Measuring the Gluon Helicity Distribution via $\vec{p}\vec{p} \to \gamma + \text{jet} + X$ with STAR

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Measurement of the net gluon contribution to a proton's longitudinal spin projection with a precision better than ± 0.5 would substantially advance our understanding of the spin substructure, clarifying also the contributions from quarks and from orbital angular momentum. This precision is attainable, along with high-quality measurements of the dependence of the gluon polarization on Bjorken x, via γ-jet coincidence detection in STAR.

Among contemplated methods, the detection of γ-jet coincidences from hard $\vec{p} - \vec{p}$ collisions allows one to approach most closely the ideal of extracting $\Delta G(x_g)$ directly from the data, at experimentally determined x_g values (see Fig. 1). Still, the envisioned extraction involves simplifying assumptions, whose (model-dependent) effect is important to estimate from simulations.

STAR will be well-suited for γ-jet coincidences when the baseline detector is supplemented by the barrel electromagnetic calorimeter (EMC), already under construction, and by an endcap EMC to be proposed to the National Science Foundation in Fall 1998. As detailed in Fig. 2, the endcap provides access to kinematic regions where the greatest statistical precision in $\Delta G(x_g)$ and the cleanest experimental determination of x_g are possible. To distinguish single γ's from π^0 or η-meson decays up to 60 GeV, the endcap will include a shower-maximum detector (SMD) comprising two orthogonal planes of scintillator strips of triangular cross section.

Simulation results (Fig. 3) indicate realistic statistical, plus some systematic, uncertainties achievable with STAR. The extracted values deviate systematically from $\Delta G(x, Q^2)$ *input* to the simulation (solid curve, based on model A of Gehrmann and Stirling, Ref. 1), because the simple data analysis neglects a number of effects included in the event generation: *e.g.*, contributions from $q\bar{q} \to g\gamma$, $qg \to q\gamma$ with $x_g > x_q$, and k_T smearing. The deviations are manageable ($\lesssim 30\%$) in magnitude, hence correctable, and become unimportant at $x_g < 0.1$, where the dominant contributions to the *integral* $\Delta G(Q^2) \equiv \int_0^1 \Delta G(x, Q^2)dx$ arise.

Simulations also demonstrate that the subtraction of π^0 and η-meson background does not seriously compromise the impact of the attainable results. As seen in Fig. 4, the imposition of isolation cuts and cuts on the shower profile measured in the SMD reduce the background/signal ratio from about 13 (generated by PYTHIA) to 0.6–0.8, roughly independent of the pseudorapidity of the detected particle or of the reconstructed x_g value. The background subtraction procedure outlined in Fig. 5 would increase error bars, over the statistical uncertainties included in Fig. 3, by a factor of 1.5–2.0, if we can determine the probability that mesons survive the SMD cut to $\pm 15\%$ from simulations. All other information needed to determine $A_{LL}(x_g)$ for direct γ production is *measured* in the experiment itself.

Measurements at two energies, $\sqrt{s}$=200 and 500 GeV, will yield $\Delta G(x_g)$ over the range $0.02 \leq x_g \leq 0.3$, with a net statistical plus background subtraction uncertainty $\lesssim \pm 0.2$ in the integral ΔG over this range. It appears feasible to control other systematic errors (including beam polarization calibration) sufficiently to maintain an overall error $< \pm 0.5$ in $\int_0^1 \Delta G(x, Q^2)dx$. Comparison of results from two energies at overlapping x_g-values will test the importance of k_T-smearing and other questionable issues in the theoretical description of direct photon production.

[1] T. Gehrmann and W.J. Stirling, Phys. Rev. **D53**, 6100 (1996).

ADVANTAGES OF $\vec{p} + \vec{p} \to \gamma + \text{jet} + X$

- one dominant partonic subprocess: $q + g \to q + \gamma$
- NLO effects relatively small
- extensive experience from *un*polarized G(x) fits
- event-by-event kinematic determination of $x_{1,2}, \theta^*$ (without reliance on poor resolution p_T(jet)): (neglecting k_T)

$$x_1 = \frac{p_T(\gamma)}{\sqrt{s_{pp}}} \left[\exp(\eta_\gamma) + \exp(\eta_{jet}) \right]$$

$$x_2 = \frac{p_T(\gamma)}{\sqrt{s_{pp}}} \left[\exp(-\eta_\gamma) + \exp(-\eta_{jet}) \right]$$

$$|\cot\theta^*| = \left| \sinh\left(\frac{\eta_{jet} - \eta_\gamma}{2} \right) \right|$$

