Physics Consequences of Various eRHIC Designs

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Physics Frontiers of eRHIC

Nucleon structure including spin

Hard scattering in nuclear environment

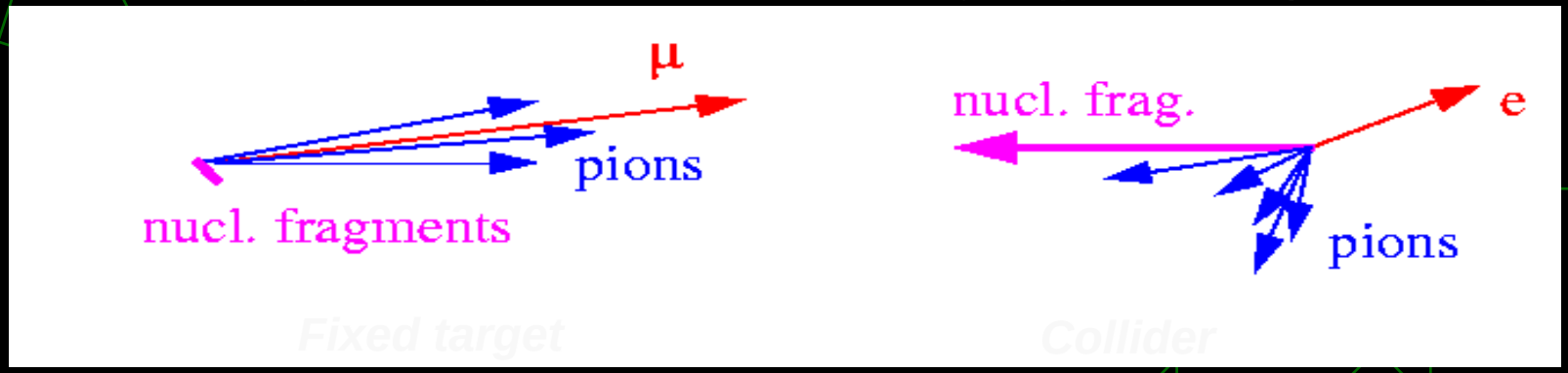
QCD in Extreme conditions

Tools needed for physics goals

- Nucleon structure including its *spin*
  - Polarized lepton
  - Polarized nucleon (proton, Helium=neutron) beams
  - High enough beam energy
  - Beam energy variability with minimal loss of luminosity and polarization
- QCD in nuclear environment
  - Nuclear targets from p to heavy nuclei Pb …. U with a few intermediate steps
  - Energy variation of the beam
- At least one state-of-the-art e-p/A detector
  - Some aspects in B. Surrow's presentation

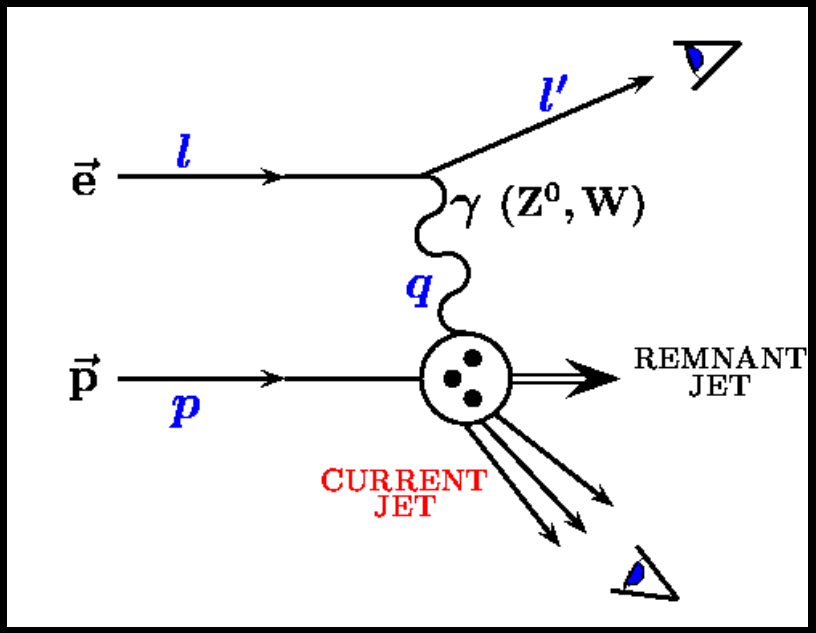
Why Collider In Future?

