Gluon polarization: status and plans for measurements at PHENIX

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For the PHENIX collaboration

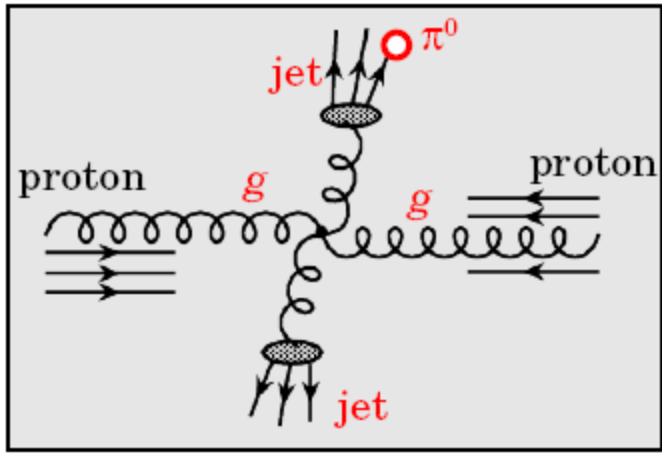
Outline

- Introduction
- RHIC performance and PHENIX experiment
- PHENIX cross section & double longitudinal asymmetry (A_{LL}) measurements
- Extracting ΔG from A_{LL}
  - resulting constraint on ΔG
- Experimental and theory uncertainties on ΔG
- Summary and Outlook

Introduction

- Proton spin structure, $\frac{1}{2}_{proton} = \frac{1}{2}\sum_q \Delta q + \Delta G + L_q + L_g$
  - Proton spin puzzle (1988 EMC experiment)
  - Global analysis, $\Delta q \sim 25\%, Q^2 = 10\ GeV^2$[PRL101:072001,2008]
  - ΔG not well constrained by fits to pDIS , $g_1(x, Q^2)$, at this time
- Polarized p+p collisions for ΔG measurement
  - π^0, jet , direct photons etc.
  - double helicity asymmetry (A_{LL})

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$



- Inclusive π^0 at mid-rapidity ($|\eta| < 0.35$) is PHENIX main channel for the determination of ΔG at this time.

Extracting ΔG from A_{LL} measurements

- Theory interpretation of A_{LL} ,

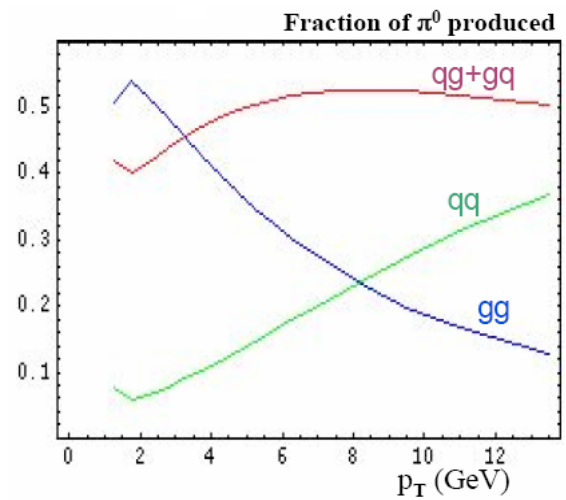
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma} \otimes D_{\pi/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{\pi/c}}$$

- pol. (Δf) and unpol. pdf's (f) from DIS (mainly)
- pol. (Δσ) and unpol. (σ) hard scattering cross section from NLO PQCD
- fragmentation functions ($D_{\pi/c}$), from $e^+ e^-$, Semi Inclusive DIS and pp

- Three processes contribute to A_{LL},

$$A_{LL} \simeq a_{gg}\Delta g^2 + b_{gq}\Delta g\Delta q + c_{qq}\Delta q\Delta q$$

- Need to make sure pQCD, factorization, universality in pdf and fragmentation WORK



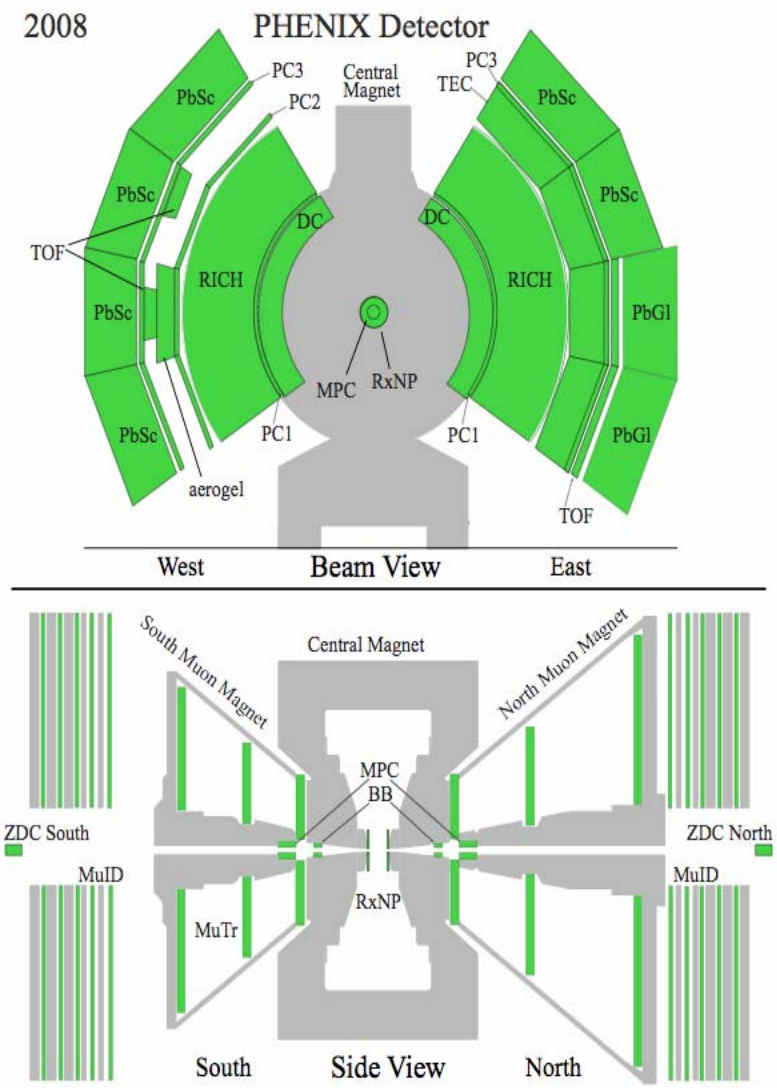
Relativistic Heavy Ion Collider (RHIC)

- Data accumulation in longitudinally polarized p+p Runs
- 2005+2006 ~ 200 times increase in FOM than 2003+2004
- 2009 run at $\sqrt{s}$ = 500 GeV , L *~ 13 pb^{-1} , P ~ 40%
- low $\sqrt{s}$ run for better sensitivity to large x

Longitudinal

Year	$\sqrt{s}$ [GeV]	L [pb^{-1}] (recorded)	Pol. [%]	FOM (P^4L)
2003	200	0.35	27	0.0019
2004	200	0.12	40	0.0031
2005	200	3.4	49	0.20
2006	200	7.5	57	0.79
2006	62.4	0.08	48	0.0042
2009	200	14	57	1.2

PHENIX Detector



π^0, η, γ detection

- Electromagnetic Calorimeter (PbSc/PbGl):
  - High p_T photon trigger to collect π^0's, η's, γ's
  - Acceptance: $|\eta|<0.35$, $\varphi = 2 \times \pi/2$
  - High granularity (~10*10mrad^2)

π^+/ π^-

- Drift Chamber (DC) for Charged Tracks
- Ring Imaging Cherenkov Detector (RICH)
  - High p_T charged pions (p_T>4.7 GeV).

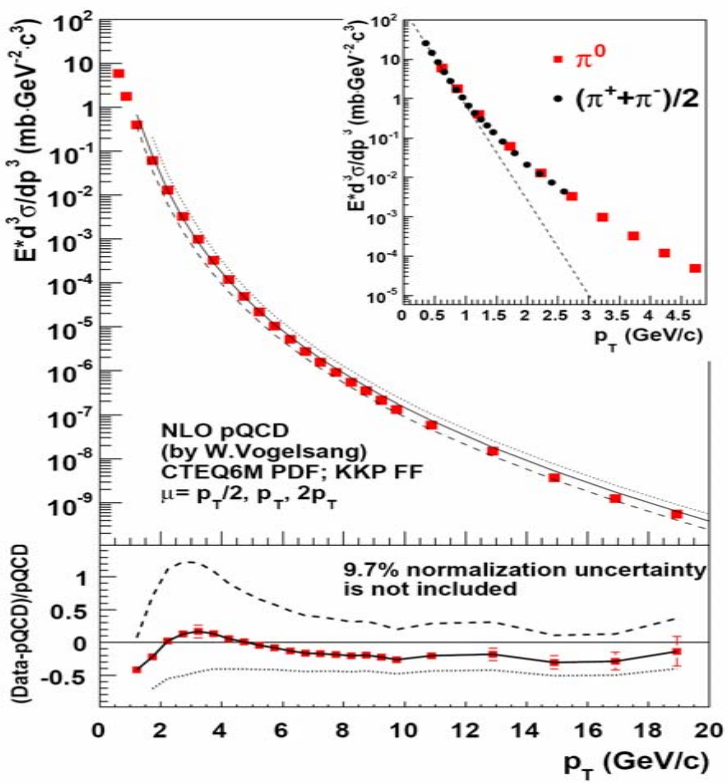
Luminosity (Global) Detectors

- Beam Beam Counter (BBC)
  - Acceptance: $3.0< \eta<3.9$
- Zero Degree Calorimeter (ZDC)
  - Acceptance: ±2 mrad about beam axis

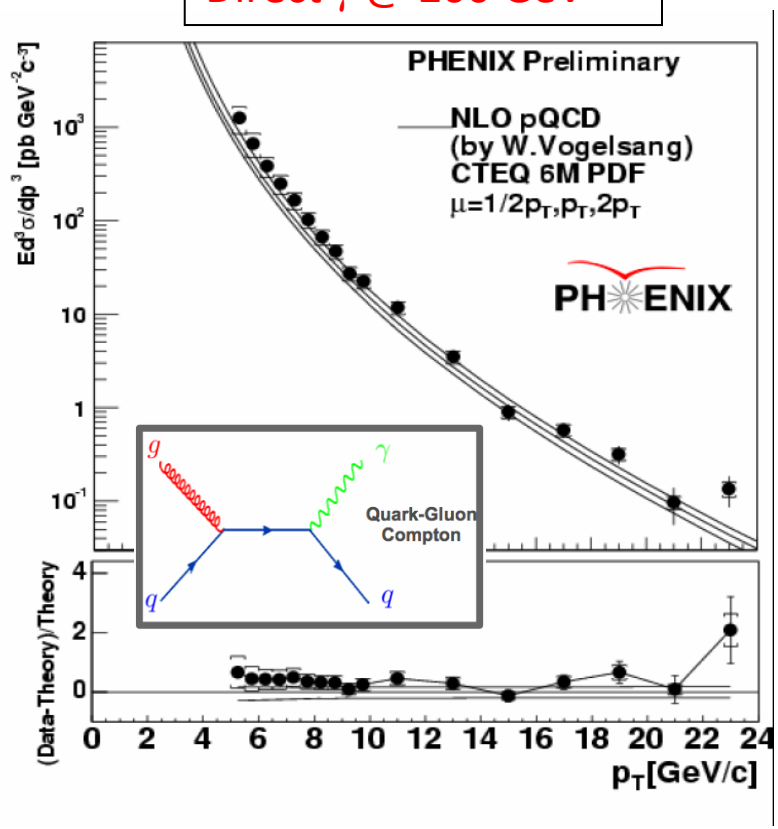
Cross section results from PHENIX

- π^0 , direct γ cross section

π^0 @ 200 GeV (PRD76, 051106)



