The Double-Longitudinal Spin Asymmetry in Charged Pion Production at PHENIX: Determining the sign of Δg

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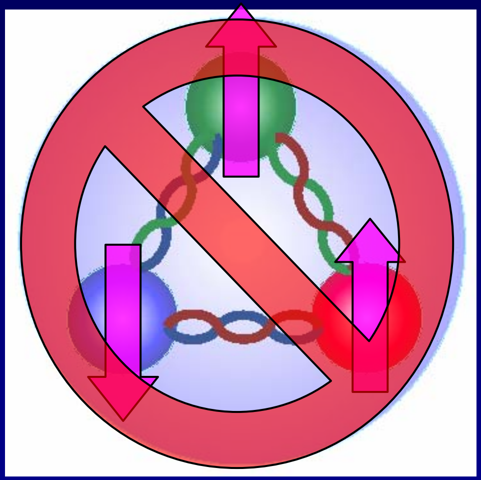
Proton Spin Structure

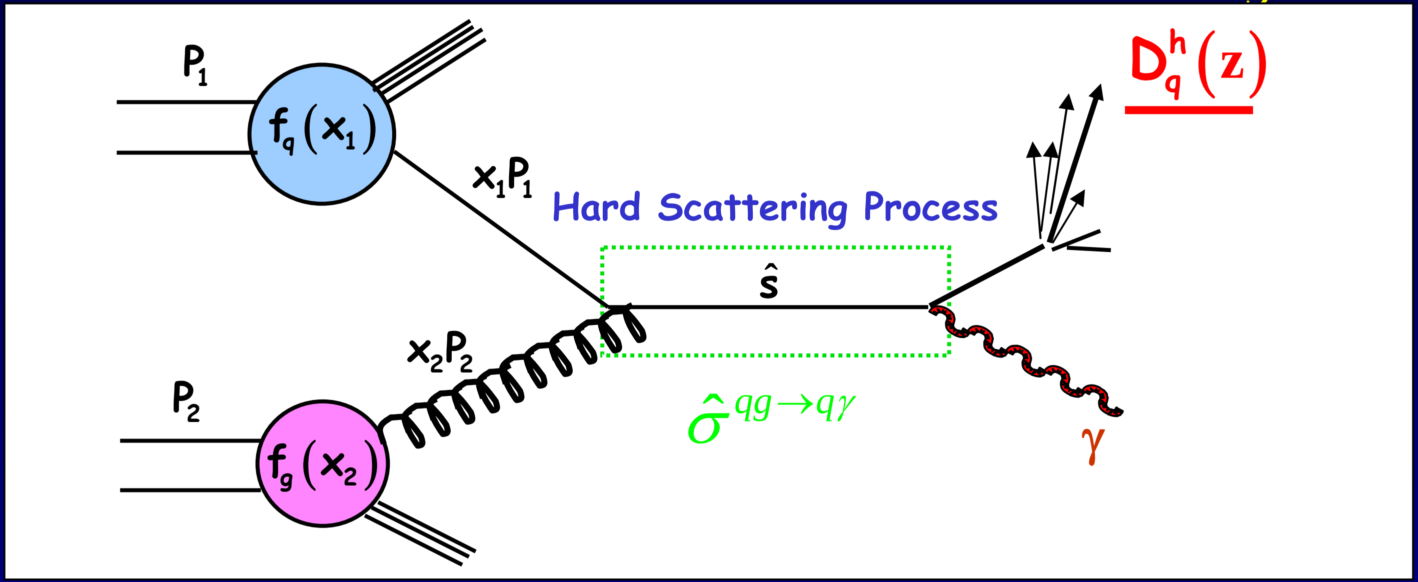
- Discovered in the late ’80’s by the EMC experiment at CERN that the naïve picture of spin carried by 3 valence quarks is not the case!
  - “Spin crisis”
  - Expect contributions from gluon spin and orbital angular momentum, but these remain to be measured!
- Spin physics program at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab seeks to better understand the breakdown of the spin of the proton



½ + ½ - ½ = ½?

Not so simple!

Hard Scattering Processes in p+p: Factorization and Universality



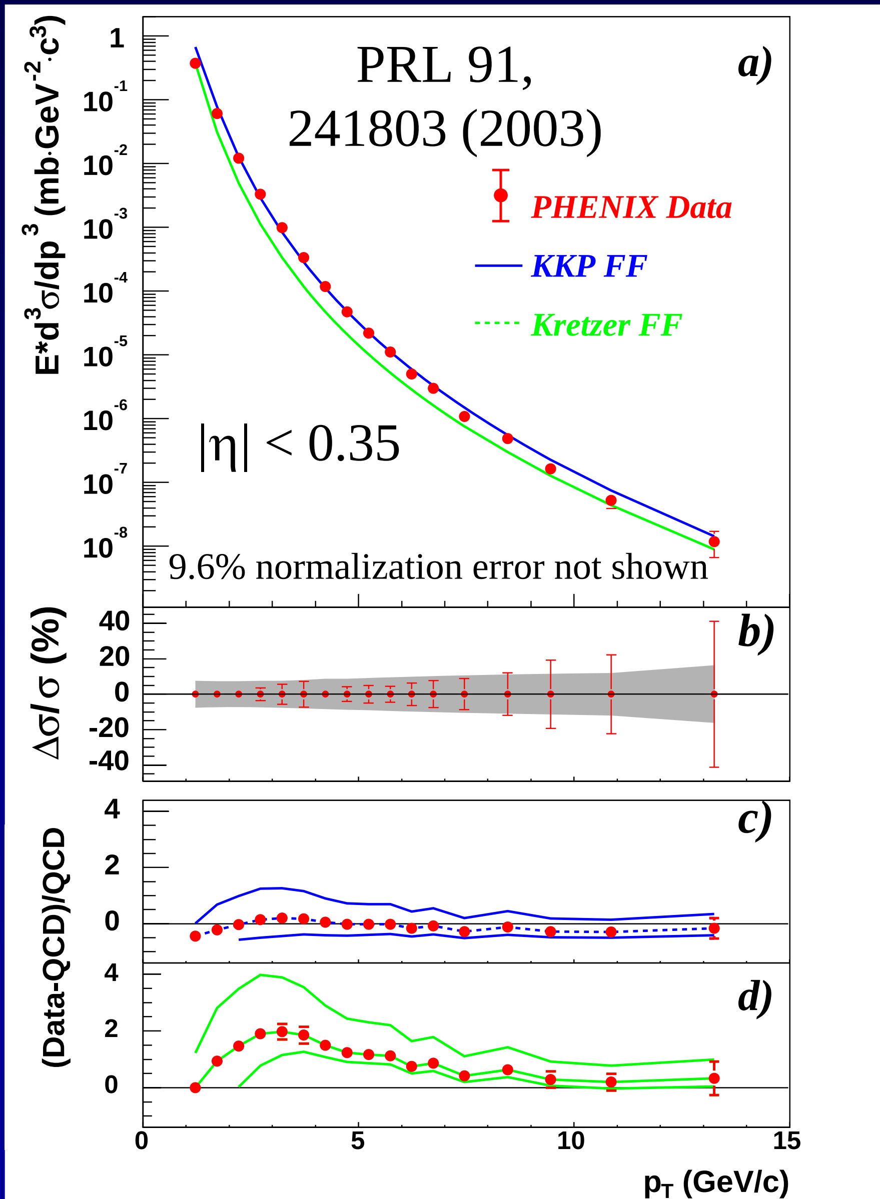
$$\sigma(pp \to \gamma X) \propto \underline{f_q(x_1) \otimes f_g(x_2)} \otimes \underline{\hat{\sigma}^{qg\to q\gamma}(\hat{s})}$$

