RHIC outlook - the next few years

RHIC overview and performance

Performance limitations

Future upgrades

- EBIS
- RHIC II luminosity upgrade
- eRHIC

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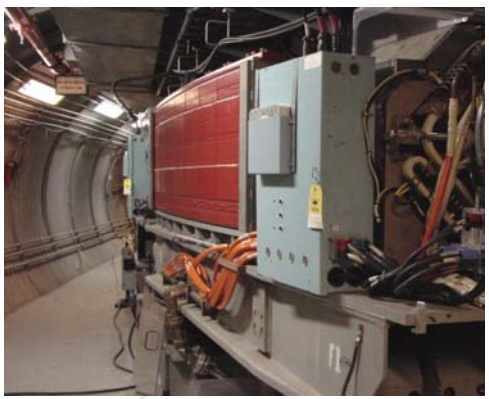
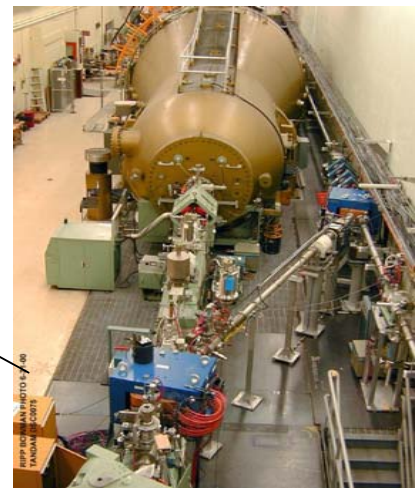
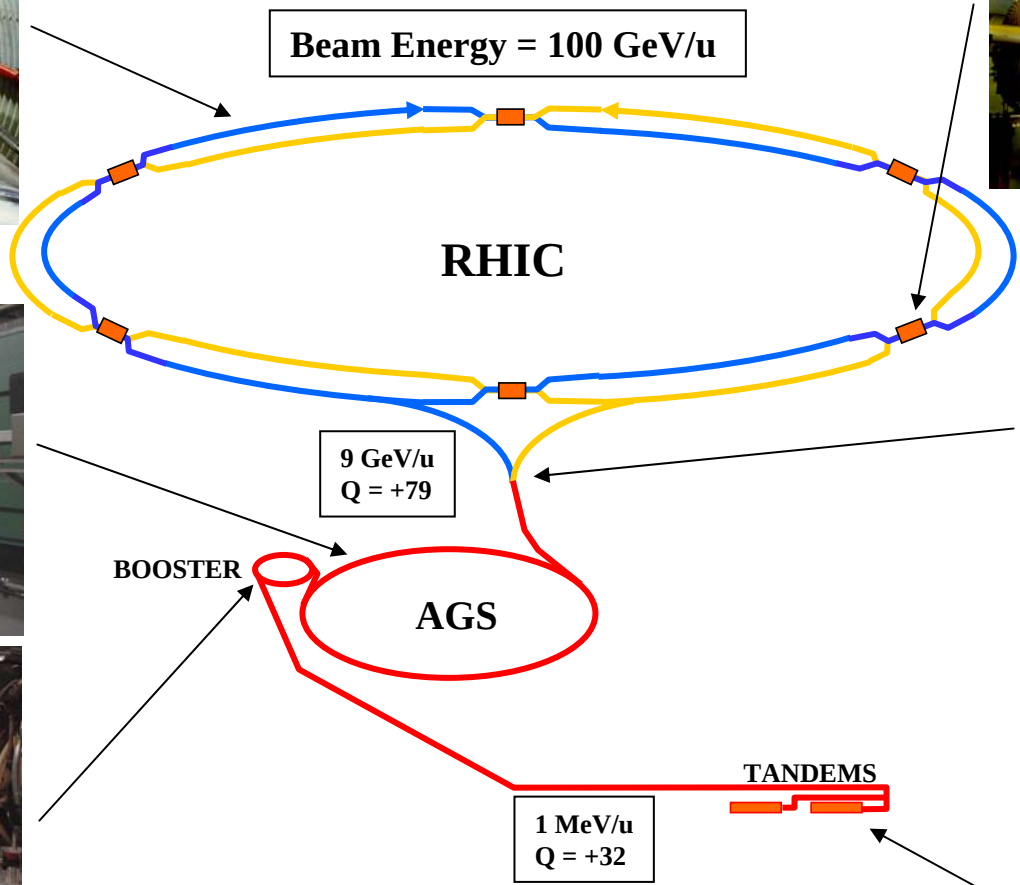
Thomas Roser
APEX 2005
November 9, 2005

