Accessing the Gluon Contribution to the Spin of the Proton via Double Longitudinal Spin Asymmetry Measurements in Polarized pp Collisions at PHENIX

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Proton Spin Puzzle

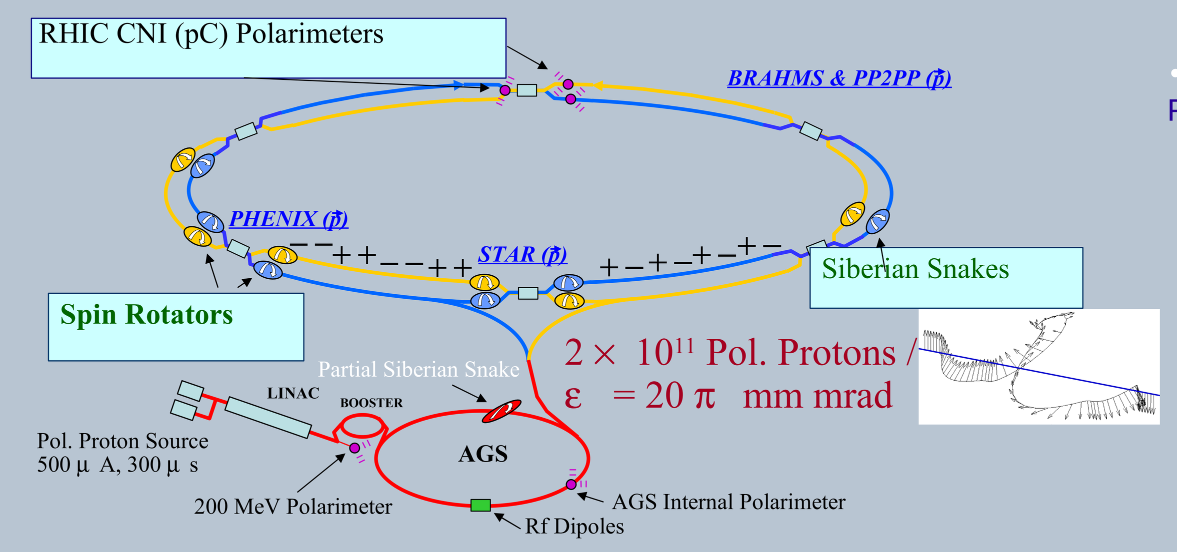
Pauli and Bohr performing early spin experiments in Sweden in 1955
Photograph by Erik Gustafson

- According to the Naive Parton Model (NPM) the proton is a collection of freely moving constituents called quarks and gluons
- In the NPM the properties of the proton should result simply from summing up the properties of the partons (mostly ignoring the gluons)
  - For example the electric charge of the proton
  - The proton is a spin ½ particle, perhaps we can build up its spin from the spin ½ quarks like we did with electrical charge?
- Birth of the Spin Crisis
  - Polarized deep inelastic collision experiments at CERN (EMC & SMC), SLAC (E143, E154, E155) , and DESY (HERMES) concluded that the quarks only constituted ~25% of the total spin of the proton!
  - One cannot simply sum the spin contributions of the quarks to get the proton spin
  - The spin must be built on a combination of the quark spin contribution (ΔΣ), the gluon spin (ΔG) and perhaps some orbital angular momentum of the quarks and gluons.

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L(q,g)$$

  - A major focus of the PHENIX Spin program is to access the gluon contribution to the spin of the proton through measurements of the double longitudinal spin asymmetry (A_{LL}).

RHIC Accelerator Facility



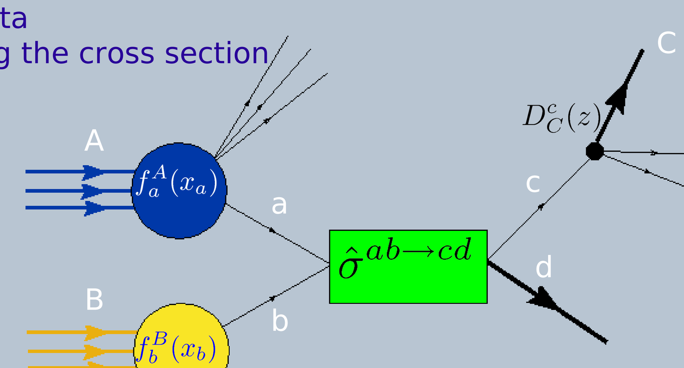
Year	Energy (c.o.m) [GeV]	Luminosity	Polarization
2005	200	3.4 pb^-1	50%
2006	200	7 pb^-1	57%
2006	62	0.08 pb^-1	48%

