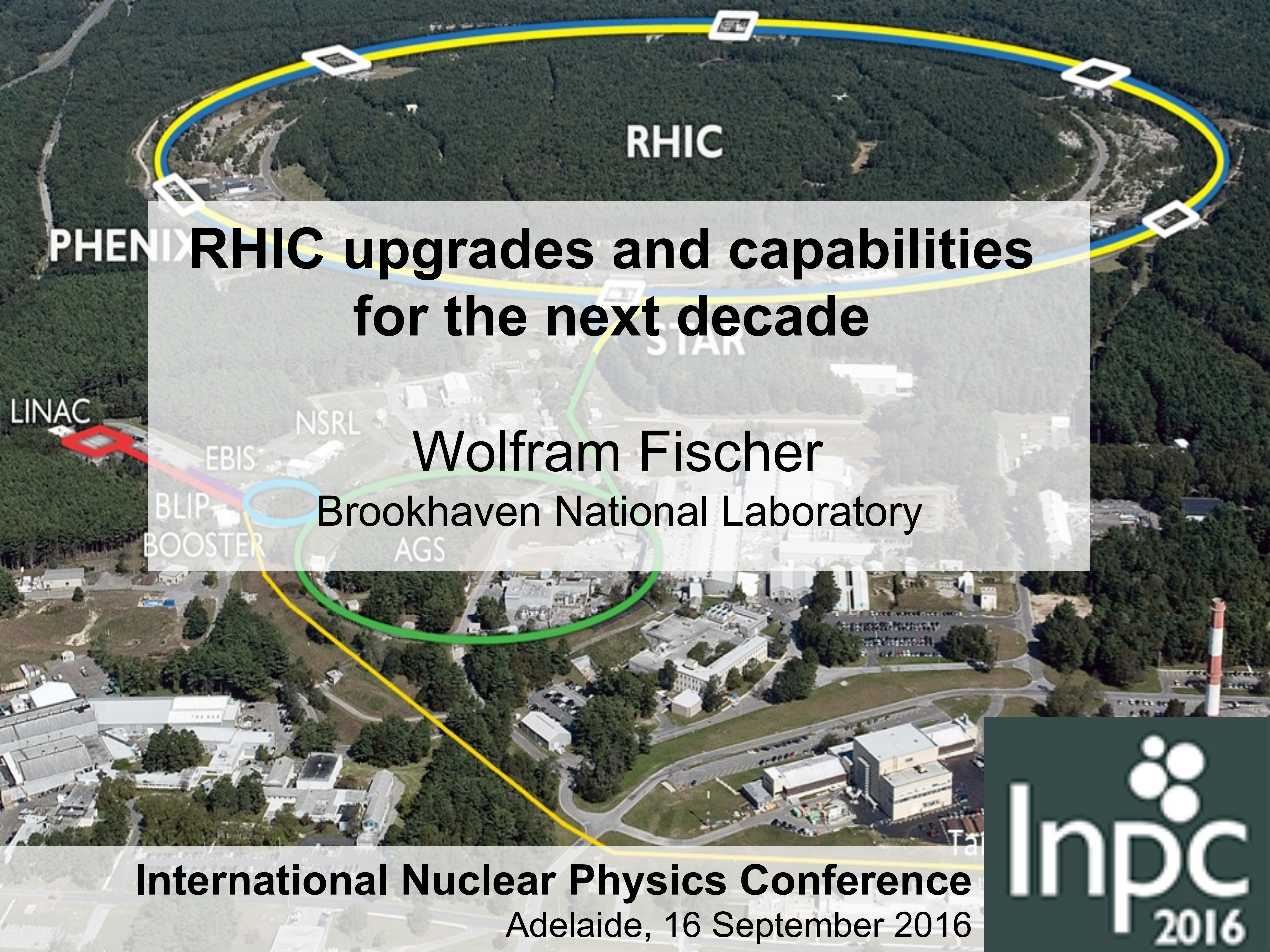
RHIC upgrades and capabilities for the next decade

Wolfram Fischer

Brookhaven National Laboratory



International Nuclear Physics Conference

Adelaide, 16 September 2016

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   species, energies, luminosity, polarization
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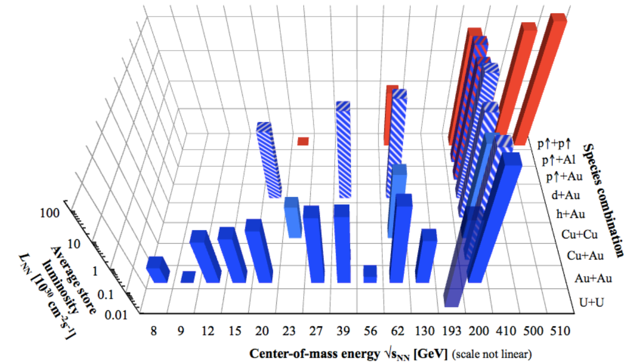
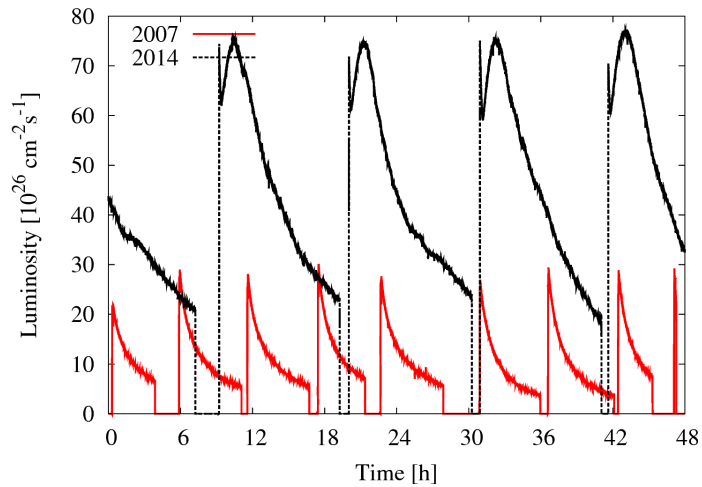
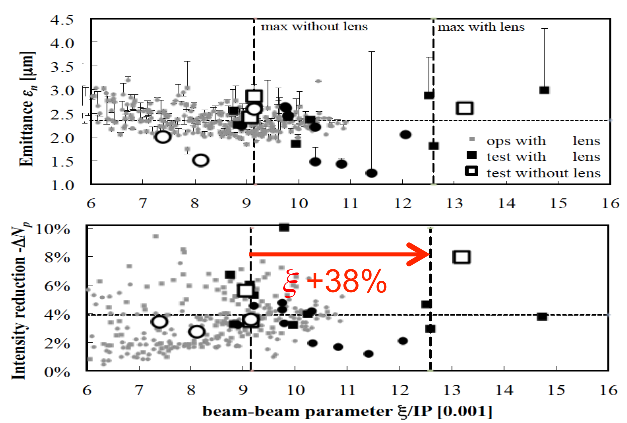
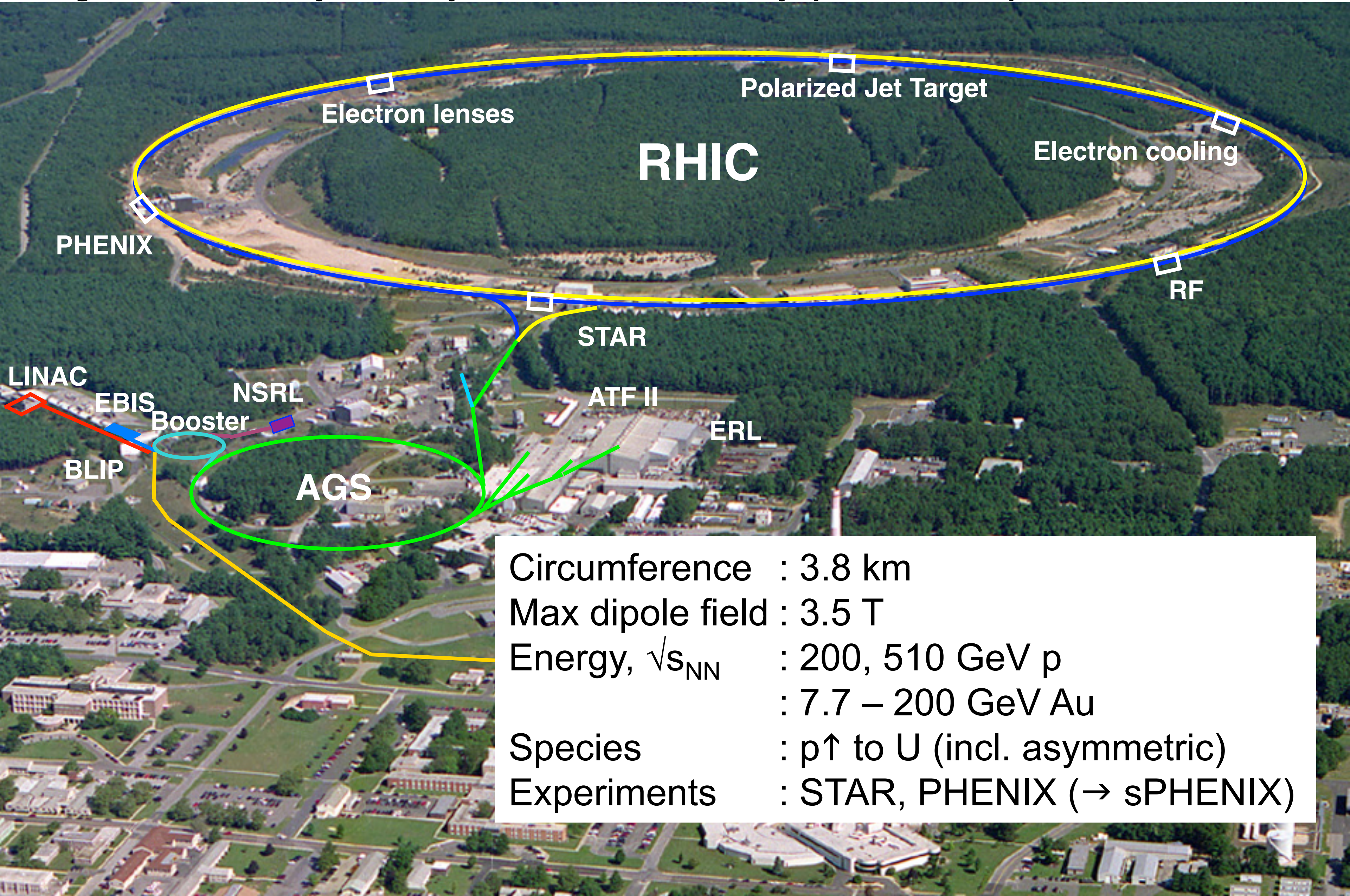
   bunch intensity + stochastic cooling
3. Upgrades for low energy A+A
   bunch intensity + electron cooling
4. Upgrades for p↑+p↑
   bunch intensity + head-on beam-beam compensation, polarization







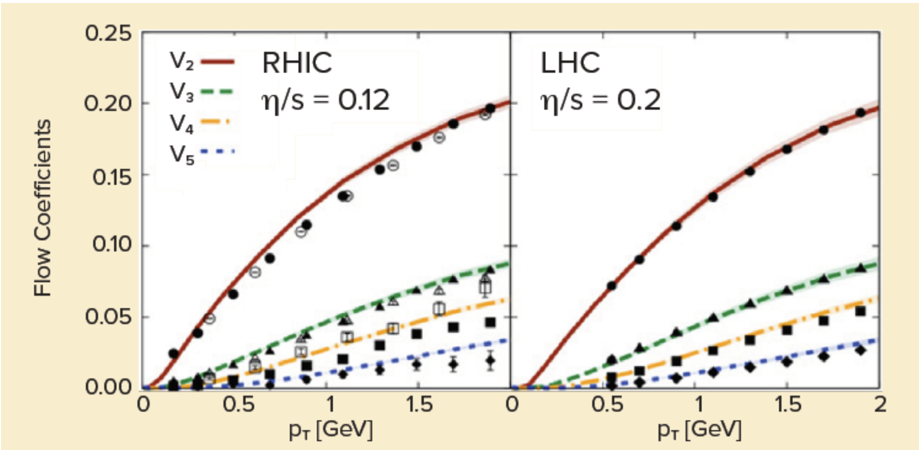
Relativistic Heavy Ion Collider –
high-luminosity heavy ion and only polarized proton collider



