Measurement of Longitudinal Spin Asymmetries for Weak Boson Production in Polarized Proton-Proton Collisions at STAR

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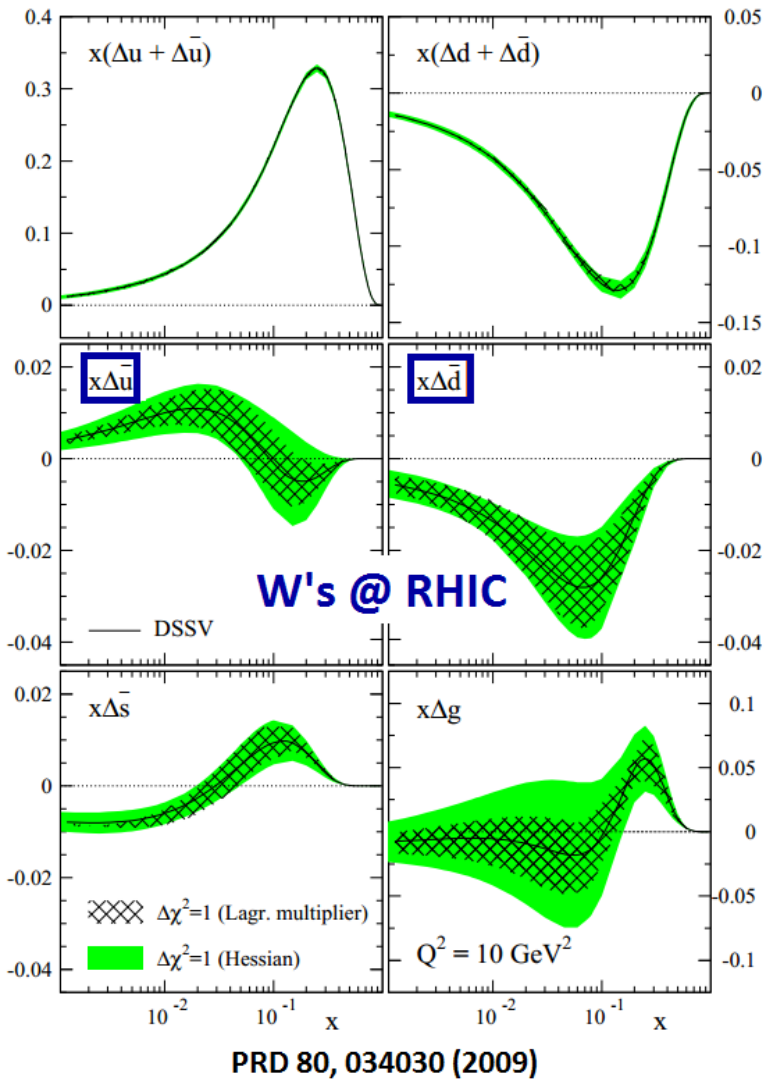
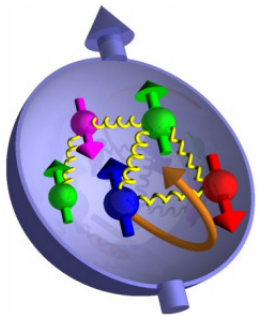
Flavor Separation of Proton Spin

DSSV Global Analysis



PRD 80, 034030 (2009)



Polarized PDFs:

$$\Delta f(x) = f^{+}(x) - f^{-}(x)$$

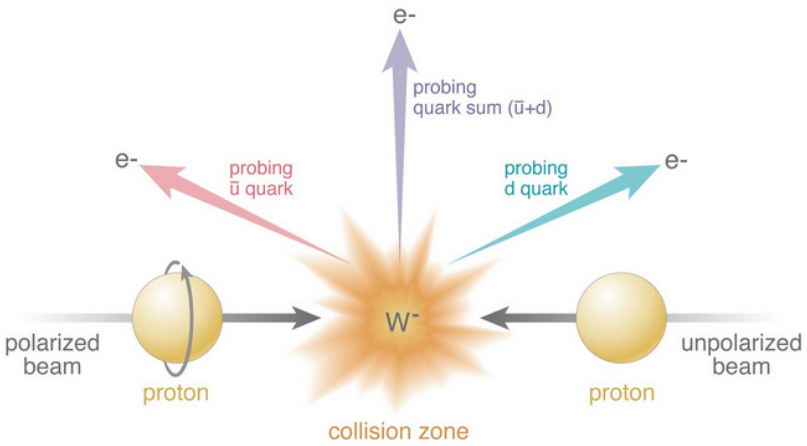
$$< S_p >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

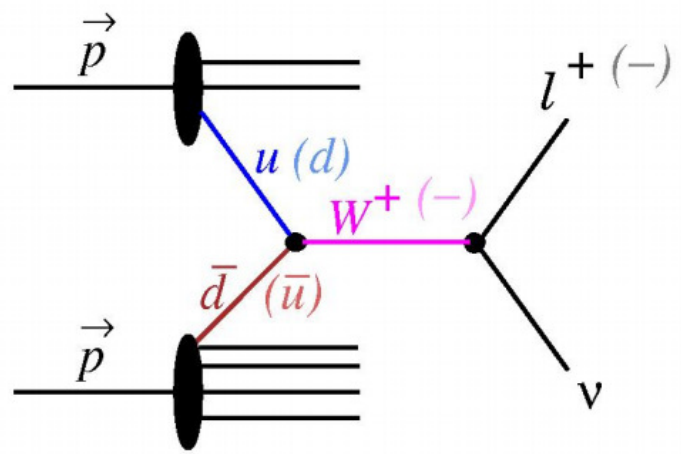
(Jaffe-Manohar, 1990)

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

- $\Delta\Sigma \sim 30\%$ from DIS data
- **Flavor separated contributions** are not well constrained yet
- RHIC W program ?

Why Ws ? — Unique Probe to Sea Quark Polarization





- 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

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

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

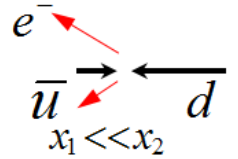
Measure parity-violating single-spin asymmetry:

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

Expectation for W A_L

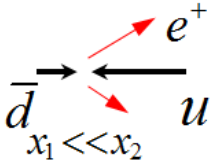
- Large parity-violating asymmetries expected.
- Simplified interpretation at forward and backward rapidity.

