From RHIC to eRHIC

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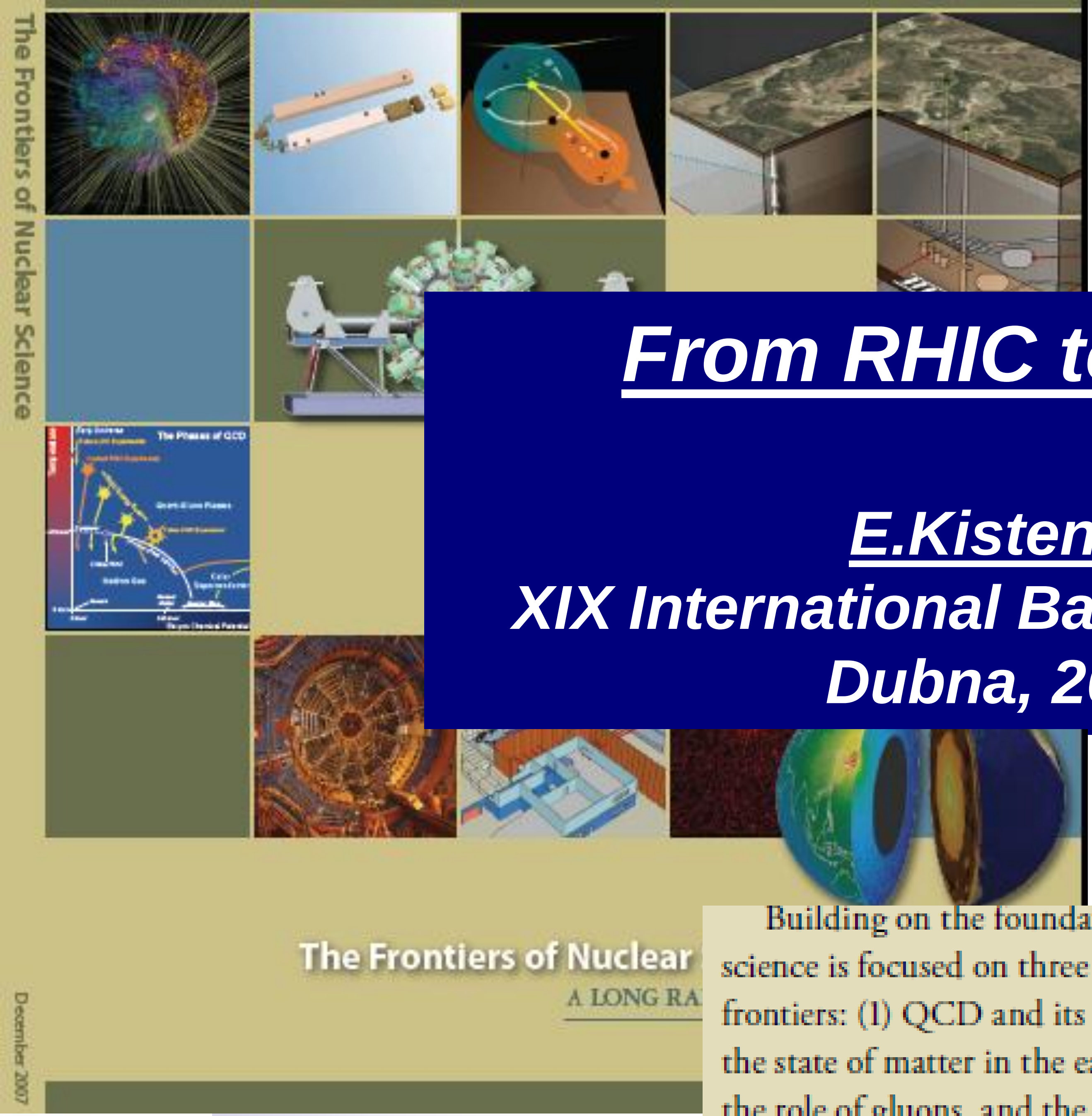
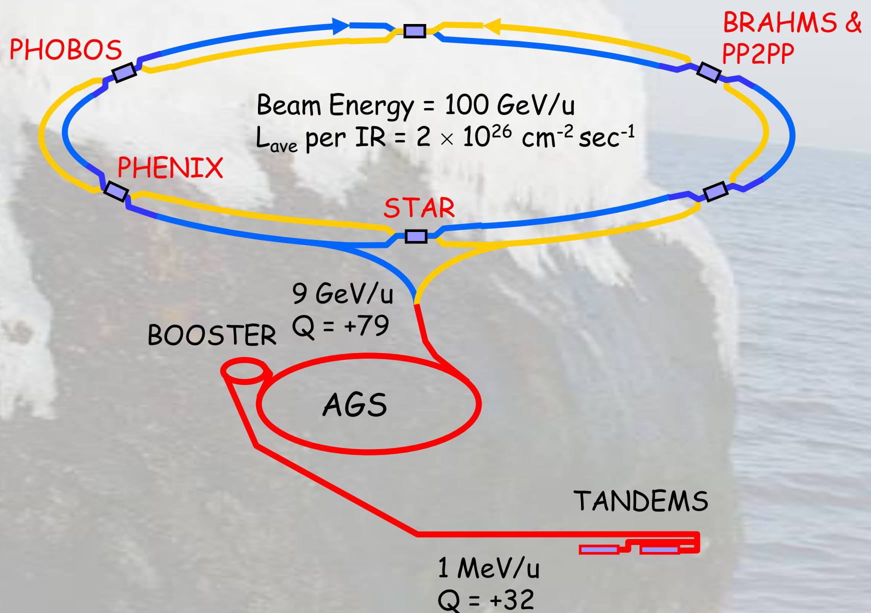
XIX International Baldin Seminar , Dubna, 2008



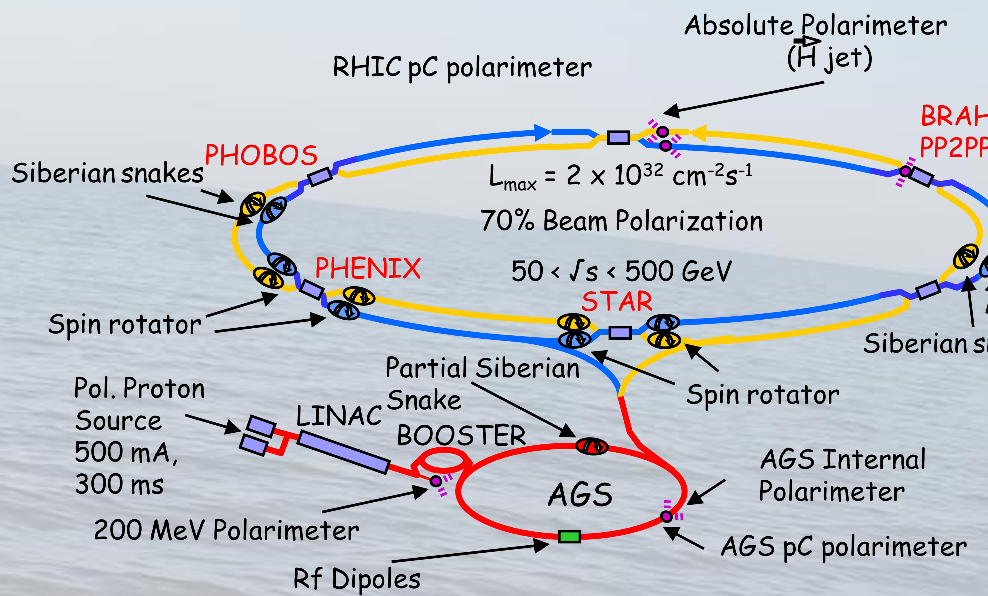
Building on the foundation of the recent past, nuclear science is focused on three broad but highly related research frontiers: (1) QCD and its implications and predictions for the state of matter in the early universe, quark confinement, the role of gluons, and the structure of the proton and neutron;

QCD factory at BNL today : RHIC

- RHIC relativistivic-heavy ion program



- RHIC spin physics program



- RHIC: Two concentric superconducting magnet rings, 3.8km circumference
- Start of construction: January 1991
- First collisions of Au-Au ions: June 2000
- First collision of trans. polarized protons: December 2001
- First collisions of long. polarized protons: May 2003

