Visions for RHIC's Short- and Long-Term Future

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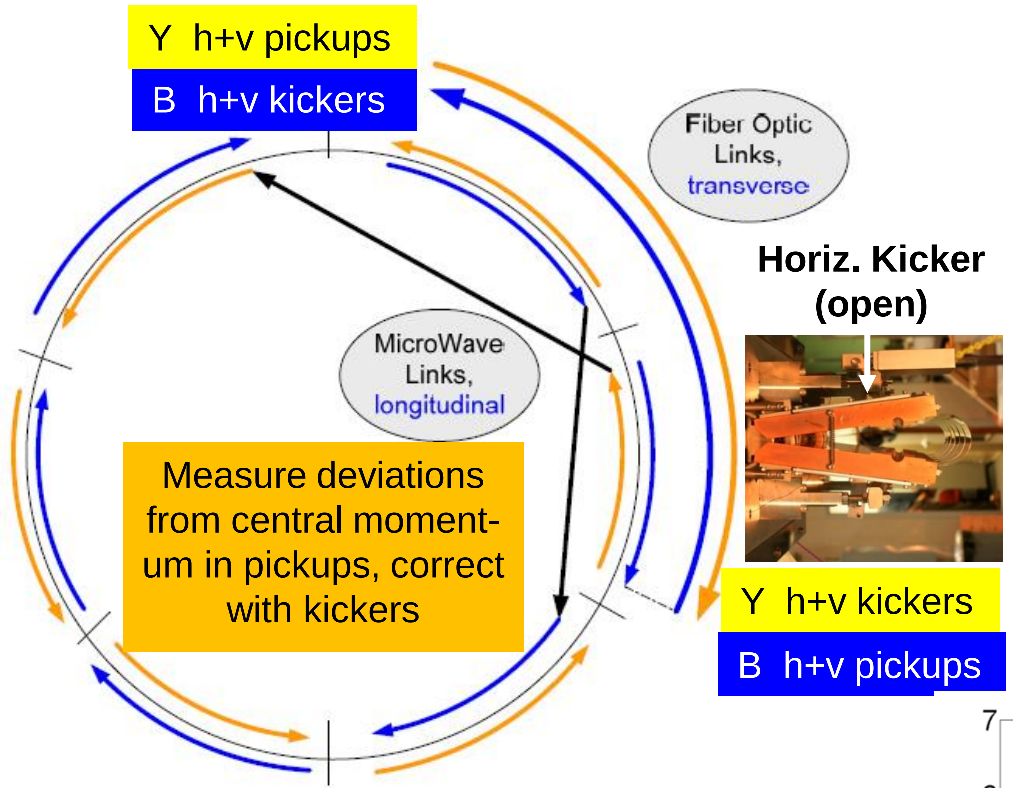
DNP Town Meeting

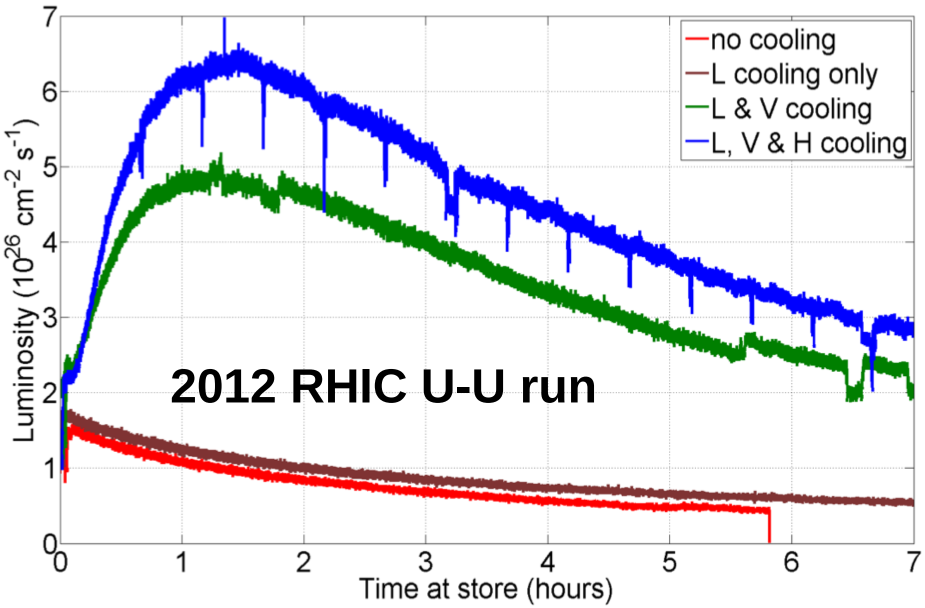
Oct. 25, 2012

I. Ongoing and Proposed Upgrades
II. Science Drivers for RHIC's 2nd Decade
III. Rough 10-Year Running Schedule & Timeline Drivers
IV. eRHIC Design

RHIC-II Era is Here, Done Very Cost-Effectively !

