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U.S. DEPARTMENT OF ENERGY
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Measurements of single-spin asymmetries, A_L for $W^{\pm}$ boson production in longitudinally polarized proton-proton collisions at STAR

- Motivation
- Theoretical Aspect
- Experimental Aspect
- Analysis
- Results
- Summary

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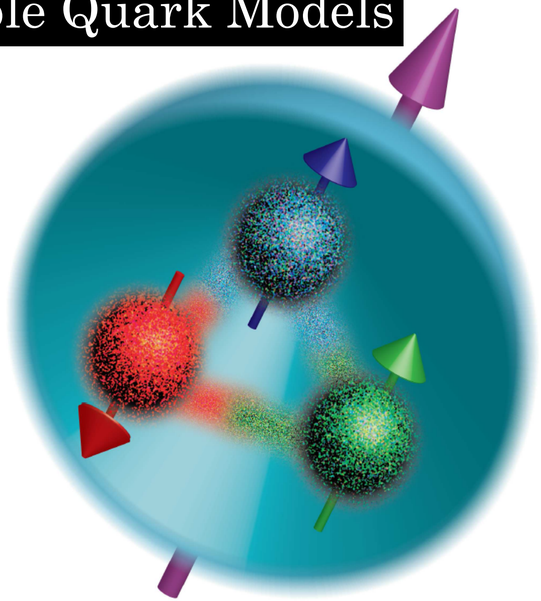
MOTIVATION : Proton Helicity Structure

Simple Quark Models

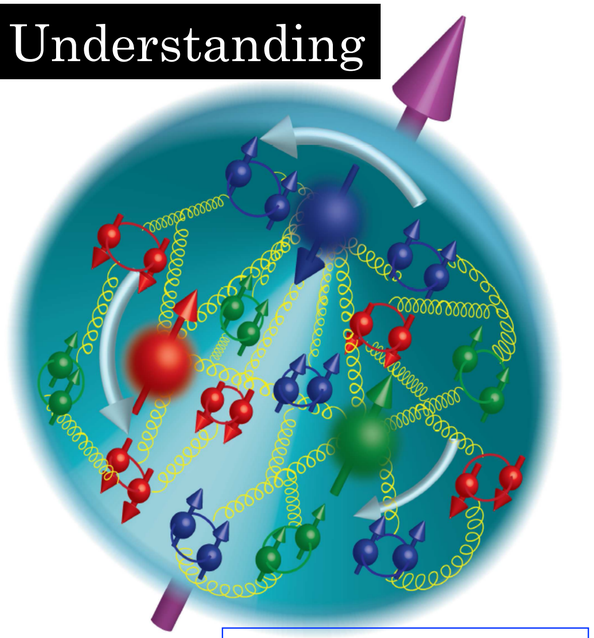


1989 : EMC : DIS

$$\Delta\Sigma = 0.12 \pm 0.09 \pm 0.14$$

"Spin Crisis"

Current Understanding



Nucl. Phys. B337, 509 (1990)

$$\frac{1}{2} = \frac{1}{2}(\Delta u_v + \Delta d_v)$$

Gluons , Sea quarks are polarized.

Parton orbital angular momentum.

$$< S_z >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

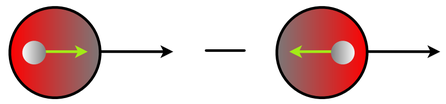
Quarks / antiquarks polarization

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

Helicity PDF

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

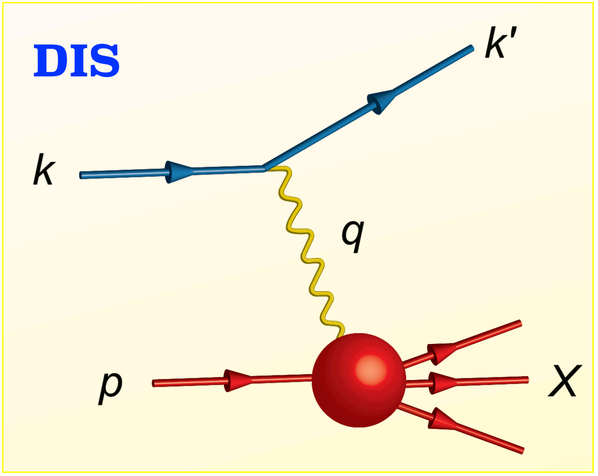
$$\Delta f(x) =$$



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

Helicity distribution

MOTIVATION : Current Knowledge of PDFs

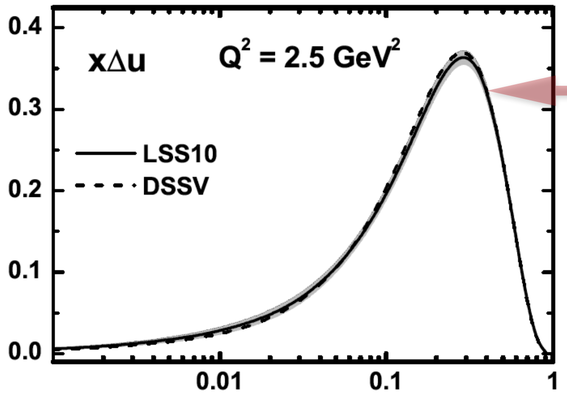


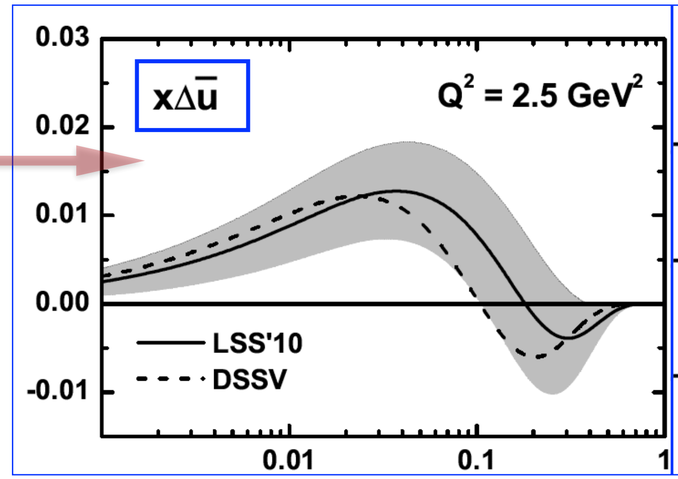
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s})dx$$

