The overview of the spin physics at RHIC-PHENIX experiment

Yoshinori Fukao
for the PHENIX collaboration

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*as of March 2005

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  - Gluon polarization in proton
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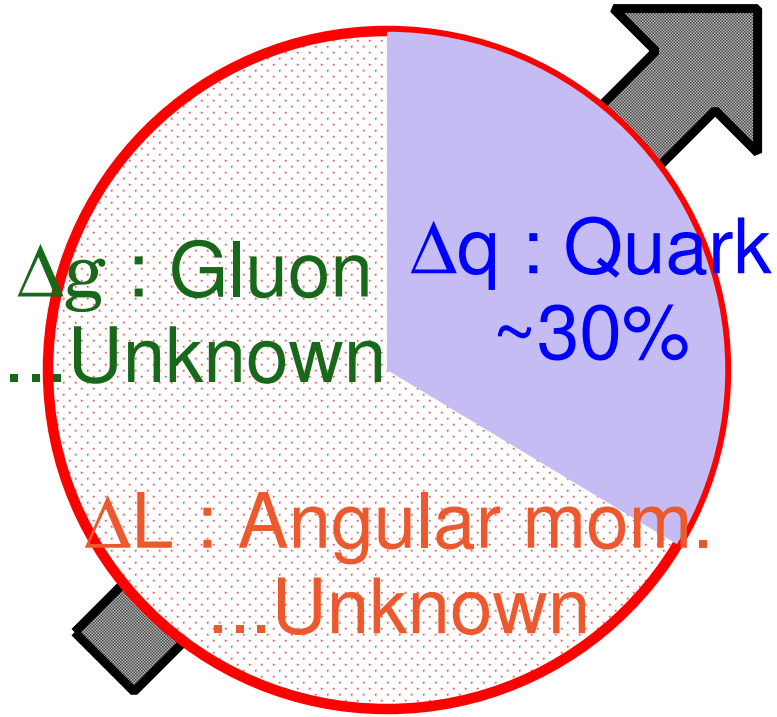
  - Direct photon
  - "Jet"
  - Charged hadrons
  - Other topics

> PHENIX in the future

> Summary

Spin Physics at RHIC-PHENIX
How much does gluon spin align to proton spin

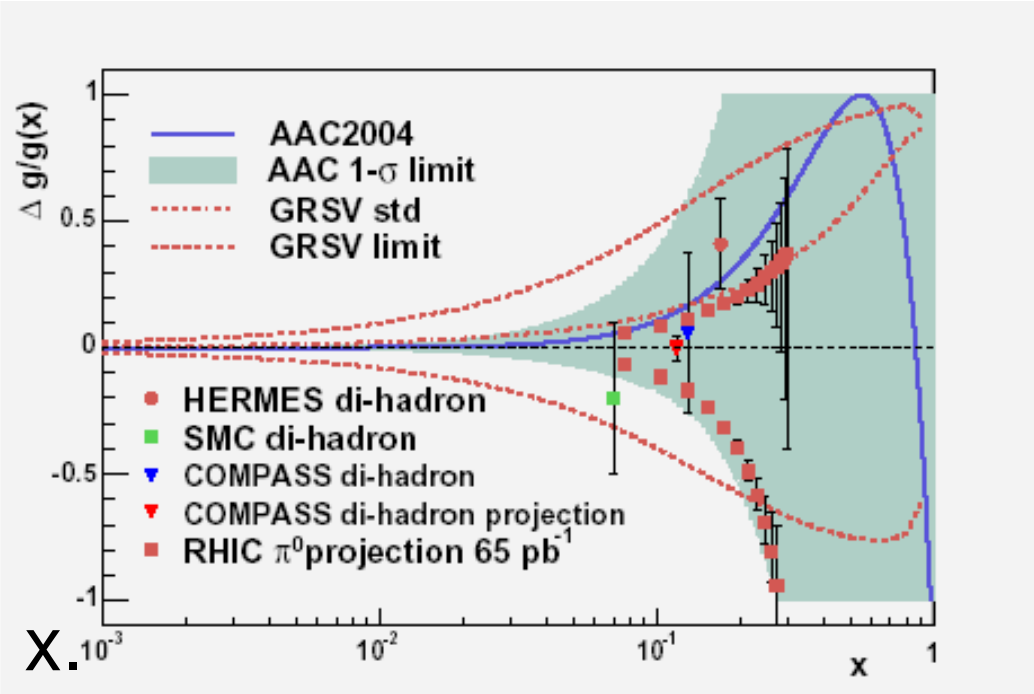


Proton structure, especially spin structure, is still unknown.

Shine a light on the gluon polarization Δg

$$\Delta g(x) = g_+^+(x) - g_+^-(x)$$

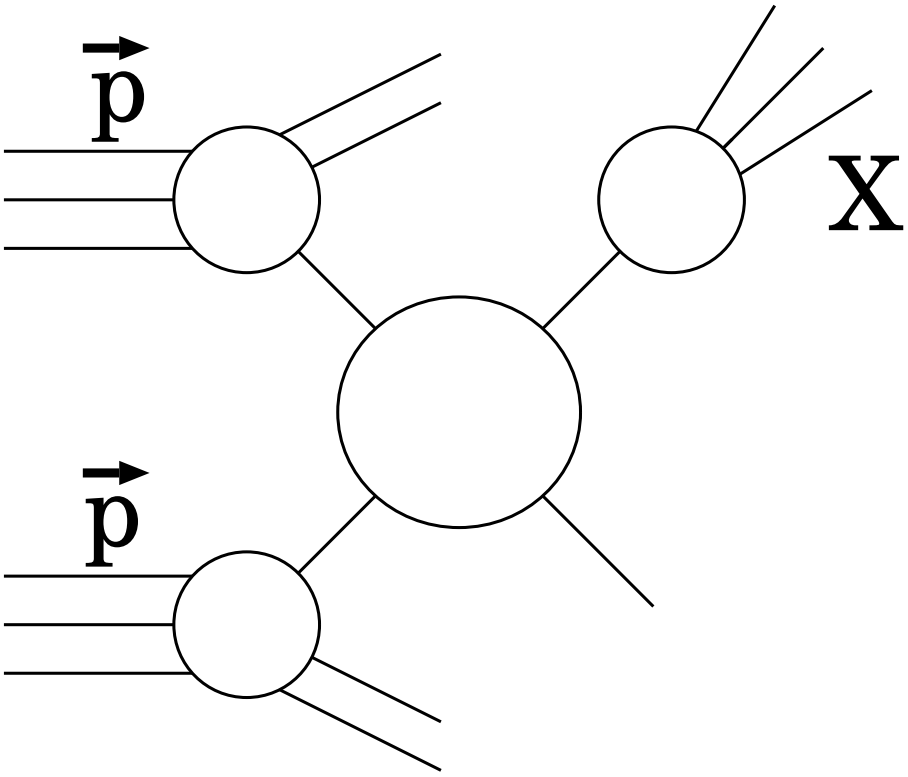
$g_+^{+(-)}(x)$: Probability to detect spin+ (spin–) gluon in spin+ proton as a function of Bjorken x.



Spin Physics at RHIC-PHENIX
How to measure Δg

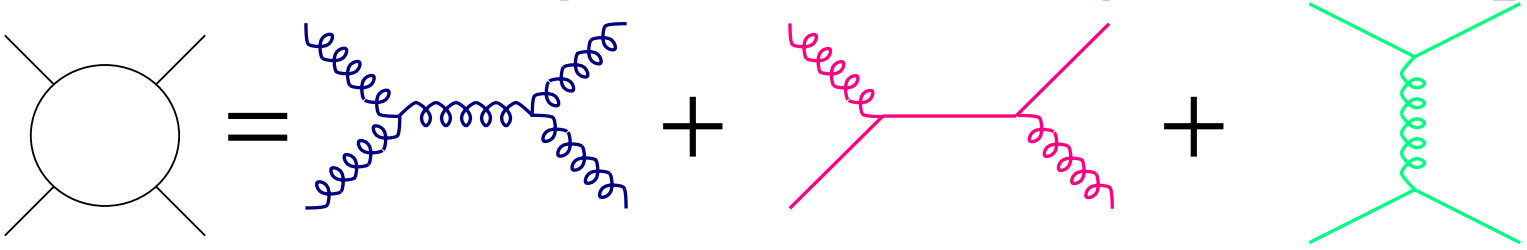
Measure A_{LL} in
$\vec{p}\,\vec{p} \rightarrow X$ production.

X : Pions
Direct photon
J/ψ
Any mesons, baryons



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

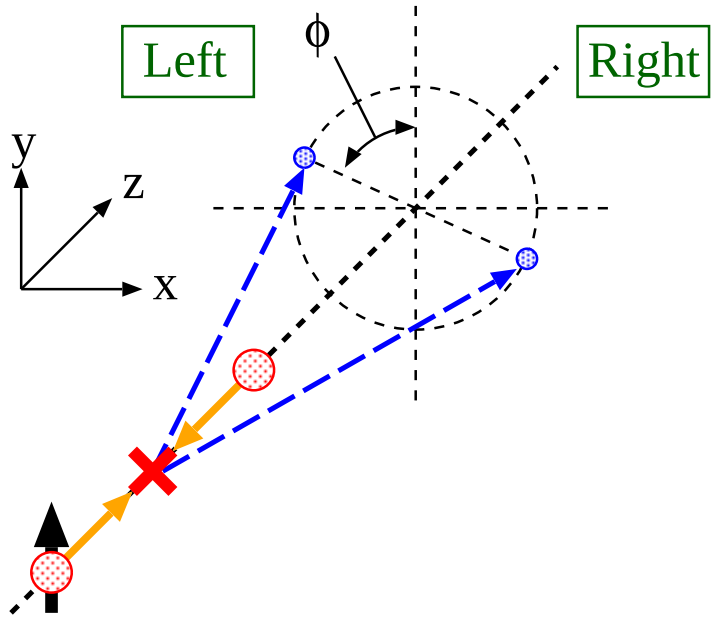
$$\sim [\omega_{gg}]\left(\frac{\Delta g}{g}\right)^2 + [\omega_{gq}\Delta q]\left(\frac{\Delta g}{g}\right) + [\omega_{qq}\left(\frac{\Delta q}{q}\right)^2]$$



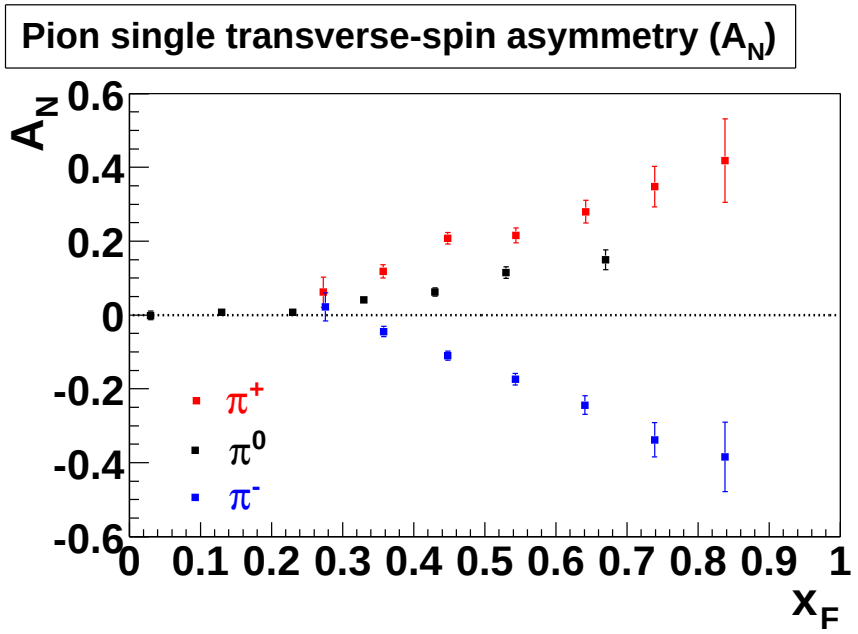
Spin Physics at RHIC-PHENIX
Single Transverse Spin Asymmetry

Left - right asymmetry by transversely polarized beam.

$$A_N = \frac{1}{\sin(\phi)} \frac{\sigma(\phi) - \sigma(\phi - \pi)}{\sigma(\phi) + \sigma(\phi - \pi)}$$



Several approaches are suggested.
(Collins effect, Sivers effect, Twist-3...)



