Physics and Prospects of RHIC Spin and eRHIC

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Workshop on QCD in Nuclear & Hadronic Physics
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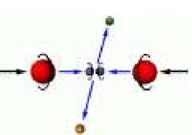
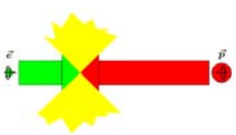




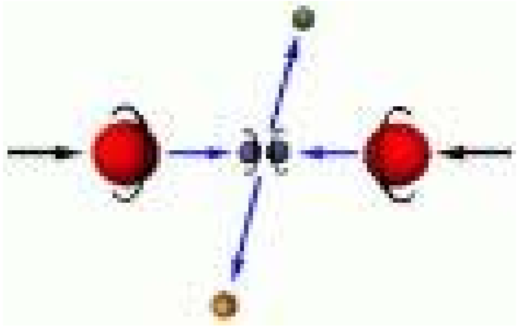

March 1, 2005, 8:15 AM Long Island NY
While I am waiting for the snow emergency to clear!

Outline

- The RHIC Spin Program status and plans
  - Relativistic Heavy Ion collider as a polarized p-p collider
  - Proton beam polarimetry
  - The Collider Detectors: PHENIX and STAR & their measurements
  - Near future prospects at time-lines
    - Accelerator development plans
    - Future physics measurements
- The eRHIC polarized & un-polarized DIS beyond RHIC
  - The eRHIC collider parameters and physics potential
  - The polarized and un-polarized physics program with eRHIC
  - The accelerator development and modifications to RHIC
    - Various options and consequences
    - Detector ideas
  - Status, plans and time scales

Nucleon Spin Structure and RHIC Spin

A near term perspective



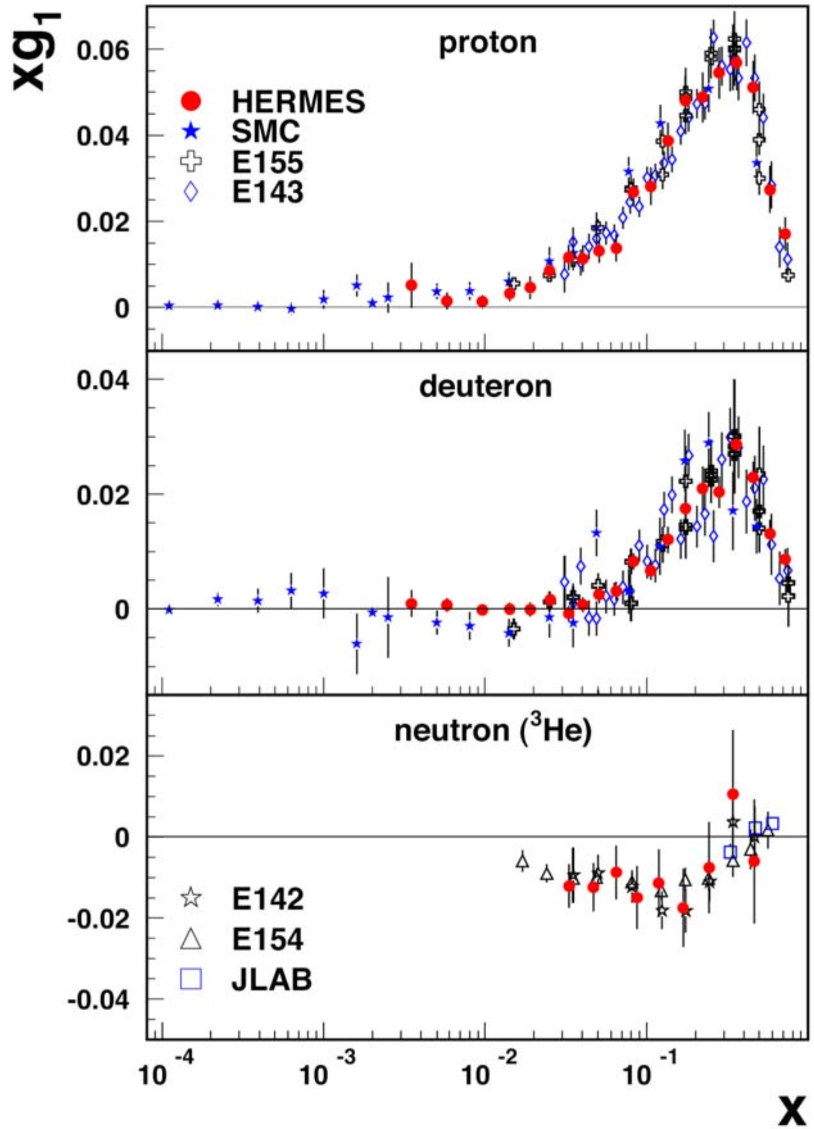
Milestones: Exploring Nucleon Spin

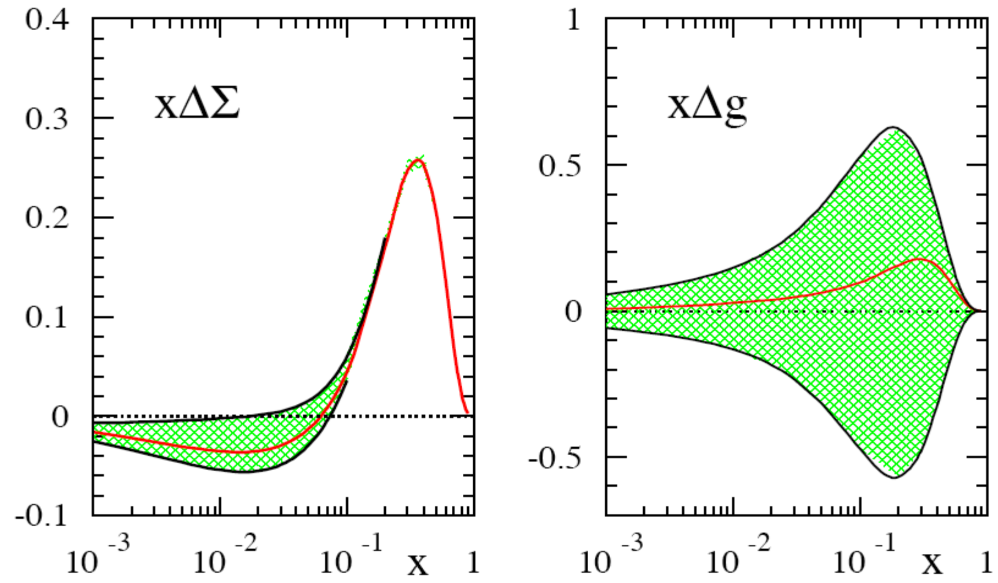
- The Proton Spin Crisis (DIS Experiment: European Muon Collaboration, EMC, 1989 at CERN)

- Many experimental efforts initiated: Spin Muon Collaboration, COMPASS at CERN, E142---E155 at SLAC, HERMES at DESY
  - Confirmed the results of the of EMC
  - New precision pushed development of precision theoretical tools
  - Attempts to understand the role of gluons in nucleon spin started
- Next-to-Leading Order calculations to analyze the data became available
  - Spin ``Crisis” turned to Spin ``Puzzle”

- ***RHIC Spi*** $\frac{1}{2} = < S_q > + < S_g > + < L_q > + < L_g >$ ***h eRHIC future***

xg_1^p, $x\Delta\Sigma$, $x\Delta G$: our present knowledge



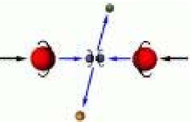


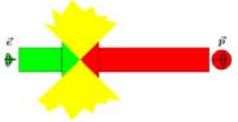
World's data on g_1 of the p, D and ^{3}He (neutrons)

Next to Leading Order pQCD analysis leads to polarized parton distributions including the gluon which has large uncertainties

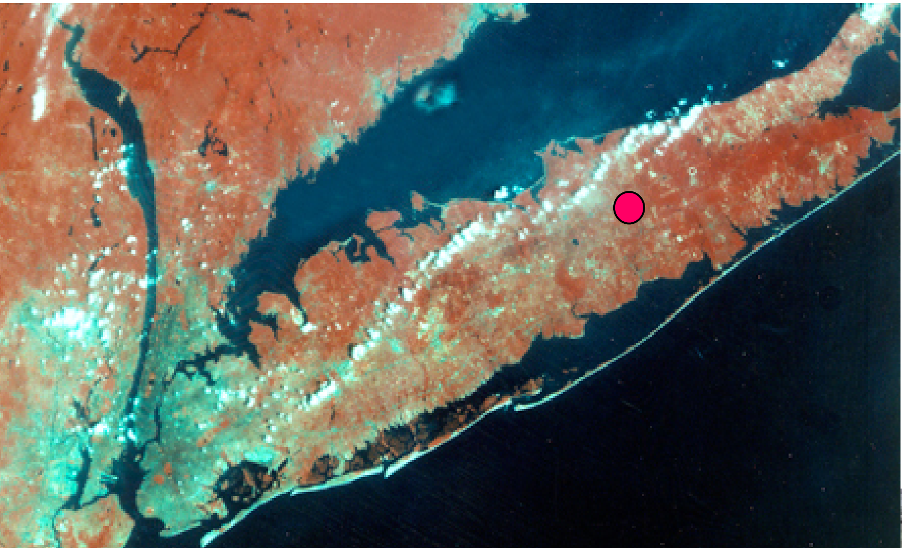
Nucleon Spin: Some compelling questions

- How do gluons contribute to the nucleon spin?
  - $1/\alpha_s(Q^2)$ evolution and significance of high scales at RHIC?
- What are the patterns of u, d, s quark and anti-quark polarizations?
  - In DIS virtual photon(s) explore (Δq+Δqbar) not individually Δq and Δqbar; separating them is of significance in view of
    - ubar - dbar non zero! From DIS and DY measurements; s-sbar quark asymmetry and NuTeV results of 3-σ anomaly in Weinberg Angle
- What orbital angular momenta do partons carry?
  - Off-forward parton distributions: a nucleon has different momenta in initial and final state
  - Measurements: certain rare exclusive processes in lepton-nucleon scattering (Deeply Virtual Compton Scattering - an example)
- What is the role of transverse spin in QCD?
  - When nucleons are transversely polarized: partons parallel or anti-parallel to the nucleon spin?
  - Many observed single spin azimuthal asymmetries in e-p and pp scattering, very few understood





Relativistic Heavy Ion Collider



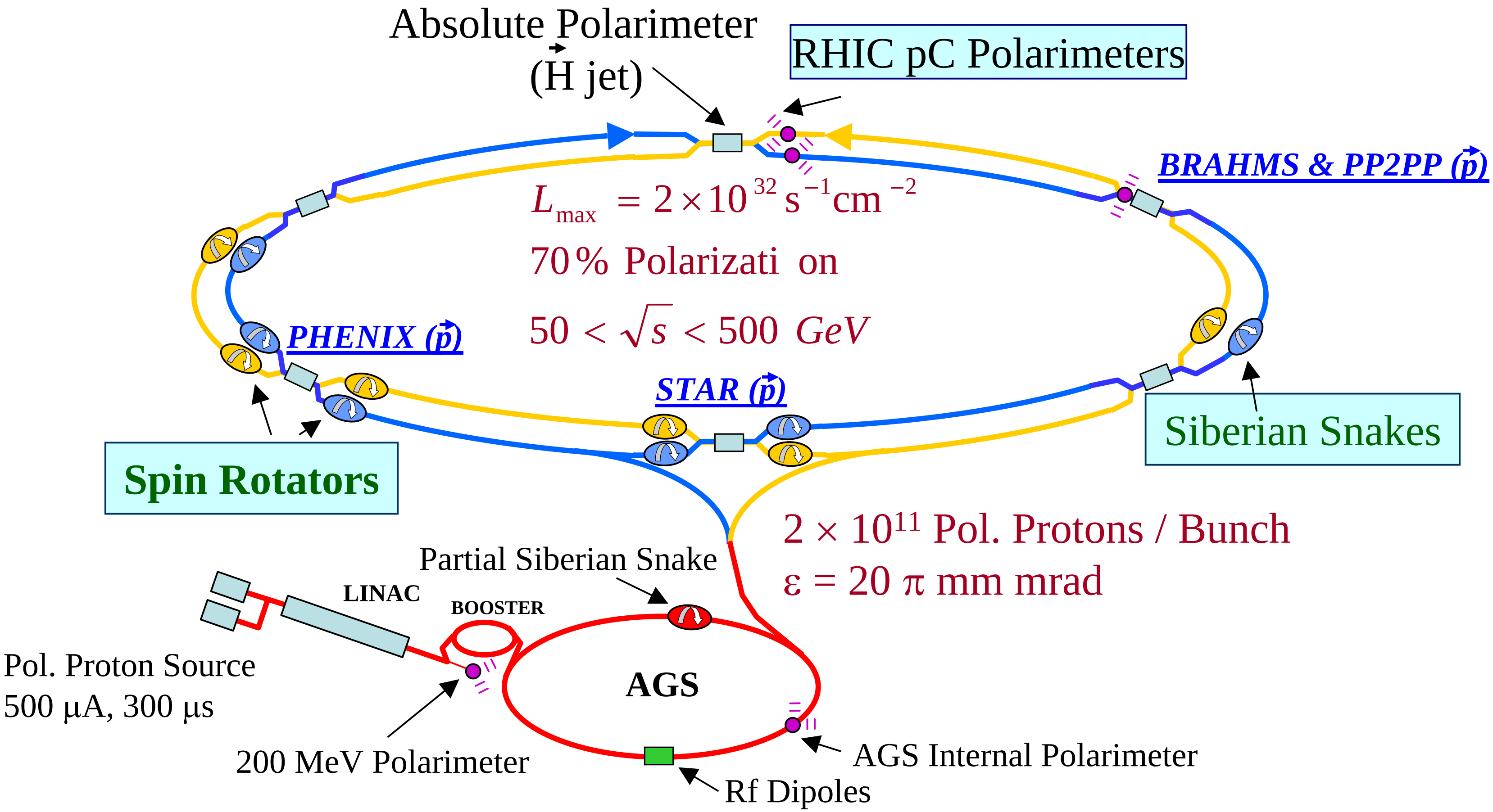
Design Parameters:

Performance	Au + Au	p+p
$\sqrt{s_{nn}}$	200 GeV	500 GeV
L [cm^{-2} s^{-1}]	2 x 10^{26}	2 x 10^{32}
Cross-section	7 barns	60 mbarn
Interaction rates	14 kHz	12 MHz

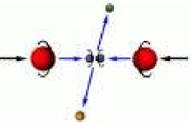
RHIC Capabilities

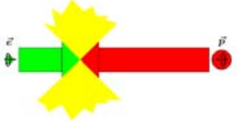
- ✓ Au + Au collisions at **200** GeV/u
- ✓ p + p collisions up to 500 GeV
  - ✓ 200 GeV tried so far
- ✓ spin polarized protons (70%)
- ✓ lots of combinations in species and energy in between

RHIC as a polarized p-p collider:



RHIC accelerates heavy ions to 100 GeV/A
and polarized protons to 250 GeV





Siberian Snakes at RHIC

(Funded by RIKEN Institute in Japan)

Depolarizing Resonance:

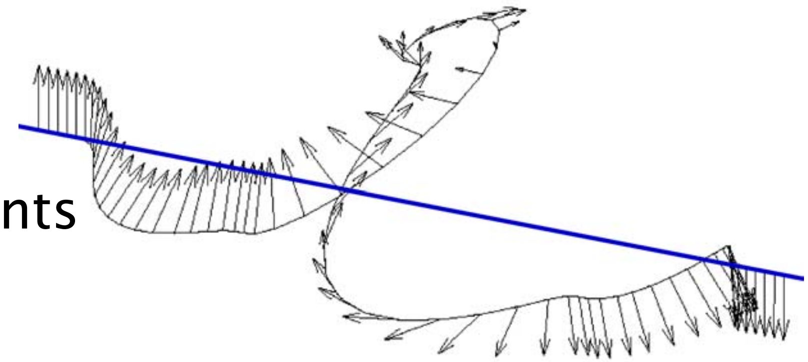
Spin tune = no. of spin kicks

Imperfection resonances:

--magnet errors & mis-alignements

Intrinsic resonances:

--vertical focusing fields



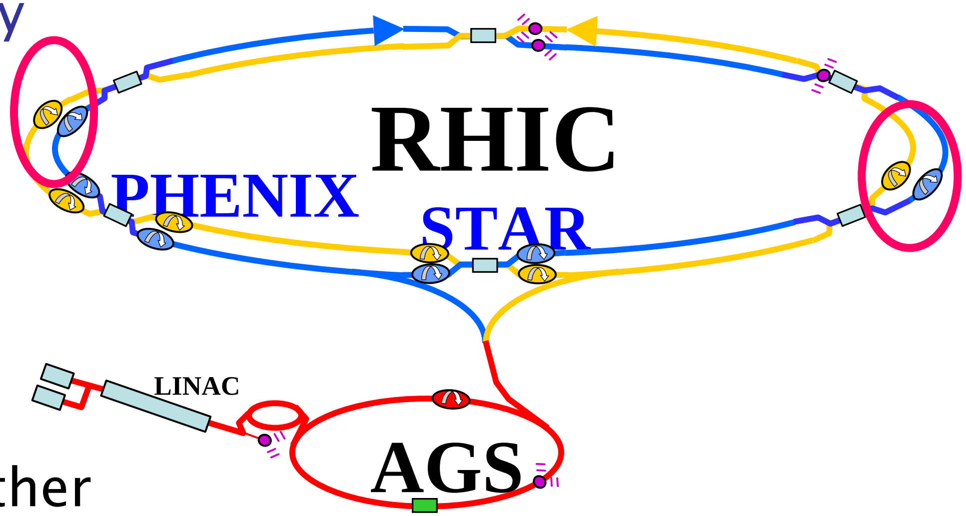
Effect of depolarizing resonances averaged out by rotating spin by large angles on each turn

