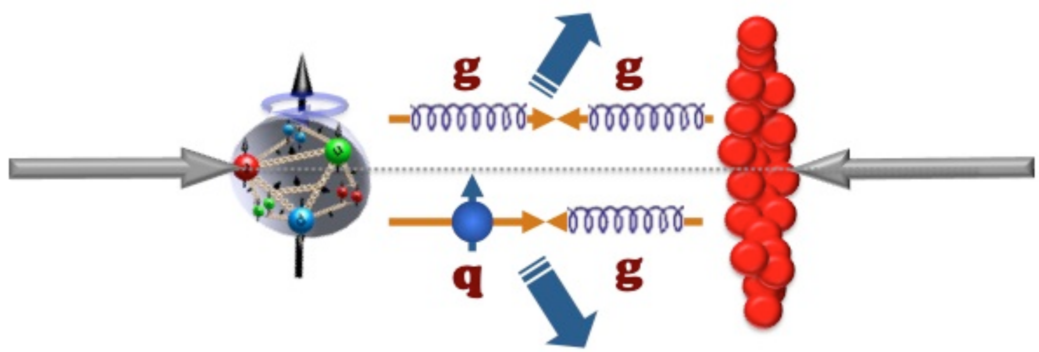
Summary of pA@RHIC Workshop

Xiaodong Jiang, Los Alamos National Laboratory

May 20th, 2013. Opportunities for Polarized Physics at Fermilab.



- A brief summary of the pA@RHIC workshop (Jan. 7th-9th, 2013 at BNL).
- Recent developments towards (polarized) p+p and p+A measurements at RHIC (mostly on the PHENIX side).
- My point of view on the opportunities of polarized p+p and p+A measurements at a FNAL fixed target experiment.

A brief summary of pA@RHIC workshop Jan. 7^{th}-9^{th}, 2013 at BNL

- A dedicated 3-day workshop on polarized proton and ion collision at RHIC.
  - Goal was to explore the physics program as well as the feasibility of the RHIC collider
  - About 100 participants.
  - Presentations include:
    - Theory overviews (spin dependent and spin-independent observables).
    - LHC p+Pb results from 2012 test run.
    - Results from past p+A fixed target measurements (AGS and FNAL)
    - Machine and detector feasibility studies and practical issues.
    - Plans of detector upgrades (PHENIX and STAR) and new ideas (zero degree EM shower detectors).
  - webpage at:

  https://indico.bnl.gov/conferenceDisplay.py?confId=553

pA@RHIC: Motivations

- p+A collision is an excellent probe to access the deep secrets of the nuclei, and to probe the gluon saturation effect as well as other nuclear effects
  - Gluon density distribution in a nuclei
  - Transvers momentum broadening.
  - Transverse spin effects through nuclear medium.
- Latest LHC proton proton p+Pb pilot run has yielded interesting results
  - away side ridge was observed through correlations.

pA@RHIC Motivations: Single-Spin Asymmetry to probe gluon saturation effects in nuclei

- The possibility of polarized proton and ion collision opens a new territory beyond pA@LHC.
  - it also allows not only measure the source of transverse asymmetry

$$\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{\frac{P_{h\perp}^2 \delta^2}{Q_{sp}^4}} \qquad \frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\gg Q_s^2} \approx 1$$

Kang, et al,

  - provides additional sensitive observable for the saturation physics study

pA@RHIC vs. pA@LHC

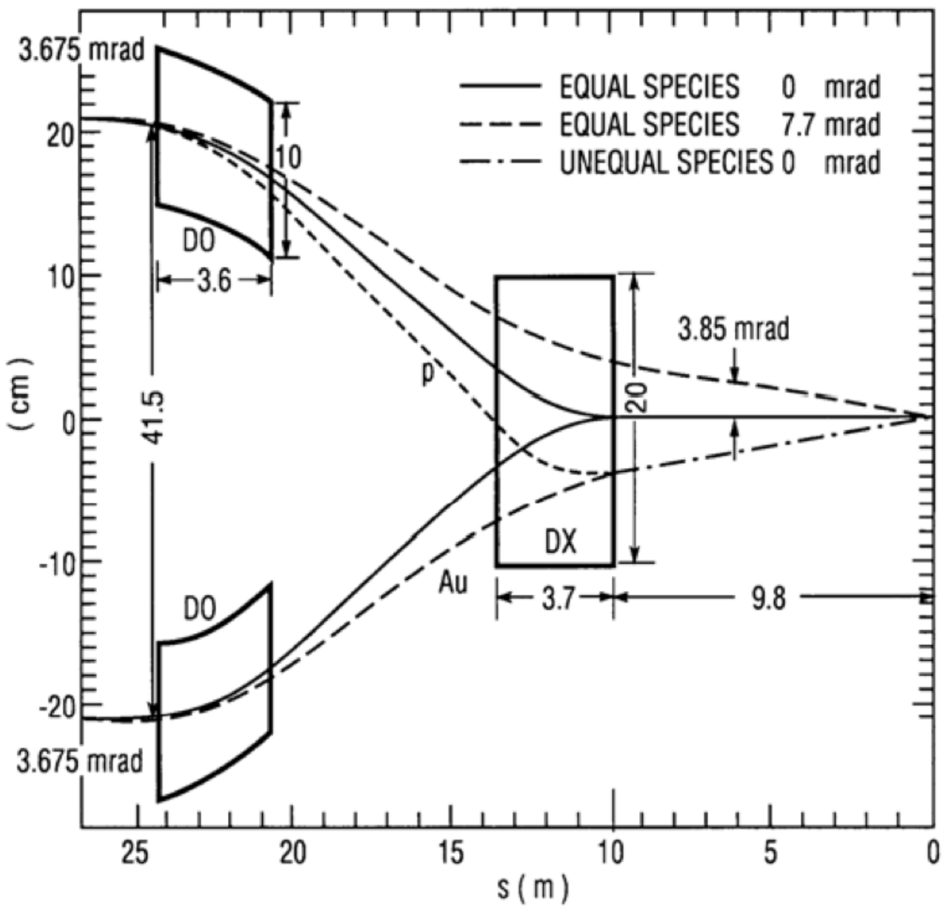
- RHIC was designed to independent bending fields for two beams. LHC is a two-in-one dipole ring, i.e. identical bending field for the two beams
  - More ion species at RHIC than at LHC, which allows the measurement of saturation effect as function of A
    - from deuteron to Uranium
- RHIC can access the low energy part that is not available to LHC
- High energy polarized proton beams is absolutely unique to RHIC
  - Measure SSA
  - More sensitive observable for saturation effects

RHIC Machine Capabilities

- RHIC was originally designed to accommodate asymmetric collision including p+A collisions.

  Two independent rings, except for the DX magnets near collision points.

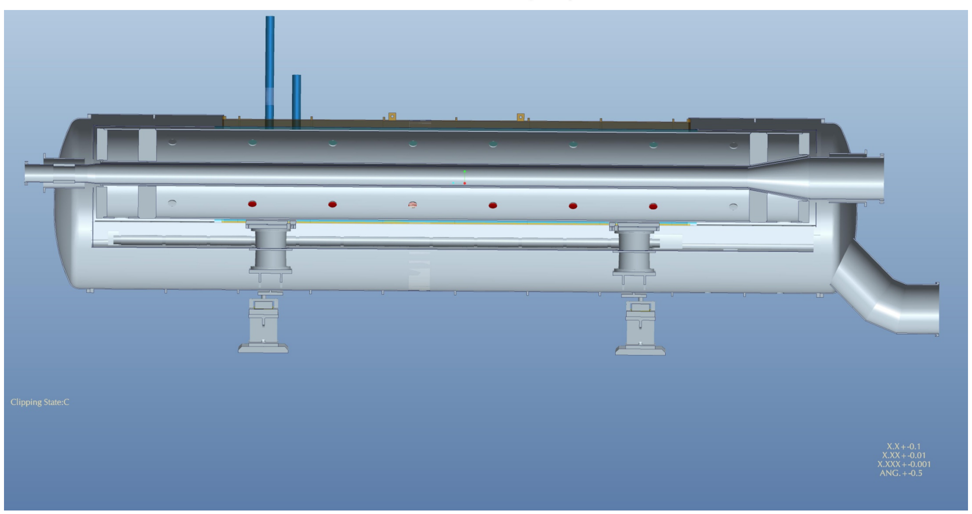
  - The DX magnets was designed to be moved sideways to center on the beam trajectory in the case of asymmetric collisions
  - The DX magnet was also designed to have adequate field uniformity in the case of asymmetric operation
  - d+Au collision has been part of RHIC operation since 2003.
  - In 2012, Cu+Au collisions were also provided.
  - New EBIS source can also provide other ions (^{12}C, ^{14}N, ^{28}Si, ^{63}Cu, ^{197}Au, ^{208}Pb …Au beam with $N_b = 2x10^9$)



RHIC Interaction Region Layout

Beam split dipole DX magnet is first magnet on either side of IP

- L_{mag} = 3.7 m, B_{max} = 4.3 T
- large aperture (18 cm coil ID)
- only magnets that need training
  (~5 for IR6/8 only)



RHIC Machine Capabilities:
the proton beam is polarized

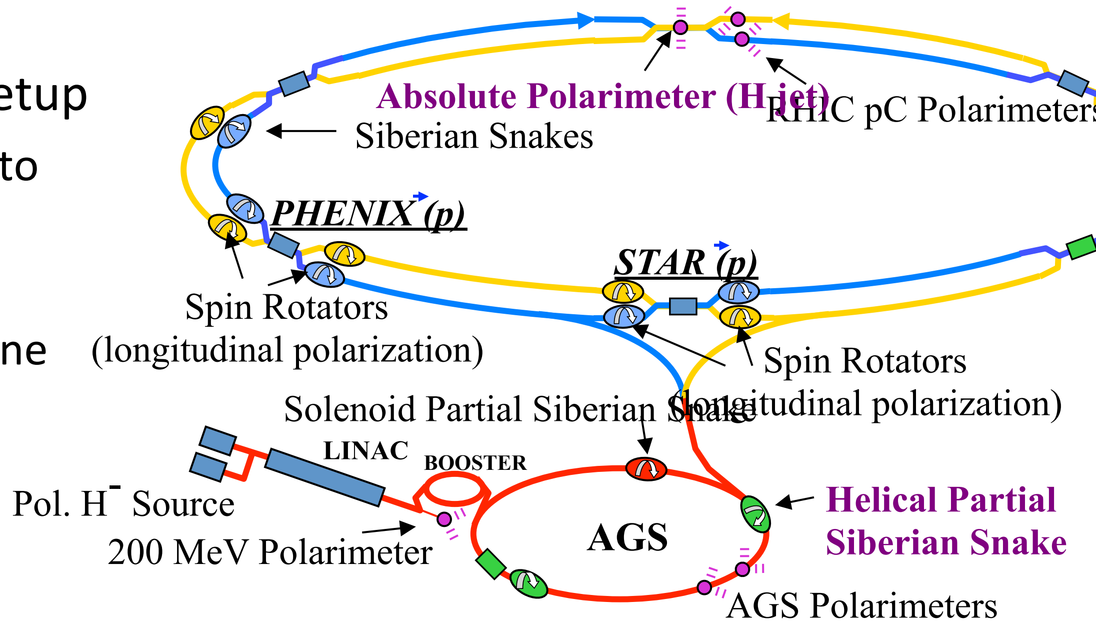
- Proton beam with N_b = 2x10^{11}, P = 55%.
  with upgrades (OPPIS): N_b = 3x10^{11}, P = 65%
- Vertical polarization is the natural spin orientation in the proton ring.
- Beam polarization is monitored by CNI (p+C elastic), and calibrated by polarized hydrogen jet (p+p elastic).

Note: in polarize p+A inclusive single-hadron single-spin asymmetry measurements, only transverse single-spin asymmetry is parity-allowed, longitudinal beam single-hadron SSA violates parity.