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

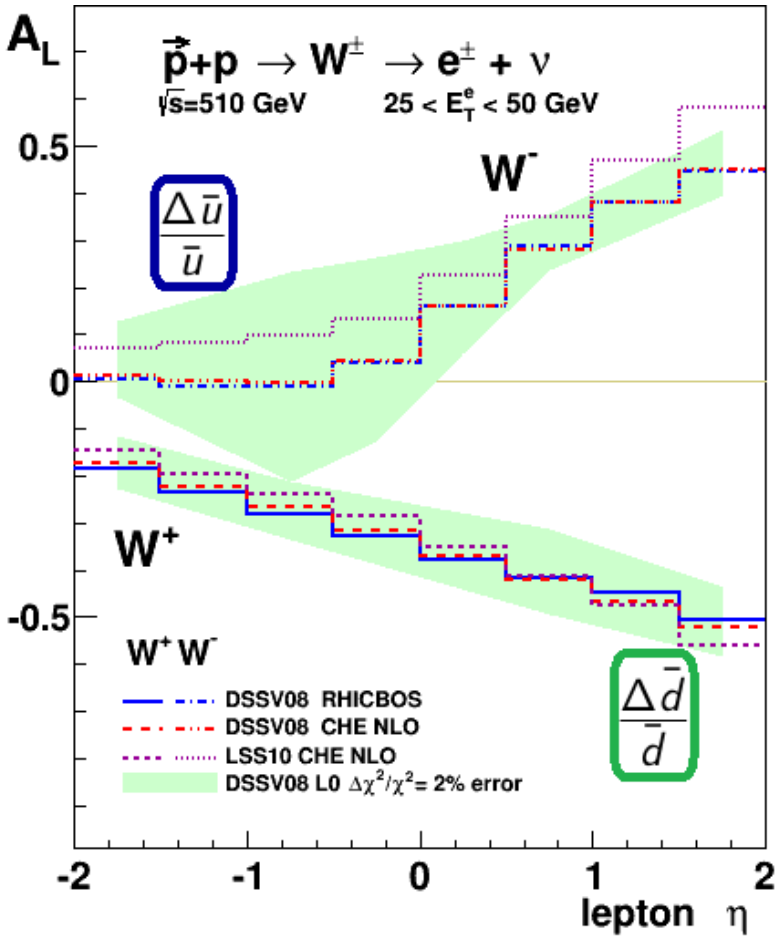


backward e^- → Parallel to W^- → $\frac{\Delta\bar{u}}{\bar{u}}$

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

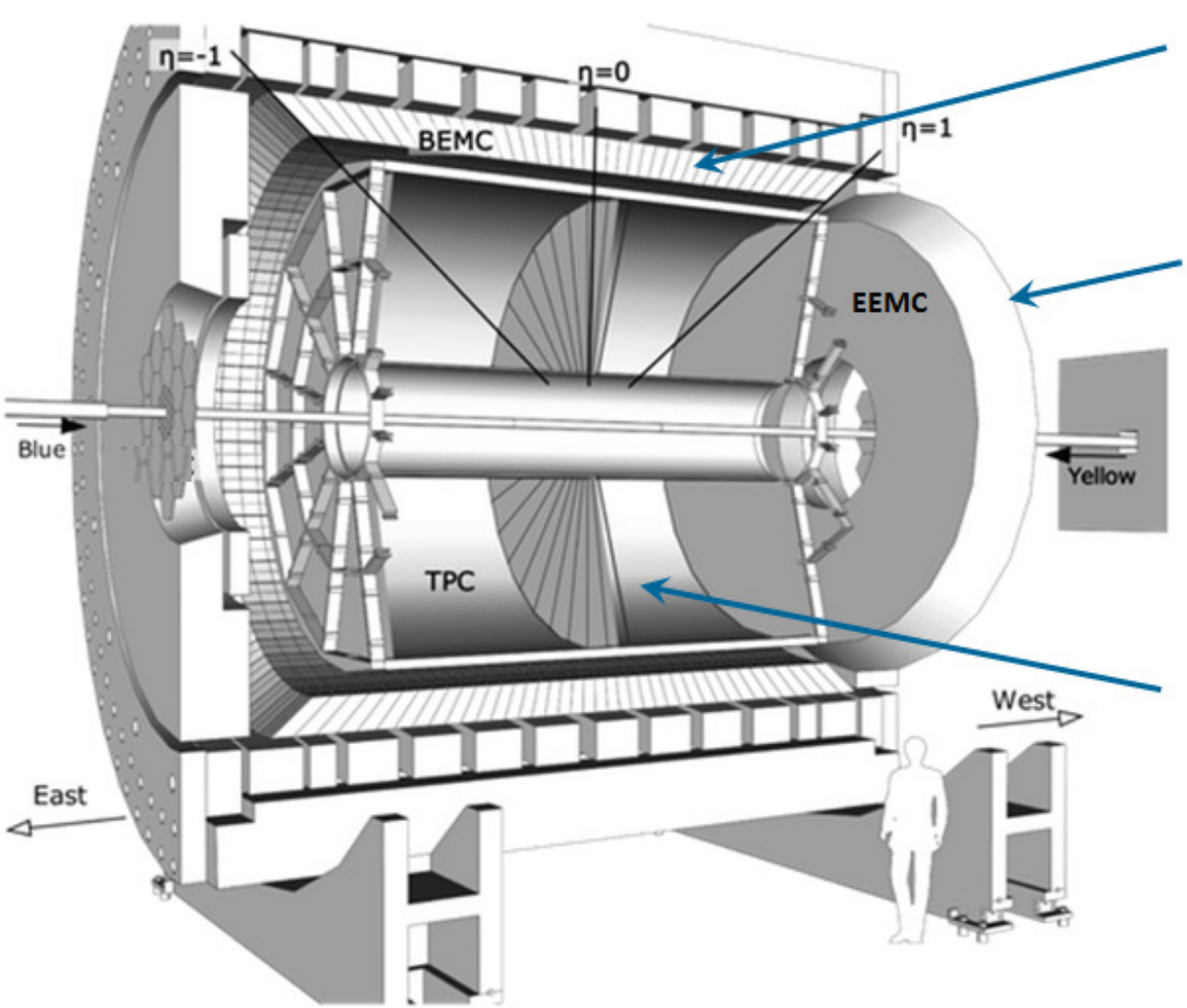


forward e^+ → Anti-parallel to W^+ → $\frac{\Delta\bar{d}}{\bar{d}}$



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

STAR Detector Overview



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

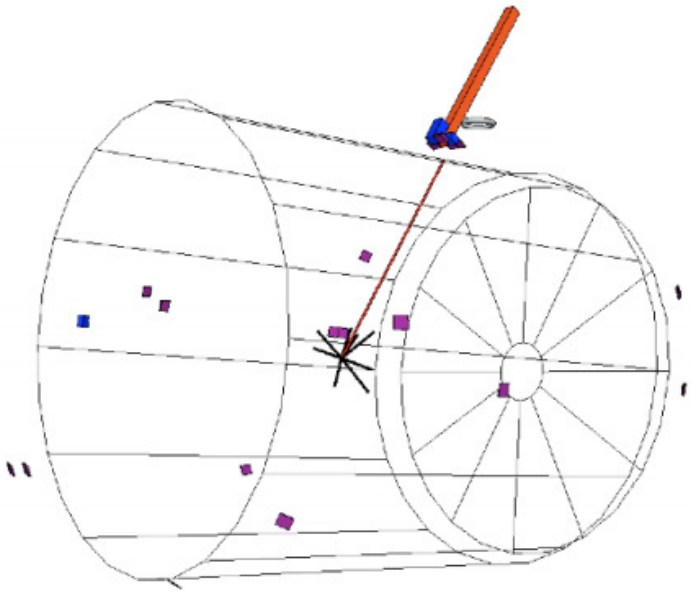
Triggering Endcap EM Calorimeter: $1.1< |\eta|<2$

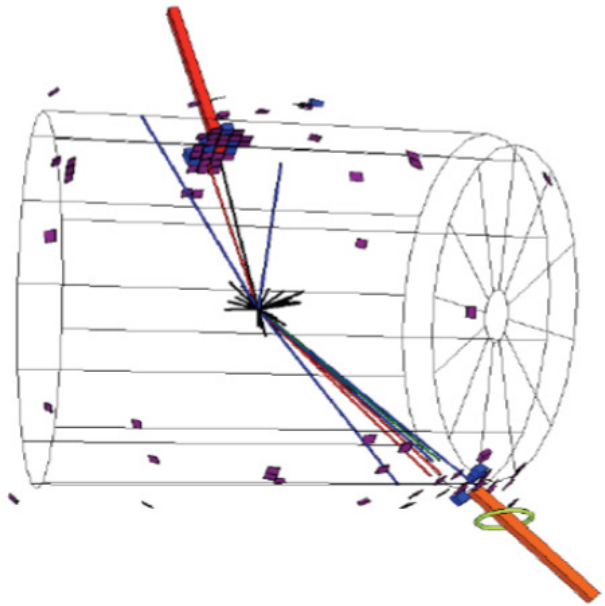
Time Projection Chamber: Charged particle tracking $|\eta|<1.3$