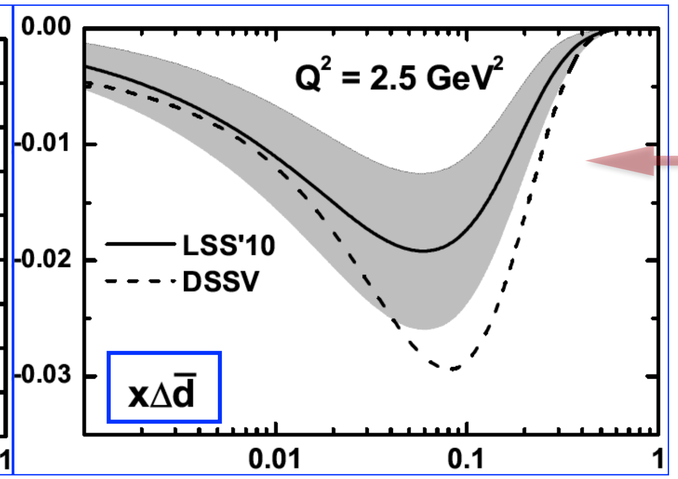
DIS
- Well measured!
- Not sensitive to flavor separation!

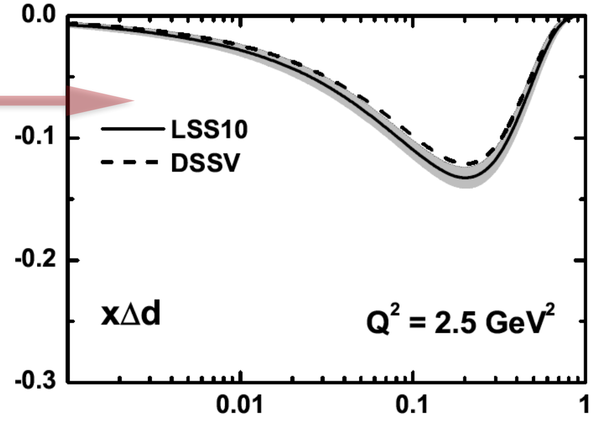
SIDIS
- FF's use to tag flavor!
- Flavor separation / quark, anti-quark separation!
- But large uncertainties in FFs.

Large uncertainties in anti-quark PDFs in comparison to quark PDFs







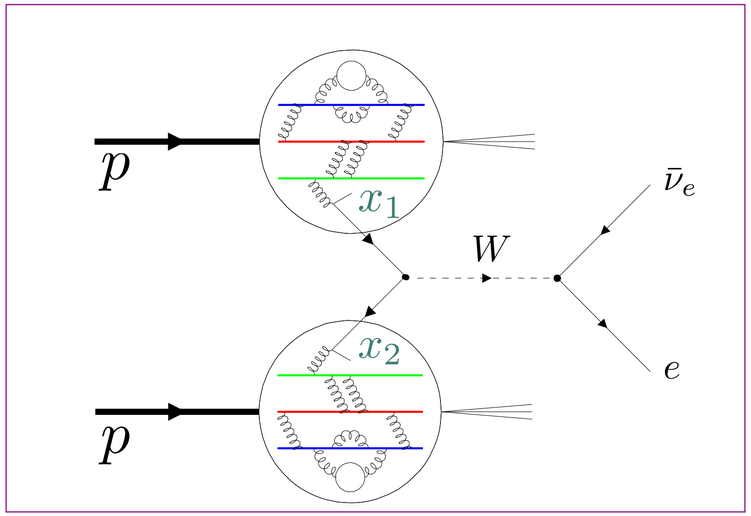


Phys. Rev. D 82, 114018 (2010)

Theoretical Aspects - W A_L

- Probing quark / anti-quark (sea) flavor structure using W boson production at RHIC

W production in p+p,



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

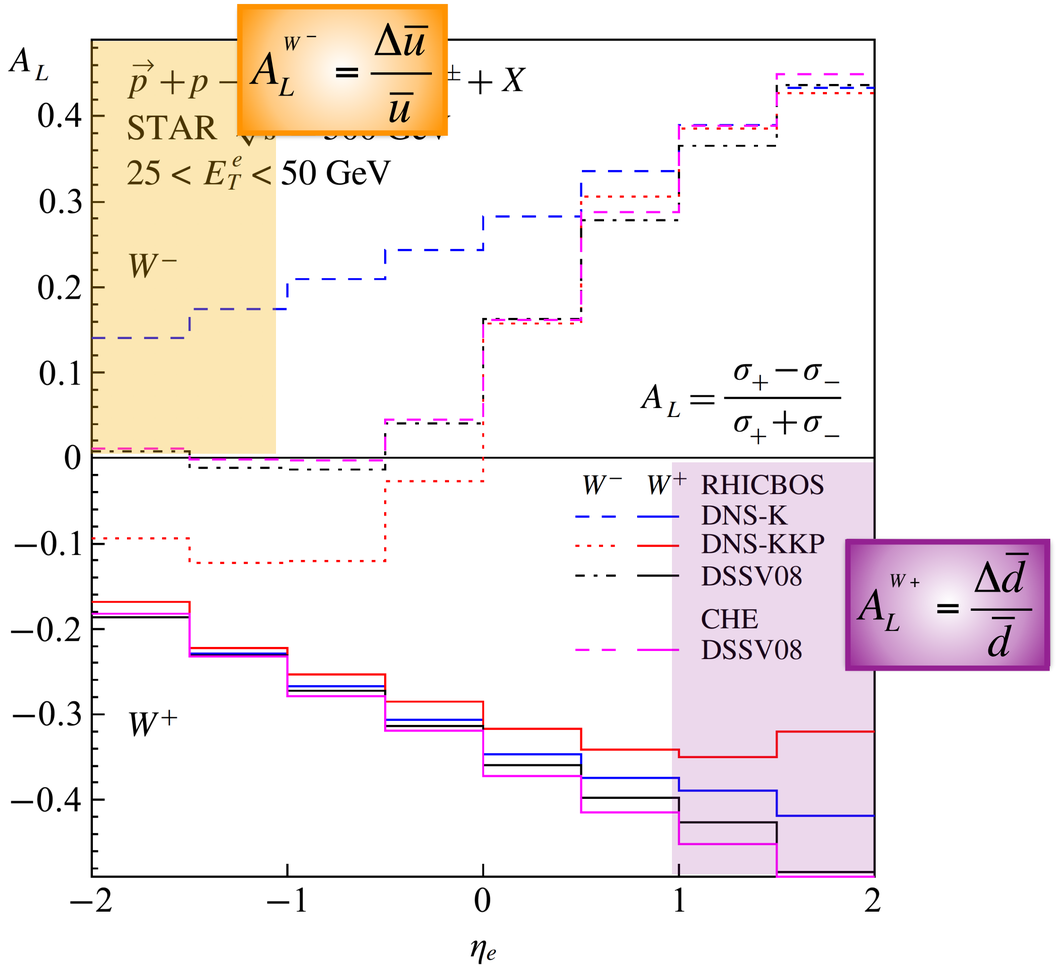
$$A_L = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

