ΔG at PHENIX

RHIC User's meeting at BNL

June 20, 2011

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On behalf of PHENIX collaboration

Outline

- ΔG measurement at RHIC
- PHENIX overview
- Various channels to probe ΔG
  - Single inclusive hadron
    - Mid-rapidity hadrons (π^0 , $\pi^\pm$, η and unidentified $h^\pm$)
    - Forward-rapidity hadrons (cluster π^0)
  - Direct photon
- Global analysis
- Transition to future
  - Vertex detector
    - Double inclusive correlation measurement
      - Photon-jet, jet-jet
    - charm and beauty separation

Intro

$$< J_z >_{proton} = \frac{1}{2} = \frac{1}{2}\sum_q (\Delta q + \Delta \bar{q}) + \Delta G + L_q + L_g$$

- ΔG has been measured at various experiments.
  - pDIS fixed target experiment
    - Indirect measurements via scale evolution : inclusive processes g_1
    - Direct measurements viaγ-g fusion : open charm & high pt hadron pairs at HERMES and COMPASS

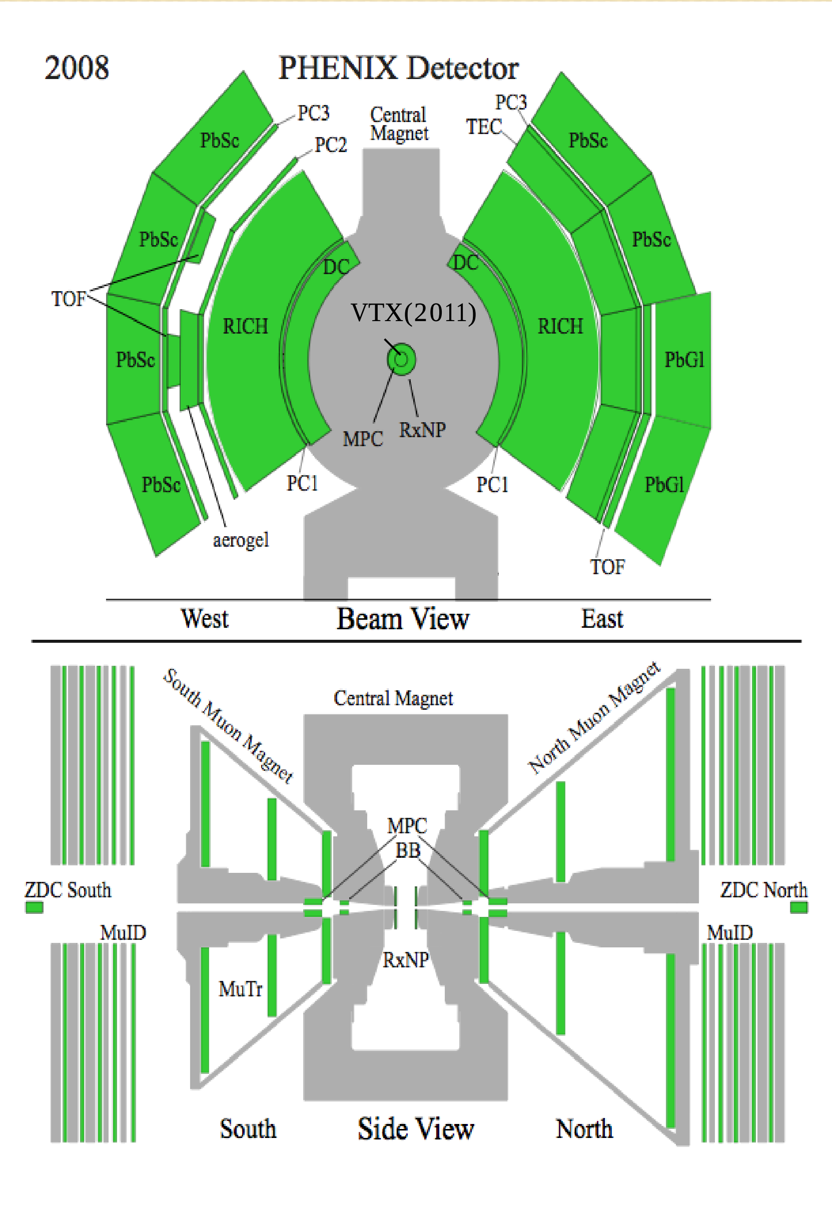
- PP collision experiment at RHIC is an independent venue for directly measuring ΔG without having to rely solely on Q^2 evolution.

ΔG measurements at PHENIX

reaction	LO subprocesses	partons probed	x-range*
$pp \to$ jets X	$q\bar{q}, qq, qg, gg \to$ jet X	Δq, Δg	$x \gtrsim 0.03$
$pp \to \pi X$	$q\bar{q}, qq, qg, gg \to \pi X$	Δq, Δg	$x \gtrsim 0.03$
$pp \to \gamma X$	$qg \to q\gamma$, $q\bar{q} \to g\gamma$	Δg	$x \gtrsim 0.03$
$pp \to Q\bar{Q}X$	$gg \to Q\bar{Q}$, $q\bar{q} \to Q\bar{Q}$	Δg	$x \gtrsim 0.01$

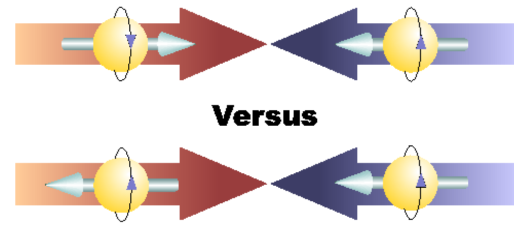
* For central arm detectors at $\sqrt{s}$ =200GeV

CURRENT PHENIX DETECTOR CONFIGURATION



- π^0, η, γ measurement
  - Electromagnetic Calorimeter (Pbsc/PbGl)
    - High p_T photon trigger to collect π^0, η, γ's
    - Acceptance: $|\eta|<0.35$, $\varphi = 2 \times \pi/2$
  - Muon Piston Calorimeter (MPC)
    - $3.1 < |\eta| < 3.9$, North/South
- $h^{\pm}$ and $e^{\pm}$
  - Hadron Blind Detector(HBD) (relevant to 2009 data
    - $e^{\pm}$, $\pi^{\pm}$ and $K^{\pm}$ (p_T > 0.01 ,4, 14 GeV/c)
  - Drift Chamber (DC) / Pad Chambers (PC) for tracking
  - Ring Imaging Cherenkov Detector (RICH)
    - $e^{\pm}$, $\pi^{\pm}$ and $K^{\pm}$ (p_T >0.017, 4.7, 16.5 GeV/c)
- Relative Luminosity
  - Beam Beam Counter ($3.0<|\eta|<3.9$)
  - Zero Degree Calorimeter (±2 mrad about beam axis)
  - BBC & ZDC together determine uncertainties on relative luminosity that is a major source of systematic uncertainty.

Observable



$$A_{LL} = \frac{d\sigma(p(+)p(+) \to h/\gamma + X) - d\sigma(p(+)p(-) \to h/\gamma + X)}{d\sigma(p(+)p(+) \to h/\gamma + X) + d\sigma(p(+)p(-) \to h/\gamma + X)}$$

- dσ : Definite helicity cross section
- p(+) : Longitudinally polarized protons in the same direction as their movement.
- p(-) : Longitud ection as their movement.

$$++ \;\to\; \textit{like sign helicity},\quad +- \;\to\; \textit{unlike sign helicity}$$

