ΔG and $\Delta\bar{q}$ measurements at PHENIX

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Pan Pacific Spin 2011

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Outline

- RHIC-PHENIX brief introduction
- $\Delta\overline{q}$ (W boson A_L)
- ΔG (hadron A_{LL})
- What's next?
- PHENIX decadal plan discussion

RHIC-PHENIX introduction

RHIC:

The polarized *p+p* collider

High energy (√s is up to 500GeV)

Longitudinal and transverse with the spin rotator

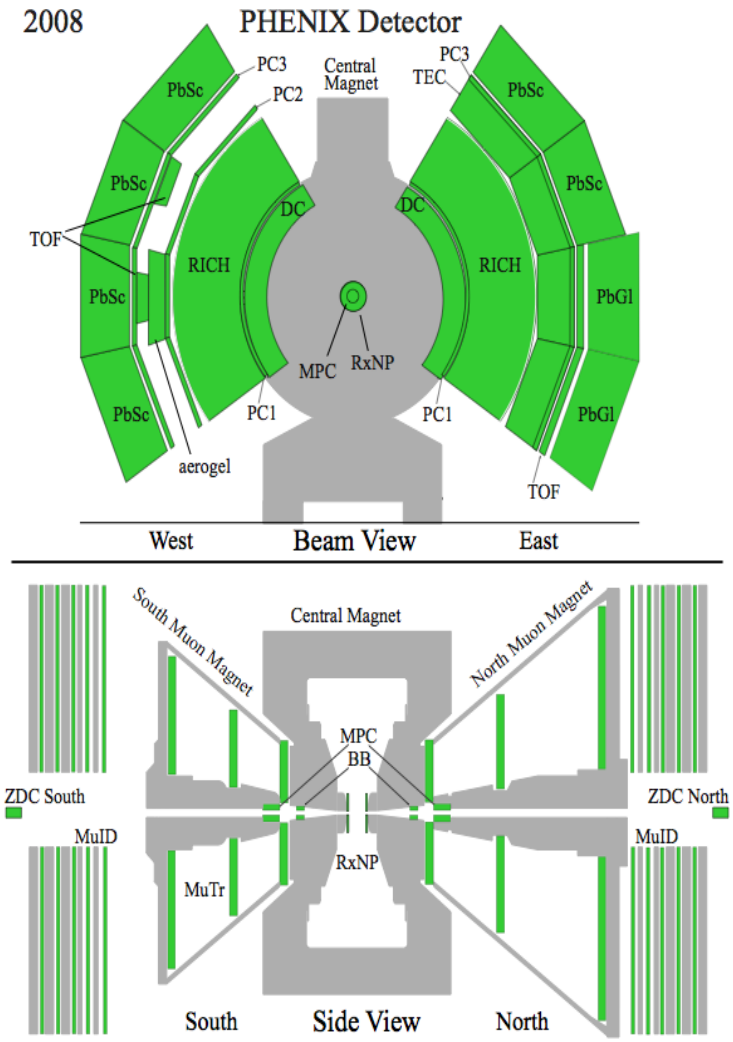
PHENIX:

Central arm (|eta|<0.35)

Forward muon arm (1.2<|eta|<2.4)

MPC (=Forward EMCal) (3.1<|eta|<3.7)

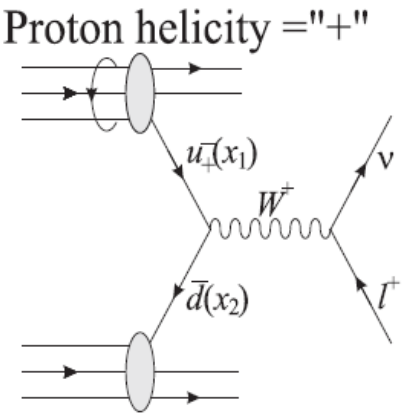
Particle ID, Trigger, fast DAQ system



$\Delta\overline{q}$ MEASUREMENT

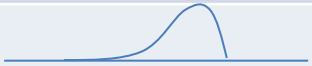
W boson for $\Delta\bar{q}$ (flavor separation)

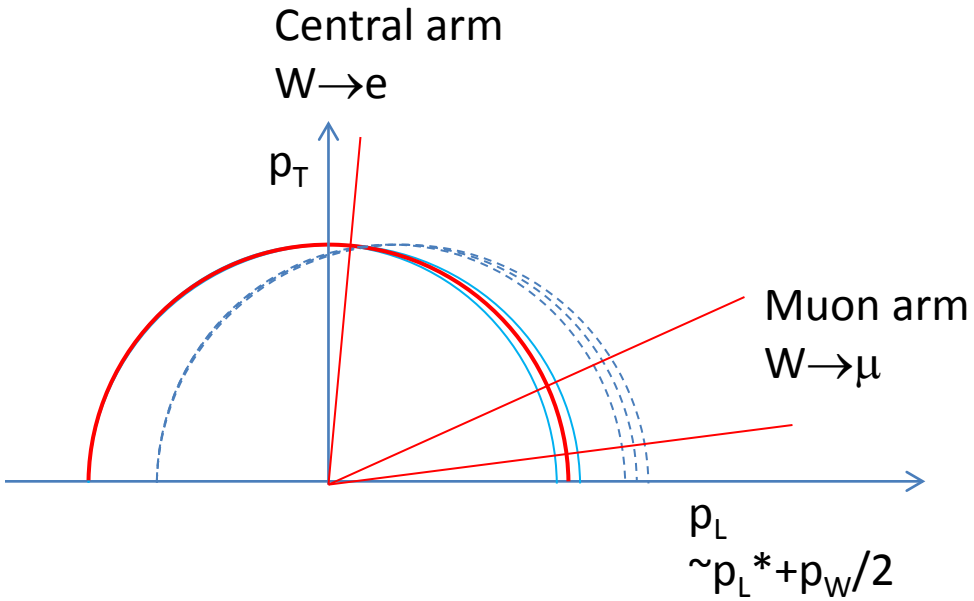
- Totally different approach to $\Delta\bar{q}$ in SIDIS
  - High Q^2 is set by W mass. pQCD calculation is reliable.
  - No fragmentation function is involved.

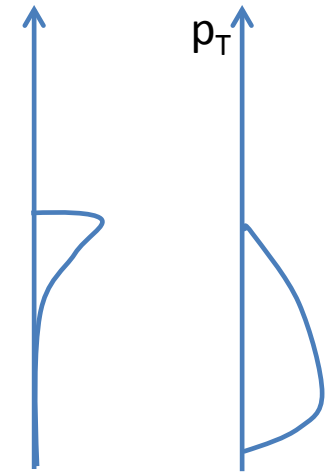


- W boson production in *p+p* $\sqrt{s}$=500GeV
- Detect decay lepton of $W \rightarrow \ell\nu$
- The parity violating asymmetry (A_L)

W→e (central), W→μ (forward)

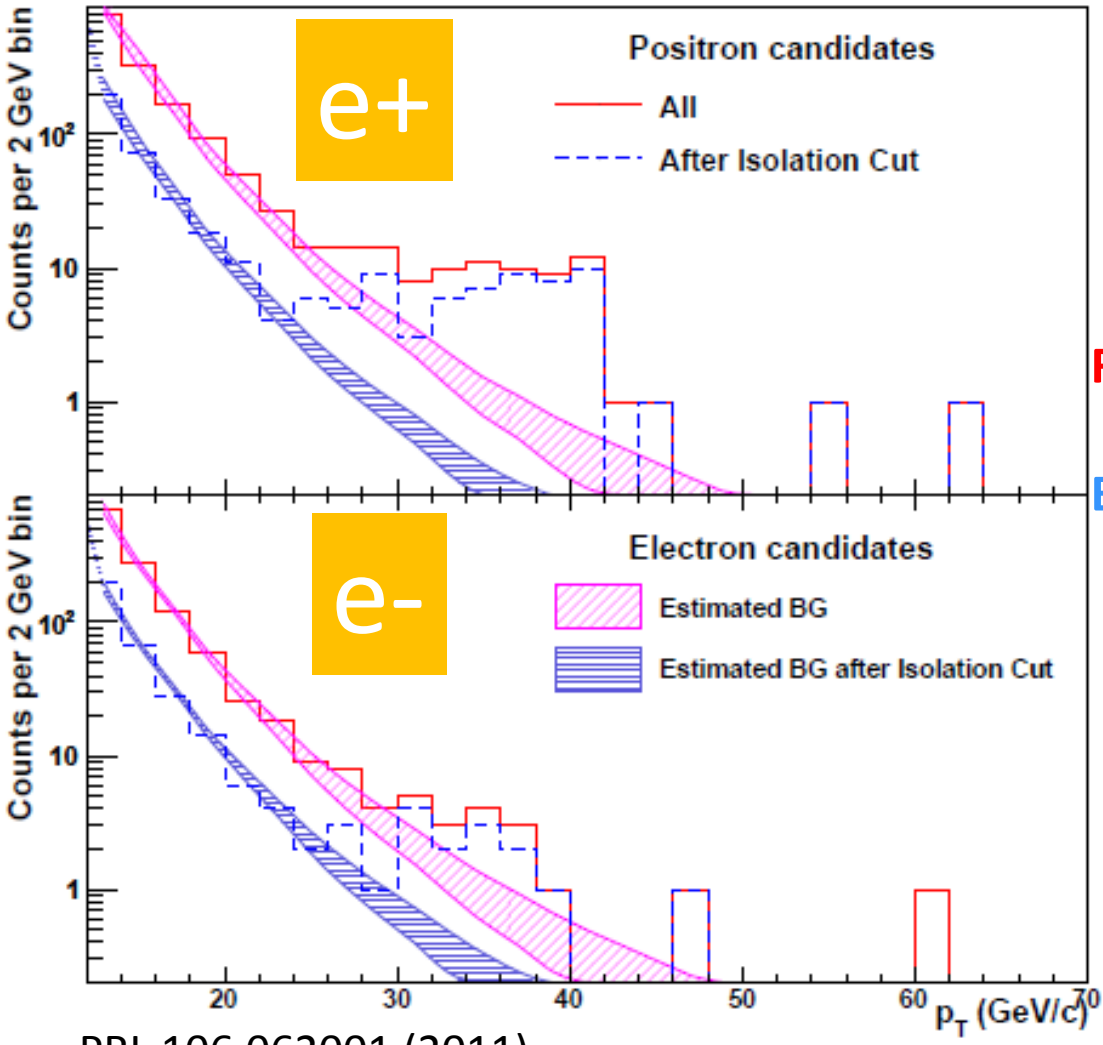
	Central arm	Muon arm
Triggered by	energy	momentum
momentum	E_{dep} in EMCal	Tracking in B field
charge	Tracking in B field	Tracking in B field
pT shape		





W→μ is more challenging.

W→e is confirmed



PRL 106,062001 (2011)

Run9 (2009) data $\int L=8.6/pb$

p_T distribution of electron candidates

Red histogram:
with minimum track requirements

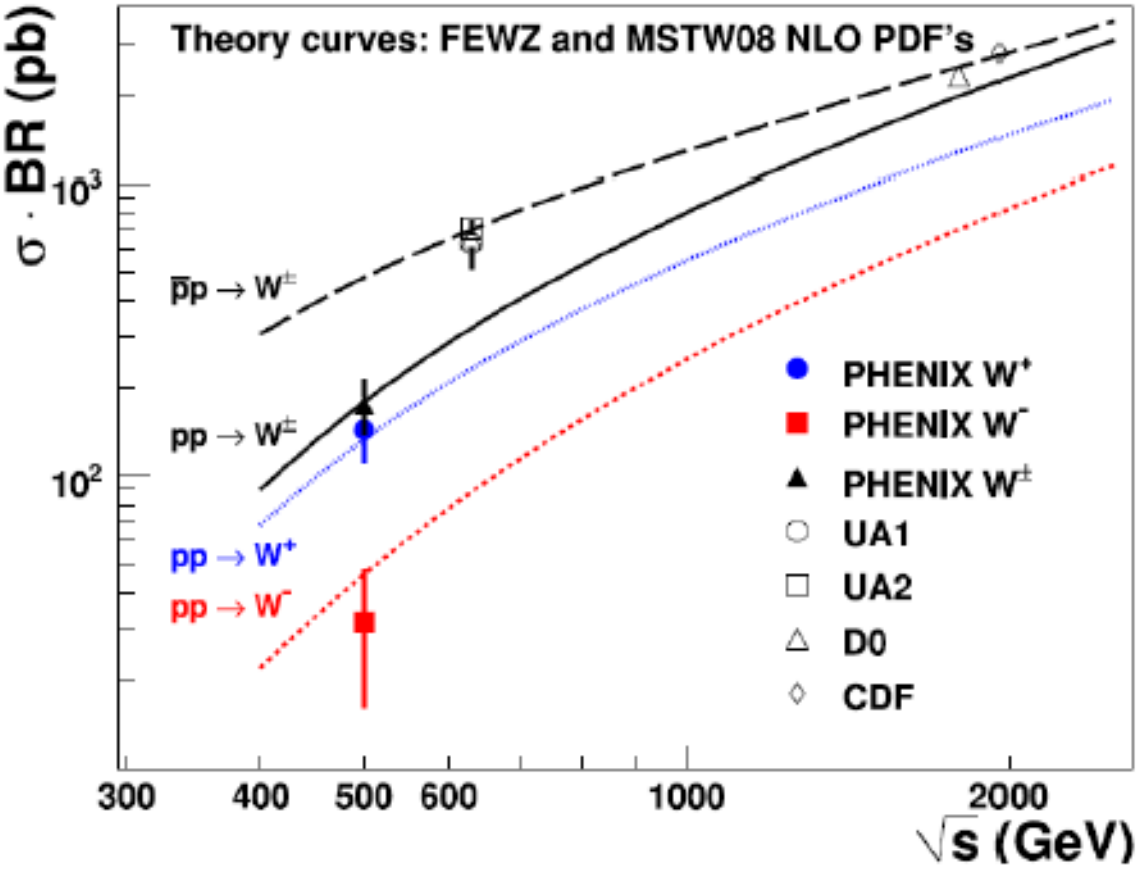
Blue histogram:
with an isolation cut

Z decay is included.

Main background :
Photon conversion
Charged hadron interaction

Convert to the total W production

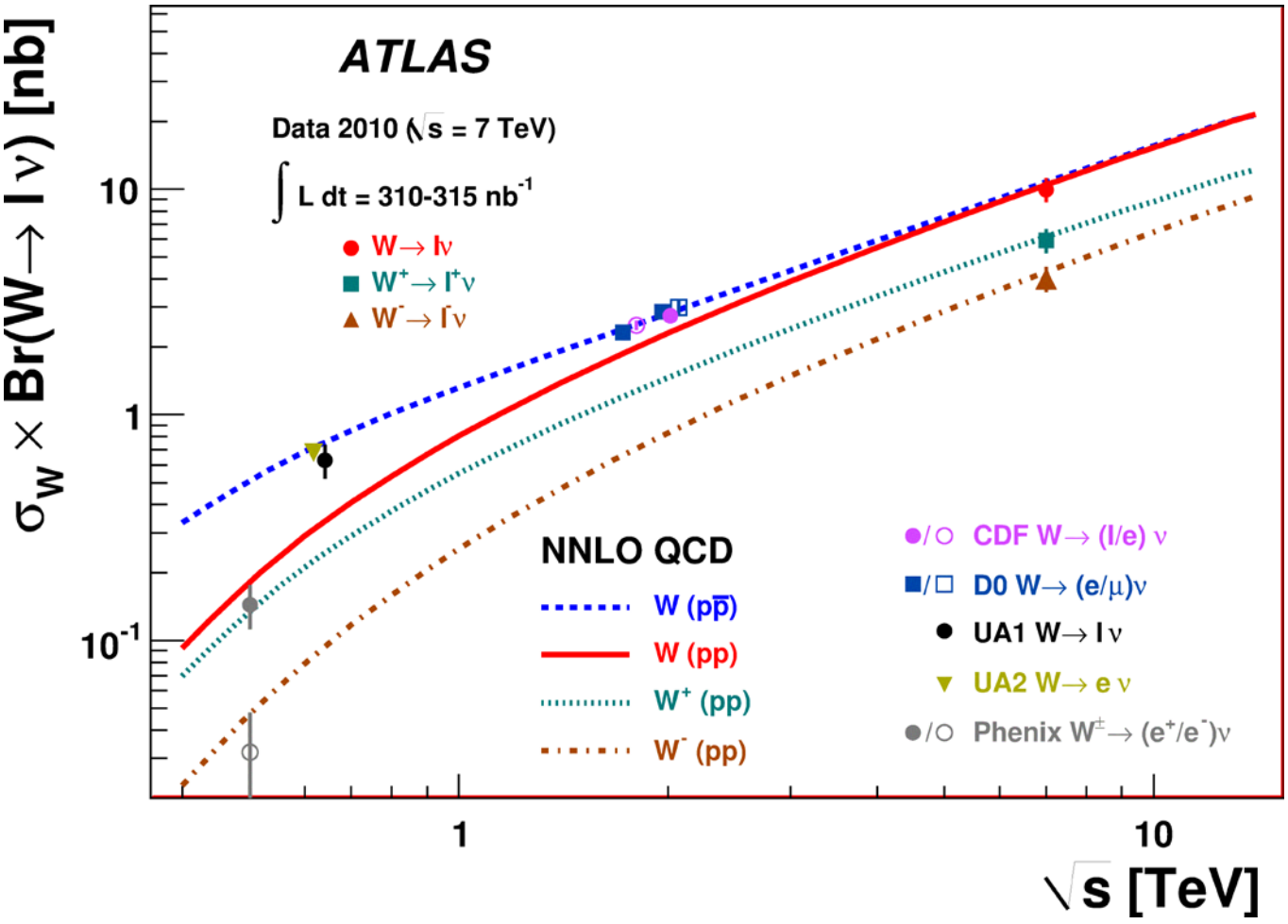
PHENIX acceptance ⟶ Full 4π
（pT>30GeV, |y|<0.35）



Z boson contribution
+ : ~7%, -: ~30%
Fraction of the PHENIX
+ : ~22%, -: ~15%

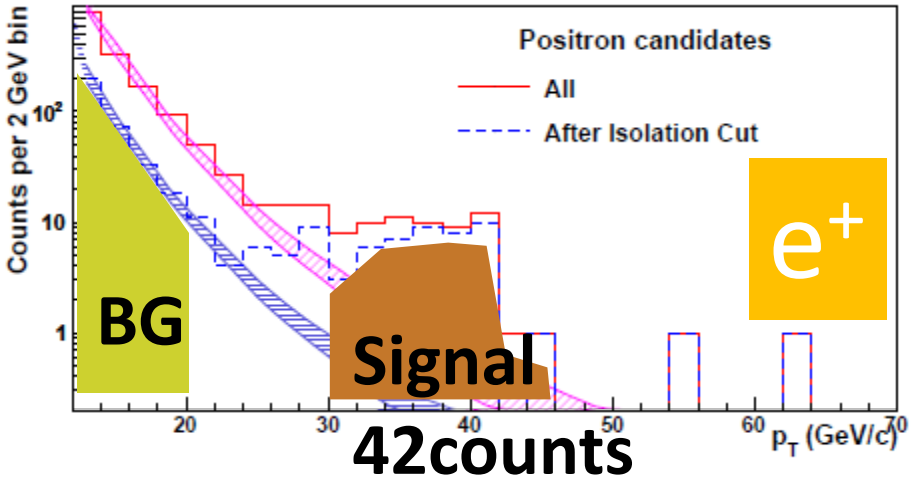
The first measurement in *p+p* collisions.

