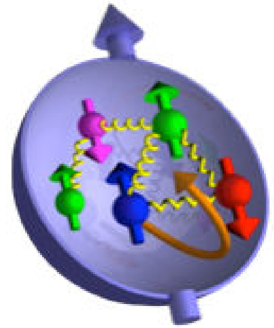
Recent results on W A_L in longitudinally polarized p+p collision at STAR

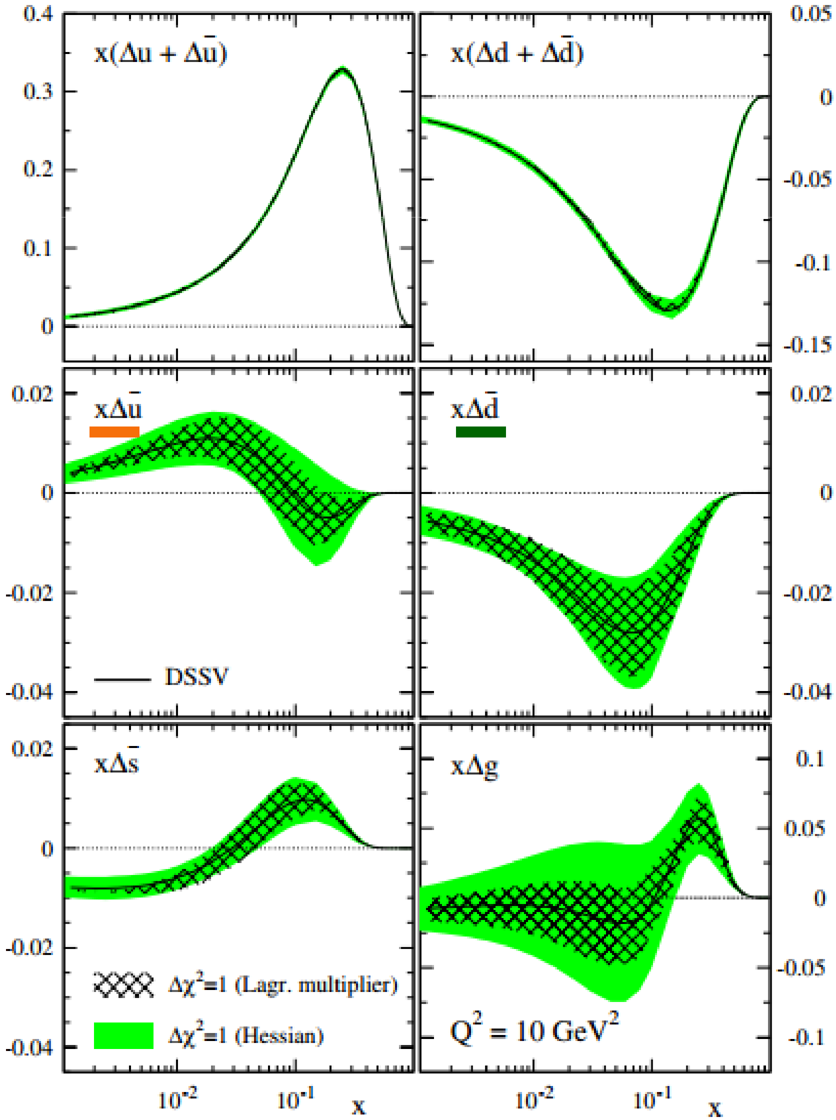
Jinlong Zhang for the STAR collaboration

DNP meeting Oct 24, 2013

Motivation



DSSV Global Analysis



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Proton Spin Puzzle :

$$\langle S_p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$ (Jaffe-Manohar, 1990)

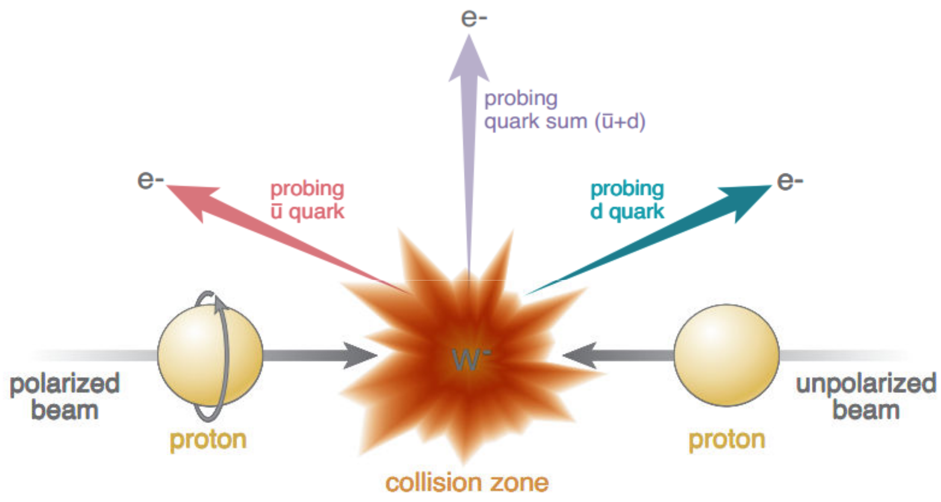
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s})\,dx$$

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

Flavor-separate anti-quark polarized PDF measurement

$$\Delta q(x) \equiv q^{+}(x) - q^{-}(x)$$

Why W ?



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

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

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

Measure parity-violating single-spin asymmetry:

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

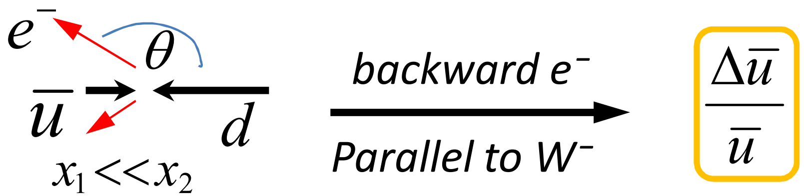
$$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} = \begin{cases} -\dfrac{\Delta u(x_1)}{u(x_1)}, y_{W^+} >> 0 \\ \dfrac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}, y_{W^+} << 0 \end{cases}$$

$$A_L^{W^-} \propto \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)} = \begin{cases} -\dfrac{\Delta d(x_1)}{d(x_1)}, y_{W^-} >> 0 \\ \dfrac{\Delta\bar{u}(x_1)}{\bar{u}(x_1)}, y_{W^-} << 0 \end{cases}$$

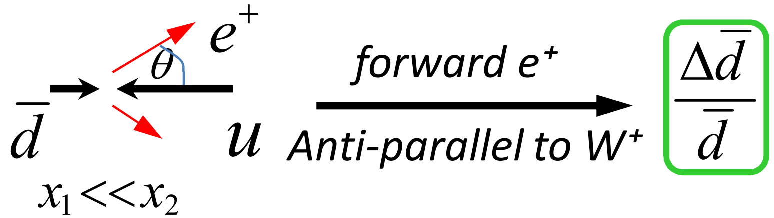
Expectations for W AL

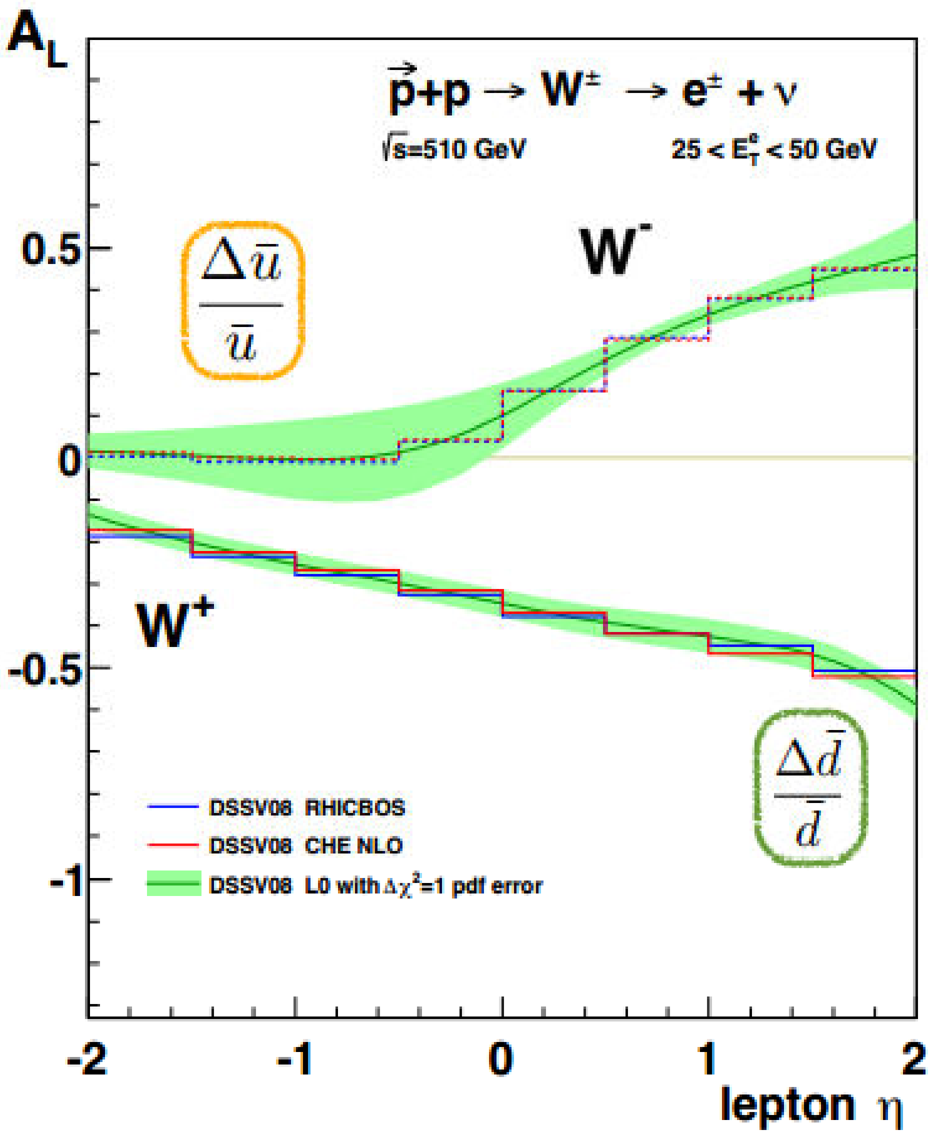
- Large parity-violating asymmetries expected.
- Simplified interpretation at forward and backward rapidity.