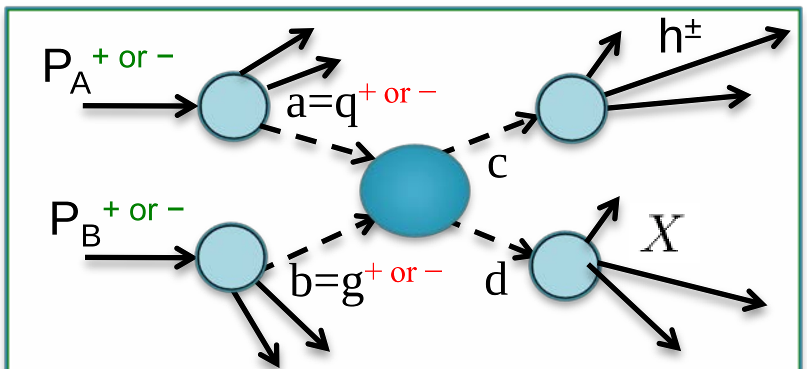
$$\textit{via parity conservation}!$$

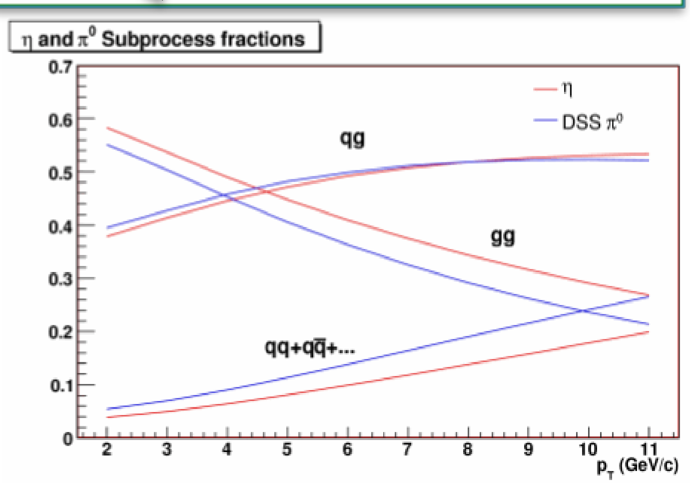
$$A_{LL} = \frac{1}{P_B P_Y} \frac{\frac{N^{++}}{\varepsilon^{++}L^{++}} - \frac{N^{+-}}{\varepsilon^{+-}L^{+-}}}{\frac{N^{++}}{\varepsilon^{++}L^{++}} + \frac{N^{+-}}{\varepsilon^{+-}L^{+-}}} = \frac{1}{P_B P_Y} \frac{N^{++} - \frac{\varepsilon^{++}}{\varepsilon^{+-}} RN^{+-}}{N^{++} + \frac{\varepsilon^{++}}{\varepsilon^{+-}} RN^{+-}}$$

- N = measured yield of final state particle measured
- ε are efficiencies (acceptance, reconstruction, trigger bias)
- L is Luminosity, R(elative Luminosity) = L^{++}/L^{+-}
- P_B, P_Y are polarizations of the two beams

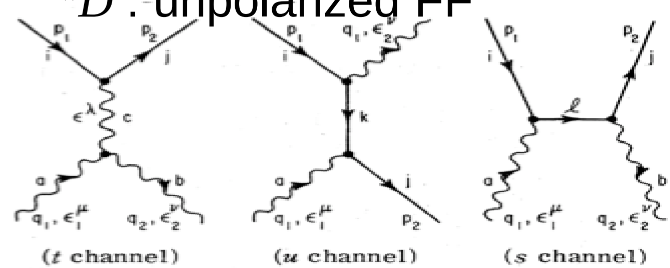
Single inclusive hadron

$$A_{LL}^{LO} \approx \frac{\sum_{qg\to cd}\int dx_q dx_g\, \Delta f(x_q,Q^2)\Delta G(x_g,Q^2)\Delta\hat{\sigma}_{qg\to cd}\, D_c^h(z_c)/(z_c\pi)+\dots}{\sum_{qg\to cd}\int dx_q dx_g\, f(x_q,Q^2)G(x_g,Q^2)(\hat{\sigma}^{++}_{qg\to cd}+\hat{\sigma}^{+-}_{qg\to cd})D_c^h(z_c)/(z_c\pi)+\dots}$$





*Δ(*f*,*G*,)
:difference between
two((++)&(+−))
helicity parton densities → Pol.
PDF
* *f*,*G*
: parton density, sum of two
helicity parton density → Unpol.
PDF
q-g processes
**D* : unpolarized FF



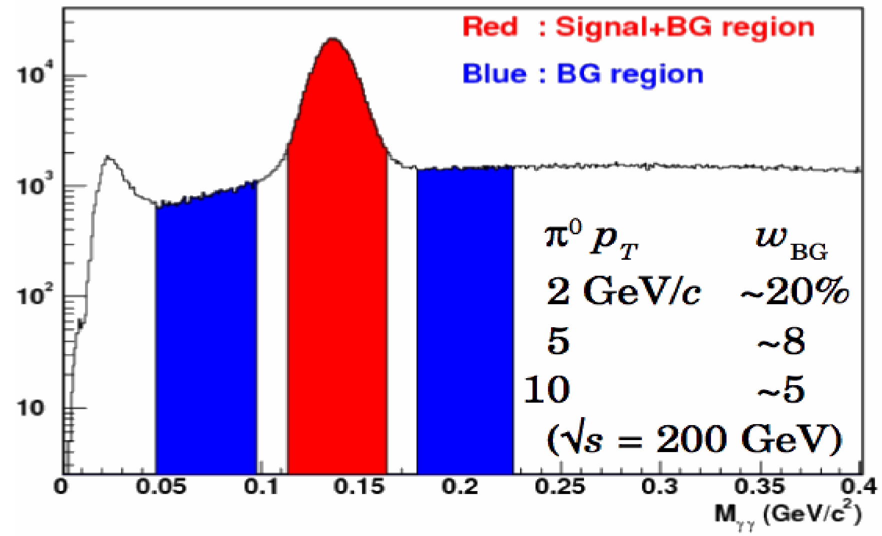
Single inclusive hadron at mid-rapidity
- Neutral pions π^0

- Count π^0 yield from reconstructing di-photon mass.
  ($\pi^0 \rightarrow \gamma\gamma$ BR ~ 98.8 %)
- Mask towers with abnormal hit frequency in EMCal to reduce combinatorial background (CB)
- Fit data with Gaussian (π^0) + polynomial (CB)

$$w_{BG} = N_{BG} / (N_{BG} + N_\pi)$$

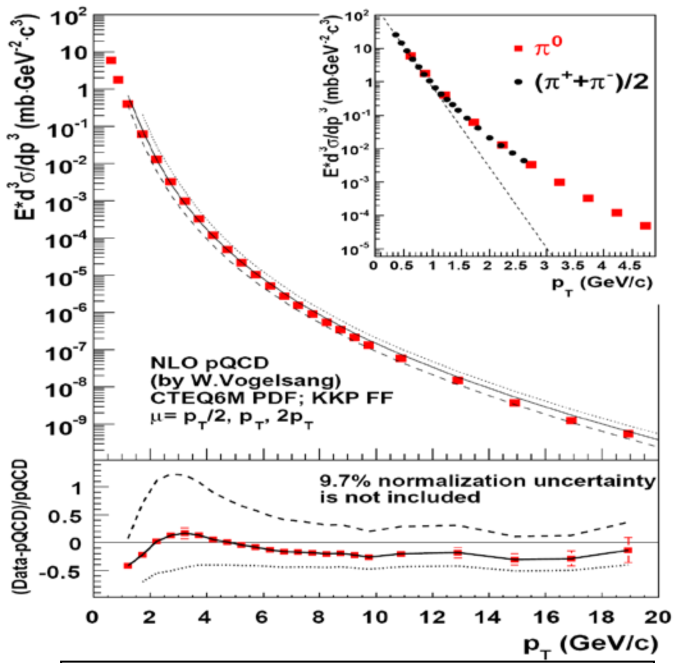
- Statistical subtraction of background asymmetry calculated from sideband (in blue)

