PHENIX Spin Results and Perspectives

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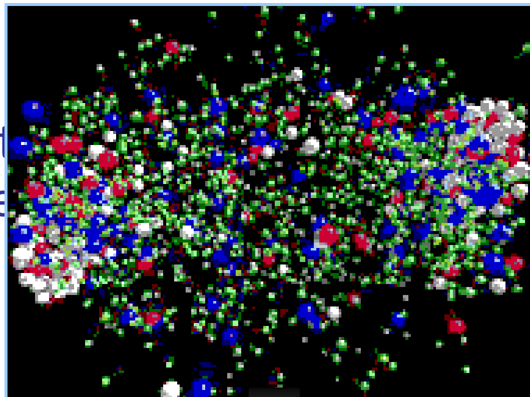
Nucleon Spin Physics

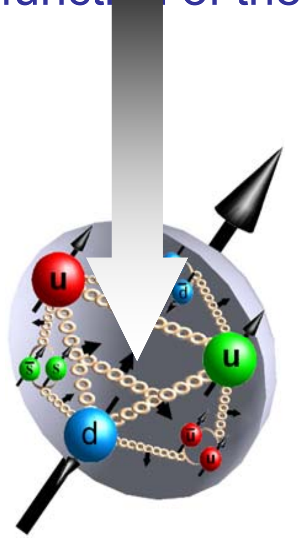


•prot stable ground state

•the understood

ed by QCD?)

•wavefuncti n of the proton?



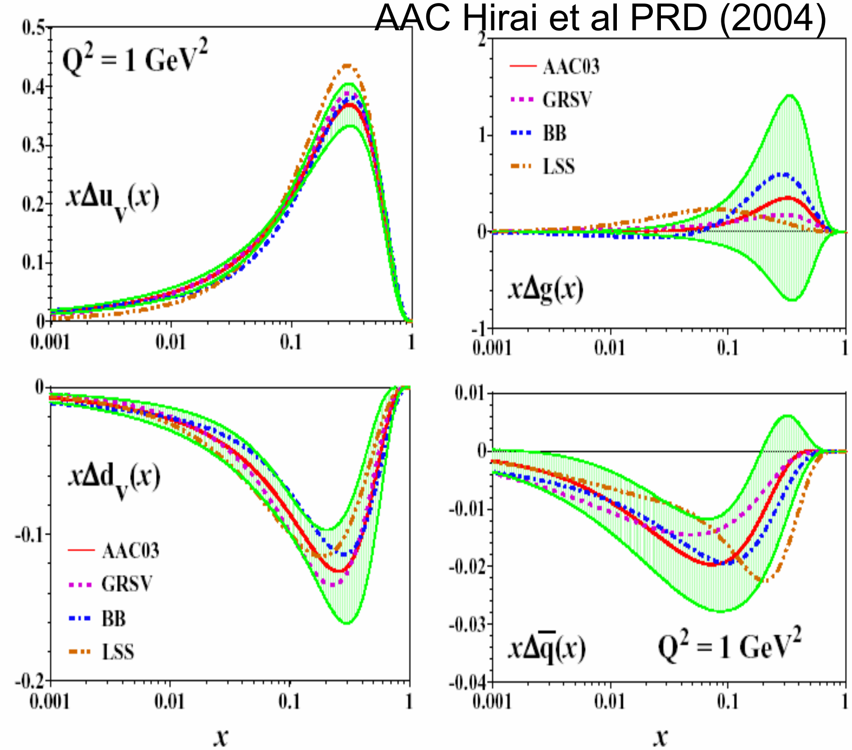
$$\frac{1}{2}_{proton} = \frac{1}{2}\Delta\Sigma + \Delta g + L_Z$$

$$\Delta\Sigma = \Delta U + \Delta D + \Delta S$$

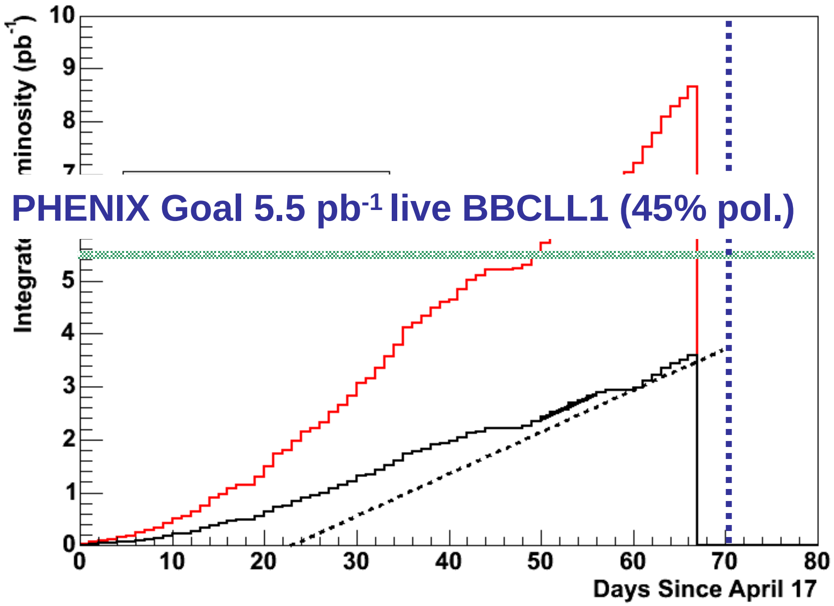
Δg : gluon polarization

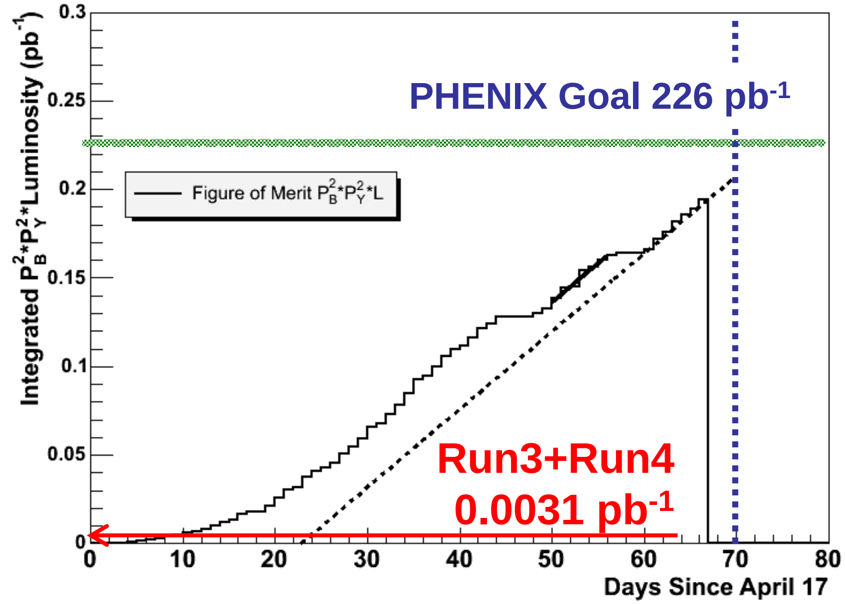
L_Z : orbital

AAC Hirai et al PRD (2004)



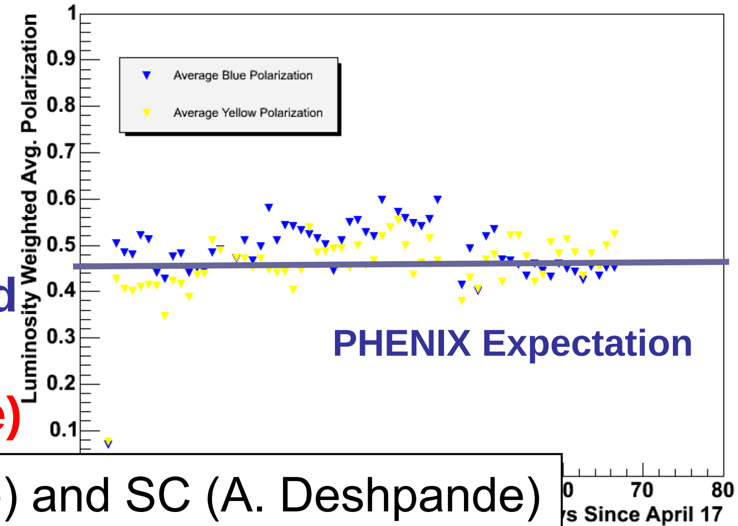
Run05 Polarized p+p Luminosity





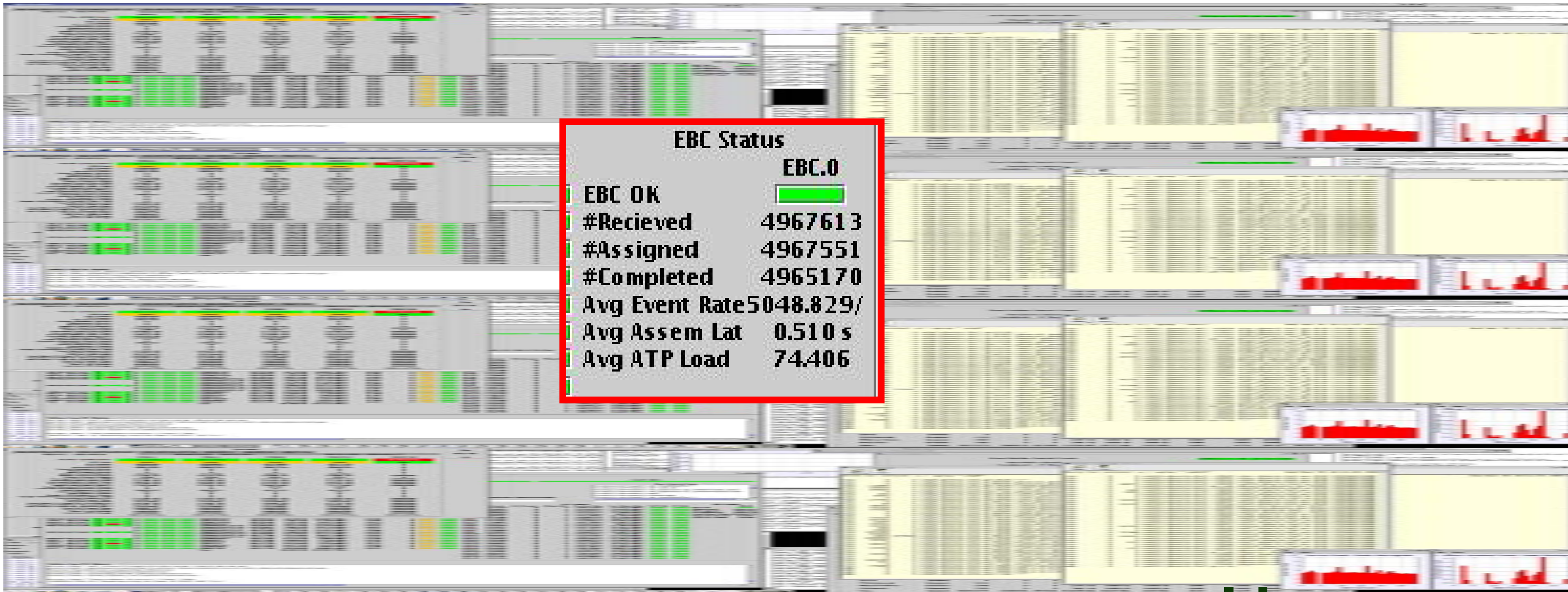
Highly Successful Polarized Run

1. 3.59 pb^{-1} live BBCLL1 (~4.0 pb-1 projected)
2. 0.194 pb^{-1} P^{4}L (~0.208 pb-1 projected)
3. 0.163 pb^{-1} 200 GeV Transverse (3 days)
4. 410 GeV Transverse Running Commissioned
   →16 hours data taking
5. 62X better FOM (~8 times better significance)



