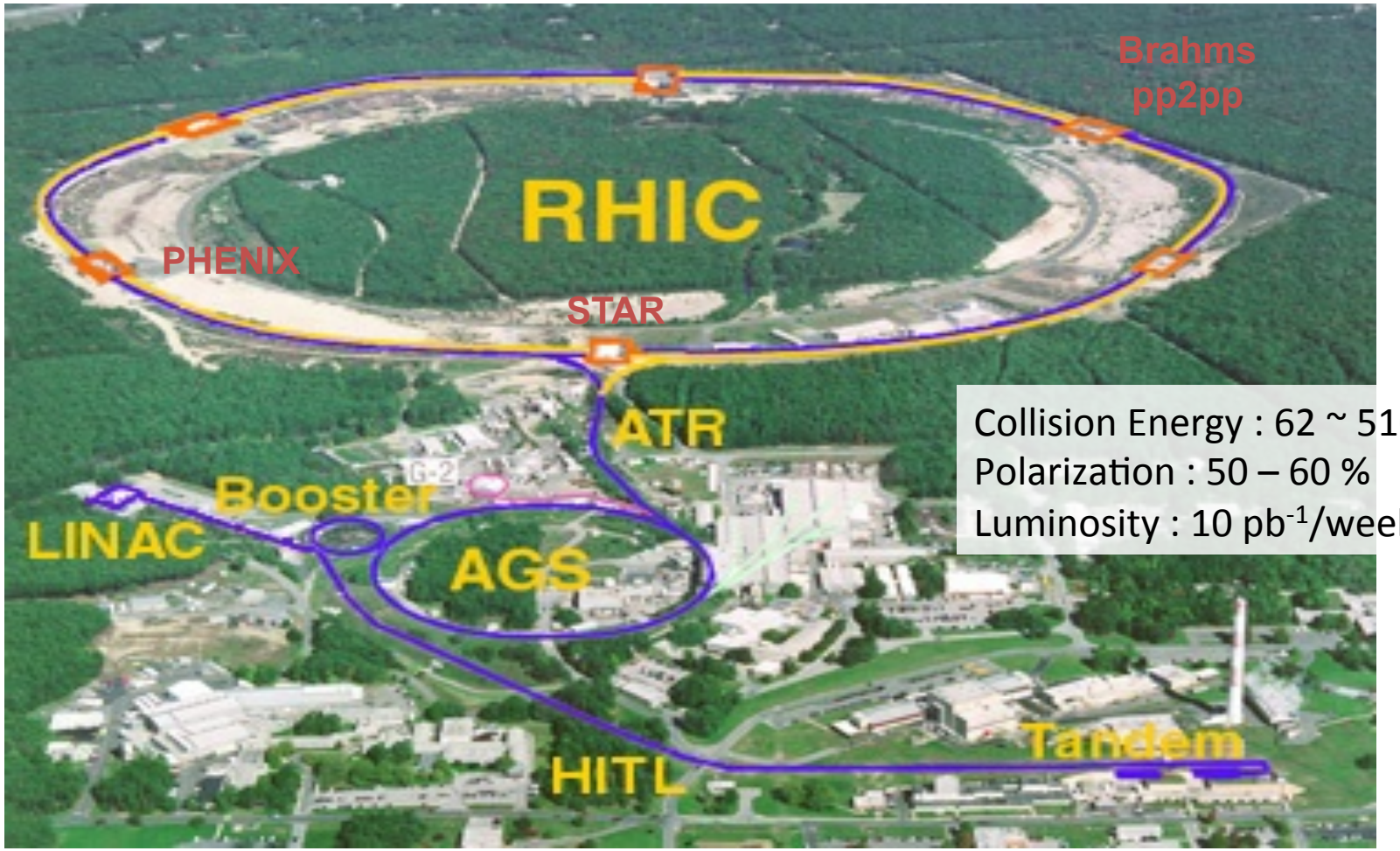
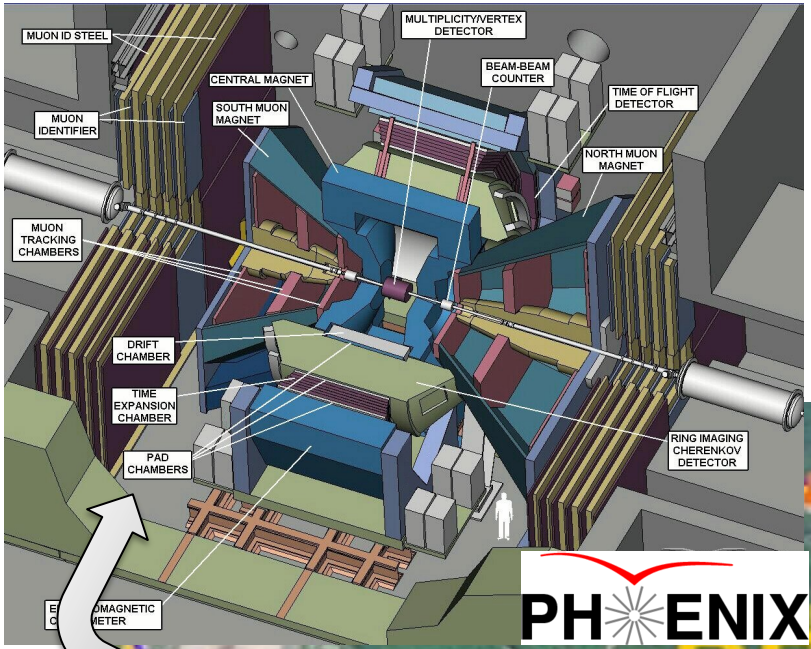
Measuring the gluon spin contribution to the proton spin in polarized p+p collisions with the PHENIX experiment

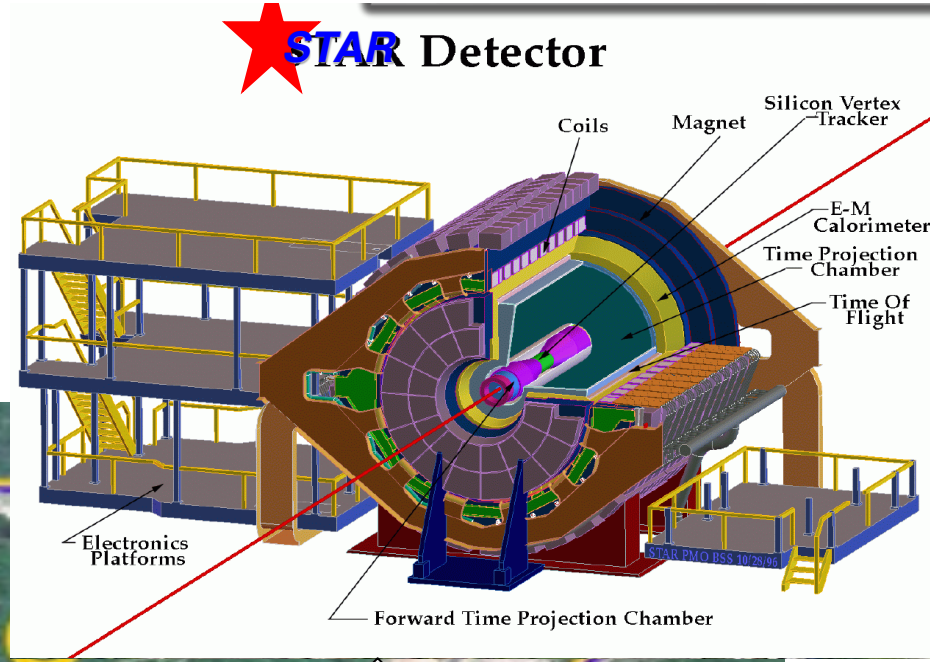
RIKEN/RBRC
Itaru Nakagawa
on behalf of PHENIX Collaboration

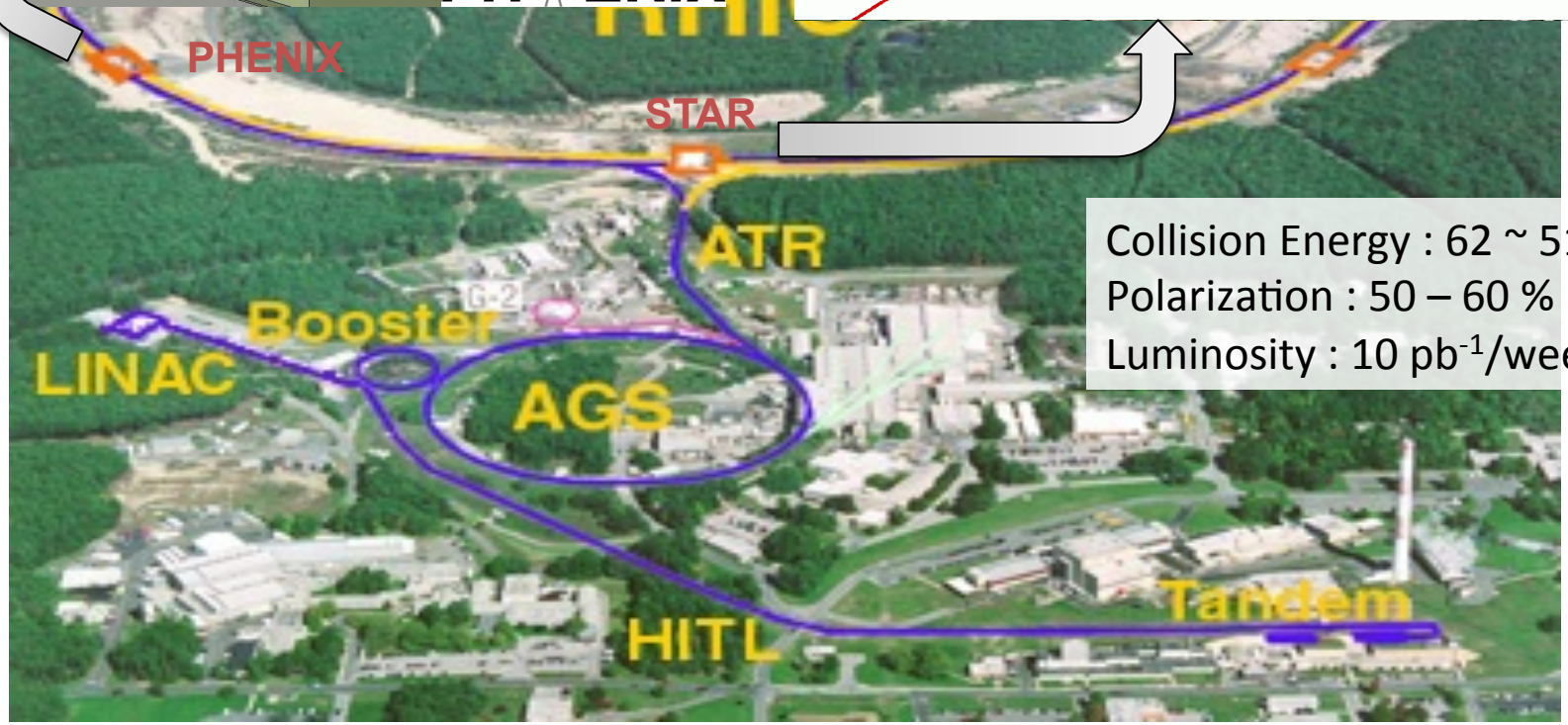
The Relativistic Heavy Ion Collider accelerator complex at Brookhaven National Laboratory



Collision Energy : 62 ~ 510 GeV
Polarization : 50 – 60 %
Luminosity : 10 pb^{-1}/week







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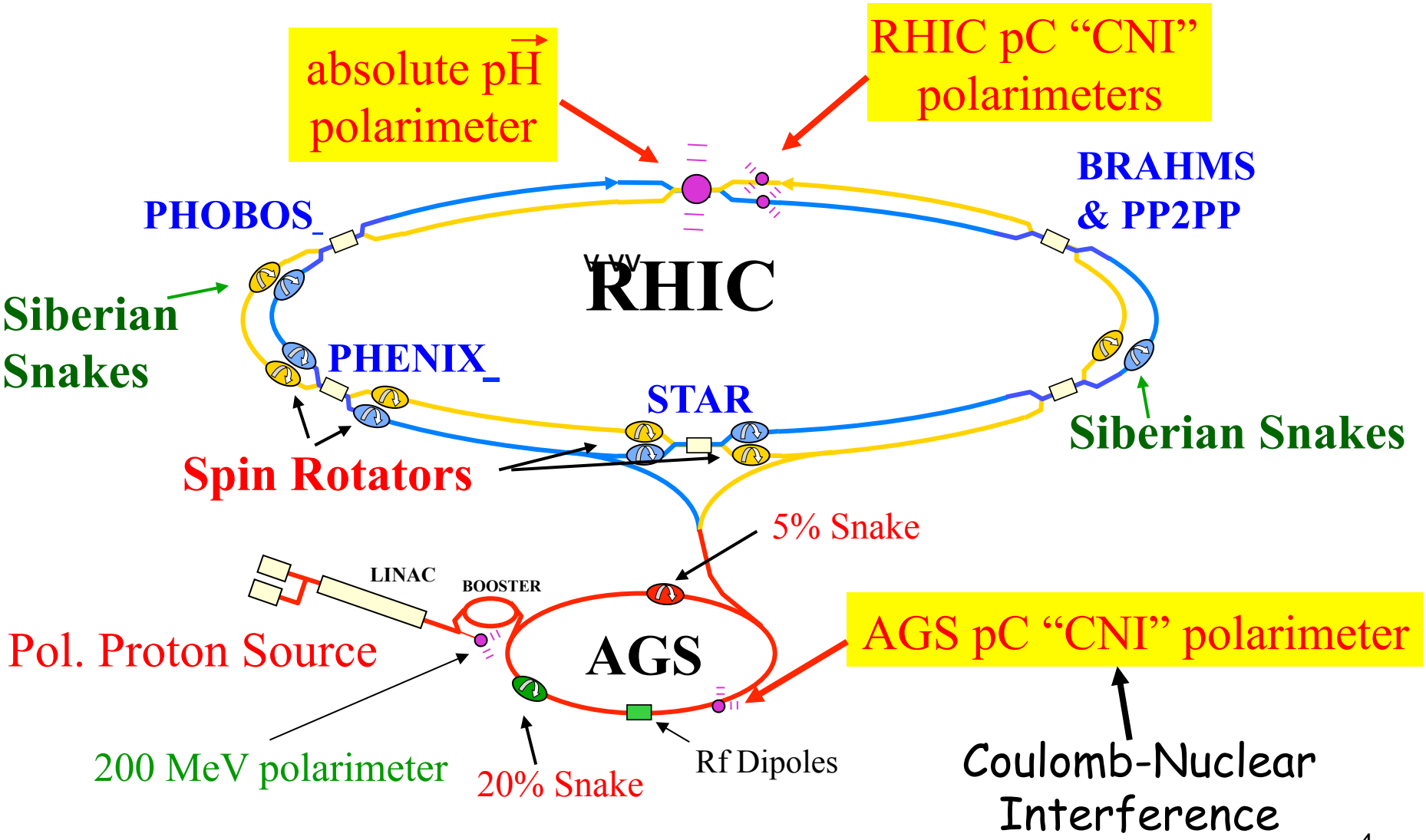
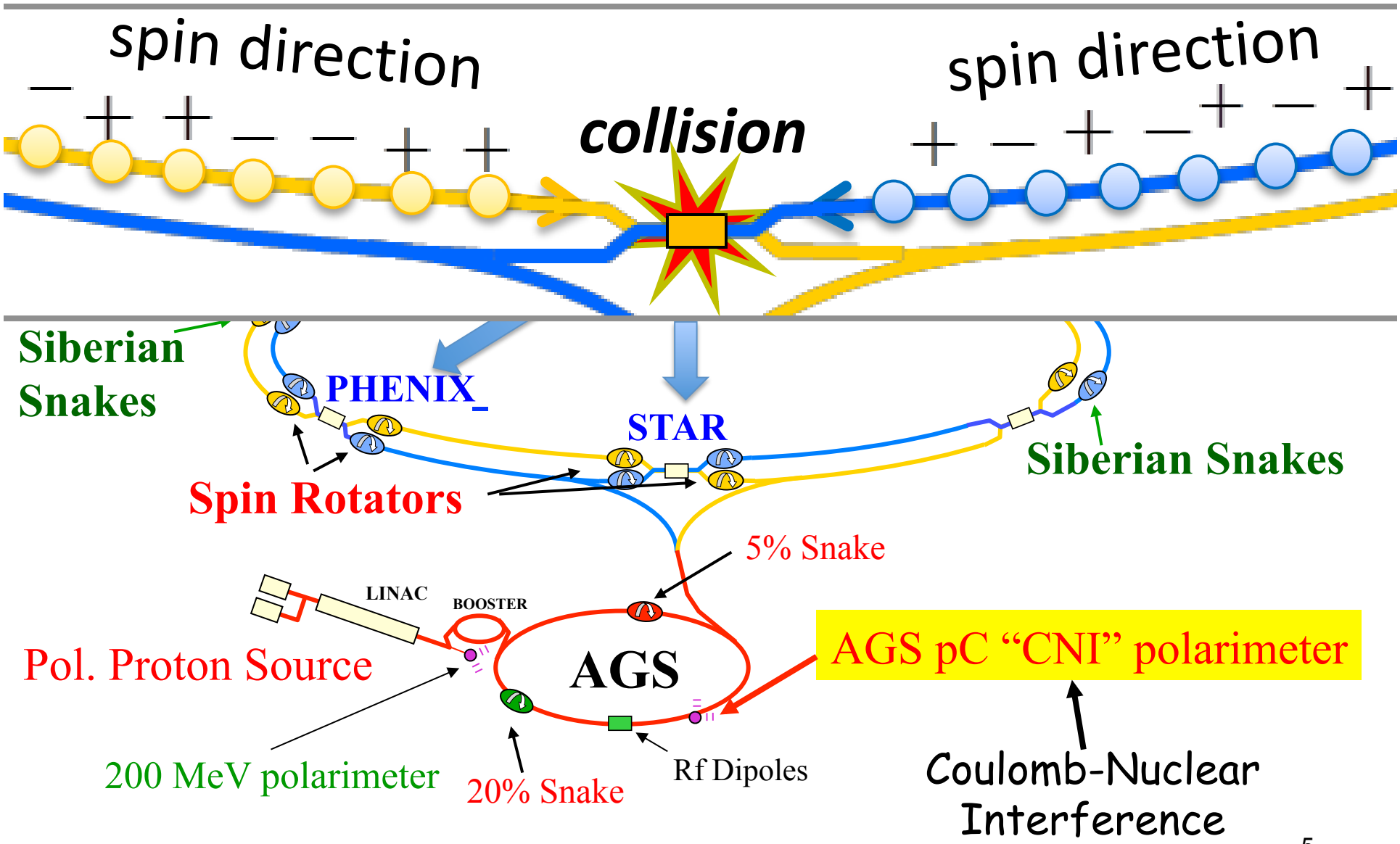
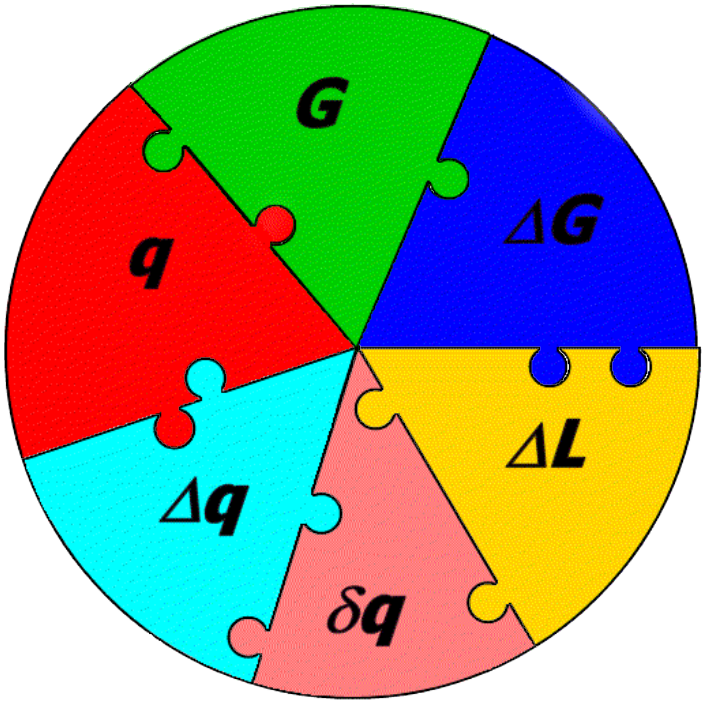
RHIC *p+p* accelerator complex