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



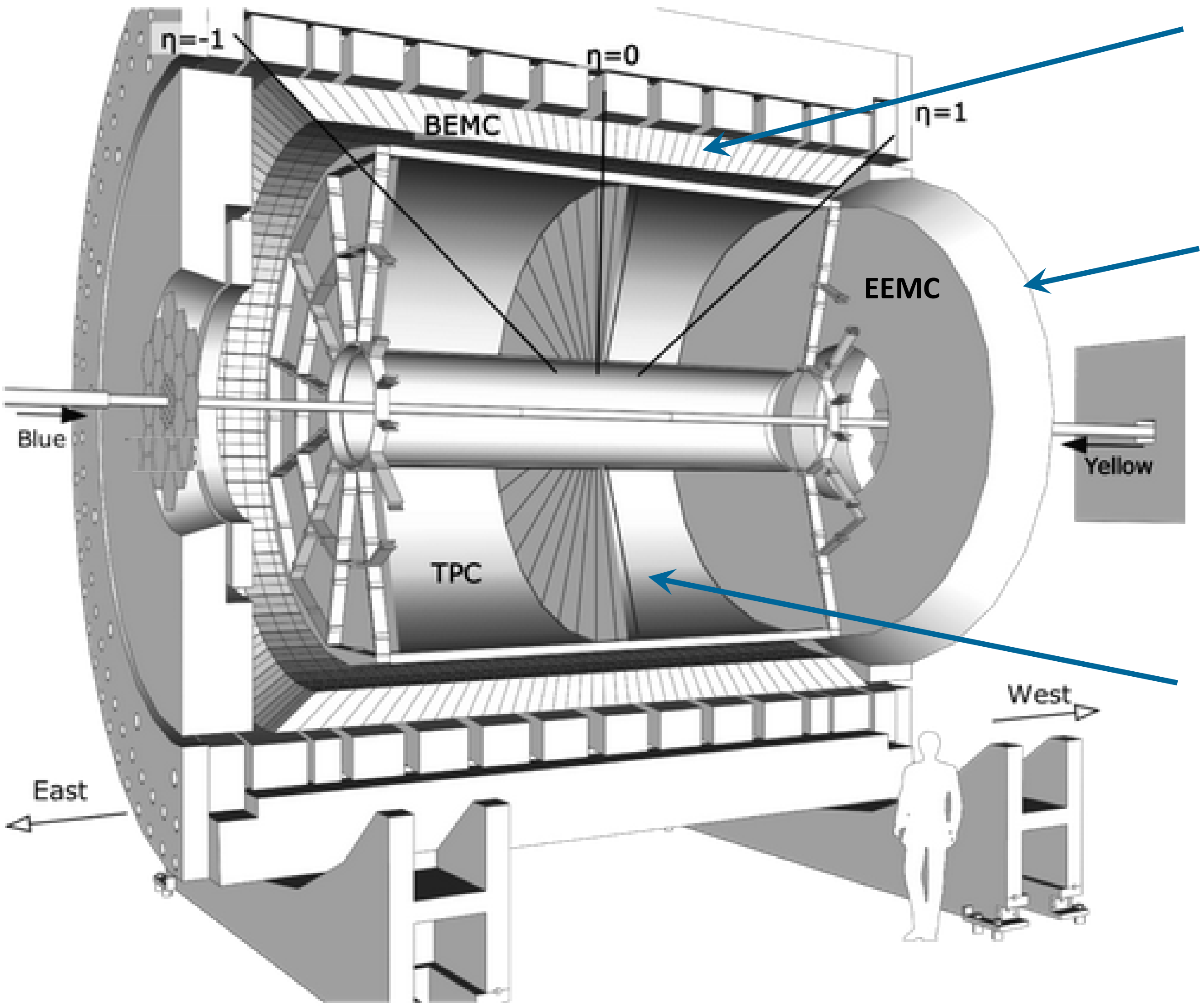
➢ $$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2)+\Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2)+\bar{d}(x_1)u(x_2)}$$





* Charged lepton tends to emit parallel (anti-parallel) to W^-(W^+) due to the handedness of produced neutrino.

STAR Detector Overview



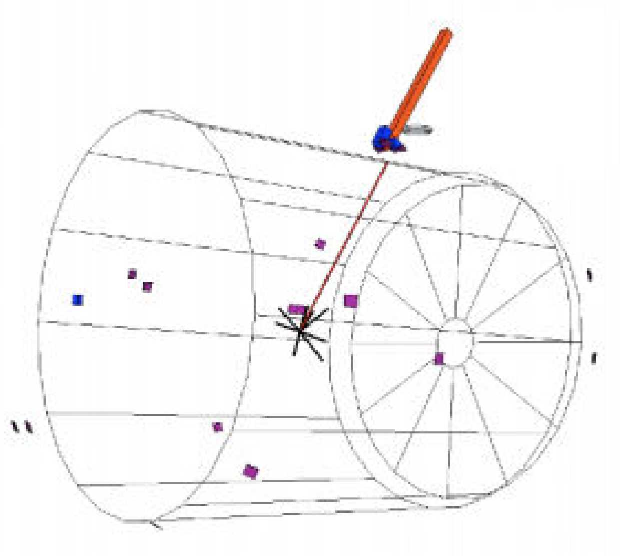
Triggering Barrel EM Calorimeter: $|\eta|<1$

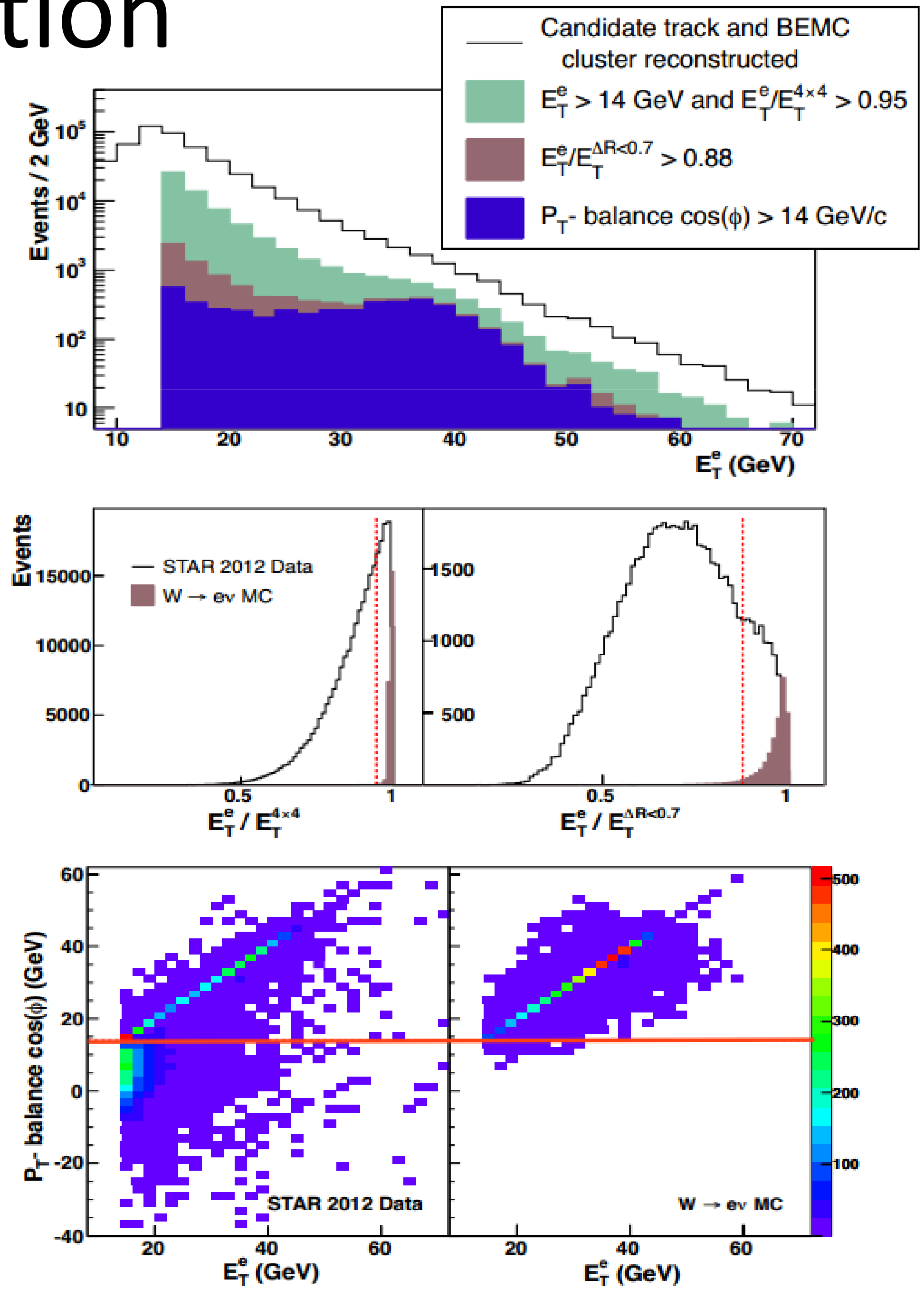
Triggering Endcap EM Calorimeter: $1.1< |\eta|<2$

