The STAR Longitudinal Spin Program

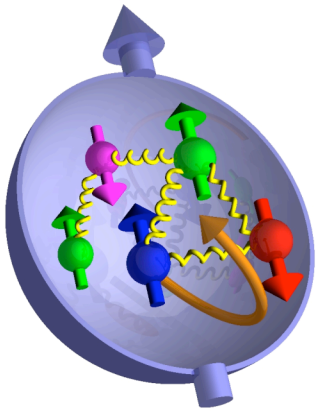
Joe Seele (MIT) for the STAR Collaboration

WWND09

Outline

- The Spin Puzzle
- The STAR experiment
- STAR Results
- Future Directions

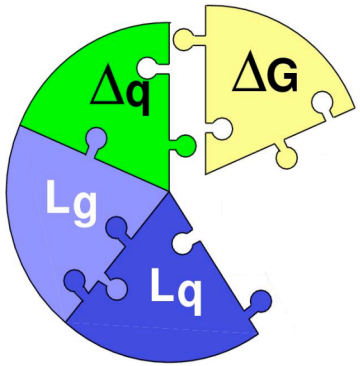
The Spin Puzzle



The proton is viewed as being a "bag" of bound quarks and gluons interacting via QCD

Spins + orbital angular momentum need to give the observed spin 1/2 of proton

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q^z + \Delta G + L_g^z$$



Fairly well measured
only ~30% of spin

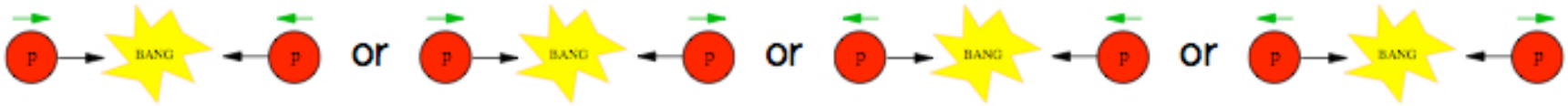
Beginning to be measured
at RHIC (and hopefully EIC)

A future challenge

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

Helicity Asymmetries

Taking the asymmetry of proton helicity configurations



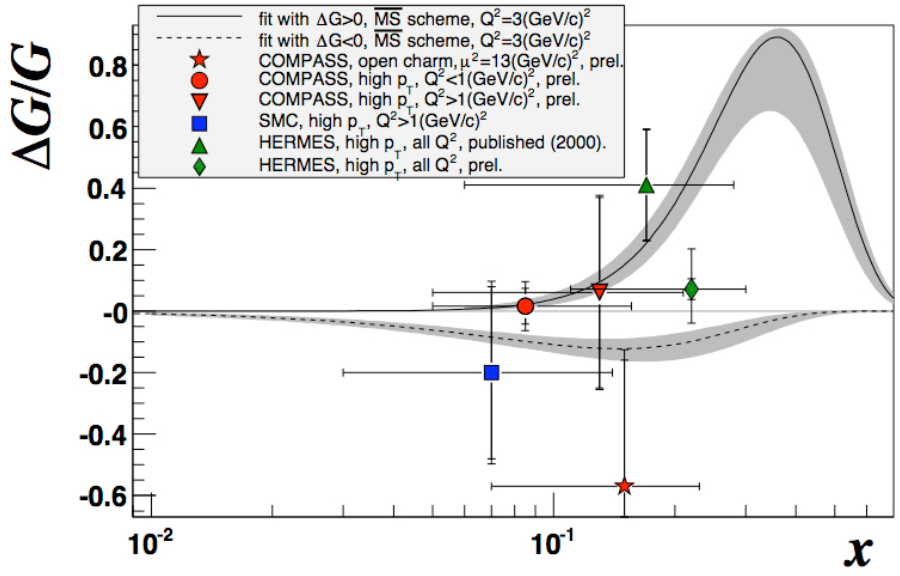
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{a,b,c} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \cdot \hat{a}_{LL}^{f_a f_b \to f_c X} \otimes D_{f_c}^{h}}{\sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes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

Needed for hadrons but not jets

and translating…

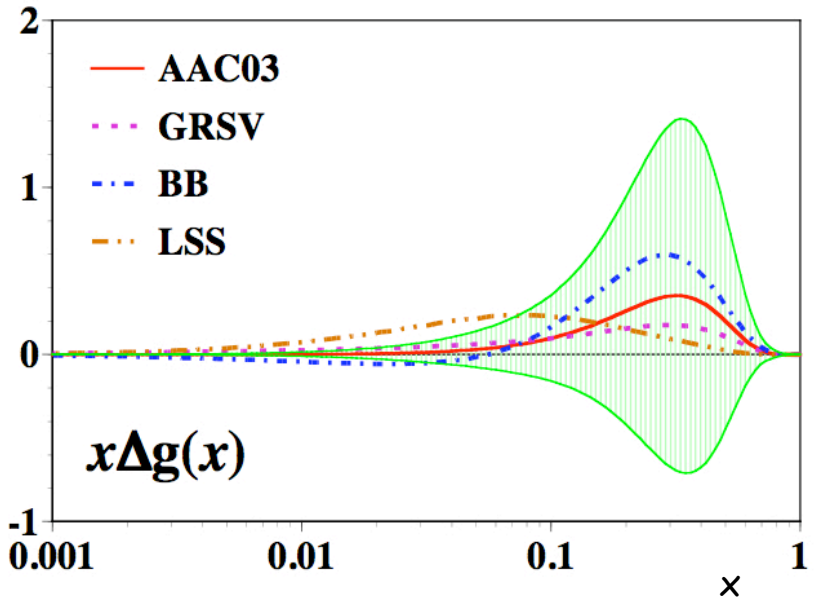
$$A_{LL} \approx a_{gg}\Delta G^2 + a_{qg}\Delta q \Delta G + a_{qq}\Delta q \Delta q'$$

What did we know about ΔG ?

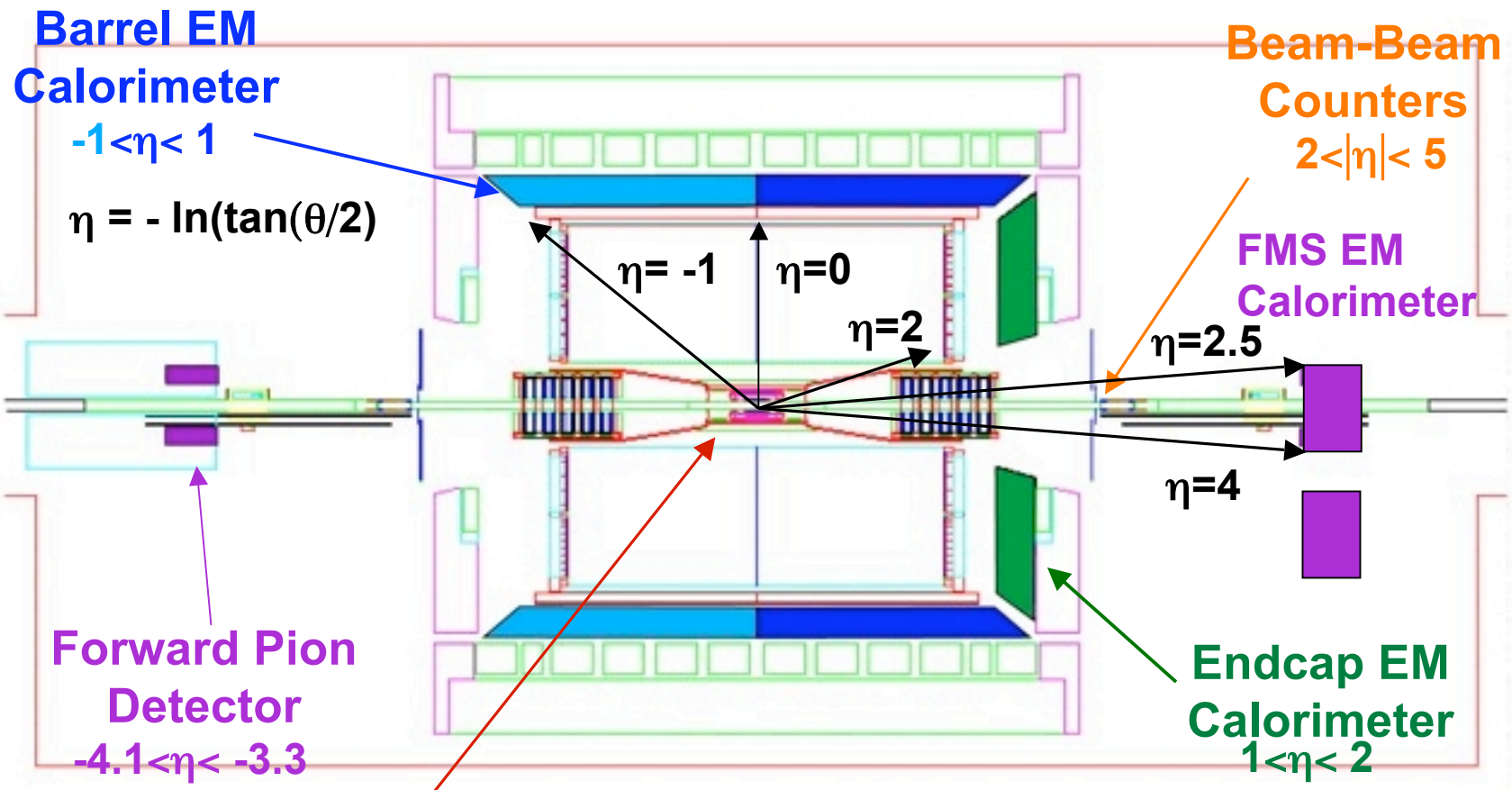


Polarized DIS data does not constrain the gluon distribution very well at present

Global fits that include DIS data do not constrain ΔG very well. Need to access gluons directly!