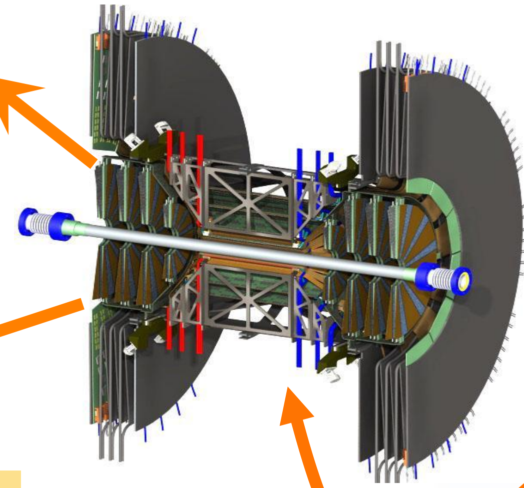


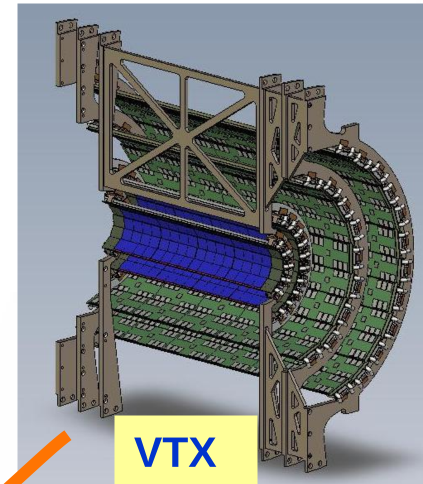
- ➢ *RHIC breakthrough in bunched-beam stochastic cooling ⇒ now ~x18 over original design HI luminosity, 5 years earlier, at ~1/7 the cost in 2007 NP LRP*
- ➢ *New Electron Beam Ion Source used in 2012 for new species, e.g., U beams*
- ➢ *Install electron lenses for 2013 run to ⇒ ~x2 polarized pp luminosity ≥ 2014*

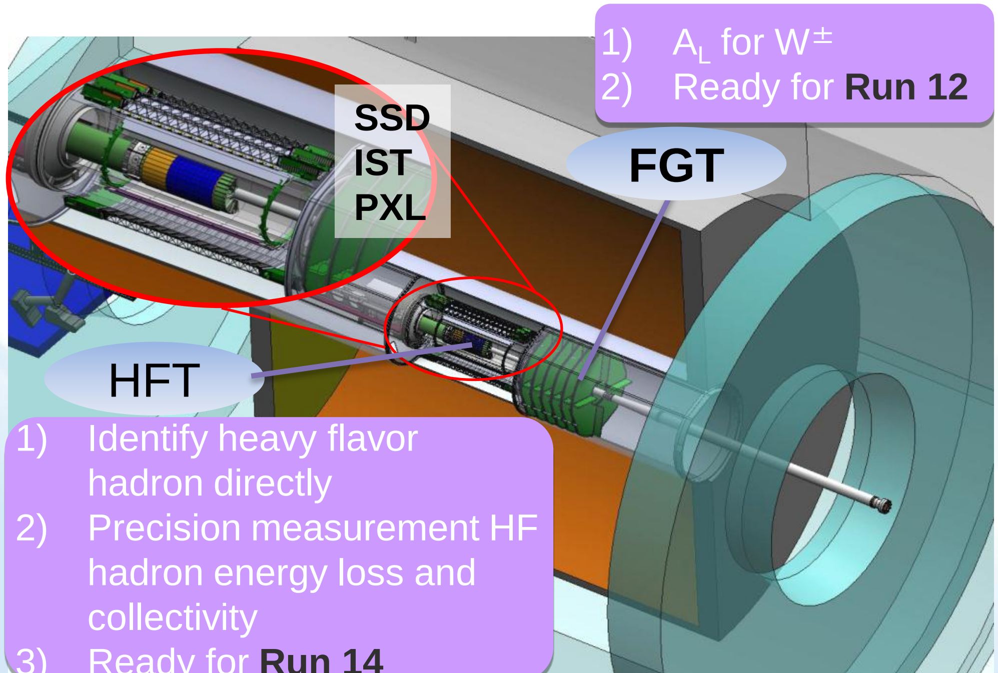


A Suite of Ongoing Detector Upgrades

- ***PHENIX VTX & FVTX upgrades greatly improve vertex resolution, heavy flavor ID***
- ***μ trigger upgrade installed in FY10-11 enhances W prod'n triggering for spin program.***







- ***STAR Heavy Flavor Tracker receives CD-2/3 review in 2011. Will permit topological recon-struction of charmed hadrons.***
- ***STAR Forward GEM Tracker to be installed for Runs 12 and 13, will enhance forward tracking, W charge sign discrimination.***
- ***STAR Muon Telescope Detector (Run 14) to improve quarkonium***

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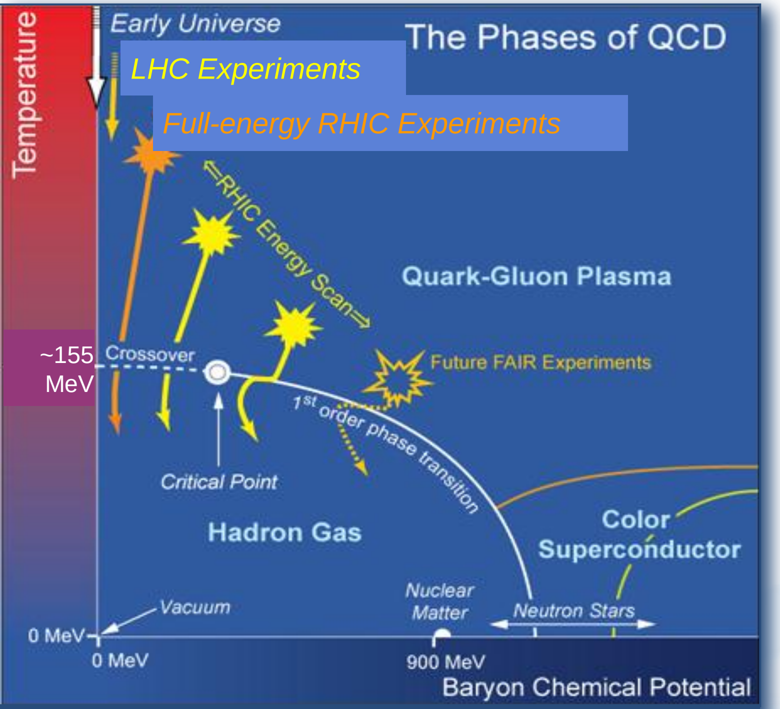
Broad Science Goals for the Next Decade

Quantify properties of the QGP and features of the QCD phase diagram, as functions of temperature and net quark density from the onset of deconfinement toward even earlier universe conditions.

Exploit new discovery potential in searches for a QCD critical point and for the nature and influence of quantum fluctuations in initial densities and the excited QCD vacuum (sphalerons).