Sample W Candidates

$W \rightarrow e + \nu$ Candidate Event:

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

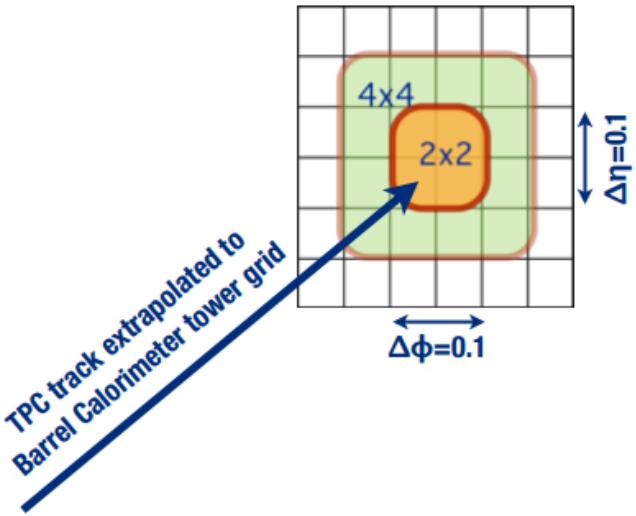


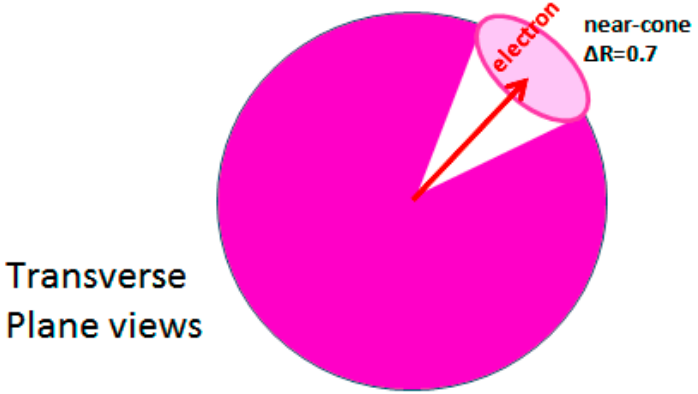


QCD Background Event:

- Several tracks pointing to EM energy deposit in several towers
- Vector p_T sum is balanced by opposite jet, no large "missing energy"

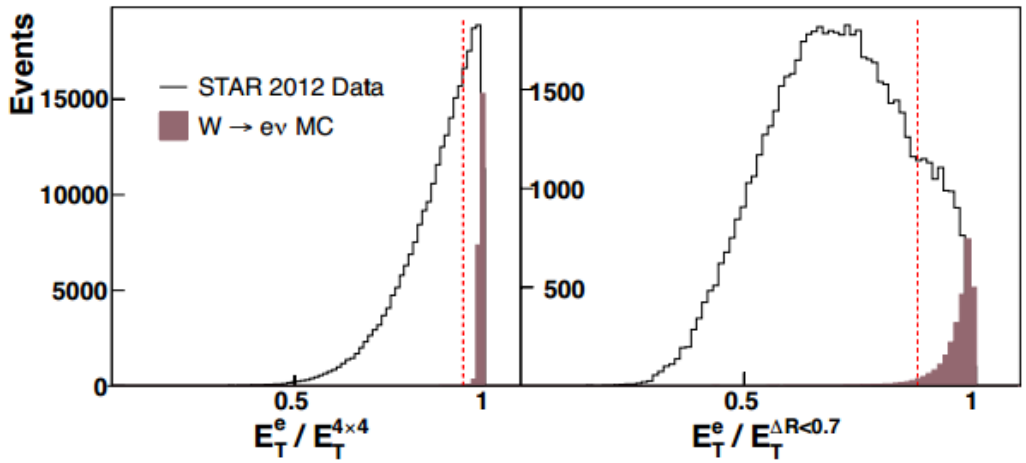
Isolation Cuts





$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

- Match $p_T > 10$ GeV track to EMC cluster
- Require the energy deposited in the next ring to be <5% of the 2x2 sum
- Require the ratio $E_T^e / E_T^{\Delta R<0.7}$ to be $> 88\%$



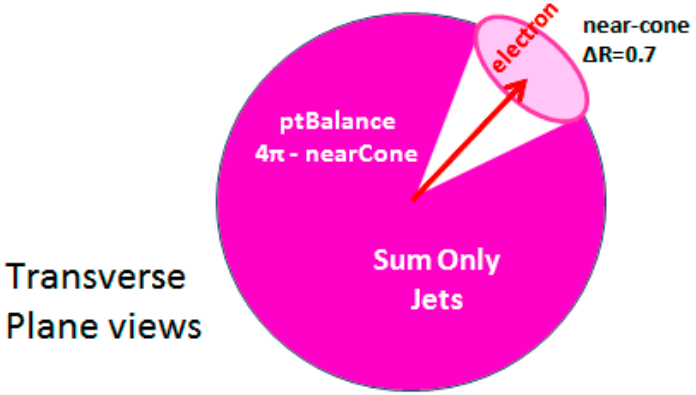
Topological Cuts

P_T-balance:

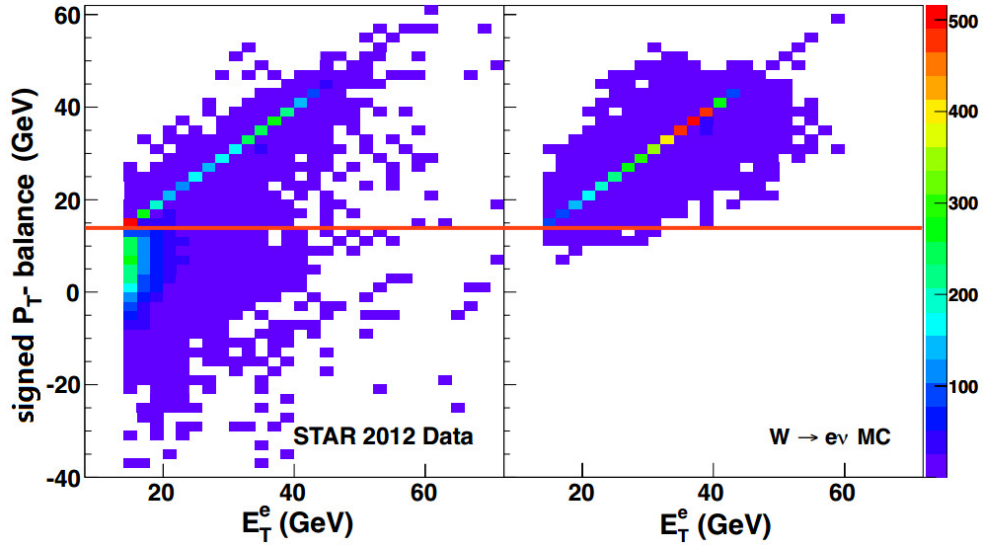
$$\vec{p_T}^{bal} = \vec{p_T}^{e} + \sum_{\Delta R>0.7} \vec{p_T}^{jets}$$

$$\text{signed } P_T\text{-balance} = \frac{\vec{p_T}^{e} \cdot \vec{p_T}^{bal}}{|\vec{p_T}^{e}|}$$

