Introduction & Spin Physics with eRHIC

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This Talk

- DIS2005 has seen excellent talks on:
  - New data from various experimental facilities
  - Lots of new theoretical ideas to understand those data
  - Many spirited discussions and disagreements

- Before we go to the Summaries of the WG and Conference we need to look at the future…..

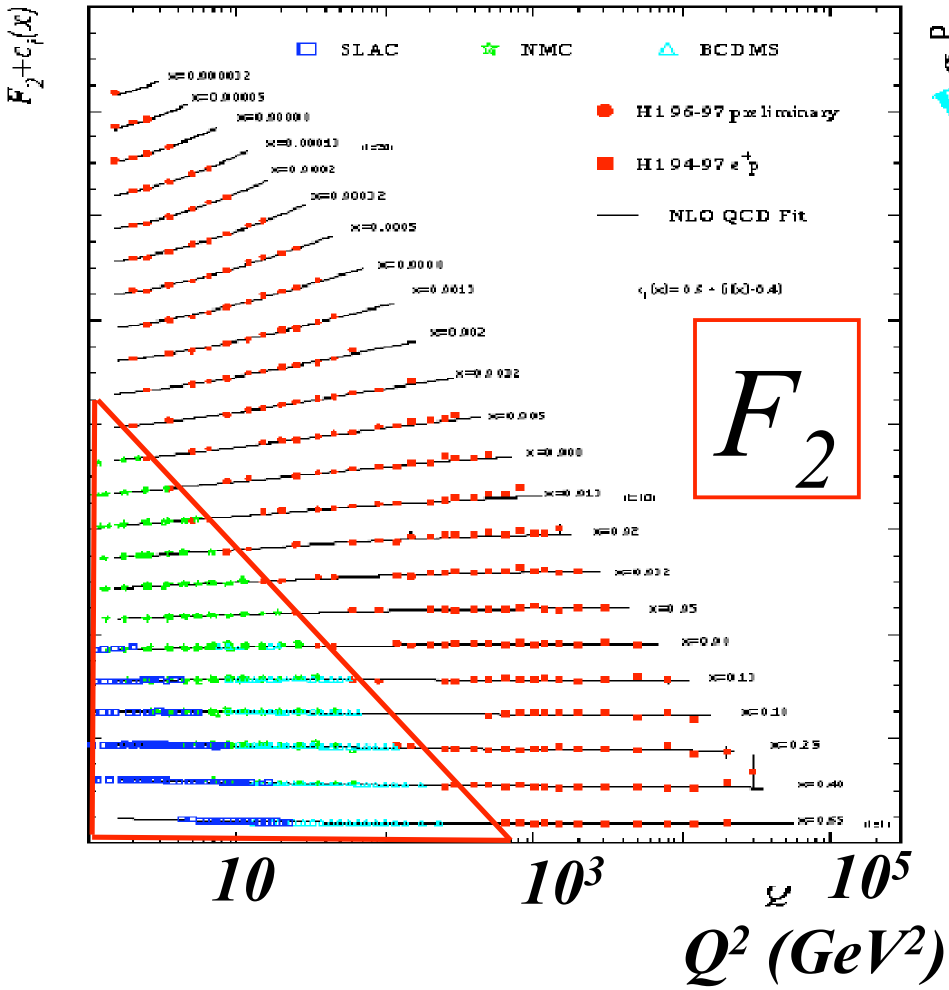
- **You are about to see a SET OF THREE TALKS on eRHIC**
  - **Introduction to eRHIC, polarized DIS & project status:** This Talk
  - **Unpolarized DIS with nuclei at eRHIC:** J. Jalilian-Marion
  - **Accelerator and Detector:** Bernd Surrow

Spin Experiment Families

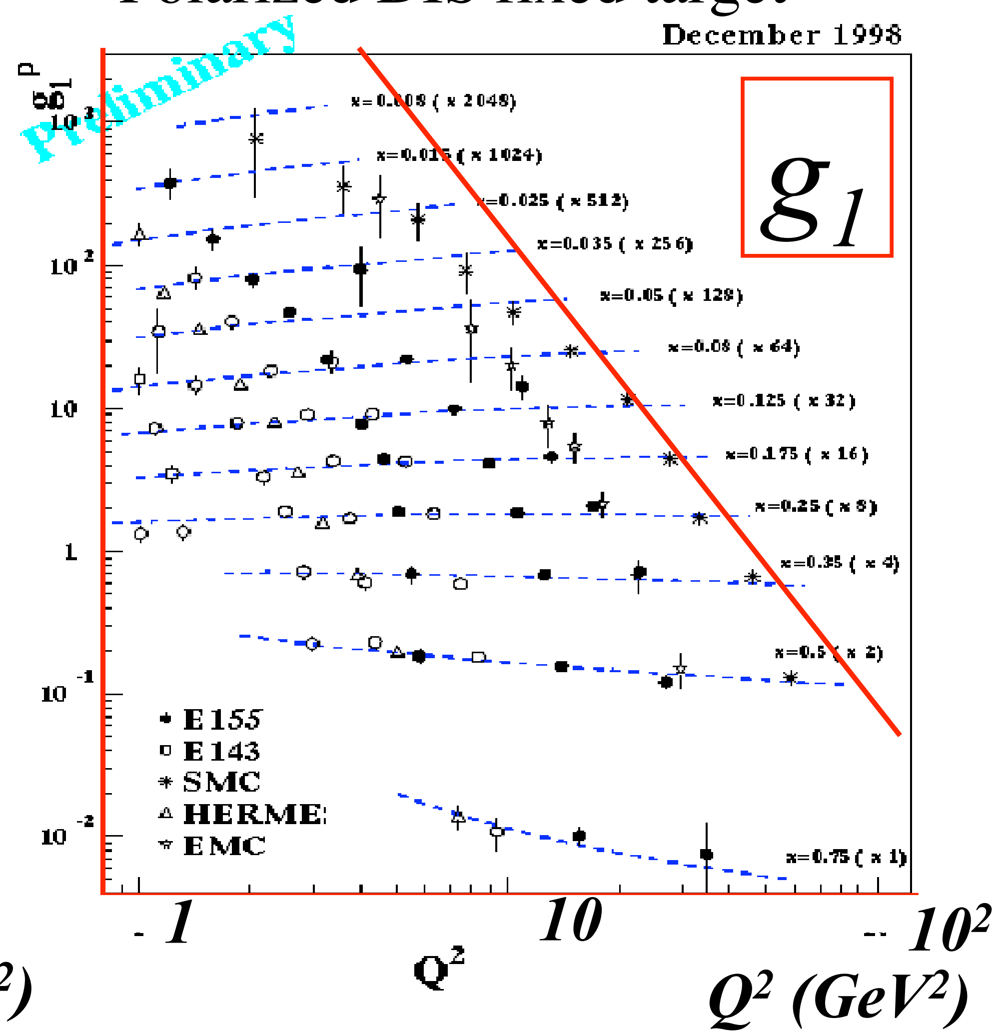
- **First Generation Polarized DIS Experiments:**
  - E80, E130 at SLAC, ***EMC*** at CERN
- **Second Generation Polarized DIS Experiments:**
  - E142, E143, E154/55 at SLAC, SMC at CERN, *HERMES at DESY*
- **Third Generation DIS & Spin Experiments (Current):**
  - *HERMES at DESY*, COMPASS at CERN, CBAF at Jlab and RHIC Spin at BNL
- **Fourth Generation Spin Experiments:**
  - **e-RHIC at BNL, New York**
  - **Electron-Light-Ion-Collider (ELIC) at Jlab, Virginia**
  - **GSI Future Spin Experiments, Neutrino DIS facility, 12 GeV upgrade at the Jlab, J-PARC in Japan**

