e+A Science @ EIC & the eRHIC Solution

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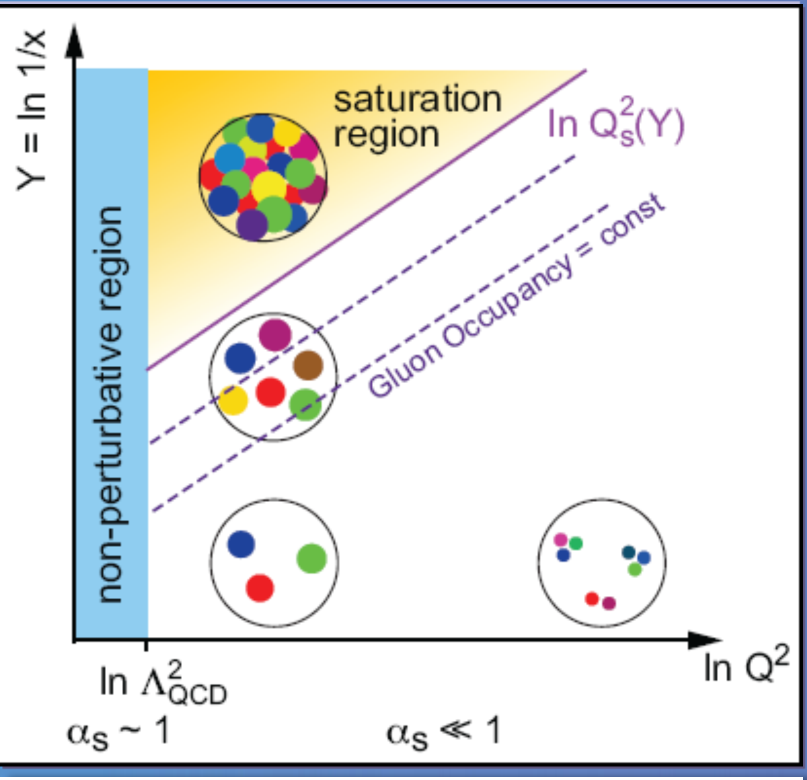
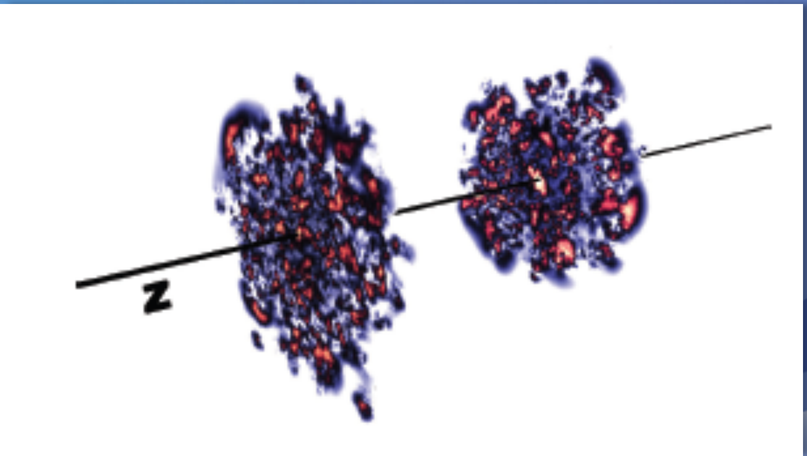
POETIC 2012

Bloomington, August 20, 2012



Studying QCD matter in the weak coupling, high density, highly non-linear regime



Illuminating the entrance channel for RHIC and LHC A+A collisions

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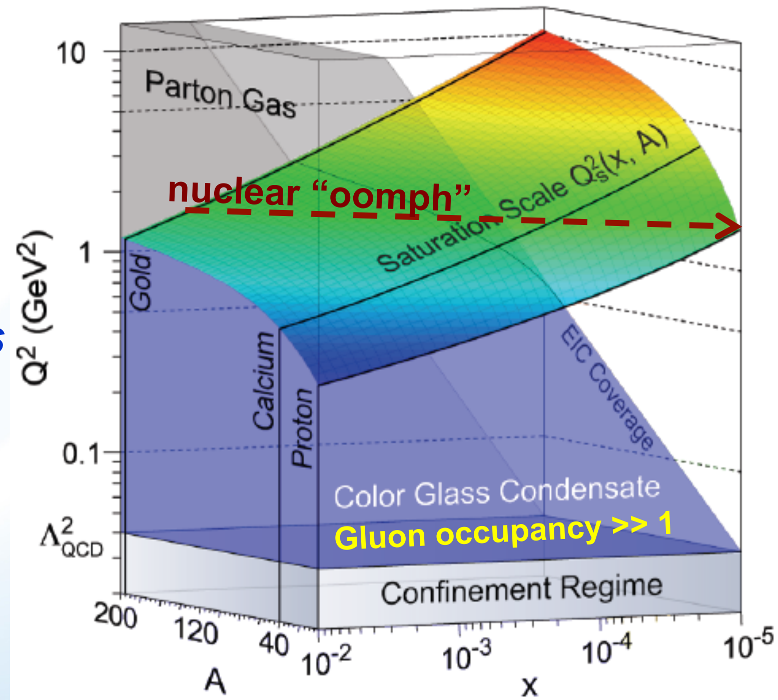
Basic Questions for e+A @ EIC (from White Paper Draft)

- **Where does the saturation of gluon densities set in?** Is there a simple boundary that separates this region from that of more dilute quark-gluon matter? If so, how do the distributions of quarks and gluons change as one crosses the boundary? Does this saturation produce matter of universal properties in the nucleon and all nuclei viewed at nearly light-speed?

- **How does the nuclear environment affect the distribution of gluons and the interactions of quarks in nuclei?** How does the transverse spatial distribution of gluons compare to that in the nucleon? How does nuclear matter respond to a fast moving color charge passing through it?