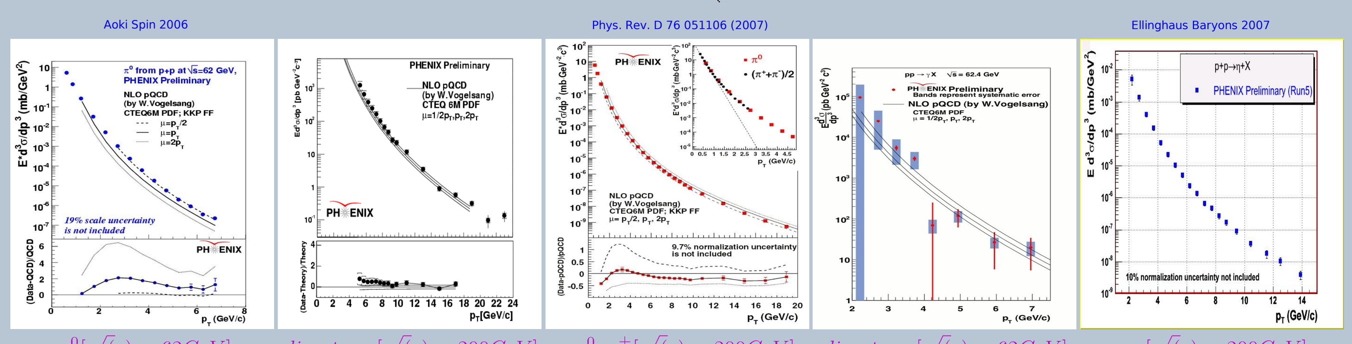
- Major components of the Polarized Proton Program at RHIC
  - Siberian Snakes
    - Helical magnets which help to preserve the proton beam polarization through the acceleration process
  - Spin Rotators
    - Magnets located at either end of the major spin experiments at RHIC, which allow each experiment to independently choose the spin orientations needed for their collisions
  - Polarimeters
    - Allow the experiments to monitor the degree of polarization during the run

The RHIC accelerator facility is capable of accelerating several species of particle, to a variety of center of mass energies.

PP Cross Section

- Quantum Chromodynamics (QCD) is the theory which describes the strong force.
- Perturbative QCD (pQCD) is the framework in which we interpret our spin results.
- Before we can interpret any asymmetry measurement at PHENIX, we must make sure we are in a regime where pQCD is applicable to our data
- We do this by first measuring the cross section

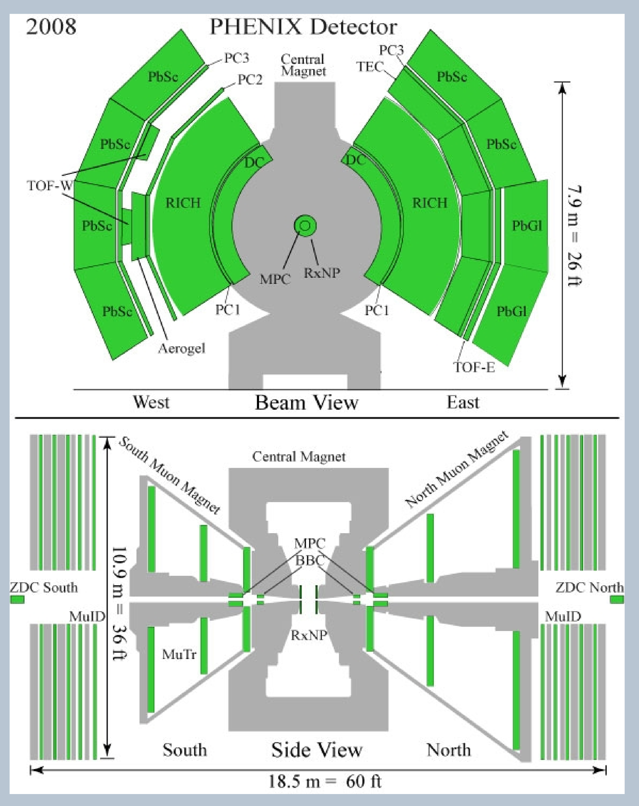




$\pi^0[\sqrt{s}=62GeV]$ $direct-\gamma[\sqrt{s}=200GeV]$ $\pi^0,\pi^+[\sqrt{s}=200GeV]$ $direct-\gamma[\sqrt{s}=62GeV]$ $\eta[\sqrt{s}=200GeV]$

PHENIX data and pQCD predictions are in agreement over several orders of magnitude in particle P_T !