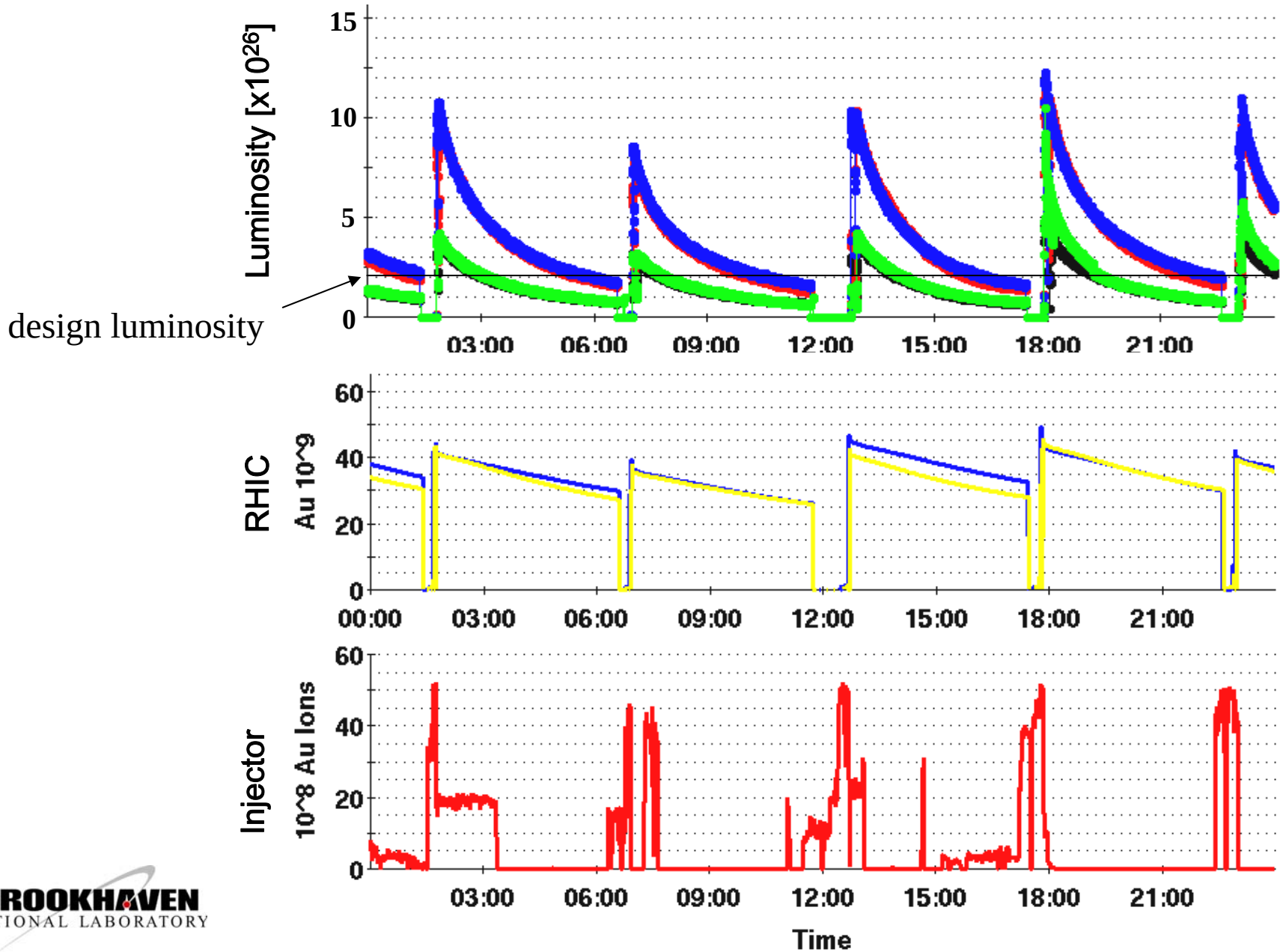
Gold Ion Collisions in RHIC







RHIC Au-Au performance – 2 x design luminosity



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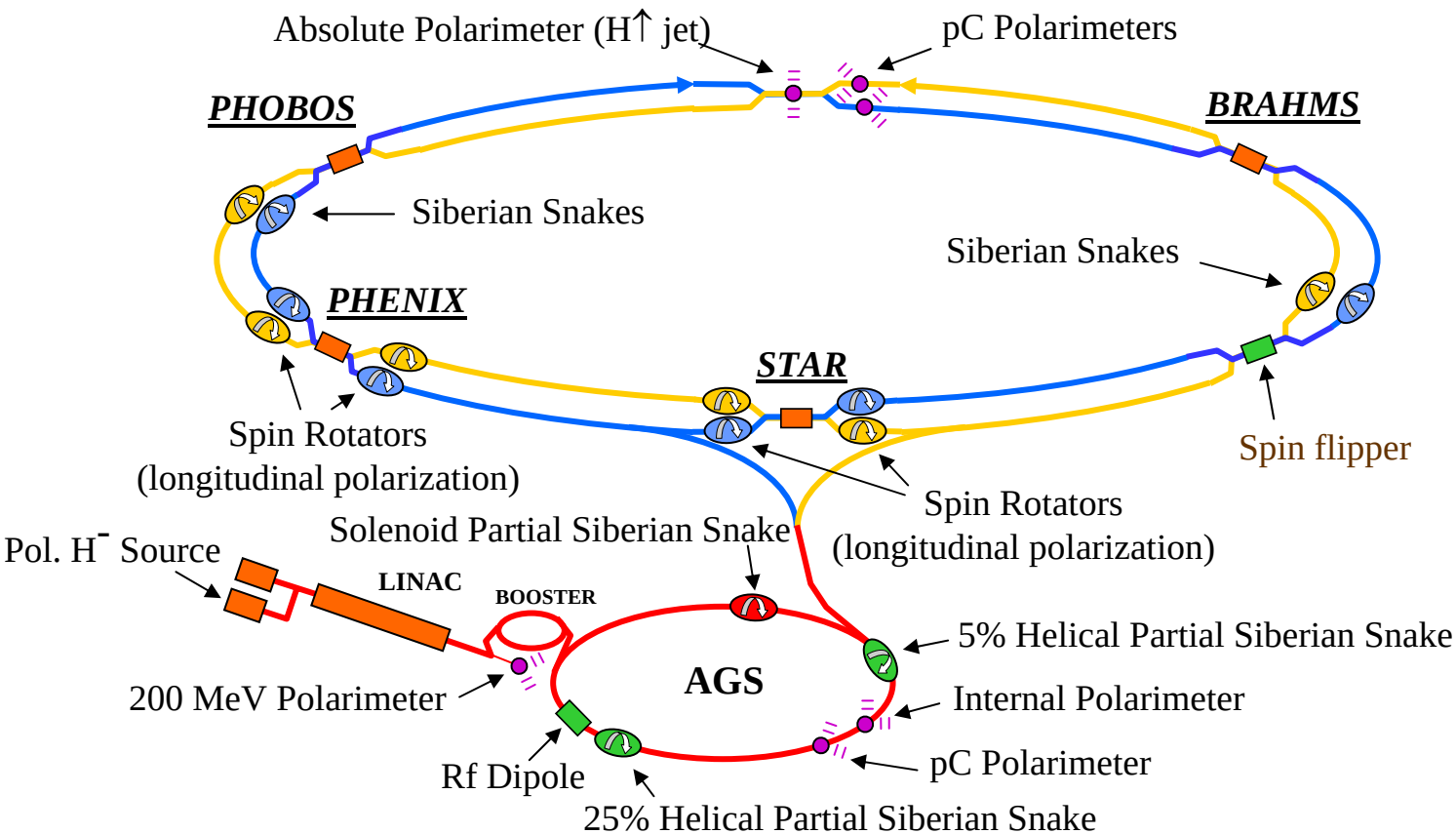
RHIC – first polarized hadron collider



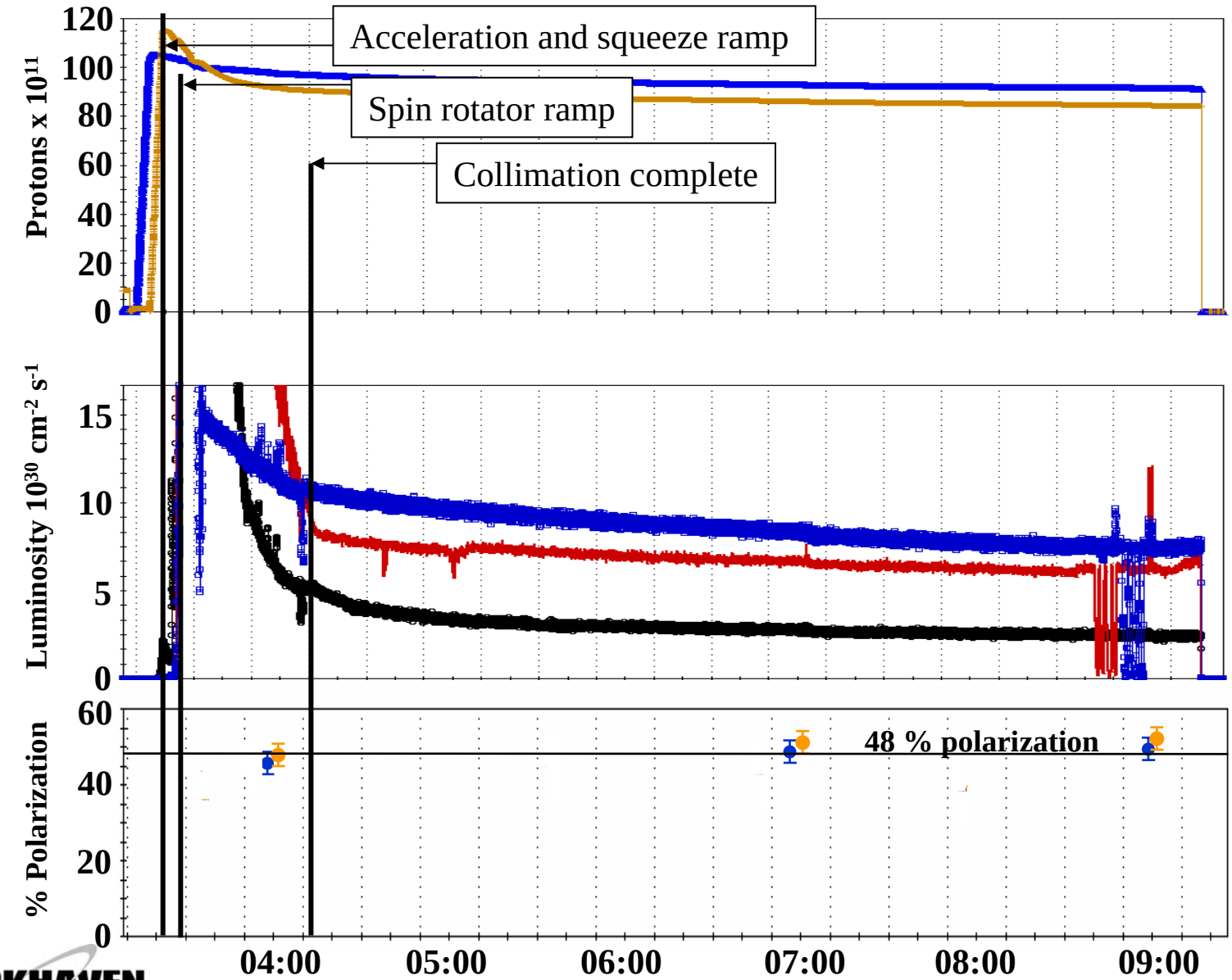
Without Siberian snakes: $\nu_{sp} = G\gamma = 1.79$ E/m $\rightarrow$ ~1000 depolarizing resonances

With Siberian snakes (local 180° spin rotators): $\nu_{sp} = ½ \rightarrow$ no first order resonances

Achieved ~ 50% beam polarization at 100 GeV

Achieved ~ 30% beam polarization at 205 GeV on first try!

