Direct Photon Cross Section and Double Longitudinal Asymmetry at PHENIX in 200 GeV pp Collisions

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Spin Puzzle

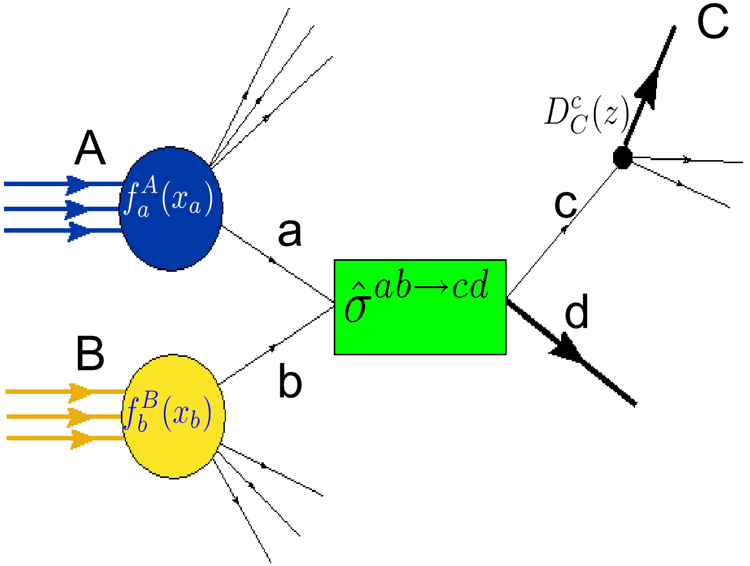
- Birth of the Spin Crisis
  - Polarized deep inelastic collision experiments at CERN (EMC & SMC), SLAC (E143, E154, E155) , and DESY (HERMES) concluded that the quarks only constituted ~25% of the total spin of the proton!
  - The spin must be built on a combination of the quark spin contribution (ΔΣ), the gluon spin (ΔG) and perhaps some orbital angular momentum of the quarks and gluons.

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

- PHENIX
  - 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}).

Accessing ΔG in PP

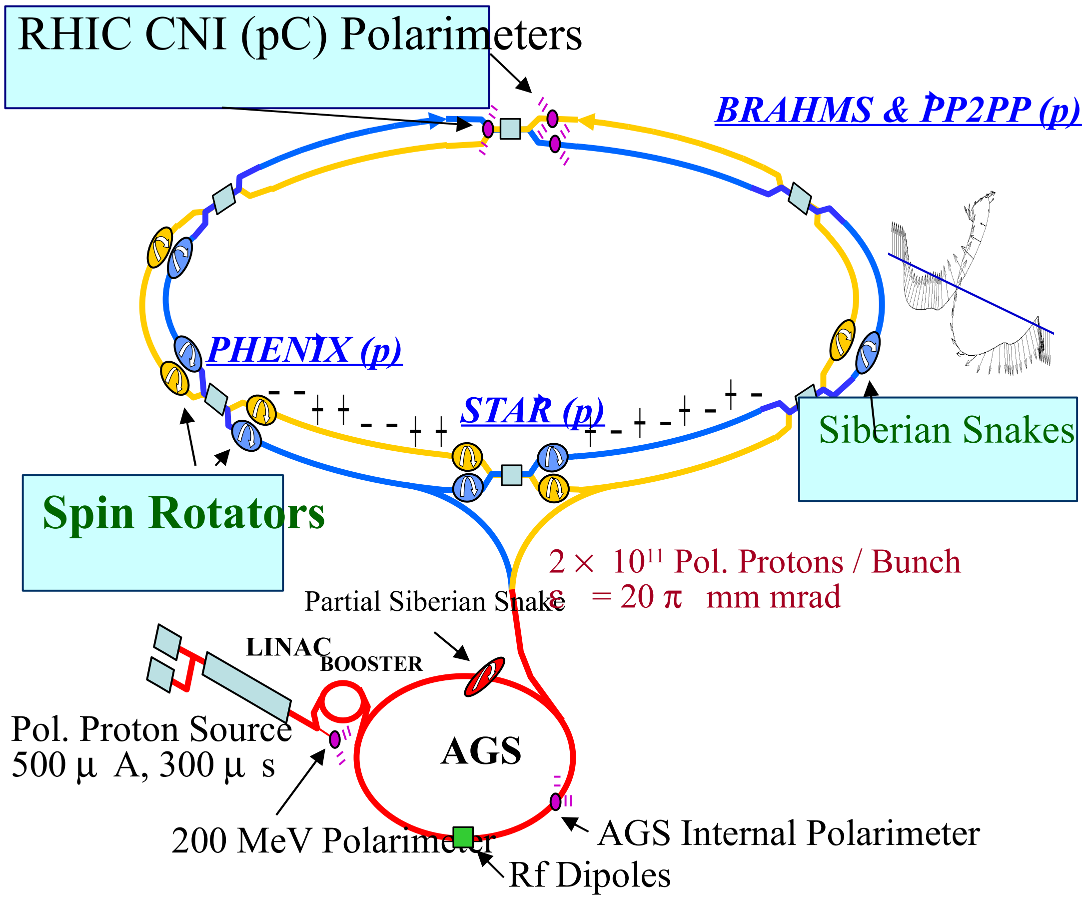
- Quantum Chromodynamics (QCD) is the theory which describes the strong force.
- Perturbative QCD (pQCD) is the framework in which we interpret our spin results.
- Before we can interpret any asymmetry measurement at PHENIX, we must make sure we are in a regime where pQCD is applicable to our data
-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