More recent measurements

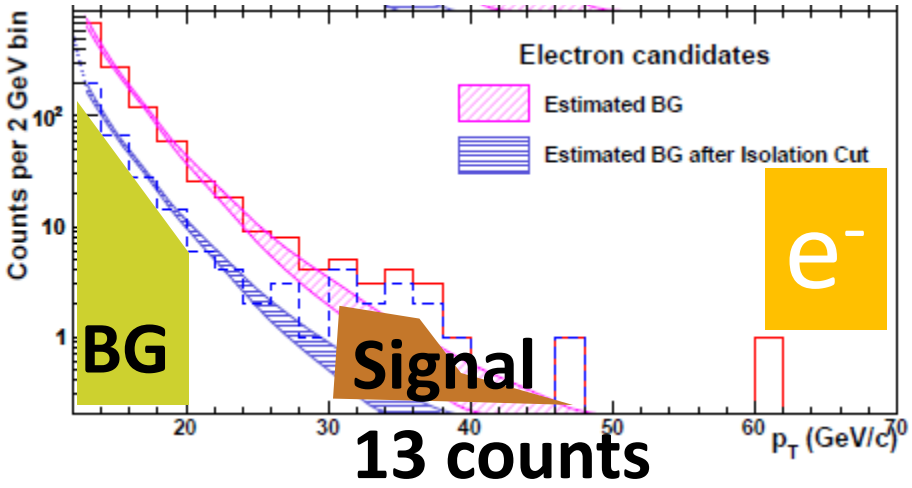


ATLAS, JHEP 1012:060,2010 (arXiv/1010.2130v1)

Parity violating raw asymmetries (ε_L)



42counts



13 counts

Sample	ϵ_L
Bkgrnd +	-0.015 ± 0.04
Signal +	-0.31 ± 0.10
Bkgrnd −	-0.025 ± 0.04
Signal −	0.29 ± 0.20

ε_L=0 for Background (as expected)

Large ε_L for Signal (especially in e^+)

Physics asymmetries (A_L)

$$A_L = \frac{\epsilon_L \cdot D}{P}$$

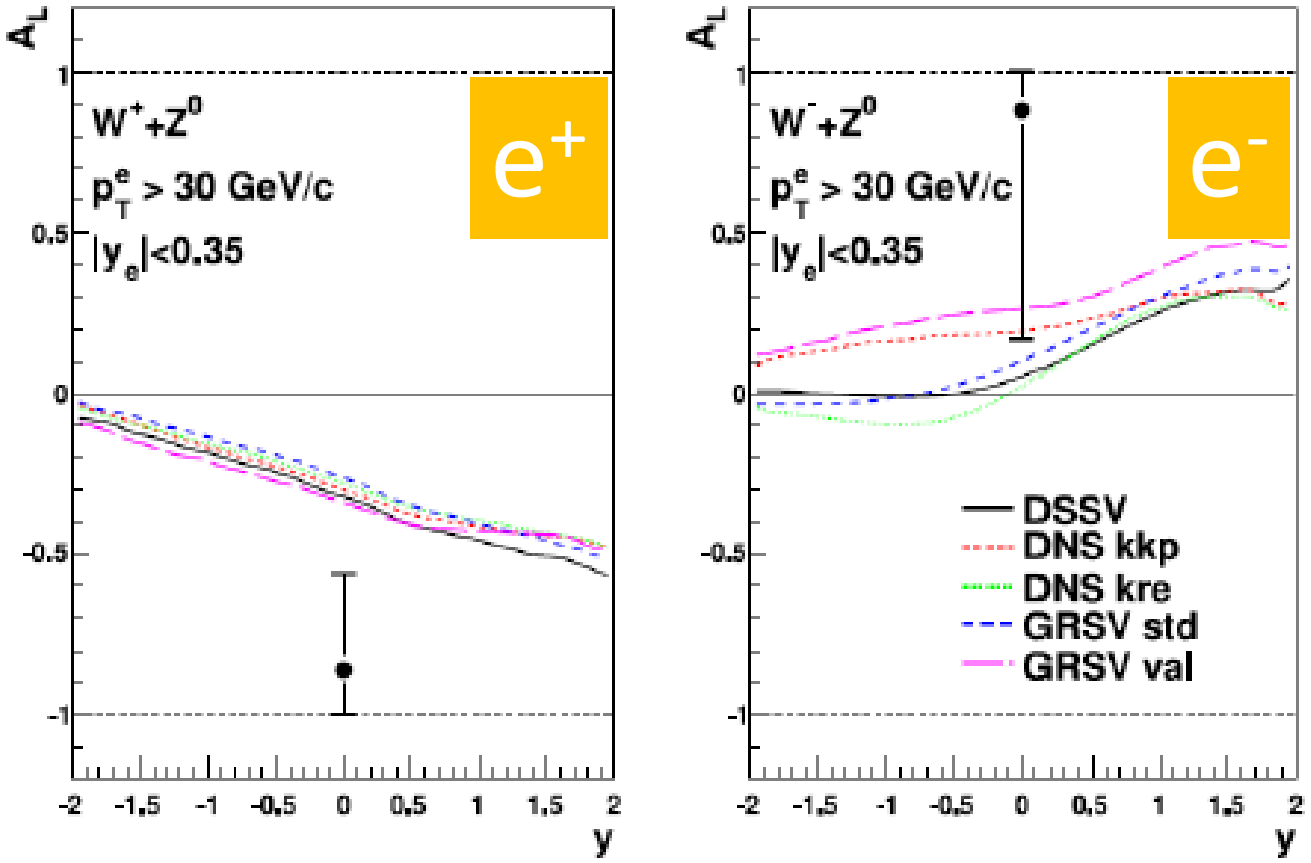
D: 1.04±0.03 (+ signal)
1.14±0.10 (- signal)
P: 0.39±0.04 (2 beam average)

Sample	ϵ_L
Bkgrnd +	-0.015 ± 0.04
Signal +	-0.31 ± 0.10
Bkgrnd −	-0.025 ± 0.04
Signal −	0.29 ± 0.20

	$A_L^e(W+Z)$	68%CL	95%CL
e^+	-0.86	$[-1, -0.56]$	$[-1, -0.16]$
e^-	$+0.88$	$[0.17, 1]$	$[-0.60, 1]$

Limited to the physical region [-1,1].

A_L (68%CL) and predictions



They are consistent with all models for now.

A non-zero asymmetry is observed in the positron signal.

2011 run is for $W \rightarrow \mu$

- Period: ~4weeks (March-April 2011)
- Integrated luminosity: (~16.7/pb for |z|<30cm)
- New muon arm trigger hardware

(I.Nakagawa talk on Wednesday)

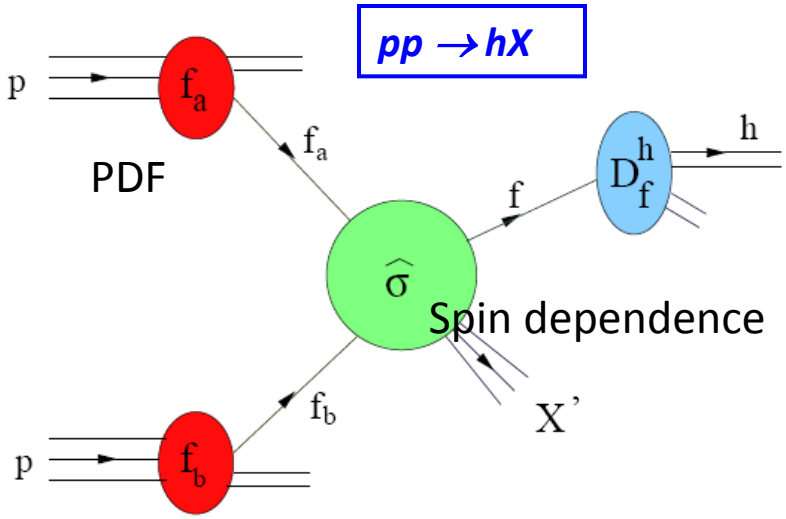
- A few more years to complete the program.
  - The current goal is to recorded luminosity of 300/pb

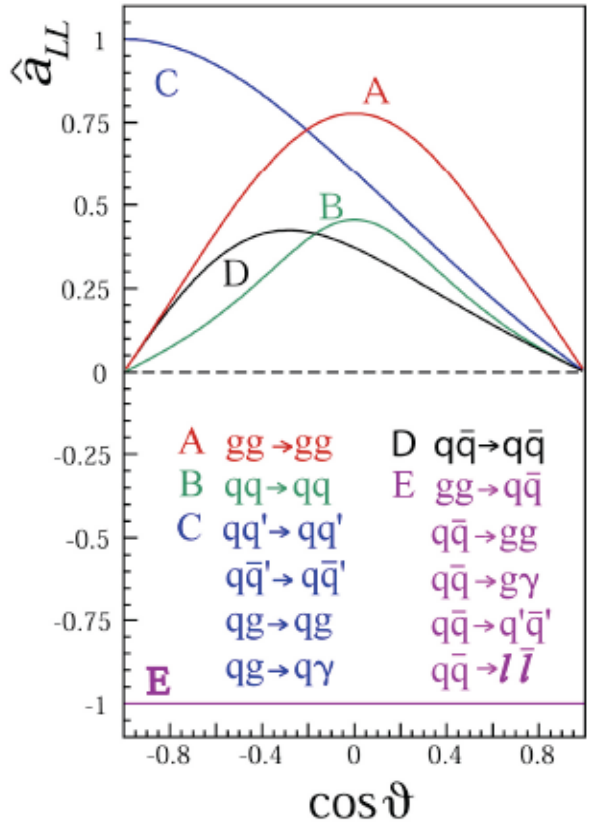
ΔG MEASUREMENT

Probing ΔG

Double longitudinal spin asymmetry (A_{LL}) is sensitive to ΔG

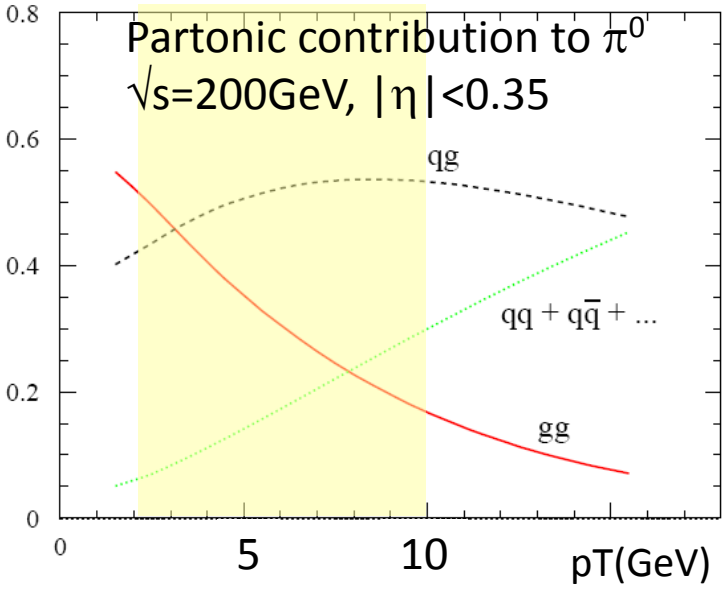
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \cdot \hat{a}_{LL}^{f_a f_b \to fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$$

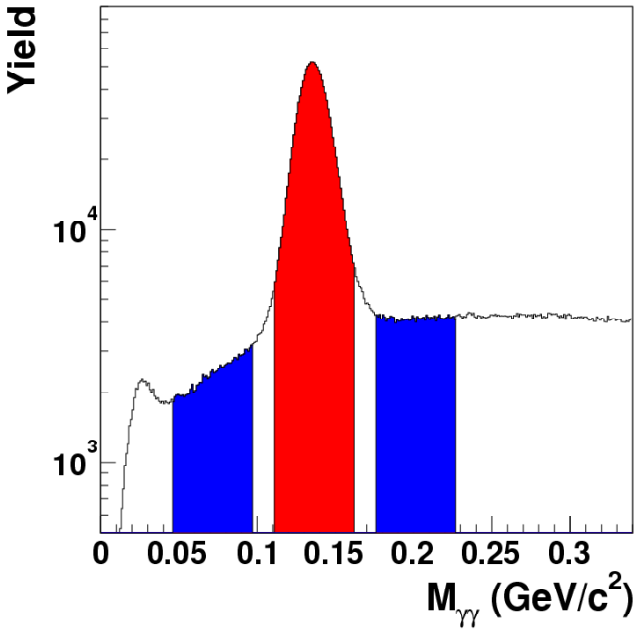




Why we always start with π^0?

- Production cross section is high and from gluon interaction.
- PHENIX EMCal Trigger friendly.
- Found in 2 photons invariant mass.



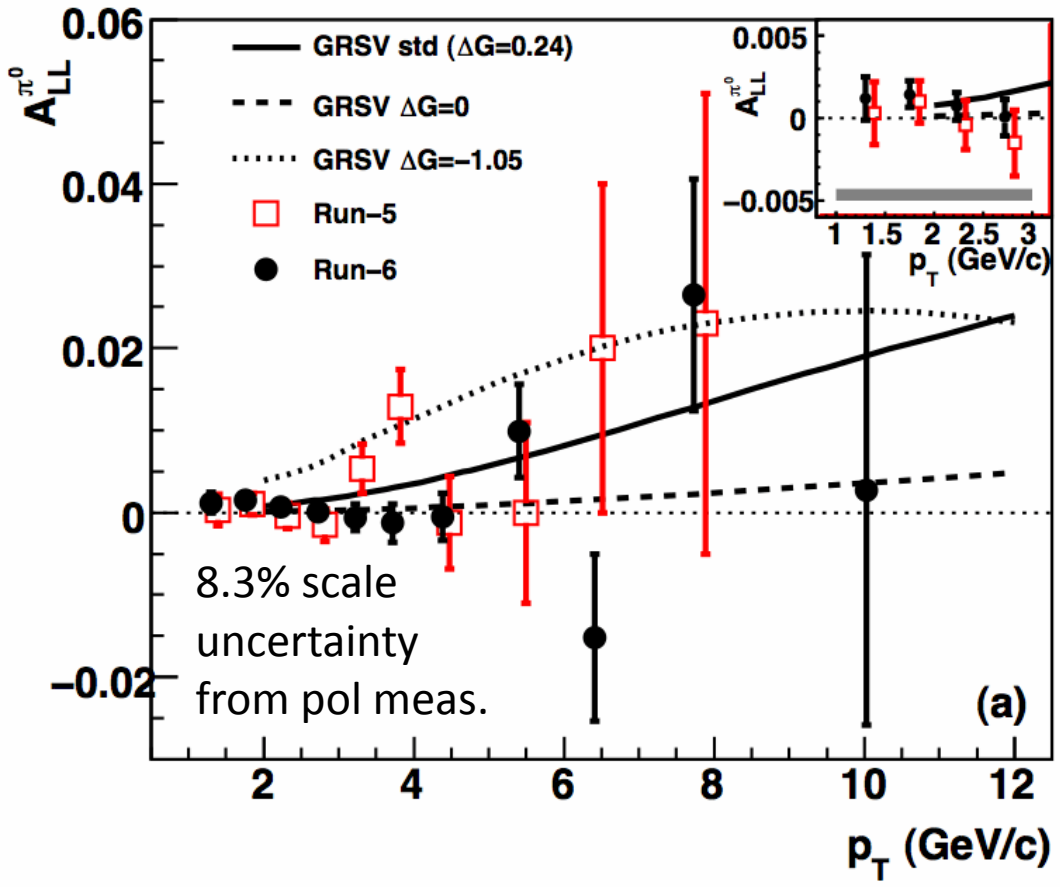


π^0 p_T	w_{BG}
2 GeV/c	20%
5	8%
10	5%

(published) π^0 A_{LL}

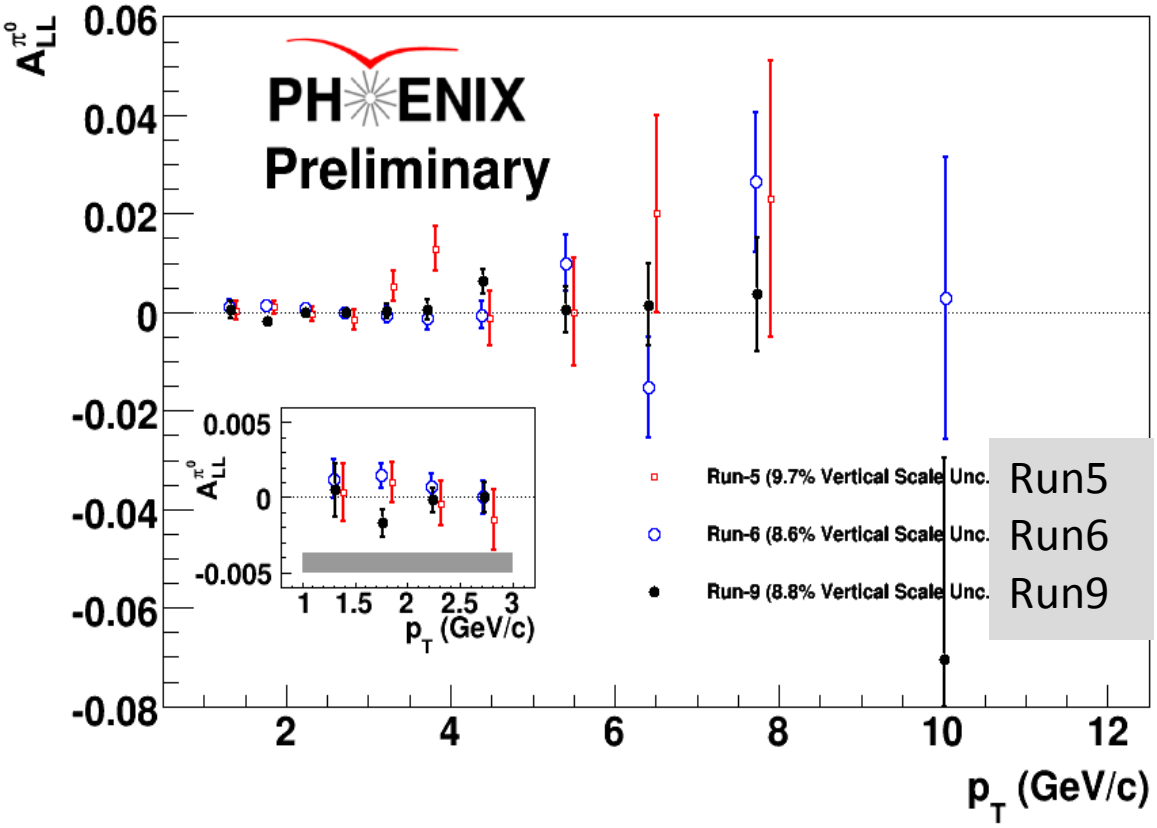
$$A_{LL}^{\pi 0} = \frac{A_{LL}^{\pi 0+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$

