Recent Results on Neutral Pion Production in Pol. p-p Collisions at RHIC at √s = 62 GeV and √s = 200 GeV

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RIKEN Nishina center

DIS2008 - London, UK

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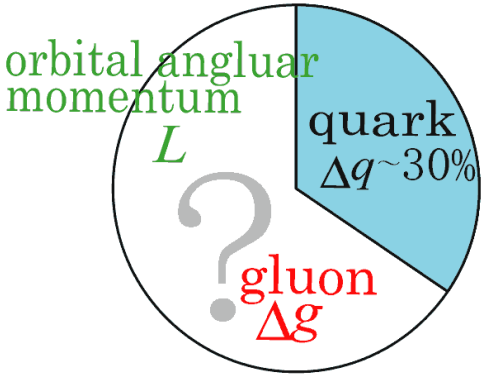
Introduction

Since it is a session for spin physics and this talk follows two nice talks from STAR I'll skip most of the introduction..



- This study aims at <u>ΔG</u>

  (gluon spin contribution to the proton)

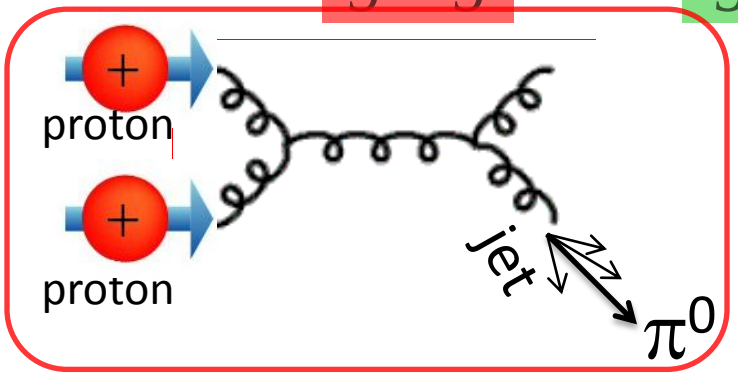
- Through "Double Helicity Asymmetry" (A_{LL}) of π^0 in pol *pp* collisions
  - gluons participate in <u>leading order</u>. suitable to probe gluon spin!

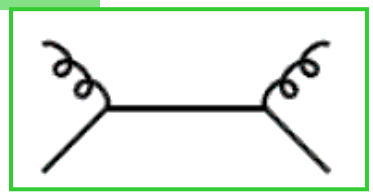
A_{LL} (of π^0) in pol. *pp* collisions

- Theoretically

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \sim \int dx_1 dx_2 \hat{a}_{LL}^{gg} \frac{\Delta g}{g}\frac{\Delta g}{g} + \hat{a}_{LL}^{qg} \frac{\Delta g}{g}\frac{\Delta q}{q} + \hat{a}_{LL}^{qq} \frac{\Delta q}{q}\frac{\Delta q}{q}$$

Proton's helicity





These two processes dominates
In our sensitive p_T region.

- Experimentally

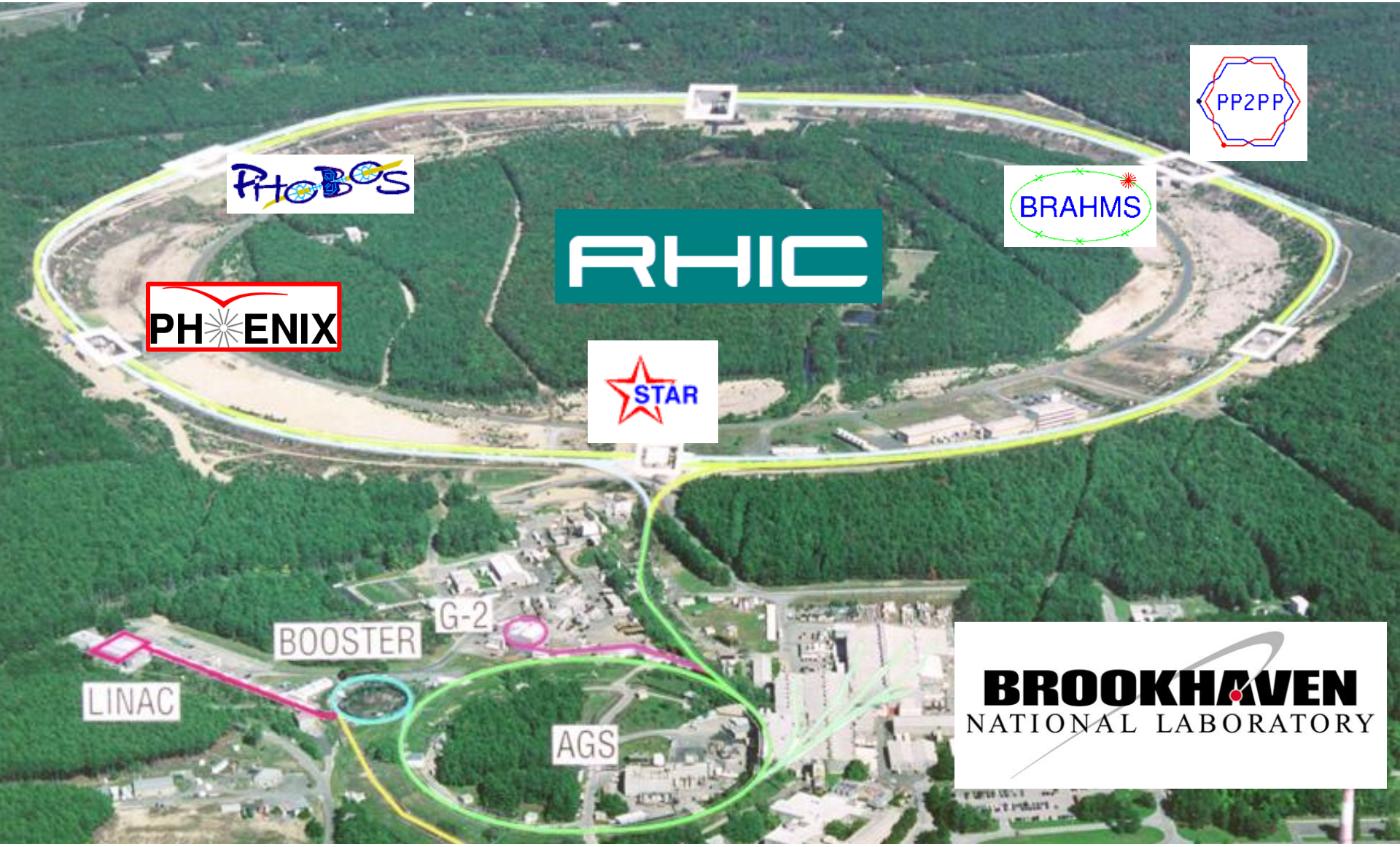
$$A_{LL} = \frac{1}{P_1 P_2} \frac{N_{++}^{\pi} - R \cdot N_{+-}^{\pi}}{N_{++}^{\pi} + R \cdot N_{+-}^{\pi}} \qquad R \equiv \frac{L_{++}}{L_{+-}}$$

- N: particle yield
- P: polarization of beams
- R: Relative Luminosity

strategy

- X-section measurement to confirm pQCD applicability
- A_{LL} measurement to extract Δg

RHIC – the world's first pol pp collider



RHIC – the world's first pol pp collider

FOM: Figure of Merit

Longitudinal spin program

RUN	√s GeV	FOM = P^4L $10^{-3}pb^{-1}$	Int. Lumi (pb^{-1})	Pol.
2003 (RUN3)	200	1.9	0.35	27%
2004 (RUN4)	200	3.1	0.12	40%
2005 (RUN5)	200	170	3.4	47%
2006 (RUN6)	200	970	7.5	60%
	62.4	5.3	0.1	48%

Transverse spin program

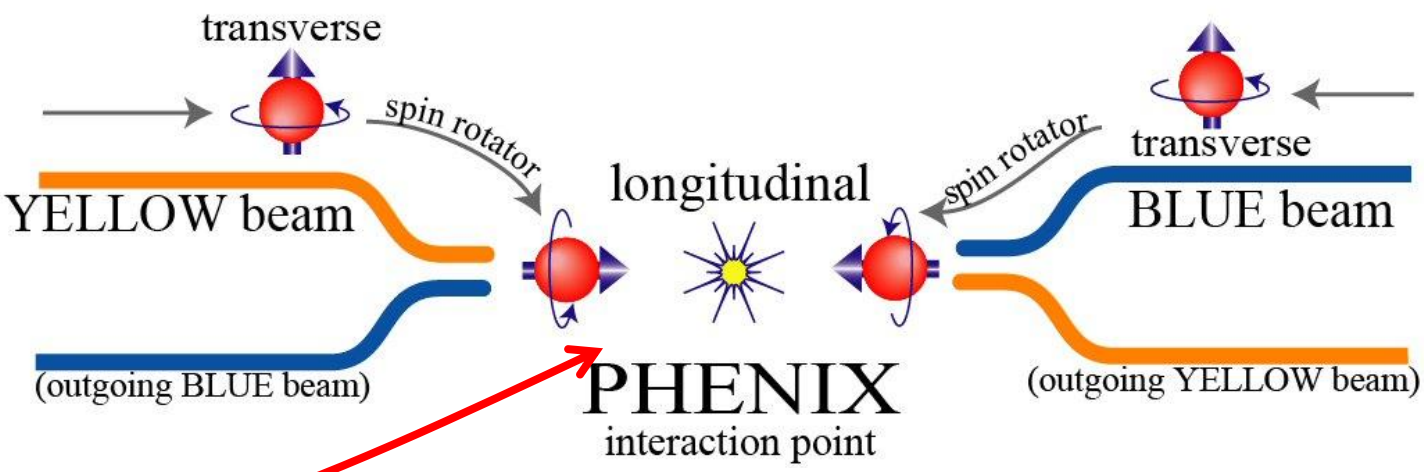
RUN	√s GeV	FOM = P^2L $10^{-3}pb^{-1}$	Int. Lumi (pb^{-1})	Pol.
2002(RUN2)	200	3	0.15	15%
2005(RUN5)	200	33	0.15	47%
2006 (RUN6)	200	290	2.7	57%
	62.4	1	0.02	48%
2008(RUN8)	200	1100	5.2	46%

This talk discuss RUN6 π^0 improvement to RUN5.

Other channels ($\pi^{+/-}$, η) by F. Ellinghaus (next)

Talk by D. Fields

RHIC beam at PHENIX IP



- Two independent beams(Blue / Yellow)
- Bunch structure (120 bunchs in ~106ns interval)
- Transverse→Longitudinal at IP (when we need it)
- Spin pattern

BLUE	: + + - - ....
Yellow:	+ - + - ....

→ We can get all possible Collision patterns.

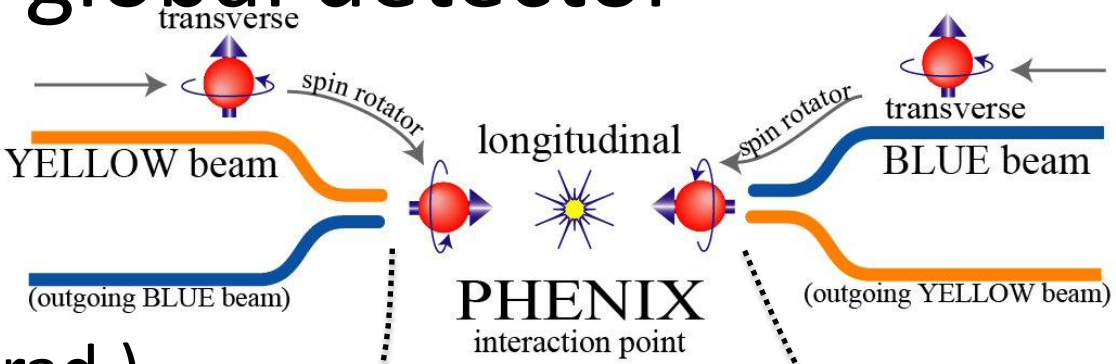
  - Syst. uncertainty from time-dep. of the det. eff. avoided.

