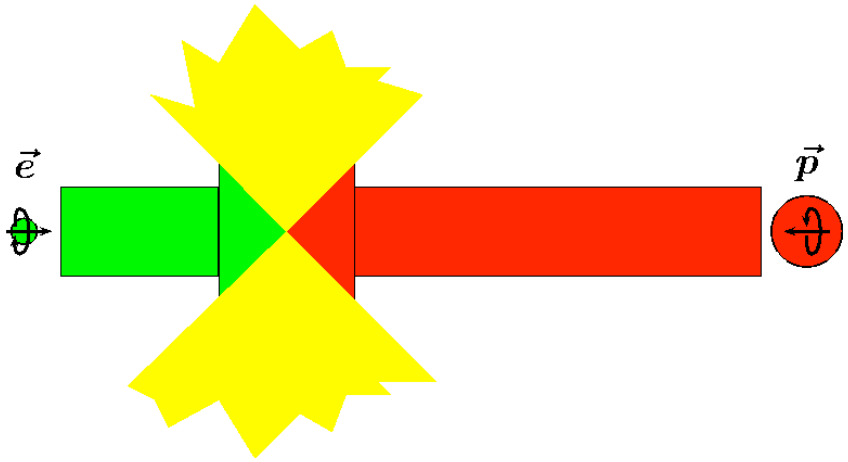
Physics With Polarized beams at eRHIC



Abhay Deshpande

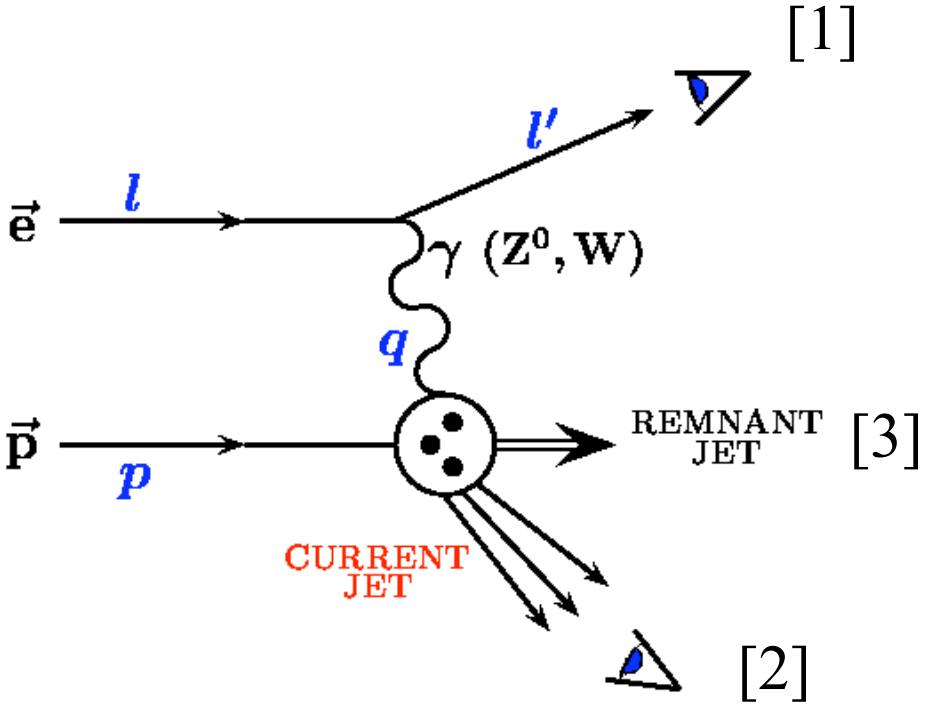
Stony Brook University & RIKEN BNL Research Center

BNL Physics Advisory Committee Meeting

March 23, 2006

STONY BROOK
STATE UNIVERSITY OF NEW YORK

Deep Inelastic Scattering



$$Q^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2p \cdot q}$$

$$y = \frac{p \cdot q}{p \cdot l}$$

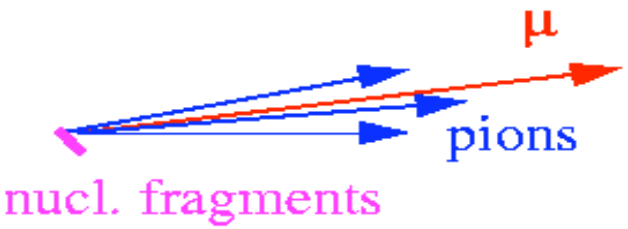
$$s = 4E_e E_p$$

$$W = (q + p)^2$$

- Observe scattered electron [1] inclusive measurement
- Observe [1] + current jet [2] semi-inclusive measurement
- Observe [1] + [2] + remnant jet [3] exclusive measurement
- Luminosity requirements go up as we go from [1] --> [2] --> [3]
- **Exclusive measurements put demanding requirement on detectors, interaction region and their integration**

Why Collider In Future?

- Polarized DIS in past only in fixed target mode, also no e-A collider in the past either!
- Collider geometry--> distinct advantages (HERA Experience)



