Measurement of the Longitudinal Single Spin Asymmetries for W Boson Production in Polarized Proton-Proton Collisions at STAR

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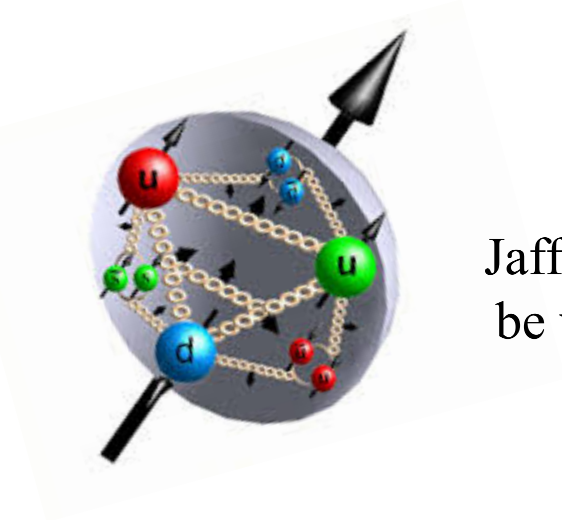


Spin Puzzle

Jaffe and Monahar showed in 1990 that the proton spin can be written as a sum of contributions from quark and gluon spin and orbital angular momentum.

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

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

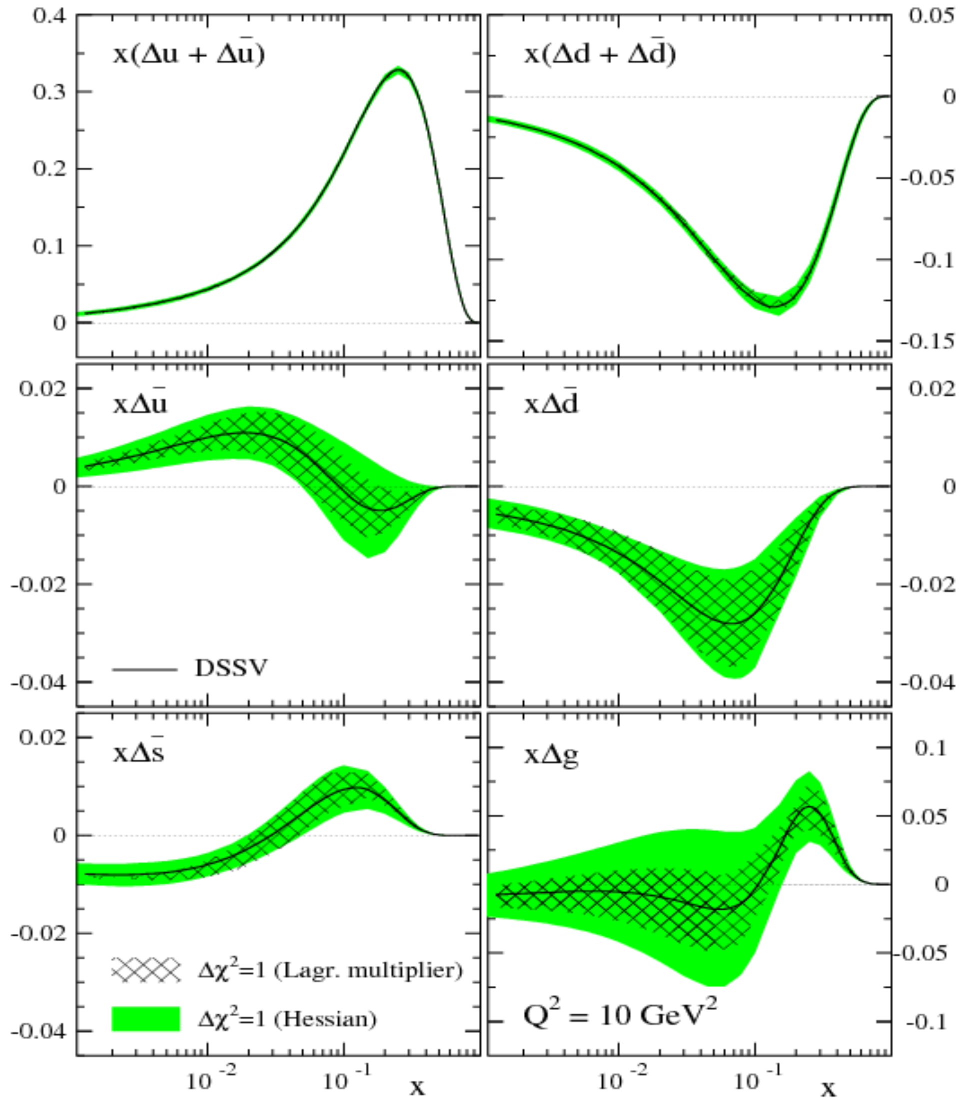
$$\Delta G = \int \Delta g(x)dx$$

Δf(x) Helicity Distribution: Probability density for finding a parton in a longitudinally polarized nucleon with flavor *f* and momentum fraction *x* in a nucleon.

Helicity Distribution

- DSSV08 global analysis.
- The total contribution of up and down quarks spin has been well constrained.
- The flavor separated contributions of the sea quarks, still have quite large uncertainties.
- The gluon polarization also shows a large uncertainty band.

Daniel de Florian, Rodolfo Sassot, Marco Stratmann and Werner Vogelsang, Phys. Rev. D80 (2009) 034030.

