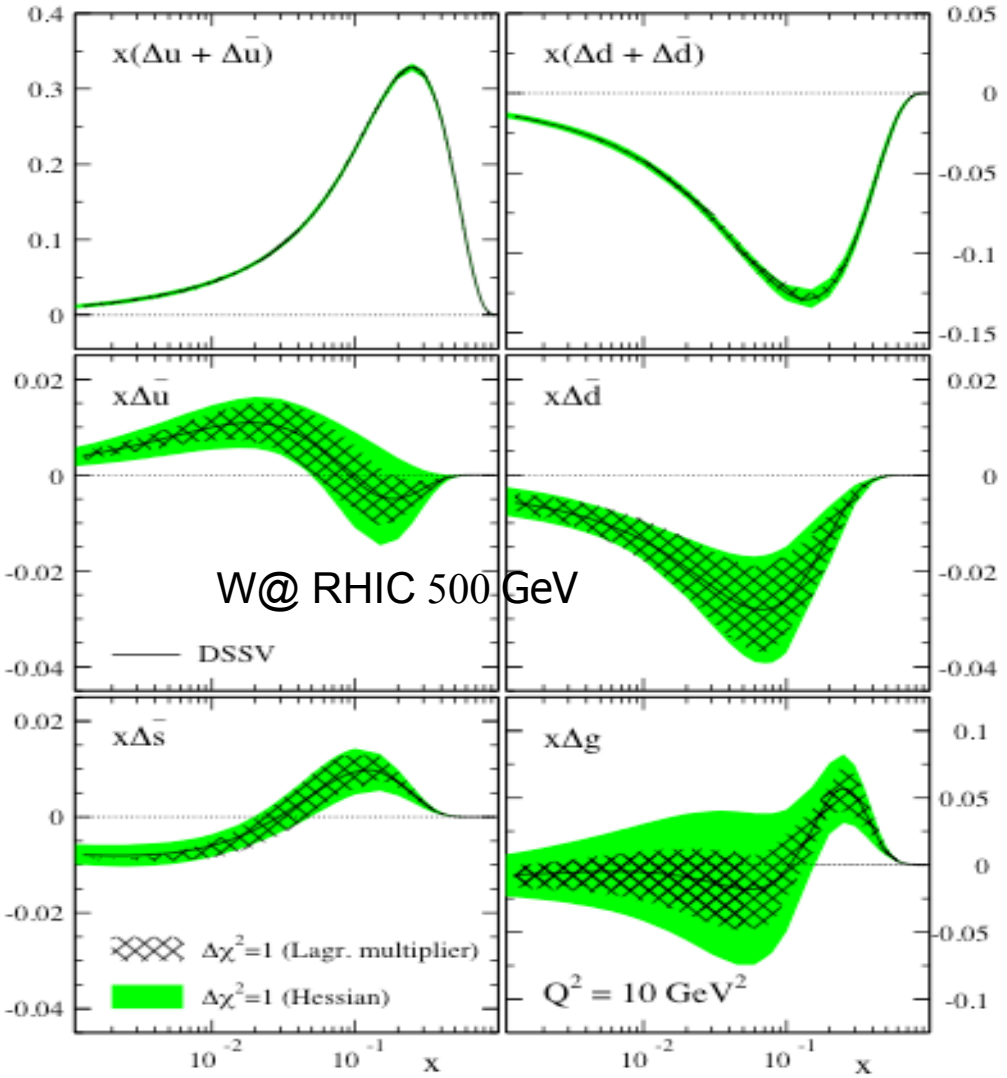
Measurement of Longitudinal Single-Spin Asymmetry for W Boson Production in p+p collisions at STAR

Qinghua Xu (Shandong University)

for the STAR Collaboration

Flavor separation of nucleon spin

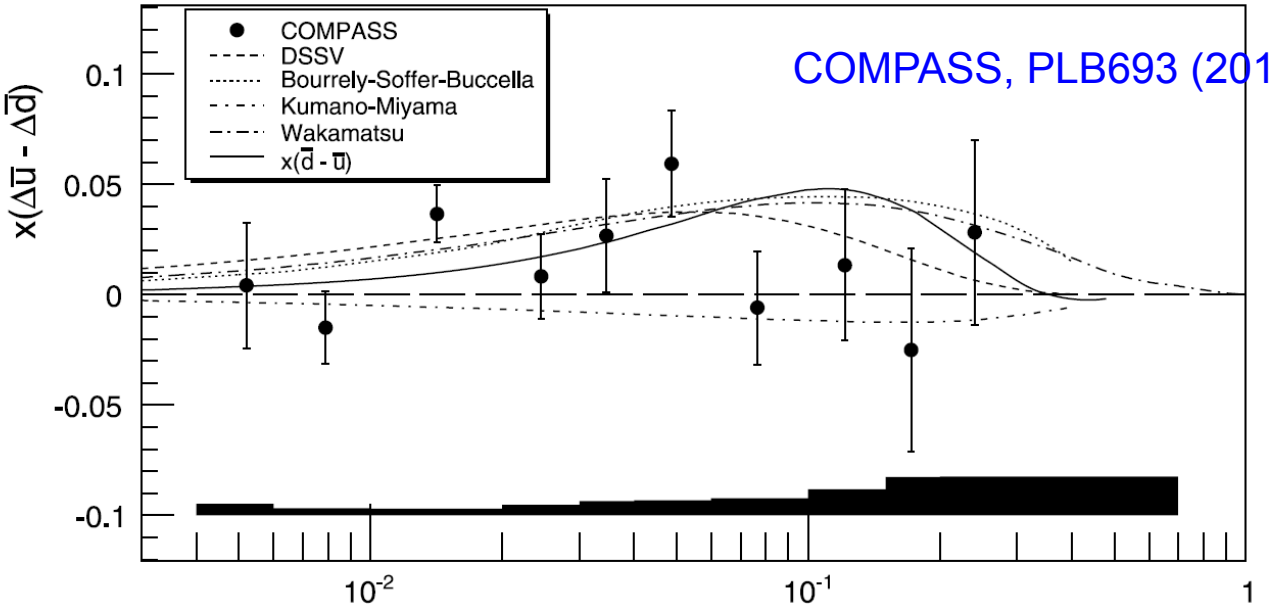
- Sea quark polarization not well constrained by DIS data yet:



D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, PRD80 (2009)034030

Flavor symmetry of the polarized sea from SIDIS

- Do we expect a symmetry breaking in the polarized sea?



COMPASS, PLB693 (2010) 227

COMPASS $\int_{0.004}^{0.3} \left(\Delta\bar{u}-\Delta\bar{d}\right)dx = 0.06 \pm 0.04 \pm 0.02 \quad @ \quad Q^2 = 3\ \left(GeV/c\right)^2$

HERMES $\int_{0.023}^{0.6} \left(\Delta\bar{u}-\Delta\bar{d}\right)dx = 0.048 \pm 0.057 \pm 0.028 \quad @ \quad Q^2 = 2.5\ \left(GeV/c\right)^2$

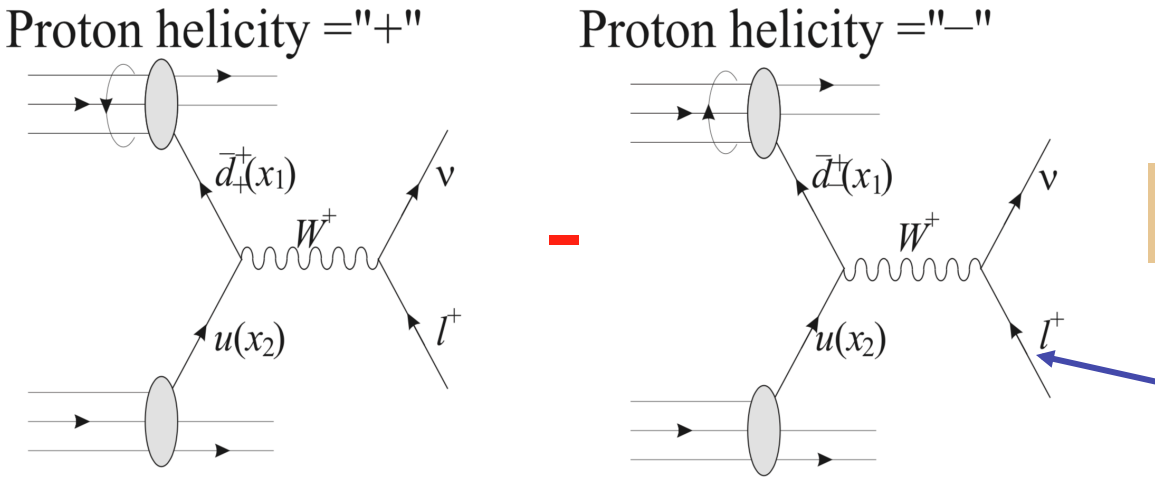
- HERMES, PRD 71 (2005) 012003

unp. E866 $\int_{0}^{1} \left(\bar{u}-\bar{d}\right)dx = -0.118 \pm 0.012 \quad @ \quad Q^2 = 54\ \left(GeV/c\right)^2$

- E866, Phys. Rev. D64 (2001) 052002

Probing sea quark polarization via W production

- Quark polarimetry with W's in p+p collision (example of W^+):



$$\propto \Delta\bar{d}(x)\,u(x)$$

W-detection through high energy lepton

- Spin asymmetry measurements:

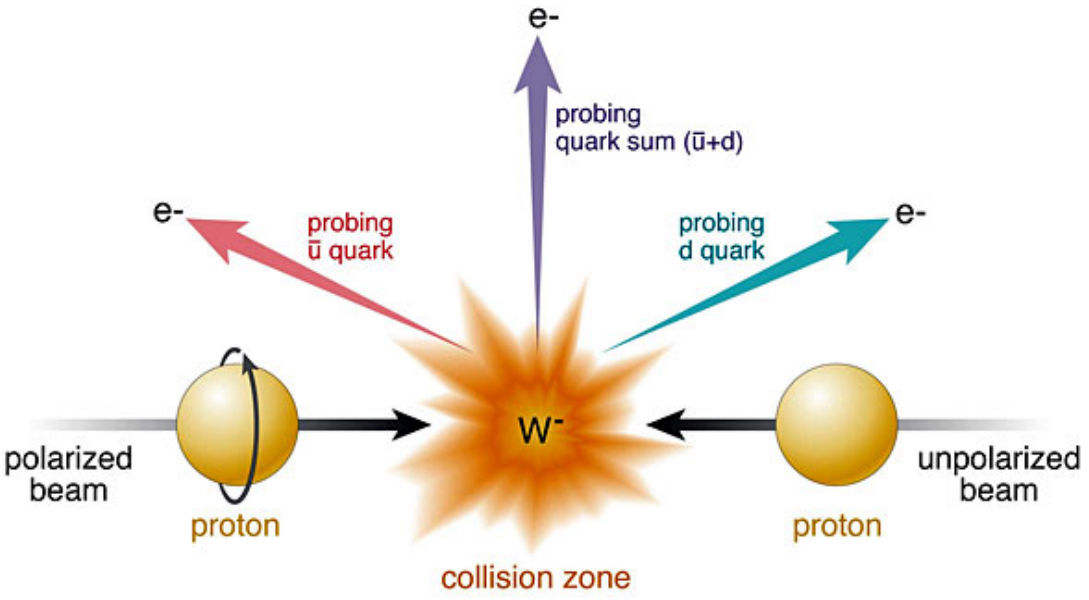
$$A_L^{W^+} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} = \begin{cases} -\dfrac{\Delta u(x_1)}{u(x_1)}, & y_{W^+} >> 0 \\ \dfrac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}, & y_{W^+} << 0 \end{cases}$$

$$A_L^{W^-} = \begin{cases} -\dfrac{\Delta d(x_1)}{d(x_1)}, & y_{W^-} >> 0 \\ \dfrac{\Delta\bar{u}(x_1)}{\bar{u}(x_1)}, & y_{W^-} << 0 \end{cases}$$

Probing sea quark polarization via W production

- W's naturally separate quark flavors
  > backward/forward region probe sea & valence quarks
- W's are 100% parity-violating
  > select only one helicity of the coupled (anti)quarks
- W's are clean theoretically
  > no fragmentation function involved
- Complementary to SIDIS: high Q^2, test universality of pdf

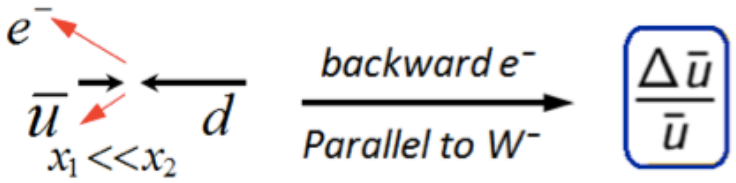
$$A_L^W = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$



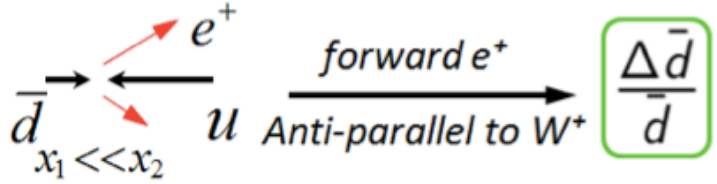
Expectation of W A_L at RHIC

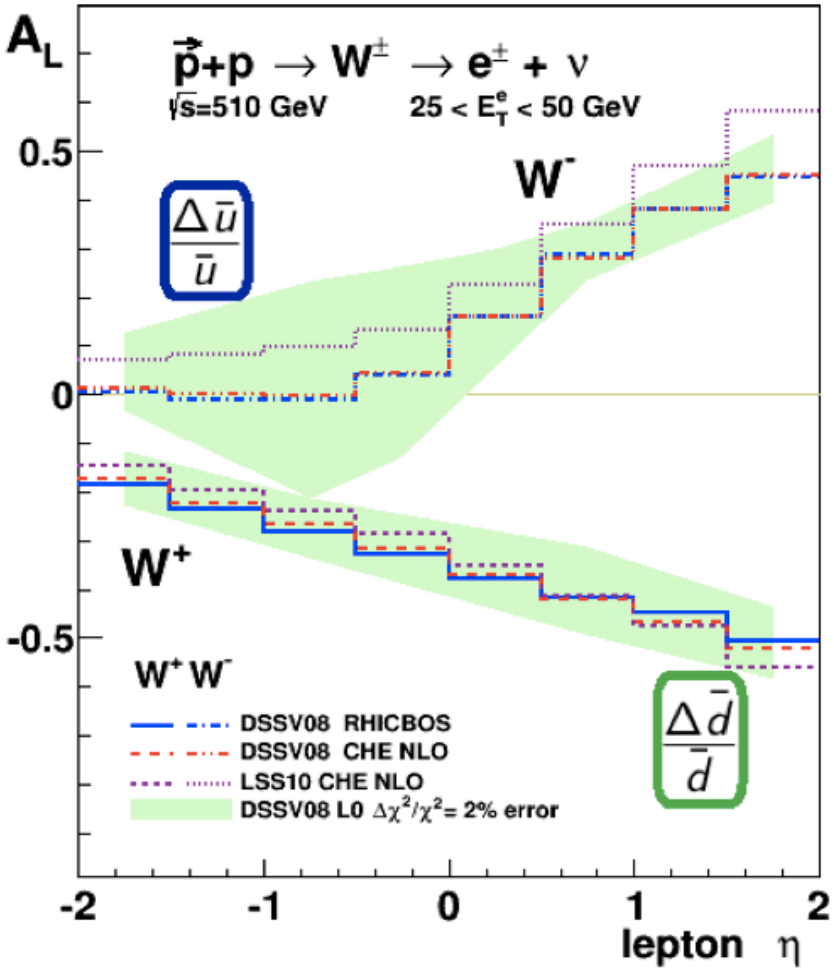
- Large parity-violating asymmetries expected.
- Simplified interpretation at forward and backward rapidity:

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

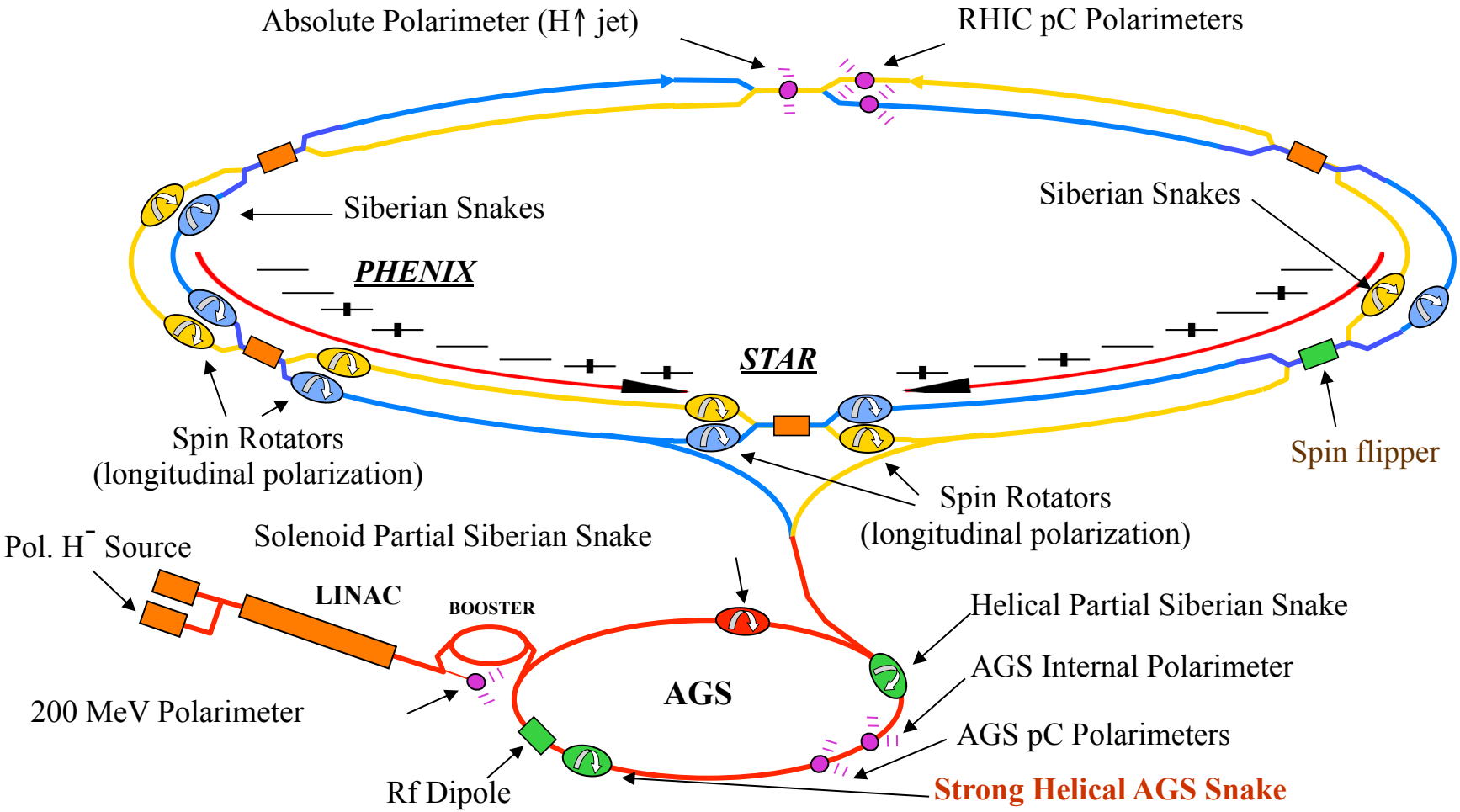


$$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2)+\Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2)+\bar{d}(x_1)u(x_2)}$$





