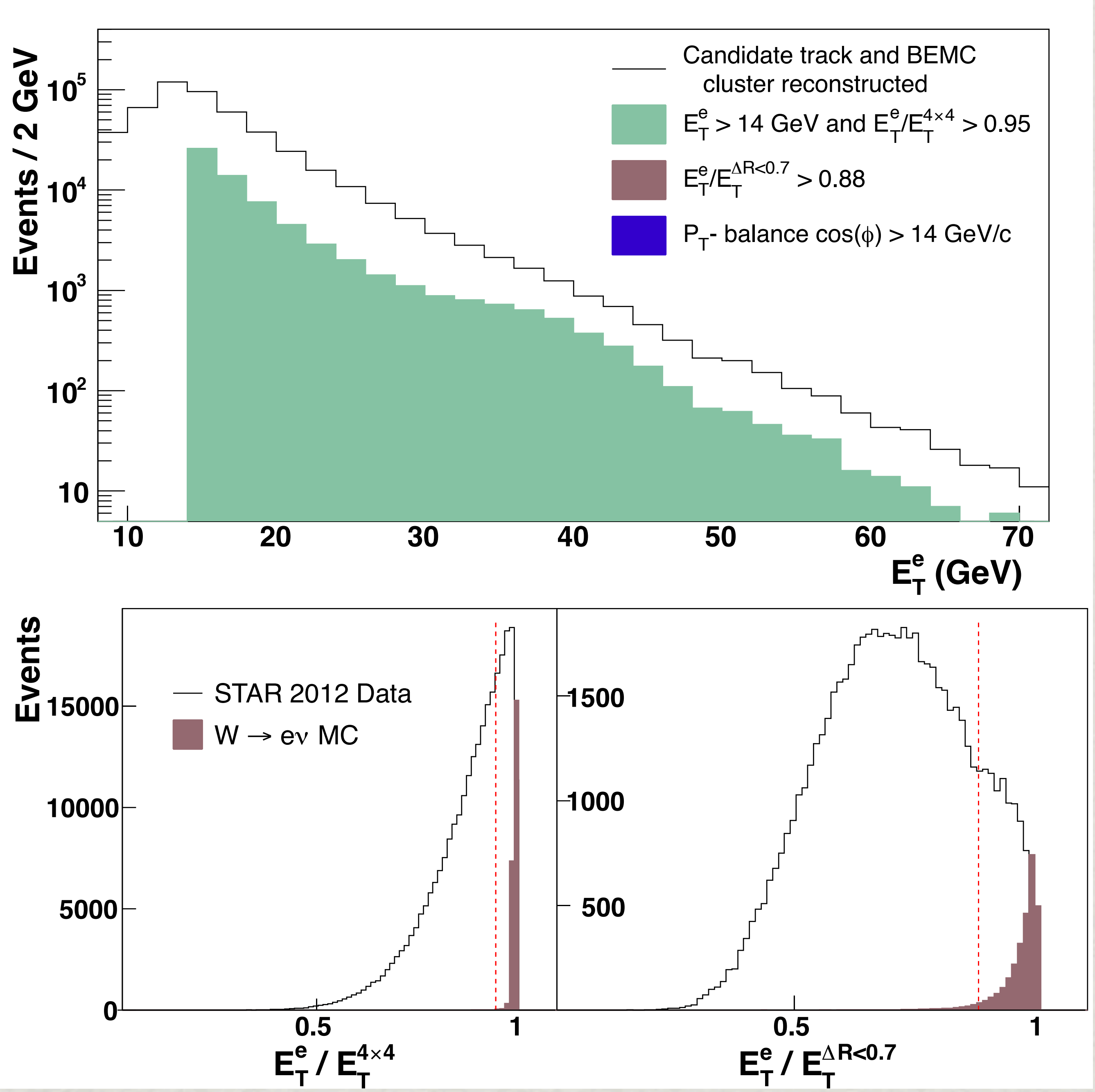




How do we find Ws?

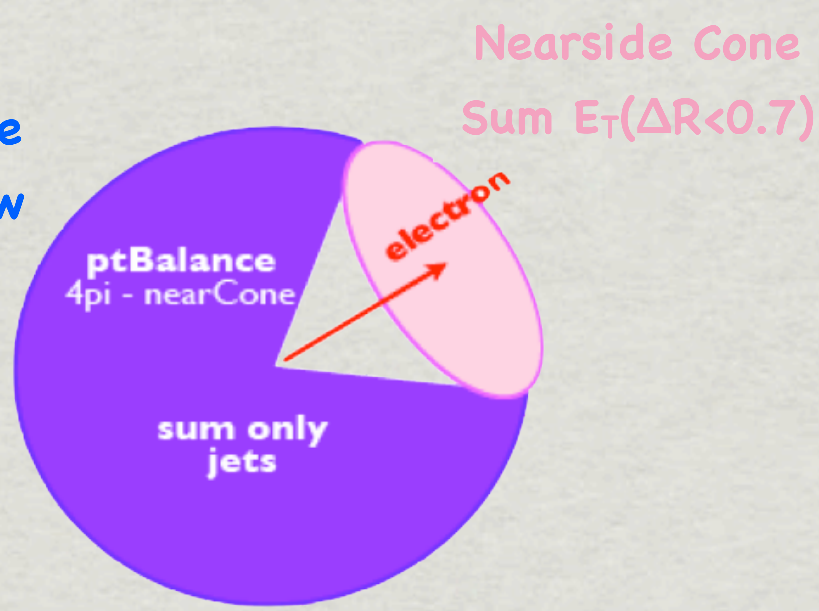
- Match $p_T > 10$ GeV track to BEMC cluster
- Isolation Ratios

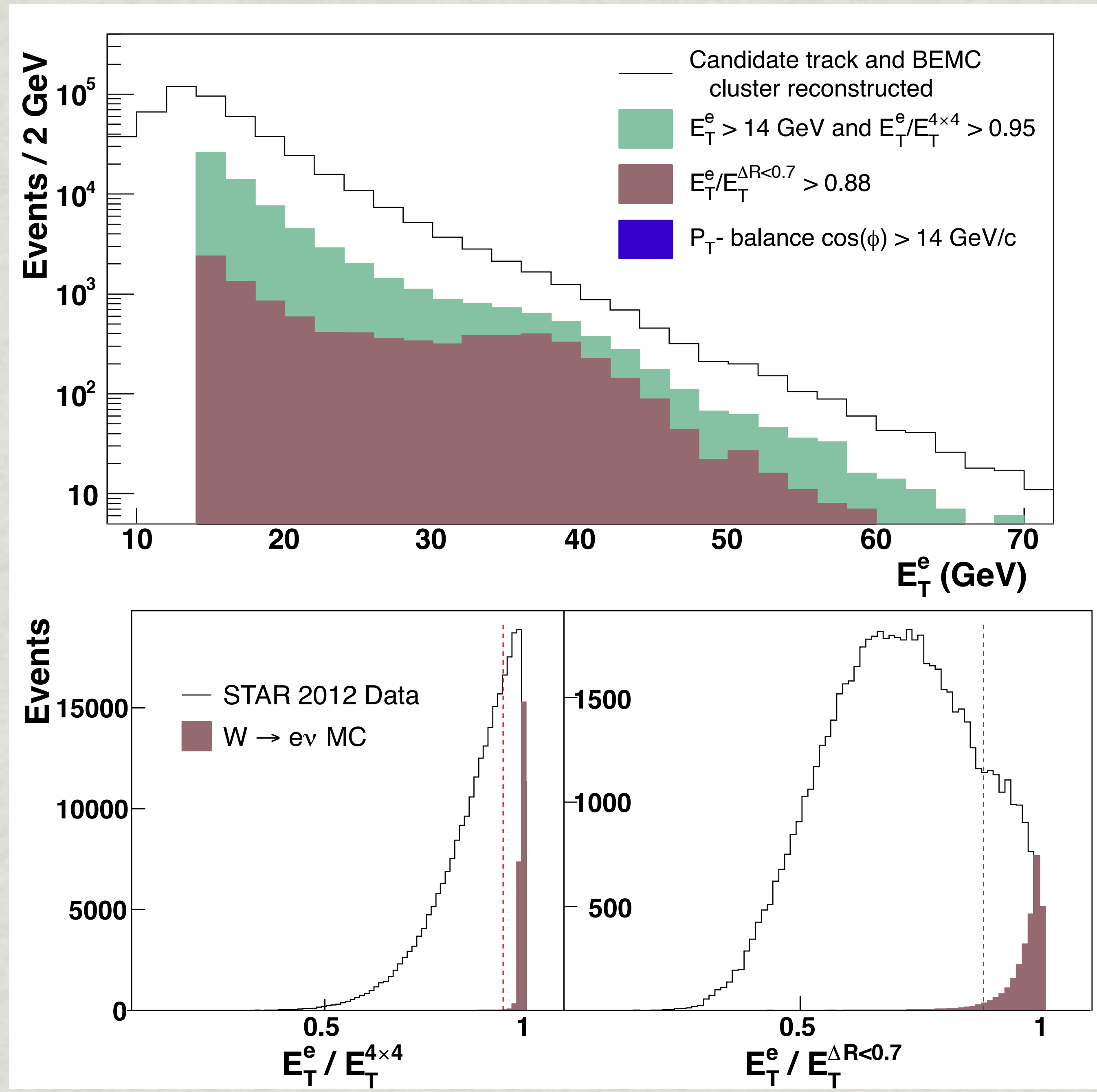




How do we find Ws?

