Measurements of single-spin asymmetries, A_L for $W^{\pm}$ boson production in longitudinally polarized proton+proton collisions at STAR
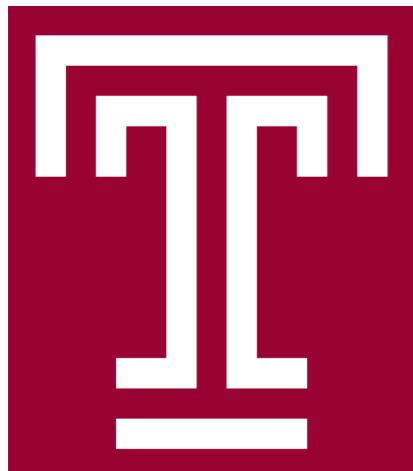
- Motivation
- Theoretical Aspect
- Experimental Aspect
- Analysis
- Results
- Summary
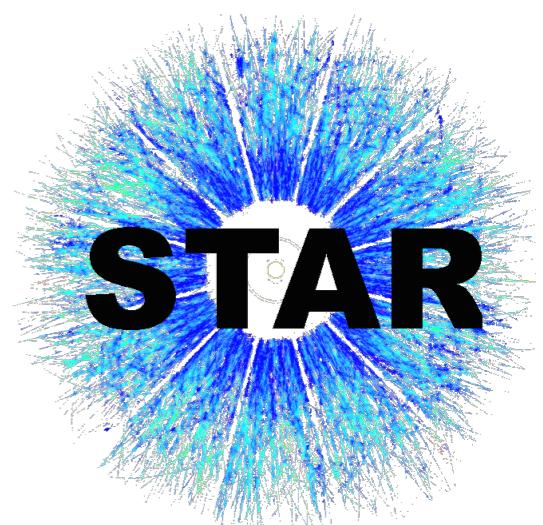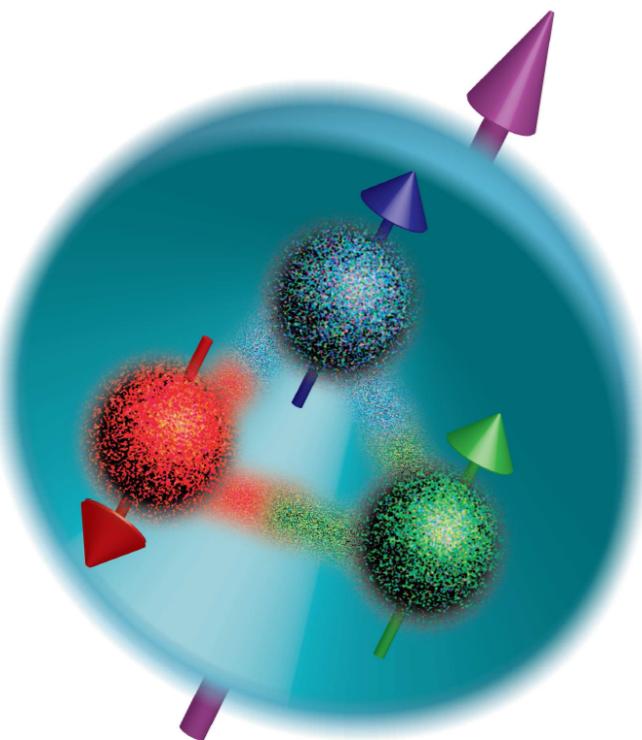
Devika Gunarathne
**(for the STAR Collaboration)**
Temple University
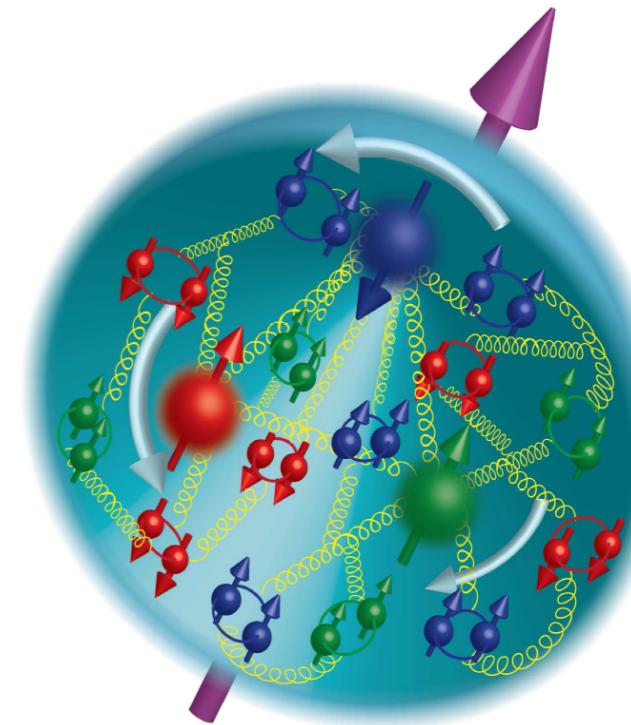
1989 : EMC : DIS

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

"Spin Crisis"

Simple Quark Models

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

Gluons , Sea quarks are polarized.

Parton orbital angular momentum.

Current Understanding

$$< S_z >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$
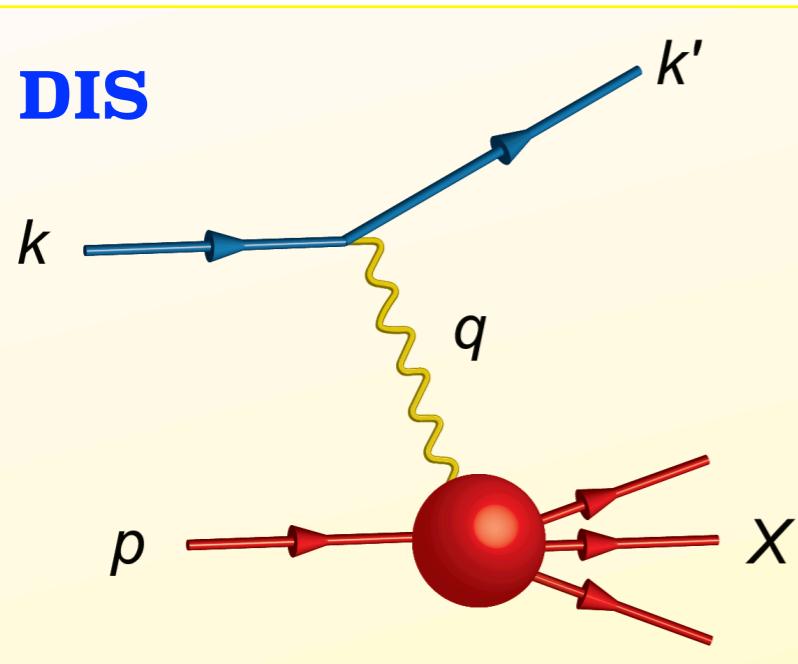
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s})dx$$