Circumference	: 3.8 km
Max dipole field	: 3.5 T
Energy, $\sqrt{s_{NN}}$	: 200, 510 GeV p
	: 7.7 – 200 GeV Au
Species	: p↑ to U (incl. asymmetric)
Experiments	: STAR, PHENIX (→ sPHENIX)

RHIC science programs

1. Creation and study of the Quark Gluon Plasma

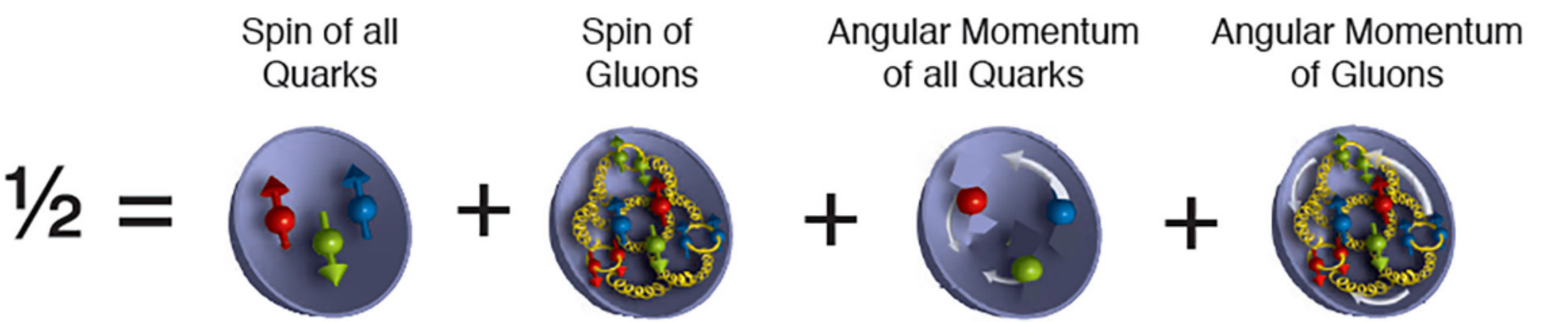


[2015 NSAC Long Range Plan for Nuclear Science]

QGP close to perfect liquid

The QGP is a strongly coupled nearly "**perfect**" liquid (η/s near the quantum limit 1/4π). RHIC's cooler QGP is (on average) closer to perfection than the 40% hotter QGP produced at LHC.

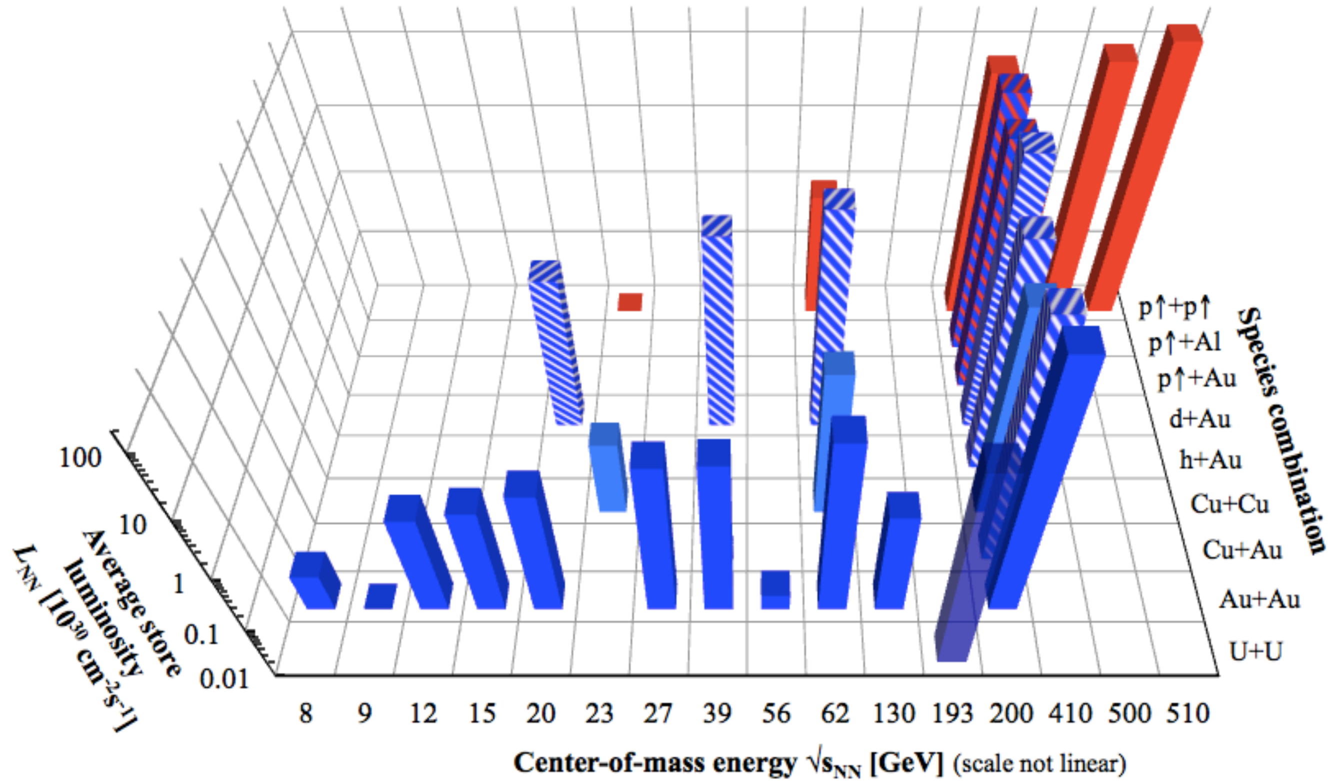
2. Origin of the proton spin



[2015 NSAC Long Range Plan for Nucl. Science]

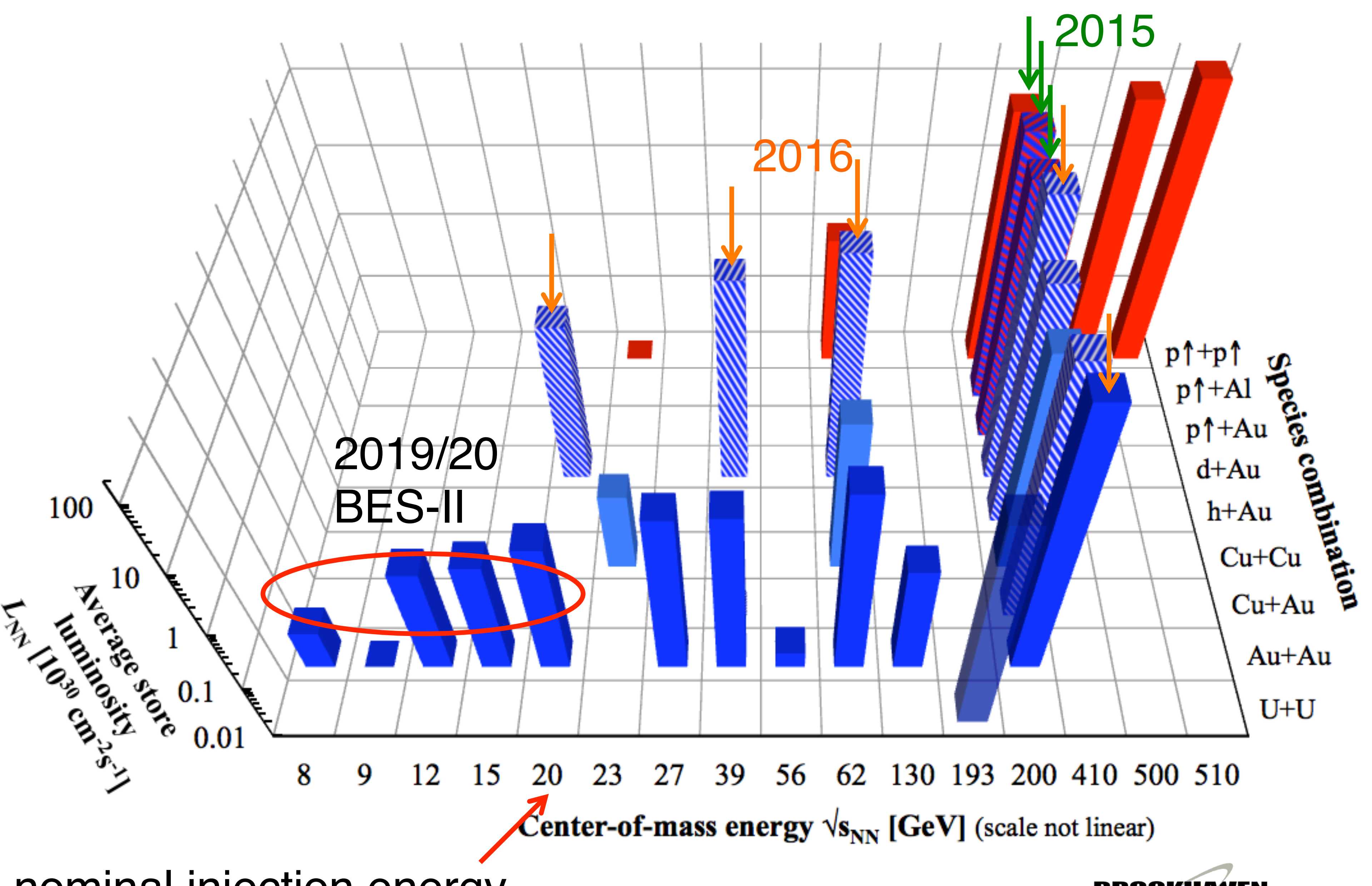
↑ **RHIC result: not zero over some x-range**

major emphasis. Data from the RHIC run in 2009 have **for the first time shown that gluons inside a proton are polarized.** The integral of $\Delta g(x,Q^2=10\,\text{GeV}^2)$ in the region $x > 0.05$ is $\mathbf{0.20^{+0.06}_{-0.07}}$ at 90% C.L.