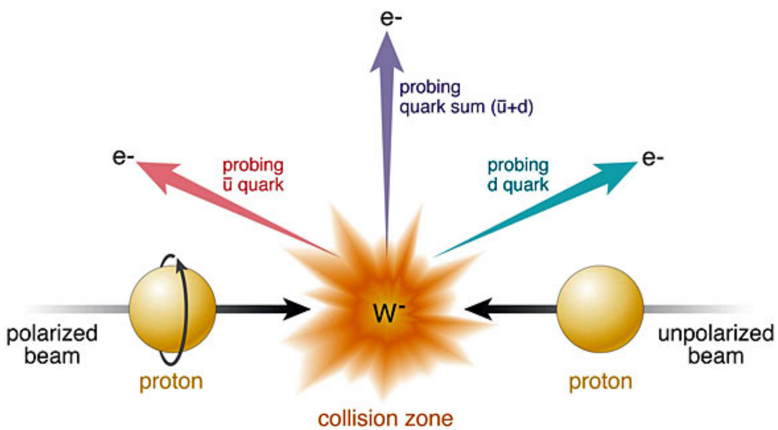


Weak Boson Production

The production of W boson in polarized proton-proton collisions is an independent method of probing the polarization of the light quarks and antiquarks.

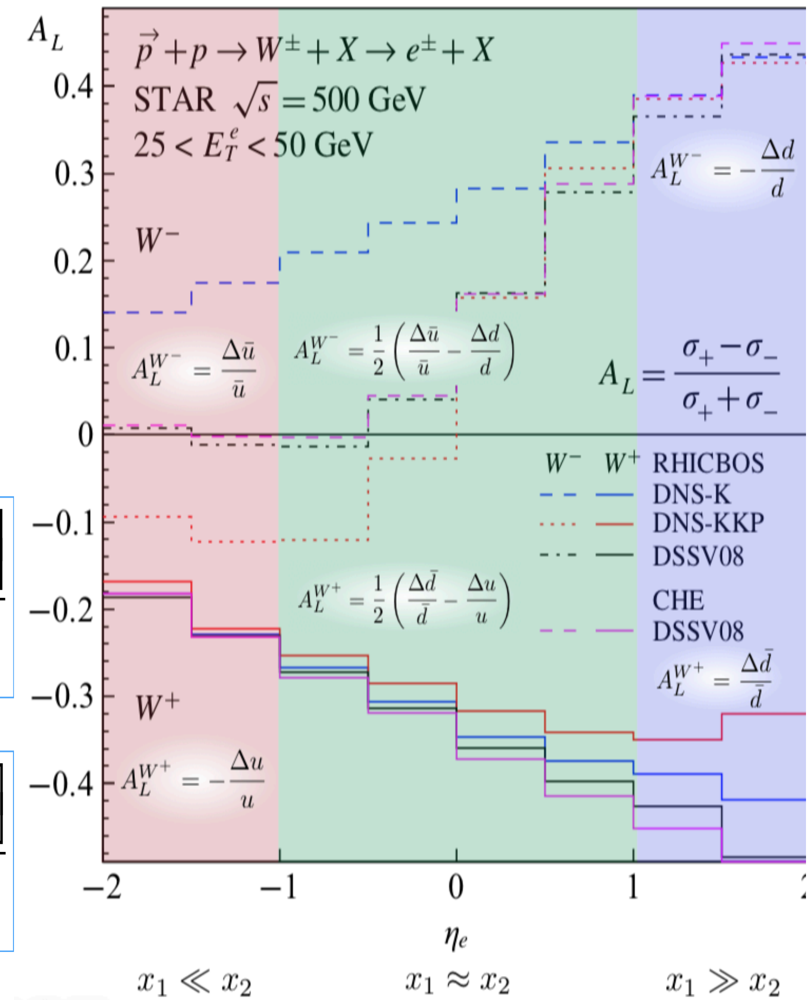
- W production provides direct sensitivity to the u and d quark and antiquark helicity distributions.
- Large-scale defined by *W mass* (~80 GeV).
- Simple final state of charged lepton: no dependency on fragmentation functions.
- V-A coupling of the weak interaction leads to perfect spin separation.