Direct γ @ 200 GeV

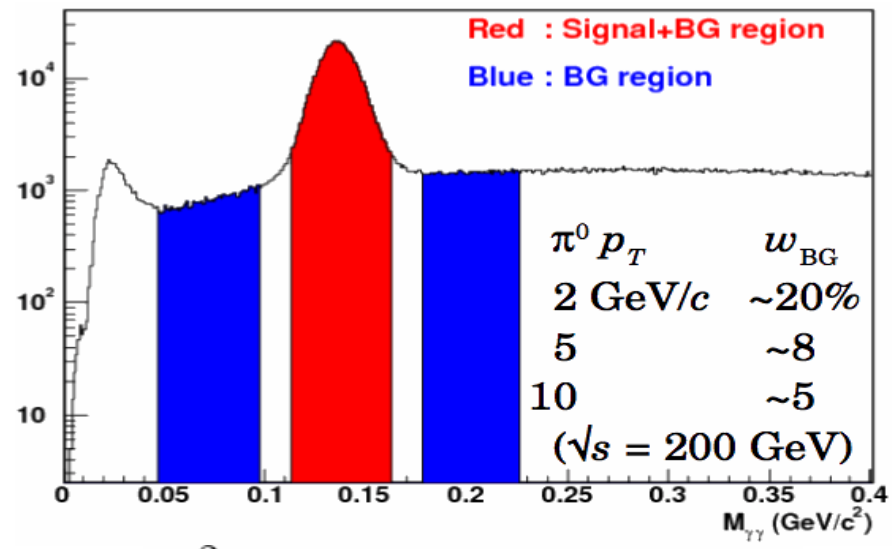


- NLO pQCD shows agreement with the cross section data
- Ready for the extraction of ΔG using NLO A_{LL} predictions

Measurement of π^0 A_{LL}

- Well developed method
  - 2003 (PRL 91, 241803)
- π^0 yield measurement
  - $\pi^0 \rightarrow \gamma\gamma$ BR ~ 98.8 %
  - Combinatorial BG fraction

$$w_{BG} = N_{BG} / (N_{BG} + N_{\pi})$$



$$m^2_{\pi^0} = 2E_1E_2(1 - cos\theta)$$

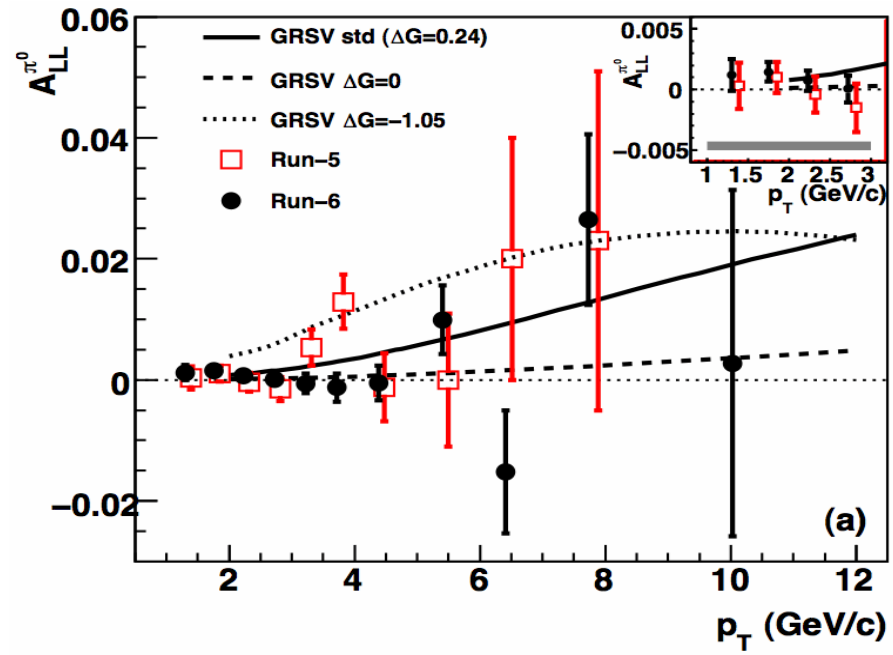
- A_{LL} measurement
  - signal A_{LL} is corrected for background A_{LL}, $A^{\pi^0}_{LL} = \frac{A^{\pi^0+BG}_{LL} - w_{BG}A^{BG}_{LL}}{1 - w_{BG}}$

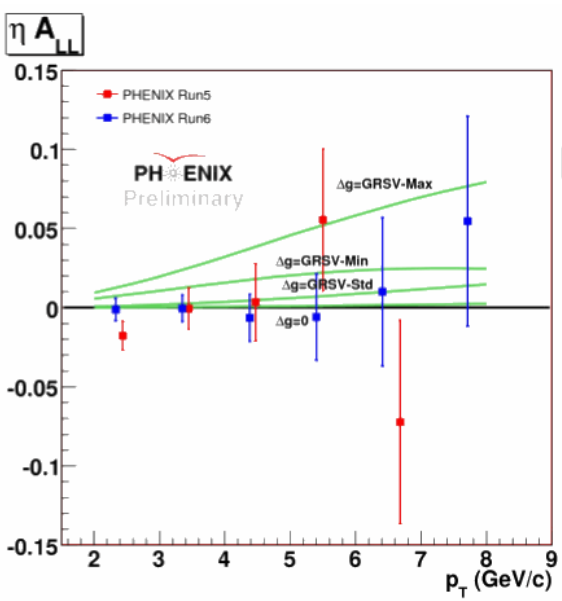
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, R = \frac{L_{++}}{L_{+-}}$$

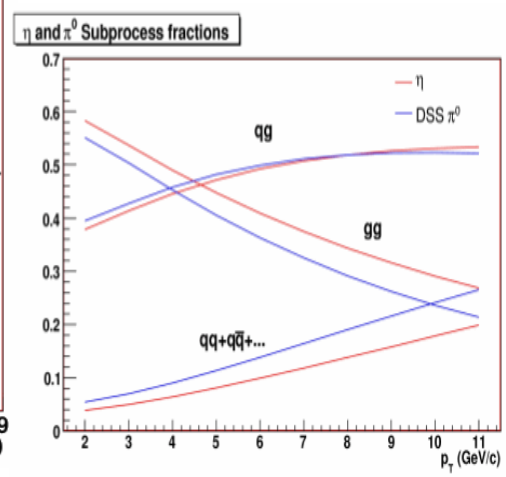
- P_B , P_Y (~55%) beam polarization , less than 10 % relative error in $P_B.P_Y$
- R : relative luminosity, $\delta_{ALL} = 2 \times 10^{-4}$ in 2005, 7×10^{-4} in 2006
- N_{++} (N_{+-}) π^0 yield with same (opposite) helicity of colliding beams

π^0 and η asymmetry results from PHENIX

- π^0 A_{LL} at 200 GeV
  - high statistics measurement
  - 2005: PRD76, 051106
  - 2006: PRL 103, 012003 (2009)



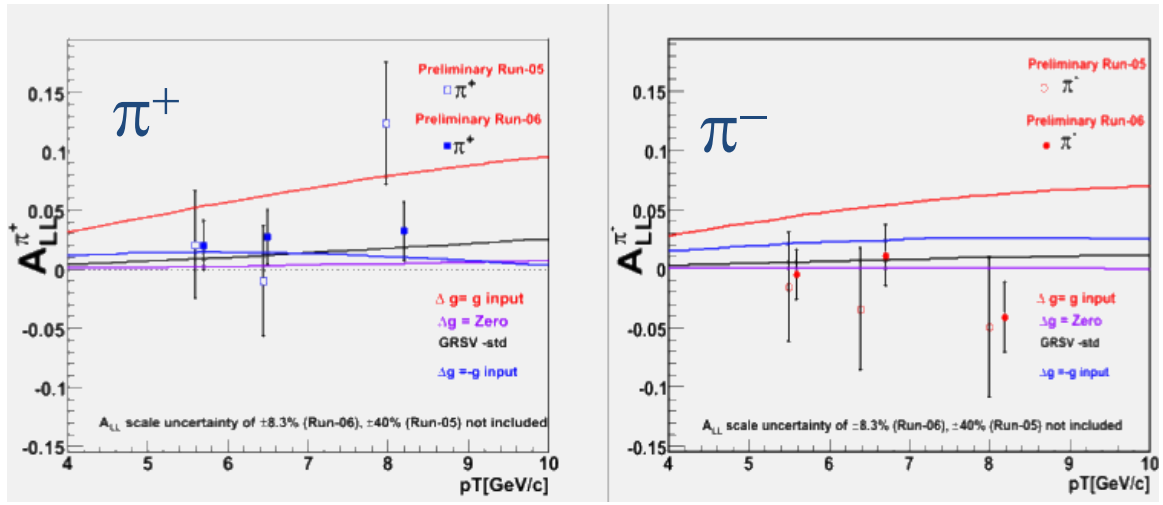




- η at 200 GeV
  - Analysis similar to π^0
  - Fractional sub process differ somewhat
  - Independent confirmation of ΔG

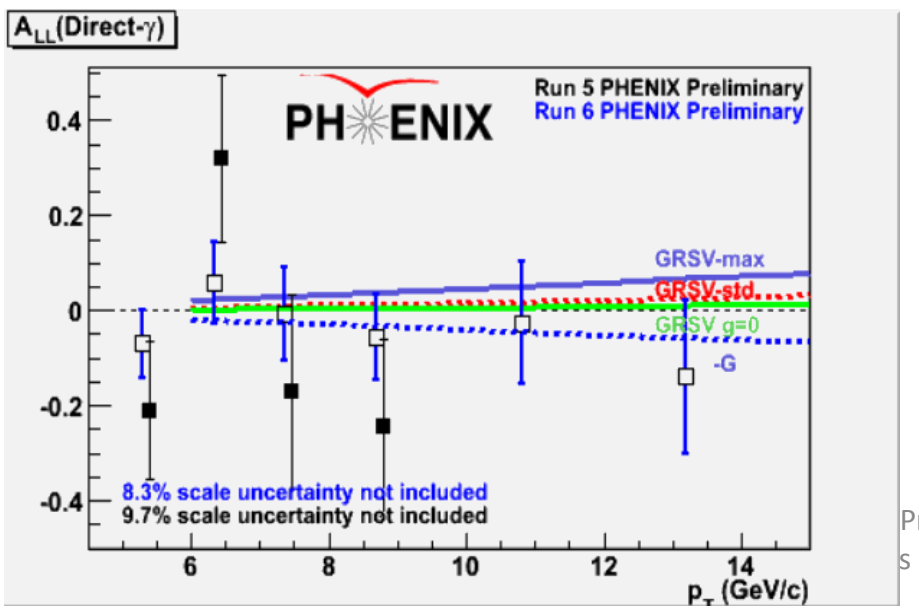
π^+, π^- and γ asymmetry results from PHENIX

- Charged pion at 200 GeV
  - Favored/Disfavored FF
    - → different *qg* contributions for π^+, π^0, π^-
    - → access sign of ΔG

