p-p physics from PHENIX forward upgrade

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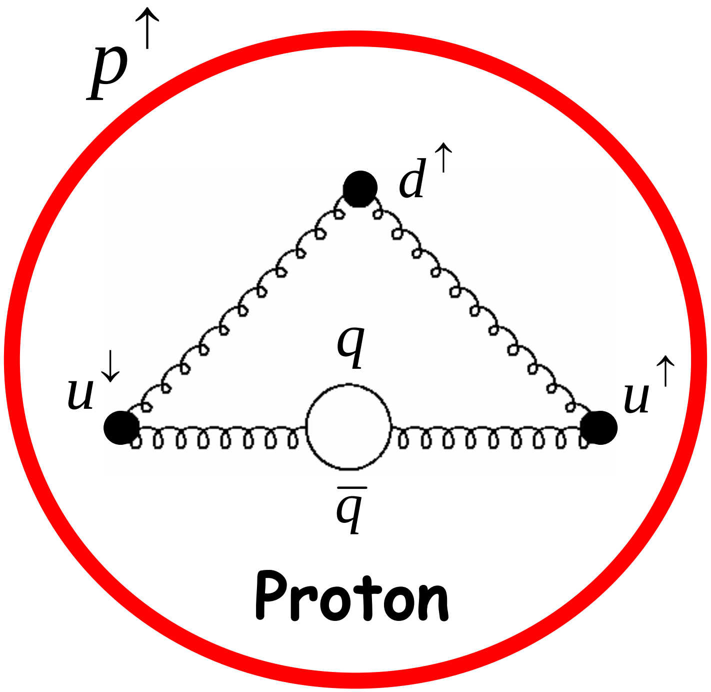
Proton Spin Structure

Naive parton model: valance quark are responsible for proton spin

$\Delta f(x) = f^{\uparrow}(x) - f^{\downarrow}(x)$, where $f^{\uparrow}(x)$ and $f^{\downarrow}(x)$ are PDF with spin parallel and anti-parallel to the proton spin.



$$\Delta\Sigma = \Delta u + \Delta d + \Delta s \approx 0.2$$ (Spin crisis)

QCD: sea quark and gluons. Parton orbital angler momentum also contribute .

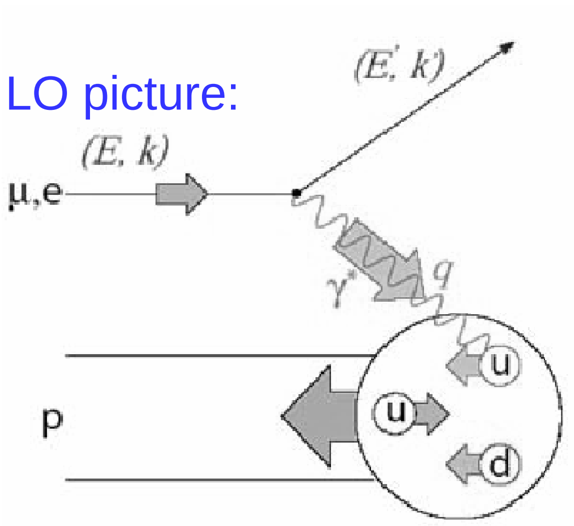
Proton spin:

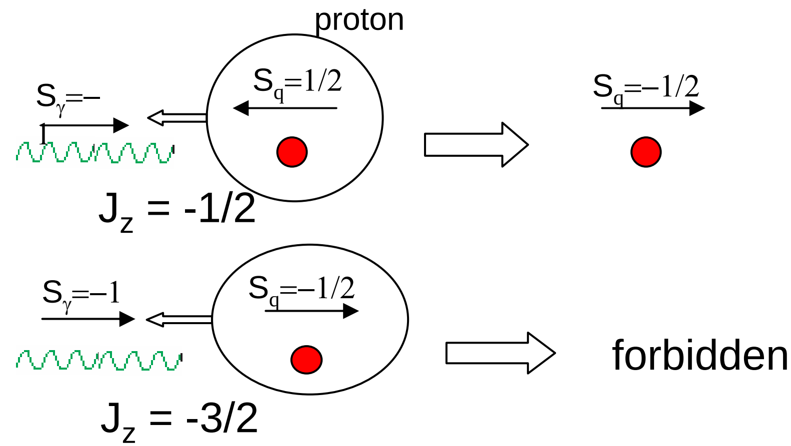
½ = ½ ΔΣ(quark)+ ΔG(gluon) + L_z

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s} \approx 0.2$$

Study Spin Structure in Deep Inelastic Scattering

LO picture:





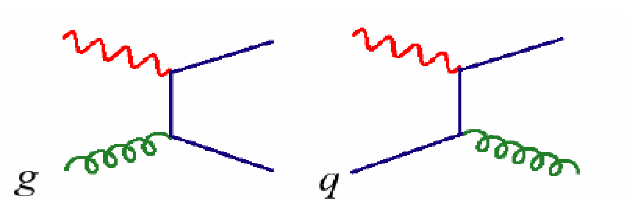
Un-polarized: $F_1(x) = \frac{1}{2}\sum_{i=u,d,s} e_i^2 f_i(x)$

polarized: $g_1(x) = \frac{1}{2}\sum_{i=u,d,s} e_i^2 \Delta f_i(x)$

$$\sigma^{\uparrow\downarrow} \propto \gamma^{\uparrow} P^{\downarrow} \propto \sum_{i=u,d,s} e_i^2 q^{\uparrow}$$

$$\sigma^{\uparrow\uparrow} \propto \gamma^{\uparrow} P^{\uparrow} \propto \sum_{i=u,d,s} e_i^2 q^{\downarrow}$$

