

Probing gluon polarization with π^0 's in longitudinally polarized proton collisions at the RHIC-PHENIX experiment.

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Motivation of π^0 ALL Measurement for Δg

Quarks : Δq
10 ~ 30 %

Gluons : Δg
Unknown...

Angular mom. : ΔL
Unknown...

Proton structure, especially spin structure, is still unknown.

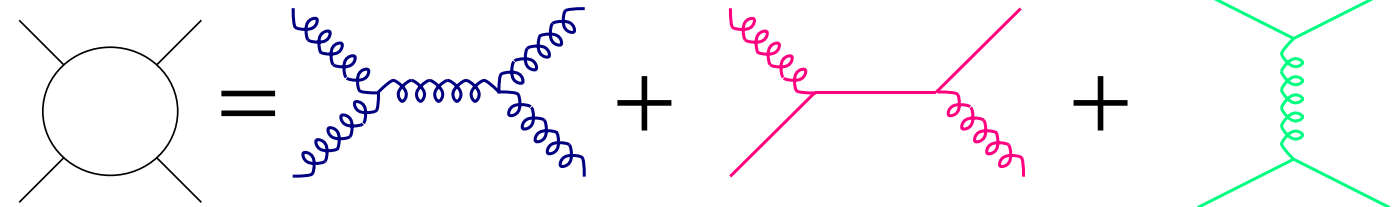
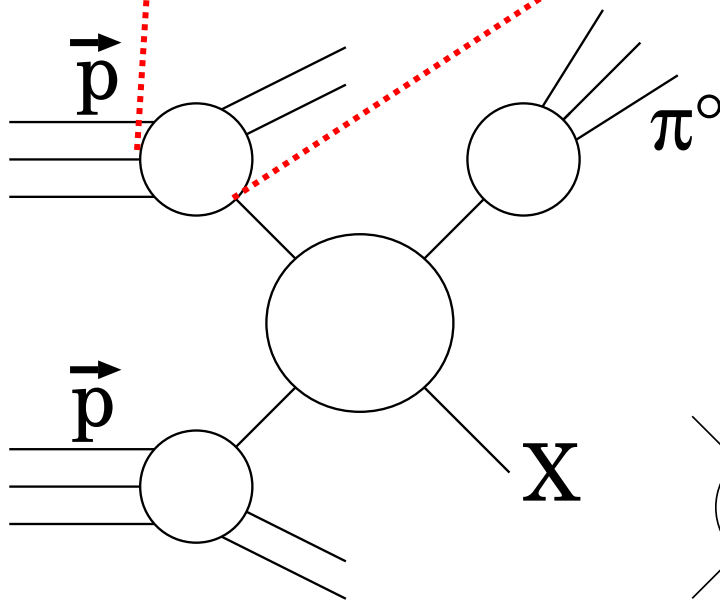


Shine a light on the gluon polarization Δg

Measure ALL in $\vec{p} \vec{p} \rightarrow \pi^0$ production.

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

$$\sim [\omega_{gg}] \left(\frac{\Delta g}{g_0}\right)^2 + [\omega_{gq}\Delta q] \left(\frac{\Delta g}{g_0}\right) + [\omega_{qq}(\Delta q)^2]$$



How to calculate A_{LL}

1. Calculate $A_{LL}(\pi^0 + \text{BG1})$ and $A_{LL}(\text{BG2})$ independently.

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

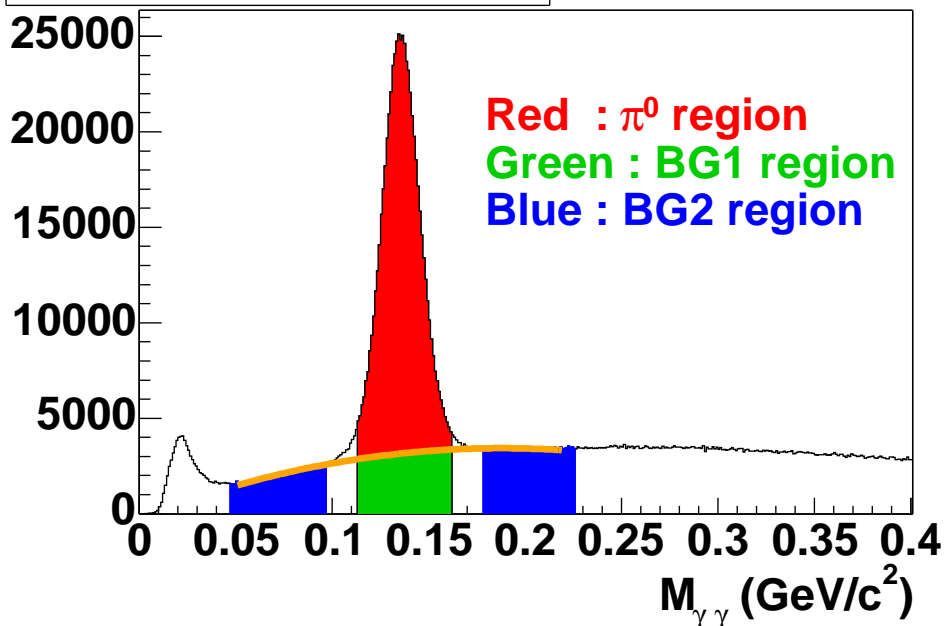
2. Fit π^0 peak to obtain fraction of π^0 .

$$w_{\pi^0} = \pi^0 / (\pi^0 + \text{BG1}). \quad (w_{BG} = 1 - w_{\pi^0})$$

3. Subtract $A_{LL}(\text{BG2})$ from $A_{LL}(\pi^0 + \text{BG1})$ and get $A_{LL}(\pi^0)$.

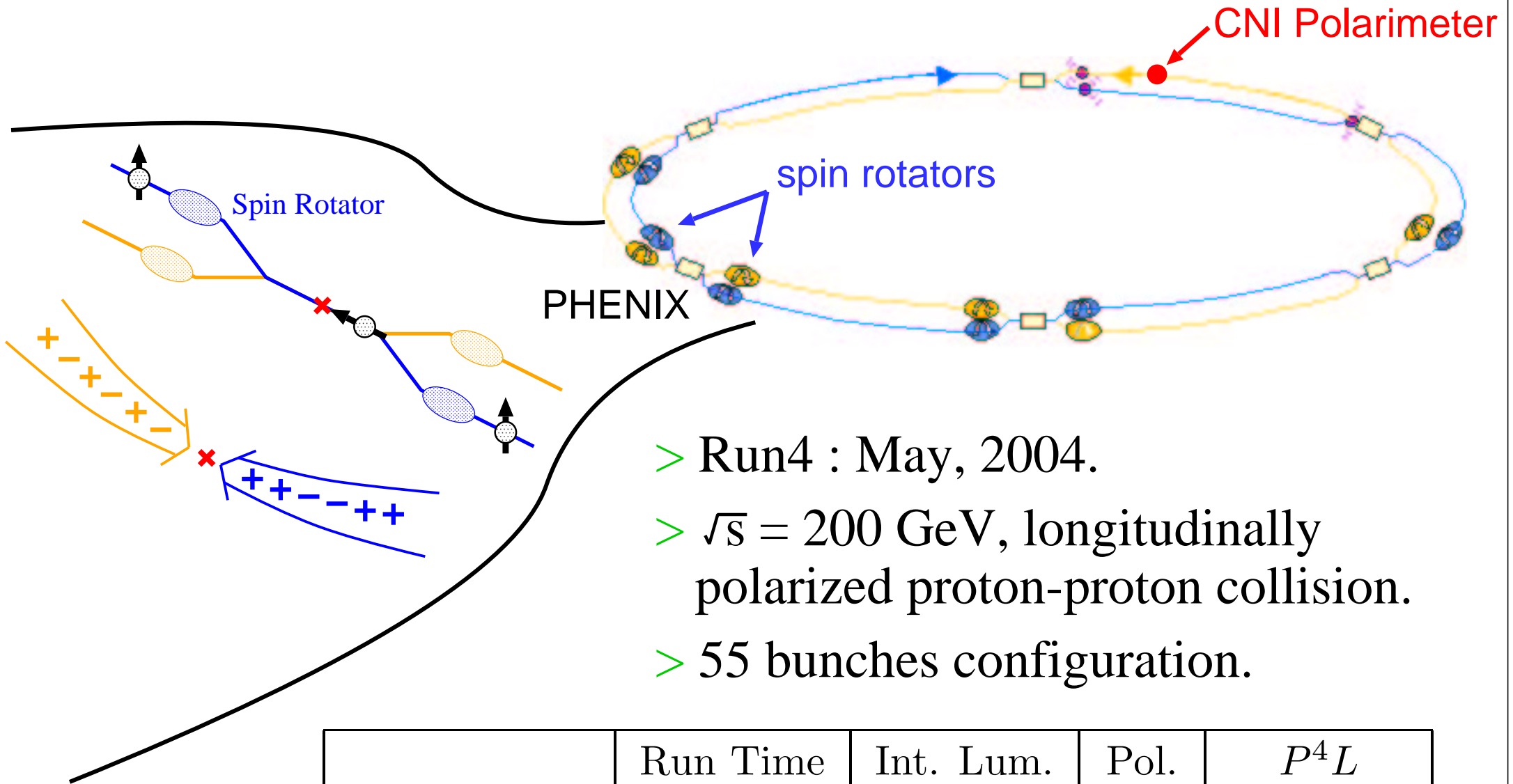
$$A_{LL}(\pi^0 + \text{BG1}) = w_{\pi^0} \cdot A_{LL}(\pi^0) + w_{BG} \cdot A_{LL}(\text{BG2})$$