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

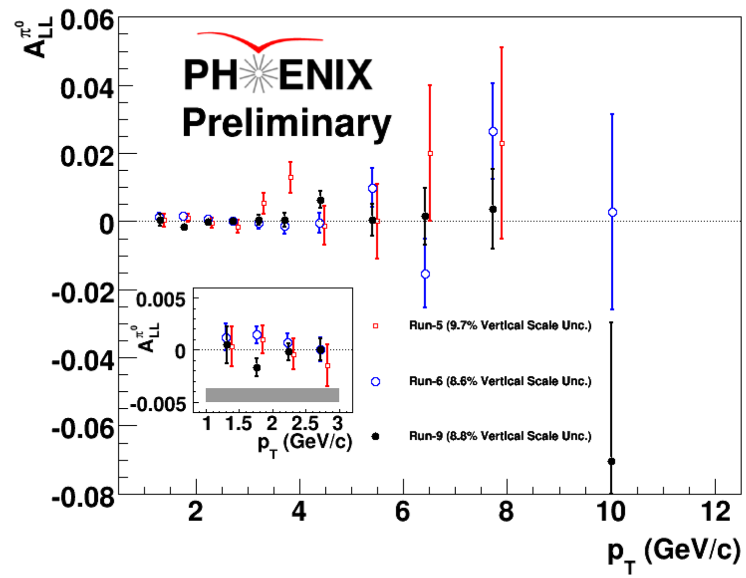


$$m_{\pi^0}^2 = 2E_1E_2(1 - cos\theta)$$

Single inclusive hadron at mid-rapidity
- Neutral pions π^0



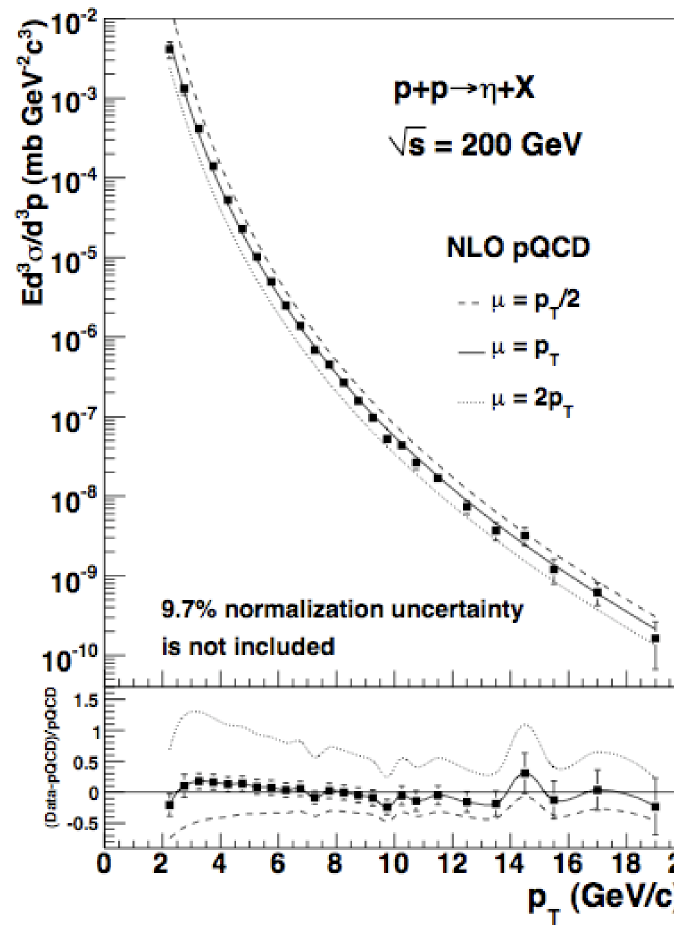
π^0 @ 200 GeV (PRD76, 051106)

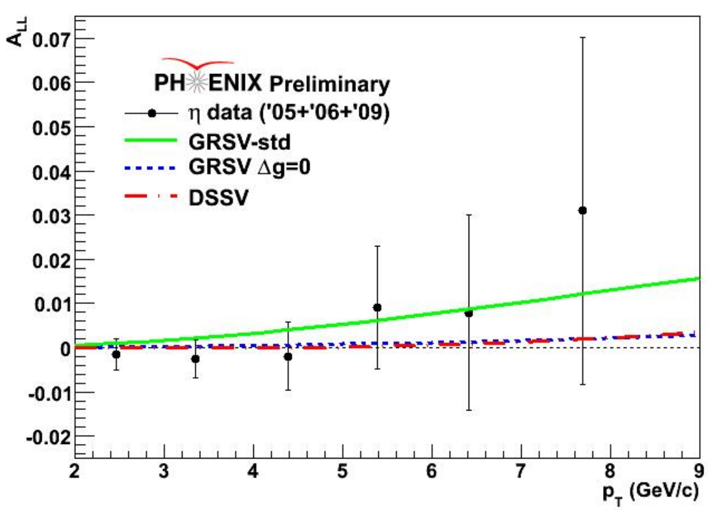


Measure efficiencies with the probability of zero method to take into account multiple collisions.
→ Reduces systematic uncertainties (efficiencies were assumed to be canceled in the past.)

Single inclusive hadron at mid-rapidity - eta η

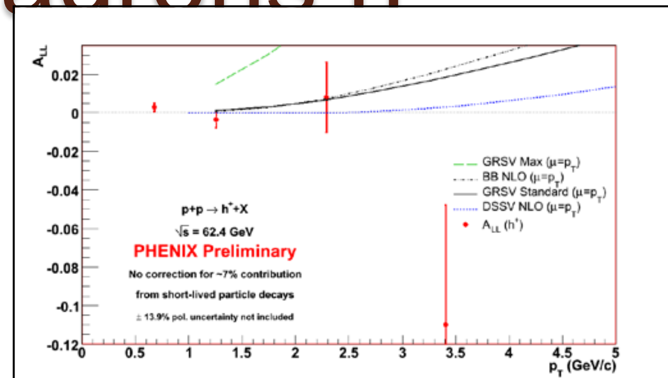
- Analysis similar to π^0. ($\eta \rightarrow \gamma\gamma$ BR ~ 39. %)
- Statistics limited compared to π^0
  - Run 2005 2.5 pb^{-1} Pol ~.49
  - Run 2006 6.5 pb^{-1} Pol~.57 (used for cross section measurement that went into global fit to improve η fragmentation function)

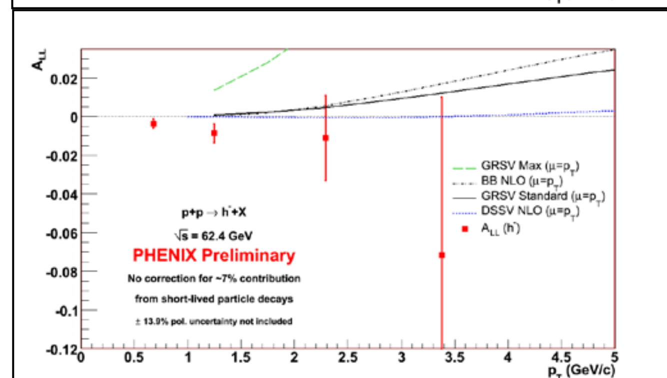


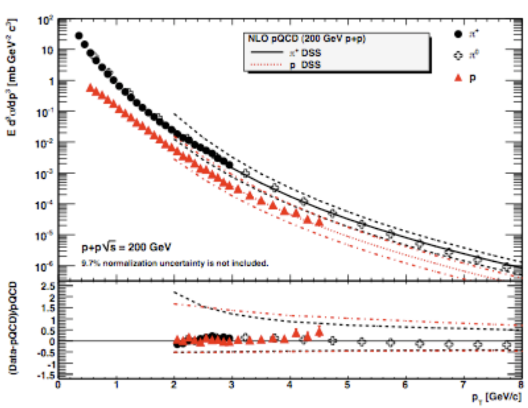


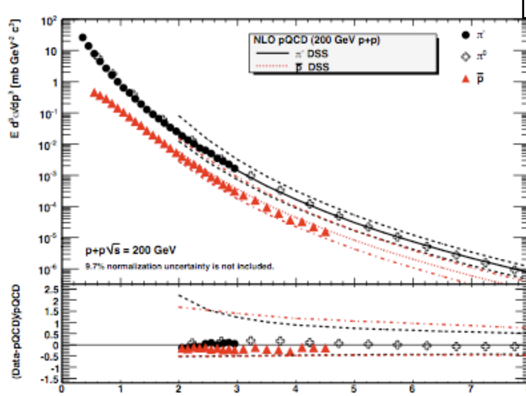
Single inclusive hadron at mid-rapidity
- Low p_t charged hadrons $h^\pm$

- Unidentified hadron ($\pi^\pm$, $K^\pm$, p etc.) counts from PHENIX tracking detectors (PC, PC).
- Electron/positron background eliminated by RICH veto.
- Access higher $x_g (0.06<x_g<0.4)$