RIKEN/BNL

4 helical dipoles ➔ S. snake

2 snakes in each ring

-- axes orthogonal to each other



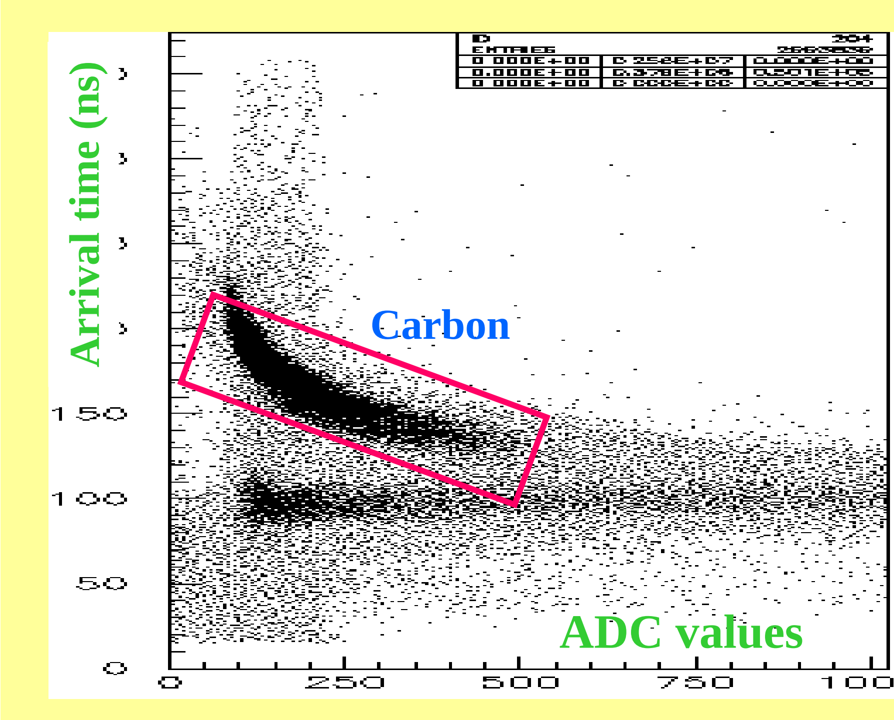
Proton beam polarimetry (I)

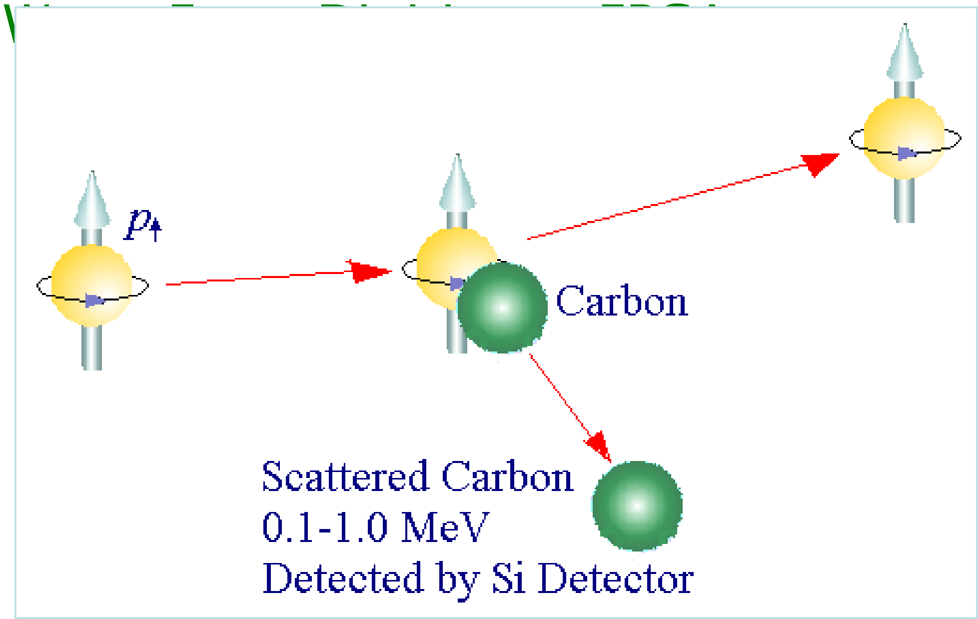
(AGS-E950 Experiment 1999/2000)

Carbon filament target ($5\mu g/cm^2$) in the RHIC beam

Measure recoil carbon ions at q~90°

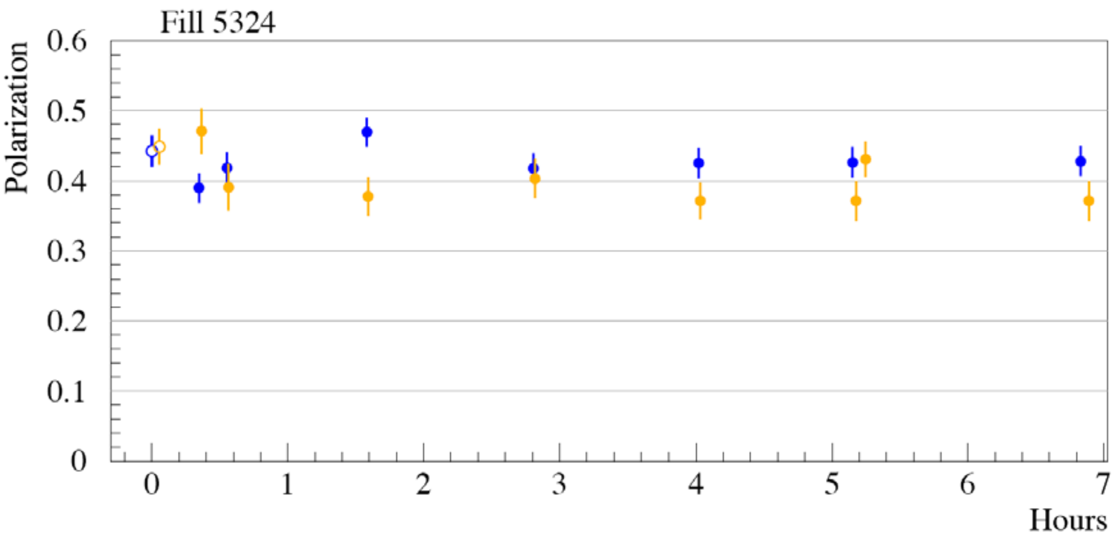
100 keV < E_{carbon} < 1 MeV





ANL, BNL, Kyoto, RIKEN/RBRC & Yale Collaboration

RHIC polarimetry p-C and H-Jet-Target



- 2004 ~40-45% beam polarization routinely achieved
- Absolute beam polarization DP/P = +/- 0.07 with H-Jet Polarimeter
  - Polarized atomic gas jet (92+/-2)% polarization (BR polarimeter)
  - Tgt pol. Reversed/8 min
  - Si detectors for pp elastic scattering: left/right asym
  - Study w.r.t. sign of the tgt polarization flipping each bunch every 200ns
  - Absolute polarization is determined

RUN	#proton/bunch [x10^9]	#bunch	Beta* (m)	Emittance ($\pi\mu$m)	Luminosity 10^{30} cm^{-2}s^{-1}	Pol. (%)
2001-2002	70	55	3	25	1.8	15-25
2002-2003	100	55	1	25	16	25-35
2005-	100	37-55	0.85	16-20	40	>45
Design	200	112	1	20	80	70

RHIC Spin Physics Program

Gluon Polarization

ΔG

$\pi^{0,+,-}$ Production

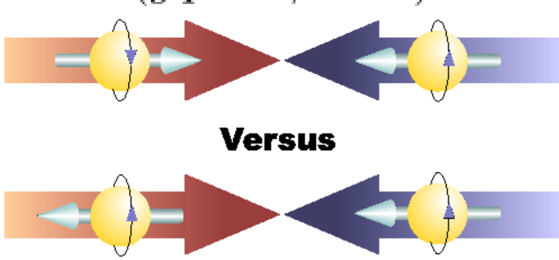
$A_{LL}(gg, gq \to \pi^{0,\pm} + X)$

Heavy Flavors

$A_{LL}(gg \to c\bar{c}, b\bar{b} + X)$

Prompt Photon

$A_{LL}(gq \to \gamma + X)$



Flavor Decompsition

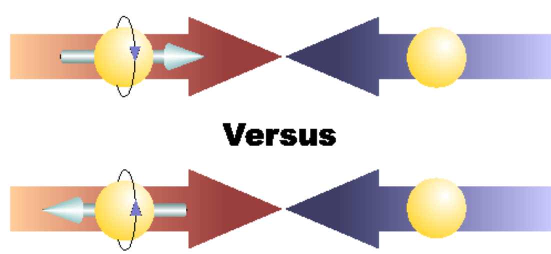
$\frac{\Delta u}{u}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta d}{d}, \frac{\Delta \bar{d}}{\bar{d}}$

W physics

$A_L(u + \bar{d} \to W^+ \to l^+ + \nu_l)$

$A_L(\bar{u} + d \to W^- \to l^- + \bar{\nu_l})$

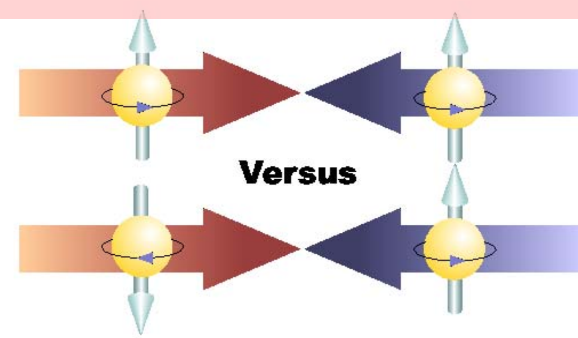
Longitudinal single spin physics

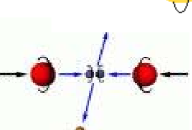


Transverse single/double spin physics

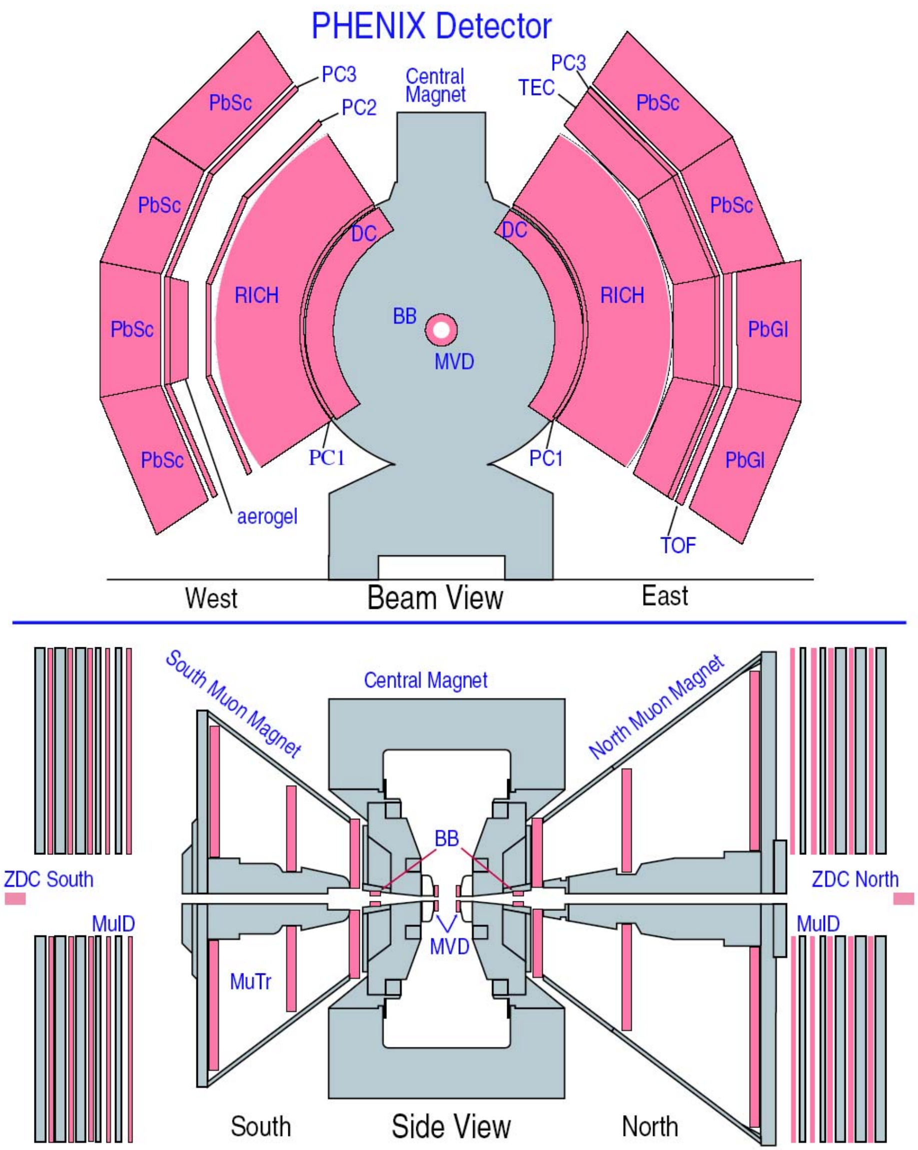
Transversity:
Sivers vs. Collins effects
& physics of higher twists;
Pion interf. Fragmentation

Transverse single spin physics
Phenix-Local Polarimetry



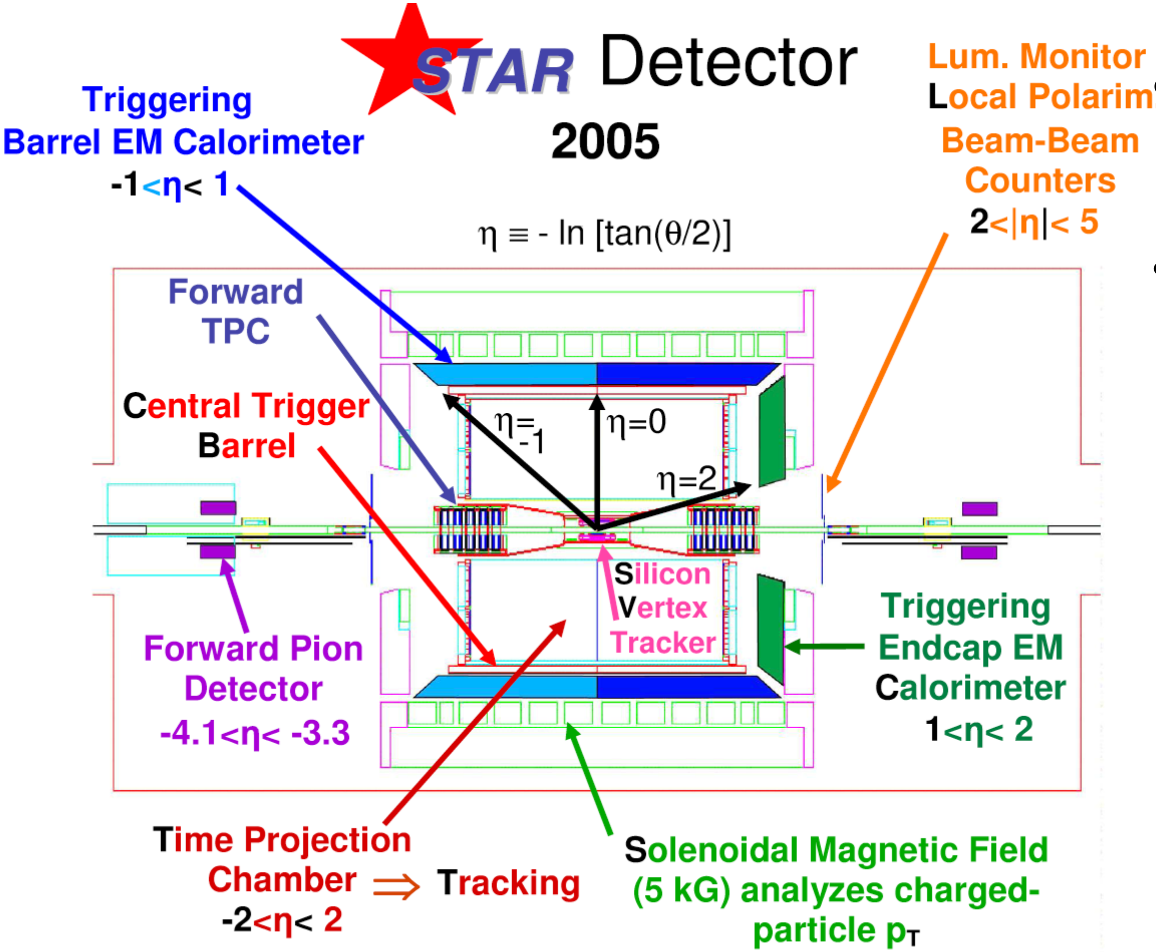


PHENIX Detector at RHIC



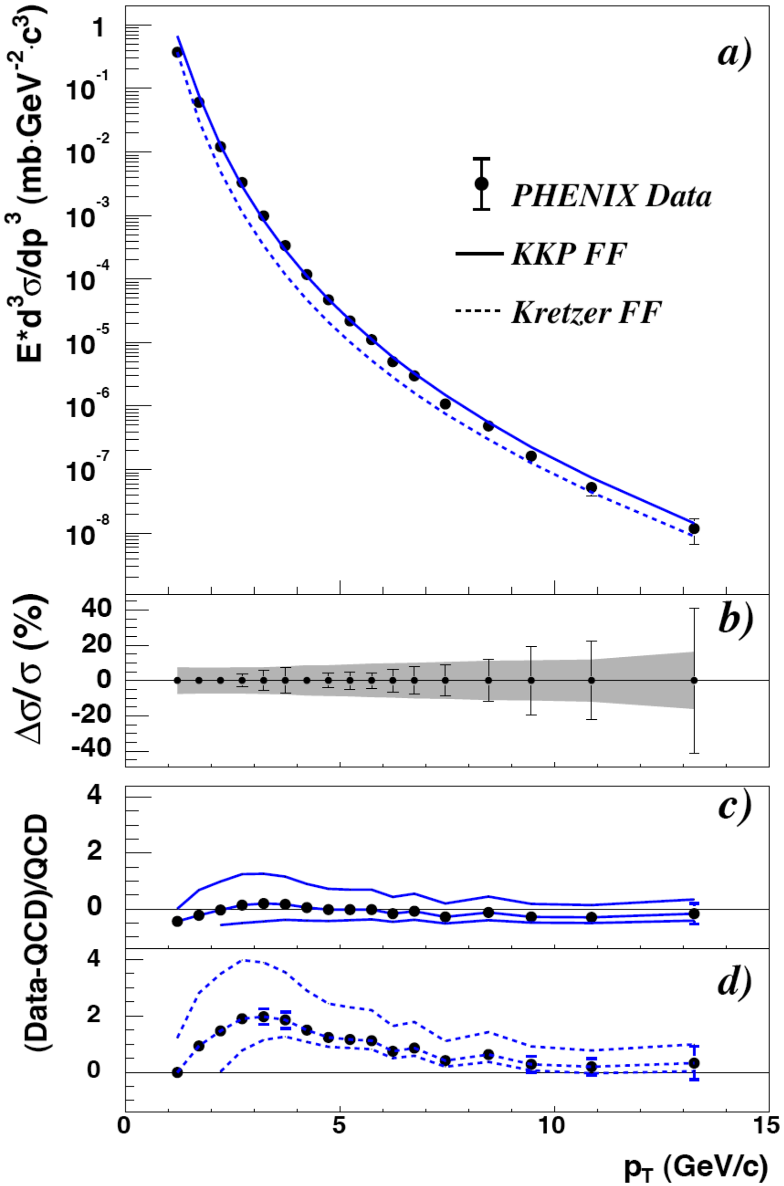
- ***Design philosophy:***
  - ***High resolution limited acceptance***
  - ***High rate capability DAQ***
  - ***Excellent triggers for rare events***
- Central arm
  - Tracking: Drift chambers, pad chambers, time expansion chamber
  - Superb EM Calorimetry PbGl, PbSc
    - $\Delta\phi$ x $\Delta\eta$ ~ 0.01 x 0.01 at 5m from beam
    - π^0 to 2γ resolved up to 25 GeV pT
  - Particle Identification: RICH, TOF
- Forward Muon Arms:
  - Muon tracker, muon identifiers
- Global detectors:
  - Beam beam collision (BBC) counter, Zero Degree Calorimeters (ZDCs)
- Online monitoring, calibration and production