- ***Saturation must set in to avoid unitarity violation in high-energy p+p collisions***
- ***Exploit heavy ion beams for precocious access to saturation regime***
- ***In low-x e+A DIS, when γ^* coherence length $L \sim (2m_N x)^{-1}$ > nuclear diam., probe interacts coherently with all partons along path.***
- ***e+A can reach comparable gluon densities to e+p at factor ~ A lower Bjorken x***

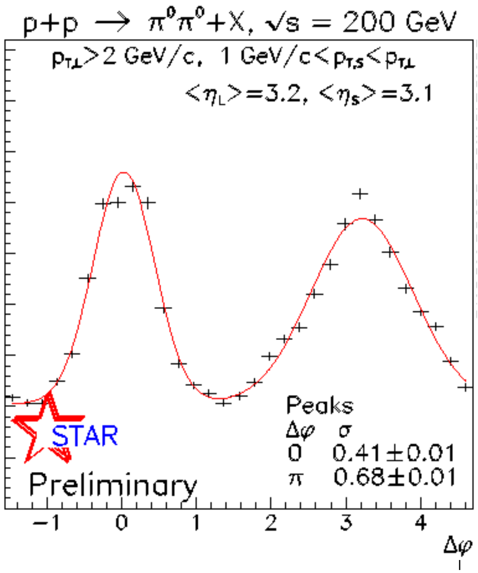
$$(Q_s^A)^2 \approx c\, Q_0^2 \left(\frac{A}{x}\right)^{1/3}$$



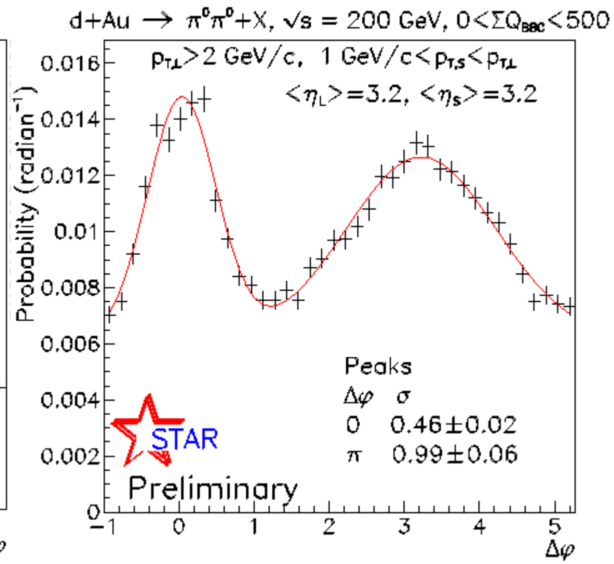
Gluon Saturation: What Have We Learned at RHIC?

Uncorrelated Coincidence Probability (radian^{-1})

pp data

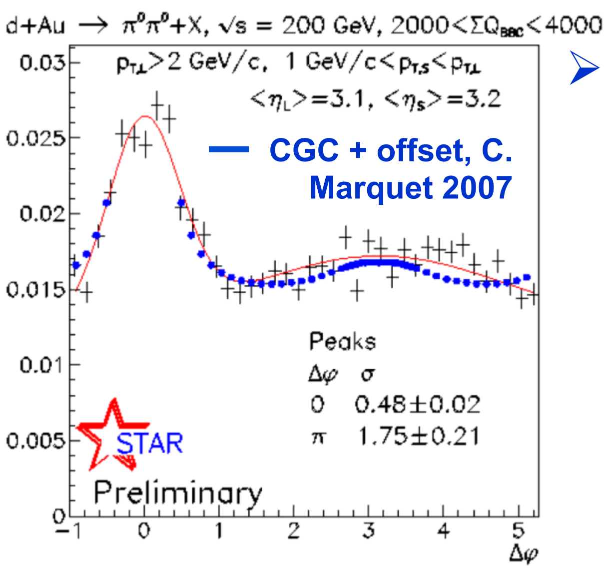


dAu peripheral

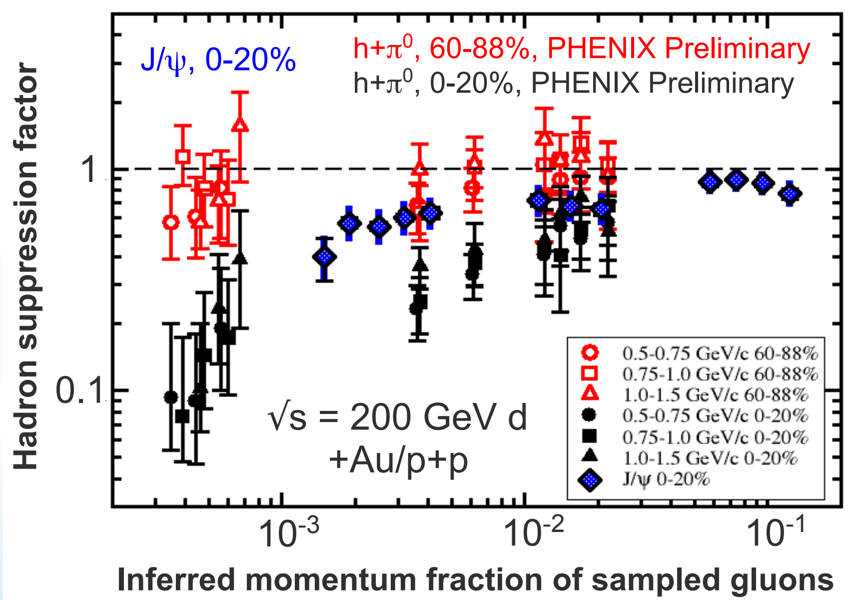


- *Forward di-hadron coincidences probe very asymmetric parton collisions, involving low-x gluon from one beam*
- *In CGC regime, expect 2→2 parton scattering to be replaced by scattering from a coherent gluon field ⇒ "monojets"*