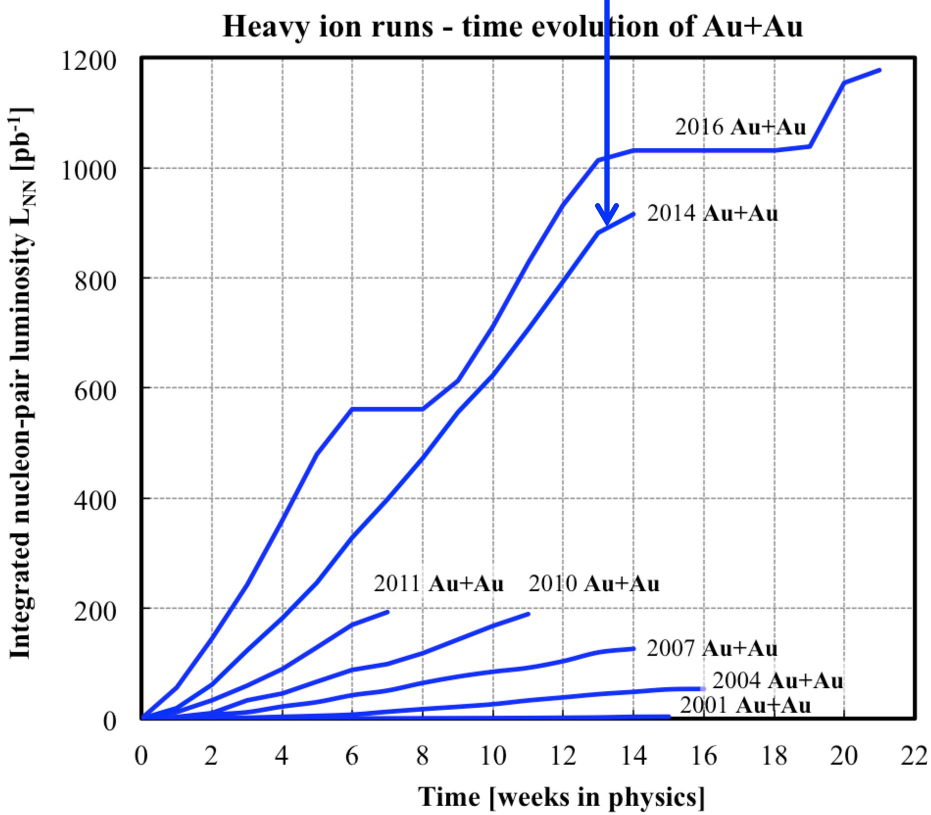
A short history and outlook of RHIC

RHIC – all running modes to date

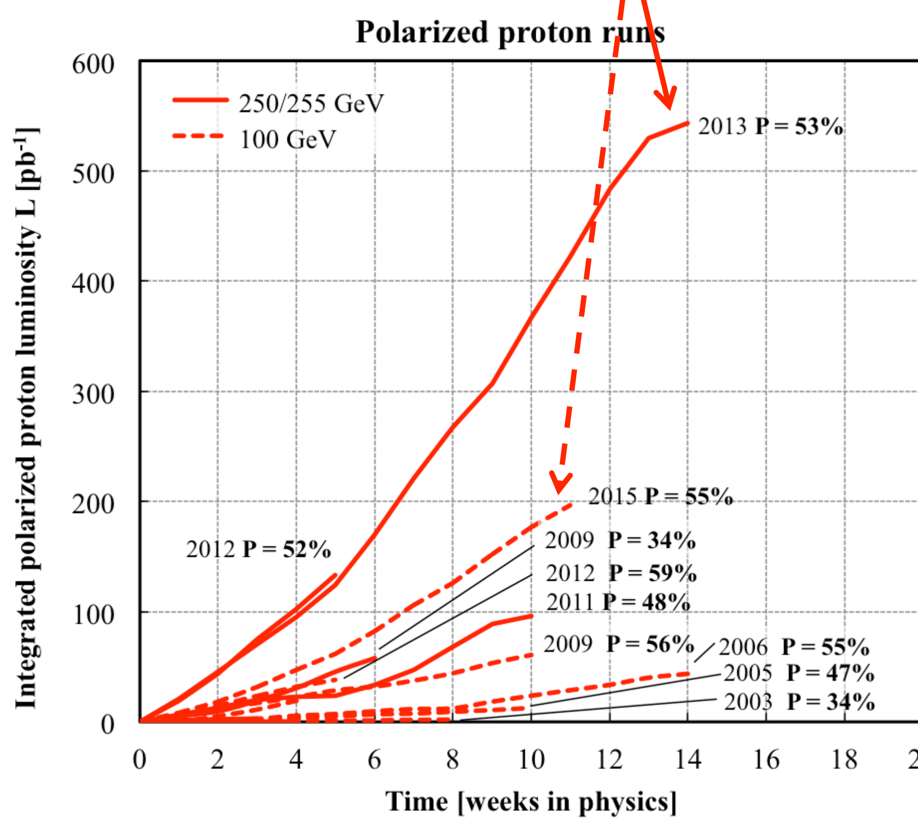


Delivered Integrated Luminosity – symmetric species

Run-14 Au+Au luminosity exceeds all previous Au+Au runs combined



Run-13 p+p luminosity exceeds all previous p+p runs combined,
Run-15 all previous 100 GeV runs



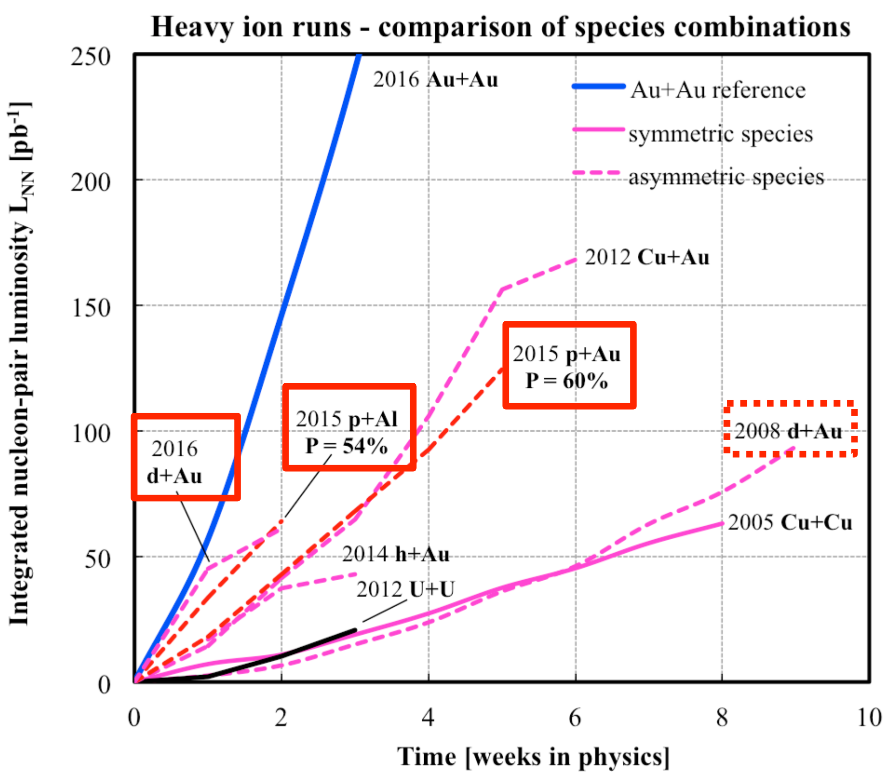
Nucleon-pair luminosity: luminosity calculated with nucleons of nuclei treated independently; allows comparison of luminosities of different species; appropriate quantity for comparison runs.

Dramatic increase in performance as a result of R&D, capital projects, Accelerator Improvement Projects, and replacement of obsolete technology

Delivered Integrated Luminosity – asymmetric species

5 asymmetric combination to date:
- p↑+Au,
- p↑+Al (never done before)
- h+Au
- d+Au (at 4 different energies)
- Cu+Au

can collide any species with any other species



Best week d+Au Run-16 10x better than Run-8

Asymmetric operation requires:
- sources for two different beams (laser ion source + EBIS; Tandems)
- reliable injector switch-over during RHIC injection (AGS cold snake turn on/off for p↑)
- accommodation of tighter apertures in IRs (DX magnet move for p↑+A, limitations from CeC PoP chamber in Run-16)
- in p↑+A: acceleration of A to plateau near transition for proton injection
- increased experimental protection (PHENIX MPC-EX damage in Run-15)

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RHIC proposed run plan – extents to mid 2020s

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2016	High statistics Au+Au d+Au beam energy scan	Complete heavy flavor program First measurement of Λ_c Collectivity in small systems	Coherent e-cooling test I
2017	High statistics Pol. p+p at 510 GeV	Transvers	est II
2018	$^{96}Zr+^{96}Ru$ at 200 GeV eV ?	Establish	g
2019-20	7.7-20 GeV Au+Au (BES-2)	Search for of deconfi	
2021	TBD	Contingency for BES-2 extension ?	sPHENIX installation
2022-??	200 GeV Au+Au with upgraded detectors Pol. p+p, p+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport Color scre	
mid-2020s	Transition to eRHIC ?	Gluon stru	

today

natural abundance of
3% and 6% respectively

High-energy p↑+↑p and A+A
STAR (need leveled *L*)

Low-energy A+A
STAR (*L* requests require new e-cooler)

High-energy p↑+p↑, A+A, p↑+A
STAR and sPHENIX
(sPHENIX *L* requests require upgrades)

RHIC ultimate luminosity and polarization goals at high energy

parameter	unit	achieved		goals	
Au-Au operation		**2016**		**≥ 2021** 56 MHz SRF + AGS + 9 MHz RF	
energy	GeV/nucleon	100		100	
no colliding bunches	…	111		111	
bunch intensity	10^9	2.0		2.5 (2.0)	
avg. luminosity	10^{26} cm^{-2}s^{-1}	**87** 44× design		**175** (100) 2× achieved	
p↑-p↑ operation		**2015**		**≥ 2021** OPPIS + 9 MHz RF + e-lenses	
energy	GeV	100	255	100	255
no colliding bunches	…	– 111 –		– 111 –	
bunch intensity	10^{11}	2.25	1.85	3.0	3.0
avg. luminosity	10^{30} cm^{-2}s^{-1}	**63** 1× design	**160** 1.3× design	**175** 2.8× achieved	**600** 3.8× achieved
avg. polarization*	%	**55**	**52**	**60**	**55**

Last year's numbers (in parentheses)

*Intensity and time-averaged polarization as measured by the H-jet. Luminosity-averaged polarizations are higher.