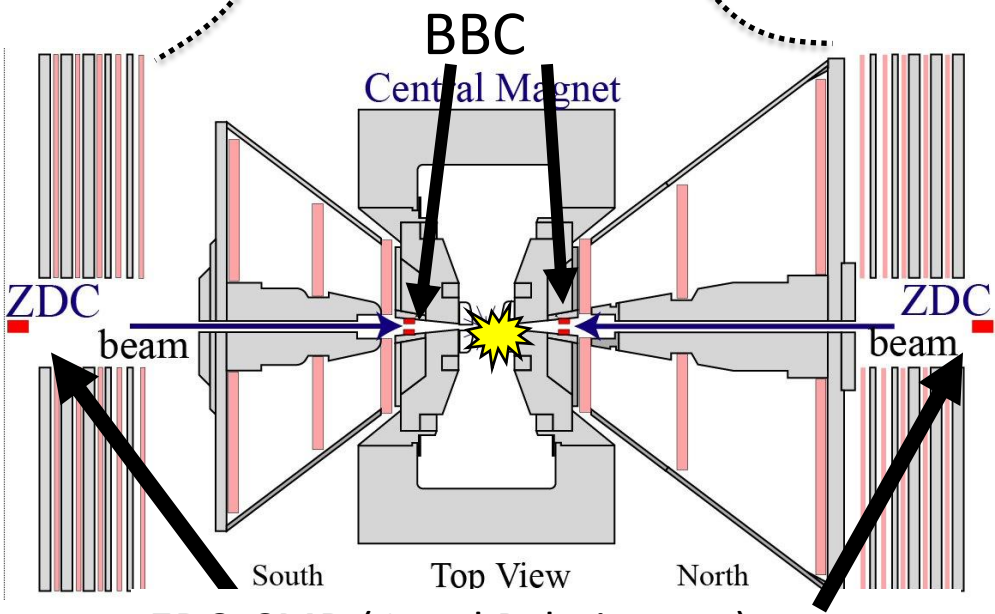
PHENIX global detector

Luminosity Measure

- BBC 3.0<|η|<3.9
  - Quartz Cherenkov det.
- ZDC |η|>6.6 (+/- 2.8mrad.)
  - Hadron Calorimeter

These two independent lumi. measure are compared to find out uncertainty on Relative Lumi.





Local Polarimetry

- SMD (+ ZDC).
  - Scintillator hodoscopes.
  - Measures transverse component of beam through A_N of neutron.

ZDC+SMD (Local Polarimeter)

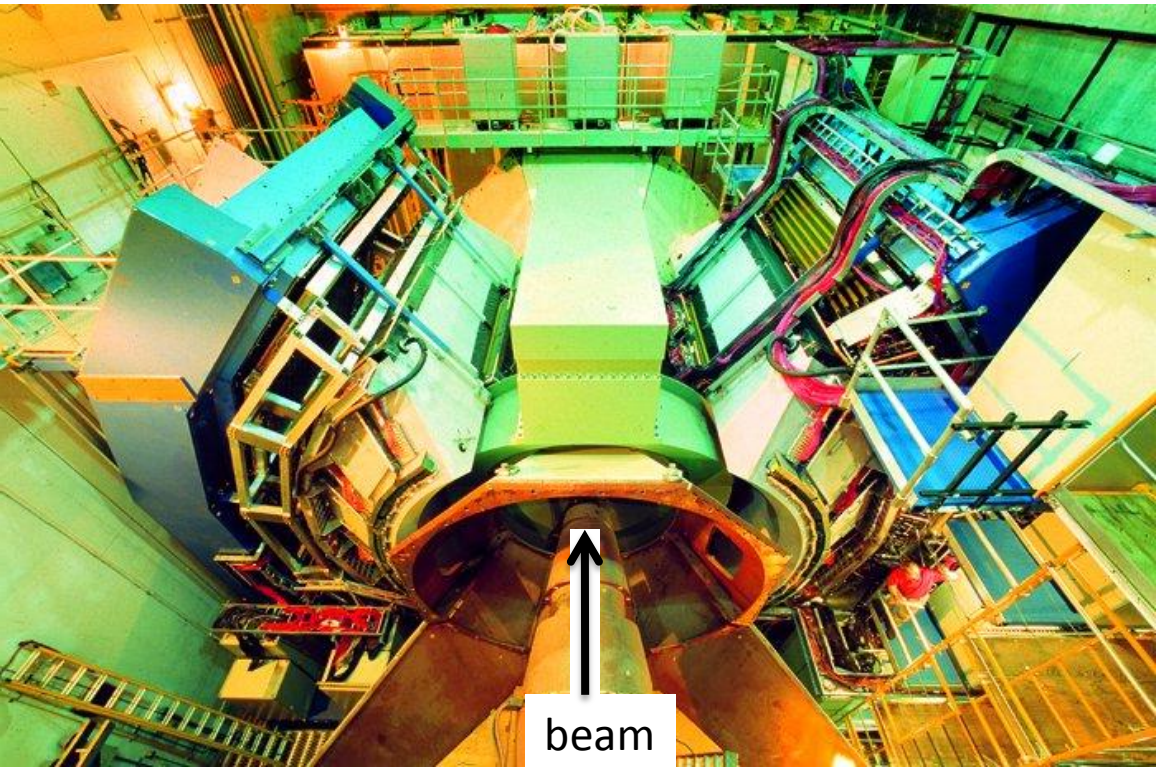
$$A_{LL} = \frac{1}{P_1 P_2} \frac{N^{\pi}_{++} - R \cdot N^{\pi}_{+-}}{N^{\pi}_{++} + R \cdot N^{\pi}_{+-}}$$

PHENIX Detector

- PHENIX has ability to detect various final state particles such as π^0,π^{+-},γ,e^{+-} and μ^{+-}. Here I concentrate on π^0(or γ) detection.

Central Arm

- $|\eta|$<0.35, $\Delta\phi$ ~ 2 x 90deg
- EMCal(PbSc,PbGl) for γ measurement. π^0 detected via $\gamma\gamma$ decay.
- High energy photon trigger available



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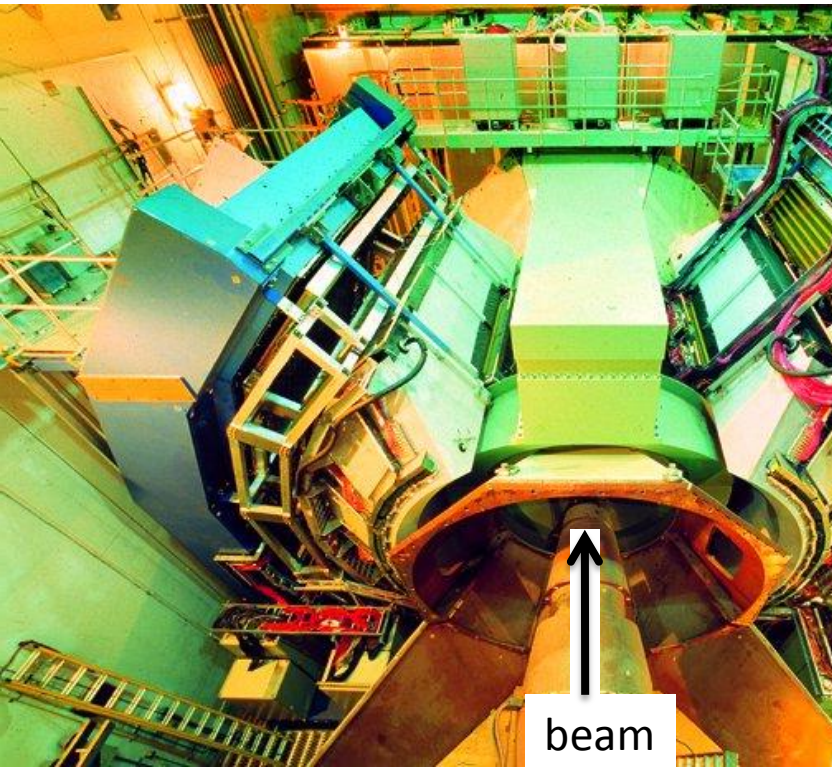
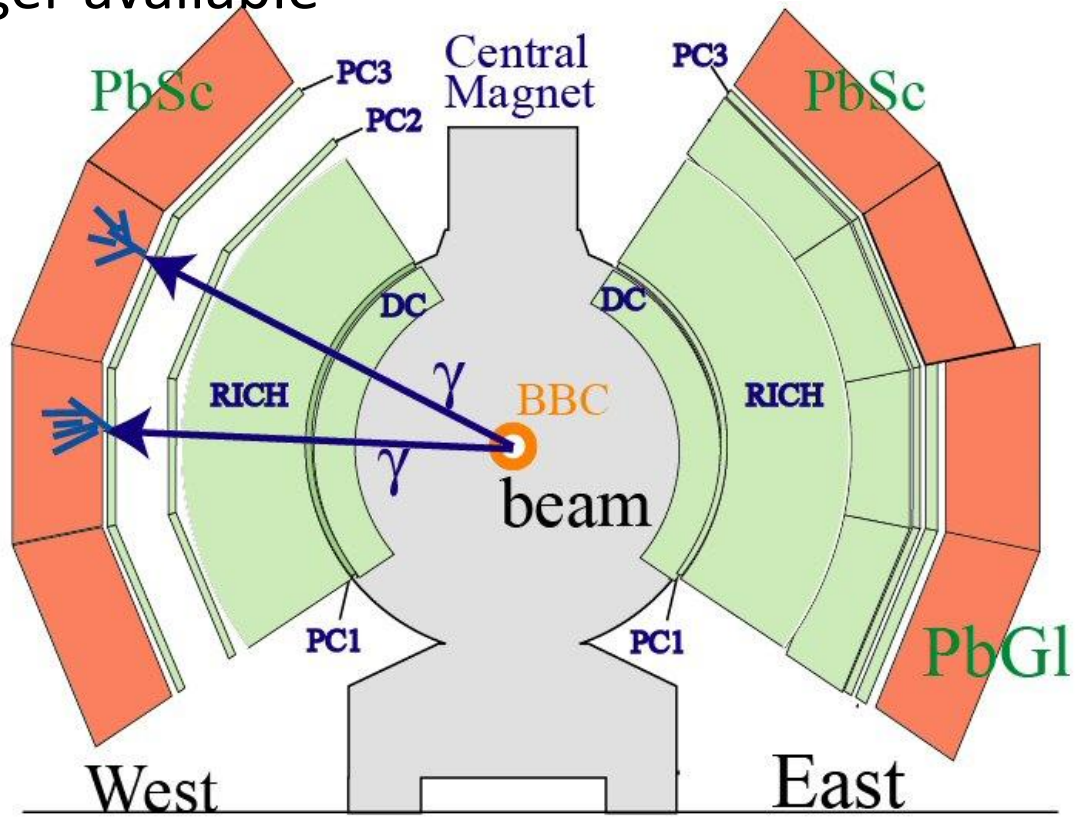
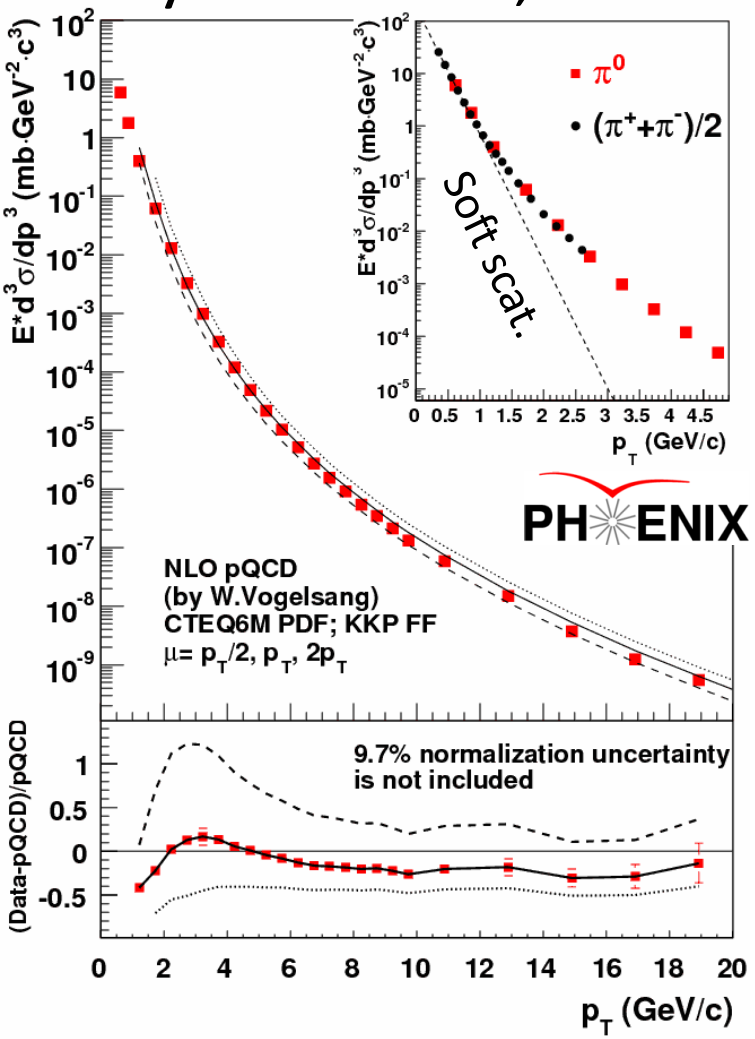




cross section – pQCD applicability

RUN5 200GeV -- π^0

Phys. Rev. D76, 051106(2007)

