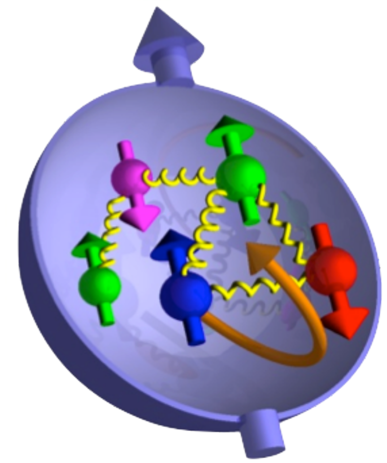
Probing Sea Quark and Gluon Polarization at STAR

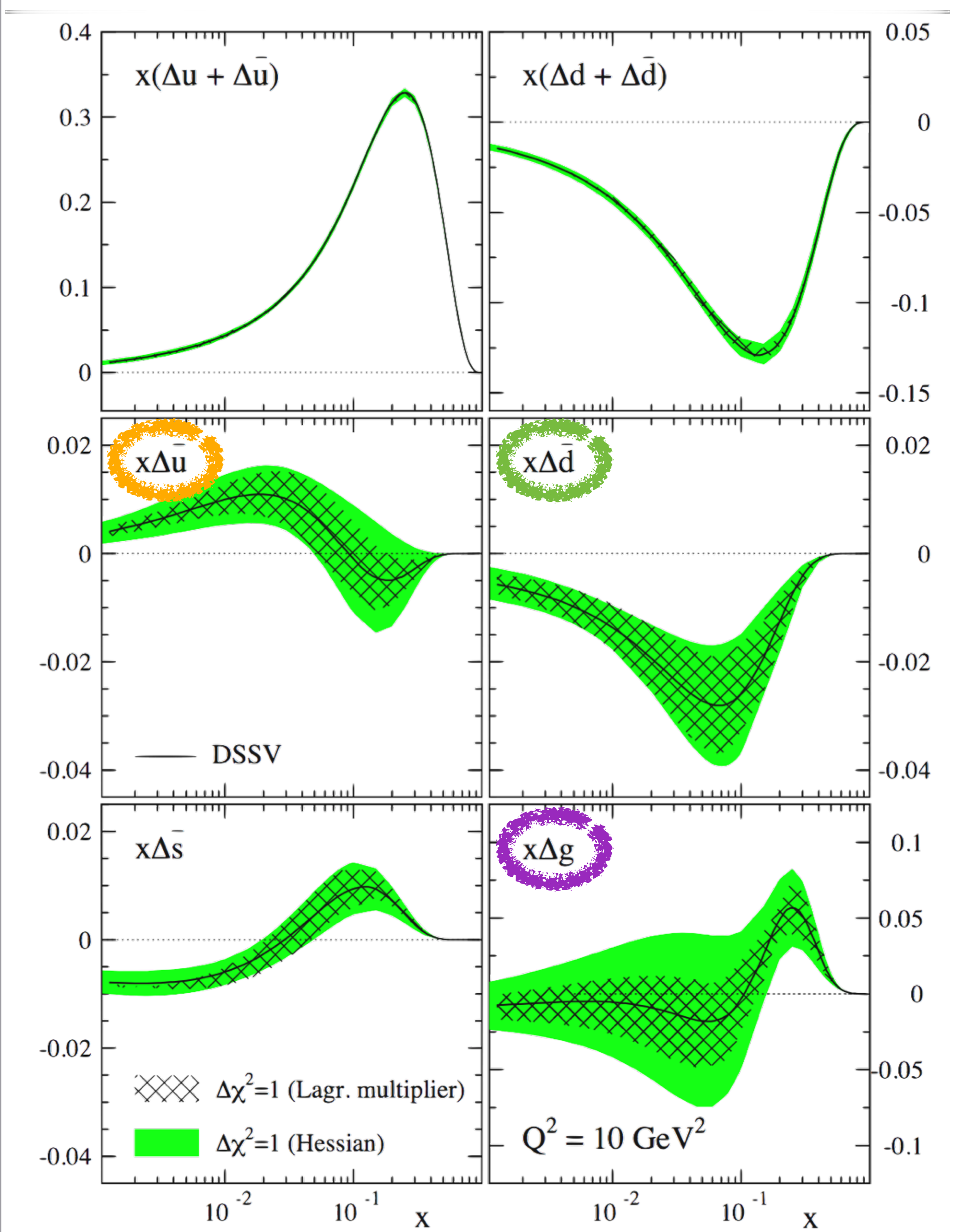
Justin Stevens (STAR Collaboration)

DIS 2014

Proton Spin Puzzle



DSSV Global Analysis



PRD **80**, 034030 (2009)

$$\langle S_p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

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

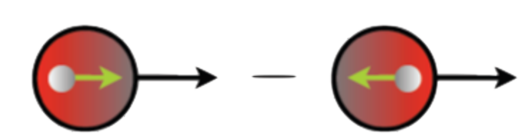
Integral of quark polarization is well measured in DIS to be ~30%, some info on decomposition from SIDIS but sea not well constrained

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

Indirectly constrained by DIS and a primary focus of the RHIC spin program

Helicity PDF

$\Delta f(x) =$

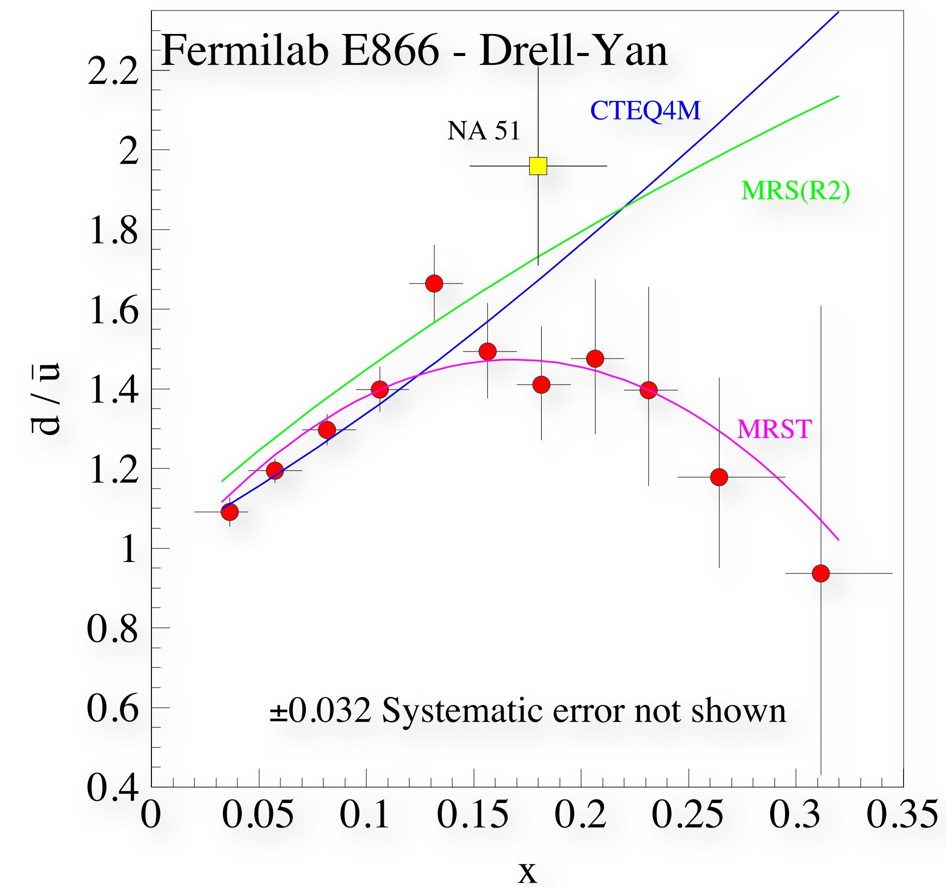


$f^+(x) - f^-(x)$

Flavor Asymmetry of the Sea

Unpolarized Flavor Asymmetry:

- Quantitative calculation of Pauli blocking does not explain $\bar{d}/\bar{u}$ ratio
- Non-perturbative processes may be needed in generating the sea
- E866 results are qualitatively consistent with pion cloud models, chiral quark soliton models, instanton models, etc.



PRD **64**, 052002 (2001)

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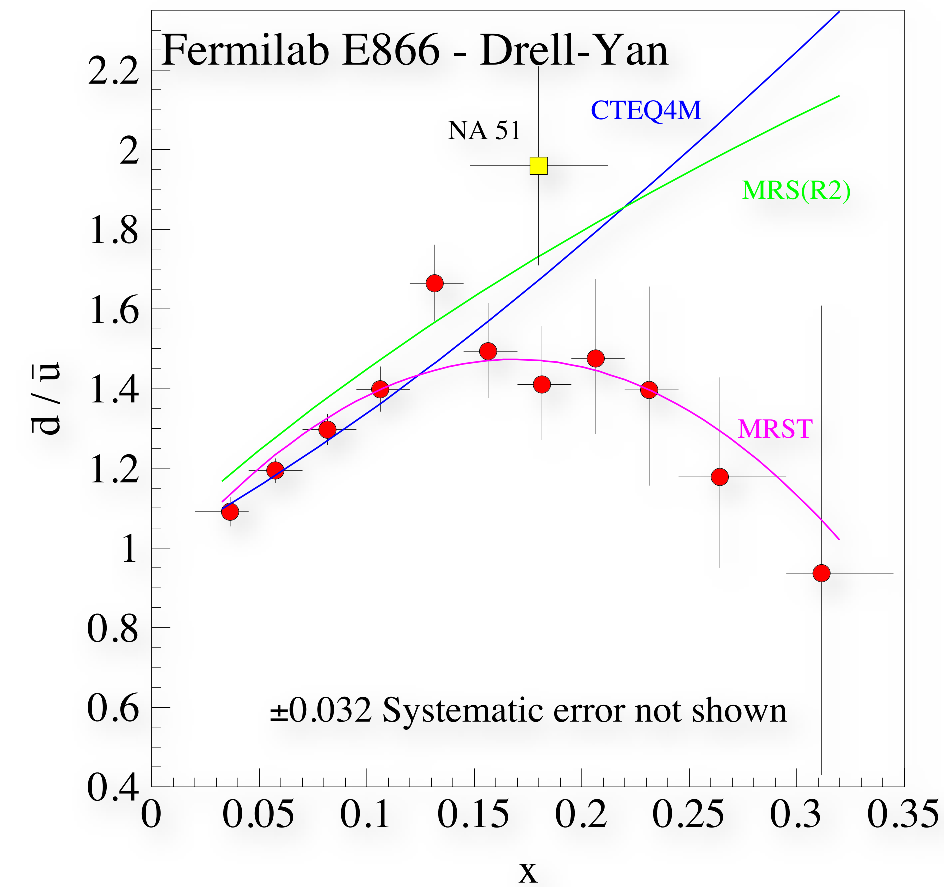
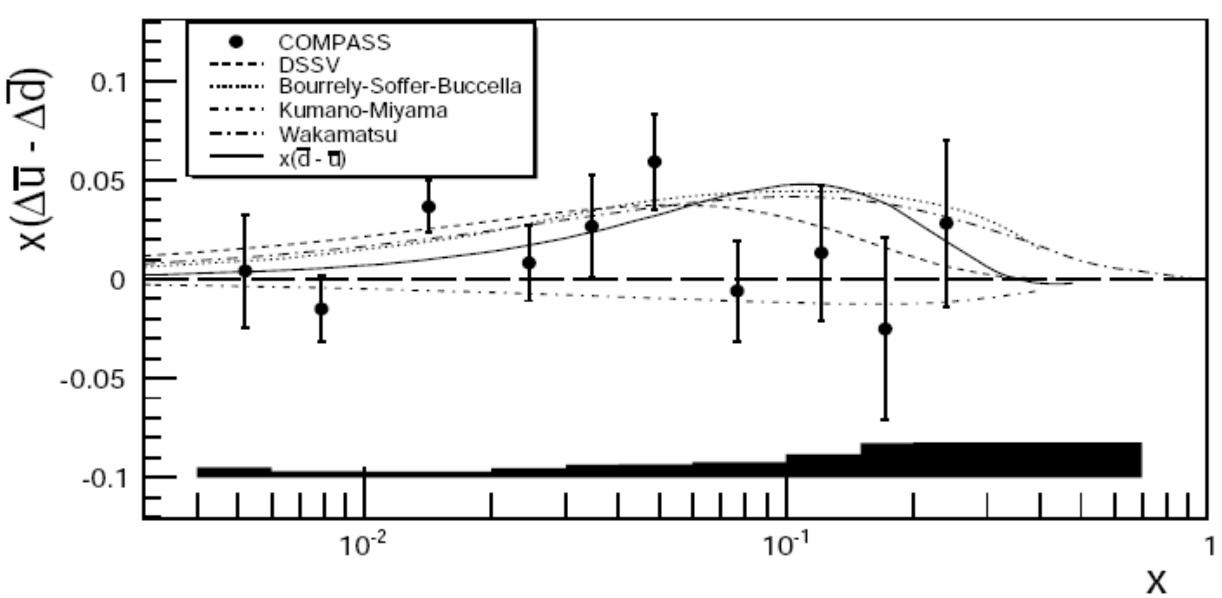


PRD **64**, 052002 (2001)



PLB **693**, 227 (2010)

Polarized Flavor Asymmetry:

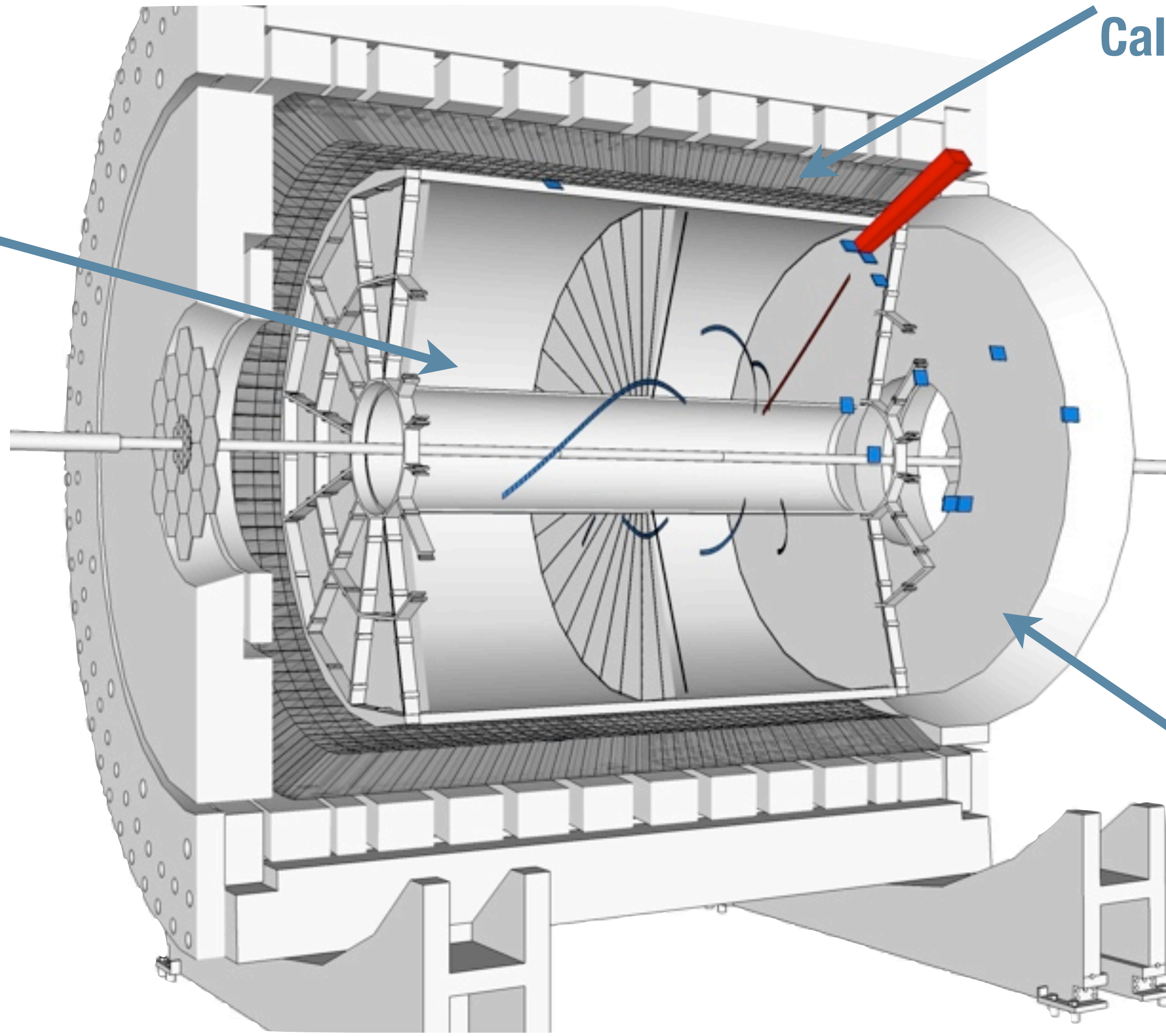
- Valence u and d distributions are well determined from DIS
- Polarized flavor asymmetry $x(\Delta\bar{u} - \Delta\bar{d})$ could help differentiate models
- SIDIS results depend on FFs

