Exploring the nucleon helicity structure with pp collisions

October 4, 2006

Abhay Deshpande

Stony Brook University

RIKEN BNL Research Center

THIS IS NOT A SUMMARY TALK!

Those were done already on Monday afternoon by each experiment

So if you do not see your favorite slide or your own work,

I apologize

Outline

- Aftermath of EMC Spin Crisis
- Motivation of a proton-proton collider

- The RHIC Spin program at BNL
  - Status: An experimentalist's view
- Double spin asymmetry results
  - Limitations and aspirations: short term outlook
  - Needs

- Summary & closing comments

The spin crisis & its aftermath

- European Muon Collaboration's discovery in 1988/89
  - Quarks (+ anti-quarks) do not carry the expected fraction of nucleon spin!

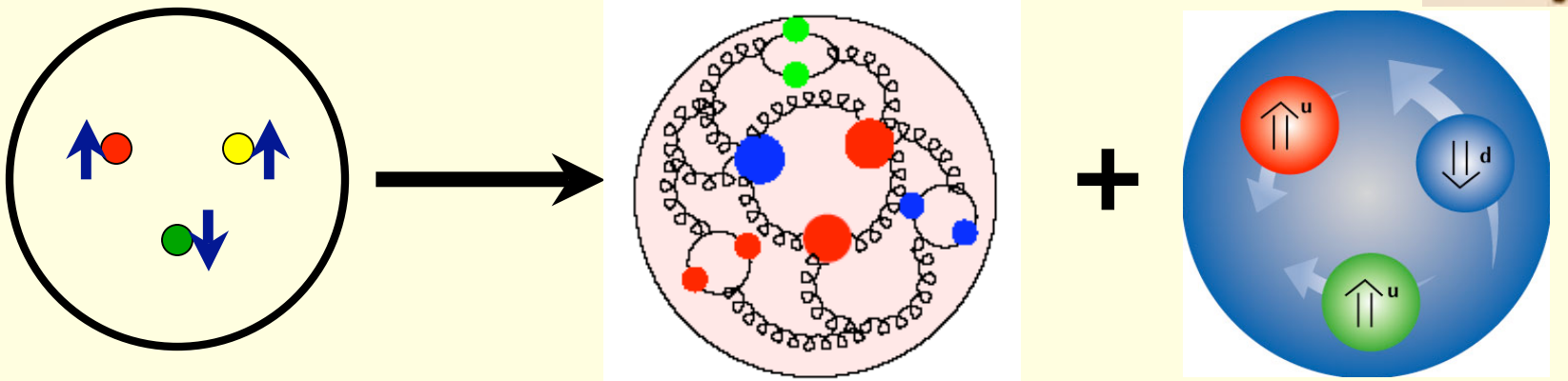
- Nature's message: Look again, look elsewhere....

Ellis's beer

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + I_{Q\&G}$$

Quark Model

QCD + Orbital motion



PDFs & Fixed target DIS

Limitations:

- Virtual photon can not directly interact with gluons
  - Charge-less gluons and colorless quarks: don't see "eye-to-eye"
  - Indirect contacts: Photon-Gluon-Fusion process(es)

- Fixed target experiments ==> low center of mass:
  - clean interpretation of results using pQCD difficult in certain processes

- Virtual photon can not distinguish quarks from anti-quarks: To accomplish this one has to consider fragmentation functions π,Ks etc.... uncertainties arise.

***Not** "limitations" of polarized DIS, but of **fixed target** polarized DIS*
See talks on October 7, by K. De Jaeger & S. Aronson

What other options do we have?

- Why not collide **protons on protons?**
  - Each is an ample source of "glue", could be used to probe the gluon's role *directly*

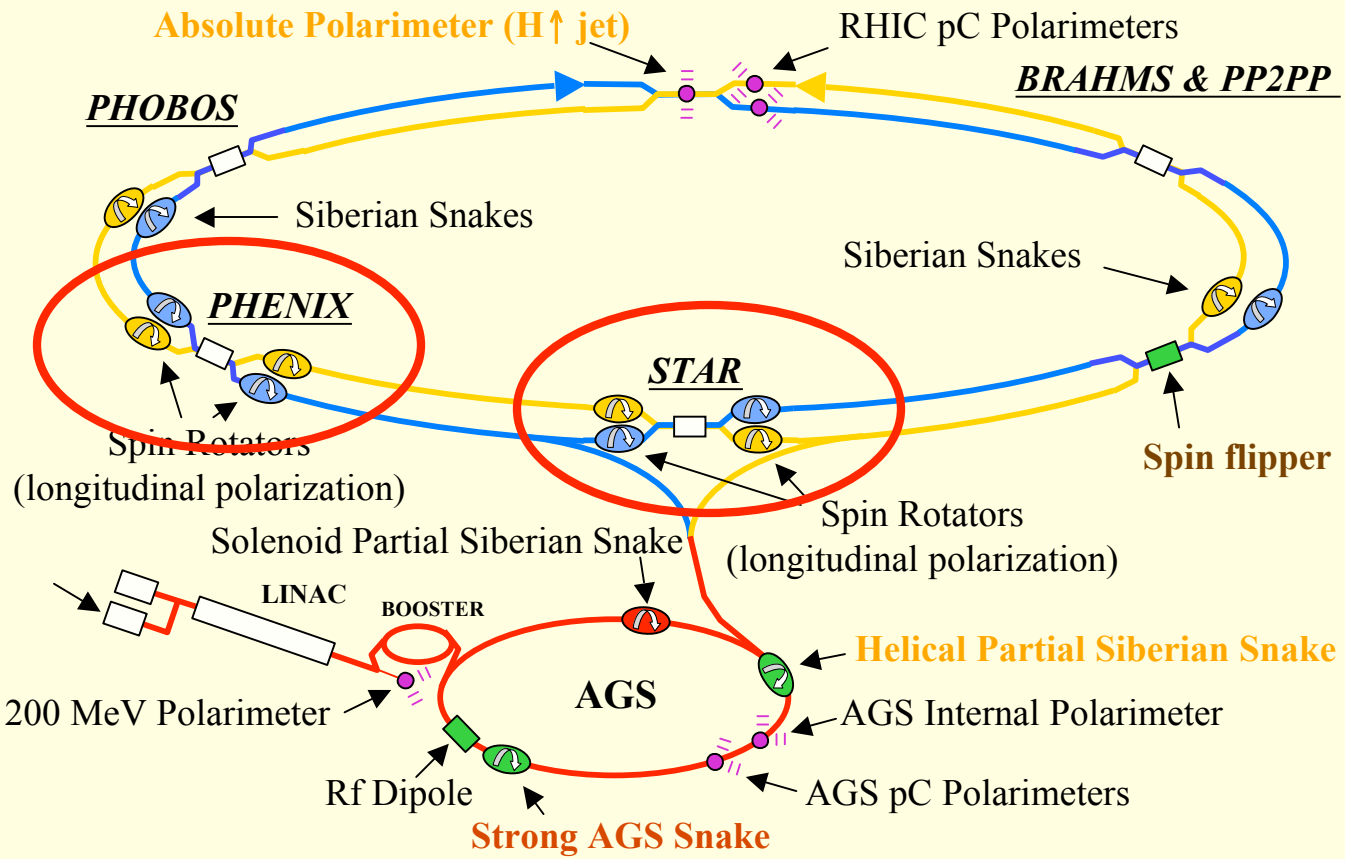
- To keep the **interpretation of results clean** using pQCD
  - A collider at *high energy*

This was the motivation for

the RHIC Spin program

It also allows a beautiful & elegant way to explore the **quark vs anti-quark** spin contribution

RHIC as A Polarized Collider



M. Bai's talk Oct.2, 2006

- Installed and commissioned during FY04 run
- Commissioned during FY05 run
- Installed and commissioned during FY05 run

Polarized Collider Development

Parameter	Unit	2002	2003	2004	2005	**2006**
No. of bunches	--	55	55	56	106	**111**
bunch intensity	10^{11}	0.7	0.7	0.7	0.9	**1.4**
store energy	GeV	100	100	100	100	**100**
β*	m	3	1	1	1	**1**
peak luminosity	$10^{30}cm^{-2}s^{-1}$	2	6	6	10	**35**
average luminosity	$10^{30}cm^{-2}s^{-1}$	1	4	4	6	**20**
Collision points	--	4	4	4	3	**2**
average polarization, store	%	15	35	46	47	**60-65**

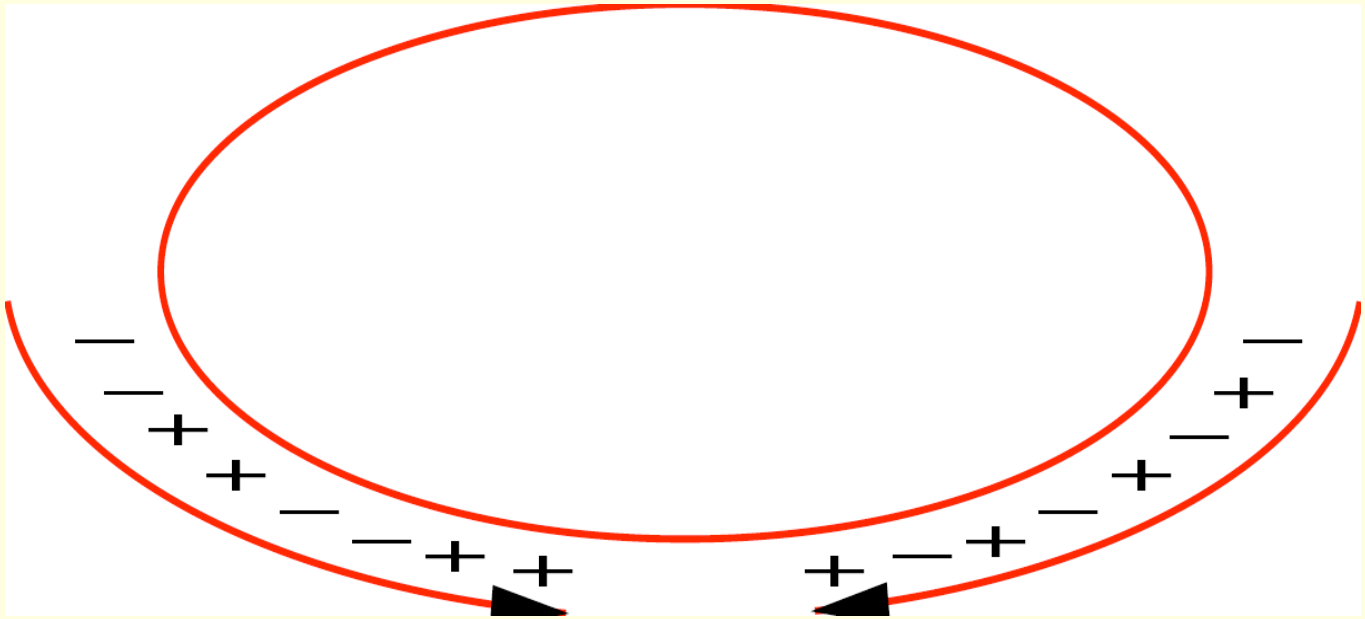
The RHIC Spin: Physics

1. Direct determination of the polarized **gluon distribution** using many independent probes
   - Requires double longitudinally polarized pp collisions