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

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

In comparison to SIDIS,

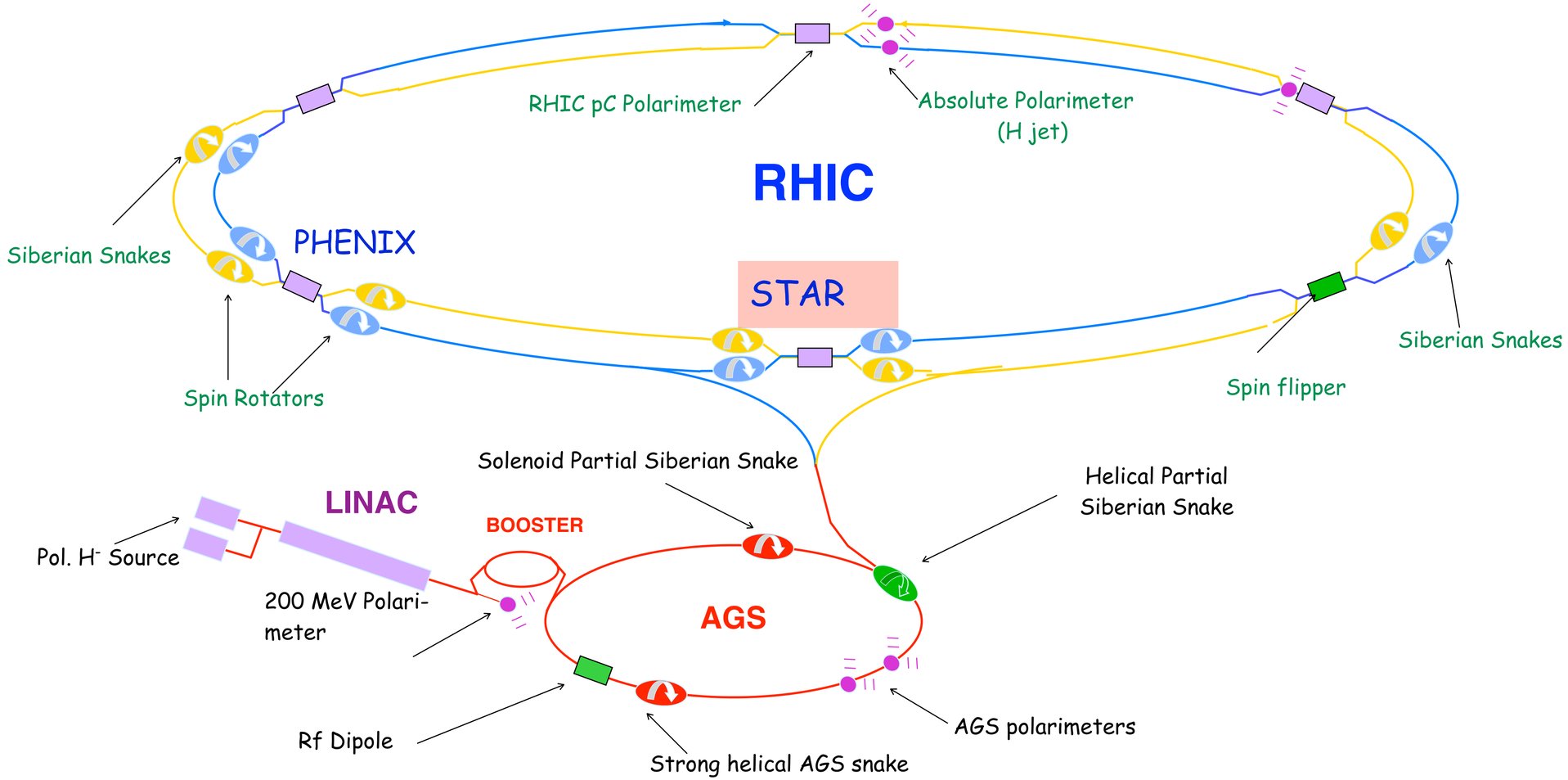
- Direct sensitivity to ū, d̄.
- Large Q^2 defined by W mass (more reliable perturbative calculation / higher twist effects unimportant!).
- Parity violating coupling gives rise to single-spin asymmetry which is directly related to anti-quark helicity PDFs.
- Free of FFs.
- Easy detection via decay leptons.



EXPERIMENTAL ASPECT - RHIC

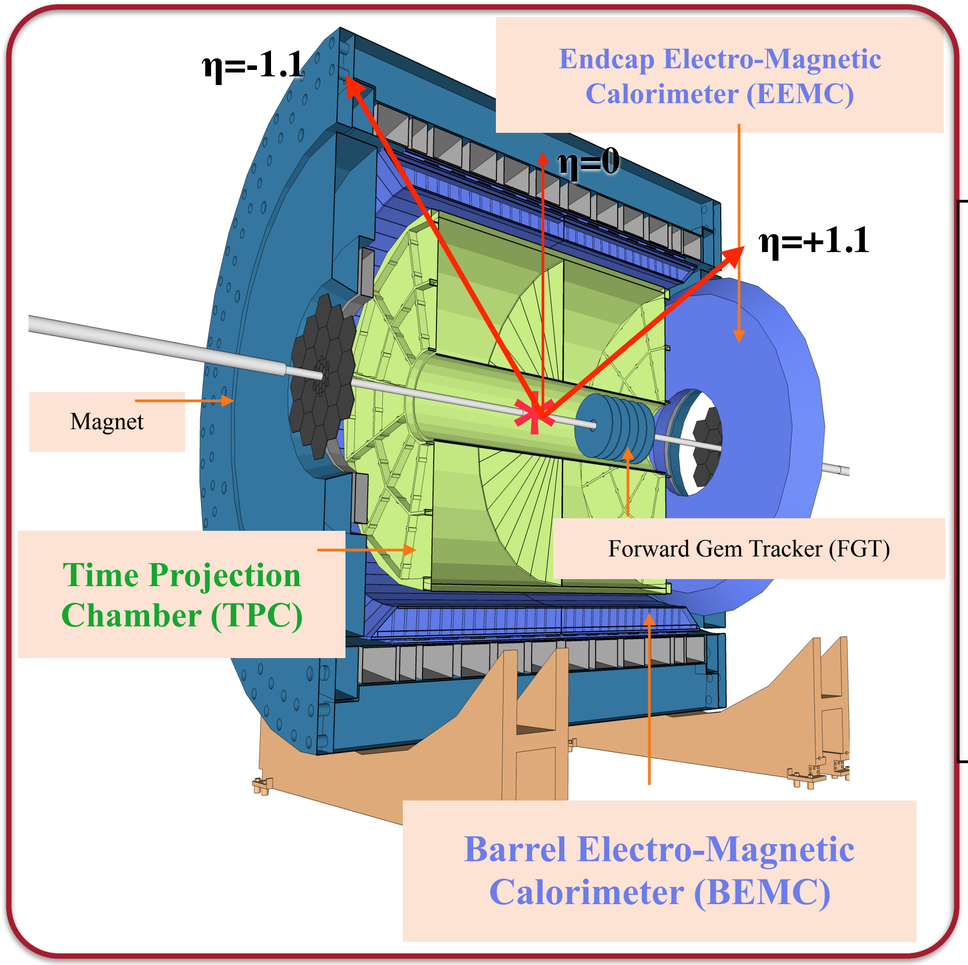
- **RHIC : Relativistic Heavy Ion Collider** The World's first and only polarized hadron collider!