- A_N of pions is measured by many experiment. (E704, STAR, BRAHMS, BELLE)
- A_N of pion, neutron is measured by PHENIX

Spin Physics at RHIC-PHENIX
Anti-quark distribution with W

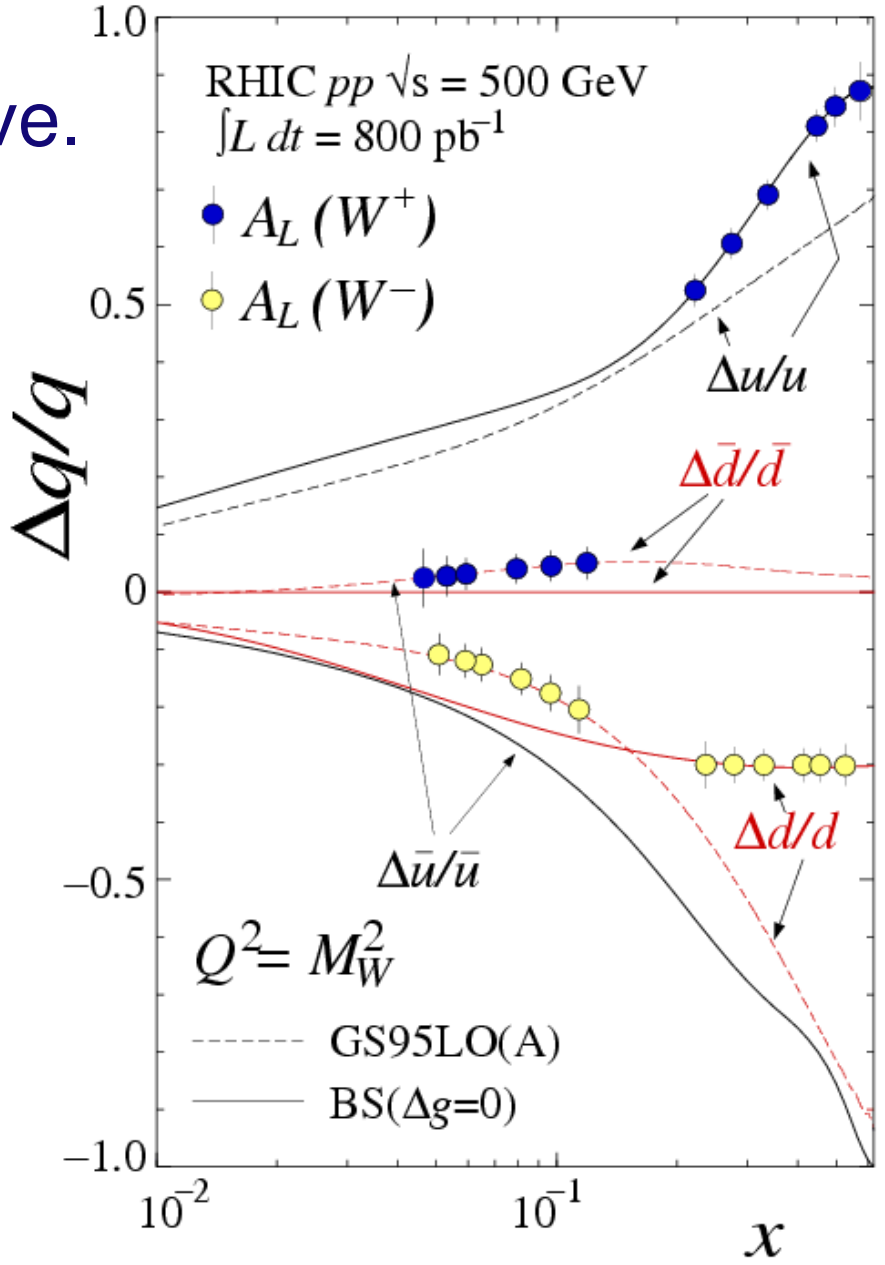
W couples quarks in the alternative.
($u\bar{d}$ -> W^+, $\bar{u}d$ -> W^-)
---> Anti-quark distribution can be extracted.

The operation with $\sqrt{s}$ = 500 GeV is planned in the future.

Measure parity violating A_L.

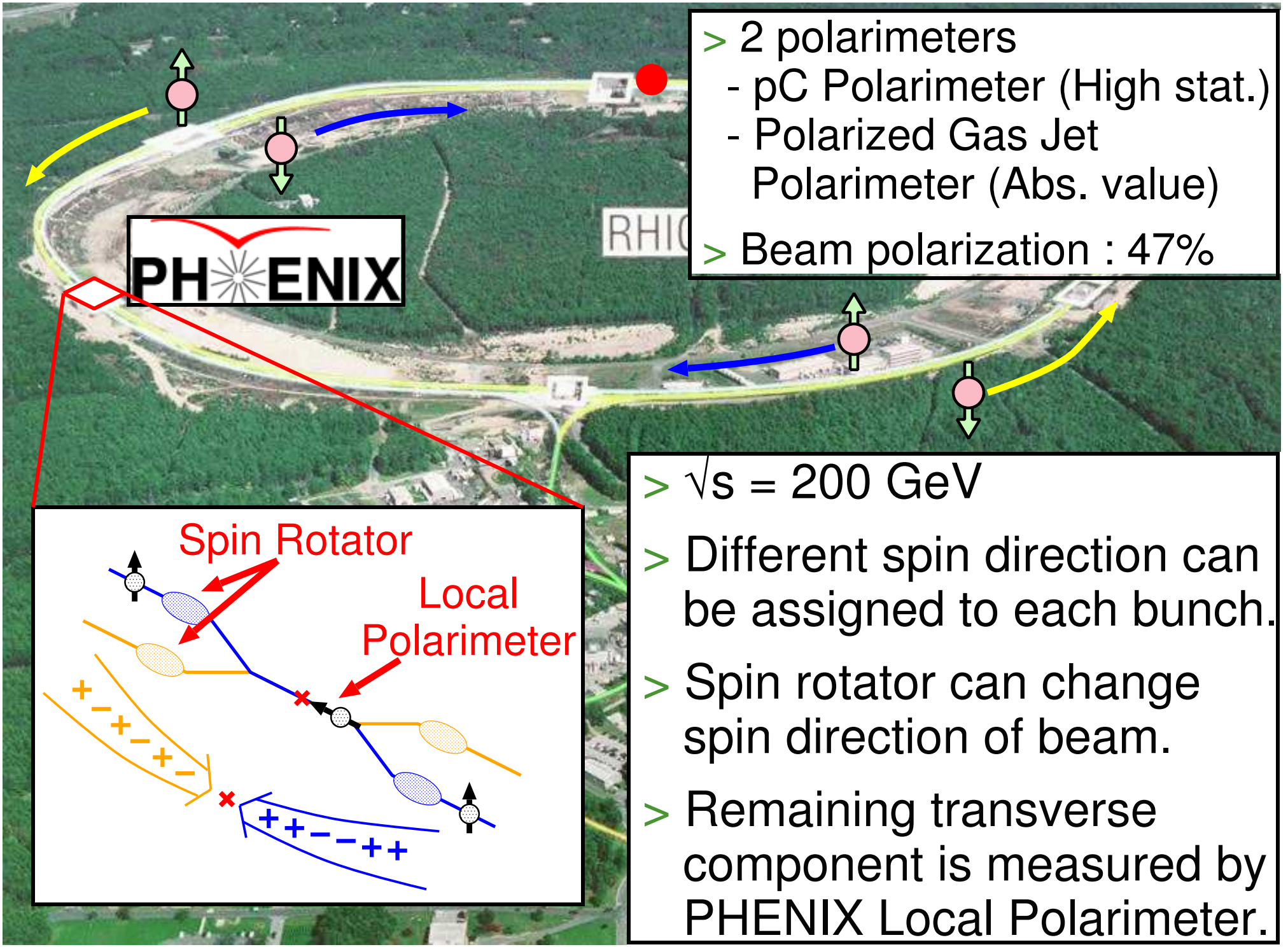
$$A_L(W^+) = \frac{\Delta u \cdot \bar{d} - \Delta \bar{d} \cdot u}{\Delta u \cdot \bar{d} + \Delta \bar{d} \cdot u}$$

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



RHIC

RHIC



> 2 polarimeters
  - pC Polarimeter (High stat.)
  - Polarized Gas Jet Polarimeter (Abs. value)

> Beam polarization : 47%

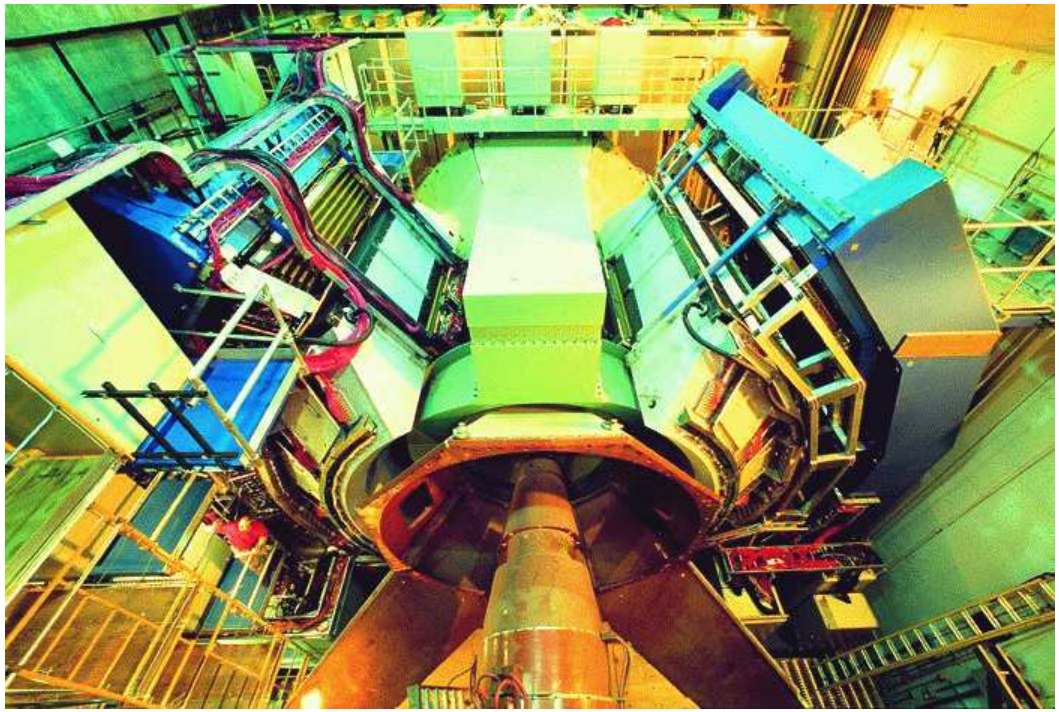
> $\sqrt{s}$ = 200 GeV

> Different spin direction can be assigned to each bunch.

> Spin rotator can change spin direction of beam.

> Remaining transverse component is measured by PHENIX Local Polarimeter.

PHENIX



Beam-Beam-Counter &
Zero Degree Counter

> BBC : $3.0 < |\eta| < 3.9$
> ZDC : $|\eta| > 6.6$ ($\theta > 2.8$mrad)
> Minmum Bias Trigger (BBC)
> Relative Luminosity (BBC&ZDC)
> Local Polarimeter (ZDC)
> Physics : Neutron (ZDC)

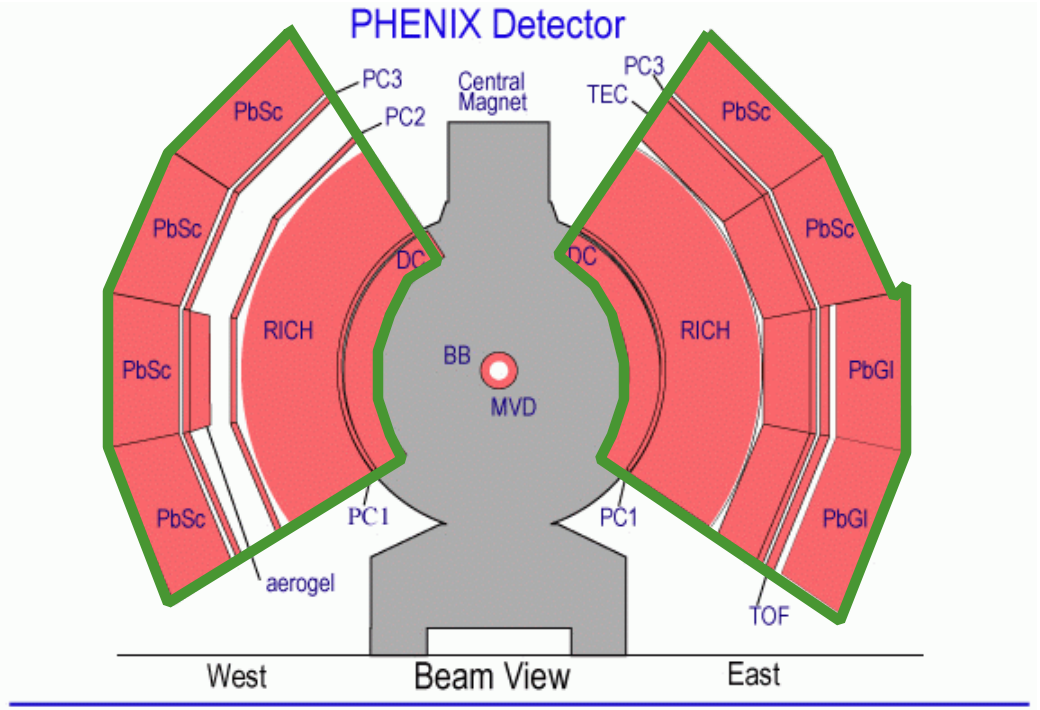
Central Arm

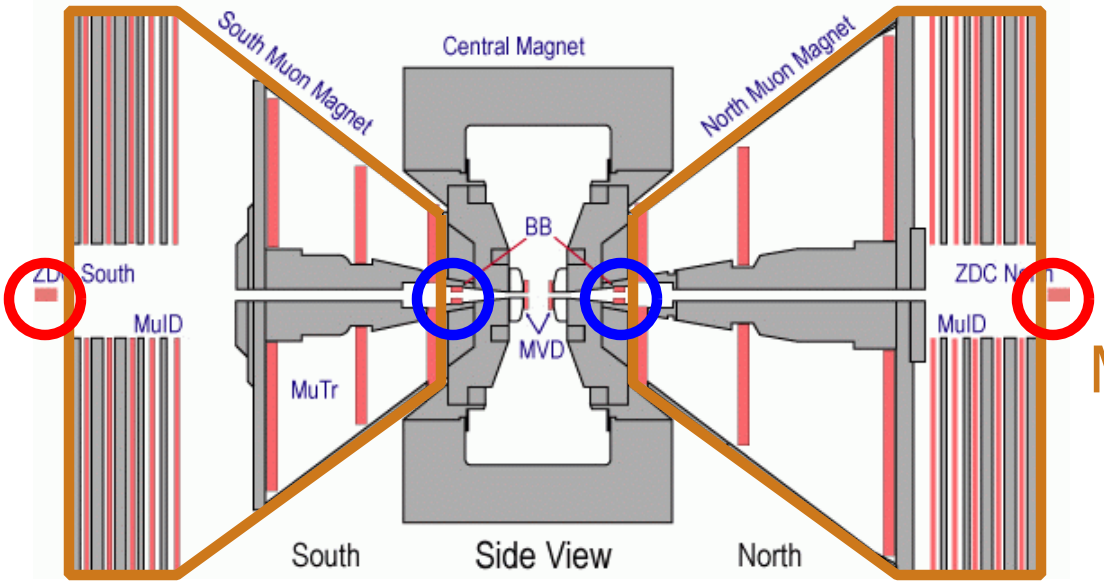
> $|\eta| < 0.35$, $\Delta\phi = \pi$
> EMCal, RICH, Tracker
> Physics : π°, photon,
charged hadrons, electron.