Helicity PDF

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

DIS

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

DIS
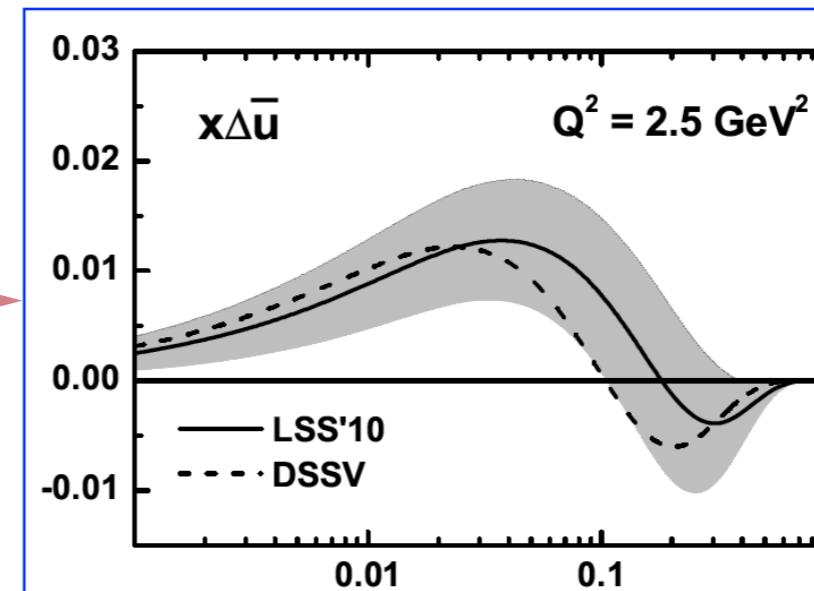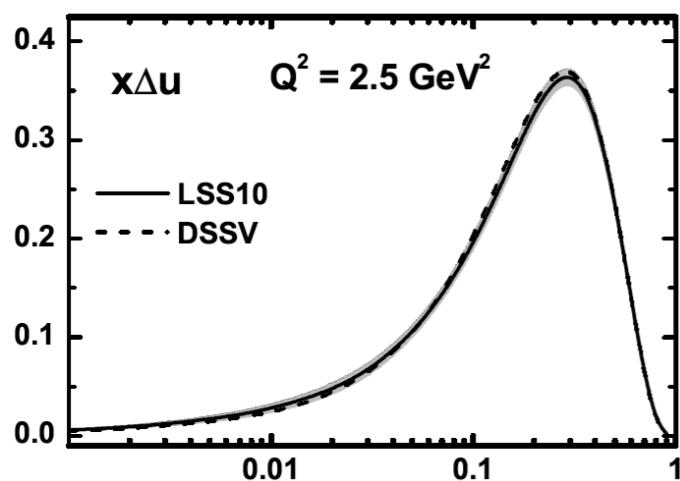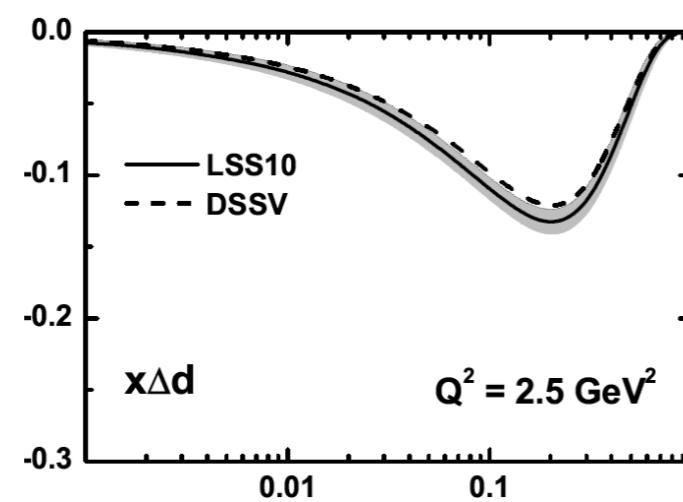
SIDIS

- Well measured!
- Not sensitive to flavor separation!
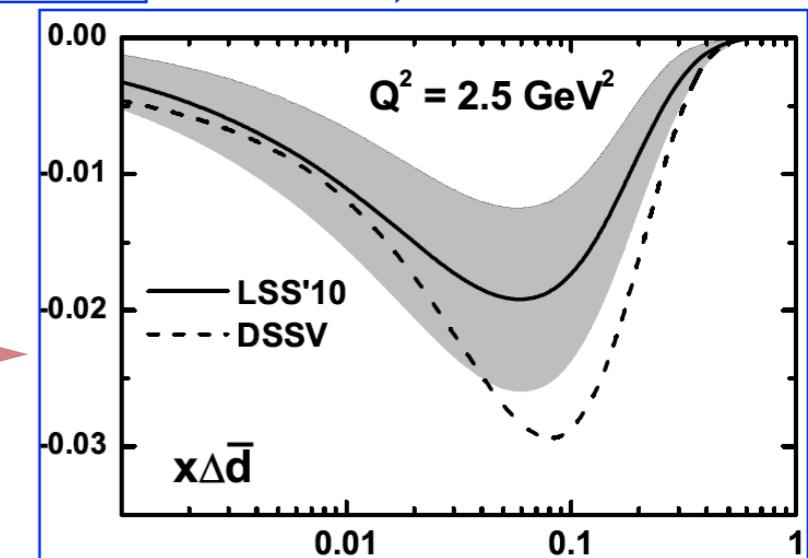
- FF's use to tag flavor!
- Flavor separation / quark, anti-quark separation!
- But large uncertainties in FFs.

Large uncertainties w.r.t quark PDFs
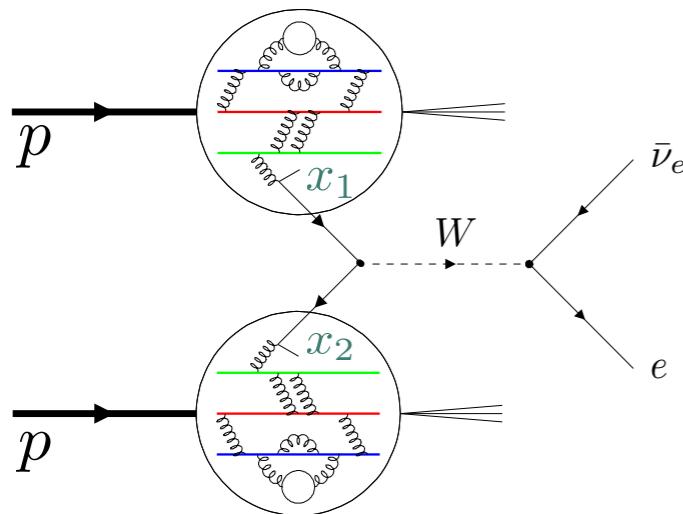
Phys. Rev. D 82, 114018 (2010)

