RHIC operational status and upgrade plans

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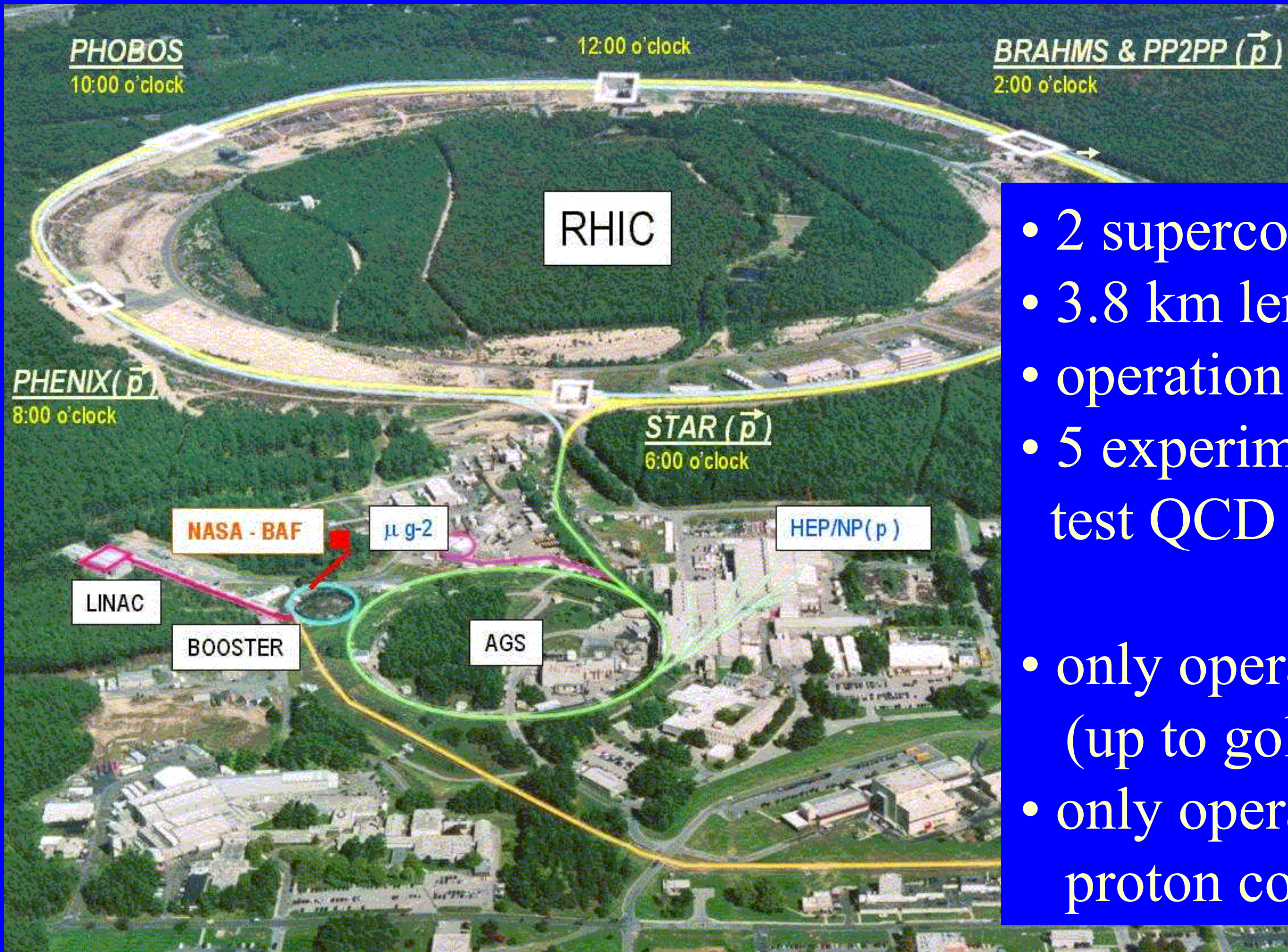
Thanks to many at BNL.