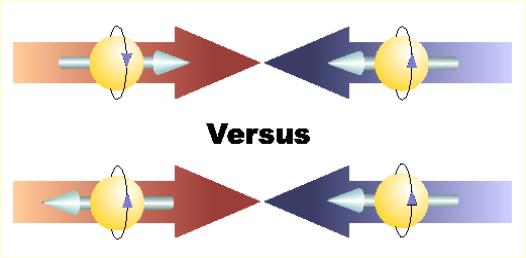
2. Direct determination of the **polarized quark & anti-quark polarization** using $W^{+/-}$ production in pp collisions and its PV decay
   - Requires at least one beam longitudinally polarized
   - Also 500 GeV in CM

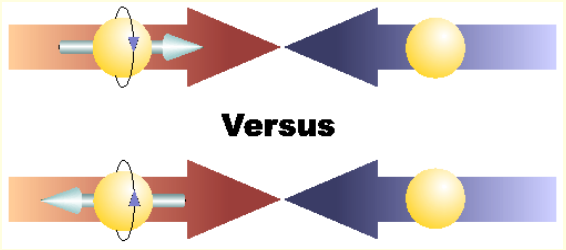
3. **Transversity and other transverse spin effects** which may lead to better understanding of the transverse spin structure of the proton
   - Requires at least one transversely polarized proton beam
   - This will be described in A. Ogawa's talk which follows

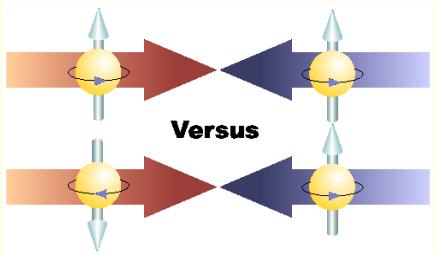
Exquisite Control: Systematic Uncertainties



Bunch crossing intervals 100's of ns







I will not have a detector slide!

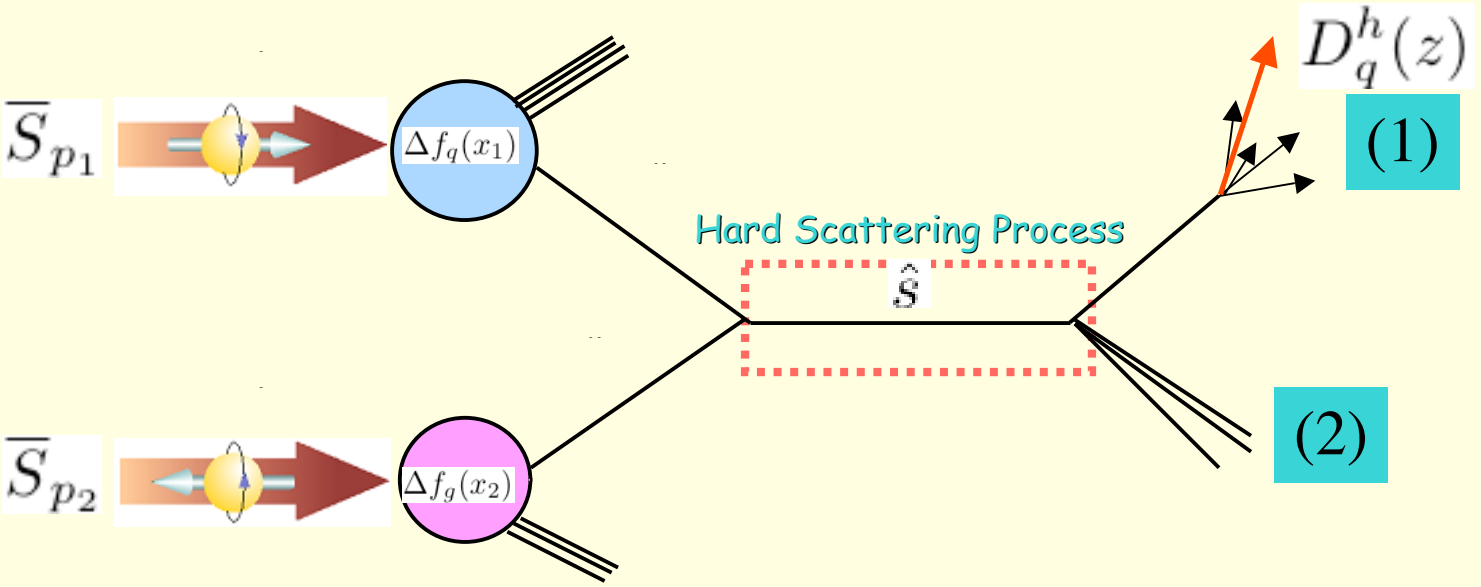
- PHENIX Design philosophy: (details in Ken Barish's talk, 2A, Monday)
  - Detector Redundancy
  - Fine Granularity, Mass Resolution
  - High Data Rate
  - Good Particle ID
  - Limited Acceptance in central calorimetry and forward muon detectors

- STAR (details in B. Surrow's talk, 2A, Monday)
  - Large acceptance with azimuthal symmetry
  - Good tracking, particle ID
  - Central & forward calorimetry

- Both have collisions counters and zero-degree-calorimeters to characterize events

YOU HAVE SEEN THEM IN MANY TALKS!

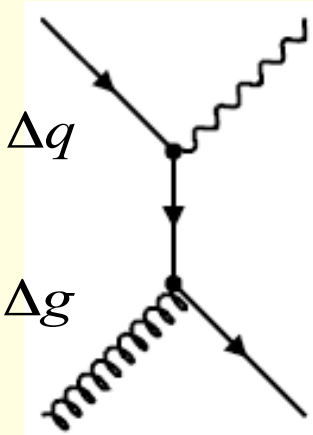
Method of accessing ΔG: example



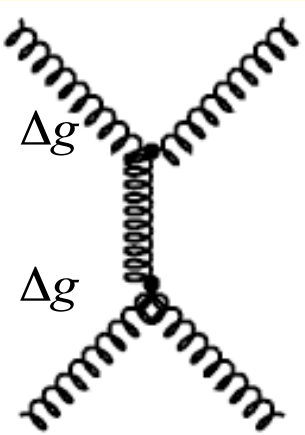
- Different hard scattering process: which result in final states (1) and (2)
  - They could be: 2-Jets, Jet-photon
  - Jets --> hadronize/fragmentation--> (π, K, p...)
    - Fragmentation function required for the appropriate process
  - Inclusive and semi-inclusive: measurements in RHIC detectors

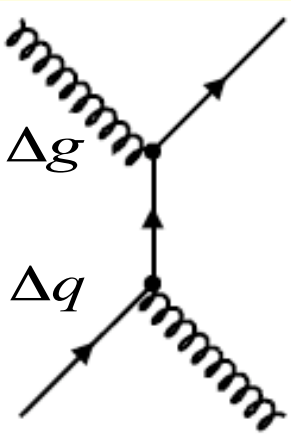
The Processes..... On a partonic level

Direct Photon

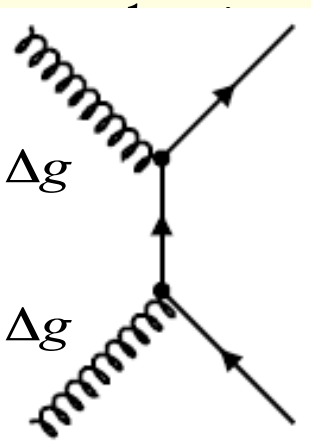


Di-Jet production





Heavy Quark



Double Longitudinal Asymmetry

- The measurement:

$$A_{LL} = \frac{1}{P_y P_b} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}} \qquad R = \frac{N_{++}}{N_{+-}}$$

- Where + and - indicate (longitudinal) spin orientations
- R is a ratio of the number of collisions with [++ vs. +-] spin orientations in the experiment: Relative Luminosity ratio

- Experiments have to confirm that the spin orientation is indeed longitudinal when they collide in the experimental IR
  - Local Polarimetry
  - Does not really measure polarization; only checks spin orientation in collisions