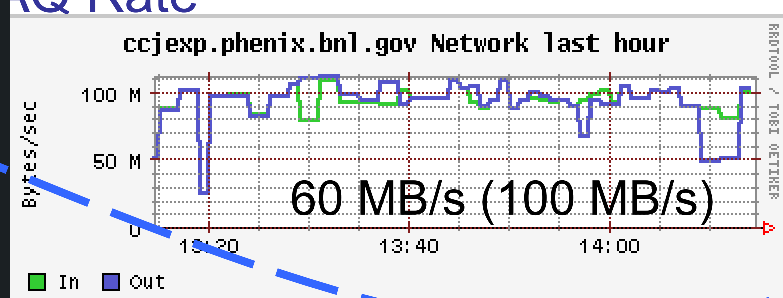
Success has a lot to do with RC (J. Lajoie) and SC (A. Deshpande)

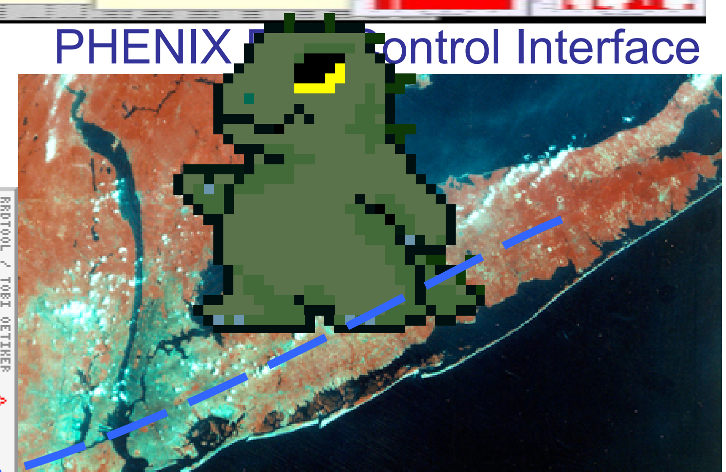
Data Collection and Processing



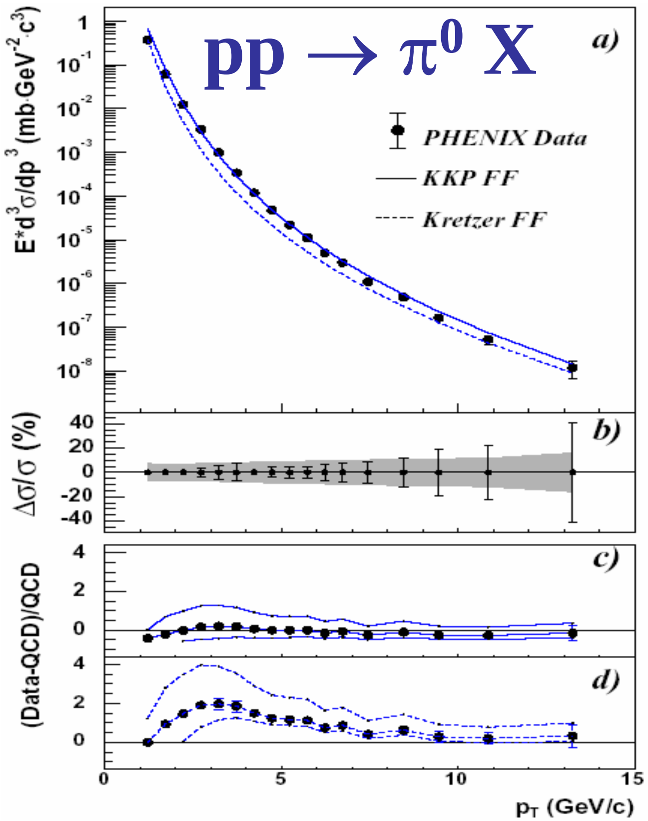
PHENIX R ontrol Interface

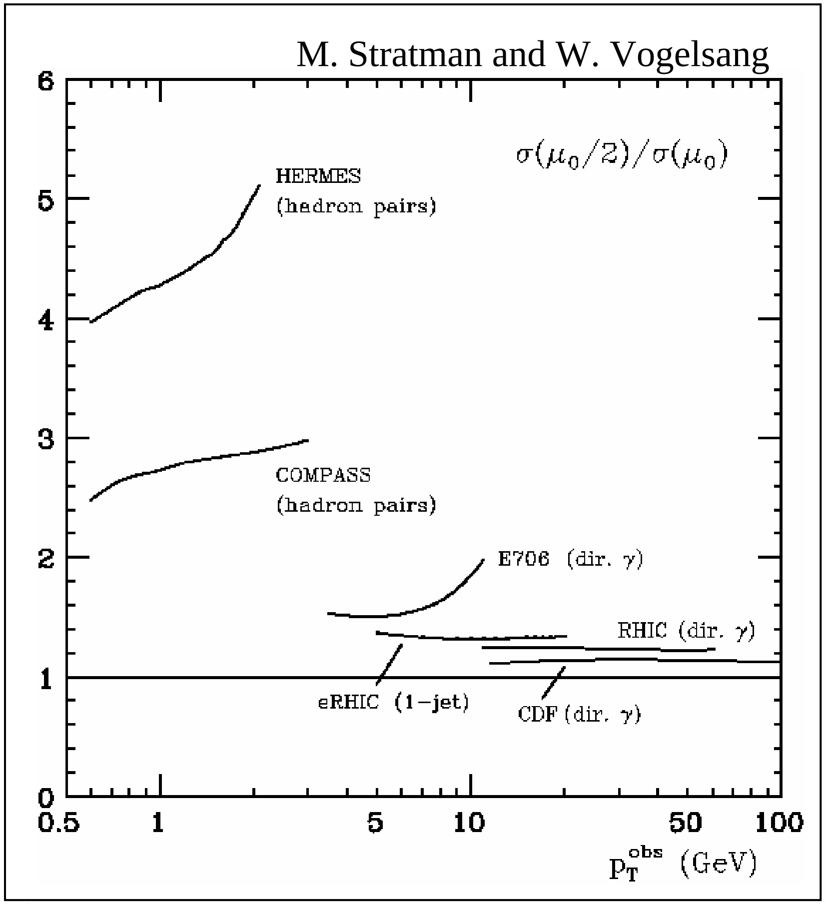
05
AQ Rate





Theory Under Control





- Measured un-polarized cross section at $\sqrt{s}$=200 GeV well described by **NLO pQCD**
- non-identified charged hadrons, η also measured (and agree well w/ NLO)

$$\Delta\sigma = \sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}$$

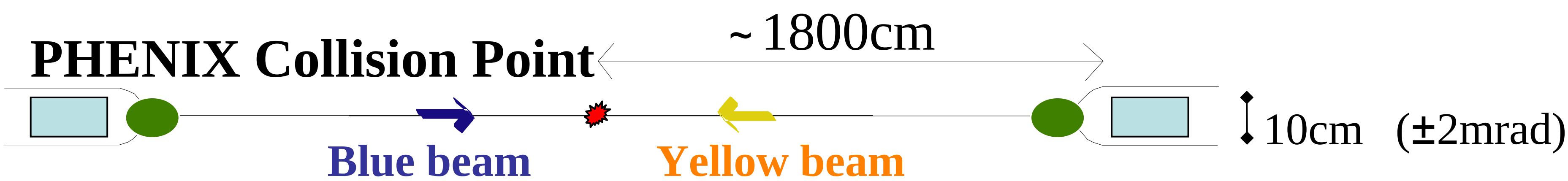
$$d\Delta\sigma = \Delta f_{a/A}(x_a) \otimes \Delta f_{b/B}(x_b) \otimes d\Delta\hat{\sigma}^{ab\to cd} \otimes D_{h/c}(z_h)$$

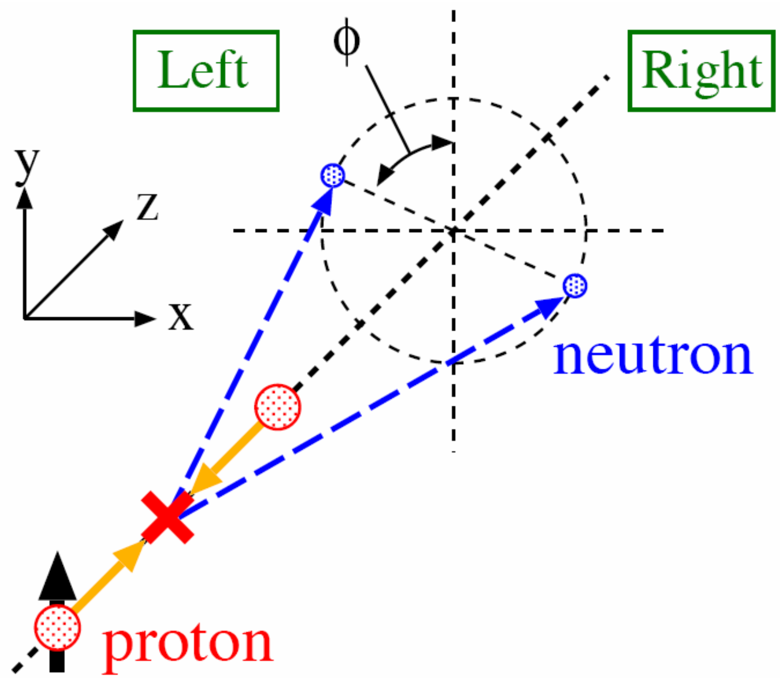
Measuring A_{LL}

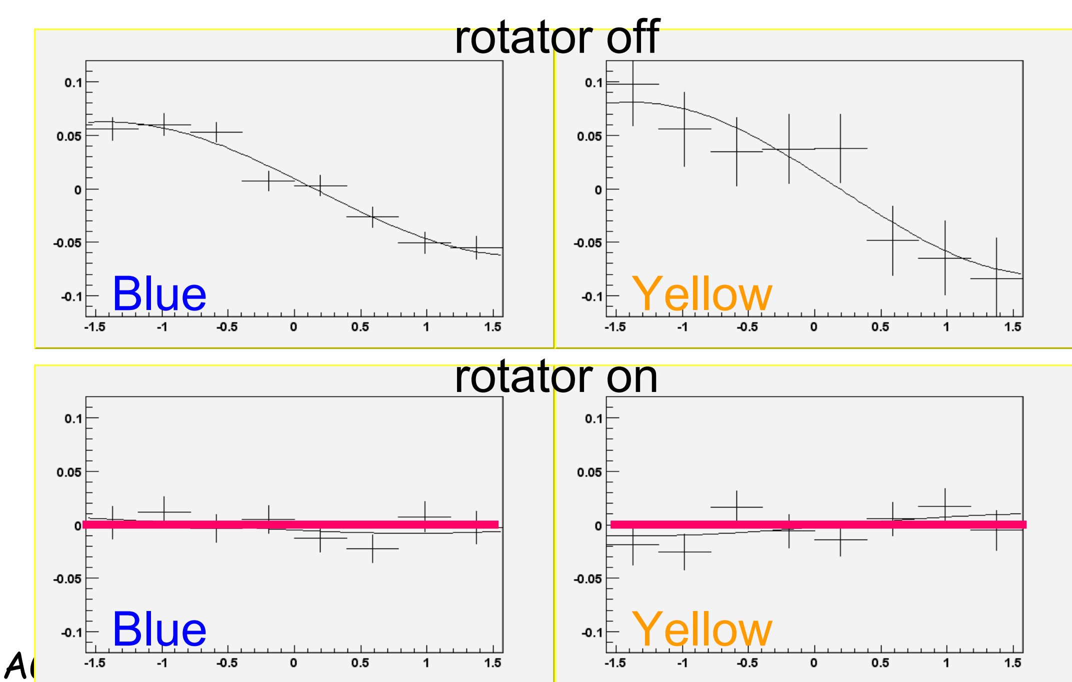
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P \cdot P} \cdot \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \text{where} R = \frac{L_{++}}{L_{+-}}$$

