22nd International Spin Symposium [SPIN 2016]
September 25-30, 2016 at UIUC
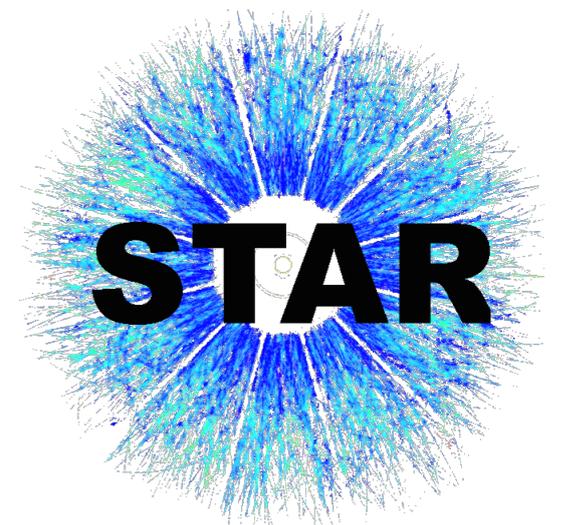
Measurements of W single spin asymmetries and W cross section ratios at STAR
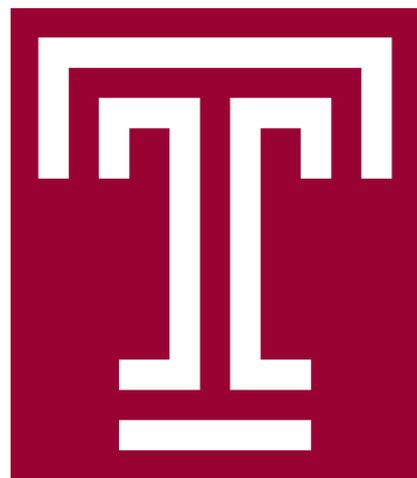
Devika Gunarathne
(for the STAR Collaboration)
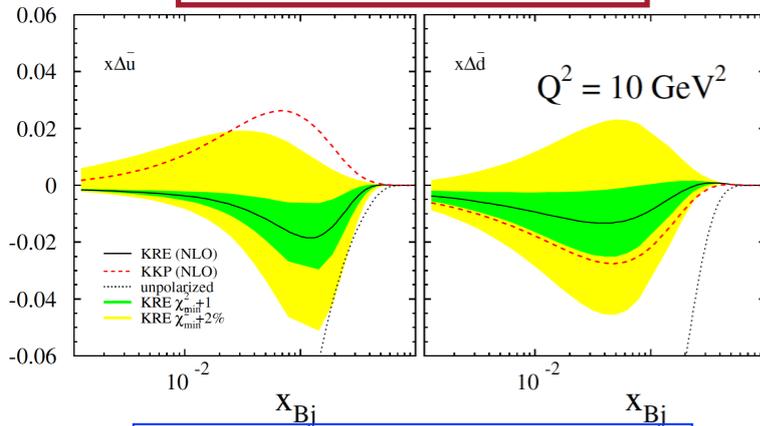**Temple University**

1

OUTLINE

- **Current Knowledge**
  - Anti-quark polarization
  - Flavor asymmetry of the sea

- **Theoretical Foundation [W Asymmetry (A_L) / W cross section ratio (R_W)]**

- **Experimental Aspects [RHIC / STAR]**

- **Results**
  - W A_L
  - W R_W

- **Summary**

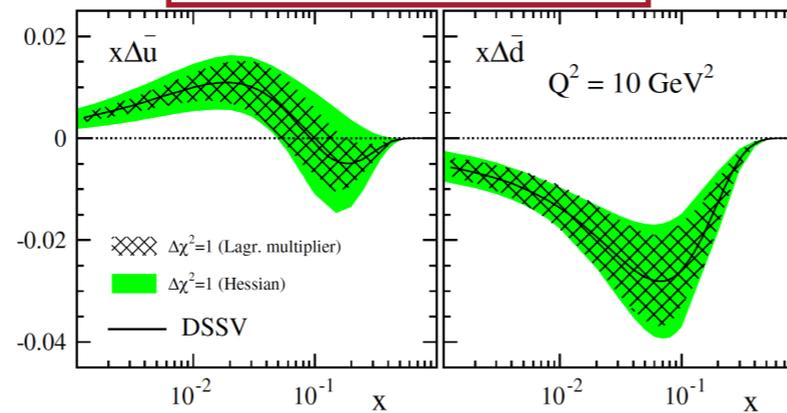# Light anti-Quark Polarization: Current Knowledge

- NLO calculations   · Mainly SIDIS

DNS : data < y2000   DSSV : data < y2004   LSS : data < y2006
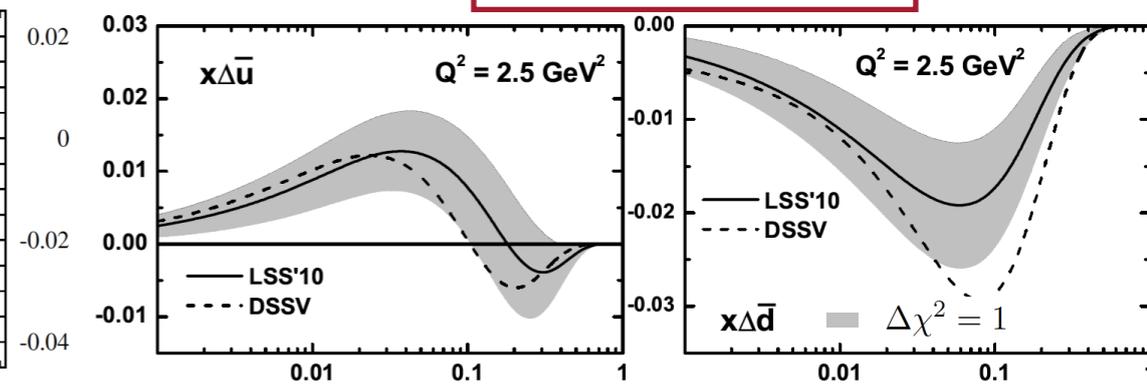

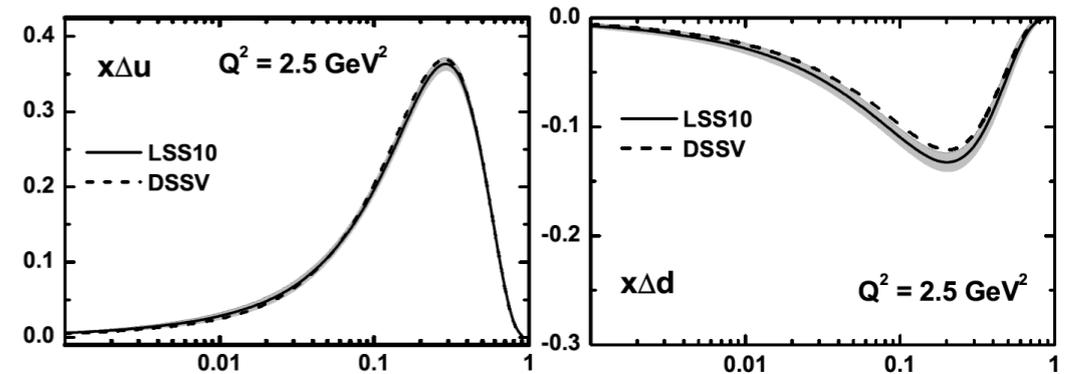Phys. Rev. D 71, 094018 (2005)   Phys. Rev. D 80, 034030 (2009)   Phys. Rev. D 82, 114018 (2010)

More Precise / large / increased kinematic range - DATA sets
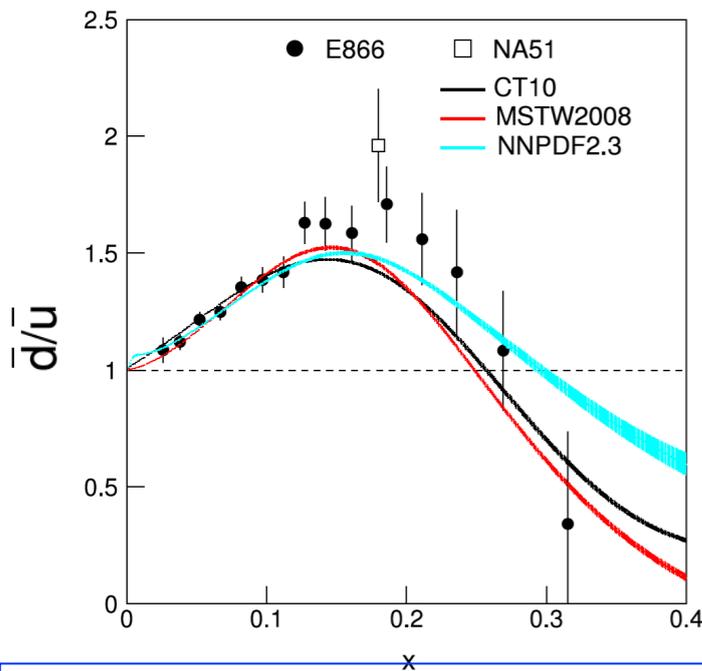
More Precise FFs   Improved global fitting tools

But still less precise, in comparison to valance sector
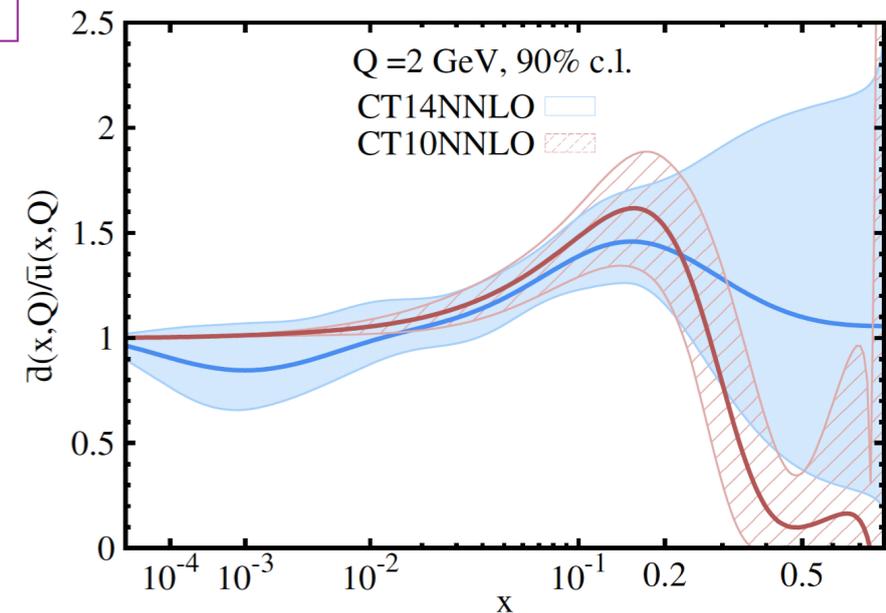

W A_L measurements at RHIC provide a unique (direct sensitivity to $\bar{u}, \bar{d}$) and clean approach (free of FFs) to constrain anti-quark helicity PDFs at much larger Q^2 scale set by W mass (~6400 GeV^2).

Progress in Particle and Nuclear Physics 79(2014)95-135

- E866 in comparison to recent NNLO

- Recent (CT10,etc) NNLO Fits seems to follow the shape but still relatively large uncertainties at large x.

- The most recent (CT14) suggest a constant approach towards 1 at large x, with large uncertainties.

arXiv:1506.07443v3

Need more data / experiment to understand $\bar{d}/\bar{u}$ behavior!

- SeaQuest E906 - Preliminary

B. Kerns et al. (SeaQuest Collaboration), APS April Meeting, 2016
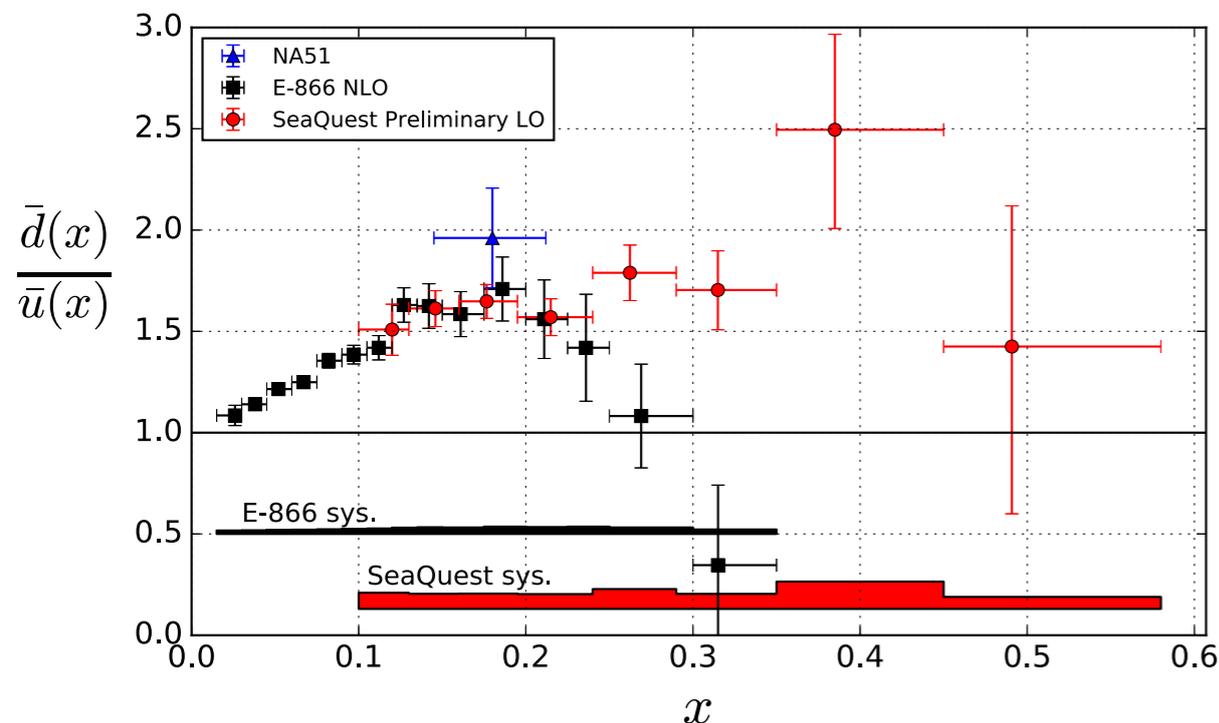
- Lower Q^2 than Drell-Yan E866.
- Measurement extended to large x.
- Will help to minimize any process dependent assumptions.