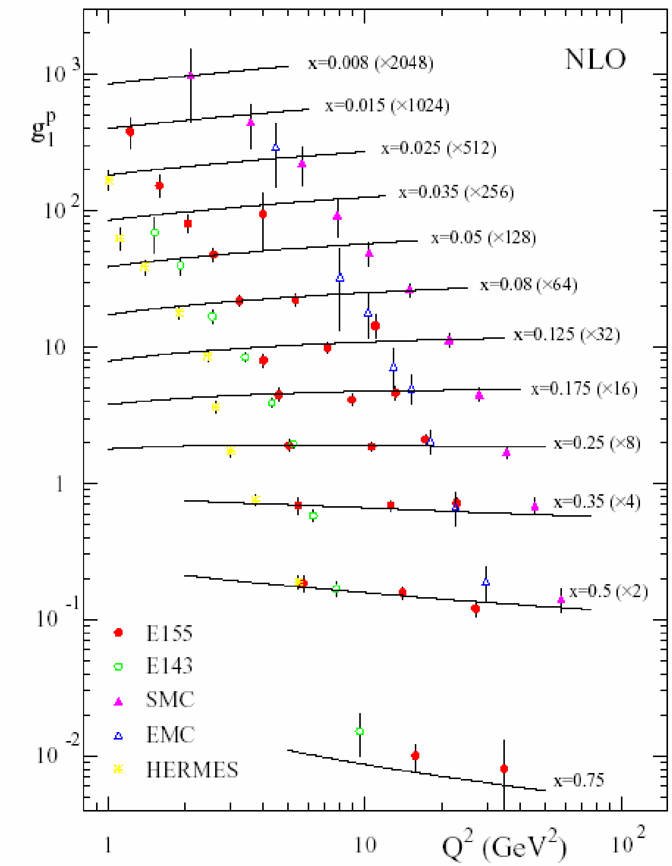
Gluon included in NLO:

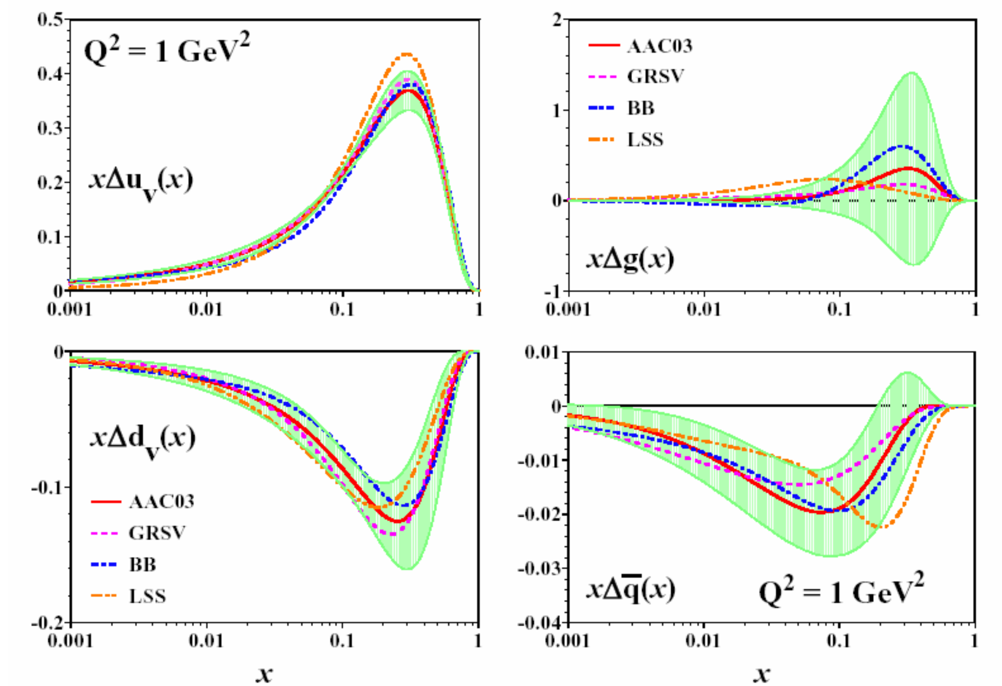


Experimental measurement:

$$A_{LL} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{\sum_{i=u,d,s} \Delta q_i(x)}{\sum_{i=u,d,s} q_i(x)} = \frac{g_1}{F_1} \equiv A_1$$

Current Measurement on Quark and Gluon spin





- **SLAC: E80, E130, E142, E143, E154, E155 (1978-2001)**
- **CERN: EMC, SMC, COMPASS (1988-2004)**
- **DESY: HERMES (1995-2004)**