Two photon invariant mass



p_T (GeV/c)	π^0 stat. (w_{BG})
1-2	1151k (31%)
2-3	510k (13%)
3-4	91k (7%)
4-5	17k (5%)

RHIC (Relativistic Heavy Ion Collider)

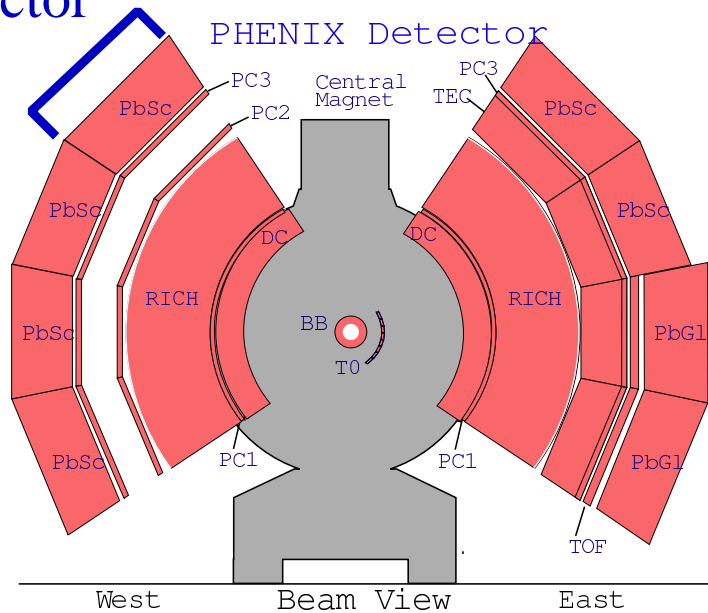


- > Run4 : May, 2004.
- > $\sqrt{s} = 200$ GeV, longitudinally polarized proton-proton collision.
- > 55 bunches configuration.

	Run Time	Int. Lum.	Pol.	P^4L
Run 3 (2003)	4 weeks	220 nb ⁻¹	27%	1.17 nb ⁻¹
Run 4 (2004)	4 days	75 nb ⁻¹	40%	1.92 nb ⁻¹

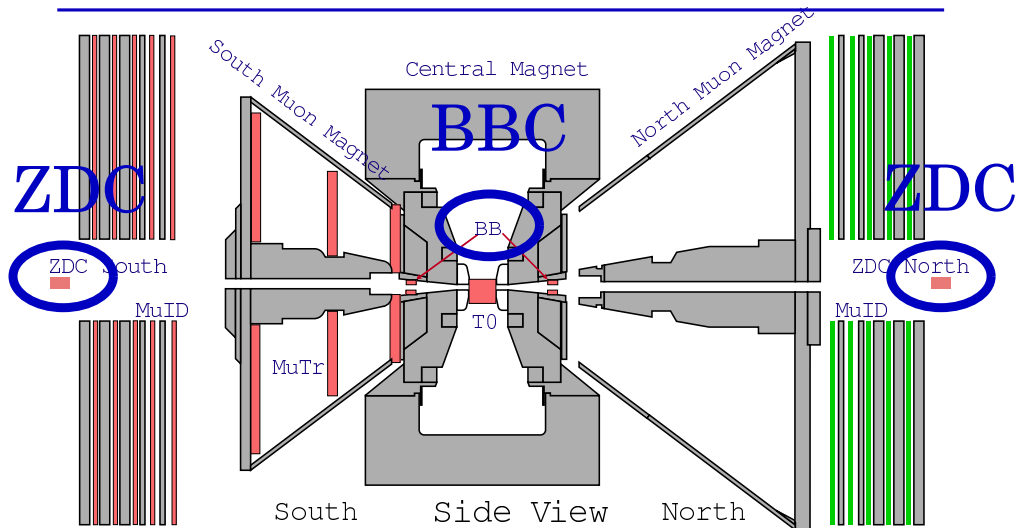
PHENIX detector

EMCal 1 sector



Electromagnetic Calorimeter (EMCal)

- > Measure photon energy and position. ($\pi^0 \rightarrow \gamma\gamma$)
- > Acceptance
 - 5m far from collision point.
 - $|\eta| < 0.35$, $\phi : 90+90$ degree.
- > PbSc(6 sectors) and PbGl(2 sectors).
Fine segmented. ($\Delta\eta \cong \Delta\phi \cong 0.01$)
- > Energy resolution
 - PbSc : $8.1\%/\sqrt{E(\text{GeV})} \oplus 2.1\%$
 - PbGl : $5.9\%/\sqrt{E(\text{GeV})} \oplus 0.8\%$
- > Position resolution
 - PbSc : $5.7\text{mm}/\sqrt{E(\text{GeV})} \oplus 1.6\text{mm}$
 - PbGl : $8.4\text{mm}/\sqrt{E(\text{GeV})} \oplus 0.2\text{mm}$



Beam-Beam Counter (BBC)

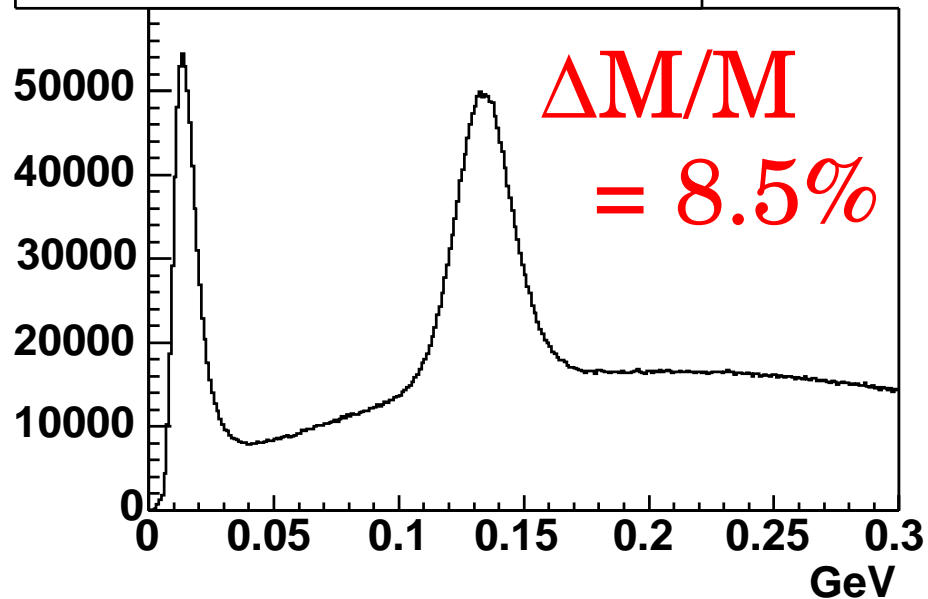
- > Used for relative luminosity measurement.
- > Acceptance : $3.0 < \eta < 3.9$

Zero Degree Calorimeter (ZDC)

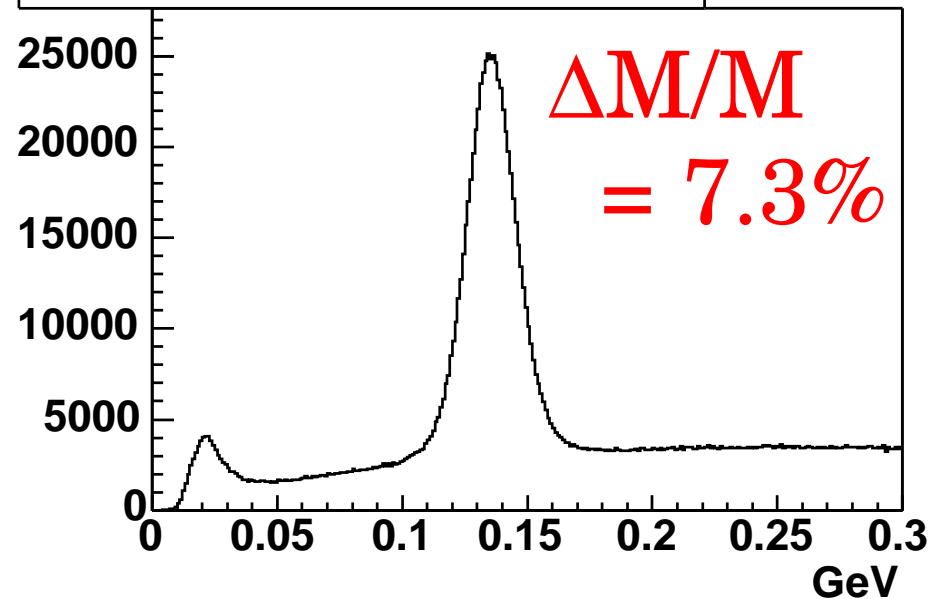
- > Used for relative luminosity measurement.
- > Acceptance : ± 2 mrad