- A_{LL} is related to ΔG in the frame work of pQCD:

$$\mathbf{\Delta G \propto A_{LL} \otimes A_1^p \otimes \hat{\sigma}_{pQCD}}$$

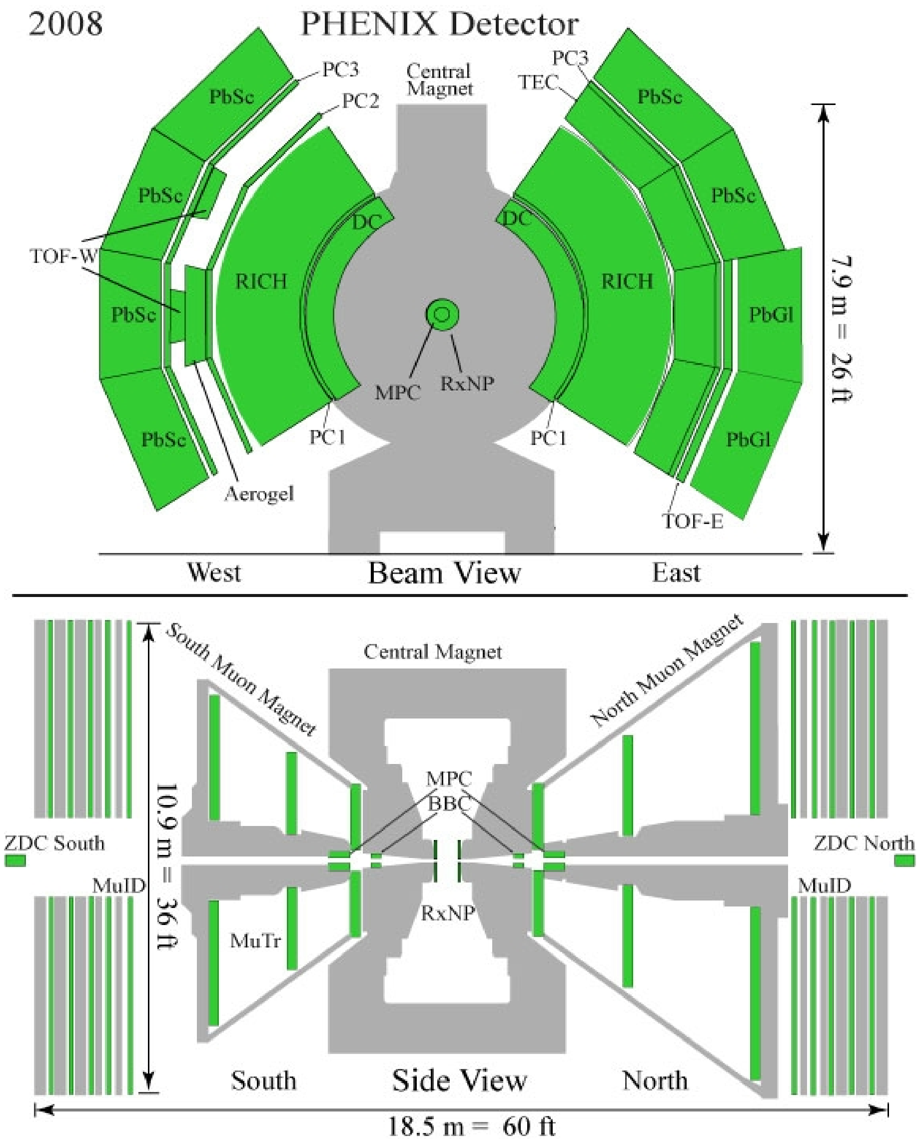
RHIC Accelerator Facility



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%

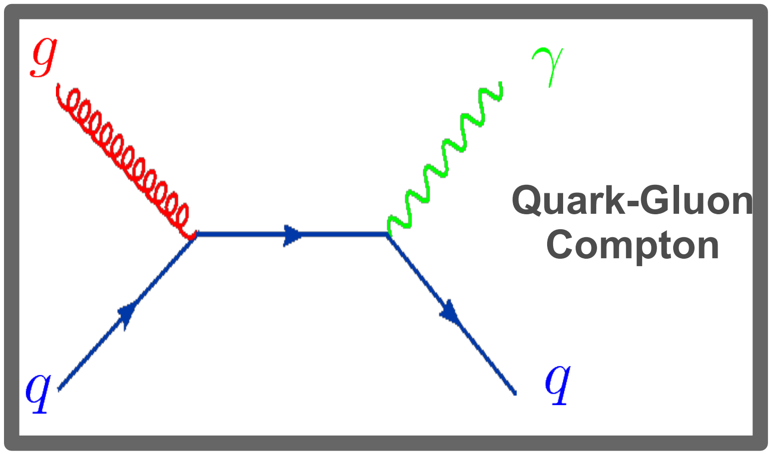
- Essential equipment for the polarized proton program at RHIC
  - Siberian Snakes
    - Helical magnets which help to preserve the proton beam polarization through the acceleration process
  - Spin Rotators
    - Magnets located at either end of the major spin experiments at RHIC, which allow each experiment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