- Match p_T > 10 GeV track to BEMC cluster
- Isolation Ratios





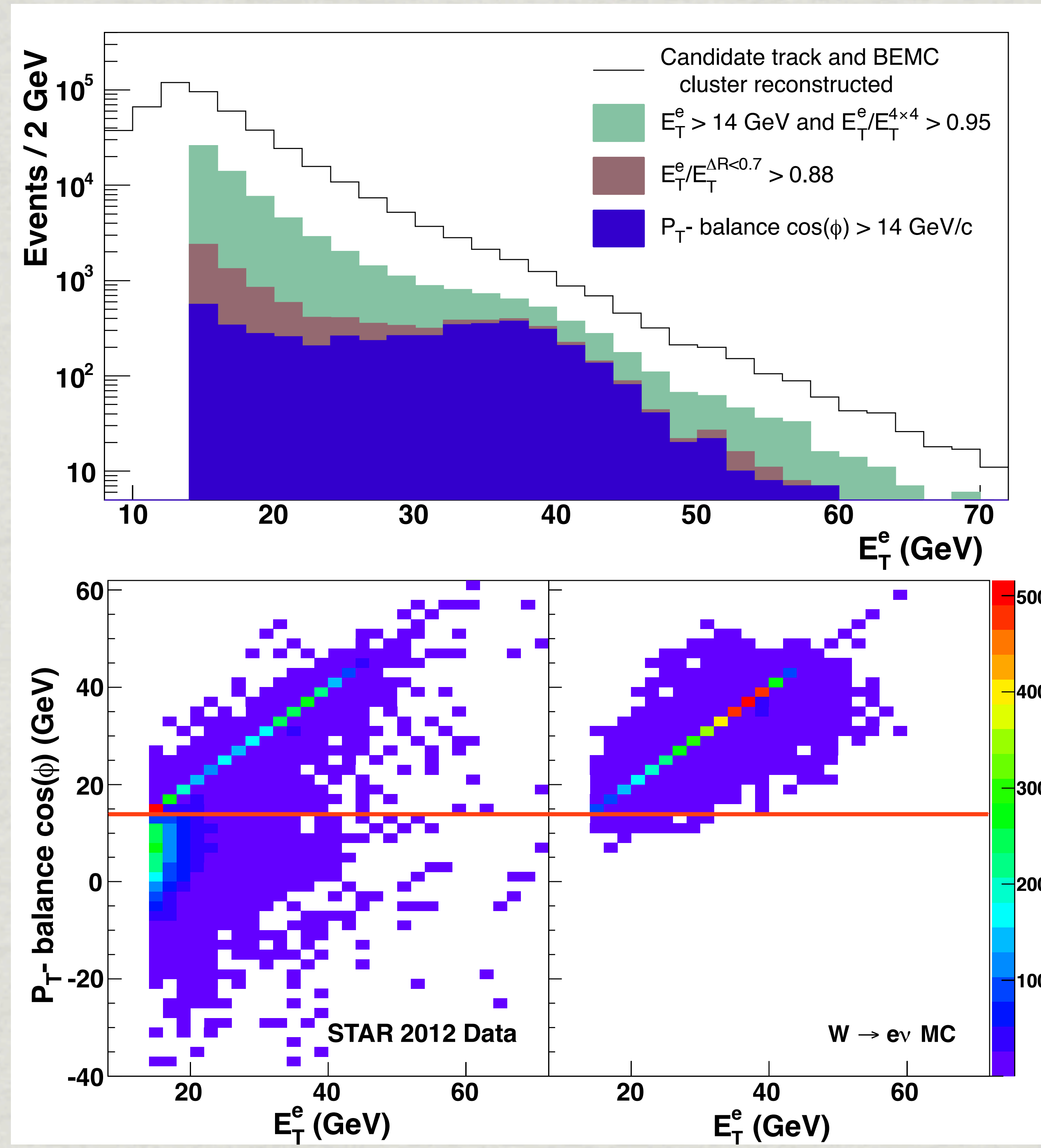
How do we find Ws?

- Match $p_T > 10$ GeV track to BEMC cluster
- Isolation Ratios
- P_T-balance

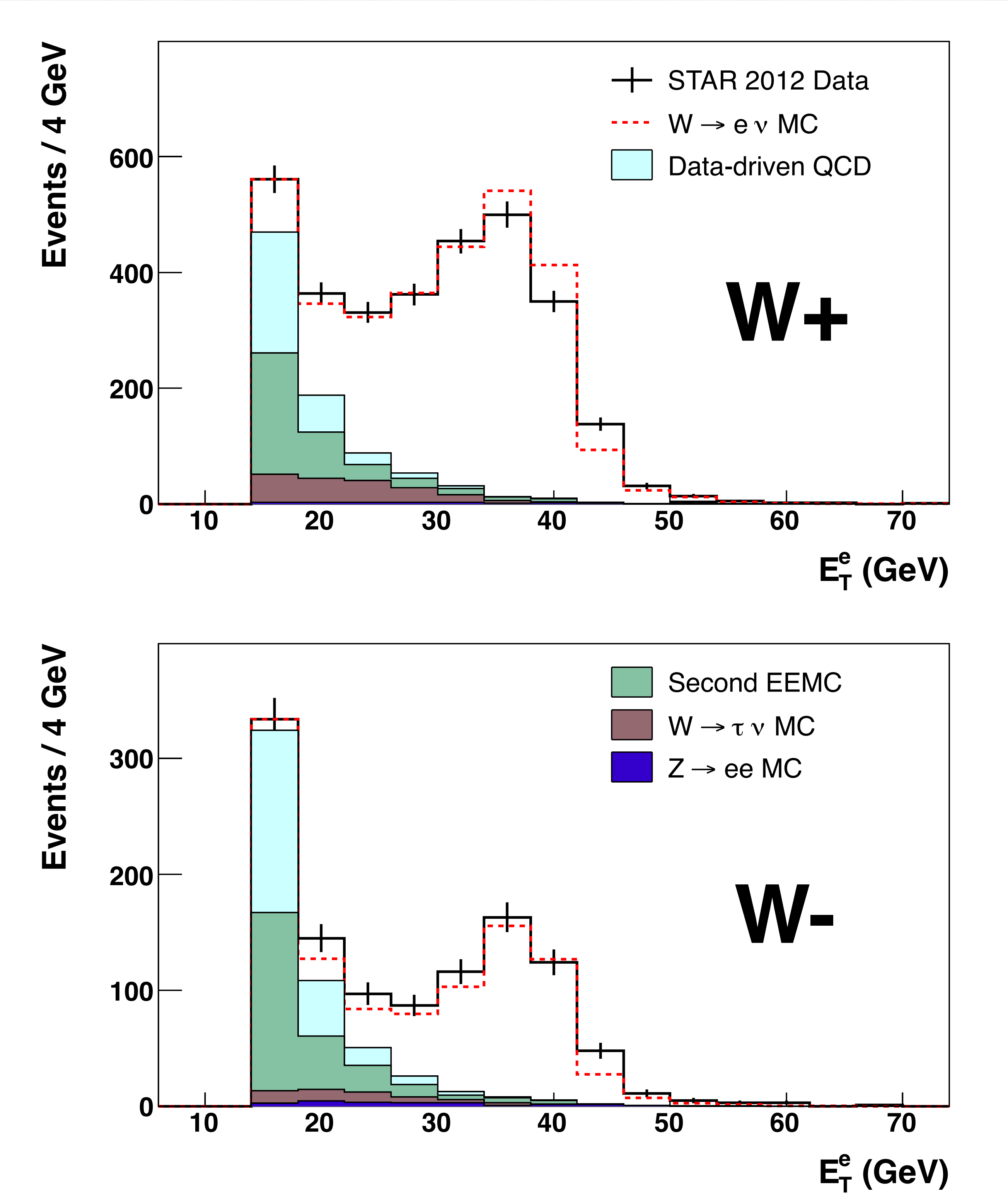
$$\vec{p_T}^{\,bal} = \vec{p_T}^{\,e} + \sum_{\Delta R > 0.7} \vec{p_T}^{\,jets}$$

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

Transverse Plane View



Mid-rapidity Background Estimation



W Signal

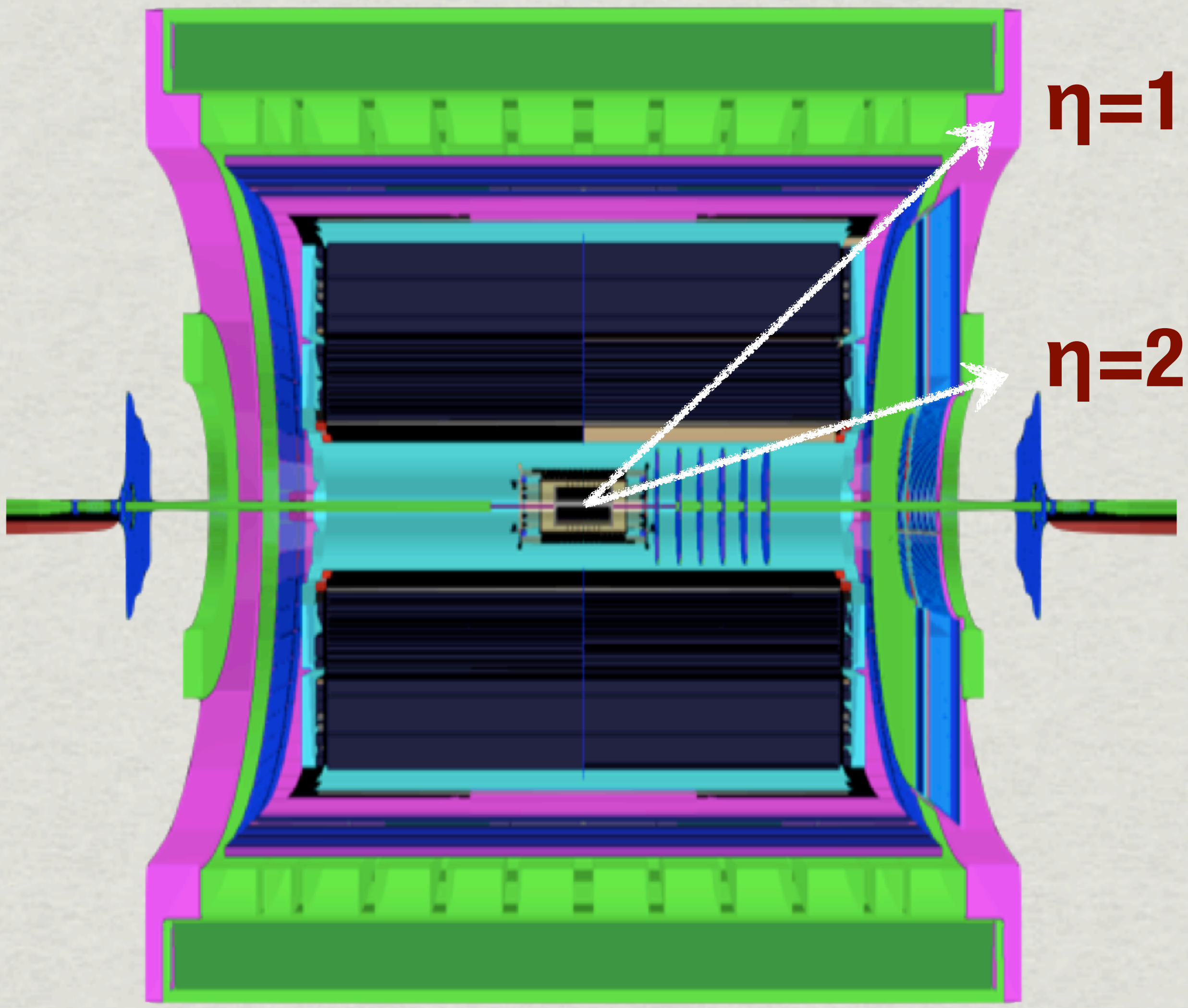
- "Jacobian Peak"