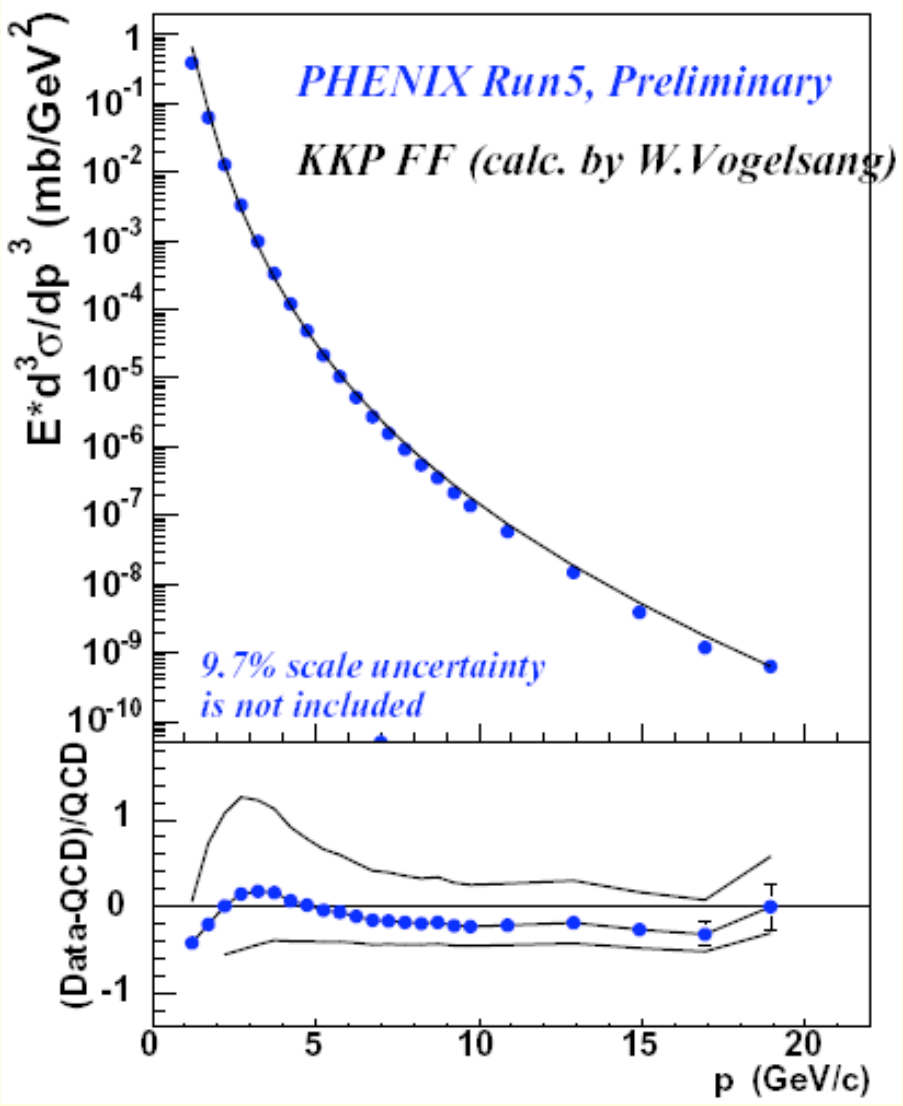
Interpretation of A_{LL}

- The measured double longitudinal asymmetries have to be interpreted in terms of ΔG:
  - This is done in the framework of perturbative QCD

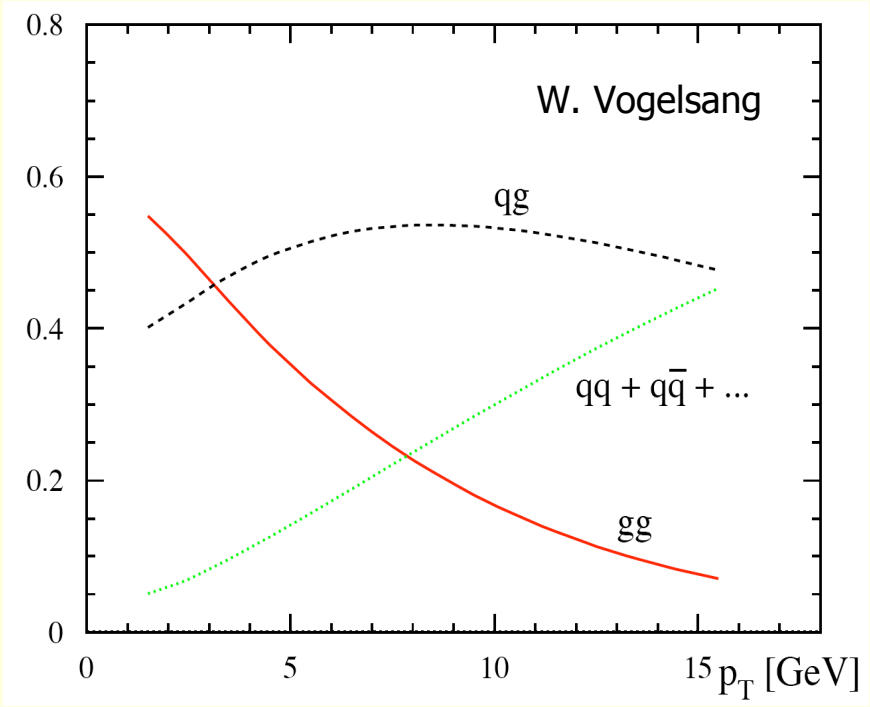
- How do we know that the perbative QCD approach is appropriate for the kinematics in which A_{LL} is measured?

- Compare the NLO pQCD calculations in the kinematics of the experiment with their data

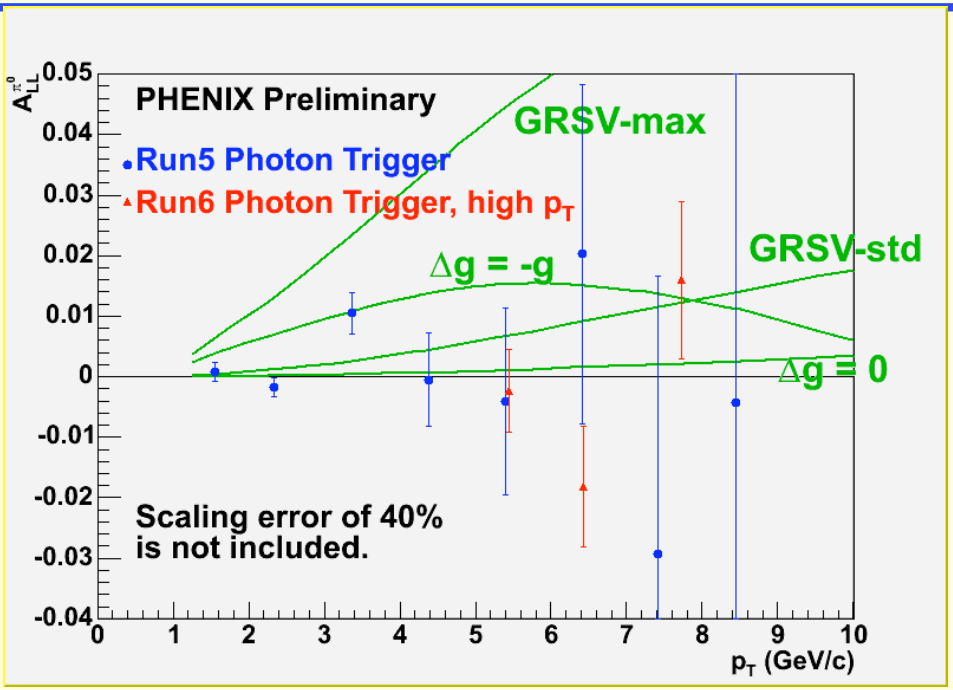
p+p->π°+X, 200 GeV CM & central rapidity



- Central rapidity of PHENIX experiment
- Next-to-Leading order calculations match very well with the available data



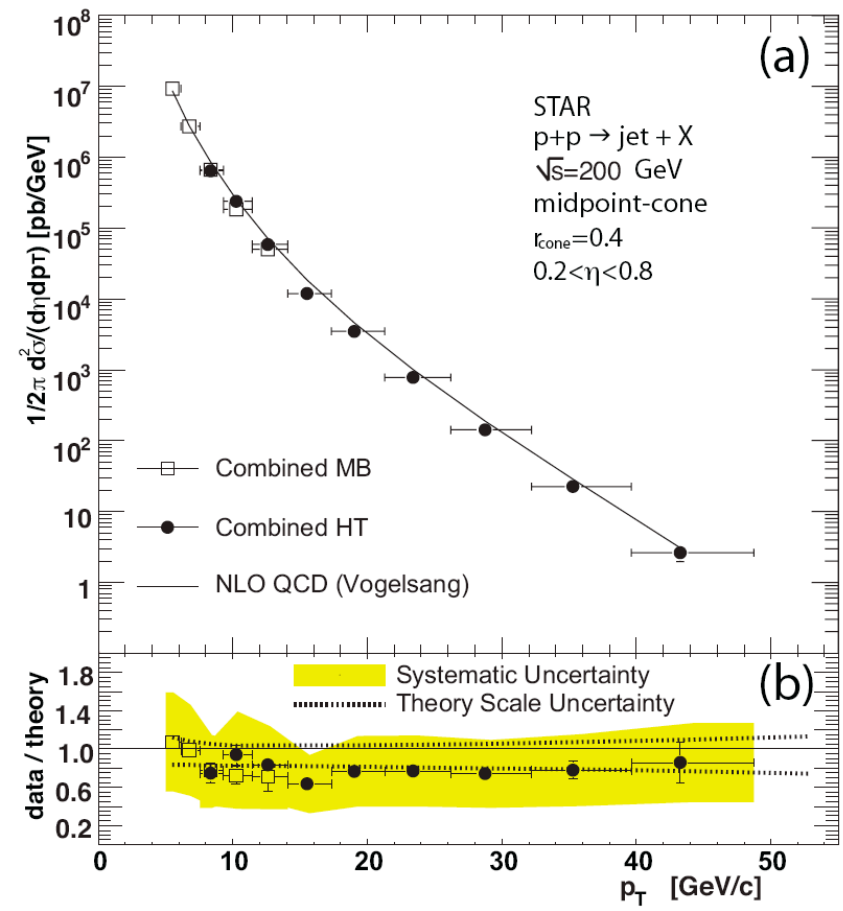
π^0 asymmetry at 200 GeV CM

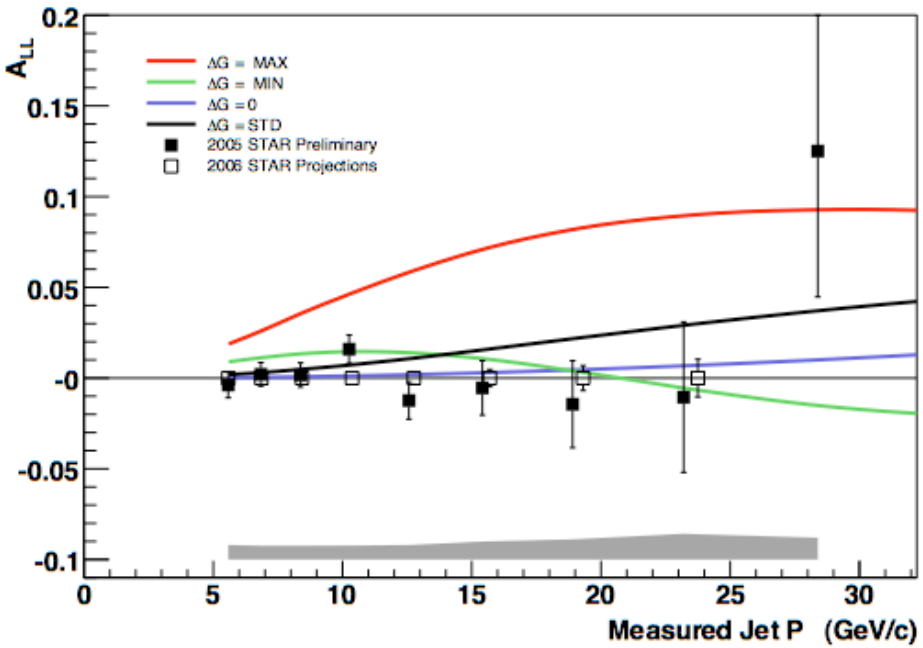


	C.L. (%)		
Theory model	Run5	Run6	Run5 & Run6
GRSV-std	18.0-22.1	0.5-7.0	1.5-8.8
GRSV-max (ΔG=G)	0.0-0.0	0.0-0.0	0.0-0.0
GRSV ΔG=0	16.9-18.6	14.2-16.5	11.1-12.2
GRSV ΔG=−G	0.0-0.9	0.0-1.1	0.0-0.0

- Run-5 (preliminary) + Run-6 (partial, preliminary)
- Compared with the different ΔG scenarios coming from DIS fixed target experiments & some model dependent inputs to them
- **Preliminary**: Zero Gluon more likely than the GRSV-Std (after Run-6 inclusion) ??
- Caveat: the variation in theory uncertainty is not considered in these Confidence Level calculations yet. Detailed analyses underway.