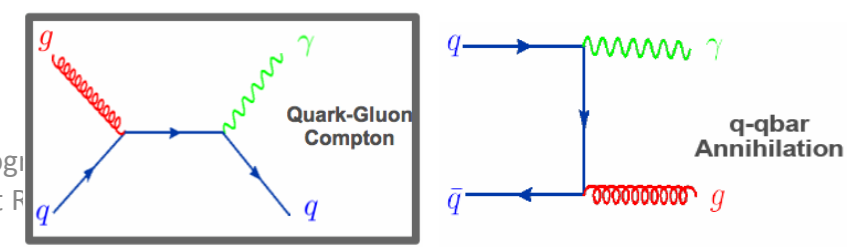


$$A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-} \Rightarrow \Delta G > 0$$

$$A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-} \Rightarrow \Delta G < 0$$



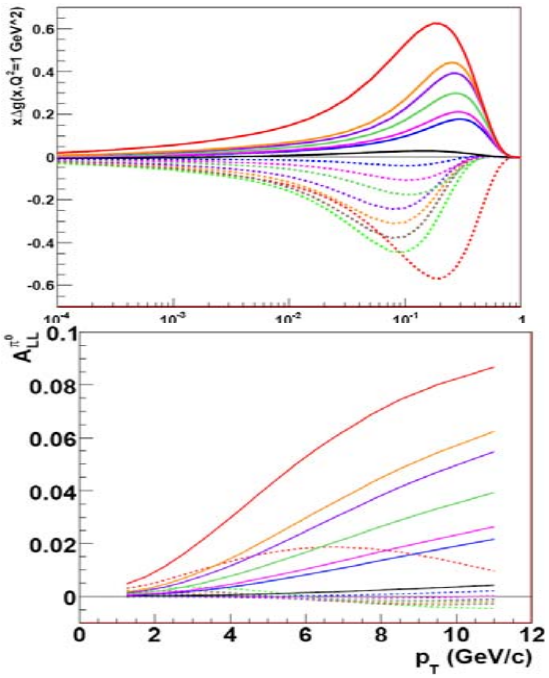
- Direct photon A_{LL} at 200 GeV
  - quark gluon scattering dominates
  - clean channel, isolation cut, linear in ΔG
  - higher statistics needed

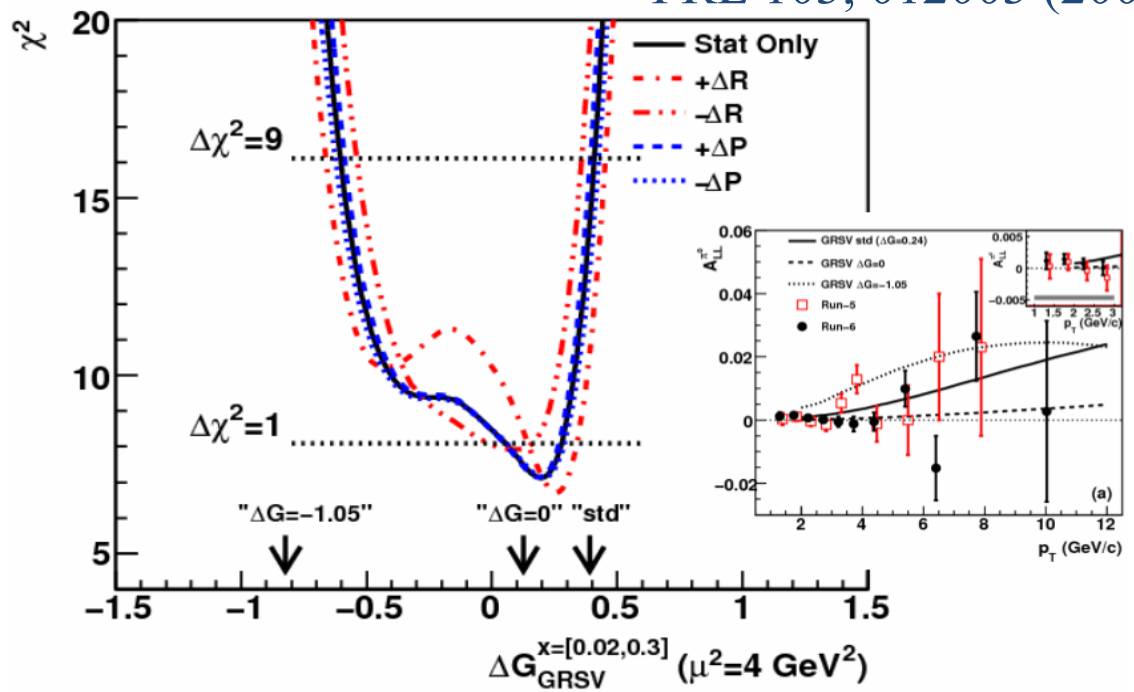


Constraining ΔG

- Vary ΔG in GRSV fit, generate A_{LL} , calculate χ^2 for each expectation curve, plot profile.

PRL 103, 012003 (2009)





- χ^2 profile is asymmetric so $\Delta\chi^2$ =1 and 9 (1σ and 3σ) are significant.

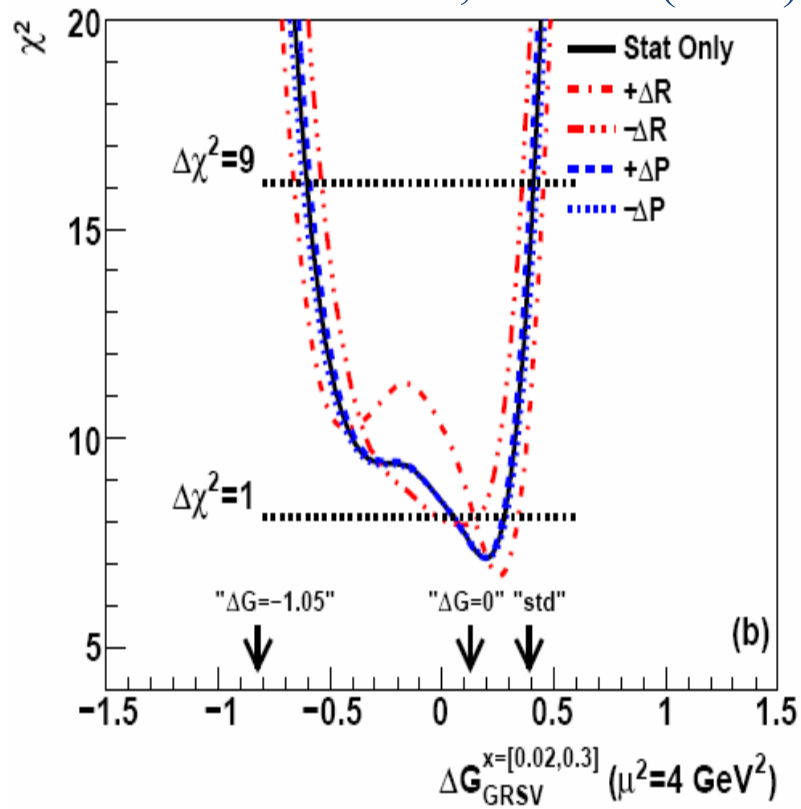
From just the statistical uncertainty :

$$\Delta G_{\rm GRSV}^{[0.02,0.3]} = 0.2 \pm 0.1 \ (1\sigma) \ \text{and} \ 0.2^{+0.2}_{-0.8} \ (3\sigma)$$

Experimental Uncertainty

PRL 103, 012003 (2009)

- Systematic uncertainty
  - The two primary systematic uncertainties are from polarization (ΔP) and relative luminosity (ΔR).
  - The polarization uncertainty is insignificant when extracting ΔG.
  - Uncertainty in relative luminosity while small is significant when extracting ΔG.

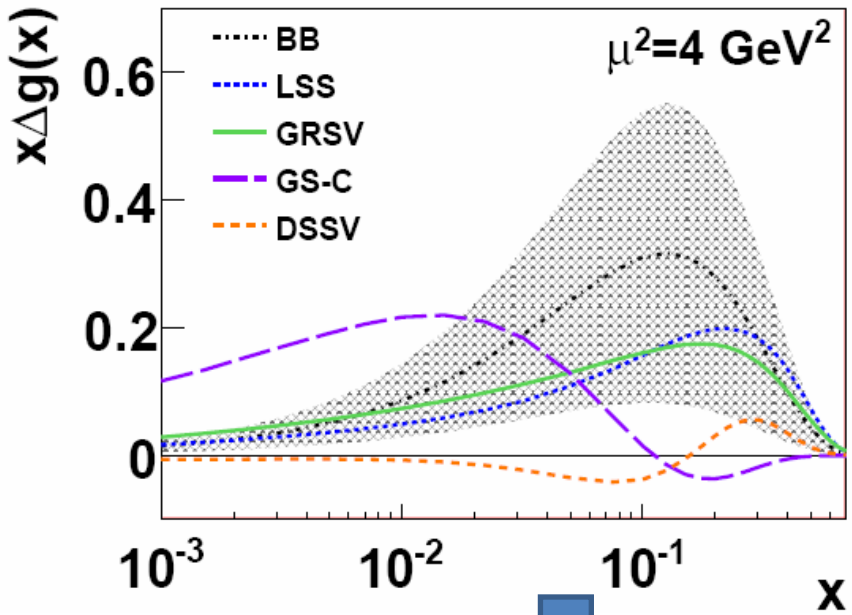


Systematic uncertainty gives an additional +/- 0.1

Theoretical uncertainty

- PDF functional form dependence as a function of x.
- Theory energy scales, μ (factorization scale, fragmentation scale and renormalization) dependence.
- Uncertainty in fragmentation functions (DSS, KKP).
- Strong coupling constant uncertainty dependence.

Uncertainty from parameterizations

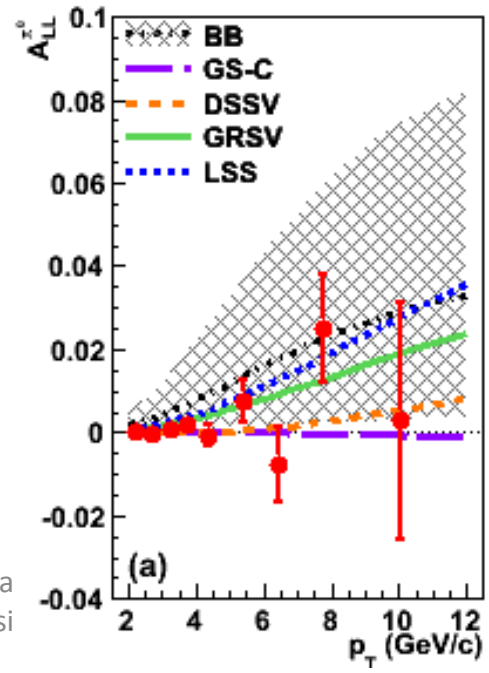


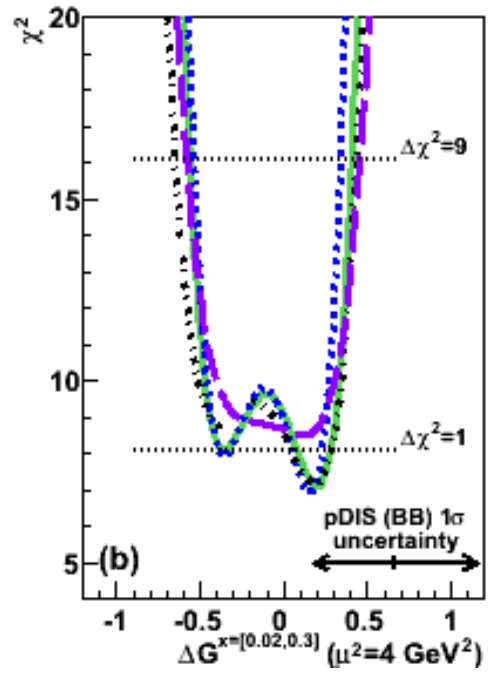
- The gluon polarization distribution as a function of x from five fits to polarized DIS data.