The cross section of a hard scattering process is proportional to:

- Parton distribution functions (need experimental **input)**
- **pQCD hard scattering rates (calculable in pQCD)**
- **Fragmentation functions (need experimental input)**

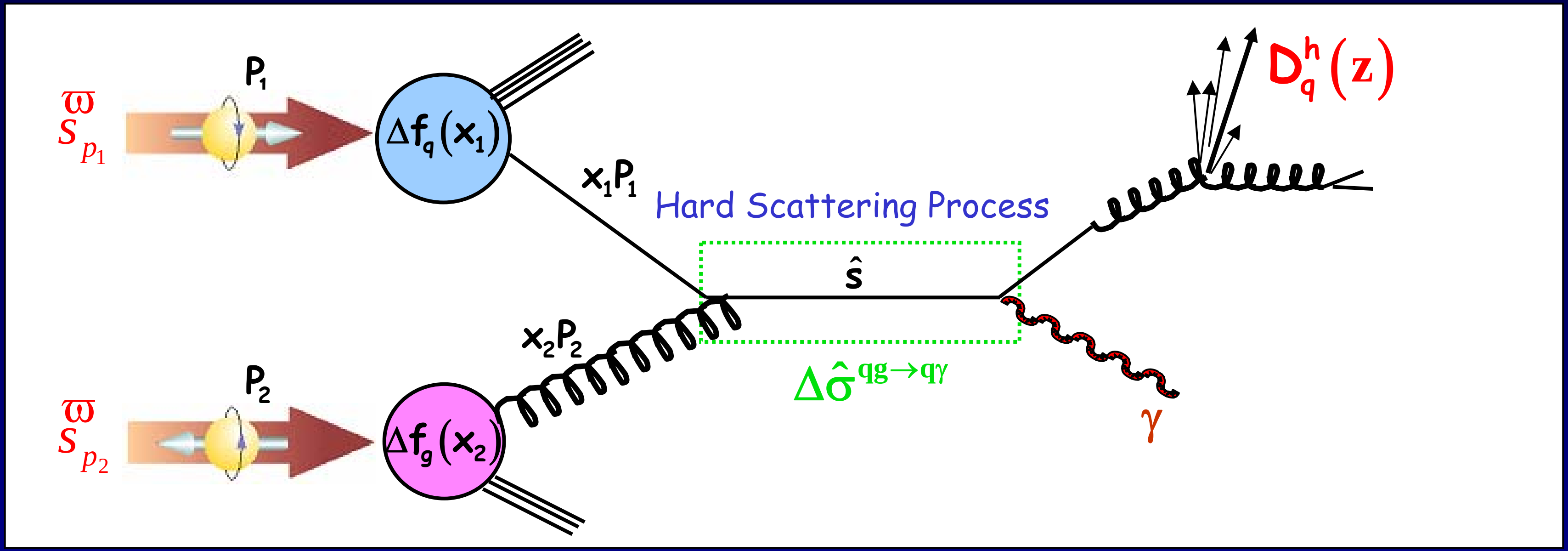
$\Big\}$ Universality

π^0 Cross Section Measured at PHENIX



- NLO pQCD consistent with data within theoretical uncertainties
- Important confirmation of theoretical foundation for spin program
  - Will be able to use factorization in pQCD to describe polarized data as well!

Hard Scattering in ***Polarized*** *p+p*



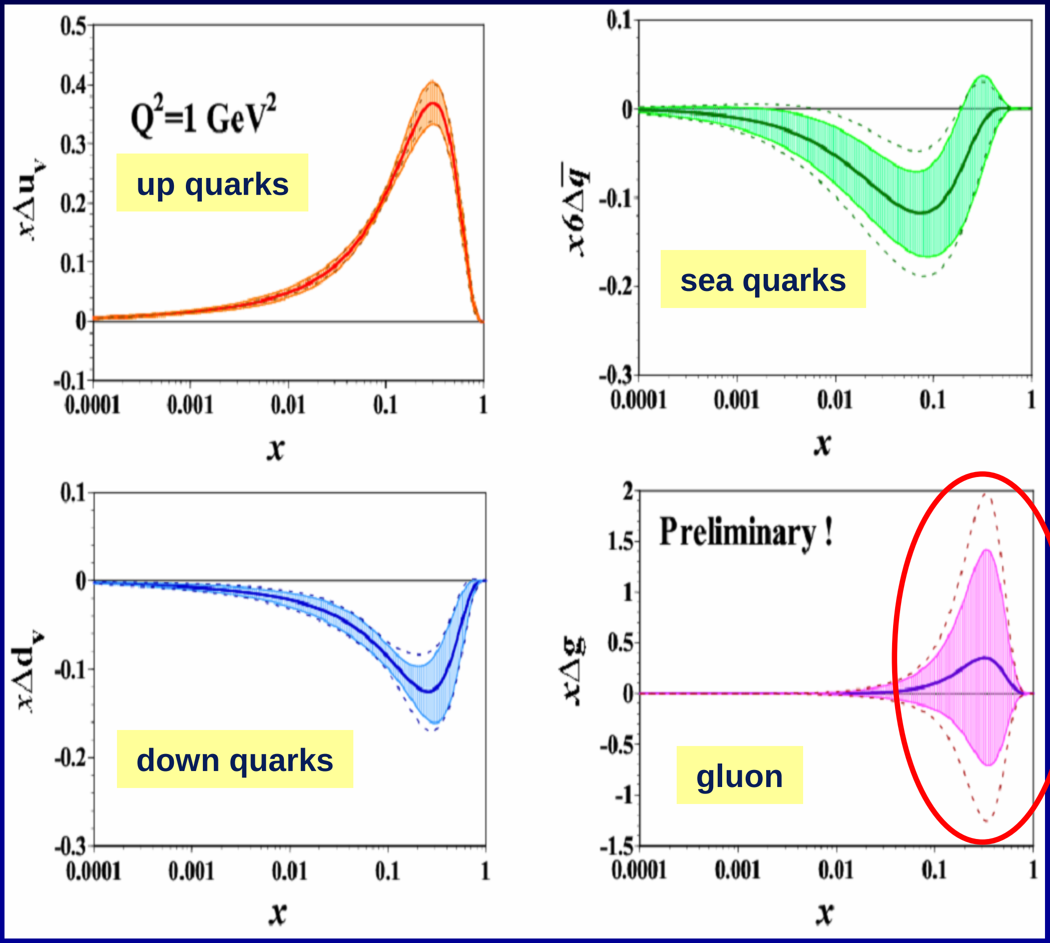
$$\Delta\sigma(pp \to \gamma X) \propto \underline{\Delta f_q(x_1) \otimes \Delta f_g(x_2)} \otimes \Delta\hat{\sigma}^{qg\to q\gamma}(\hat{s})$$

The *difference* in cross section between collisions with different spin configurations is proportional to …

…*polarized* pdf's!

