Measurements & Detector at eRHIC

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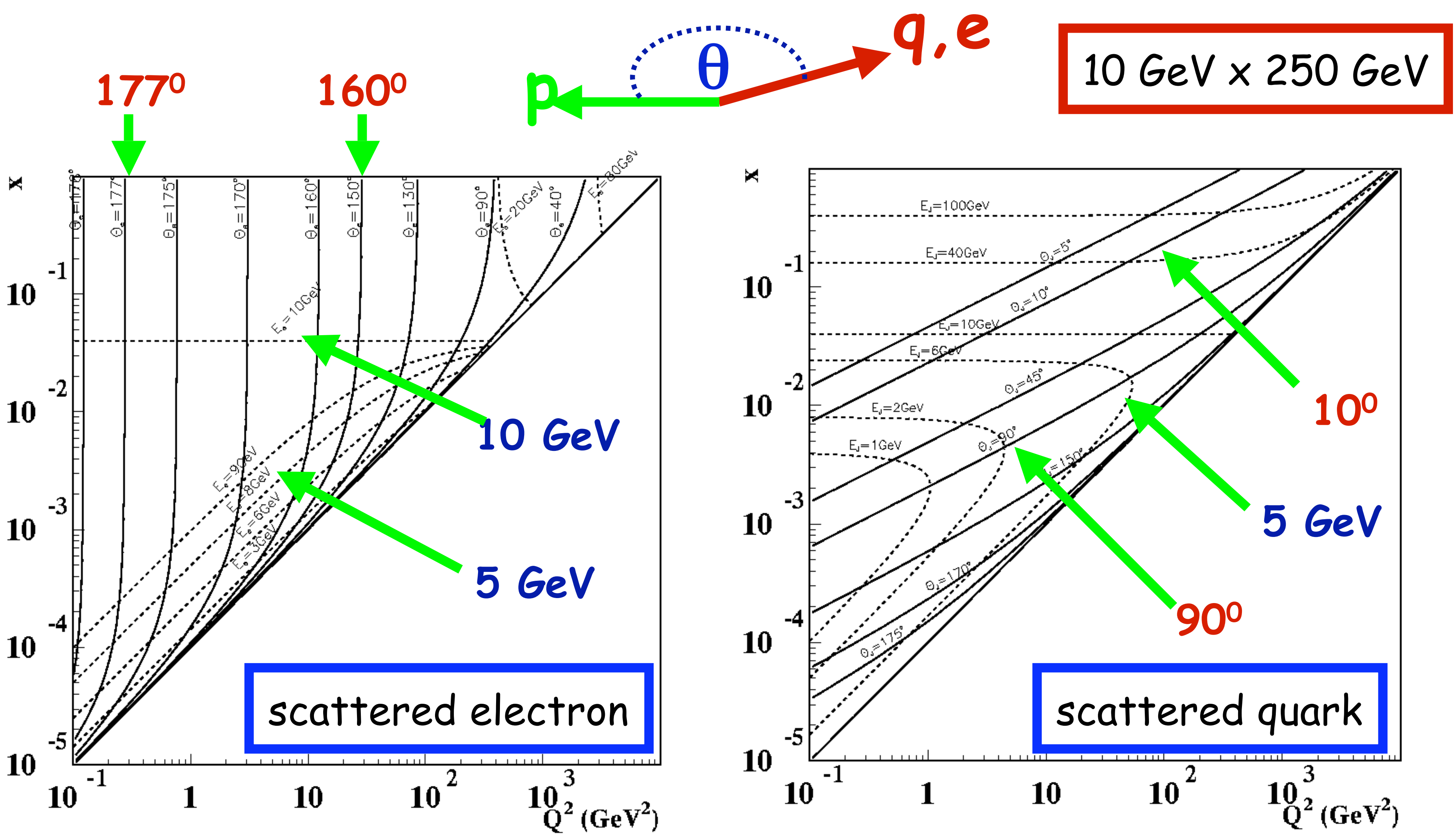
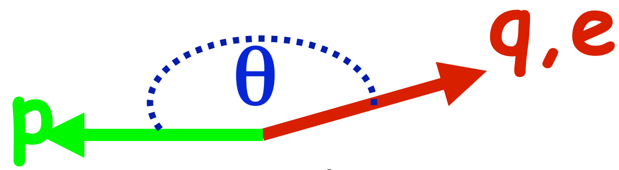
NSAC Subcommittee meeting at BNL
June 4, 2004

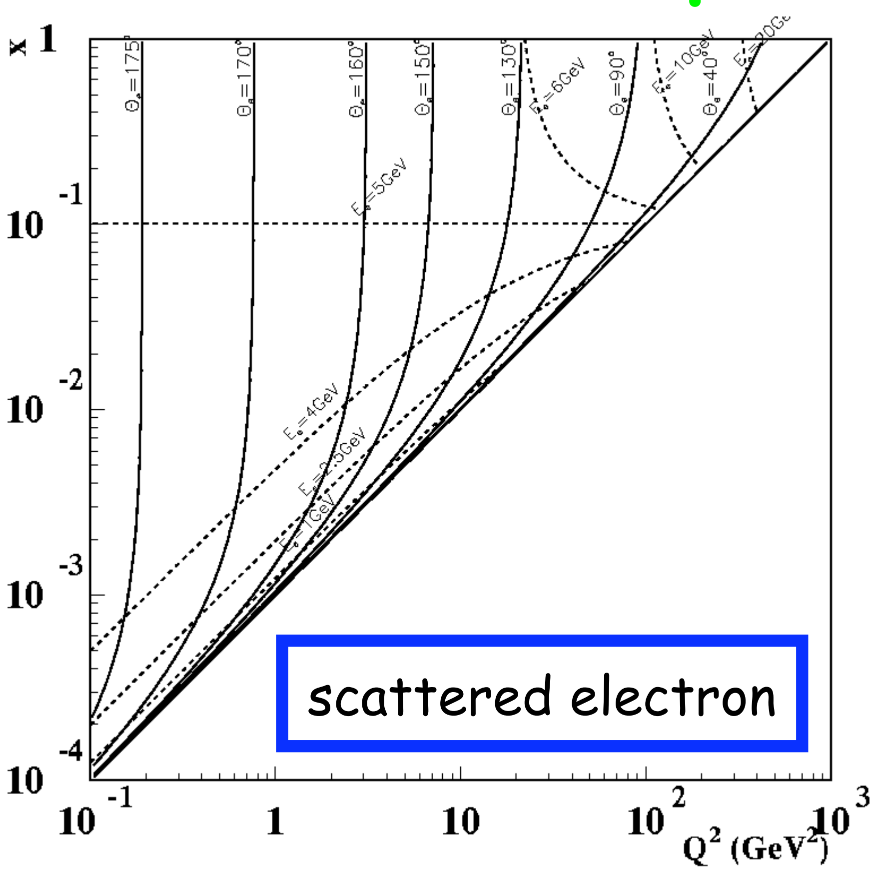
Where do electrons and quarks go?

