Future Physics at RHIC

Evolution of Physics & the Facility from RHIC to eRHIC

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Special thanks to Paul Stankus for input on HI issues, and Tom Ludlam and Sam Aronson for comments & suggestions

Roadmap for this talk

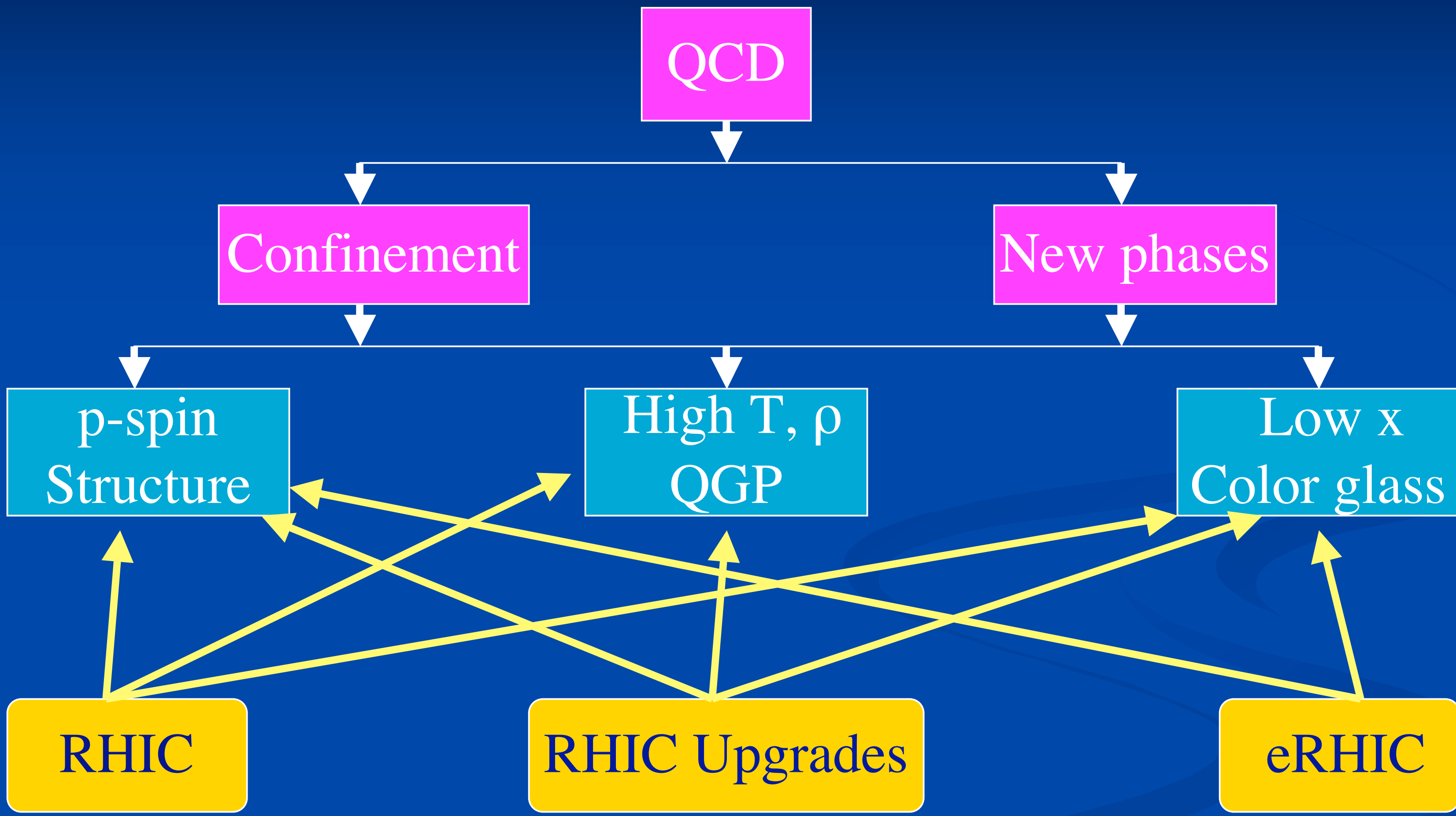
- Recent RHIC results: Heavy ion excitement and spin physics

- RHIC Luminosity & detector upgrades
  - RHIC accelerator evolution, ongoing projects: expected luminosities
  - Physics potential with RHIC detector upgrade (selected topics)

- A collider upgrade leading to eRHIC
  - Precision studies with e-A collisions & polarized e-p collisions at high energy --> *Only* selected highlights
  - *Unique facility* exploring fundamental aspects of QCD complimentary to RHIC, both for polarized and un-polarized scattering
  - *Compelling physics, global interest & cost effective* as well --> A logical upgrade of the RHIC facility!

- Summary

RHIC, A Unique QCD Laboratory



Discovery ➡ Exploration ➡ Precision ➡ Discovery

Experimental Reviews: White Papers by all four Experiments
And complementary publications by theorists

Recent Excitement

- Discovery of "jet quenching …." ---> "ultra dense matter"
- Discovery of "substantial collective flow" ---> "nearly perfect liquid"
- Observation of "differences" in d & A sides of d-A collisions ---> Early indication of "Gluon Saturation"(?)
- With only minimal polarized proton running so far
  - Gluon spin program started: Capability demonstrated; Precise results soon
  - Transverse spin physics started a lot more is around the corner
  - Demonstration of 205 GeV x 205 GeV polarized proton collisions!

- *All* this was possible in such a *short time* because of the unique, multipurpose & flexible tool that RHIC and the experiments are.
- It would be hard to find facilities around the world which produced so many significant measurements in such short time after turn on. *Indeed, some have argued that RHIC could be a standard against which future facilities & programs would be judged.*

Important Physics which will greatly benefit from RHIC upgrades

- High T QCD (AA, pA and pp)
  - Heavy flavors (c,b production)
  - Jet tomography (jet-jet and γ-jet)
  - Quarkonium (J/ψ, ψ',χ_c, Y(1s,2s,3s)) states
  - Electromagnetic radiation (e+e- pair continuum)
- Spin structure of the nucleon (polarized pp)
  - Flavor separation of quark distributions (W-production)
  - Gluon spin structure $\Delta G/G$ (heavy flavor & γ-jet correlations)
- Low x phenomenon (pA/dA)
  - Gluon saturation in nuclei (particle production in high rapidity)

Could be accomplished with detector and/or RHIC luminosity upgrade

Collider Accelerator Upgrades

Useful not only for RHIC Physics
as well as
eRHIC Physics!

T. Roser

Machine goals & plans

- Enhanced RHIC luminosity (112 bunches, b* = 1m)
- Au-Au : 8 x 10^{26} cm^{-2} sec^{-1} (100 GeV/nucleon)
- For protons 2 x 10^{11} protons/bunch (no IBS)
- p - p 60 x 10^{30} cm^{-2} sec^{-1} (100 GeV)
  150 x 10^{30} cm^{-2} sec^{-1} (250 GeV)
  (2 IRs, averaged luminosity over a store)

EBIS (low maintenance linac-based pre-injector, all species including U and *polarized* He^3; avoid Tandem investment and 3 year pay-back period)

RHIC luminosity upgrade (e-cooling, ~ x ***10 more luminosity*** R&D in progress)

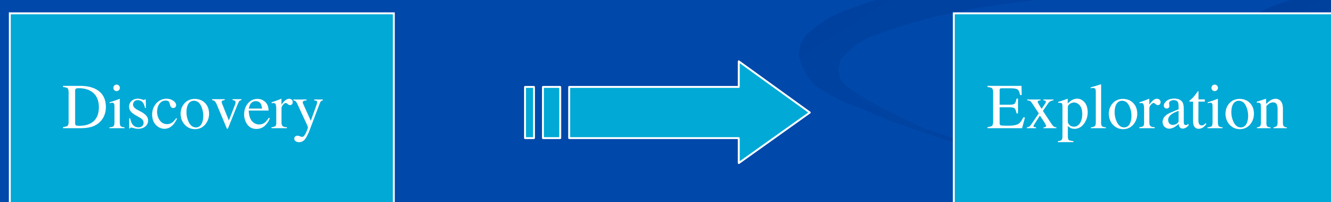
eRHIC (high luminosity (1 x 10^{33} cm^{-2} sec^{-1}) polarized e-p, eA collider)