Time Projection Chamber: Charged particle tracking

W Selection

- Match P_T>10GeV track to EMC cluster
- Isolation Ratio
- P_T-balance
- e+ vs. e- charge separation
- At forward region , improve background rejection by additionally using Endcap Shower Maximum Detector (ESMD)





Background Estimation

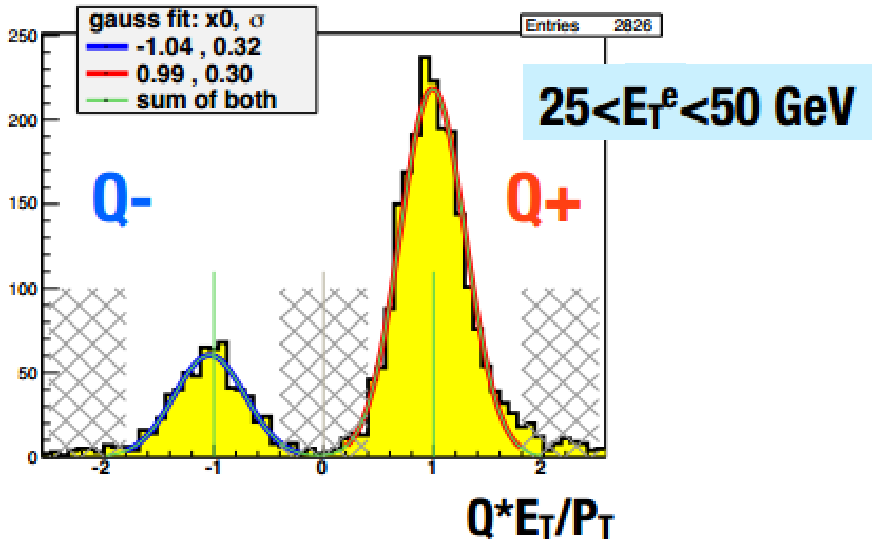
W signal :

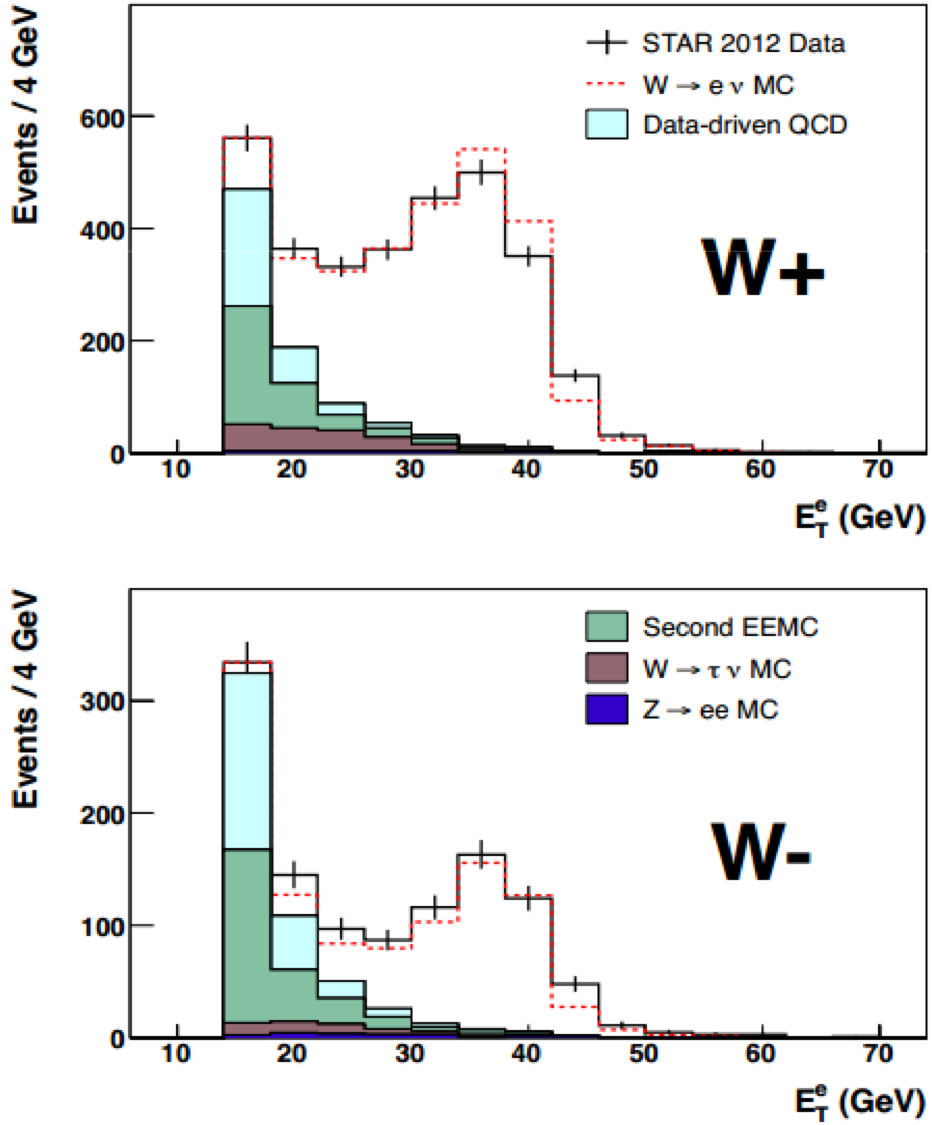
* “Jacobian Peak”

Background:

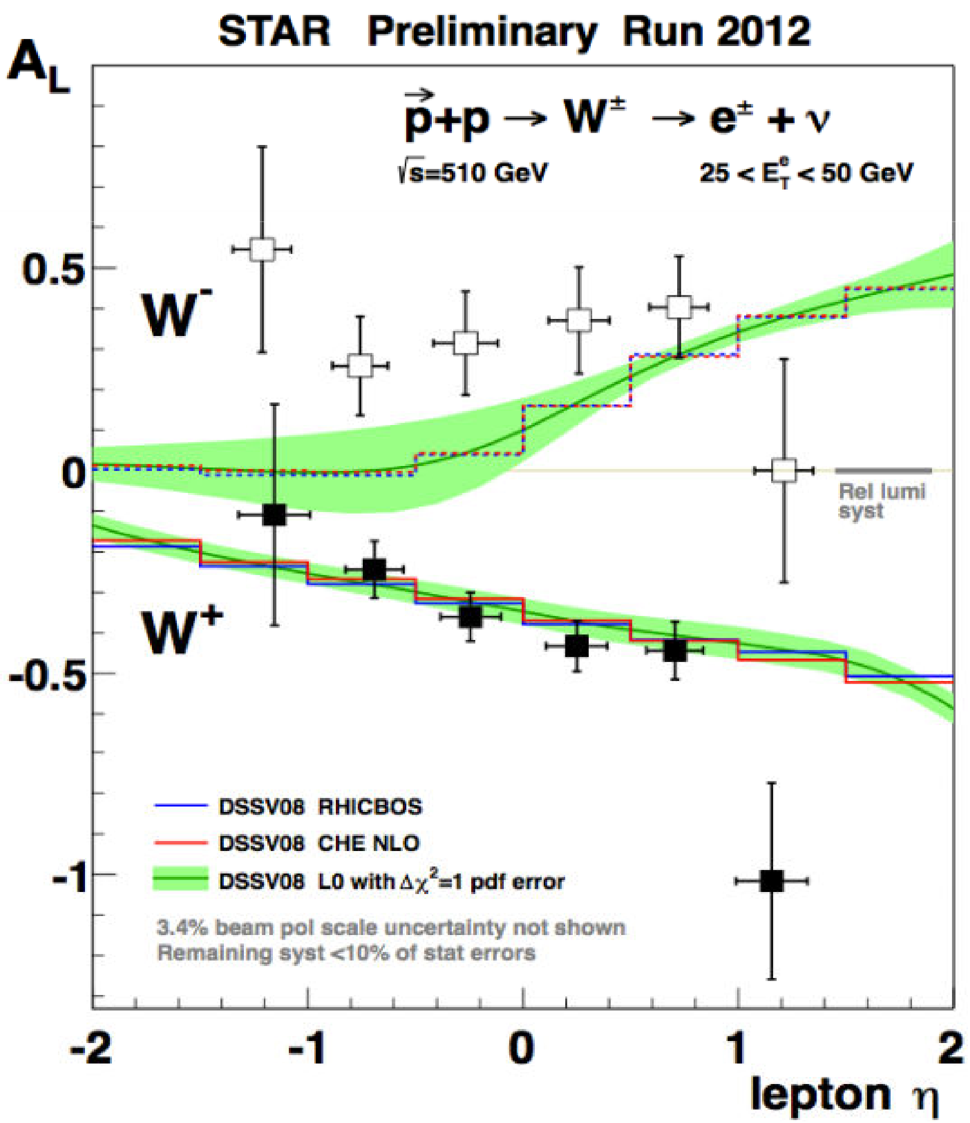
* Electroweak (from Pythia)
    * Z → ee Embedding MC
    * W→ τν Embedding MC
* Second EEMC
* Data-driven QCD