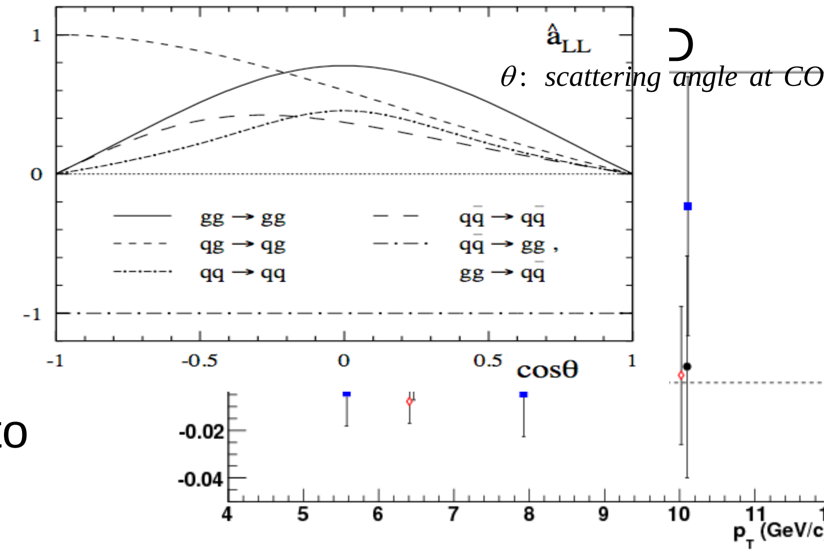


arXiv:1010.1521

Single inclusive hadron at mid-rapidity - High p_t charged pions $\pi^{\pm}$

$$\hat{a}_{LL} = \frac{\hat{\sigma}^{++} - \hat{\sigma}^{+-}}{\hat{\sigma}^{++} + \hat{\sigma}^{+-}} \quad : partonic\ \ asymmetry$$

θ: scattering angle at COM frame



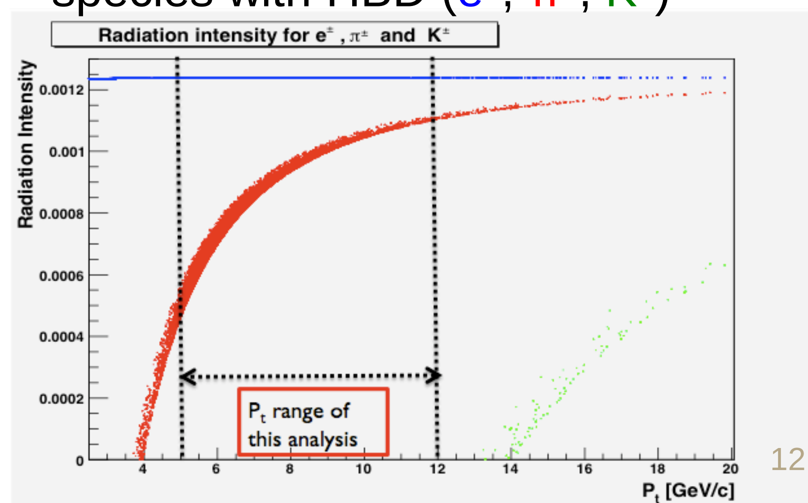
- Pion charge asymmetry is sensitive to sign of $\Delta G(x, Q^2)$:
  - $D_u^{\pi+} > D_u^{\pi0} > D_u^{\pi-}$, $f_u > 0$
  - $D_d^{\pi+} < D_d^{\pi0} < D_d^{\pi-}$, $f_d < 0$

    For positive ΔG :

    $A^{\pi+}_{LL} > A^{\pi0}_{LL} > A^{\pi-}_{LL}$
  - Can be readily incorporated into global fit

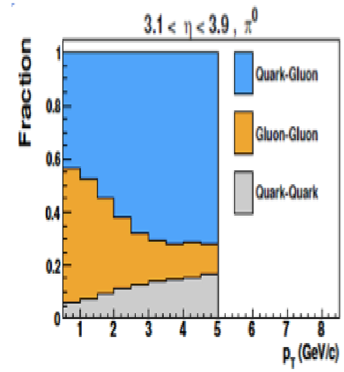
- Data set: ERT data
  - Run 2005 : 2.3 pb^{-1} , Pol ~.49
  - Run 2006 : 5.8 pb^{-1} , Pol ~.57
  - Run 2009 : 11.4 pb^{-1} , Pol~.57
    - Analyzed w/o HBD (preliminary shown top left)
    - With HBD, significantly improved purity as well as gain in statistics. Asymmetry & cross section analysis work in progress.

Clean separation between particle species with HBD ($e^{\pm}$, $\pi^{\pm}$, $K^{\pm}$)

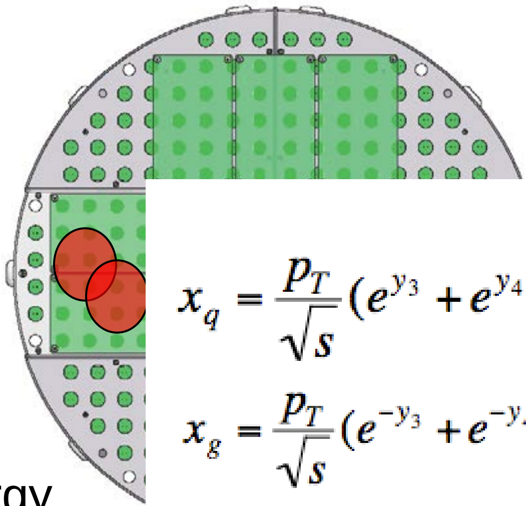


Single inclusive hadron at forward-rapidity

MPC Cluster(> 80% π^0)



- Forward π^0 shows similar fraction of sub processes
- First measurement with Muon



$$x_q = \frac{p_T}{\sqrt{s}}(e^{y_3} + e^{y_4})$$

$$x_g = \frac{p_T}{\sqrt{s}}(e^{-y_3} + e^{-y_4})$$

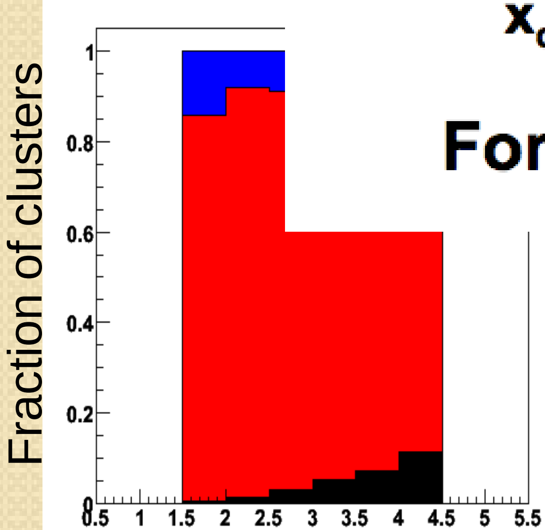
Muon Piston Calorimeter (3.1<|η|<3.9)