STAR Detector at RHIC



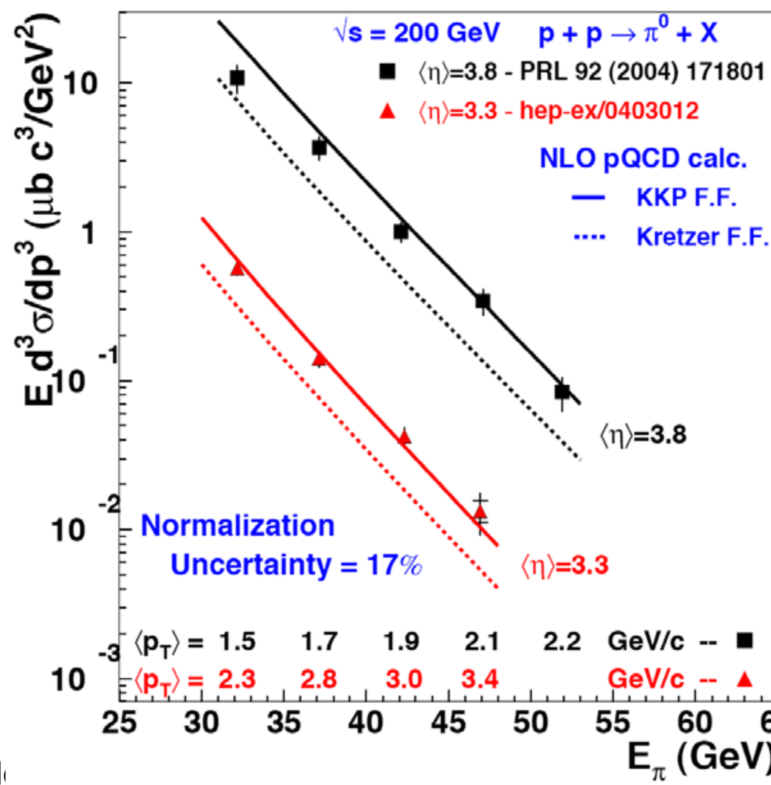
- ***Design Philosophy:***
  - *Maximize acceptance*
  - *lower resolution*
- **Subsystems:**
  - $\phi = 2\pi$ acceptance in EM calorimetry Barrel and EndCap Total: $-1 < \eta < 2$
  - Time Projection Chamber
  - Separate Forward pion detector
  - Silicon vertex tracker
  - Beam-Beam Counters
  - Zero Degree Calorimeter

(un-polarized) p+p ==> π^0+X at RHIC

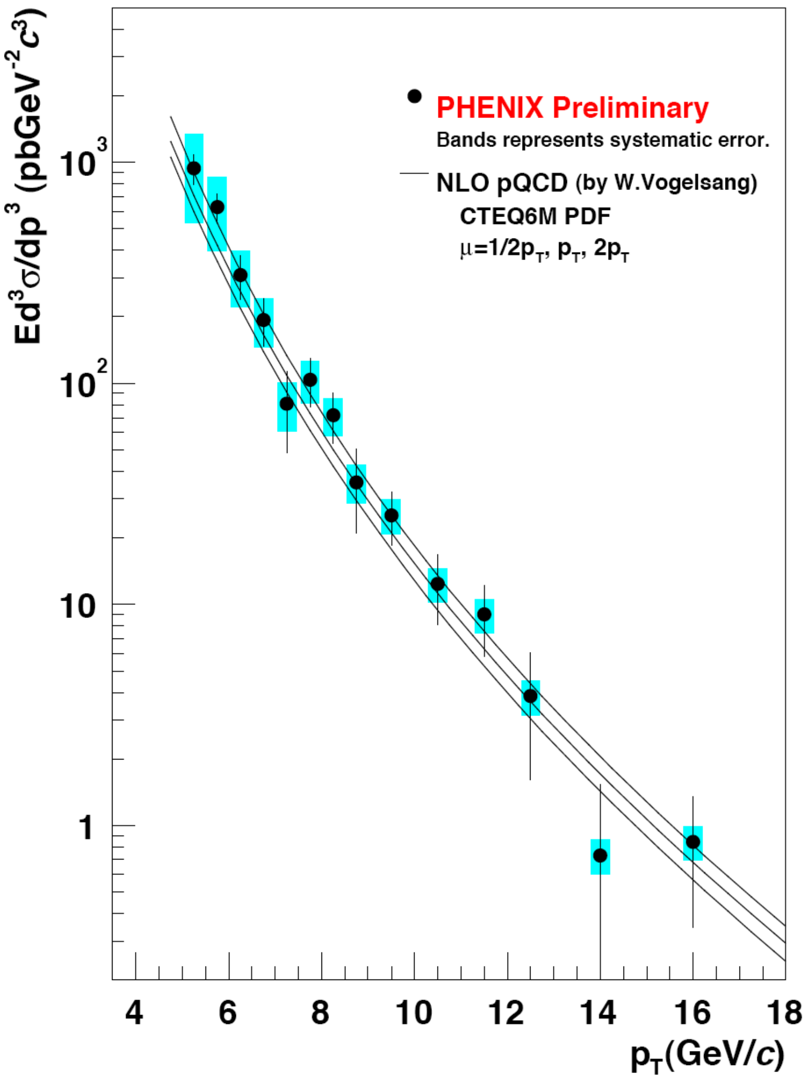


shpand

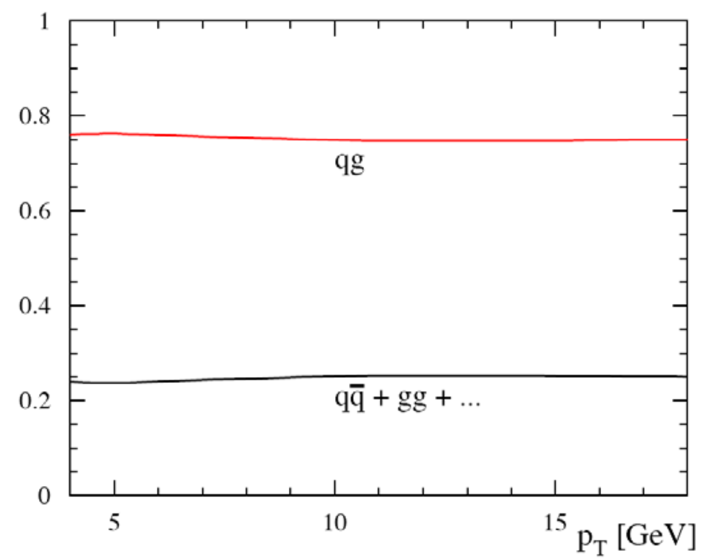
- Data vs. NLO pQCD calculation for p+p ==> π^0 + X
  - PHENIX Mid rapidity
  - STAR forward rapidity
  - Sqrt(s) = 200 GeV



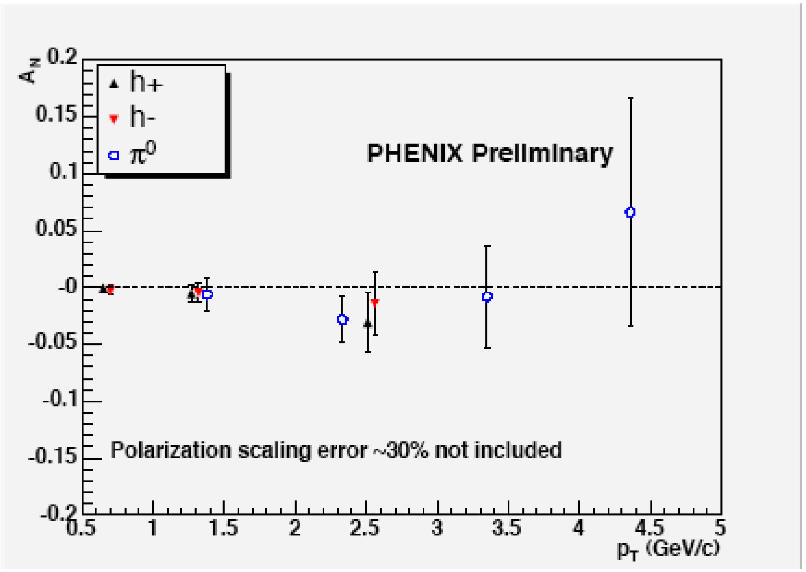
PHENIX: p+p ==> γ+X

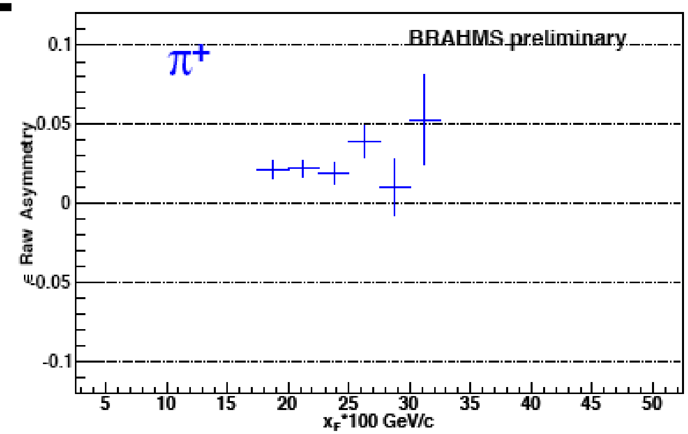


- Inclusive direct photon (prompt) photon production
- Compared with NLO calculation in pQCD
- The quark gluon process contributes about 75% in this pT range



Single transverse spin asymmetries A_N





Phenix central rapidity $|\eta| < 0.35$

- No asymmetry seen

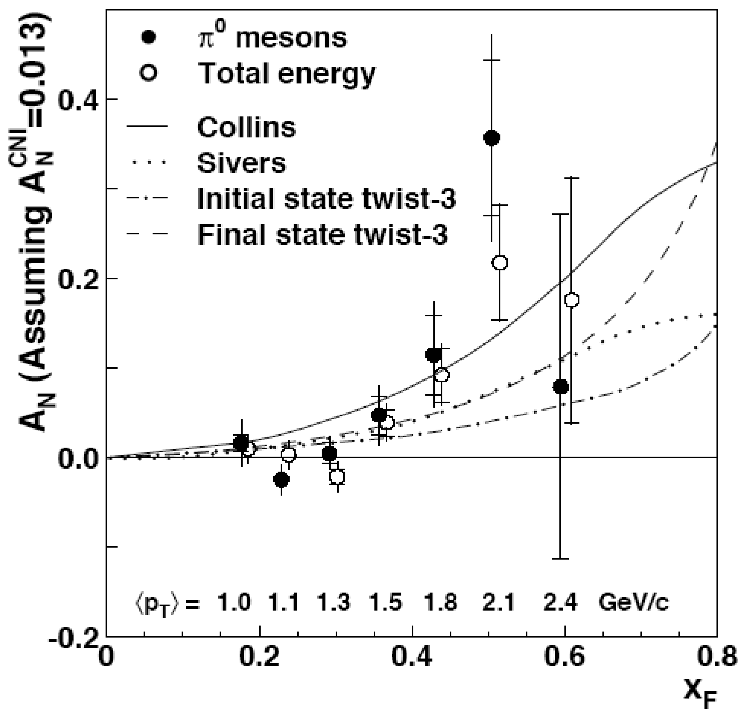
BRAHMS $2.3^0 < \theta < 3.5^0$ vs. x_f

- Large asymmetry

STAR Forward Pion Detector

- Large asymmetry

Together: what is nature telling us?

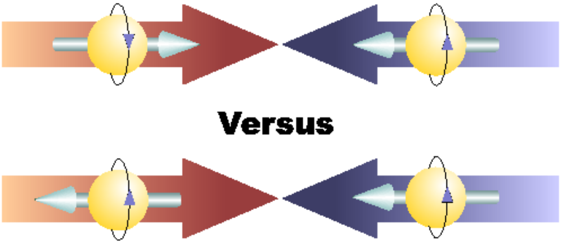


Double spin asymmetry

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}$$

++ same helicity

+– opposite helicity



(P) Polarization -- absolute scale and “longitudinal”ness

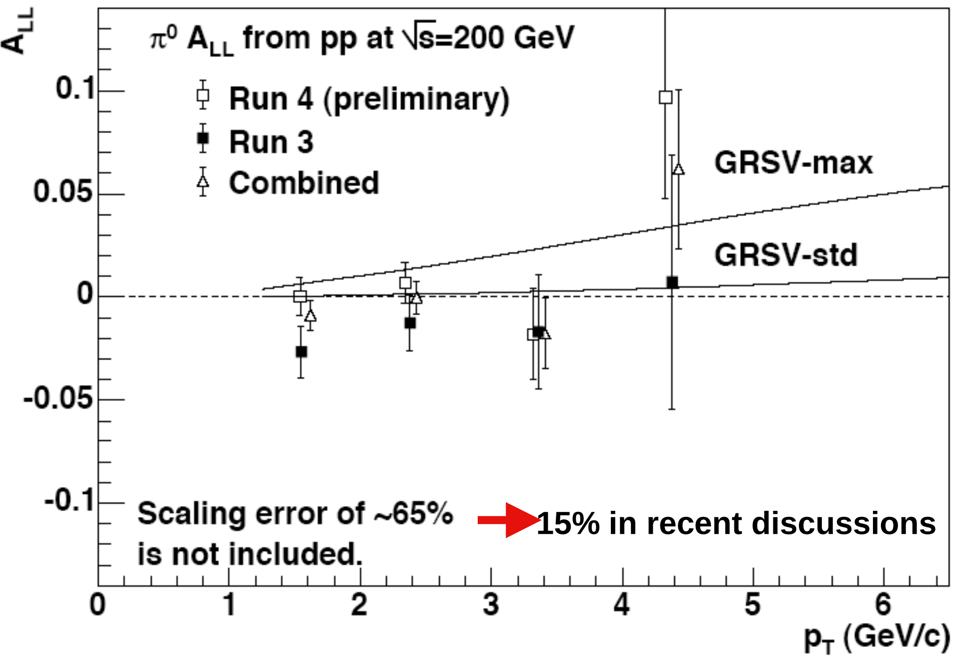
- Local Polarimeter: Longitudinal-ness of proton spins

(L) Relative Luminosity -- bunch to bunch variation

- BBC vs. ZDC vs. (anything else) vs. bunch number
- Bunch crossing every 200 ns
- Studies indicate variations < 2.5×10^{-4}

(N) Number of π^0s -- triggers and efficiencies etc.

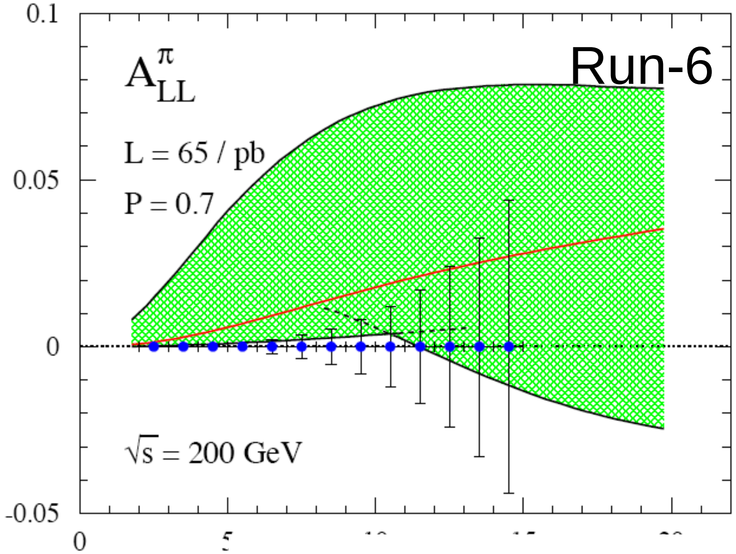
First double spin asymmetry at RHIC



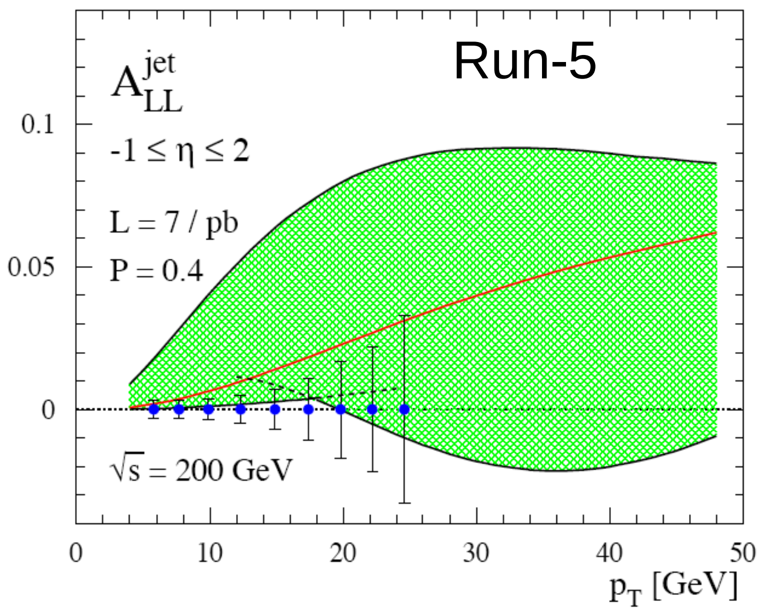
- GRSV: best fits and maximum allowed within the framework of pQCD NLO fits to the world sample of Deep Inelastic Scattering data
- PHENIX vx. Best fit χ^2 confidence level of ~30%

