RHIC Operations in the Recent Past and Near Future

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I. Budget Impacts on Recent Operations

II. Recent Research Highlights

III. CR Impact on 2009-10 Runs

IV. Facility Development and Running Plans for FY09-14

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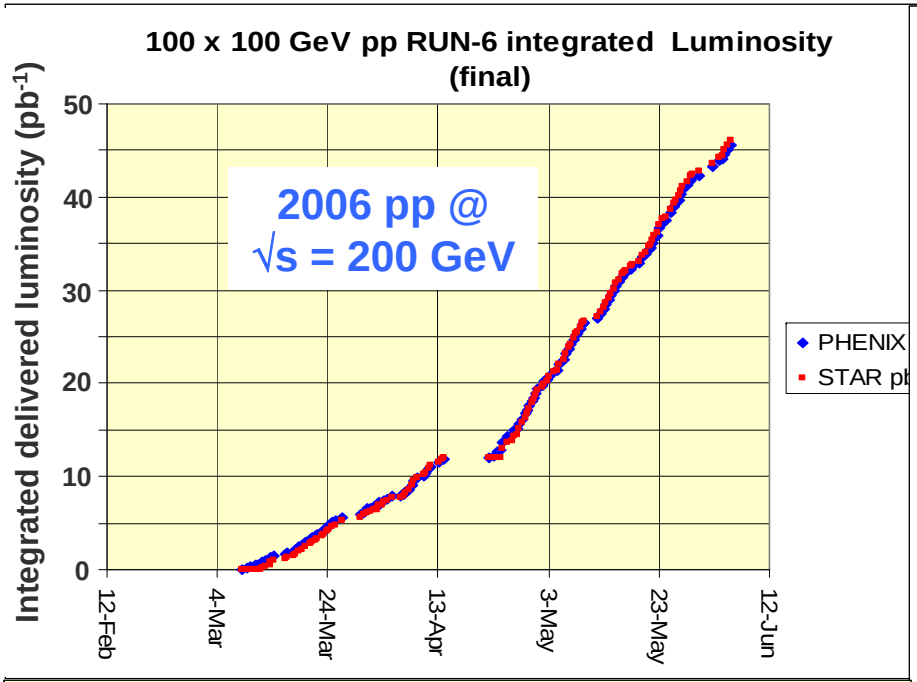
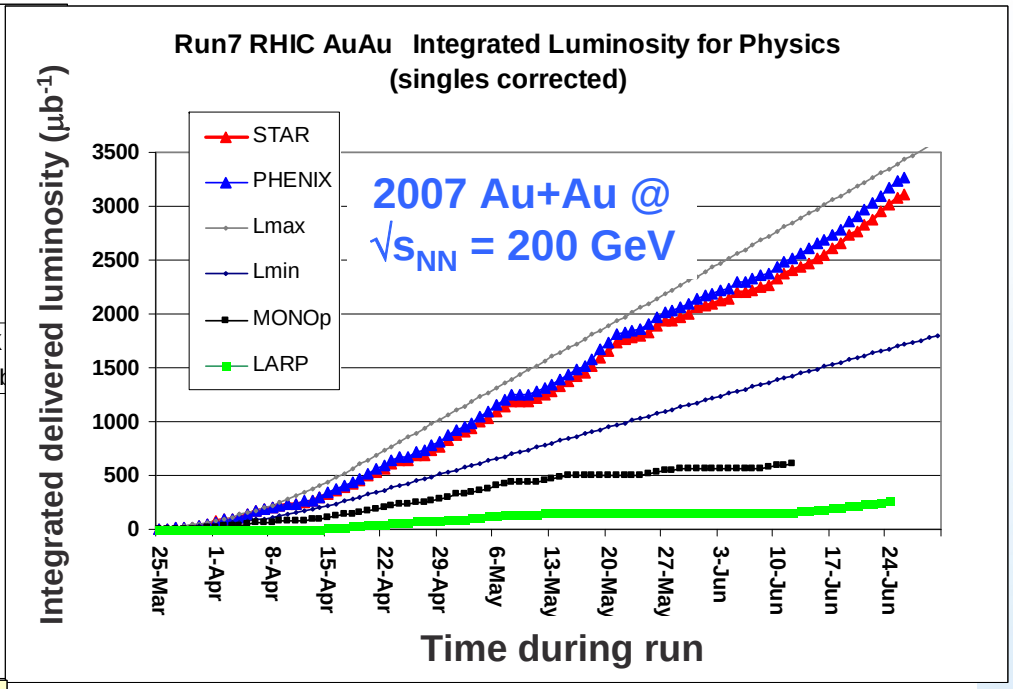
Office of Science U.S. DEPARTMENT OF ENERGY

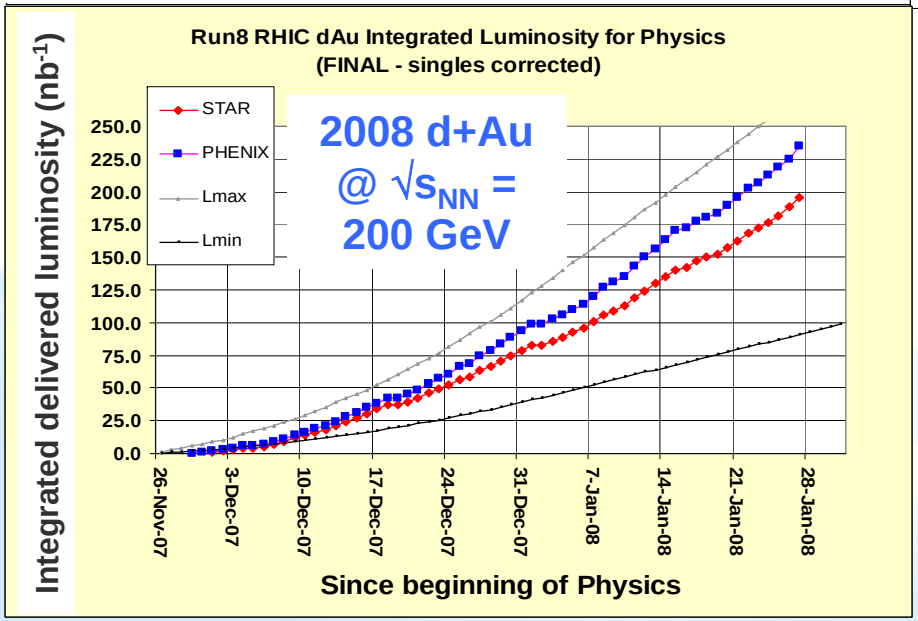
Budget Impacts on FY06-08 Runs

- *"Optimal" RHIC run is 30 cryoweeks, including 3 for cool-down/warm-up + 2 per beam species in collision commissioning ⇒ 23 physics prod'n weeks divided between 2 species*
- *Incremental operating cost/cryoweek ≈ $0.5M*
- *FY06: federal funding alone insufficient to support run, but $13M incremental grant from Renaissance Technologies allowed 21 cryoweeks, interrupted by 2-week arc flash incident ⇒ 13 production weeks for $\vec{p}+\vec{p}$ collisions (2 energies)*
- *FY07: CR prevented run start until Feb. 12 ⇒ 20 cryoweeks, devoted to full-energy Au+Au. Polarized p run deferred.*
- *FY08: carry-forward funds from FY07 permitted on-time (Nov. 1) start despite CR, but omnibus funding bill forced early end to run on March 13 ⇒ full d+Au run, but drastically shortened p+p focusing on (unpolarized) reference data for CGC tests, etc. in d+Au*

