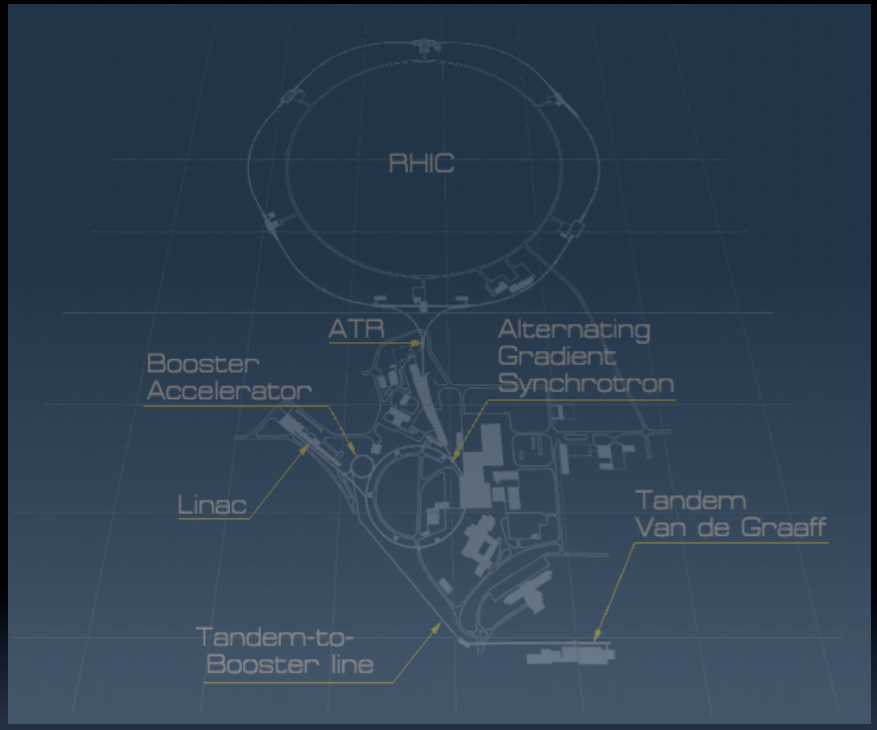
Recent results from the RHIC Longitudinal Spin program



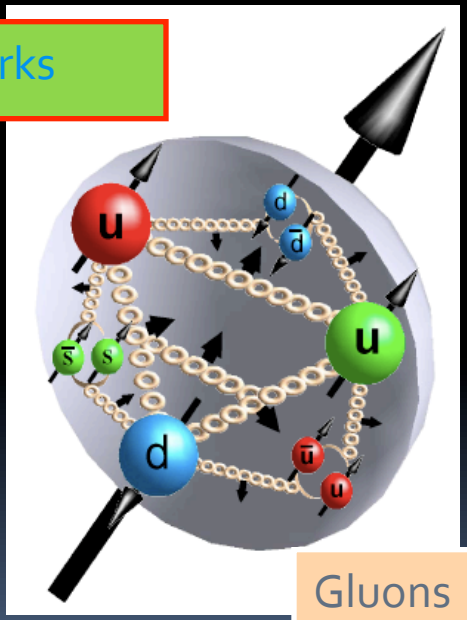
Renee Fatemi

10-24-2012

How do quarks and gluons combine to form the well known proton spin?

Proton

Quarks



Gluons

S_q **Quark spin**

S_G **Gluon spin**

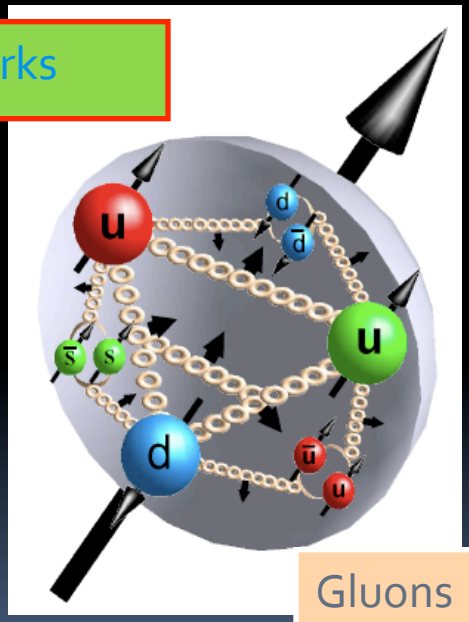
L_q **Quark orbital angular momentum**

L_G **Gluon orbital angular momentum**

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_Q + L_G$$

Proton

Quarks



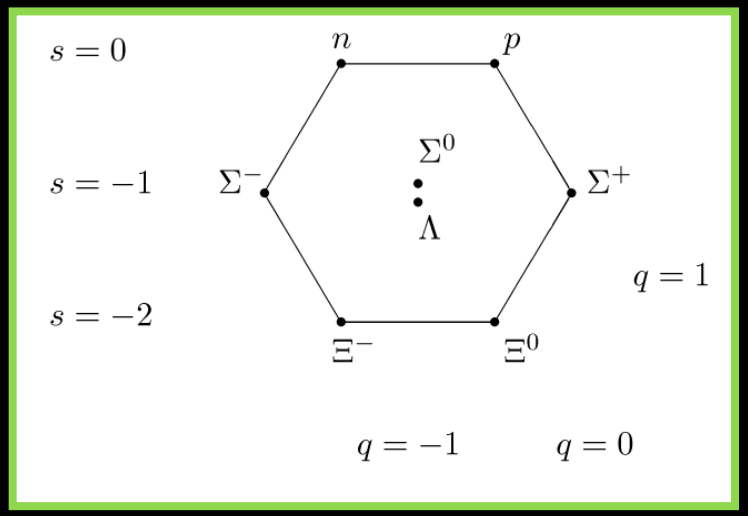
Gluons

S_q	Quark spin
S_G	Gluon spin
L_q	Quark orbital angular momentum
L_G	Gluon orbital angular momentum

Proton Spin Structure

The magnetic moment of a particle is related to its spin

$$\vec{\mu} = g \frac{e}{2mc} \vec{S}$$

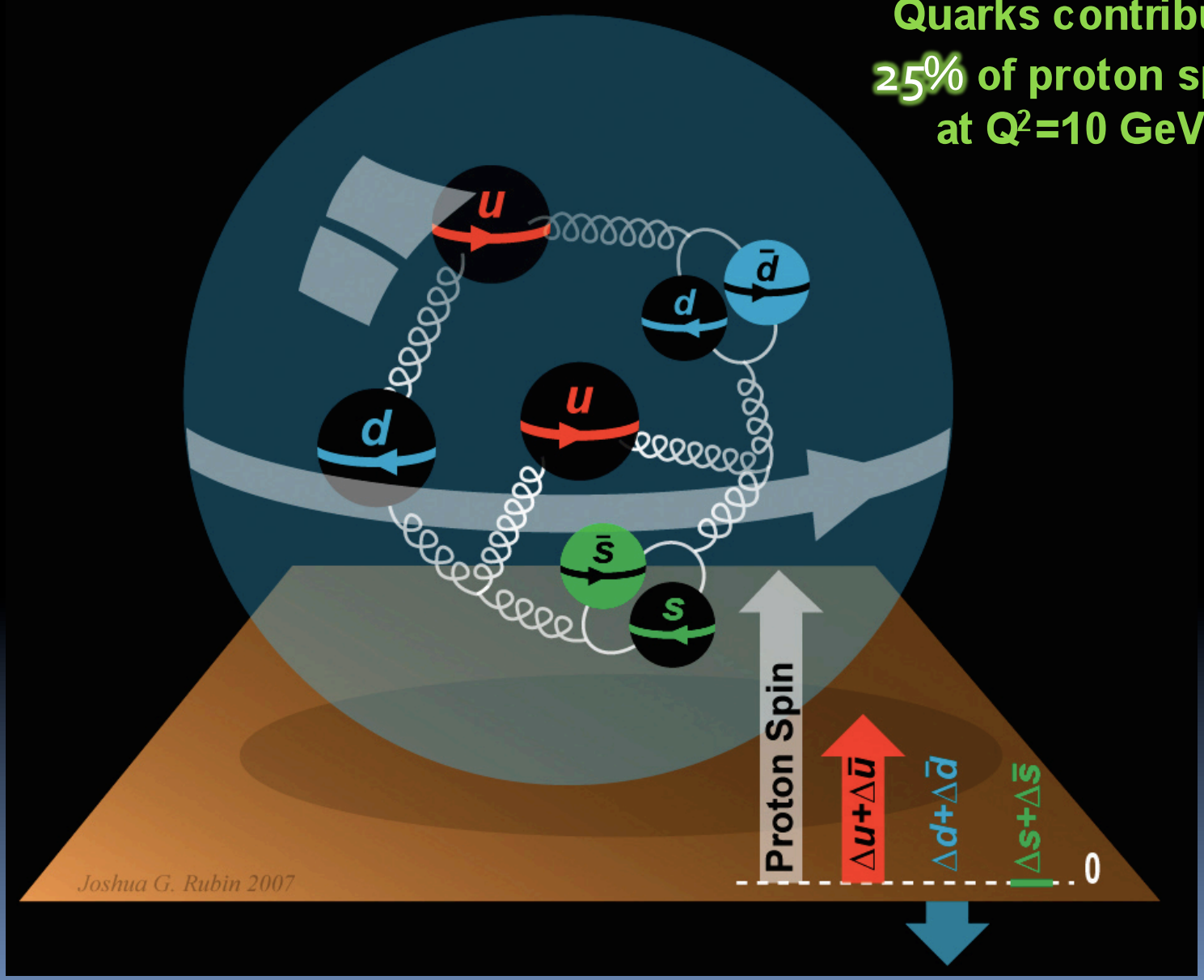


For Dirac particles g = 2. In 1933 Frisch and Stern measured g = 5.59 for the proton. ***CLEAR INDICATION OF SUBSTRUCTURE!***

The Constituent Quark Model reproduces the mass and magnetic moments of baryons fairly well so …. ***INDICATES PRIMARILY VALENCE U + D CONTRIBUTION?***

After 20 Years…

Quarks contribute 25% of proton spin! at Q^2=10 GeV^2



After 20 Years…

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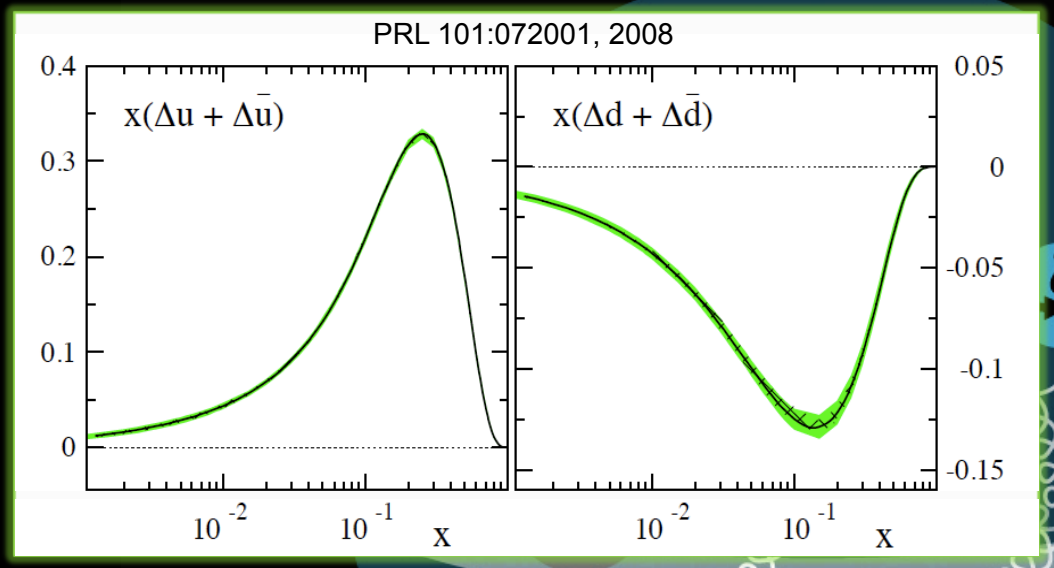

After 20 Years…

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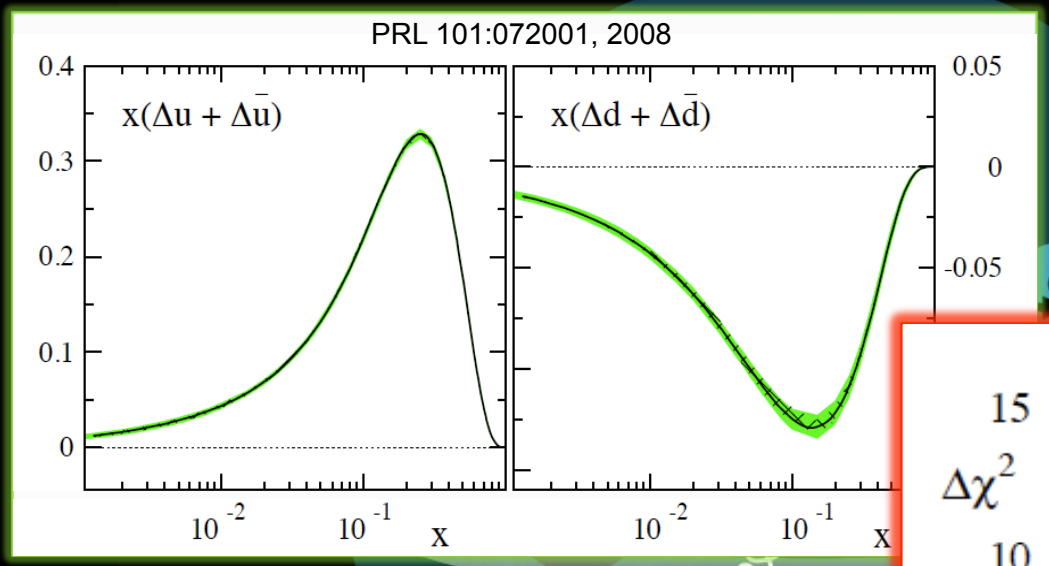
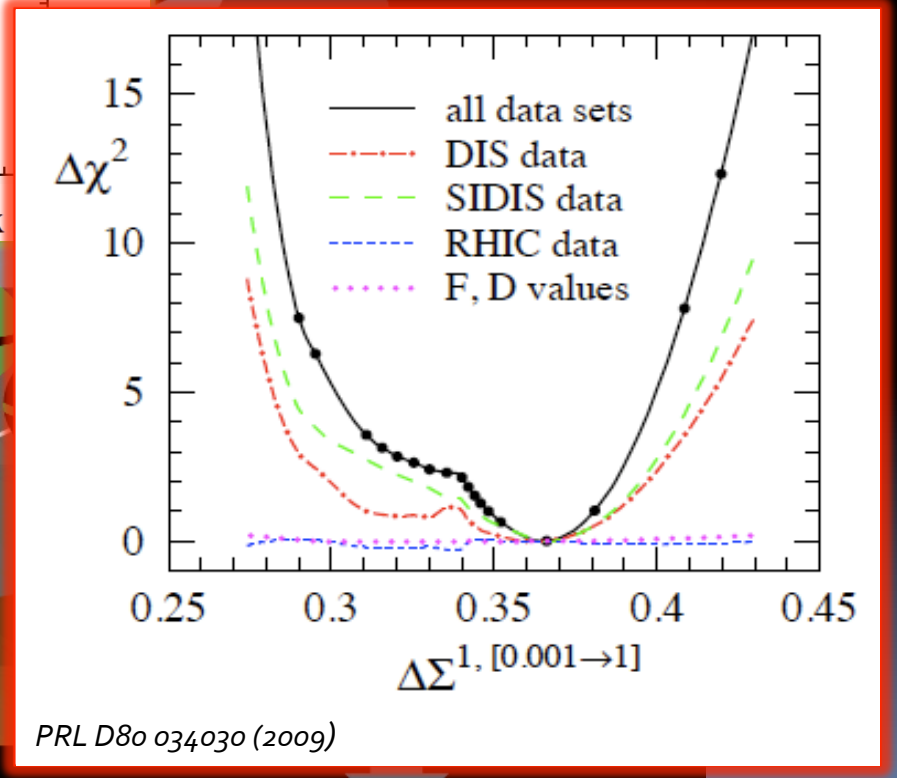
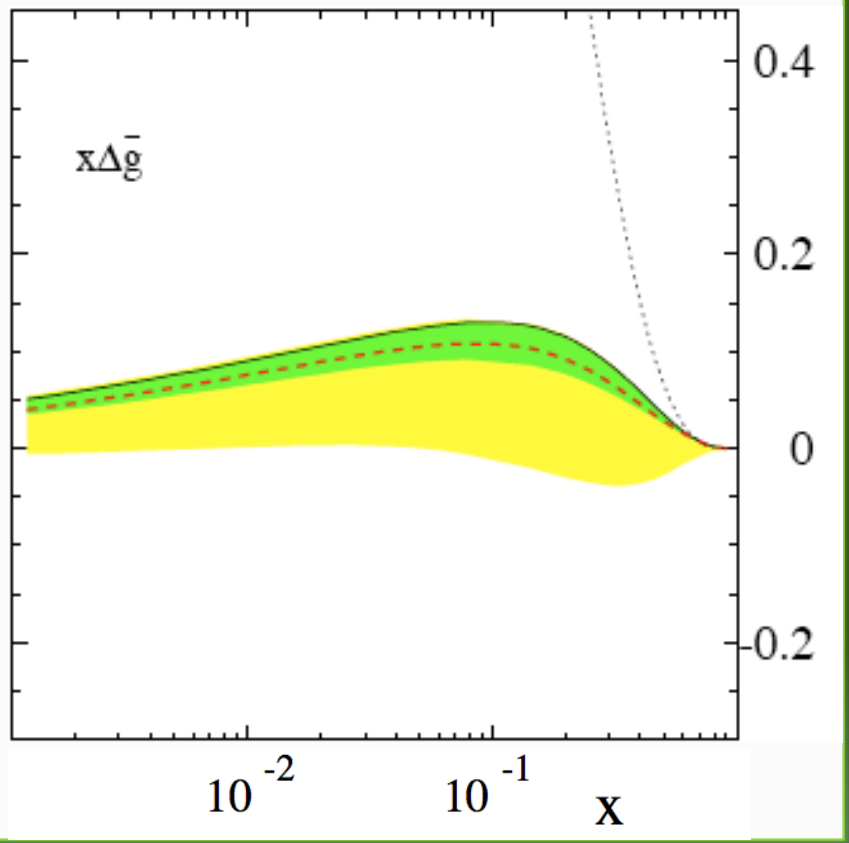




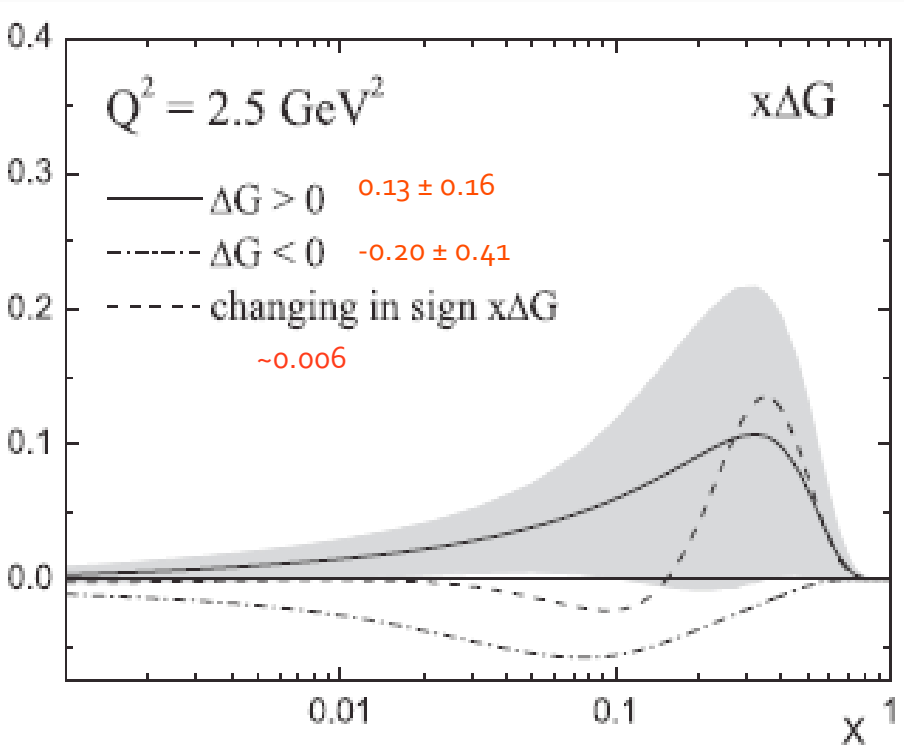
PRL D80 034030 (2009)

"Sans-RHIC" $\Delta g(x)$

Phys. Rev. D71 094018 (2005)