Polarization survival in RHIC



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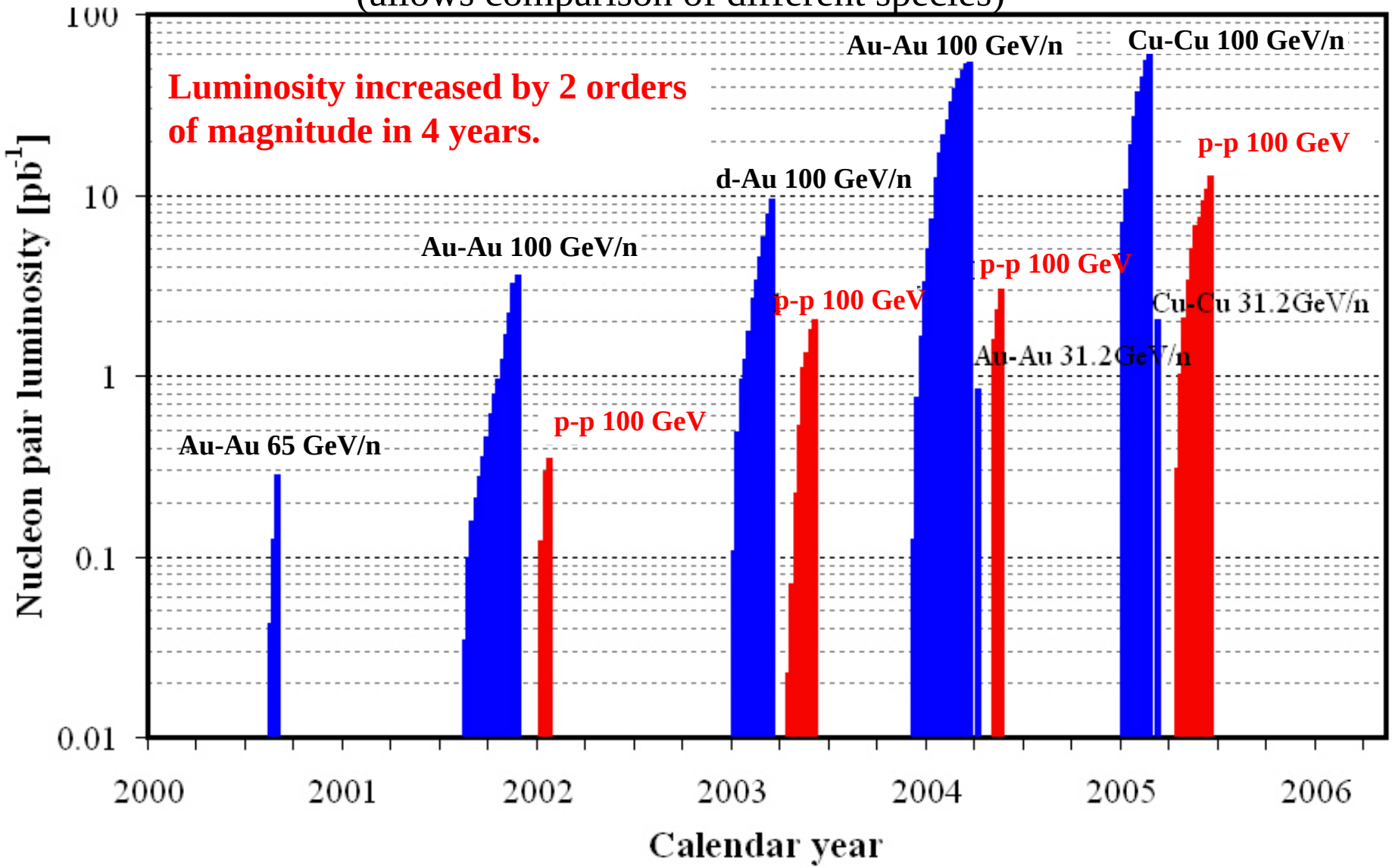
RHIC – a Uniquely Flexible High Luminosity Collider

Nucleon-pair luminosity A_1A_2L delivered to PHENIX
(allows comparison of different species)



RHIC design and achieved parameters

Mode	No of bunches	Ions/bunch [10^9]	β* [m]	Beam pol.	$\mathcal{L}_{store\ ave}$ [$cm^{-2}s^{-1}$]	$A_1A_2\mathcal{L}_{store\ ave}$ [$cm^{-2}s^{-1}$]	$A_1A_2\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$]
			Design values (1999)				
Au – Au	56	1.0	2		2×10^{26}	8×10^{30}	31×10^{30}
p – p	56	100	2		4×10^{30}	4×10^{30}	5×10^{30}
			Achieved values (up to 2005)				
Au – Au	45	1.1	1		4×10^{26}	16×10^{30}	58×10^{30}
d – Au	55	120/0.7	2		3×10^{28}	6×10^{28}	24×10^{30}
Cu – Cu	36	4.5	1		80×10^{26}	32×10^{30}	79×10^{30}
p↑ – p↑	106	90	1	49/44%	7×10^{30}	7×10^{30}	10×10^{30}
p – p	56	170	1		10×10^{30}	10×10^{30}	15×10^{30}

$$\mathcal{L} = \frac{3 f_{rev}\gamma}{2}\frac{N_B N^2}{\varepsilon\beta^*}$$

Other high luminosity hadron colliders:

	achieved	goal	scaled to 200 GeV
Tevatron (2 TeV)	162×10^{30}	200×10^{30}	20×10^{30}
LHC (14 TeV)		10000×10^{30}	140×10^{30}

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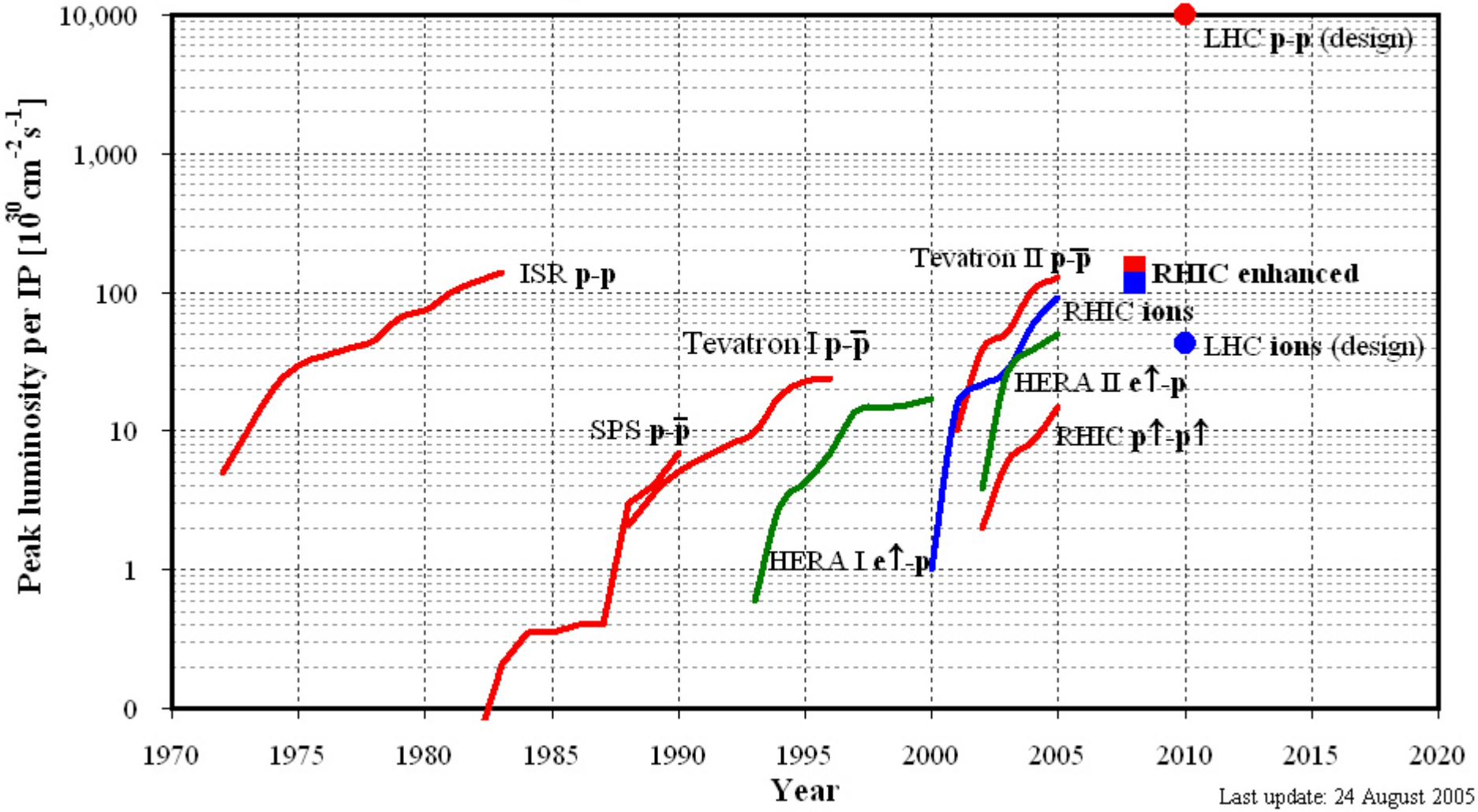
Luminosity evolution of hadron colliders