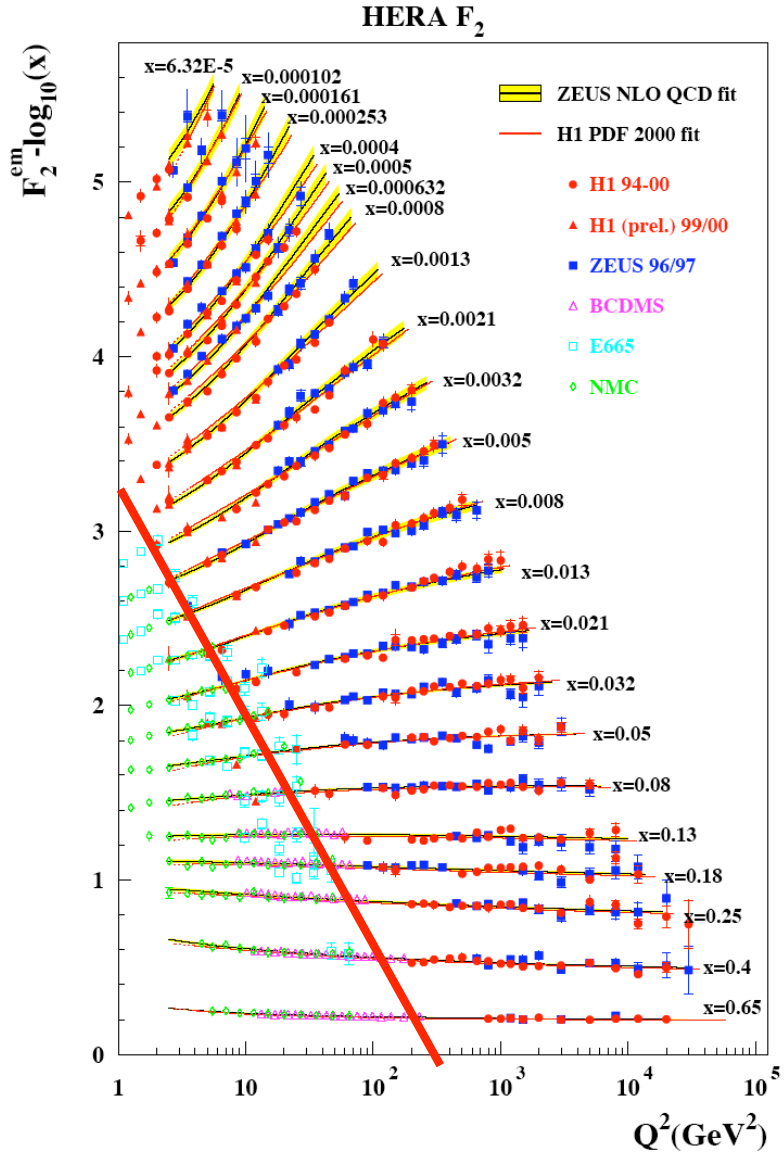
Fixed target

Collider

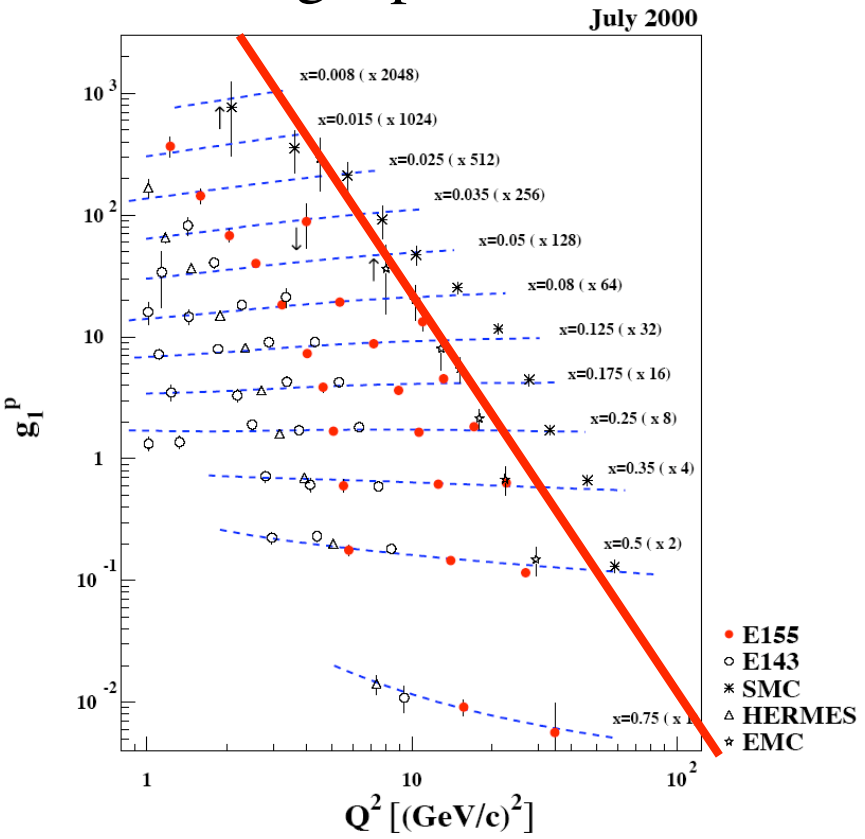
- Better angular resolution between beam and target fragments
  - Better separation of electromagnetic probe
  - Recognition of rapidity gap events (diffractive physics at HERA)
  - Better measurement of nuclear fragments
- Higher Center of Mass energies reachable
- **Tricky issues: integration of interaction region and detector**

Our Knowledge of Structure Functions

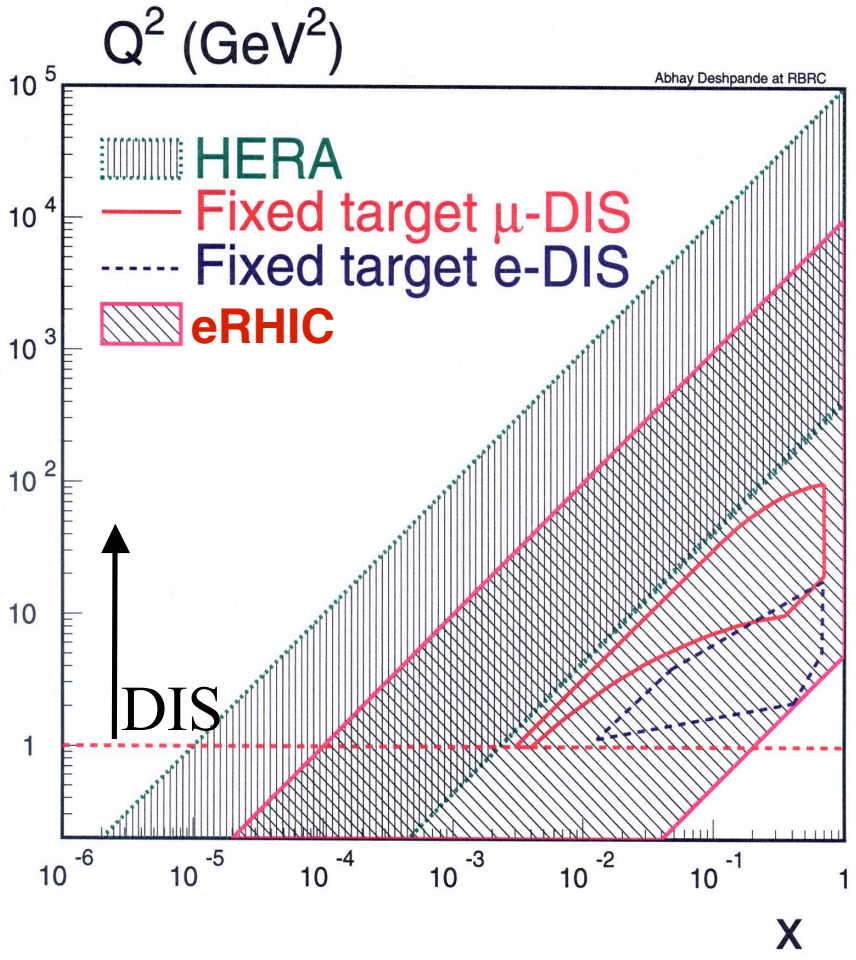
HERA un-polarizd DIS



Fixed target polarized DIS



eRHIC vs. Other DIS Facilities



- **New kinematic region**
- E_e = 10 GeV (~5-12 GeV variable)
- E_p = 250 GeV (~50-250 GeV variable)
- E_A= 100 GeV
- **Sqrt[S_{ep}] = 30-100 GeV**
- Kinematic reach of eRHIC:
  - X = 10^{-4} --> 0.7 (Q^2 > 1 GeV^2)
  - Q^2 = 0 --> 10^4 GeV^2
- Polarization of e,p and light ion beams at least ~ 70% or better
- Heavy ions of ALL species at RHIC
  - High gluonic densities
- Luminosity Goal:
  - **L(ep) ~$10^{33\text{-}34}$ cm^{-2} sec^{-1}**

Accelerator details in Vadim Ptitsyn's Talk

Scientific Frontiers Open to eRHIC

- **Nucleon Spin structure**
  - Polarized quark and gluon distributions **(LOWEST POSSIBLE X)**
    - Longitudinal spin structure
    - Transverse spin structure
  - Correlations between partons
    - Exclusive processes --> Generalized Parton Distributions
  - Fundamental tests of in QCD

This talk

- **Un-polarized Nucleon Structure**
  - Understanding confinement with low x/lowQ^2 measurements
  - Un-polarized quark and gluon distributions
- **Nuclear Structure, role of partons in nuclei**
  - Confinement in nuclei through comparison e-p/e-A scattering
- **Hadronization in nucleons and nuclei & effect of nuclear media**
  - How do knocked off partons evolve in to colorless hadrons
- **Partonic matter under extreme conditions**
  - For various A, compare e-p/e-A

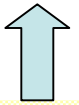
Raju Venugopalan's talk

Polarized DIS at eRHIC

- Spin structure functions g_1 (p,n) at **low x**, high precision [1]
  -- g_1(p-n): Bjorken Spin sum rule 1-2% accuracy
- **Polarized gluon distribution function $\Delta G(x,Q^2)$*** **[1,2]**
  -- at least three different experimental methods
- Precision measurement of $\alpha_S(Q2)$ from g_1 scaling violations [1]
- Spin structure of the photon from photo-production [2]
- Electroweak s. f. g_5 via virtual **$W^{+/-}$ production*** **(heavy quarks)** **[2]**
- Deeply Virtual Compton Scattering (DVCS), exclusive VM production
  >> Generalized Parton Distributions (GPDs) [3]
- **Transverse Spin Phenomena*** **[2,3]**
- Drell-Hearn-Gerasimov spin sum rule test at high ν [1]
- Flavor separation of PDFs through semi-inclusive DIS [2]
- Target/Current fragmentation studies [2,3]
- *… and many more ……*

***Also being pursued at RHIC Spin Now.**

[1] --> inclusive, [2]--> semi-inclusive
[3] --> exclusive measurements



Luminosity Requirement

A Detector for eRHIC
A 4π Detector

- Scattered electrons to measure kinematics of DIS
- Scattered electrons at small (~zero degrees) to tag photo production
- Central hadronic final state for kinematics, jet measurements, quark flavor tagging, fragmentation studies, particle ID
- Central hard photon and particle/vector detection (DVCS)
- ~Zero angle photon measurement to control radiative corrections and in e-A physics to tag nuclear de-excitations
- Missing E_T for neutrino final states (W decays)
- Forward tagging for 1) nuclear fragments, 2) diffractive physics

- ***Lot of experience from HERA… use it!***
  - What was good about HERA detectors?
  - What was bad? How/What can we improve?