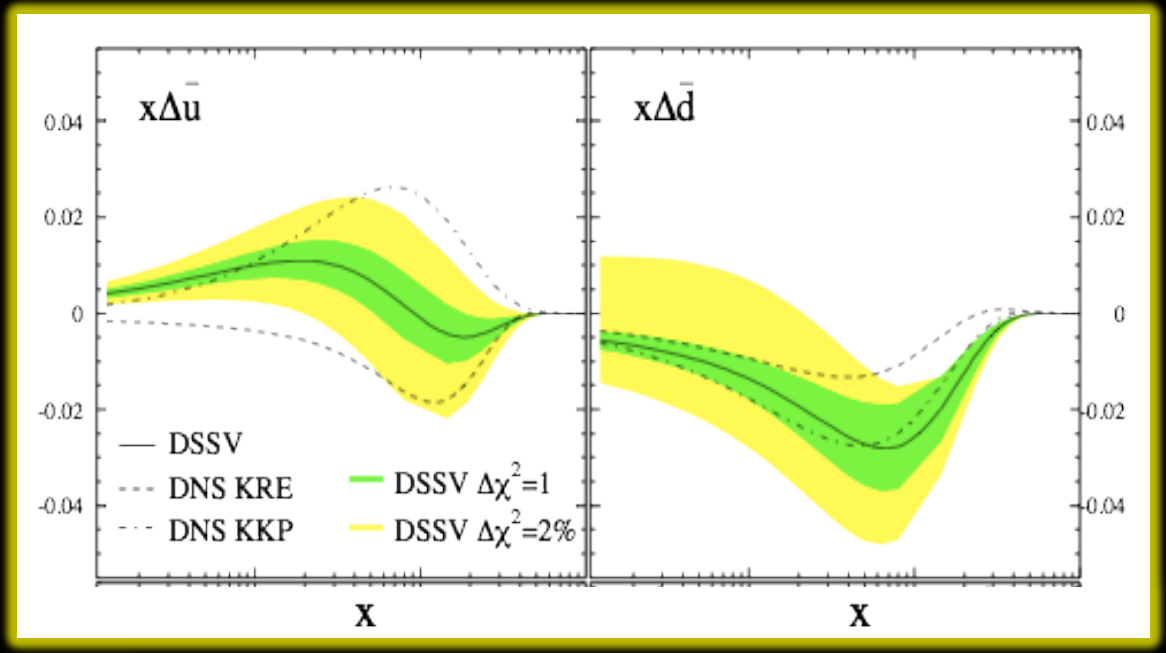


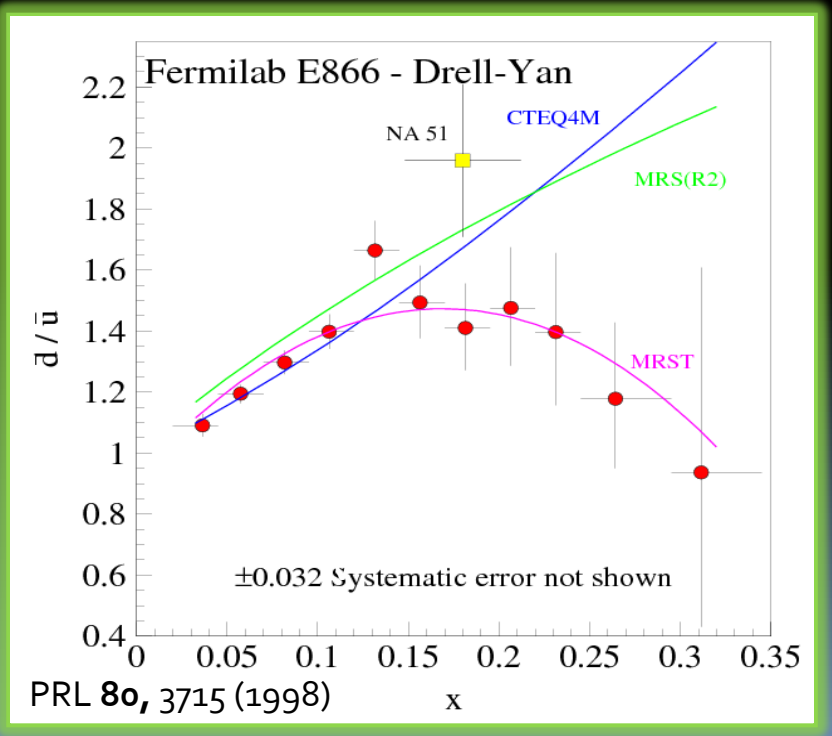
PRD 75, 074027 (2007)



Neither the sign or the magnitude of ΔG are well constrained by DIS + SIDIS Data!

"Sans-RHIC" $\Delta\bar{u}(x)$ & $\Delta\bar{d}(x)$

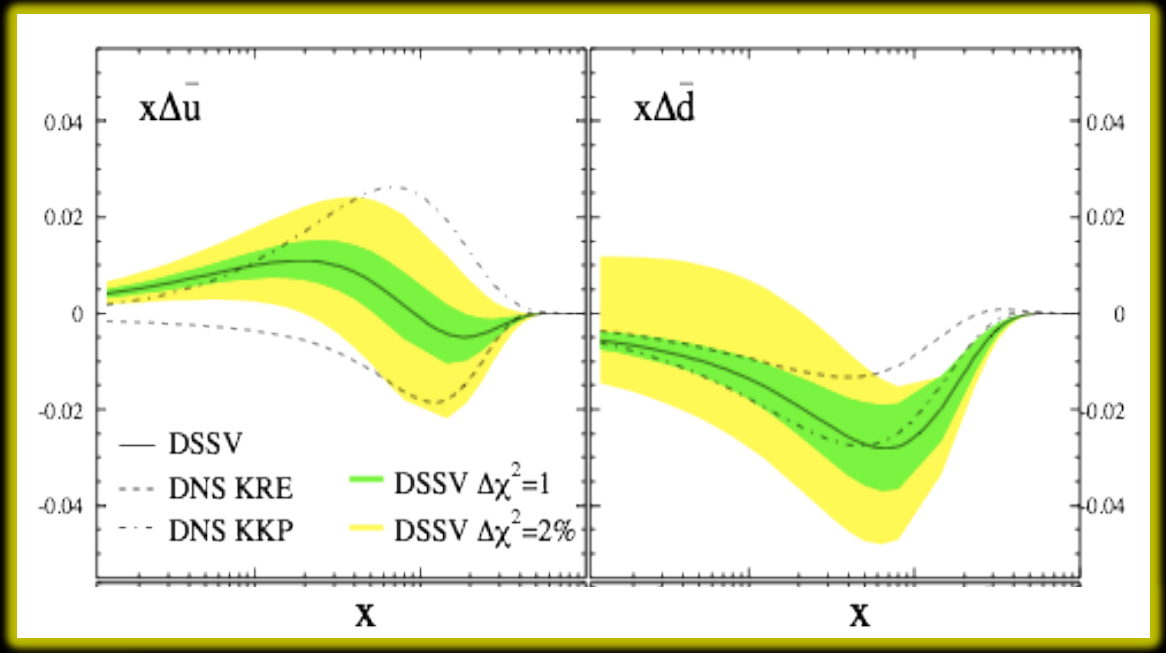


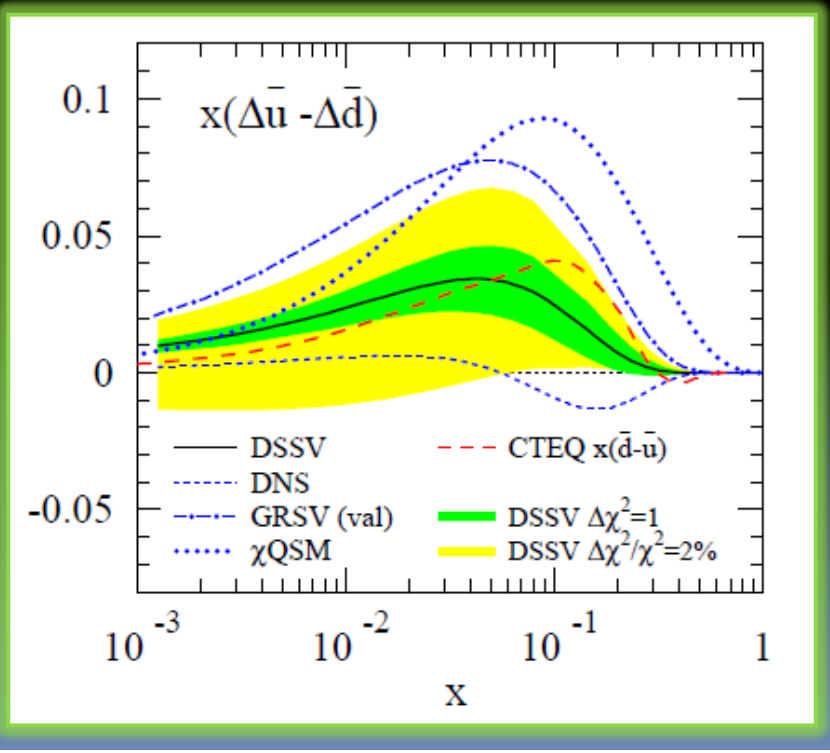


PRL **80,** 3715 (1998)

- More constrained than Δg… but much less than Δu/Δd.
- Current extractions from SIDIS data rely on FF measurements.
- Measurements lend insight into mechanism behind generation of light sea.

"Sans-RHIC" $\Delta\bar{u}(x)$ & $\Delta\bar{d}(x)$





- More constrained than Δg… but much less than Δu/Δd.
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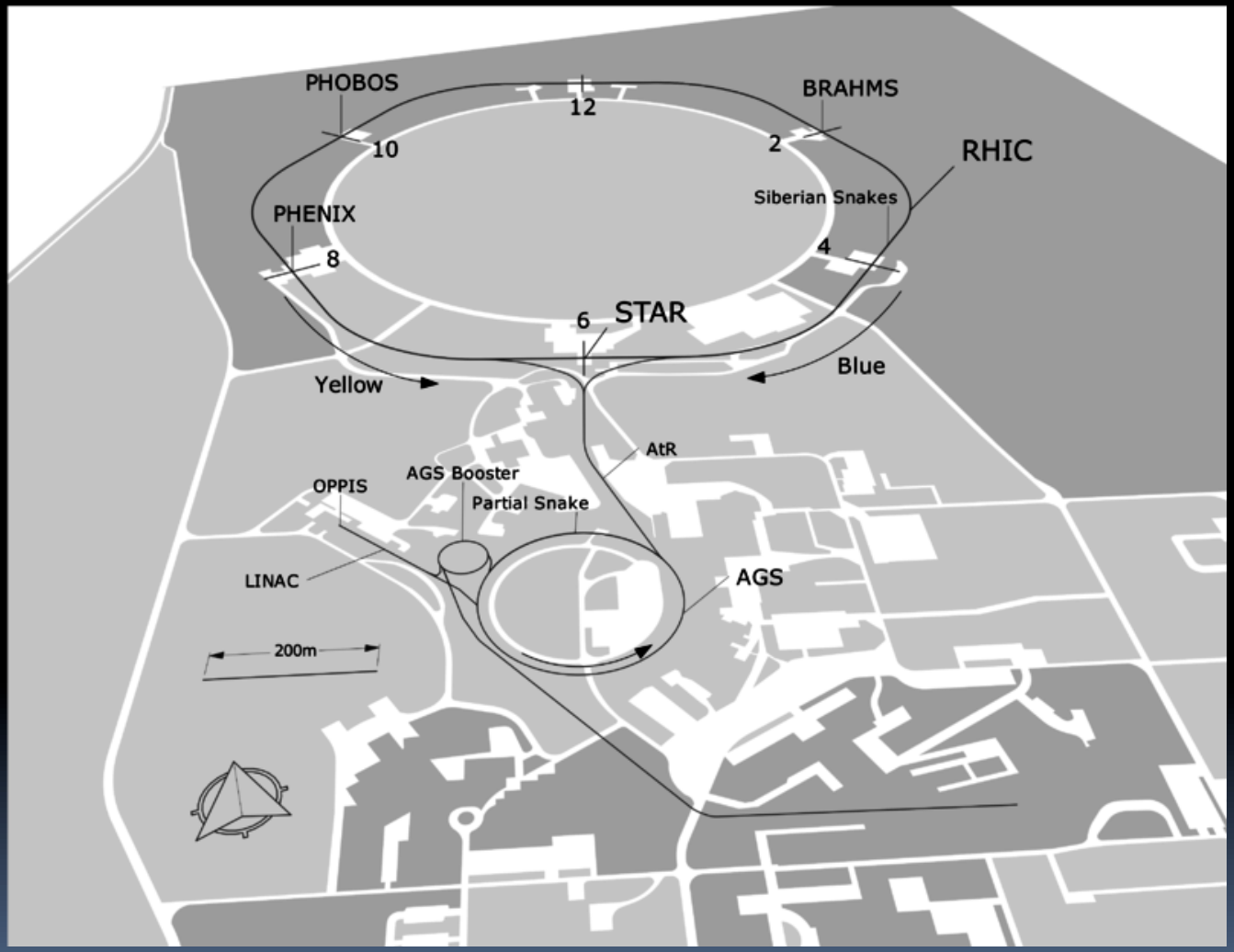
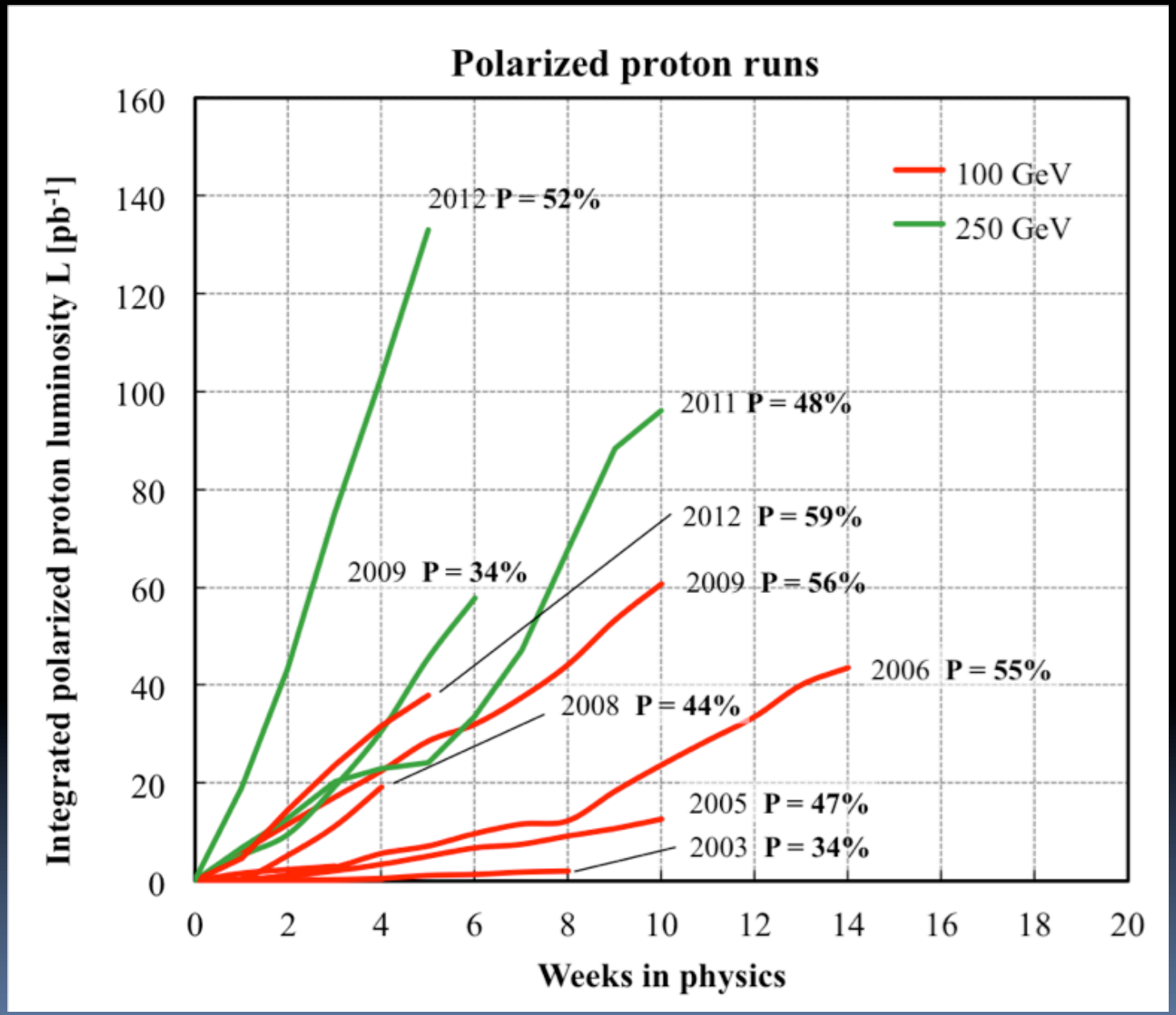
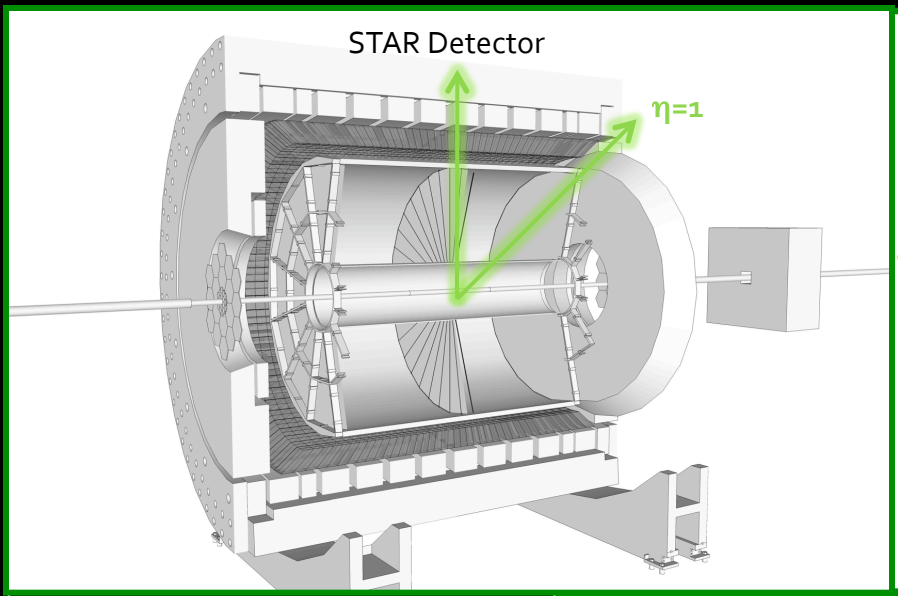
- Measurements lend insight into mechanism behind generation of light sea.

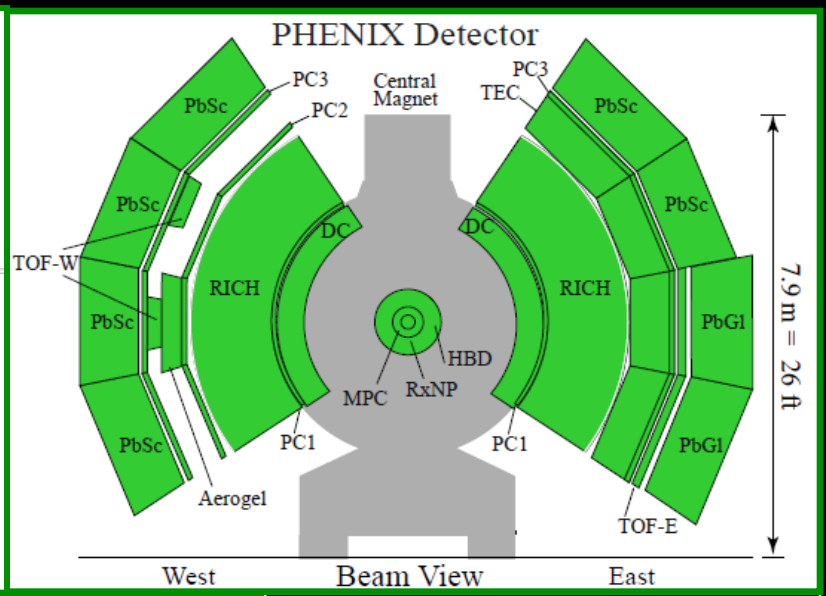
Relativistic Heavy Ion Collider



…worlds 1st and only $\vec{p}\vec{p}$ Collider!