dAu central

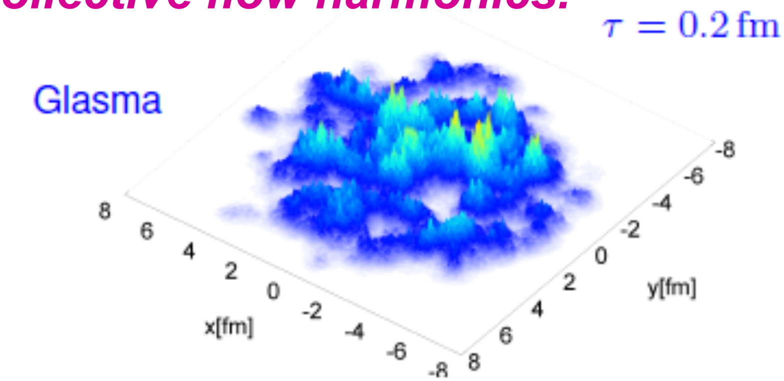


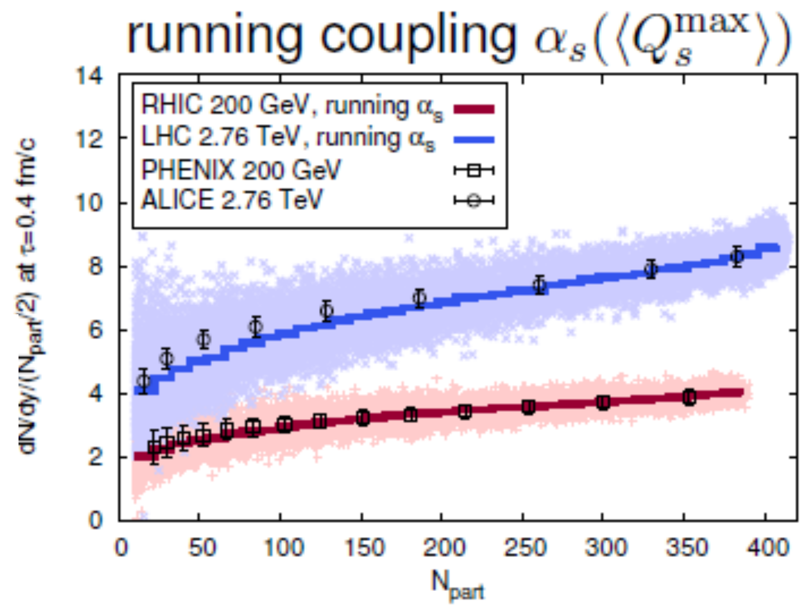
- *New STAR & PHENIX data confirm disappearance of away-side jet in central d+Au forward-forward di-hadron coinc.*



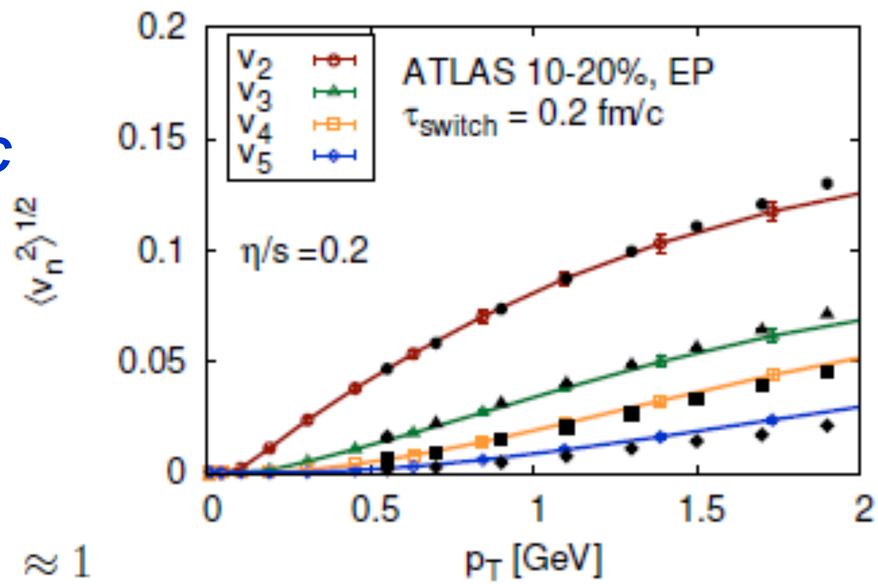
Other Hints from RHIC & LHC

- *Viscous 3+1-D hydro calcs. starting from initial densities and quantum fluctuations based on CGC/glasma now yielding remarkably successful account of A+A particle multiplicities and collective flow harmonics.*



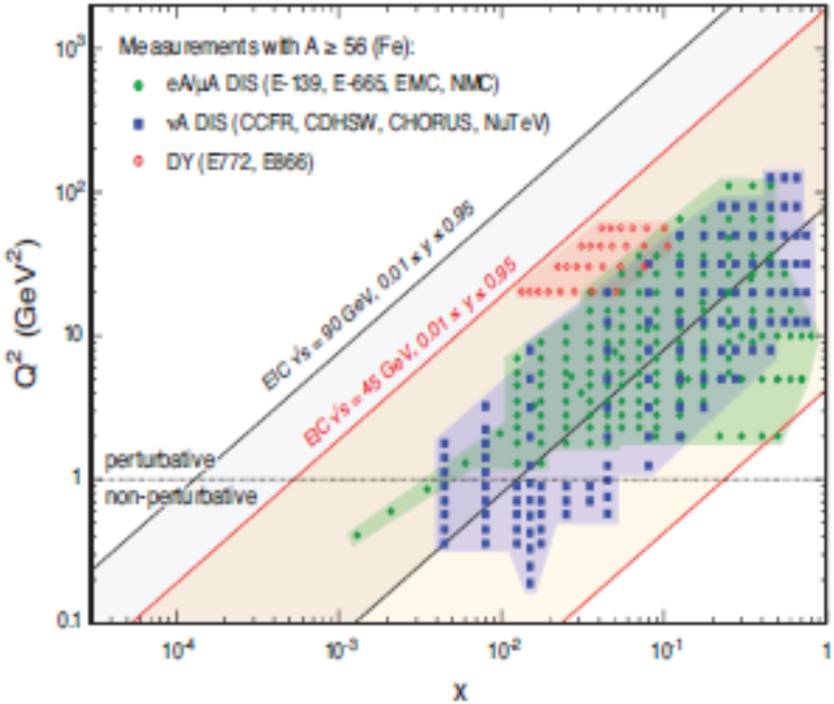


- *First p+Pb run at LHC (2013) and new forward γ prod'n studies in p+A @ RHIC (2014-15) should $\Rightarrow$ more quantitative info on low-x gluon densities*
- *Kang & Yuan (arXiv:1106.1375): transverse spin asyms. for forward h prod'n in $\vec{p}$+A/$\vec{p}$+p should probe satur'n scale:*