Background Estimation

- Electroweak
  - Z → ee MC
  - W → τν MC
- Second EEMC
- Data-driven QCD

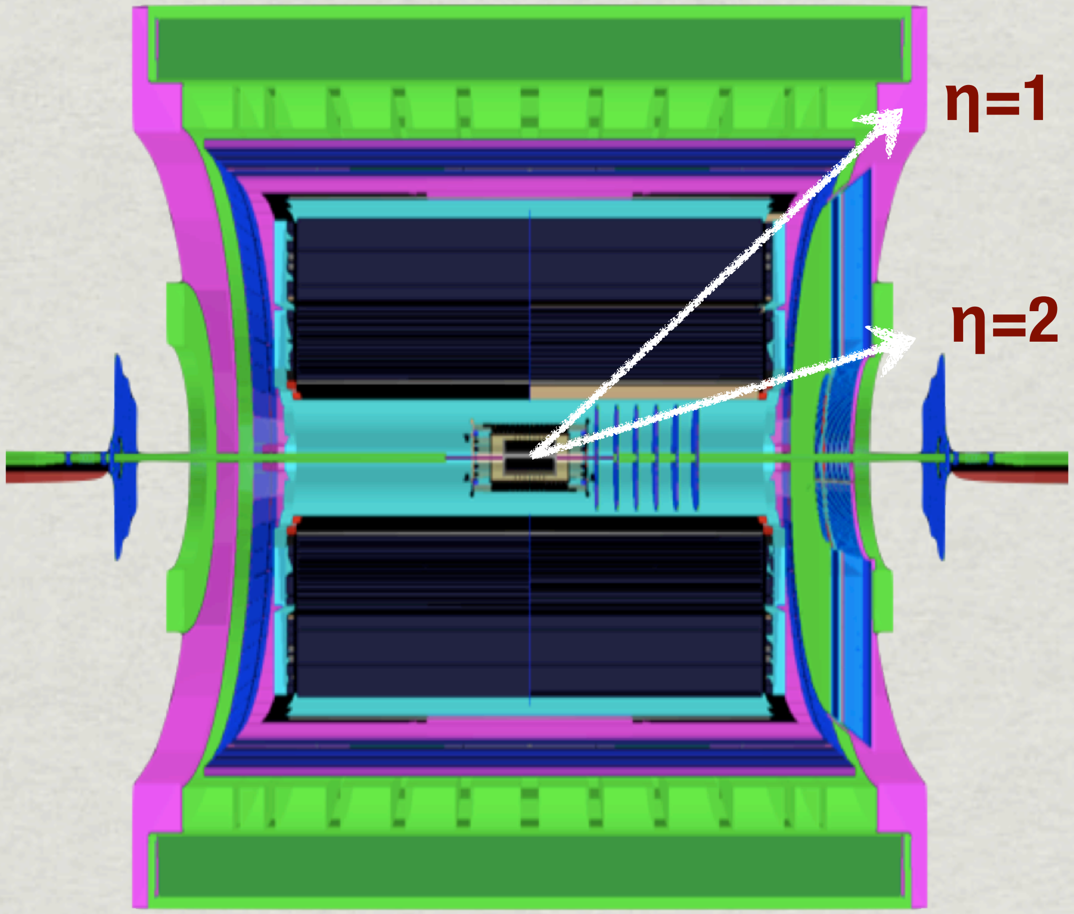
NEW!

Forward Rapidity Ws at STAR

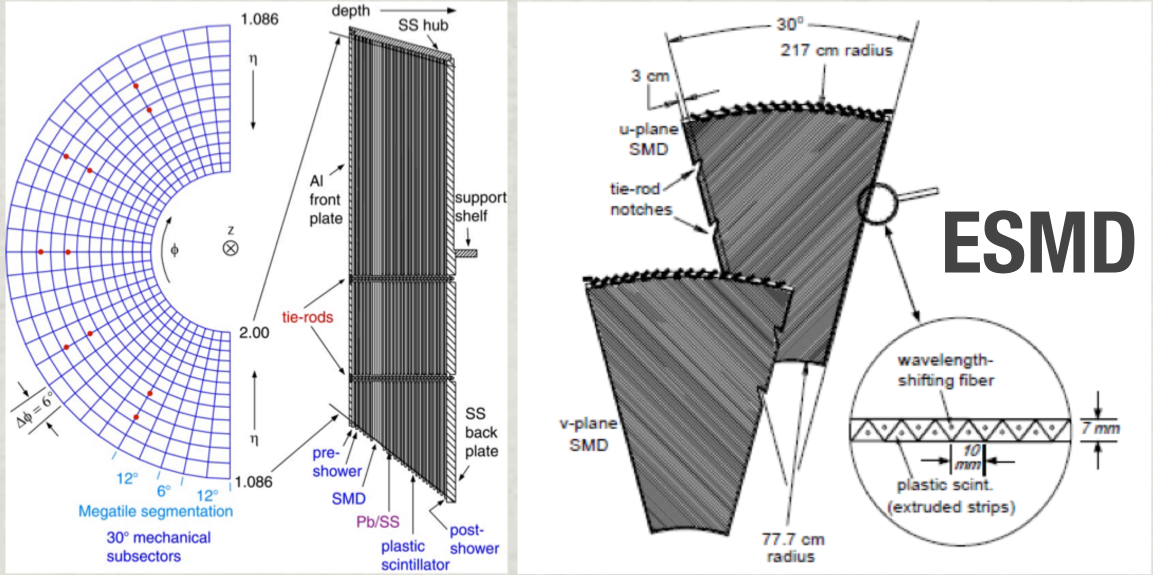


Forward Rapidity Analysis

- Similar concept as mid-rapidity:
  - Utilize TPC which extends to η ~1.4 to reconstruct high p_T TPC track
  - Use isolation ratios and vector p_T imbalance to reduced QCD background
- Improve background rejection by using the Endcap Shower Maximum Detector



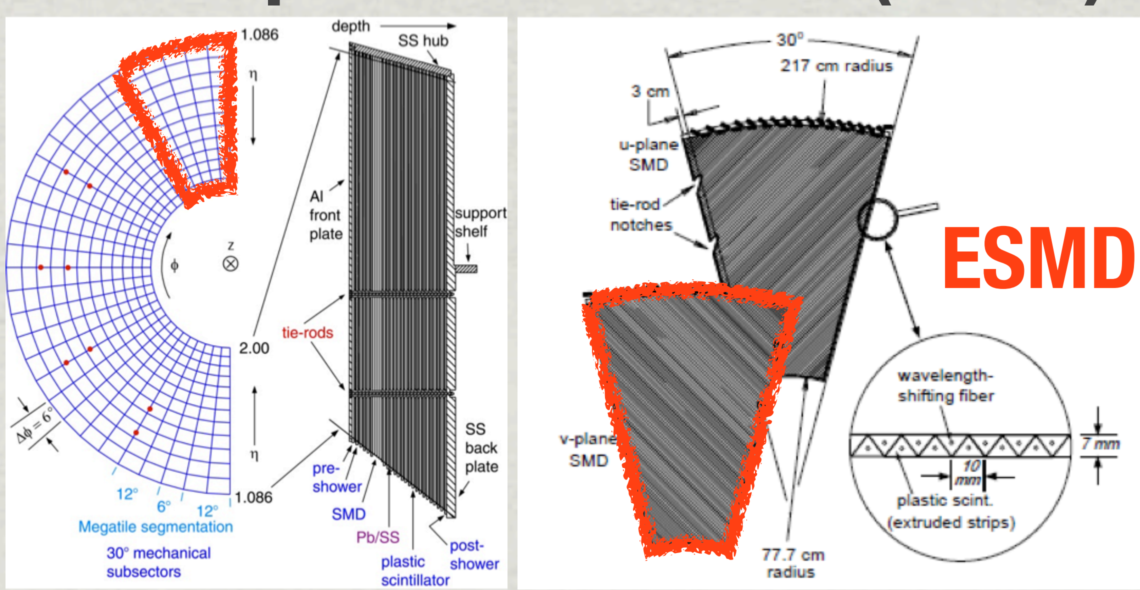
Endcap EM Calorimeter (EEMC)



Forward Rapidity Analysis

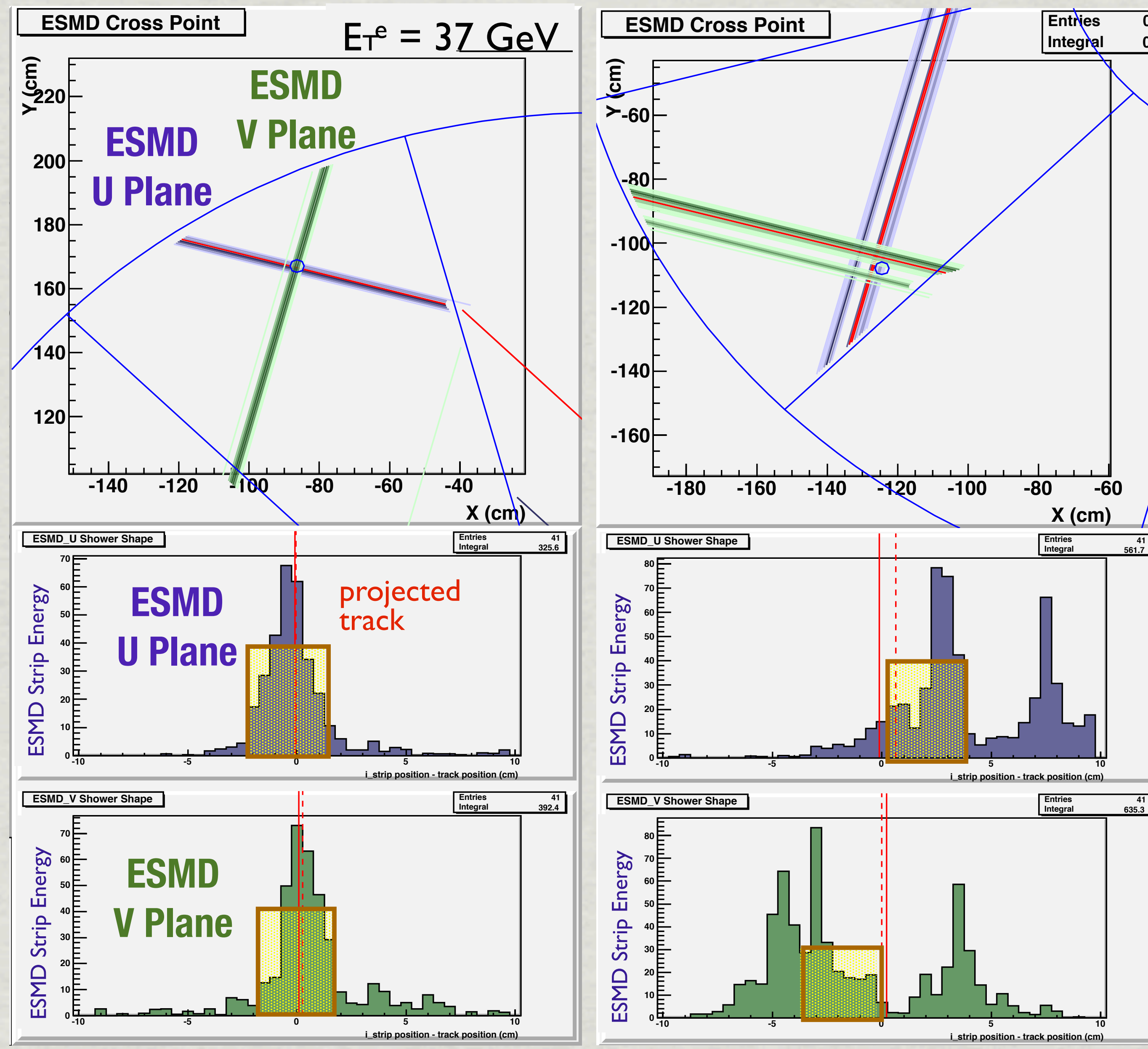
- Similar concept as mid-rapidity:
  - Utilize TPC which extends to η ~1.4 to reconstruct high p_T TPC track
  - Use isolation ratios and vector p_T imbalance to reduced QCD background
- Improve background rejection by using the Endcap Shower Maximum Detector

Endcap EM Calorimeter (EEMC)