- Need Longitudinal Beam – spin rotator magnets
- How to verify – use a local polarimeter
    - Forward neutron asymmetry discovered by PHENIX

$P_L/P > 0.99$ blue & yellow







Relative Luminosity

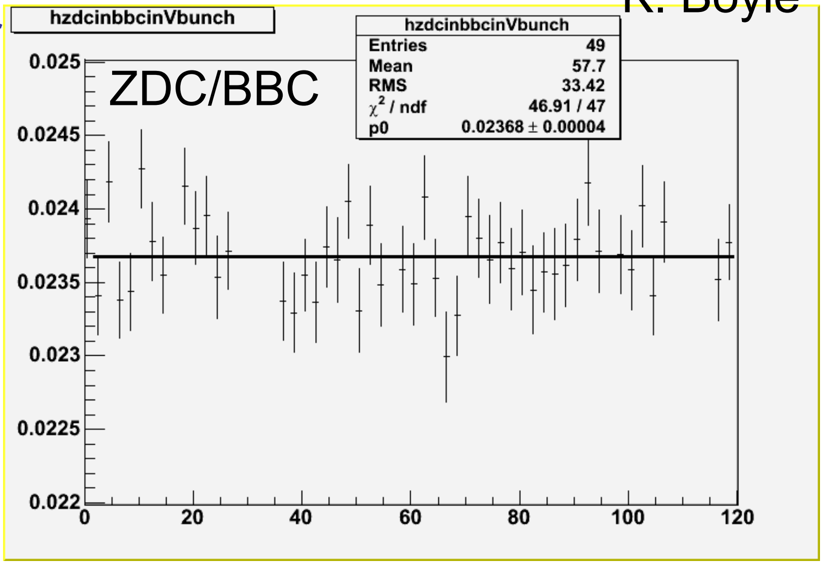
K. Boyle

- Relative Luminosity important source of error

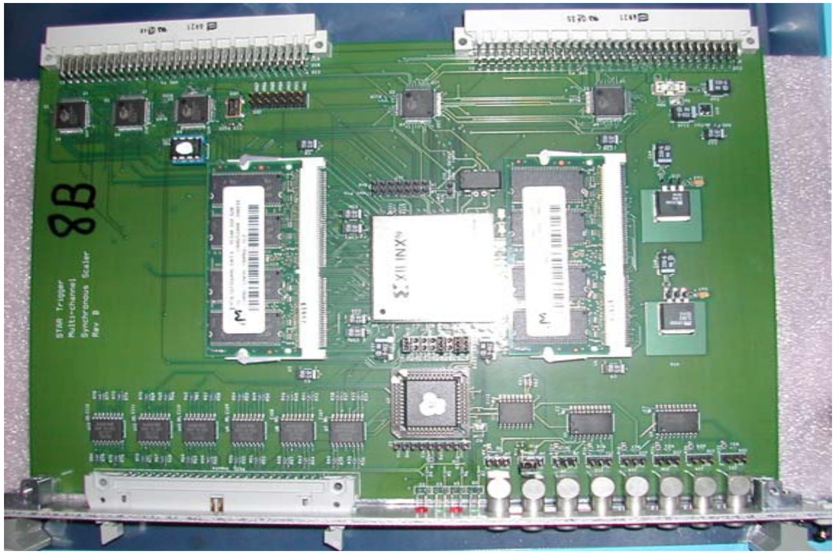
$$\delta A_{LL} \sim \frac{\delta R}{2 P_B P_Y}$$

- Use BBC Counts to measure R
  - high statistics (ε ~ 51%)
  - low background
- Use ZDC as a cross-check
  - different systematics and kinematics
  - achieved high precision in Run03/04:

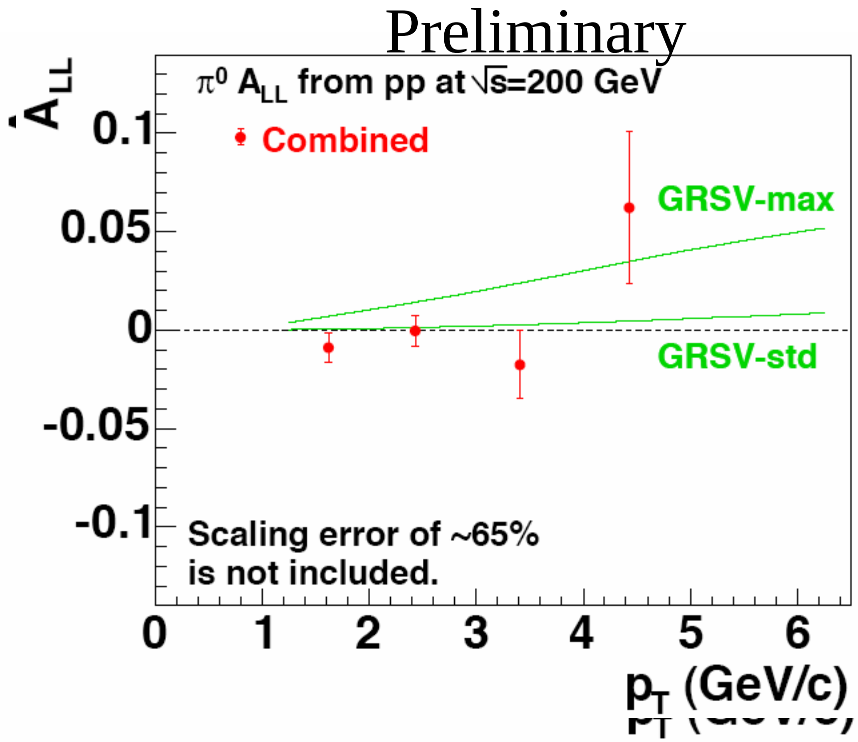
δR = δ(L++/L+-) < 2.5 x 10^{-4}



- STAR Scaler Boards Commissioned
  - 25 inputs (24 ch + RHIC CLK)
  - 80 MB Histogram Memory
  - Zero Suppression
  - Coarse and Vernier Delay Registers
  - Streaming Mode
  - Prepared for high luminosity
    - Greater variety of Relative Luminosity Monitors available



Comparison with theory



- GRSV-std: best fit to DIS data

$$\int_0^1 \Delta G(x)dx \sim \ 0.7 \text{ at } Q^2 \ 1 \text{ GeV}^2$$

- GRSV-max

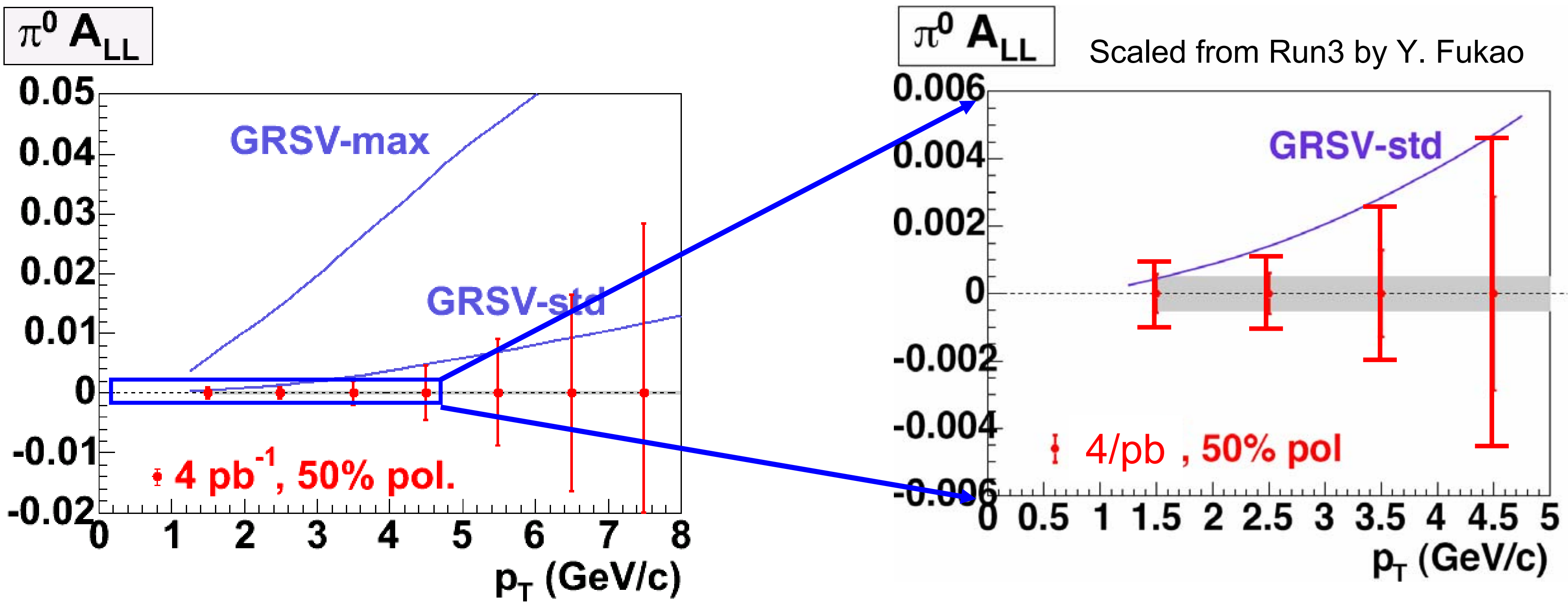
$$\Delta G(x) = G(x) \text{ at } Q^2_{\text{input}} = \ 0.40 \text{ GeV}^2$$

- Data prefers the GRSV-std curve (and hence the gluon distribution and its first moment)
  - B. Jaeger et al. Phys. Rev. D67, 054005 (2003)

Confidence Levels

	GRSV-std	GRSV-max
4 points (1-5 GeV/c)	21-24%	0.00-6%
3 points (2-5 GeV/c)	27-29%	0.01-13%