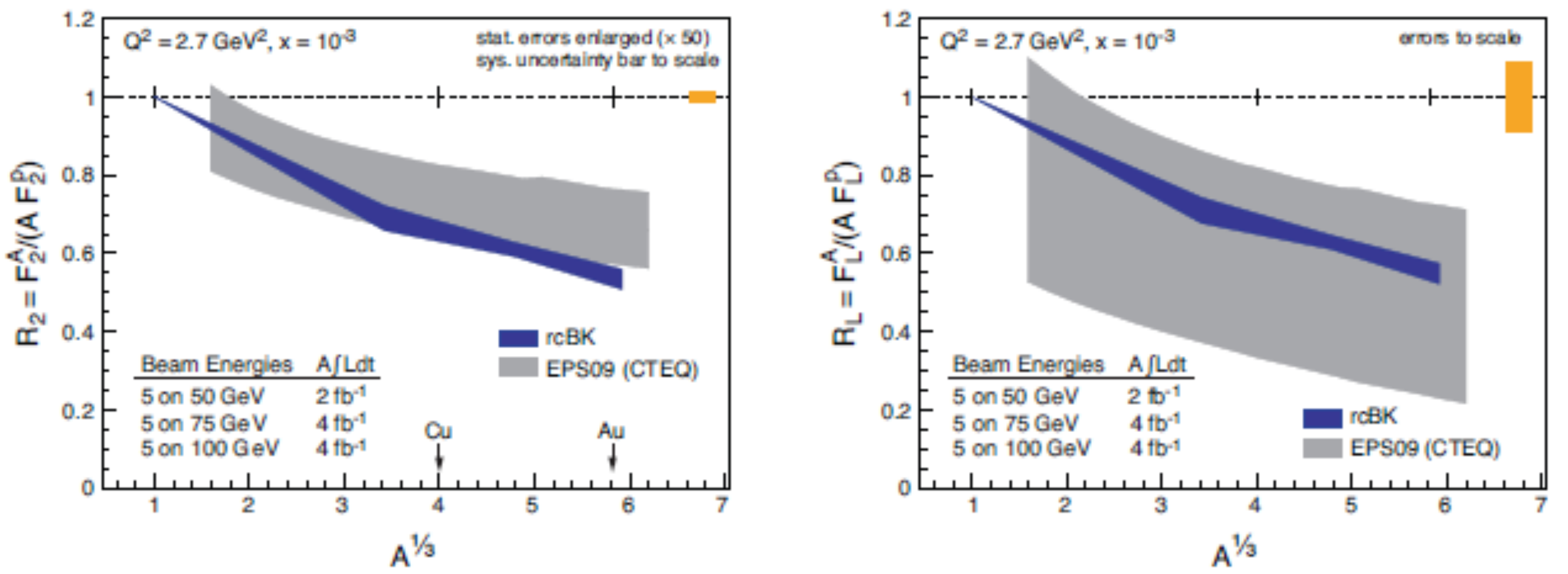


$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 \ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2}\, e^{\frac{P_{h\perp}^2 \delta^2}{Q_{sp}^4}}, \quad \left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 \gg Q_s^2} \approx 1$$

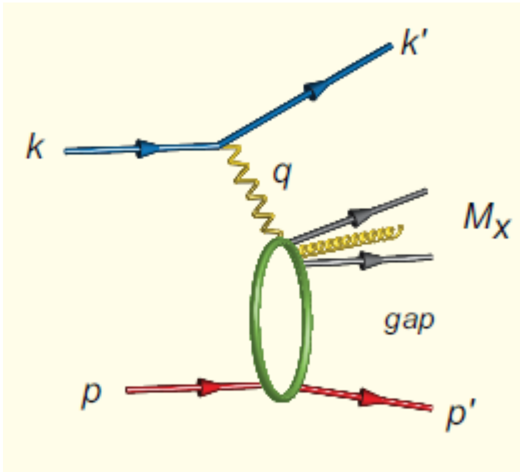
Bringing the Precision of e+A to Bear

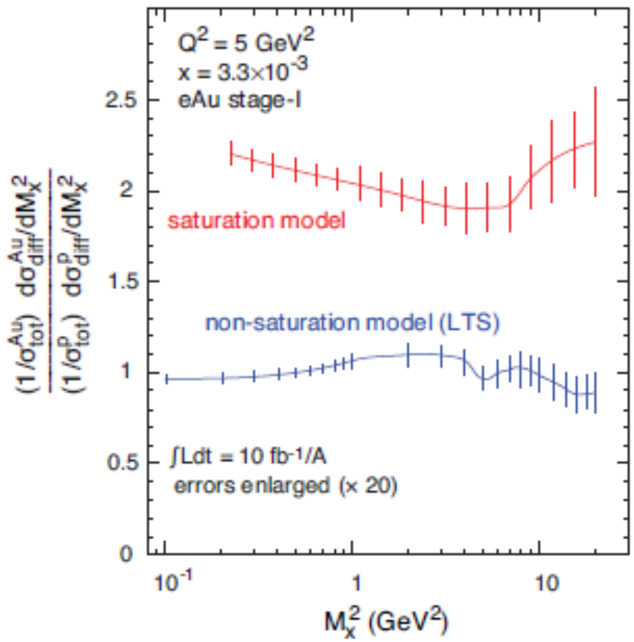


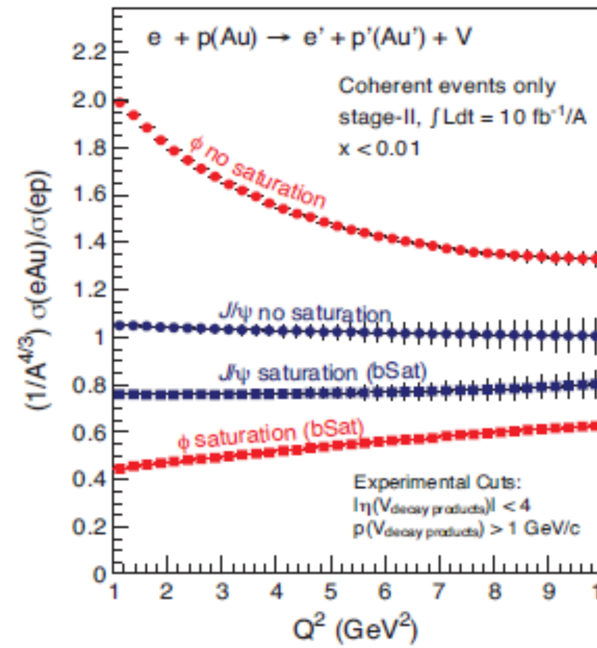
- *Need quantitative control of EM processes with low-order QCD corr'ns to determine gluon densities precisely.*
- *EIC will substantially increase kinematic coverage of e+A DIS over existing fixed-target experiments.*
- *Measurement of DIS structure fcns. F_2 & F_L will provide stringent test of CGC predictions for low-x gluon densities. F_L requires energy variability.*
- *May not be able to distinguish satur'n from other shadowing parameteriz'ns.*