RHIC Polarized Proton Beam

RHIC polarized proton beam setup

- 2 full Siberian snakes per ring to avoid all first order spin depolarizing resonances
- Polarization is monitored by one absolute polarimeter and one relative polarimeter per ring



parameter	unit	achieved		goals			
p↑-p↑ operation		**2012**		**≥ 2013** source		**≥ 2014** source + e-lenses	
energy	GeV	100	255	100	250	100	250
no colliding bunches	…	– 107 –		– 107 –		– 107 –	
bunch intensity	10^{11}	1.6	1.7	1.6	2.0	1.8	2.5
avg. luminosity	10^{30} cm^{-2}s^{-1}	**33**	**105**	**30**	**150**	**60**	**300**
avg. polarization*	%	**59**	**52**	**– 60 –**		**– 65 –**	

Jianwei Qiu's summary at the workshop

Conclusions on physics opportunities of pA:

- Will produce a novel information on strong interactions in the high gluon density kinematics for fixed nuclear thickness as a function of energy: *parton , groups of partons propagation through media in soft and hard regime including spin effects*

- Will complement pA run at LHC - critical for understanding how small x dynamics changes with energy

- Will allow to measure inelastic diffraction at the highest energy where it is still comparable/larger than e.m. contribution

- Check the color fluctuation dynamics for generic inelastic pA collisions

Strikman

pA@RHIC can start in Run-2015

from PHENIX beam use proposal, May 2013:

Run-15 Proposal (22 cryo-weeks)

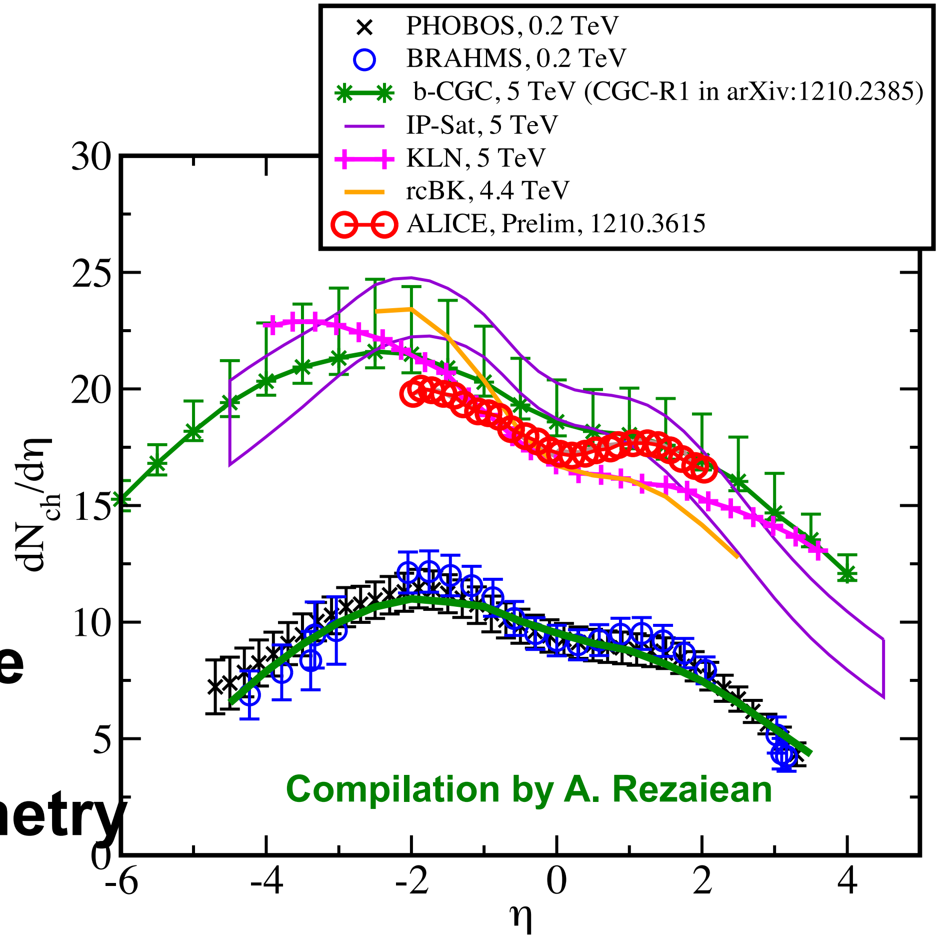
- p+p @ 200 GeV with transverse polarization for 9 weeks [Physics driven goal is 50 pb^{-1} recorded within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- p+Au @ 200 GeV with transverse polarization of the proton for 4 weeks [Physics driven goal is 150 nb^{-1} sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- Geometry studies with d+Au @ 200 GeV and ^{3}He+Au @ 200 GeV for 1 week each [Physics driven goal is recording 1 billion minimum bias events for each]
- p+Si, p+Cu @ 200 GeV for 2 weeks each [Physics driven goal is 450 nb^{-1} and 225 nb^{-1}, respectively, sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]

Charged particle multiplicity for pA@RHIC

In saturation models

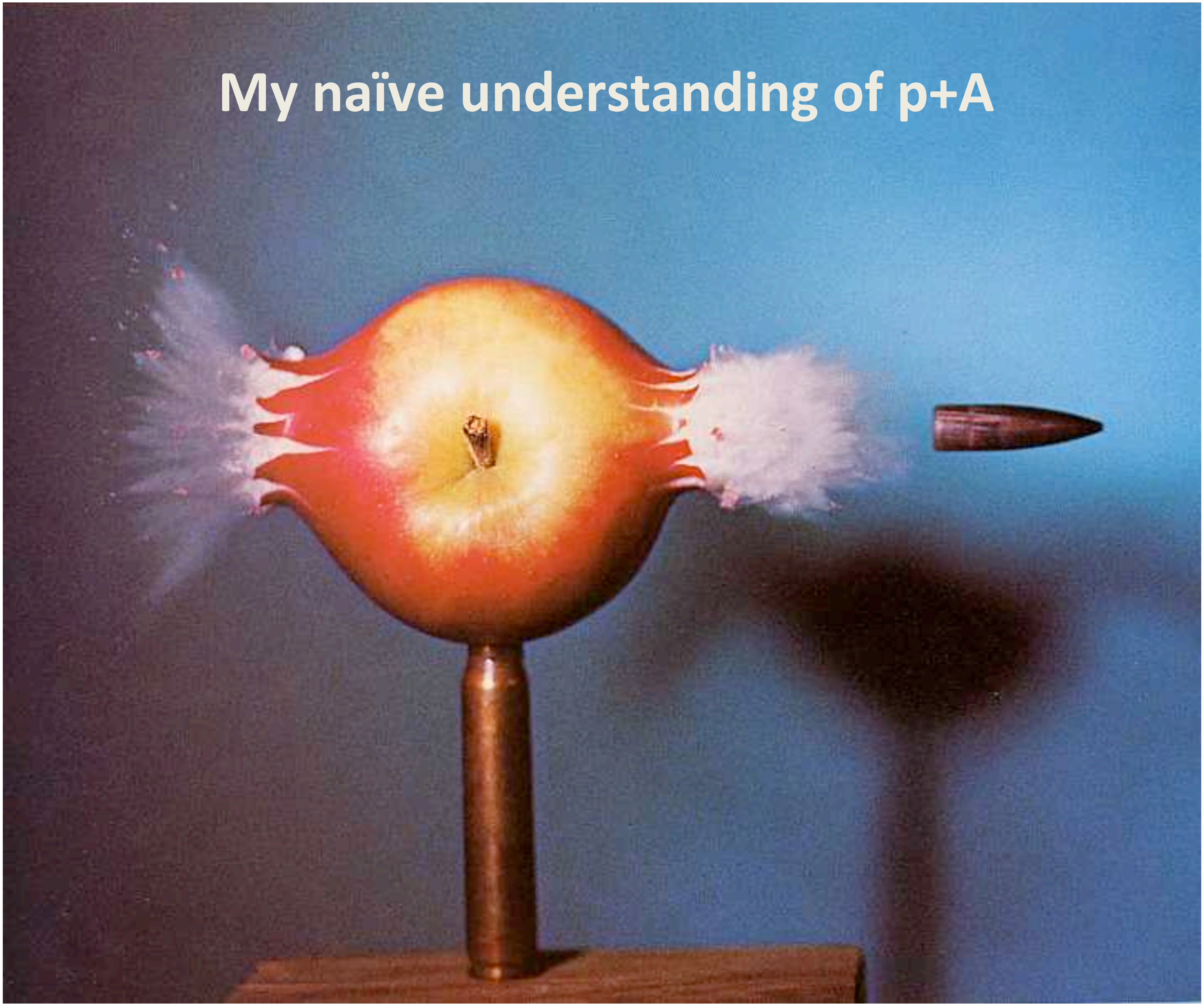
$$\frac{dN}{d\eta} \propto \frac{Q_S^2\, S_\perp}{\alpha_S(Q_S)}$$

Multiplicities have some sensitivity to "infrared" non-pert. physics/geometry



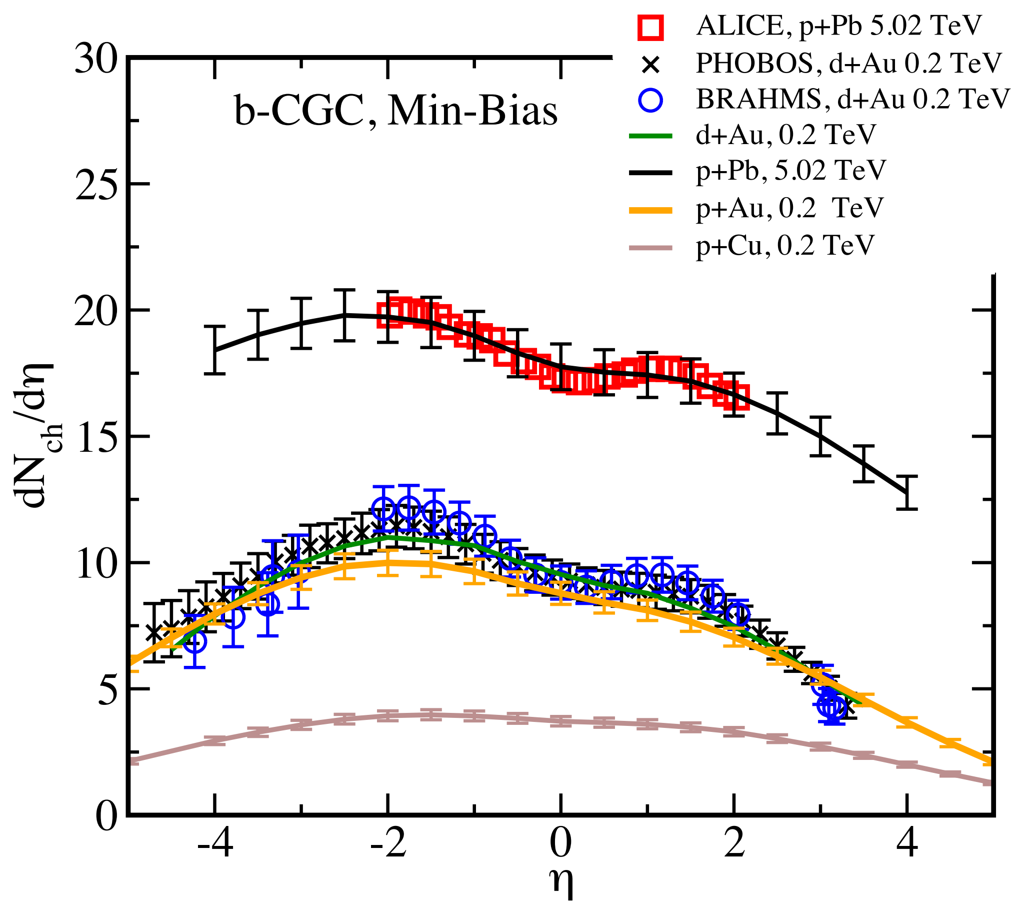
From Raju Venugopalan's talk.

My naïve understanding of p+A

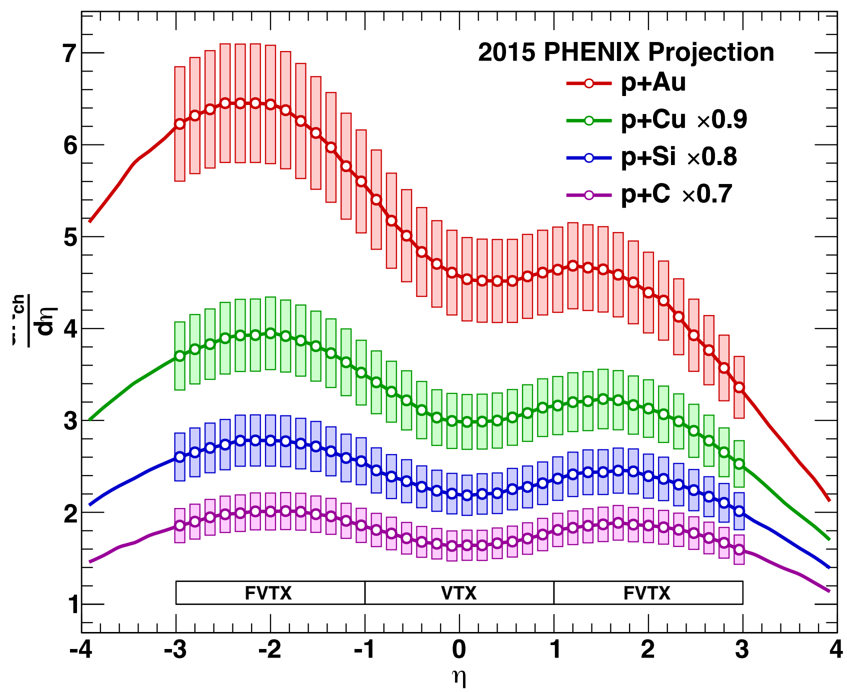


Q: the impacts of new RHIC data p+Au, p+Cu (or p+Si) to CGC-type theory models ?
other model predictions ?

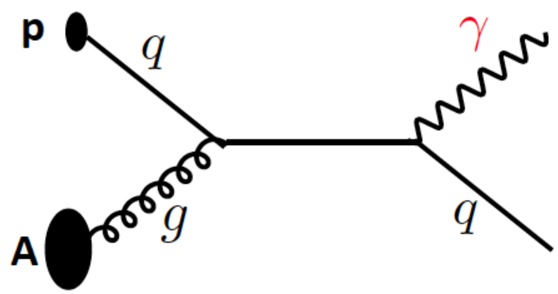
A. Rezaeian, private communications (April, 2013).