Single Spin Asymmetry of W



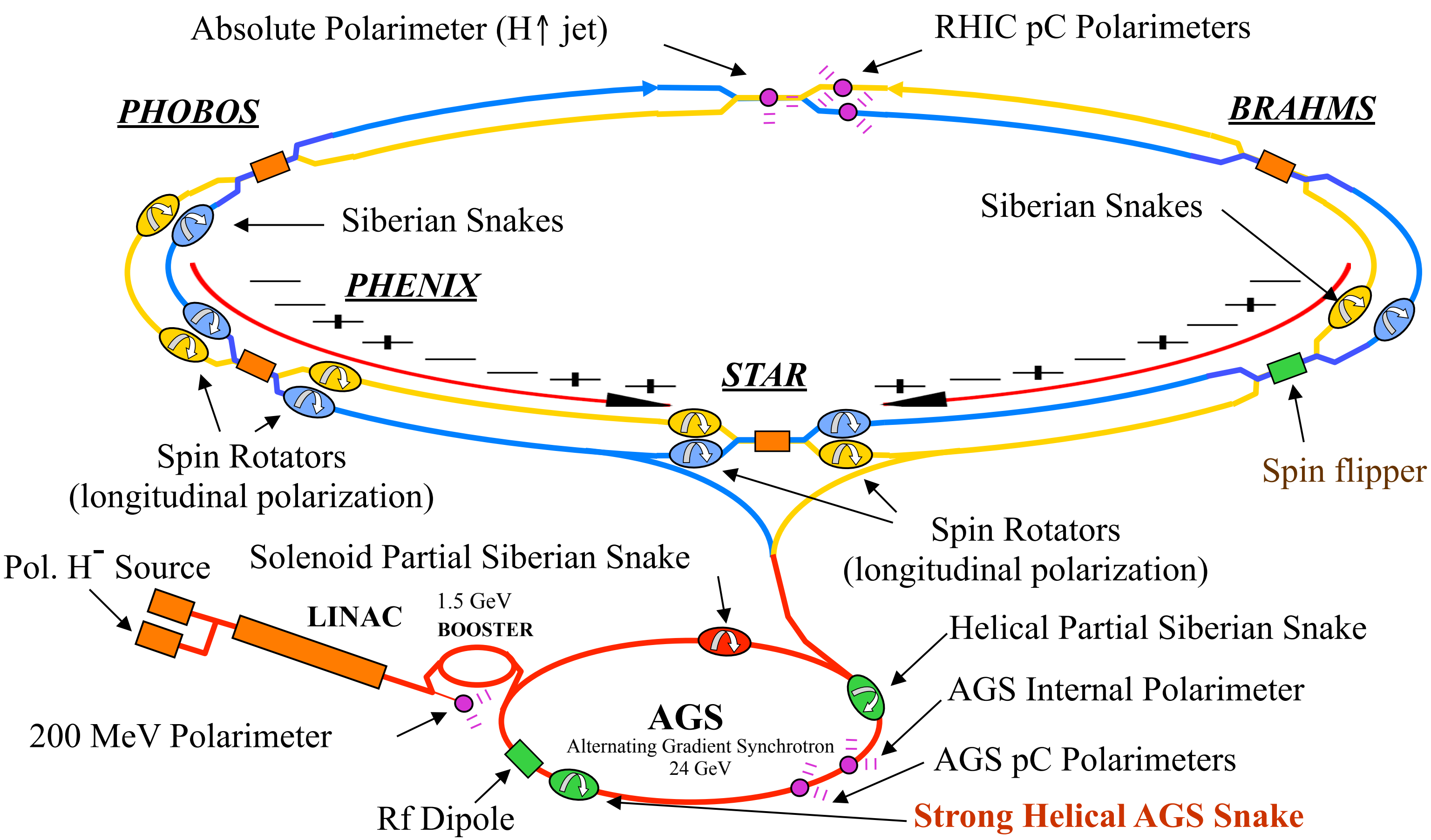
$$A_L^{e-} \approx \frac{\int_{\otimes(x_1,x_2)} \left[\Delta\bar{u}(x_1) d(x_2)(1-\cos\theta)^2 - \Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2 \right]}{\int_{\otimes(x_1,x_2)} \left[\bar{u}(x_1) d(x_2)(1-\cos\theta)^2 + d(x_1)\bar{u}(x_2)(1+\cos\theta)^2 \right]}$$

$$A_L^{e+} \approx \frac{\int_{\otimes(x_1,x_2)} \left[\Delta\bar{d}(x_1) u(x_2)(1+\cos\theta)^2 - \Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2 \right]}{\int_{\otimes(x_1,x_2)} \left[\bar{d}(x_1) u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2 \right]}$$



Relativistic Heavy-Ion Collider (RHIC)

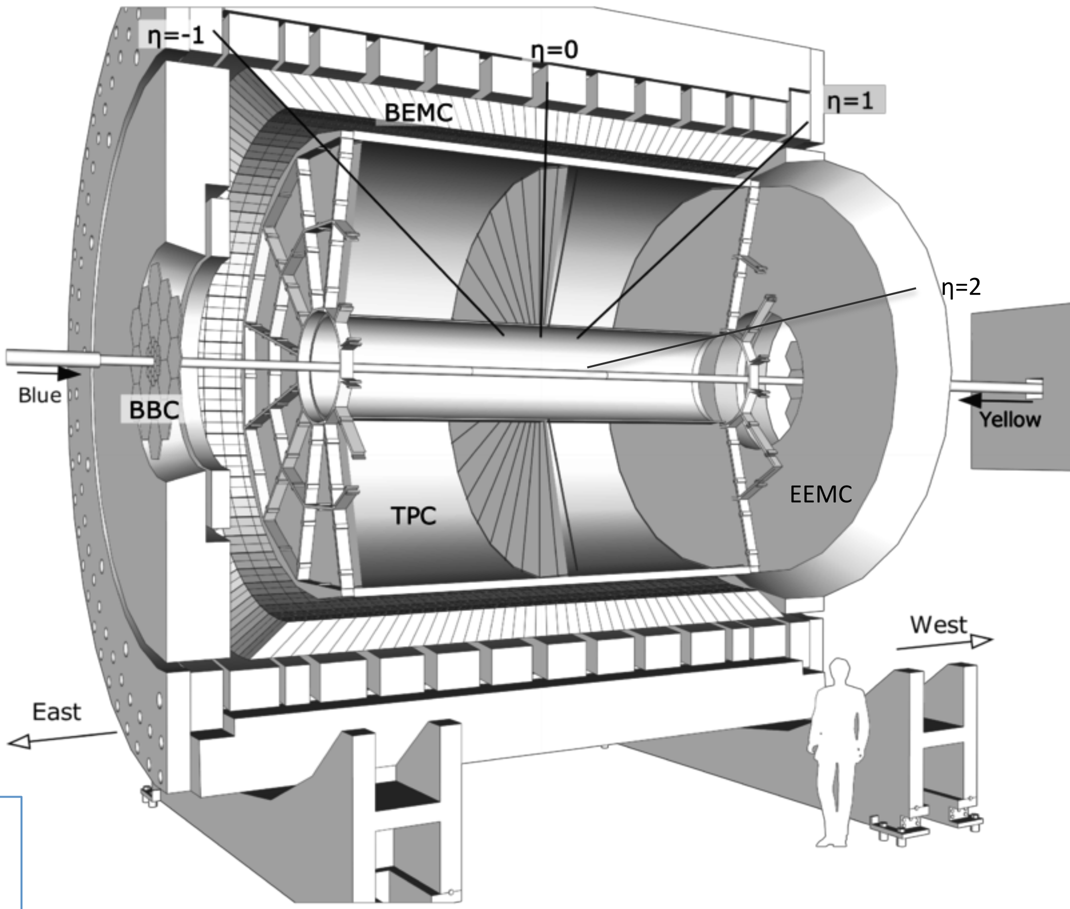
RHIC is the world's first polarized proton collider