Polarization direction varies from bunch to bunch. Spin pattern changes from fill to fill. Spin rotators provide choice of spin orientation.



EXPERIMENTAL ASPECT - STAR

- **STAR : Solenoidal Tracker At RHIC**



TPC :
$-1.3 < \eta < +1.3$

BEMC:
$-1.0 < \eta < +1.0$

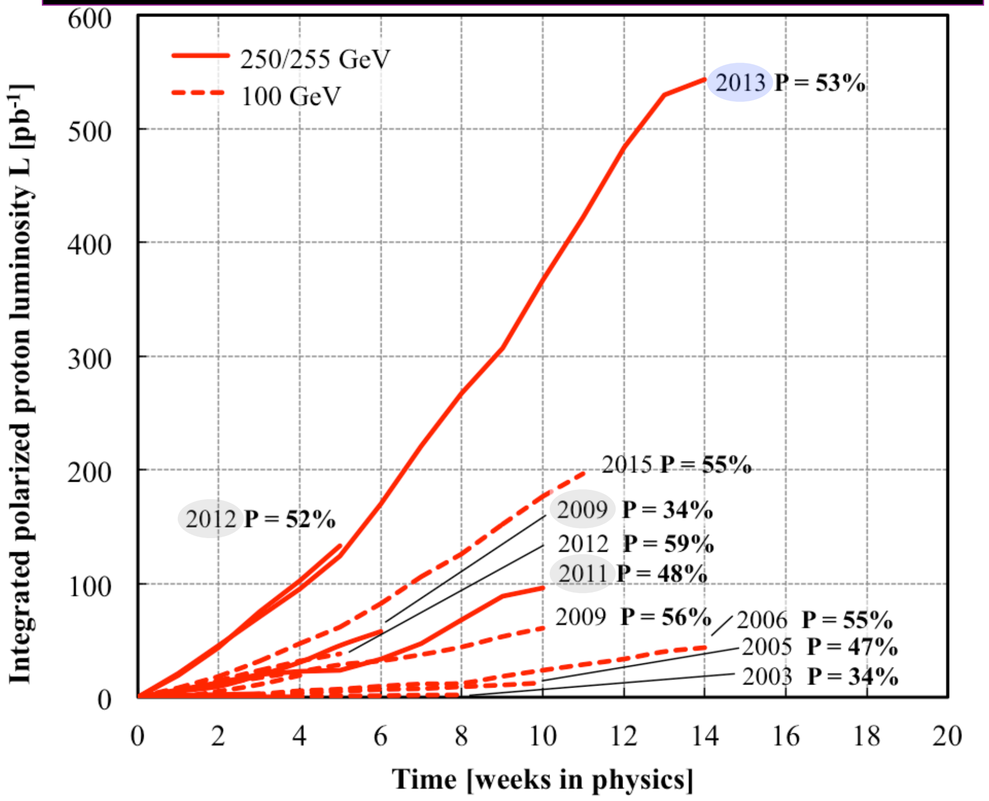
EEMC:
$+1.1 < \eta < +2.0$

FGT:
$+1.0 < \eta < +2.0$

TPC: Charged particle tracking

BEMC, EEMC: EM Calorimetry

RHIC polarized p+p runs : Luminosity

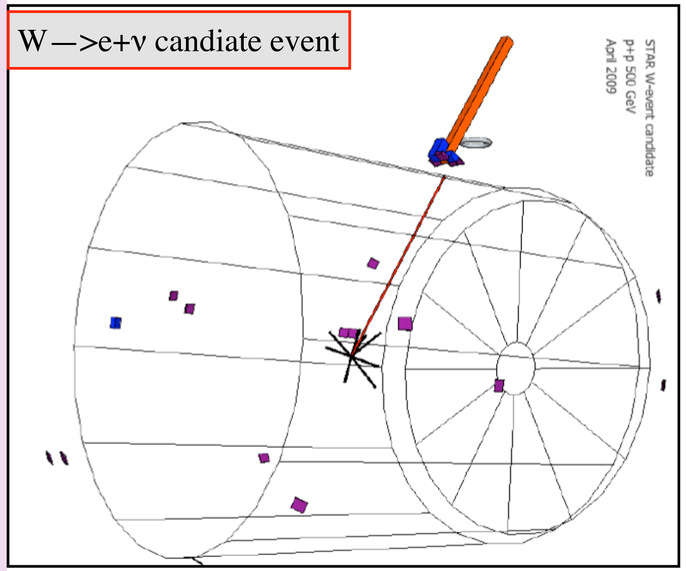


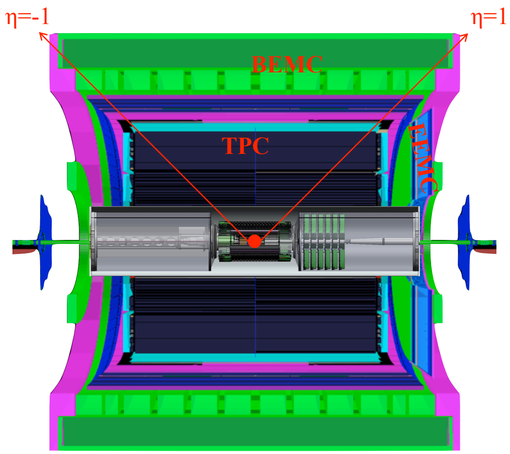
Run	L (pb^{-1})	P (%)	FOM (P^2L) (pb^{-1})
2009	12	0.38	1.7
2011	9.4	0.49	2.3
2012	77	0.56	24
2013	246.2	0.56	77.2