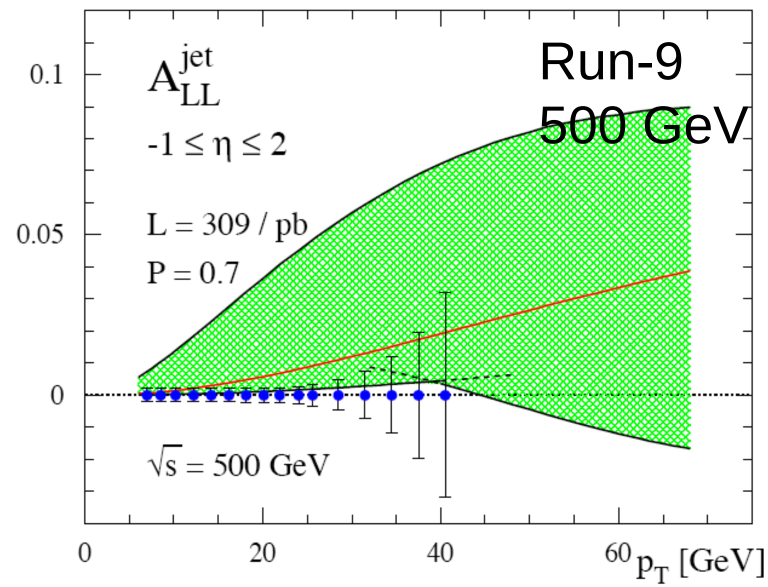
- Data collected over 2 runs
  - Approx. 300 nb^{-1} data
  - Run 3 polarization 27% (PRL)
  - Run 4 polarization 40% (Spin2004)
- Improvement expected in Run-5
  - Approx. 5 pb-1 data
  - > 45% beam polarization overall expected
  - P^4L improvement in the figure of merit
- In future charged pion asymmetries will allow to determine the sign of the gluon distribution

Near term future:

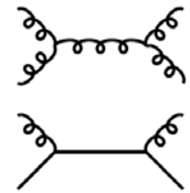
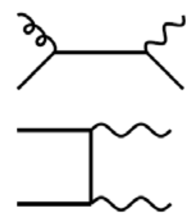
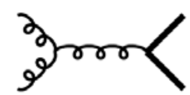
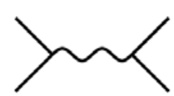
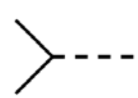


- Double Spin asymmetries with
  - PHENIX pions (jet surrogates) left
  - STAR jet asymmetries (below)
- In the next few years many probes of gluon distribution at RHIC see table next page
- Next step level of precision measurements with eRHIC (see later)





RHIC Spin Program: ΔG Measurements

Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$ [61, 62]	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \mathrm{jet(s)} + X$ [71, 72]	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \mathrm{jet} + X$ $\vec{p}\vec{p} \to \gamma\gamma + X$ [67, 73, 74, 75, 76]	$\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{\bar{q}} \to \gamma\gamma$	Δg Δg $\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to DX, BX$ [77]	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	
$\vec{p}\vec{p} \to \mu^+\mu^- X$ (Drell-Yan) [78, 79, 80]	$\vec{q}\vec{\bar{q}} \to \gamma^* \to \mu^+\mu^-$	$\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to (Z^0, W^\pm)X$ $p\vec{p} \to (Z^0, W^\pm)X$ [78]	$\vec{q}\vec{\bar{q}} \to Z^0,\ \vec{q}'\vec{\bar{q}} \to W^\pm$ $\vec{q}'\bar{q} \to W^\pm,\ q'\vec{\bar{q}} \to W^\pm$	$\Delta q, \Delta\bar{q}$	

A Research Plan for Spin Physics at RHIC
February 11, 2005; PRELIMINARY

Key processes at RHIC
For determining the pdfs of
Longitudinally polarized
Proton along with the
Dominant sub-processes, pdf
Predominantly probed, and
Representative leading
Order Feynmann diagrams.

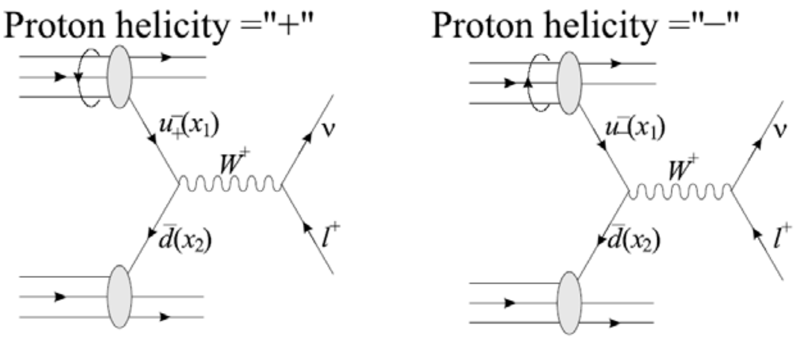
The references are all NLO
Calculations for the particular
Sub-process

The program will be conducted
At 200 GeV and 500 GeV
Center of Mass energy

Δq-Δqbar at RHIC via W production

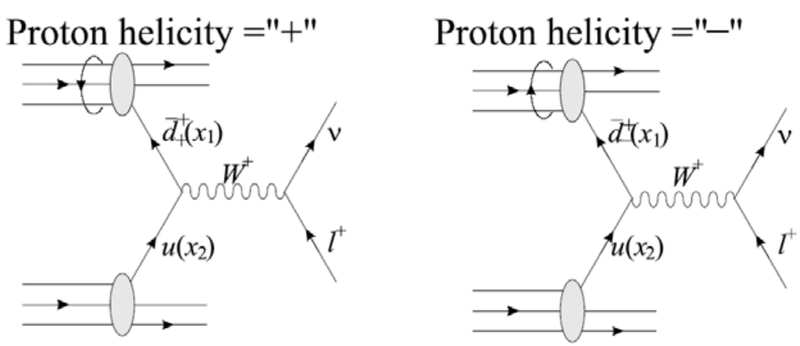
- Single longitudinal scattering asymmetry A_L
- W production dominated by u,ubar, d,dbar quarks with minimal contamination from c,cbar,s,sbar quarks
- W+ implies (u+dbar) and W- implies (ubar+d) at leading order

(a)



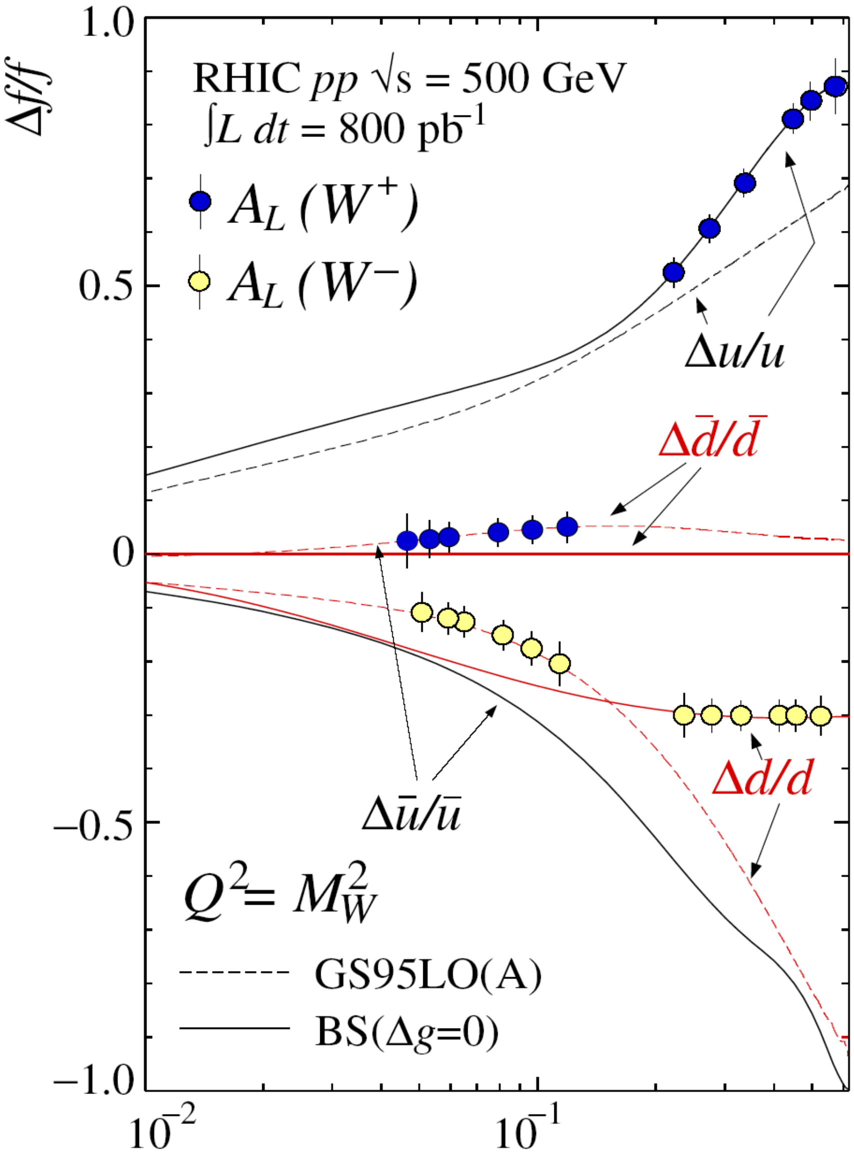
$$A_L^{W^+} = \frac{u^-_-(x_1)d(x_2) - u^-_+(x_1)d(x_2)}{u^-_-(x_1)\bar{d}(x_2) + u^-_+(x_1)\bar{d}(x_2)} = \frac{\Delta u(x_1)}{u(x_1)}$$

(b)



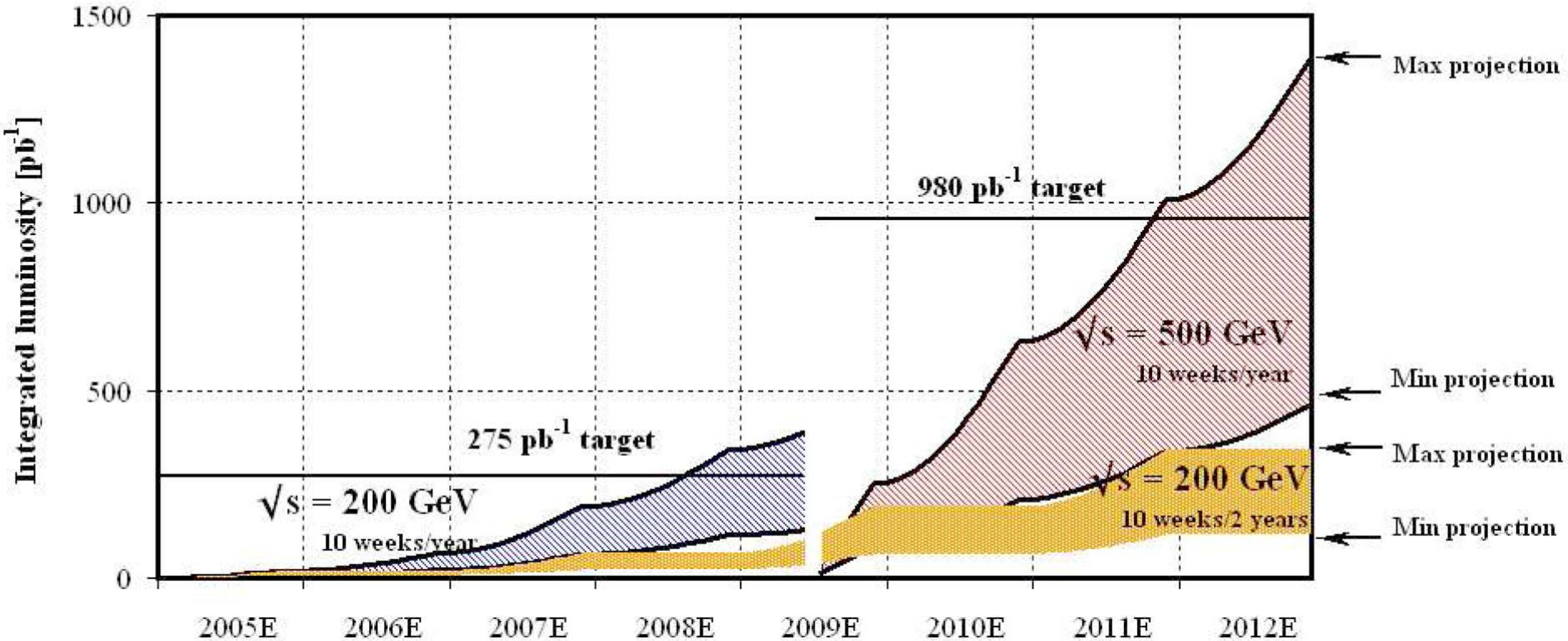
$$A_L^{W^+} = \frac{\bar{d}^+_-(x_1)u(x_2) - \bar{d}^+_+(x_1)u(x_2)}{\bar{d}^+_-(x_1)u(x_2) - \bar{d}^+_+(x_1)u(x_2)} = -\frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}$$

Flavor separation of u,d,ubar,dbar



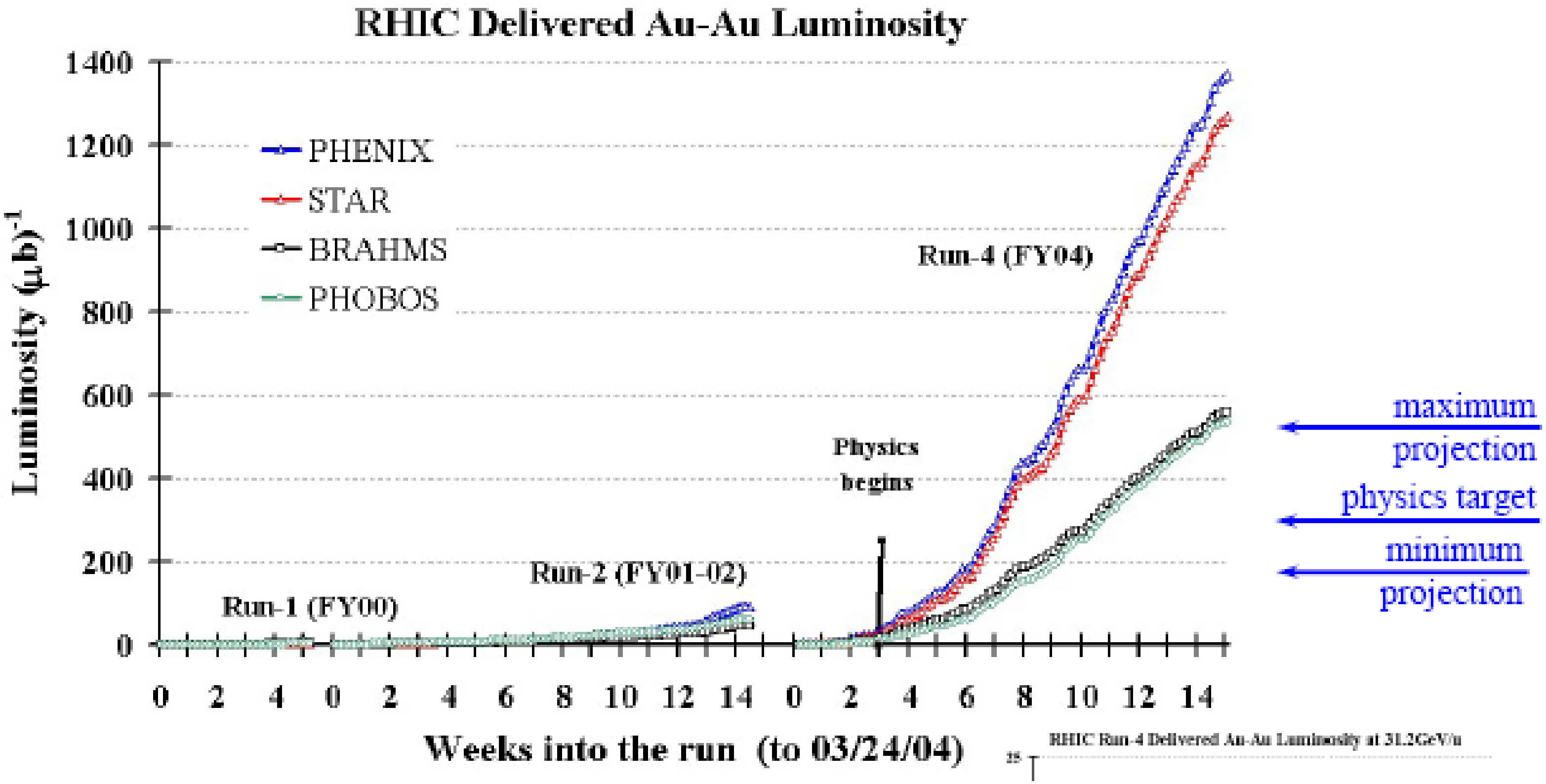
- With 500 GeV Center of Mass
- 800 pb^{-1} integrated luminosity to tape
- Both PHENIX and STAR will need detector upgrades in the forward region to accomplish this
  - New Group Welcome to Join!
- Blue for W+, Yellow for W-
- Various theoretical expectations shown as curves
  - GS95LO is Gehrmann & Stirling, D53, PRD 1995
  - BS is Bourley and Soffer, B445, NP 1996
- Beyond this, heavy quark vs. anti-quark separation at eRHIC (see later in this talk)

RHIC Delivered Luminosity Projections



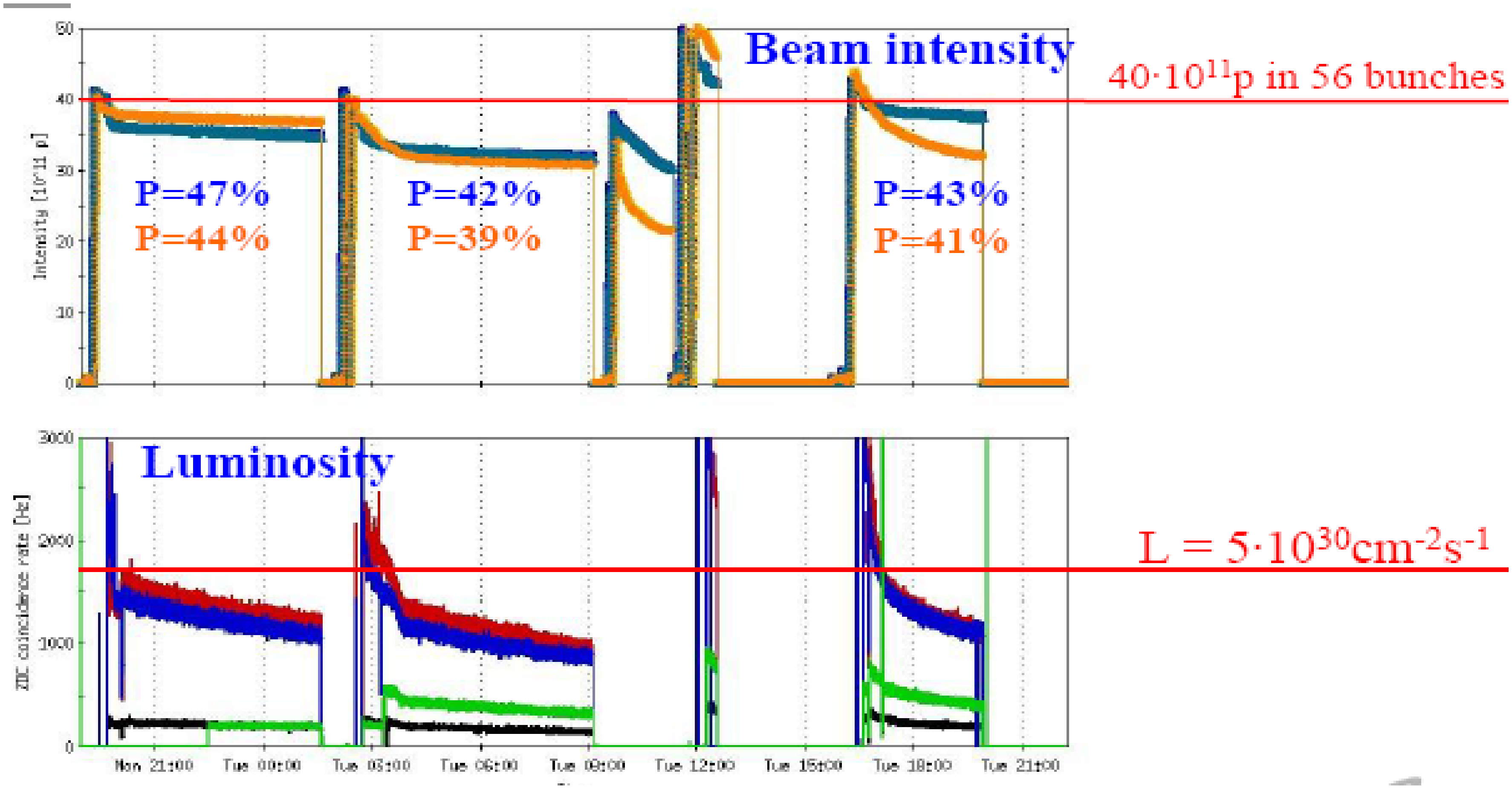
- Assumptions: 10 weeks/year running, tests of 500 GeV in 2005 but physics start in 2008/9 when detector upgrades of W physics would be ready for PHENIX and STAR
  - **Delivered** luminosity * Vertex distribution within acceptance * Experiment Uptime typically makes "**accepted** luminosity" by experiments
- A 5 weeks/year scenario ends up completing the program in 2019 hence deemed COMPLETELY UNACCEPABLE

At RHIC no one should doubt the luminosity projections!