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

W production in p+p,

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

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

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

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

$$A_L^{W^-} = \frac{\Delta\bar{u}}{\bar{u}}$$

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

$$A_L^{W^+} = \frac{\Delta\bar{d}}{\bar{d}}$$

In comparison to SIDIS,
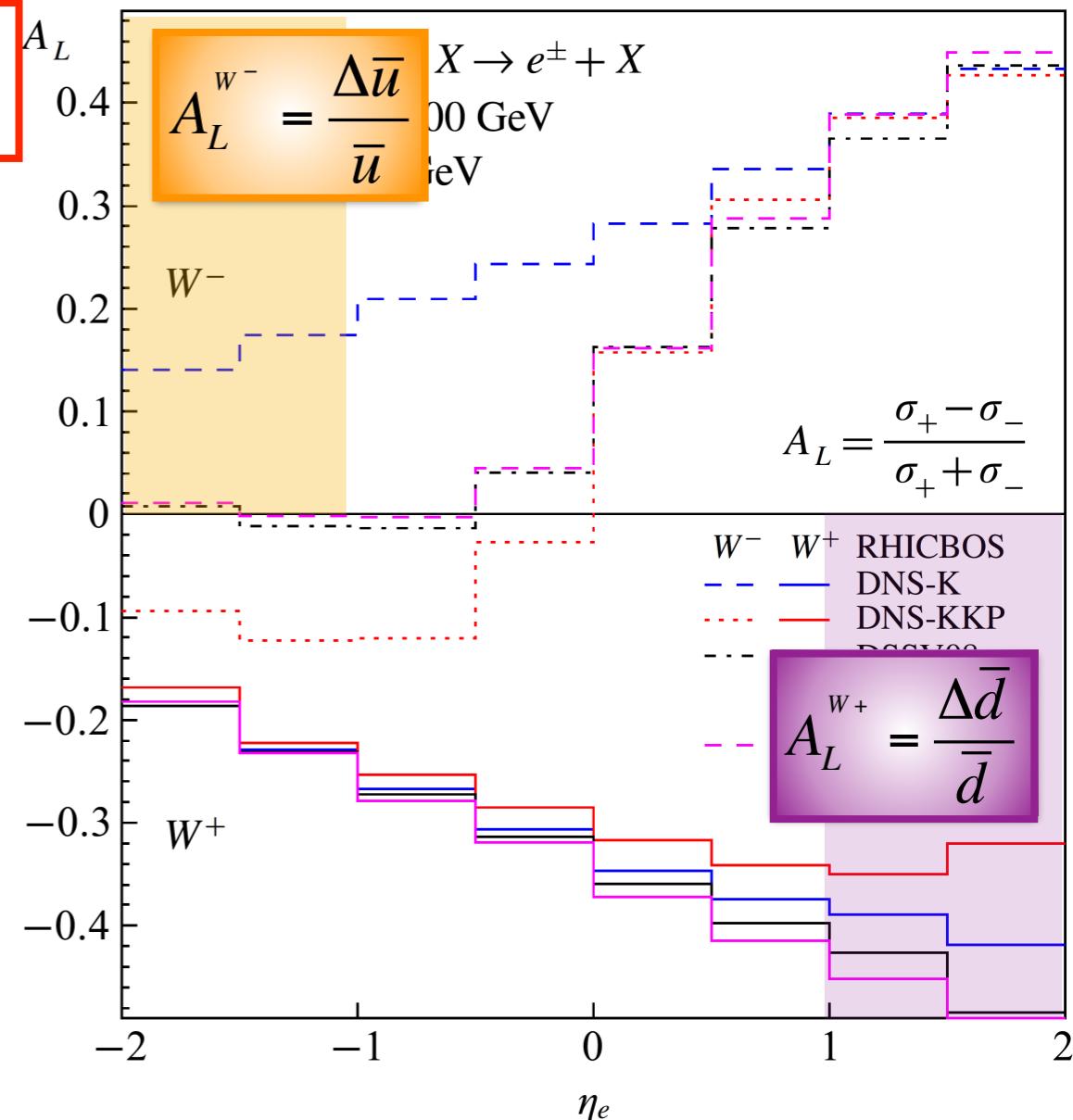