Improved Collision Luminosity 2006-8



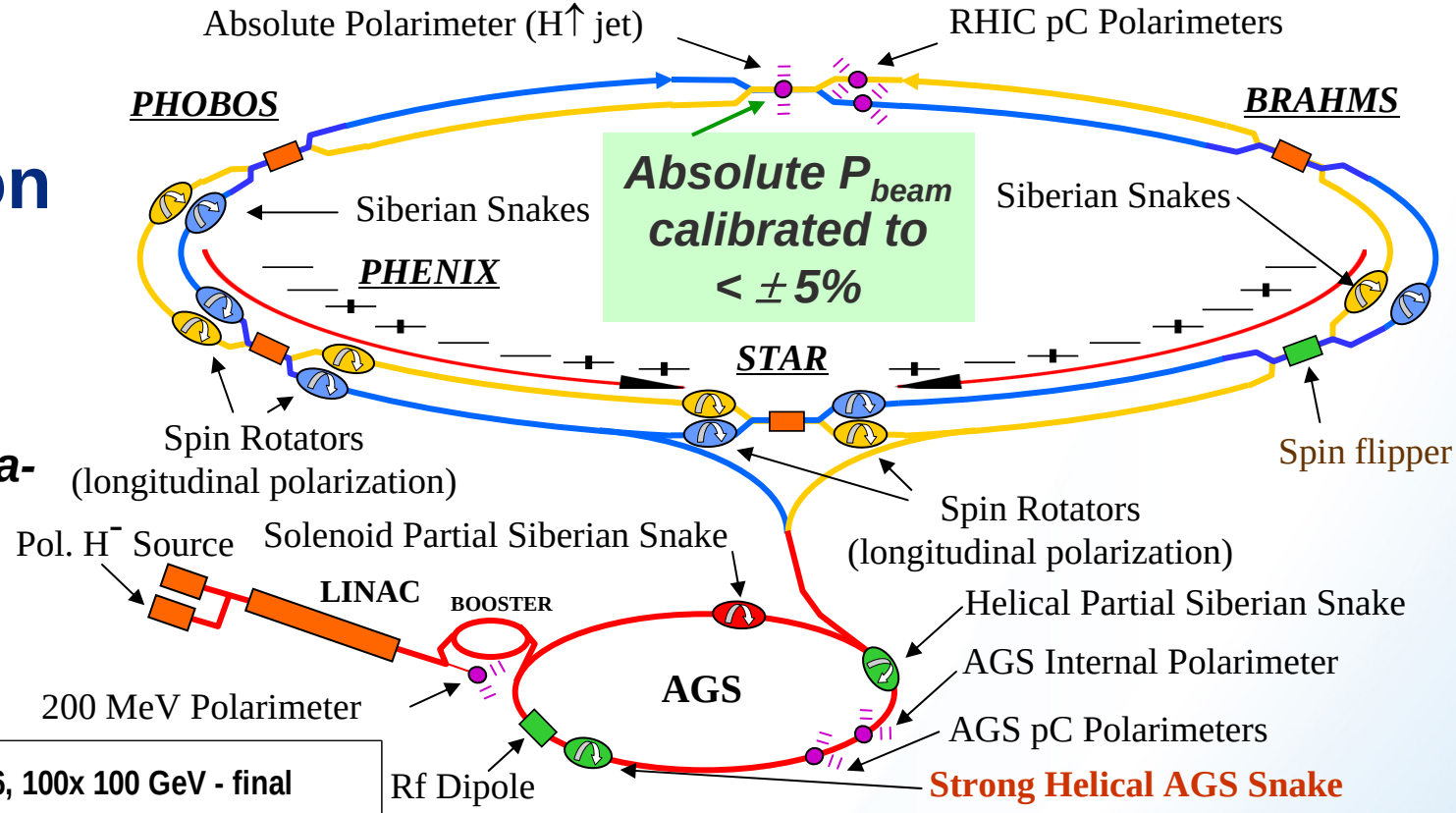


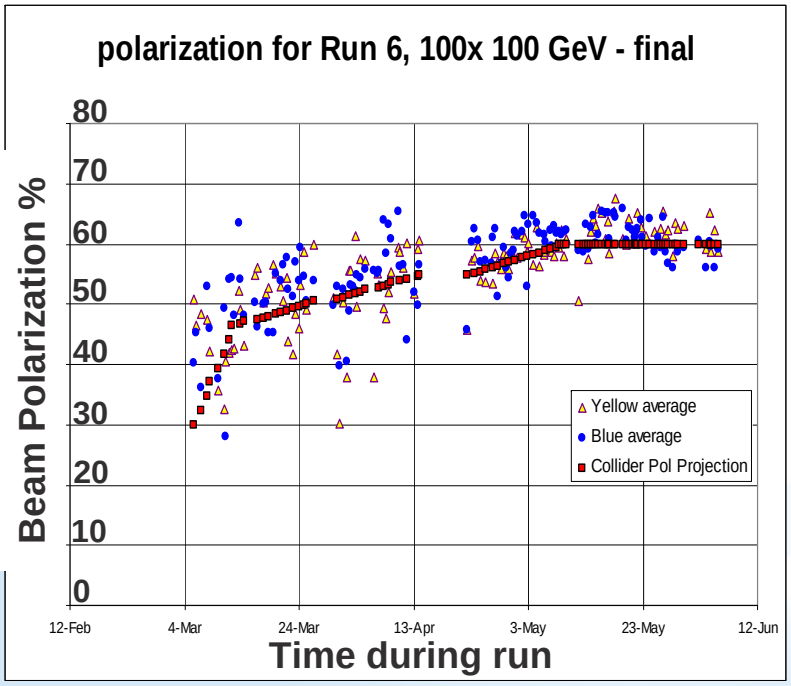


- ***Delivered luminosity each year has come close to maximum projected***
- ***Full energy Au+Au in 2007 already exceeded RHIC design goal luminosity***
- ***Another factor ~3 over 2006 L needed to reach enhanced pp design goal***
- ***d+Au completed in 2008 ⇒ x 10 over previous ∫L dt; short p+p run ⇒ small improvement over 2006 luminosity***

Improving Proton Polarization

Significant learning curve with unique & complex polarization-preserving equipment in AGS & RHIC

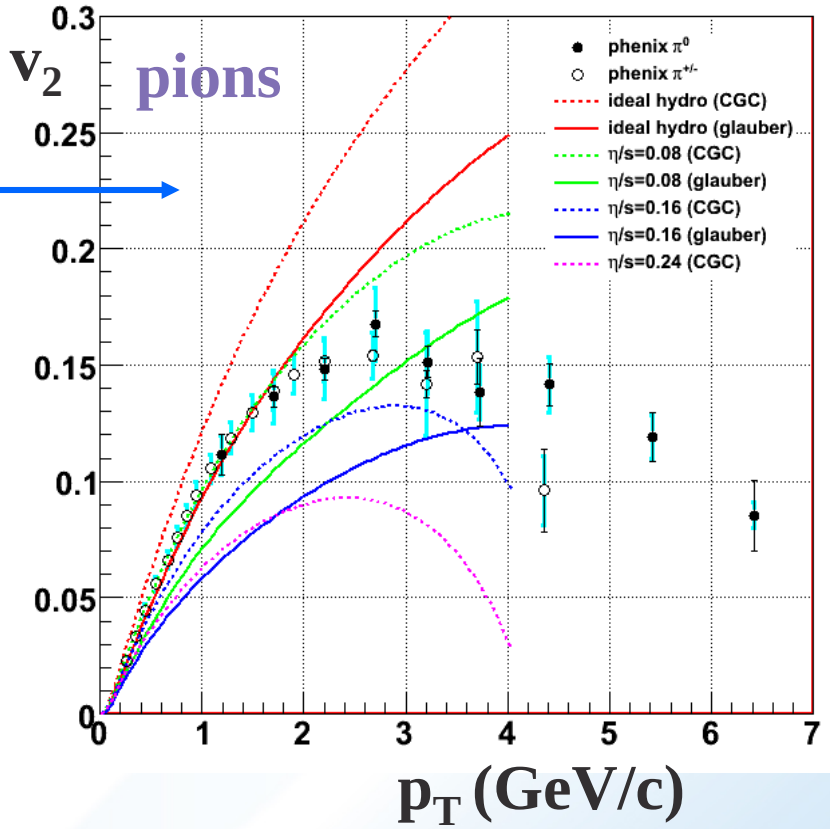


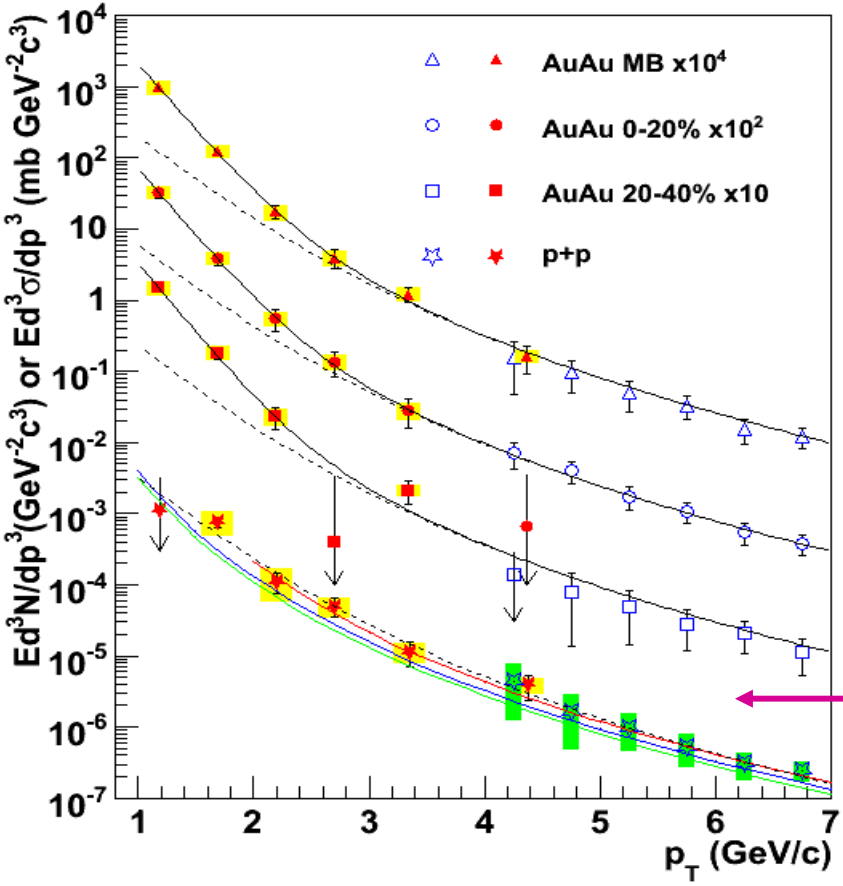


- ***60% beam polarization achieved reliably in 2006, compared to 70% goal***
- ***Some fallback in 2008 due to shortened run focused on unpolarized reference data***
- ***Absolute calibration of beam polarization to better than design goal accuracy achieved***
- ***Polarization survival to 250 GeV maximum energy demonstrated***

Recent RHIC Research Highlights: Beginning to Quantify Properties of the "Perfect" Liquid

1) *Comparisons of viscous hydro calcs. with RHIC elliptic flow data ⇒ shear viscosity to entropy density ratio ≲ 2 × conjectured (AdS/CFT) quantum lower bound*



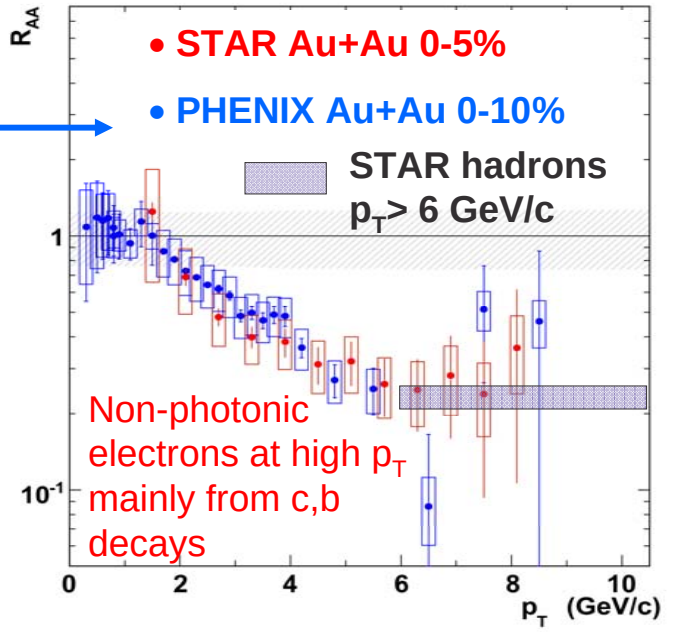


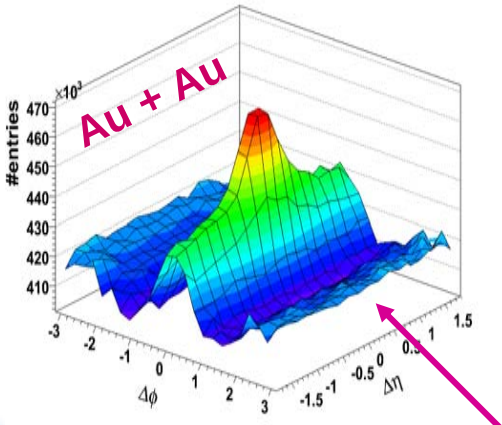
2) *Observed excess e^+e^- pairs at M_{ee} < 300 MeV, p_T = 1-4 GeV/c in Au+Au vis-à-vis p+p ⇒ direct thermal γ^* measure of early collision temp., consistent with hydro equilibration at ~2 x T_c^{LQCD}*

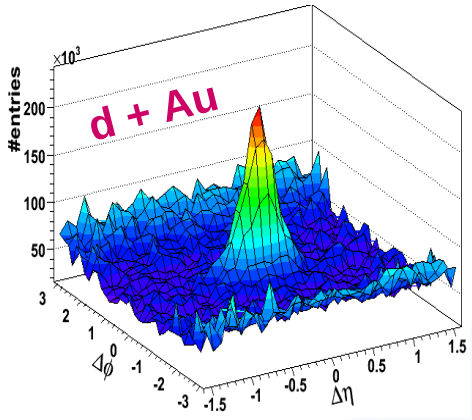
Recent RHIC Research Highlights: Medium Response to Hard Parton Passage

3) ~equal opacity for all high-p_T hadrons in central Au+Au suggests similar E loss for light quarks, heavy quarks and gluons, in marked contrast to pQCD predictions! Need to rethink basic mechanisms of quark/gluon interactions in dense colored matter?