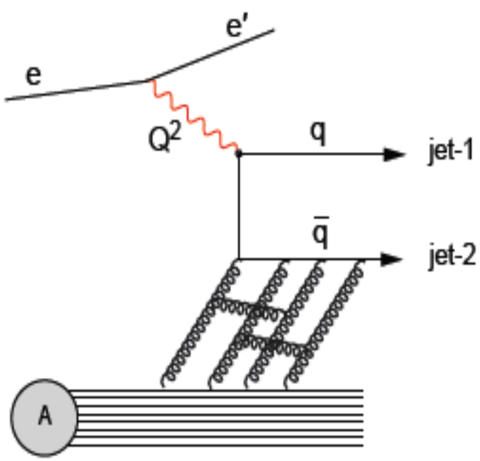


Probing Saturation with Diffraction and Di-Jets

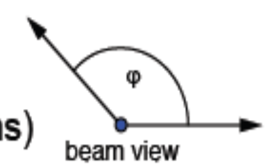


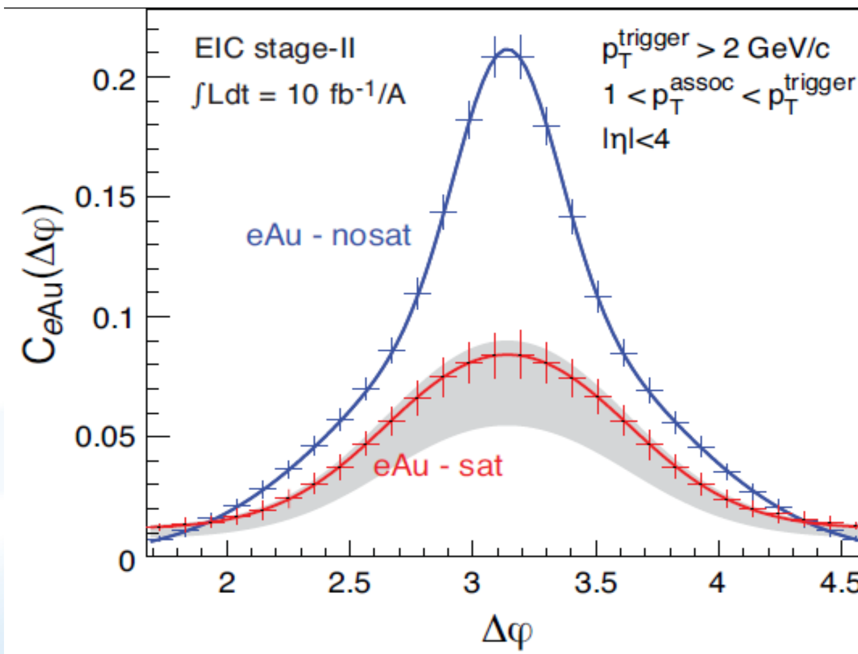




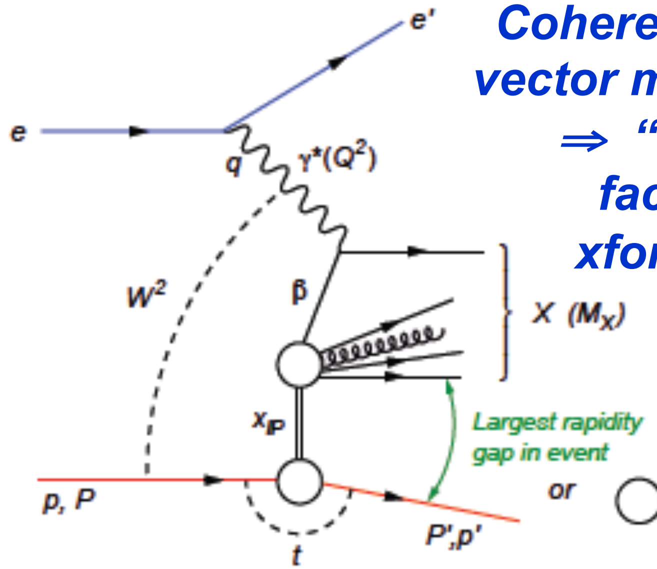


Either Jets or use leading hadrons from jets (dihadrons)

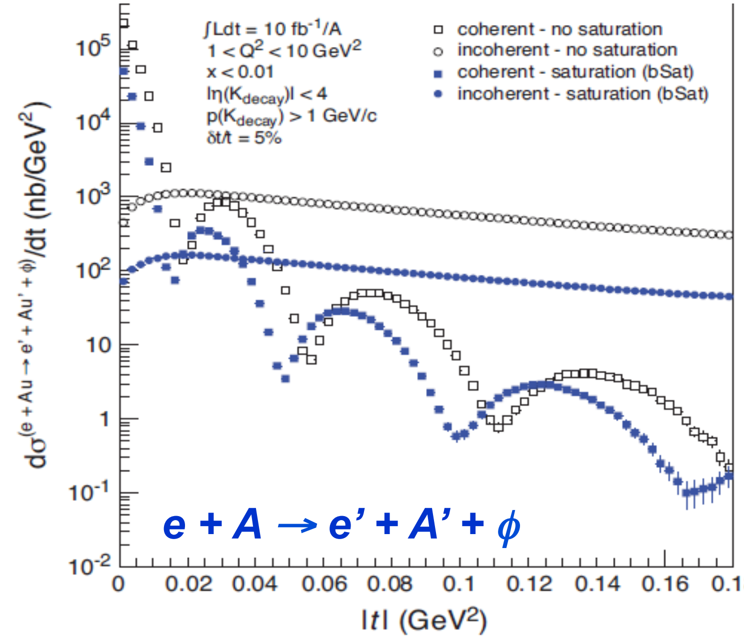




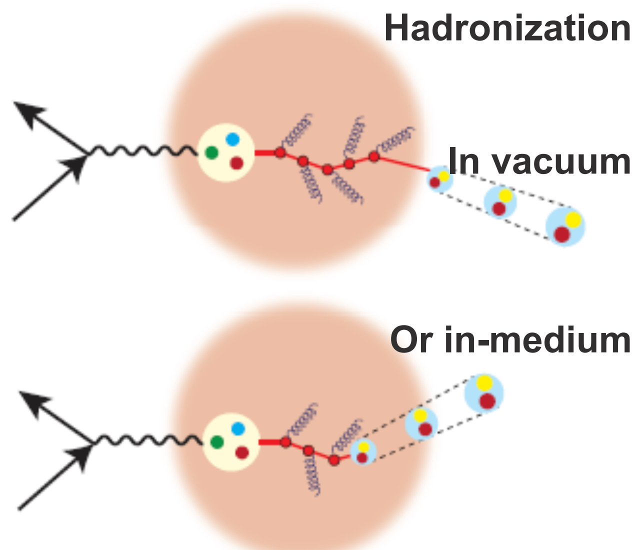
Gluonic Form Factors and Parton Propagation in Cold Nuclei