π^0 mass spectrum

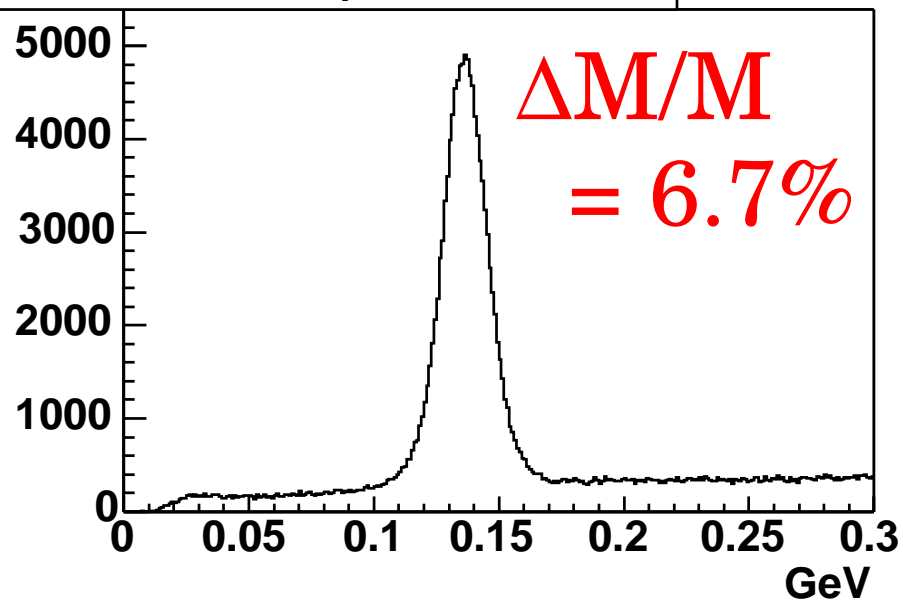
1.0 GeV/c $< p_T < 2.0$ GeV/c



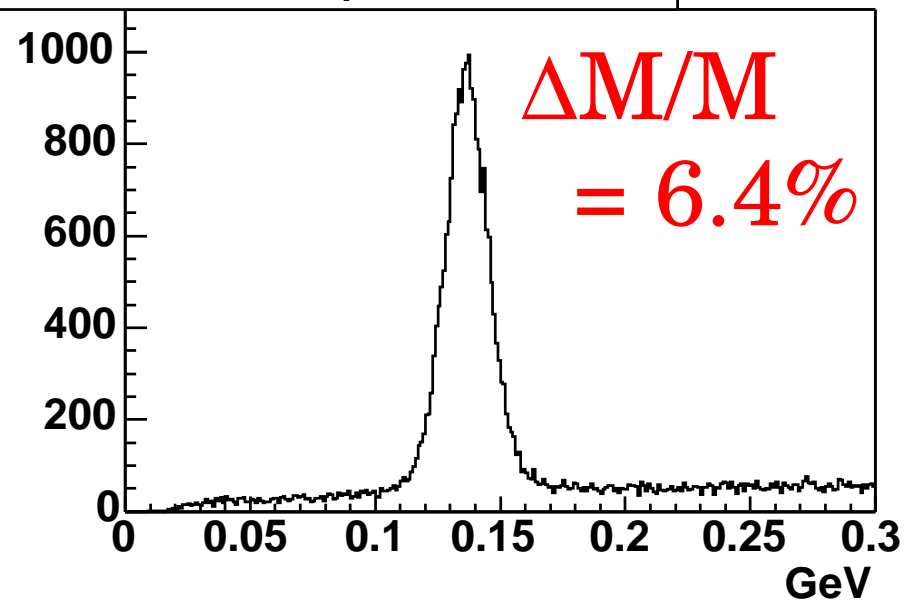
2.0 GeV/c $< p_T < 3.0$ GeV/c



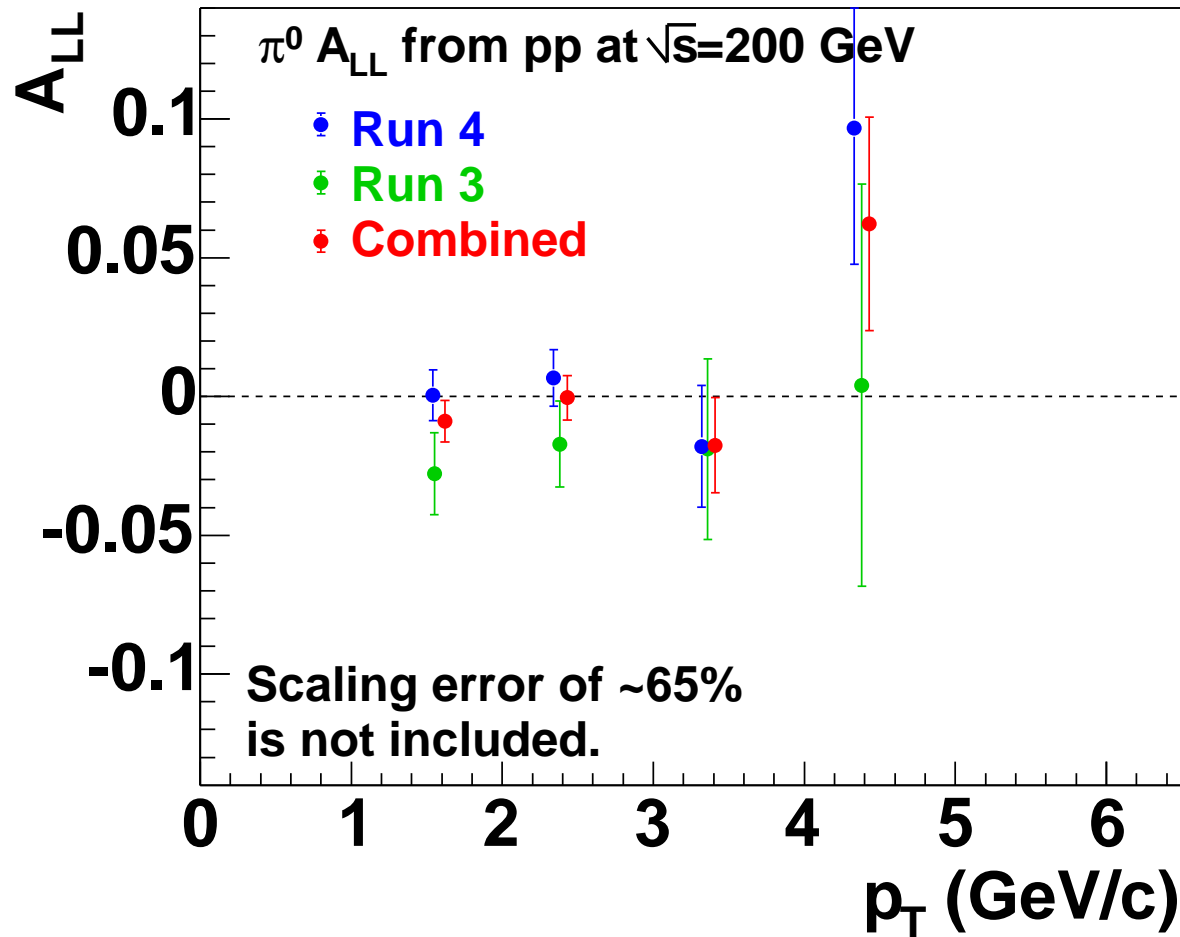
3.0 GeV/c $< p_T < 4.0$ GeV/c



4.0 GeV/c $< p_T < 5.0$ GeV/c



ALL results



Chi-square test to check consistency between Run-3 and Run-4.