- Au-Au design luminosity achieved in the 2nd year of operations
- Au-Au delivered luminosity exceeded by factor 2 routinely during Run-4
- This was not a chance occurance, they repeated this in Run-5 Cu-Cu (currently underway)

And same for polarized p-p collisions

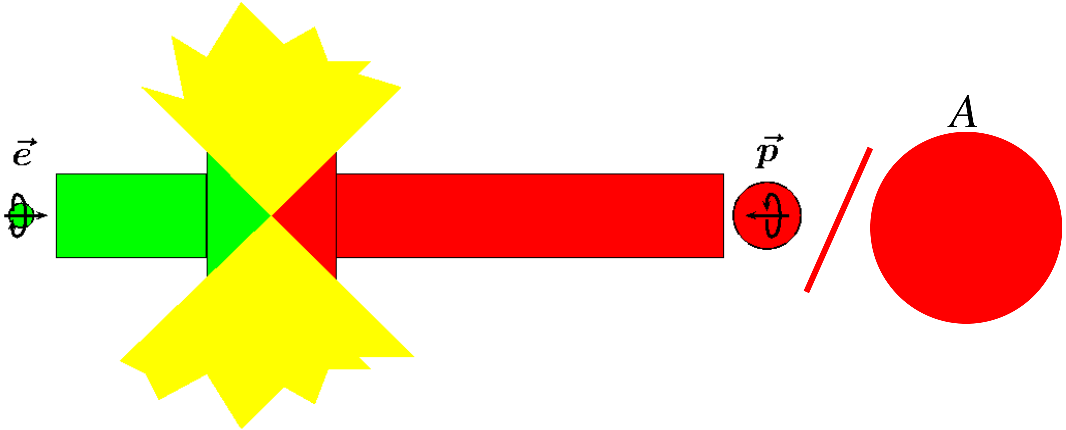


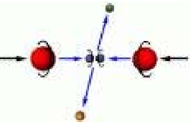
Proton-Proton collision design luminosity exceeded in Run-4
Polarizations of ~40% routinely achieved.
Steps to increase polarization to 65%-70% on the way.

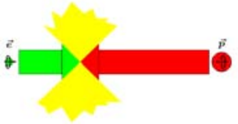
RHIC Physics and “to-disk” data written

Fiscal year	Spin Weeks	CME(GeV)	P	L(pb^{-1})	Remarks
2002	5	200	0.15	0.5	First pol. pp collisions! Transverse spin
2003	4	200	0.3	1.6	Spin rotators commissioned, first helicity measurements
2004	3	200	0.4	3	New betatron tune developed, first jet absolute meas. P
2005	10	200	0.5	14	$A_{LL}(\pi^0, \text{jet})$, also 500 GeV studies
2006	10	200	0.7	32	AGS Cold Snake commissioned, NEG vacuum coating complete
2007	10	200	0.7	88	
2008	10	200	0.7	106	Direct γ
2009	5	200	0.7	35	target complete for 200 GeV;
	5	500	0.7	180	PHENIX μ trig.; W starts
2010	10	500	0.7	266	STAR forward tracker; W physics
2011	10	500	0.7	266	
2012	10	500	0.7	266	Completes 500 GeV target

Electron Ion Collider at BNL: eRHIC
a longer term perspective





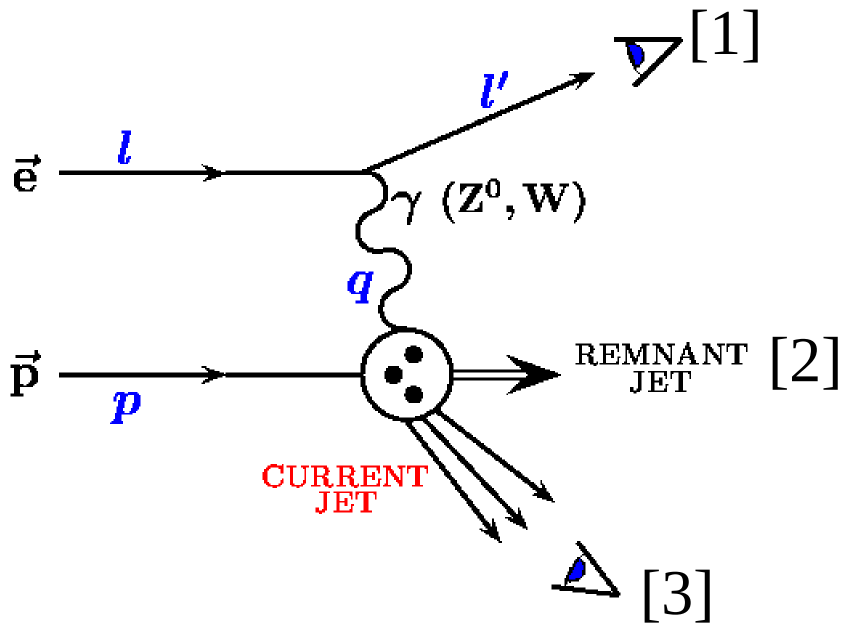


Open questions in QCD

- Do we understand the momentum distribution and spin structure of the nucleon in terms of fundamental quarks and gluons?
- In hard scattering gluons are knocked out but only hadrons are seen. Do we understand hadronization in QCD?
- Do we understand the exact roles quarks and gluons play in the microscopic structure of atomic nuclei, the basis for the physical world? What is the exact nature of short range inter-nucleon forces?
- Will we observe a new phenomena predicted by QCD involving saturation of gluons at high energies, similar to the Bose-Einstein condensation in atoms at low temperatures?

An Electron Ion Collider (EIC) at RHIC/BNL "eRHIC" will try to answer these questions with unprecedented precision and will address the most fundamental and universal aspects of QCD. ***It is proposed that such a machine be available for physics measurements early next decade.***

Deep Inelastic Scattering



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

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

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

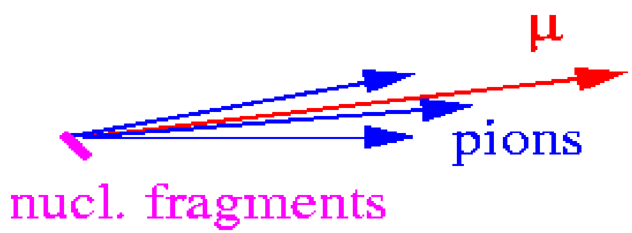
$$s = 4E_e E_p$$

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

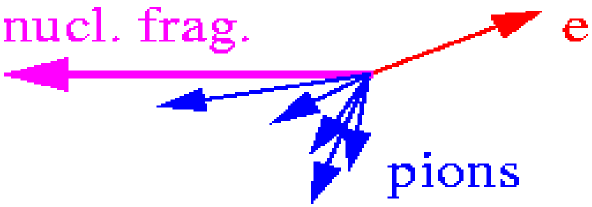
- Observe scattered electron [1] inclusive measurement
- Observe [1] + current jet [2] semi-inclusive measurement
- Observe [1] + [2] + remnant jet [3] exclusive measurement
- Luminosity requirements goes up as we go from [1] --> [2] --> [3]
- **Exclusive measurements put demanding requirement on detectors,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

Why Collider In Future?

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



Fixed target

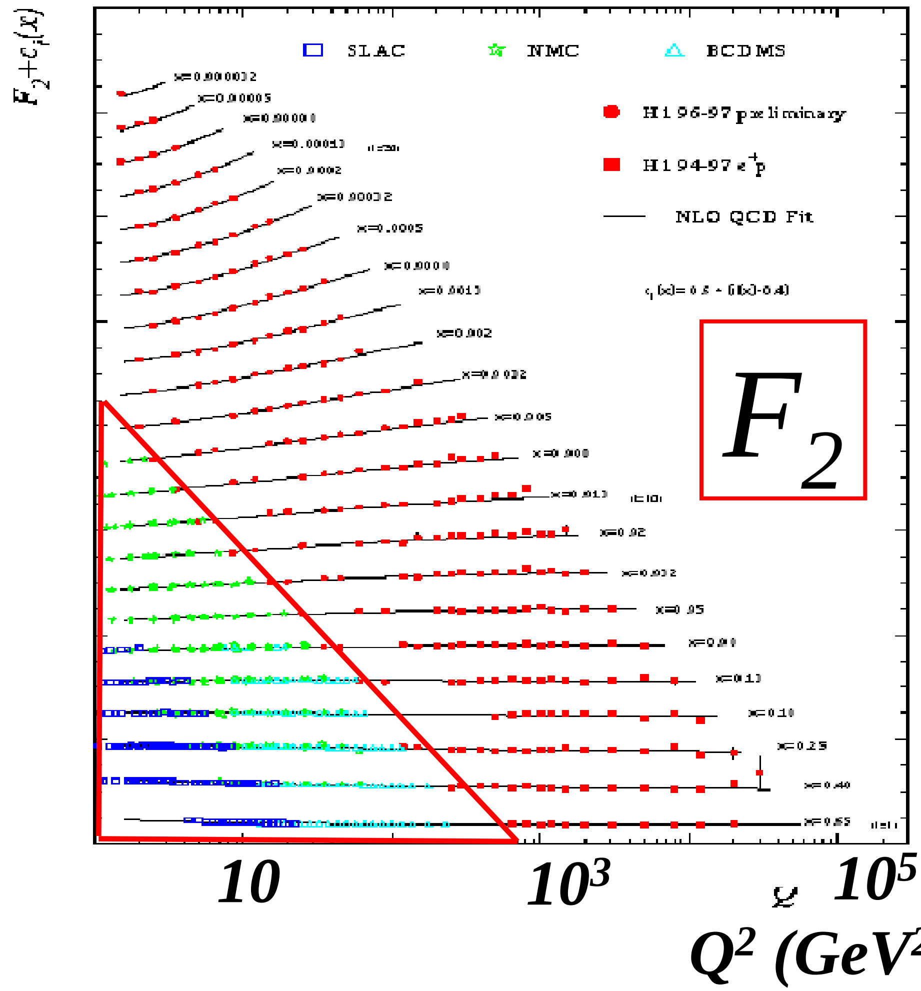


Collider

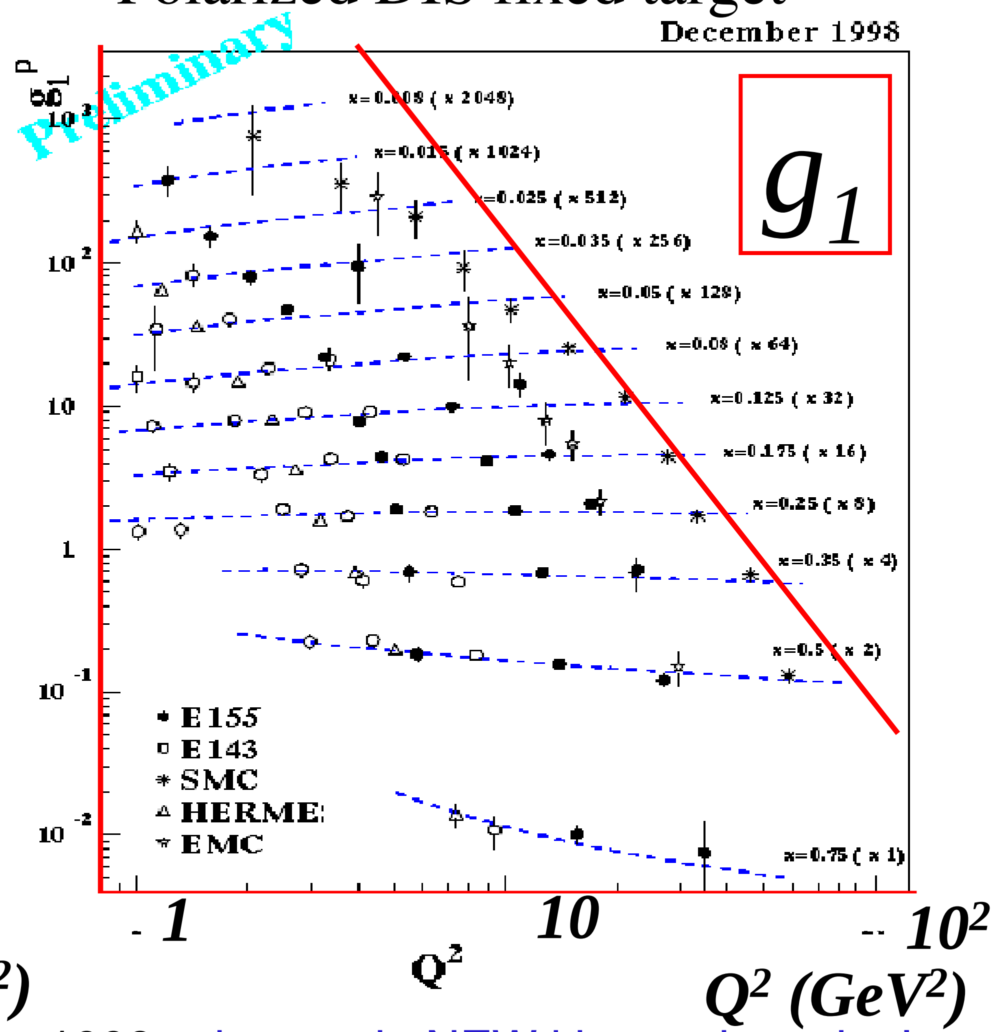
- Higher Center of Mass energies reachable
- Better angular resolution between beam and target fragments
  - Better separation of electromagnetic probe
  - Recognition of rapidity gap events (diffractive physics at HERA)
  - Better measurement of nuclear fragments
- **Tricky issues**: **integration of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

Our Knowledge of Structure Functions

HERA Collider Un-polarized



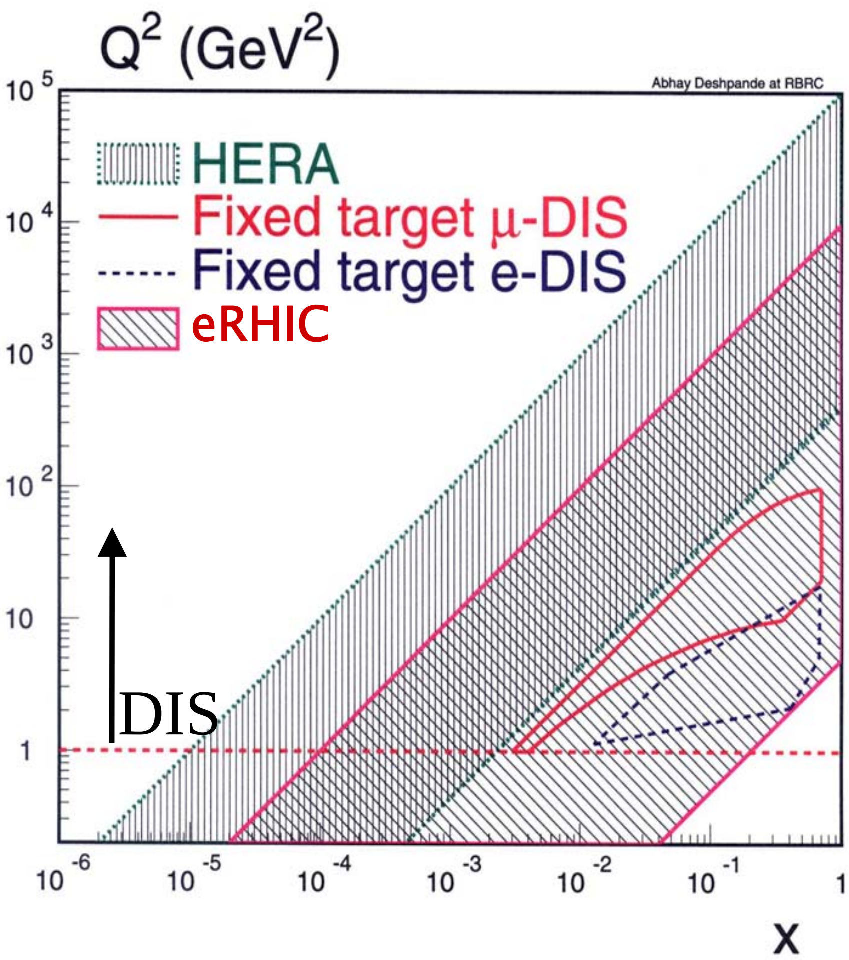
Polarized DIS fixed target



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

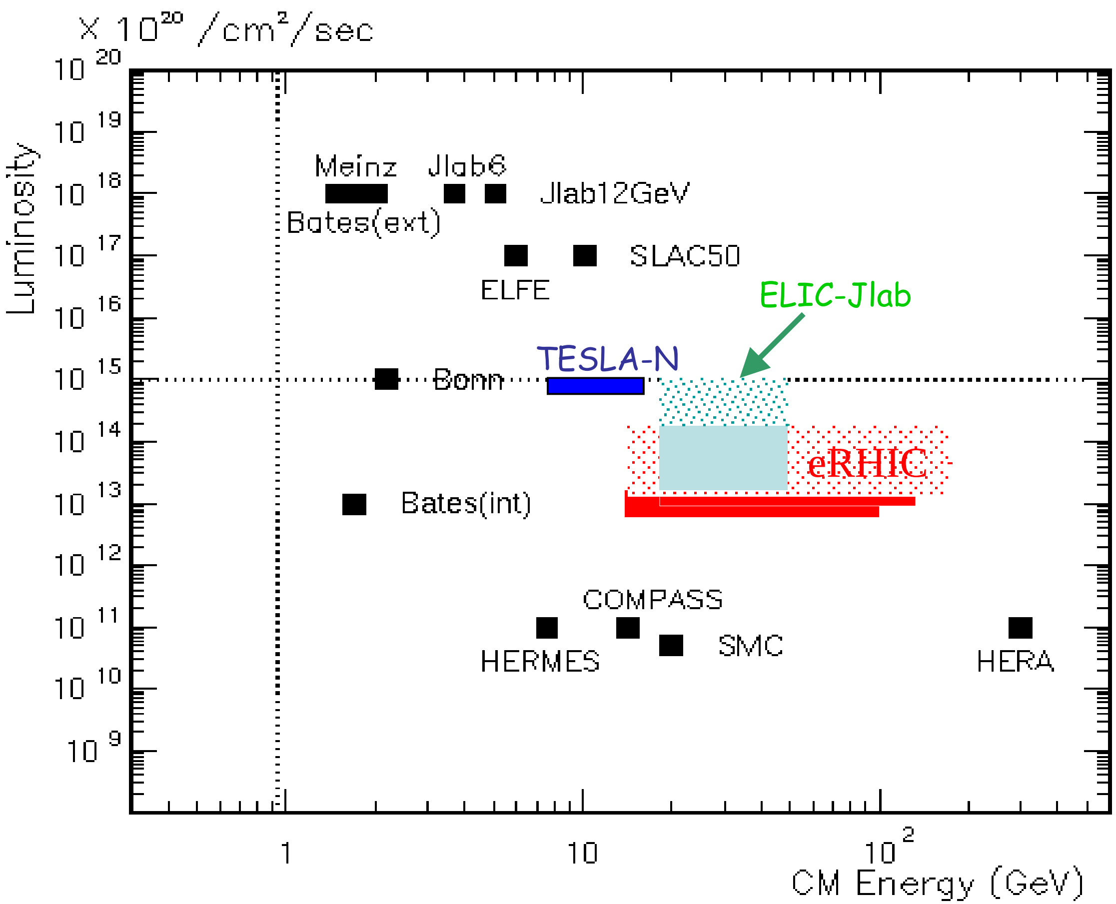
Nothing on nuclear targets in collider kinematics!