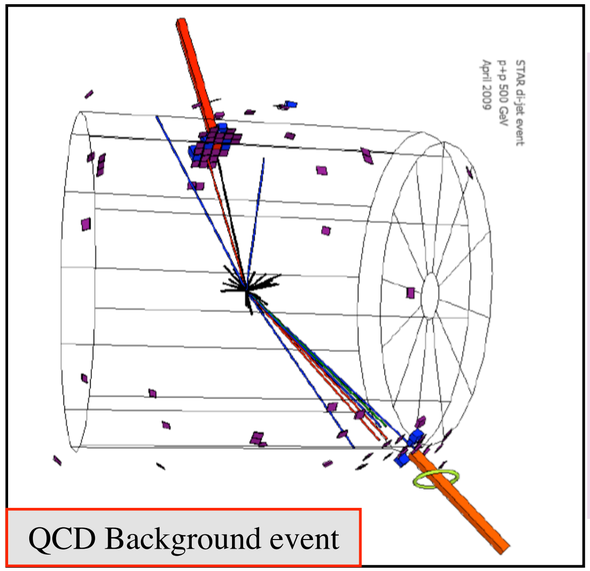
ANALYSIS -MID RAPIDITY STAR W SELECTION CRITERIA

- Isolated high P_T track pointing to isolated EMC cluster.
- Large Imbalance in the reconstructed vector P_T sum in 4π due to undetected neutrino.

W —>e+ν candiate event



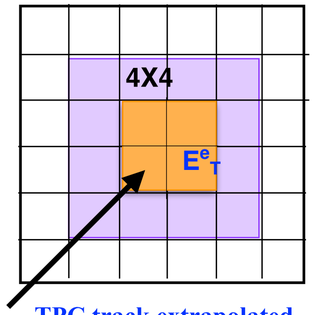




QCD Background event

- Several tracks pointing to several EMC clusters.
- Vector P_T sum is balanced by the Jet opposite in azimuth.

- Mid-rapidity STAR W selection criteria

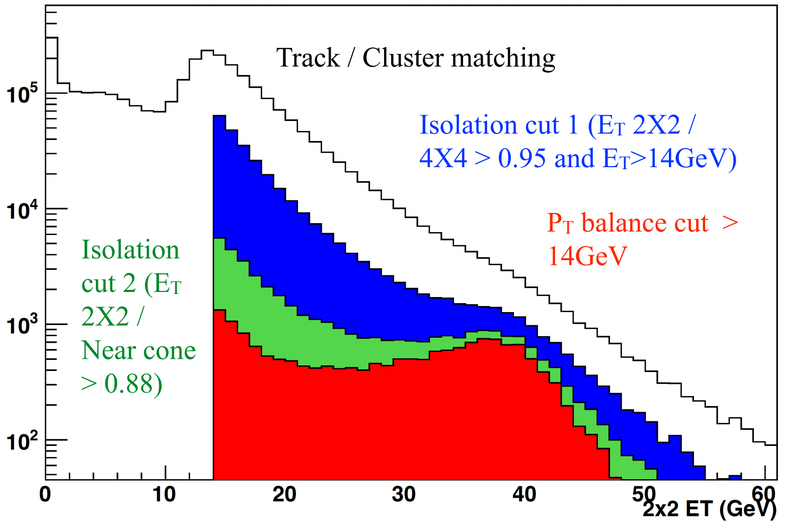


TPC track extrapolated to Barrel colorimeter tower grid

- Match $P_T > 10$ GeV track to BEMC cluster
- 2x2 cluster $E_T > 14$ GeV
- Isolation ratio 1

$$E^e_T \,/\, E_T^{4X4} > 95\%$$

PROGRESSION OF SELECTION CUTS



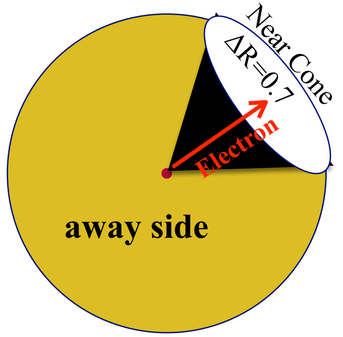
- Isolation ratio 2

$$E^e_T \,/\, E_T^{\Delta R < 0.7} > 88\%$$

- P_T-balance cut

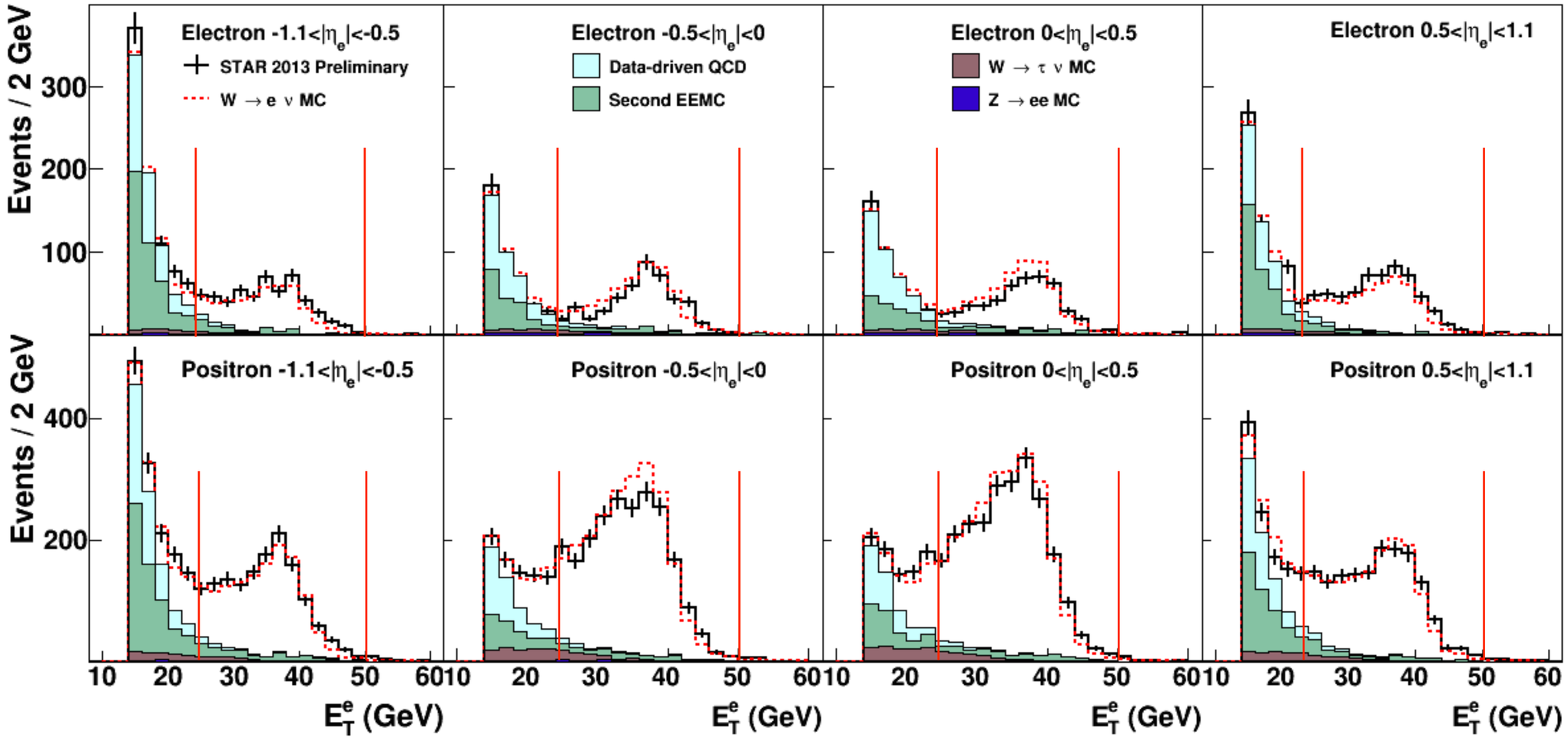
$$\vec{p_T}^{\,bal} = \vec{p_T}^{\,e} + \sum_{\Delta R > 0.7} \vec{p_T}^{\,jets}$$