Search for a QCD Critical endpoint via low-energy scan in RHIC-II era

Continue explorations of the role of soft gluons in cold nuclear matter (gluon saturation, contributions to proton spin).

RHIC and LHC are complementary. Both are needed to explore the temperature-dependence of QGP properties (span factor ~1000 in √s). RHIC has unique reach to search for the QGP onset, unique ion species versatility and unique polarized proton capability, until EIC is realized. And QCD matter is RHIC's primary focus.

10 Basic Questions Going Into the RHIC Era

	Basic questions going into the RHIC era	RHIC/LHC answers to date
	1) Is RHIC's kinematic reach sufficient to create matter in the anticipated Quark-Gluon Plasma (QGP) phase?	Yes
	2) Is the QGP weakly coupled, with approximately ideal gas (i.e., asymptotic freedom) behavior?	No
	3) Can we experimentally demonstrate the transition from hadronic to quark-gluon degrees of freedom in reaching QGP?	Hints[a)]
	4) Do partons lose energy rapidly in traversing QGP?	Yes
	5) Does color screening in the QGP suppress the formation of quarkonium (i.e., bound states of same flavor quark-antiquark systems)?	Strong Hints[a)]
	6) Can we find evidence of high-temperature excited QCD vacuum fluctuations, analogous to the electroweak sphalerons postulated as the source of the universe's baryon asymmetry?	Hints[a)]
	7) Is there a locus of first-order phase transitions and a Critical Point in the QCD phase diagram?	Hints[a)]
p/d + A	8) Do we see evidence of gluon density saturation in cold nuclear matter at low Bjorken x?	Strong Hints[a)]
→→ p+p	9) Do gluon spin preferences account for a significant part of the "missing" proton spin?	Yes
	10) Is there a significant flavor-dependence in sea quark polarizations within a polarized proton?	Insufficient data to date

It is the responsibility of RHIC and LHC to design measurements to address the more quantitative 2nd-generation questions emerging from the definitive answers above, and to resolve the hints surrounding the others.

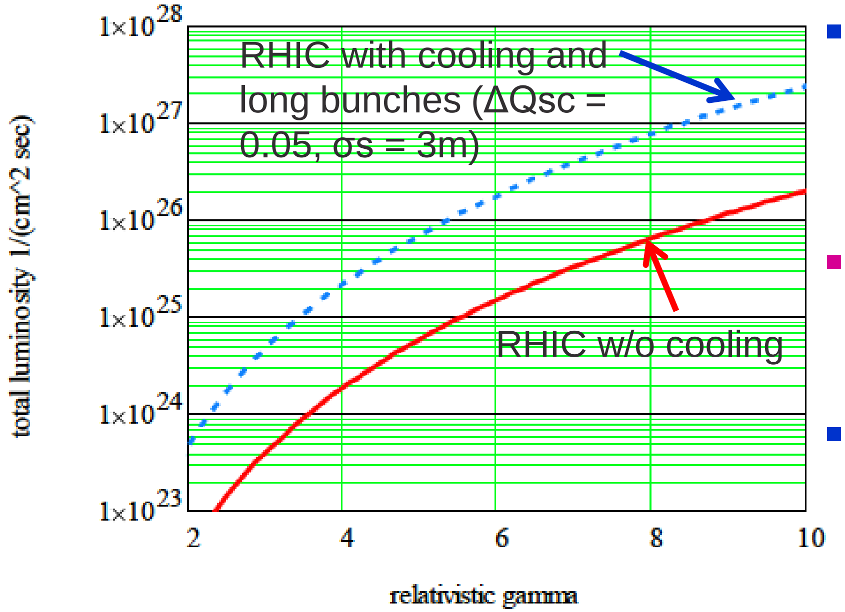
Questions For the Next Decade

Question	Facilities Needed to Answer	Comments	Related Table 1 Question #'s
1) How perfect is "near-perfect" liquid?	RHIC & LHC (& ⇒ BOTH REQ'D)	Flow power spectra, next 5 years	1 + 2
2) Nature of initial density fluctuations?	RHIC, LHC & EIC	Benefits from asymmetric ion collisions at RHIC	2 + 8
3) How does strong coupling emerge from asymptotic freedom?	RHIC & LHC	Following 5 years @ RHIC; jets need sPHENIX upgrade	2 + 4
4) Evidence for onset of deconfinement and/or critical point?	RHIC; follow-up @ FAIR, NICA	Phase 2 E scan in following 5 years, needs low-E electron cooling	3 + 7
5) Sequential melting of quarkonia?	RHIC & LHC	LHC mass resolution a plus; RHIC det. upgrades help; $\sqrt{s}$-dependence important	5
6) Are sphaleron hints in RHIC data real?	Mostly RHIC	Exploits U+U and $\mu_B \neq 0$ reach at RHIC	6
7) Saturated gluon densities?	RHIC, LHC & EIC	Want to see onset at RHIC; need EIC to quantify	8
8) Where is missing proton spin?	RHIC & EIC	EIC will have dramatic impact	9 + 10

Addressing these questions requires an ~10-year program of A+A (various ion species), p+p and p/d + A runs at various RHIC energies.