STAR


Barrel EM Calorimeter
-1<η< 1
η = - ln(tan(θ/2)
η= -1
η=0
η=2
Beam-Beam Counters
2<|η|< 5
FMS EM Calorimeter
η=2.5
η=4
Forward Pion Detector
-4.1<η< -3.3
Endcap EM Calorimeter
1<η< 2
Time Projection Chamber
-2<η< 2
Solenoidal Magnetic Field 5kG
2008

STAR Measurements

Inclusive Measurements

Reconstruct a piece of the final state without considering the structure of the event

e.g. $\vec{p} + \vec{p} \rightarrow Jet + X$ or $\vec{p} + \vec{p} \rightarrow h + X$

Currently all STAR longitudinal spin results are inclusive measurements

A Pro

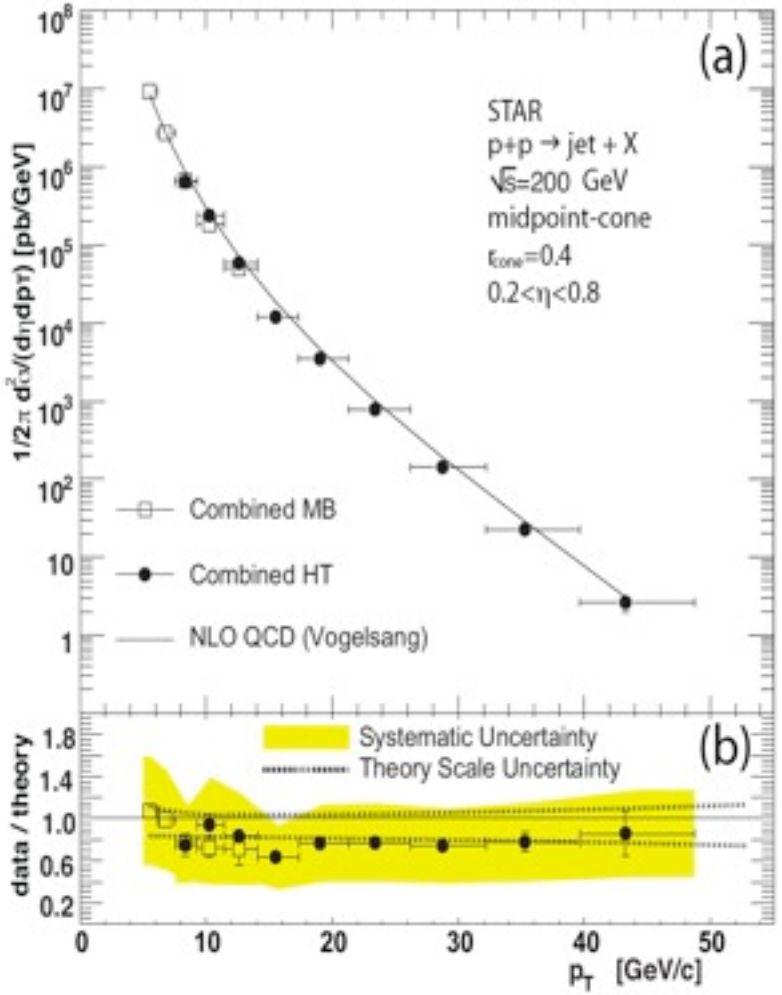
Larger cross section than exclusive or correlation measurements

A Con

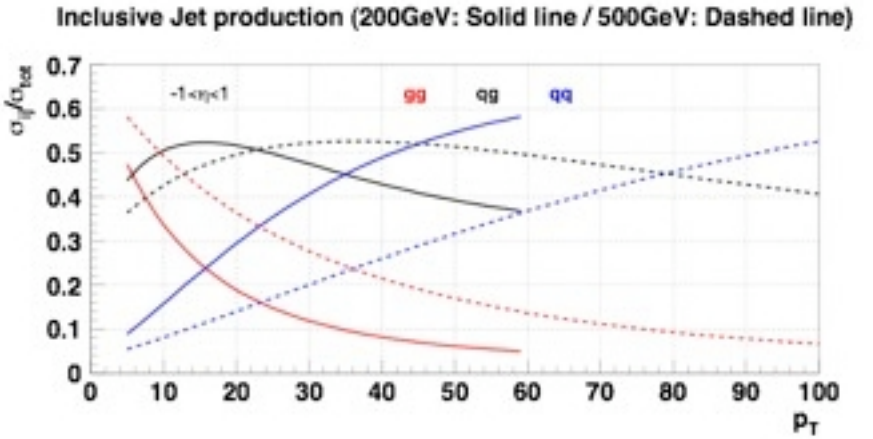
Does not constrain initial parton kinematics well (e.g. a jet of a given p_T could have come from an initial parton with a range of x values)

Inclusive Jets

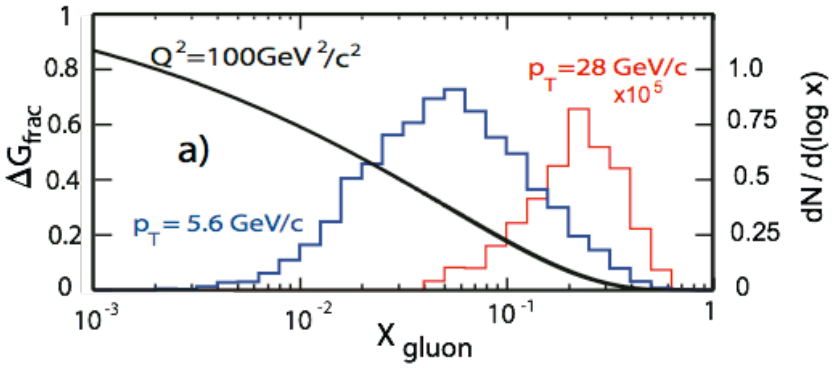
$$\vec{p} + \vec{p} \rightarrow Jet + X$$



Phys. Rev. Lett. 97 (2006) 252001

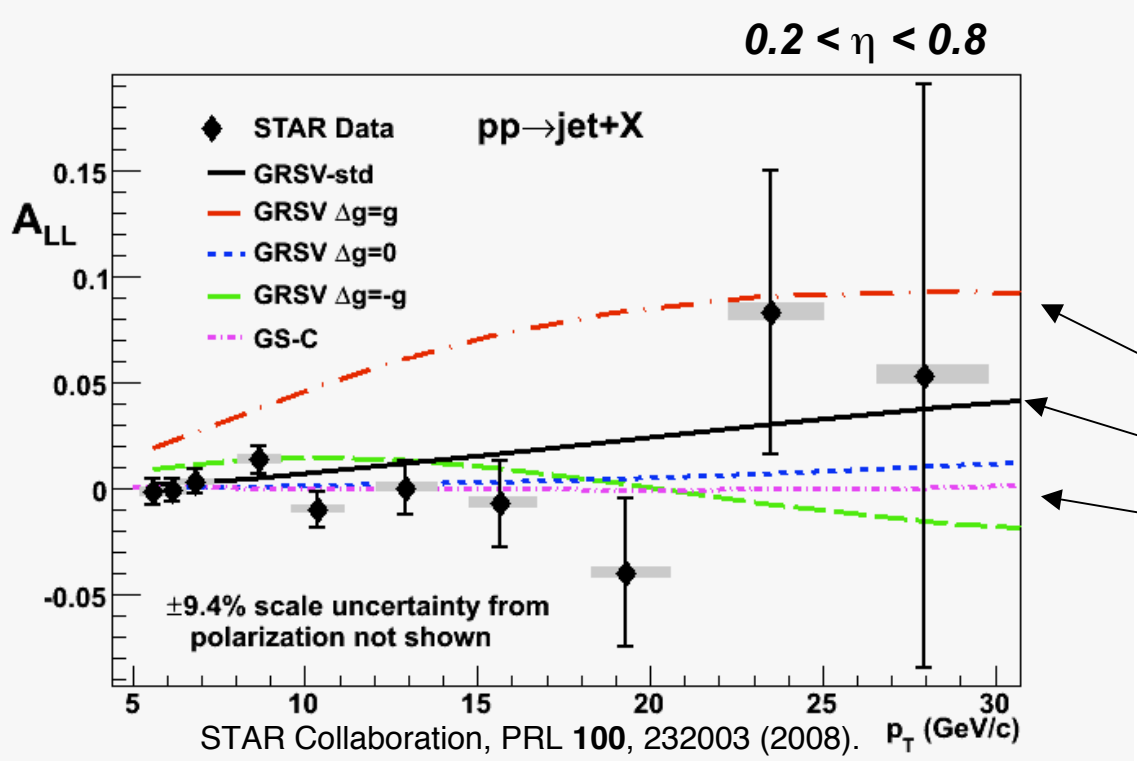


Jets at each p_T are a different mix of subprocesses



Smeared x-range for jets at a few p_Ts

Inclusive Jets A_{LL} (2005)



STAR Collaboration, PRL **100**, 232003 (2008).