—> $\chi^2/\text{NDF} = 5.7 / 4$

Figure of merit

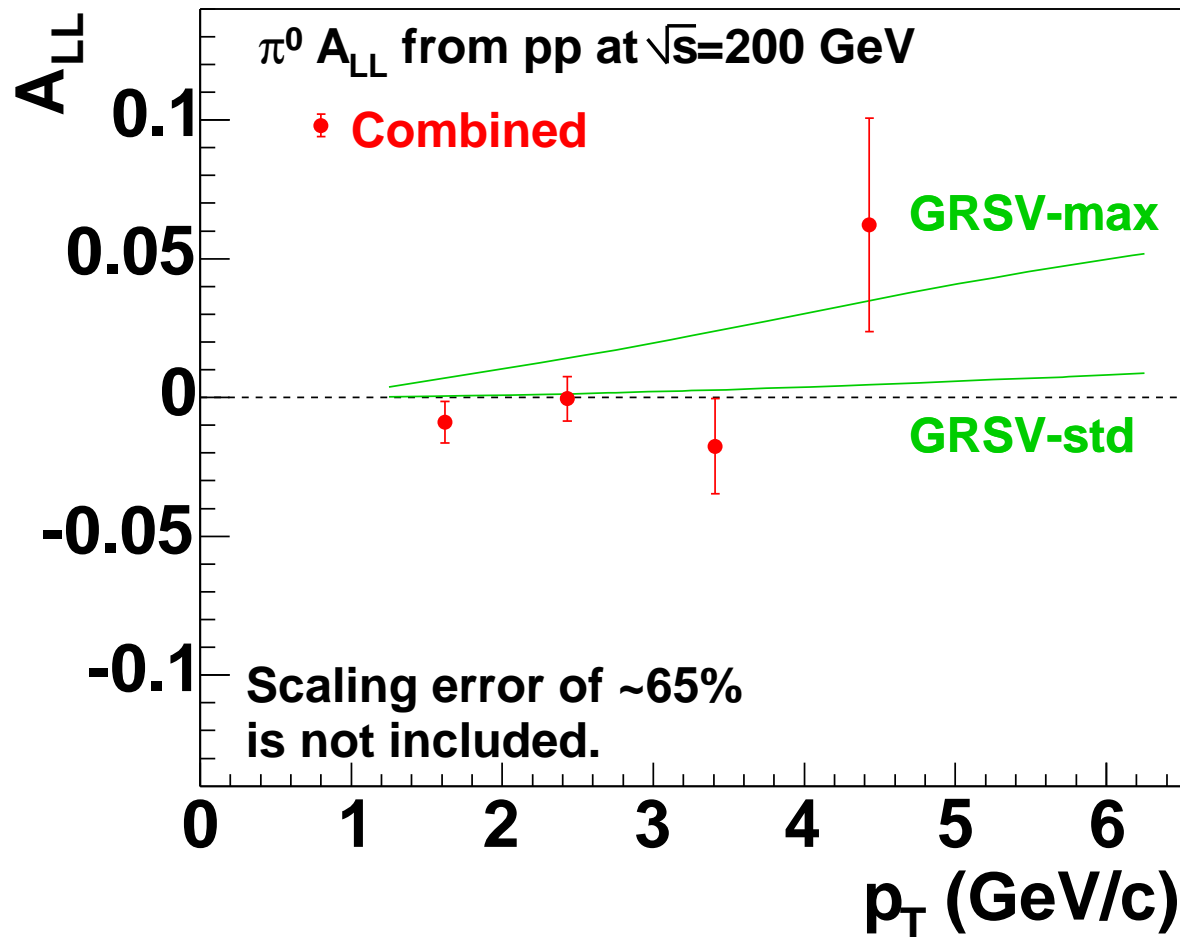
Run-3 : 1.17

Run-4 : 1.92

—> ALL uncertainty become smaller.

p_T (GeV/c)	$A_{LL}^{\pi^0}$ (Run 4) (%)	$A_{LL}^{\pi^0}$ (Run 3) (%)	$A_{LL}^{\pi^0}$ comb. (%)
1-2	0.0 ± 0.9	-2.7 ± 1.3	-0.9 ± 0.7
2-3	0.7 ± 1.0	-1.3 ± 1.3	0.0 ± 0.8
3-4	-1.8 ± 2.2	-1.7 ± 2.8	-1.8 ± 1.7
4-5	9.7 ± 4.9	0.7 ± 6.2	6.2 ± 3.8

Comparison with theory



GRSV-std :

$$\int \Delta g \, dx = 0.7 \text{ at } Q = 2.2 \text{ GeV}$$

GRSV-max :

$$\Delta g(x) = g(x) \text{ at the input scale.}$$

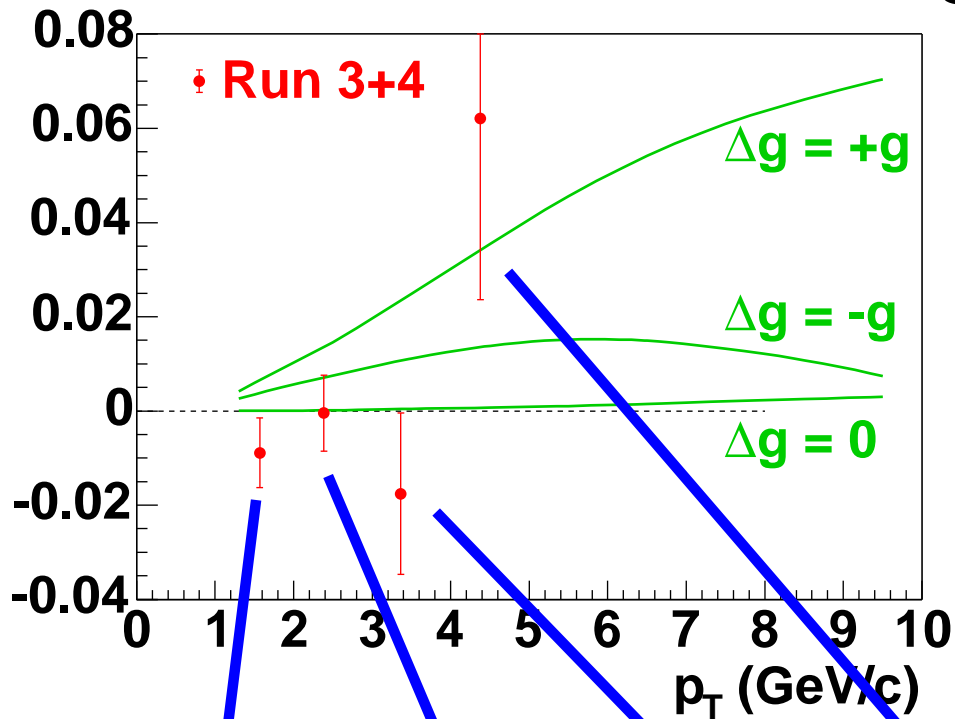
Confidence level between theory and Run-3 & Run-4 combined data shows measurement supports GRSV-std model.

(B. Jager et.al., PPhys. Rev. D67, 054005 (2003))

	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%

We got Δg ?

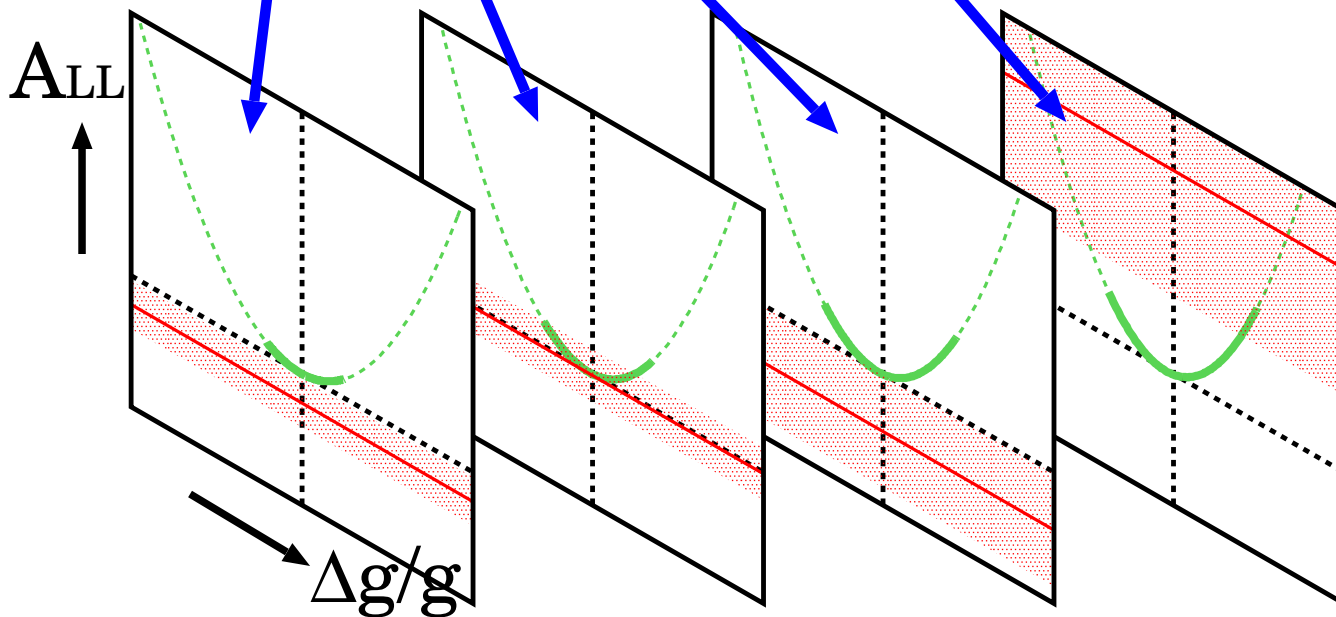
$\pi^0 A_{LL}$



$$A_{LL} \sim a \left(\frac{\Delta g}{g} \right)^2 + b \left(\frac{\Delta g}{g} \right) + c$$