- eRHIC will provide: 1) Variable beam energies 2) different hadronic species, some of them polarization, 3) high luminosity

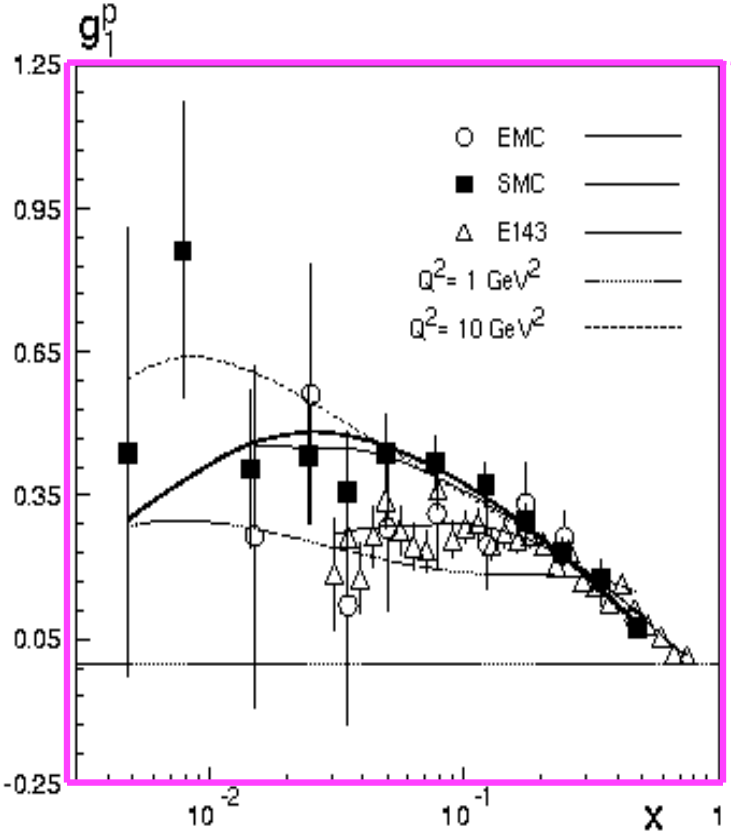
Discussion in Bernd Surrorw's talk

A.D. & V. Hughes

Low x Proton Spin Structure

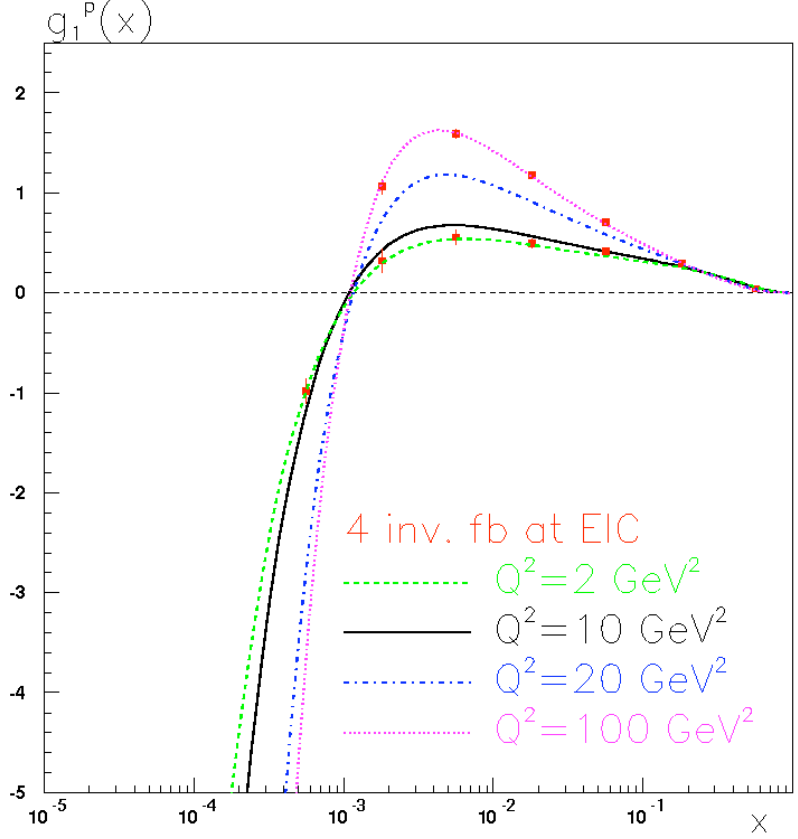
Fixed target experiments

1989 – 1999 Data



eRHIC 250 x 10 GeV

Luminosity = ~85 inv. pb/day

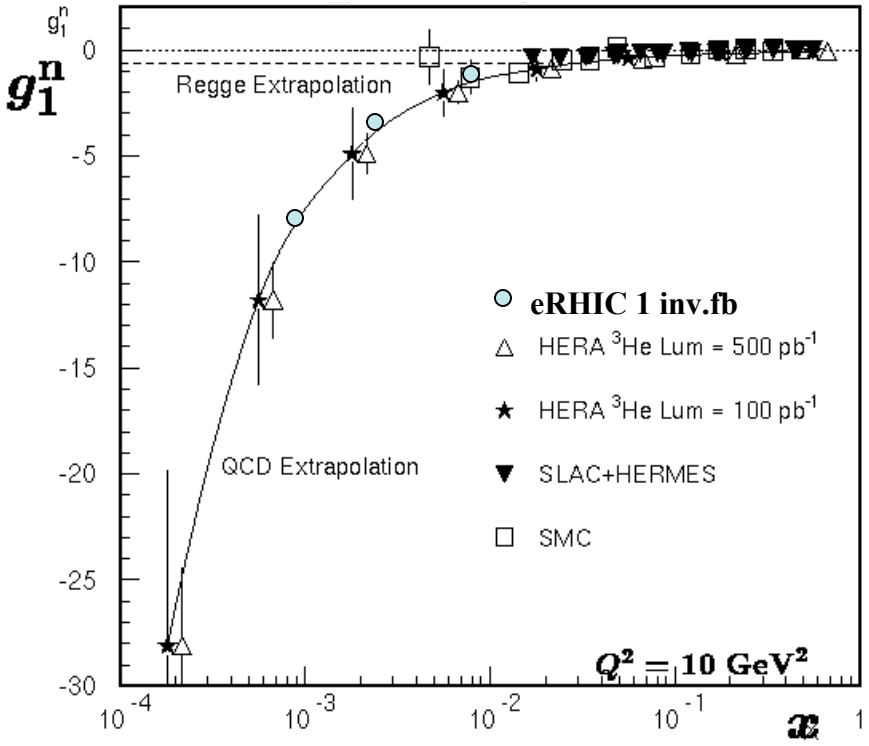


Studies included statistical error & detector smearing to confirm that asymmetries are measurable. No present or future approved experiment will be able to make this measurement

$\Rightarrow$ Bjorken sumrule $\int_0^1 dx(g_1^p - g_1^n)(x, Q^2)$ ~ 1-2% precision at eRHIC

A.D. & V. W. Hughes
G. Igo, T. Sloan

Spin Structure of Neutron at Low x



- With polarized He
- ~ 2 weeks of data at EIC
- Compared with SMC(past) & possible HERA data
- **If combined with g1 of proton results in Bjorken sum rule test of better than 1-2% within a couple of months of running**

Helium beams **can be stored & manipulated** in RHIC with **existing magnets**
Intense enough He beams & polarimetry need to be developed.
Both efforts need to start now!

Bj Sum Rule & Determination of α_s

$\alpha_s(M_Z)$ has been determined from Bj spin sum rule by many groups:

1. J. Ellis & M. Karliner, Phys. Lett. B341, 387 (1995)
2. G. Altarelli et al., Nucl. Phys. B496, 337 (1997)
3. B. Adeva et al. SMC Collaboration, Phys. Rev. D58 (1998) 112002
4. …….