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Performance limitations with partial to-do list

- Intra-beam scattering (heavy ions)
  - Low dispersion lattice
  - Stochastic and electron cooling at 100 GeV/n
- Dynamic pressure rise from electron clouds
  - NEG coating of warm sections
  - Pre-pumping of cold sections
- Instabilities (at transition)
  - Adjust chromaticity (chromaticity jump?)
  - Avoid electron clouds
- Beam-beam (light ions and protons)
  - Eliminate ~10 Hz orbit oscillation
  - Electron lens ??
- Polarization (protons)
  - AGS: strong partial snake (maybe need 2 strong partial snakes?)
  - RHIC: 100 GeV: OK
  - RHIC: 250 GeV: ring alignment, orbit correction

Future plans for RHIC

Machine goals for next few years with upgrades in progress:

- **Enhanced RHIC luminosity (112 bunches, $\beta^* = 1$m):**
- **Au – Au: 8×10^{26} cm^{-2} s^{-1} (100 GeV/nucleon)**

$2 \times$ achieved

- **For protons also 2×10^{11} protons/bunch (no IBS):**
- **p↑ – p↑: 60×10^{30} cm^{-2} s^{-1}; 70 % polarization (100 GeV)**
  150×10^{30} cm^{-2} s^{-1}; 70 % polarization (250 GeV)
  (luminosity averaged over store delivered to 2 IRs)

$6 \times$ achieved !!

EBIS (low maintenance linac-based pre-injector; all species incl. U and pol. He3)

RHIC luminosity upgrade (e-cooling, ~10 × more luminosity, R&D in progress)

eRHIC (high luminosity (1×10^{33} cm^{-2} s^{-1}) eA and pol. ep collider)

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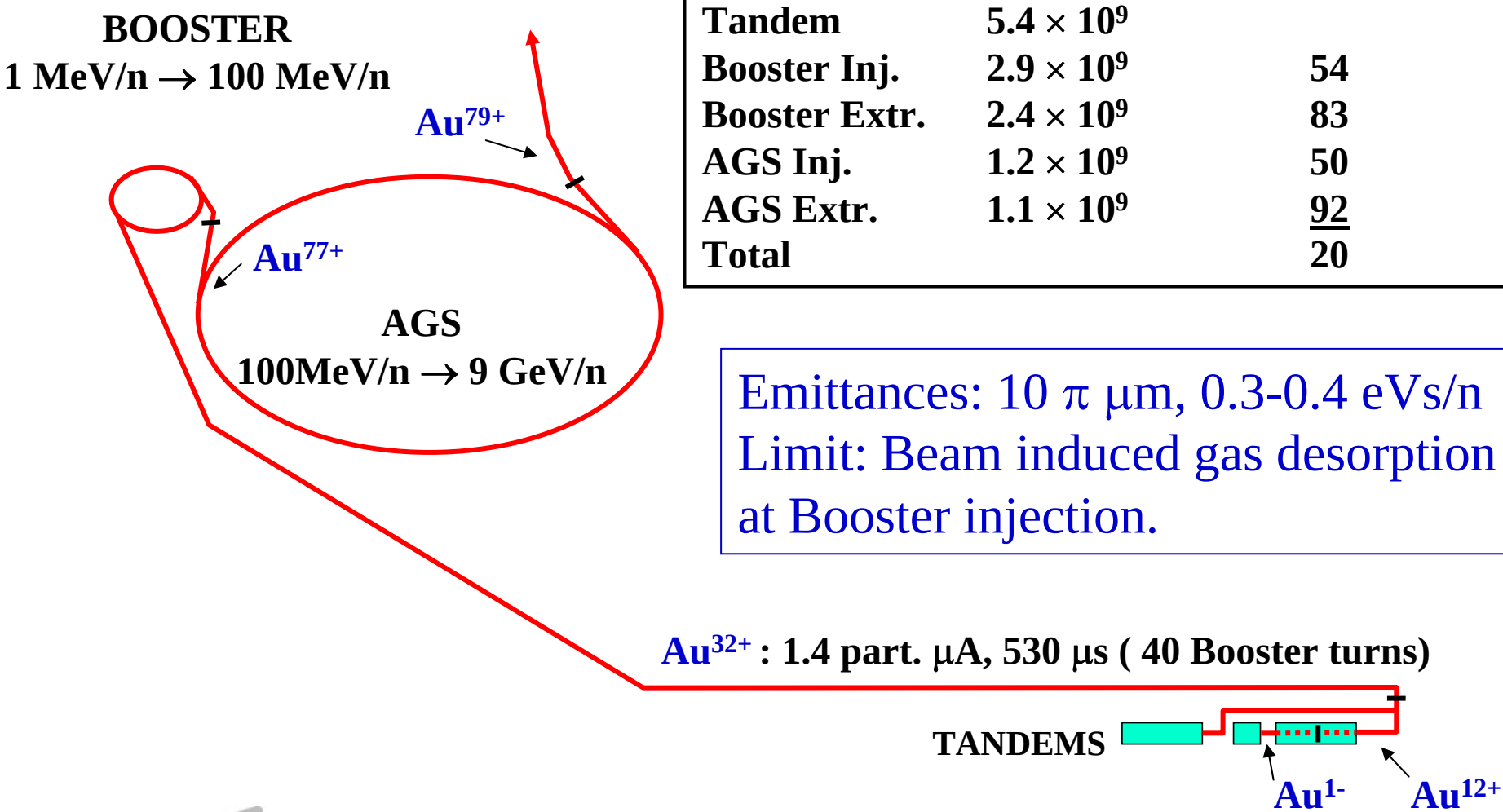
Injector performance – bright bunches for collider



	Intensity/RHIC bunch	Efficiency[%]
Tandem	5.4×10^9	
Booster Inj.	2.9×10^9	54
Booster Extr.	2.4×10^9	83
AGS Inj.	1.2×10^9	50
AGS Extr.	1.1×10^9	92
Total		20

Emittances: 10 π μm, 0.3-0.4 eVs/n
Limit: Beam induced gas desorption at Booster injection.

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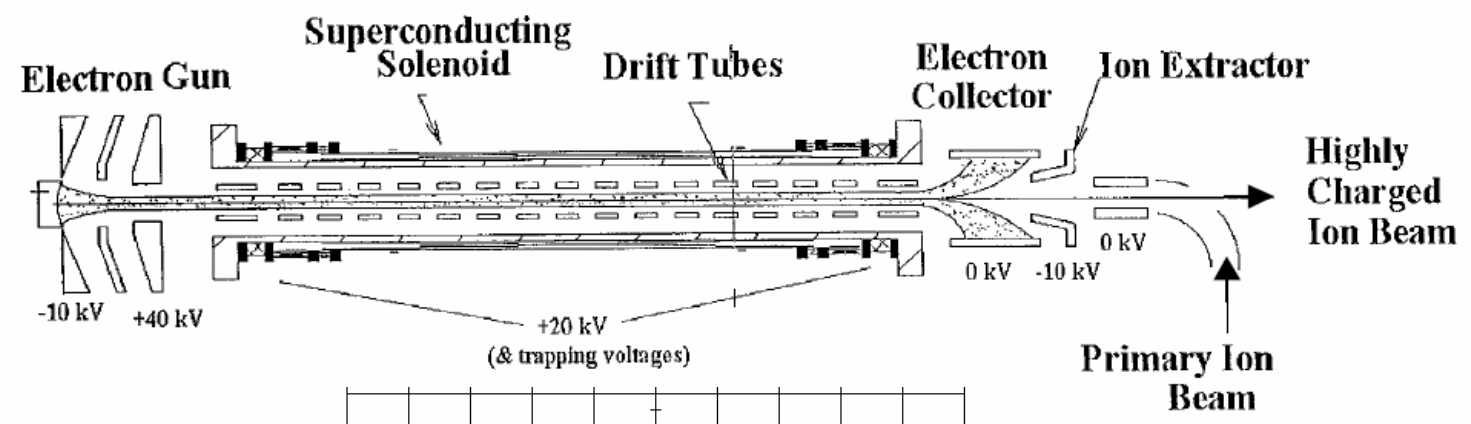
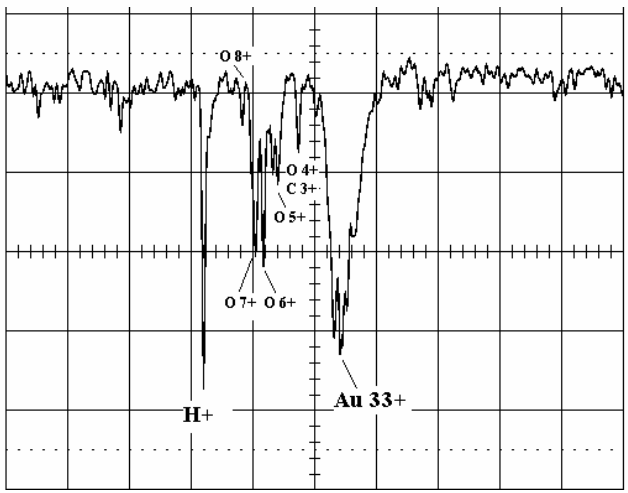
Electron Beam Ion Source (EBIS)