- Polarized DIS in past only in fixed target mode
- Collider geometry--> distinct advantages (HERA Experience)



- Better angular resolution between beam and target fragments
  - Better separation of electromagnetic probe
  - Recognition of rapidity gap events (diffractive physics)
  - Better measurement of nuclear fragments
- Higher center of mass energy w.r.t. fixed target
- For spin experiments, lowest “dilution factors”
- ***Tricky issues*: *integration of interaction region and detector***

Deep Inelastic Scattering



[1]

[3]

[2]

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

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

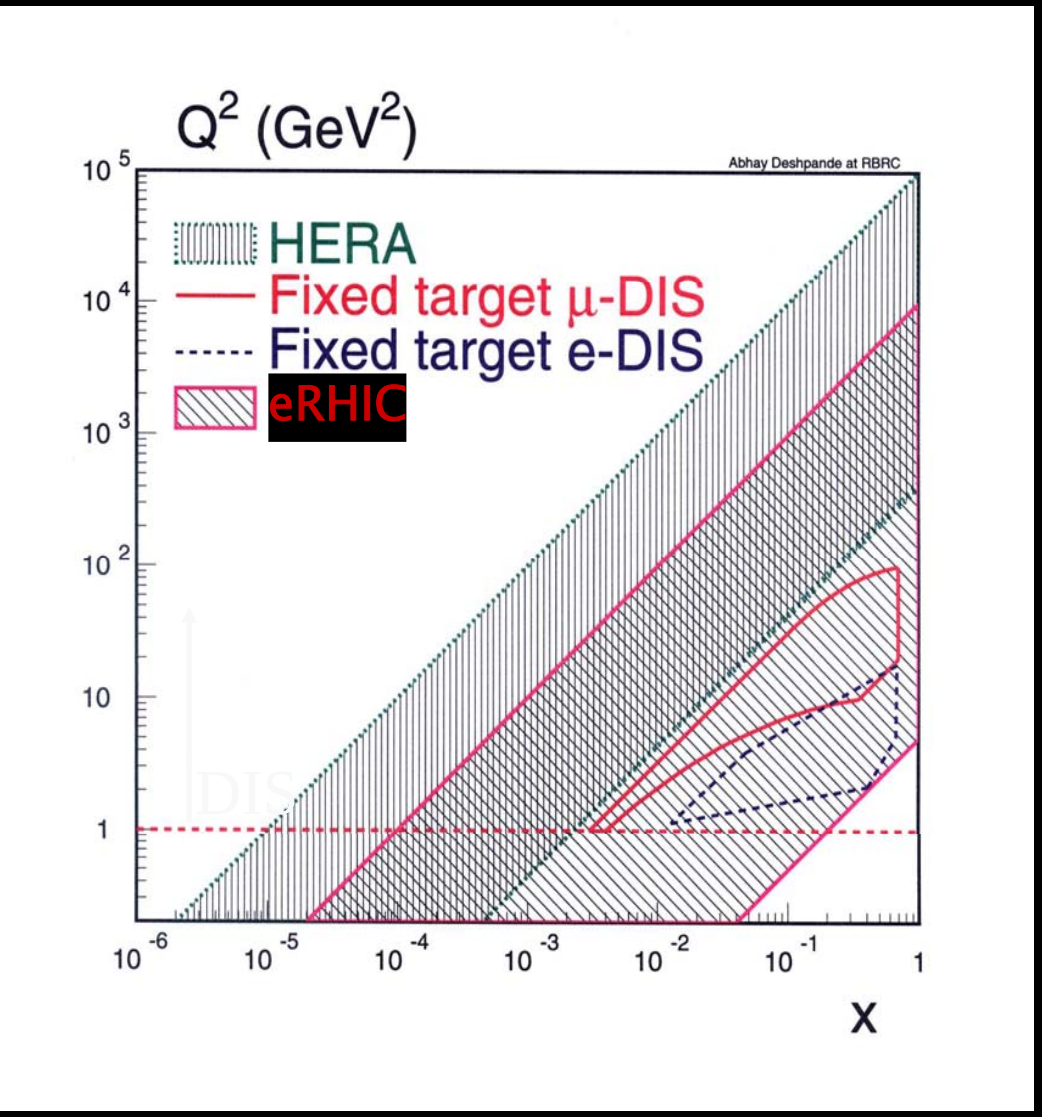
$$y = \frac{p \cdot q}{p \cdot l}$$

$$s = 4E_e E_p$$

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

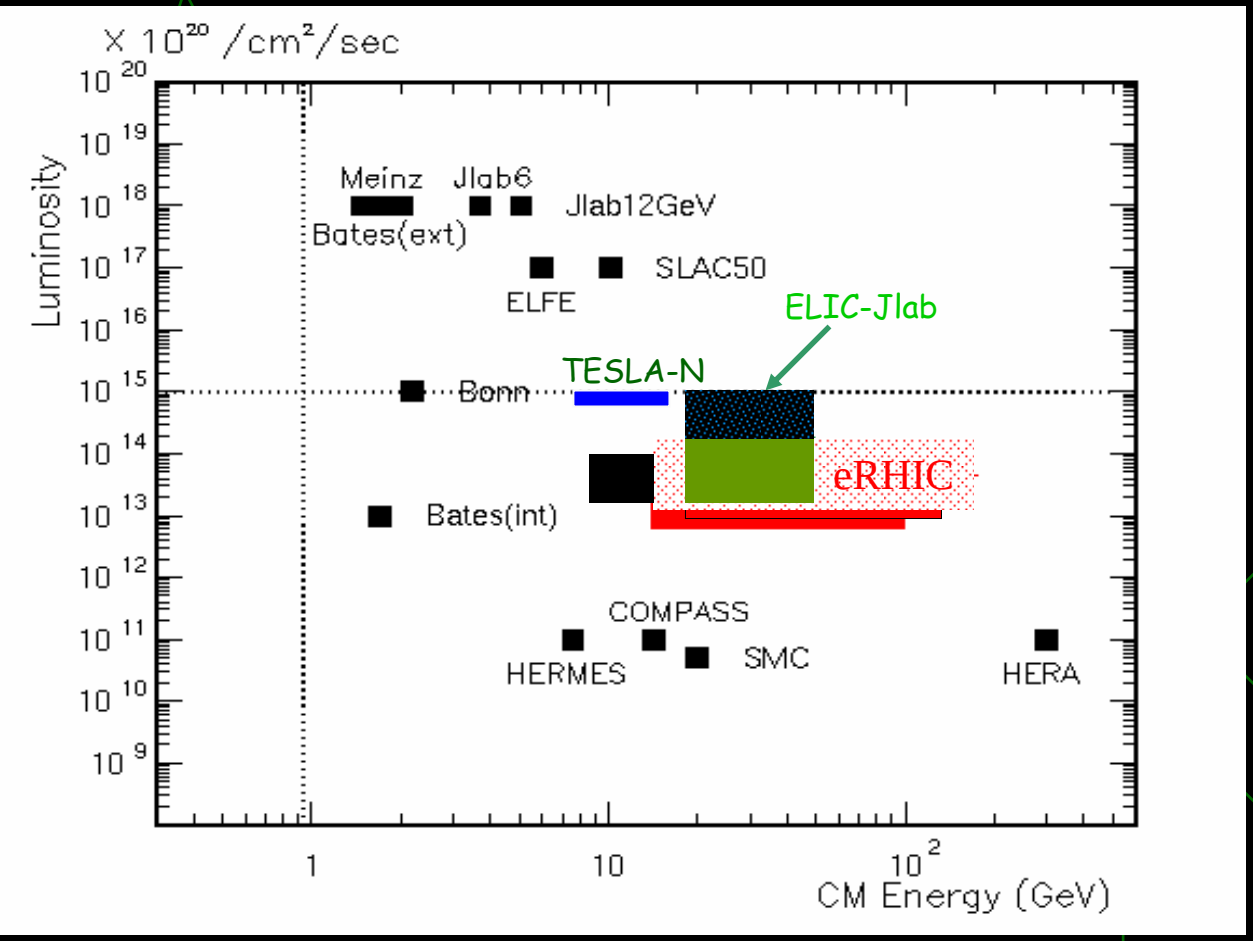
- Observe scattered electron [1] inclusive measurement
- Observe [1] + current jet [2] semi-inclusive measurement
- Observe [1] + [2] + remnant jet [3] exclusive measurement
- Luminosity requirements goes up as we go from [1] --> [2] --> [3]
- **Exclusive measurements put demanding requirement on detectors, interaction region and their integration**
  - Examples of difficulties in B. Surrow and C. Montag's talks