2012 data events which satisfy all previous cuts

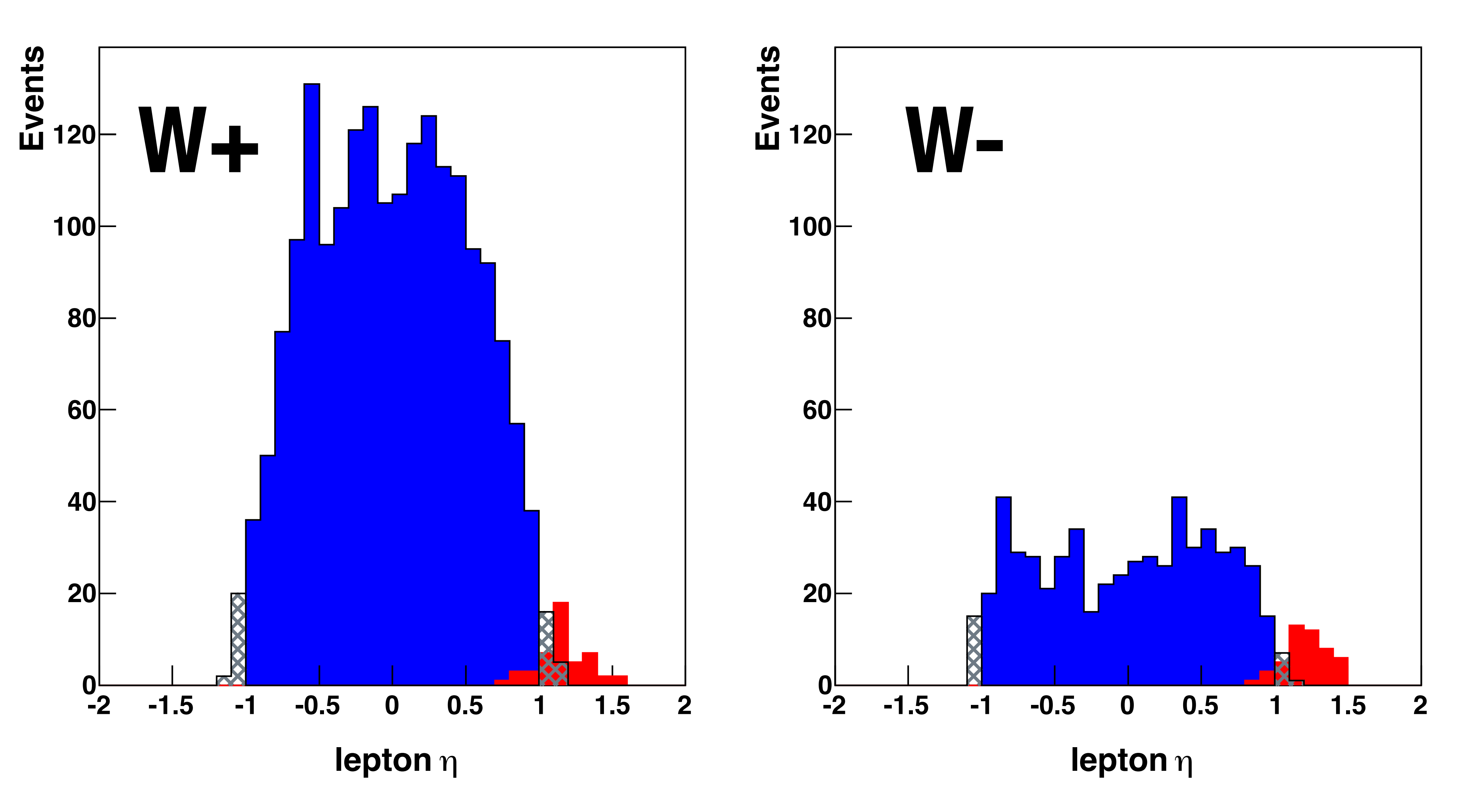
Signal Example | **Background Example**



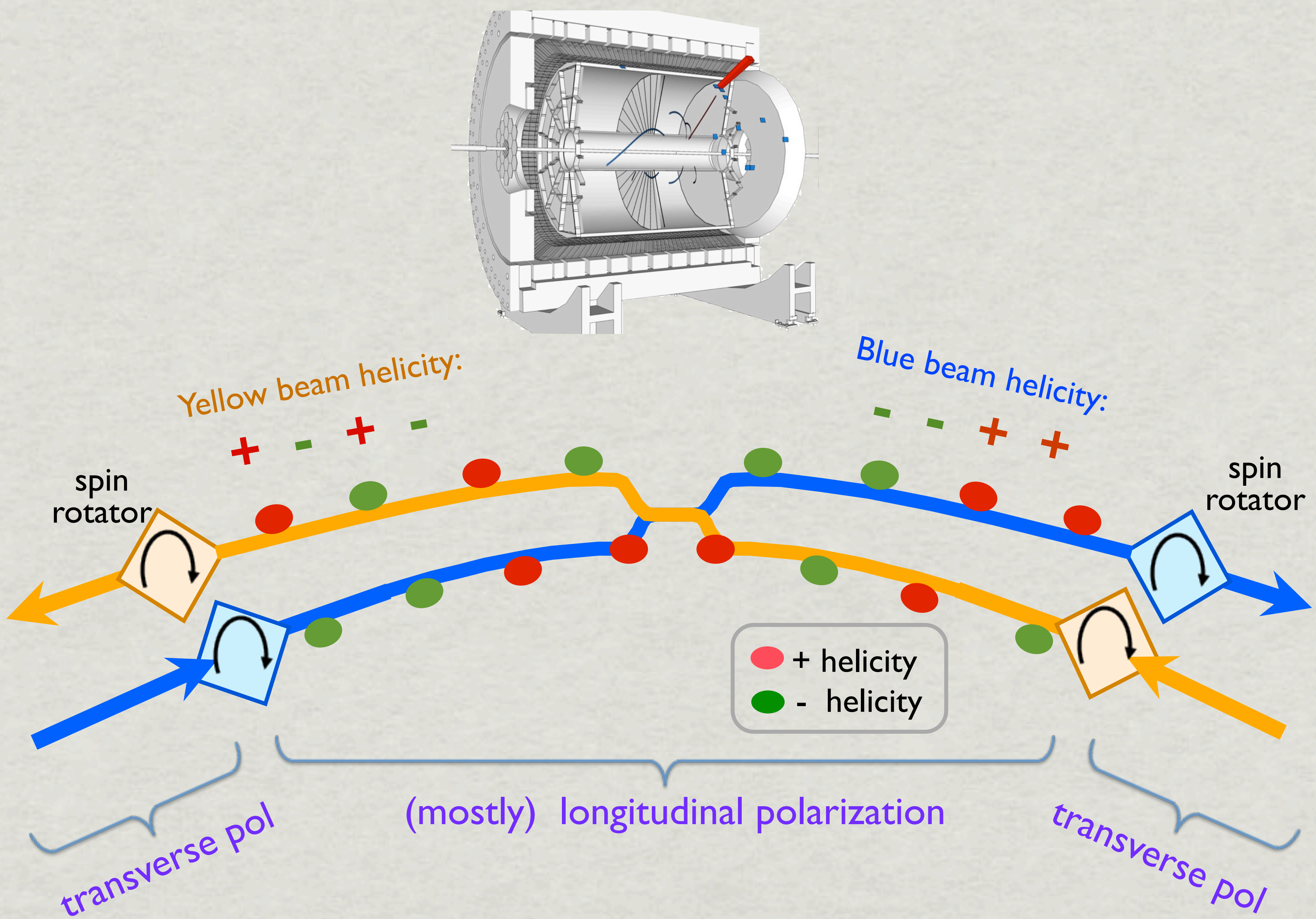
2012 STAR W Candidate Yields vs η

Mid-rapidity (Barrel) Ws

Forward rapidity (Endcap) Ws



Spin Asymmetry: $A_L(\eta_e)$



STAR sees four helicity configurations

Single Asymmetric η Slice

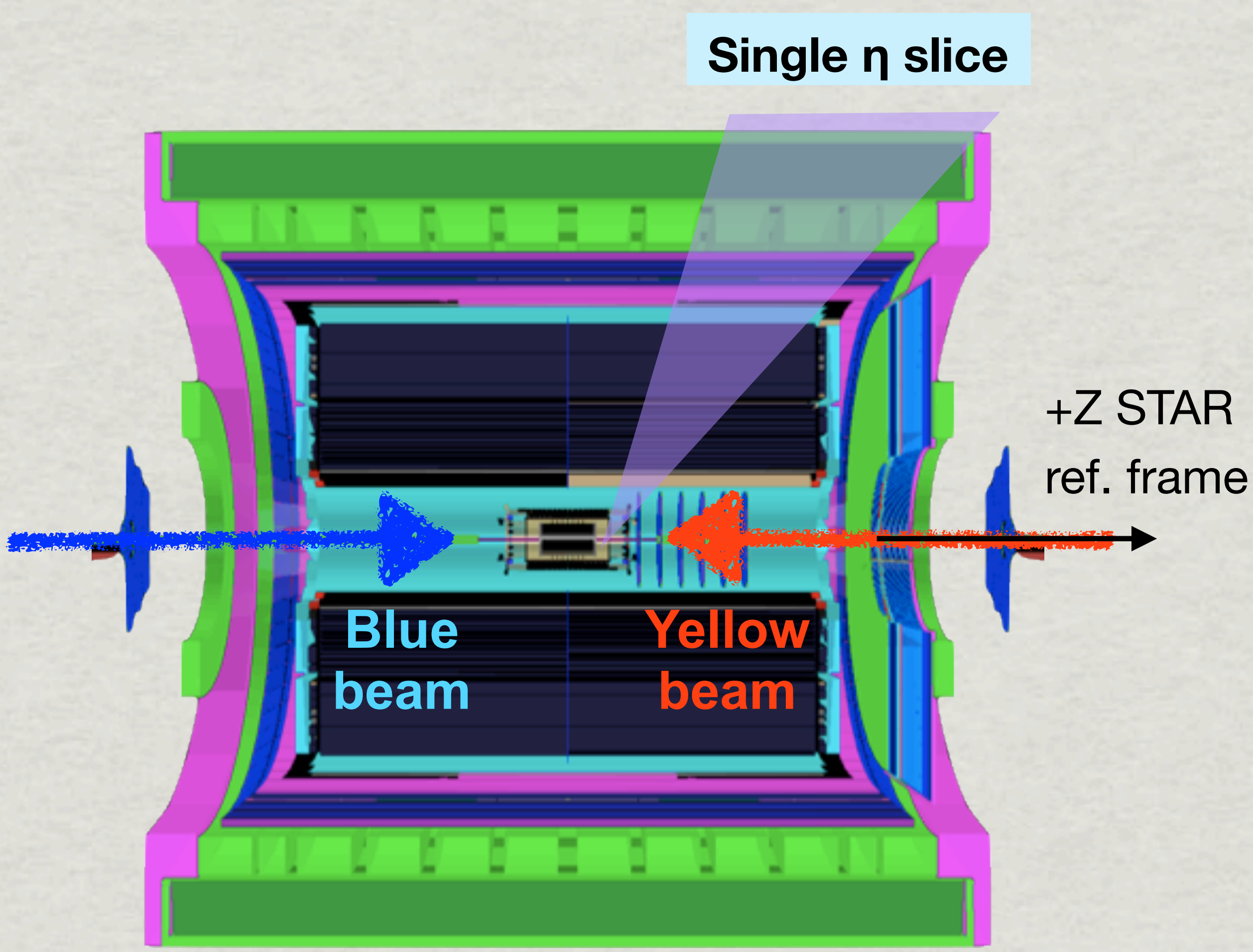
$$
\begin{aligned}
N^{++}_{\eta STAR}/\mathcal{L}^{++} &= \mathcal{C}_{\eta STAR}\,[\,1 + A_L(\eta)P_1^L + A_L(-\eta)P_2^L + A_{LL}(|\eta|)P_1^L P_2^L\,] \quad \#1 \\
N^{+-}_{\eta STAR}/\mathcal{L}^{+-} &= \mathcal{C}_{\eta STAR}\,[\,1 + A_L(\eta)P_1^L - A_L(-\eta)P_2^L - A_{LL}(|\eta|)P_1^L P_2^L\,] \quad \#2 \\
N^{-+}_{\eta STAR}/\mathcal{L}^{-+} &= \mathcal{C}_{\eta STAR}\,[\,1 - A_L(\eta)P_1^L + A_L(-\eta)P_2^L - A_{LL}(|\eta|)P_1^L P_2^L\,] \quad \#3 \\
N^{--}_{\eta STAR}/\mathcal{L}^{--} &= \mathcal{C}_{\eta STAR}\,[\,1 - A_L(\eta)P_1^L - A_L(-\eta)P_2^L + A_{LL}(|\eta|)P_1^L P_2^L\,] \quad \#4
\end{aligned}
$$