Polarized proton runs
Integrated polarized proton luminosity L [pb-1]
Weeks in physics
100 GeV
250 GeV
2012 P = 52%
2011 P = 48%
2012 P = 59%
2009 P = 34%
2009 P = 56%
2006 P = 55%
2008 P = 44%
2005 P = 47%
2003 P = 34%
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12
14
16
18
20

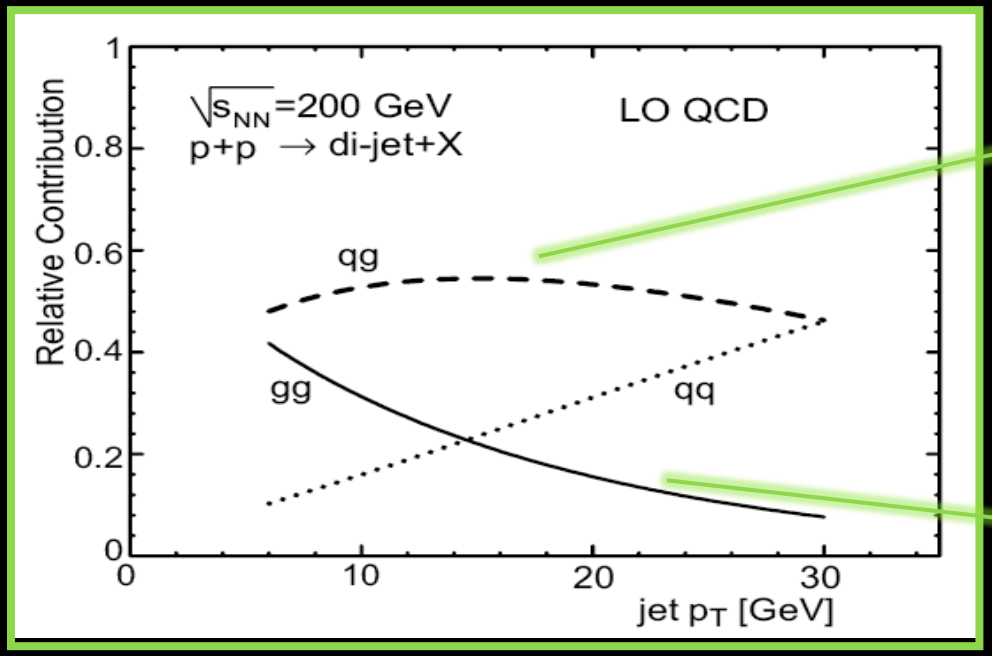


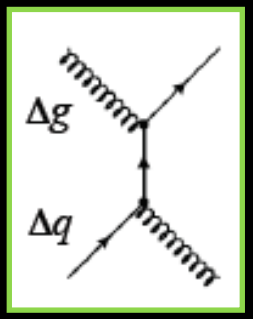


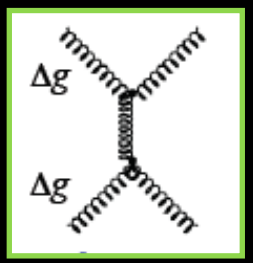
TIME PROJECTION CHAMBER	**CHARGED PARTICLE TRACKING**	DRIFT + PAD CHAMBERS
TPC + TOF	**CHARGED PARTICLE IDENTIFICATION**	RICH +TOF
EM CALORIMETER 5520 (PbSc) towers	**EM PARTICLE DETECTION HIGH PT TRIGGERING**	EM CALORIMETER 15552 (PbSc) towers 9216 (PbGl) towers
BEAM BEAM COUNTERS ZERO DEGREE COUNTERS	**RELATIVE LUMINOSITY MINIMUM BIAS TRIGGERING**	BEAM BEAM COUNTERS ZERO DEGREE COUNTERS
LARGE ACCEPTANCE (-1<η<2)	**STRENGTHS**	HIGH RESOLUTION HIGH RATE READOUT

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_Q + L_G$$

How to access ΔG at a $\vec{p}\vec{p}$ collider?



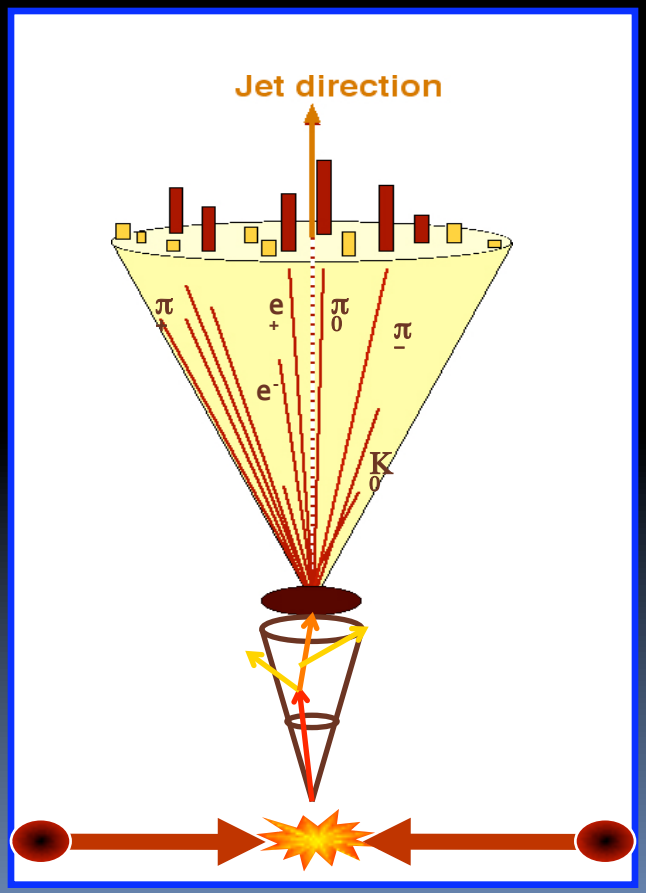


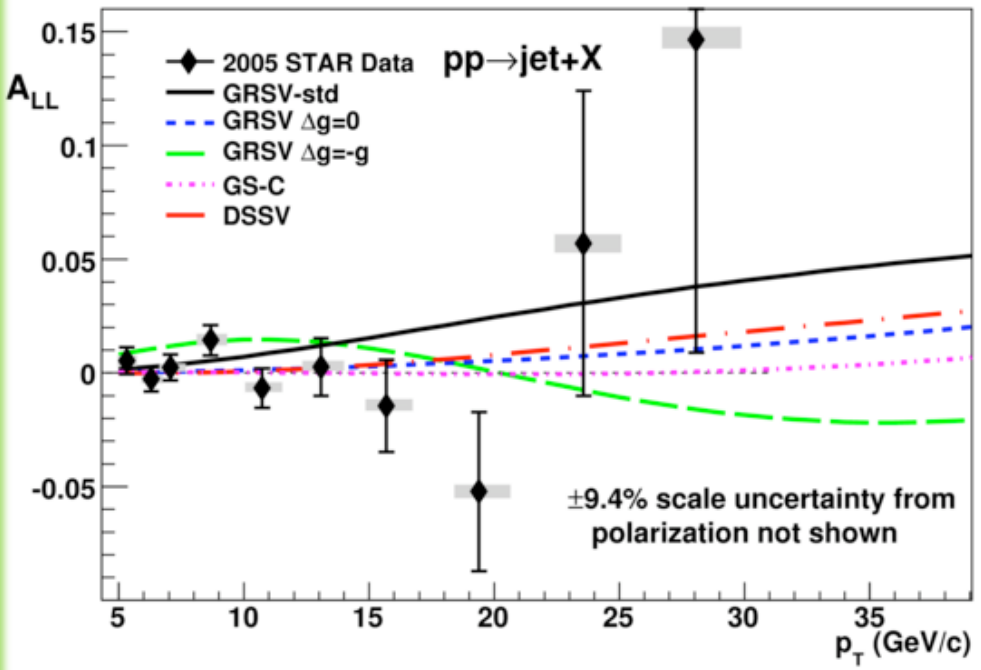


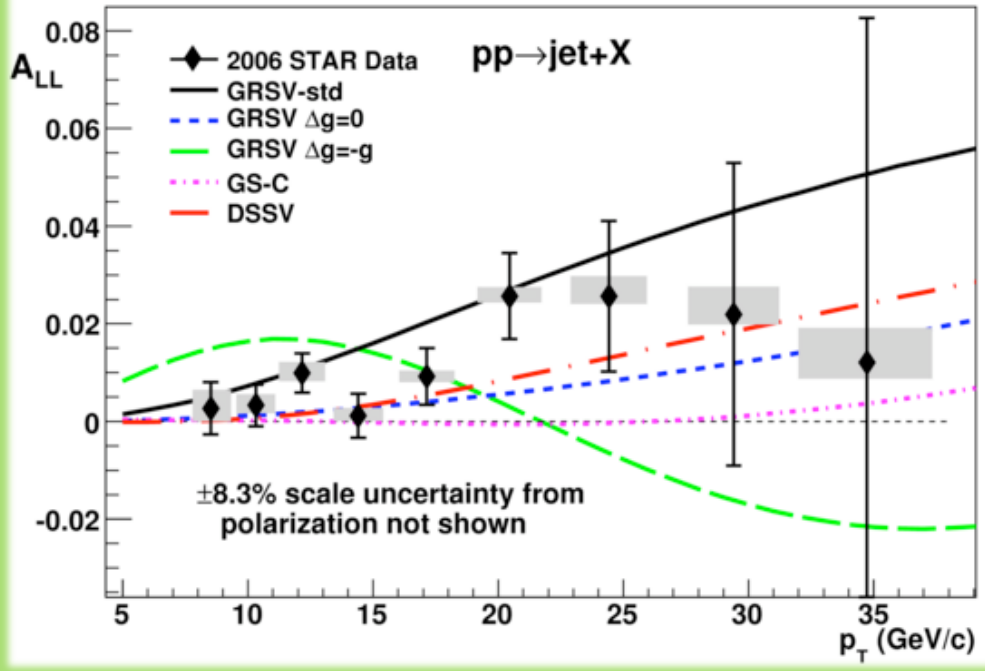
Double Spin Asymmetries of jets and pions are ideal!

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \sum_{f_A f_B f_C} \frac{\Delta f_A \Delta f_B \times \Delta\sigma_{AB\to CX} \times D_C}{f_A f_B \times \sigma_{AB\to CX} \times D_C}$$

STAR 2005 & 2006 Inclusive Jet A_{LL}



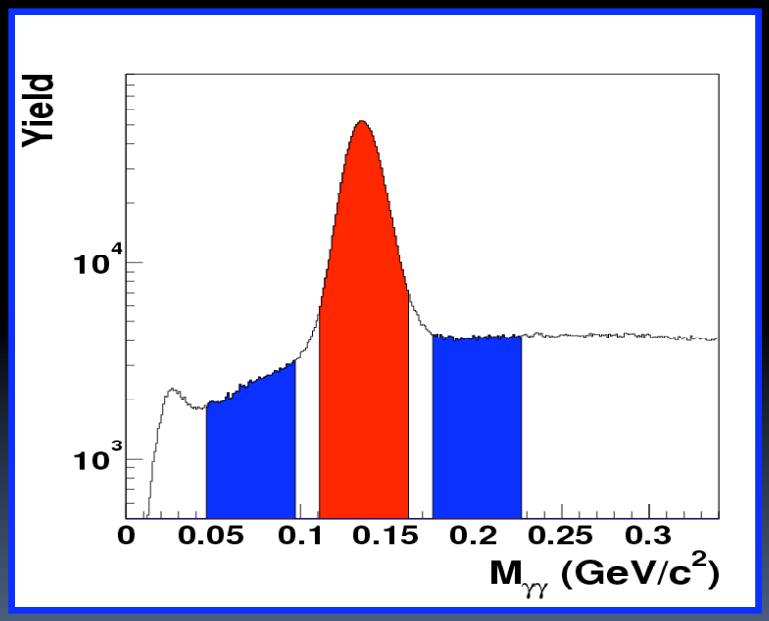


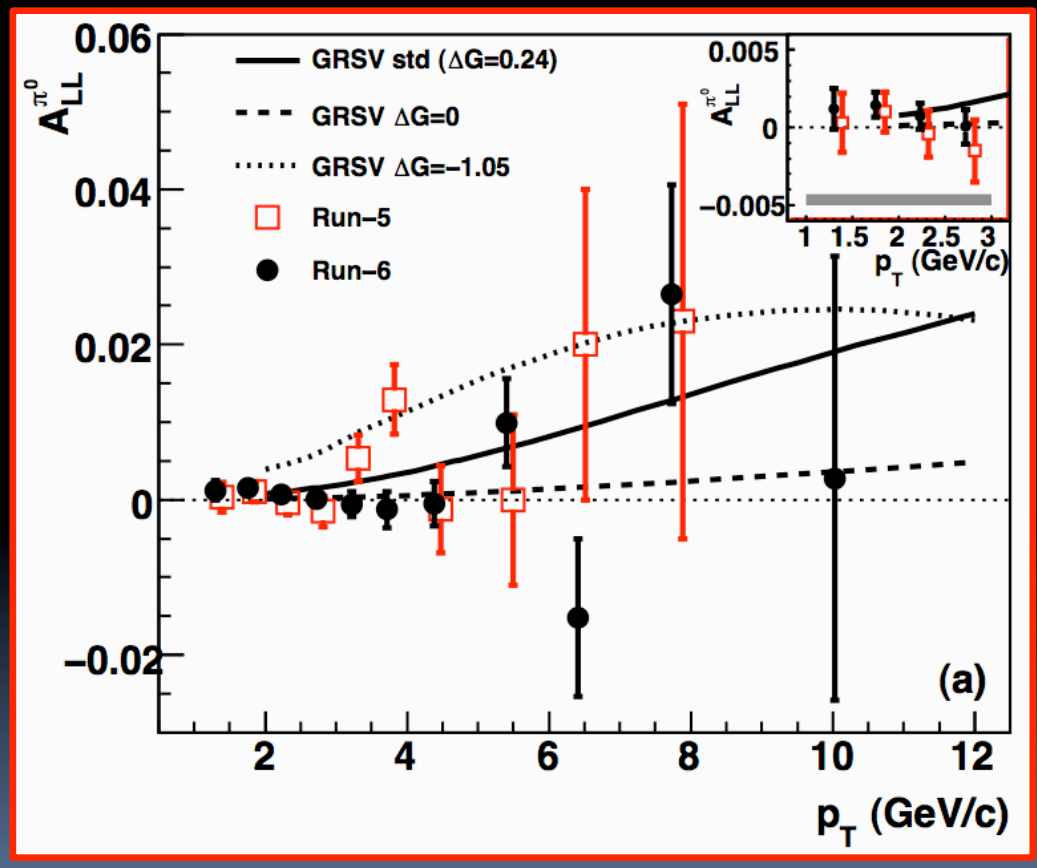


PRD 86, 032006 (2012)

PHENIX 2005+2006 midrapidity π^0 A_{LL}

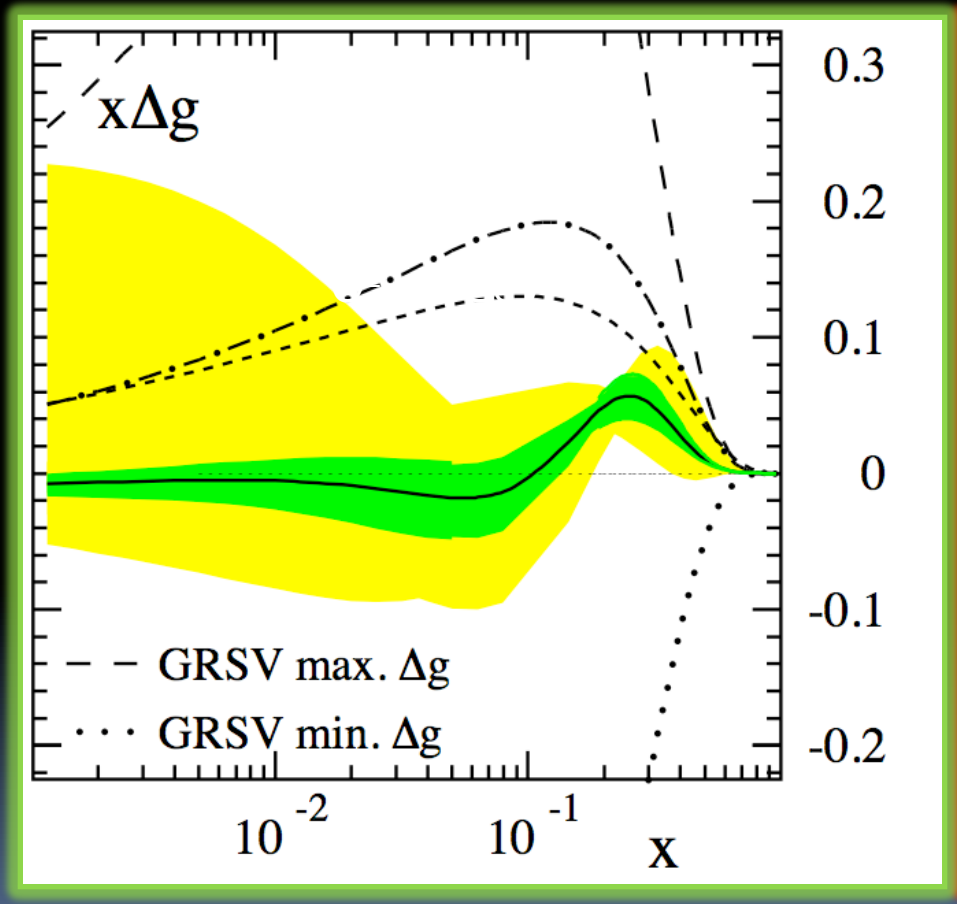
$$A_{LL}^{\pi 0} = \frac{A_{LL}^{\pi 0 + BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$

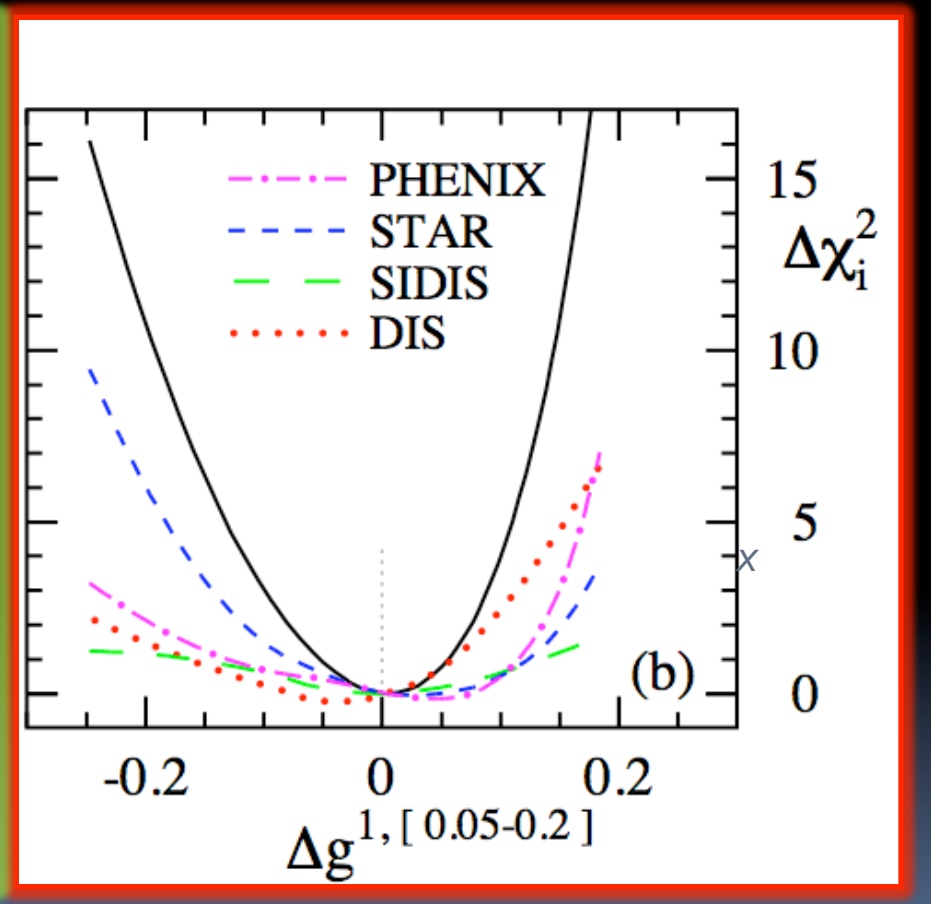




PRL103, 012003 (2009)

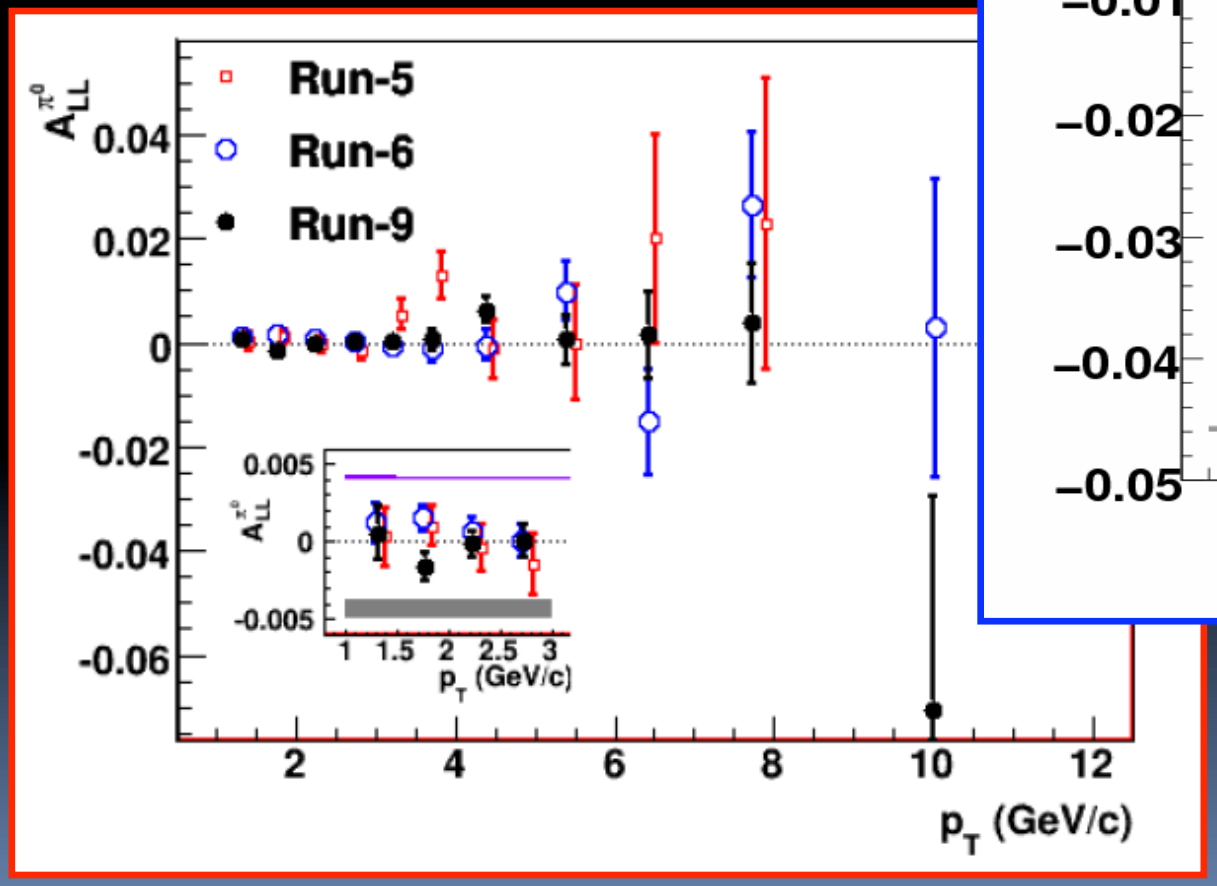
Global Analysis of World Data – including 2005+2006 RHIC results!

