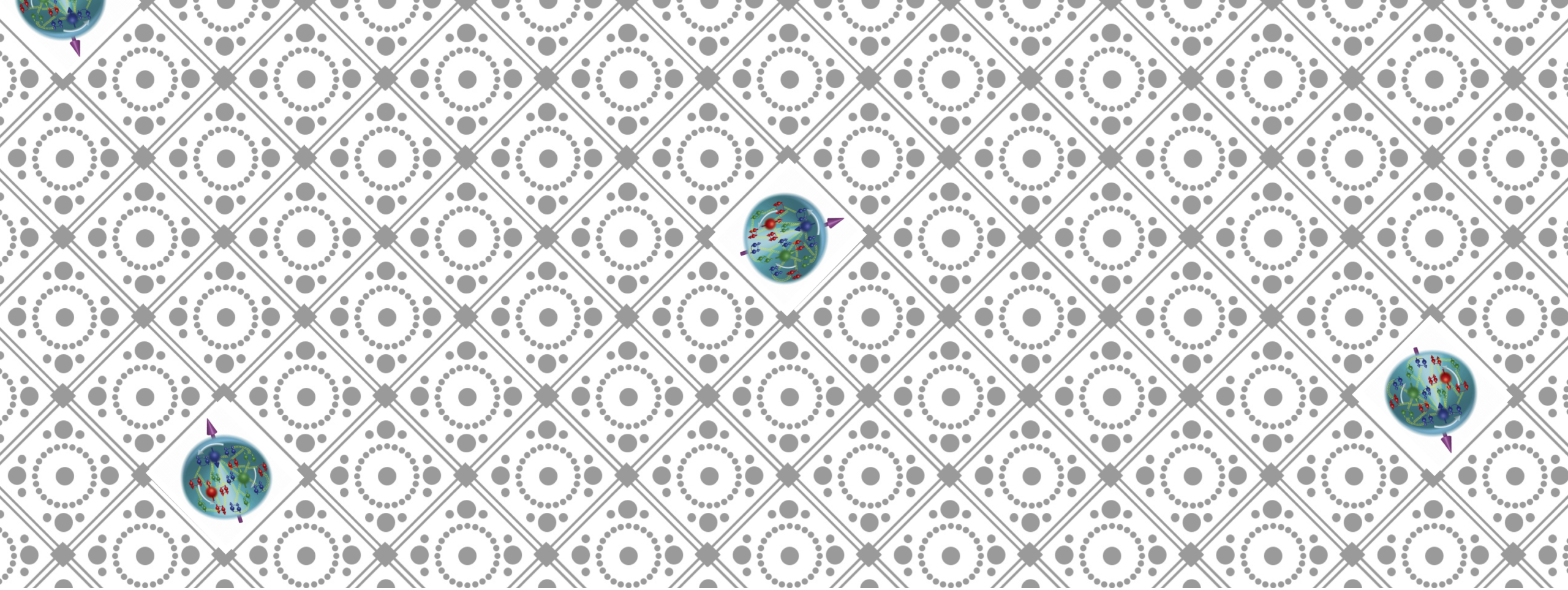

NEWS FROM RHIC

RENEE FATEMI
UNIVERSITY OF KENTUCKY

THE RHIC REVIEW

Protons · Sea-Quarks · Polarized Gluons · TSSAs · Heavy Ions

Issue: 20 The World's Best Selling Newspaper Est - 2000

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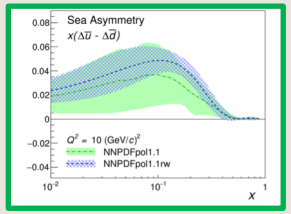

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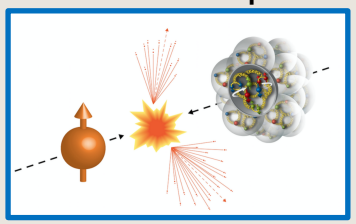

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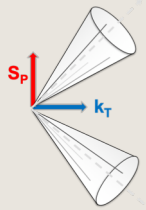

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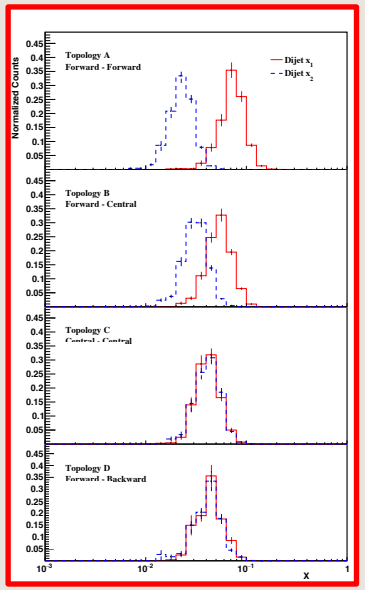
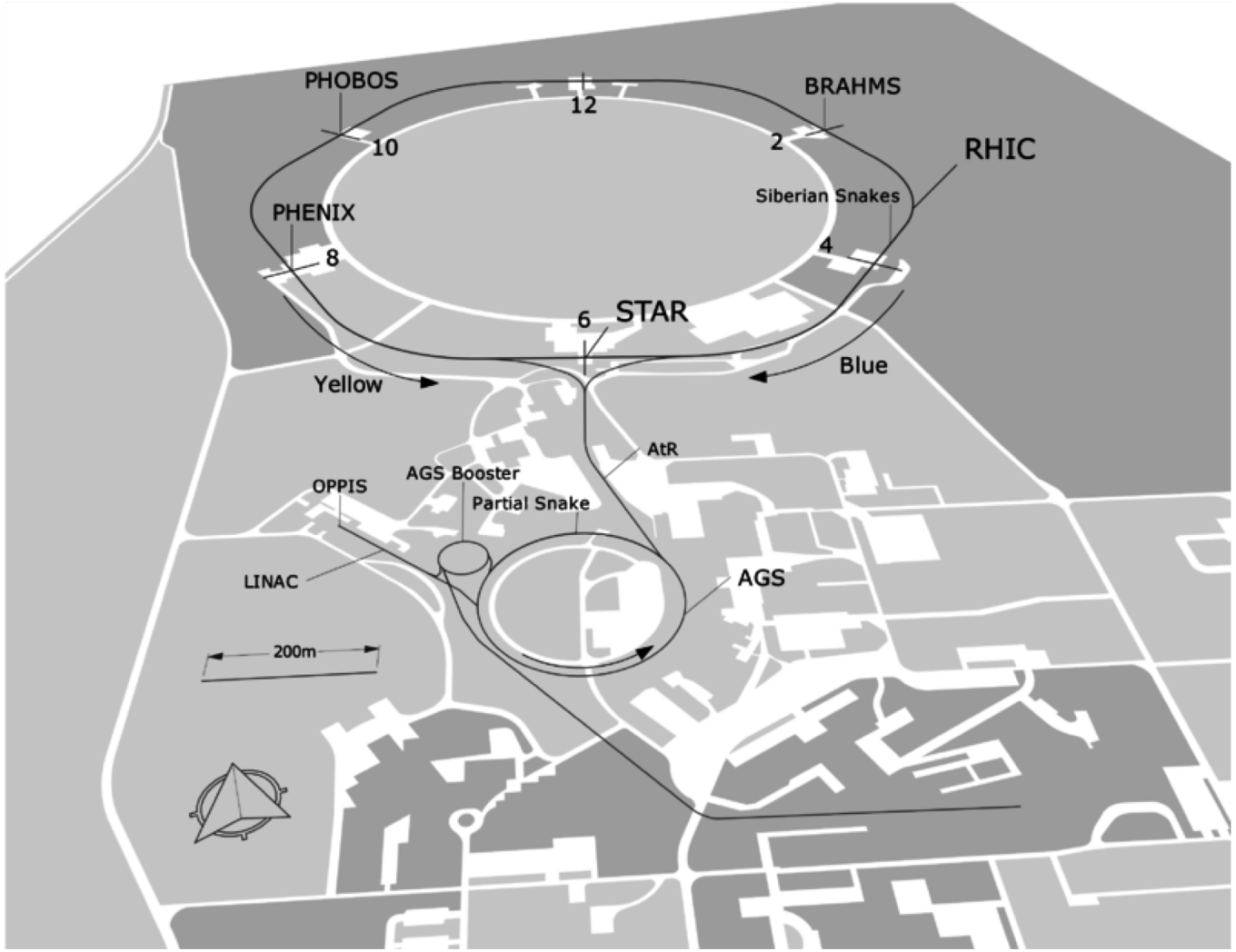


RELATIVISTIC HEAVY ION COLLIDER

the world's only polarized proton collider…



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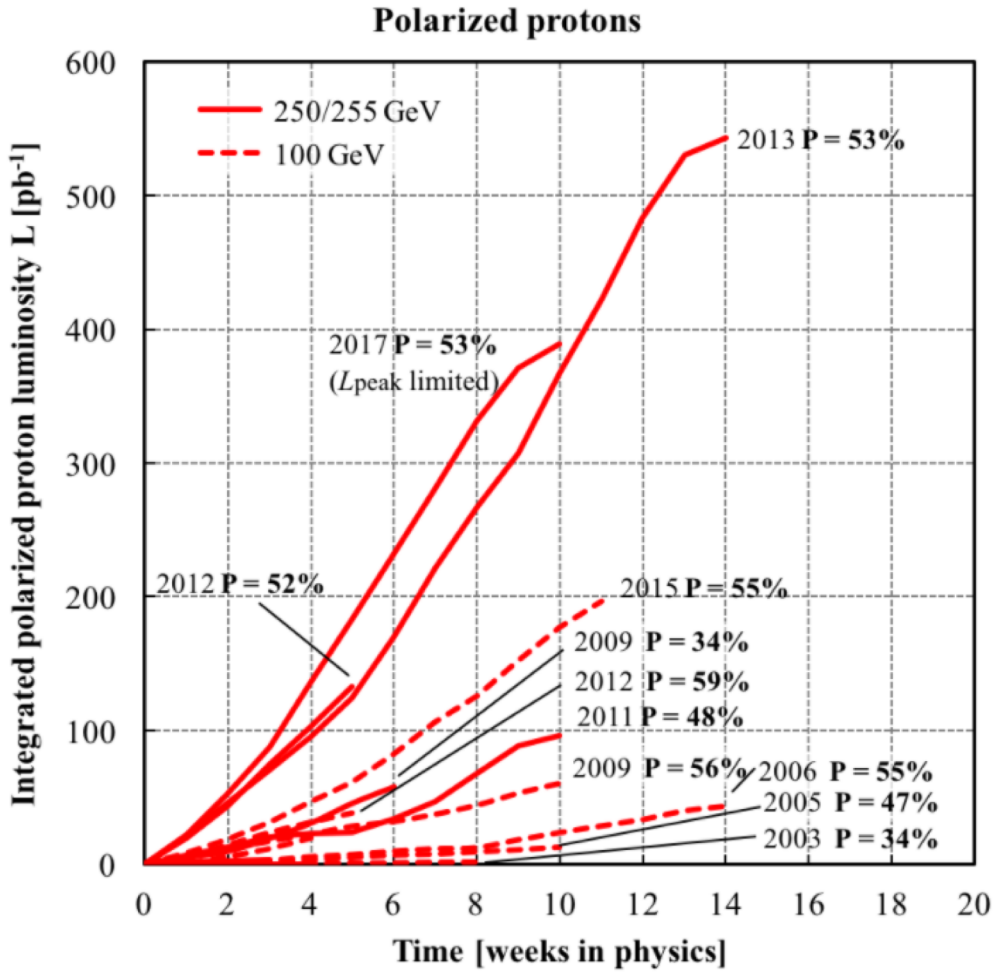
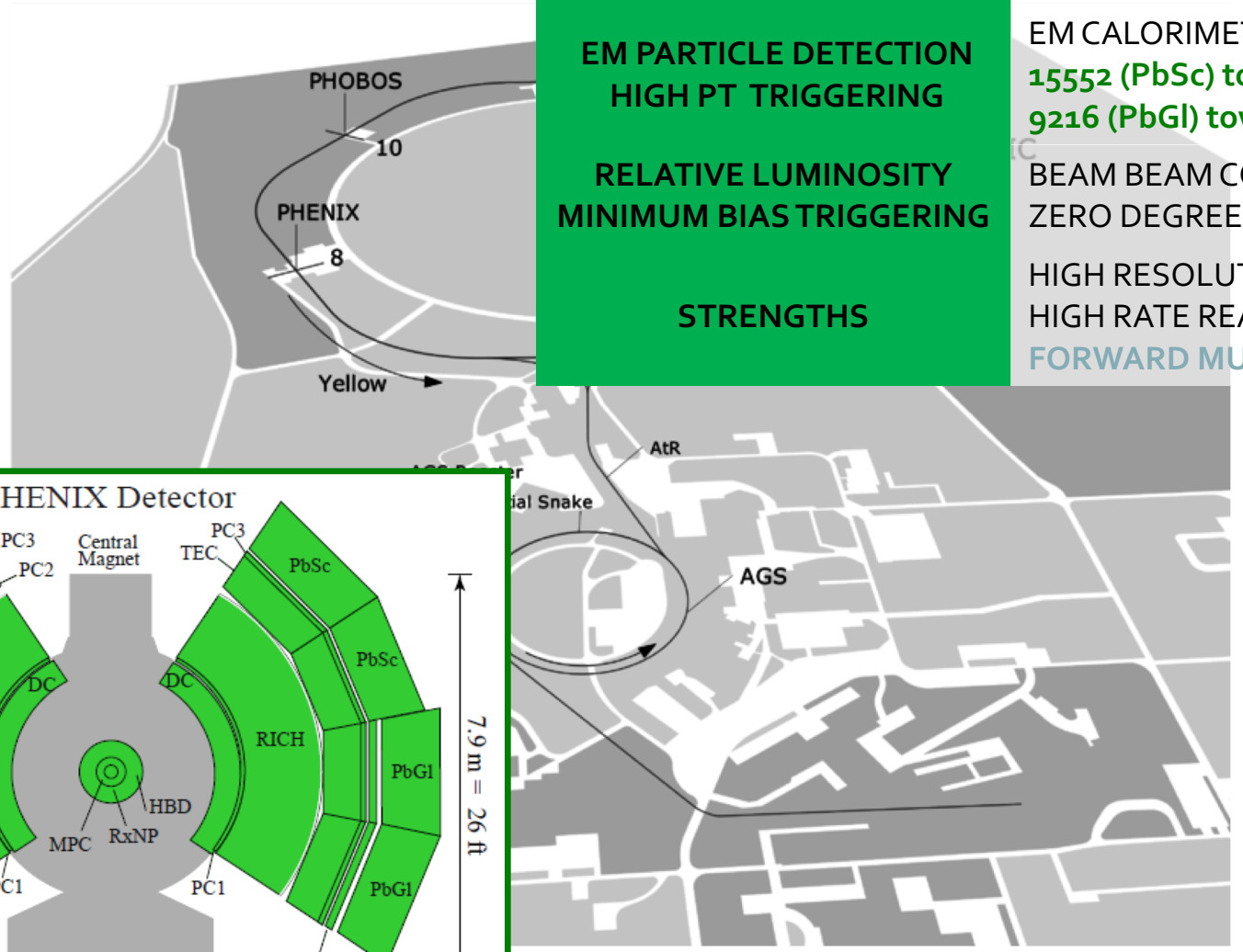
Run	Species	$\sqrt{s}$ (GeV)	Spin
12	p+p	200	transverse
12	p+p	510	longitudinal
13	p+p	510	longitudinal
15	p+p	200	longitudinal
15	p+p p+Al p+Au	200	transverse



PHENIX

CHARGED PARTICLE TRACKING	DRIFT + PAD CHAMBERS
CHARGED PARTICLE IDENTIFICATION	RICH +TOF
EM PARTICLE DETECTION HIGH PT TRIGGERING	EM CALORIMETER **15552 (PbSc) towers** **9216 (PbGl) towers**
RELATIVE LUMINOSITY MINIMUM BIAS TRIGGERING	BEAM BEAM COUNTERS ZERO DEGREE COUNTERS
STRENGTHS	HIGH RESOLUTION HIGH RATE READOUT FORWARD MUON ARMS



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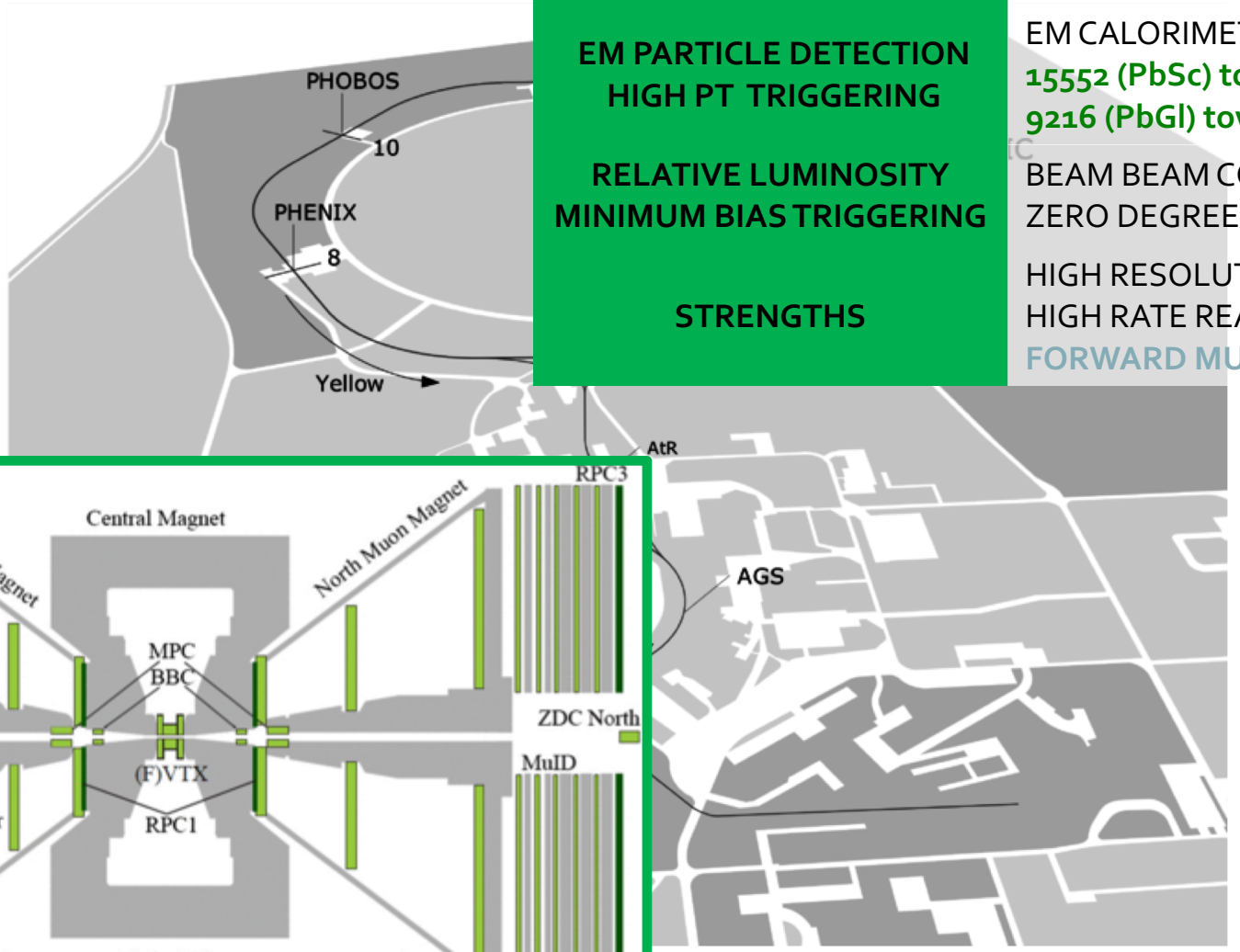

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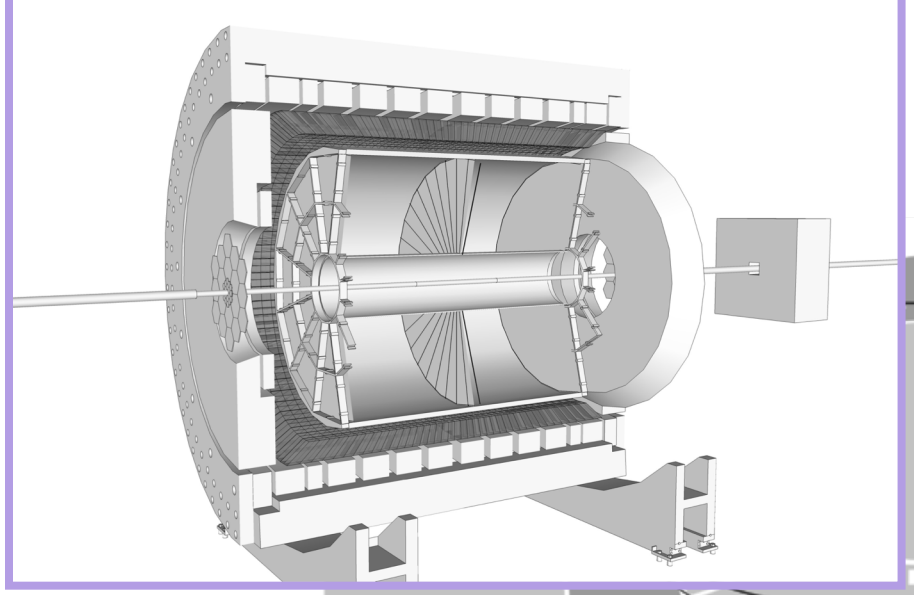

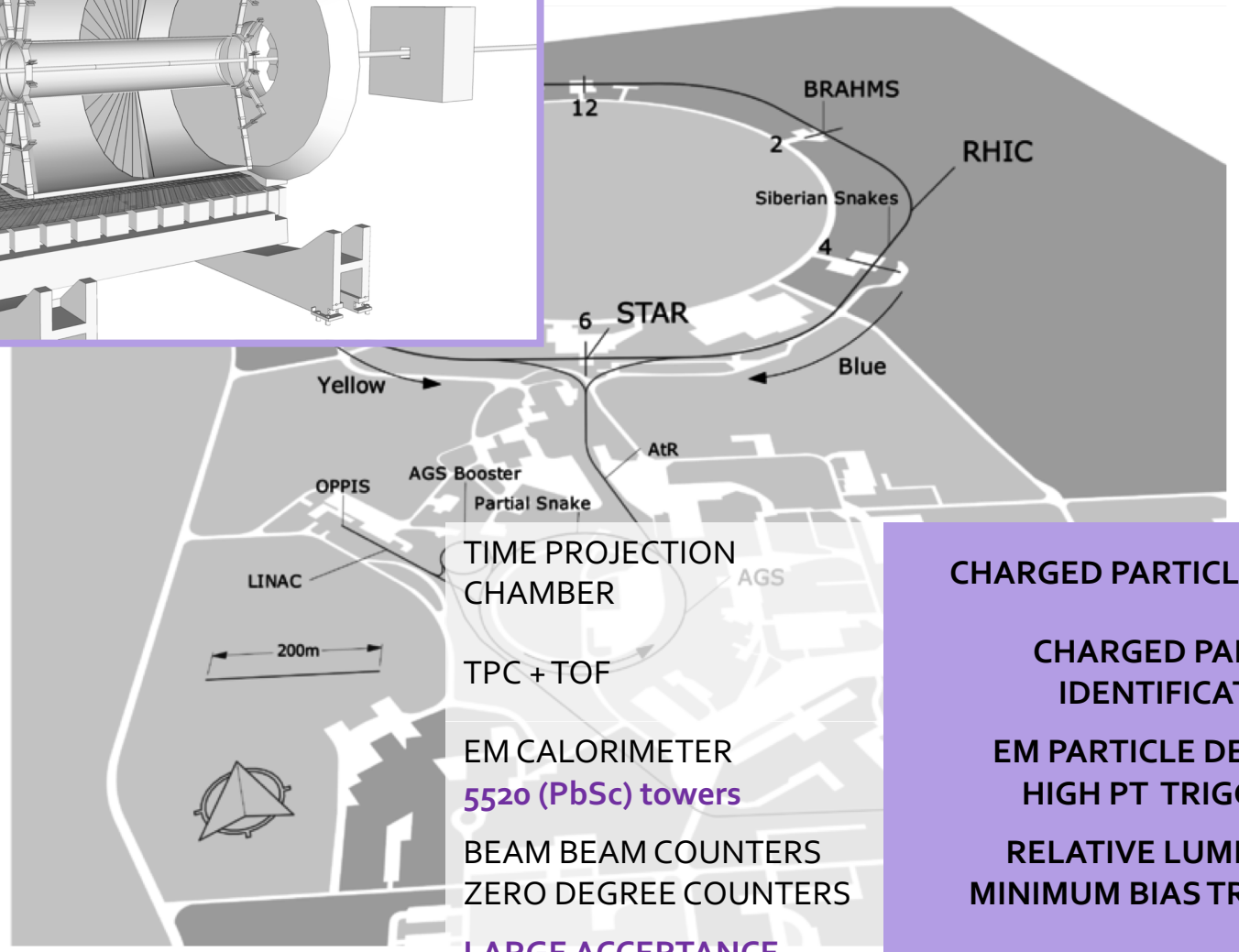

TIME PROJECTION CHAMBER

TPC + TOF

EM CALORIMETER
5520 (PbSc) towers

BEAM BEAM COUNTERS
ZERO DEGREE COUNTERS

LARGE ACCEPTANCE
($-1<\eta<2$)

CHARGED PARTICLE TRACKING

CHARGED PARTICLE IDENTIFICATION

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STRENGTHS

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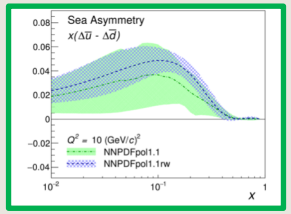

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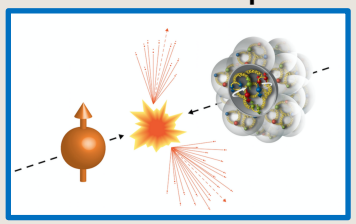

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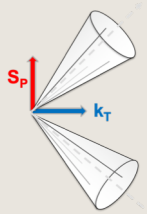

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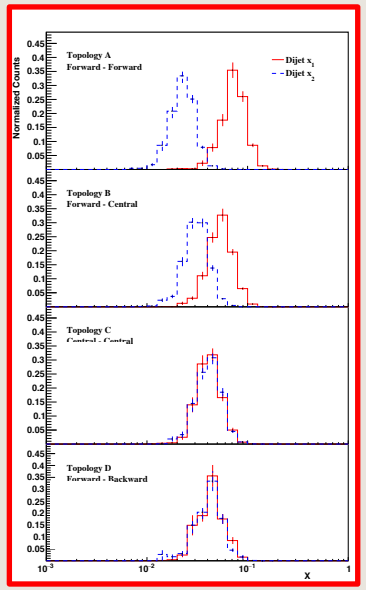
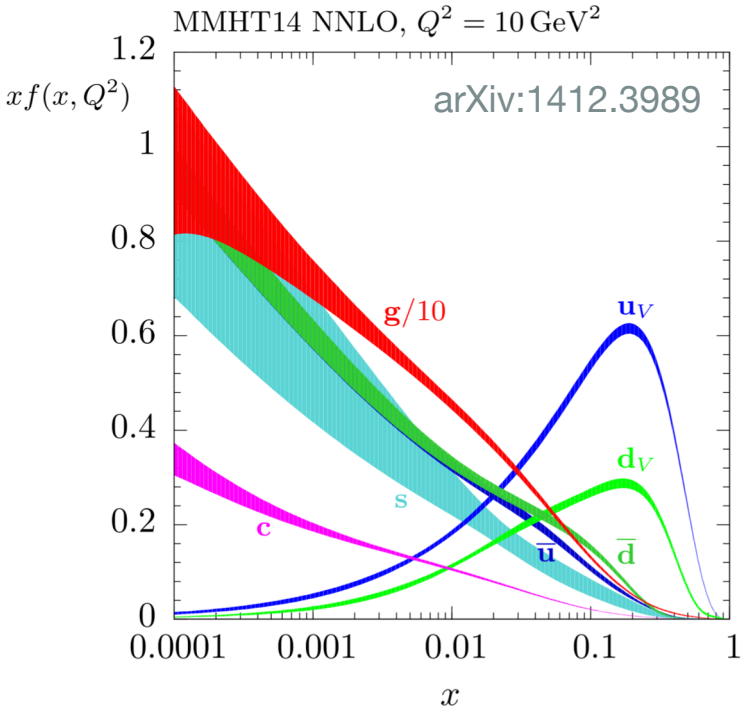
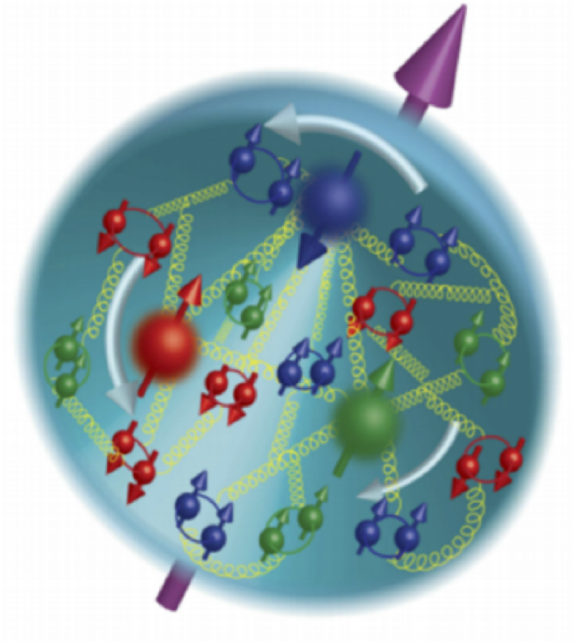


SEA QUARKS AND FLAVOR SYMMETRIES





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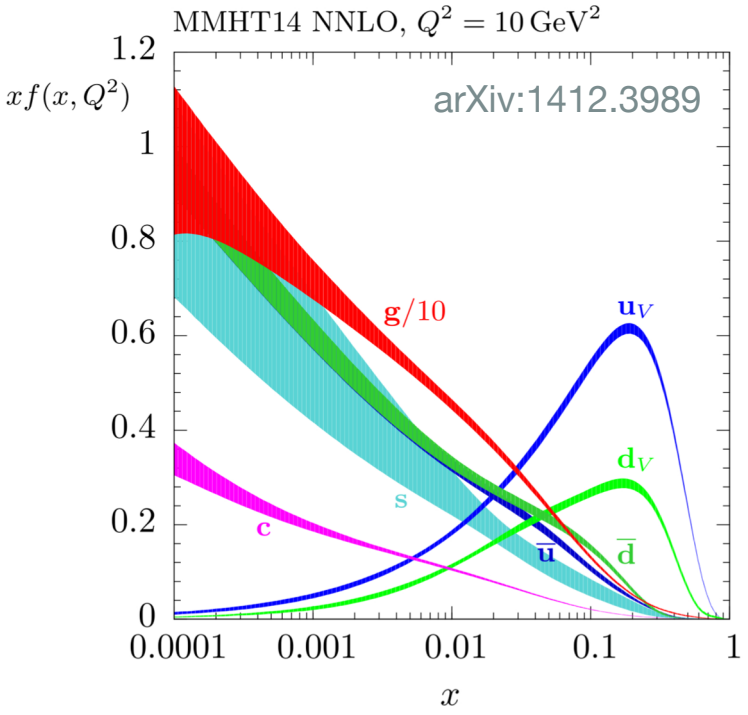

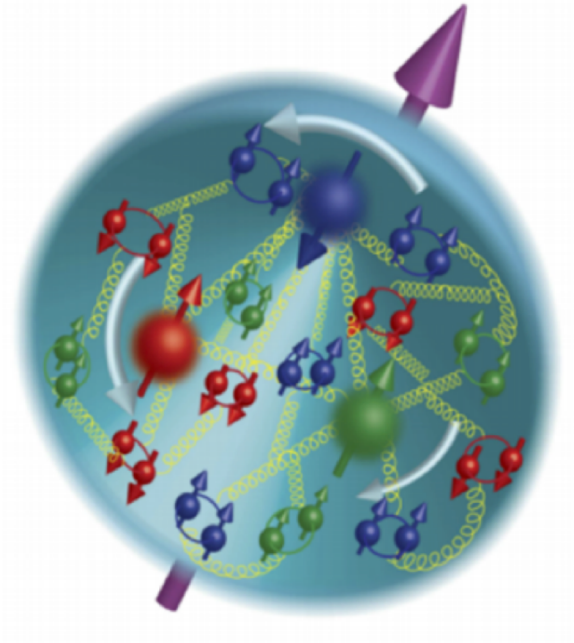

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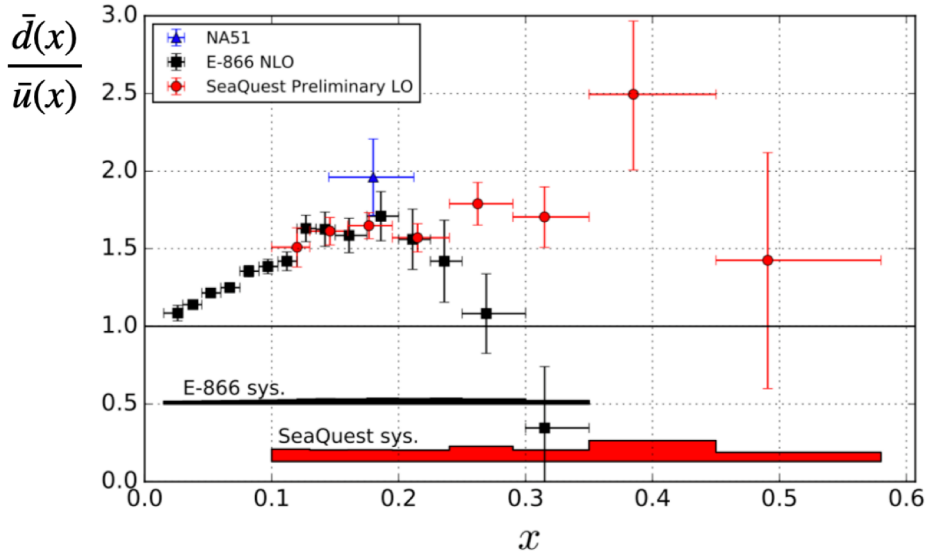

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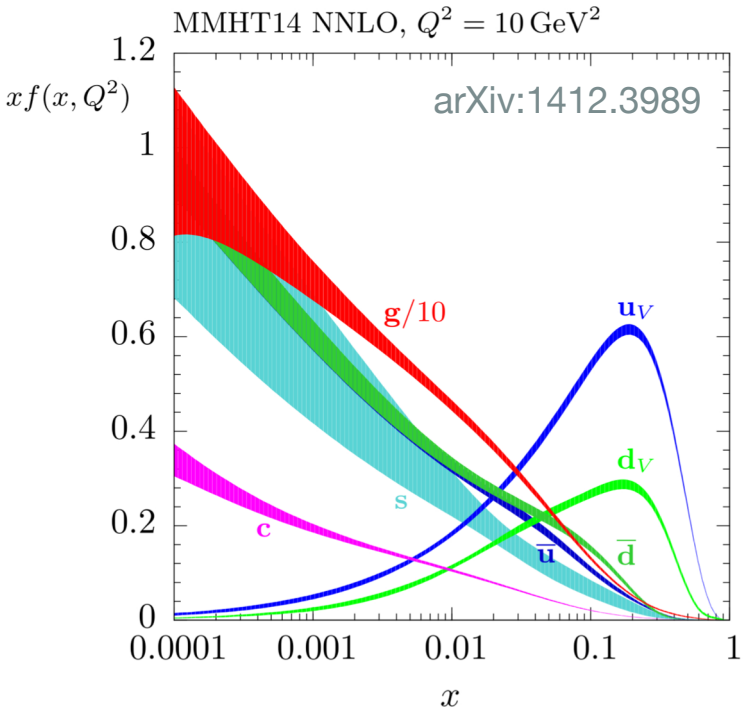