STAR: PRL 98, 192301 (2007);
PHENIX: PRL 98, 172301 (2007)



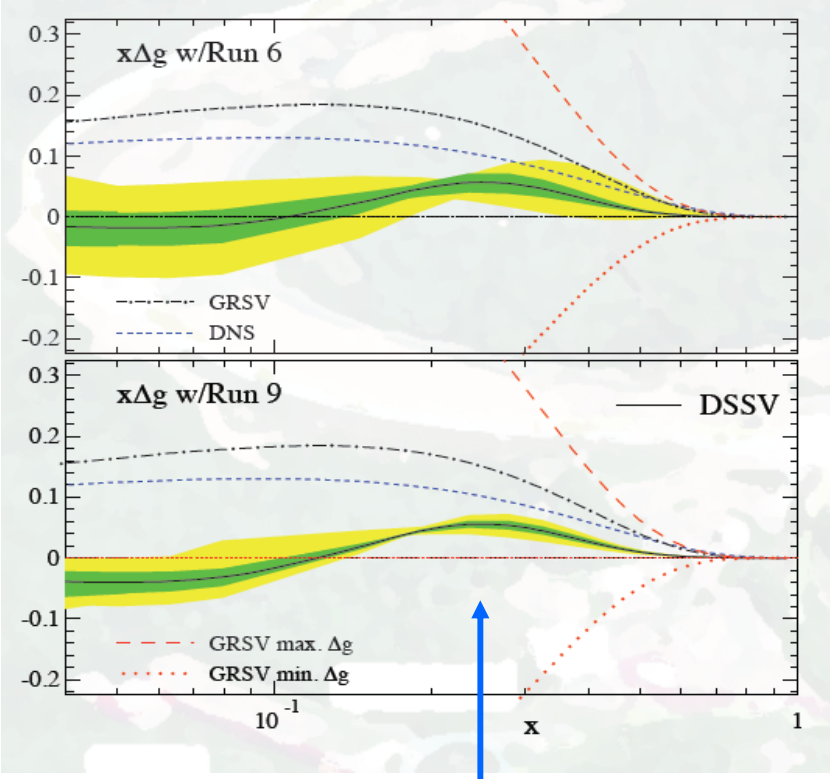


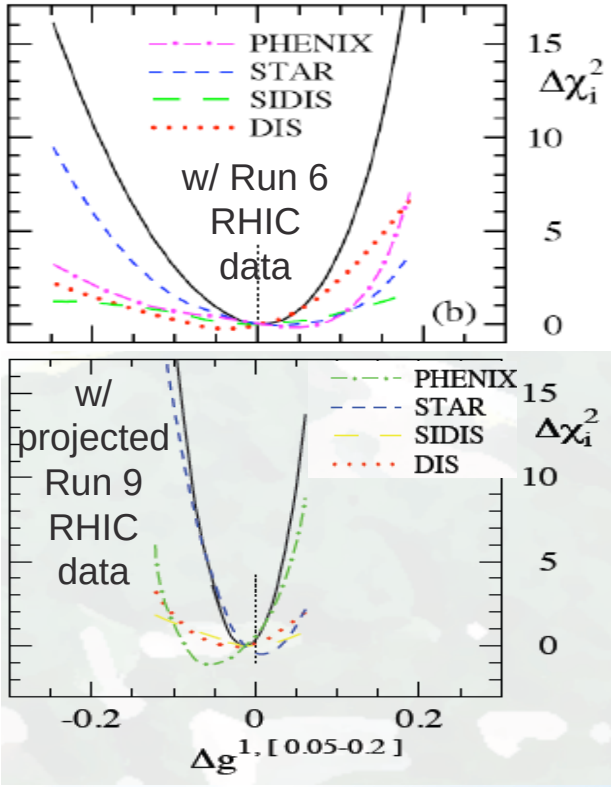


4) Hard-soft 2- and 3-hadron correlations reveal collective medium response:

Near-side "ridge": particles focused azimuthally around emerging jet, but spread along directions of emerging remnant nuclei;
Away-side conical emission: reminiscent of Mach cone, provides possible path to speed of sound in medium.

Recent RHIC Research Highlights: Constraining the Role of Gluons in Cold Nuclear Matter





5) *1st NLO pQCD analysis (de Florian, Sassot, Stratmann & Vogelsang, arXiv:0804.0422) incorporating RHIC spin inclusive jet and π^0 A_{LL} (2006) data ⇒ complementary constraints to DIS on shape & magnitude of gluon polarization; RHIC should dominate after Run 9*

6) *Run 8 d+Au hadron correlation results should definitively test CGC prediction of mono-jets from scattering on coherent low-x gluon field*

Take-Away Message #1

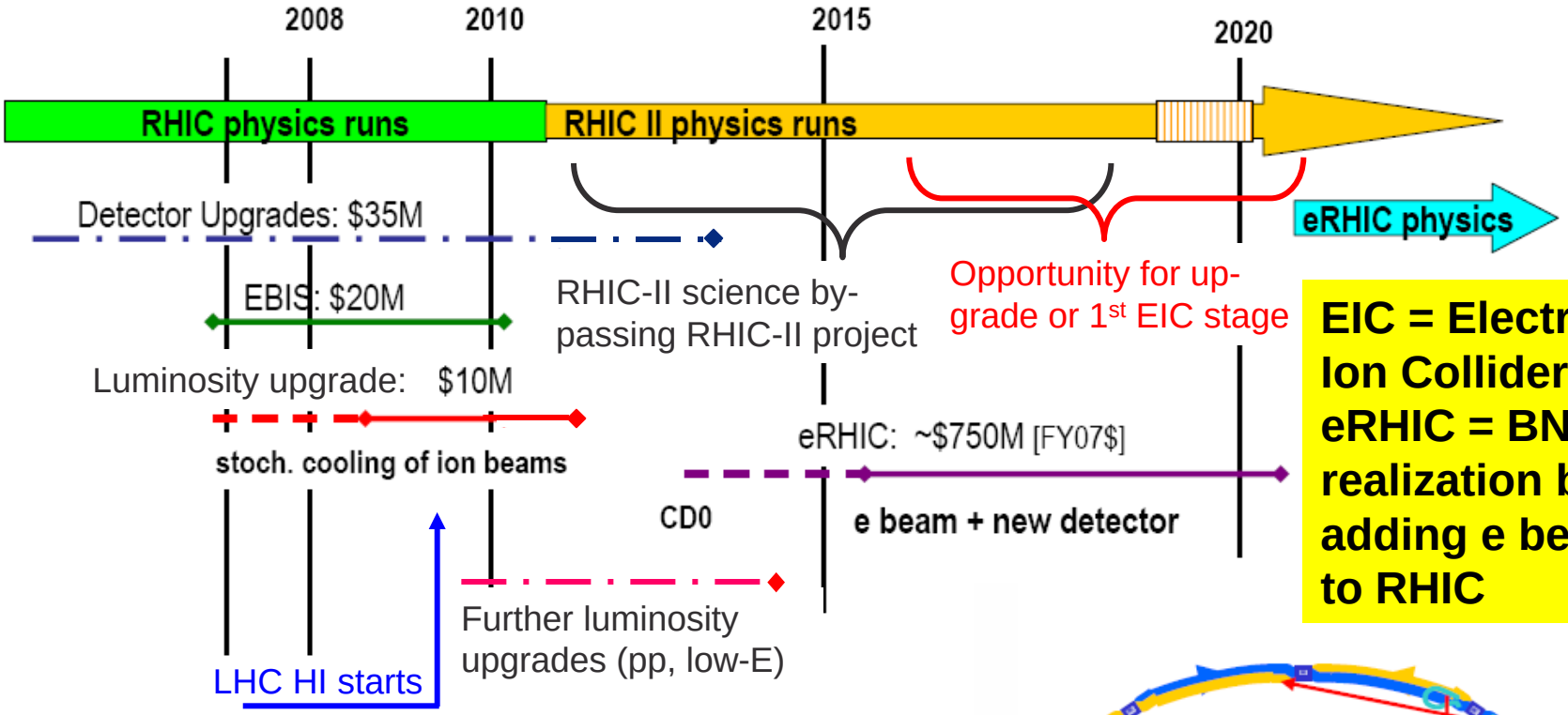
- Despite three successive runs shortened by federal budget problems, RHIC continues to make important progress toward fulfilling its scientific missions.
- However, repeated postponements associated with late budget action disrupt sensible planning, slow the science output and have a serious negative cumulative effect on user interest, patience and morale. Foreign investors in RHIC are particularly dismayed.

Plans for RHIC Run 9

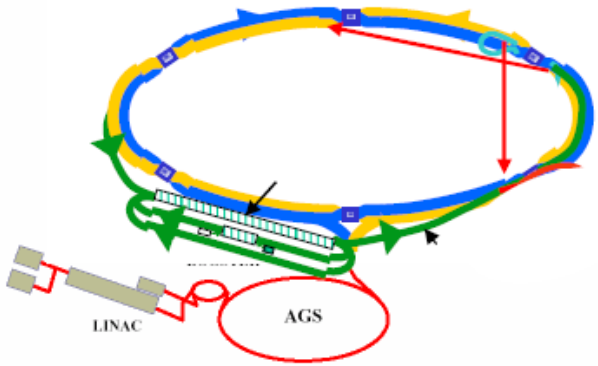
- ***Highest priority for both STAR and PHENIX for p+p: long run at 200 GeV to advance on $\Delta G(x)$, plus first results at 500 GeV***
- ***President's FY09 budget request would support ~28 cryo-weeks, given other recent developments: 1) $1.5M FY08 supplement; 2) 1-year extension of NYPA power contract for BNL; 3) increase in BNL fuel surcharge (2 and 3 ~ cancel!)***
- ***Running past June inefficient in power costs and reliability***
- ***With FY08 supplement, but in light of likely CR, we plan to:***

1) ***start cooldown in mid-February 2009, leading to cash flow problems under CR beginning about April 1;***
2) ***If receive at least half FY09P increment for 2nd 6 months, run through June 30, for 19 cryoweeks total, emphasizing 200 GeV;***
3) ***If CR >> 6 months, delay some other spending to squeeze out 8 cryoweeks, sufficient for minimal 500 GeV pp run;***
4) ***If FY09 budget outlook is promising early enough, try to start cooldown ~Feb. 1, to accommodate both 200 and 500 GeV pp.***