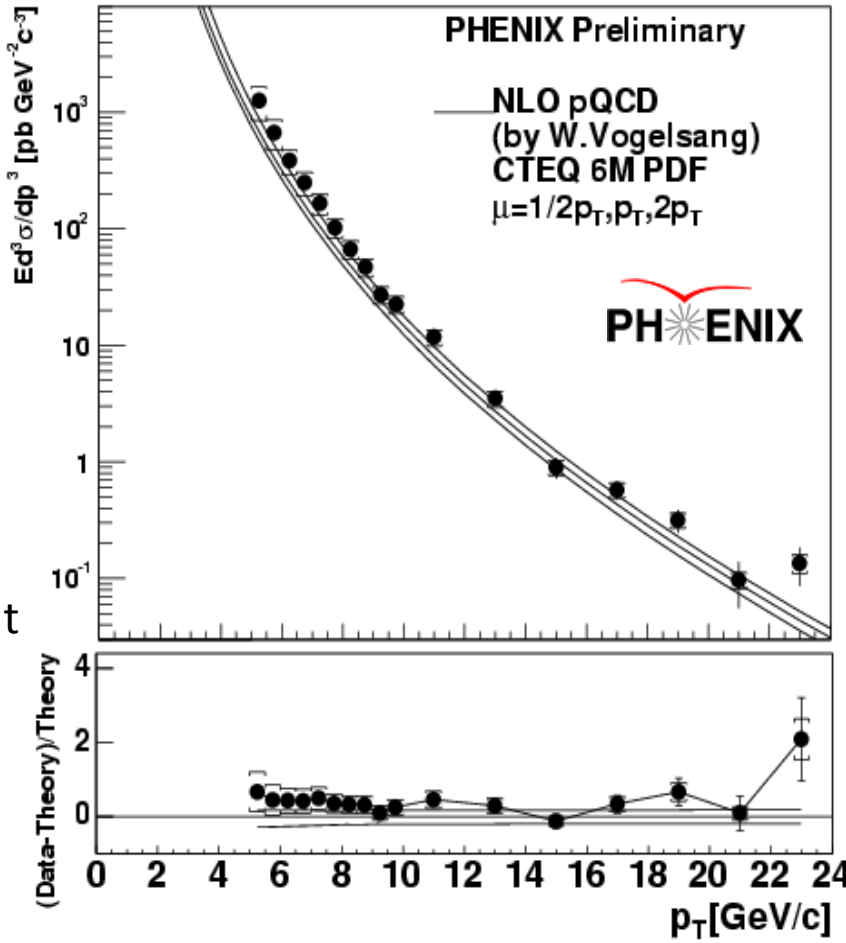


pQCD works

But…

A concern about soft scat. effect on low pT.

RUN5 200GeV – direct γ



Influence of soft scat. on A_{LL}

$$A_{LL}^{\text{sig}} = \frac{A_{LL}^{\text{sig+BG}} - rA_{LL}^{\text{BG}}}{1-r}$$

$$r = \frac{\text{BG}}{(\text{sig}+\text{BG})}$$

Signal = hard scat.

BG = soft scat.

numbers

δA_{LL} ~ 0.08% at p_T 2.0-2.5 GeV/*c*

scale uncertainty ~10%

- Influence of denominator
  - r < 10% desirable

Less than scale uncertainty from polarization (~10%)

- Influence of numerator
  - OK if $\underline{r \times A_{LL}^{BG} < 0.08\%}$
    - In case of r ~ 10%
      - $A_{LL}^{BG} < 0.8\%$ required

Less than measured asymmetry uncertainty (~0.08%)

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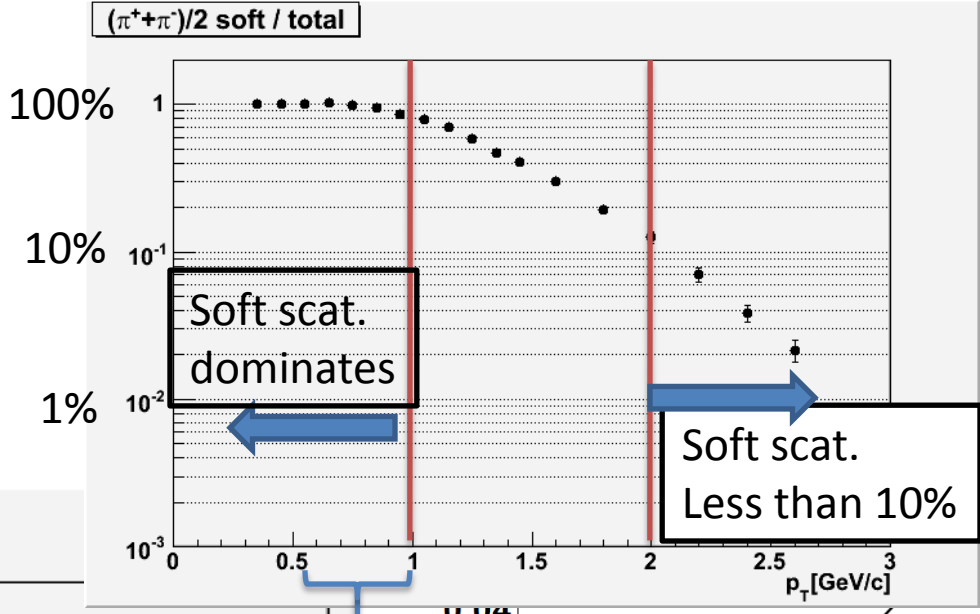
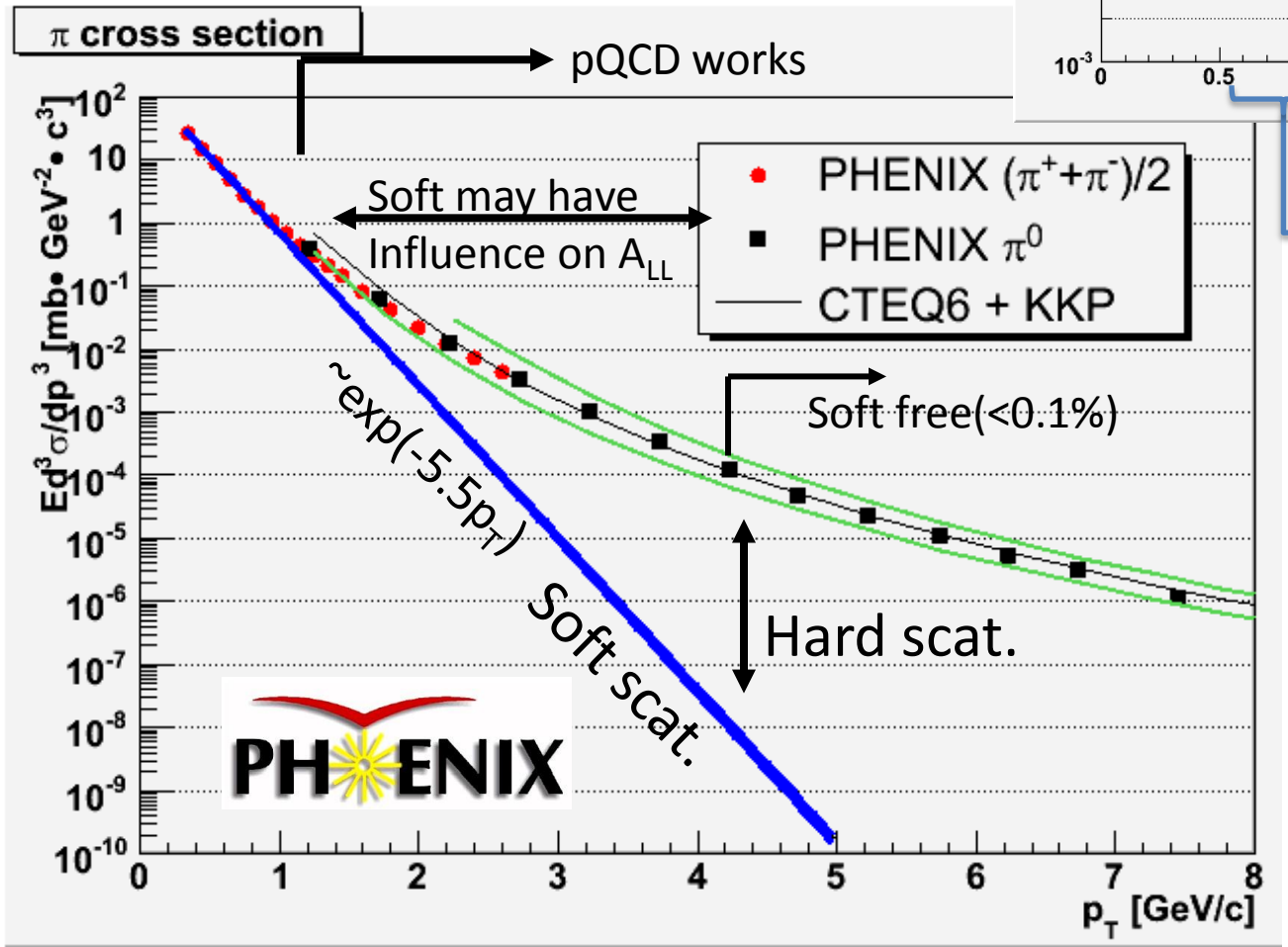
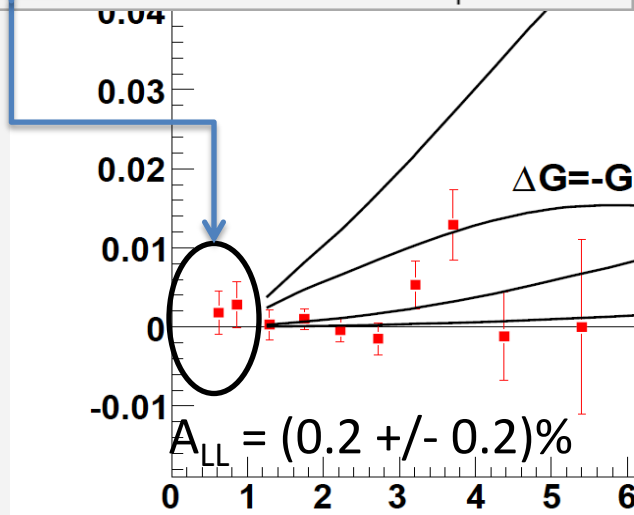
The amout of soft scat.

Estimated by fit to exponential*







*S.M. Berman, J.D.Bjorken, J.B. Kogut PhysRevD**4**,3388

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Influence of soft scat. on A_{LL}

$$A_{LL}^{\mathrm{sig}} = \frac{A_{LL}^{\mathrm{sig+BG}} - rA_{LL}^{\mathrm{BG}}}{1-r}$$

$$r = \frac{\mathrm{BG}}{(\mathrm{sig}+\mathrm{BG})}$$

Signal = hard scat. (← pQCD)

BG = soft scat.

numbers

δA_{LL} ~ 0.08% at p_T 2.0-2.5 GeV/*c*

scale uncertainty ~10%

- Influence of denominator
  - r < 10% desirable

Soft scat. Less than 10% at p_T>2GeV/c

- Influence of numerator
  - OK if $\underline{r \times A_{LL}^{BG} < 0.08\%}$
    - In case of r ~ 10%
      - $A_{LL}^{BG} < 0.8\%$ required

A_{LL} = (0.2 +/- 0.2)% at $0.5 < p_T < 1$ GeV/c where soft scat. dominates.

At p_T>2GeV/c, the requirements above is satisfied.

⇒ pQCD is applicable and can be used to extract ΔG!!