RHIC *p+p* accelerator complex



Highlights of RHIC Spin Program (Outline)



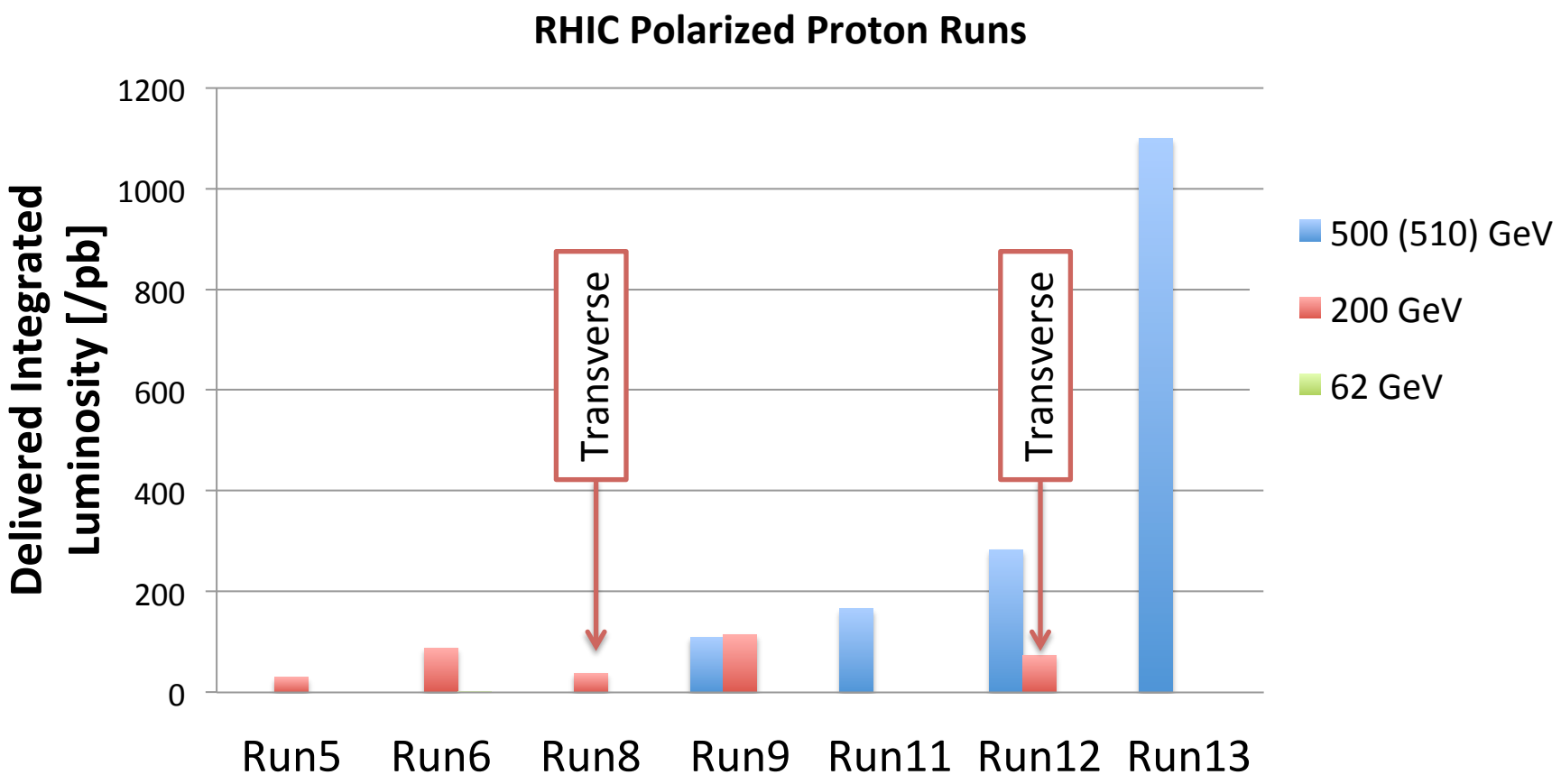
Spin Puzzle

Longitudinal Spin Structure
- **<u>Gluon Spin</u>** (this talk)
- **Sea Quark** (following talks)

Transverse Spin Structure
- Sivers Effect
- Collins Effect
- Higher Twist …

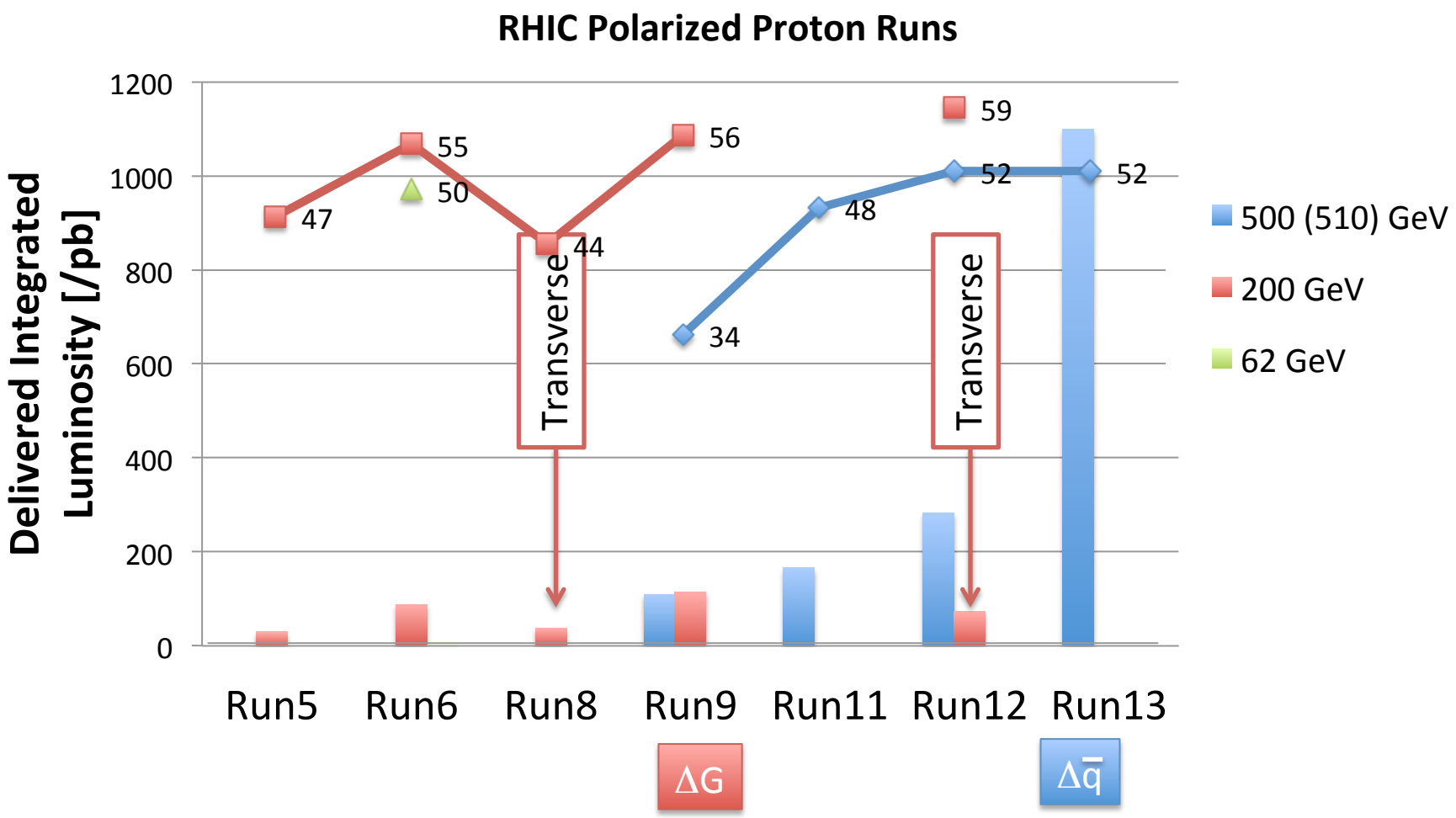
Future Upgrades

RHIC Polarized Spin Program



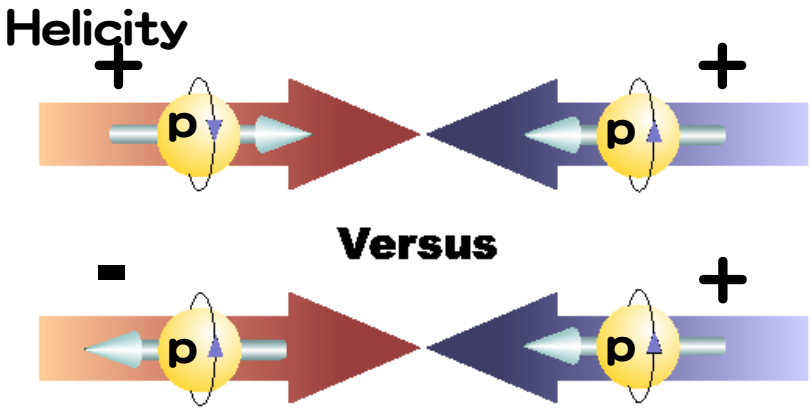
RHIC Polarized Spin Program

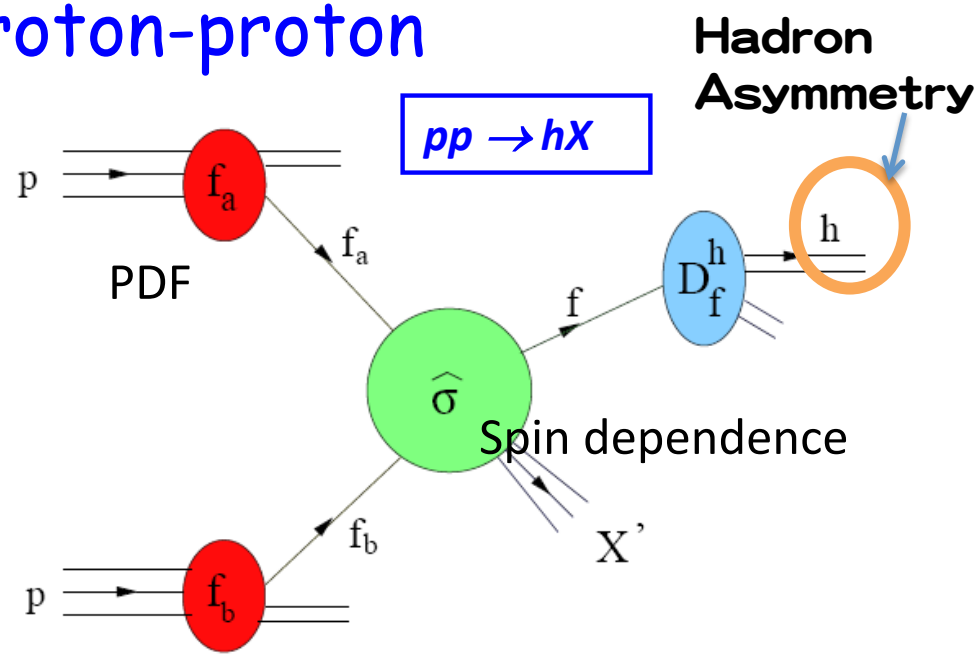
Beam Polarization



Longitudinal Spin Structure

Longitudinally Polarized proton-proton



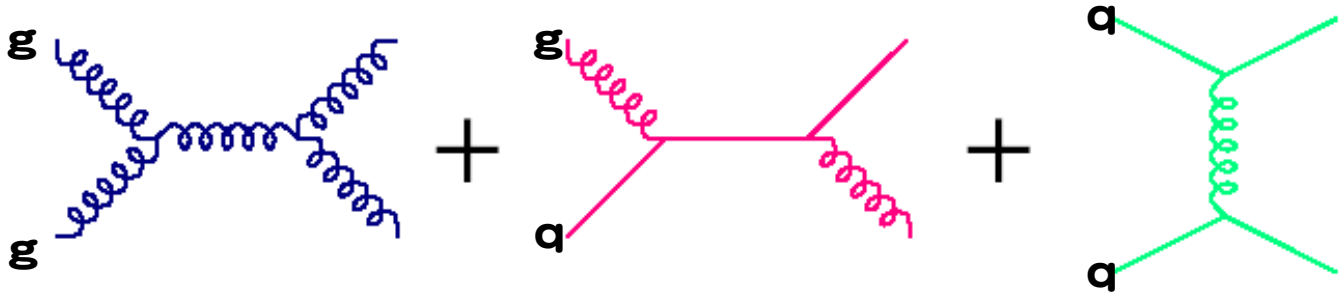


Fragmentation Function

Helicity Asymmetry

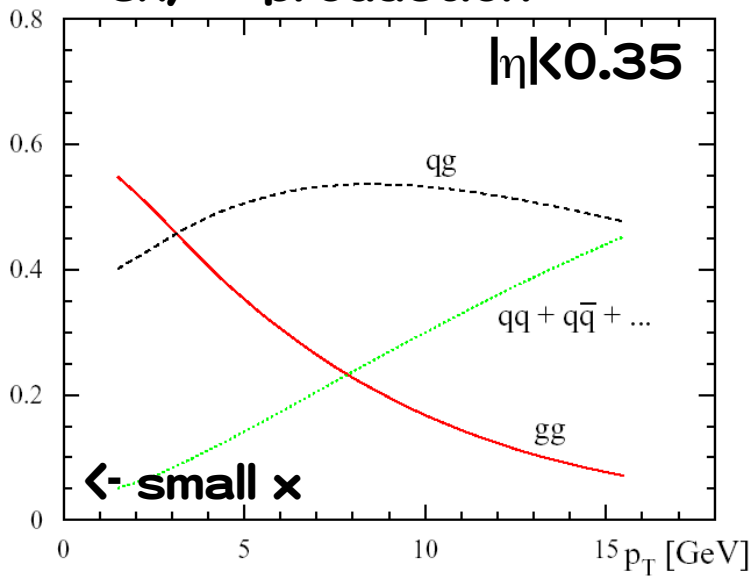
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \cdot \hat{a}_{LL}^{f_a f_b \to fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$$