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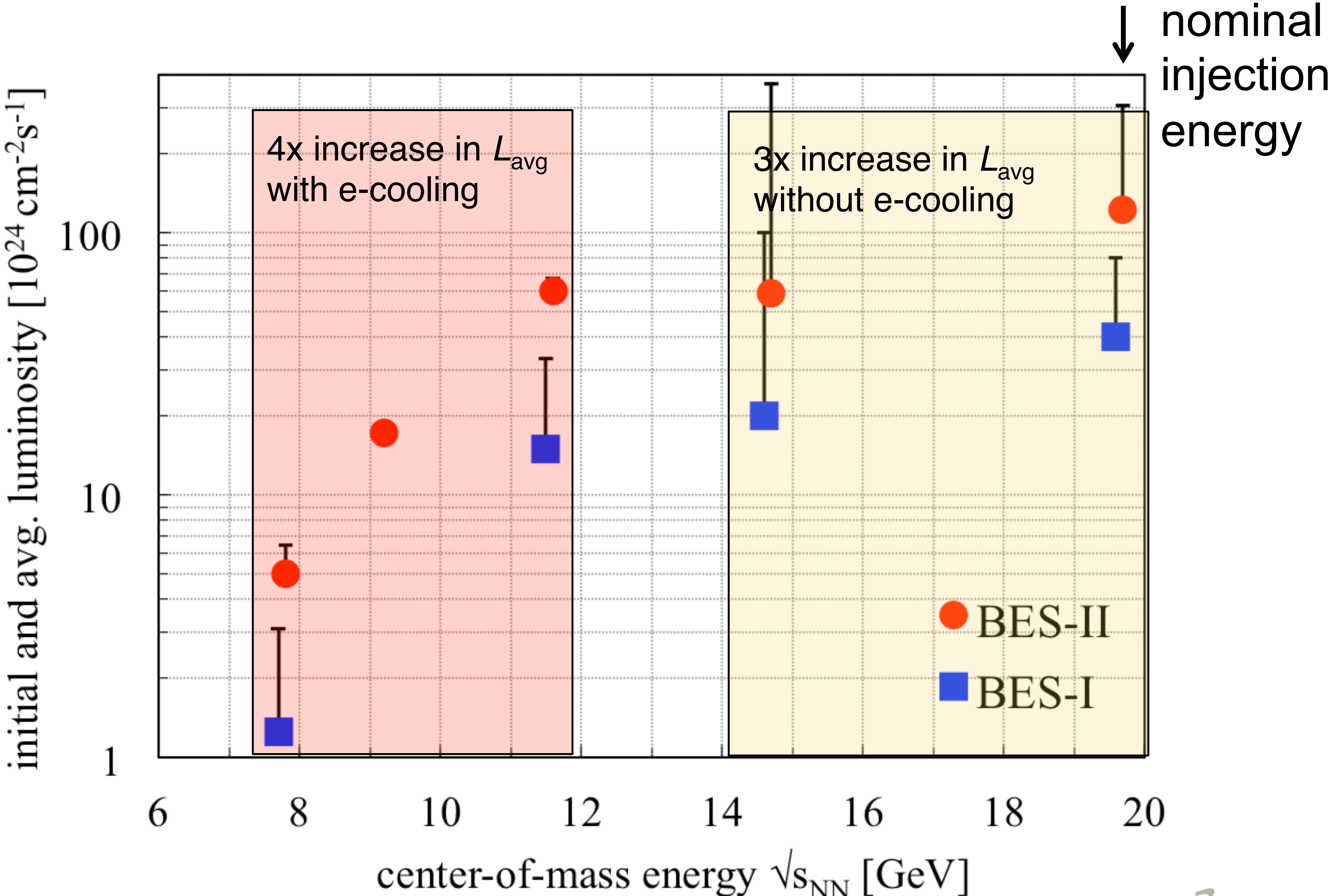
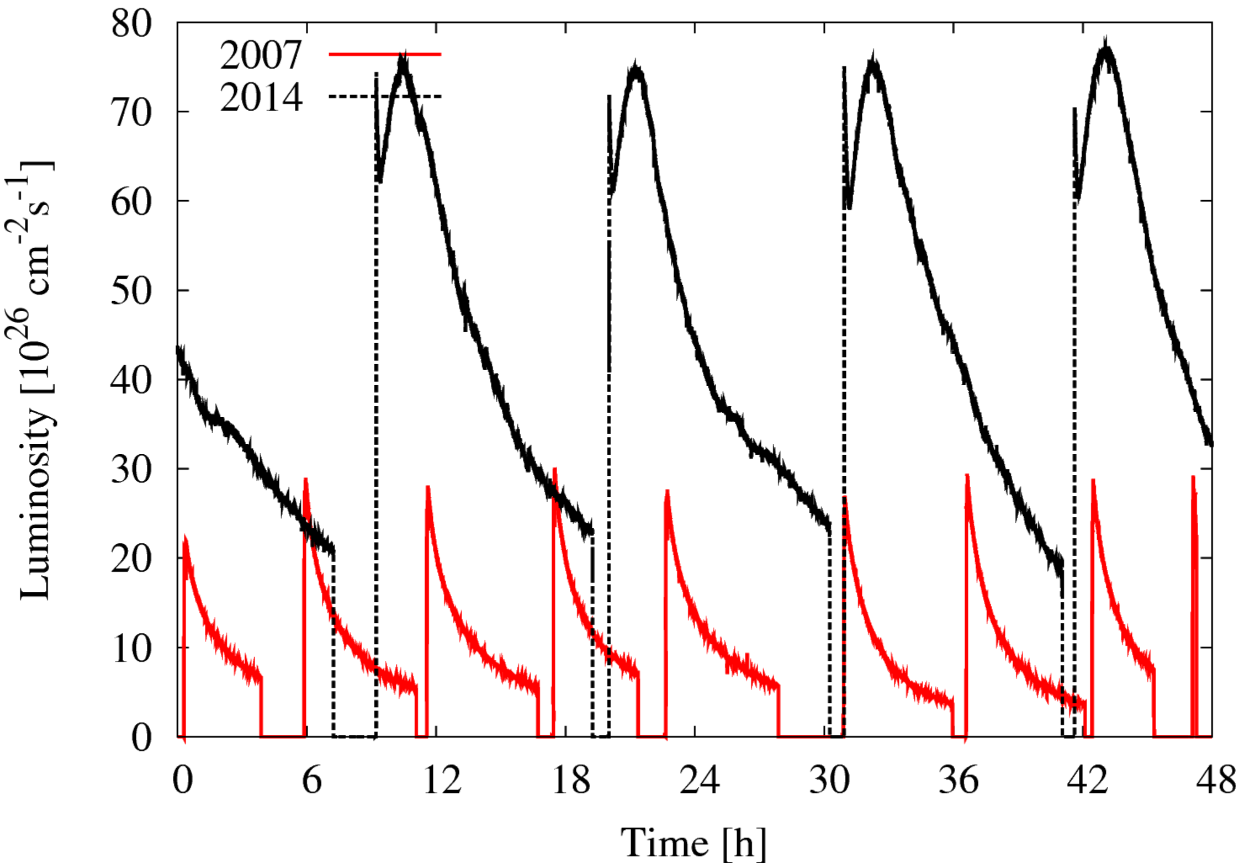
Physics integration

BES-I and BES-II luminosities

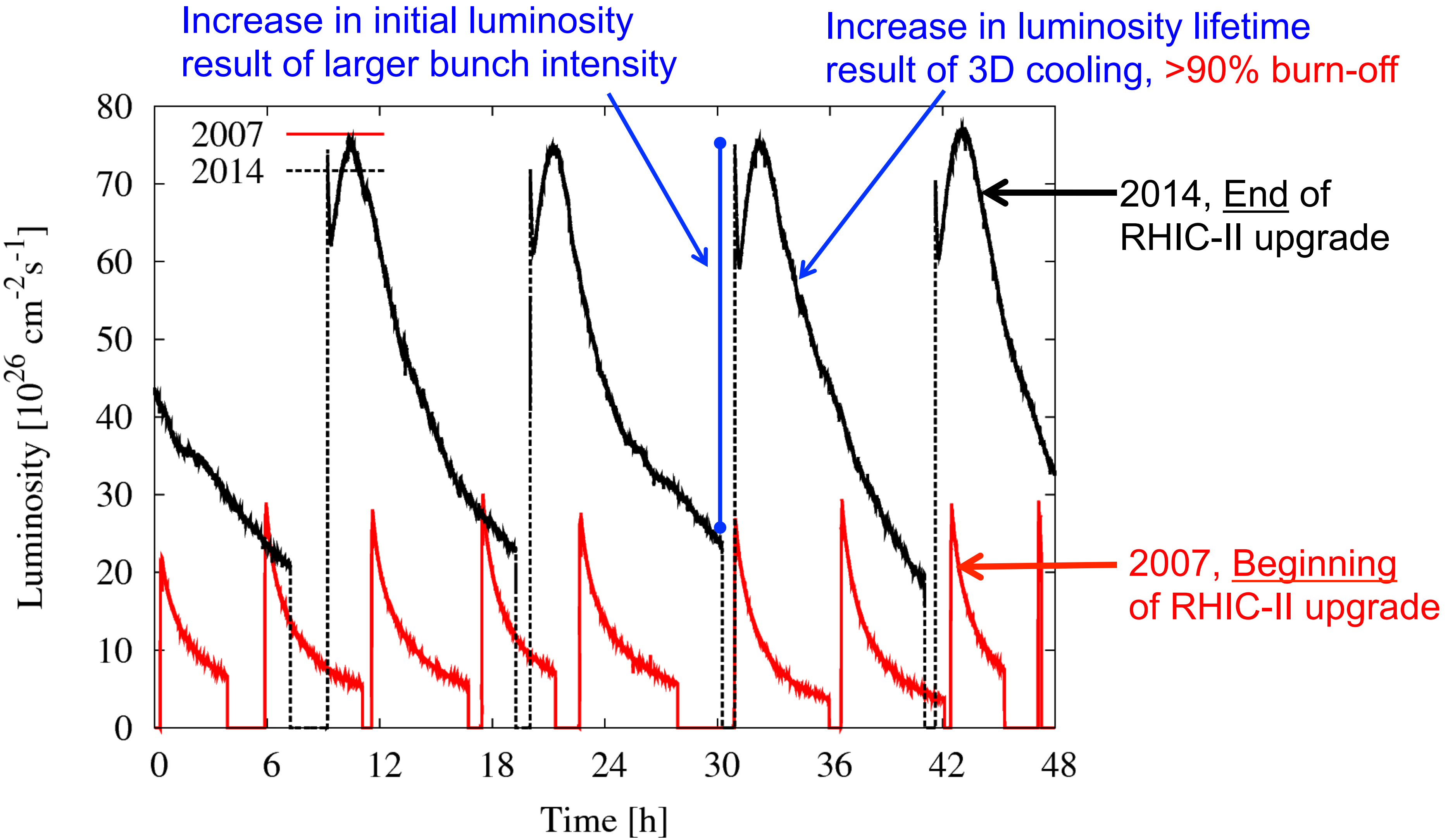




RHIC high-energy A+A operation with stochastic cooling

RHIC Run-14

Delivering RHIC-II luminosity



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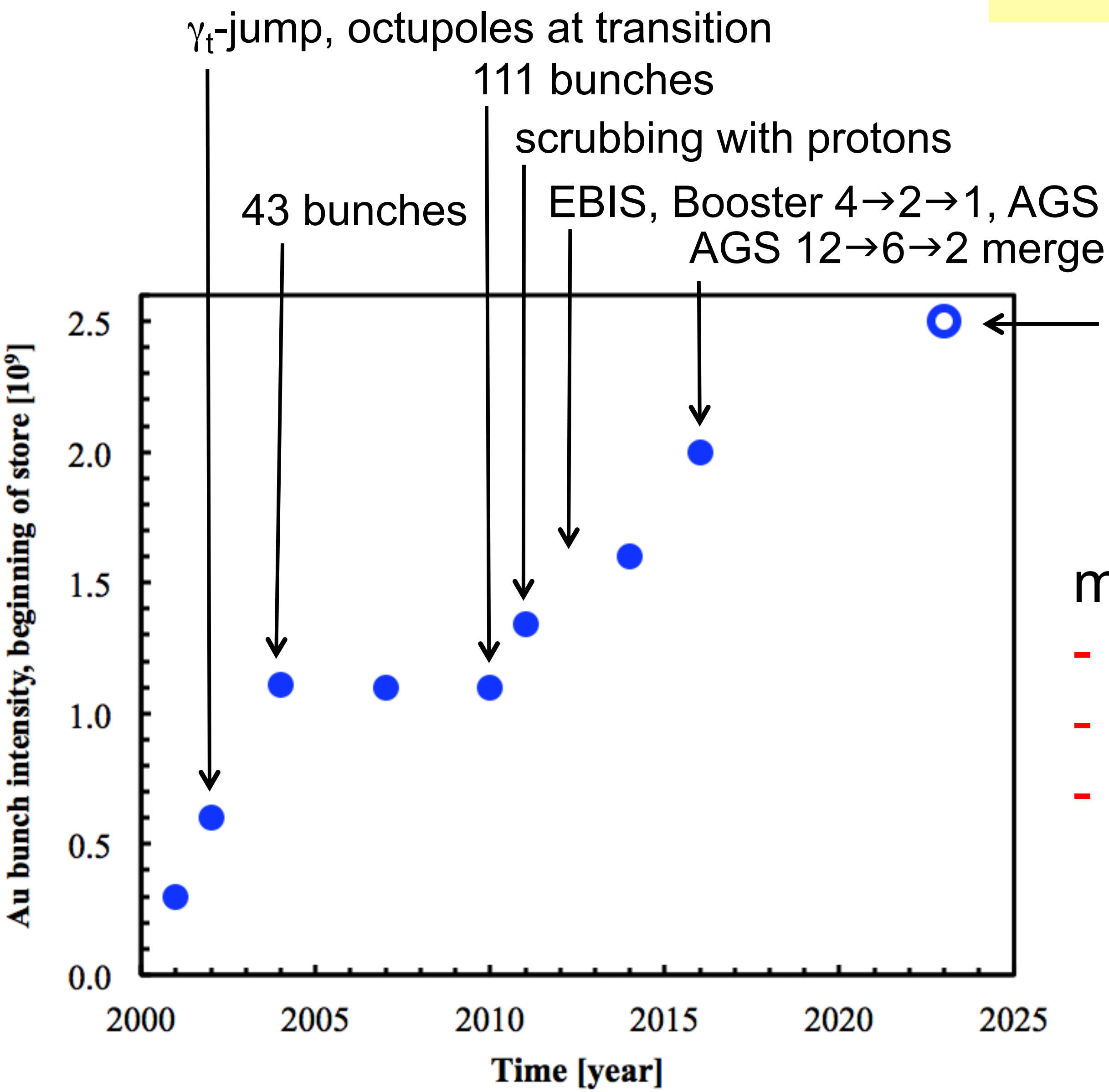
Au bunch intensity evolution

$$L(t) = \frac{1}{4\pi} f_0 N \frac{N_b^2(t)}{\varepsilon(t)\beta^*(t)} h(\beta^*, \sigma_s, \theta)$$