x

low and **high** energy π^0s

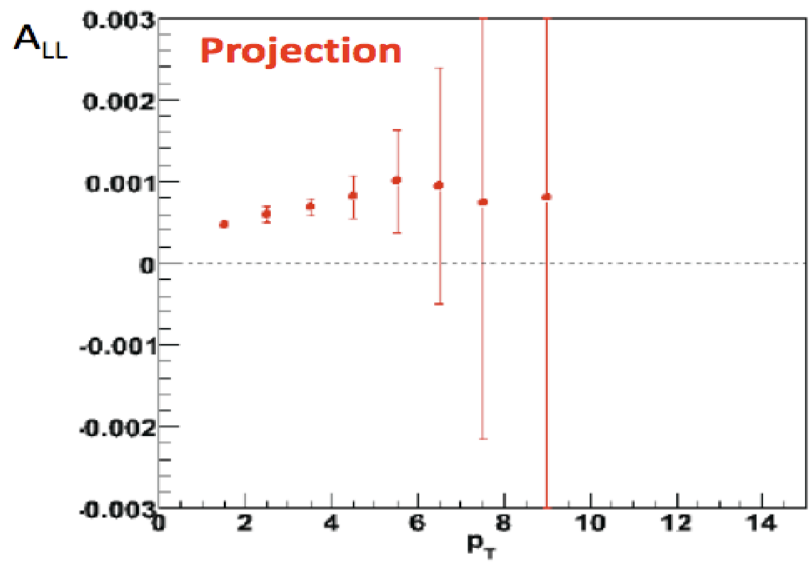
x_q

Forward bo

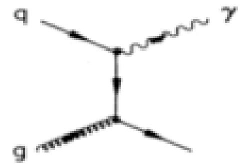


photon
π^0
Direct photon

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

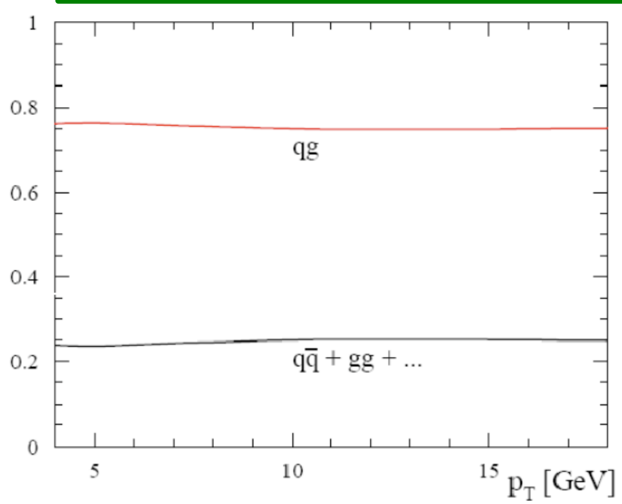


Direct photon

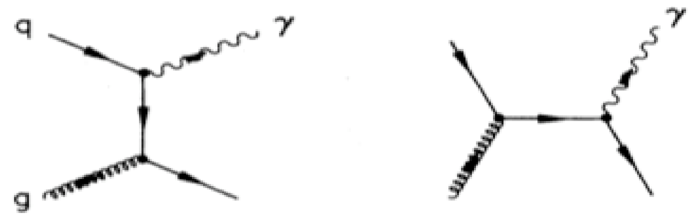


- Clean channel to probe gluon polarization
  - Asymmetry is odd in ΔG(x, Q^2) due to Compton scattering dominance at LO[O($\alpha\alpha_s$)] and thus sensitive to sign
  - FF =1 at LO : Uncertainties on FFs are much smaller than other channels(~30%) and thus smaller uncertainties on ΔG when accumulating enough statistics.

$$A_{LL} \approx \frac{\int dx_q dx_g g_1(x_q, Q^2)\Delta G(x_g, Q^2)(\hat{\sigma}_{qg}^{++} - \hat{\sigma}_{qg}^{+-}) + \ldots}{\int dx_q dx_g \frac{F_2(x_q, Q^2)}{x_q} G(x_g, Q^2)(\hat{\sigma}_{qg}^{++} + \hat{\sigma}_{qg}^{+-}) + \ldots}$$

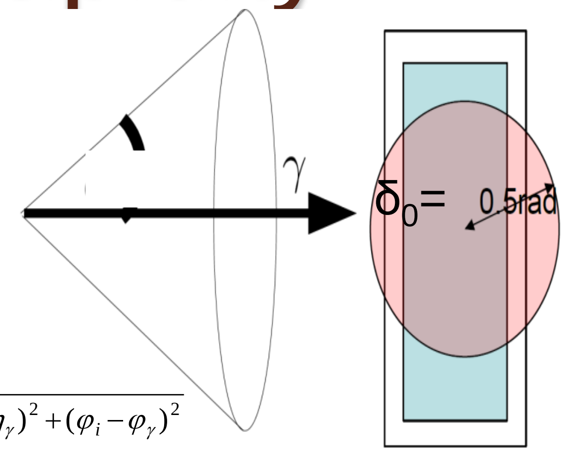


Compton scattering



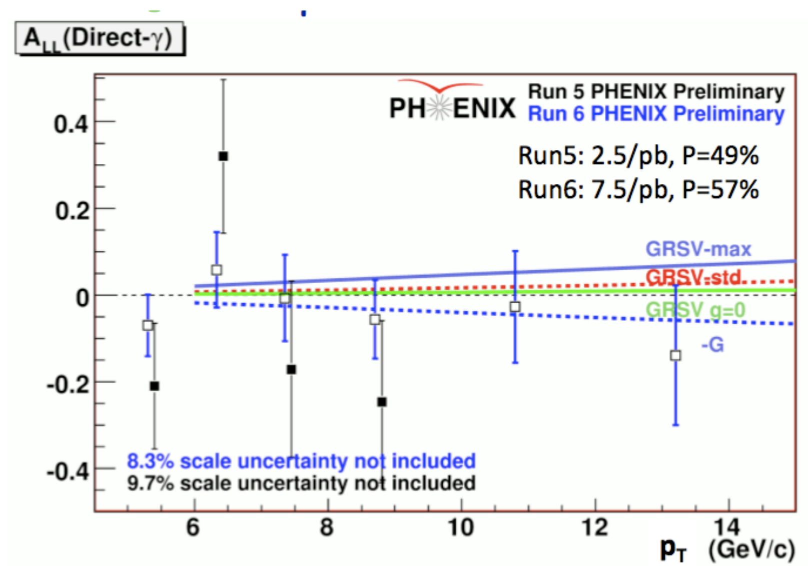
Direct photon at mid-rapidity

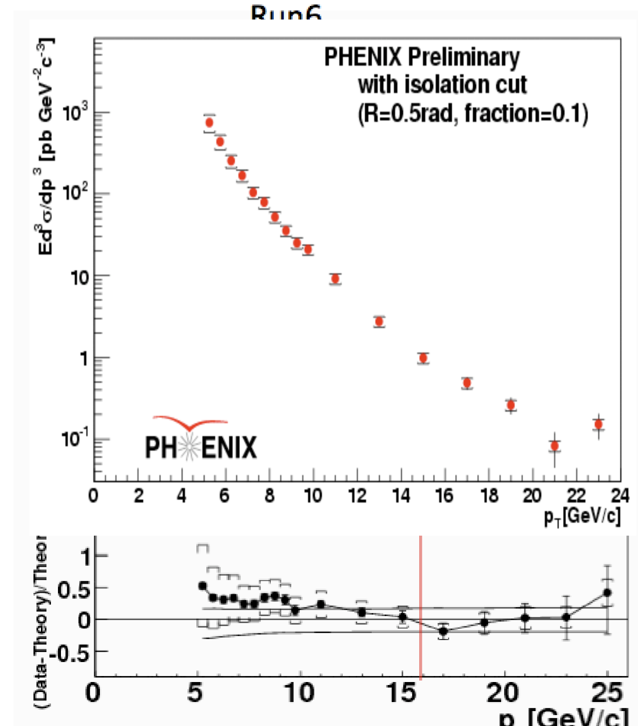
- Two methods to identify γ
  - Isolated cut method
    - Fraction of γenergy is allowed : allow for soft g radiation to cancel infra. div. , i.e. infrared safe.
    - Suitable for PP : lower event multiplicity environment allows for large enough isolation cone, i.e. effectively veto collinear parton fragmentation.
  - statistical subtraction method
- Statistics limited :
  - Run2005 : 2.5 pb^{-1}
  - Run2006 : 7.5 pb^{-1}
  - Run2009 : analysis under way



$$R_{i\gamma} = \sqrt{(\eta_i - \eta_\gamma)^2 + (\varphi_i - \varphi_\gamma)^2}$$

$$\sum_i E_T(i)\ \theta(\delta - R_{i\gamma}) \le .1\ E_\gamma \quad for \quad all \quad \delta < \delta_0$$