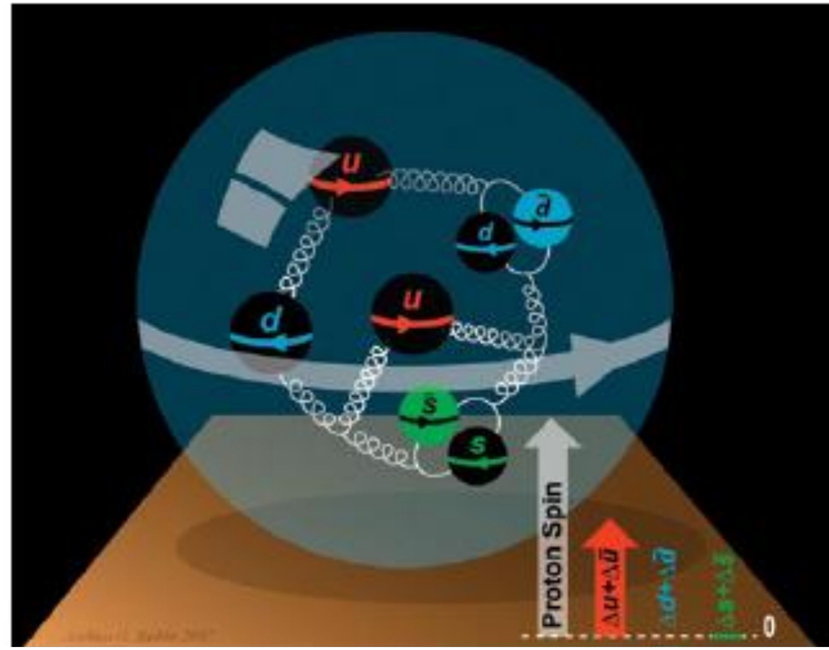
Achieved configuration:

- Au+Au: √s = 130 and 200 Ge
- d+Au: √s = 200 GeV
- p+p: √s = 200 GeV

QCD at RHIC – years of discoveries

Quantum Chromodynamics

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What is the internal landscape of the nucleons?
- What does QCD predict for the properties of strongly interacting matter?
- What governs the transition of quarks and gluons into pions and nucleons?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?
- What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?



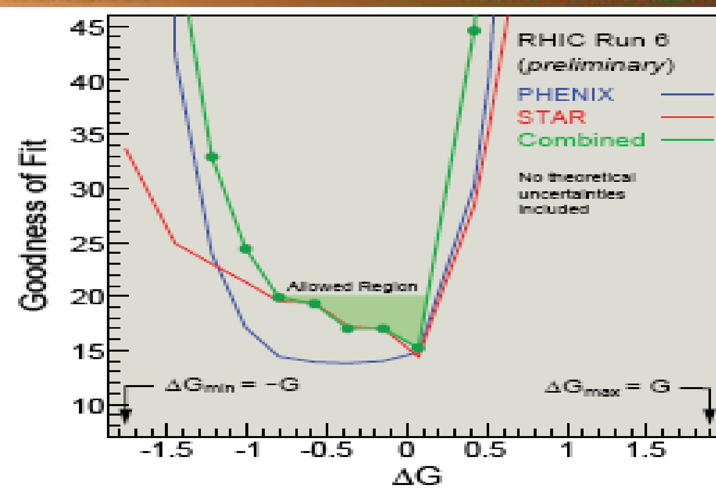


Figure 2.4: Constraints on the gluon contribution to the proton's spin from data collected in 200-GeV polarized proton collisions at RHIC in 2006.

QCD factory beyond RHIC

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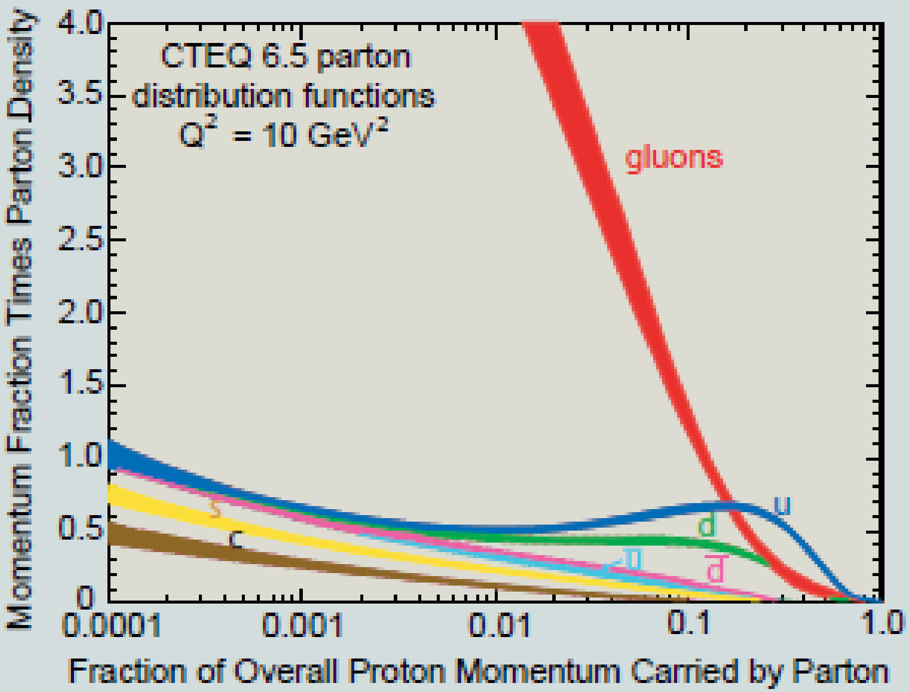


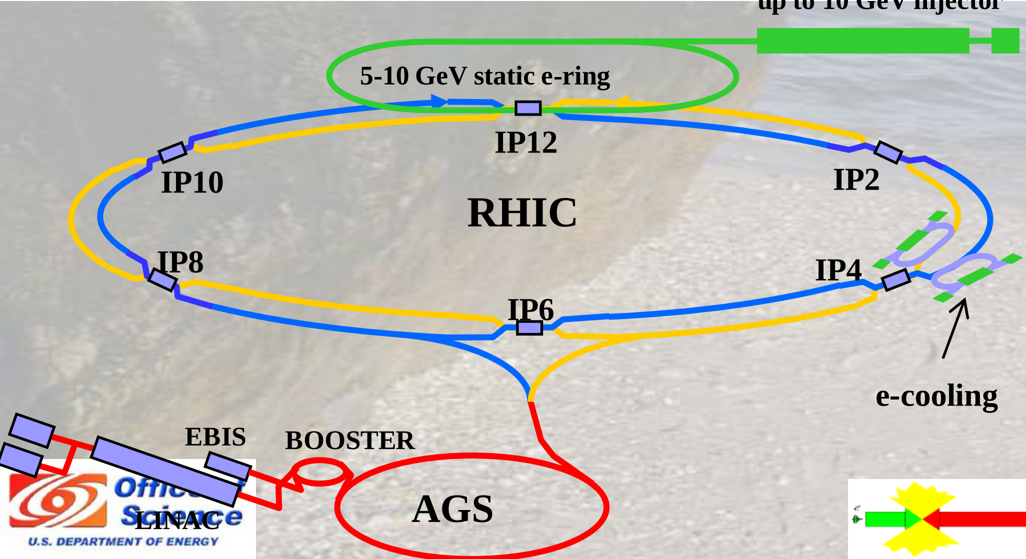
The number density of gluons and of various types of quarks and anti-quarks inside the proton, as a function of momentum fraction carried by the quark or gluon (parton). The curves are from fits to high-energy scattering data. The width of each band represents the uncertainty.

The Color Glass Condensate. At high collision energ the production of particles with small longitudinal momentum can be thought of as the liberation of partons from the saturated gluonic matter that exists in each of the colliding nuclei. The predicted universal properties of this state, together with the large scale given by its saturation momentum Q_s, offer the hope for controlled, first-principle calculations of the initial state properties of the dense matter created in nuclear collisions at RHIC and LHC. This "shattering of two colliding sheets of color glass" creates most of the entropy observed in the final state, converting the initial, coherent nuclear wave functions into a disordered state in which partons move through strong remnant color fields. Like the more common electromagnetic plasmas, such a state is predicted to have severe plasma instabilities whose exponential growth leads to rapid randomization of the parton momenta, possibly explaining the rapid thermalization of QCD matter observed at RHIC.