$$-0.7 < \Delta G^{[0.02,0.3]} < 0.5$$

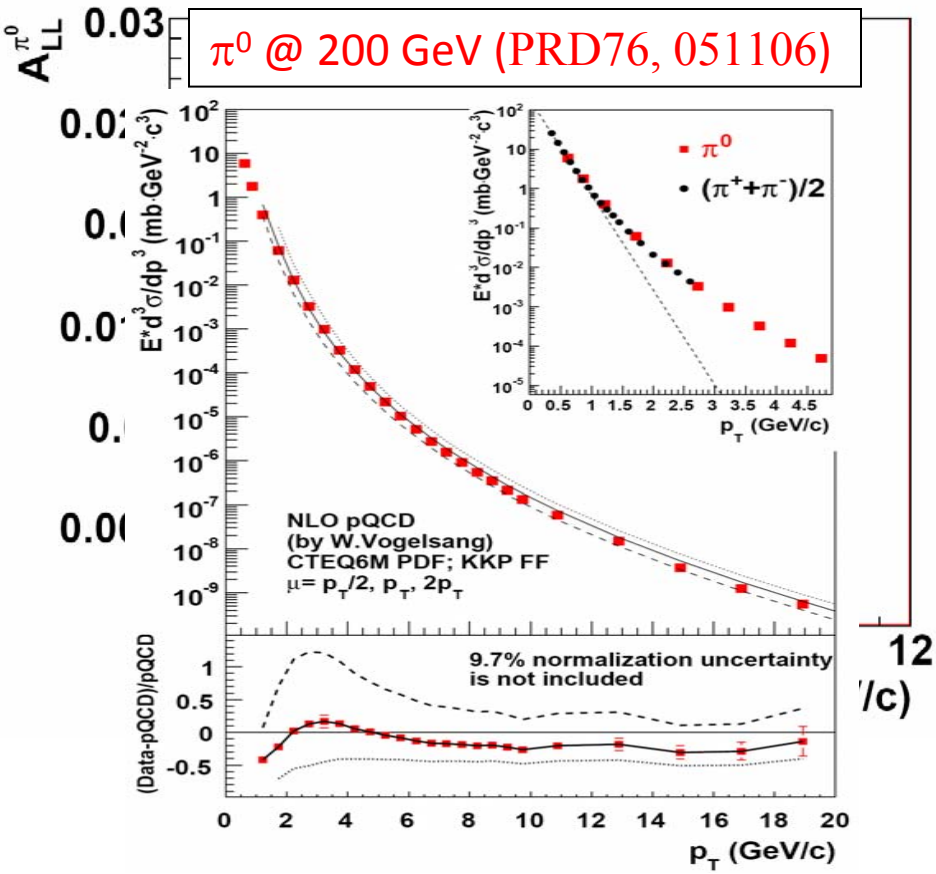
PRL 103, 012003 (2009)

Group	Published best fit $\Delta G^{[0,1]}$	$\Delta G^{[0.02,0.3]}$
GS-C	0.95	0.18
DSSV	-0.05	-0.03
LSS	0.60	0.37
GRSV	0.67	0.38
BB	0.93	0.67

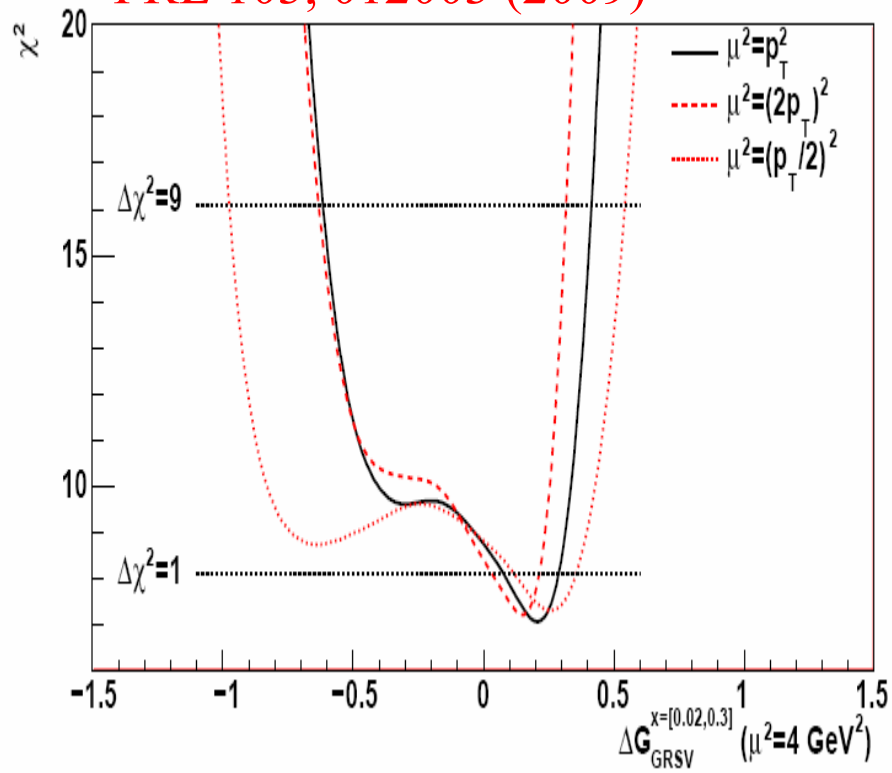




Theoretical uncertainty (Energy scale dependence)



PRL 103, 012003 (2009)



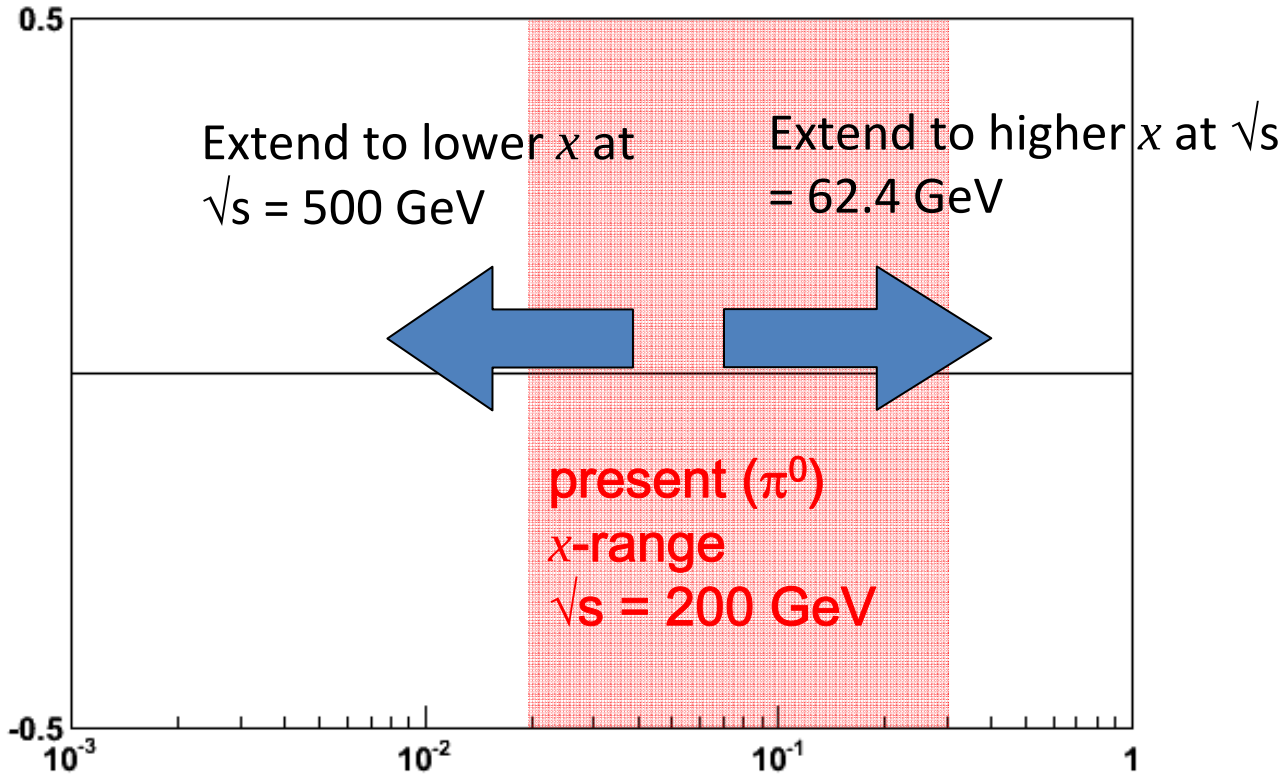
Uncertainty from scale is small (0.1) for the positive values of ΔG but is sizable for negative values.

Extending x range

- To measure ΔG, need as wide an *x* range as possible.

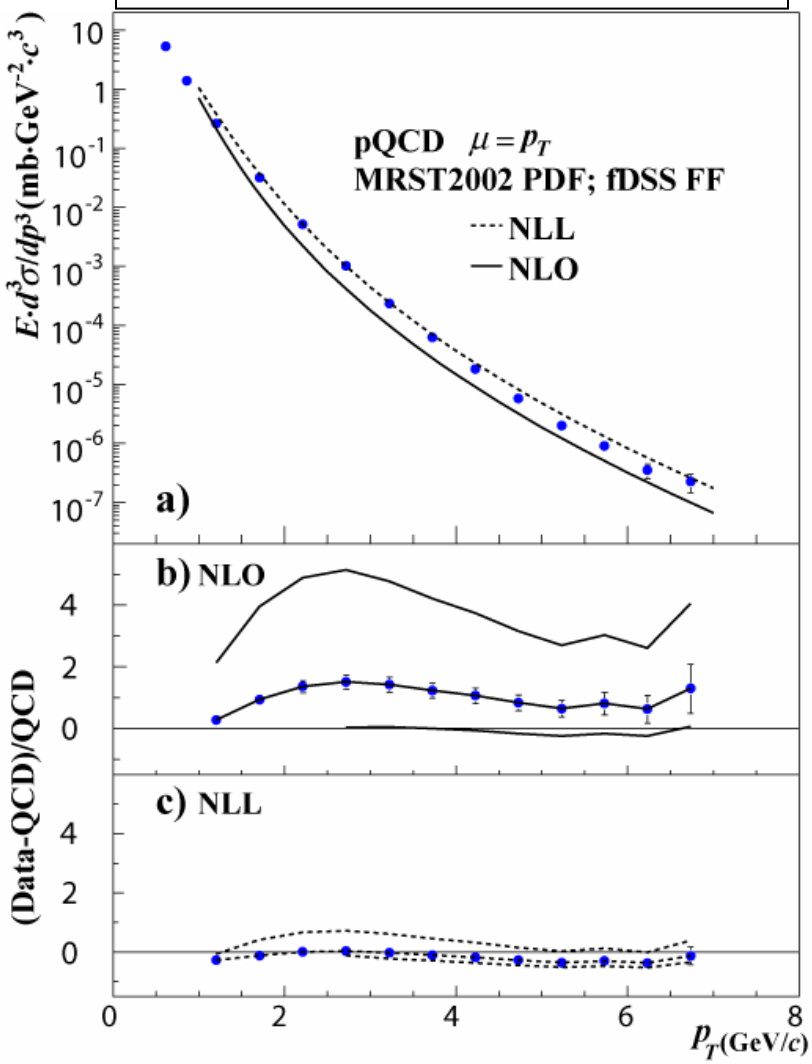
  - We can extend our *x* coverage towards lower *x* at √s = 500 GeV. → Run9