A_{LL} is calculated when $\Delta g(x) = +g(x)$, $-g(x)$ and 0 at the input scale, $Q^2 = 0.4 \text{ GeV}^2$.
(W. Vogelsang, hep-ph/0405069)

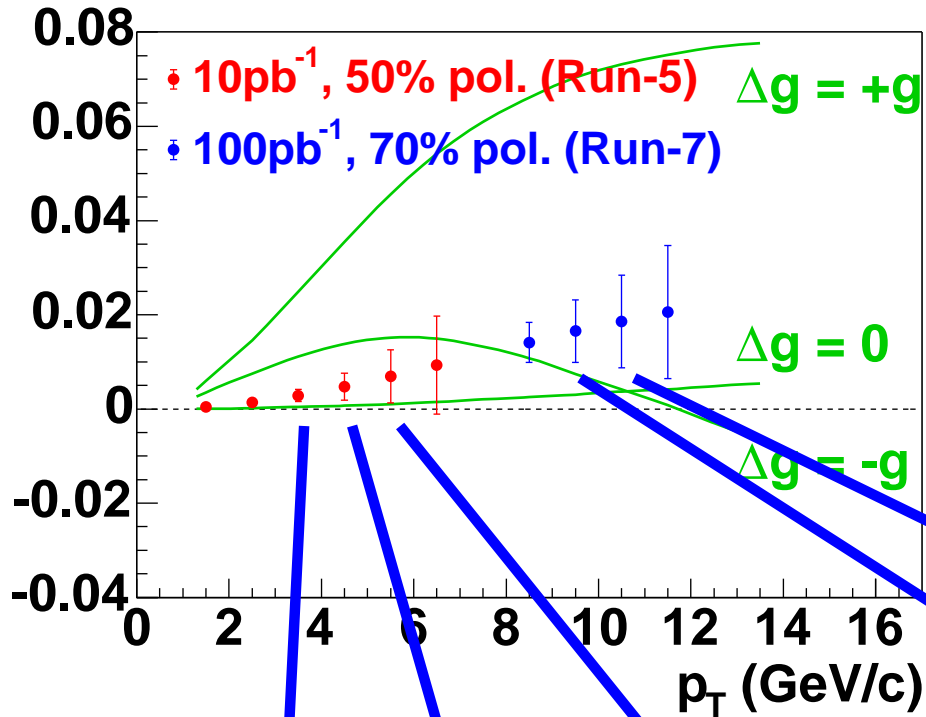
Relation of Δg and $\pi^0 A_{LL}$ is determined in this rough model.



Possible Δg corresponds to the region green curve and red band crossing.

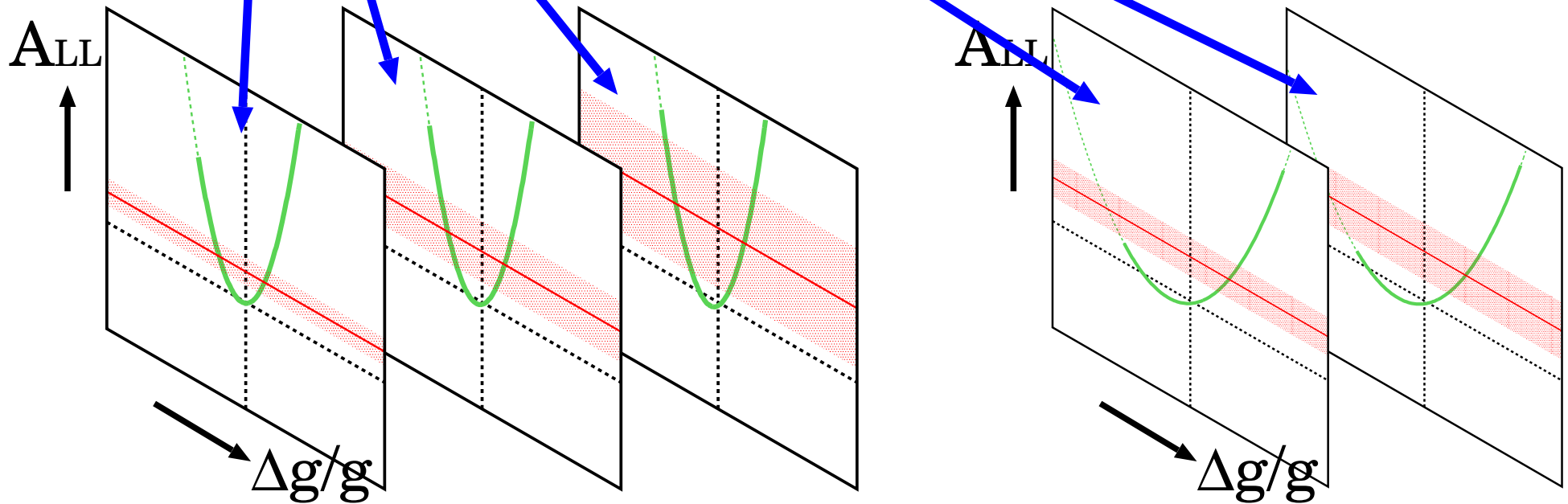
How about Run-5 ?

$\pi^0 A_{LL}$



Center of points is in case of GRSV-std.

We will get further constraints on Δg in Run 5.



Summary

We measured π^0 A_{LL} in polarized pp collisions at RHIC in May 2004.

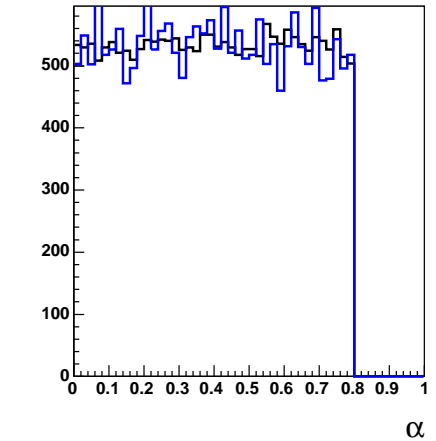
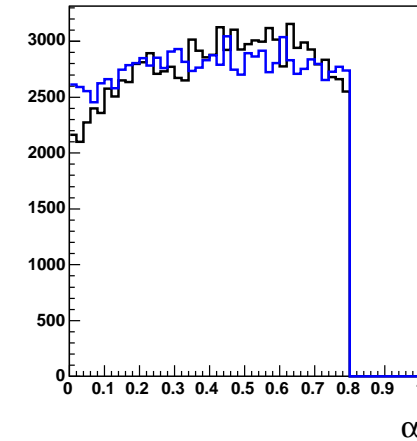
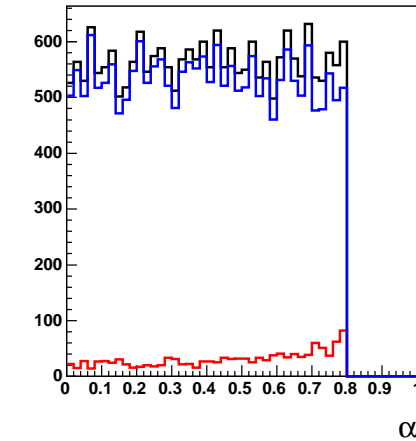
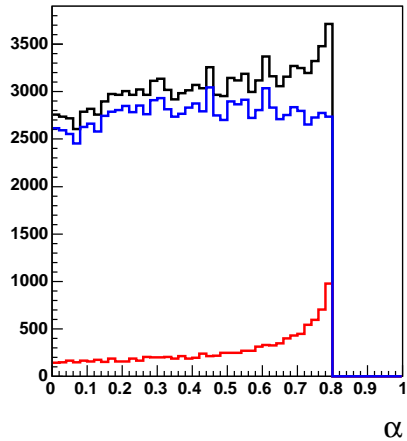
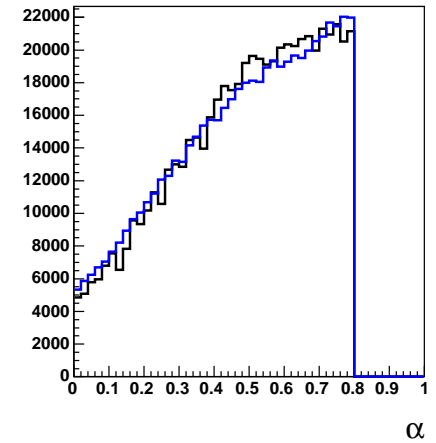
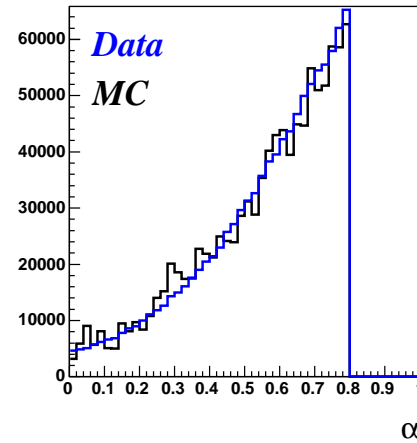
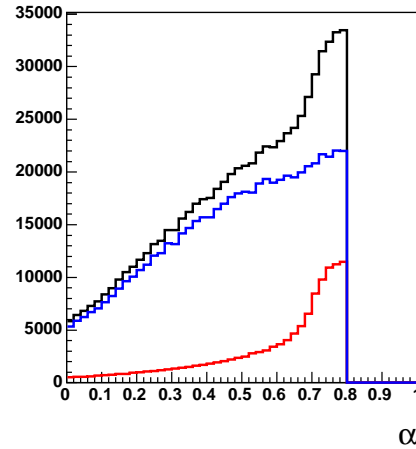
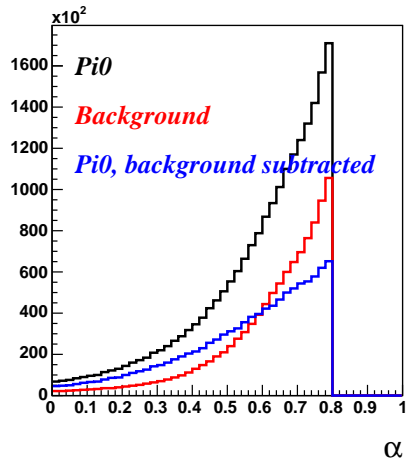
$\sqrt{s} = 200$ GeV, $1 < p_T < 5$ GeV/c, $|\eta| < 0.35$.