STAR Inclusive Jet measurement





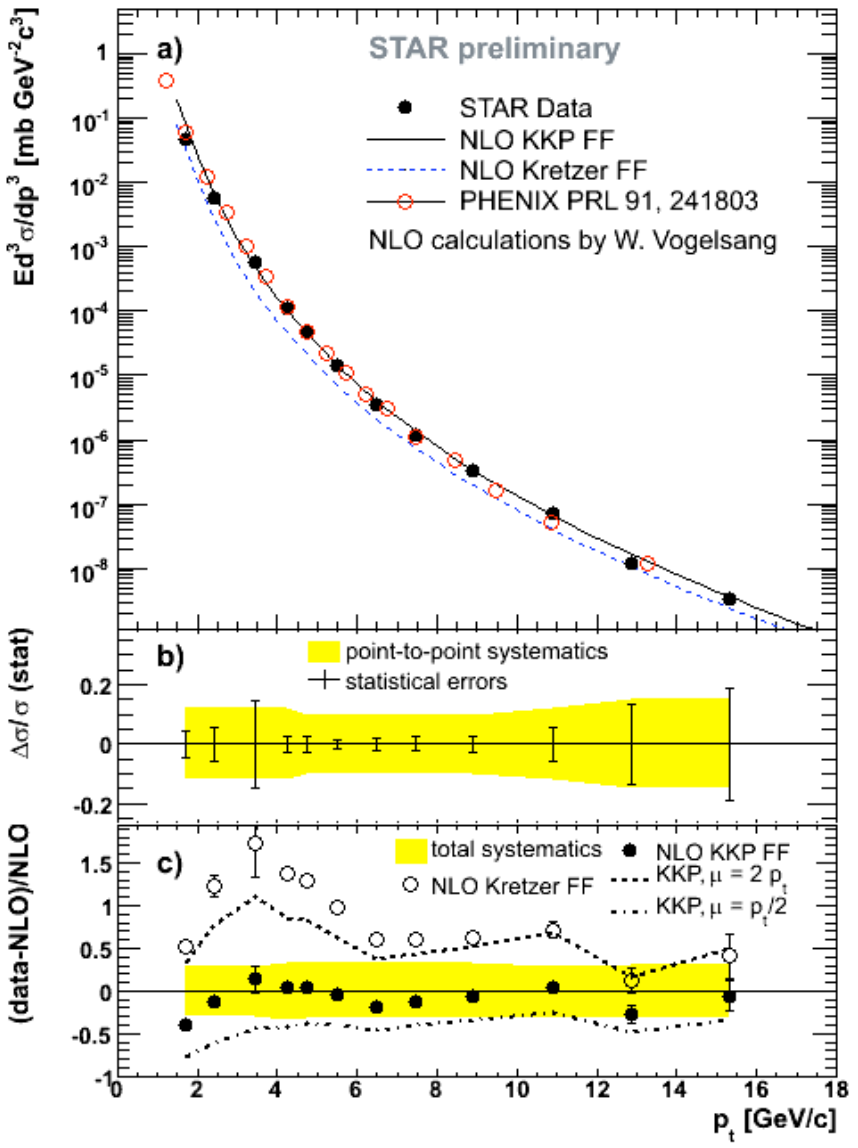
Inclusive jet cross section at NLO in agreement with the data over 7 orders of magnitude and wide pT

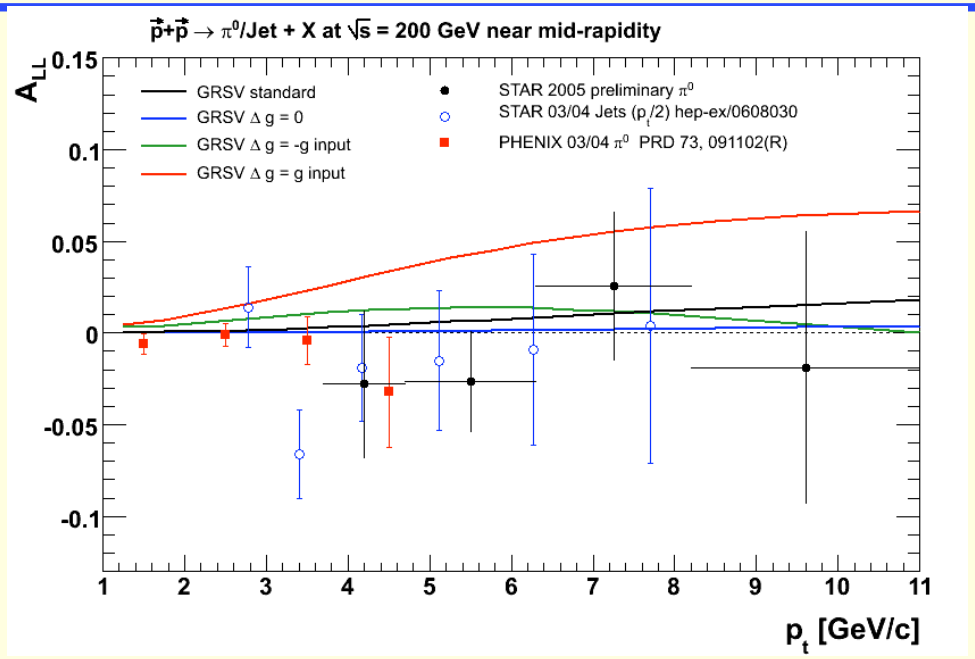
χ^2 conf. levels

GRSV-STD:	1.1
ΔG = G:	12
ΔG = 0:	0.7
ΔG = -G:	1.4

Rules out ΔG=G (Run-5 data)

STAR: π° production

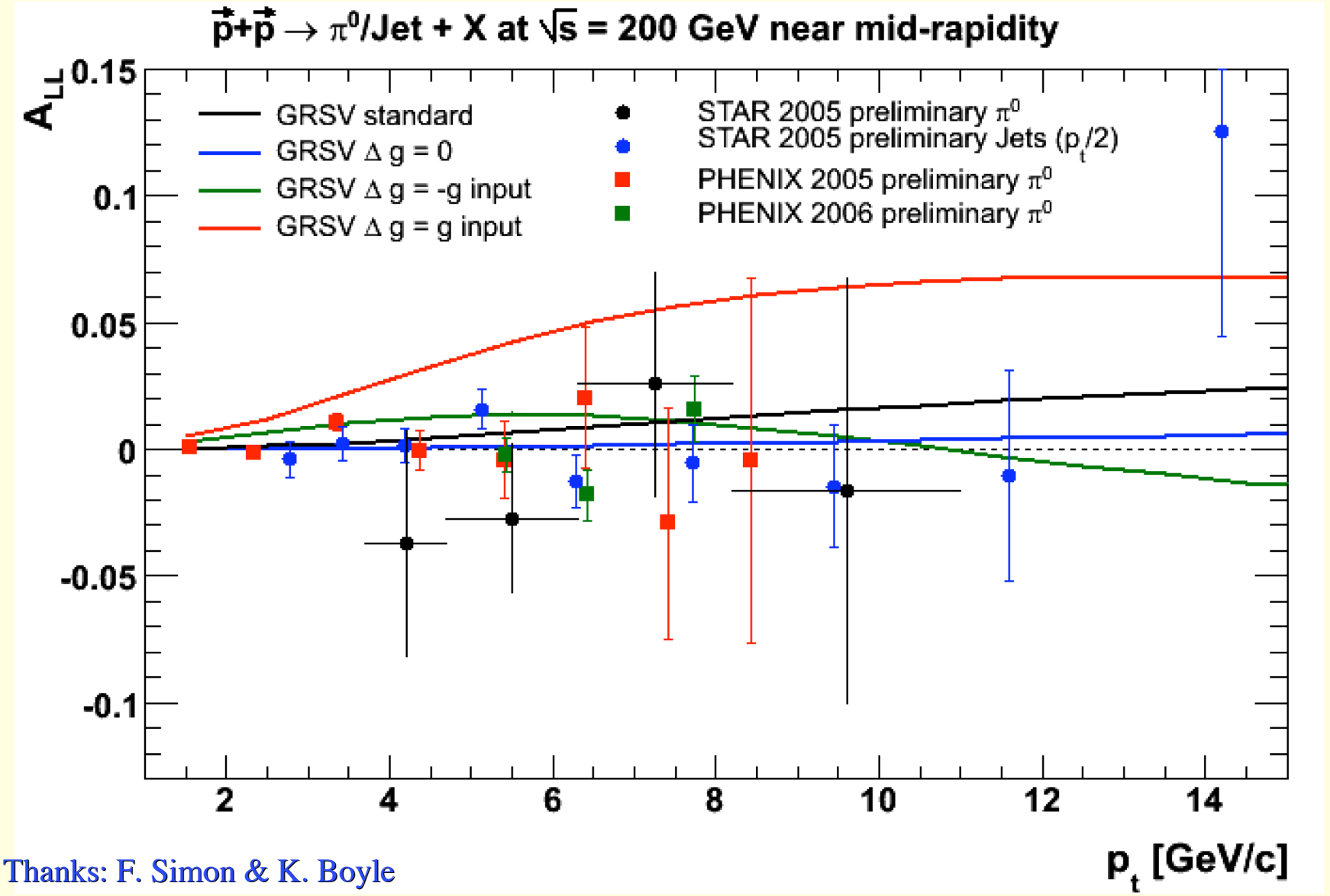




- Cross section at NLO in agreement with data
- First asymmetry measurement
- Consistent with PHENIX previously released and new data.