The Electron-Ion Collider embodies the vision of our field for reaching the next QCD frontier: the study of the glue that binds all atomic nuclei.

THE ELECTRON-ION COLLIDER

The detailed requirements for the machine complex and detectors at an EIC are driven by the need to access the relevant kinematic region that will allow us to explore gluon saturation phenomena and image the gluons in the nucleon and nuclei with great precision. These considerations constrain the basic design parameters to be a 3 to at least 10 GeV energy electron beam colliding with a nucleon beam of energy between 25 and 250 GeV or with nuclear beams ranging from 20 to 100 GeV/nucleon.



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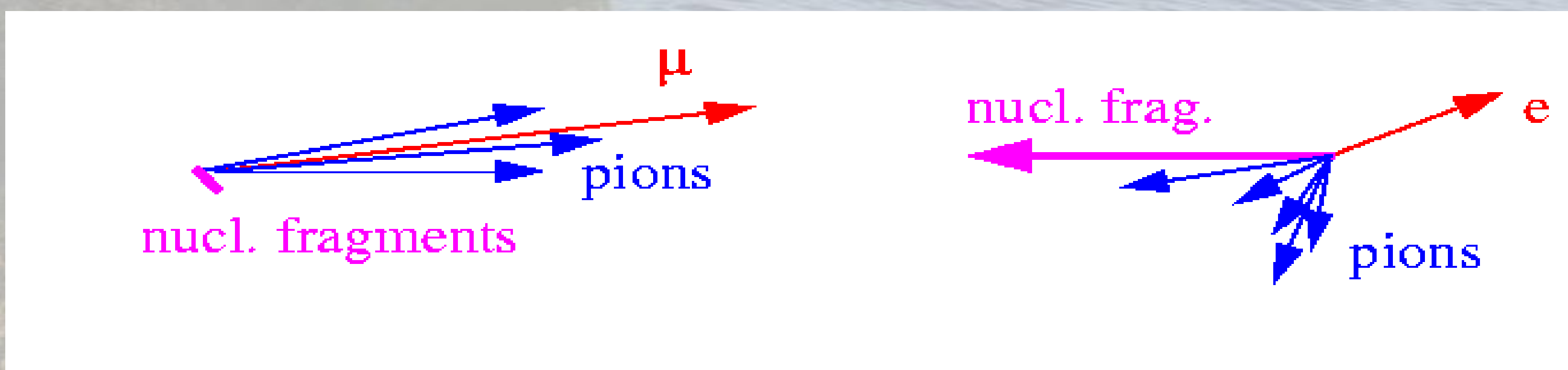
BROOKHAVEN NATIONAL LABORATORY

DIS at Collider vs Fixed target

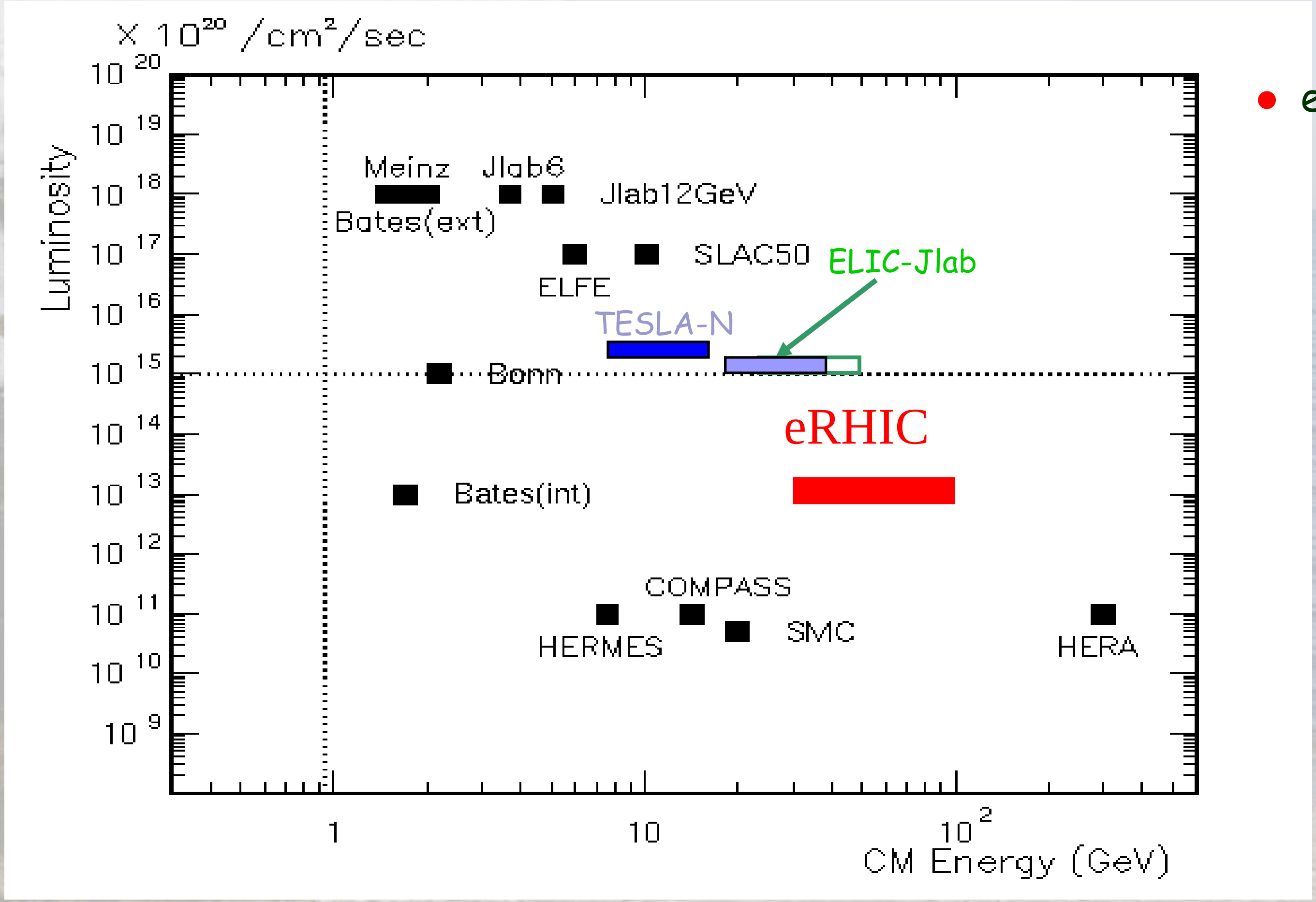
- Wide range of A
- High luminosity
- **Polarized beams**
- **Collision geometry**

- 3D structure of nuclear matter
- Spin structure
- **QCD dynamics in much greater detail**