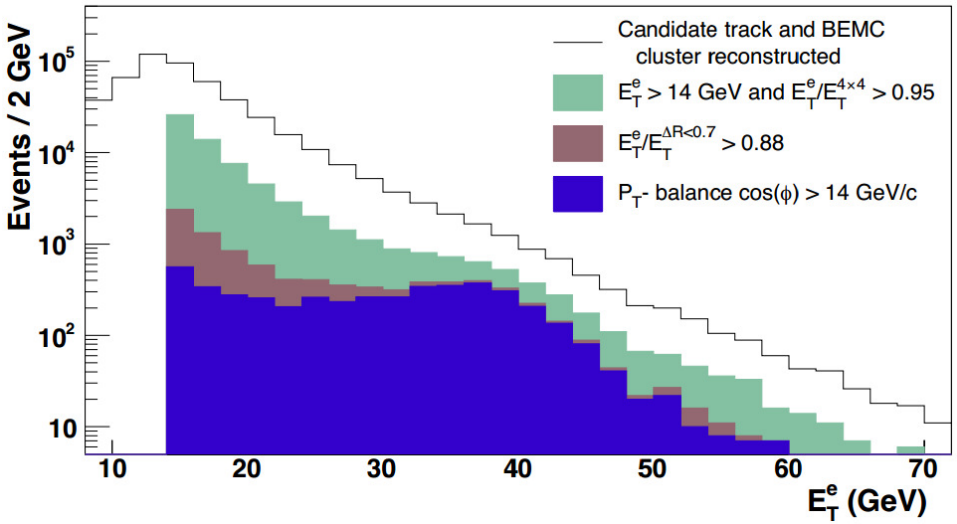
required to be $>$ 14GeV



$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

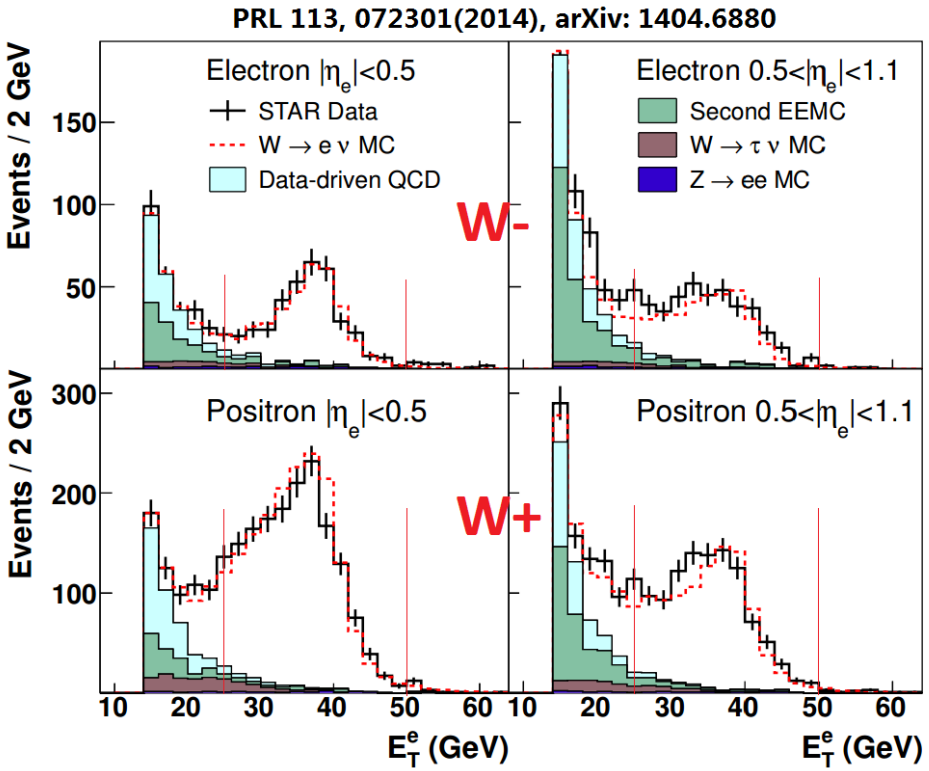


* Signed p_T-balance vs. E_T^e (data on the left and W MC embedded simulation on the right)



* E_T^e distribution as background cut away

Mid-rapidity Background Estimation



W^+ β: ~ 0.95, W^- β: ~ 0.9

where $\beta = Signal/(Signal + Background)$

W signal

- "Jacobian Peak"

Primary Background:

Satisfy W selection cuts but contain jets escaping detection at $\eta < -1$ and $\eta > 2$.

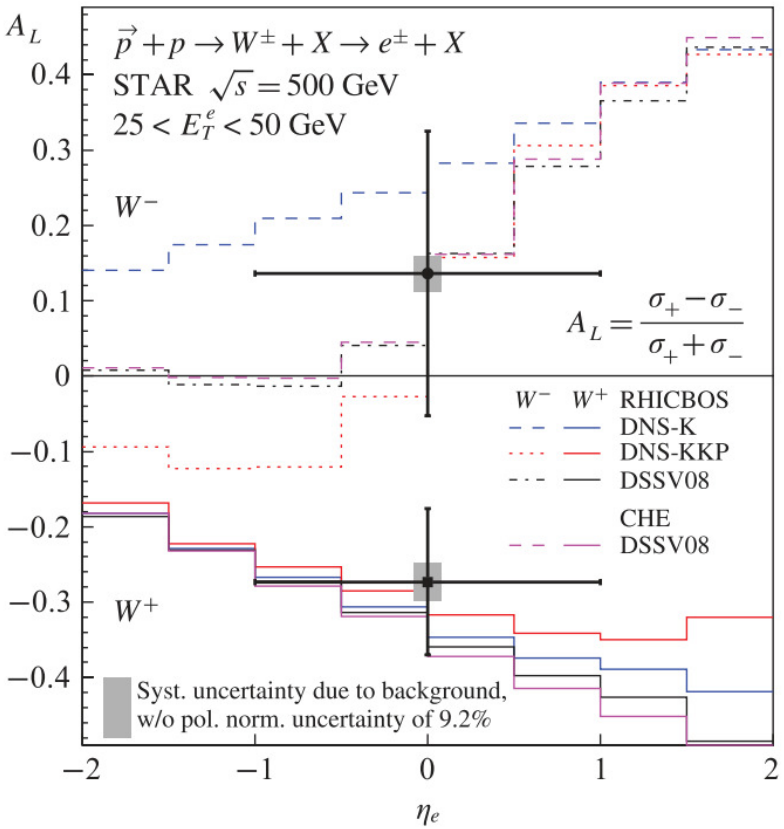
- **Second EEMC**
  Estimate non-existent "east" EEMC background based on real west EEMC
- **Data-driven QCD**

Electroweak Background:

Determined from Monte-Carlo simulation.

- **Z $\rightarrow$ ee MC**
- **W $\rightarrow \tau\nu$ MC**

W Data from 2009 to 2012



PRL 106, 062002 (2011)