π^0 A_{LL} Expectations from Run05

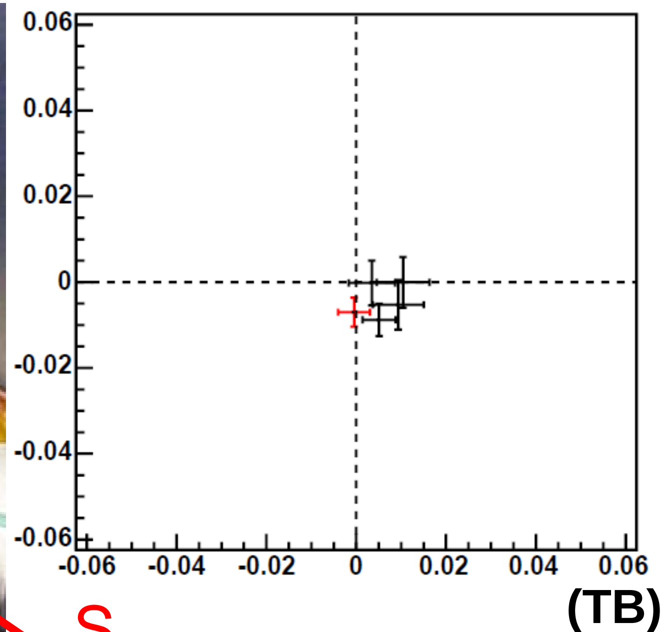


Run03+Run04
distinguished between GRSV-max and GRSV-std

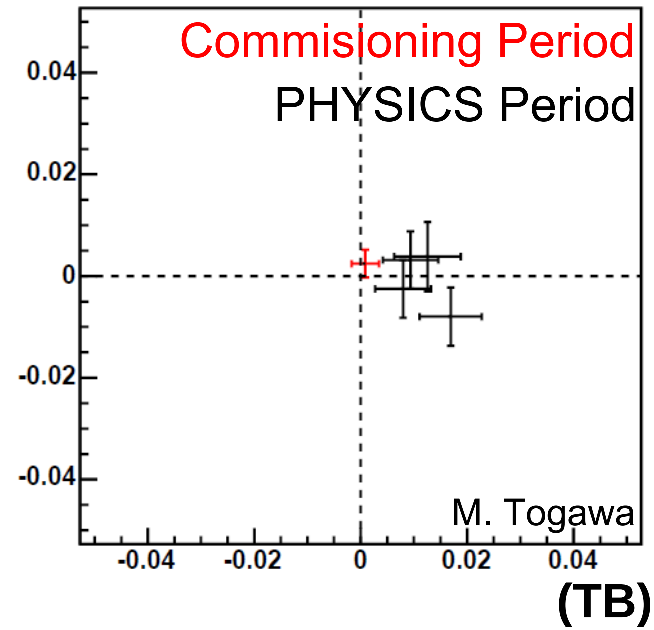
Run05
will distinguish between GRSV-std and $\Delta G = 0$ (or GRSV-min).

Radial component in Run05?

(LR) **BLUE (A_N = 6.24%)**



(LR) **YELLOW (A_N = 5.27%)**



Blue : 10.3% ± 3.9%

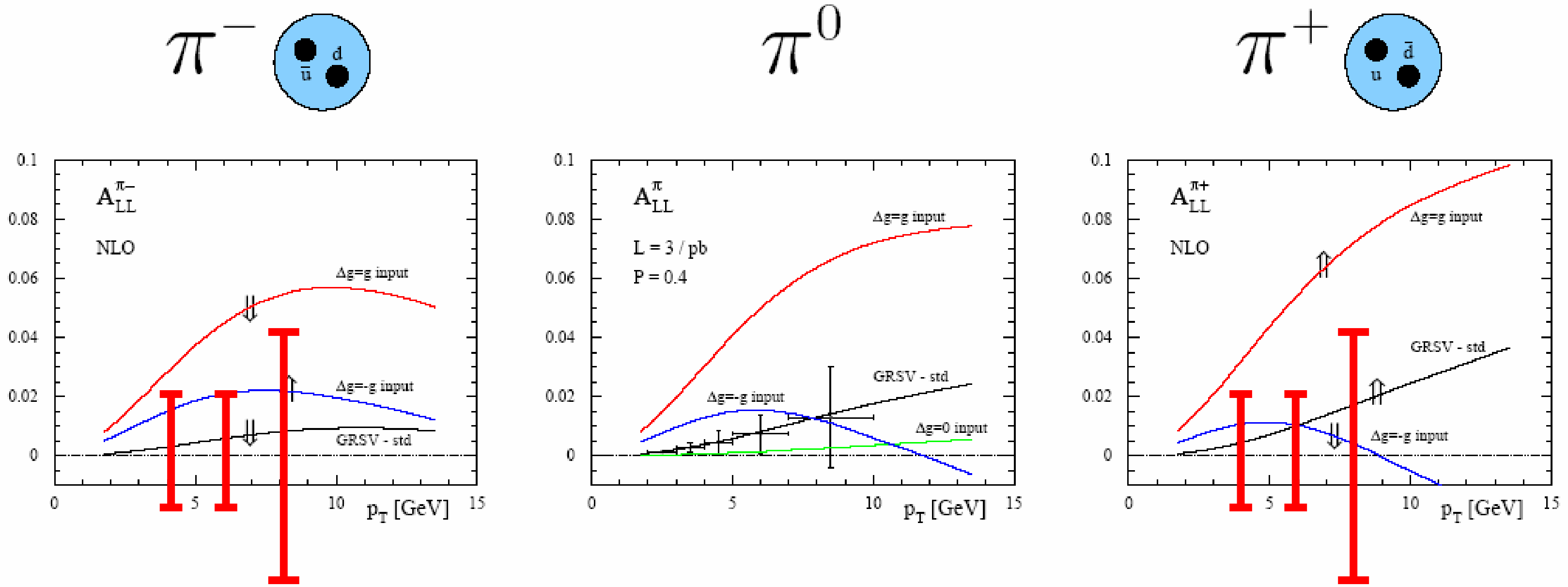
Yellow : 21.5% ± 5.3%

- Transverse component seems to systematically have a radial component
- Vertical component seems ~ 0.

$$A_{raw} \sim pol_L^2 \cdot A_{LL} + pol_T^2 \cdot A_{TT} \sim Pol^2 \left(\boxed{A_{LL} + \frac{pol_T^2}{Pol^2} \cdot A_{TT}} \right) \quad = \mathbf{A}$$

$\pi^{\pm}$ A_{LL}

Stratmann Lecture, BNL 1st Spin School

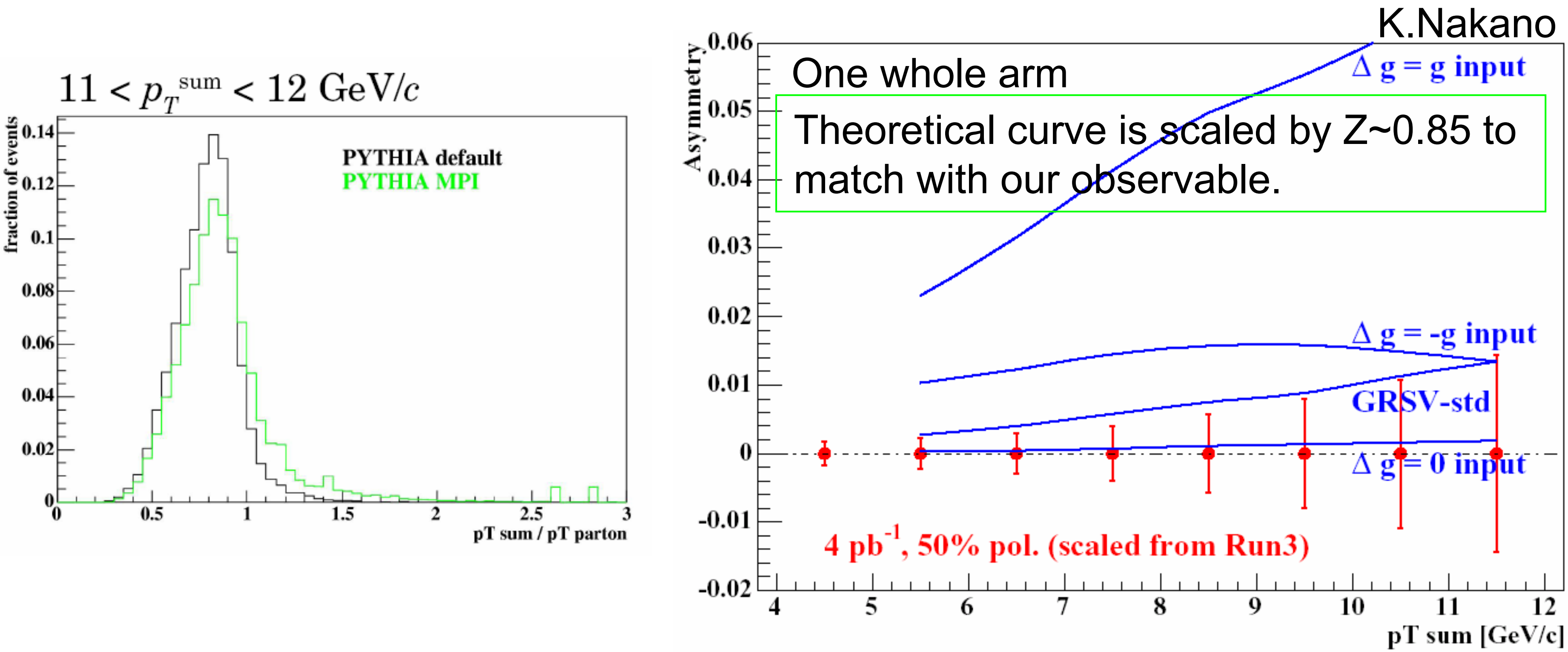


idea: qg starts to dominate for $p_T \gtrsim 5\,\mathrm{GeV}$ and $D_u^{\pi^+} > D_u^{\pi^0} > D_u^{\pi^-}$, $D_g^{\pi^+} = D_g^{\pi^-}$

expect: sensitivity to sign of Δg, e.g., positive Δg: $A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$

- 5-15 GeV $\pi\pm$ identified by RICH and EMC hadronic shower
- Not yet possible to determine sign of Δg

A_{LL} of Jet?



Even with a limited acceptance in PHENIX central arm, we can capture most of a Jet.
→ Tag one photon, sum all energy in one arm.