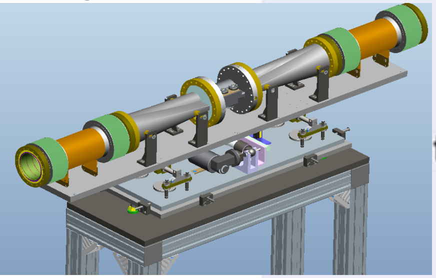
ultimate goal
(raised from 2.0x10⁹ this year)

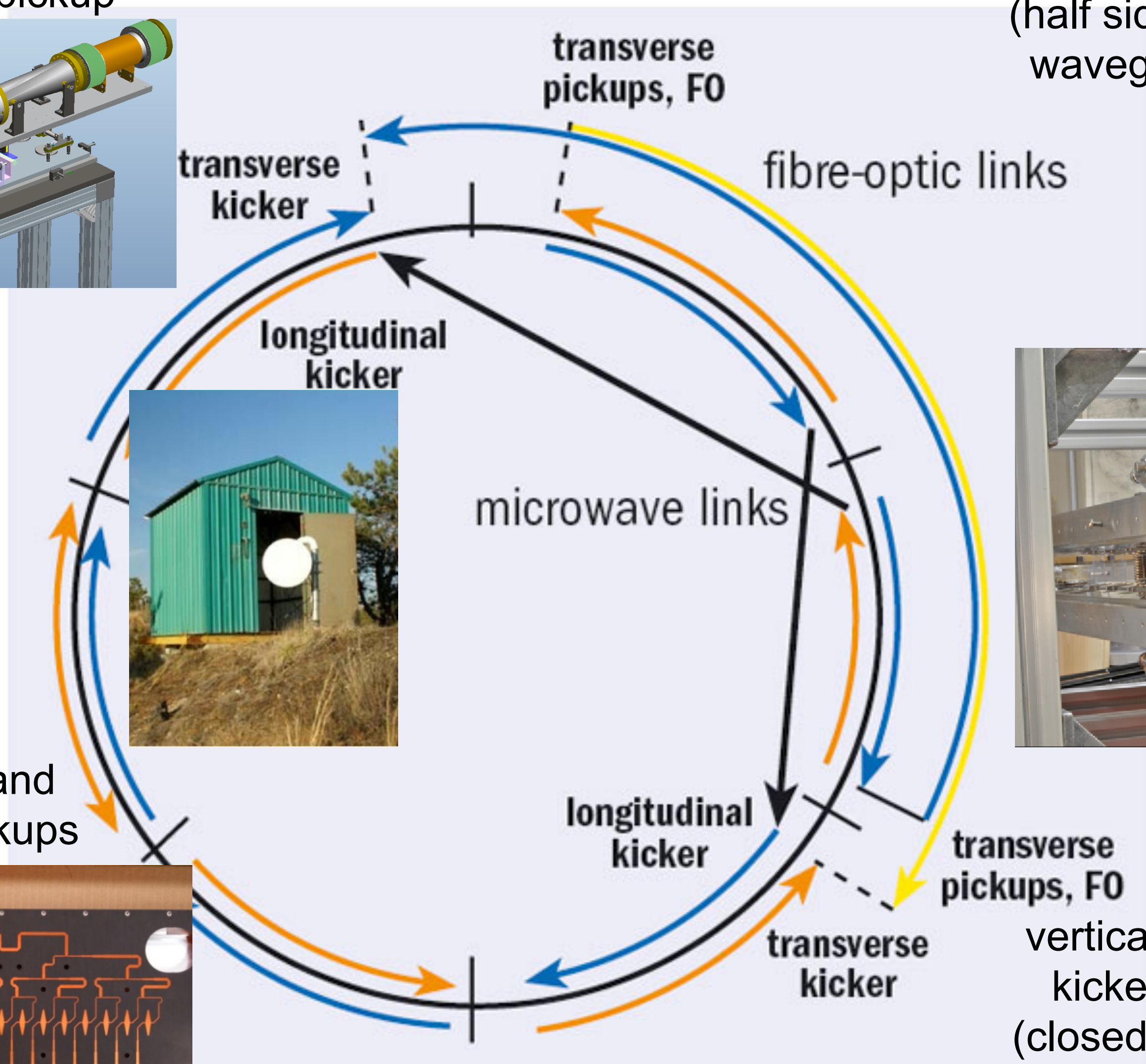
main limits:
- injectors output
- e-cloud in RHIC
- transition instability in RHIC

H. Huang, K. Gardner, K. Zeno, RF, et al.

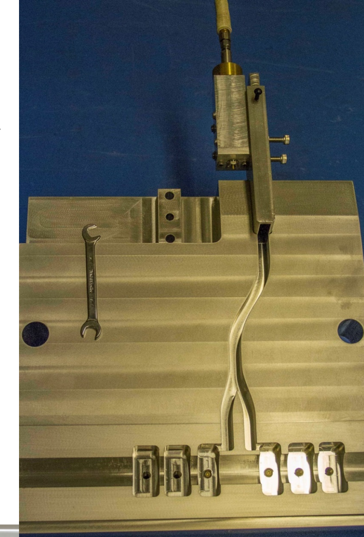
3D stochastic cooling for heavy ions

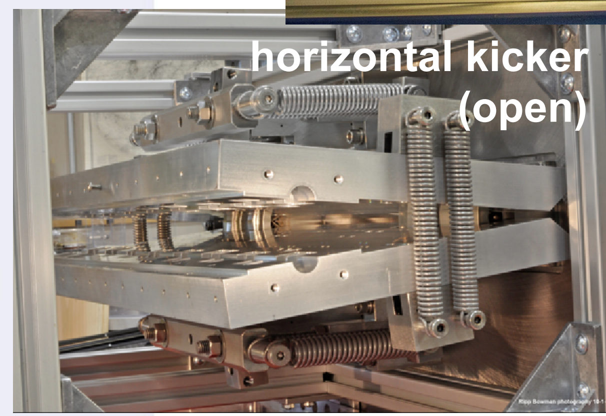
longitudinal pickup



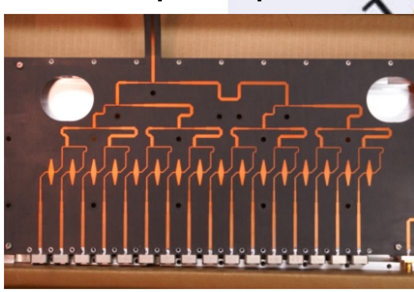


longitudinal kicker cavity (half side with waveguides)

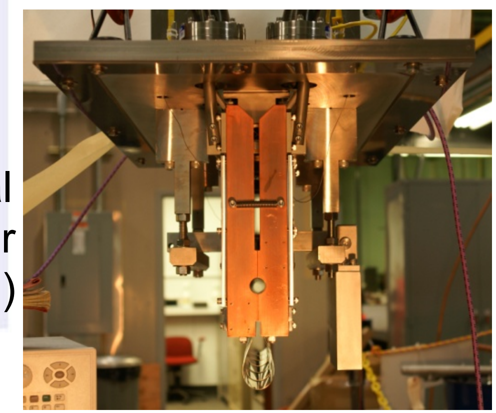




horizontal and vertical pickups



vertical kicker (closed)



5-9 GHz, cooling times ~1 h

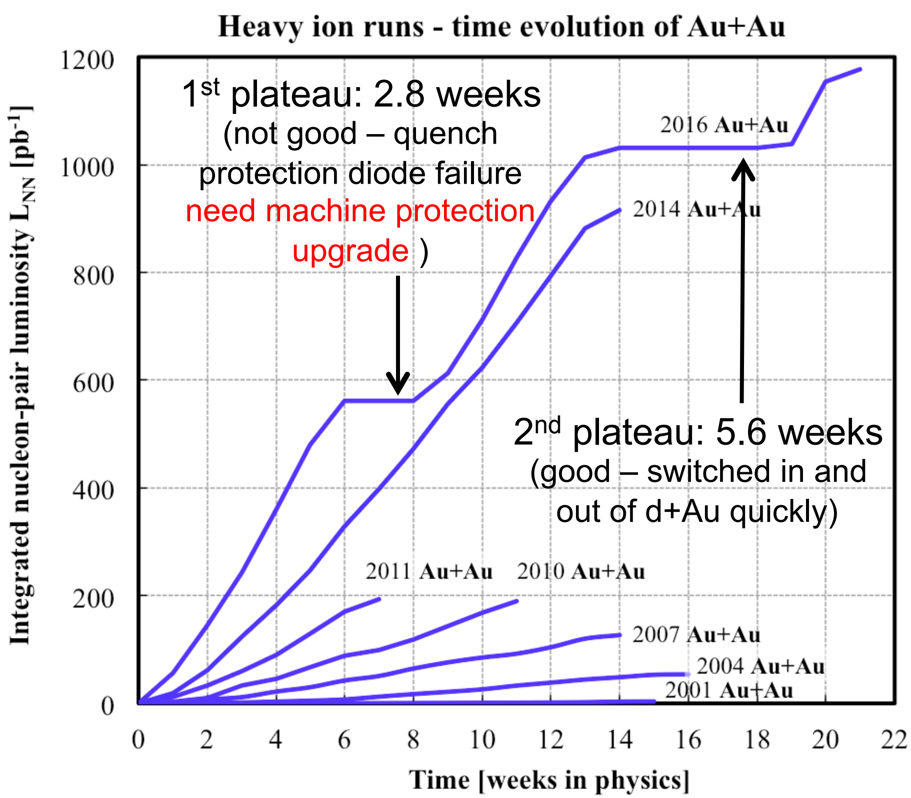
M. Brennan, M. Blaskiewicz, F. Severino, PRL **100** 174803 (2008); K. Mernick PRSTAB, PAC, EPAC