Polarized Parton Distribution Functions

M. Hirai et al (AAC collab)



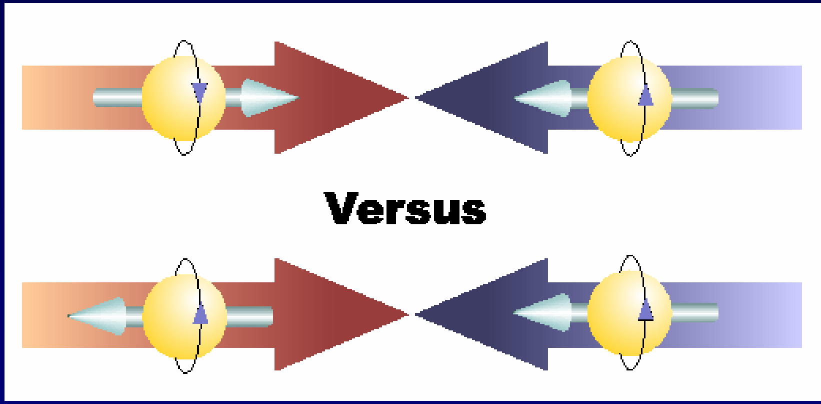
EMC, SMC at CERN
E142 to E155 at SLAC
HERMES at DESY

- *Polarized* pdf--the *difference in probability* between scattering off of a parton with one spin state vs. the other
  - Function of $x_{Bjorken}$, the momentum fraction of the proton carried by the parton

Not even the sign of Δg has been constrained!

Asymmetries to Probe Polarized pdf's

Investigate the difference in particle production for same-helicity (++) vs. opposite-helicity (+-) collisions

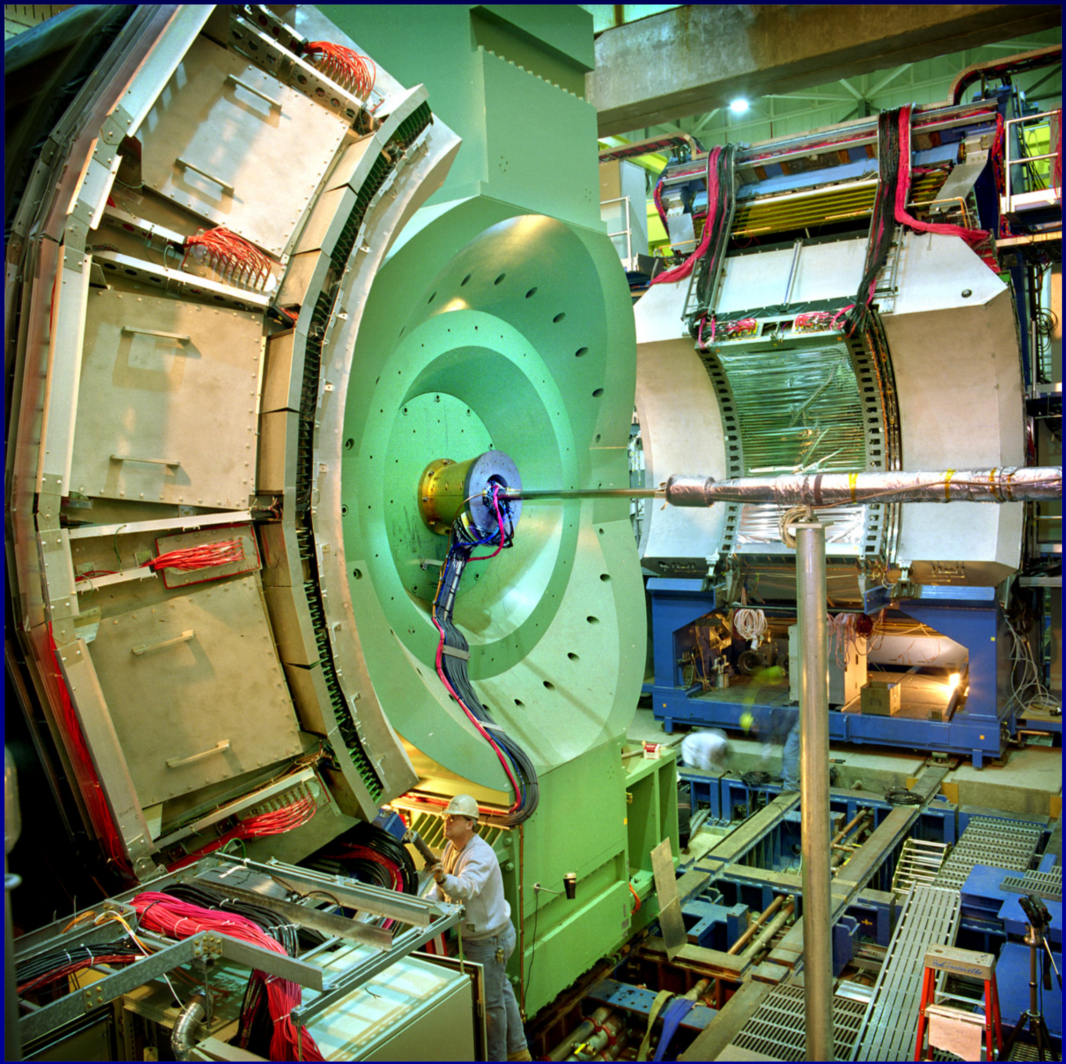


$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{total}}$$

Many elements of the cross section cancel when you take the ratio, so experimentally only need the (non-normalized) *yields*.

$$= \frac{\Delta q(x_1)}{q(x_1)} \otimes \frac{\Delta g(x_2)}{g(x_2)} \otimes \frac{\hat{\sigma}_{++} - \hat{\sigma}_{+-}}{\hat{\sigma}_{total}} (qg \to \pi X) \otimes D_g^{\pi}(z)$$