PRL 103,012003(2009)

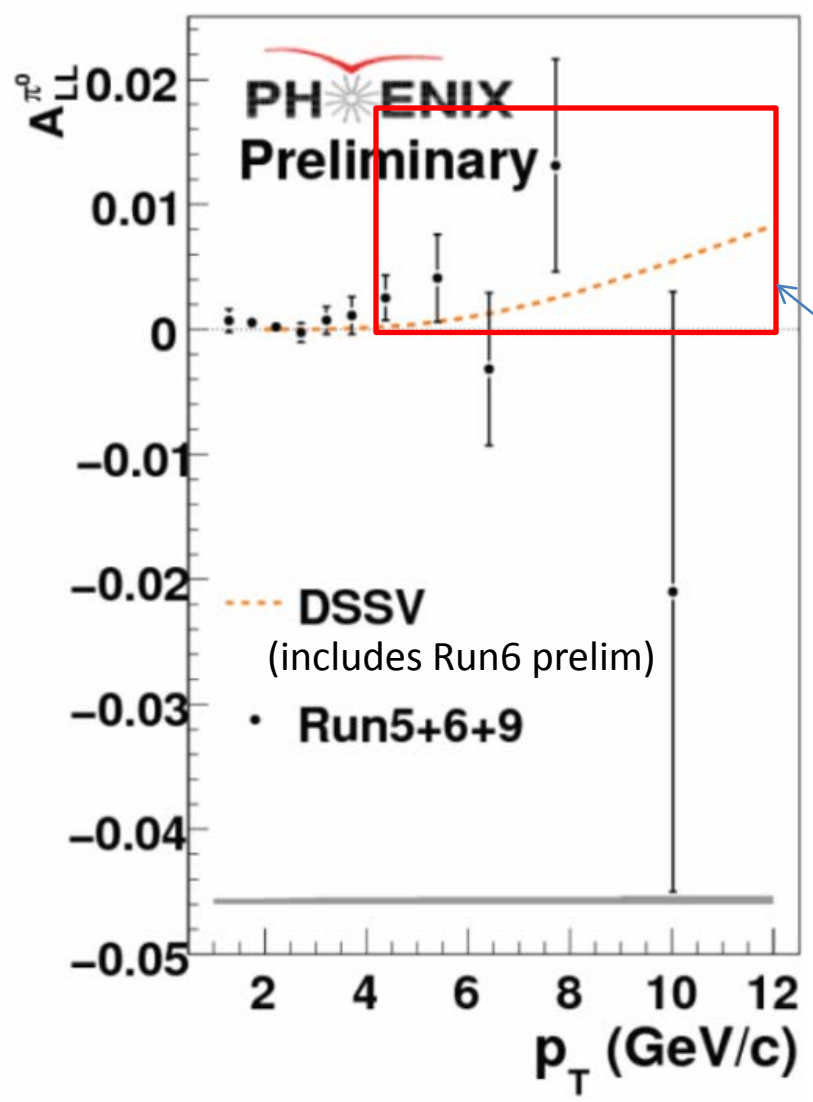


+Run9 ($\sqrt{s}$=200GeV)

Dataset	$<P_B>$ (%)	$<P_Y>$ (%)	$L_{analyzed}$ (pb^{-1})	FOM (P^4L)
Run5	50	49	2.5	0.15
Run6	56	57	6.5	0.66
Run9	57	57	14	1.5



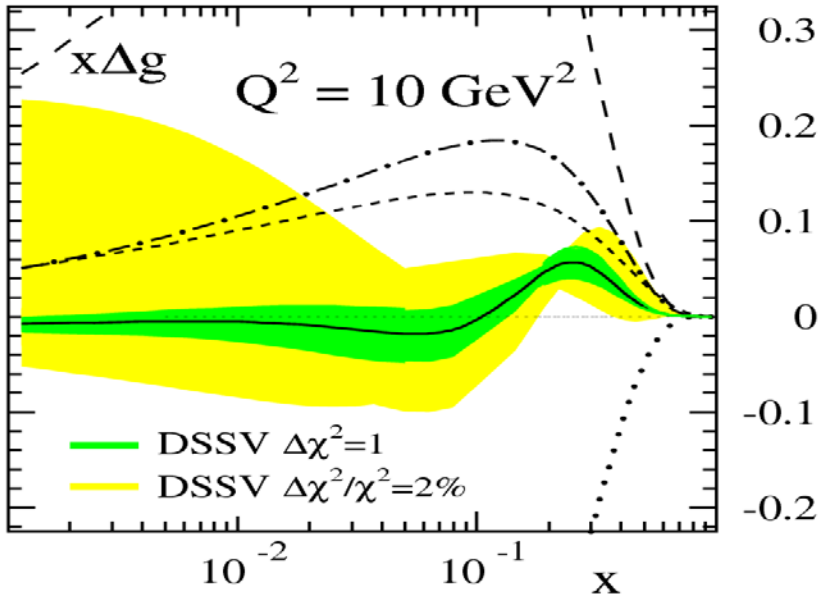
Run5+6+9 combined



DSSV undershoots the data points?
The global fit will be different.

$A_{LL} \rightarrow \Delta G$

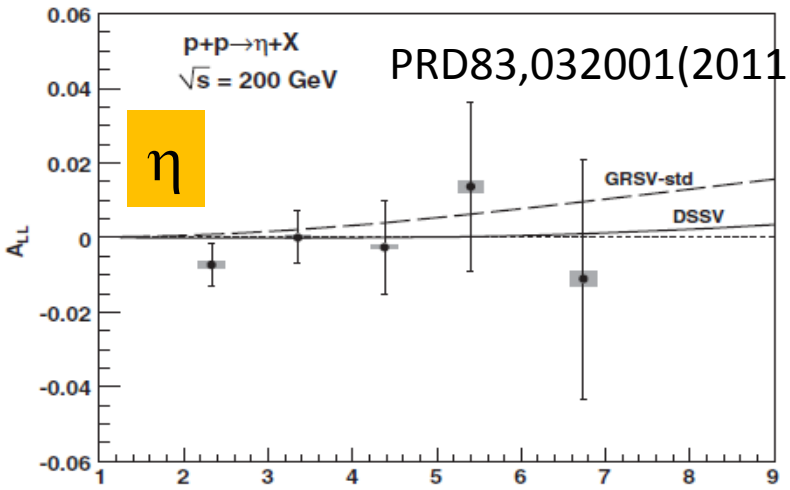
- Global fits (DIS, SIDIS, p+p)
- Does $\Delta g(x)$ have a node?

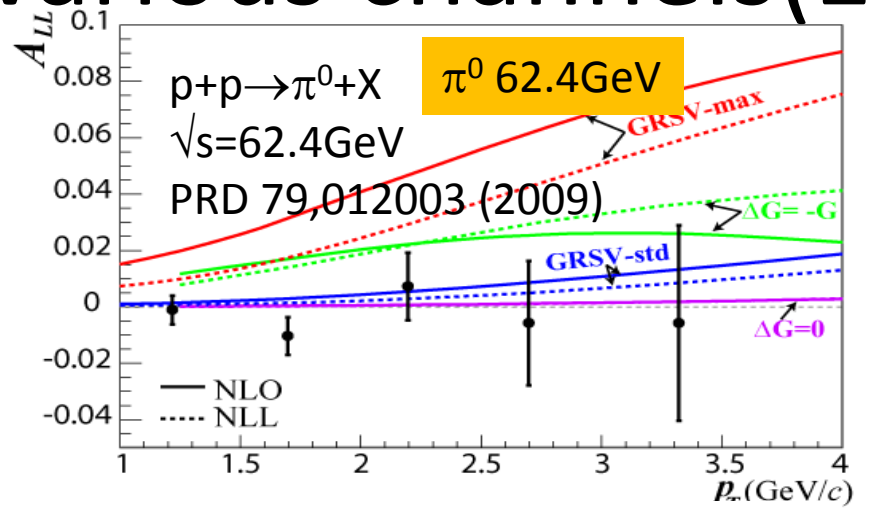


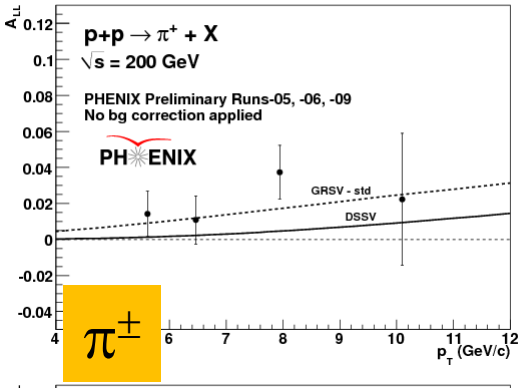
Caveat:
no data constrains small-x behavior.

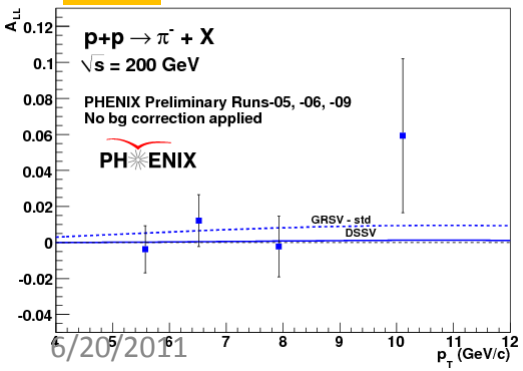
DSSV(2008) does not include Run9 PHENIX π^0 result

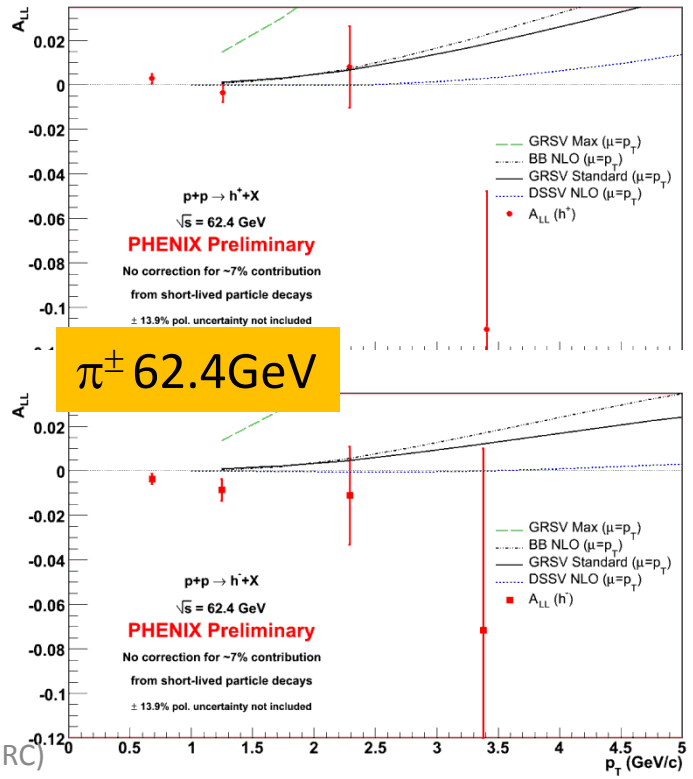
More info. from various channels(1)











More info. from various channels(2)

arXiv:1009.4921 accepted to PRD

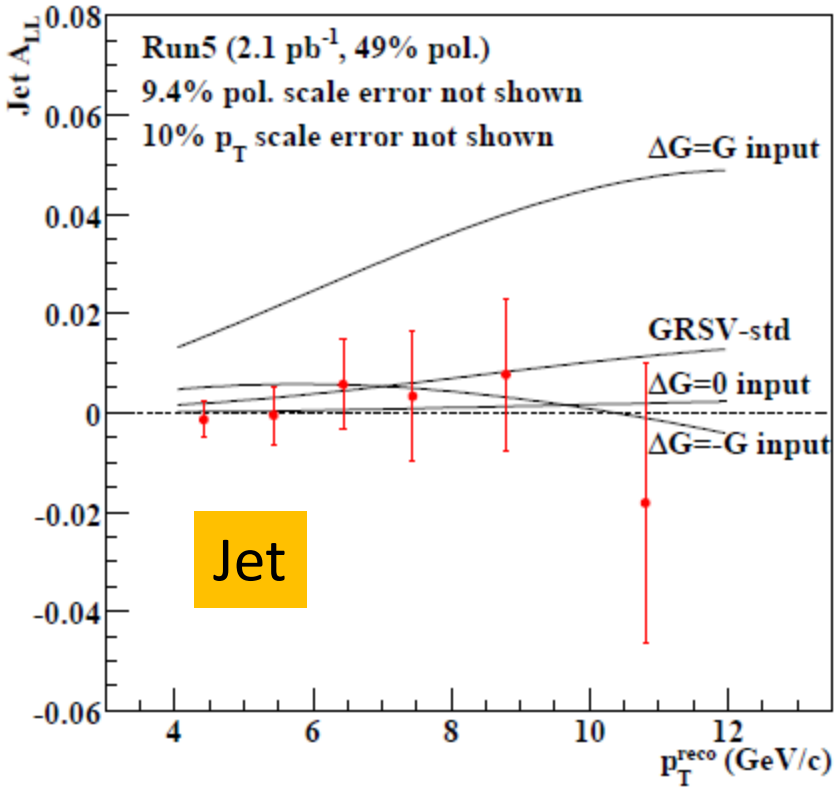


FIG. 18: (color online) Reconstructed-jet A_{LL} as a function of $p_T^{\rm reco}$. (red points) Measurement with statistical error bars. (black lines) Calculation based on four $\Delta G(x)$ functions and the PYTHIA MPI + GEANT simulation.

However statistically they are not as strong as 200GeV π^0.

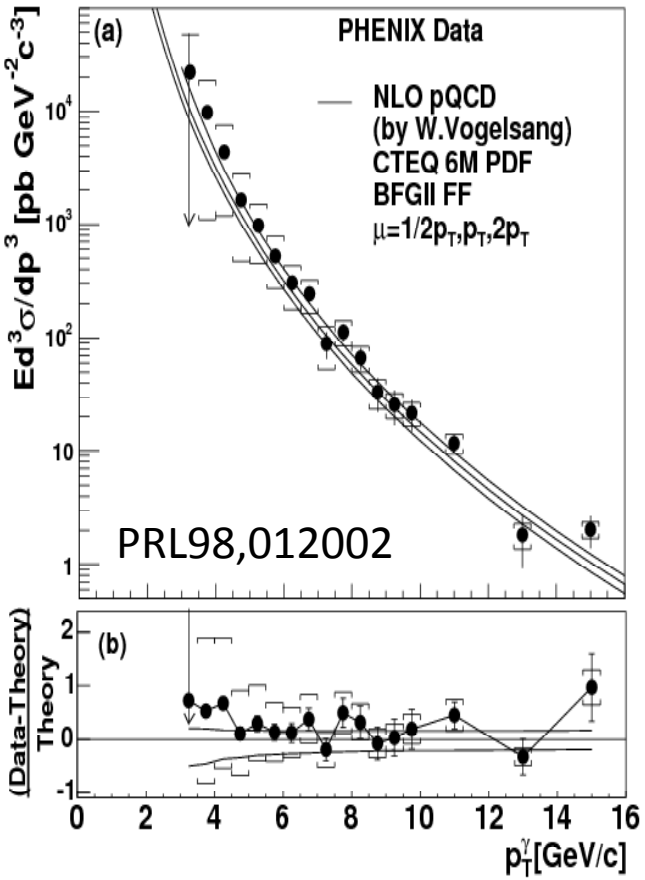
WHAT'S NEXT?
IS PHENIX ΔG PROGRAM OVER?