Run-16 Au+Au at 100 GeV/nucleon

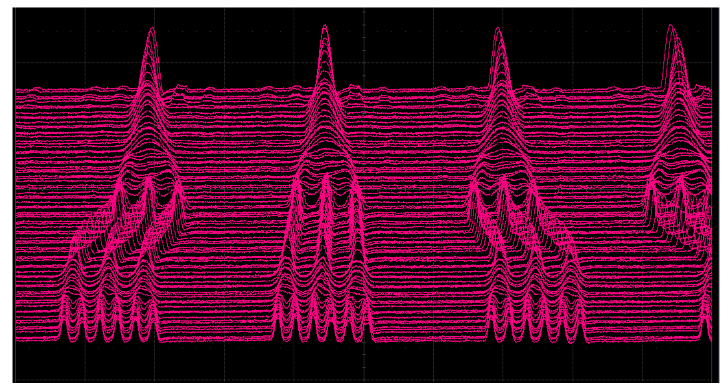
Luminosity

Run Coordinator: Xiaofeng Gu

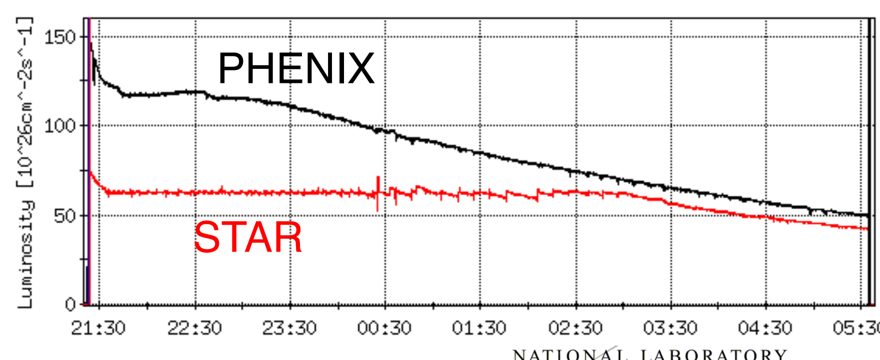
- More collisions in 10 min than in entire 5-week commissioning run in 2001
- L_{avg} now 44x design

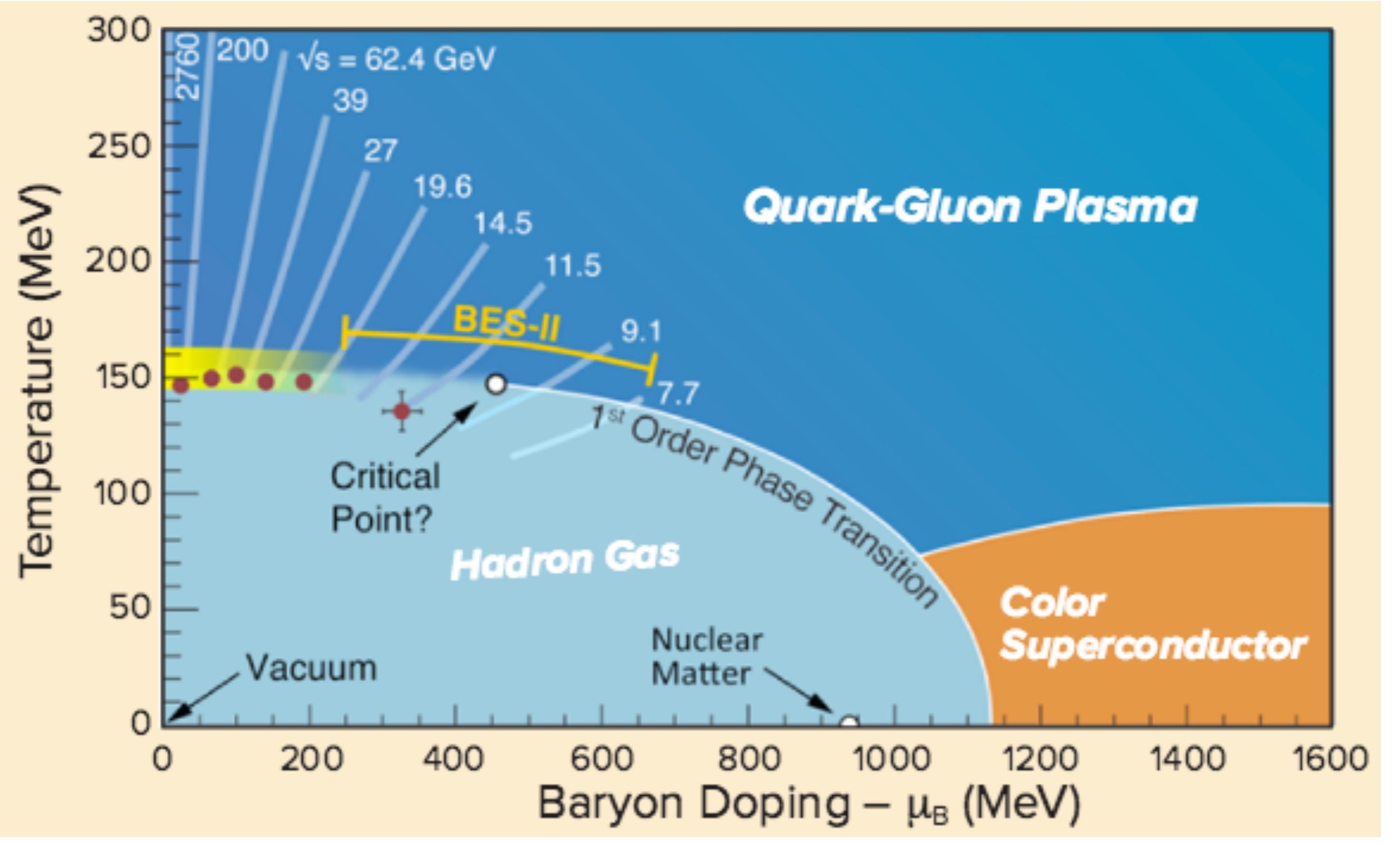


25% increase in bunch intensity due to AGS bunch merging scheme at injection change from 8→4→2 to 12→6→2
(with minimal increase in longitudinal emittance!)



Maximized *L* to PHENIX and delivered leveled *L* to STAR using stochastic cooling and transverse offset at IP





[2015 NSAC Long Range Plan for Nuclear Science]

RHIC low-energy A+A operation with electron cooling

LEReC Physics integration BES-II required events

RHIC Beam Energy Scan II (BES-II) for search of critical point in QCD phase diagram

center-of-mass energy $\sqrt{s_{NN}}$	GeV	7.7	9.1	11.5	14.6	19.6
events BES-I, actual	M	4.3		11.7	24	36
events BES-II, **min goal**	M	80	100	150	200	300
events BES-II, **full goal**	M	100	160	230	300	400

General strategy to maximize integrated luminosity:

Cooling at the 3 lowest energies (4x gain in L_{avg}),
no cooling at the 2 highest energies (3x gain in L_{avg})
=> demonstrated at $\sqrt{s_{NN}}$ = 19.6 GeV in Run-16

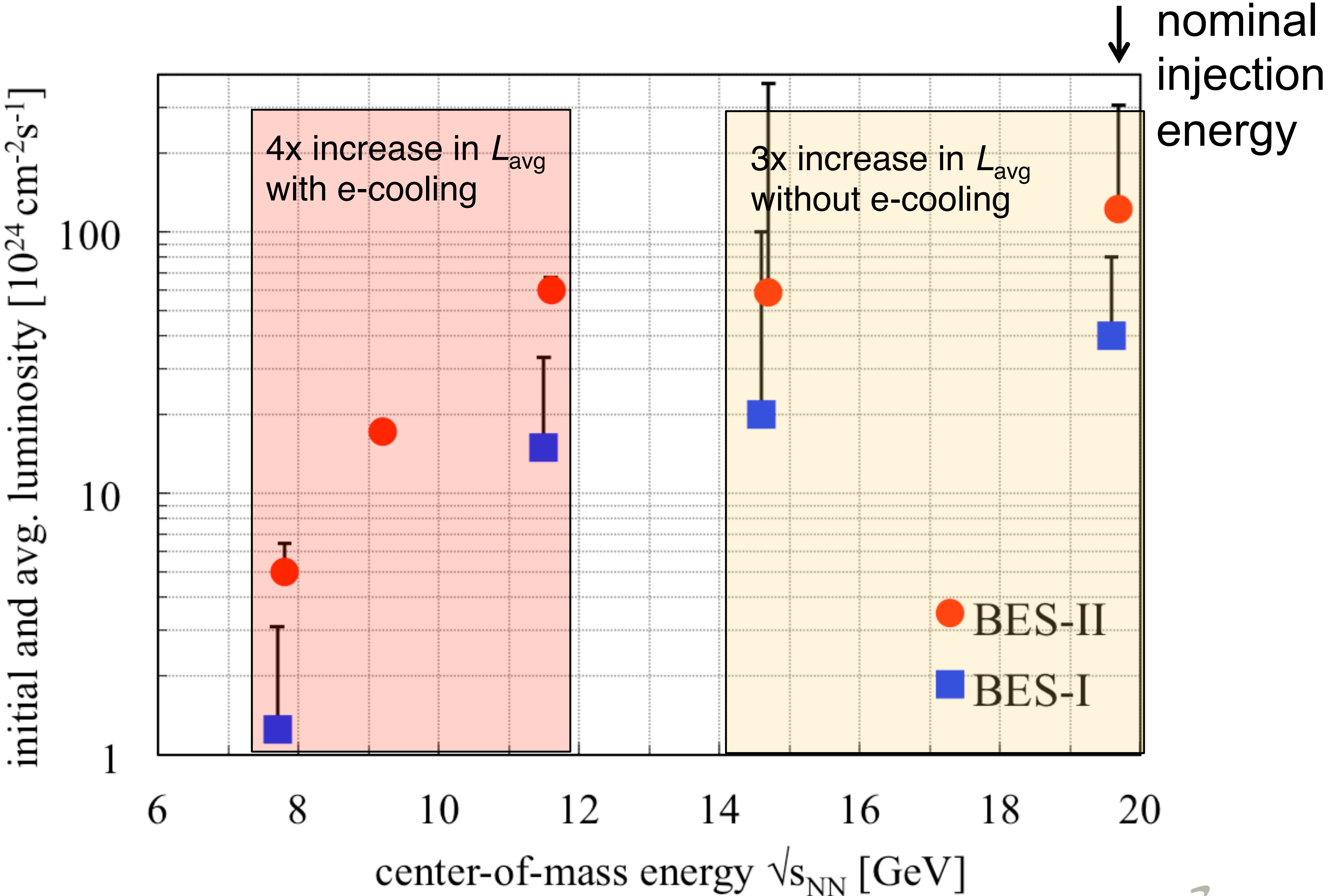
Start BES-II at highest energies (machine ready w/o cooling)

Interleave cooling commissioning with physics operation

Finish BES-II at lowest energies (largest gain in L_{avg} and time)