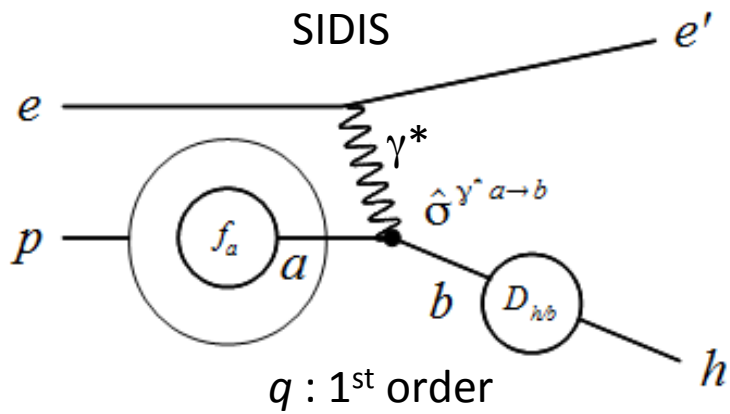
Subprocess of pp



$$A_{LL} \propto [\omega_{gg}]\Delta g \Delta g + [\omega_{gq}\Delta q]\Delta g + [\omega_{qq}\Delta q \Delta q]$$

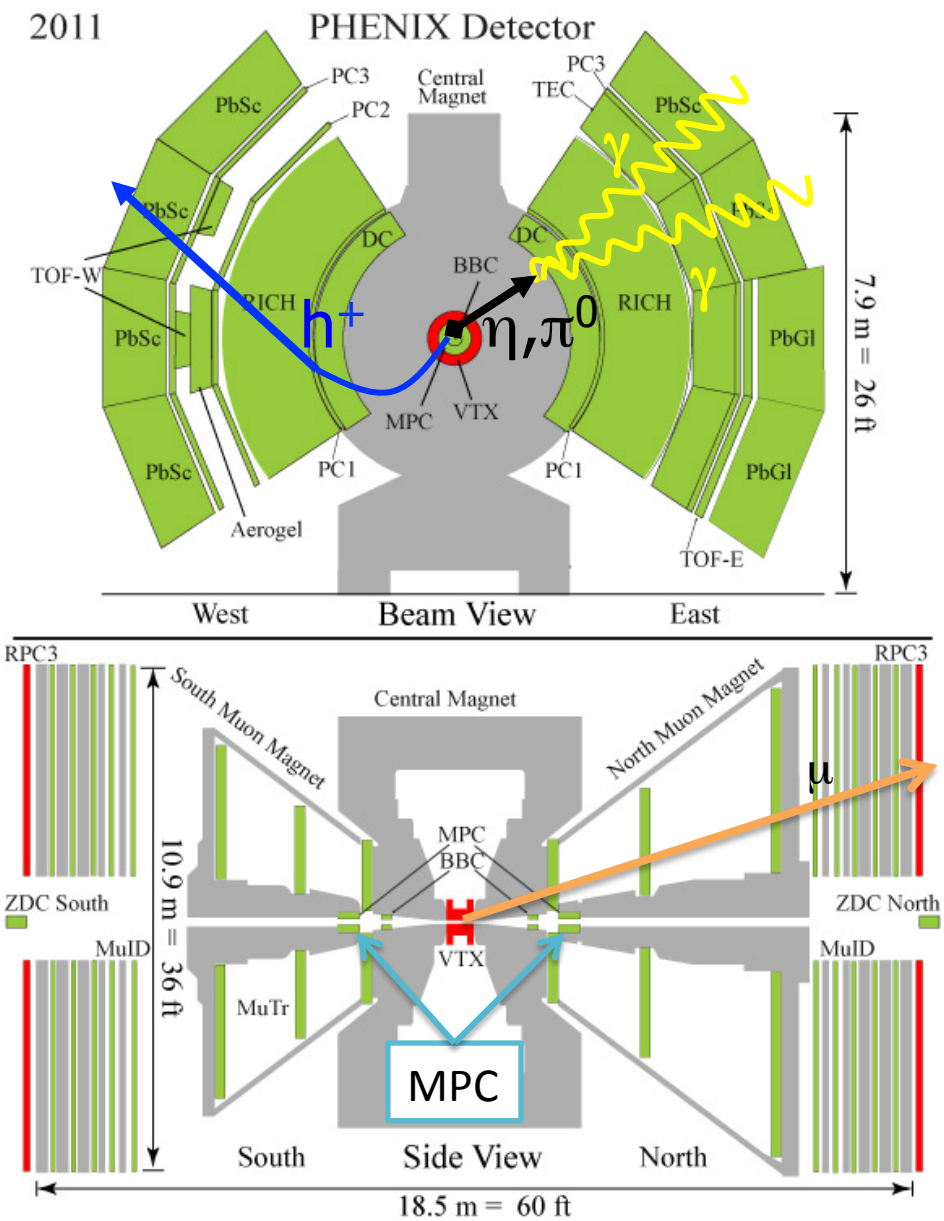
ex) π^0 production



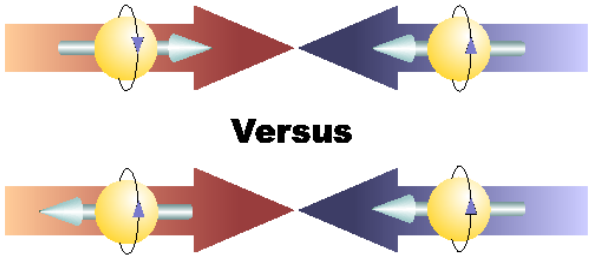


Gluon is the major player compared to DIS/SIDIS

The PHENIX Detector



- Philosophy
  - high resolution & high-rate at the cost of acceptance
  - trigger for rare events
- Central Arms
  - $|\eta| < 0.35$, $\Delta\phi \sim \pi$
  - Momentum, Energy, PID
- Muon Arms
  - $1.2 < |\eta| < 2.4$
  - Momentum (MuTr)
- Muon Piston Calorimeter
  - $3.1 < |\eta| < 3.9$



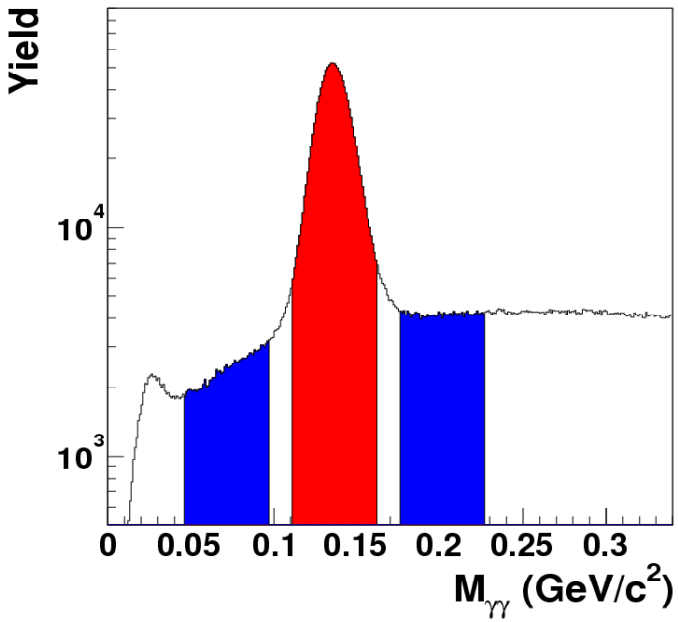
ΔG
DOUBLE HELICITY A_{LL} RESULTS

Probe	Advantage
π^0	Statistics
η	Different fragmentation
π^0 - π^0 correlation	Kinematic constraint
charged π	ΔG sign
heavy flavor decay e^-	Lower x, g-g dominant
MPC cluster	Lower x

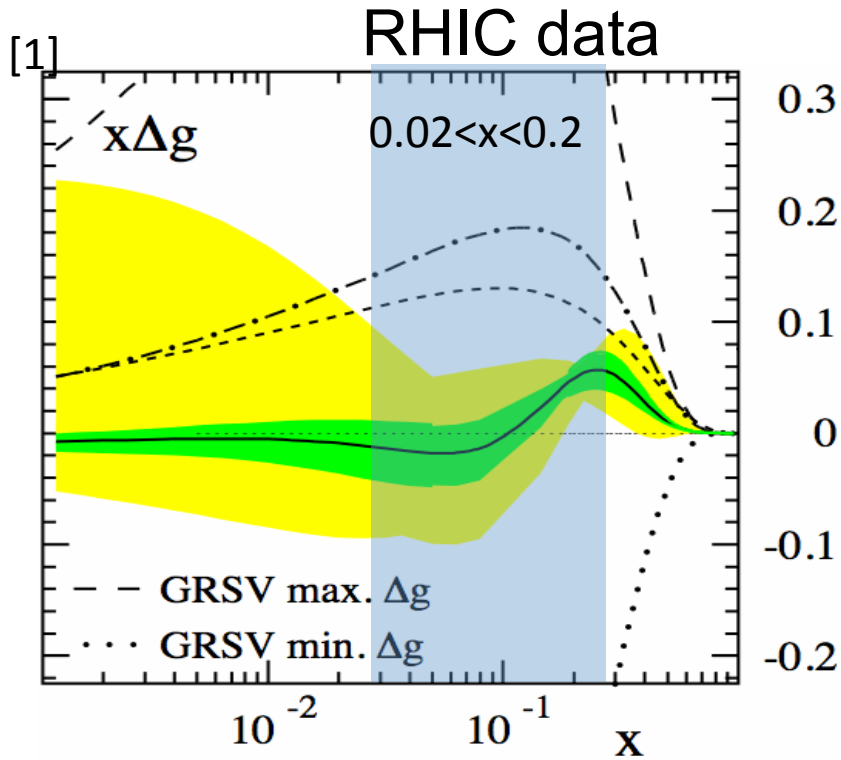
Central Arm π^0, η

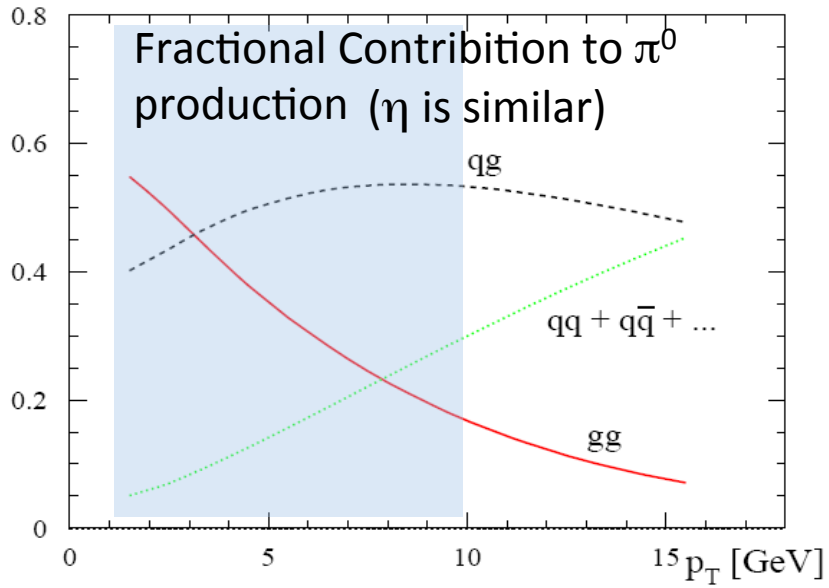
- Production cross section is high and from gluon interaction
- PHENIX EMCal trigger friendly
- Found in 2 photons invariant mass

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

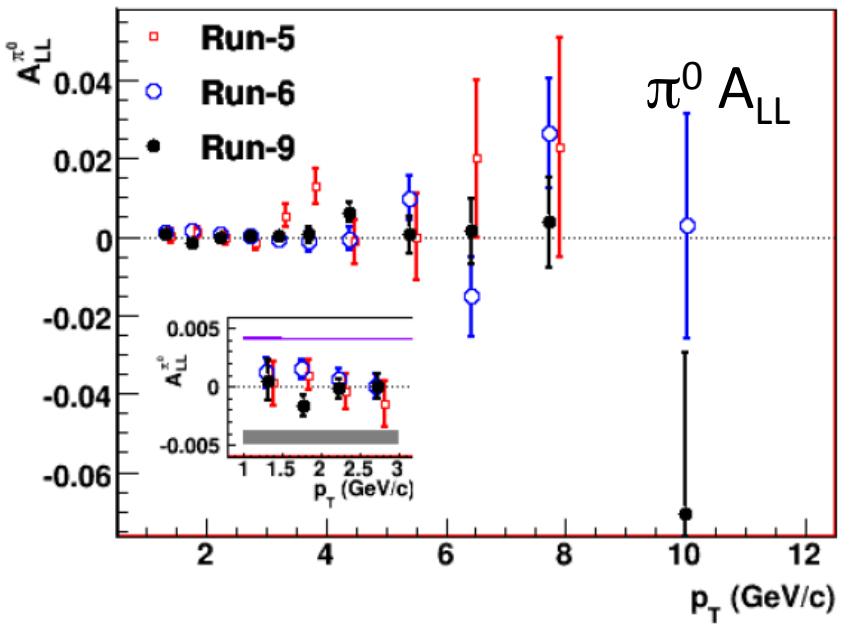


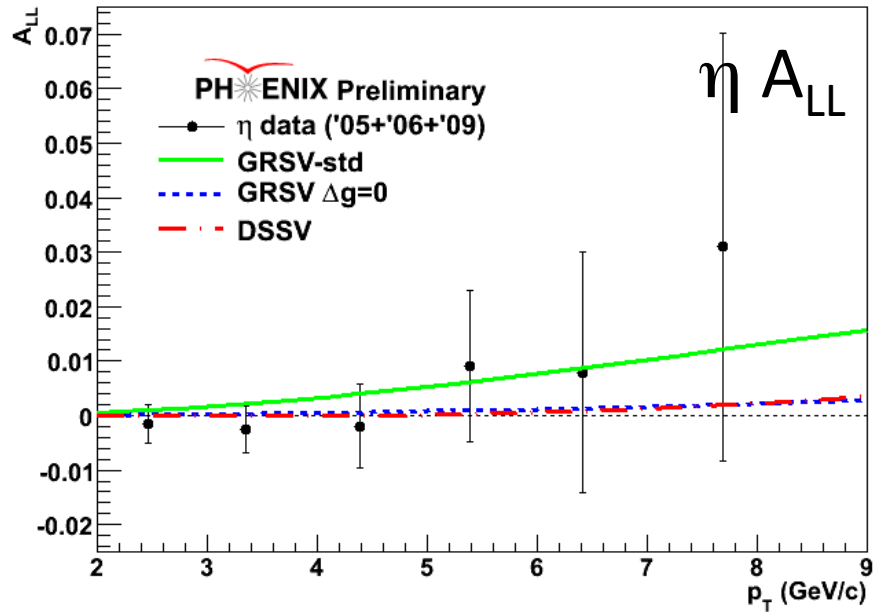
Phys. Rev. Lett. 101, 072001(2008)





A_{LL} : Central Arm π^0, η





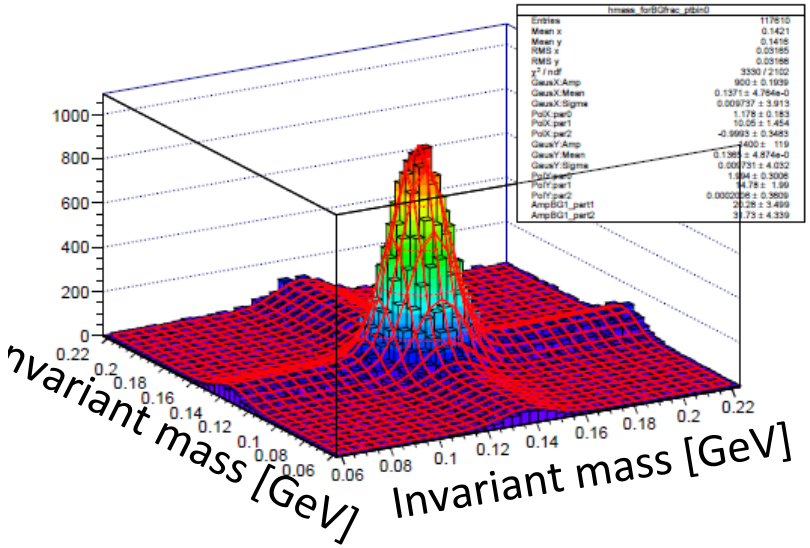
Statistically enriched observable

Need to control Systematic uncertainties (relative luminosity)