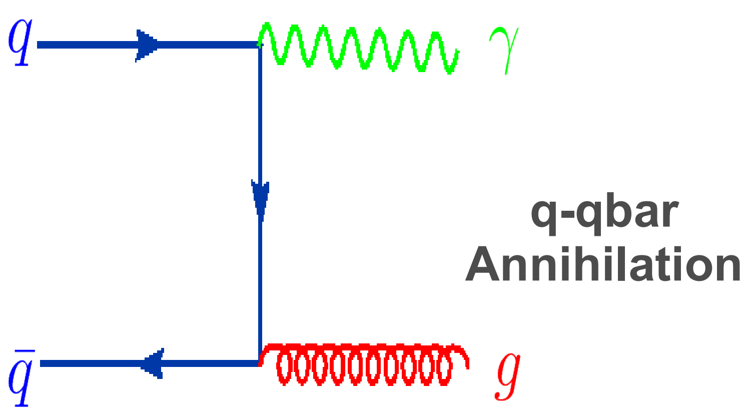
The PHENIX Detector



- Electromagnetic Calorimeter
  - Provide high P_t particle trigger.
  - High granularity (~10x10 mrad²)
  - Acceptance: $|\eta| < 0.35$, $\phi = 2 \times \pi/2$
- 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

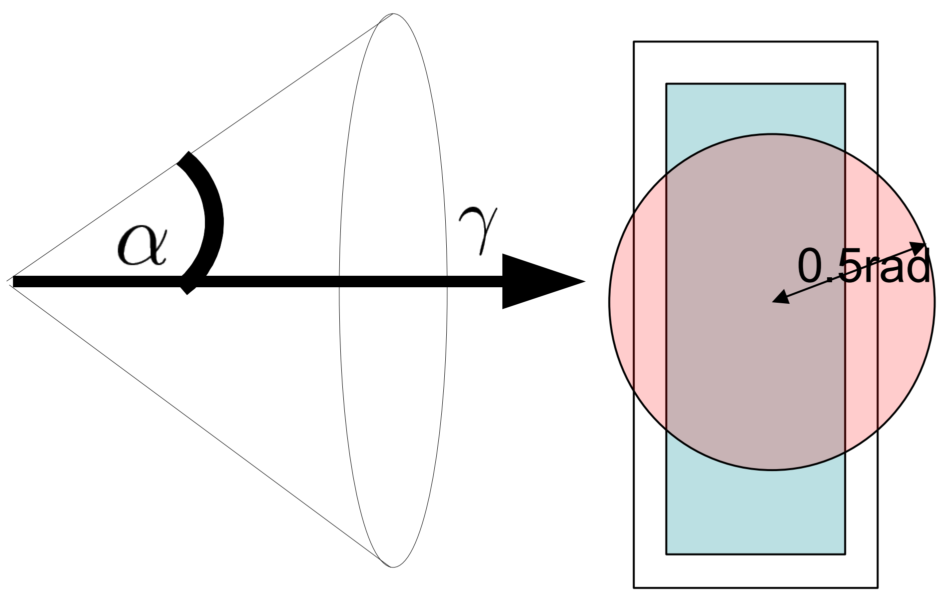
Direct Photons





- $pp \rightarrow \gamma - X$
- Direct photon is a photon originating from the hard scattering process.
- In pp collisions the Quark-Gluon Compton process dominates.
- The direct photon asymmetry, A_{LL}, is linear in ΔG, therefor sensitive to both the magnitude and sign of ΔG.
  - The measurement will be a complimentary measurement to the pion analysis
- This is a theoretically clean channel, but quite difficult to measure due to the large decay photon back ground
- Looking for isolated photons will help increase the signal to background

Isolated Photons

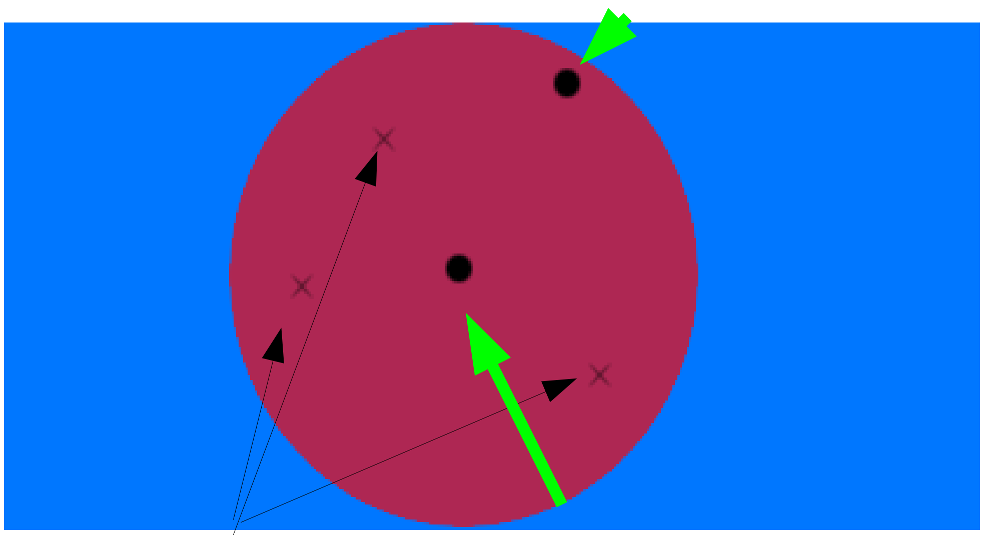


- Define a cone a around a prospective direct photon. $\alpha = 0.5rad$
- We then look for neutral particle energy deposited in the EMC and charged particle momentum, found by the DC, inside the cone.
- The following cut is then made:

$$\sum_i E_i^{neutral} + \sum_i P_i^{charged} < 0.1 \times E_\gamma$$

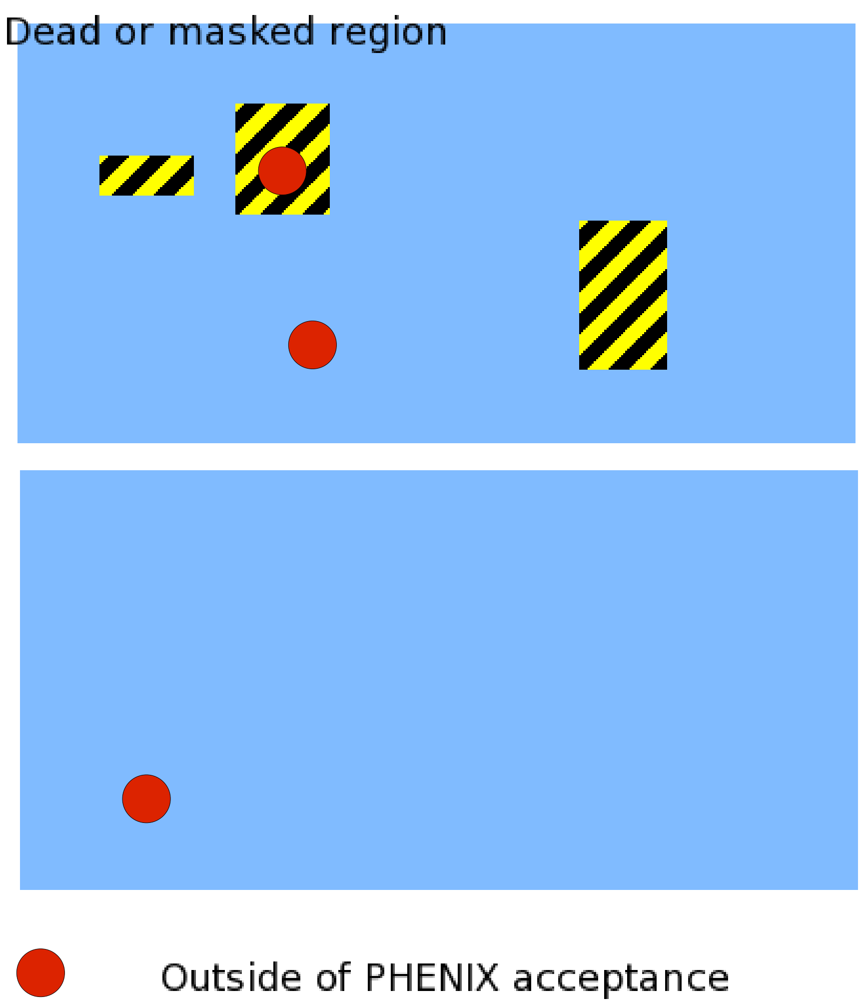
- If sufficiently energetic particles are found in the proximity of the prospective photon, it is no longer a candidate
- The Isolation cut serves to purify our photon sample.
- Remaining hadronic contamination can be estimated by MC

$n_{\pi^0}^{iso}$



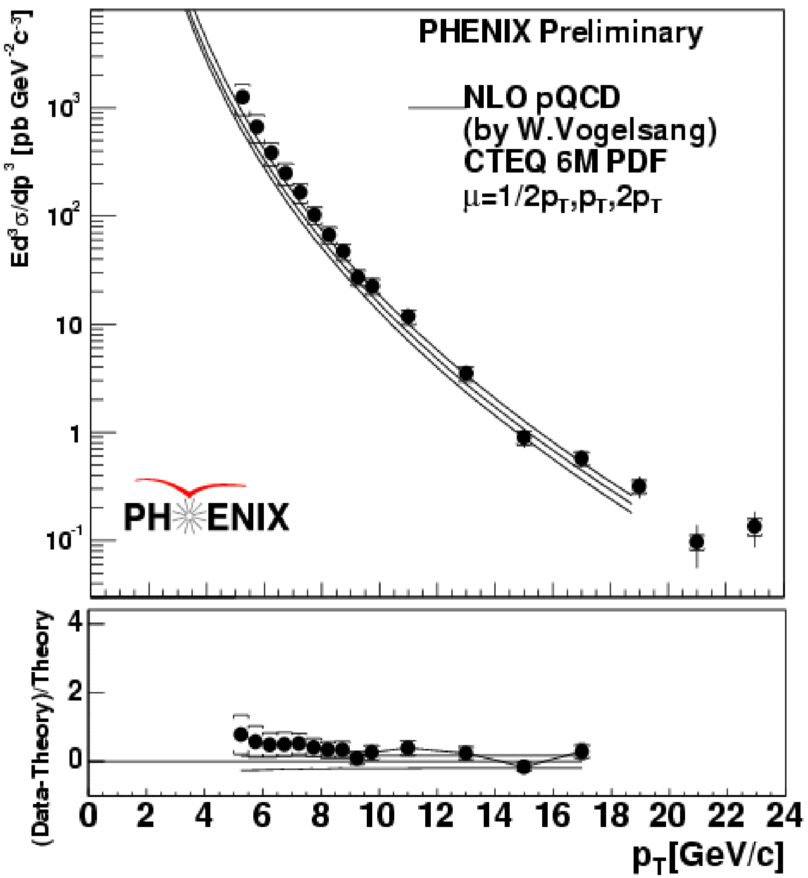
- The first type of background to consider are π^0 decay photons in the PHENIX acceptance, but still passing the isolation cut
- Start with the isolated photon sample and create invariant mass pairs
- There is almost zero combinatorial background. So we simply remove photons from our sample inside π^0 mass($\pi^0 \pm 30MeV$)
- These photons are identified and removed event by event