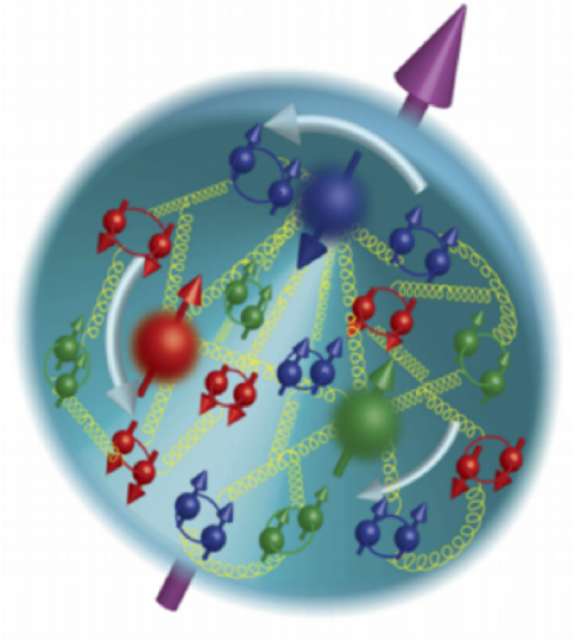

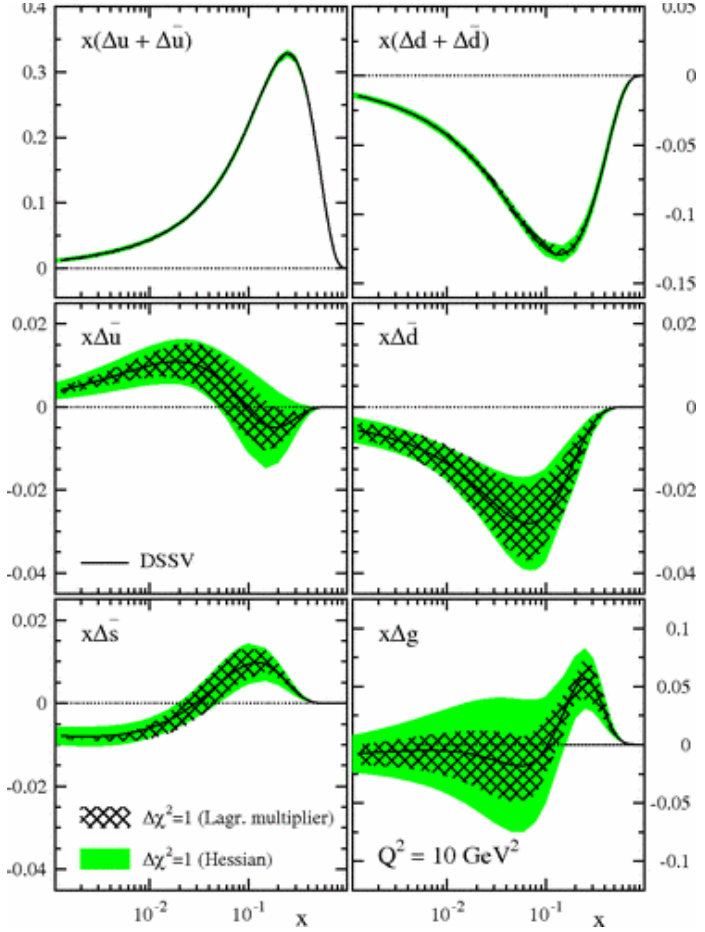

DSSV PRD 80 (2009) 034030

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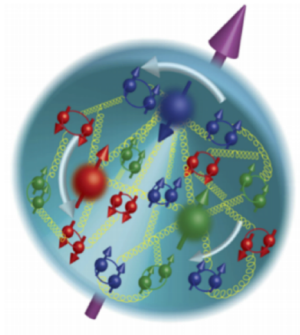
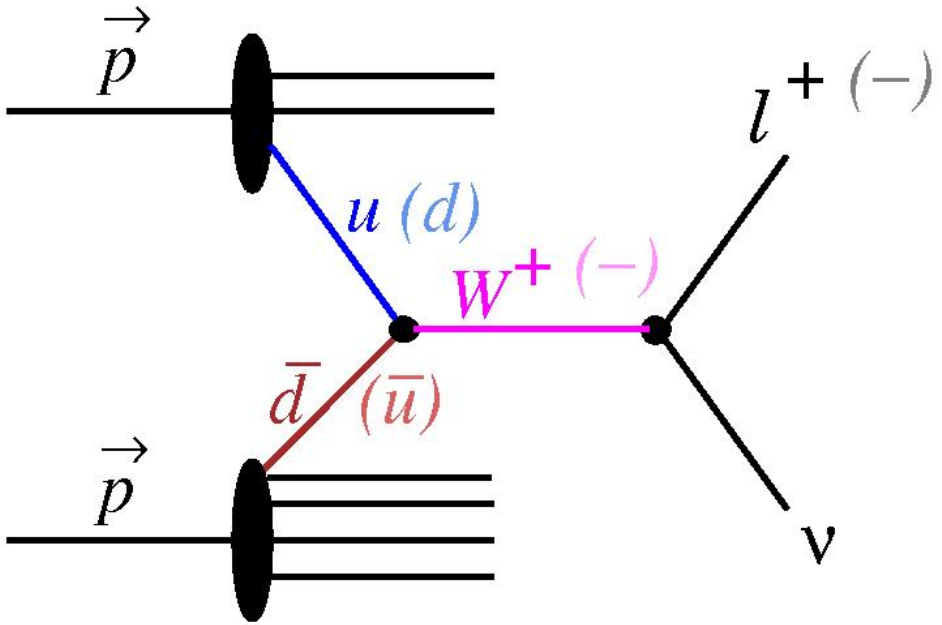


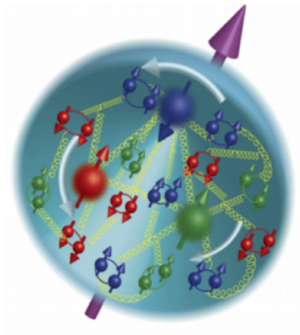


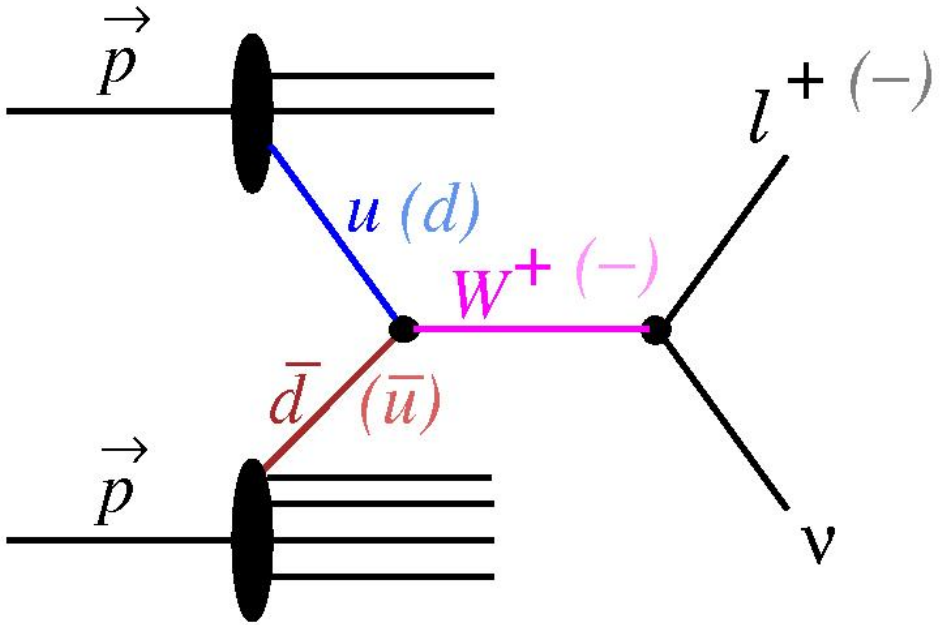
$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

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

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

SEA QUARKS AND FLAVOR SYMMETRIES





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

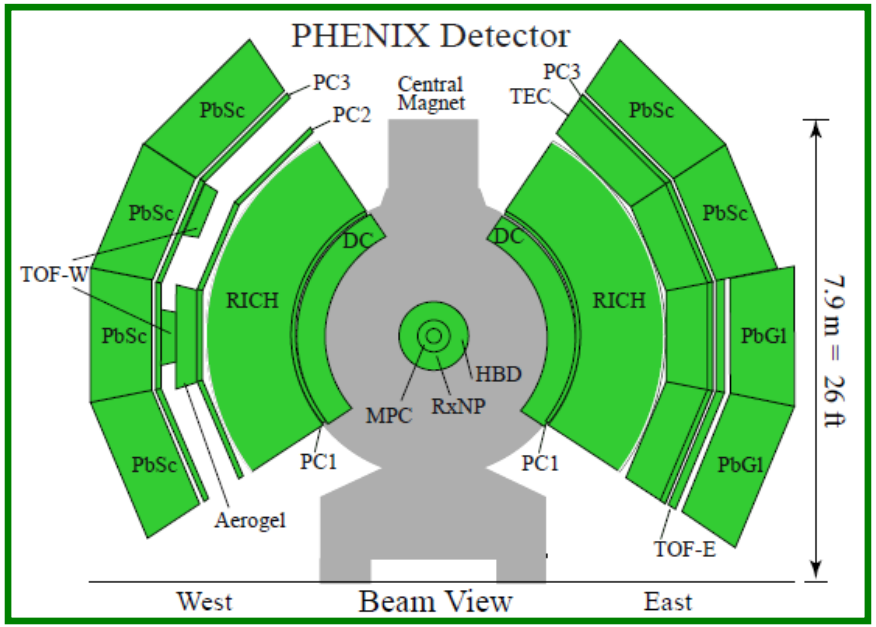
Forward

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

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

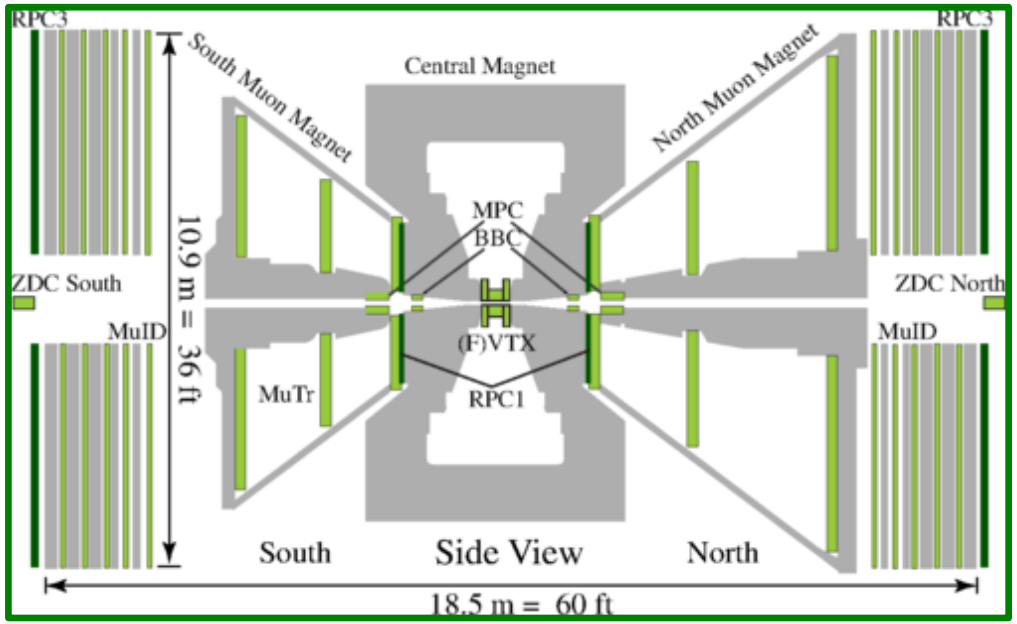
PHENIX $W^{+/-}$ A_L

MIDRAPIDITY



$W^{+/-} \rightarrow e^{+/-} + \nu_e$

FORWARD



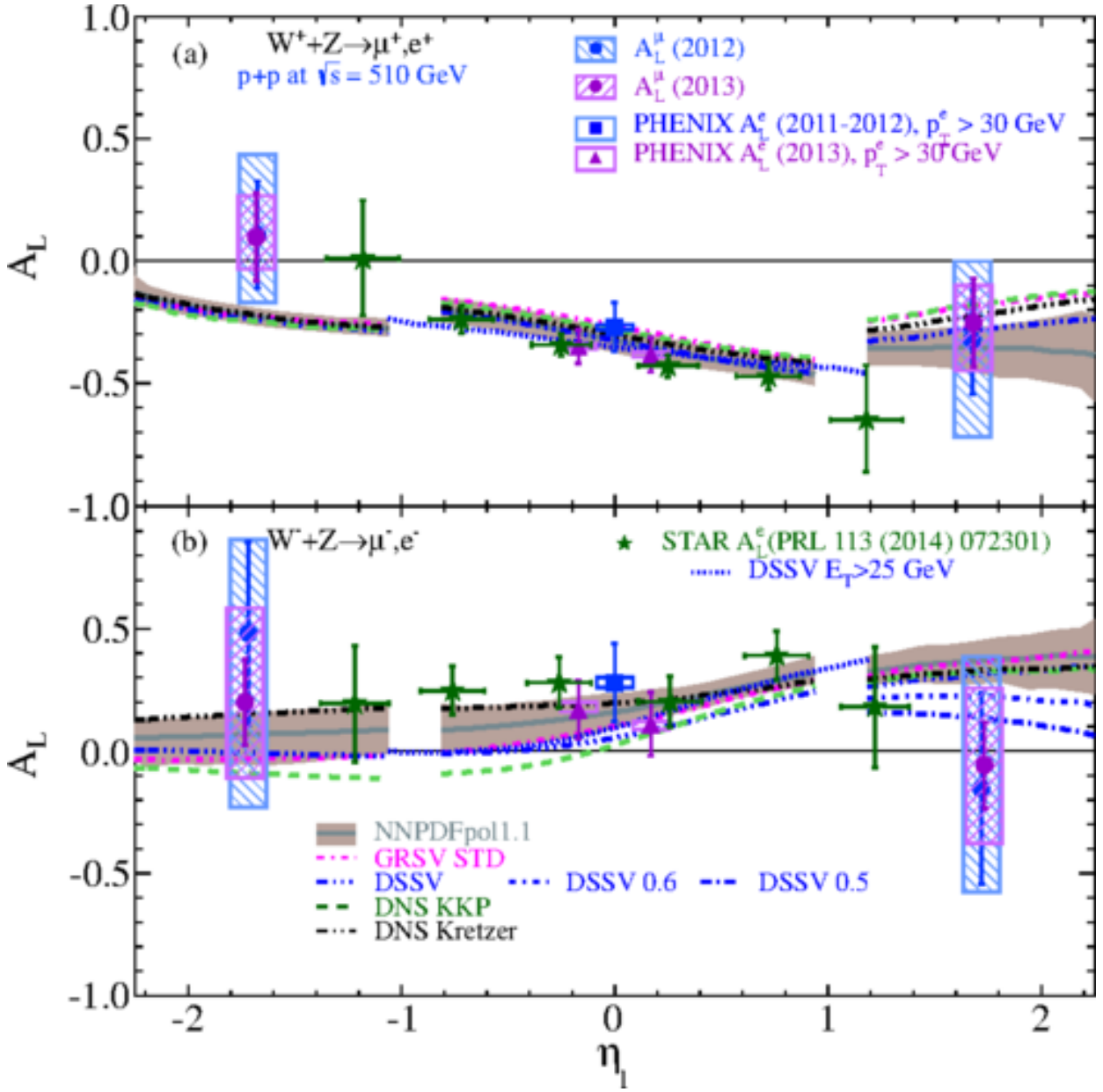
$W^{+/-} \rightarrow \mu^{+/-} + \nu_e$

PHENIX

$W^{+/-}$ A_L

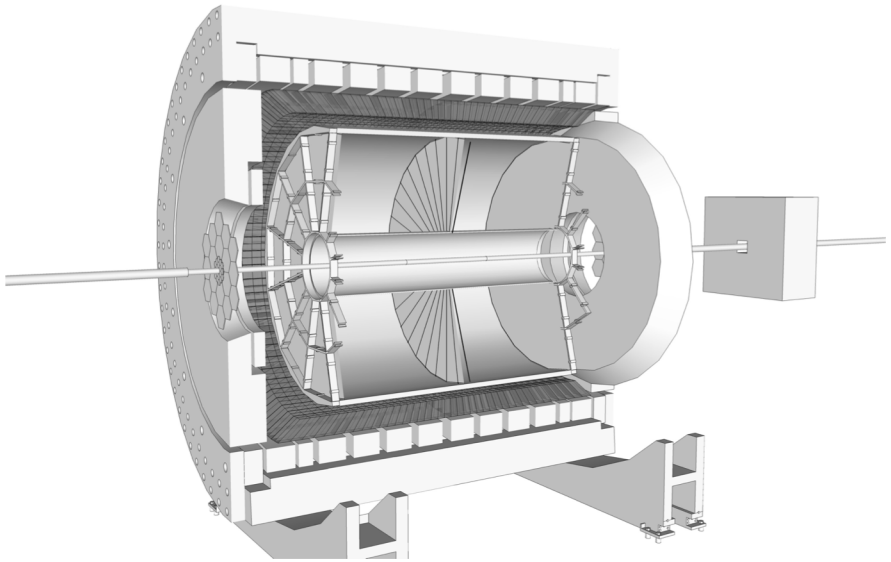
PHYS. REV. D 98, 032007 (2018)

- **First muon channel W A_L !**
- Theoretical curves use the polarized NLO generator CHE with various global fits implemented.
- Backward μ^- are at upper limit of uncertainty bands indicating $\Delta\bar{u}$ is larger than fits without RHIC data indicate – similar to mid-rapidity data.
- Forward μ^- ($\sim\Delta d/d$) is below DSSV08 → could be explained by sign change in Δd for x > 0.5 ?
- Backward μ^+ show smaller than predicted asymmetries. Possibly due to under-estimated error bars in unpolarized sector due to large $\bar{d}$ contribution in data.



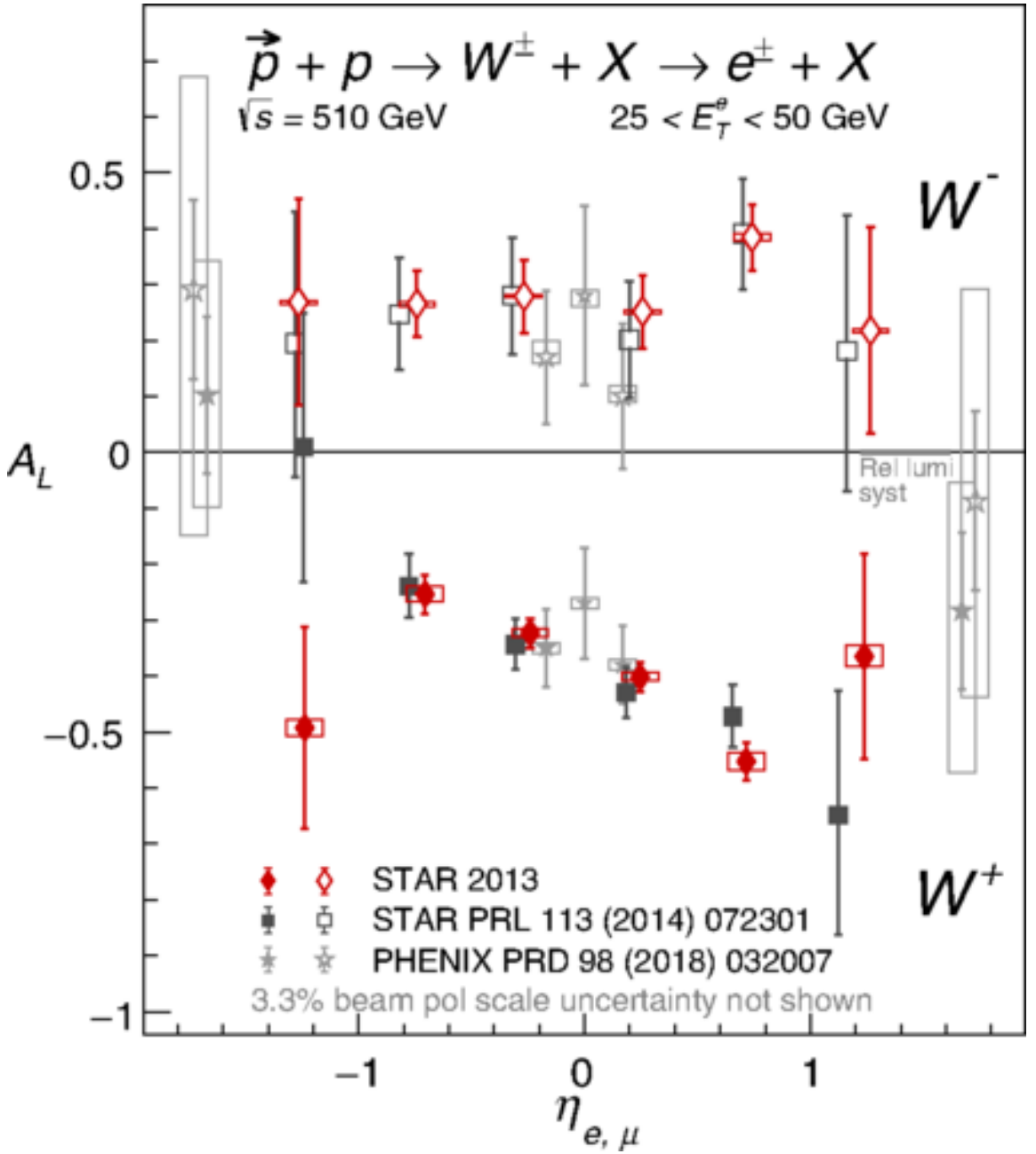
$W^{+/-}$ A_L

$-1 < \eta < 2$



$W^{+/-} \rightarrow e^{+/-} + \nu_e$

Phys. Rev. D **99**, 051102 (2019)



$W^{+/-}$ A_L

- 2013 results are consistent with previous STAR and PHENIX results
- 2013 confirms enhanced $\Delta\bar{u}$ first seen in the 2011-2012 data.

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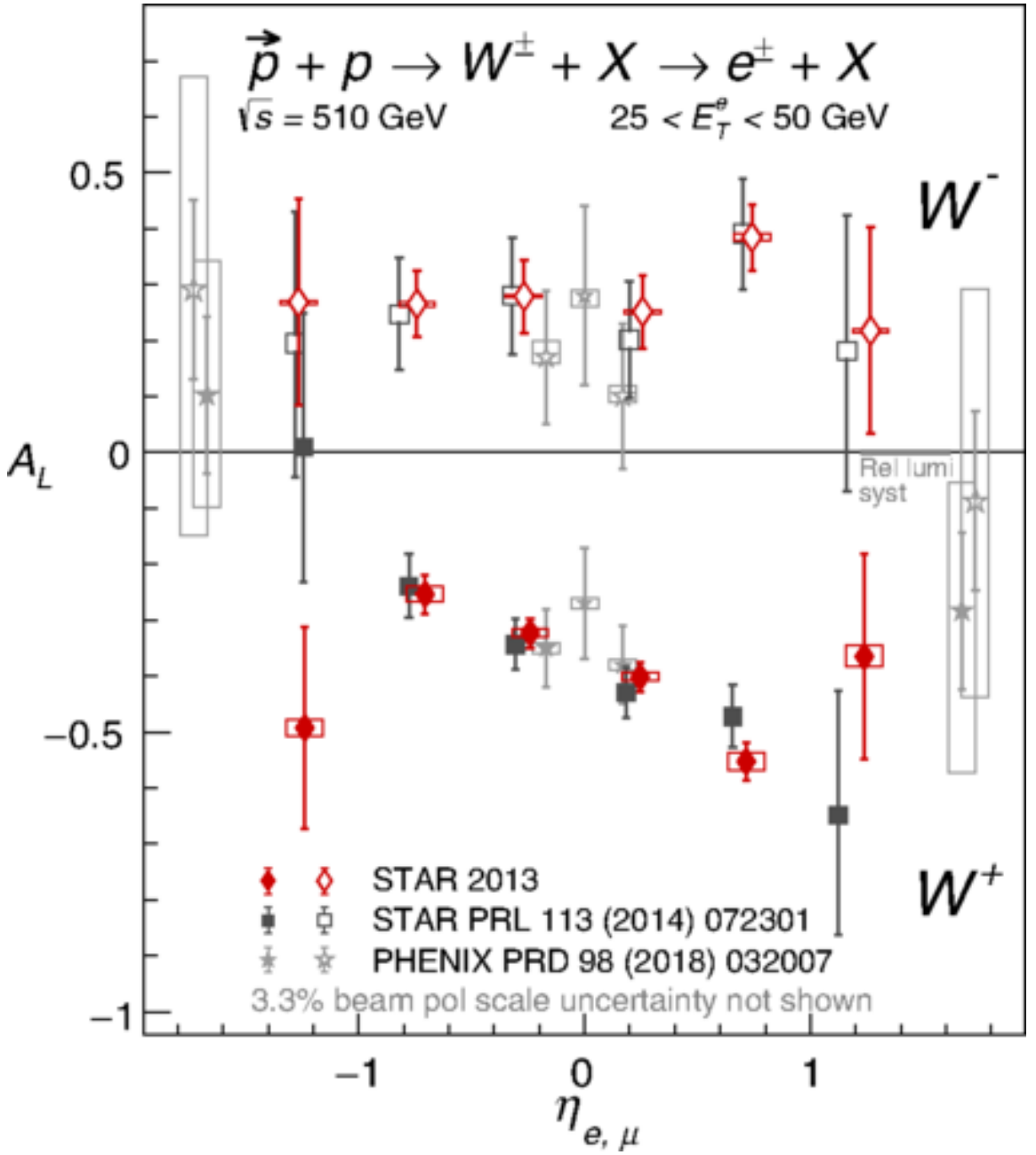
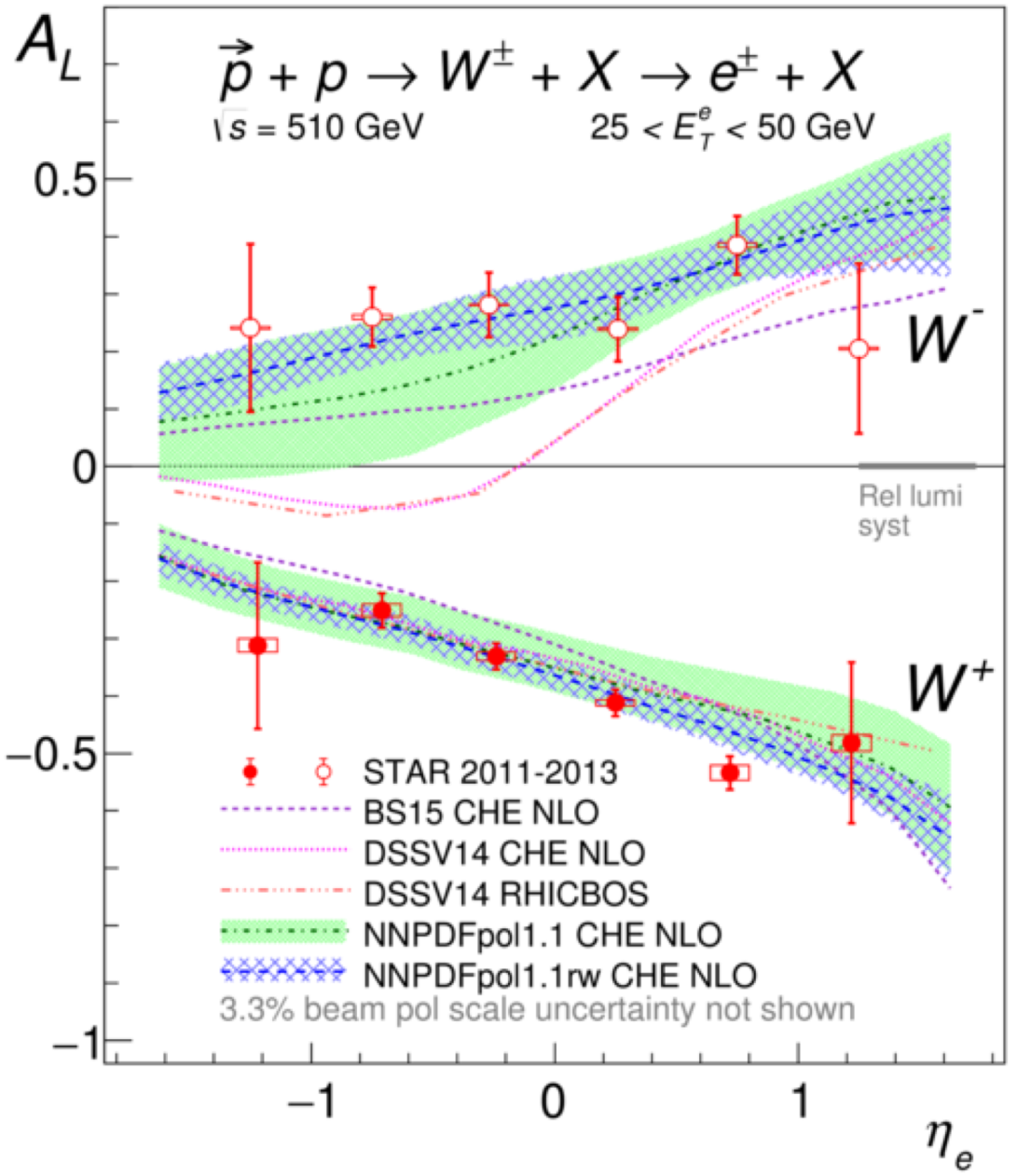


$W^{+/-}$ A_L

- 2013 results are consistent with previous STAR and PHENIX results
- 2013 confirms enhanced $\Delta\bar{u}$ first seen in the 2011-2012 data.
- These data show a significant preference for a $\Delta\bar{u} > \Delta\bar{d}$ for $0.05 < x < 0.25$ at $Q^2 = 10$ GeV.

Phys. Rev. D **99**, 051102 (2019)



$W^{+/-}$ A_L

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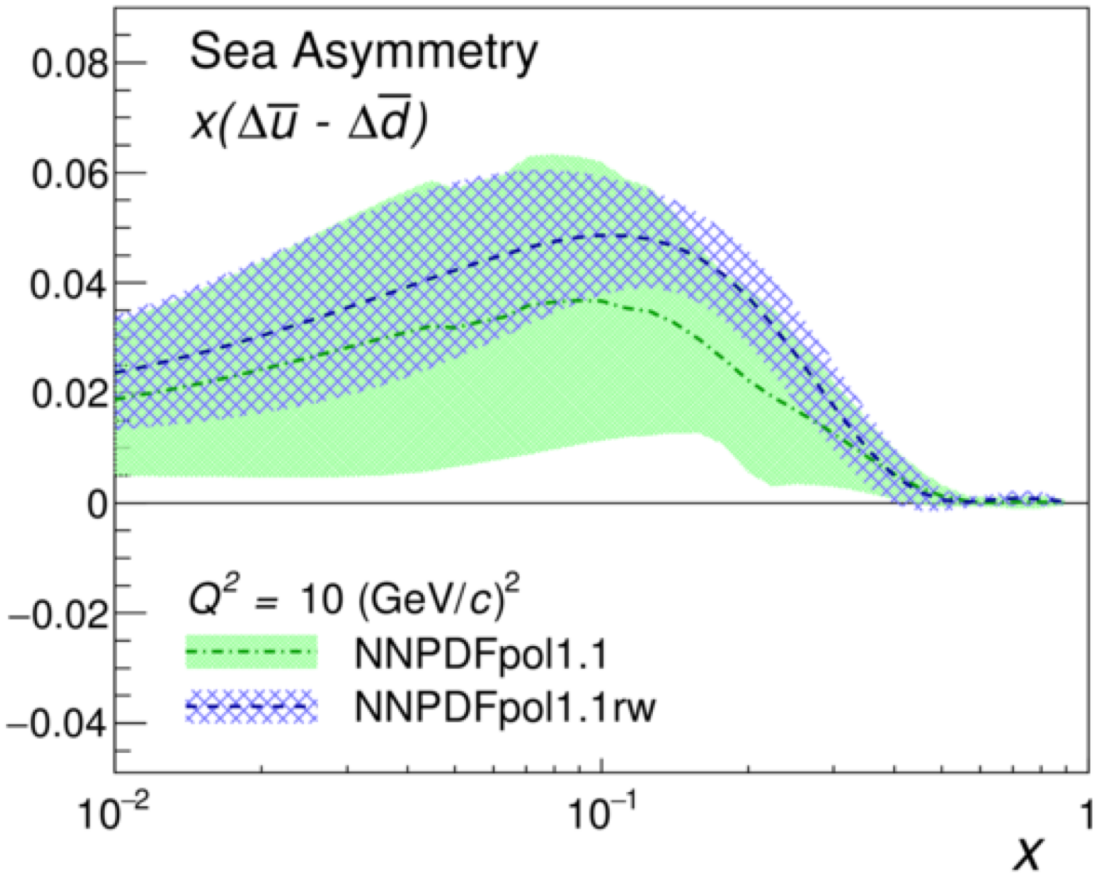

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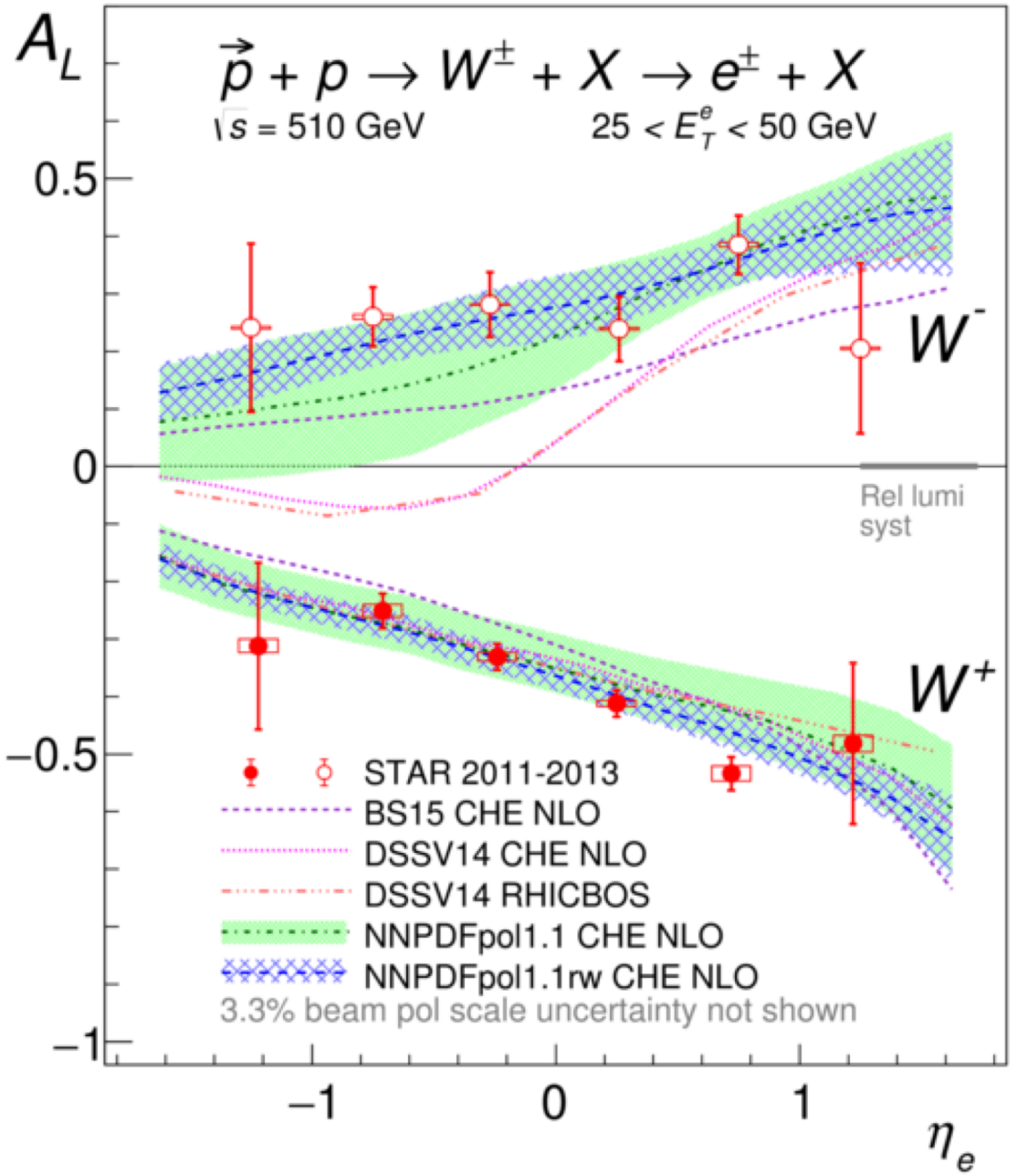
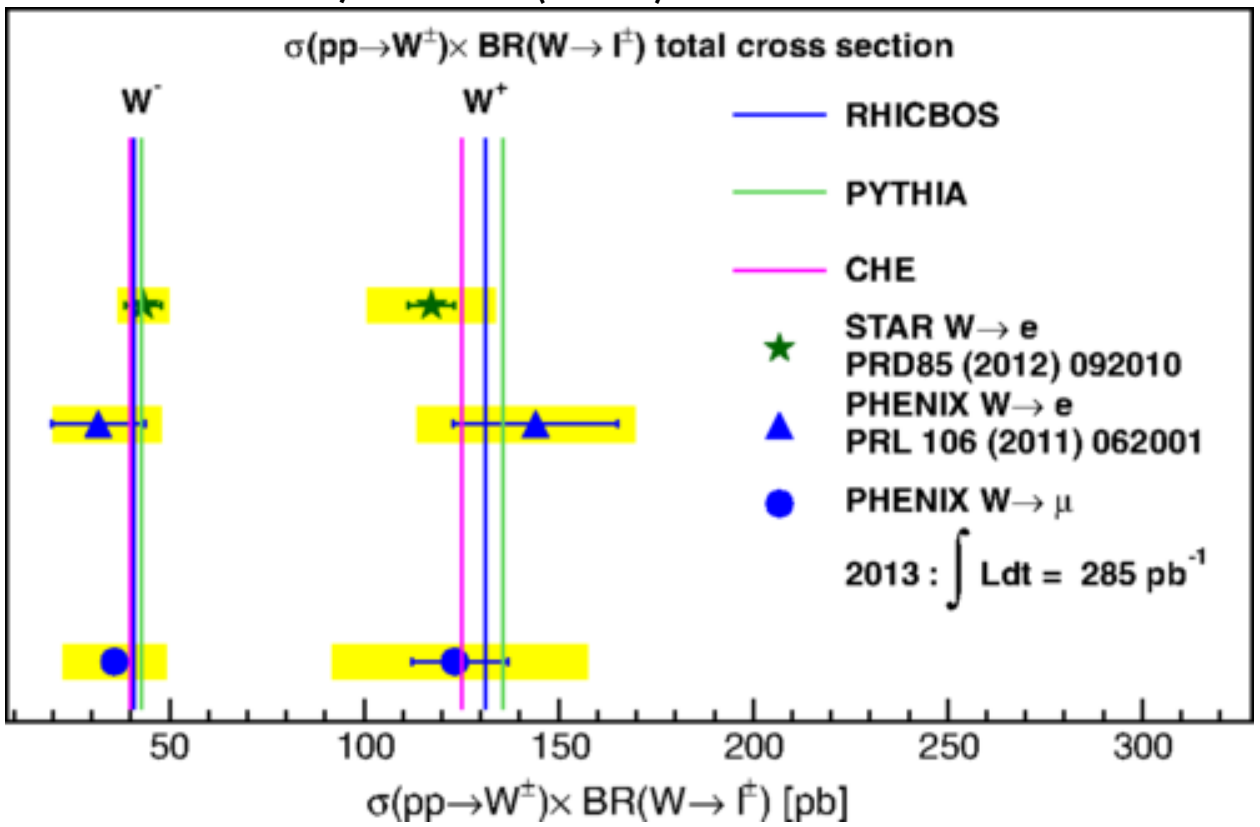