STAR Detector Overview

0.5 T Solenoidal Magnet

Triggering Barrel EM Calorimeter (BEMC): $|\eta|<1$

Time Projection Chamber (TPC): Charged particle tracking $|\eta|<1.4$

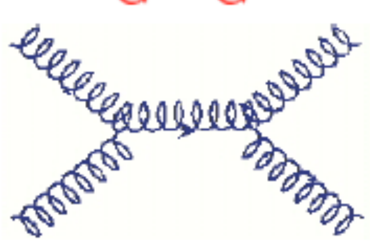


Triggering Endcap EM Calorimeter (EEMC): $1.1<\eta<2$

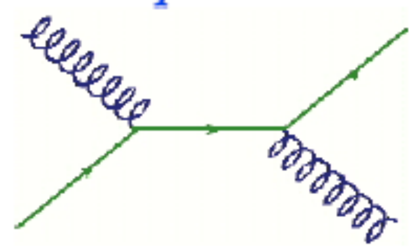
Gluon polarization at RHIC

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

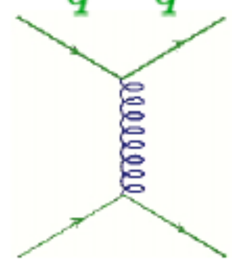
$\frac{\Delta G}{G} \frac{\Delta G}{G}$

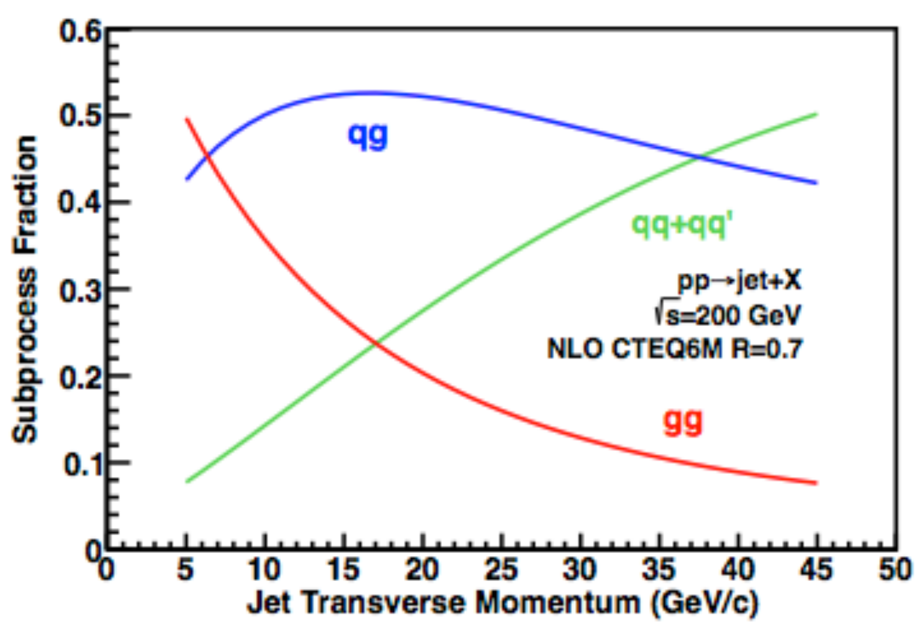


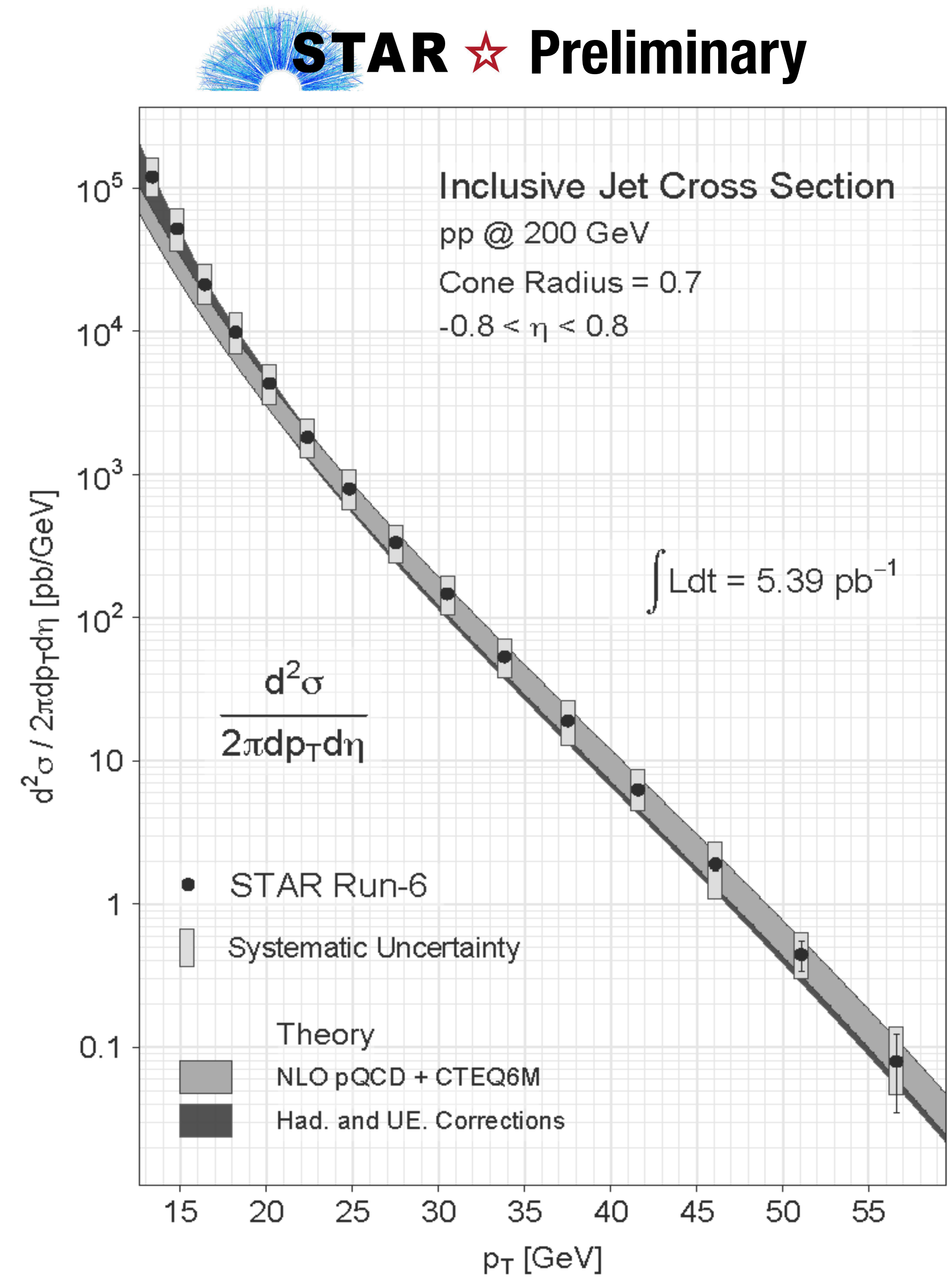
$\frac{\Delta q}{q} \frac{\Delta G}{G}$



$\frac{\Delta q}{q} \frac{\Delta q}{q}$

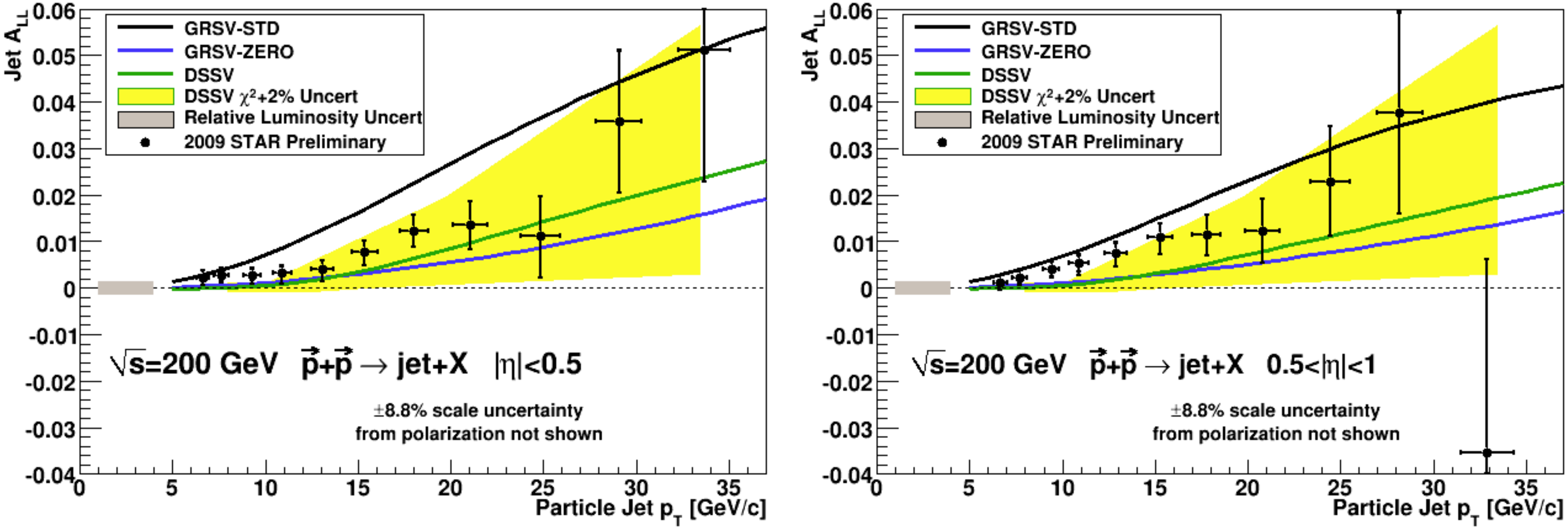






- For most of the RHIC kinematics, **qg** and **gg** dominate, making A_{LL} for inclusive probes (jets, π^0s, etc) sensitive to gluon polarization
- Jet cross sections at RHIC well described by NLO pQCD calculations

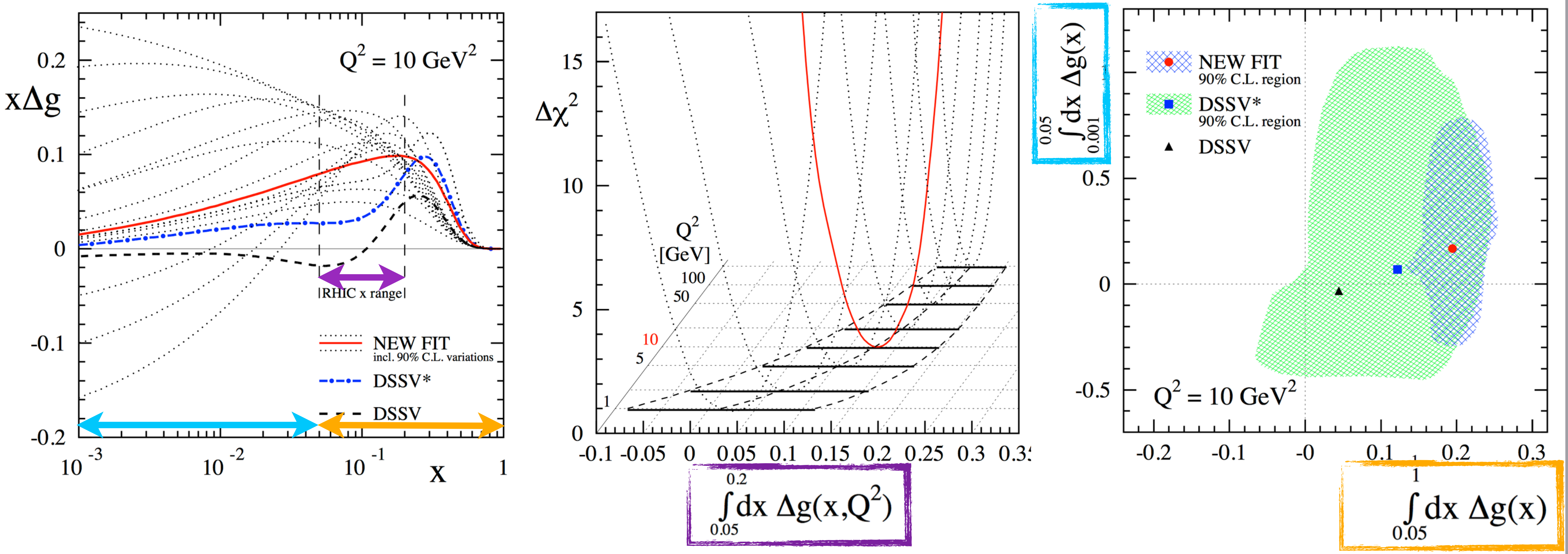
STAR Inclusive Jet A_{LL}



- Statistics from 2009 sufficient to bin in η
- Inclusive jet A_{LL} falls between DSSV and GRSV-STD
- What have we learned about Δg(x)?

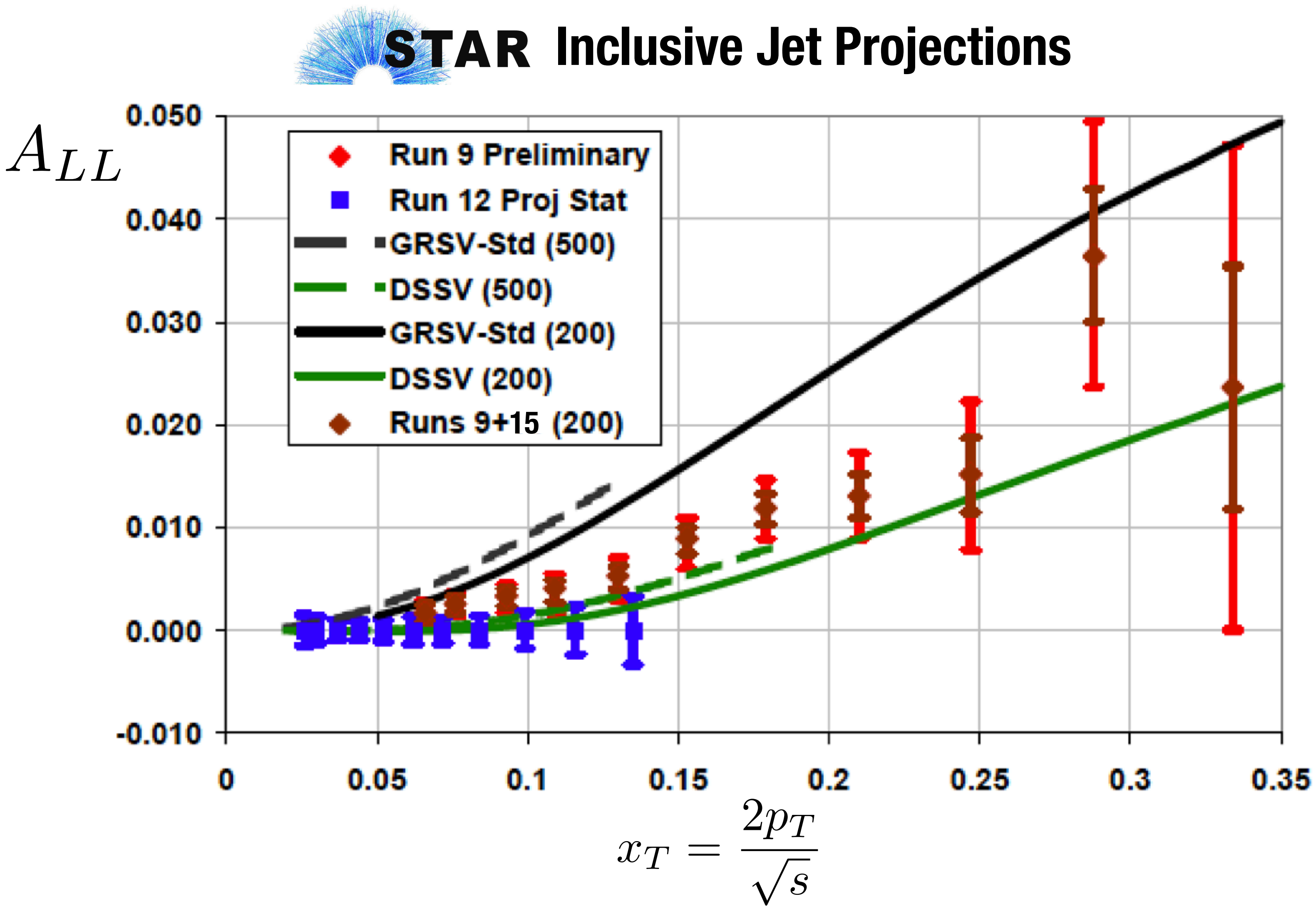
Gluon polarization in global fits

New DSSV Fit: arXiv:1404.4293



- DSSV has a new, global analysis which includes 2009 PHENIX and STAR A_{LL} data
- First experimental evidence of non-zero gluon polarization in the RHIC range (**0.05 < x < 0.2**)
- Consistent with results from NNPDF group (see talk by E. Nocera this afternoon)

Inclusive jet projections

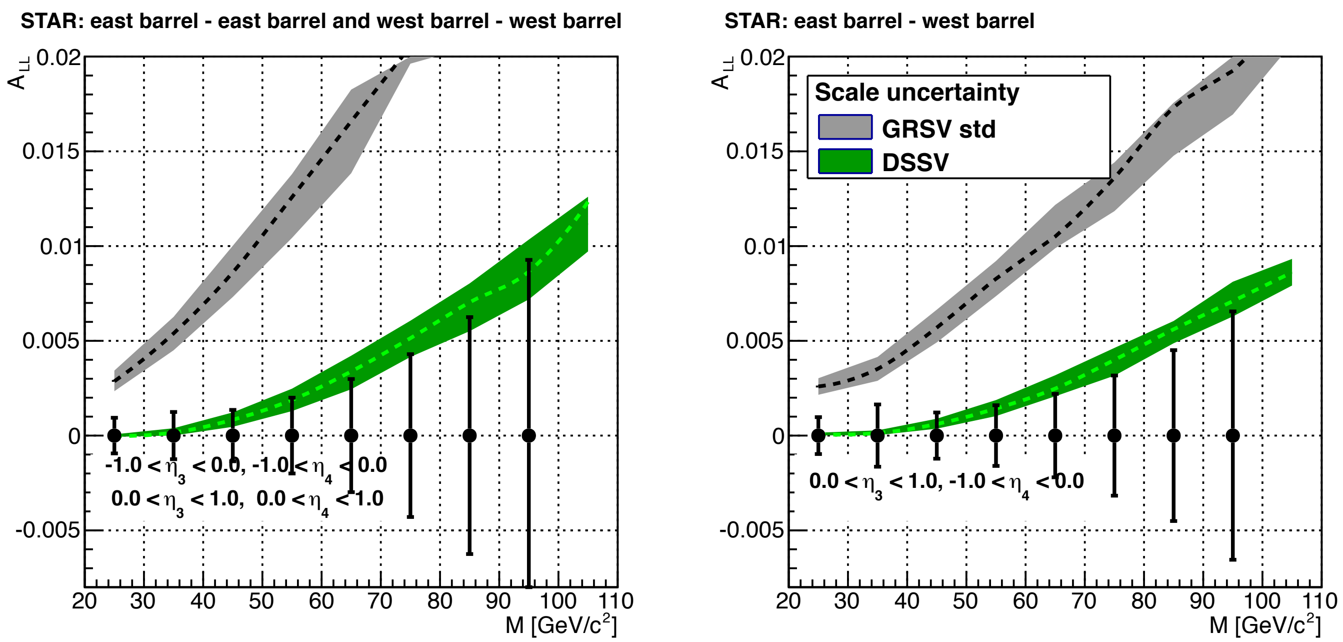


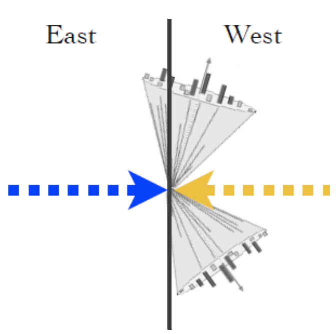
- Significant improvement in statistical precision with data collected in 2011-2013 and expected in 2015
- Expect to reduce uncertainties on Δg by a factor of ~2