- Estimate wrong sign contamination by using Q*E_T/P_T





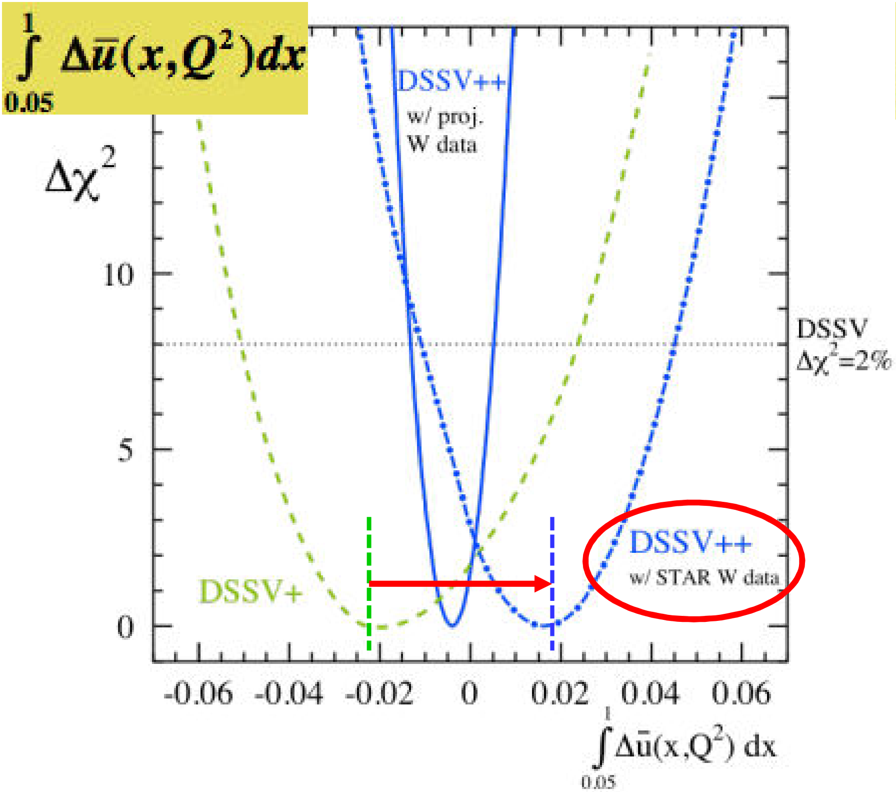
STAR 2012 W $A_L(\eta_e)$

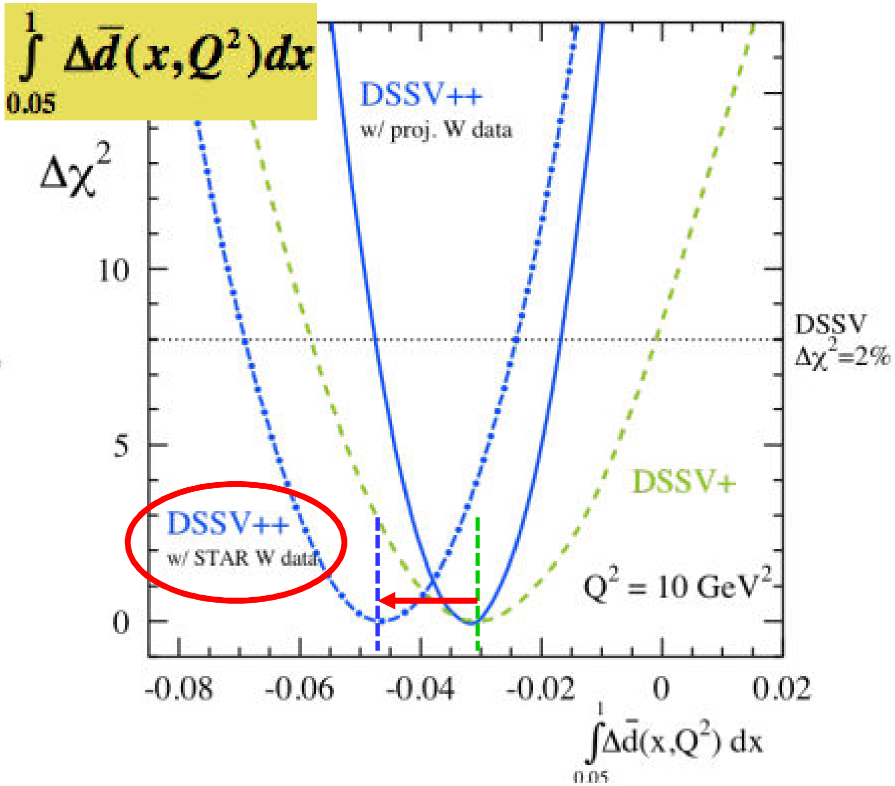


- $A_L(W-)$ is systematically larger than the DSSV predictions
  - The enhancement at $\eta_e<0$, in particular, is sensitive to the $\Delta\bar{u}$ polarized antiquark distribution
- $A_L(W+)$ is consistent with theoretical predictions using the DSSV polarized PDFs
- The systematic uncertainties for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

DSSV++ Global Analysis

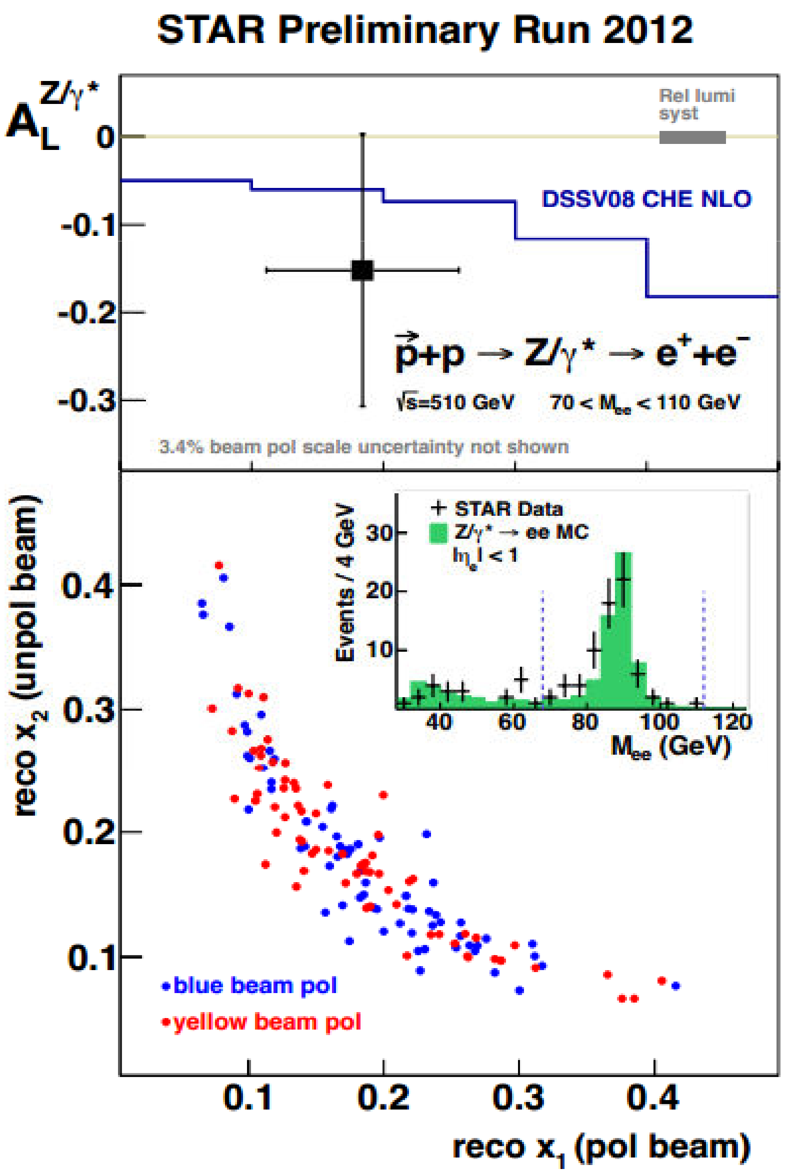
- A preliminary global analysis from the DSSV group that includes preliminary RHIC 2009 A_{LL} data and STAR 2012 W A_L data.
- Shift in central values for $\Delta\bar{u}$ & $\Delta\bar{d}$.
- STAR run12 W results provide significant constraints on $\bar{u}$ & $\bar{d}$ polarization.