European Particle Accelerator Conference, Edinburgh
27 June 2006

Outline

1. Status
   – Achieved performance
   – Performance limits
2. Upgrades
   – Enhanced Design parameters
   – Electron Beam Ion Source (EBIS)
   – RHIC II (electron cooling)
   – eRHIC

Relativistic Heavy Ion Collider



- 2 superconducting rings
- 3.8 km length
- operation since 2000
- 5 experiments so far, test QCD

- only operating ion collider (up to gold 100 GeV/n)
- only operating polarized proton collider

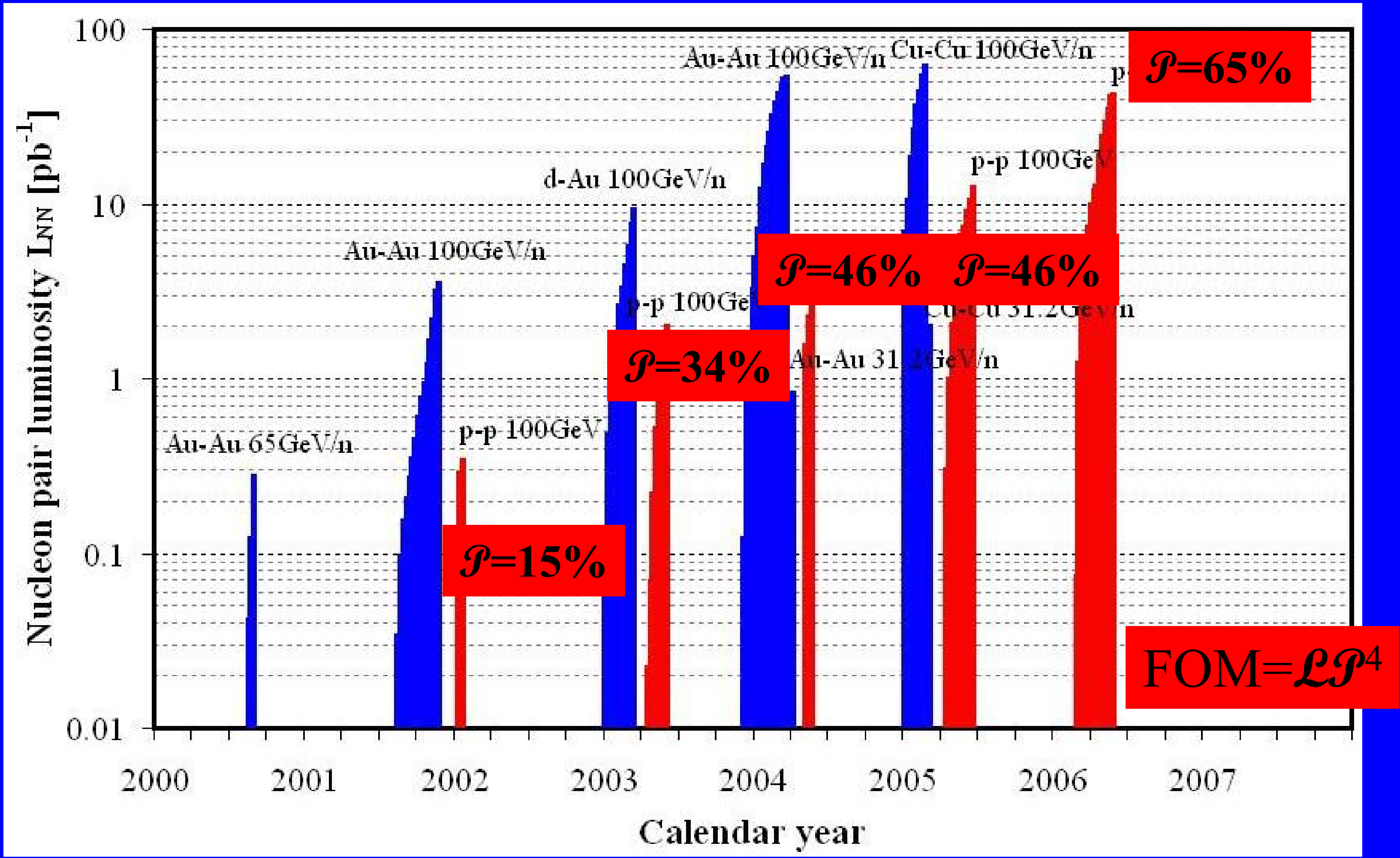
RHIC running modes

Au–Au	10, 28, 31, 65, <u>100</u> GeV/n
d–Au	<u>100</u> GeV/n ← **Important control experiment in physics program**
Cu–Cu	11, 31, <u>100</u> GeV/n
polarized p–p	11, 31, <u>100</u>, 205, 250 GeV

Some modes only for days – fast machine setup essential.