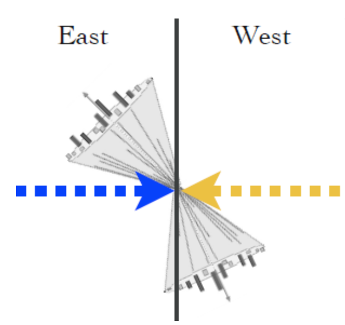
Gluon polarization: low-x_g

- Higher $\sqrt{s}$ and forward rapidities probe the low-x_g region
- Correlated probes are sensitive to the x dependence of Δg
- 2011-2013 collected large dataset at $\sqrt{s}$ = 500 GeV

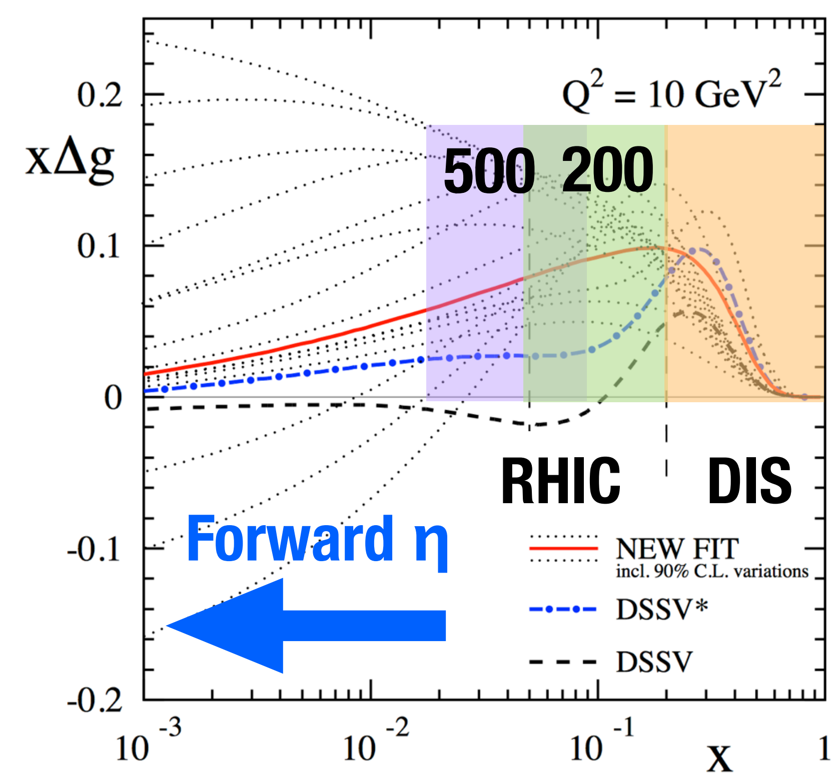
STAR Di-jet Projection







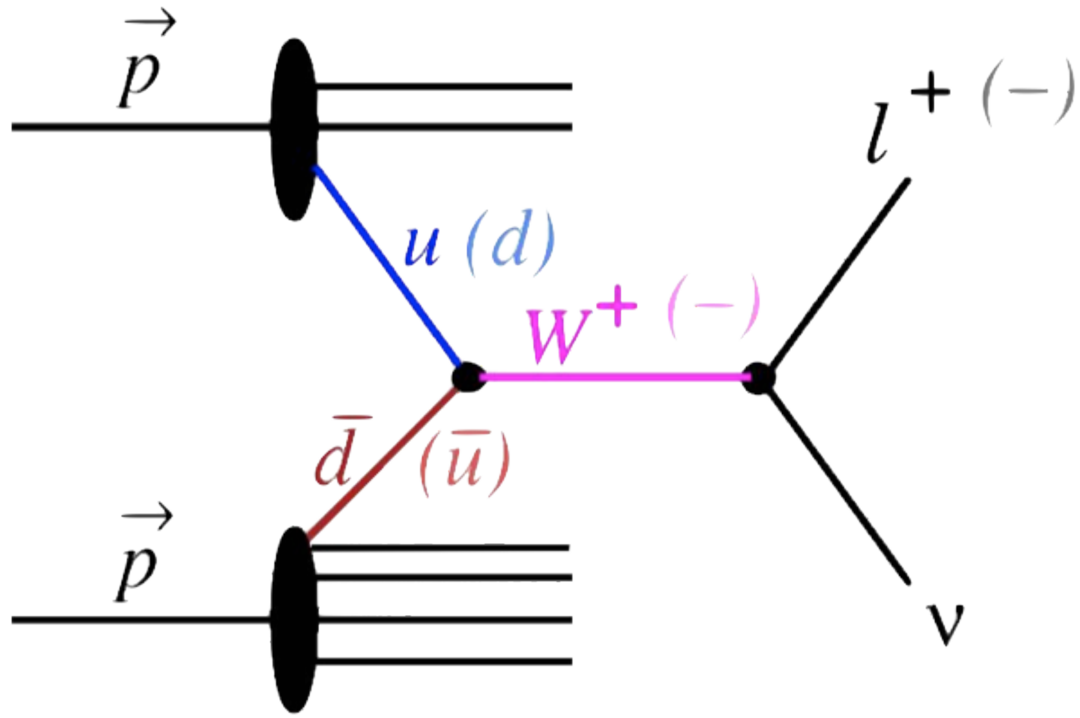
$$x_1, x_2 = \frac{M}{\sqrt{s}} \exp\left(\pm\frac{\eta_3 + \eta_4}{2}\right)$$



Talk by B. Surrow Thursday in WG6+WG7 joint session

Probing sea quark polarization through W production

Why Ws?



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

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

- Ws couple directly to the quarks and antiquarks of interest
- Detect Ws through e+/e- decay channels
- V-A coupling of the weak interaction leads to perfect spin separation

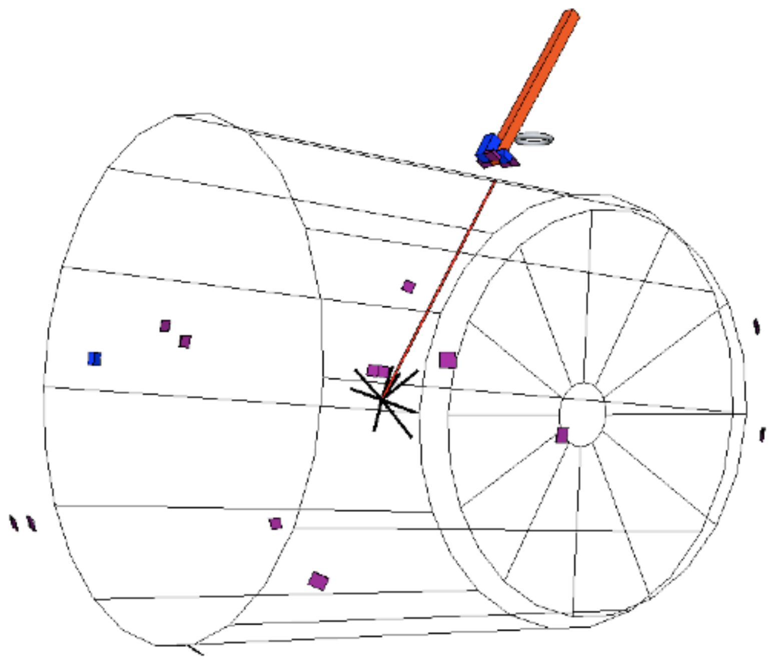
Measure parity-violating single-spin asymmetry:

(Helicity flip in one beam while averaging over the other)

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

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

What do W decays look like?



W → e + ν Candidate Event

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

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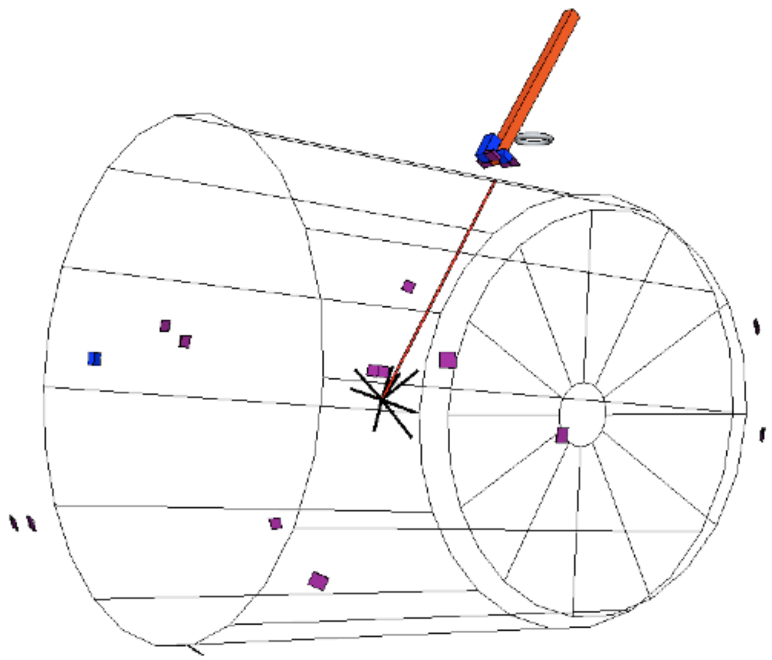
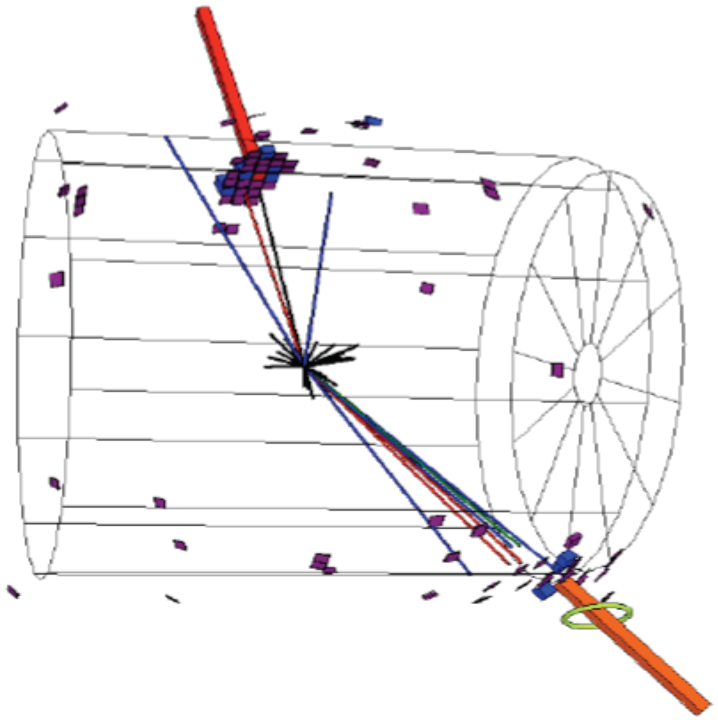


$W \rightarrow e + \nu$ Candidate Event

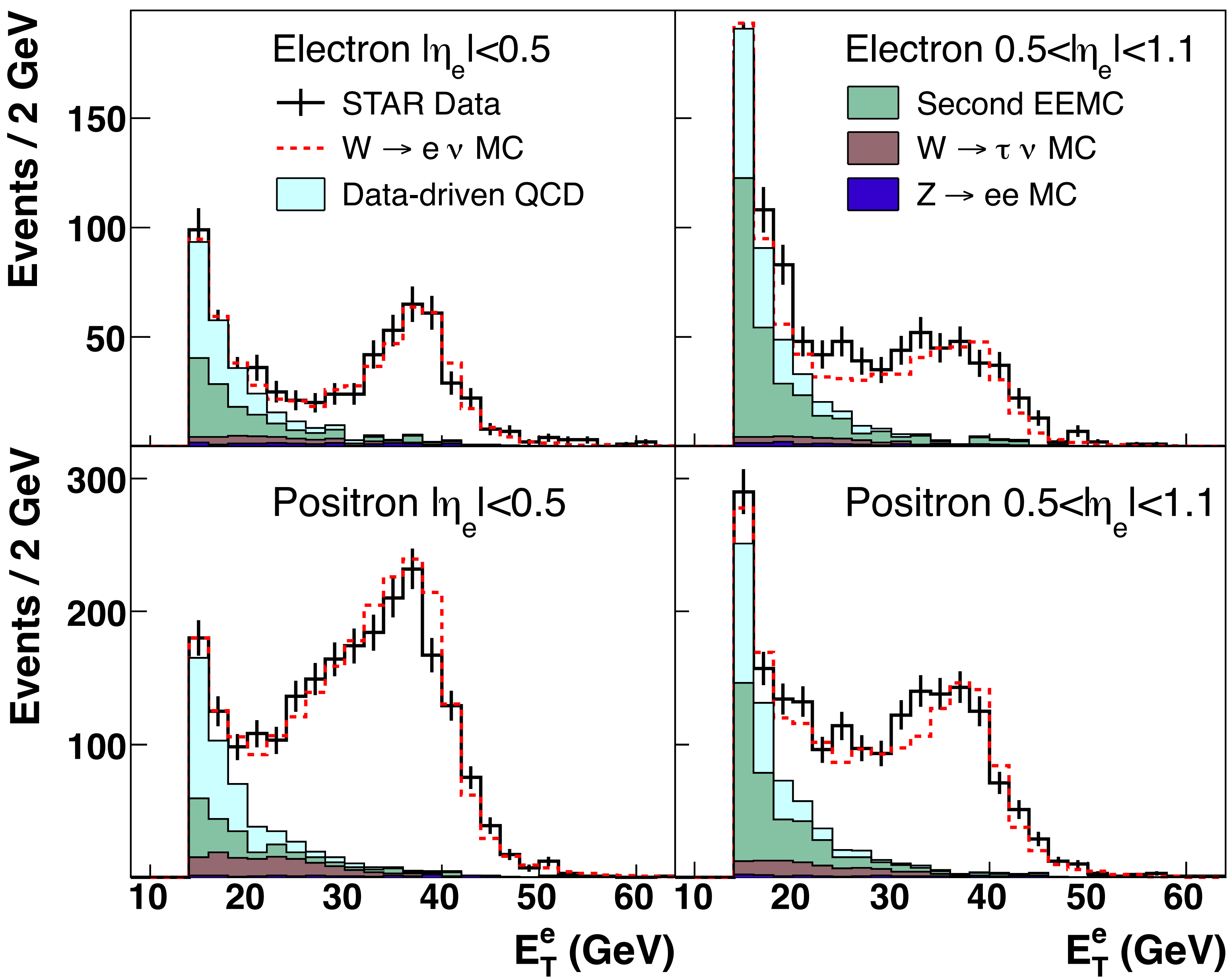
- Isolated track pointed to isolated EM cluster in calorimeter
- Large "missing energy" opposite the electron candidate

Di-jet Background Event

- Several tracks pointing to EM energy deposit in several towers
- Vector p_T sum is balanced by opposite jet, "missing energy" is small



Mid-rapidity background estimation



W Signal

- "Jacobian Peak"

Electroweak

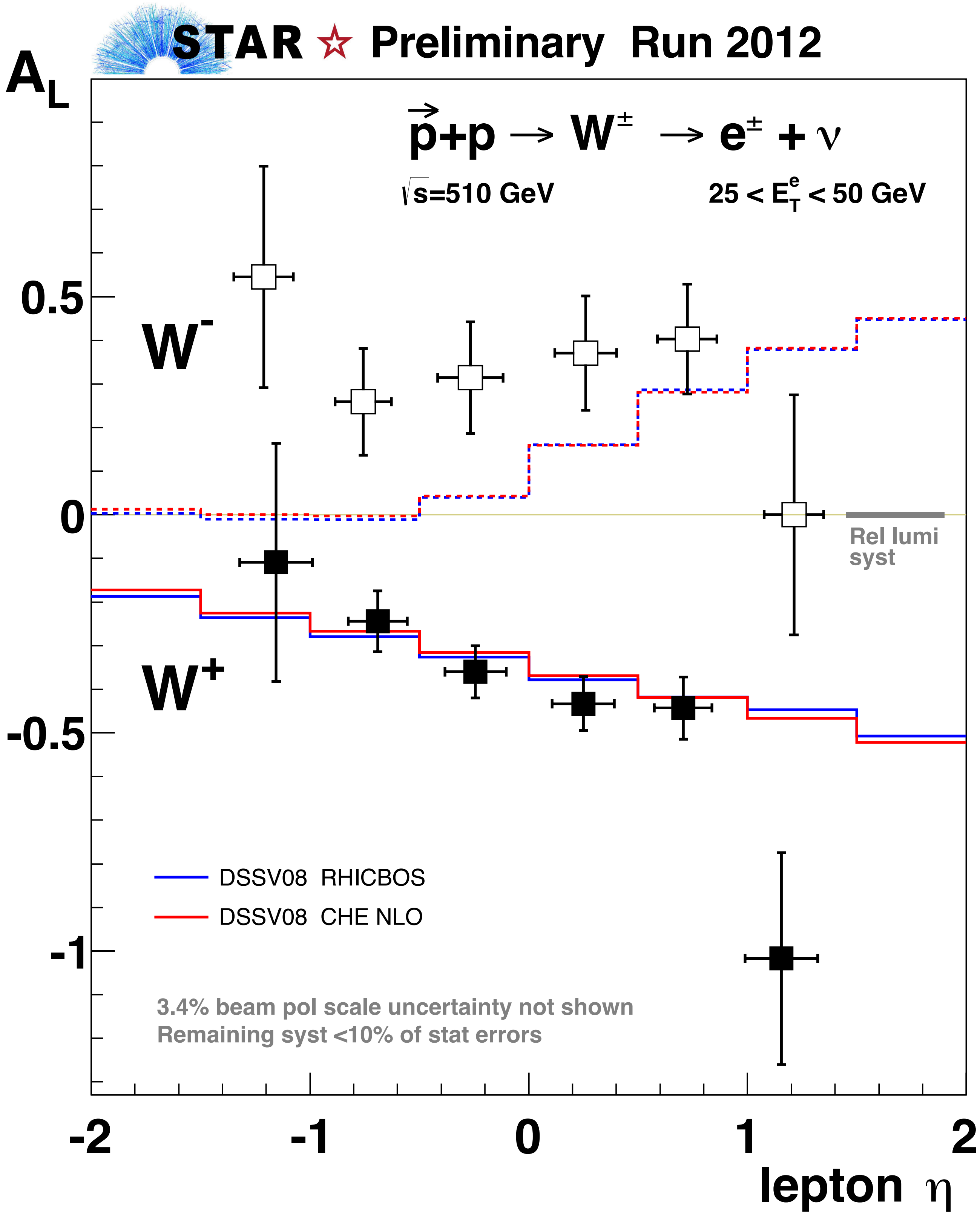
- $Z \rightarrow ee$ MC
- $W \rightarrow \tau\nu$ MC