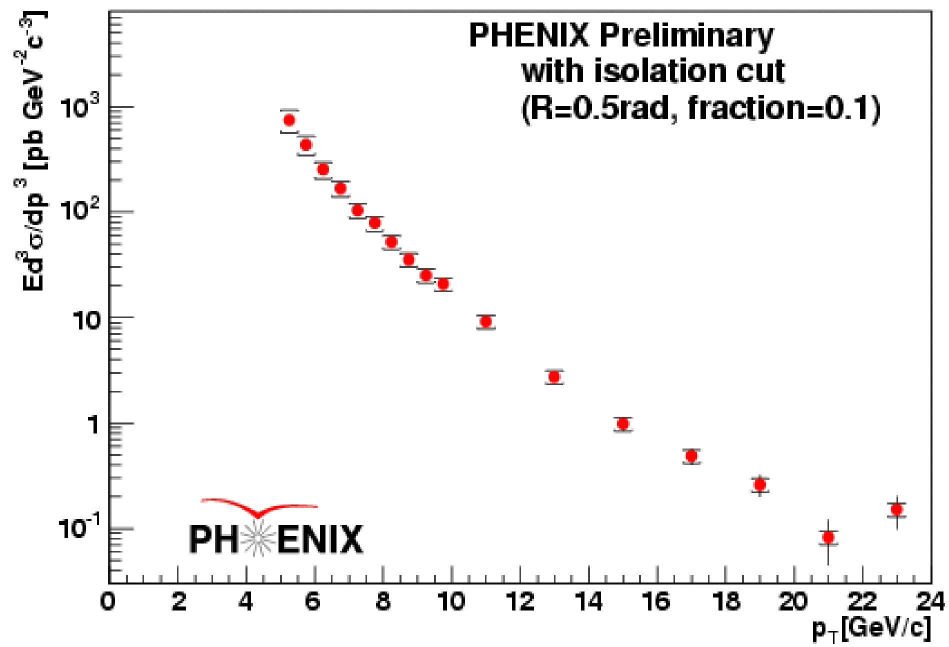
$N^{iso}_{\pi^0}$



- Also included in isolated photon sample, are hadronic decays where the partner photon lands in a dead/masked region or misses PHENIX completely
- This number is estimated by first counting the number of isolated pi0 pairs in PHENIX and scaling this number by the 1Tag/2Tag ratio (R) obtained from fast MC
- Finally the number of eta, omega, etc... can be estimated by knowing the number of isolated $\pi^0 s$

Direct Photon Cross Section





- The direct photon cross section was measured in Run5 by two methods (Isolation cut & Statistical Subtraction).
- Consistent with theory and eachother over several orders of magnitude
- Run 6 analysis is ongoing

Subtraction method

$$N_{direct\gamma} = N_{incl\gamma} - N_{\pi}(R+1) - A(1+R)N_{\pi}$$

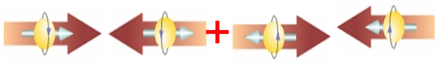
Isolation Cut

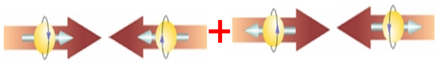
$$N^{iso}_{direct\gamma} = N^{iso}_{incl\gamma} - (n^{asymm}_{\pi} + N^{isopair}_{\pi} R) - A(1+R)N^{isopair}_{\pi}$$

Evaluation of A_{LL} and Background Correction

- 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.