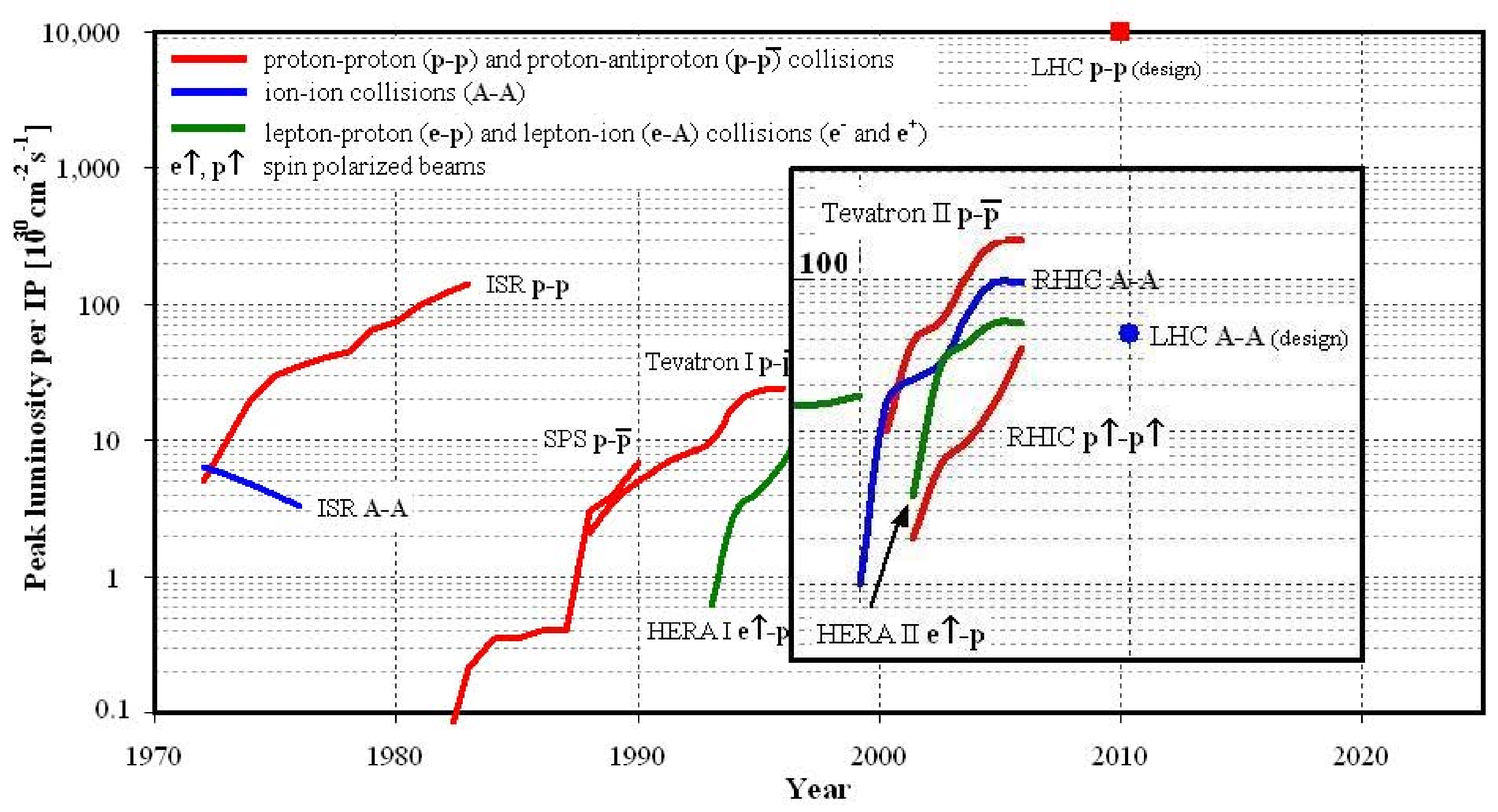
RHIC delivered luminosity

Delivered luminosity increased by 2 orders of magnitude in 5 years.



