Experimental Aspects of Determining ΔG from Direct Photon + Jet Events in Polarized pp Collisions Using the STAR Detector at RHIC.

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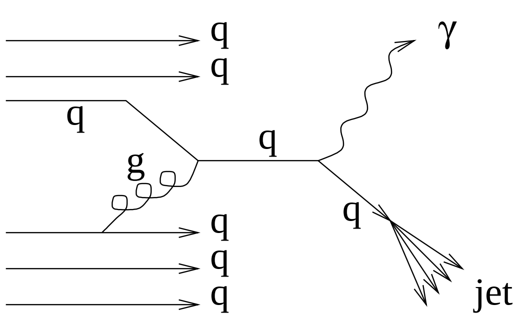
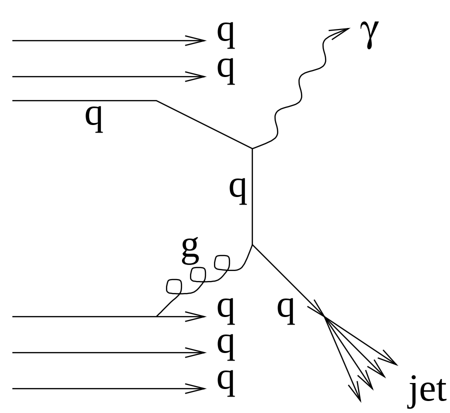
Polarized Direct Photon + Jet Production:

STAR will measure $\vec{p}\vec{p} \rightarrow \gamma + \text{jet} + X$ at $\sqrt{s} = 200$ GeV and 500 GeV with longitudinally polarized beams to determine the fraction of the proton's spin carried by gluons.

- STAR detects γ + jet IN COINCIDENCE.
- Photon $P_T > 10$ GeV/c.





(Quark-gluon Compton scattering is the dominant contribution to direct photon production.)

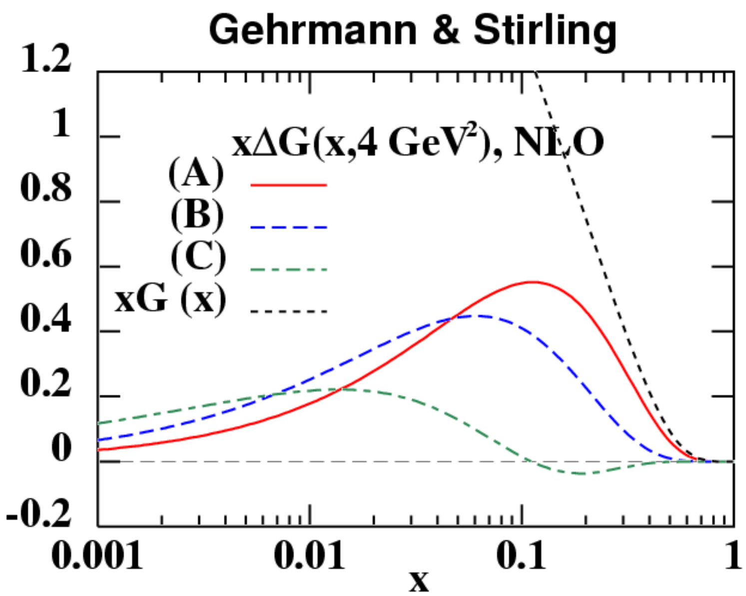
The spin of the proton is given by

$$\frac{1}{2} = \frac{1}{2}\Sigma + \boxed{\Delta G} + L_Z^q + L_Z^G.$$

The gluon fraction of the proton spin is given by

$$\Delta G(Q^2) = \int_0^1 \Delta G(x, Q^2) dx,$$

where $\Delta G(x, Q^2) = G_{\rightarrow g}^{\rightarrow p}(x, Q^2) - G_{\leftarrow g}^{\rightarrow p}(x, Q^2)$ is the polarized gluon structure function.