W production at RHIC at much larger Q^2 than Drell-Yan

Provides an important, completely independent cross check of flavor asymmetry of the sea through measurements of W cross section ratio!

Theoretical Foundation - W A_L

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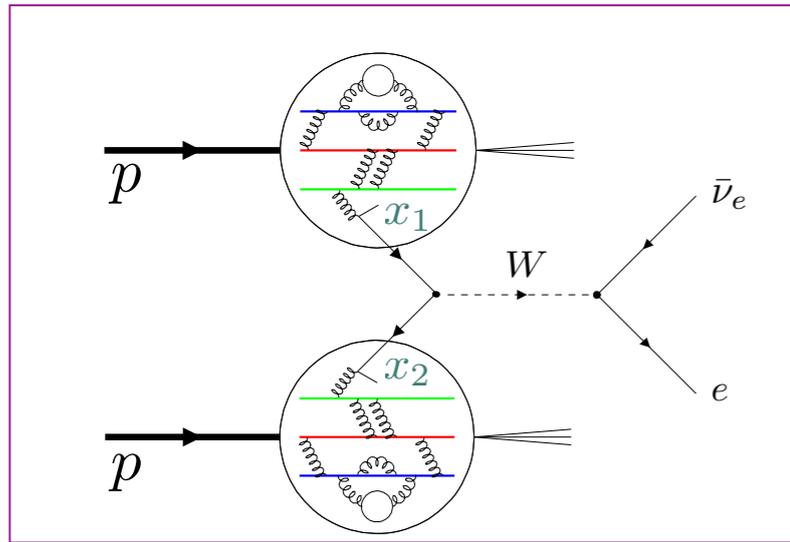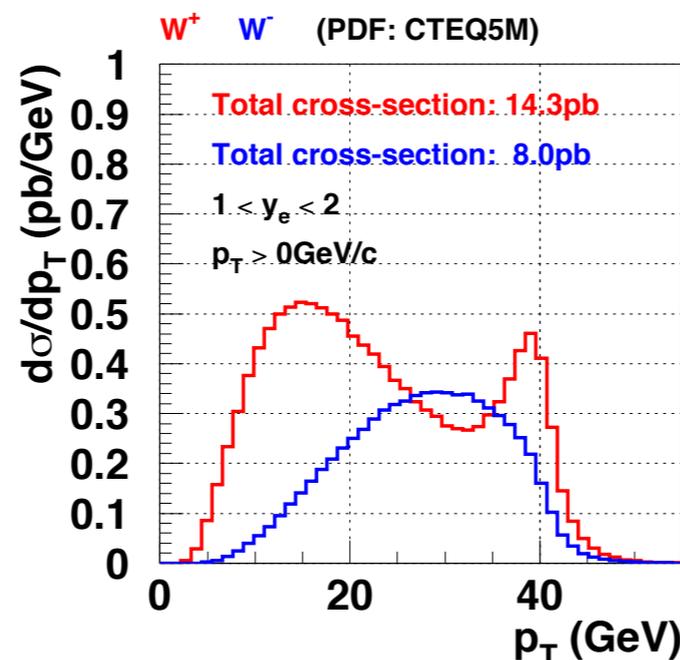

In comparison to SIDIS,

- Direct sensitive to $\bar{u}, \bar{d}$
- Large Q^2 defined by W mass (more reliable perturbative calculation / hight twist effects unimportant!)
- Large parity violating coupling give rise to singe-spin asymmetry which directly related to anti-quark helicity PDFs.
- Free of FFs.
- Easy detection via decay leptons.

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

At RHIC kinemetics
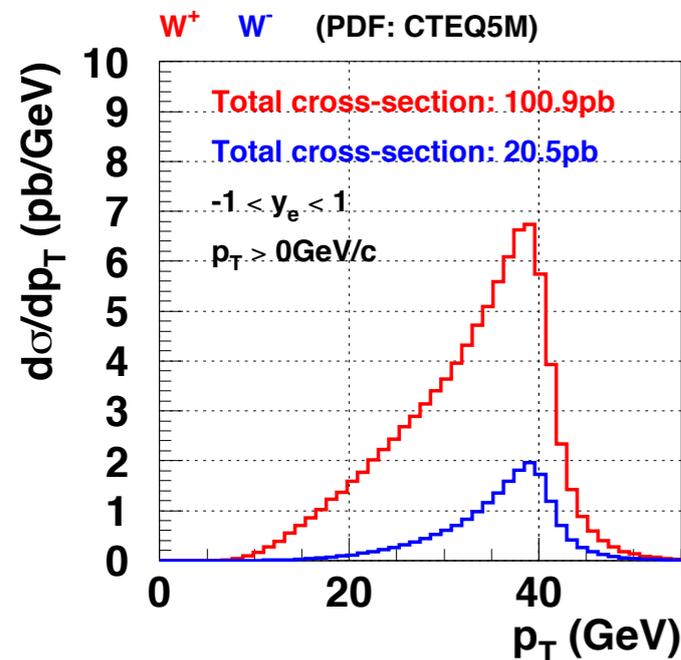
- Reconstruct W decay lepton kinematics ($P_T \sim M_W/2$, η_e)

$$y_l = y_W + \frac{1}{2} \ln \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$

$$p_T = p_T^* = \frac{M_W}{2} \sin\theta^*$$

$$x_{1,2} = \frac{M_W}{\sqrt{s}} e^{\pm y_w}$$

$$\frac{M_W}{\sqrt{s}} = 0.16$$

- STAR now can also reconstruct full W kinematics via its recoil => used for cross section analysis

Rapidity dependance of W A_L provides sensitivity to partonic kinematics.

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

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

η <<< 0 ⟶ x_1 <<< x_2

η >>> 0 ⟶ x_1 >>> x_2

η = 0 ⟶ x_1 ~ x_2

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

$$\eta <<< 0 \rightarrow x_1 << x_2, \theta \rightarrow \pi$$

$$\eta >>> 0 \rightarrow x_1 >> x_2, \theta \rightarrow 0$$

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

e^- θ $\bar{u}$ $x_1 << x_2$ d

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

$$A_L^{w^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$

$$A_L^{w^-} = -\frac{\Delta d}{d}$$

$$A_L^{w^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

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

$$A_L^{w^+} = -\frac{\Delta u}{u}$$

e^+ θ $\bar{d}$ $x_1 << x_2$ u

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

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

$\pm + X \rightarrow e^\pm + X$
= 500 GeV
0 GeV

0.2 0.1 0 −0.1 −0.2

W^- W^- W^+ RHICBOS

−2 −1 0 1 2

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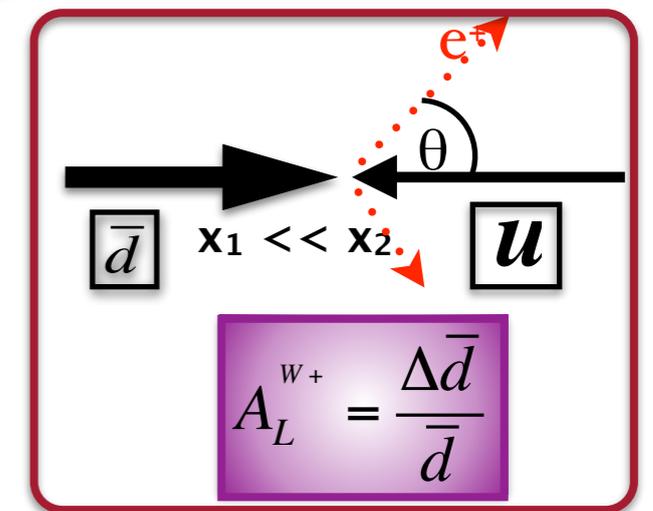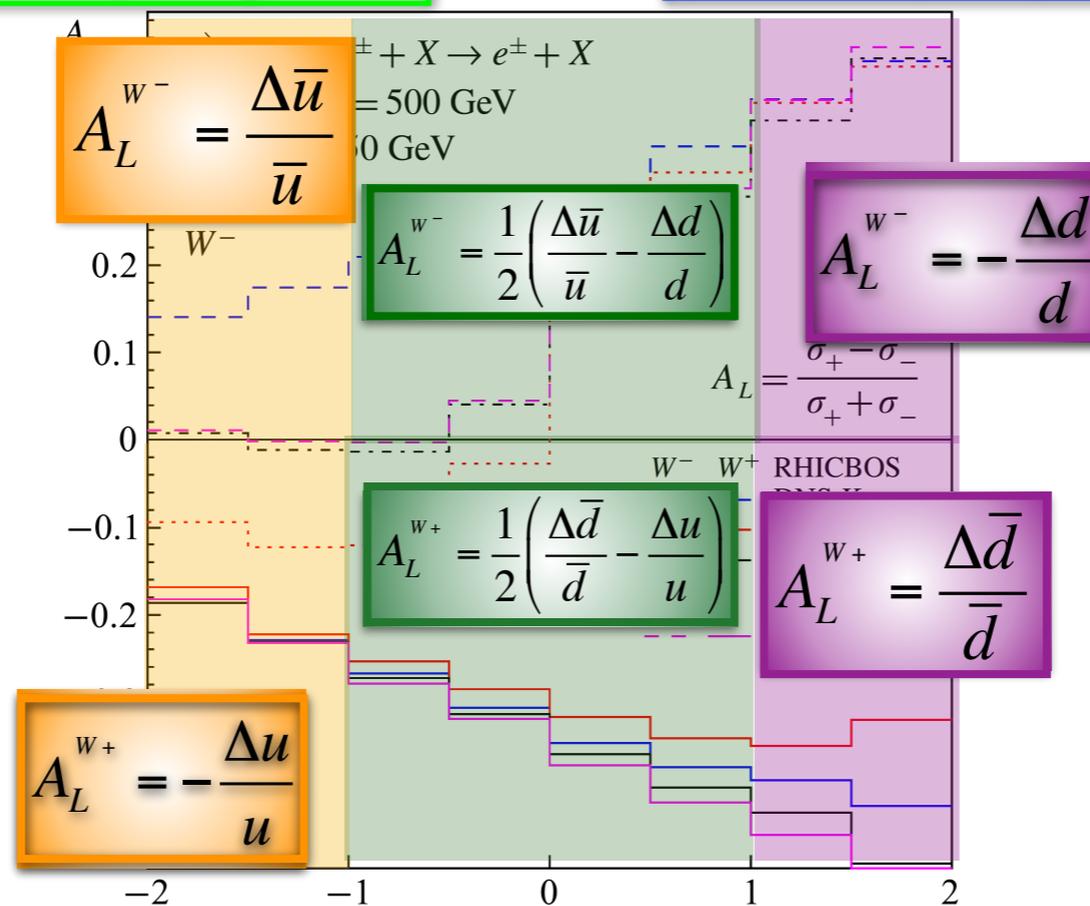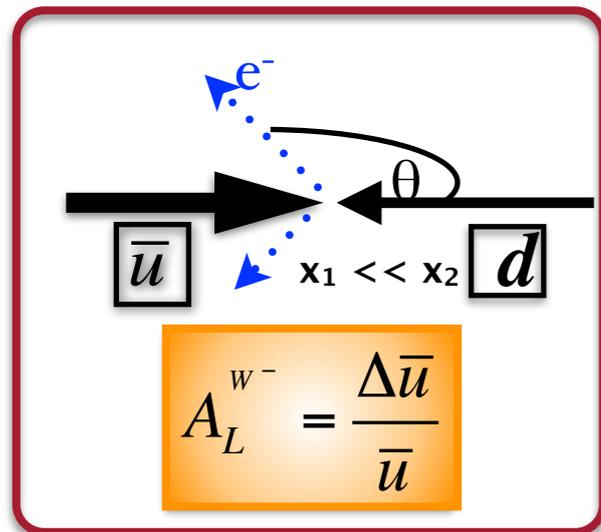
$$A_L^{e^+} \approx \frac{\int_{\otimes(x_1,x_2)} \left[\Delta\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 - \Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2\right]}{\int_{\otimes(x_1,x_2)} \left[\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2\right]}$$

W unpolarized cross section ratio

$$R(x_F) \equiv \frac{\sigma_W^+}{\sigma_W^-} = \frac{u(x_1)\,\bar{d}(x_2) + \bar{d}(x_1)\,u(x_2)}{\bar{u}(x_1)\,d(x_2) + d(x_1)\,\bar{u}(x_2)}$$
$$+ NLO + NNLO + ...$$