Directions

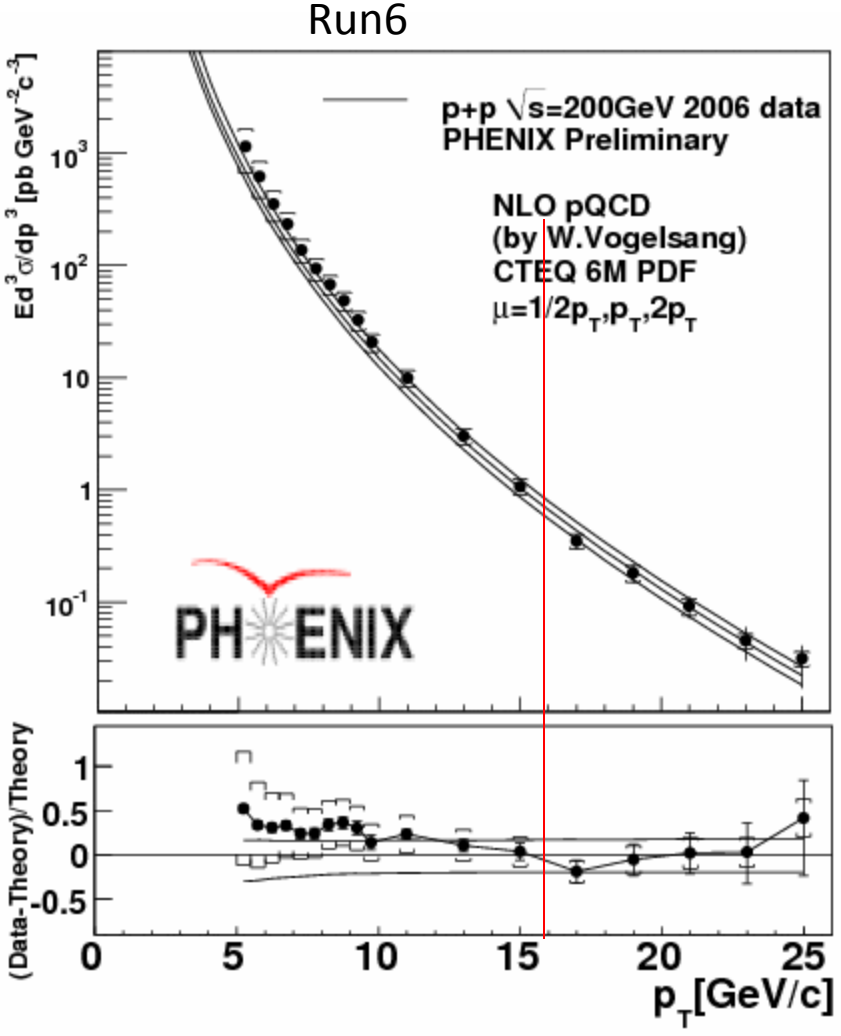
- Expansion of the x coverage (to low x)
- Cleaner process (direct photon, charm)

Clean q+g process (Direct photon)

Run3

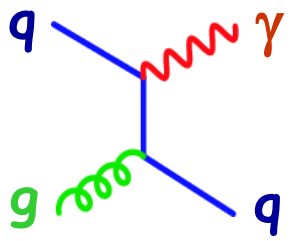


Run6



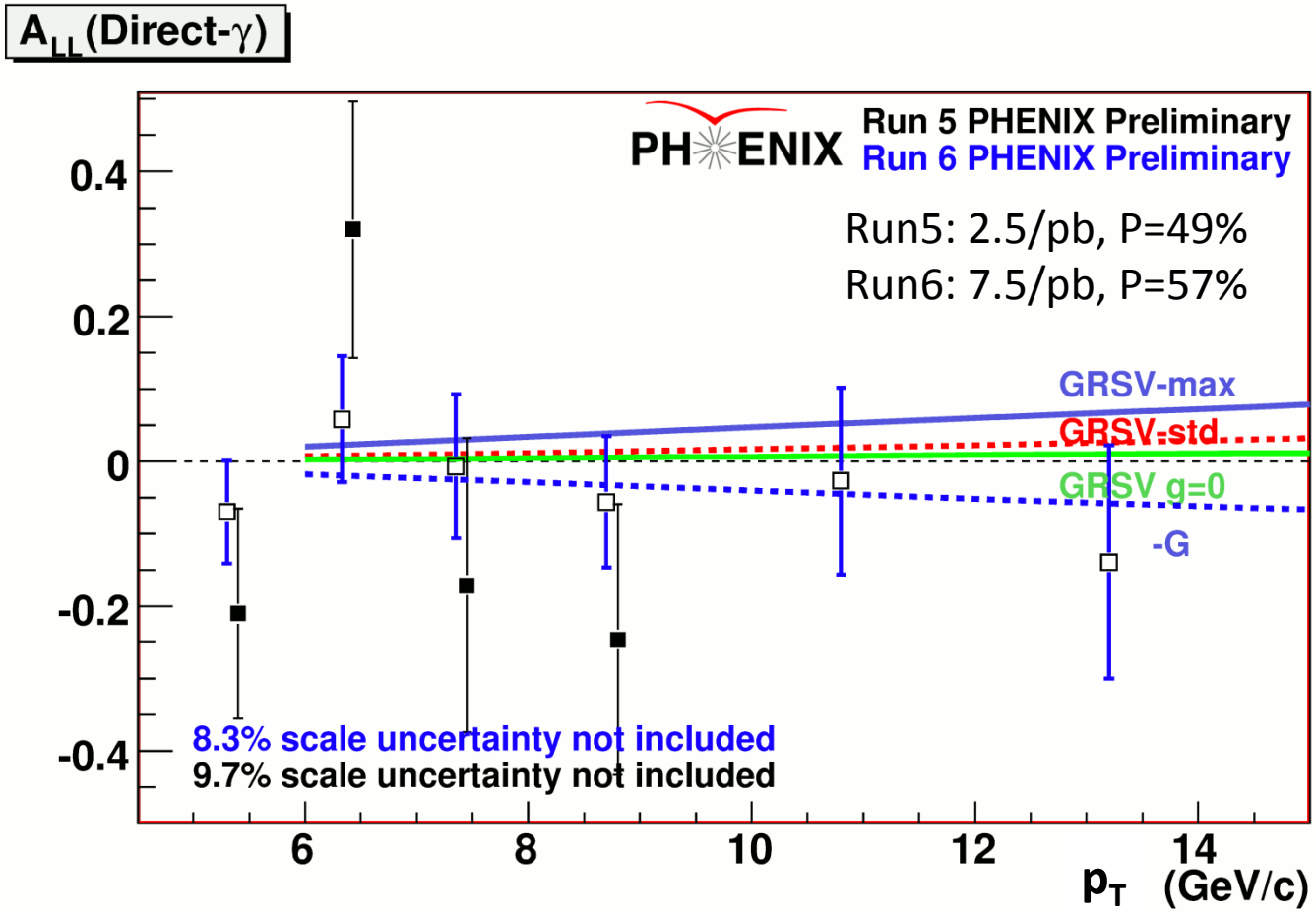
It's getting improved.

Direct photon A_{LL}



clean channel

sensitive to the sign of ΔG



Better S/B in high pT

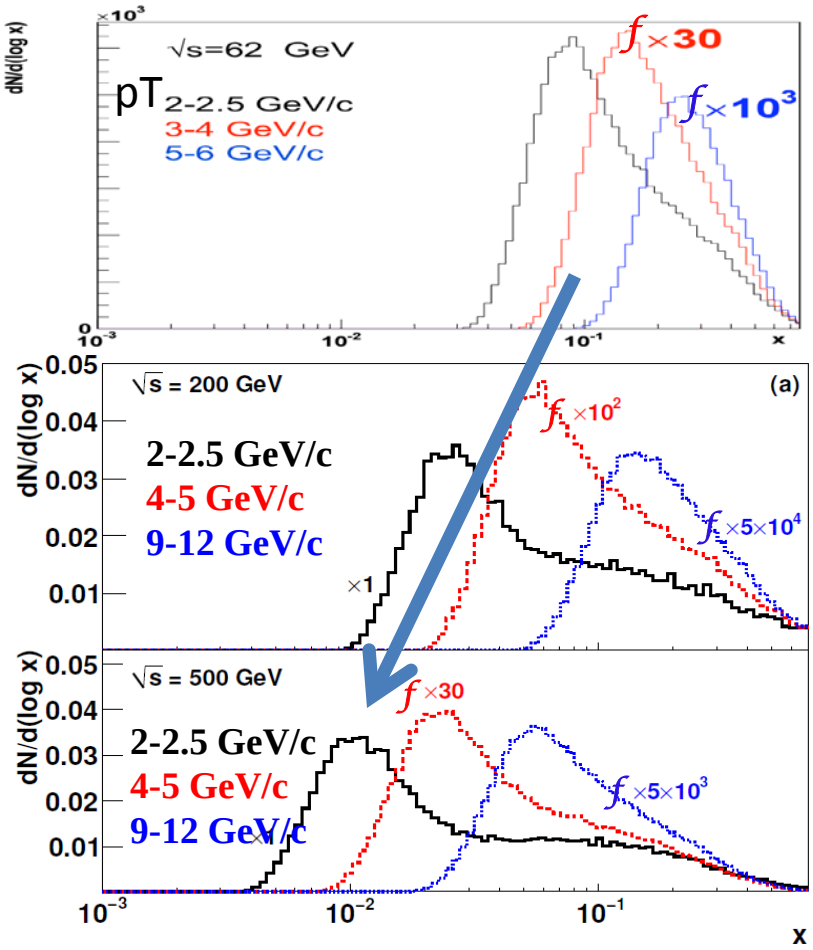
Statistically limited.

To small-x (high $\sqrt{s}$ and Forward)

- *p+p* at $\sqrt{s}$=500GeV
- Forward detector (MPC) and correlation

Probe low x with high √s

Mid rapidity (|η|<0.35)



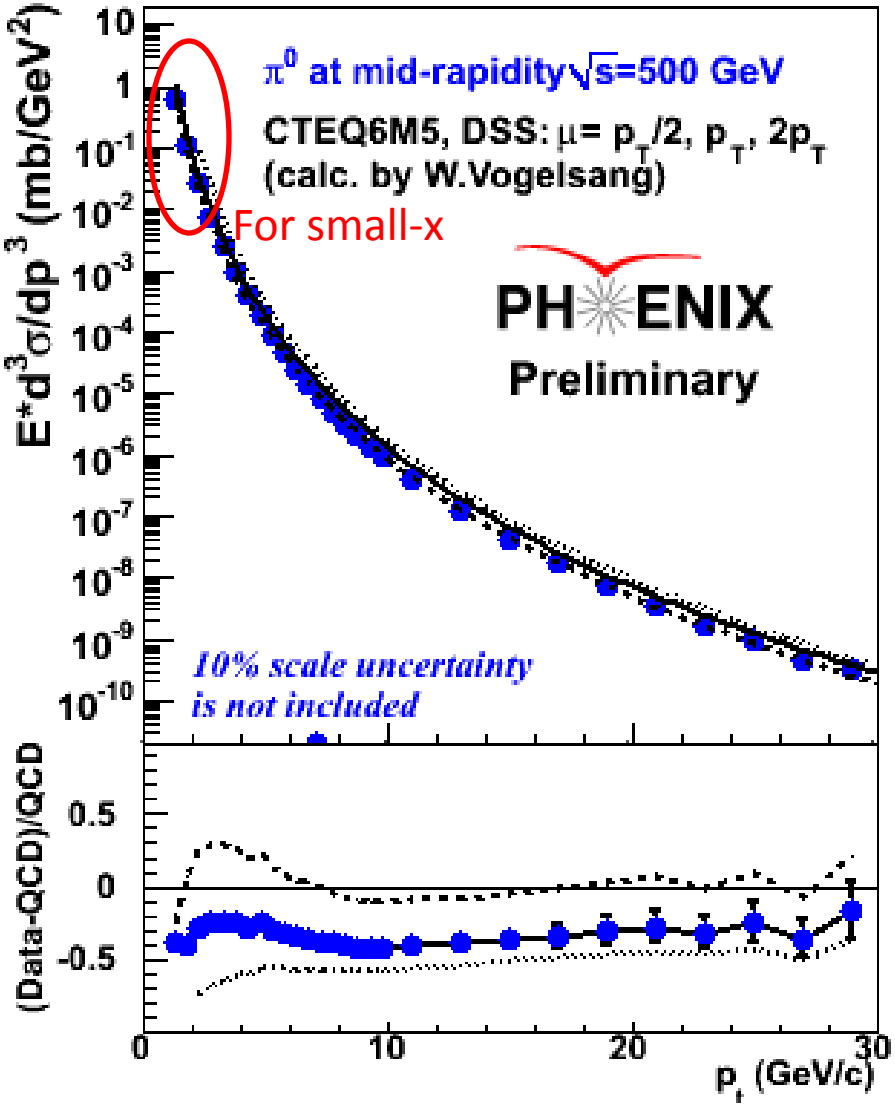
√s

62.4GeV

200GeV

500GeV

π^0 500GeV (Run9)



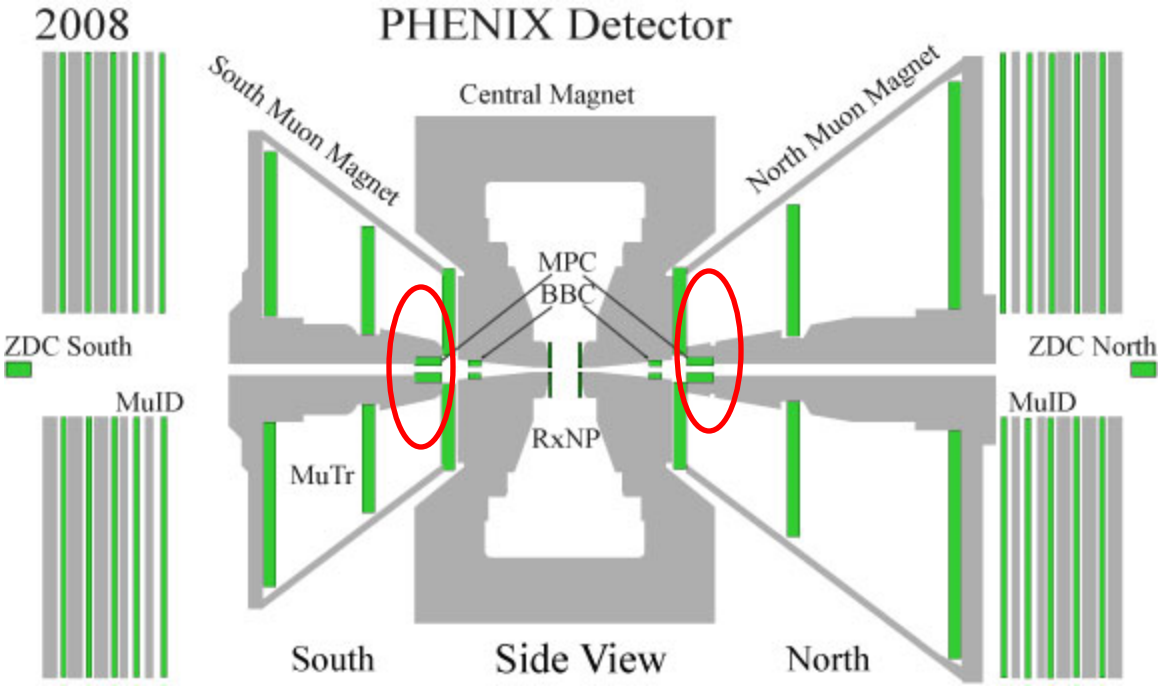
pi0's are collected.

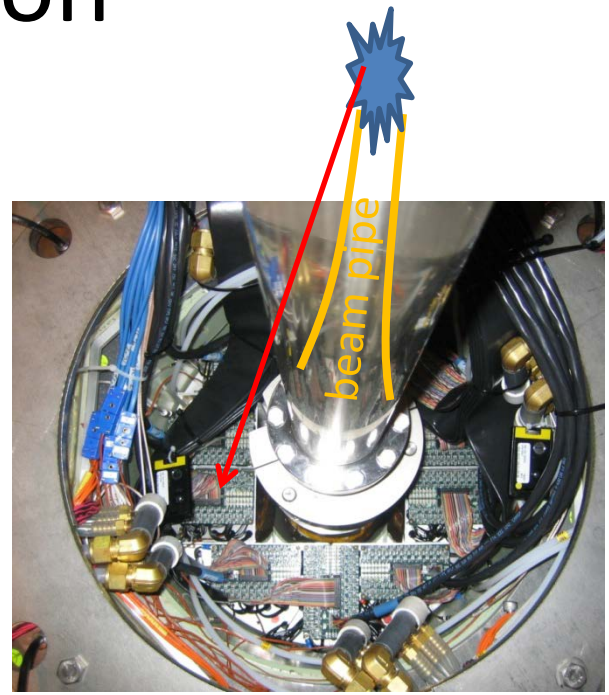
Lowest pT sample is the key to access small-x.

Asymmetry analysis is under way.
Experimentally, it is much difficult
than the one of 200GeV.

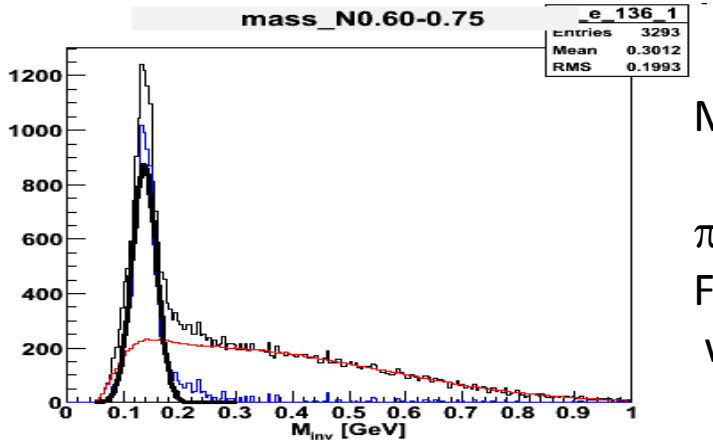
It comes along with $\Delta\bar{q}$ program.

MPC for low x region





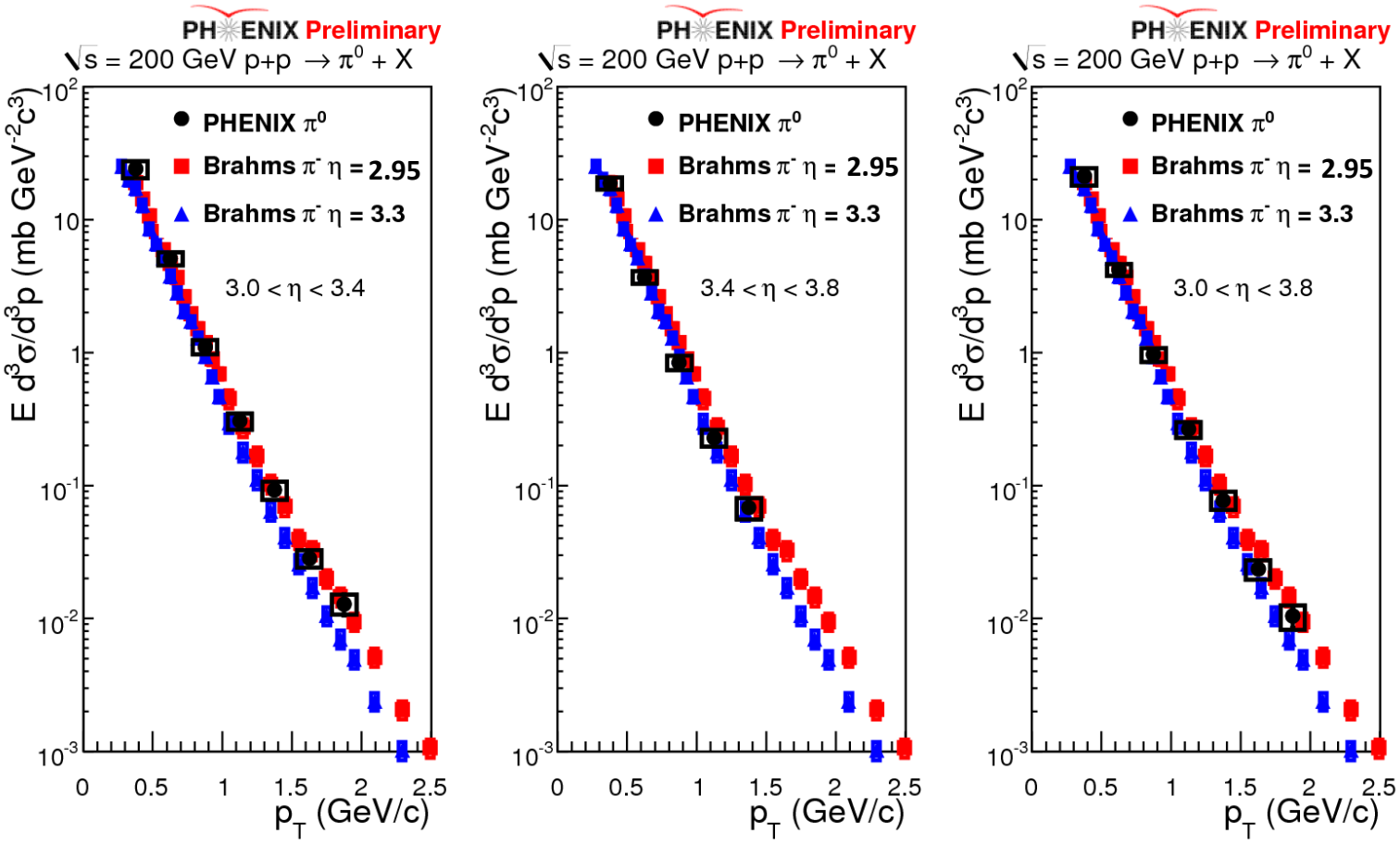
3.1<|η|<3.9



MPC detects EM shower.