QCD Background

- Second EEMC
- Data-driven QCD

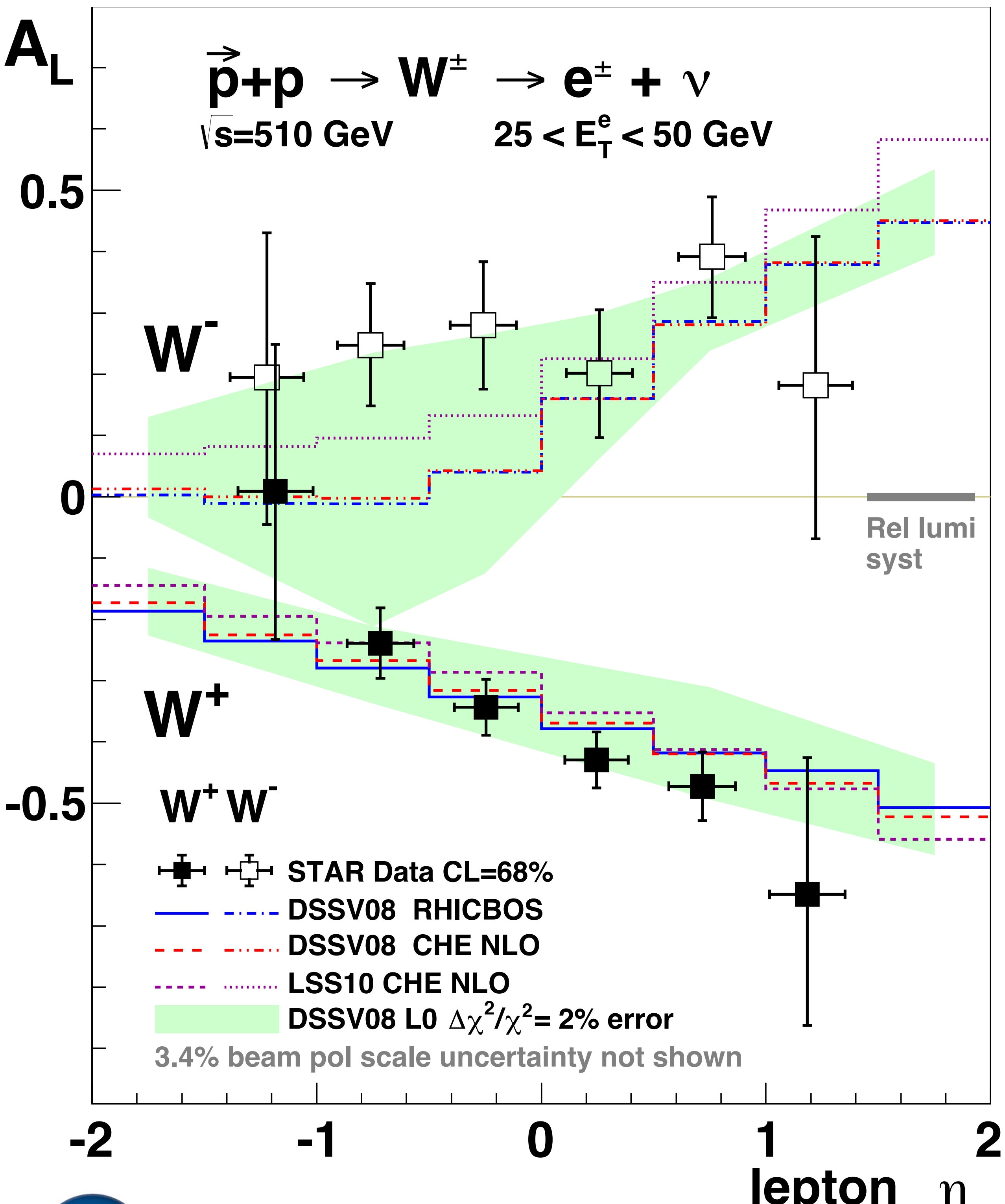
NEW arXiv:1404.6880

STAR W $A_L(\eta)$



- $A_L(W+)$ is consistent with the theoretical predictions constrained by polarized SIDIS data
- $A_L(W-)$ is larger than the predictions for $\eta_e<0$, which is particularly sensitive to $\Delta\bar{u}$
- What have we learned about sea quark polarization?

STAR W $A_L(\eta)$



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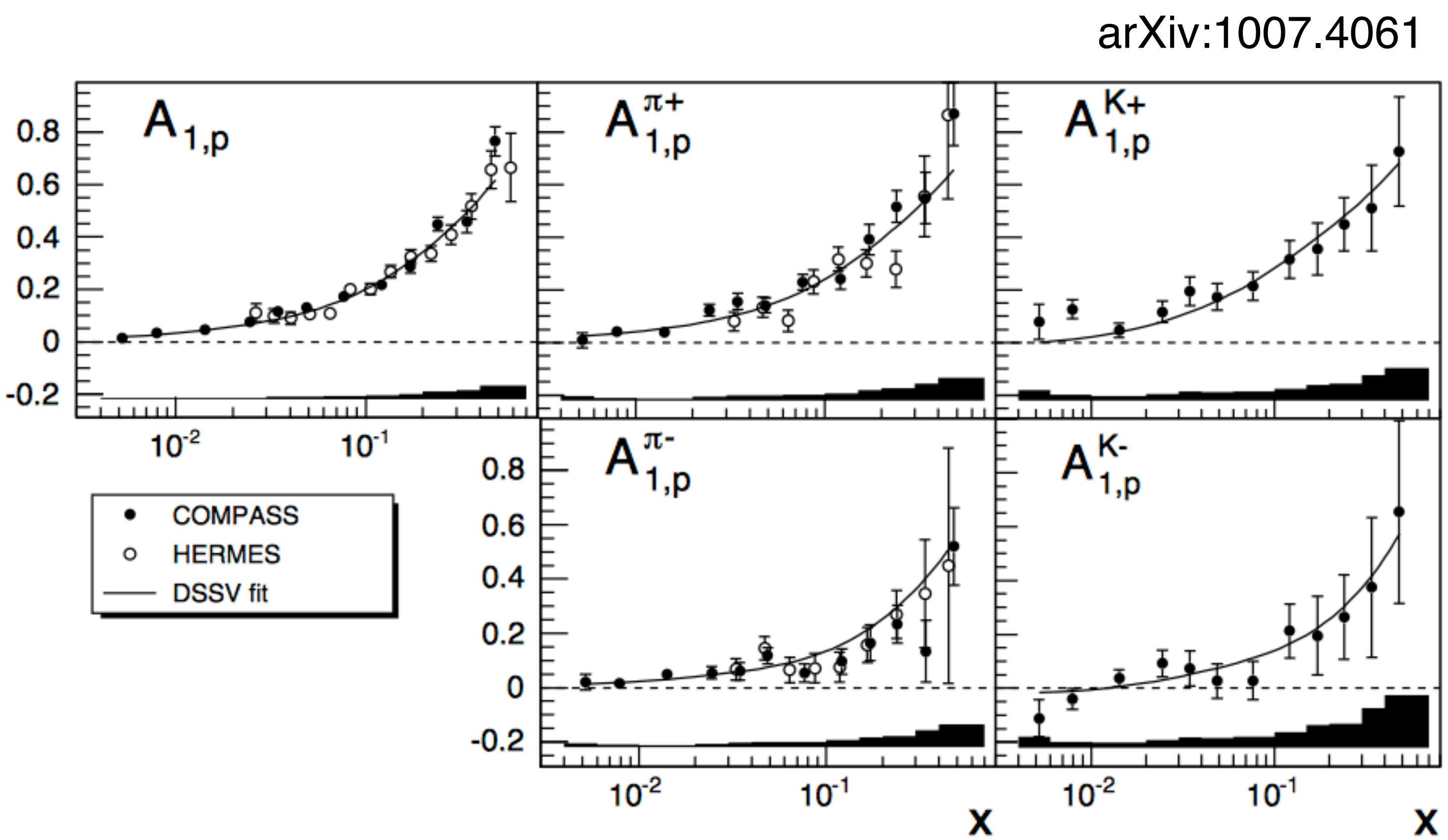
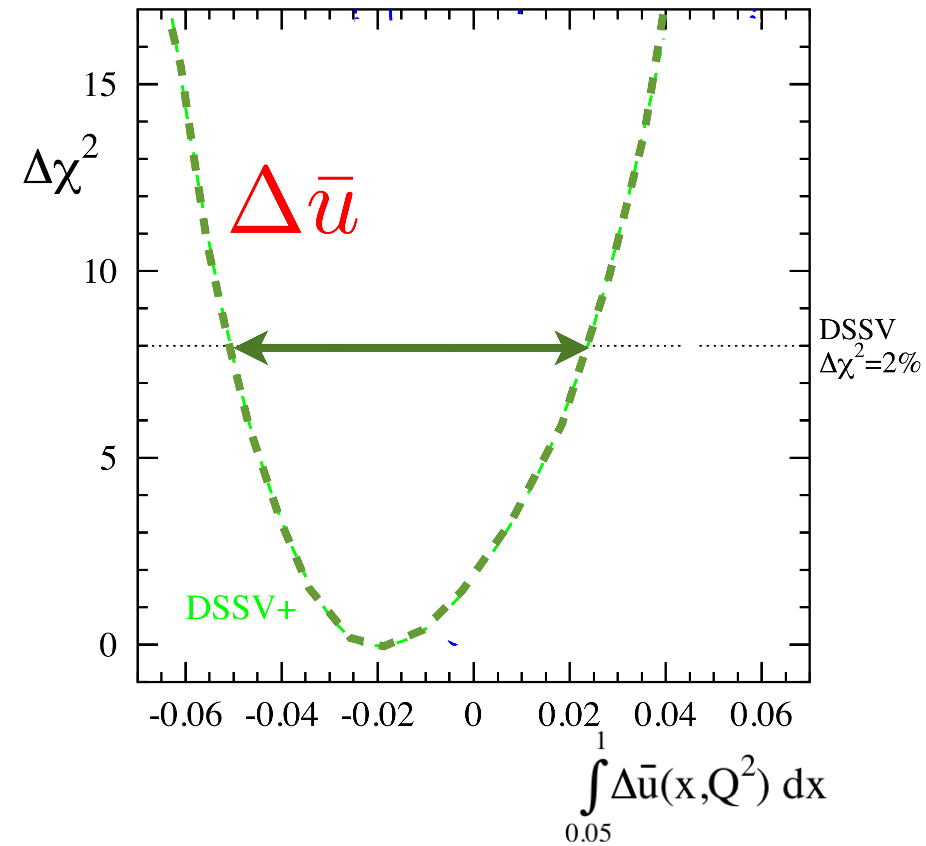
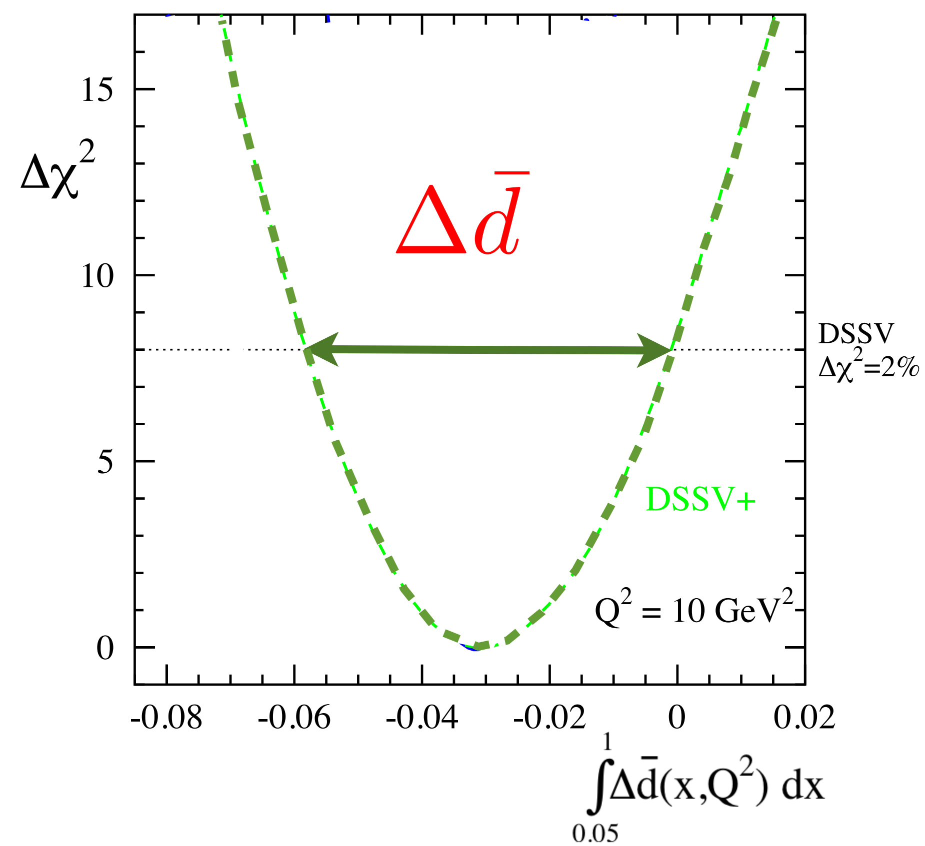
Sea quark polarization in global fits