Fixed target ***Collider***

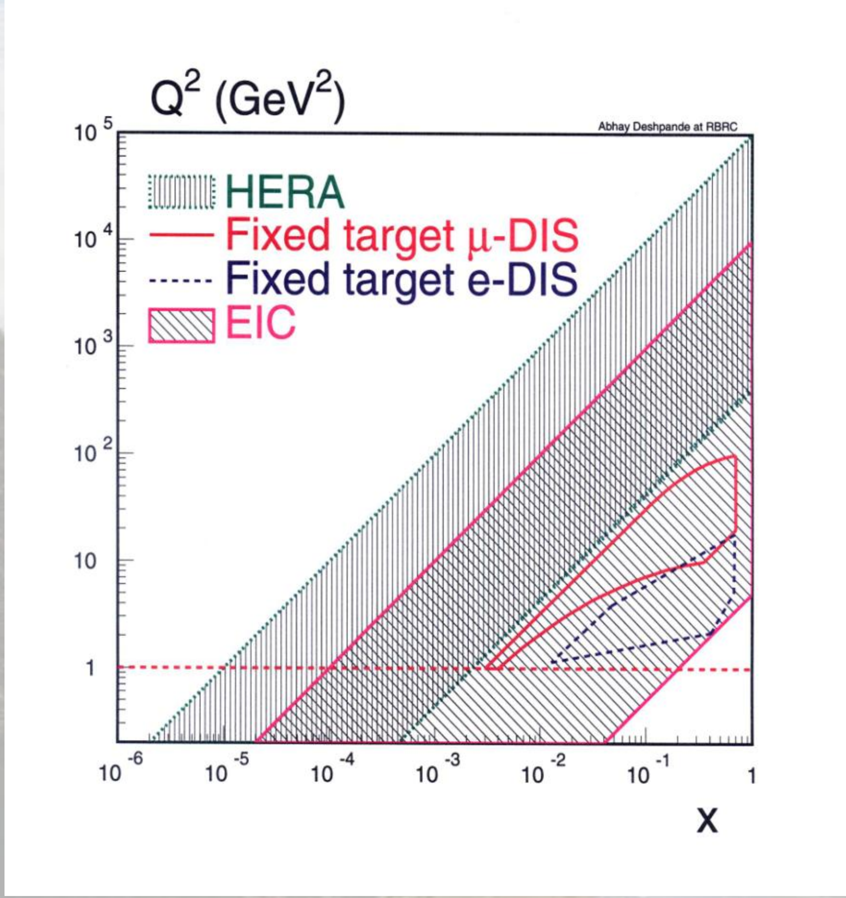


eRHIC in comparison to other DIS facilities



- eRHIC features:
  - Variable beam energy
  - p and ion beams
  - Proton and light ion polarization
  - Large luminosity

eRHIC vs. Other DIS Facilities



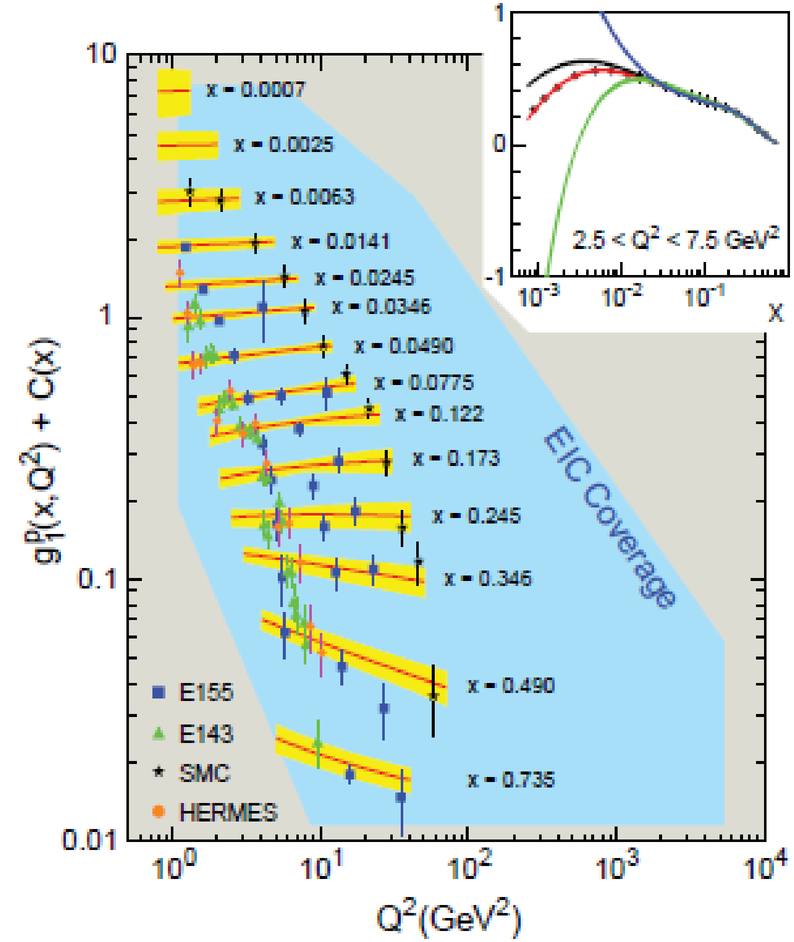


Figure 2.16: The world database of polarized deep-inelastic scattering results for the proton, from SLAC experiments E143 and E155, CERN-SMC, and DESY-HERMES. The curves (and error bands) are from a global QCD fit by Boetcher and Bluemlein. The blue-shaded area represents the enlarged (x,Q^2) area accessible by an EIC. The insert shows one example of the consequent physics reach, comparing projected data as a function of x in one Q^2 bin for about one year of EIC running with theoretical predictions based on global QCD fits to the present world data under differing assumptions for gluon spin preferences.

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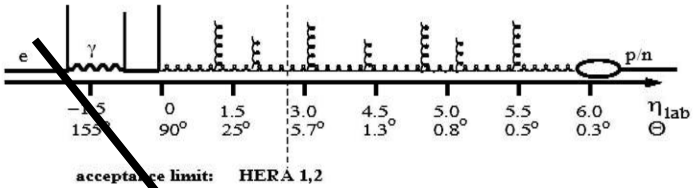
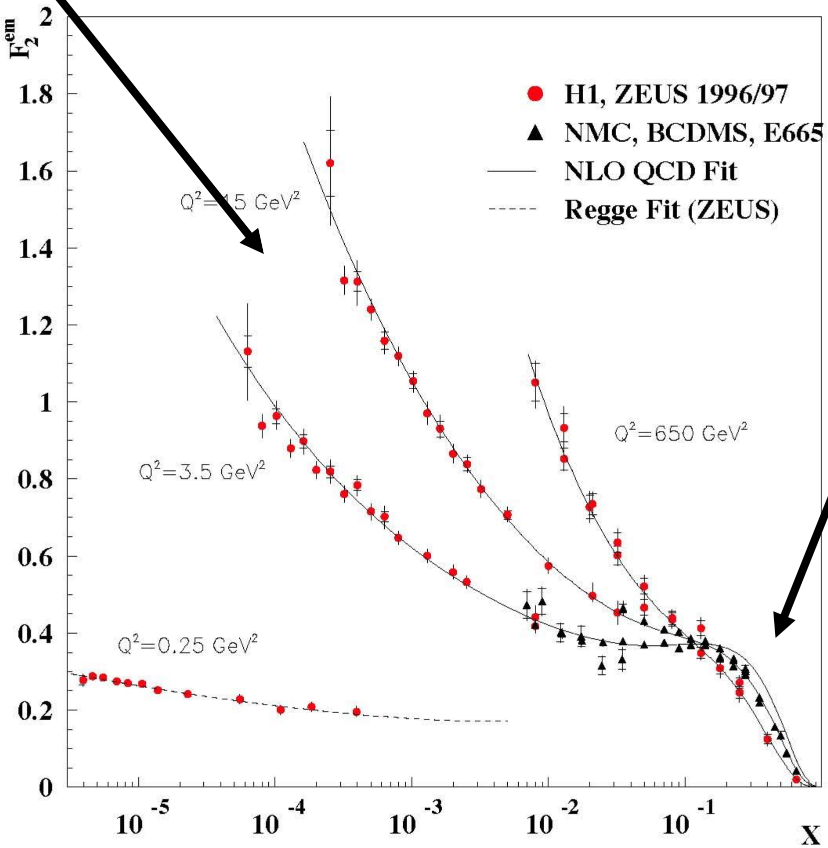
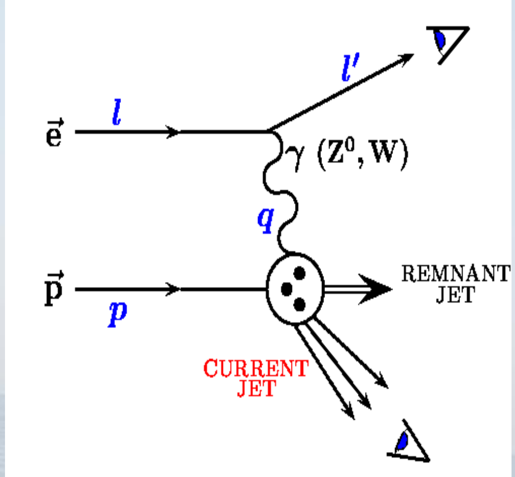
Collision kinematics and RHIC frontiers

Low x

x<0.01 measure universal structure of QCD radiation.