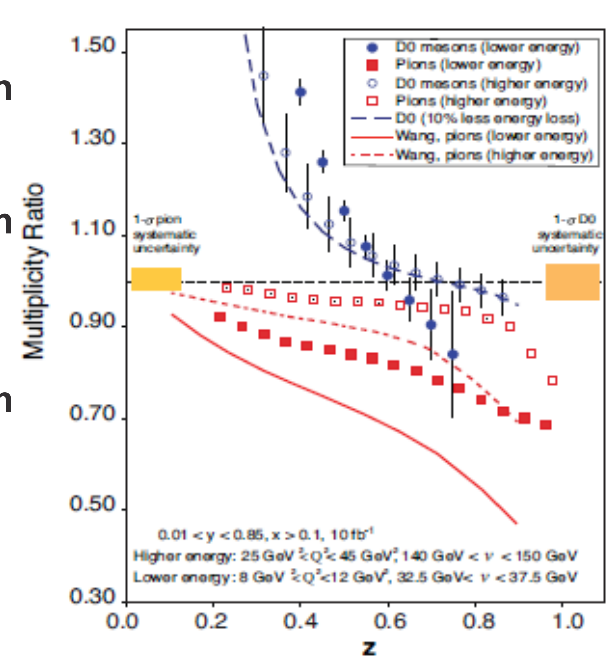


Coherent diffractive vector meson prod'n ⇒ "gluonic form factor", Fourier xform of $\rho_{glue}(b)$.

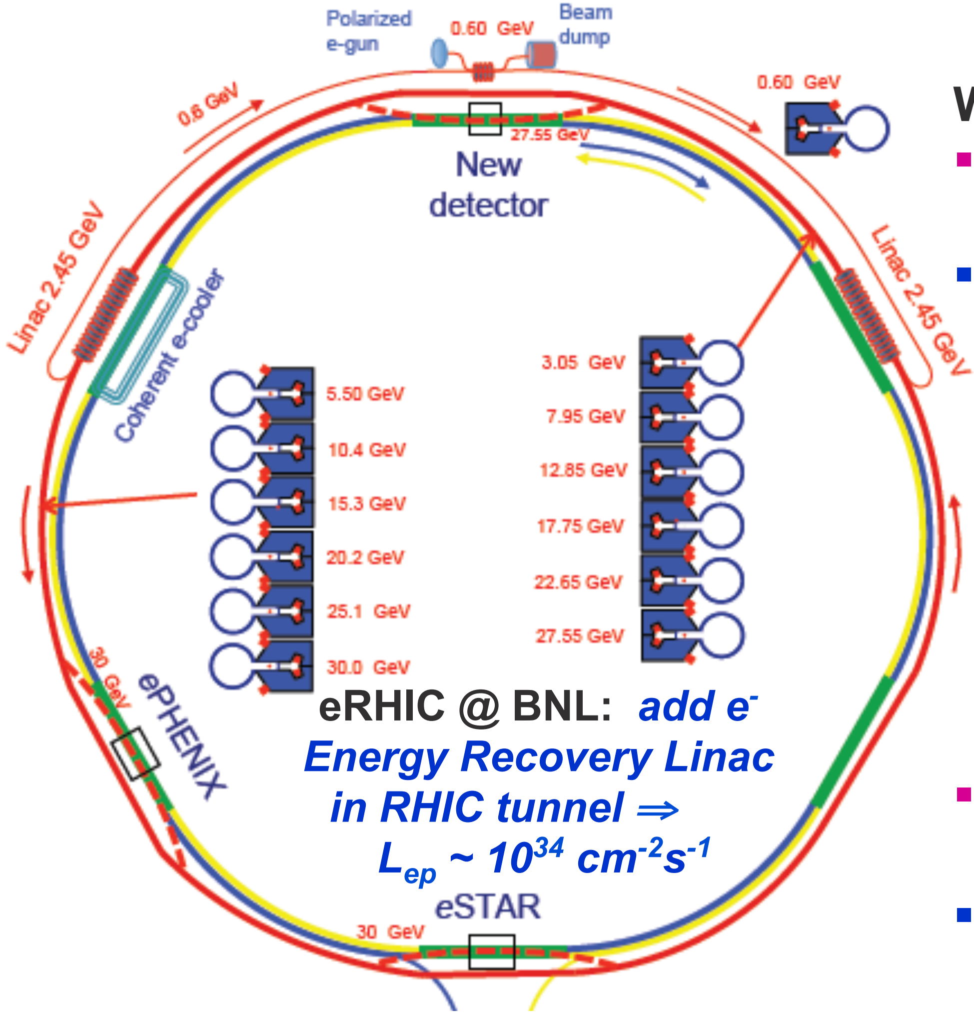


Mysteries at RHIC & LHC regarding rate of energy loss of heavy vs. light quarks traversing hot QCD matter should be illuminated by studies of D^0(blue)/π (red) yield ratios in cold nuclear matter for e+A/e+d, as fcn. of energy transfer ν and meson momentum fraction z.