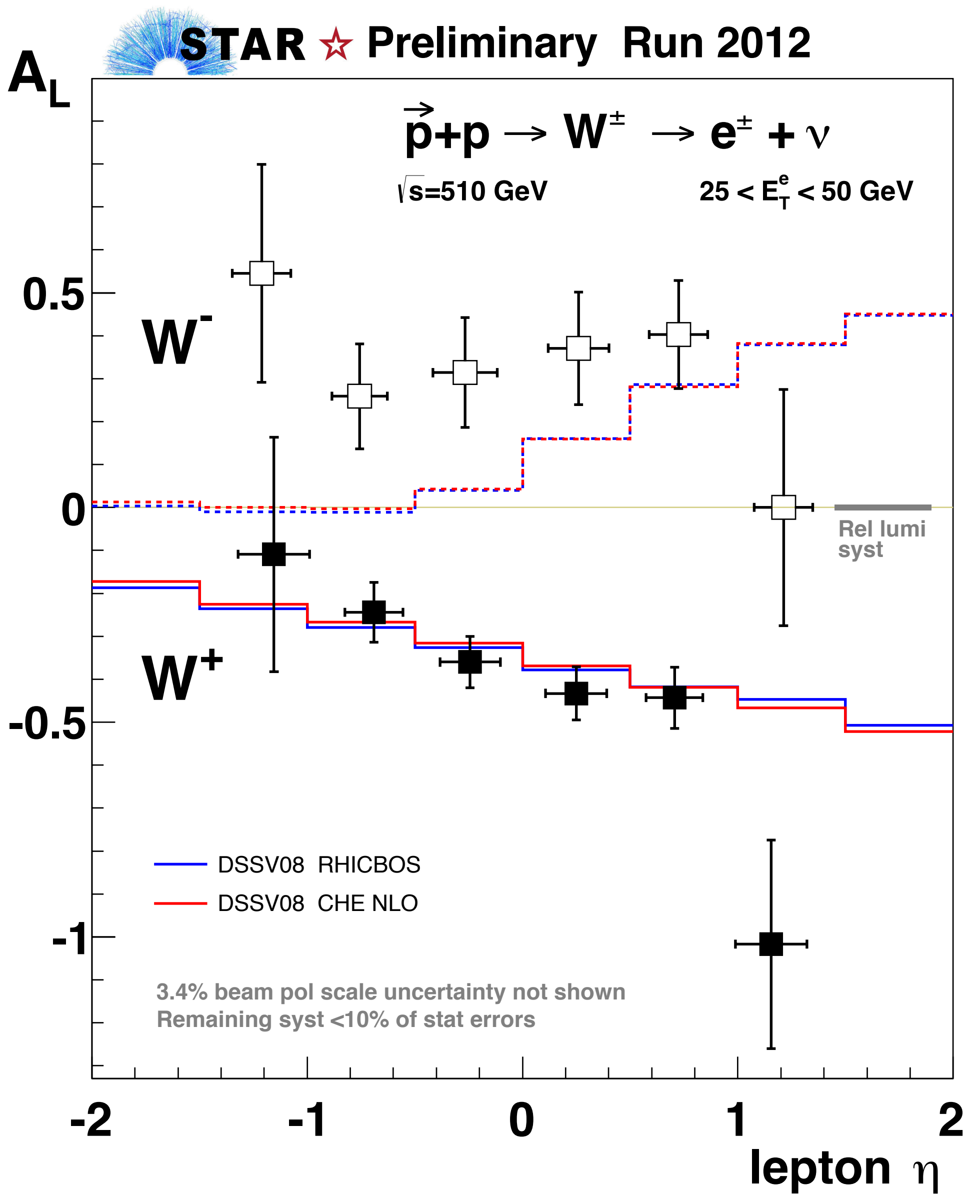


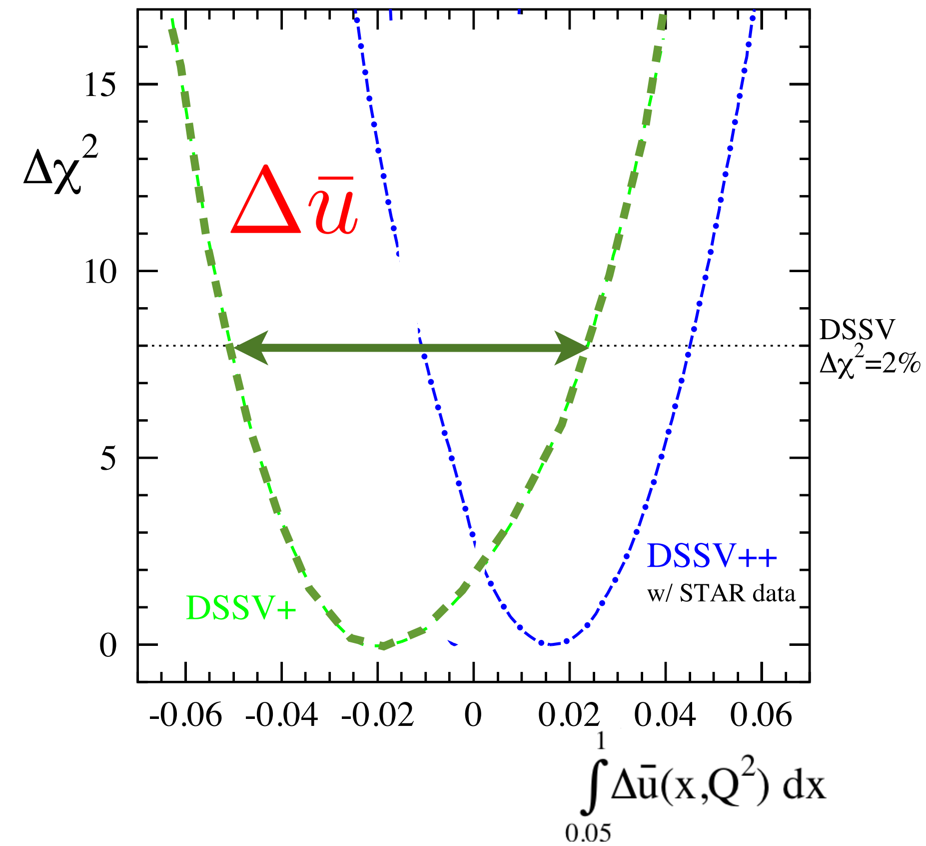


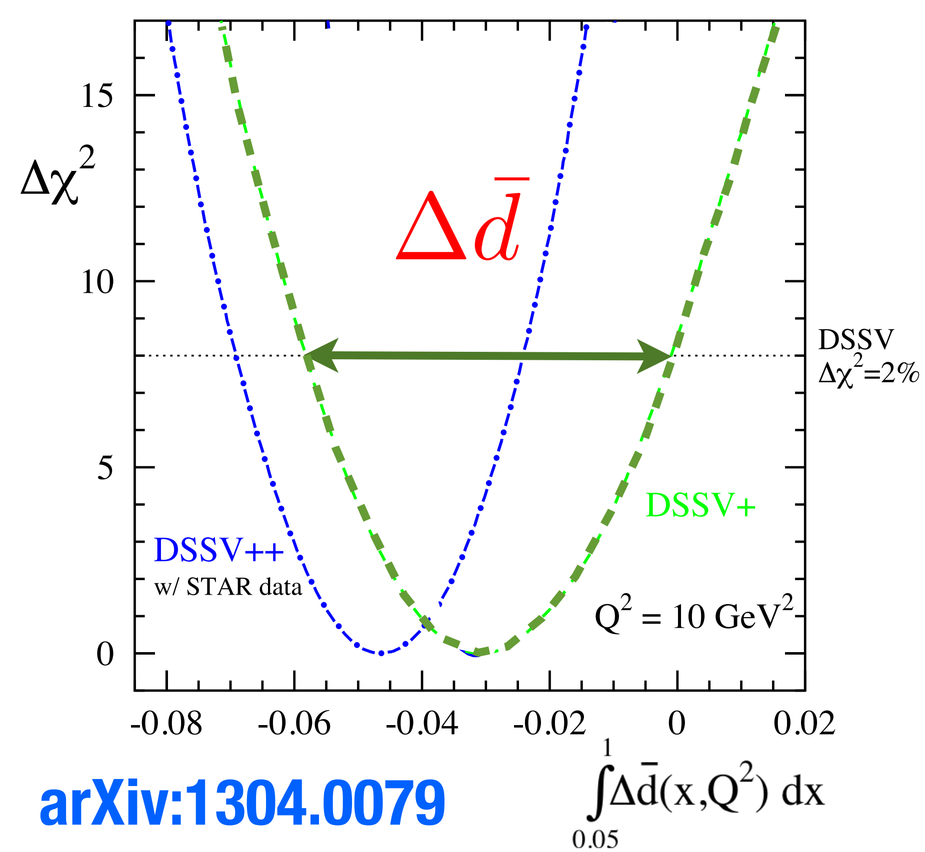


- **DSSV+** (arXiv:1108.3955) includes higher precision DIS and SIDIS data from COMPASS compared to DSSV08

Sea quark polarization in global fits



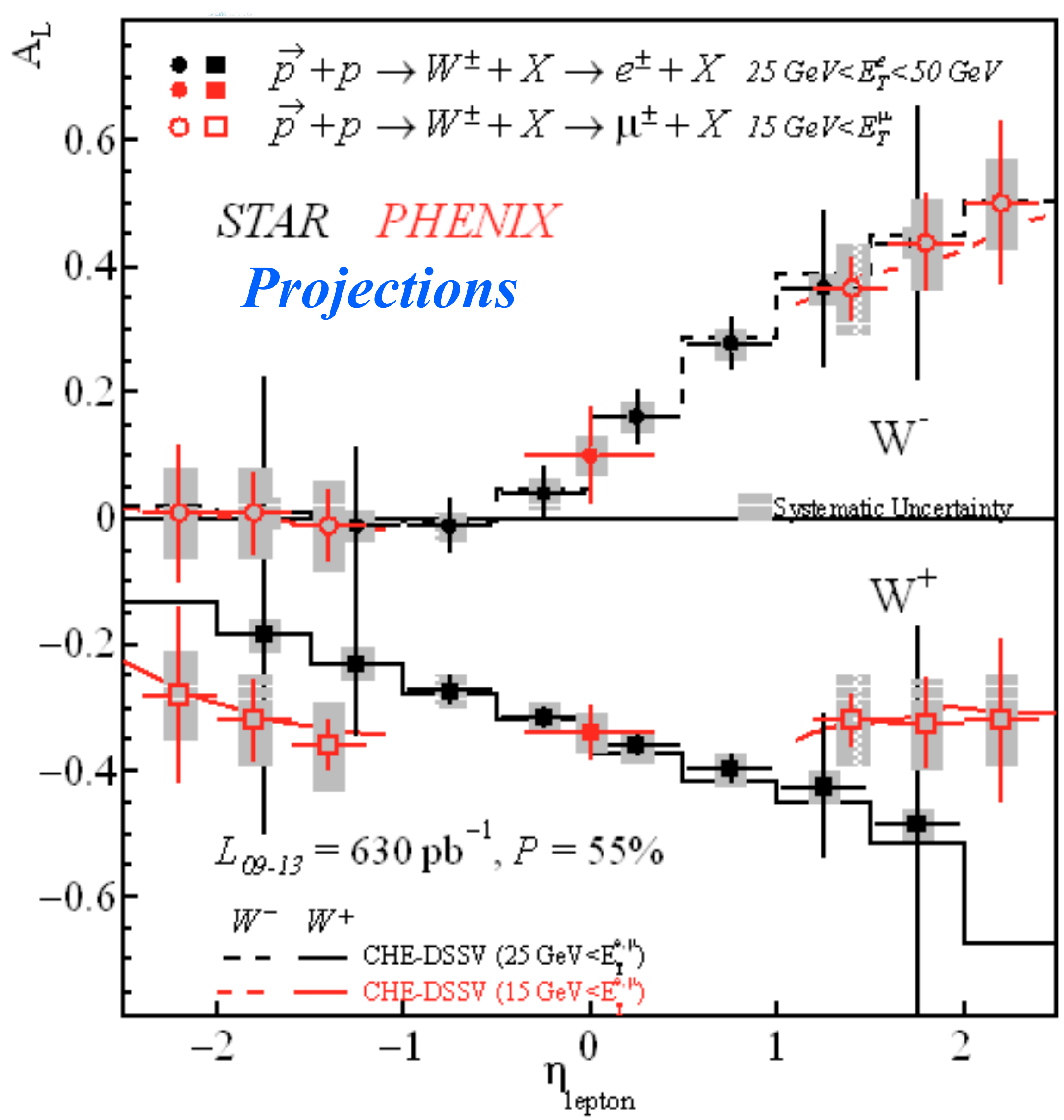


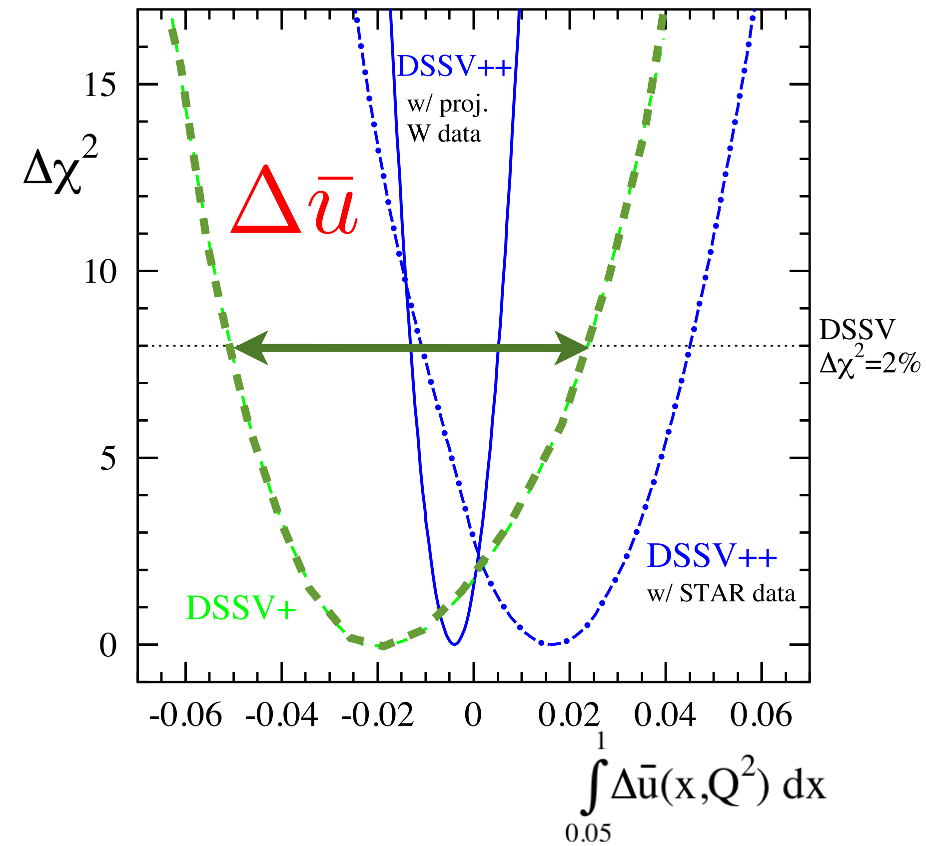


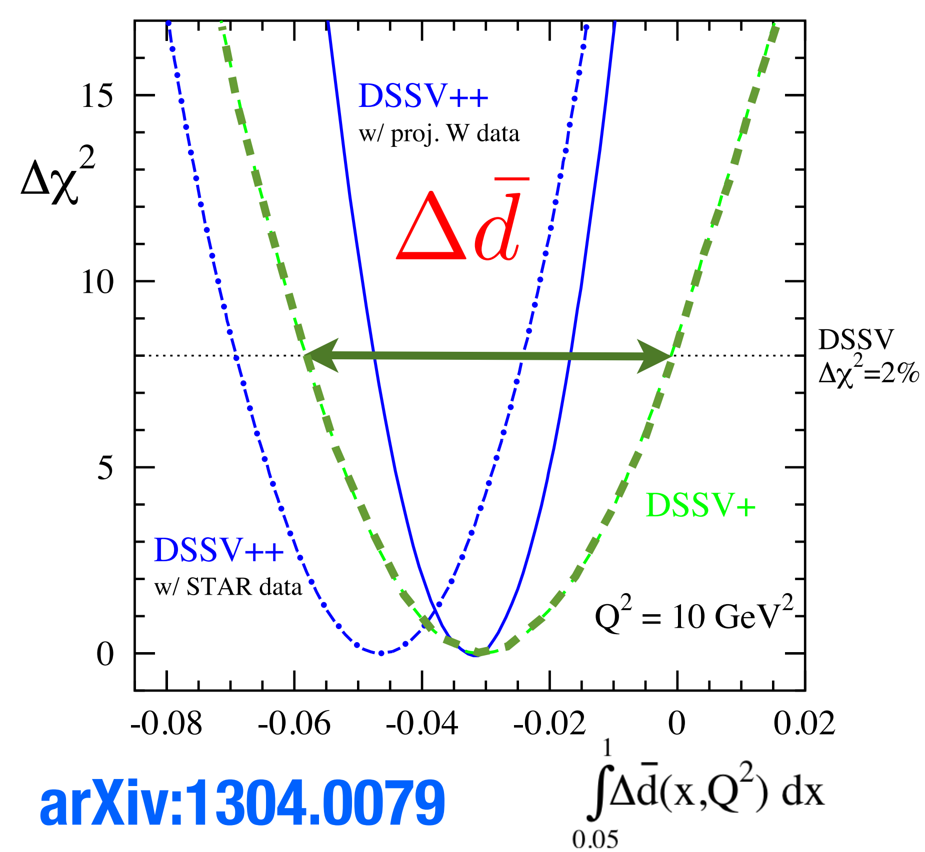
- **DSSV++** is a new, preliminary global analysis from the DSSV group which includes 2012 STAR W A_L
- Higher precision data already collected in 2013 will further improve the constraints on the sea quark polarization

arXiv:1304.0079

Sea quark polarization in global fits







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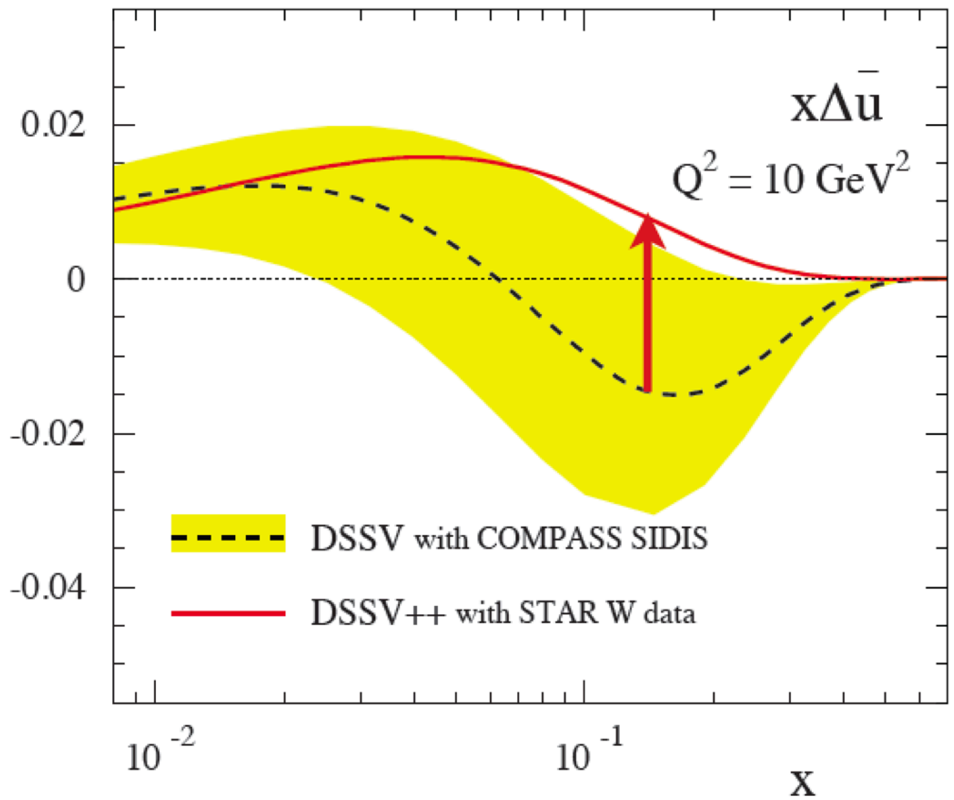
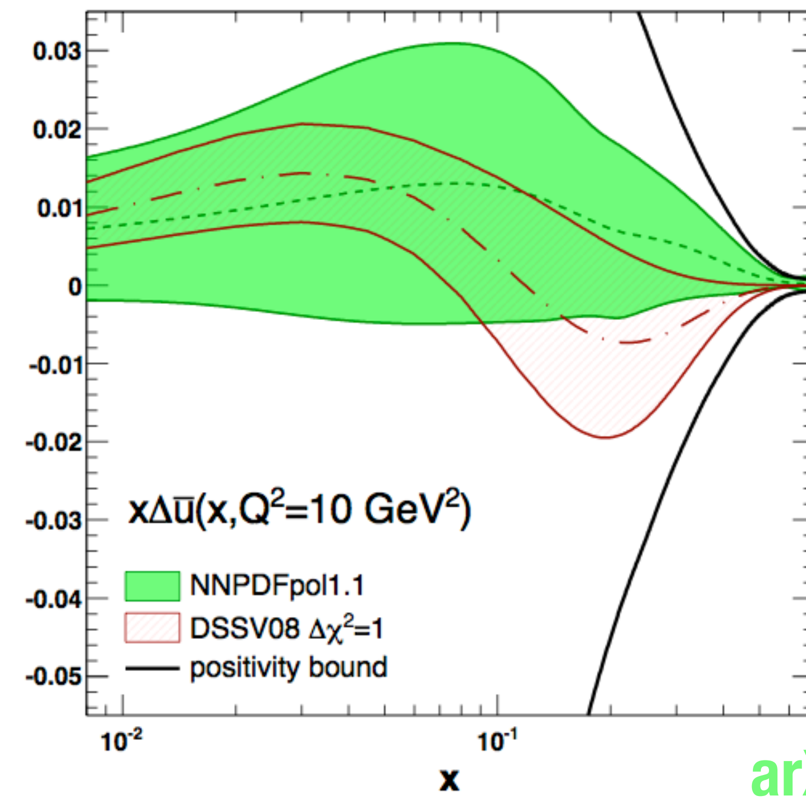
Sea quark polarization

DSSV++ (prelim.)