• Direct sensitivity to ū, d̄.
• Large Q^2 defined by W mass (more reliable perturbative calculation / higher twist effects unimportant!).
• Parity violating coupling gives rise to single-spin asymmetry which is directly related to anti-quark helicity PDFs.
• Free of FFs.
• Easy detection via decay leptons.
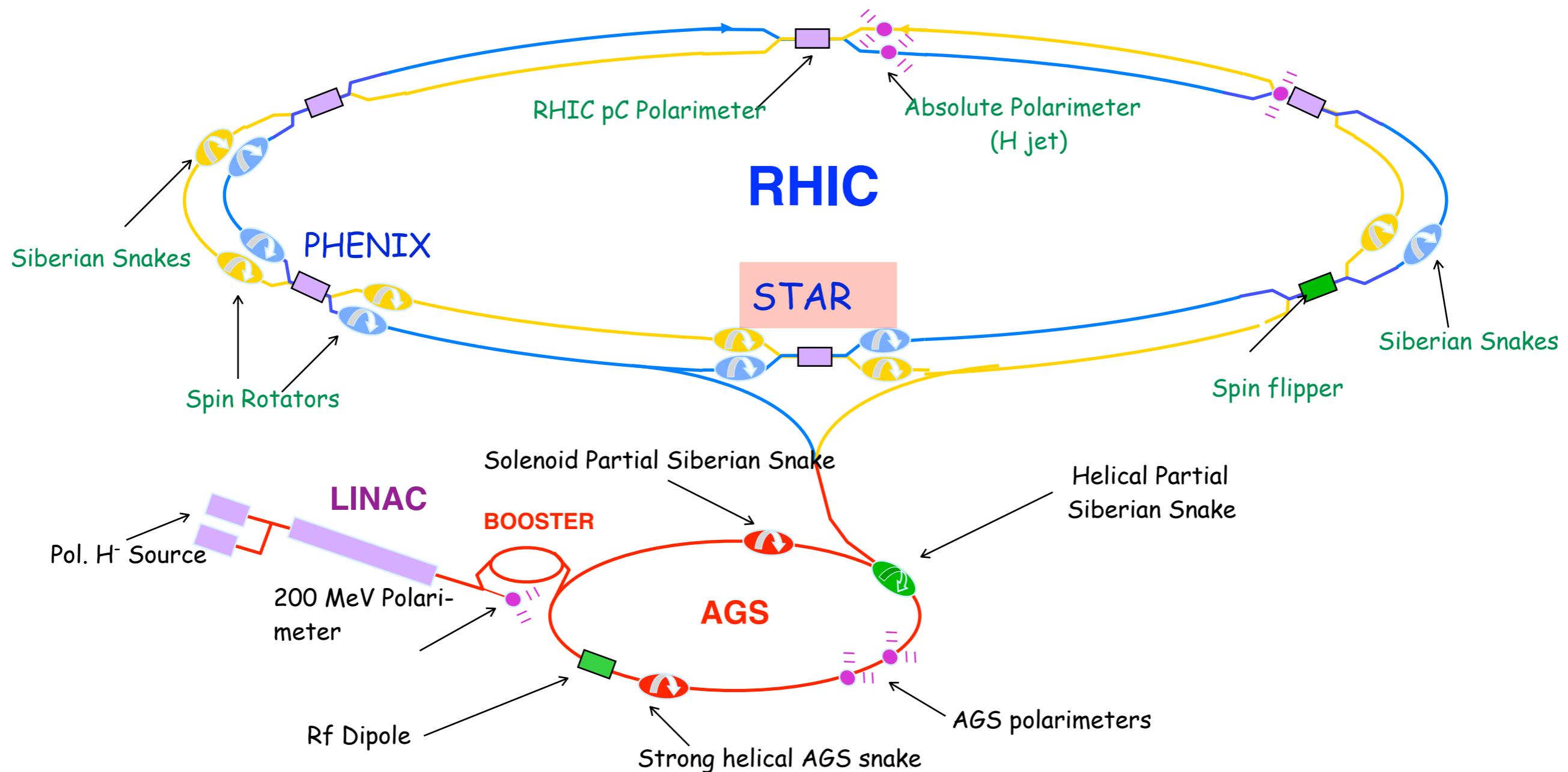
- **RHIC** : **R**elativistic **H**eavy **I**on **C**ollider
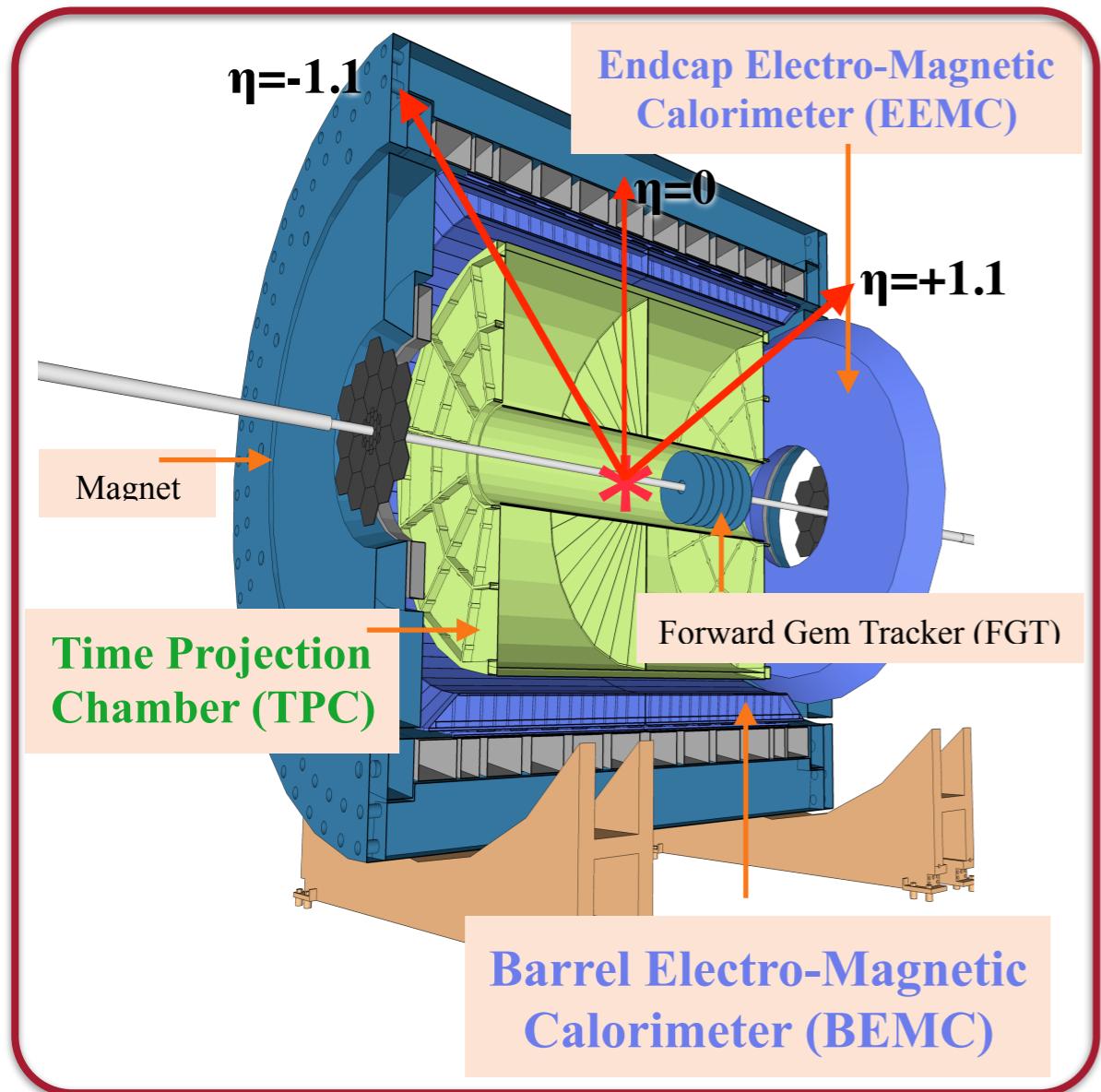
The World's first polarized hadron collider!