  - We can extend our *x* coverage towards higher *x* at √s = 62.4 GeV. → Run6

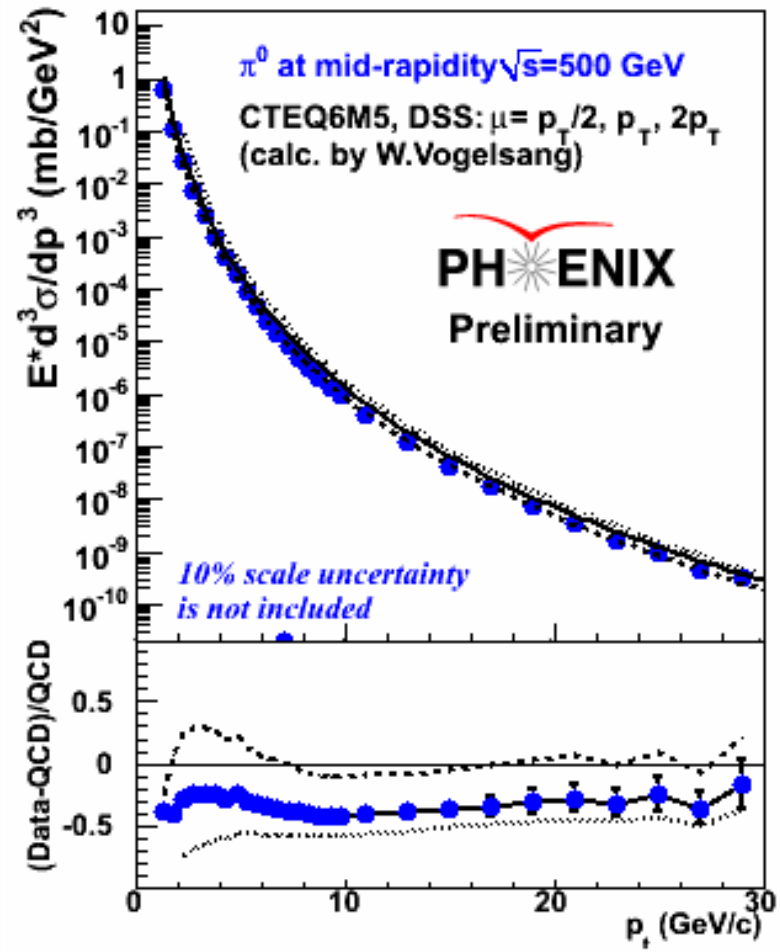


Cross section results from PHENIX

π^0 @ 62.4 GeV(PRD79, 012003)



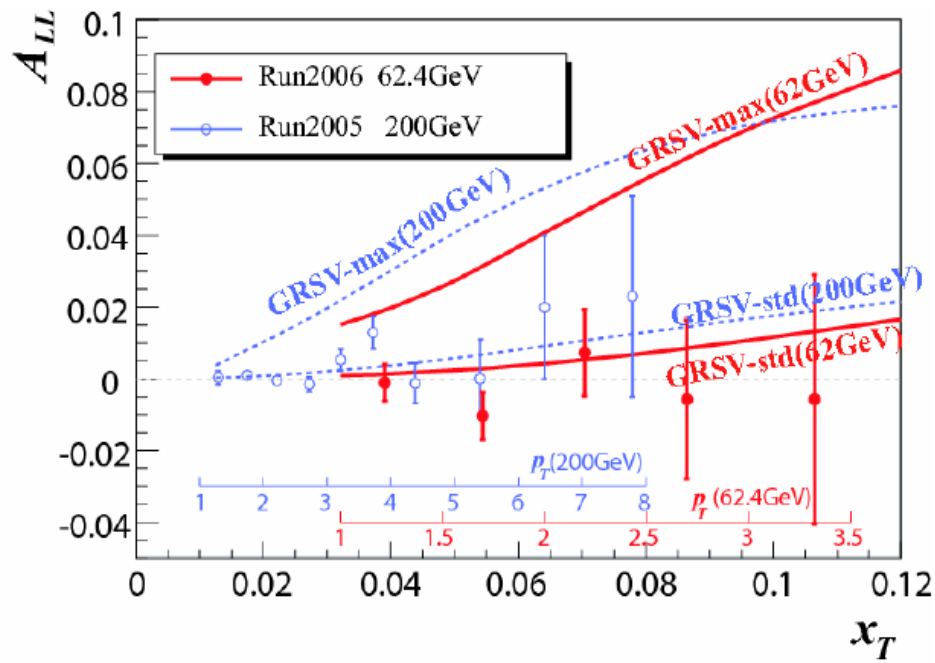
π^0 @ 500 GeV (2009)

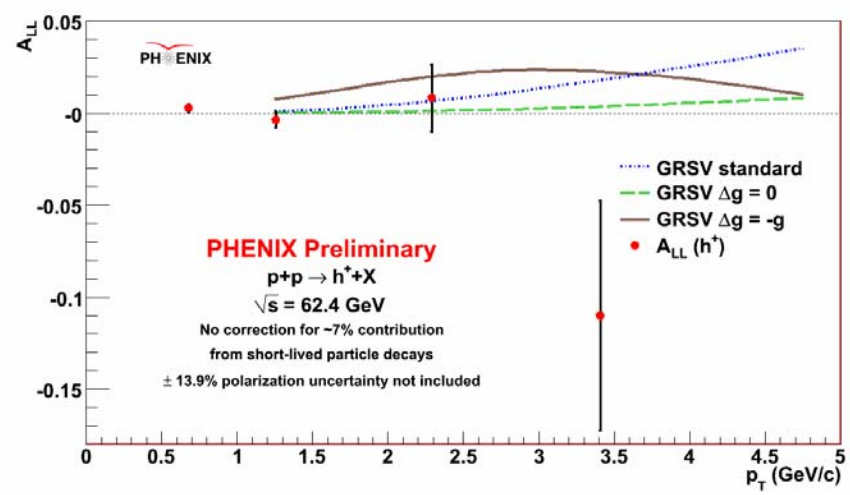


Extending x range to large x

PRD79, 012003

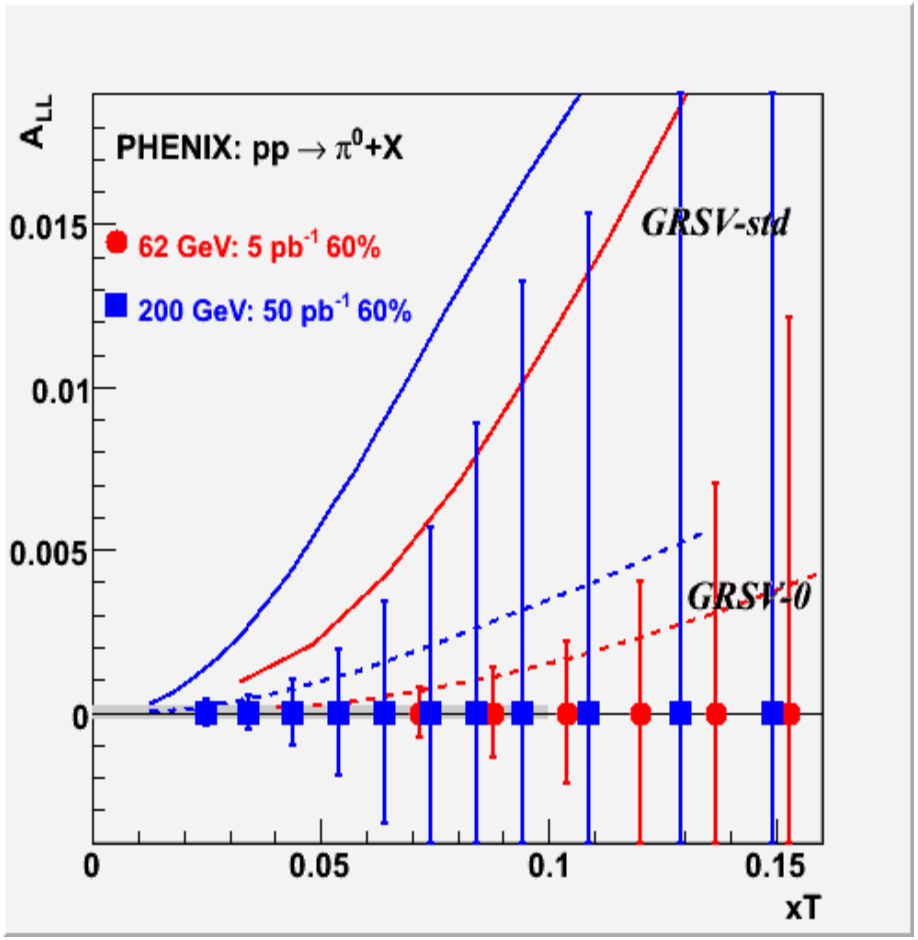
- π^0 A_{LL} at 62.4 GeV
  - clear statistical improvement at large x_T
  - increased sensitivity to large x (0.06<x< 0.4)
  - overlap with 200 GeV A_{LL} providing measurements at same x_g but different p_T
  - a preliminary version of this data set already a part of a global analysis
  - Charge hadron at 62.4 GeV

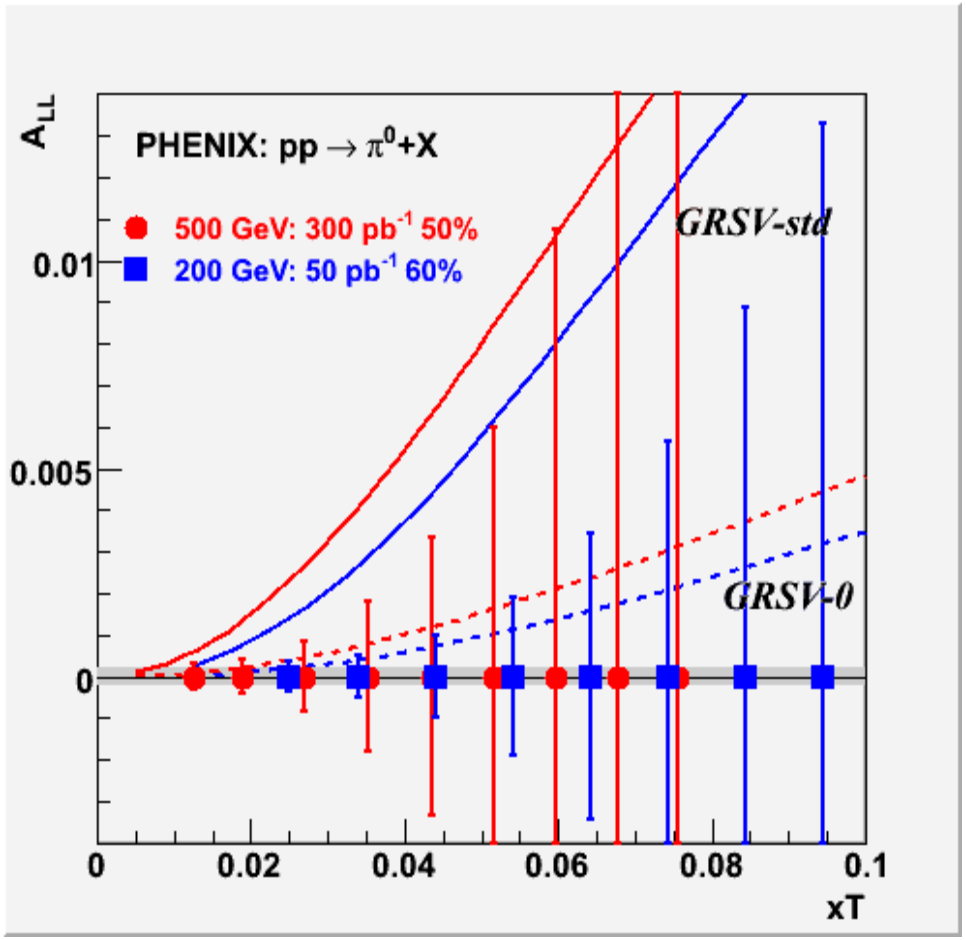




Incl. π0 √s=62, 200 and 500 GeV η~0

Based on real efficiencies and yields from PHENIX data (Run6 and Run9)