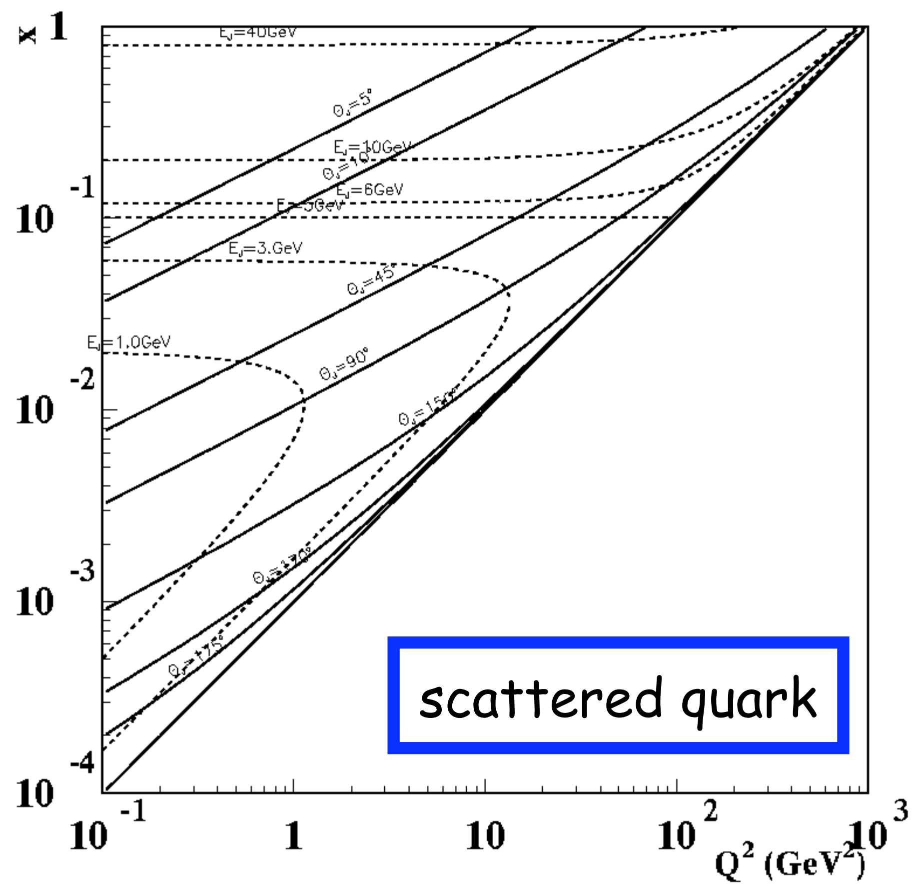


Electron, Quark Kinematics



5 GeV x 50 GeV





A Detector for eRHIC → A 4π Detector

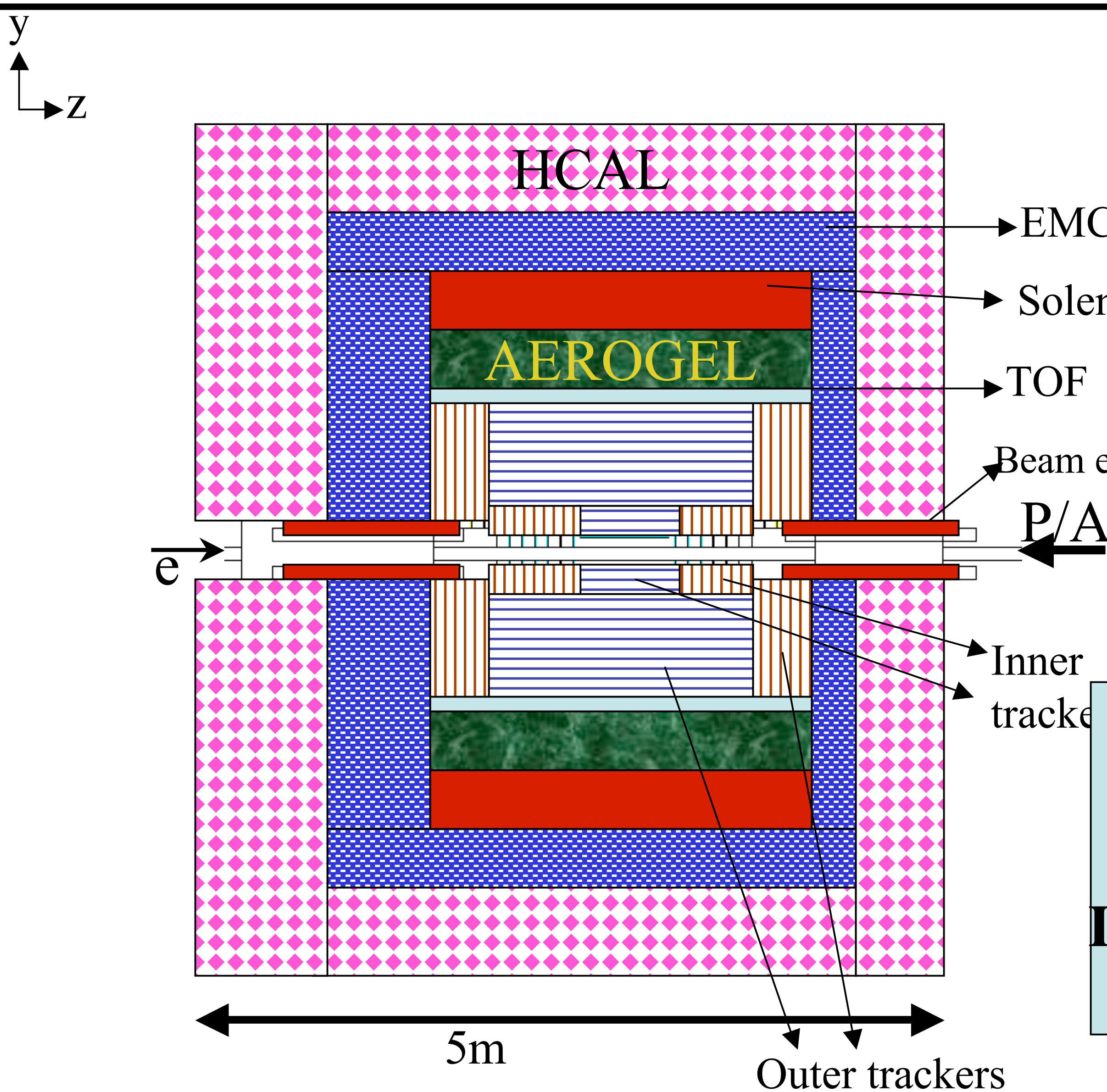
- Scattered electrons to measure kinematics of DIS
- Scattered electrons at small (~zero degrees) to tag photo production
- Central hadronic final state for kinematics, jet measurements, quark flavor tagging, fragmentation studies, particle ID
- Central hard photon and particle/vector detection (DVCS)
- ~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

B. Surrow, N. Smirnov, A. D.

Detector Design HERA like…+ PID



(Not to scale)

A HERA like Detector with dedicated PID:
>>Time of flight
>>Aerogel Ckov

AND

Forward detectors including Roman Pots etc…
Integrated in to the beam Elements!

Scientific Frontiers Open to the eRHIC

- **Nucleon structure, role of quarks and gluons in the nucleons**
  - Unpolarized quark and gluon distributions, confinement in nucleons
  - Polarized quark and gluon distributions
  - 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

Polarized DIS at eRHIC

- Spin structure functions g_1 (p,n) at low x, high precision
  -- g_1(p-n): Bjorken Spin sum rule better than 2% accuracy [1]
- 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
- Polarized s.f. of the photon from photo-production [1]
- Electroweak s. f. g_5 via $W^{+/-}$ production ★ [1]
- Flavor separation of PDFs through semi-inclusive DIS [1,2]
- Deeply Virtual Compton Scattering (DVCS) [1]
  >> Generalized Parton Distributions (GPDs) [1,2]
  [3]
- Transversity ★ [1]
- Drell-Hern-Gerasimov spin sum rule test at high ν [1]
- Target/Current fragmentation studies
- … etc…. [2,3]

Luminosity Requirement

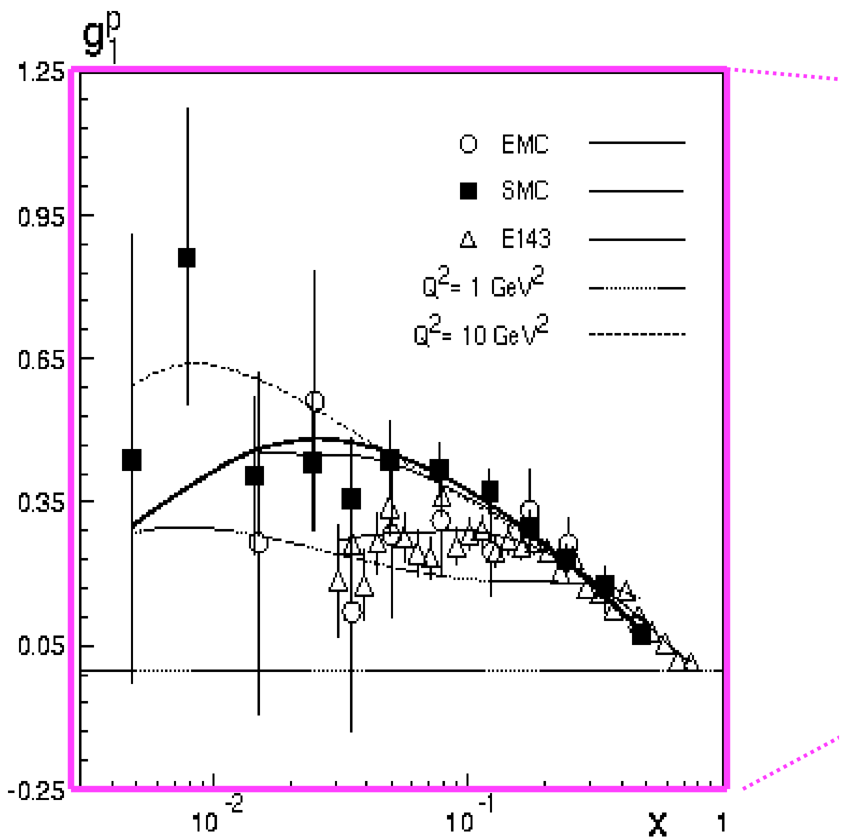
★ Also at RHIC SPIN; [1] --> inclusive, [2]--> semi-inclusive
[3] --> exclusive measurements

A.D. & V. W. Hughes

Proton Spin Structure at Low x

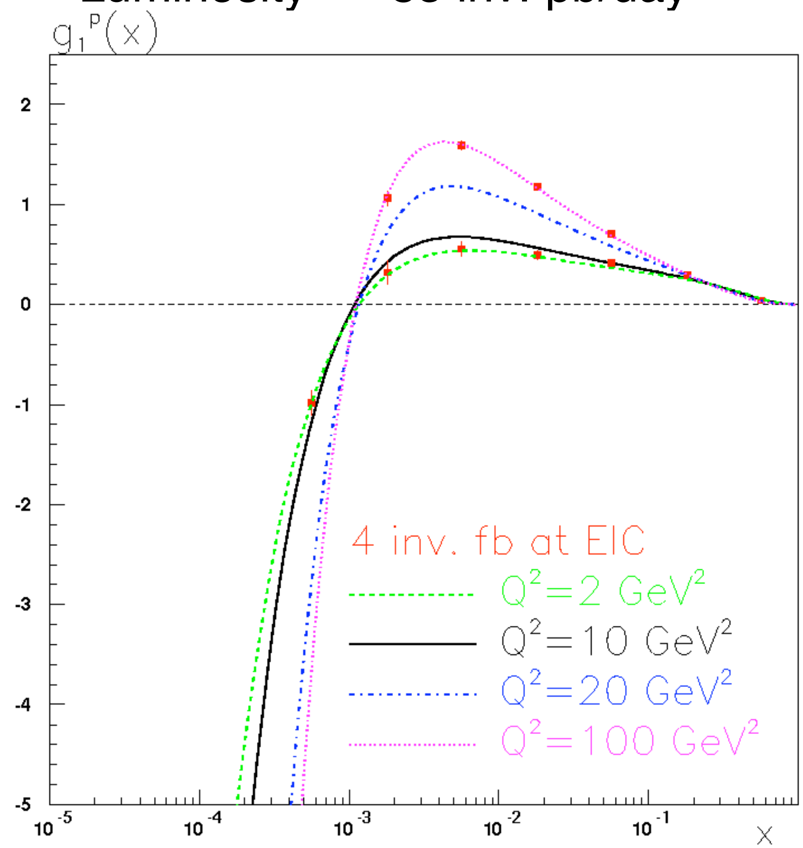
Fixed target experiments

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

Consequence of Precision Bj SR

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

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

Values range from 0.114-119 with uncertainties:

+/- 0.004 (experimental)

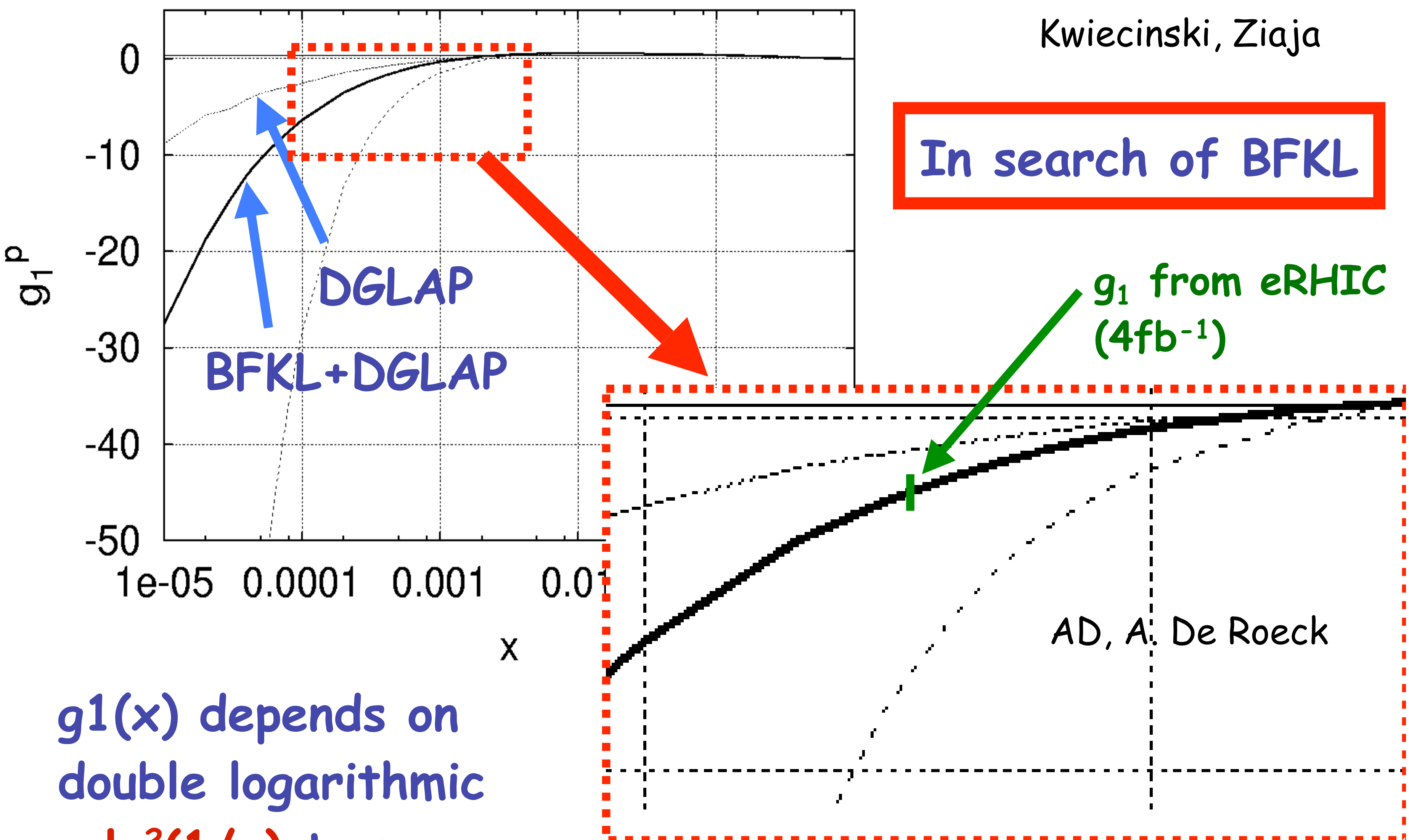
+/- 0.010 (theory/ low x extrapolation)

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



g1(x) depends on double logarithmic $\alpha_s \ln^2(1/x)$ terms

Fits of $g_1(x,Q^2)$+jets

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

Constrain better the shape and the first moment

ΔG determined from the Scaling violations of g1

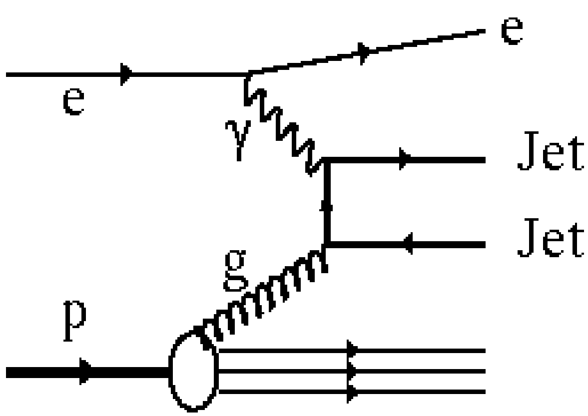
SMC Published 1998: First Moment of $\Delta G(x)$

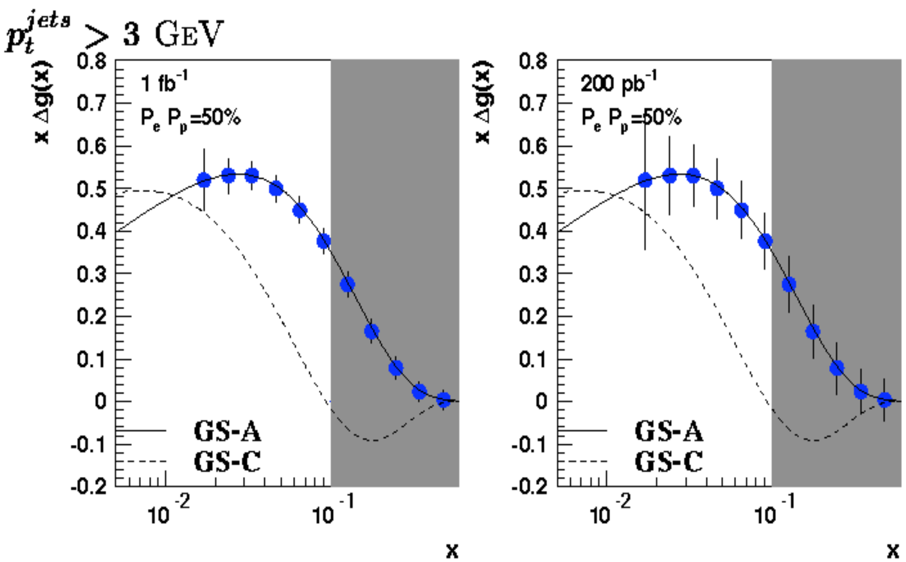
$\int \Delta G(x)dx =$ 1.0 +/- 1.0 (stat) +/- 0.4 (exp.syst) +/- 1.4 (theory)

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

-- low x --> strong coupling, functional form at low -x, renorm. & fact. scales

Di-Jet at eRHIC:

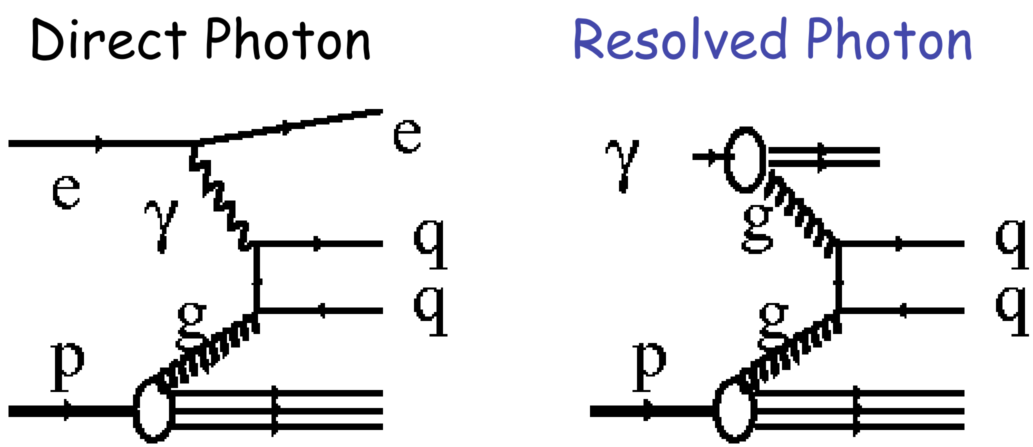


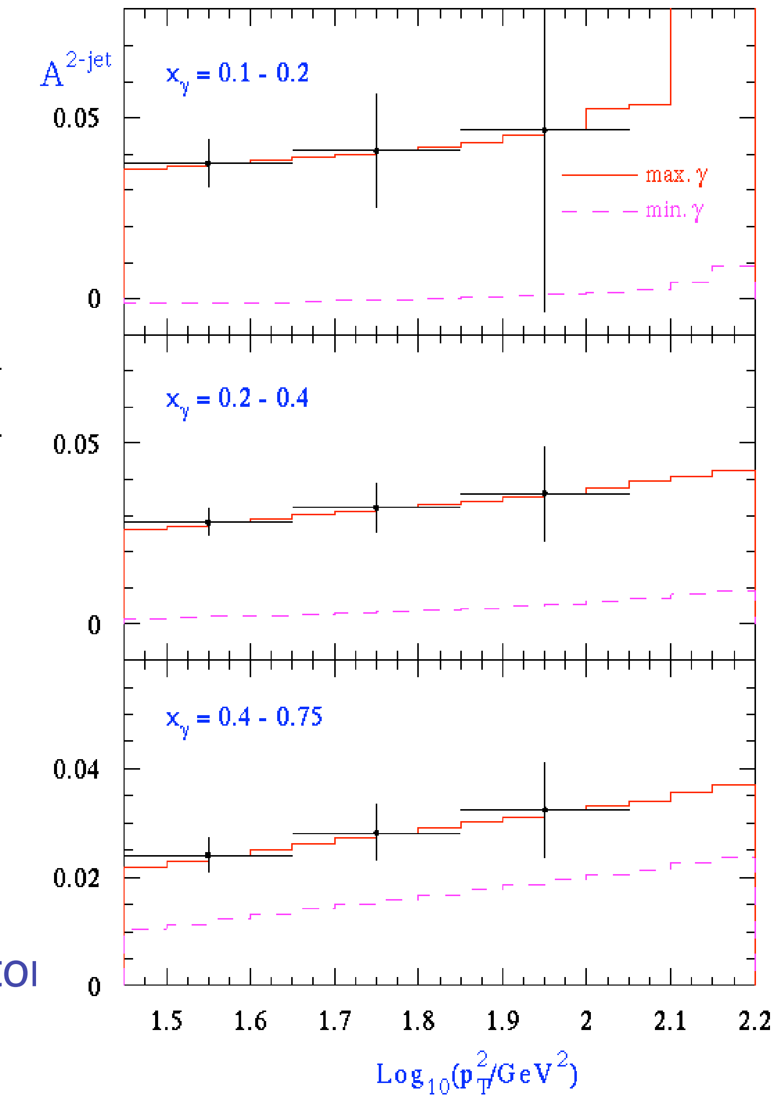


M. Stratmann, W. Vogelsang

Polarized PDFs of the Photons

- Photo-production studies with single and di-jet

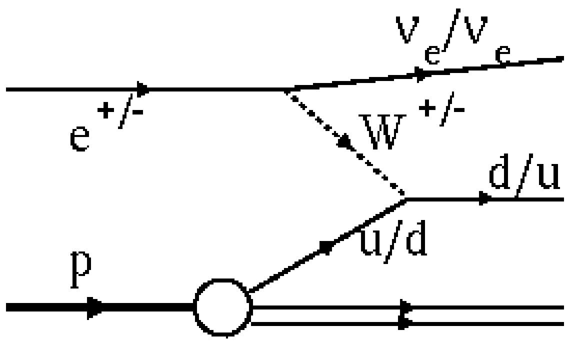




- Photon Gluon Fusion or Gluon Gluon Fusion (Photon resolves in to its partonic contents)
- Resolved photon asymmetries result in measurements of spin structure of the photon
- 1 fb-1 (~3 weeks) data, ZEUS acceptance: ample data to explore the QCD/spin structure of the photoı

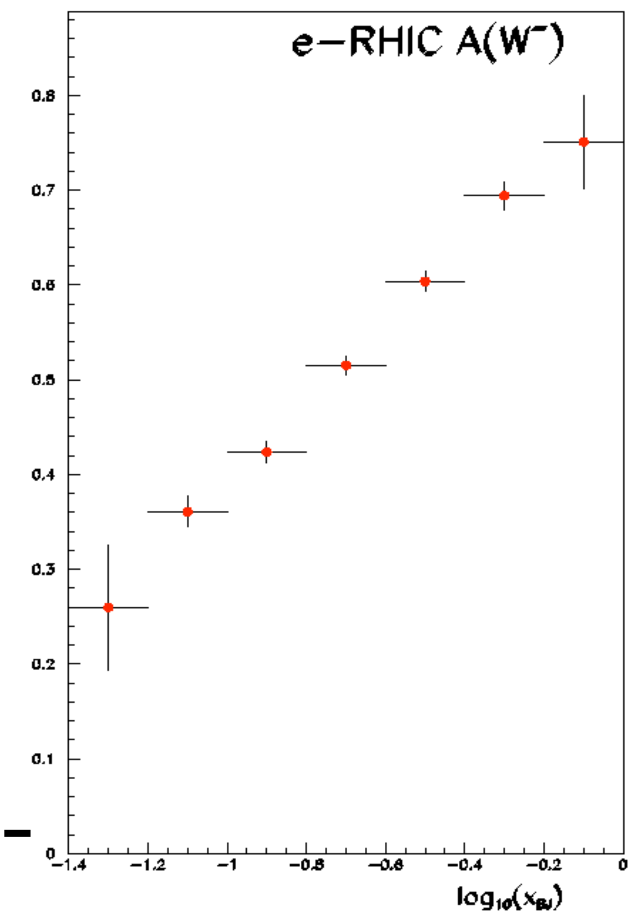
J. Contreras, A. De Roeck

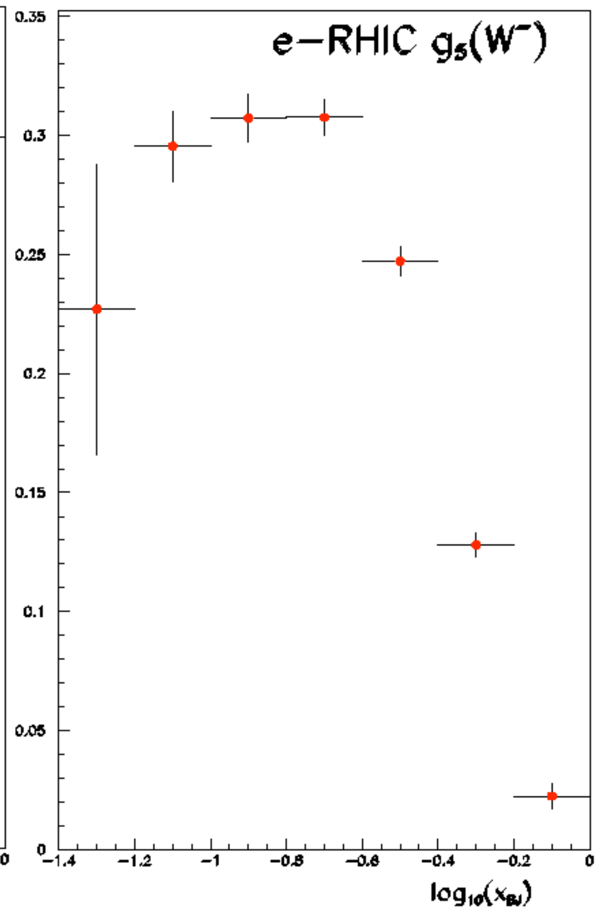
Measurement Accuracy PV g_5 at eRHIC



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

Need hermetic detector like ZEUS/H1





Assumes:

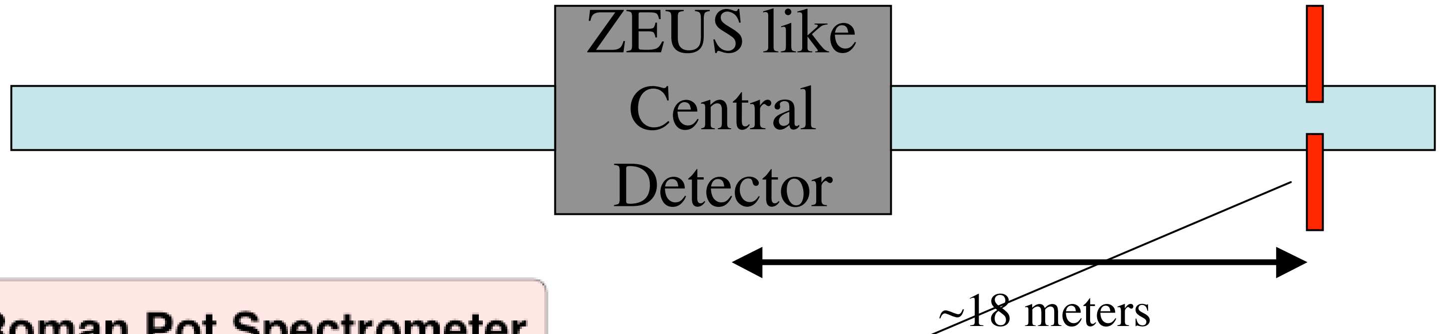
1. Input GS Pol. PDfs
2. xF_3 measured
3. 4 fb^{-1} luminosity