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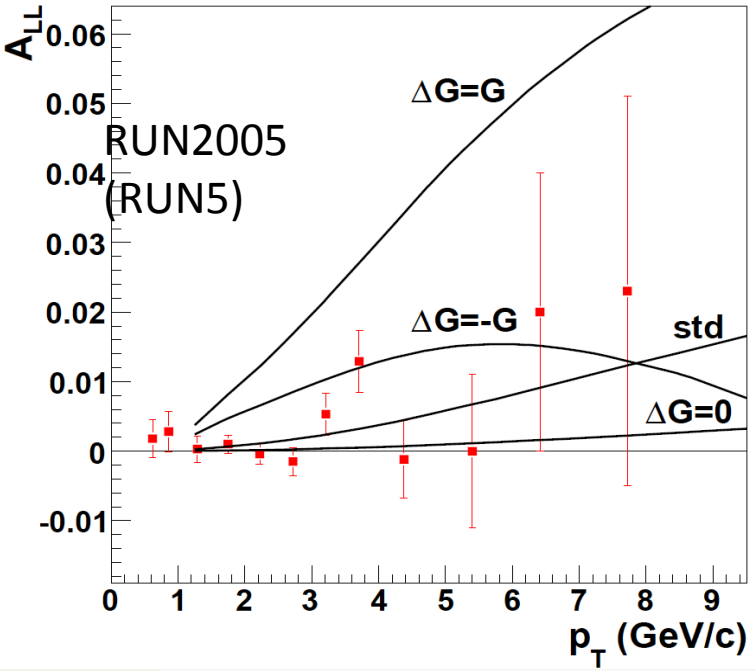
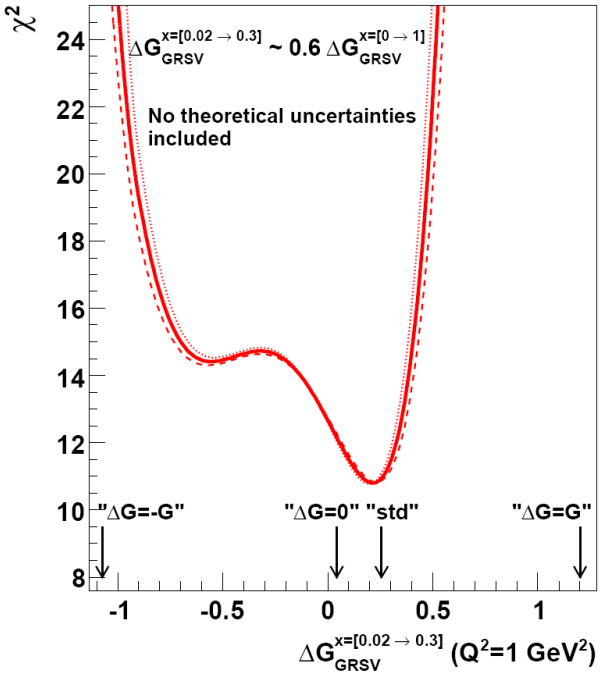
RUN5 π^0 results

- PHENIX measured π^0 A_{LL} at 200GeV (RUN2005)
  - Among four GRSV models, allowed by DIS,
    - ΔG=+G,-G are rejected.

    measured x range (0.02—0.3)
  - Need more statistics for (straightforward) improvement.



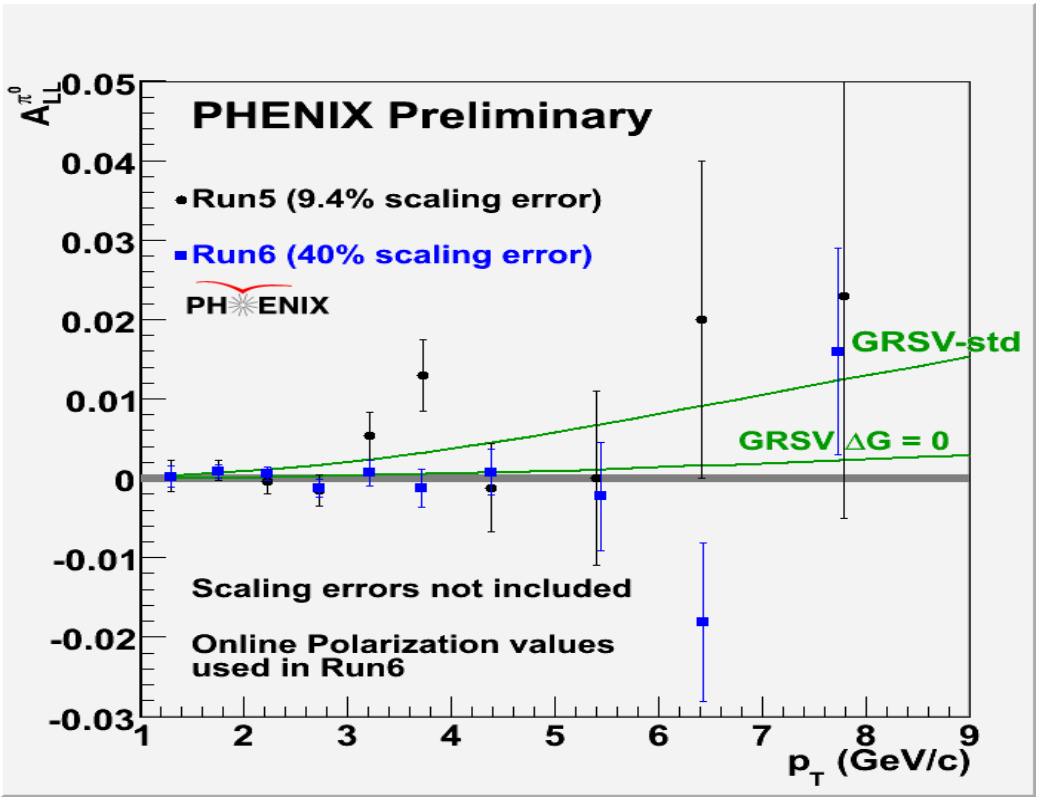


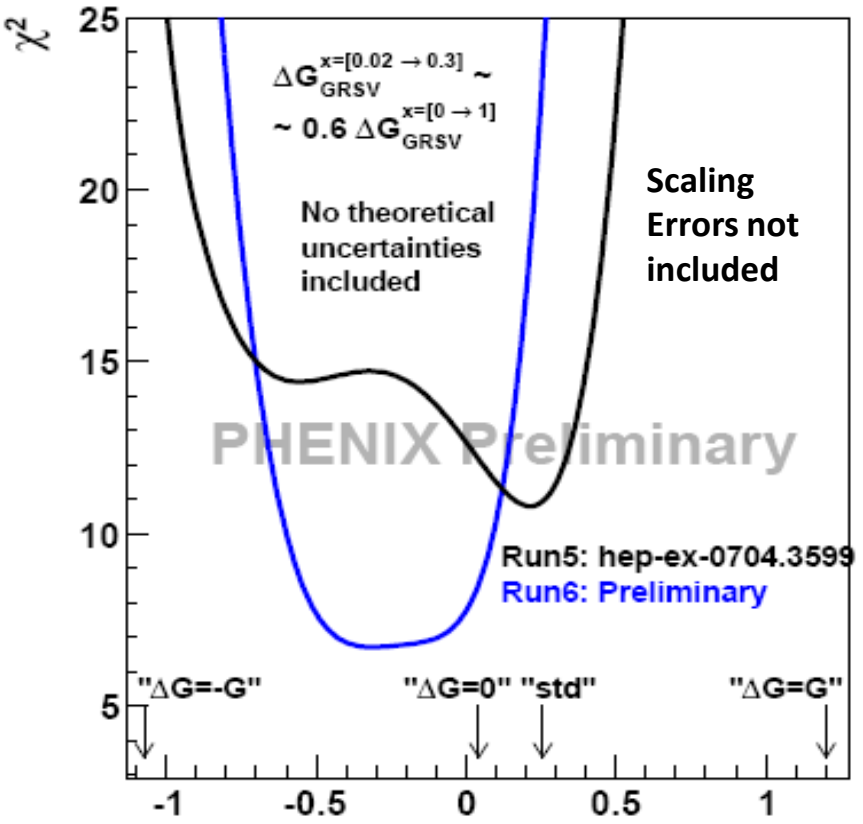
π^0 A_{LL} at 200GeV – RUN6 improvement

200GeV RUN5 2.5pb^{-1} (47%) ~10weeks

200GeV RUN6 6 pb^{-1} (60%) ~6weeks

- χ^2 test based on GRSV





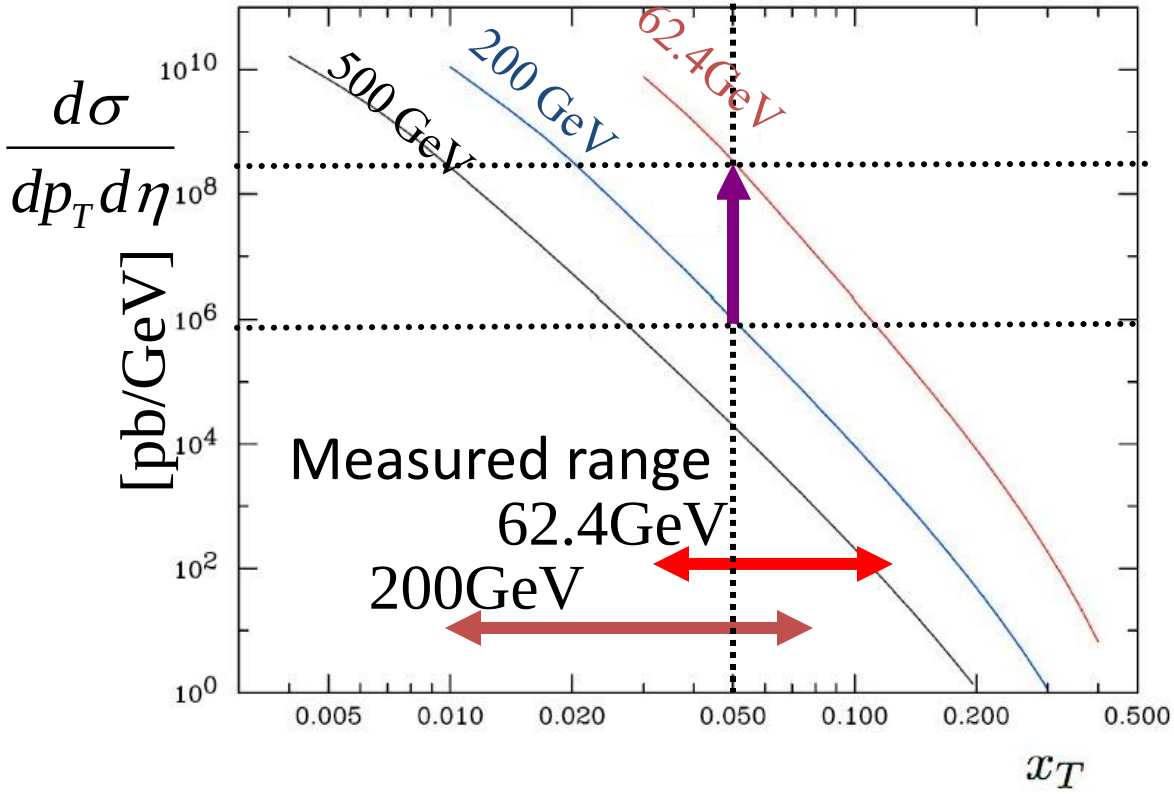
- GRSV theory curves
  - Std: best fit to DIS data - rejected
  - ΔG=0 still allowed

ΔG [x=0.02→0.3] (Q^2=1GeV^2)

Another way to improve access high x with lower energy

- Probed x scales with x_T.
- At fixed x_T, x-sec is 2 orders of magnitude higher at 62.4GeV than at 200GeV. → easier to access high x