eRHIC vs. Other DIS Facilities



- **New kinematic region**
- E_e = 10 GeV (5-12 GeV variable)
  - 20 GeV *``dream-able"*
- E_p = 250 GeV (~50-250 GeV variable)
- E_A= 100 GeV/Nucleon
- **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 Luminosity:
  - **L(ep) ~10^{33-34} cm^{-2} sec^{-1}**

eRHIC CM vs. Luminosity



- Variable beam energy
  - CM: 30-100 GeV
- P-U ion beams
  - 100 GeV/nucleon
- Proton, Helium polarization
- Large luminosity
  - ep ~ 10^{33} cm^{-2} sec^{-1}
  - eA ~ 10^{31} cm^{-2} sec^{-1}

Nucleon structure: e-p

- What is left to do after HERA?
- Physics topics of interest & accelerator/detector requirements
  - High statistics measurement of c,b physics
    - High enough energy, and H1 or ZEUS like detector
  - Low x, low Q^2 physics: very forward acceptance
    - High enough energy & long machine element free region
  - Transition from QCD to perturbative QCD
    - Large luminosity and good continuous acceptance function of x, Q^2
  - F_L measurement
    - Center of mass variability without significant loss in luminosity
  - Precision Diffractive physics measurements
- Sever constraints on IR design: C. Montag's talk
- *This physics does not seem to prefer either of the lepton species over the other. Whatever gives low backgrounds and high luminosity will work.*

Spin Physics with 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 (He beams!) [1]
  - *Precision measurement of $\alpha_S(Q^2)$ from Bj sum rule*
- Polarized gluon distribution function $\Delta G(x,Q^2)$
  -- at least three different experimental methods [1]
- Spin structure of **the photon** from photo-production [1]
- Electroweak s. f. g_5 via virtual **$W^{+/-}$ production (heavy quarks)** [1,2] [1]
- Deeply Virtual Compton Scattering (DVCS), exclusive VM production [1,2] [3]
  >> Generalized Parton Distributions (GPDs) [1]
- Transversity: Single and Double Spin Measurements [1]
- Drell-Hern-Gerasimov spin sum rule test at high ν [1]
- Flavor separation of PDFs through semi-inclusive DIS [2,3]
- Target/Current fragmentation studies
- … *and many more ……*