RHIC Luminosity upgrade with e-cooling

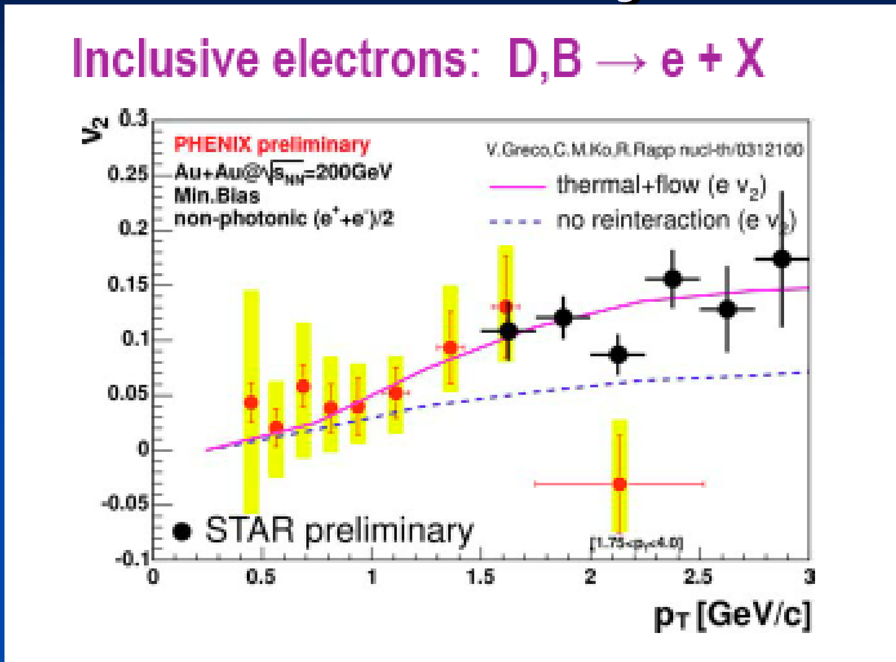
Au-Au Collisions 100 GeV/n x 100 GeV/n	w/o cooling	e-cooling
Emittance (95%) π μm	15-40	15-3
Beta function at IR [m]	1.0	1.0- 0.5
Number of bunches	112	112
Bunch population [10^9]	1	1-0.3
Beam-beam parameter per IR	0.0016	0.004
Average store luminosity [10^{26} cm^{-2} sec^{-1}]	*8*	*70*

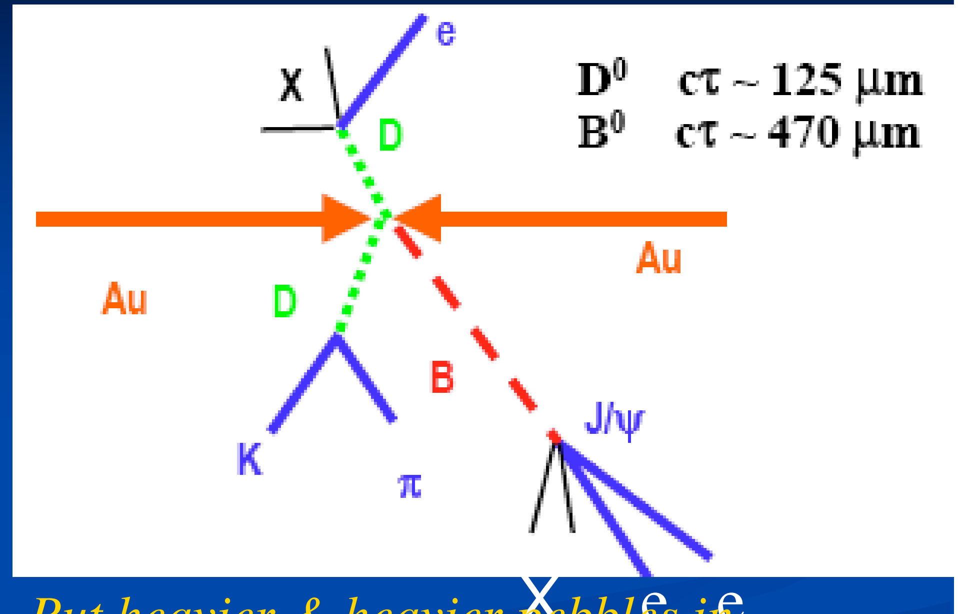
Pol. proton collisions (250 GeV x 250 GeV)		
Emittance (95%) π μm	20	12
Beta function at IR [m]	1.0	0.5
Number of bunches	112	112
Bunch population [10^{11}]	2	2
Beam-beam parameter per IR	0.007	0.012 (?)
Average store luminosity [10^{32} cm^{-2} sec^{-1}]	*1.5*	*5.0*

Detector Upgrades
driven by
Exploration of matter just discovered



Heavy Flavor Production



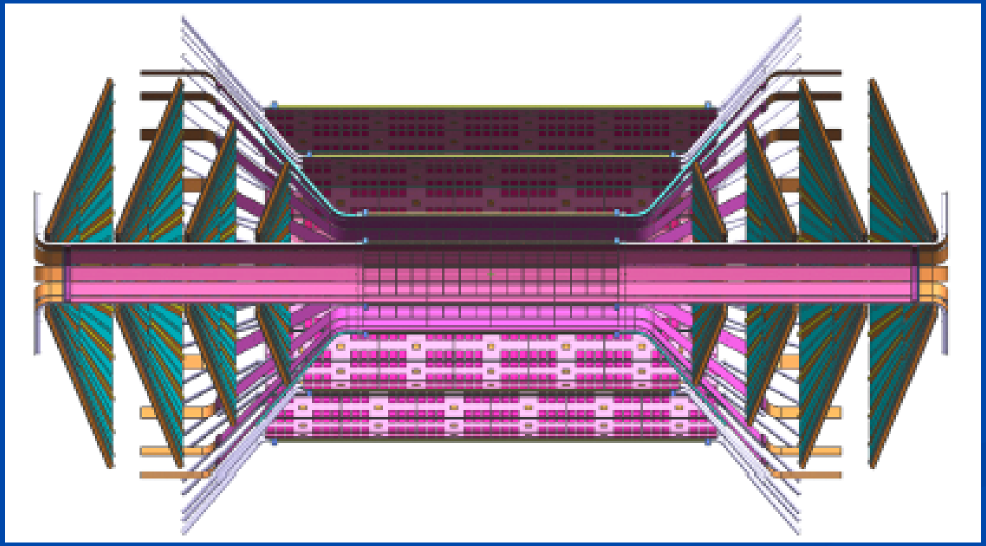


Put heavier & heavier pebbles in the stream to study viscosity, drag..

- Physics Goal: Test hydrodynamic properties of sQGP
  - Look for charm: heavy & produced in primary collisions only
  - It also interacts strongly with medium
- Experimental challenge:
  - Direct observation of charm and beauty (secondary vertices)
  - Intrinsically low rate for beauty and high p_T charm production
- Need Silicon Vertex Trackers for high vertex resolution & luminosity upgrade

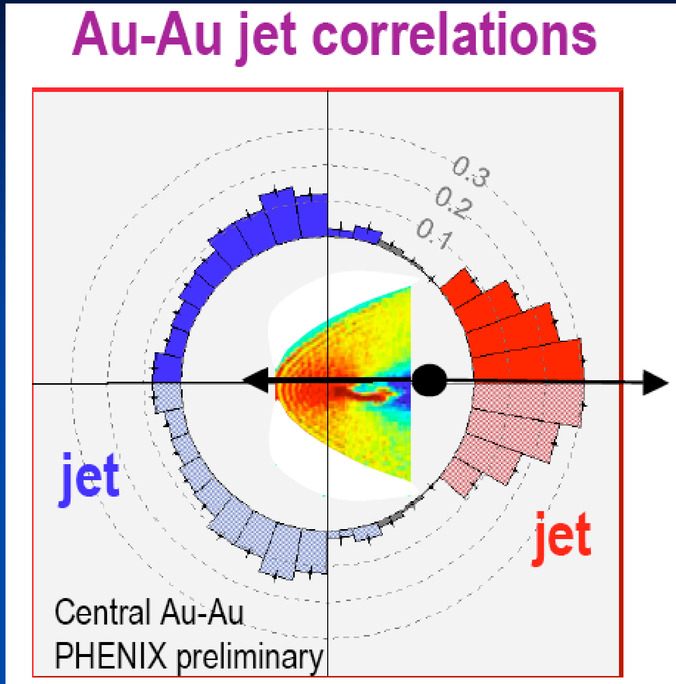
Silicon Vertex Trackers

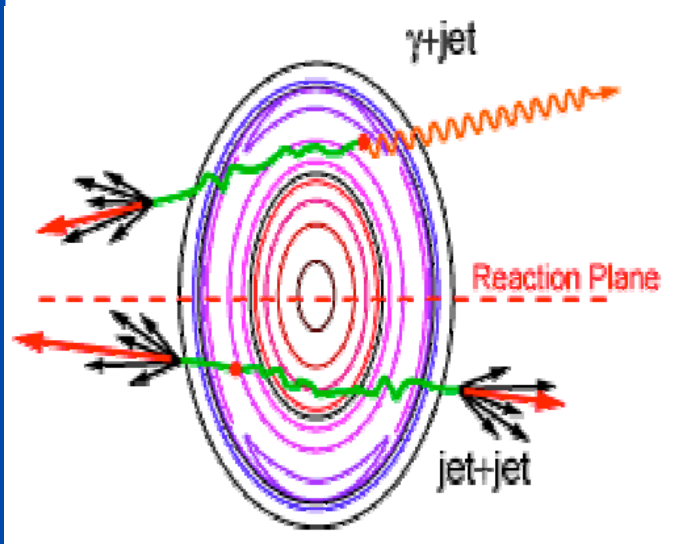
- PEHNIX VTX collaboration
  - BNL,FSU,ISU, KEK, Kyoto,LANL,Niigata, ORNL, RBRC, Stony Brook, UNM, EPT, Saclay
  - Proposal submitted to DOE
  - Proposed DOE Funding FY07/08, Partial RIKEN funding already