Values range from 0.114-119 with uncertainties:

+/- 0.004 (experimental)

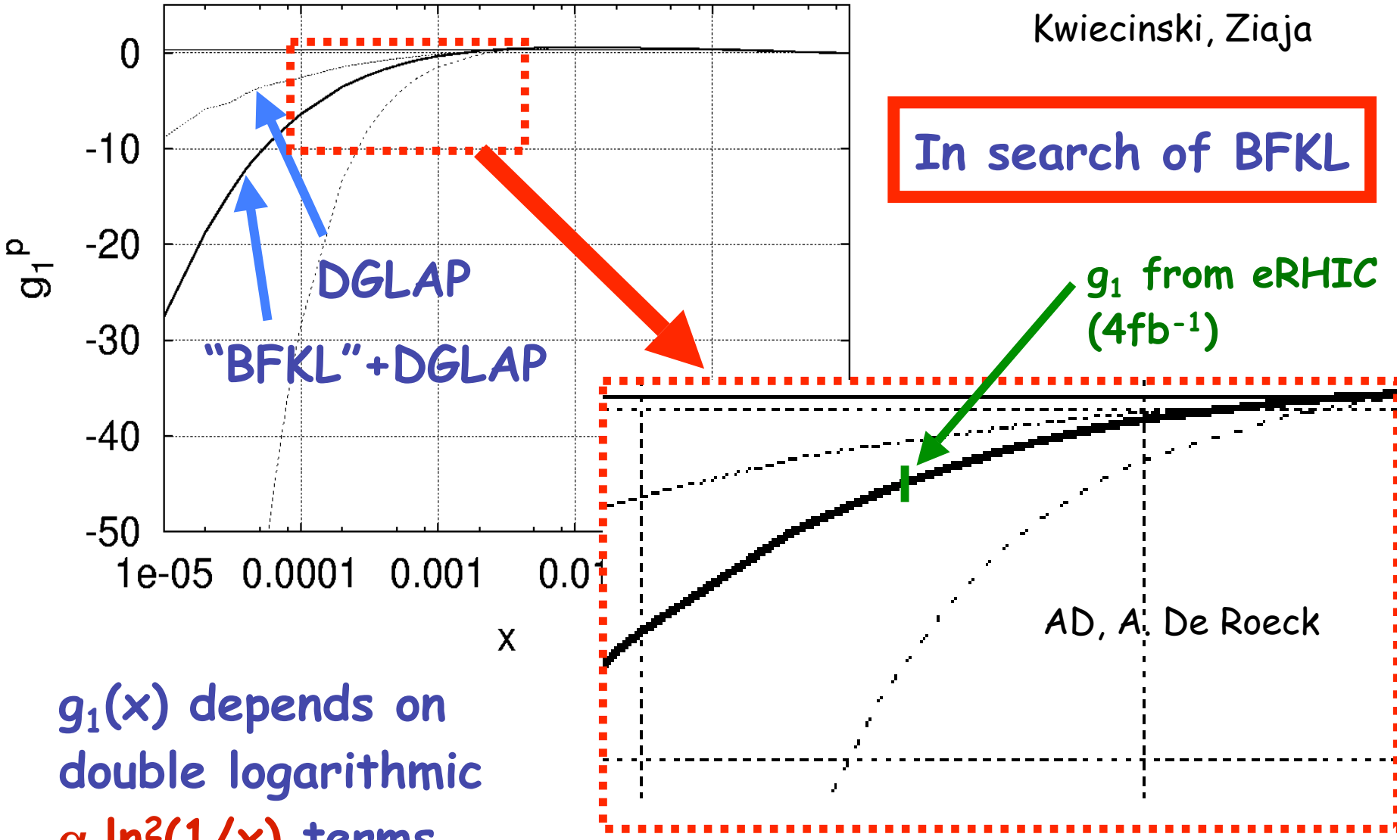
+/- 0.010 (theory/ low x extrapolation)

Determining power comes from the data collected at different Q^2 and x, and using the evolution of the difference in the spin structure functions of proton & neutron

Particle Data Book (2002, 2004), Extended version:

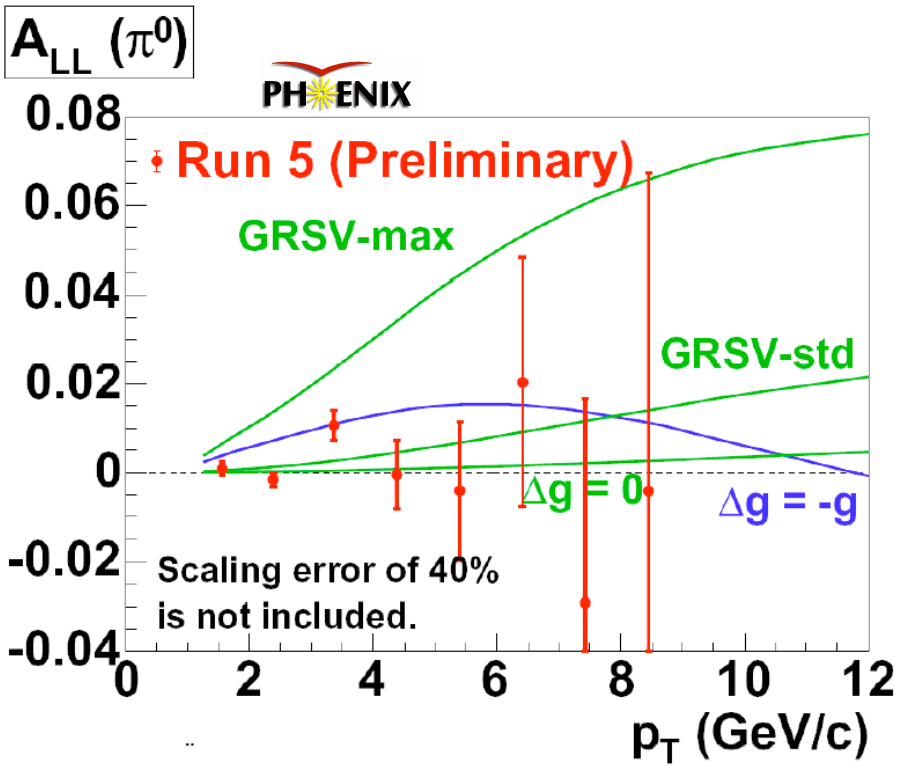
"Theoretically, this sum rule is better for determining α_s because perturbative QCD result is known to higher order ($o(\alpha_s^4)$), and these terms are important at low Q^2……. **Should data at lower x become available**, so that the low x extrapolation is more tightly constrained, the ***Bj sum rule method could give the best determination of α_s***"

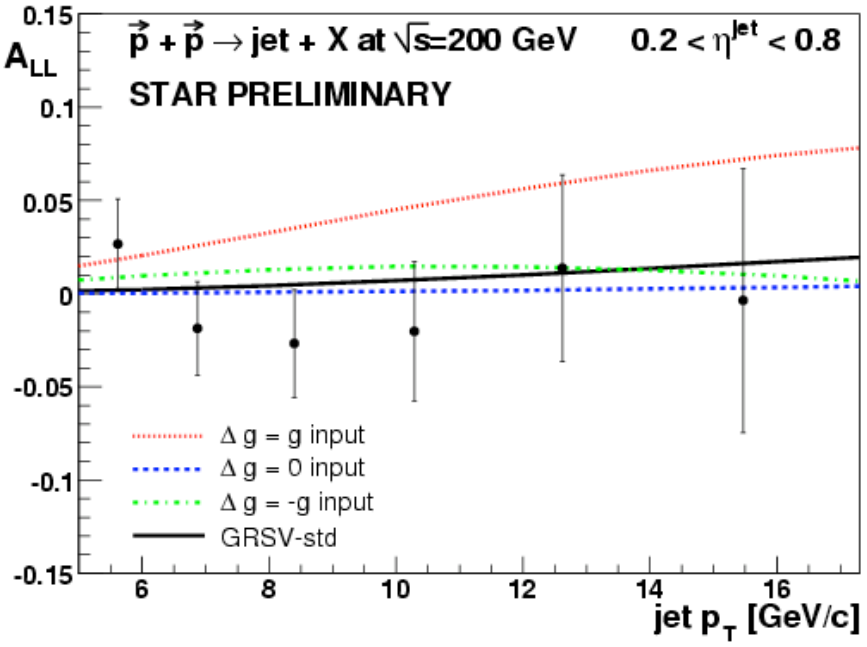
Precision Low-x Measurement



$g_1(x)$ depends on double logarithmic $\alpha_s \ln^2(1/x)$ terms

New Data from RHIC Spin:

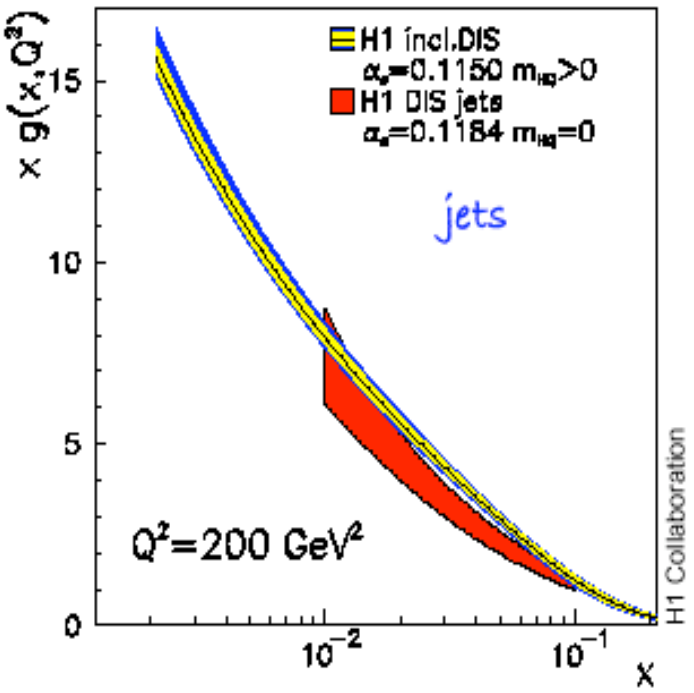


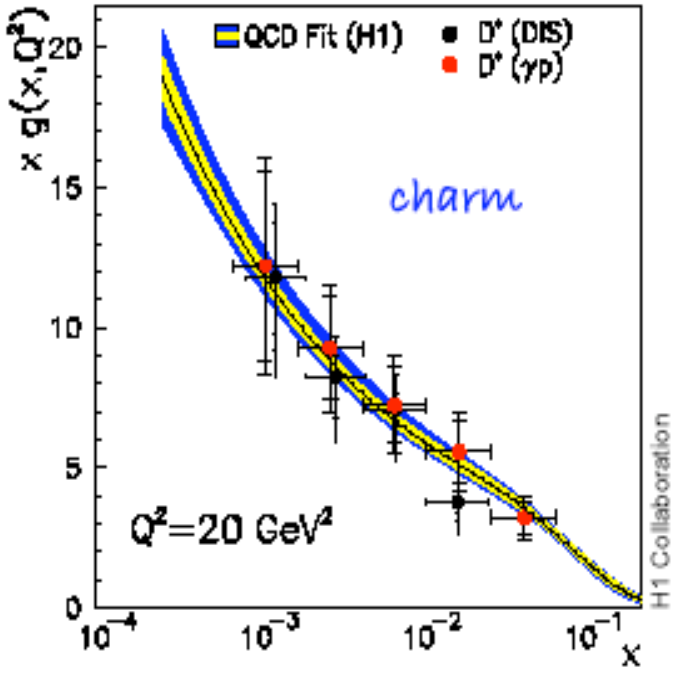


In the approximate x-range (0.05-0.2) covered by experiments, ΔG seems to be small

Focused direct and indirect ΔG measurements at low x and high precision are of *even* greater importance

Unpolarised gluon at HERA





Various ways for direct gluon measurements

After ~10-14 years of HERA running

Uncertainties in ΔG From Scaling Violations Superior to other 'direct' methods

Methods are complementary and great for independent systematic checks

Polarized Gluon Measurement at eRHIC

Fixed target polarized DIS experiments established the smallness of quark contribution to nucleon spin

& started making measurements of the Polarized Gluon Distribution

- **However, measurement methods/techniques inadequate:**
  - For g_1 scaling violations, the x-Q^2 range was extremely limited
  - For other "direct measurements" of gluon, the **p_Ts of particle/jets too low** to be interpreted cleanly in pQCD

- ***eRHIC overcomes BOTH THESE BARRIERS & extends the presently pursued RHIC Spin measurements towards precision frontier***
  - **Deep Inelastic Scattering kinematics at eRHIC**
    - Scaling violations (pQCD analysis at NLO) of g_1
    - (2+1) jet production in photon-gluon-fusion process
    - 2-high pT hadron production in PGF
  - **Photo-production (real photon) kinematics at eRHIC**
    - Single and di-jet production in PGF
    - Open charm production in PGF

ΔG: Fits of $g_1(x,Q^2)$

Constrain better the shape and the first moment

STEP 1

ΔG determined from the Scaling violations of g1

SMC Published 1998: First Moment of $\Delta G(x)$

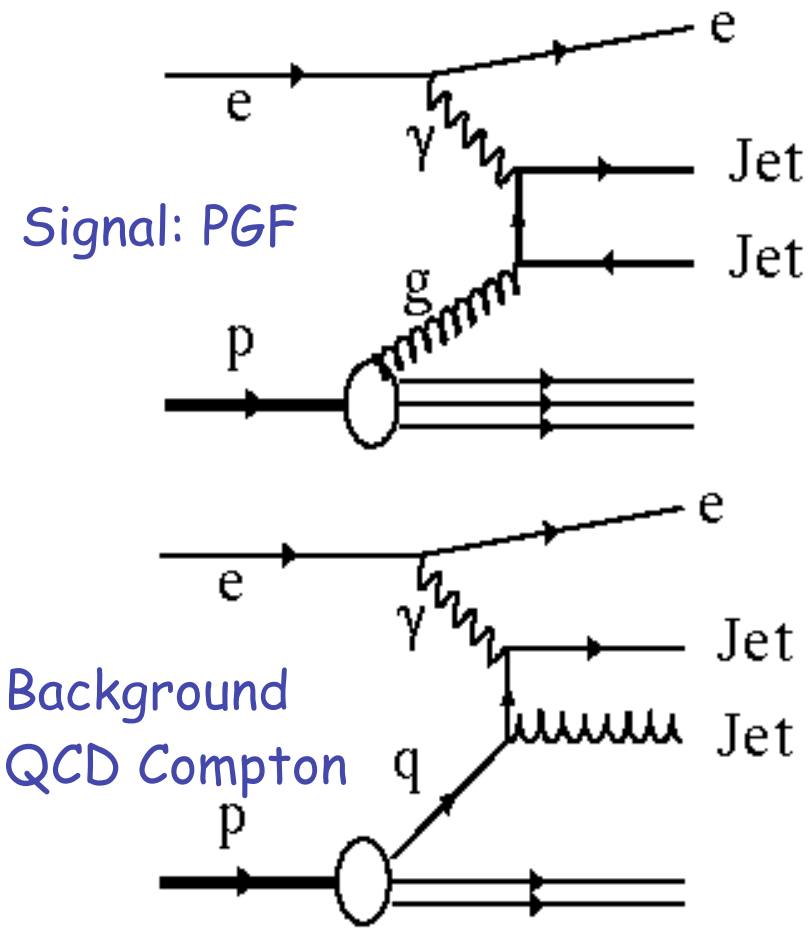
$$\int \Delta G(x)dx = 1.0 \pm 1.0\ (\text{stat}) \pm 0.4\ (\text{exp.syst}) \pm 1.4\ (\text{theory})$$

-- one week eRHIC reduces statistical & theory errors by ~3

-- low x (~10^{-4})--> strong coupling, functional form at low -x, renorm. & fact. scales