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

EXPERIMENTAL ASPECT - STAR
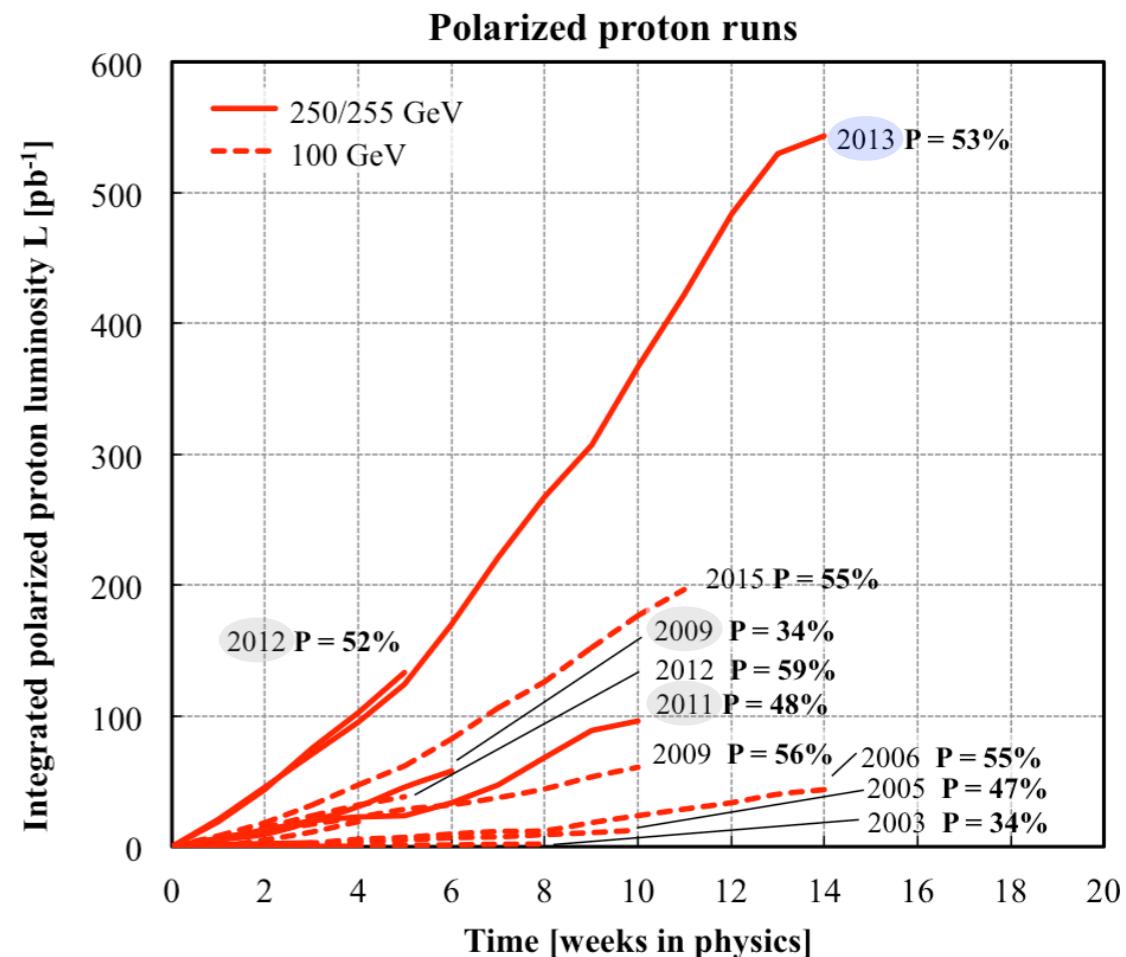
- ## STAR : Solenoidal Tracker At RHIC

η=-1.1

Endcap Electro-Magnetic Calorimeter (EEMC)

η=0

η=+1.1

Magnet

Time Projection Chamber (TPC)

Forward Gem Tracker (FGT)

Barrel Electro-Magnetic Calorimeter (BEMC)
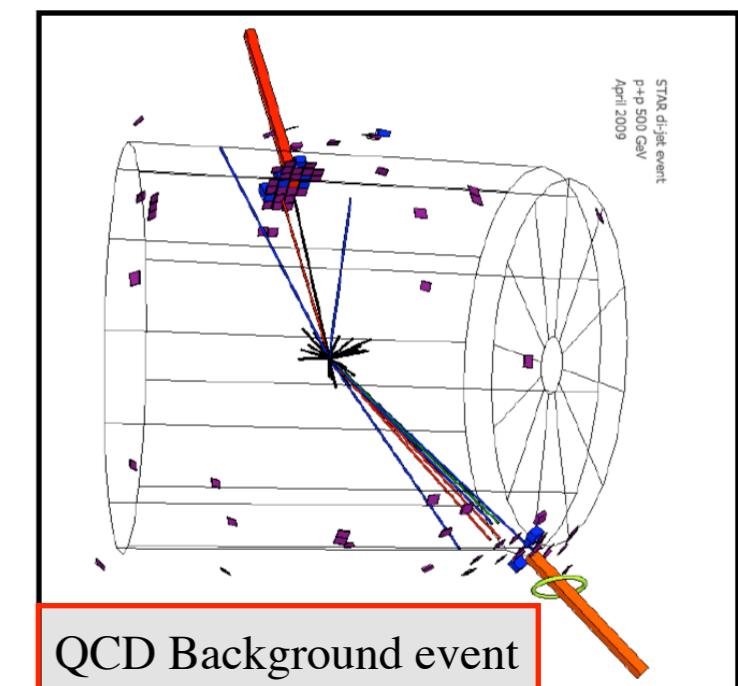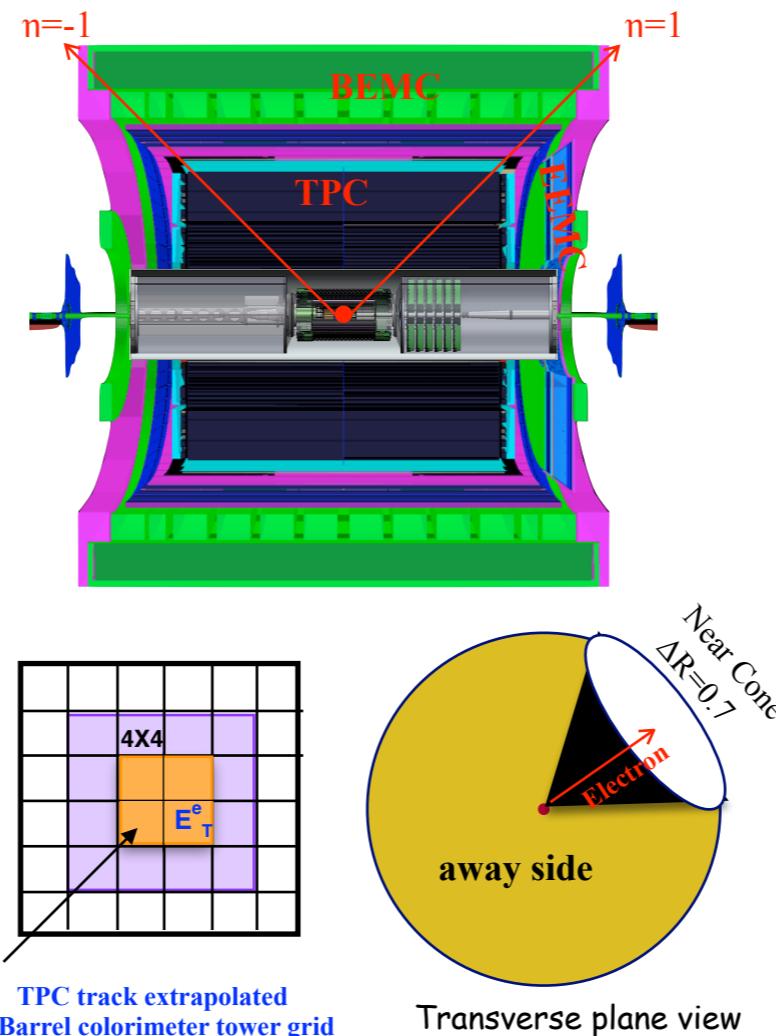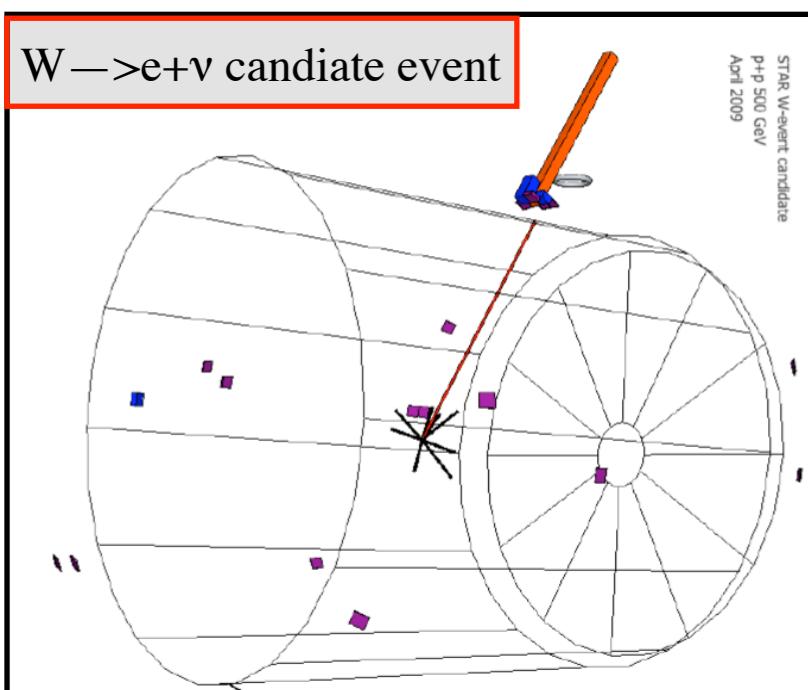
TPC : -1.3 < η < +1.3	**TPC: Charged particle tracking**
BEMC : -1.0 < η < +1.0	
EEMC : +1.1 < η < +2.0	**BEMC, EEMC: EM Calorimetry**
FGT : +1.0 < η < +2.0	