- STAR Heavy Flavor Tracker
  - BNL,UC Irvine, UCLA, NPI Prague, IRS Strasbourg, MIT, LBL, OSU
  - Proposal in preparation

High T QCD: Jet Tomography of QGP





- Physics goal
  - To determine plasma properties such as: speed of sound, opacity, viscosity,equation of state…
- Tools
  - Collective behavior, transmission of hard probes, modification of jet fragmentation
- Challenges:
  - Detailed angular correlations over large acceptances, particle ID over large pT range (high pT)
  - Low rates of γ-jet, heavy flavor-jet events
- Upgrades:
  - STAR PID up to 4 GeV (Time of Flight) over a wide acceptance; increased rate capability
    - TOF proposed to be funded FY06/07
  - PHENIX PID up to 10 GeV (Aerogel); improved tracking(VTX); forward calorimetry (Nose Cone Calorimeter)
    - NCC being proposed
  - RHIC luminosity upgrade

Quarkonium Spectroscopy

- Physics goal
  - Study (de)confinement: J/ψ, ψ', χ_c , and Υ(1s,2s,3s)
- Challenges
  - Low rates… will require highest possible luminosities

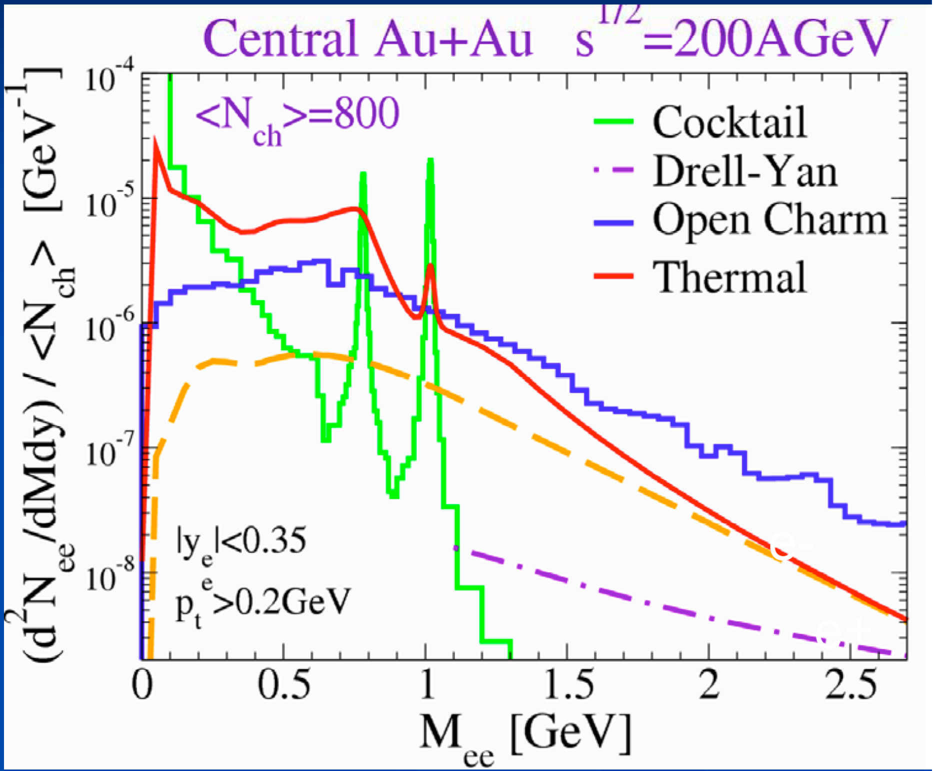
Example of expected quarkonium statistics from future Au-Au runs (PHENIX)

	RHIC (1.5 nb^{-1})	RHIC upgrade (30 nb^{-1})
J/ψ (ψ') $\rightarrow \mu\mu$	38,000 (1400)	760,000 (28,000)
$\Upsilon \rightarrow \mu\mu$	35	700

  - Measurement of γ in coincidence
- Upgrades:
  - RHIC: Luminosity upgrade (e-cooling)
  - PHENIX forward calorimeter (χ_c --> J/ψ +γ)
  - STAR rate capability (DAQ) & additional electron identification (TOF)

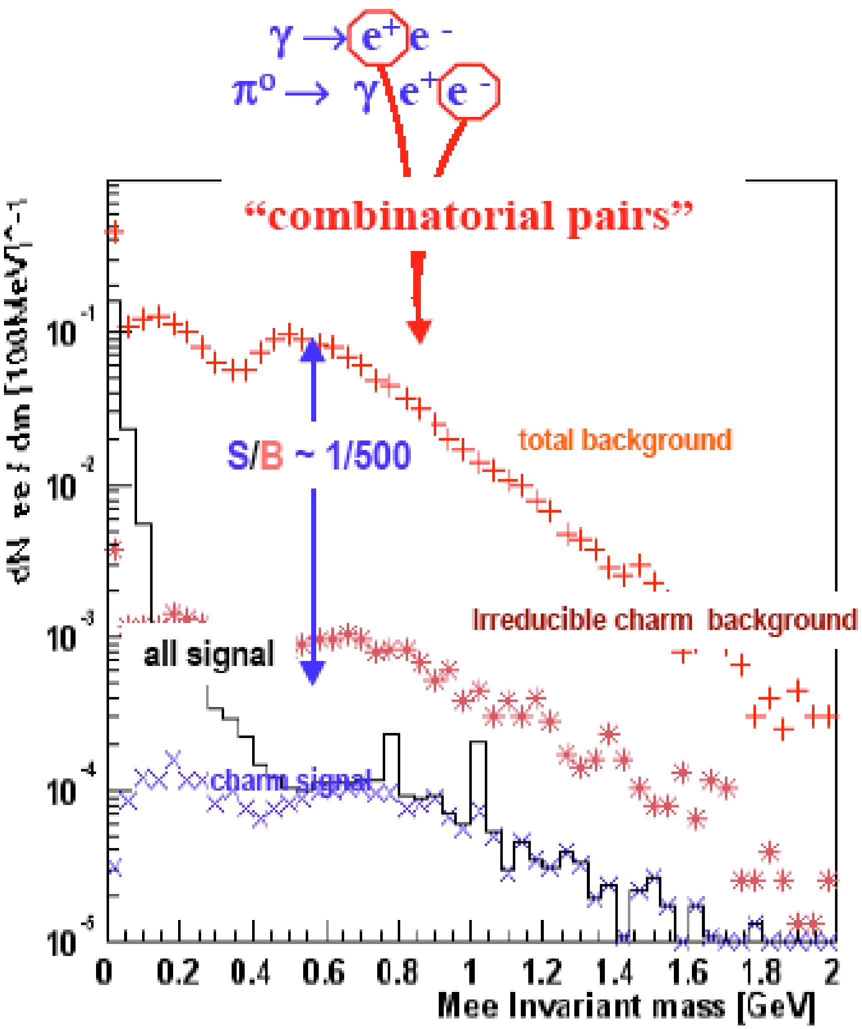
High T QCD: Low-Mass e^+e^- Pairs

- Use sensitivity of e+e- pair production to
  - Thermal radiation
  - Chiral transition (creation of mass)
  - Quasi particles in strongly coupled QGP (sQGP)