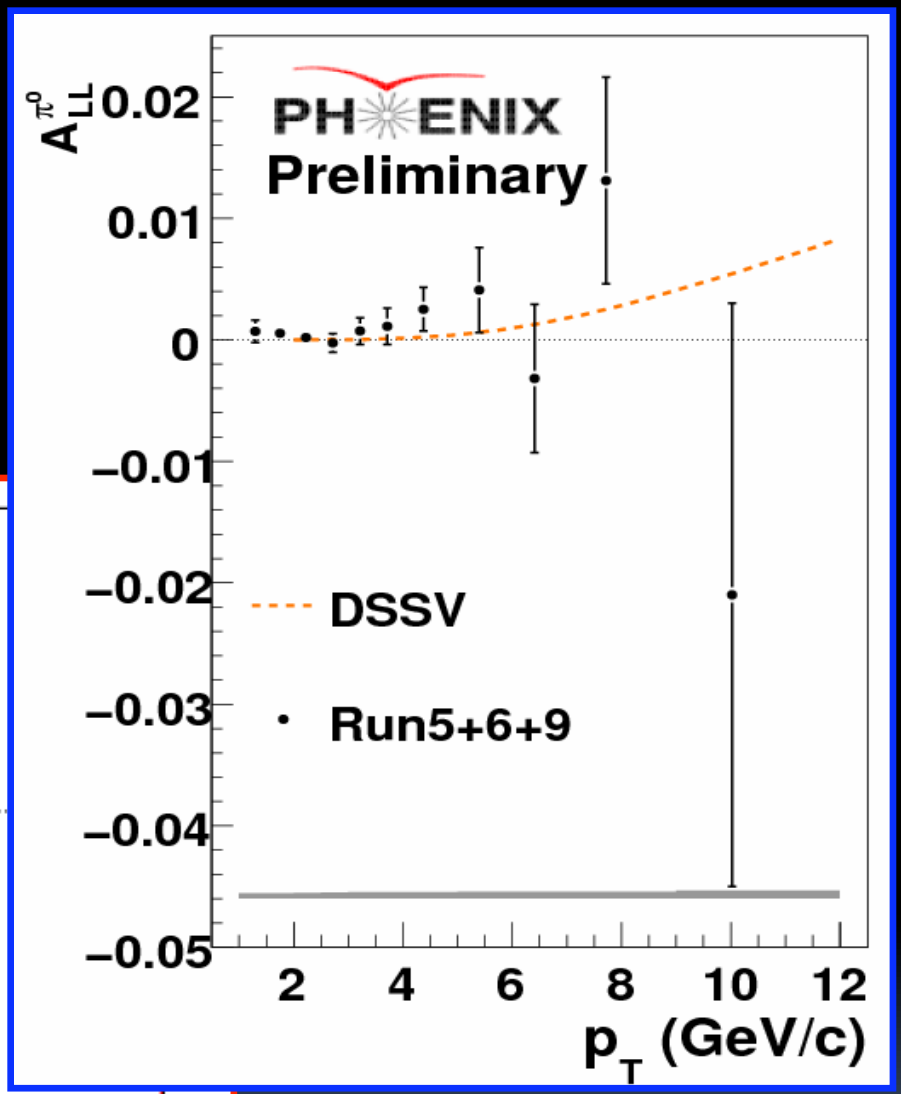




DeFlorian, Sassot, Stratmann and Vogelsang, Phys.Rev.Lett. 101:072001, 2008

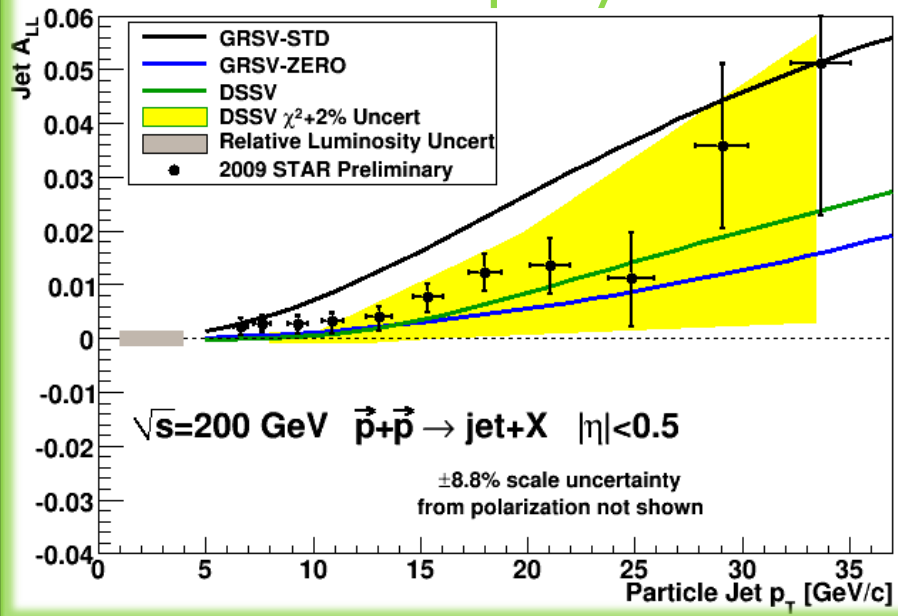
PHENIX 2009 mid-rapidity π^0 A_{LL}



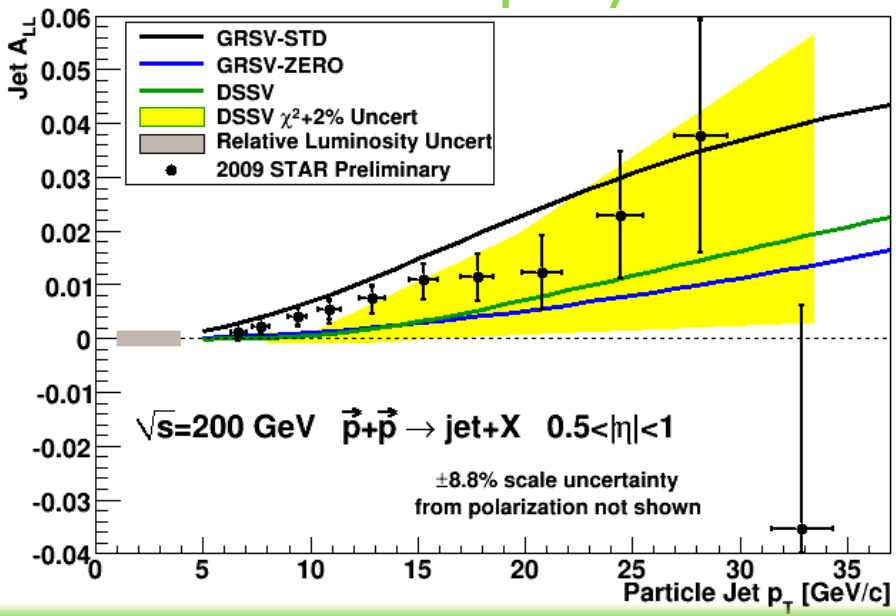


2009 STAR inclusive jet A_{LL}

Mid rapidity



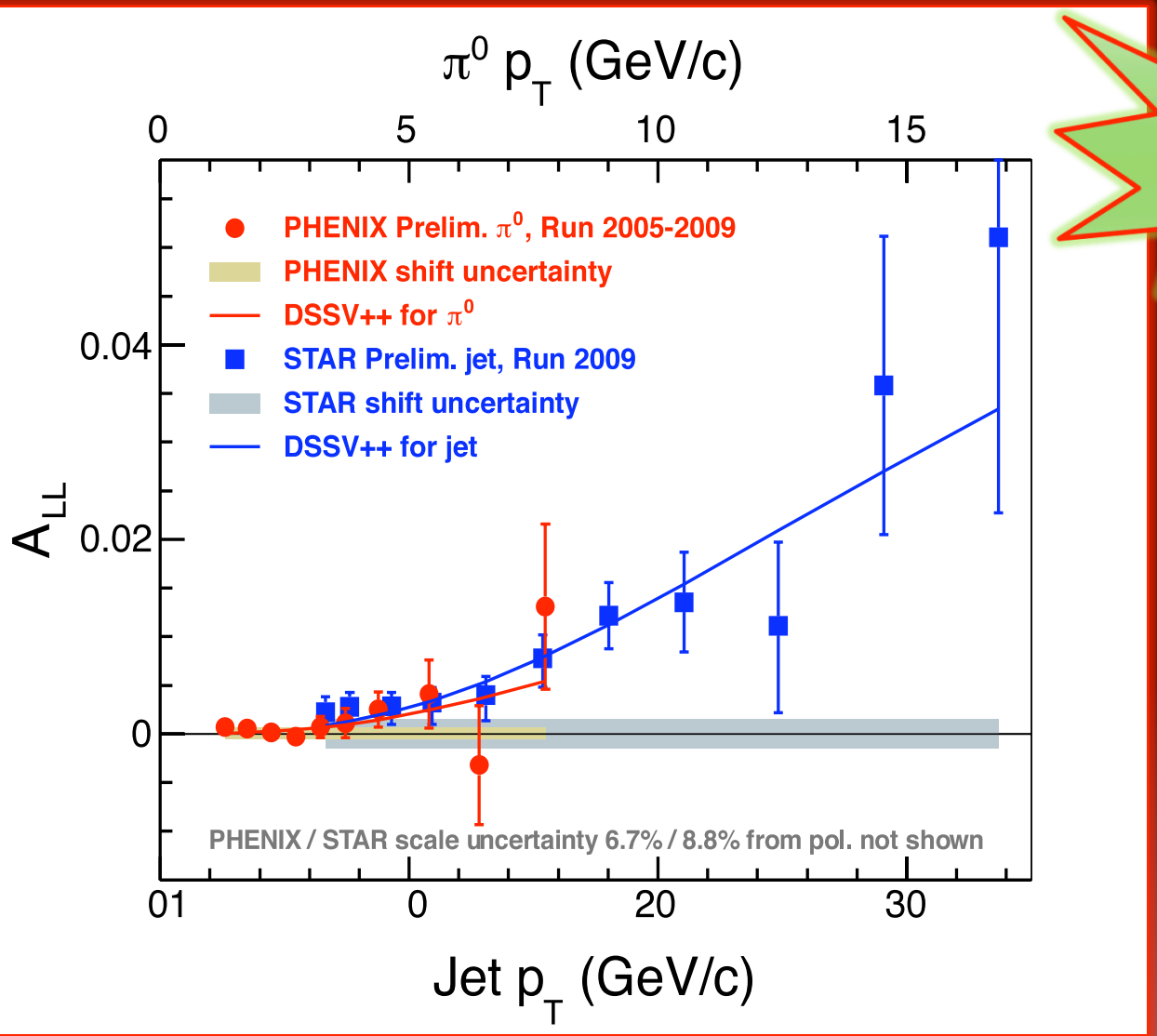
Forward rapidity



- Increased statistical power due to sampling 25 pb^{-1} of data combined with improvements in triggering and data collection rate.
- Forward jets sample larger fraction of quark-gluon sub-process
- Forward jets have larger $|\cos(\theta^*)|$, which reduces partonic a_{LL}

A_{LL} falls between the predictions of DSSV and GRSV-STD!!

Are PHENIX and STAR data consistent?



YES!

Thank you to de Florian, Sassot, Stratmann & Vogelsang for preliminary DSSV++ curves!

What is Run 9 Impact on ΔG ?

DSSV

Phys.Rev.Lett

101:072001, 2008

$$\int_{0.05}^{0.2} g(x)dx = 0.005^{+0.129}_{-0.164}$$

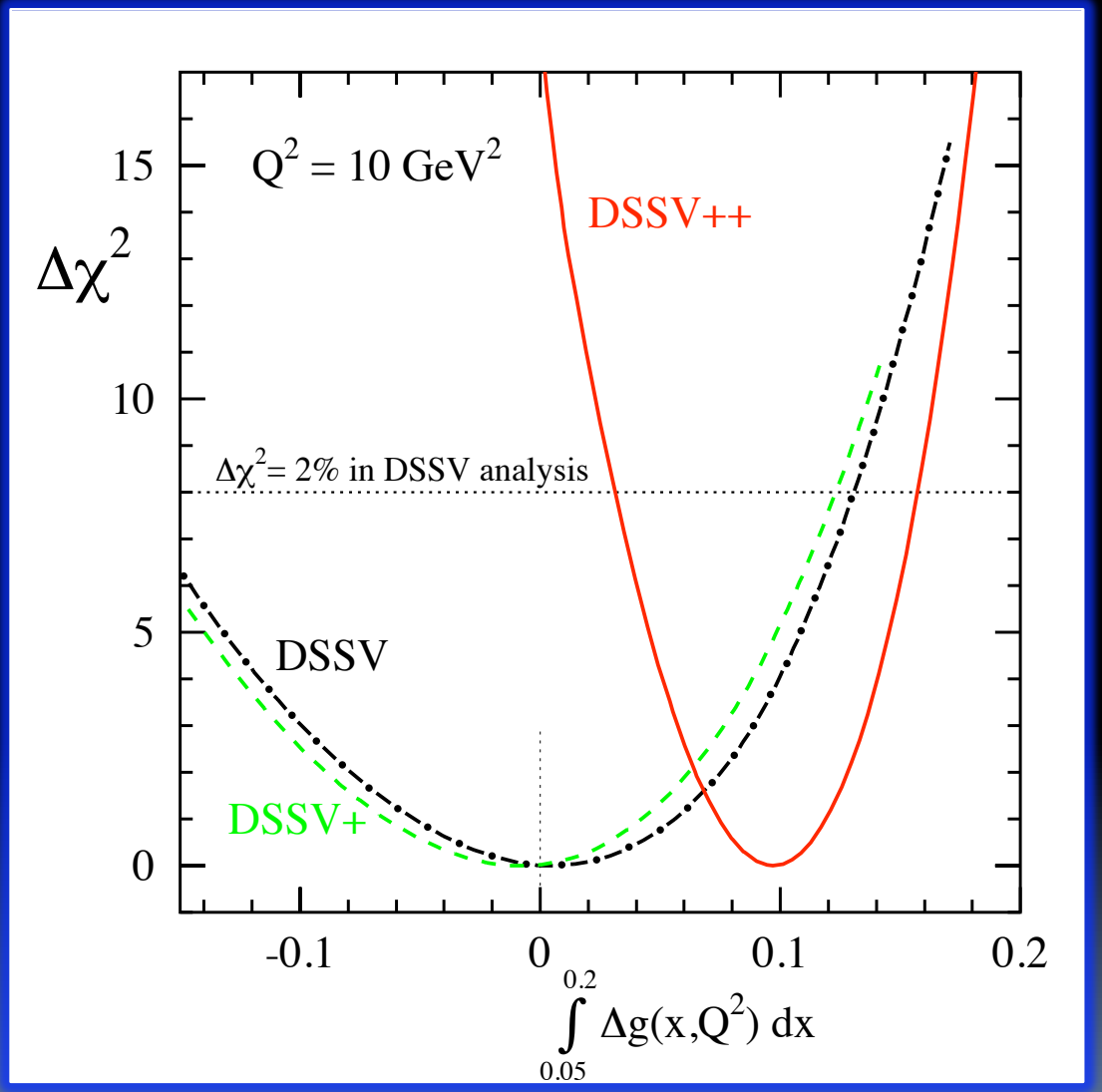
DSSV+

DSSV & COMPASS

DSSV++

DSSV+ & RHIC Run 9

$$\int_{0.05}^{0.2} g(x)dx = 0.097^{+0.06}_{-0.03}$$

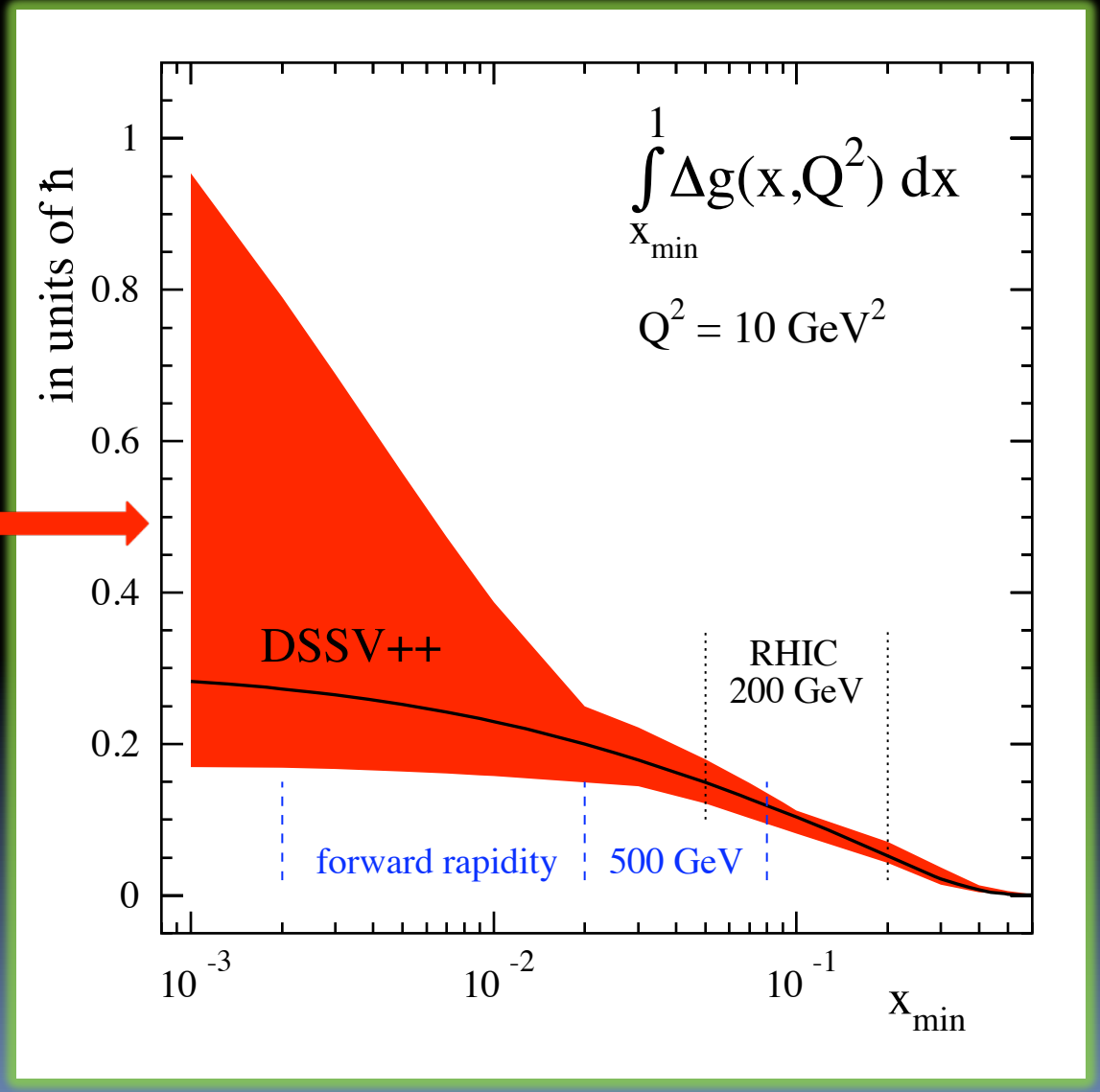


Preliminary DSSV++ curves provided by de Florian, Sassot , Stratmann & Vogelsang!

How does this ADD UP?