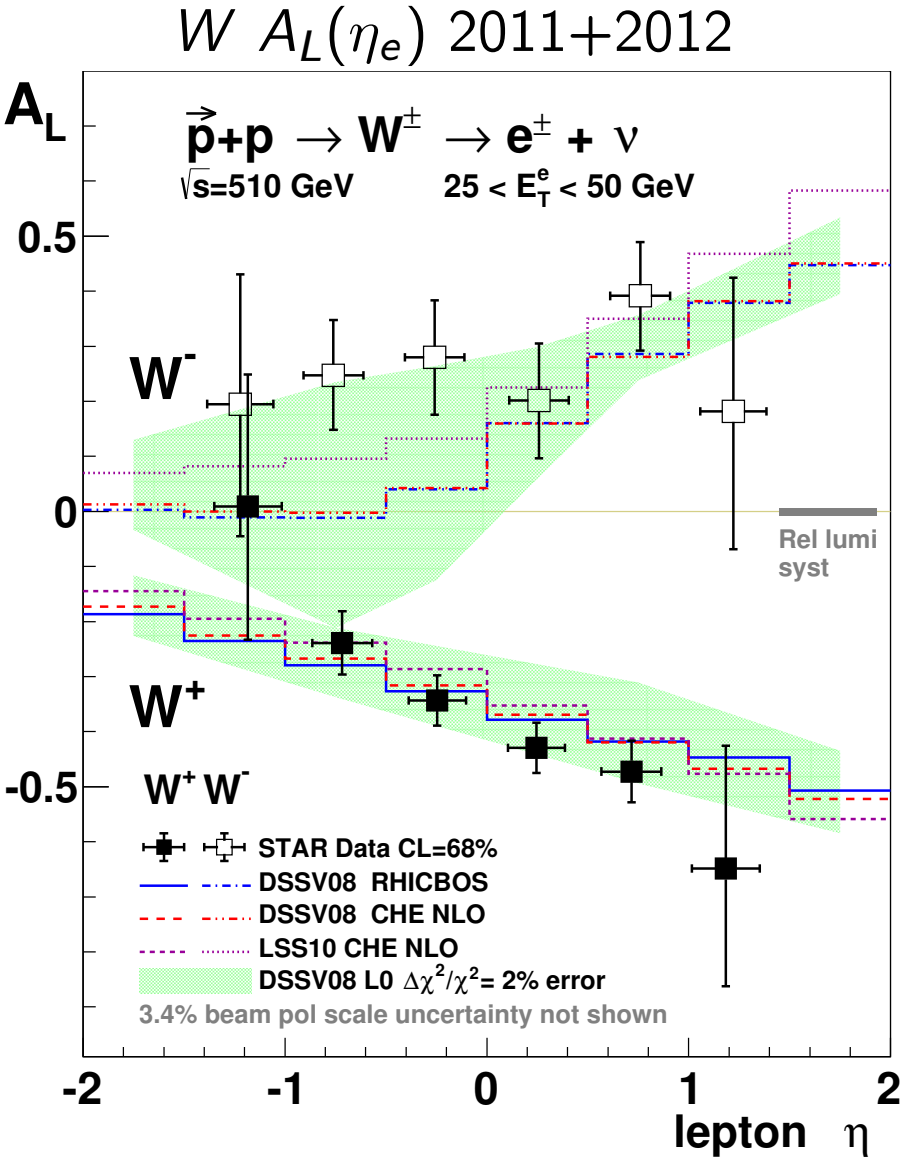
- 2009 was a very successful first 500 GeV physics run

Statistics increase by an order of magnitude from 2009 to 2012:

STAR pp500 Longitudinal			
Run	$L\ (pb^{-1})$	$P^2L(pb^{-1})$	$W^+(W^-)$
2009	12	1.7	462 (192)
2011	9	2.3	342 (103)
2012	77	24	2417 (734)

- ✓ With larger statistics, we can look into lepton pseudo-rapidity, η_e, dependence of spin asymmetry
- ✓ To accommodate the low statistics of 2011 dataset, Profile Likelihood method was used in combination of 2011 and 2012

W A_L Result of 2011+2012

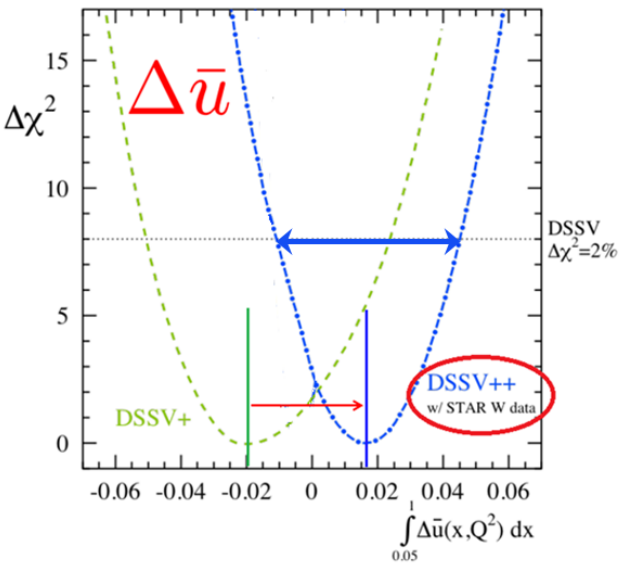


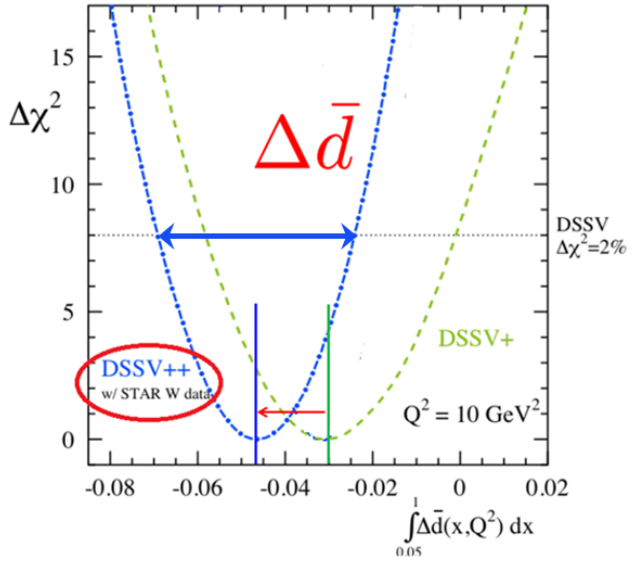
PRL 113, 072301 (2014)

- STAR measured the parity-violating single-spin asymmetry A_L for $|\eta_e| < 1.4$ from 2011 and 2012 data
- Provide the first detailed look at the asymmetry's η_e dependence
- $A_L(W^+)$ is consistent with theoretical prediction
- $A_L(W^-)$ is larger than the predictions for $\eta_e < 0$, which is particularly sensitive to $\Delta\bar{u}$