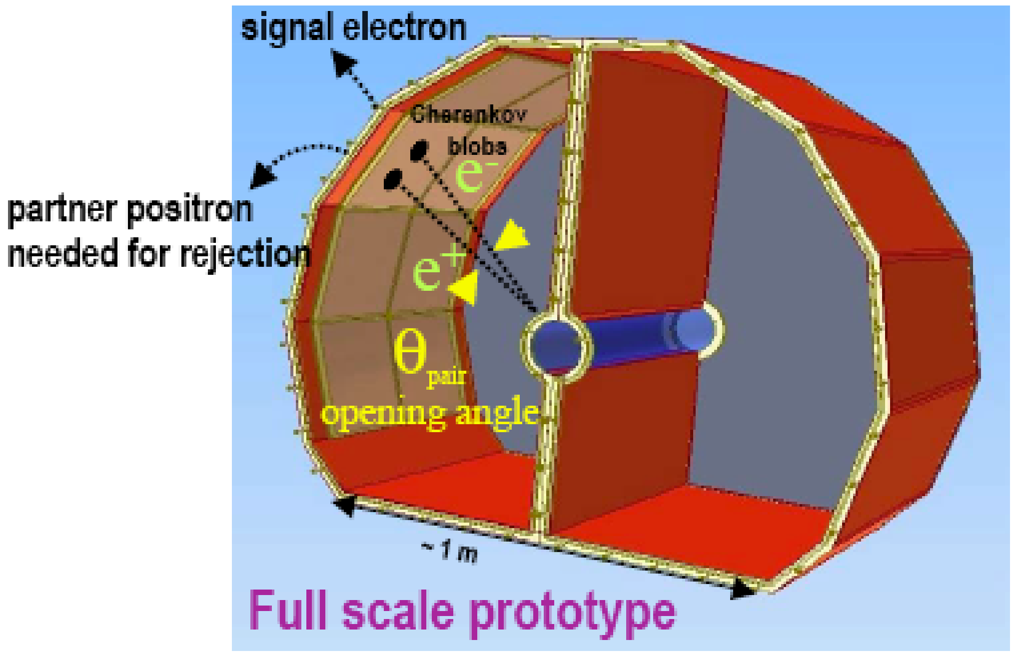


- Experimental challenges
  - Large charm contribution
  - Combinatorial background from γ--> e+e- and Dalitz decay of π^0
- PHENIX: Hadron Blind Detector (HBD)

HBD for PHENIX



- Full scale prototype under construction
  - Weizmann, Stony Brook, BNL, Columbia, FIT, CNS-Tokyo, U. Mass., RBRC



Detector upgrades for Spin Physics

<u>Understanding Nucleon Spin (NS) & hence its fundamental structure</u>

Gluon Spin Contribution to NS ---> VTX (PHENIX),HFT(STAR): Alreaady Mentioned
Quark & anti-quark spin contribution--->Forward tracker (STAR), Mu Trigger(PHENIX)

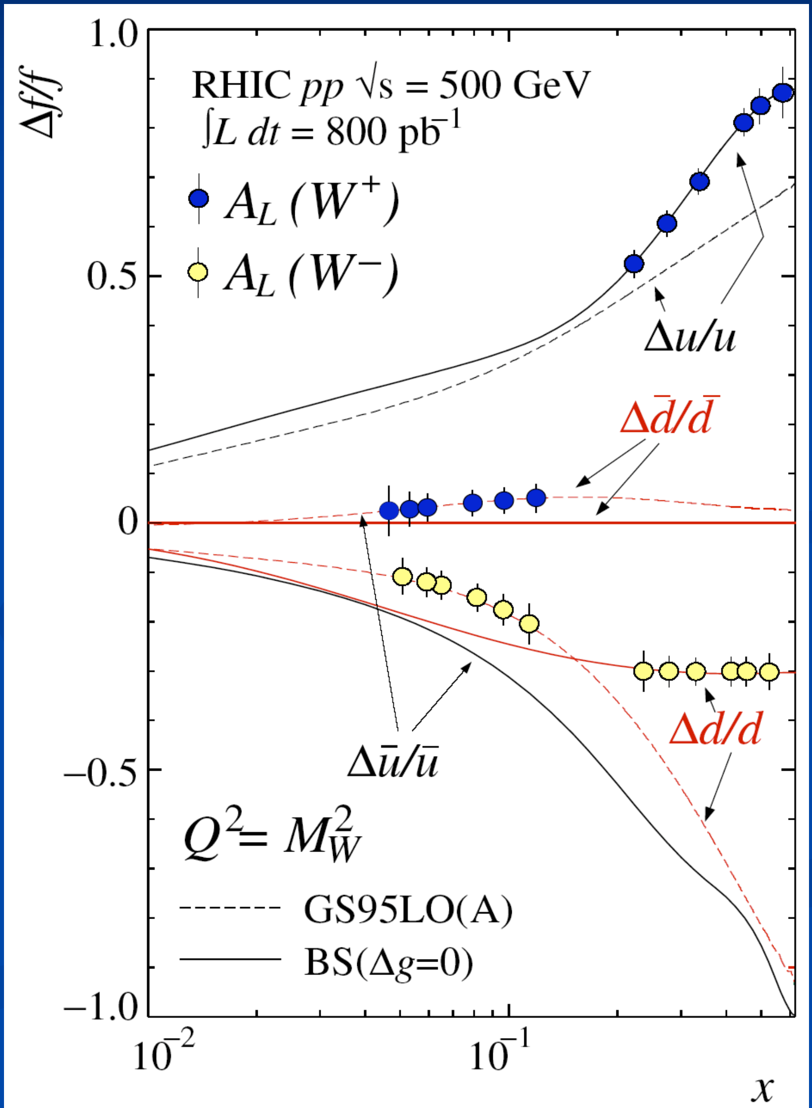
Role of transversity in NS (new detector?)
And that of Orbital angular momenta of partons…. (eRHIC?)

Δq and Δqbar from W production

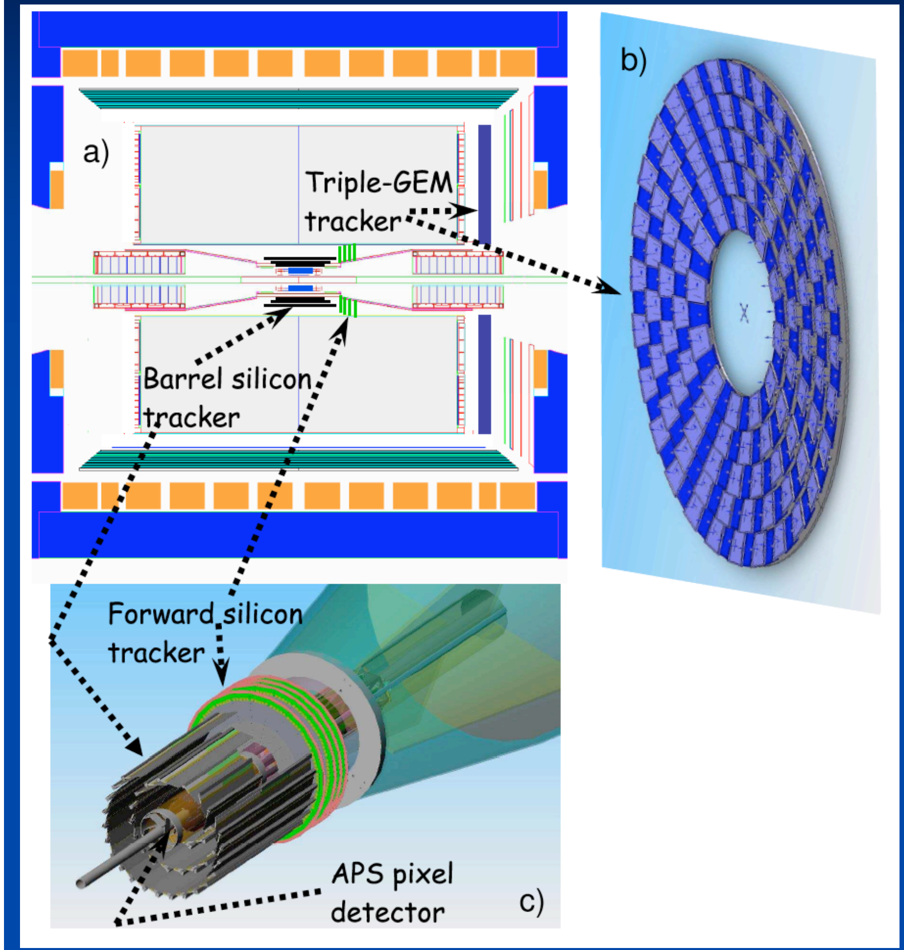
$$\Delta d + \bar{u} \rightarrow W^-$$
$$\Delta \bar{u} + d \rightarrow W^-$$
$$\Delta \bar{d} + u \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$

$$\mathbf{A_L} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- Single spin parity violating $W^{+/-}$ production
- Cleanest method to determine the role of quarks and anti-quarks in determining the nucleon spin
- Requires: 500 GeV polarized pp collisions
  - STAR capability of separating W+ and W- in large rapidity regions
  - PHENIX high pT single muon trigger to suppress background due to hadronic decays