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

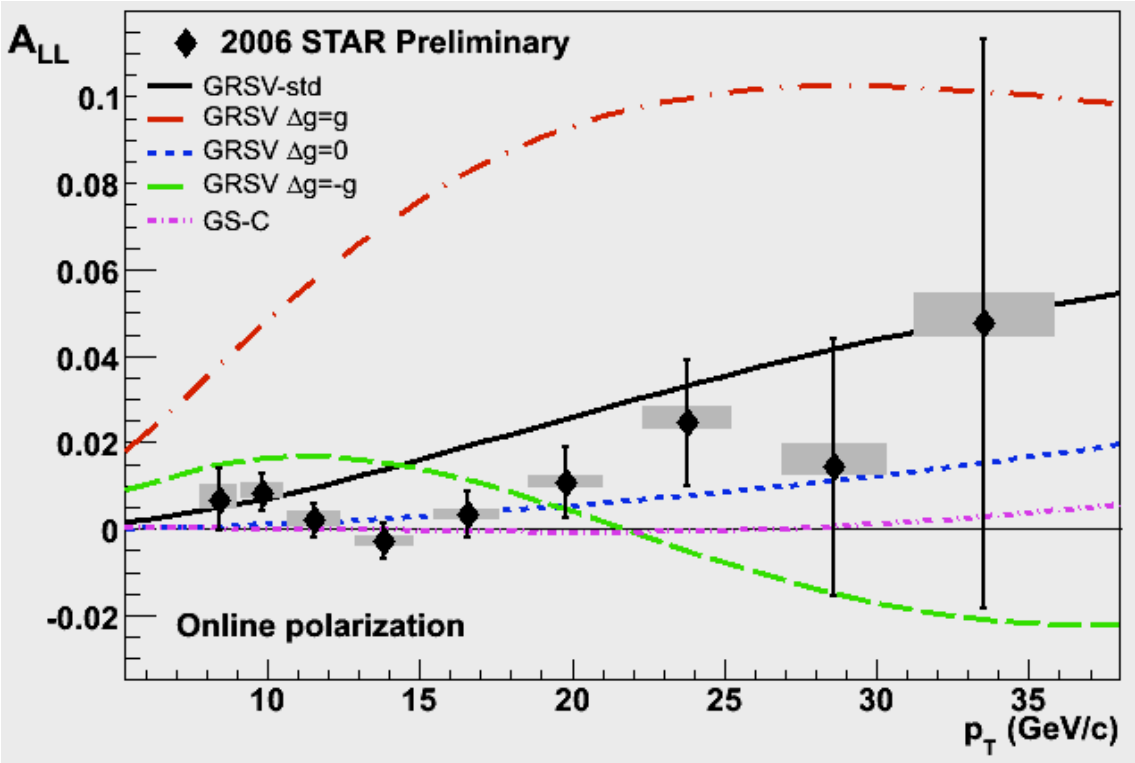
$\Delta G(Q^2 = 1GeV^2) \approx 1.8$

$\Delta G(Q^2 = 1GeV^2) \approx 0.4$

$\Delta G(Q^2 = 1GeV^2) \approx 1.0$

Maximum gluon polarization scenario (GRSV-MAX) ruled out

Inclusive Jets A_{LL} (2006)



A_{LL} systematics	(x 10^{-3})
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1st bin ~ 0.5 else ~ 0.1

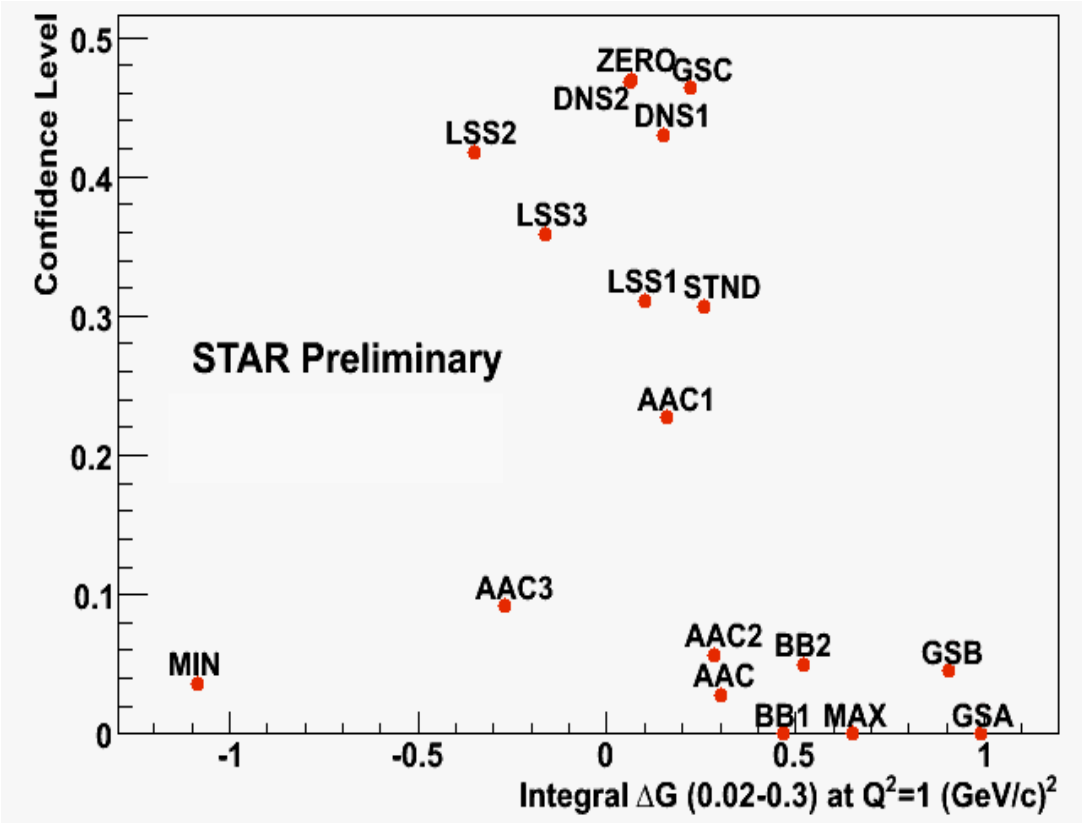
p_T systematic	± 6.7%

With the increased statistics in 2006 (~x10) the uncertainties are greatly reduced

Inclusive Jets - Constraint on ΔG

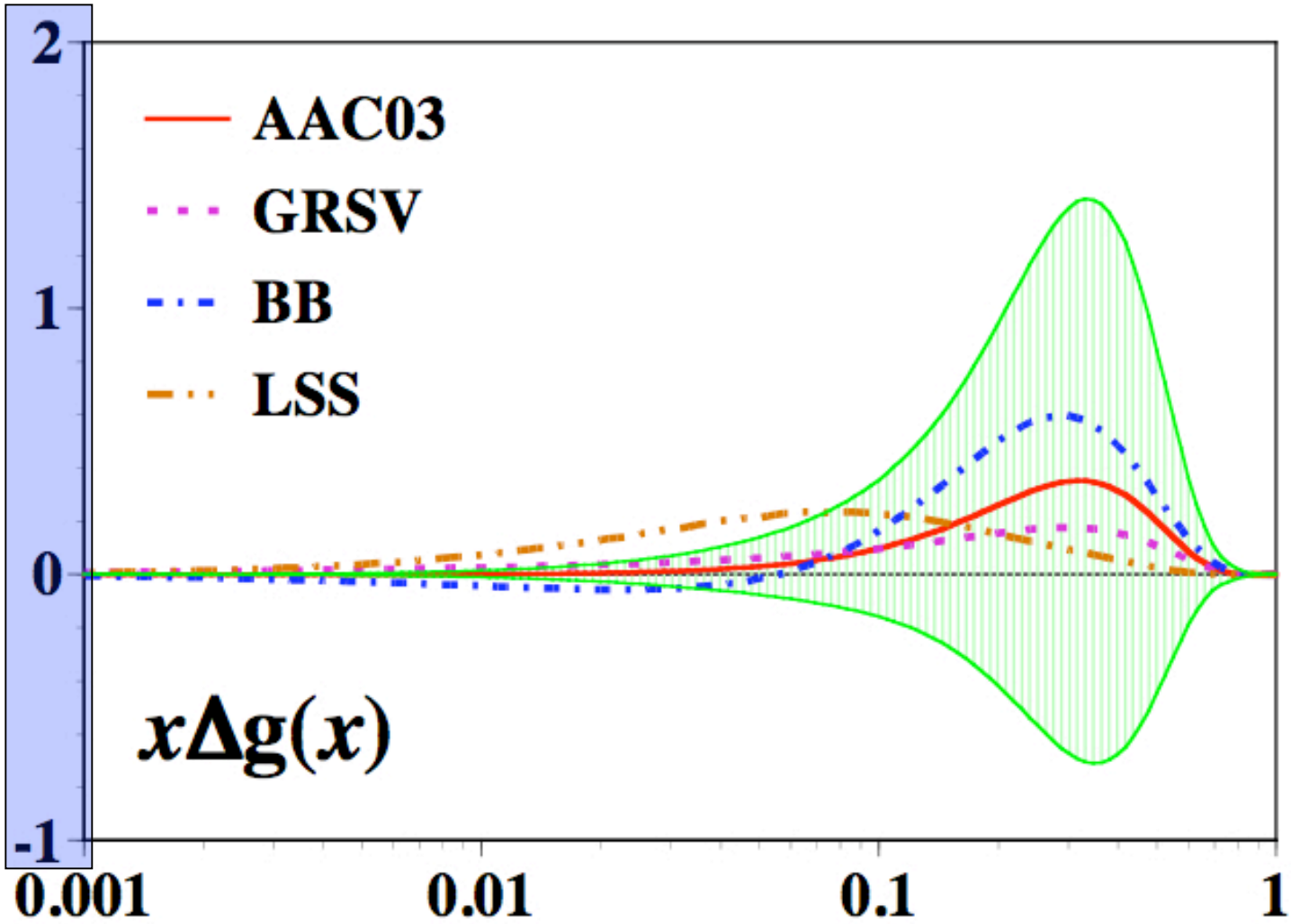
Using the available fits the confidence level is calculated using the 2005+2006 data sets

