Δg measurements at PHENIX

RIKEN
Yoshinori Fukao
for the PHENIX collaboration

PHENIX

- University of São Paulo, São Paulo, Brazil
- Academia Sinica, Taipei 11529, China
- China Institute of Atomic Energy (CIAE), Beijing, P. R. China
- Peking University, Beijing, P. R. China
- Charles University, Faculty of Mathematics and Physics, Ke Karlovu 3, 12116 Prague, Czech Republic
- Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, 11519 Prague, Czech Republic
- Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 182 21 Prague, Czech Republic
- Laboratoire de Physique Corpusculaire (LPC), Universite de Clermont-Ferrand, 63 170 Aubiere, Clermont-Ferrand, France
- Dapnia, CEA Saclay, Bat. 703, F-91191 Gif-sur-Yvette, France
- IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, BP1, F-91406 Orsay, Fra
- Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS-IN2P3, Rout Saclay, F-91128 Palaiseau, France
- SUBATECH, Ecòle des Mines at Nantes, F-44307 Nantes France
- University of Muenster, Muenster, Germany
- KFKI Research Institute for Particle and Nuclear Physics at the Hungari Academy of Sciences (MTA KFKI RMKI), Budapest, Hungary
- Debrecen University, Debrecen, Hungary
- Eövös Loránd University (ELTE), Budapest, Hungary
- Banaras Hindu University, Banaras, India
- Bhabha Atomic Research Centre (BARC), Bombay, India
- Weizmann Institute, Rehovot, 76100, Israel
- Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
- Hiroshima University, Higashi-Hiroshima 739, Japan
- KEK - High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
- Kyoto University, Kyoto, Japan
- Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
- RIKEN, The Institute of Physical and Chemical Research, Wako, Saitama 351-0198, Japan
- RIKEN – BNL Research Center, Japan, located at BNL
- Physics Department, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima, Tokyo 171-8501, Japan
- Tokyo Institute of Technology, Oh-okayama, Meguro, Tokyo 152-8551, Japan
- University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi Ibaraki-ken 305-8577, Japan
- Waseda University, Tokyo, Japan
- Cyclotron Application Laboratory, KAERI, Seoul, South Korea
- Kangnung National University, Kangnung 210-702, South Korea
- Korea University, Seoul, 136-701, Korea
- Myong Ji University, Yongin City 449-728, Korea
- System Electronics Laboratory, Seoul National University, Seoul, South Korea
- Yonsei University, Seoul 120-749, Korea
- IHEP (Protvino), State Research Center of Russian Federation "Institute for High Energy Physics", Protvino 142281, Russia
- Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
- Kurchatov Institute, Moscow, Russia
- PNPI, Petersburg Nuclear Physics Institute, Gatchina, Leningrad region, 188300, Russia
- Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Vorob'evy Gory, Moscow 119992, Russia
- Saint-Petersburg State Polytechnical Univiversity, Politechnicheskayastr, 29, St. Petersburg, 195251, Russia

13 Countries; 62 Institutions; 550 Participants*

- Lund University, Lund, Sweden
- Abilene Christian University, Abilene, Texas, USA
- Brookhaven National Laboratory (BNL), Upton, NY 11973, USA
- University of California - Riverside (UCR), Riverside, CA 92521, USA
- University of Colorado, Boulder, CO, USA
- Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
- Florida Institute of Technology, Melbourne, FL 32901, USA
- Florida State University (FSU), Tallahassee, FL 32306, USA
- Georgia State University (GSU), Atlanta, GA, 30303, USA
- University of Illinois Urbana-Champaign, Urbana-Champaign, IL, USA
- Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
- Los Alamos National Laboratory (LANL), Los Alamos, NM 87545, USA
- Lawrence Livermore National Laboratory (LLNL), Livermore, CA 94550, USA
- University of New Mexico, Albuquerque, New Mexico, USA
- New Mexico State University, Las Cruces, New Mexico, USA
- Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Department of Physics and Astronomy, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37831, USA
- University of Tennessee (UT), Knoxville, TN 37996, USA
- Vanderbilt University, Nashville, TN 37235, USA

*as of March 2005

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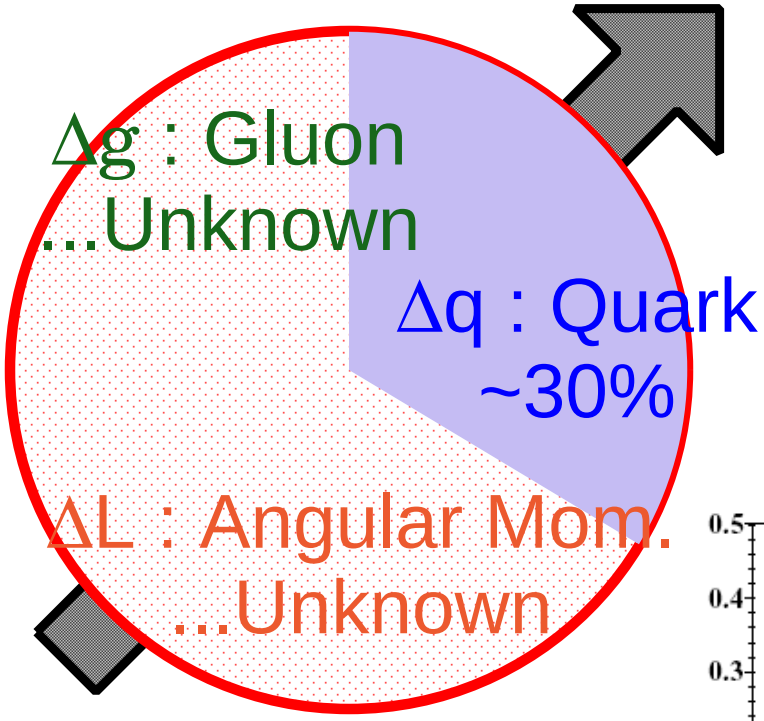
Motivation



Measure polarized parton distributions in the proton.

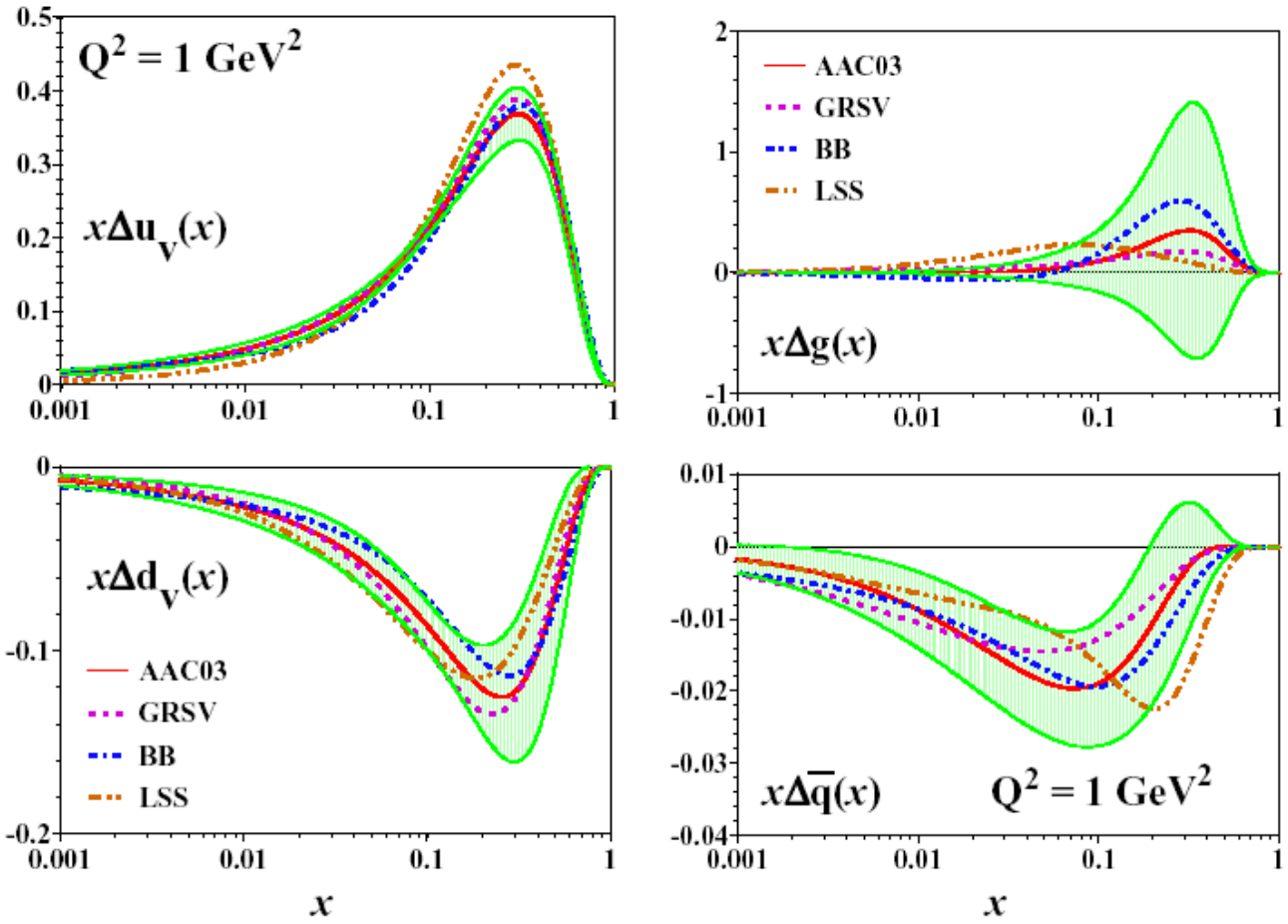
Uncertainty of Δg and $\Delta\bar{q}$ is large.

I will concentrate on Δg.

$$\Delta f(x) = f_+^+(x) - f_+^-(x)$$

$f_+^{+(-)}(x)$:

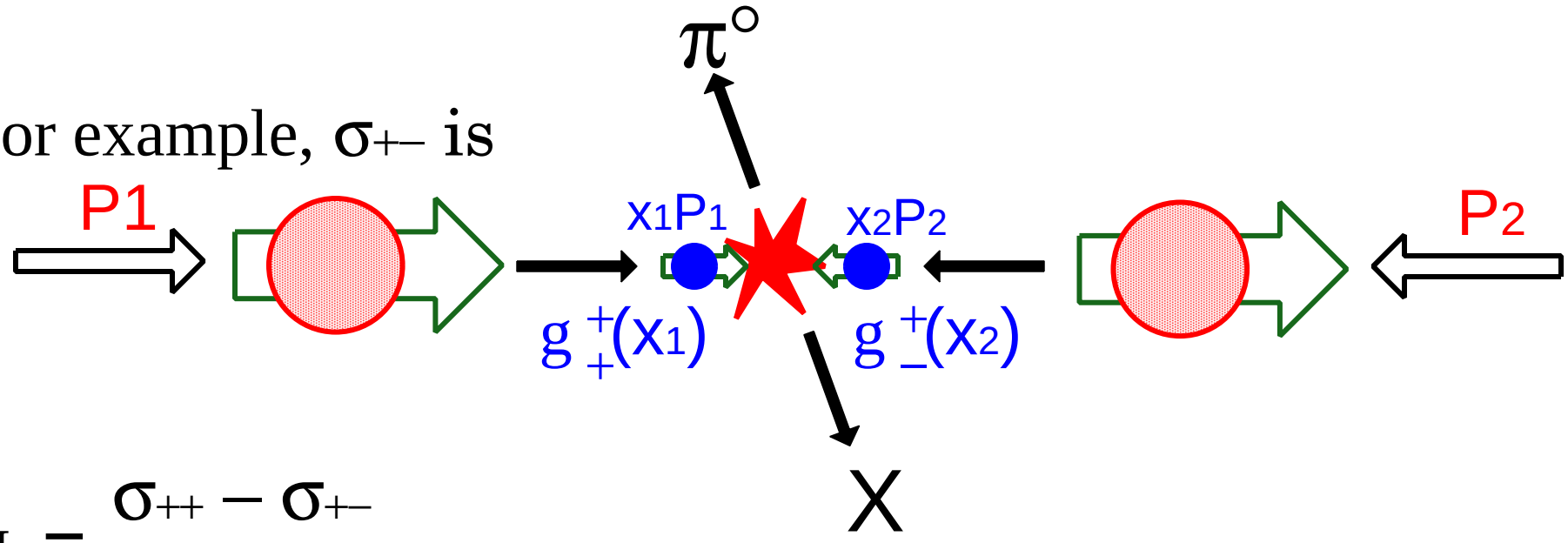
Probability distribution to detect spin+ parton in the spin+ proton as a function of Bjorken x.