Though data size in Run-4 is about 1/3 of last year, uncertainty of A_{LL} becomes smaller due to higher beam polarization. In this different experimental condition, the results of Run-4 are consistent with Run-3 within error.

p_T (GeV/c)	$A_{LL}^{\pi^0}$ (Run 4) (%)	$A_{LL}^{\pi^0}$ (Run 3) (%)	$A_{LL}^{\pi^0}$ comb. (%)
1-2	0.0 ± 0.9	-2.7 ± 1.3	-0.9 ± 0.7
2-3	0.7 ± 1.0	-1.3 ± 1.3	0.0 ± 0.8
3-4	-1.8 ± 2.2	-1.7 ± 2.8	-1.8 ± 1.7
4-5	9.7 ± 4.9	0.7 ± 6.2	6.2 ± 3.8

In coming Run-5 from this winter, more precise measurement will be done and it is expected to obtain further constraints on Δg by π^0 A_{LL} .

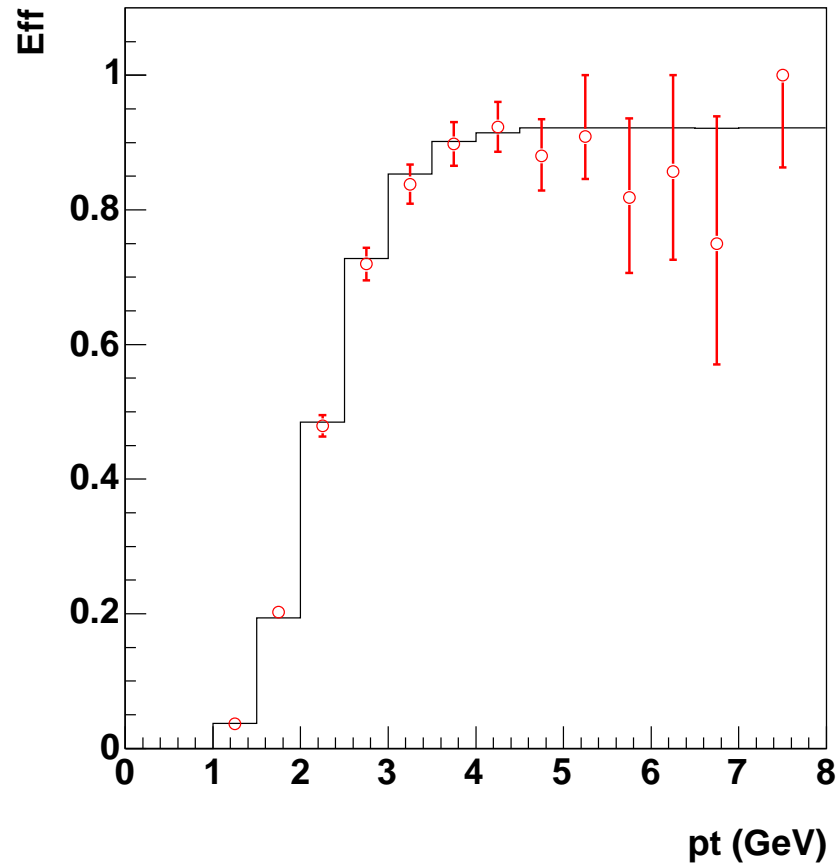
Energy asymmetry (α) comparison between MC simulation and data.



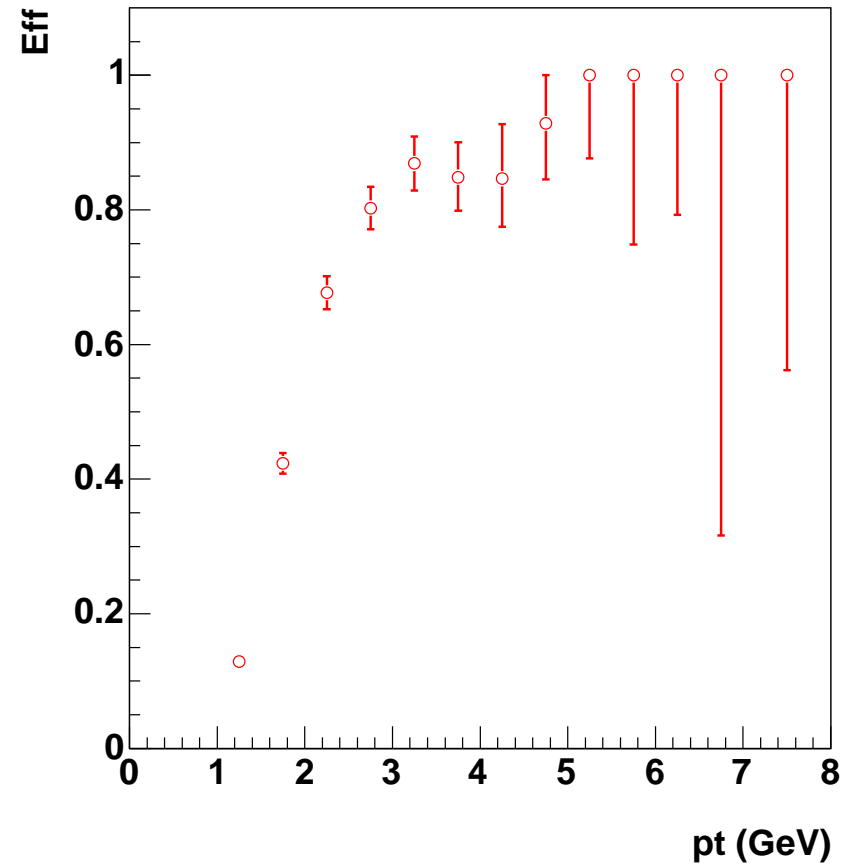
- > MC simulation matches real data well.
- > α of BG region reproduce a of BG under the π^0 peak.