The PHENIX Detector



- Electromagnetic Calorimeter
  - Provide high P_T particle trigger.
  - High granularity (~10x10 mrad²)
  - Acceptance: |η |<0.35, ϕ = 2 x π /2
- Charged Track Systems
  - Drift Chamber and Pad Chambers
- Beam Beam Counters (BBC)
  - Collision counters
  - Provide minimum bias trigger
  - Longitudinal vertex determination
  - Relative Luminosity
- Zero Degree Calorimeter (ZDC)
  - Hadronic Calorimeter
  - Used in Relative Luminosity Measurements
  - Used in combination with the Shower Max Detector for Local Polarimetry
- Ring Imaging Cherenkov
  - Charged particle identification
- Muon Arms
  - 1.2 < η <2.2 (2.4)
  - Will be integral in future W boson measurements

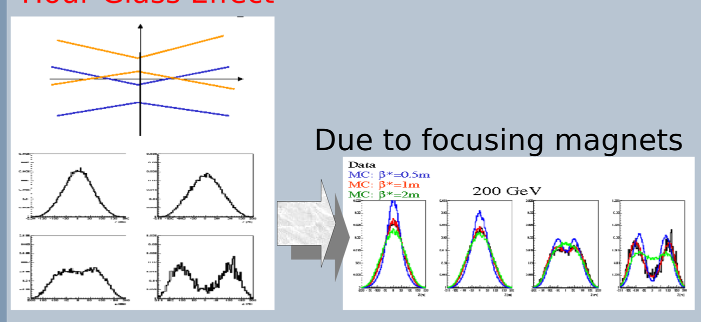
Absolute Luminosity Determination

- Aside from center of mass energy the most important parameter at a collider experiment is the luminosity
- The Vernier scan technique allows PHENIX to measure the luminosity delivered to the experiment and to calibrate our detectors
- During the Vernier scan one beam is held steady while the other is scanned vertically and then horizontally across the face of the other beam
- Rates are measured in collision counters (BBC) at PHENIX during this process
- The transverse extent of the beam can be extracted and used to calculate the luminosity at PHENIX

$$L = \frac{f_{rev} N_b N_y}{2\pi\sigma_x\sigma_y} \qquad \sigma_{BBC} = \frac{\dot{N}}{L}$$

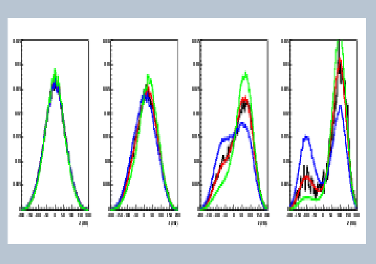
Several factors will affect the true luminosity.

Hour Glass Effect

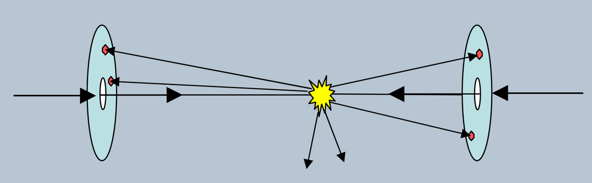


Due to focusing magnets

Crossing Angle



Geometric Acceptance

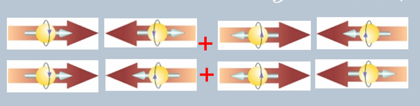


A novel technique of using the Wall Current monitors (WCM) to obtain the longitudinal extent of the beam distribution was developed. By comparing results of a Monte Carlo simulation that takes the convolution of longitudinal distribution (from WCM) and the transverse beam size (via Vernier scans) we are able to show that PHENIX is sensitive to the value of beta star and the beam crossing angle. From the simulations we have been able to calculate corrections to the luminosity at both 200 and 62 GeV collisions due to these effects.

Asymmetries

- We define the double longitudinal asymmetries (A_{LL})as the difference between reaction cross sections observed when the colliding proton spins are aligned compared to anti-aligned, over the sum.

$$A_{LL} = \frac{\sigma^{++}-\sigma^{+-}}{\sigma^{++}+\sigma^{+-}} \Leftrightarrow A_{LL} = \frac{\epsilon}{\epsilon P_b P_y}\frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}} = \frac{1}{P_b P_y}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$



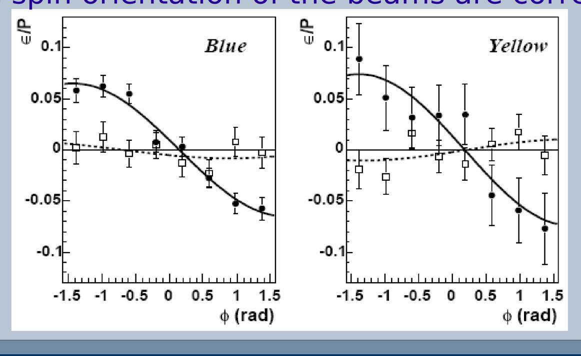
- A_{LL} is then related to ΔG in the frame work of pQCD: $\mathbf{\Delta G \propto A_{LL} \otimes A_1^P \otimes \hat{\sigma}_{pQCD}}$