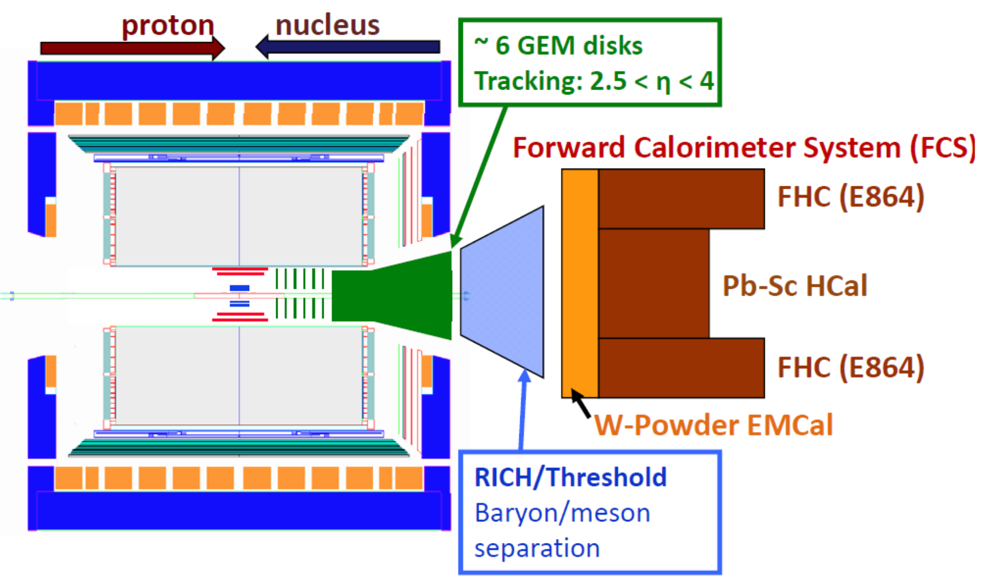
Contemplated Future Upgrades

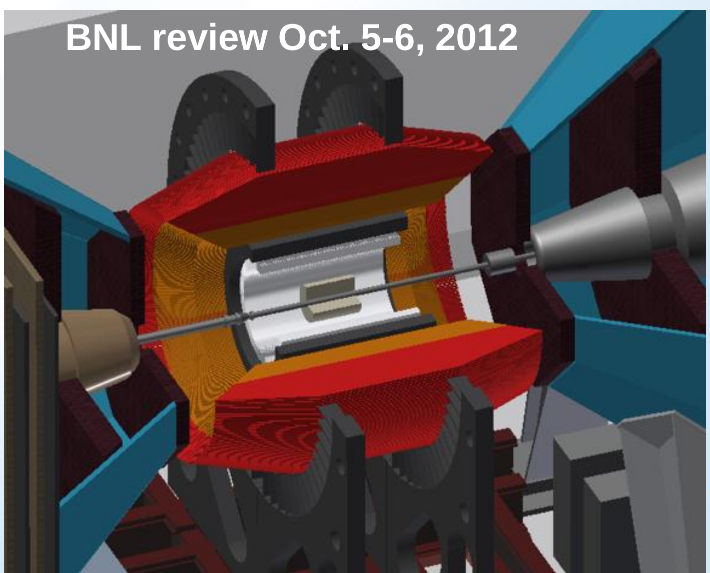
Will likely use high brightness SRF electron gun for bunched beam electron cooling; up to ~10x L; ready after 2017 [Fermilab Pelletron (cooled 8 GeV pbar for Tevatron use) is alternative option]



Other machine possibilities: pol'd ^{3}He; coherent e-cooling for $\mathscr{L}_{pp}$

- *Low-E electron cooling for further pursuit of onset of deconfinement/CP*
- *sPHENIX solenoid, EMCAL + HCAL for jet physics @ RHIC*
- *STAR forward up-grade for p+A and transverse spin (e.g., DY) physics*
- *PHENIX MPC-EX, STAR TPC pad rows*





Timeline for RHIC's Next Decade

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p} + \vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 GeV p+p (needed for new det. subsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Extension (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p} + \vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p} + \vec{p}$ • 200 GeV $\vec{p} + A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different $q\bar{q}$ states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades

Schedule Drivers: Technically Driven Project Timelines, Plus Running Period Lengths for Desired Uncertainties

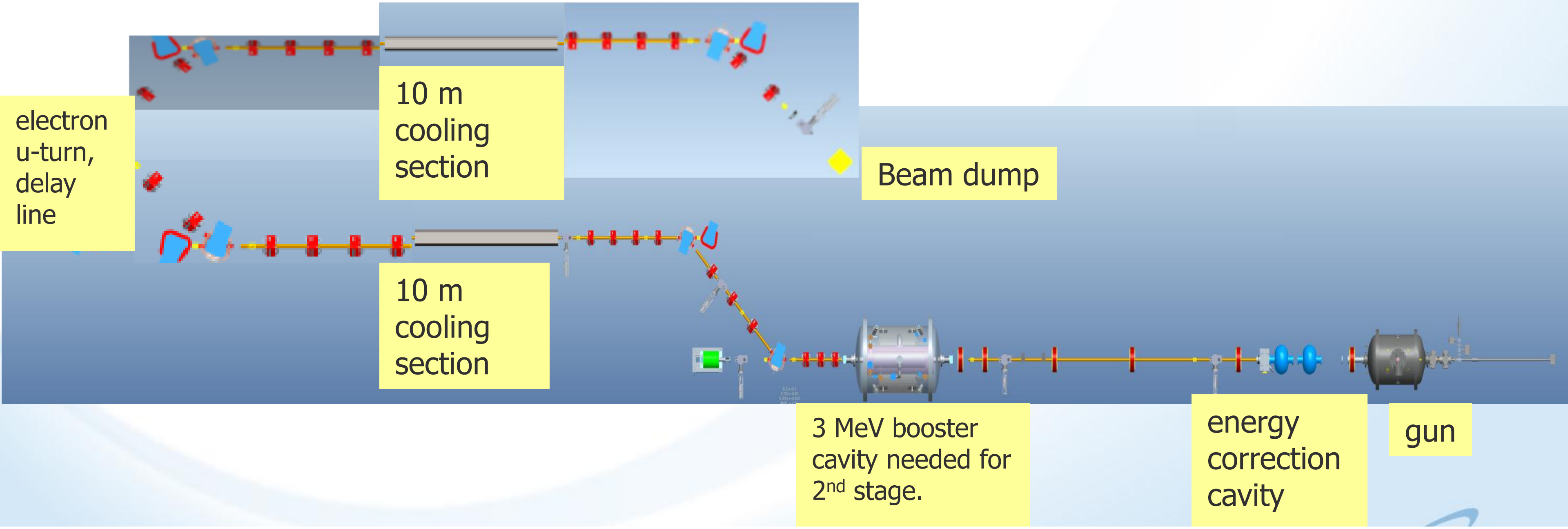
E.g., low-energy electron cooling can be implemented in 2 phases:

Phase I (available for use in 2017)

$\sqrt{s_{NN}}$ = 5-9 GeV (e-beam energy 0.9-2 MeV)

Phase II (2018+) [additional 3 MeV booster cavity]

$\sqrt{s_{NN}}$ = 9-20 GeV (e-beam energy 2-5 MeV)



Schematic of electron cooler in warm sector 3 based on CeC proof-of-principle layout, and using technology and/or components from R&D ERL + CeC PoP

Timelines for Possible Projects

Low-energy cooling Accelerator Improvement Project:

Requires start of the project (engineering phase) at the end of 2012 with high priorities and resources from C-AD.