The PHENIX Detector



2 central spectrometers

- Track charged particles and detect electromagnetic processes

2 forward spectrometers

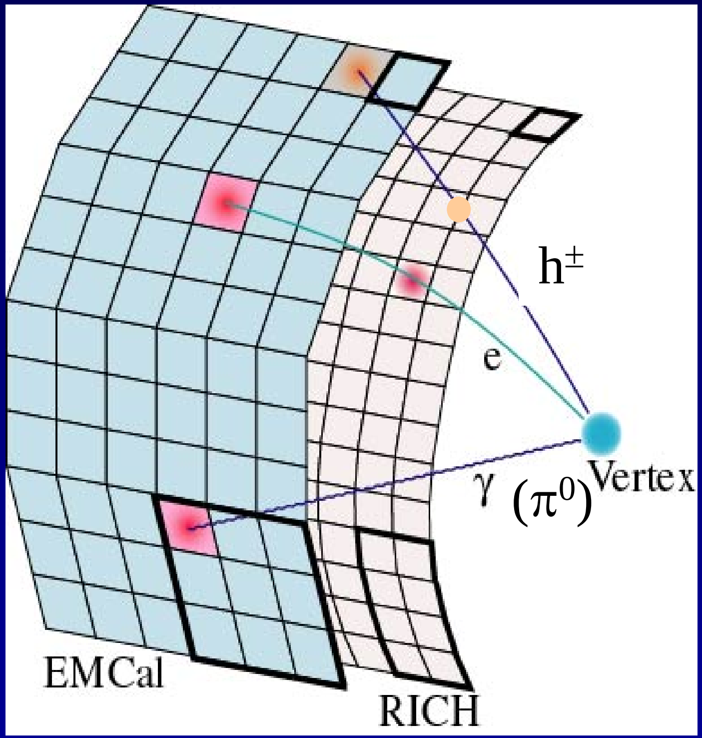
- Identify and track muons

3 global detectors

- Determine when there’s a collision

Pion Identification

EMCal-RICH trigger

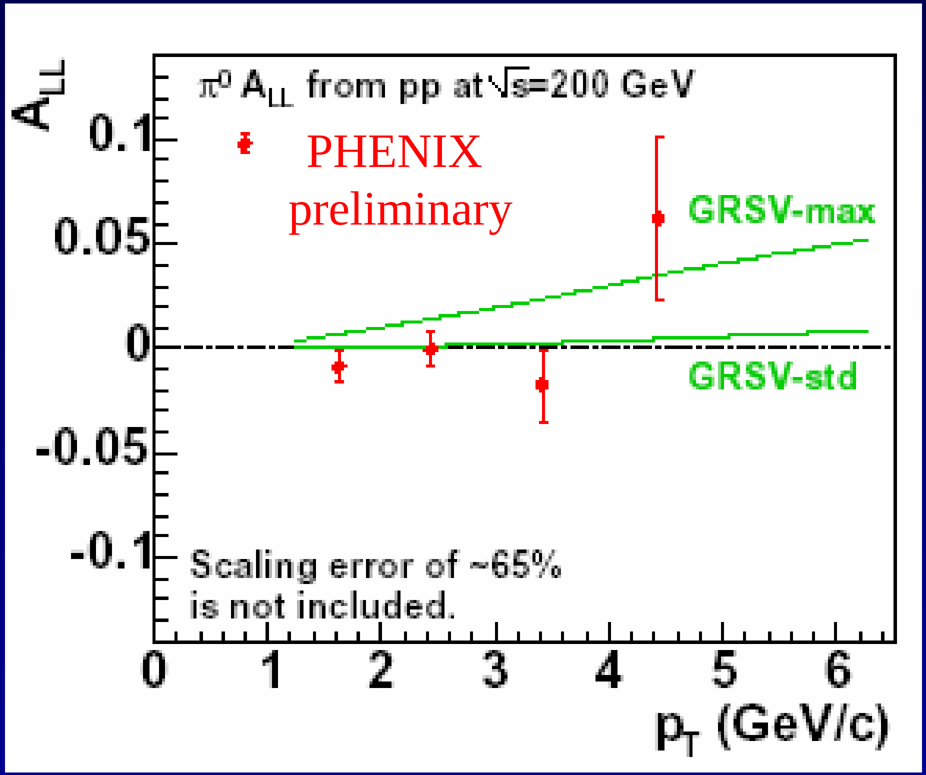


- Measure $\pi^0 \rightarrow \gamma\gamma$ using EMCal
- Measure high-p_T π^+/π^- using
  - tracking detectors
    - drift chamber, pad chambers
  - RICH for pion identification
    - threshold 4.7 GeV/c
- Background in charged analysis
  - electrons from conversions and decays with misreconstructed momentum
  - RICH threshold 0.017 GeV/c
- Background elimination
  - Momentum-dependent energy cut on the EMCal shower

  OR

  - Look for jet-like event structure

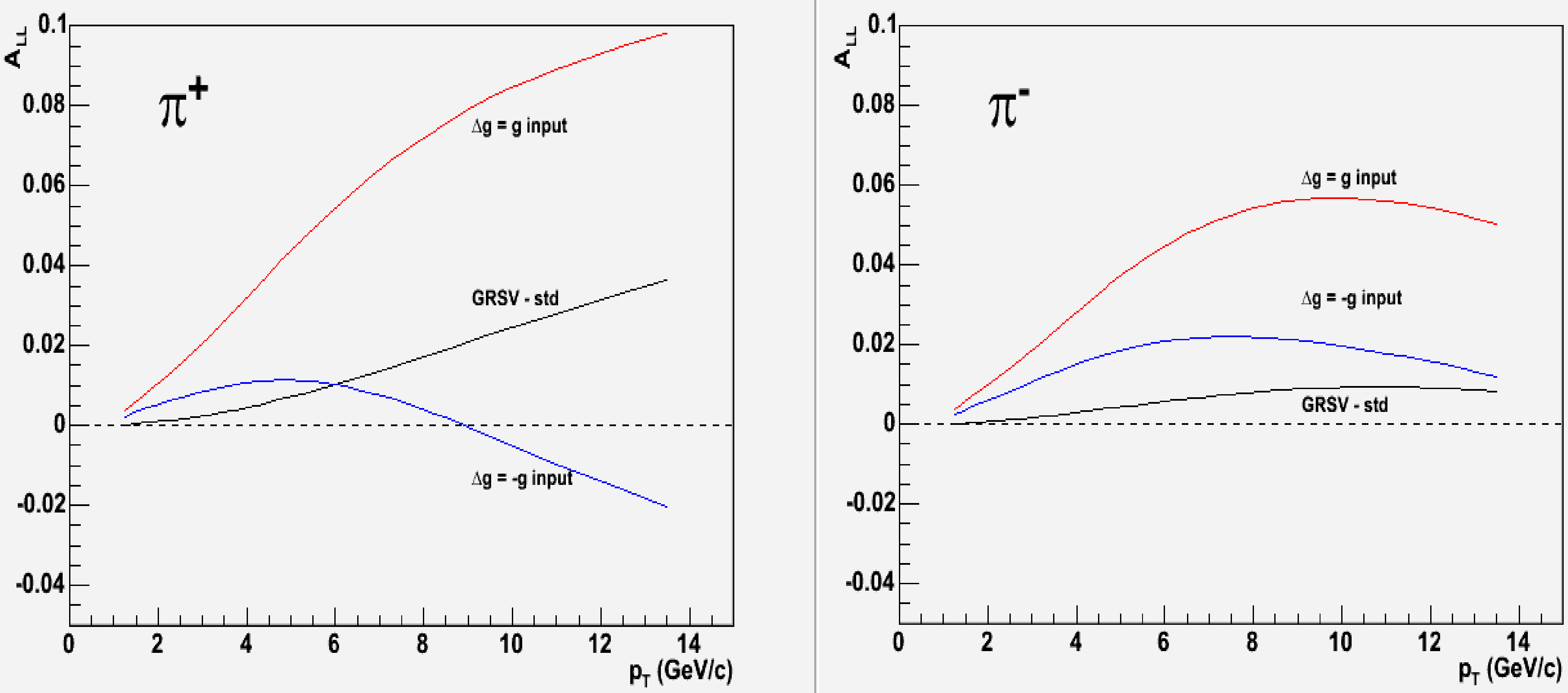
π^0 A_{LL} and Δg



- Pion production largely from gg scattering at similar values of x_{Bj} in this kinematic region
- Therefore the asymmetry is proportional to $(\Delta g)^2$ and provides information on the magnitude of Δg but not its sign!