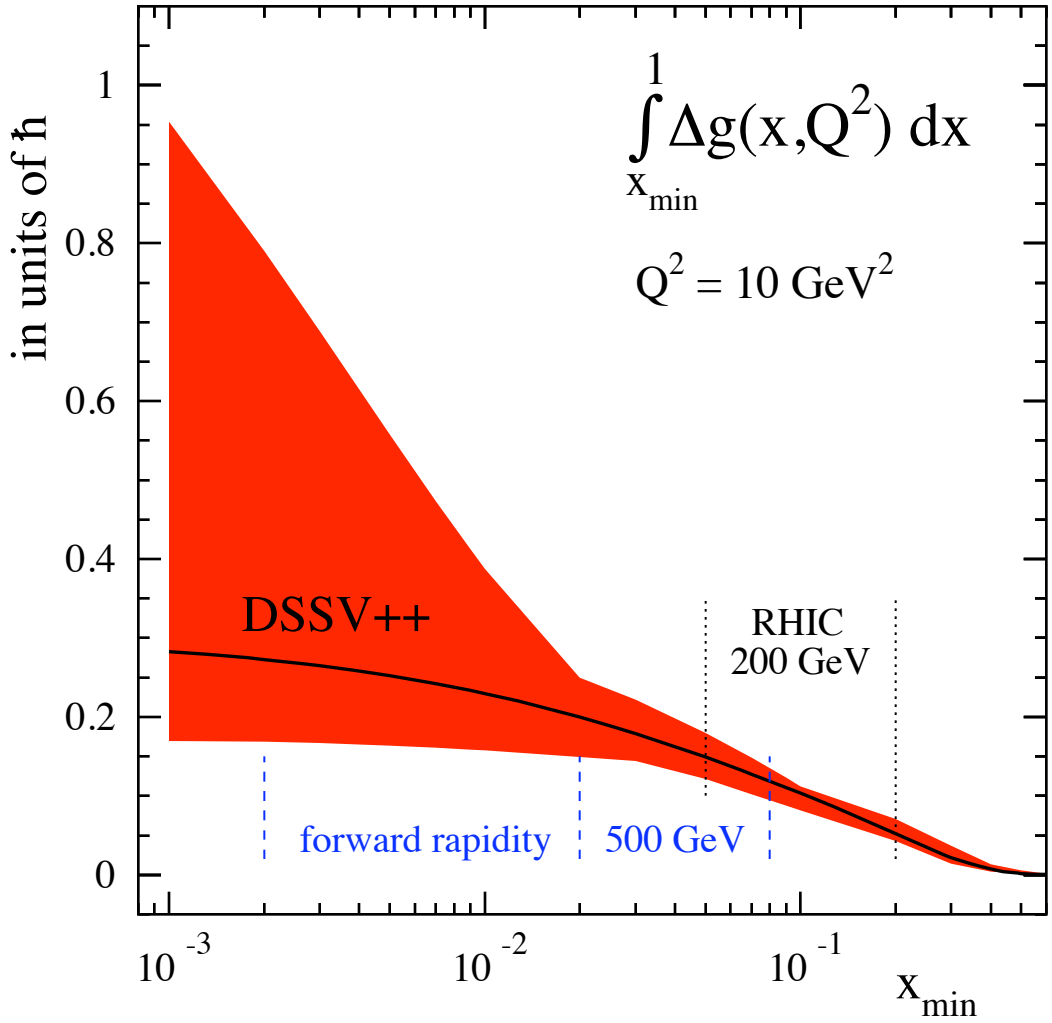
...Integration over full x range

PROTON SPIN



This preliminary DSSV++ plot brought to you by de Florian, Sassot , Stratmann & Vogelsang!

How does this ADD UP?



At Q^2 = 10 GeV

DSSV $\Delta\Sigma$ = **0.242**

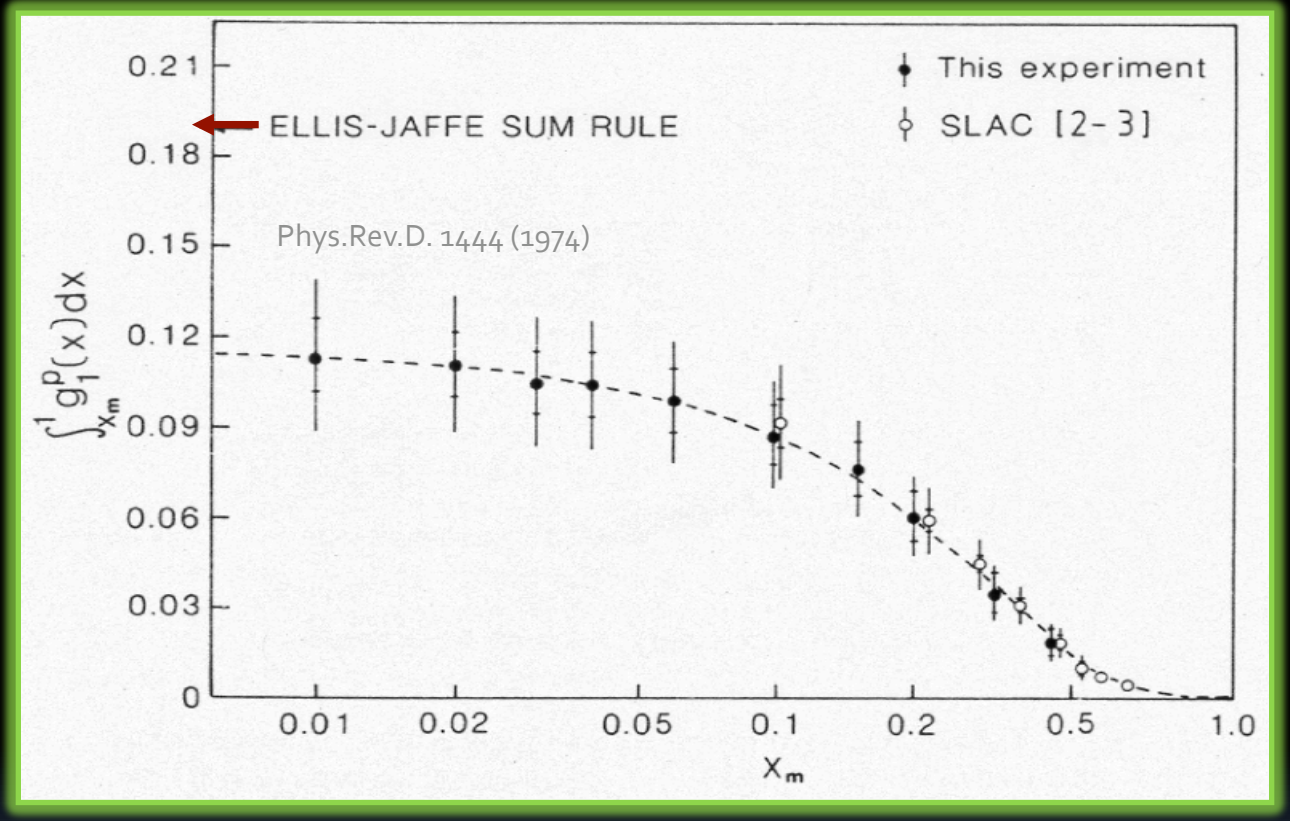
DSSV++ ΔG ➔ **0.3?**

$1/2\ \Delta\Sigma + \Delta G$ ~ **0.421 !**

This sum is INTRIGUING but … ERROR BARS for $\Delta g(x)$ are VERY LARGE at low X!

Historically same trend with $\Delta\Sigma$!

EMC Collaboration Nucl. Phys. B328, 1 (1989)



EMC 1989: $\Delta\Sigma(Q^2 = 10.7GeV) = 0.12 \pm 0.094 \pm 0.138$

DSSV 2x bigger than EMC $\Delta\Sigma$ - but still CONSISTENT!

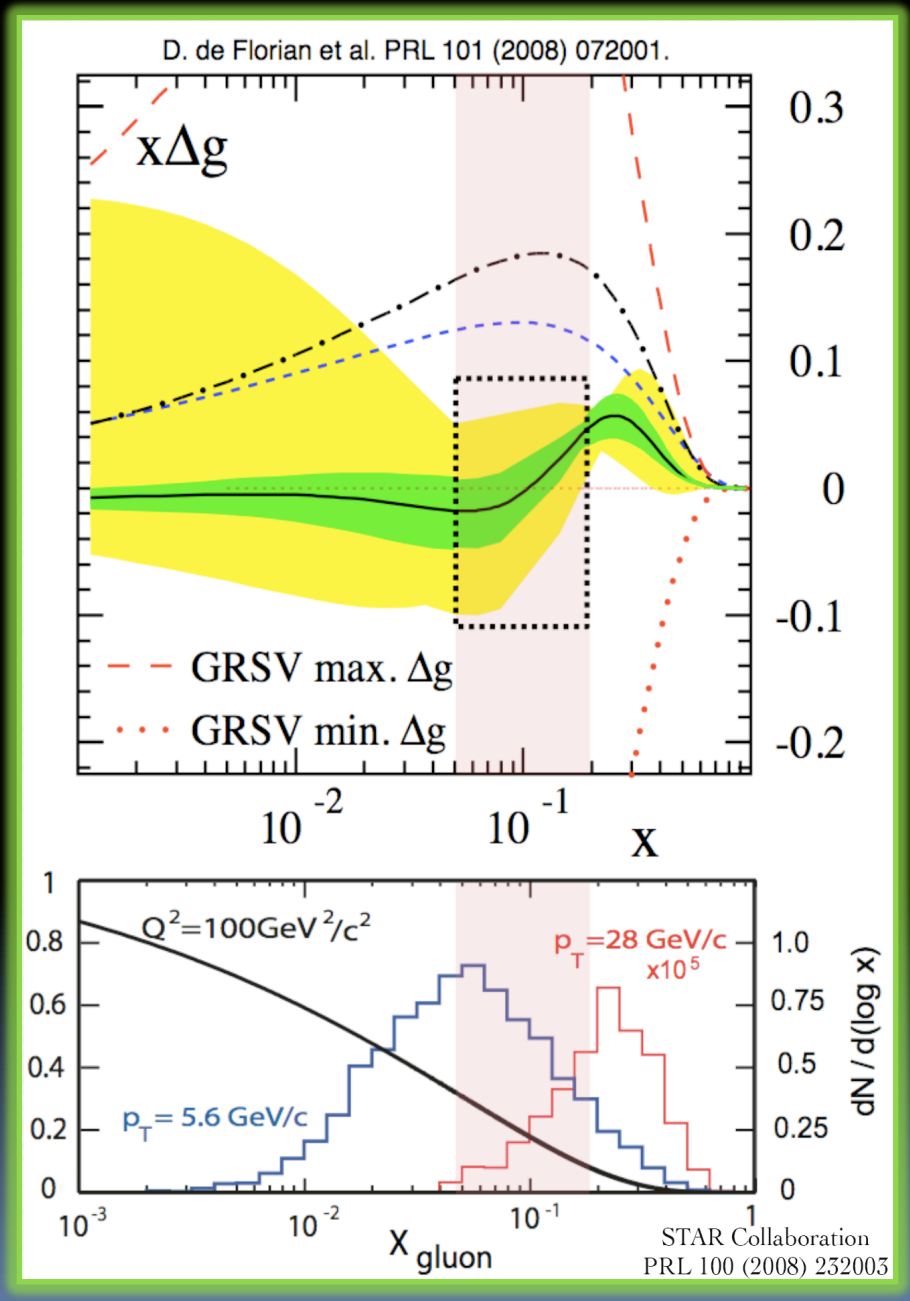
Path Forward I: Functional Form

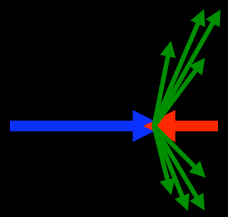
Correlation Measurements provide access to partonic kinematics.

- Di-jet A_{LL}
- Di-pion A_{LL}
- Photon-jet A_{LL}

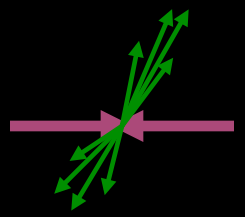
$$x_{1(2)} = \frac{1}{\sqrt{s}}\left(p_{T3}e^{+(-)\eta_3} + p_{T4}e^{+(-)\eta_4}\right)$$

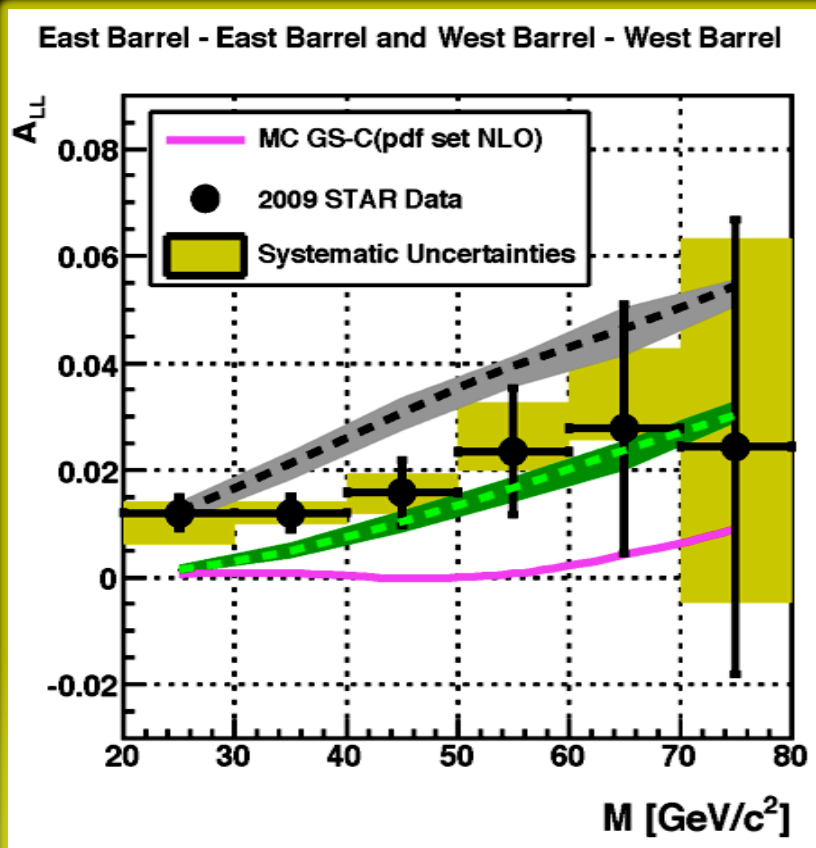
$$|\cos\vartheta^*| = \tanh\frac{|\eta_3 - \eta_4|}{2}$$

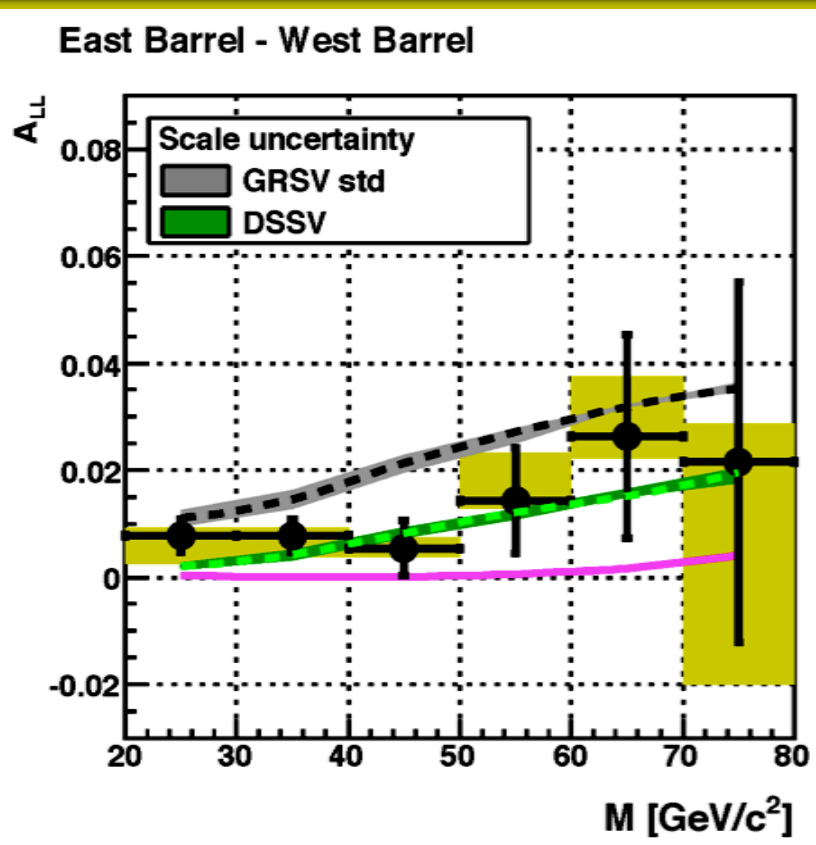




2009 *STAR* Dijet A_{LL}





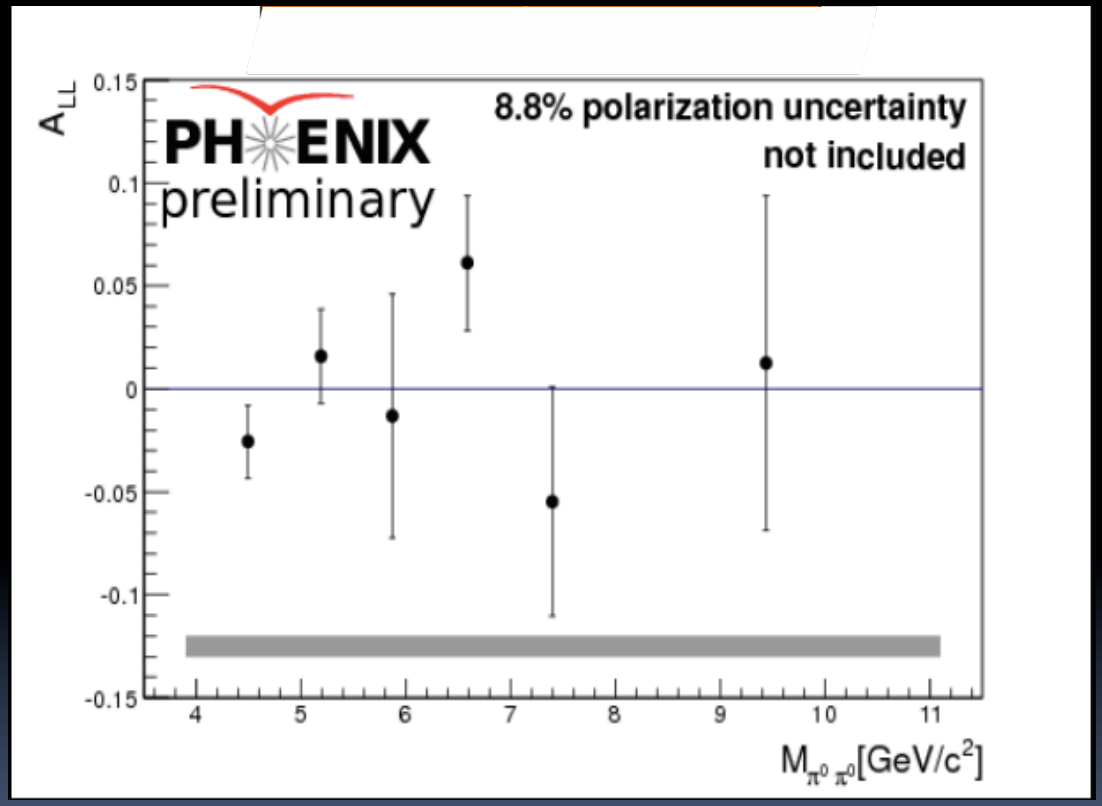


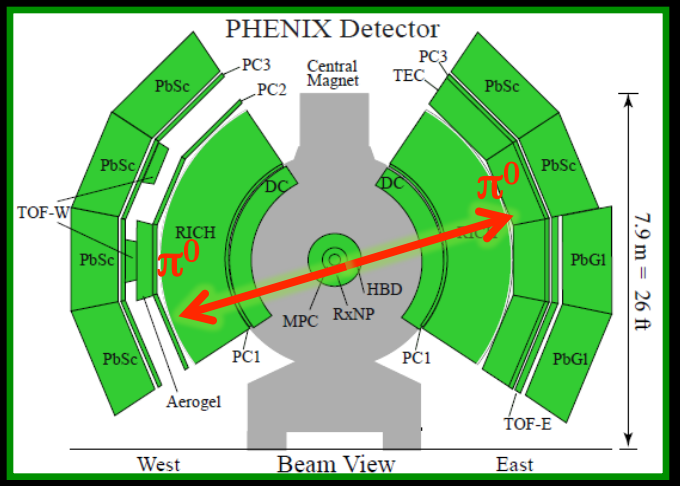
Dijets in the Forward Region
- **Brian Page**
- Session HG

Photon-jet Reconstruction
- **Seema Damija**
- Session FG

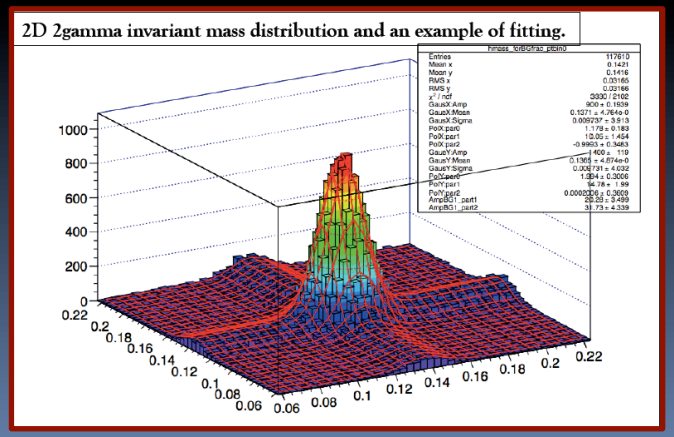
Inclusive pions in EEMC
- **Steve Gliske**
- Session FG