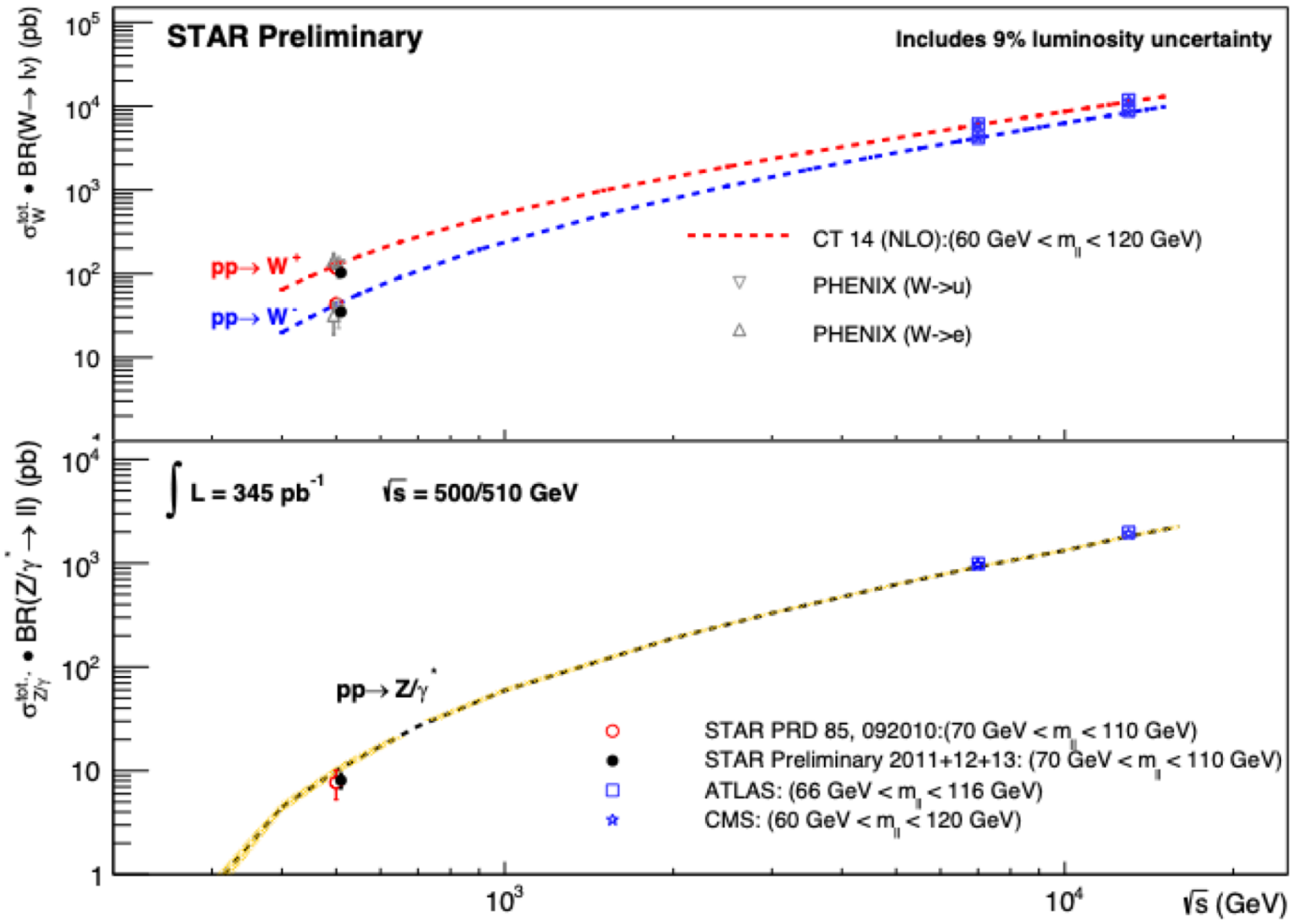
$W^{+/-}$ CROSS-SECTIONS

PHYS. REV. D 98, 032007 (2018)



- Measured at forward and backward rapidity and averaged over arms
- 2013 $W \rightarrow \mu$ systematic error is dominated by the large uncertainty on the signal-to-background ratios.
- Good agreement with previous measurements and theoretical predictions.

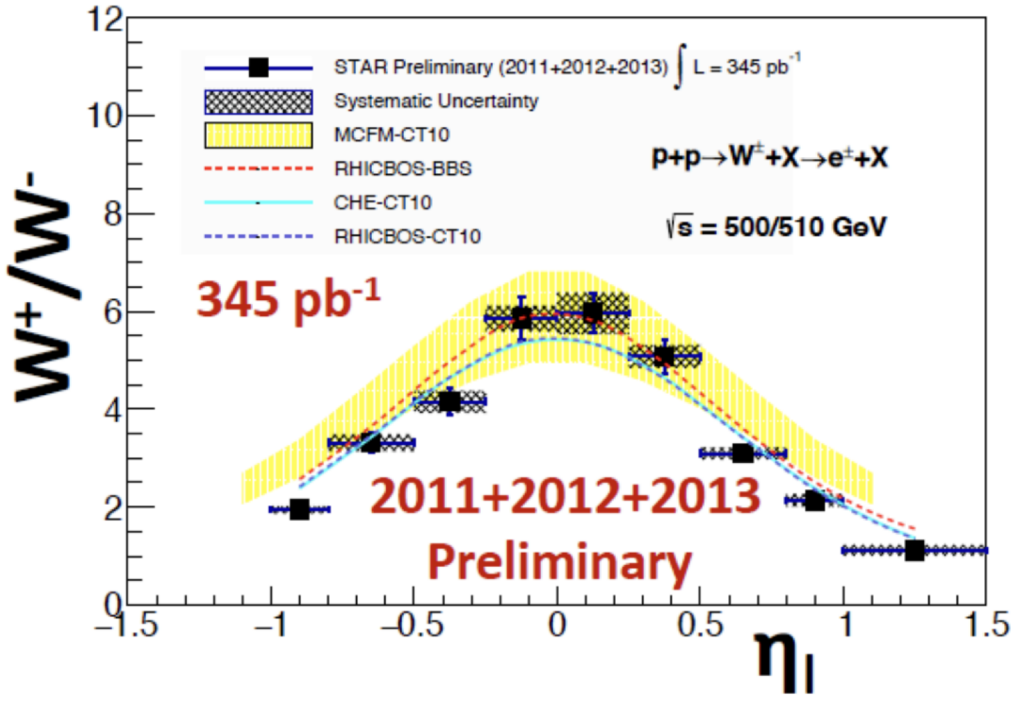
$W^{+/-}$ CROSS-SECTIONS AND Z TOO!

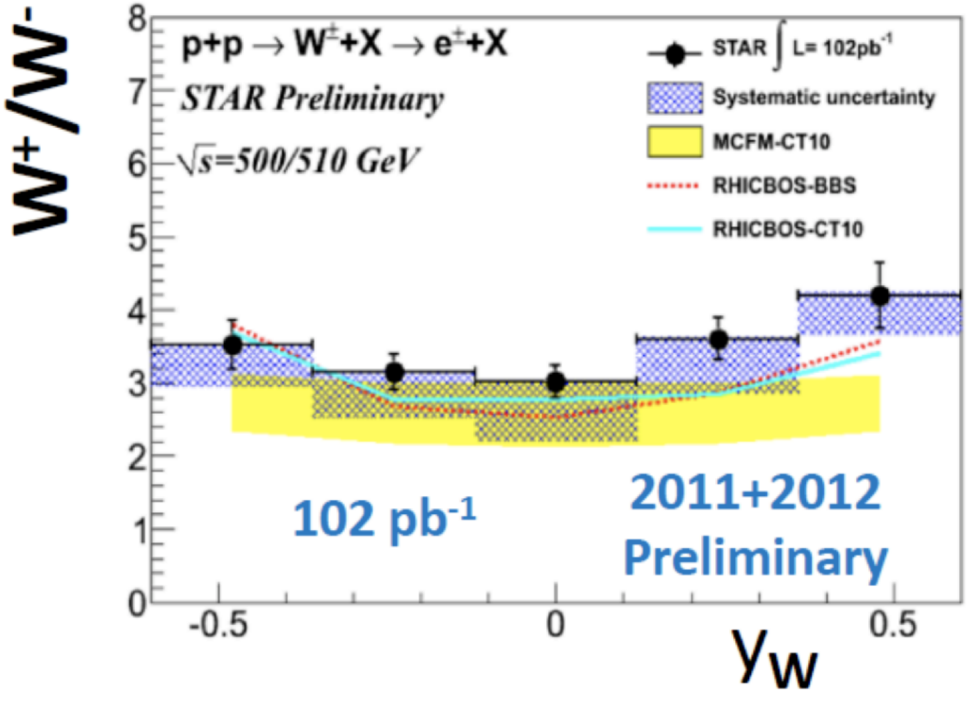


$W^{+/-}$ CROSS-SECTION RATIOS

Can be used to constrain sea quark PDFs!

$$\frac{\sigma_{W+}}{\sigma_{W-}} \approx \frac{u(x_1)\,\bar{d}(x_2) + u(x_2)\bar{d}(x_1)}{d(x_1)\bar{u}(x_2) + d(x_2)\bar{u}(x_1)}$$





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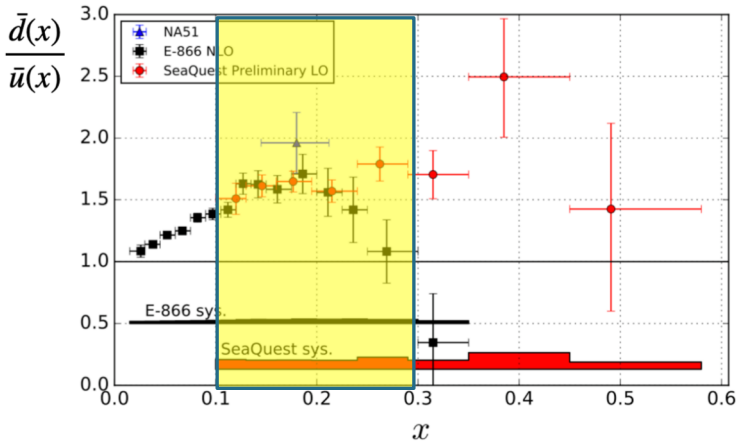
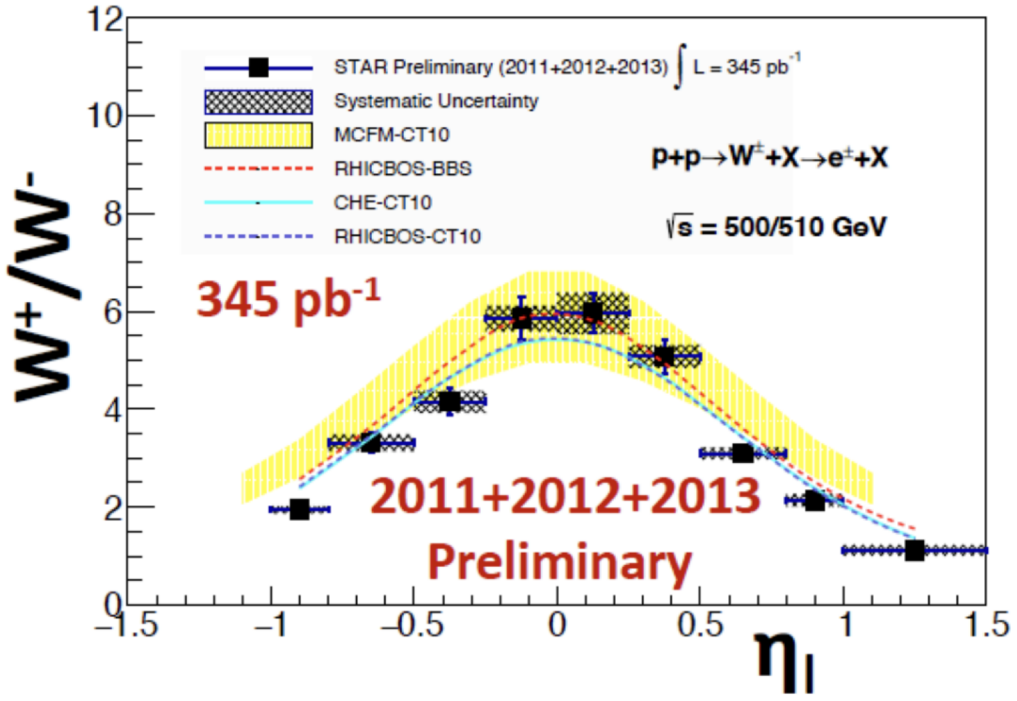
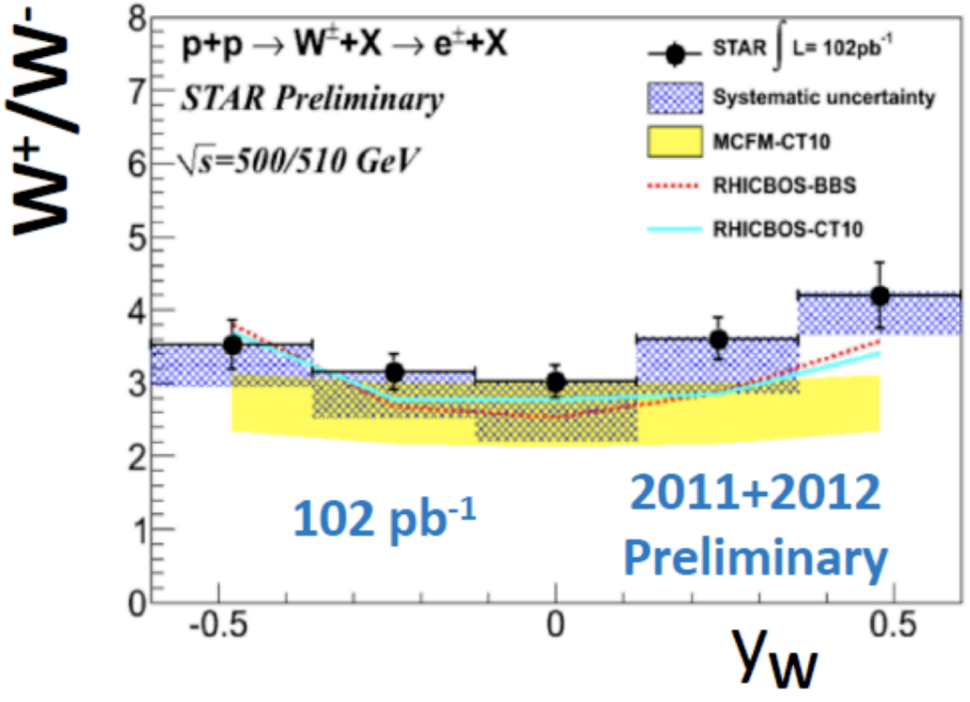


Kinematic coverage $0.1 < x < 0.3$ for $\sqrt{s} = 500$ GeV





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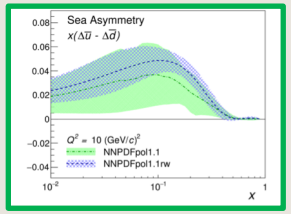

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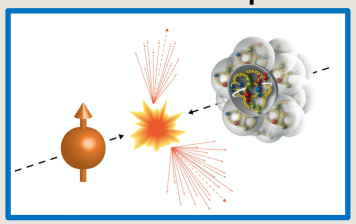
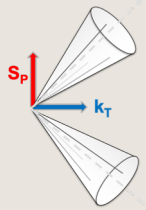


XKCD comics on page 10



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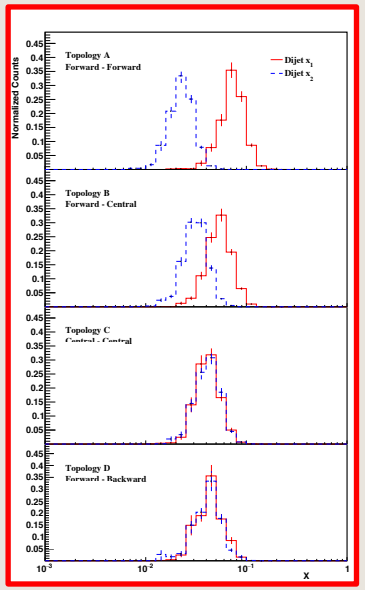
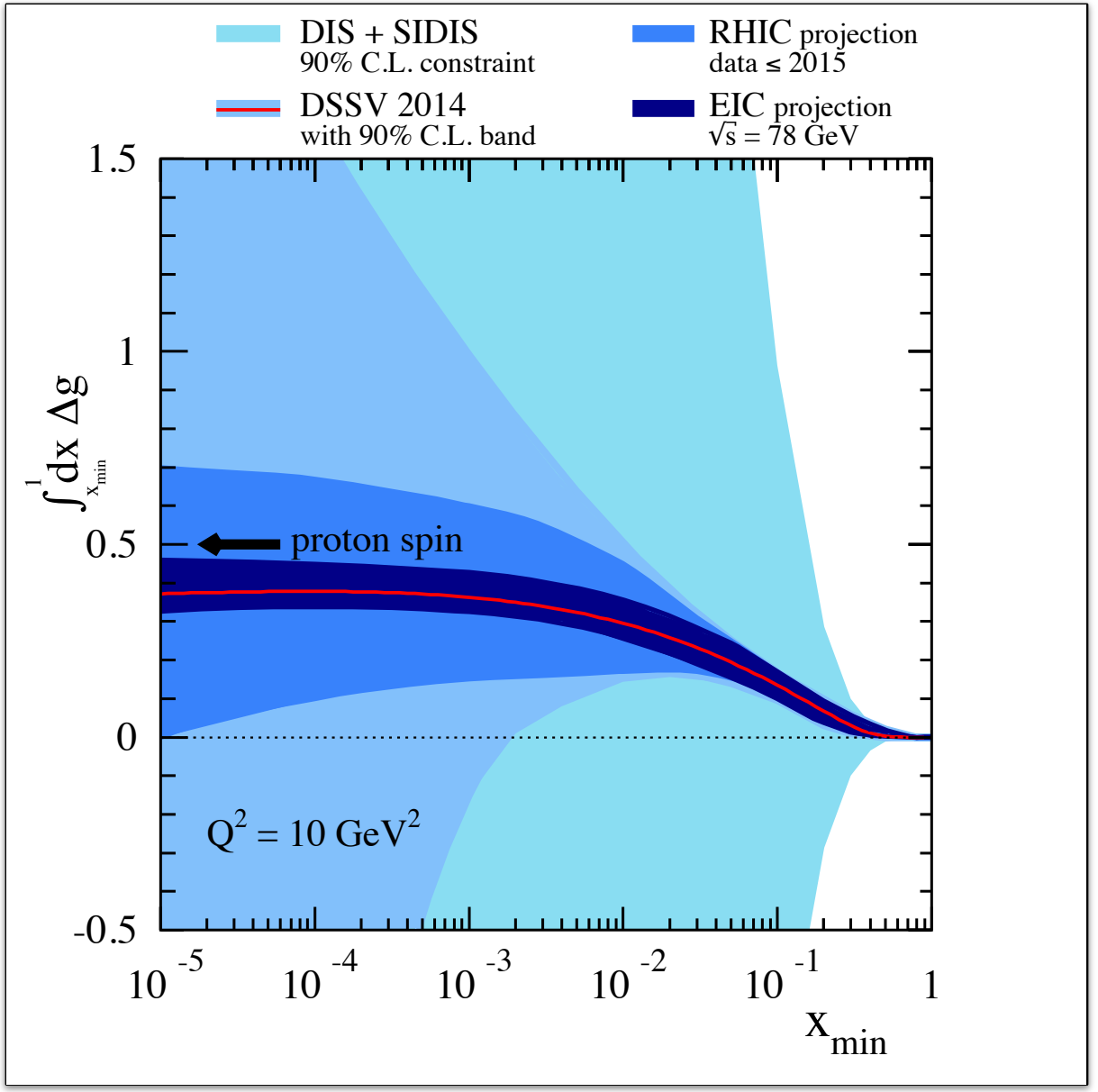
New inclusive jet and dijet measurements at √s = 500 GeV push constraints on gluon helicity distributions to lower x – ***what does this mean for ΔG?***



ΔG STATUS CIRCA ~2015

- Based on DSSV14 and includes PHENIX inclusive π^0 π^+ π^- and STAR inclusive jets and forward π^0 at 200 and 62 GeV.
- ΔG saturates at ~10^{-3} and 70% of proton spin
- Uncertainties increase dramatically outside kinematic reach of existing data.
- Two approaches to reduce uncertainties:
  1) Measure correlation observables to help map out shape of Δg(x).
  2) Measure asymmetries sensitive to lower x



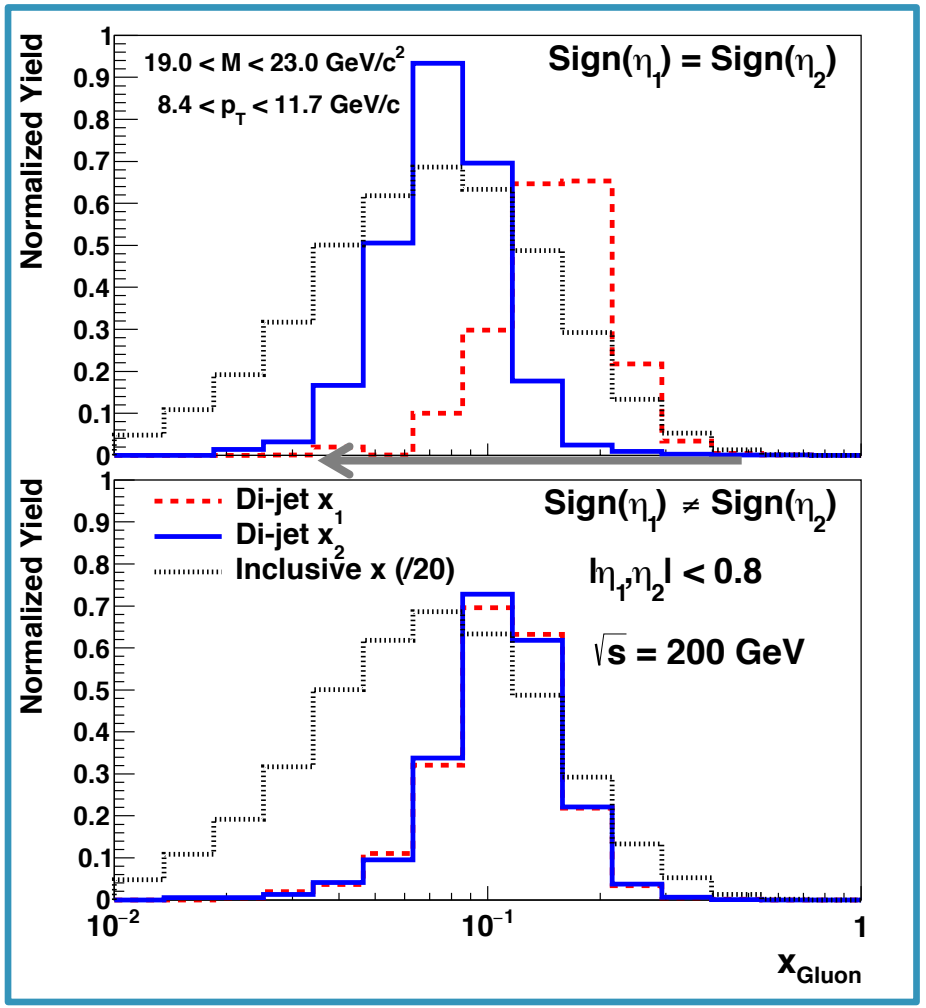
Phys.Rev. *D92*, 094030 (2015)

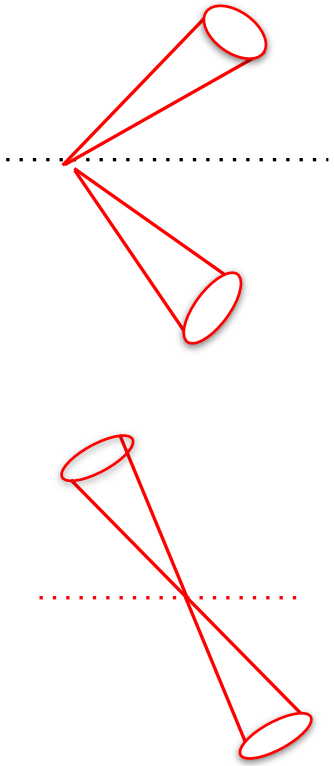
200 GEV MID-RAPIDITY DIJETS

- Inclusive jets sample **broad range** of parton momentum fraction x.
- This limits constraints on the functional form of $\Delta g(x)$ and **increases uncertainty at lower x**.
- Dijets allow for reconstruction of the **initial parton x_1 and x_2** at leading order.

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

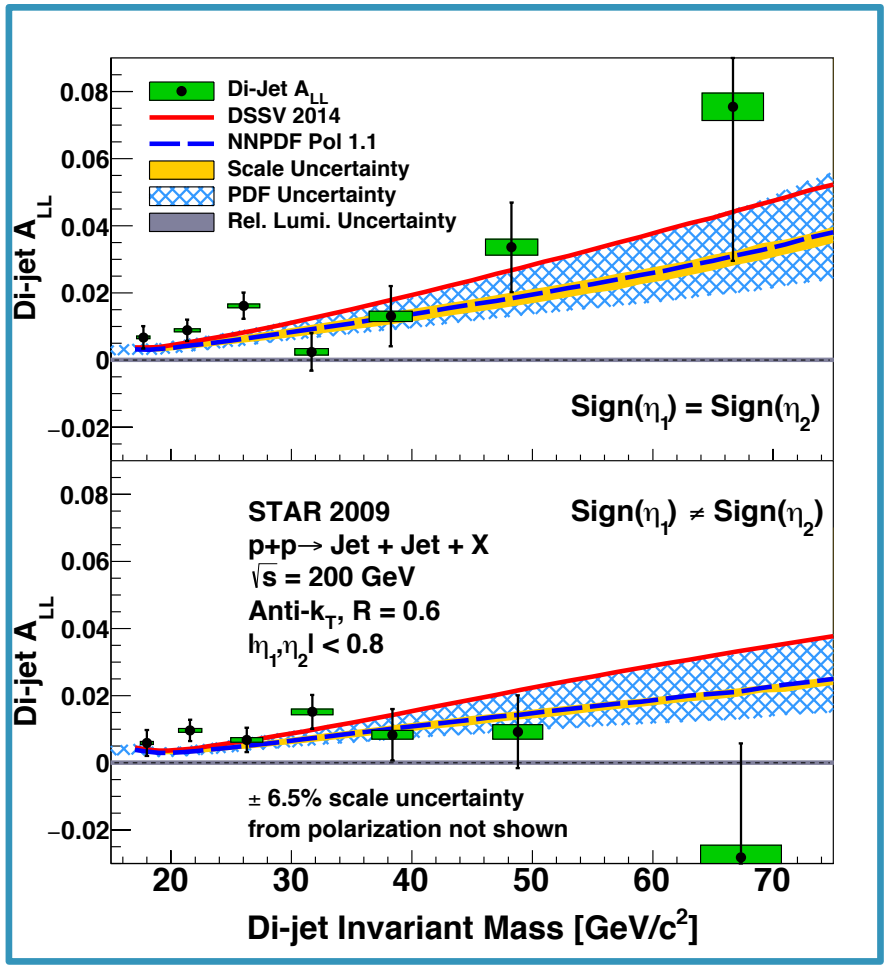
$$|\cos\theta^*| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$

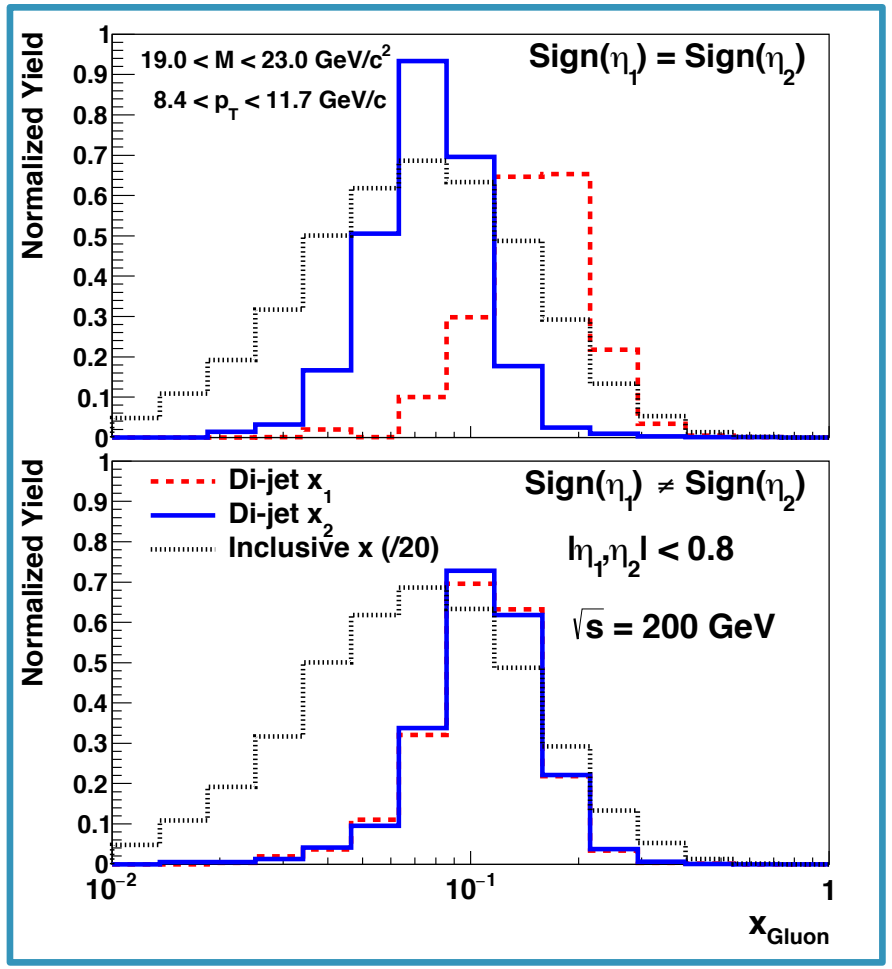


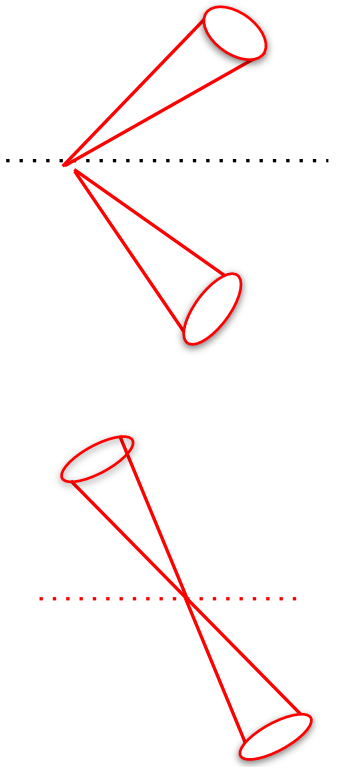


200 GEV MID-RAPIDITY DIJET A_{LL}

$$A_{LL} \propto \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

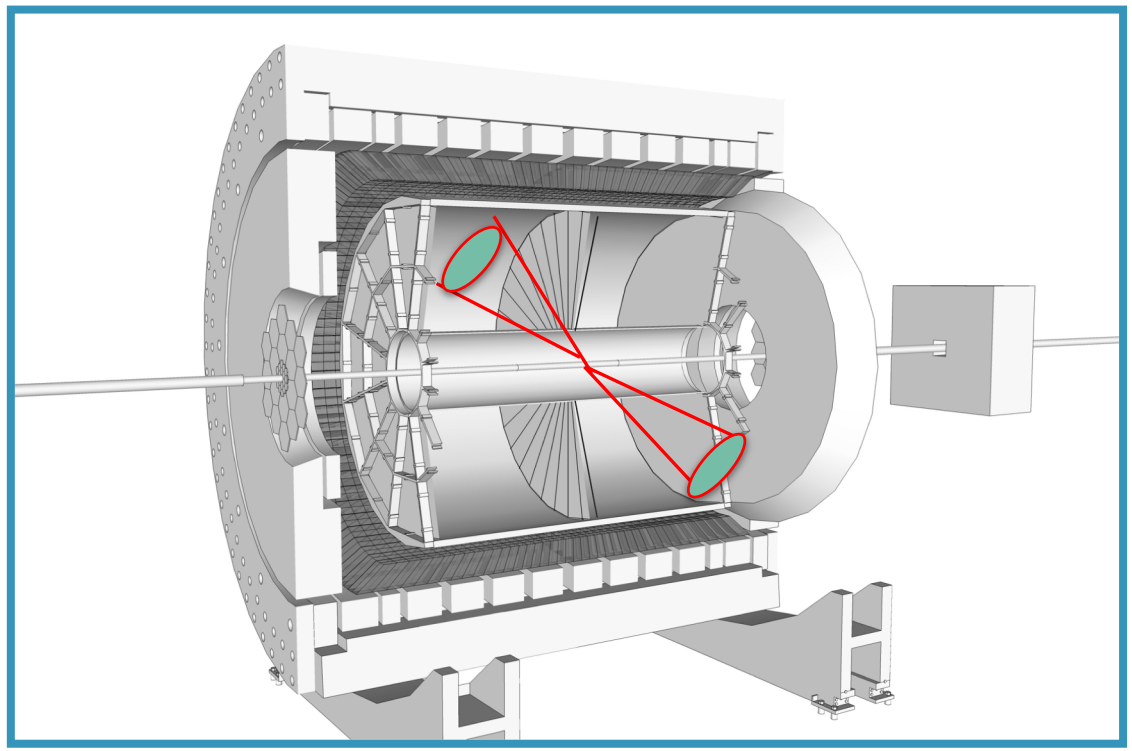


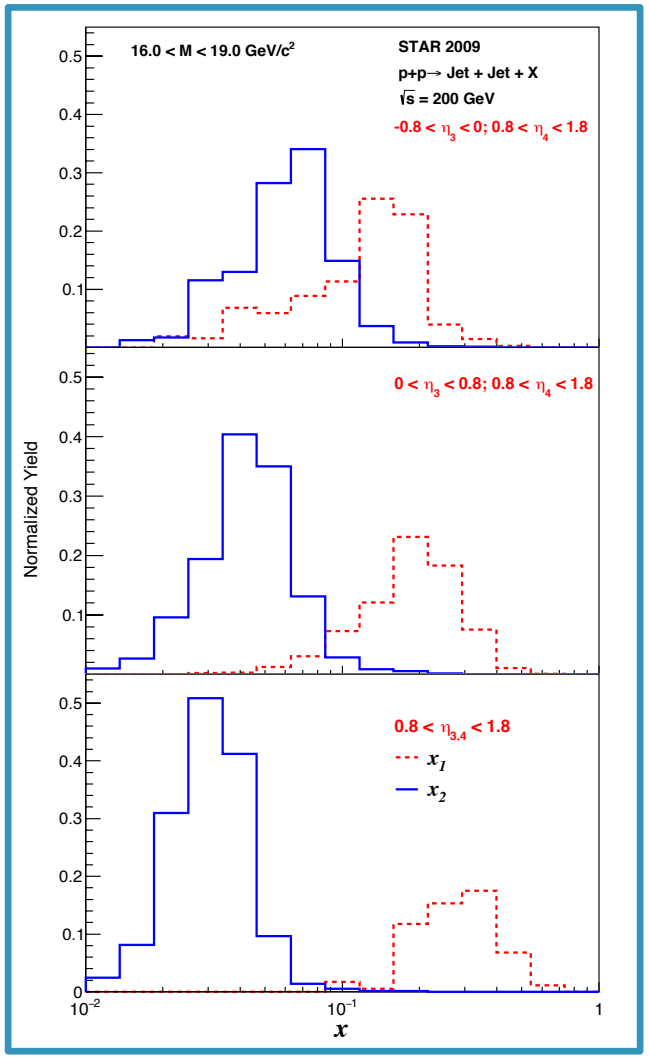




Phys.Rev. D95, 071103 (2017)