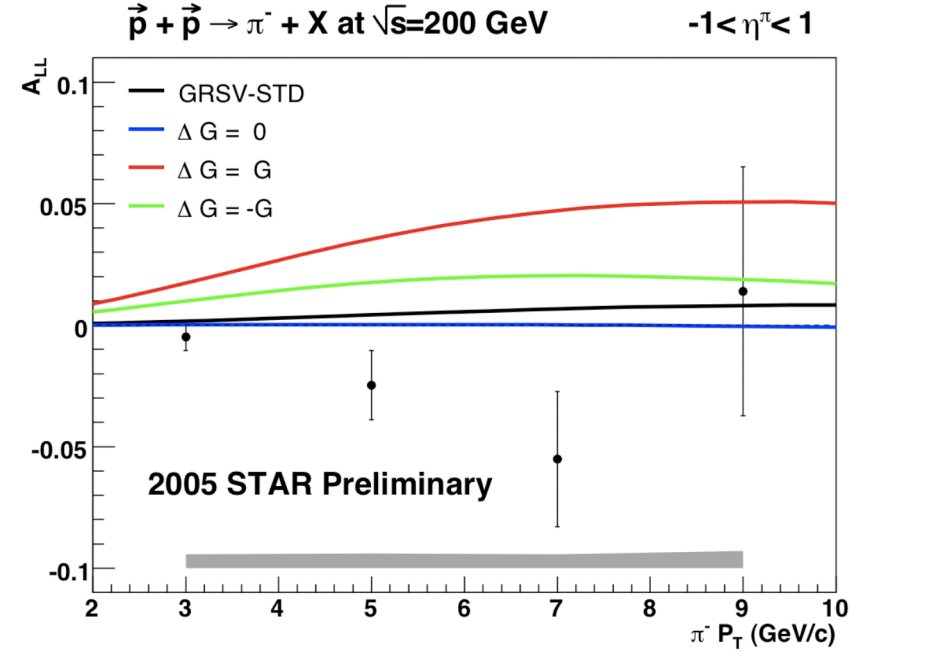
consistent with previous results from PHENIX

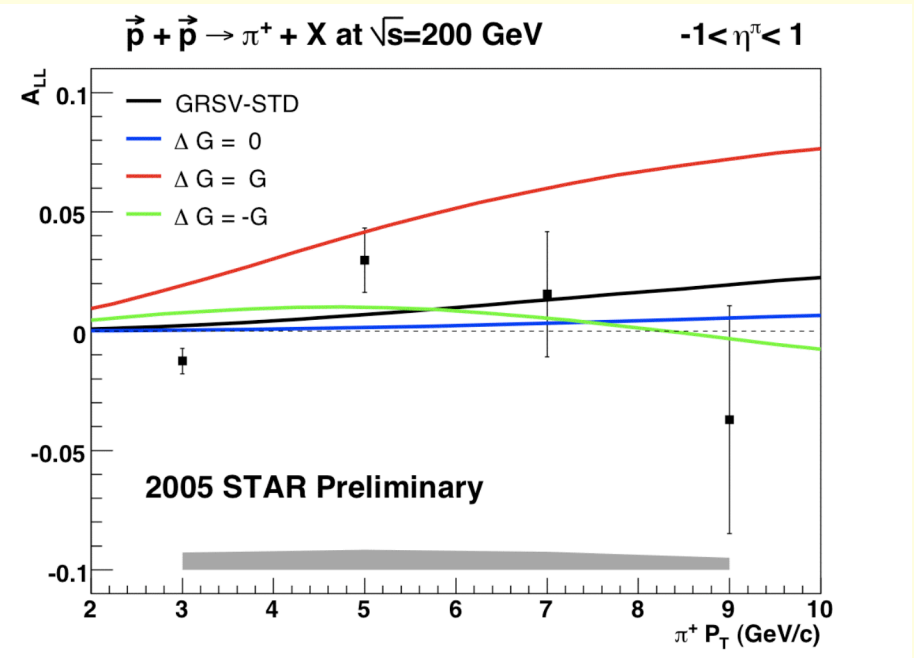
RHIC Spin: inclusive π^0 and jet



Thanks: F. Simon & K. Boyle

STAR 2005 Inclusive $\pi^{+/-}$ A_{LL}



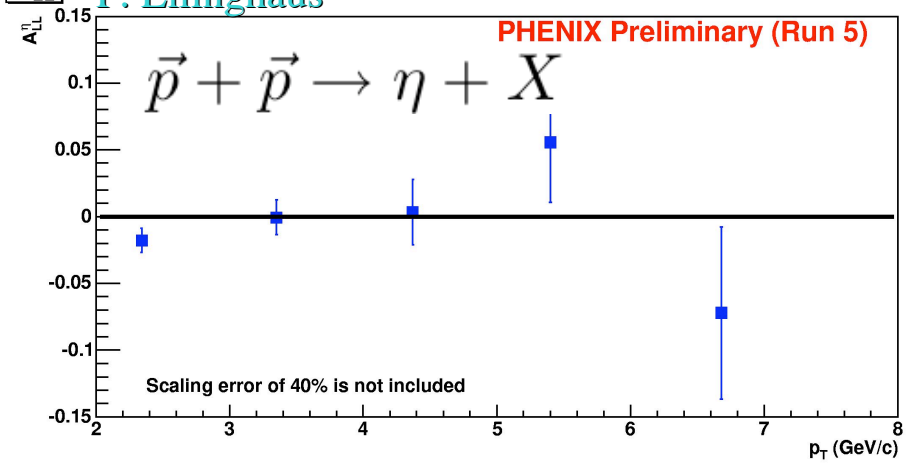


Charged pion measurements
luminosity hungry

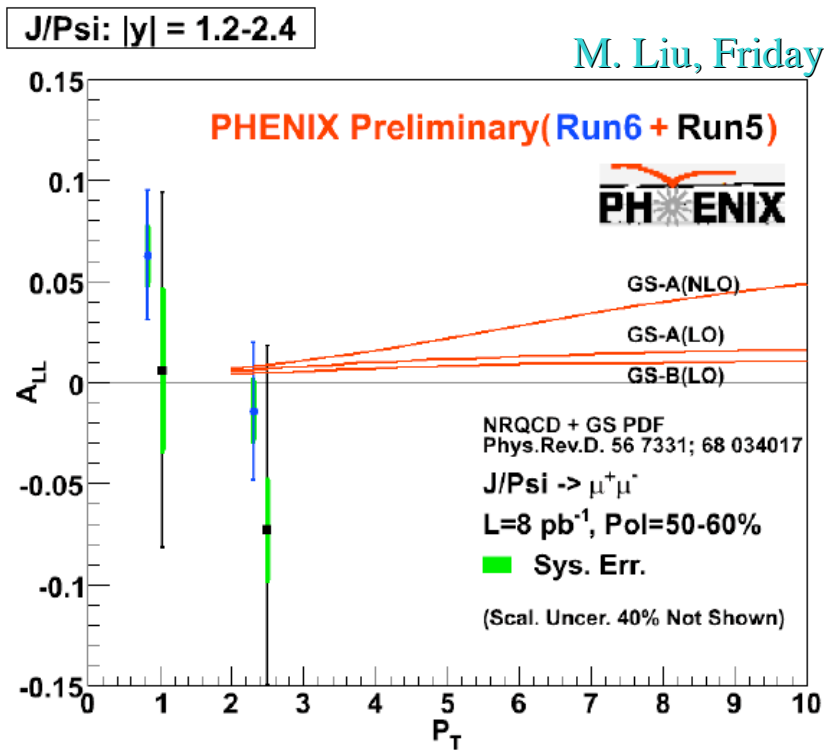
Theoretical calculations
agree with the expectations