Relative Luminosity

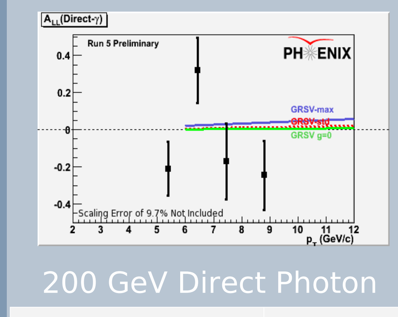
- In measuring A_{LL} false asymmetries can arise due to differences in luminosity between like and unlike helicity beams
- This is accounted for in relative luminosity studies

Local Polarimetry

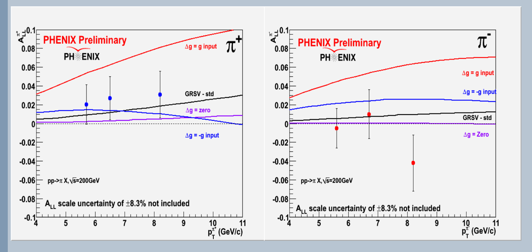
- By observing physical asymmetries of very forward neutrons in the ZDC, PHENIX can confirm the spin orientation of the beams are correct.



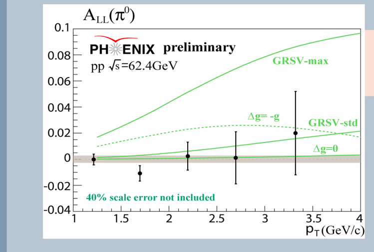
Double Longitudinal Spin Asymmetry



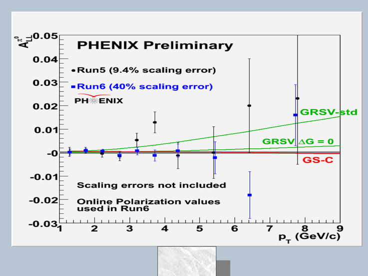
200 GeV Direct Photon

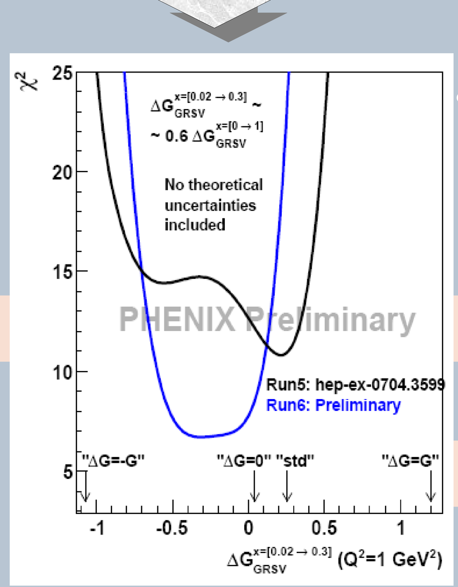


200 GeV Charged Pions



62 GeV Neutral Pion





- A_{LL} has been measured as a function of transverse momentum (P_T) for several different channels at PHENIX at two different center of mass energies.
- Comparisons of the data with theoretical models show that PHENIX measurements are capable of constraining the gluon spin contribution.
- A very thorough analysis of the neutral pion asymmetry, reveals PHENIX data favors ΔG=0 in the GRSV model, while ruling out the maximal predicted value of the gluon contribution to the spin of the proton

Spin Outlook

- Several exciting results have come from the recent data runs
  - Cross section analysis have confirmed the applicability of pQCD to RHIC spin measurements at two center of mass energies.
  - New techniques were developed during the vernier scan analysis which help us better understand the RHIC accelerator.
  - The neutral pion result at 200 GeV has provided us new insight into the spin structure of the proton.
- Although the PHENIX neutral pion data can already be used to constrain the gluon spin contribution to the proton spin, no single measurement will solve the spin puzzle.
  - So, we look forward to future analysis of the other channels
- New prospects in W-physics with the upcoming 500 GeV running will allow for flavor separated spin analyses.
- The Transverse Spin Program, also offers exciting possibilities to probe the orbital angular momentum of quarks and gluons in the proton.
- A lot of progress has been made, though there is still much to do. We look forward to the up coming spin run, and the prospect of new results.