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

>> reason for keeping the option of positrons in eRHIC

A. Sandacz, A.D.

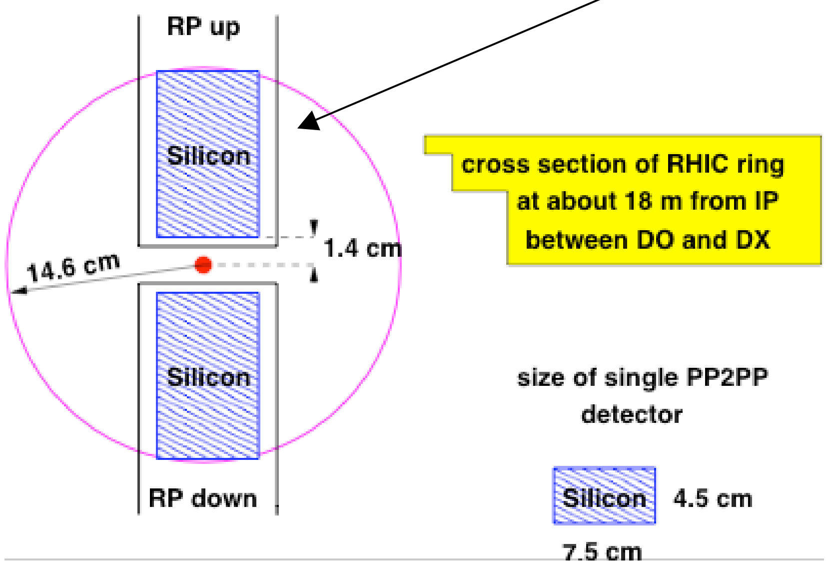
Roman Pots for eRHIC



Roman Pot Spectrometer

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

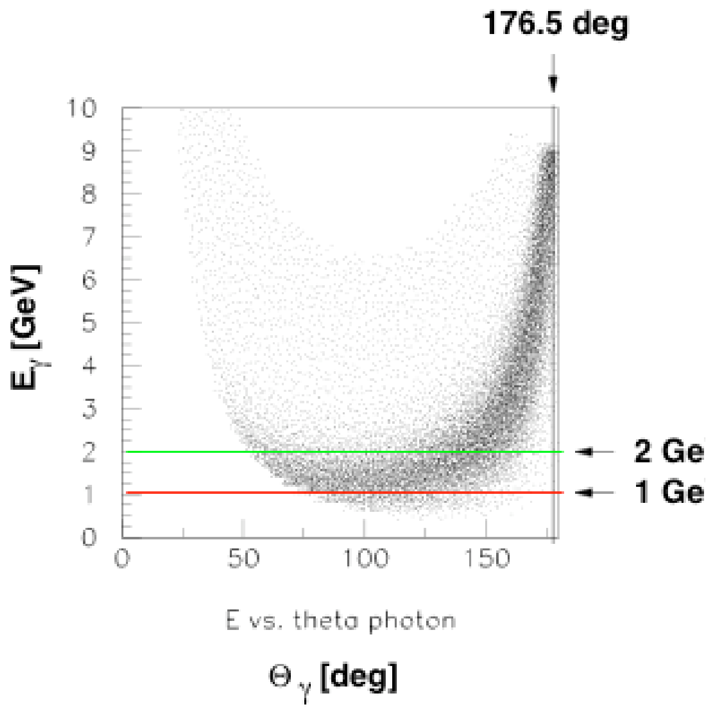
Generate DVCS events with Frankfurt et al. PRD58 (1998)



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)

Study DVCS acceptance



Central Detector Acceptance

$2.2 < \Theta_{e'} < 176.5$ deg

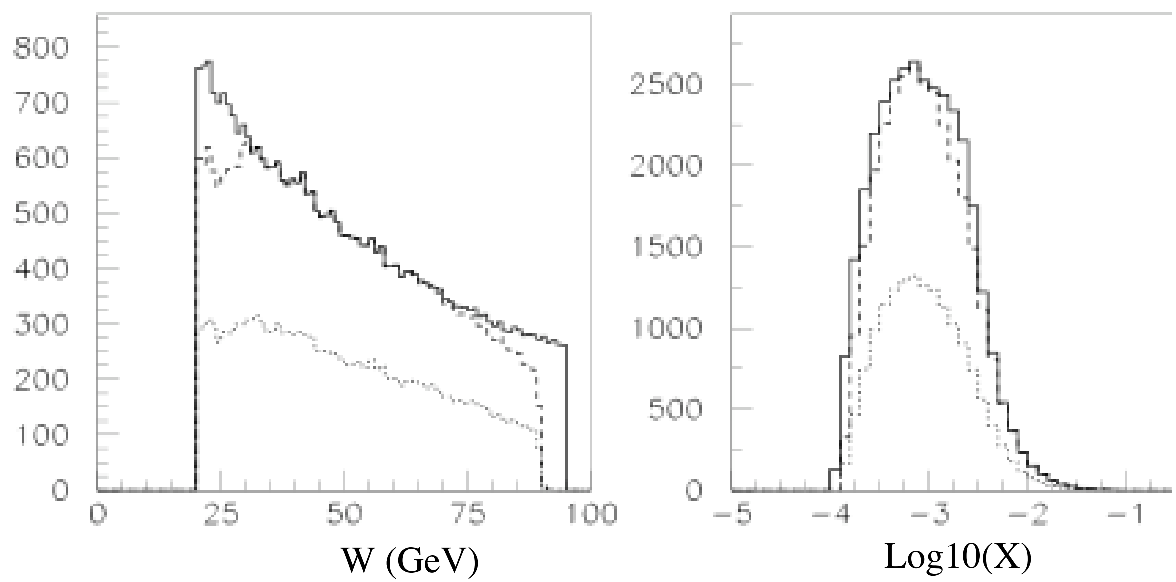
$2.2 < \Theta_\gamma < 176.5$ deg

$\Theta_{e'\gamma} > 3.1$ deg

$E_{e'} > 2$ GeV

$E_\gamma > 1$ GeV

$E_\gamma > 1$ GeV



Signatures of Novel Small x Physics (I)

Inclusive measurements:

Structure functions $F_2(x,Q^2)$, $dF_2/d\ln Q^2$, $dF_2/d\ln x$

- $dF_2/d\ln Q^2$ at fixed x at high Q^2 is the gluon distribution
  >> CGC vs. conventional pQCD predict very different
- Quark shadowing ($F_2^A/A*F_2^N$) in fixed target experiments observed
- Gluon shadowing ($G^A/A*G^N$) indirect evidence only… pQCD at NLO
- Gluon measurements using semi-inclusive… **di-jet final states**
- eRHIC collider-detector ideal

Longitudinal structure function $F_L = F_2 - 2xF_1$

- Provide independent gluon distribution measurement
- Needs variable electron beam (sqrt(s)) energy → Possible at eRHIC

Signatures of Novel Small x Physics (II)

DIFRACTION at eRHIC:

Shadowing and diffraction:

- Measurements of diffractive structure functions F_2^D and F_2^L as functions of (x,Q2,t,x_pomeron) --> Examine relation with shadowing (Gribov)

  >> Will need good acceptance/tracking in" forward/backward" acceptance regions

Hard Diffraction $e + A \rightarrow e' + \gamma^* + A \rightarrow e' + X + A;\ M_X^2 >> \Lambda_{QCD}^2$

- Large rapidity gap between current and target fragmentation region. At HERA 7-10% cross section diffractive.

  In e-A at eRHIC, diffractive processes may contribute 30-40% to the total cross section.

  >> Also good acceptance/tracking in "forward & backward" regions

Coherent & Inclusive vector meson production:

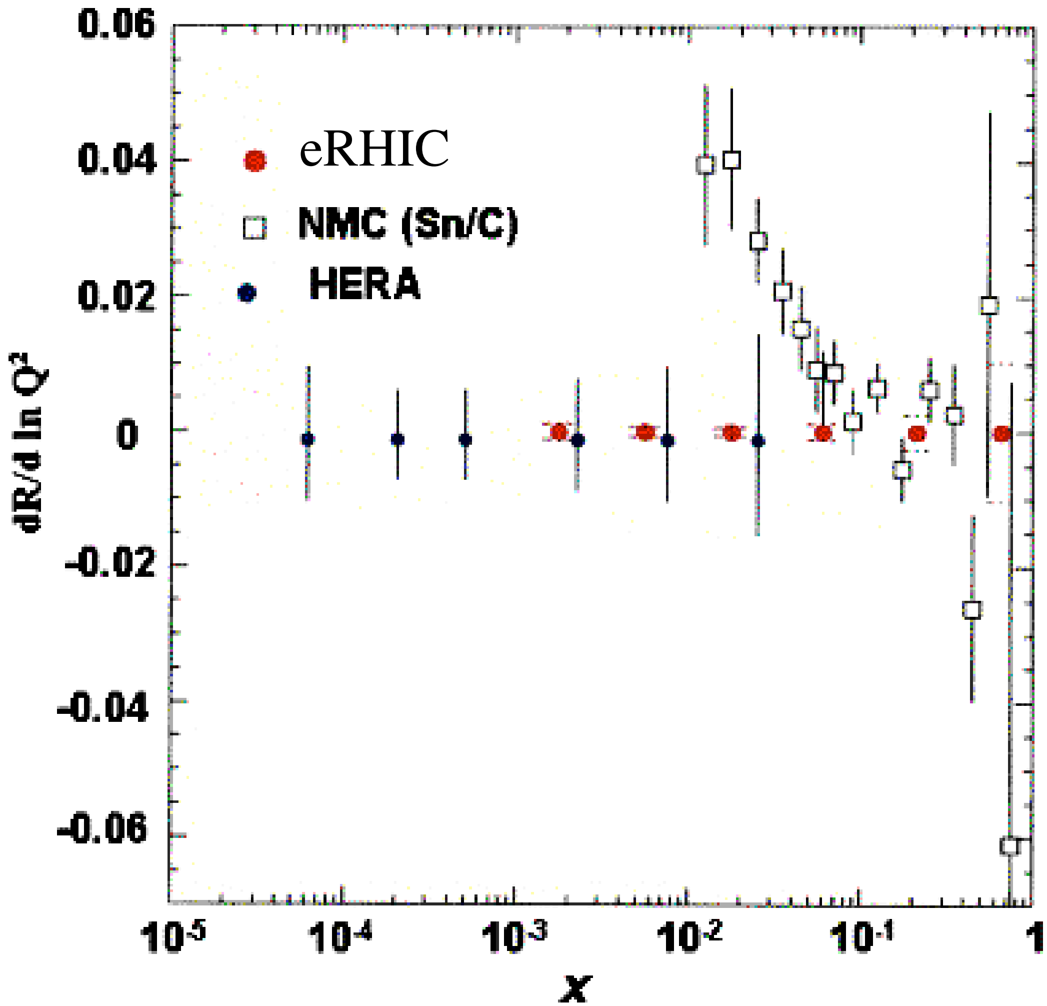
- For light vector mesons diff. Cross section. = 0.5 (inclusive)