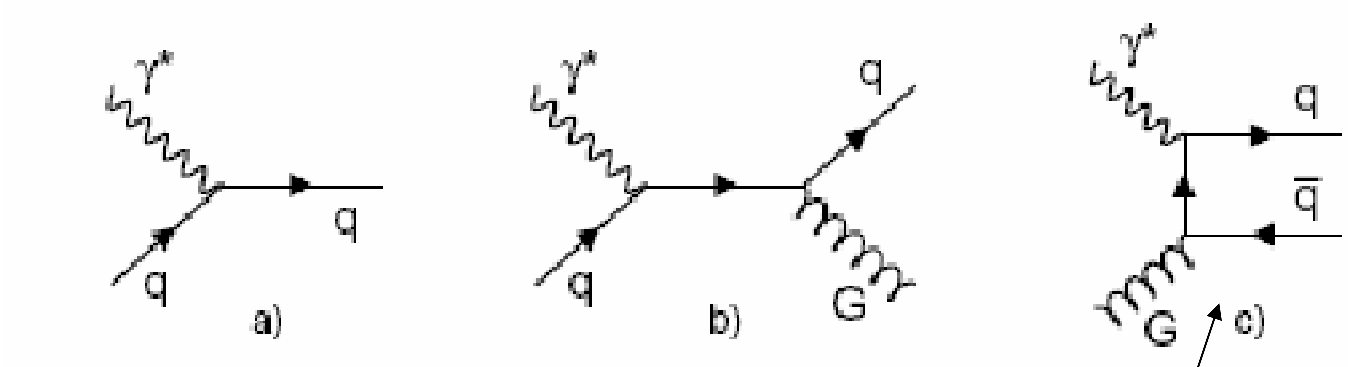
Quark spin : well constrained

Sea Quark spin : large uncertainty

Gluon spin: Unknown

Current DIS experiment for ΔG measurement through hadron pair production

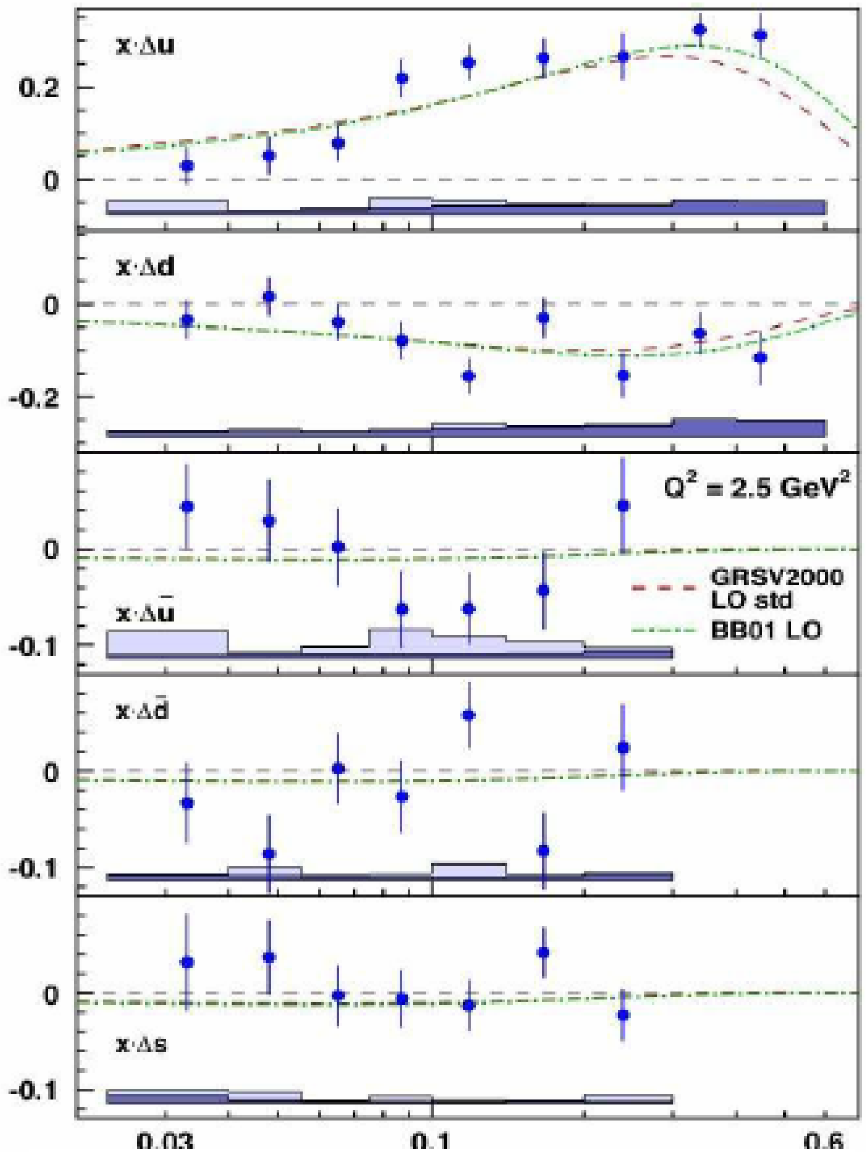
Contributions to the asymmetry measurement



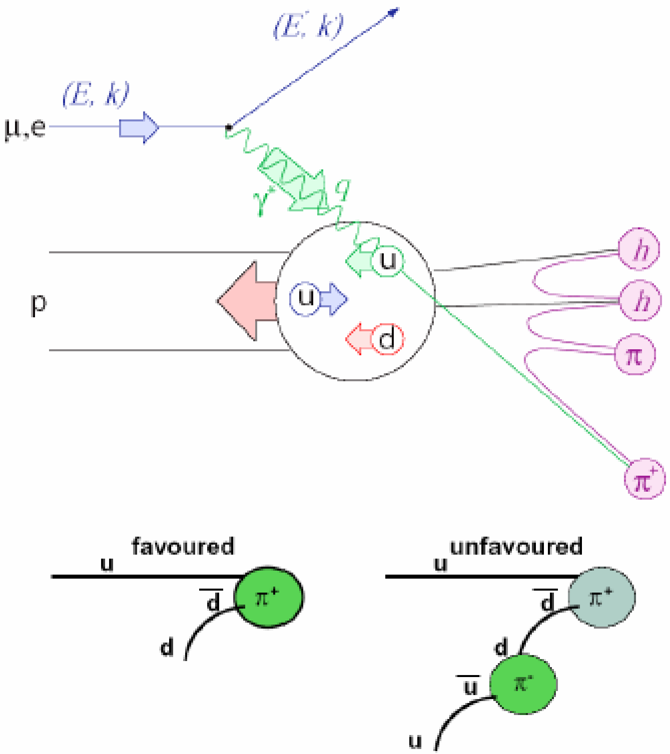
$$A_{LL} \approx a_{LL}^{\gamma q \to qg} \frac{\Delta q}{q} + a_{LL}^{\gamma g \to q\bar{q}} \frac{\Delta g}{g}$$

Relative low Q^2 and need long running time.