How to measure Δg

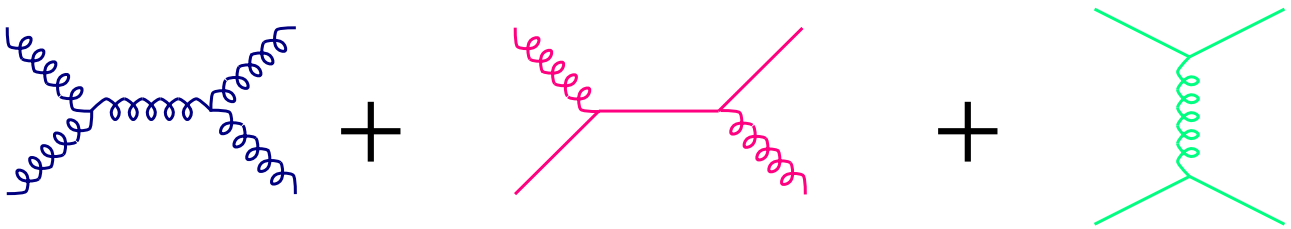
Measure A_{LL} in the production of any probes from the collision of longitudinally polarized protons.

For example, σ_{+-} is



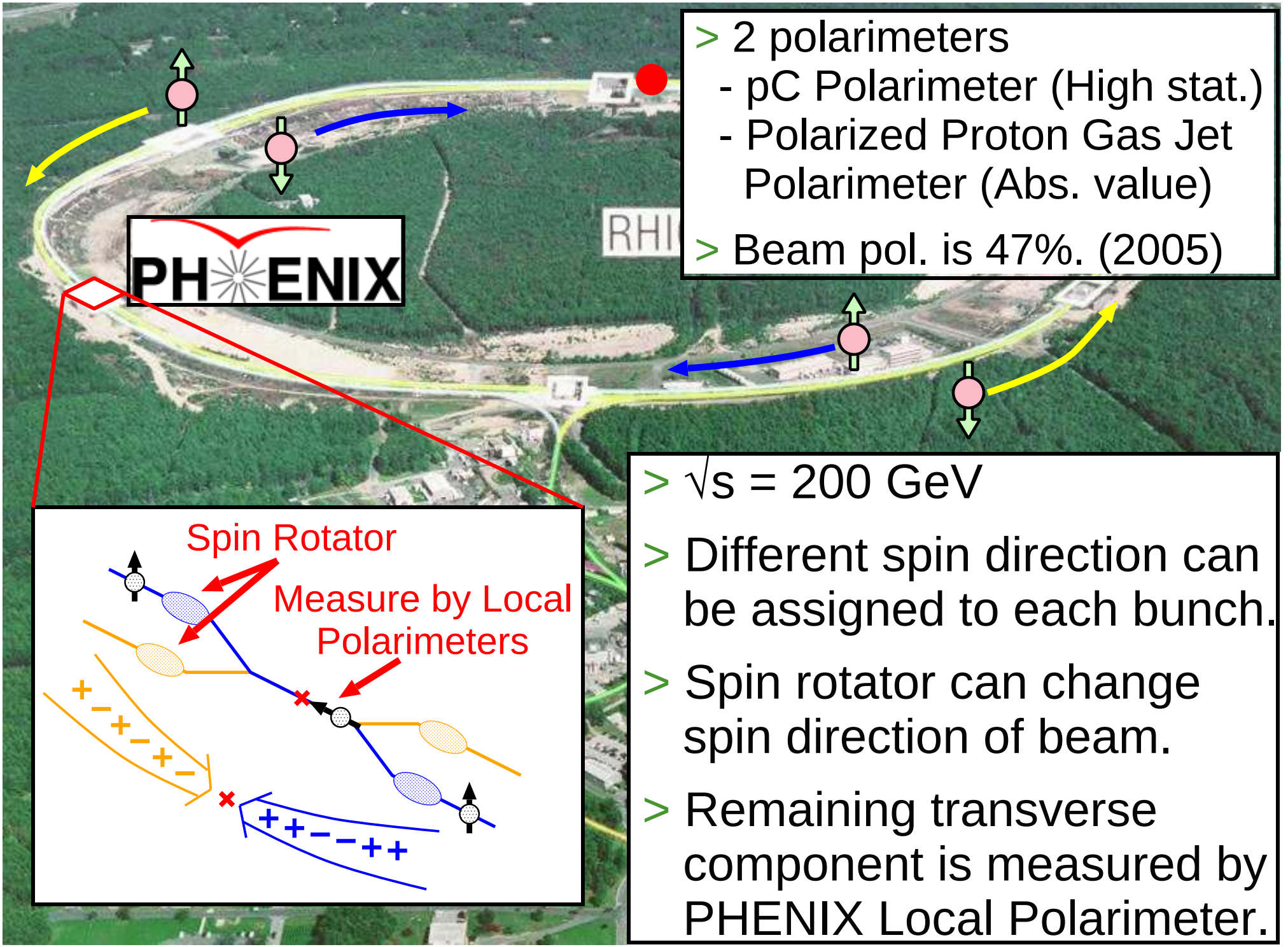
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

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



RHIC

RHIC



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

> Beam pol. is 47%. (2005)

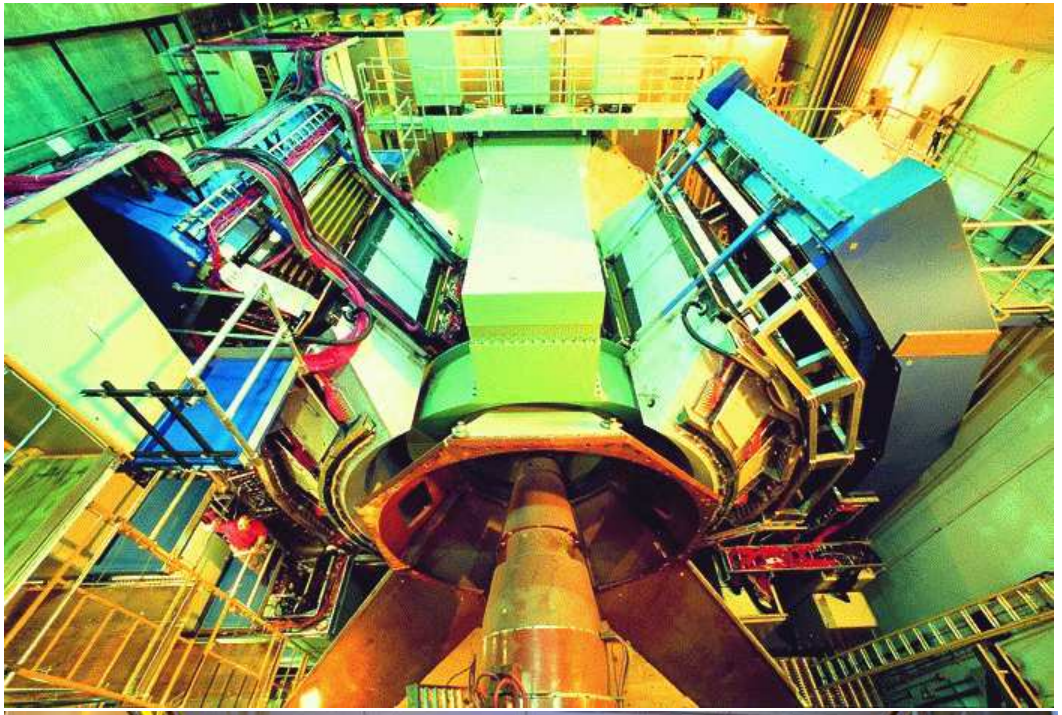
> $\sqrt{s}$ = 200 GeV

> 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

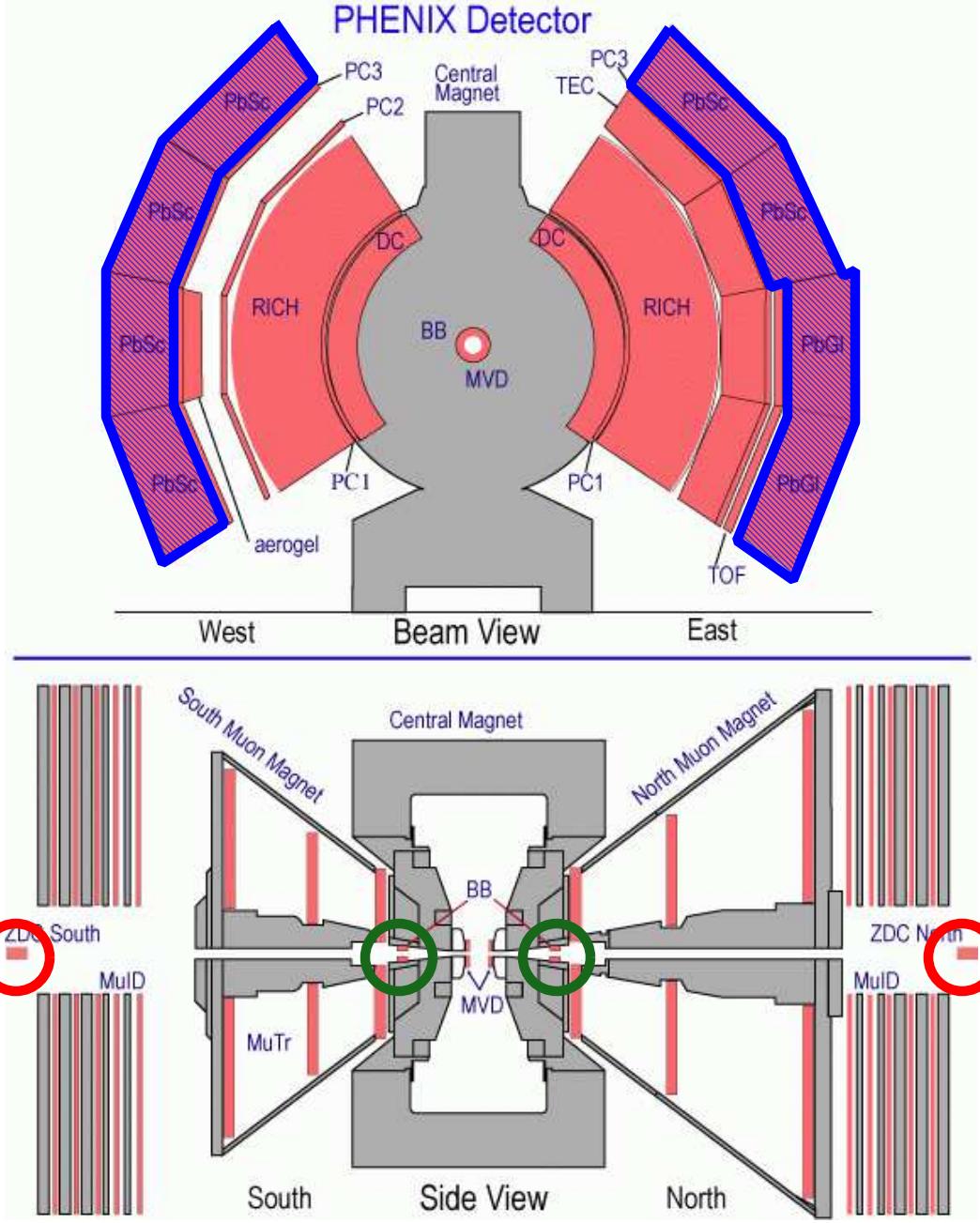


Beam-Beam-Counter &
Zero Degree Counter
> BBC : $3.0 < |\eta| < 3.9$
> ZDC : $|\eta| > 6.6$ ($\theta < 2.8$mrad)
> Minmum Bias Trigger (BBC)
> Relative Luminosity (BBC&ZDC)
> Local Polarimeter (ZDC)
> Physics : Neutron (ZDC)