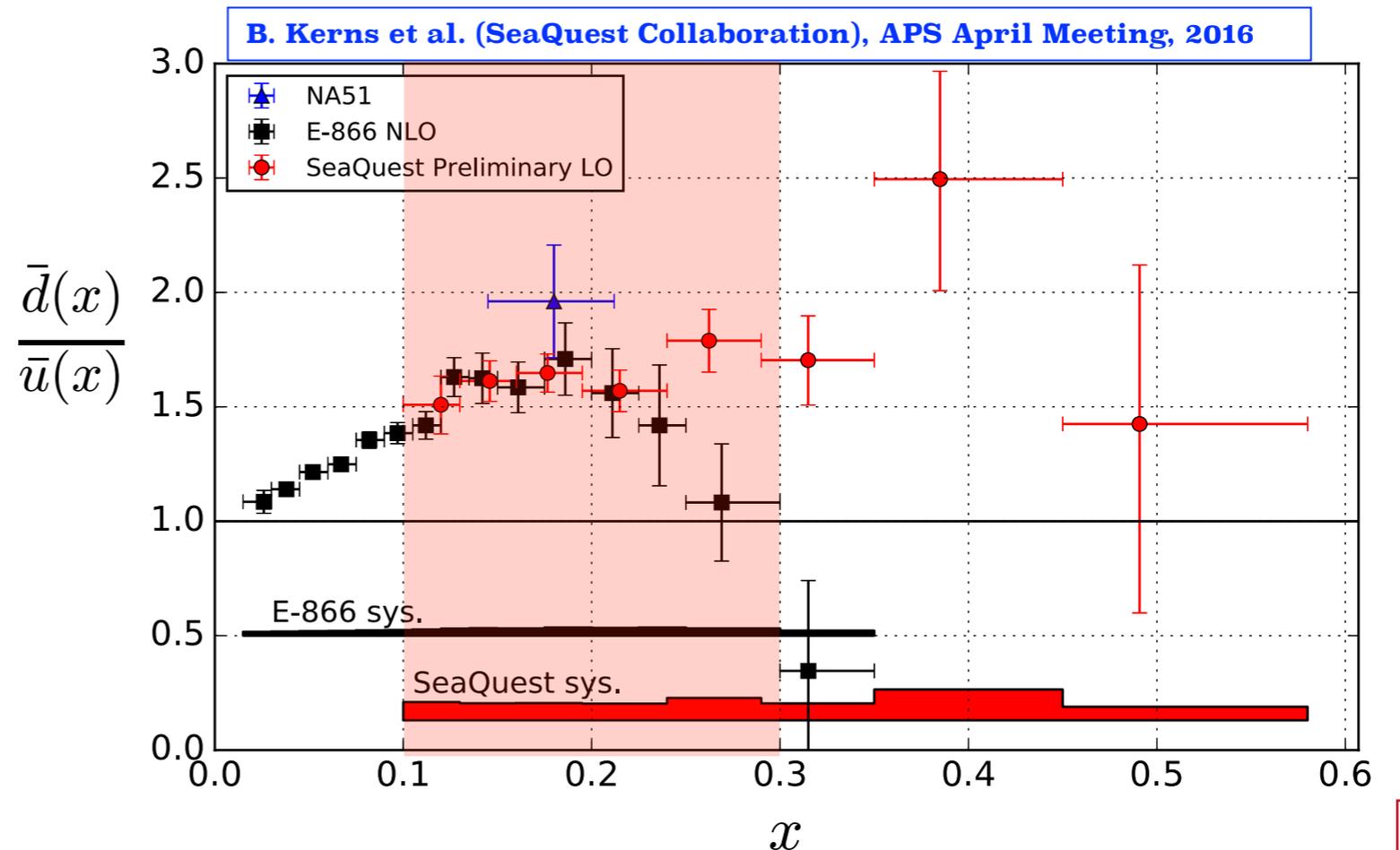$$R = \frac{N_O^+ - N_B^+}{N_O^- - N_B^-} \cdot \frac{\epsilon^-}{\epsilon^+}$$

$N_O^{+(-)}$ = measured positron (electron) decay events

$N_B^{+(-)}$ = Positive (negative) background events

ε = lepton detection efficiency

- Approximate kinematic range at RHIC:

$0.06 < x < 0.4$ for $-2 < \eta < 2$

mid-rapidity => $|\eta| < 1$, $0.1 < x < 0.3$

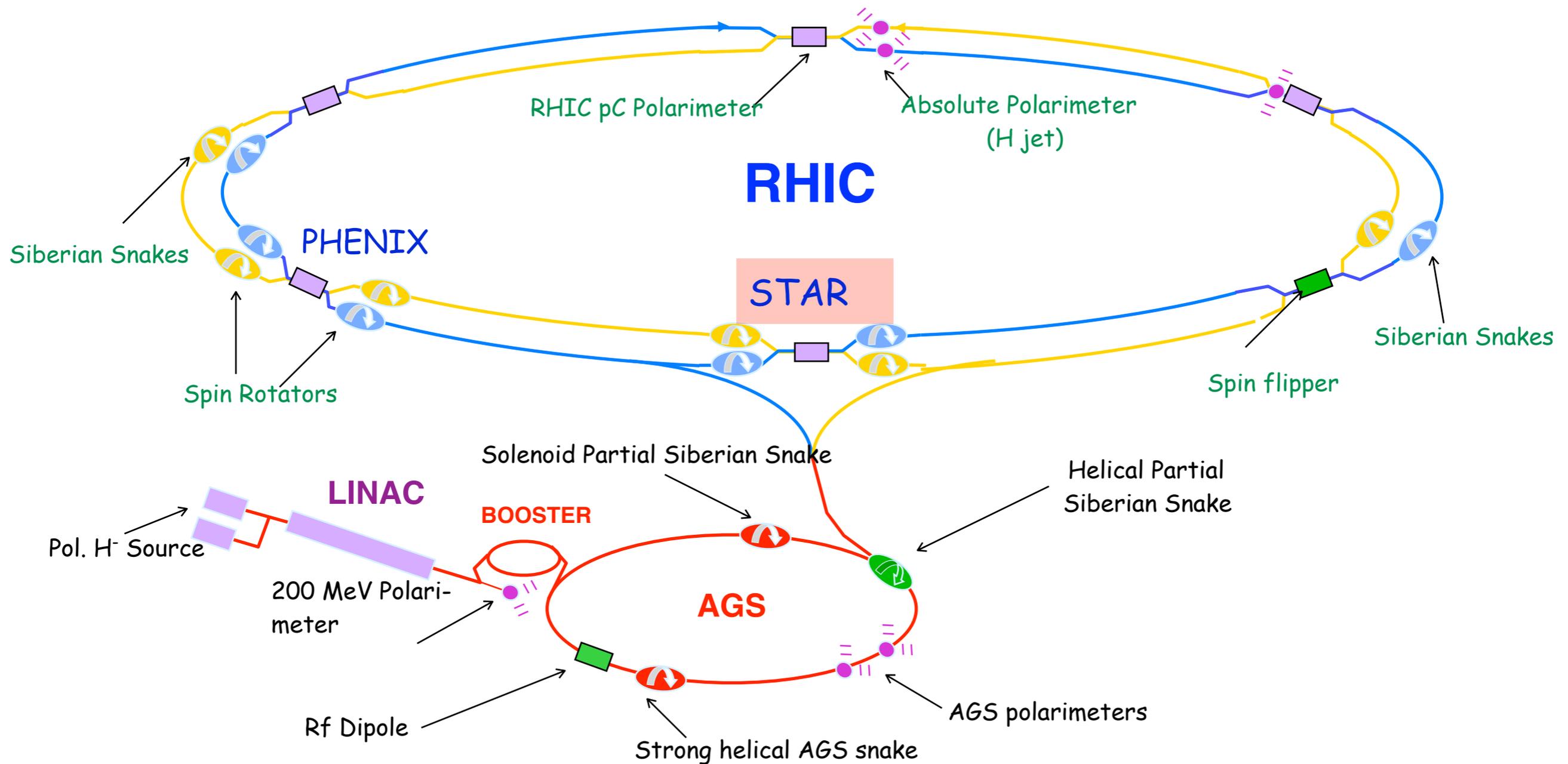RHIC kinematic coverage (mid-rapidity) is sensitive in particular to "turn over" region of x in đ̄/ū of E866.

B. Kerns et al. (SeaQuest Collaboration), APS April Meeting, 2016

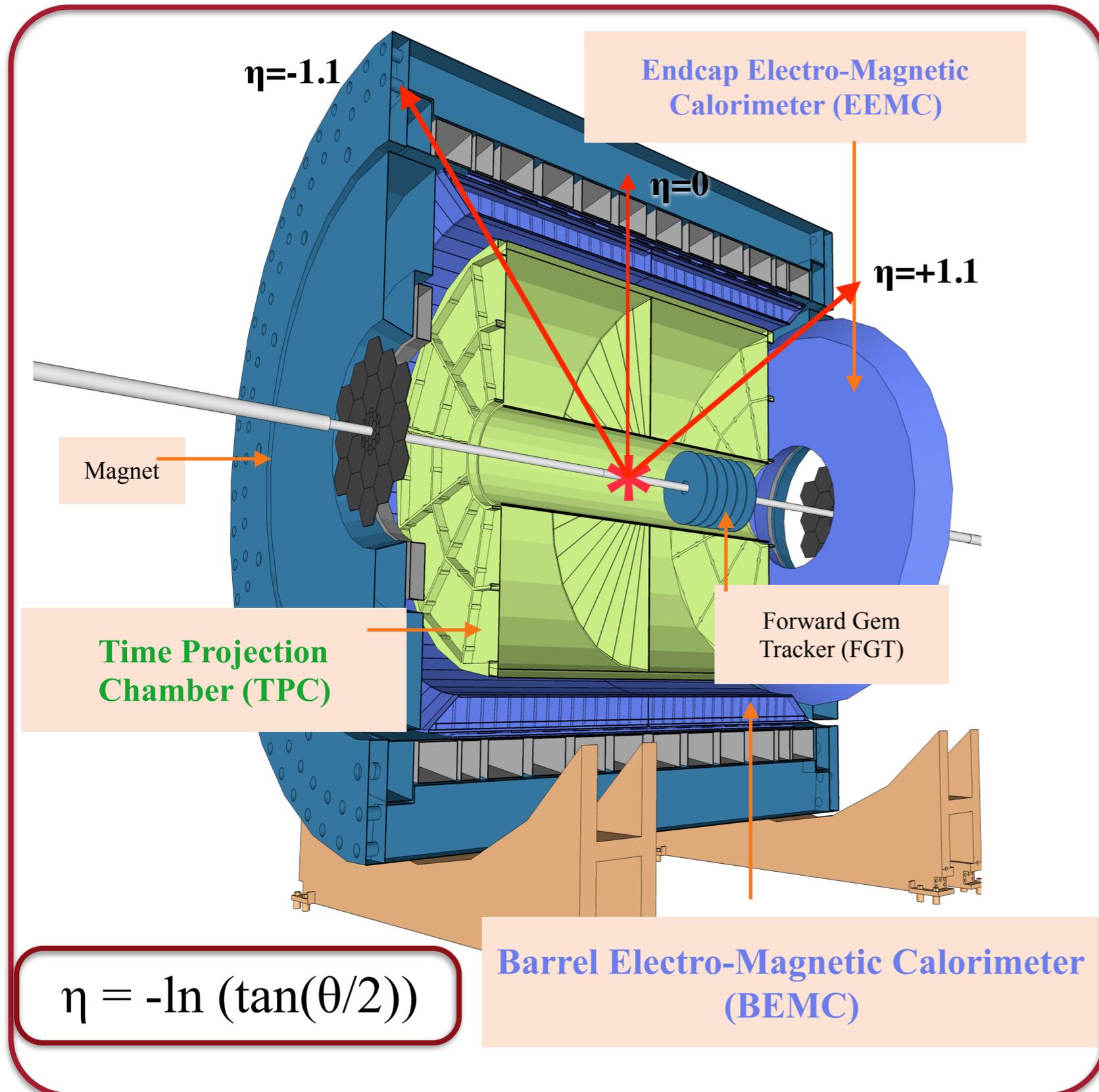- **RHIC** : **R**elativistic **H**eavy **I**on **C**ollider

The World's first polarized hadron collider!