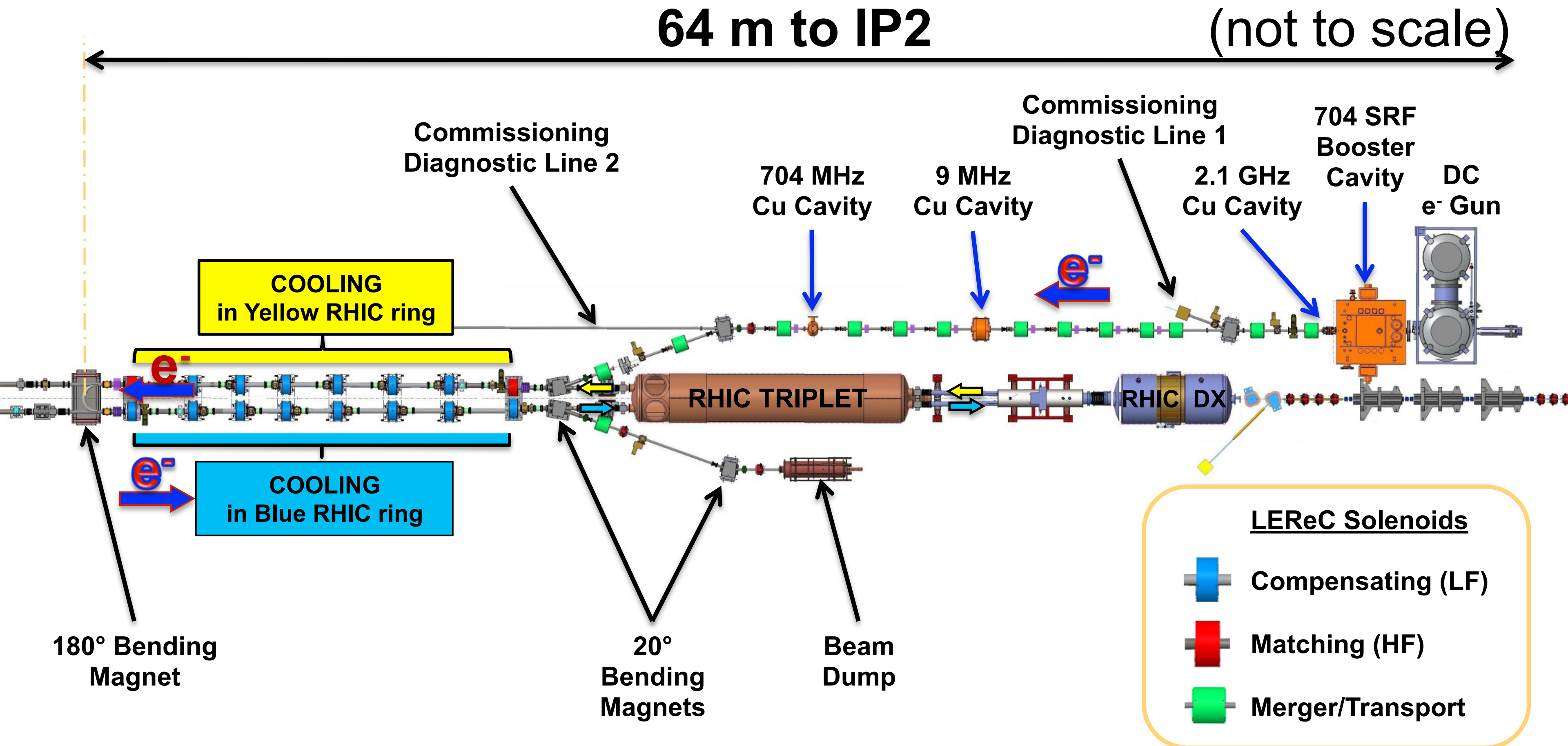
Physics integration

BES-I and BES-II luminosities



Low Energy RHIC electron Cooling (LEReC)

A. Fedotov et al.



Energies E : 1.6, 2.0 (2.65) MeV

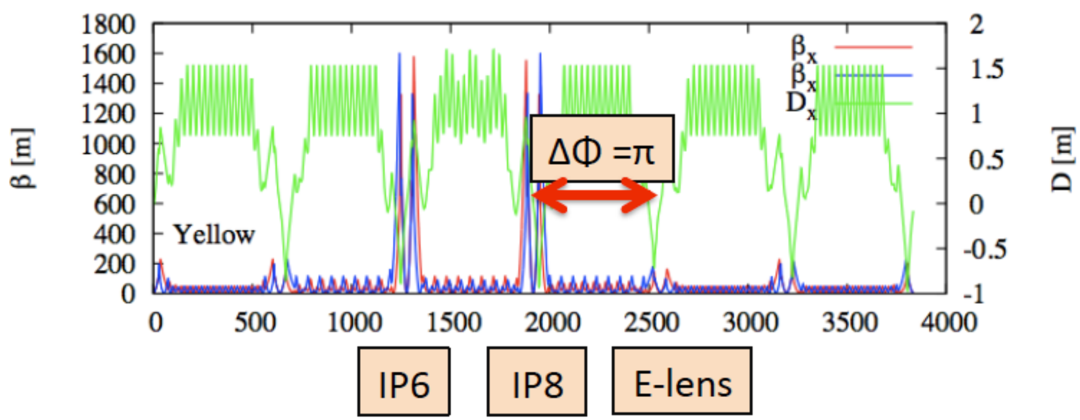
Avg. current I_{avg} : 27 mA

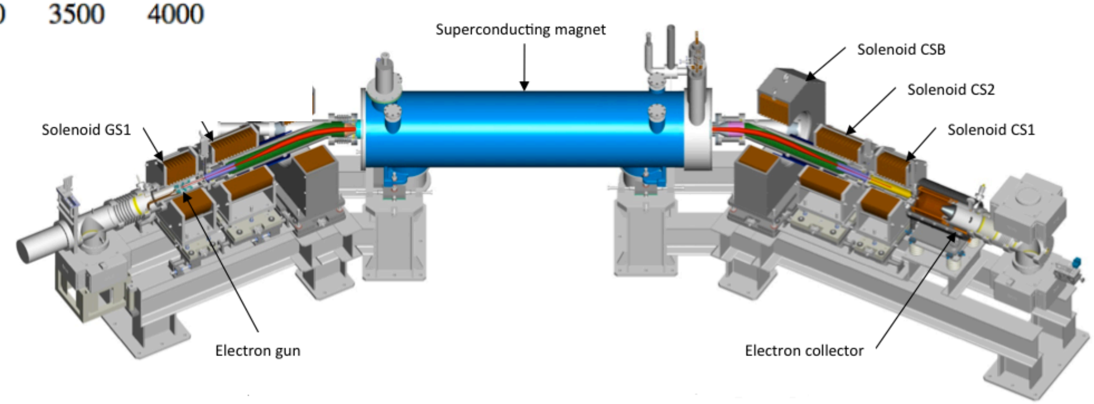
Momentum $\delta p/p$: 5×10^{-4}

Luminosity gain : 4×

1st bunched beam electron cooler

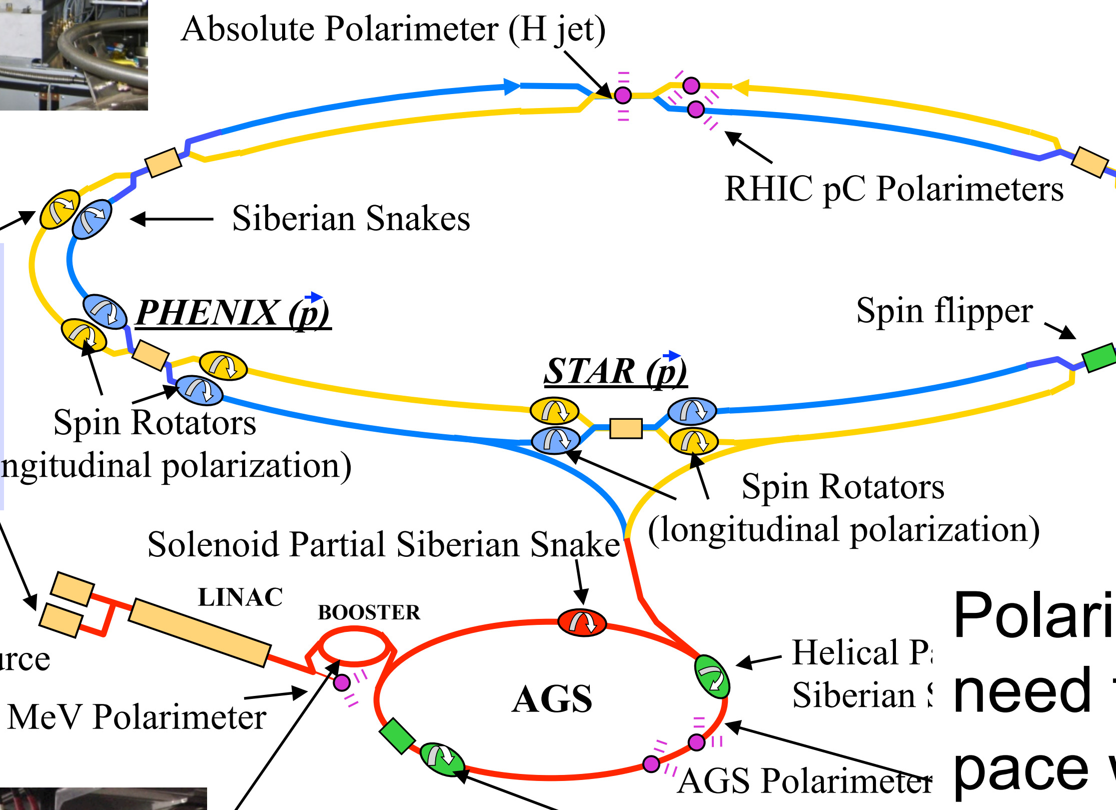
planned operation in 2019/2020

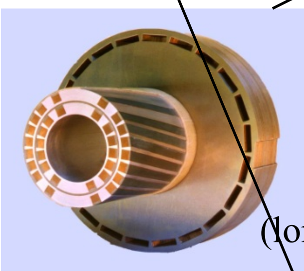


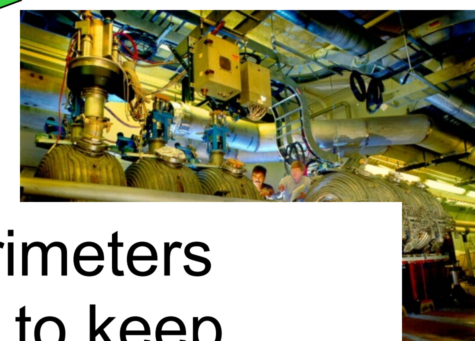


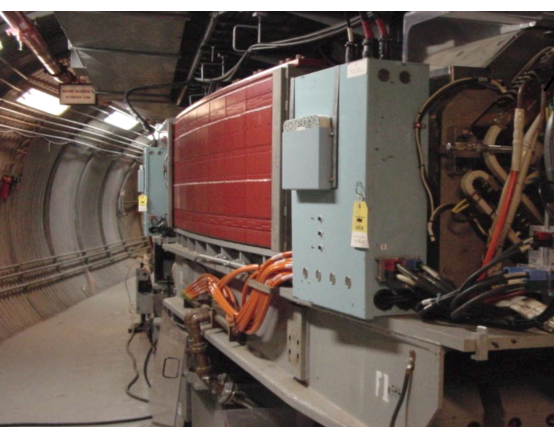
RHIC p↑+p↑ operation with head-on beam-beam compensation

Special devices for polarized protons: source, polarimeters, snakes, rotator, flipper