  Heavy vector mesons this decreases…finally reaching 1/lnQ2

  eRHIC will measure for different nuclei, $\rho,\omega,\phi,J/\psi,\Upsilon$ cross sections

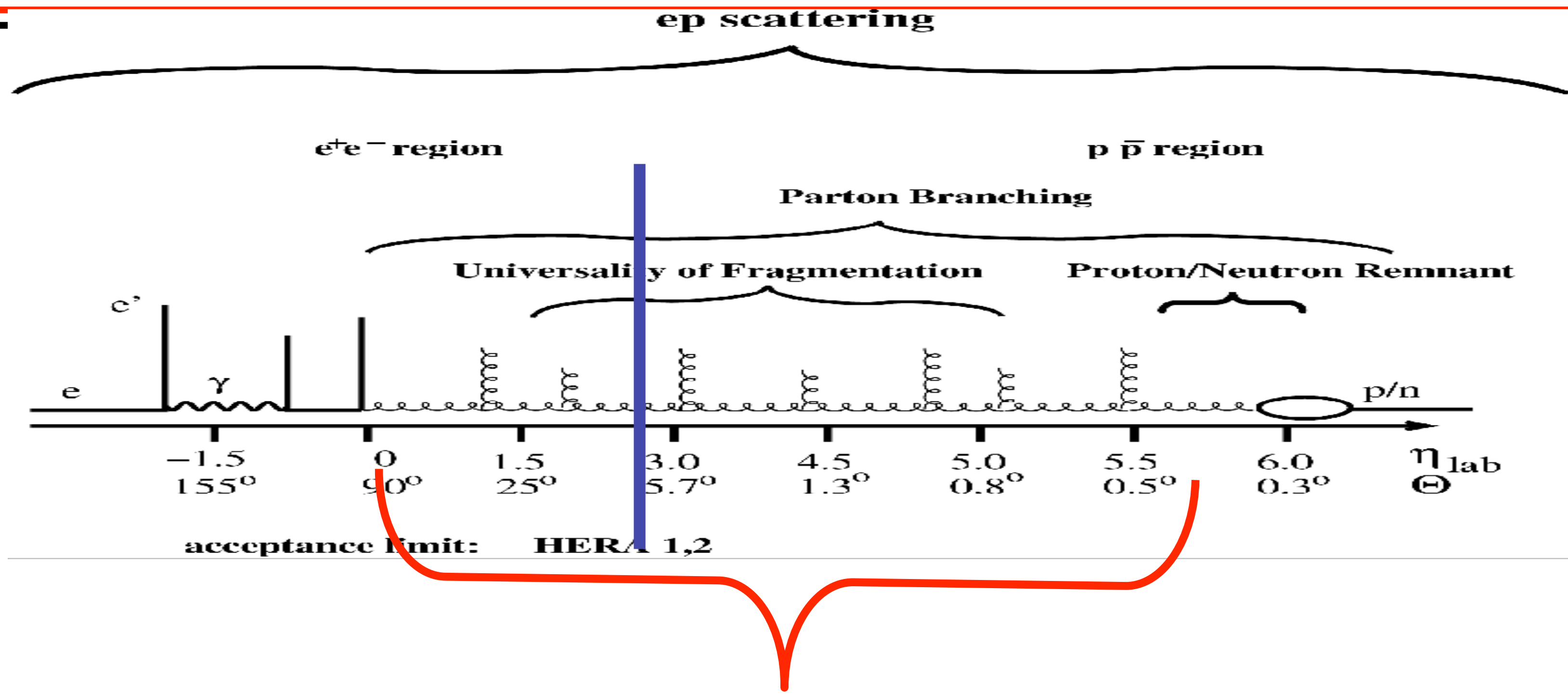
T. Sloan

Statistical Precision at eRHIC for e-A



- High precision at eRHIC shown statistical errors for 1 pb^{-1}/A
- Recall: eRHIC will ~85 pb^{-1} per day
- NMC data $R=F_2(Sn)/F_2(D)$
- eRHIC's Q^2 range between 1 and 10 GeV^2
- Will explore the interesting low x region!