Measure quark spin of specific flavor through hadron tag



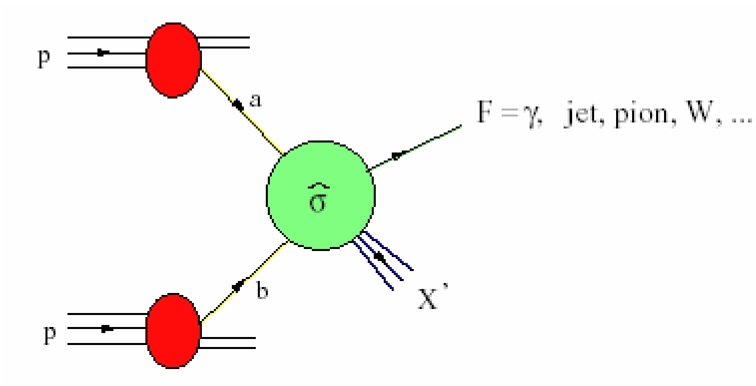
Hermes: Phys.Rev.Lett 92 (2004) 012005



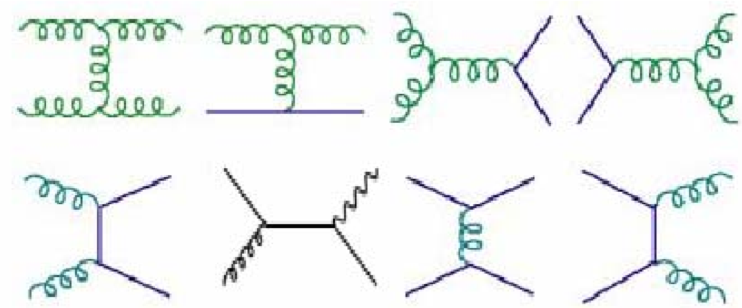
Q^2 is low

"Hadron taging" technique relies on knowledge of fragmentation functions

Study Spin Structure in polarized p-p collision



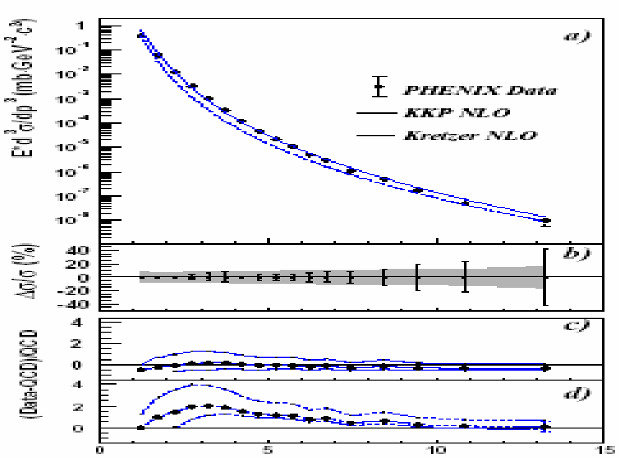
LO:

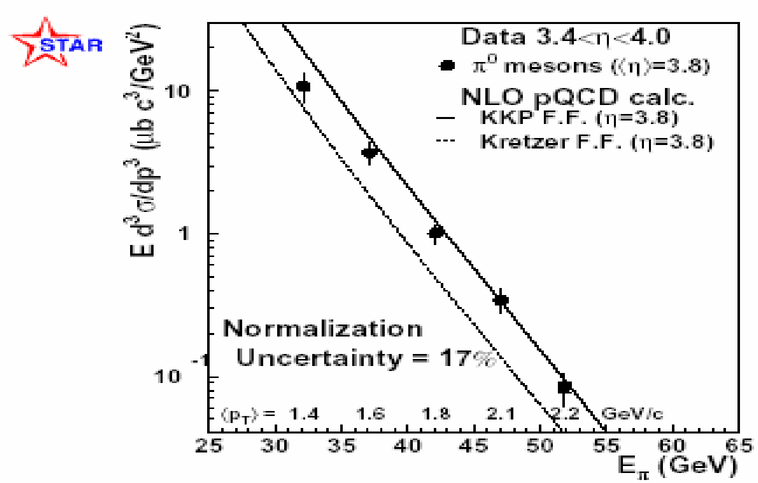


Many different channel to measure ΔG, e.g. prompt photon production:

$$A_{LL} = a_{LL}(qg \to q\gamma)\frac{\Delta g}{g}\frac{\sum_{i=u,d,s} e_i^2 \Delta f_i}{\sum_{i=u,d,s} e_i^2 f_i} = a_{LL}(qg \to q\gamma)\frac{\Delta g}{g} A_1$$

Solid theoretical support:





What PHENIX can Contribute

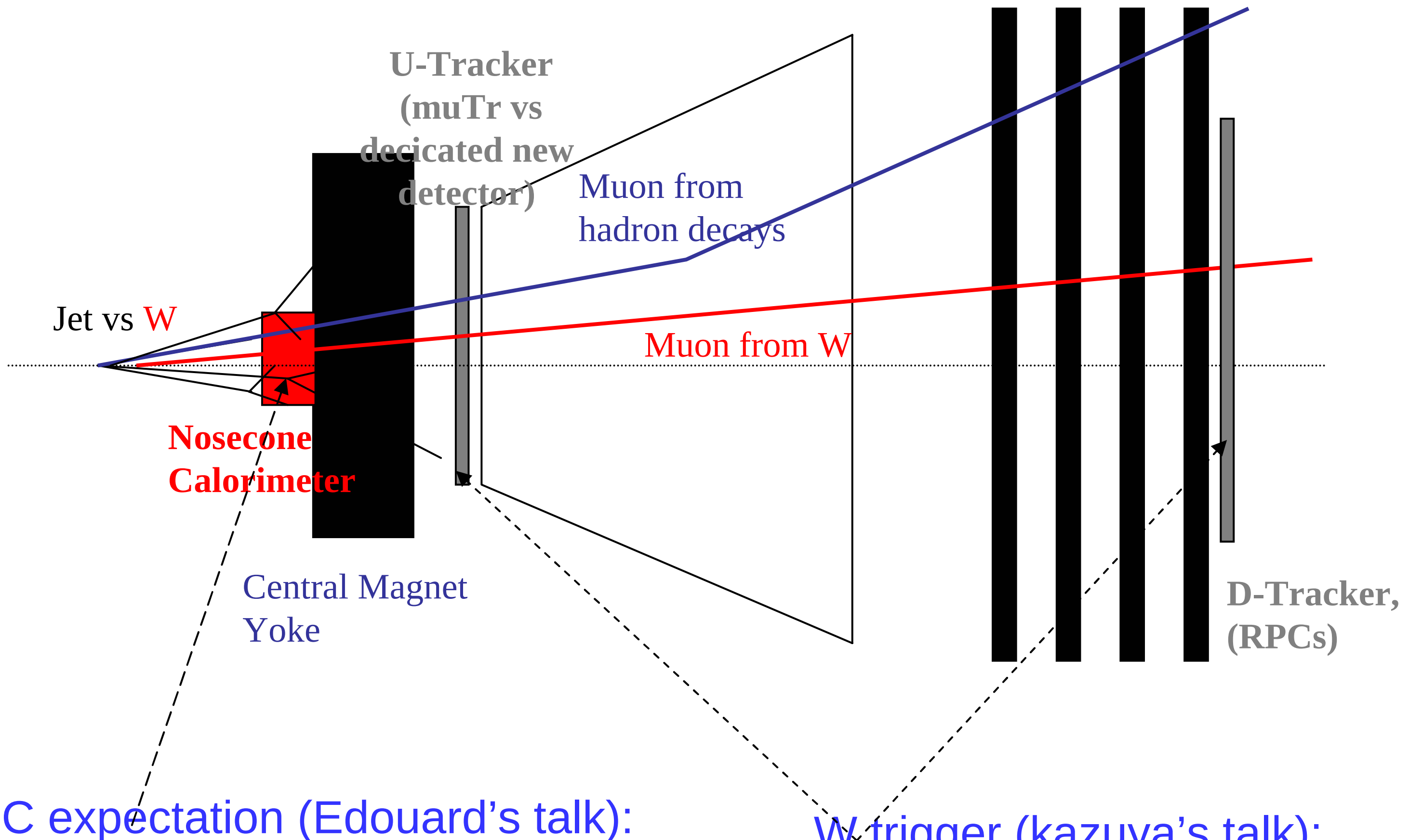
With current setup:

- A_{LL}(gg, gq->pi$^{0,+/-}$ +X) in central arm. x>0.03, Q^2~10-10^2
- Prompt photon in central arm. x>0.03, Q^2~10^2-10^3
- Heavy flavor via e^+e^- and u^+u^- or e-u (might need vertex detector), x>0.01, Q^2~10

With forward upgrade detector:

- W production: flavor decomposition. X>0.06, large $Q^2=M_w^2=6400GeV^2$.
  - low rate, need to upgrade the trigger.
- Gamma-jet: nosecone calorimeter, broadly extend the dynamic range.

Schematic of μ-spectrometer upgrade



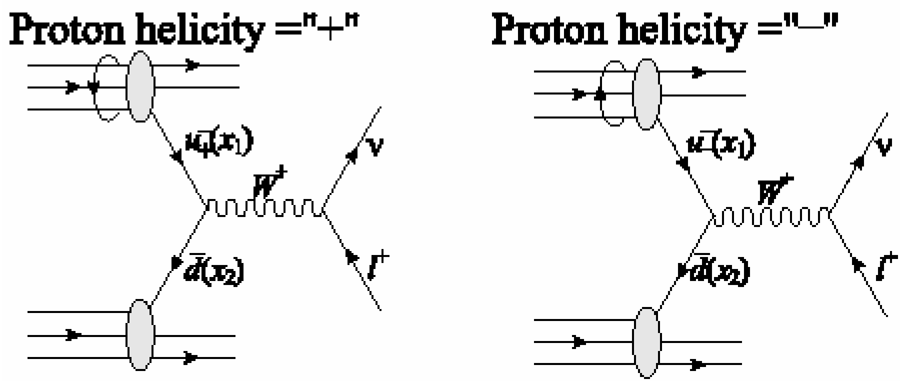
NCC expectation (Edouard's talk):