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

+ - = Unlike Sign Helicity= 

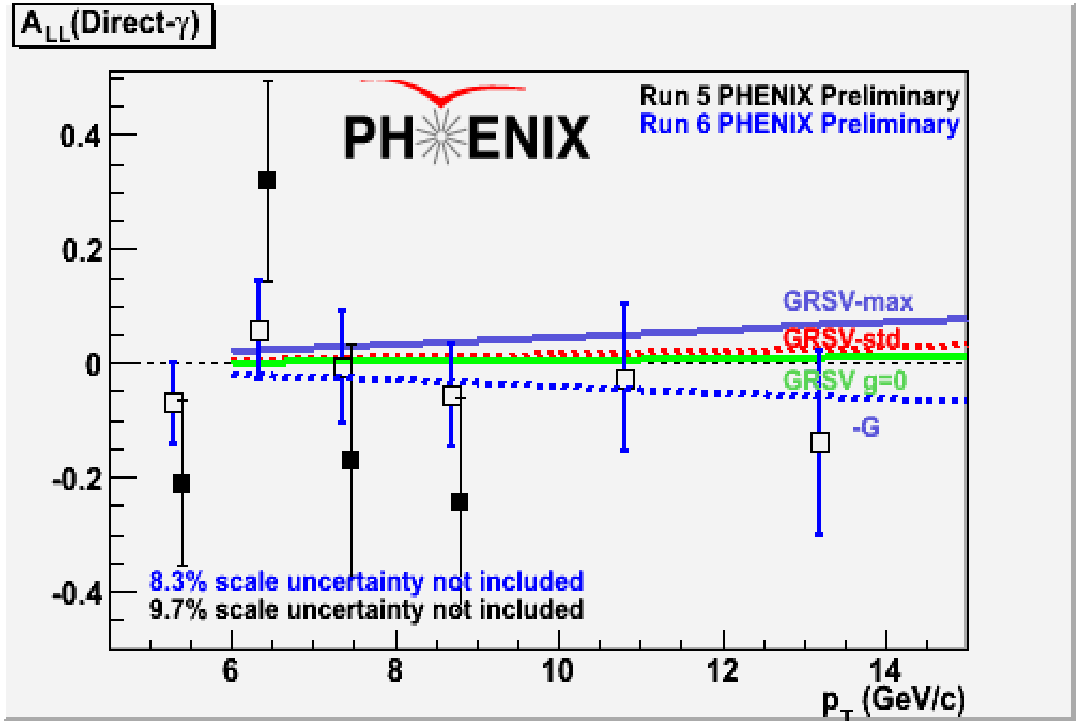
+ + = Like Sign Helicity = 

$$R = \frac{L^{++}}{L^{+-}}$$

$$A_{LL}(sig) = \frac{A_{LL}(iso - n_{\pi^0}) - rA_{LL}^{bg}}{1-r} \qquad r = \frac{N_{bg}}{N_{iso-n_{\pi^0}}}$$

$$\Delta A_{LL}(sig)^2 = \frac{\Delta A_{LL}^2(iso - n_{\pi^0}) + r^2 \Delta A_{LL}^2(bg)}{(1-r)^2}$$

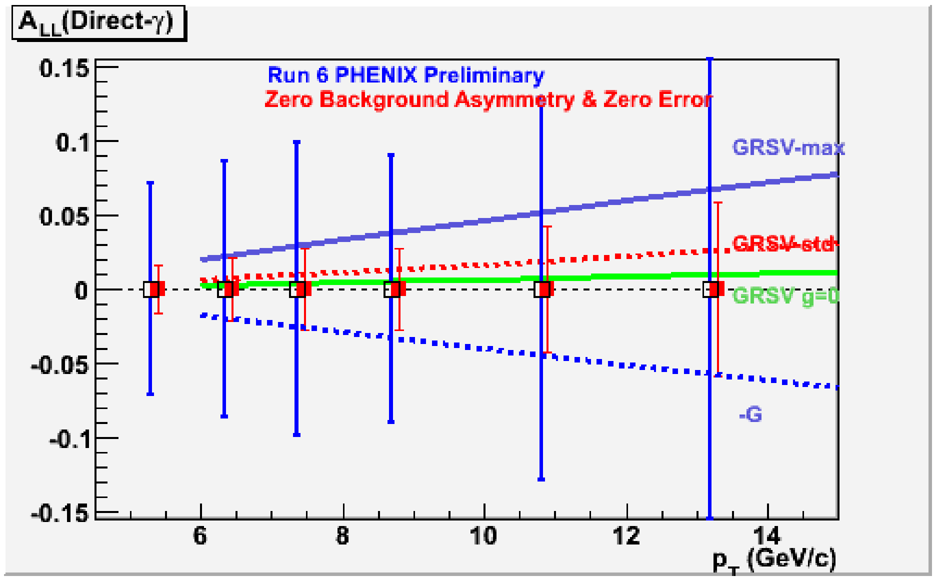
Direct Photon Asymmetry Results



Pt	"r" Isolate Photon	"r" (no isolationcut) Statistical Subtraction
"5-6"	0.660	0.79
"6-7"	0.529	0.74
"7-8"	0.432	0.7
"8-10"	0.320	0.64
"10-12"	0.183	0.54
"12-15"	0.104	0.44

- The direct photon A_{LL} is measure and plotted vs transverse photon momentum for the Run6 data set (7pb^-1 57% pol)
- Results from bunch shuffling show that any systematic uncertainties are small compared to the statistical error
- We confirmed the utility of the isolation cut, as evidenced in the comparison of the dilution factor measured with the isolation cut and without.
- At the moment we are limited by statistics, so it is difficult to make any constraint of ΔG with the direct photon

How Can We Proceed?



