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

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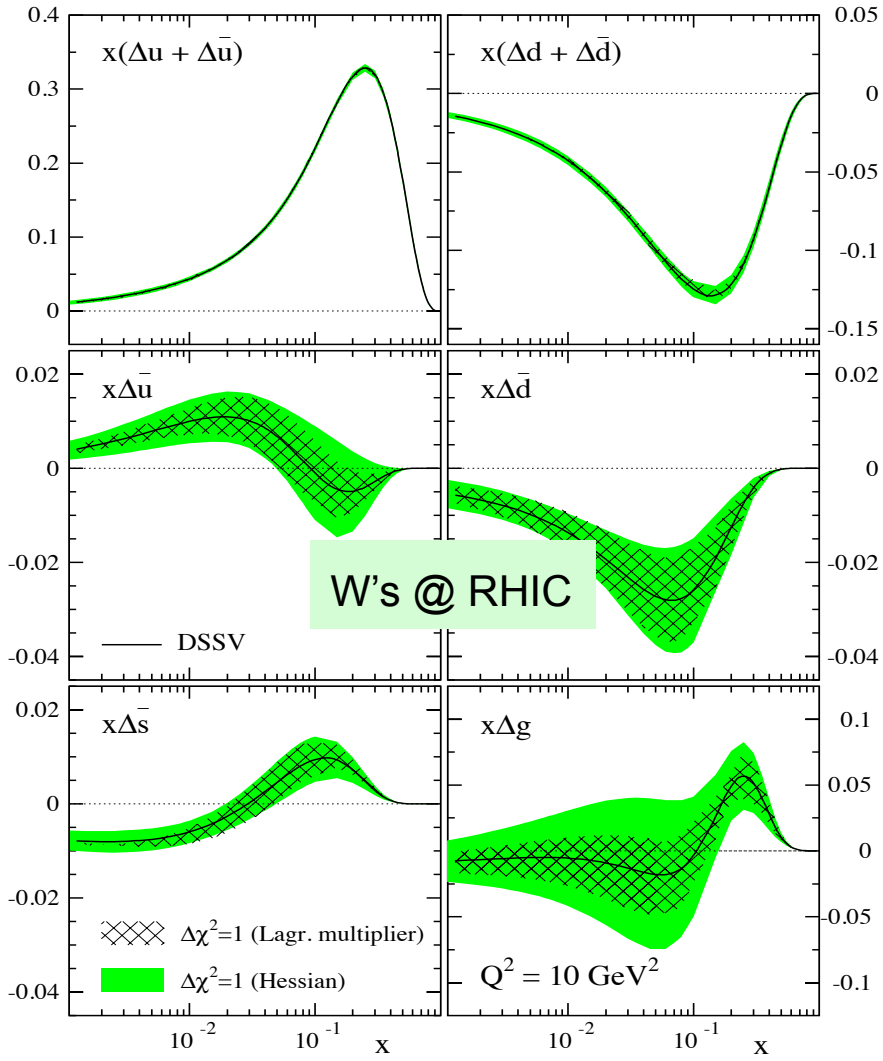
for the STAR Collaboration

Flavor separation of nucleon spin

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

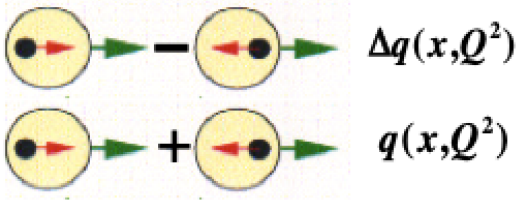


- Spin sum rule (longitudinal):

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + < L_{q,g} >$$

Quark spin, (~30%) -DIS	Gluon spin, Poorly known, RHIC	Orbital Angular Momenta Little known

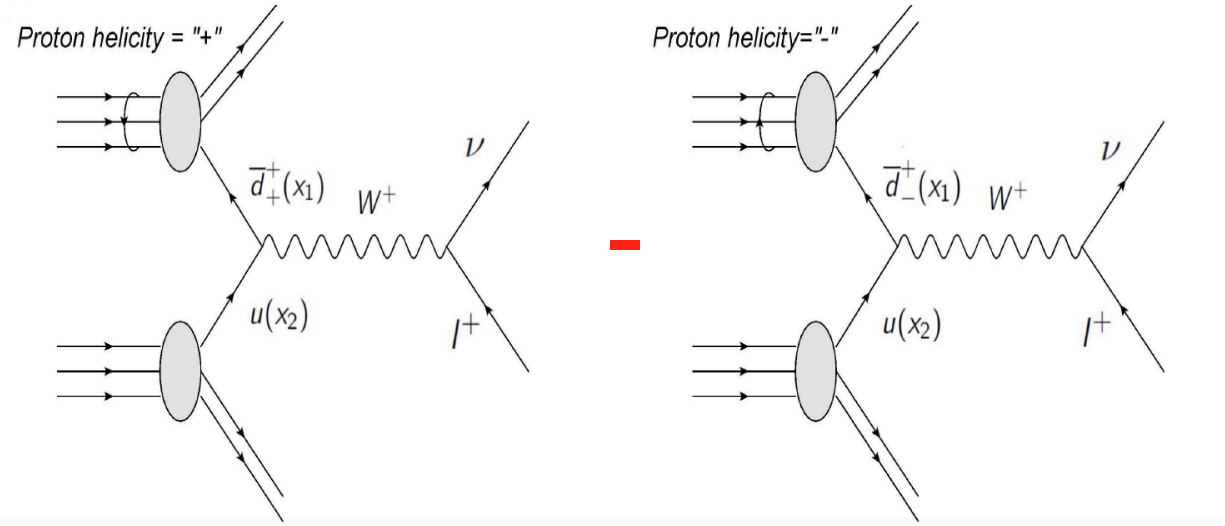
$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



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

Probing sea quark polarization via W production

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



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

- Spin asymmetry measurements:

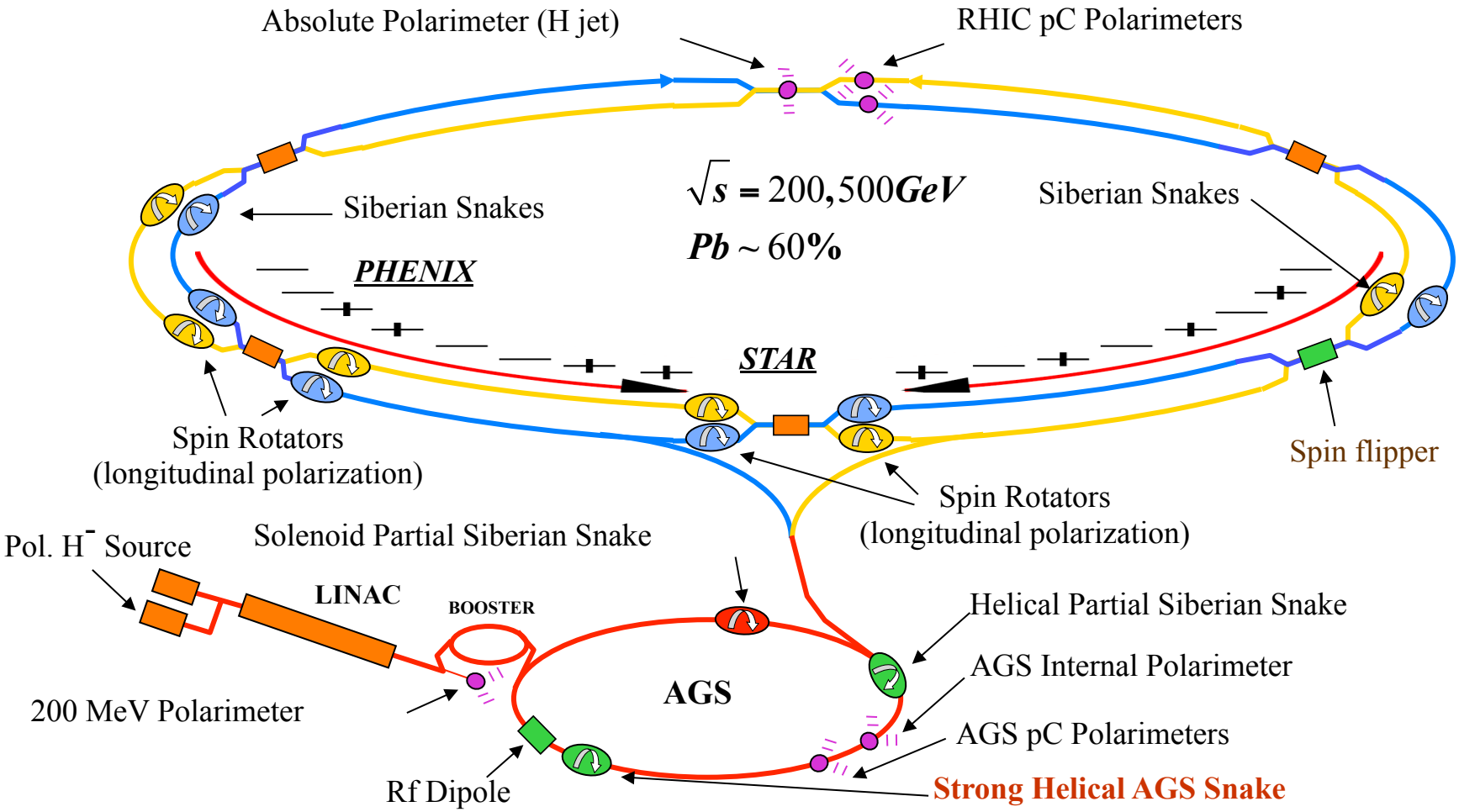
$$A_L^{W^+} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} = \begin{cases} -\dfrac{\Delta u(x_1)}{u(x_1)}, & y_{W^+} >> 0 \\ \dfrac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}, & y_{W^+} << 0 \end{cases}$$

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

★ W's naturally separate quark flavors

★ no fragmentation function involved

RHIC- a polarized proton+proton collider

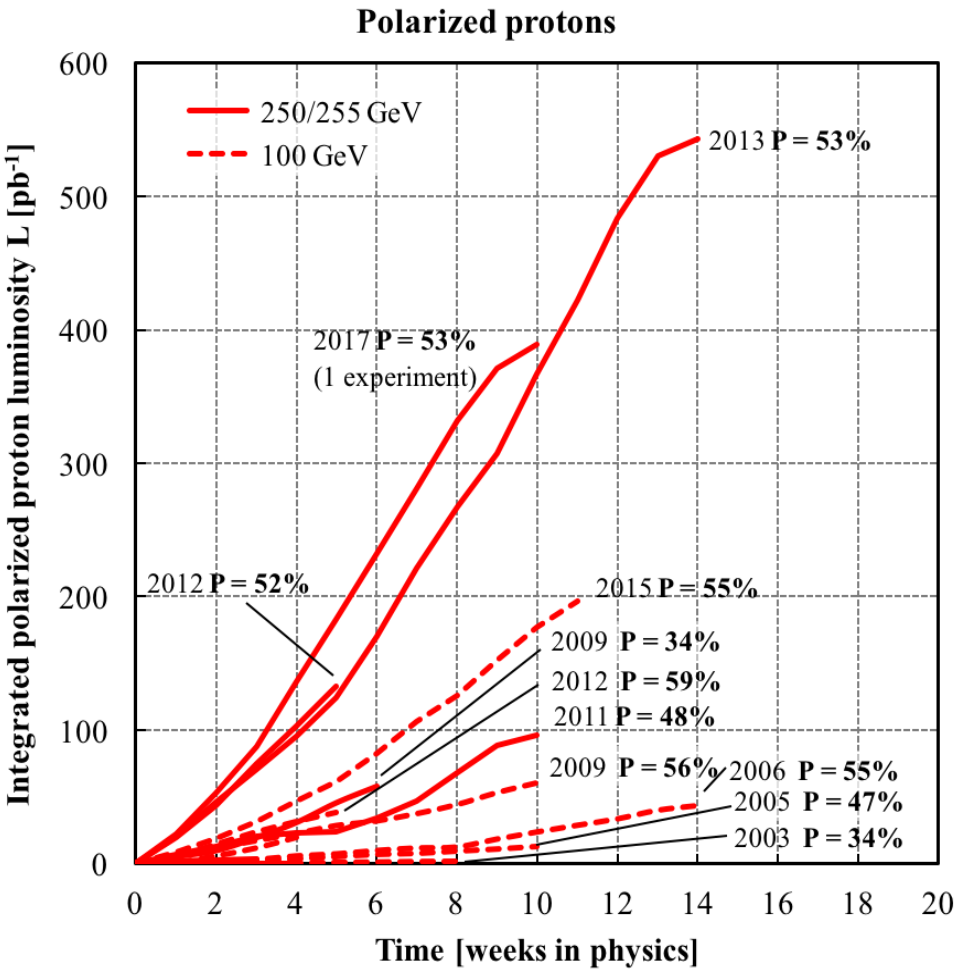


- Polarization direction changes from bunch to bunch
- Spin rotators provide choice of spin orientation

RHIC performance with p+p collisions

- p+p collisions at 500/510 GeV with long. polarization in 2009, 2011, 2012, 2013.
- STAR data samples for W boson 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

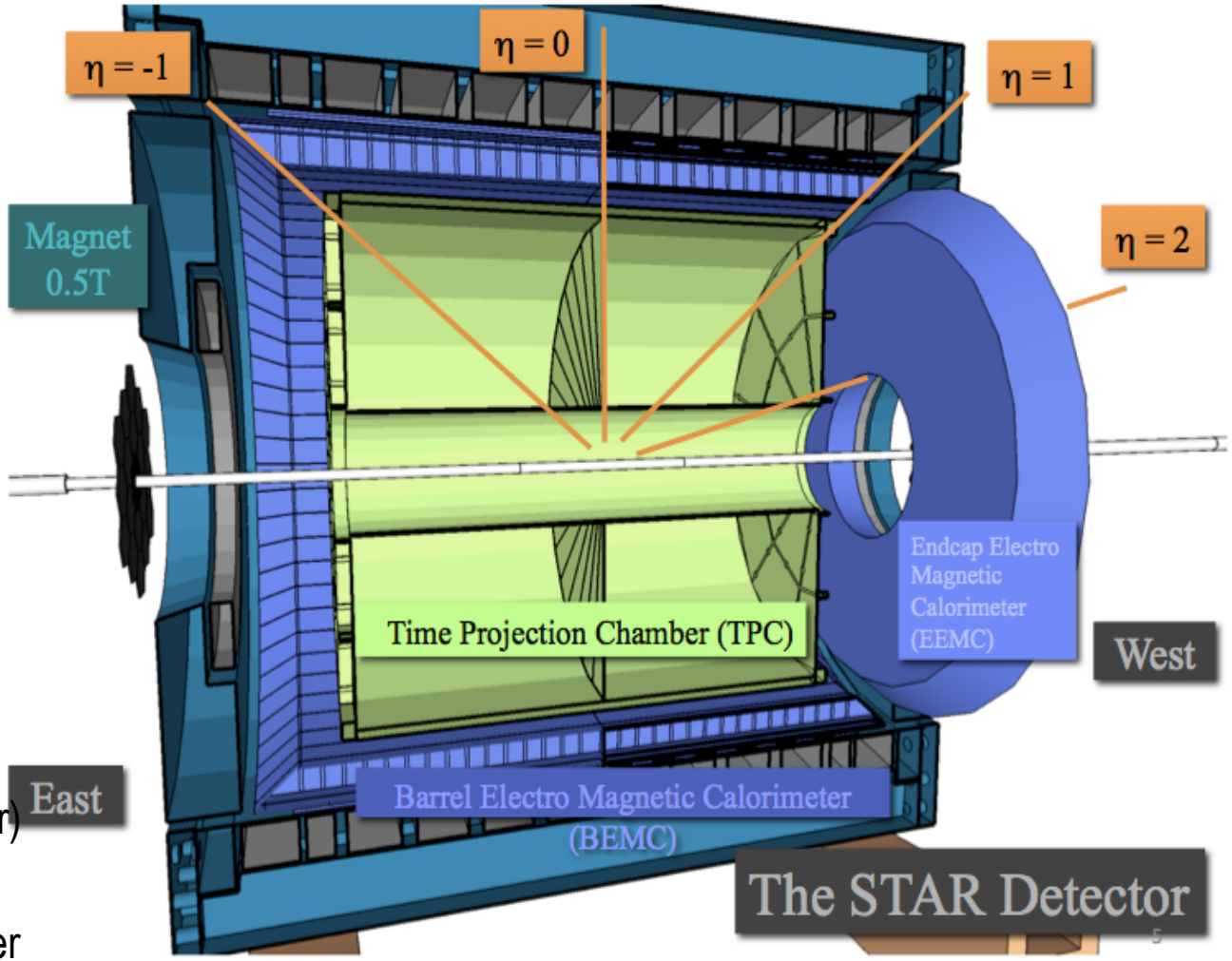
- Beam-Beam Counters
  - $3.4 < |\eta| < 5.0$
- Zero Degree Calorimeters
- Vertex Position Detector