2009 PHENIX Di-pion A_{LL}





First Correlation Spin Measurement at PHENIX

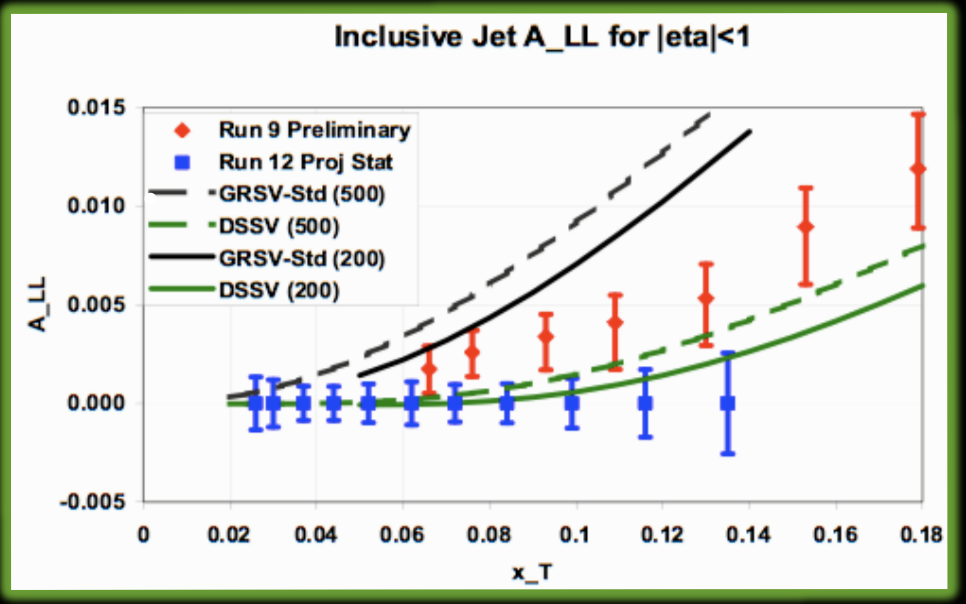


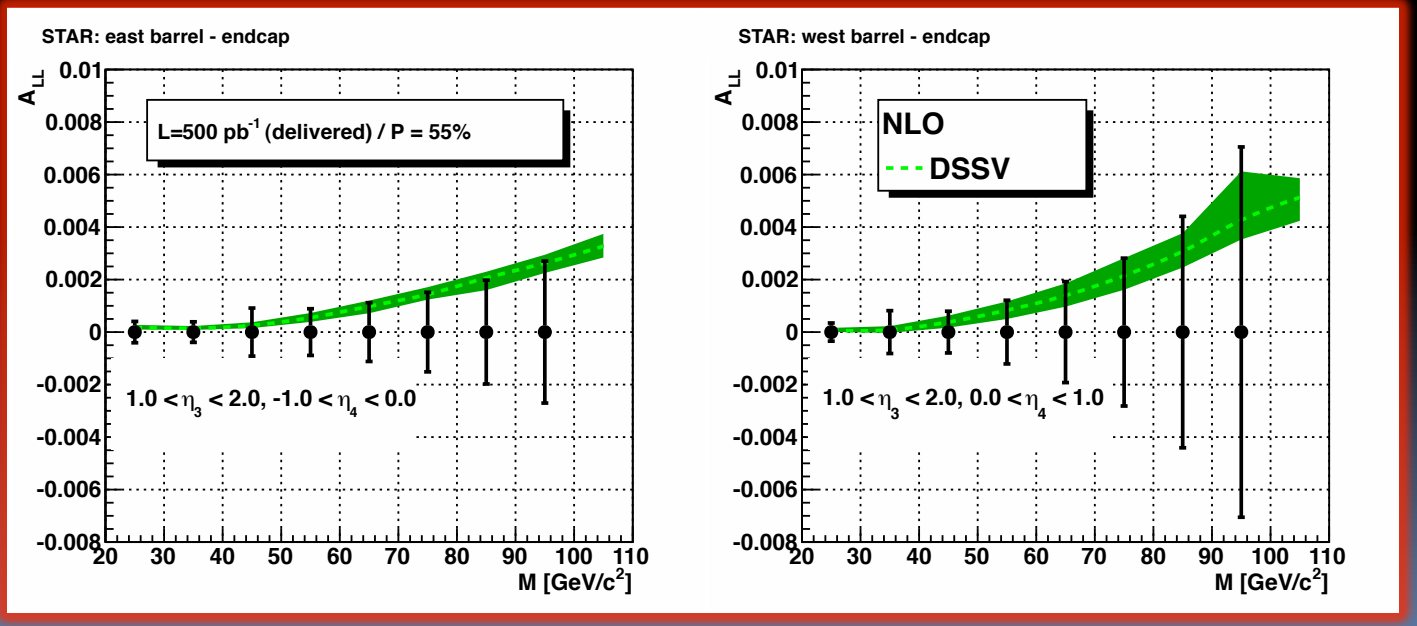
Opens door for π^0-h+/- and π^0-jet

Path Forward II: Push to lower X

-√s=500 GeV Inclusive + Dijet A_{LL}

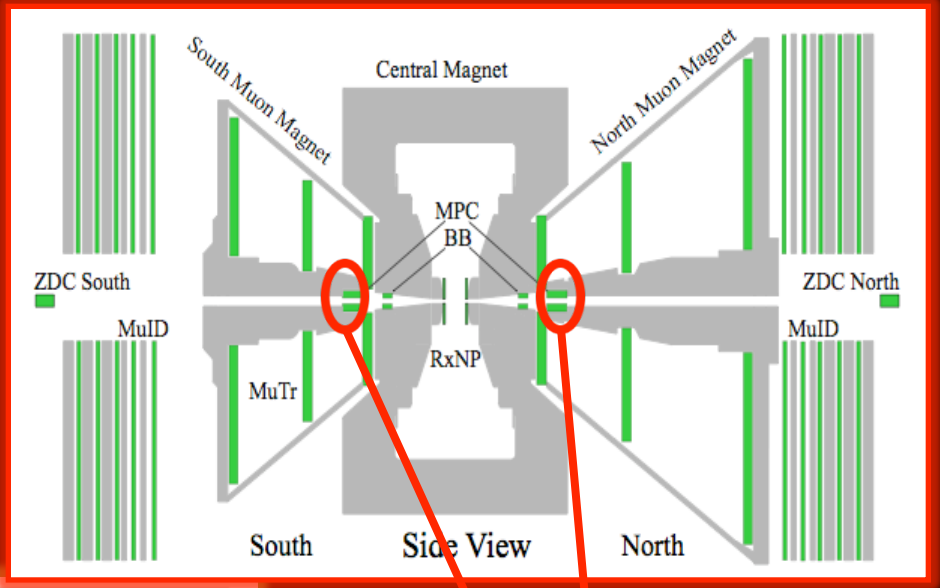
- Push Dijets forward into EEMC

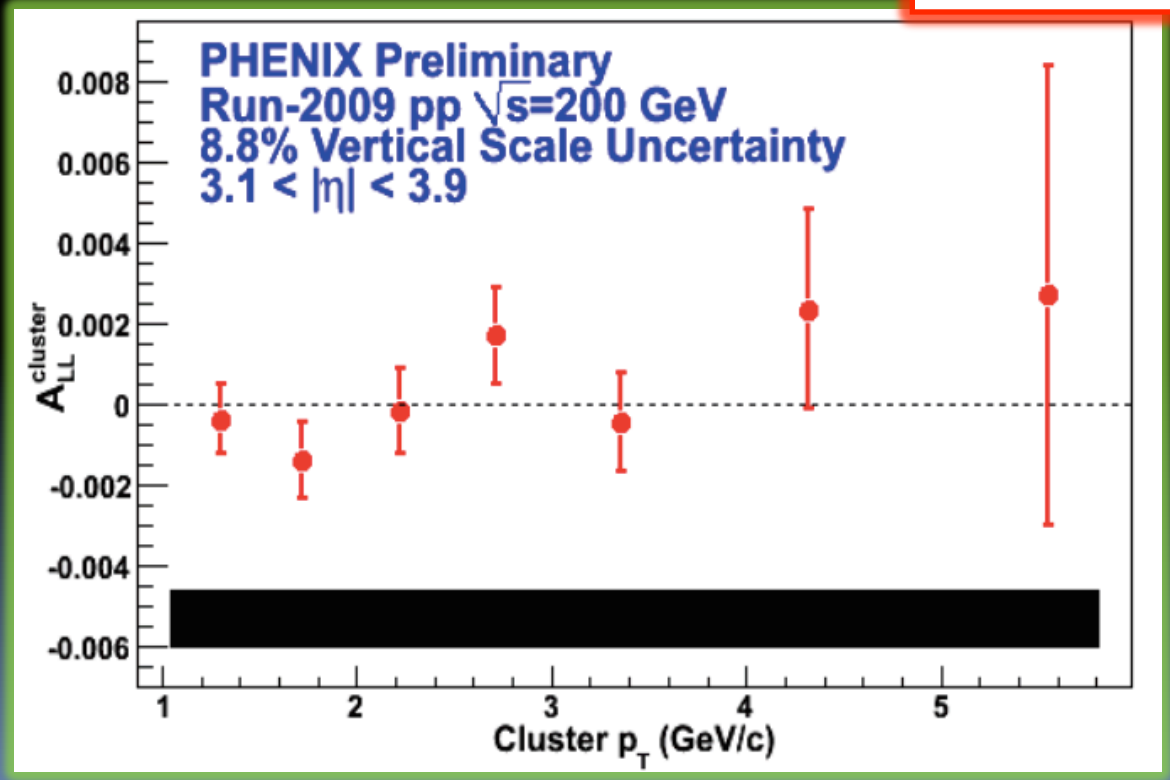


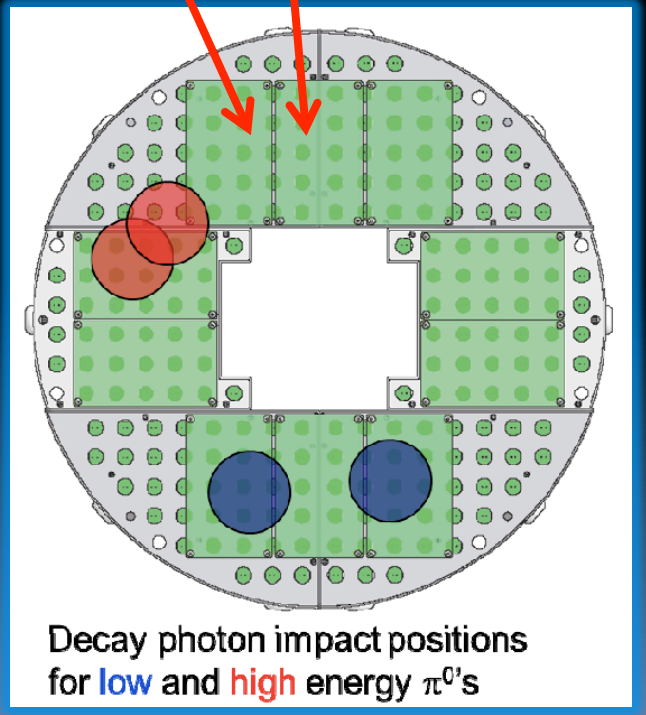


Dijets at √s=500 GeV
-Grant Webb
-Session HG

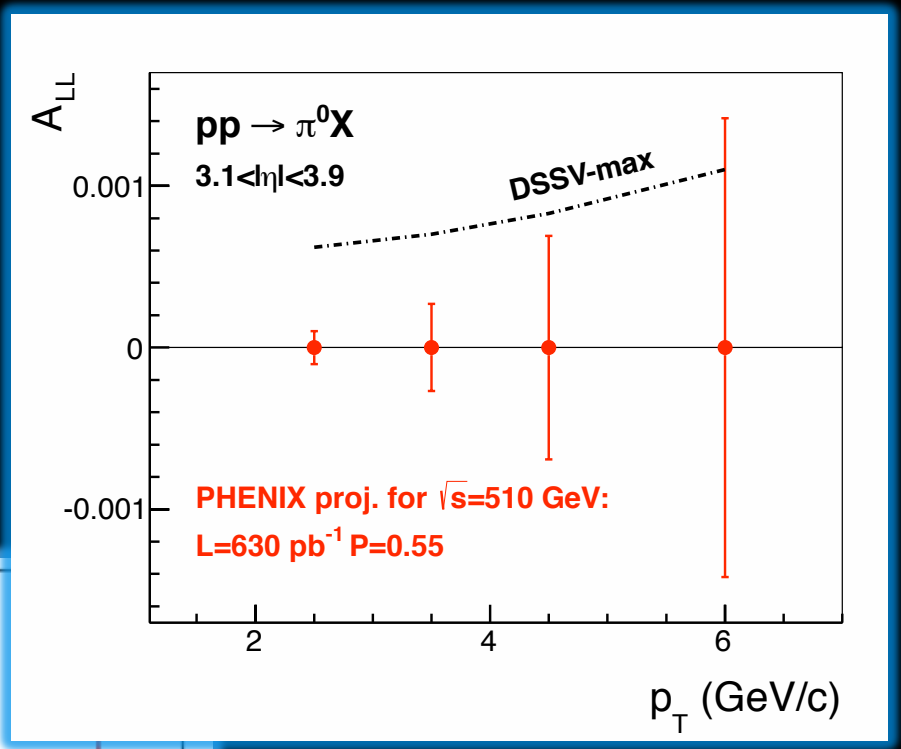
PHENIX Muon Piston Chambers access lower X region

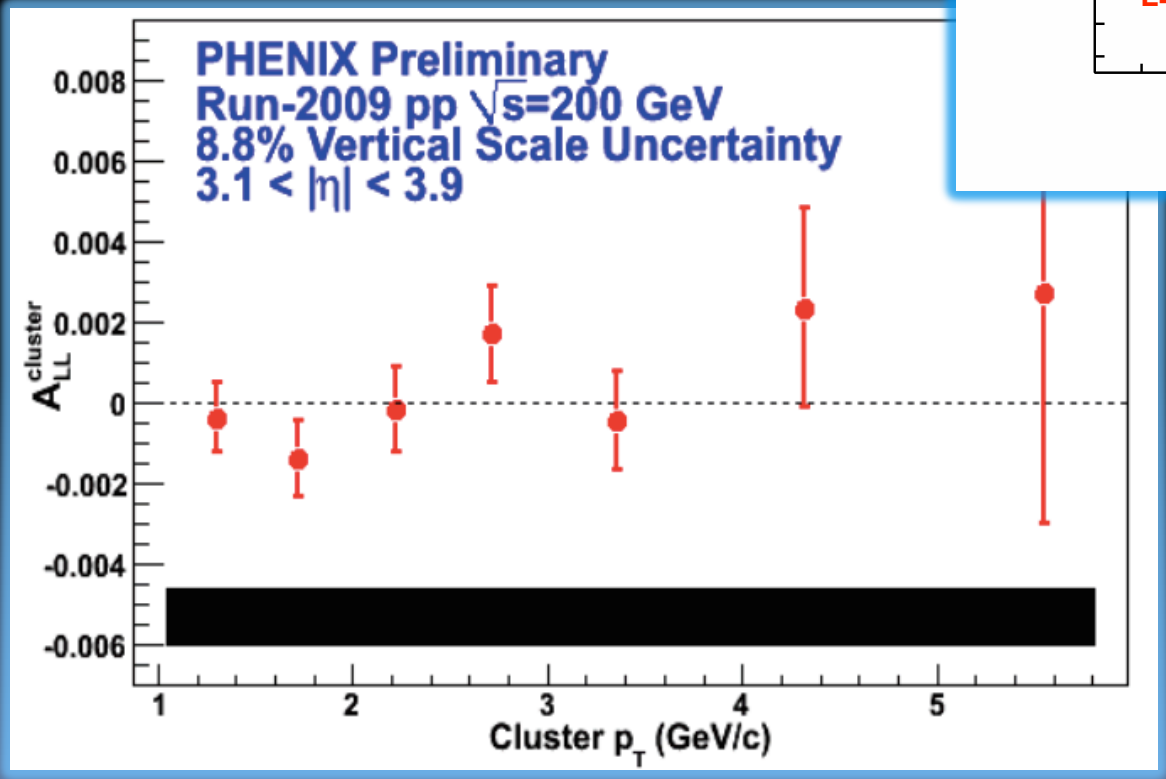






Path Forward II: Low X Error Reduction

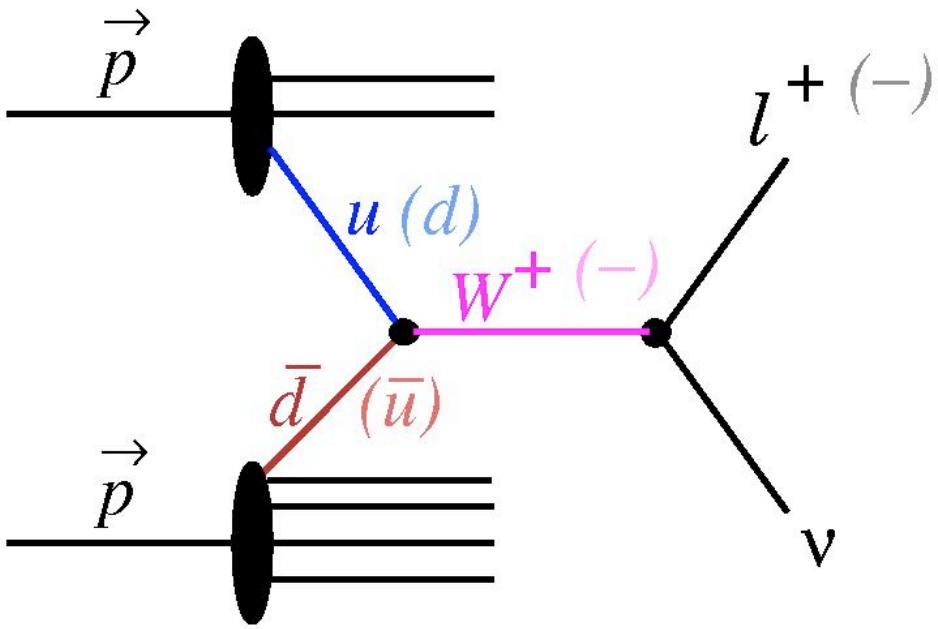




Electromagnetic clusters in the forward PHENIX Muon Piston Chamber should push x coverage down to 0.002!

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

Probing the Sea Through W Production

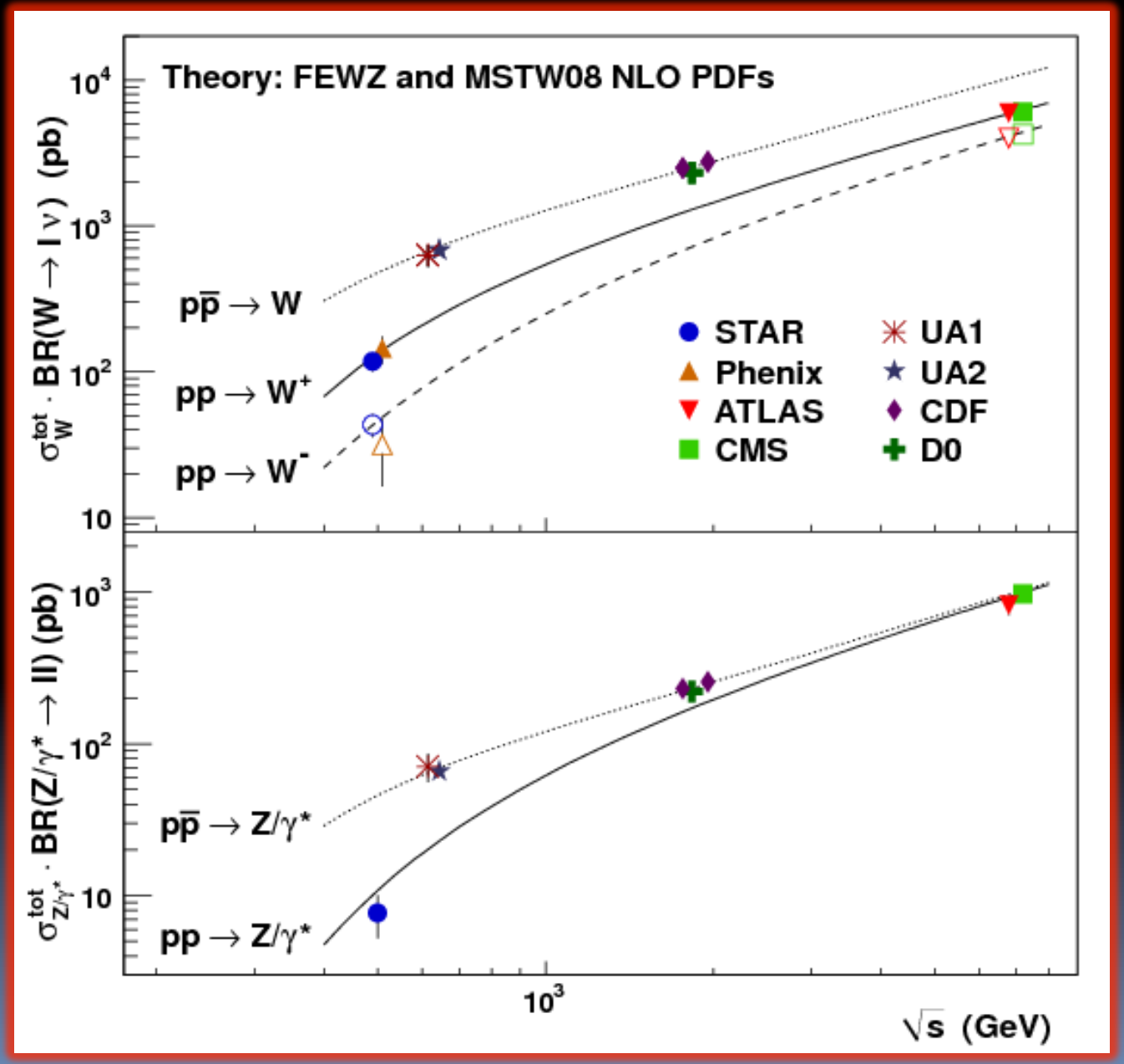


Measure parity-violating single-spin asymmetry of detected leptons:

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

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

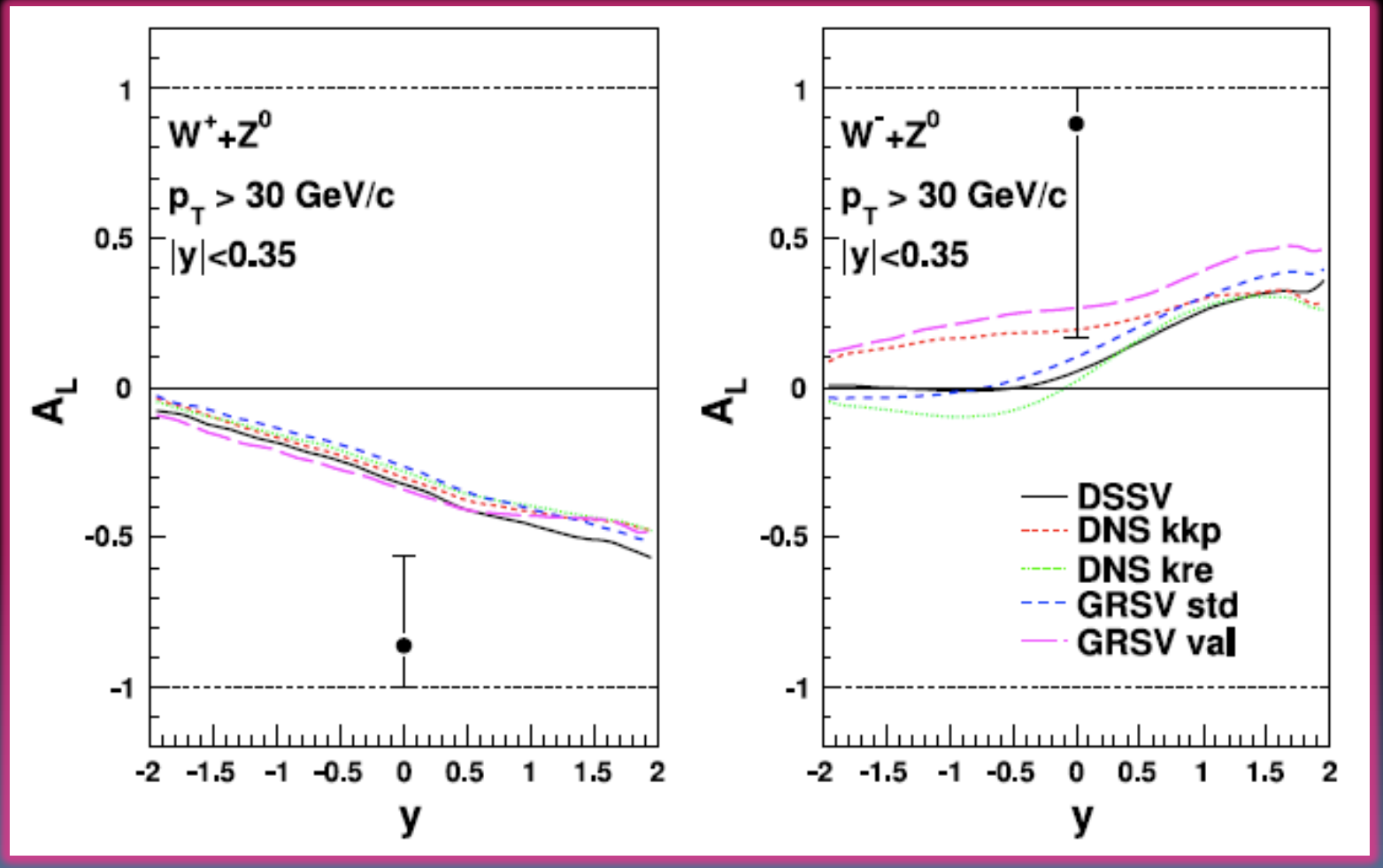
$W^{+/-}$ & Z Cross Sections



2009 PHENIX W A_L

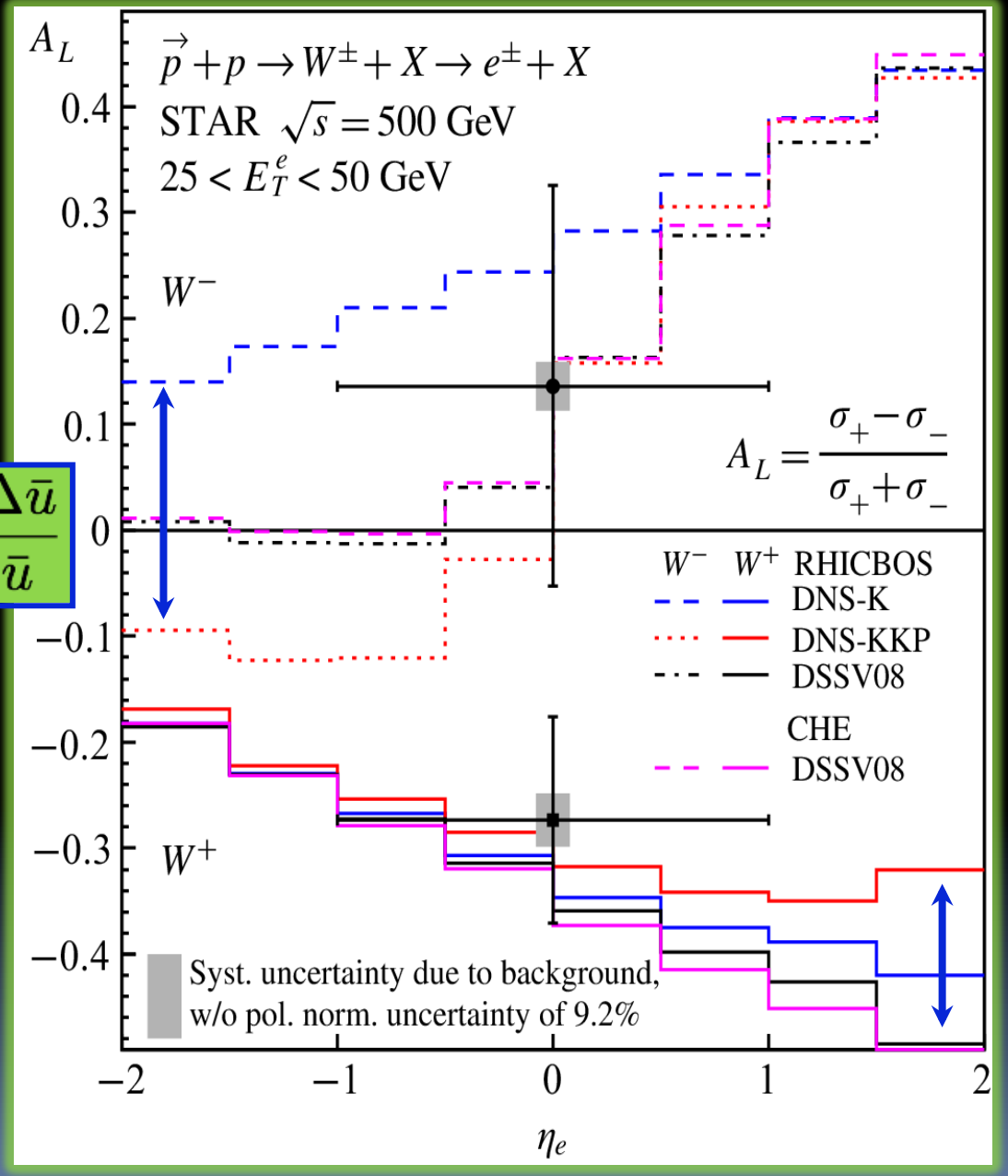
$$A_L(W^+) = -0.86^{+0.30}_{-0.14}$$

$$A_L(W^-) = 0.88^{+0.12}_{-0.71}$$



Phys.Rev.Lett 106:062001 (2011)

2009 STAR W A_L



$\frac{\Delta\bar{u}}{\bar{u}}$

$\frac{\Delta\bar{d}}{\bar{d}}$

Run 9 :
10 pb-1 of data
~40% polarization

$$A_L(W^+) = -0.27 \pm 0.10 \pm 0.02$$

$$A_L(W^-) = 0.14 \pm 0.19 \pm 0.02$$

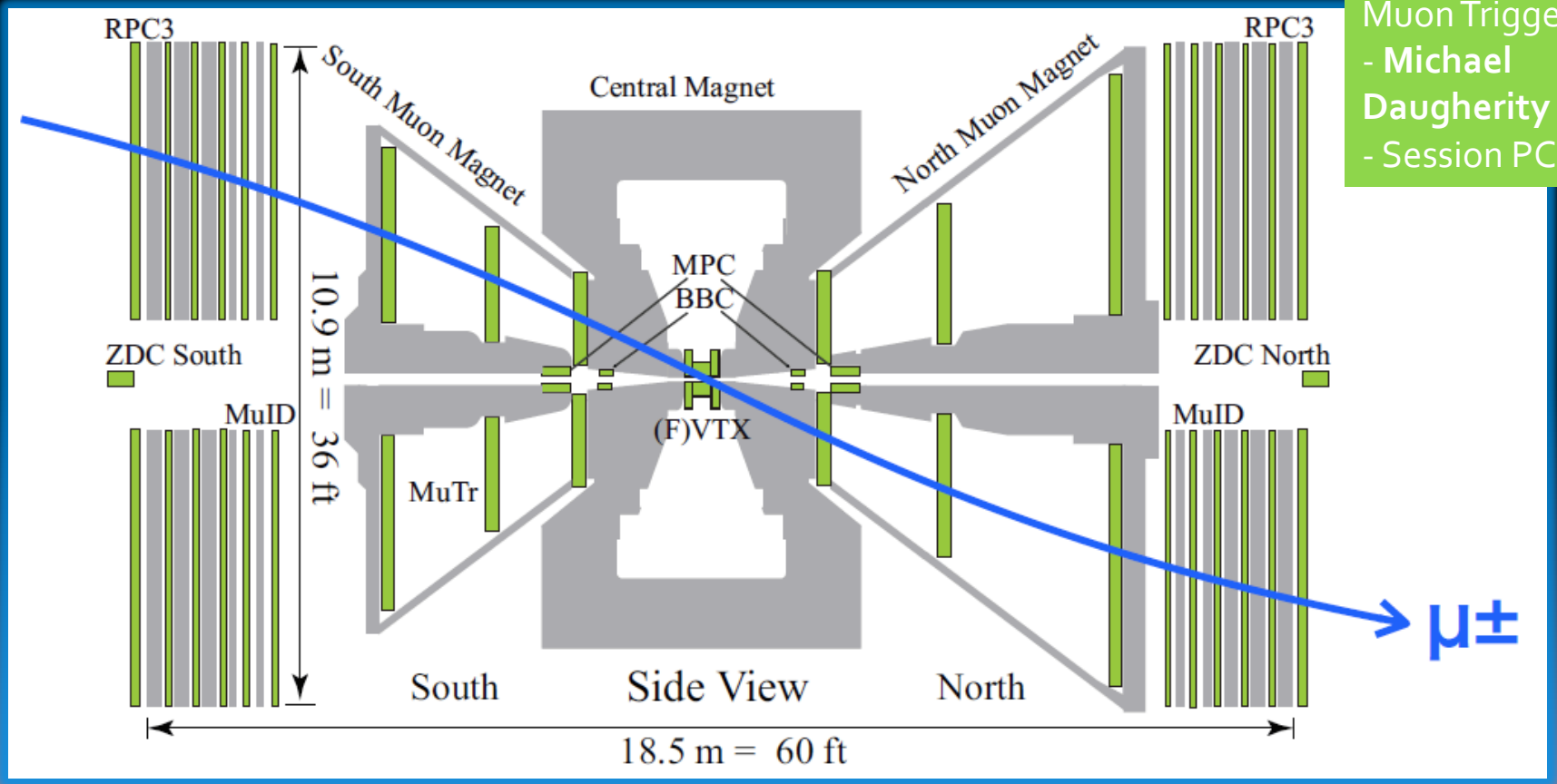
PRL 106, 062002 (2011)

PHENIX: First forward W A_L

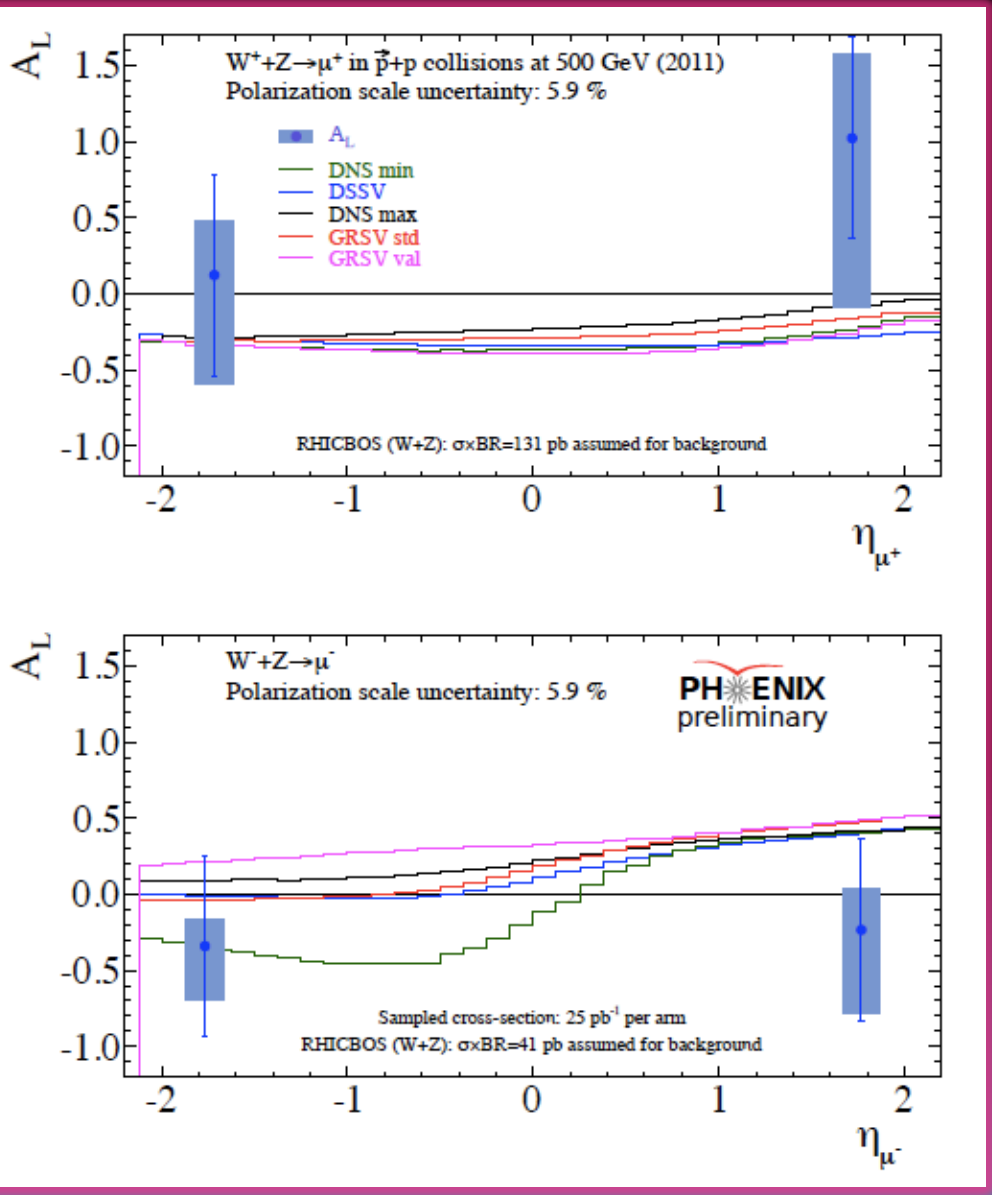
- 25 pb-1 collected in 2011 with ~50% polarization
- Uses MuTr, MuID and RPC's for trigger and ID.
- Very difficult analysis -> no Jacobian peak in forward region and significant backgrounds from low pT hadrons.

Forward Dimuon A_{LL} & A_L
- **Jin Huang**
-Session HB

Muon Trigger
- **Michael Daugherity**
- Session PC



PHENIX: 2011 Forward W A_L



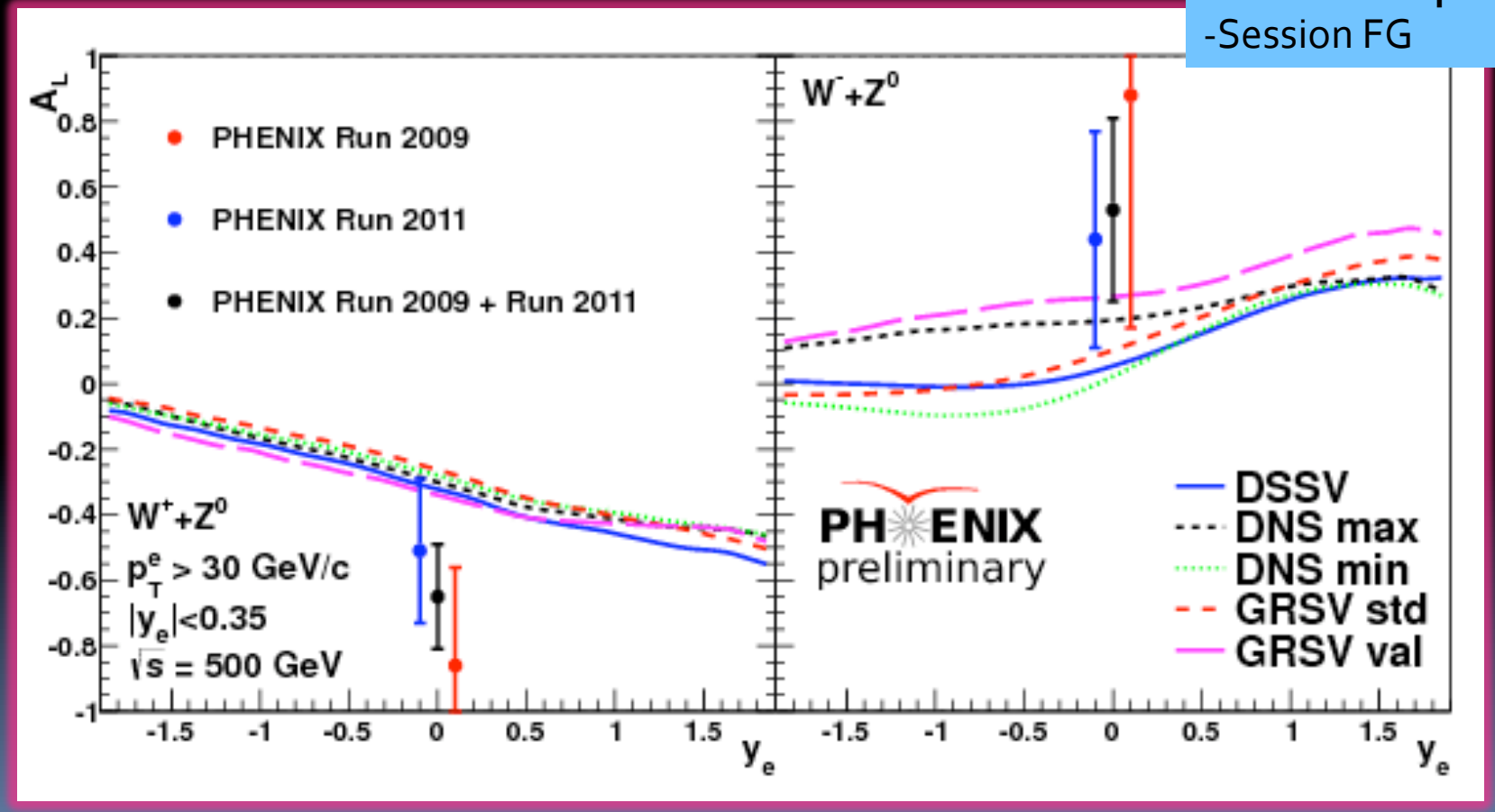
- First A_L in forward region!
- Systematic errors are conservative & rely on MC S/B estimation
- Final systematic errors will be reduced via data driven techniques
- Improvements in trigger + FVTX will reduce background for future measurements.