A.Bazilevsky,
RHIC Spin: Next Decade
Berkeley, Nov 20-22, 2009

A global analysis approach (DSSV)

Input World Data

- Data Selection:

"classic" inclusive DIS data

routinely used in PDF fits

! $\Delta q + \Delta \bar{q}$

semi-inclusive DIS data

so far only used in DNS fit

! flavor separation

first RHIC pp data (never used before)

! Δg

experiment	data type	data point fitted
EMC, SMC	DIS	34
COMPASS	DIS	15
E142, E143, E154, E155	DIS	123
HERMES	DIS	39
HALL-A	DIS	3
CLAS	DIS	20
SMC	SIDIS, $h^{\pm}$	48
HERMES	SIDIS, $h^{\pm}$	54
	SIDIS, $\pi^{\pm}$	36
	SIDIS, $K^{\pm}$	27
COMPASS	SIDIS, $h^{\pm}$	24
PHENIX (in part prel.)	200 GeV pp, π^0	20
PHENIX (prel.)	62 GeV pp, π^0	5
STAR (in part prel.)	200 GeV pp, jet	19
TOTAL:		467

467 data pts in total (10% from RHIC)

Marco Stratmann, Spin'08

Global Analysis Setup

- Parametrization defined at $Q_0^2 = 1\ \mathrm{GeV}^2$

$$x\Delta f_j(x, 1\ \mathrm{GeV}) = N_j\, x^{\alpha_j}\,(1-x)^{\beta_j}\left[1 + \kappa_j\sqrt{x} + \gamma_j x\right]$$

possible nodes

input scale

for sea quarks and delta g , simple forms $k_j = 0$.

- Positivity a basic assumption,

$$|\Delta\sigma| \leq \sigma \qquad |\Delta f| \leq f$$

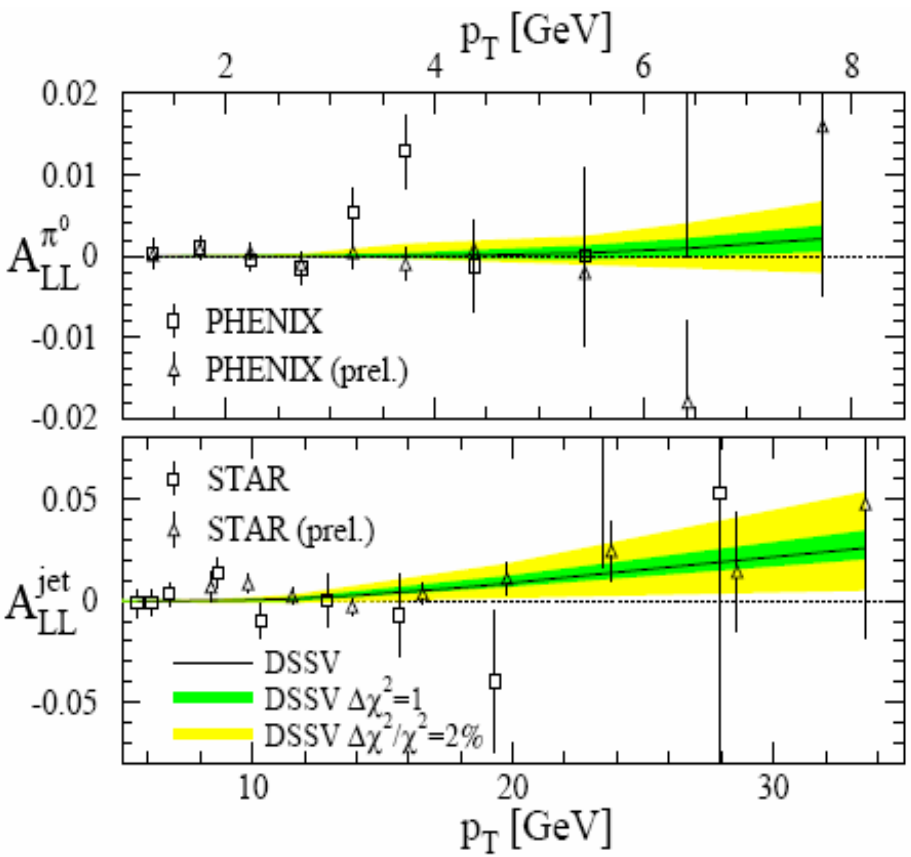
- assumptions on parameters unless data cannot discriminate,

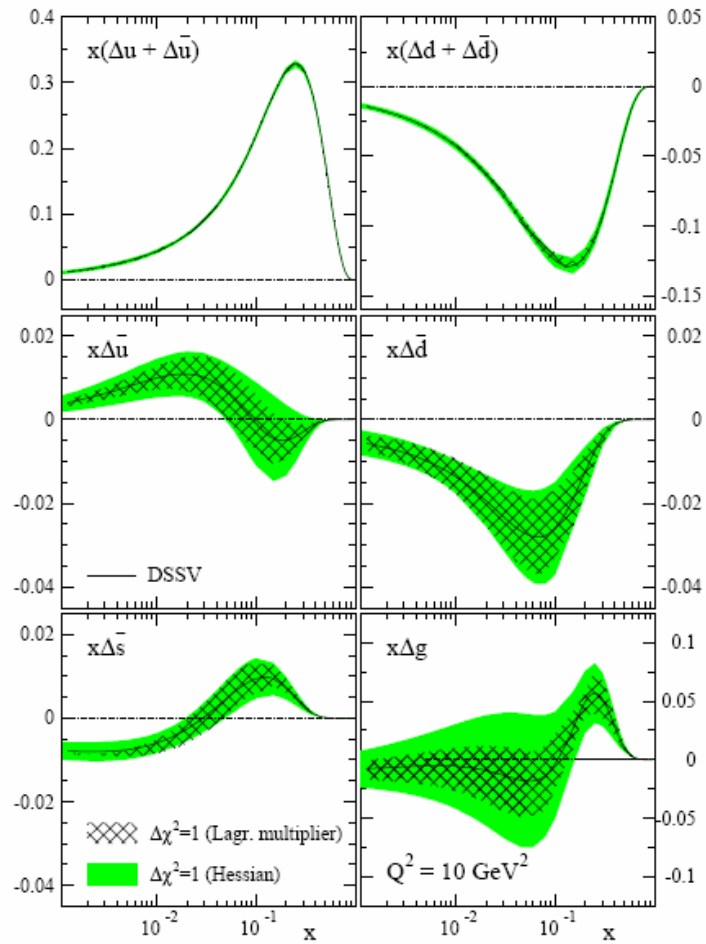
impose: $\alpha_{\bar{u}} = \alpha_{u+\bar{u}} \qquad \alpha_{\bar{d}} = \alpha_{\bar{s}} = \alpha_{d+\bar{d}}$

$$\Delta s = \Delta\bar{s}$$

Do a fit !!

PDFs results and uncertainties from global analysis





From A_{LL} to ΔG (62.4, 200 and 500 GeV)

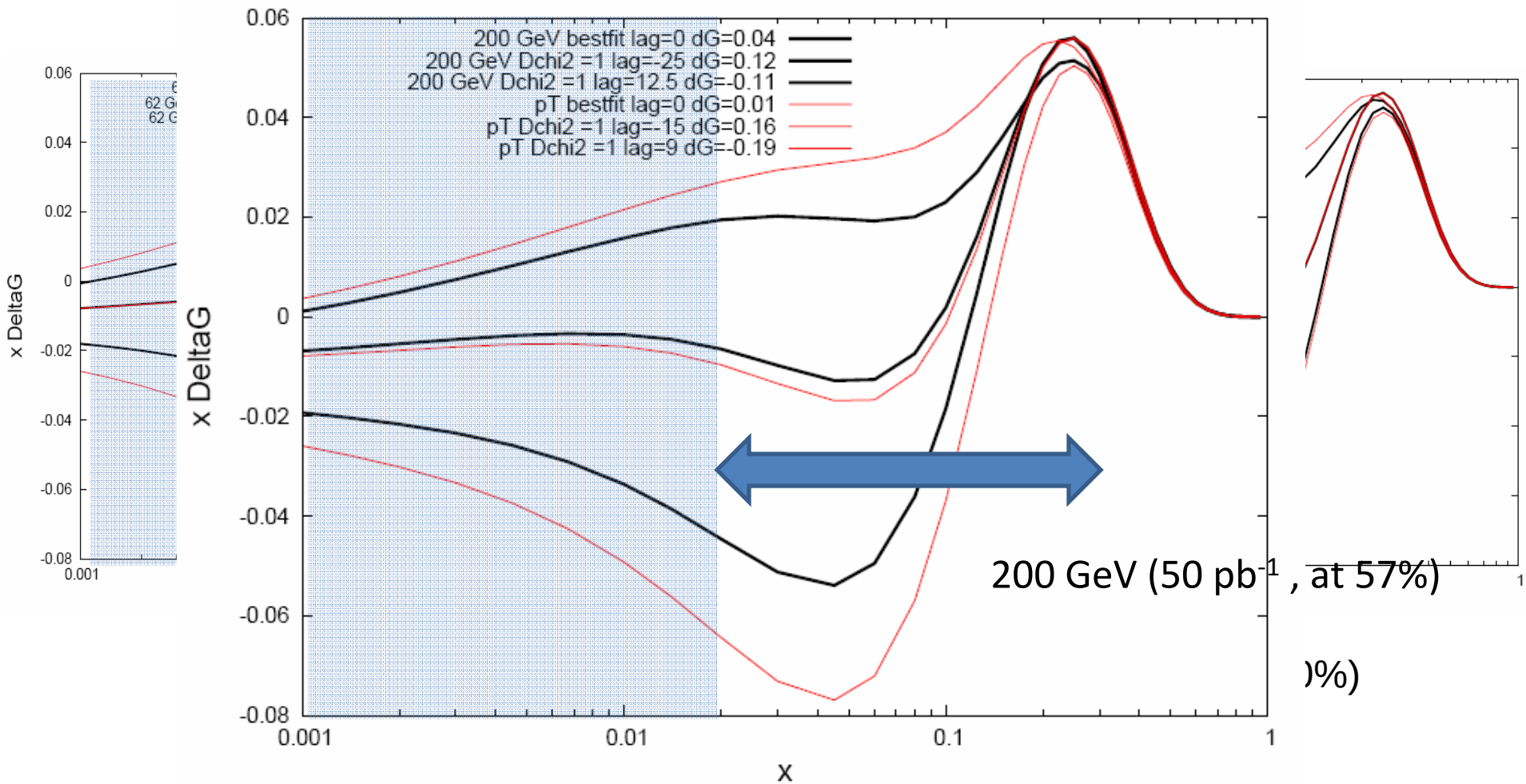
Non PHENIX exercise

- Calculate π^0 A_{LL} based on best fit Pdfs from DSSV.
- Formulate a χ^2 using projected uncertainties, from real efficiencies and yields from PHENIX data (Run6 and Run9), and the above calculated A_{LL} as experimental data .
- Do a global analysis with this χ^2 and get the best fit for ΔG.
- Use Lagrange Multiplier to find a $\Delta\chi^2 = 1$ uncertainty.

$$\chi'^2 = \chi^2 + \lambda\ \Delta f^{[a,b]} \qquad \Delta f = \Delta\Sigma, \Delta G$$

$$\Delta f^{[a,b]} \equiv \int_a^b dx \Delta f(x, \mu^2)$$

ΔG projections based on DSSV



Caution : The true uncertainties are only in the measured x region .