Other PHENIX measurements

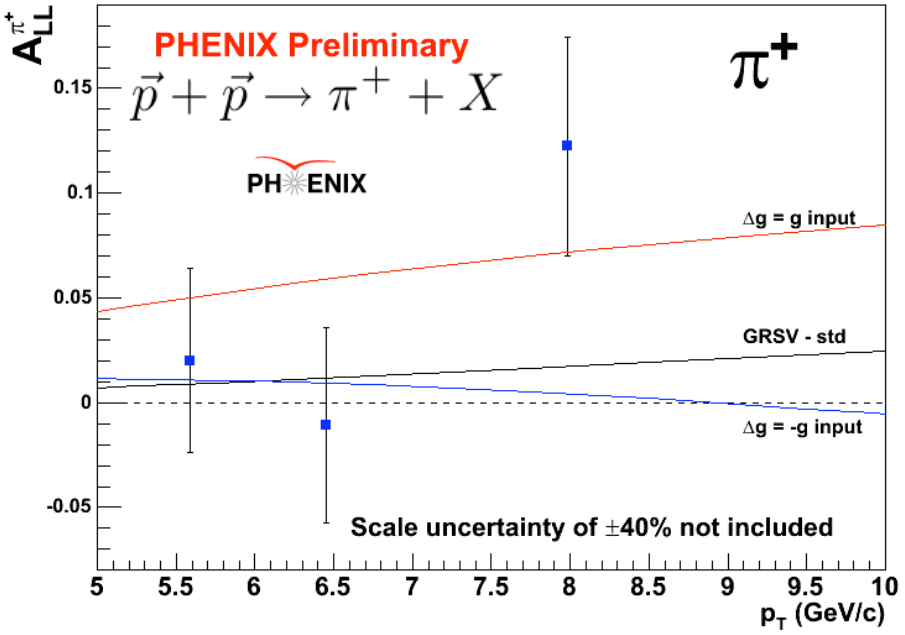
F. Ellinghaus

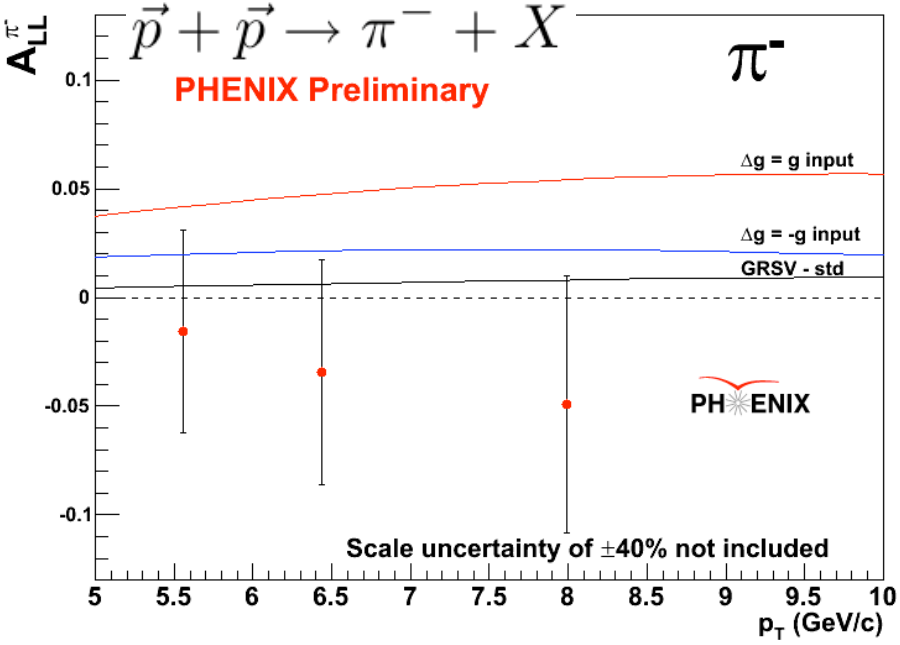


M. Liu, Friday

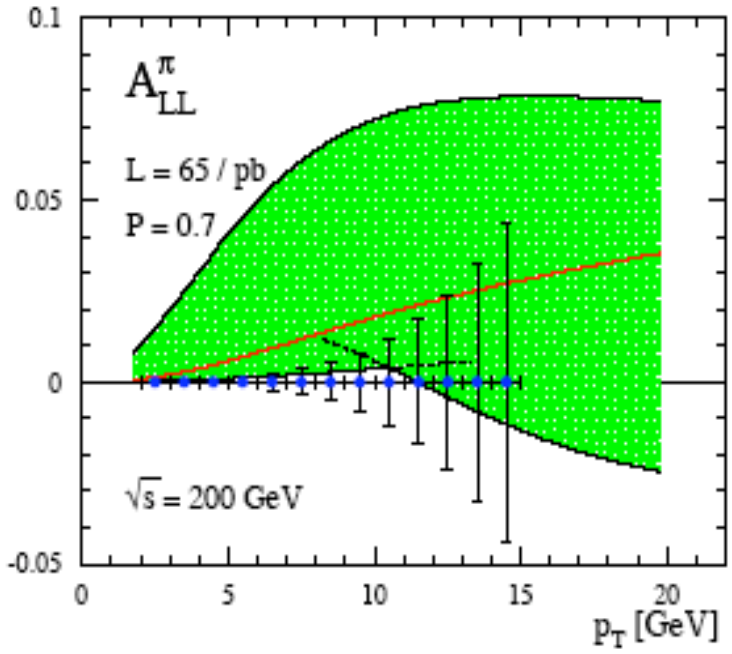


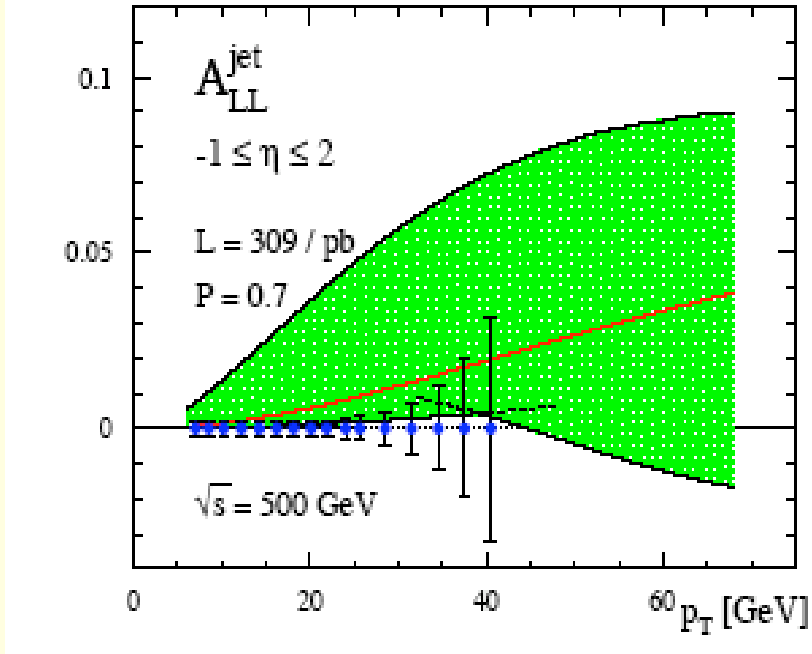
A. Morreales





ΔG Prospects



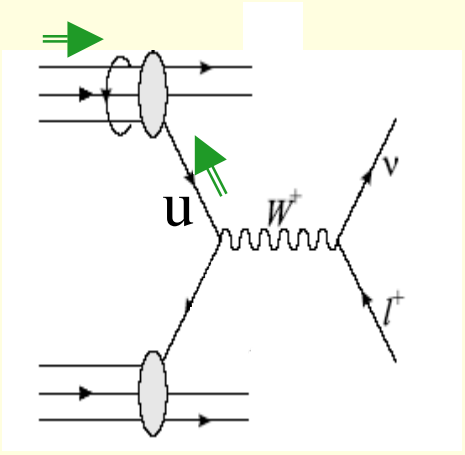


- **Left:** A_{LL} (π^0) prospects by 2009 (65 pb-1 luminosity intregrated by **PHENX** using π^0 double spin asymmetries
- **Right:** A_{LL} (jets) prospects by 2012 by **STAR** with 500 GeV in Center of Mass data

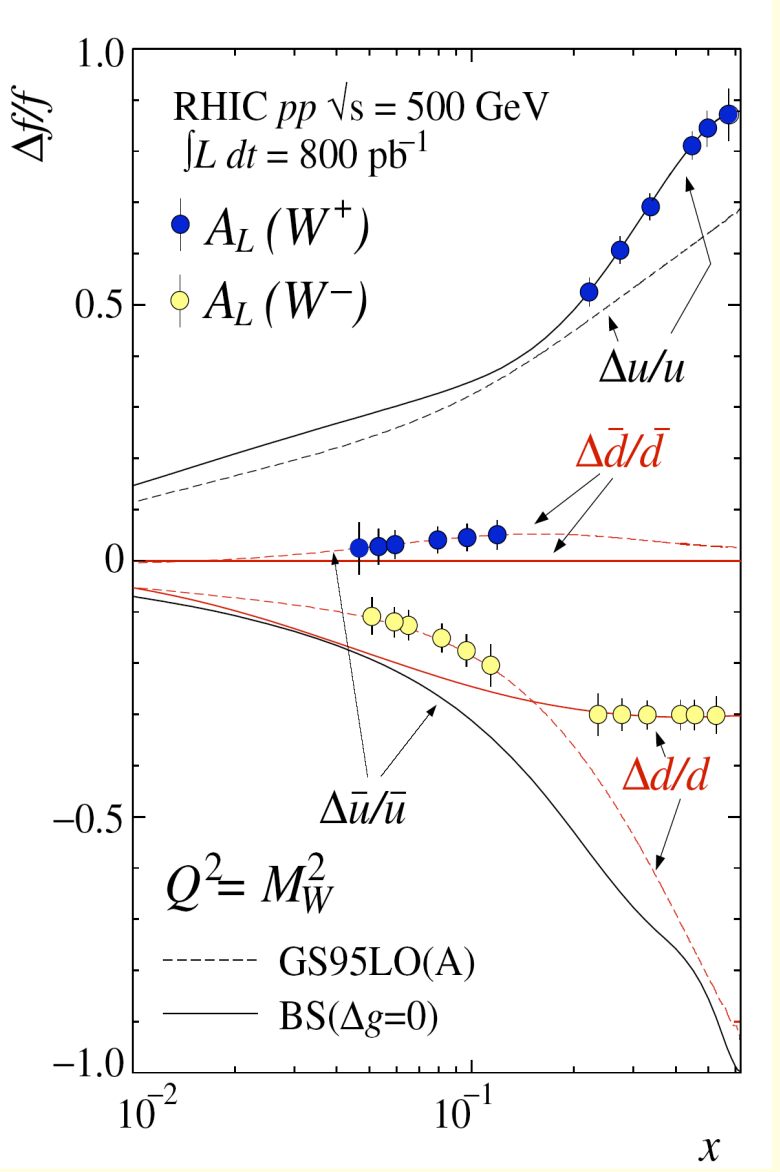
Anti Quark Polarization

- Measured through single longitudinal proton collisions at 500 GeV center of mass

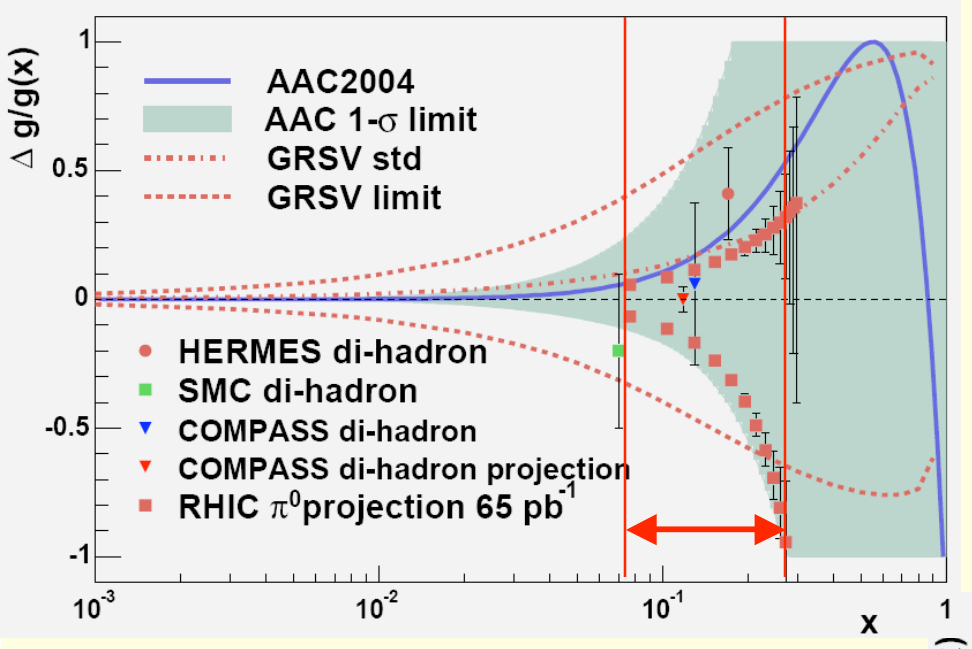
$$\Delta d + \bar{u} \rightarrow W^-$$
$$\Delta \bar{u} + d \rightarrow W^-$$
$$\Delta \bar{d} + u \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$



- PHENIX needs Muon Trigger upgrade (funded NSF, JSPS) and the STAR detector needs the forward tracker (proposal being written)



Now in the x space... how does this look?