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

RHIC pC Polarimeter

Absolute Polarimeter (H jet)

RHIC

Siberian Snakes

PHENIX

STAR

Siberian Snakes

Spin Rotators

Spin flipper

Solenoid Partial Siberian Snake

Helical Partial Siberian Snake

LINAC

BOOSTER

Pol. H⁻ Source

200 MeV Polari-meter

AGS

Rf Dipole

Strong helical AGS snake

AGS polarimeters

Devika Gunarathne — **W A**$_L$ **and W cross-section ratio measurements at STAR** — **SPIN 2016** — **Sep 25-30 2016 at UIUC**

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- **STAR** : **S**olenoidal **T**racker **A**t **R**HIC

Endcap Electro-Magnetic Calorimeter (EEMC)

η=-1.1

η=0

η=+1.1

Magnet

Time Projection Chamber (TPC)

Forward Gem Tracker (FGT)

Barrel Electro-Magnetic Calorimeter (BEMC)

$$\eta = -\ln(\tan(\theta/2))$$

TPC: **Charged particle tracking**

BEMC, EEMC: **EM Calorimetry**

TPC	: -1.3 < η < +1.3
BEMC	: -1.0 < η < +1.0
EEMC	: +1.1 < η < +2.0
FGT	: +1.0 < η < +2.0

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

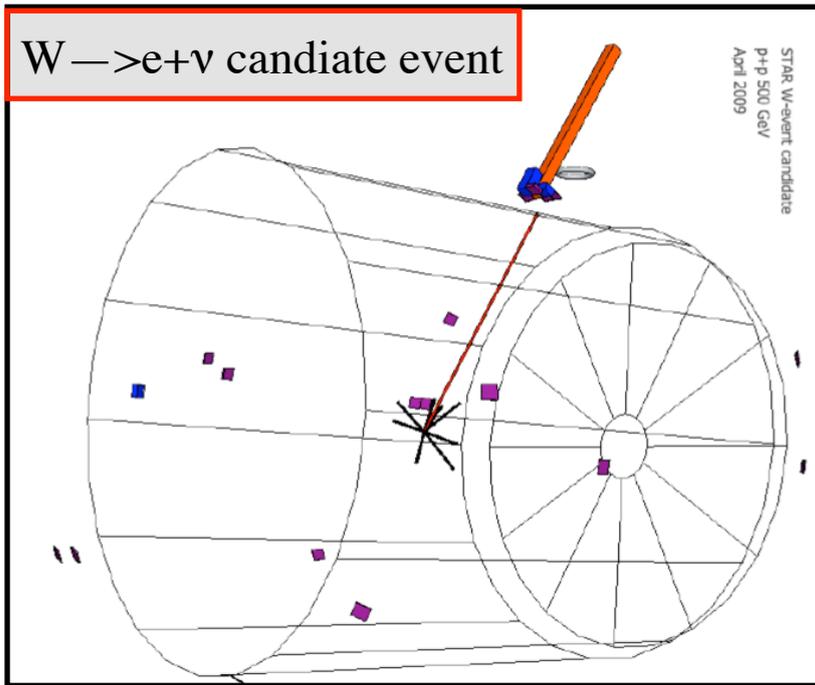 W production (Quark polarization) / Jet and Hadron production (Gluon polarization)

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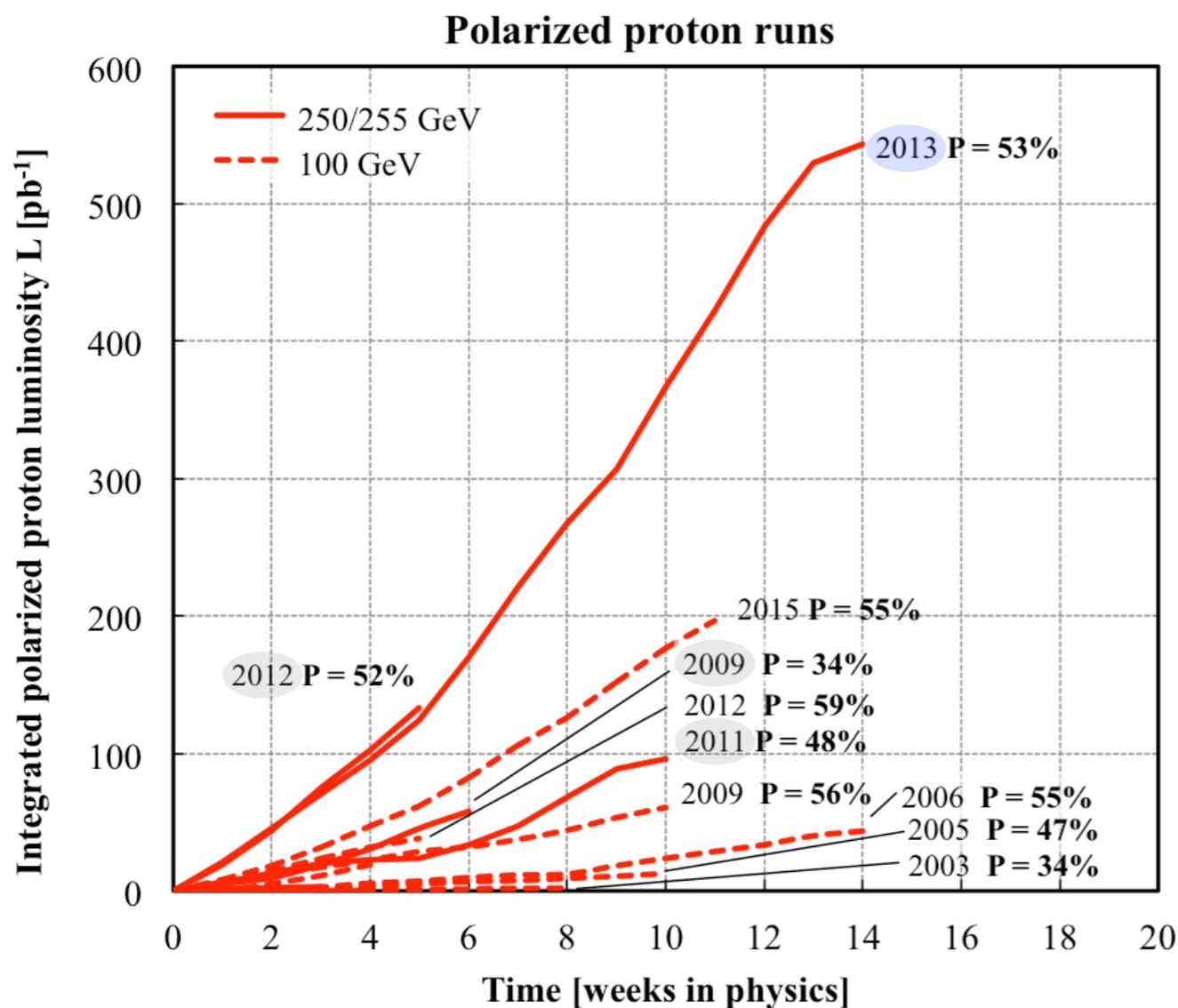
Run	L (pb^{-1})	P (%)	FOM (P^2L) (pb^{-1})
2009	12	0.38	1.7
2011	9.4	0.49	2.3
2012	77	0.56	24
2013	**246.2**	**0.56**	**77.2**

- W A_L recent result present today is from data collected during year 2013, the largest data set STAR ever collected!

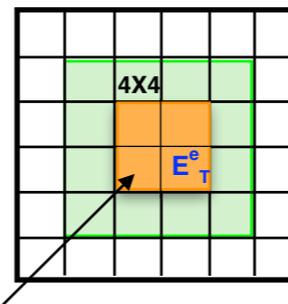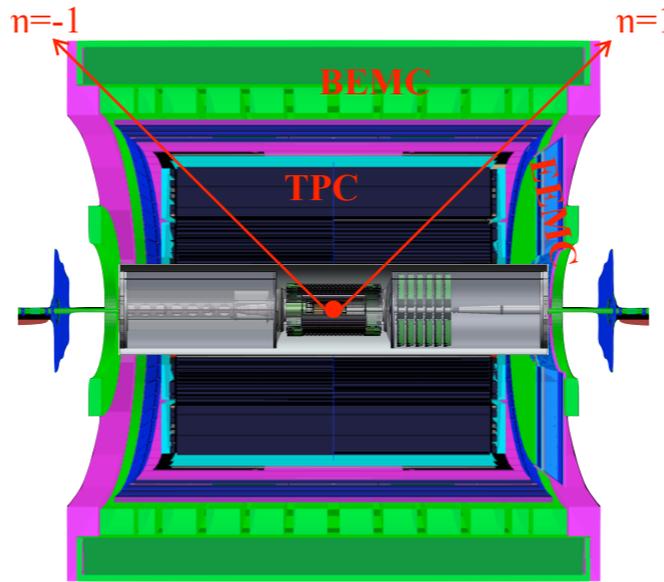- Prior W A_L analysis from data collected during 2009 and 2011+2012 are published!

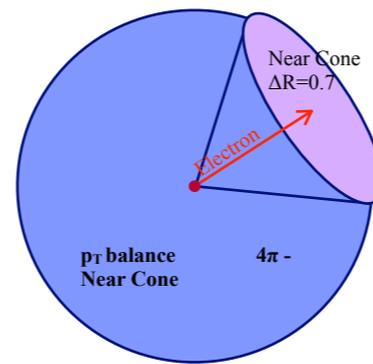 STAR: PRL 106, 062002(2011)   STAR: PRL 113, 072301(2014)
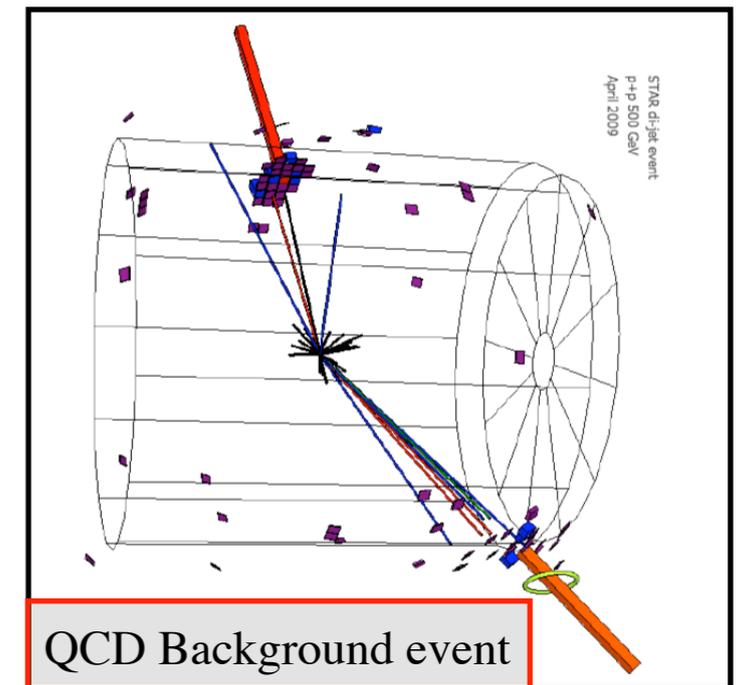
W—>e+ν candiate event

- Isolated high PT track pointing to isolated EMC cluster
- Large Imbalance in the reconstruct vector PT sum in 4π due to undetected neutron

TPC track extrapolated to Barrel colorimeter tower grid

Transverse plane view

QCD Background event

- Several tracks pointing to several EMC clusters.
- PT sum is balanced by the Jet opposite in π.
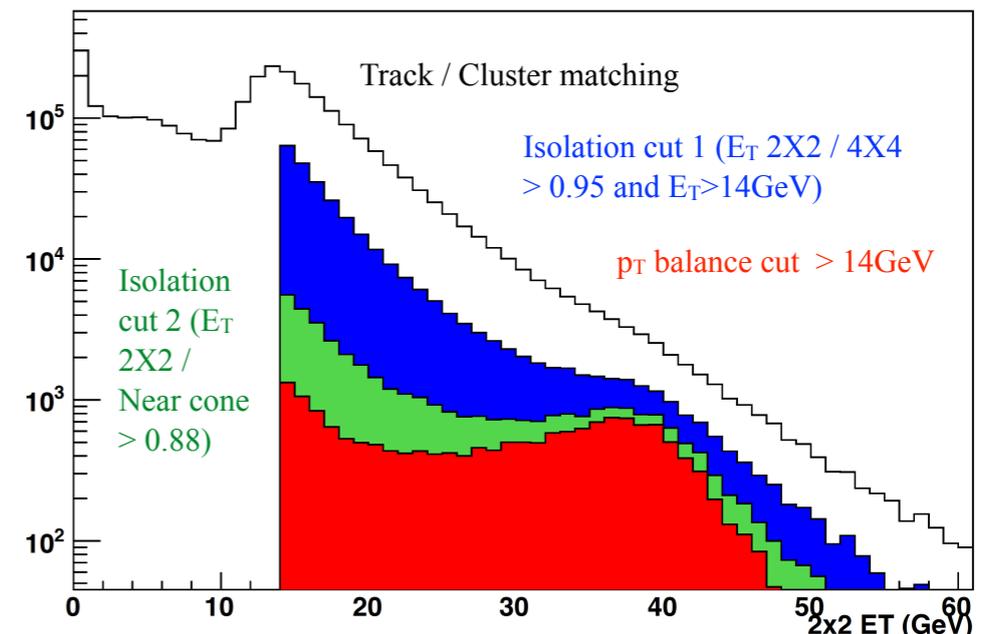
- Mid-rapidity STAR W selection criteria
  - Match p_T > 10 GeV track to BEMC cluster
  - Isolation ratio 1 / Isolation ratio 2
  - p_T-balance cut