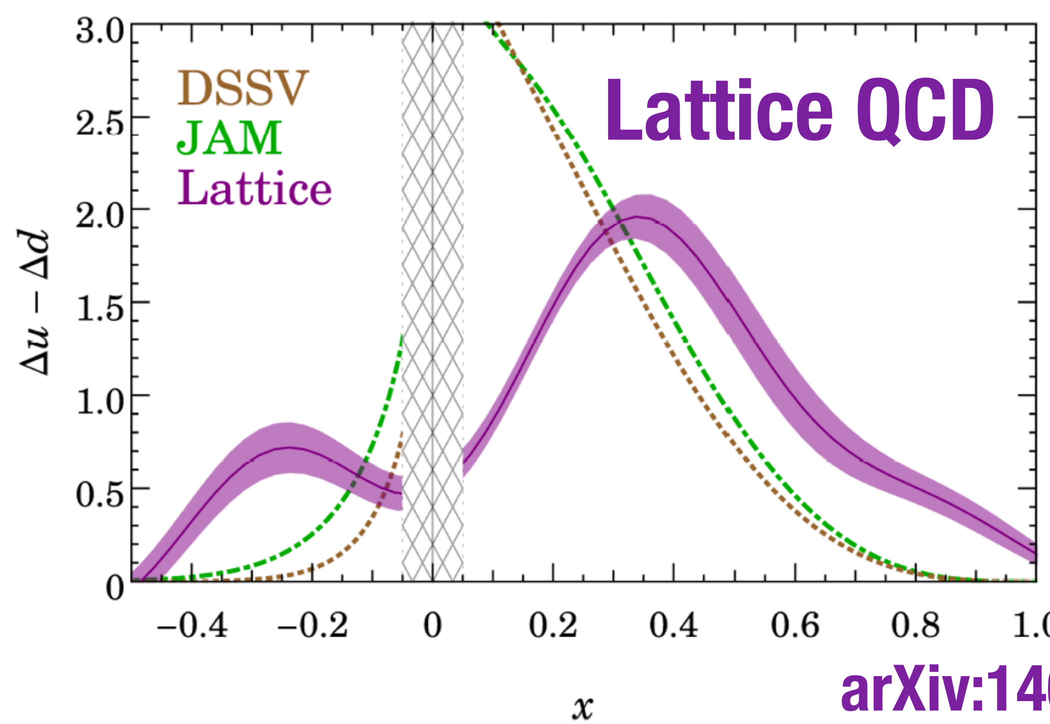


NNPDFpol1.1



arXiv:1403.0440

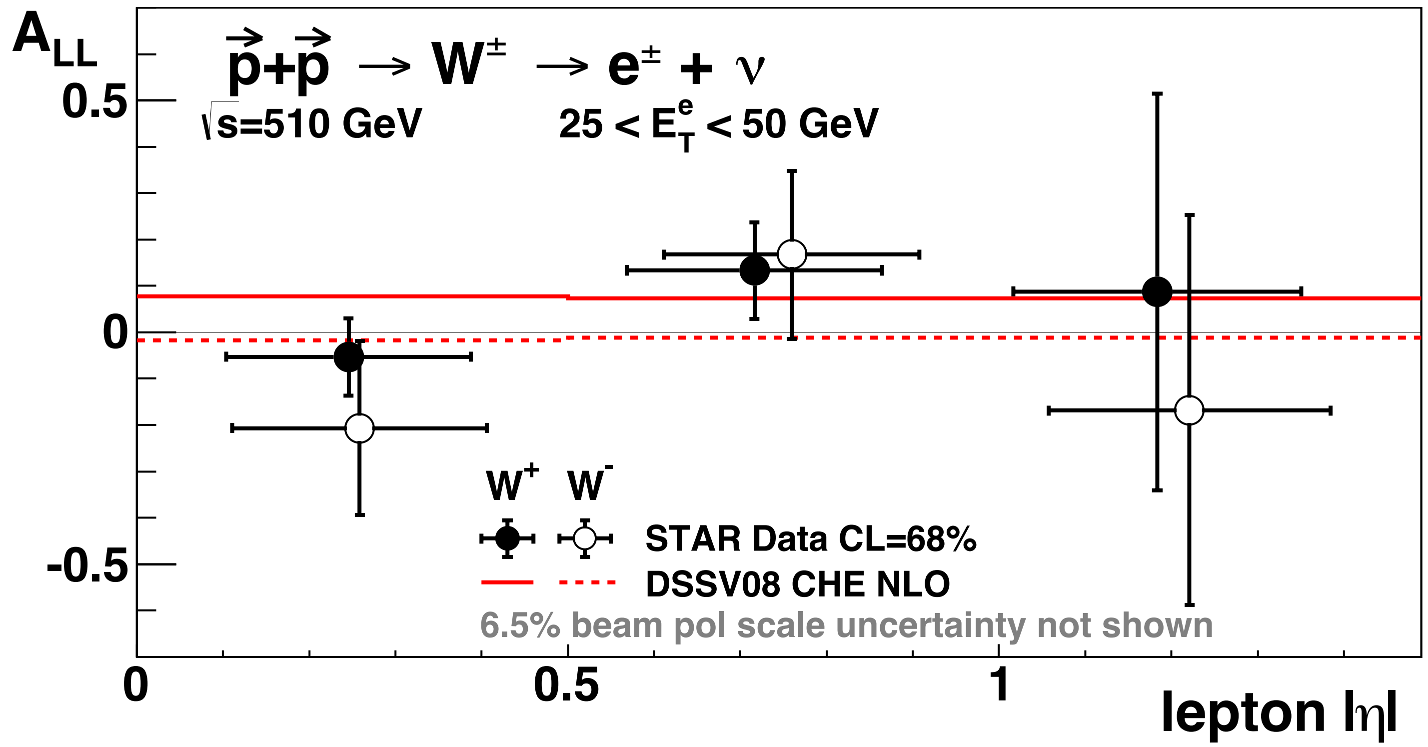
- Lots of recent progress!
- Preliminary STAR data included in fits by **DSSV** and **NNPDF** (talk by E. Nocera)
- Even first attempts to calculate flavor asymmetry in **lattice QCD**



arXiv:1402.1462

STAR W A_{LL}

NEW arXiv:1404.6880

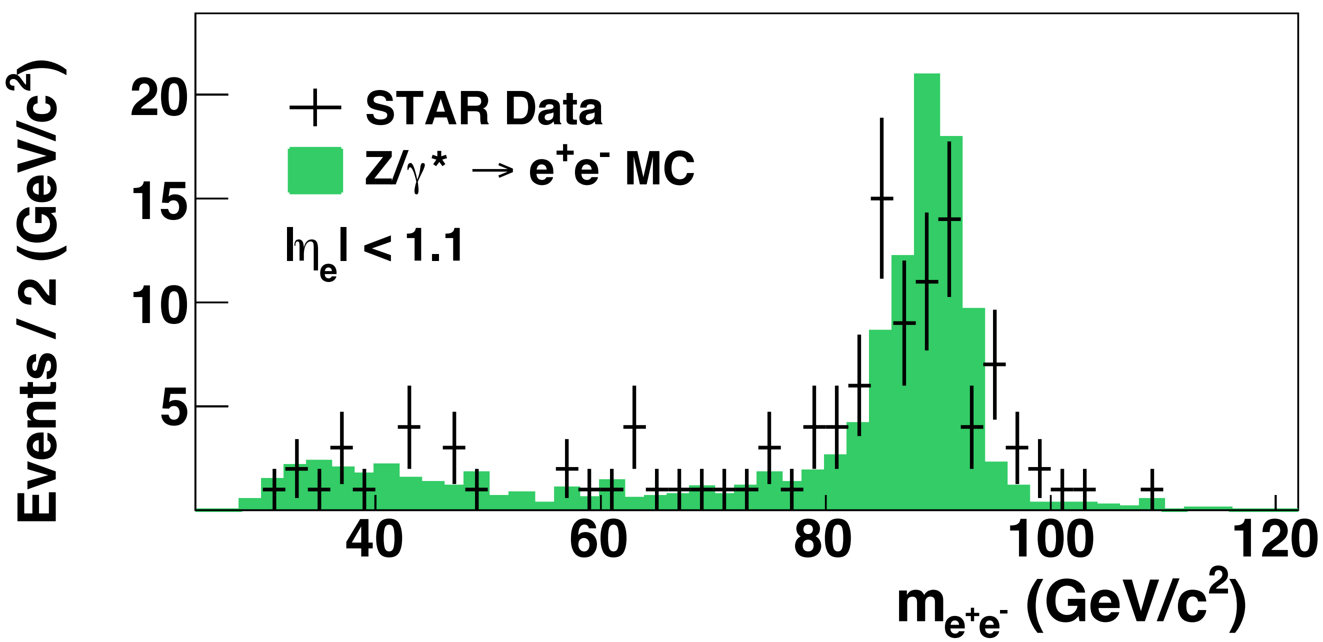


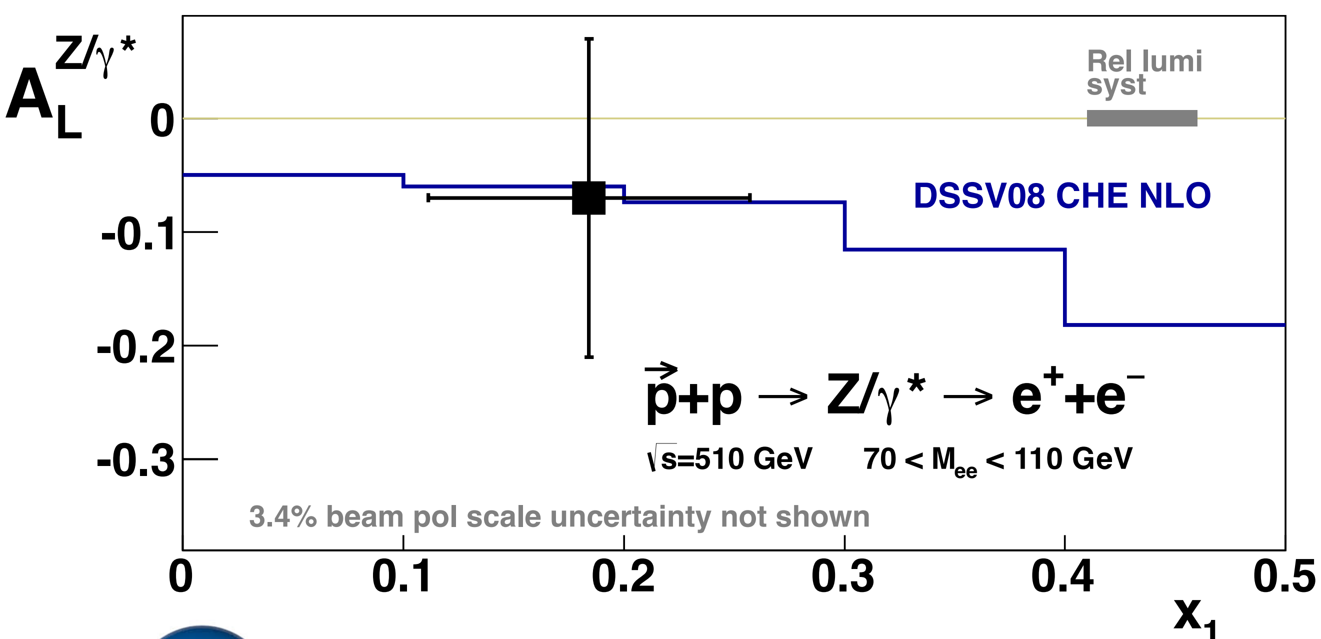
- Probes different combination of quark polarizations

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

- Asymmetries expected to be smaller, and first measurement consistent with predictions from DSSV