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

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

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

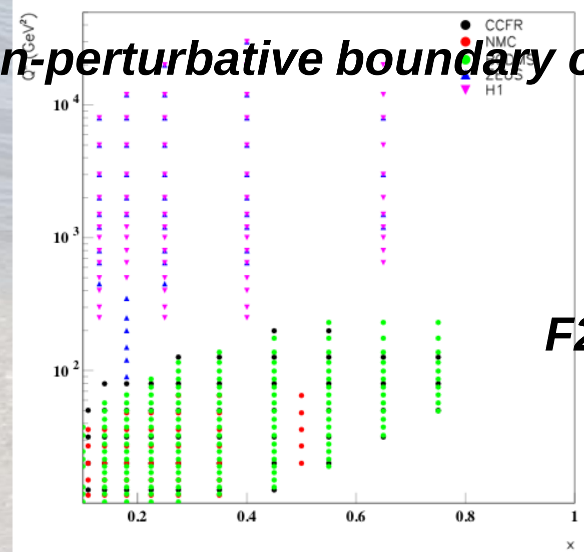
$$s = 4E_eE_p$$

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

Large X

x>0.1 measure hadronic structure.

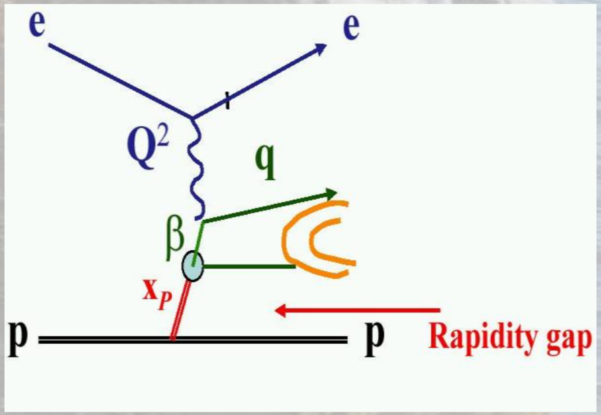
Non-perturbative boundary conditions.

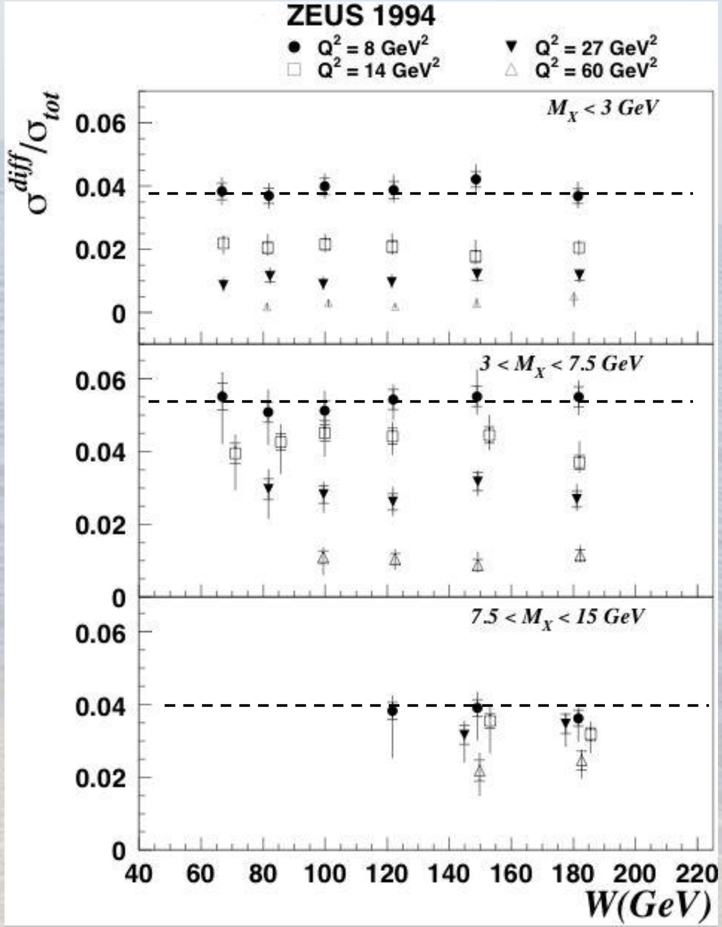


F2 up to x=0.75

Diffraction

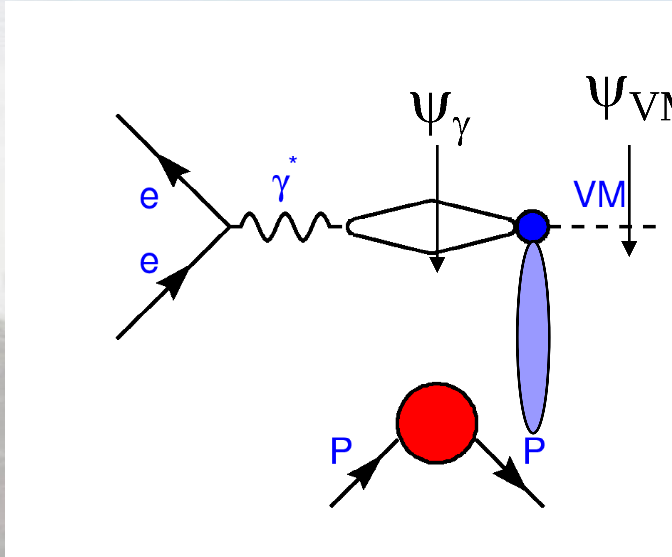
1. A large diffractive cross section is now measured even in DIS (ca. 20 %)
2. The diffractive and total cross sections have similar energy dependences