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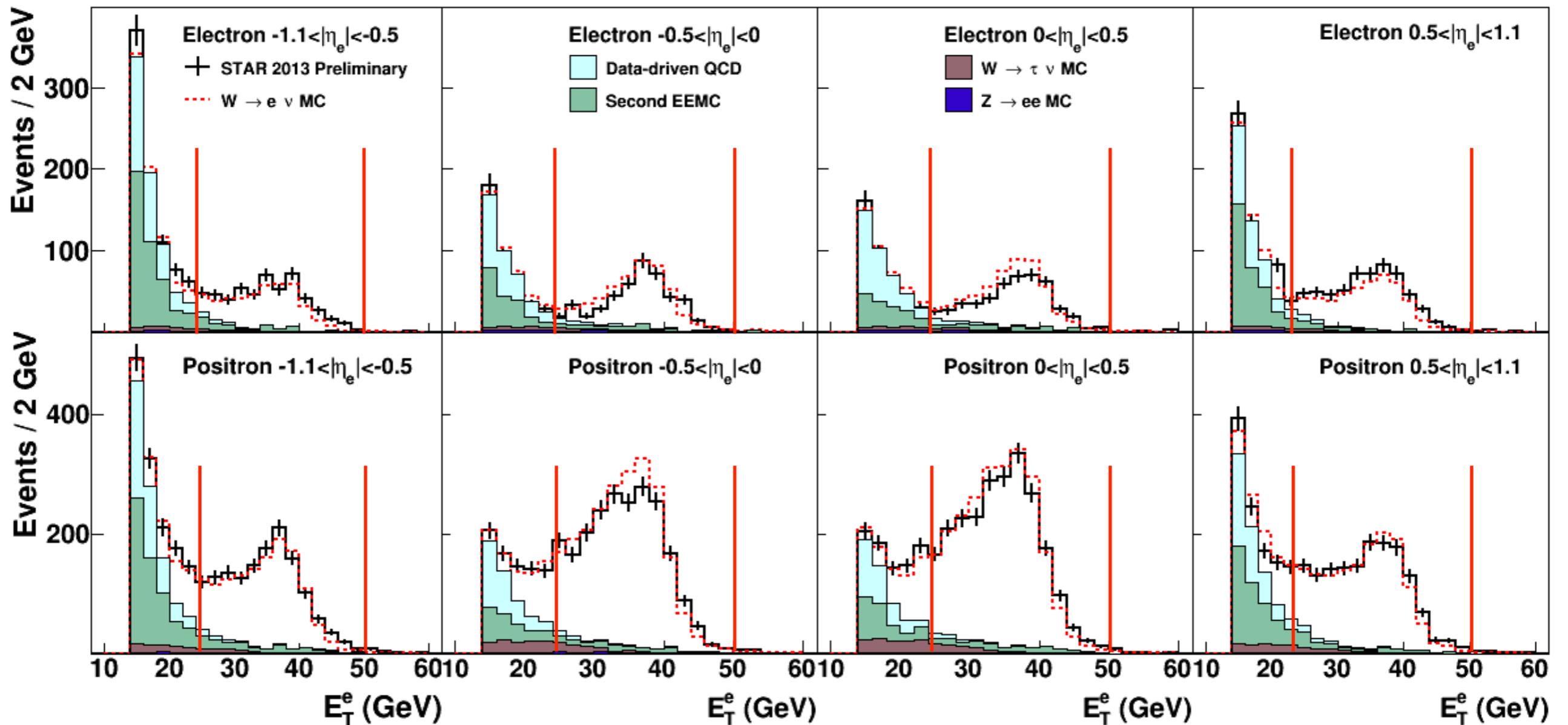
$$E_T^e \ / \ E_T^{\Delta R < 0.7} \quad > 88\%$$

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

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

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 , $|\eta|>2$.

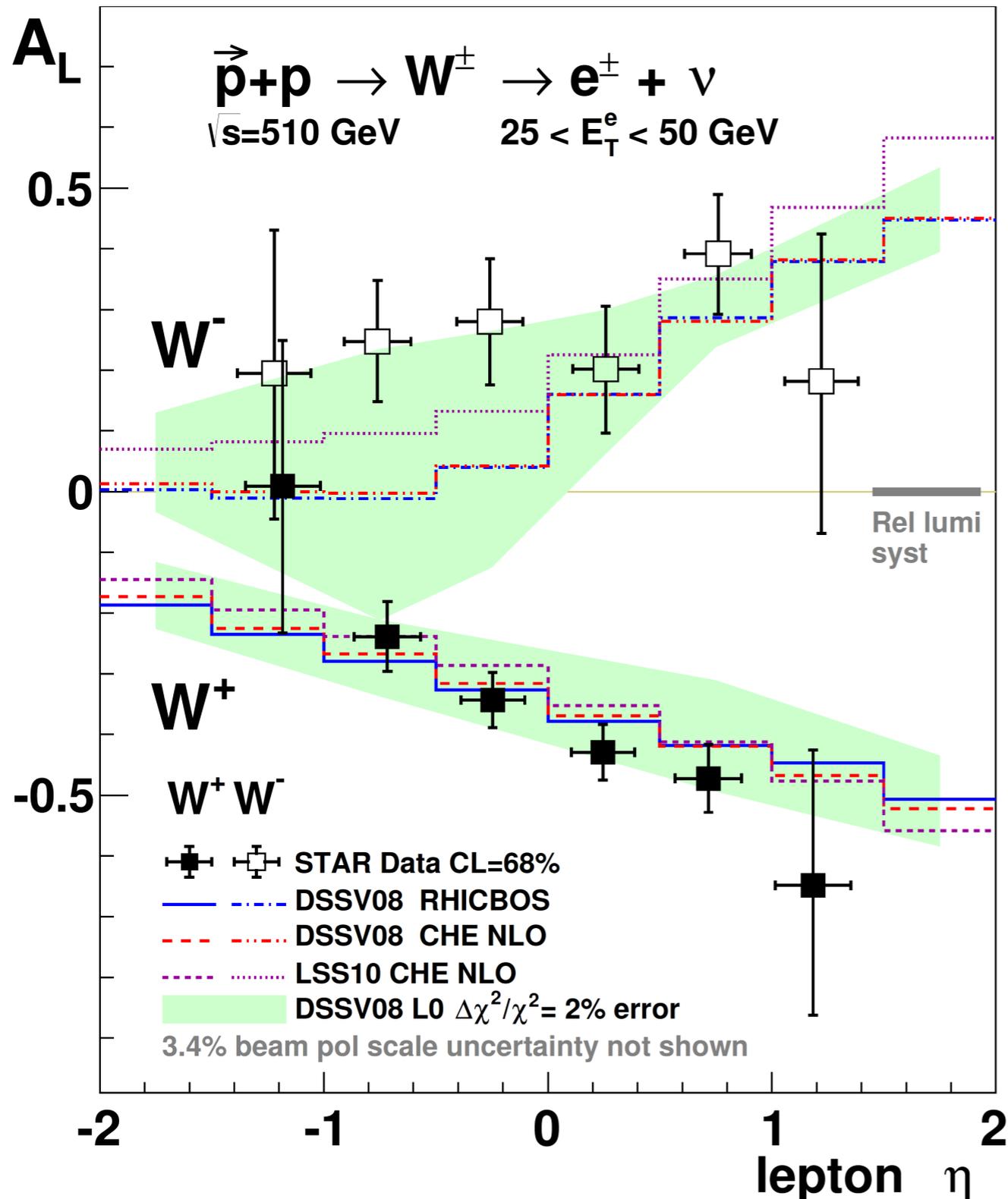- Second EEMC : due to "jet" escape detection at "non-existent" East EEMC, estimate based on "real" West EEMC

- Determine from MC simulation

  $Z \longrightarrow e^+ + e^-$

  $W \longrightarrow \tau + \nu$

- 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<η<0.2.

- Impact on helicity PDF from DSSV [STAR 2012 W A$_L$ Preliminary]

- Anti u quark polarization
- Anti d quark polarization

Only DIS + SIDIS data
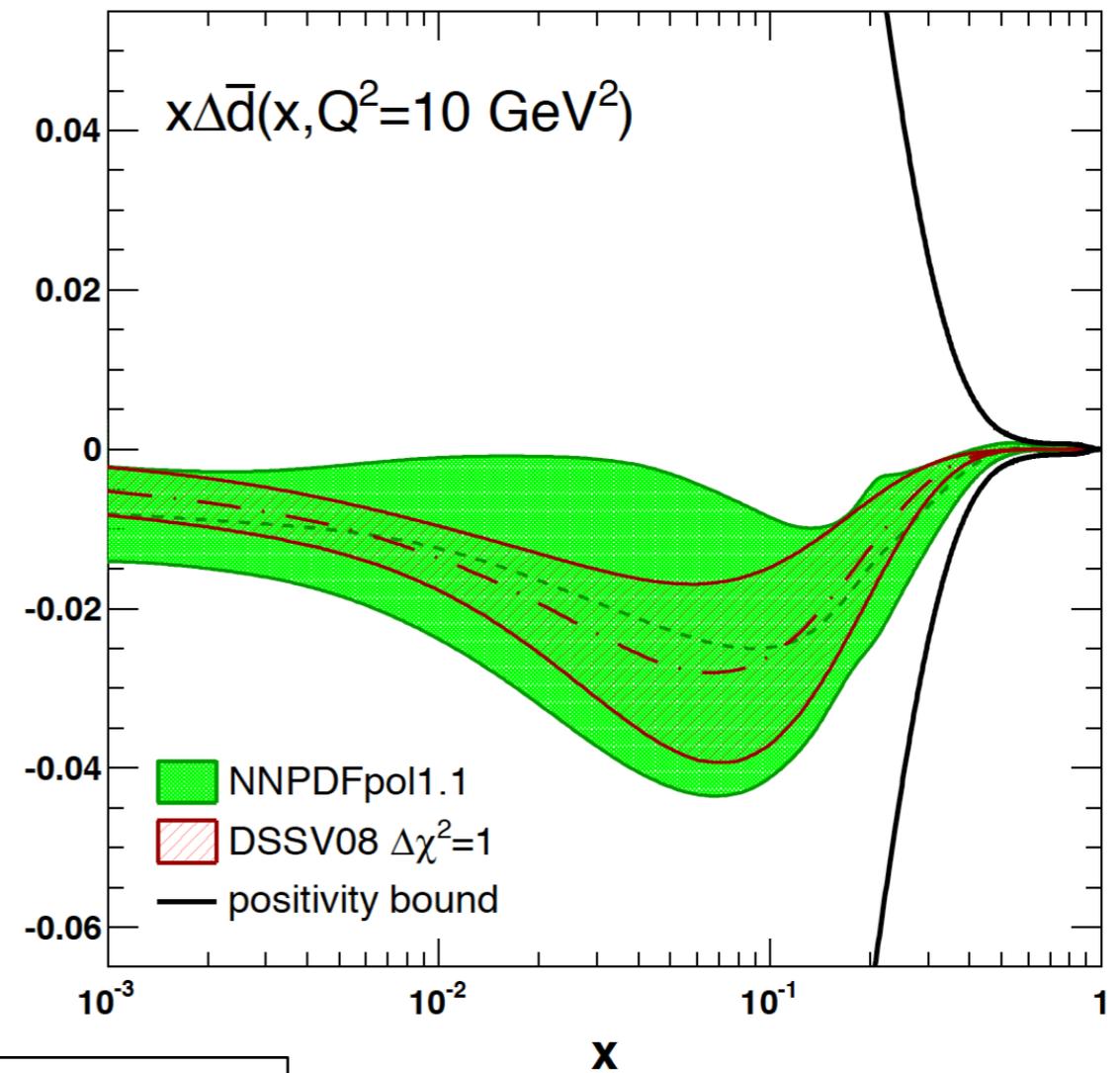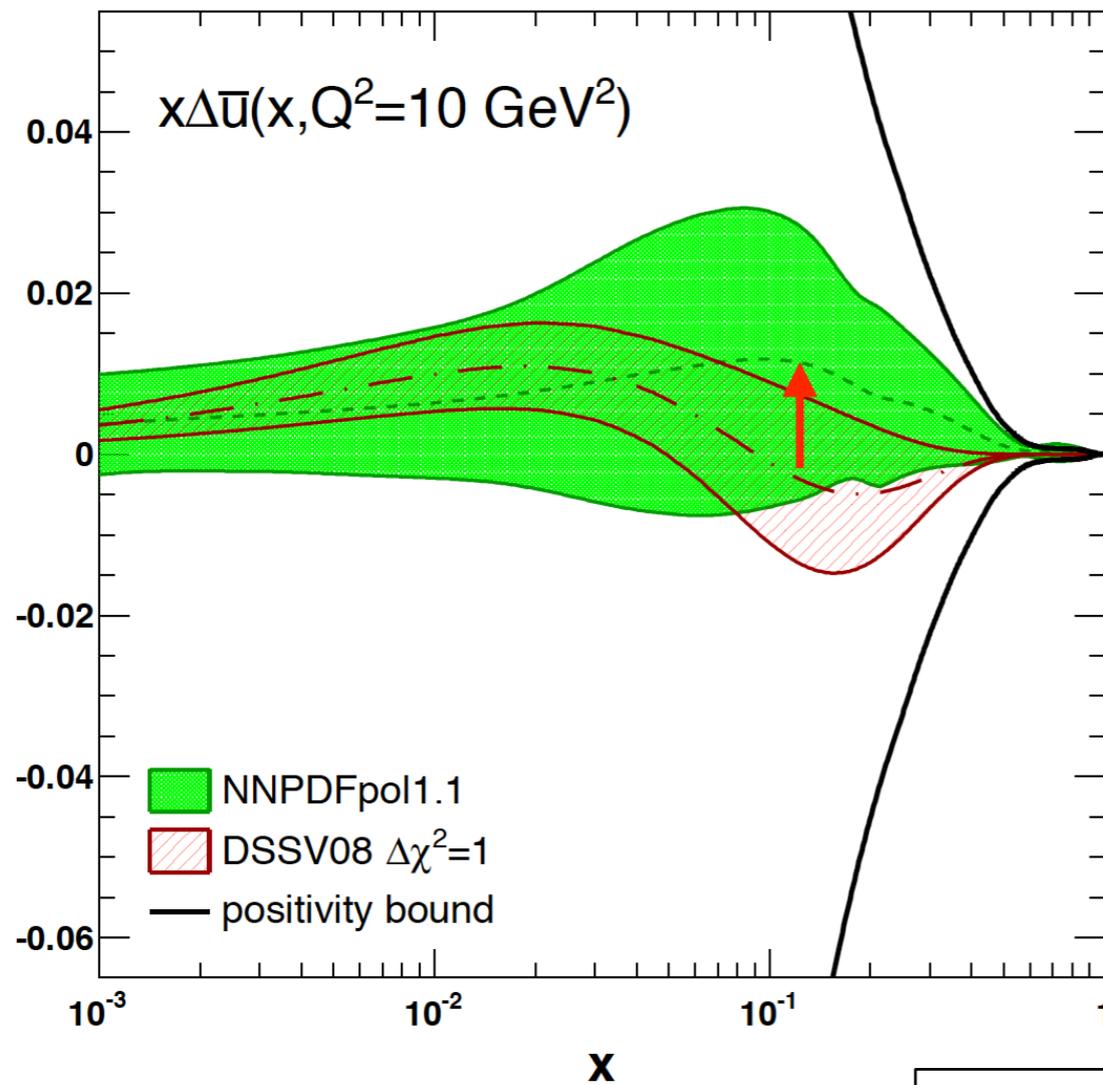
DIS + SIDIS + STAR W A$_L$ data