A Long Term (Evolving) Strategic View for RHIC



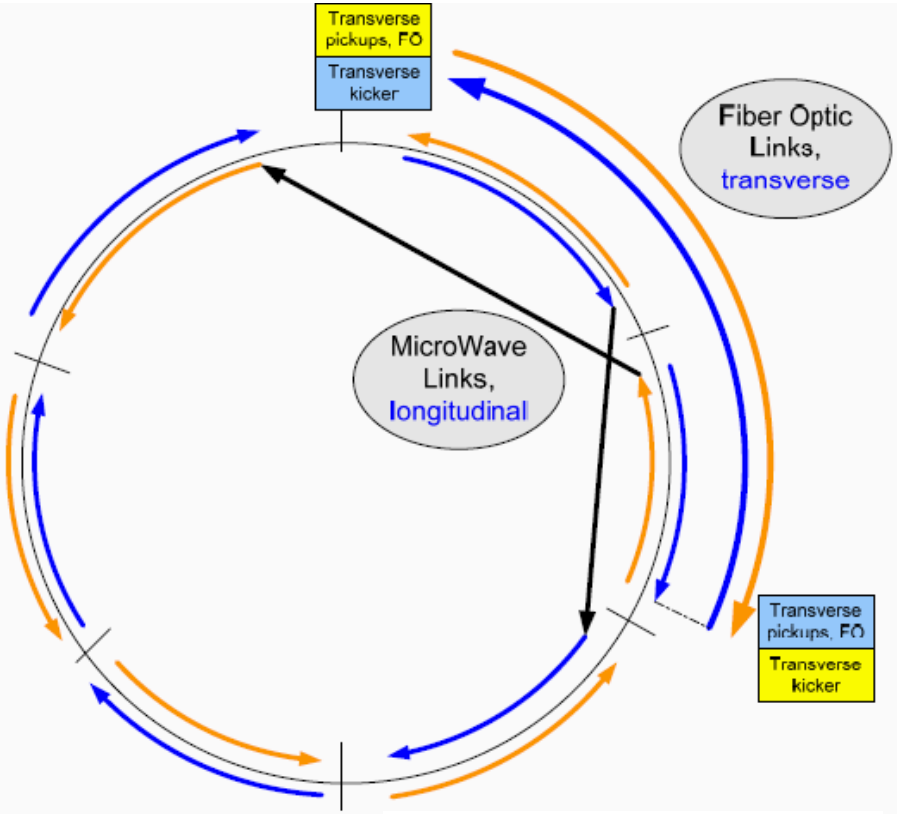
EIC = Electron-Ion Collider; eRHIC = BNL realization by adding e beam to RHIC

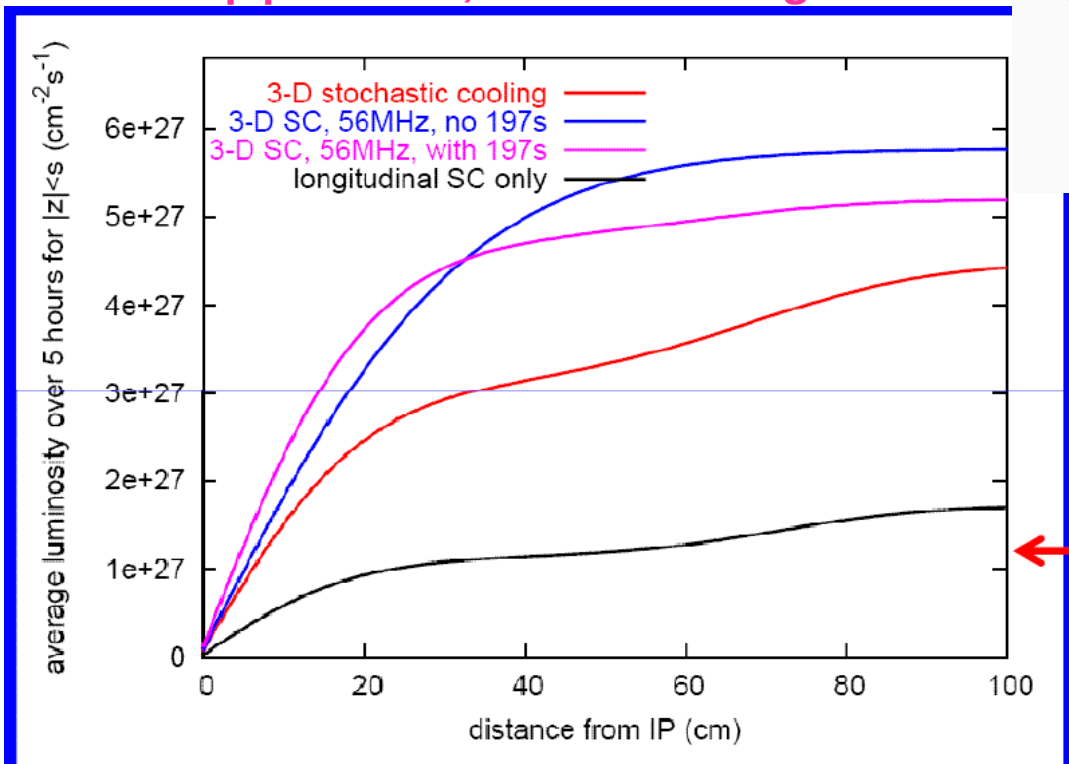


Stochastic Cooling Facilitates RHIC-II Science Without RHIC-II Project

- ***By 2012: 1 transverse cooling system per ring ⇒ rely on coupling between radial and vertical betatron tunes to transfer cooling to 2nd transverse plane***

- ***Anticipate gain factor ~ 6-8 in ∫L dt within |z| < 20 cm, vs. no cooling***





Achieved in Run-7

Yellow longitudinal stochastic cooling only.

Calculation by M. Blaskiewicz.

- ***56 MHz SRF reduces leakage to neighboring rf beam buckets***

- ***Combine 56 with present 197 MHz RF ⇒ tighten vertex distrib'n, as needed with short micro-vertex upgrades.***

Tentative RHIC Run Plan Following 2008 PAC Recommendations

(assumes 6-month FY09 CR, 2-species runs in FY10-14 & best info on detector upgrade schedules)

Fiscal Year	Colliding Beam Species/Energy	Comments
2009	200 GeV p+p	~12 physics weeks to complete 200 GeV A_{LL} measurements – could be swapped with 500 GeV Run 10 if >6-month FY09 CR likely; STAR DAQ1000 fully operational
2010	500 GeV p+p	~5-6 physics weeks to commission collisions, work on polarization & luminosity and obtain first W production signal to meet 2011 RIKEN milestone
	200 GeV Au+Au	9-10 physics weeks with PHENIX HBD, STAR DAQ1000 & TOF permits low-mass dilepton response map and 1st HI collision test of transverse stochastic cooling (one ring)
2011	Au+Au at assorted low E	1st energy scan for critical point search, using top-off mode for luminosity improvement – energies and focus signals to be decided; commission PHENIX VTX (at least prototype)
	200 GeV U+U	1st U+U run with EBIS, to increase energy density coverage
2012	500 GeV p+p	1st long 500 GeV p+p run, with PHENIX muon trigger and STAR FGT upgrades, to reach ~100 pb^{-1} recorded for substantial statistics on W production and ΔG measurements
	200 GeV Au+Au	Long run with full stochastic cooling, PHENIX VTX and prototype STAR HFT installed; focus on RHIC-II goals: heavy flavor, γ-jet, quarkonium, multi-particle correlations
2013	500 GeV p+p	Reach ~300 pb^{-1} to address 2013 DOE performance milestone on W production
	200 GeV Au+Au or 2nd low-E scan	To be determined from 1st low-E scan and 1st upgraded luminosity runs, progress on low-E e-cooling, and on installation of PHENIX FVTX and full STAR HFT
2014	200 GeV Au+Au or 2nd low-E scan	Run option not chosen for 2013 run – low-E scan addresses 2015 DOE milestone on critical point, full-E run addresses 2014 (γ-jet) and 2016 (identified heavy flavor) milestones. Proof of principle test of coherent electron cooling.
	200 GeV p+p	Address 2015 DOE performance milestone on transverse SSA for γ-jet; reference data with new detector subsystems; test e-lenses for p+p beam-beam tune spread reduction

Run Plan, Detector & Luminosity Upgrades Address All New RHIC-Related Performance Milestones

Year	#	Milestone
2013	HP8	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
2013	HP12 (update of HP1)	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.
2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering
2014	DM9 (new)	Perform calculations including viscous hydrodynamics to quantify, or place an upper limit on, the viscosity of the nearly perfect fluid discovered at RHIC.
2014	DM10 (new)	Measure jet and photon production and their correlations in A≈200 ion+ion collisions at energies from medium RHIC energies to the highest achievable energies at LHC.
2015	DM11 (new)	Measure bulk properties, particle spectra, correlations and fluctuations in Au + Au collisions at √sNN between 5 and 60 GeV to search for evidence of a critical point in the QCD matter phase diagram.
2016	DM12 (new)	Measure production rates, high pT spectra, and correlations in heavy-ion collisions at √sNN = 200 GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma.
2018	DM13 (new)	Measure real and virtual thermal photon production in p + p, d + Au and Au + Au collisions at energies up to √sNN = 200 GeV.

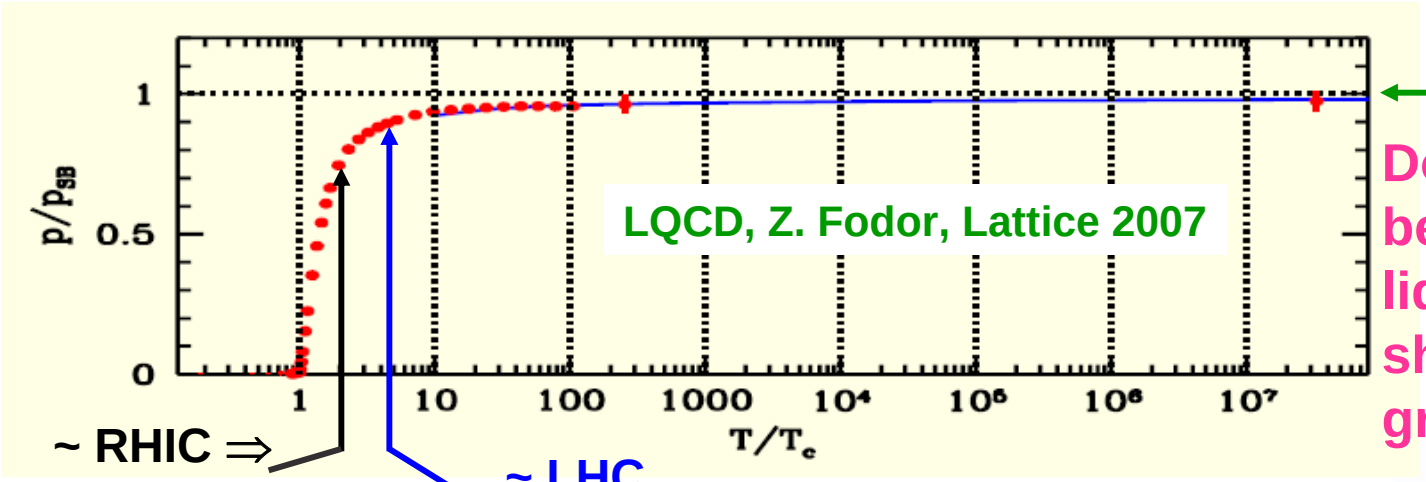
N.B. Some will be missed if budgets do not permit 2 species/year runs in FY10-14