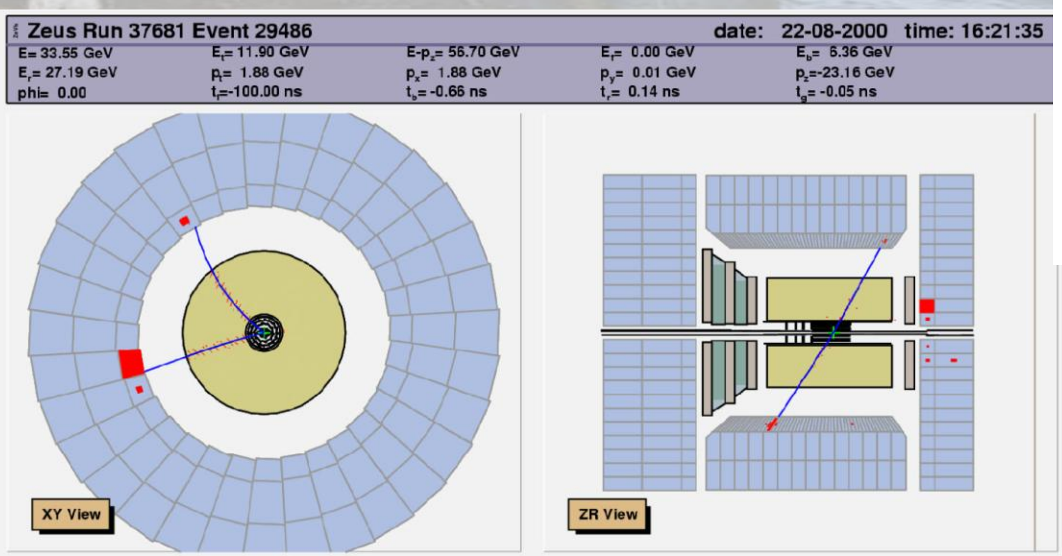


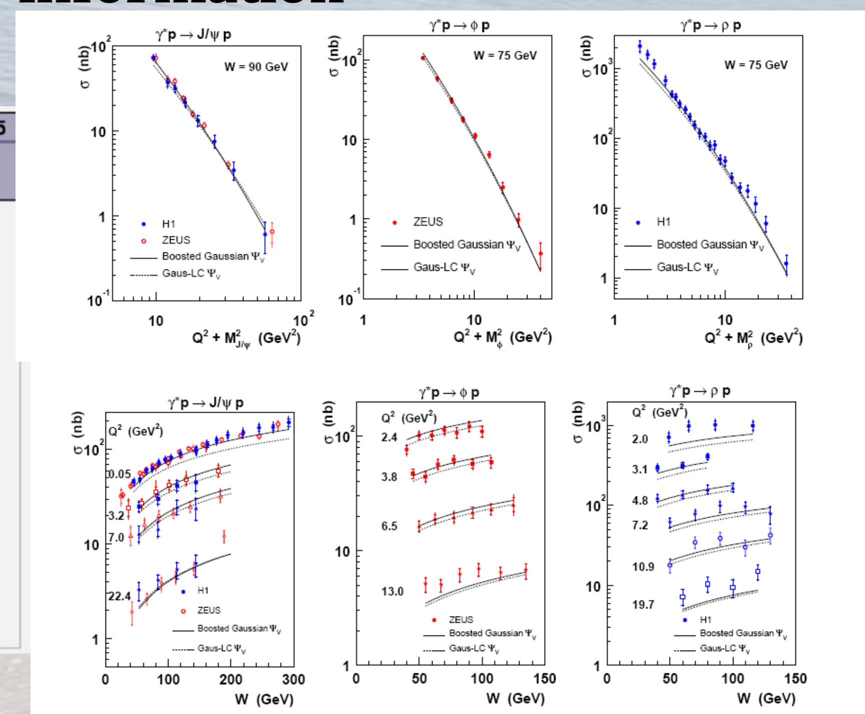
A.Coldwell

• Exclusive Processes (VM and DVCS)



Clean process - has been measured for many different vector mesons differentially in many variables - wealth of information

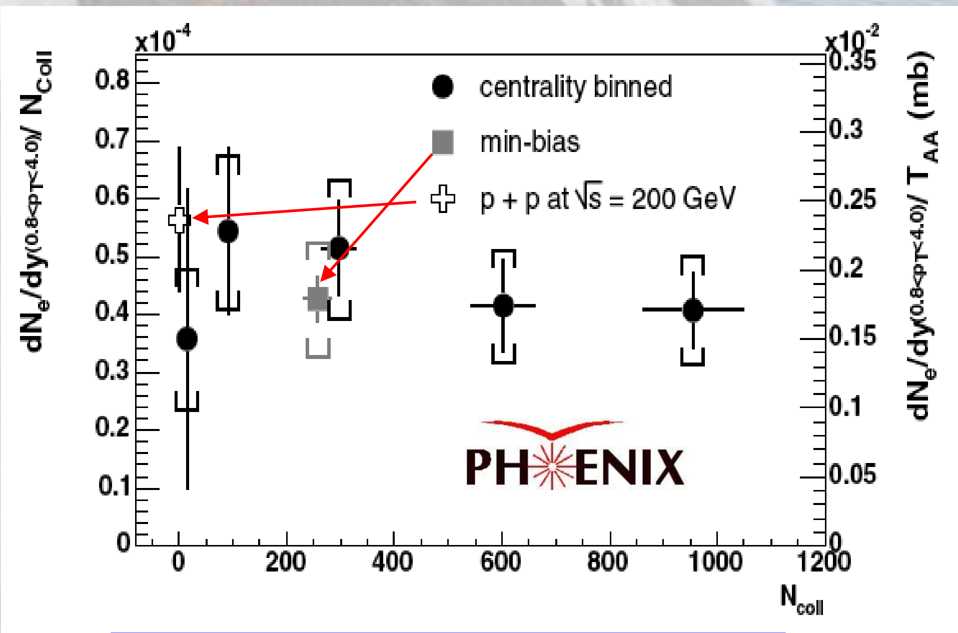


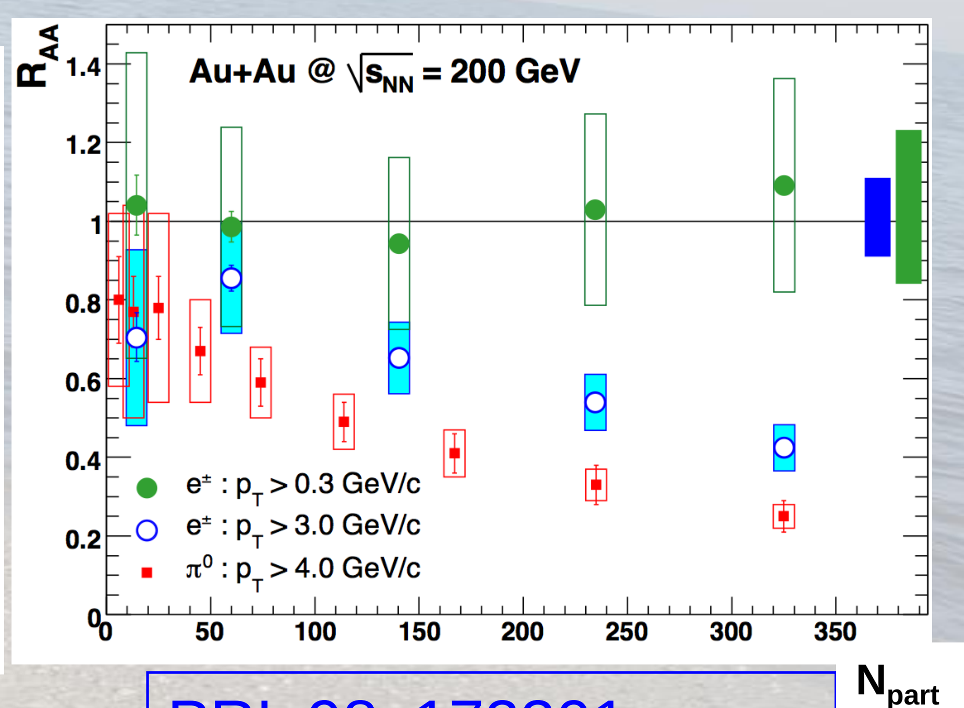


In Au+Au, total production of charm is pointlike but p_T spectrum shows suppression

- total charm yield determined from integral of single electron spectrum
  - charm decay dominant source of intermediate p_T electrons

- not only high p_T π^0 from light quarks and gluons but also very heavy quarks lose energy trying to escape system: very opaque





PRL 94, 082301 (2005)

PRL 98, 172301 (2007)

"Yukawa's gold mine" by Nino Zichichi

- ***since the origin of the quark masses is still not known, it cannot be excluded that in a QCD coloured world (i.e. QGP), the six quarks are all nearly massless and that the colourless condition is 'flavour' dependent."***

- **MJT: "Wow! Massless *b* and *c* quarks in a color-charged medium would be the simplest way to explain the apparent equality of gluon, light and heavy quark suppression indicated by the equality of RAA for $\pi 0$ and direct-single e± in regions where both *c* and *b* quarks dominate."**

- Stan Brodsky:"Oh, you mean the Higgs Field can't penetrate the QGP."

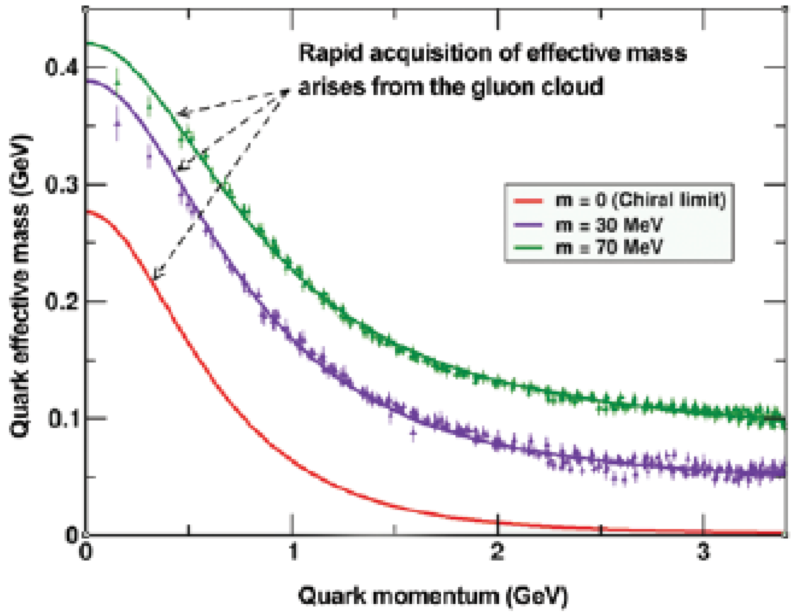


Figure 2.1: Mass from nothing. In QCD a quark's effective mass depends on its momentum. The function describing this can be calculated and is depicted here. Numerical simulations of lattice QCD (data, at two different bare masses) have confirmed model predictions (solid curves) that the vast bulk of the constituent mass of a light quark comes from a cloud of gluons that are dragged along by the quark as it propagates. In this way, a quark that appears to be absolutely massless at high energies (m = 0, red curve) acquires a large constituent mass at low energies.