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

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

PHENIX



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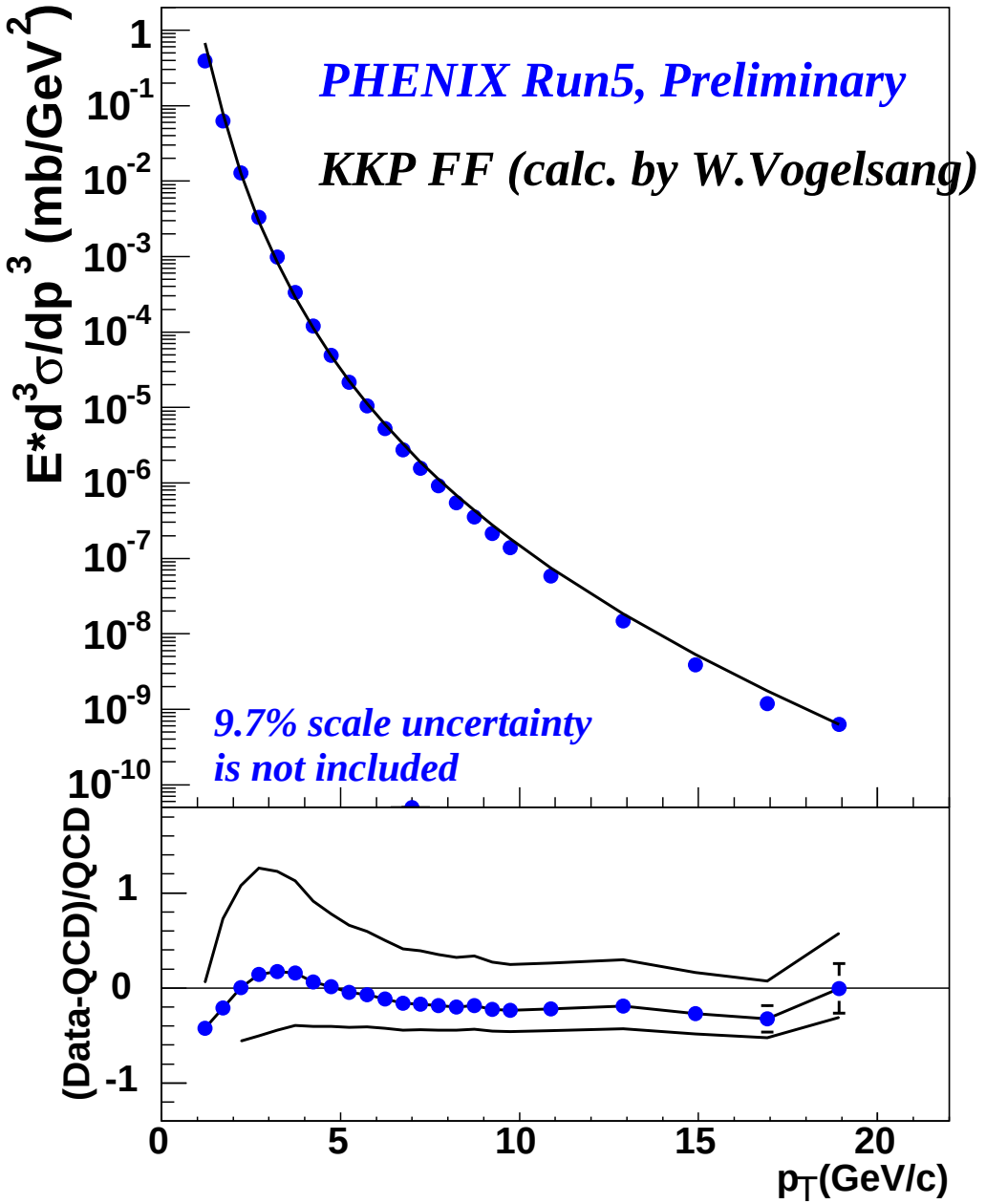
> Physics : muon, J/ψ, W

π° Cross Section

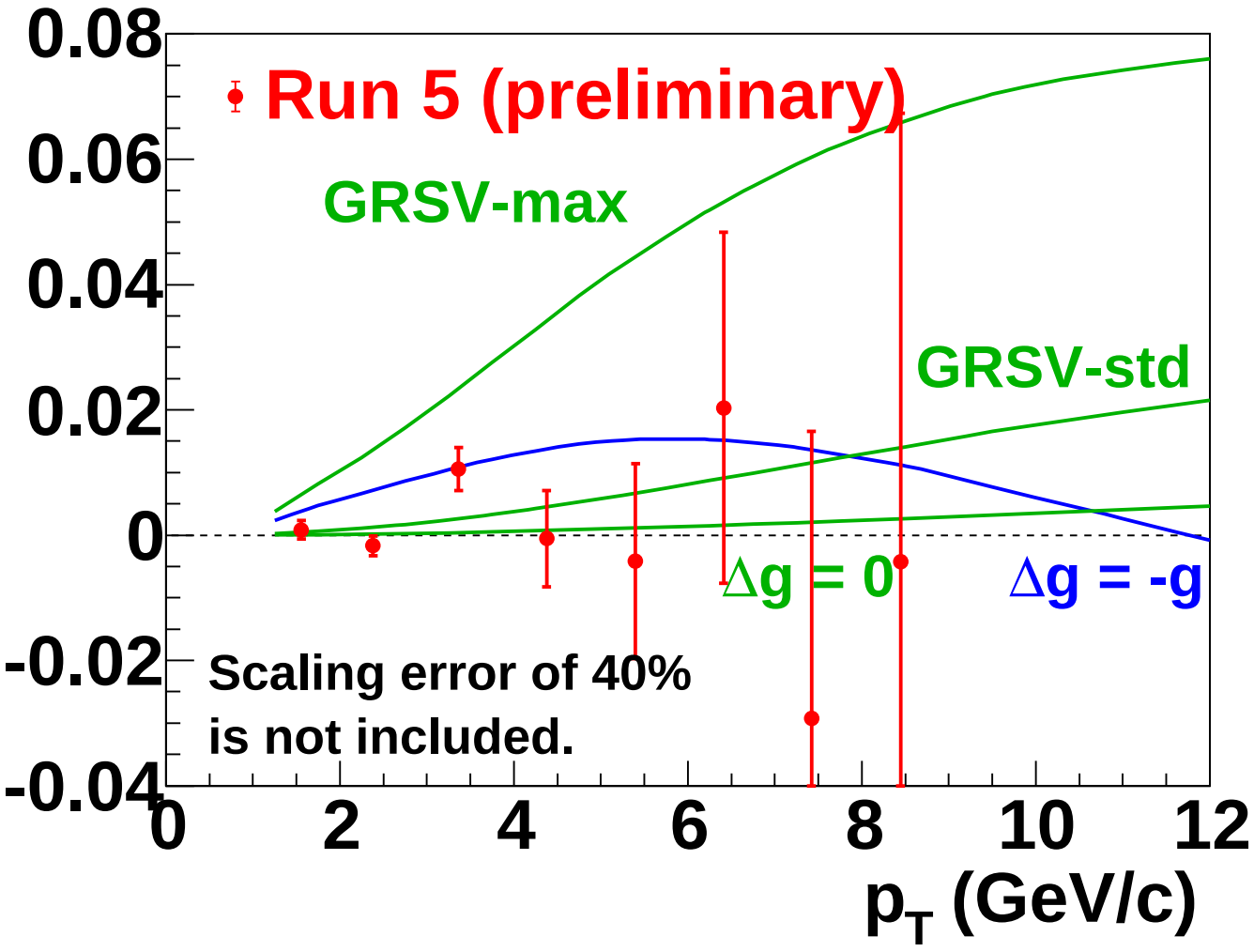
> Data points extend from 1 to 20 GeV/c in pT.

> pQCD calculation with KKP FF describes the data well over all measured pT region. (range of 10^9)

> The cross section of other channel, for example charged pion, is also useful to test pQCD.



π° A_{LL}

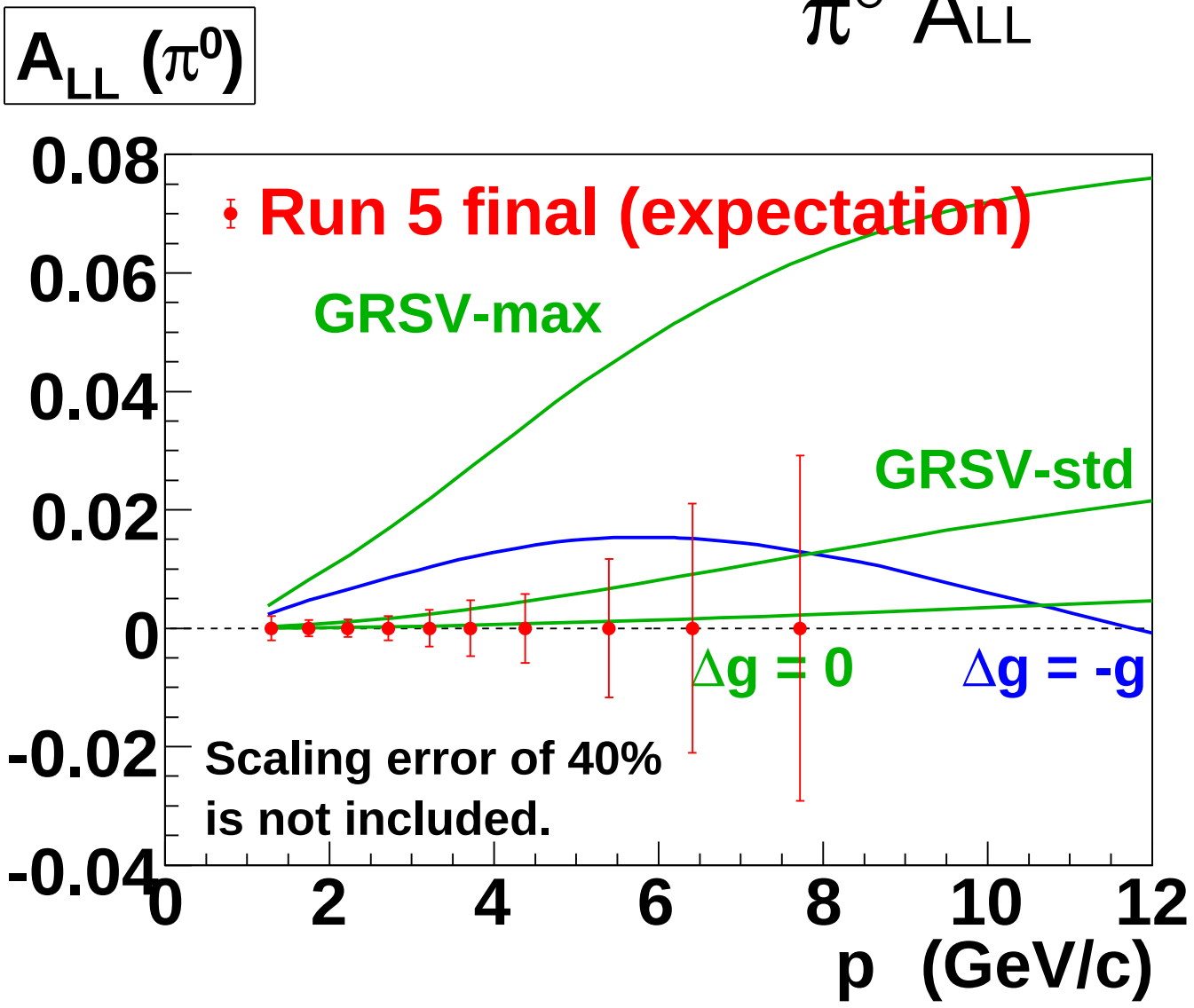


Theory Model	C.L. (%)
GRSV-std	21.7-17.1
GRSV-max	0.0-0.0
GRSV $\Delta g = 0$	16.7-18.4
GRSV $\Delta g = -g$	0.7-0.0

Out results exclude the GRSV-max. More statistics is needed

C.L. is dominated by lower pT bins where pQCD calculation may be suspect. That's why we are trying to test pQCD with other channels.