Muon Arm

> $1.2 < |\eta| < 2.4$
> Muon Idetifier, Muon Tracker.
> Physics : muon, J/ψ, W

PHENIX





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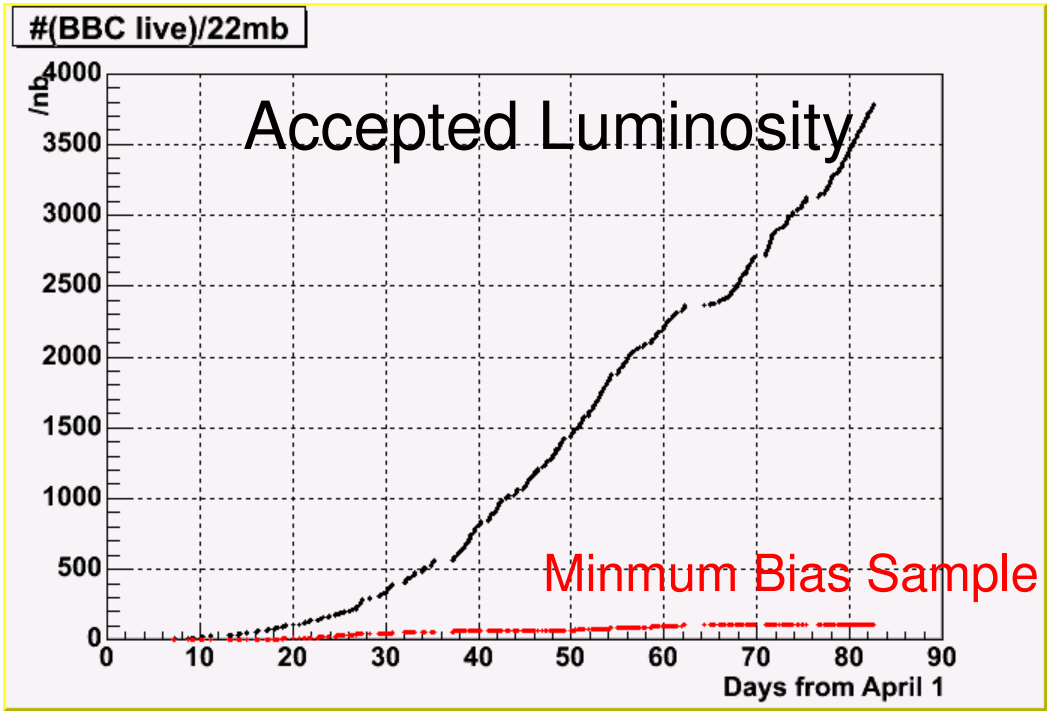
Luminosity & History

2001-2002 transverse spin run (First polarized proton run) P=15% L=0.15 pb-1
2003 longitudinal spin run P=27% L=0.35 pb-1 FOM=1.86nb-1
2004 commisioning run (longitudinal spin) P=40% L=0.12 pb-1 FOM=3.1nb-1
2005 longitudinal spin run (w/ short transverse spin run) P=47% L=3.8 pb-1 FOM=185nb-1

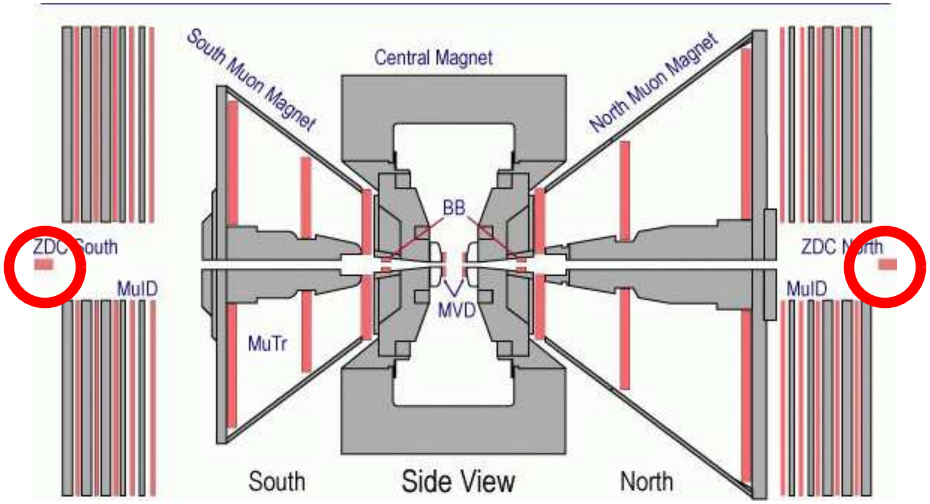


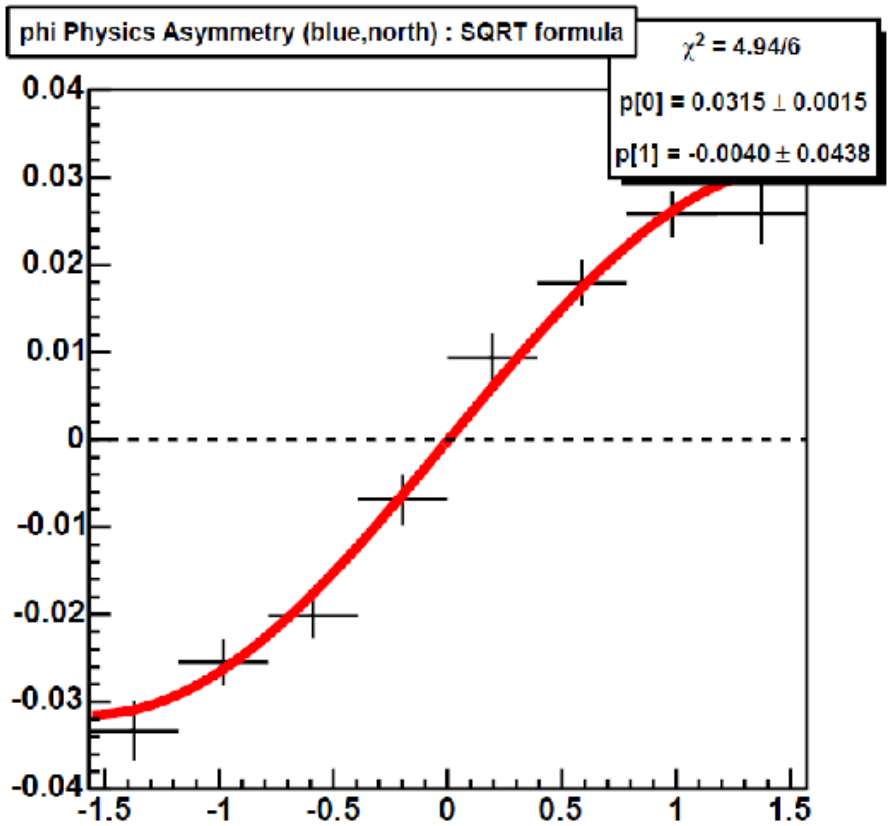
FOM : Figure of merit = P^4L

We had first long longitudinal spin run in 2005.

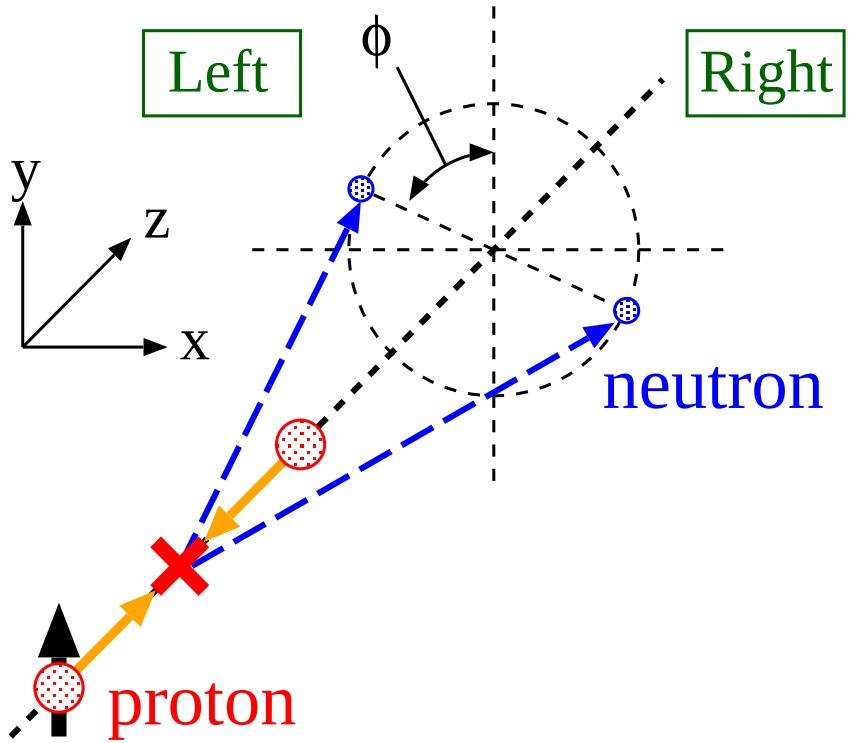
Figure of merit is 40 times larger than past years.

Local Polarimeter





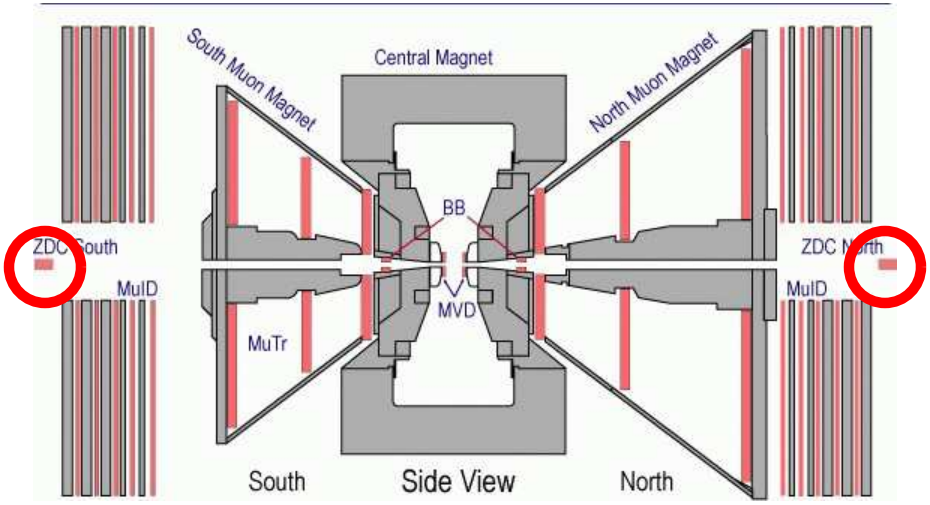
Detect neutron in very foward region.

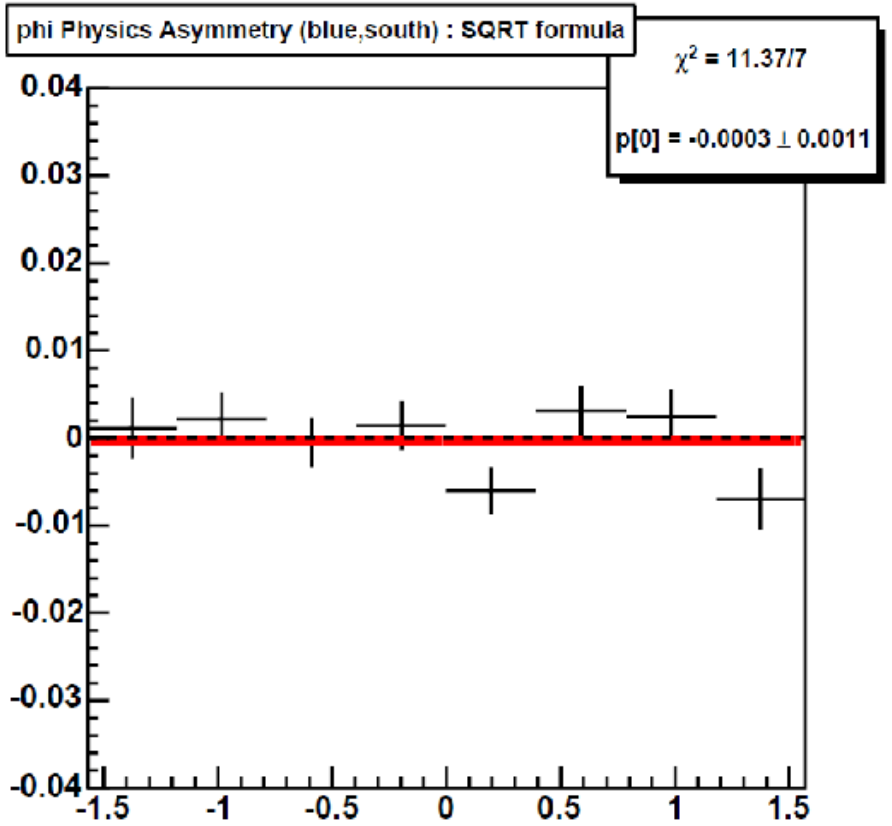


Rotator OFF

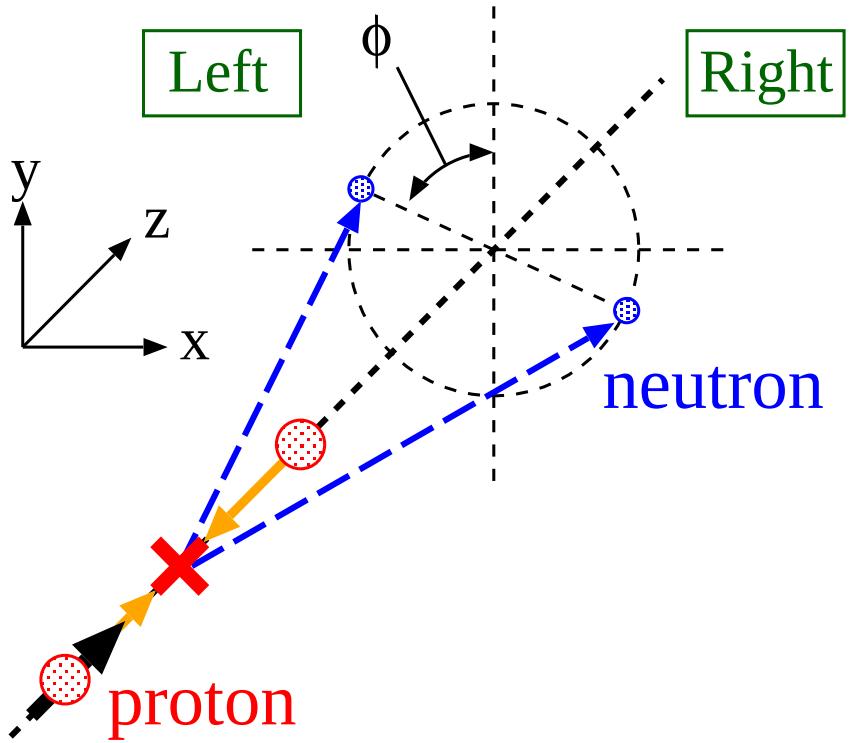
Clear asymmetry is measured.