Polarimeters need to keep pace with intensity upgrades

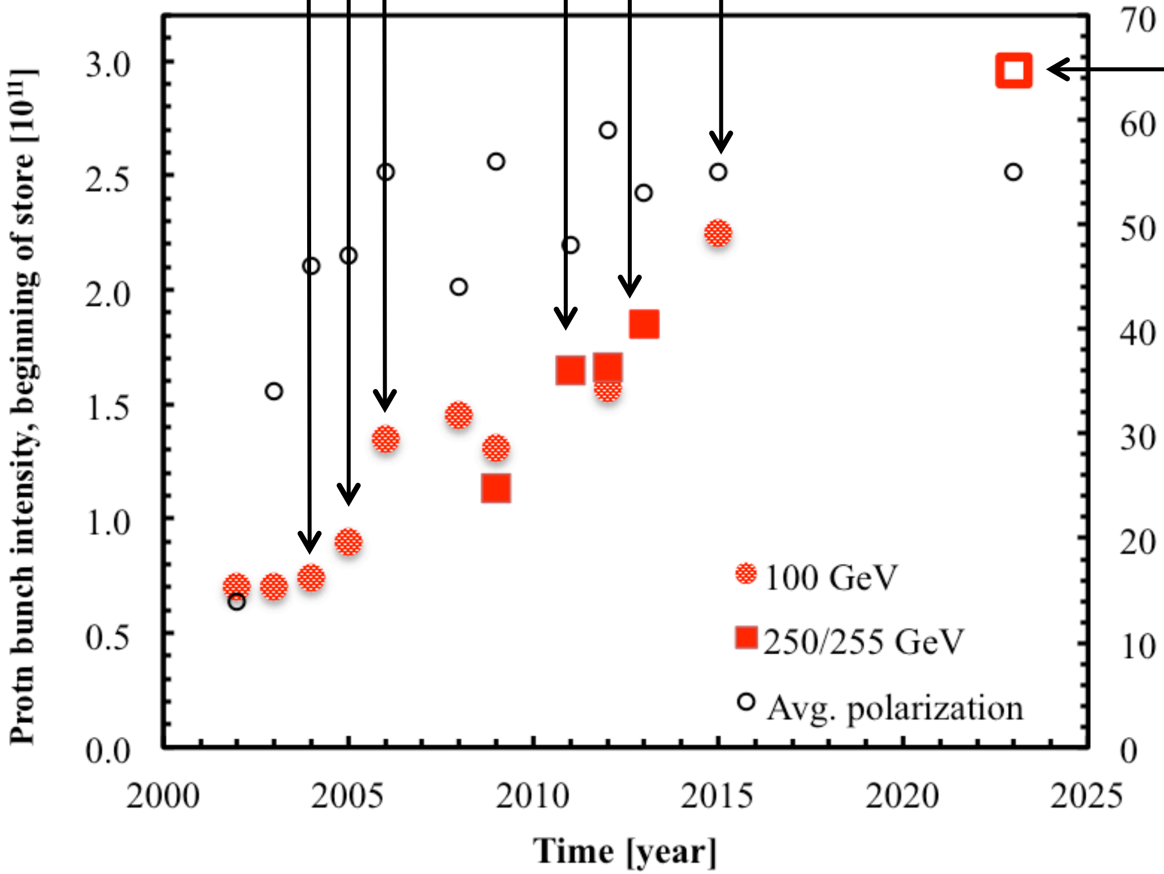
p bunch intensity and polarization

$$L(t) = \frac{1}{4\pi} f_0 N \frac{N_b^2(t)}{\varepsilon(t)\beta^*(t)} h(\beta^*, \sigma_s, \theta)$$

$$FOM = LP^4 \sim N_b^2 P^4$$

(double spin experiments)

AGS warm snake
polarized source upgrade with sc solenoid
AGS cold snake
AGS tune jumps, RHIC 9 MHz RF
polarized source upgrade with Atomic Beam Source
beam-beam compensation



ultimate goal

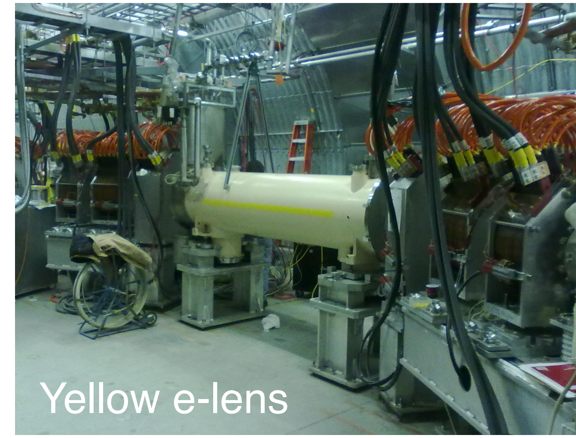
main limits:

- injectors output
- polarization
- e-cloud in RHIC
- beam-beam in RHIC

A. Zelenski, H. Huang,
K. Gardner, K. Zeno, RF, et al.

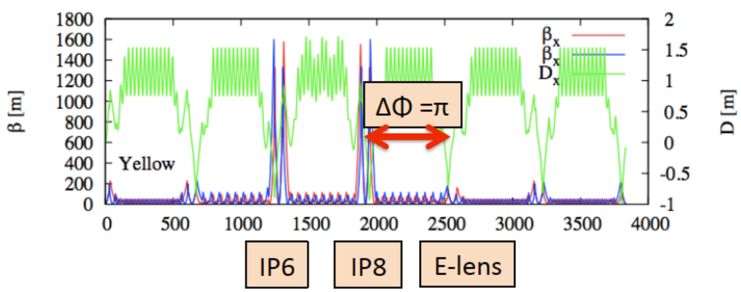
Run-15 p↑+p↑ at 100 GeV

Beam-beam compensation



First hadron collider with head-on beam-beam compensation: lattice + e-lenses

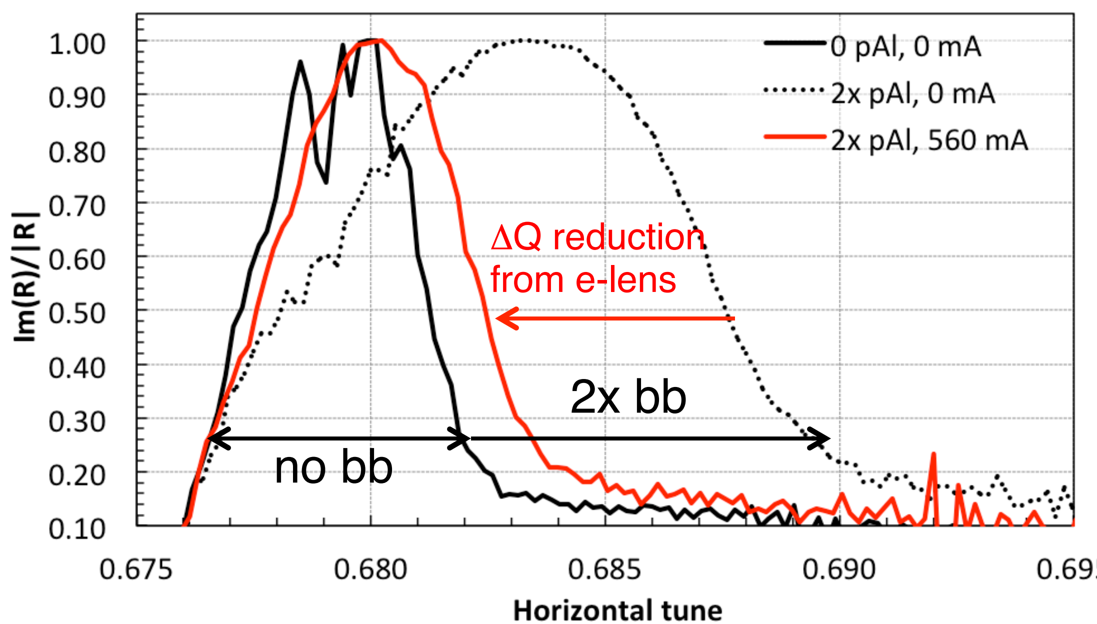
New lattice (ATS type, S. White) – phase advance $k\pi$ between IP8 and e-lens minimizes beam-beam resonance driving terms



New lattice has larger off-momentum dynamic aperture and accommodates higher beam-beam parameter ξ

Electron lenses – reduce beam-beam induced tune spread

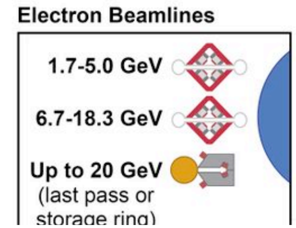
Tune width measurement: imaginary part of complex beam transfer function (BTF); p+Al – no coherent bb modes

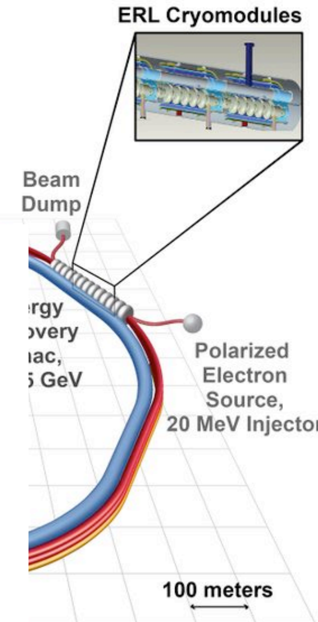


Transition to an electron-ion collider, mid 2020s eRHIC

White paper requirements:

70% polarized e and p/d/h beams ✔
Ion beams from d to Pb/U ✔
E_{com} from 20 to 100 (150) GeV ✔
Luminosit
Possibility





Jefferson Lab also working on an EIC

Highest lu
many desi

Plenary presentation this afternoon:

Linac-Ring

Abhay Deshpande, Stony Brook

highest ult

Ring-Ring

lower ultin

“Science and status

of the Electron-Ion Collider in the US”

Technolog

High-curre ... g gun)
Highly-damped SRF (LR) – LDRD at BNL
FFAG multi-pass ERL (LR) – Cβ at Cornell – d
SRF crab cavities (LR+RR) – R&D at BNL and CERN (HL-LHC)
Strong hadron cooling (LR+RR) – R&D at BNL and JLab

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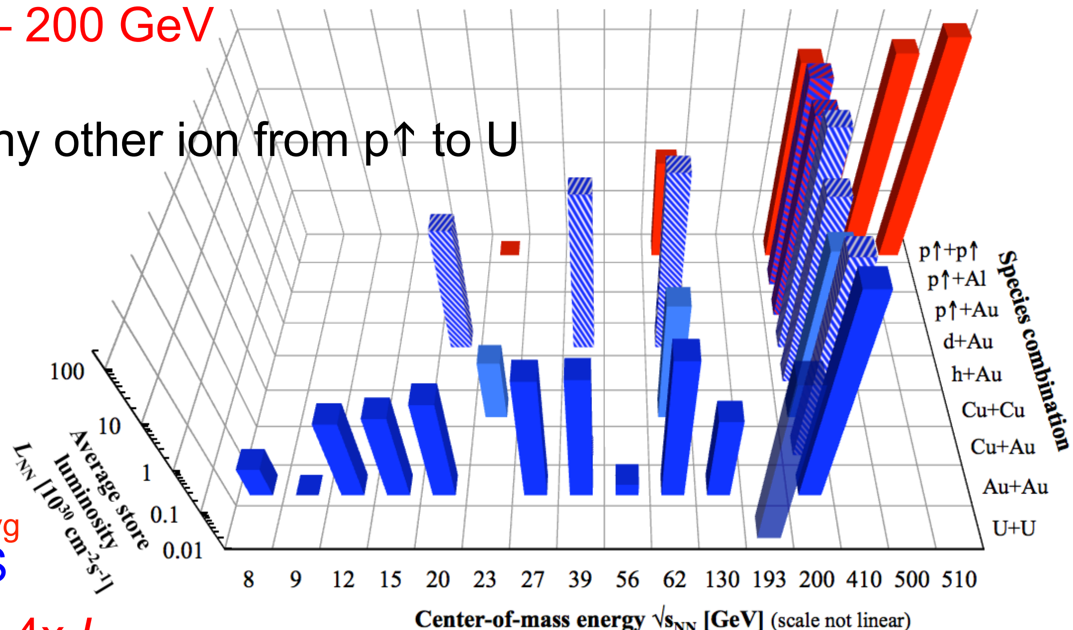
RHIC for the next decade

Summary

Status

- Au+Au L_{avg} = 8.7x10^{27} cm^{-2}s^{-1} (44x design)
- p↑+p↑ L_{avg} = 1.6x10^{32} cm^{-2}s^{-1} (1.3x design), P_{avg} = 53%
- Au+Au energy range $\sqrt{s_{NN}}$ = 7.7 – 200 GeV
  (lowest *E* ~1/3 of nominal injection)
- flexibility to collide any ion with any other ion from p↑ to U
- leveled luminosity for STAR



Upgrades

- Au+Au at $\sqrt{s_{NN}}$ = 200 GeV: 2x L_{avg}
  increase in bunch intensity, MPS
- Au+Au at $\sqrt{s_{NN}}$ = 7.7 – 20 GeV: 3-4x L_{avg}
  increase in bunch intensity, construction of 1st bunched beam electron cooler
- p↑+p↑ : 3-4x L_{avg}
  increase in bunch intensity while maintaining polarization
  full use of head-on beam-beam compensation
- maintain flexibility