π° A_{LL}



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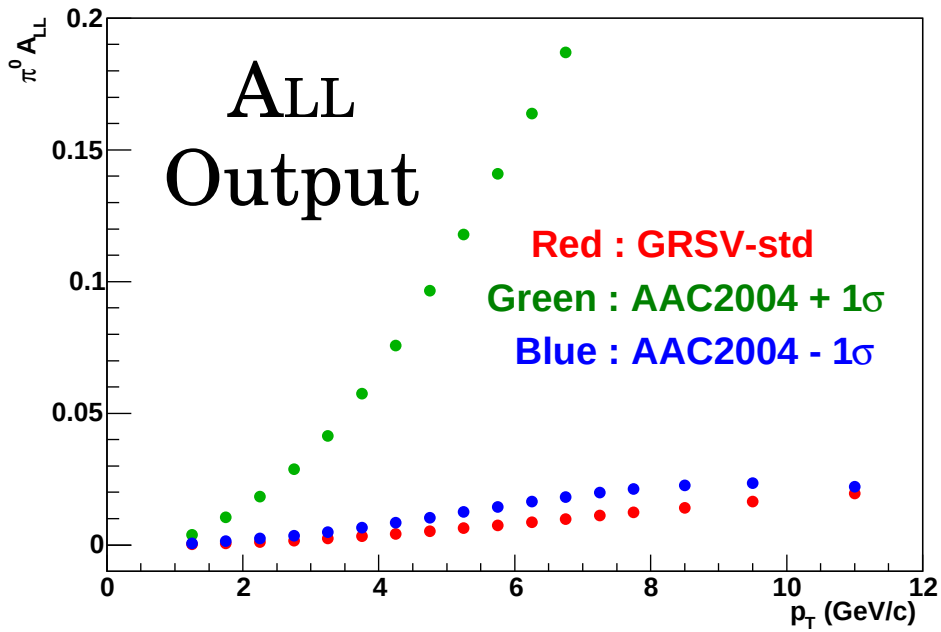
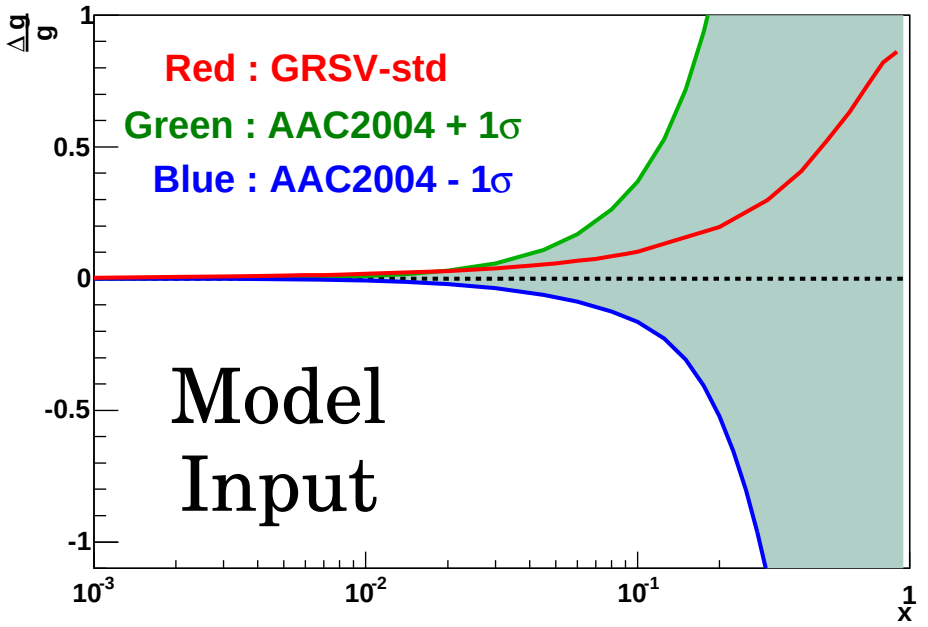
Δg extraction with simple model





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

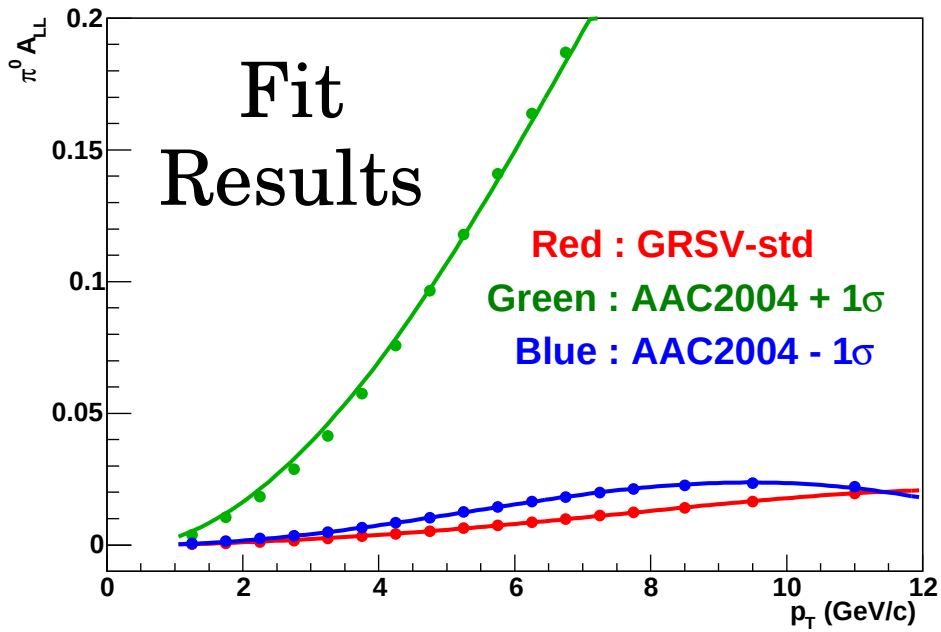
a, b, c and $\langle x_{bjorken} \rangle$ can be extracted as a function of pT from several models of Δg. (Thanks to M. Stratmann, W. Vogelsang et. al.)

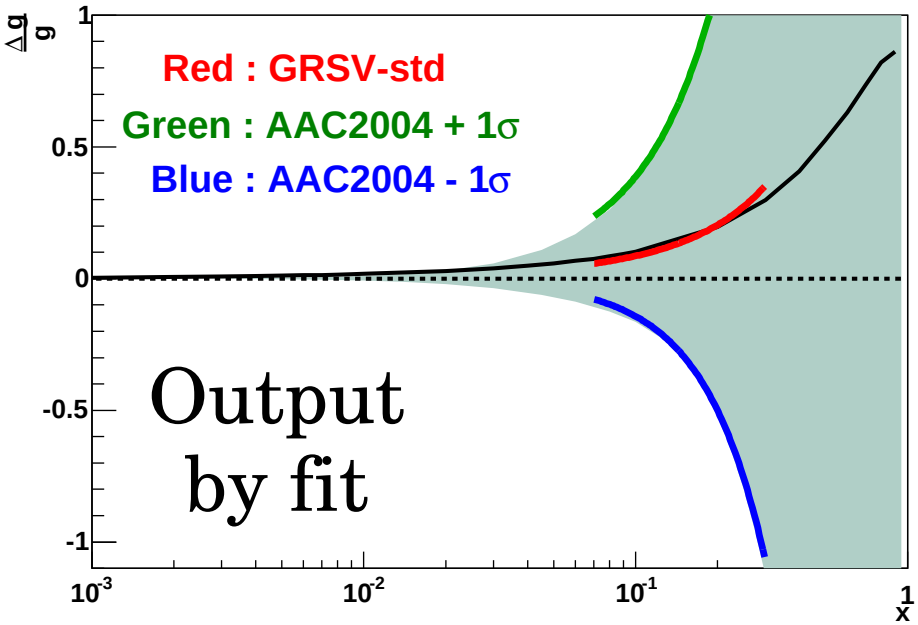
Assume $\left(\frac{\Delta g}{g}\right)$ is independent from Q^2.

Fit function

$$\left(\frac{\Delta g}{g}\right) = A\langle x \rangle^2 + B\langle x \rangle$$

Δg extraction with simple model





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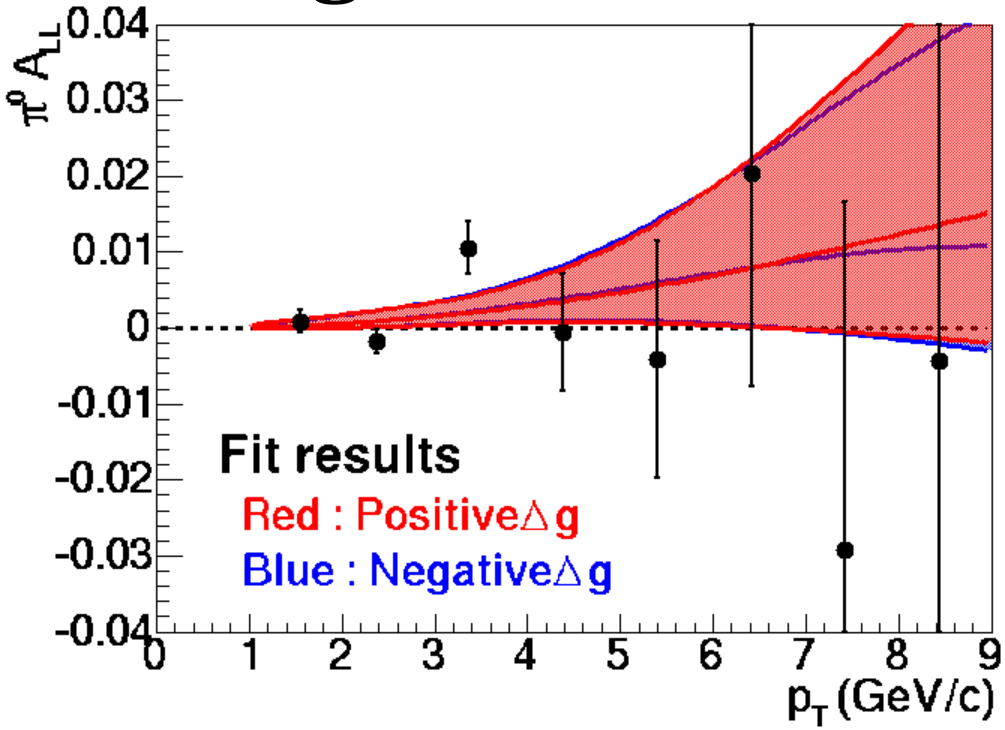
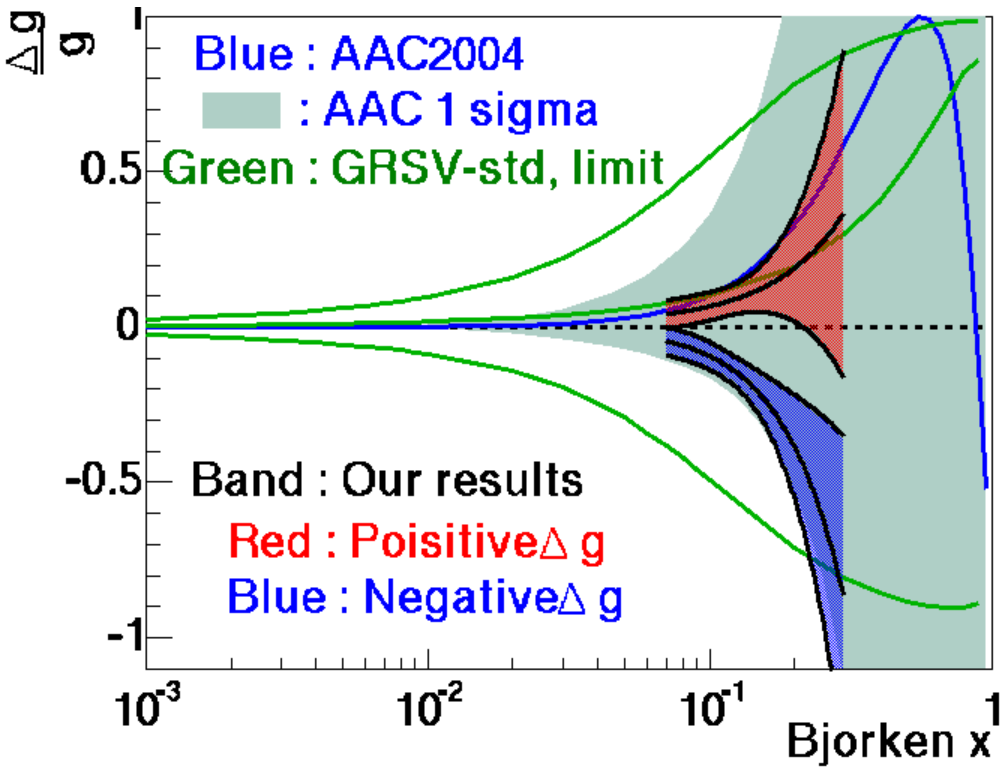
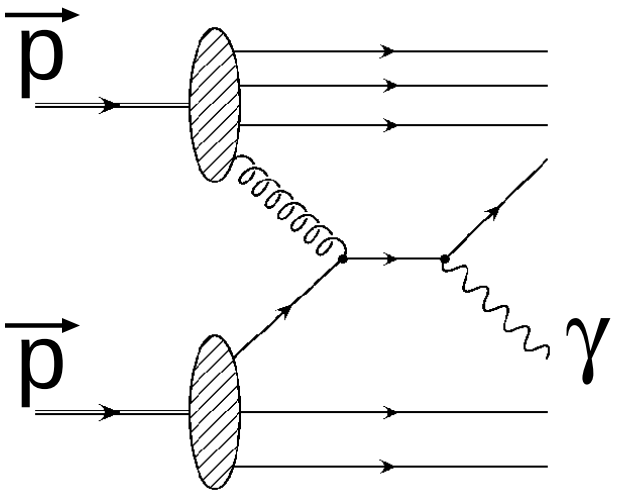




Two solutions for Δg from π° are obtained since ALL is quadratic equation of Δg
--> Other approaches are needed.