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
  - $2.5 < \eta < 4.0$

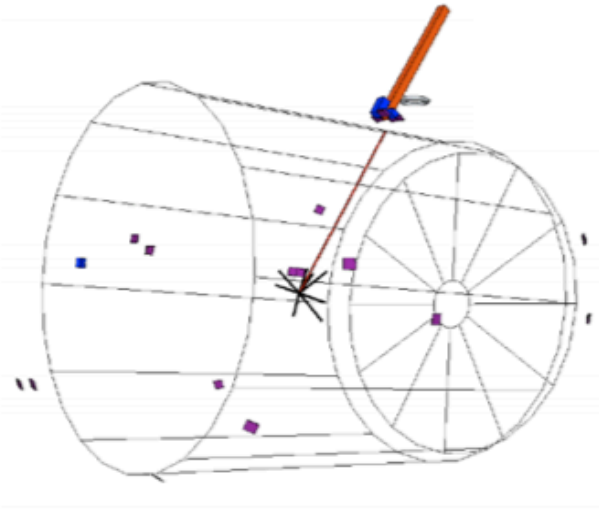


(- those marked red are relevant to W analysis)

W selection via W -> ev at STAR

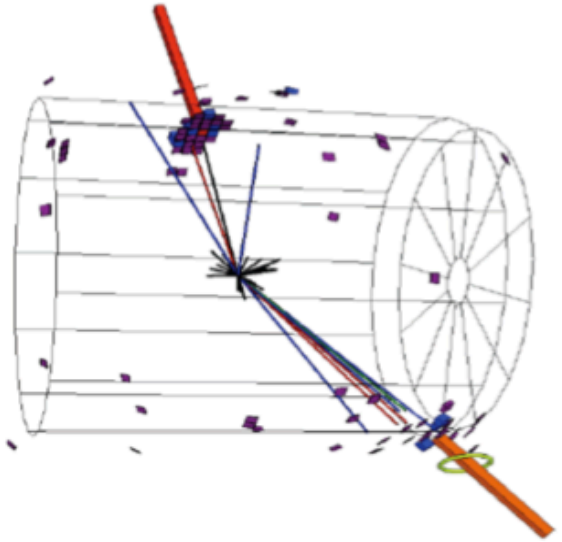
$W \rightarrow e + \nu$ Candidate Event:

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

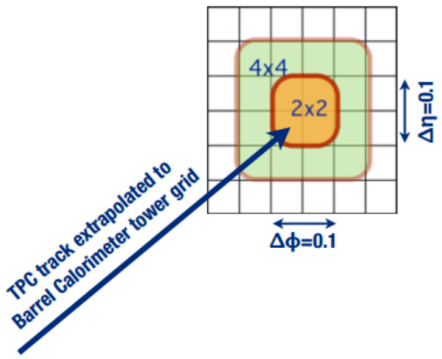


QCD Background Event

- 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

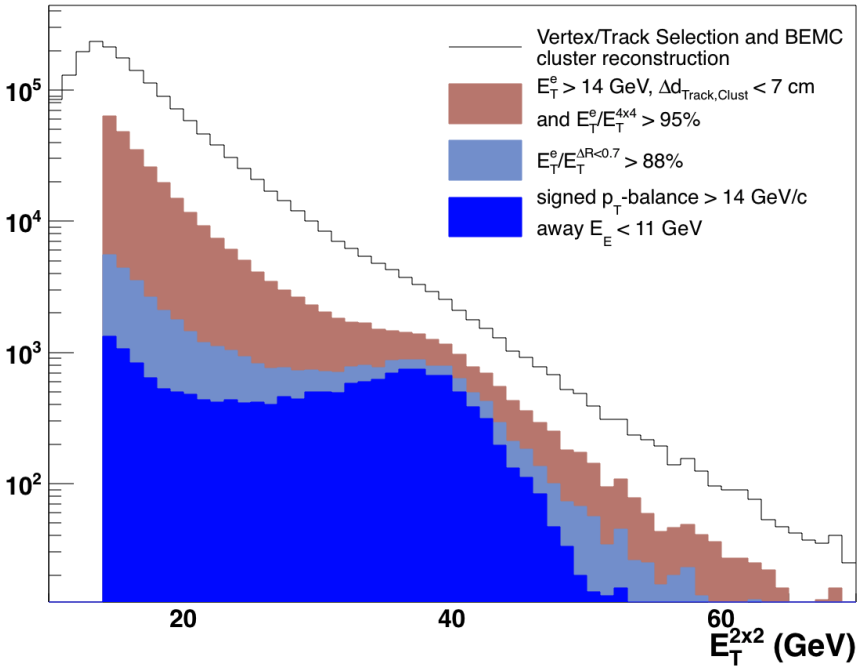


$$\vec{p_T}^{bal} = \vec{p_T}^{e} + \sum_{\Delta R>0.7} \vec{p_T}^{jets}$$

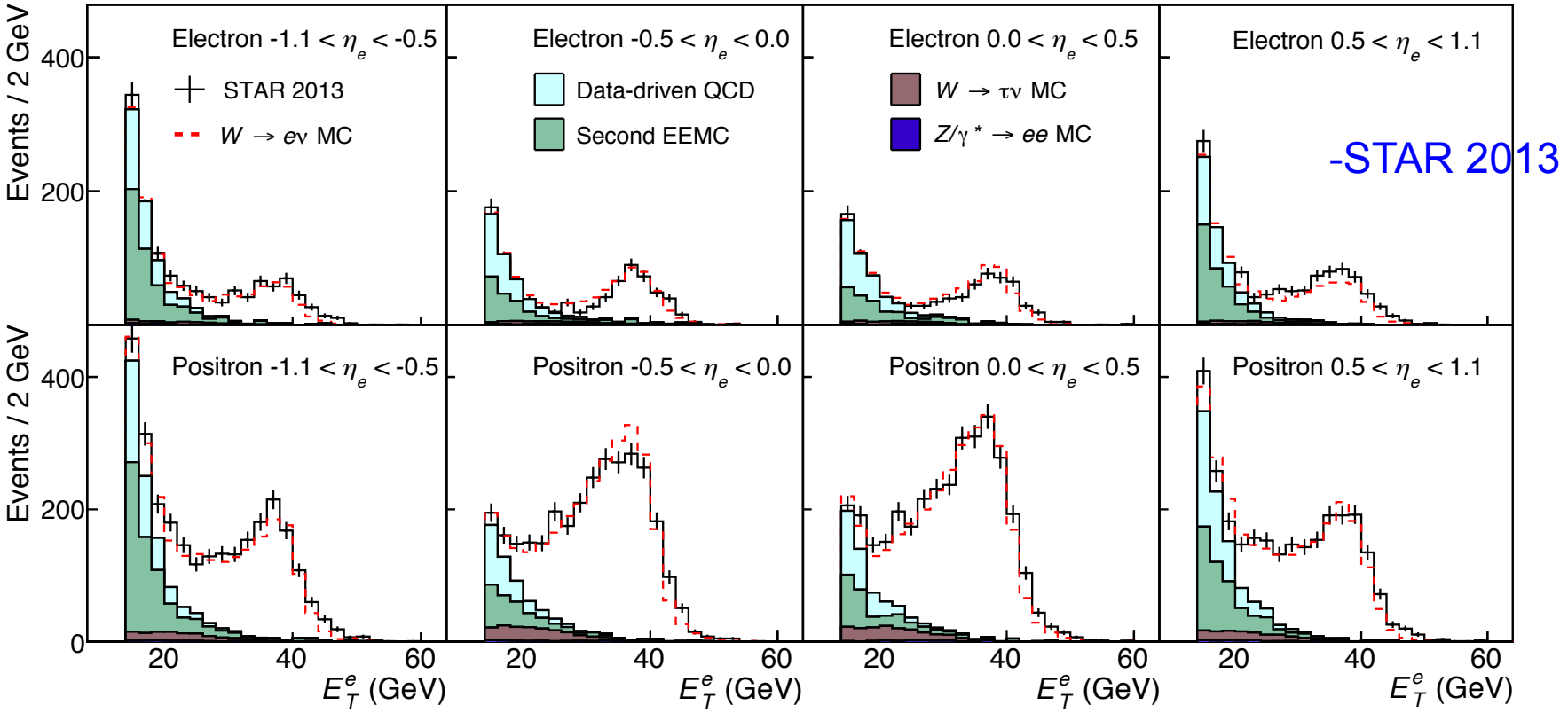
- Isolation ratio $E_{2\times2}/E_{4\times4} > 95\%$
- Isolation ratio $E_T^e/E_T^{\Delta R<0.7} > 88\%$
- Signed P_T-balance $= \frac{\vec{p_T}^{e}\cdot\vec{p_T}^{bal}}{|\vec{p_T}^{e}|} > 14$GeV
- away $E_T < 11$GeV

Signal of Jacobian peak with E_T distribution after selection :

-STAR 2013 with BEMC ($|\eta|<1$)



W selection (|η|<1) : BG Estimation



- Primary Background

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

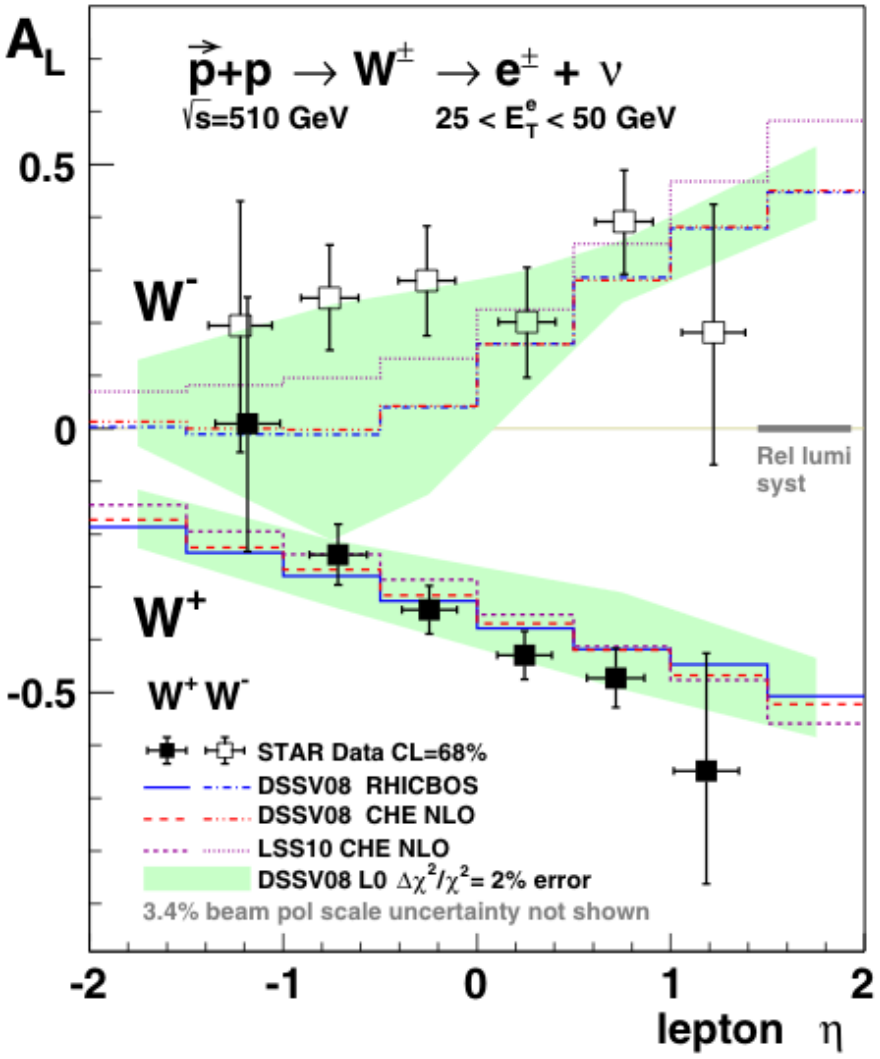
  Second EEMC : due to "jet" escape without East EEMC based on real West EEMC

- Weak decay Background

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

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.