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{1}{P}\frac{N_+/\mathcal{L}_+ - N_-/\mathcal{L}_-}{N_+/\mathcal{L}_+ + N_-/\mathcal{L}_-}$$

Blue beam pol: $A_L(+\eta)$

Yellow beam pol: $A_L(-\eta)$

A_{LL} |η|



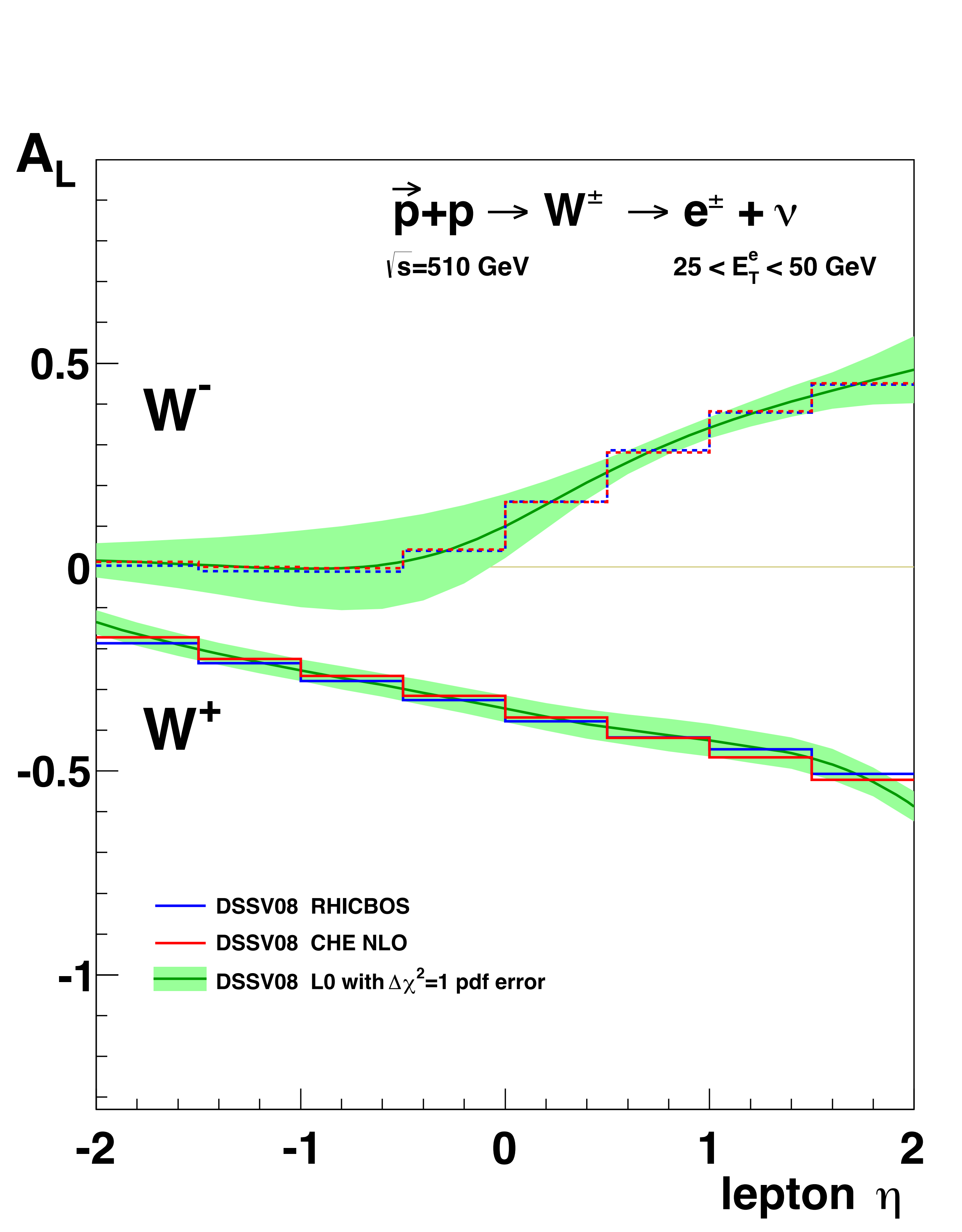
A_L for both beams measured from 4 spin dependent yields

$$A_L^{sig}(+\eta) = \frac{1+2-3-4}{P_1^L \cdot \Sigma 1\ldots 4}$$

$$A_L^{sig}(-\eta) = \frac{1-2+3-4}{P_2^L \cdot \Sigma 1\ldots 4}$$

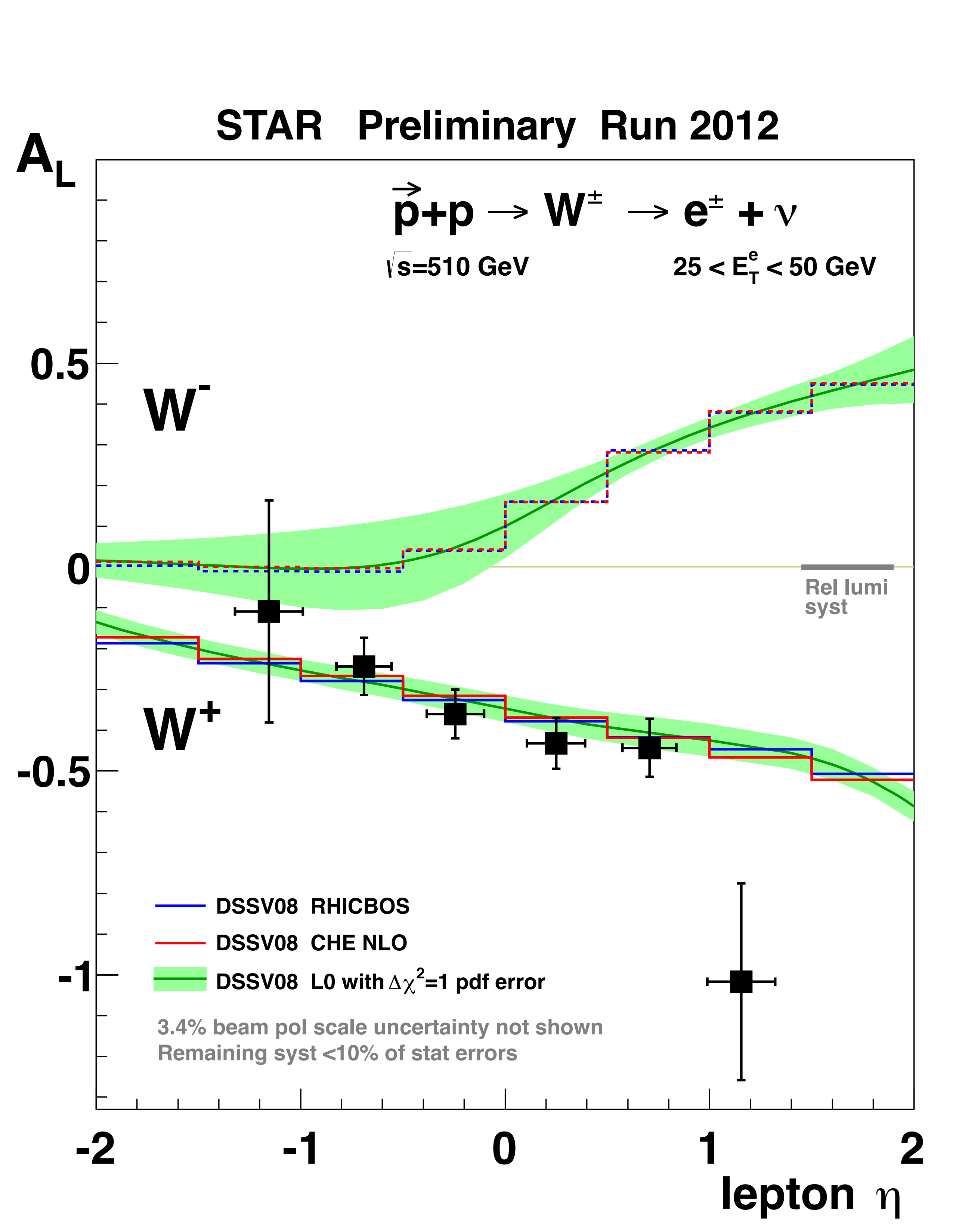
NEW!

STAR 2012 W $A_L(\eta)$



NEW!