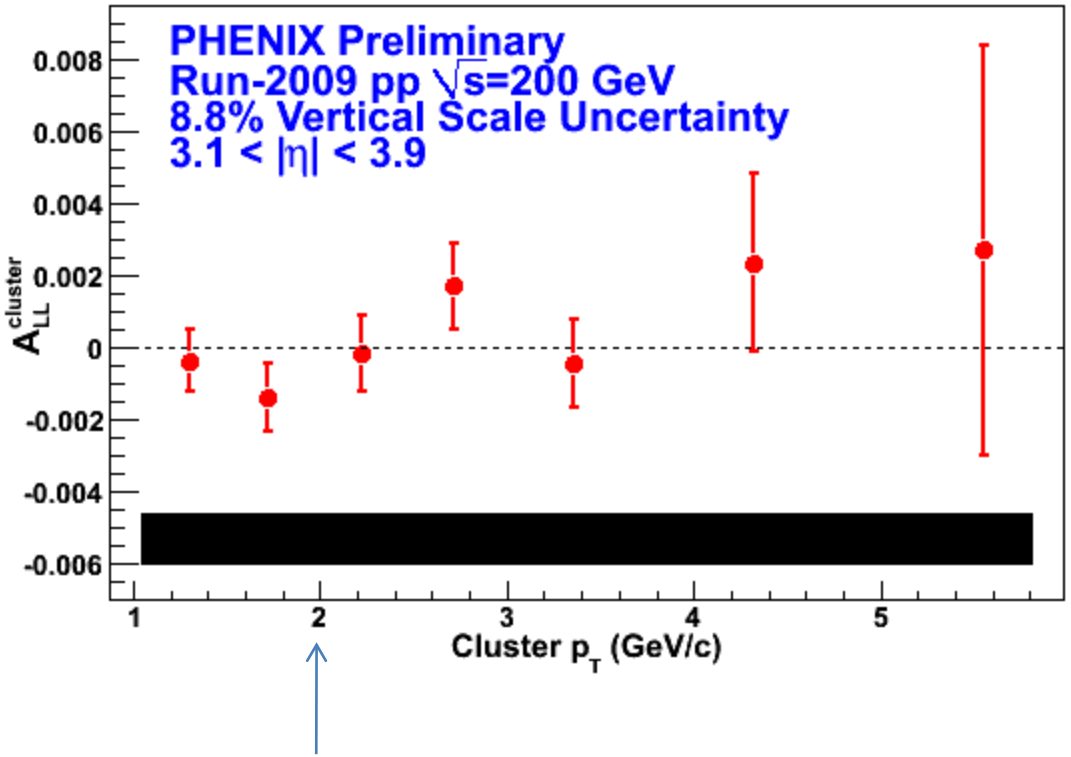
π^0's are reconstructed from 2 photons.
For high pT π^0's (pT>~2GeV), a merged cluster analysis was used. (80% is π^0 from PYTHIA.)

MPC measures π^0 cross section

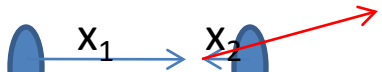


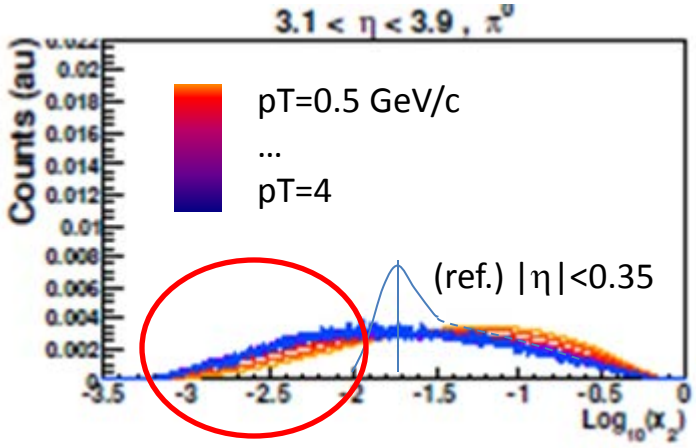
They look reasonable, consistent with other experimental result.

MPC cluster A_{LL}



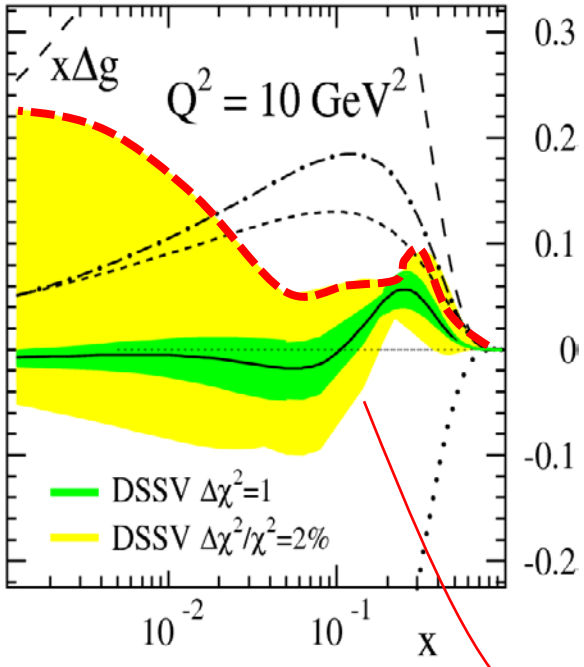
pL=~40GeV





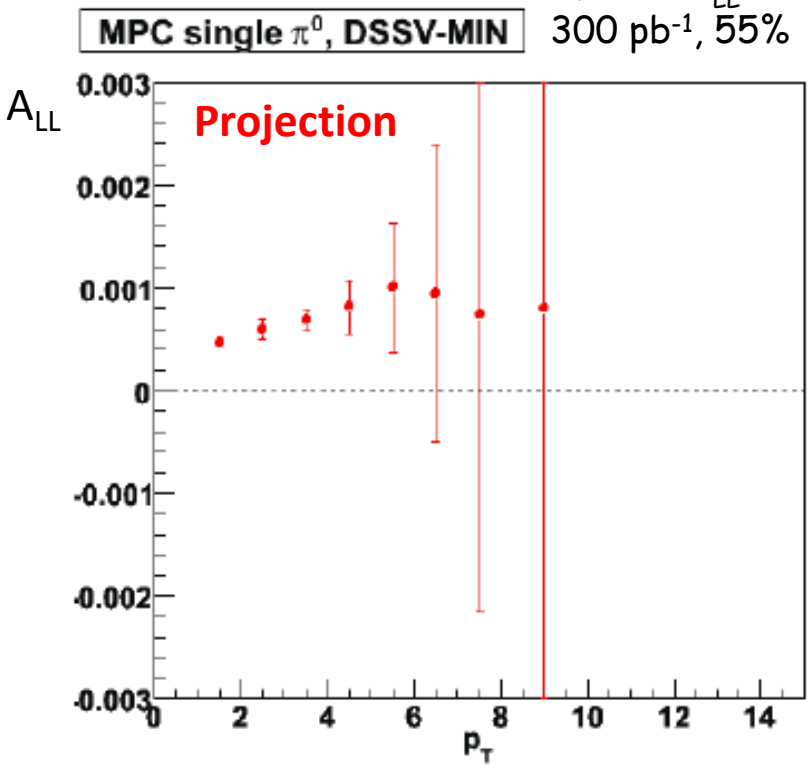
We can access to lower x.

MPC π^0 is sensitive

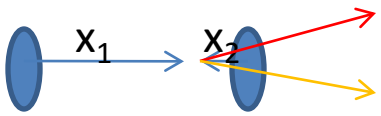


π^0 yield in the MPC

MPC π^0 A_{LL} 500 GeV
300 pb^{-1}, 55% (x~5*10-3)



Forward di-jet selection

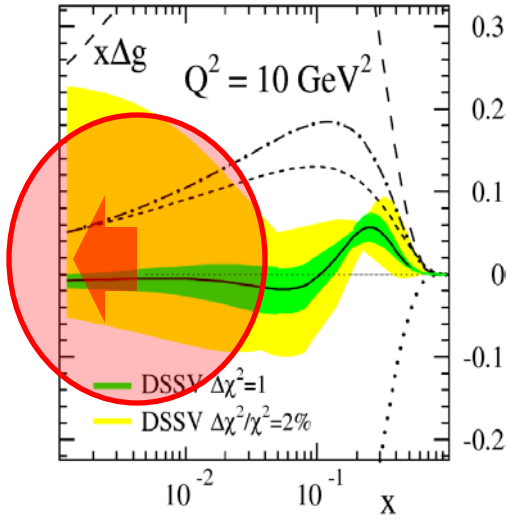


Di-hadron in MPC
→ Di-jet in MPC

In $2 \rightarrow 2$ process,

$$x_1 = \frac{p_T}{\sqrt{s}}\left(\exp(y_1) + \exp(y_2)\right)$$

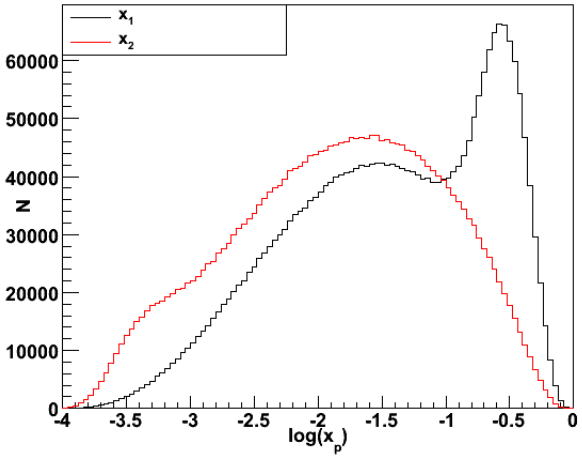
$$x_2 = \frac{p_T}{\sqrt{s}}\left(\exp(-y_1) + \exp(-y_2)\right)$$



PYTHIA study

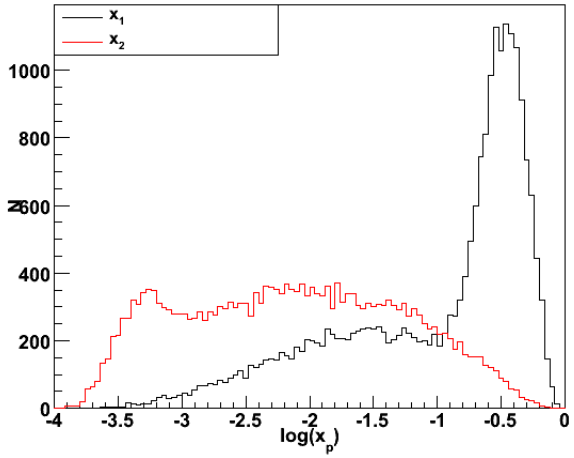
x_1 ——— x_2 ———

(pt1>1.000000) && (pt2>0.500000)



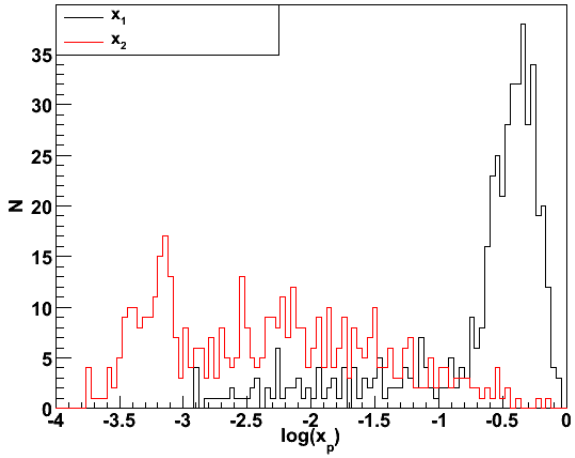
$p_{T,1}$>1.0 GeV/c,
$p_{T,2}$>0.5 GeV/c
$\langle x_2 \rangle \approx 0.014$

(pt1>2.000000) && (pt2>1.000000)



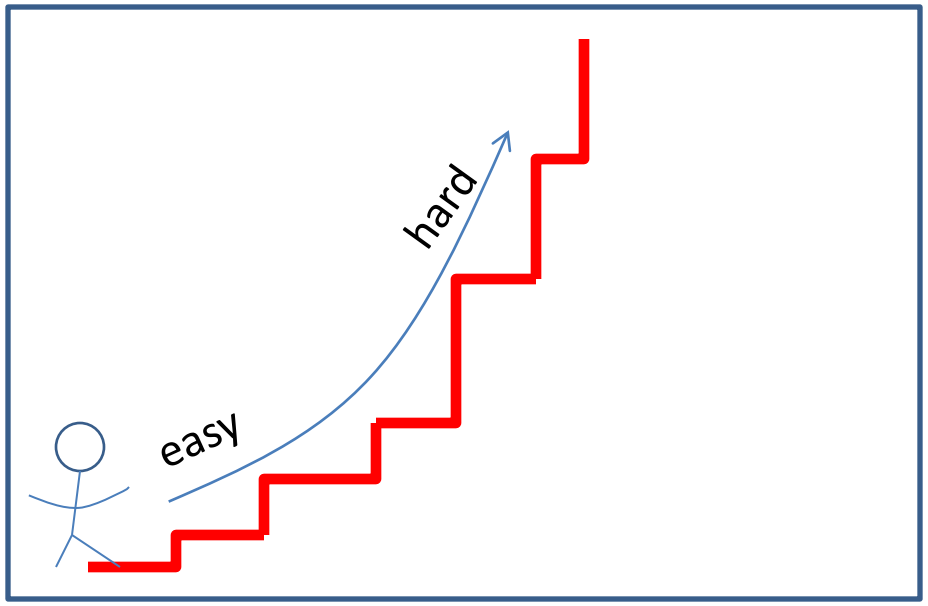
$p_{T,1}$>2.0 GeV/c,
$p_{T,2}$>1.0 GeV/c
$\langle x_2 \rangle \approx 7.2 \times 10^{-3}$

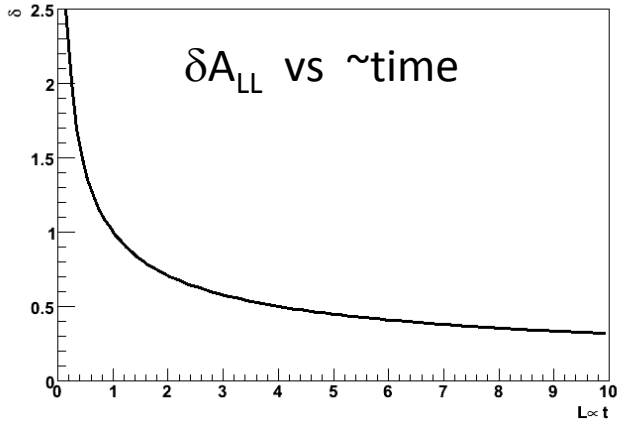
(pt1>3.000000) && (pt2>1.500000)



$p_{T,1}$>3.0 GeV/c,
$p_{T,2}$>1.5 GeV/c
$\langle x_2 \rangle \approx 4.8 \times 10^{-3}$

Life gets harder





- $\delta A_{LL} \propto 1/(P^2\sqrt{L})$
- Smaller signal (asymmetry) for low x.
- High collision rate introduces multiple collisions.

  $\rightarrow$ Systematic error challenge

From OK to ...

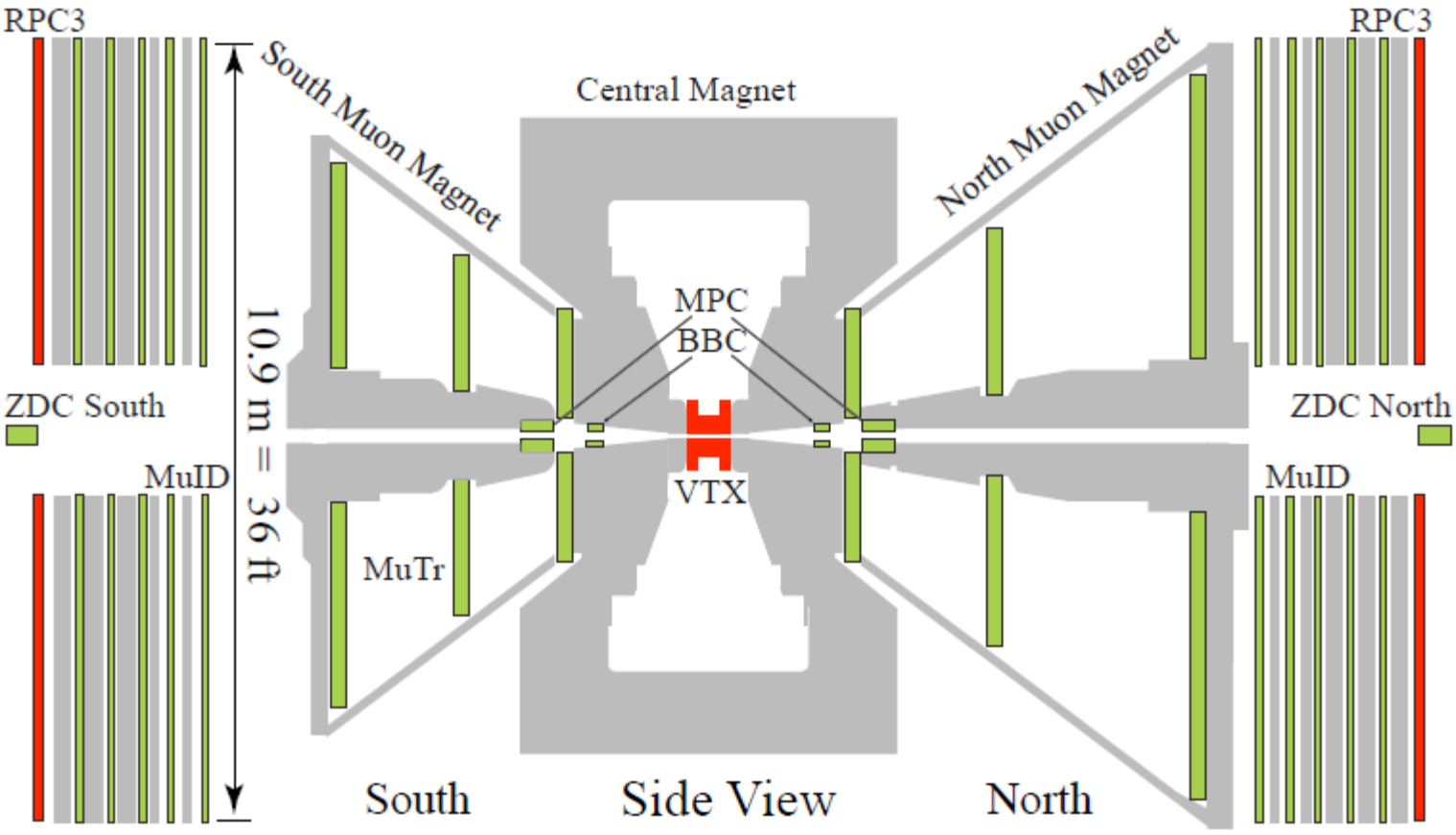
Awesome!