E.Aschenauer, et.al. arXiv:1304.0079
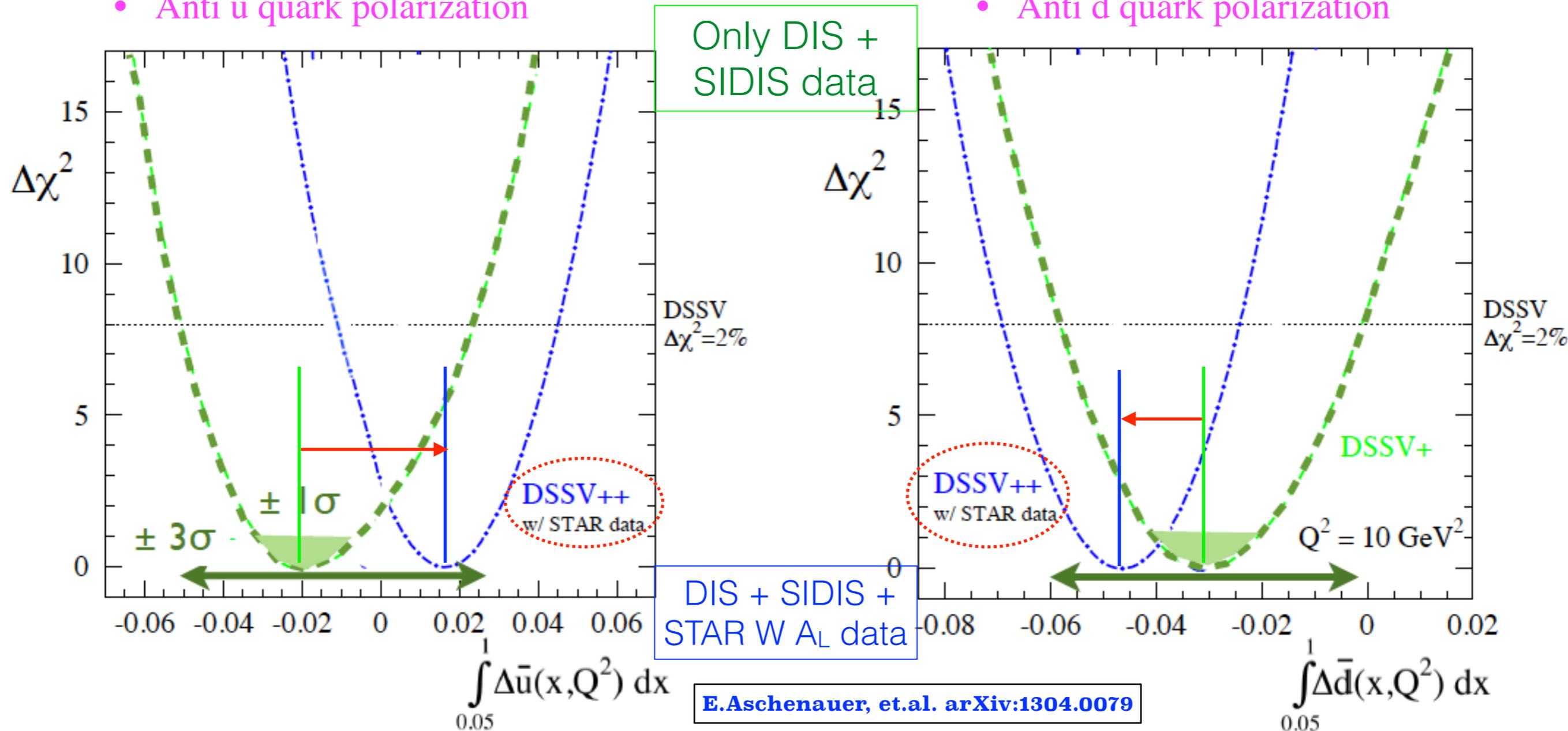
- Significant constraints on both Δū and Δd̄.

- Significant shift of Δū central value from STAR 2012 W A$_L$ data.

- Impact on helicity PDF from NNPDF [RHIC W A_L]

- Anti u quark polarization

- Anti d quark polarization

Nucl.Phys. B887 (2014) 276-308

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

Devika Gunarathne — **W A_L and W cross-section ratio measurements at STAR** — **SPIN 2016** — **Sep 25-30 2016 at UIUC**

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- STAR 2013 W A$_L$ Preliminary Results => | Just Released @ INPC 2016!!!
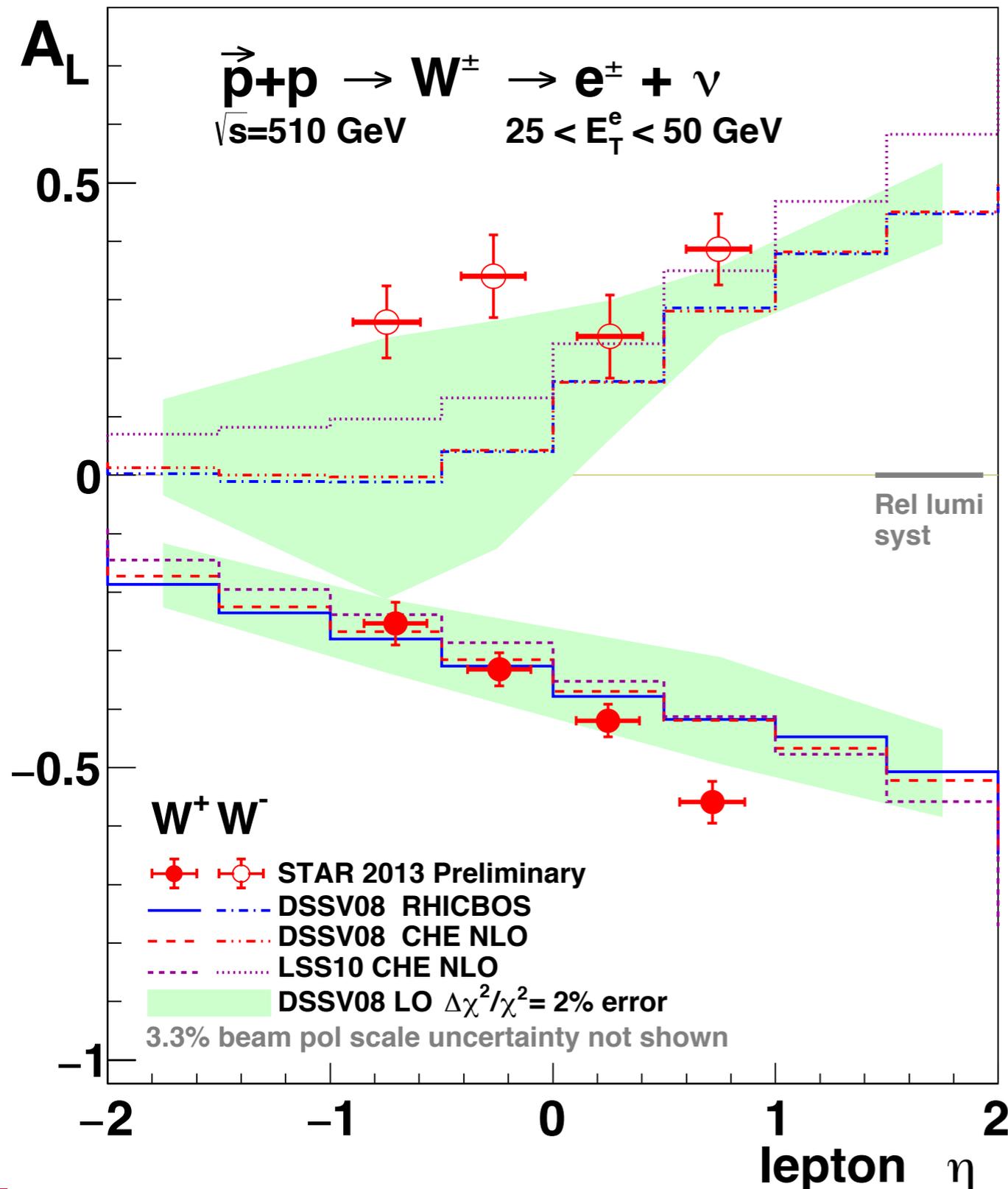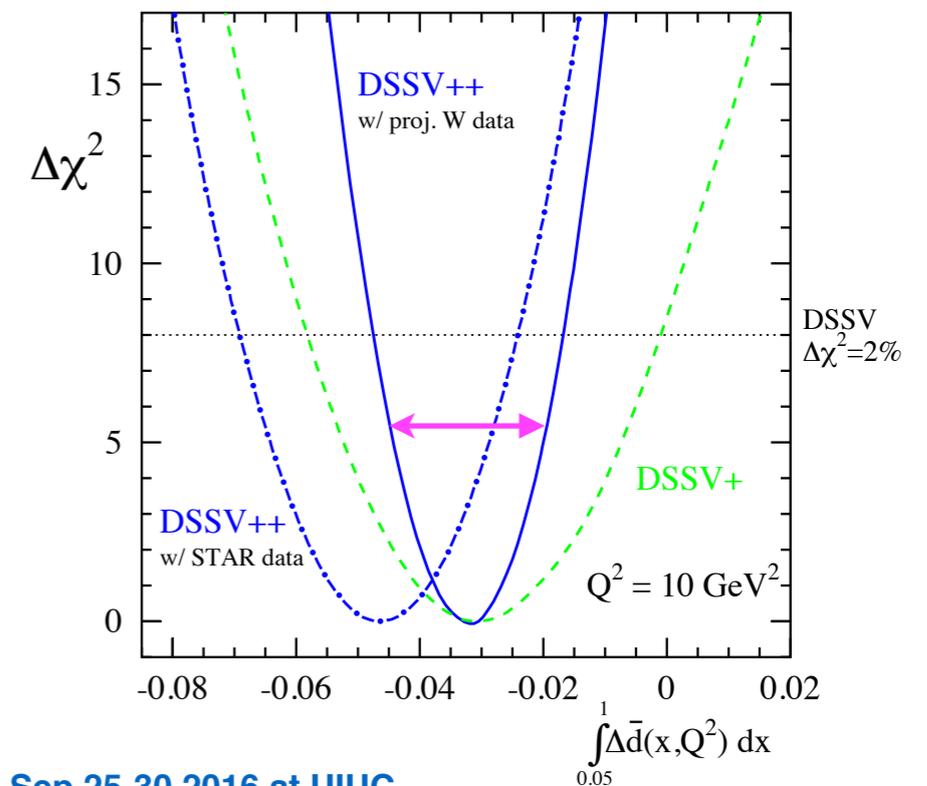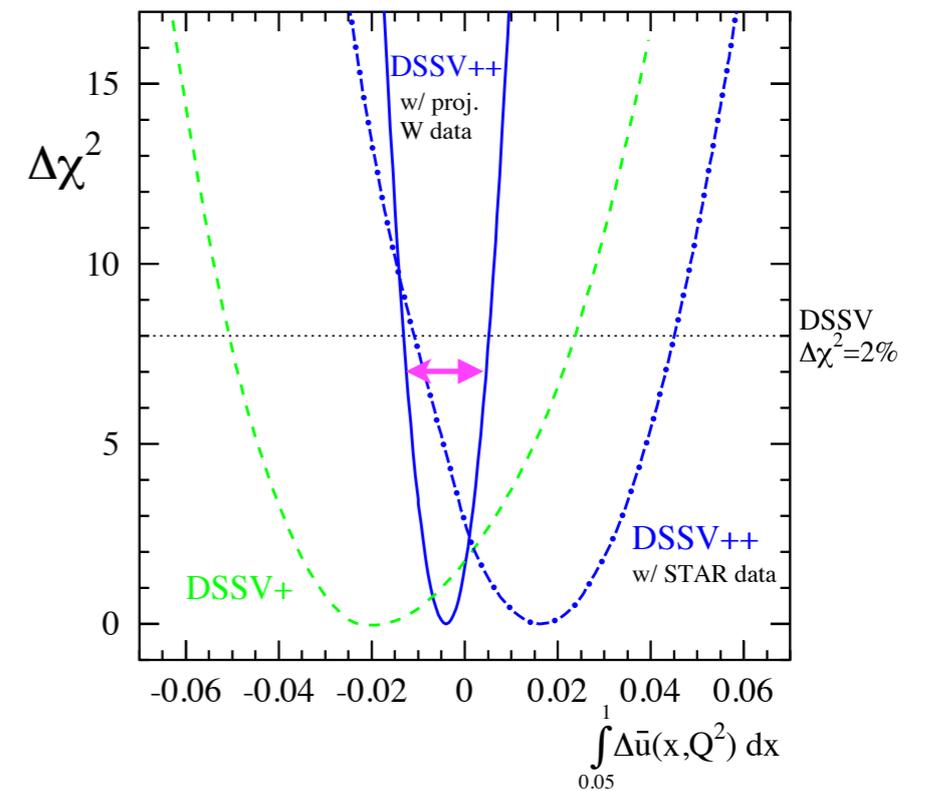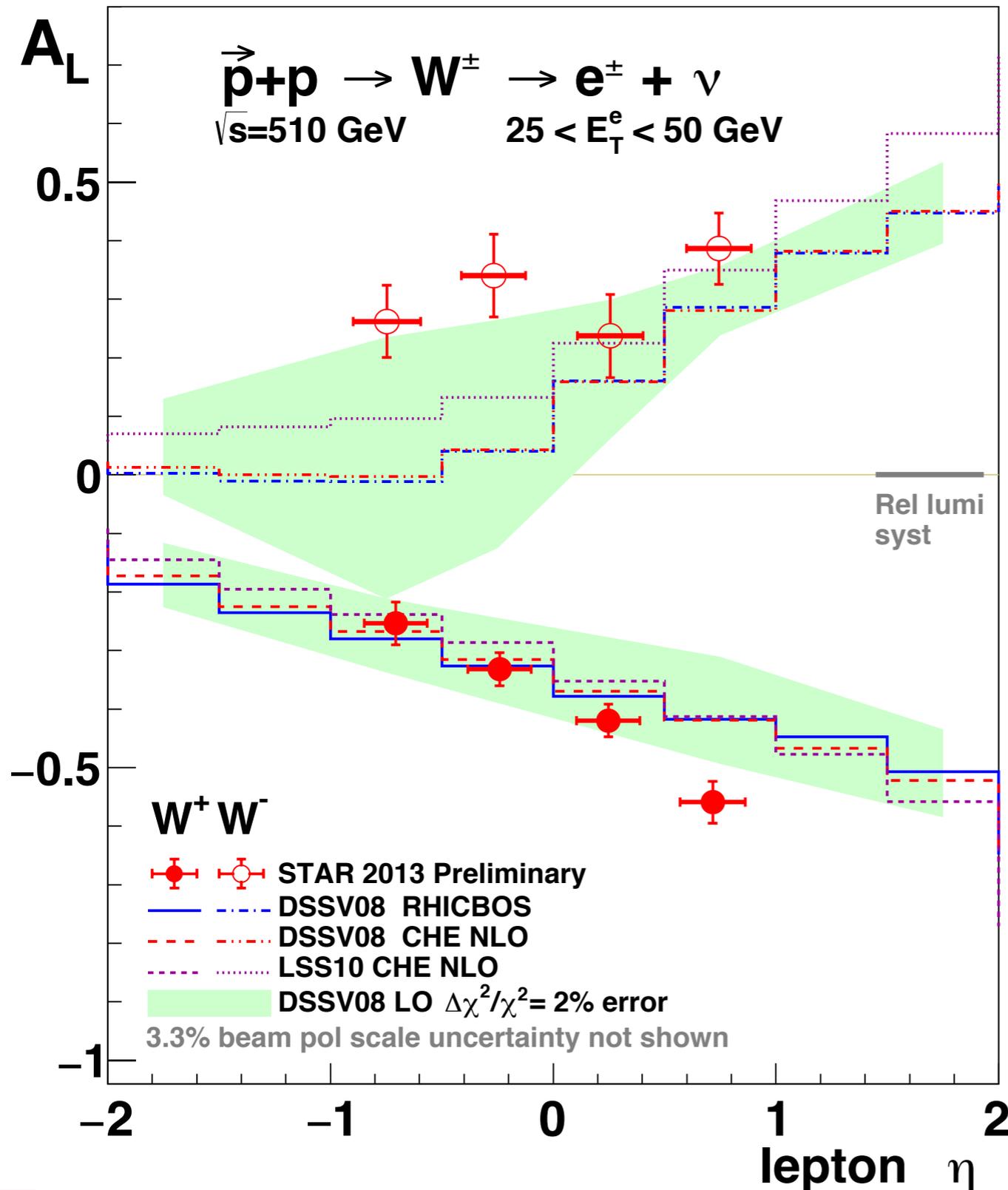