Many of the sets with large gluon polarization (neg or pos) are ruled out

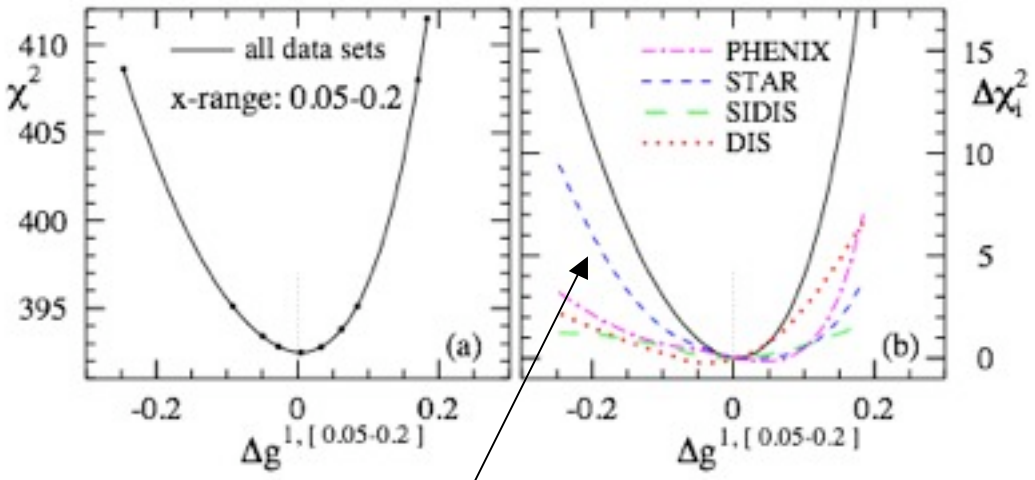


Integral constrained to be over the x range probed by STAR

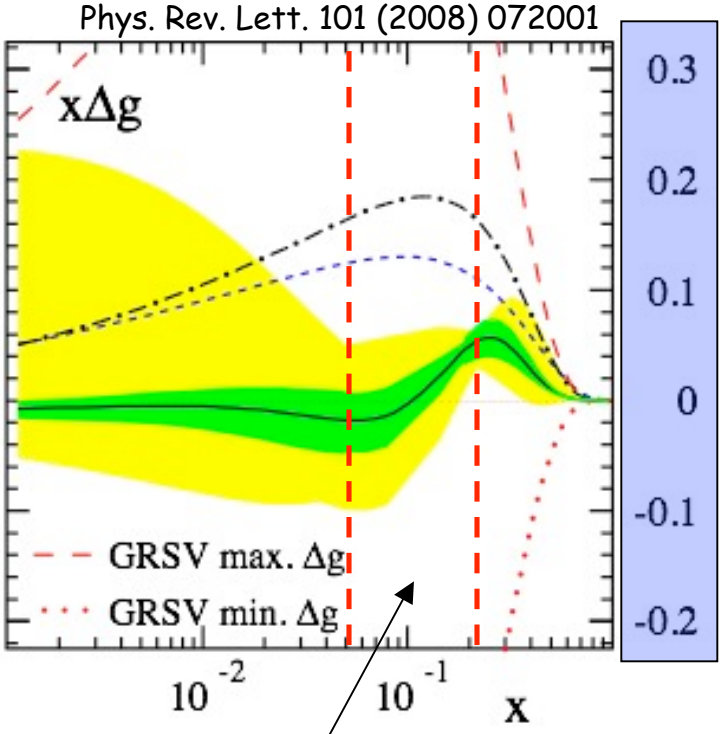
A Reminder



Inclusive Jets - Impact on Global Fits



Phys. Rev. Lett. 101 (2008) 072001



The STAR data provides a strong constraint on ΔG over $0.05<x<0.2$

The data favor a small gluon polarization in this range of x

RHIC range

There is a big need for a true mapping of the x dependence of the gluon polarization and an increased range in x

Inclusive Jets vs. Inclusive Hadrons

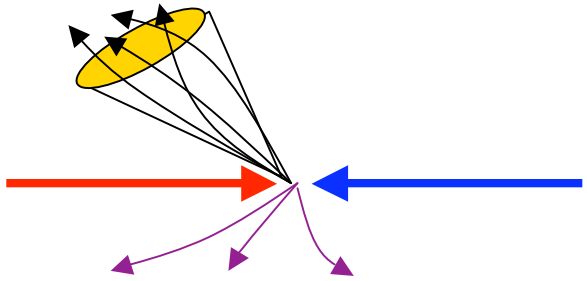
Information from inclusive hadron measurements is complementary to inclusive jet measurements

Jets $\vec{p} + \vec{p} \rightarrow Jet + X$

No fragmentation functions

Jet definition provides a complication when relating theory and measurement

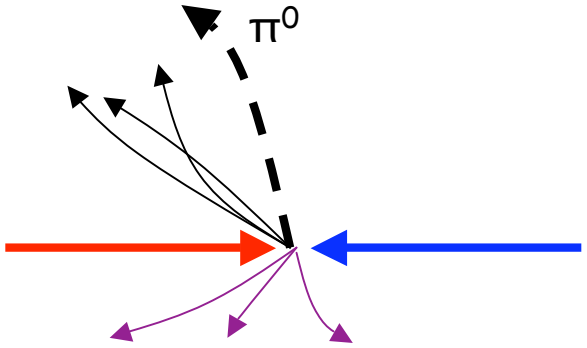
Suffers from JES uncertainty



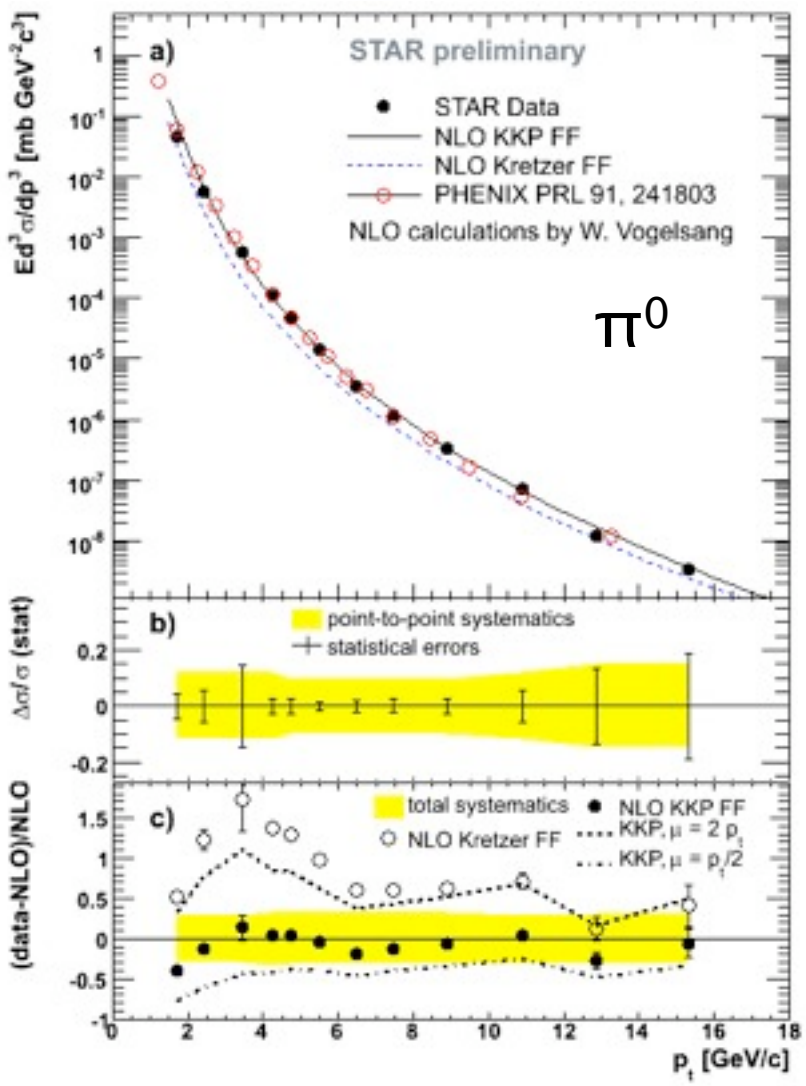
Hadrons $\vec{p} + \vec{p} \rightarrow h + X$

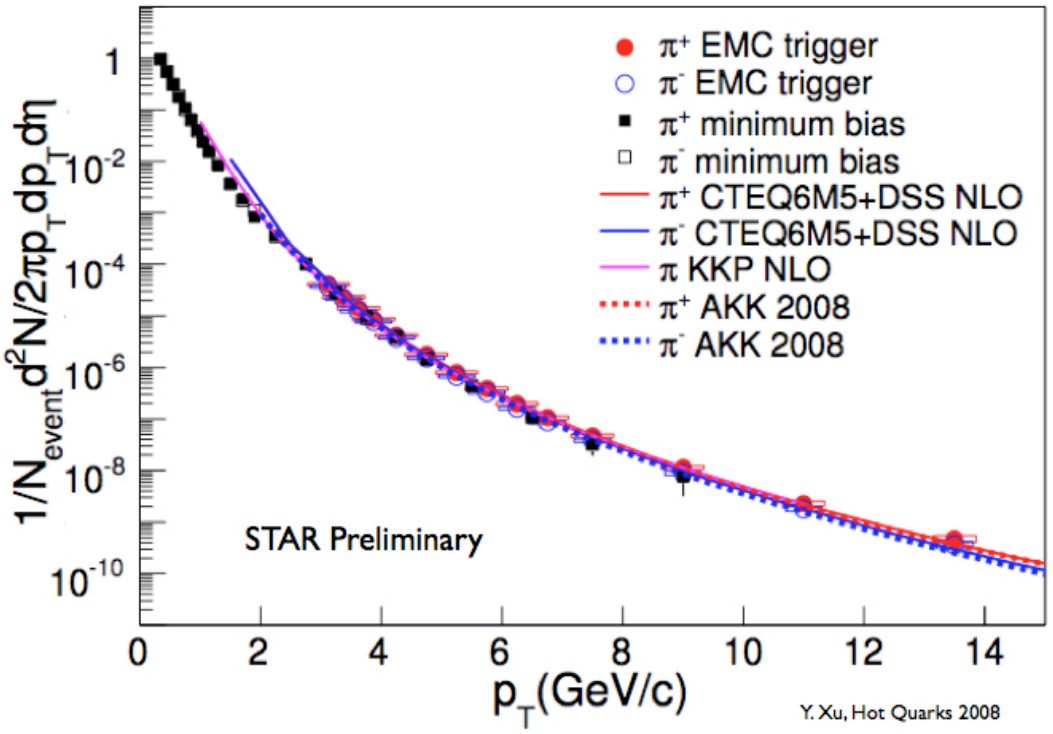
Needs a convolution with FFs but this gives a selectivity to different flavors