Local Polarimeter





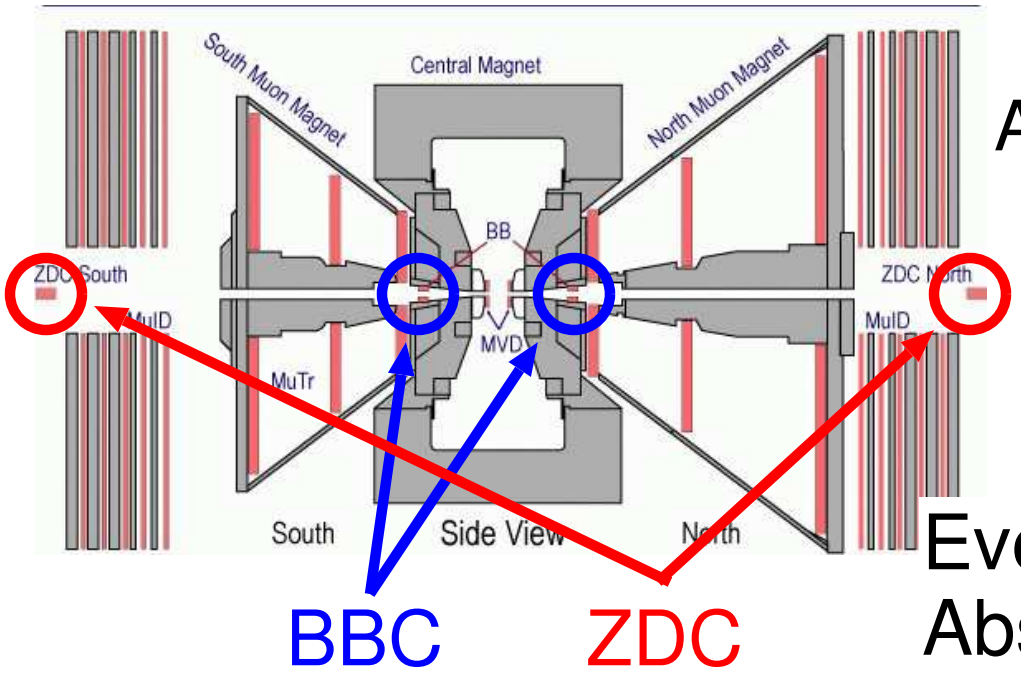
Detect neutron in very foward region.



Rotator ON
Asymmetry disapears.

Longitudinal component > 98%

Relative Luminosity



$$A_{LL} = \frac{1}{P \cdot P} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}} \qquad R = \frac{L_{++}}{L_{+-}}$$

R : Relative Luminosity
N : Number of measured particles
P : Beam polarization

Events detected by BBC are used.
Absolute scale is not necessary.

Systematic uncertainty evaluation

> Compare two detector with different acceptance.
- BBC : $3.0 < |\eta| < 3.9$
- ZDC : $|\eta| > 6.6$ ($\theta < 2.8$ mrad)

$$r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)}$$ should be constant.
(i : crossing number)

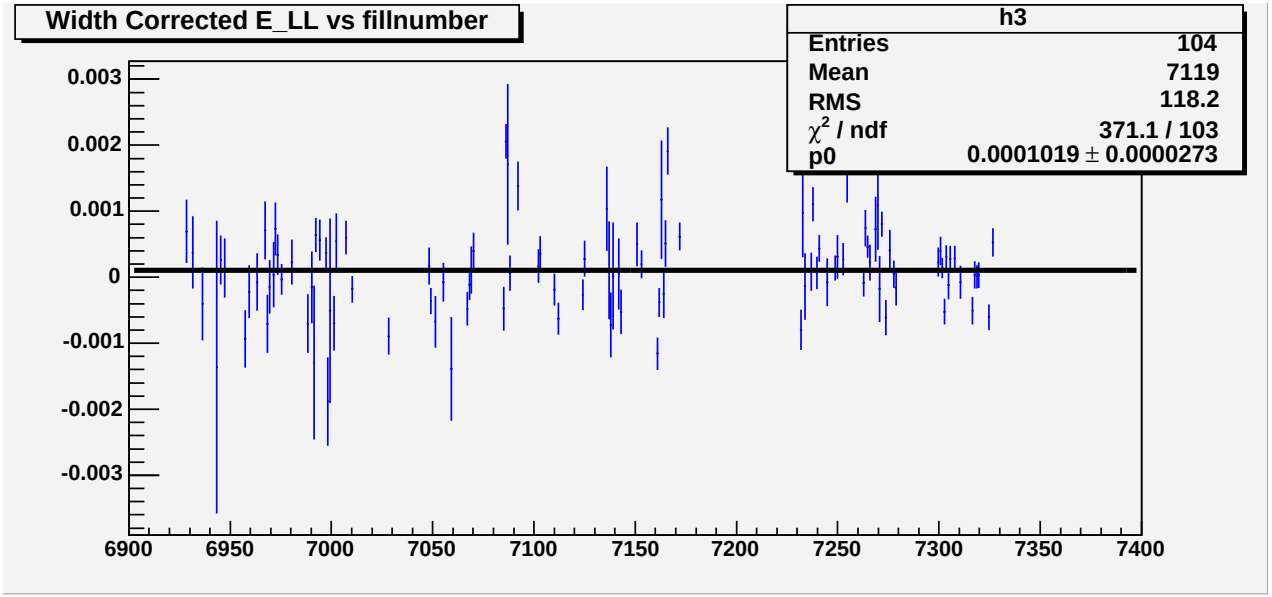
Relative Luminosity

Compare two rel. lum. detectors : BBC vs. ZDC

$r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)}$ should be constant. (i : crossing number)

Fit r(i) to $C[1+ \alpha P_B(i)P_Y(i)]$: α is possible asymmetry.

δA_{LL} from rel. lum. is $\frac{\delta R}{2 P_B P_Y} = \delta\alpha$



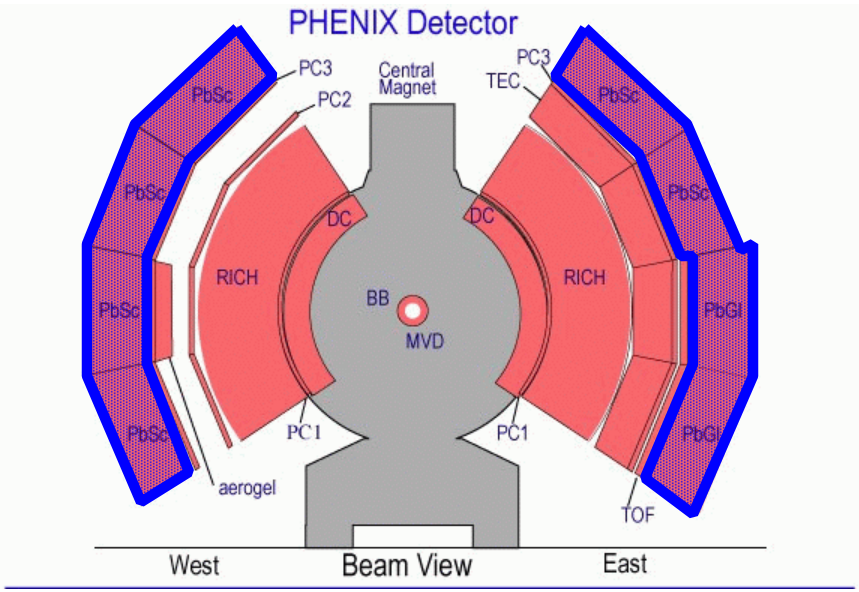
After renormalization by chisquare,

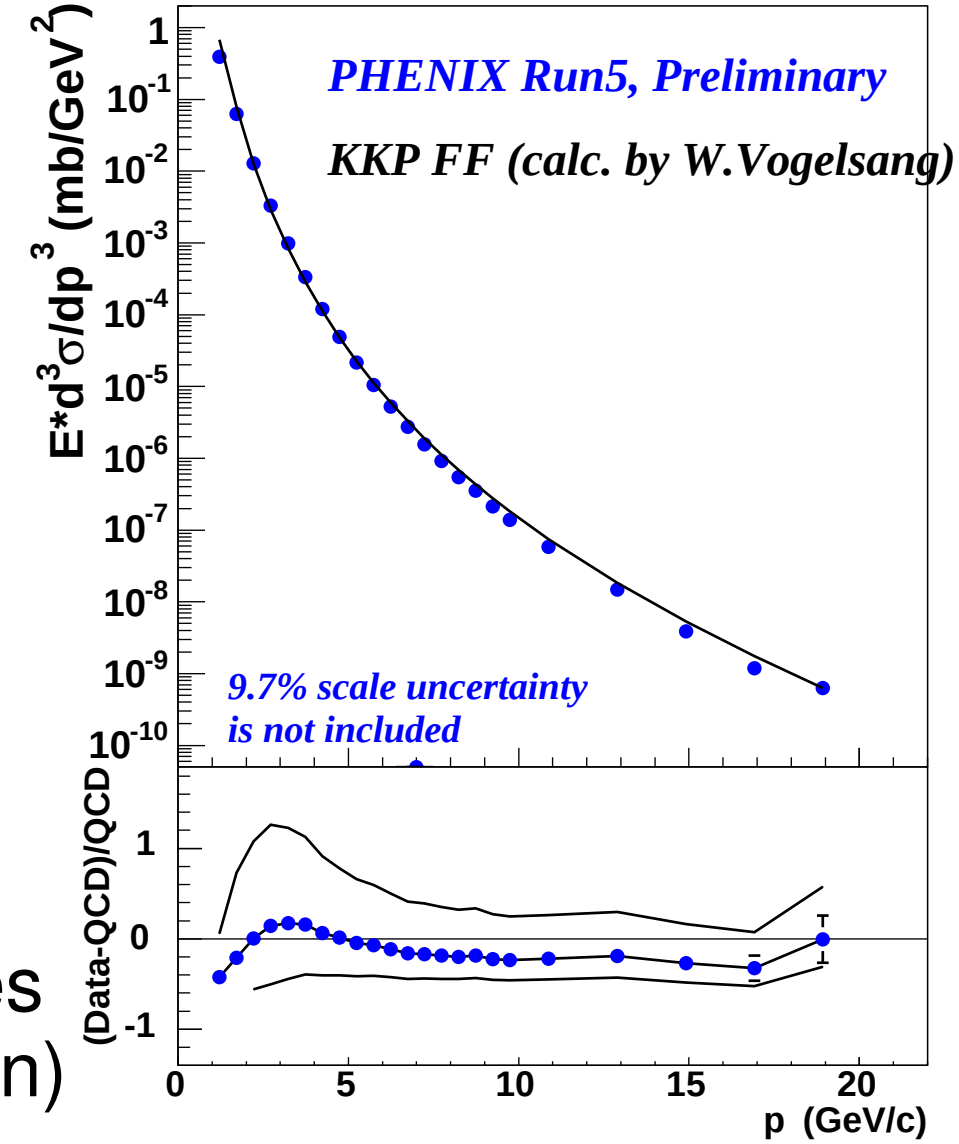
a) $\delta R = 1.0 \times 10^{-4}$

b) $\delta A_{LL} = 2.3 \times 10^{-4}$ for 47% beam polarization

c) A_{LL} of BBC relative to ZDC is consistent with 0

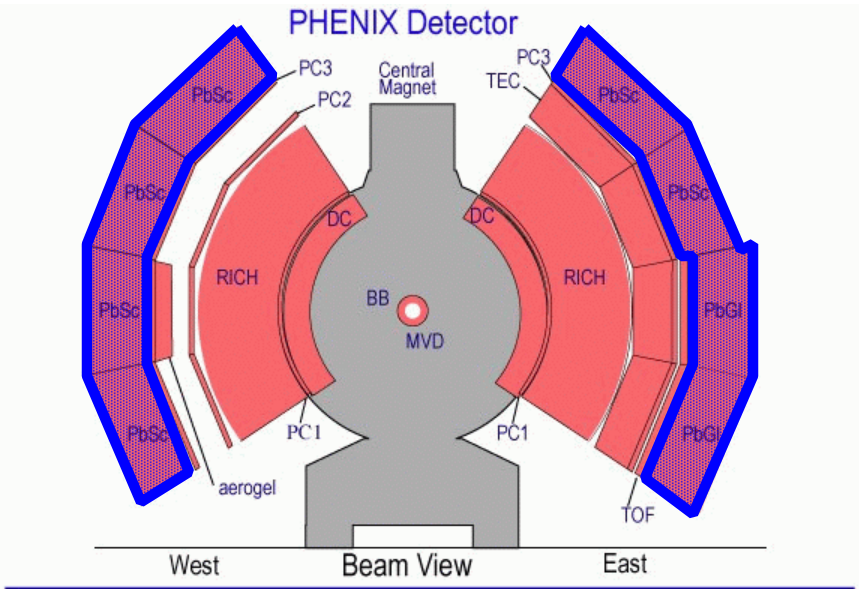
PHENIX results - neutral pion





- High statistics
- Clean measurement by fine segmented EMCal. ($\Delta\eta \cong \Delta\phi \cong 0.01$)
- pQCD calculation describes the data well. (cross section)