- $\hat{\sigma}(\theta^*)$, parton distribution functions both favor assignment:

$$x_g = \min\{x_1, x_2\}; \qquad x_q = \max\{x_1, x_2\}$$

$\Rightarrow$ removes ambiguity re sign of $\cot\theta^*$ (preference strongest when $|x_1 - x_2| > 0.1$, $|\cos\theta^*| \gtrsim 0.5$), allows approx. LO direct extraction:

$$\frac{\Delta G(x_g)}{G(x_g)} \cong \frac{\varepsilon_{LL}^{meas.}}{P_{b_1} P_{b_2} A_1^{DIS}(x_q, Q^2)\, \hat{a}_{LL}^{Compton}(\theta^*)}$$

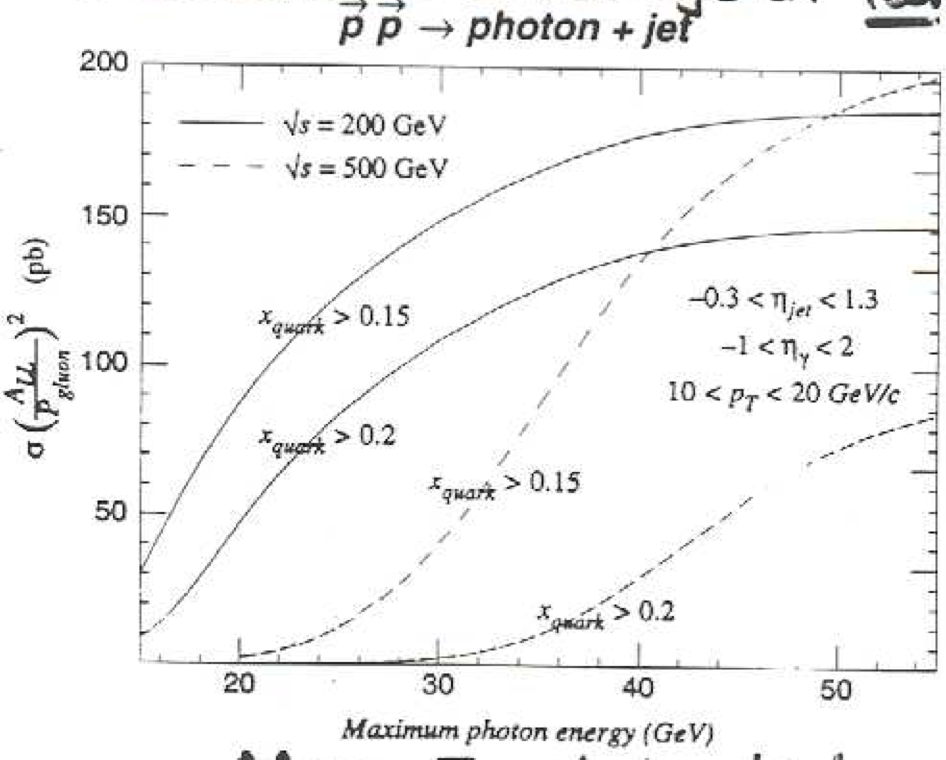
- **perform simulations to test effects of neglecting:**

  $q\bar{q} \to g\gamma$; $x_g \leftrightarrow x_q$ misidentification;
  θ^* reconstruction errors; k_T - smearing + g radiation;
  eventually, NLO contributions

Endcap ⇒ Access To:

1) highly asymmetric partonic collisions:
   ⇒ highly pol'd quarks @ $x_q > 0.2$ to probe gluon pol'n @ $x_g < 0.1$
2) backward θ^* in $q + g \rightarrow q + \gamma$
   ⇒ peak $\hat{\sigma}$ and $\hat{a}_{LL}$ ⇒ greatest figure of merit for determining $\Delta G/G(x)$
3) least confusion in assigning x_g vs. x_q
   ⇒ both $\hat{\sigma}(\theta^*)$ and PDF's favor $x_g = x_{min}$
4) greatly enhanced jet acceptance
   ⇒ enhanced coverage at large x_g