RHIC- a polarized proton+proton collider

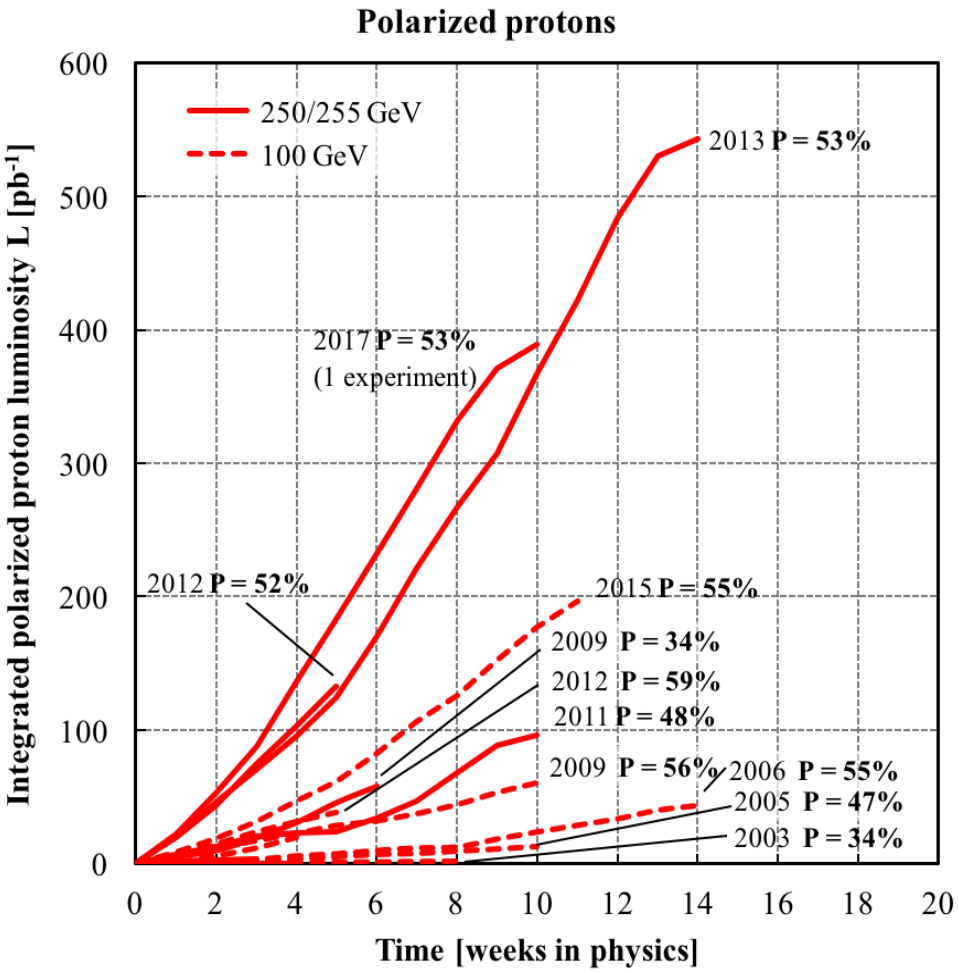


- Polarization direction changes from bunch to bunch
- Spin rotators provide choice of spin orientation

RHIC performance with p+p collisions

- p+p collisions at 500/510 GeV with long. polarization in 2009, 2011, 2012 and 2013.
- STAR data sample for W A_L analysis:

STAR Longitudinal pp 500/510			
Run	L (pb^{-1})	P	P^2L (pb^{-1})
2009	12	38%	1.7
2011	9.4	49%	2.3
2012	77	56%	24
2013	**246.2**	**56%**	**77.2**



STAR - Solenoid Tracker At RHIC

Magnet

- 0.5 T Solenoid

Triggering & Luminosity Monitor

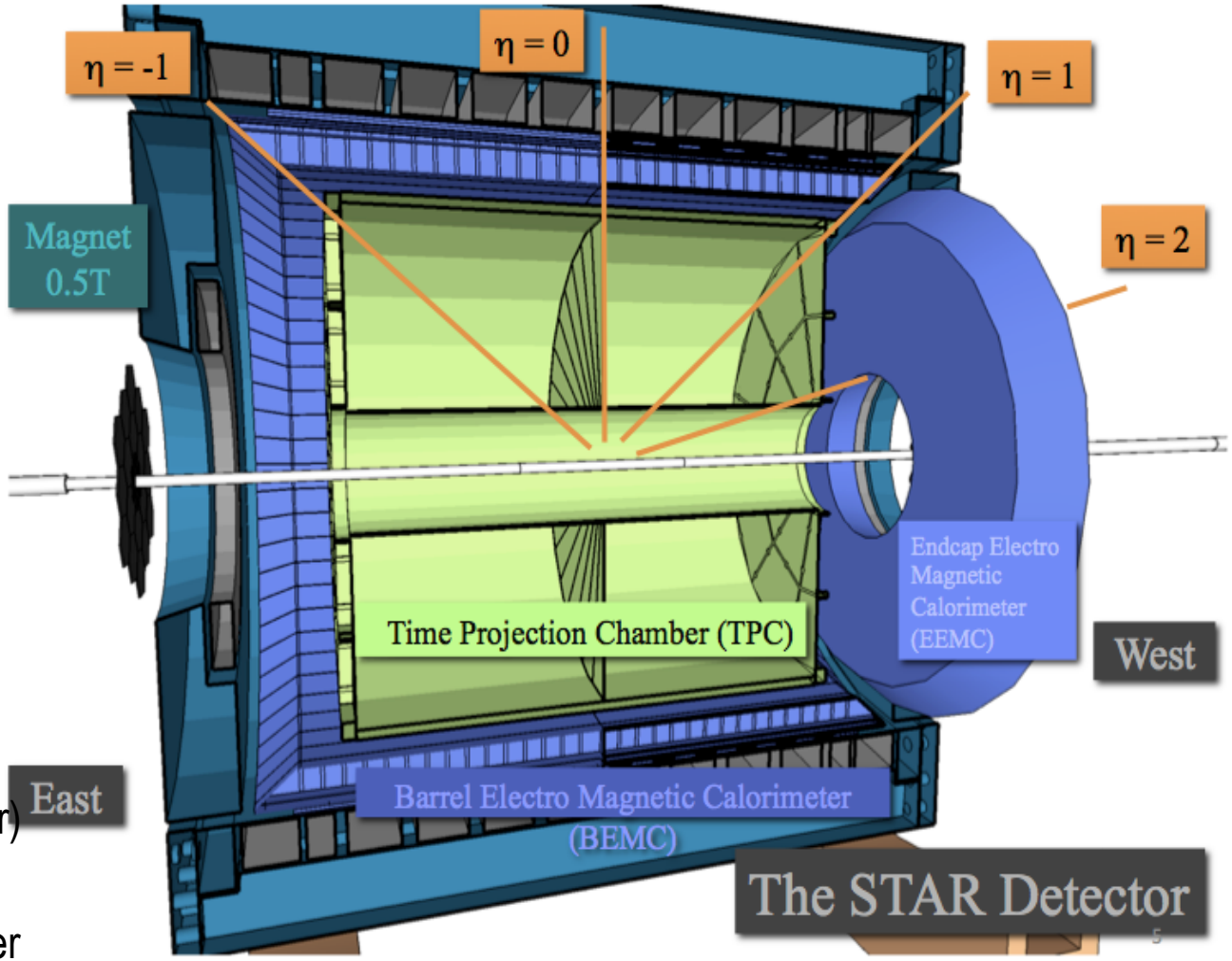
- Beam-Beam Counters
  - $3.4 < |\eta| < 5.0$
- Zero Degree Calorimeters
- Vertex Position Detector

Central Tracking

- Large-volume TPC
  - $|\eta| < 1.3$

Calorimetry

- Barrel EMC (Pb/Scintilator)
  - $|\eta| < 1.0$
- Endcap EMC (Pb/Scintillator)
  - $1.0 < \eta < 2.0$
- Forward Meson Spectrometer
  - $2.5 < \eta < 4.0$

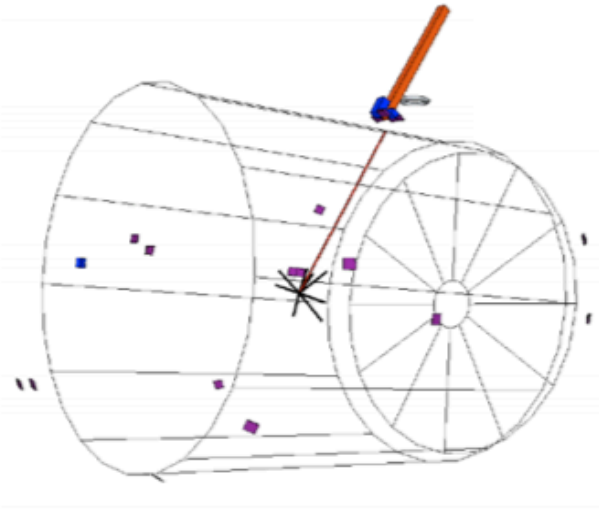


(- those marked red are relevant to W analysis)