Impact of STAR Result

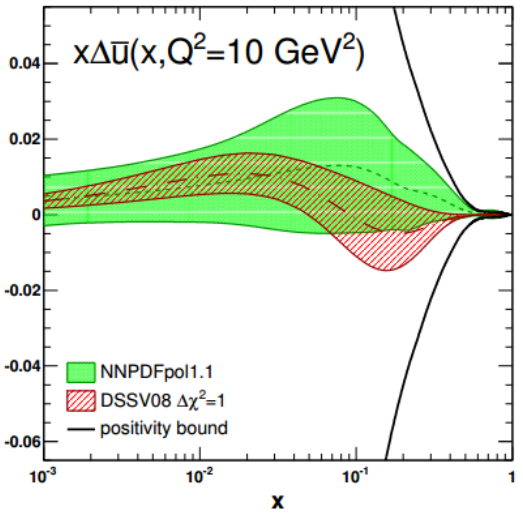
DSSV++





arXiv: 1304.0079

NNPDFpol1.1

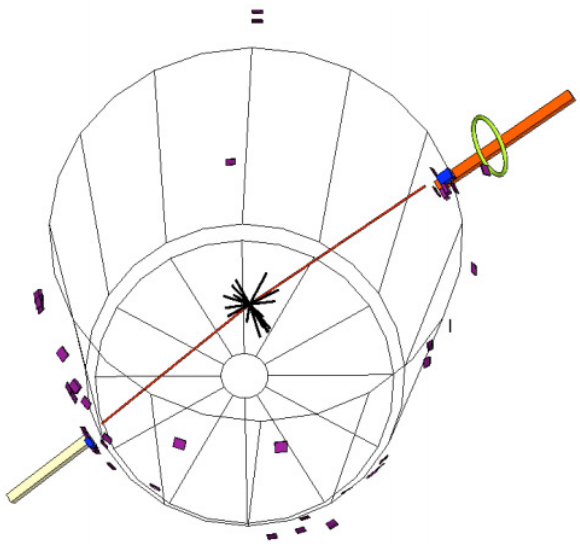


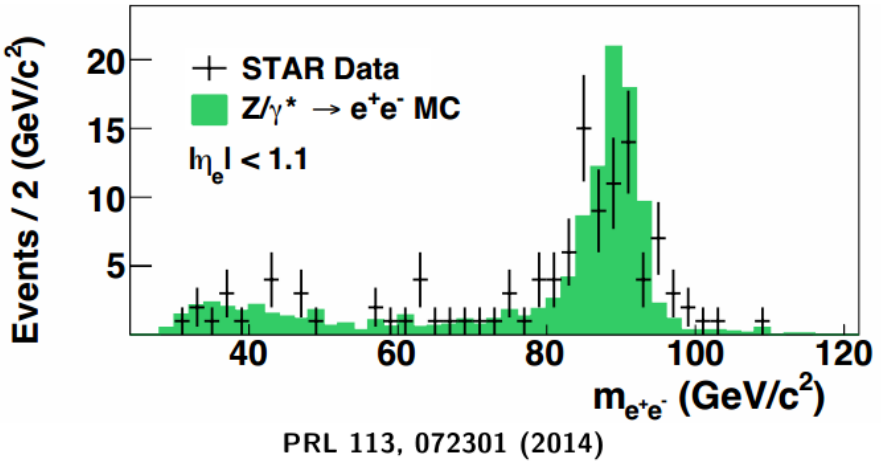
Nucl.Phys.B 887(2014) 276-308

- STAR 2012 results included in global fits by **DSSV** and **NNPDF**.
- STAR run 2012 W results provide significant new constraints on $\bar{u}$ and $\bar{d}$ polarization.
- Shift in best fit values for $\Delta\bar{u}$ and $\Delta\bar{d}$ after including STAR new results

Z A_L Result of 2011+2012

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

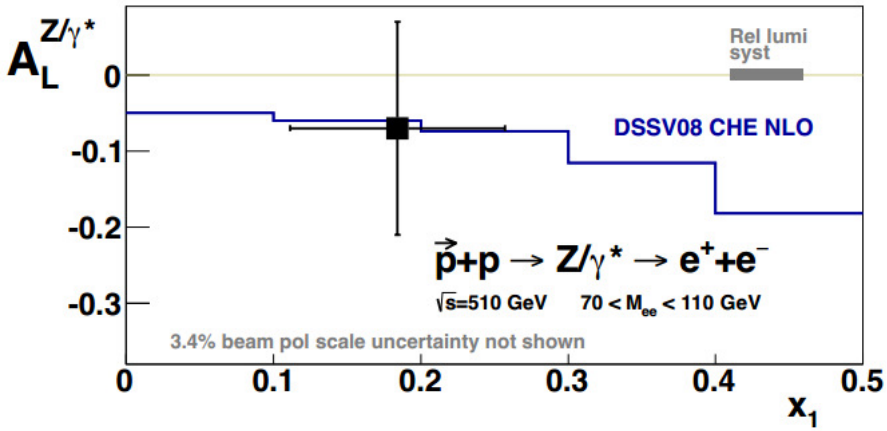




PRL 113, 072301 (2014)

- **Fully reconstructed e^+e^- final state.**
- **Reconstruct initial state kinematics at leading order:**

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



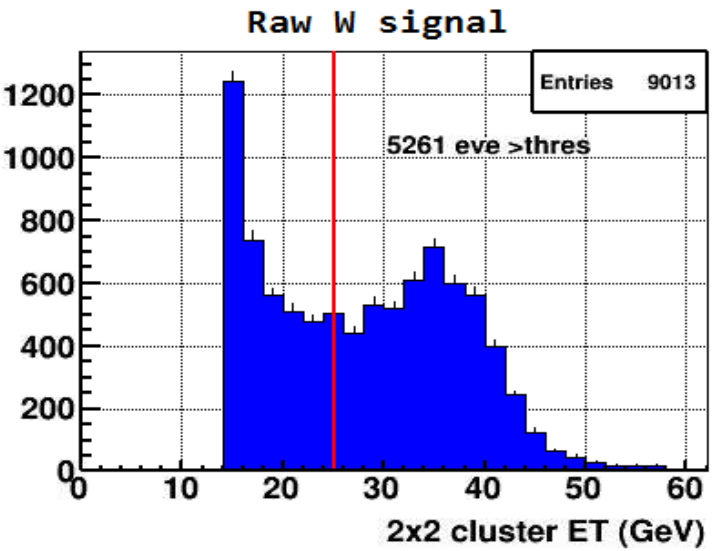
Run 2013 Dataset

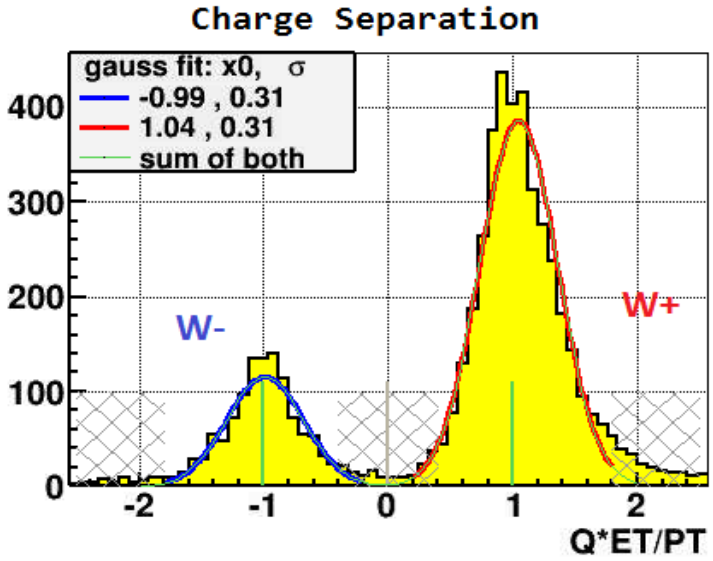
STAR pp500 Longitudinal			
Run	$L\ (pb^{-1})$	P	FOM
2009	12	0.38	1.7
2011	9.4	0.49	2.3
2012	77	0.56	24
2013	**$\sim$300**	**$\sim$ 0.53**	**$\sim$84**

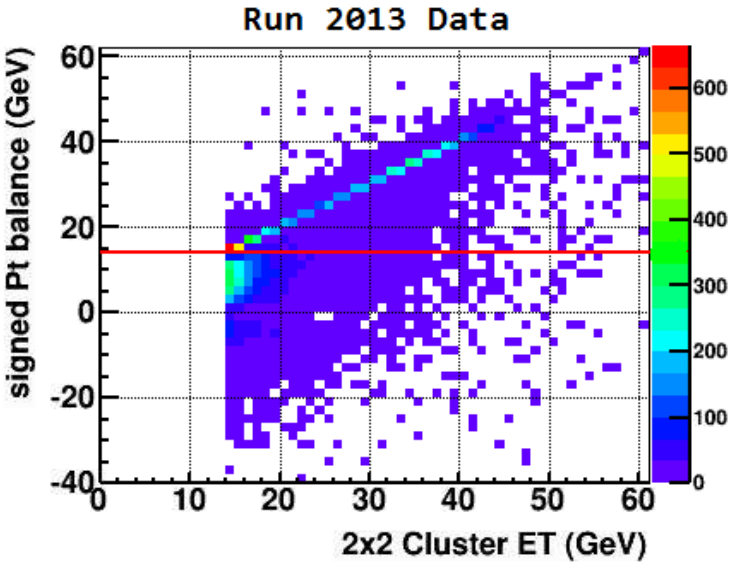
* where FOM stands for figure of merit, $P^2 L\ (pb^{-1})$