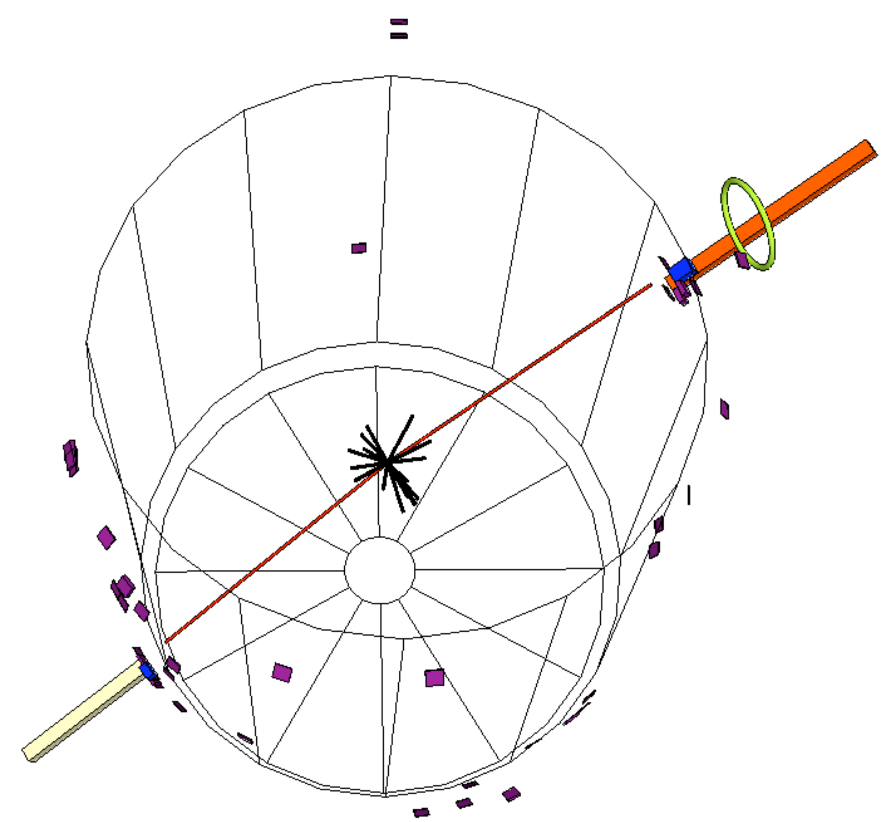
STAR Z A_L





NEW **arXiv:1404.6880**

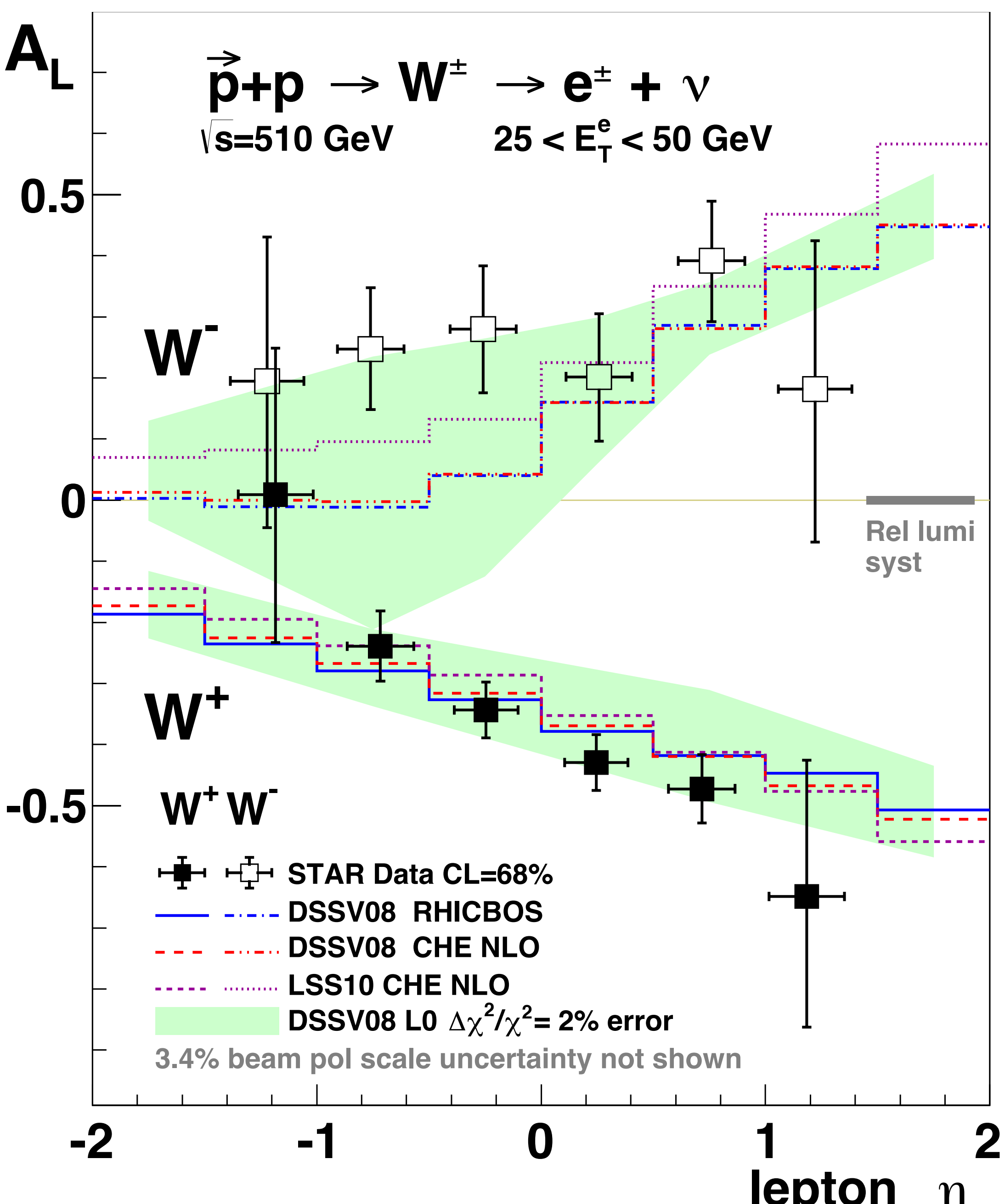
$Z \rightarrow e^+e^-$ Candidate



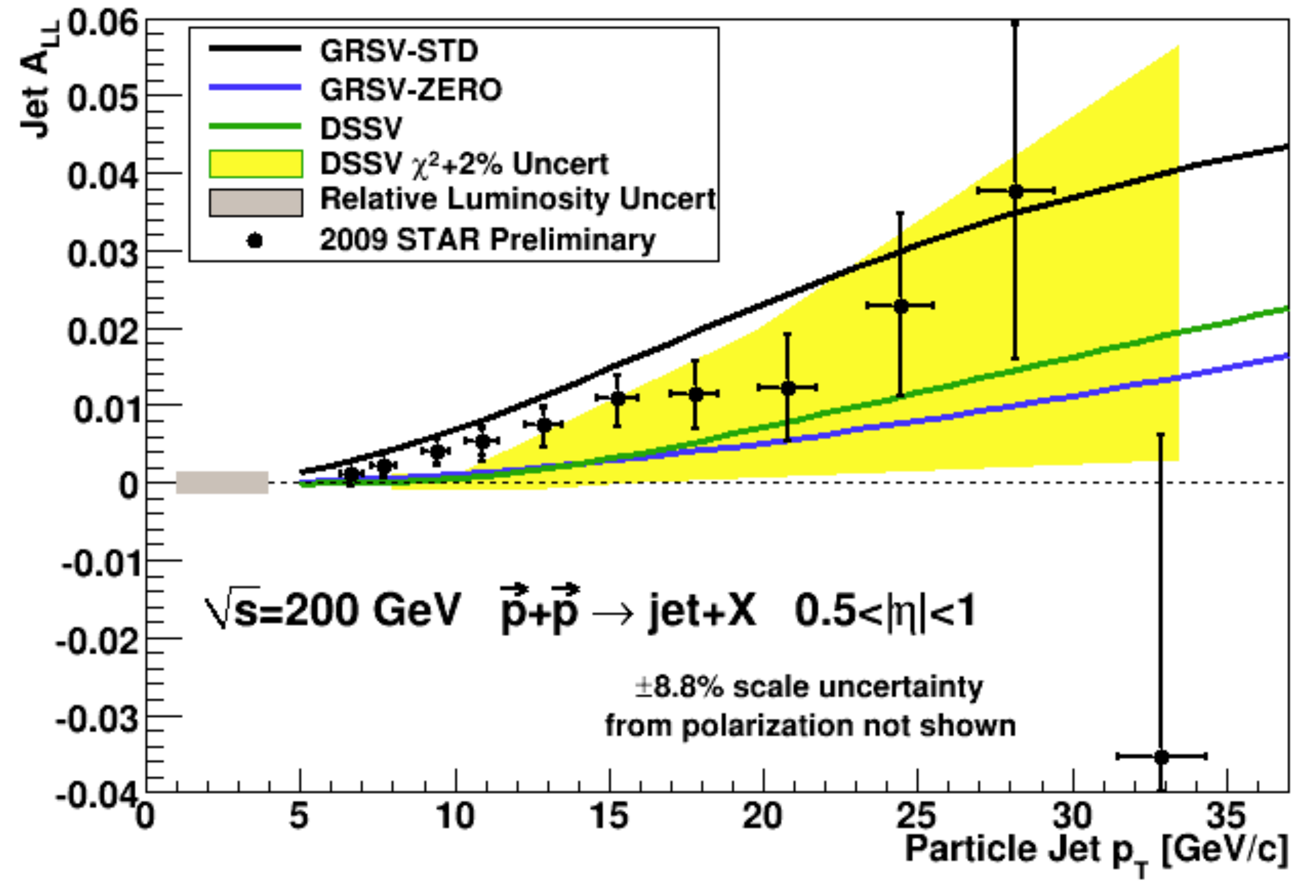
Reconstruct initial state kinematics at leading order:

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

Summary



arXiv:1404.6880



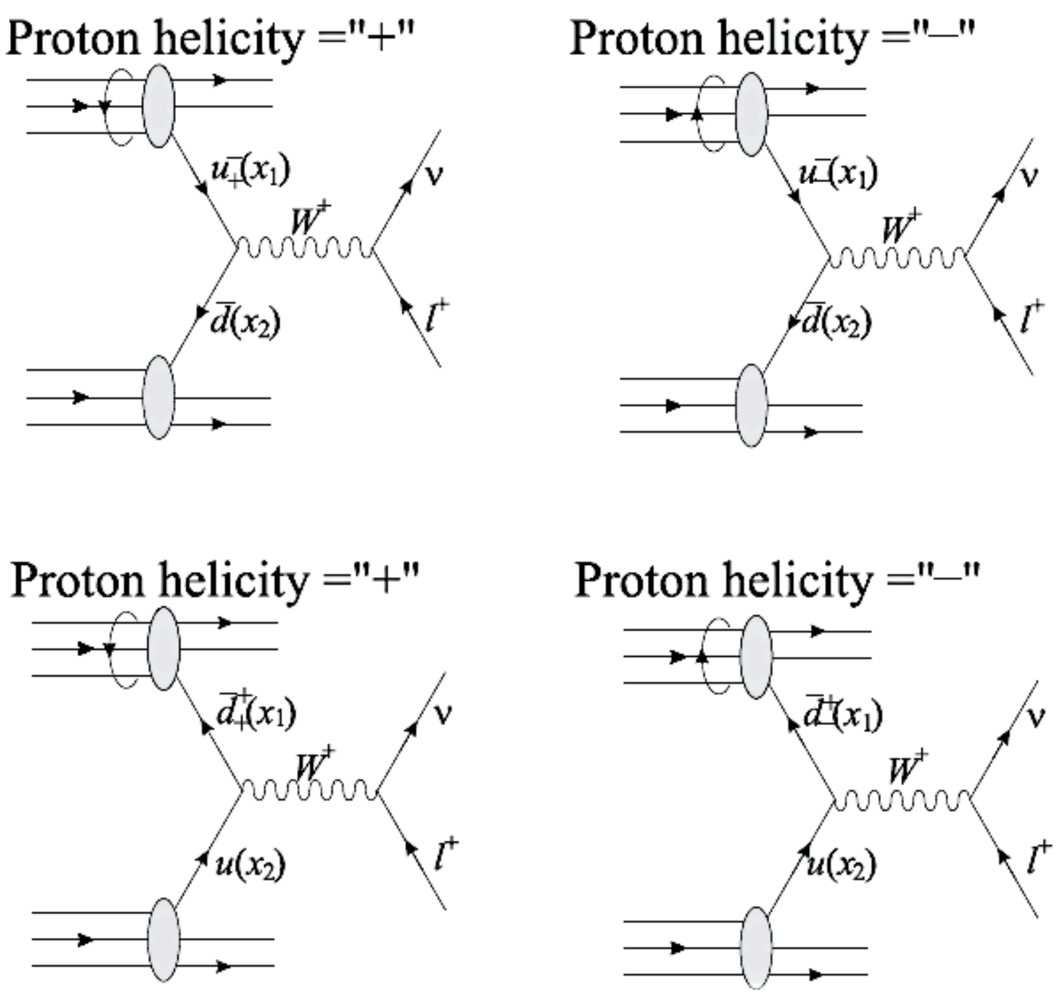
- Inclusive jet results provide evidence for a non-zero Δg in the x range probed at RHIC
- New constraints on light quark sea polarization from W data, preferring a positive $\Delta\bar{u}$
- Higher precision data being analyzed now from Run 13

Backup

Parity-Violating Asymmetry: A_L

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

- V-A coupling of the weak interaction leads to perfect spin separation
- Only LH quarks and RH anti-quarks



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

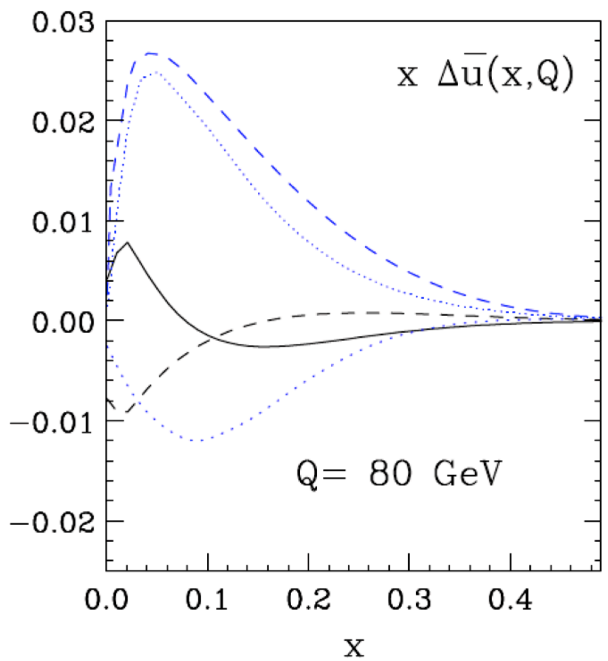
+

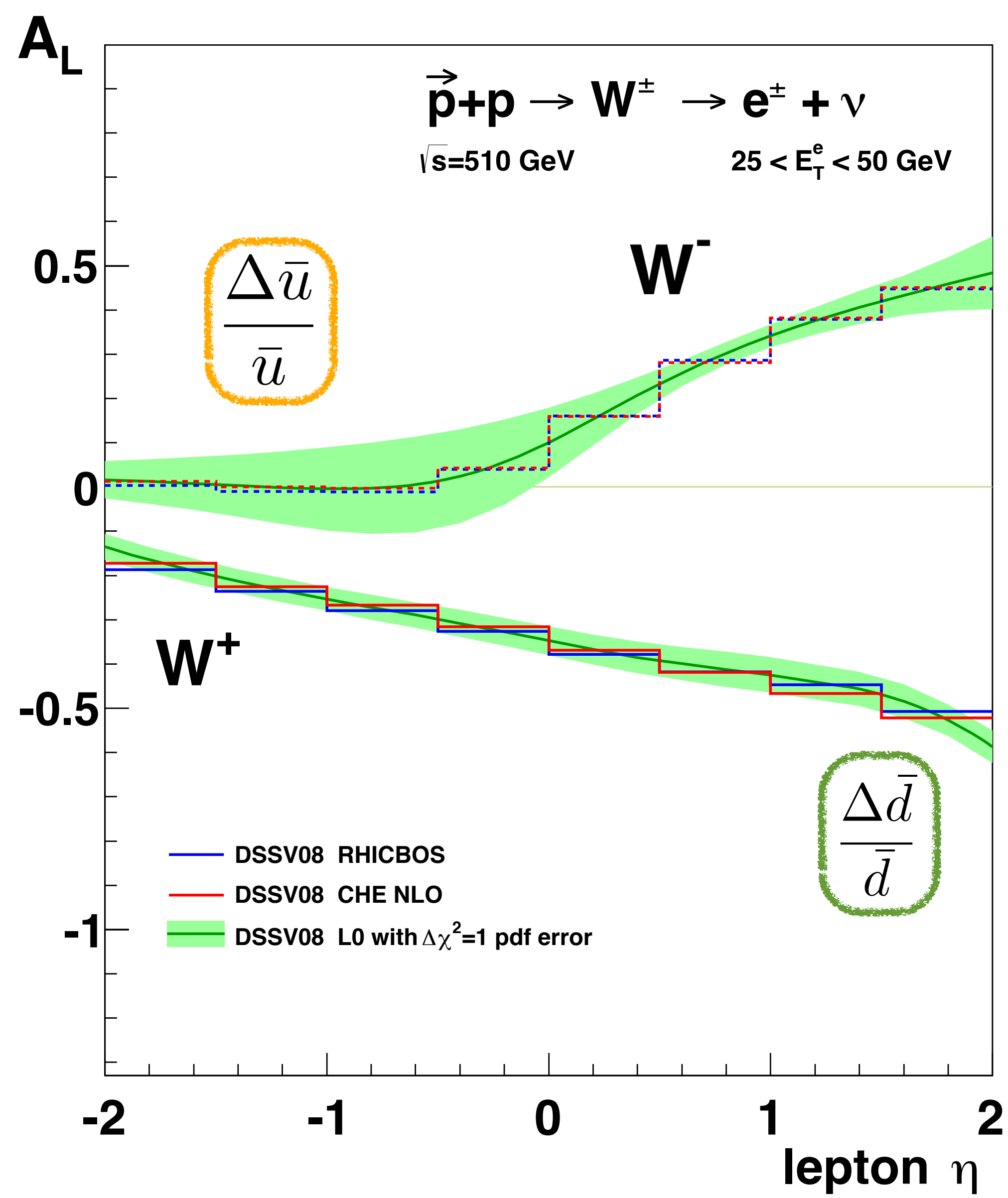
$$A_L^{W+} \propto \frac{\bar{d}_+^+(x_1)u(x_2) - \bar{d}_-^+(x_1)u(x_2)}{\bar{d}_+^+(x_1)u(x_2) + \bar{d}_-^+(x_1)u(x_2)} = \frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}$$

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

Expectations for W A_L

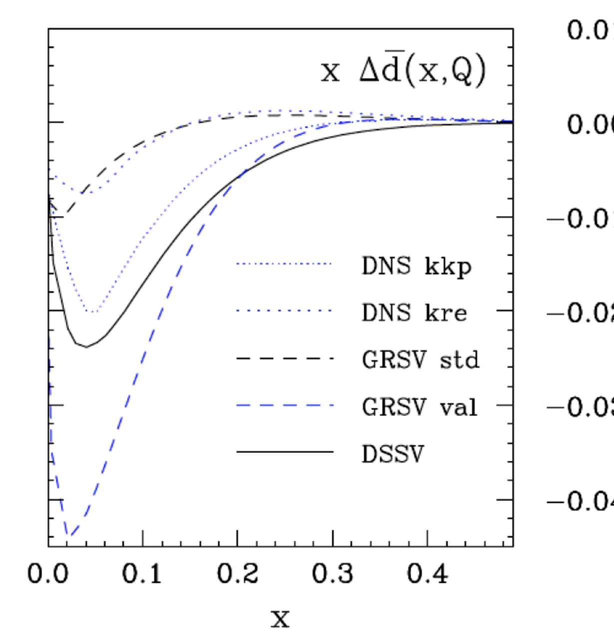
$$A_L^{W-} \propto \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)} \qquad A_L^{W+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$





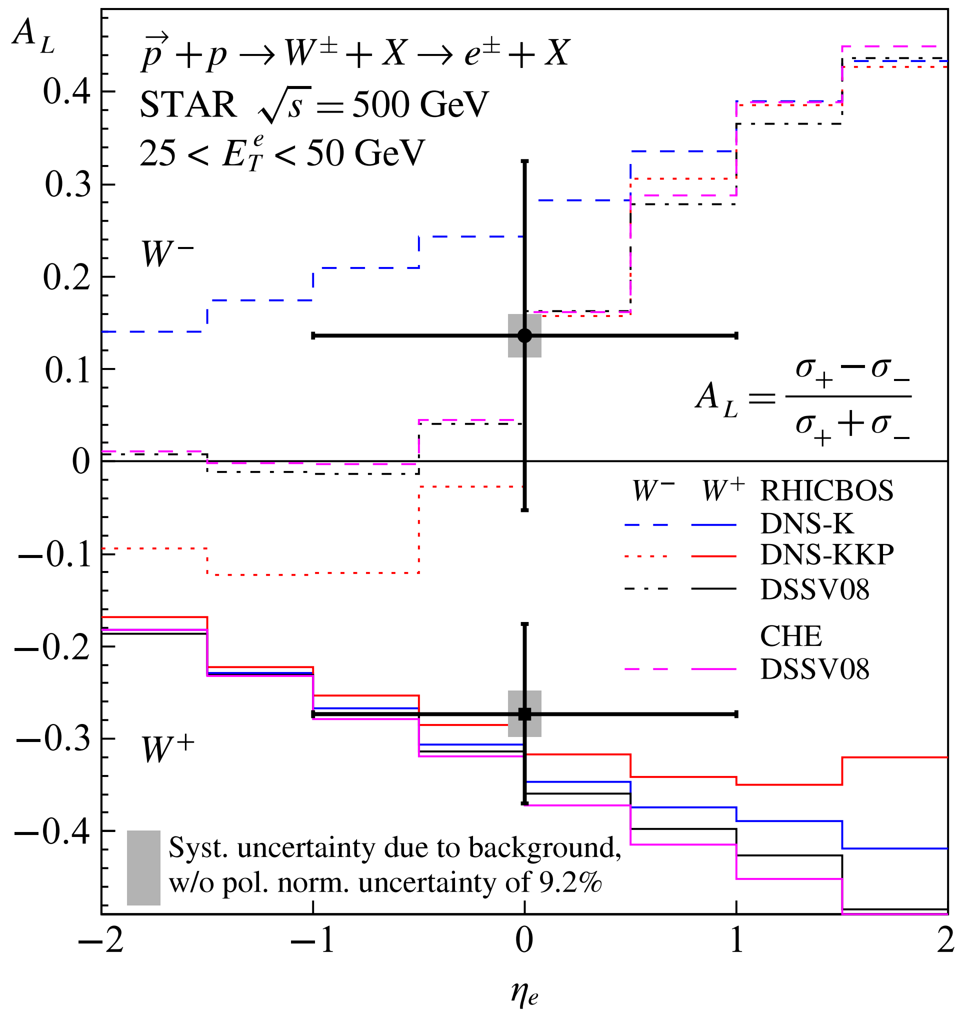
- Large parity-violating asymmetries expected
- Simplified interpretation at forward and backward rapidity