Take-Away Message #2

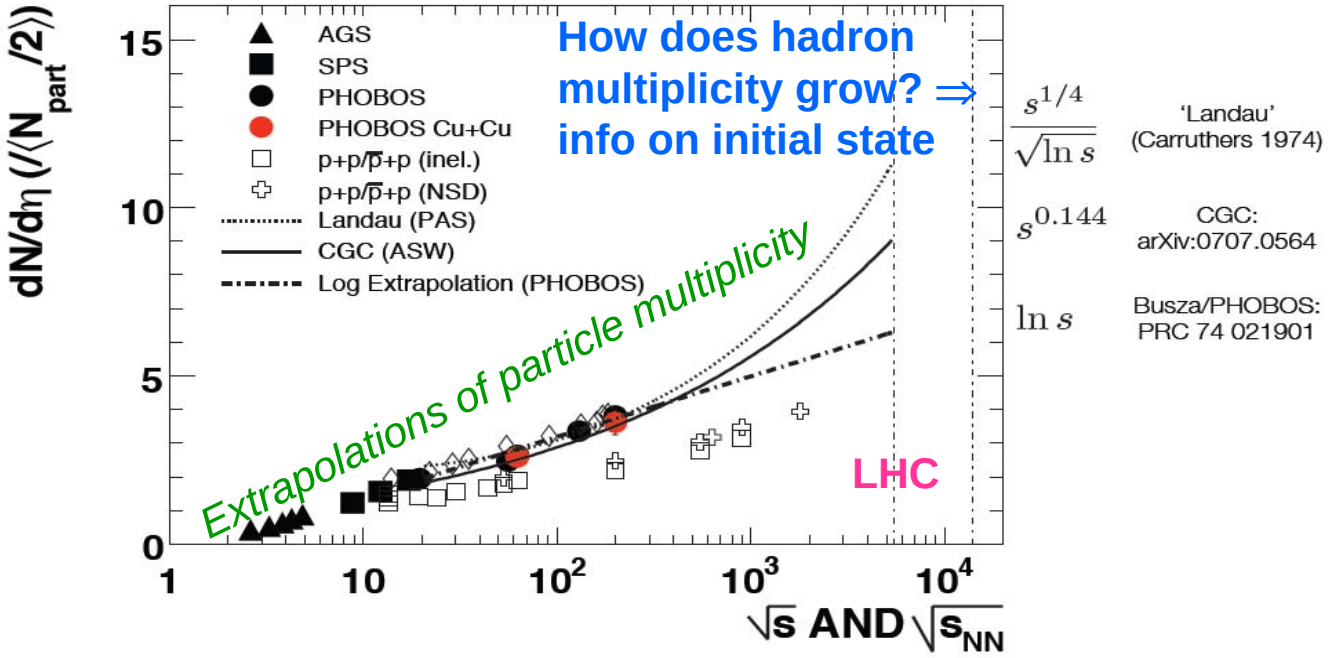
- We are developing detailed strategic planning to optimize the impact of RHIC results during period when LHC HI starts. RHIC's versatility, creative accelerator physicists, aggressive detector upgrade plans are critical to the success of this plan, as are budgets sufficient to run two beam species per year.
- RHIC will focus on systematic measurements to enhance understanding and discovery potential: quantifying properties of perfect liquid; searching for QCD critical point; improving constraints on polarization of gluons and sea antiquarks in a polarized proton.
- The plan accommodates a 6-month CR in FY09, but would be impacted by a much longer CR.
- RHIC-II science continues well beyond 6-year run plan shown, fueled by further possible luminosity improvements from stochastic cooling upgrades (HI) and electron lenses (pp).

Backup Slides

Where Do Heavy-Ion Collisions at LHC Fit In?



Does matter still behave as an ideal liquid, or does shear viscosity grow from RHIC?



Some pump/probe tools get sharper at LHC -- *e.g., full jet reconstruction/ resolution* -- but effects of interest *(parton E loss)* may be small or vanishing perturbations: *LHC is exploratory.*

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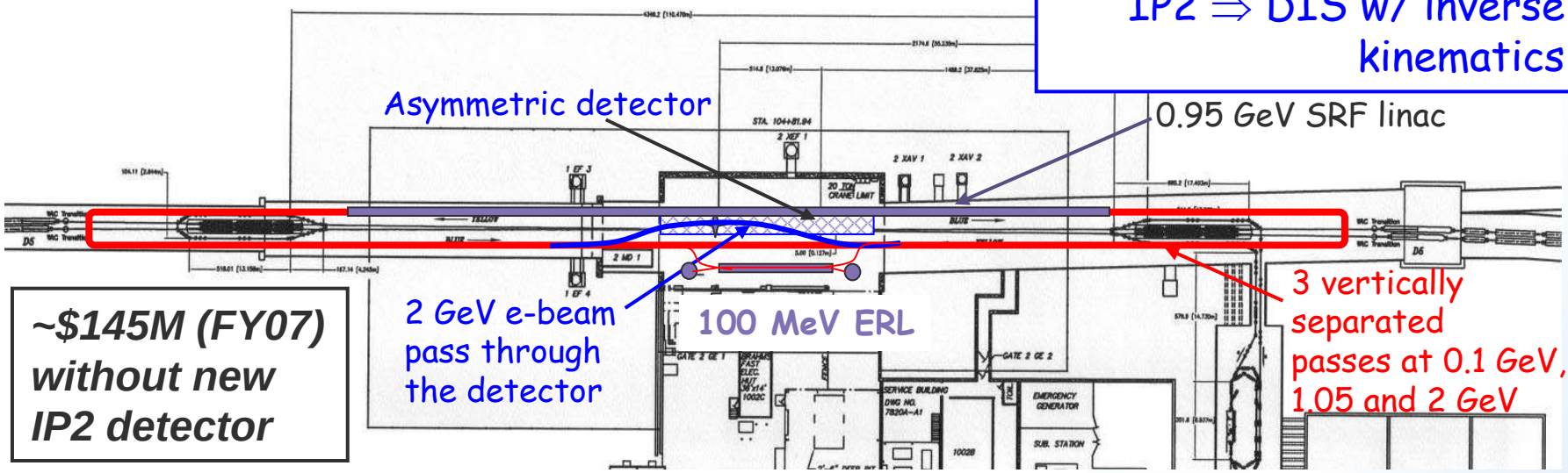
Intermediate-Term Possibilities: 1st (Medium Energy) Stage of EIC?

MEIC with 2 GeV ERL @ IP2 ⇒ DIS w/ inverse kinematics

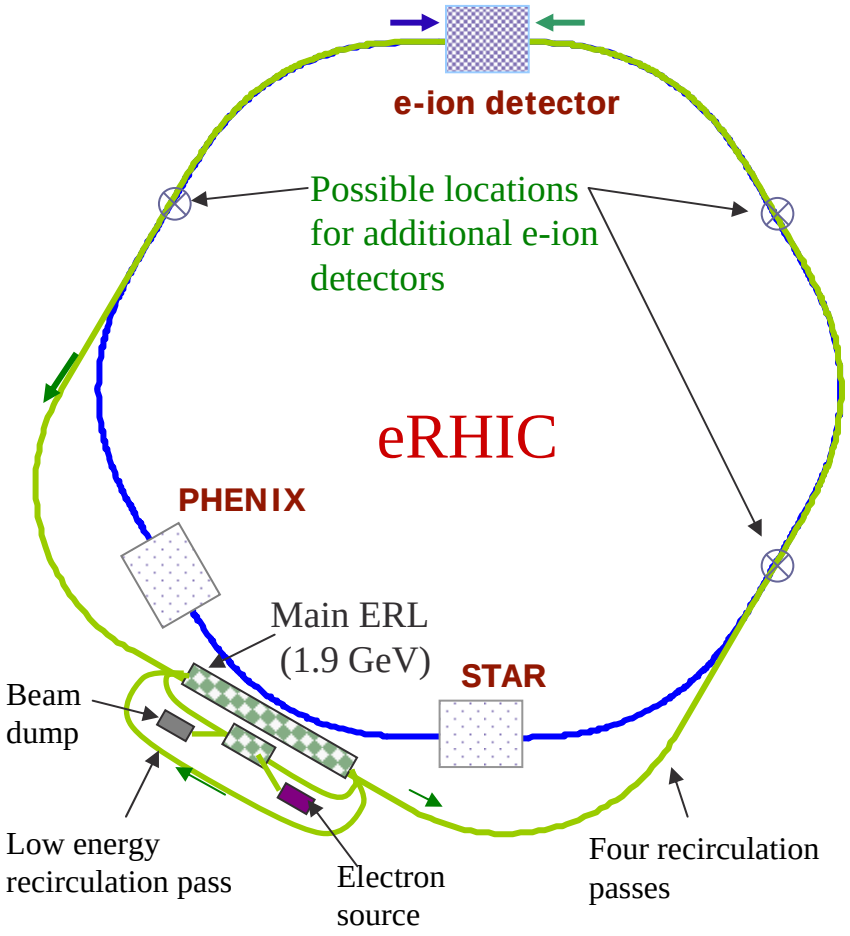


~$145M (FY07) without new IP2 detector

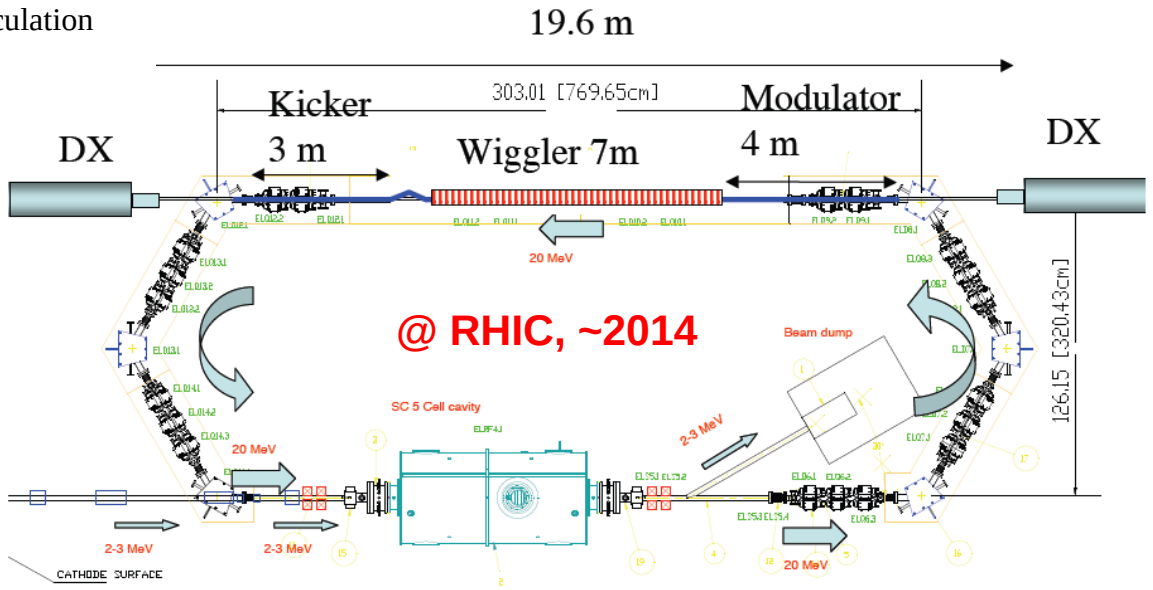
- ***Would enable 2 GeV $\vec{e}$ on 100 GeV/N heavy ions and 250 GeV $\vec{p}$***
- ***First look at saturation surface for nuclei, emphasizing diffraction tests of high gluon occupancy***
- ***e-p program emphasizing detection of target fragments to probe spin-dependent correlations in proton internal wave function***
- ***Need $\mathcal{L} \sim 10^{33}$ cm^{-2}s^{-1} to be competitive? Develop science case.***
- ***Most equipment would be reused later in full EIC***