Photon Gluon Fusion at eRHIC

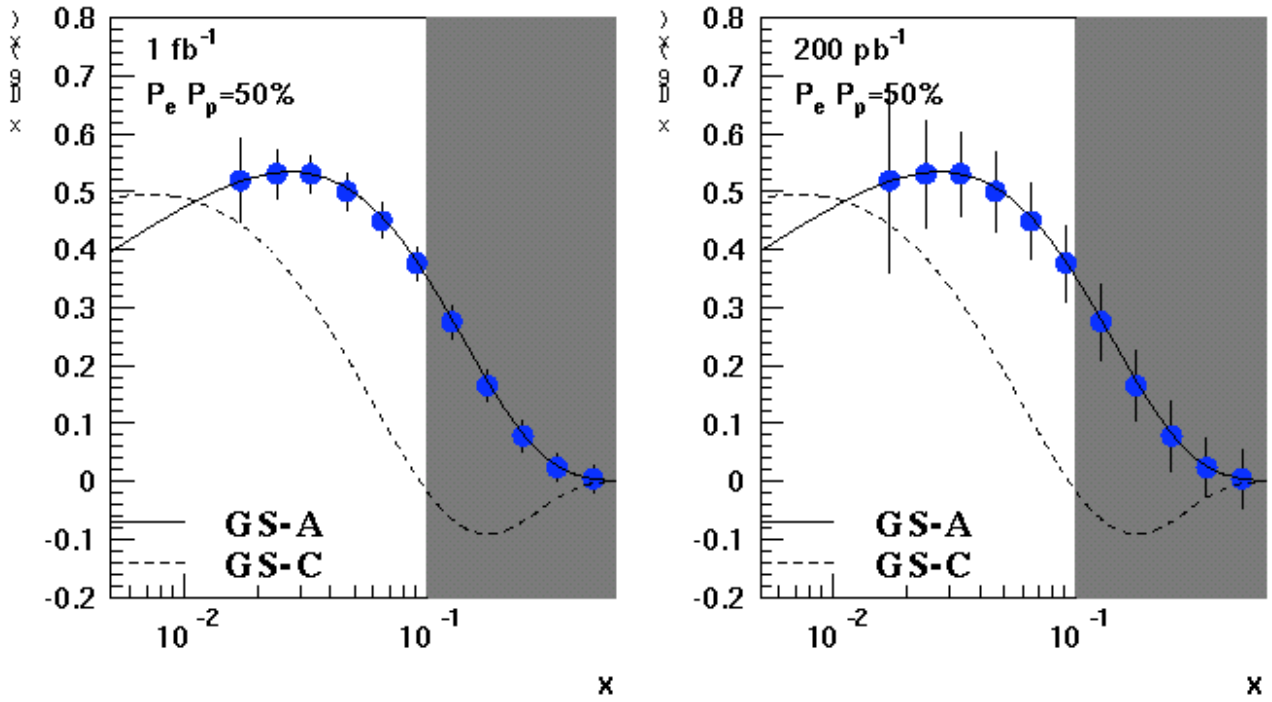
STEP 2



- "Direct" determination of ΔG
  -- Di-Jet events: (2+1)-jet events
  -- High pT hadrons
- High Sqrt(s) at eRHIC
  --Small theoretical ambiguities regarding interpretation of data
- Both methods tried at HERA in un-polarized gluon determination & both are successful!
  -- NLO calculations exist
  -- H1 and ZEUS results
  -- Consistent with scaling violation F_2 results on G

A.De Roeck,A.Deshpande, V. Hughes, J. Lichtenstadt, G. Radel
(Method: EPJ, C6 (1999) 121)

Di-Jet events at eRHIC: Analysis at NLO



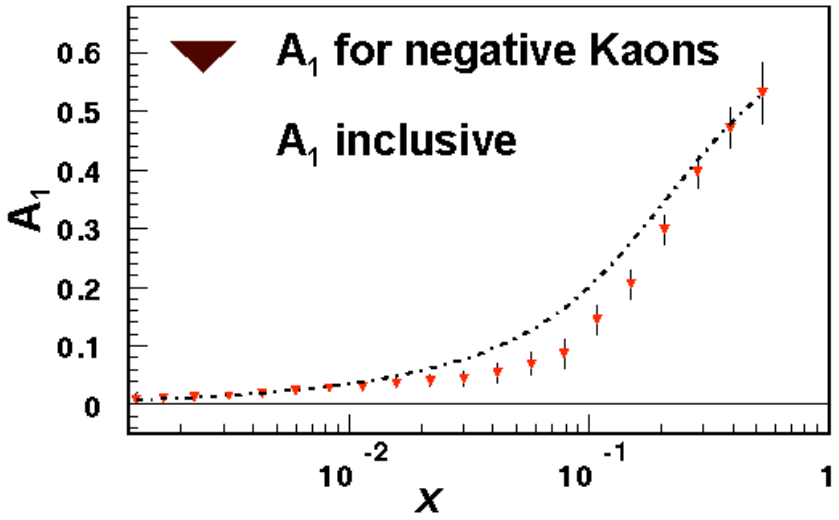
- Stat. Accuracy for two luminosities
- Detector smearing effects considered
- NLO analysis

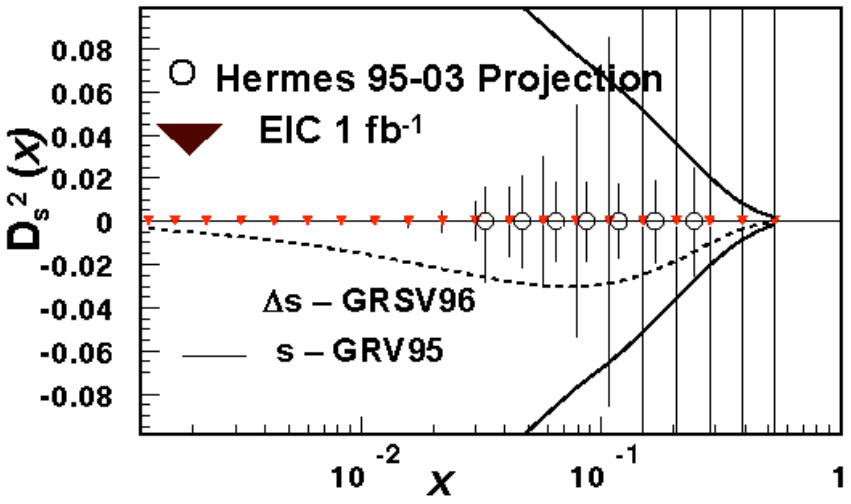
- Easy to differentiate different ΔG scenarios: **factor 3 improvements** in **~2 weeks**
- If combined with scaling violations of g_1: **factors of 5 improvements** in uncertainties observed in the same time.

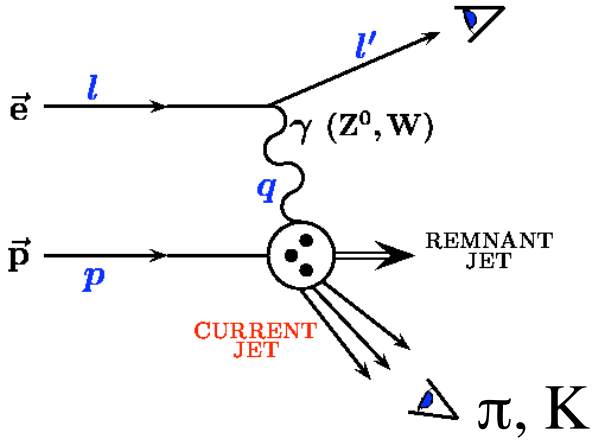
STEP 3

- **Better than 3-5% absolute uncertainty can be expected from eRHIC ΔG program limited by experimental systematic errors**

Strange Quark Distributions at eRHIC



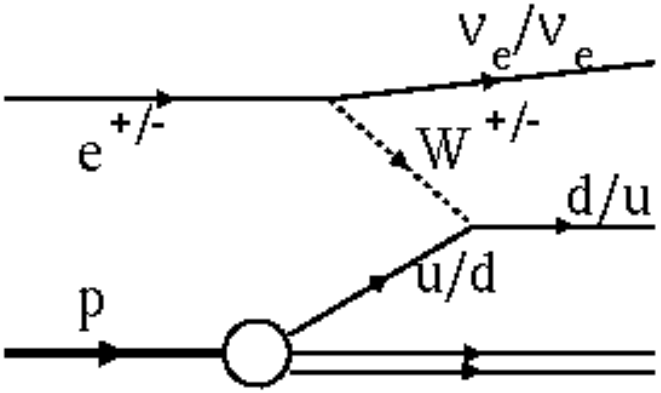




Detector with good Particle ID: pion/kaon separation

- Upper Left: statistical errors for kaon related asymmetries shown with A_1 inclusive
- Left: Accuracy of strange quark distribution function measurements possible with eRHIC and HERMES (2003-05) and some theoretical curves on expectations.