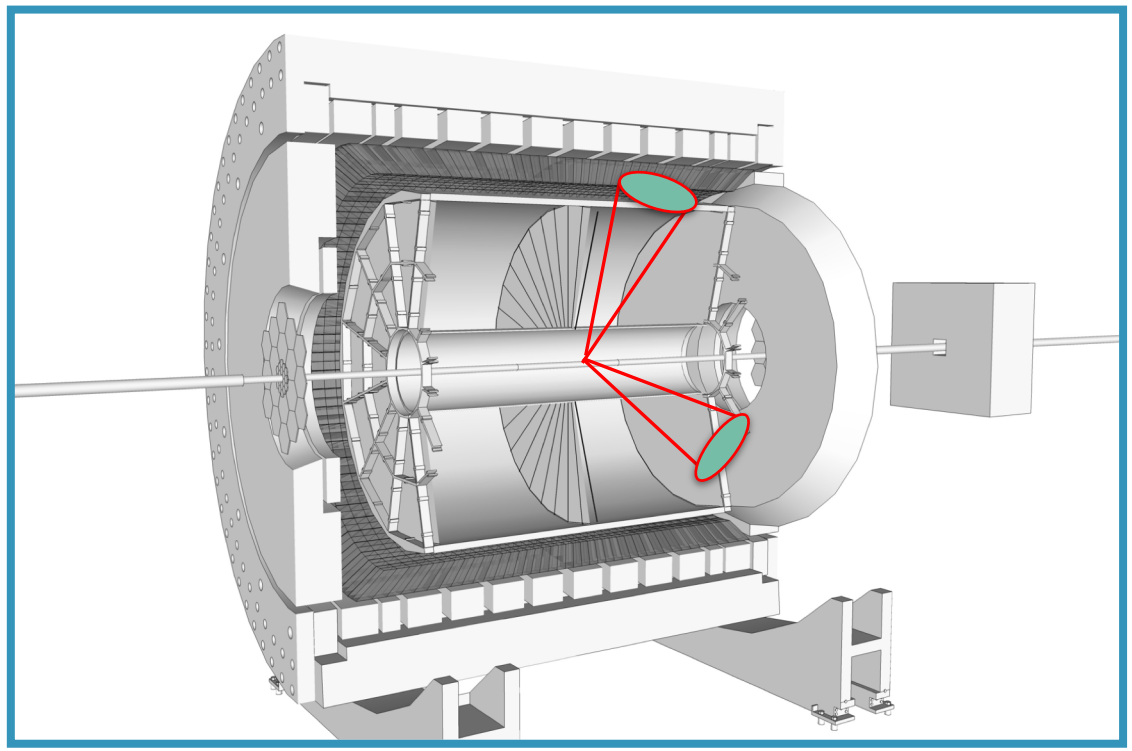
200 GEV FORWARD-RAPIDITY DIJET

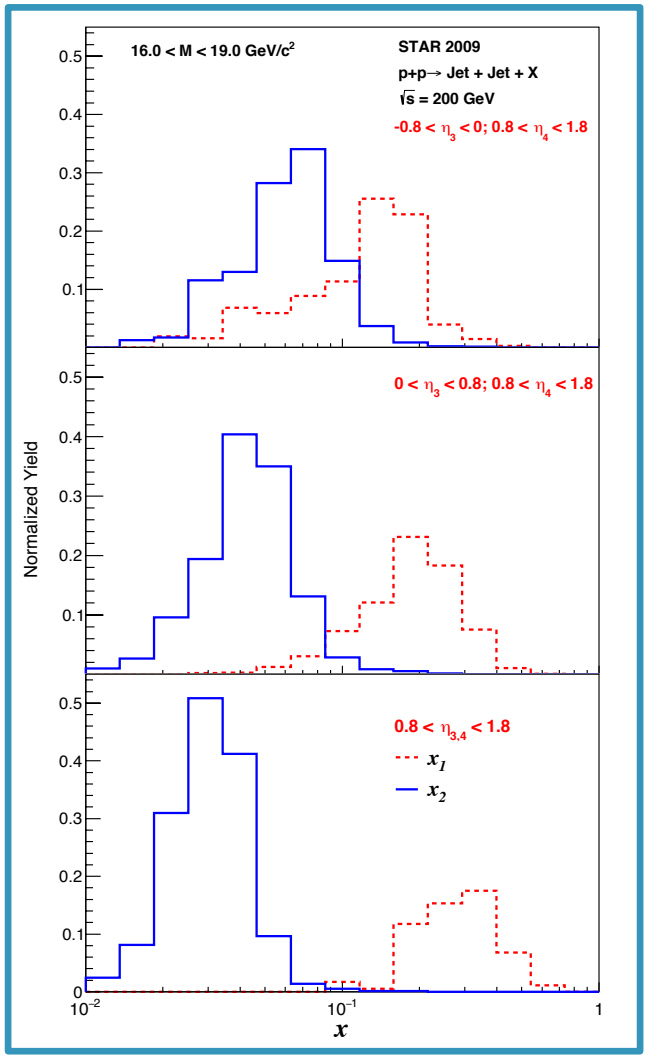




Can push to smaller x by using endcap calorimeter in forward region.

200 GEV FORWARD-RAPIDITY DIJET





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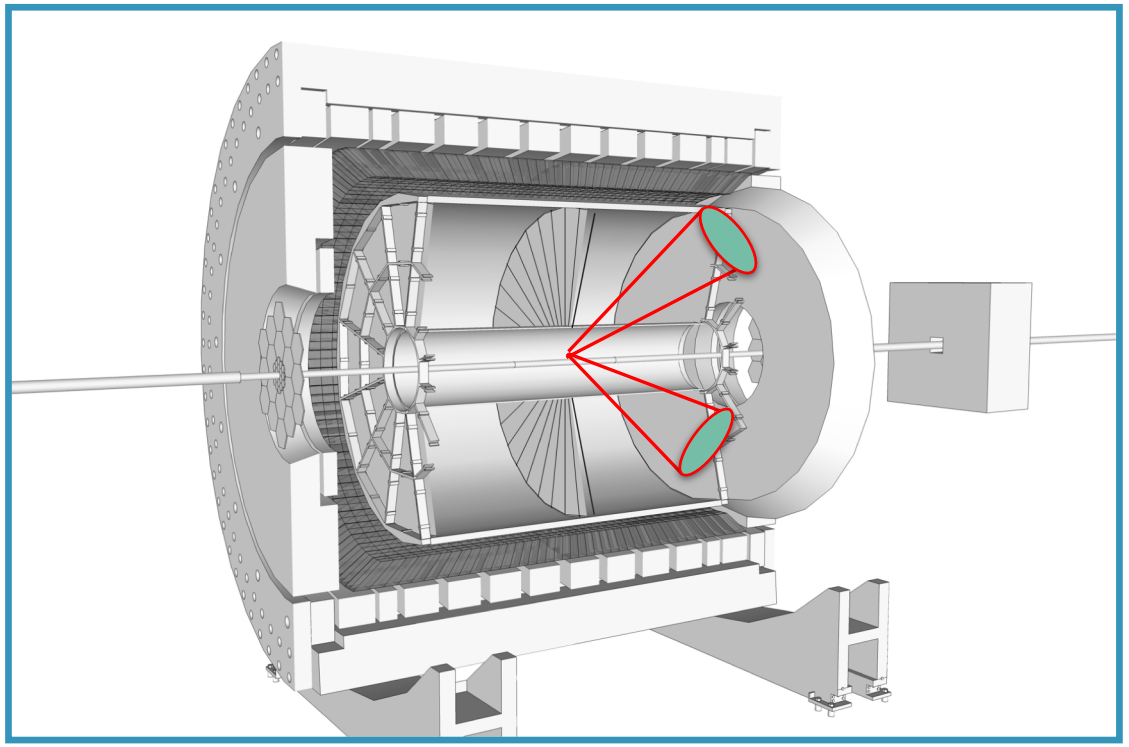
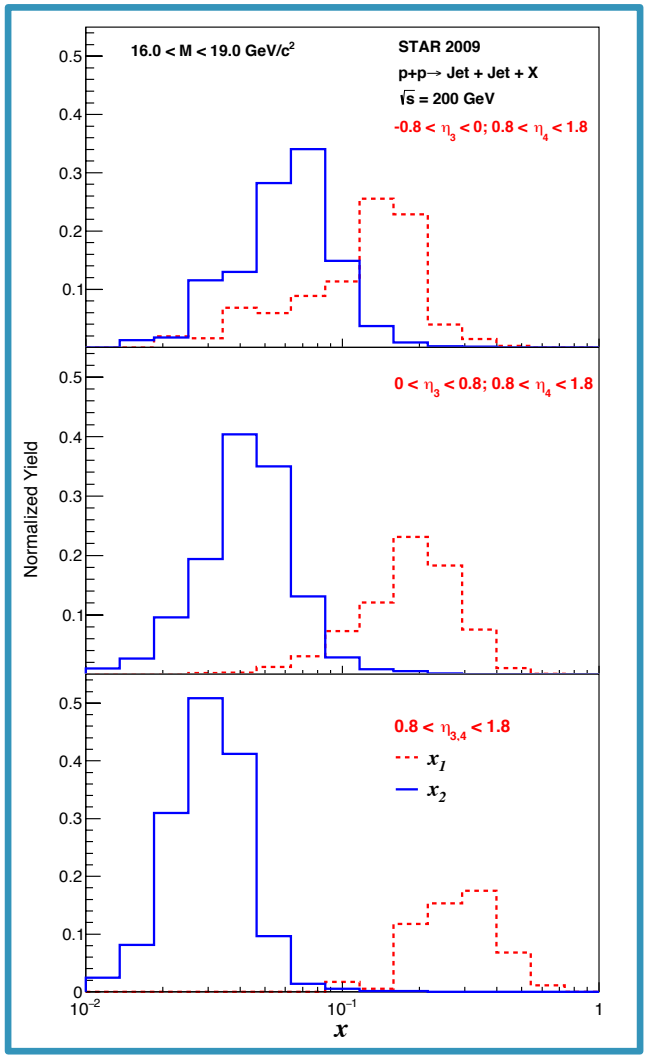
200 GEV FORWARD-RAPIDITY DIJET

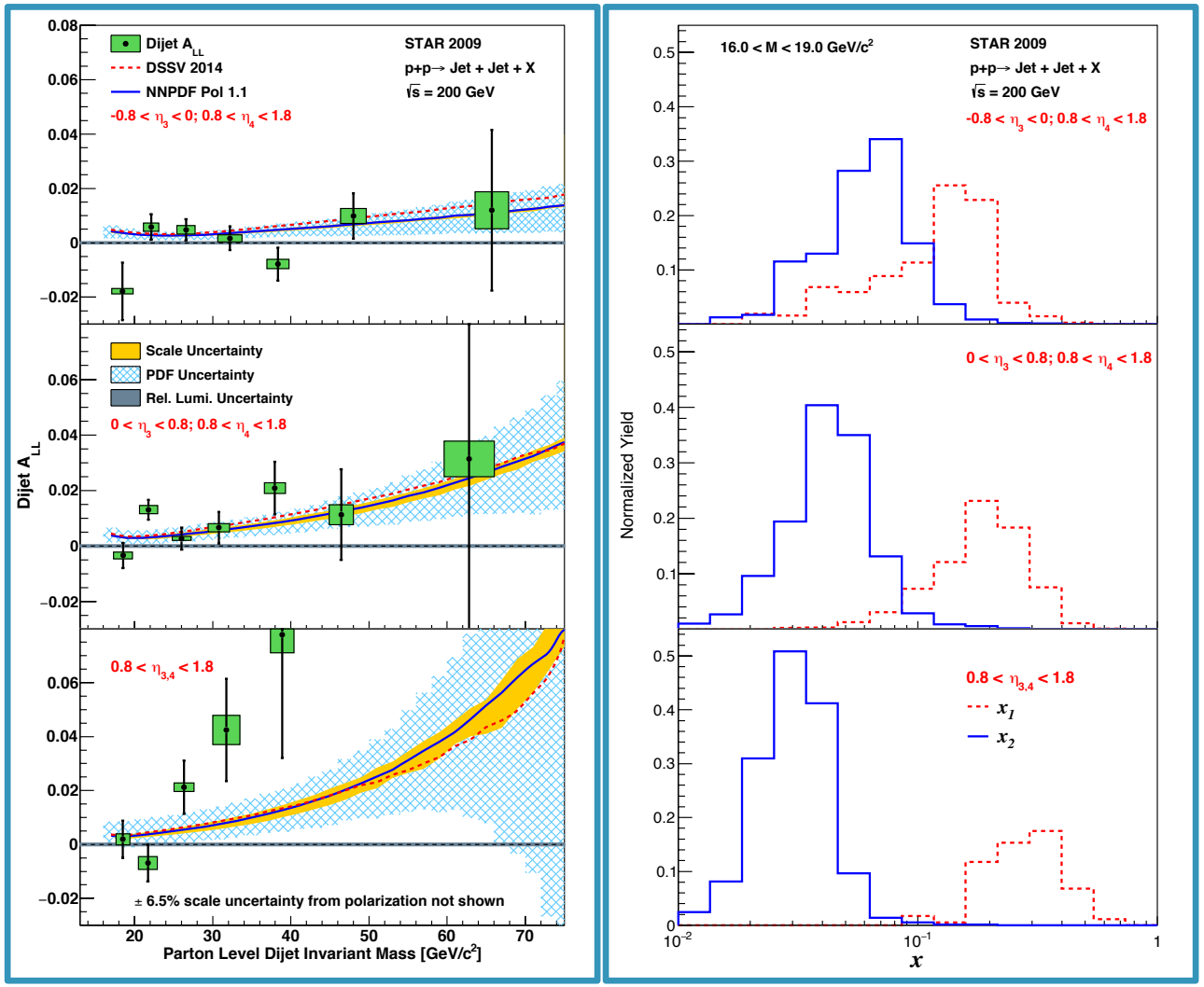




Can push to smaller x by using endcap calorimeter in forward region.

200 GEV FORWARD-RAPIDITY DIJET A_{LL}

- First forward jet analysis
- Utilized machine learning techniques to deal with dropping TPC efficiency
- Incorporated underlying event subtraction
- Asymmetries sample both low x gluons and high x quarks!



Phys. Rev. D **98** (2018) 32011

PAUSE … FOR A THEORETICAL INTERLUDE

arXiv 1902.10548

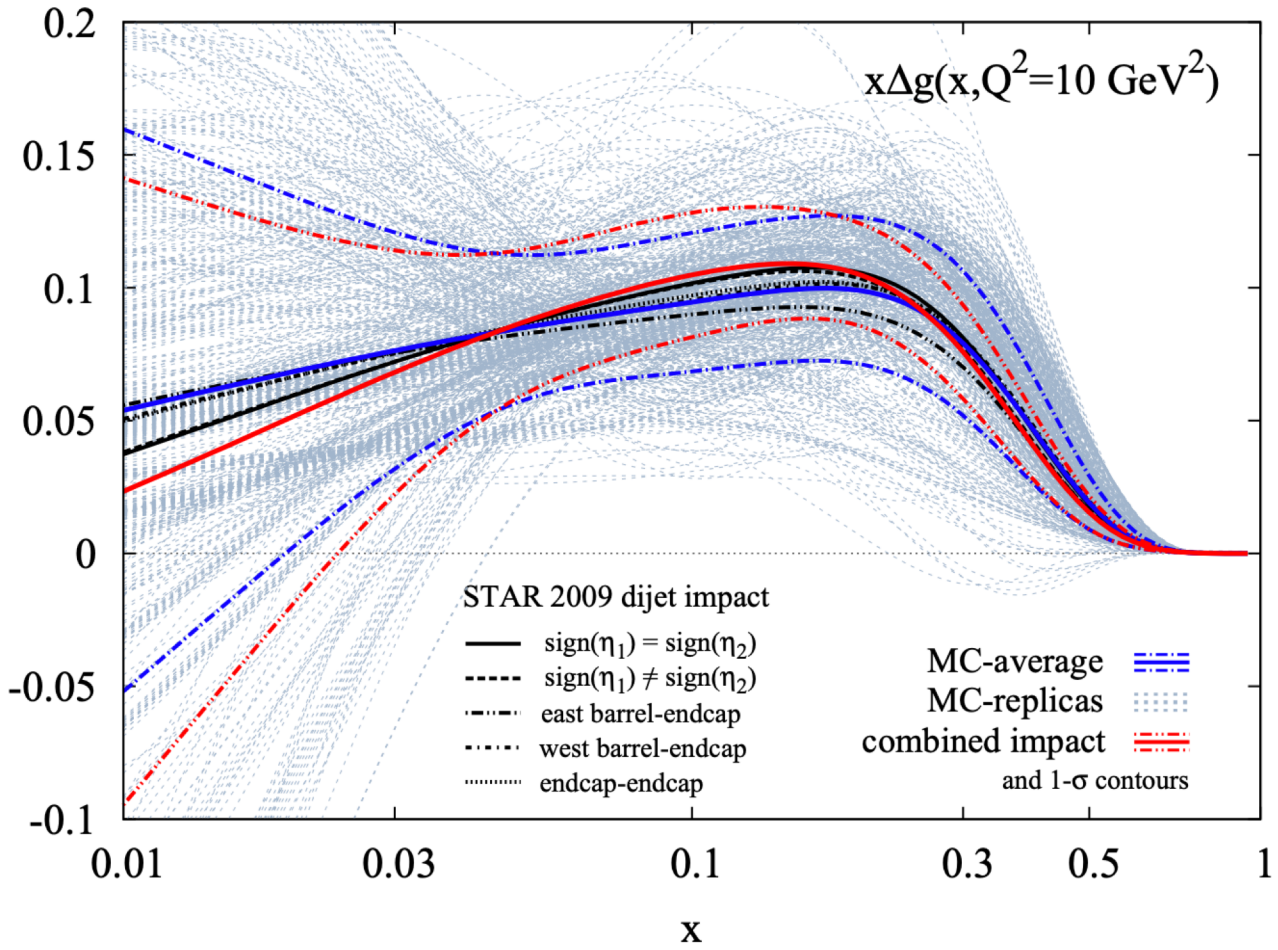
Monte Carlo sampling variant of the DSSV14 set of helicity parton densities

Daniel de Florian*
International Center for Advanced Studies (ICAS), UNSAM, Campus Miguelete, 25 de Mayo y Francia (1650) Buenos Aires, Argentina

Gonzalo Agustín Lucero† and Rodolfo Sassot‡
Departamento de Física and IFIBA, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón 1 (1428) Buenos Aires, Argentina

Marco Stratmann§ and Werner Vogelsang¶
Institute for Theoretical Physics, University of Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

- New paper implements reweighting with STAR 200 GeV mid+forward rapidity dijets .
- Moderate increase of gluon polarization in the range $0.05 < x < 0.2$ - change is within uncertainty of the DSSV14 replicas.
- Sizable reduction of width of 1-sigma uncertainty band, especially for $x > 0.2$.

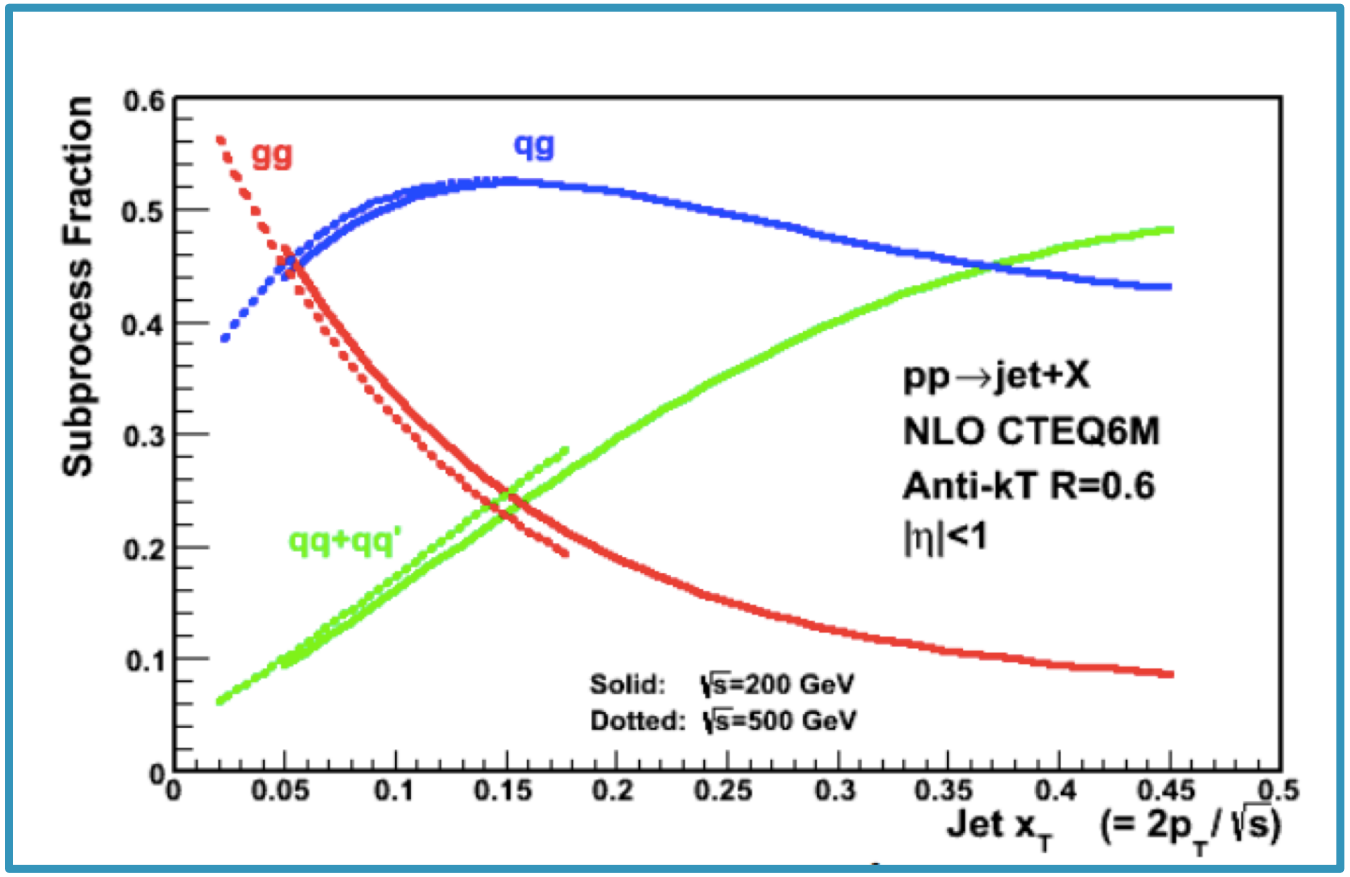


500 GEV MID-RAPIDITY INCLUSIVE AND DIJET A_{LL}

- Measurements at higher $\sqrt{s}$ access lower partonic x

$$x \approx x_T e^{\pm\eta} = \frac{2p_T}{\sqrt{s}} e^{\pm\eta}$$

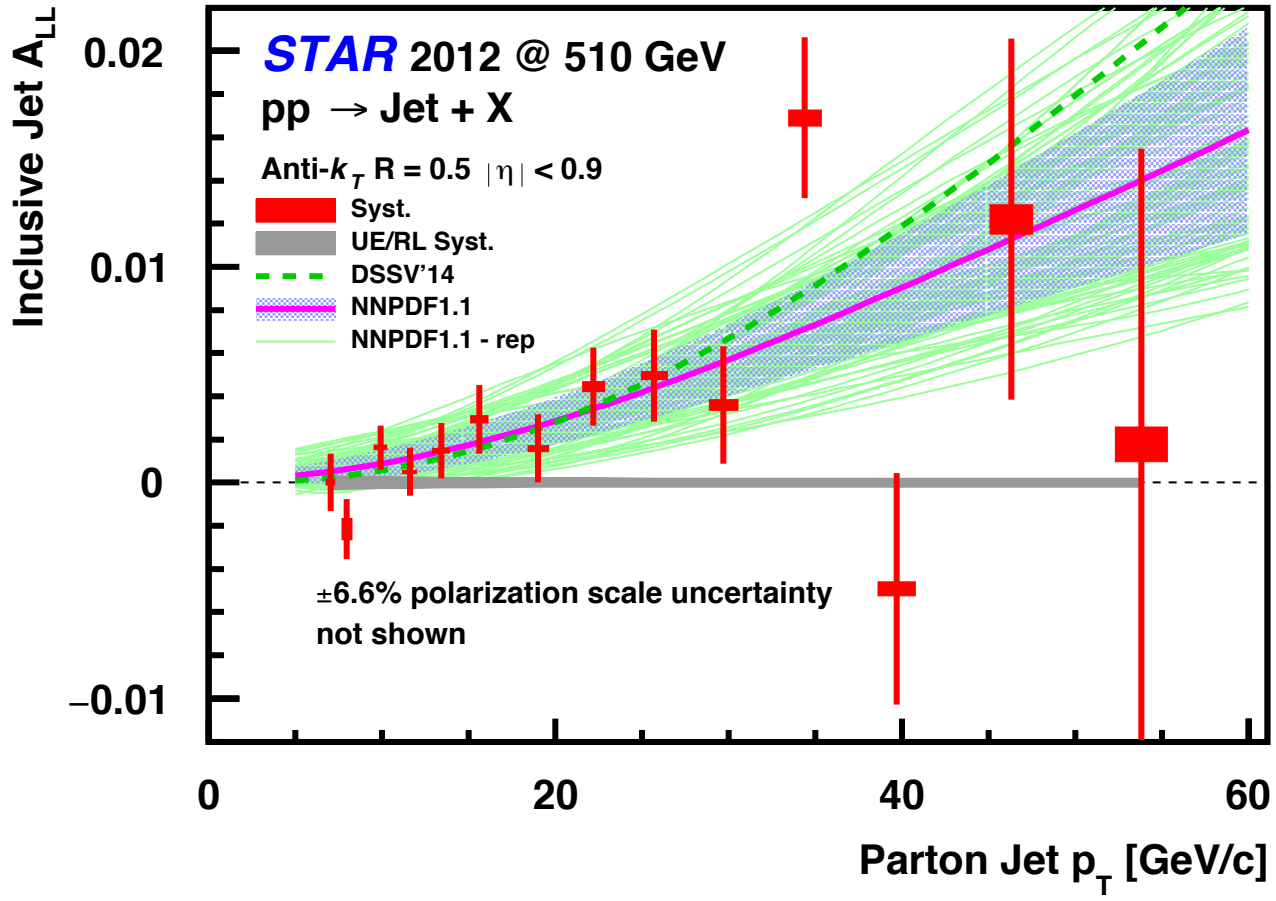
- Optimize $R_{jet} = 0.5$ to accommodate increased UE and pileup at higher center of mass energies



RUN12 510 GEV MID-RAPIDITY INCLUSIVE JET A_{LL}

- Excellent agreement with theoretical expectations
- Data-driven event-by-event UE subtraction developed for this result.

Phys.Rev. D100 (2019) no.5 052005

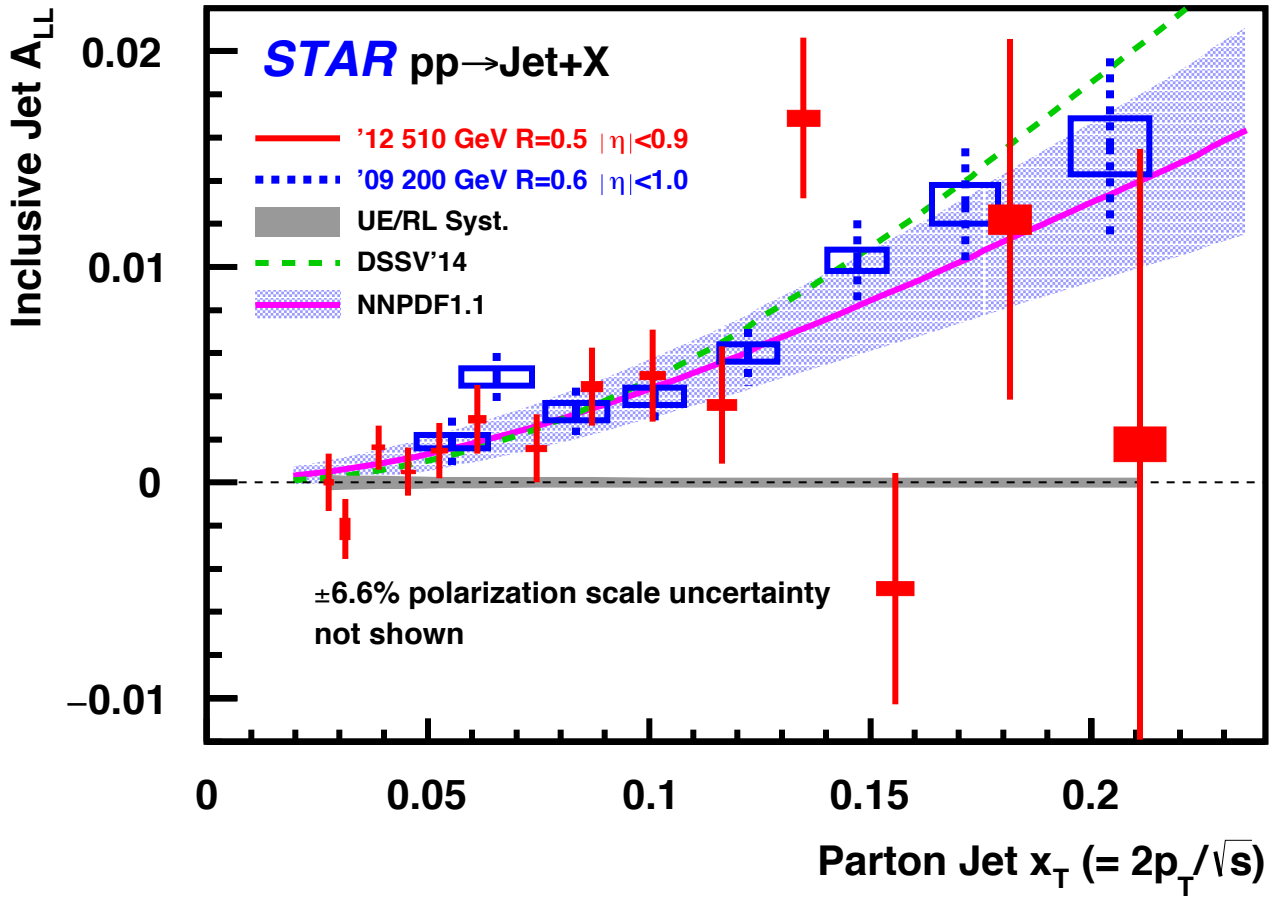


RUN 12 510 GEV MID-RAPIDITY INCLUSIVE JET A_{LL}

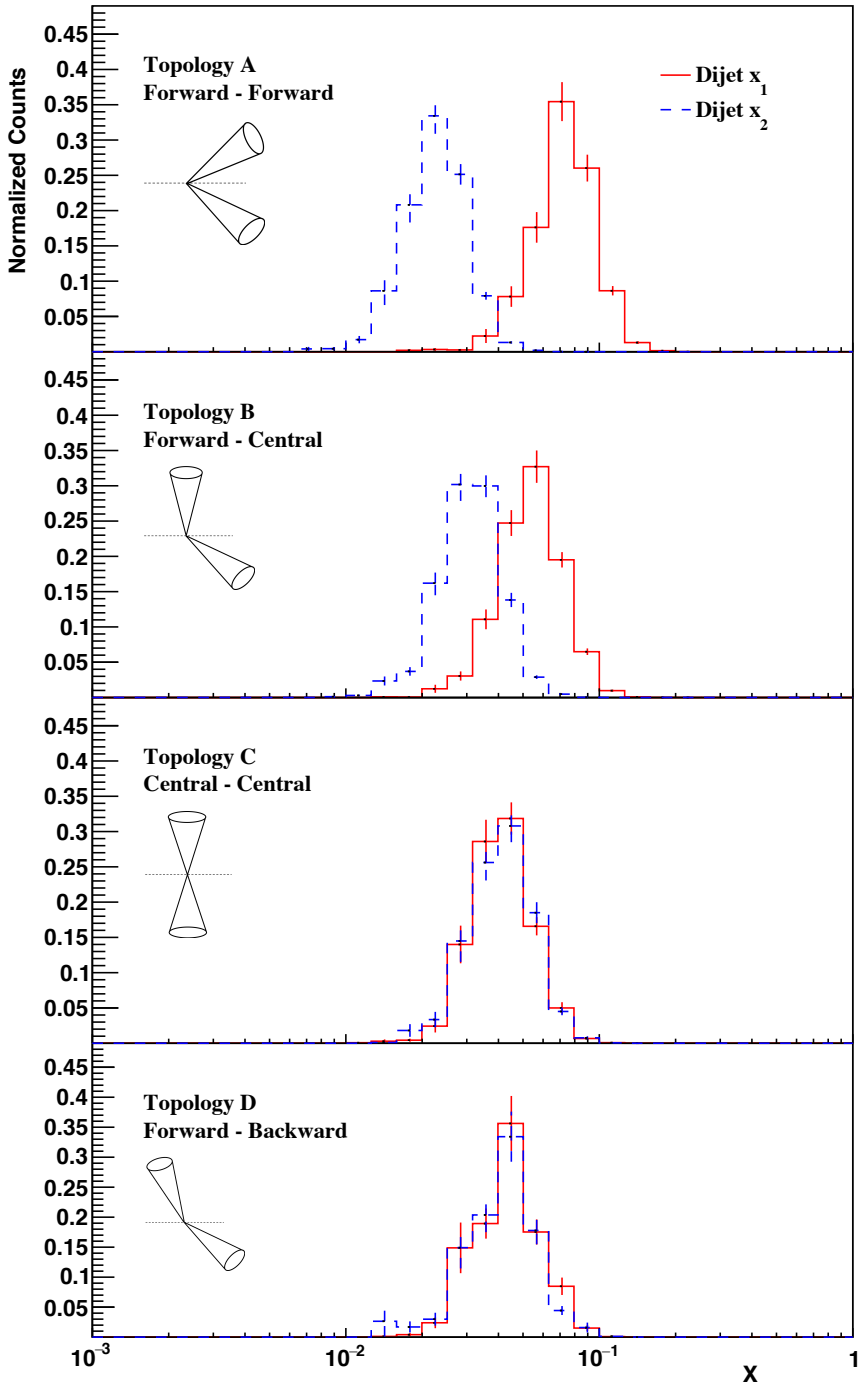
- Excellent agreement with theoretical expectations
- Data-driven event-by-event UE subtraction developed for this result.
- Reduced x_T ~0.025