STAR Detector

$$\eta = -ln\, tan\frac{\theta}{2}$$

- Calorimetry system with 2π coverage:
  - BEMC (-1 < η < 1)
  - EEMC (1 < η < 2)
- TPC: Tracking and particle ID
  - (|η|<1.3)



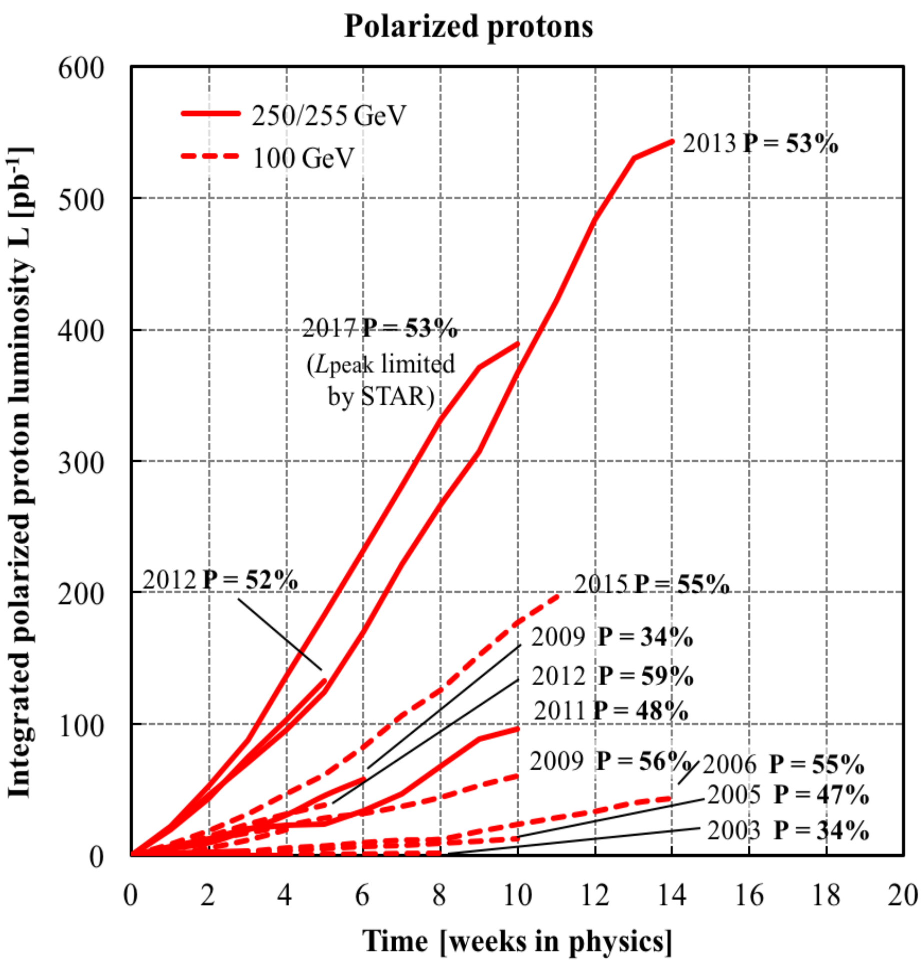
Approximate kinematic range at RHIC
-2 < η < 2 0.06 < x < 0.4

Run 2013 Dataset

Production runs at √s=500/510GeV (long. polarization) in 2009, 2011, 2012 and 2013:

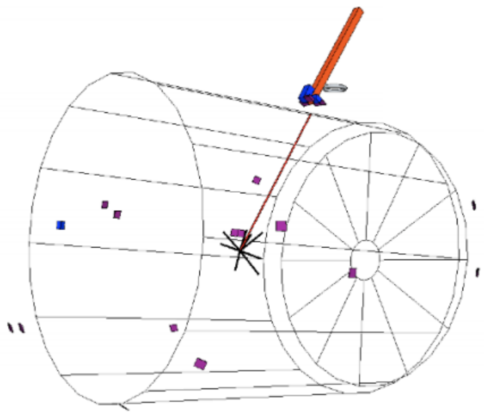
- W production (Quark polarization)
- Jet and Hadron production (Gluon polarization)

Run	L (pb^{-1})	P (%)	FOM (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	200	0.56	63



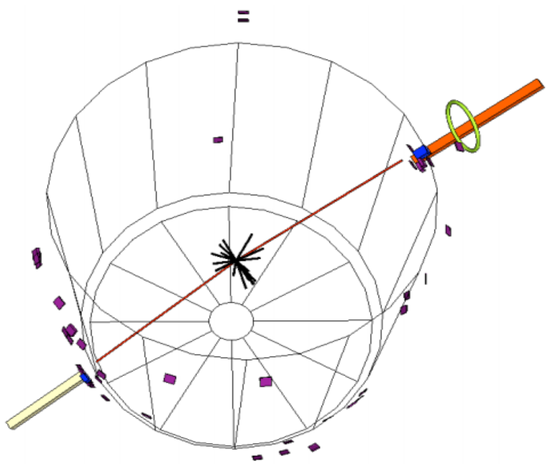
W Selection at STAR

The W selection algorithm is built based on the topological and kinematic differences between W events and QCD events



$$p + p \rightarrow W \rightarrow e + \nu$$

- Isolated track pointing to isolated cluster in the calorimeter.
- Missing energy in the opposite azimuthal direction.