WE NEED A RADICAL CHANGE?

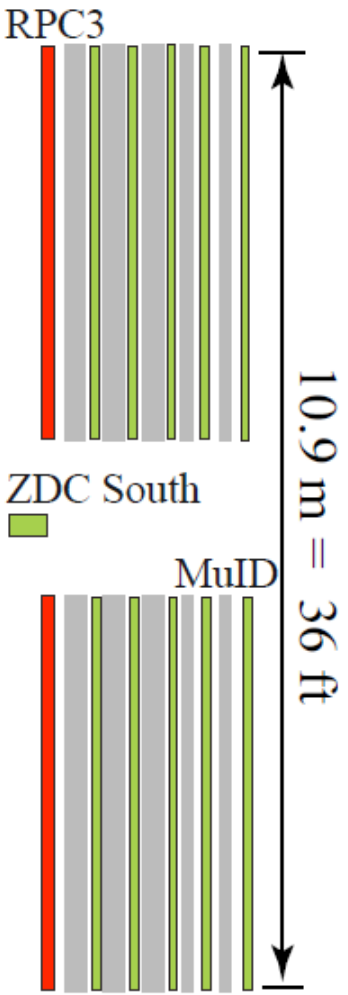
PHENIX upgrades

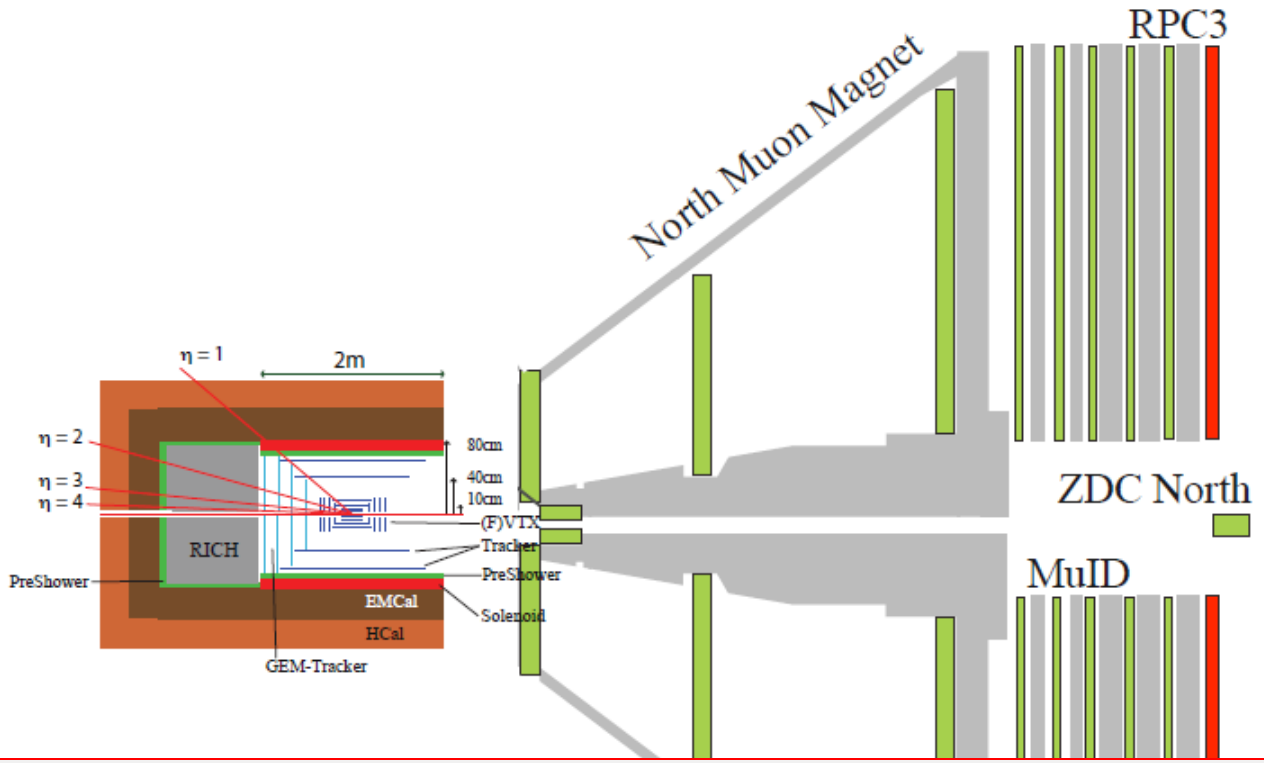
- VTX (inner silicon vertex tracker) is installed.
- Decadal plan discussion is on going.

PHENIX (now 2011)



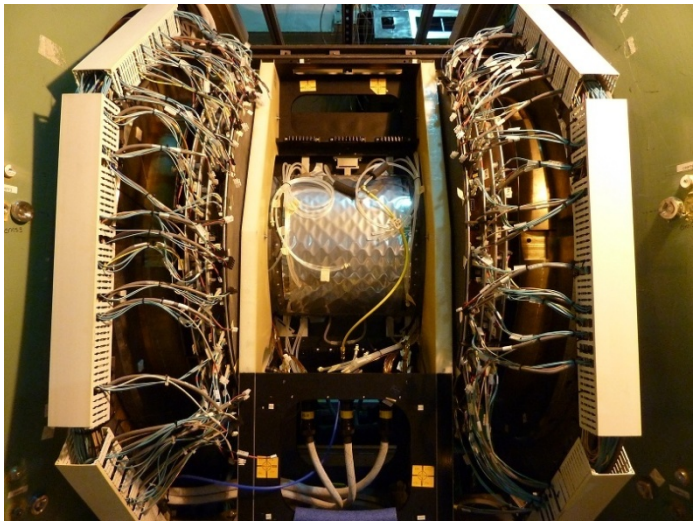
sPHENIX (~2020)





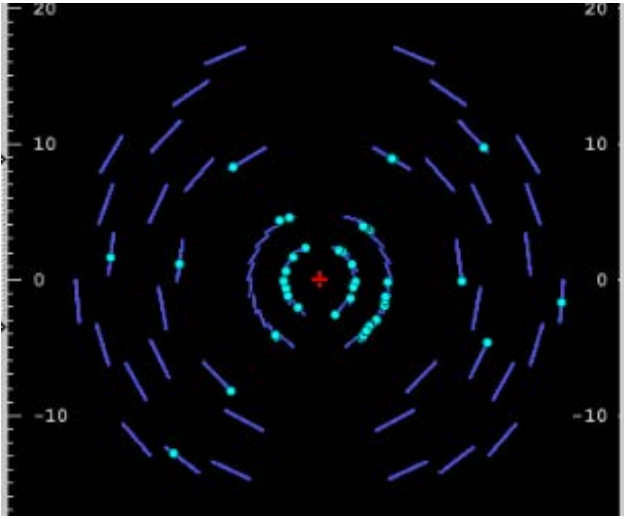
- It is closer to 4π coverage.
- Currently the design is motivated by full jet in AuAu.
- Forward part is also important for transverse spin physics
- Connection to eRHIC first stage.

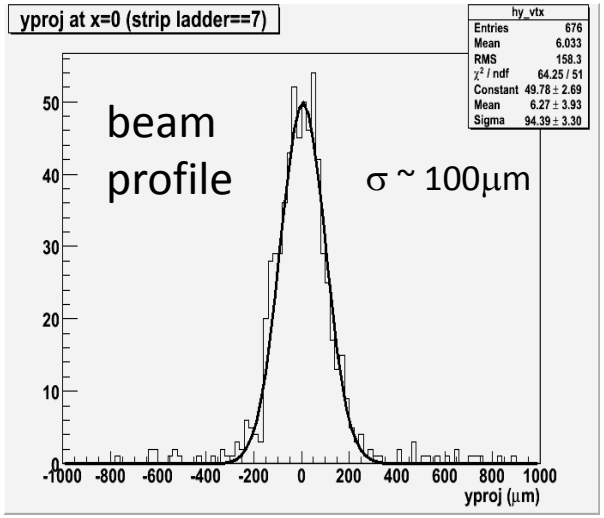
Silicon Vertex Detector is installed



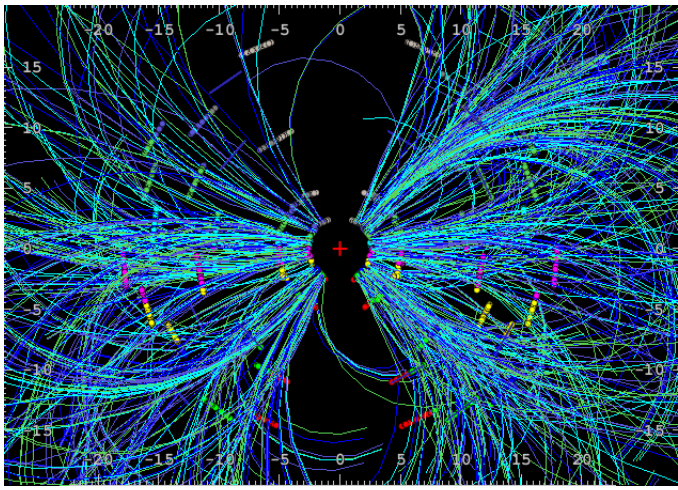
- in 2011 run
- *It will identify Charm/Bottom particles.*
- *For the spin asymmetry, low pT electron trigger is the key issue.*

Hits: p+p@500 GeV, 2011





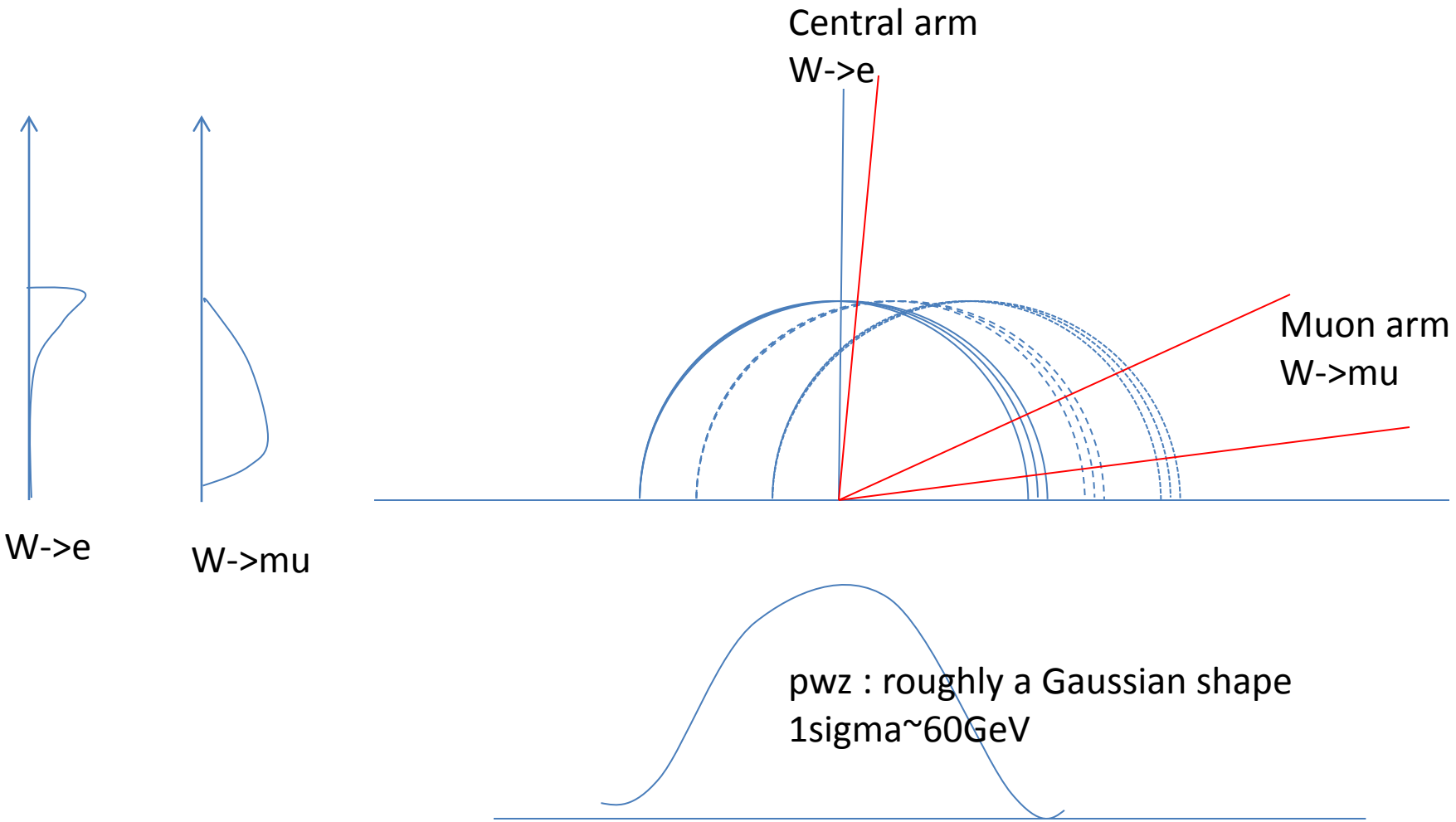
Hits and tracks:
Au+Au@200 GeV, 2011



Summary

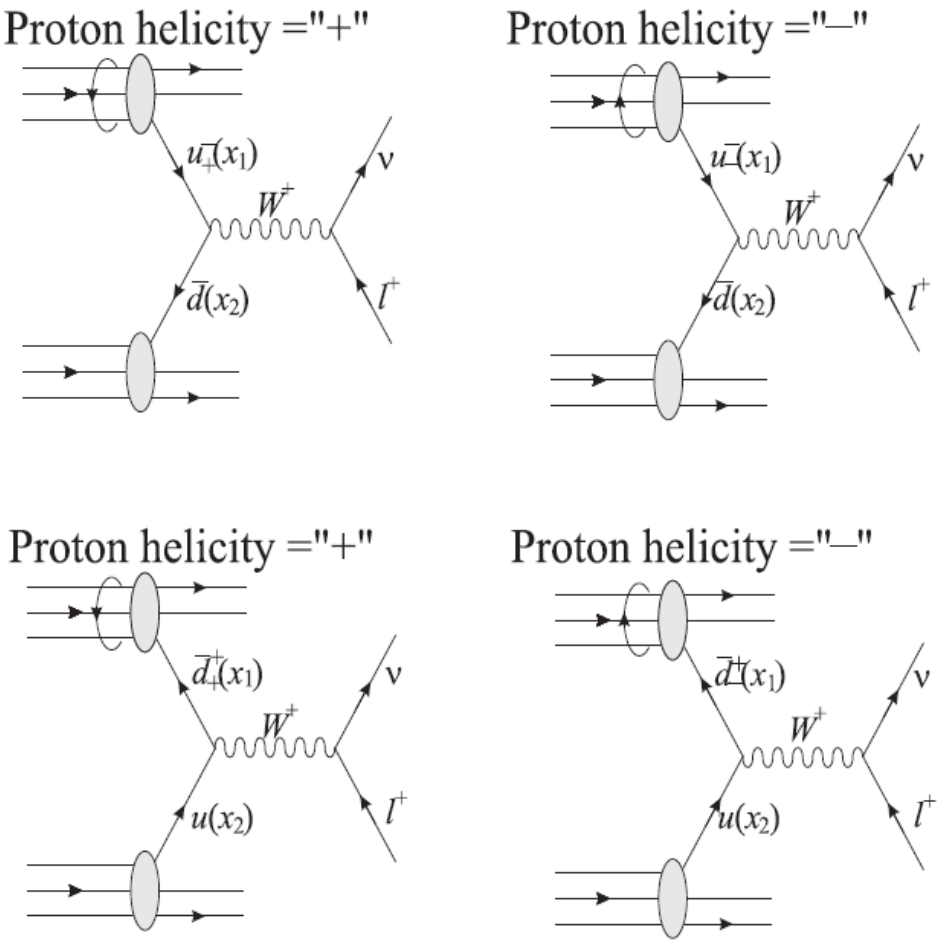
- W boson is detected.
- $\Delta\bar{q}$ is the current primary focus in the PHENIX spin program.
- ΔG program needs to extend the x coverage. Differential measurements might not fit to the current concept of PHENIX.
- A major detector upgrade is discussed for the next decade.