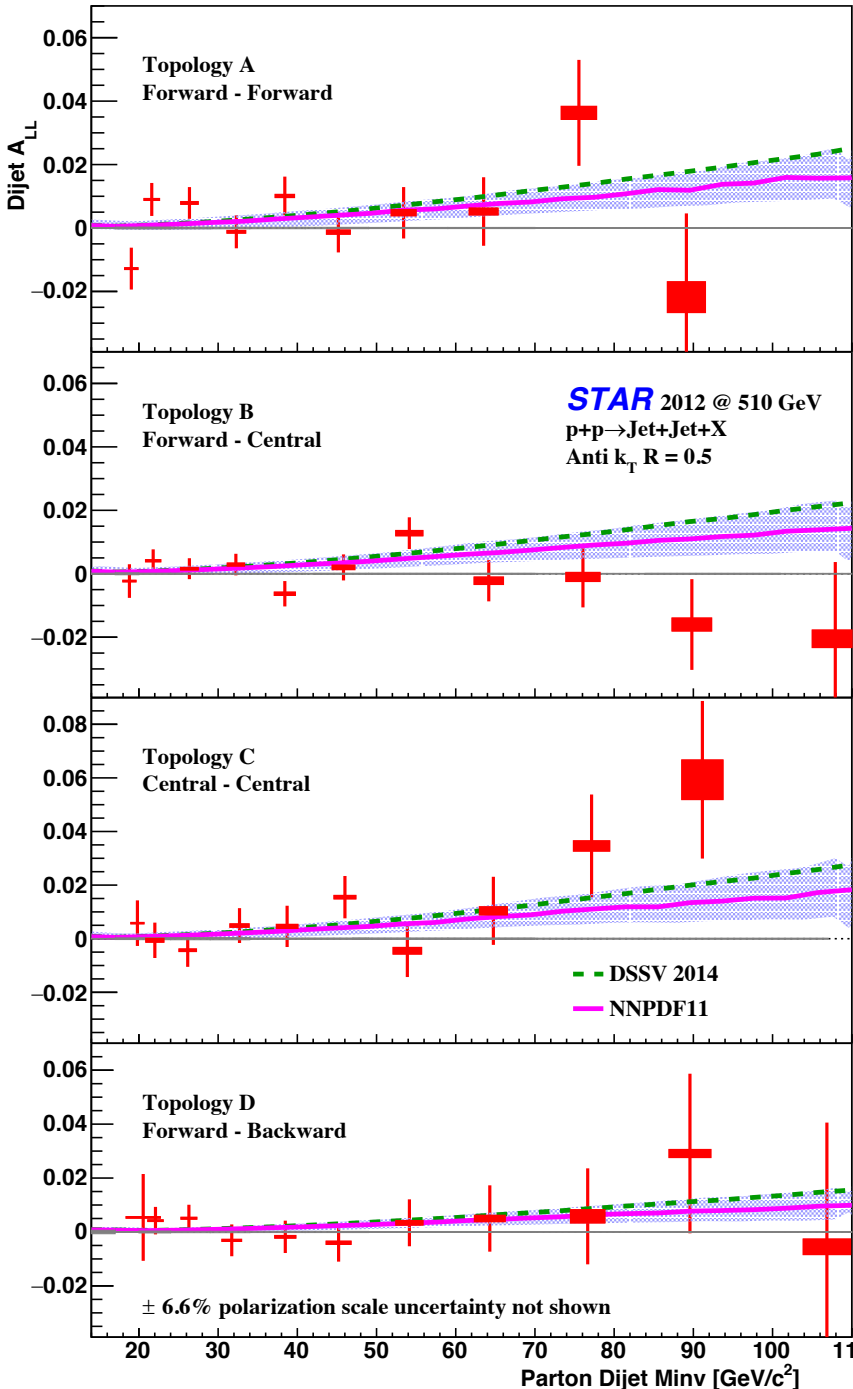
$$x \approx x_T e^{\pm\eta} = \frac{2p_T}{\sqrt{s}} e^{\pm\eta}$$

Phys.Rev. D100 (2019) no.5 052005



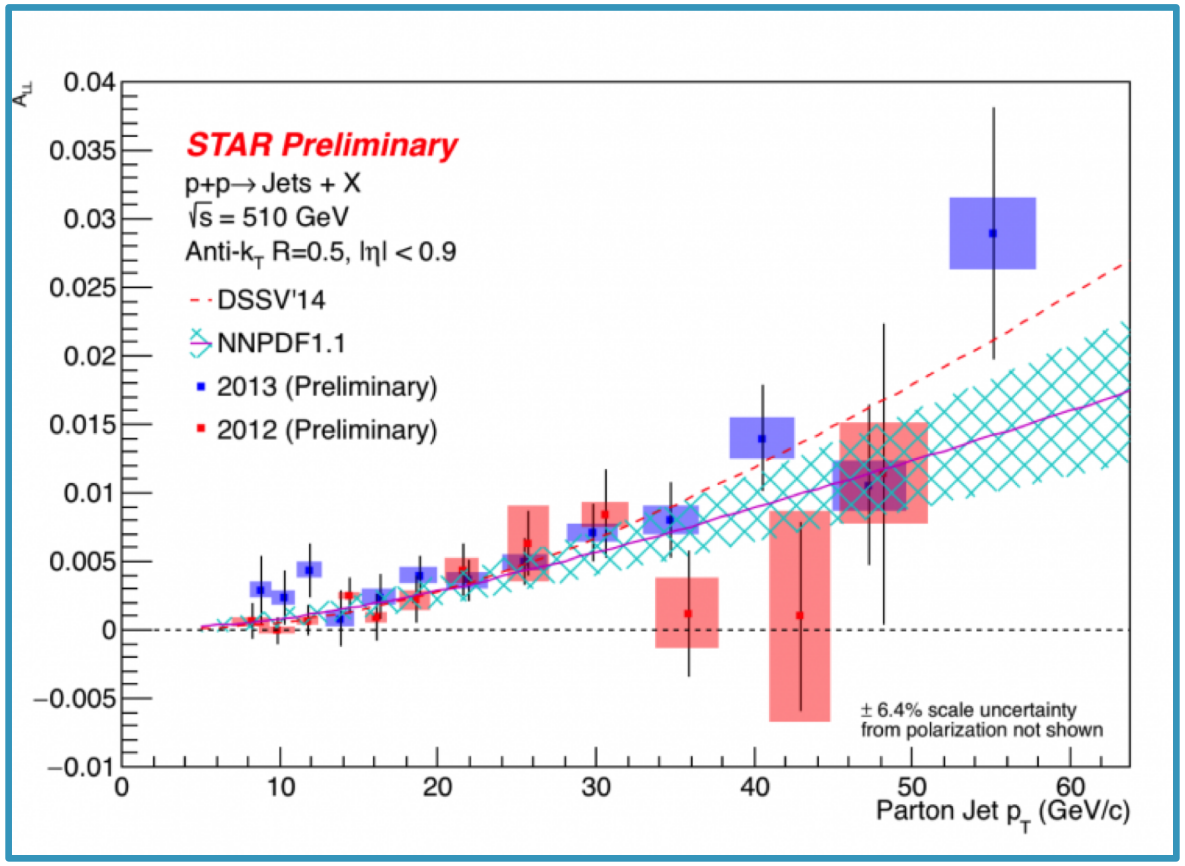
RUN 12
510 GEV
MID-RAPIDITY
DIJET A_{LL}



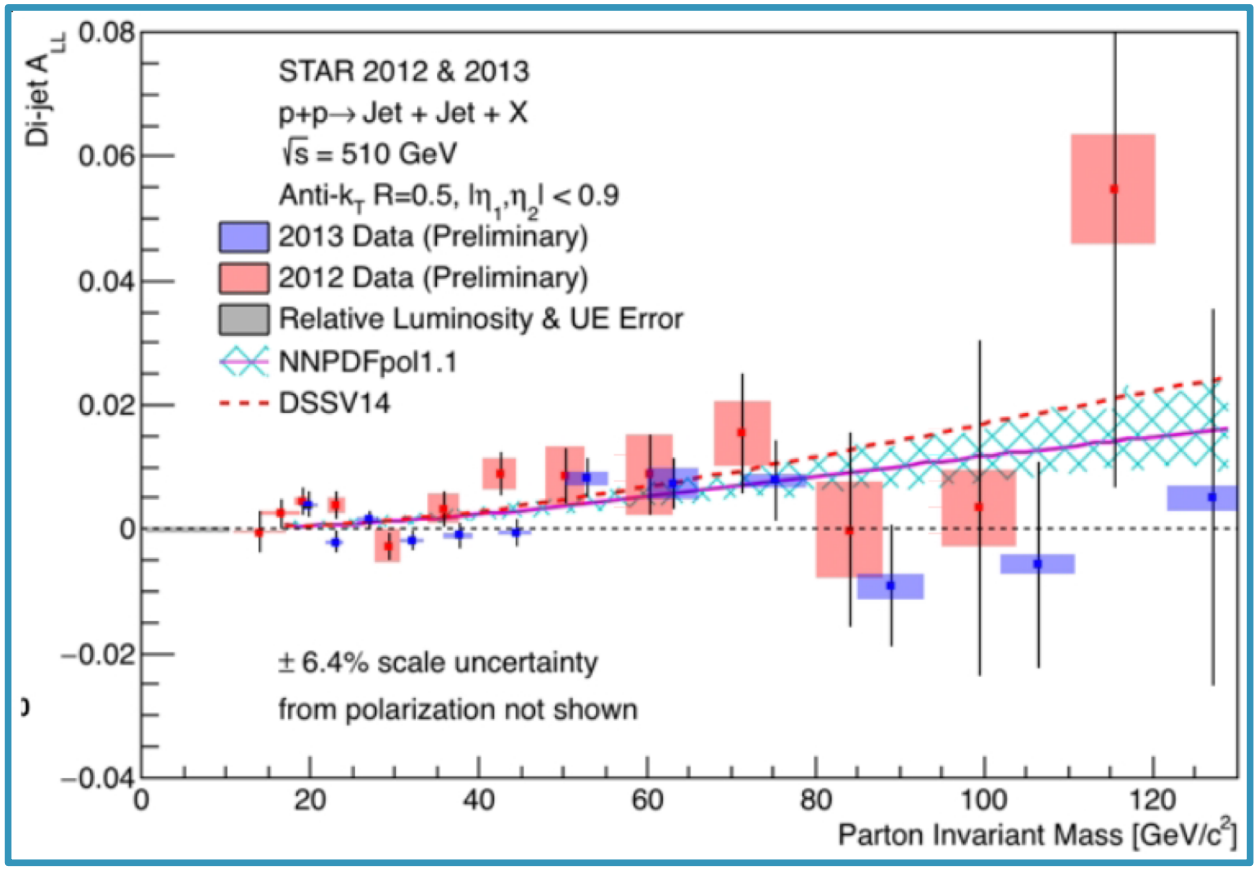


Phys.Rev. D100 (2019) no.5 052005

RUN 13 510 GEV MID-RAPIDITY INCLUSIVE AND DIJET A_{LL}



INCLUSIVE JET

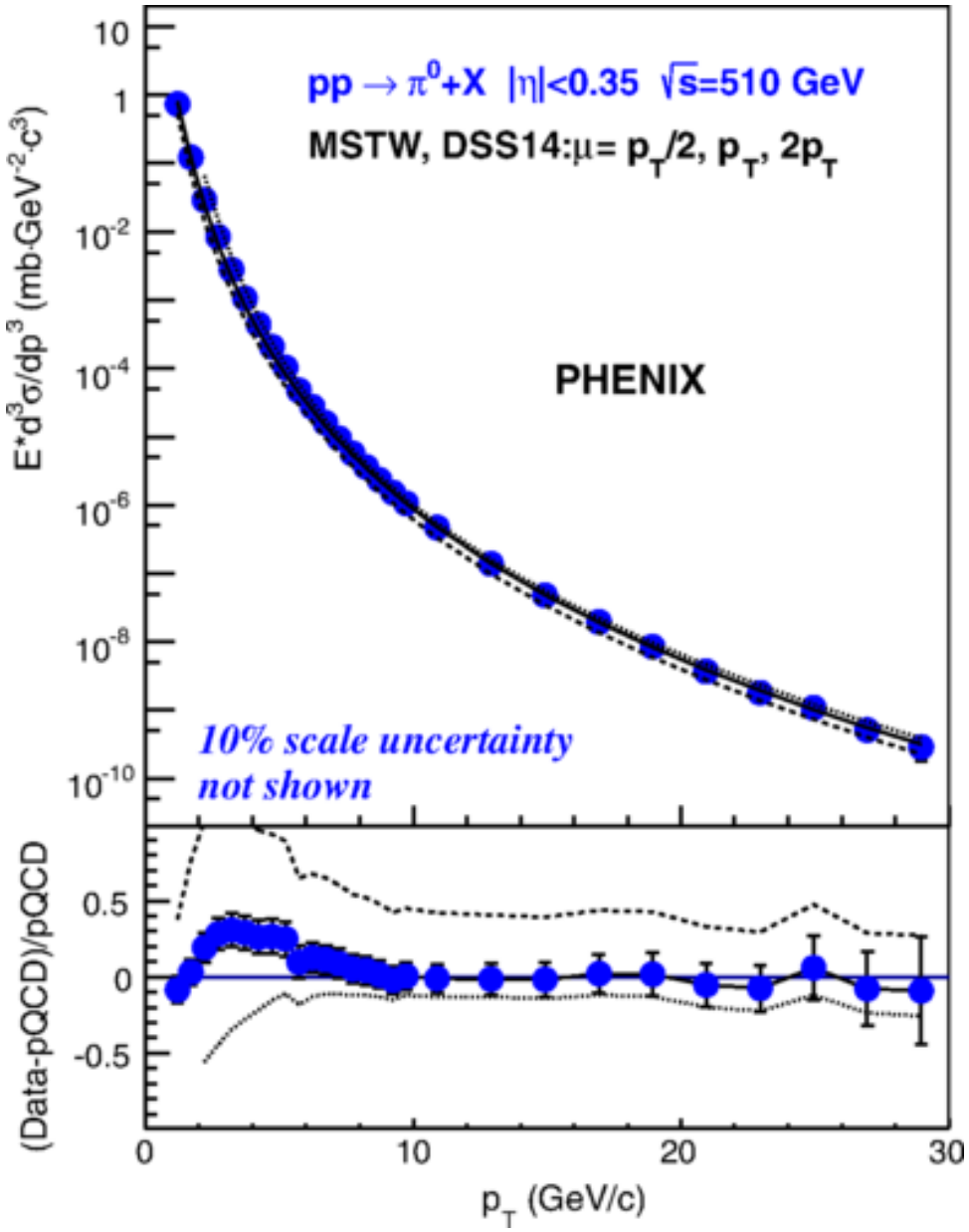


DIJET

510 GEV INCLUSIVE MIDRAPIDITY π^0

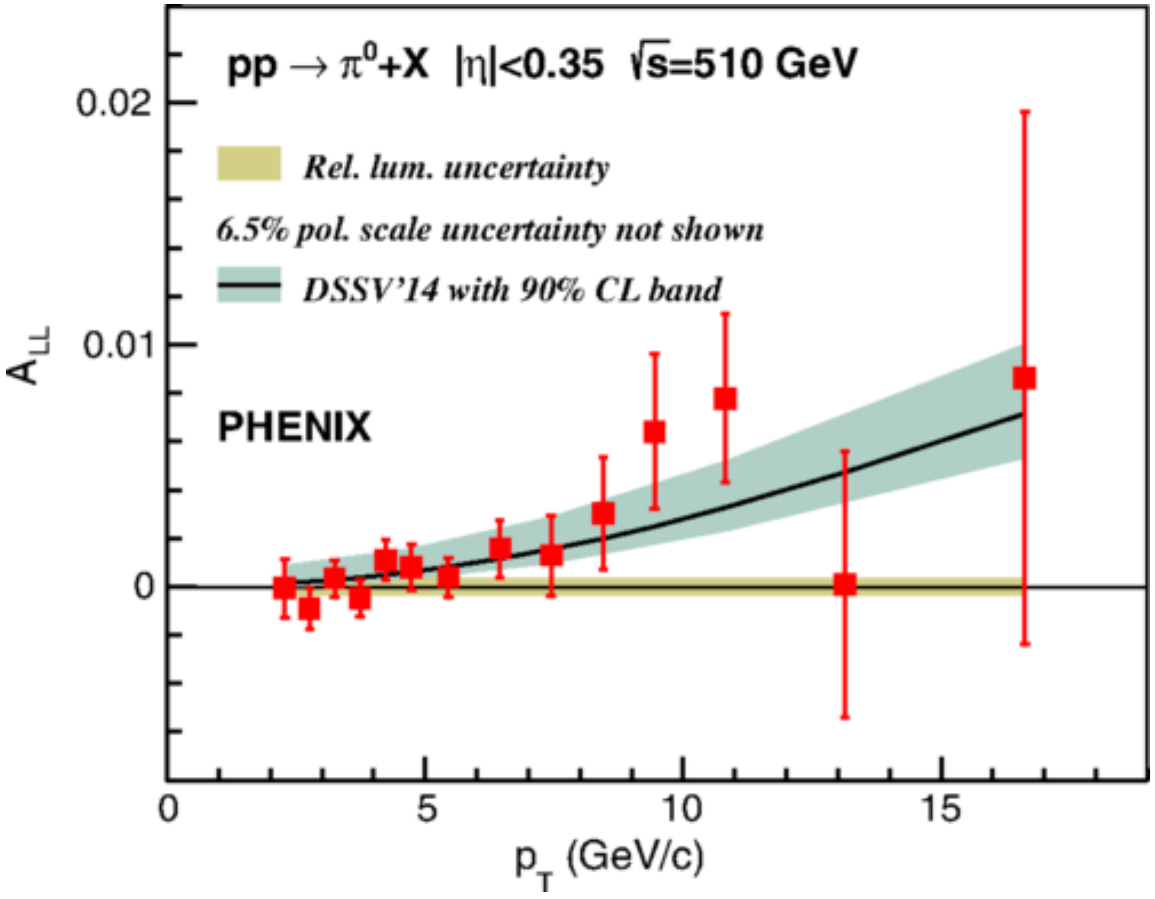
Excellent agreement between data and theory!

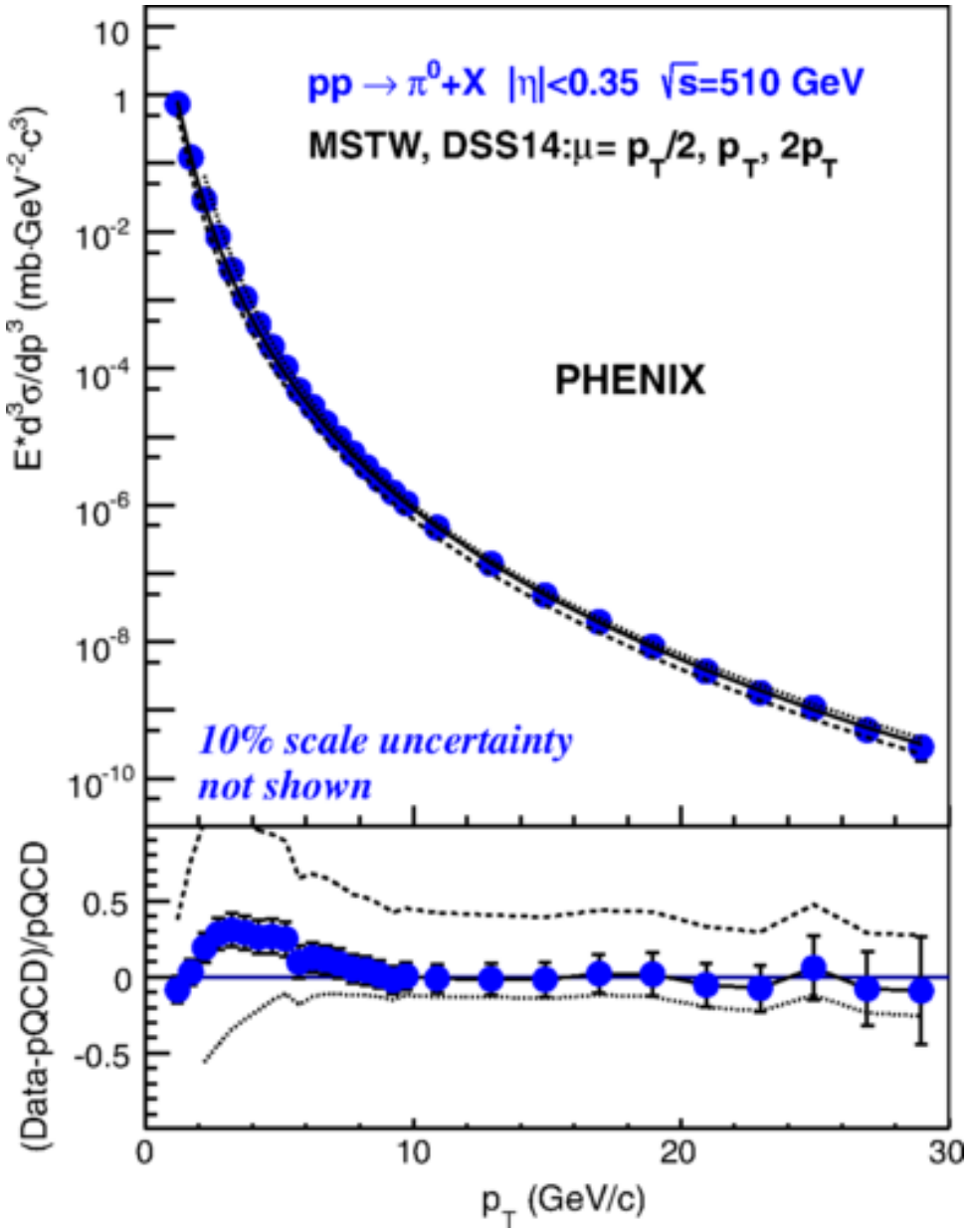
Phys. Rev. D **93,** 011501(R)



510 GEV INCLUSIVE MIDRAPIDITY Π^0

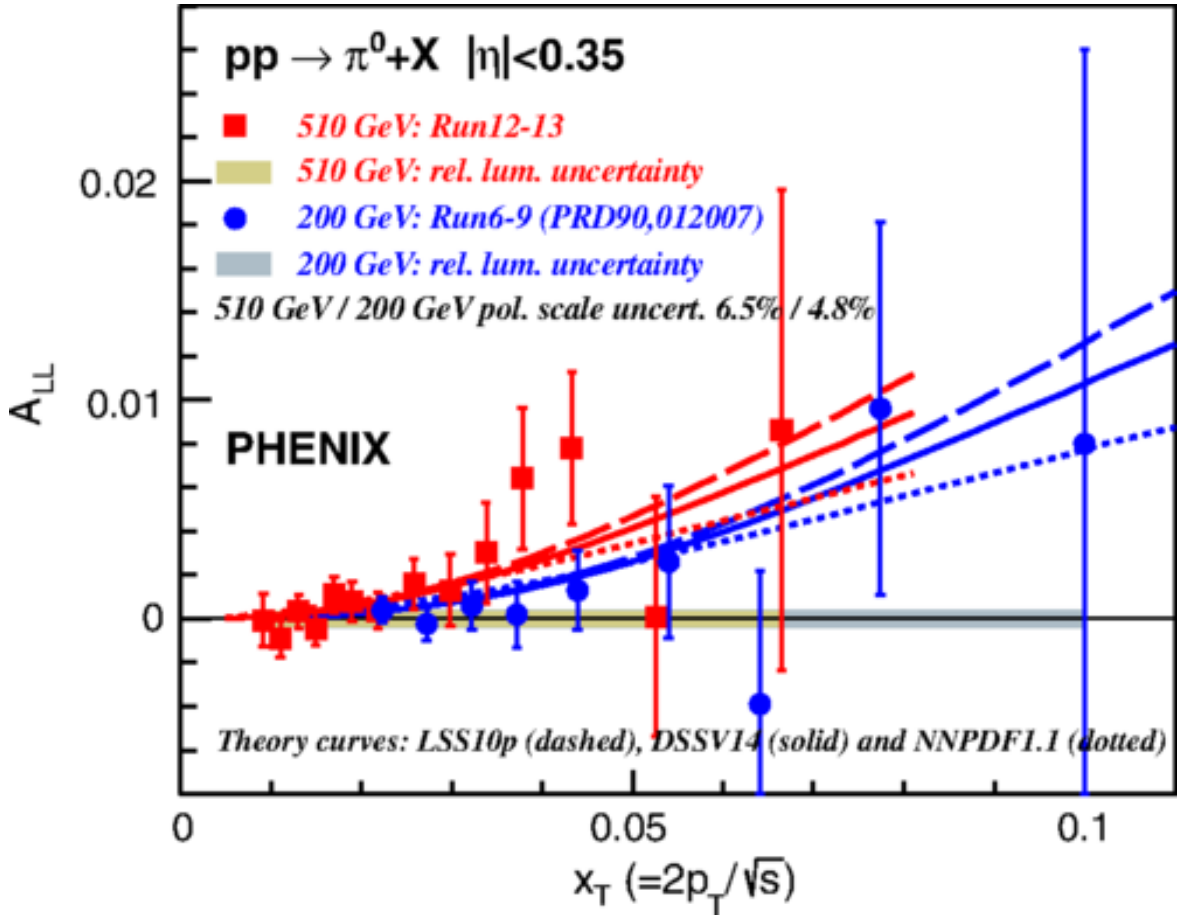
Phys. Rev. D **93,** 011501(R)

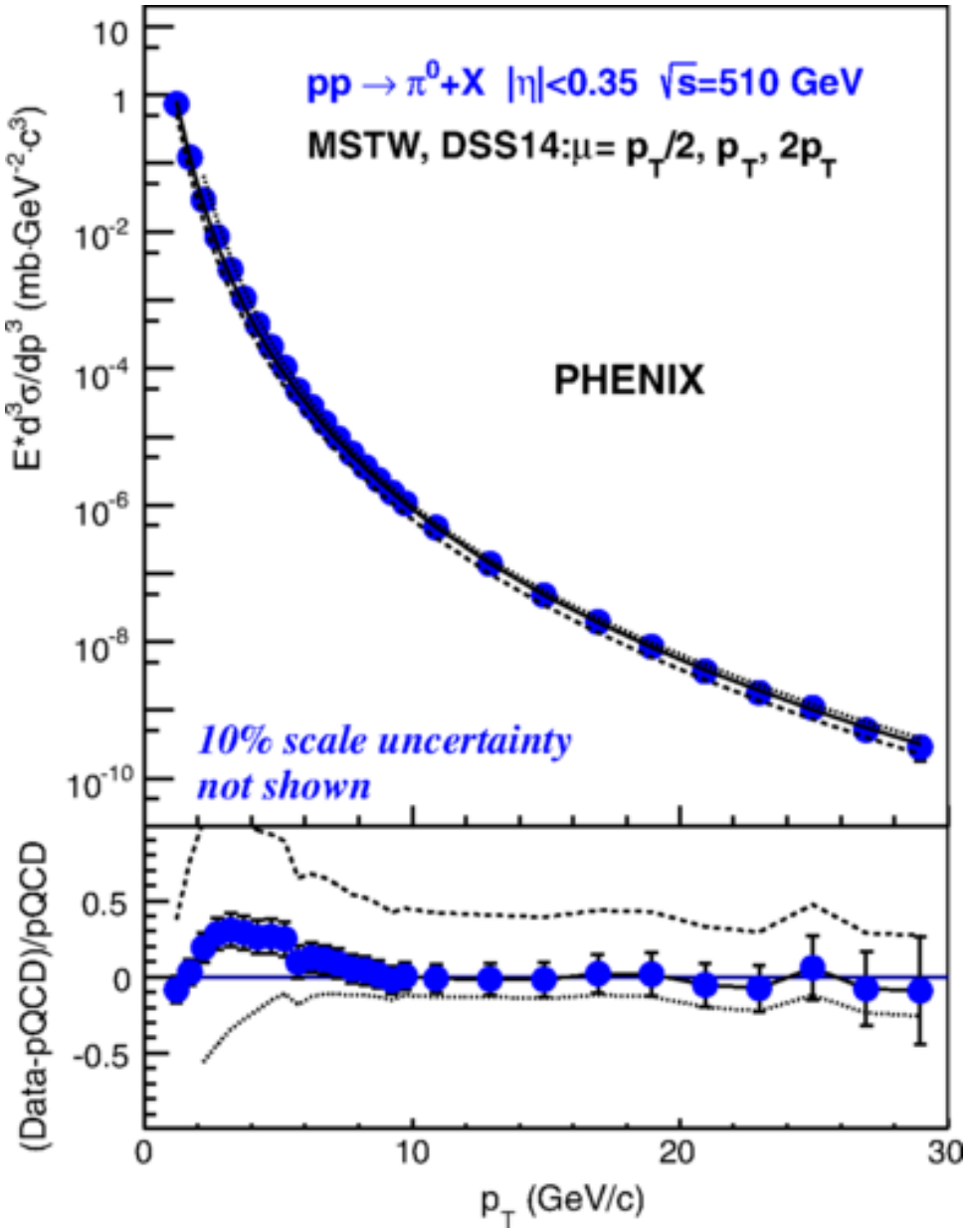




510 GEV INCLUSIVE MIDRAPIDITY Π^0

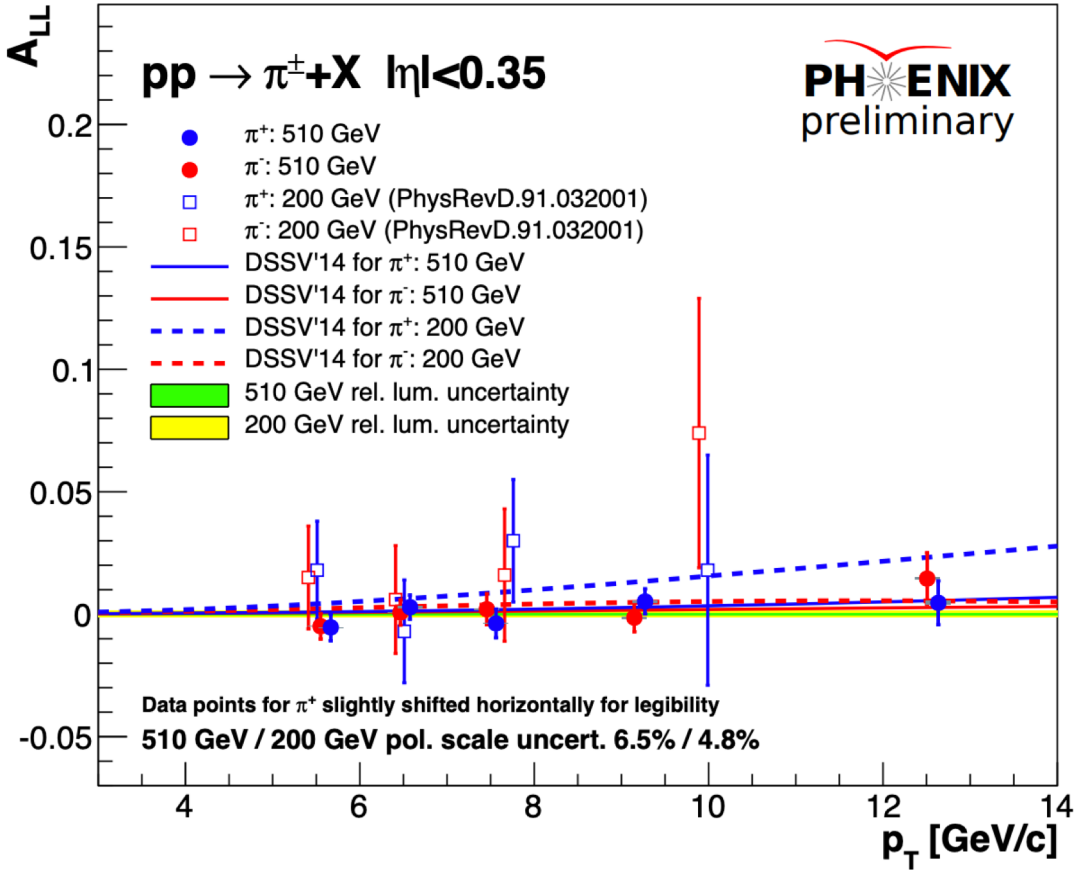
Phys. Rev. D **93,** 011501(R)



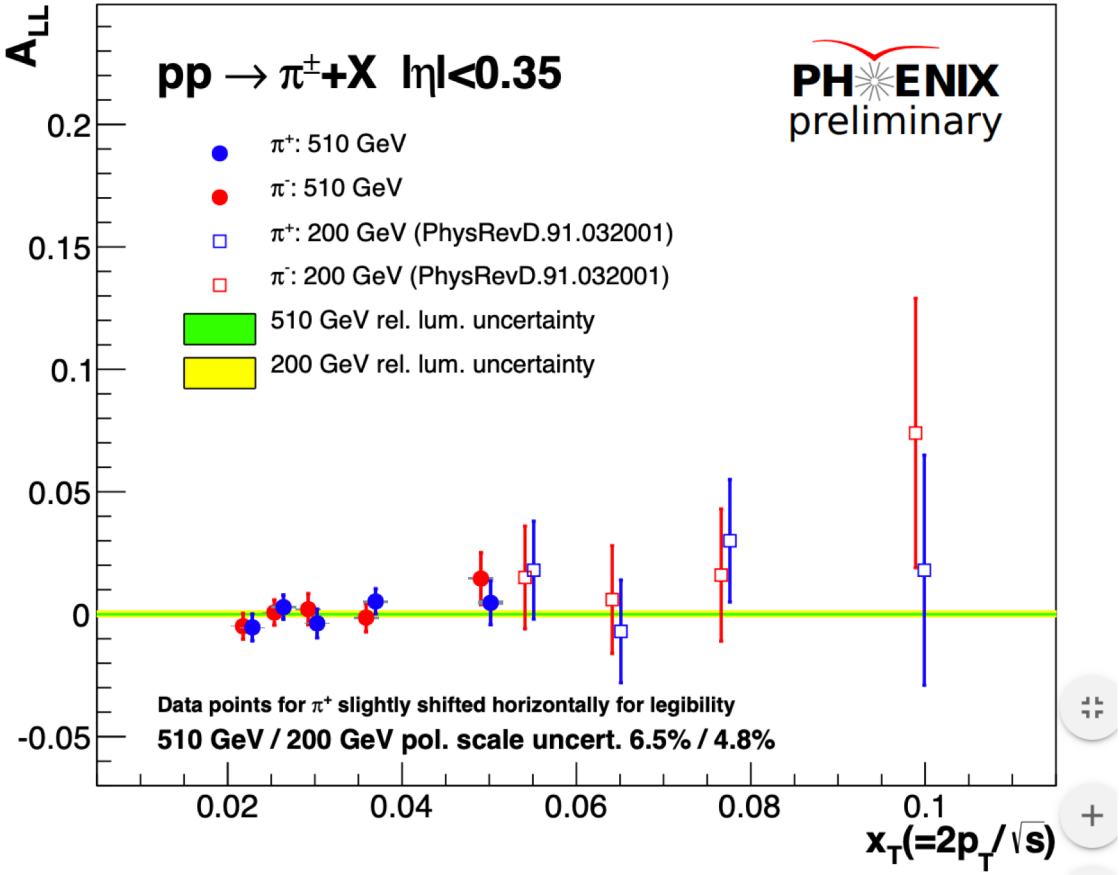


PHENIX 510 GEV INCLUSIVE MIDRAPIDITY $\Pi^{+/-}$

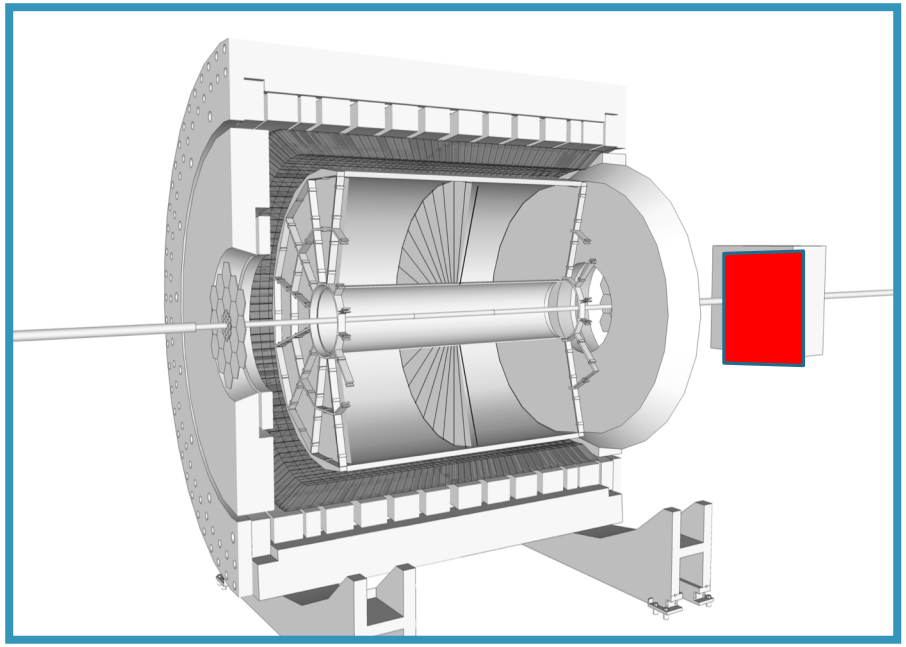
Sensitive to the sign of ΔG - $A_{LL}^{+} > A_{LL}^{-}$