eRHIC vs. Other DIS Facilities



- **New kinematic region**
- E_e = 10 GeV (5-12 GeV variable)
  - 20 GeV ``dream-able"
- E_p = 250 GeV ($\sim$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
  - Study of high gluon densities in nuclei
- High Luminosity:
  - **L(ep) $\sim 10^{33-34}$ cm^{-2} sec^{-1}**

CM vs. Luminosity

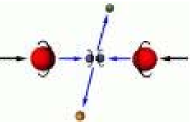


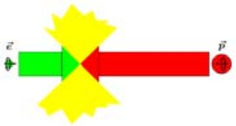
eRHIC at BNL

- Variable beam energy
- P-U ion beams
- Light ion poalrization
- Large luminosity

ELIC at Jlab

- 6 GeV e X 30-100 GeV polarized protons
- Variable beam energy
- Light ion polarization
- 10^{34} cm^{-2} sec^{-1} 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

Polarized DIS at eRHIC

- Spin structure functions g_1 (p,n) at **low x**, high precision

  -- g_1(p-n): Bjorken Spin sum rule 1-2% accuracy
- **Polarized gluon distribution function $\Delta G(x,Q^2)$**

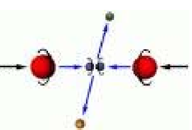
  -- at least three different experimental methods
- Precision measurement of α_S(Q2) from g_1 scaling violations
- Spin structure of the photon from photo-production
- Electroweak s. f. g_5 via virtual **$W^{+/-}$ production (heavy quarks)**
- Deeply Virtual Compton Scattering (DVCS), exclusive VM production

  >> Generalized Parton Distributions (GPDs)
- **Transversity: Single and Double Spin Measurements**
- Drell-Hern-Gerasimov spin sum rule test at high ν
- Flavor separation of PDFs through semi-inclusive DIS
- Target/Current fragmentation studies
- … *and many more ……*

[1]
[1]
[1]
[1]
[1,2]
[1]
[1,2]
[3]
[1]
[1]
[1]
[2,3]

Luminosity Requirement

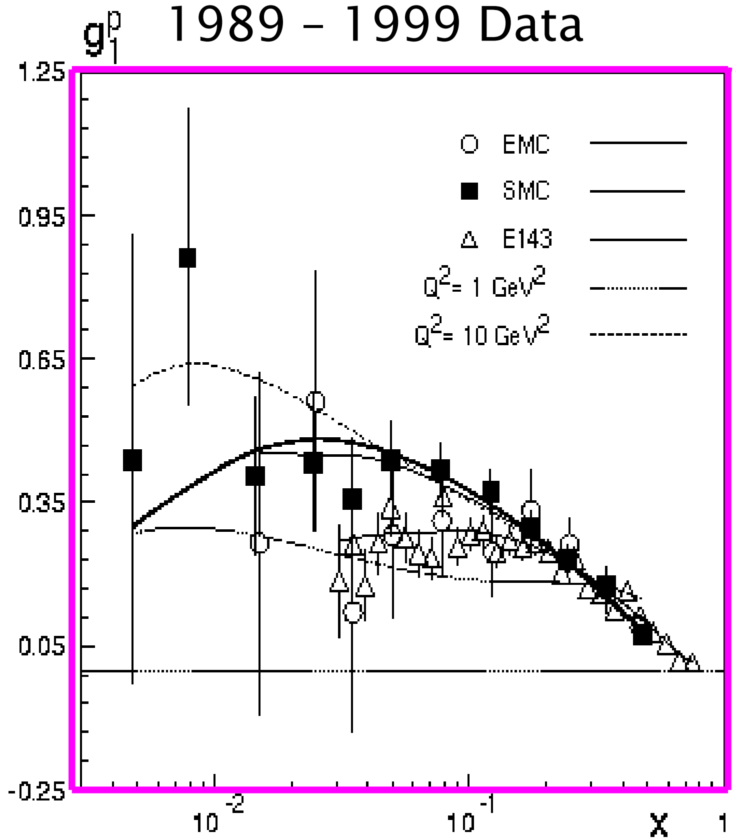
[1] --> inclusive, [2]--> semi-inclusive
[3] --> exclusive measurements



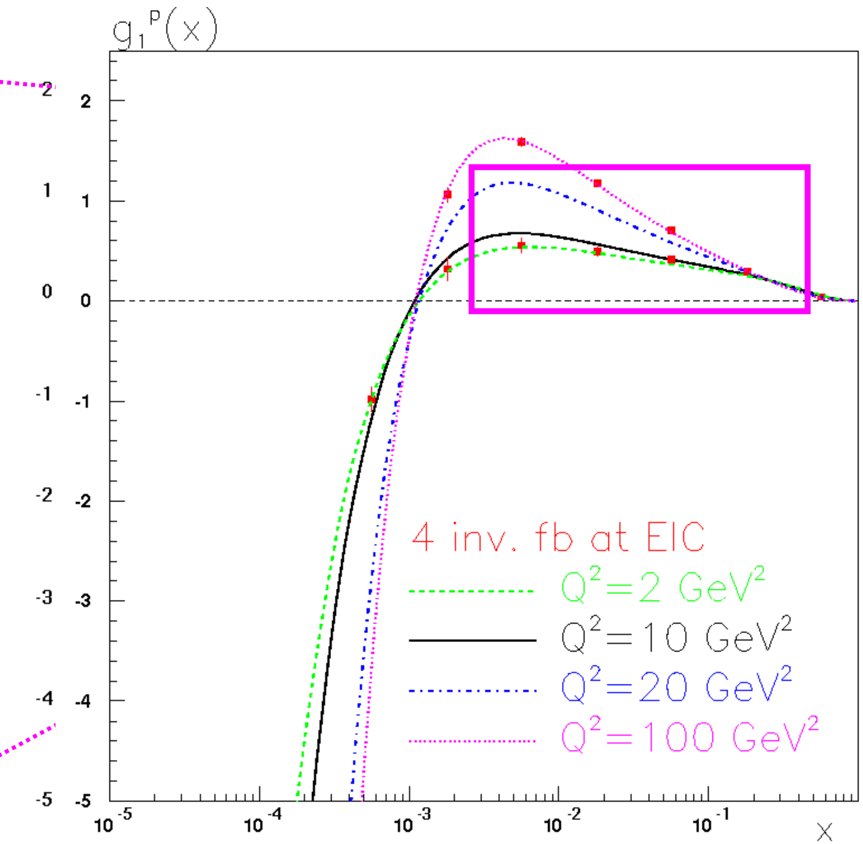
Low x Proton Spin Structure

AD & V. W. Hughes

Fixed target experiments
1989 – 1999 Data



eRHIC 250 x 10 GeV; 85 pb^{-1}/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:

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

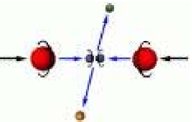
Values range from 0.114-119 with uncertainties:

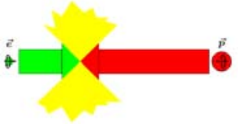
+/- 0.004 (experimental)

+/- 0.010 (theory/ low x extrapolation)

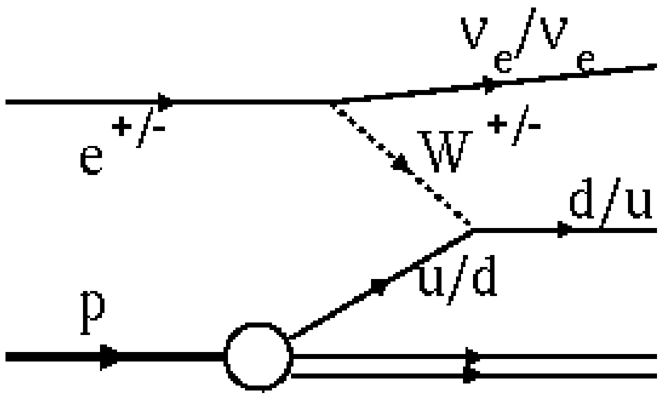
Particle Data Book (2002), Extended version:

"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***"





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

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

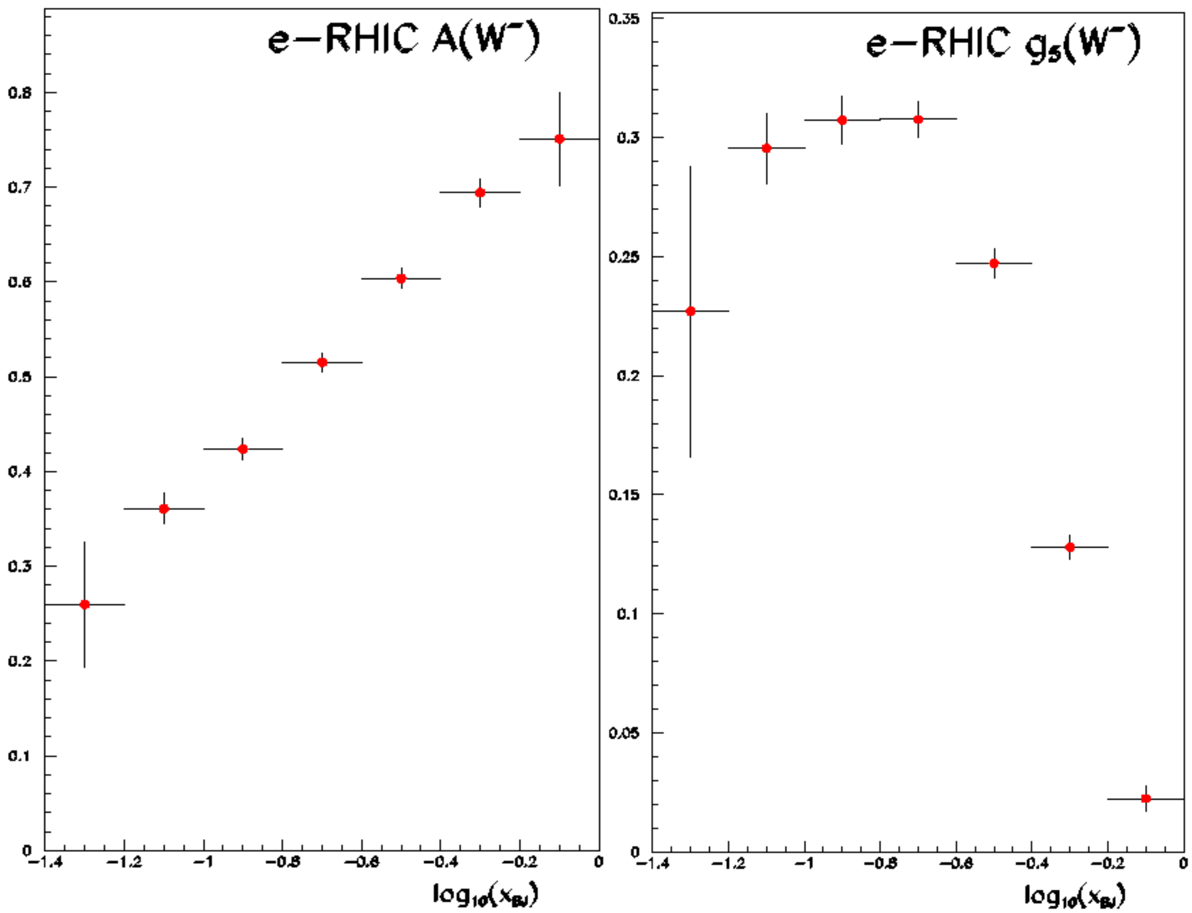
$\Longrightarrow g_5$ dominates $\rightarrow$ Extract g_5

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

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

Measurement Accuracy PV g_5 at eRHIC

J. Contreras, A. De Roeck



Assumes:

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

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

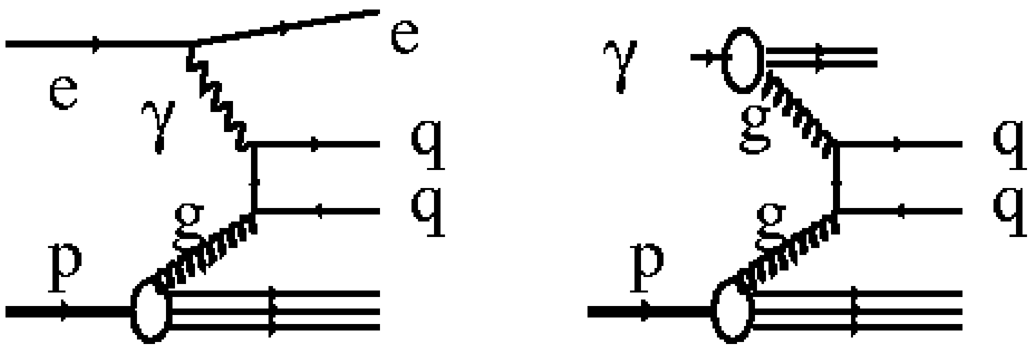
>> reason for keeping the option of positrons in eRHIC