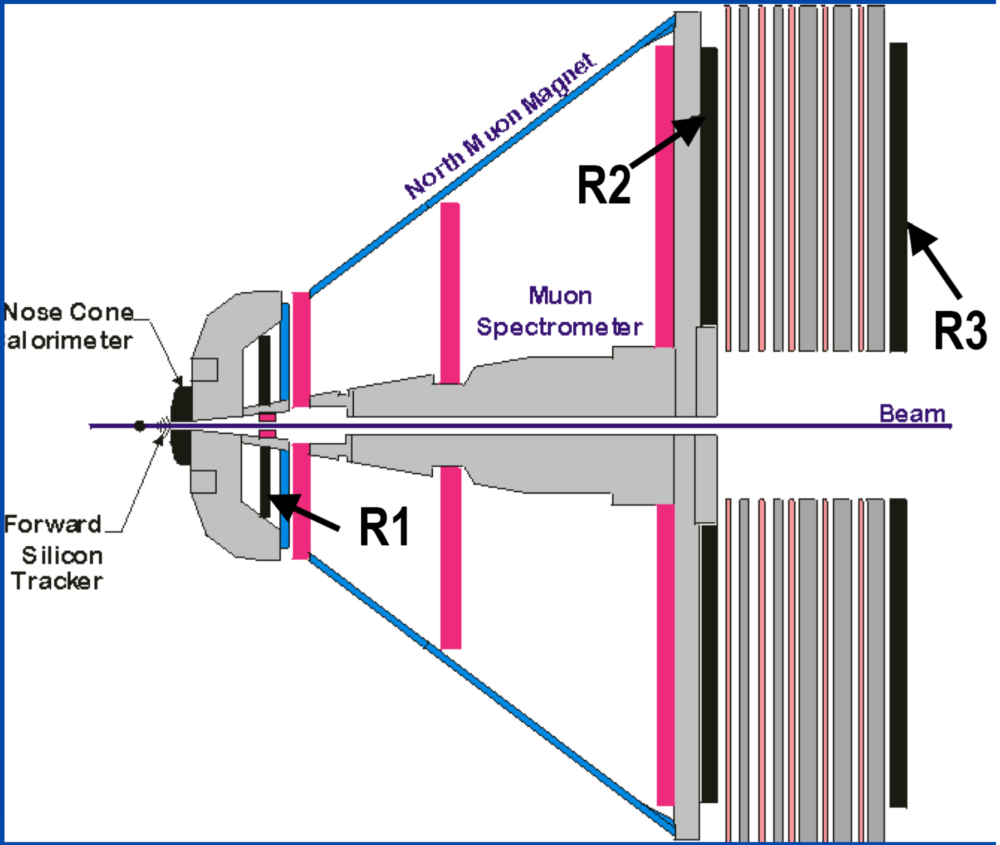
Upgrades for W physics



STAR Forward Tracker Upgrade

- R&D on going
- ANL, BNL, IU,LBL, MIT, Yale, Zagreb

- PHENIX μ-Trigger upgrade
  - Proposal approved by NSF!
  - UIUC,UC-Riverside, ISU, ACU, Colorado, Peking U.

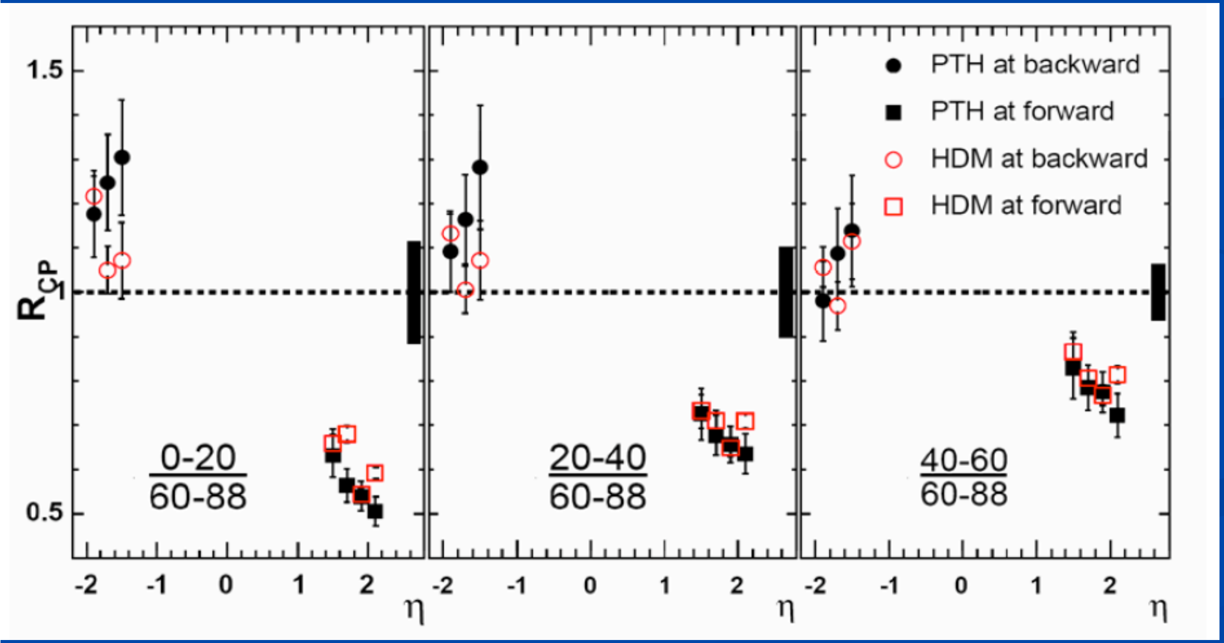


New Detectors for RHIC

- R2D (RHIC-2-Detector) A large acceptance detector for RHIC (Harris et al.)
  - Tracking: high rate capable (pixel,silicon, GEM-type), precision inner tracker
  - Particle ID over a large momentum range
  - EM and Hadronic calorimetry, specialized very forward calorimetry
  - High rate capability, trigger, DAQ
  - Proposes to use equipment decommissioned from other labs
  - Debate underway on the
    - physics gains vs. costs, man power, time scales
- Dedicated forward physics detector?
- Recently we have also heard in a transverse spin workshop here for a possible idea of a new detector at RHIC dedicated to transverse spin
  - Too preliminary at present to comment

Low x physics

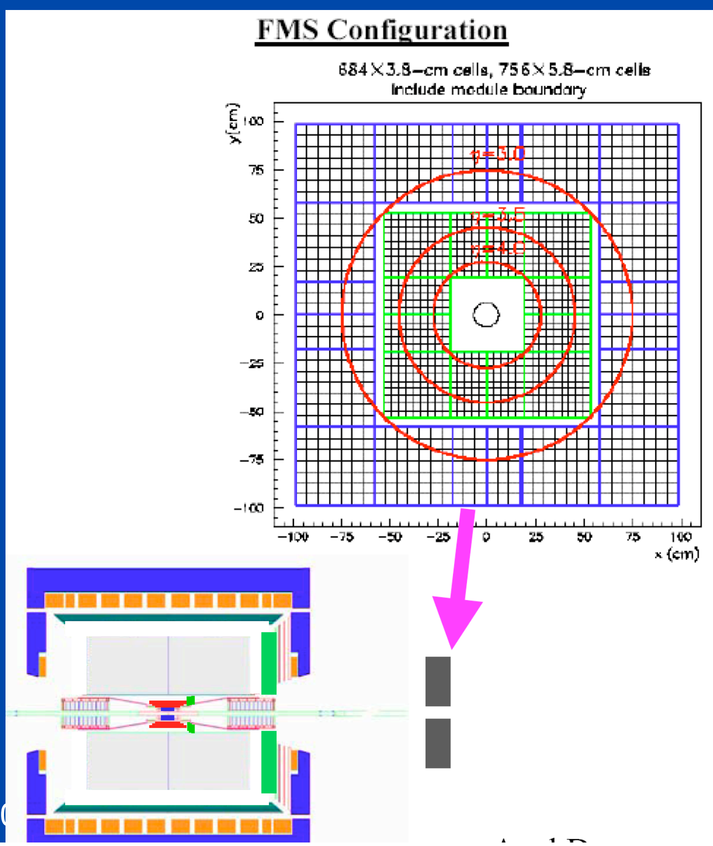
- Evidence of saturation phenomena at HERA and now at RHIC?
- Color Glass Condensate(?):
  - McLerran/Venugopalan et al original ideas
  - Kharzev et al. Application to RHIC
- Requires measuring gluon density in x 0.001 < x < 0.1 in Au in d-Au collisions
- Hadron detection in very forward rapidity region for this and other physic
  - STAR forward meson spectrometer
  - PHENIX forward EM calorimeter and Si Tracker