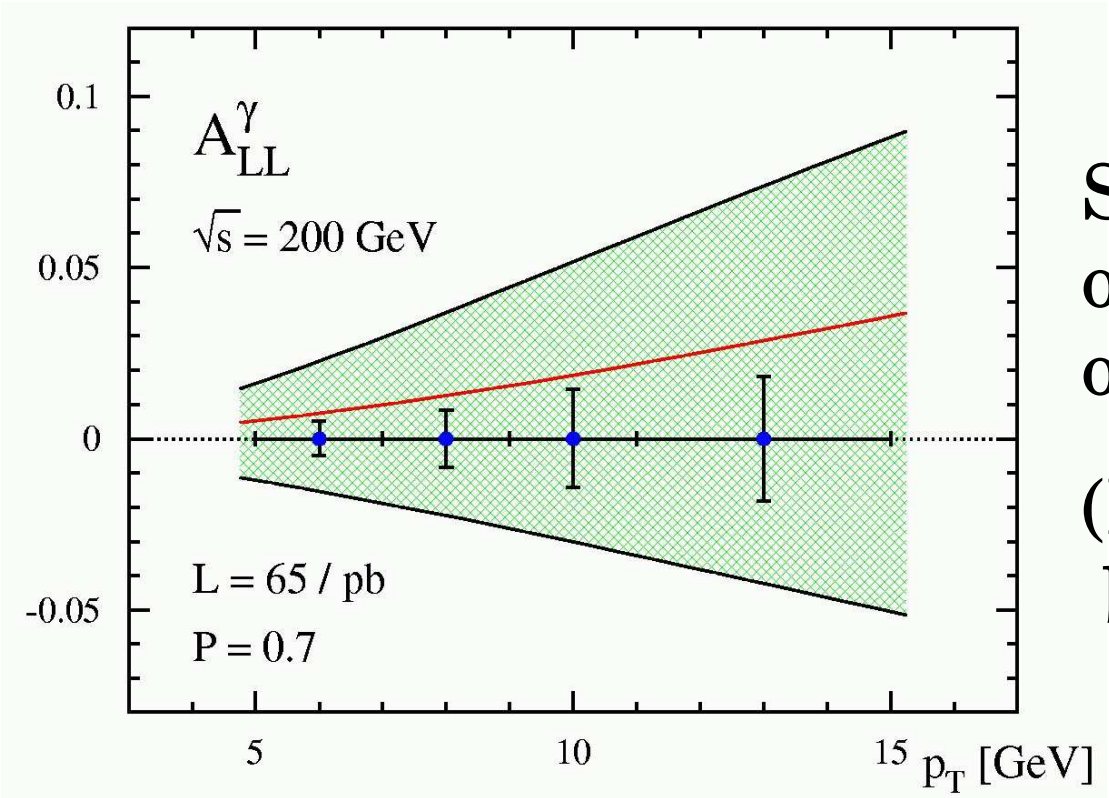
Our measurement covers limited x region.
--> ALL with √s=500 GeV can reach smaller x and it will constrain the error of negative Δg.
(M. Hirai et. al., hep-ph/0603213)

A_{LL} of Direct-Photon



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

A_{LL} can be described as linear equation of Δg due to no gluon fusion process.
---> Disentangle
the sign of Δg.



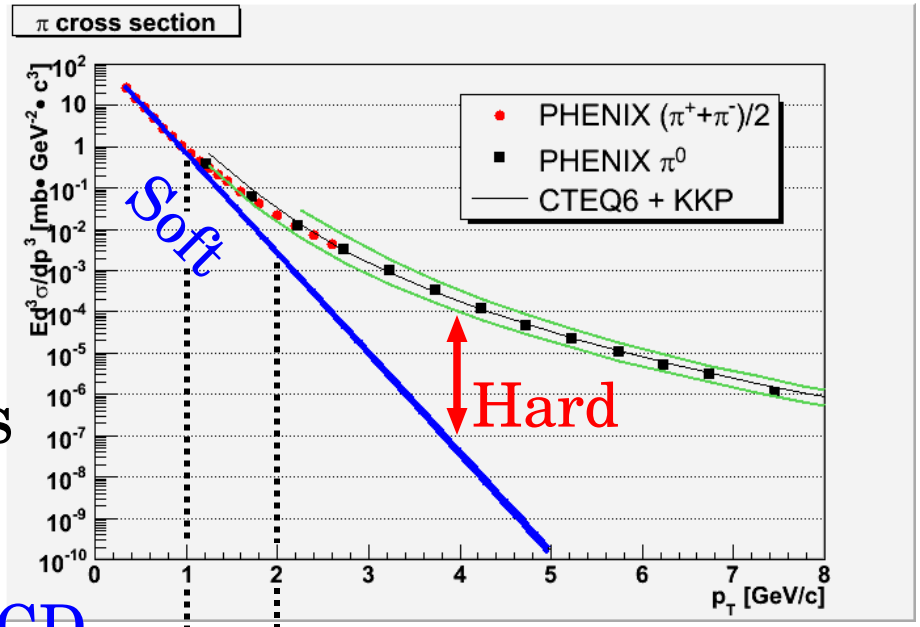
Significant measurement of Direct-Photon A_{LL} will be obtained in the near future.

(Presice measurement will be done by π° A_{LL}.)

ALL of charged pion

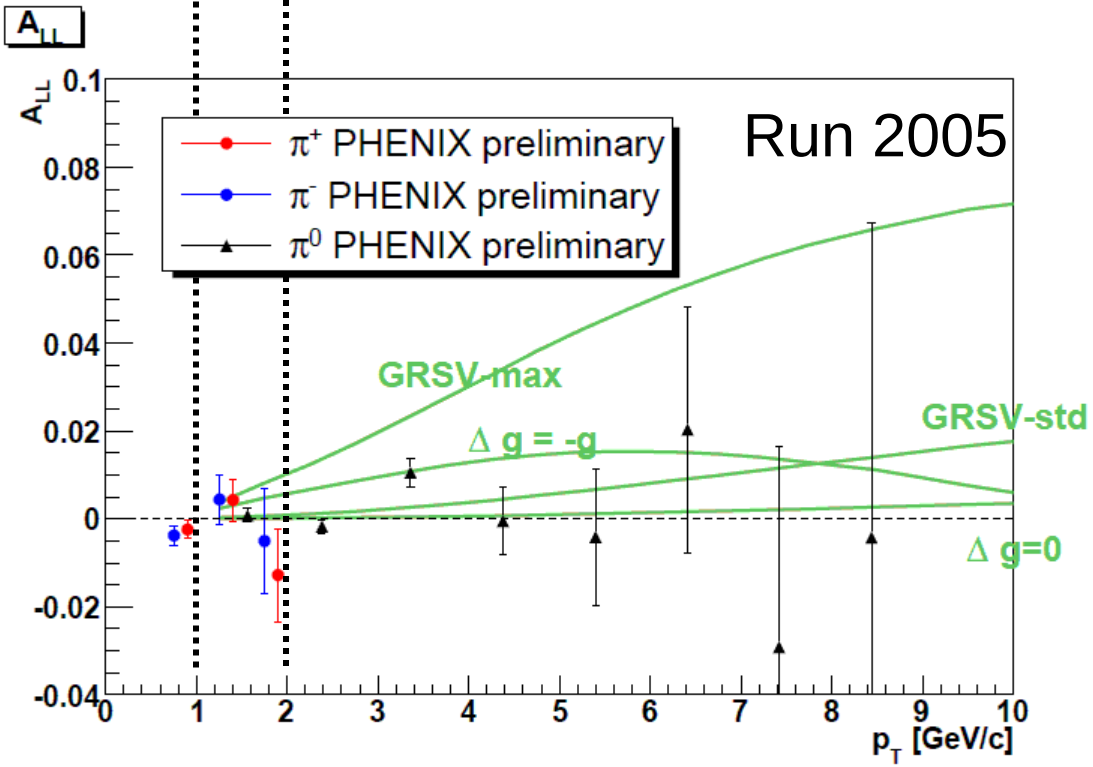
Soft QCD component is roughly evaluated as exponential.

pT < 1 GeV/c : Soft dominates
pT > 2 GeV/c : Soft < 10 %



Soft QCD dominates

Hard QCD > 90%



ALL of charged pion < 1%
---> Contribution of soft QCD to ALL is less than 0.1% at pT > 2 GeV/c.

Summary

> The study of Δg is on going at the RHIC-PHENIX experiment at Brookhaven National Laboratory in U.S.

> The model of large Δg is excluded by the data of π° A_{LL} measured in 2005 run.

> It is necessary to combine π° results and other probes. A_{LL} of Direct-Photon is promising to determine the sign of Δg. On-going analyses are jet, J/ψ, Λ, heavy flavor...

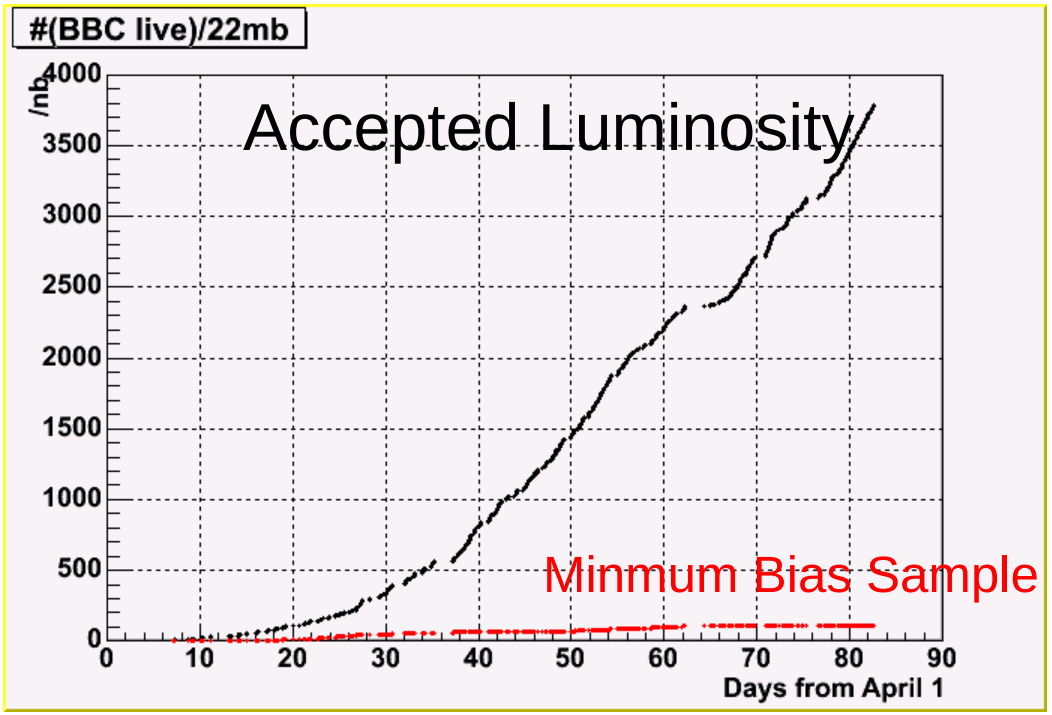
> Contribution of soft QCD component to A_{LL} of pions is evaluated by charged pions. It is negligible at $pT > 2$ GeV/c.

> It is needed to cover wide range of Bjorken x to determine the integral of Δg. Run at $\sqrt{s} = 500$ GeV can reach smaller x region.