Our Knowledge of Structure Functions

HERA Collider Un-polarized



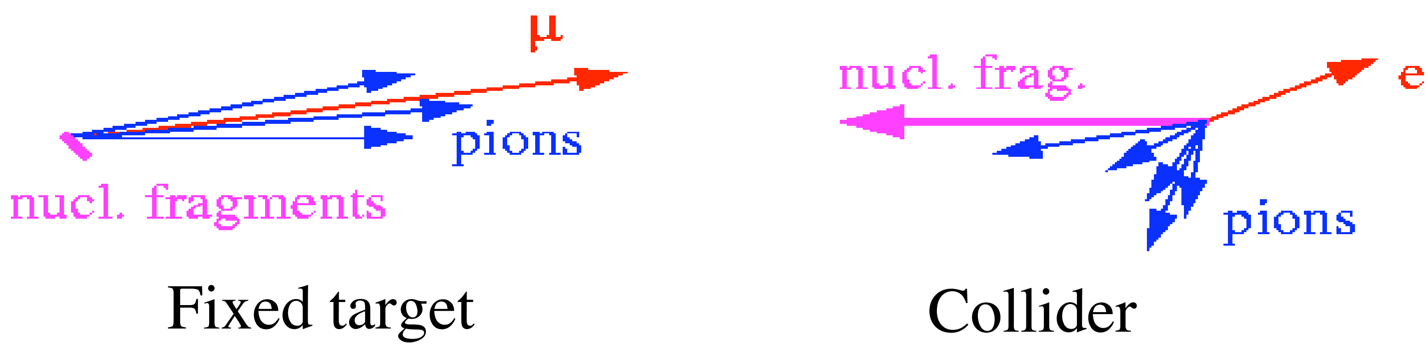
Polarized DIS fixed target



Large amount of polarized DIS data since 1998… but not in NEW kinematic region!

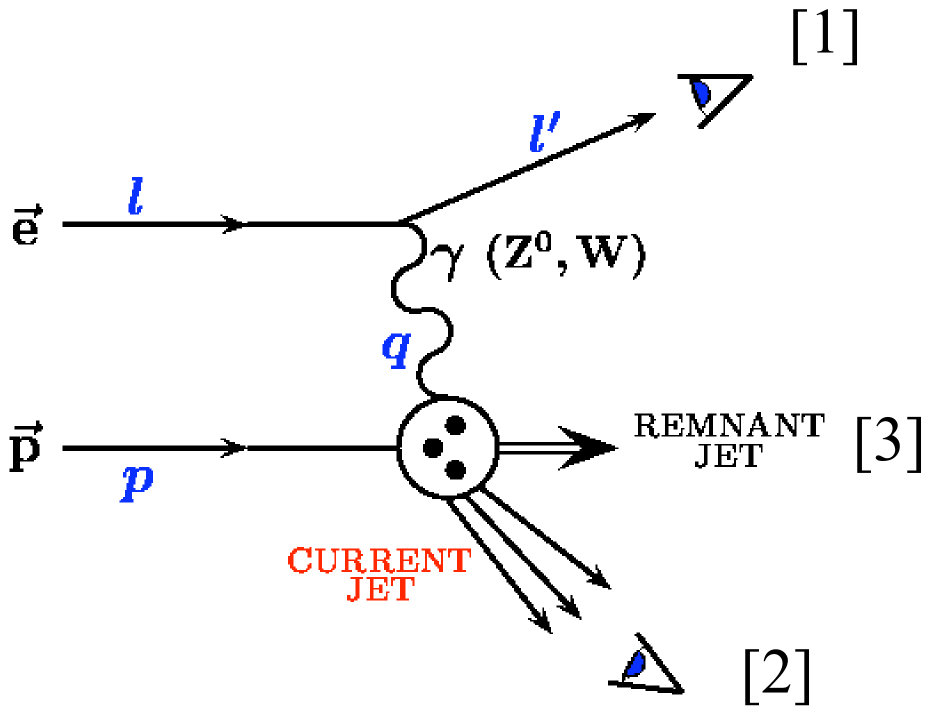
Why Collider In Future?

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



- Higher Center of Mass energies reachable
- 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
- **Tricky issues**: **integration of interaction region and detector**

Deep Inelastic Scattering



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

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

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

$$s = 4E_eE_p$$

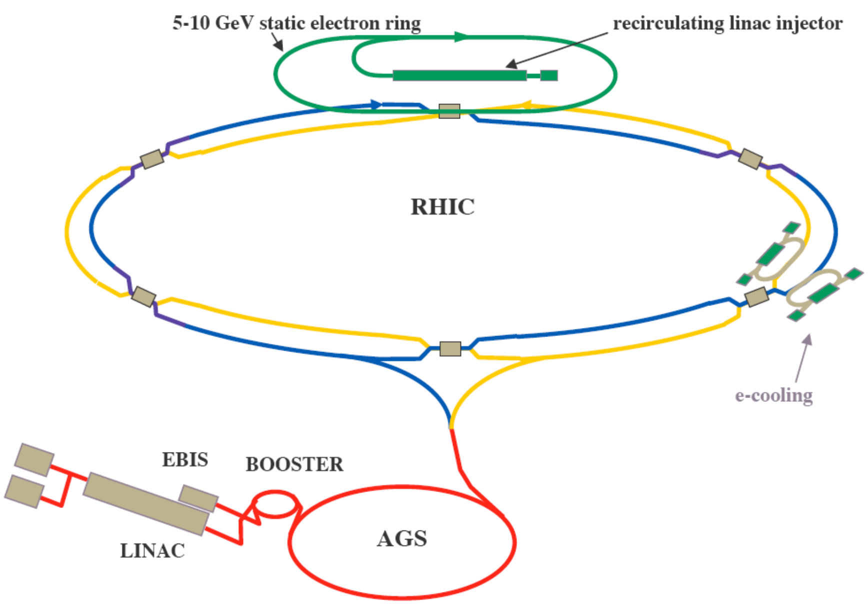
$$W = (q+p)^2$$

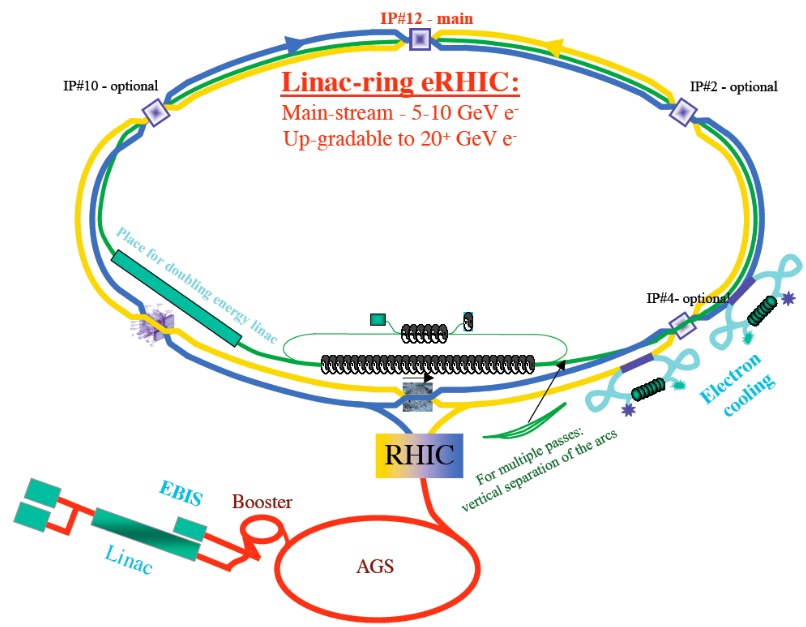
- Observe scattered electron [1] inclusive measurement
- Observe [1] + current jet [2] semi-inclusive measurement
- Observe [1] + [2] + remnant jet [3] exclusive measurement
- Luminosity requirements goes up as we go from [1] --> [2] --> [3]
- **Exclusive measurements put demanding requirement on detectors,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