The x dependence of $\Delta G(x, Q^2)$ is not strongly constrained by data or theory, and must therefore be measured. (Plots are from fits to data for $\Delta G(x, Q^2 = 4\text{GeV}^2)$ in T. Gehrmann and W. J. Stirling, *Phys. Rev.* D**53**, 6100 (1996).)

The peaks in the above curves shift to lower x at higher Q^2 where STAR will measure. This puts a premium on measuring at low x for determining the integral.

$A_{LL}(x, Q^2)$:

STAR will measure $A_{LL}(x, Q^2)$, which to leading order is

$$A_{LL}(x, Q^2) = \frac{\Delta G(x, Q^2)}{G(x, Q^2)} A_1^p(x, Q^2) \hat{a}_{LL}(cos\theta^*).$$

$G(x, Q^2)$ = unpolarized gluon structure function.

(Known from global fit to published data.)

$A_1^p(x, Q^2)$ = asymmetry measured in polarized DIS.

(Known from published PDIS data.)

$\hat{a}_{LL}(cos\theta^*)$ = qg Compton spin correlation coefficient.

(Known from PQCD.)

Measurement of $A_{LL}(x, Q^2)$ therefore determines $\Delta G(x, Q^2)$ directly.

$A_{LL}(x, Q^2)$:

Experimentally speaking,

$$A_{LL}(x) = \left(\frac{1}{P_{b1}P_{b2}}\right) \cdot \epsilon(x),$$

where P_{b1}, P_{b2} are the longitudinal polarizations of the colliding proton beams, and $\epsilon(x)$ is a function of luminosity-normalized counts for the different combinations of beam states:

$$\epsilon(x) = \frac{n_{++} + n_{--} - n_{+-} - n_{-+}}{n_{++} + n_{--} + n_{+-} + n_{-+}},$$

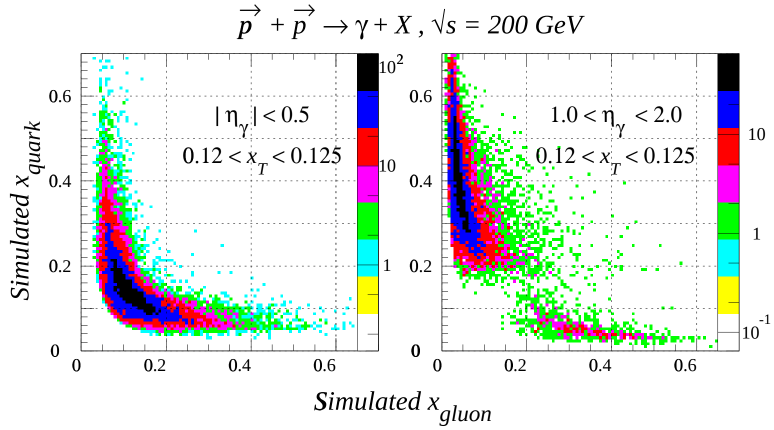
with

$$n_{ij}(x) = \frac{N_{ij}(x)}{\mathcal{L}_{ij}},$$

where $N_{ij}(x)$ is the number of γ + jet events in beam polarization state ij in some bin of x, and $\mathcal{L}_{ij}$ is the number of counts in some luminosity monitor for state ij.

Coincidence of γ + jet $\Rightarrow$ full parton kinematic reconstruction:

Inclusive photons from a narrow x range can come from wide ranges of parton x:



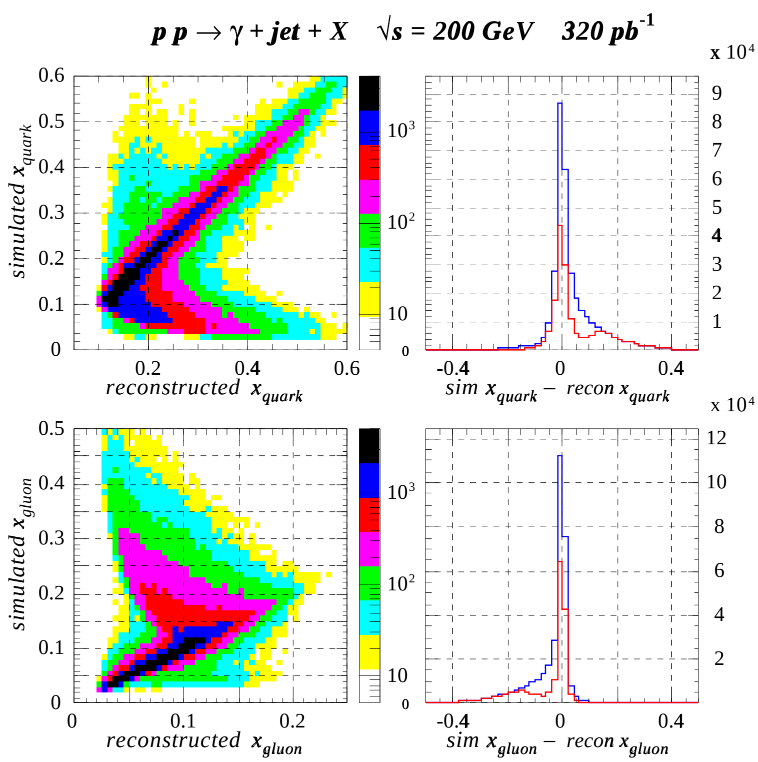
γ + jet in coincidence $\Rightarrow$ reconstruction of x_g and x_q event by event:

Assuming collinearity of the colliding partons,

$$x_1 \approx \frac{2P_T}{\sqrt{s}} \left(\frac{e^{\eta_\gamma} + e^{\eta \text{ jet}}}{2} \right) \qquad x_2 \approx \frac{2P_T}{\sqrt{s}} \left(\frac{e^{-\eta_\gamma} + e^{-\eta \text{ jet}}}{2} \right),$$

$$\eta_\gamma = -ln \left[\tan \left(\frac{\theta_\gamma}{2} \right) \right], \qquad \eta_{\text{jet}} = -ln \left[\tan \left(\frac{\theta_{\text{ jet}}}{2} \right) \right],$$

$$\sqrt{s} = 2 \cdot E_{\text{beam}}, \quad P_T = E_\gamma \sin\theta_\gamma, \quad \text{pick } x_g = min(x_1, x_2):$$



Meeting major challenges for determining A_{LL}:

RHIC Polarimetry:

5% relative errors in $P_{b1}, P_{b2} \Rightarrow$ 10% rel. error in A_{LL}.

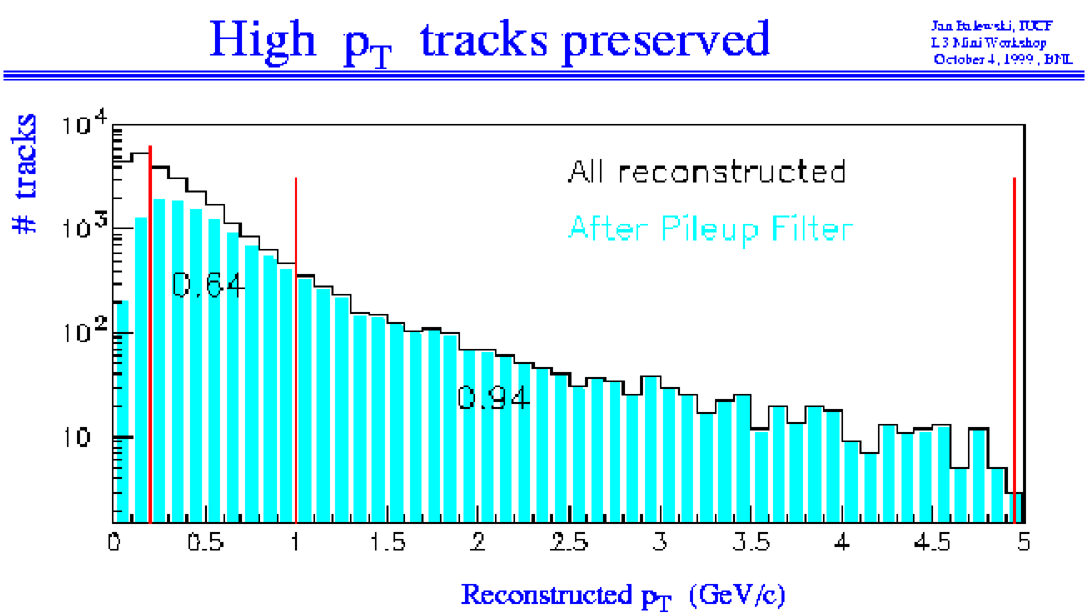
Pileup Rejection:

Full RHIC luminosity $= 2{\times}10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1} \Rightarrow\ > 1$Mhz interaction rate.

40μs TPC drift time $\Rightarrow$ 1000's of low-P_T background tracks in TPC.

Filter Software:

- retains 94% of jet tracks w/$P_T > 1.0$ GeV/c.
- Rejects nearly all background tracks.



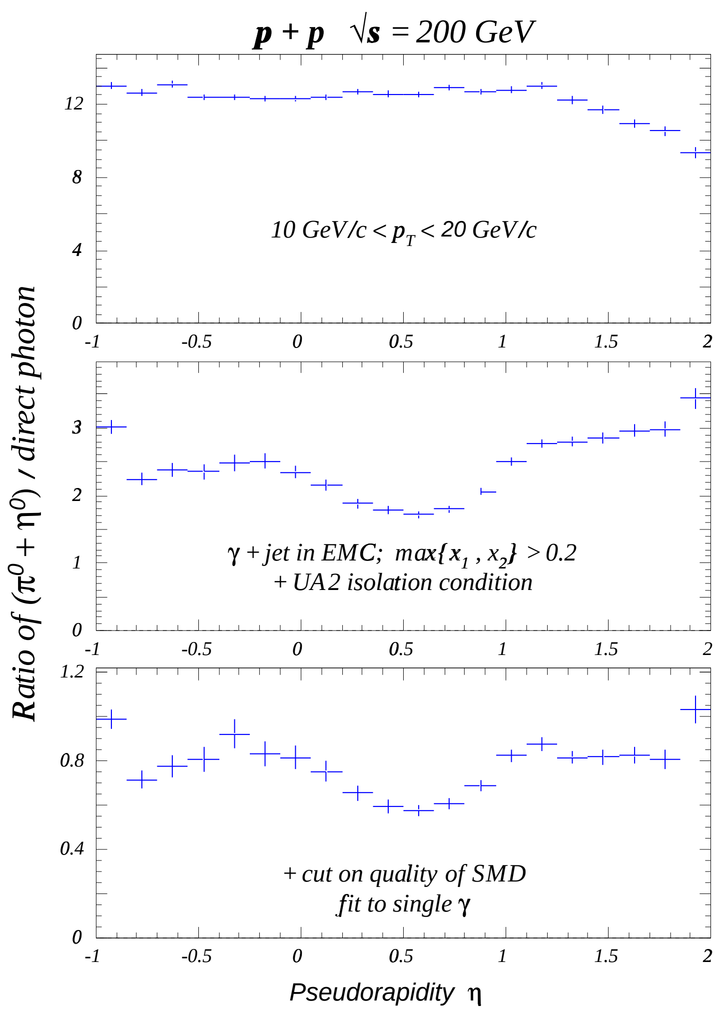
Meeting major challenges for determining A_{LL}:

Direct γ Identification:

Calorimeters must identify single direct γ's, reject γ pairs from π°'s, η's.

Condition	Description	sig.:bkgnd
$10 < P_T < 20$ GeV/c	Photon P_T requirement	1 : 13
Isolation Cut	No nearby tracks or cal. energy	1 : 3
Shower Shape	Shower Max (<10 mm pos. resol.)	1 : 0.8

Background subtraction raises stat. error in A_{LL} by factor of 1.5-2.0.



Meeting major challenges for determining integral $\Delta G(Q^2)$:

Calorimeter Energy Calibration:

Effect: Shape of $\Delta G(x, Q^2)$ is distorted, especially at large x.