Parity Violating Structure Function g_5



$$\frac{d^2\sigma}{dxdQ^2} \sim \{a[F_1 - \lambda bF_3] + \delta[ag_5 - \lambda^2 bg_1]\}\frac{1}{(Q^2 + M_W^2)^2}$$

where

$a = 2(y^2 - 2y + 2)$; $b = y(2 - y)$; $\lambda = \pm 1$ for $e^{\pm}$

$\delta = \pm 1$ for $\uparrow\downarrow$ and $\uparrow\uparrow$ spin orientations

- Experimental signature is a huge asymmetry in detector (neutrino)
- Unique measurement
- Unpolarized xF_3 measurements at HERA in progress
- Will access heavy quark distribution in polarized DIS

$$A_{cc}^{W^+} = \frac{-2bg_1 + ag_5}{aF_1 - bF_3} \qquad A_{cc}^{W^-} = \frac{+2bg_1 + ag_5}{aF_1 + bF_3}$$

For eRHIC kinematics $a \gg b$

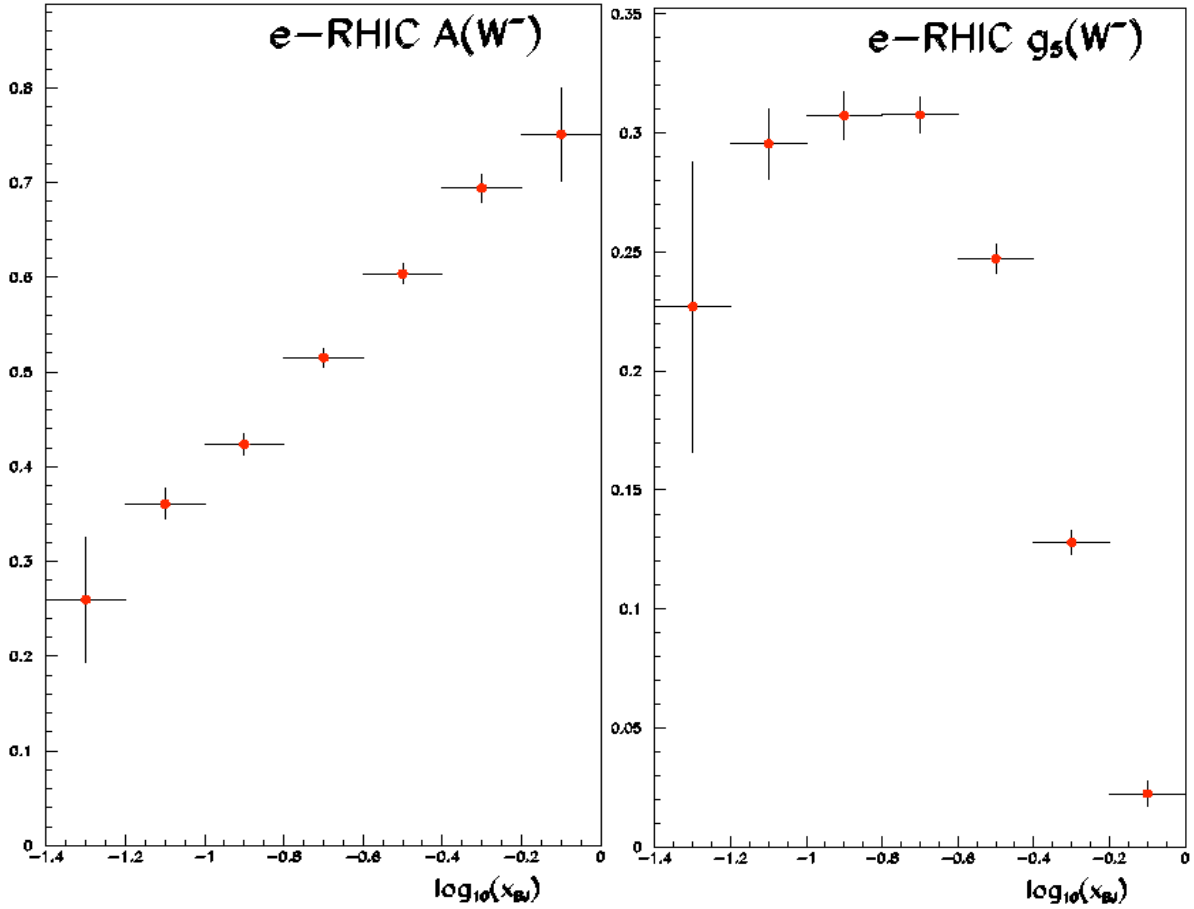
$\Rightarrow g_5$ dominates $\rightarrow$ Extract g_5

$$g_5^{W^-} = \Delta u + \Delta c - \Delta\bar{d} - \Delta\bar{s}$$

$$g_5^{W^+} = \Delta d + \Delta s - \Delta\bar{u} - \Delta\bar{c}$$

Need electron and positron beams in eRHIC

Measurement Accuracy PV g_5 at eRHIC



Assumes:

1. Input GS Pol. PDfs
2. xF_3 measured by then
3. 4 fb^{-1} luminosity

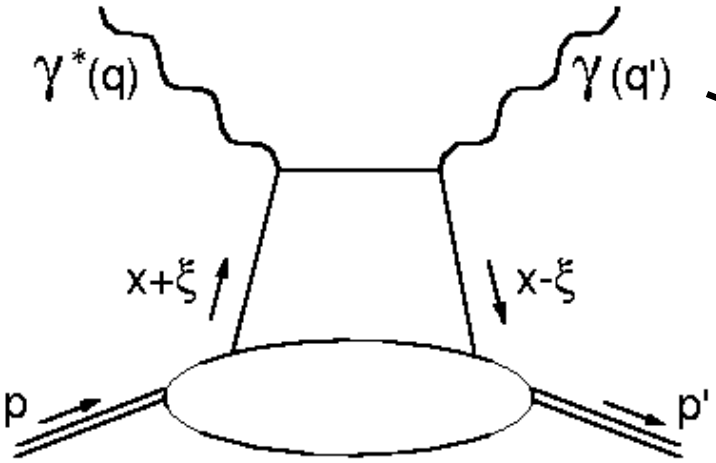
Positrons & Electrons in eRHIC ➔ $g_5(+)$

>> reason for keeping the option of positrons in eRHIC

>> **Ring-Ring needed**

>> For LINAC-Ring, enormous effort on intense enough positron source R&D needed, deemed unrealistic for now

DVCS/Vector Meson Production



- Hard Exclusive DIS process
- γ (default) but also **vector mesons** possible
- Remove a parton & put another back in!

➔ Microsurgery of Baryons!

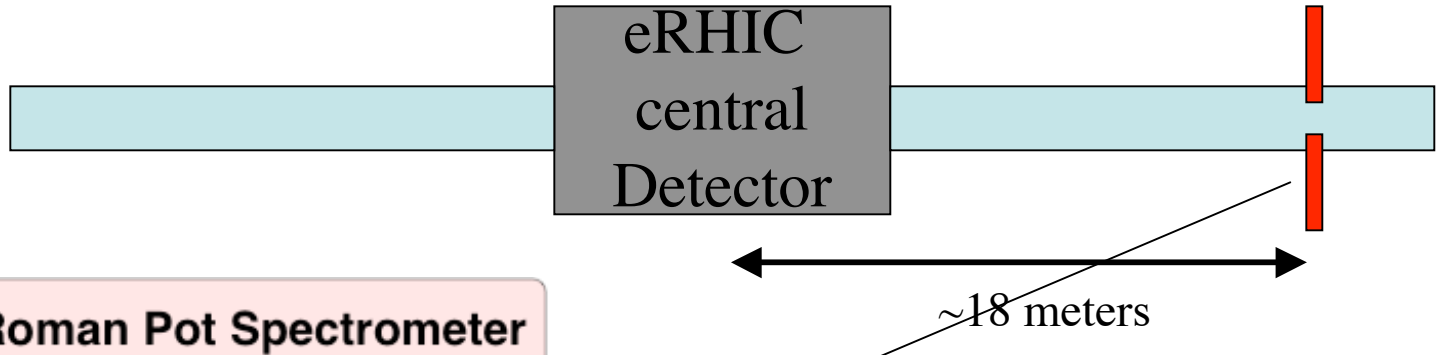
- Claim: Possible access to skewed or off forward PDFs?
  Polarized structure: Access to quark orbital angular momentum?