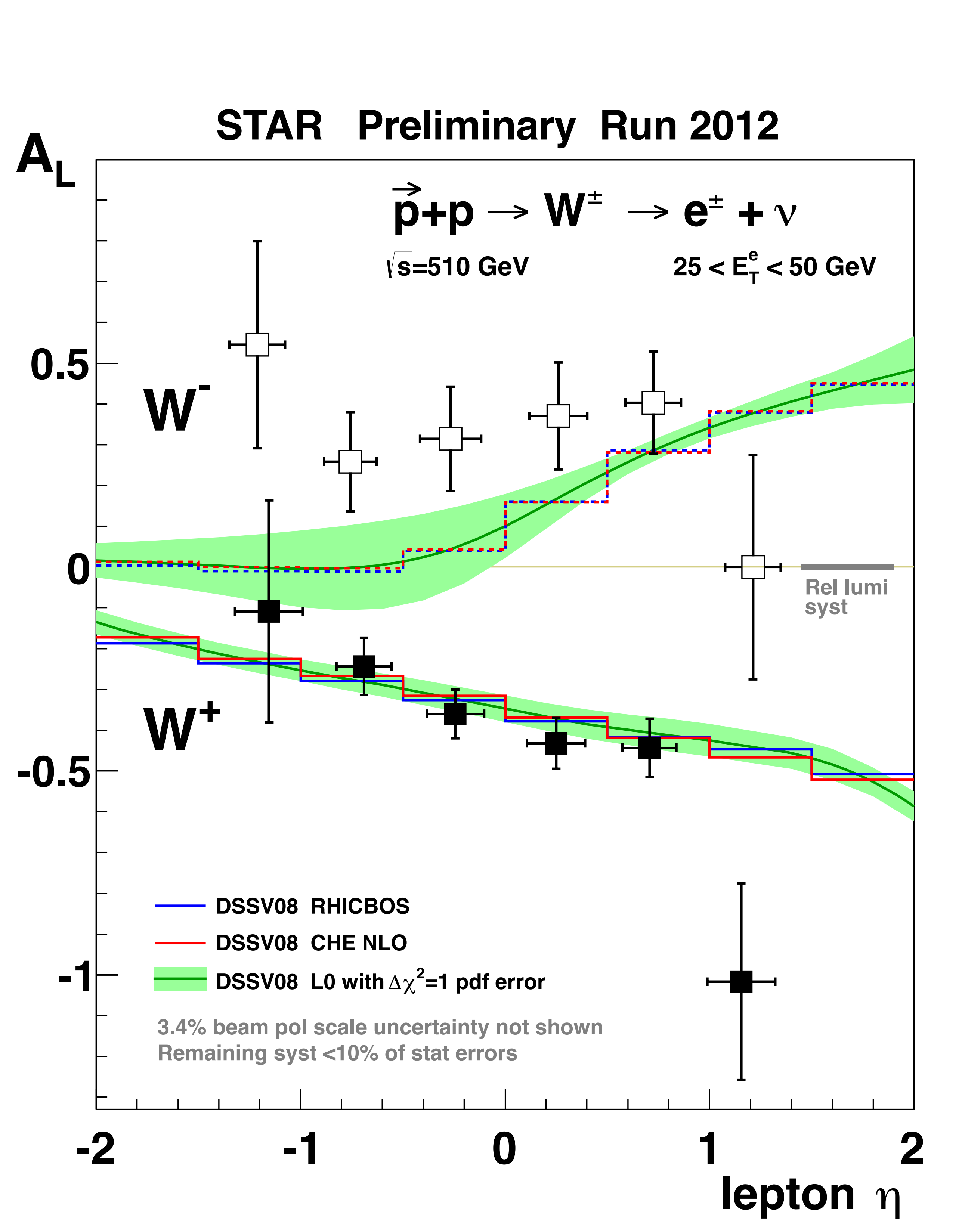
STAR 2012 W $A_L(\eta)$



- $A_L(W+)$ is consistent with theoretical predictions using the DSSV polarized PDFs

NEW!

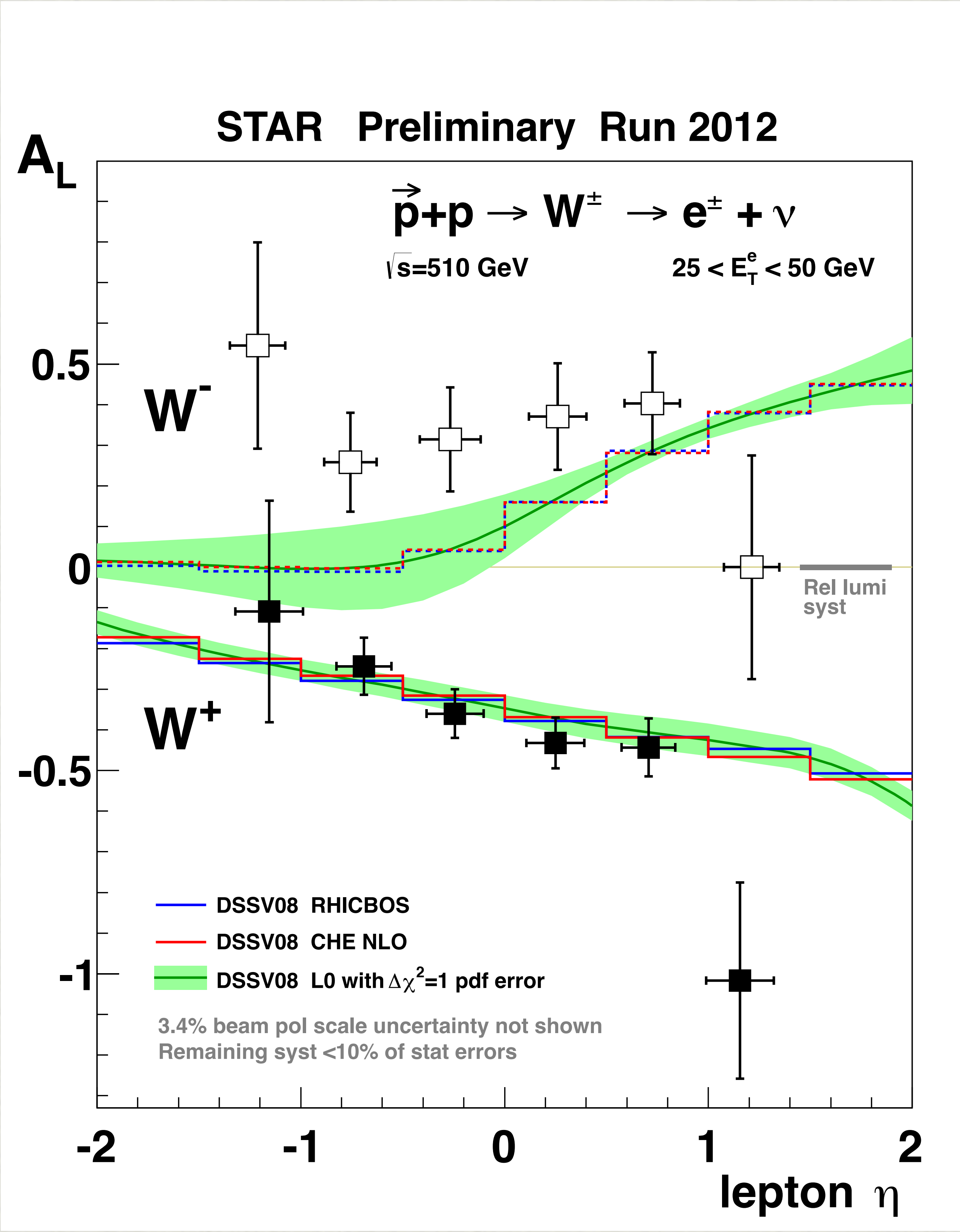
STAR 2012 W $A_L(\eta)$



- $A_L(W-)$ is systematically 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

NEW!

STAR 2012 W $A_L(\eta)$



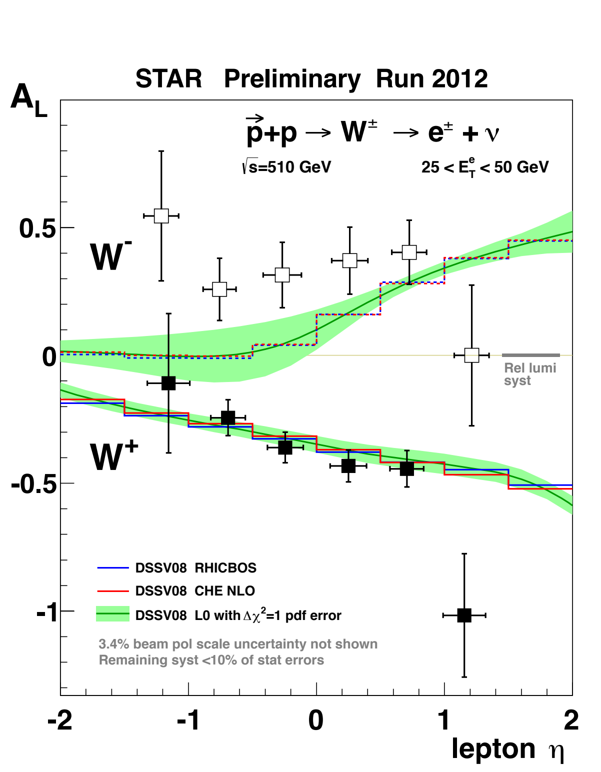
- $A_L(W-)$ is systematically larger than the DSSV predictions
  - The enhancement at $\eta_e<0$, in particular, is sensitive to the $\Delta\bar{u}$ polarized antiquark distribution
- $A_L(W+)$ is consistent with theoretical predictions using the DSSV polarized PDFs
- The systematic uncertainties for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

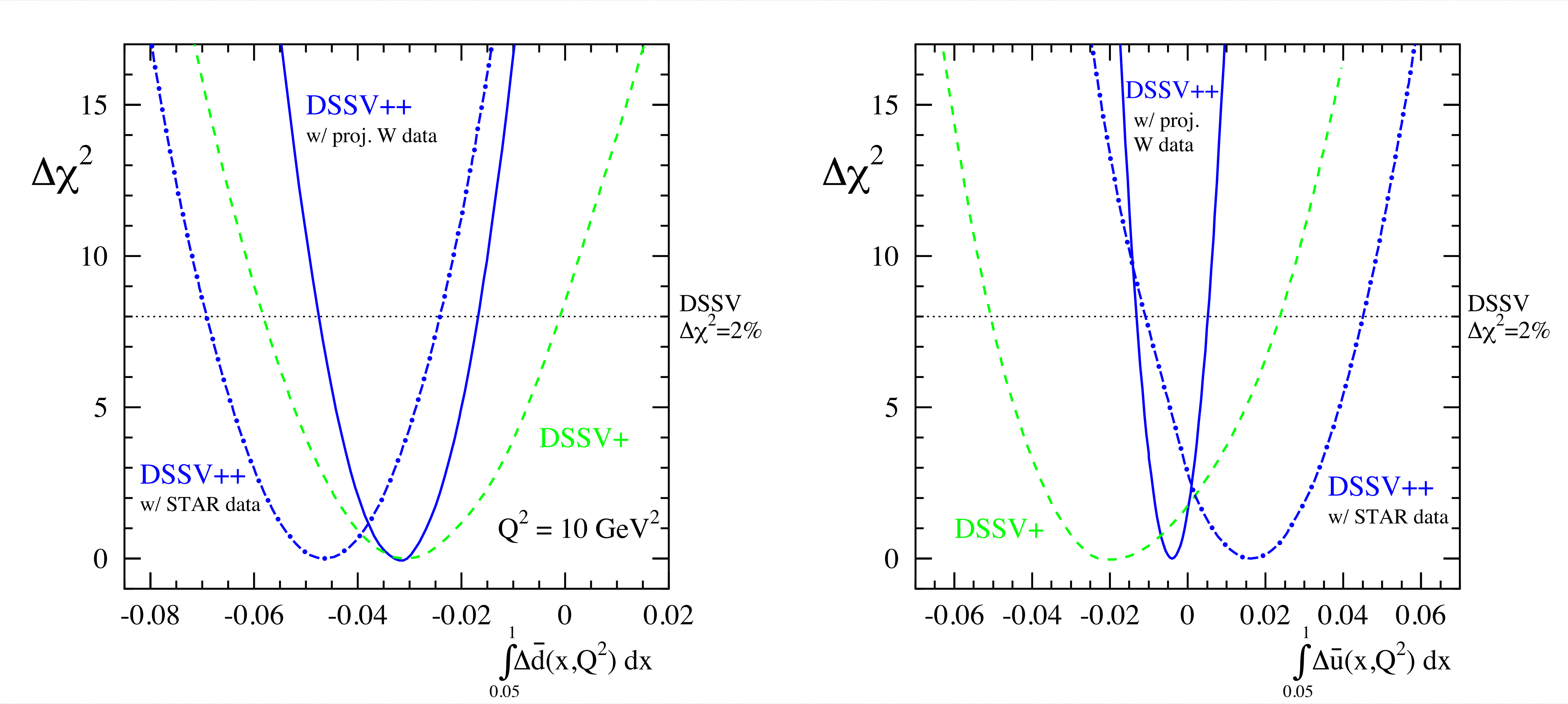
NEW!