Planning for the Full EIC

- ***Considering various layouts & staging scenarios (V. Litvinenko)***
- ***Reuse most equipment from medium-energy stage***
- ***Keep A+A and p+p options alive***
- ***Reduce demand on I(pol'd e) via coherent e-cooling of ion beams***

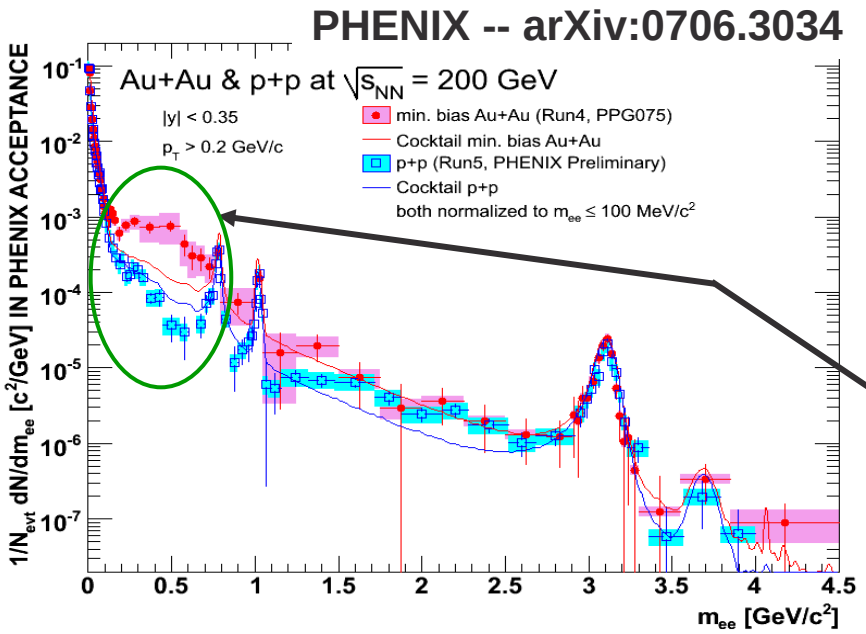


IR-2 layout for Coherent Electron Cooling proof-of-principle experiment



- ***Subsequent stages/ alternative layouts could increase e-beam & ion-beam energies and L from nominal 10 × 250 GeV, ~4 × 10^{33} $cm^{-2}s^{-1}$ e+p***

Recent RHIC Research Highlights IV: Signatures for Transformation of the Vacuum ?



The nature of the QCD vacuum itself can be altered at high temp.

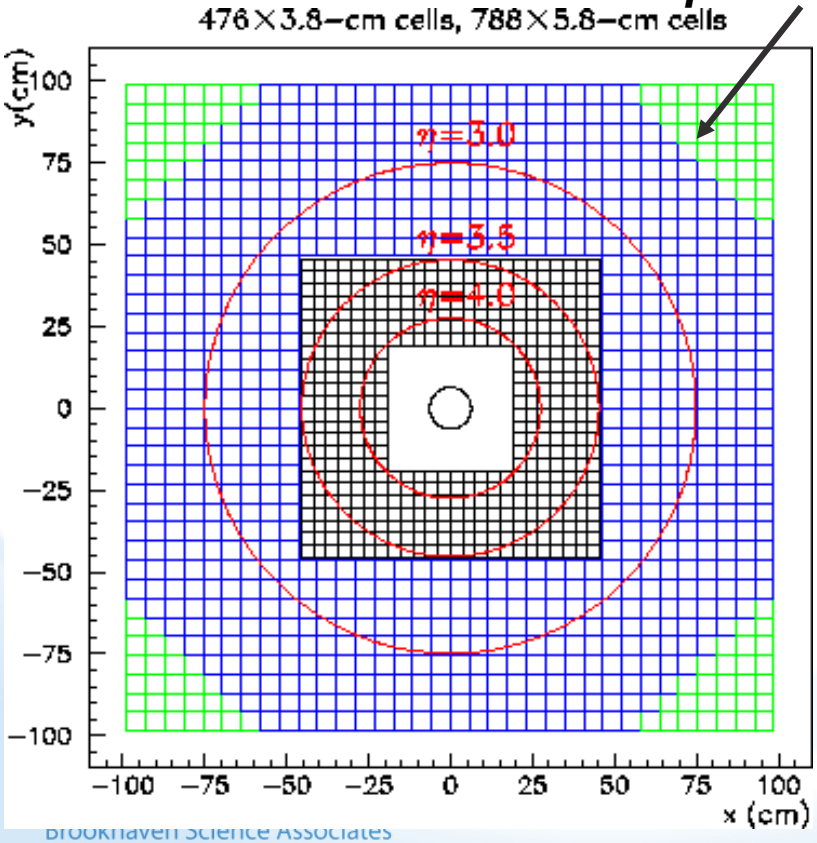
Restoration of chiral symmetry -- spontaneously broken at low temp. -- is predicted.

Does low-mass (low-p_T) dilepton surplus seen by PHENIX (and at SPS) signal chiral restoration via modified ρ - response?

CP-symmetry, conserved at low temperature, may be spontaneously broken at high temp. Are there correlated CP-even signals for CP violation that changes sign from event to event? STAR sees EDM-like charge correlations $\perp$ reaction plane, but more mundane interpretations are not ruled out.

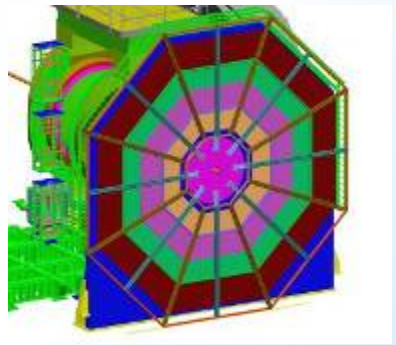
Detector Upgrades in Progress

- ***Both STAR and PHENIX upgrading DAQ/trigger to handle higher data rates, select rarer probes with upgraded luminosity***
- ***PHENIX specifically upgrading muon trigger for W production program***
- ***STAR Forward Meson Spectrometer detects photons at large rapidity to probe gluon saturation effects in d+Au, spin effects for forward π^0 and γ, …***
- ***STAR Time-of-Flight MRPC detector enhances particle ID, especially useful for QCD critical point search***

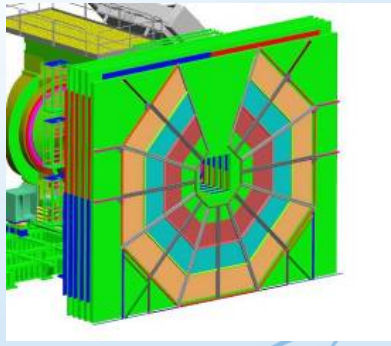


MuTrig Station 1

MuTrig Station 2



MuTrig Station 3



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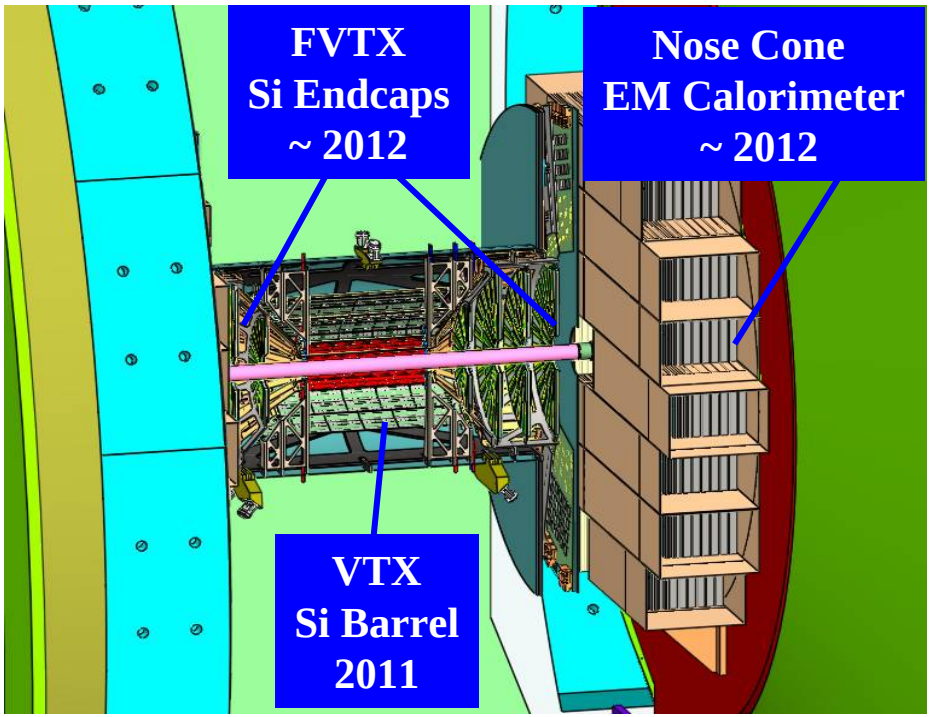
Ongoing Detector Upgrades are Critical to RHIC and RHIC-II Science Program

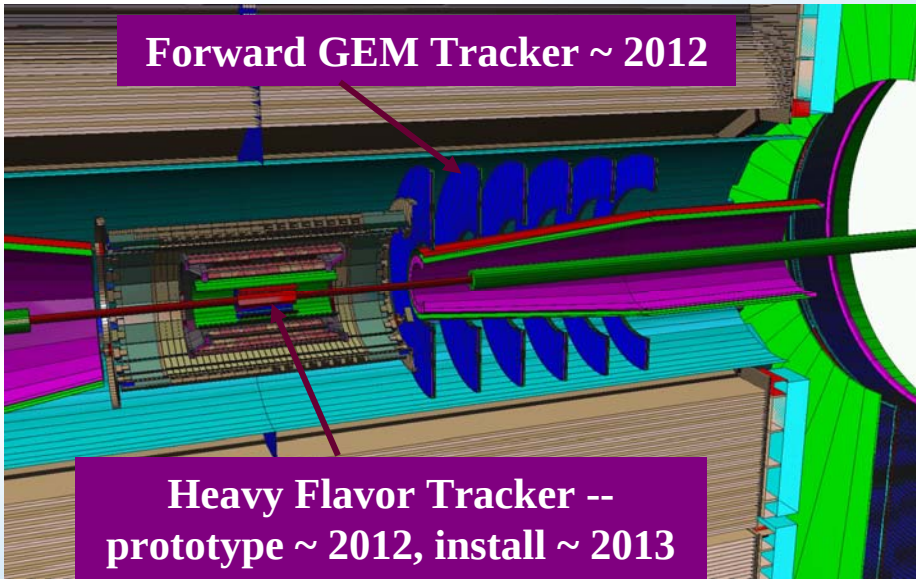


~1-2 new subsystems/year in PHENIX & STAR have immediate physics payoff: e.g., low-mass dileptons; CGC tests; W production triggering and cleanliness; heavy flavor physics; γ - jet acceptance …

See Jacak, Xu, Ludlam and O'Brien talks for details.