More detailed tests of radiation in QCD: forward jets



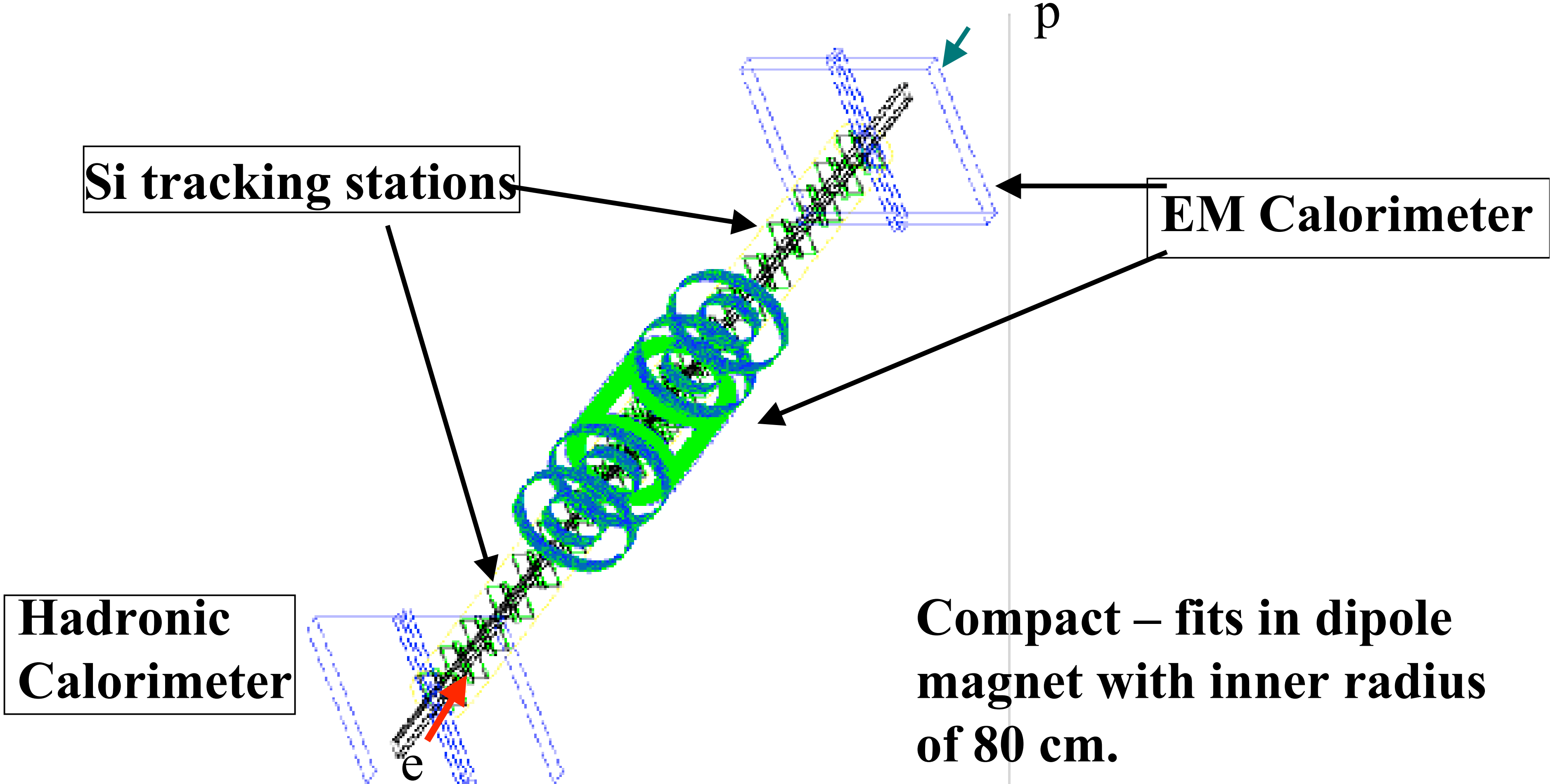
Investigate this region

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

A. Caldwell et al.

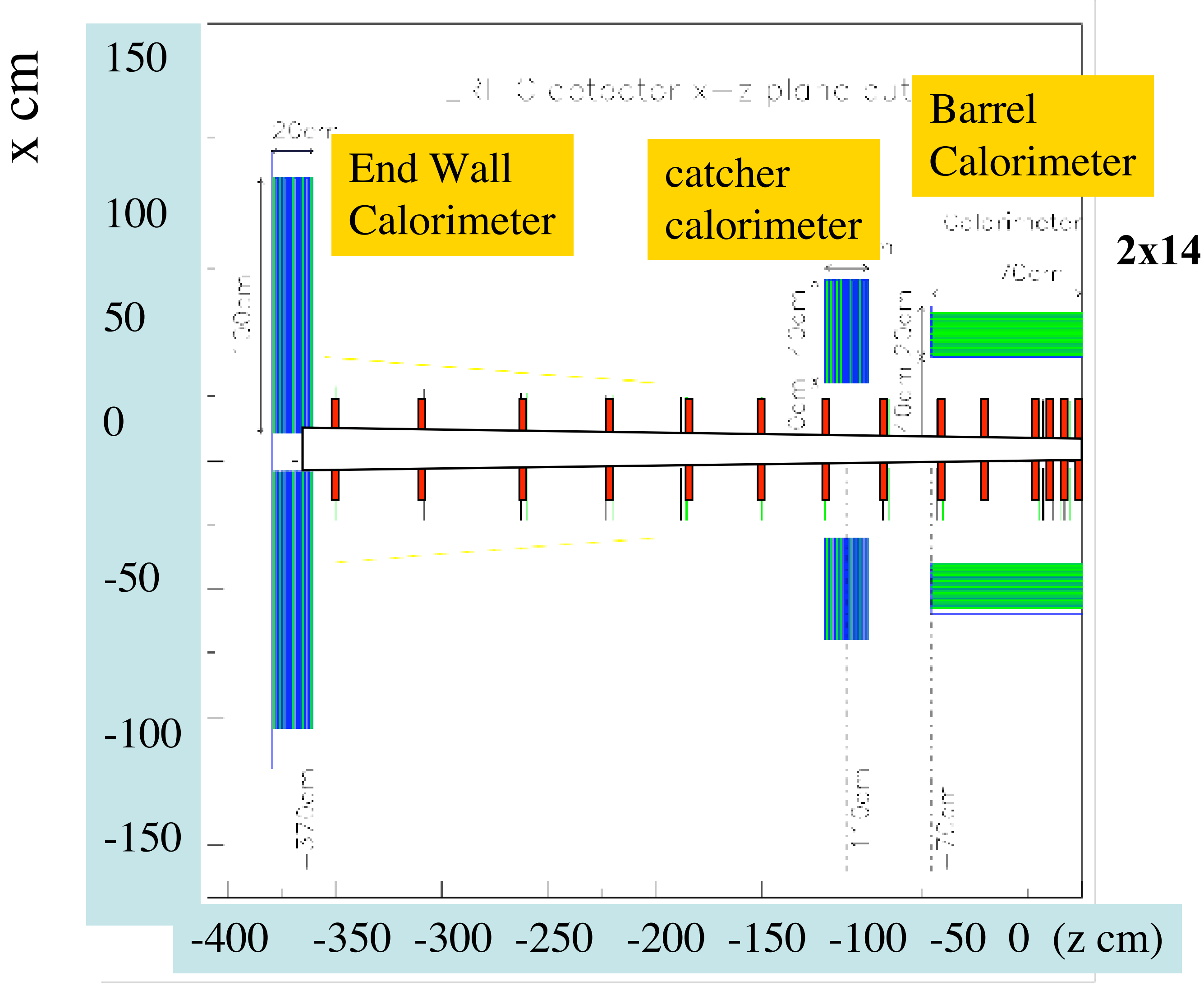
A new detector to study strong interaction physics

A. Caldwell et al.



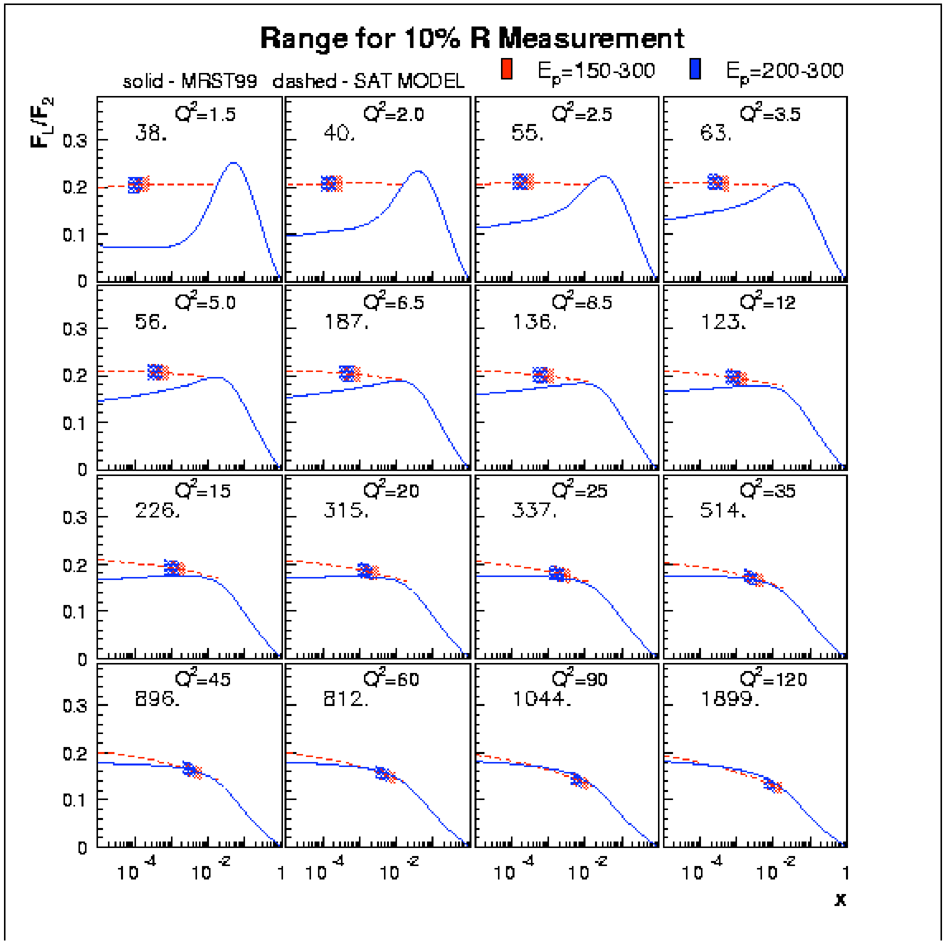
Compact – fits in dipole magnet with inner radius of 80 cm.
Long - |z|≤5 m

Low x Detector studies for eRHIC



2x14 Si tracking stations

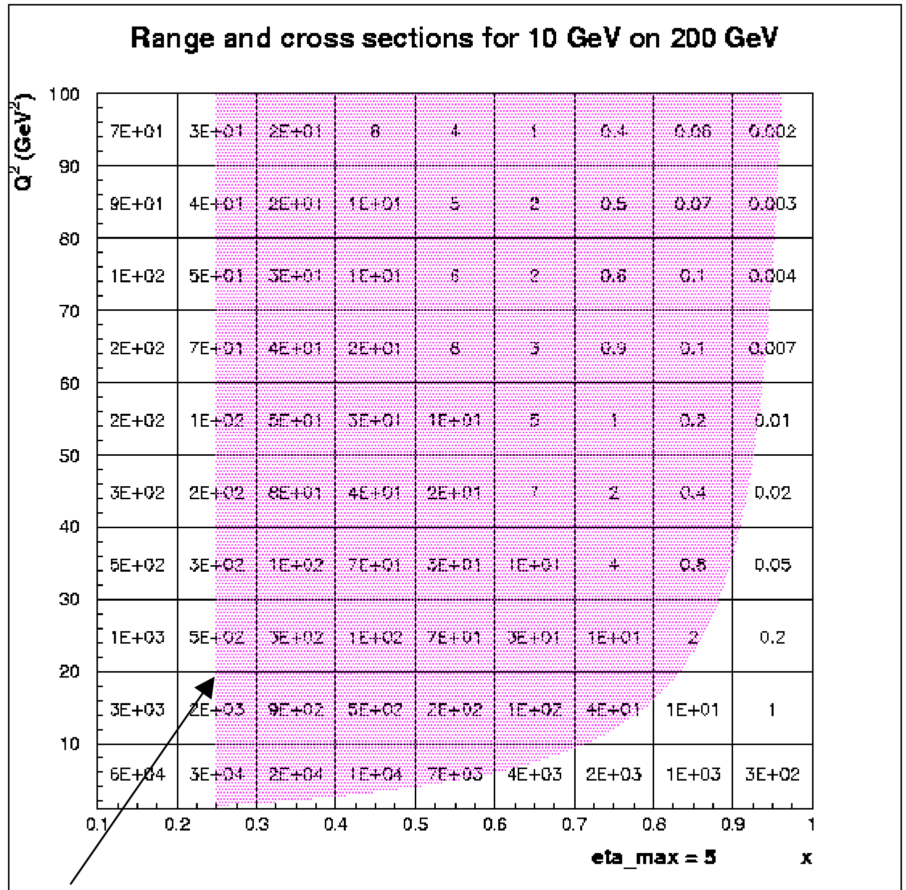
F_L/F_2 vs. x for different Q^2



High x measurement

W^2>5 GeV^2

Cross sections in pb



Q^2 \ x	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1
90–100	7E+01	3E+01	2E+01	8	4	1	0.4	0.06	0.002
80–90	9E+01	4E+01	2E+01	1E+01	5	2	0.5	0.07	0.003
70–80	1E+02	5E+01	3E+01	1E+01	6	2	0.6	0.1	0.004
60–70	2E+02	7E+01	4E+01	2E+01	8	3	0.9	0.1	0.007
50–60	2E+02	1E+02	5E+01	3E+01	1E+01	5	1	0.2	0.01
40–50	3E+02	2E+02	8E+01	4E+01	2E+01	7	2	0.4	0.02
30–40	5E+02	3E+02	1E+02	7E+01	3E+01	1E+01	4	0.8	0.05
20–30	1E+03	5E+02	3E+02	1E+02	7E+01	3E+01	1E+01	2	0.2
10–20	3E+03	2E+03	9E+02	5E+02	2E+02	1E+02	4E+01	1E+01	1
0–10	6E+04	3E+04	2E+04	1E+04	7E+03	4E+03	2E+03	1E+03	3E+02

Summary:

- eRHIC promises to be truly a next generation collider experiment
  - detector ideas dictated by the physics are developing
  - over the next year, the focus will be to refine them and 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 the fruits of these ideas:***

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

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

  -- Technically driven schedules (Milner,Aronson,Kirk)

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

Many involved….