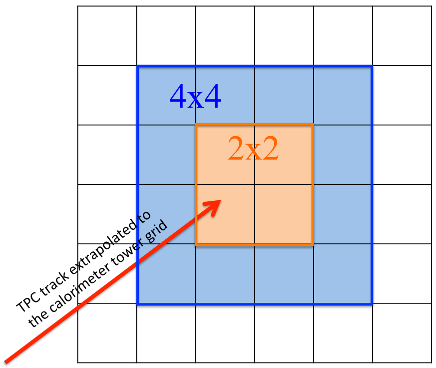


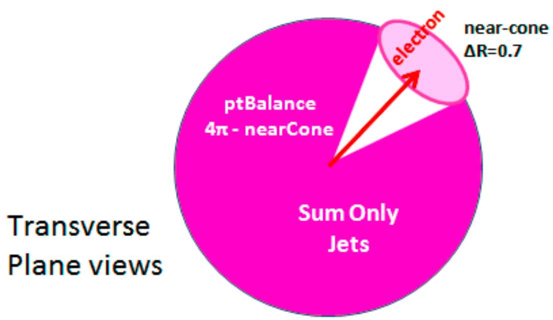
$$p + p \rightarrow QCD \rightarrow jets$$

- Several tracks pointing to several towers.
- Vector p_T sum is balanced by opposite jet.

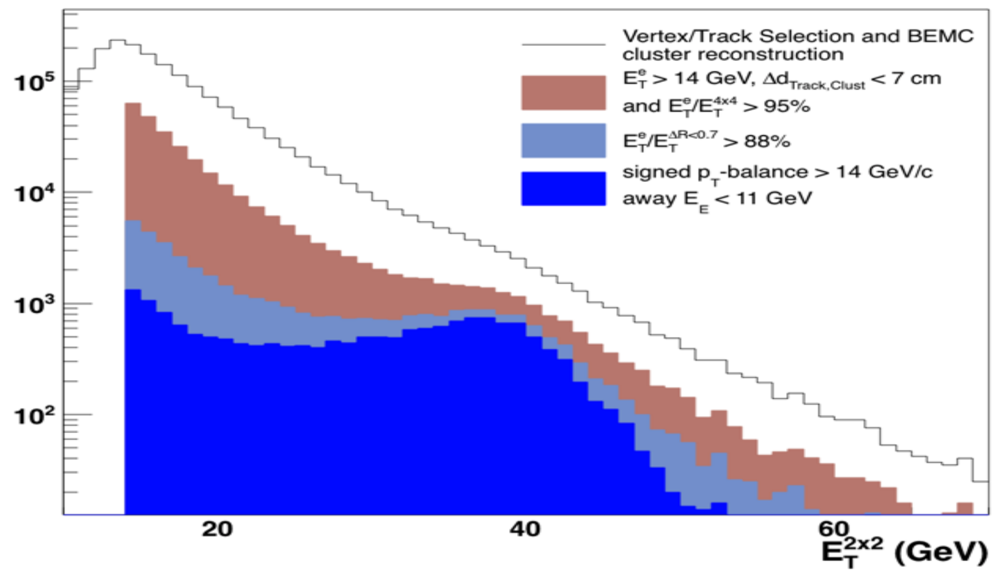
Jacobian Peak

- $E_T^{2x2}/E_T^{4x4} > 0.95$
- $E_T^{2x2}/E_T^{\Delta R<0.7} > 0.88$
- Signed p_T balance > 14 GeV/c
- Away E_T <11 GeV





Signal of Jacobian Peak with E_T distribution after selection cuts



Background Estimation

Electroweak Background:
This background arises from well-understood electroweak processes:

- $Z \rightarrow e^- + e^+$
- $W \rightarrow \tau + \nu$

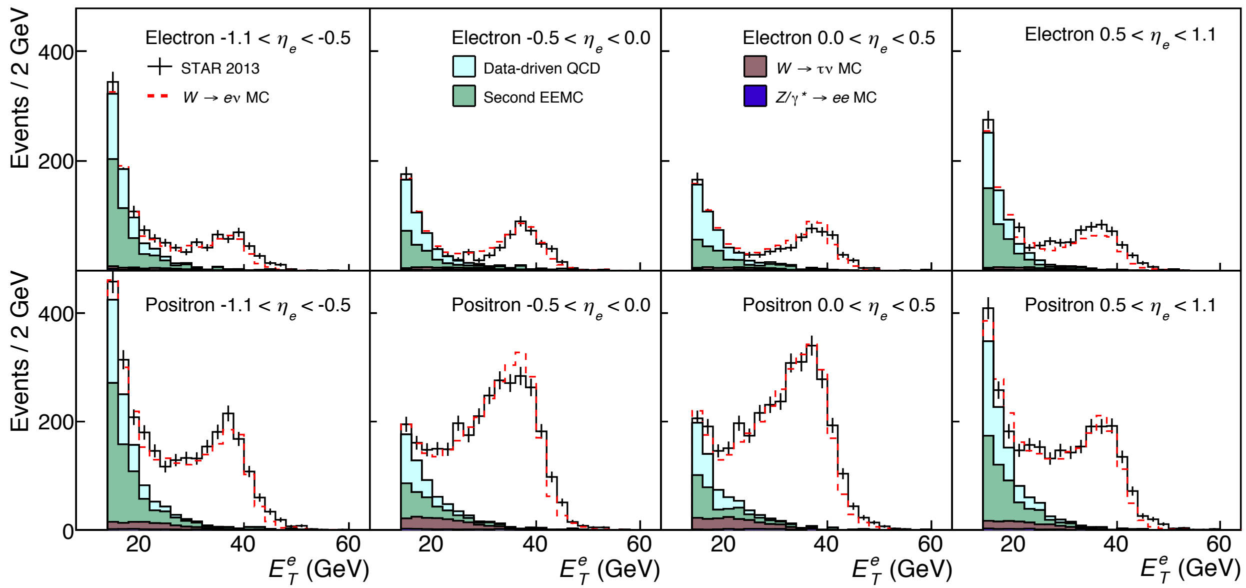
QCD Background:

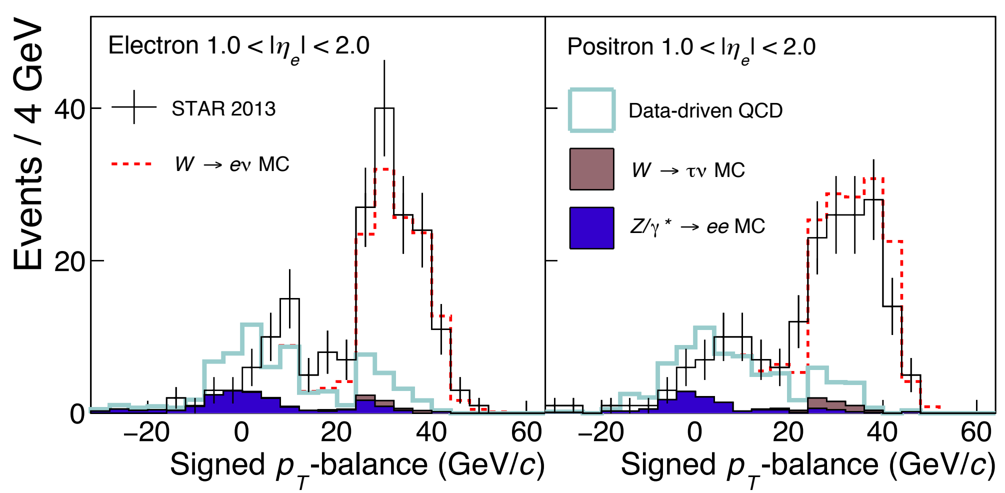
- **Second EEMC:**

Background (di-jets) which counts as a W event by escaping detection through non-existing calorimeter coverage ($-2 < \eta < -1$).

- **Data–driven QCD:**

Background which passes $e^{\pm}$ isolation cuts.