PHENIX results - neutral pion



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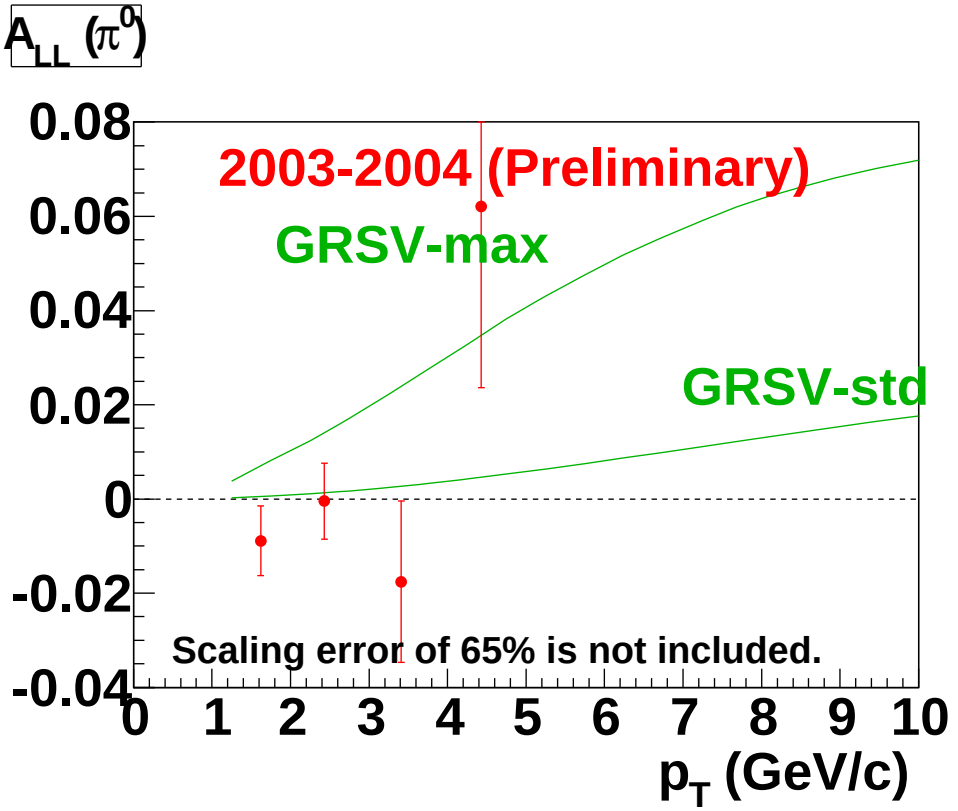
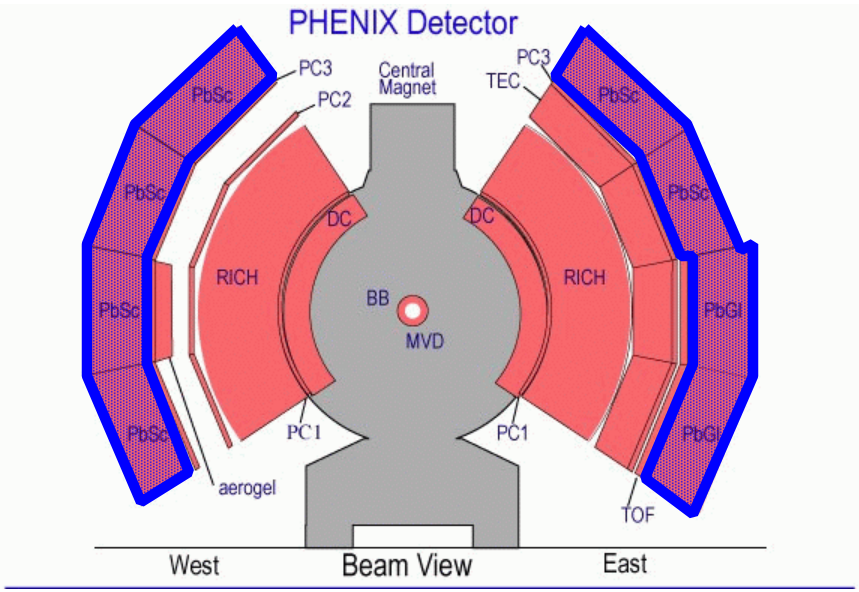


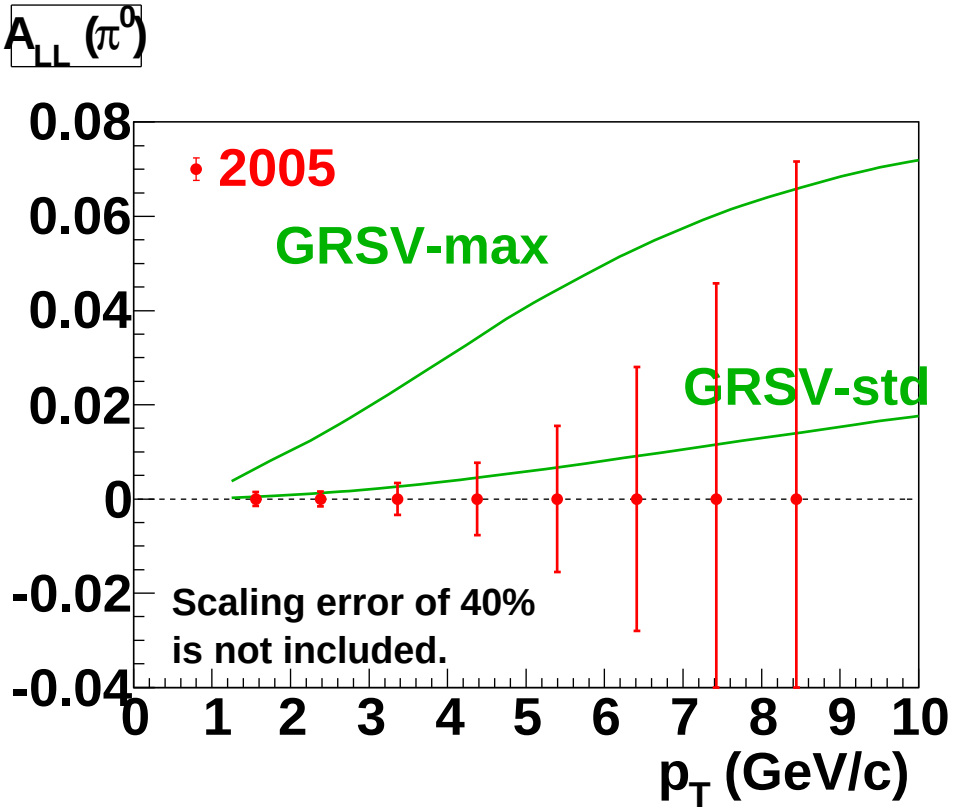
PHENIX results - neutral pion



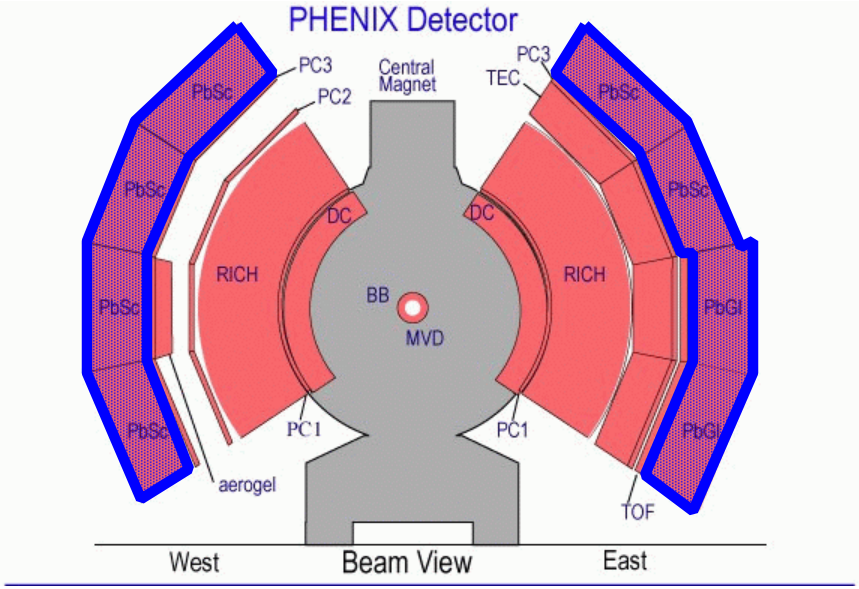
Statistics becomes much smaller. GRSV-std and GRSV-max can be distinguished.

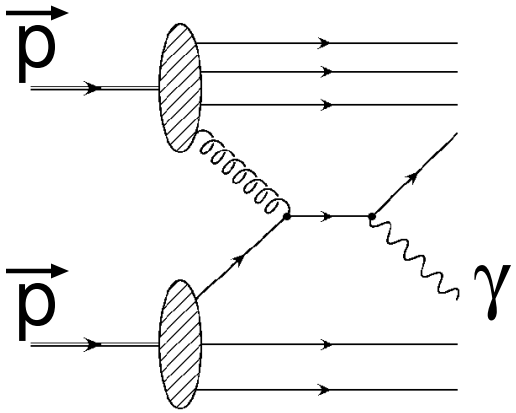
---> K. Boyle's talk in section III.4

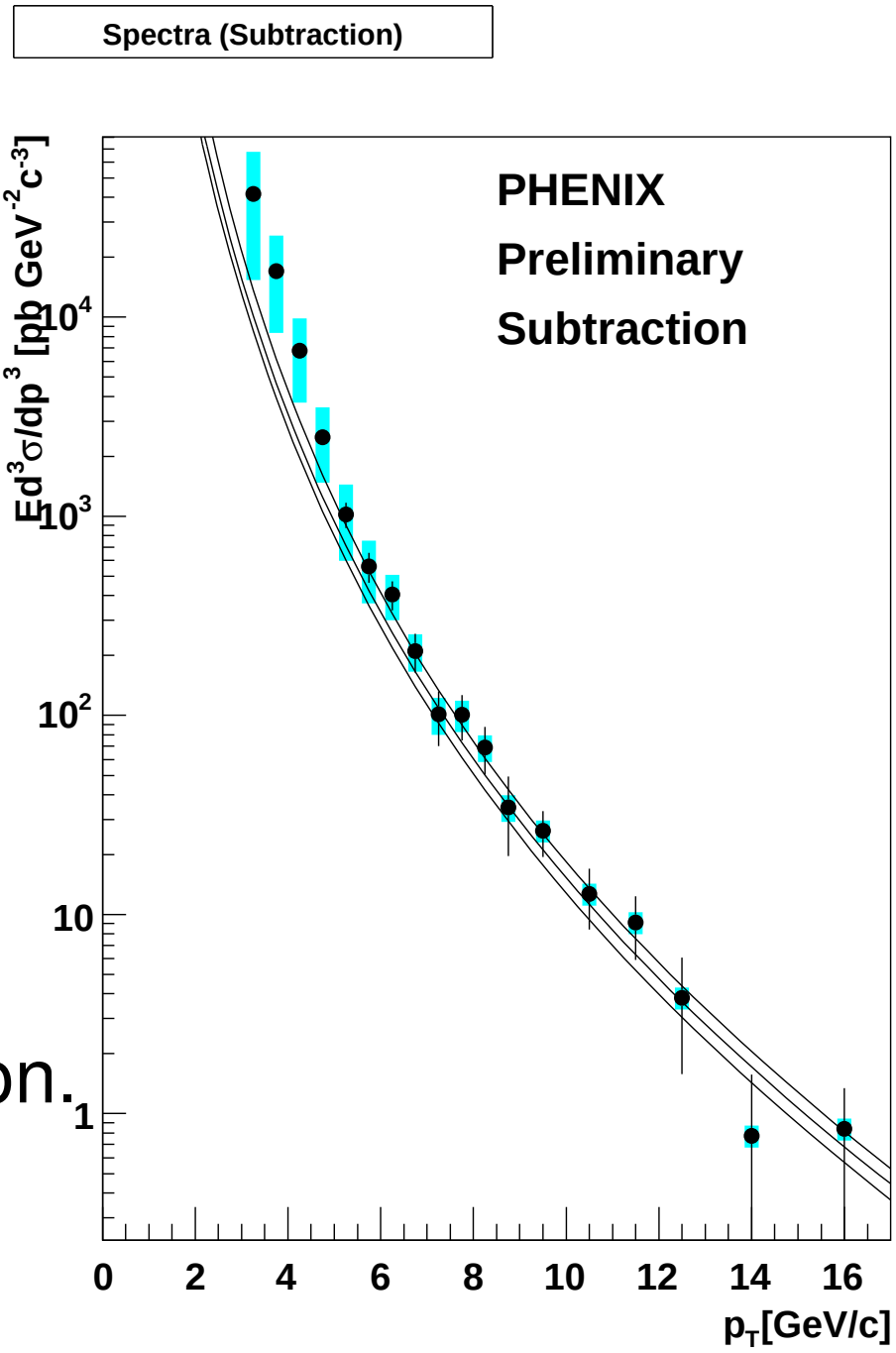
- High statistics
- Clean measurement by fine segmented EMCal. $(\Delta\eta \cong \Delta\phi \cong 0.01)$
- pQCD calculation describes the data well. (cross section)