W selection via W -> ev at STAR

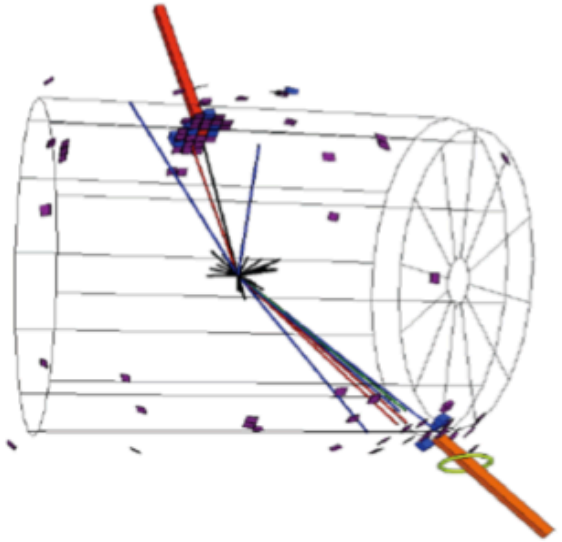
$W \rightarrow e + \nu$ Candidate Event:

- Isolated track pointing to isolated EM cluster in calorimeter
- Large “missing energy” opposite the electron candidate

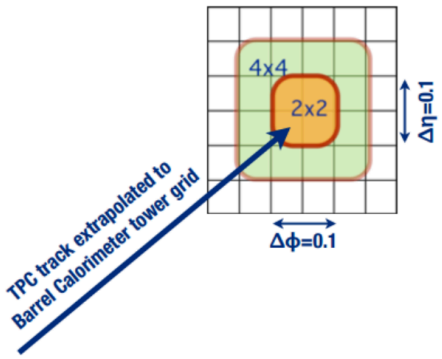


QCD Background Event

- Several tracks pointing to energy deposit in several towers
- p_T sum is balanced by di-jet, no large “missing energy”



W selection at STAR : Jacobian peak

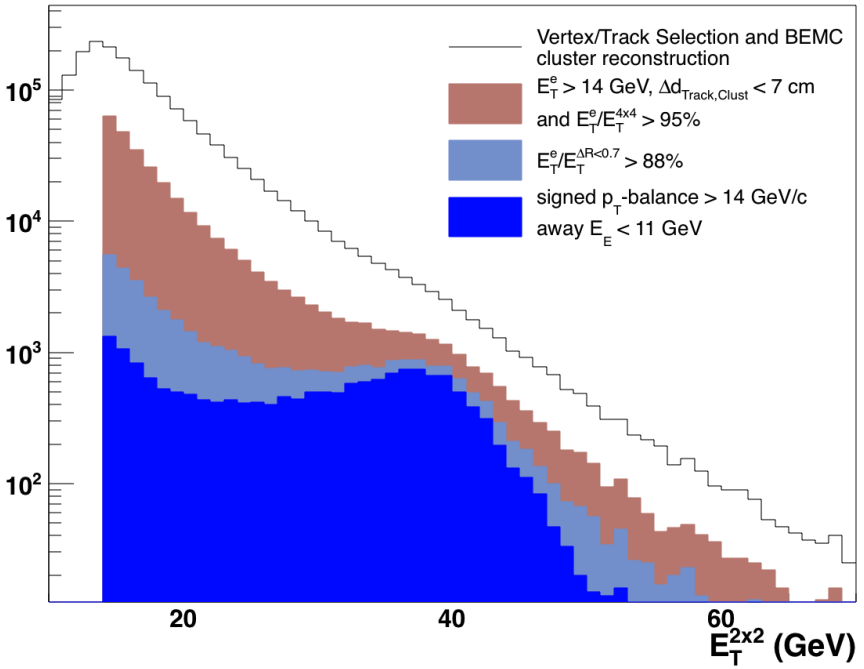


$$\vec{p_T}^{bal} = \vec{p_T}^{e} + \sum_{\Delta R>0.7} \vec{p_T}^{jets}$$

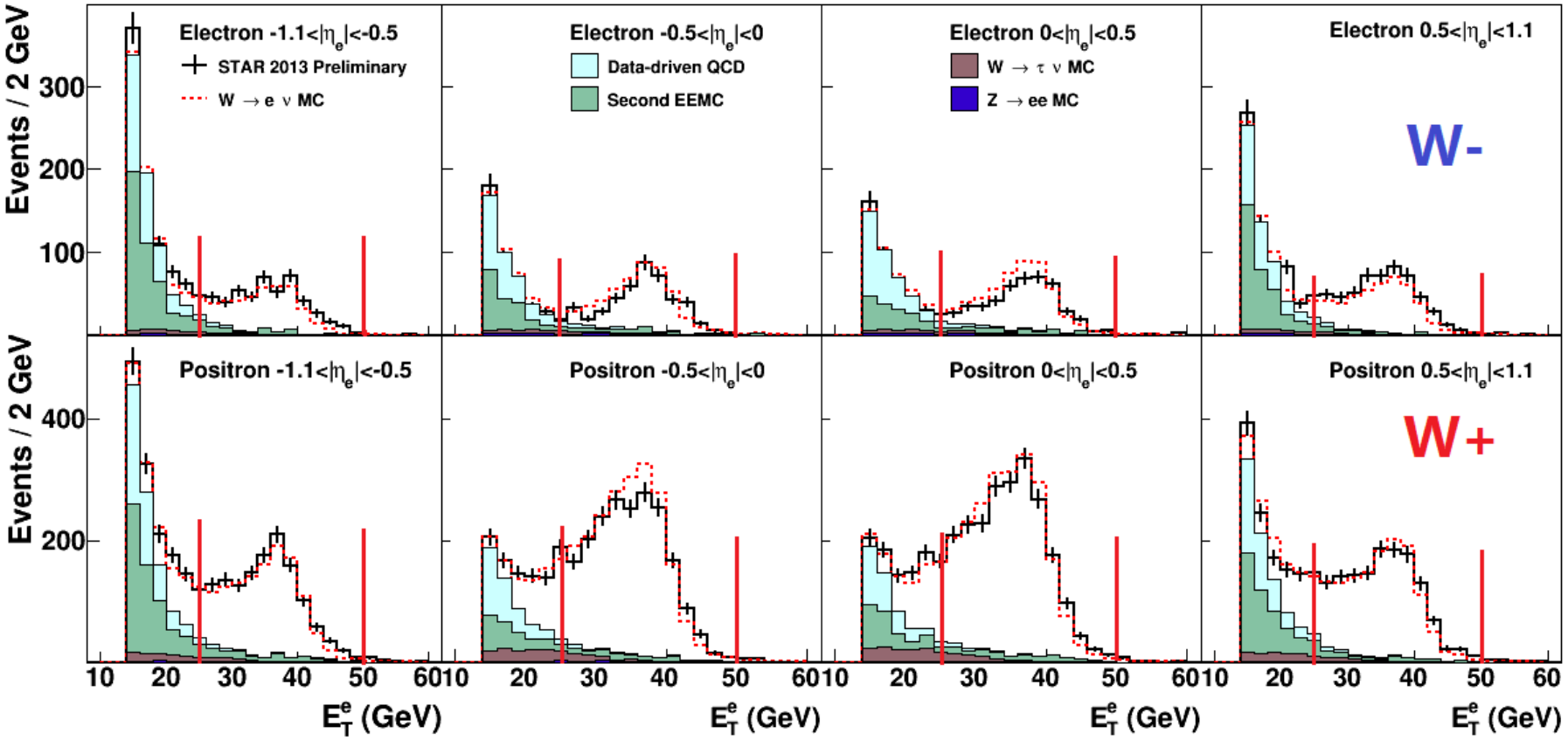
- Isolation ratio $E_{2\times2}/E_{4\times4} > 95\%$
- Isolation ratio $E_T^e/E_T^{\Delta R<0.7} > 88\%$
- Signed P_T-balance $= \frac{\vec{p_T}^{e} \cdot \vec{p_T}^{bal}}{|\vec{p_T}^{e}|} > 14$GeV
- away $E_T < 11$GeV

Signal of Jacobian peak with E_T distribution after selection :

-STAR 2013 with BEMC (|η|<1)



W selection (|η|<1) : BG Estimation



-STAR 2013

- Primary Background

  Data-driven QCD : BG Events which satisfy e+/- candidate isolation cuts

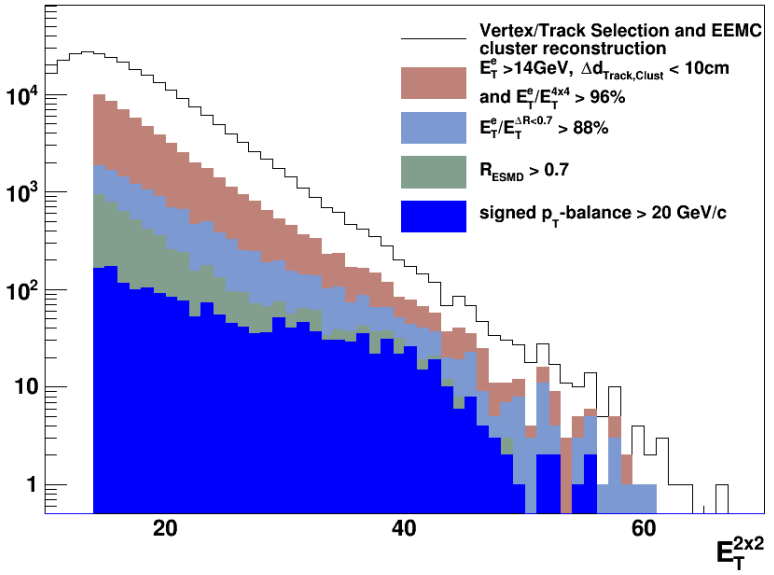
  Second EEMC : due to "jet" escape without East EEMC based on real West EEMC