Back Up

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 commissioning 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

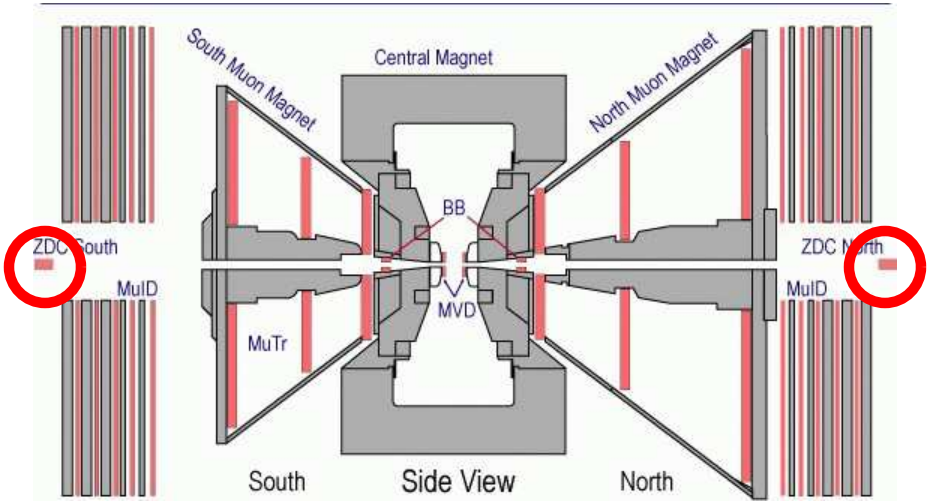


FOM : Figure of merit = P^4L

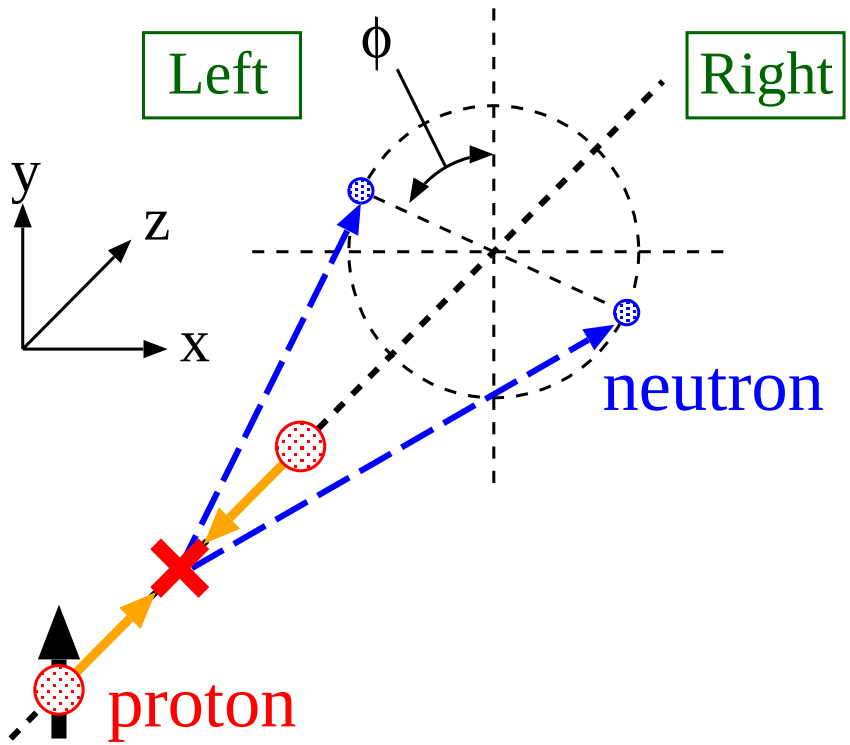
We had first long longitudinal spin run in 2005.

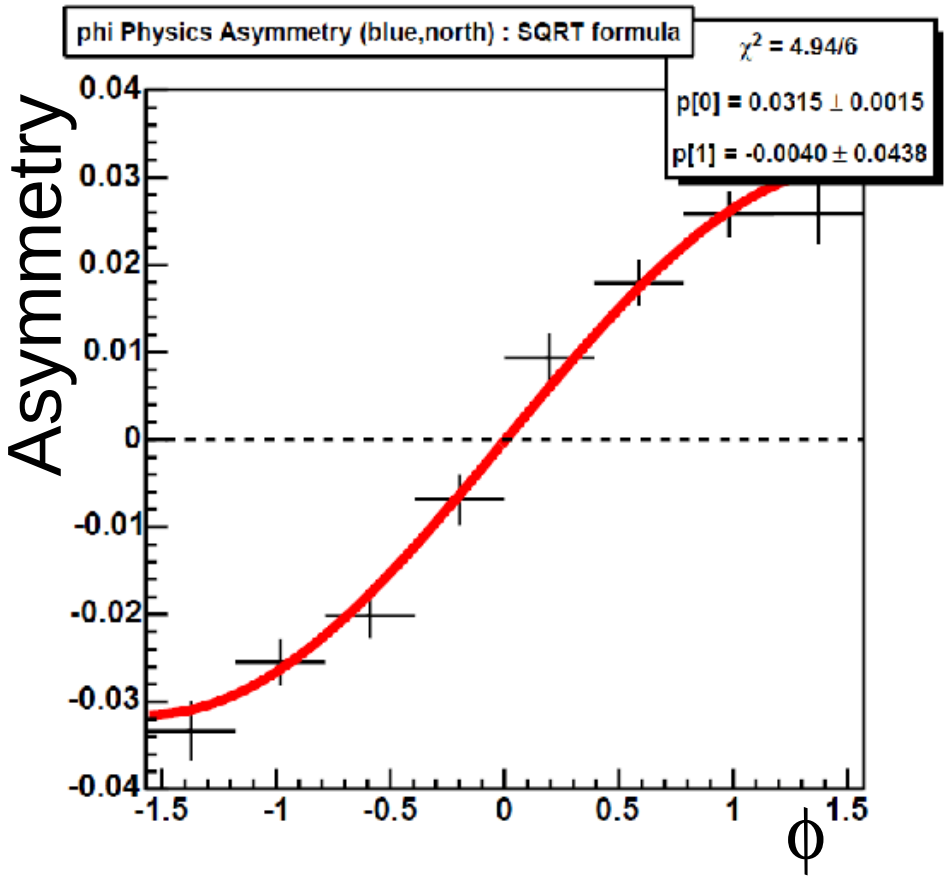
Figure of merit is 40 times larger than past years.

Local Polarimeter



Measure A_N of neutron in very foward region.

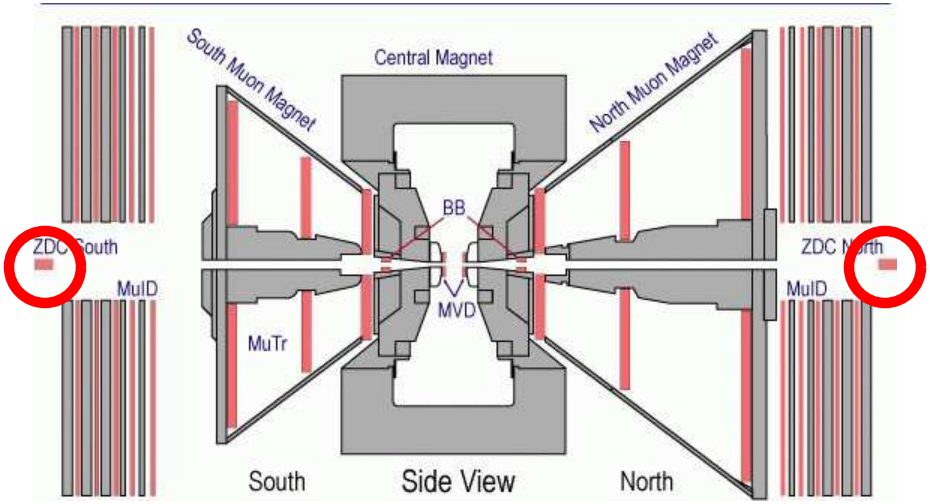




Rotator OFF

Clear asymmetry is measured.

Local Polarimeter



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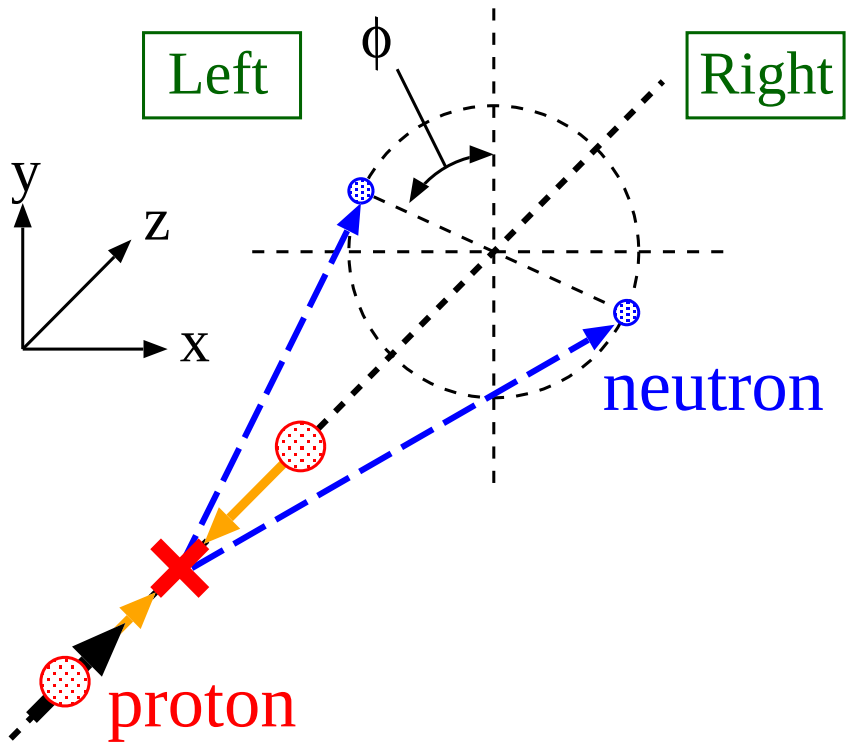
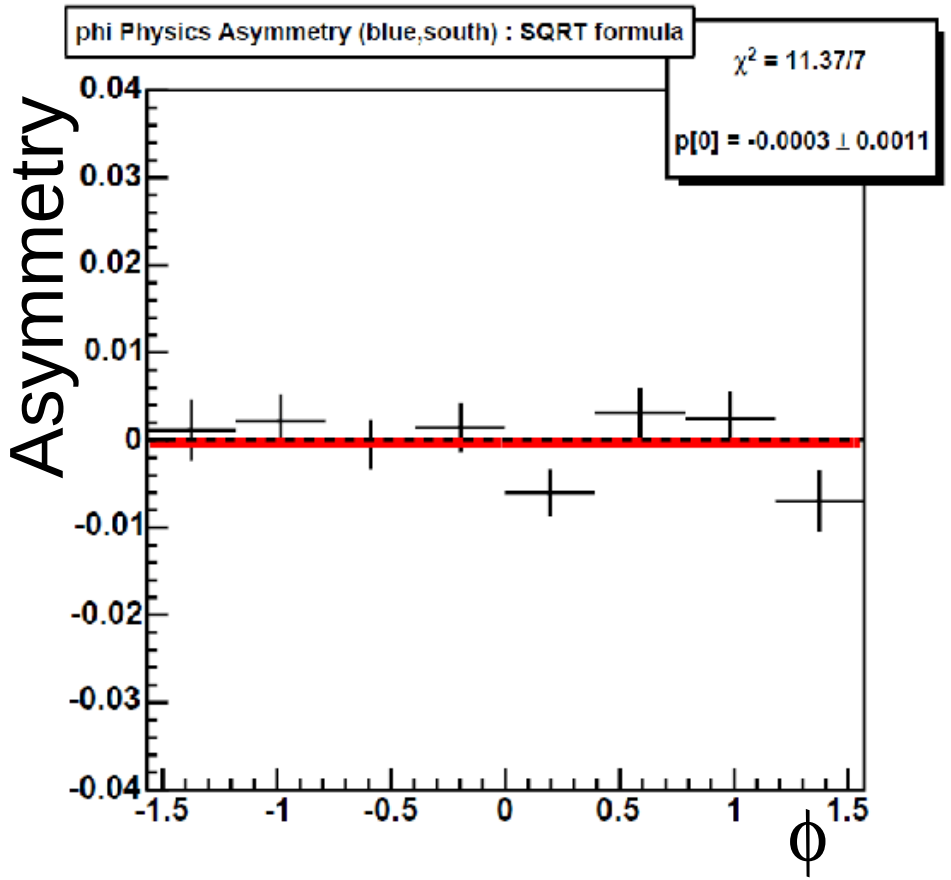
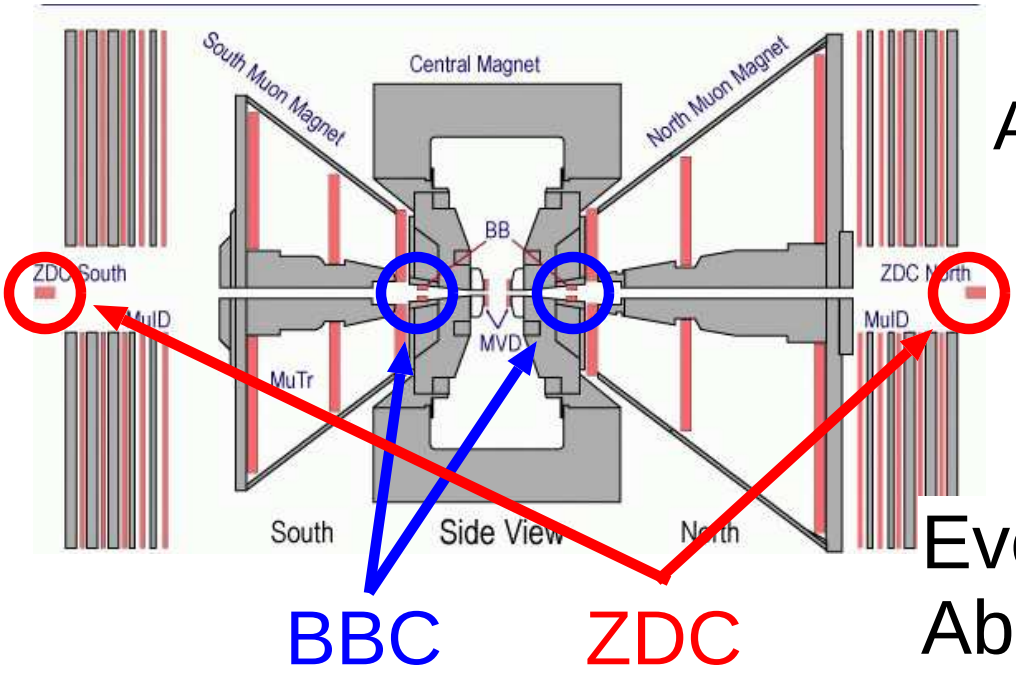