RHIC p+p runs : Luminosity

Polarized proton runs

Run	L (pb⁻¹)	P (%)	FOM (P²L) (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**

W—>e+ν candiate event

BEMC
TPC
EEMC
n=-1   n=1

QCD Background event

- 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.

4X4

E^e_T

TPC track extrapolated
to Barrel colorimeter tower grid

Near Cone
$\Delta R=0.7$

Electron

away side

Transverse plane view

- 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
  - Match $P_T > 10$ GeV/c track to BEMC cluster
  - Isolation ratio 1 / Isolation ratio 2
  - P_T-balance cut

$$E^e_T / E_T^{4X4} > 95\%$$
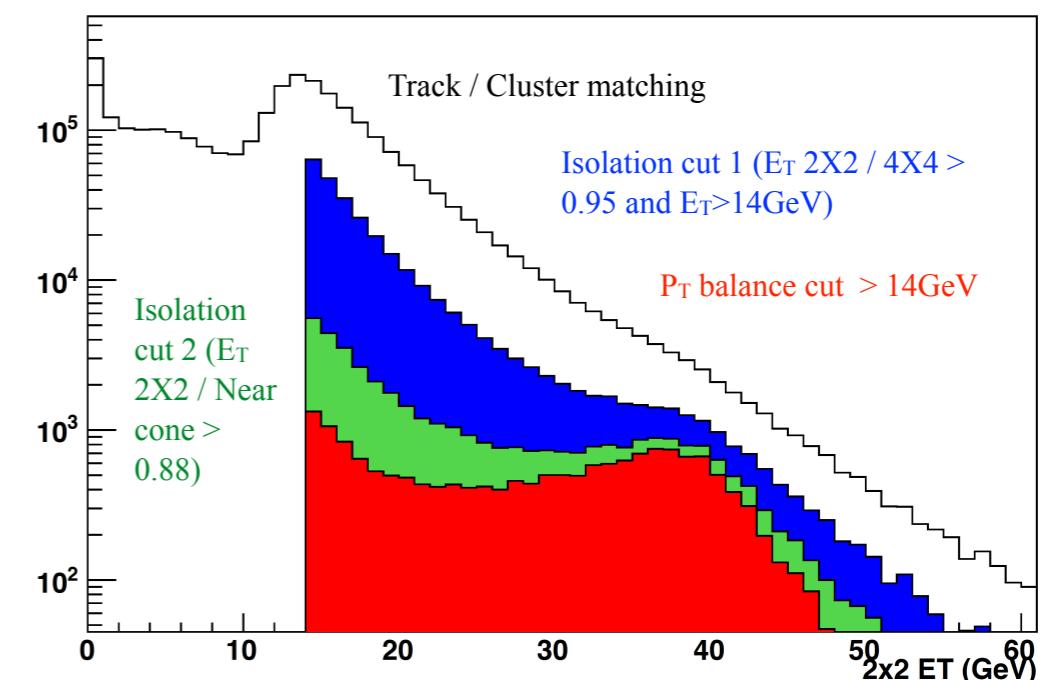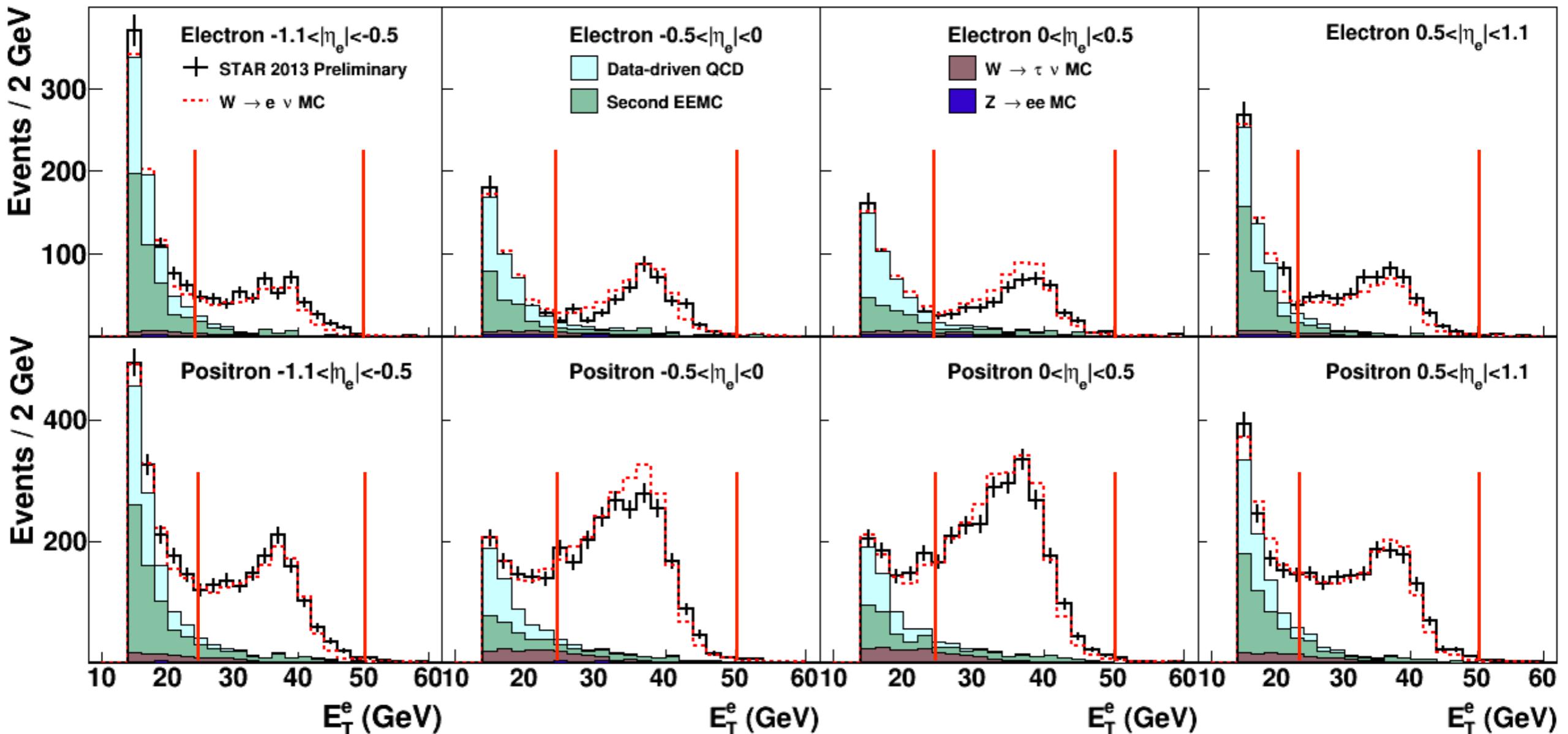
$$E^e_T / E_T^{\Delta R < 0.7} > 88\%$$