ΔG

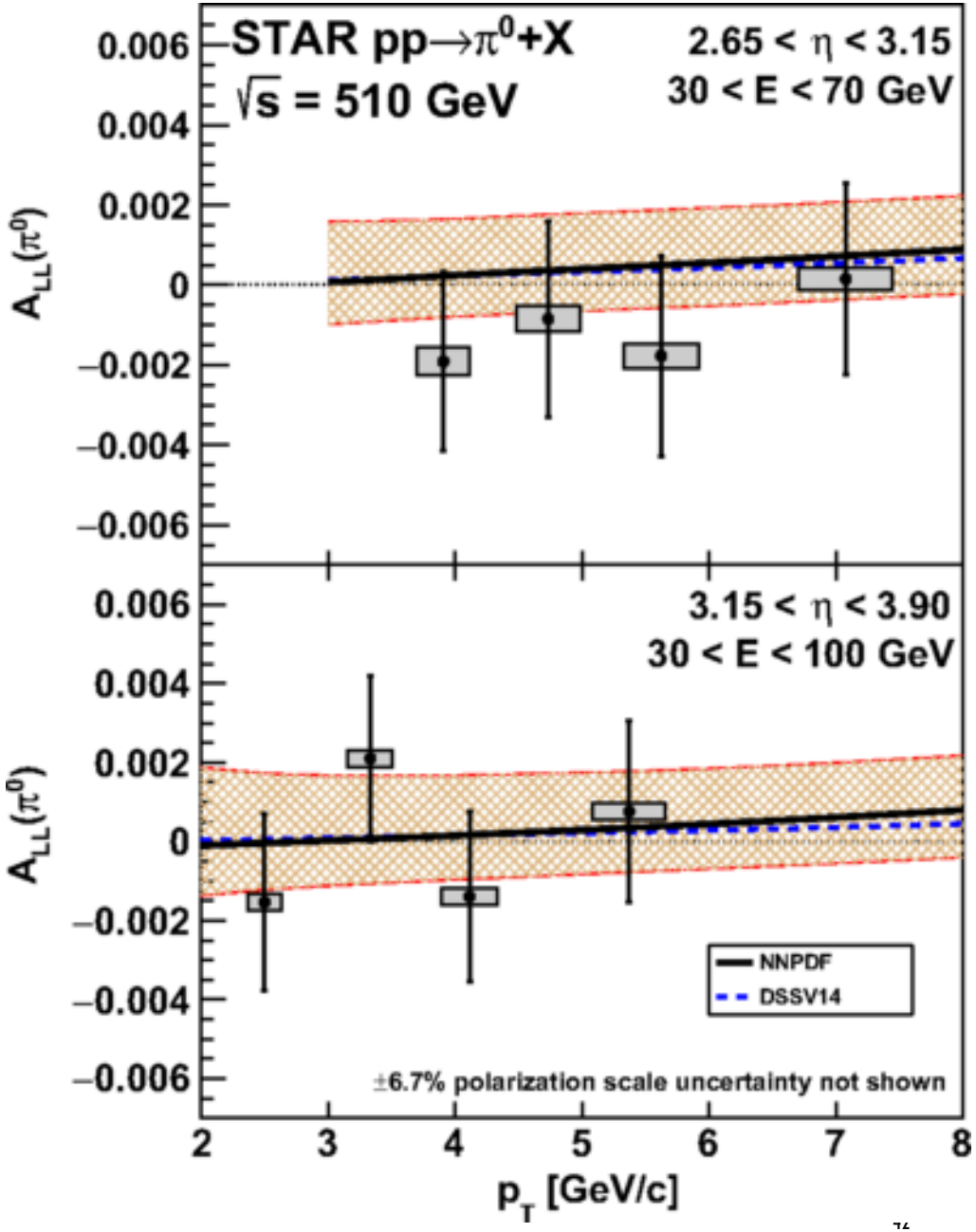


510 GEV FORWARD INCLUSIVE Π^0 A_{LL}

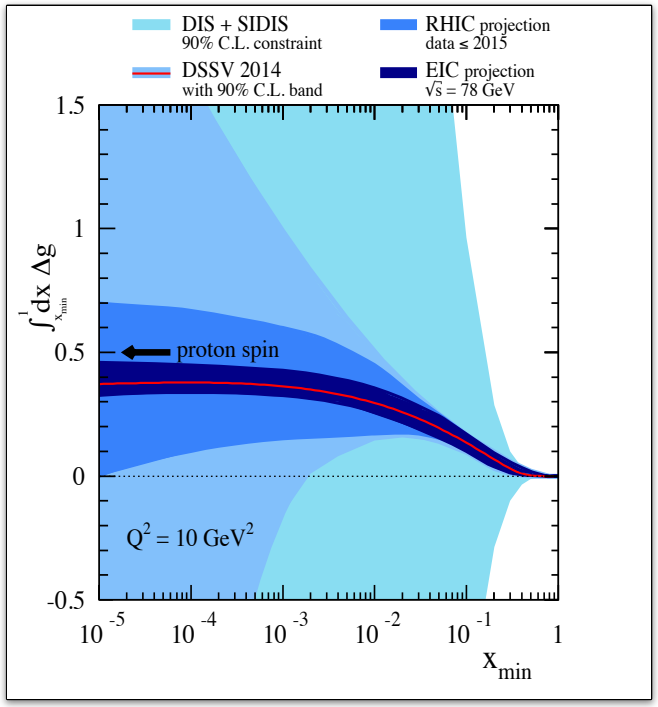


- Sensitivities down to x ~ 10^{-3} !
- All theoretical curves use DSS FF

Phys. Rev. D **98,** 032013



510 GEV FORWARD INCLUSIVE Π^0 A_{LL}



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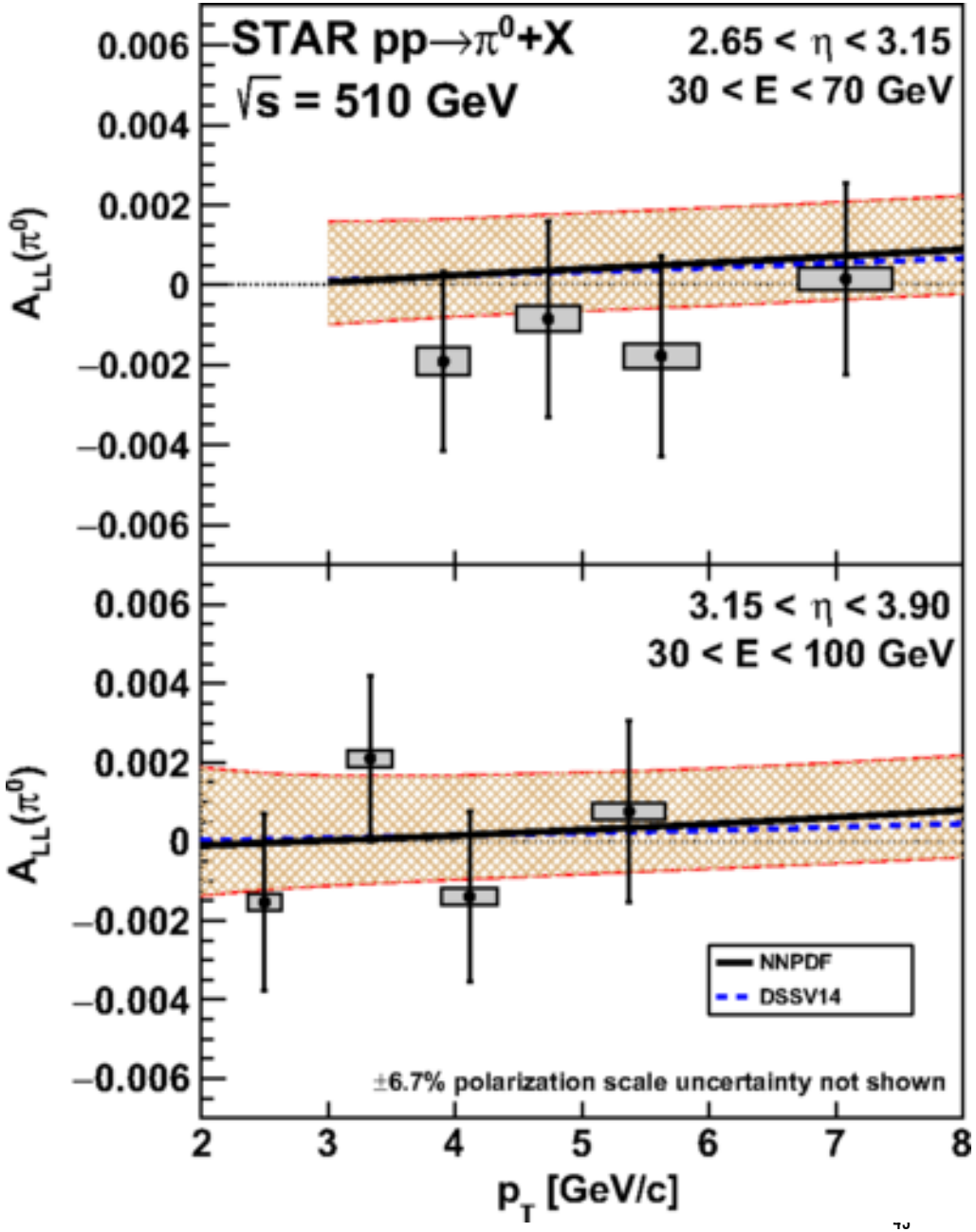
Phys. Rev. D **98**, 032013



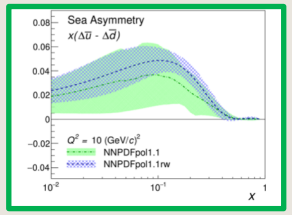
THE RHIC REVIEW

Protons · Sea-Quarks · Polarized Gluons · TSSAs · Heavy Ions

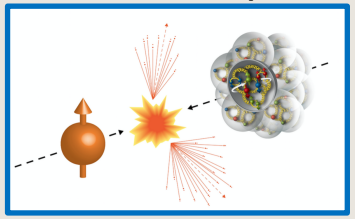
Issue: 20 The World's Best Selling Newspaper Est - 2000

First Edition October 29, 2019

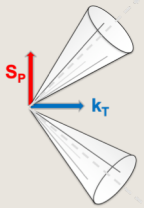
The end of an era – Final $W^{+/-}$ asymmetries provide strong evidence for flavor symmetry breaking in the light sea for the polarized sector.



The mystery continues to unfold – The A dependence of forward hadron TSSAs in p+A collisions continues to fuel theoretical work.



XKCD comics on page 10



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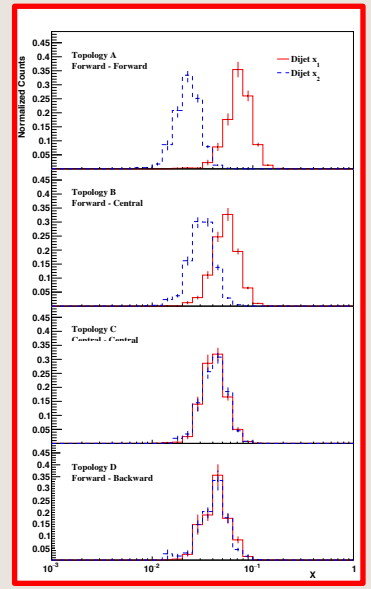
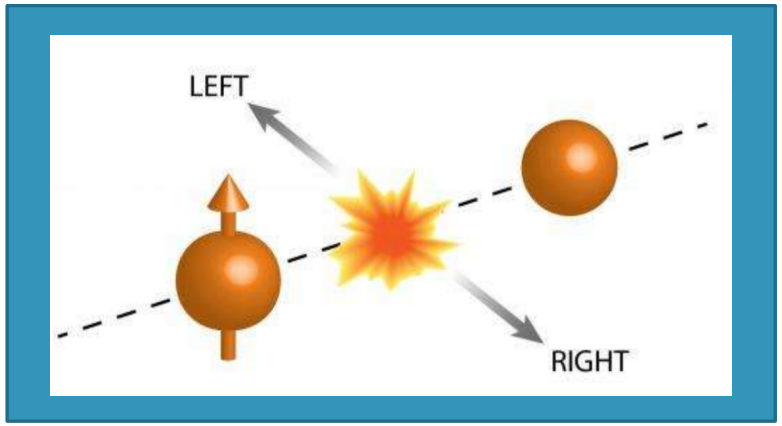


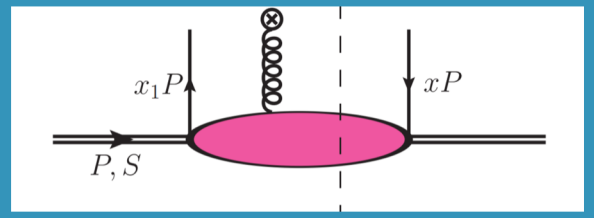
TRANSVERSE SINGLE SPIN ASYMMETRIES

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

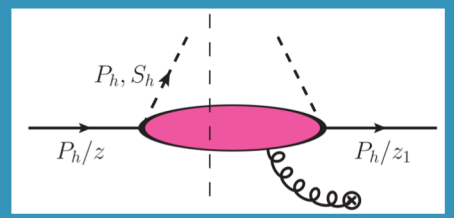
- Collide transversely polarized proton with "unpolarized" proton beam.
- Count the # of hadrons that scatter left vs. right.
- Theoretically TSSAs are described by multi-parton correlators in a collinear twist-3 framework.



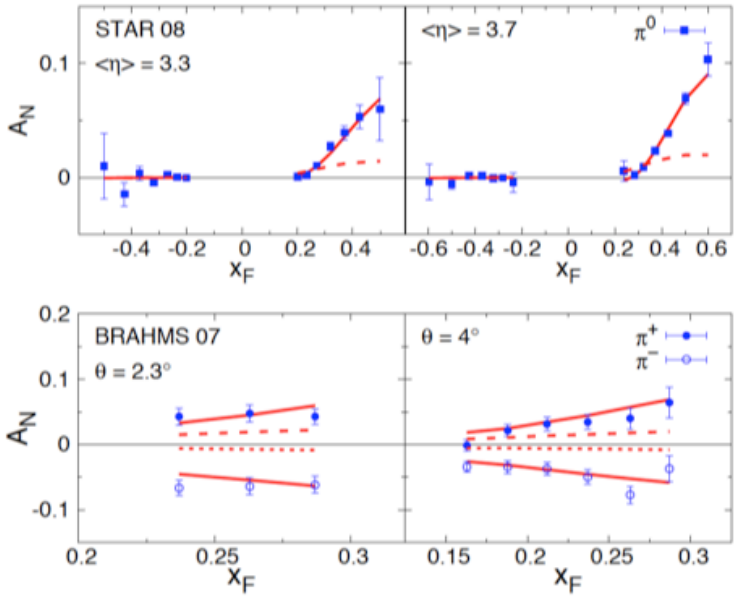
qgq Twist-3 initial state



qgq Twist-3 final state



D. Pitonyak, International Journal of Modern Physics A31, No. 32 1630049

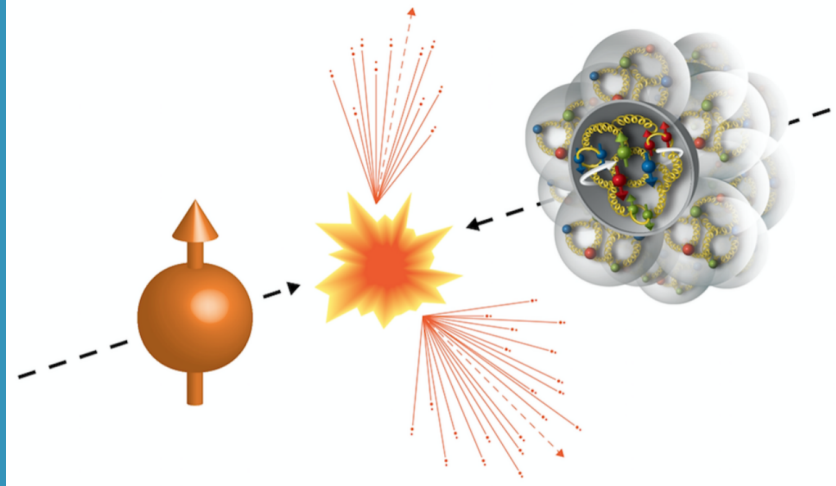


Phys. Rev. D89, 111501

TRANSVERSE SINGLE SPIN ASYMMETRIES

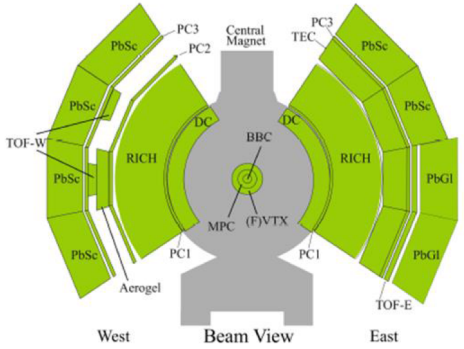
$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

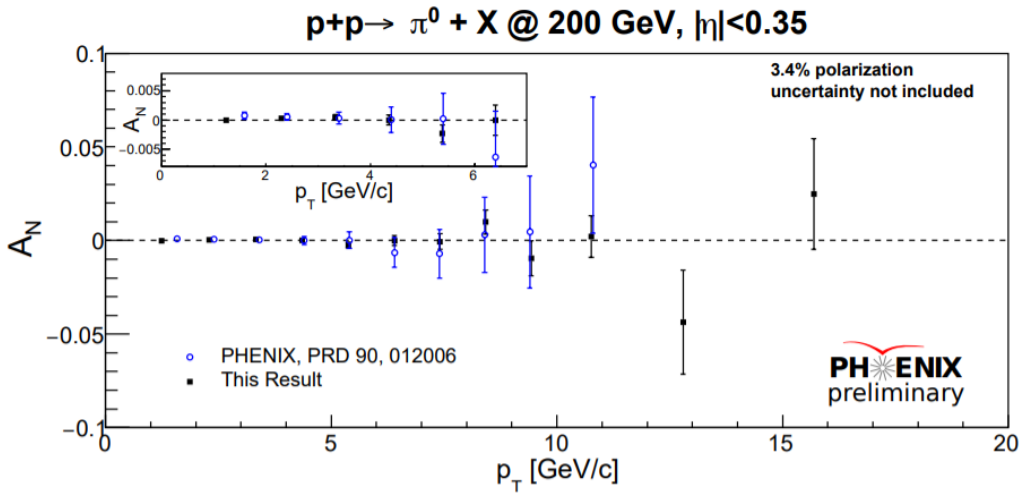
- Replace unpolarized proton beam with ion beam.
- Count the # of hadrons that scatter left vs. right.
- In the case of forward scattering, a high x polarized parton will scatter from multiple low x partons, many likely to be gluons, before fragmenting. Leads naturally to the question - ***How do TSSAs change in a nuclear environment?***
- Intense theoretical work has tried to answer this question by extending gluon saturation frameworks to include spin effects.
- Data from RHIC Run 15 p+p, p+Al and p+Au collisions will give us necessary experimental feedback.

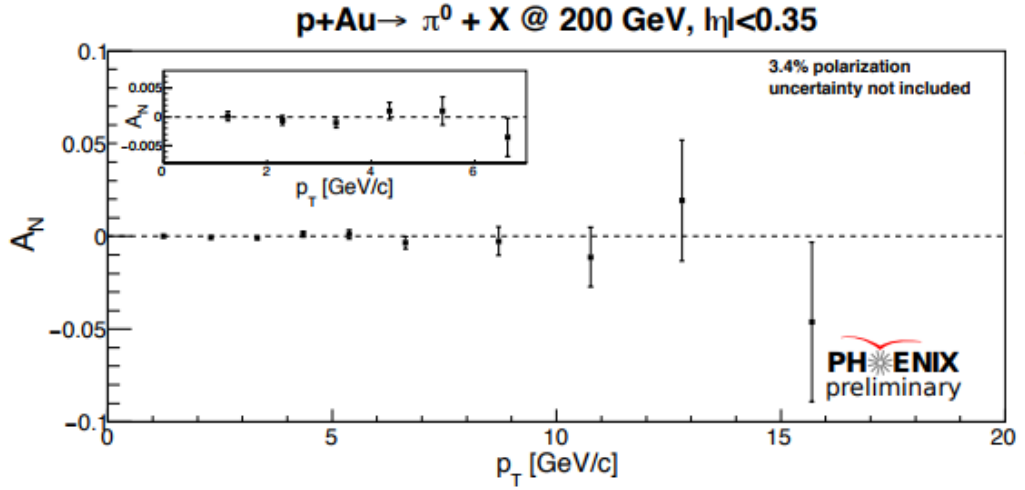


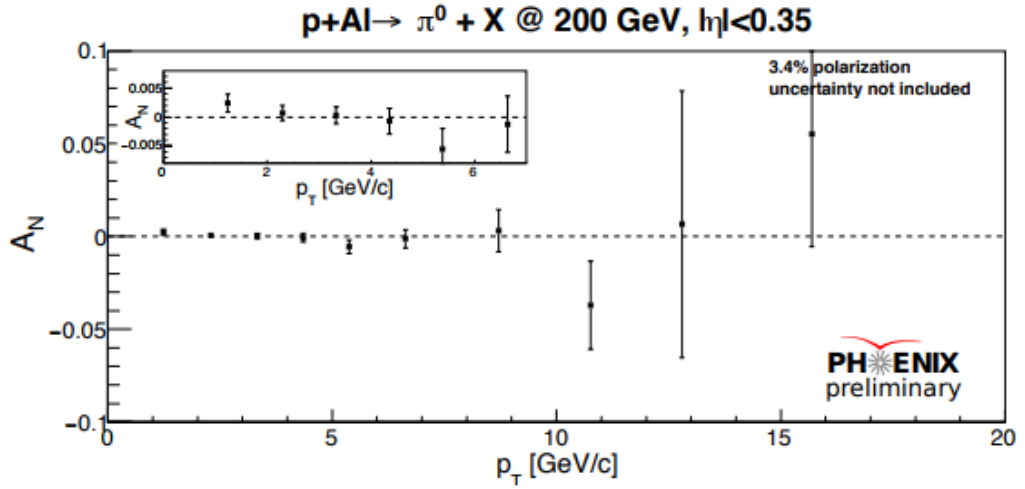
Phys.Rev. D 74, 074018 (2006)
Phys.Rev. D 84, 034019 (2011)
Phys.Rev. D 86, 034028 (2012)
Phys.Rev. D 94, 054012 (2016)
Phys.Rev. D 95, 014008 (2017)
Phys.Rev. D 99, 094012 (2019)

RUN 15 MIDRAPIDITY π^0 A_N



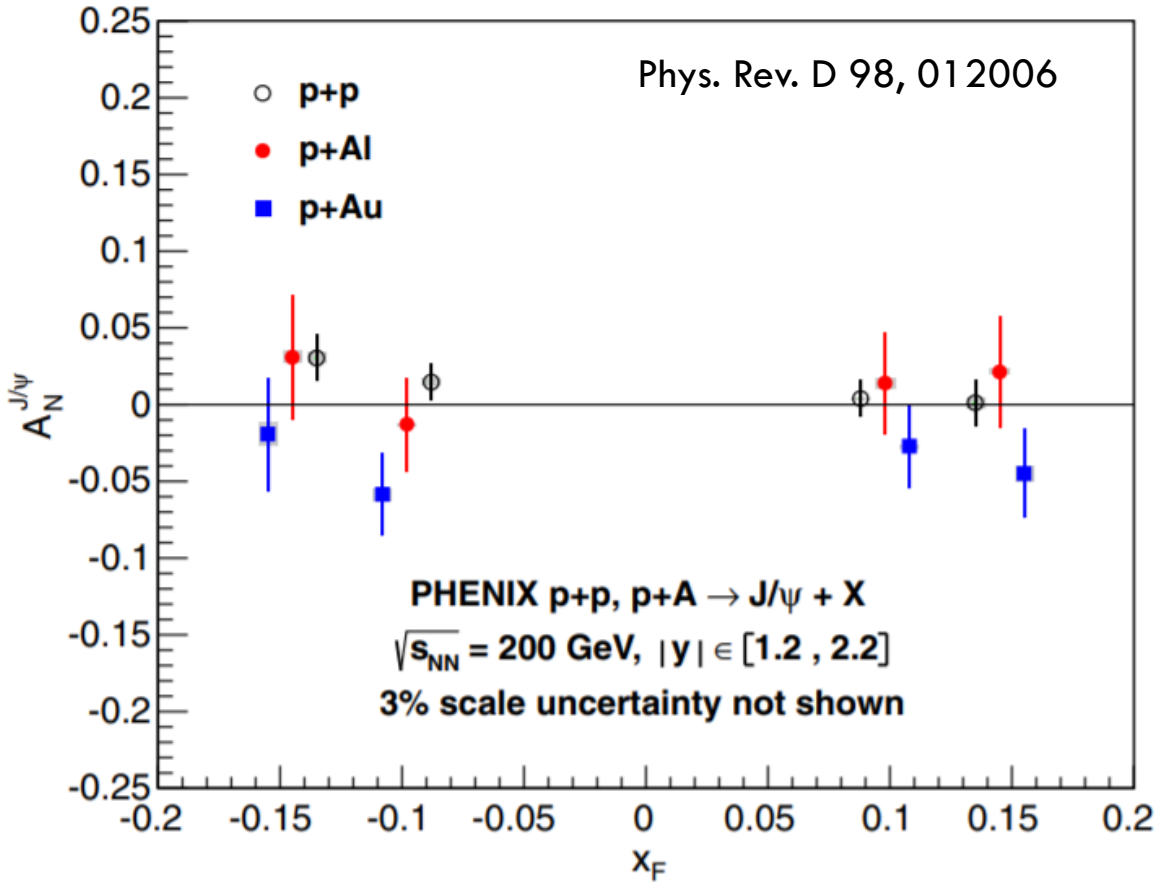


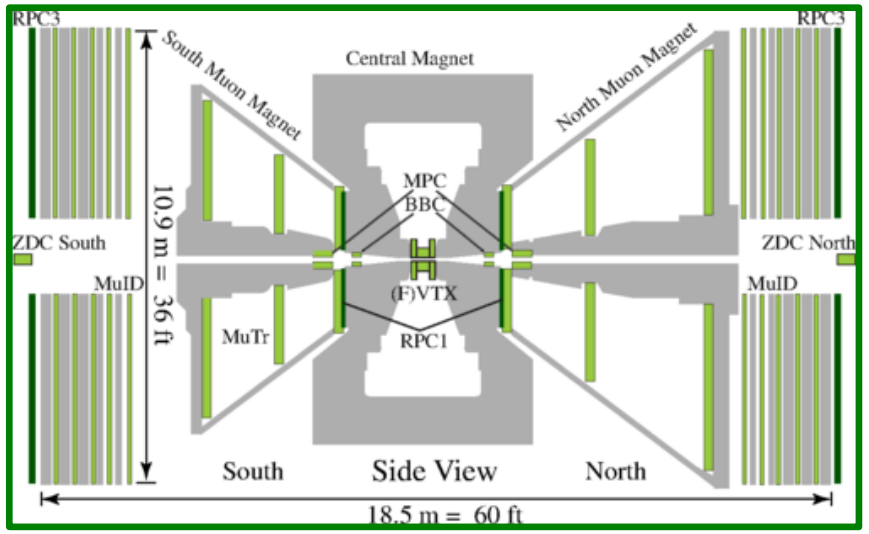




- Central EMCal used for π^0 reconstruction.
- A_N in p+p is zero at the ~10^{-4} level at mid-rapidity.
- This is typical for mid-rapidity charged and neutral inclusive hadron asymmetries in p+p collisions.

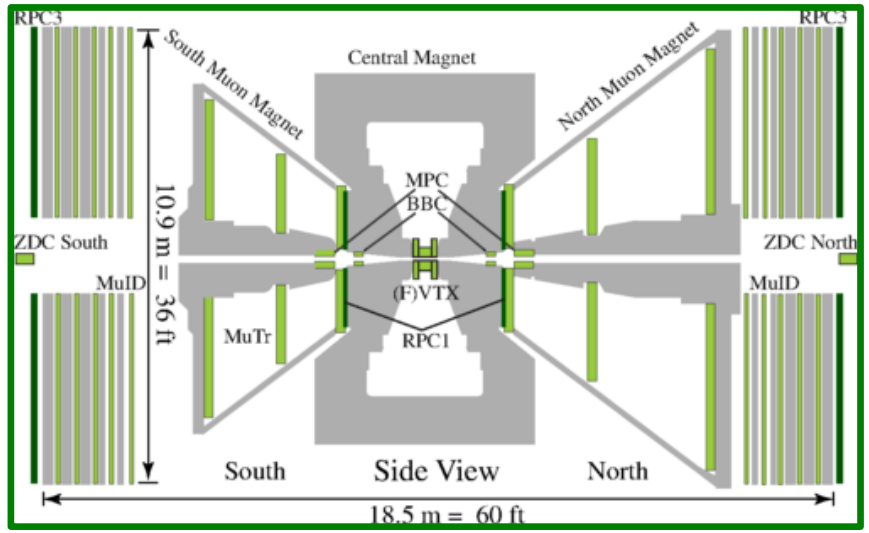
PHENIX FORWARD J/ψ A_N

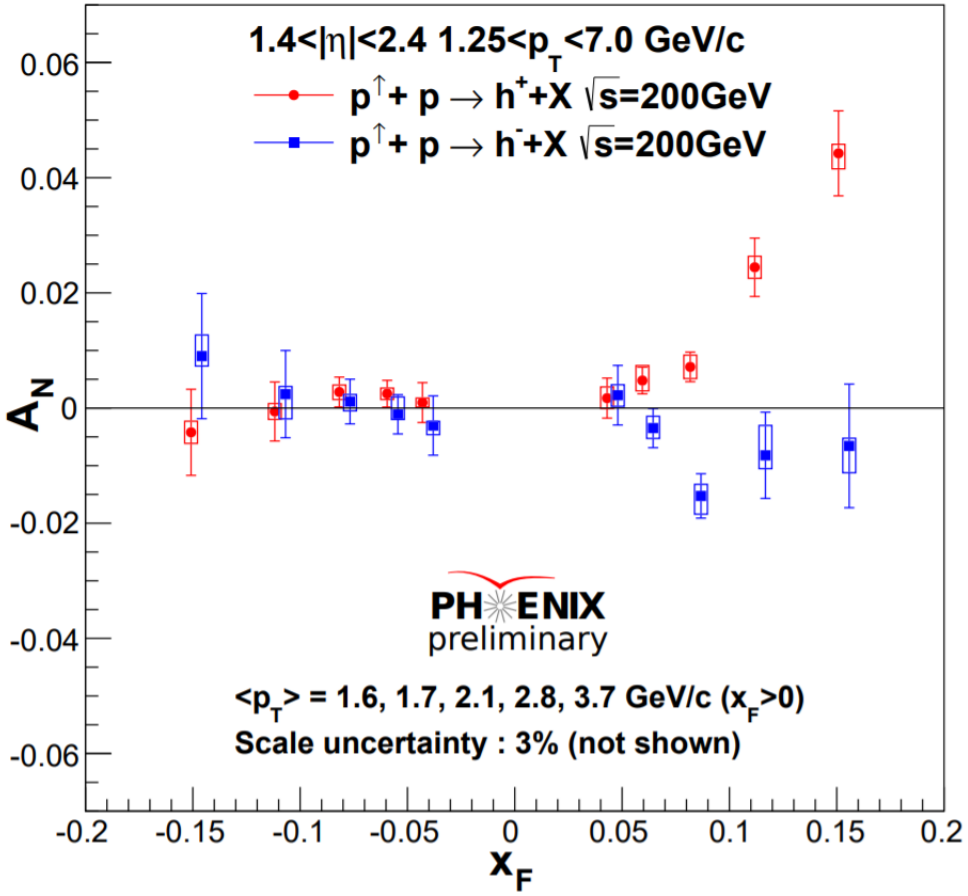




- Use forward muon trackers (1.2 $|\eta| < 2.4$) to detect muons and reconstruct J/ψ.
- J/Psi production predominately from gg fusion at $\sqrt{s_{NN}}$=200 GeV
- Probes gluon distributions in nuclei
- No clear A dependence - only p+Au trends negative

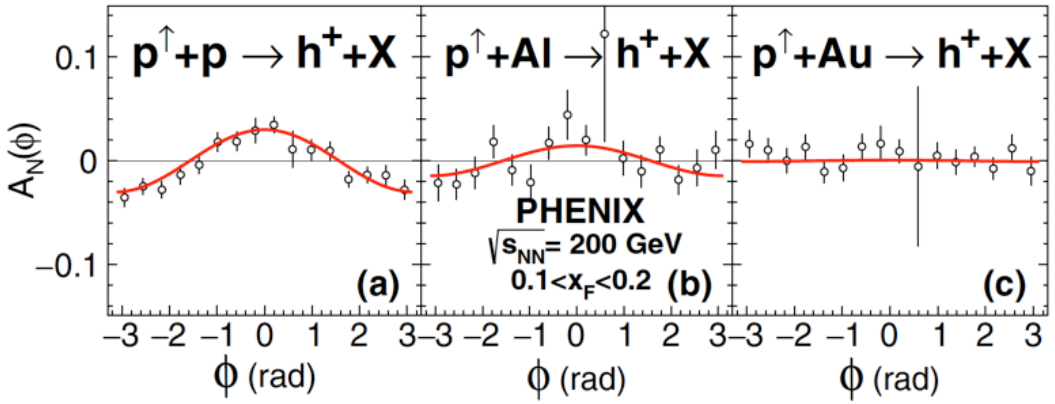
FORWARD CHARGED HADRON A_N IN P+P





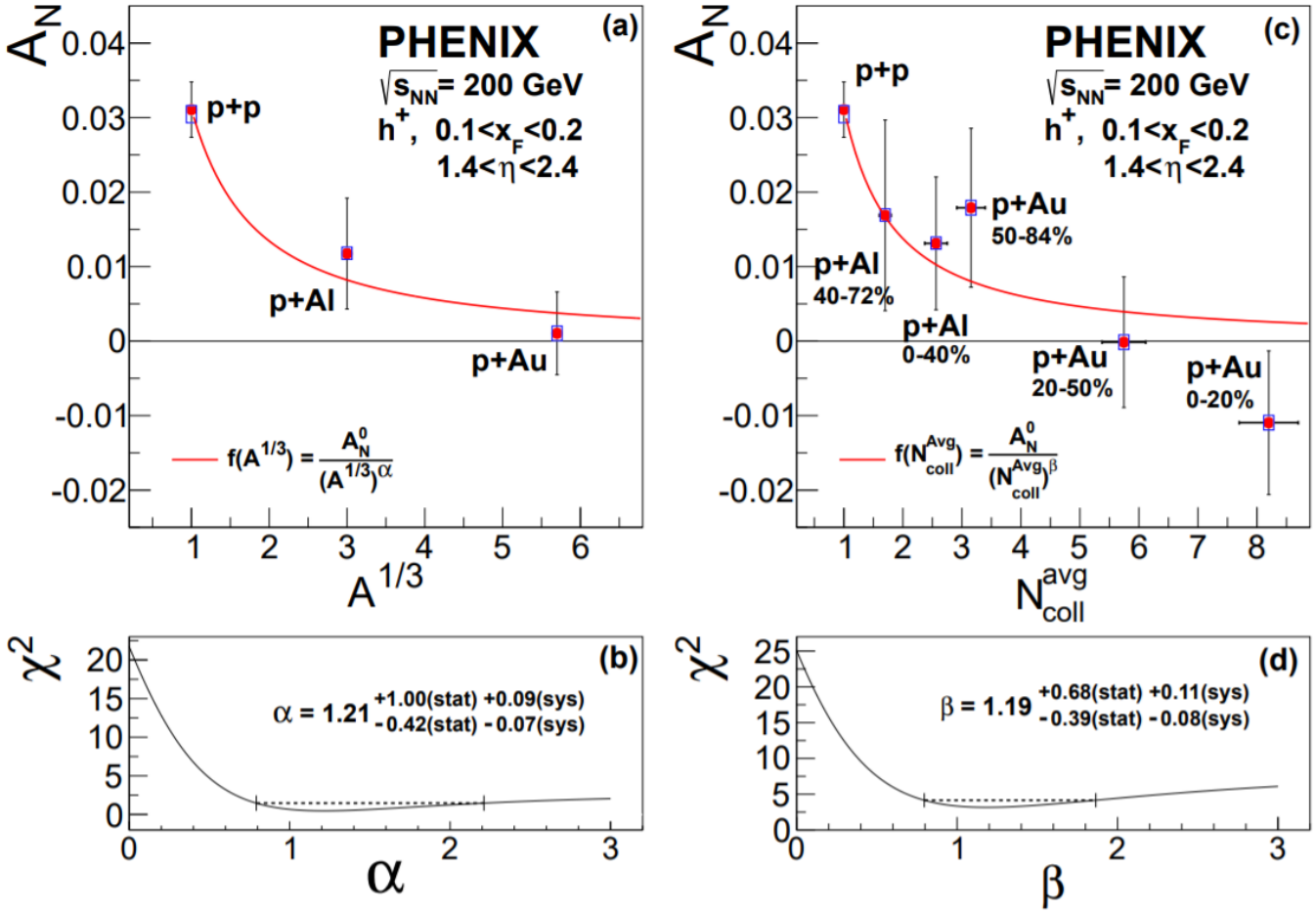
- Use MuID to tag charged hadrons that stop in 3rd or 4th plane due to hadronic interactions.
- Equal parts pions and Kaons, 5% protons
- As expected, A_N increases with x_F.
- K^- and π asymmetries are opposite sign – causing some cancelation for the negative hadron signal.