Gamma3 Trigger Efficiency

PbSc efficiency



PbGl efficiency



p_T (GeV/c)	1-2	2-3	3-4	4-5
Efficiency	7%	54%	86%	90%

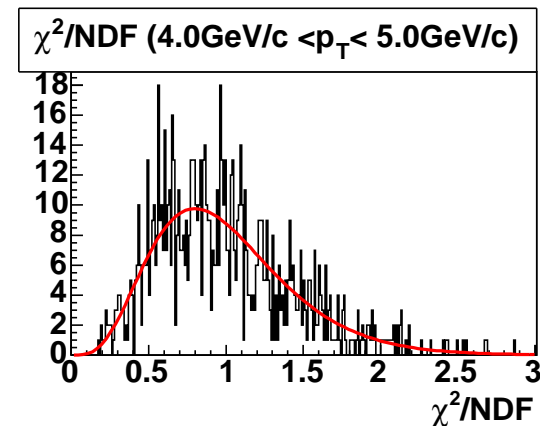
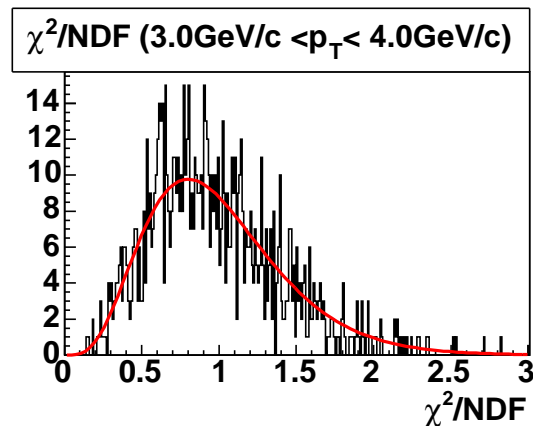
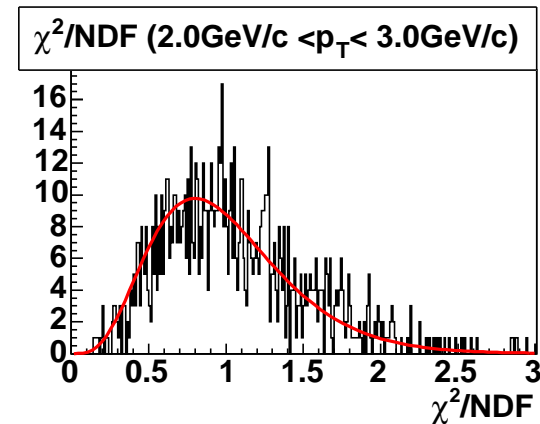
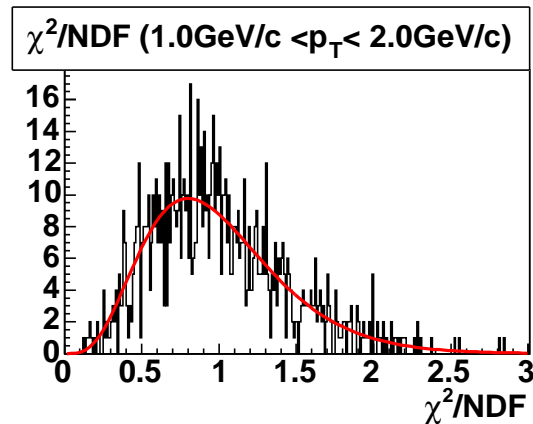
p_T (GeV/c)	1-2	2-3	3-4	4-5
Efficiency	20%	71%	86%	90%

Systematic error from bunch shuffling

Bunch shuffle :

Randomly assigns helicity for each crossing.

Check chi-square from fitting fill vs. ALL.



Reduced chi-square distribution from bunch shuffling has good agreement with statistically expected curve.
(All non-correlated syst. error are negligible compared to stat. errors)

How to measure A_{LL}

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

P : Beam Polarization

R : Relative Luminosity

$N_{++(+)}$: Yield with same(opposite) helicity

Measurement consists of 3 part.

1. P : Beam polarization

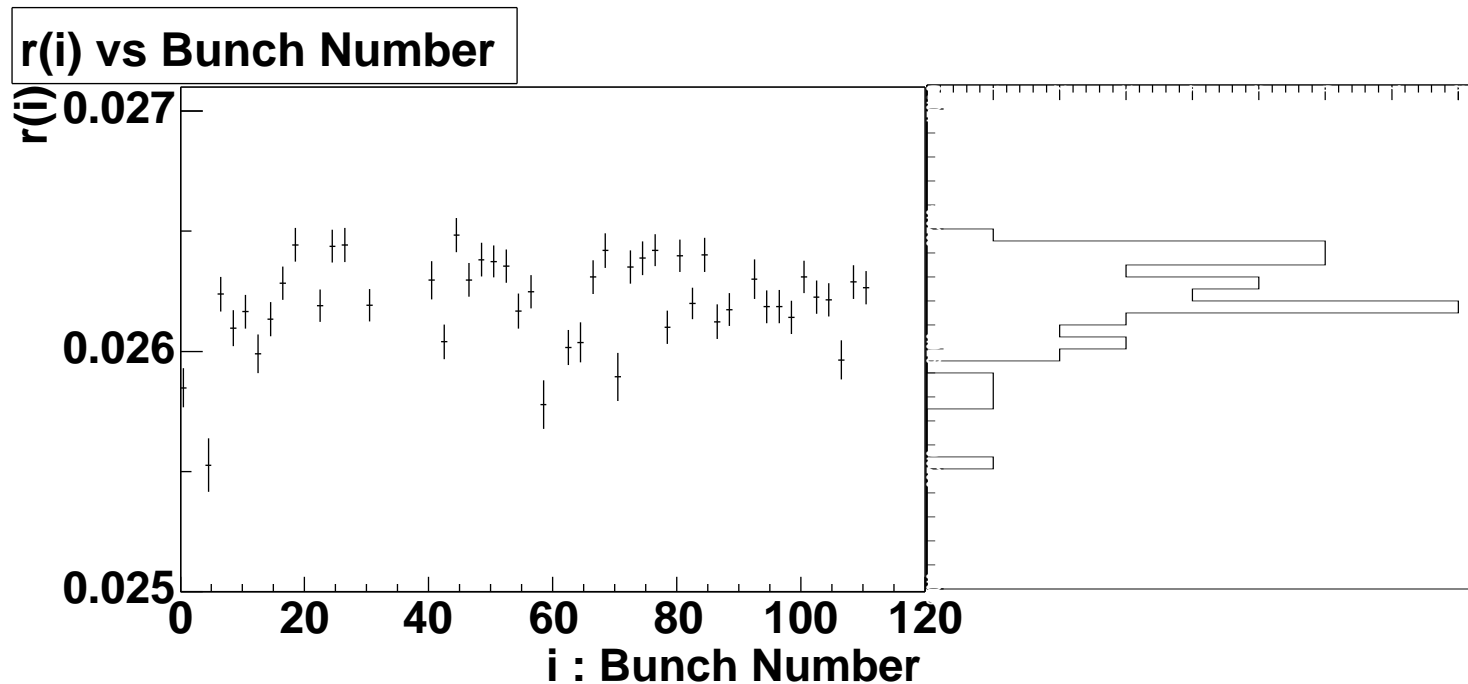
(CNI polarimeter, PHENIX Local polarimeter)

2. R : Relative luminosity (BBC and ZDC)

3. N : π^0 detection (EMCal)

Relative Luminosity

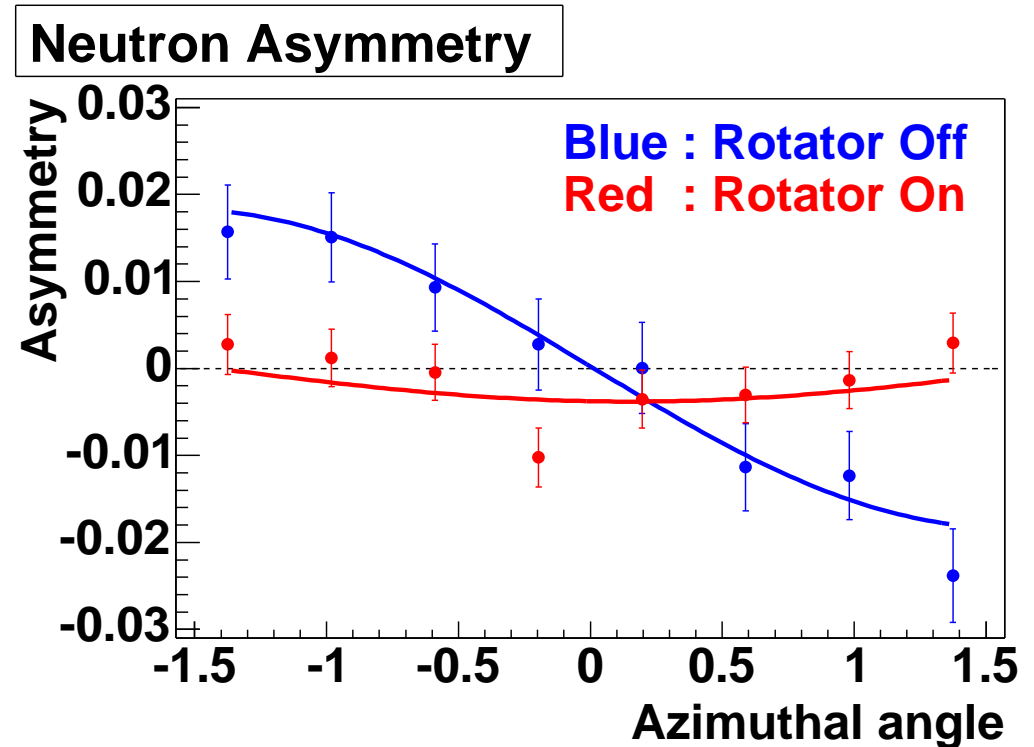
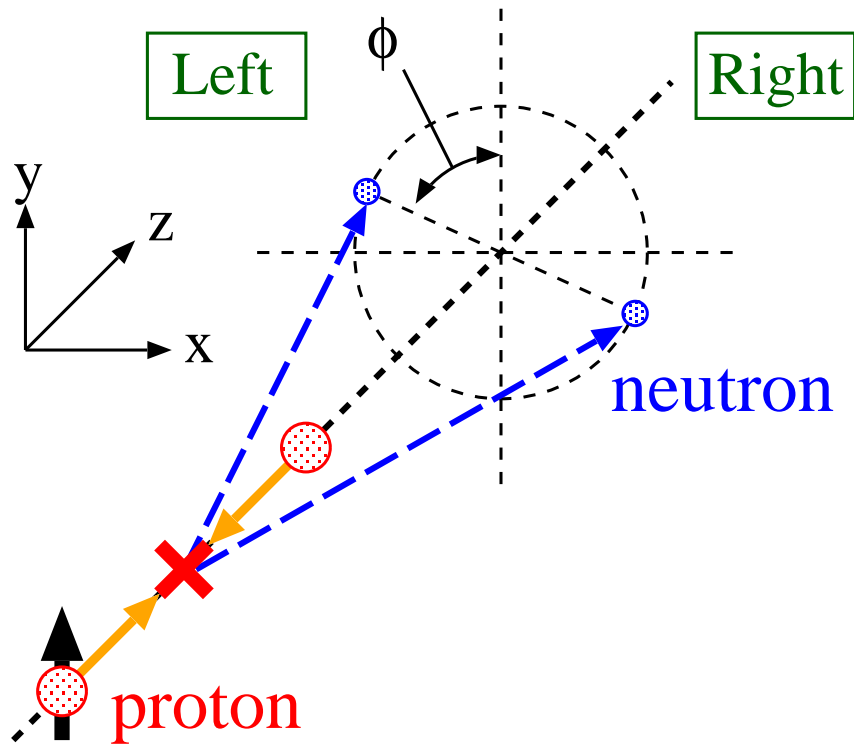
- > Number of event measured by BBC is used as R.L.
- > $r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)}$ should be constant. (i : bunch number)