- New high brightness, high charge-state pulsed ion source, ideal as source for RHIC
- Produces beams of ALL ion species including noble gas ions, uranium (RHIC) and polarized He^3 (eRHIC)
- Achieved 1.7×10^9 Au^{33+} in 20 μs pulse with 8 A electron beam (60% neutralization)
- CD0 and CD1 received, construction schedule: FY2006 – 09





Gold charge state with only 40 ms confinement time.

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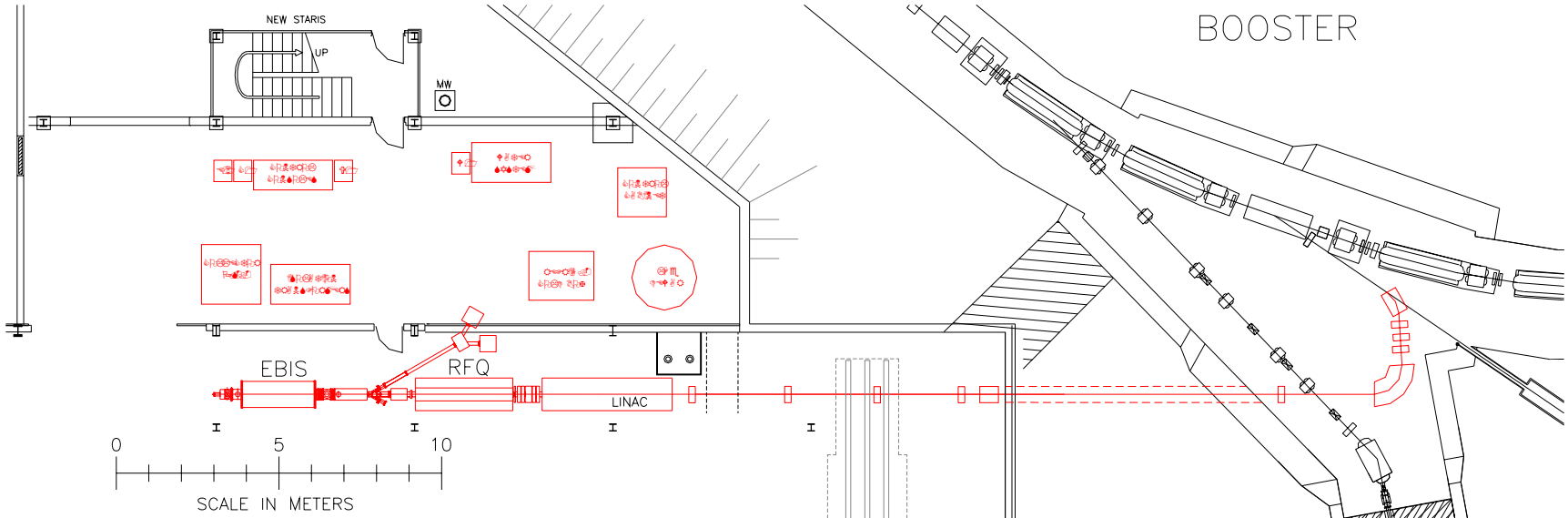
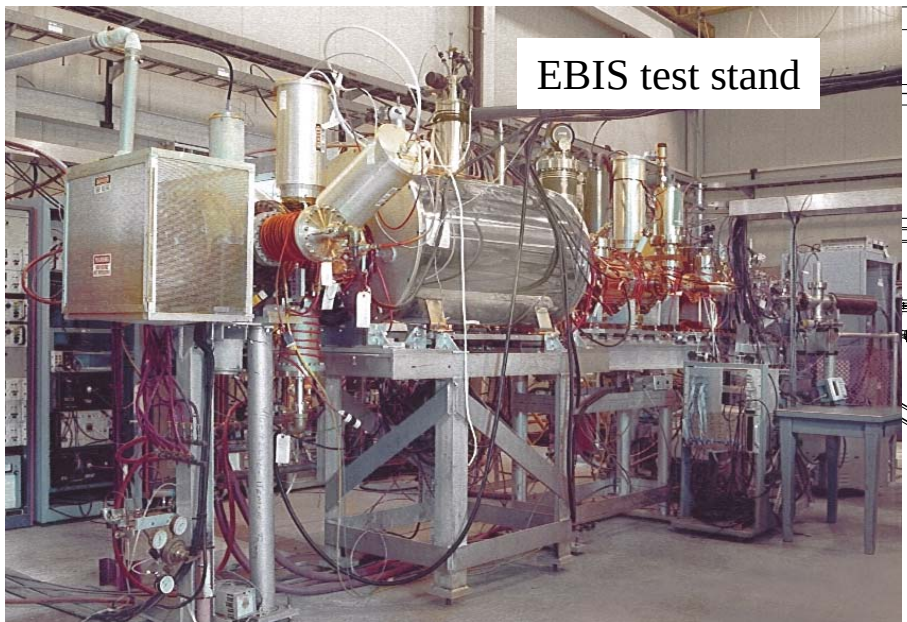
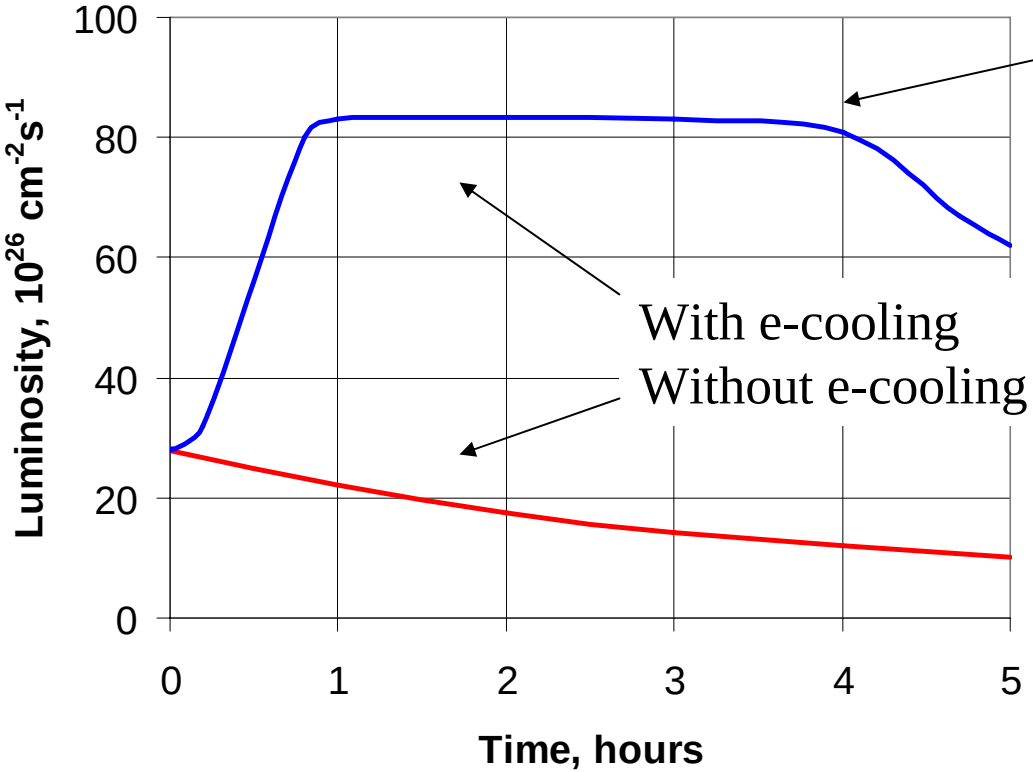
EBIS layout