Less uncertainty in p_T measurement



Inclusive Hadrons





MinBias Data - Phys. Lett. B 637 (2006) 161

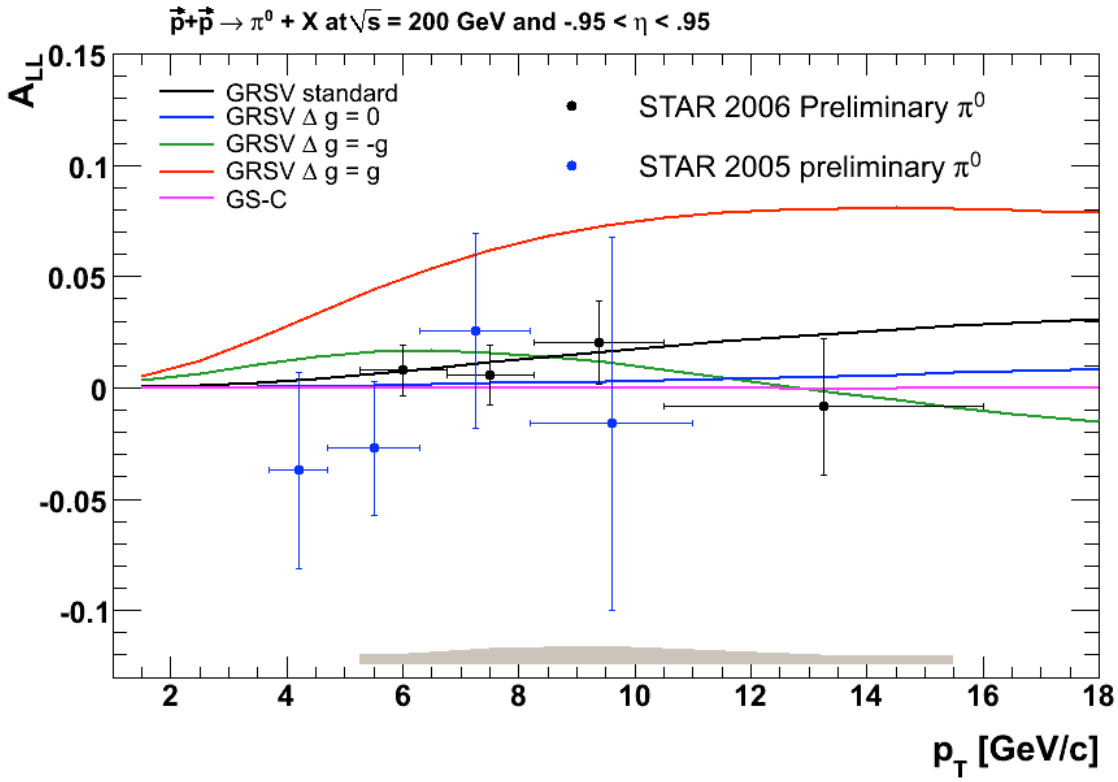
Good agreement between theory and data over large range in p_T

Neutral Pion A_{LL} (2005+2006)

Reconstructed using the di-photon decay channel

Maximum gluon polarization Scenario (GRSV-Max) is ruled out

2006 preliminary result uncertainties are comparable to PHENIX at p_T~8 GeV/c and data extend to a high p_T than PHENIX



$\Delta G(Q^2 = 1GeV^2) \approx 1.8$

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Charged Pion A_{LL} (2005)

Charged pions are useful for measuring ΔG

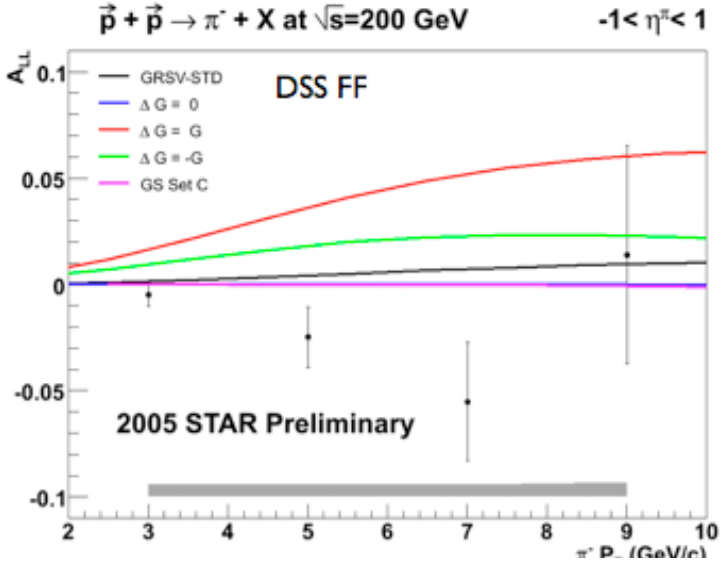
1. Can give the sign of Δg

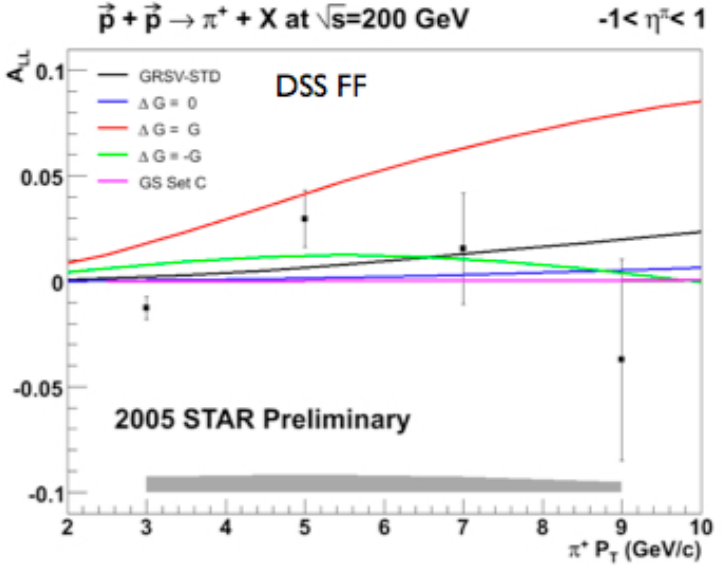
$$\Delta g > 0 \rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^-}$$

$$\Delta g < 0 \rightarrow A_{LL}^{\pi^+} < A_{LL}^{\pi^-}$$

2. π^+ is a strong "lever-arm" for measuring Δg especially since Δg is small

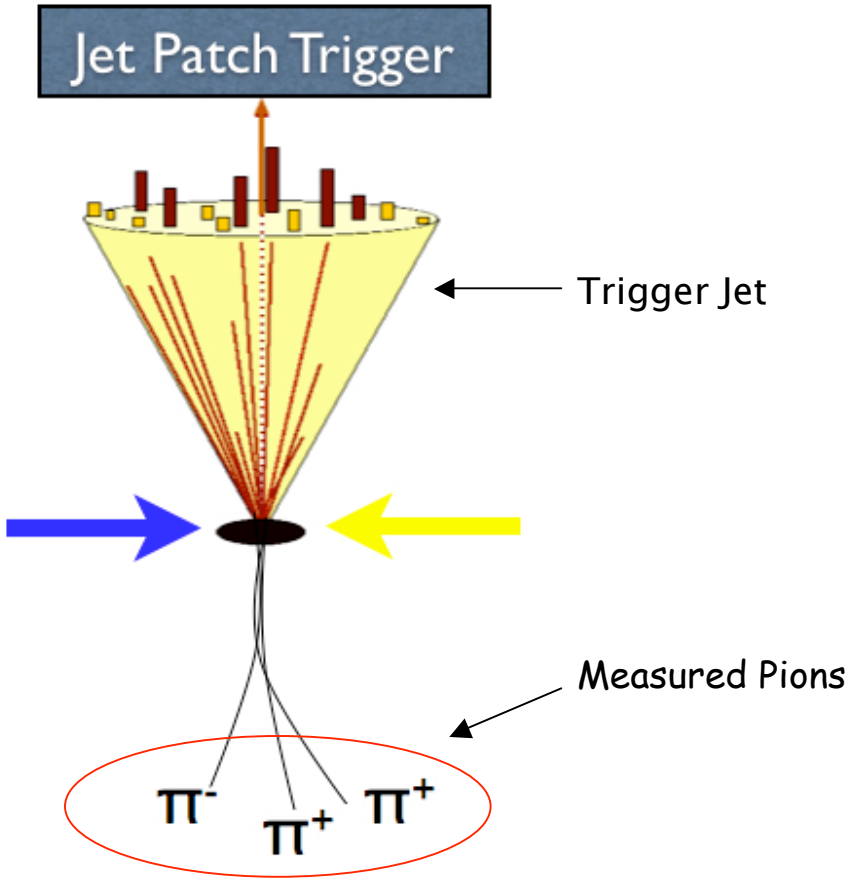
$$A_{LL}^{\pi^+} \propto \Delta g \Delta g + \Delta g \Delta u \rightarrow \Delta g \Delta u$$

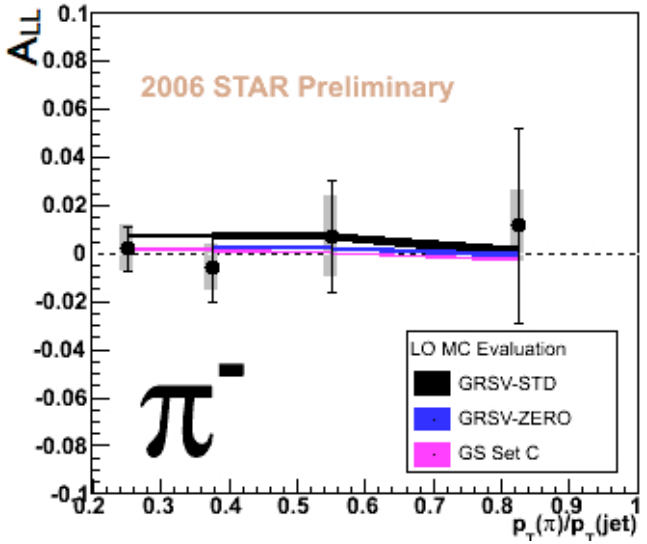


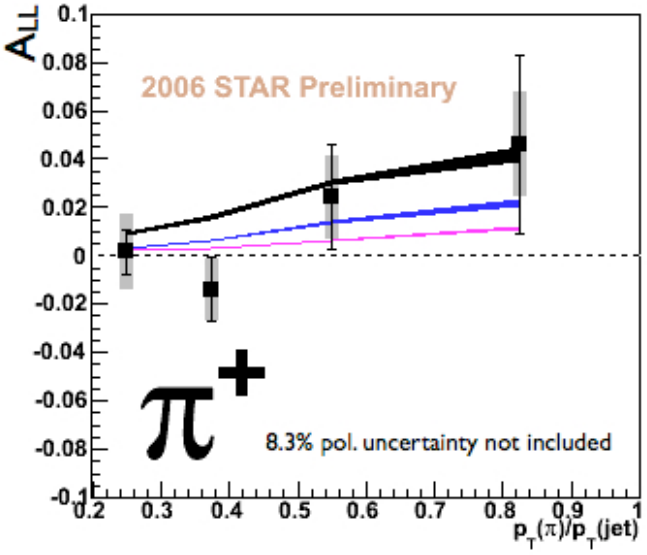


Charged Pion A_{LL} (2006)

A new way of measuring the charged pion. Triggering on a jet and measuring away side pion gives less trigger bias. Allows less biased measurement of something akin to z.