- Weak decay Background

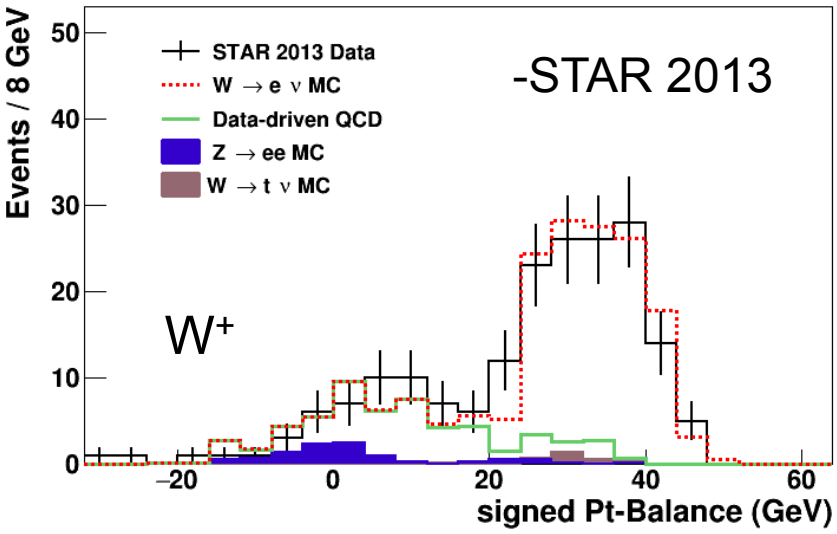
  From Z->ee, and W->τν, determined from MC

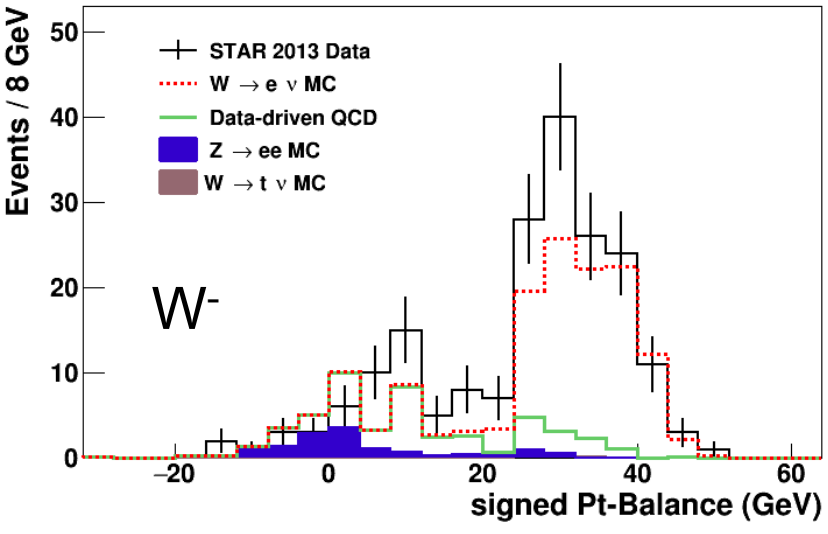
W selection at forward region with EEMC

Signal of Jacobian peak with similar selection cuts at $1<\eta<2$:



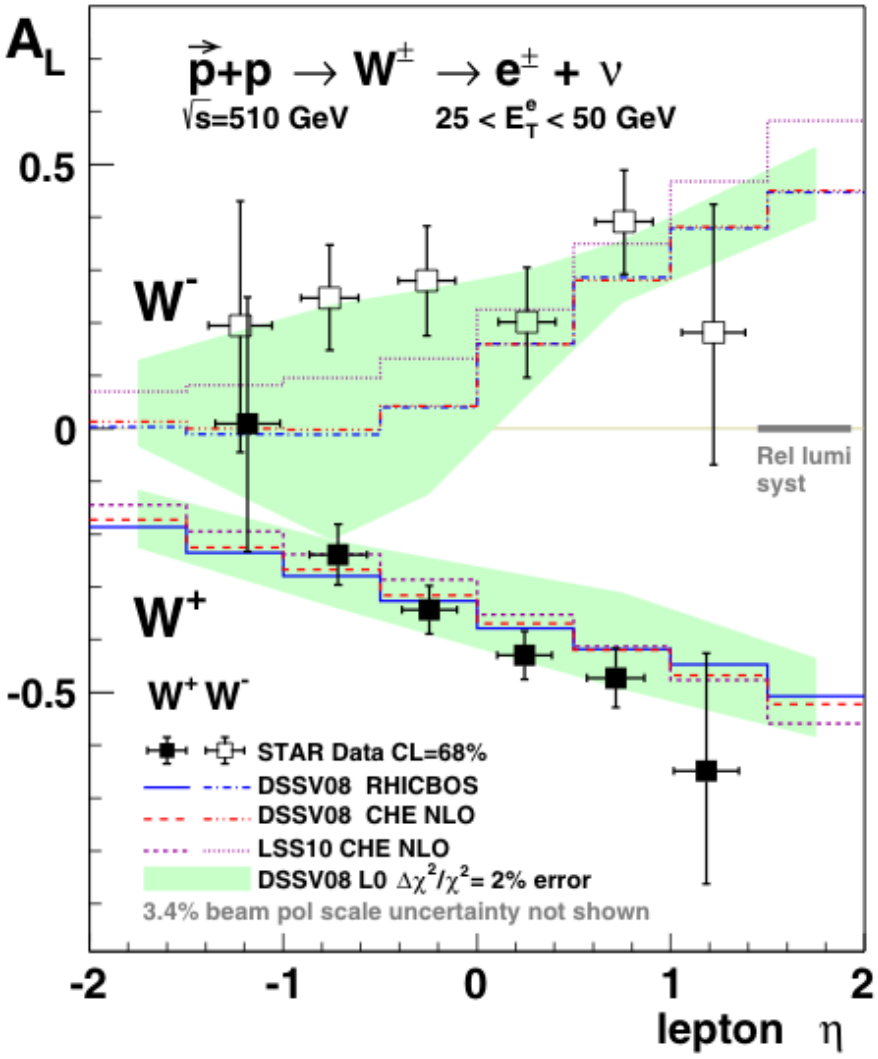
Background estimation at $1<\eta<2$:





STAR mid-rapidity W A_L –2011+2012

- First multiple-eta-bin A_L results from 2011+2012 data:



- 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.

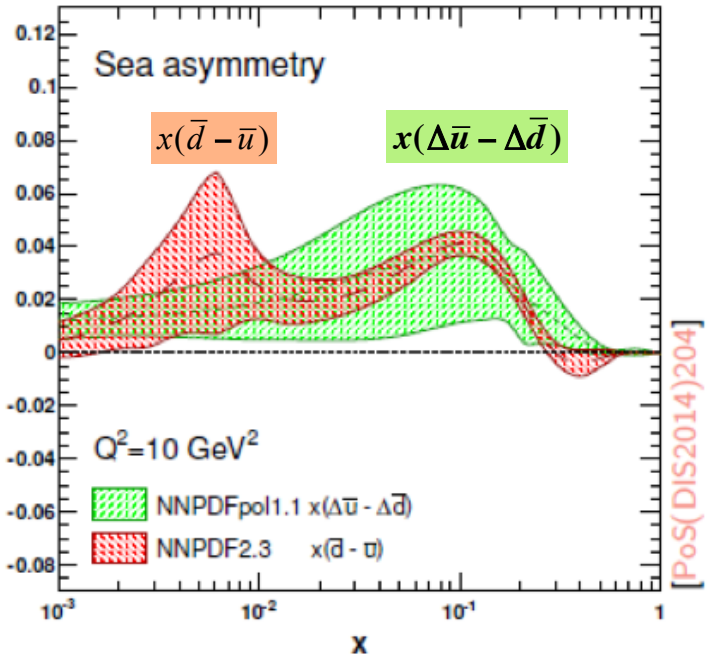
STAR, PRL113(2014)72301

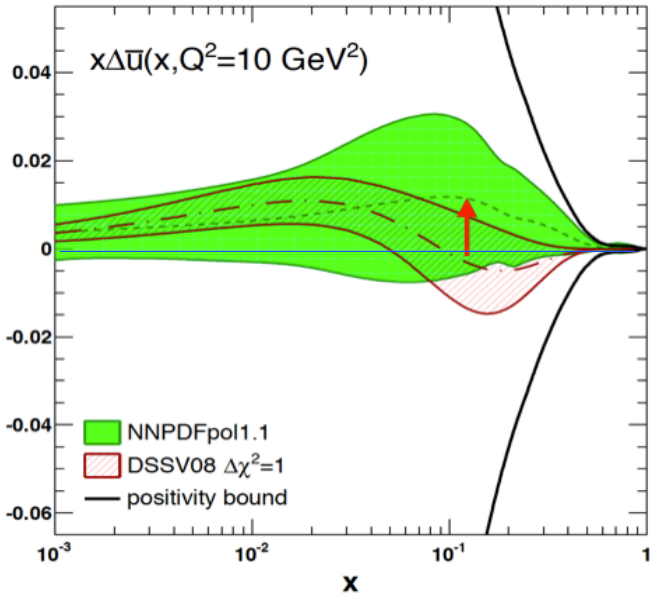
Global Analysis with STAR W A_L results

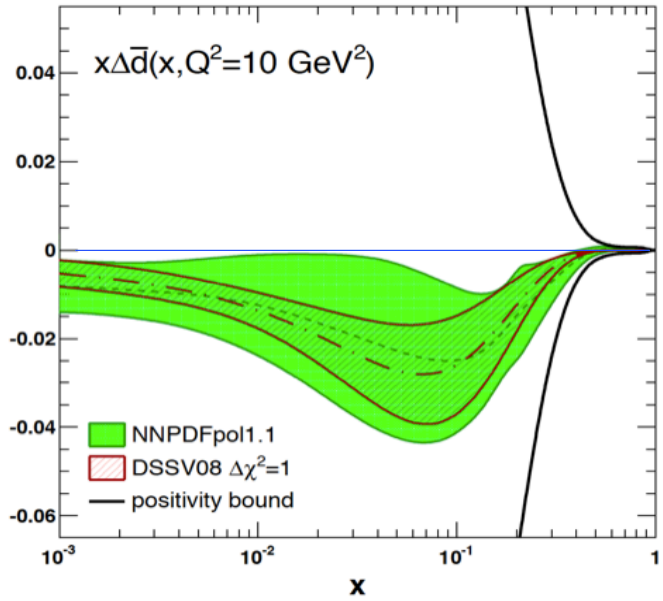
- Big impact seen in NNPDFpol1.1 global analysis after including STAR A_L data.