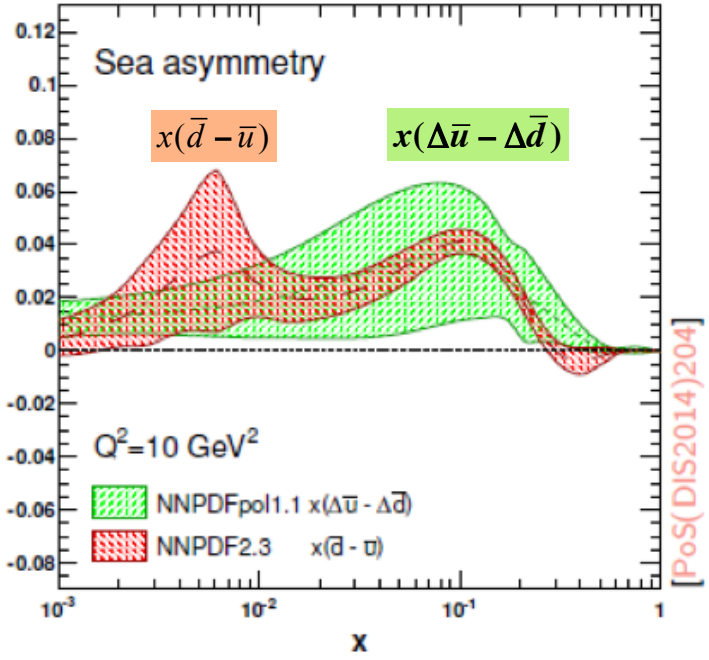
STAR, PRL113(2014)72301

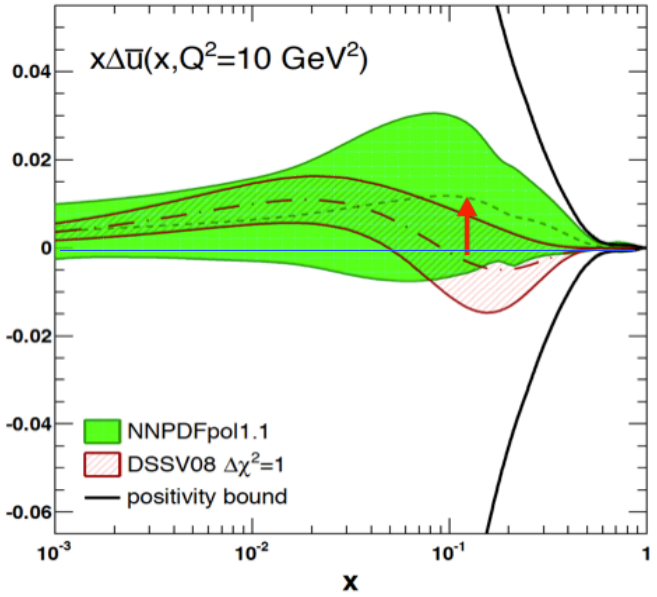
Global Analysis with STAR W A_L results

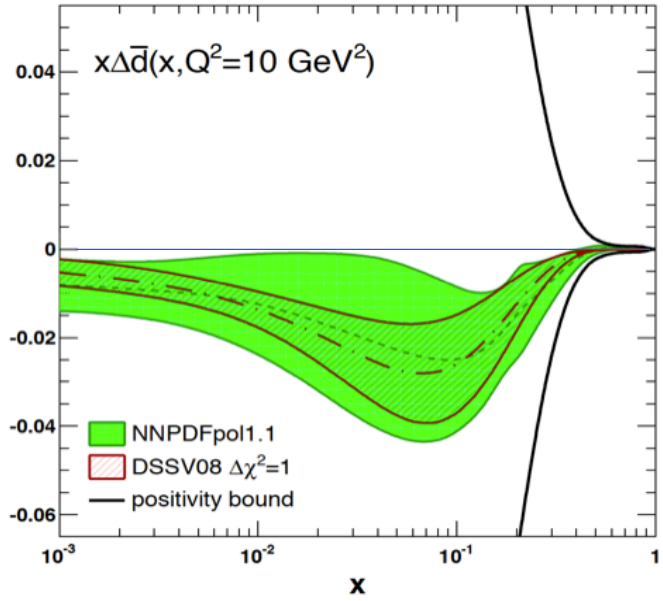
- Big impact seen in NNPDFpol1.1 global analysis after including STAR A_L data.

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

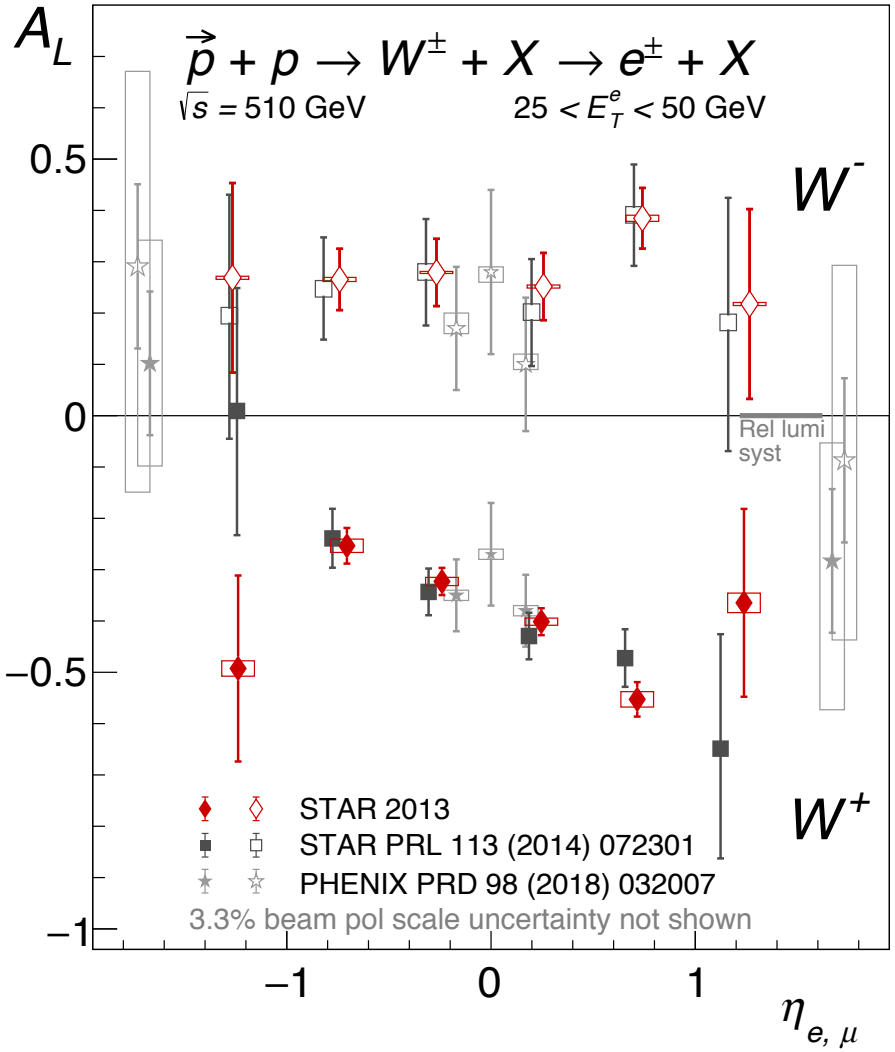
- Polarized sea asymmetry:







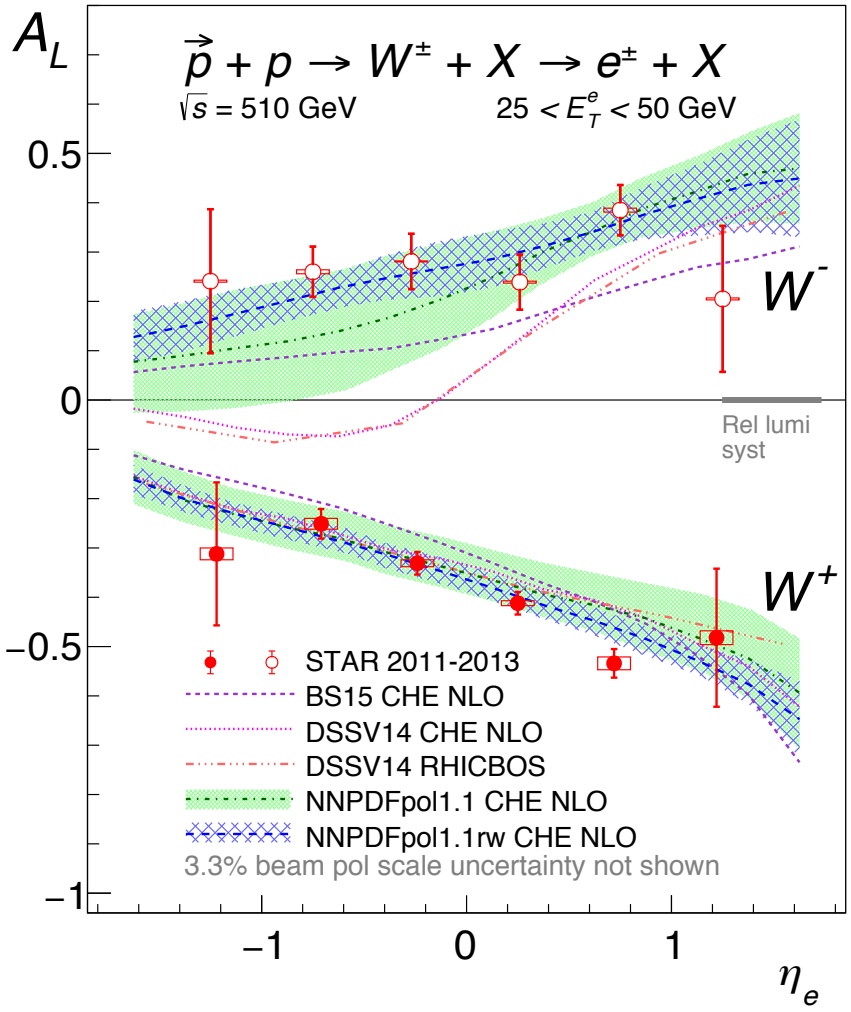
W A_L results – STAR 2013



STAR, PRD99, 051102R(2019)