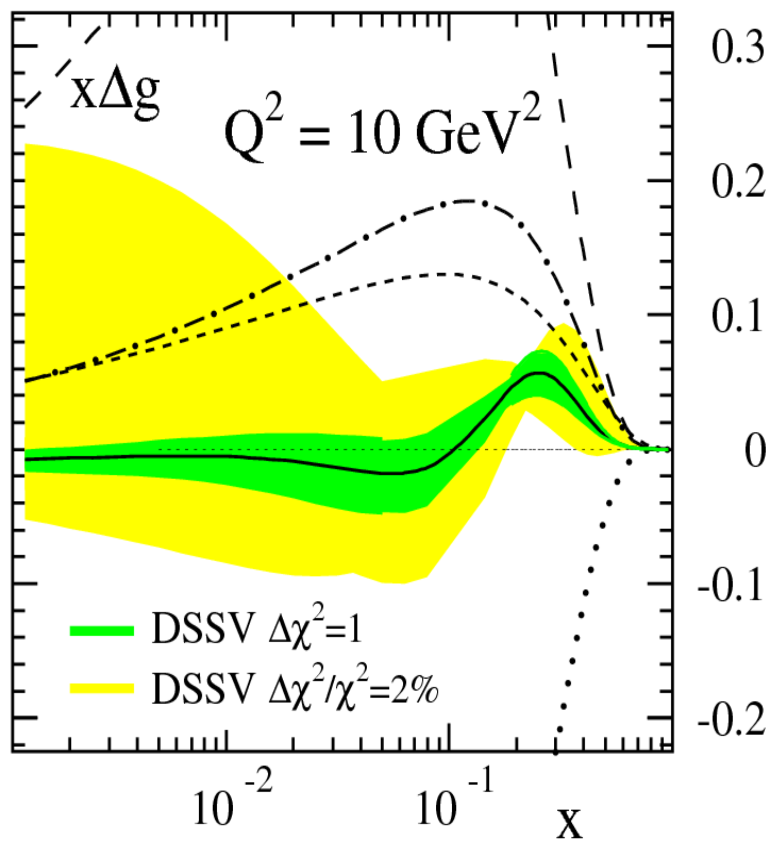
Global Analysis

$$\chi^2(\{a_i\}) = \sum_{n=1}^{N_{\rm exp}} \sum_{j=1}^{N_{\rm data}^{(n)}} \omega_j \left(\frac{D_j - T_j(\{a_i\})}{\delta D_j} \right)^2$$

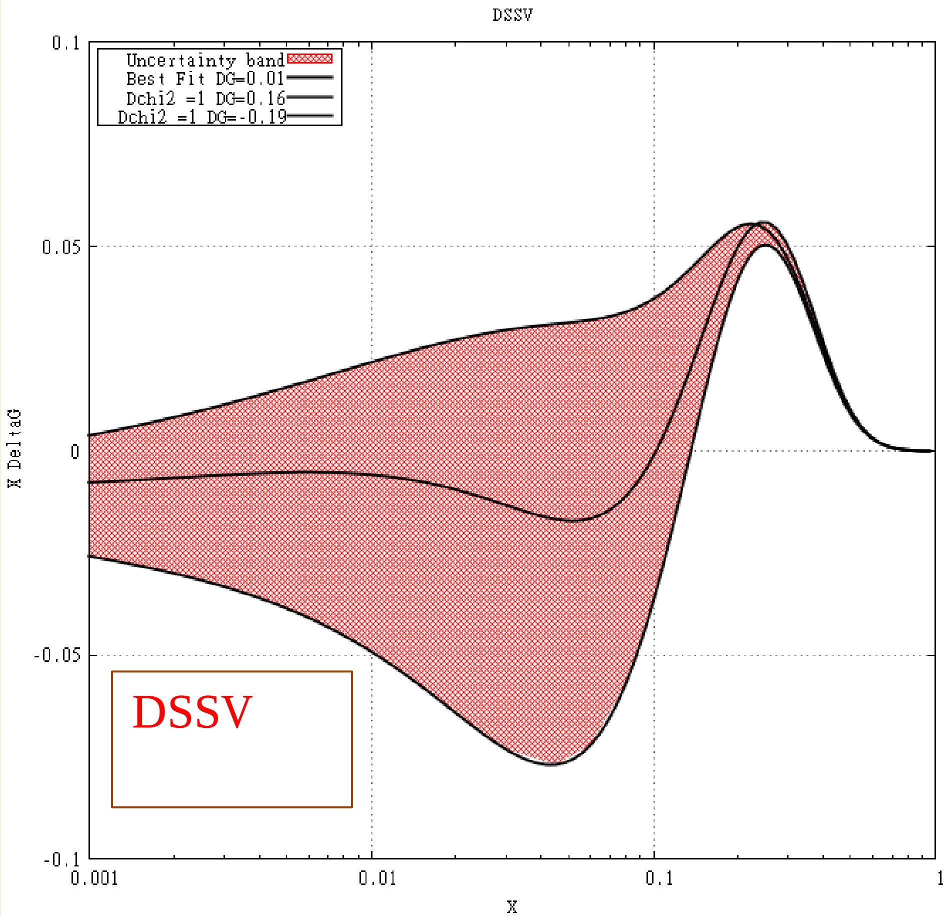
N_{exp}: # of experimental data sets,
N_{data}: # of data points,
w_j : weight factor,
$\{a_i\}$: theory par. (determine PDF, FF at μ_0)
D_j : Data value,
$T_j(\{a_i\})$: Theoretical estimate.

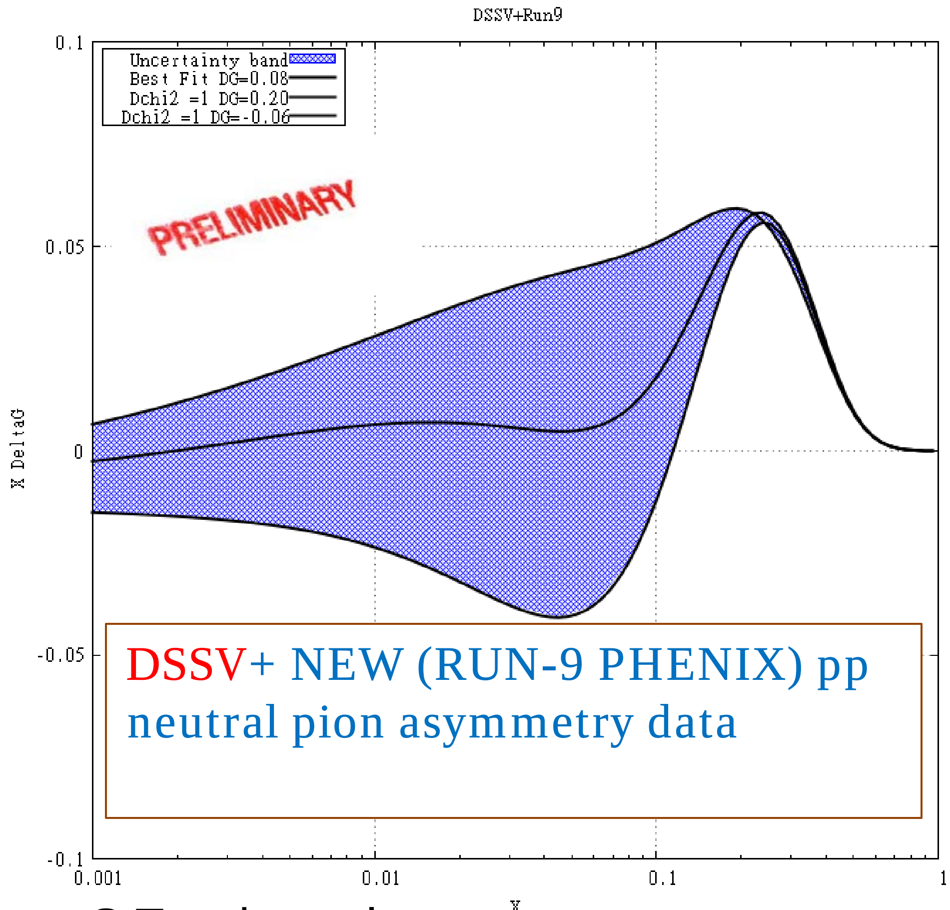
- pDIS, pSIDIS, pp data used
- NLO corrections to decrease the scale dependence of calculation.
- PHENIX $\sqrt{s}$ = 200 and 62 GeV π^0 data used
- RHIC data significantly constrain ΔG in range

Phys.Rev.Lett.101:072001,2008



Impact of PHENIX on $\Delta G(x,Q^2)$ (Non PHENIX analysis)



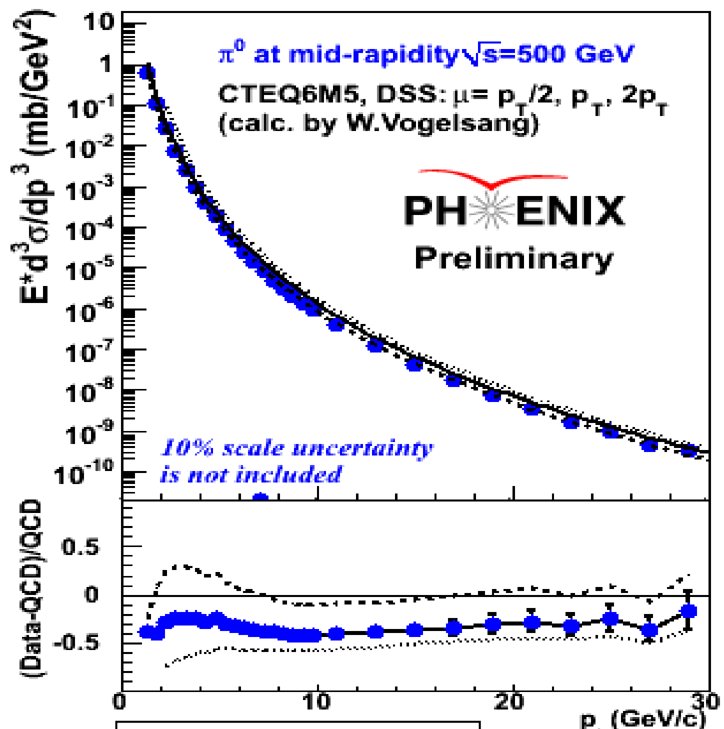


S.Tanejs at al.