- γ/π^0 separation: 20GeV
- $\Delta\phi = 2\pi$
- $|\Delta\eta|$=1.0-3.0

W trigger (kazuya's talk):

- LUT + angle cut to select high momentum muons
- Timing cut to reject beam background

Quark flavor separation via W production



W is produced through V-A process, helicity of quark is fixed:

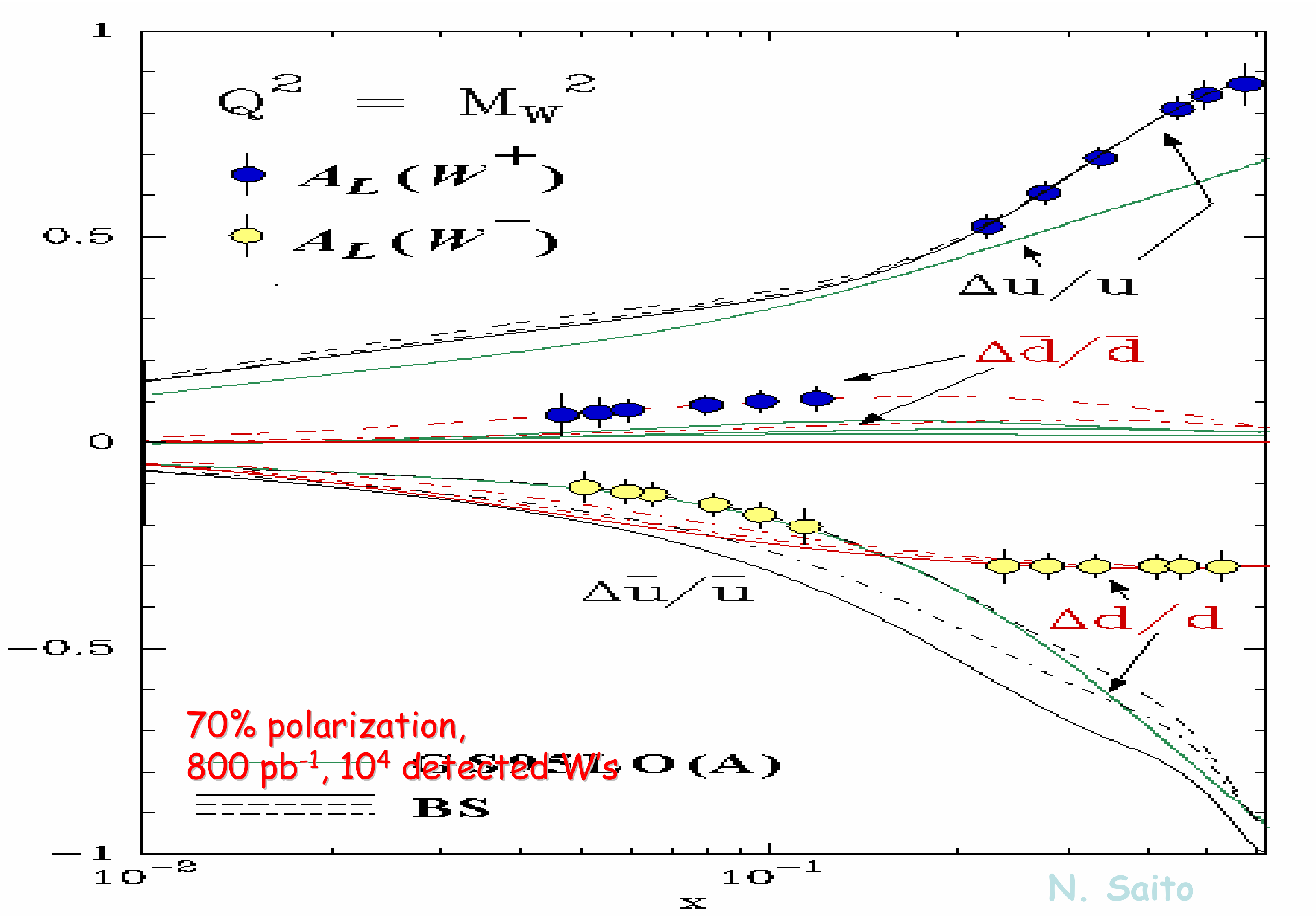
$$A_L^{W^+}(y) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

$$A_L(W^+) = -\frac{\Delta u(x_a)}{u(x_a)}$$ *,When* $X_a >> X_b$

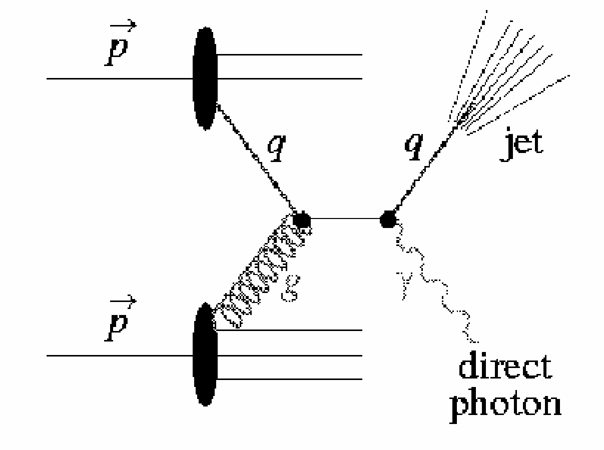
$$A_L(W^+) = -\frac{\Delta\bar{d}(x_b)}{\bar{d}(x_b)}$$ *,When* $X_b >> X_a$