Curves from HIJING with PHENIX projections, with 10% relative systematic uncertainties.



Prompt photon in p+A to access gluon density in nuclei



PHENIX beam use proposal for run-2015

Address the basic scientific question: **What is the gluon density in nuclei ?**

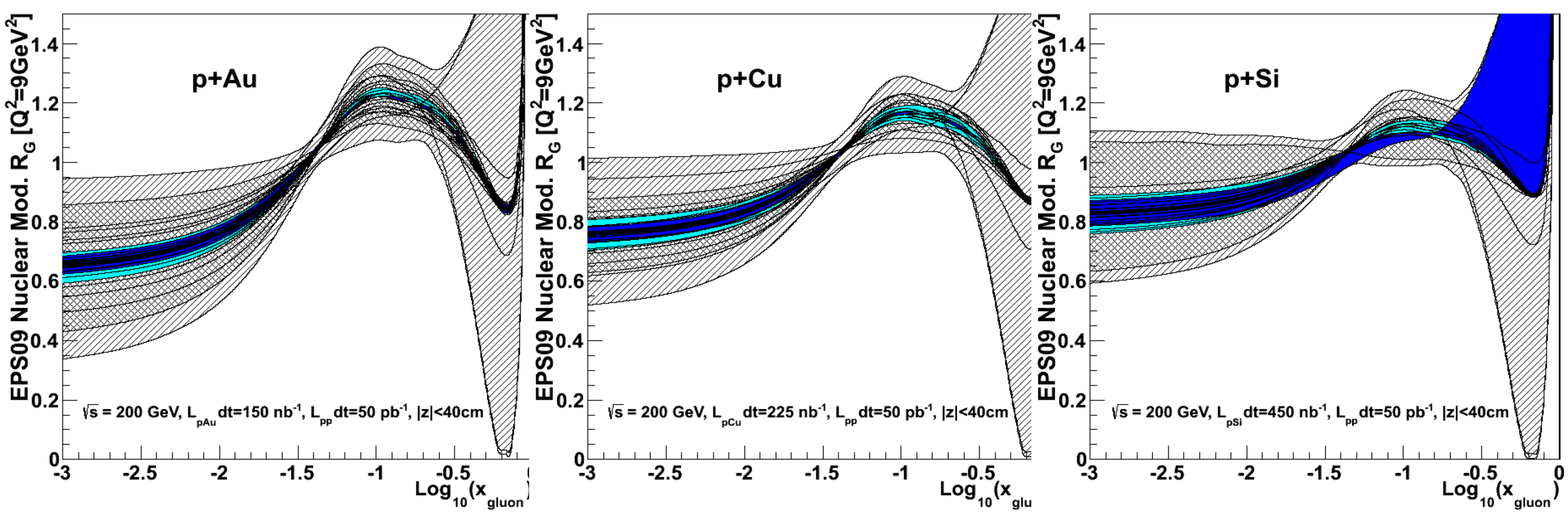
- How much is it modified compared to a free proton ?
- Are there "smoking gun" evidences of the onset of gluon saturation ?

detect high energy prompt photons in p+A collisions with MPX-EX detector at PHENIX.

- Extract gluon density in several nuclei (A=^{28}Si, ^{63}Cu and ^{197}Au, for $A^{1/3}$ scaling check).

Experimental observable:

$$R^{\gamma}_{pA}(x_g,Q^2)=\frac{Photon\ Yield\ in\ p+A}{A\times(Photon\ Yield\ in\ p+p)}\propto\frac{f_g^A(x_g,Q^2)}{f_g^p(x_g,Q^2)}$$



Need more theory guidance in details on the impacts of polarized observables for pA@RHIC.

- Polarized pA at RHIC provides a completely new testing ground for QCD

  Dynamics cannot be accessed by unpolarized x-section

  QCD is much richer than the leading power!

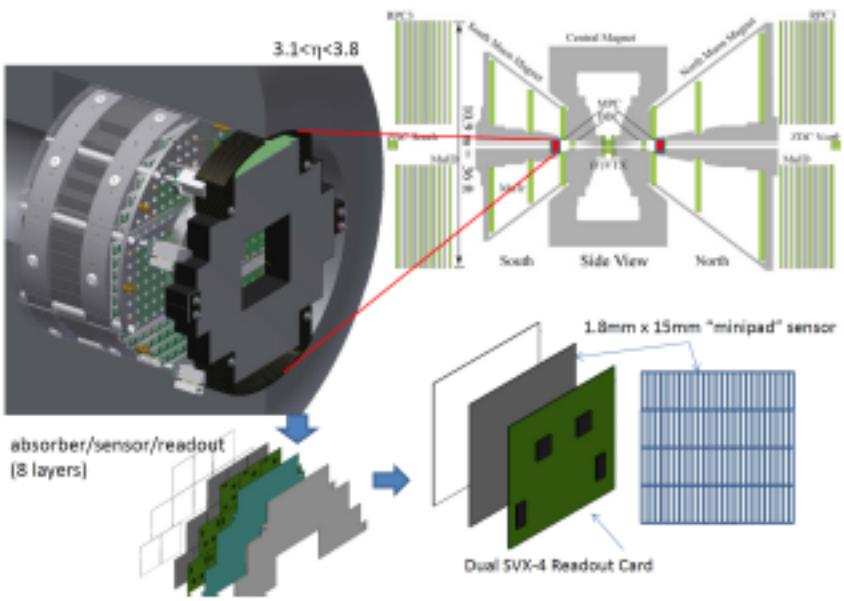
- SSA in pA is an excellent observable to study small-x physics in a nucleus

PHENIX Beam Use Proposal for Run-2015 p+A

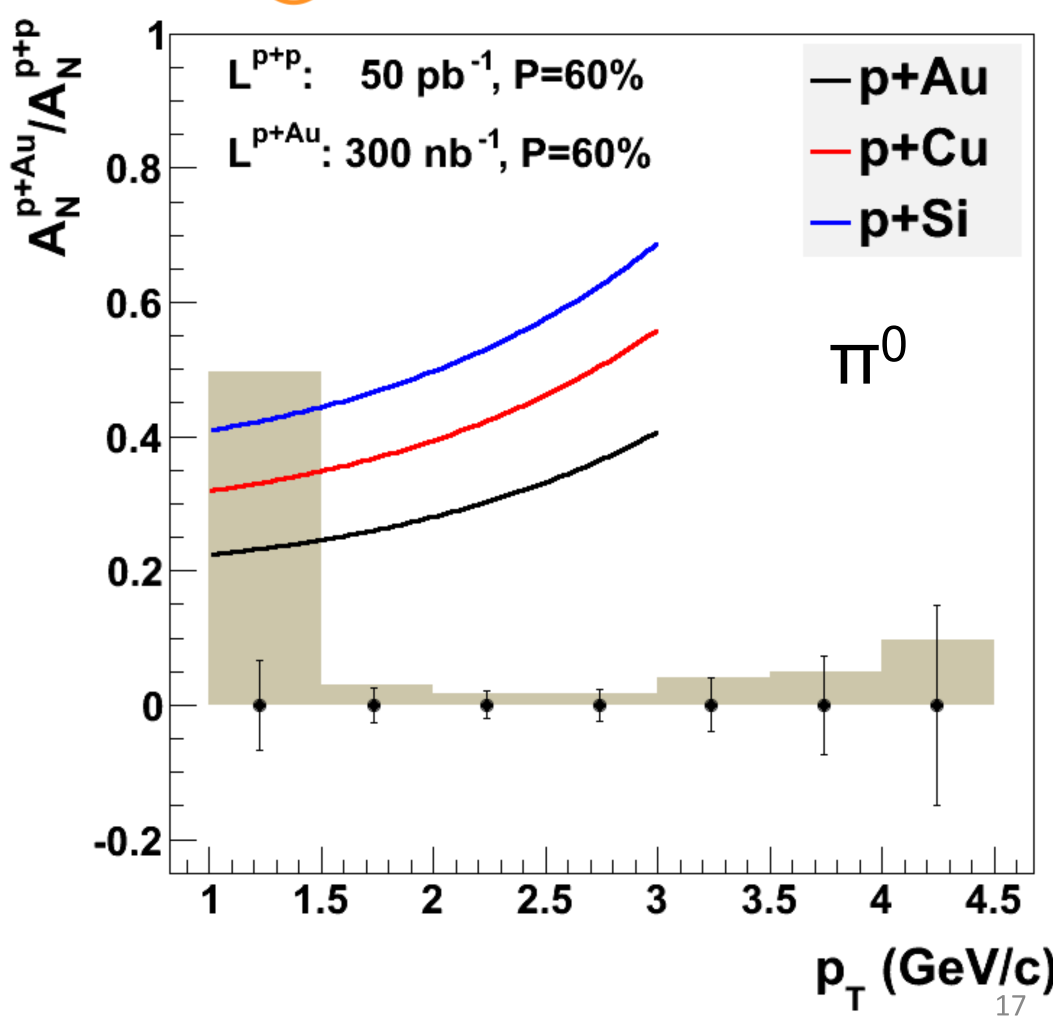
Single-Spin Asymmetry of forward π^0 through MPC-EX calorimeter

Ratios of SSA p+A vs p+p

$$\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{\frac{P_{h\perp}^2\,\delta^2}{Q_{sp}^4}} \qquad \frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\gg Q_s^2} \approx 1$$



MPC-EX: forward EM calorimeter



my comments on polarized p+p and p+A at FNAL fixted-target measurements:

What (polarized) p+p and p+A@RHIC cannot do

(at least in the near future)

- Forward rapidity charged hadron production: $\pi^{\pm}$, $K^{\pm}$, φ, p, Λ, Ξ, pbar, anti-Λ etc. forward charged particle spin-correlations.
  STAR and PHENIX limited by the current magnets and detector design.

- Final state particle polarization at forward rapidity.
  spin-transfer, induced polarization etc.

- High statistic measurements at a lower collision energy.
  reactions dominated by quark-gluon and gluon-gluon hard-scattering.

- High statistic Drell-Yan measurements.
  - a clean access to sea quarks' density, helicity and angular motion without the complication of quark to hadron fragmentation functions.

my point of view:

Polarized p+p and p+A@FNAL fixted-target measurements should consider:

- Hadron production: $\pi^{\pm}$, π^0, η, $K^{\pm}$, K_s, φ, p, Λ, Ξ, pbar, anti-Λ etc.
  - $\pi^{\pm}$, π^0, η, $K^{\pm}$, K_s, proton single-spin asymmetries. Left-right bias originated from valence quarks.
  - φ, pbar, anti-Λ single-spin asymmetries. Left-right bias originated from sea quarks, including strange quarks.
  - Spin transfer to Λ and Ξ: access quark transversity.
  - Forward two-hadron transverse spin-correlations: access quark transversity.

- Hadron production and spin asymmetries in p+A:
  - parton distributions in nuclei, EMC effects.
  - cold near matter effects.
  - Collins effect, transversely polarized quark fragment through a nuclei, use nuclei as a filter.

my point of view:

Polarized p+p and p+A@FNAL fixted-target measurements should consider (cont.):

- High statistic Drell-Yan in p+p
  - to access sea quark information without the complication of fragmentation functions.
- High statistic Drell-Yan in p+A
  - Sea quark density asymmetry in nuclei.
  - Quark energy loss.
  - Quark transverse momentum broadening through nuclei.

my point of view:

If we build a polarized beam capability at FNAL, we should definitely build a general purpose magnetic spectrometer.

- Hadron production: $\pi^{\pm}$, π^0, η, $K^{\pm}$, K_s, φ, p, Λ, Ξ, pbar, anti-Λ etc.
- Drell-Yan ($\mu^+\mu^-$)
- with a reasonable acceptance, high-rate tracking capability, ~1mm level vertex resolution.

my point of view:

… and definitely, we should build a high luminosity polarized target.

- High statistic polarized Drell-Yan in p+p, to access sea quark information without the complication of fragmentation functions.

  - Target single-spin asymmetry A_N: access sea quark's angular motion (Sivers distribution).

  - Beam-target double-spin asymmetry A_{TT}: to access sea quark's transverse spin distribution (transversity).

  - Longitudinal double-spin asymmetry A_{LL}: to access sea quark's helicity distribution.