2012 – feasibility study

2013-2014 – engineering design, drawings, purchase orders, and manufacturing for gun, magnets, power supplies, RF, etc.

2014-2015 – installation

2016 – commissioning of electron beam and transport; start cooling of ion beam – first 3-D electron cooling in a collider, expect some learning curve and optimization before luminosity improvement.

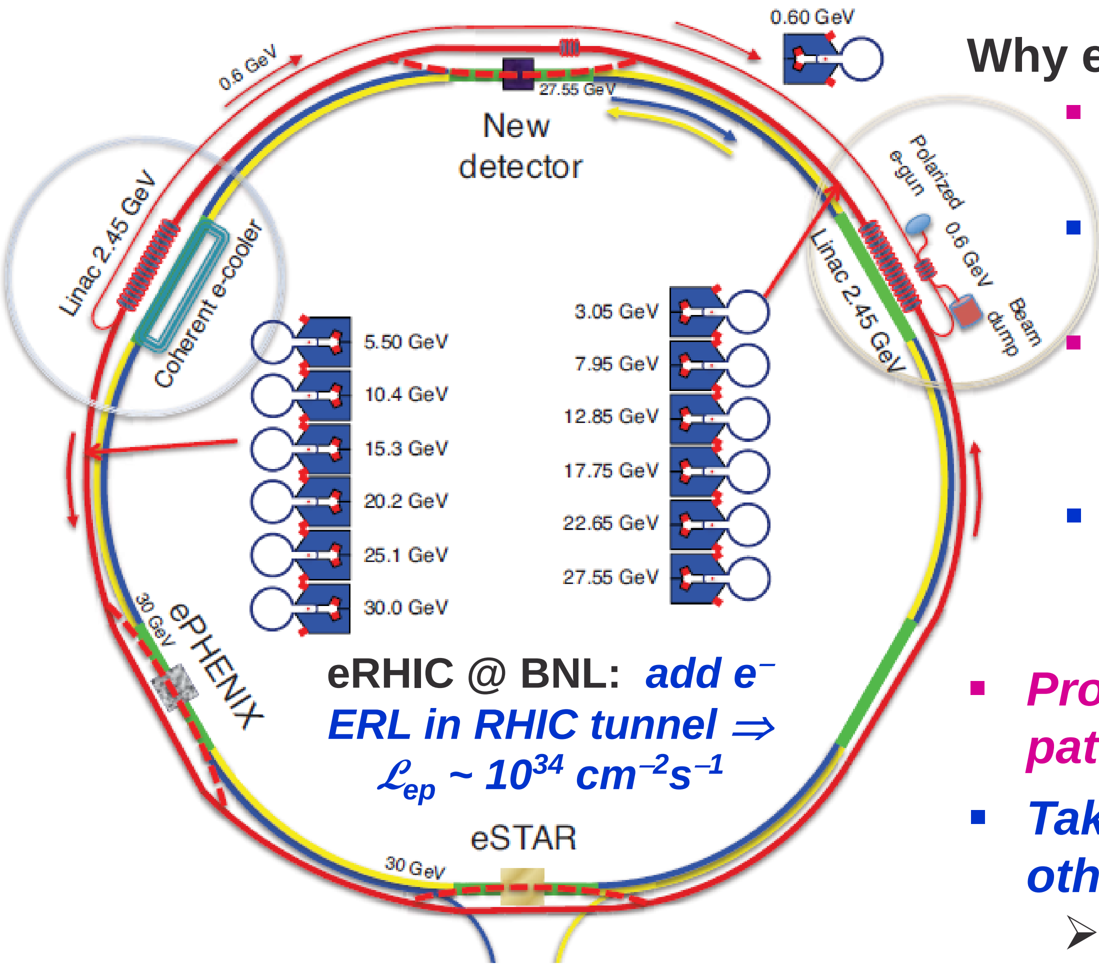
2017 – luminosity improvement in physics – Phase I

2018+ – luminosity improvements in physics – Phase II

Aggressive Critical Decision timeline for sPHENIX upgrade:

- **CD0 2QFY2013** allows R&D funds to be expended and PED funds to be requested (these are part of TPC)
- **CD1 1QFY2014** PED funds can be expended
- **CD 2/3 1QFY2015** A year of design brings the project to a CD2 review; CD3 approval allows procurement to begin on long lead time items like the solenoid
- **CD4 4QFY2018** 3.5 years of construction (2Q2015-4QFY2018)
- **4QFY2019** Commissioning complete

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.