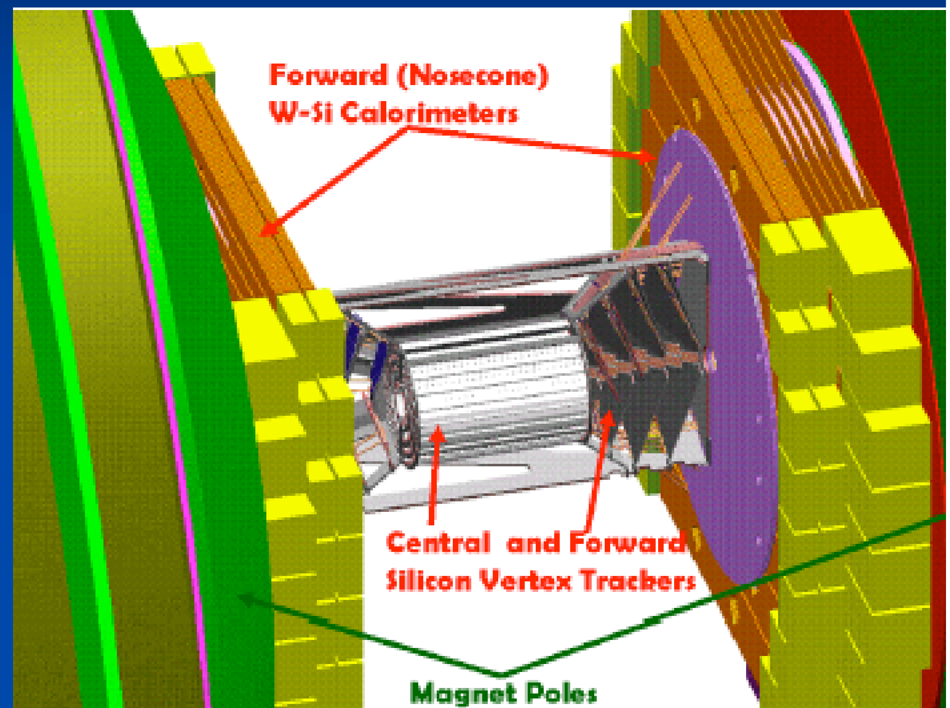
Punch Through Hadrons PTH
Hadronic Decay Muons HDM

Forward Calorimeters

- STAR
  - Calorimeter modules at hand
  - Readout needed, funding request/proposal with NSF
  - Penn State, BNL, UC Berkeley, IHEP Protvino, Texas A&M



- PHENIX
  - Forward nose-cone calorimeter



  - R&D ongoing
  - BNL, UC-Reverside, JINR-Dubna, Moscow State, Charles U., Czech Tech. U., Czech Inst. Of Physics

Low x physics is of high interest!

L. McLerran at al arrived at ideas of Color Glass Condensate, Saturation Physics, as it was called in Europe.

- At low x even if the coupling is weak, physics may be non-perturbative due to high field strengths generated by large number of partons
- Is it really a new state of matter?
- Application of these ideas to RHIC (d-Au) data by D. Kharzeev et al
  - new interest and excitement

Experimental Verification:

An Electron (**heavy**) Ion Collider: "EIC"

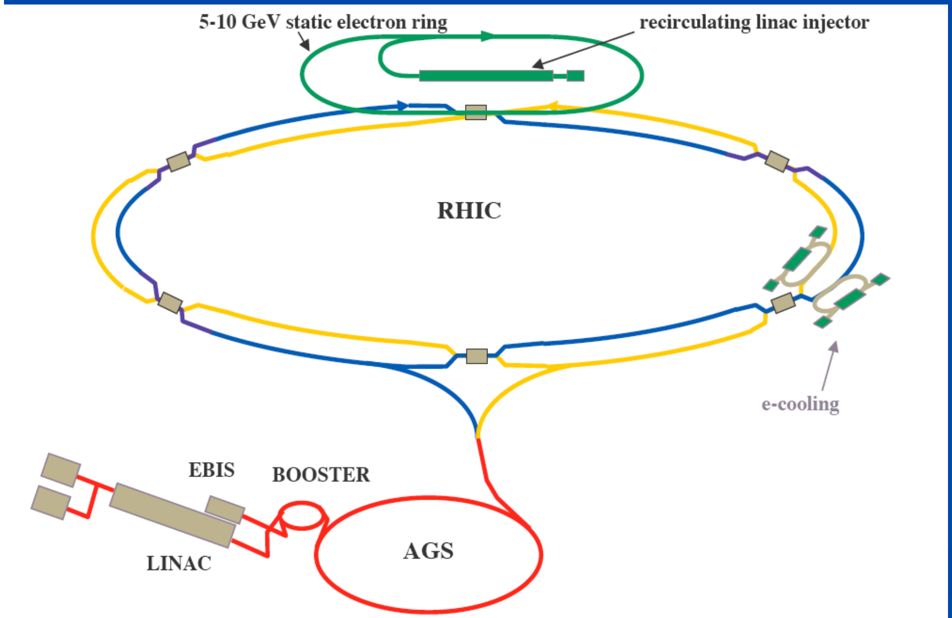
- First proposed construction of an electron ion collider
- We quickly realized that this would also be a *fantastic* physics program with *polarized* e-p scattering
- EIC at BNL: "eRHIC" Christened by R. Venugopalan (BNL)

eRHIC at BNL

THE PROPOSAL

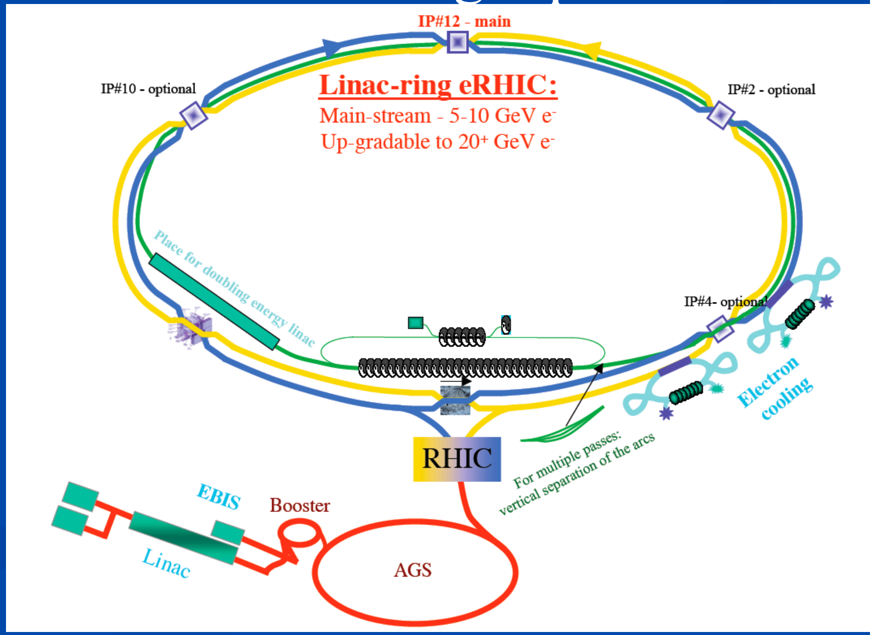
A high energy, high intensity polarized electron/positron beam facility at BNL to colliding with the existing heavy ion and polarized proton beam would significantly enhance RHIC's ability to probe **fundamental and universal aspects of QCD**