Fig. of Merit for $\frac{\Delta G(x)}{G(x)}$

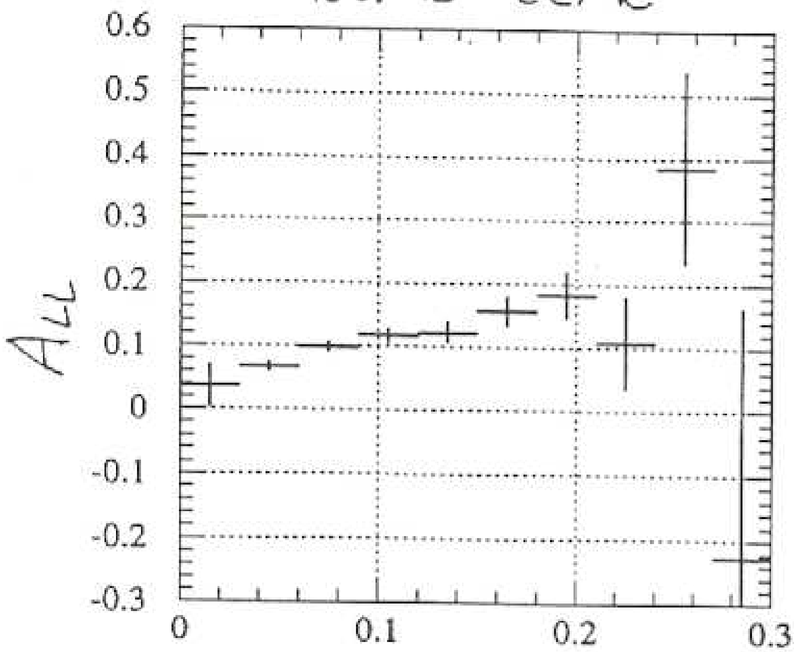


Max. E_γ detected

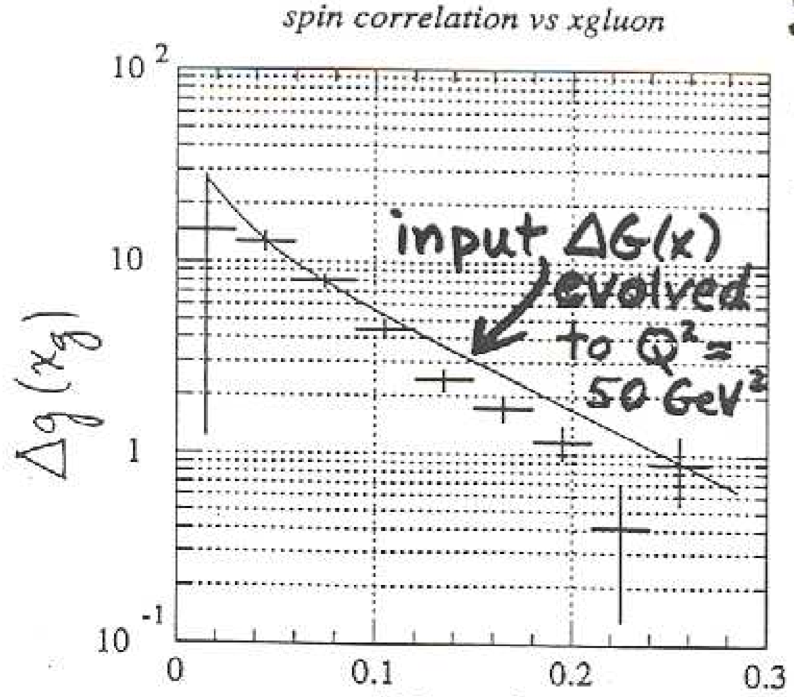
Simulated Data for $\vec{p}+\vec{p} \rightarrow \gamma + \text{jet} + X$ for STAR + endcap EMC

$\sqrt{s} = 200$ GeV ; 320 pb^{-1}

BEMC + EEMC



error bars are statistical (± 0.005 syst. instrumental asym. included in $\epsilon_{LL}^{meas.} \Rightarrow \pm 0.010$ in A_{LL})



Systematic deviation from input $\Delta G(x, Q^2)$ from neglect of:

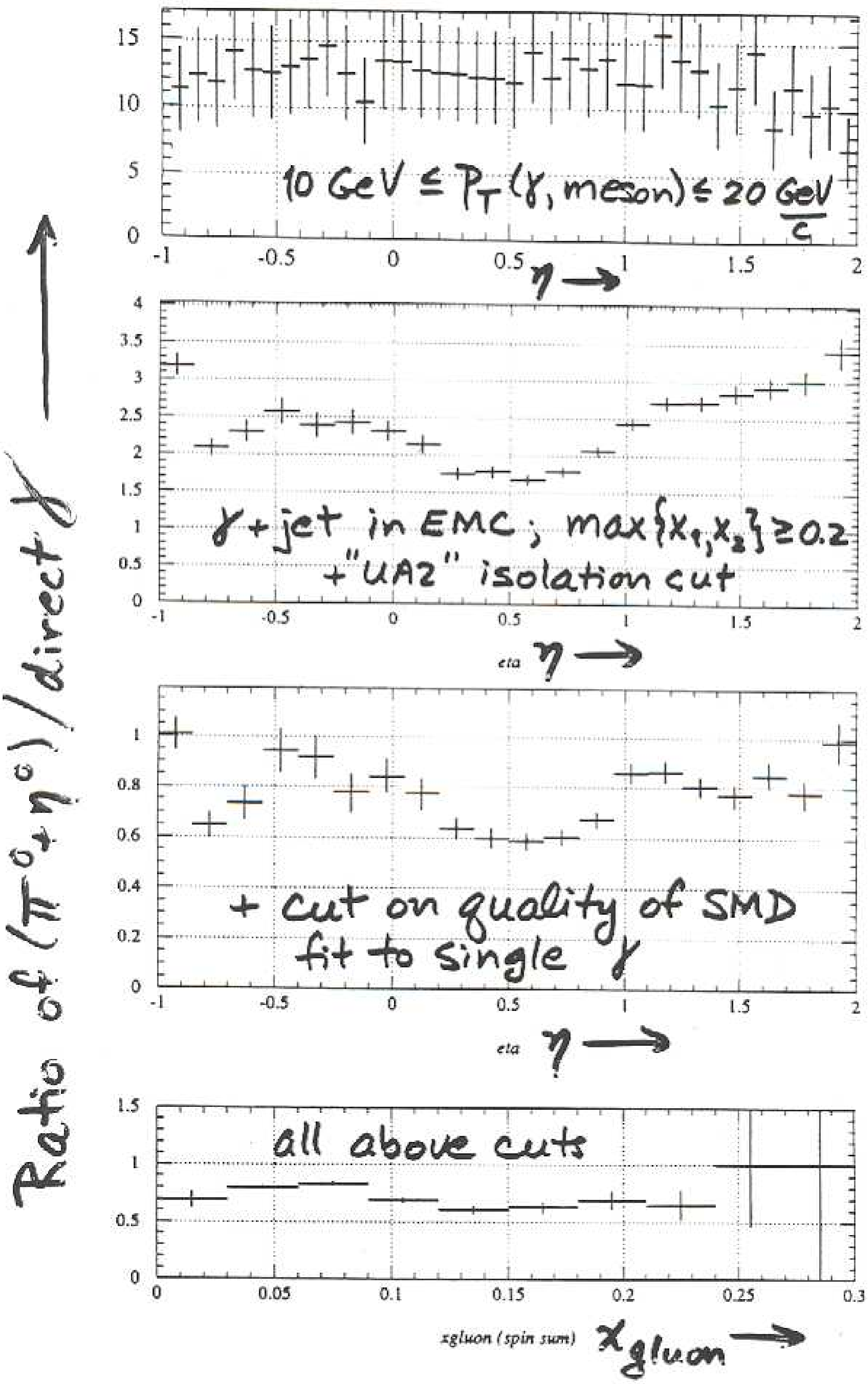
$q\bar{q} \rightarrow \gamma g$
$x_g \leftrightarrow x_q$
$\cos\theta^*$ resol'n

all tend to reduce $\epsilon_{LL}^{meas.}$!

k_T-smearing

Effects ≈ 0 at $x_g < 0.1$, where get largest contrib'ns to $\int_0^1 \Delta G(x)$

$\sqrt{s} = 200$ GeV



π^0/η^0 Background Subtraction Analysis:

For each x_g^{recon} bin, measure:

N, A_{LL} for SMD pass & SMD fail samples

+ use simulations, tuned to fit $\frac{N_{pass}}{N_{fail}}$ (SMD cut), to predict*:

P_π = prob. that meson passes SMD cut $\simeq 0.2$

$$\Rightarrow \boxed{A_{LL}^{\gamma} = A_{LL}^{pass} + \frac{(A_{LL}^{pass} - A_{LL}^{fail})}{\left[\left(\frac{N_{pass}}{N_{fail}}\right)\left(\frac{1}{P_\pi} - 1\right) - 1\right]}}$$

Simulation results then $\Rightarrow$

$$\sigma_{A_{LL}^{\gamma}} \simeq \left\{ 2.2\, \sigma^2_{A_{LL_\gamma}^{simul.stat.}} + 25 A^2_{LL,\gamma}\, \sigma^2_{P_\pi} \right\}^{1/2}$$

Assuming $\sigma_{P_\pi} \simeq \pm .03$ ($\Rightarrow$ 15% error in P_π)

$\Rightarrow$ increase simulated stat. errors by factor $\simeq$ 1.5 – 2.0 to account for bkgd. subt. uncertainty

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*P_π can also be constrained independently via preshower conversion probabilities