- DSSV $\Delta\chi^2 = 1$ band underestimates the theoretical uncertainty (and Lagrange multiplier estimates for a $\Delta\chi^2/\chi^2$ = 2% error are in progress)

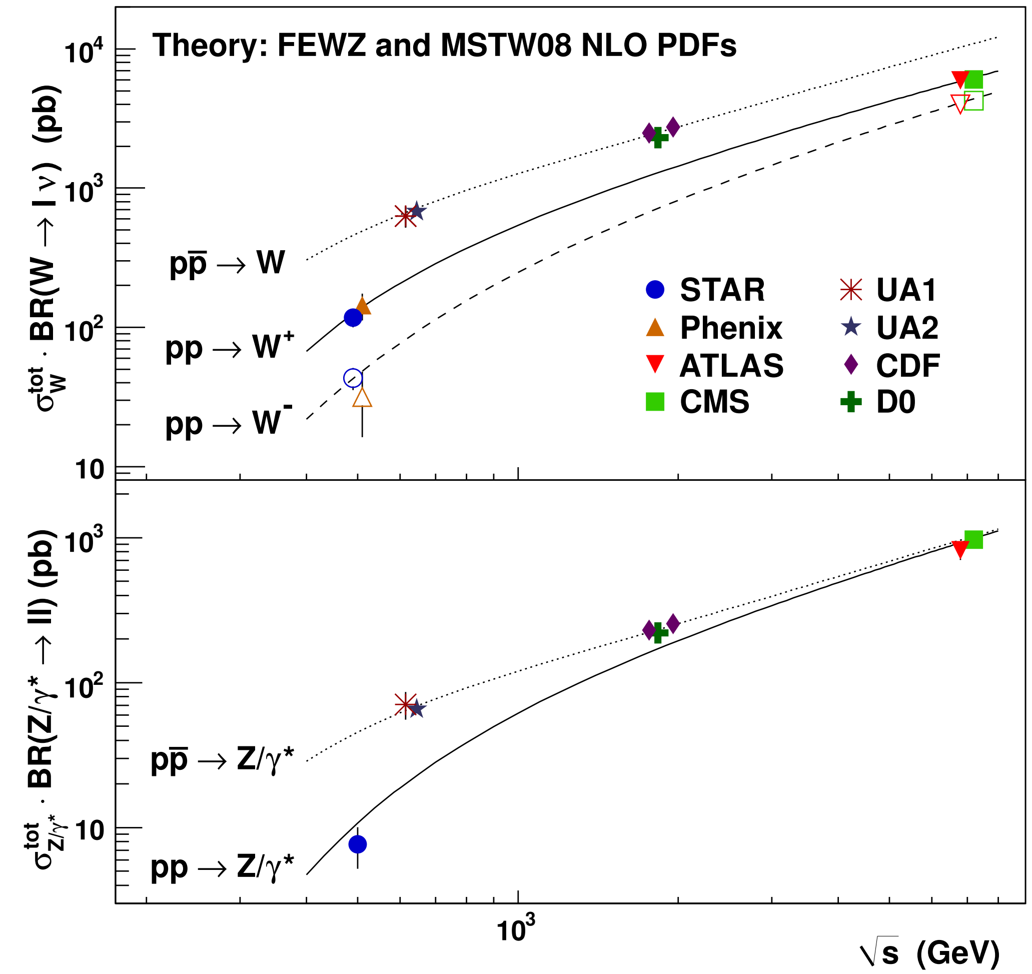


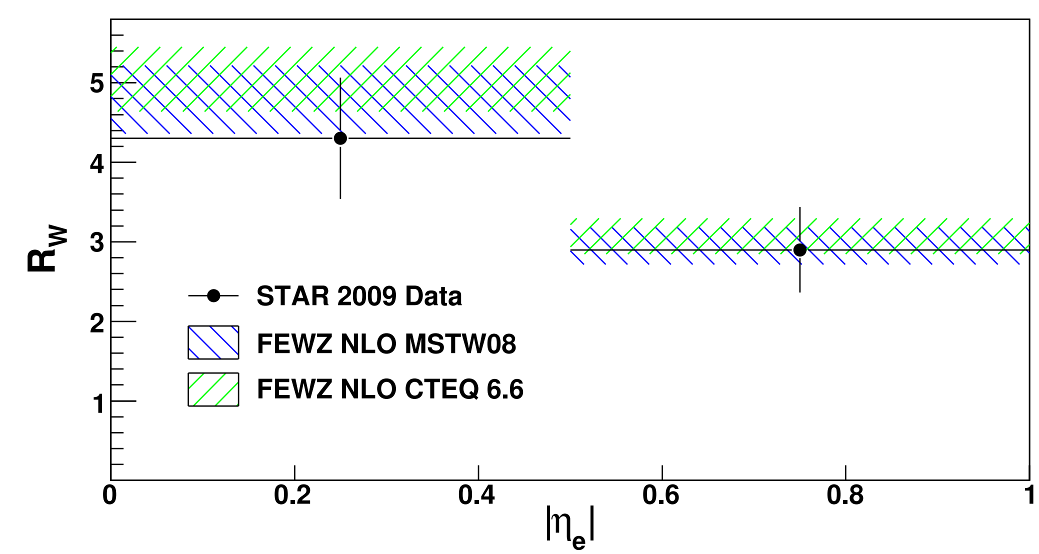
Previous STAR Measurements

PRL **106,** 062002 (2011)



- 2009 was a very successful first 500 GeV physics run
- Increase in FOM = P^2L of an order of magnitude!





PRD **85,** 92010 (2012)

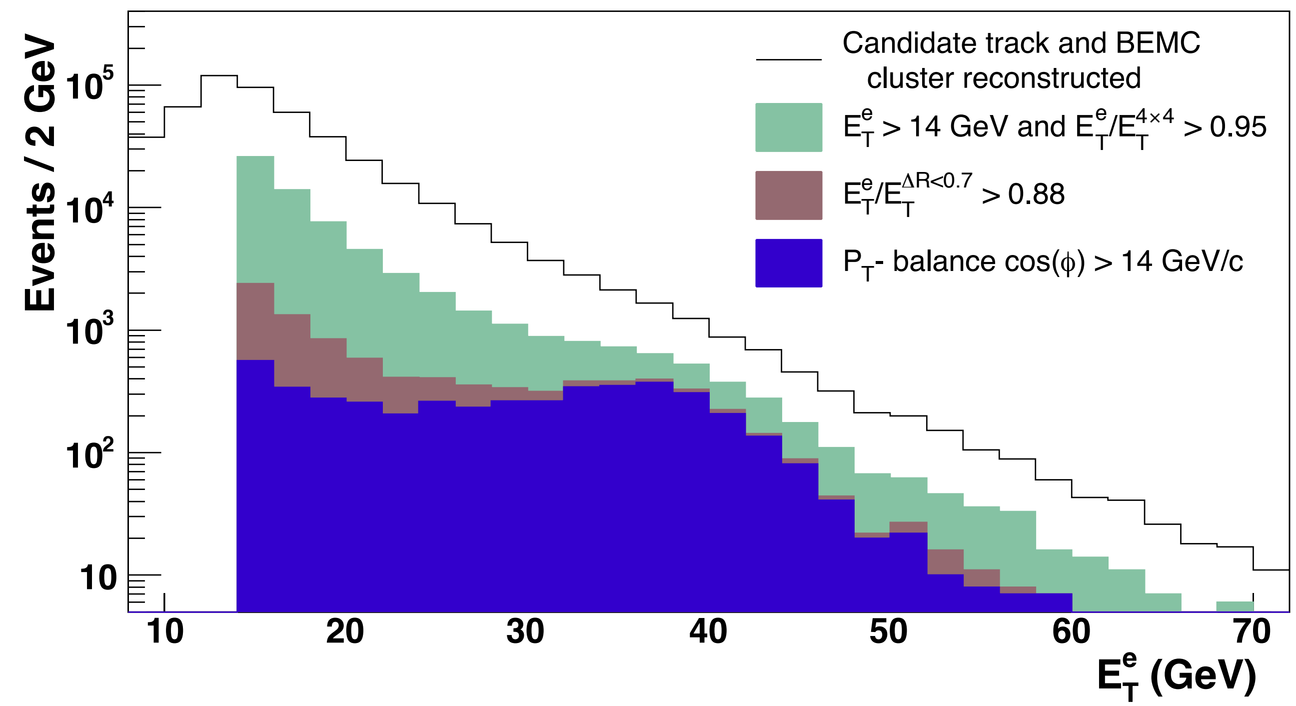
How do we find Ws?

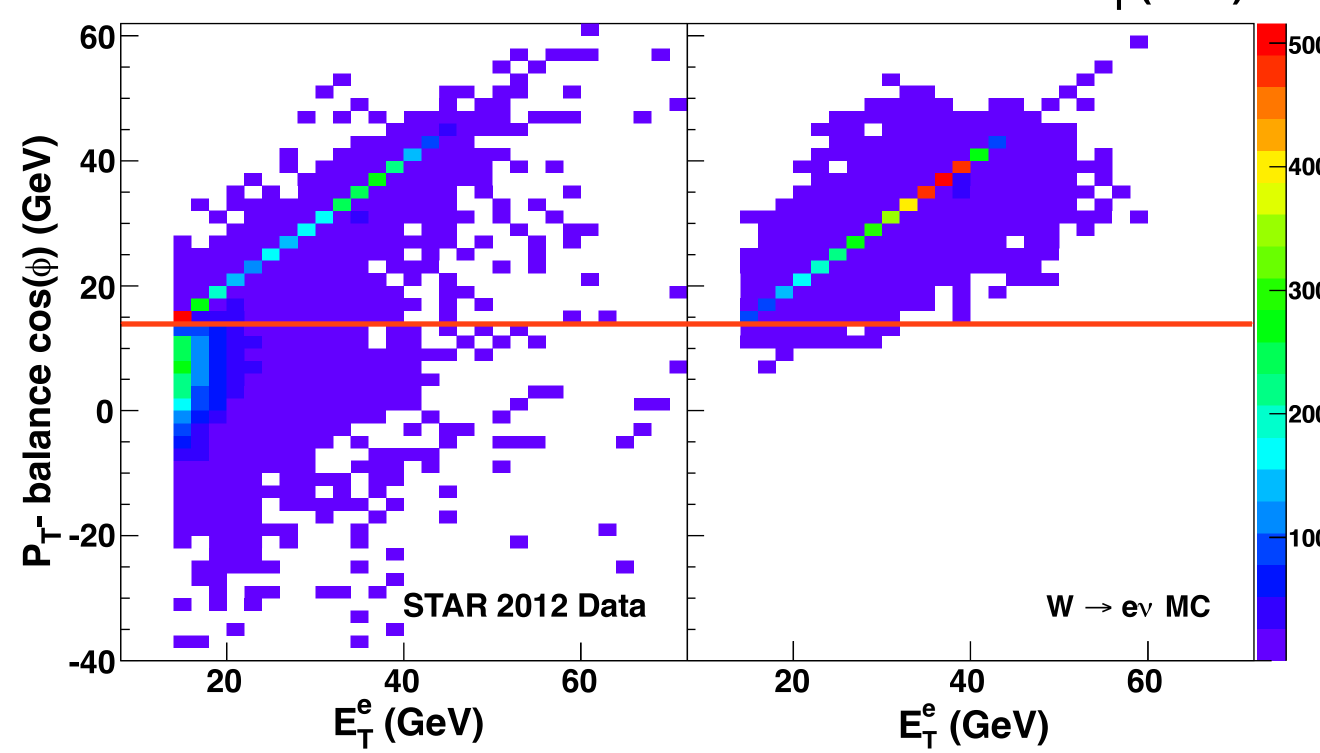
- Match $p_T > 10$ GeV track to BEMC cluster
- Isolation Ratios
- P_T-balance

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

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

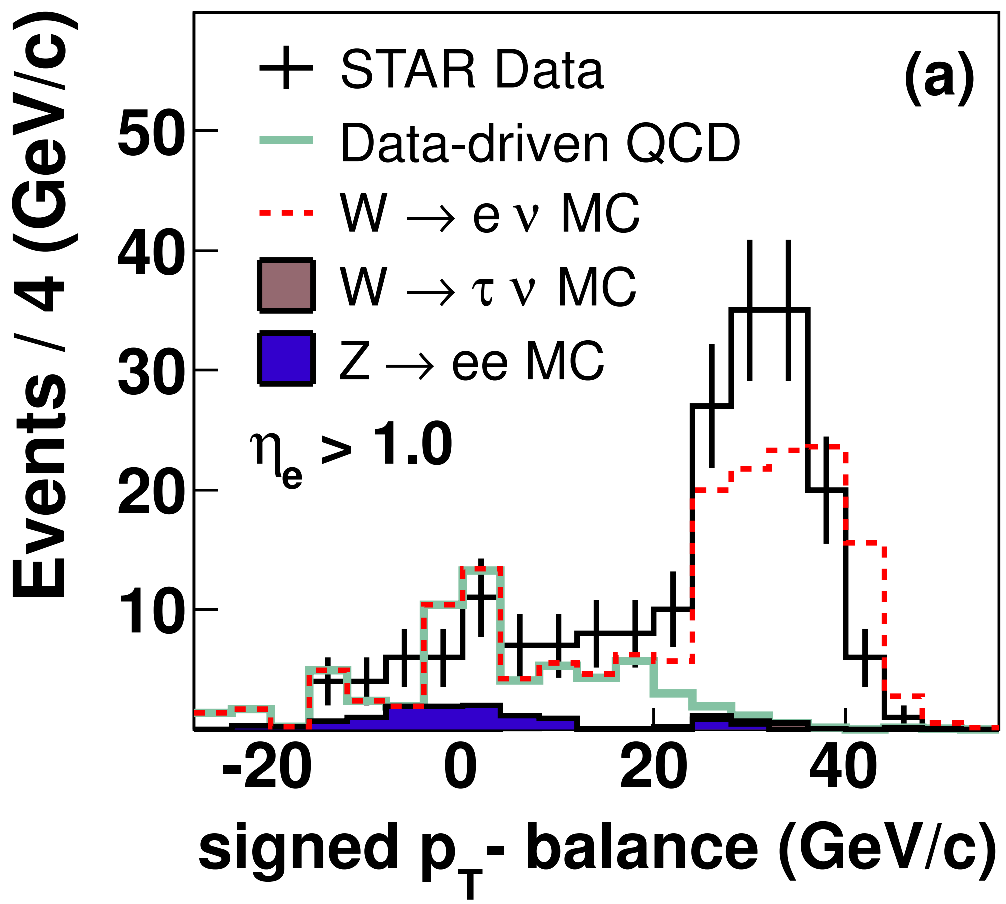
Transverse Plane View

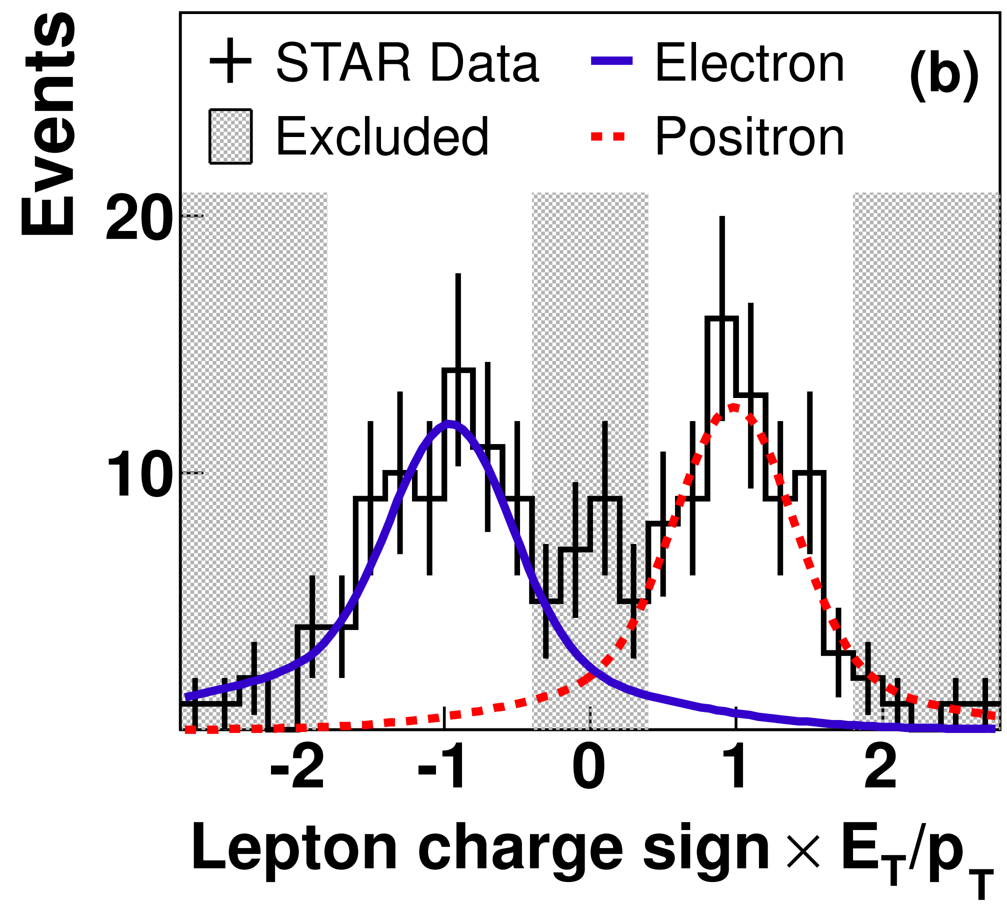




Forward rapidity

NEW arXiv:1404.6880





p+p 500 vs 510

- Expect negligible difference in A_L from change in $\sqrt{s}$
- CHE (NLO) curves with DSSV confirm this expectation