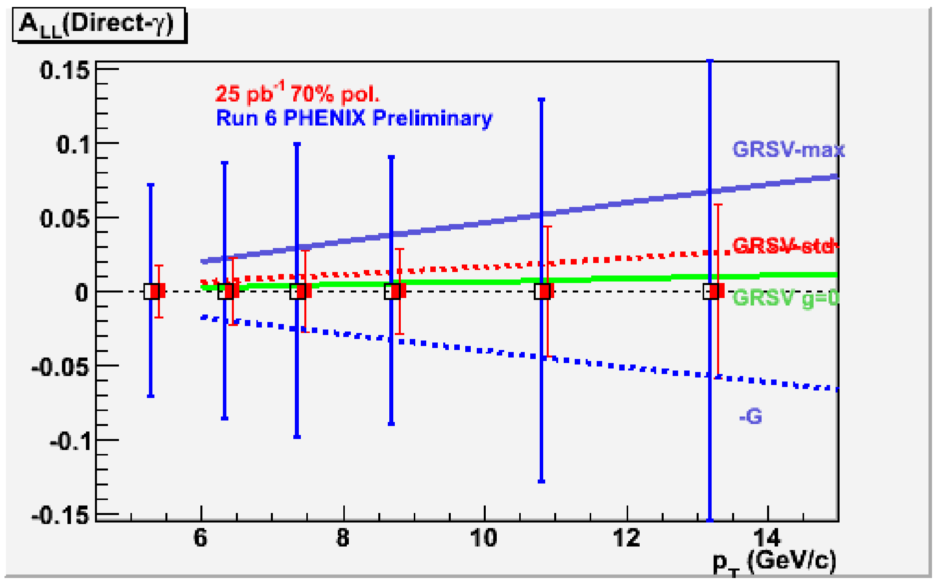
- How can we decrease the uncertainty on the direct photon measurement?

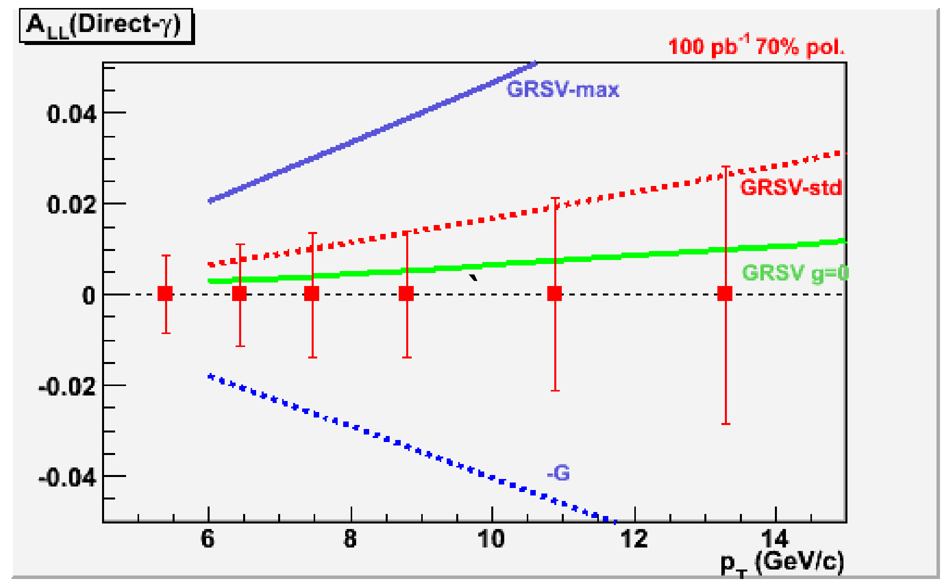
  1) Dilution Factor (r) : It may be tough to squeeze more out of the dilution factor

  2) Uncertainty of the background asymmetry:

     - We know it is small from the pion and eta analyses, can we assume it to be zero?
     - Convolution of the pion result with its production spectrum
     - STAR Jet Result

Projections for Future Runs





Projection for Run9

PHENIX Wishlist

- A measurement equivalent in statistics to the Run6 neutral pion result is a ways off
- A good measurement is in our reach, perhaps in the upcoming Run9 data set.