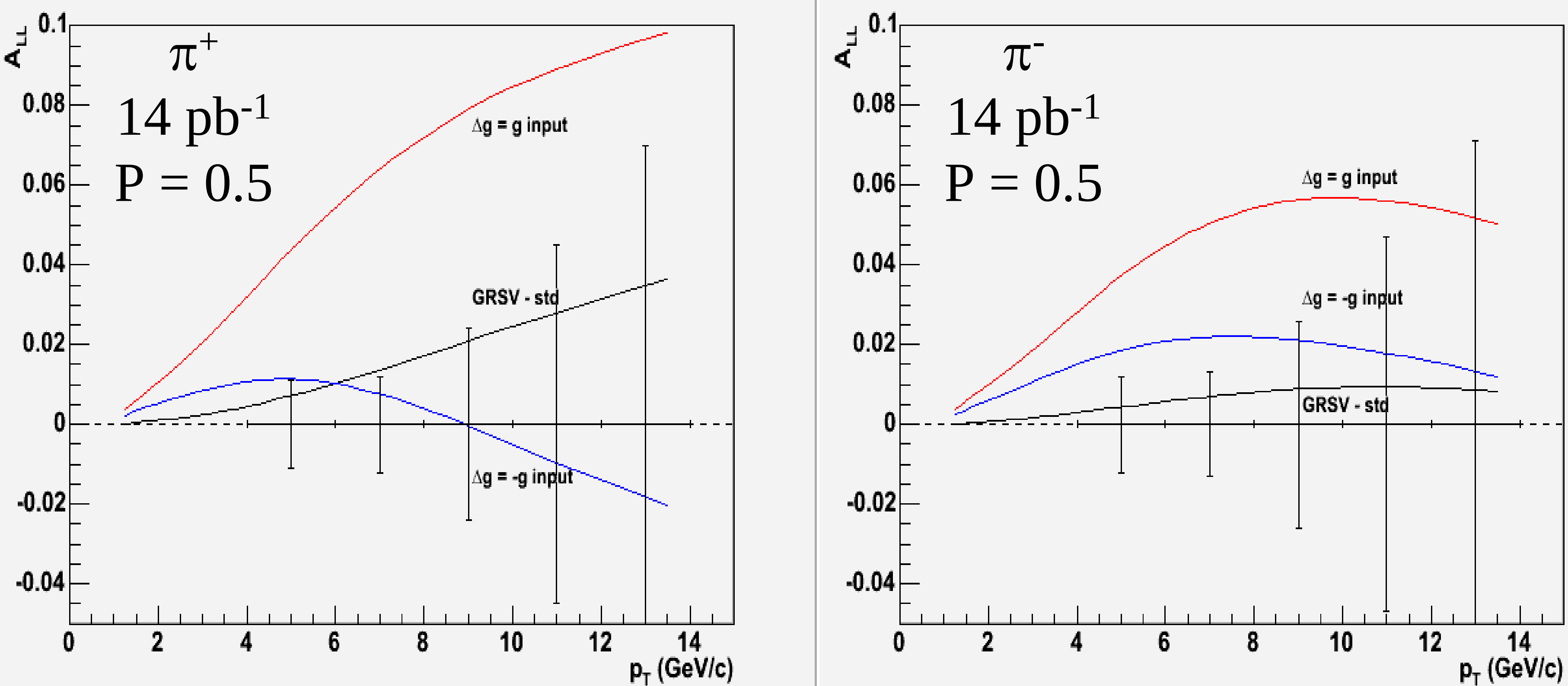
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \rightarrow \frac{1}{|P_1 P_2|} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, R = \frac{L_{++}}{L_{+-}}$$

π^+, π^- A_{LL} and Δg



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

Projected Uncertainties



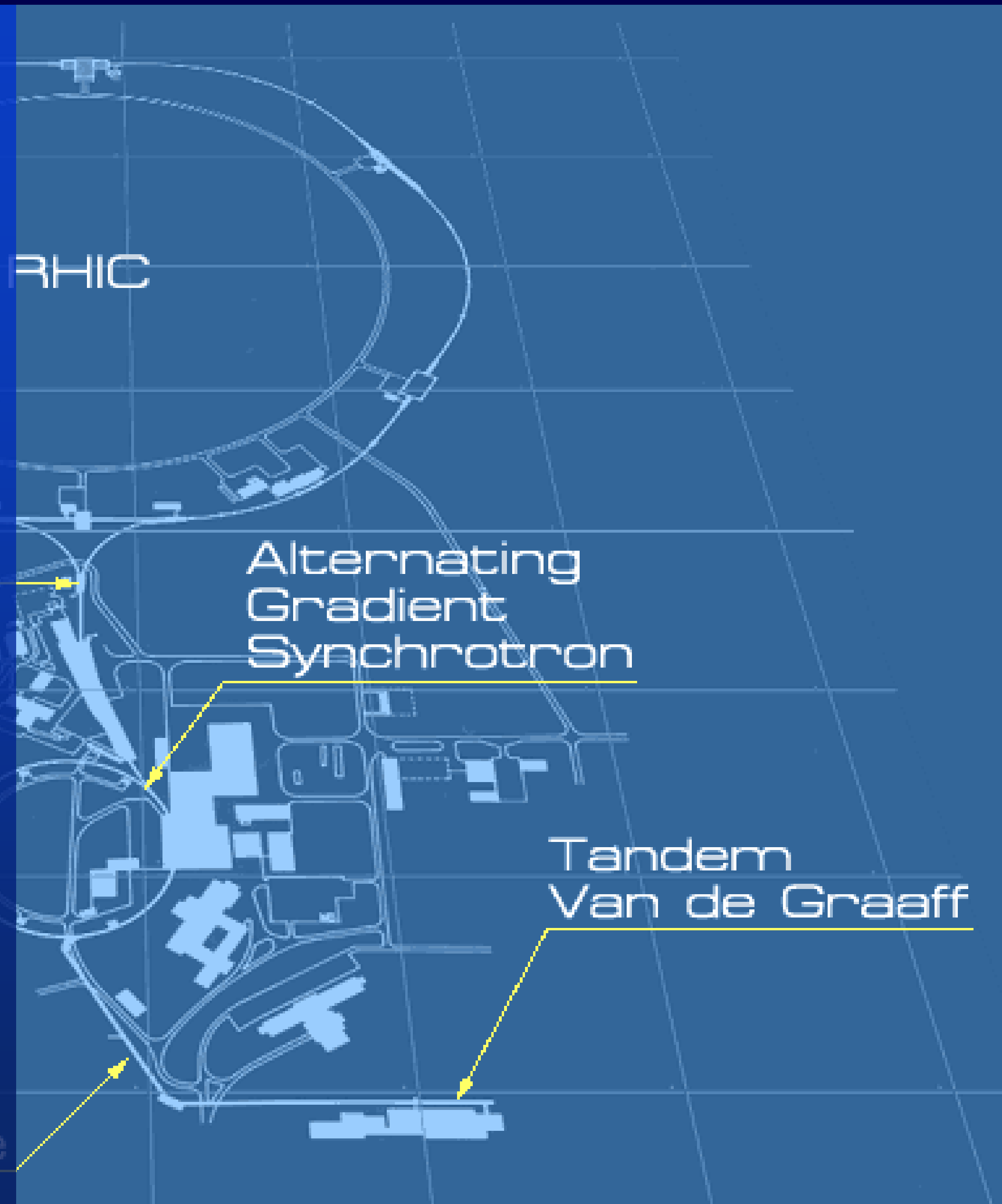
Summary

- The high-energy, polarized proton collisions at RHIC make it an ideal facility for studying the gluon's contribution to the spin of the proton
- Pion production in longitudinally polarized collisions serves as a probe to measure Δg
- A combination of neutral and charged pion measurements at PHENIX will be able to determine both the magnitude and sign of Δg