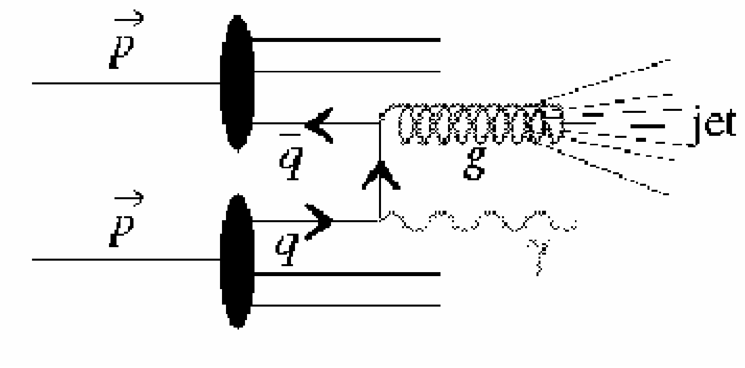
$A_L(W^-)$ access Δubar and Δd

Expected Measurement Significance With One Year Full Luminosity $\sqrt{s}=500GeV$ p-p running at RHIC I



ΔG measurement from gamma-jet





~90% of the production are from gluon compton scattering

$$X_1 = \left(\frac{2P_T}{\sqrt{s}}\right)\left(\frac{e^{\eta_\gamma} + e^{\eta_{jet}}}{2}\right)$$

$$X_2 = \left(\frac{2P_T}{\sqrt{s}}\right)\left(\frac{e^{-\eta_\gamma} + e^{-\eta_{jet}}}{2}\right)$$

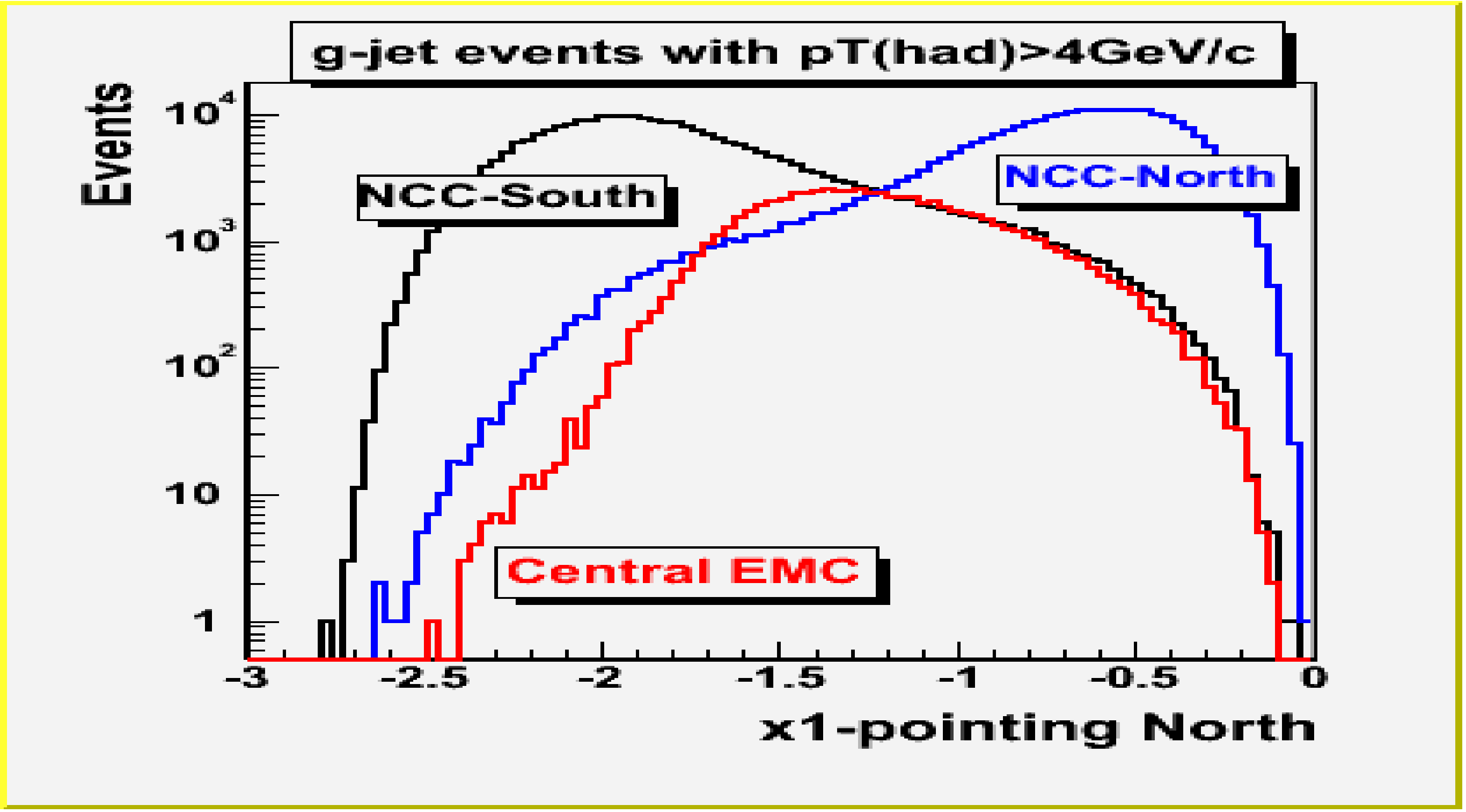
$$Q^2 = 4p_T{}^2 \cosh^2\left(\frac{y_3 - y_4}{2}\right) \sim 4p_T{}^2 \cosh^2\left(\frac{\eta_3 - \eta_4}{2}\right)$$