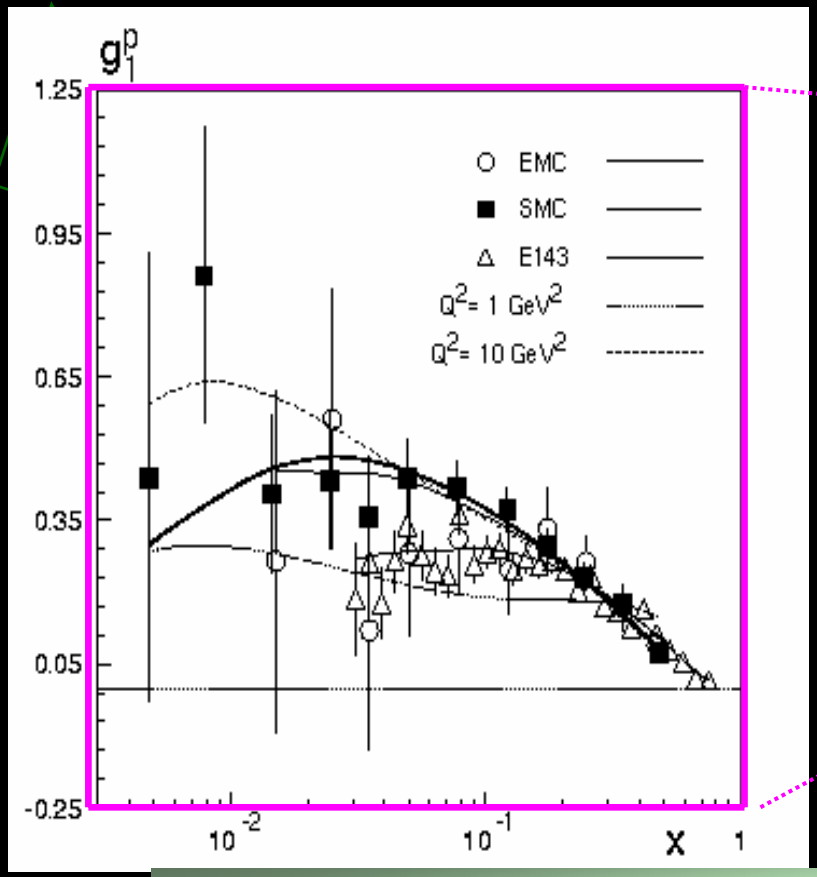
Luminosity Requirement

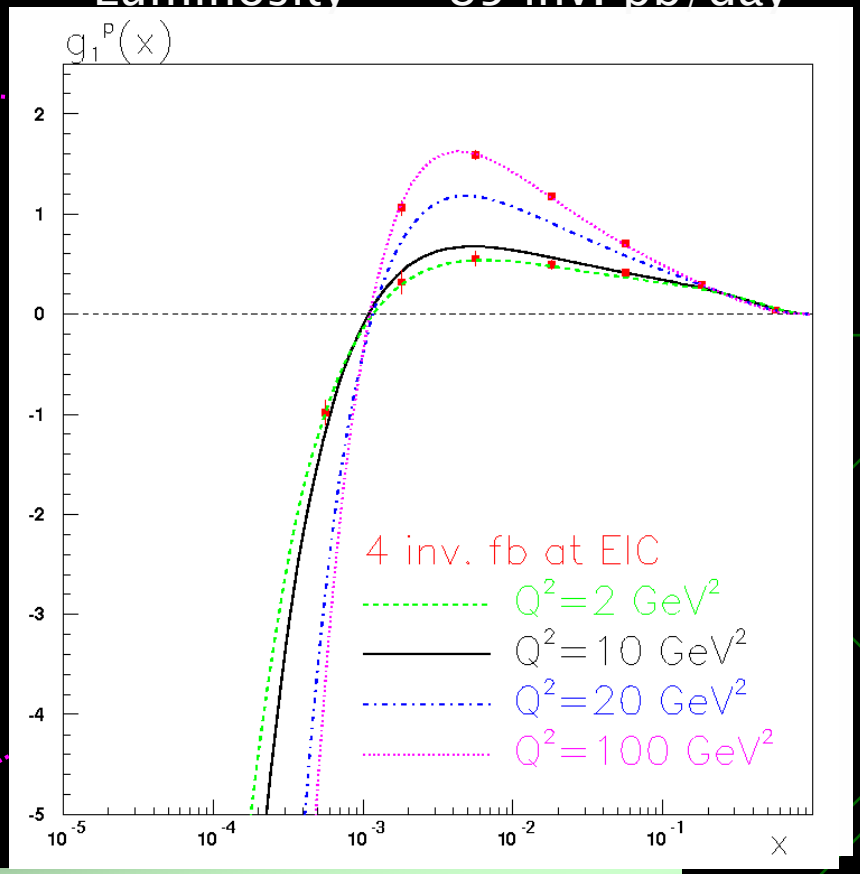
Require e+ and e- beams

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

Bj Sum Rule & Determination of α_s

$$\Gamma_1^p - \Gamma_1^n = \frac{1}{6} g_A$$

$\alpha_s(M_Z)$ 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:

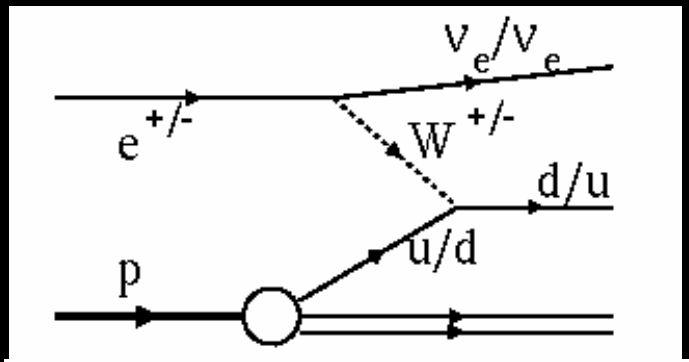
+/- 0.004 (experimental)

+/- 0.010 (theory/ low x extrapolation)

Particle Data Book (2002), Extended version:

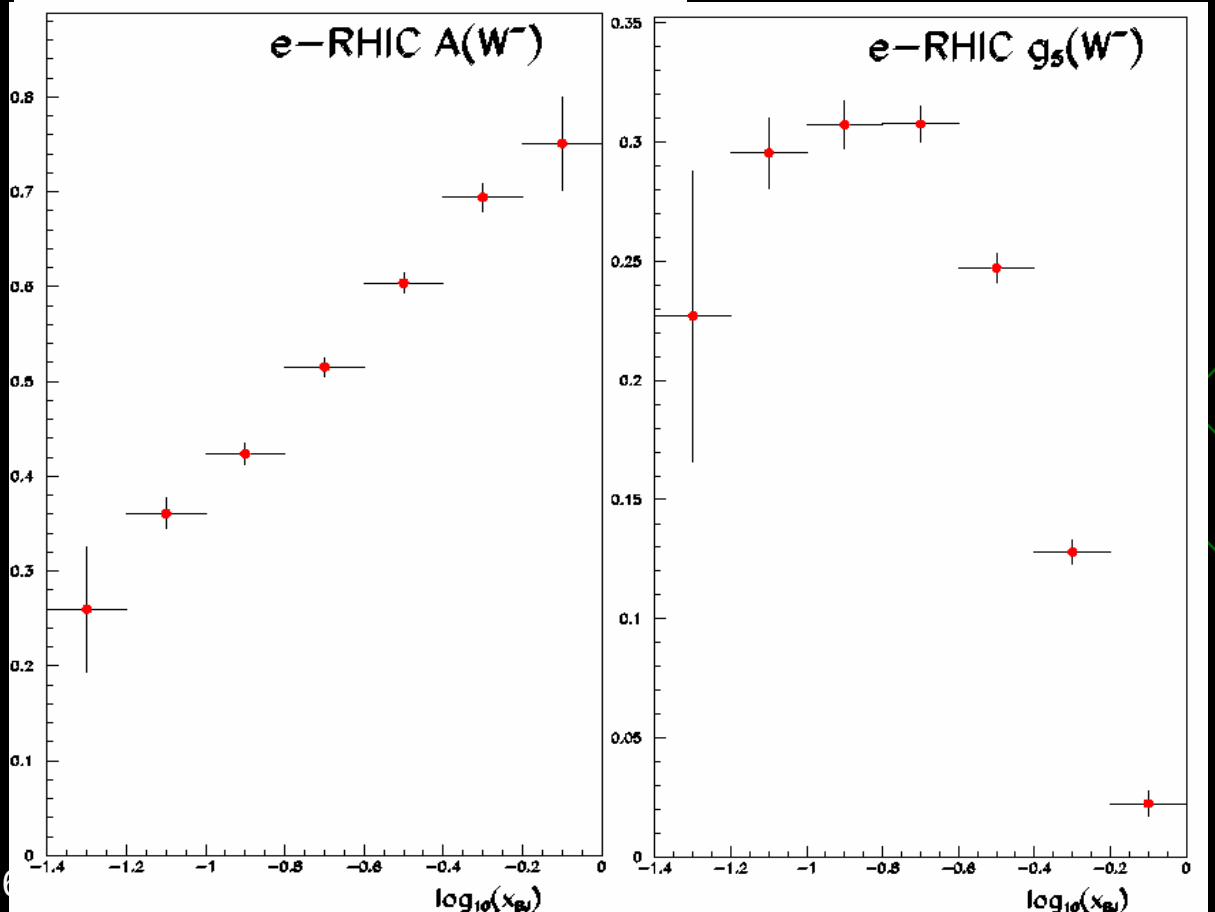
"Theoretically, this sum rule is better for determining α_s because perturbative QCD result is known to higher order ($o(\alpha_s^4)$), and these terms are important at low Q^2…… **Should data at lower x become available**, so that the low x extrapolation is more tightly constrained, the *Bj sum rule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