The Proposal

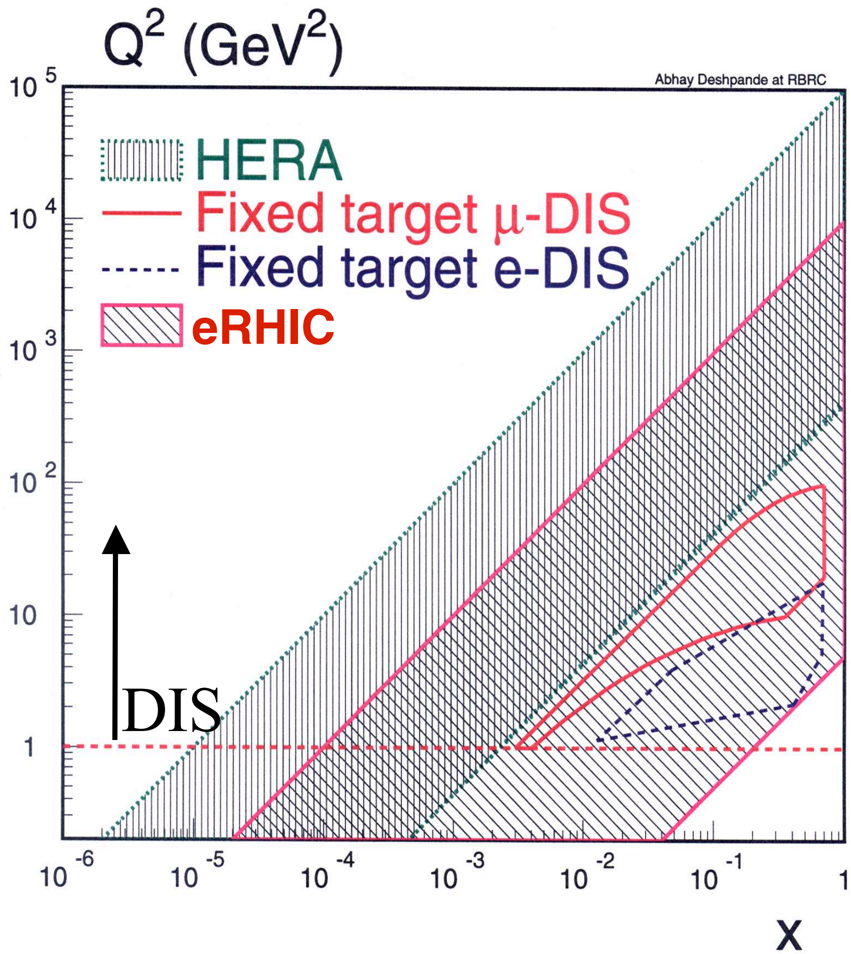
eRHIC at BNL

A high energy, high intensity polarized electron/positron beam facility at BNL to colliding with the existing heavy ion and polarized proton beam would significantly enhance RHIC's ability to probe **fundamental and universal aspects of QCD**



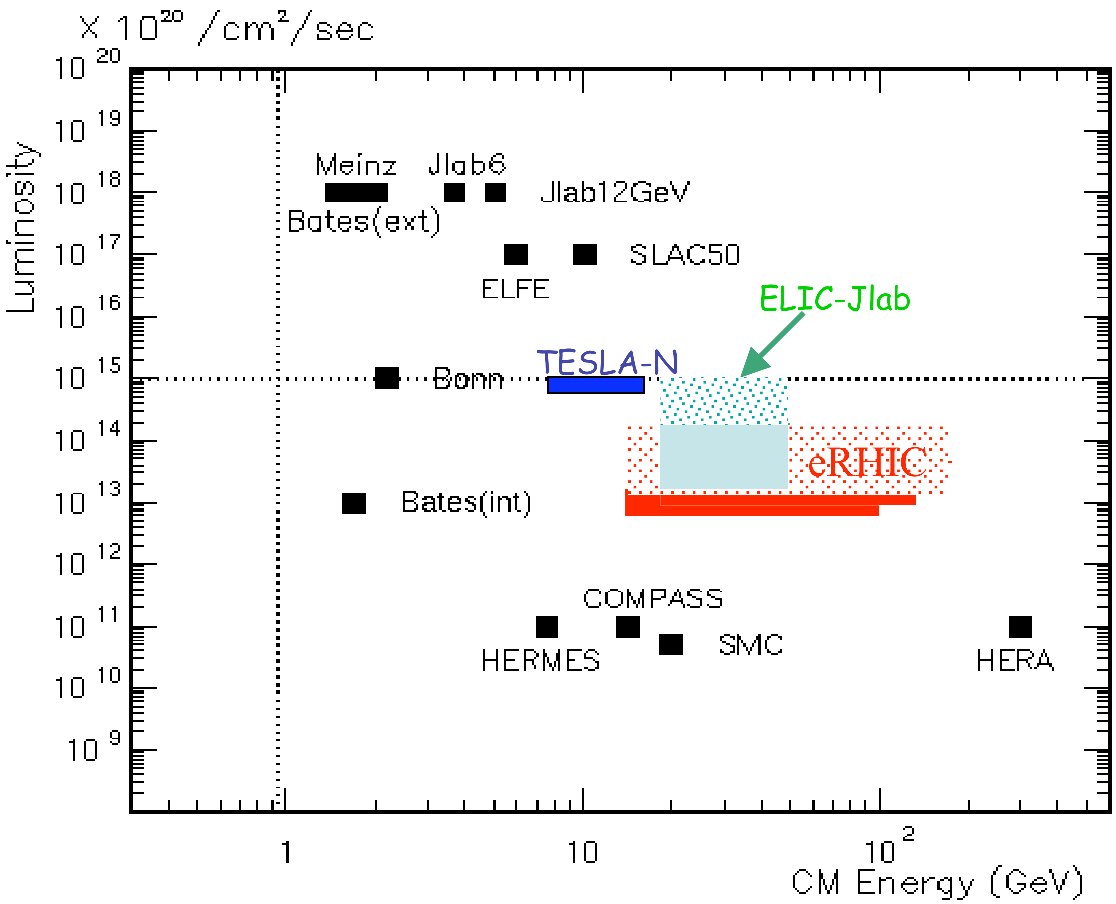


eRHIC vs. Other DIS Facilities



- **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^{33-34} cm^{-2} sec^{-1}**