ΔG through
- a different flavor structure
- fragmentation function

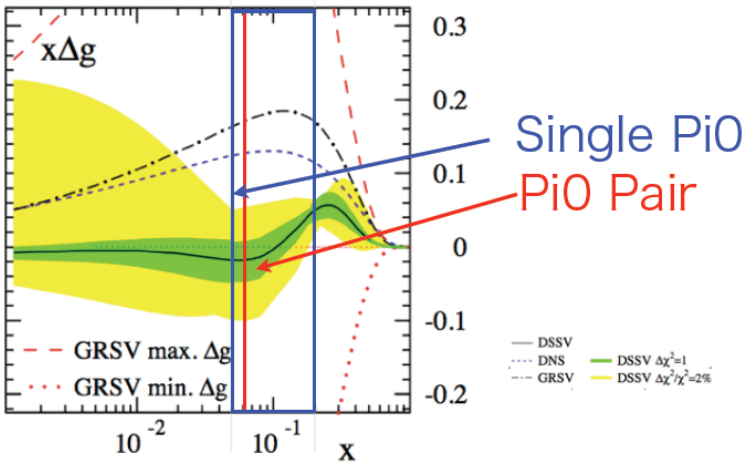
Statistically Challenging

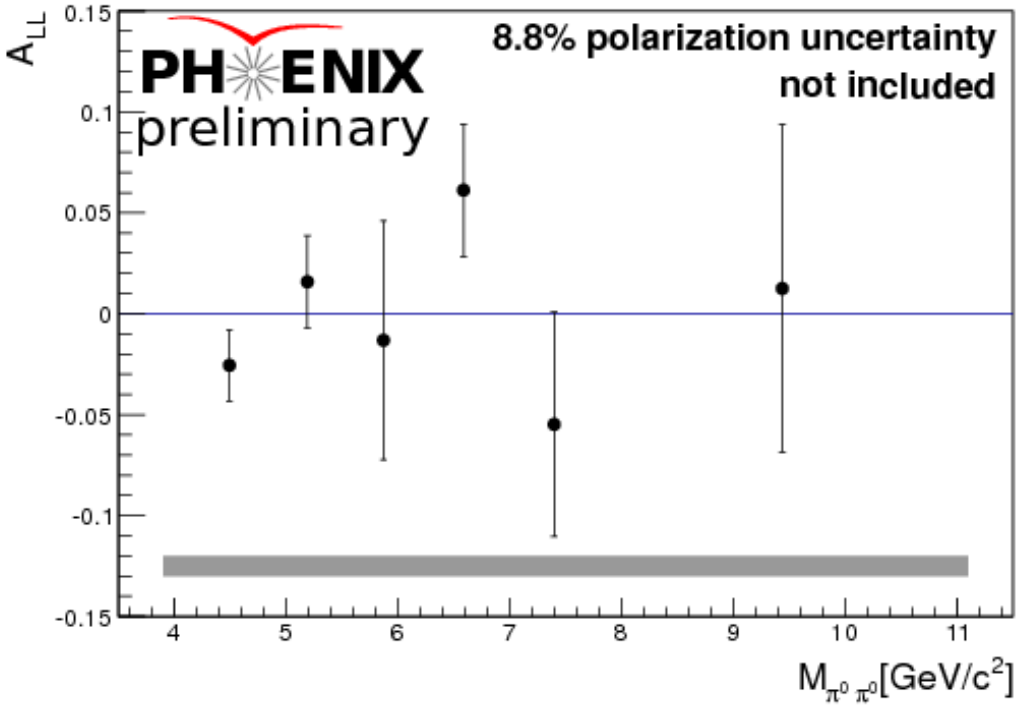
More Challenging Attempt : π^0-π^0 correlation



Constrains event kinematics further

Cost Statistics, need high P^4L



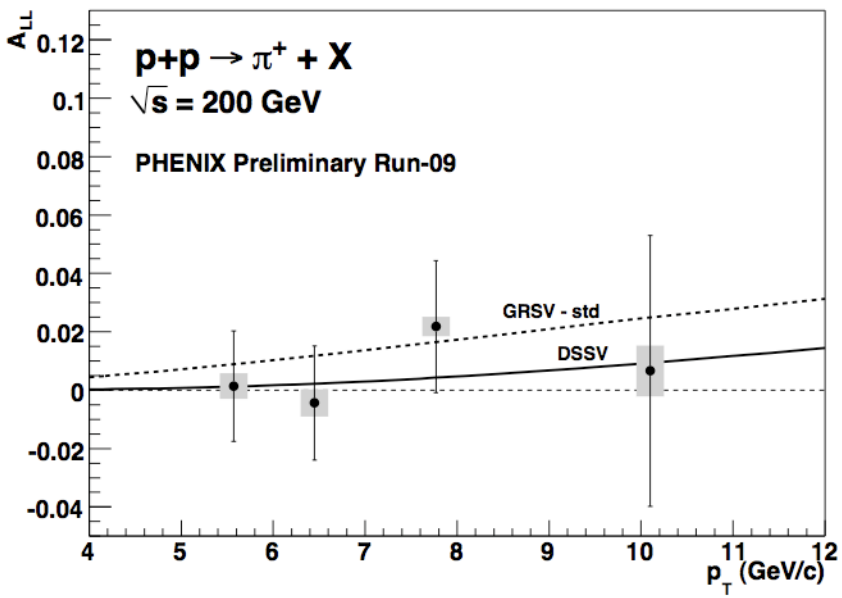


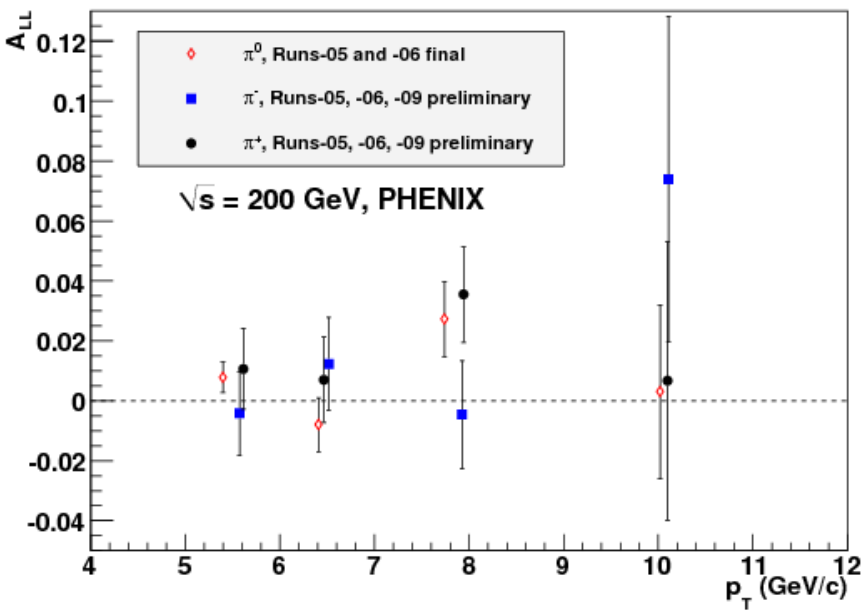
Preliminary Charged pion A_{LL}

- $\pi^{\pm}$ charge asymmetry is sensitive to sign of $\Delta g(x, Q^2)$:
  - $D_u^{\pi+} > D_u^{\pi0} > D_u^{\pi-}$, $\Delta u > 0$
  - $D_d^{\pi+} < D_d^{\pi0} < D_d^{\pi-}$, $\Delta d < 0$

  For positive Δg :

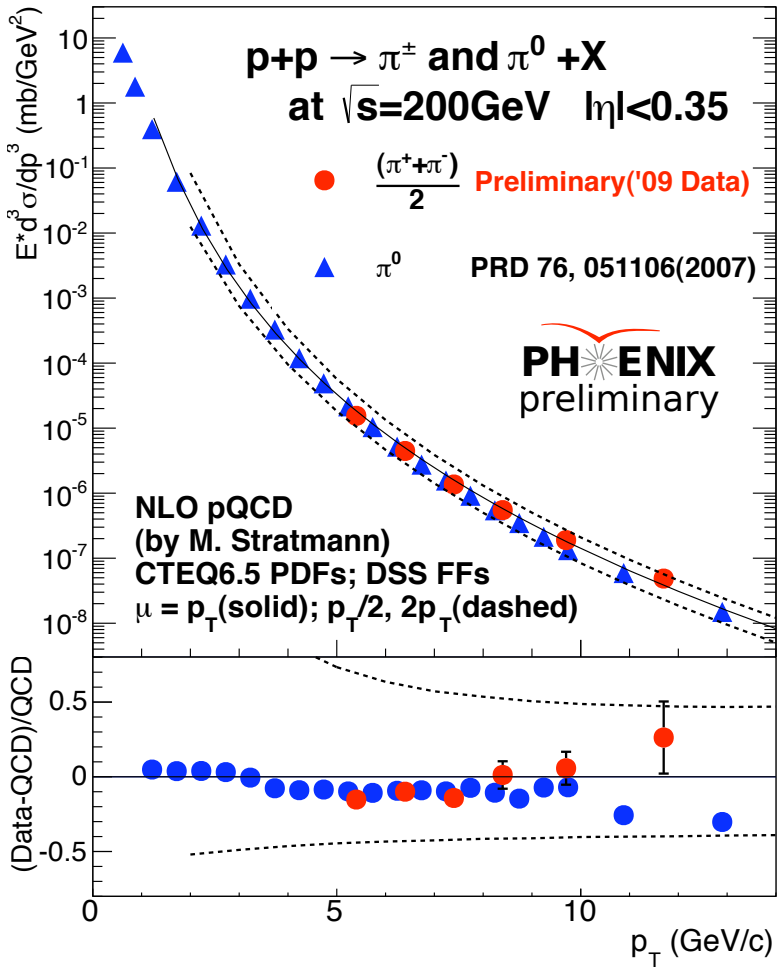
  $A^{\pi+}_{LL} > A^{\pi0}_{LL} > A^{\pi-}_{LL}$

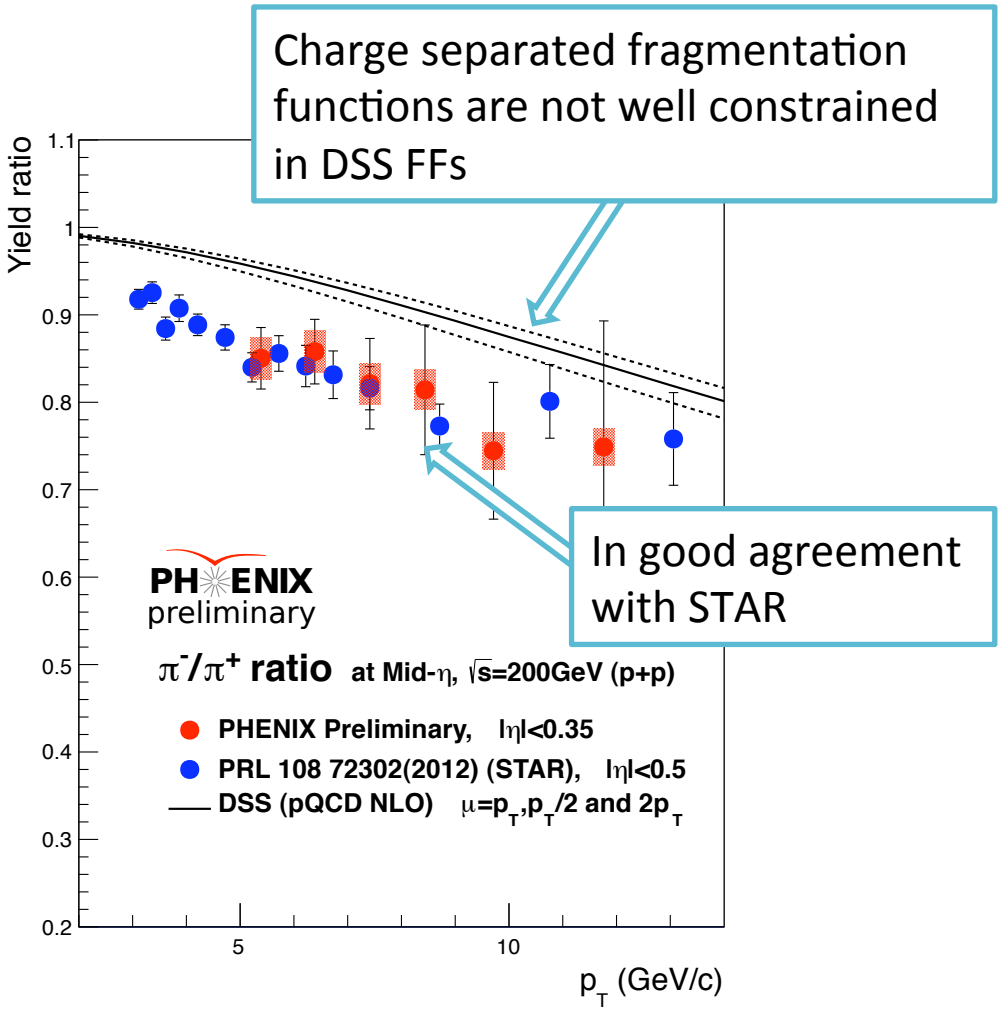




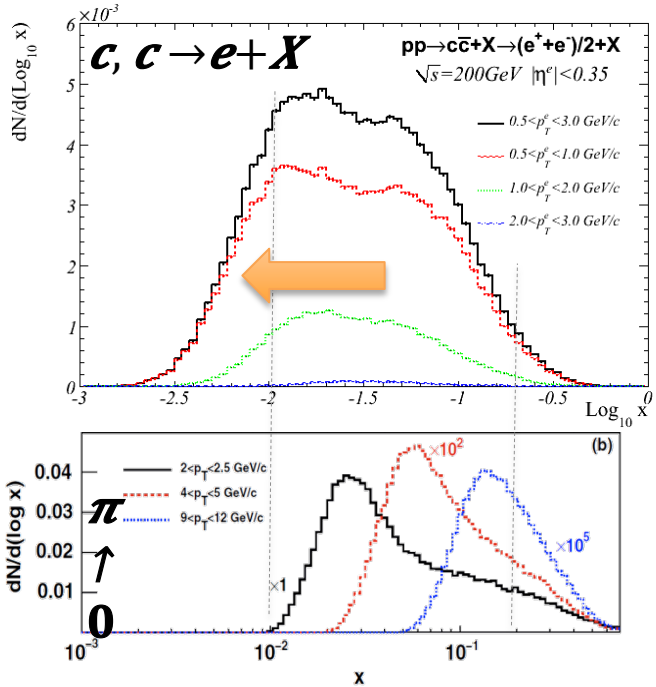
- p_T range of this analysis covers $\langle x_g \rangle \sim 0.1$

Charged pion Cross Section

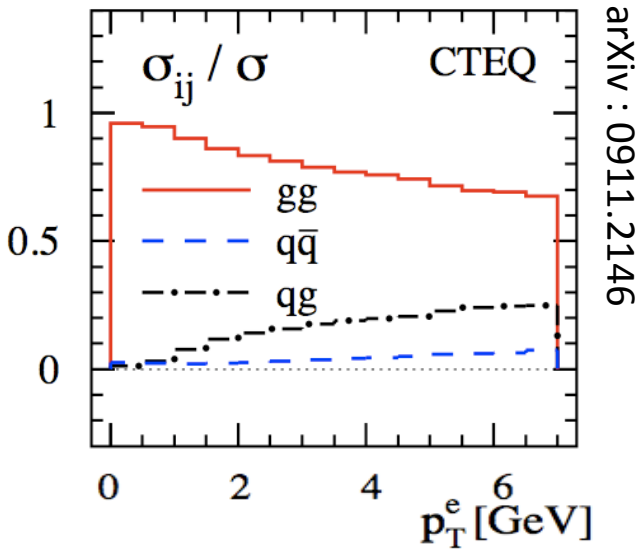




Heavy Flavor Decay Electrons

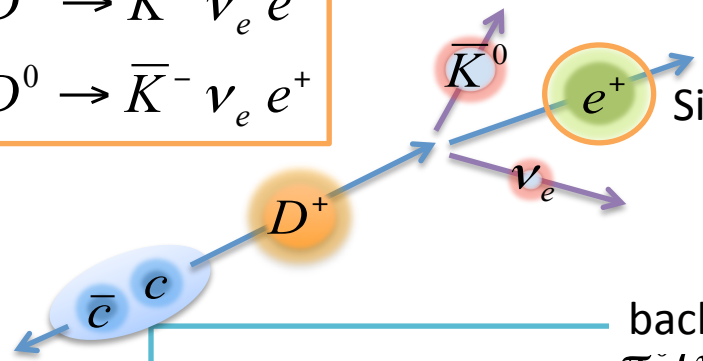


Subprocess fraction at NLO



signal

$$\begin{cases} D^{+} \rightarrow \overline{K}^{0}\, \nu_e\, e^{+} \\ D^{0} \rightarrow \overline{K}^{-}\, \nu_e\, e^{+} \end{cases}$$