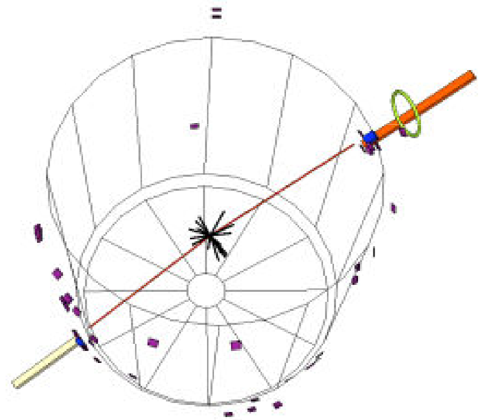


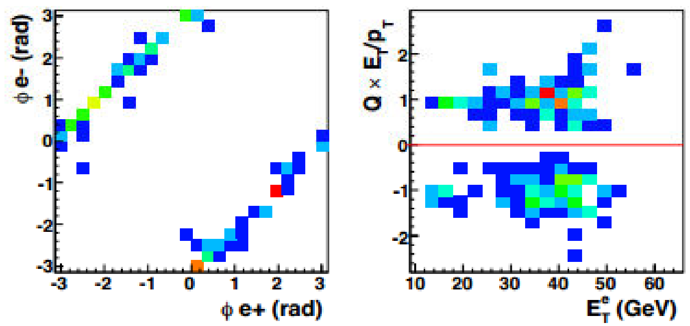
arXiv:1304.0079

STAR 2012 Z AL



Z → e⁺e⁻ Candidate

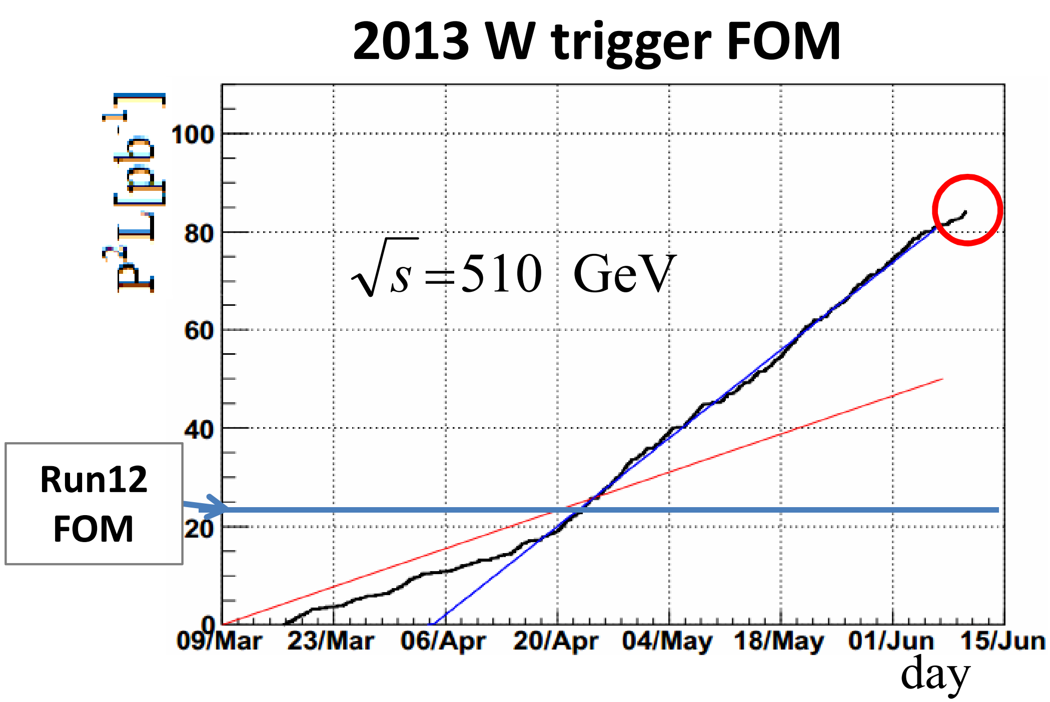


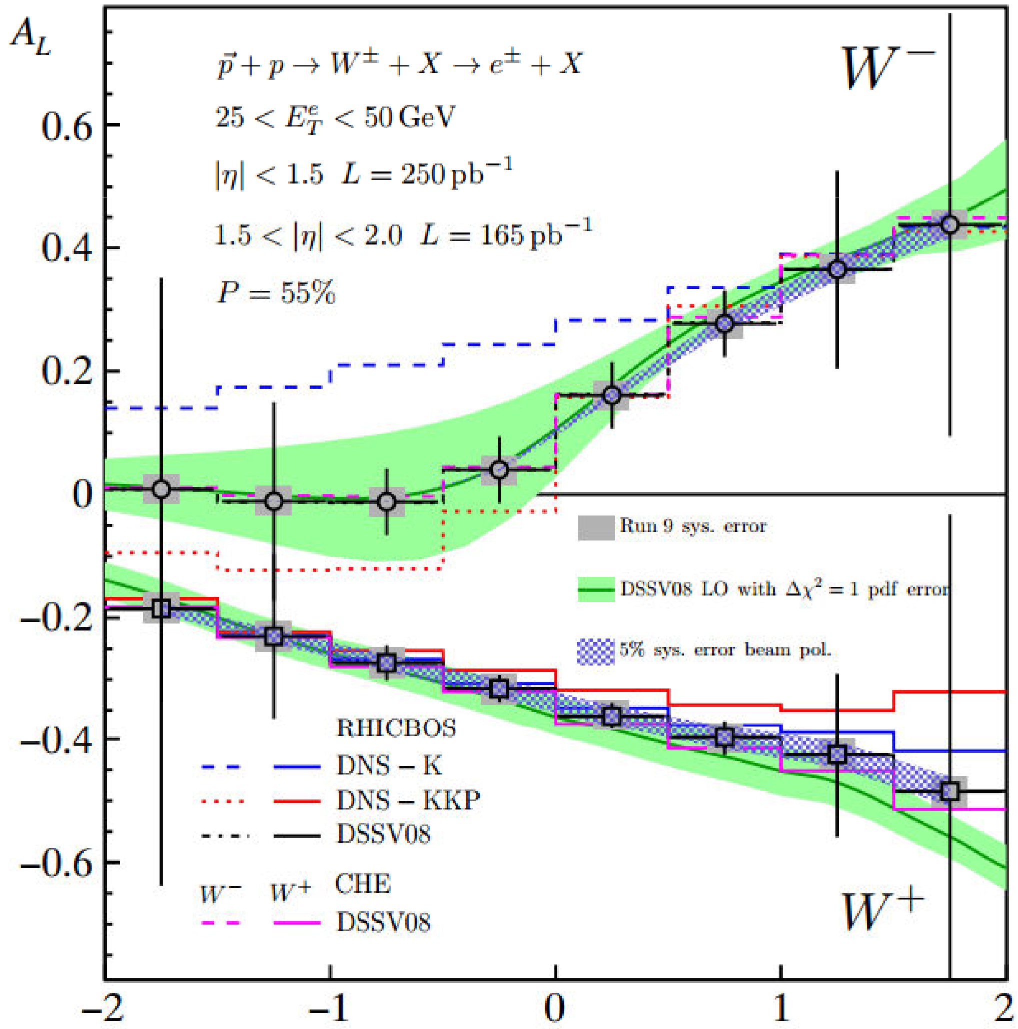


Reconstruct initial state kinematics at leading order:

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

Projection of Run 2013





- FOM(P^2L) of Run 2013(~85pb^{-1}) are 4 times higher than run 2012.
- Extension of backward / forward acceptance enhances sensitivity to ū / d̄ quark polarization

Summary and Outlook

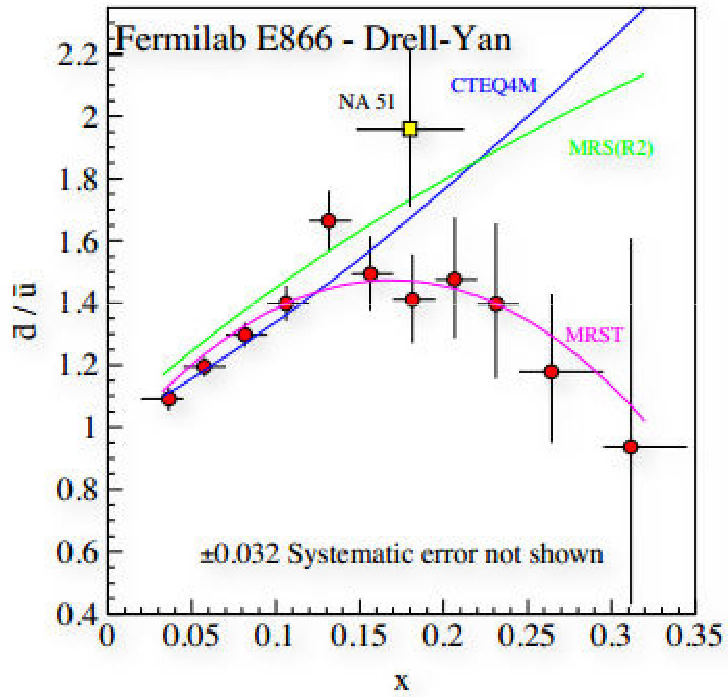
- The production of W bosons in polarized p+p collisions provides a powerful tool to study the spin-flavor structure of proton.
- STAR has measured the parity-violating A_L of W bosons as a function of lepton η_e, which provide significant constraints on $\Delta\bar{u}$ and $\Delta\bar{d}$.
- A_L for Z/γ^* production was also measured, and is consistent with the theoretical predictions.
- Ongoing work will give final results from final production of Run12 and Run11 dataset.
- Upcoming Run 2013 W A_L analysis is expected to give more accurate result of $A_L(\eta_e)$ and further constraints on $\bar{u}$ & $\bar{d}$ polarization.