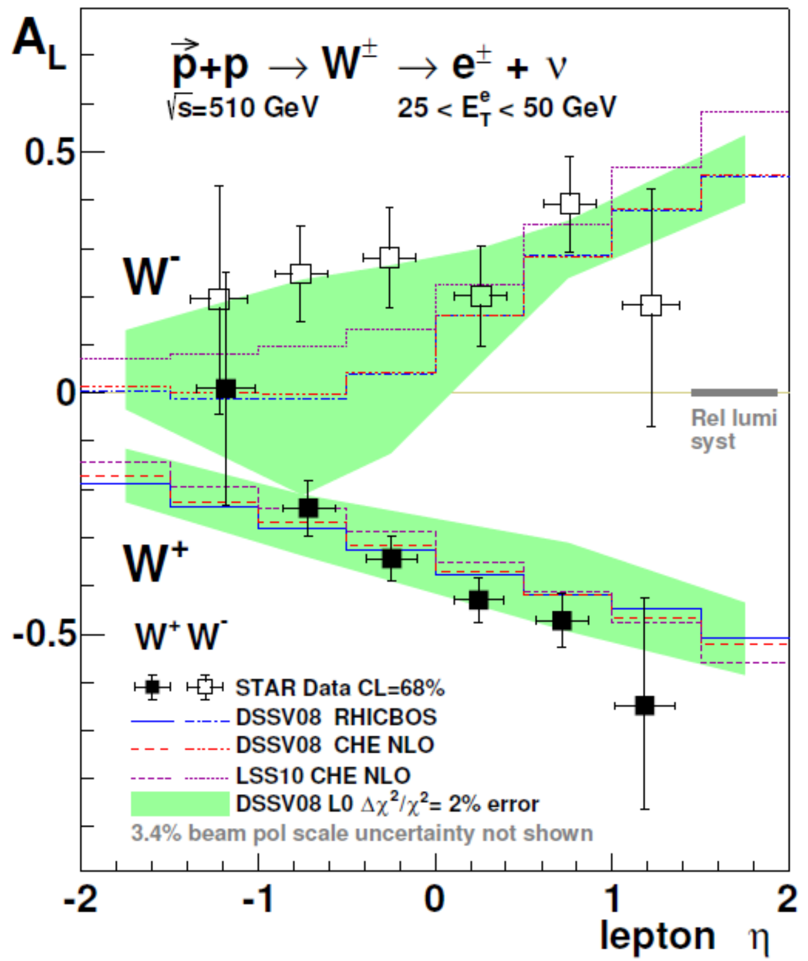




W A_L from Run 2011+2012

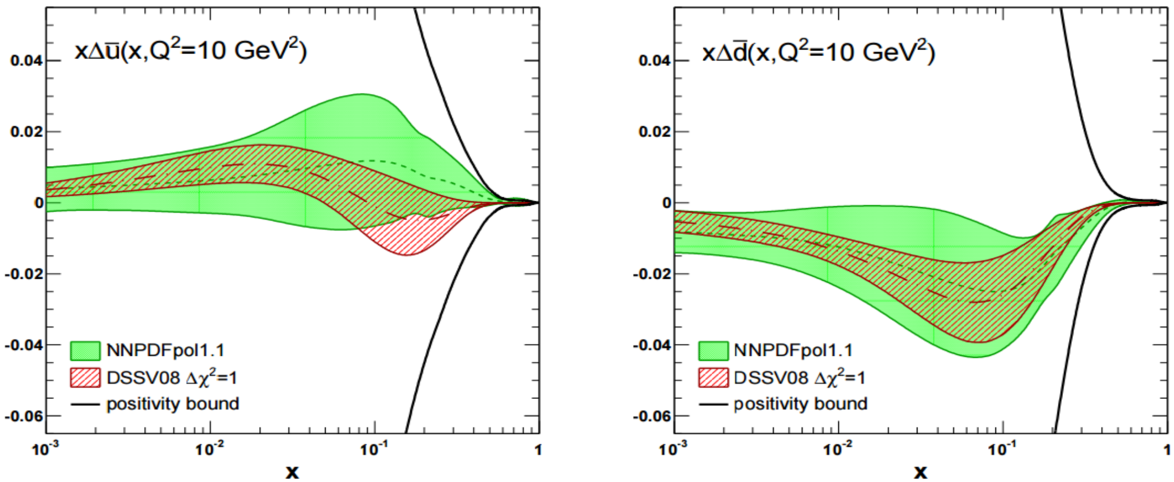
- A_L of W^- shows indication that data are larger than the DSSV predictions.
- A_L of W^+ is consistent with theoretical predictions with DSSV pdf.
- Indication of symmetry breaking of polarized sea.

PRL 113 (2014) 072301

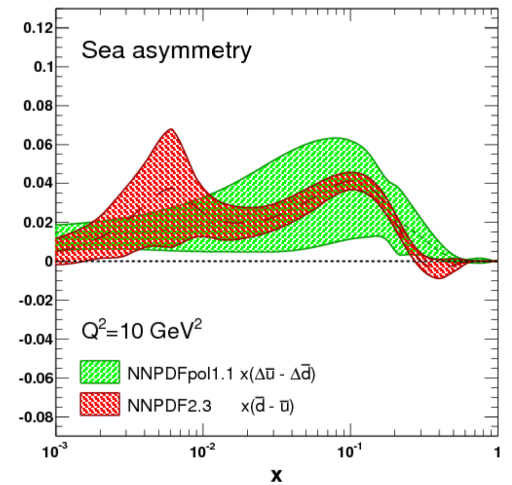


Impact of STAR 2011+2012 W A_L Measurements (NNPDF)

R. Ball et al. (NNPDF Collaboration), Nucl. Phys. B887 (2014) 276.



E. Nocera. PoS DIS2014 (2014) 204.



- The flavor asymmetry of polarized antiquarks in the nucleon is positive

- It has almost the same absolute size as the flavor asymmetry of unpolarized antiquarks

W A_L from Run 2013

- Most precise W A_L results from 2013 dataset.
- Consistent with 2011+2012 published results, with 40% uncertainty reduced.
- Further confirmed the polarized sea asymmetry.

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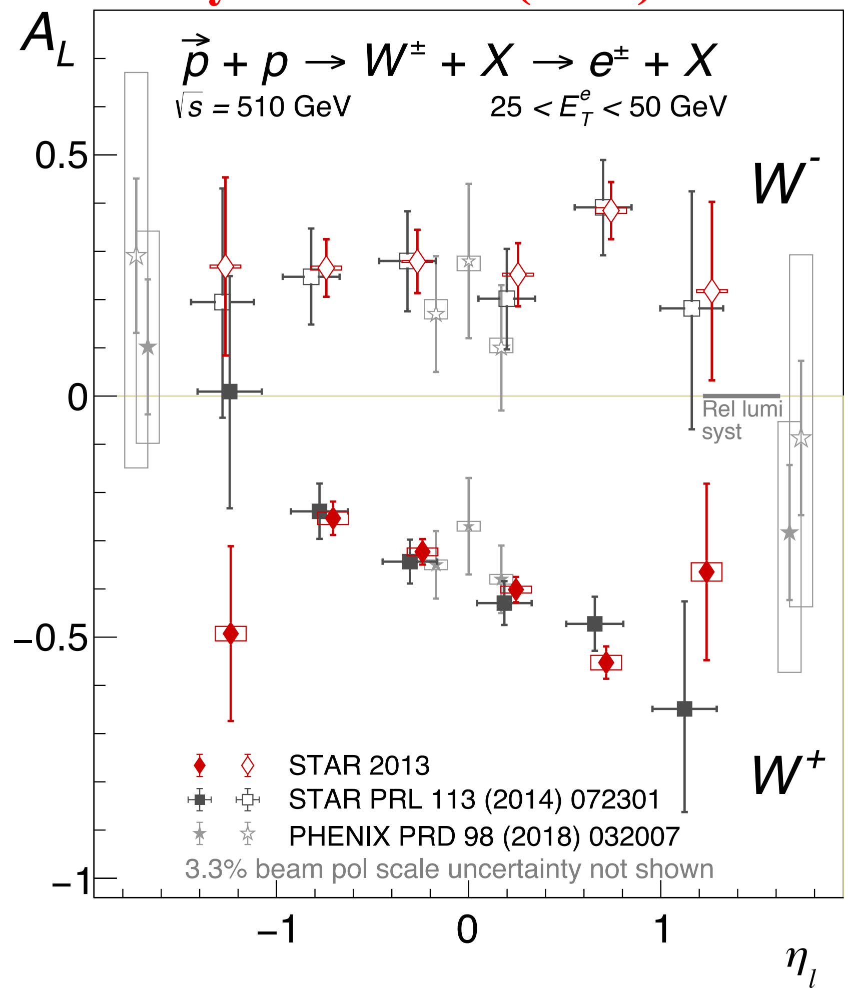

Impact of STAR 2013 W A_L Measurements (NNPDF)