$$x_T = \frac{2p_T}{\sqrt{s}}$$

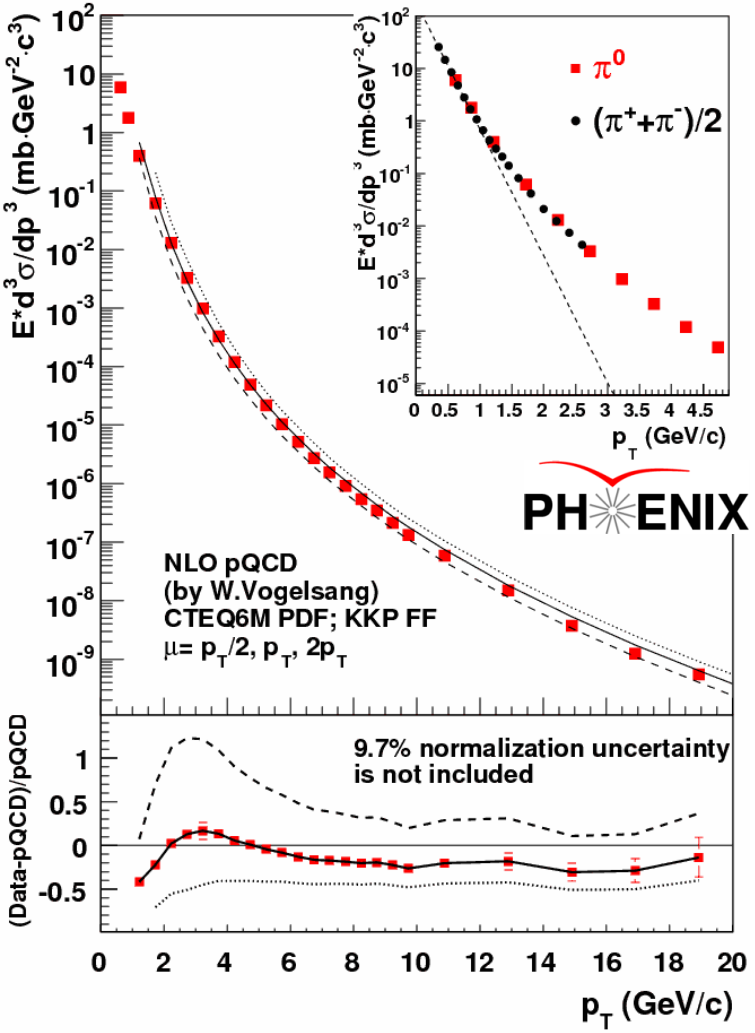


cross section – pQCD applicability

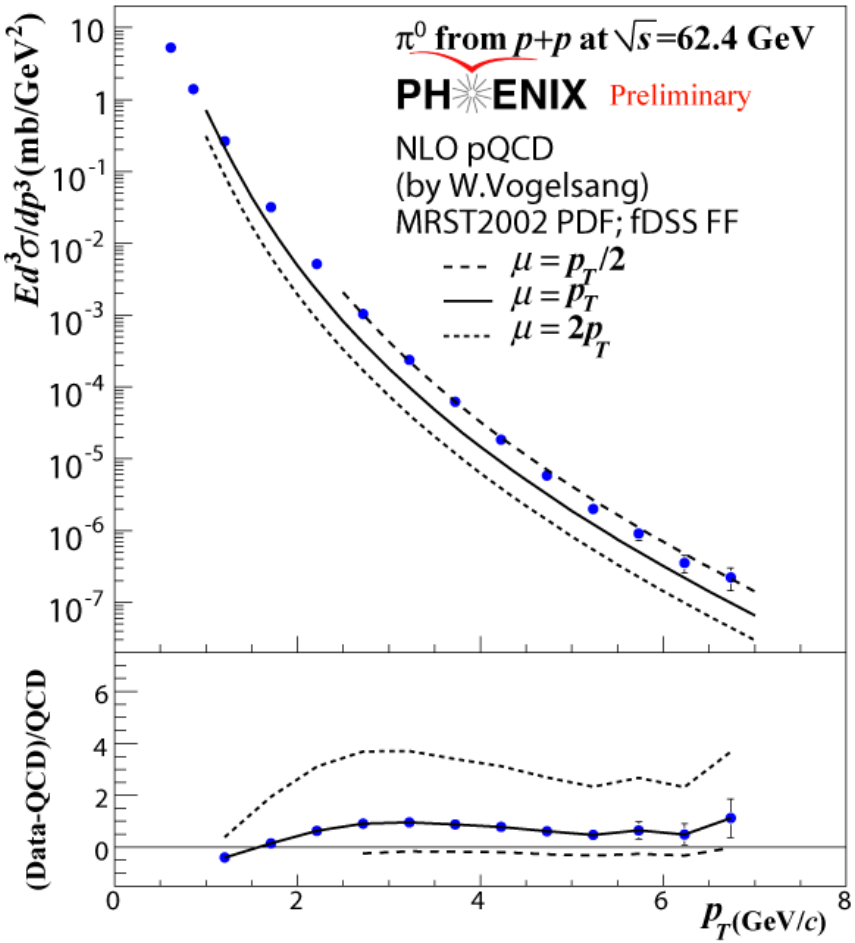
RUN5 200GeV -- π^0

Phys. Rev. D76, 051106(2007)

RUN6 62.4GeV -- π^0



pQCD works



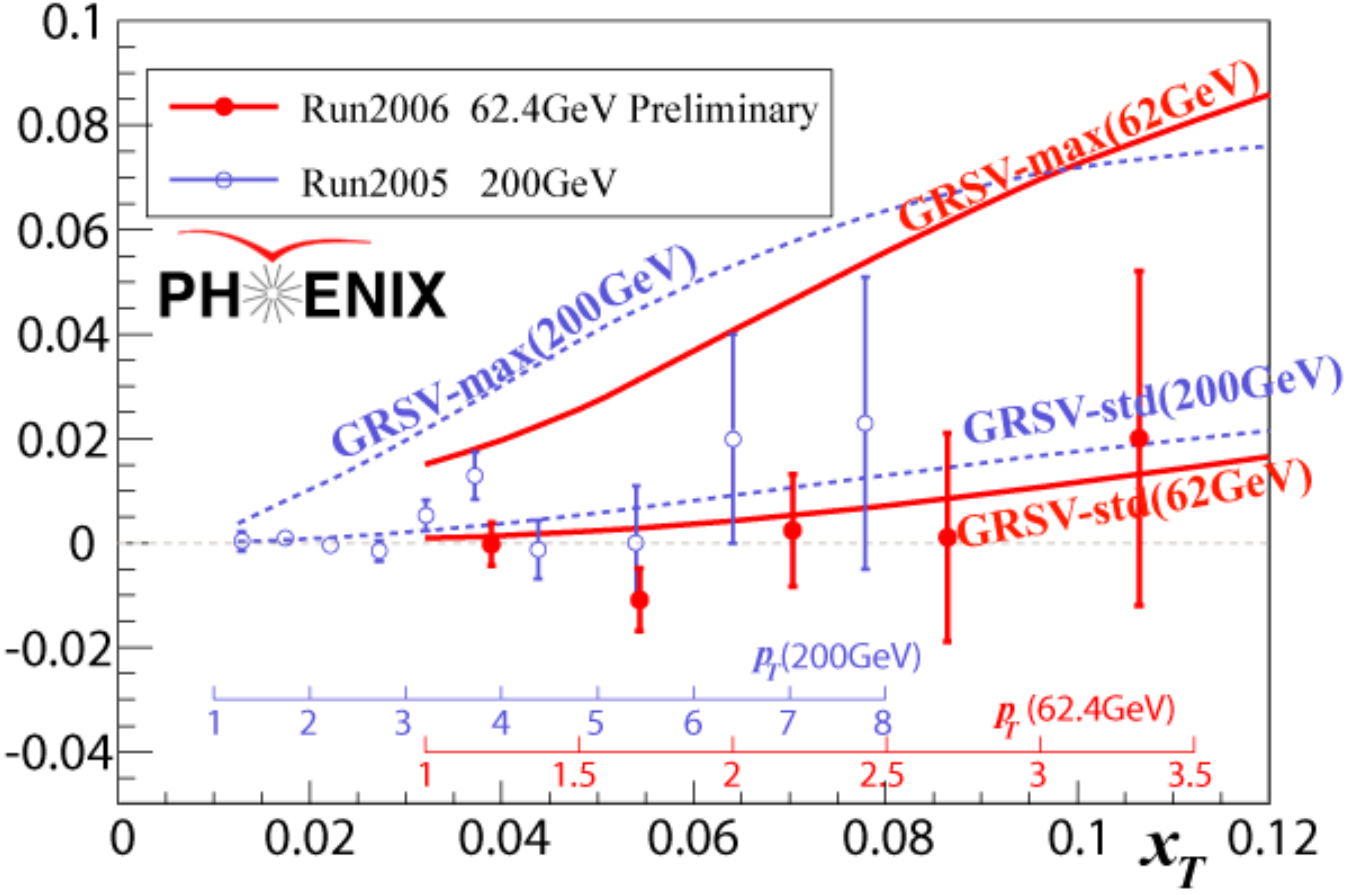
π^0 A_{LL} at 62.4GeV

- Significant statistical improvement in high x_T even with short data taking period (and small int.lumi)

		pol	
200GeV	2.5pb^{-1}	(47%)	~10weeks
62.4GeV	0.04 pb^{-1}	(48%)	~ 1week

$A_{LL}(\pi^0)$

GRSV – max is rejected also in higher x_T.

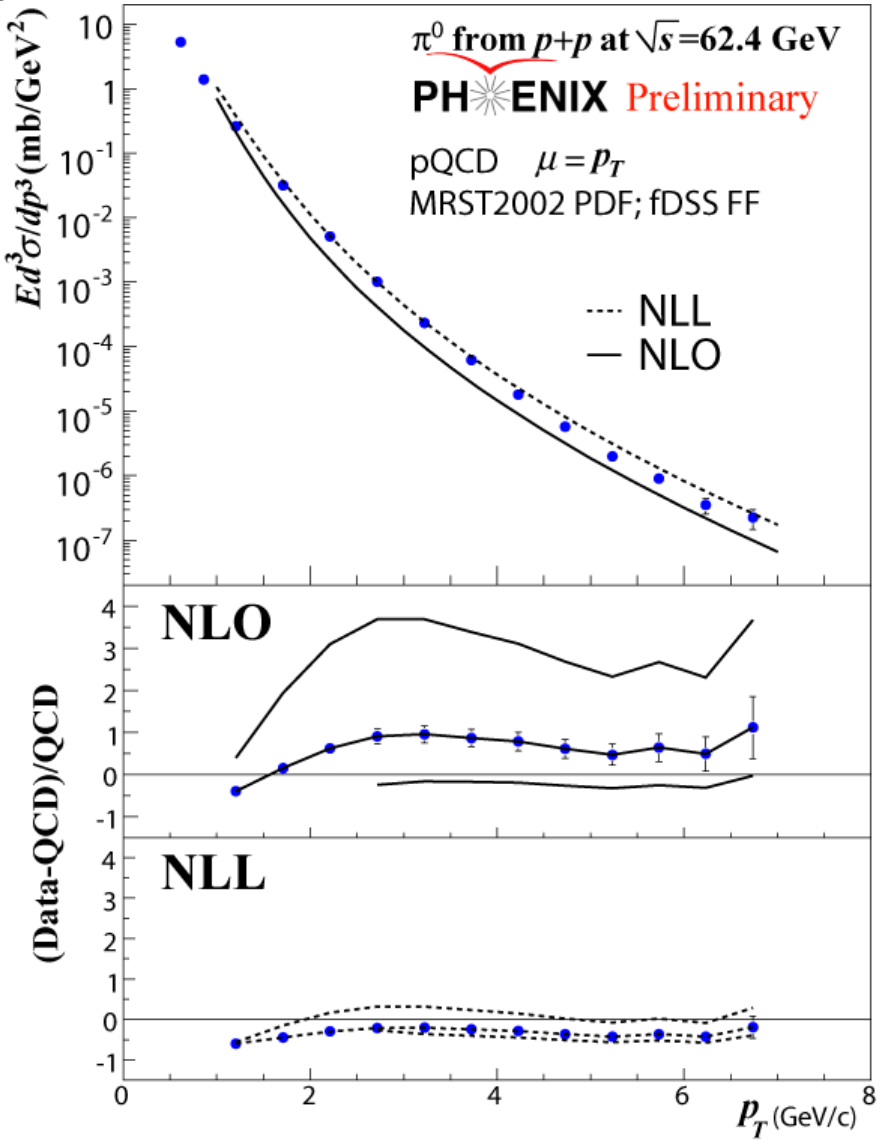


Scaling variable

$$x_T = \frac{2p_T}{\sqrt{s}}$$

Theoretical progress
NLO and NLL at sqrt(s)=62.4GeV

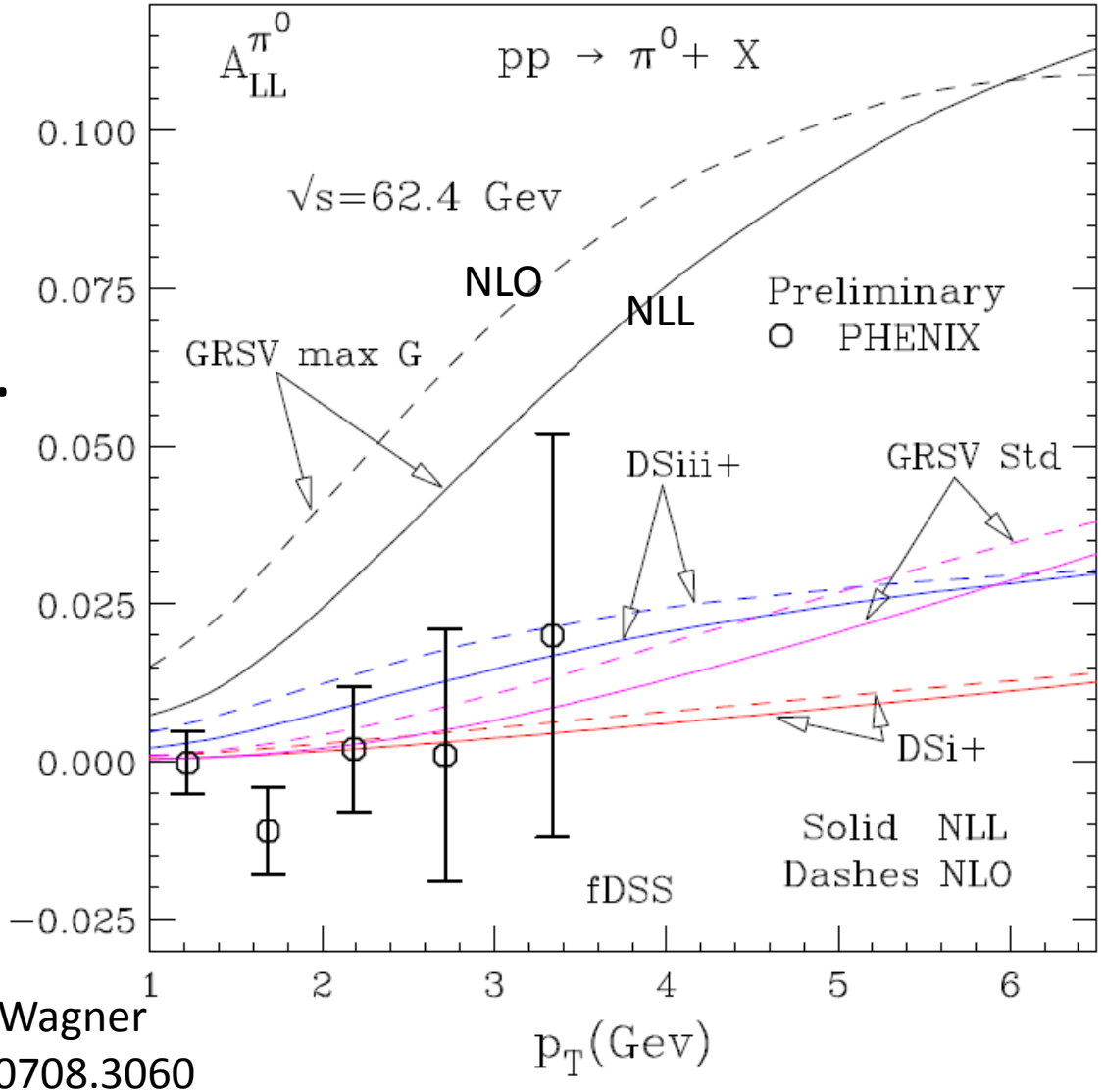
- NLL (Next-to-Leading Log) theory calculation available
- Improved agreement btw data and theory.
- Reduced scale dependence
- In Both NLO and NLL cases, data and theory agrees within theoretical uncertainty.