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



Transverse plane view

ANALYSIS -MID RAPIDITY STAR W BG ESTIMATION



ElectroWeak Backgrounds

- Determine from MC simulation

Z——> $e^+ + e^-$

W——> $\tau + \nu$

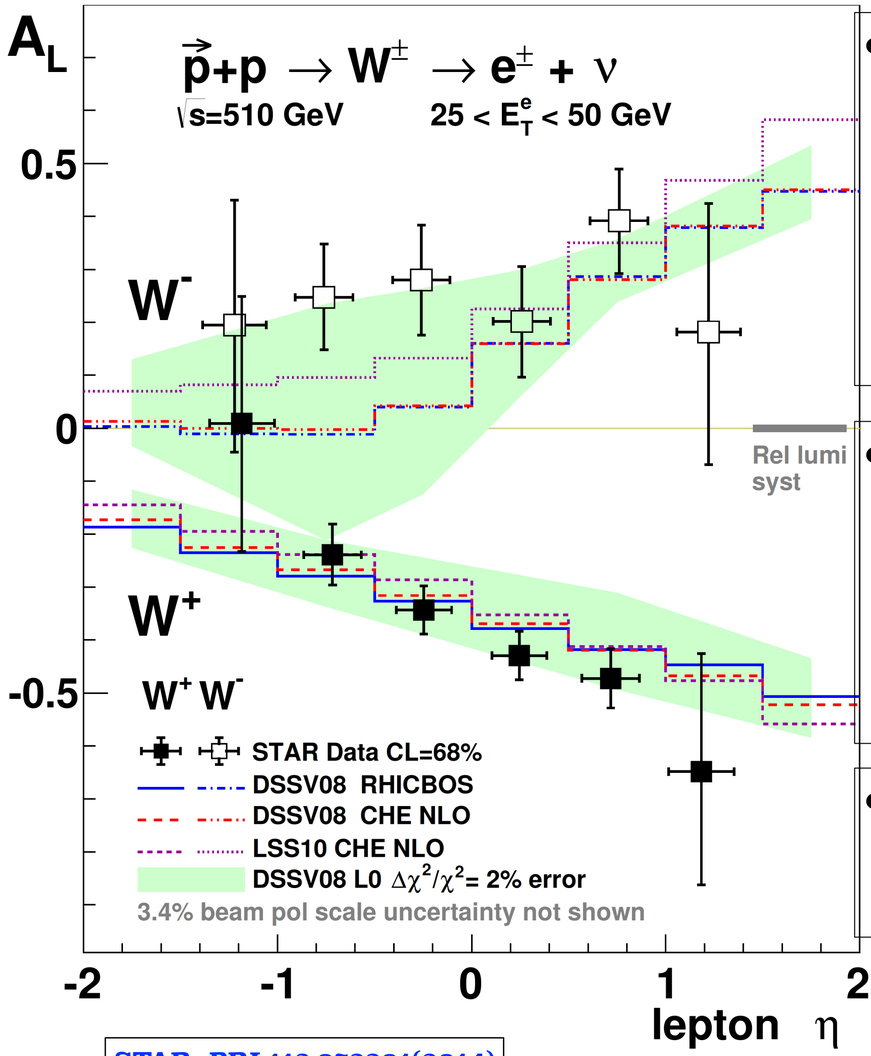
- Data-driven QCD : BG Events which satisfy $e^{+/-}$ candidate isolation cuts due to "jet" escape detection outside STAR acceptance , $|\eta|>2$.

Primary Background : QCD

- Second EEMC : due to "jet" escape detection at "non-existent" East EEMC, estimate based on "real" West EEMC

RESULTS - W A_L - STAR 2011+2012 (published)

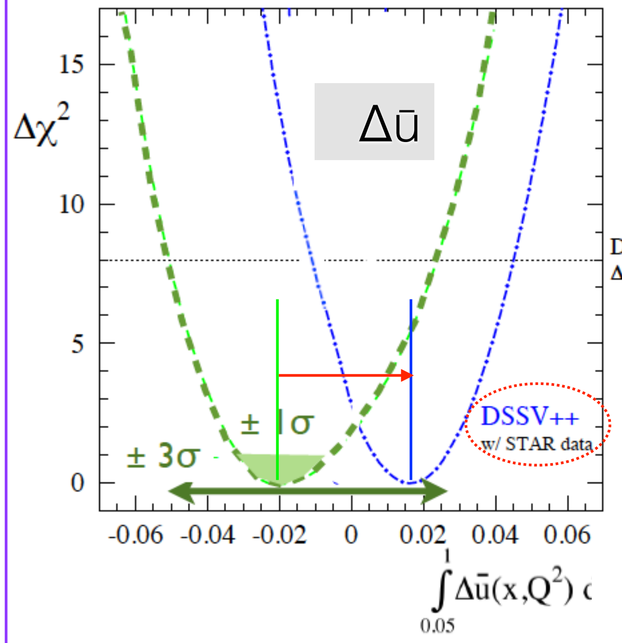
- STAR 2011 + 2012 W AL Published Results