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

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

Track / Cluster matching

Isolation cut 1 (E_T 2X2 / 4X4 > 0.95 and E_T >14GeV)

P_T balance cut > 14GeV

Isolation cut 2 (E_T 2X2 / Near cone > 0.88)

2x2 ET (GeV)

Primary Background

ElectroWeak Background

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

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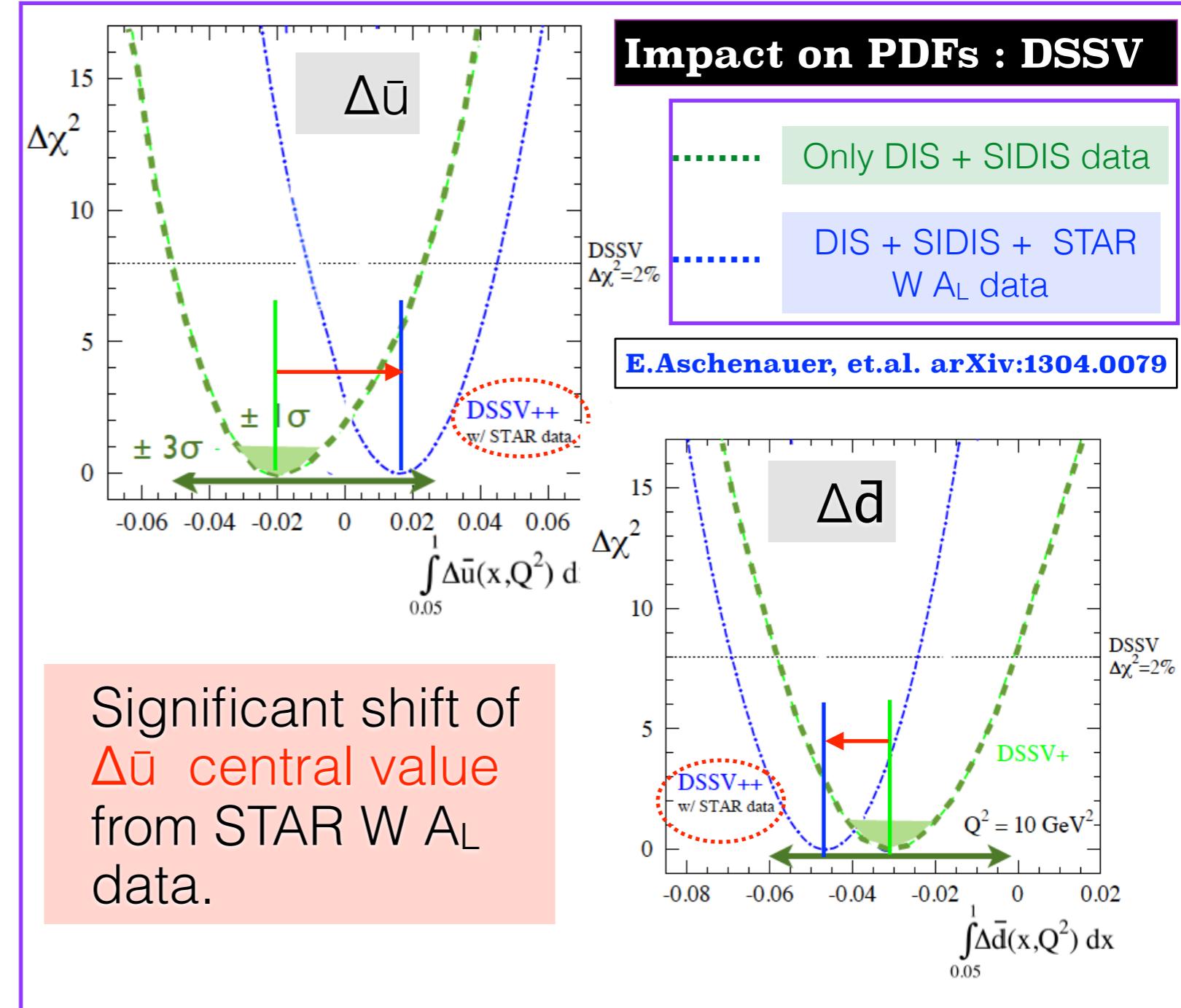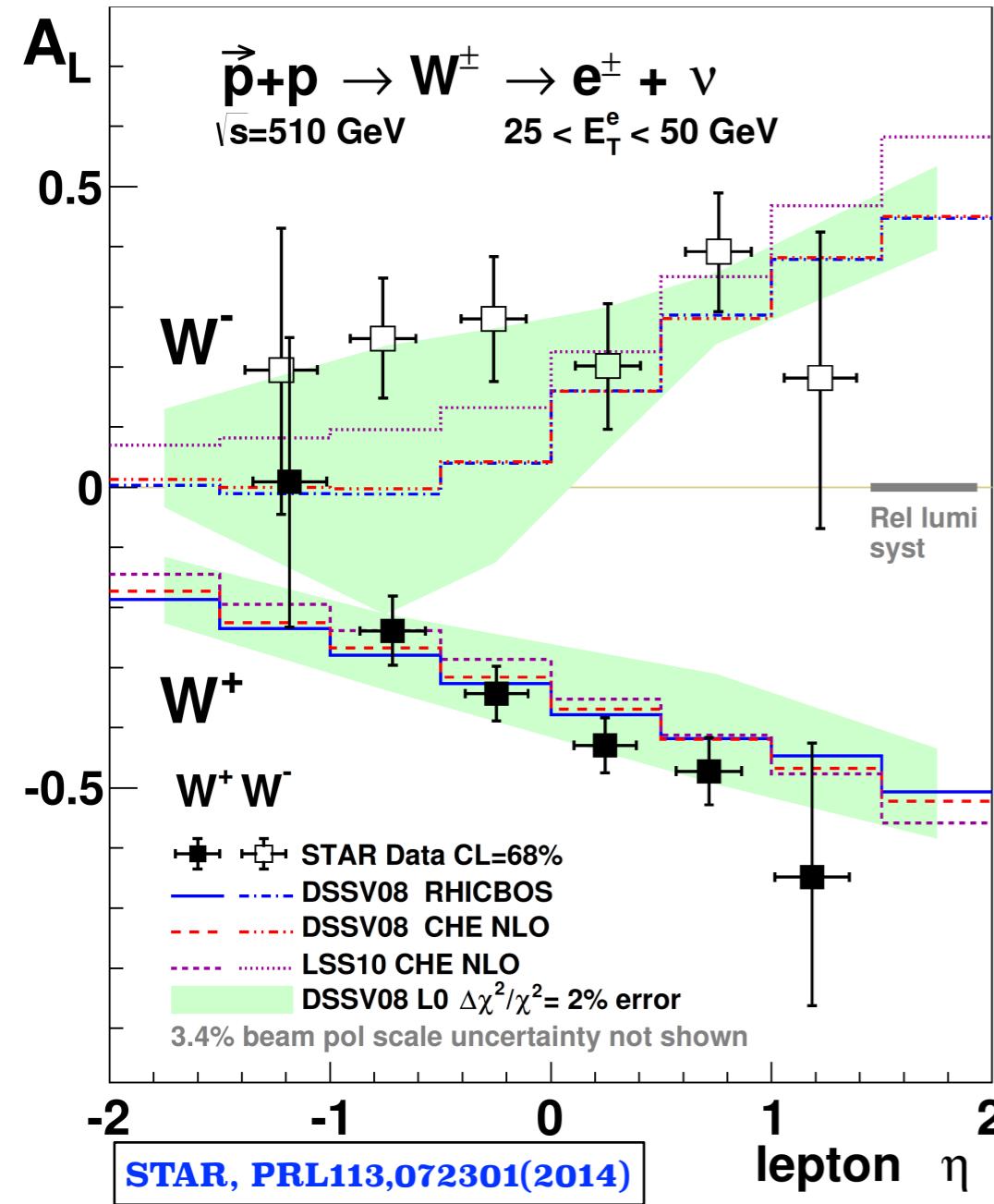
- Determine from MC simulation