CM vs. Luminosity



- **eRHIC**
  - Variable beam energy
  - P-U ion beams
  - Light ion poalrization
  - Huge luminosity

Scientific Frontiers Open to eRHIC

- **Nucleon structure, role of quarks and gluons in the nucleons**
  - Un-polarized quark and gluon distributions, confinement in nucleons
  - Polarized quark and gluon distributions **(LOWEST POSSIBLE X)**
  - Correlations between partons
    - Exclusive processes--> Generalized Parton Distributions
  - Understanding confinement with low x/lowQ^2 measurements
- **Meson Structure:**
  - Goldstone bosons and play a fundamental role in QCD
- **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

This talk

J. Jalilian-Marion'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]
  -- at least three different experimental methods
- Precision measurement of α_S(Q2) from g_1 scaling violations [1]
- Spin structure of the photon from photo-production [1]
- Electroweak s. f. g_5 via virtual **$W^{+/-}$ production* (heavy quarks)** [1,2]
- Deeply Virtual Compton Scattering (DVCS), exclusive VM production [1] [1,2]
  >> Generalized Parton Distributions (GPDs) [3]
- **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 [1]
- Target/Current fragmentation studies [2,3]
- … *and many more ……*

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

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

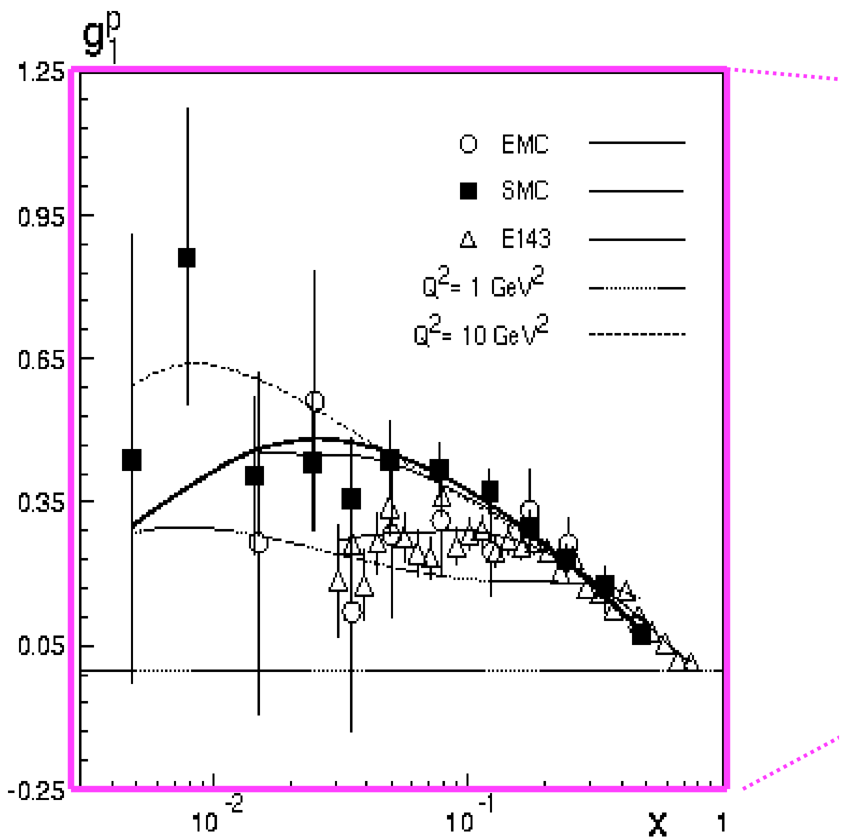