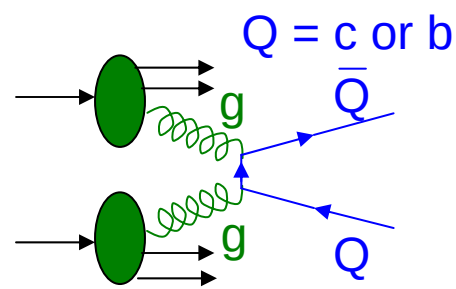
Other plans

- Forward rapidities at PHENIX : MPC, FOCAL
  - access low x and large x simultaneously
  - With γ-jet (or possibly γ-π^0), one could extract Δg(x)/g(x) at LO

$$x_1 = \frac{m_T}{\sqrt{s}}(e^{y_3} + e^{y_4})$$

$$x_2 = \frac{m_T}{\sqrt{s}}(e^{-y_3} + e^{-y_4})$$

- Silicon Vertex Detector for PHENIX
  - gluon spin (ΔG) with heavy flavor A_{LL}
  - improved x determination in γ-jet A_{LL} for ΔG



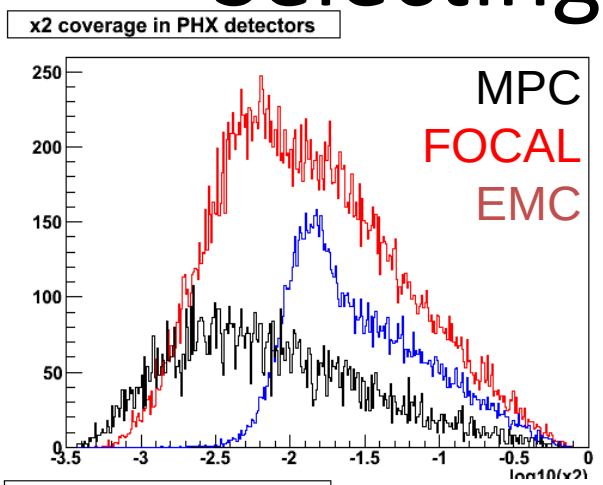
Summary & Outlook

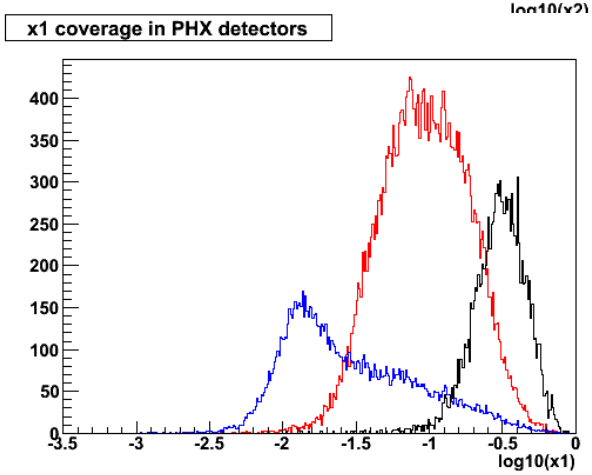
- PHENIX π^0 data offers strong constraint on ΔG as found by DSSV.
- Other probes also can constrain ΔG, and will be used in future global fits.
- 200 GeV data from Run9 and future runs will further significantly constrain ΔG.
- ΔG at lower x range ($x<0.02$) is presently being explored with $\sqrt{s}$ = 500 GeV at RHIC (2009 polarized pp run).

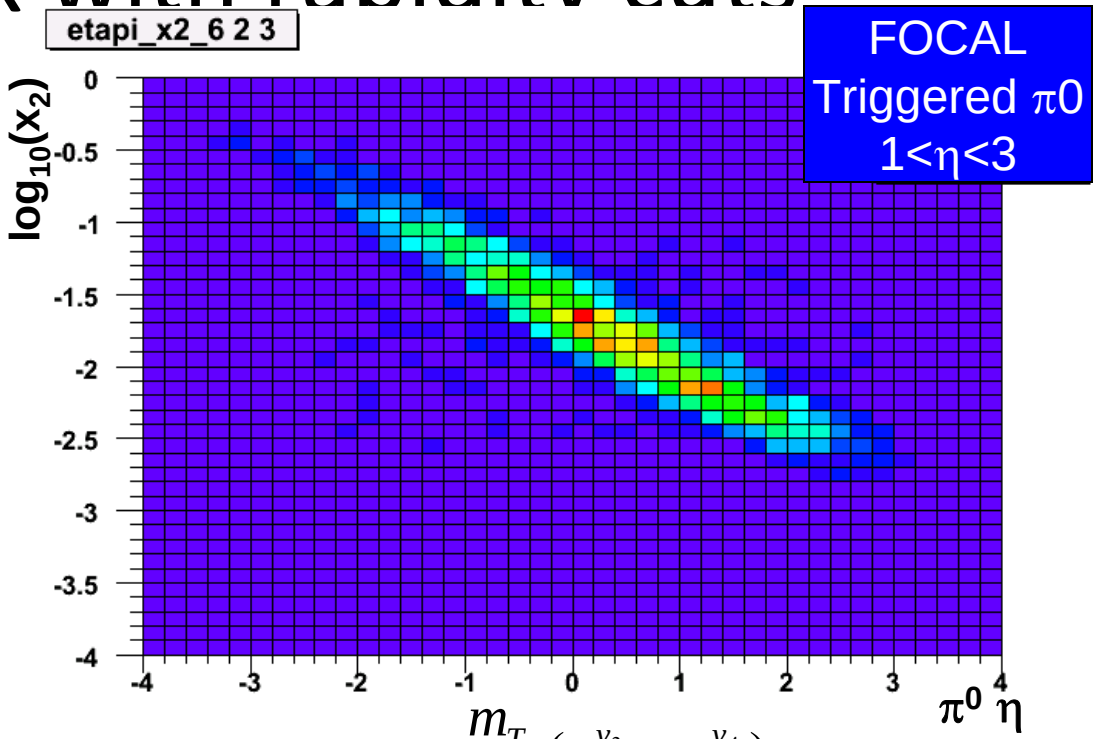
  - Future measurement at 500 GeV will help constrain ΔG given > 50%
- It is much too early to claim that $\Delta G=0$, as uncertainty in range $0<x<1$ is large

Back up

Selecting x with rapidity cuts





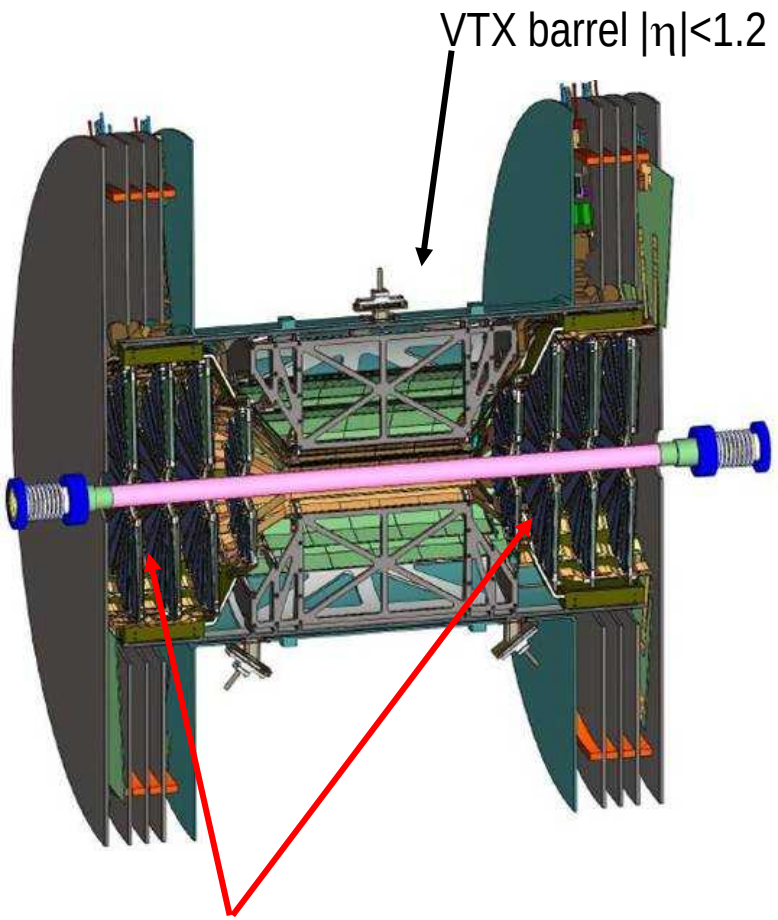


$$x_1 = \frac{m_T}{\sqrt{s}}(e^{y_3} + e^{y_4})$$

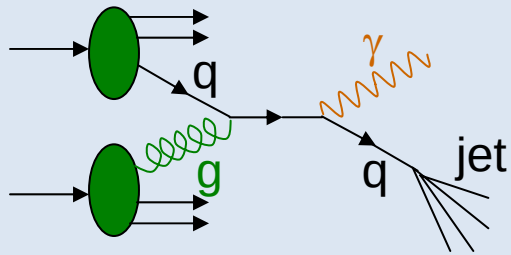
$$x_2 = \frac{m_T}{\sqrt{s}}(e^{-y_3} + e^{-y_4})$$

- Above plots are for jets into the acceptance of the specified detector and for p_T>2.5 GeV.
- The more forward one goes, the lower one can go in x. Also note one selects also a higher x parton along with the lower x one, simultaneously, so going forward isn't just low x – it's broader x coverage.
- FOCAL.N statistics for pt>4 GeV jets is 3x EMC and also 3x MPC.
  - Two FOCAL would have 6 times the statistics of the EMC
- PYTHIA tells us if we measure the energy and rapidity of the 2 jets in a dijet we can explicity measure x with a best resolution on the x of ~20%. We need to fold in the detector resolution to determine the final x resolution.
- The forward detectors cover from x ~ 10^{-3} to x ~ 1. An order of magnitude lower in x than without them.