Rotator ON
Asymmetry disapears.

Longitudinal component > 98%

Relative Luminosity



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

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

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)

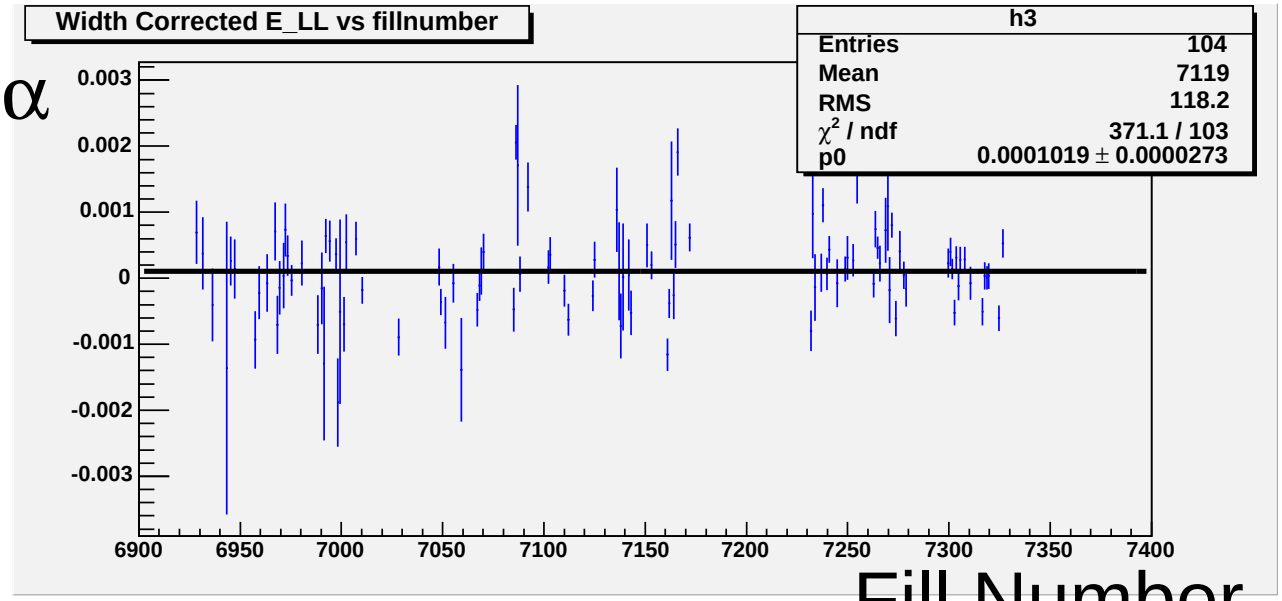
Relative Luminosity

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 $\frac{\delta R}{2 P_B P_Y} = \frac{\delta \alpha}{P_B P_Y}$



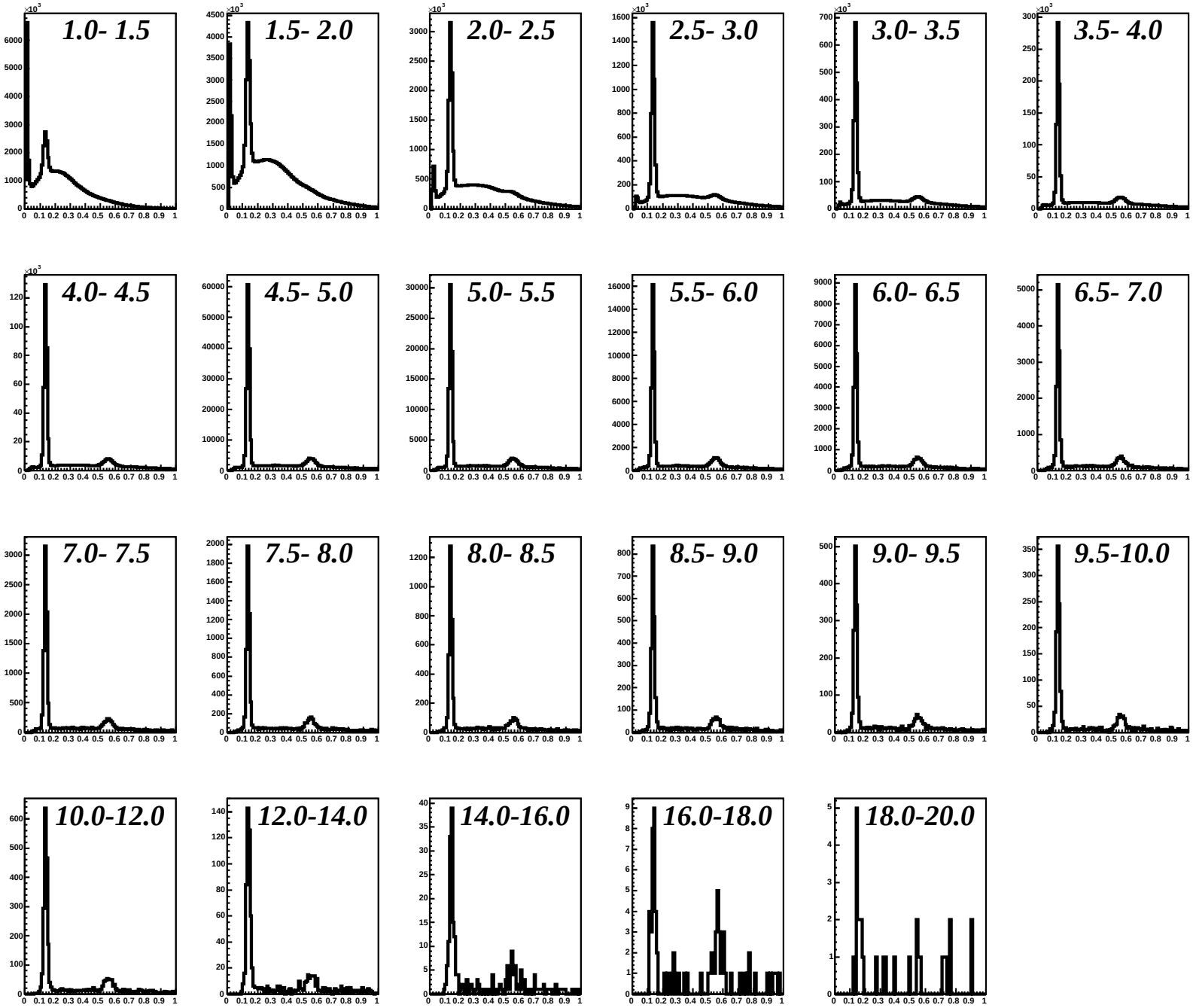
After renormalization by chisquare,

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

2-photon invariant mass spectrum (1<pT<20 GeV/c)



Summary of systematic error

> Relative Luminosity

The error to A_{LL} is 0.023% which is much smaller than statistical error. The error is 0.011% for A_L.

> Beam Polarization

20% is assigned as relative systematic error.
This introduces 40% (20%) scale error for A_{LL} (A_L).

> Local Polarimeter

$\langle P_L/P \rangle = 99.48 \pm 0.12 \pm 0.02$ (%) for Blue beam

$\langle P_L/P \rangle = 98.94 \pm 0.21 \pm 0.04$ (%) for Yellow beam

This is negligible compared to the error of absolute beam polarization.

> A_{TT}

$\langle P_B P_Y \rangle = 0.22$, $\langle P_{Bx} P_{Yx} \rangle = 0.0022$, $\langle P_{By} P_{Yy} \rangle = 0.0001$

The effect of A_{TT} is suppressed by factor 100 compared to A_{LL}. It is assumed that A_{TT} is smaller than A_{LL} and uncertainty due to A_{TT} is negligible in this case.
We will measure A_{TT} using runs with transverse polarization.

> Bunch Shuffling

Bunch-to-bunch or fill-to-fill systematic error is negligible compared to statistical error.

A_{LL} of high-energy photon trigger

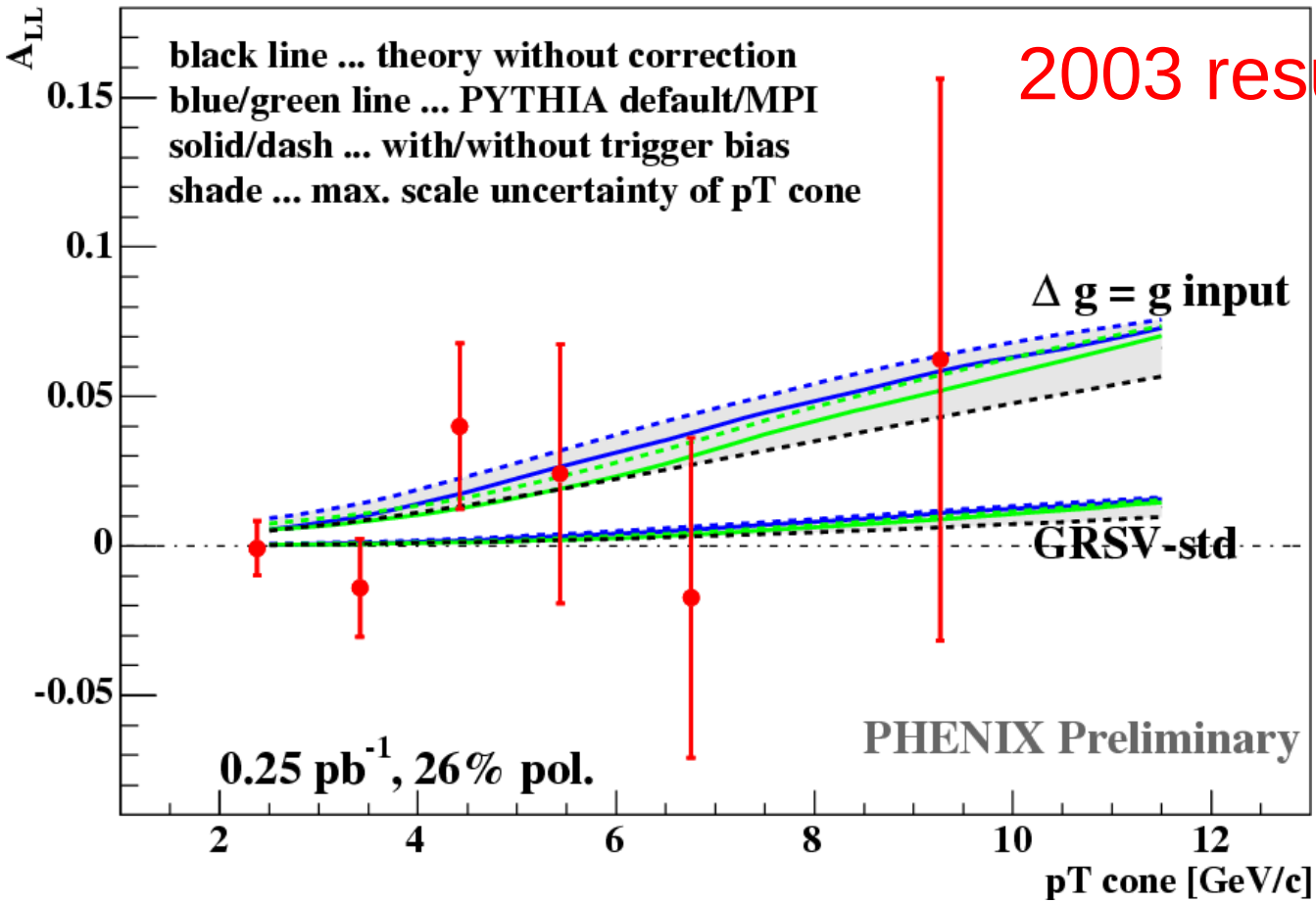
Bunch Fitting : Fit $\frac{N(i)}{L(i)}$ to $R\,[\,1 + P_B(i)\,P_Y(i)\,A_{LL}\,]$.

i is bunch # of beam.