- ✓ Most precise W A_L results from 2013 STAR dataset
- ✓ Consistent with published RHIC results; with 40-50% smaller uncertainties than STAR 2011+2012 results
- ✓ Confirmed positively polarized anti-up quark first seen in the 2011+2012 data.

W A_L results – STAR 2013



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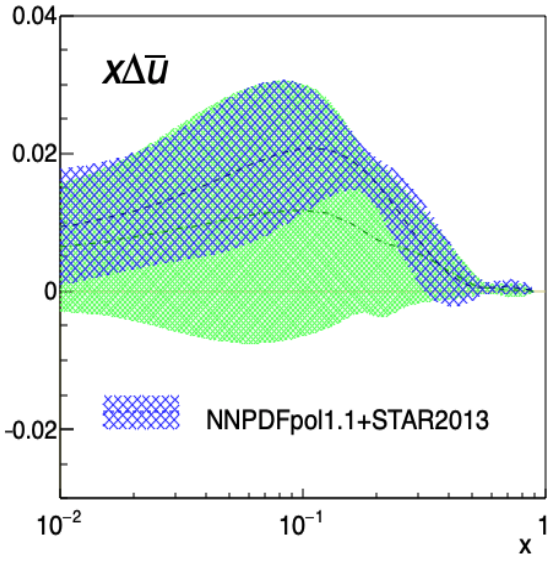
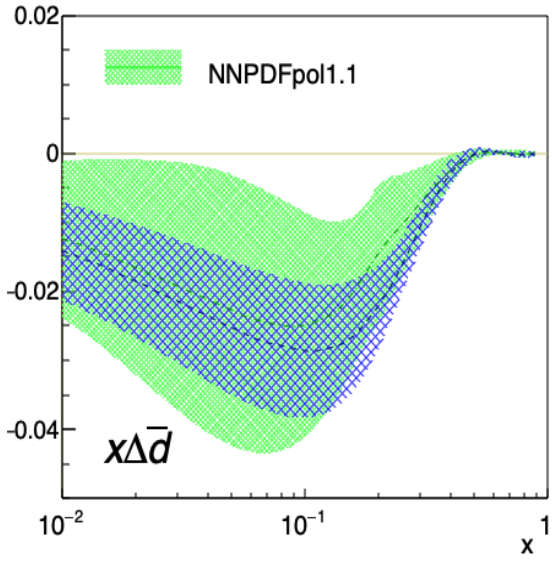
- ✓ Most precise W A_L results from 2013 STAR dataset
- ✓ Consistent with published RHIC results; with 40-50% smaller uncertainties than STAR 2011+2012 results
- ✓ Confirmed positively polarized anti-up quark first seen in the 2011+2012 data.
- ✓ Combined STAR 2011-2013 results in comparison with theoretical predications

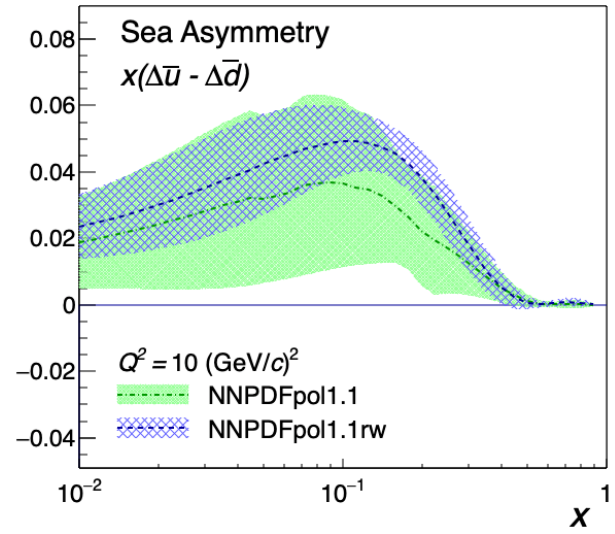
Impact of STAR 2013 W A_L results

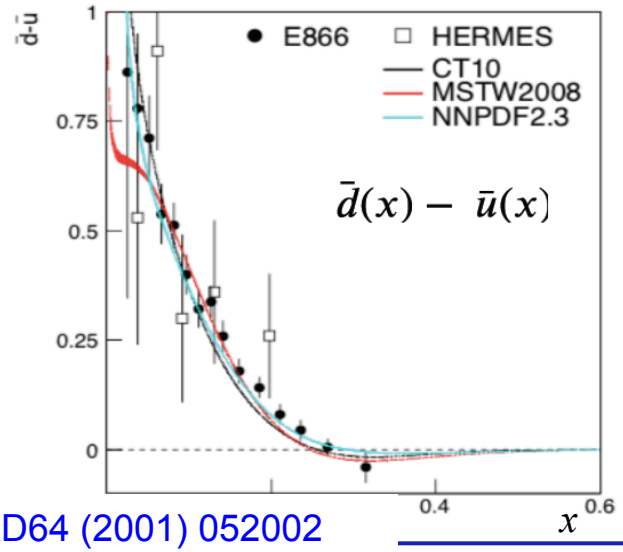
- Reweighting based on NNPDF pol1.1 confirmed the polarized sea asymmetry: $\Delta\bar{u} > \Delta\bar{d}$

STAR, PRD99, 051102R(2019)







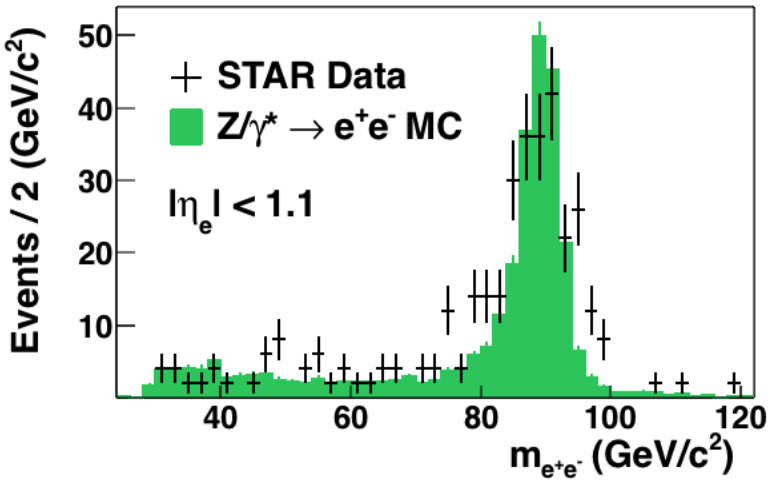


- ✓ The polarized flavor asymmetry is opposite to the unpolarized case !
- ✓ Compatible with Pauli suppression by the polarized valence quarks, among different models.