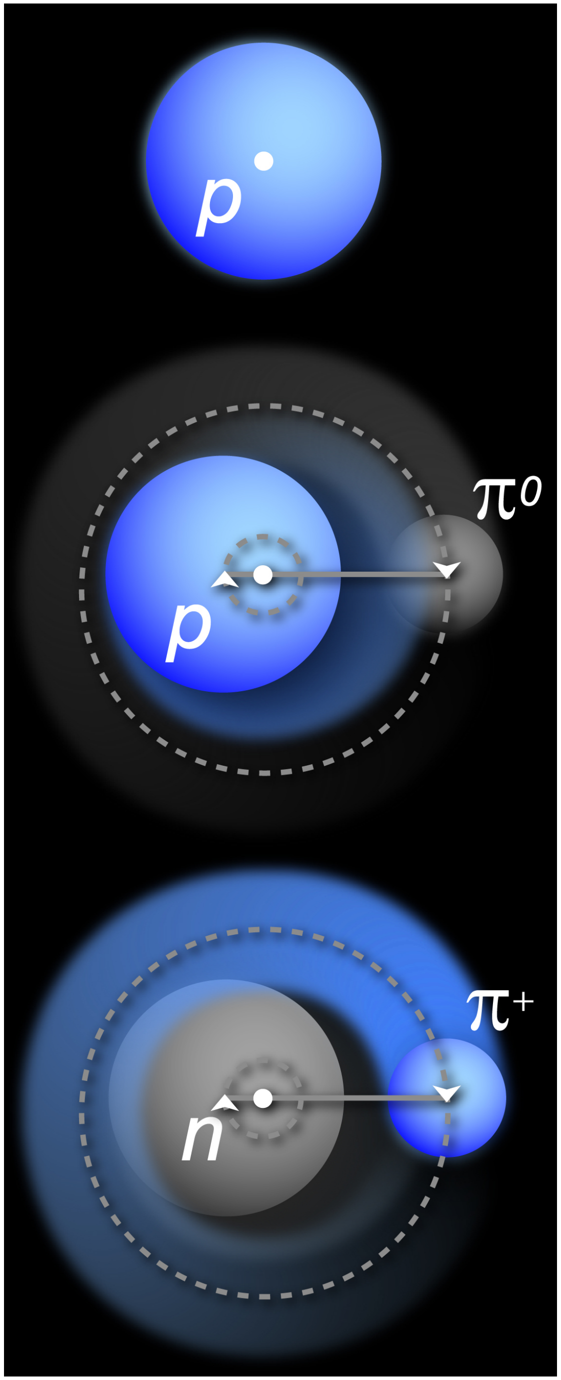
Need to build a ~10 cm long polarized proton (NH3) target (3x of Jlab-HallC target).
More comments tomorrow on this point, during the discussion session.

In summary:

if you give a mouse a cookie, he will ask for a glass of milk to go with it...,

and definitely he will need a straw.

Backup Slides
and Slides for Discussions



in a meson cloud model quarks should have angular motions

Experimental evidences of valence quarks' angular motion

Introduction: single-spin asymmetry in $p\,p^{\uparrow} \rightarrow \pi X$

E704 √s =20 GeV.

PLB 264 (1991) 462.

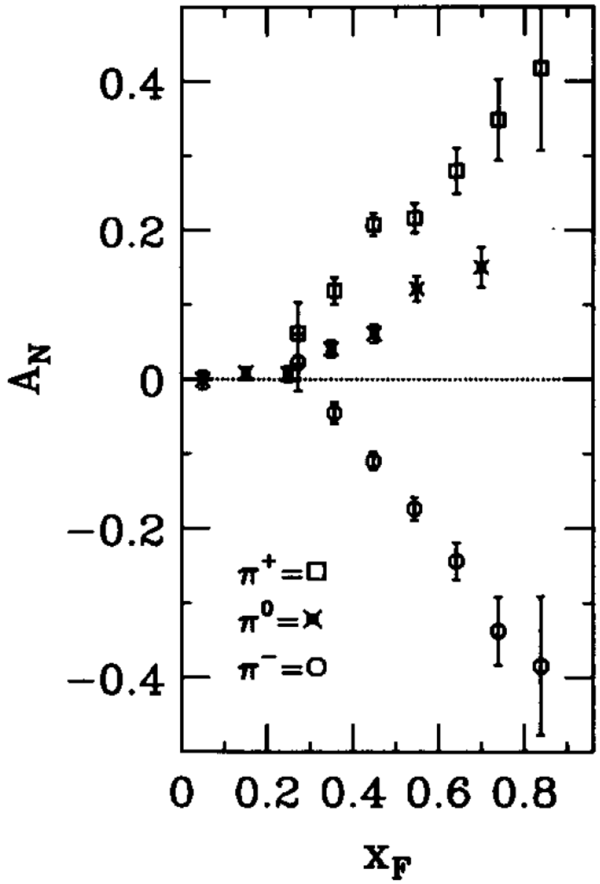
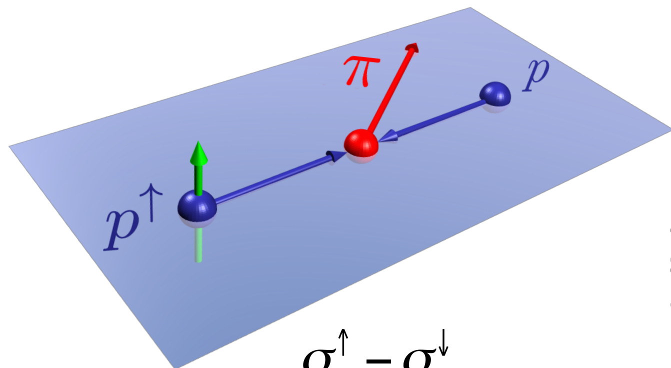


Fig. 4. A_N versus x_F for π^+, π^- and π^0 data.



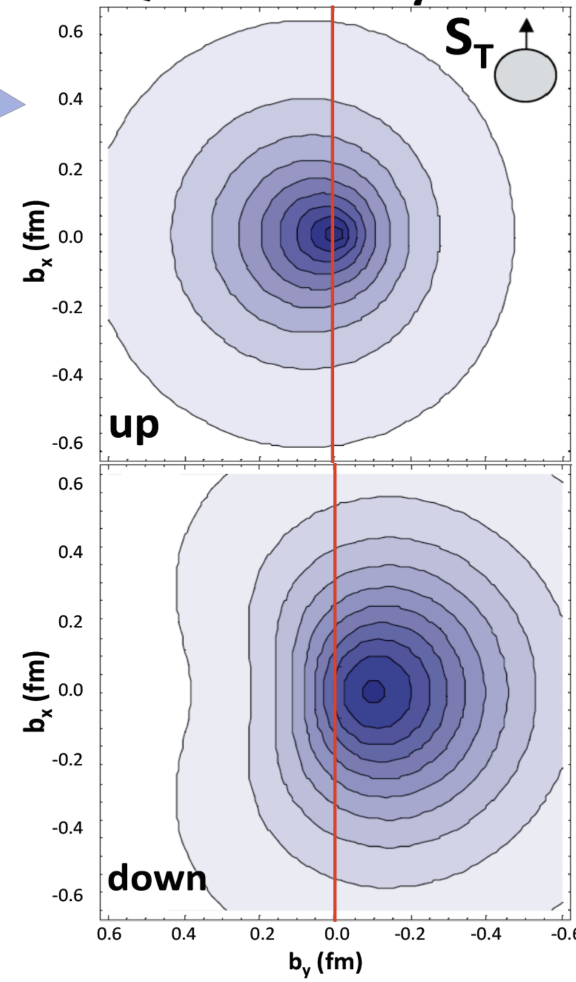
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$\pi^{+}\ (u\bar{d})$ favors left

$\pi^{-}\ (d\bar{u})$ favors right

One possible explanation (Sivers effect): quark transvers motion generates a left-right bias.

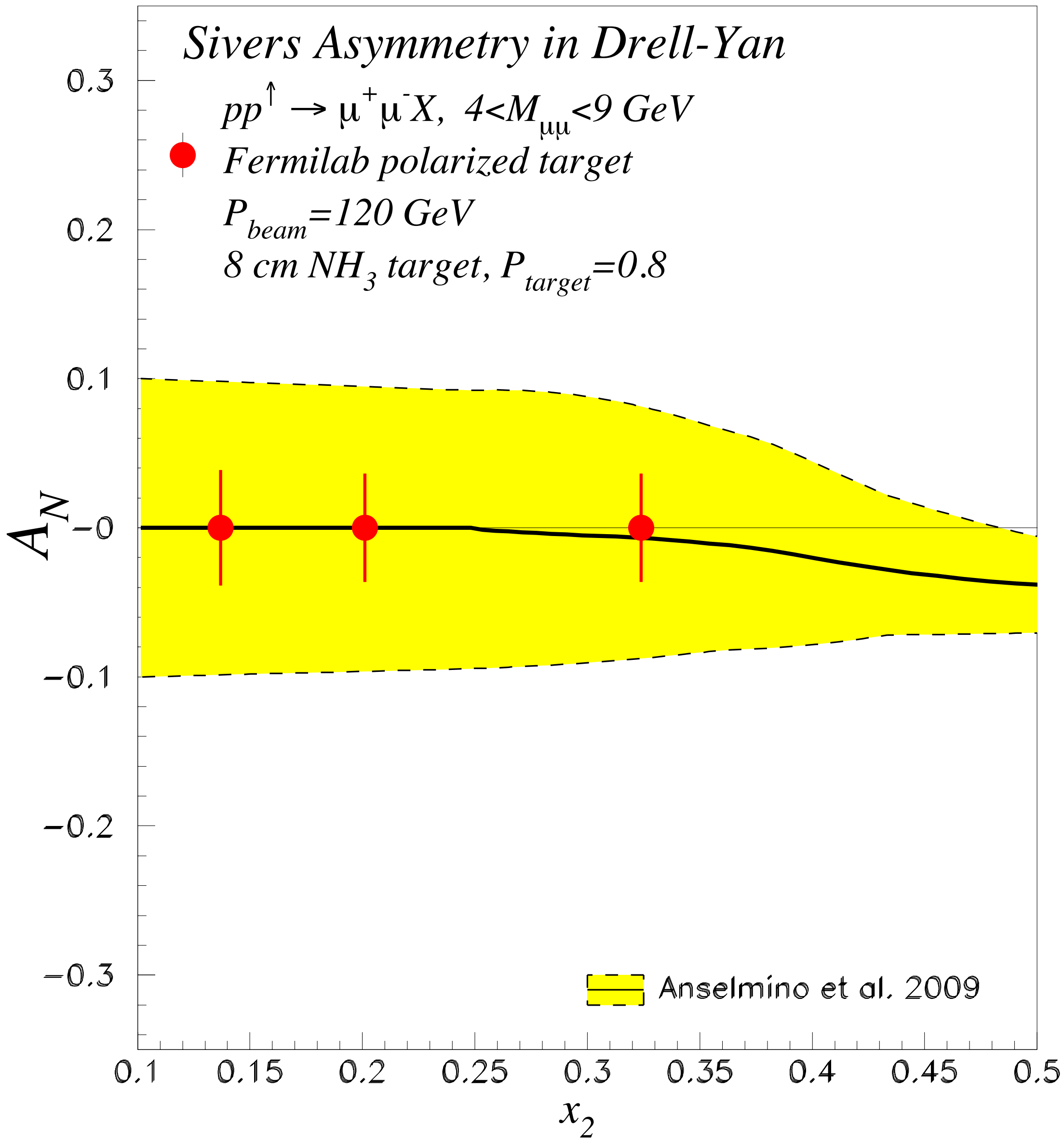
Quark Density in 2D



Lattice QCD PRL98:222001,2007.

Quarks in a transversely polarized nucleon can tell left-right, up-quarks favor left, down-quarks favor right.

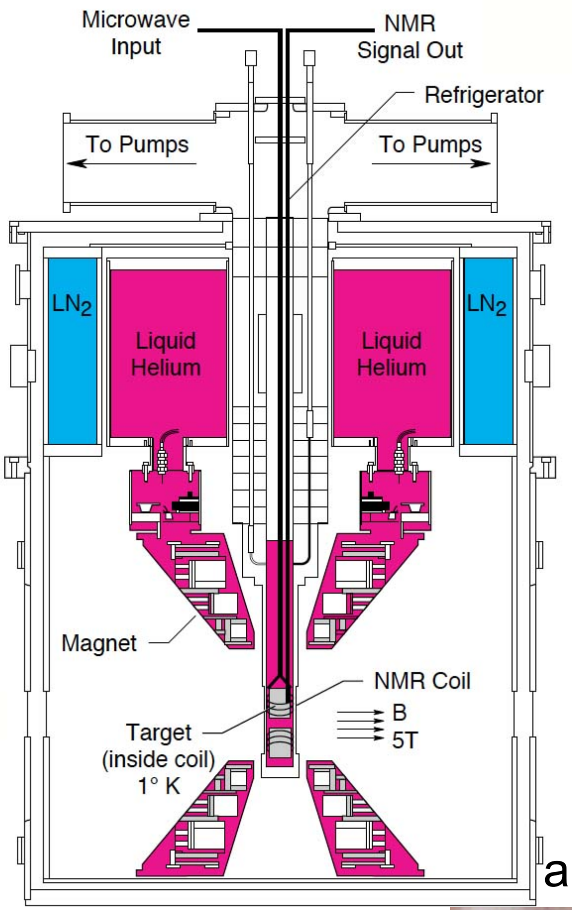
LOI projected precisions



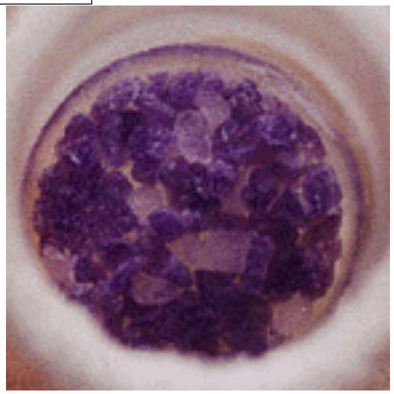
Existing SIDIS data do not have enough constrain on sea quarks Sivers distribution.