χ^2/NDF is larger than unit. ---> Bunch dependence.

$\Delta A_{LL}(\text{trigger}) \sim 0.08\%$ after enlarging the error to become $\chi^2/\text{NDF} = 1$. Since $\Delta A_{LL}(\pi^\circ) \sim 0.1\%$, this bunch dependence will affect the error of $A_{LL}(\pi^\circ)$ when luminosity becomes 1.5 times higher.

"Jet" A_{LL}

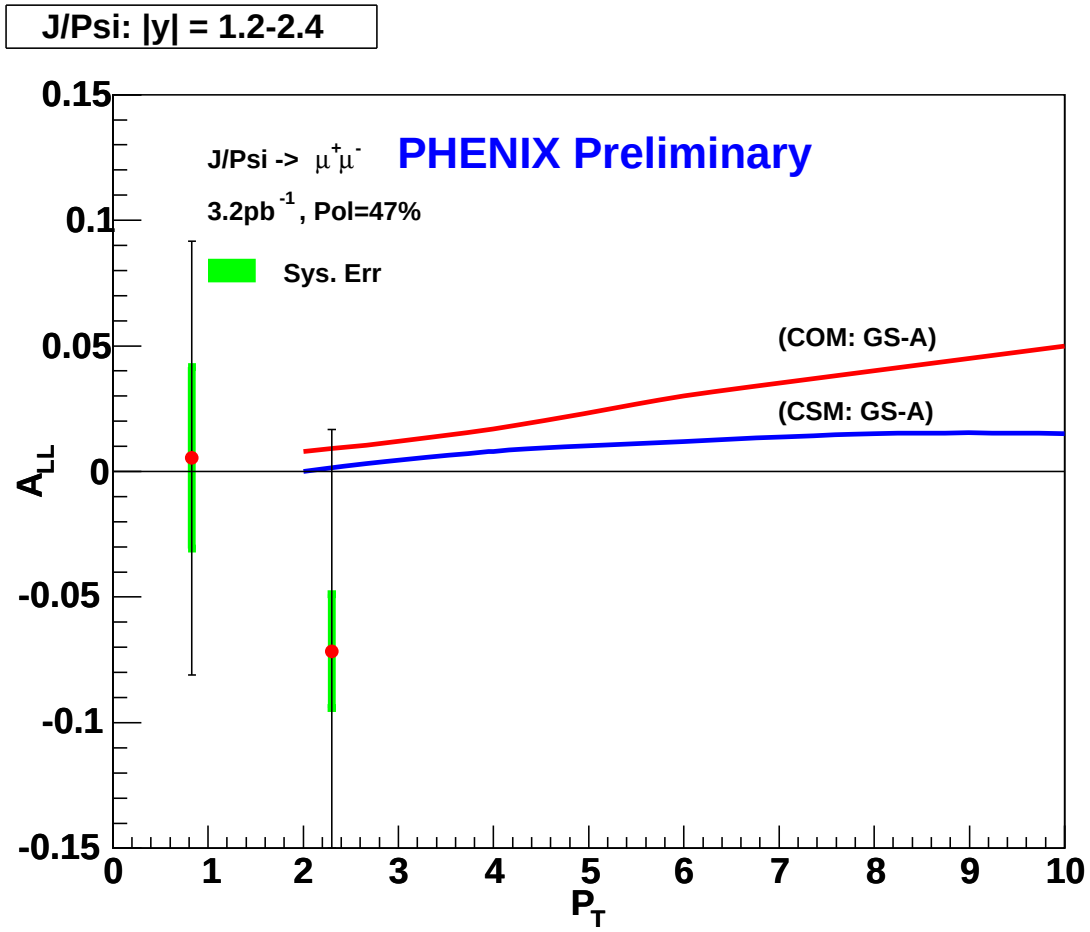


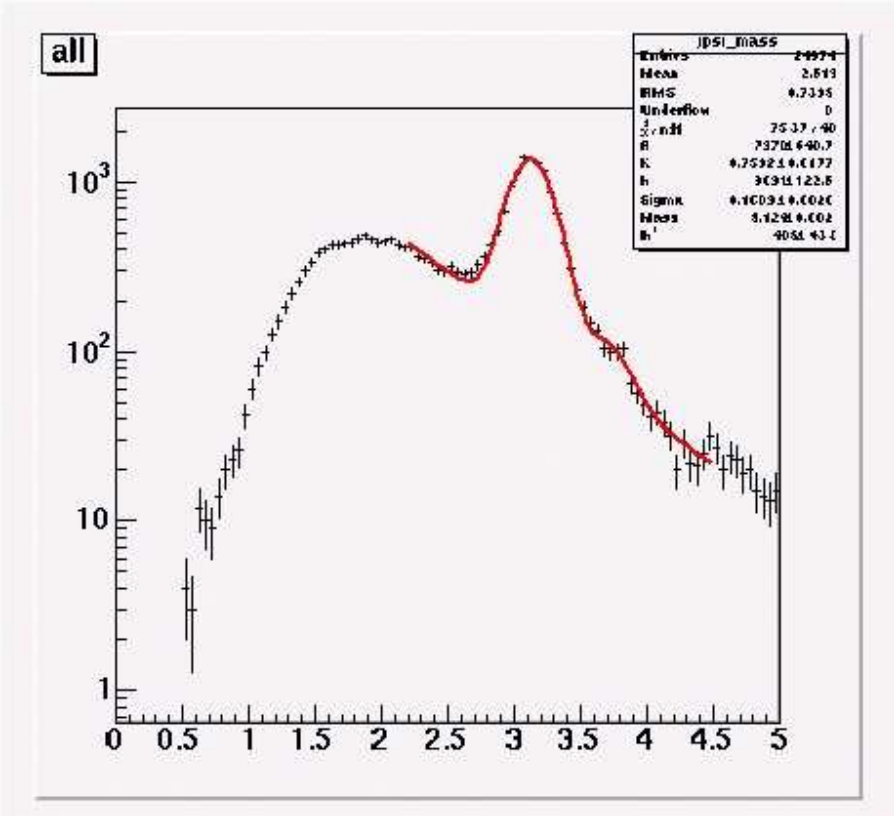
"Jet" detection : Tag one high energy photon and sum energy of nearby photons/charged particles.

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.

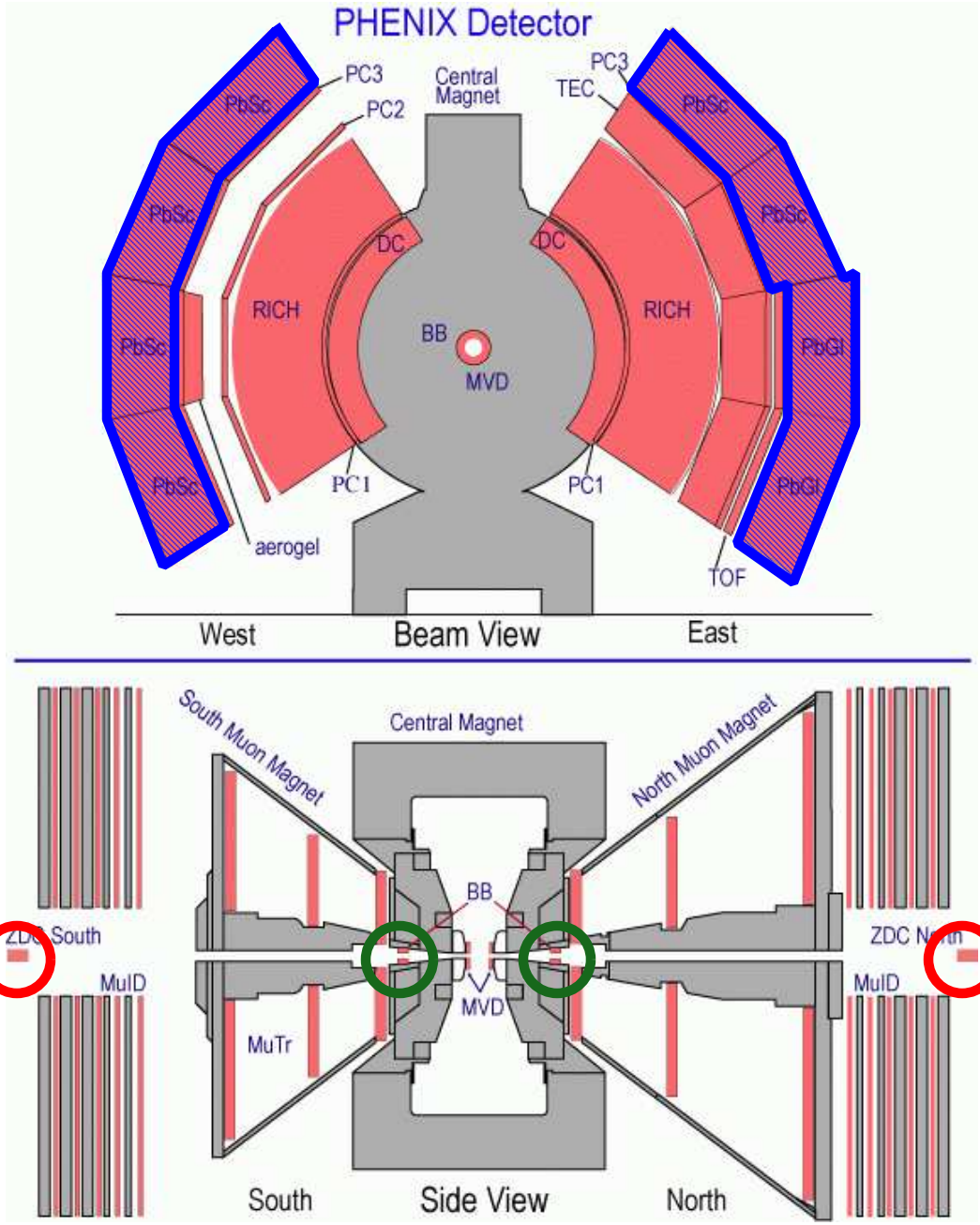
J/ψ





> Measurement is done using muon arm (1.2<|η|<2.4)
> More statistics is needed.
> A_{LL} depends on the production mechanism of J/ψ.

PHENIX



Electromagnetic Calorimeter (EMCal)

> Measure photon energy and position. ($\pi^0 \rightarrow \gamma\gamma$)

> Acceptance
$|\eta| < 0.35$, ϕ : 90+90 degree.
5m far from collision point.

> Fine segmented.(5cm x 5cm)

> High pT photon trigger.

Beam-Beam Counter (BBC)

> MB trigger.

> Used for relative luminosity measurement.

> Acceptance : $3.0 < \eta < 3.9$

Zero Degree Calorimeter (ZDC)

> Used for relative luminosity measurement.

> Acceptance : ±2 mrad