DSSV++ Global Analysis

- DSSV++ is a new preliminary global analysis from the DSSV group that includes RHIC 2009 A_{LL} data and STAR 2012 W A_L data

- Significant shift in $\Delta\bar{u}$ due to A_L W-



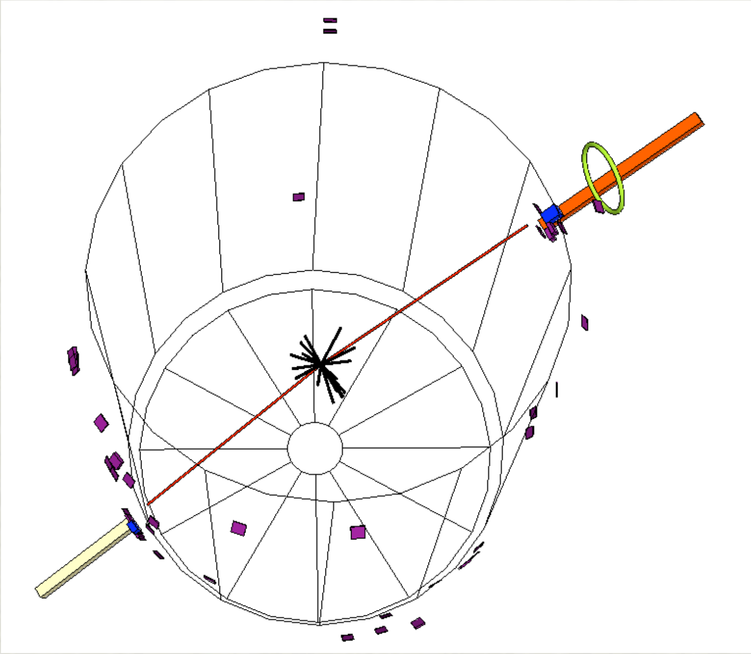


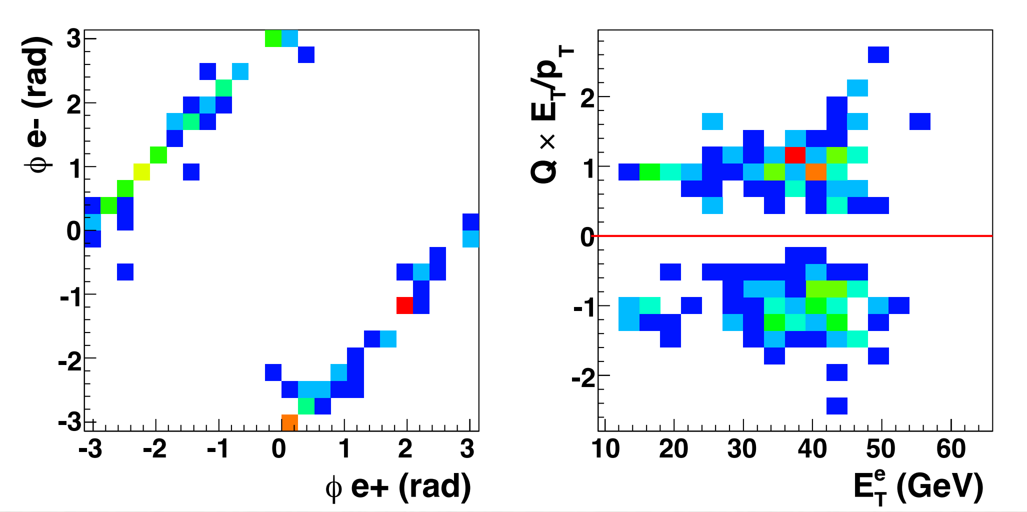
Special thanks to the DSSV group!

NEW!

STAR 2012 Z A_L

$Z \rightarrow e^+e^-$ Candidate

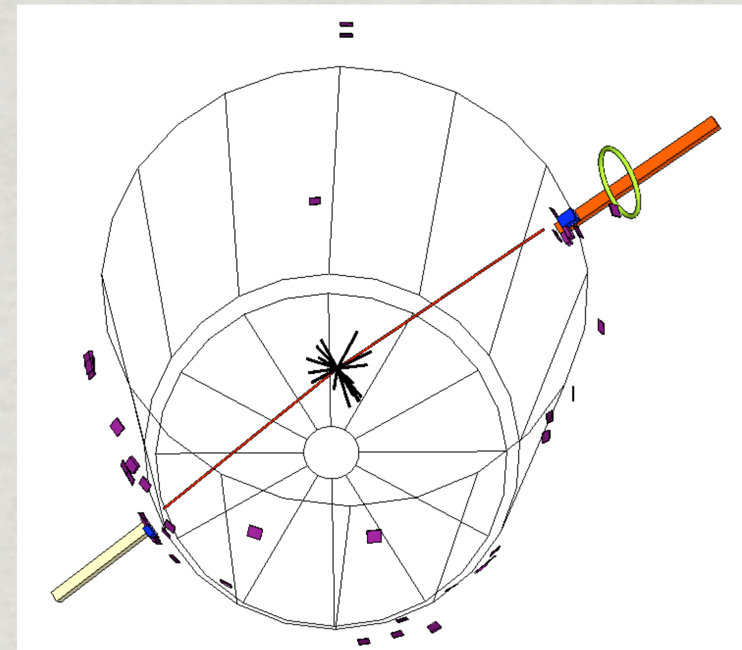


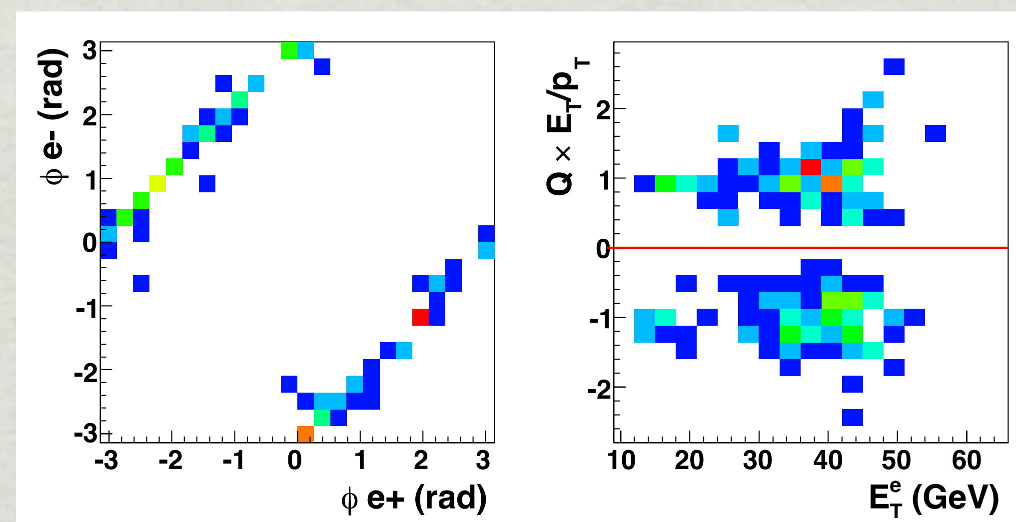


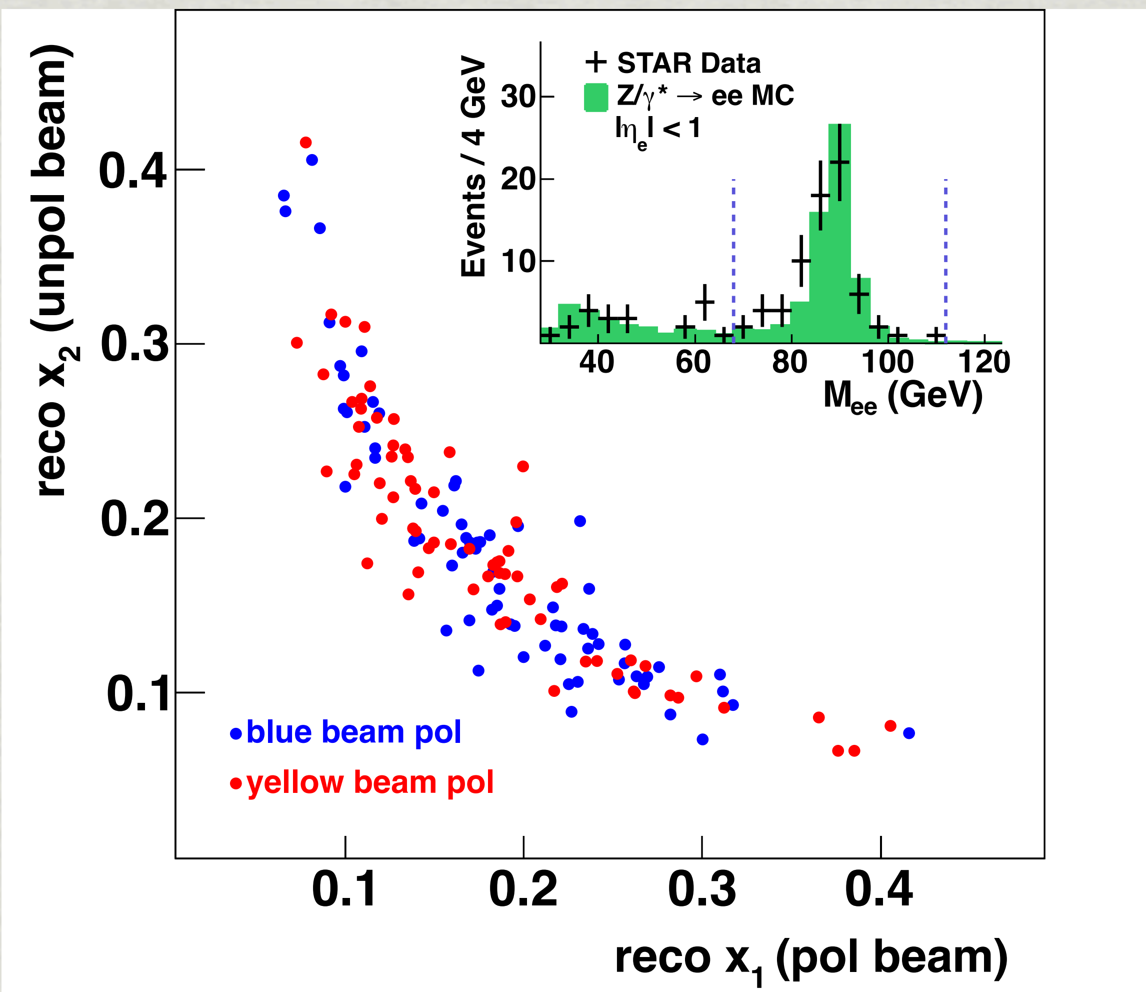
NEW!