D. De Florian, W. Vogelsang, and F. Wagner
Phys.Rev.D76,094021(2007), arXiv:0708.3060

π^0 A_{LL} at 62.4GeV - NLL

- When we go NLL accuracy, GRSV-max A_{LL} decreases slightly.
- Still inconsistent with our data.



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summary

- Double Helicity Asymmetry A_{LL} of π^0 production is utilized for measurement of ΔG
- RUN2005 π^0 A_{LL} at $\sqrt{s}$ =200GeV put constraint on ΔG.
  - Needs more statistics for further improvement.
- Improvement obtained in RUN2006 in two ways
  - 200GeV: Collect more stat.
    - much improved ΔG sensitivity.
      - ΔG = std, in addition to ΔG=G,-G are rejected.
  - 62.4GeV : Lower energy to access higher x.
    - Improved higher x sensitivity with short data taking period
    - GRSV-max is rejected also in high x_T region in NLO.
    - Theory update - NLL
    - Our data is inconsistent with GSRV-max even in NLL.

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Information on the session

Contribution List | Time Table

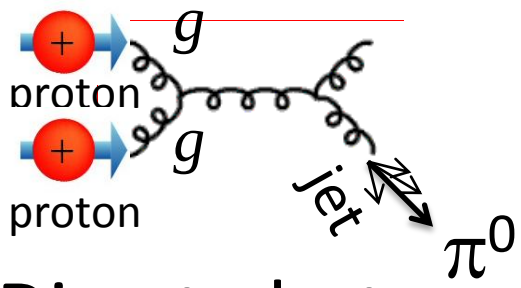
Monday, 07 April 2008

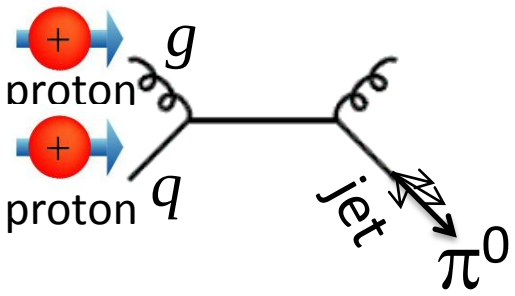
16:00	[173] **Recent STAR Results on Jet Production in Polarized pp Collisions at RHIC at sqrt(s)=200GeV** by Carl GAGLIARDI (Texas A&M) (A1: 16:20 - 16:40)
	[174] **Recent STAR Results on Charged Pion and Neutral Pion Production in Polarized pp collisions at RHIC at sqrt(s)=200GeV** by Alan HOFFMAN (MIT) (A1: 16:40 - 17:00)
17:00	[176] **Recent PHENIX results on Neutral Pion Production in Polarized pp Collisions at RHIC at sqrt(s)=62GeV and sqrt(s)=200GeV** by Kazuya AOKI (Kyoto University) (A1: 17:00 - 17:20)
	[175] **Recent PHENIX results on Charged Pion and Eta Production in Polarized pp Collisions at RHIC at sqrt(s)=200GeV** by Frank ELLINGHAUS (University of Colorado at Boulder) (A1: 17:20 - 17:40)
	[177] **Gluon polarization and higher twist effects** by E. LEADER (Imperial College London) (A1: 17:40 - 18:00)

BACK UP SLIDES

Various channels available at PHENIX to explore gluon pol.

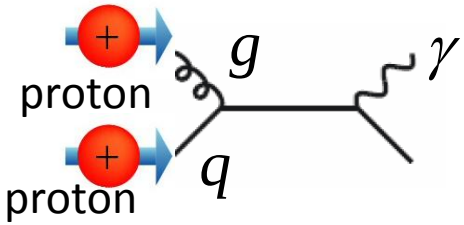
- Jet (or a component of jet)





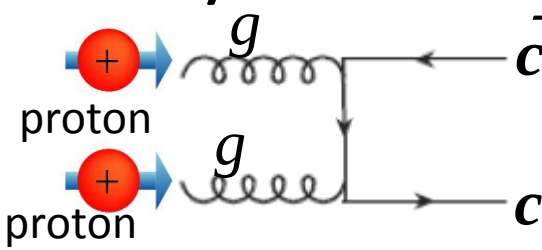
- π^0 , η $(\rightarrow \gamma\gamma)$
- π^{+-}
- *jet*-like cluster

- Direct photon



- γ

- Heavy Flavor



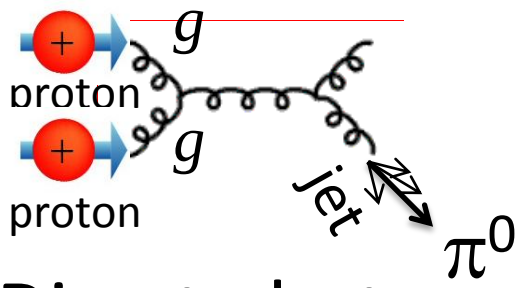
$\bar{c} \rightarrow D \rightarrow e$ or μ

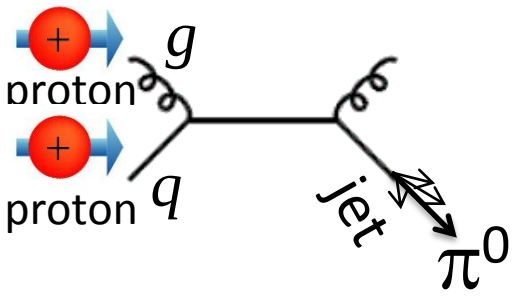
or $\bar{c}c \rightarrow J/\psi$

- e^{+-}
- μ^{+-}
- $J/\psi (\rightarrow e^+e^-, \mu^+\mu^-)$

Various channels available at PHENIX to explore gluon pol.

- Jet (or a component of jet)

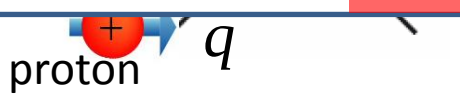




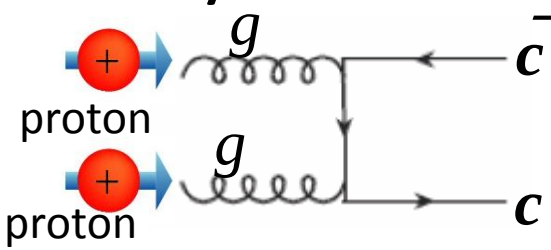
- π^0 , η ($\rightarrow \gamma\gamma$)
- π^{+-}
- *jet*-like cluster

$$A_{LL} \sim \int dx_1 dx_2 \hat{a}_{LL}^{gg} \frac{\Delta g}{g}\frac{\Delta g}{g} + \hat{a}_{LL}^{qg} \frac{\Delta g}{g}\frac{\Delta q}{q}$$

- γ



- Heavy Flavor



- e^{+-}
- μ^{+-}
- $J/\psi (\rightarrow e^+e^-, \mu^+\mu^-)$

Various channels available at PHENIX to explore gluon pol.

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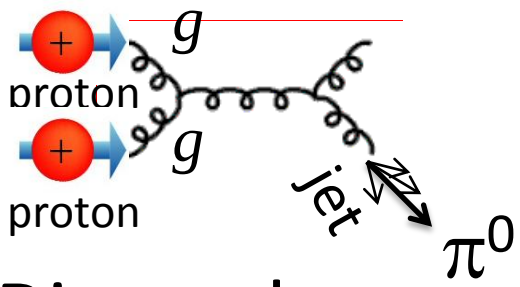
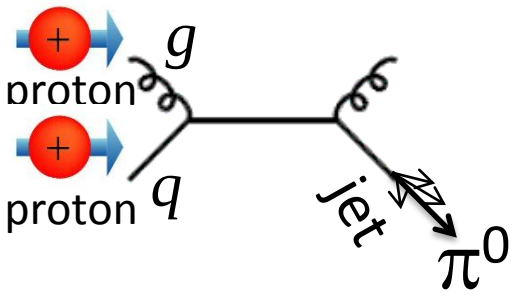
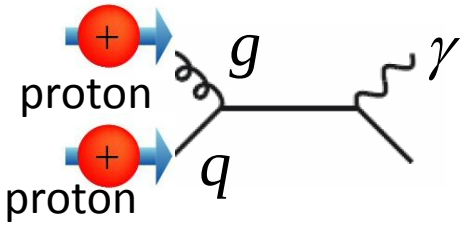




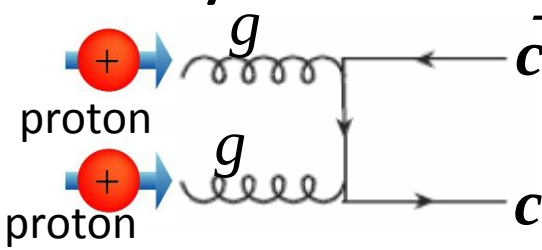
- π^0 , η $(\rightarrow \gamma\gamma)$
- π^{+-}
- *jet*-like cluster

- Direct photon



- γ

- Heavy Flavor



$\bar{c} \rightarrow D \rightarrow e$ or μ

or $\bar{c}c \rightarrow J/\psi$

- e^{+-}
- μ^{+-}
- $J/\psi (\rightarrow e^+e^-, \mu^+\mu^-)$

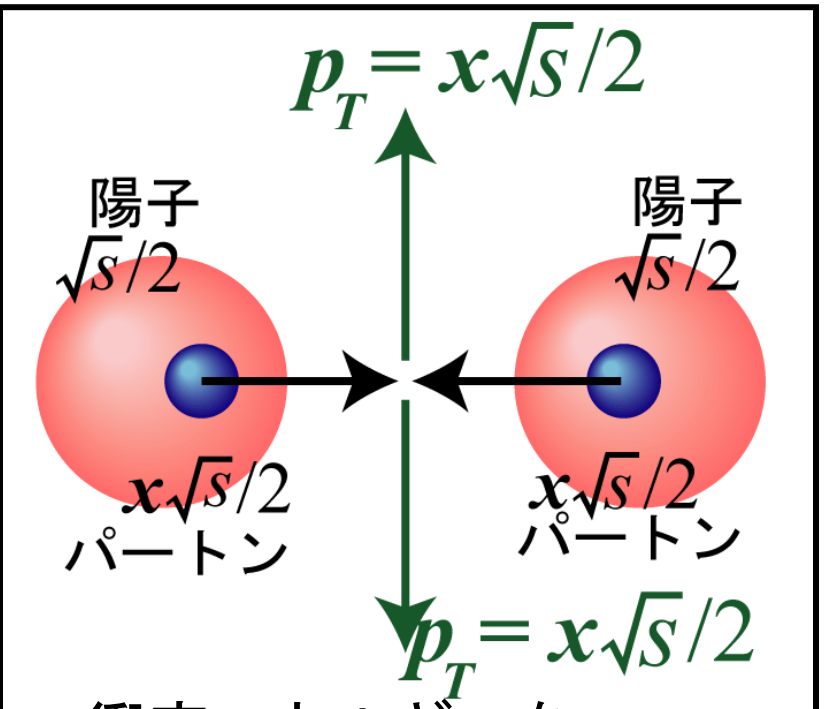
summary

- PHENIX longitudinal spin program is to reveal the spin structure of proton, especially Δg which has a large uncertainty.
- PHENIX cross-section measurements are shown. The results confirm pQCD applicability which Δg extraction framework relies on.
- PHENIX - A_{LL} π^0 excludes large $|\Delta g|$ scenarios.
  - Statisical improvement expected in the next run.
- complementary measurements will be obtained from other channels.
- We'll accumulate 70pb^{-1}(70% pol.) at 200GeV in 2008(RUN8)