Backup

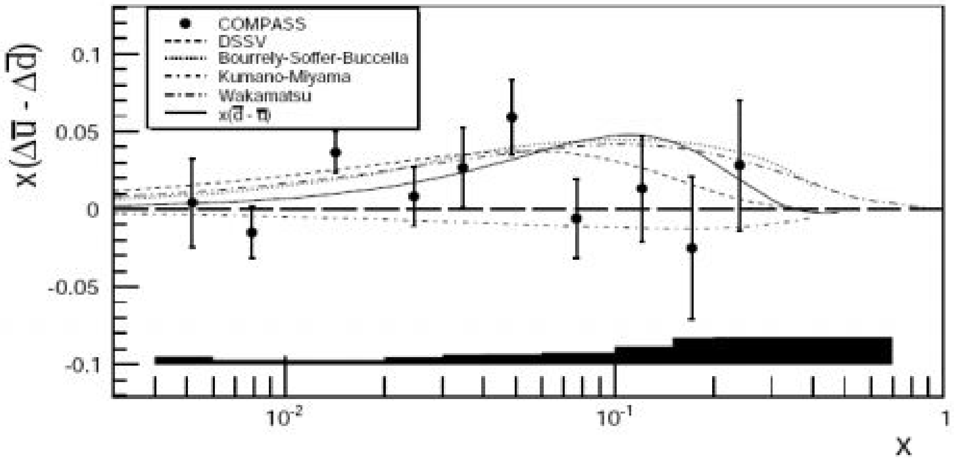
Flavor Asymmetry of the Sea

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)

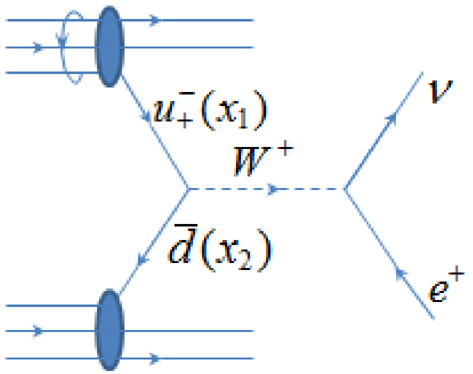
Polarized Flavor Asymmetry:

- 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

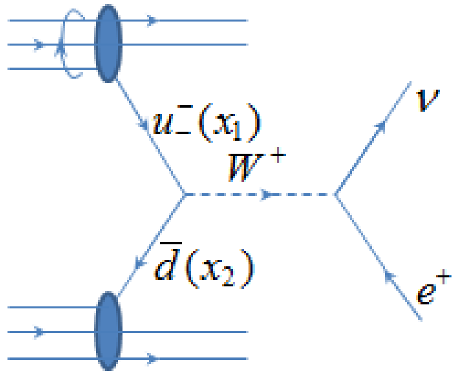
Why W ?

A. Polarized (subscript) proton provides *u*

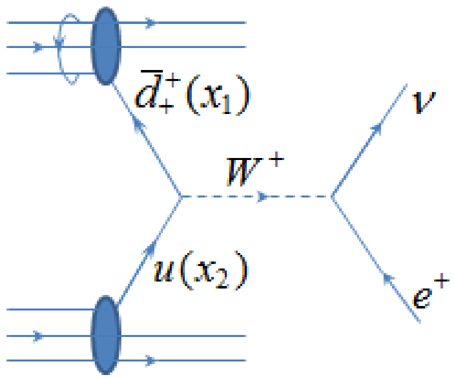
B. Polarized (subscript) proton provides $\bar{d}$



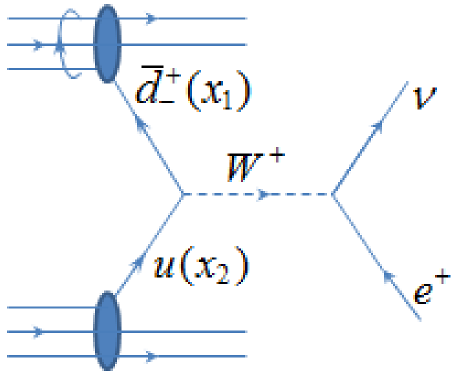
A.1 Proton helicity = “+”



A.2 Proton helicity = “-”



B.1 Proton helicity = “+”



B.2 Proton helicity = “-”

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

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

Superpose **A** and **B** :

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

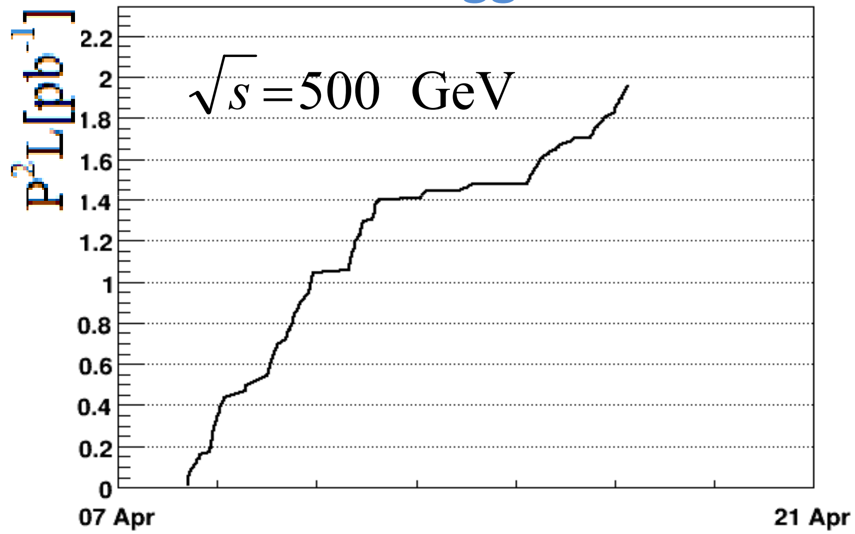
Switch *u* and *d* :

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

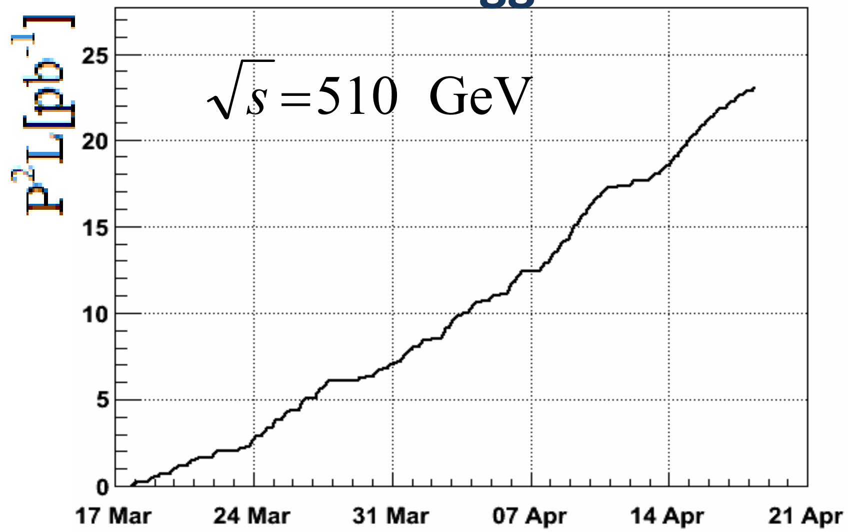
Ongoing combined 2012+2011 Analysis

- More Ws have been found in Final production.
- Include low luminosity dataset of Run2011.
- The asymmetries may be measured yields of a few counts, where assumptions of Gaussian uncertainties break down.
- Exploring **profile likelihood method** to extract the asymmetry .

2011 W trigger FOM



2012 W trigger FOM



Year	L(pb^{-1})	P*	P^2L(/pb^{-1})	W yield**
2011	9.4	0.49	2.3	417
2012	77.4	0.56	22.6	2965

* Average beam polarization for blue and yellow
** Charge summed yields ET=[25,50]GeV

Profile Likelihood

Simplified example:

for a two spin state experiment, we have a 3-D likelihood function.

$$L_\Omega(A^W, N^0, \beta) \equiv L_{PHY}(A^W) \cdot L_{SPIN}(A^W, N^0, \beta) \cdot L_{BCK}(\beta)$$

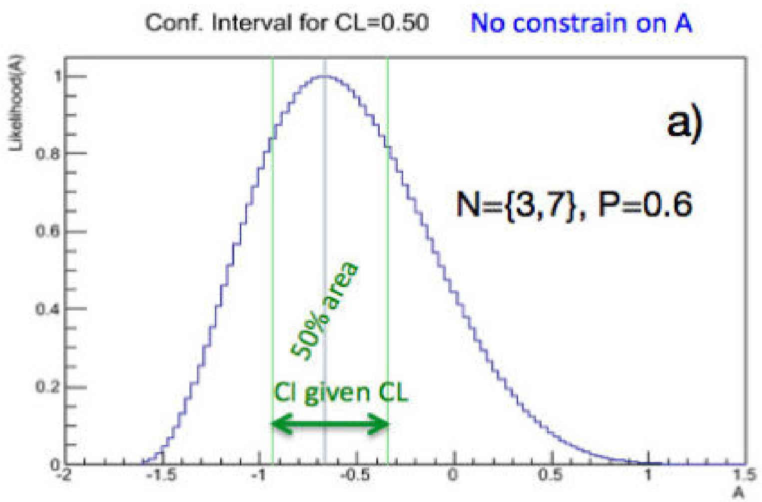
$L_{PHY}(A^W) = H(1 - |A^W|)$: Physical constraint on $|A^W| < 1$