BACKUPS



relativistic : tan(x)=80*sin(x*)/(sqrt(p_w^2+80^2)+p_w)
geometric : tan(x)=40*sin(x*)/(40*cos(x*)+p_w/2)

The consistency is not bad when p_w<40GeV,


Proton helicity ="+"
$u_+(x_1)$
W^+
ν
$\bar{d}(x_2)$
l^+
Proton helicity ="–"
$u_-(x_1)$
W^+
ν
$\bar{d}(x_2)$
l^+
Proton helicity ="+"
$\bar{d}_+(x_1)$
W^+
ν
$u(x_2)$
l^+
Proton helicity ="–"
$\bar{d}_-(x_1)$
W^+
ν
$u(x_2)$
l^+

Relativistic Heavy Ion Collider (RHIC)

- Data accumulation in longitudinally polarized p+p
  - 2005+2006 ~200 times increase in FOM compared to 03'+o4'
  - Low √s run for better sensitivity to large x (x ~ 1/ √s)

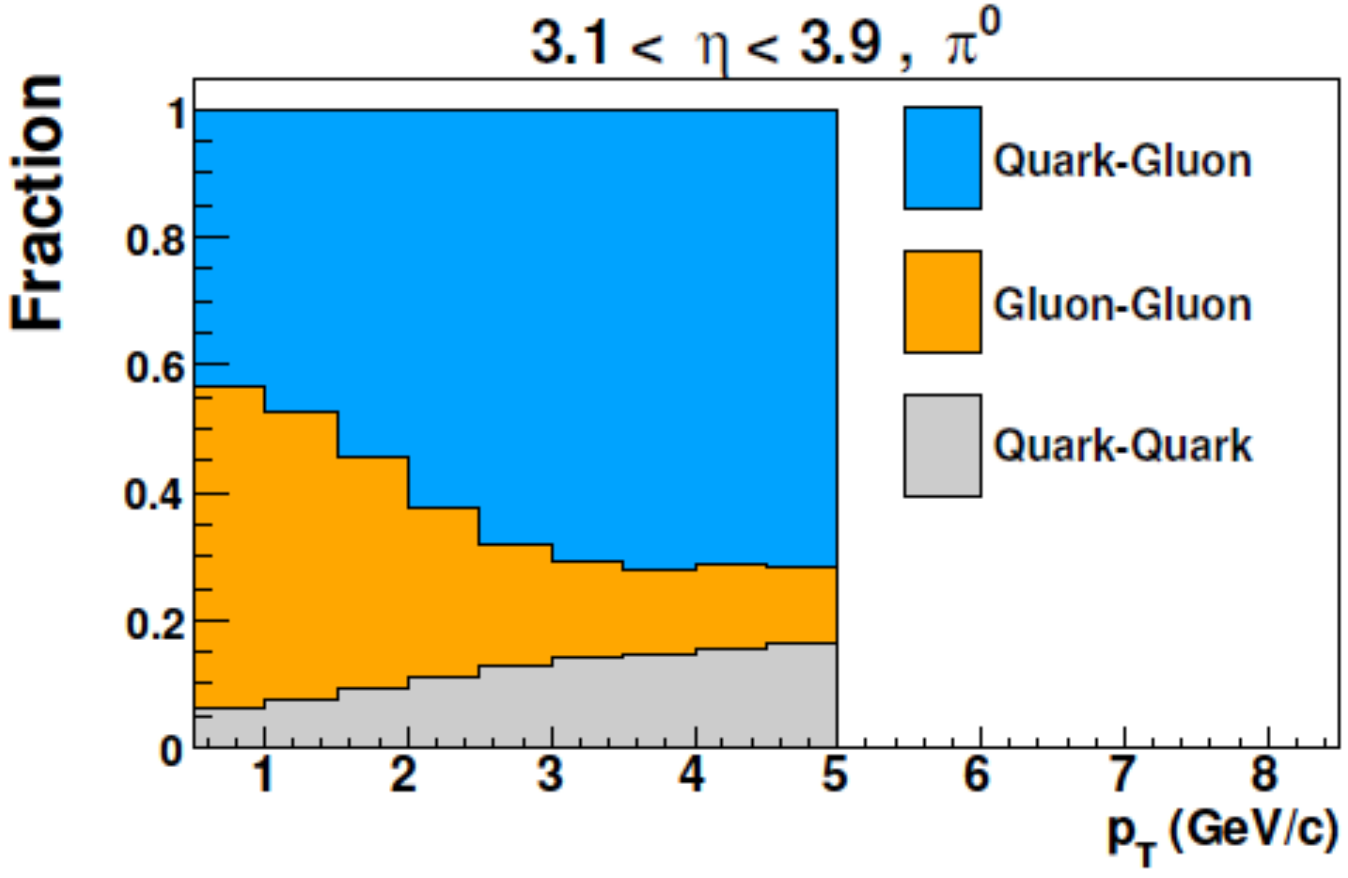
Longitudinal

Year	√s [GeV]	L [pb^{-1}] (recorded)	Pol. [%]	FOM (P^4L)
2003	200	0.35	27	0.0019
2004	200	0.12	40	0.0031
2005	200	3.4	49	0.20
2006	200	7.5	57	0.79
2006	62.4	0.08	48	0.0042
2009	200	16	55	1.5
2009	500	14,10,-	39	
2011	500	28,17,10	44	

w/o vtx cut, 30cm, 15cm

Backups – Subprocess Fractions

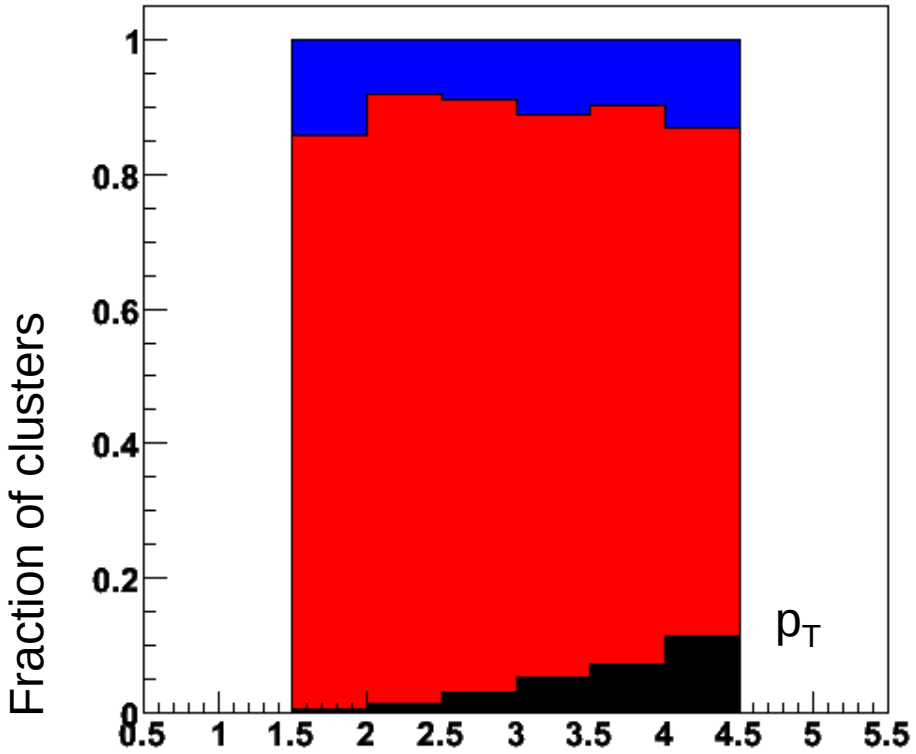
MPC cluster



*John Koster

Backups - Cluster Decomposition - PYTHIA

MPC cluster



Decay photon

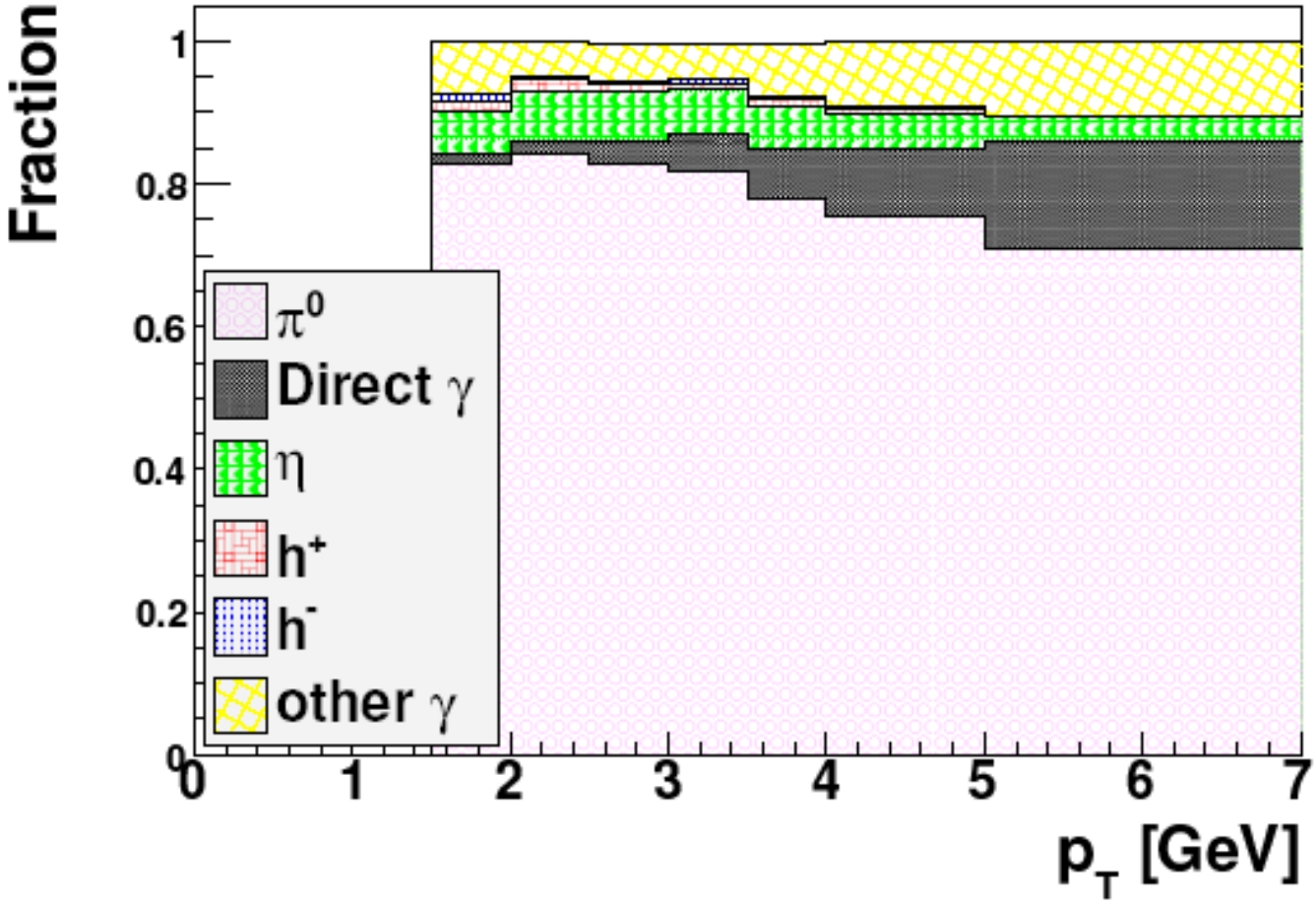
π^0

Direct photon

*John Koster

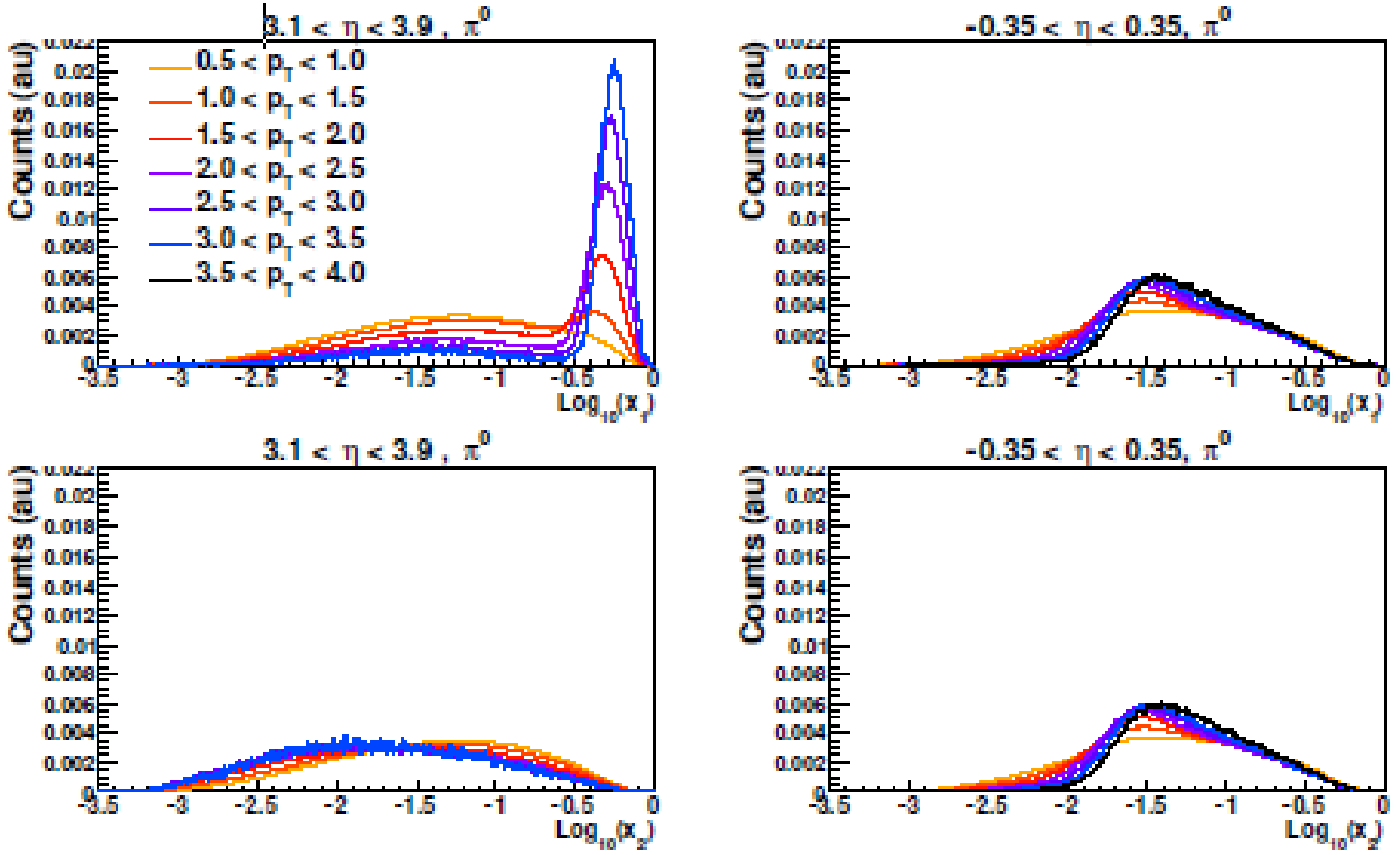
Backups - Cluster Decomposition: GEANT

MPC cluster



*Anslem Vossen

Backup


3.1 < η < 3.9 , π0
0.5 < pT < 1.0
1.0 < pT < 1.5
1.5 < pT < 2.0
2.0 < pT < 2.5
2.5 < pT < 3.0
3.0 < pT < 3.5
3.5 < pT < 4.0
Counts (au)
Log10(x1)
-0.35 < η < 0.35, π0
Counts (au)
Log10(x1)
3.1 < η < 3.9 , π0
Counts (au)
Log10(x2)
-0.35 < η < 0.35, π0
Counts (au)
Log10(x2)

PRD 83,032001 (2011)

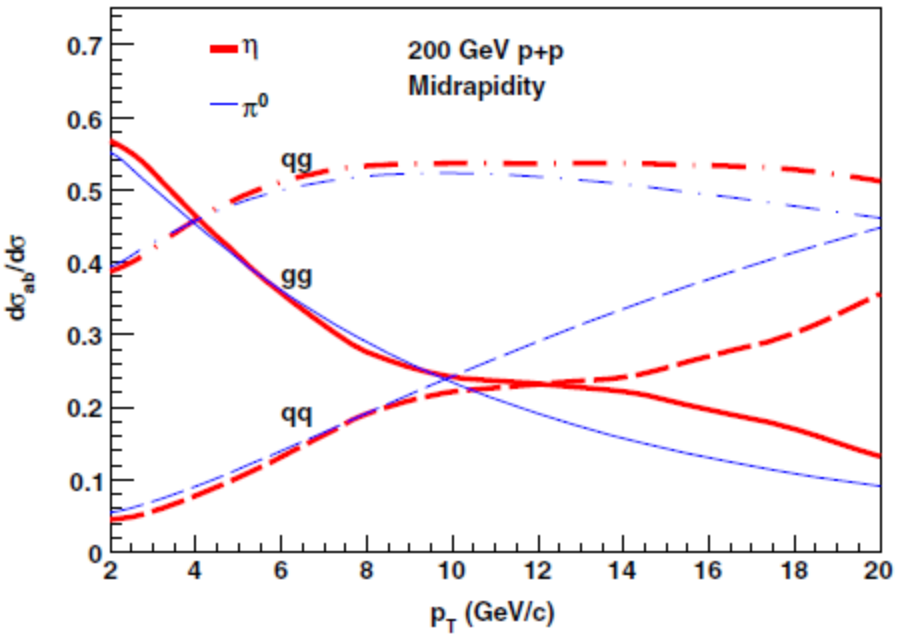


FIG. 4 (color online). The fractional contribution of gluon-gluon (gg), quark-gluon (qg), and quark-quark (qq) scattering to the η production in the pQCD calculation of Fig. 3, and to the π^0 production [24], as a function of p_T.

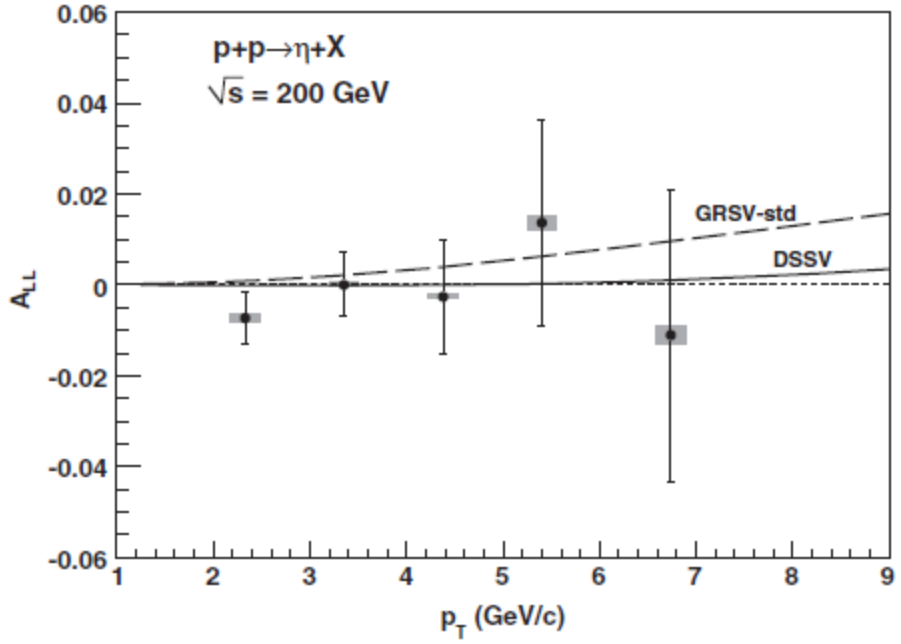


FIG. 6. The double-helicity asymmetry for midrapidity inclusive η production from the combined 2005 and 2006 data at $\sqrt{s} = 200$ GeV as a function of p_T. The gray boxes are point-to-point systematic uncertainties due to polarization and relative luminosity uncertainties and are correlated point-to-point, moving all points in the same direction but not by the same factor. An additional systematic uncertainty of 4.8% on the vertical scale due to the uncertainty in the beam polarizations is not shown. The results are compared to NLO pQCD calculations using two different sets of polarized PDFs [6,32]. See text for details.