NNPDF1.1, Nucl.Phys. B887,276 (2014)

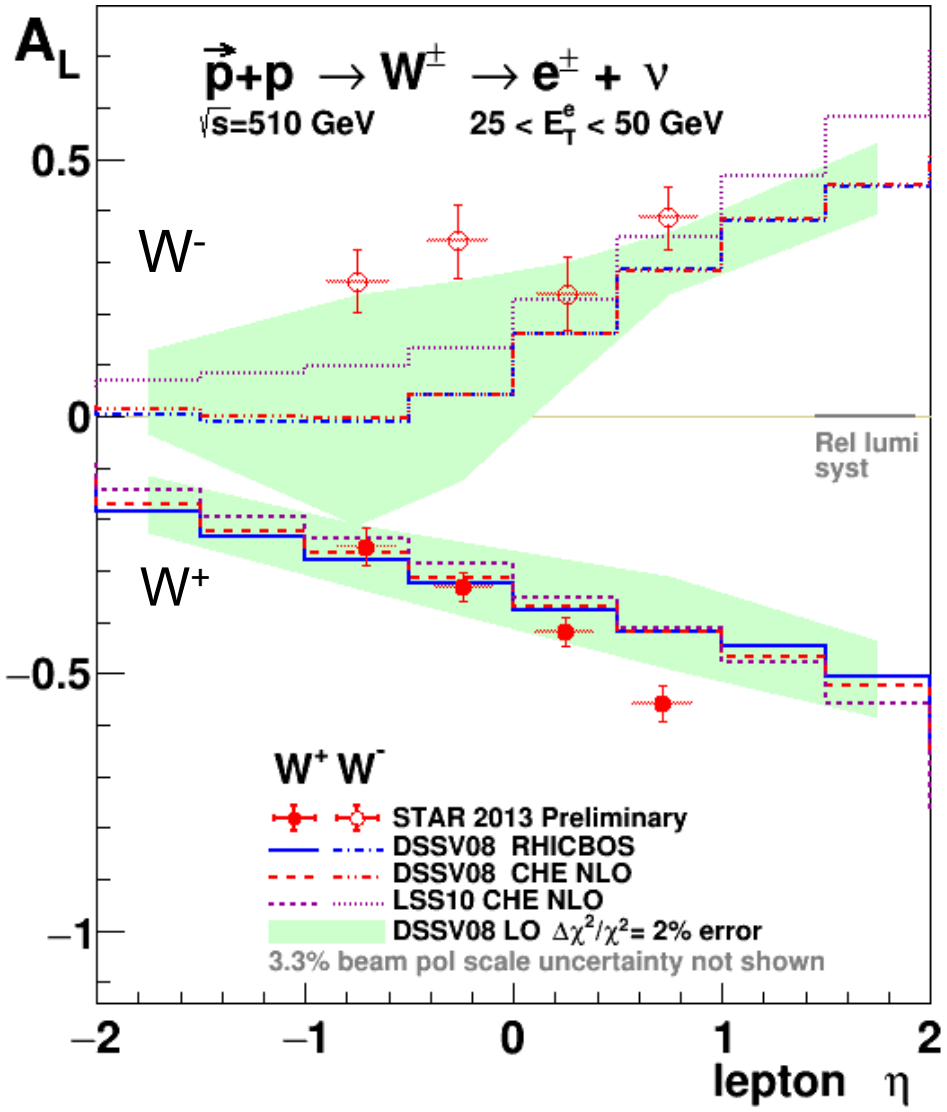
- Polarized sea asymmetry:







W A_L results – STAR 2013



- STAR 2013 W A_L results:
  - Most precise A_L results so far
  - Further constraints on $\Delta\bar{u}$, $\Delta\bar{d}$

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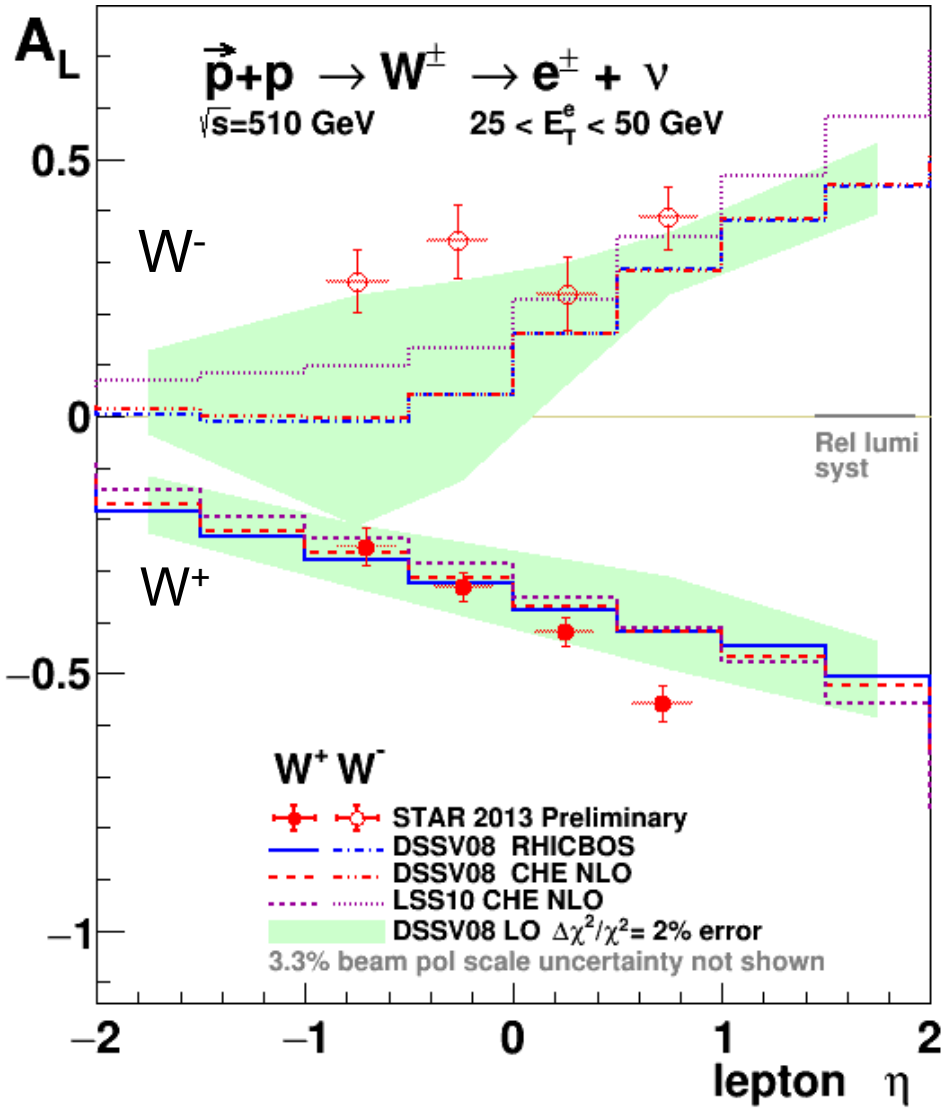