Model of yield for a given A^W (product of Poisson functions)

$$L_{SPIN}(A^W, N_0, \beta) = \prod_i^2 f(N_i|\mu_i(A^W, N^0, \beta)) : \mu_\pm = l_\pm N^0 \, (1 \pm P\beta A^W)$$

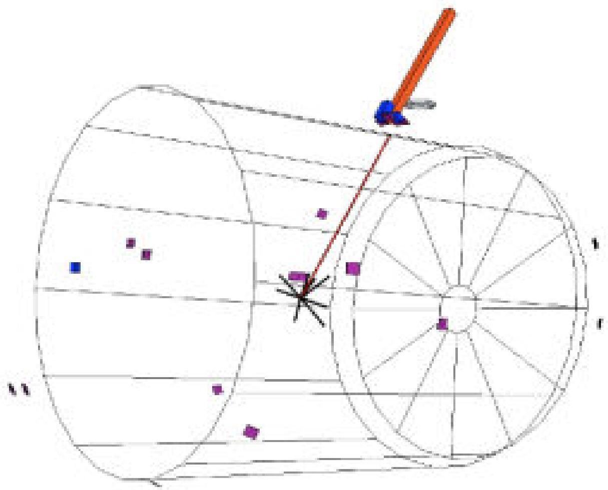
Model for background dilution (gaussian estimated separately):

$$L_{BCK}(\beta) = g(\beta - \hat{\beta}, \sigma_\beta) \quad \beta = \frac{f_W}{f_W + f_Z + f_E + f_Q}$$



- Reduce 3-D likelihood function to 1-D only depends on A^W by finding the nuisance parameters set which maximize the Likelihood function.
- The maximum is the central value for the measured asymmetry.
- The upper and lower error bounds are found by the integrating out to the desired CL from the central value.

What do W decays look like?

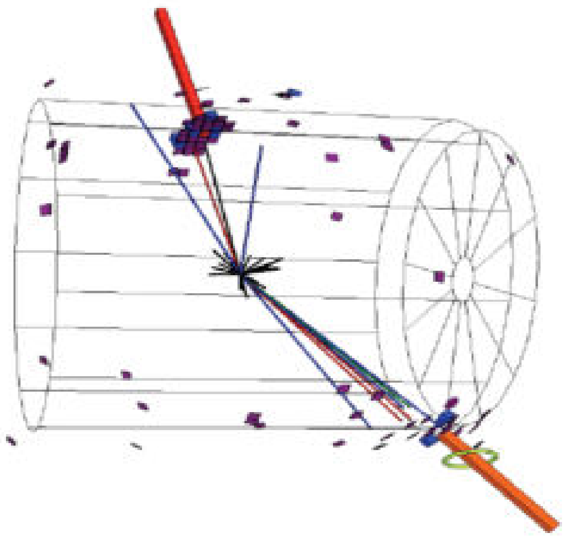


W → e + ν Candidate Event

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

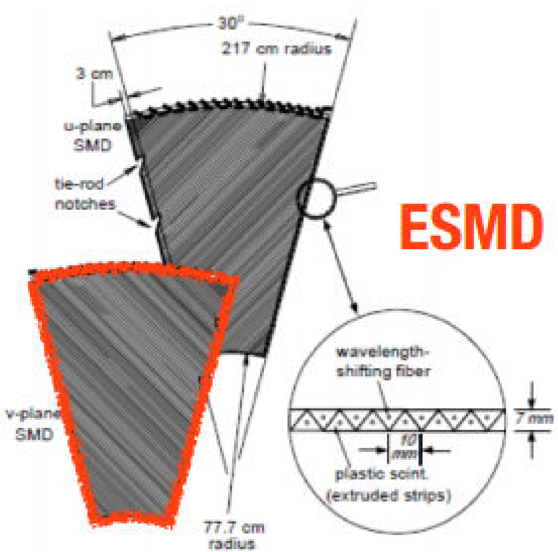
Di-jet Background Event

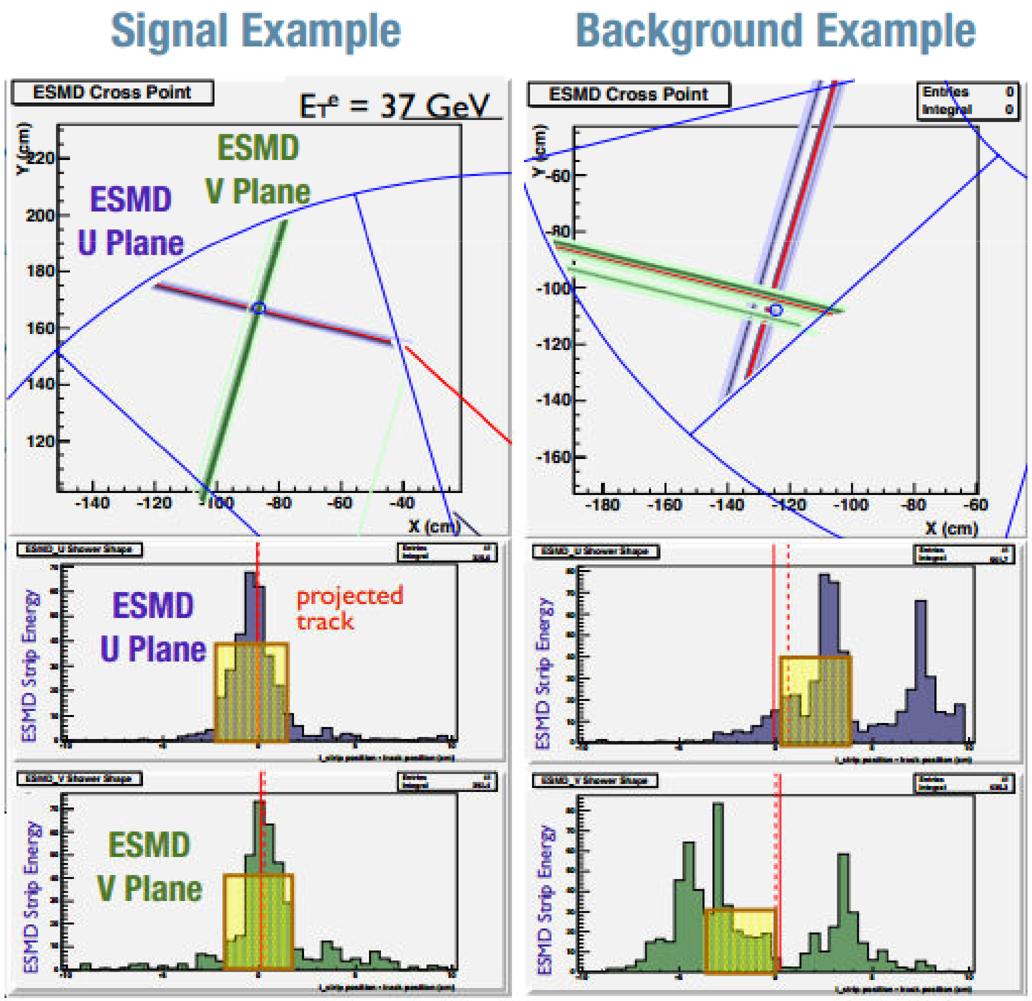
- Several tracks pointing to EM energy deposit in several towers
- Vector p_T sum is balanced by opposite jet, "missing energy" is small



Forward Rapidity(η_e>1) W Selection

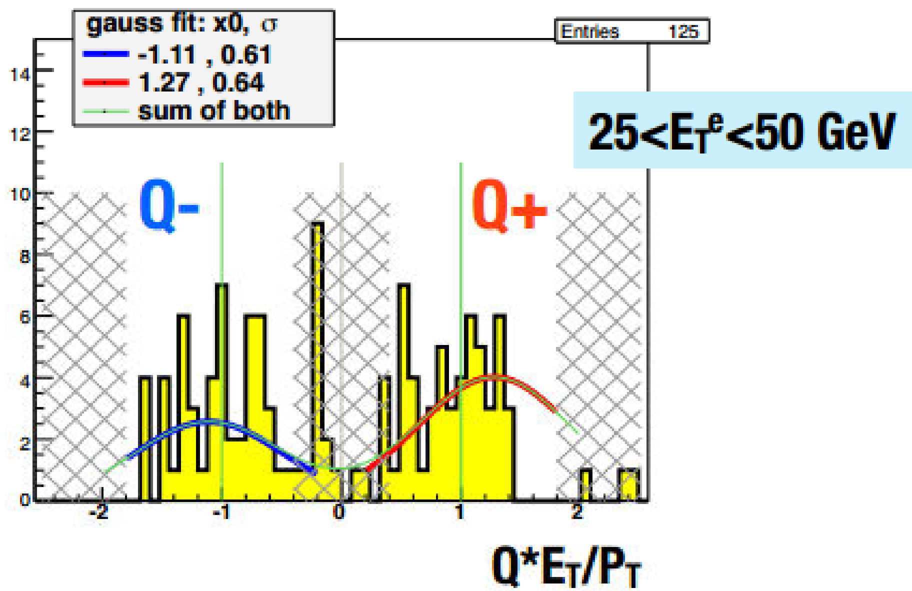
- **Similar concept as mid-rapidity:**
- **Utilize TPC which extends to η ~1.4 to reconstruct high p_T TPC track**
- **Use isolation ratios and p_T imbalance to reduced QCD background**
- **Improve background rejection by using the Endcap Shower Maximum Detector (ESMD)**