- The Most Precise measurements of W A$_L$ up to date!
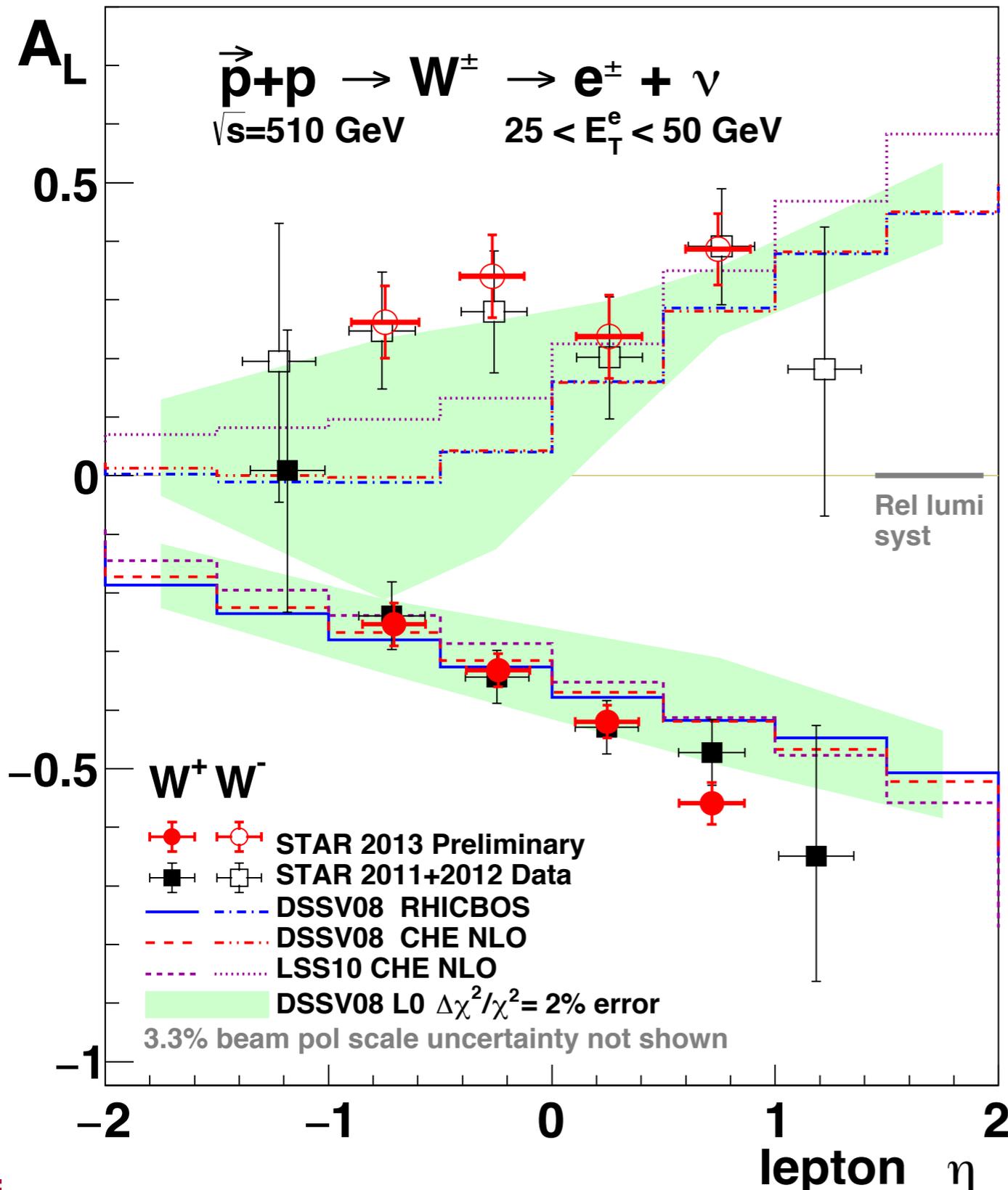
- Expect to further constrain $\Delta\bar{u}$ and $\Delta\bar{d}$.

- STAR 2013 Preliminary Results => Just Released !!!!

- Uncertainties projection from STAR 2013 W AL data !!!!

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

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

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

Rel lumi syst

W$^+$ W$^-$

STAR 2013 Preliminary
STAR 2011+2012 Data
DSSV08 RHICBOS
DSSV08 CHE NLO
LSS10 CHE NLO
DSSV08 L0 $\Delta\chi^2/\chi^2$= 2% error
3.3% beam pol scale uncertainty not shown

- STAR 2013 W AL 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 %

- STAR 2013 Preliminary Results in comparison to STAR 2011+2012 published results , PHENIX 2011+2012, PHENIX 2013 W AL results
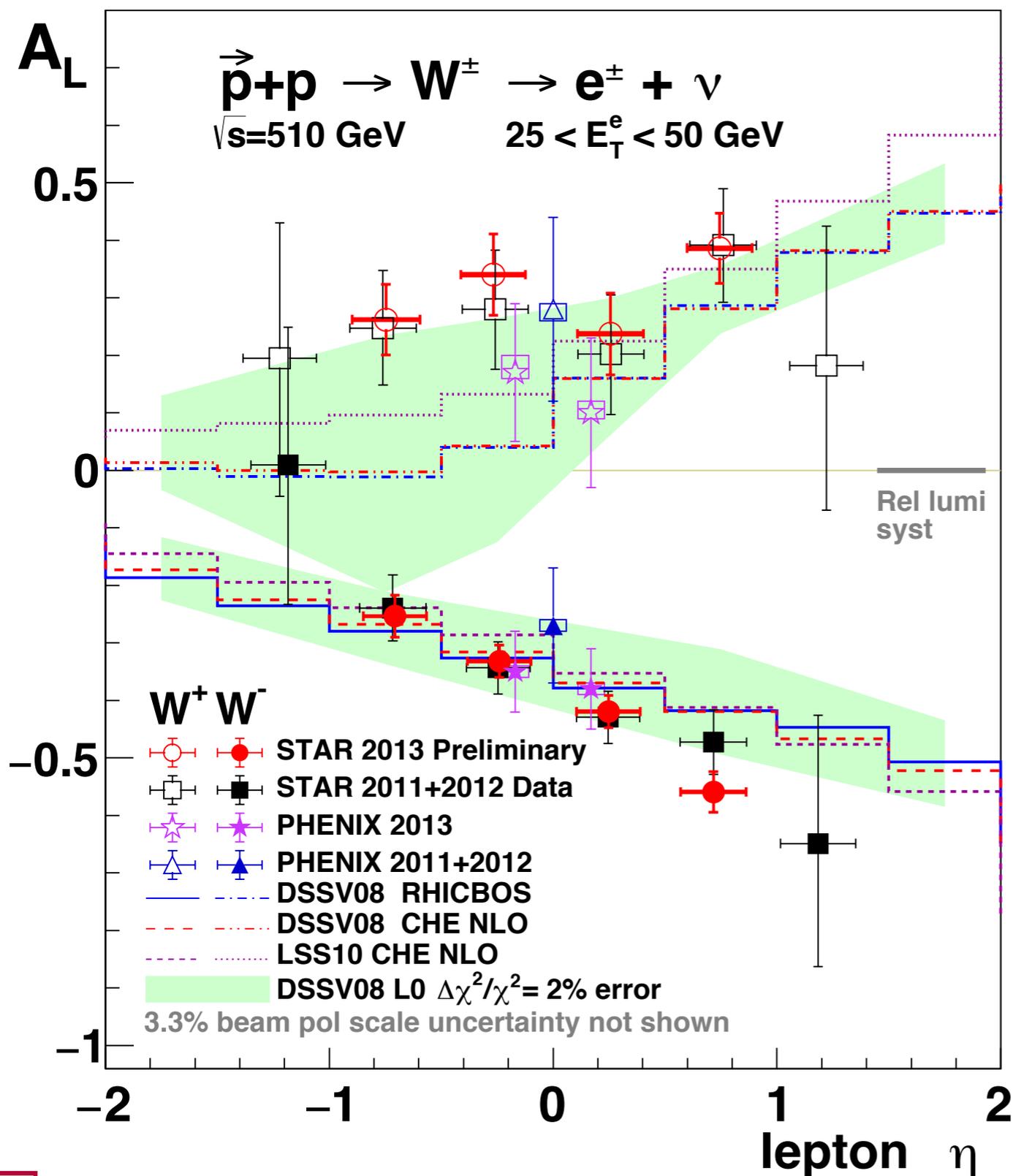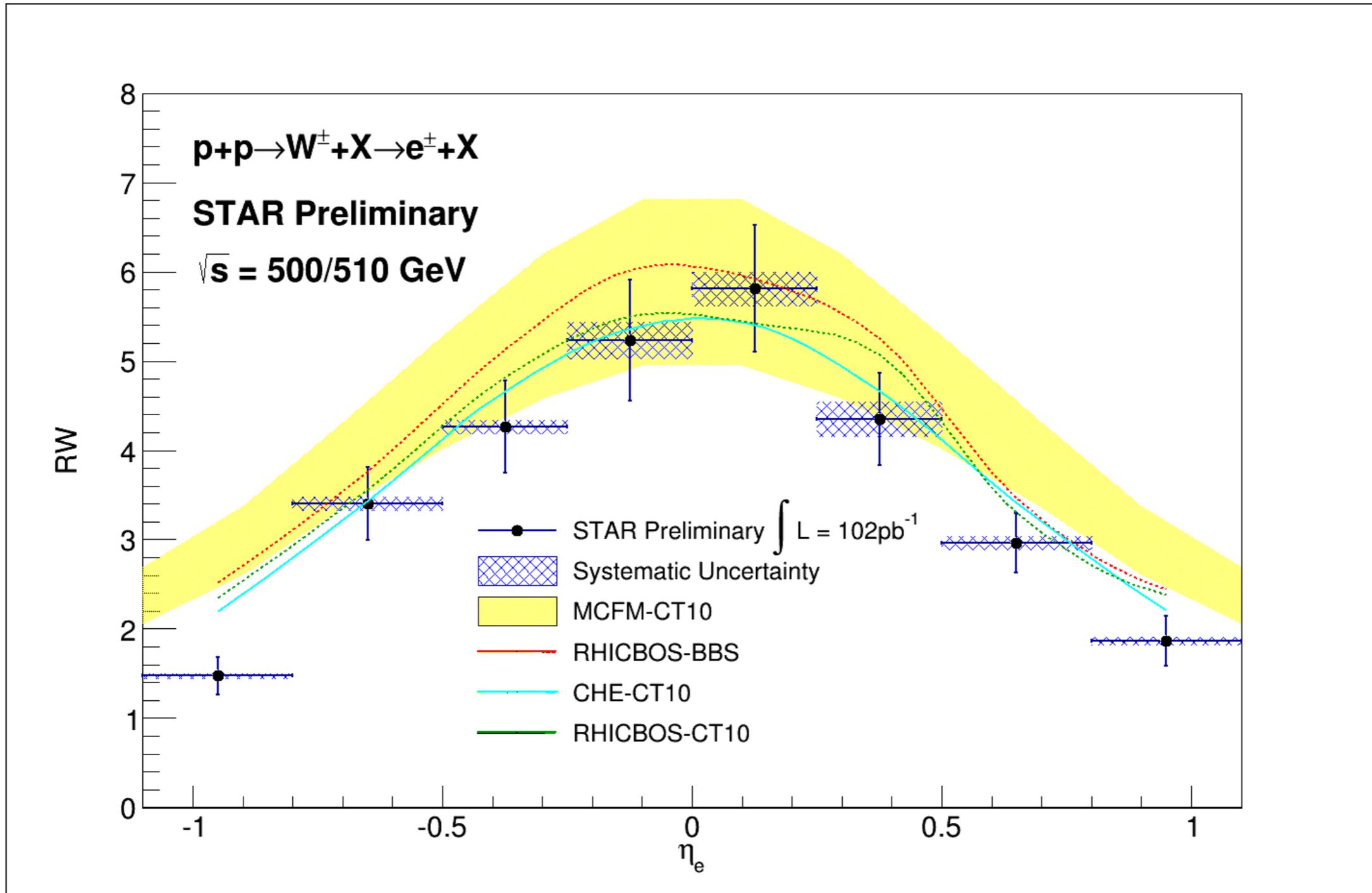