$\pm 2\%$ absolute error in $E_\gamma \Rightarrow 2\%$ relative error in x

$\Rightarrow \pm 5\%$ error in integral ΔG.

Extrapolation:

- Contribution to integral is small above $x > 0.3$.
- Extrapolation to low x is crucial.

With the endcap calorimeter, STAR will cover $0.01 < x < 0.3$.

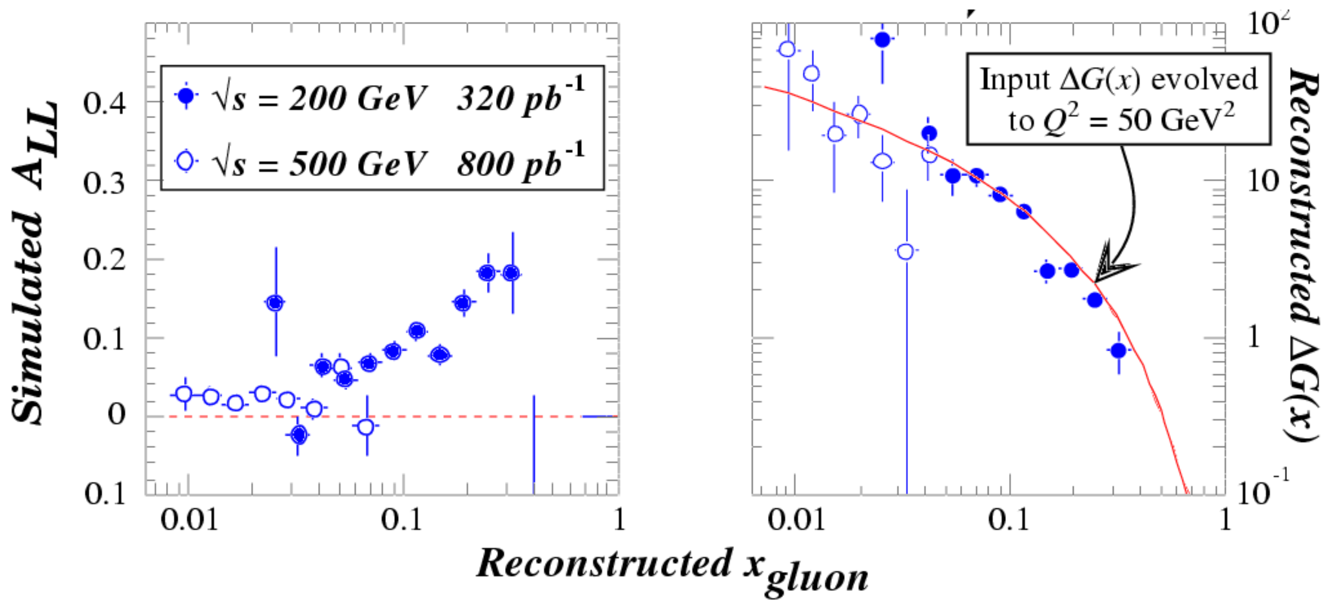
The final error in

$$\Delta G(Q^2) = \int_0^1 \Delta G(x, Q^2) dx$$

will be about $\boxed{\boxed{\pm 0.5.}}$

Expected uncertainty in integral ΔG:

Simulations based on assumptions of 320 pb^{-1} at $\sqrt{s}$ = 200 GeV and 800 pb^{-1} at $\sqrt{s}$ = 500 GeV (10 weeks of running at each energy), $P_{b1} = P_{b2}$ = 70%, give the following results:



(Simulated events were generated at IUCF using a prediction for $\Delta G(x)$ in T. Gehrmann and W. J. Stirling, *Phys. Rev.* D**53**, 6100 (1996). Plots are by L. Bland for the Conceptual Design Report of the STAR Endcap Electromagnetic Calorimeter.)

Simulation results indicate that the final value of the integral

$$\Delta G = \int_0^1 \Delta G(x)dx$$

will be determined to about $\boxed{\pm 0.5.}$