何故 $\sqrt{s}$ = 62.4GeVがうれしいか？

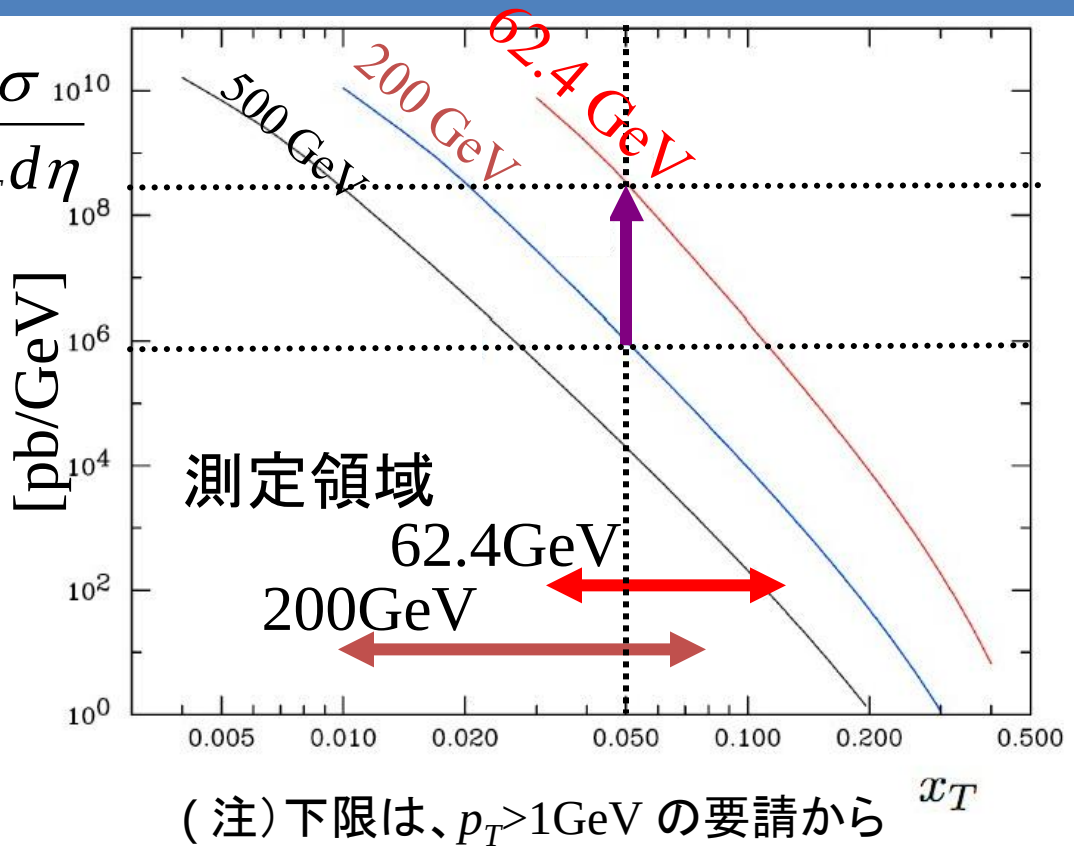
スケーリング変数

$$x_T = \frac{2p_T}{\sqrt{s}}$$



- 衝突エネルギーを、全て横に持って行った場合。

•高い x_T は、高い x をプローブする。



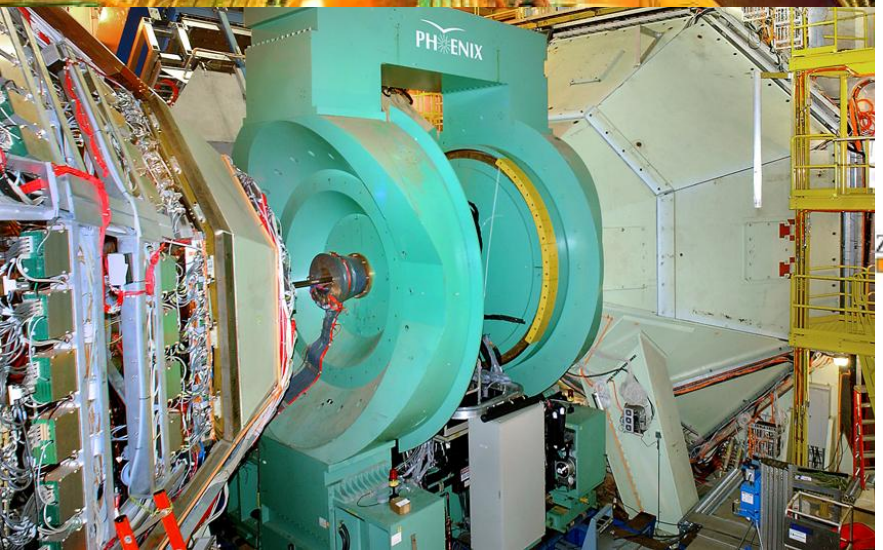
（注）下限は、p_T>1GeV の要請から

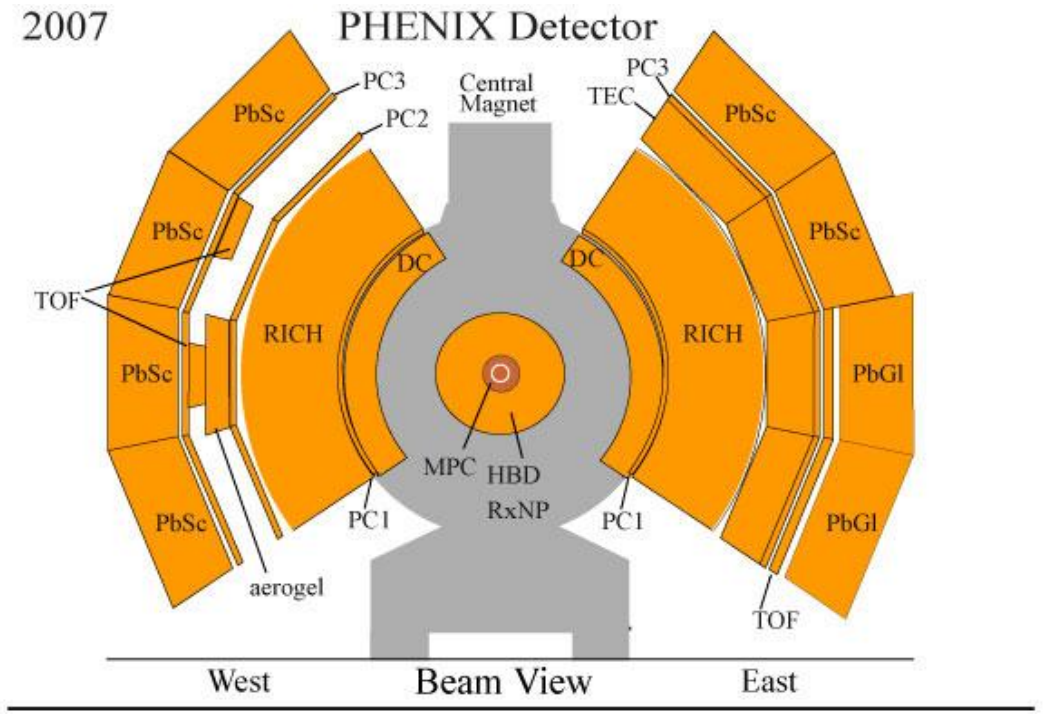
•同じ x_T で比較して、200 GeVと比べて2桁大きい。

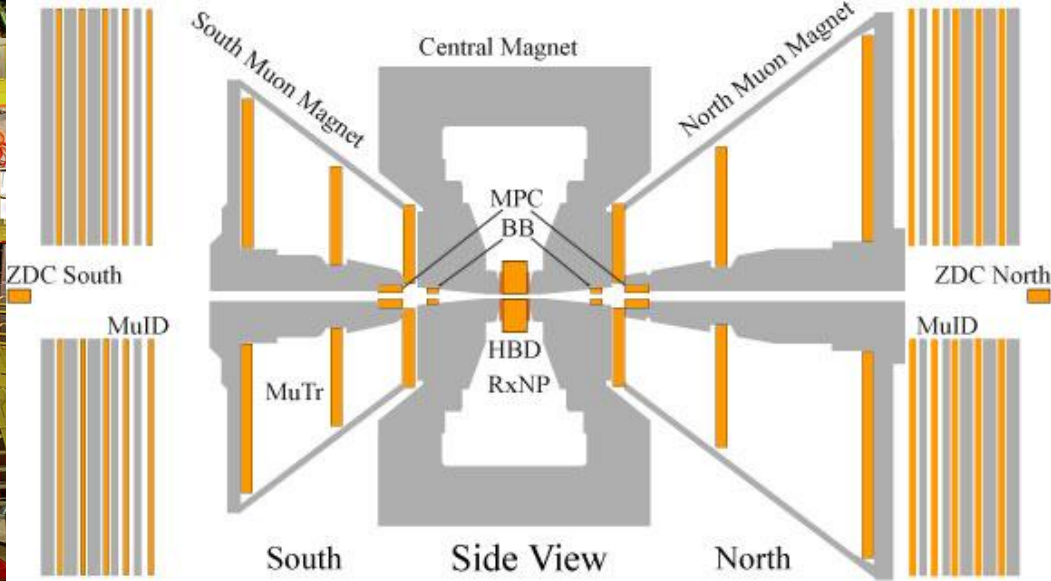
↓

•少ない積分輝度で、有意な結果が得られる。

PHENIX Detector – Central Arm







PHENIX: γ detection.(62GeV)

EMCal

- Acceptance - $|\eta|<0.35$, $\Delta\phi=90 \times 2$
- Energy resolution

  $8.1\% / \sqrt{E} \oplus 2.1\%$ (PbSc)

  $5.9\% / \sqrt{E} \oplus 0.8\%$ (PbGl)
- Position resolution

  $5.7\text{mm} / \sqrt{E} \oplus 1.6\text{mm}$ (PbSc)

  $8.4\text{mm} / \sqrt{E} \oplus 0.2\text{mm}$ (PbGl)

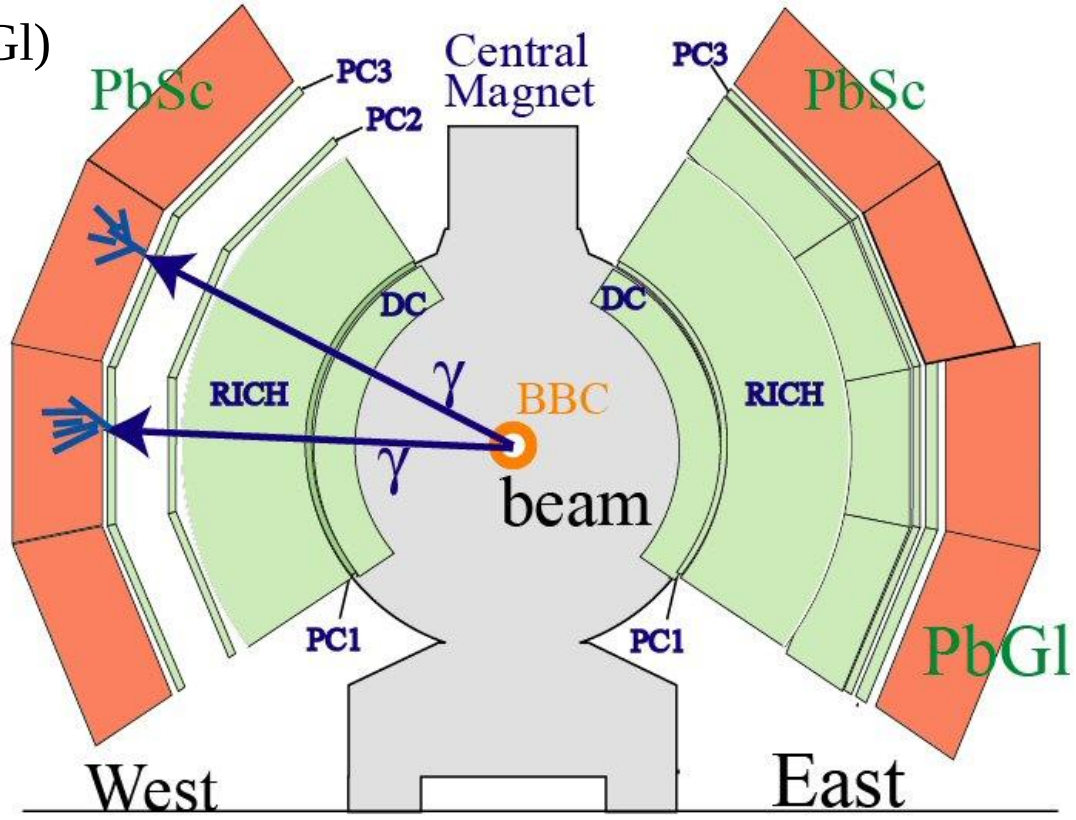
π^0 reconstruction

- Minimal photon energy cut
  - –0.1 GeV for PbSc
  - –0.2 GeV for PbGl
- Shower profile cut
- Energy asymmetry cut
- Trigger tile matching. (for higher energy cluster)