PHENX results - Direct photon

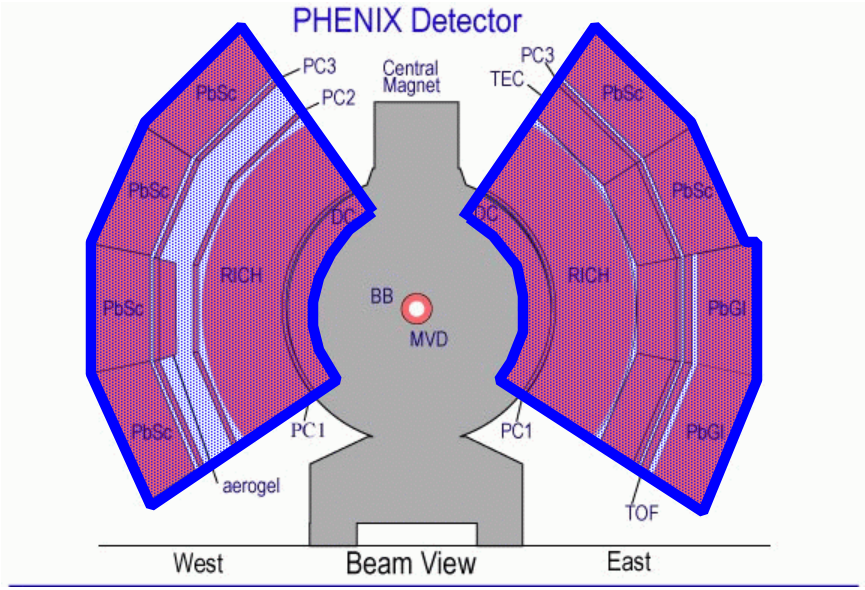






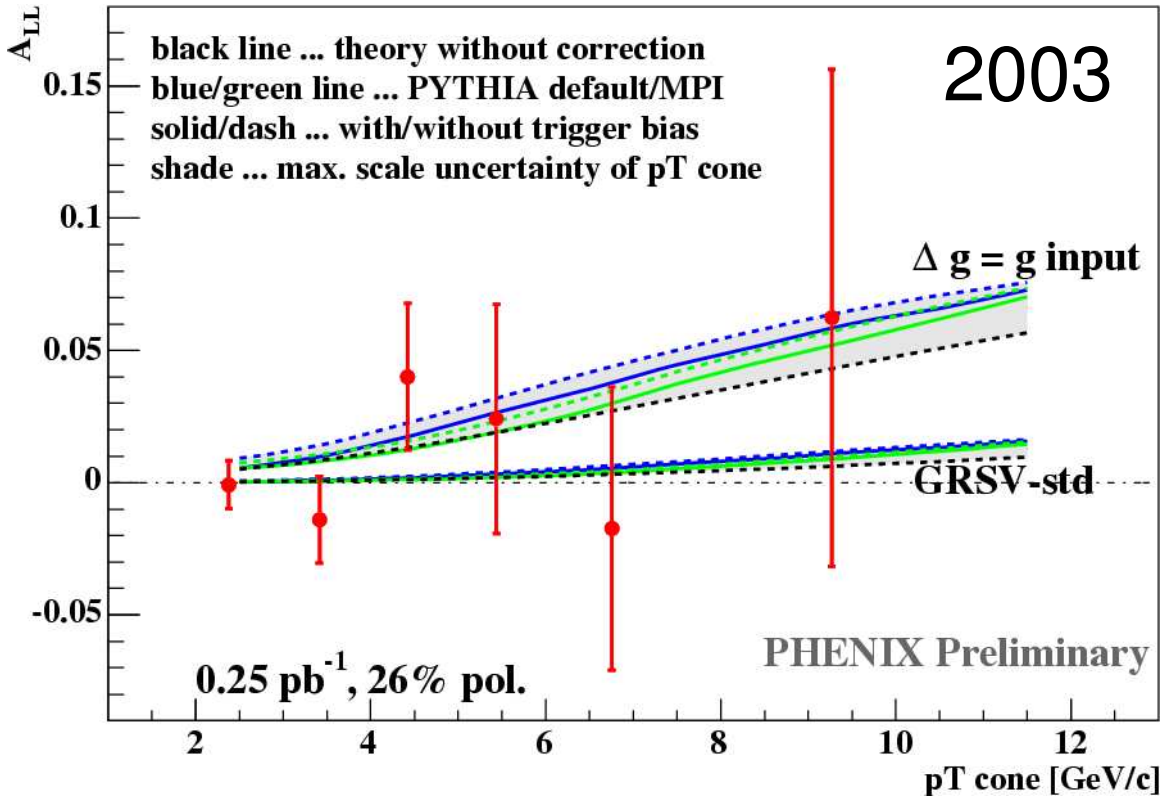
> Independent from fragmentaion.
> Sensitive to sign of Δg
> Low statistics
> Theory describes data well.

PHENIX results - "Jet"



"Jet" detection

Tag one high energy photon and sum energy of nearby photons/charged particles.

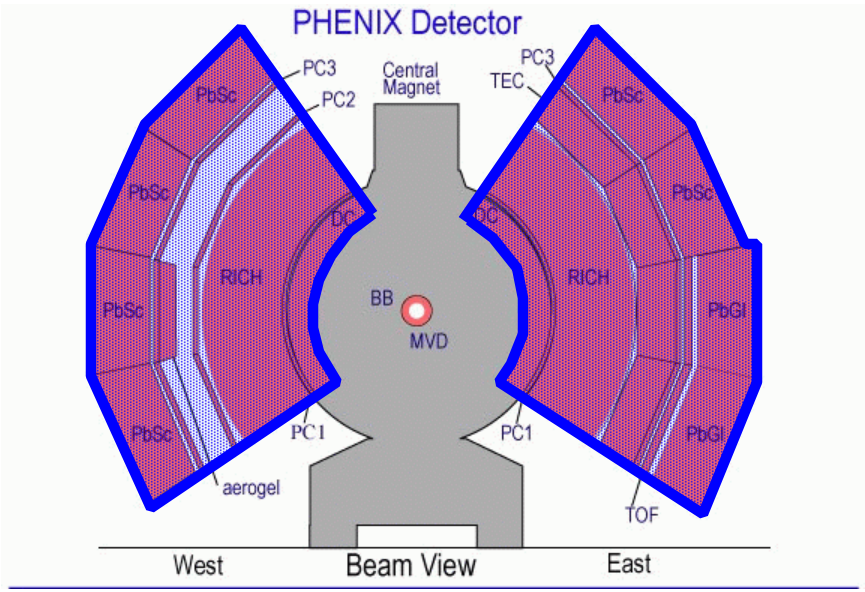


Definition of "pT cone"

Sum of p_T measured by EMCal & Tracker with $R = \sqrt{|\phi|^2 + |\eta|^2} < 0.3$

Real p_T of jet is evaluated by modified PYTHIA.

PHENIX results - "Jet"



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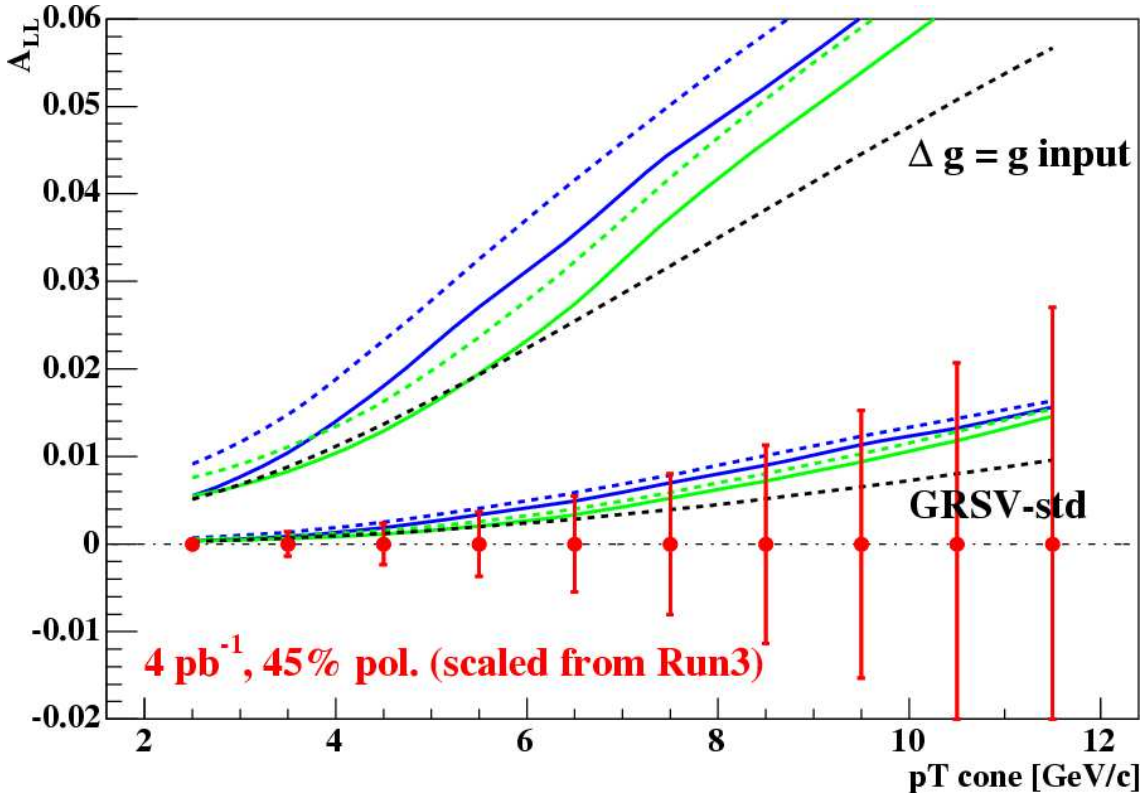

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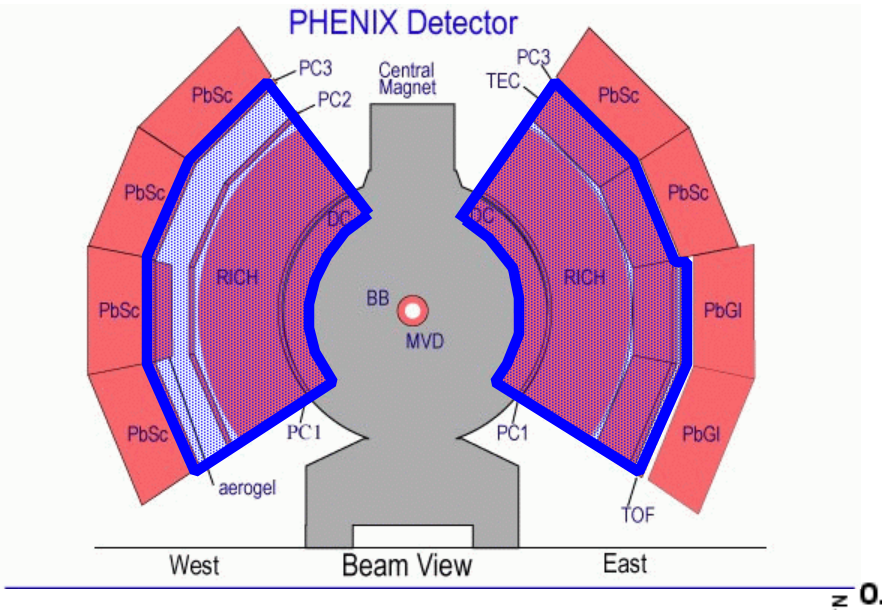
Sum of p_T measured by EMCal & Tracker with $R = \sqrt{|\phi|^2 + |\eta|^2} < 0.3$

p_T of real jet is evaluated by modified PYTHIA.

PHENIX results - A_N of pions

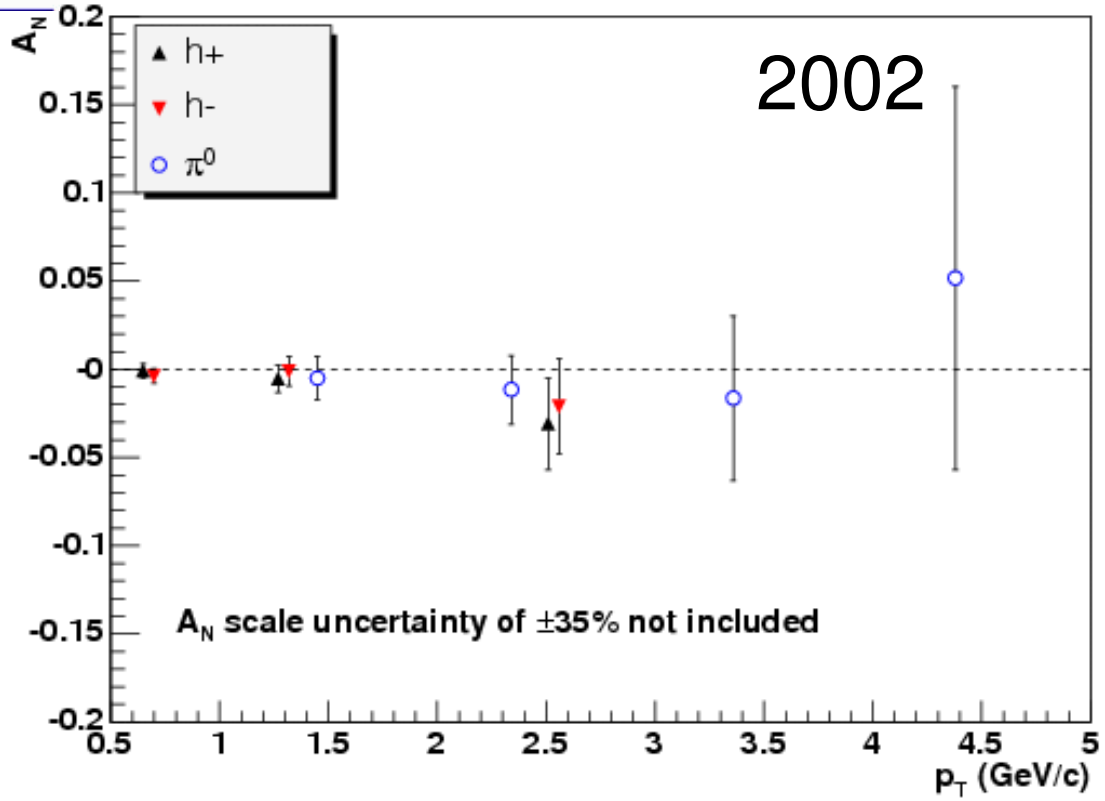


Large asymmetry is observed in forward region. (E704, STAR...)