NEW STARIS
UP
MW
EBIS
RFQ
LINAC
0
5
10
SCALE IN METERS


EBIS test stand

BOOSTER
H–
INJECTION
LINE

RHIC luminosity upgrades

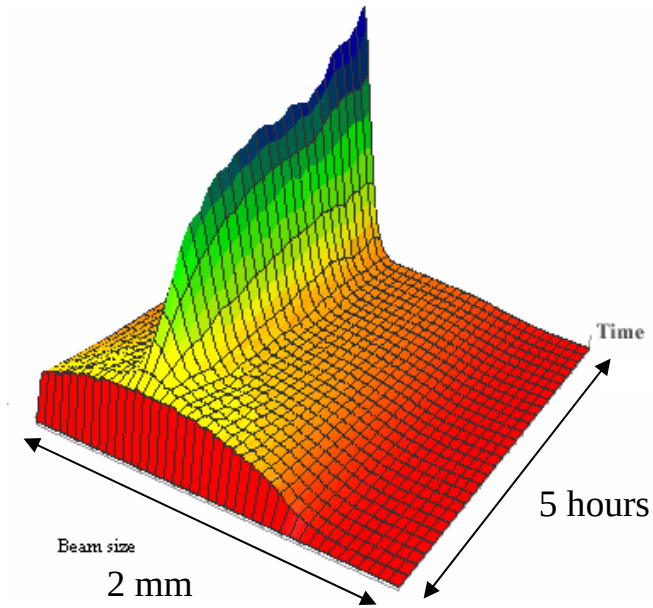


Luminosity leveling through continuously adjusted cooling

Store length limited to 4 hours by "burn-off"

Four IRs with two at high luminosity

Transverse beam profile during store



Also may be able to pre-cool polarized protons at injection energy

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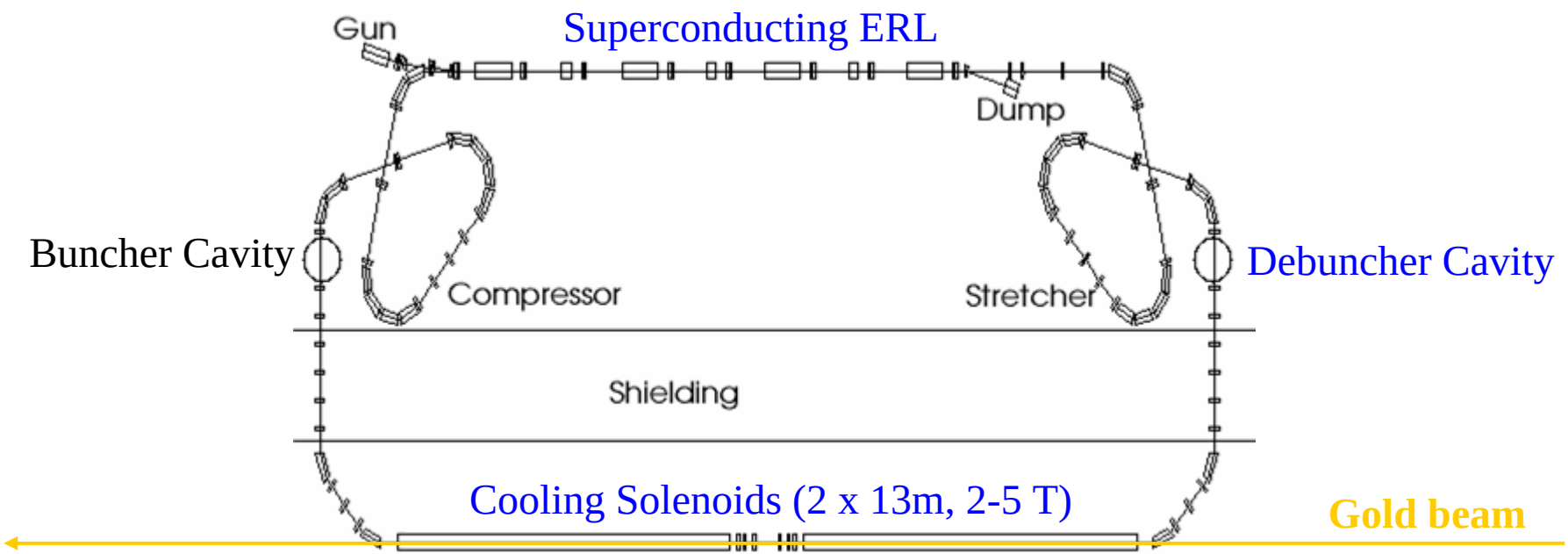
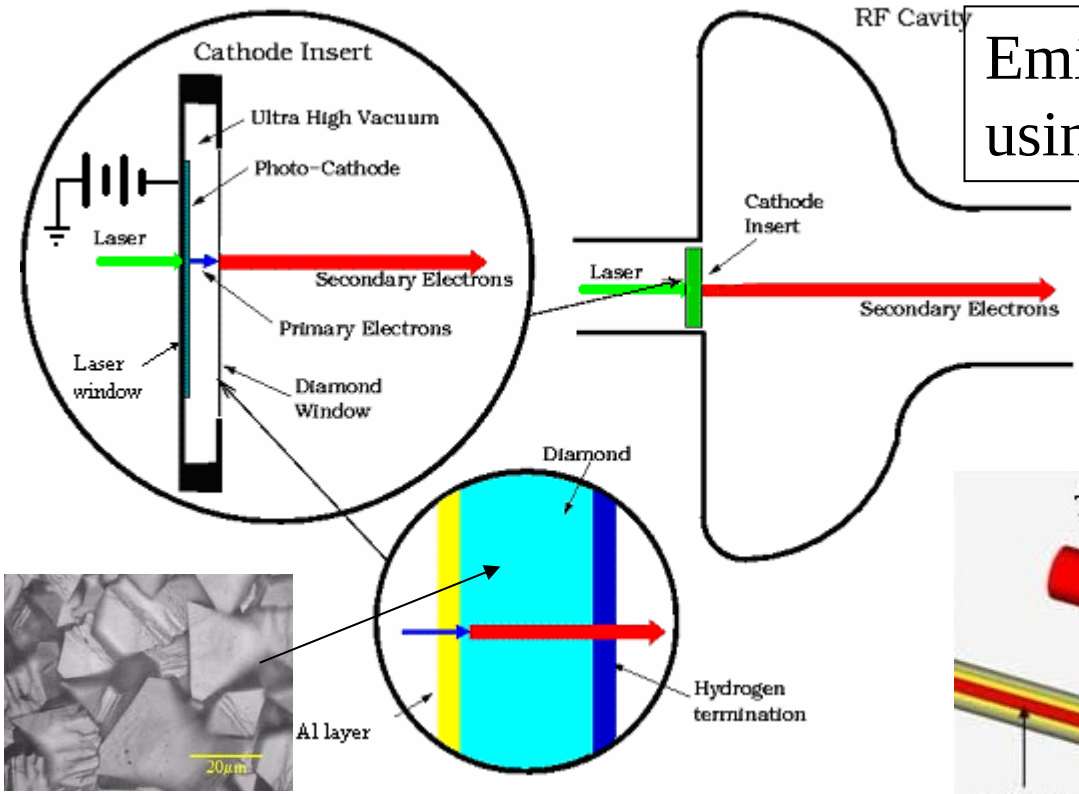
(Magnetized) electron cooling R&D