Extra

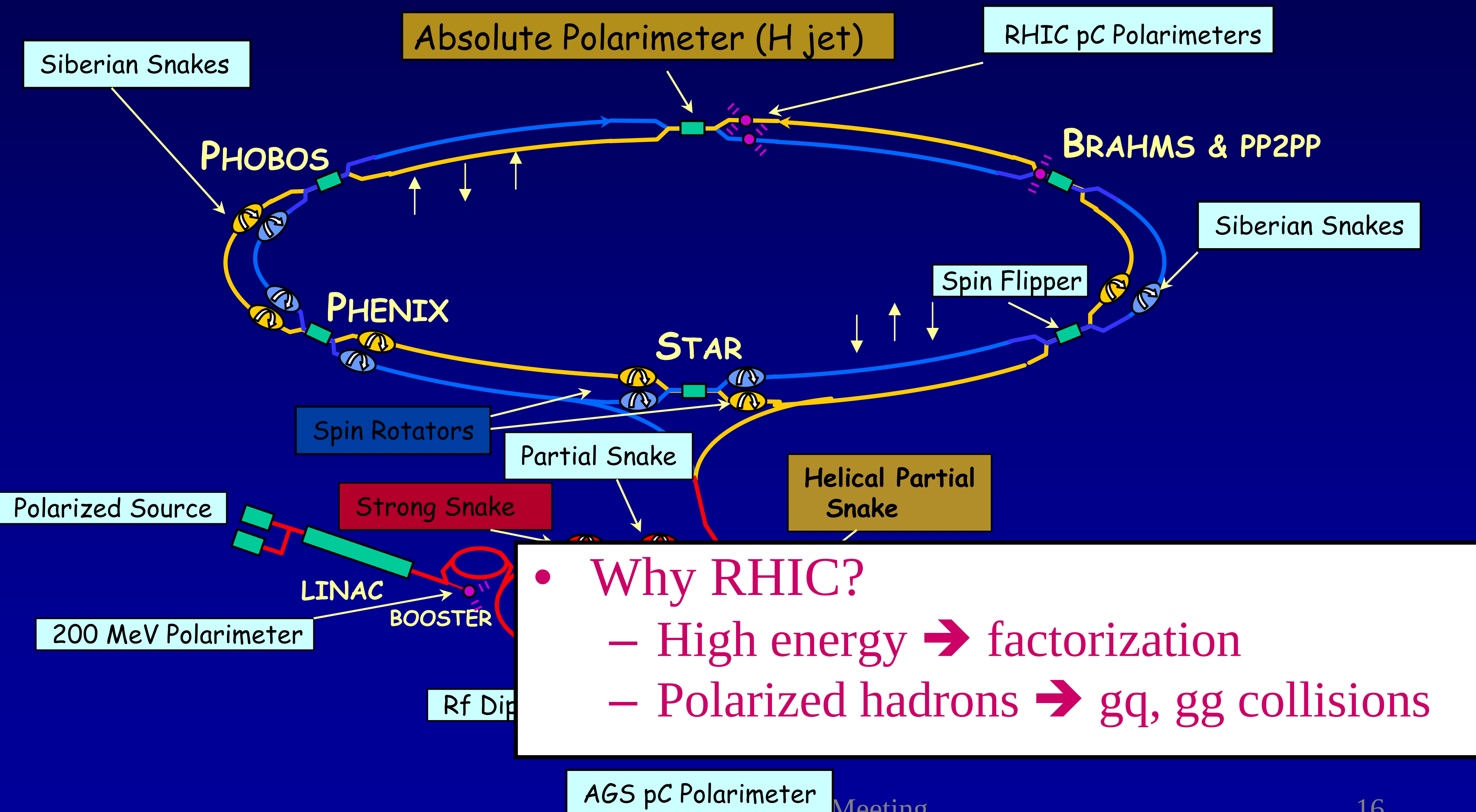
RHIC Specifications

- 3.83 km circumference
- Two independent rings
  - Up to 120 bunches/ring
  - 106 ns crossing time
- Energy:
  - ➔ Up to 500 GeV for p-p
  - ➔ Up to 200 GeV for Au-Au (per N-N collision)
- Luminosity
  - Au-Au: 2×10^{26} cm^{-2} s^{-1}
  - p-p : 2×10^{32} cm^{-2} s^{-1} (<u>*polarized*</u>)



RHIC as a Polarized p-p Collider

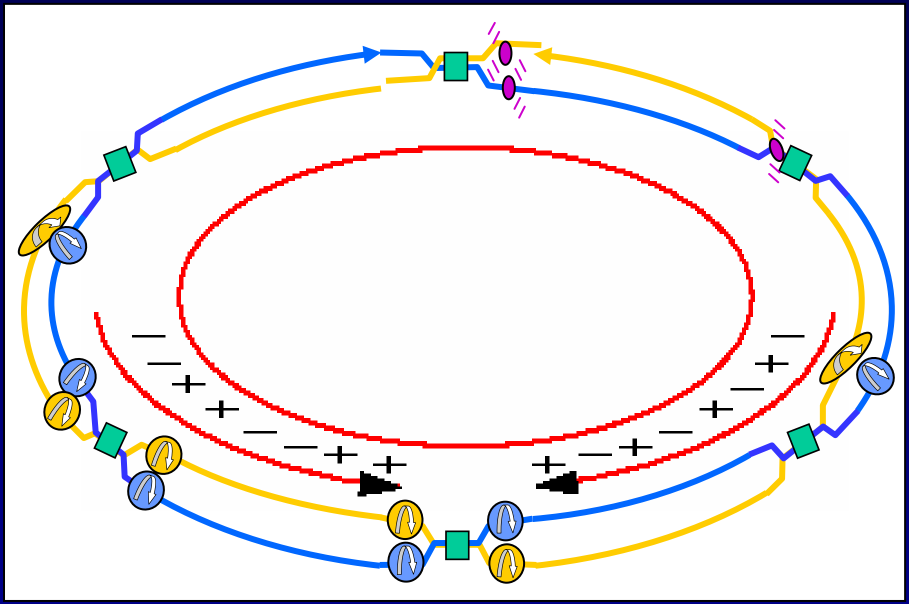
source: Thomas Roser, BNL



- Why RHIC?
  - High energy ➔ factorization
  - Polarized hadrons ➔ gq, gg collisions

Spin Running at RHIC So Far

- 2001-2
  - ***Transversely*** polarized p+p collisions
  - Average polarization of ~15%
  - Integrated luminosity 0.15 pb^{-1}
- 2003
  - ***Longitudinally*** polarized p+p collisions achieved
  - Average polarization of ~27%
  - Integrated luminosity 0.35 pb^{-1}
- 2004
  - 5 weeks commissioning
  - 1 week data-taking
  - Average polarization ~45%
- 2005
  - 11 weeks of data-taking scheduled
  - In progress!