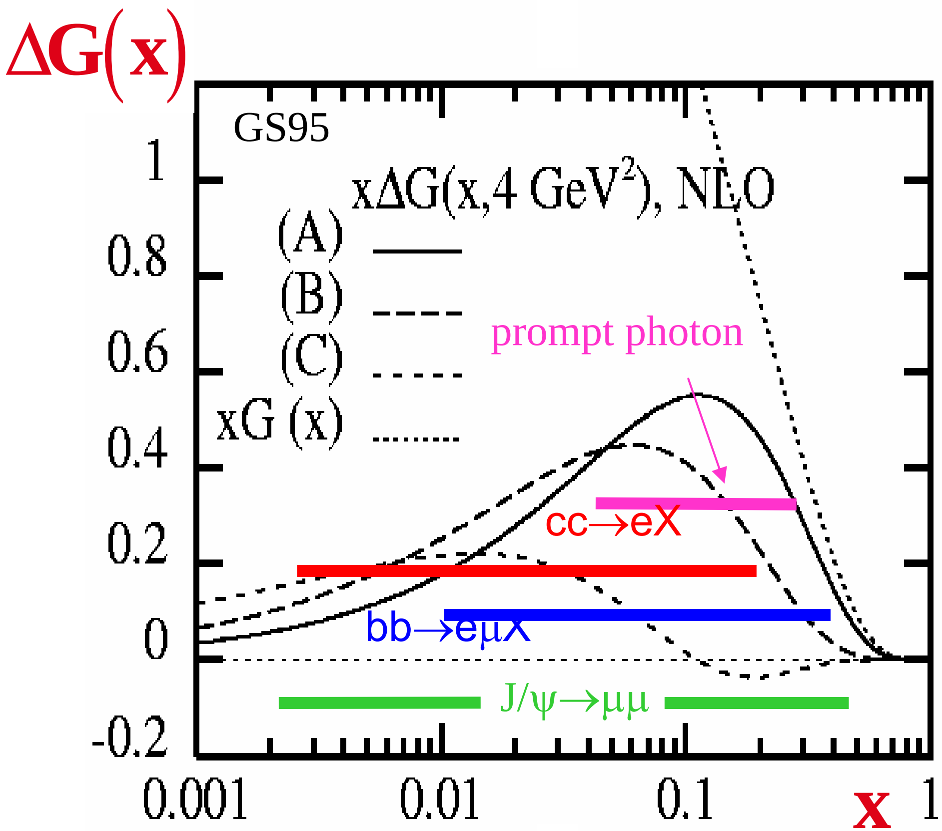
Question :

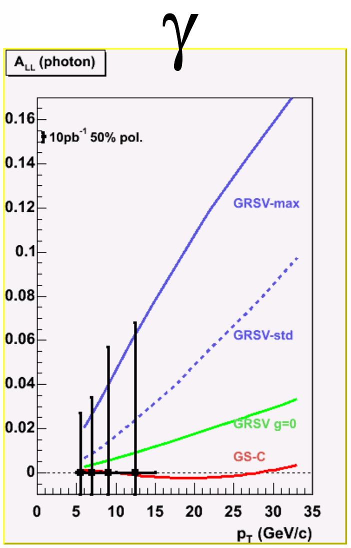
1. Are those really jets? (agreement much worse at low p_T)
2. How much fraction (Z) do we catch? How much is its ambiguity (ΔZ)?

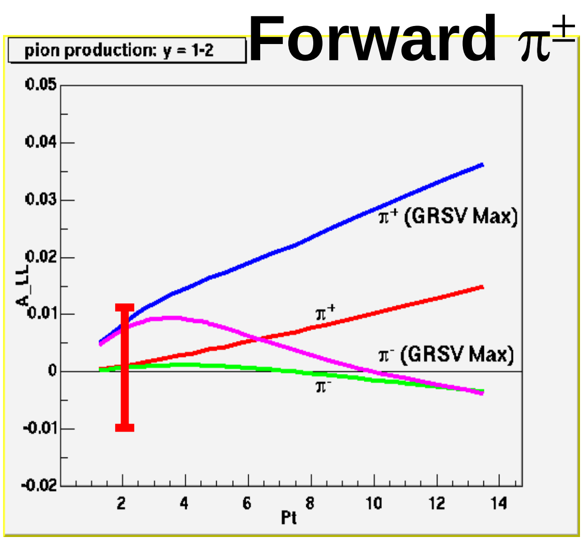
Compared to pi0:

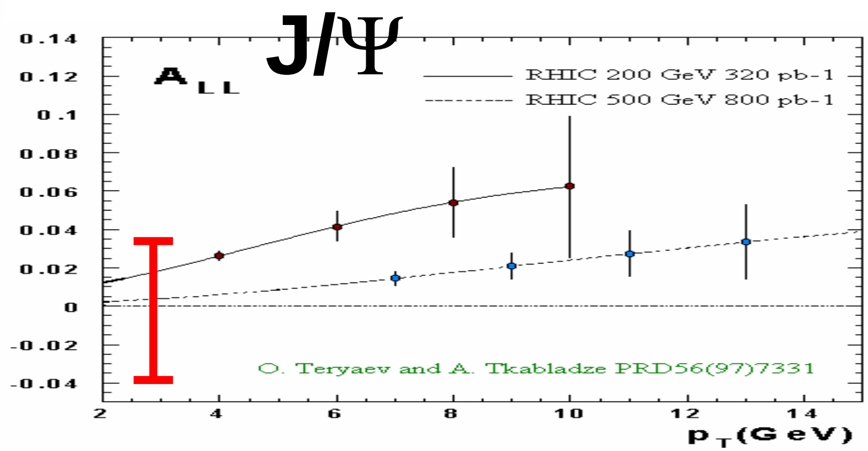
— More statistics, but Systematic uncertainty in interpretation

Panoply of Processes in PHENIX









- Important to measure a variety of processes
  - reduce exp. and th. systematics
  - extend x coverage
- At least another order of magnitude needed…

PHENIX Spin Fest at RIKEN Wako

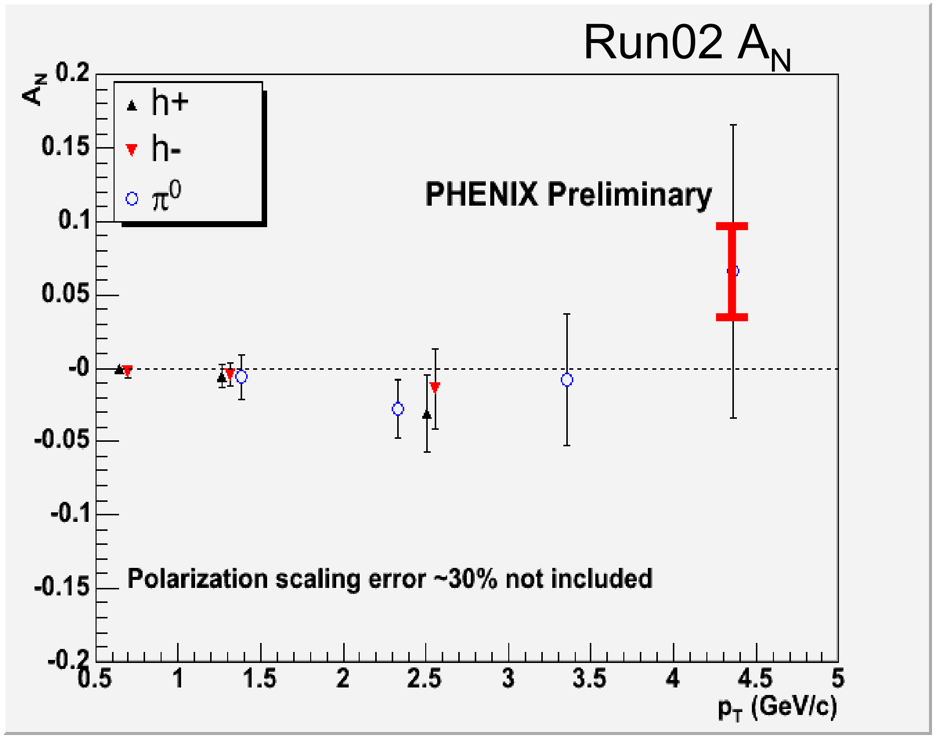
- π^0
  - Sasha, Kieran, Yoshi, Dave, …
- direct γ
  - Kensuke, Robert, Kenichi, Sasha, Takuma, Dave, …
- η
  - Frank, Joe, …
- $h^\pm/\pi^\pm$
  - Kieran, …
- jet
  - Kenichi, …
- $e^\pm$
  - Manabu, …
- J/Ψ
  - Ming, Imran, …
- Λ
  - Ran, …
- A_N, A_{TT}
  - Hiro, Mickey, …

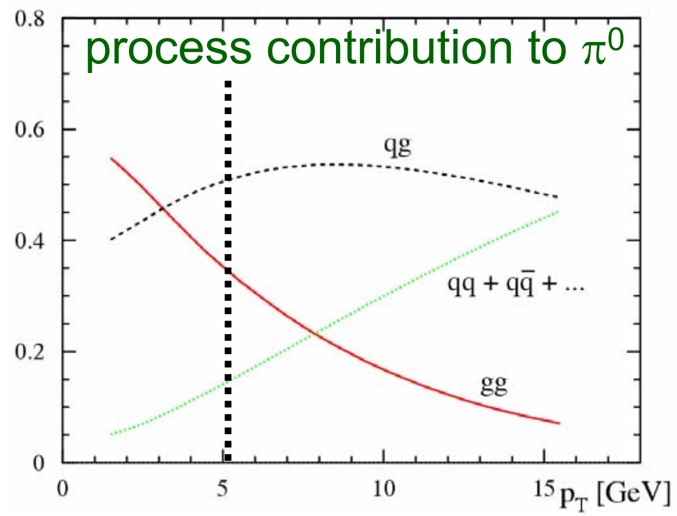
▲Wako Main Campus・Wako Institute

•Goal: to make the most efficient use of the nice data we have just taken
- •Get all experts together with the data to calibrate, produce, and analyze
- •Share expertise and knowledge amongst PHENIX collaborators
- •Get results out to the community in a timely manner

Single Spin Asymmetry of π^0 and Non-Identified Charged Hadrons at $x_F \sim 0$ vs p_T

A_N for both charged hadrons and neutral pions consistent with zero at midrapidity.

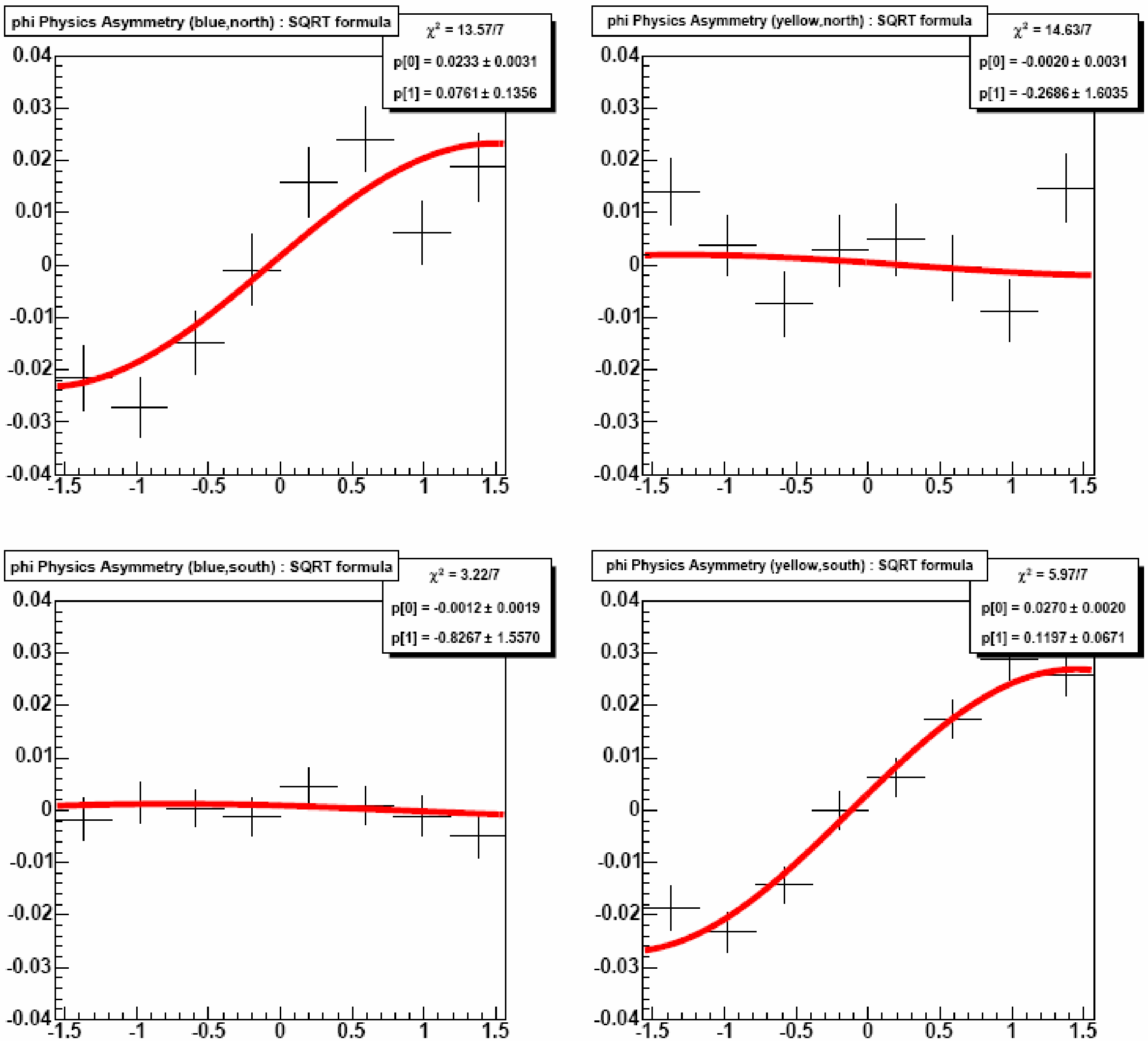




More statistics needed to map out $p_T \leftrightarrow x \leftrightarrow g/q$ dependence