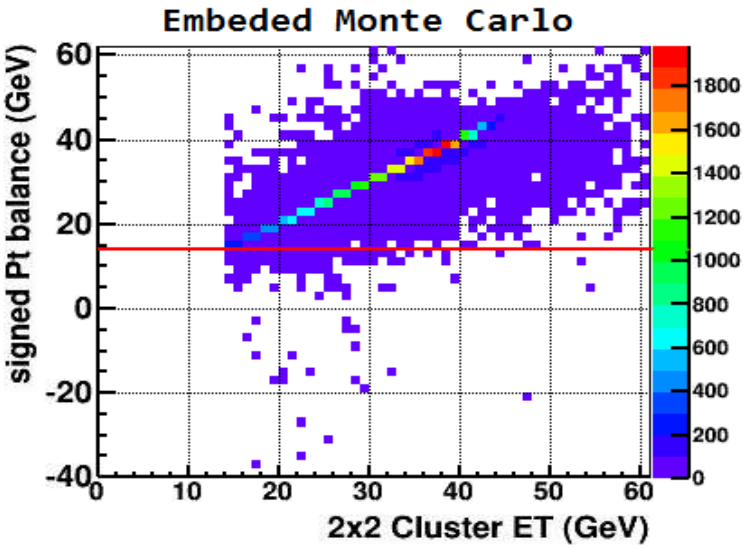
- In 2013, STAR collected an integrated luminosity of $\sim$300 pb^{-1} at $\sqrt{s} = 510$ GeV with an average beam polarization of $\sim$53%, which is 3 times greater than total of previous years in FOM.

Analysis Status of W A_L for Run 2013



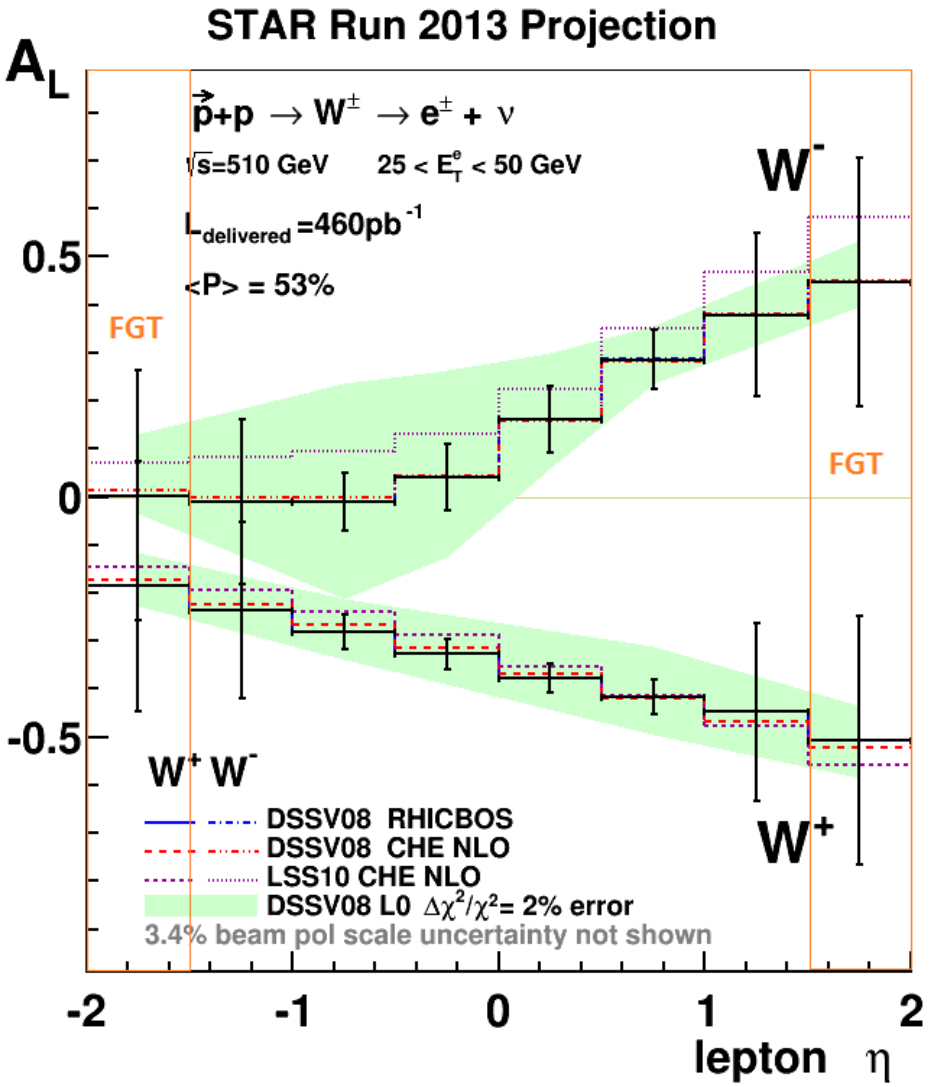


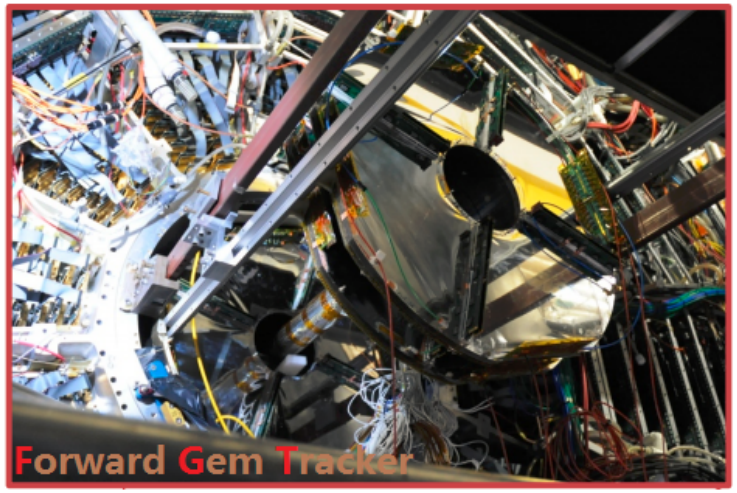




* roughly half of the total statistics of run 2013

Projection of W A_L for Run 2013





FGT was fully installed for Run13

- Extension of backward and forward acceptance enhances sensitivity to $\bar{u}$ and $\bar{d}$ quark polarization
- Higher precision result is expected from much larger statistics of run13 database (being analyzed).