Future Measurements

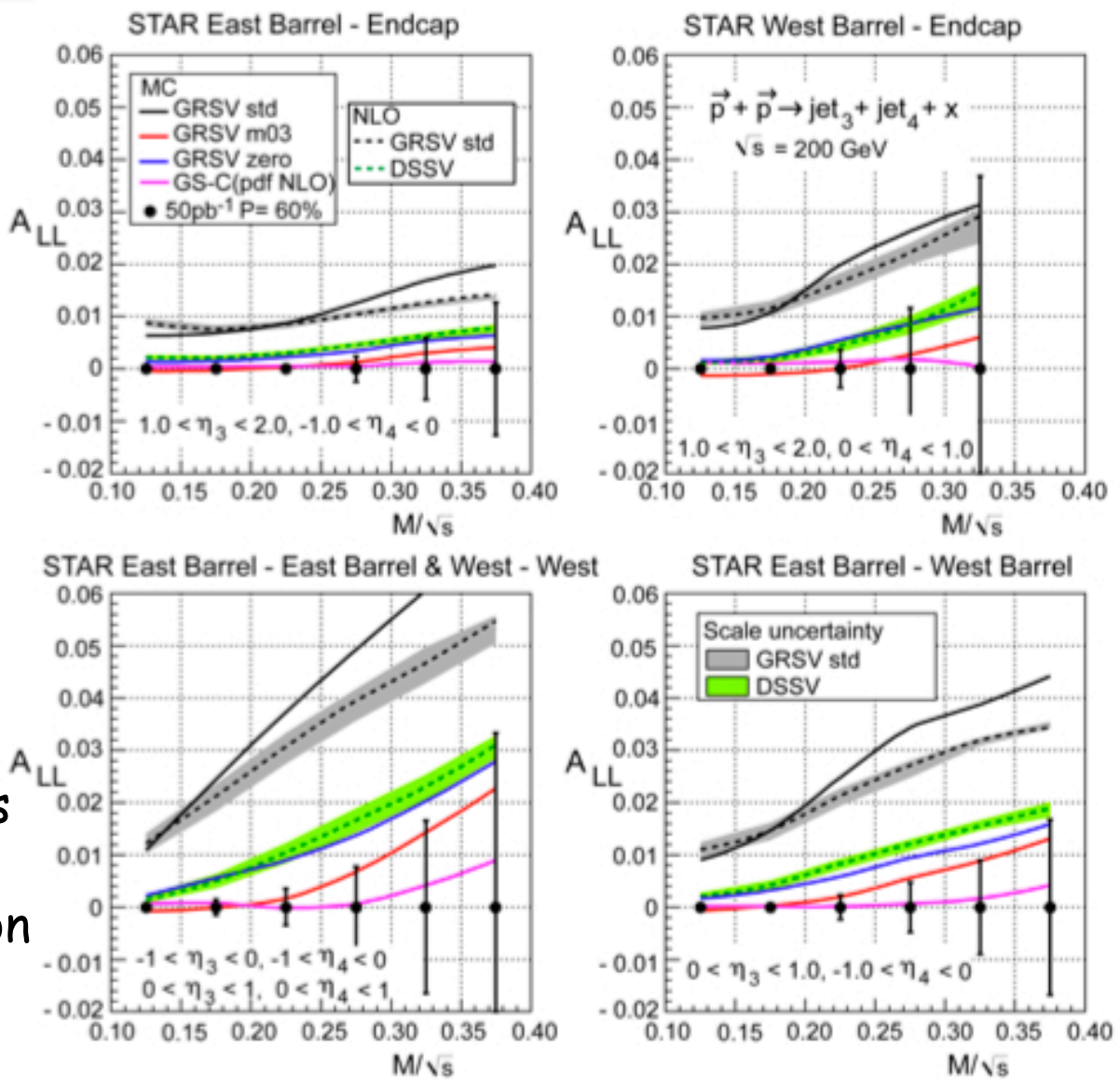
Di-jets at STAR

Correlation measurements provide information about x_1 and x_2 which can be used to get the shape of Δg

At LO

$$\frac{M}{\sqrt{s}} = \sqrt{x_1 x_2} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

The plots are expectations from STAR run9 BUR with 50pb^{-1} and 60% polarization



Ws at STAR (mid-rapidity)

At sqrt(s)=500 GeV, W's will be produced in p+p collisions

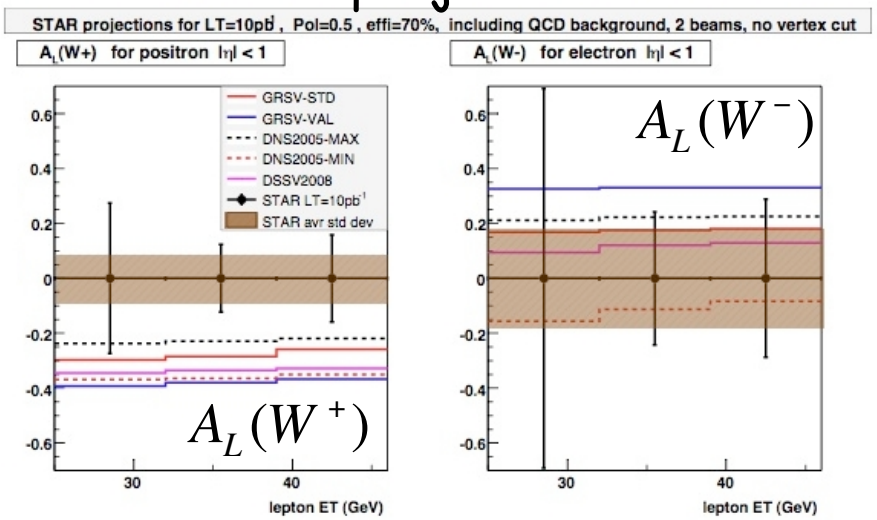
$$u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2) \rightarrow W^+$$
$$\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2) \rightarrow W^-$$

They can be tagged through their lepton+neutrino decay channel

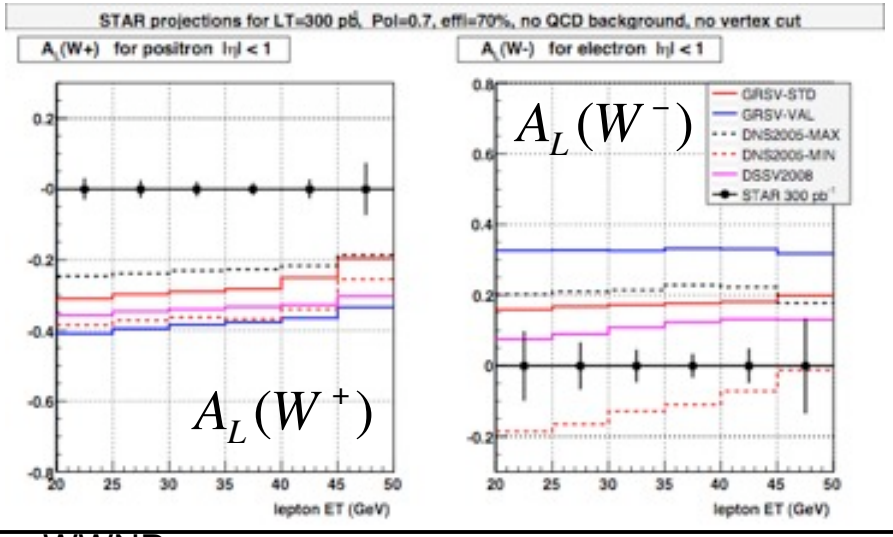
Single spin asymmetries can be measured to give information about polarized quark pdfs.

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

Run9 projections



500 GeV Program Projections

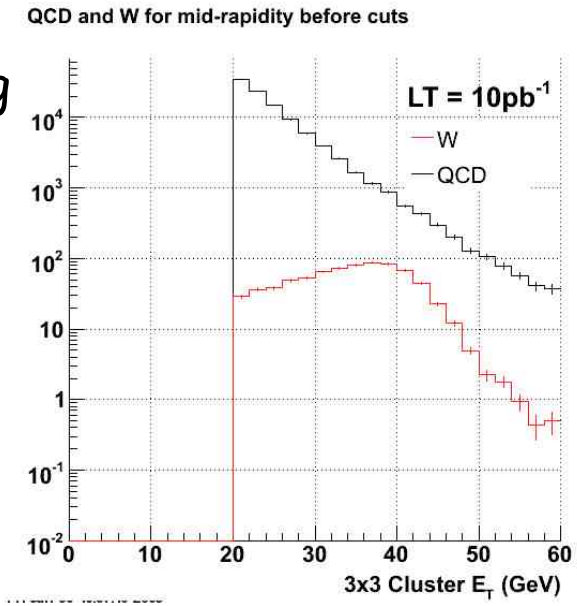


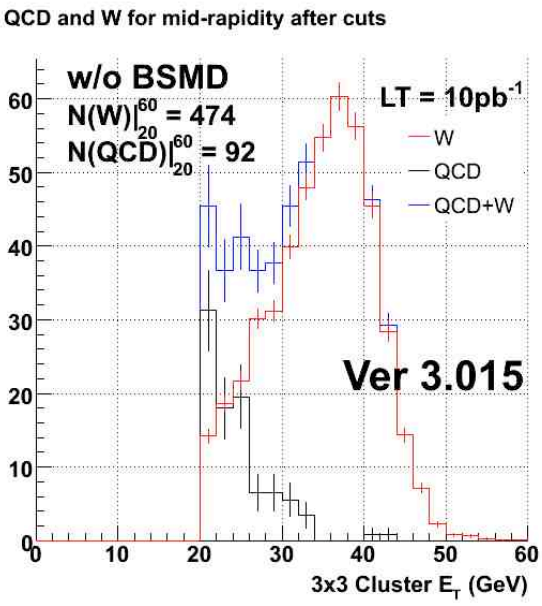
Ws at STAR (mid-rapidity)

In preparation for the upcoming 500 GeV run, STAR has been studying the reconstruction of the W.