  Z ———> $e^+ + e^-$

  W ———> $\tau + \nu$

- STAR 2011 + 2012 W AL Published Results

$$\vec{p}+p \rightarrow W^{\pm} \rightarrow e^{\pm} + \nu$$

$\sqrt{s}=510$ GeV $25 < E_T^e < 50$ GeV

W^-

W^+

$W^+ W^-$

Rel lumi syst

STAR Data CL=68%
DSSV08 RHICBOS
DSSV08 CHE NLO
LSS10 CHE NLO
DSSV08 L0 $\Delta\chi^2/\chi^2$= 2% error
3.4% beam pol scale uncertainty not shown

STAR, PRL113,072301(2014)

lepton η

Impact on PDFs : DSSV

Only DIS + SIDIS data

DIS + SIDIS + STAR W A_L data

E.Aschenauer, et.al. arXiv:1304.0079

$\Delta\bar{u}$

$\pm 1\sigma$

$\pm 3\sigma$

DSSV++ w/ STAR data

DSSV $\Delta\chi^2=2\%$

$\Delta\bar{d}$

DSSV++ w/ STAR data

DSSV+

$Q^2 = 10$ GeV^2

DSSV $\Delta\chi^2=2\%$

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

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

• STAR 2011 + 2012 W AL Published Results

$\vec{p}$+p $\rightarrow$ W$^{\pm}$ $\rightarrow$ e$^{\pm}$ + ν

$\sqrt{s}$=510 GeV   25 < E$_T^e$ < 50 GeV

W$^-$

Rel lumi syst

W$^+$

W$^+$ W$^-$

STAR Data CL=68%
DSSV08 RHICBOS
DSSV08 CHE NLO
LSS10 CHE NLO
DSSV08 L0 $\Delta\chi^2/\chi^2$= 2% error

3.4% beam pol scale uncertainty not shown

STAR, PRL113,072301(2014)

lepton η

Impact on PDFs : NNPDF

Only DIS + SIDIS

DIS + STAR W A$_L$ data

Nucl.Phys. B887 (2014) 276-308

x$\Delta\bar{u}$(x,Q^2=10 GeV^2)

$\Delta\bar{u}$

NNPDFpol1.1
DSSV08 $\Delta\chi^2$=1
positivity bound

x$\Delta\bar{d}$(x,Q^2=10 GeV^2)

$\Delta\bar{d}$

NNPDFpol1.1
DSSV08 $\Delta\chi^2$=1
positivity bound

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

• 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.

- STAR 2013 W A_L Preliminary Results in comparison to STAR 2011+2012 published results

- STAR 2013 W A_L Preliminary results are the Most Precise measurements of W A_L up to date!

- STAR 2013 preliminary W AL results are consistent 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.

- New prelim. result of STAR 2013 W A_L is the most precious measurement up to date. These results will help to further constrain antiquark helicity distributions.

- New STAR 2013 W AL prelim. results consistent with published STAR 2011+2012 results.