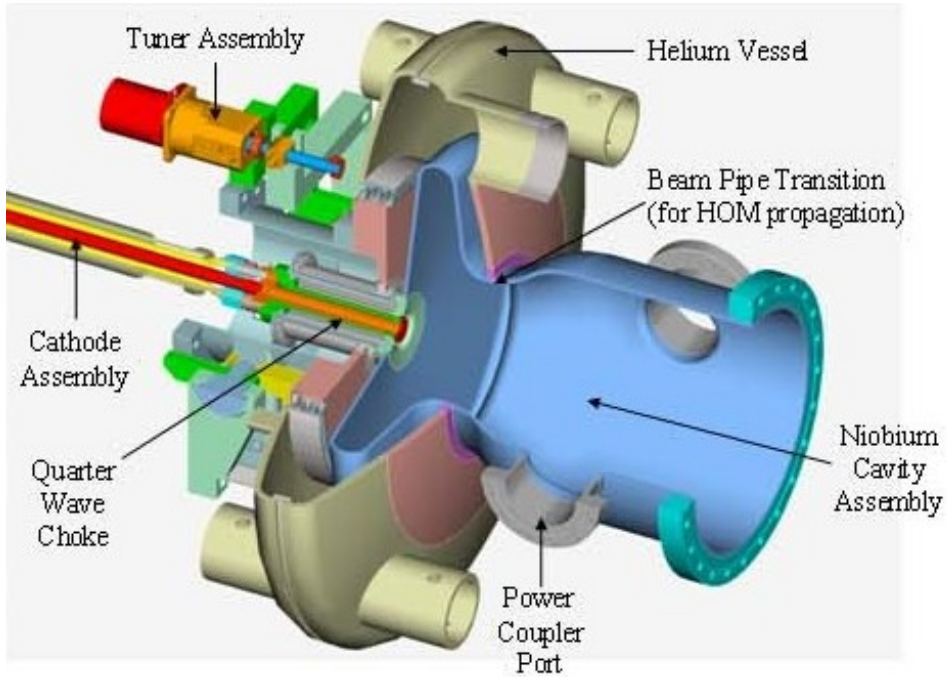


- Benchmarking of IBS and cooling simulation codes
- (Demonstrate high precision (<10 ppm) solenoid (2-5 T))
- Demonstrate 20 nC, 100-200 mA 703.8 MHz CW SCRF electron gun
- Develop 703.8 MHz CW superconducting cavity for high intensity beams
- Build R&D Energy Recovering Linac (ERL)

CW Photo-cathode and Superconducting rf Gun R&D



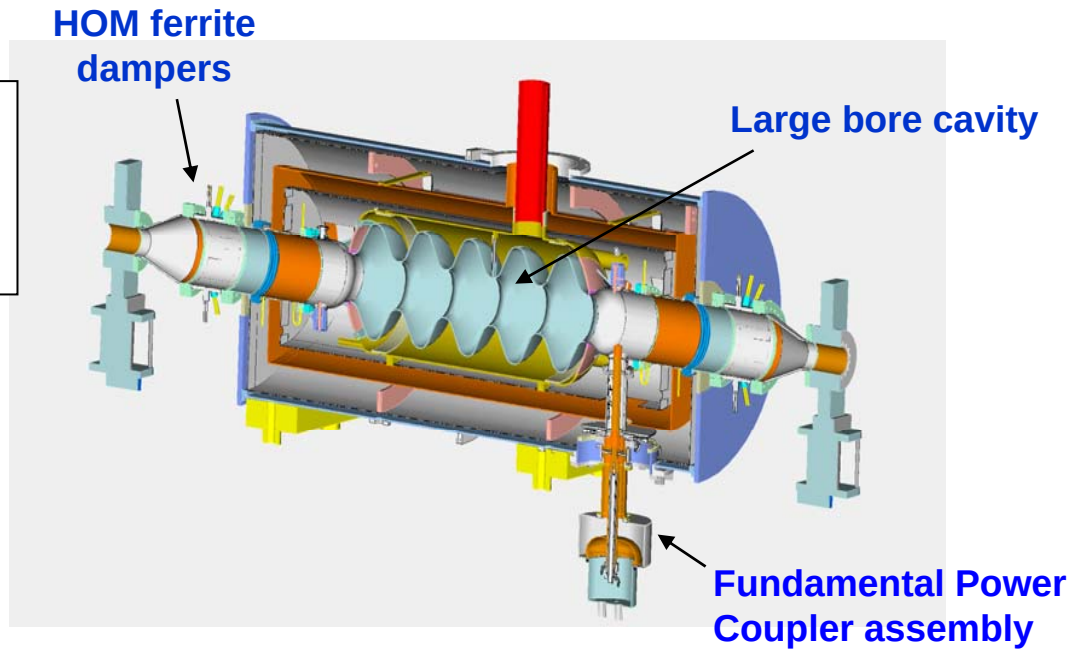
Emission enhancement (x 30-80) using a diamond window

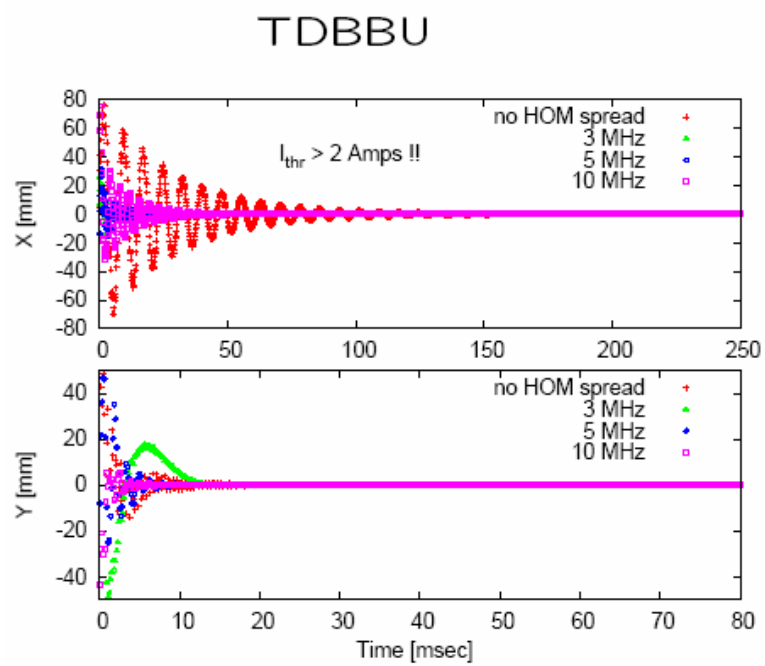


Initial design for a superconducting gun with diamond amplified photo-cathode.

SRF cavity for ampere current.

CW cavity without trapped HOM and with room temp. ferrite dampers Designed for 0.5 A CW e-beam.





Copper model tested successfully

RHIC II Luminosities with Electron Cooling

Gold collisions (100 GeV/n x 100 GeV/n):	**w/o e-cooling**	**with e-cooling**
Emittance (95%) $\pi\mu m$	$15 \rightarrow 40$	$15 \rightarrow 3$
Beta function at IR [m]	1.0	$1.0 \rightarrow 0.5$
Number of bunches	112	112
Bunch population [10^9]	1	$1 \rightarrow 0.3$
Beam-beam parameter per IR	0.0016	0.004
Ave. store luminosity [10^{26} cm^{-2} s^{-1}]	8	70
Pol. Proton Collision (250 GeV x 250 GeV):		
Emittance (95%) $\pi\mu m$	20	12
Beta function at IR [m]	1.0	0.5
Number of bunches	112	112
Bunch population [10^{11}]	2	2
Beam-beam parameter per IR	0.007	0.012
Ave. store luminosity [10^{32} cm^{-2} s^{-1}]	1.5	5.0

Mid-term strategy plan (preliminary)