Opposite spin of bunches every ~100 or 200 ns aids in eliminating systematic errors

Proton Spin Structure at PHENIX

Gluon Polarization

ΔG

π Production $A_{LL}(gg, gq \to \pi + X)$

Prompt Photon $A_{LL}(gq \to \gamma + X)$

Heavy Flavors $A_{LL}(gg \to c\bar{c}, b\bar{b} + X)$

Flavor decomposition

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

W Production

$$A_L(u + \bar{d} \to W^+ \to l^+ + \nu_l)$$

$$A_L(\bar{u} + d \to W^- \to l^- + \bar{\nu}_l)$$

Transverse Spin

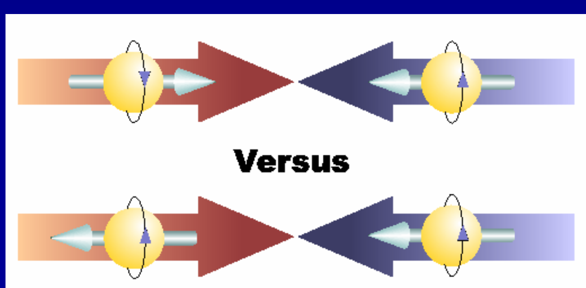
Transversity δq:

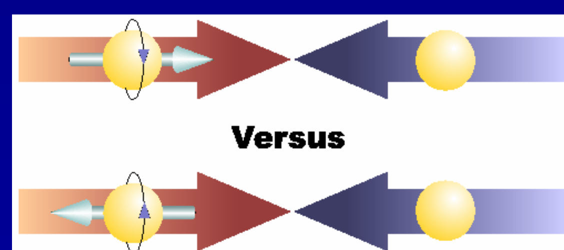
π^+, π^- Interference fragmentation:

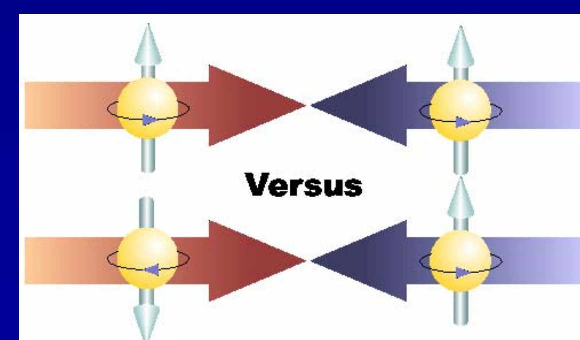
$$A_T\left(p_\perp p \to (\pi^+, \pi^-) + X\right)$$

Drell Yan A_{TT}

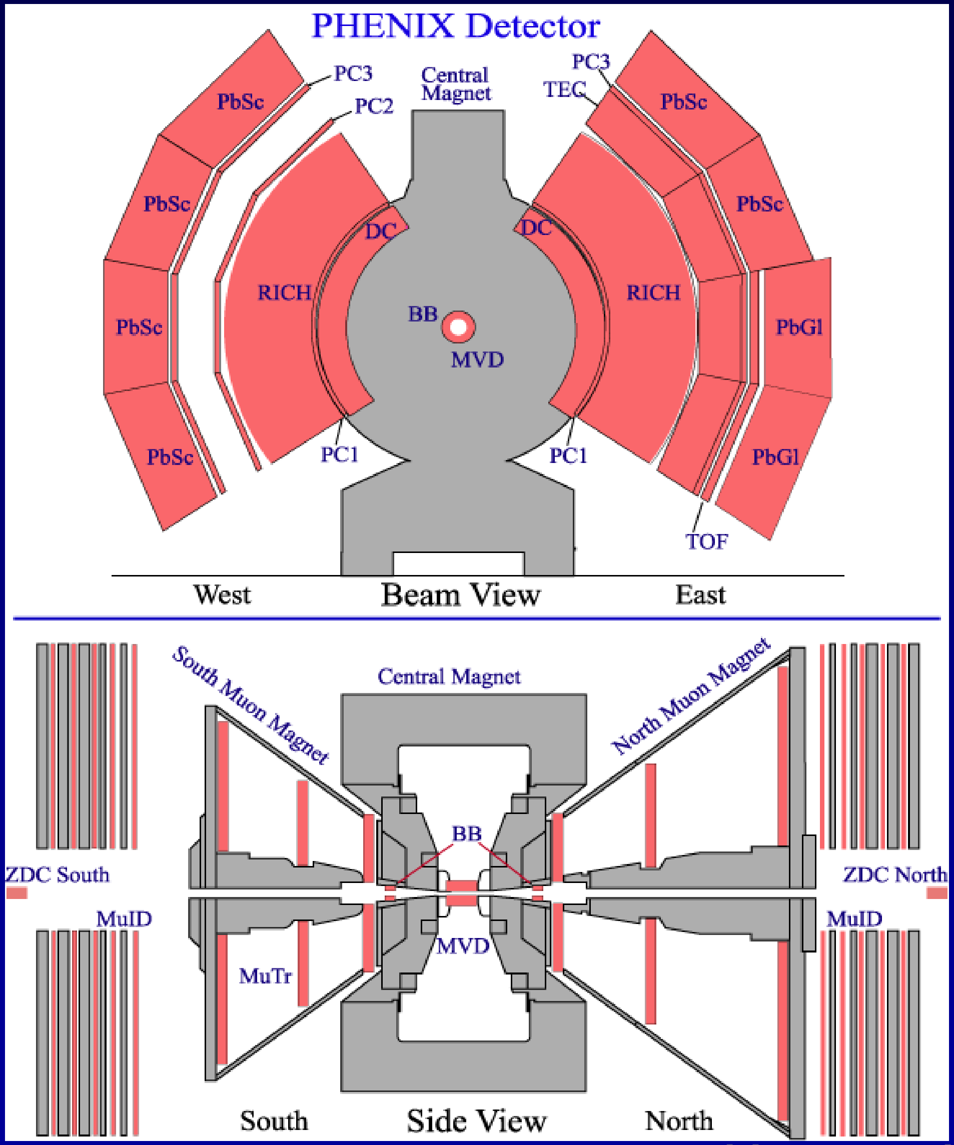
Single Asymmetries A_N







PHENIX Detector Overview



Central arms

Photons, electrons, identified charged hadrons

$|\eta| < 0.35$

$\Delta\phi = 180$ degrees

Forward muon arms

Track and identify muons

$1.2 < |\eta| < 2.4$

$\Delta\phi = 2\pi$

A_{LL} *Measurements*

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad \delta_{A_{LL}} = \frac{1}{|P_B P_Y|} \frac{1}{\sqrt{N_{++} + N_{+-}}}$$