Assuming minimum photon pT=5GeV

- Central arm only(η=0): $X_1 \sim X_2 \sim 0.05$, $Q^2 \sim 10^2 - 10^3$
- Central arm + forward: $X_2 \sim 0.025$, $X_1 \sim 0.52$, $Q^2 \sim 10^3$
- Both in forward(η=3): $X_2 \sim 0.0025$, $X_1 \sim 1.0$, $Q^2 \sim 10^2 - 10^3$

Significantly increase dynamic range

pythia simulation of gamma-jet production



Details see talk from E. Kistenev

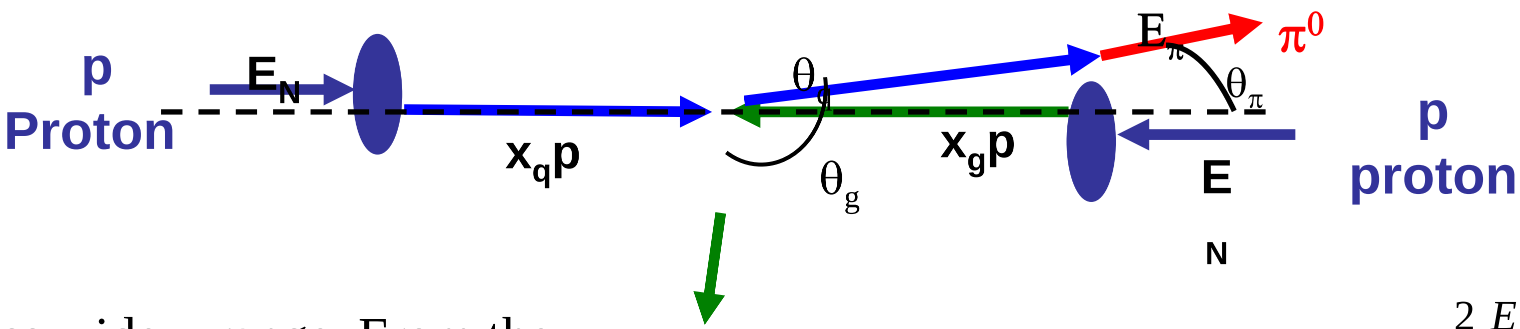
Summary

PHENIX forward upgrade should be able to :

- dramatically extend the dynamic range on ΔG measurement through gamma-jet productionin Nosecone calorimeter.
- Measure spin of different quark flavors at large Q^2 which is complementary to the DIS measurement.

backup

Forward π^0 production



- Access wide x range. From the calculation for eta=3.8. For very high energy pi0. E>30GeV.
  - **0.3 < x_q < 0.7**
  - **0.001 < x_g < 0.1**

$$Q^2 \sim p_T^2$$

$$\sqrt{s} = 2E_N$$

$$\eta = -\ln(\tan(\frac{\theta}{2}))$$

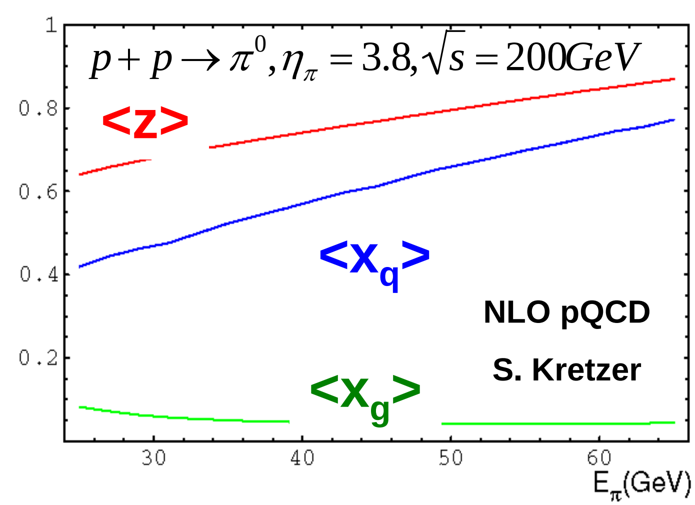
$$x_q \approx x_F / \langle z \rangle$$

$$x_F \approx \frac{2E_\pi}{\sqrt{s}}$$

$$z = \frac{E_\pi}{E_q}$$

$$x_g \approx \frac{p_T}{\sqrt{s}} e^{-\eta g}$$

•NCC can not reach it because the gamma/pi0 separation is about 15GeV. Extrapolation from the right plot shows, x_q and x_g ~0.1 at 15GeV. At Egamma>30GeV, where pT~15GeV, signal/background ~ 20% assuming no rapidity dependence on signal/background. Therefore one can not assume the energy is not from direct photon.



Past DIS experiment

- Past experiments: Deep Inelastic Scattering (DIS)

  Fixed target experiments, probe nucleon structure using virtual photons

  - **EMC, SMC at CERN:**
    -- polarized muon beams (~190 GeV/c)
    → on polarized solid state targets
  - **SLAC(E80,E130,E142,E143,E154,E155,X)**
    -- polarized electron beams (~10→49 GeV/c)
    → on polarized solid/gaseous targets

  } Spin crisis
  E-J, Bj Sum rules

  - **HERMES at DESY**
    -- polarized electron/positron beam (~27 GeV/c)
    → on polarized gas/jet targets

  } Semi-inclusive