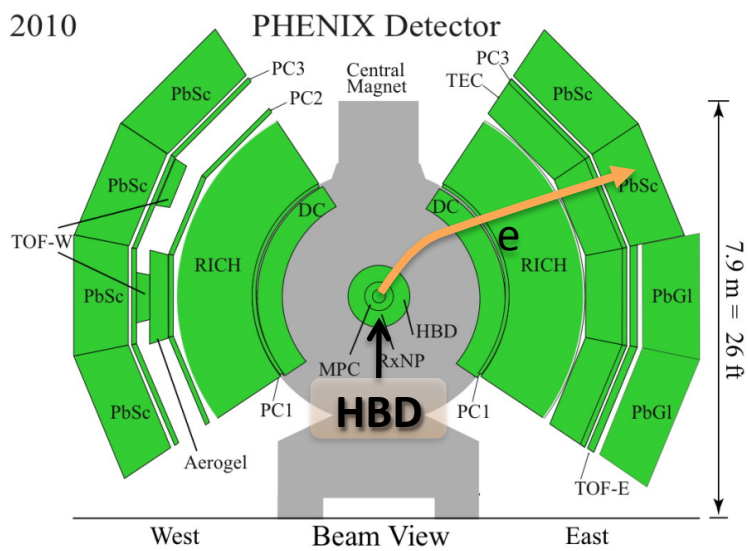


Signal electron

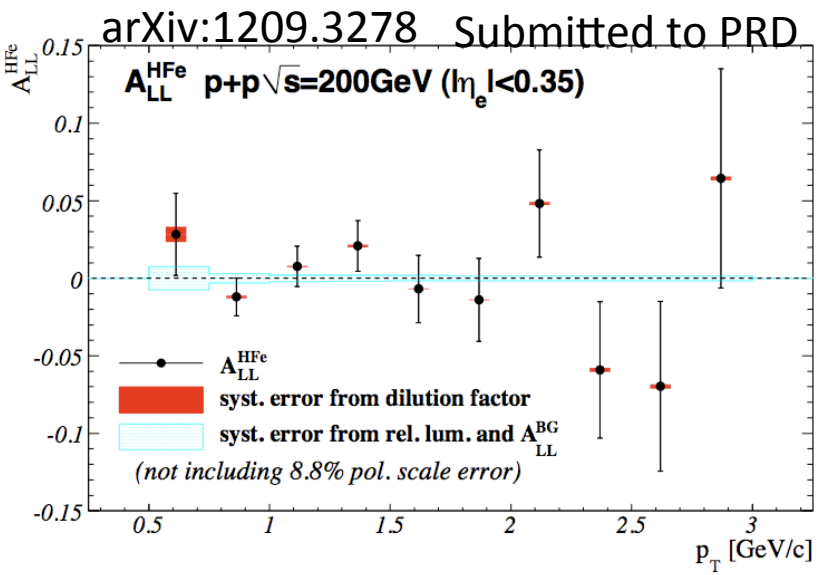
backgrounds

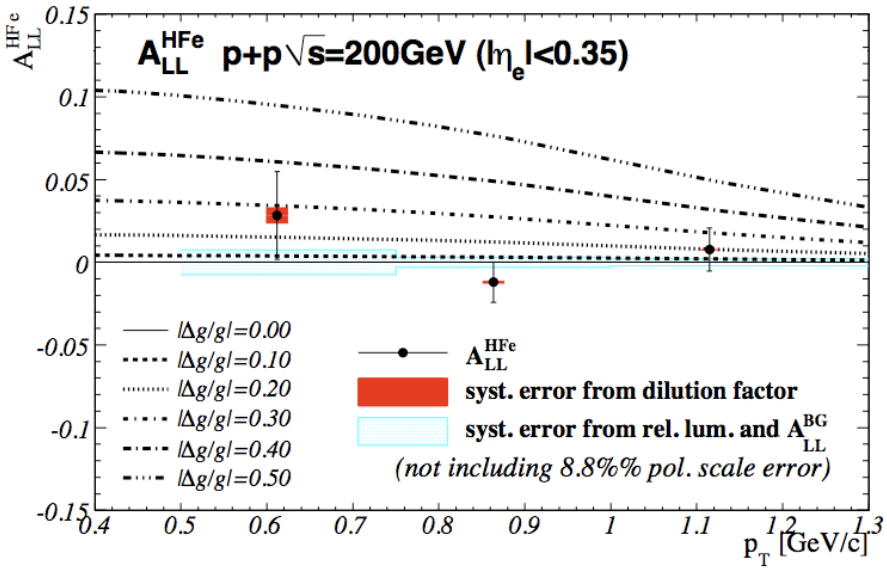
$$\pi^{0}(\eta) \rightarrow \gamma\, e^{+} e^{-}$$

$$\pi^{0}(\eta) \rightarrow \gamma\gamma \quad \gamma \rightarrow e^{+}e^{-} \text{ (in material)}$$



ΔG Extraction from A_{LL}^{HFe}



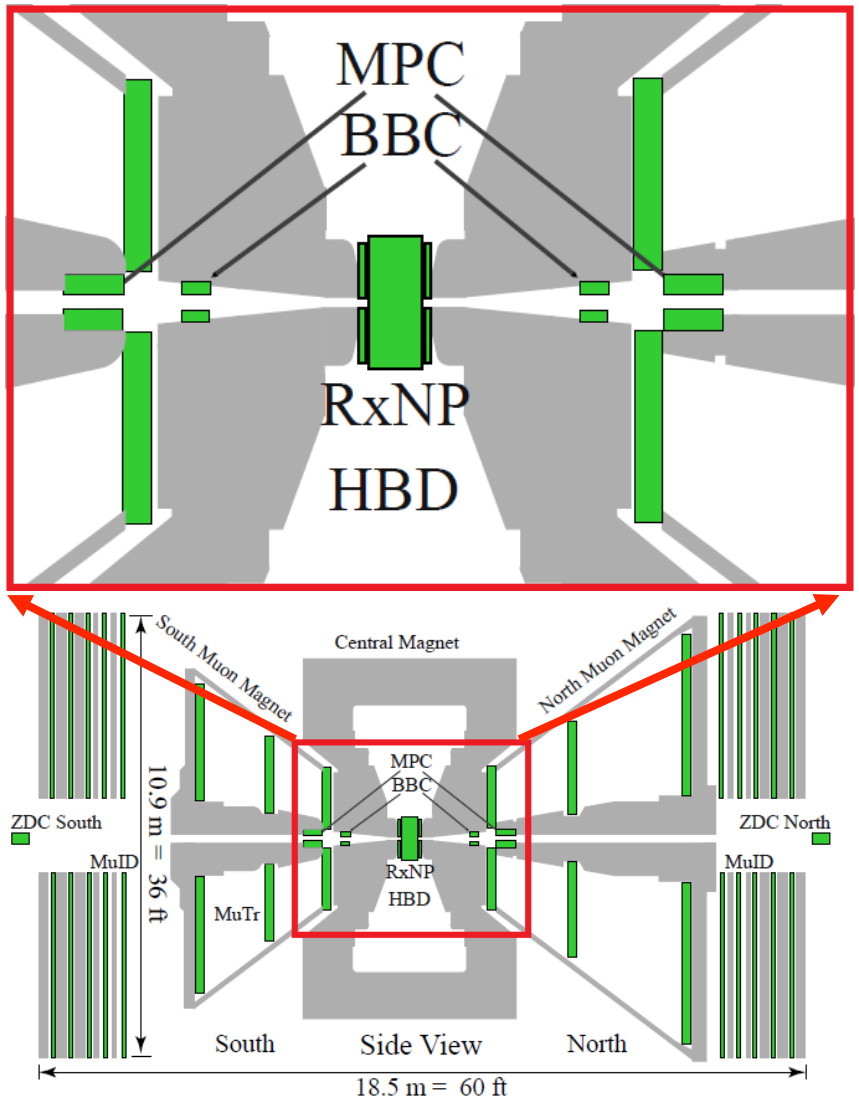


- This results largely benefited from using HBD in eliminating photo-conversion and Dalitz decay background.
- Decay electrons include J/ψ , bottom production and other vector meson as well as open charm contributions.
- Open charm production dominates in p_T range of 0.50 < pT < 1.25 GeV/c

  (J/ψ <2%, b quark<5%)
- $|\Delta g/g(\langle \log x \rangle, \mu)|^2 < 3 \times 10^{-2}$ (1σ)

  (0.01 ~ x ~ 0.08)

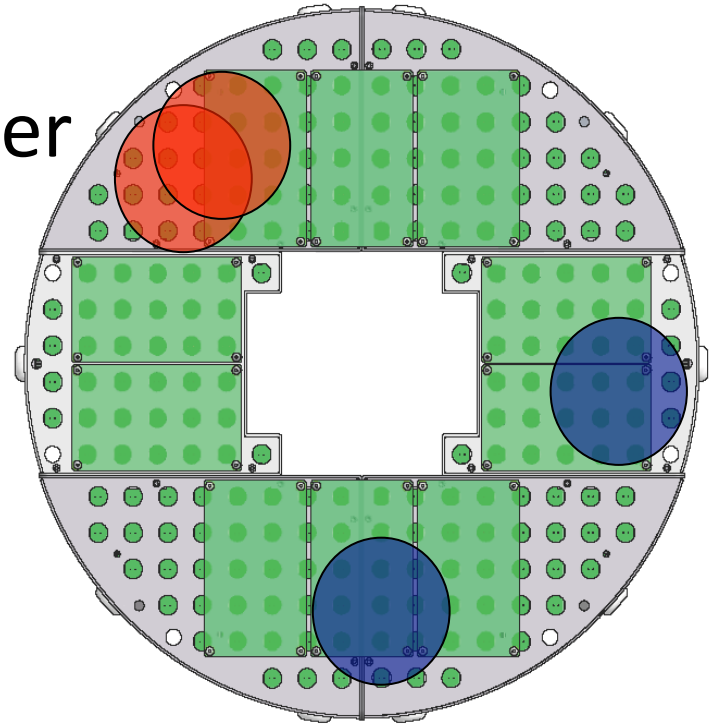
Exploring Lower-x by Forward MPC



Muon Piston Calorimeter
3.1<|η|<3.9

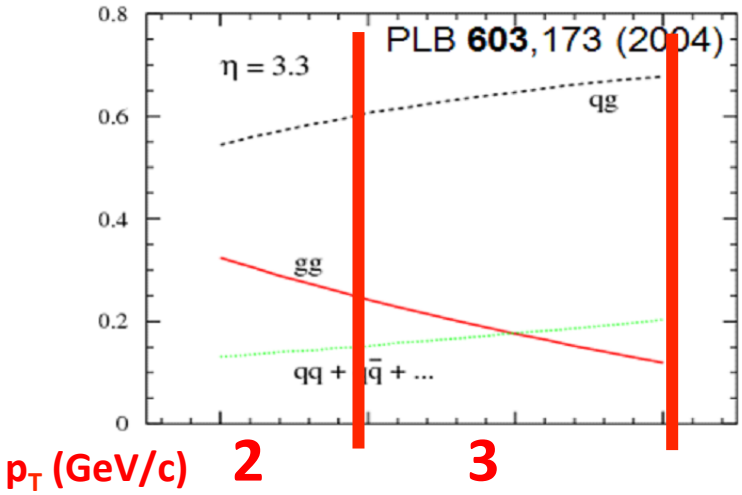
- **Low P_T Reconstructed π^0**
- **High PT Merged π^0**

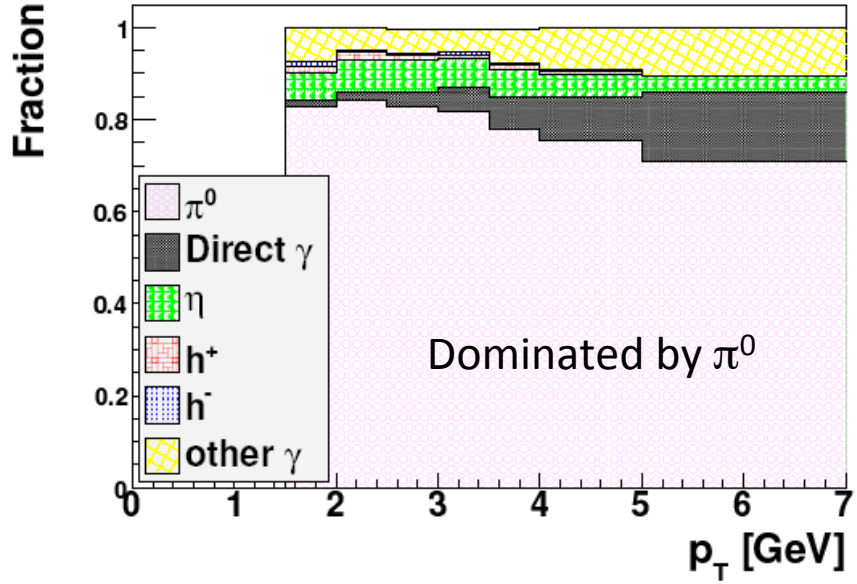
cluster

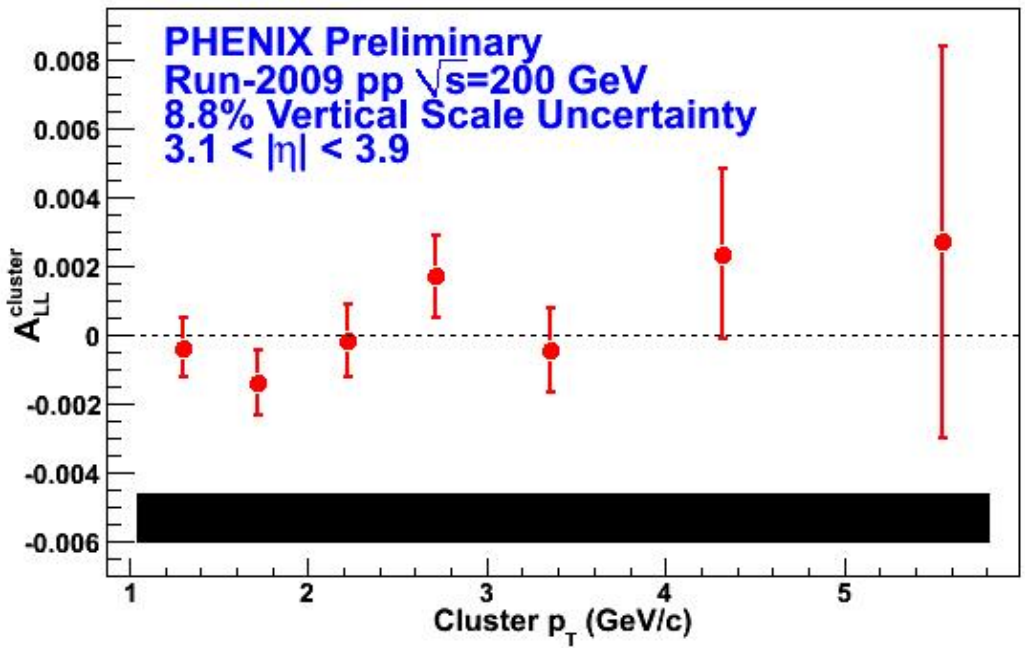


Range
0.05<x<0.2

Cluster A_{LL}

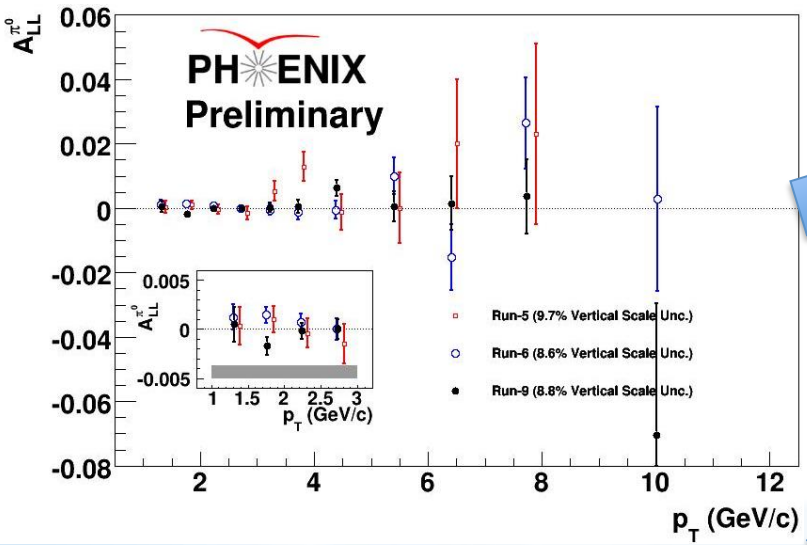


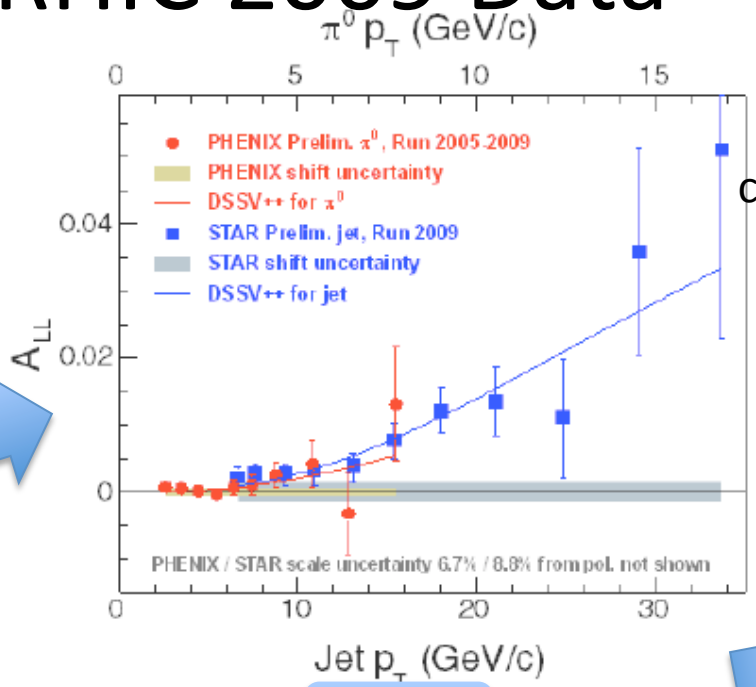




- Still consistent with zero at lower x
- Systematic error starts to defeat statistics
- Good control of relative luminosity required for better precision