The simulations use full detector response and realistic QCD background.

Run9 W Algorithm Simulation Results





The main source of background is hadrons so good e/h separation is necessary.

The current analysis uses a combination of tracking, shower shape, isolation style, missing energy style, and event shape cuts.

Ws at STAR (forward rapidity)

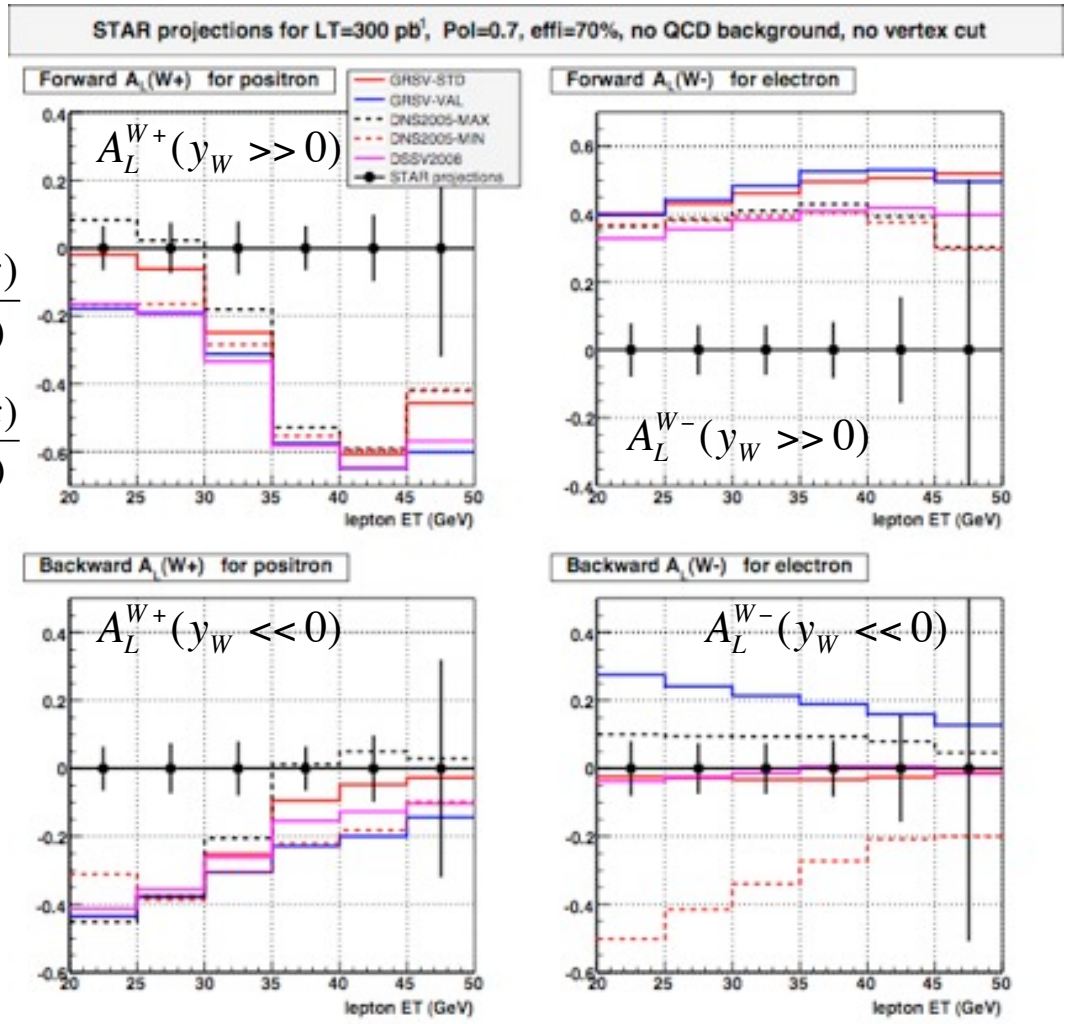
At forward or backward rapidity (defined by single polarized proton), the formulas for the single spin asymmetries simplify to

$$A_L^{W^+}(y_W >> 0) \approx \frac{\Delta u(x)}{u(x)} \qquad A_L^{W^-}(y_W >> 0) \approx \frac{\Delta d(x)}{d(x)}$$

$$A_L^{W^+}(y_W << 0) \approx -\frac{\Delta \bar{d}(x)}{\bar{d}(x)} \qquad A_L^{W^-}(y_W << 0) \approx -\frac{\Delta \bar{u}(x)}{\bar{u}(x)}$$

At forward and backward rapidity the rapidity of the lepton, the rapidity of the W and the partonic x are all strongly correlated.

500 GeV Program Projections



Summary

- STAR inclusive measurements at sqrt(s)=200 GeV have made a strong contribution to our knowledge of Δg.
- STAR will continue to impact our knowledge Δg as higher statistics sqrt(s)=200 GeV and sqrt(s)=500 GeV inclusive measurements are included in the global fits.
- Future di-jet (and other correlation) measurements will constrain the shape of Δg.
- The STAR W measurements will probe the polarizations of the anti-quarks in the proton.

Backup Slides

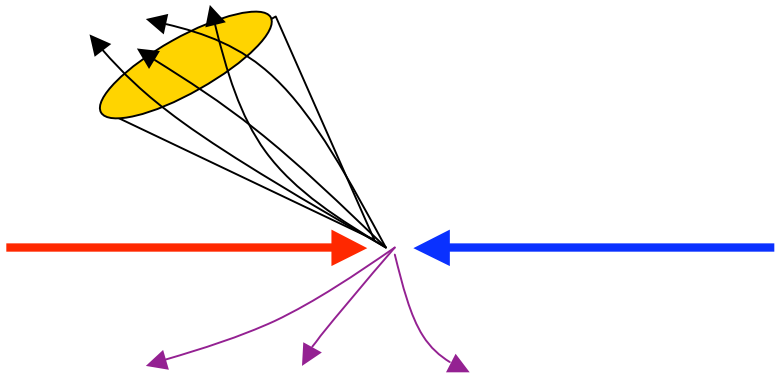
Inclusive Jets

$$\vec{p} + \vec{p} \rightarrow Jet + X$$

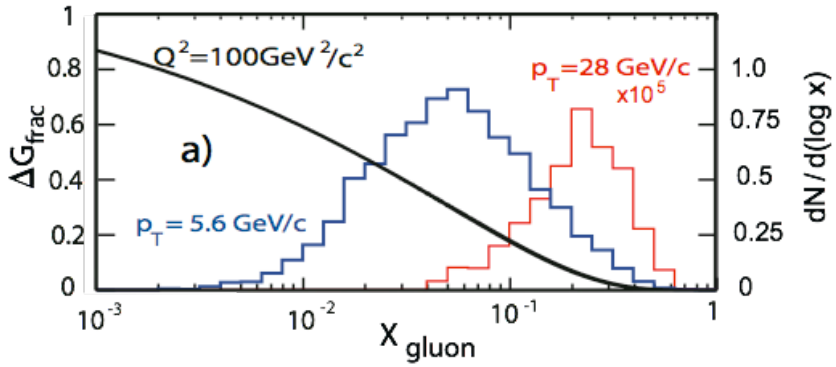
Require jet p_T be large to be in hard scattering region

No fragmentation functions but relation of measurement to theory is complicated

Suffers from JES uncertainty



Jets at each p_T are a mix of subprocesses from a range in x



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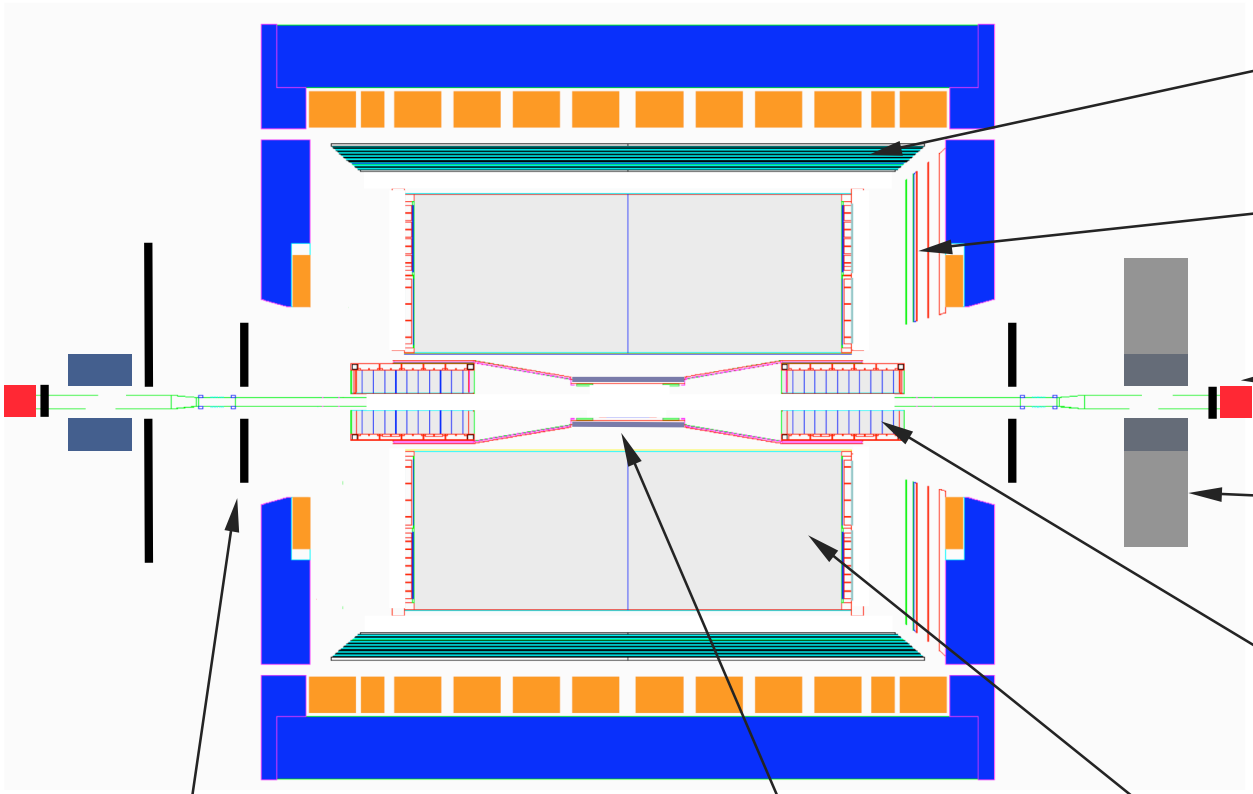