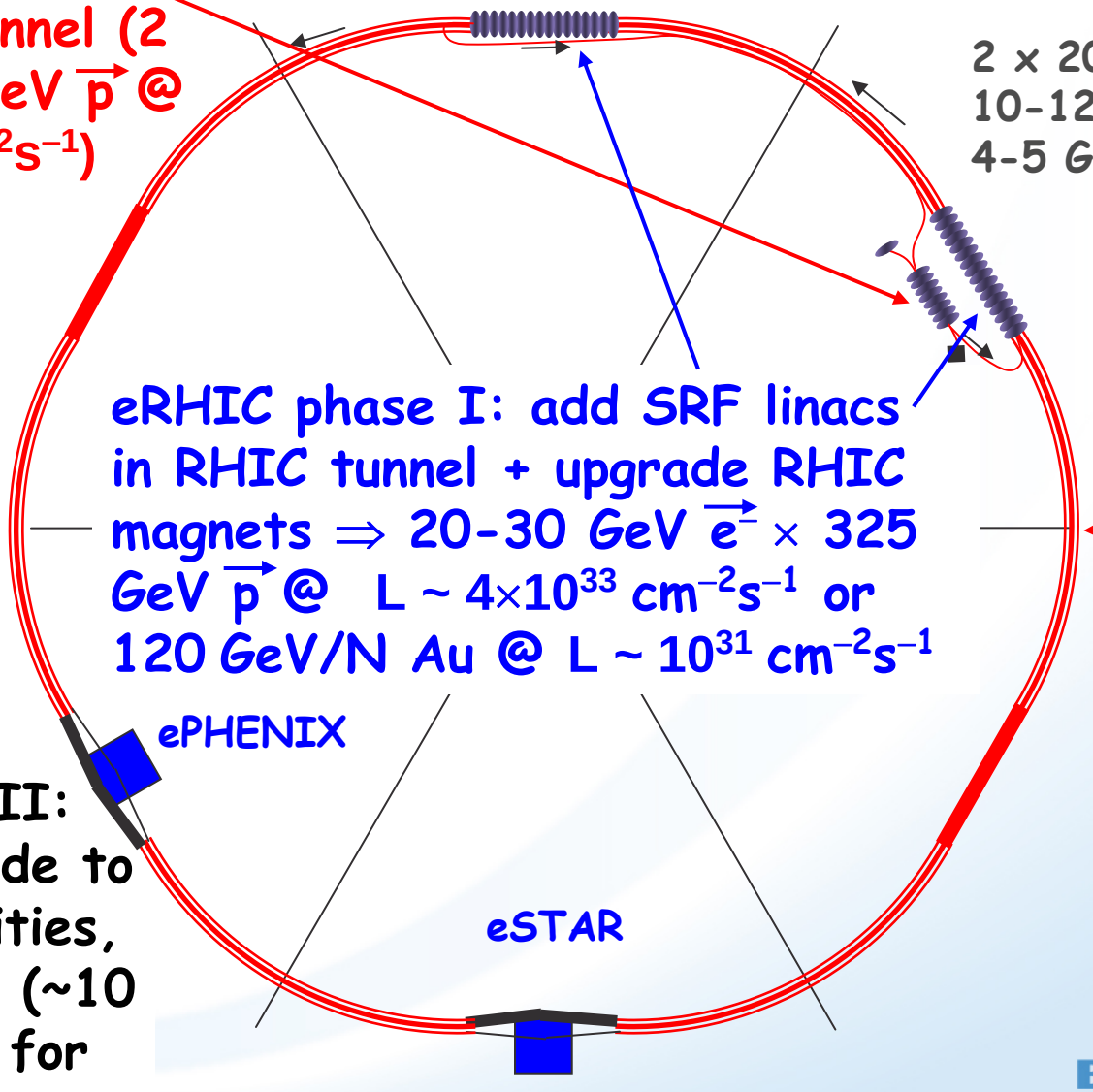
Ongoing suite of upgrades should be completed ~2013-14.

Closer BNL supervision & consulting on project management issues needed to smooth recent glitches (see O'Brien).



Possible EIC Staging (as per V. Litvinenko)

MEIC - RHIC + ERL inside RHIC tunnel (2 GeV $\vec{e}^-$ × 250 GeV $\vec{p}$ @ L ~ 10^{32} $cm^{-2}s^{-1}$)



eRHIC phase II: Luminosity upgrade to ~10^{35} (crab cavities, etc.) at reduced (~10 GeV e) energy for exclusive reactions

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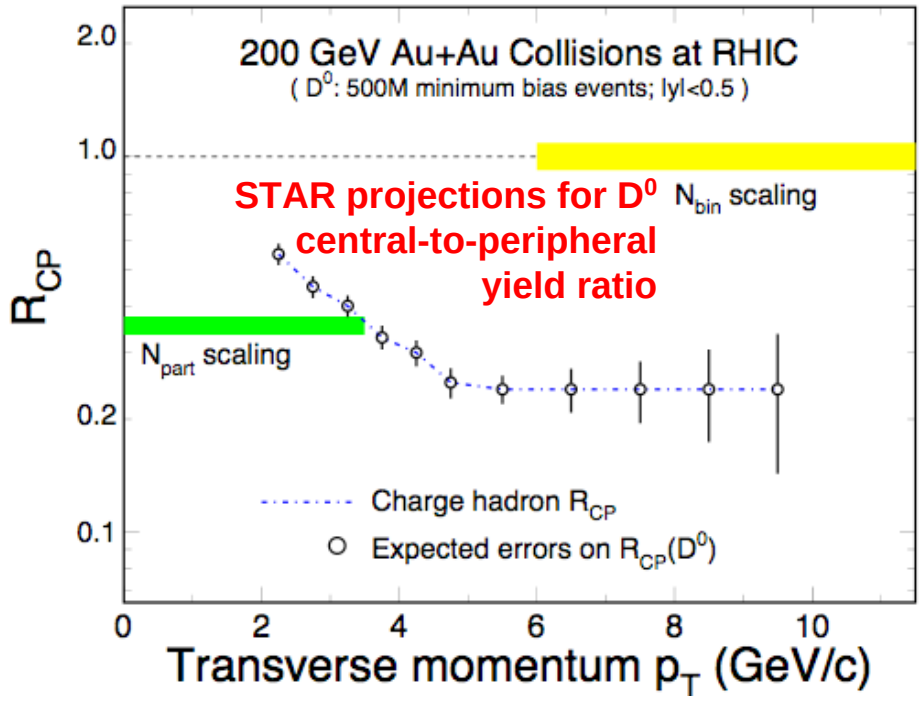
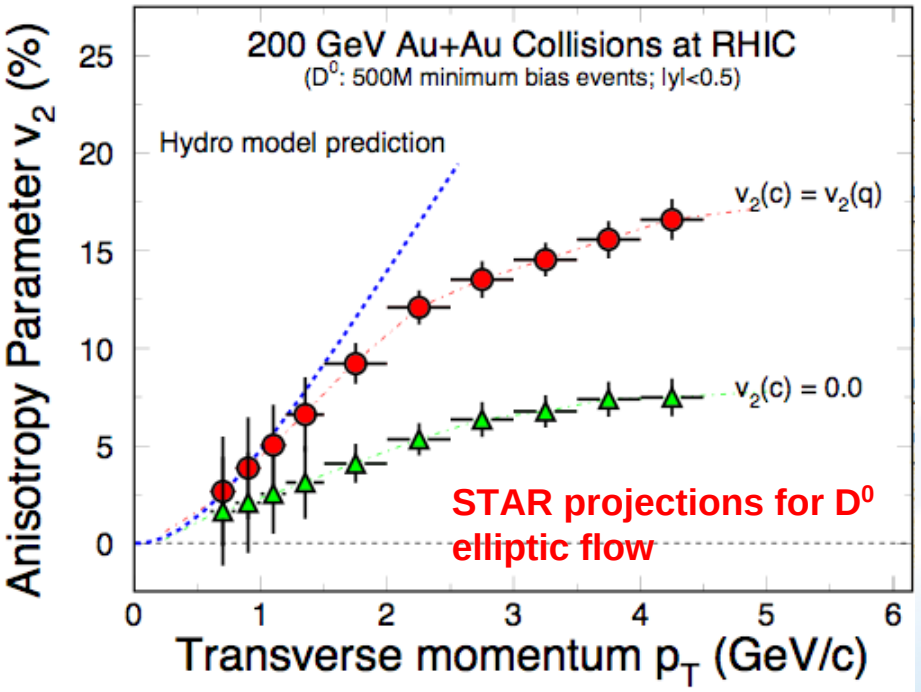
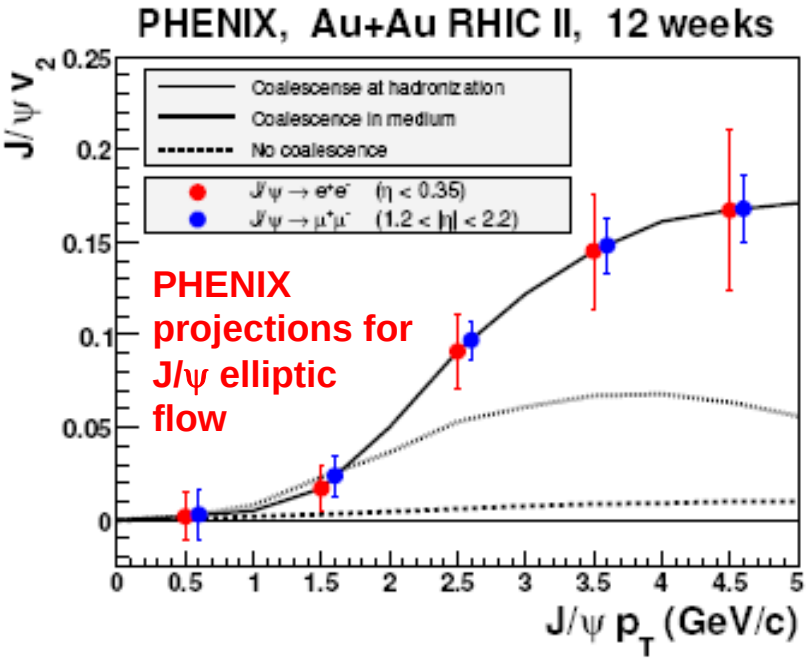
Detector & Luminosity Upgrades ⇒ New Physics Milestones





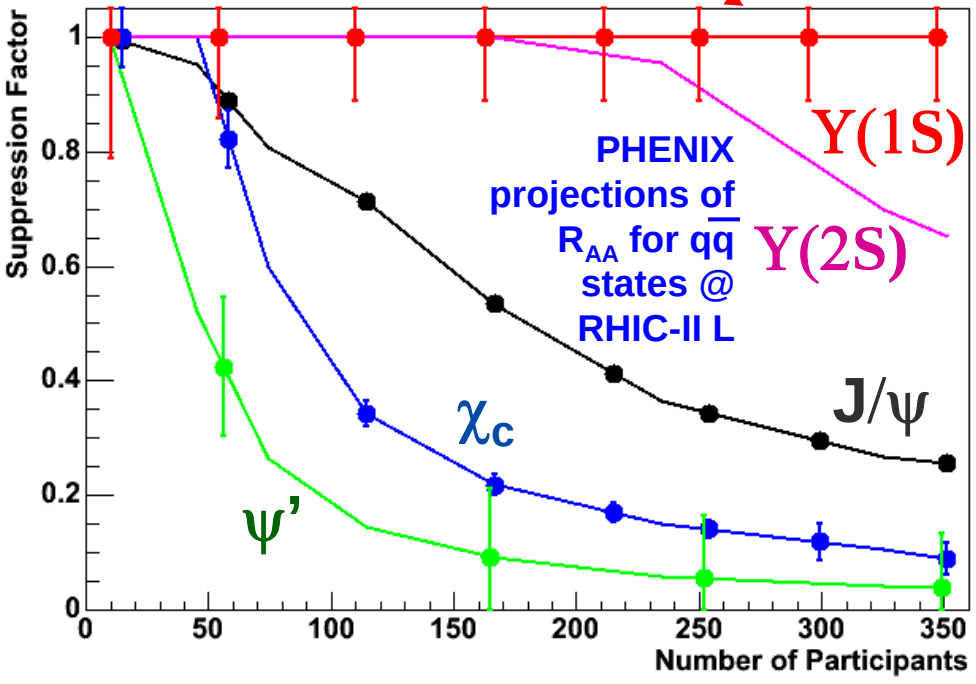
Measure hadron suppression and flow for identified heavy-quark mesons, possibly baryons (Λ_c)