World data of W A$_L$

- STAR 2013 W AL Preliminary results is the Most Precise measurements of W A$_L$ up to date!

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

- Uncertainties were reduced by 40 %

- Also consistent with PHENIX results

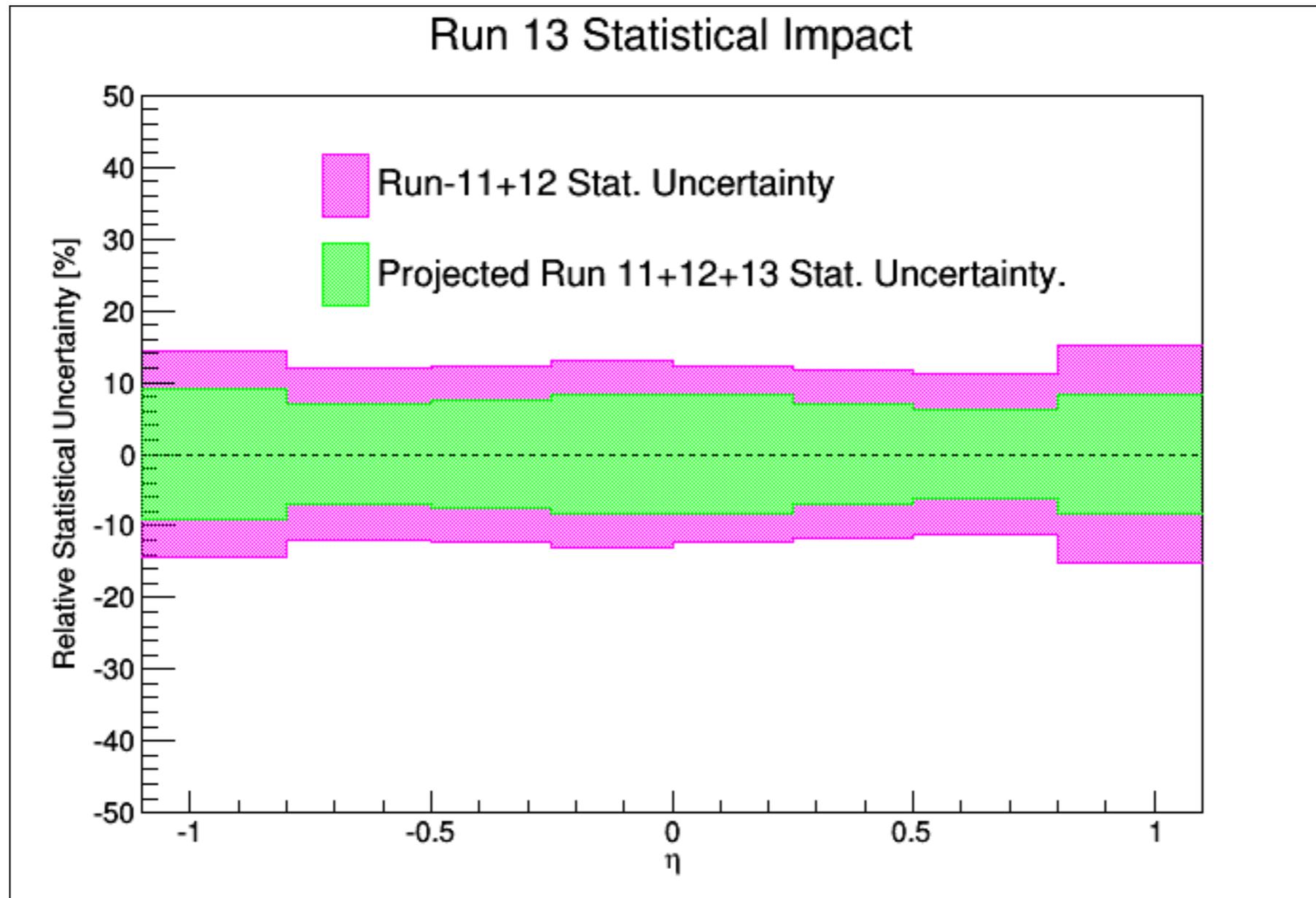- STAR 2011+2012 Preliminary Results

- Projected STAR Run 13 Statistical Impact

Inclusion of **Run-13** data will **improve** precision of the cross section ratios. Run-17 will add additional data of ~400 Pb^{-1} to improve further.

- R_W vs W Rapidity

- W boson rapidity can be determined by reconstructing the W kinematics via its recoil
- Recently through the combination of data and MC simulations, a procedure for reconstructing the W boson rapidity has been established at STAR.
- This procedure has been applied to the 2011 + 2012 combined data set.
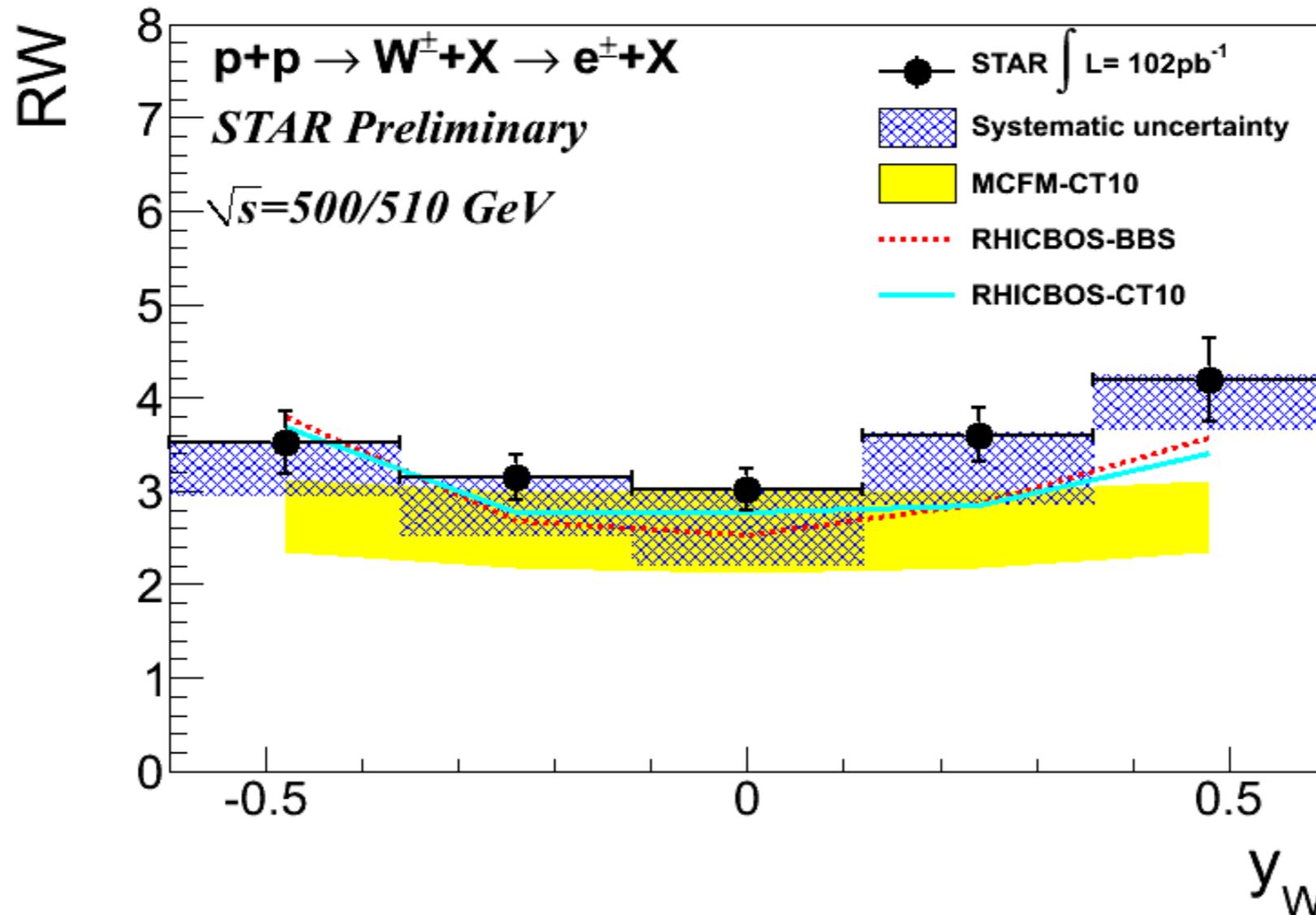
- Mid-rapidity (Run 11/12): Published W asymmetry results suggest large anti-u quark polarization along with broken QCD sea

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

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

- Prelim. cross-section ratio measurement (Run 11/12): Strong physics case of unpolarized dbar/ubar probe using W production complementary to SeaQuest.

- Run 13 data (~300 pb , analyzing) and Run 17 data (~400 pb , next year) will further improve precision of W cross section ratio measurements at STAR.

BACK UP

STAR W AL 2011+2012, 2013 - Consistance checking

STAR 2013 W A_L Preliminary		
Lepton η Range	W^+ A_L	W^- A_L
$-1.1 < \eta < -0.5$	-0.254 ± 0.037	0.262 ± 0.062
$-0.5 < \eta < 0$	-0.332 ± 0.028	0.340 ± 0.071
$0 < \eta < 0.5$	-0.420 ± 0.028	0.237 ± 0.071
$0.5 < \eta < 1.1$	-0.559 ± 0.036	0.386 ± 0.061

STAR 2011+2012 W A_L		
Lepton η Range	W^+ A_L	W^- A_L
$-1.1 < \eta < -0.5$	-0.239 ± 0.057	0.247 ± 0.100
$-0.5 < \eta < 0$	-0.343 ± 0.045	0.280 ± 0.104
$0 < \eta < 0.5$	-0.429 ± 0.045	0.202 ± 0.104
$0.5 < \eta < 1.1$	-0.472 ± 0.056	0.391 ± 0.099

	W^+ A_L	W^- A_L
χ^2/n.d.f	1.83/4	0.32/4

- Background estimation:
  - From data-driven procedure, statistics of embedding sample
  - Less than 10% of statistical error
  - Negligible polarized background contribution

- BEMC gain calibration:
  - 4.5%

- Beam polarization uncertainty:
  - Correlated scale 3.3%

- Relative luminosity uncertainty:
  - Estimated from a high-p_T [25,50]GeV, QCD sample
  - Correlated offset 0.007 (2011+2012), 0.004 (2013)

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- BG ESTIMATION

TPC

vertex

200 cm of tracking

BEMC

Q+ PT = 5 GeV

Q- PT = 5 GeV

gauss fit: x0,	σ
-0.97 ,	0.36
1.07 ,	0.33
sum of both	

Q*ET/PT