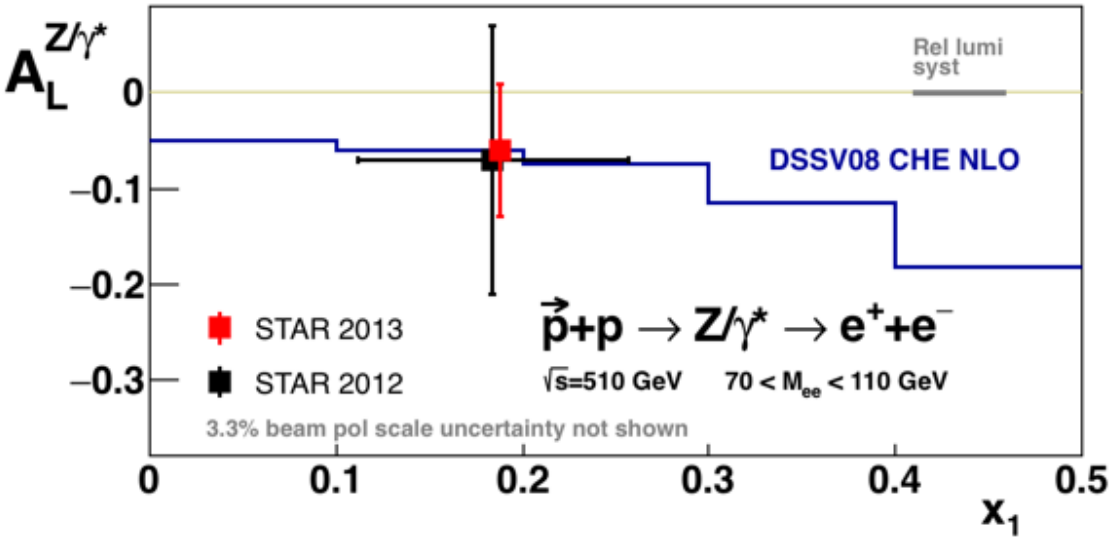
- E866, PRD64 (2001) 052002
- NNPDF2.3, NPB867 (2013) 244

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 .



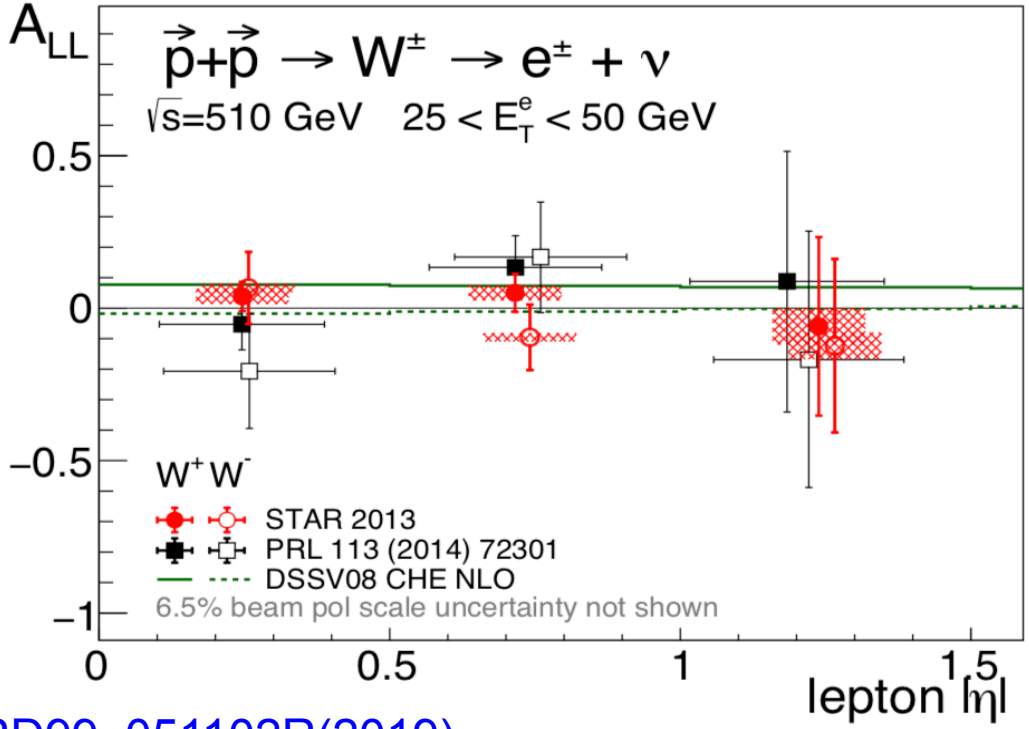
STAR, PRD99, 051102R(2019)

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



STAR, PRD99, 051102R(2019)

Summary

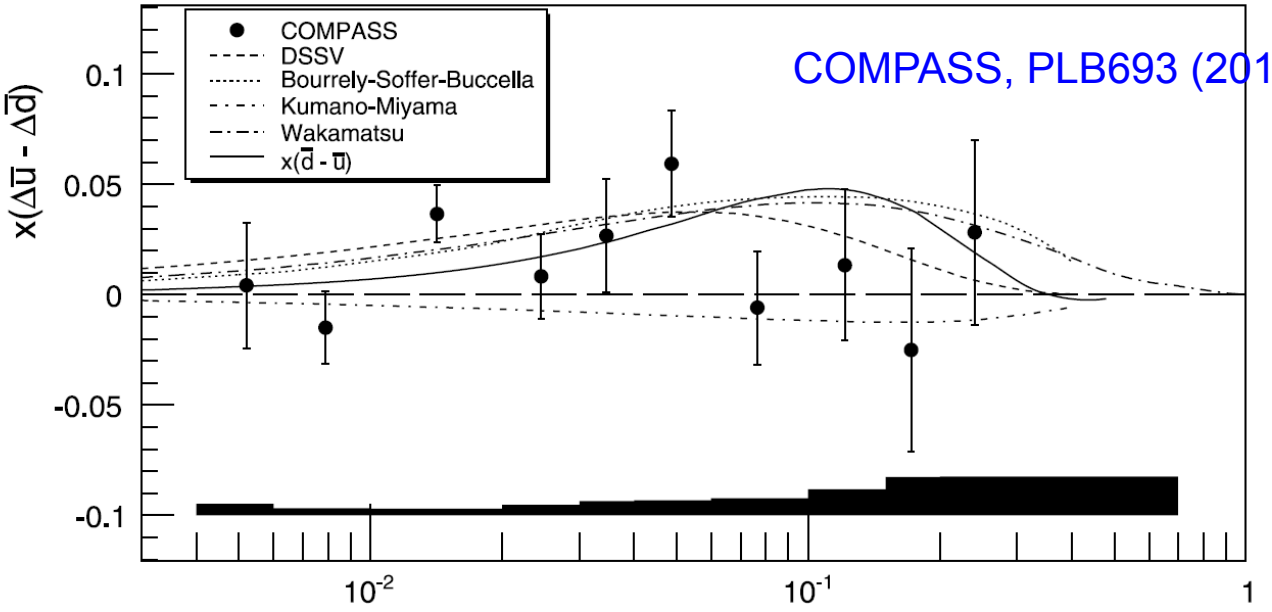
- Sea quark polarization plays an important role in understanding the nucleon spin structure.
- Unique clean probe of sea quark polarization via W production at RHIC:
  - ✓ W A_L results provide important constraints on $\Delta\bar{u}, \Delta\bar{d}$.
- Most precise W A_L results from STAR 2013 data set:
  - ✓ 40% uncertainty reduced compared to 2011+2012 data.
  - ✓ Clear evidence of flavor asymmetry for polarized sea, with opposite sign to the unpolarized case.