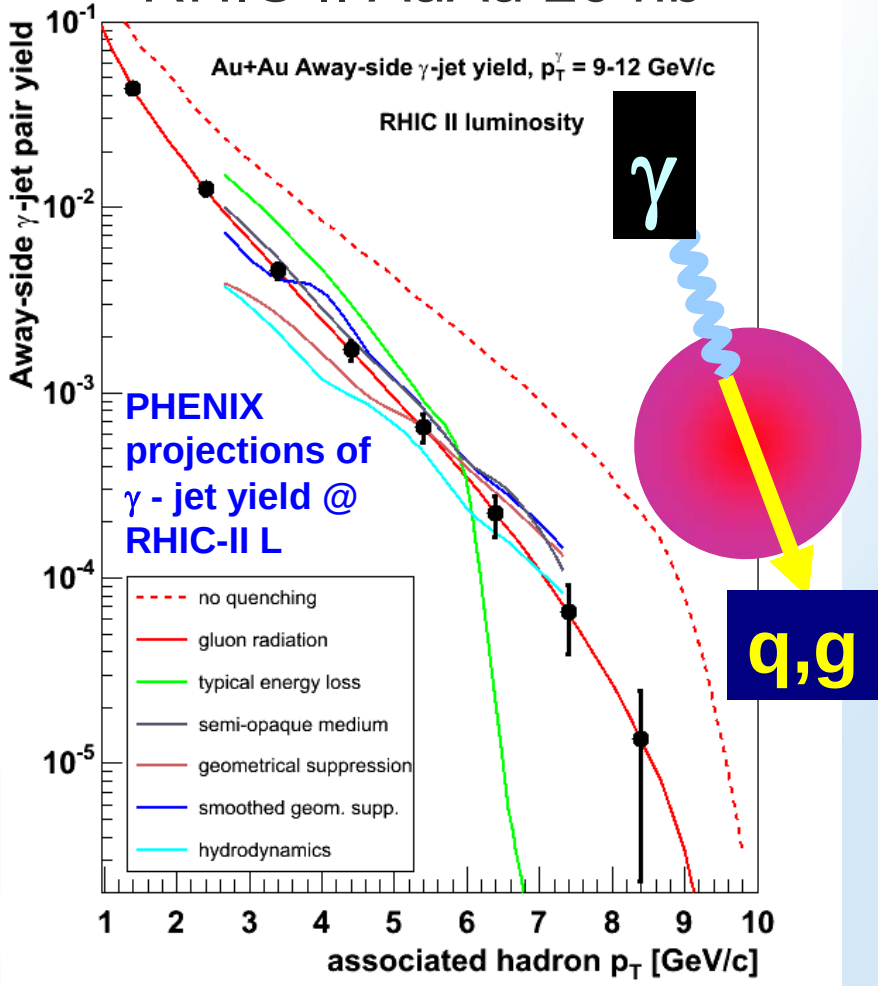
Addresses new 2016 NP milestone (DM12) covering "identified hadrons with heavy-flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma"

Detector & Luminosity Upgrades ⇒ New Physics Milestones

- ***Calibration of light-quark energy loss via γ - tagging (DM10, 2014)***
- ***Definitive map of quarkonium melting, to search for effects of deconfinement and probe the (heavy) quark-quark interaction in the medium***



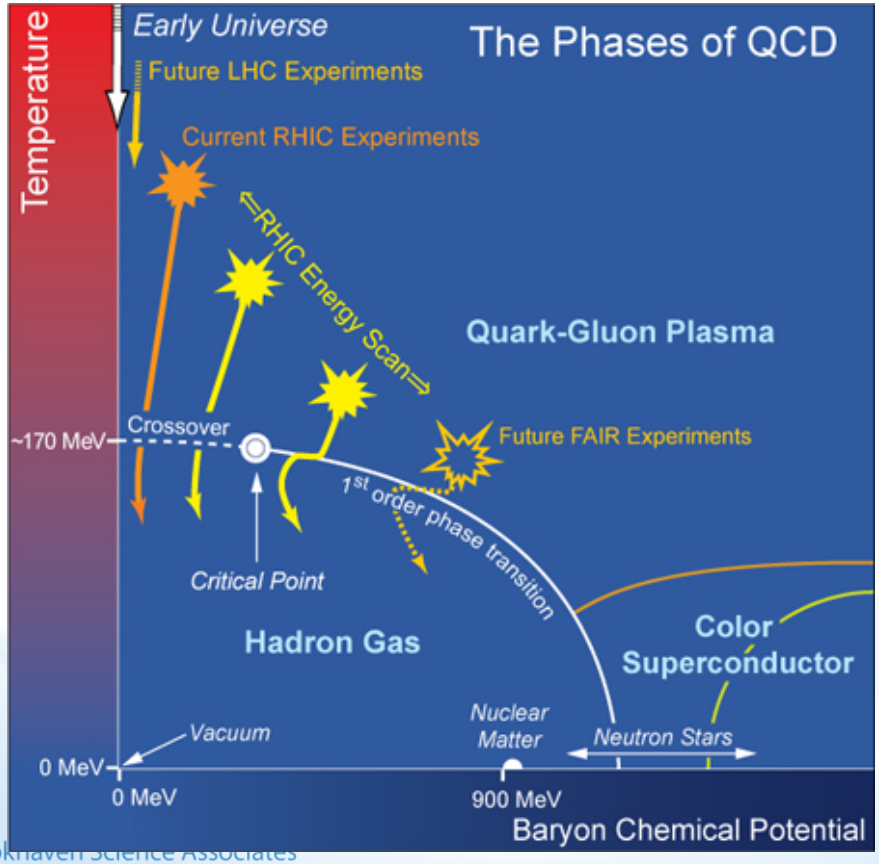
RHIC II AuAu 20 nb^{-1}



RHIC-II Science: Quantifying Properties of the Perfect Liquid

II. Facilitate rare- and multi-particle correlation measurements: γ + jet to quantify energy loss transport coefficient; multi-hadron to study possible Mach cone, extract speed of sound.

III. Improve exp't-theory comparison of particle-identified (esp. heavy quark) flow, to quantify shear viscosity.

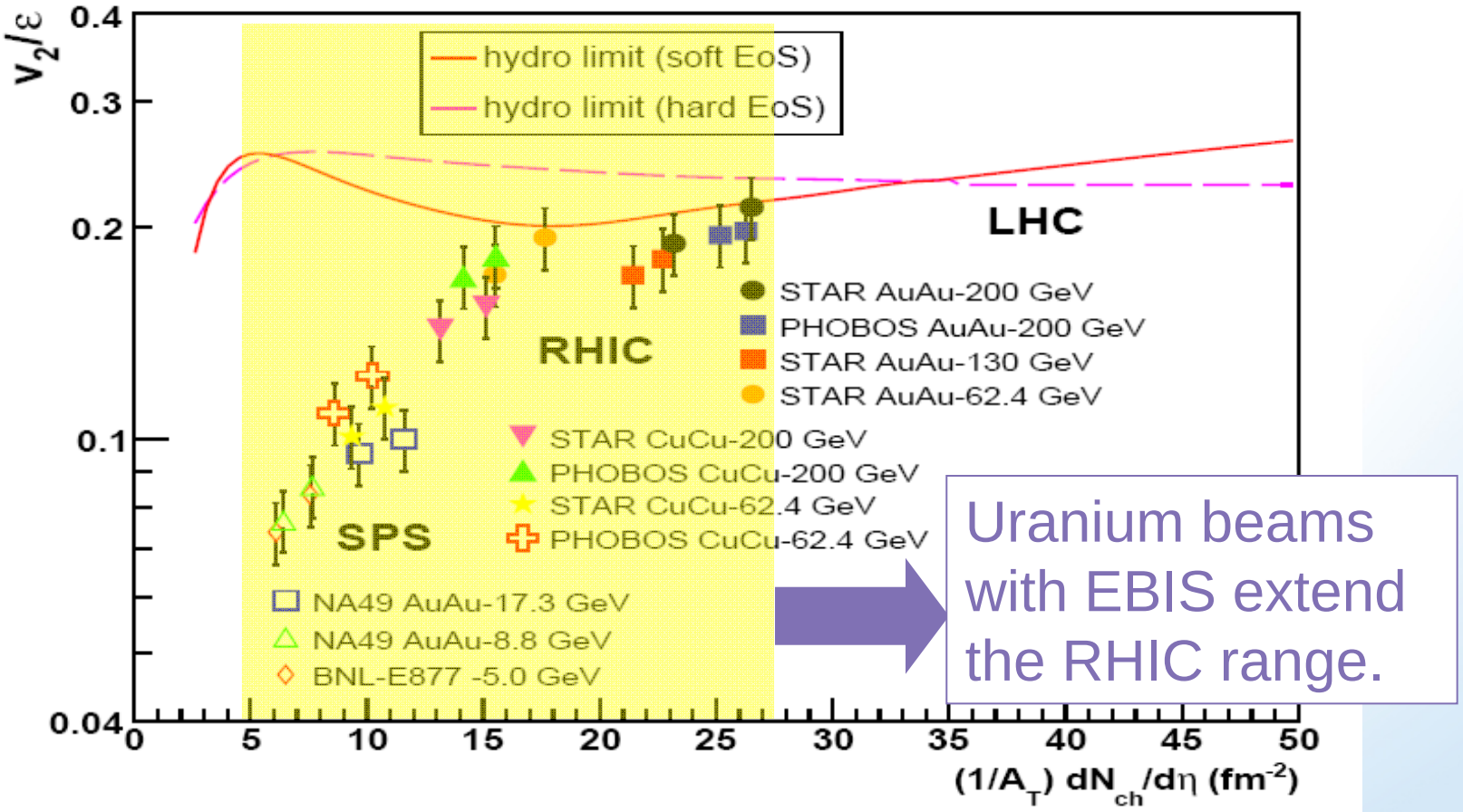


IV. Improve fluctuation measurements at low collision E to search for QCD critical point.

LHC and RHIC-II HI results should be complementary & mutually stimulating: similar matter produced? How do properties evolve? Thermalization consistent?

Quantitative interpretation of both requires coherent theory assault!

One Example



Uranium beams with EBIS extend the RHIC range.