WHAT HAPPENS IN P+A?

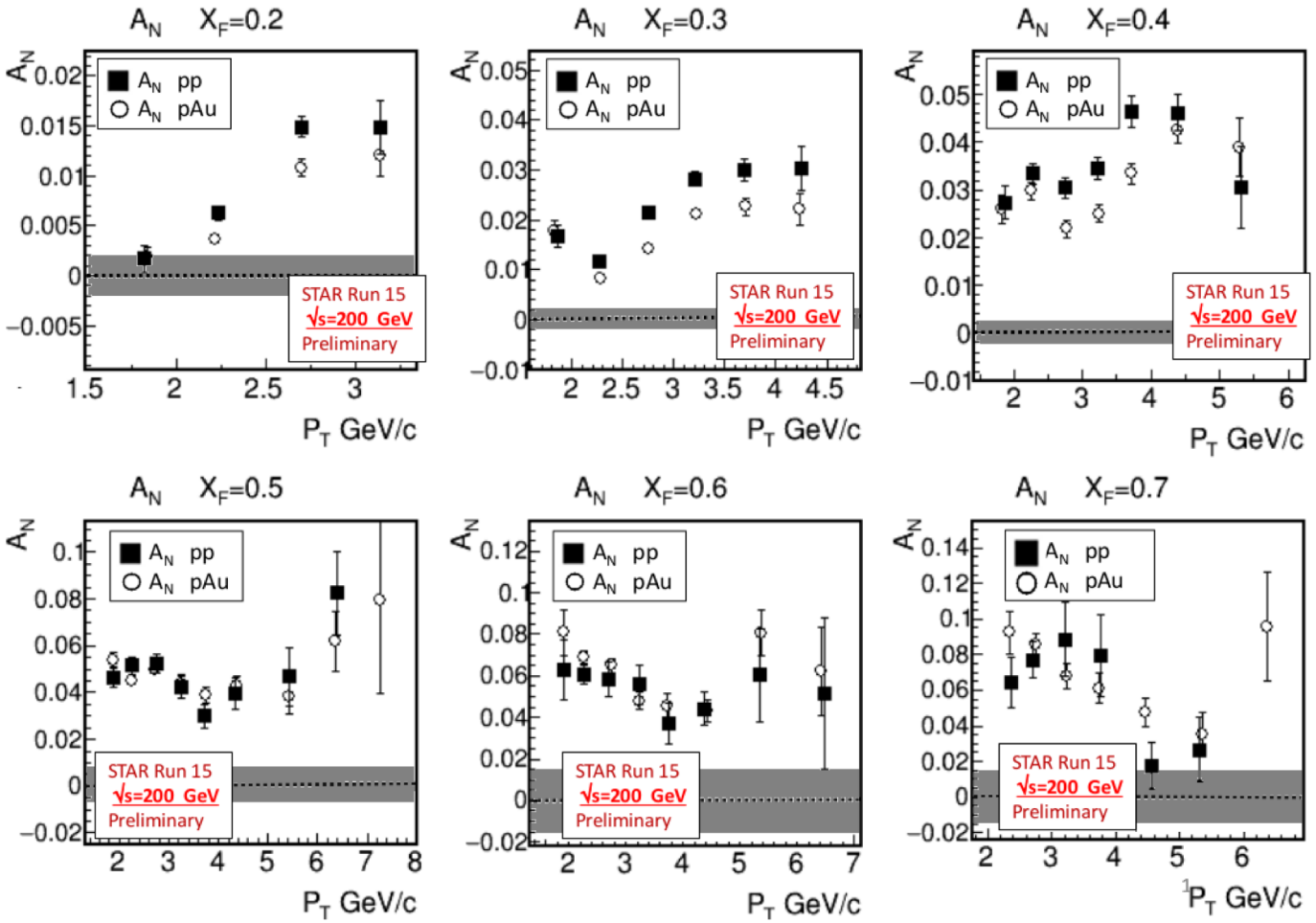


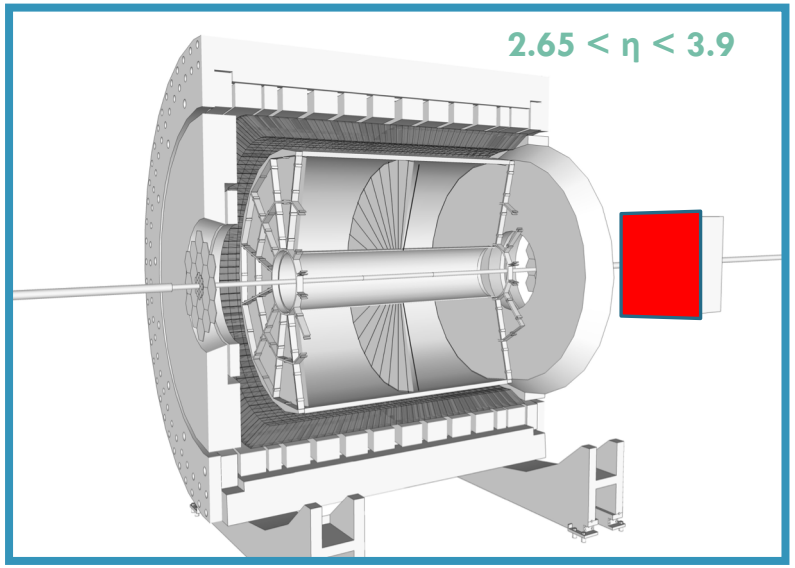
- Clear A dependence in azimuthal asymmetry of the yield.
- Fit is a function of $A^{-\alpha/3}$ motivated by the expectation (Phys.Rev.D 94, 054013) that the twist-3 FF should modify like $A^{-\alpha/3}$ for low momentum hadrons. Here $\langle p_T \rangle$ = 2.9 GeV.

Phys.Rev.Lett. 123 (2019) no.12, 122001



FORWARD Π^0 A_N



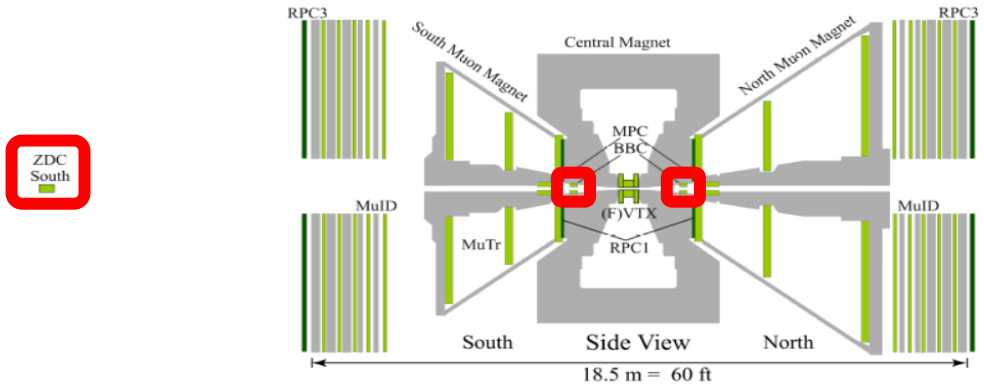


- Pions are reconstructed in the Forward Meson Spectrometer
- Asymmetries measured for a large X_F range 0.2-0.7.
- p+Au asymmetries are nearly as large as p+p asymmetries.
- No large A dependence observed.

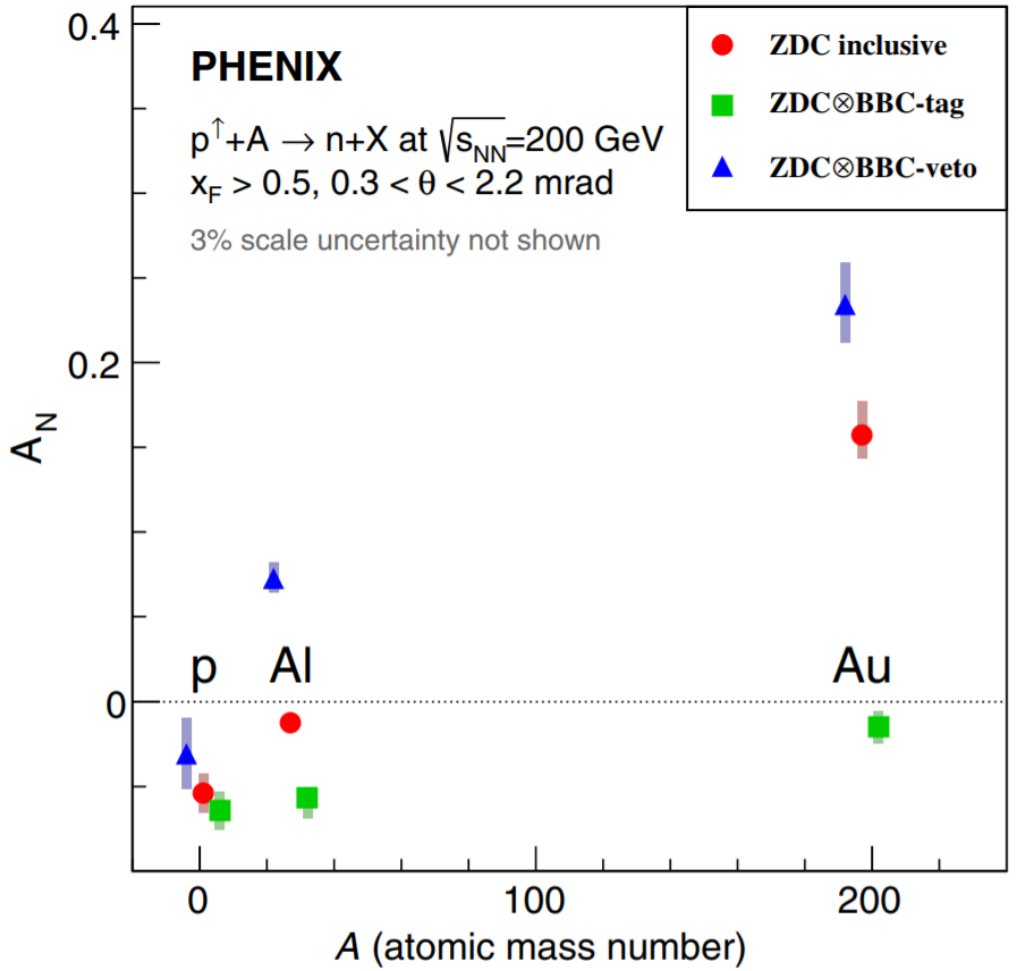
PHENIX FORWARD NEUTRON A_N

PRL **120**, 022001 (2018)

- Neutrons detected in ZDCs at $|\eta| > 5.9$



- Clear A dependence
- Asymmetries increase with BBC veto – no signals in either BBC. Points to a possible diffractive component?



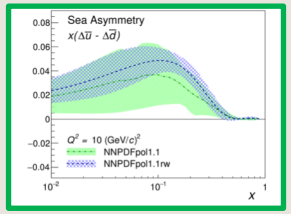
THE RHIC REVIEW

Protons · Sea-Quarks · Polarized Gluons · TSSAs · Heavy Ions

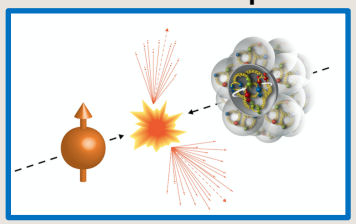
Issue: 20 The World's Best Selling Newspaper Est - 2000

First Edition October 29, 2019

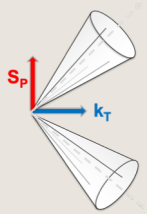
The end of an era – Final $W^{+/-}$ asymmetries provide strong evidence for flavor symmetry breaking in the light sea for the polarized sector.



The mystery continues to unfold – The A dependence of forward hadron TSSAs in p+A collisions continues to fuel theoretical work.

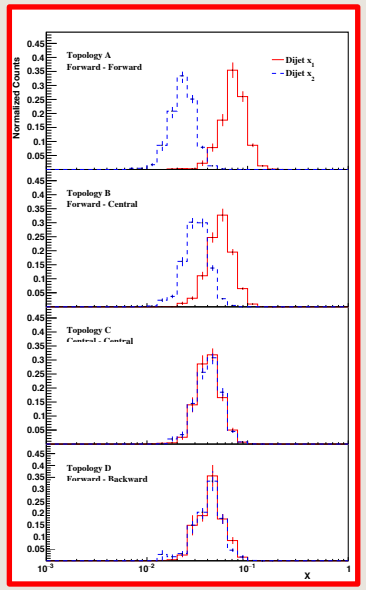


XKCD comics on page 10

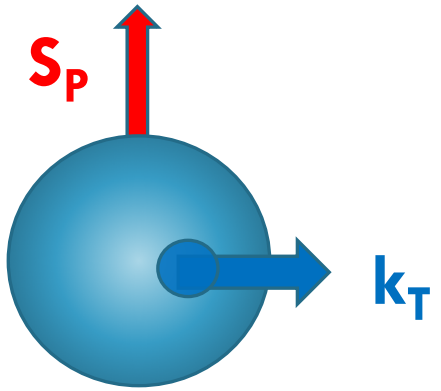


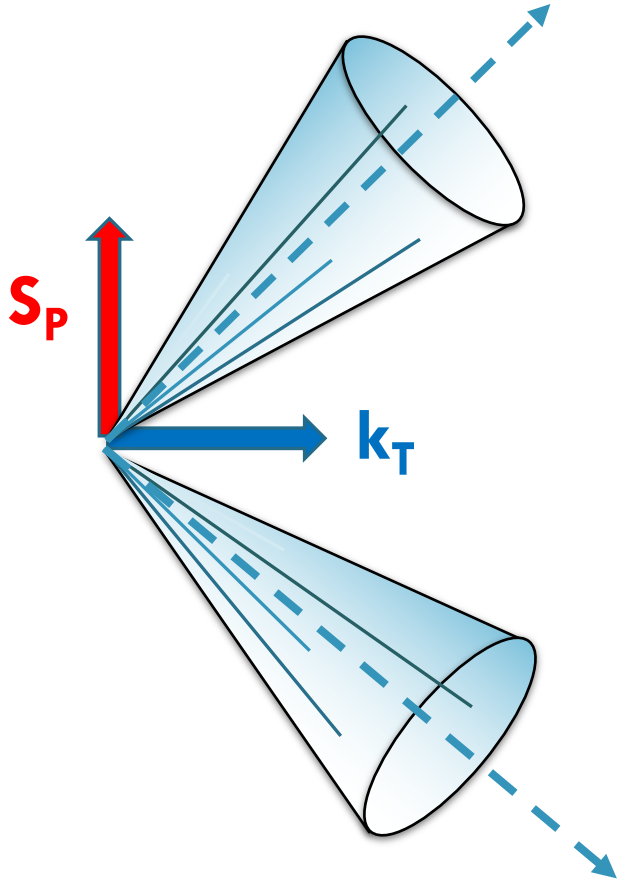
Breaking News! First flavor tagged dijet Sivers asymmetry released for DNP. Details on page 23.

New inclusive jet and dijet measurements at $\sqrt{s}$ = 500 GeV push constraints on gluon helicity distributions to lower x – ***what does this mean for ΔG?***



SIVERS EFFECT IN DIJET PRODUCTION





$$\langle \vec{S}_{proton} \cdot (\vec{P}_{proton} \times \vec{k}_T) \rangle$$

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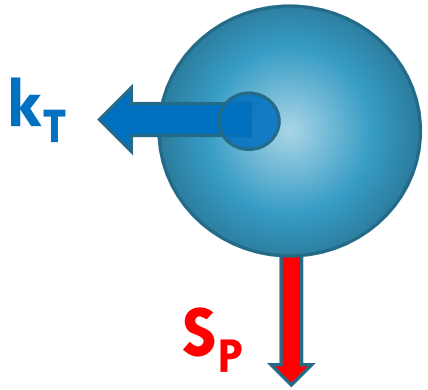

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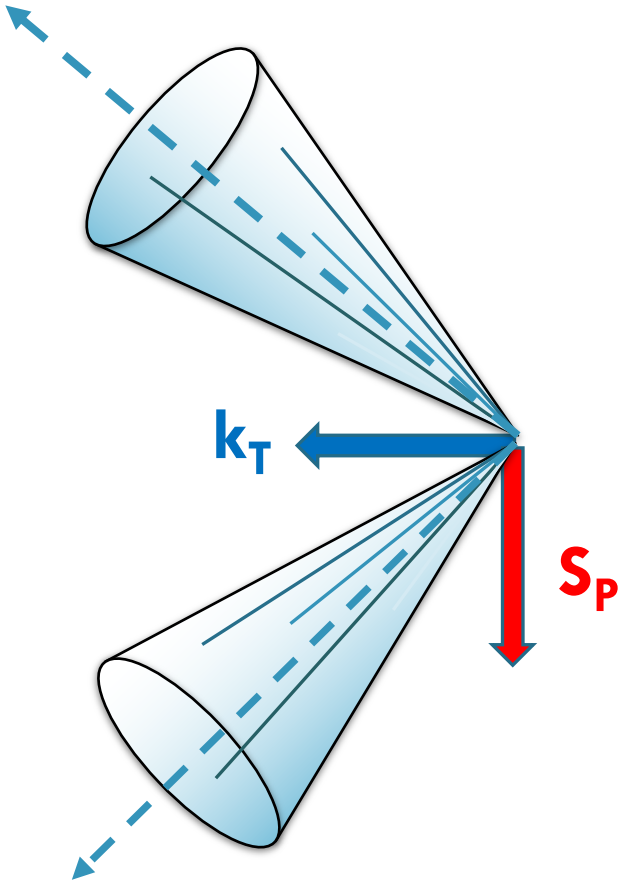
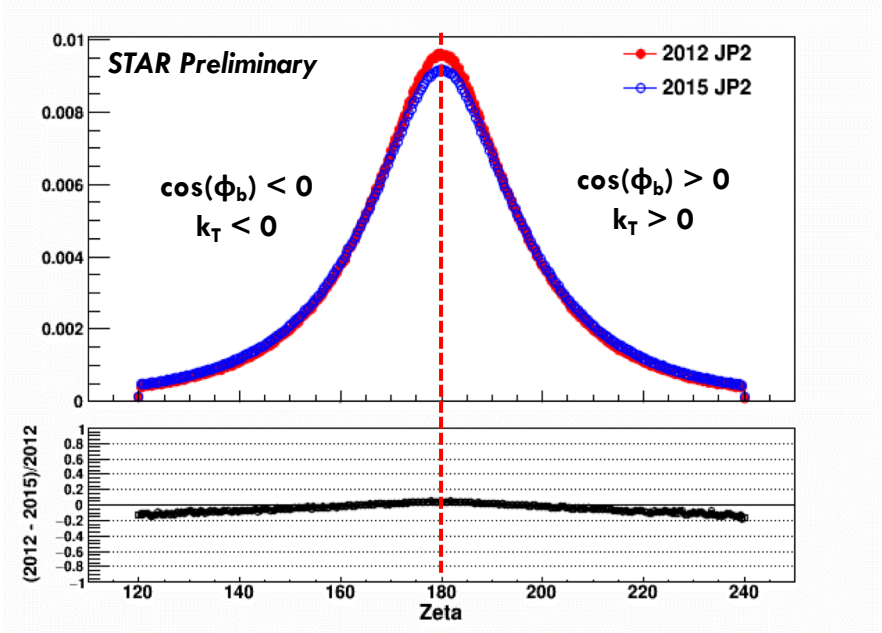
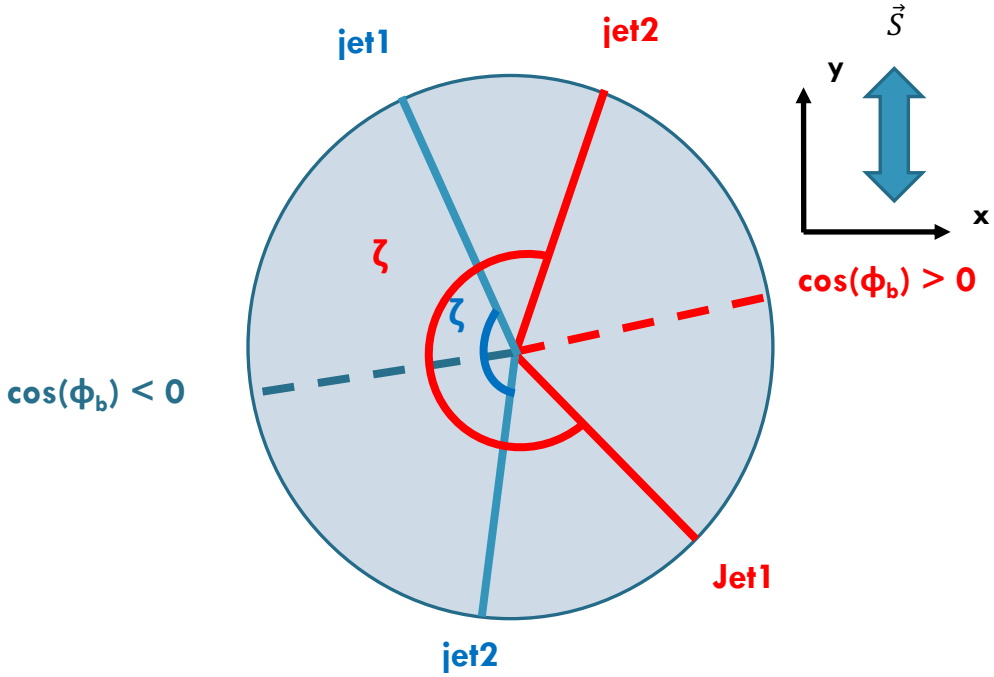


OBSERVABLE IN DIJET PRODUCTION

- ϕ_b is di-jet bisector angle (the ray points to the tilt direction of the two jets)
- ζ is the opening angle of dijet in the transverse plane $\zeta > \pi$ when $\cos(\phi_b) > 0$
  $\zeta < \pi$ when $\cos(\phi_b) < 0$

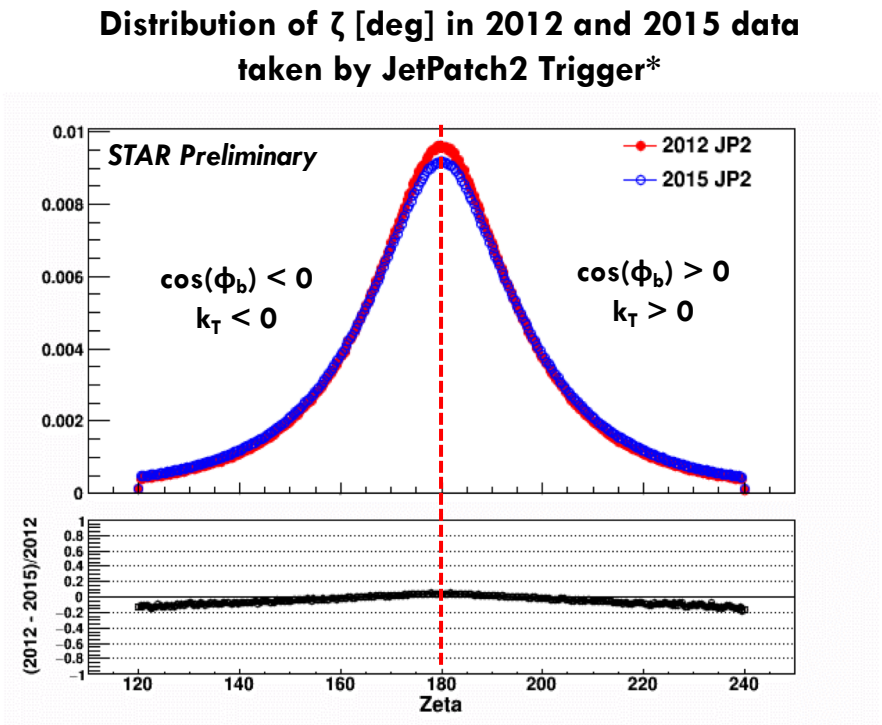
Distribution of ζ [deg] in 2012 and 2015 data taken by JetPatch2 Trigger*

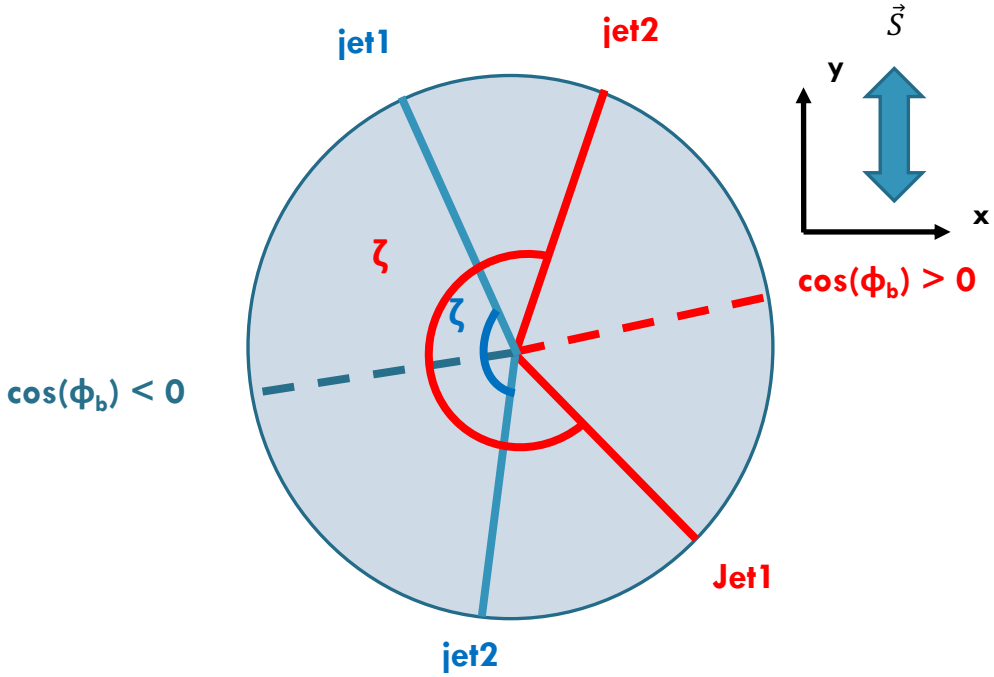




OBSERVABLE IN DIJET PRODUCTION

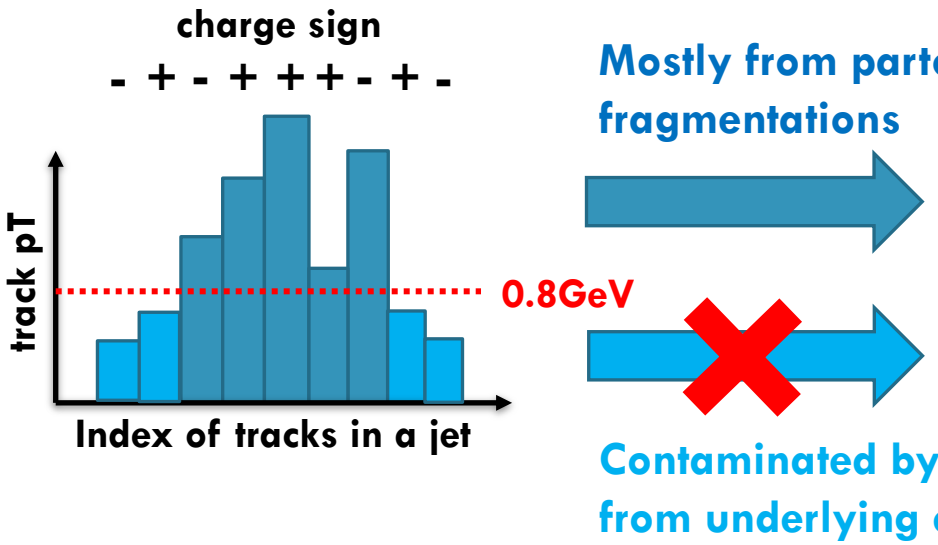
$$A = \frac{\langle \xi + \rangle - \langle \xi - \rangle}{P}$$





JET FLAVOR "TAGGING"

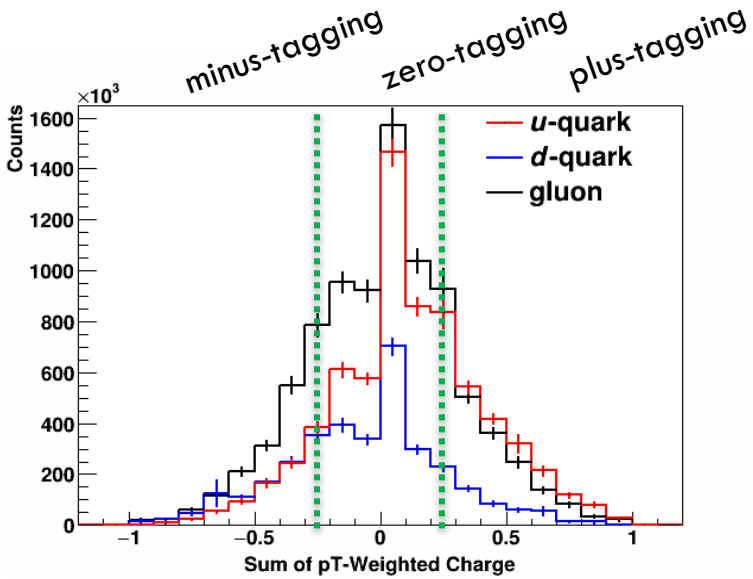
Tag associated jets to enhance the purities of ***u*-quarks and *d*-quarks** separately.



$$Q = \sum_{\substack{all\ the\ tracks \\ with\ pT>0.8GeV}} \frac{track\ pT}{jet\ pT} \cdot track\ charge$$

Data is divided into three groups:

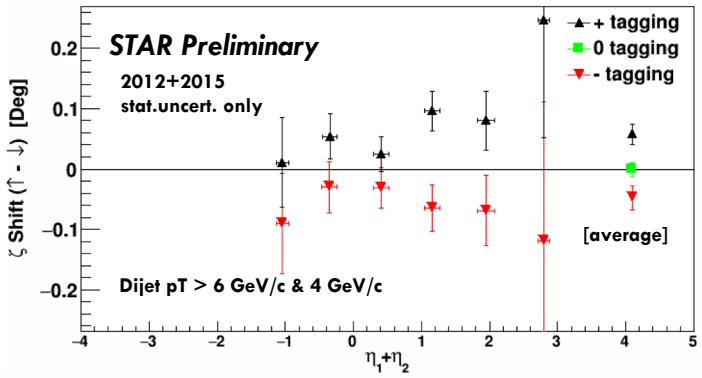
1. **Plus-tagging** (Q > 0.25) : enhances the *u*-quark purity.
2. **Minus-tagging** (Q < -0.25) : enhances the *d*-quark purity.
3. **Zero-tagging** (-0.25 < Q < 0.25) : *u* /*d* fractions are more balanced than the other two taggings.



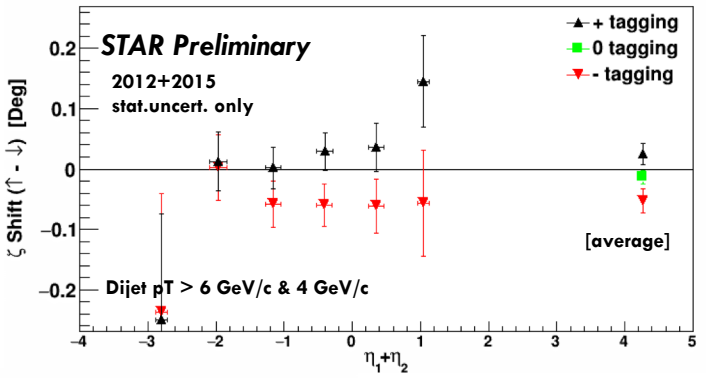
Distribution of Q for Events taken by JetPatch2 Trigger (2012 embedding with Pythia6)

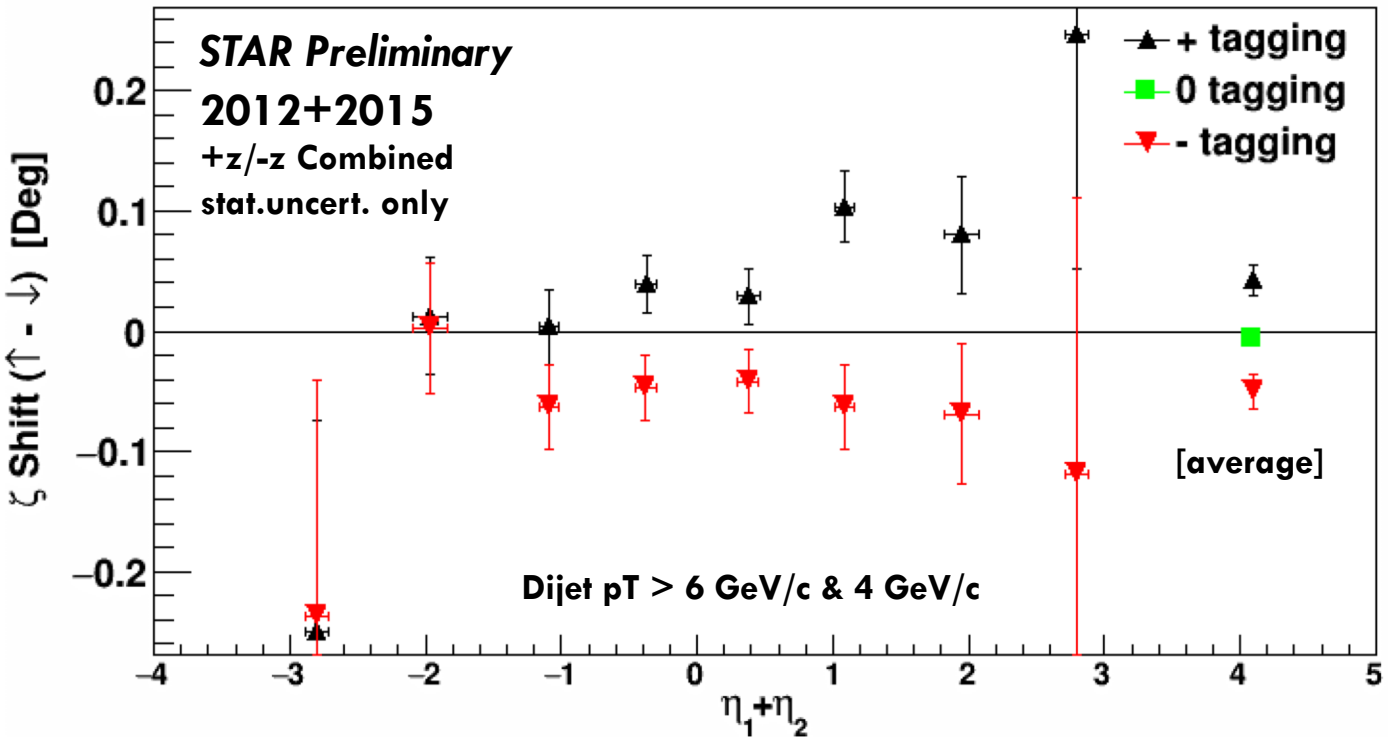
2012+2015 Data — Dijet Sivers Asymmetry

+z Beam



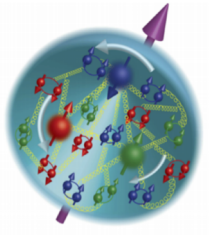
-z Beam (flipped to be along +z)





- Nice separation between plus-tagging and minus-tagging.
- There appears to be an η1+ η2 dependency: an enhanced kinematical selection of qg events is expected at larger η1+ η2.
- zero-tagging is consistent with zero.