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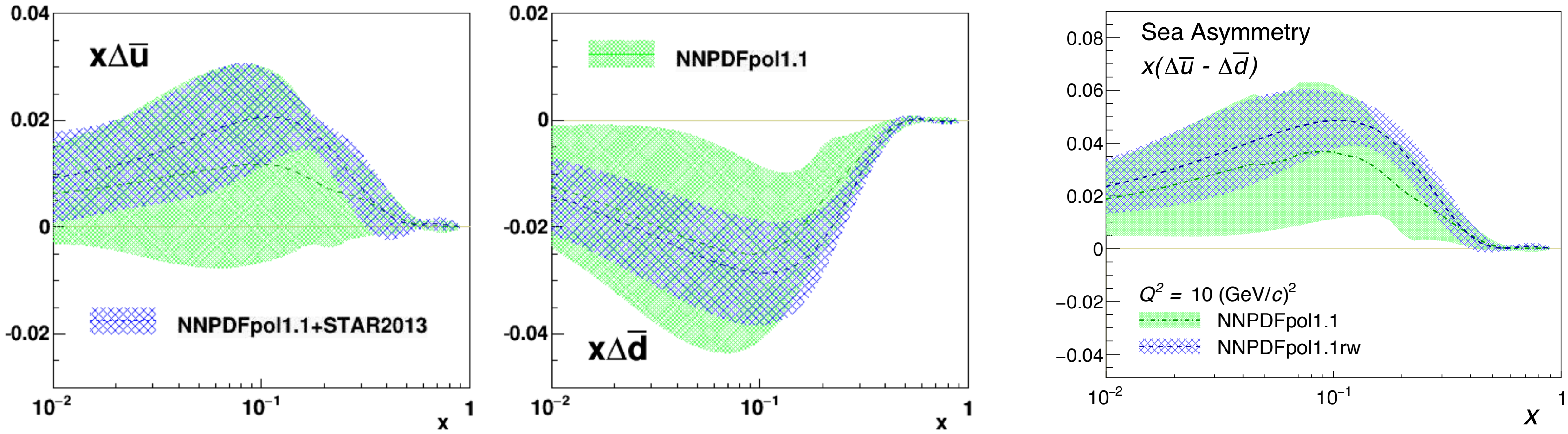

- The data confirm the existence of a sizable, positive u-bar polarization in the range $0.05 < x < 0.2$.
- The data confirm the existence of a flavor asymmetry in the polarized quark sea.

W A_{LL} from Run 2013

Double spin asymmetry of W can also provide access to u-bar, d-bar polarization

$$A_{LL}^{W^+} \propto \frac{\Delta u}{u} \frac{\Delta \bar{d}}{\bar{d}}$$

$$A_{LL}^{W^-} \propto \frac{\Delta d}{d} \frac{\Delta \bar{u}}{\bar{u}}$$

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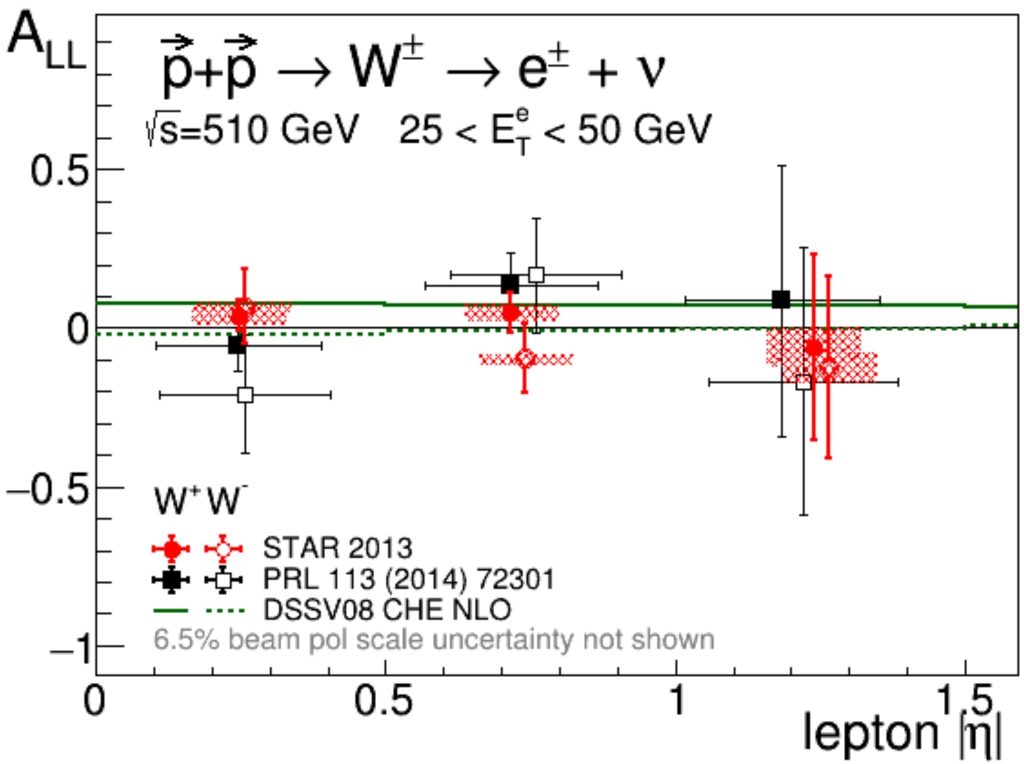

Summary

- Sea quark polarization plays an important role in understanding the nucleon spin structure.
- STAR W A_L place unique and significant constraints on the polarized quark and antiquark distributions.
- Significant shift of the central value of $\Delta\bar{u}$ by including the new STAR 2013 W A_L results.
- First clear evidence of the flavor-asymmetry in the polarized quark sea.

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