Ring Ring Option

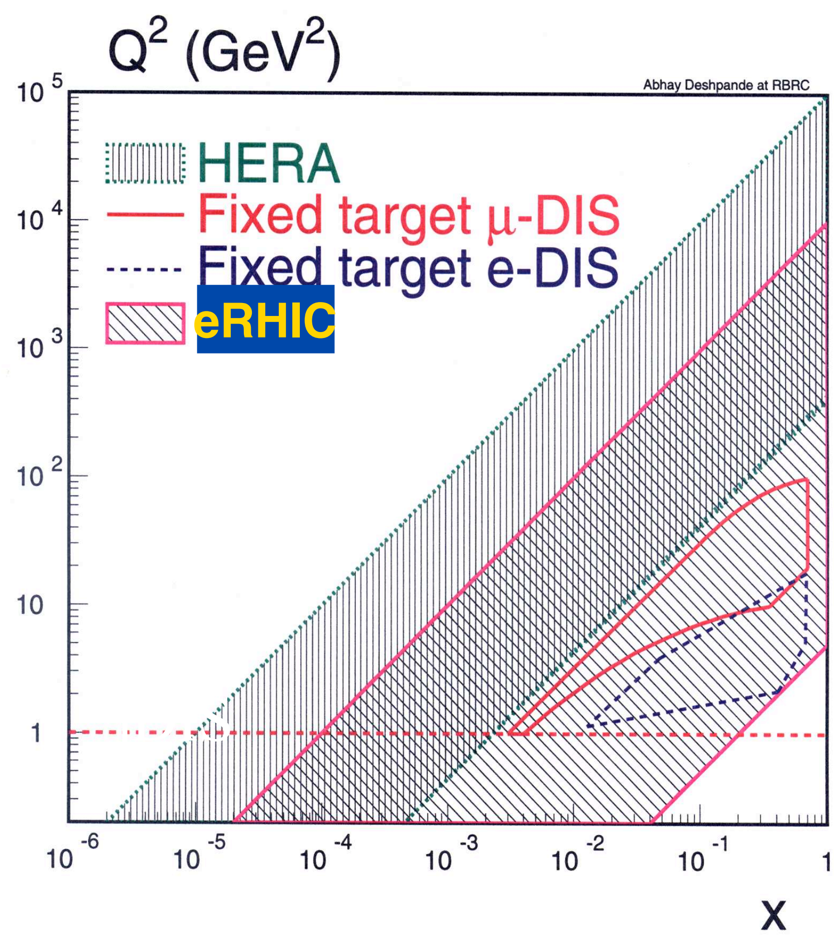


Main Design

Linac Ring Option

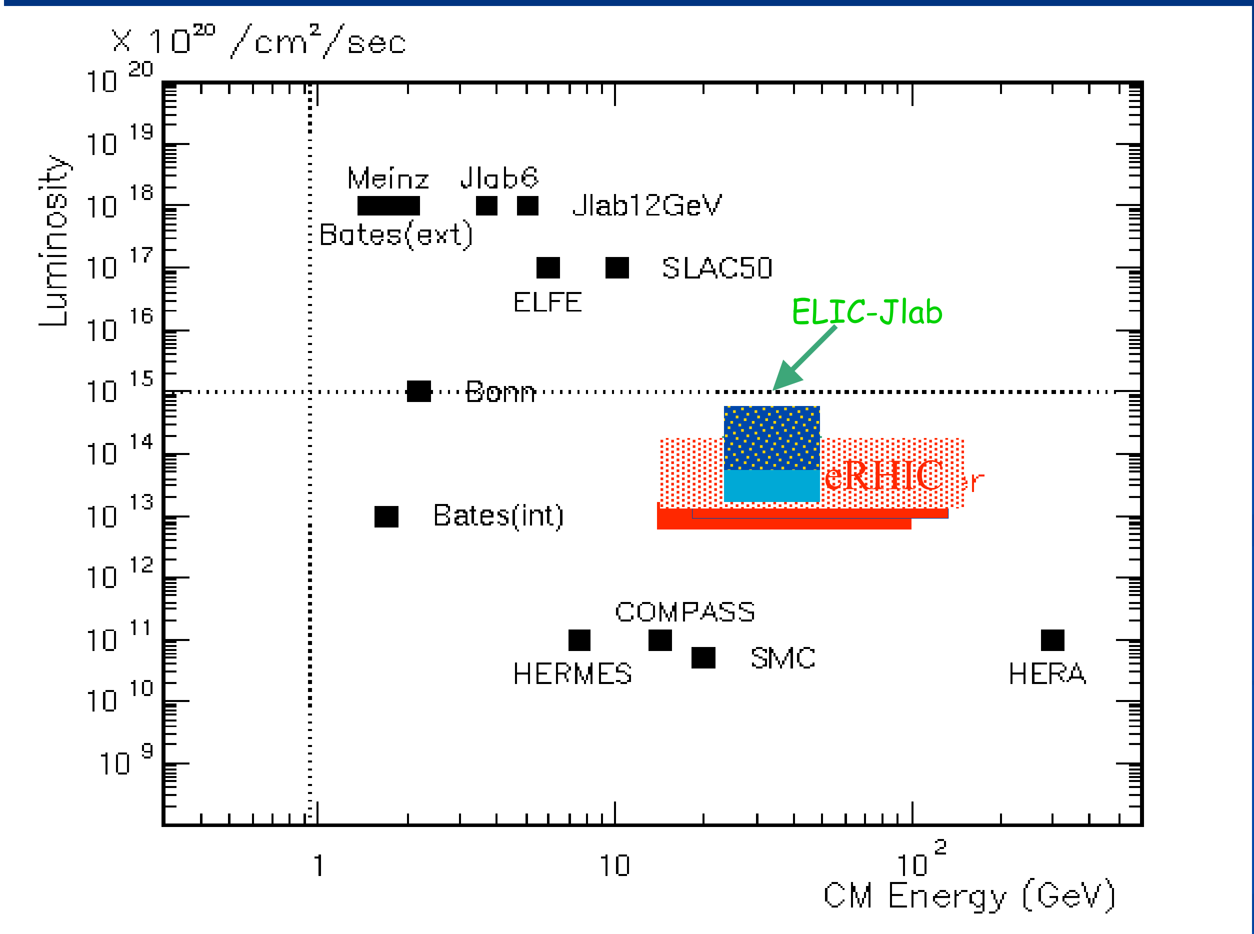


eRHIC vs. Other DIS Facilities



- **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 beams (~70%) and He^3 beams ~30-40% polarized
- Heavy ions of ALL species at RHIC
- **Luminosity Goal:**
  - **L(ep) ~10^{33-34} cm^{-2} sec^{-1}**

CM vs. Luminosity



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

Scientific Frontiers

- Nucleon structure, role of quarks and gluons in the nucleons
  - Un-polarized quark and gluon distributions
  - Polarized quark and gluon distributions (LOWEST POSSIBLE X)
  - Correlations between partons in hard collisions
    - Exclusive processes--> Generalized Parton Distributions
  - Understanding confinement with low x/lowQ^2 measurements

- Nuclear Structure & hadronization:
  - role of partons in nuclei

- Effect of nuclear medium

- Partonic matter under extreme conditions
  - For various A, compare e-p/e-A

Will need at least one new detector for pursuing the e-p/eA physics

Signatures of Novel Small x Physics

Inclusive & semi-inclusive measurements:

Measurement of Gluon Distribution in Nuclei

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

Longitudinal Structure function $F_L = F_2 - 2xF_1$

H1 or Zeus "like" eRHIC collider-detector would be ideal

Needs variable electron beam (sqrt(s)) energy → Possible at eRHIC

Diffractive measurements at eRHIC:

Diffraction as a probe of CGC

- At HERA e-p scattering sees 6-8% of the cross section in diffractive domain
- If CGC in eA at eRHIC: diffractive cross section will be 30-40%!

- Will need good forward acceptance and tracking in detector & IR design

Highlights: Spin Physics with eRHIC

Unique Measurements:

- Low x g_1 spin structure function of proton and neutron(polarized He^3)
- Bjorken spin sum rule & precision measurement of $\alpha_s(Q^2)$
- QCD structure of the photon
- Electroweak spin structure function g_5^W

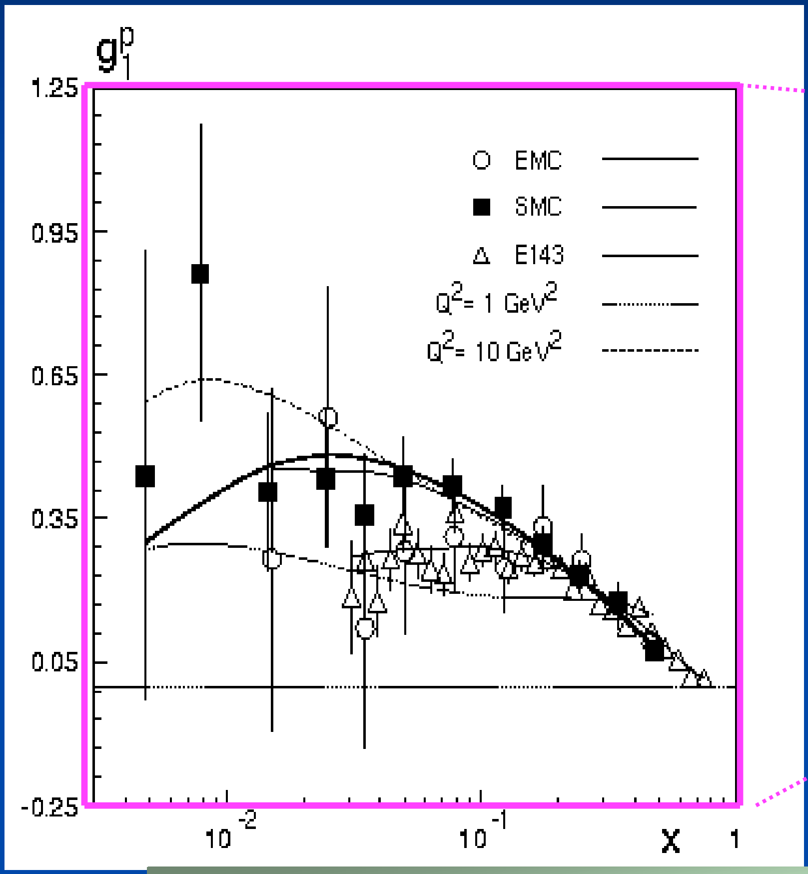
High precision measurements in the next decade:

- Polarized gluon distribution (scaling violations, di-jet production, di-hadron production)
- Semi-Inclusive light and heavy flavor DIS
- Transverse spin physics
- Generalized PDFs: DVCS, vector meson production leading to orbital angular momenta of partons(?)
- Many more….

Low x Proton Spin Structure

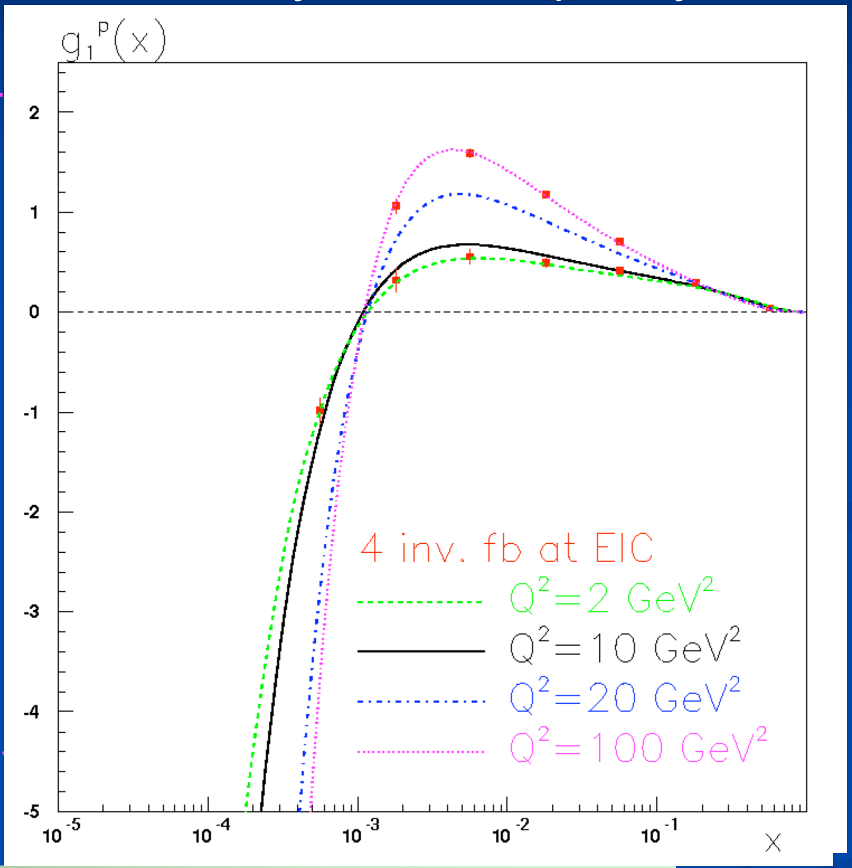
Fixed target experiments

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

Bj Sum Rule & Determination of α_s

$$\Gamma_1^p - \Gamma_1^n = \frac{1}{6} g_A C_{ns}(\alpha_S^n(Q^2))$$

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

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. …….

Largest uncertainty comes from low x behavior of the structure functions.

Particle Data Book (2002), Extended version:

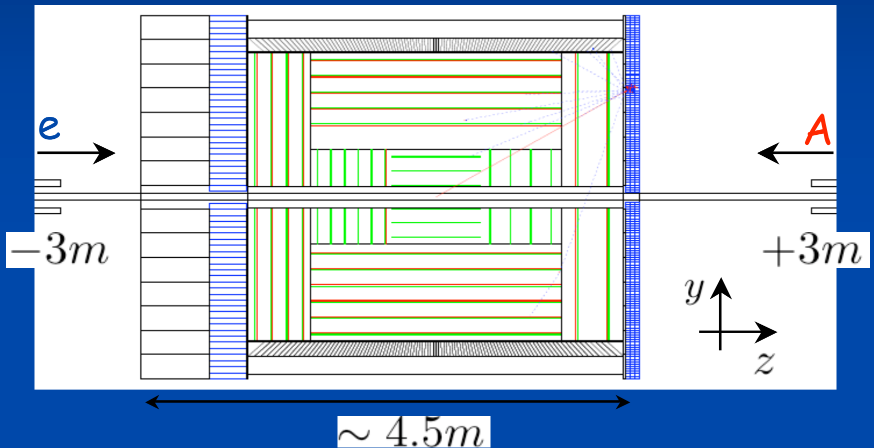
"Theoretically, this sum rule is better for determining α_s because perturbative QCD result is known to higher order ($o(\alpha_s^4)$), and these terms are important at low Q^2……… **Should data at lower x become available**, so that the low x extrapolation is more tightly constrained, the ***Bj sum rule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

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

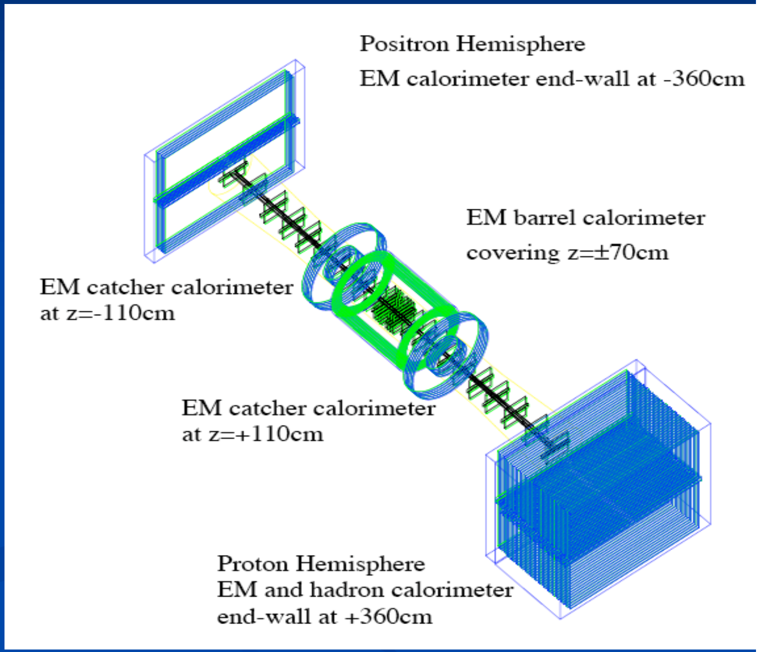
Detector Ideas being pursued now…

- A HERA like design



- Physics detector group: BNL, Colorado, Jefferson Lab,LBL, MIT SBU,UIUC
- Preliminary MC simulation: "ELECTR-A" recently released B. Surrow et al.
- Expected to develop over the next year or so

- HERA-III proposal modified for eRHIC



- I. Abt et al. Hep-ex/0407053
- Dedicated detector for forward physics (only)
- Letter of intent will be submitted as soon as requested by BNL management

eRHIC status & plans

- Informal collaboration, Steering Committee
- 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
- ***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.
  - BNL-MIT-Budker-DESY collaboration
  - **RHIC Machine Advisory Committee: Review June 2005**
- **Will request formal backing of the NSAC in the next LRP with a preliminary design of detector, IR and collider technical design**

http://www.bnl.gov/eic

Summary

- RHIC is allowing us to study and understand QCD as no other facility has before, both for HI physics as well as spin physics

- We are moving from the **discovery to a exploration** phase of the HI program that ***need well justified investments in RHIC luminosity upgrade and the detector upgrades***
  - **Spin physics is embarking up on the discovery phase as we speak**
  - http://www.bnl.gov/rhicIIscience

- eRHIC will allow us another fundamental and unique look in to the workings of QCD
  - **Global interest in this facility for studying QCD in the next decade**
  - http://www.bnl.gov/eic

You seriously want more?