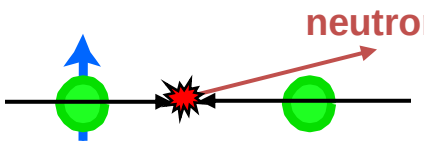
Trigger

high energy cluster at EMCal. (~800MeV) w/o BBC

–BBC efficiency for π^0 event(hard scattering) is low (~40%)

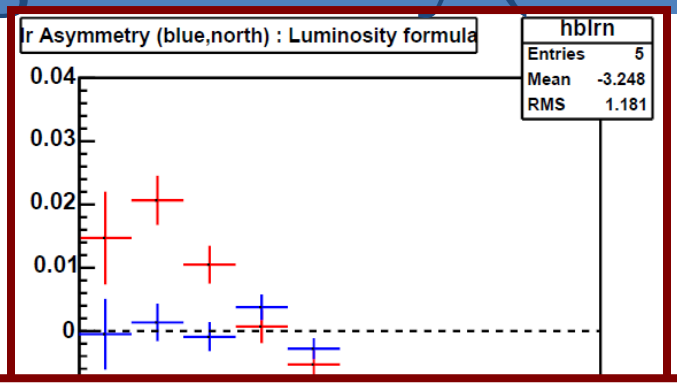


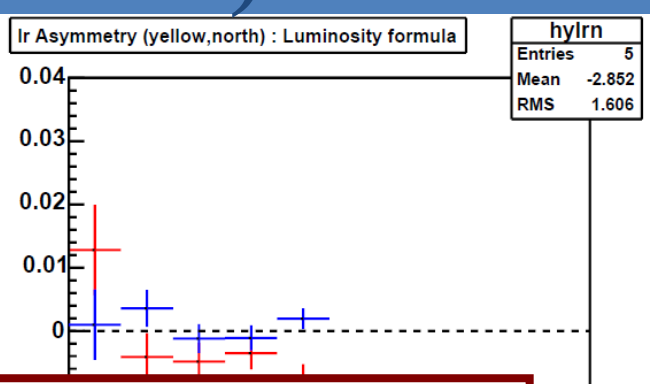
Longitudinality (62.4GeV)



$$A_N \equiv \frac{1}{P}\frac{N_\uparrow - RN_\downarrow}{N_\uparrow - RN_\downarrow}$$

$$R = \frac{L_\uparrow}{L_\downarrow}$$





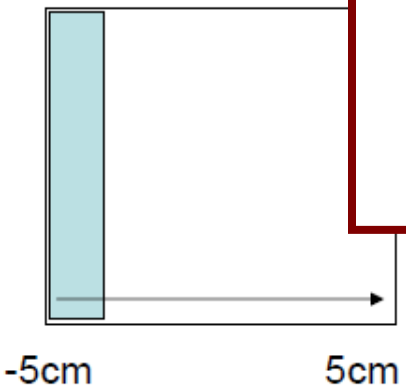
Longitudinal 100% (-2.2%)

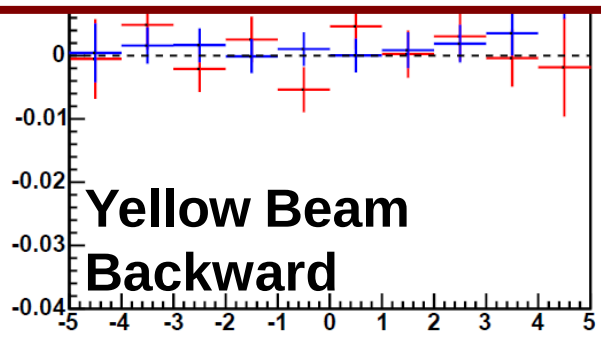
Transverse 21% (1σ uncertainty)

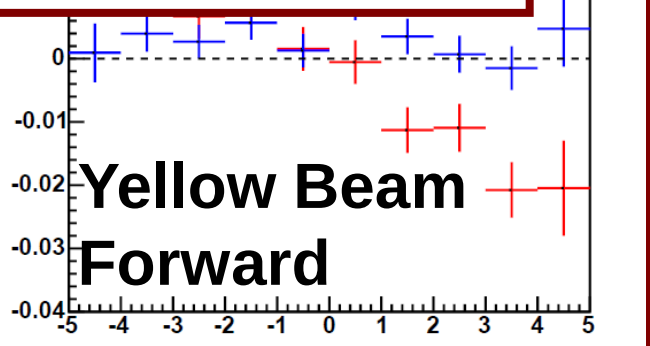
$$A_{raw} = p_L^2 \cdot A_{LL} + p_T^2 \cdot A_{TT}$$

What we measure. What we want.

ZDC detect

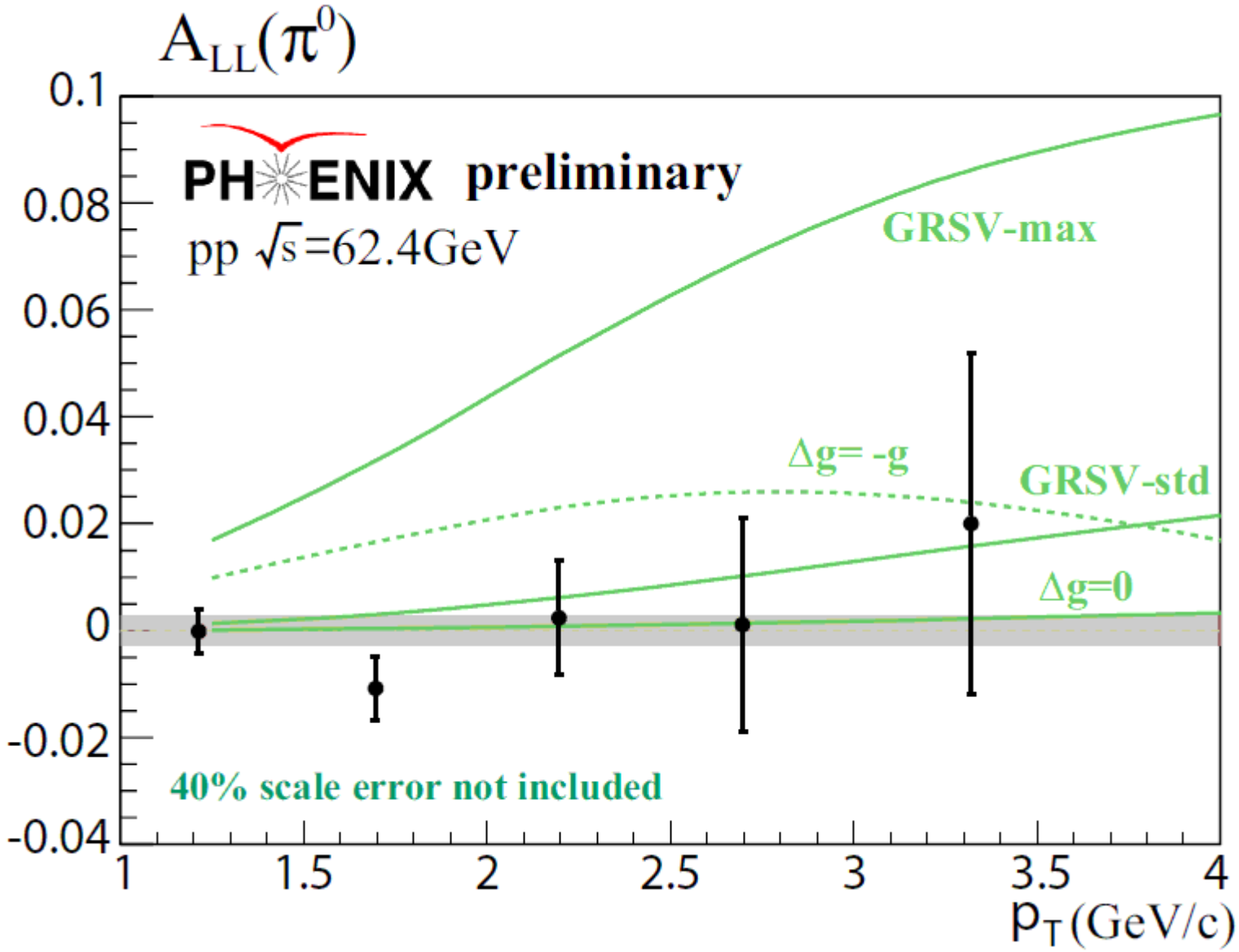






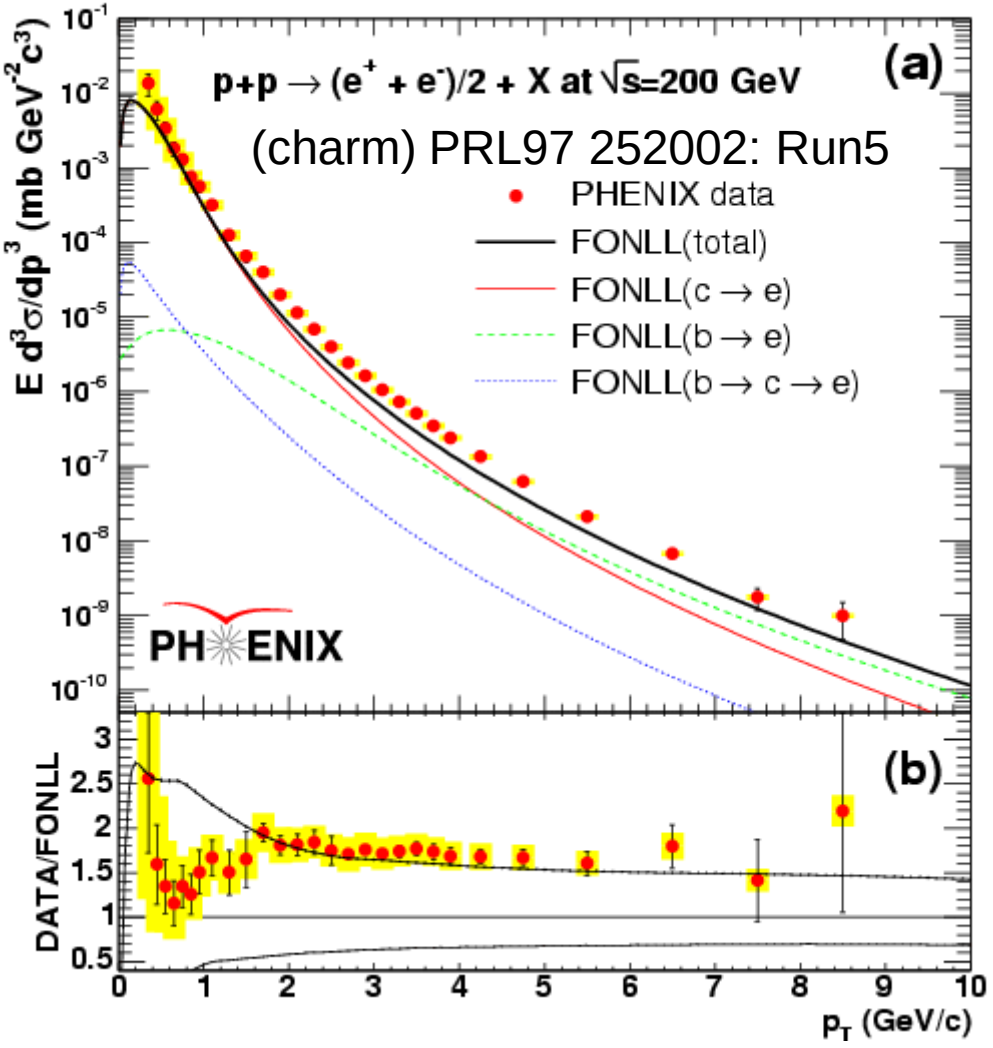
Red : Rotator OFF

Blue : Rotator ON



Theory curve by W. Vogelsang

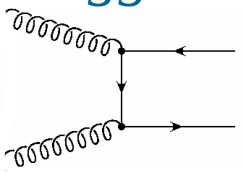
Cross section measurements



Electron

(from Charm, Beauty)

$$gg \to Q\bar{Q}$$



$$\Delta g \cdot \Delta g$$