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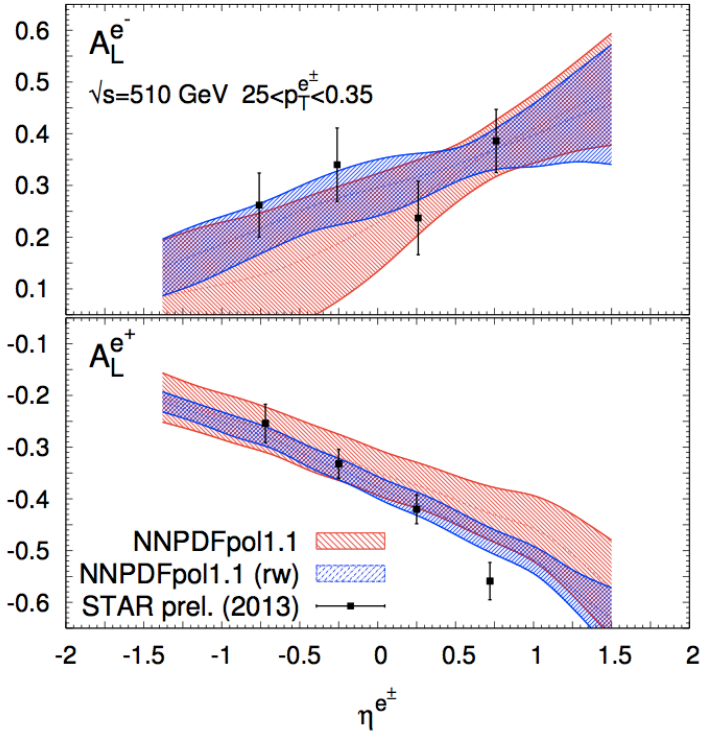
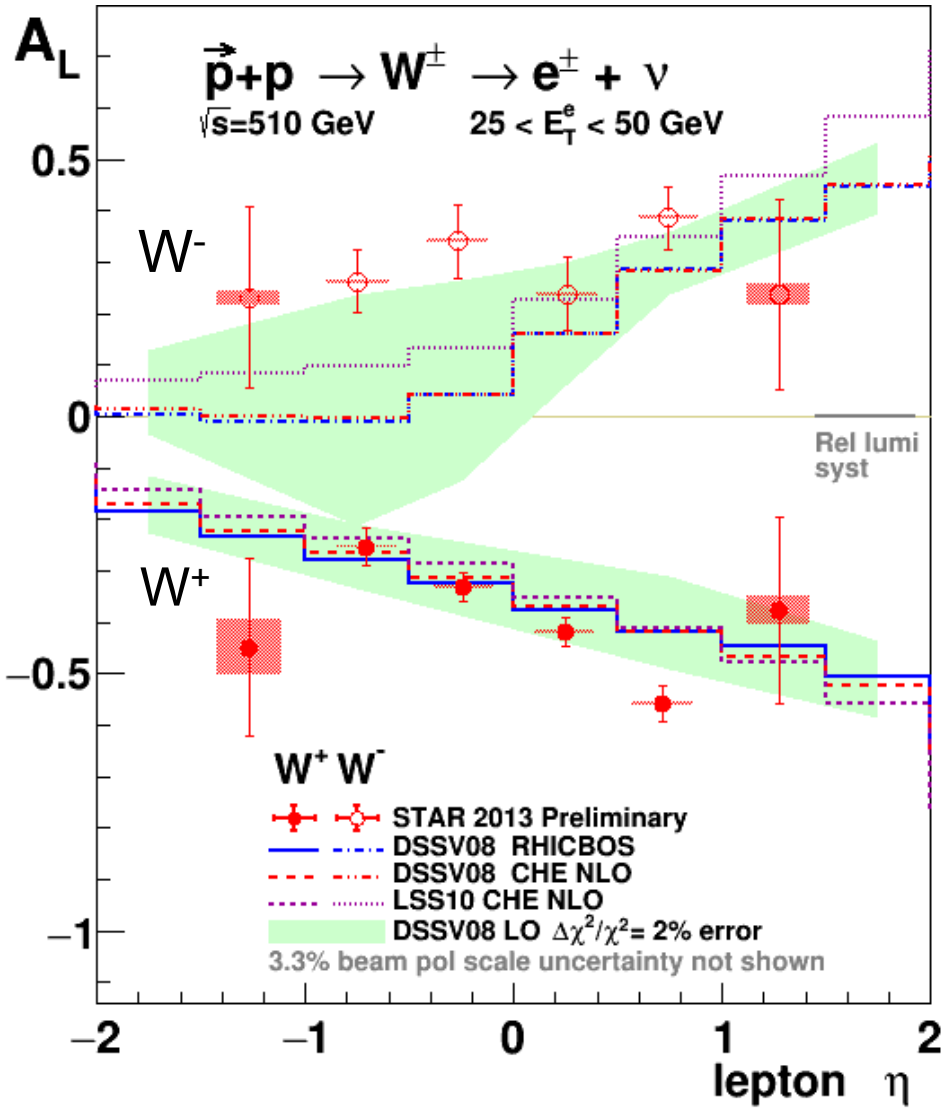
- Impact in reweighting NNPDFpol1.1



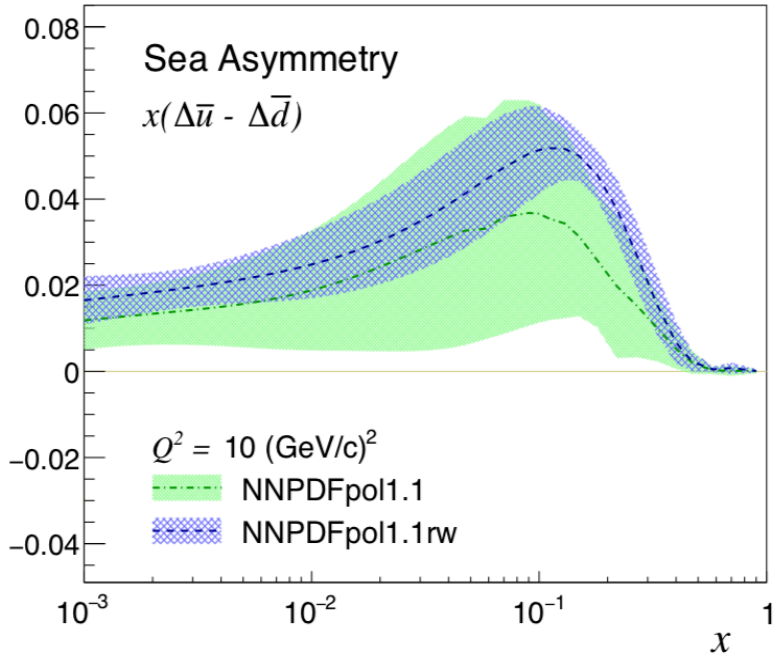
E. Nocera, arXiv:1702.05077

W A_L results – STAR 2013

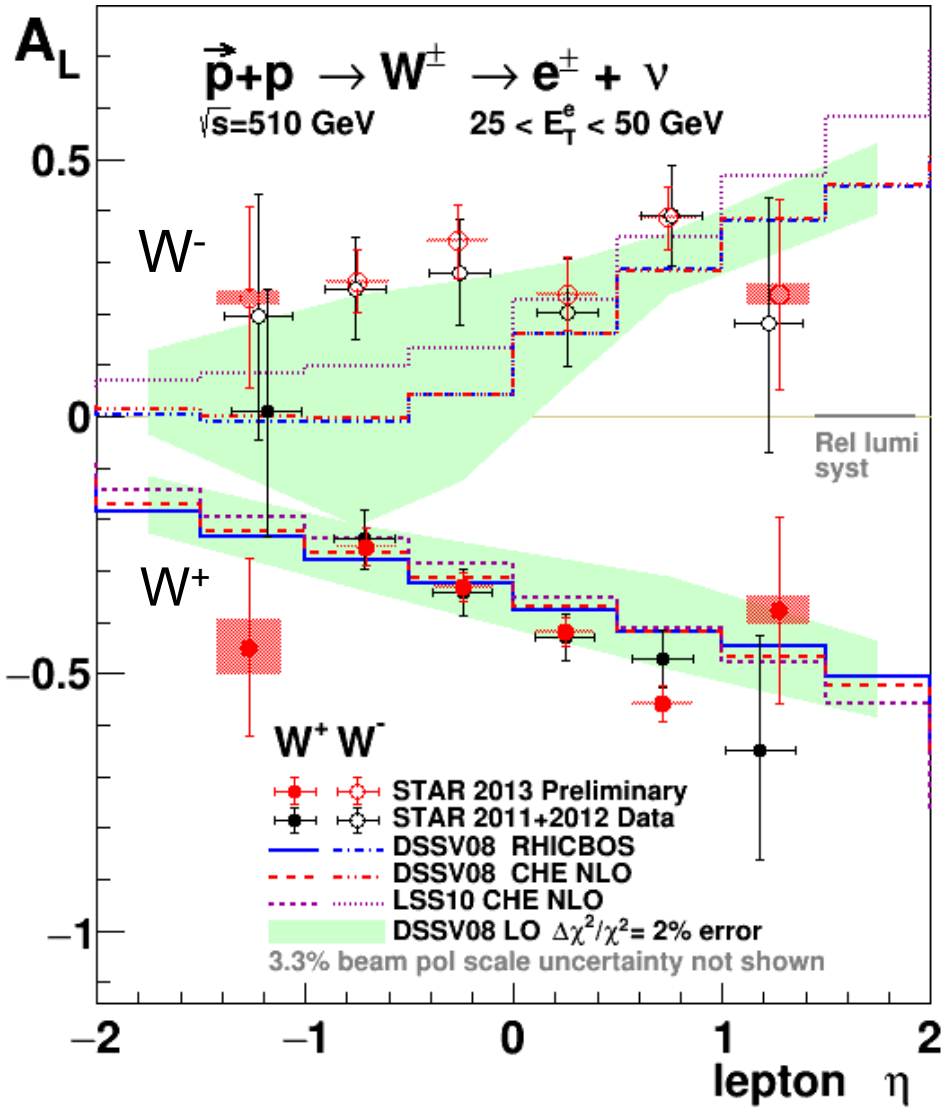


- A_L results at near-forward rapidity added.
- Further confirmed the polarized sea asymmetry:

$$\Delta\bar{u} > \Delta\bar{d}$$



W A_L results – STAR 2013



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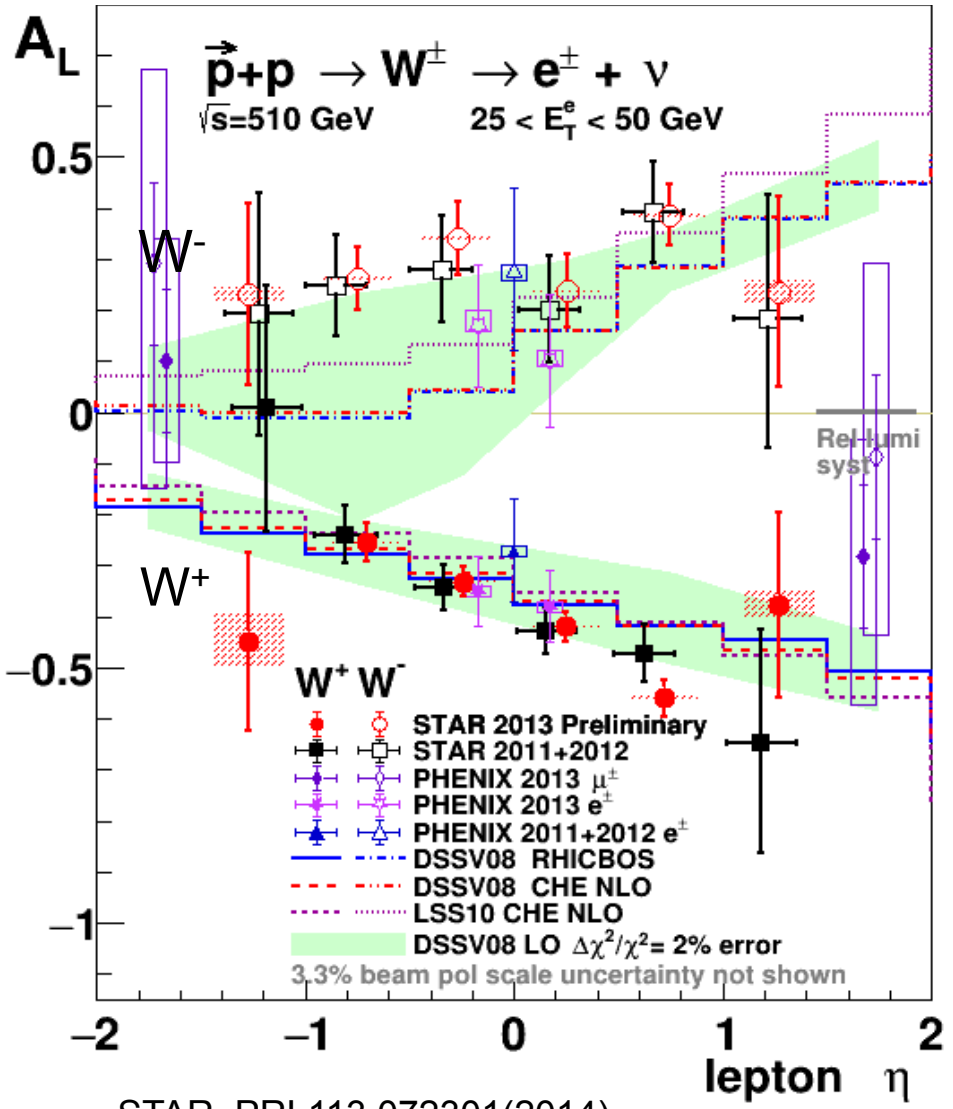
- STAR 2013 results are the most precise measurements of W A_L so far.
- Consistent with 2011+2012 published results, with 40% uncertainty reduced.

W A_L results – STAR 2013



- STAR, PRL113,072301(2014)
- PHENIX, PRD93,051103(2016);PRD98,32007(2018)

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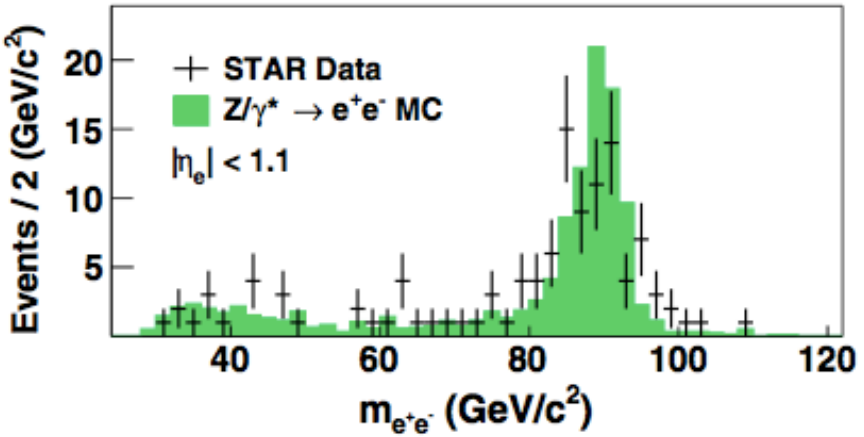
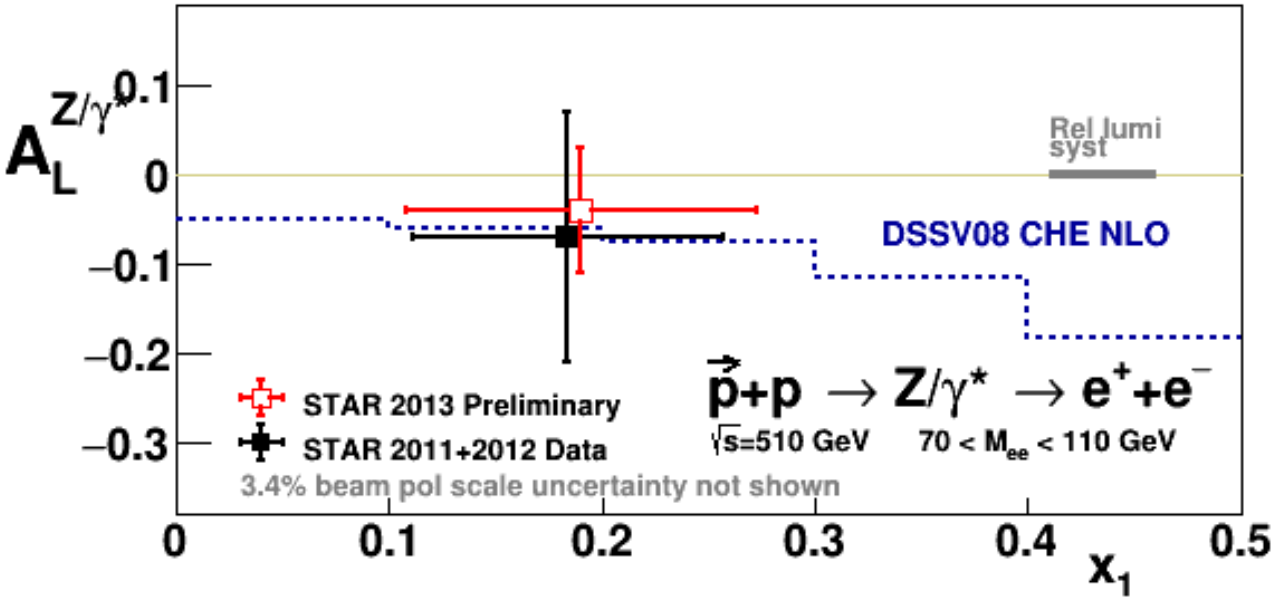
Z/γ^* A_L results from STAR

- A_L from Z^0 can provide additional constraints on $\Delta\bar{u}$, $\Delta\bar{d}$, though statistics limited.



- STAR 2013 A_L results from Z/γ^*:

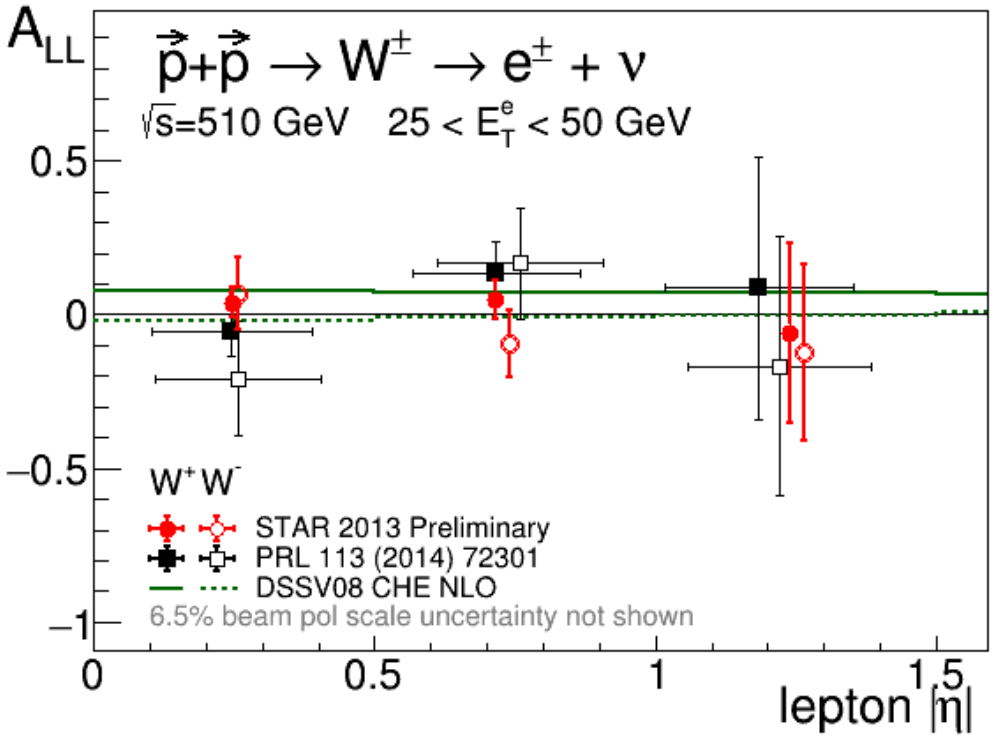


W A_{LL} results from STAR

- Double spin asymmetry of W can also provide access to $\Delta\bar{u}$, $\Delta\bar{d}$ with a different combination:

$$A_{LL}^{W^+} \propto \frac{\Delta u}{u}\frac{\Delta \bar{d}}{\bar{d}}, \quad A_{LL}^{W^-} \propto \frac{\Delta d}{d}\frac{\Delta \bar{u}}{\bar{u}} \qquad \left(A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}\right)$$

- STAR A_{LL} results is consistent with predictions from DSSV



Summary

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- Unique clean probe of sea quark polarization via W production at RHIC:
  - RHIC W A_L results provided important constraints on $\Delta\bar{u}, \Delta\bar{d}$. First clear evidence of flavor asymmetry for polarized sea.
- Most precise W A_L results from STAR 2013 data set:
  - ✓ 40% uncertainty reduced compared to 2011+2012 data.
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Thanks!