RHIC's 3rd Decade: Reinvention as eRHIC ⇒ Path Forward for Cold QCD Matter



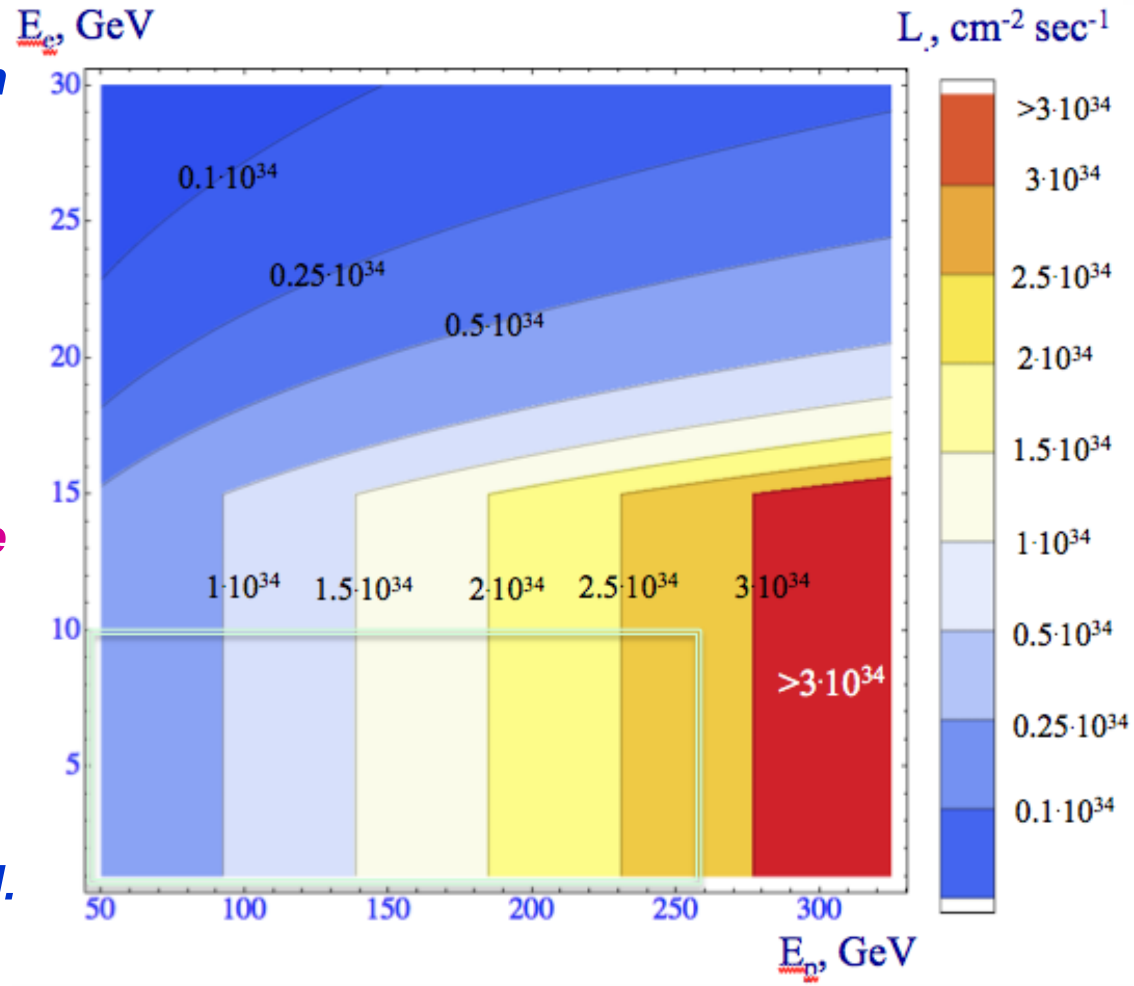
Design allows easy staging (start w/ 5-10 GeV, upgrade to ~20 GeV e^-). Underwent successful technical design review in 2011. Bottom-up cost eval. + value engineering in progress.

Why eRHIC is a cost-effective approach:

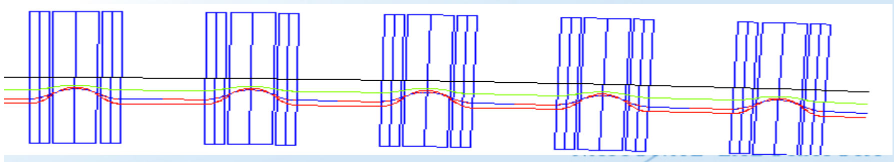
- ***Reuses RHIC tunnel & detector halls ⇒ minimal civil construction***
- ***Reuses significant fractions of existing STAR & PHENIX detectors***
  - ***Exploits existing HI beams for precocious access to very high gluon density regime***
  - ***Polarized p beam and HI beam capabilities already exist – less costly to add e^- than hadron accelerator***
- ***Provides straightforward upgrade path by adding SRF linac cavities***
- ***Takes advantage of RHIC needs and other accelerator R&D @ BNL:***
  - ➢ ***E.g., coherent electron cooling can also enhance RHIC pp lumi.***
  - ➢ ***E.g., FFAG developments for muon collider considered for significant cost reductions***

eRHIC Luminosity and Design Options

- ***High luminosity & full electron polarization transparency allowed by ERL-ring design with one collision pass – accept large collision disruption of electron beam bunch.***
- ***Luminosities increased from earlier numbers due to consideration of space charge compensation for RHIC's hadron beams.***
- ***L scales with $\gamma_{hadron\ beam}$, but is independent of electron energy until synch. radiation loss limit (10 MW) approached.***
- ***Box in figure contains 1st-stage reach.***



- ***Permanent magnet FFAG recirc. arcs being considered as alternative may allow more acceleration passes, higher electron energy, lower cost.***



Main Accelerator Challenges

In red –increase/reduction beyond the state of the art

	eRHIC at BNL
	Polarized electron gun – 10x increase
	Coherent Electron Cooling – New concept
	Multi-pass SRF ERL 5x increase in current 30x increase in energy
	Crab crossing New for hadrons
	Polarized ^{3}He production
	Understanding of beam-beam affects New type of collider
	β^*=5 cm 5x reduction
	Multi-pass SRF ERL 3-4x in # of passes
	Feedback for kink instability suppression Novel concept

August 2011 external review ⇒ The committee is very impressed by the ingenious design of eRHIC. The design includes a number of outstanding and novel elements…The committee did not see any significant holes in the concept.

EIC Science White Paper by DNP, Oct. 24-27, 2012

Steering committee to draft science White Paper for EIC (both designs) appointed by BNL and JLab management in 2011, in preparation for next NP Long Range Plan. Now useful to provide long-range insights for field's future in Tribble-II Panel consideration of priorities within tight budget constraints.