Measurement Accuracy PV 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 hermetic detector like ZEUS/H1

Assumes:

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

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

>> reason for keeping the option of positrons in

QCD in extreme conditions: e-A

- Intermediate and low x physics
- Intermediate x physics first time in collider mode, ability to study target as well as current fragments
- Low x physics believed to be gluon dominated
  - **Meaure gluon distributions in nuclei with high precision**
  - What to measure? What will it crucially need?
    - Scaling violations of F_2 of heavy nuclei
    - F_L measurements: beam energy variation in nuclear beams
    - Semi-inclusive: di-jet physics, hermetic detector
    - Diffractive or high rapidity gap events, large acceptance detector
- Most of these measurements will require **large CM** energy, some **energy variability**, **high forward detector acceptance**. ***No condition on lepton species.***

Ring-Ring Design Consequence

- Most physics goals presented could be achieved in 2-4 years of running (assume 2 fb^{-1}/year : 85 pb^{-1}/day)
  - Acceptance in IR good
  - Luminosity should not drop by more than factor 4 compared to original design request 10^{33} cm^2/sec
- Exclusive physics program promises to lead to orbital angular momentum (OAM) **in future.** *This could be challenging at Luminosity<10^{33} cm^{-2} sec^{-1}*
  - DVCS, Vector meson production leading to Generalized Parton Distributions (GPDs) and then to OAM
  - Is the theory clear enough?
  - *Does low x play a role? A significant one?*
    - ***Just beginning to be explored***

Consequences of Linac-Ring Design

- High luminosity, upgrade possibility of future for energy and number of IRs, transparency in beam polarization through the CM energy: all very attractive features

- No polarized positron beams
  - No W+/-, disentanglement of heavy quark distributions
    - ***Only W- studies interesting in themselves?***
  - Do GPD studies of the future need polarized positron as well as electron beams?
    - ***Opinion is divided… even amongst experts. Under discussion***

Correlated Issues!

Other Ring-Ring vs. Linac-Ring issues

- Number of IRs
  - Ring-Ring: One IR, sequential running of different detector experiments?
  - Linac-Ring only interesting if 4 IRs?
- Luminosity comparison
  - Linac-Ring seems to out-do Ring-Ring
  - Only one IR Linac-Ring: Still worth going for?
- Future upgrade issues: 10-to-20 GeV e beam energy?
  - Seem clearly technically easy for Linac-Ring
- Time scale for technical feasibility
  - Interests of different physics groups
  - Willingness to go ahead with project from DOE
- Serious Cost comparison with Physics interest in future

Concluding thoughts

- No matter which design realizes eRHIC will be a unique facility for QCD in the next decade
- Interest growing and expected to increase
  - May impose more stringent constraints on luminosity, polarization, detector requirement
  - Multiple IRs may solve part of the problems, but cost and time will play a role
- Far from any final decisions on the design