$$\int x dx [H(x,t,\xi) + E(x,t,\xi)] = 2J_{quark} = \Sigma + 2L_q$$

0 0

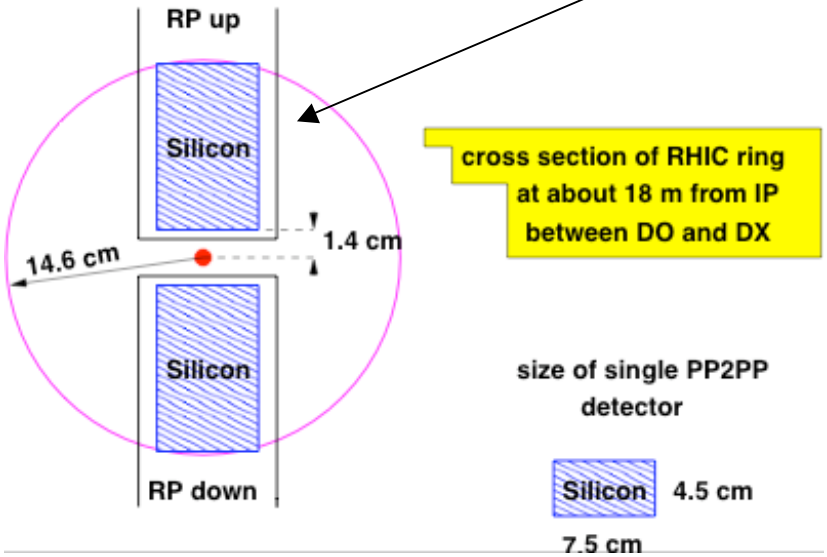
Experimental effort just beginning…To fully explore this physics beam Charge asymmetries need to be measured… electron/positron both Needed

Roman Pots for eRHIC



$$ep \rightarrow e'p\gamma$$

Generate DVCS events with Frankfurt et al. PRD58 (1998)



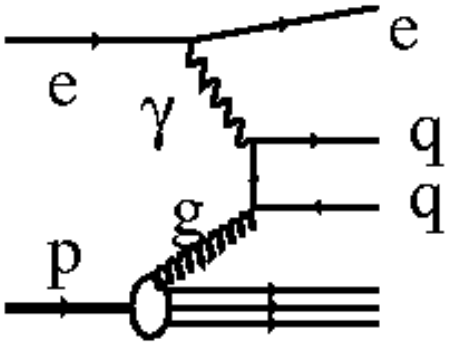
For Deeply Virtual Compton Scattering:

- Central tracker
  (for scattered e')
- Central and forward EMCal
  (for scattered e' and γ)
- Roman Pots a la PP2PP@RHIC
  (for scattered p)

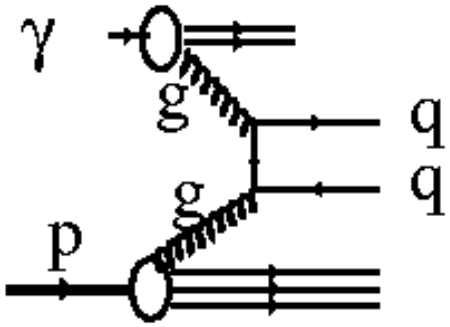
Polarized PDFs of Photons

- **Photo-production** studies with single and di-jet

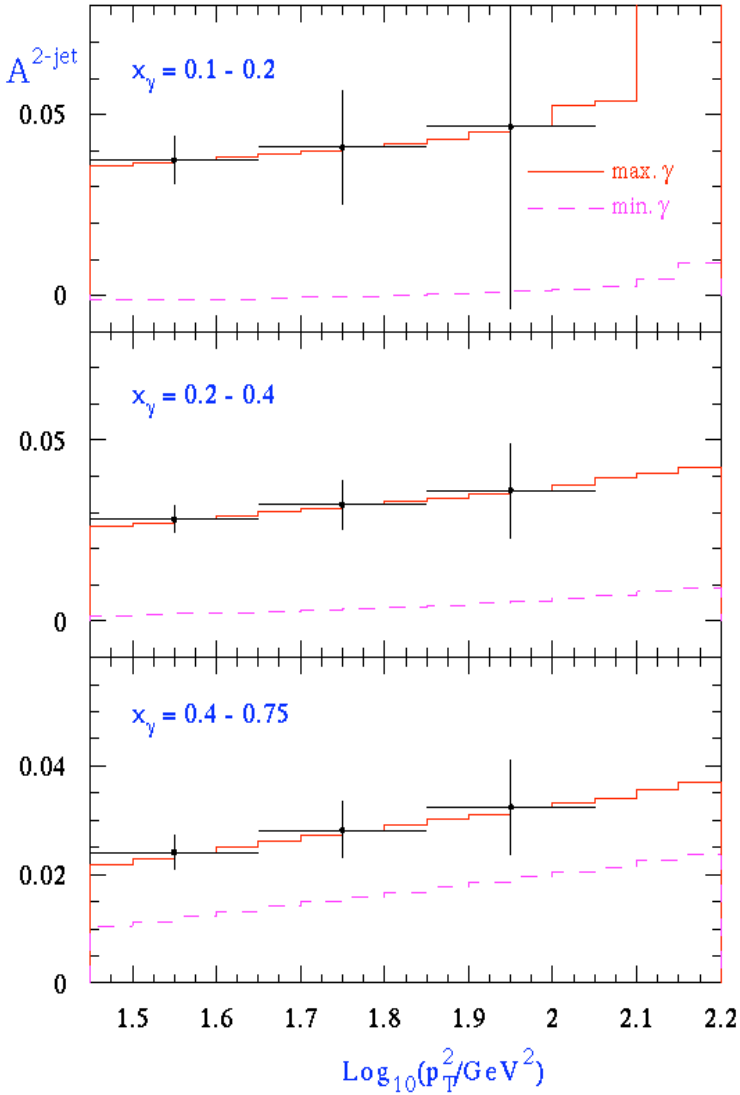
Direct Photon



Resolved Photon



- Photon Gluon Fusion or Gluon Gluon Fusion (Photon resolves in to its partonic contents)
- Resolved photon asymmetries result in measurements of spin structure of the photon
- 1 fb^{-1} data, ZEUS acceptance: ample data to explore the QCD/spin structure of the photon



CONCLUDING THOUGHTS

- **Science case polarized eRHIC is (EXTREMELY) compelling!**
  - New knowledge of nucleon spin structure
  - Fundamental tests of QCD
  - The entire Spin DIS spin community & a large fraction of RHIC Spin community agrees & sees this as natural evolution of their research program

- **Timely realization** of this effort is of great importance:
  - **SLAC Spin DIS experiments are long over**
  - **CERN, DESY Experiments will end in 2008/10**
  - RHIC SPIN (I AND II) will continue through ~2012…

- **To attract this community to get involved in eRHIC would need quick action:**
  - **THEY ARE LOOKING FOR BNL'S LEAD & ACTION**
  - **Getting them involved early on will also help RHIC physics in near & intermediate term future**

eRHIC Project at BNL

- **Significant amount** of work needs to be done at BNL to prepare
  - NSAC Long Range Planning followed by…
  - CD0,….. CD3 & beyond

- **VOLUNTARY WORK BY INTERESTED PERSONS NOT ENOUGH ANY MORE: NEED FOR A CENTRALIZED GROUP AT BNL IS OF PARAMOUNT IMPORTANCE**
  - **Accelerator issues, beam polarimetry, IR design….**
  - **Physics generators and studies**
  - **Detector design & technology choices (Some ideas in B. Surrow's talk)**

- **TECHNICAL ISSUES (POLARIZED ^{3}He BEAMS for example) HAVE LONG REALIZATION TIME, THEY NEED TO START *NOW*!**
  - **There might be others which might need to be identified**

- REGULAR GUIDANCE AND CORRESPONDENCE WITH PAC