Luminosity Requirement

AD & V. Hughes

Low x Proton Spin Structure

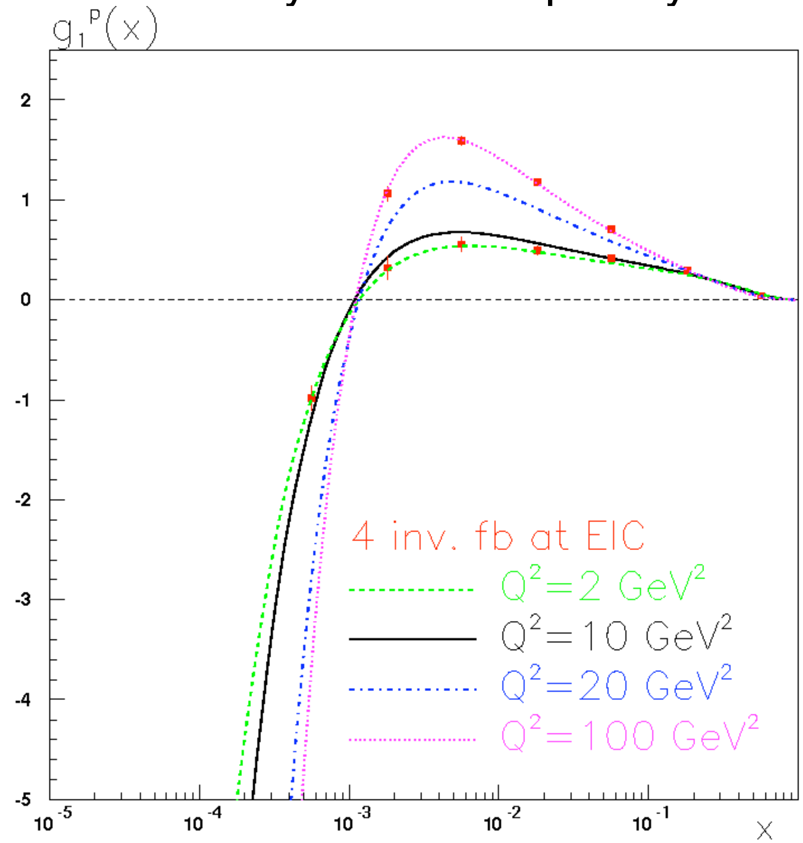
Fixed target experiments

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

Bj Sum Rule & Determination of α_s

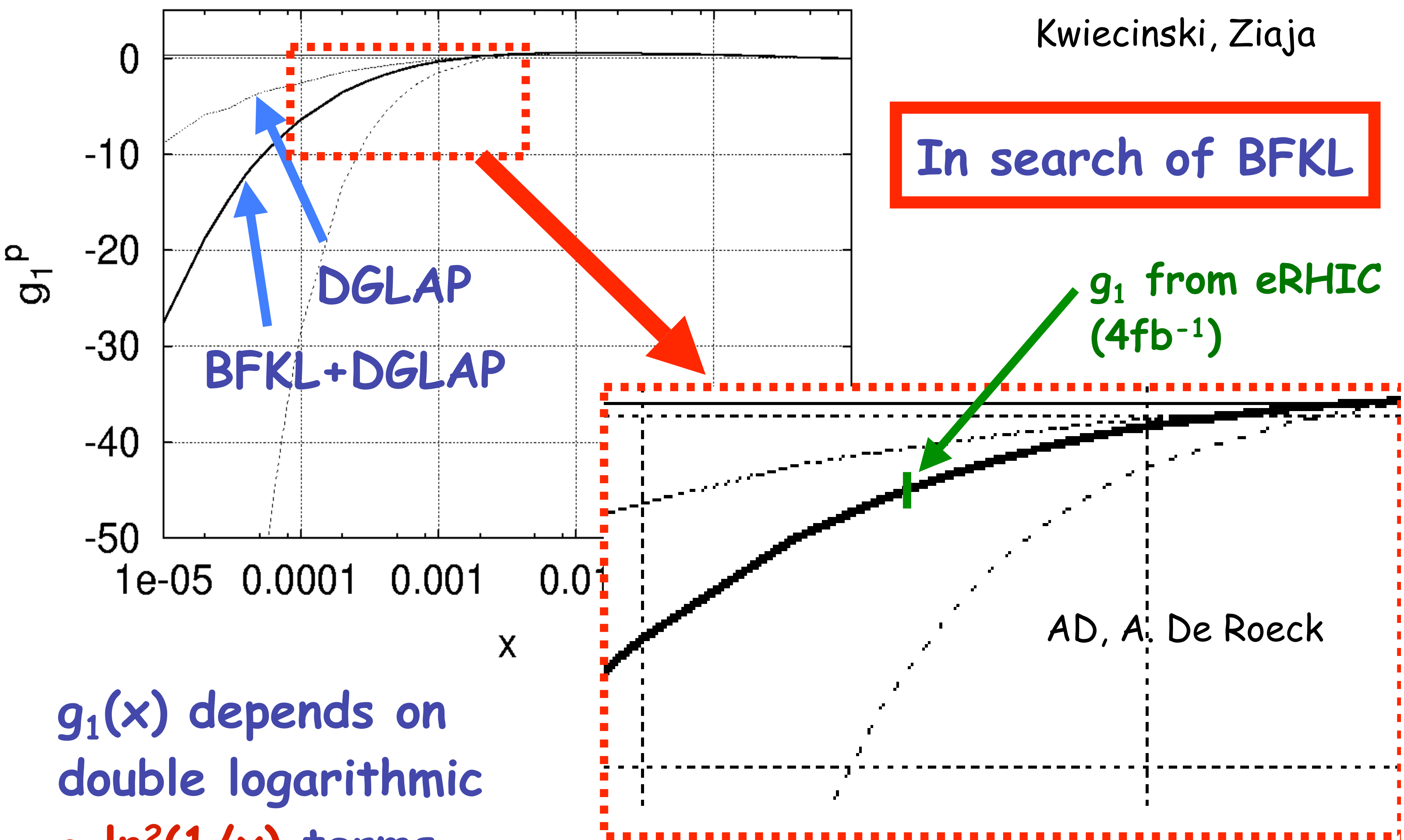
$\alpha_s(M_Z)$ has been determined from Bj spin sum rule by many groups:

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)

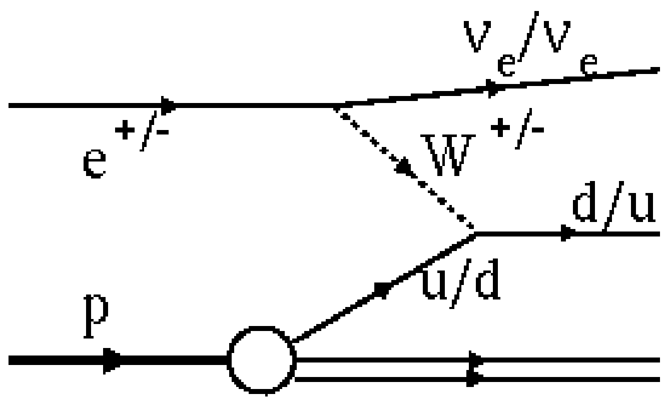
Particle Data Book (2002), Extended version:
"Theoretically, this sum rule is better for determining α_s because perturbative QCD result is known to higher order ($o(\alpha_s^4)$), and these terms are important at low Q^2……… **Should data at lower x become available**, so that the low x extrapolation is more tightly constrained, the ***Bj sum rule method could give the best determination of α_s***"

Low-x measurements



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

Parity Violating Structure Function g_5



$$\frac{d^2\sigma}{dx\,dQ^2} \sim \{a[F_1 - \lambda b F_3] + \delta[a g_5 - \lambda^2 b g_1]\}\frac{1}{(Q^2+M_W^2)^2}$$

where

$a = 2(y^2 - 2y + 2)$; $\quad b = y(2-y)$; $\quad \lambda = \pm 1$ 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

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

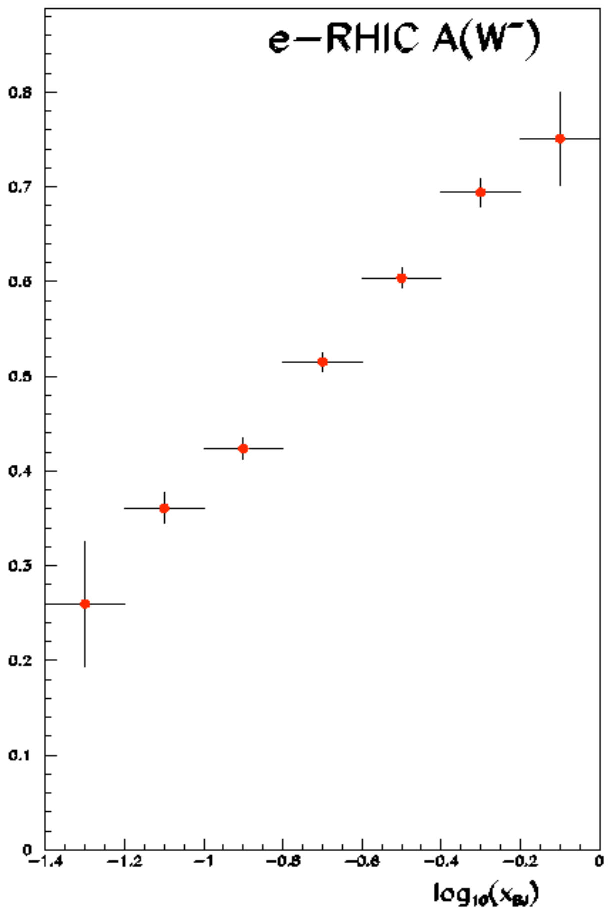
For eRHIC kinematics $a \gg b$

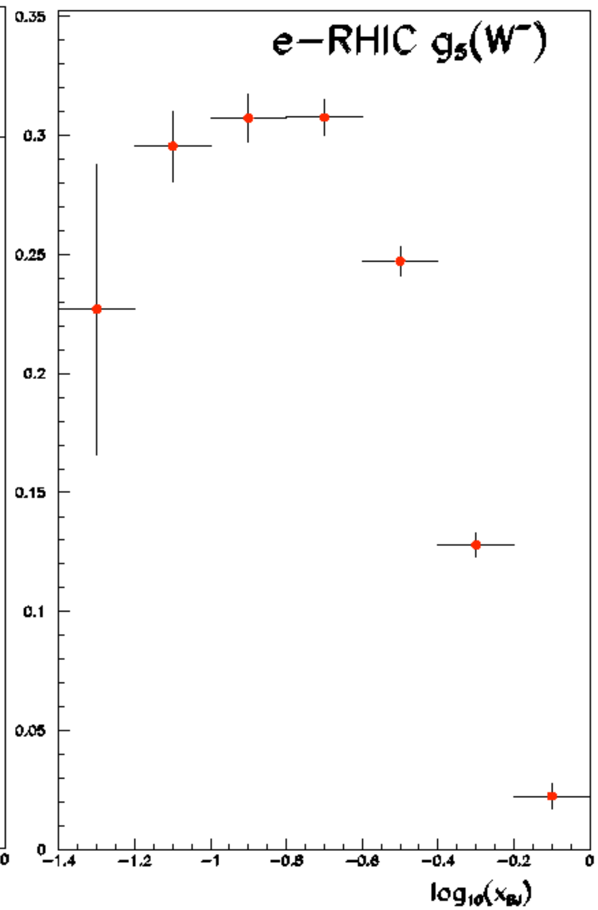
$\Rightarrow g_5$ dominates $\rightarrow$ Extract g_5