What are the limits of sea quarks' Sivers distribution ?

5T magnet for JLab Hall A/C polarized target



ammonia (NH_3



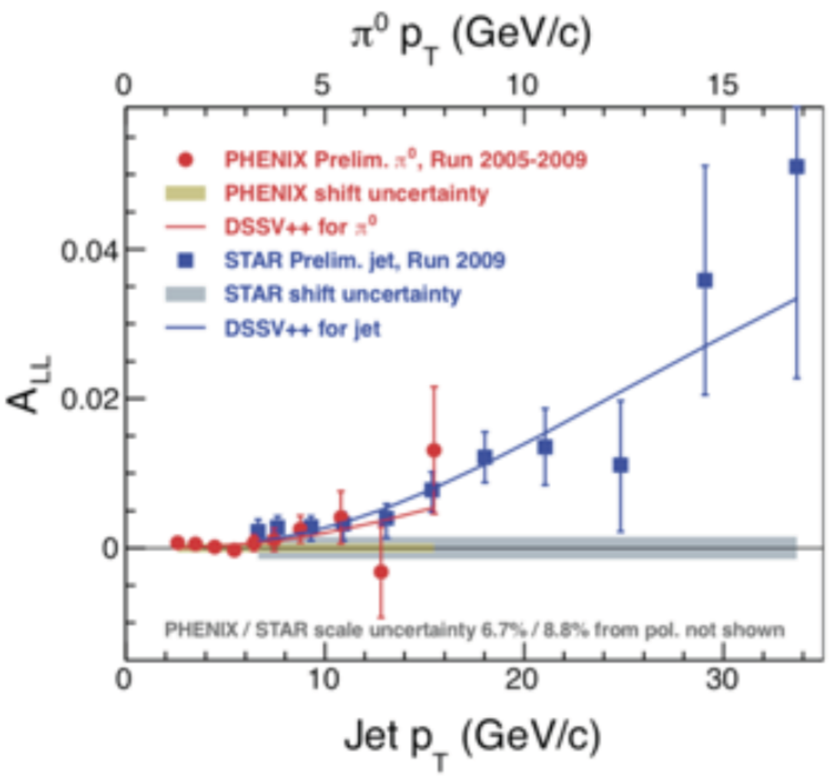
Do sea quarks carry any longitudinal spin (helicity) of the proton ?

DIS2013 4/22/2013.
M. Stratmann.

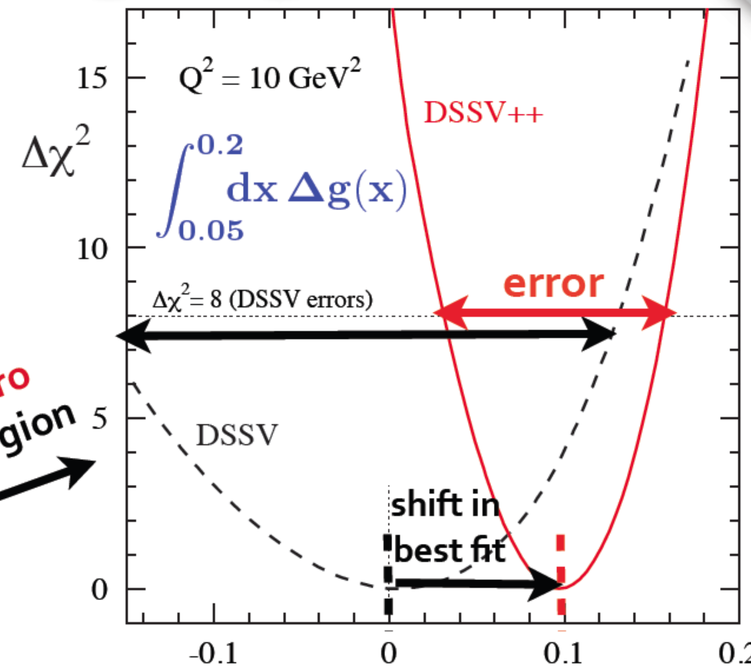
Δg from RHIC – gaining weight

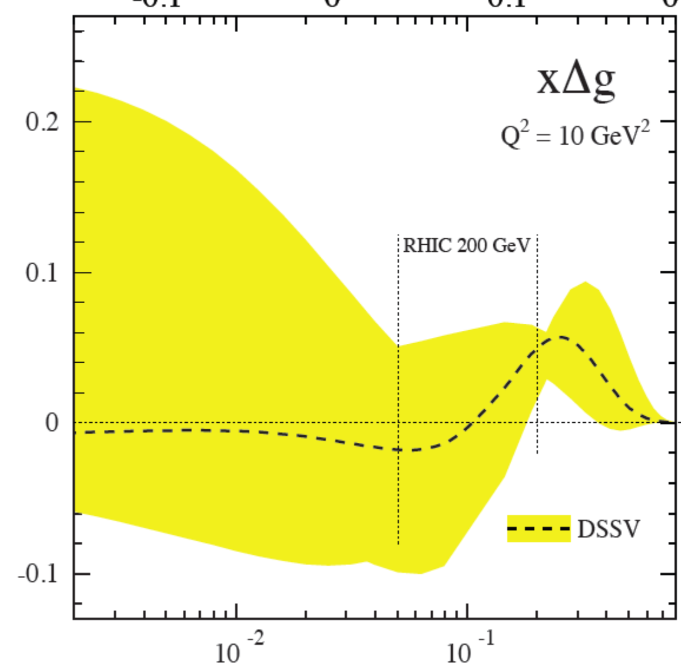
Δg

new RHIC data included in DSSV++



lead to non-zero Δg in RHIC x-region





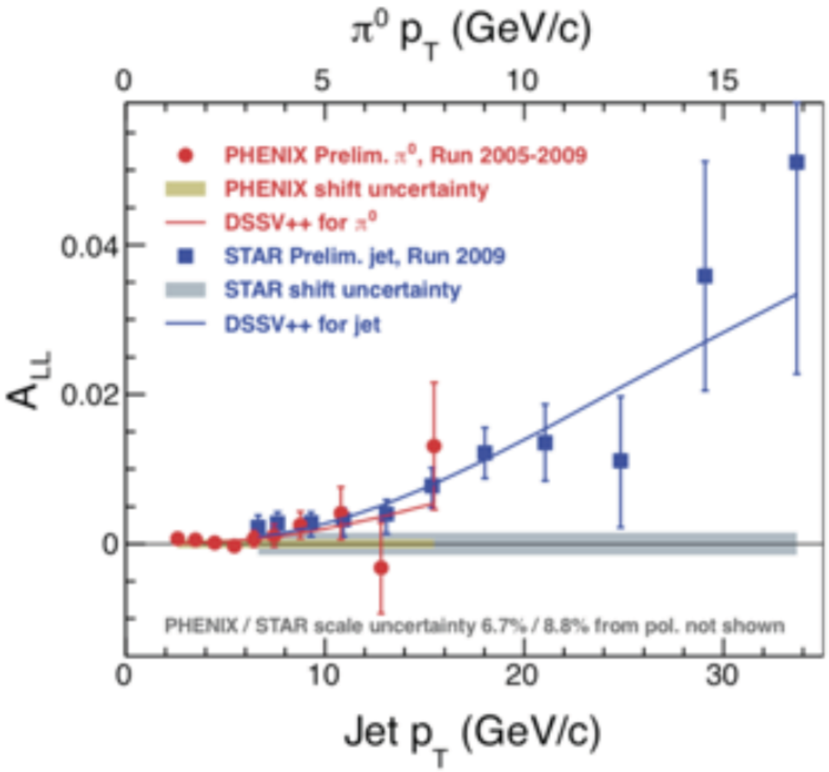
$$\int_{0.05}^{0.2} dx\, \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2) = 0.1^{+0.06}_{-0.07}$$

fully compatible with old DSSV error estimate

Chiu, Gagliardi
Δg from RHIC (Tue)

Δg from RHIC – gaining weight

new RHIC data included in DSSV++



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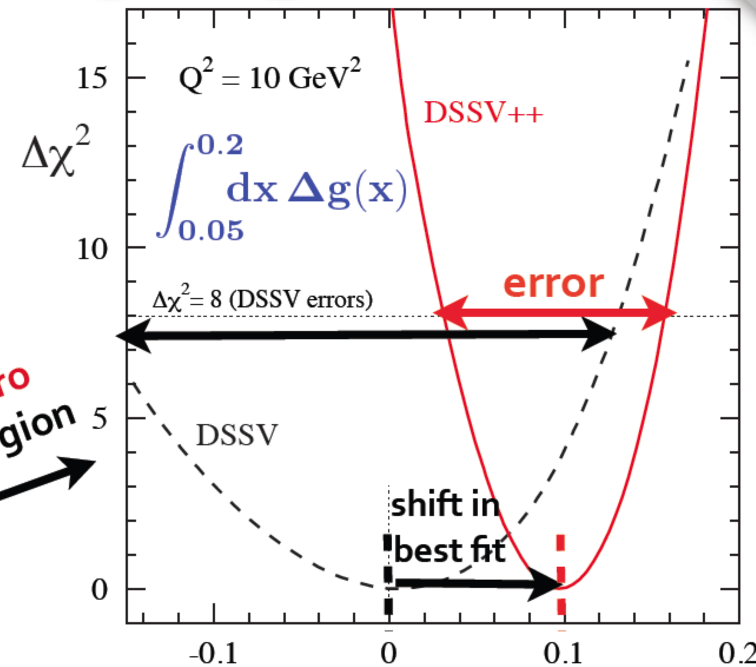
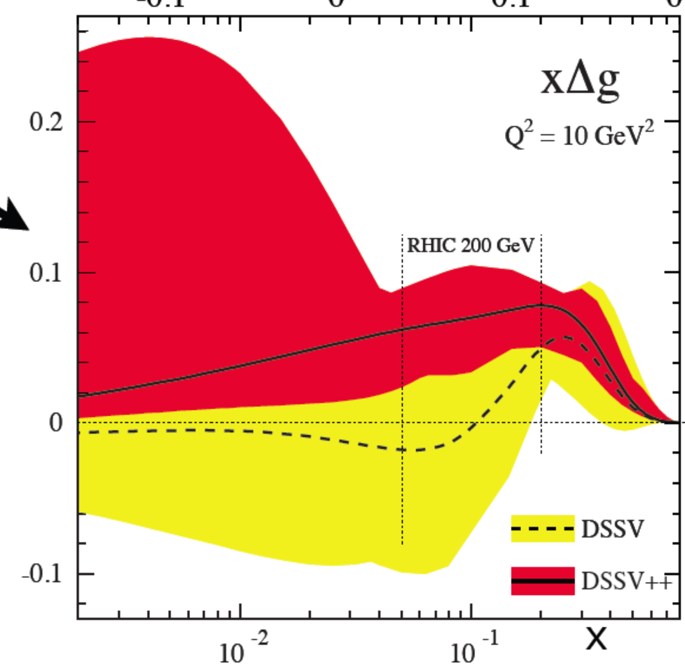