-STAR, PRD99, 051102R(2019)

Backup slides

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

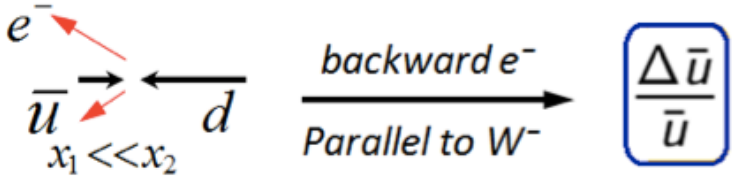
unp. E866 $\int_{0}^{1} \left(\bar{u}-\bar{d}\right)dx = -0.118 \pm 0.012 \quad @ \quad Q^2 = 54\ \left(GeV/c\right)^2$

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

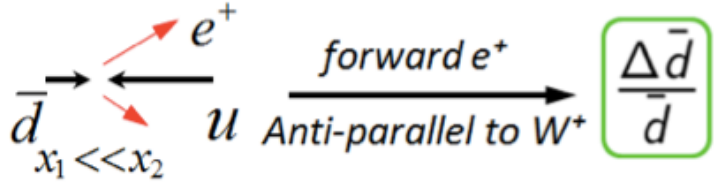
Expectation of W A_L at RHIC

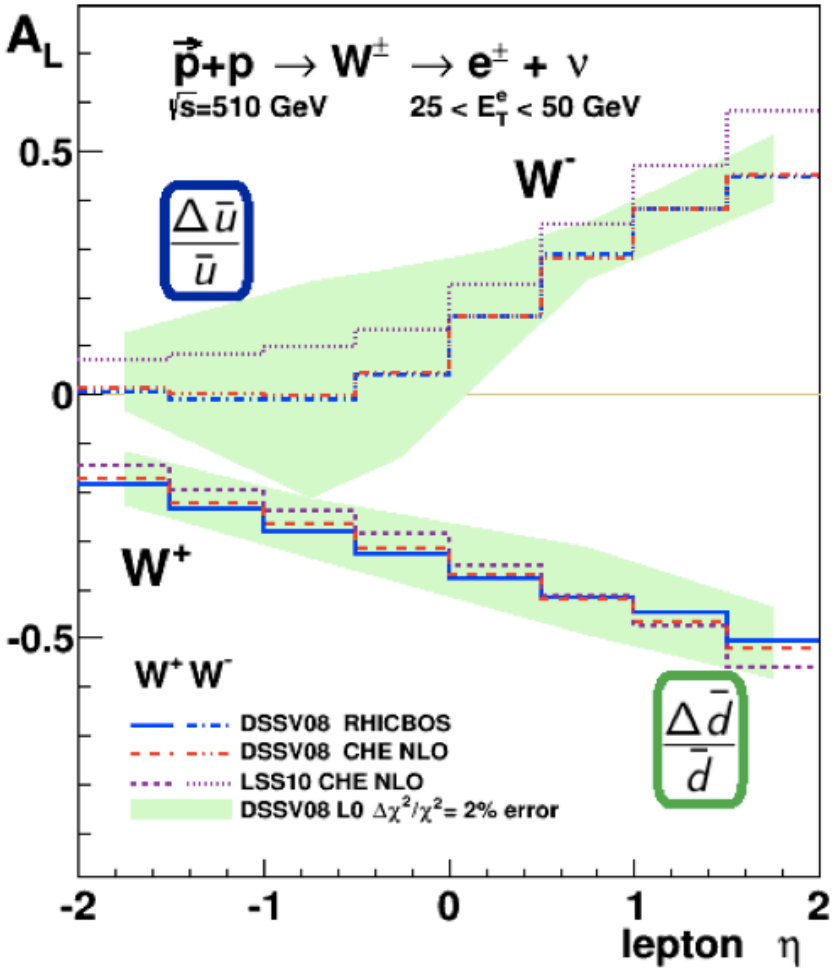
- Large parity-violating asymmetries expected.
- Simplified interpretation at forward and backward rapidity:

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



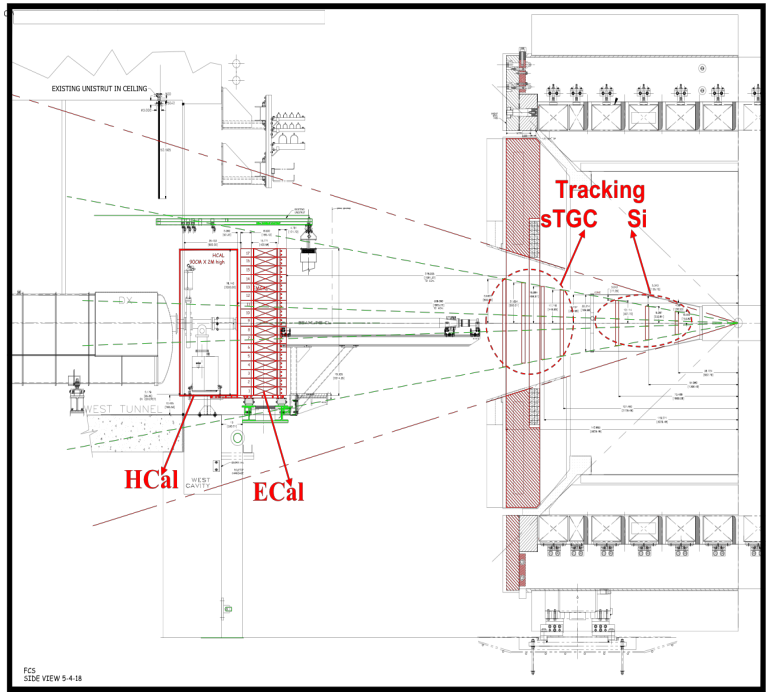
$$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2)+\Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2)+\bar{d}(x_1)u(x_2)}$$





STAR forward detector upgrade

- **STAR forward upgrade:**
  - ✓ located at the West side of STAR
  - ✓ coverage: 2.5 < h < 4



- **Key components:**
  - ✓ Calorimetry: ECal and HCal
  - ✓ Tracking:
    Silicon tracker and
    small-strip Thin Gap Chambers (sTGC)

- **Operation:**
  pp, pA and AA data taking in FY2021~2025 in parallel with sPHENIX data taking period.

- **Physics:**
  enables unique opportunities to cold QCD and Heavy ion physics

Future RHIC Spin in 2021+

Year	√s (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
2021/22	$p^{\uparrow}p$ @ 510	1.1 fb^{-1} 10 weeks	TMDs at low and high x	A_{UT} for Collins observables, i.e. hadron in jet modulations at $\eta > 1$	Ecal + Hcal +Tracking
2021/22	$\vec{p}\,\vec{p}$ @ 510	1.1fb^{-1} 10 weeks	$\Delta g(x)$ at small x	A_{LL} for jets, di-jets, h/γ-jets at $\eta > 1$	Ecal + HCal
2024	$p^{\uparrow}p$ @ 200	300 pb^{-1} 8 weeks	Subprocess driving the large A_N at high x_F and η	A_N for charged hadrons and flavor enhanced jets	Ecal + Hcal +Tracking
2024	$p^{\uparrow}Au$ @ 200	1.8 pb^{-1} 8 weeks	Nature of the initial state and hadronization in nuclear collisions Clear signatures for Saturation	R_{pAu} direct photons and DY Dihadrons, γ-jet, h-jet, diffraction	Ecal + Hcal +Tracking
	$p^{\uparrow}Al$ @ 200	12.6 pb^{-1} 8 weeks	A-dependence of nPDF, A-dependence for Saturation	R_{pAl}: direct photons and DY Dihadrons, γ-jet, h-jet, diffraction	Ecal + Hcal +Tracking

Forward detector upgrade required

STAR → **sPHENIX**

EIC detector

- RHIC is the world's only polarized hadron hadron collider
- Unique physics opportunities in pp and pA