- Run02: 0.15 pb^{-1} and 15 % polarization
- Run05: 0.16 pb^{-1} and 50% polarization
  - ~3X better statistical significance

410 GeV Transverse Polarization



M. Togawa

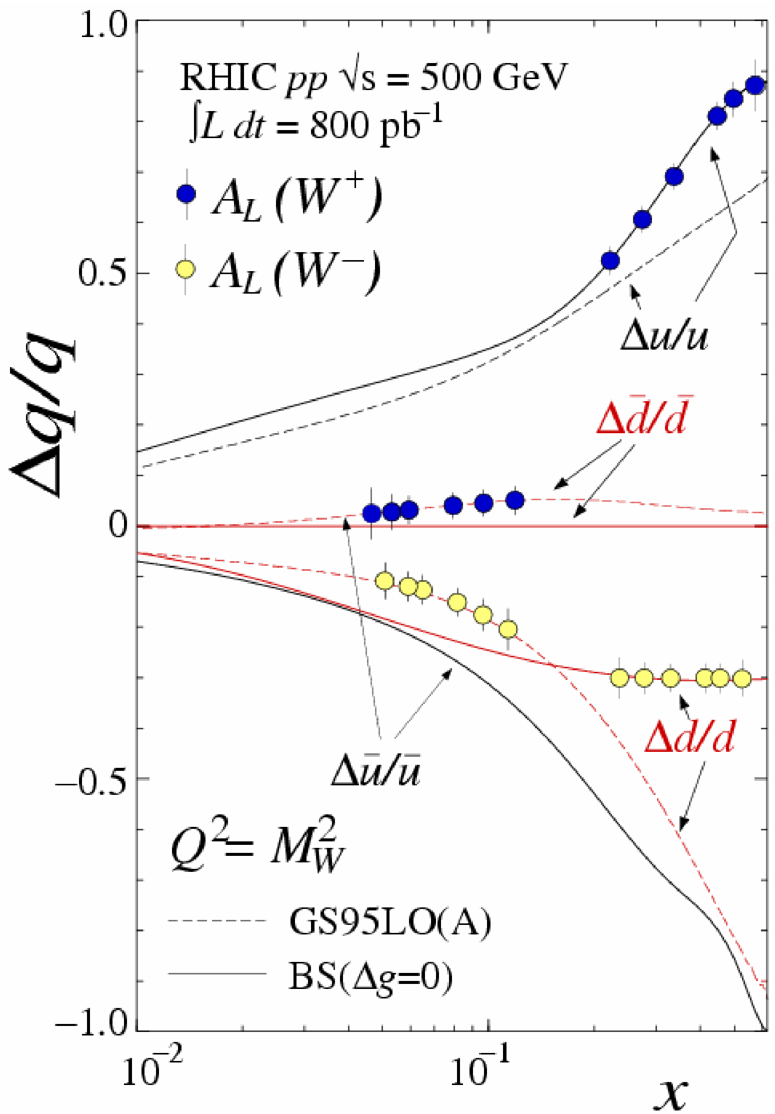
Polarization

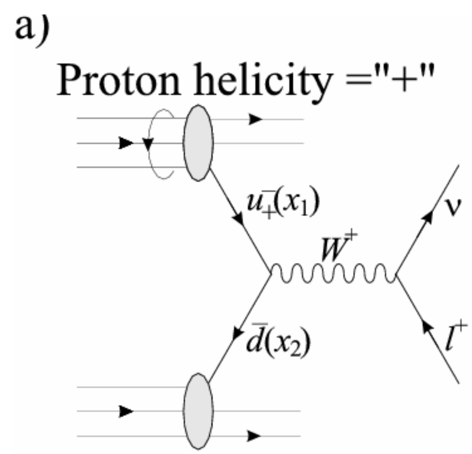
blue : ~33%

yellow : ~49%

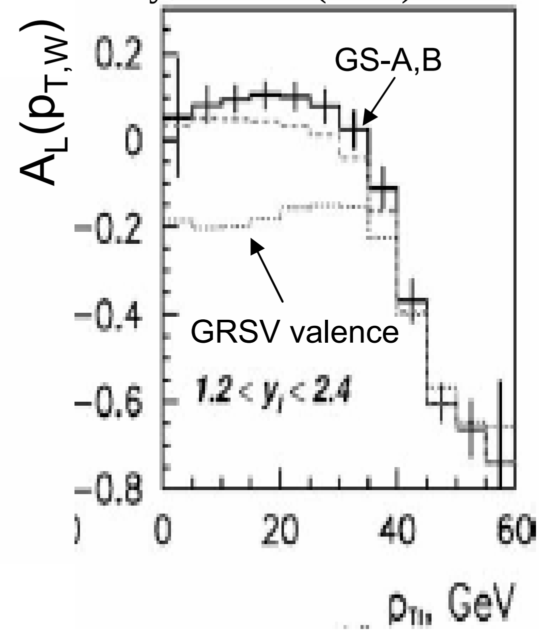
- Analyzing power of PHENIX Local Polarimeter roughly the same despite doubling of energy
  - Local Polarimeter can be used at higher $\sqrt{s}$
- Demonstrates that RHIC is capable of accelerating to higher $\sqrt{s}$ without losing all polarization
- Will provide first look at A_N for higher $\sqrt{s}$

$\Delta q/q$ via $W^{\pm} \rightarrow \mu^{\pm}\nu$





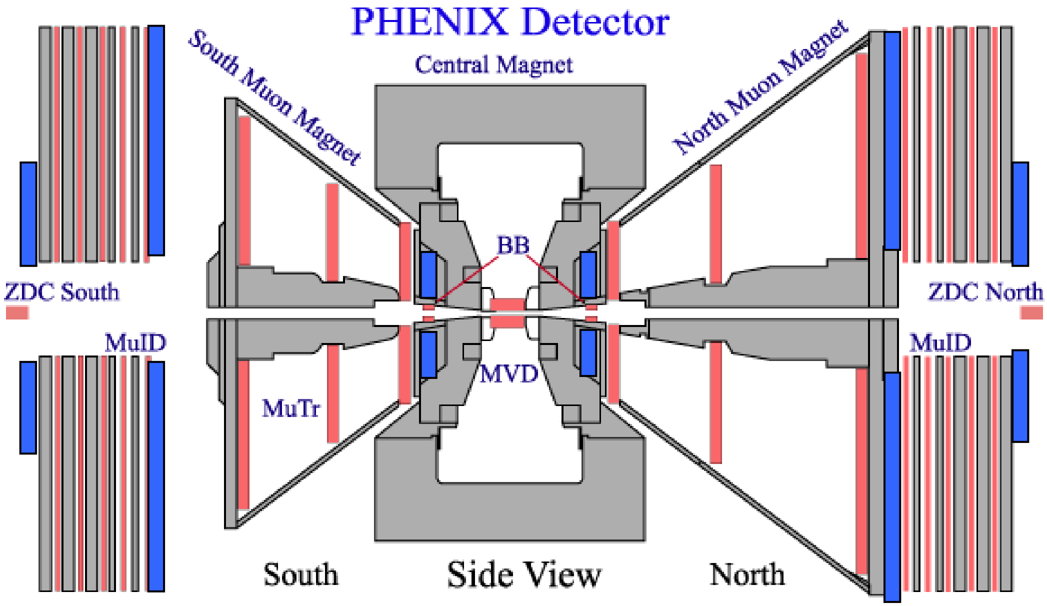
Nuclear Physics B666(2003)31-55



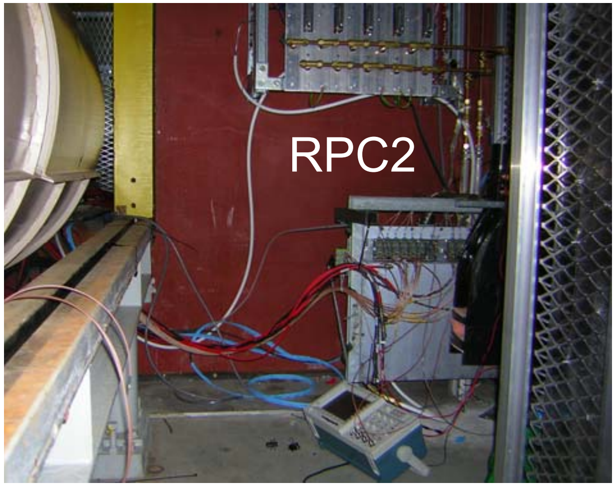
$$A_L^{W^+}(y) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

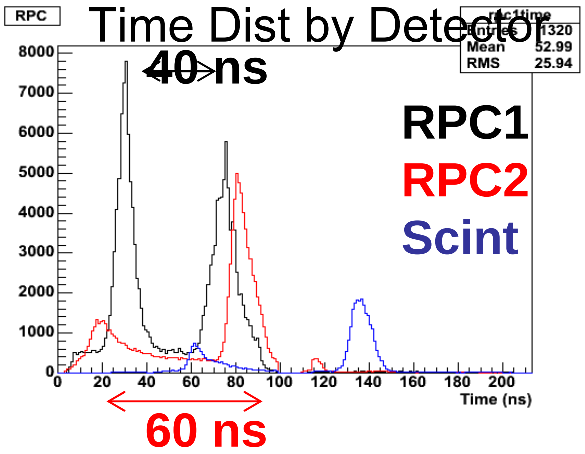
- At $\sqrt{s}$=500 GeV, high rates from heavy flavor and jets overwhelm existing muon trigger
- Requires Muon Trigger Upgrade