Silicon Vertex tracker (VTX & FVTX)



Available in 2011/12

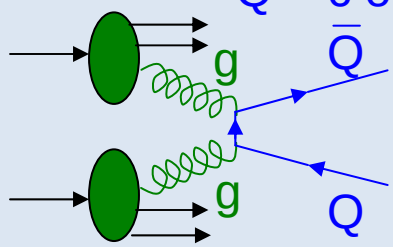


$$x_1 = \frac{p_T}{\sqrt{s}}\left(e^{\eta_3} + e^{\eta_4}\right)$$

$$x_2 = \frac{p_T}{\sqrt{s}}\left(e^{-\eta_3} + e^{-\eta_4}\right)$$

FOCAL: p_T and η_{photon}
VTX: η_{jet}

Q = c or b



Rejects hadronic background
c/b separated measurements

May be luminosity (and polarization) hungry

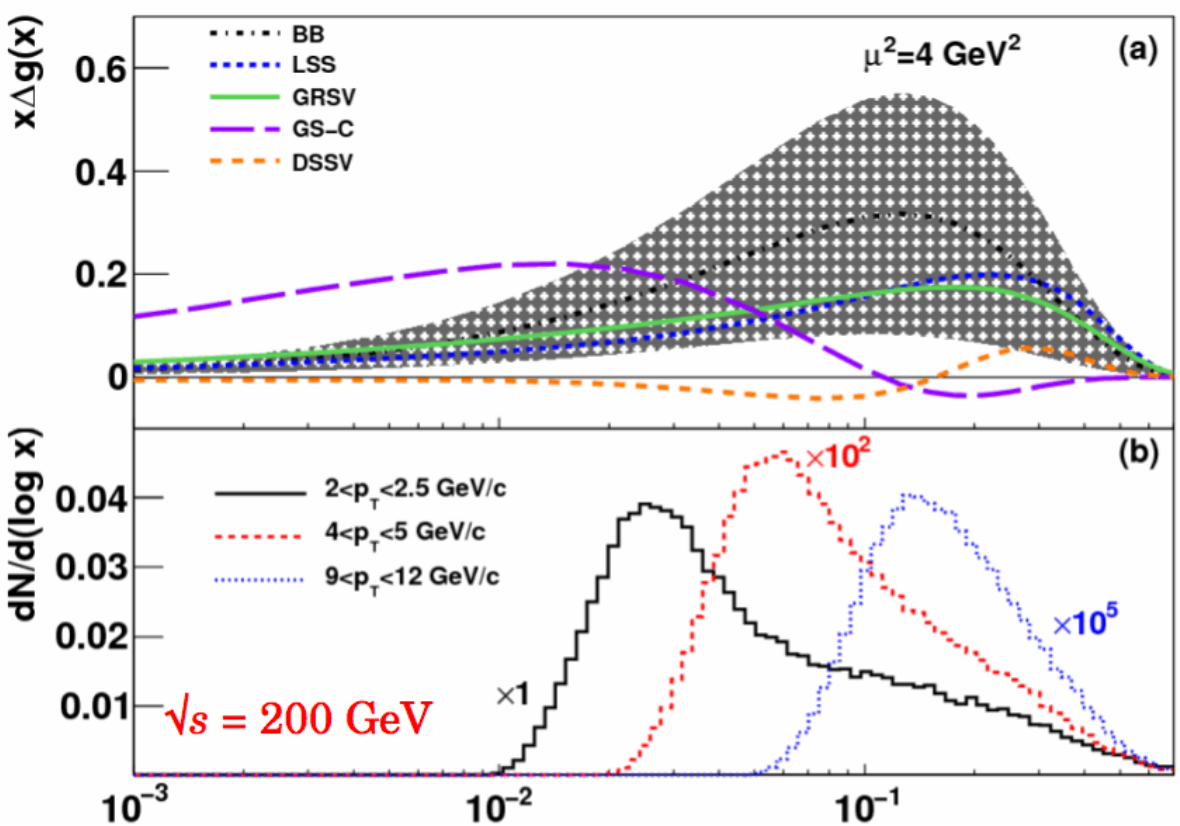
Relative Luminosity

- $R = L_{++}/L_{+-}$; L = luminosity.
- Luminosity is given by the number of BBC triggered events (N_{BBC}).
- For estimate of uncertainty, measure A_{LL} in the ratio of our two luminosity detectors

$$r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)}$$

Year	[GeV]	δA_{LL}
2005 *	200	2e-4
2006 *	200	7e-4

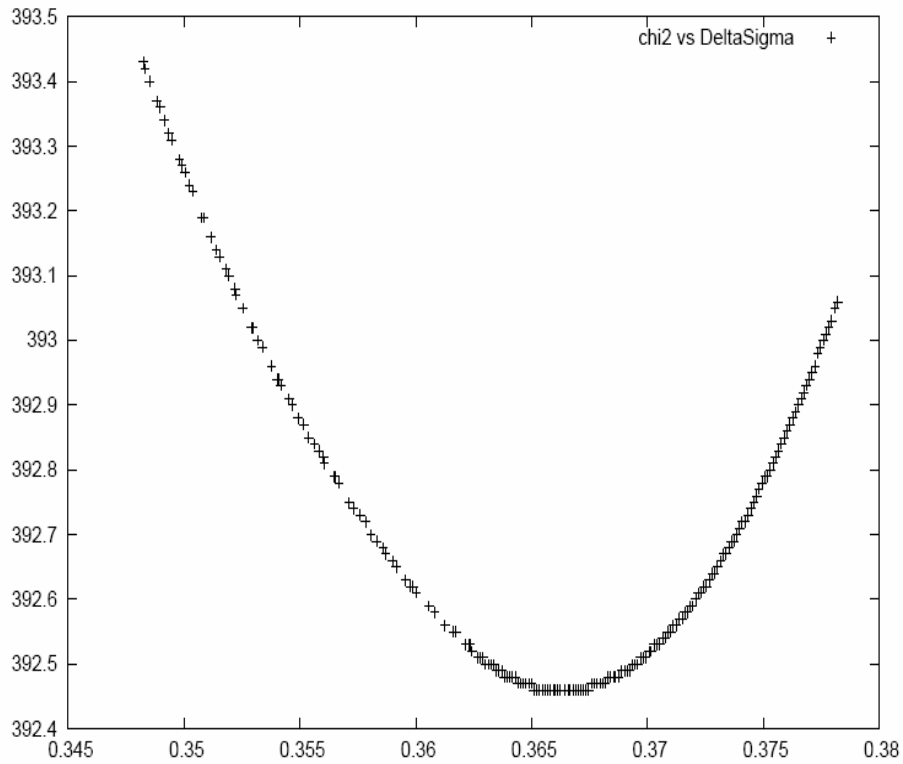
* Longitudinal

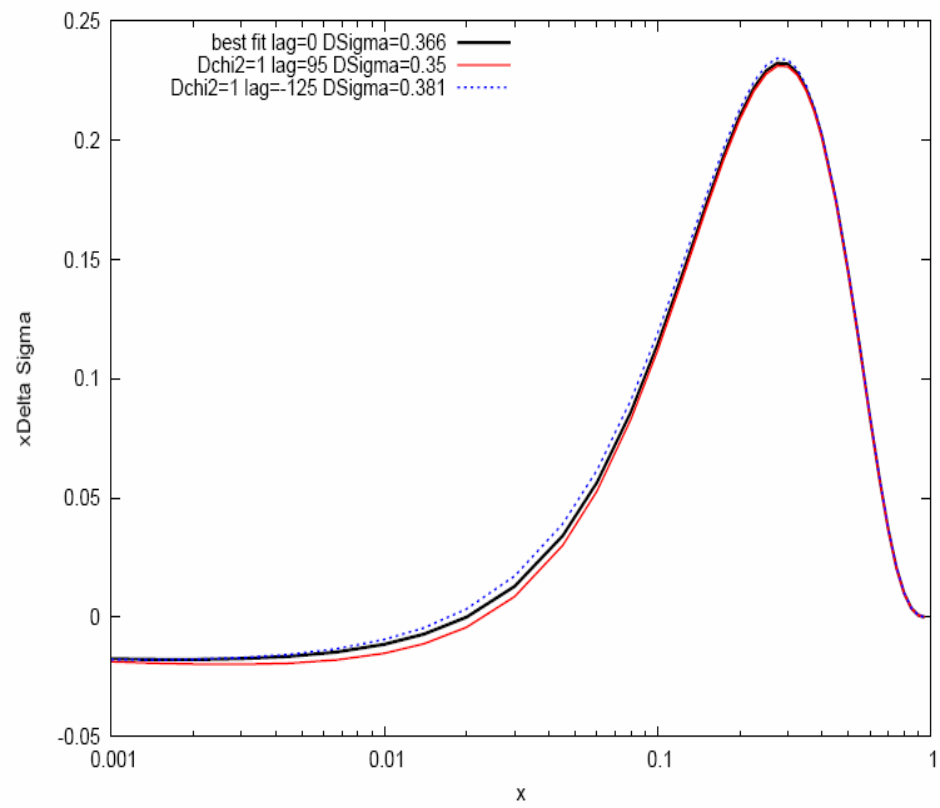


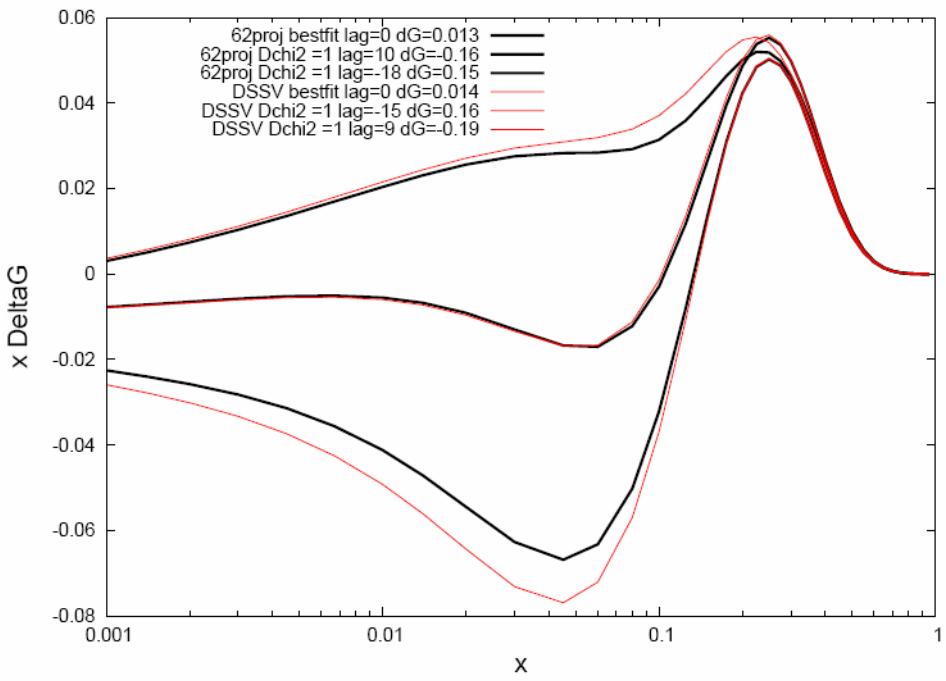
- NLO pQCD calculation of x distribution for 3 π^0 p_T bins.

χ^2 distribution vs. $\Delta\Sigma$ (x range 0.001, 1)

- $\chi^2 = \sum_i \frac{(T_i - E_i)^2}{\delta E_i^2}$ vs $\Delta\Sigma^{[a,b]} \equiv \int_a^b dx \Sigma(x, \mu^2 = 10GeV^2)$



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DSSV bestfit lag=0 dG=0.014
DSSV Dchi2 =1 lag=-15 dG=0.16
DSSV Dchi2 =1 lag=9 dG=-0.19
x DeltaG
x
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0.001
0.01
0.1
1