STAR 2012 Z A_L

$Z \rightarrow e^+e^-$ Candidate





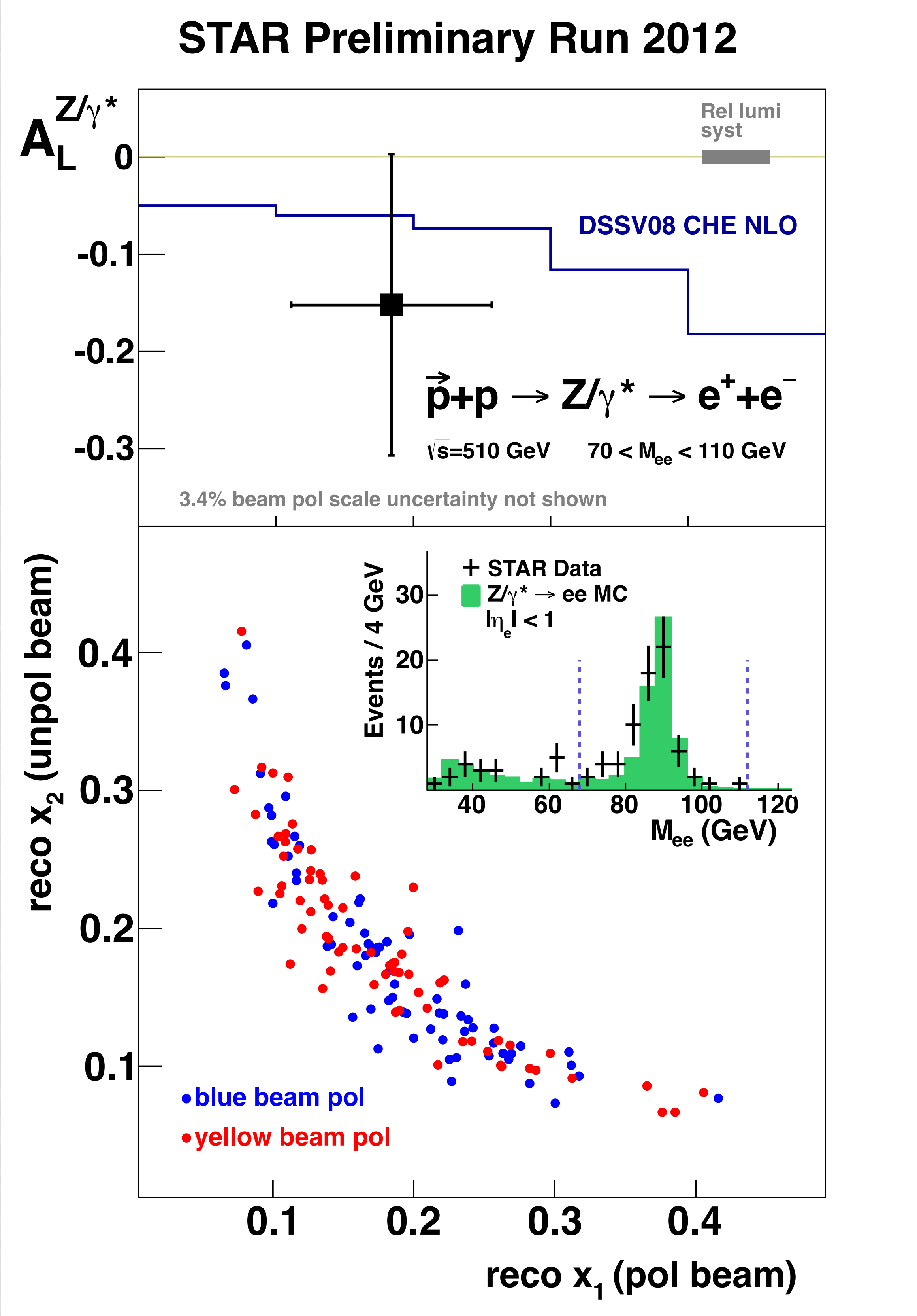


Reconstruct initial state kinematics at leading order:

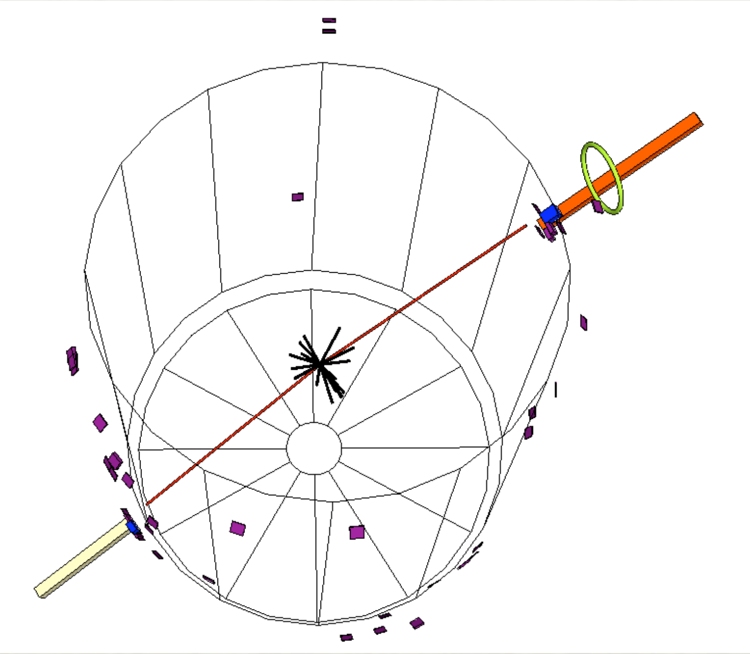
$$x_{1(2)} = \frac{M_{ee}}{\sqrt{s}} e^{\pm y_Z}$$

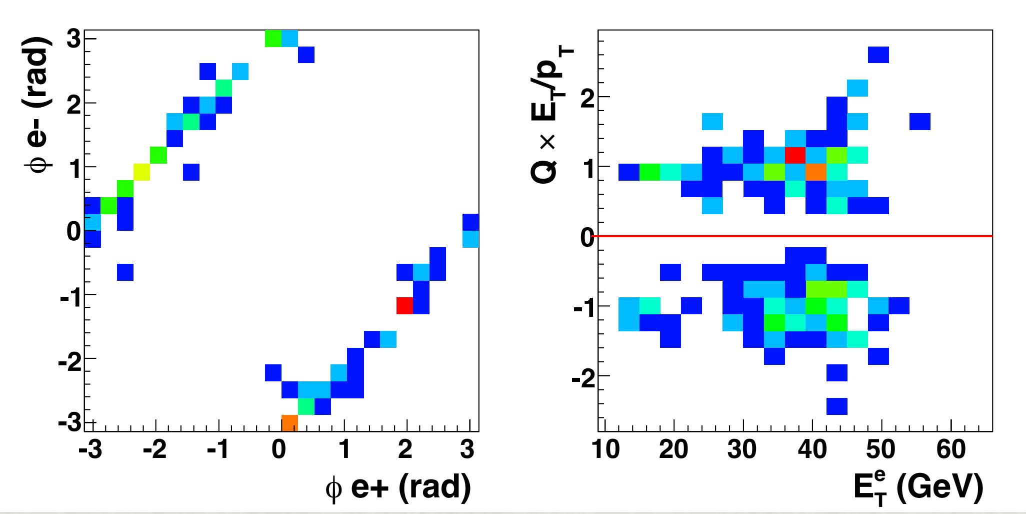
NEW!

STAR 2012 Z A_L



Z → e+e- Candidate

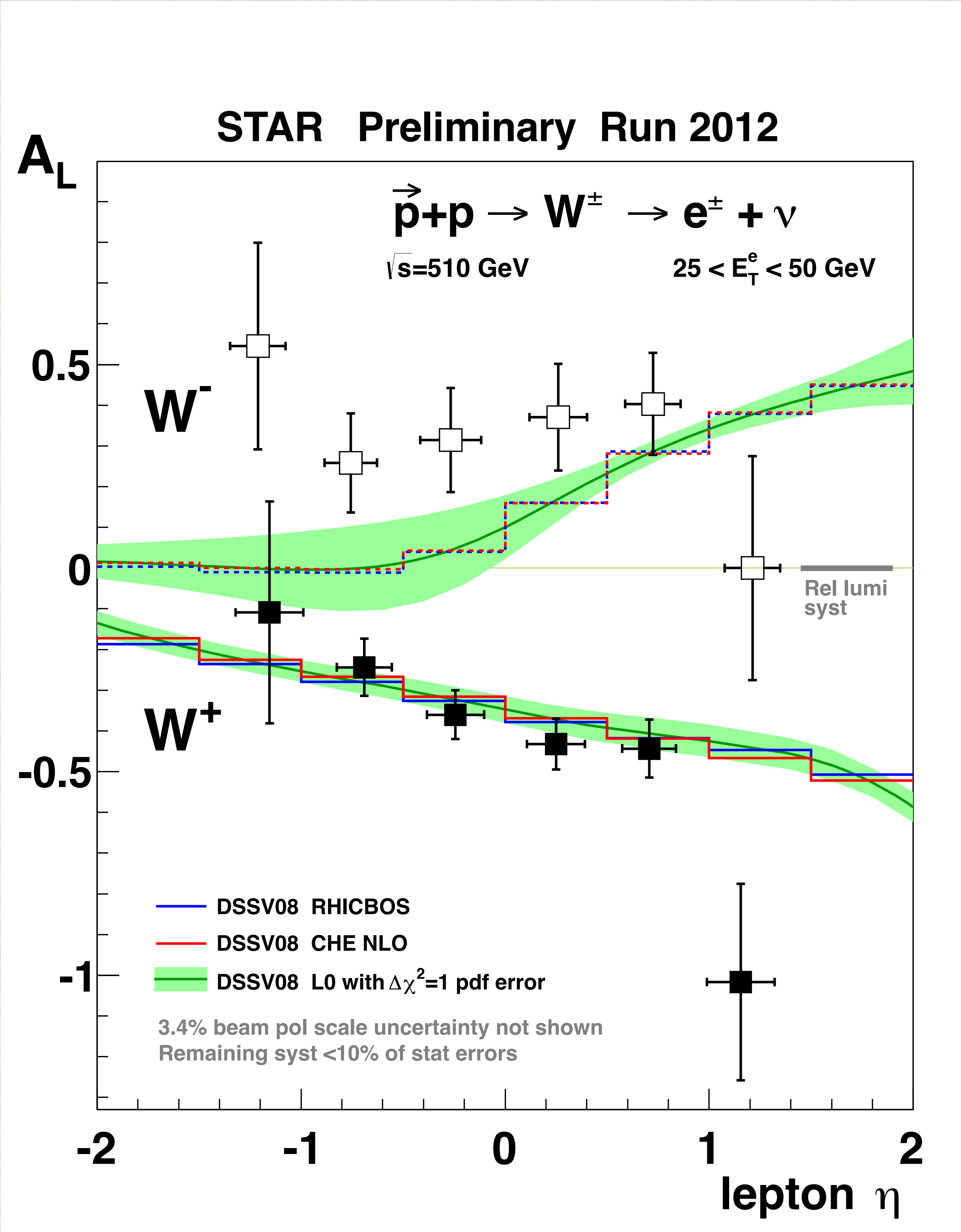




Reconstruct initial state kinematics at leading order:

$$x_{1(2)} = \frac{M_{ee}}{\sqrt{s}} e^{\pm y_Z}$$

Summary



- The production of W bosons in polarized p+p collisions provides a new means of studying 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 Run 12 data, providing the first detailed look at the asymmetry's η_e dependence
- A_L for Z/γ^* production was also measured, and is consistent with the theoretical predictions