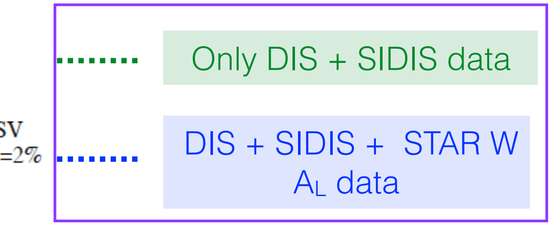


STAR, PRL113,072301(2014)

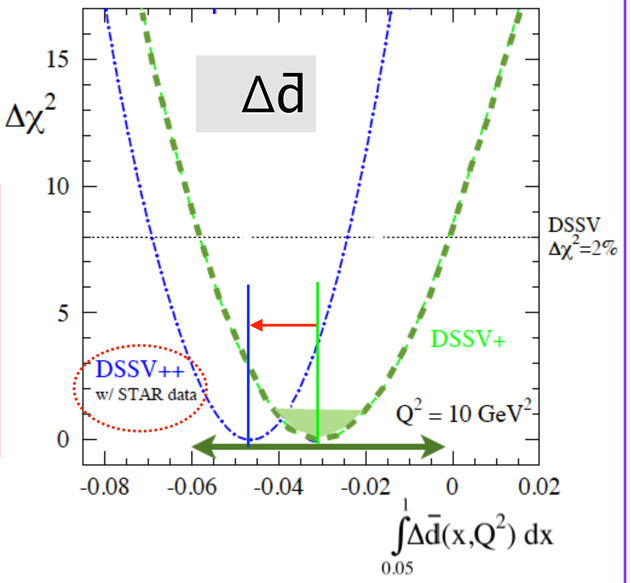
- A_L for W^+ is consistent with theoretical predictions constrained by polarized SIDIS data.
- A_L for W^- is larger than the prediction for η_e <0 ,which suggest large $\Delta\bar{u}$.
- Indication of positive $\Delta\bar{u}$ at 0.05<x<0.2.

Impact on PDFs : DSSV





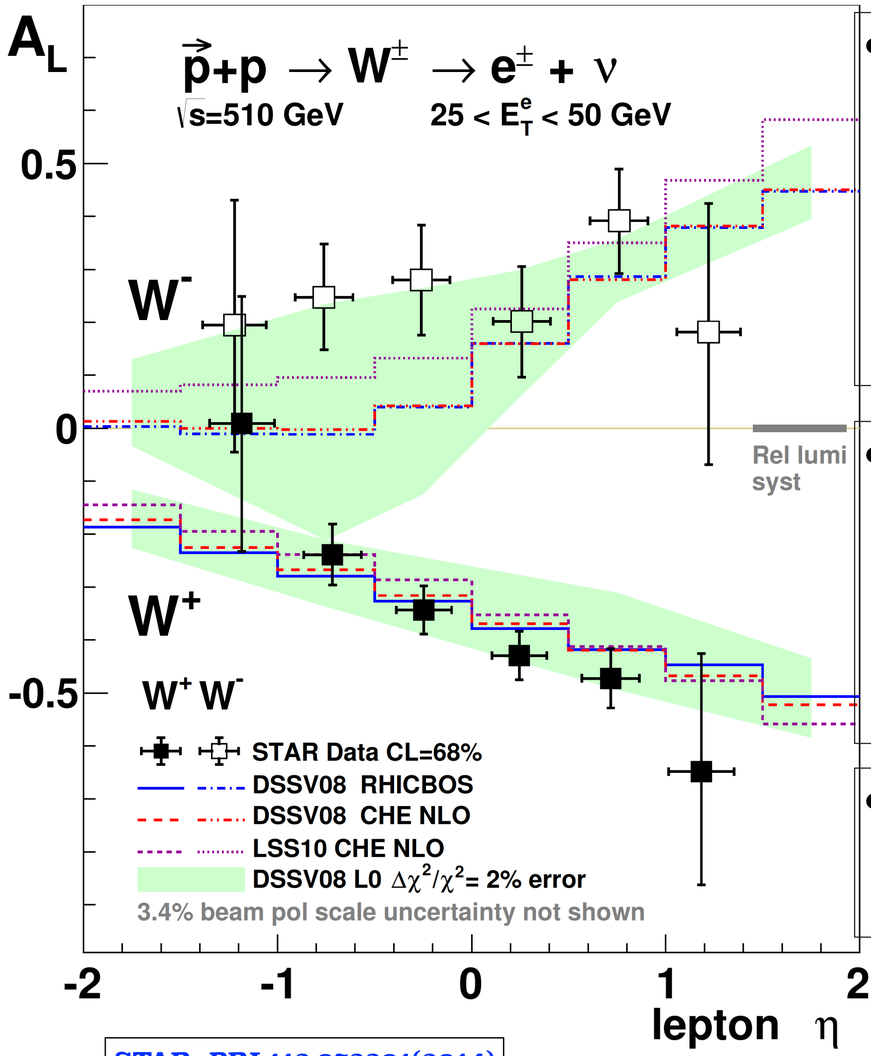
E.Aschenauer, et.al. arXiv:1304.0079



Significant shift of $\Delta\bar{u}$ central value from STAR W A_L data.

RESULTS - W A_L - STAR 2011+2012 (published)