BEMC (Barrel Electromagnetic Calorimeter: -1 < η < 1)

EEMC (Electromagnetic Endcap Calorimeter: 1.09 < η < 2)

ZDC (Zero-Degree Calorimeter)

FMS (Forward Meson Spectrometer: 2.5 < η < 4)

FTPC (Forward Time Projection Chamber)

TPC (Time Projection Chamber)

BBC (Beam-Beam Counter)

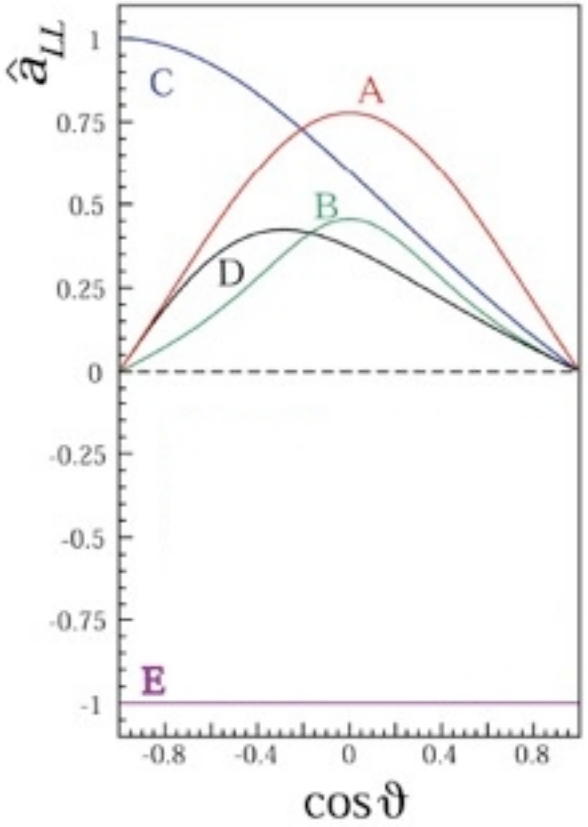
SSD (Silicon-Strip Detector)

Helicity Asymmetries

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

The LO result for a_{LL} is nonzero for all subprocesses

A	$gg \to gg$	D	$q\bar{q} \to q\bar{q}$
B	$qq \to qq$	E	$gg \to q\bar{q}$
C	$qq' \to qq'$		$q\bar{q} \to gg$
	$q\bar{q}' \to q\bar{q}'$		$q\bar{q} \to g\gamma$
	$qg \to qg$		$q\bar{q} \to q'\bar{q}'$
	$qg \to q\gamma$		$q\bar{q} \to l\bar{l}$



Inclusive Hadrons

$$\vec{p} + \vec{p} \rightarrow h + X$$

A type of final state particle is measured regardless of rest of event

More statistics than jets, but not as clean because of FFs
But also have flavor information to use

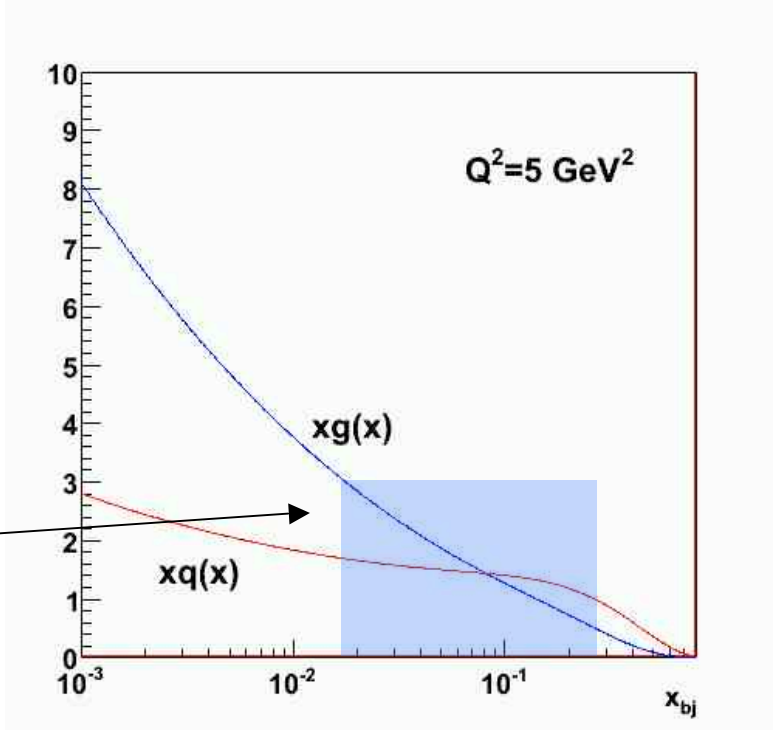
ΔG in Polarized p+p Collisions

Three Things Needed to Measure ΔG

1) Gluons in colliding protons
2) Detectable final state sensitive to gluon scattering
3) Helicity dependent cross section

In hard interactions at RHIC energies the proton is roughly 40% glue

STAR mid-rapidity



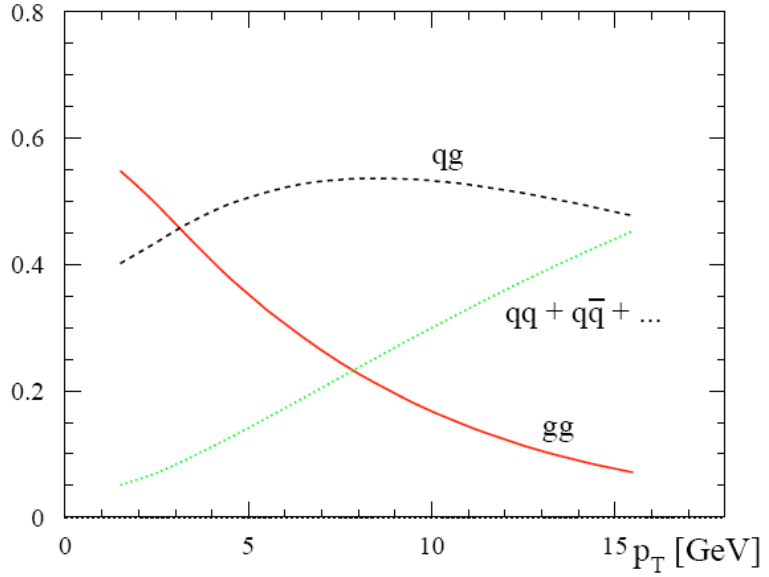
ΔG in Polarized p+p Collisions

Three Things Needed to Measure ΔG

1) Gluons in colliding protons
2) Detectable final state sensitive to gluon scattering
3) Helicity dependent cross section

Gluons enter p+p scattering at leading order and are dominant in the collisions at low p_T

e.g. π^0 subprocess fractions at mid-radpidity



ΔG in Polarized p+p Collisions

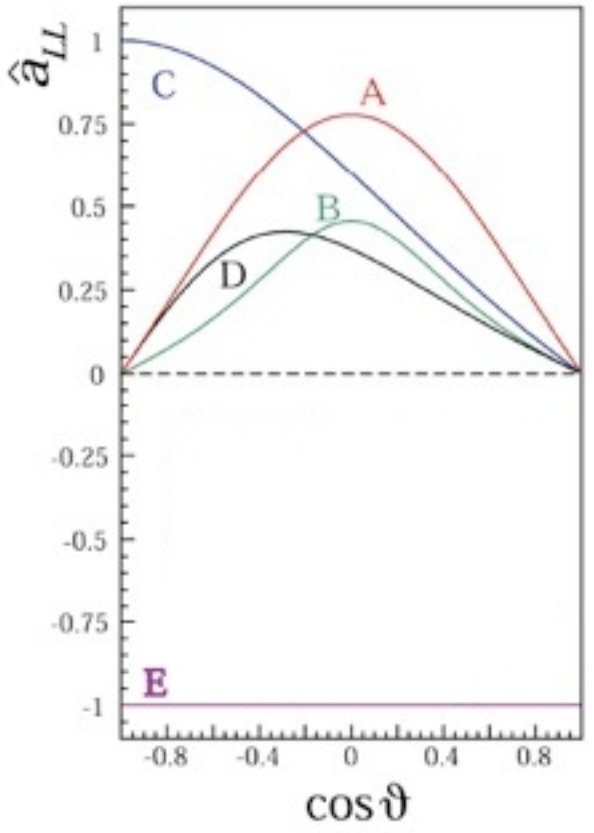
Three Things Needed to Measure ΔG

1) Gluons in colliding protons
2) Detectable final state sensitive to gluon scattering
3) Helicity dependent cross section

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

The LO result for a_{LL} is nonzero for all subprocesses

A	$gg \to gg$	D	$q\bar{q} \to q\bar{q}$
B	$qq \to qq$	E	$gg \to q\bar{q}$
C	$qq' \to qq'$		$q\bar{q} \to gg$
	$q\bar{q}' \to q\bar{q}'$		$q\bar{q} \to g\gamma$
	$qg \to qg$		$q\bar{q} \to q'\bar{q}'$
	$qg \to q\gamma$		$q\bar{q} \to l\bar{l}$



Spin Transfer