Ongoing analyses

- Run9 500GeV $\pi^{0,}$ 200GeV π^0 , $\pi^{\pm}$, $h^{\pm}$, direct γ

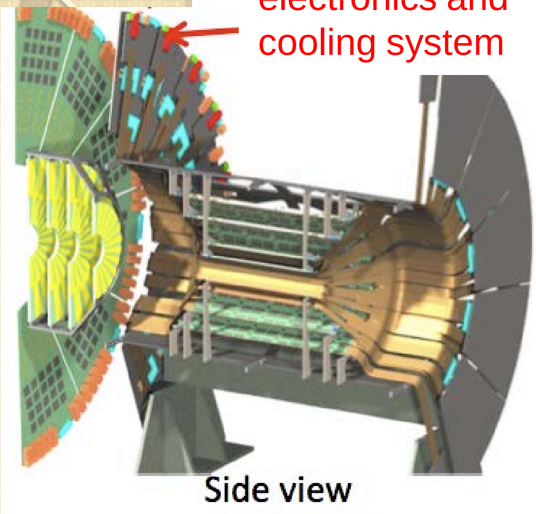
- Studies reveal sources of uncertainties on relative luminosity are residual transverse component of polarization → will be able to reduce systematic uncertainties in



π^0 @ 500 RUN 9

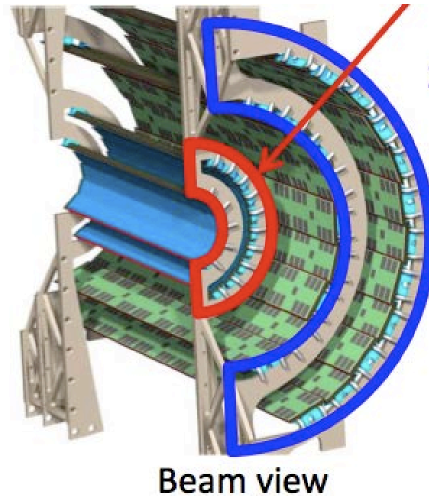
Vertex detector(VTX) installed

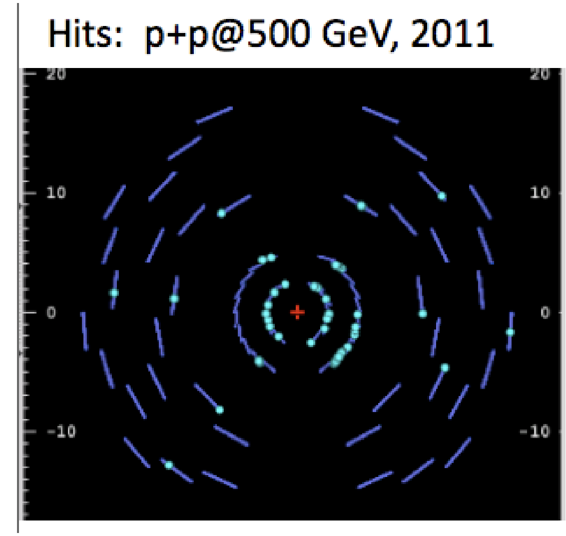
Wheel holding electronics and cooling system

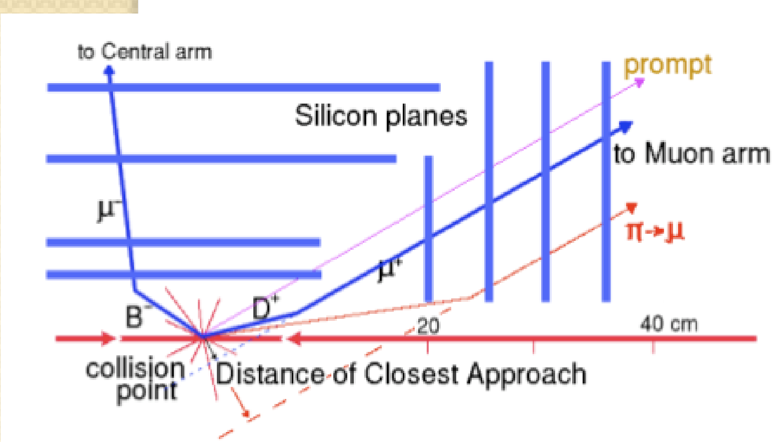


2 pixel layers (R=2.5, 5cm)

2 Stripixel layers (R=11.7, 16.9cm)



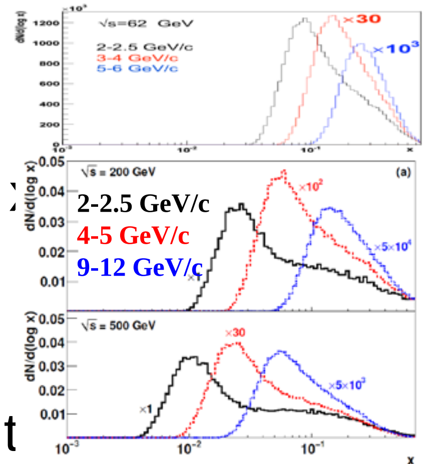




- VTX installed in Run 2011
- Coverage : $|\eta| < 1.2$, $\Delta\phi \sim 2\pi$
- Resolution (DCA) ~40μm(pixel)

Outlook

- Double inclusive (correlation) measurement to better determine :
  - γ-jet (ideal)
  - jet-jet
- Open charm & beauty separation t reach further smaller x_g
  - Charm production via semi leptonic decay to $e^{\pm}$
    - DCA cut with VTX remove Dalitz decay & photo conversion background and thus improve the purity of event sample (50→90%)
  - Beauty production with two additional channels aside from eμ
    - Single electron : high statistics
    - B→J/ψ+X : charm semi leptonic decay, Dalitz decay and photo conversion reduced by DCA

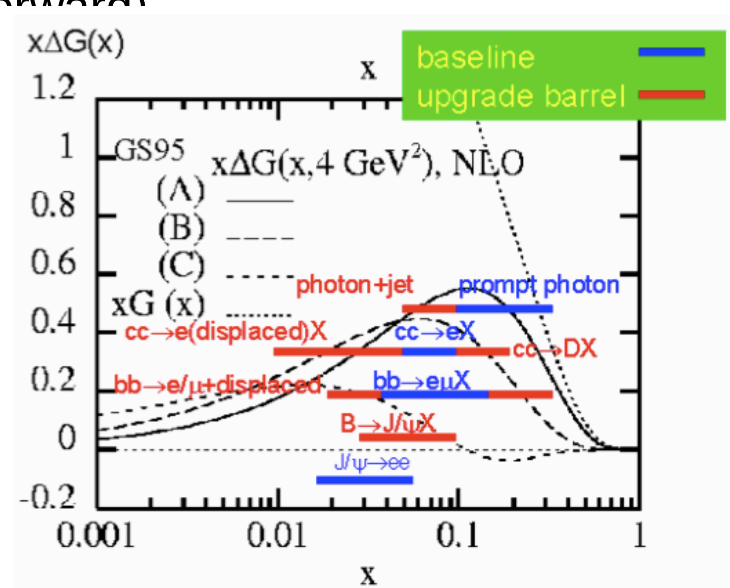


Single inclusive (central, similarly wide for forward)

Doublde inclusive

Will be able to probe narrower broken up range of x.