++ same helicity

+– opposite helicity

N: # pions

R: luminosity++/luminosity+-

Procedure

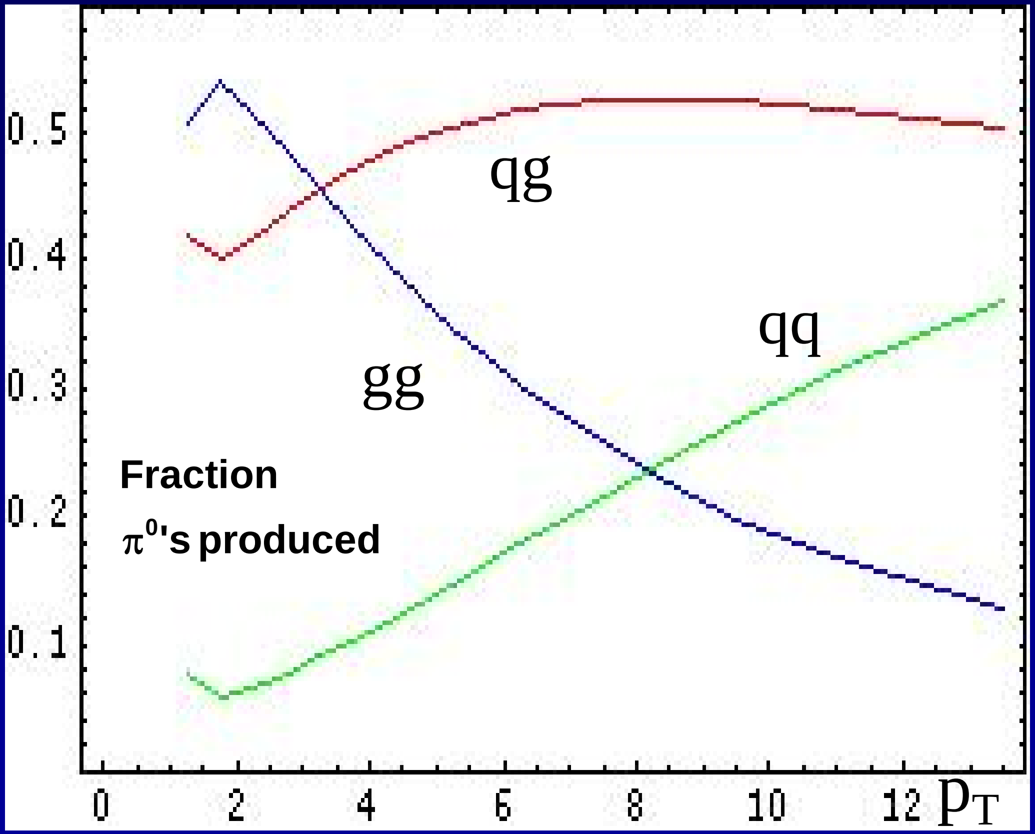
1. Count *N* and luminosity for ++ and +– configurations (sum over all crossings) and calculate A_{LL} for each store
2. Average A_{LL} over stores; use χ^2/NDF to control fit quality
3. Perform checks

Relative Luminosity

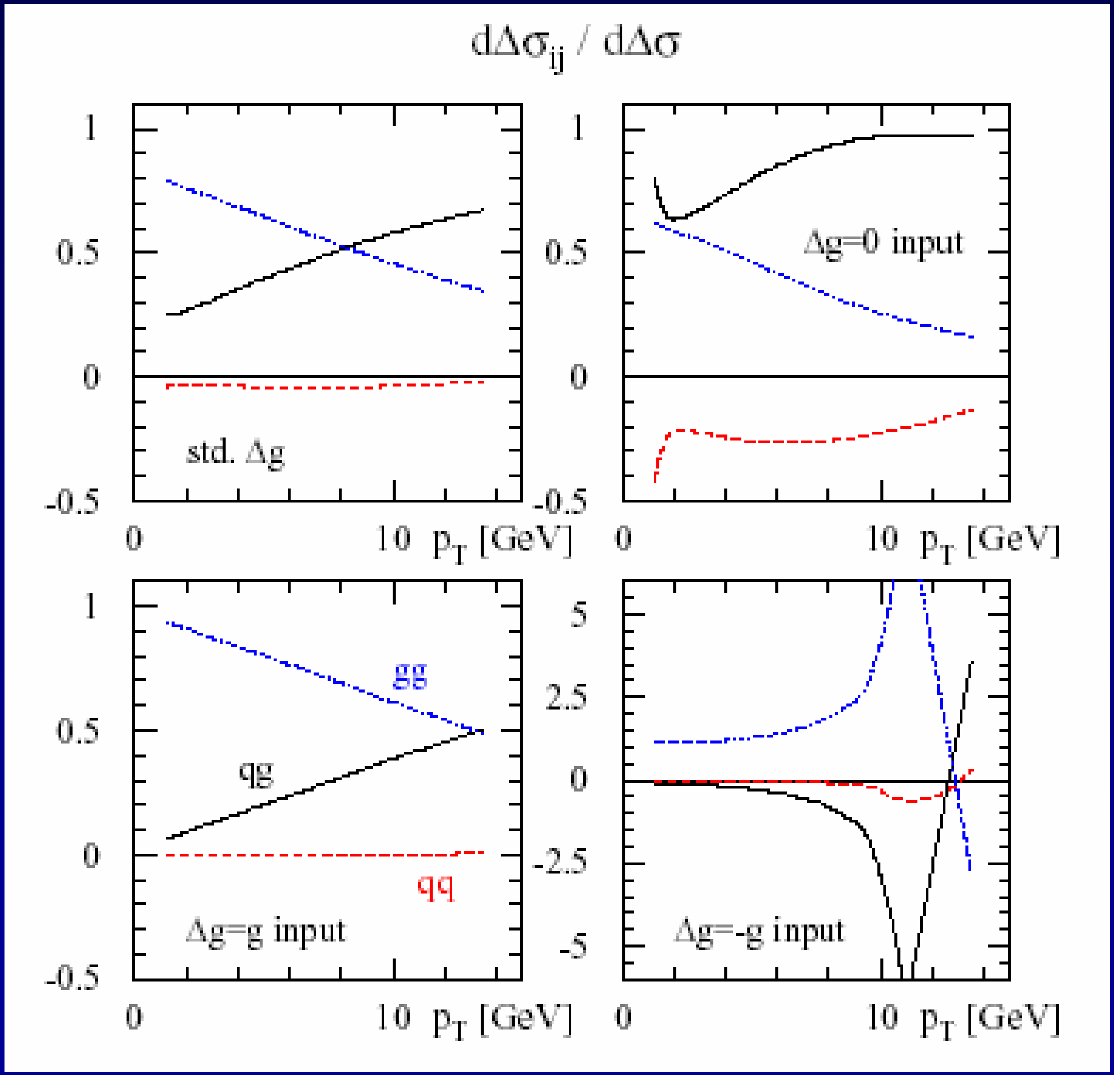
- Must combine yields from *different bunch crossings* to obtain asymmetries
- Important to know that relative luminosity between same-helicity and opposite-helicity bunch crossings is being counted correctly
- Don't get fooled by asymmetries in the luminosity detectors themselves!

Compare relative luminosity measurements from two different detectors situated in two different kinematic regions.
Beam-Beam Counter (BBC): quartz Cherenkov counter
Zero-Degree Calorimeter (ZDC): hadronic calorimeter

Partonic process contributions to pion production at mid-rapidity



Subprocess Contributions to π^0 Production for Four Different Assumptions on Δg



Jaeger, Kretzer, Stratmann, Vogelsang

gg scattering dominates for $p_T < 10$ GeV/c in all cases.

This means that Δg will enter squared!

Then for any sign of Δg, a positive partonic asymmetry will give a positive A_{LL}!