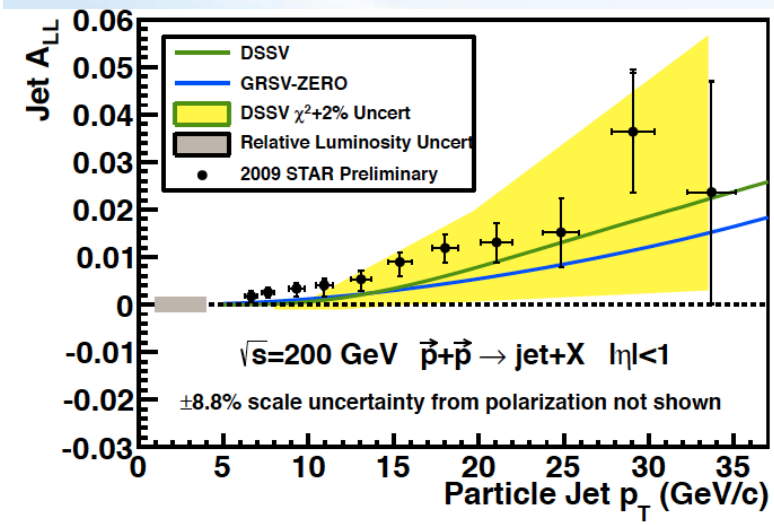
Impact of RHIC 2009 Data

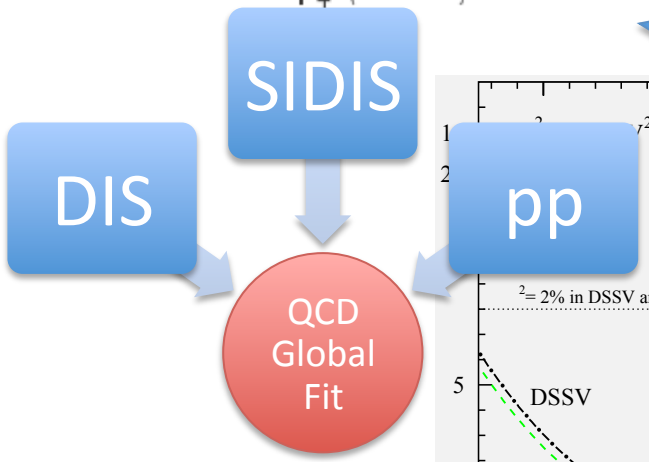


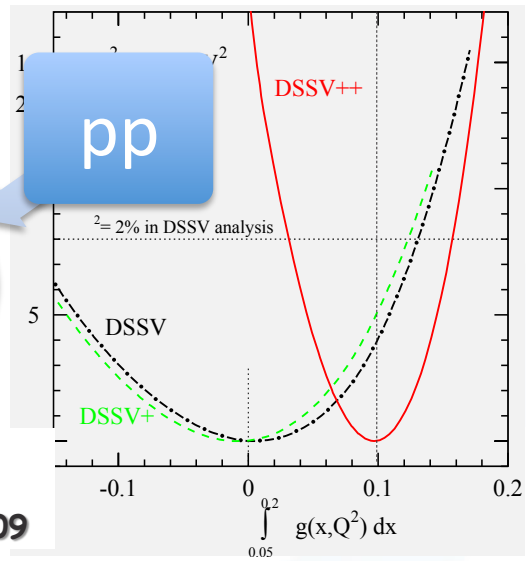


consistent!

Global Fit



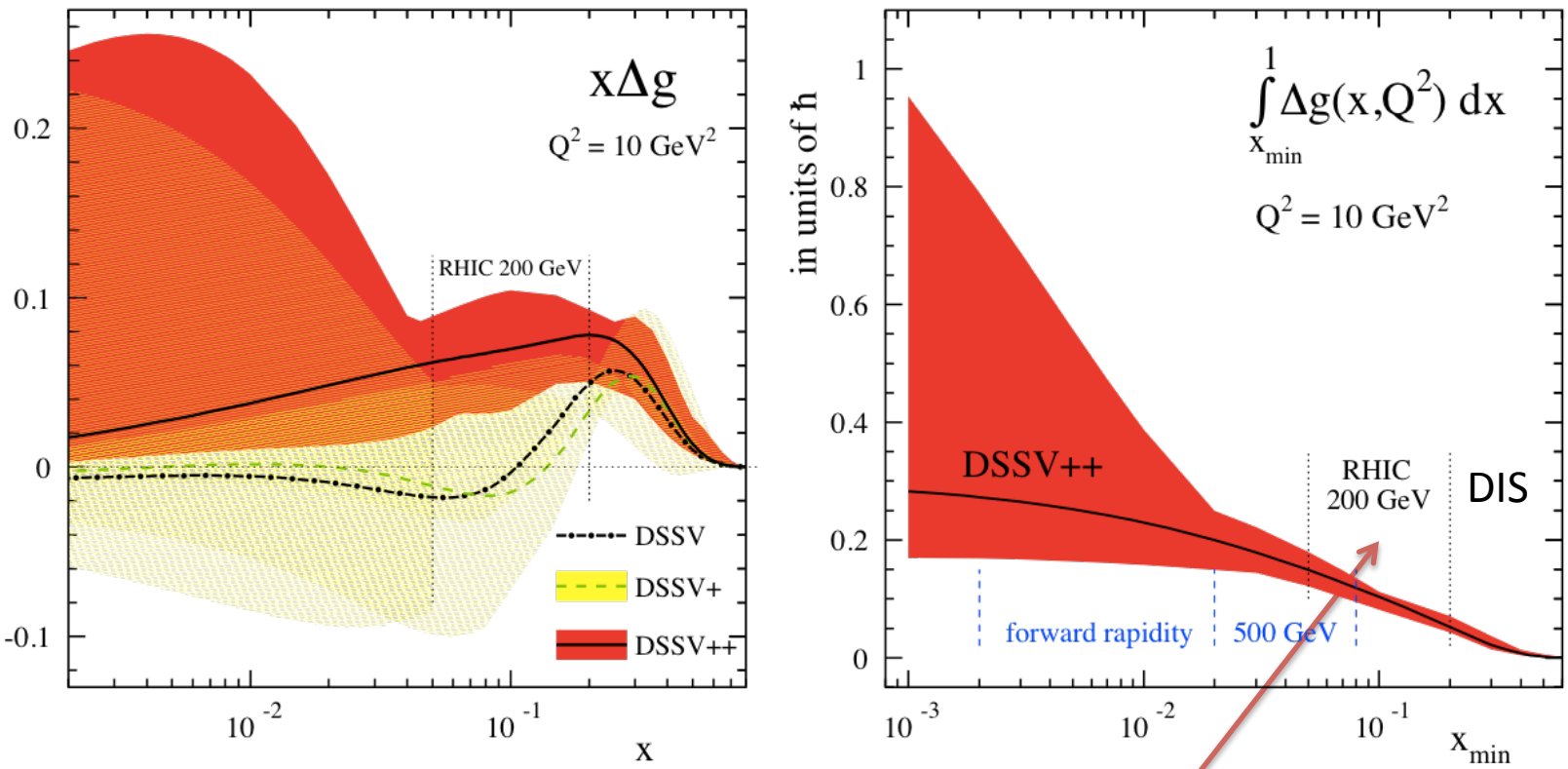




DSSV: arXiv:0904.3821
DSSV+: DSSV+COMPASS
DSSV++: DSSV+ & RHIC 2009

pQCD Fit on Latest (Run9) Data

DSSV++ (with latest results)



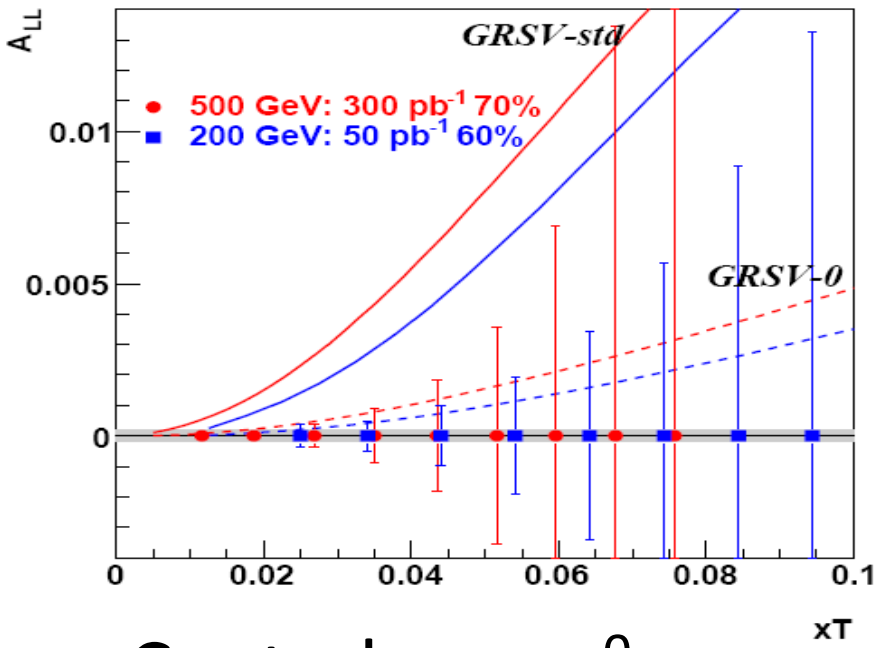
First Positive Polarization ΔG Result : $\int_{0.05}^{0.2} \Delta g(x)\, dx = 0.1 \pm^{0.06}_{0.07}$

http://www.bnl.gov/npp/docs/RHIC-Spin-WriteUp-121105.pdf

ΔG @ 510 GeV

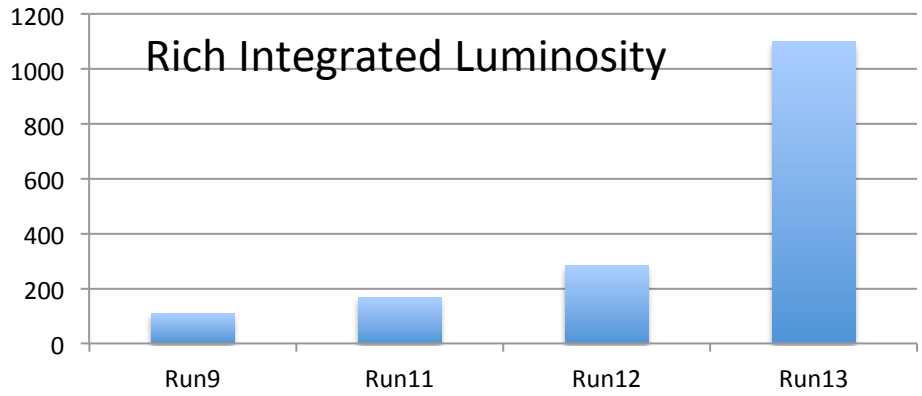
Access to smaller x region

Larger error @ overlapping x compared to 200GeV

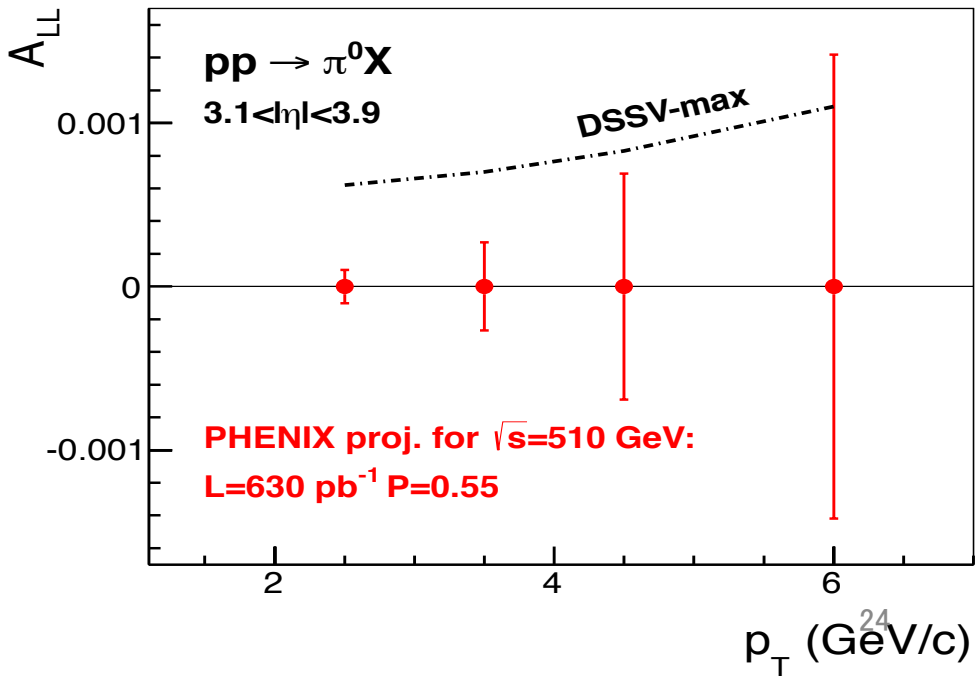


Central arm π^0

500 (510) GeV Integrated Luminosity (Delivered)



MPC π0 for ΔG at low x

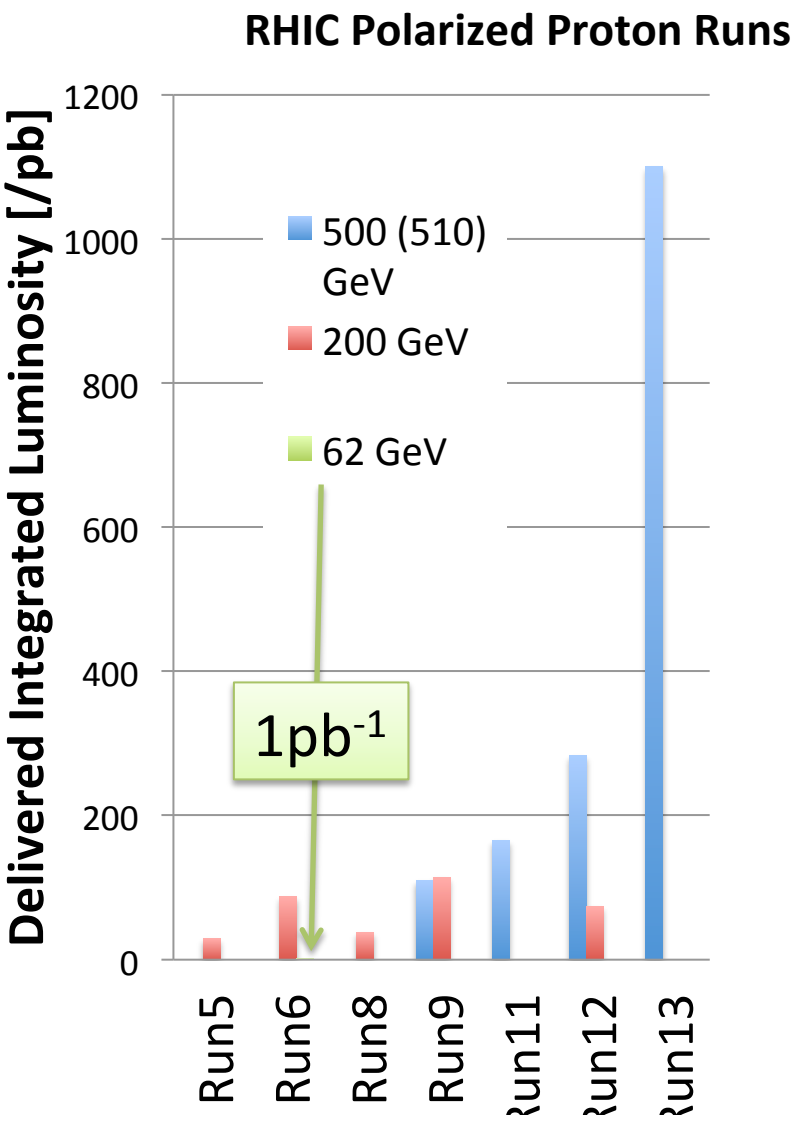


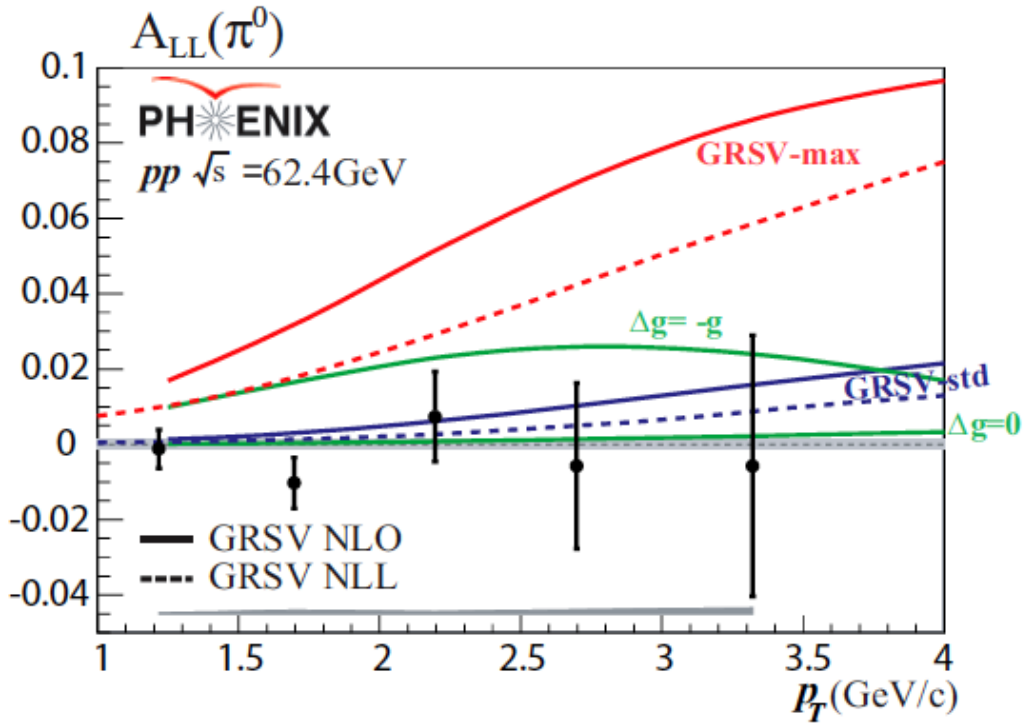
Summary

- Measurements of gluon polarization at PHENIX through double longitudinal asymmetry.
- Various observables provide different sensitivities on ΔG sign, fragmentation functions.
- The first indication of positive ΔG from 2009 200 GeV data.
- More data to come from 510 GeV which cover smaller x region.