- STAR 2011 + 2012 W AL Published Results



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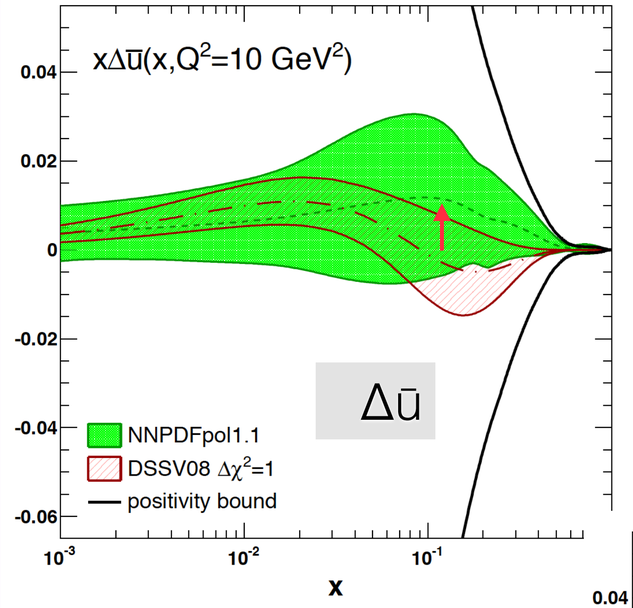
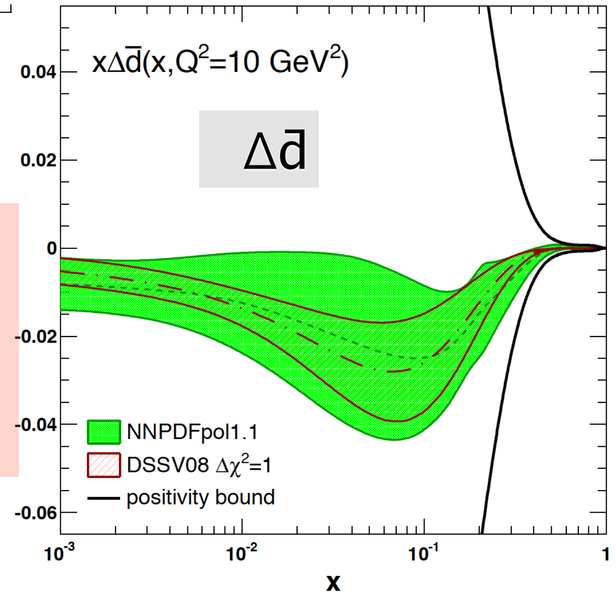
Impact on PDFs : NNPDF



Only DIS + SIDIS

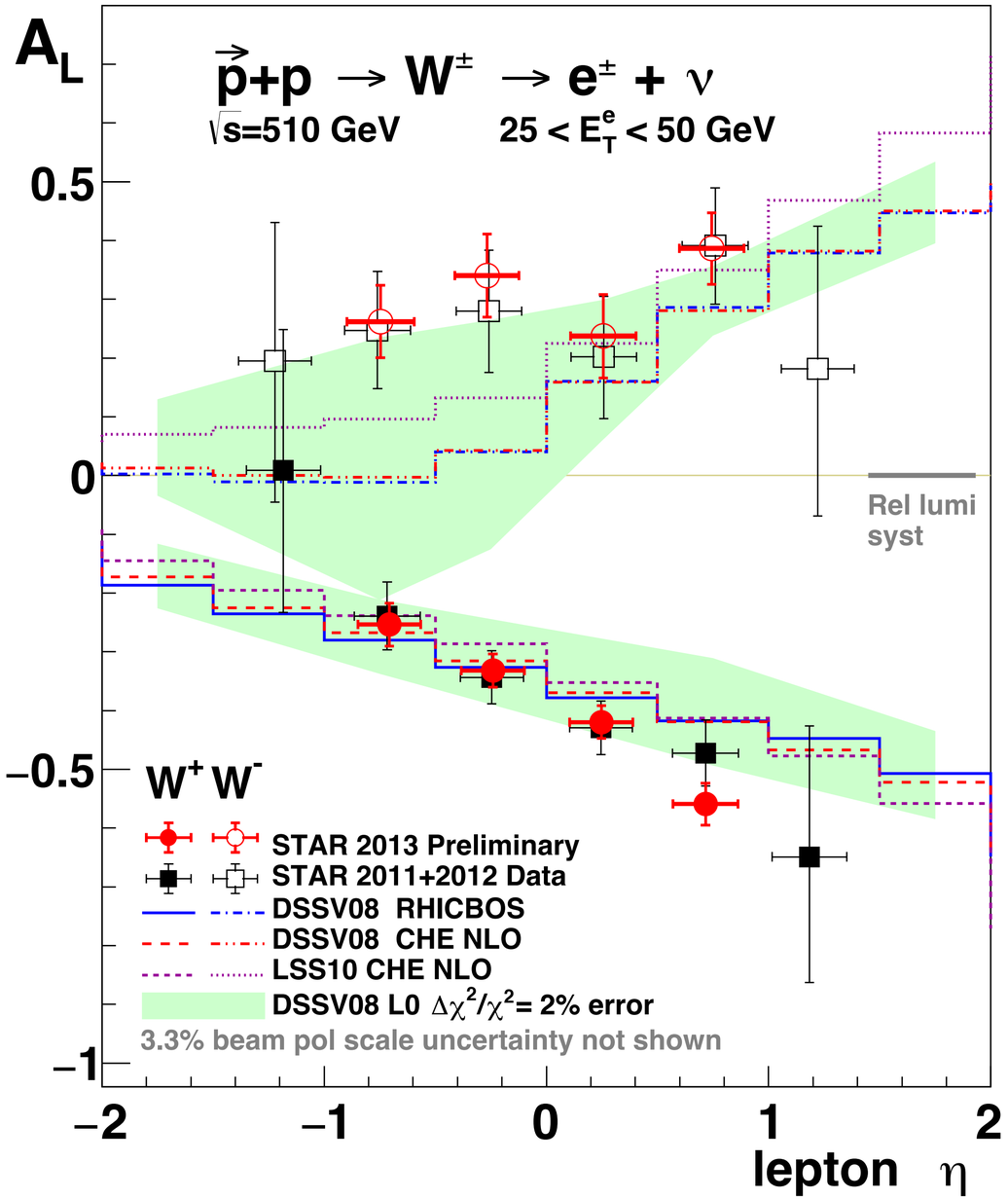
DIS + STAR W A_L data

Nucl.Phys. B887 (2014) 276-308



Significant shift of $\Delta\bar{u}$ central value from STAR W A_L data.

RESULTS - W A_L - STAR 2013 Preliminary vs Published



- STAR 2013 W A_L Preliminary results is the Most Precise measurements of W A_L up to date!
- STAR 2013 preliminary W AL results consist with published 2011 + 2012 results.
- Uncertainties were reduced by 40 %.
- Forward rapidity analysis: refer : Amani Kraishan's talk

SUMMARY

- W boson production in longitudinally polarized p+p collisions at RHIC is a unique tool to probe quark antiquark helicity PDFs of the nucleon.
- Mid-rapidity (Run 11/12): Published W longitudinal single spin asymmetry results suggest large anti-u quark polarization along with broken QCD sea.
- The new preliminary results of STAR 2013 W A_L are the most precious measurement of W A_L up to date.
- These results consistent with published STAR 2011+2012 results with reduced uncertainty by ~40%, and will help to further constrain antiquark helicity PDFs.