SUMMARY



- The polarized sea is not flavor symmetric. We can definitively say that $\Delta\bar{u} > 0$ and $\Delta\bar{d} < 0$ in the valence region. This asymmetry is opposite to that of the unpolarized sea.

- The gluon contribution to the proton spin is positive and large ~60% in the region $0.05 < x < 0.2$. This result is supported by the recent inclusion of the 200 GeV dijet A_{LL}. The community eagerly awaits the inclusion of the 510 GeV pion, jet and dijet asymmetries into the existing global analyses.

- TSSA are extremely small at mid-rapidity but grow substantially at forward rapidity for a variety of observables – charged and neutral hadrons as well as neutrons. A substantial A dependence is observed for charged hadrons and neutrons but not for neutral pions. The story continues to unfold …

- The first flavor tagged dijet asymmetry has yielded significant asymmetries that flip with charge sign. Work continues to make the connection between dijet opening angle and k_T more robust.

- There is a lot of fabulous physics that I wasn't able to discuss – lets talk more over lunch.

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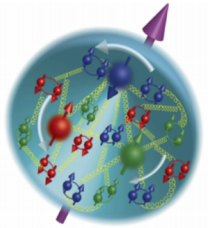

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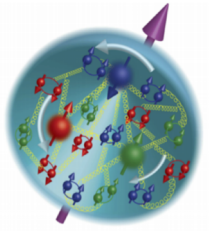

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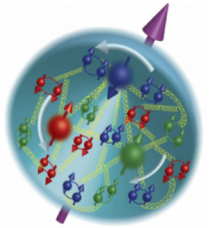

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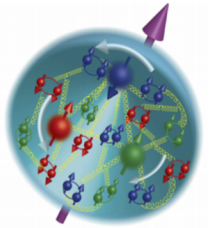

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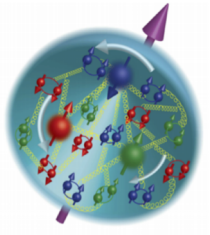

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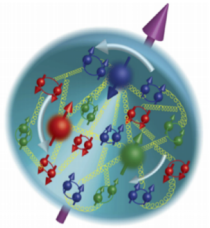

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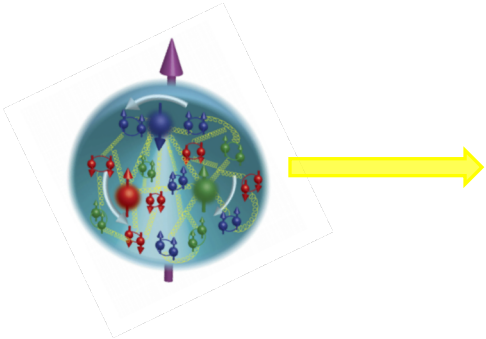
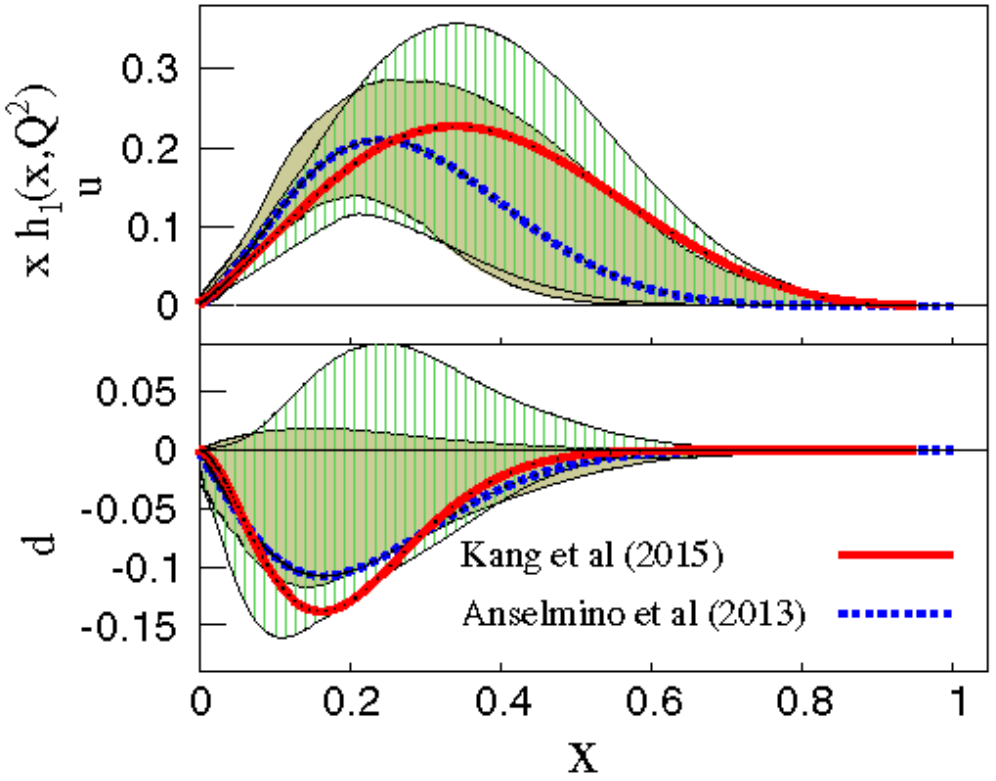
SO YOU WANT MORE?

TRANSVERSITY

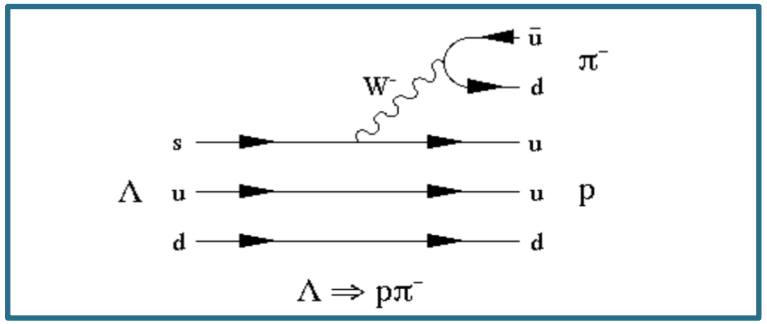


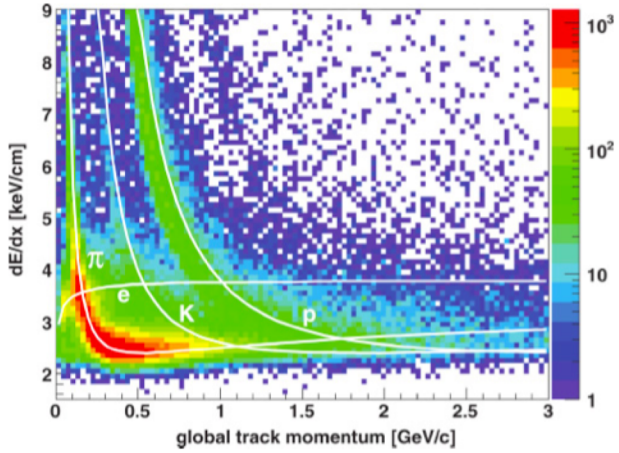
- QUARK POLARIZATION ALONG THE SPIN OF A TRANSVERSELY POLARIZED PROTON
- Distributions are not well constrained due to chiral-odd nature.
- Must couple to another chiral-odd function, typically a fragmentation function.
- May be a collinear or a transverse-momentum-dependent function.

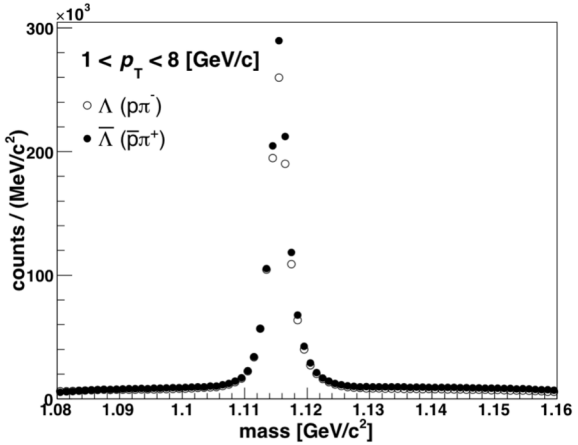


LAMBDA TRANSVESE SPIN TRANSFER D_{TT}

$$D_{TT} = \frac{d\sigma^{p\uparrow p\to\Lambda\uparrow X} - d\sigma^{p\uparrow p\to\Lambda\downarrow X}}{d\sigma^{p\uparrow p\to\Lambda\uparrow X} + d\sigma^{p\uparrow p\to\Lambda\downarrow X}} = \frac{d\Delta_T\sigma}{d\sigma}$$





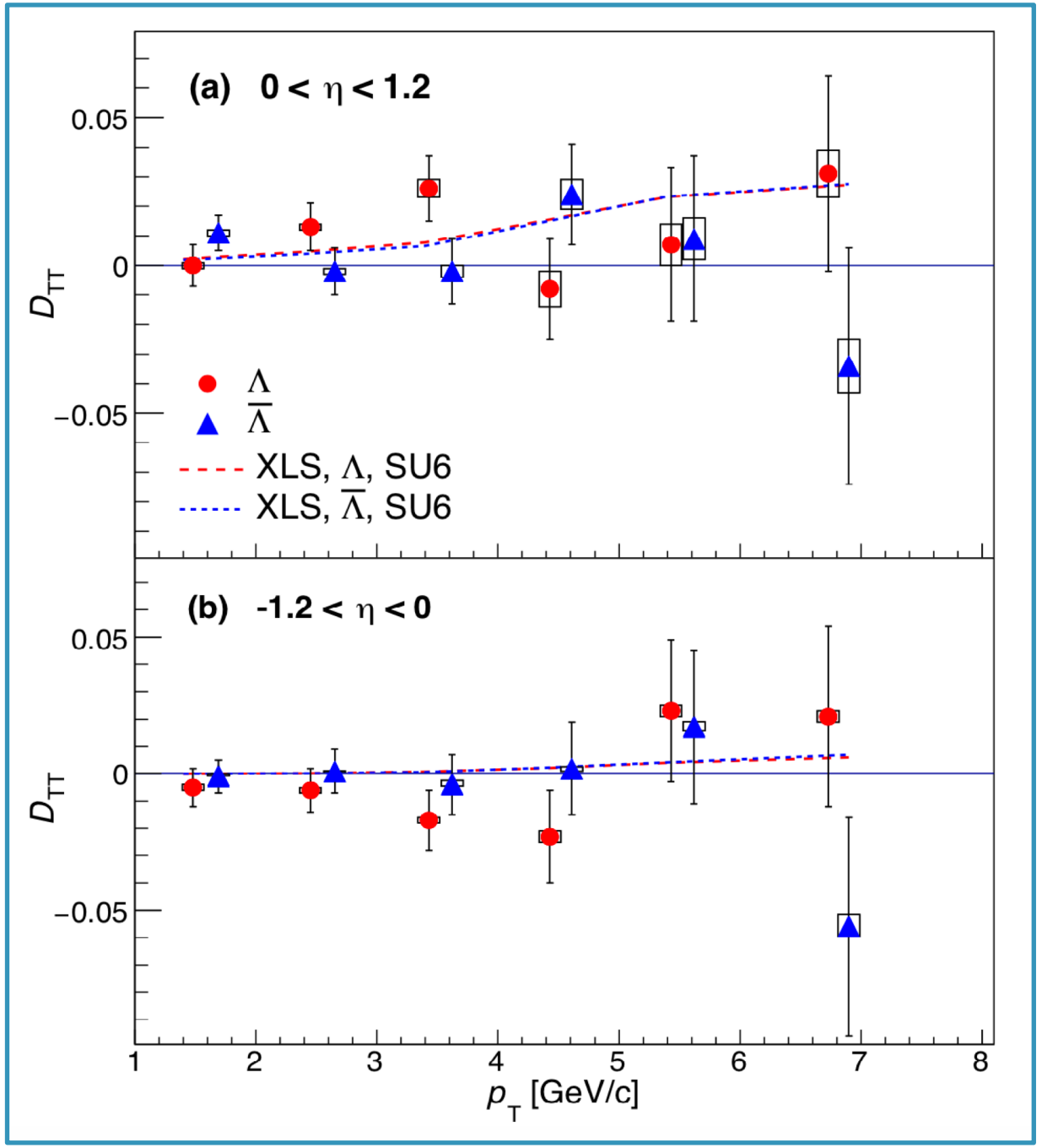


If the Λ spin direction is highly correlated with the strange constituent quark spin orientation, $|\Lambda\rangle = (ud)_{00}s^{\uparrow}$, then D_{TT} is sensitive to both the strange transversity PDF and the transversely polarized Λ FF.

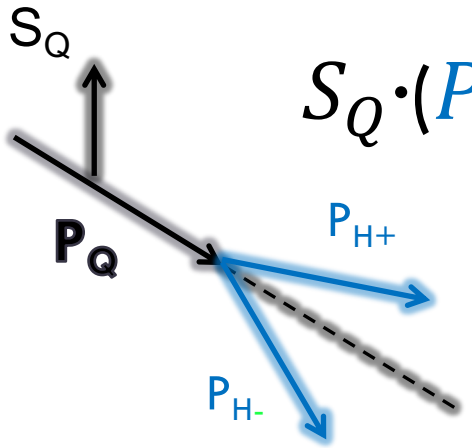
LAMBDA D_{TT}

- First extraction of D_{TT} from18 pb^{-1} in $\sqrt{s}$ = 200 GeV p+p collisions.
- Lambda asymmetries are consistent with model predictions by Xu, Liang and Sichtermann, PRD 73 (2006) 077503
- Lambda asymmetries are also consistent with zero.

Phys.Rev. D98, 091103 (2018)



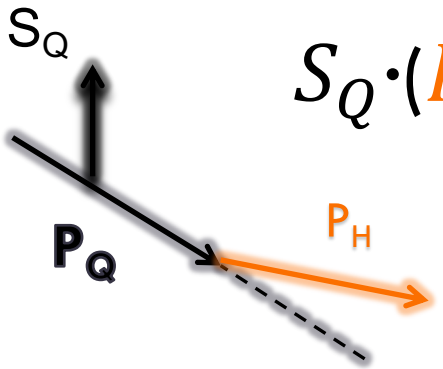
TRANSVERSITY



$$S_Q \cdot (P_{H-} \times P_{H+})$$

Interference Fragmentation Functions

Correlation between spin of transversely polarized quark and momentum cross-product of dihadron pair.



$$S_Q \cdot (P_Q \times P_H)$$

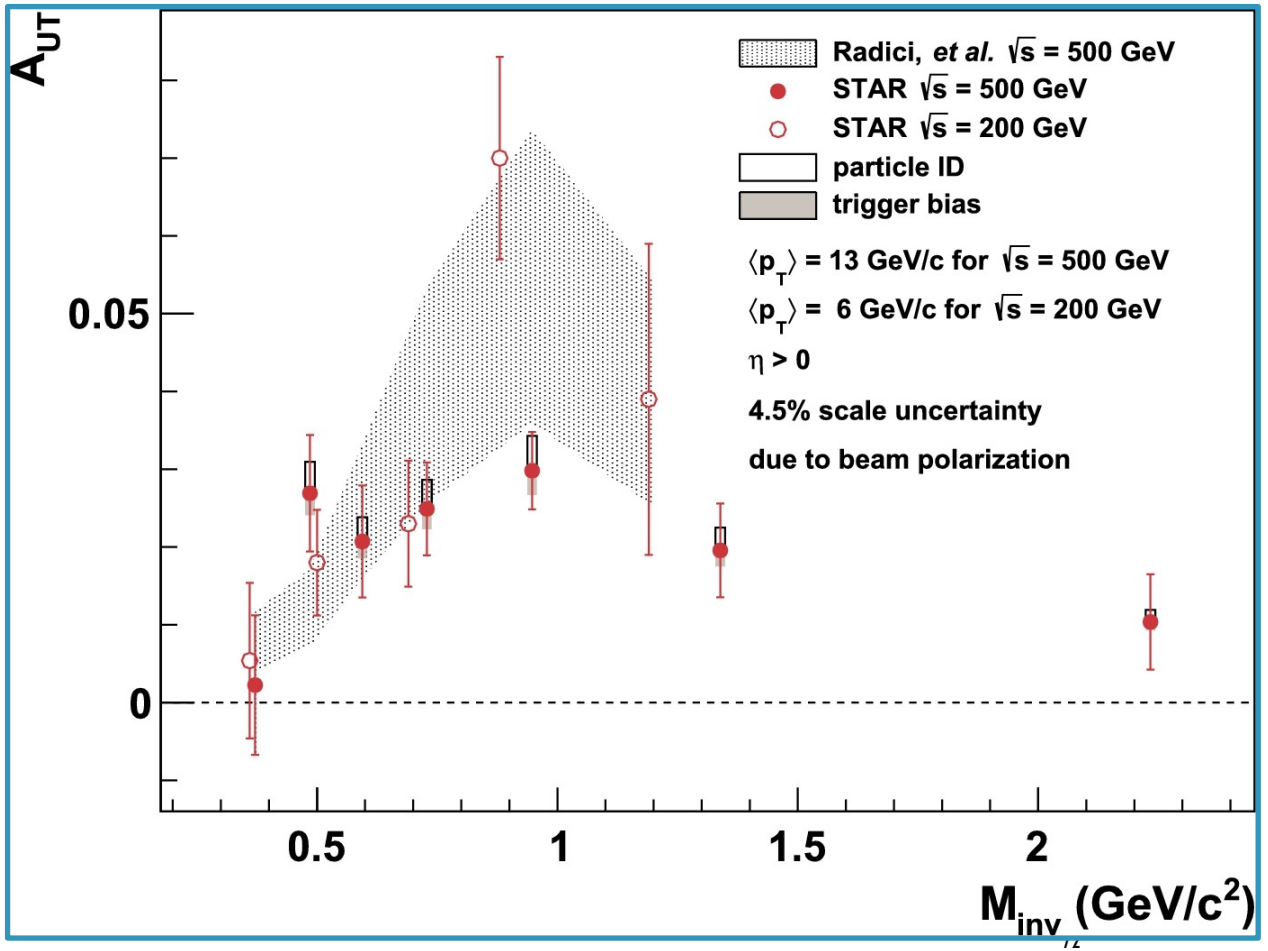
Collins Fragmentation Functions

Correlation between spin of transversely polarized quark and transverse momentum kick given to fragmentation hadron.

TRANSVERSITY ⊗ IFF

- First significant transversity signal measured in proton-proton collisions.
- Despite different scales asymmetries are very similar in 200 and 500 GeV when $<x_T>$ is similar.
- STAR data are well described by IFF theoretical calculations incorporating SIDIS and e+e- data.
- Recent global analysis by Radici and Bacchetta (PRL 120, 192001) shows significant reduction in uncertainty for u quark transversity distributions from STAR data.

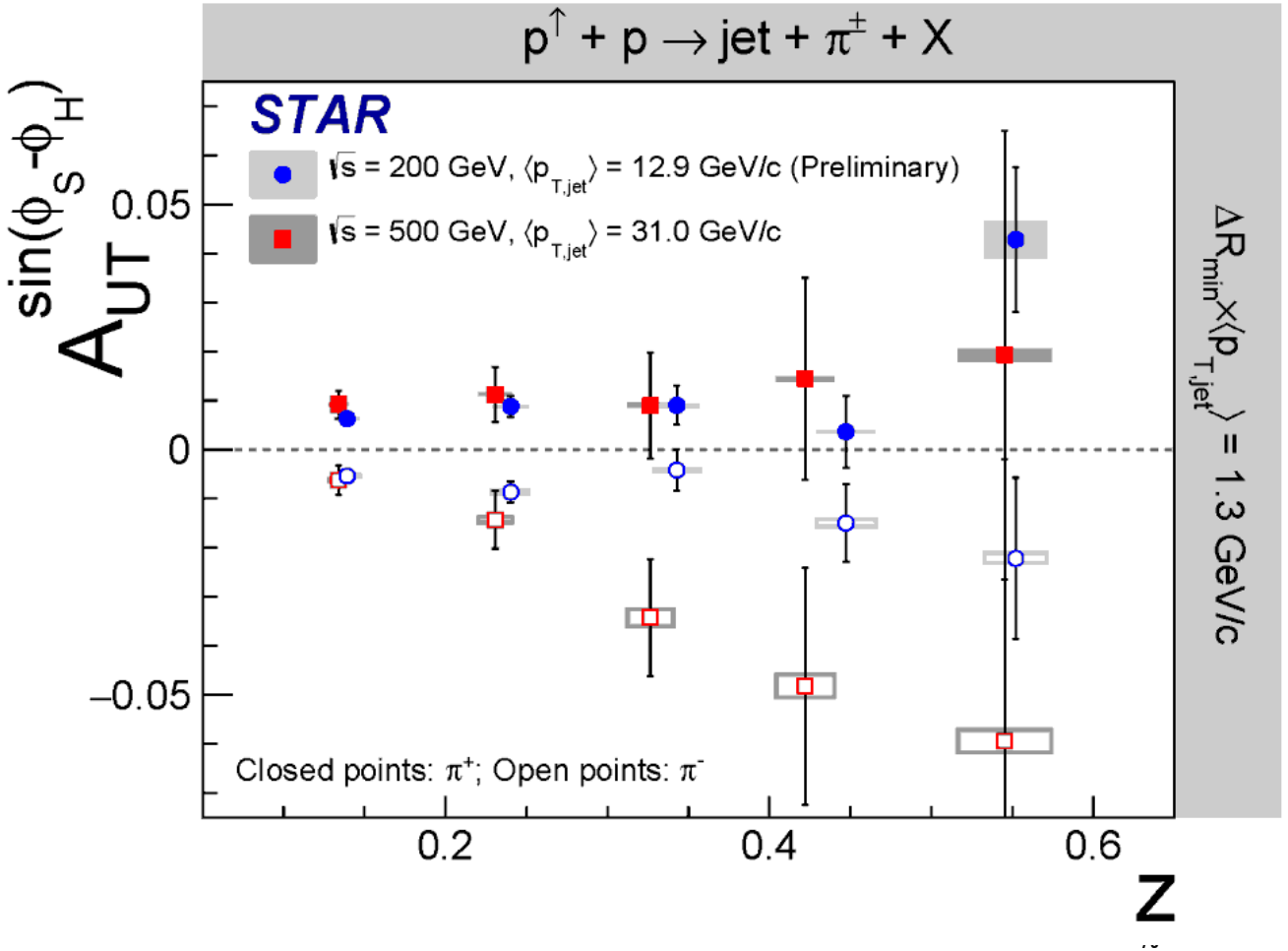
Phys.Lett. B780 (2018) 332



TRANSVERSITY ⊗ COLLINS FF

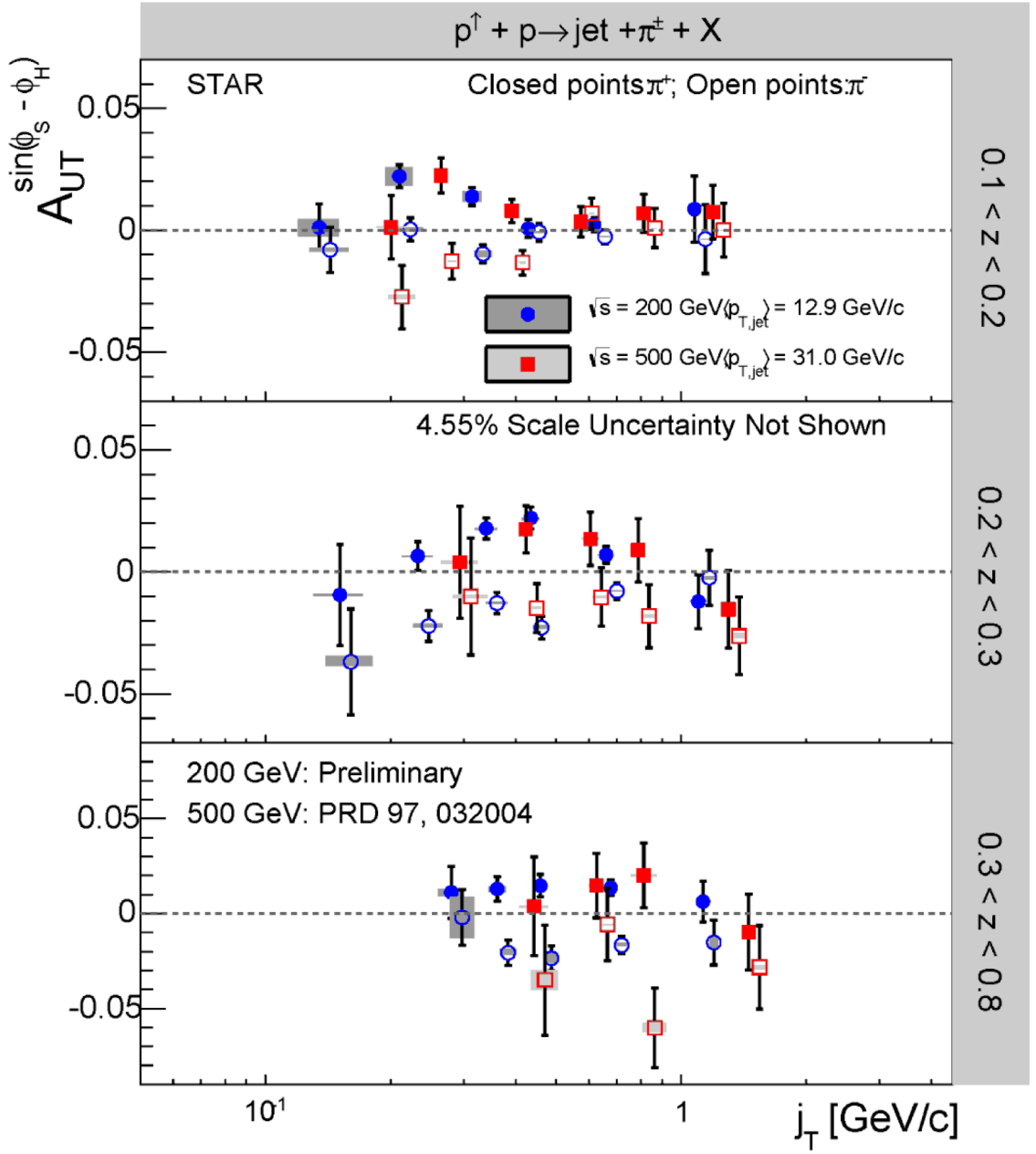
Phys. Rev. **D 97** (2018) 32004

- Complementary TMD channel to the collinear dihadron channel.
- Again asymmetries are very similar in 200 and 500 GeV.
- Additional statistics for both 200 and 500 GeV are on tape!
- Provides input on TMD evolution, which cannot be calculated fully from first principles.



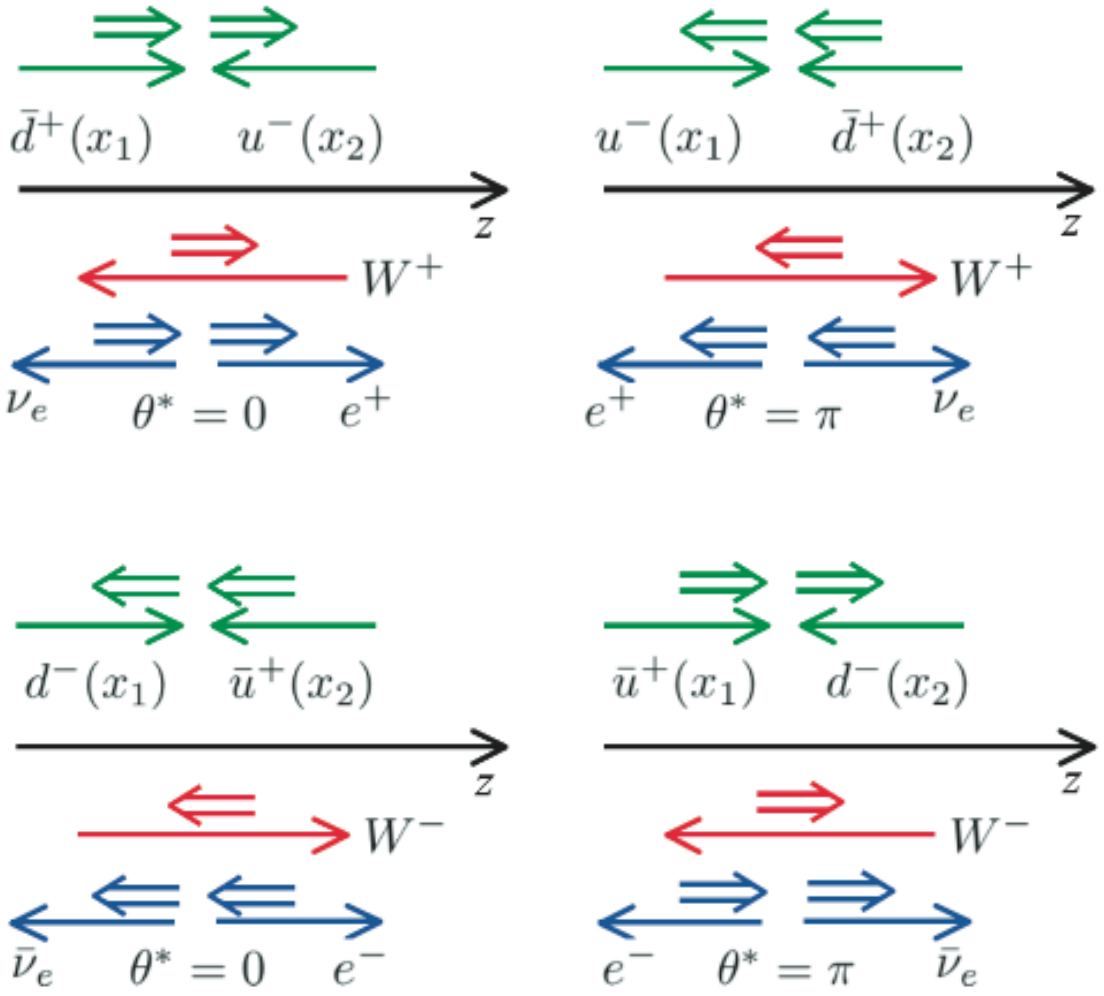
TRANSVERSITY ⊗ COLLINS FF

- 200 and 500 GeV tell the same story.
- Shape of j_T changes with z.
- Peak of distribution moves towards higher $\langle j_T \rangle$ as z increases.
- Hadron j_T is independent of initial state transverse momentum.



Phys. Rev. **D 97** (2018) 32004

LEPTON DECAY KINEMATICS

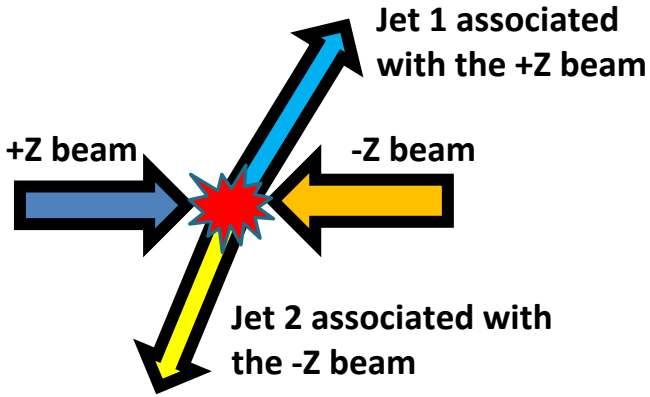


- W is Left handed
- $\bar{\nu}$ /ν R/L Handed (99.9999%)
- lepton decay direction, in the W rest frame, is set by conservation of angular momentum
- Lepton momentum aligned (anti-aligned) with W^- (W^+) momentum

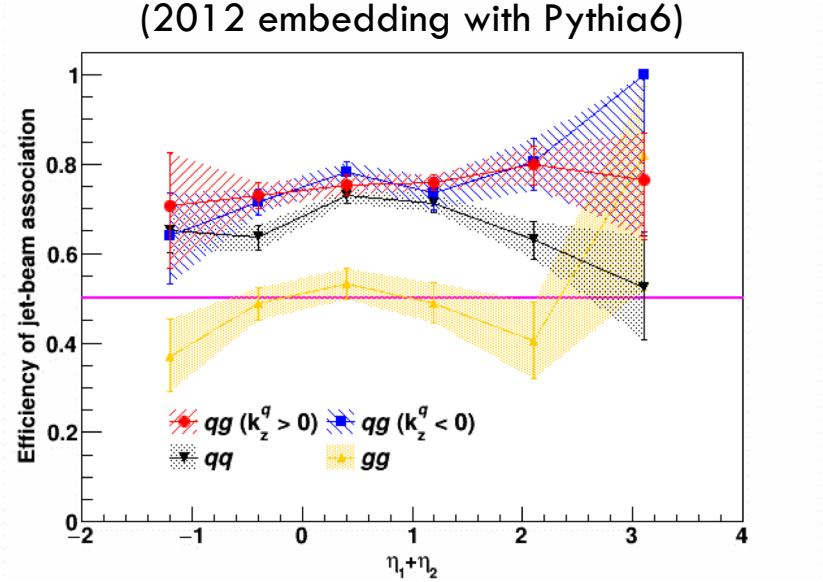
Jet-Beam Association

To figure out the "parton flow" from beam to jets, a jet-beam association is performed.

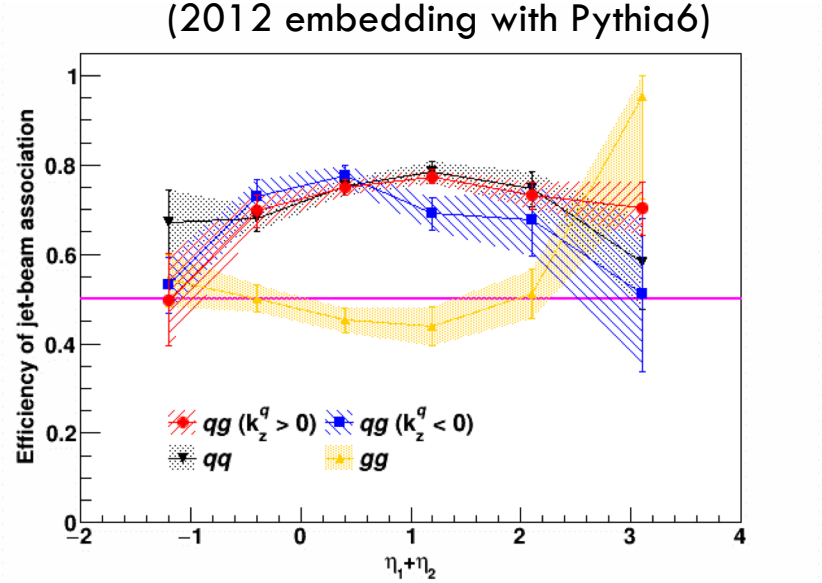
We assume the forward (backward) jet is more likely fragmented from the parton that comes out of +z (-z) beam.



Association efficiency for Events taken by JetPatch2 Trigger (2012 embedding with Pythia6)



Association efficiency for Events taken by JetPatch1 Trigger (2012 embedding with Pythia6)



* The efficiency represents how often we get the association right.
* The error bar/band represents the statistical error.