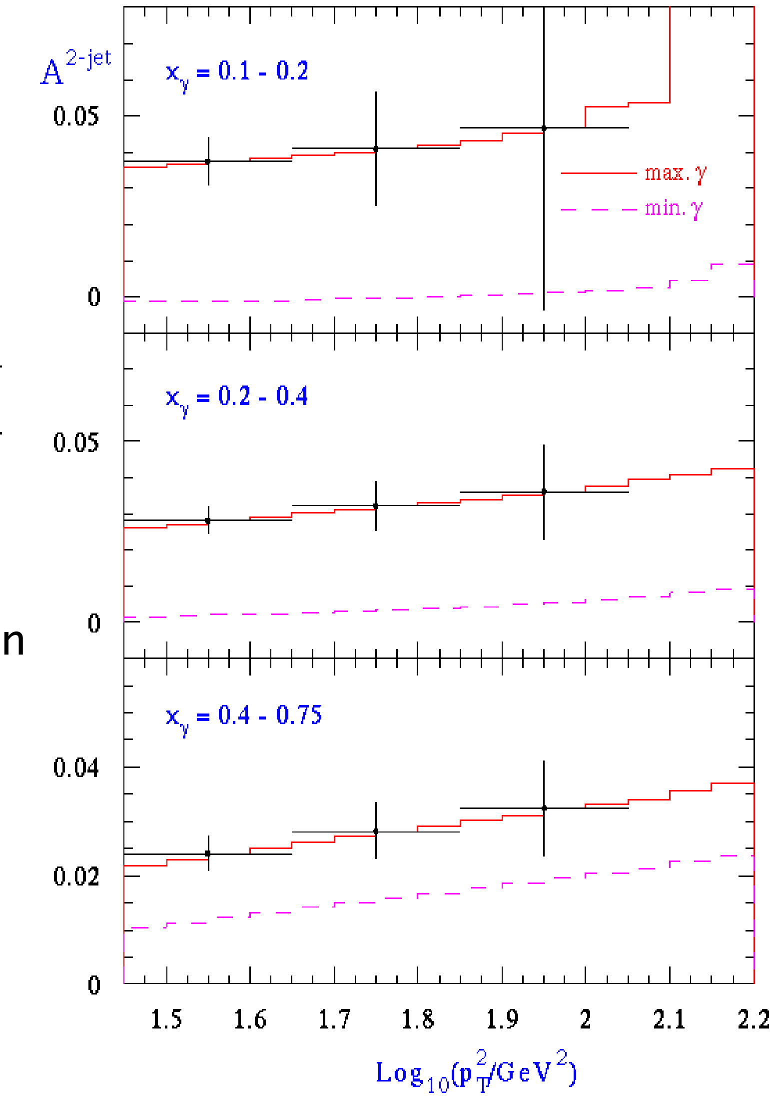
Polarized PDFs of Photons

M. Stratmann, W. Vogelsang

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

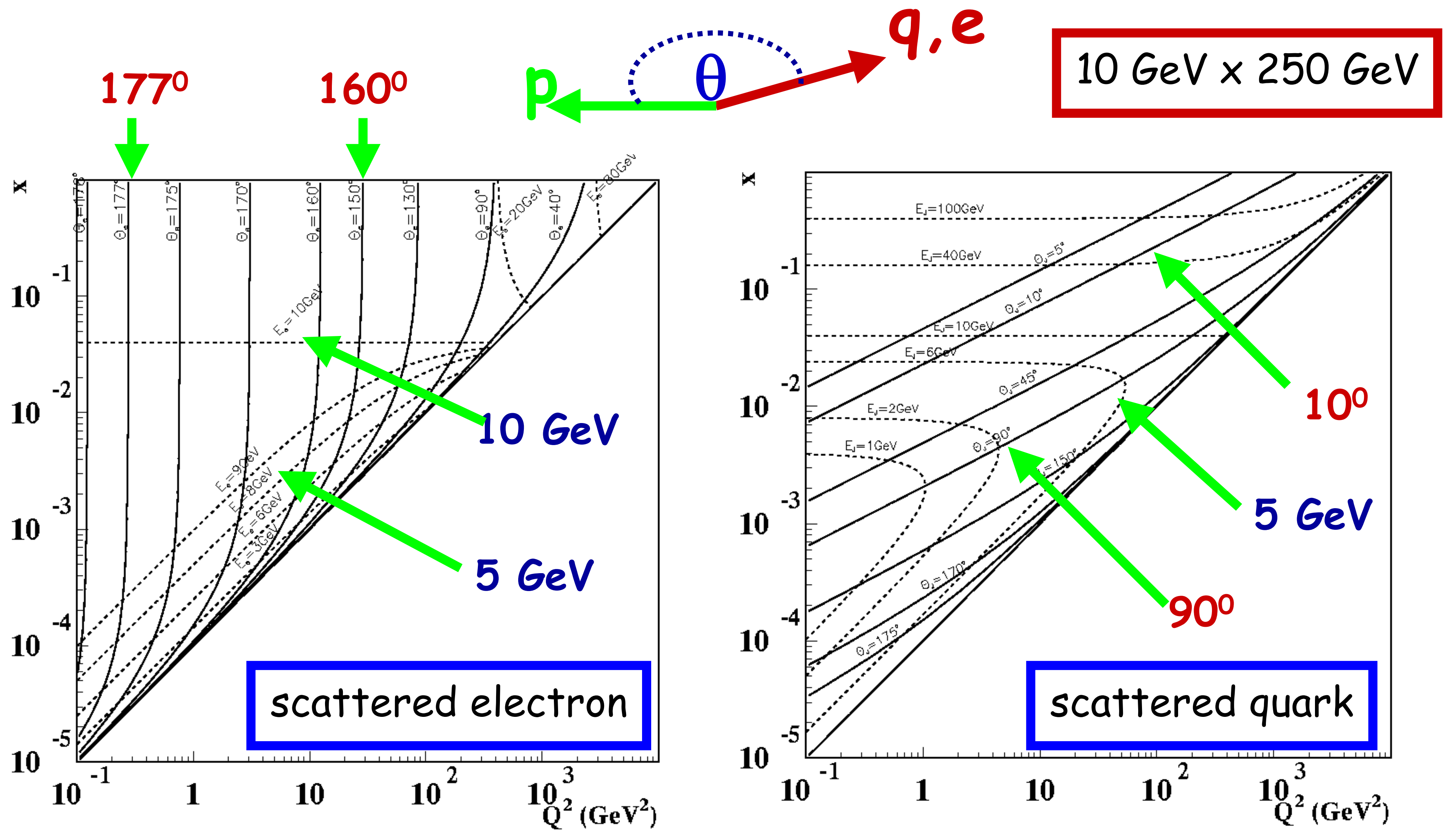
A 4π Detector detector for eRHIC

- 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

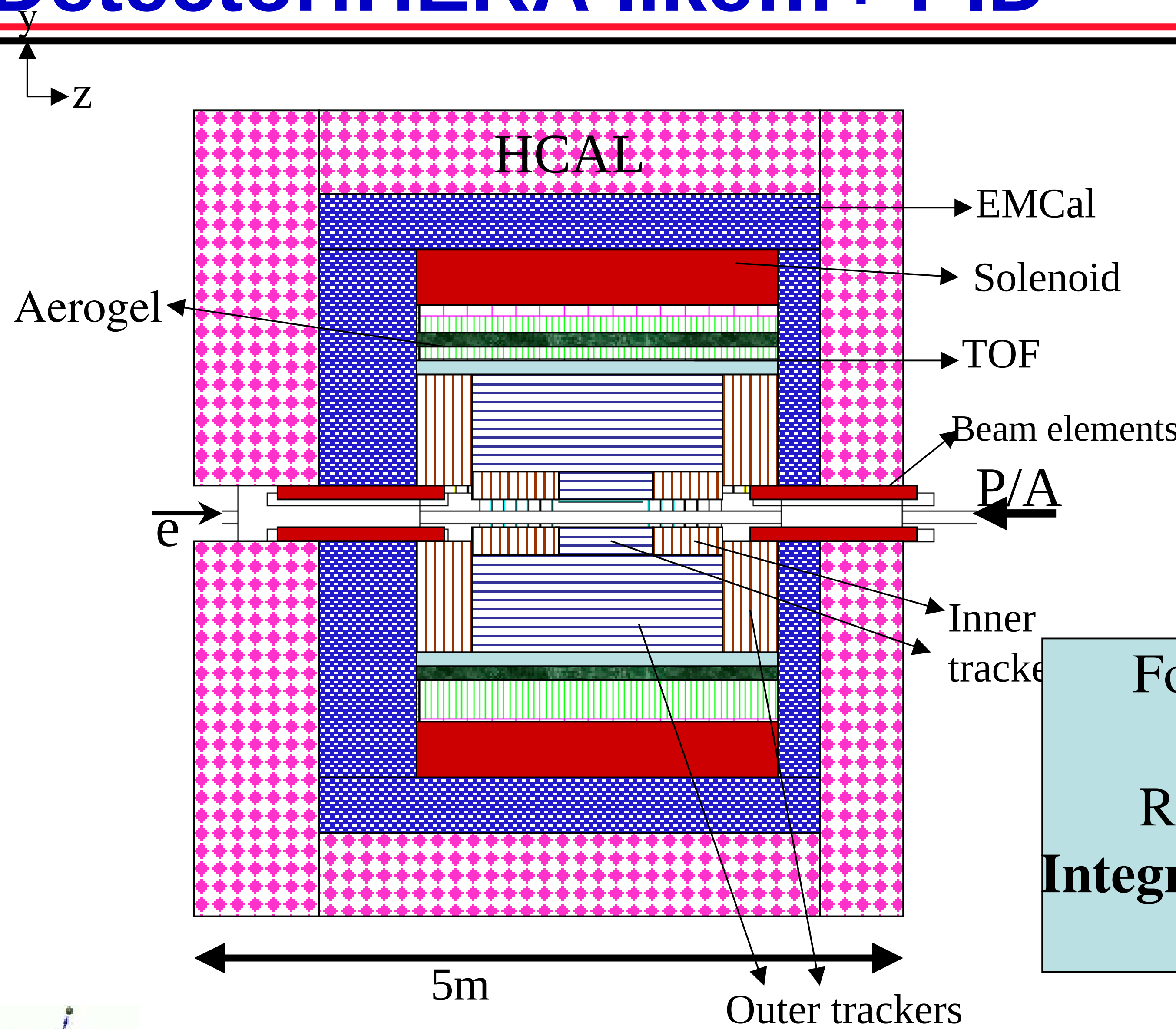
Where do electrons and quarks go?



Detector:HERA like…+ PID

B. Surrow, N. Smirnov, AD

(Not to scale)

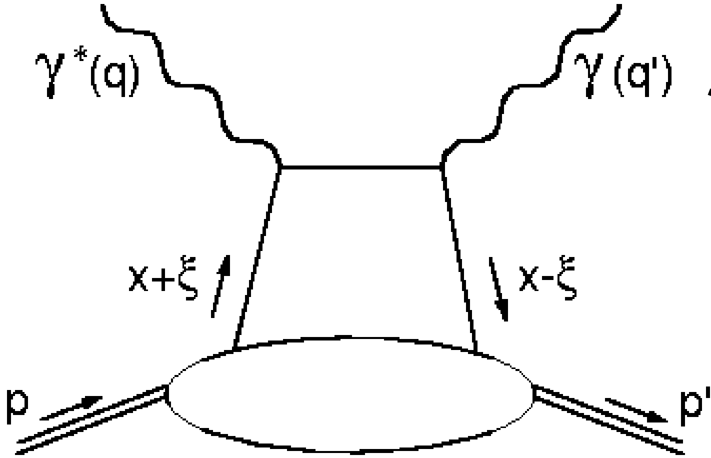


A HERA like Detector with dedicated PID:
>>Time of flight
>>Aerogel Ckov

AND

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

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?

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

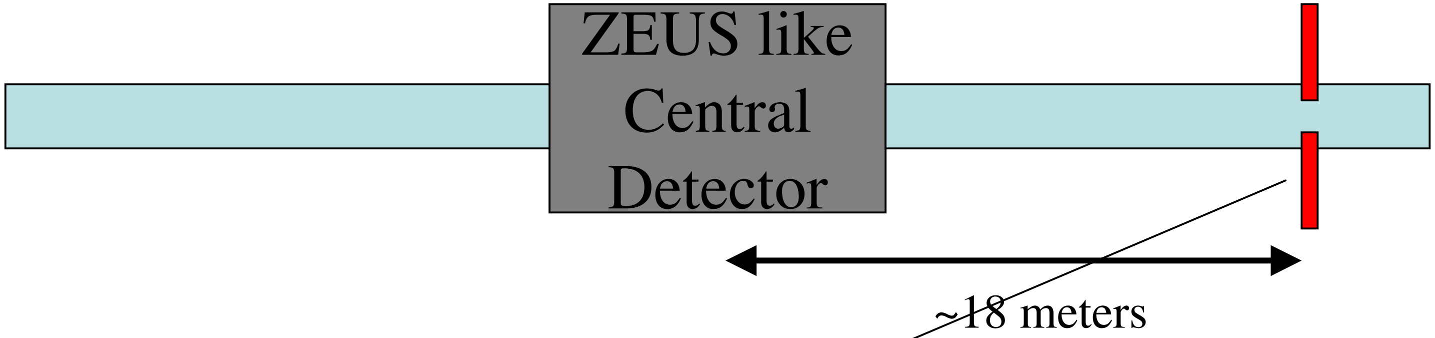
$t \downarrow 0 \qquad t \downarrow 0$

On going theoretical debate… experimental effort just beginning…

--A. Sandacz, AD

Roman Pots for eRHIC

A. Sandacz,AD



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

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

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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)

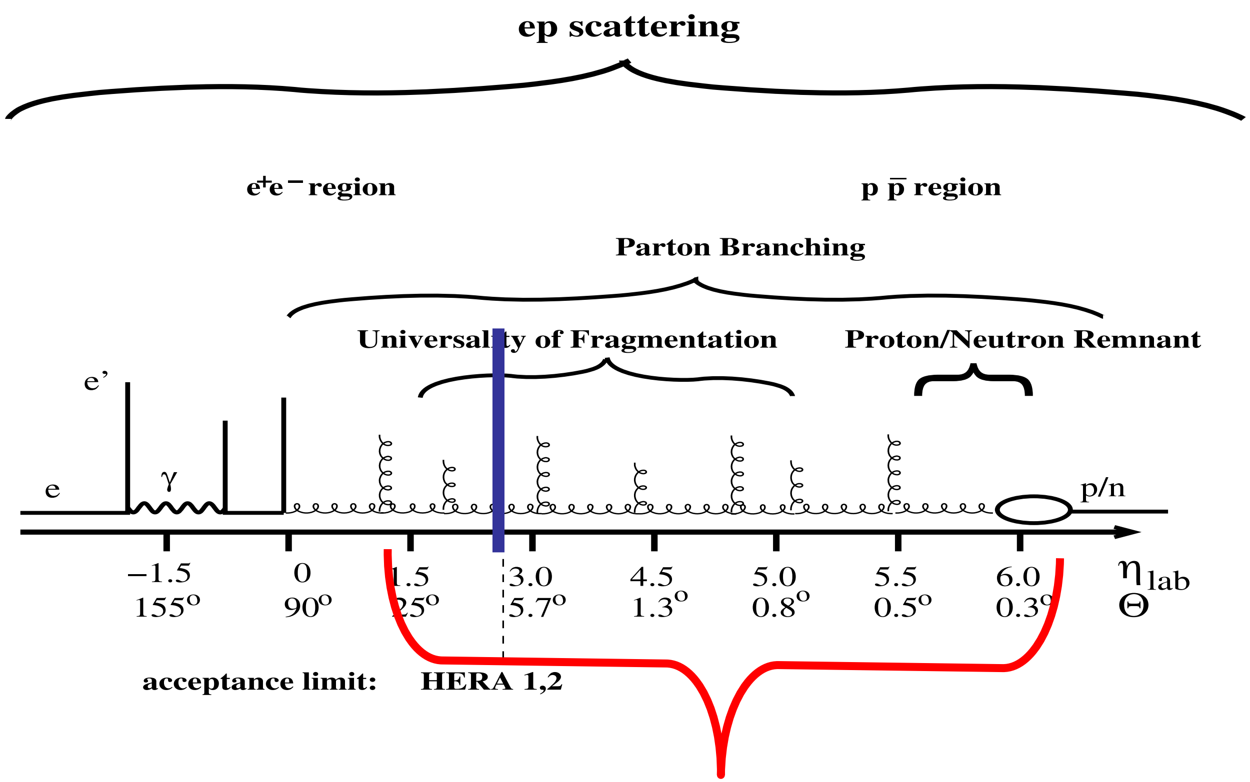
Recent interest in eRHIC from HERA-users

- Latest from HERA-III: probably no prospects for any Phyiscs 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 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
- A. Caldwell, I. Abt et al from MPI Munich have led this study and may plan submit a Letter of Intent at the appropriate time.

A detailed study of radiation in QCD: forward jets

A. Caldwell et al.

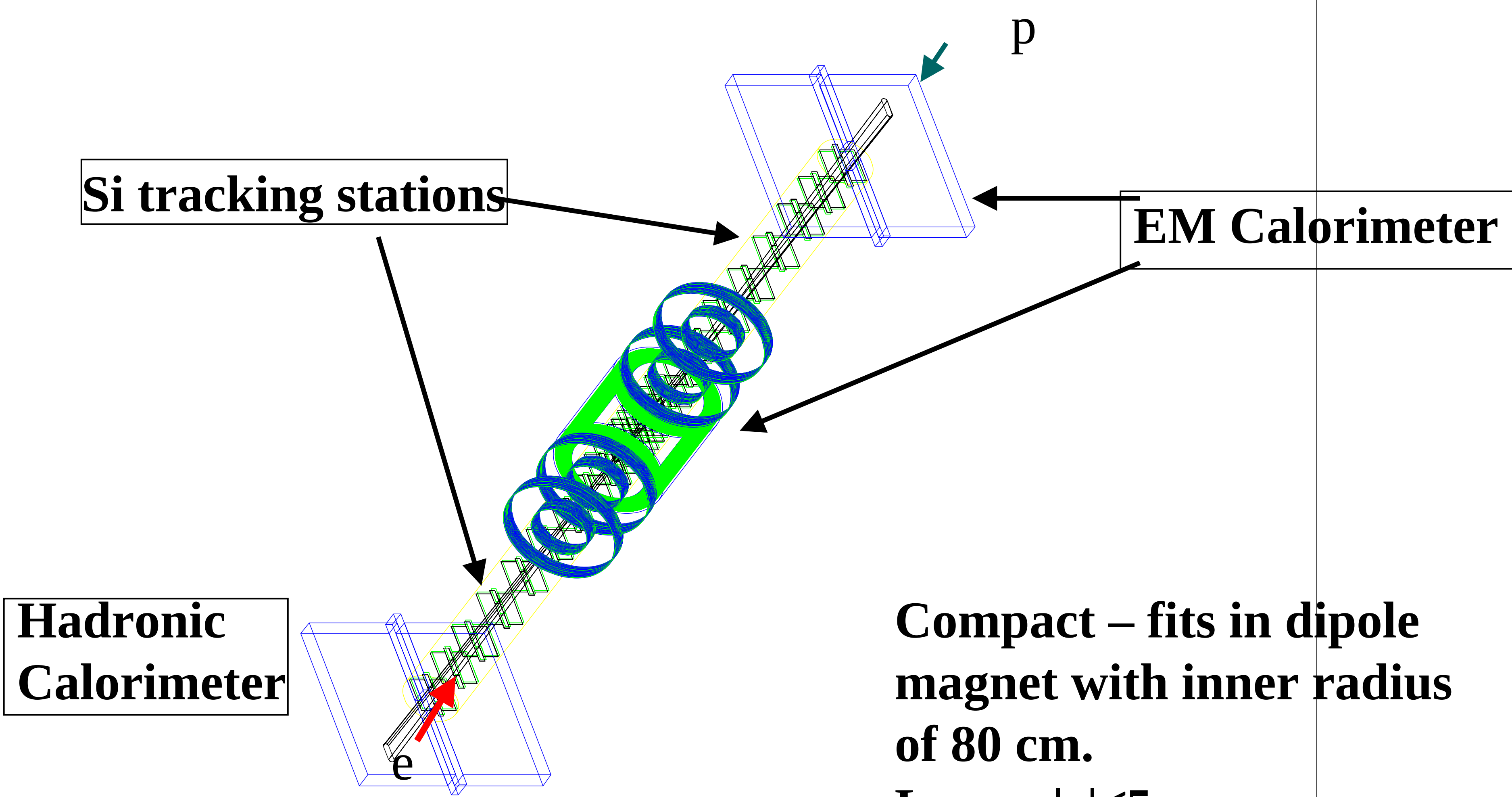


Investigate this region

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

A new detector to study strong interaction physics

A Caldwell et al.



Compact – fits in dipole magnet with inner radius of 80 cm.