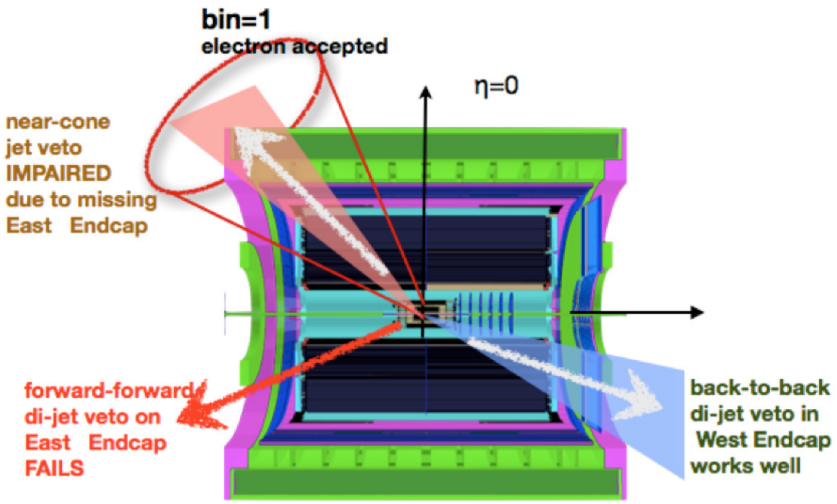
Summary

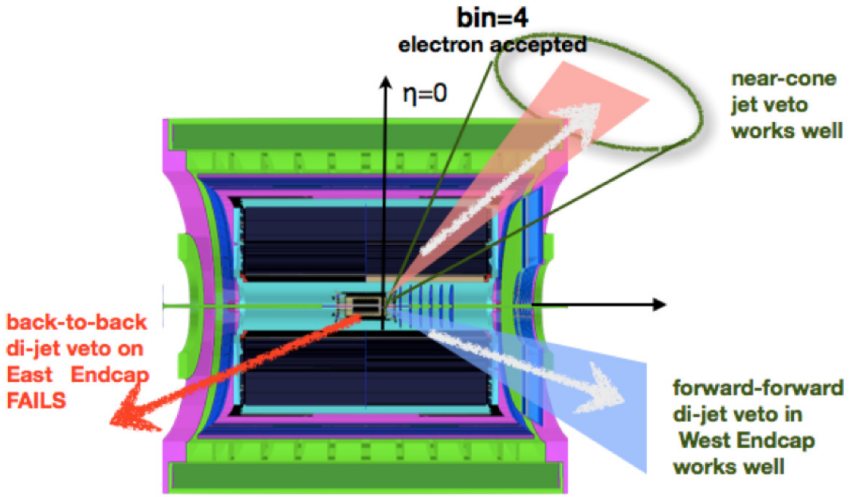
- STAR has measured the parity-violating A_L of W bosons as a function of decayed lepton pseudo-rapidity, η_e, which provides significant constraints on $\Delta\bar{u}$ and $\Delta\bar{d}$
- New constraints on light sea quark polarization from W data, preferring a positive $\Delta\bar{u}$
- Higher precision data being analyzed now from Run 13.

New results are coming!

Backup

Second EEMC Background





The background events rejected by the **real** EEMC which are measured in the positive detector η bins correspond to the background event that would be removed from the signal yield in the negative detector η bins by a **fictitious** EEMC on the east side of STAR.

Systematic Uncertainties

- Beam polarization uncertainty: correlated scale 3.4%
- Relative luminosity uncertainty: correlated offset $\Delta A_L = 0.007$
- Background estimation: less than 10% of statistical error

W A_{LL} Result of 2011+2012

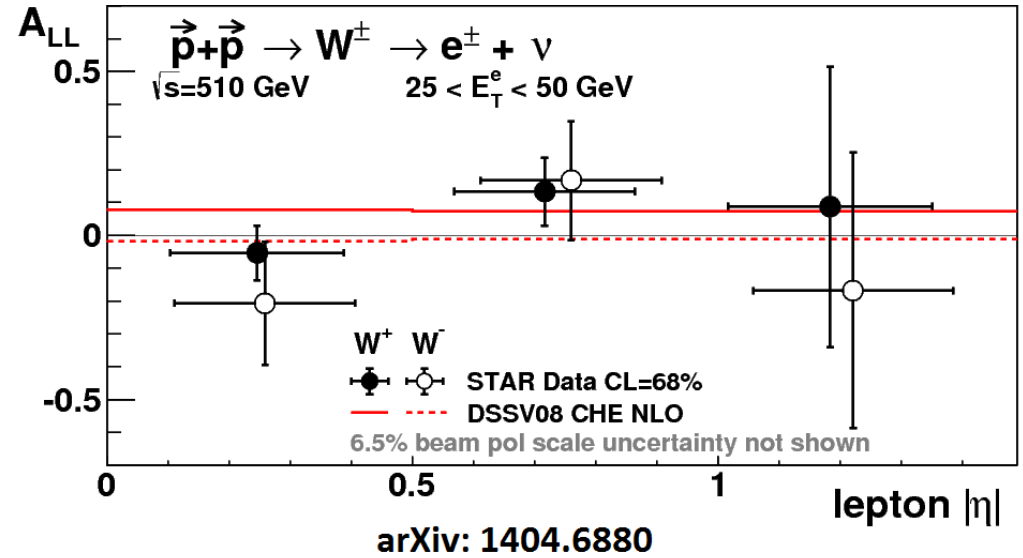
Measure double spin asymmetry:

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

- Probes different combination of quark polarizations

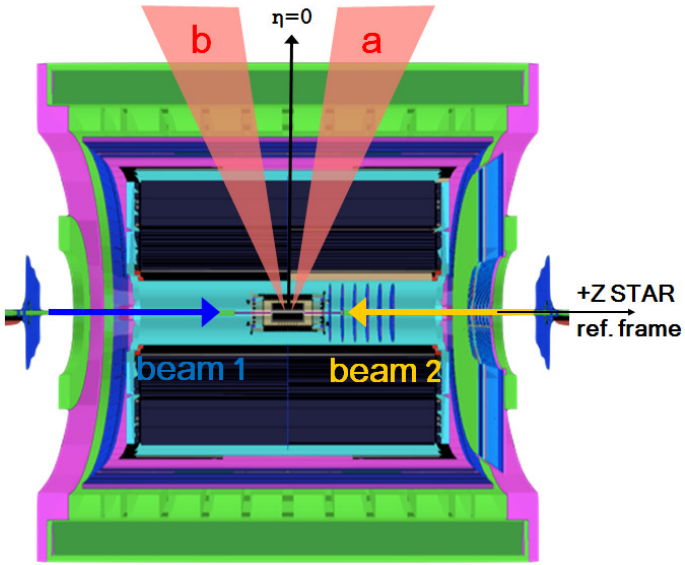
  $A_{LL}^{W^+} \sim \frac{\Delta u}{u}\frac{\Delta \bar{d}}{\bar{d}}$ $\quad$ $A_{LL}^{W^-} \sim \frac{\Delta d}{d}\frac{\Delta \bar{u}}{u}$

- Proposed to test positivity constraints using a combination of A_L and A_{LL}
- First measurement is consistent with predictions from DSSV



Extract Spin Asymmetry with Profile Likelihood Method

- ✓ Profile Likelihood method was used in combination of 2011 and 2012
- ✓ Accommodate the low statistics of 2011 dataset



Define a likelihood function for 8 spin-dependent yields from pair of symmetric η region of STAR :

$$L = \prod_i^4 \mathcal{P}(M_i^a|\mu_i^a)\mathcal{P}(M_i^b|\mu_i^b)g(\beta^a)g(\beta^b)$$

- $\mathcal{P}(M_i|\mu_i)$ *is Poisson probability, for measured spin sorted yield* M_i *in the expected value* μ_i *given by :*

$$\mu^a_{++} = l_{++}N(1 + P_1\beta A_L^{+\eta e} + P_2\beta A_L^{-\eta e} + P_1P_2\beta A_{LL})$$
$$\mu^a_{+-} = l_{+-}N(1 + P_1\beta A_L^{+\eta e} - P_2\beta A_L^{-\eta e} - P_1P_2\beta A_{LL})$$
$$\mu^a_{-+} = l_{-+}N(1 - P_1\beta A_L^{+\eta e} + P_2\beta A_L^{-\eta e} - P_1P_2\beta A_{LL})$$
$$\mu^a_{--} = l_{--}N(1 - P_1\beta A_L^{+\eta e} - P_2\beta A_L^{-\eta e} + P_1P_2\beta A_{LL})$$

**where* $P_1(P_2)$ *beam polarization,* $A_L^{+\eta e}(A_L^{-\eta e})$ *single-spin asymmetry,* A_{LL} *double-spin asymmetry,* N_a *spin averaged yield,* $l_{\pm\pm}$ *the relative luminosity*

- $g(\beta)$ *is Gaussian probability for estimated dilution background,* $\beta = S/(S+B)$.

Extract asymmetries from likelihood function $L_{2011} \times L_{2012}$