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

J. Contreras, A. De Roeck

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

AD, A.De Roeck,V. Hughes., J.Lichtenstadt.,G.Radel

ΔG: Fits of $g_1(x,Q^2)$ + Di-Jets

Constrain better the shape and the first moment

ΔG determined from the Scaling violations of g1

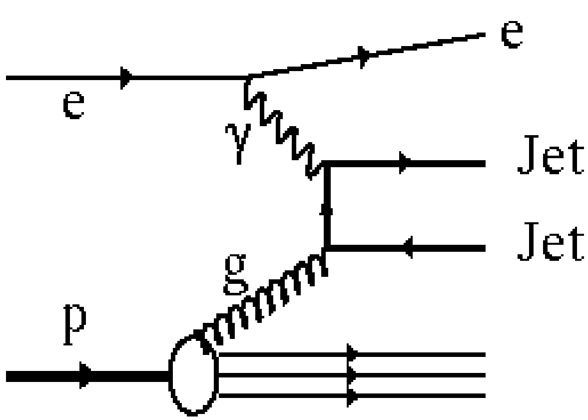
SMC Published 1998: First Moment of ΔG(x)

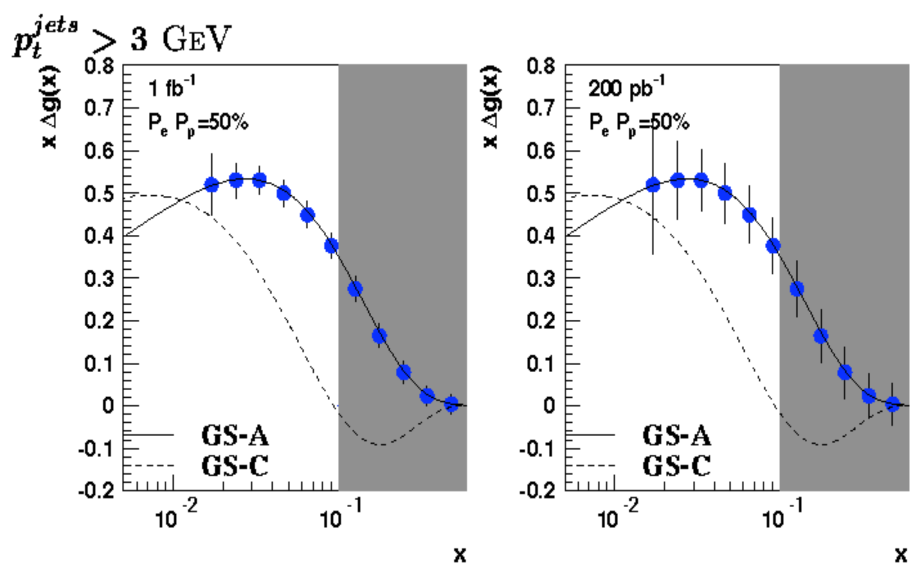
$\int \Delta G(x)dx =$ 1.0 +/- 1.0 (stat) +/- 0.4 (exp.syst) +/- 1.4 (theory)