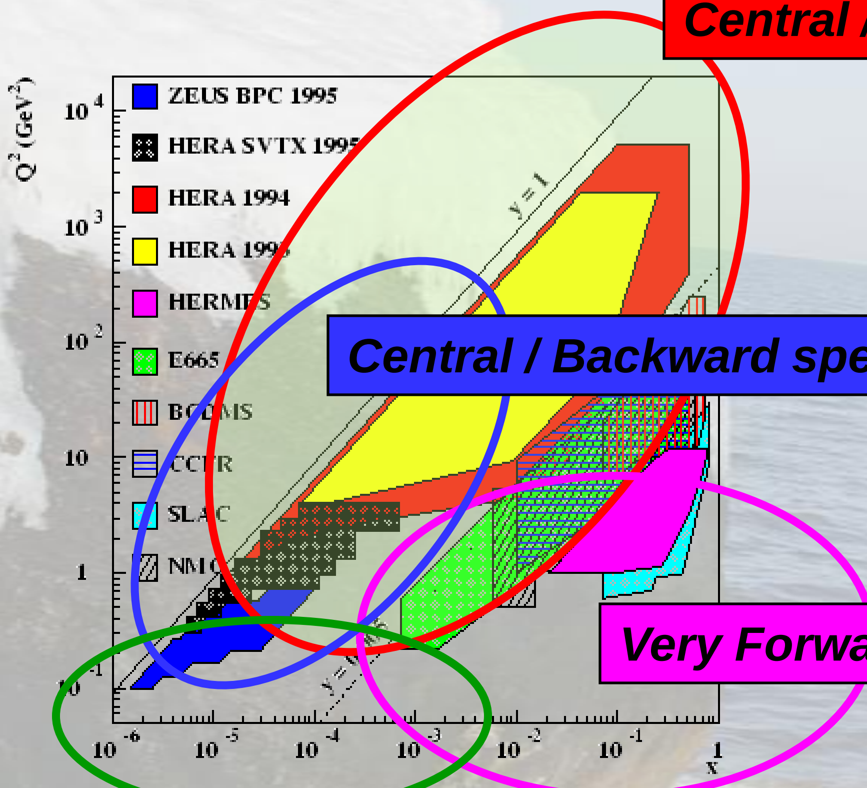
A Detector for eRHIC → A 4π Detector

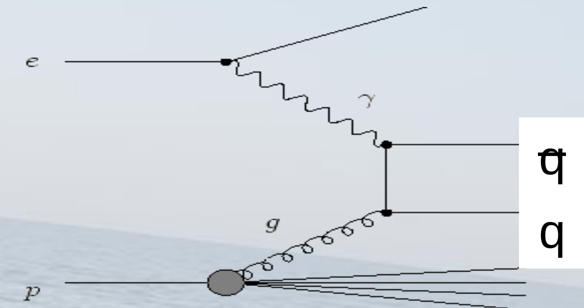
- Scattered electrons to measure kinematics of DIS
- Scattered electrons at small (~zero degrees) to tag photo production
- Central hadronic final state for kinematics, jet measurements, quark flavor tagging, fragmentation studies, particle ID
- Central hard photon and particle/vector detection (DVCS)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