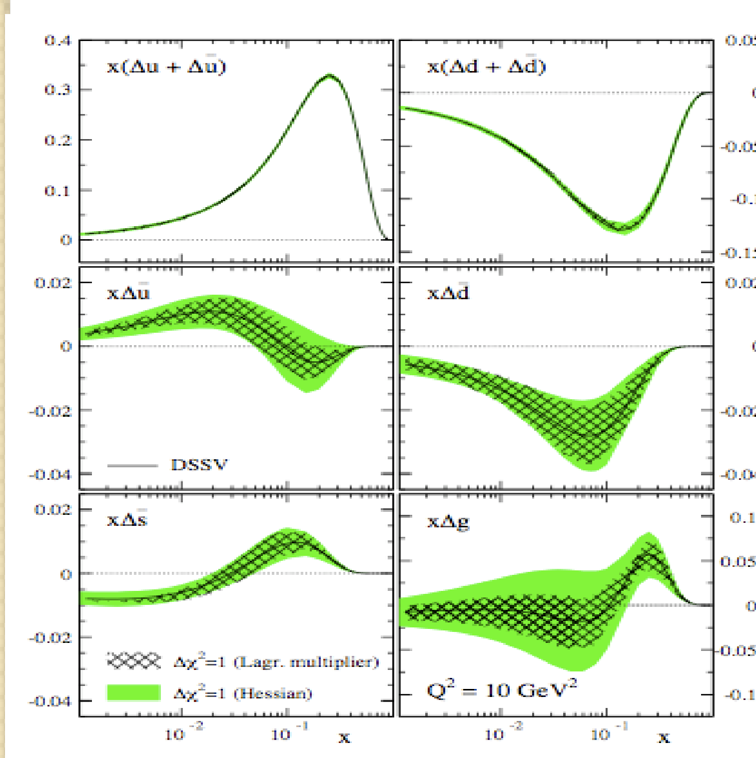
For example,
$[x_f] \approx [x_{ff}, x_{bf}]$
$x_{bf} > x_{cf} > x_{ff}$



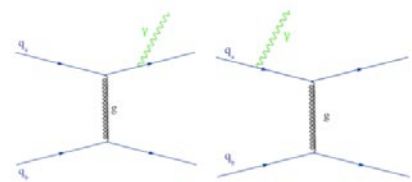
Summary

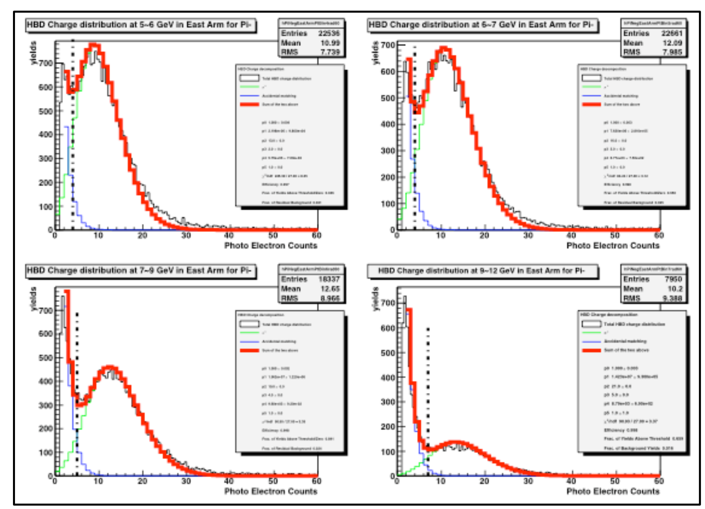
- PHENIX measurements(π^0,jet) imposed a significant constraint on ΔG.
- New detector (VTX) installed and running will allow for improved/independent measurements on ΔG.
- Further constraints to be made possible by high luminosity coming in future is of great interest.

backup

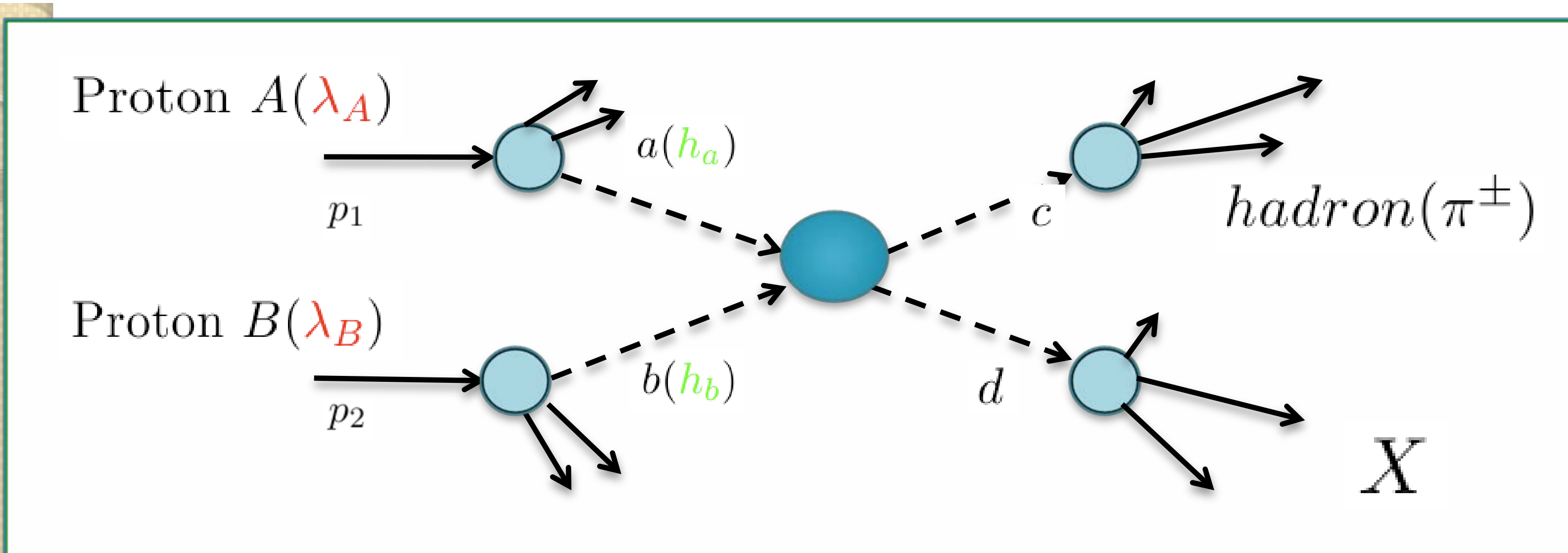


DSSV PRD80:034030(2009)





Parton Model for Polarized Proton Collisions (for single inclusive hadron production)



$$d\sigma_{\lambda_A \lambda_B} = \left(\sum_{ab \to cd} \int dx_a \int dx_b \right) \sum_{h_a h_b} f_{a(h_a)/A_{\lambda_A}} f_{b(h_b)/B_{\lambda_B}} \frac{d\hat{\sigma}_{h_a h_b}}{d\hat{t}} D_c^{\pi^{\pm}} \frac{1}{z_c \pi}$$

Helicity parton density

Hard scattering Cross section

Fragmentation function

(Un)Polarized Parton Distribution Functions

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

Polarized PDF

$$\Delta f_{a/A} = f_{a(+)/A(+)} - f_{a(+)/A(-)}$$

Numerator

$$\sum_{ab\to cd} \int_{x_{a_{min}}}^{1} dx_a \int_{x_{b_{min}}}^{1} dx_b \Delta f_{a/A}(x_a) \Delta f_{b/\ldots} \ldots \frac{\ldots}{z_c\,\pi} \frac{d\Delta\hat{\sigma}}{d\hat{t}}(ab \to cd)$$

Integrate over x

helicity sum rule (A+=0 gauge)

Jaffe, Manohar; Ji; …

$$\frac{1}{2}\hbar = \langle P, \frac{1}{2} | J^z_{\mathrm{QCD}} | P, \frac{1}{2} \rangle = \sum_q \frac{1}{2} S^z_q + S^z_g + \sum_q L^z_q + L^z_g$$

$$\sum_{ab\to cd} \int_{x_{a_{min}}} dx_a \int_{x_{b_{min}}} dx_b f_{a/A}(x_a) f_{b/B}(x_b) D_c(z_c) \frac{\ldots}{z_c\,\pi} \frac{\ldots}{d\hat{t}}(ab \to cd)$$