-- one week eRHIC reduces statistical & theory errors by ~5

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

Di-Jet at eRHIC: constraints shape mid x

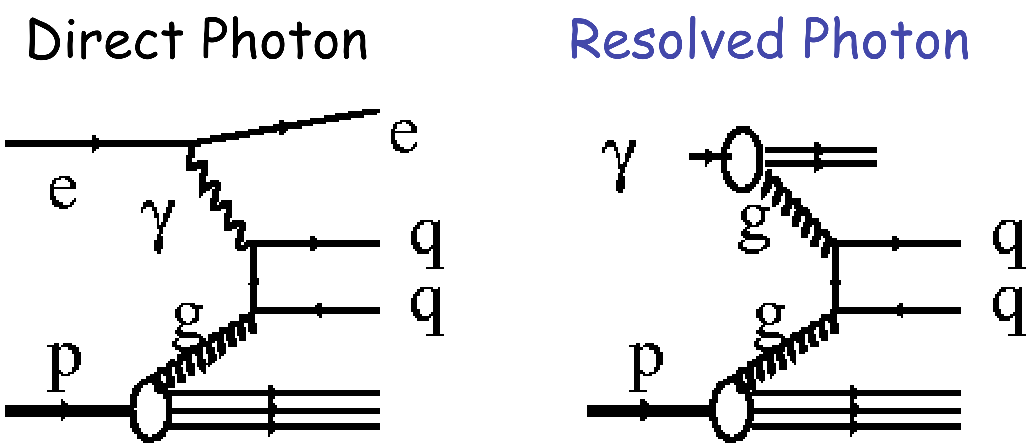


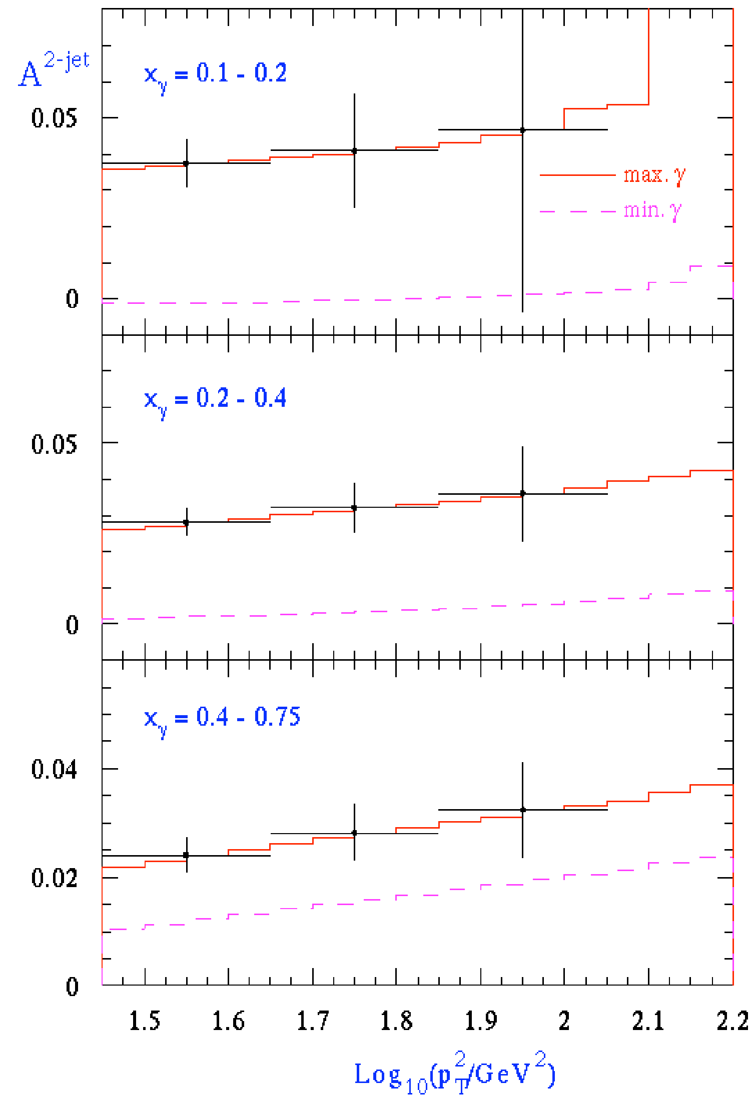


M. Stratmann, W. Vogelsang

Polarized PDFs of Photons

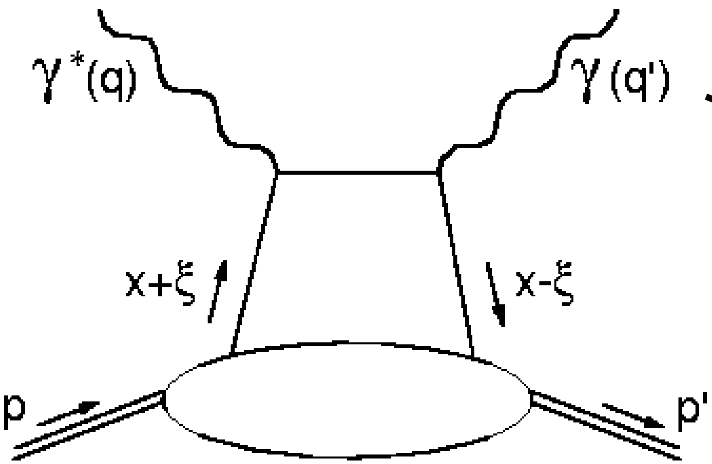
- Photo-production studies with single and di-jet





- 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 (~3 weeks) data, ZEUS acceptance: ample data to explore the QCD/spin structure of the photon

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!

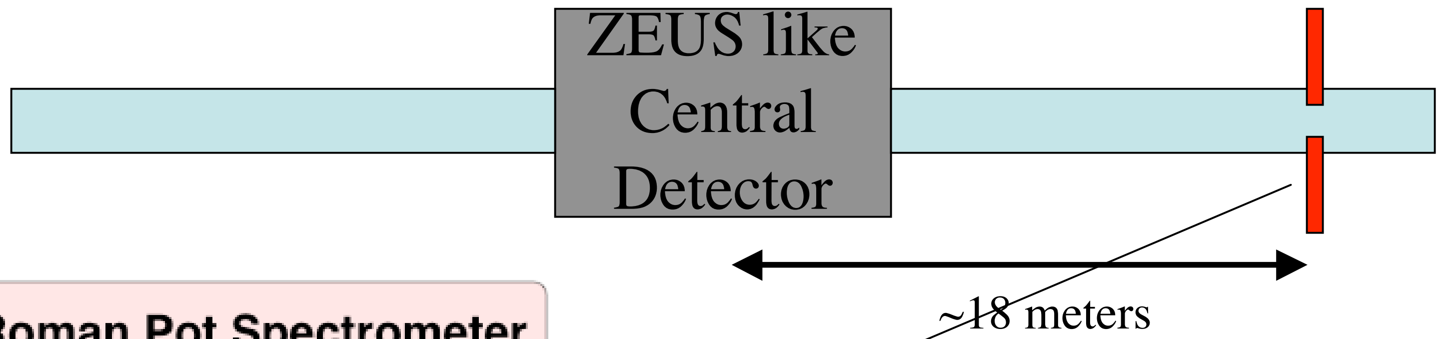
•Claim: Possible access to skewed or off forward PDFs?
Polarized structure: Access to quark orbital angular momentum?

$$\int x dx [H(x, \underset{\downarrow\, 0}{t}, \xi) + E(x, \underset{\downarrow\, 0}{t}, \xi)] = 2J_{quark} = \Sigma + 2L_q$$

On going theoretical debate… experimental effort just beginning…

A. Sandacz et al.

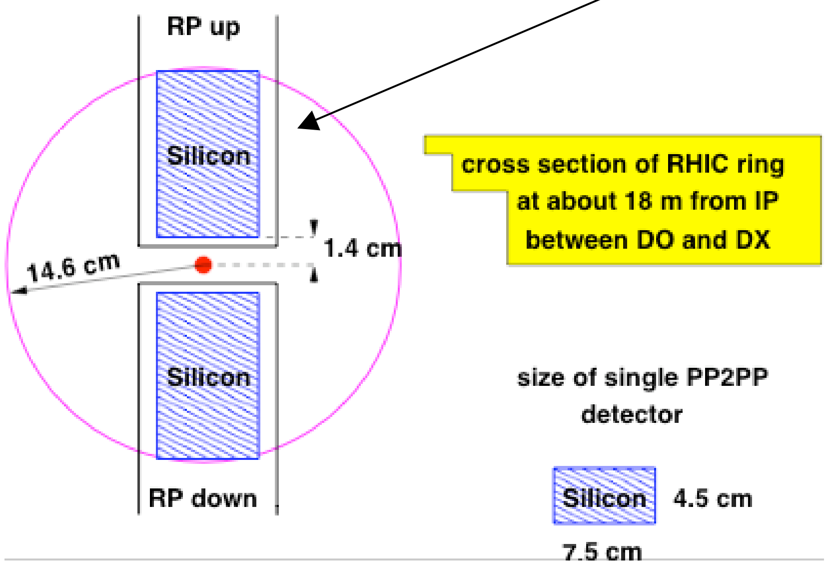
Roman Pots for eRHIC



Roman Pot Spectrometer

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

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)