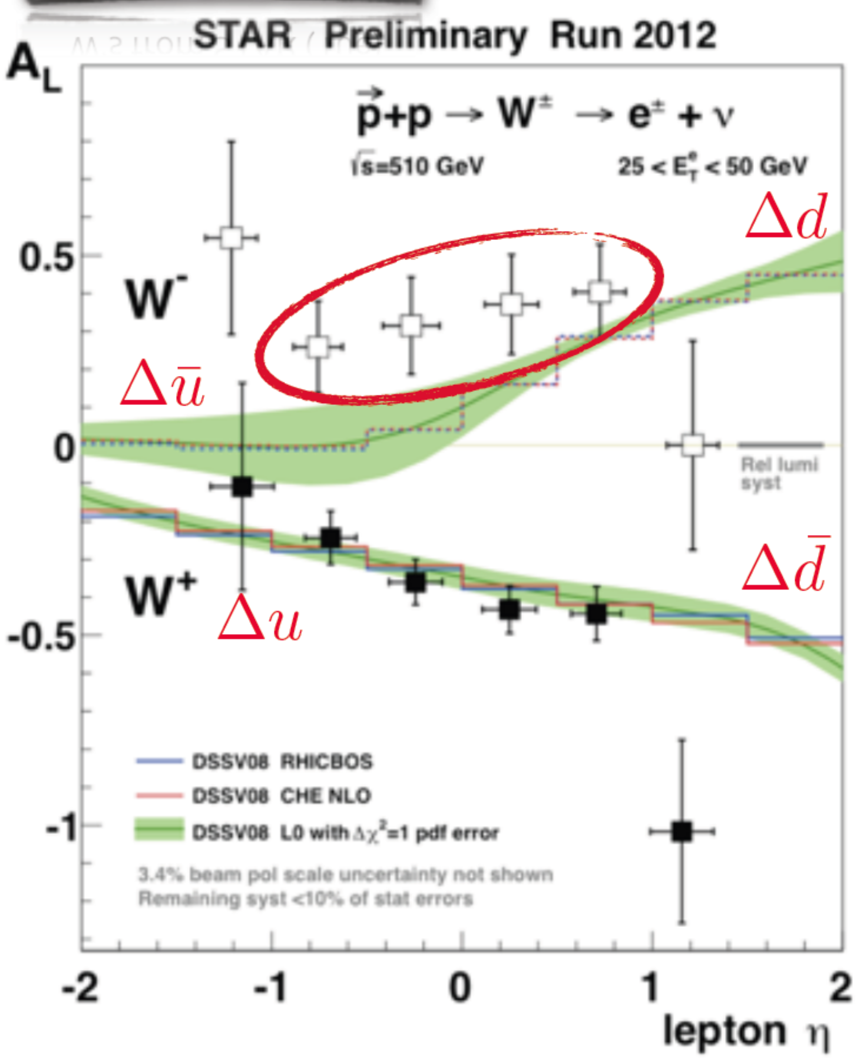
positive Δg in RHIC x-region



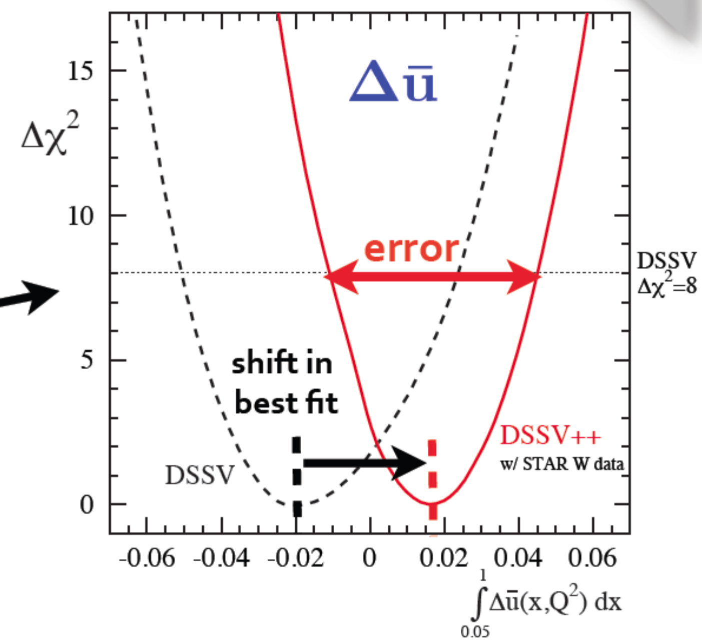
preliminary 2012 STAR data & impact

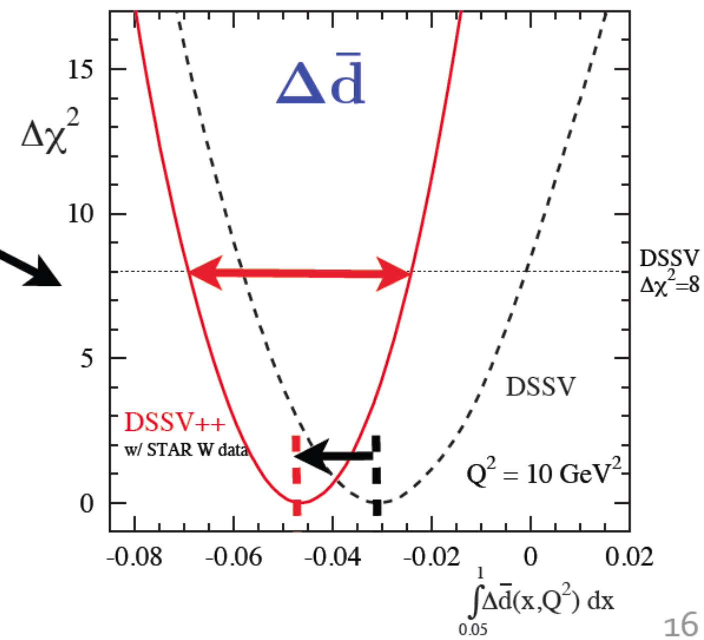
$\Delta\bar{u}$ $\Delta\bar{d}$

Surrow
W's from STAR (Tue)



run 12 data already have a significant impact



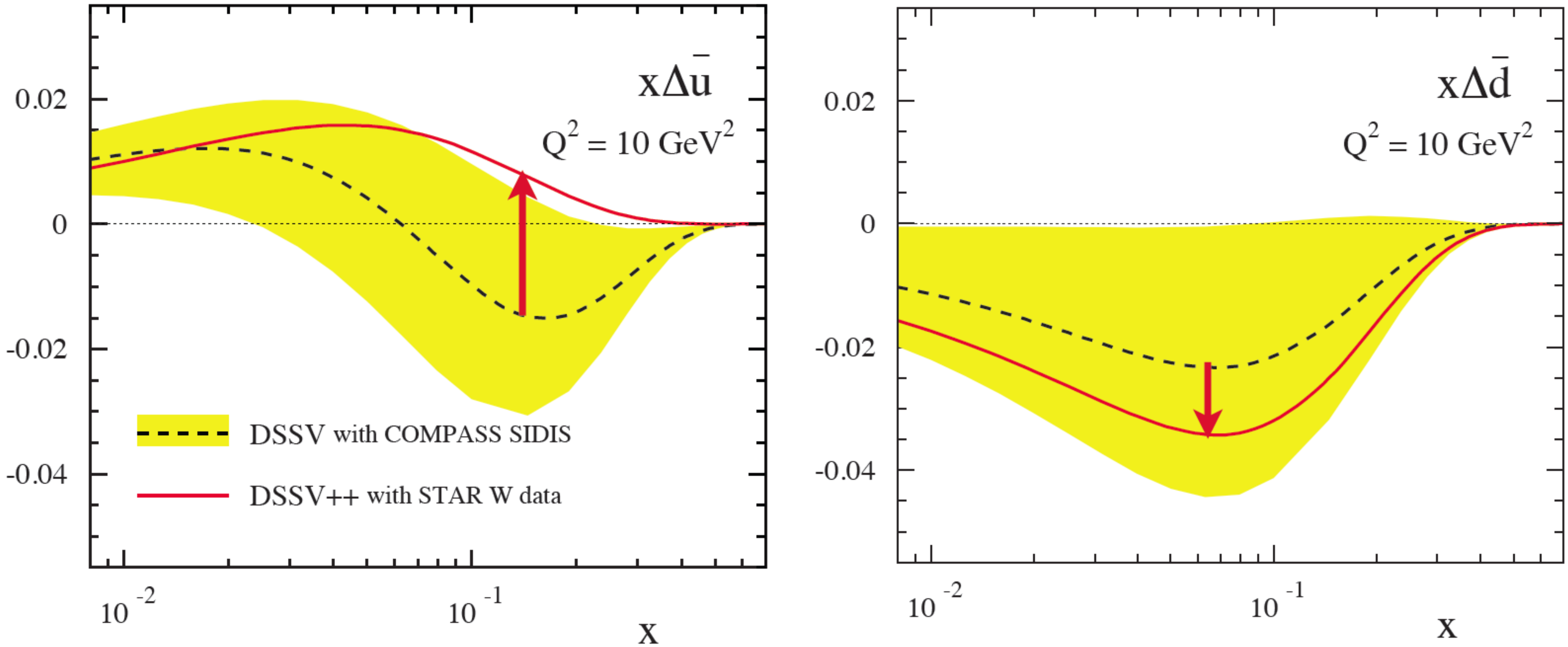


much more to come from current RHIC run

impact in terms of $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$

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

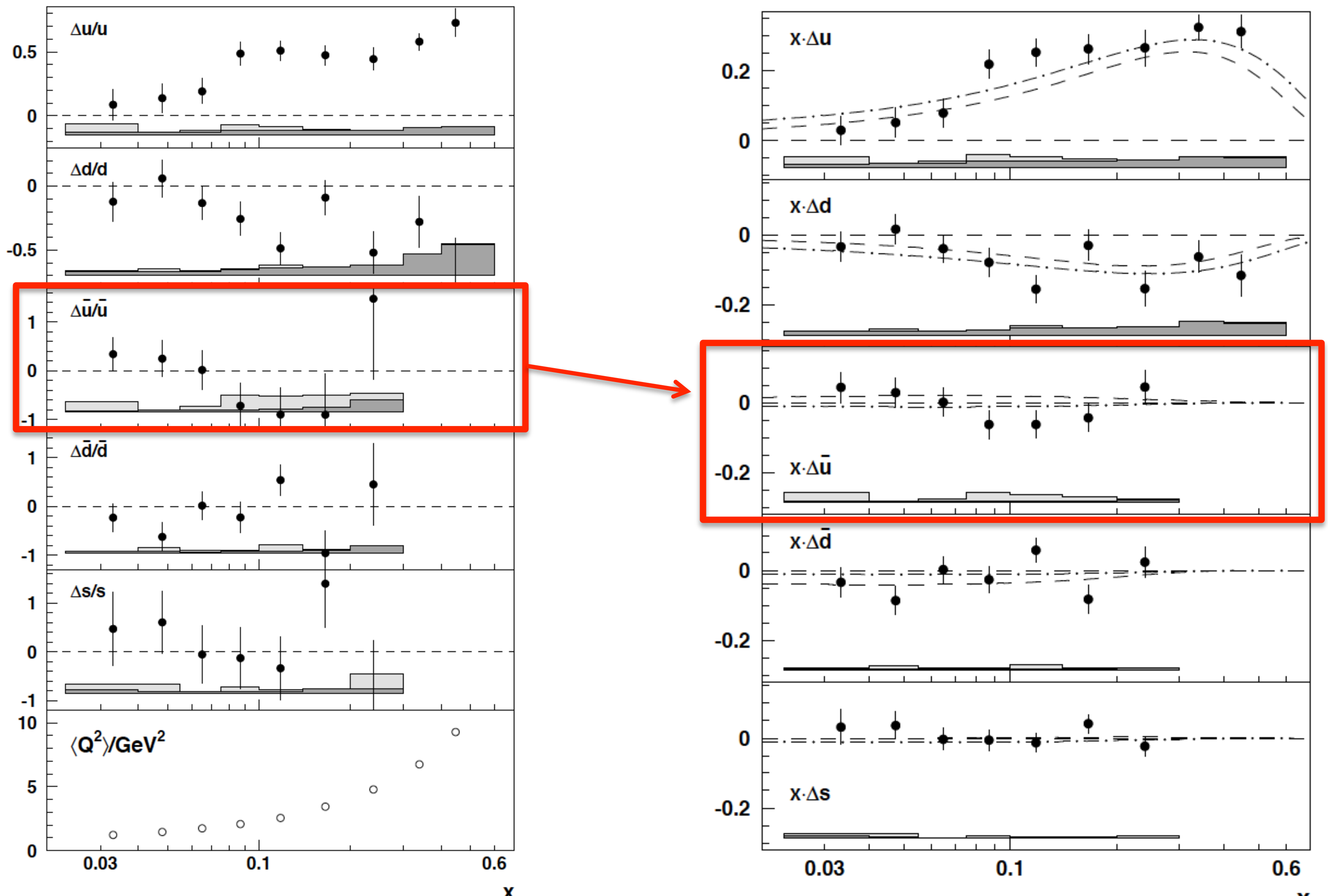
still very preliminary !