DSSV PRL101,072001 (2008)

q+q doesn't make a large asymmetry yet.

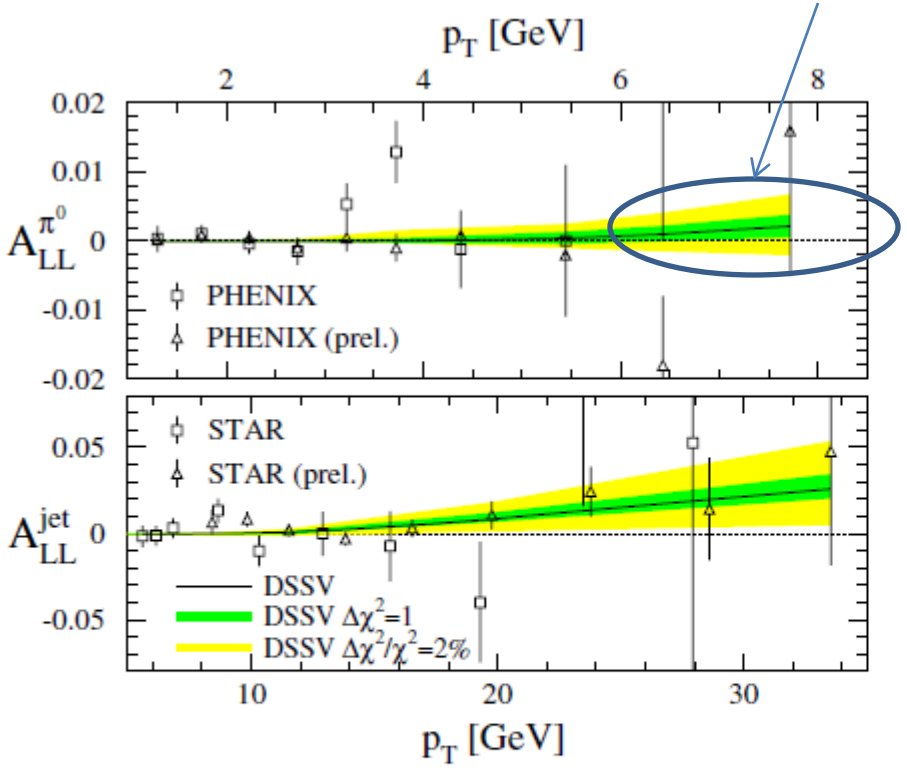


FIG. 1 (color online). Comparison of RHIC data [4] and our fit. The shaded bands correspond to $\Delta\chi^2 = 1$ and $\Delta\chi^2/\chi^2 = 2\%$ (see text).

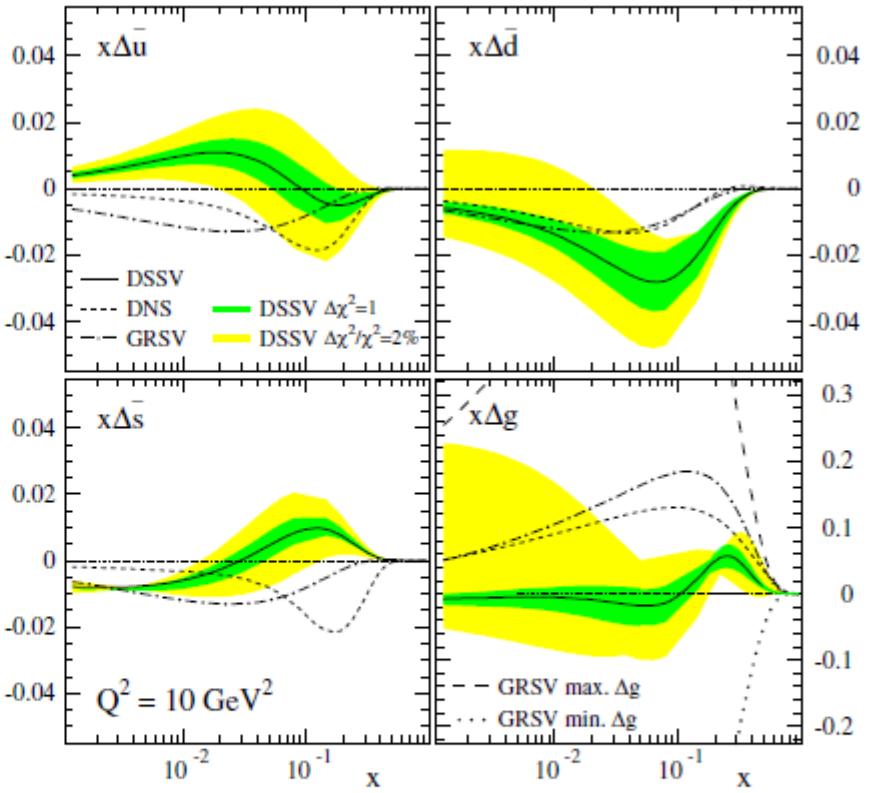
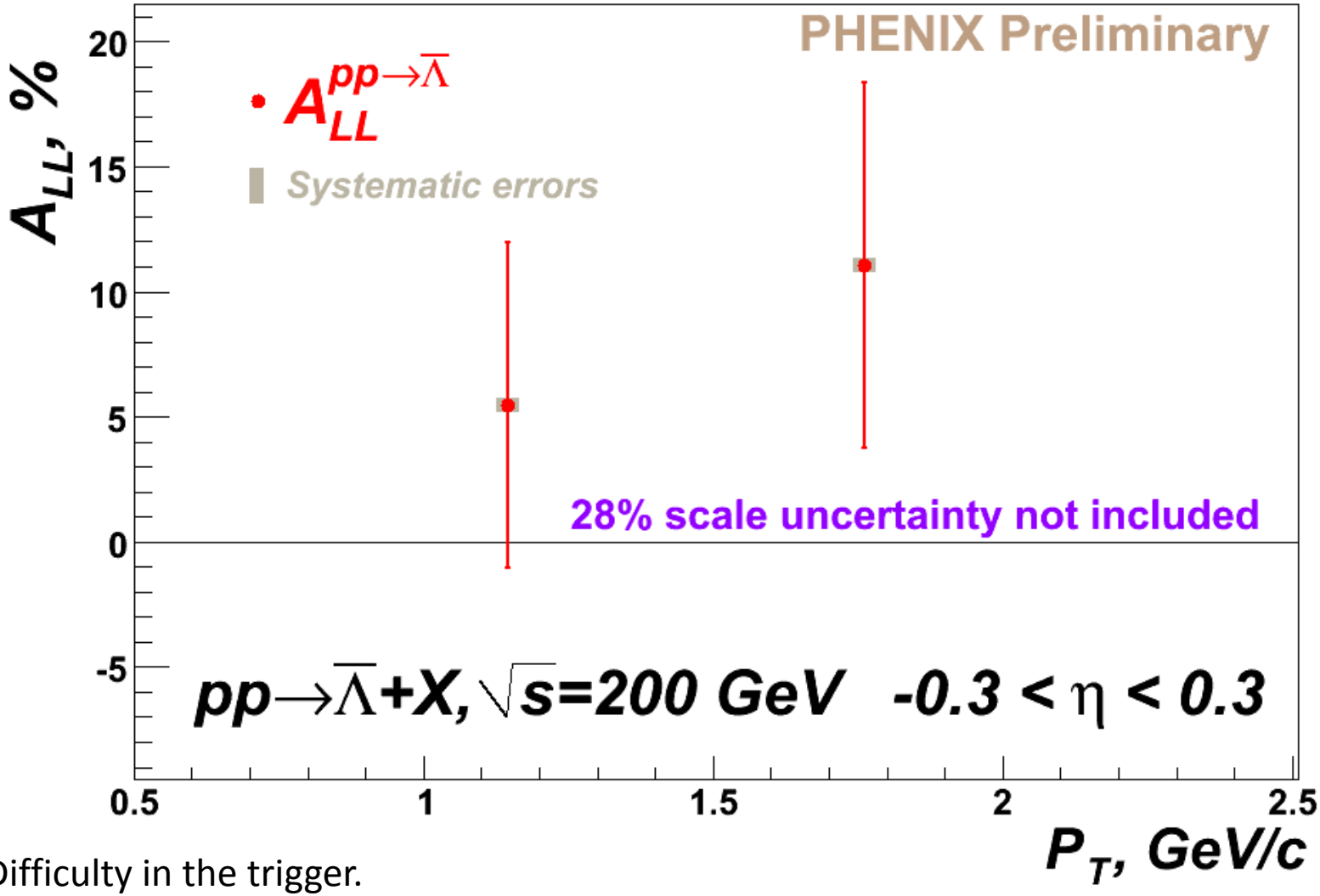
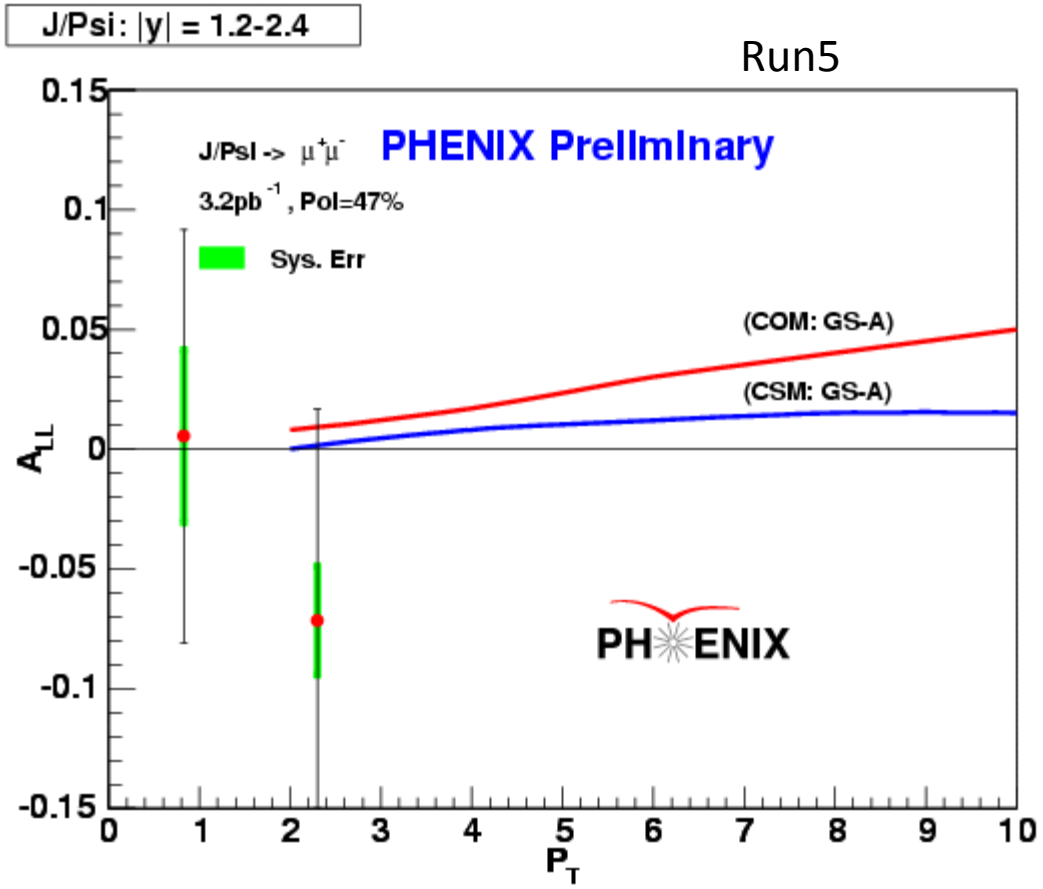
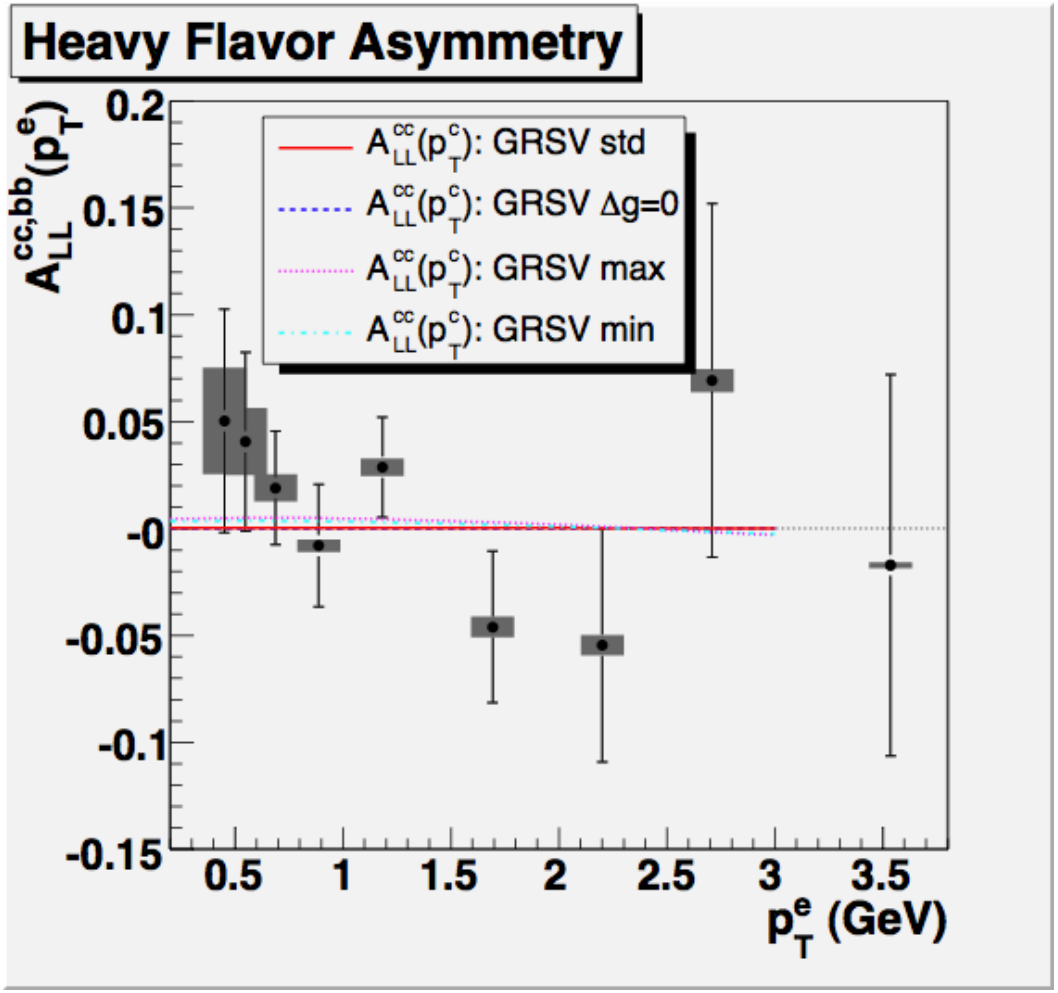


FIG. 2 (color online). Our DSSV polarized sea and gluon densities compared to previous fits [6,8]. The shaded bands correspond to alternative fits with $\Delta\chi^2 = 1$ and $\Delta\chi^2/\chi^2 = 2\%$ (see text).



Difficulty in the trigger.


J/Psi: |y| = 1.2-2.4
Run5
PHENIX Preliminary
J/Psi -> μ+μ-
3.2pb-1, Pol=47%
Sys. Err
(COM: GS-A)
(CSM: GS-A)
PHENIX
ALL
PT
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0
1
2
3
4
5
6
7
8
9
10



better S/N with HBD, VTX

Run5 analysis (Patty Nov.9, 2007)
I think it is a preliminary plot.

BUP 2011

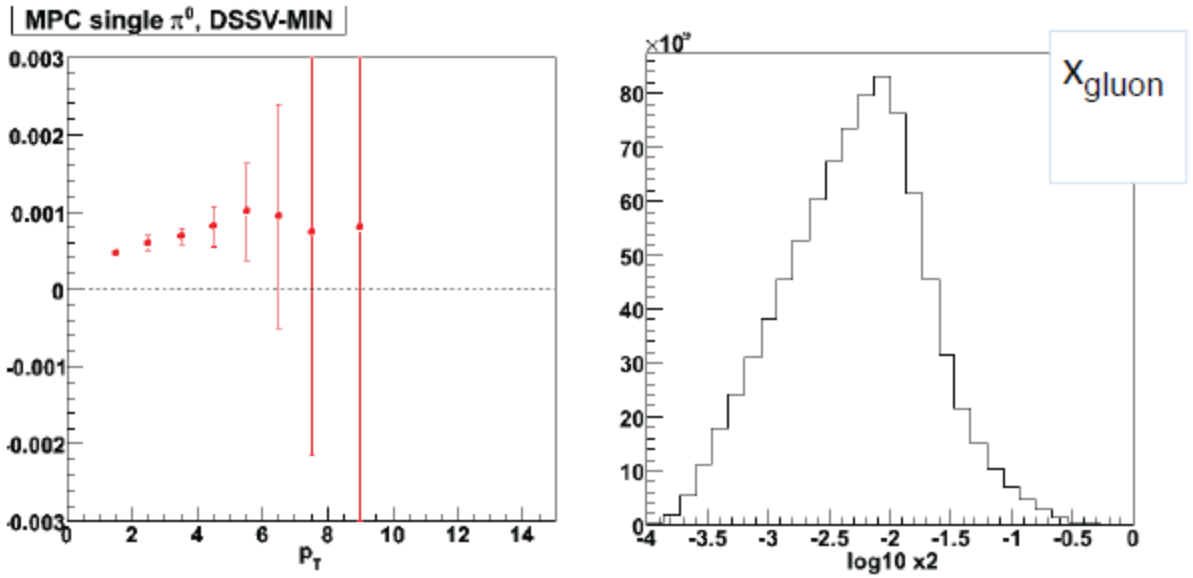


Figure 23: Expected uncertainties in the MPC cluster A_{LL} as a function of p_T for $\int Ldt = 300\,\mathrm{pb}^{-1}$ and $P = 0.55$. The asymmetries have been obtained by setting $\Delta G(x)$ to DSSV-min in the simulations. Also shown is the x_g distribution for this channel.