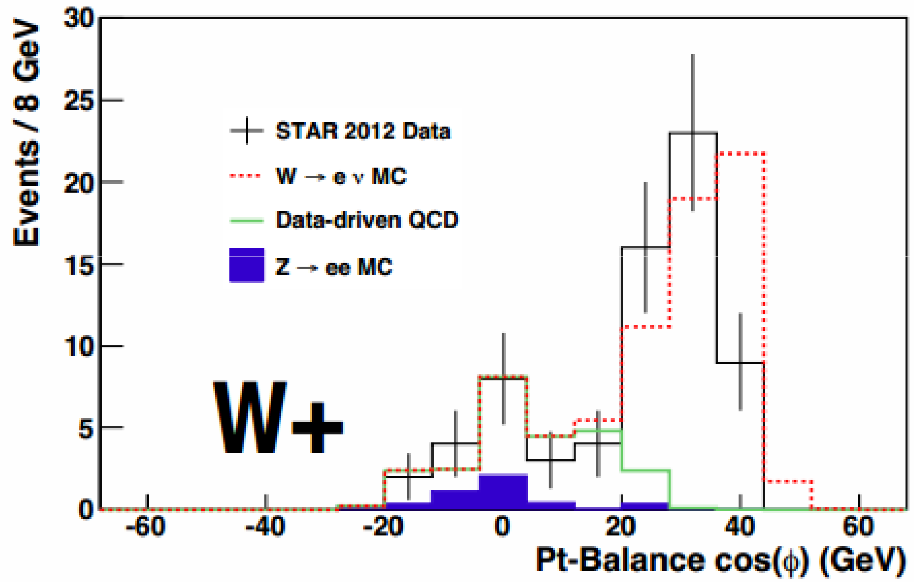


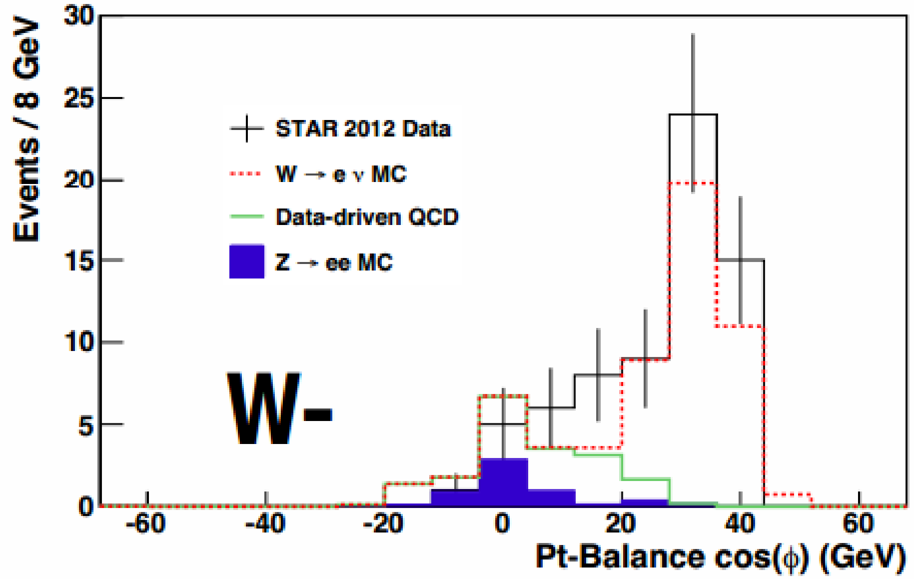


Forward Background Estimation

- Similar with mid-rapidity background estimation.
- Fewer TPC points at forward rapidity cause worse charge sign solution.





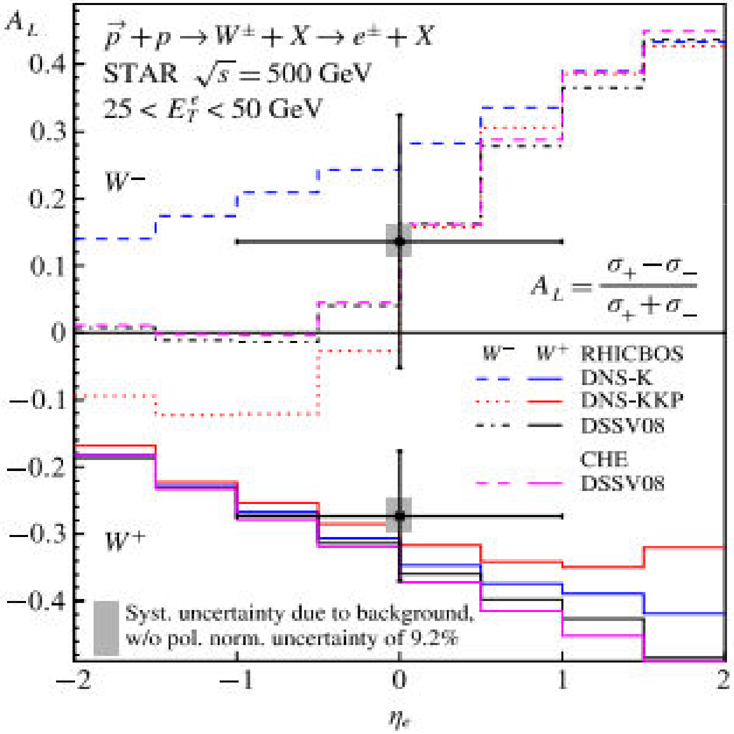


Systematic Uncertainties

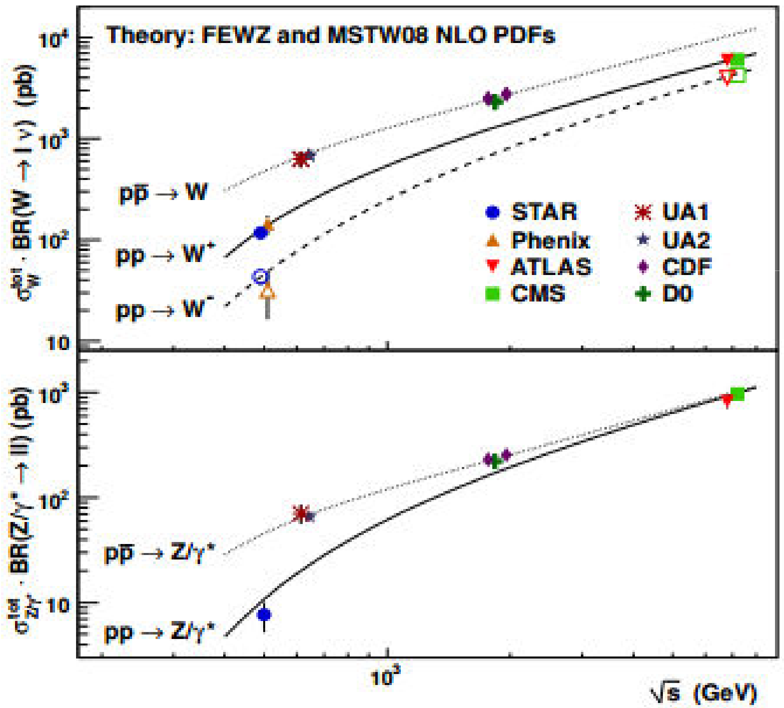
- **Beam polarization uncertainty: correlated scale 3.4%**
- **Relative luminosity uncertainty: correlated offset ΔA_L = 0.007**
  - Accounts for possible parity-violating asymmetry in QCD events used for luminosity monitor
  - A_L is consistent with zero for a sample of high-p_T QCD events (invert isolation ratio and P_T-Balance requirements)
  - Systematic uncertainty estimated as half the statistical error on A_L for this high-p_T QCD sample
- **Background estimation: less than 10% of statistical error**
  - Uncertainty on unpolarized background contribution β: uncorrelated between points less than 10% of statistical error
  - Uncertainty on polarized background contribution α: negligible

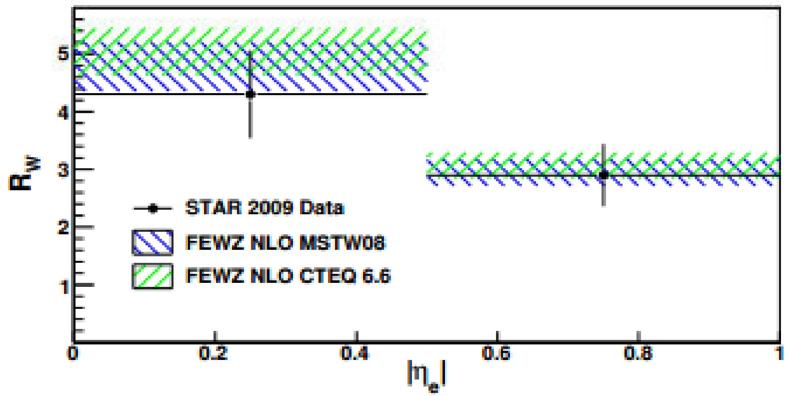
Previous STAR measurements

PRL **106,** 062002 (2011)



- 2009 was a very successful first 500 GeV physics run
- 2012 increase in FOM = P^2L of an order of magnitude!





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