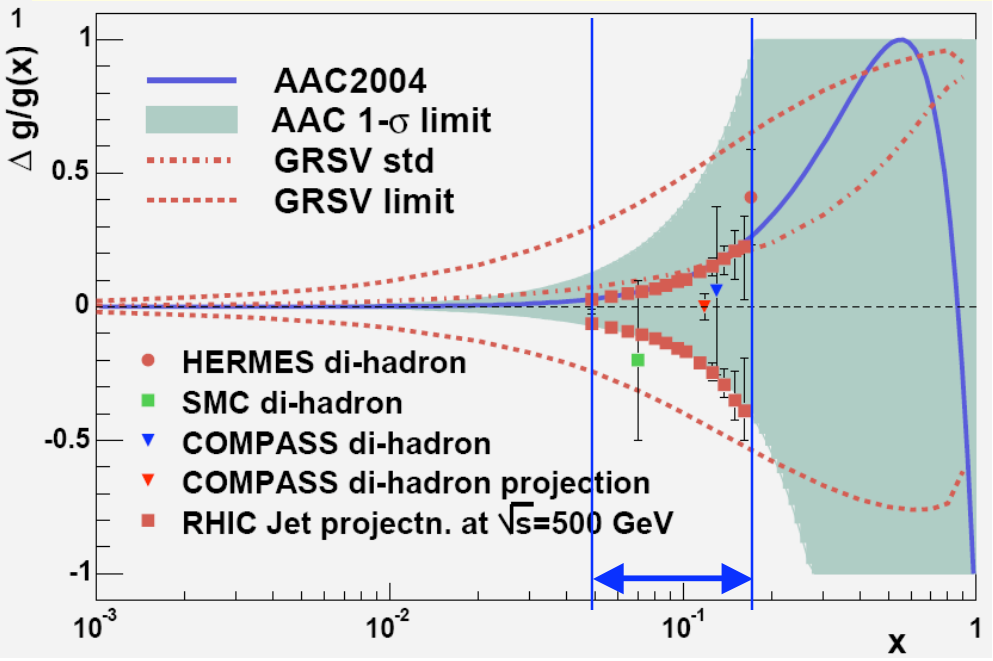


- Spin plan:
  - 65 pb^{-1} at √s=200GeV & 70% pol
  - 309 pb^{-1} at √s=500GeV & 70% pol

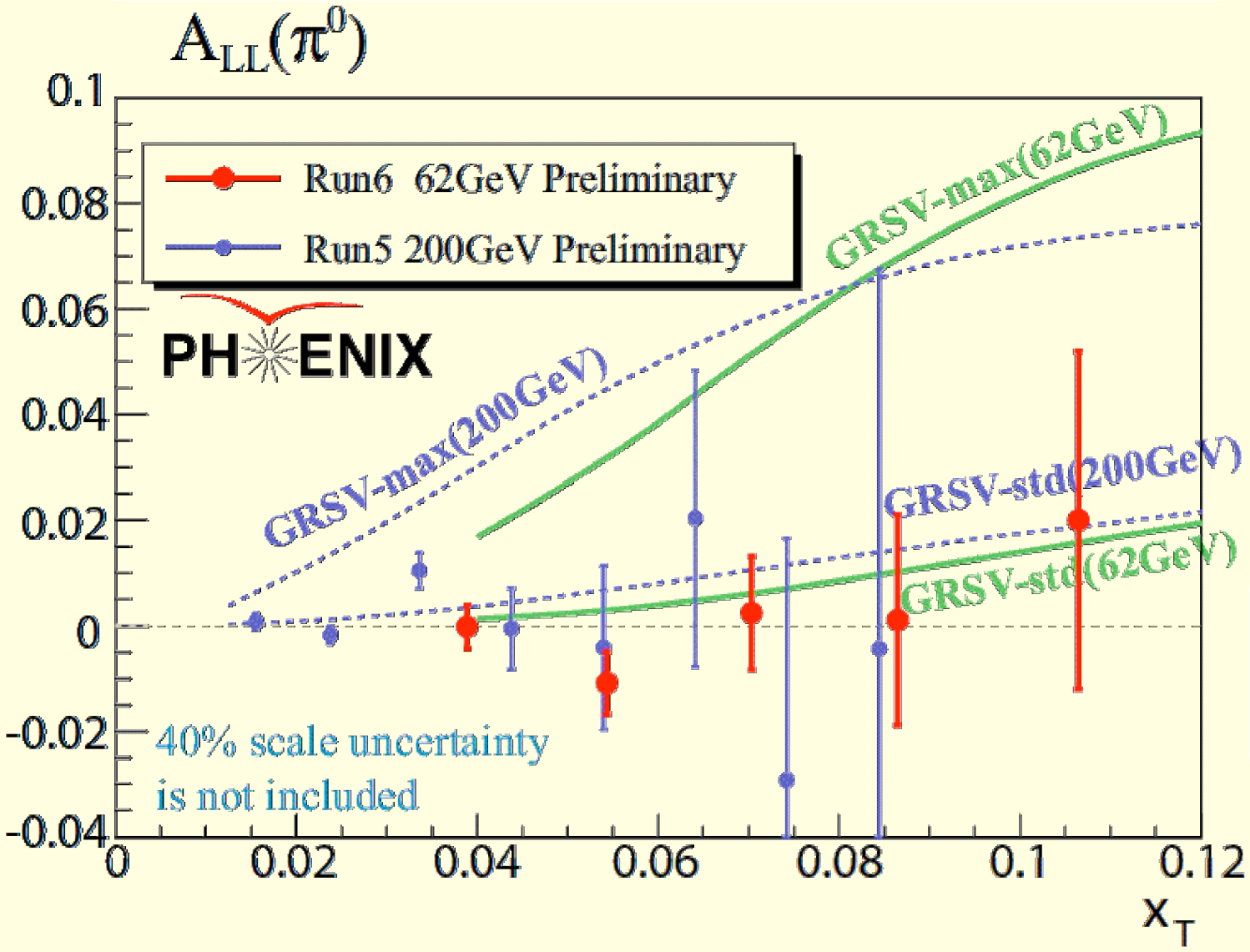
RHIC Spin Plan 2005, Feb. 11

Note the limited x range!

RHIC will constrain ΔG(x) very significantly, but how do we utilize these constraints to its maximal impact?



62 GeV CM: probes a different x



Cross section not yet released!

$$x_T = \frac{2p_T}{\sqrt{s}}$$

Maximal utilization of the facility.....

- Vary the range of CME at RHIC: 62 GeV --> 200 GeV --> 500 GeV.
  - Difficult and with limited gain in x range...
  - A_{LL}s and quark-anti-quark parton distributions would be available

- What else?
  - Different probes
    - Di-Jets, photon-Jet, open heavy quark production....
    - W production and decay (anti-quark distributions..)
  - Detector upgrades to increase the physics cabapabilities: heavy quark program
    - Si VTX tracker for PHENIX
    - Inner tracker for STAR

- Last but not the least: A *comprehensive pQCD analysis at NLO of the global data set*: A Global Analysis

Global Analysis... an urgent need!

- To most fruitfully utilize all the data ==> to get the best possible determination of polarized parton distributions we need

  a Global Analysis of all available data sets:

- Perturbative QCD at the highest possible level of sophistication needs to be used to analyze these data (presently NLO)

- An example : The Successful multi-year effort by the CTEQ collaboration
  - Experiments and theorists come together to and extract the un-polarized parton distribution and their uncertainties
  - Judicious input from experimentalists **and** theorists on various issues
  - Statistical, experimental systematics and its correlation, and theory uncertainties need to be dealt with

The method: A simplistic view

DIS data

pp Data

Theoretical framework

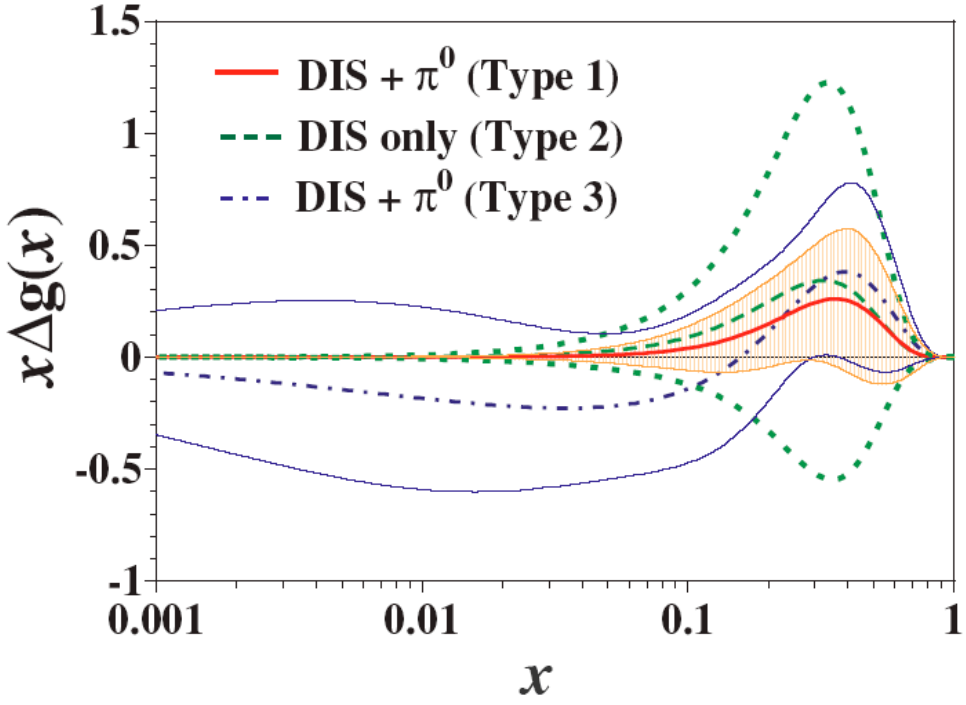
χ^2 minimization

$$\Delta f(x, Q^2) \pm \delta(\Delta f(x, Q^2))$$

$$\pm\delta(\Delta f(x, Q^2)) \longrightarrow \pm(\mathrm{stat}_{\mathrm{data}}) \pm (\mathrm{syst}_{\mathrm{data}}) \pm (\mathrm{syst}_{\mathrm{theory}})$$

- **Observation:**
  - **Stat+Syst errors**: mostly added in "quadrature" ignoring all correlations: this can clearly be improved
  - $\mathrm{Syst}_{\mathrm{theory}}$ often least emphasized... but typically large

One "recent" attempt of global analysis....