A timeline for physics operation, detector upgrades, machine evolution

FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012

Au-Au, d-Au, Ion scans
pp 200 & pp 500 development

High statistics Au Au; 500 GeV Spin Runs

Short-term upgrades:
HBD, TOF, DAQ, FMS, Muon Trigger

Mid-Term Upgrades:
Vtx detectors, NCC, forward tracking

RHIC II Construction

Machine and detector R&D; continued luminosity improvements

LHC Heavy Ion Program

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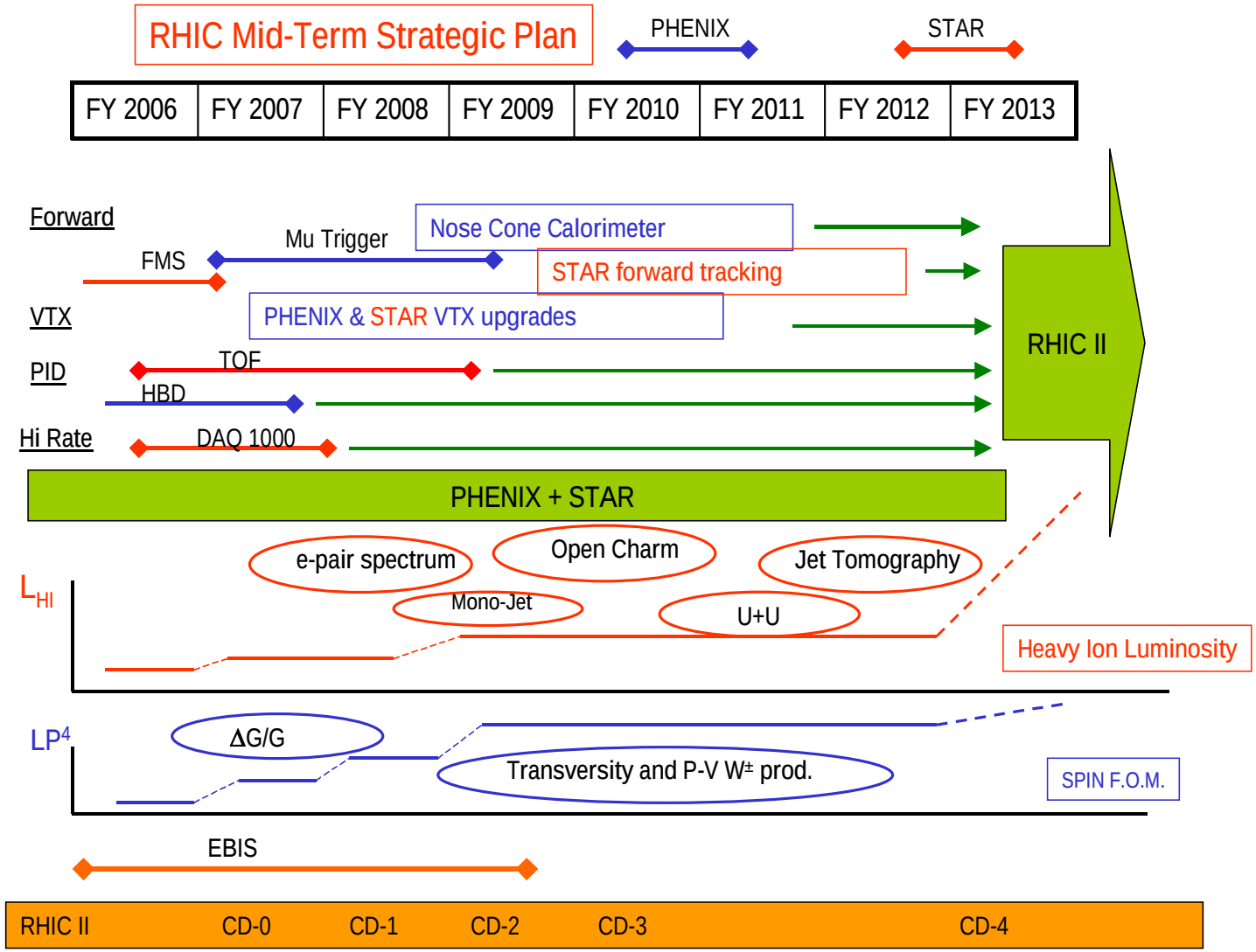
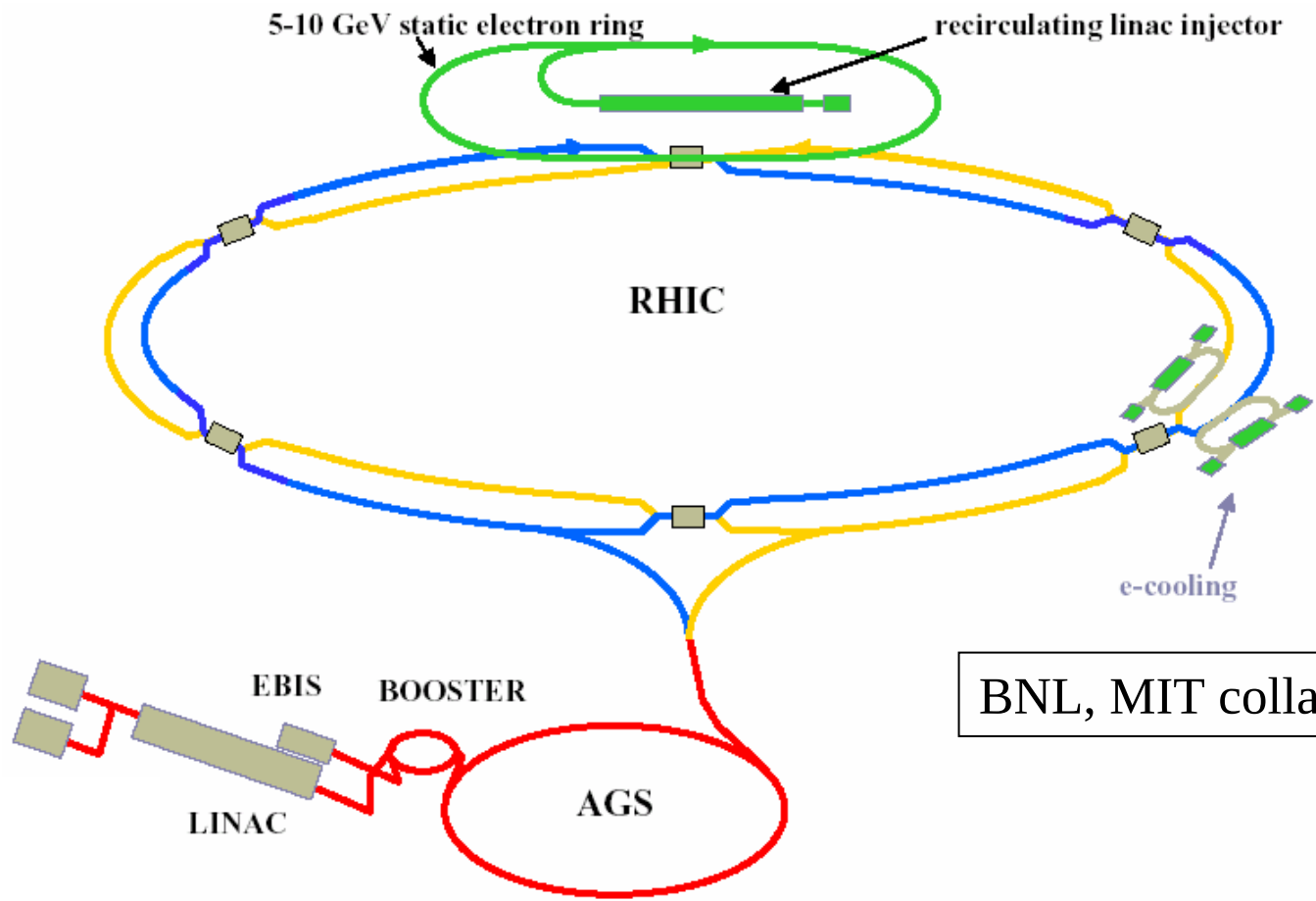
Mid-term strategy plan (preliminary)



Electron-Ion Collider at RHIC: eRHIC

- 10 GeV, 0.5 A e-ring with 1/3 of RHIC circumference (similar to PEP II HER)
- 10 GeV electron beam → $s^{1/2}$ for e-A : 63 GeV/u; $s^{1/2}$ for e↑-p↑: 100 GeV
- Electron cooling required for high luminosity e-A and low energy e-p collisions
- Polarized e-He3 (e-n) collisions with EBIS
- Existing RHIC interaction region allows for typical asymmetric detector
- Luminosity: up to 1×10^{33} $cm^{-2}s^{-1}$ per nucleon (1×10^{34} $cm^{-2}s^{-1}$ with linac – ring scheme)



BNL, MIT collaboration

Summary

Since 2000 RHIC has collided, for the first time,

- Heavy ions
- Light on heavy ions
- Polarized protons (45% beam polarization)

Heavy ion luminosity increased by factor 100

For next 4 years planned:

- Factor 2 increase in heavy ion luminosity
- Factor 6 increase in proton luminosity with 70 % polarization

Future upgrades:

- RHIC luminosity upgrade (~10x) using electron cooling at store
- Electron-ion collider eRHIC