BACKUP SLIDES

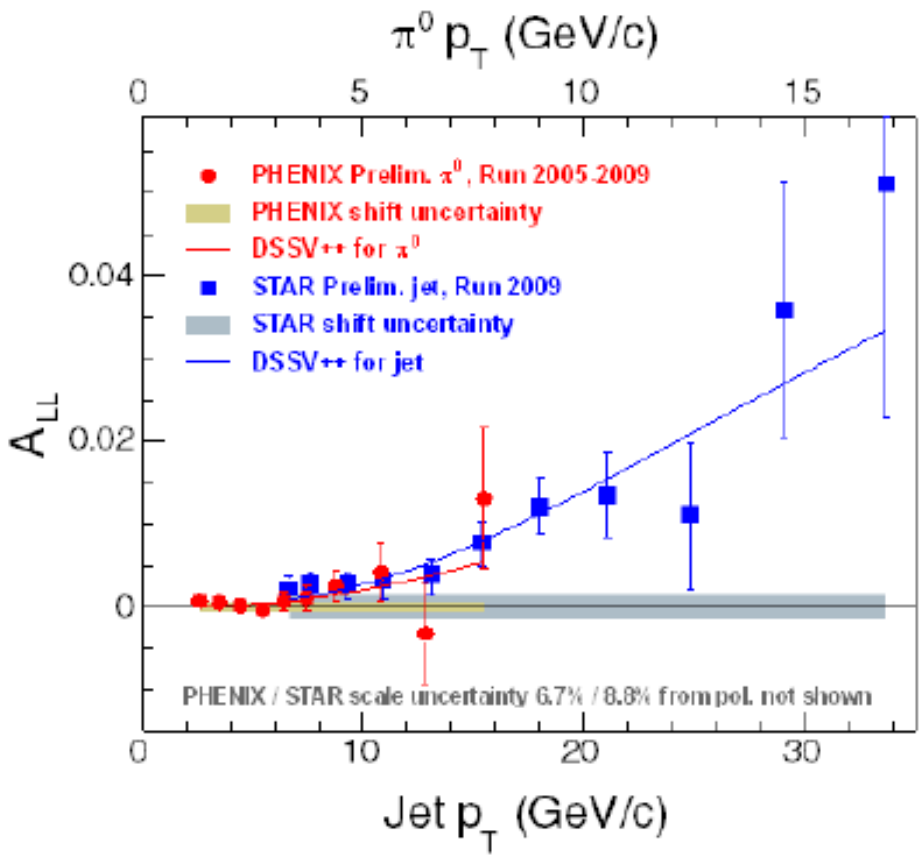
ΔG @ 62 GeV

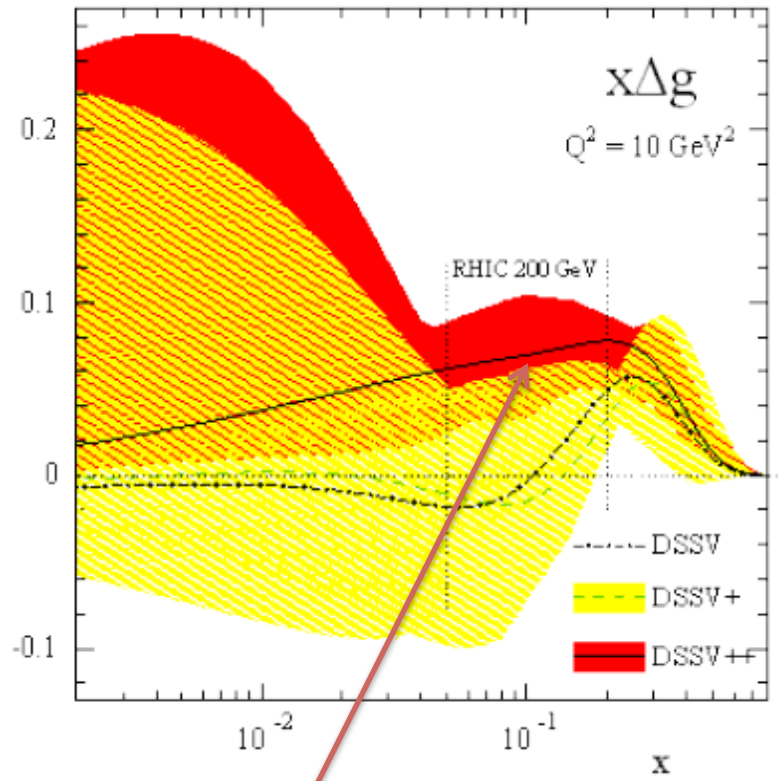

RHIC Polarized Proton Runs
Delivered Integrated Luminosity [/pb]
1200
1000
800
600
400
200
0
500 (510) GeV
200 GeV
62 GeV
1pb-1
Run5
Run6
Run8
Run9
Run11
Run12
Run13


$A_{LL}(\pi^0)$
PHENIX
pp $\sqrt{s}$ =62.4GeV
GRSV-max
Δg= -g
GRSV-std
Δg=0
GRSV NLO
GRSV NLL
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
1
1.5
2
2.5
3
3.5
4
p_T(GeV/c)

pQCD Fit on Latest (Run9) Data

DSSV++ (with latest results)



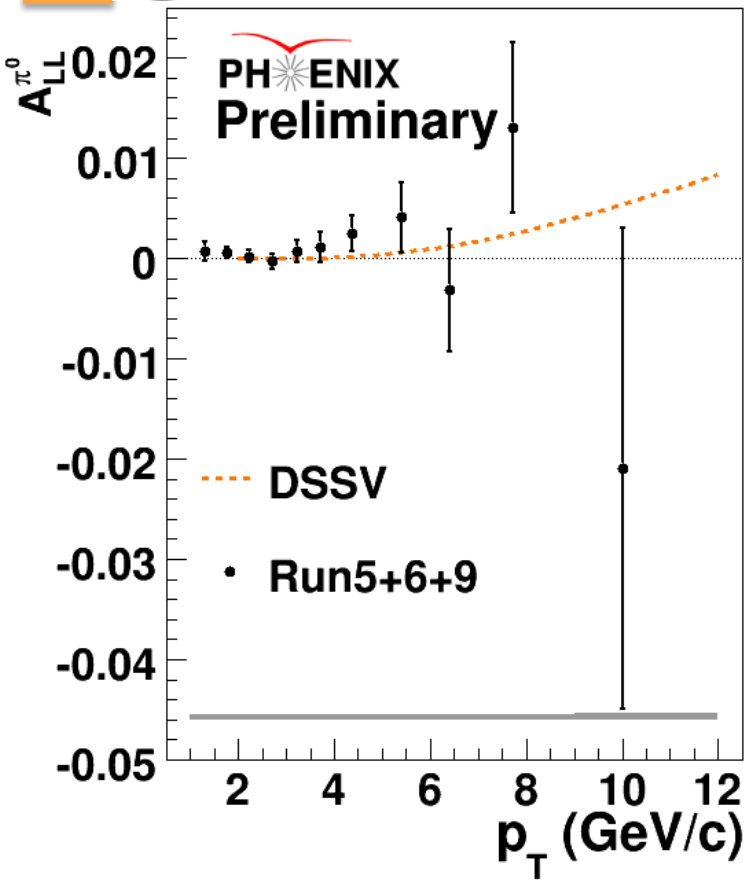


First Positive Polarization ΔG Result : $\int_{0.05}^{0.2} \Delta g(x)\, dx = 0.1 \pm^{0.06}_{0.07}$

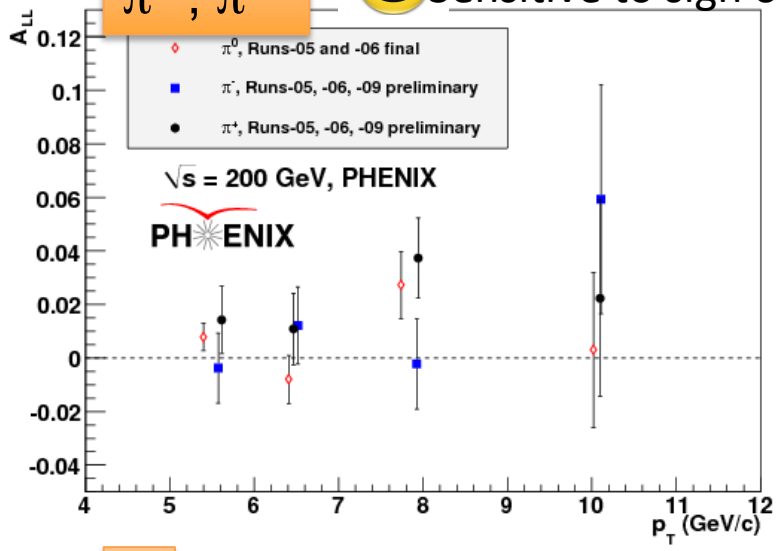
Polarized gluon distribution (I)

- *Central Rapidity*

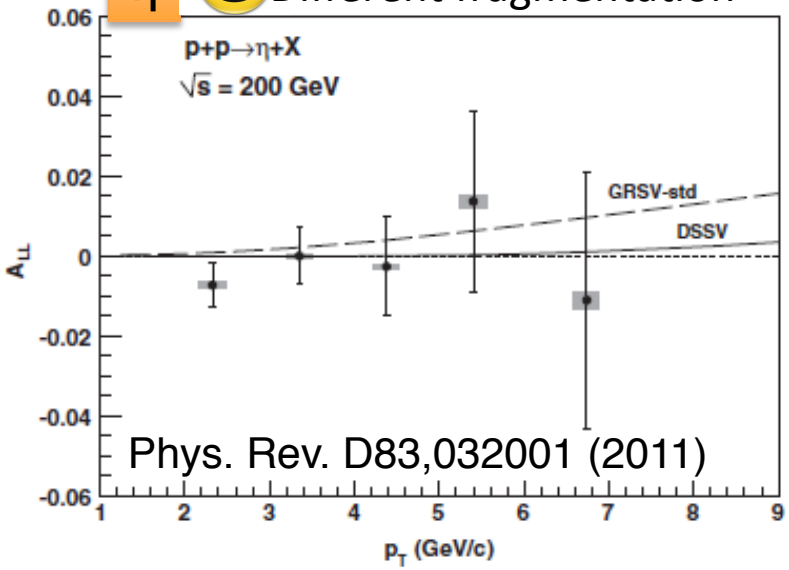
π^0 Abundant Statistics



π^0 , $\pi^{+/-}$ Sensitive to sign of Δg



η Different fragmentation



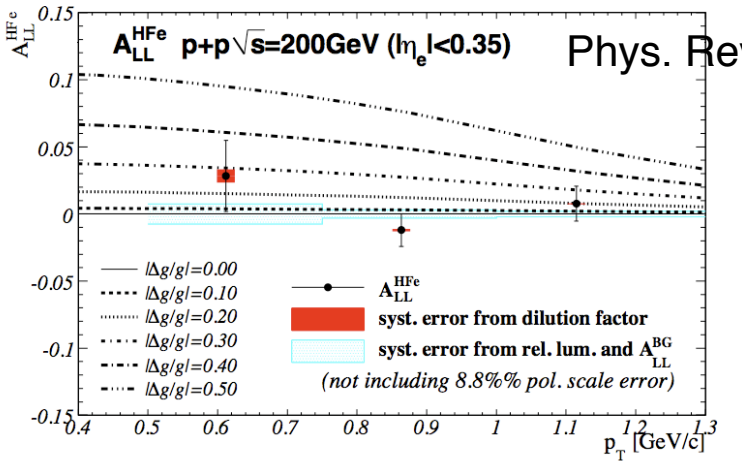
Phys. Rev. D83,032001 (2011)

Polarized gluon distribution (II)

- *Central + Forward Rapidity, Low Energy*

Single e

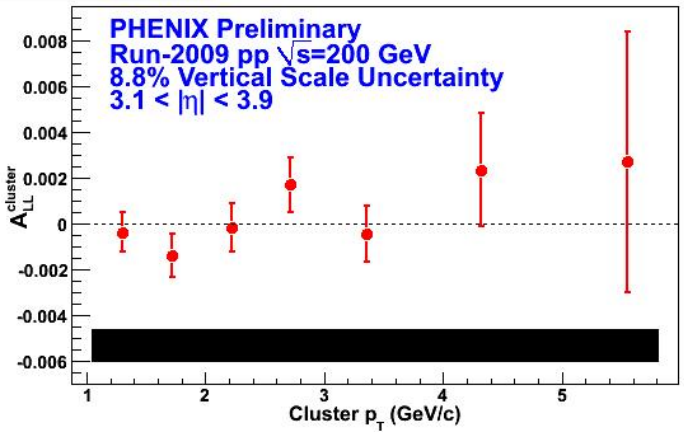
High purity of glue-glue subprocess



Phys. Rev. D87, 012011 (2013)

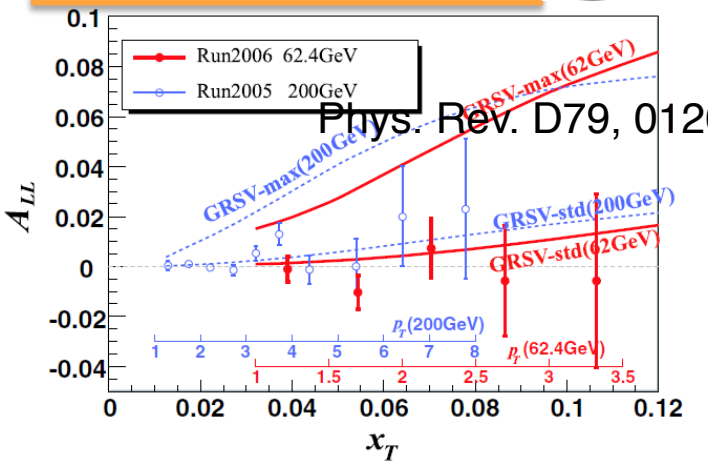
Forward Cluster

Small x ~ 10^{-3}



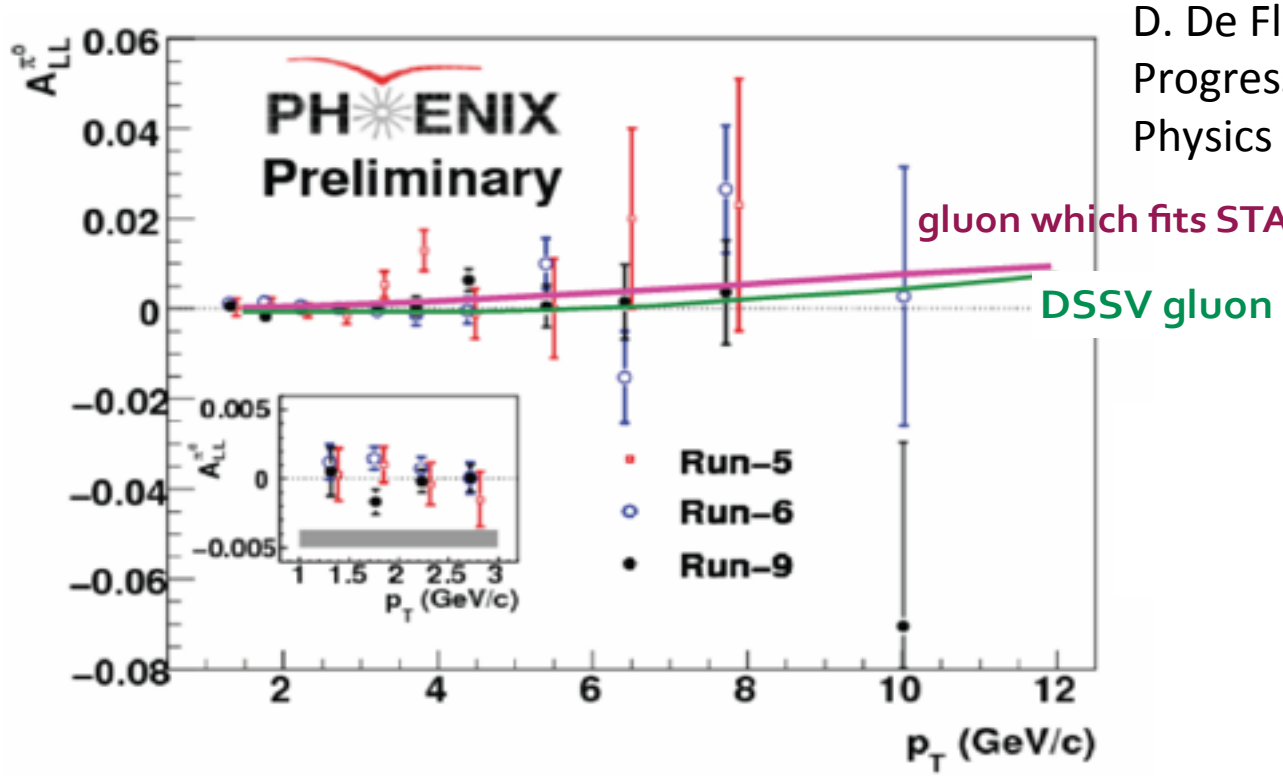
π^0 at $\sqrt{s}$ = 62.4 GeV

High x



Phys. Rev. D79, 012003 (2009)