W→μν Trigger Upgrade



Trigger RPC Locations





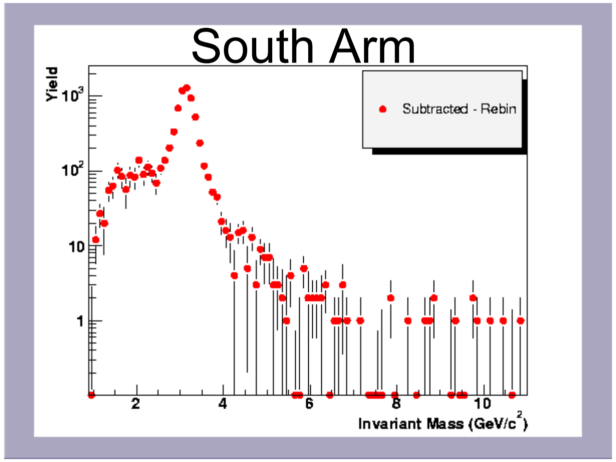
- Resistive Plate Chamber technology chosen by PHENIX
  - Cheap – wide coverage possible
  - Can leverage existing RPC R&D from CMS
  - Timing information
    - reject beam backgrounds
    - track association with correct bunch
  - 3-dim space point for enhanced pattern recognition
- Two small prototypes successfully tested in Run05
- Recently approved NSF-MRI – 1st Arm in Run08, 2nd Arm in Run09

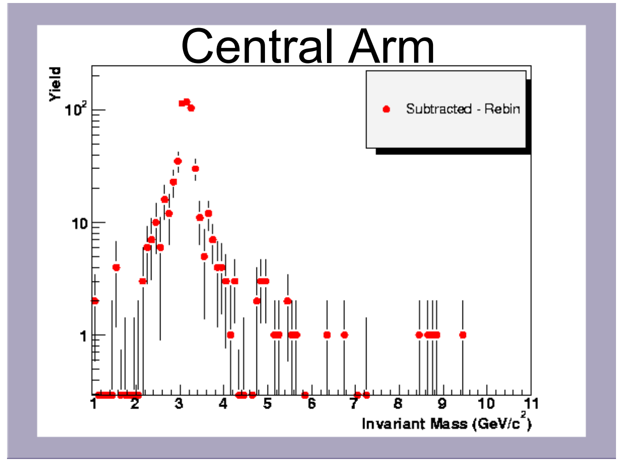
Summary

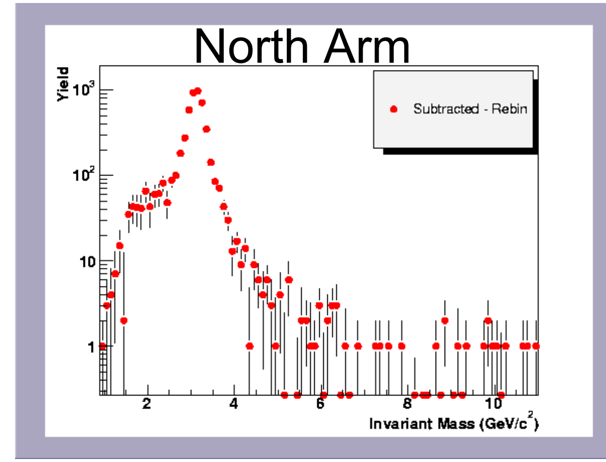
- Successful runs enable PHENIX to have a very rich program of spin physics
    - Run03+Run04 has already provided strong constraints on Δg
    - Run05 will provide ~8.5 times the statistical significance
        - Separation from $\Delta g = 0$
- First looks at many other processes
- Longitudinal Spin Physics
    - π^0, η, γ, $h^{\pm}$, $\pi^{\pm}$, J/Ψ, Λ, Λbar, μ, e
- Transverse Spin Physics (Single Spin Asymmetries)
    - A_N for π^0, $h^{\pm}$
    - Correlations
        - Sivers vs Collins vs Higher Twist
        - Orbital Angular Momentum?
- RHIC is clearly becoming the world leader in QCD Spin Physics

Backup Slides

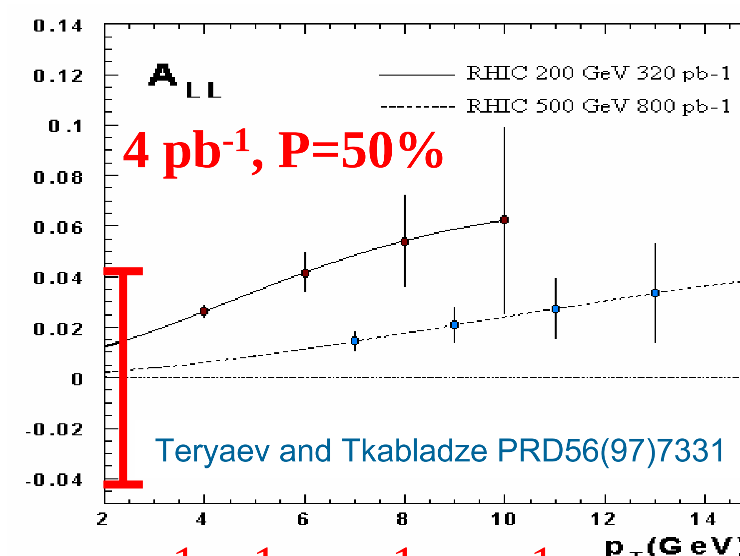
J/Ψ A_{LL}







- Online Reconstruction of J/Ψ from Lvl-2 Triggered Data
- First crude look at J/Ψ from Run05

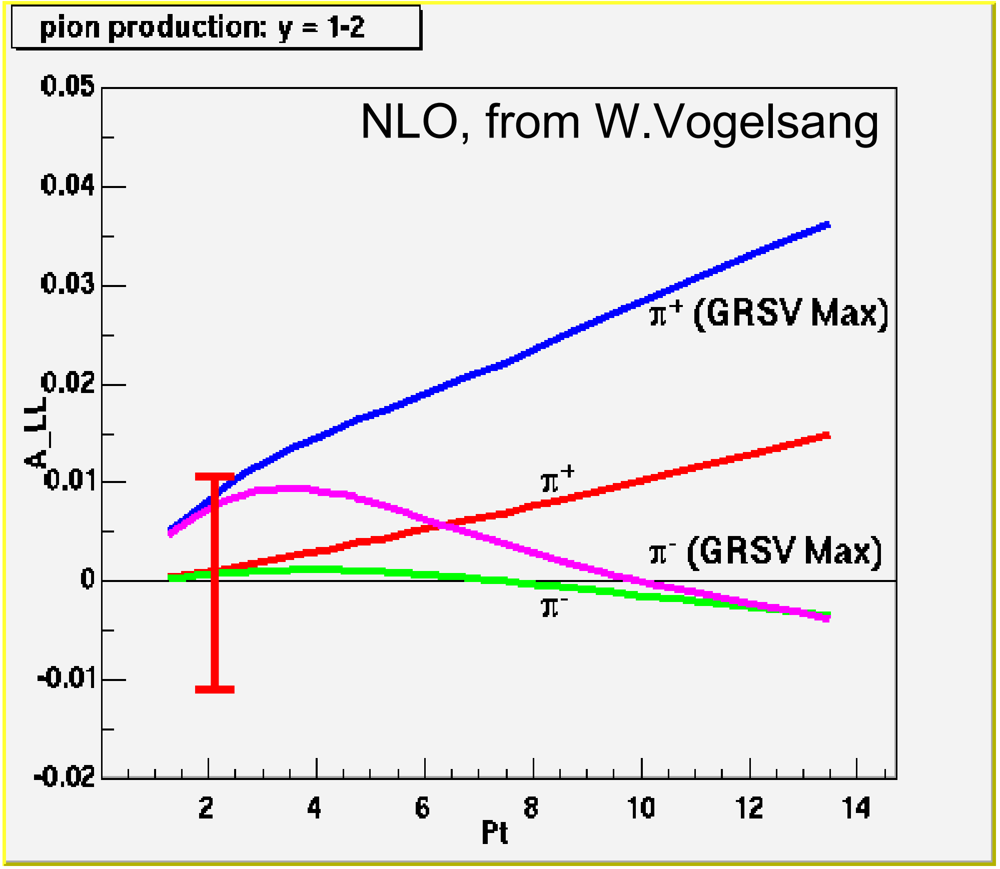


$$\Delta A_{LL}(J/\Psi) = \frac{1}{p^2}\frac{1}{\sqrt{N}} \sim \frac{1}{0.5^2}\frac{1}{\sqrt{10{,}000}} = 4\%$$

$\pi^{\pm}$ A_{LL} in forward rapidity

- Inclusive muon measurements
  - π,K decays
  - Heavy quark decays
- Muons from π decay
  - momentum dep.
  - 3 GeV pions, 0.3%
- π punch through
  - Tagged by stopping in MUID gap
- Statistics: ΔA_LL from run05
  - Pt = 1 -> 0.1%
  - Pt = 2 -> 1%
  - Pt = 4 -> 10%