- The **eRHIC steering committee** (Richard M.'s talk)

- **The eRHIC Accelerator Group**: BNL, MIT/Bates, DESY, PNPI

  >> Accelerator ZDR: Ed. V. Ptitsyn (BNL)

  M. Farkondeh (MIT/Bates)

  and~40 other collaborators… (see ZDR front page)

- **Monte Carlo Simulation & Detector Group** (meets every 3-4 months)

  A. Bruell (Jlab), A.D.(Stony Brook/RBRC), R. Ent (Jlab), E. Kinney (Colorado), N. Makins (UIUC), E. Sichtermann(LBL), B. Surrow (MIT) and a special mention for Grad. Student Joe Seele (Colorado)

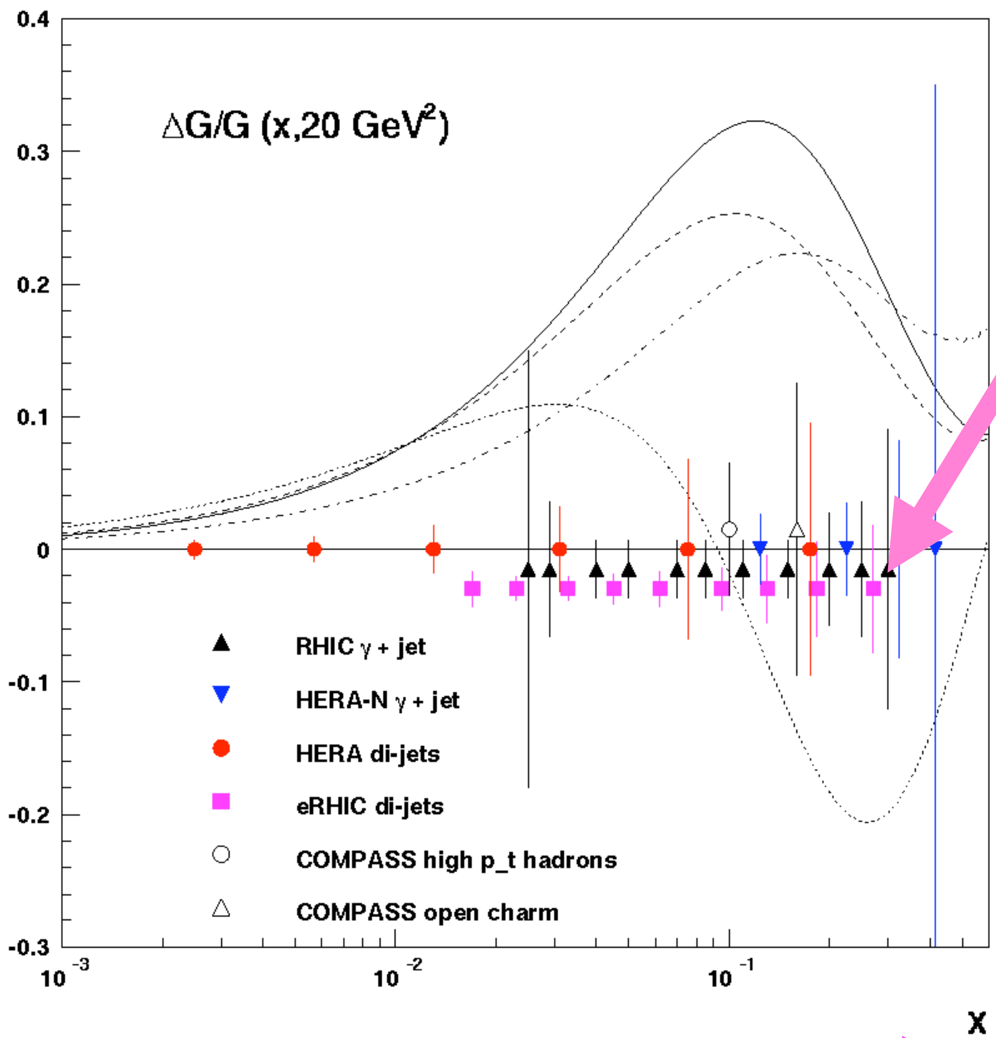
  "Collaboration:"

  \+ ~100 or so people who contributed to the Whitepaper 2001/2

- **Friendly Theorists**: L. McLerran (BNL), R. Venugopalan (BNL), W. Vogelsang (BNL), M. Stratmann (Regensburg) M. Strikmann(PSU), X. Ji(Maryland), S.Kretzer(BNL)

G. Radel, A. De Roeck
AD

Di-Jet at eRHIC vs. World Data for ΔG/G



eRHIC Di-Jet DATA 2fb^{-1}
(half a run)

(RHIC at 200 GeV CM Only…)

Good precision

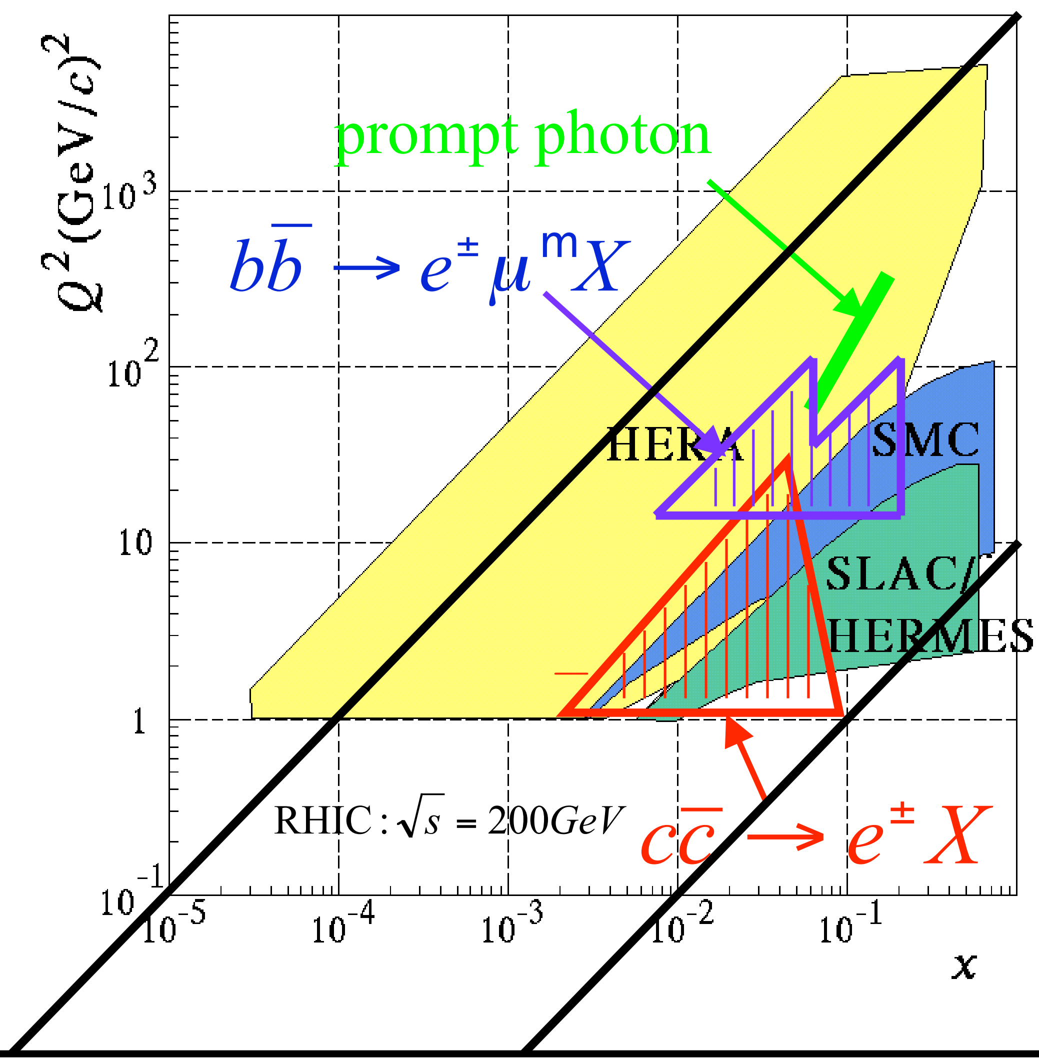
Clean measurement in x range 0.01< x < 0.3

Constrains shape of ΔG(x)

Polarization in HERA will not happen!.

ΔG from scaling violations $> x_{min} \sim 10^{-4}$ at eRHIC

RHIC vs. eRHIC extension



NOTE:
-- RHIC/PHENIX plots for 200 GeV CM
-- At 500 GeV these will increase low x reach by ~1/2 a decade in low x

eRHIC region denoted by two Dark black lines.
-- Continuous coverage