Long - $|z| \leq 5$ m

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

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

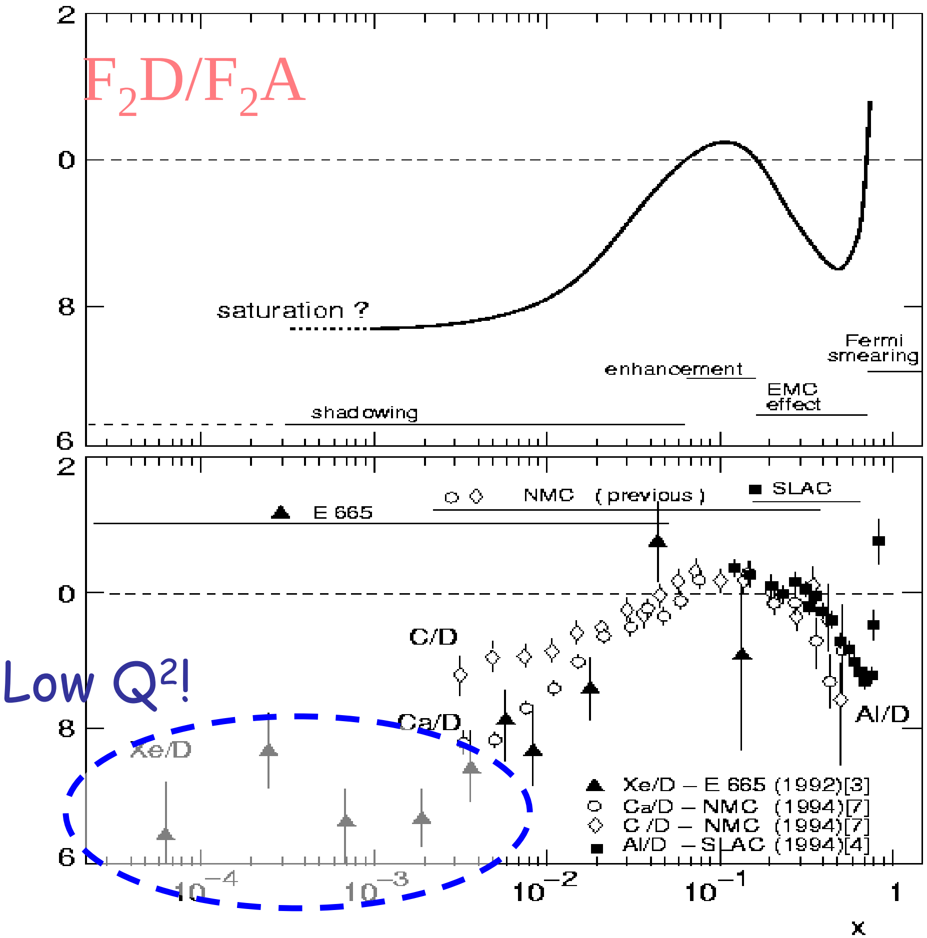
  saturation effects or high density partonic matter also called the Color Glass Condensate (CGC)

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

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

DIS in Nuclei is Different!

E665, NMC, SLAC Experiments



Regions of:

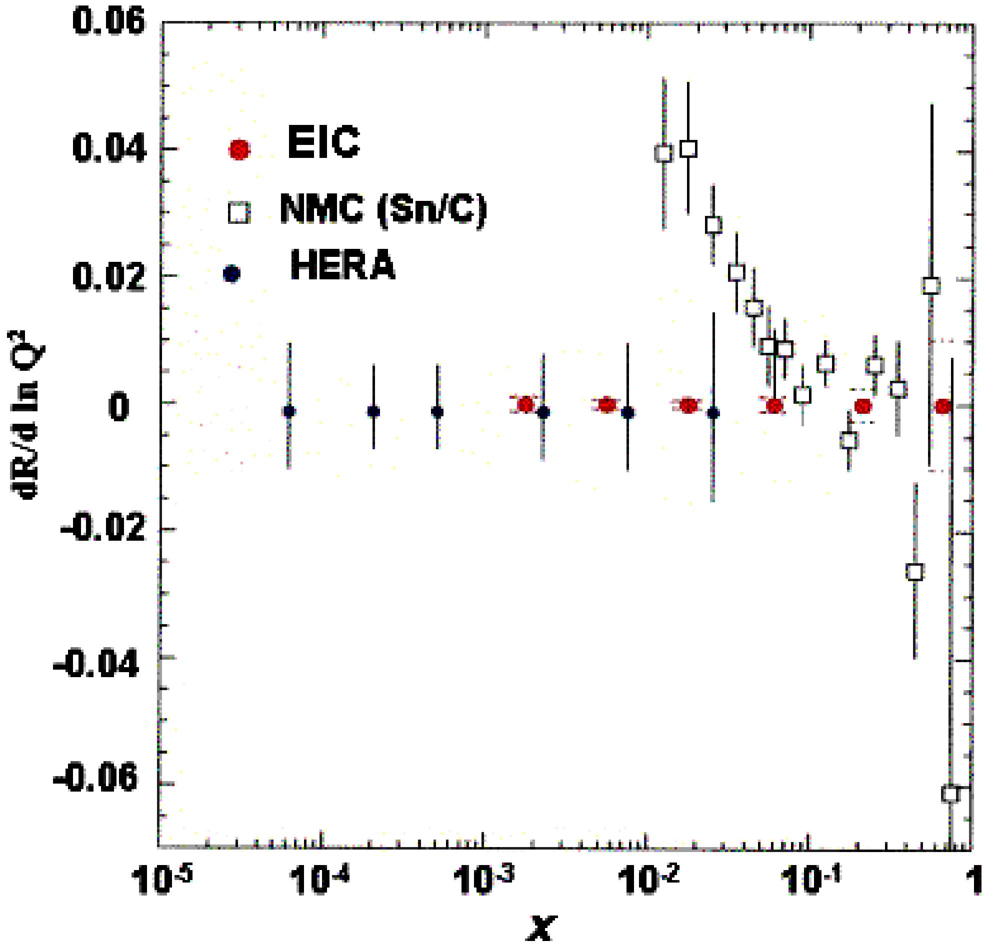
- Fermi smearing
- EMC effect
- Enhancement
- Shadowing
- Saturation?

Regions of shadowing and saturation mostly around Q^2 ~1 GeV^2

An e-A collision at eRHIC can be at significantly higher Q^2

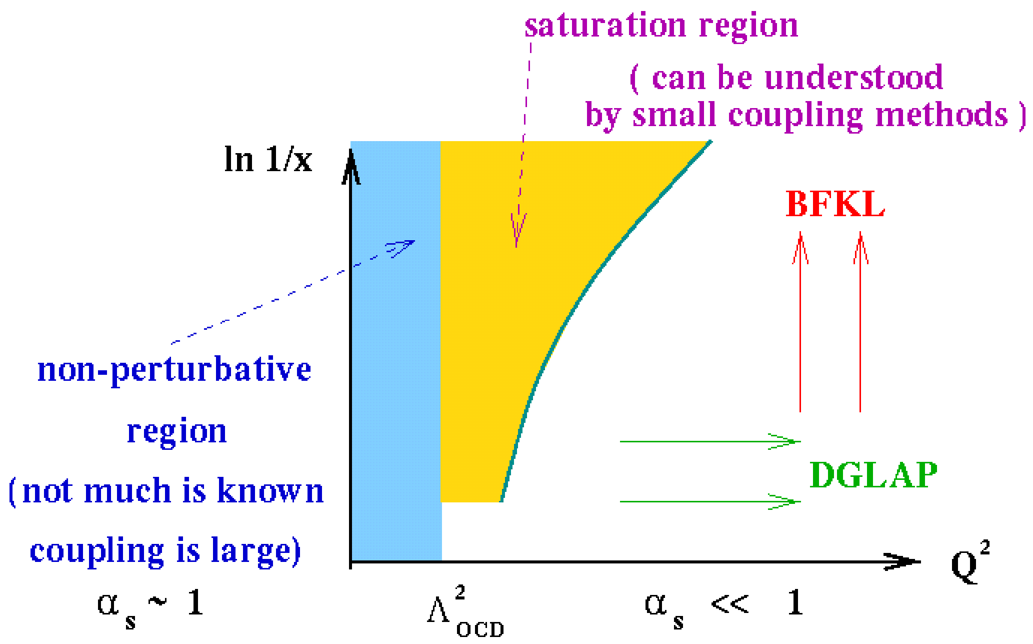
Statistical Precision at eRHIC for e-A

T. Sloan, eRHIC WP 2002



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

The Saturation Region…



- As parton densities grow, standard pQCD break down.
- Even though coupling is weak, physics may be non-perturbative due to high field strengths generated by large number of partons.
- A new state of matter???

An e-A collider/detector experiment with high luminosity and capability to have different species of nuclei in the same detector would be ideal… ➔ Low x --> Need the eRHIC at BNL

A Color Glass Condensate?

E. Iancu, L. McLerran, R. Venugopalan, et a

- At small x, partons are rapidly fluctuating gluons interacting weakly with each other, but still strongly coupled to the high x parton color charges which act as random static sources of COLOR charge
  - Analogous to spin GLASS systems in condensed matter: a disordered spin state coupled to random magnetic impurities
- Gluon occupation number large; being bosons they can occupy the same state to form a CONDENSATE
  - Bose Einstein condensate leads to a huge over population of ground states
- A new "state matter"(??): Color Glass Condensate (CGC) at high energy density would display dramatically different, yet simple properties of glassy condensates

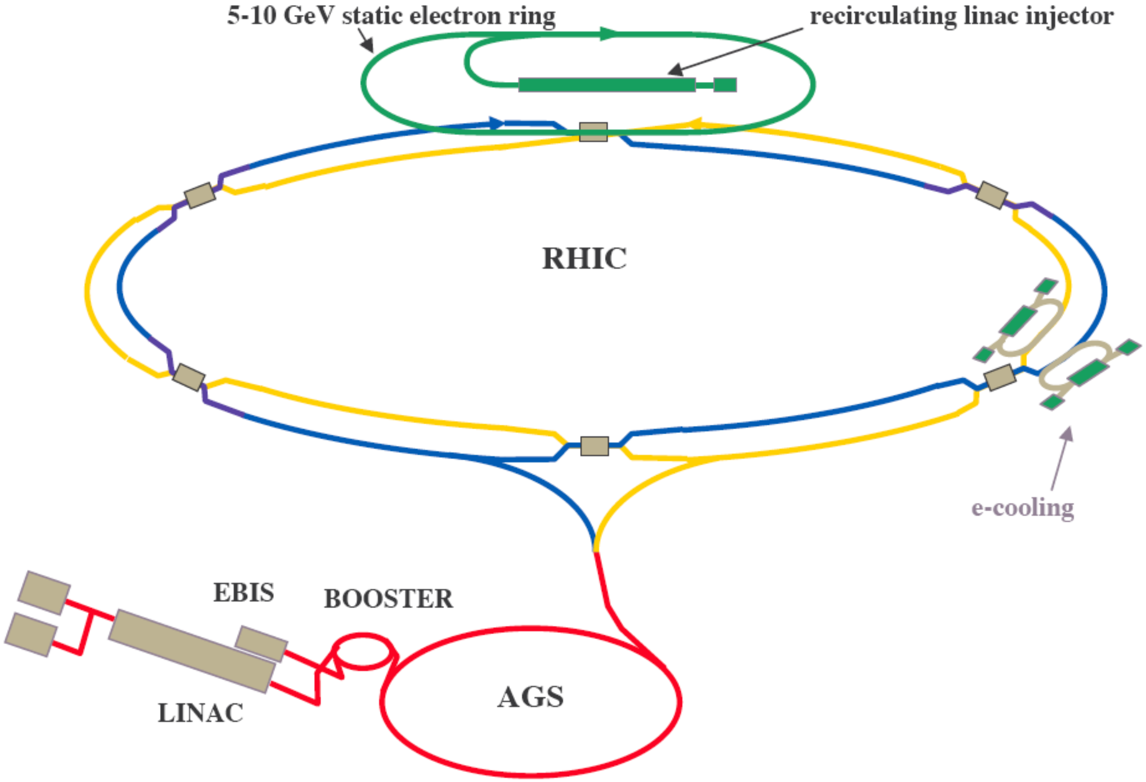
Signatures of Color Glass Condensate (I)

- Measure structure functions and their slopes F_2,dF_2/lnQ^2,$dF_2/dlnx$
  - $dF_2/dlnQ^2$ at fixed x is the gluon distribution
  - CGC theory and conventional QCD predict very different behavior
  - We will need to make precise gluon distribution measurements of nuclei using photon-gluon fusion in nuclei (di-Jet events)
  - Data with eRHIC luminosities and systematic uncertainties at the order of those achieved at HERA would easily differentiate between the different scenarios
- Longitudinal structure function $F_L = F_2 - 2xF_1$
  - Provides an independent measurement of gluon density
  - Beam energy variability built in to the machine (with minimal loss of luminosity or polarization)
- Measurement of nuclear shadowing
  - F_2^A/AF_2^N Quark shadowing observed before
  - G^A/AG^N Gluon shadowing has been observed indirectly (pQCD analysis at NLO)
  - May be observed in the extremely low x and moderate Q^2 kinematic region accessible with eRHIC

Signatures of CGC (II)

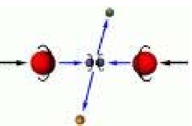
- CGC relates shadowing and diffraction very differently than conventional pQCD
  - eRHIC would be a natural place to study this as a function of A, nuclear size
- Large rapidity gap events caused by hard diffraction
  - Large rapidity gap between current and target fragments a sign of diffractive events. At HERA they were of the order of 7% of total cross section. CGC predicts in nuclei they should be as large as 30-40%. This would be easily measurable, systematically, as a function of A
- Coherent inclusive vector meson production
  - Light vector meson production diffractive cross section ~50%
  - Heavy vector meson diffractive cross section decreases with the vector meson mass and eventually goes to 1/lnQ2
  - eRHIC will produce and study this in abundance with production of $\rho,\omega,\phi,J/\psi$ ….

The eRHIC Ring-Ring Lay Out



- Full energy injection
- Polarized e- source & unpolarized e+ --> (polarization via synchrotron radiation)
- 10 GeV main design but up to 5 GeV reduction possible with **minimal polarization loss**
- Fill in bunch spacing 35ns
- See eRHIC ZDR for more details

Plus Points: Both positrons/electrons positrons…..
Most advanced in technical feasibility



Minus Points: Multiple detectors or/and Interaction Regions?

IR, Synchrotron Radiation, Hadron Beam Modification

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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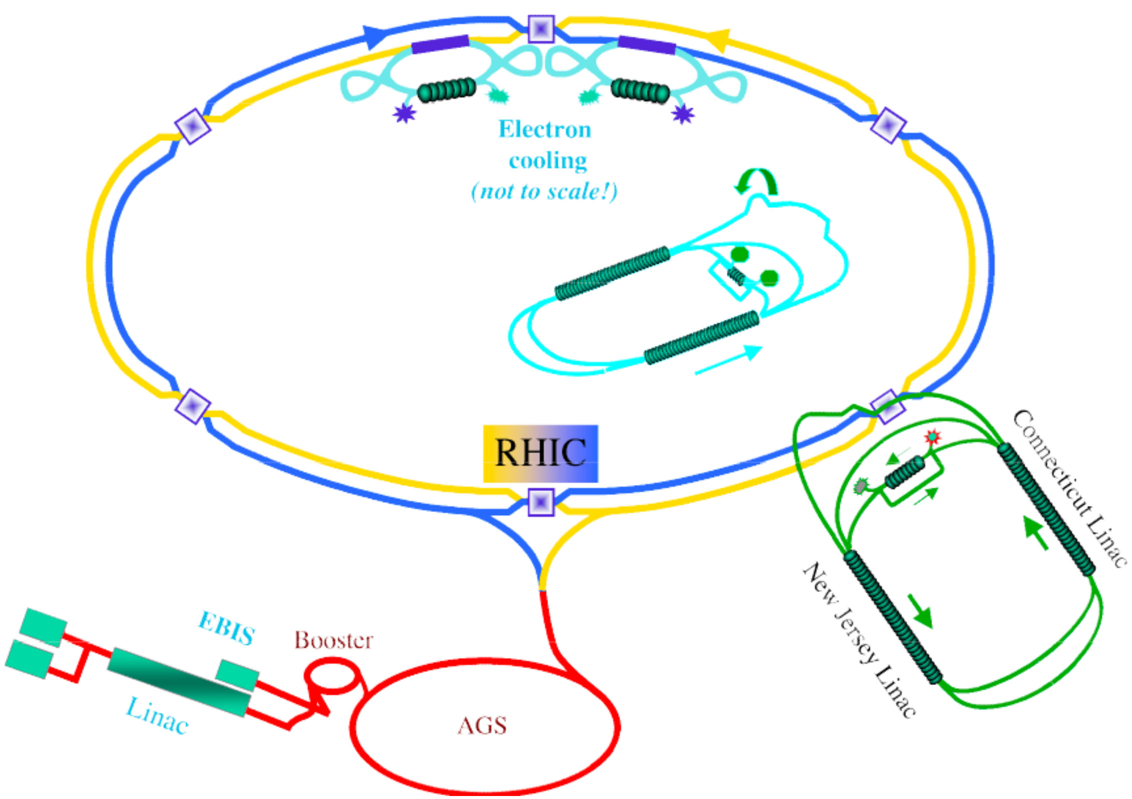
TIFF (LZW) decompressor
are needed to see this picture.

eRHIC:

- Zeroth Design Report
    - April 04
    - Review May’05

eRHIC: Linac-Ring Option

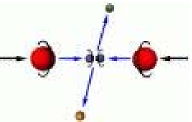


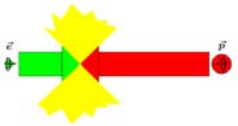
Features:

- Up to L(ep) ~10^{34} $cm^{-2}sec^{-1}$
- Polarization transparency at all energies
- Multiple IRs and detectors
  - 1 low 1 high lumi/pol
- Long element free regions (+/- 5-7 m)
- Full range of CM Energies without loss of polarization & luminosities
- Future upgrades to 20 GeV straightforward

Limitations:

Positron beams not possible
Physics implications?
Time to get on mass shell longer





eRHIC Linac-Ring (Cadilac Version)

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Up to 4 Irs
Up to 20 GeV
Electron beams

eRHIC Status & Design Ideas

http://www.bnl.gov/eic

- 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)
  - 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
  - Review planned in near future (May 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**
- **Technical Feasibility** to start construction evaluated **to be 2009/2010**.

Many involved, but room for many more!

- **eRHIC steering committee:**
  - A. Caldwell (Munich,MPI), A. Deshpande (Stony Brook/RBRC), 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***
- **Extremely 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), and many others!

Concluding thoughts (I)

- The case for a future ep/eA collider is very strong already and is being continuously improved
- eRHIC at BNL, **ZDR is now ready**; will seek approval from NSAC in the next LRP (2006/7) and prepare the CD0

- eRHIC promises to be a truly next generation collider facility
  - Accelerator, Interaction Region and detector ideas being developed simultaneously with other in mind
  - Many technical challenges need to solved, but none is deemed impossible
  - Help, advice and collaboration from the experienced HERA community is critical we are determined to accept

- **We hope that the DIS collider seeking communities join forces now to realize this chance of a future collider(s) for QCD studies**

Concluding thoughts (II)

- It is critical for those communities interested in eRHIC get behind it quickly and make their physics interest and willingness to take collaborative responsibilities known to US DOE and BNL management
  - Our responses and interests become their initiatives!
  - We ought to pursue an accelerated path to eRHIC realization
- Early initiative of eRHIC is not only good for those want it, but is essential for the field
  - No significant university and laboratory based groups can sustain themselves in high level of intellectual activity unless there is continuity.
  - The natural time line of eRHIC are perceived so far conforms to all these
- All eyes should be on the next long range planning activity of the Nuclear Science Advisory Committee (NSAC) of the US DOE 2006/7

http://www.bnl.gov/eic --> register email eic/news servers