- Asymmetry analysis collaboration (AAC)
  - Hirai, Kumano, Saito
- Pre-print: hep-ph/0603213
- Recent: hep-ph/0607063
  - This new paper **deals with large x only (!)** and only shows error bars of the fit type 1 and 2

- Recently the hep/ph 607063 was quoted (not by authors) and value of ΔG and its uncertainty:

  >> 0.30 +/- 0.30

  >> **ignoring theoretical uncertainties (low x)**

hep-ph/0607063: clearly says....

The large uncertainty in type-3 $\Delta g(x)$ in the smaller-x region is also reflected to the first moment: -0.56 ± 2.16. The large error comes from the small-x region, where there is no experimental data which constrains the small-x behavior of $\Delta g(x)$. In fact, if the type-3 $\Delta g(x)$ is

Initiation of the global analysis

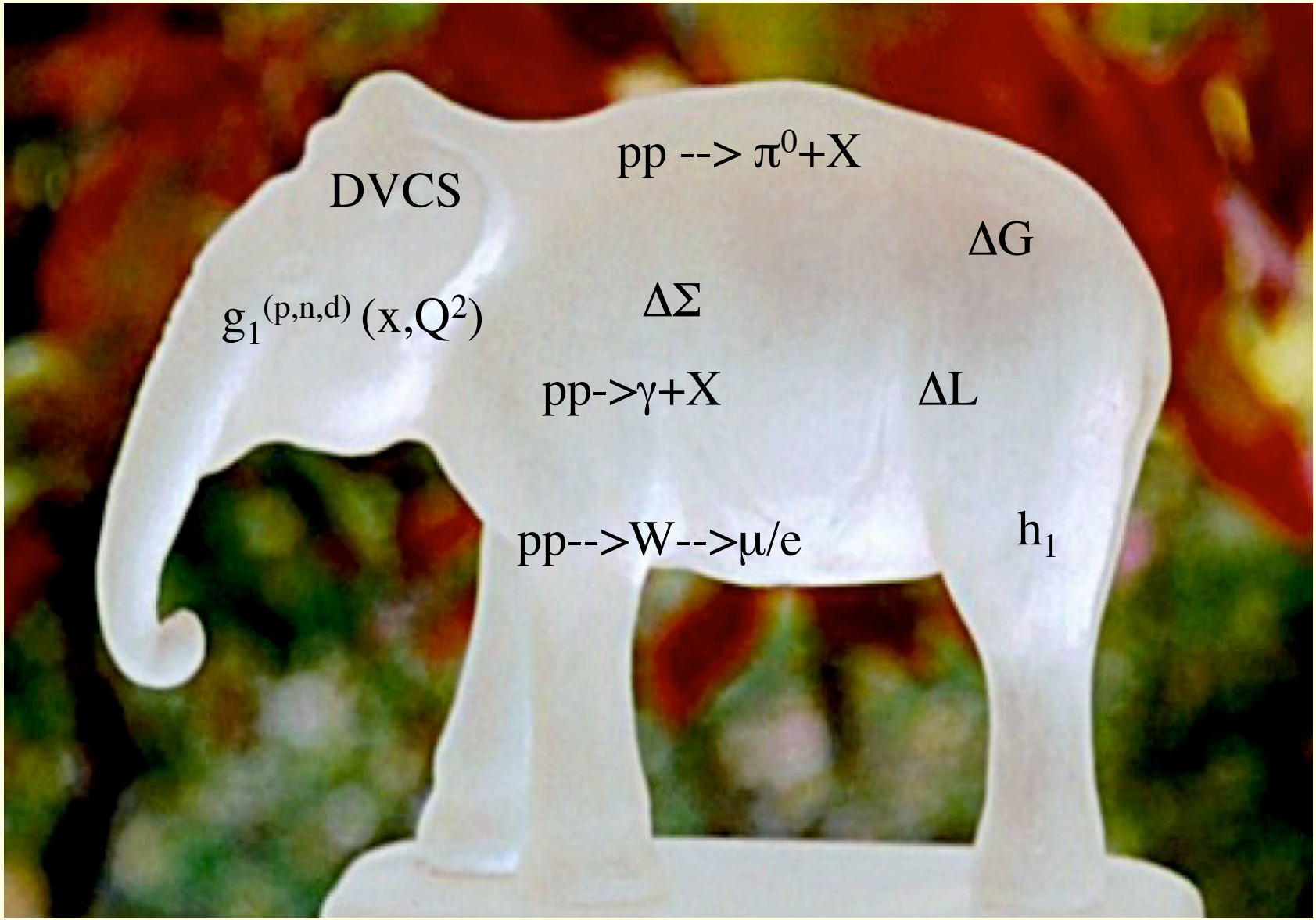
- As RHIC data starts becoming significant (next year or so), it is absolutely timely that we have a framework in which they can be analyzed in the most comprehensive manner

- A group of people not unlike the CTEQ collaboration is needed:
  - *AAC collaboration* exists (could this be a seed?)
  - Other theoretical groups already are working developing novel techniques
    - A fast Method for analysis of Inclusive DIS + RHIC pp data
      M. Stratmann, W. Vogelsang PRD64, (2001) 114007
    - Inclusive & Semi-Inclusive data + PHENIX π^0 data
      D. de Florian et al, PRD71 (2005) 094018
    - Others?... apologies for not mentioning...
  - Many experimenters are interested...

- Let this effort begin... earlier the better!

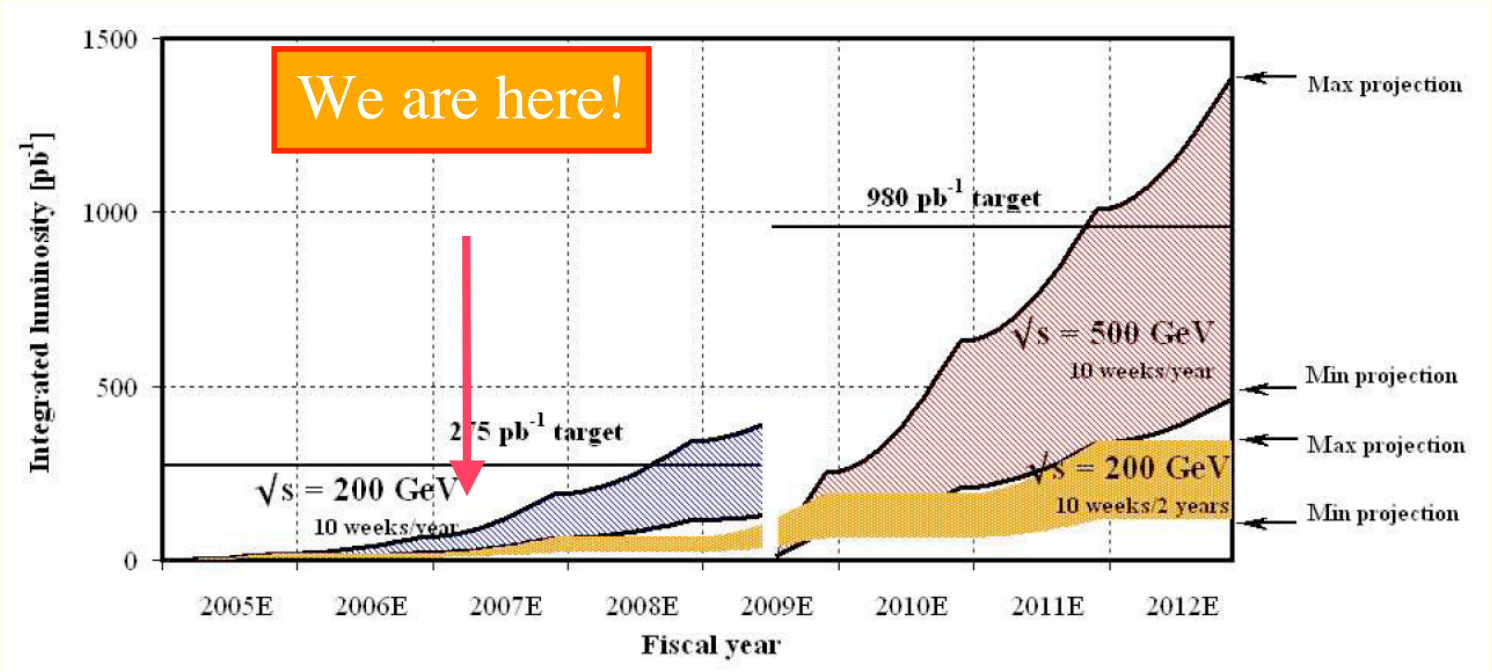
The Elephant & the village of the blind

~~The Elephant~~ The nucleon spin.....



Summary

- RHIC Spin program has begun: early data already on tape
- Exciting prospects for new data and unraveling of nucleon spin!
- While there is a lot to do in the next few years, the returns may be phenomenal: Many exciting results anticipated in the SPIN2008, 2010, 2012 symposia....
- Stay tuned...



That's it!

You want more???!!