- ☑ starts to test of what we know about sea quarks from SIDIS with pions
- ☑ new fit points towards rather sizable $\Delta\bar{u}(x) - \Delta\bar{d}(x)$ of interest for models

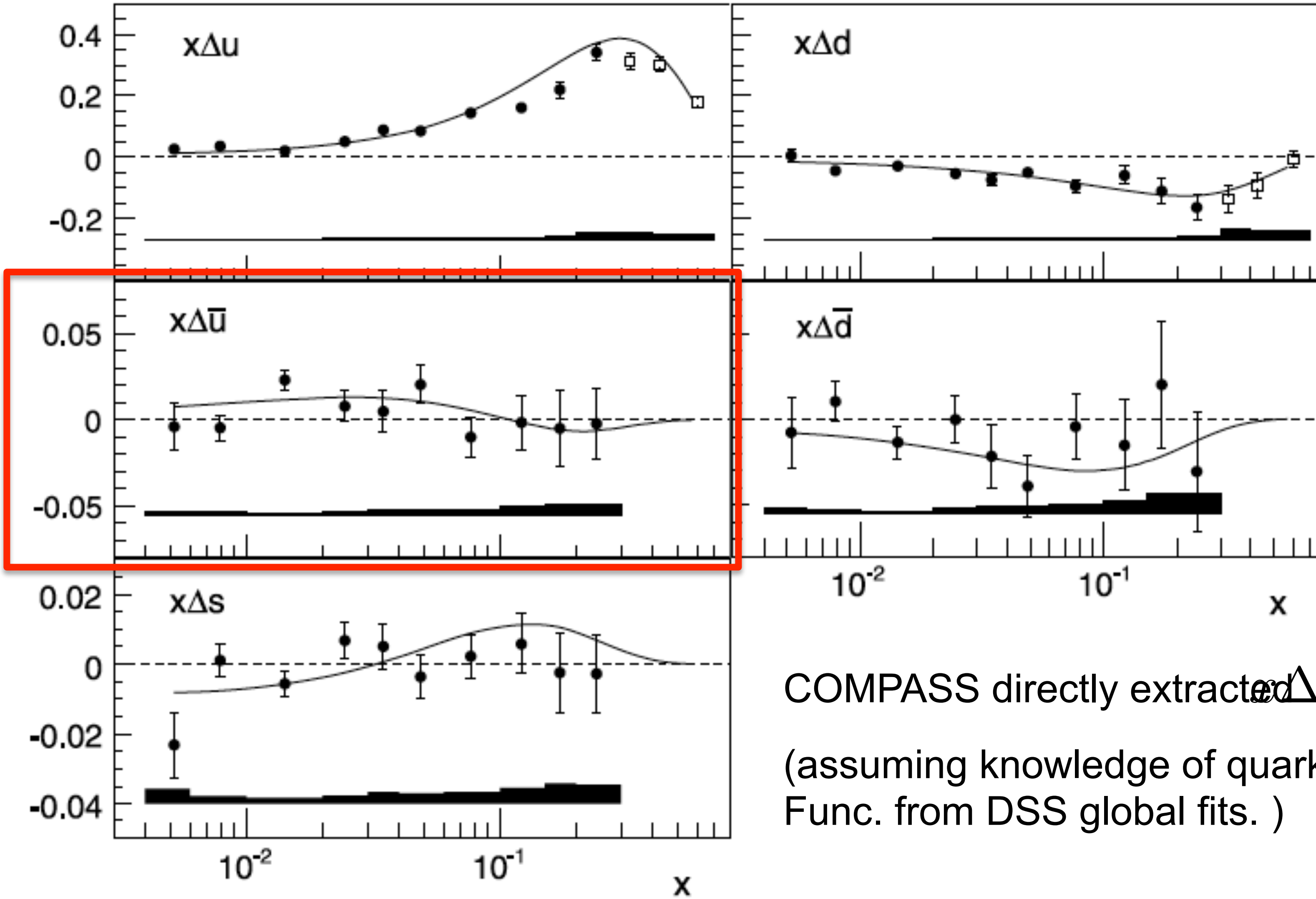
looming (mild ?) tension with SIDIS data

HERMES 2005 Results of Spin-Flavor Decomposition:
from SIDIS Double-Spin Asymmetries



(assuming knowledge of quark Frag. Func. from Monte Carlo simulations.)

COMPASS 2010 Spin-Flavor Decomposition



COMPASS directly extracted $x\Delta\bar{u}$

(assuming knowledge of quark Frag. Func. from DSS global fits.)

COMPASS data are not shown the format of $\Delta\bar{u}/\bar{u}$

A clear probe to access sea quarks' polarization:
Drell-Yan beam-target double-spin asymmetry A_{LL}

We define Drell-Yan longitudinally polarized beam-target double-spin asymmetry A_{LL} as

$$A_{LL}^{DY} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\Delta\sigma_{DY}}{\sigma_{DY}}$$

i.e, the ratio of the difference over the sum (or asymmetry) between the spin-aligned and spin-anti-aligned Drell-Yan cross sections, at the Leading Order, we have:

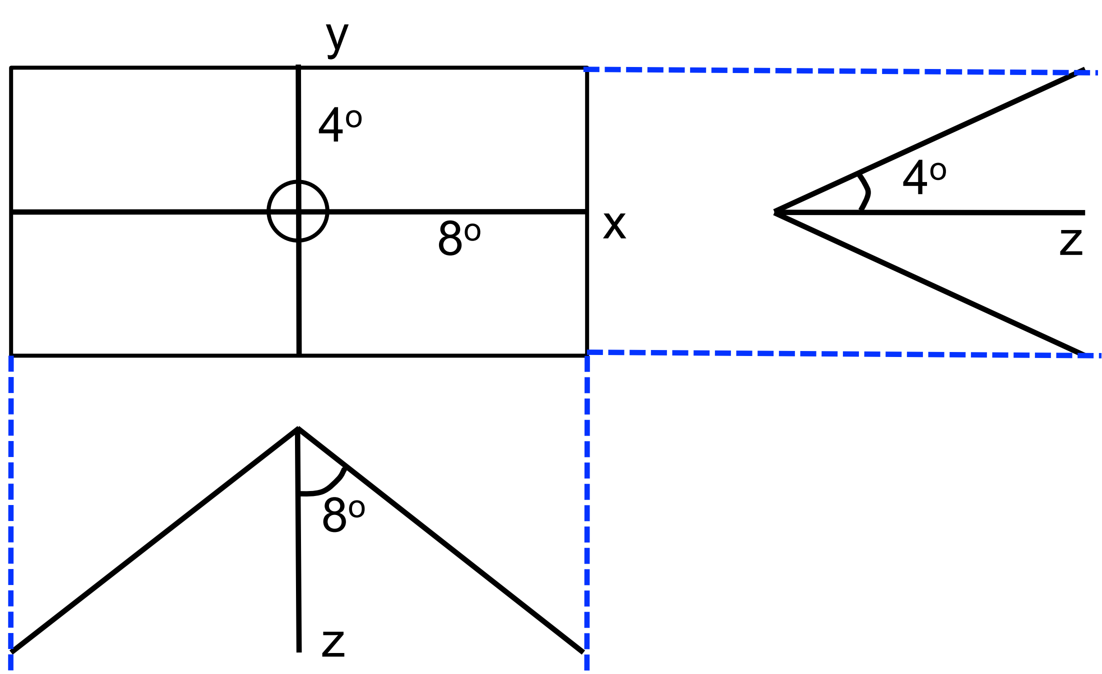
$$A_{LL}^{DY} = -\frac{\sum_q e_q^2 \{\Delta q(x_1)\Delta\bar{q}(x_2) + \Delta\bar{q}(x_1)\Delta q(x_2)\}}{\sum_q e_q^2 \{q(x_1)\bar{q}(x_2) + \bar{q}(x_1)q(x_2)\}}$$

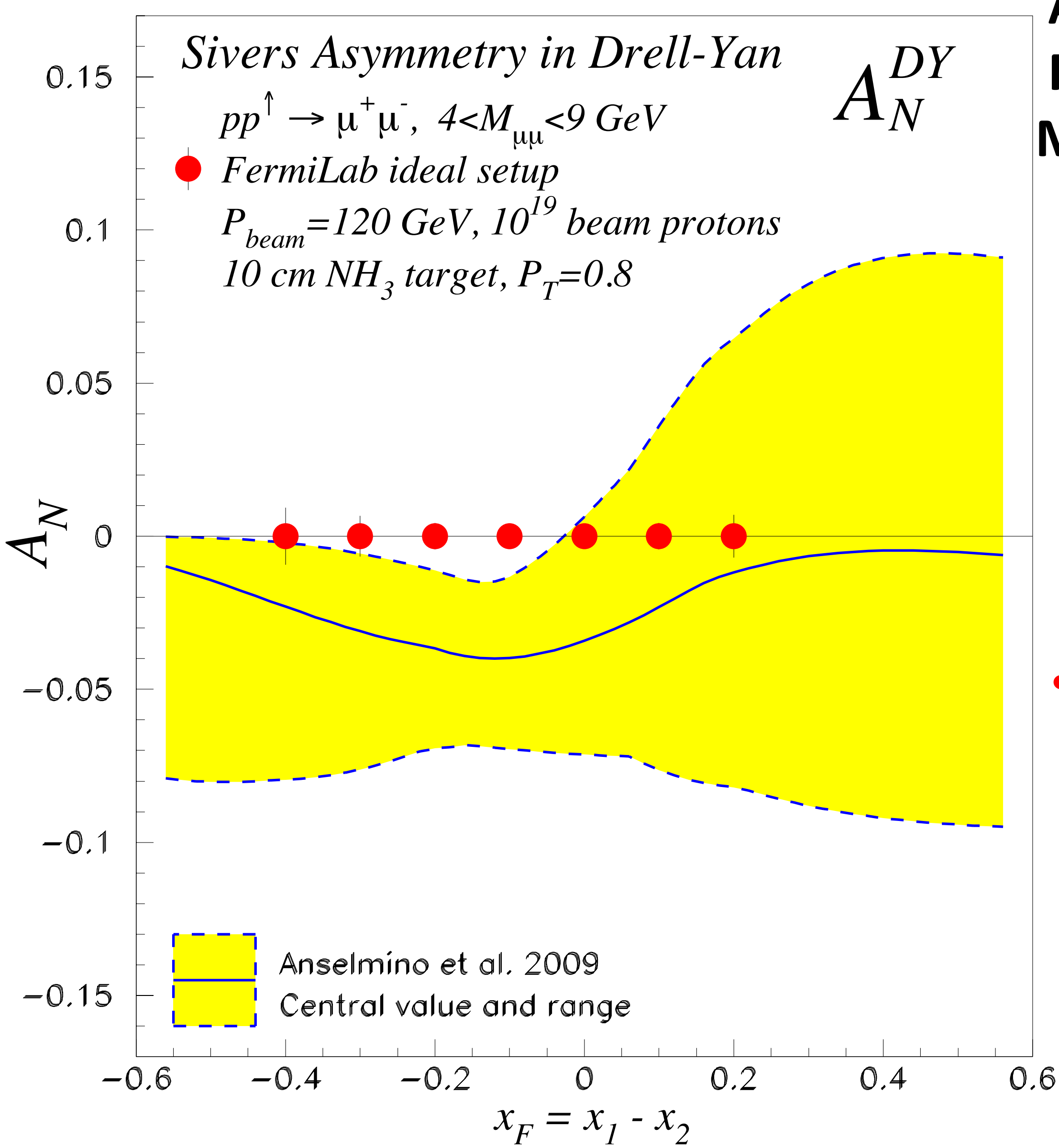
$$A_{pp} \approx -\frac{\Delta u_1}{u_1}\frac{\Delta\bar{u}_2}{\bar{u}_2} \qquad A_{pn} \approx -\frac{\Delta u_1}{u_1}\frac{\Delta\bar{d}_2}{\bar{d}_2}$$

if anti-quarks carry no spin ➔ $A_{LL}^{DY} \equiv 0$!!!

Geometry of an “ideal” spectrometer for FNAL Drell-Yan

- Vertical acceptance ±4 degree
- Horizontal acceptance ±8 degree
- Beam line ±1 degree