DSSV Interpretation of π^0 A_{LL}



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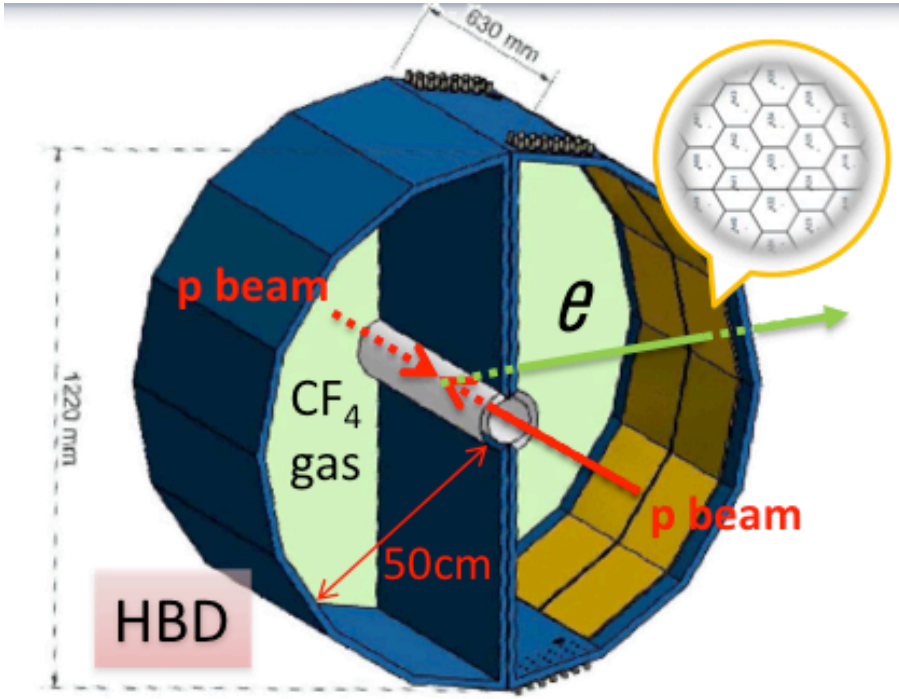
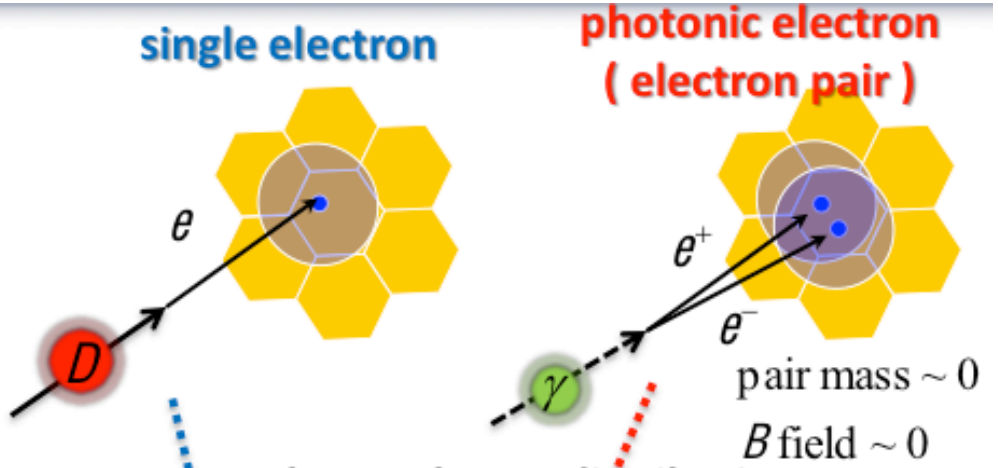
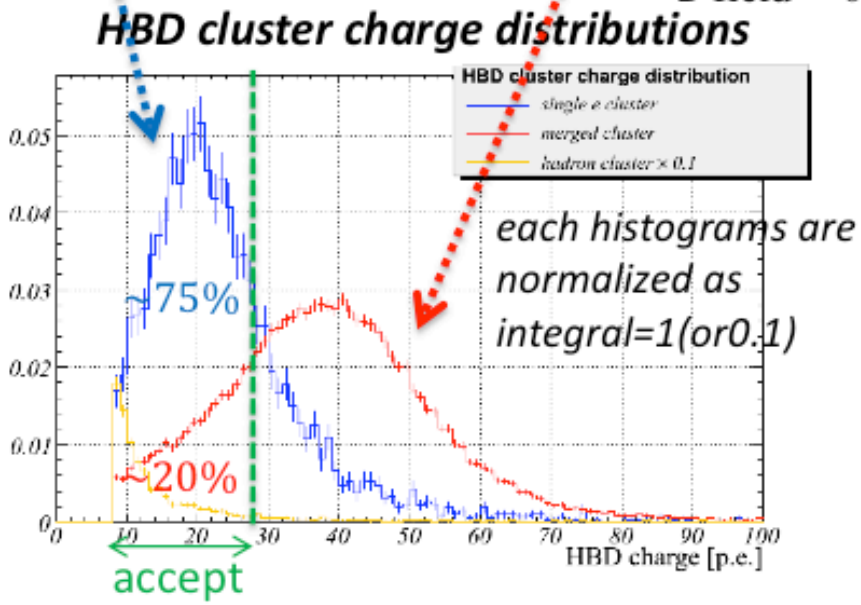
- Run5+Run6+Run9 Combined data constrain ΔG
- Consistent with small A_{LL}, but still compatible with STAR jet -> probes somewhat lower values of x

HBD Analysis for Heavy Flavor Decay e^-

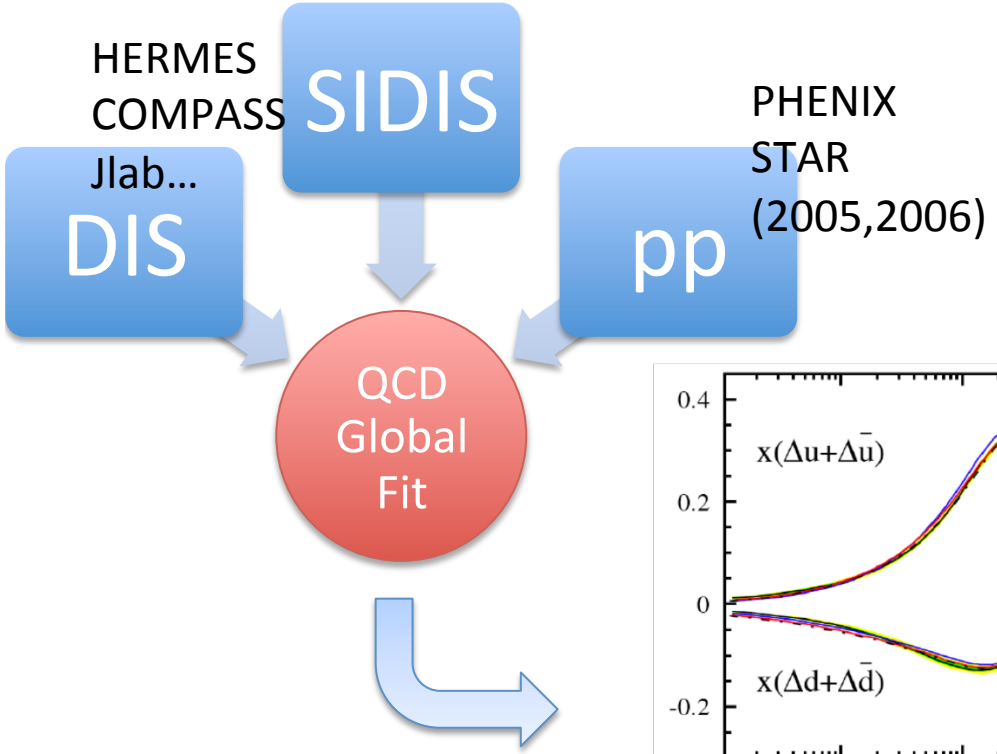




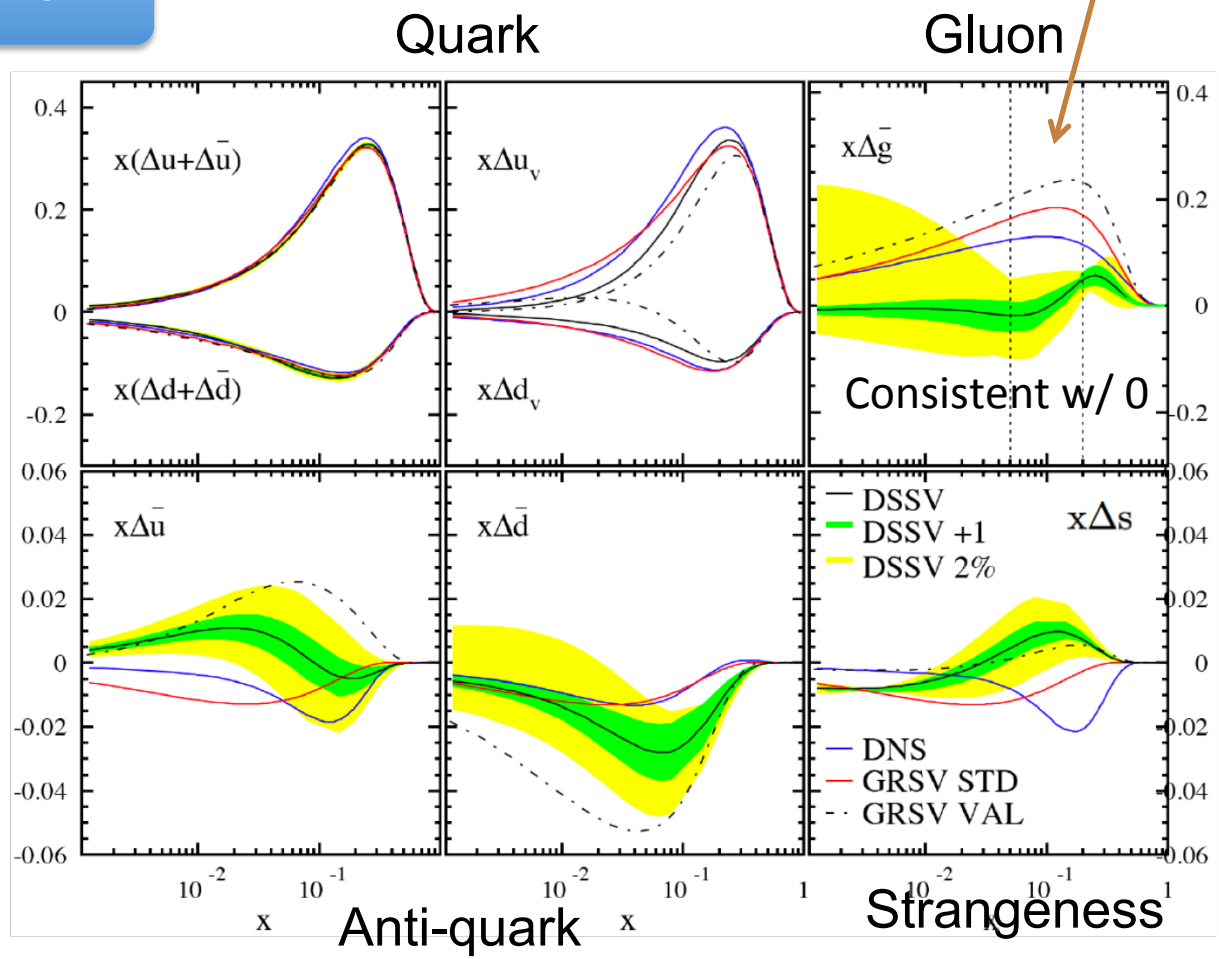


- **Hadron Blind Detector**
  - gas Cerenkov detector read out with CsI evaporated GEM
  - ***electron identification***
- **this analysis is the first time of physics measurement with HBD**

Extraction of Gluon Polarization



RHIC data constrain on gluon polarization!



PRD 83,032001 (2011)

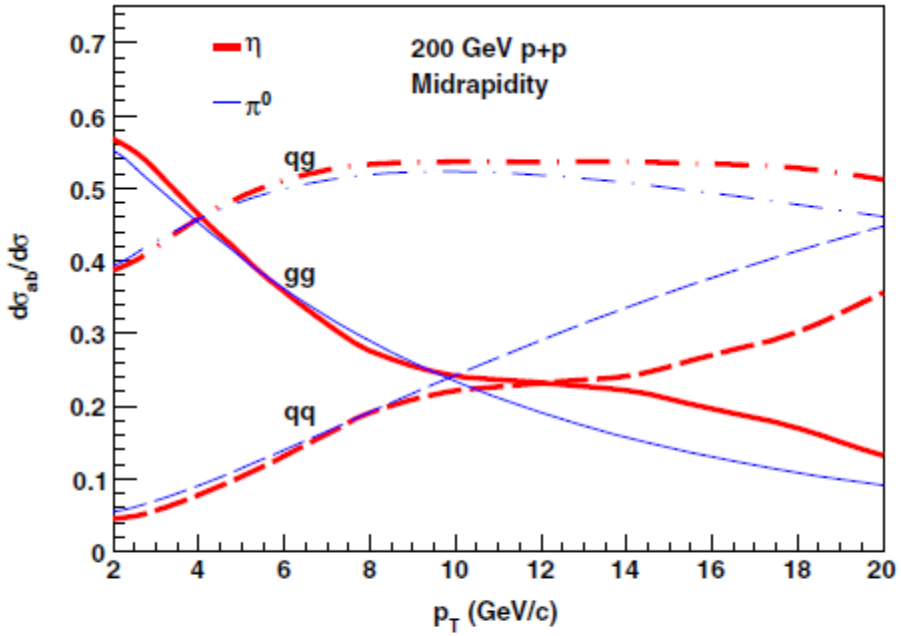


FIG. 4 (color online). The fractional contribution of gluon-gluon (gg), quark-gluon (qg), and quark-quark (qq) scattering to the η production in the pQCD calculation of Fig. 3, and to the π^0 production [24], as a function of p_T.

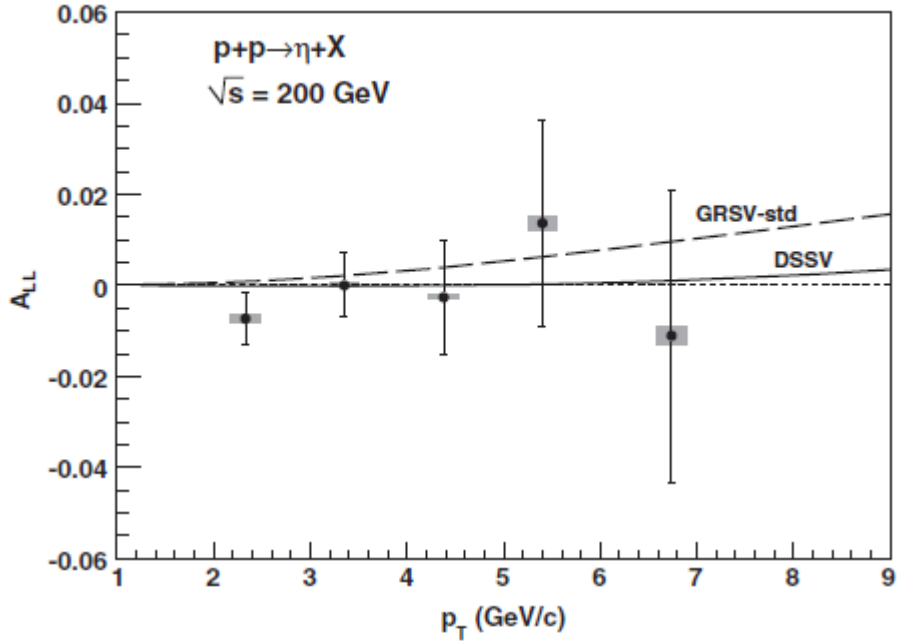


FIG. 6. The double-helicity asymmetry for midrapidity inclusive η production from the combined 2005 and 2006 data at $\sqrt{s} = 200$ GeV as a function of p_T. The gray boxes are point-to-point systematic uncertainties due to polarization and relative luminosity uncertainties and are correlated point-to-point, moving all points in the same direction but not by the same factor. An additional systematic uncertainty of 4.8% on the vertical scale due to the uncertainty in the beam polarizations is not shown. The results are compared to NLO pQCD calculations using two different sets of polarized PDFs [6,32]. See text for details.