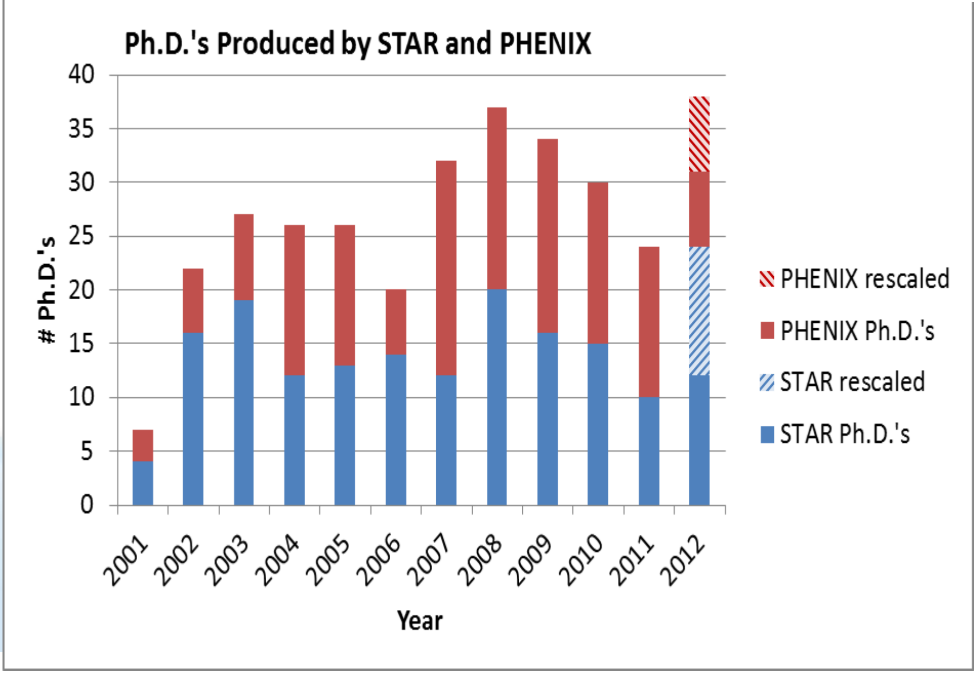
Why eRHIC is a cost-effective approach:

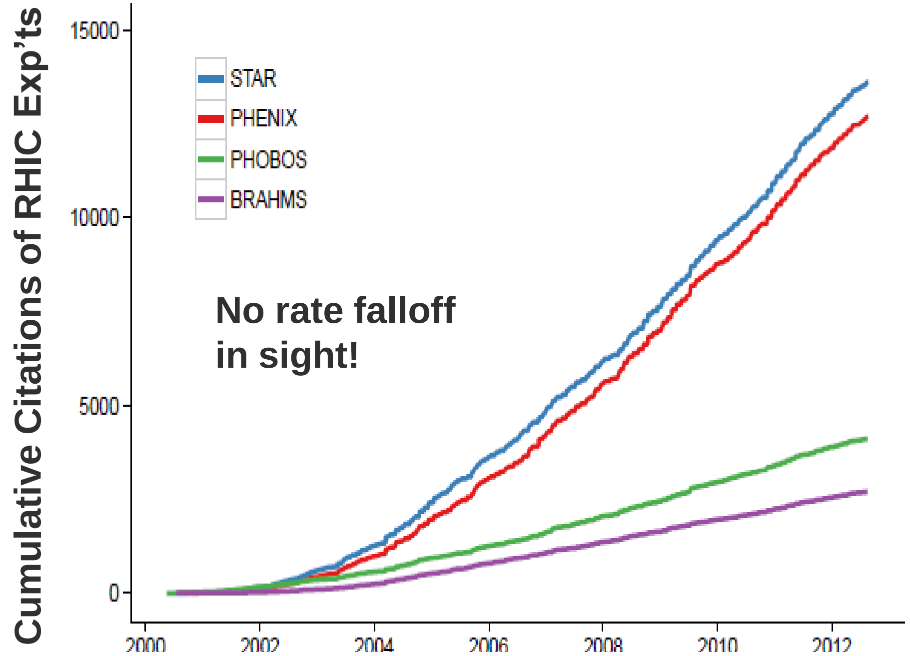
- ***Reuses RHIC tunnel & detector halls ⇒ minimal civil construct'n***
- ***Reuses significant fractions of STAR & PHENIX detectors***
- ***Exploits existing HI beams for precocious access to very high gluon density regime***
- ***Polarized p beam and HI beam capabilities already exist – saves ~$2B RHIC replacement cost***
- ***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***

RHIC's Most Important Products

Collaboration	Total # Refereed Papers	Total # Citations for Refereed Papers	# PRL's	# Citations for 2005 White Paper	Position of 2005 White Paper Among Most Cited NP Papers 2001-12	# Papers with >250 Citations
PHENIX	126	13,292	57	1358	5	12
STAR	160	14,434	54	1382	4	15
PHOBOS[a)]	39	4057	15	1049	7	1
BRAHMS[b)]	22	2649	10	1040	8	3
Total =	**347**	**34,432**	**136**	**4829**		**31**

Also, >40% of all-time top-cited Nuclear Theory arXiv papers are RHIC-related!





Plus >190 tenured faculty positions worldwide + 6 cover story articles +…

Thanks in part to vigorous foreign investment, e.g., $130M from RIKEN…

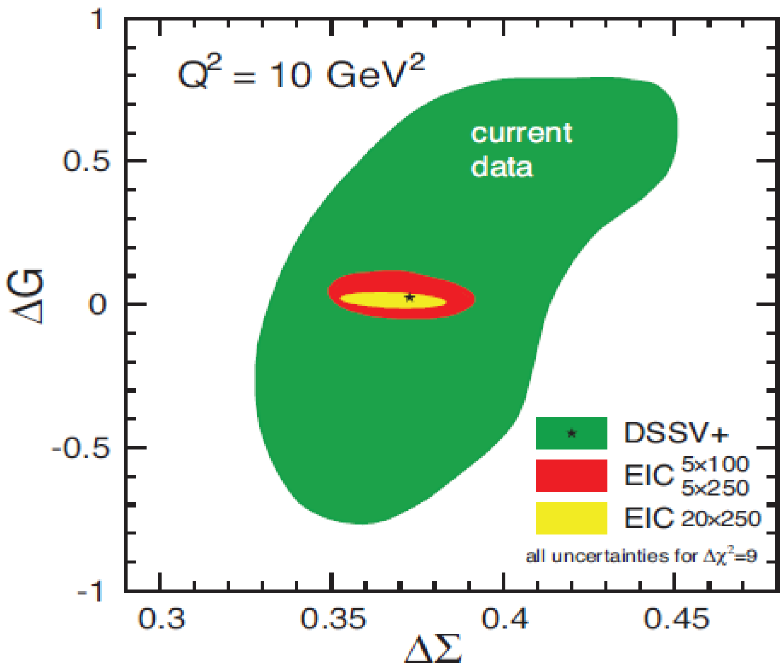
Summary

1) RHIC's first 12 years have been marked by:
   - Important discoveries in QCD matter
   - High productivity
   - High scientific impact $\Rightarrow$ increased visibility for U.S. NP
   - Great technical versatility and breakthroughs
   - Cost-effective upgrades to facility performance & versatility