Recent interest in eRHIC from HERA

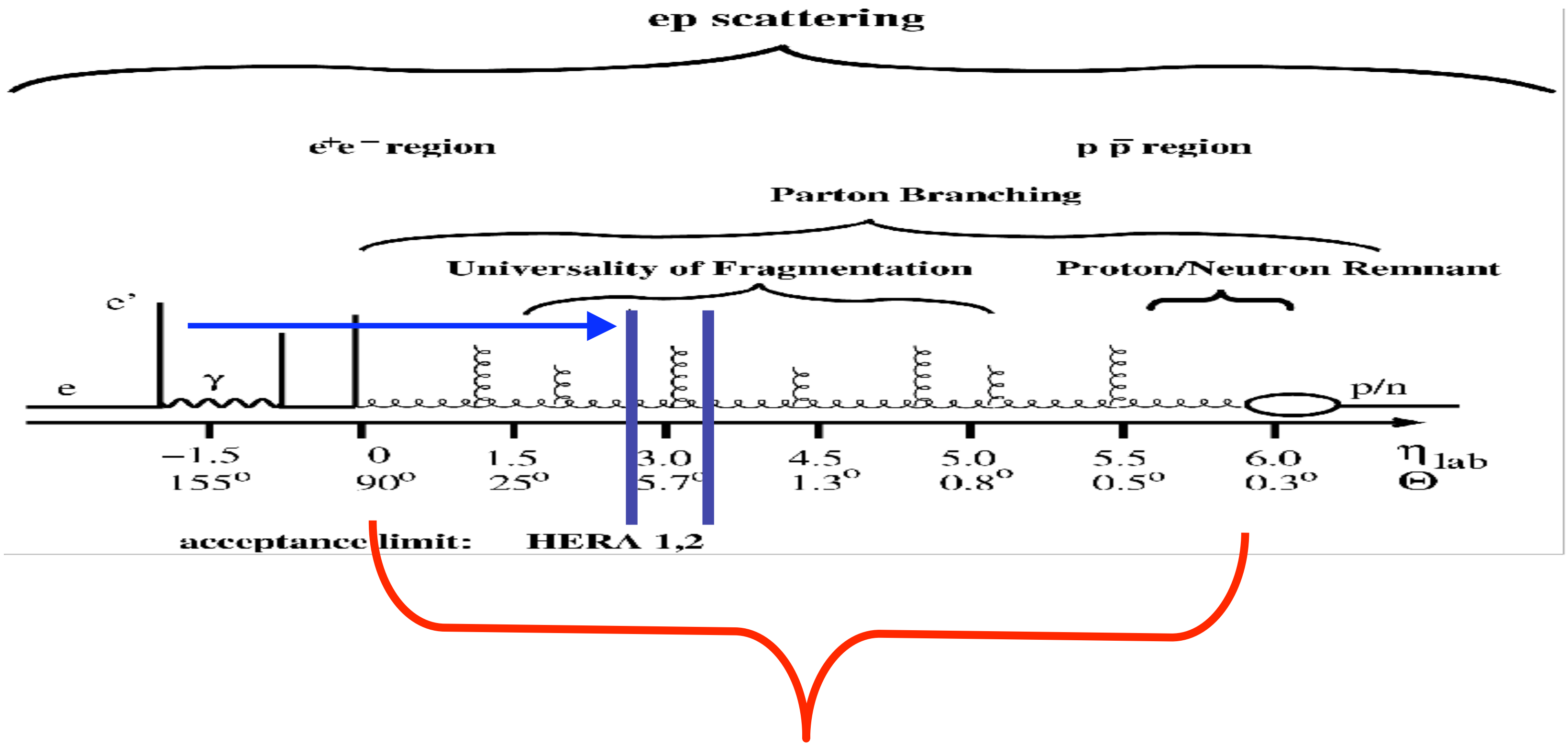
- Latest from HERA-III: probably no prospects for any Physics beyond 2007
- Physics of strong interaction, main motivation for HERA-III
  - **Understanding the radiation processes in QCD at small and large distances:**
    - Small distance scales: explores parton splitting (DGLAP, BFKL, CCFM…)
    - Large distance scales: transition from pQCD to non-pQCD regime
- Needs specially designed detector to look in to ***very forward*** directions, unprecedented so far at HERA

- Early indications are that eRHIC energies would be sufficient to study this physics… if a specially designed detector is installed in eRHIC

- Effort led by A. Caldwell, I. Abt et al. From Munich MPI

See B. Surrow's talk

A DETAILED STUDY OF RADIATION IN QCD: FORWARD JETS



Investigate this region

Large effects are expected in
Forward jet cross sections at high rapidities (also for forward particle production (strange, charm, …)

A. Caldwell et al.

See B. Surrow's talk

Highlights of e-A Physics at eRHIC

- Study of e-A physics in Collider mode for the first time
- QCD in a different environment

- Clarify & reinforce physics studied so far in fixed target e-A & μ-A experiments including target fragmentation

  QCD in: $x > [1/(2m_N R_N)] \sim 0.1$ (high x)

  QCD in: $[1/(2m_N R_A)] < x < [1/(2m_N R_N)] \sim 0.1$ (medium x)

  Quark/Gluon shadowing

  Nuclear medium dependence of hadronization

Vitev's talk yesterday

- …. And extend in to a very low x region to explore:

  saturation effects or high density partonic matter also called the Color Glass Condensate (CGC)

  QCD in: $x < [1/(2m_N R_A)] \sim 0.01$ (low x)

Jamal J. Marion's talk

Already hints of exciting physics in this from: HERA, RHIC d-A; if true, eRHIC will do a precision measurements in this regime

Many involved.... But more needed & Welcome!

- **eRHIC steering committee:**
  - A. Caldwell (Munich,MPI), **A. Deshpande (SBU),** R. Ent (Jlab), G. Garvey (LANL),R. Holt (Argonne), E. Hughes (Caltech), K. Imai (Kyoto), R. Milner (MIT), P. Paul (SBU), J.C.Peng (UIUC), S. Vigdor (Indiana)

- **The eRHIC Accelerator Group**: BNL, MIT/Bates, DESY, PNPI
  - Accelerator ZDR: Ed. V. Ptitsyn (BNL), M. Farkondeh (MIT/Bates)

  and ~40 other collaborators… from MIT, BNL, DESY,Jlab, and PNPI

- **Monte Carlo Simulation & Detector Group** (meets every 3-4 months)
  - A. Bruell (Jlab), A.D.(Stony Brook), R. Ent (Jlab), E. Kinney (Colorado), N. Makins (UIUC), C. Montag (BNL), E. Sichtermann(LBL), B. Surrow (MIT) (also pursue studies for ELIC at Jlab (lower sqrt(s) higher luminosity))
  - AND " eRHIC Collaboration:" ~100 or so people who contributed to the Whitepaper 2001/2

- **Supportive Theorists**:
  - L. McLerran (BNL), R. Venugopalan (BNL), W. Vogelsang (BNL), D. Kharzeev (BNL), M. Stratmann (Regensburg), M. Strikmann(PSU), X. Ji (Maryland), S.Kretzer (BNL), M. Diehl (DESY), J. J. Marion(UW), and many others!

If you are interested, please contact me!

eRHIC Status

- 2001 LRP: NSAC enthusiastically supported R&D and stated its would be the next major for nuclear physics (after 12 GeV Jlab upgrade)
- 2003 NSAC subcommittee's high recommendation
  - **Level 1 for physics, and level 2 for readiness**
- ***2003 One of the 28 "must-do" projects in the next 20 yrs of the DoE list***
- BNL Management Requested a Zeroth Design Report (ZDR): Ready 2004 April.
  - What can be done with minimal R&D and shortest time scale?
    - **eRHIC: Ring-Ring design (presently: "main design line")**
  - Identify parameters for enhanced machine parameters with identified R&D topics toward significant luminosity enhancement
    - **eRHIC: Ring-Ring design enhancement**
    - **eRHIC: Linac-Ring design**
  - BNL-MIT-Budker-DESY collaboration: ZDR ready April 2004
  - Includes a preliminary but realistic Cost Estimates
  - **RHIC Machine Advisory Committee: Review planned in June 2005**
- **Development on both projects ring-ring & linac-ring will continue in future until the time to make the decisions to freeze technology and design option**

http://www.bnl.gov/eic

Concluding Thoughts

- E-RHIC promises to be a truly next generation collider experiments
  - Detector ideas dictated by the physics are developing
  - Over the next couple of years come up with a "conceptual design"
  - **Many technical challenges, but none deemed unsolvable**
  - Critical issues of integration of detector + interaction region being looked in to **now**
    - Experience at HERA helps on accelerator/IR design as well as detector ideas

- ***To fully realize these ideas:***

  -- Need keep on a **fast path towards realization**

  -- Critical for the present DIS/Spin NON-RHIC experiments to have something tangible to proceed in a realistic time scale

  -- **We do not want to explore "how late" is "too late"!**

  -- **Next Step 1:** NSAC 2005/6 long range plan approval

- **The more people show interest, the better the chances for a quick realization of this project.**

http://www.bnl.gov/eic