PHENIX measured A_N of charged hadrons and pions in central region.

Results of charged pion from 2005 run.

---> K. Eyser's talk in section III.7



Other topics

> Single electron, D
- Tagging charm quark for Δg

> J/ψ
- Production mechanism
- A_{LL} for Δg
---> M. Liu's talk in section III.4

> μ
- A_N
---> H. Bataineh in poster session
---> A. Purwar in poster session

> Helicity correlated differences in Jet k_T
- This may suggest evidence of orbital angular momentum.
---> R. Hobbs's talk in section III.6

> A_N of Jet k_T
- Access to Sivers function

> η
- A_{LL} for polarized PDFs
---> J. Seele in poster session

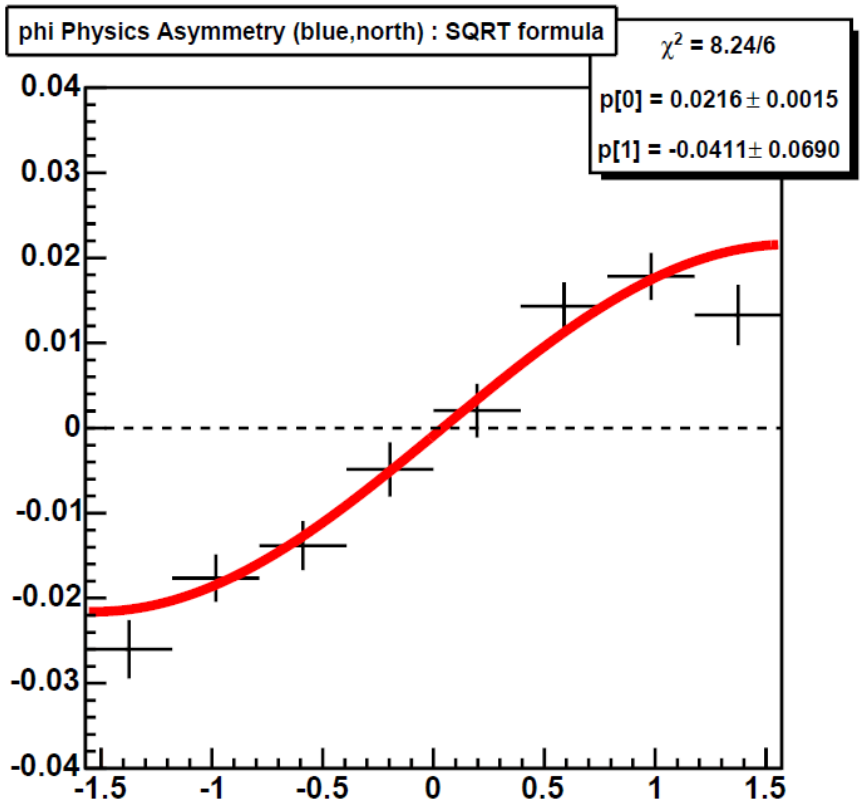
> Λ
- Spin transfer
- A_{LL} for polarized PDFs

RHIC-PHENIX in the future

> Silicon Vertex Tracker
- 2 pixel layer + 2 strip layer
- Wider acceptance for Jet
- Displaced vertex measurement for heavy flaver tagging.

> Muon Trigger Upgrade
- For W -> μ measurement at $\sqrt{s}$ = 500 GeV
- Resistive Plate Chamber (Timing, Momentum)

> Toward $\sqrt{s}$ = 500 GeV
- 410 GeV commissioning in run5
- We observed neutron asymmetry at $\sqrt{s}$ = 410 GeV.



Summary

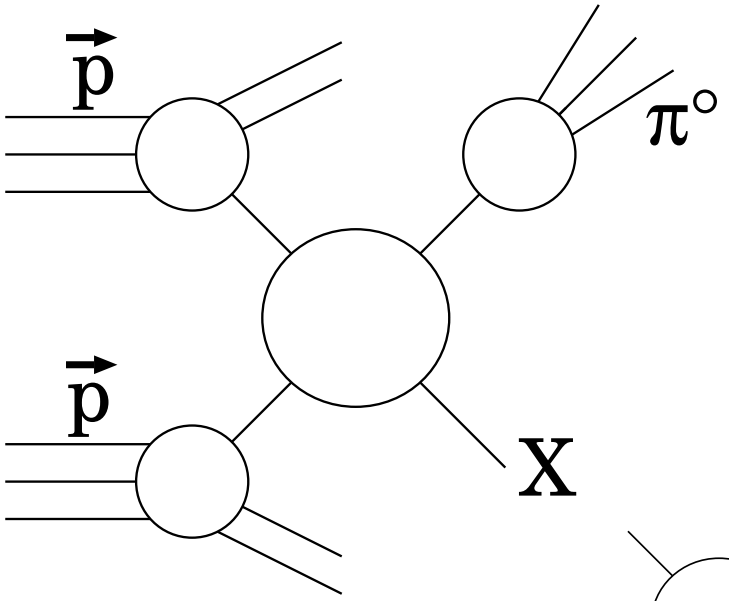
> PHENIX just has taken first long longitudinal-spin polarized-proton collision data in Run-5 (2005).
---> 40 times more statistics in figure of merit for A_{LL}.

> Δg measurement
- GRSV-std and GRSV-max can be distinguished by A_{LL} in π° production.
- Many studies of other channels to support π° are on going.

> Many other works in hard effort
- Single transverse-spin asymmetry
- Spin correlation in Jet k_T
- Production mechanism

> Toward $\sqrt{s}$ = 500 GeV run
- RHIC successfully operated polarized proton run at $\sqrt{s}$ = 410 GeV.
- PHENIX Local Polarimeter measured A_N of neutron at $\sqrt{s}$ = 410 GeV.

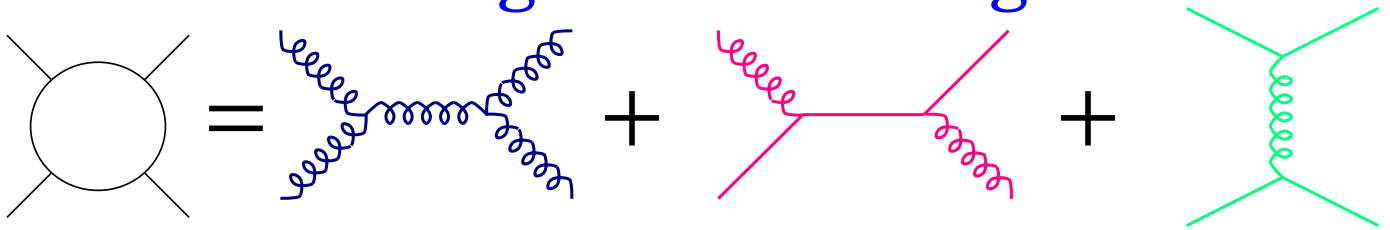
Spin Physics at RHIC-PHENIX
How to measure Δg



Measure A_{LL} in $\vec{p}\,\vec{p} \rightarrow X$ production.

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

$$\sim [\omega_{gg}]\left(\frac{\Delta g}{g}\right)^2 + [\omega_{gq}\Delta q]\left(\frac{\Delta g}{g}\right) + [\omega_{qq}(\Delta q)^2]$$



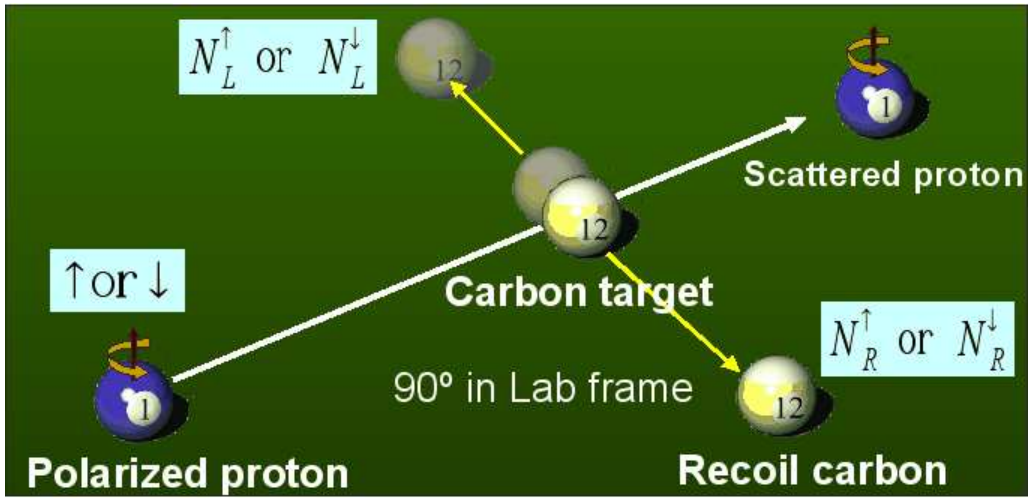
In the experiment, we calculate

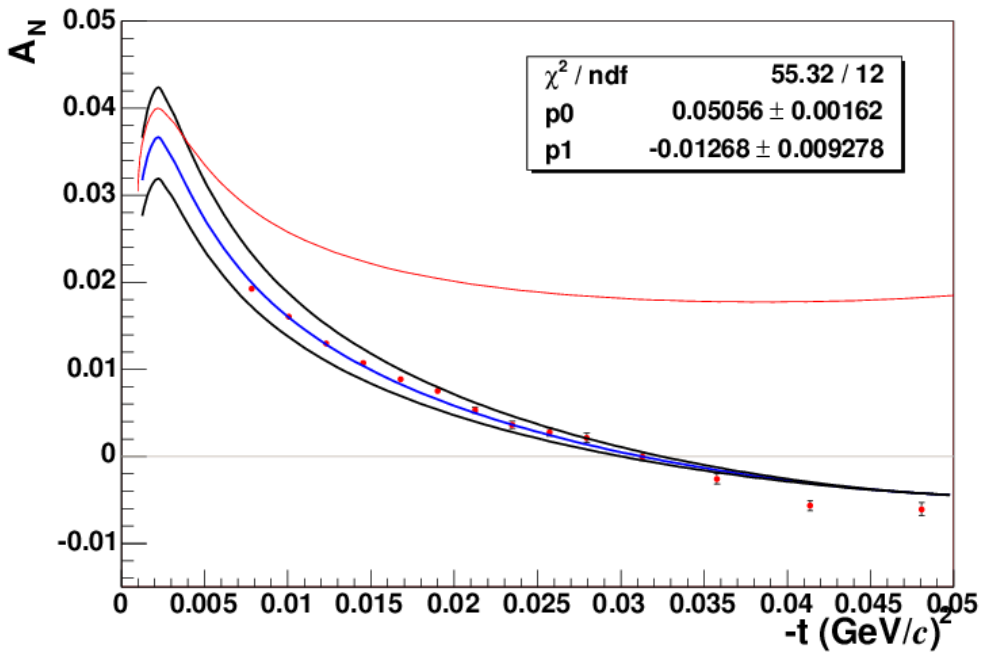
$$A_{LL} = \frac{1}{P \cdot P}\,\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \qquad R = \frac{L_{++}}{L_{+-}}$$

N : Number of particle measured in each helicity state.
P : Beam polarization.
R : Relative Luminosity