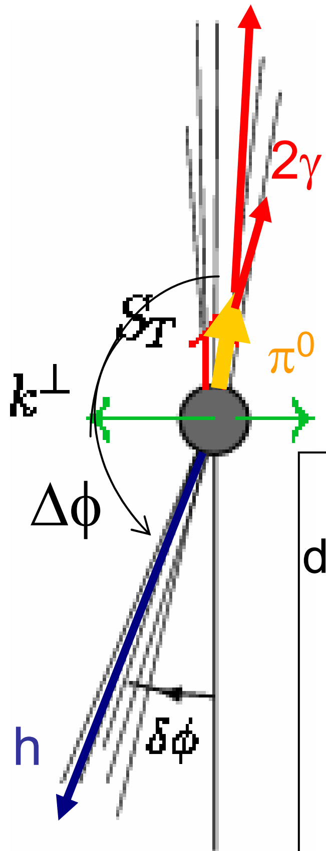
M. Liu et al

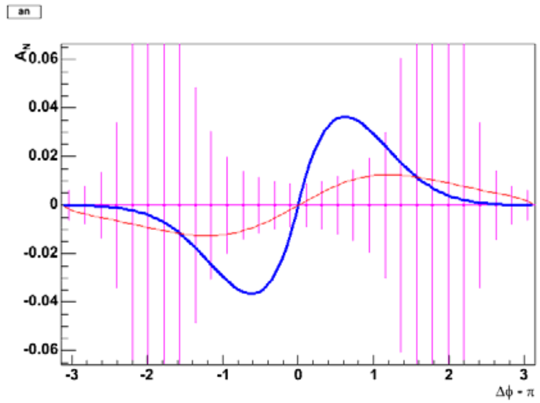


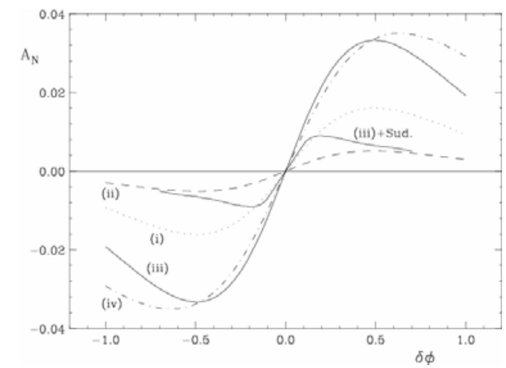
Correlation Analyses

Sivers di-Hadron Analysis

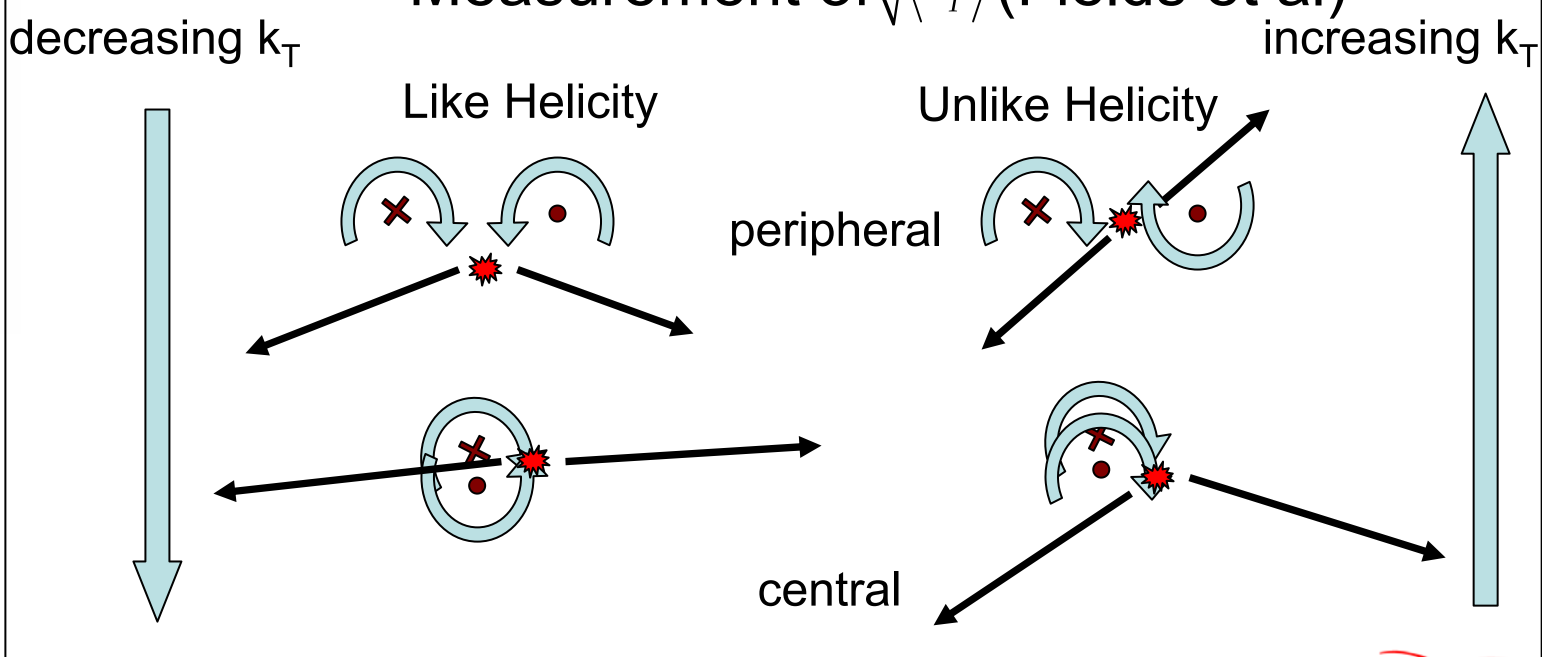
Boer and Vogelsang, Phys.Rev.D69:094025,2004, hep-ph/0312320



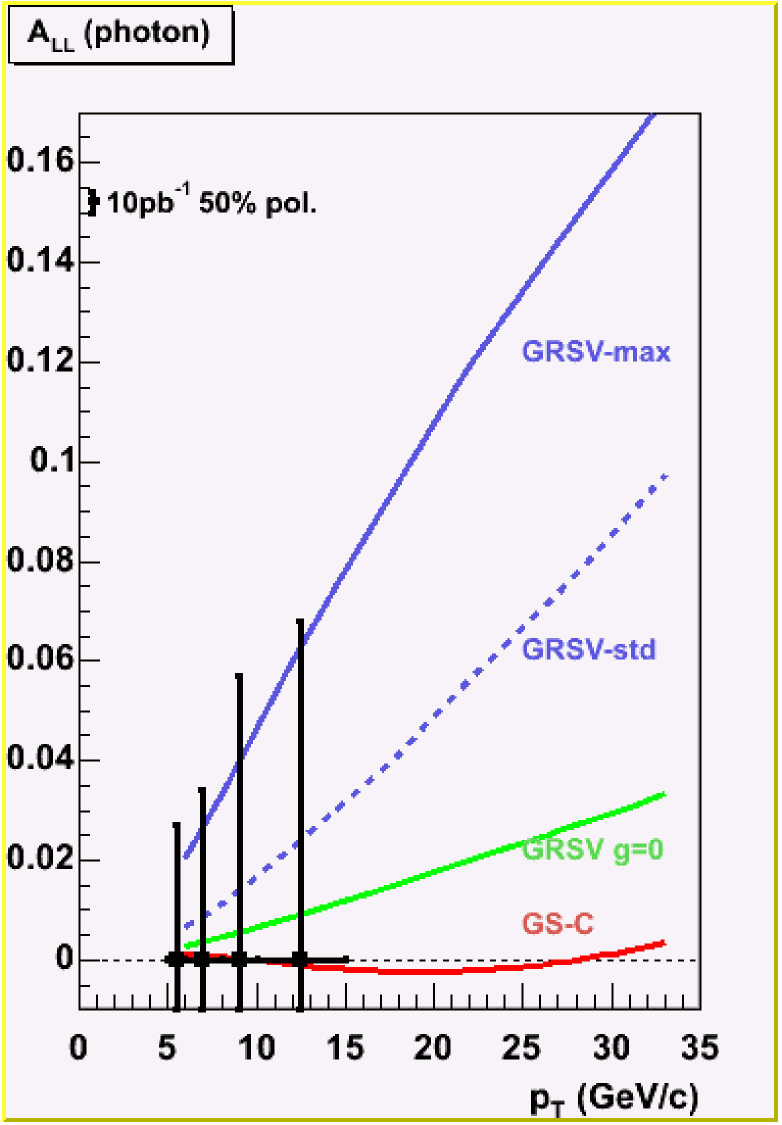




Measurement of $\sqrt{\langle k_T^2 \rangle}$ (Fields et al)



Direct photon A_{LL} estimation

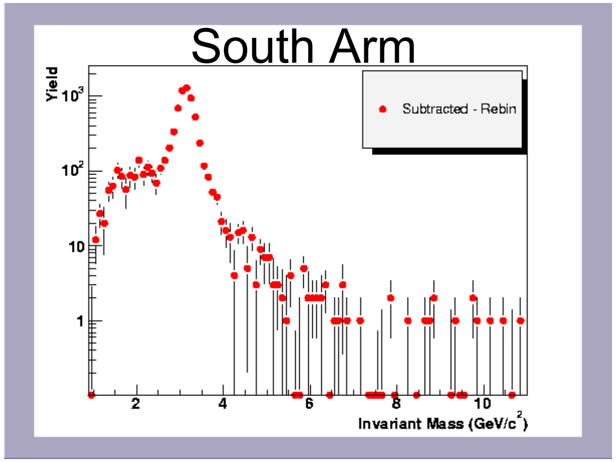


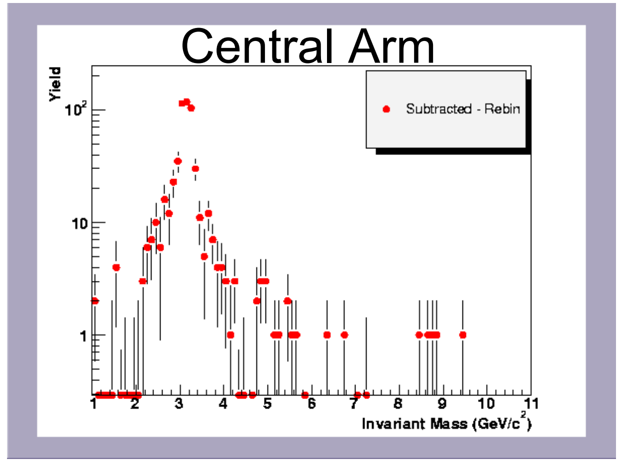
dA_{LL}_signal= D * dA_{LL}_allphoton
D: dilution factor (=all/signal)

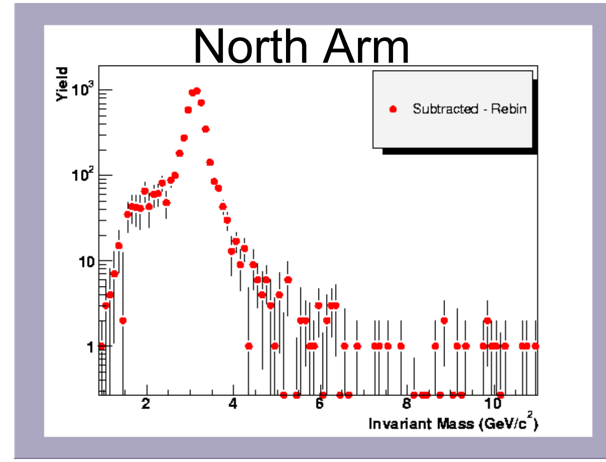
At $10pb^{-1}$ 50% pol
dA_{LL}_allphoton=
$1/0.5^2 * 1/\mathrm{sqrt}(N_{run3\_west} * 2 * 10/0.225)$

pt_range :	All_photon :	Signal :	dALL_signal
5-6	1408	596.16	0.027
6-8	660	322.68	0.034
8-10	121	81.77	0.057
10-15	51	44.48	0.068

J/Ψ A_{LL}







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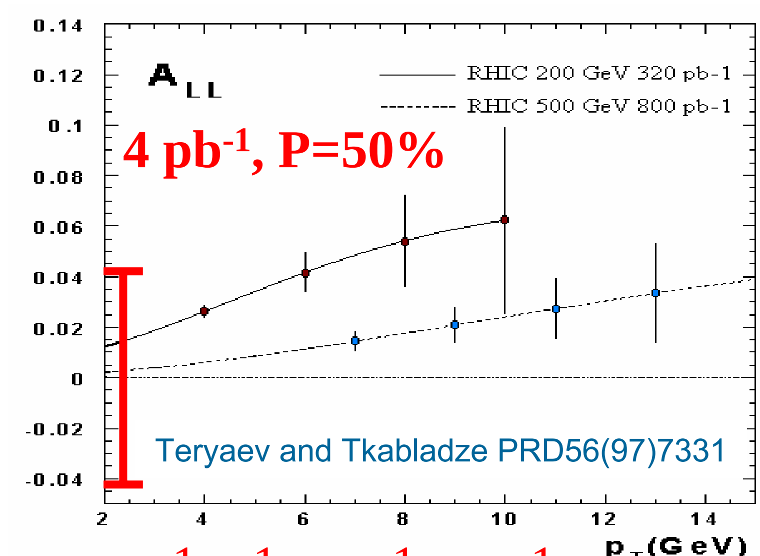
- First crude look at J/Ψ from Run05



$$\Delta A_{LL}(J/\Psi) = \frac{1}{p^2}\frac{1}{\sqrt{N}} \sim \frac{1}{0.5^2}\frac{1}{\sqrt{10,000}} = 4\%$$

$\pi^{\pm}$ A_{LL} in forward rapidity

- Inclusive muon measurements
  - π,K decays
  - Heavy quark decays
- Muons from π decay
  - momentum dep.
  - 3 GeV pions, 0.3%
- π punch through
  - Tagged by stopping in MUID gap
- Statistics: ΔA_LL from run05
  - Pt = 1 -> 0.1%
  - Pt = 2 -> 1%
  - Pt = 4 -> 10%

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