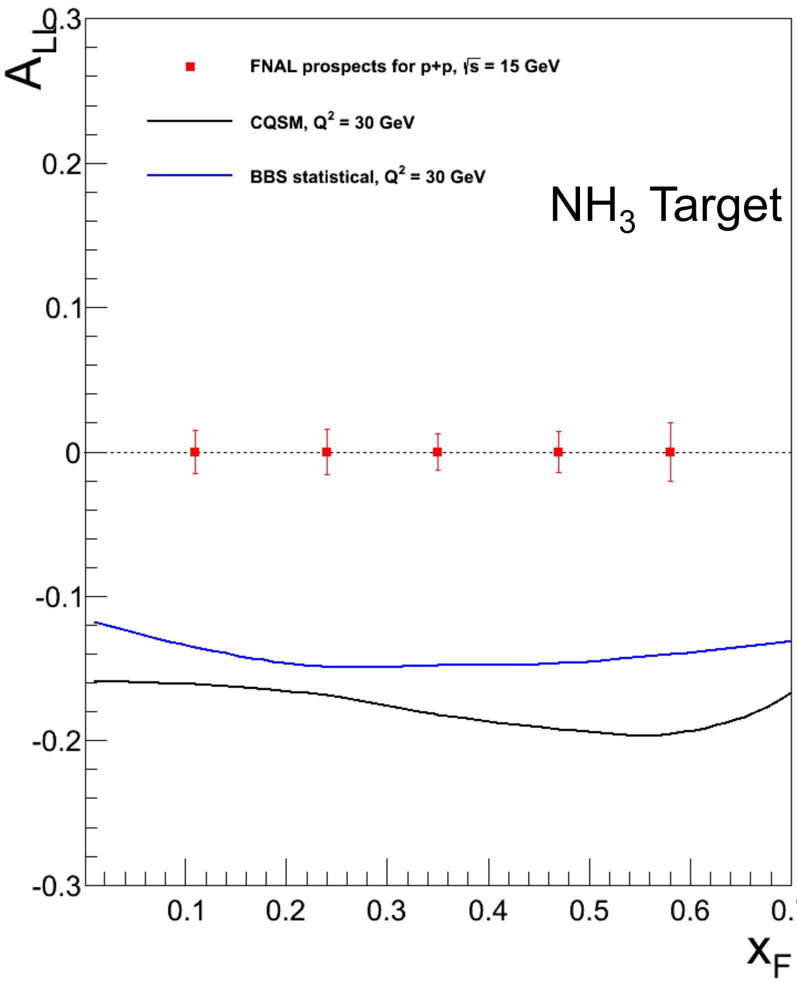


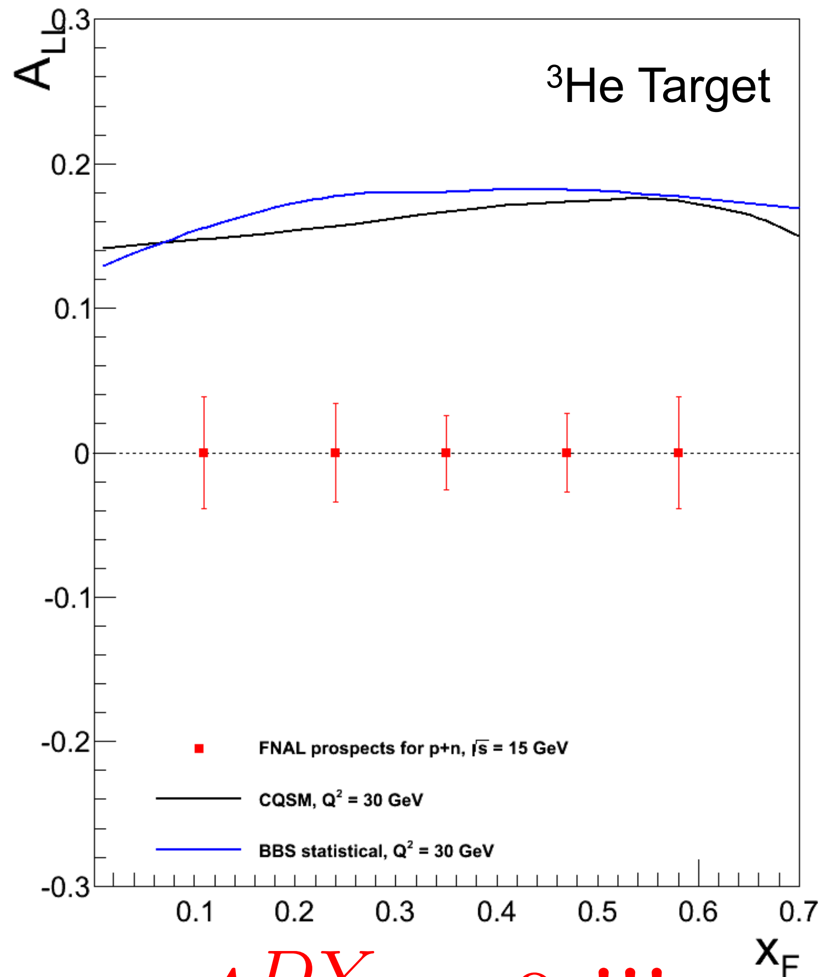
An ideal setup:
Polarized Target Drell-Yan SSA Measurement

- A new 10 cm long transversely polarized NH_3 target. P_T=0.80.
- A "re-designed" spectrometer with large angle coverage to cover $x_F<0$.

- **The first measurement of sea quark Sivers distributions.**

FNAL "prospected data" vs. theory predictions

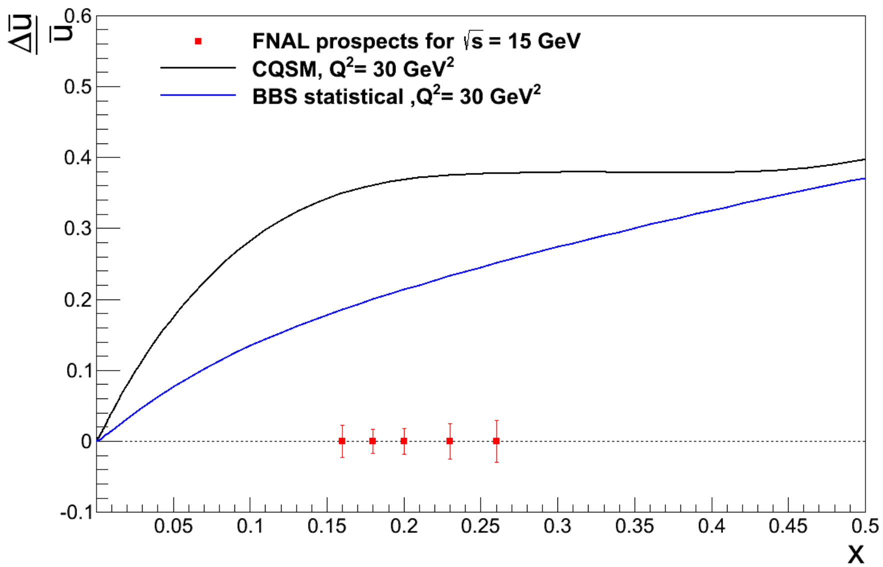


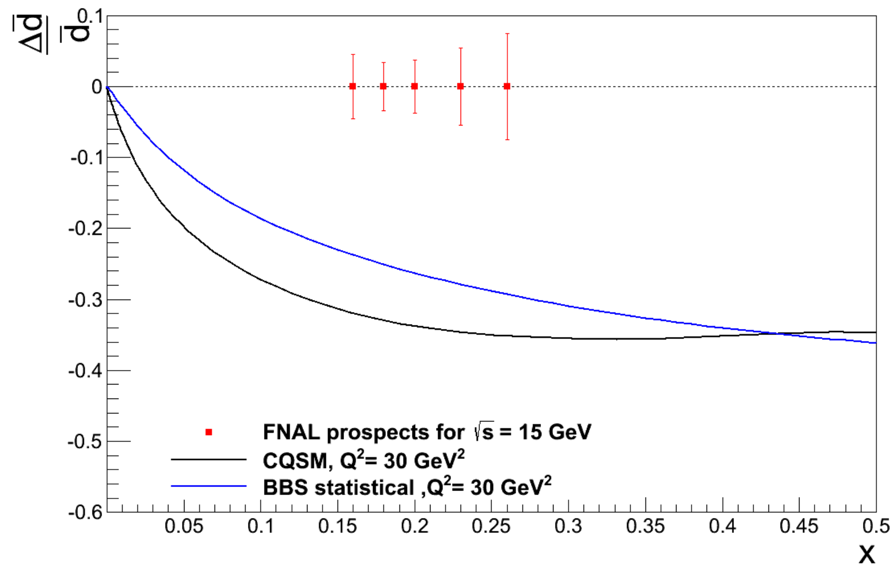


if anti-quarks carry no spin ➔ $A_{LL}^{DY} \equiv 0$!!!

Chiral Quark Soliton Model: Wakamatsu, 2010. BBS statistical model: Soffer et al 2004.

Δubar/ubar, Δdbar/dbar
- FNAL





What are the known limits of sea quarks' helicity distribution ?

Do sea quarks carry any transverse spin (transversity) in a transversely polarized proton ?

access through: Drell-Yan beam-target double-spin asymmetry A_{TT}

A_{TT} to Access Transversity

$$A_{TT}^{DY} = \frac{\sin^2\theta\cos 2\phi}{1+\cos^2\theta} \cdot \frac{\sum_q e_q^2\{\delta q(x_1)\delta\bar{q}(x_2) + \delta\bar{q}(x_1)\delta q(x_2)\}}{\sum_q e_q^2\{q(x_1)\bar{q}(x_2) + \bar{q}(x_1)q(x_2)\}}$$

where θ is the polar angle of either lepton in the rest frame of the virtual photon, and φ is the azimuthal angle between the direction of the polarization and the normal to the plane of the di-lepton decay.

$\langle\cos(2\varphi)\rangle \approx 2/\pi$, i.e. almost cover all DY azimuthal angles.

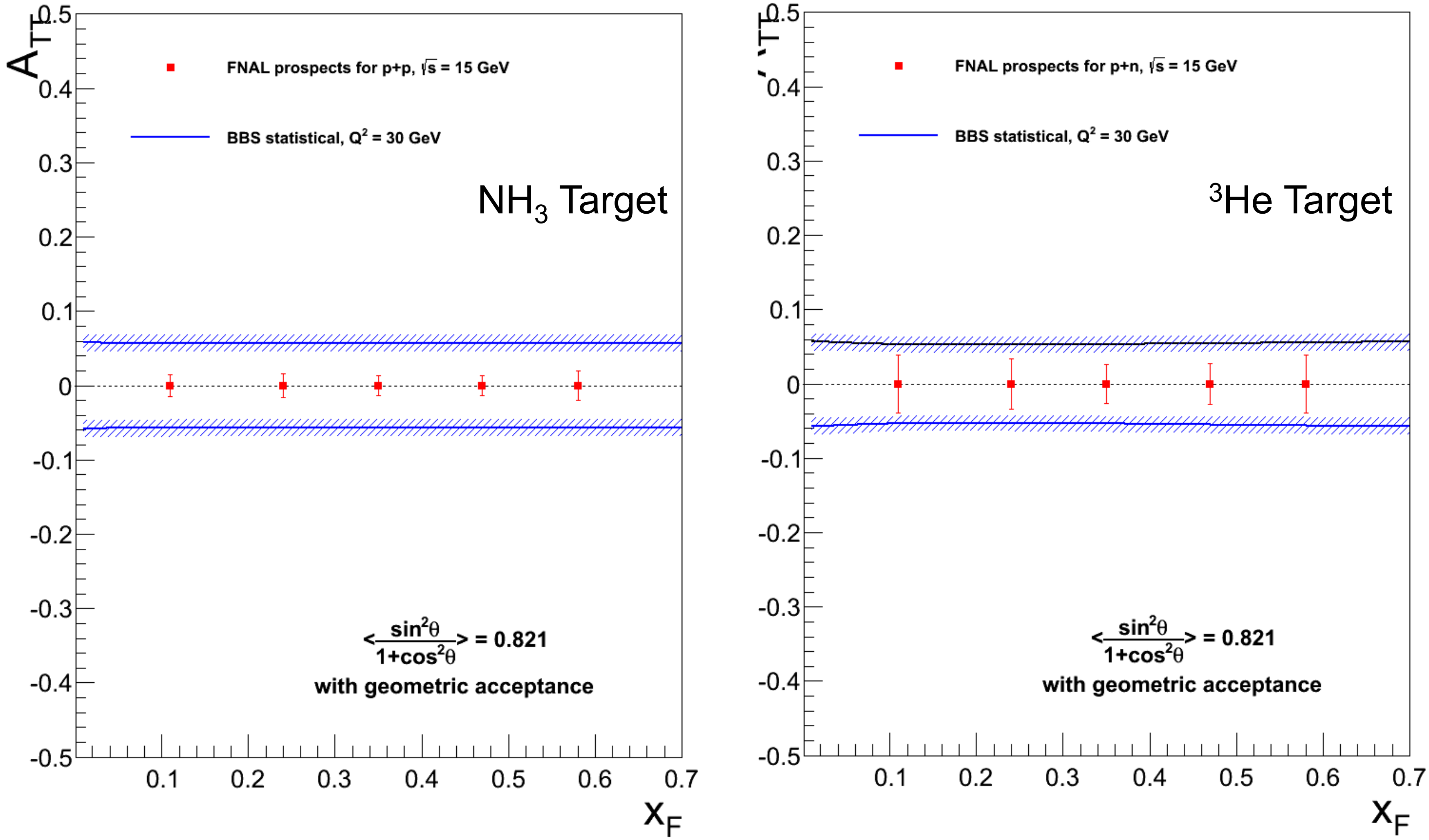
$$\left\langle \frac{\sin^2\theta}{1+\cos^2\theta} \right\rangle = 0.414$$ if cover all θ, peak at 1.0 for θ=90°.

Lacking knowledge on transversity, we took the Soffer (positivity) bounds for both quark and anti-quark, i.e:

$$\delta q(x) \le \frac{1}{2}|q(x) + \Delta q(x)| \qquad \delta\bar{q}(x) \le \frac{1}{2}|\bar{q}(x) + \Delta\bar{q}(x)|$$

We can also try Anselmino group's fits results of quark transversity, later.

A_{TT} FNAL "prospected data" vs. theory predictions



What are the known limits of sea quarks' transversity distribution ?

Expected Performance of proton↑ Au Collision

- p+Au energies:

  100.8 GeV p on 100.0 GeV/nucleon Au ($\gamma_p = \gamma_{Au} = 107.4$)

- For energy scan need to match Lorentz factor γ of both beams

Au-Au history and projections for PHENIX Parameter	unit	p 2013E	Au	p 2013E	Au
no of colliding bunches	...	111	111	111	111
ions/bunch, initial	10^9	140	1.0	180	1.4
charges per bunch	10^9e	140	79	180	107
average beam current/ring I_{avg}	mA	194	110	250	148
stored energy per beam	MJ	0.25	0.35	0.32	0.47
transverse rms emittance ε_{xy}	mm.mrad	2.9	2.9	2.8	2.8
rms bunch length σ_s	m	0.5	0.3	0.5	0.3
envelope function at IP β^*	m	0.9	0.9	0.7	0.7
beam-beam parameter ξ/IP	10^{-3}	4.3	2.4	5.9	3.1
initial luminosity L/IP	**10^{26} cm^{-2}s^{-1}**	**39**		**82**	
events per bunch-bunch crossing	...				
average / initial luminosity	%	60		70	
average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**24**		**57**	
time in store	%	55		55	
max luminosity/week	μb^{-1}			190	
min luminosity/week	μb^{-1}	78			

L_{NN}/week, min/max — pb^{-1} — 15 — 37

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