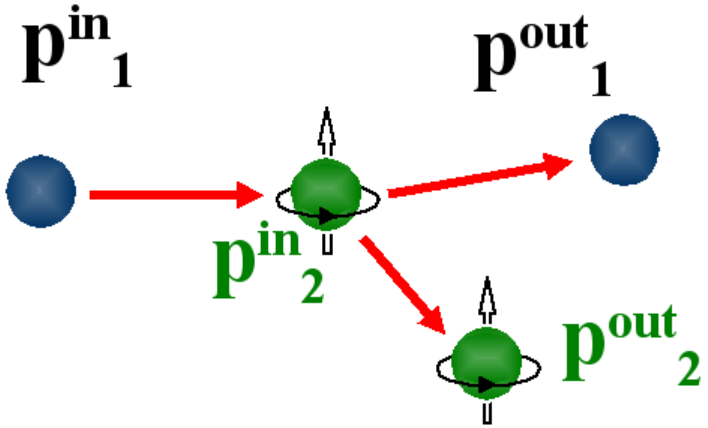
Polarimeter

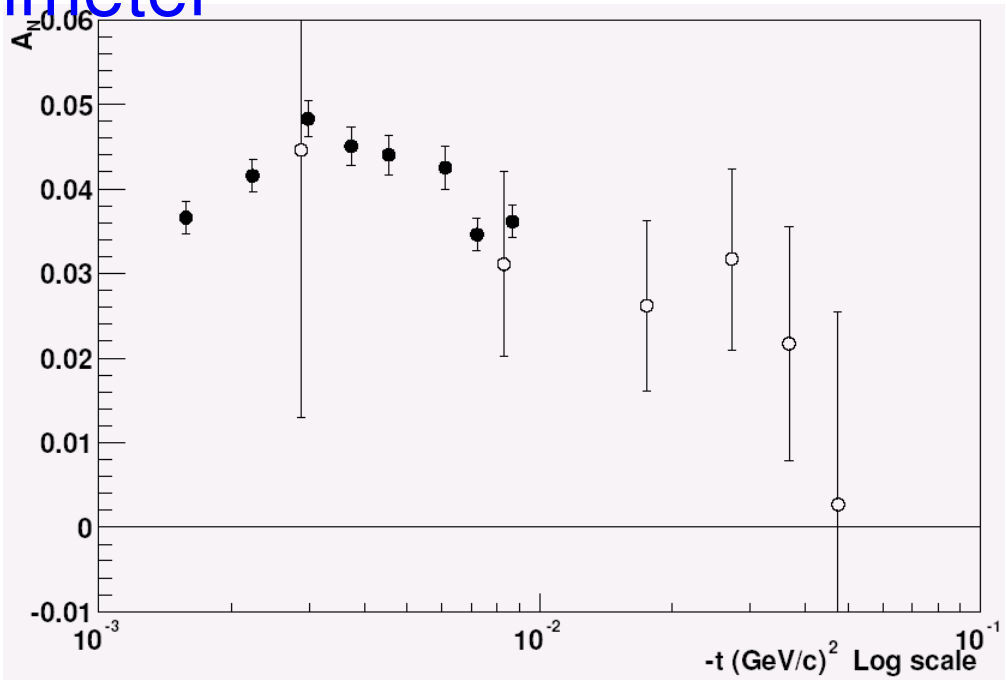
proton-Carbon polarimeter





Polarized proton gas jet polarimeter



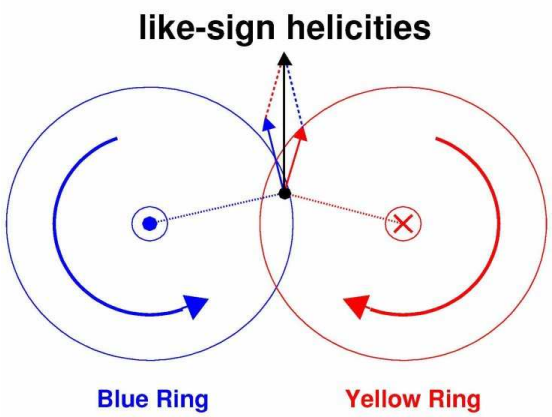


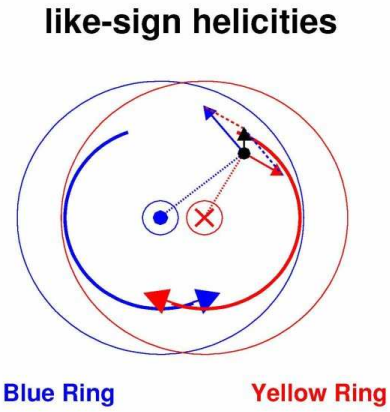
PHENIX results - Jet correlation

kT larger

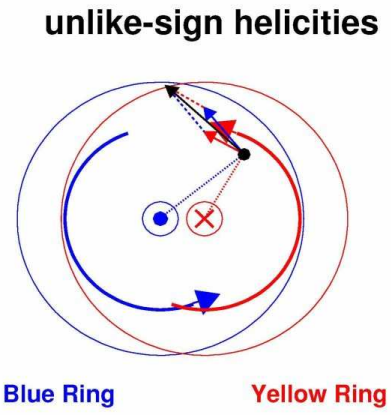
kT smaller

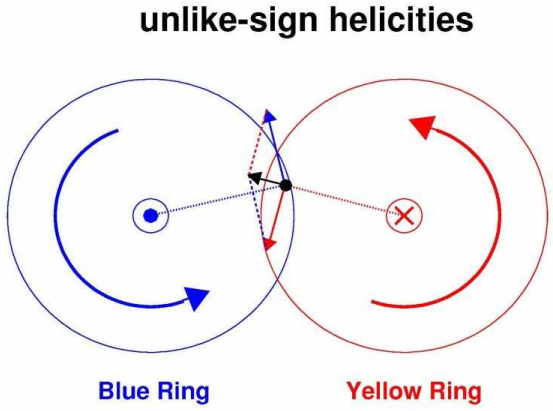
Same helicity





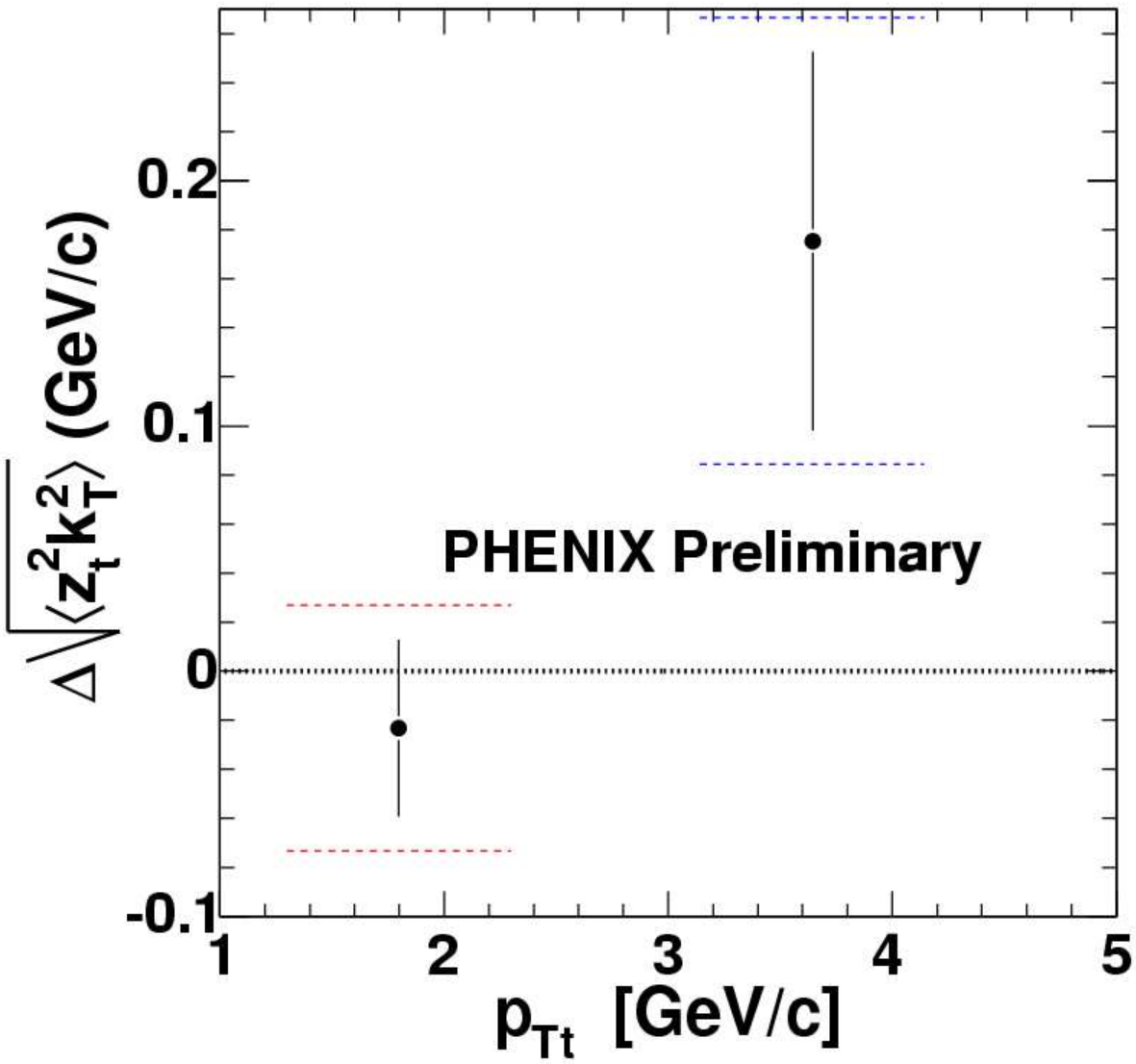
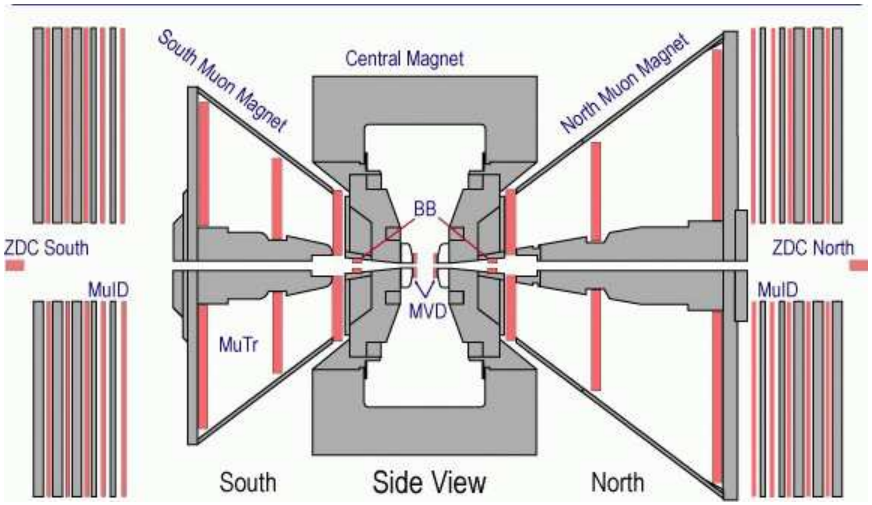
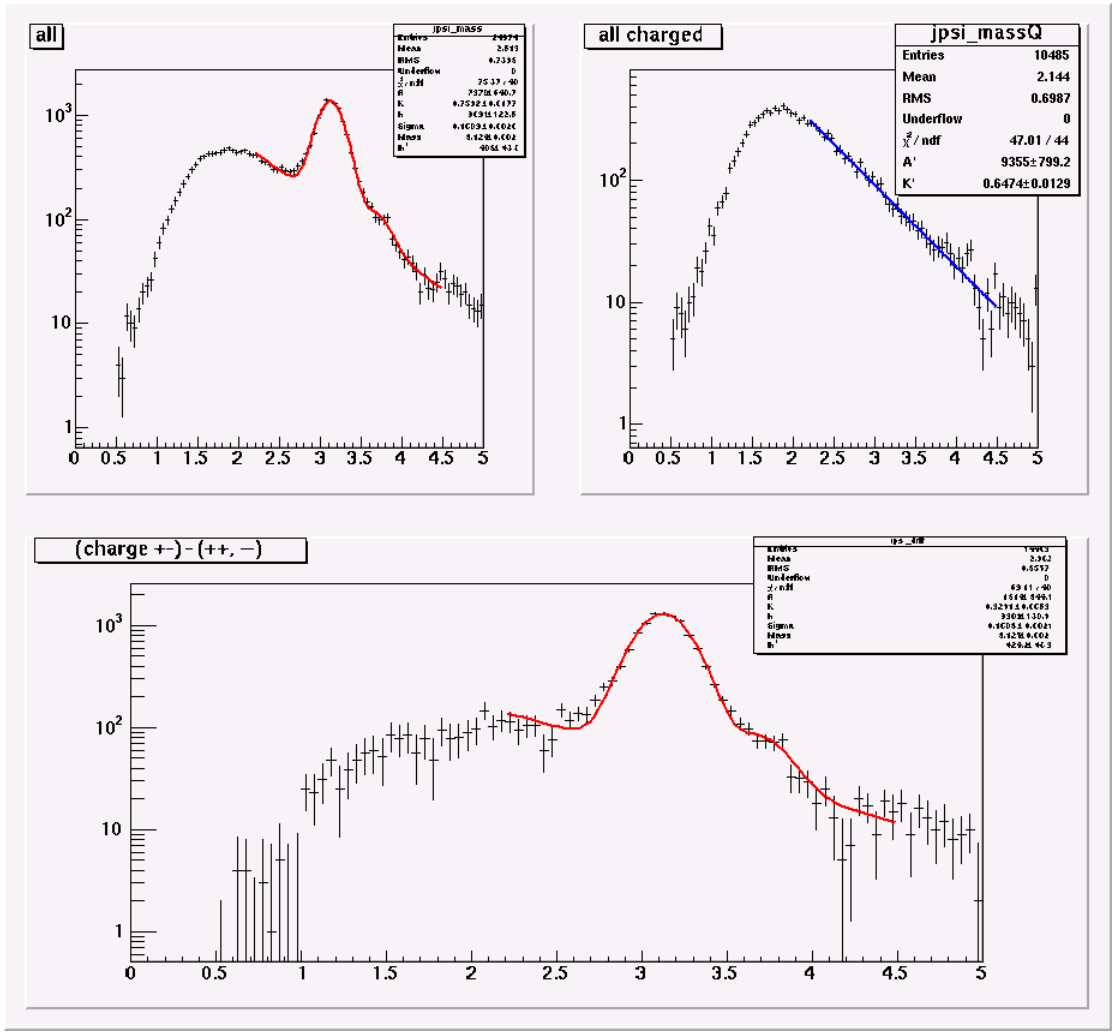
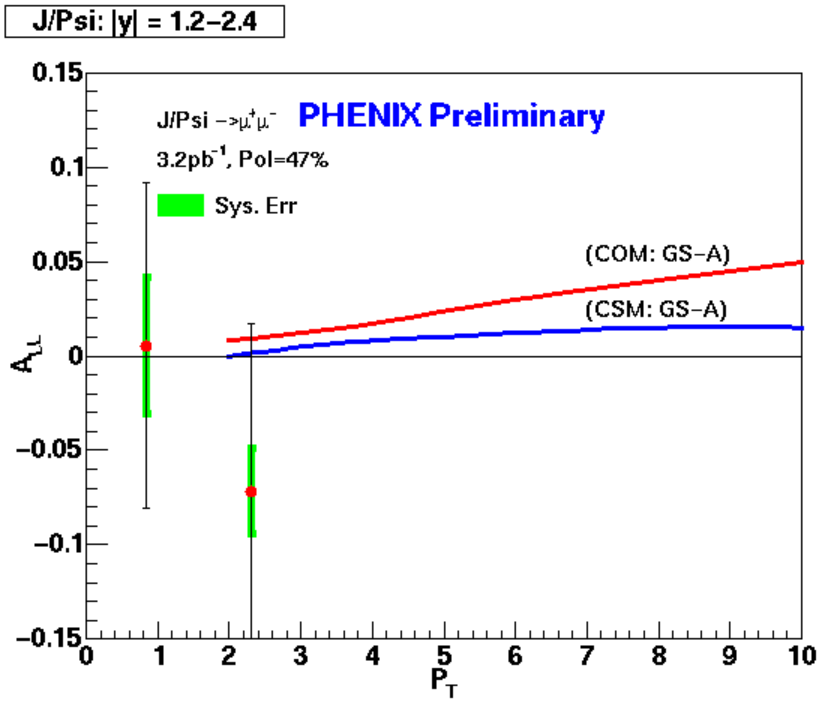
Opposite helicity





We may observe net effect
after averaging over impact factor.

PHENIX results - Jet correlation



PHENIX result - J/psi