$\Delta R = 5.8 \times 10^{-4} \longrightarrow \Delta A_{LL} = 1.8 \times 10^{-3}$ (in 40% polarization)
is achieved.

Longitudinal component of beam polarization

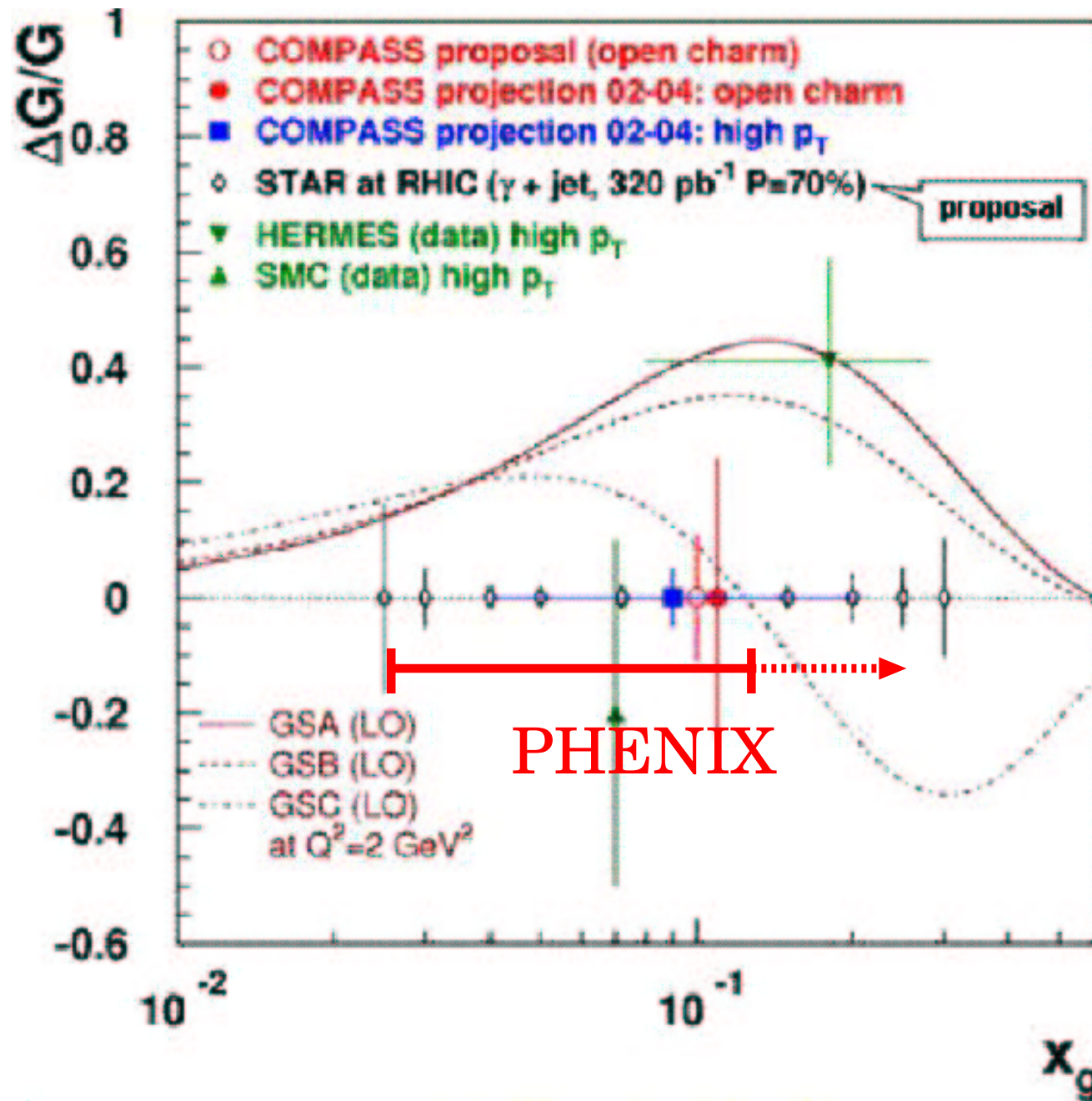
Longitudinal component of beam polarization is obtained by measuring single transverse spin asymmetry of neutrons.



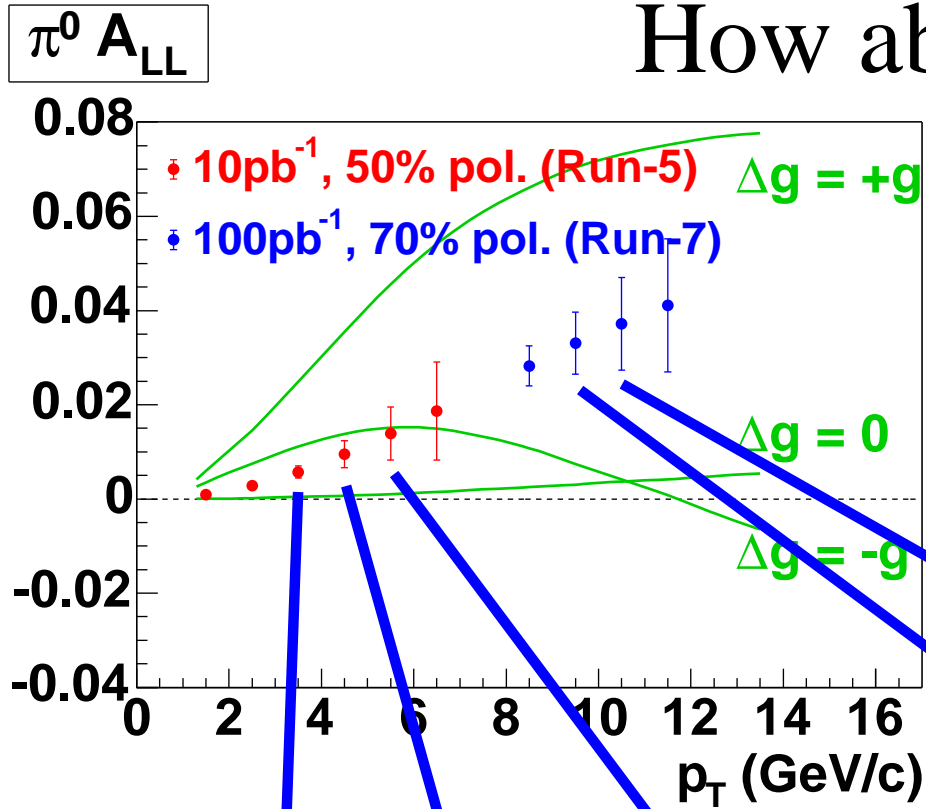
$$\langle P_{L/P} \rangle_{\text{blue}} = 99.68^{+0.21 + 0.13}_{-0.65 - 0.0}$$

$$\langle P_{L/P} \rangle_{\text{yellow}} = 99.82^{+0.16 + 0.0}_{-0.75 - 0.0}$$

x_g region by PHENIX + π^0 ALL



How about Run-5 ?



Center of points is in case of
GRSV-std x 2.

We will get further constraints
on Δg in Run 5.