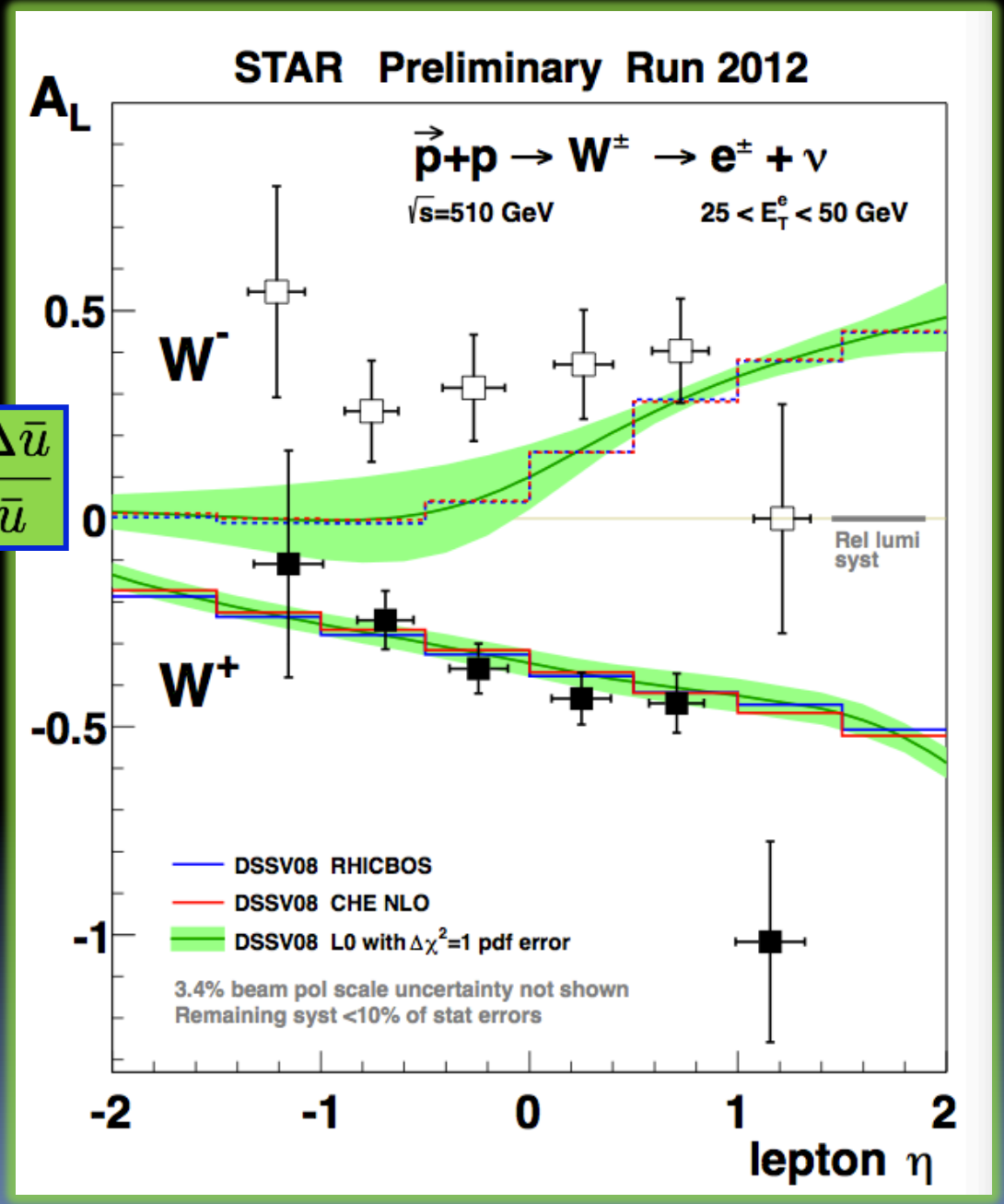
Forward W A_L using μ in RPC
- **Daniel Jumper**
- Session FG

Using FVTX to reduce background in W reconstruction
- **Abraham Meles**
-Session FG

PHENIX 2011 Mid-rapidity W A_L

Midrapidity W A_L
- **Mikhail Stepanov**
-Session FG





$\frac{\Delta\bar{u}}{\bar{u}}$

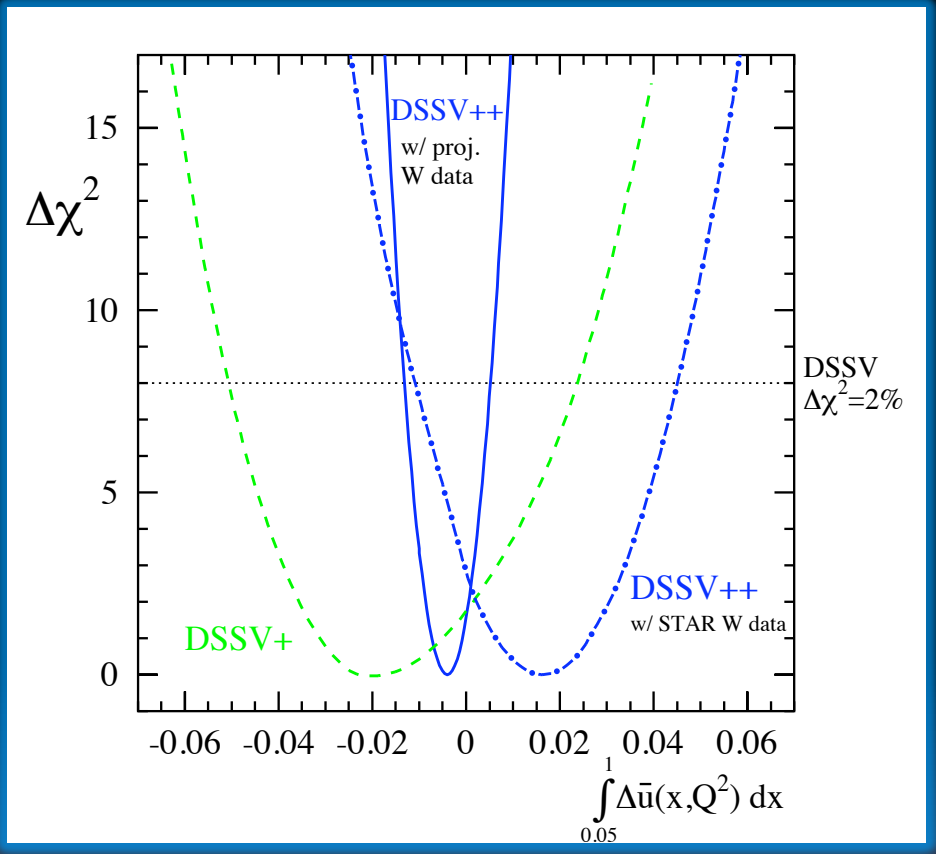
STAR 2012 Midrapidity W A_L

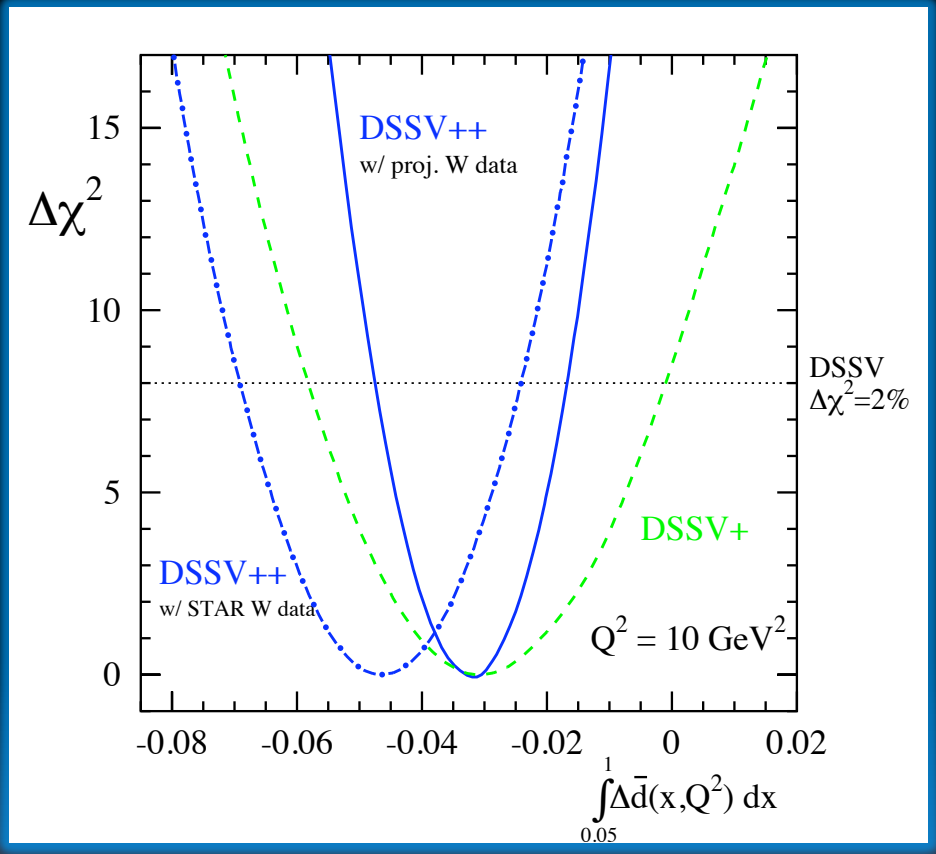
- Extended to $|\eta| < 1.4$ & divided into 6 bins.
- Very systematic errors even in forward region
- W- A_L systematically larger than DSSV mean value.

DETAILS + FIRST Z A_L!!
Jan Balewski
Session FG

Impact on $\Delta\bar{u}$ & $\Delta\bar{d}$ PDFs?

Thanks to DSSV for permission to show preliminary analysis plots!



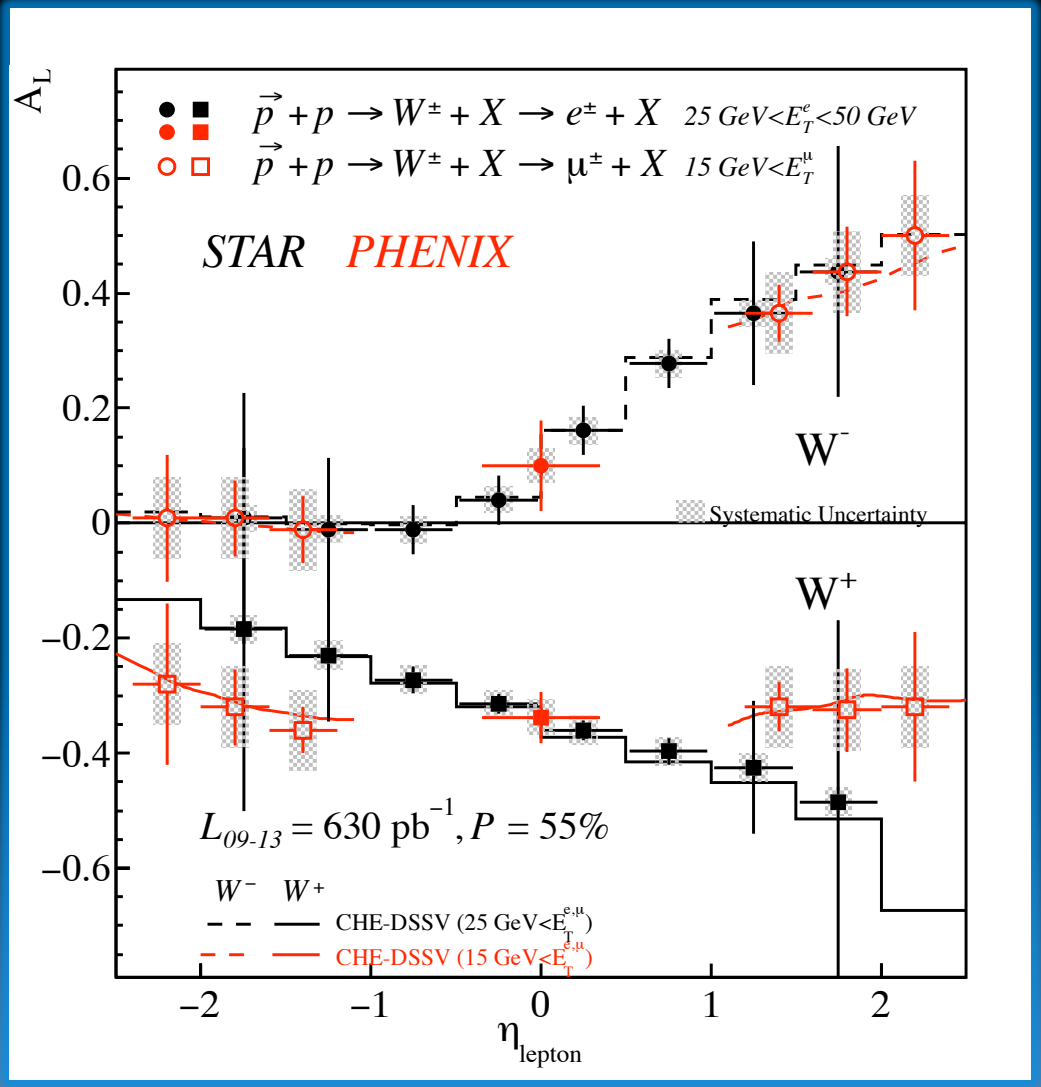


DSSV+ = DSSV & COMPASS data

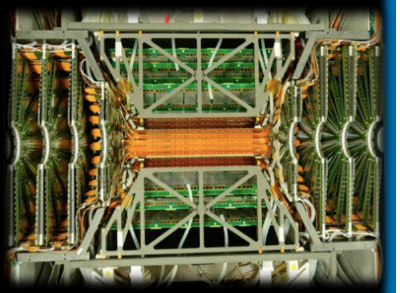
DSSV++ = DSSV+ run-9 pi0 and jet & projected W data

DSSV++ = DSSV+ run-9 pi0 and jet & STAR W

PHENIX + STAR W A_L After Run 13

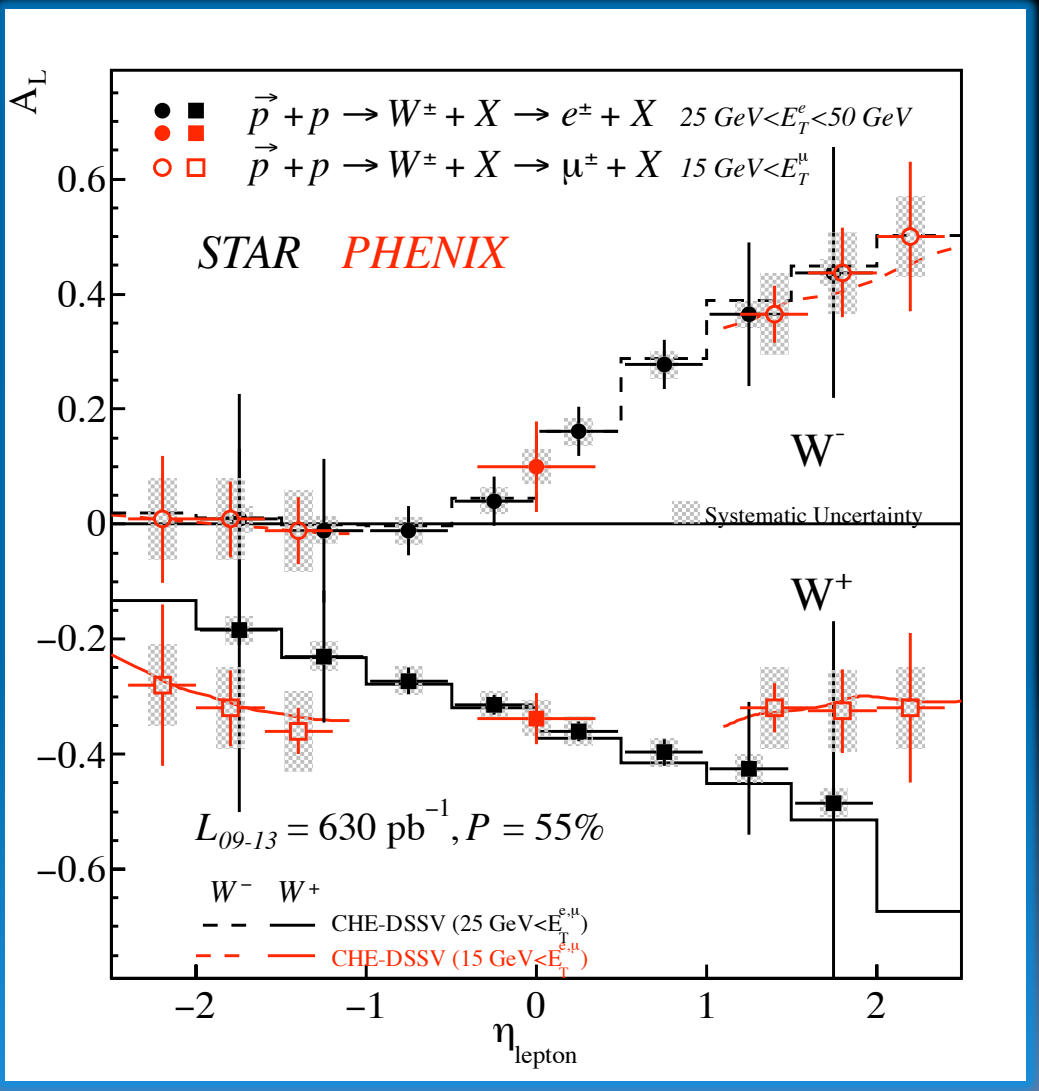


PHENIX + STAR W A_L After Run 13

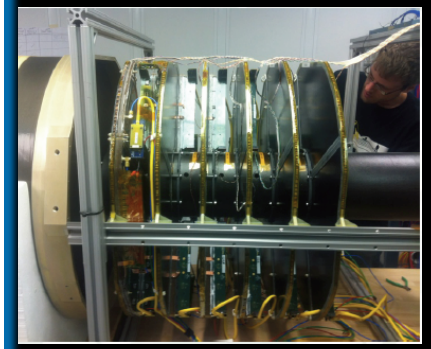


PHENIX FVTX will significantly improve S/B in forward W

FVTX
-**Jeongsu Bok**
-Session PC



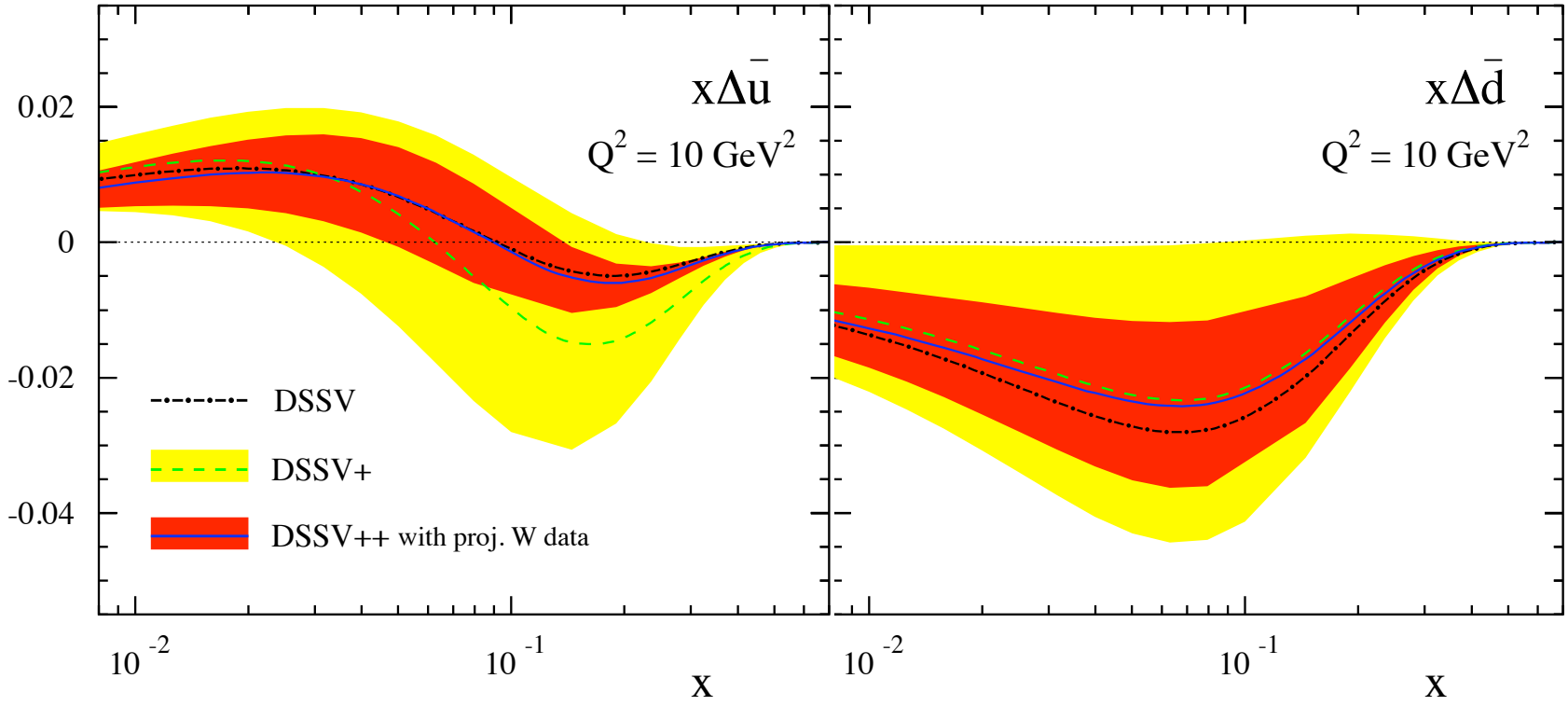
STAR FGT will extend W reconstruction to $|\eta|<2$



STAR FGT
-**Bernd Surrow**
-**Emily Zarndt**
-Session PC

Impact on $\Delta\bar{u}$ & $\Delta\bar{d}$ PDFs?

Thanks to DSSV for permission to show preliminary analysis plots!



DSSV++ DOES NOT include 2012 STAR data… only projections through Run 13

ΔG

- The inclusion of run 9 PHENIX + STAR data into the DSSV global analysis results in a gluon contribution to the spin of the proton **of ~0.1** , in the kinematic regime experimentally accessible.

- Both experiments are pursuing measurements that will access lower x ranges and help constrain the functional form of g(x).

Δu+Δd

- PHENIX has made the first W A_L measurement using muon detectors in the forward region.

- Both STAR and PHENIX have new mid-rapidity W A_L results! A stellar performance by RHIC CAD in 2012 allowed STAR to construct the first η dependent asymmetry at mid-rapidity.

- When STAR's run 12 data is included in the DSSV global analysis, the flavor asymmetry of the light sea appears to be **larger** than current DSSV