2) RHIC's next decade is required to:
   - Quantify transport properties of the Quark-Gluon Plasma
   - Pursue discovery potential unveiled by results to date
   - Combine with LHC heavy ion program to span suitably wide initial temperature range to accomplish the above
   - Reap science payoff from just completed and ongoing RHIC facility upgrades
   - Pursue the unique accelerator science and spin physics opportunities that come with only operating U.S. collider and only worldwide polarized collider
   - Provide a cost-realizable path to an Electron Ion Collider

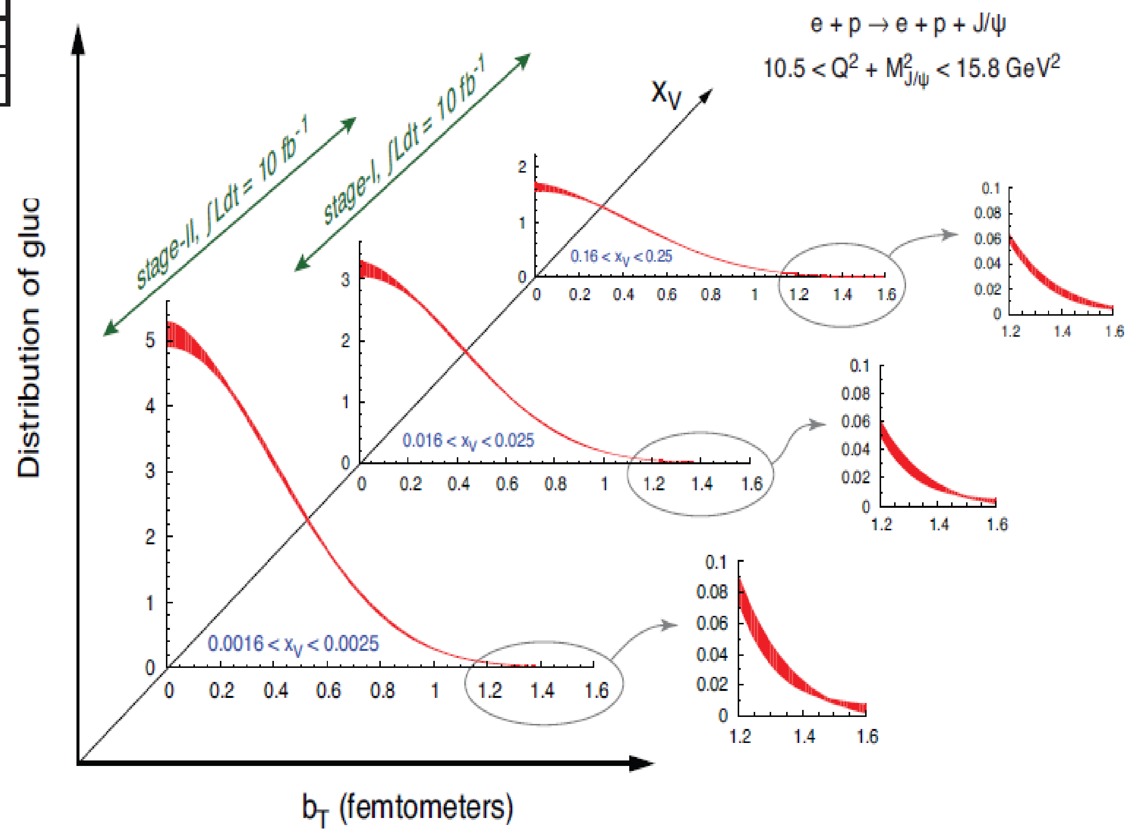
Backup Slides

How eRHIC Complements RHIC: Spin & Imaging

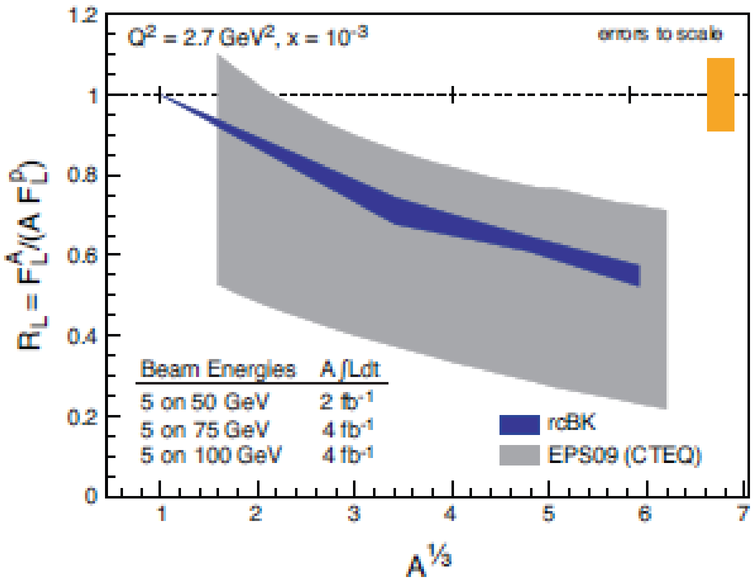


- *e+p DIS @ $\sqrt{s}$ > 50 GeV ⇒ access to softer gluons, much tighter constraints on total gluon and quark contributions to p spin*
- *Charged-current DIS ⇒ new electroweak structure functions that further constrain flavor-dependence of sea quark polariz'ns*