Summary

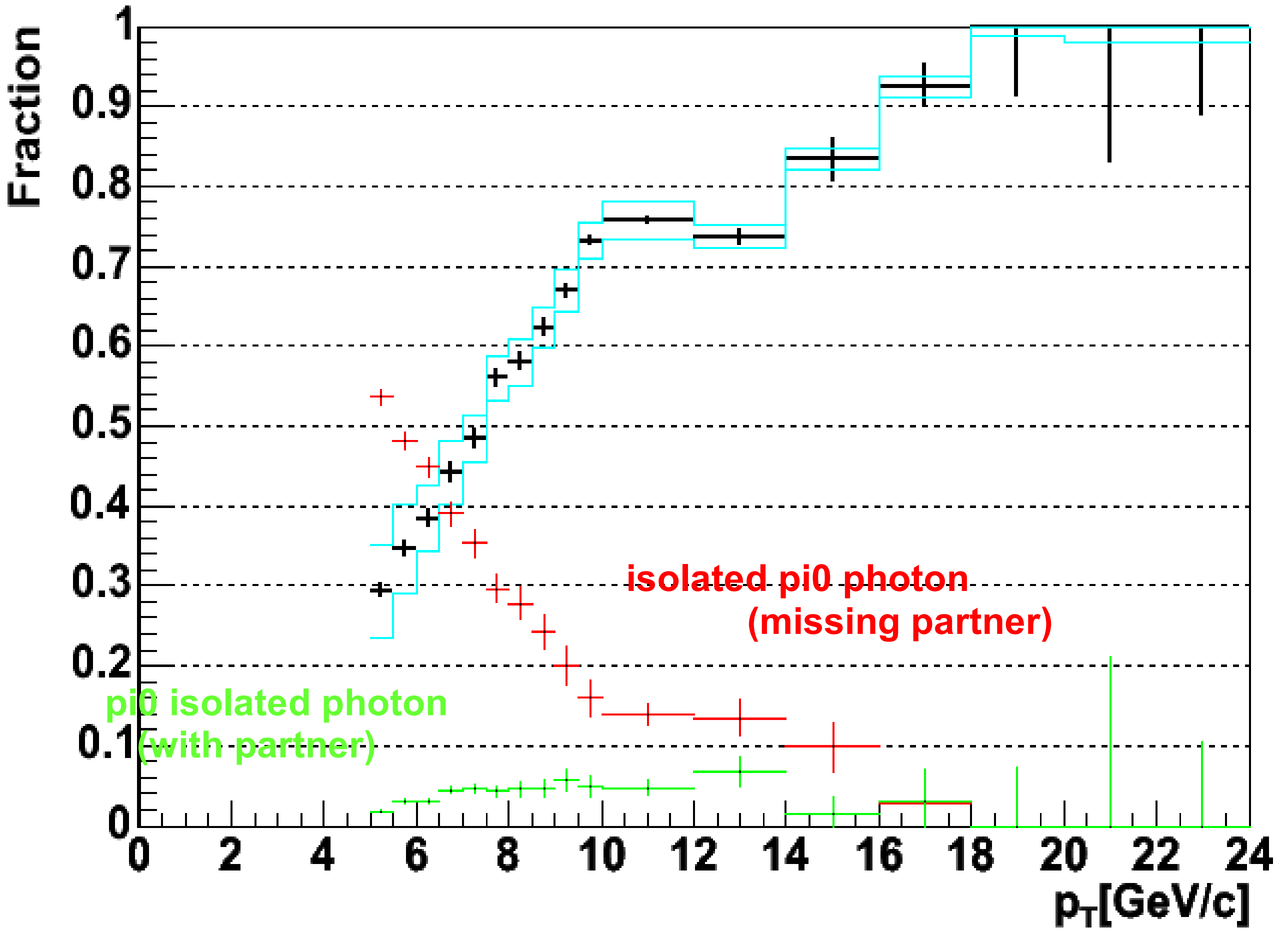
Pauli and Bohr performing early spin experiments in Sweden in 1955
Photograph by Erik Gustafson

- We have quite a difficult measurement on our hands
- There is steady progress from the previous measurement

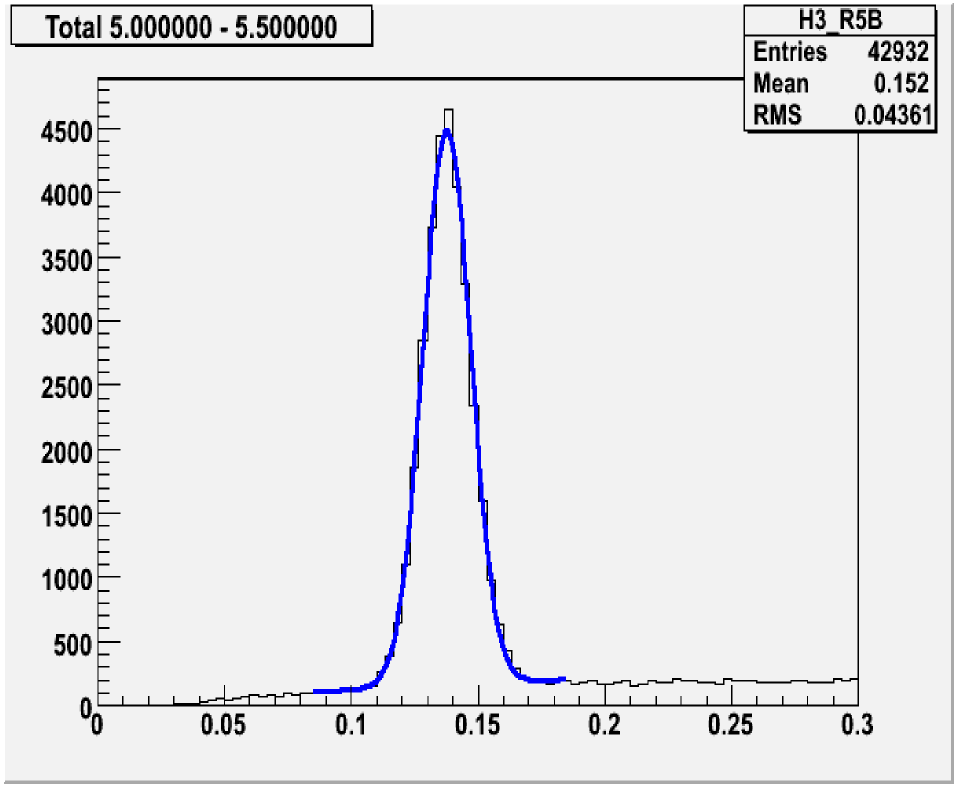
  - Factor of 2 decrease in uncertainties from Run 5 to Run 6
- Techniques were developed to treat the back ground
  - Isolation makes a significant contribution
  - New methods are are being explored
- A measurement which provides a meaningful constraint on the gluon polarization is not out of reach

Backup

Isolated Photon Signal Fration



Pi0 Background



- I found the pi0 background via three methods
- Fit (gaus+pol1)
- Fit (gaus+pol2)
- Sum Peak (60 Mev mass window around pion peak) - Sum wings
- All three methods yielded similar results at low Pt,(within 1%).
- I will use Peak-wings for consistency