A Detector for eRHIC → A 4π Detector

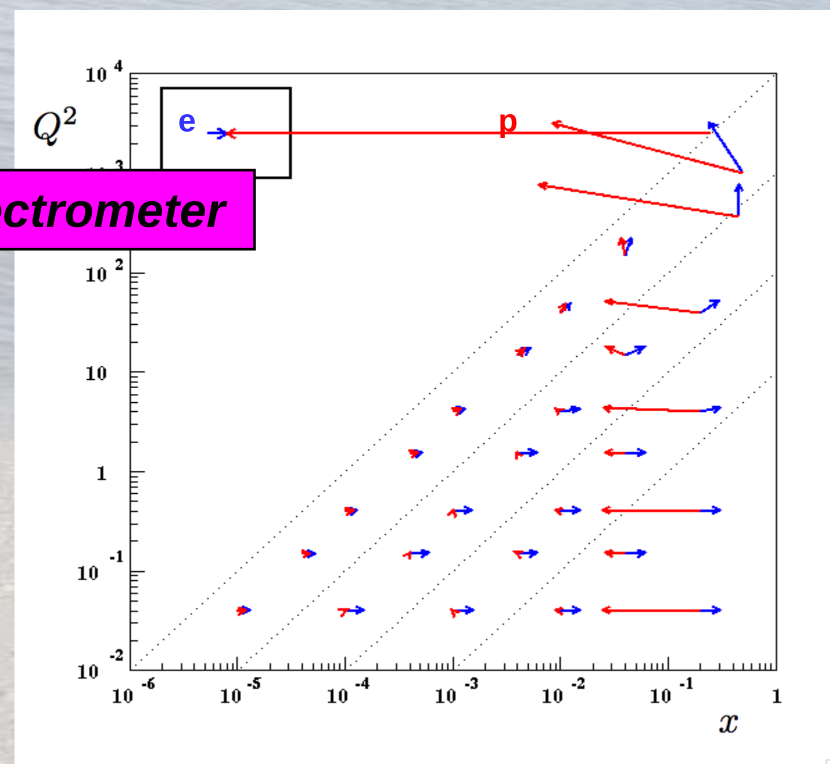
Central / Forward spectrometer

Central / Backward spectrometer

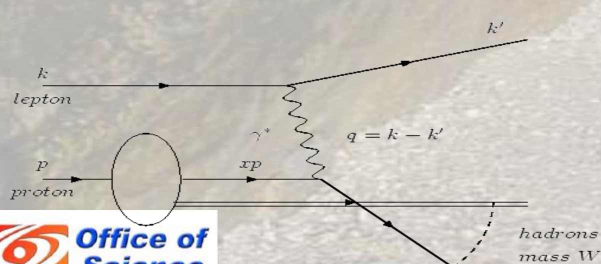




Very Forward spectrometer



Very Backward spectrometer



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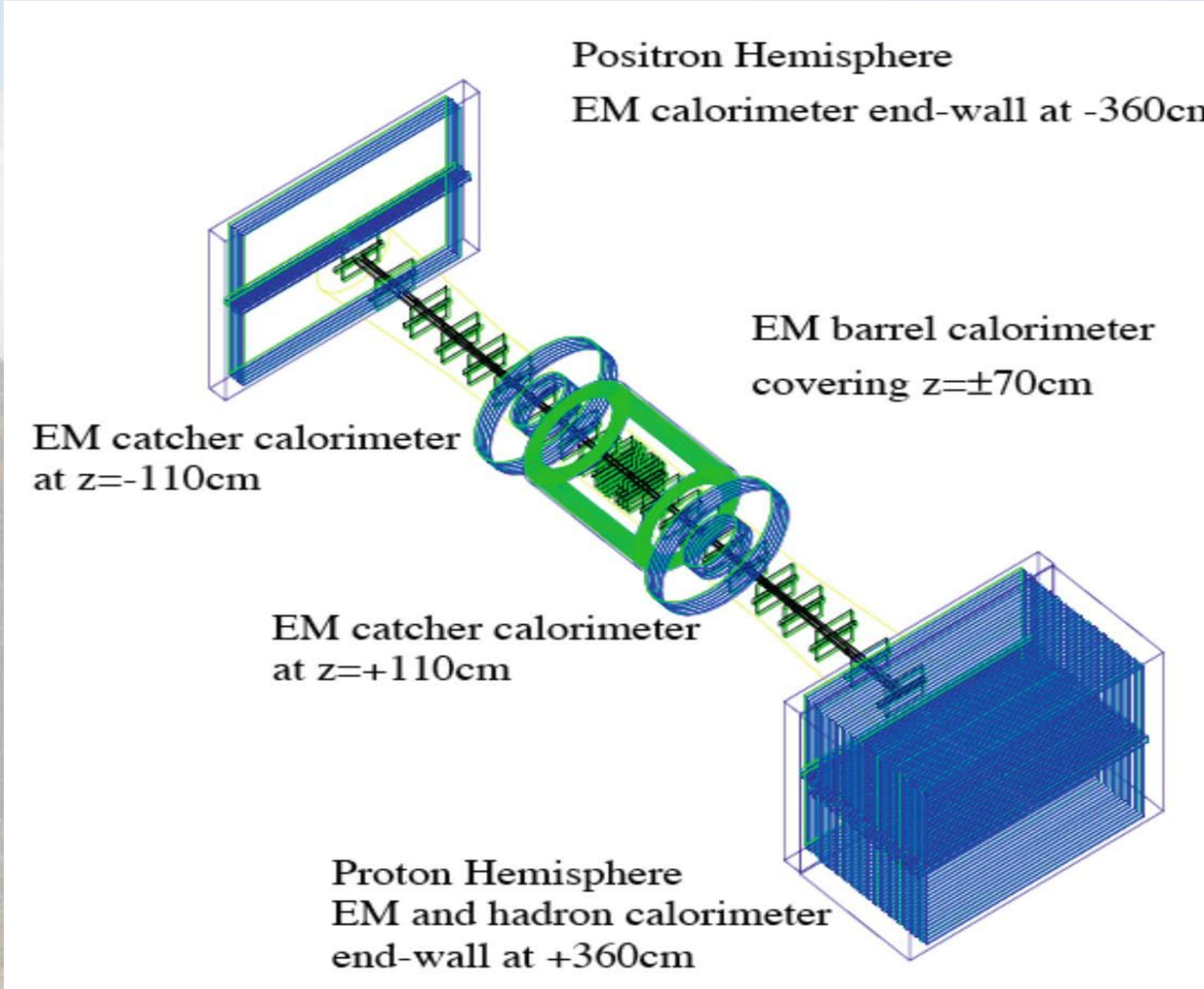
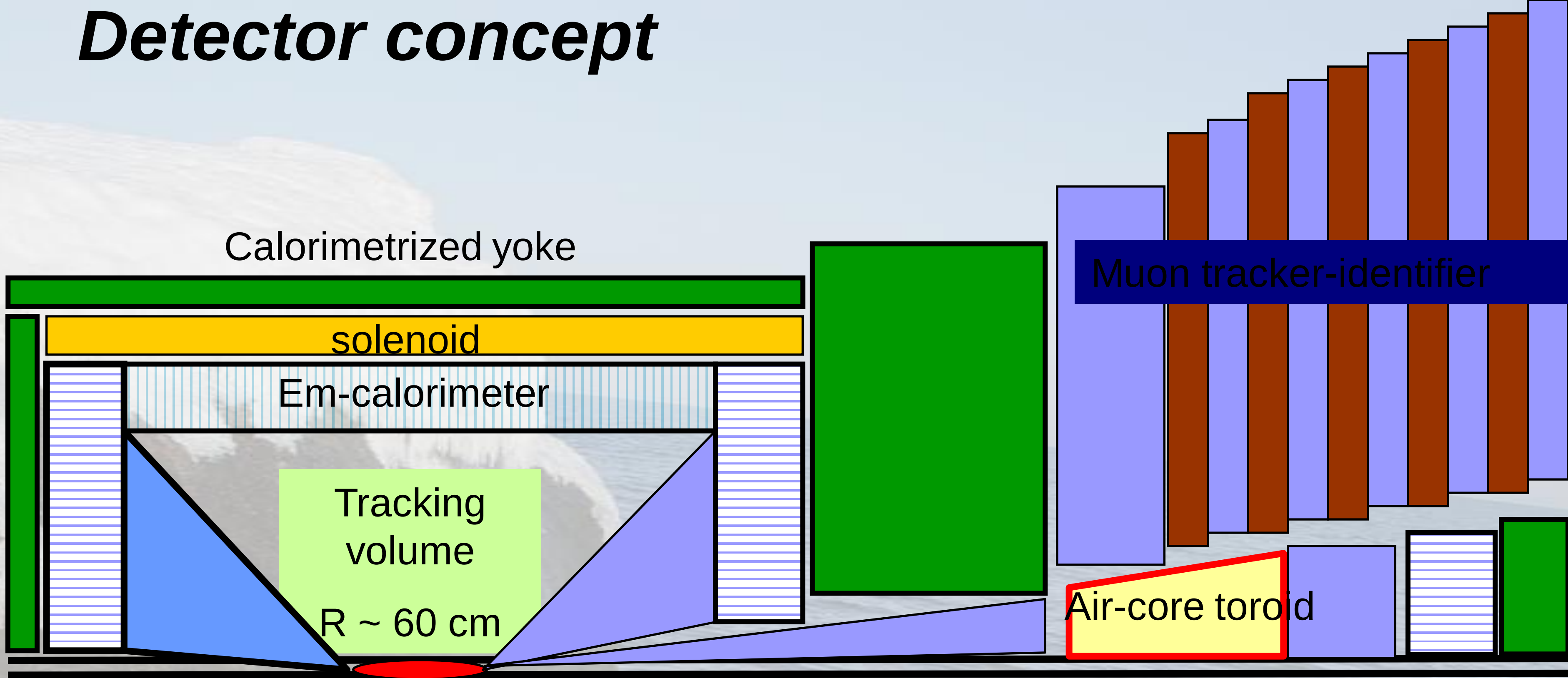
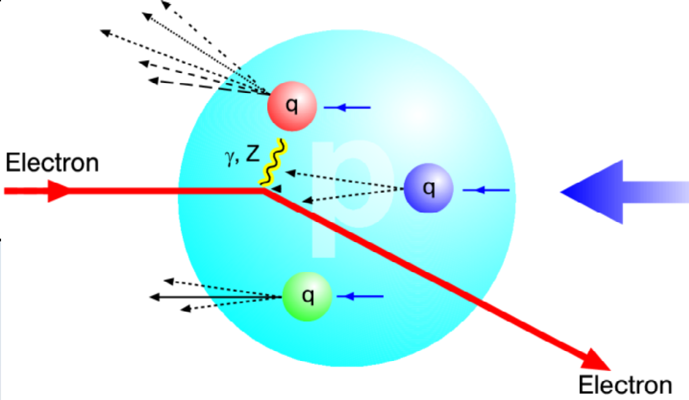

Positron Hemisphere
EM calorimeter end-wall at -360cm
EM barrel calorimeter
covering z=±70cm
EM catcher calorimeter
at z=-110cm
EM catcher calorimeter
at z=+110cm
Proton Hemisphere
EM and hadron calorimeter
end-wall at +360cm

Detector concept



- Silicon vertex tracker for jet flavor identification. Bonus: low momentum charged particle identification by dE/dx. ***It is a driver for detector size***;
  - Full Si tracking;
- Nonprojective tracking electromagnetic calorimetry inside magnet. Detailed shower shape measurements to insure lepton identification in the low pT domain;
  - Pid due dE/dx in silicon, shower shape in calorimeters and tracking-calorimeters E/p matching;
  - Muon identification is prioritized towards high pT;
- Solenoidal magnet inside of thin calorimetrized return yoke (leakage tagger) complemented by air-core toroid close to beam pipe forward;
  - Space along the beam line ~5m, central detector yoke diameter ~2.5 m.

Big picture



eRHIC would allow a precise 3D mapping of nuclear structure at different distance scales, permitting the study of the transition from partonic constituents to hadrons.

The short time-scale fluctuations of QCD which became visible at HERA could be studied in much greater detail, and with different targets.