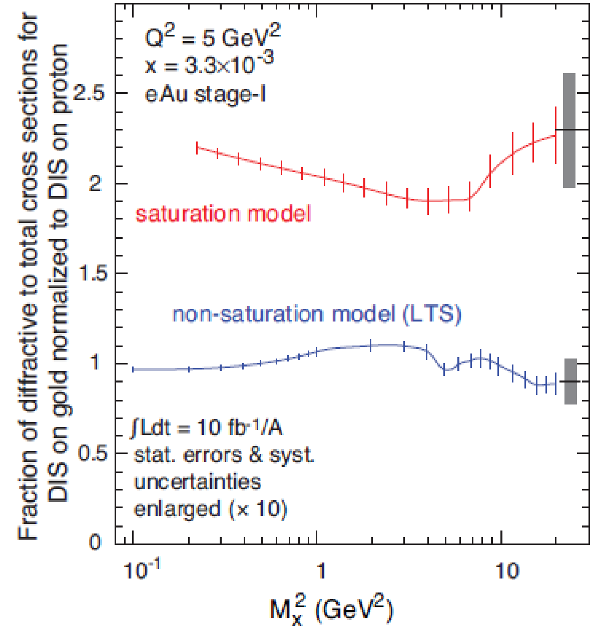
- *Semi-inclusive DIS and deep exclusive reactions take us from 1D (vs. x_{Bj}) to 3D (add transverse space or momentum dim'ns) imaging of nucleon*
- *E.g., exclusive J/ψ prod'n ⇒ unprecedented info on transverse spatial distrib'n of gluons as fcn. of x*



How eRHIC Complements RHIC: Initial State

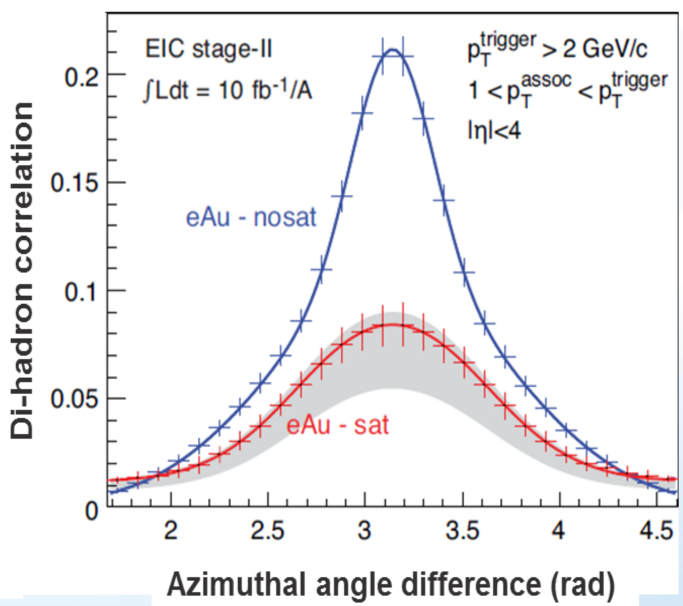


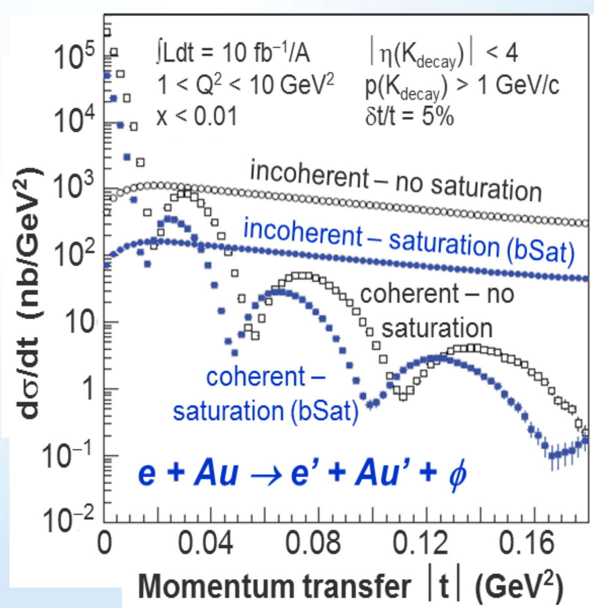
- *Coherent contrib'ns from many nucleons in heavy nucleus ⇒ precocious access to saturation regime*
- *e+A DIS measures low-x gluon density far more precisely than they are known*



- *Inclusive diffractive cross sections greatly enhanced by saturation*

- *Exclusive diffractive prod'n of vector mesons of size > $1/Q_{sat}$ ⇒ "gluonic form factor" of nuclei*
- *Di-jet and di-hadron coinc. yields suppressed in e+A*





What Would be Lost if RHIC Were Terminated?

- Opportunity to map QGP properties vs. temp., explore QCD phase diagram, and discover the possible Critical Point.
- Unique polarized pp access to nucleon spin structure.
- U.S. leadership in a vibrant NP subfield it pioneered.
- A major fraction of the productivity for U.S. NP over the better part of a decade – is this survivable for the field?
- The unmatched track record of RIKEN-BNL Research Center in funding outstanding Fellows and placing them in high-profile tenured positions.
- The last operating U.S. collider, hence a critical attractor for talented accelerator scientists and cutting-edge R&D.
- Cost-realizable path to a future EIC, taking advantage of ~$2B replacement cost (avoiding ~$1B D&D cost) of RHIC complex.
- Home research base for >1000 domestic + foreign users.
- Unusually strong foreign (esp. RIKEN) investment in U.S. facility.
- ~750 (direct, including research + indirect) FTE's @ BNL.
- Associated efforts will suffer collateral, possibly fatal, damage:
  - Lattice QCD thermodynamics leadership
  - Strong medical radioisotope production program @ BNL
  - NASA Space Radiation studies @ BNL
  - Accelerator physics offshoots, esp. in hadron radiotherapy
- Probably a sizable chunk of DOE ONP funding will be siphoned off to other agencies or program offices.