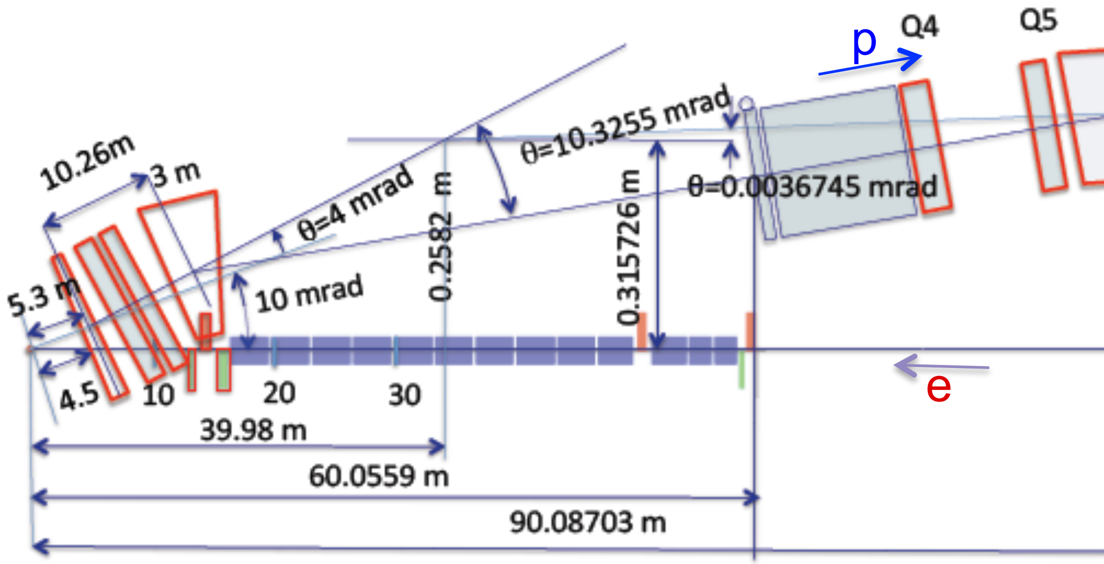
Overall editors: A. Deshpande (Stony Brook), J. Qiu (BNL) and Z.-E. Meziani (Temple)
Gluon saturation in e+A: T. Ullrich (BNL) and Y. Kovchegov (Ohio State U.)
Nucleon spin structure (mostly inclusive e+N): E. Sichtermann (LBNL) and W. Vogelsang (Tubingen)
GPD's and exclusive reactions: F. Sabatie (Saclay) and M. Diehl (DESY)
TMD's, hadronization and SIDIS: H. Gao (Duke) and F. Yuan (LBNL)
Electroweak physics: K. Kumar (U. Mass.) and M. Ramsey-Musolf (Wisconsin)
Accelerator designs and challenges: T. Roser (BNL) and A. Hutton (JLab)
Detector design and challenges: E. Aschenauer (BNL) and T. Horn (CUA)
Senior advisors: R. Holt (ANL) and A. Mueller (Columbia)

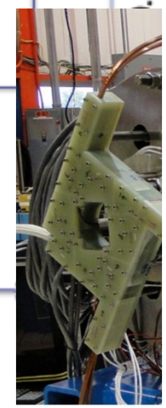
Need your feedback on current draft, posted at:

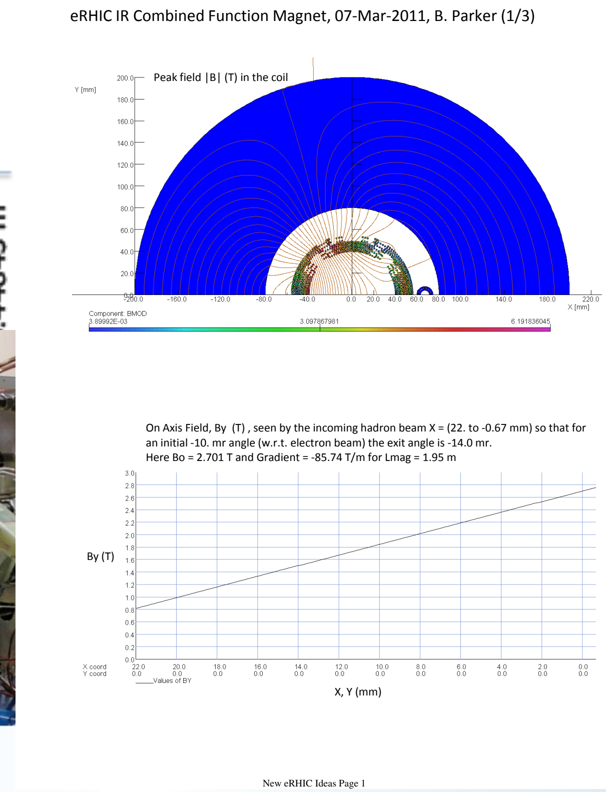
http://skipper.physics.sunysb.edu/~abhay/eicwp12/draft/EIC-WP-08162012-POETIC.pdf

Backup Slides

eRHIC high-luminosity IR with β^*=5 cm







- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb_3Sn focusing magnets
- Arranged free-field electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of the electrons to avoid SR impact in the detector

© D.Trbojevic, B.Parker, S. Tepikian, J. Beebe-Wang

Report from the ERHIC Design Review held on 1-3 August 2011

The committee is very impressed by the ingenious design of eRHIC. The design includes a number of outstanding and novel elements. The noteworthy challenges include

- A polarized e- gun with 50 mA beam current
- Coherent electron cooling of the RHIC polarized proton beams reducing their emittances by an order of magnitude
- Energy recovery for high-current beam over a factor 3000 energy range with 12 passes through the same linac (1.5 GW of reactive power)
- Crabbing system for hadron beams at several harmonic frequencies with a total crab voltage of order 50 MV (about 25 times the KEKB value)
- Large-aperture high-gradient SC IR magnets with a low-field exit hole for the electron beam
- About 20 km of beam lines with more than 10000 magnets
- Very low aperture magnets
- Operating with an increased number of hadron bunches (+50%), bunch intensity (+25%), and shorter bunch length (from about 50 cm down to 8 cm) in RHIC
- Constraints from the existing infrastructure

The committee is highly satisfied with the material presented, covering most of the relevant subjects. **The committee did not see any significant holes in the concept.**

For the project success it is crucial to experimentally demonstrate feasibility of a 50-mA polarized electron gun with reasonable lifetime and coherent electron cooling.

We support further development of the concept, which must proceed in parallel with a prioritized strong experimental R&D program towards demonstrating feasibility of major technologies.