Delivered to PHENIX, one of RHIC's high-luminosity experiments.

Hadron collider luminosities

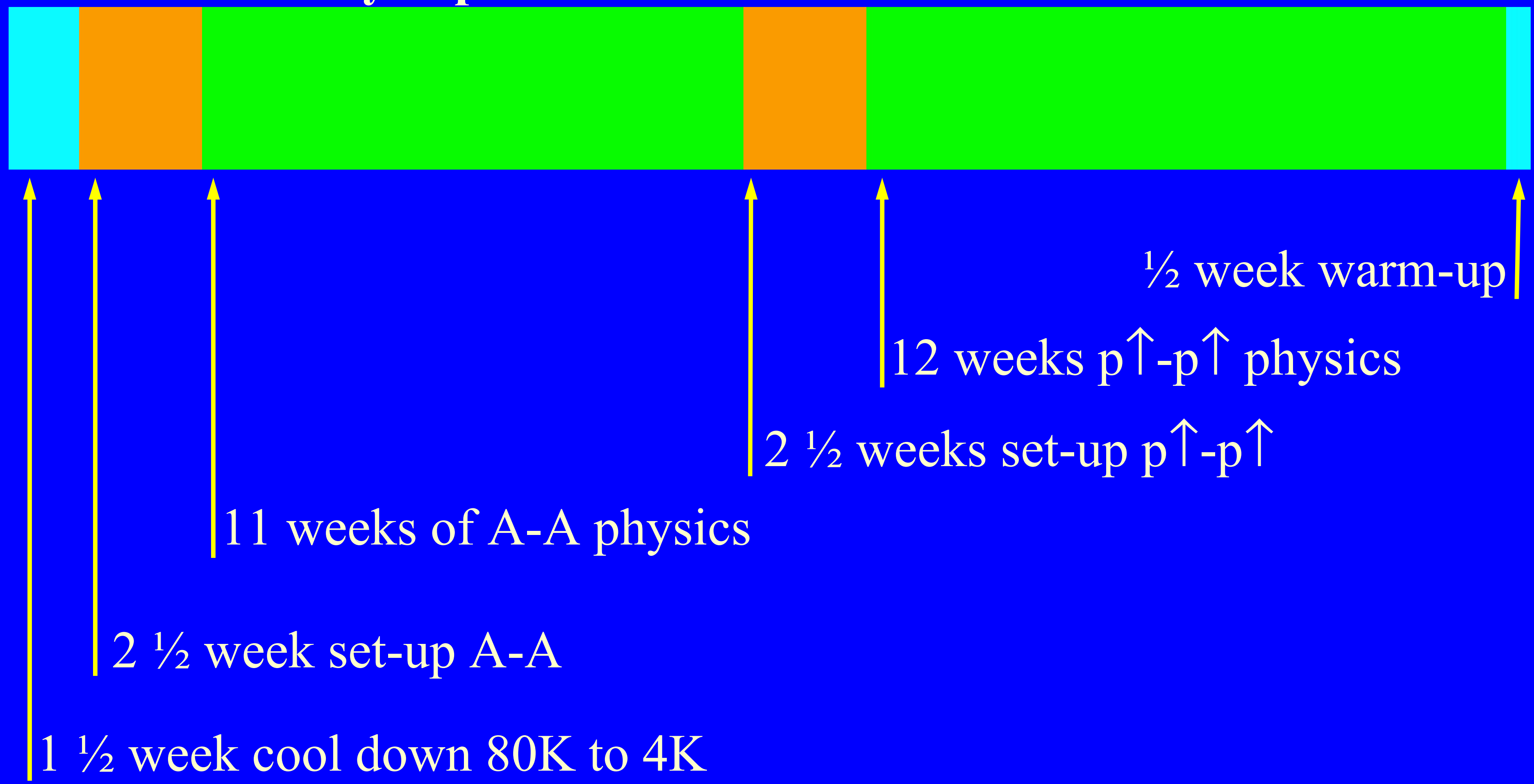


Show nucleon-pair luminosity for ions: $\mathcal{L}_{NN}(t) = A_1 A_2 \mathcal{L}(t)$

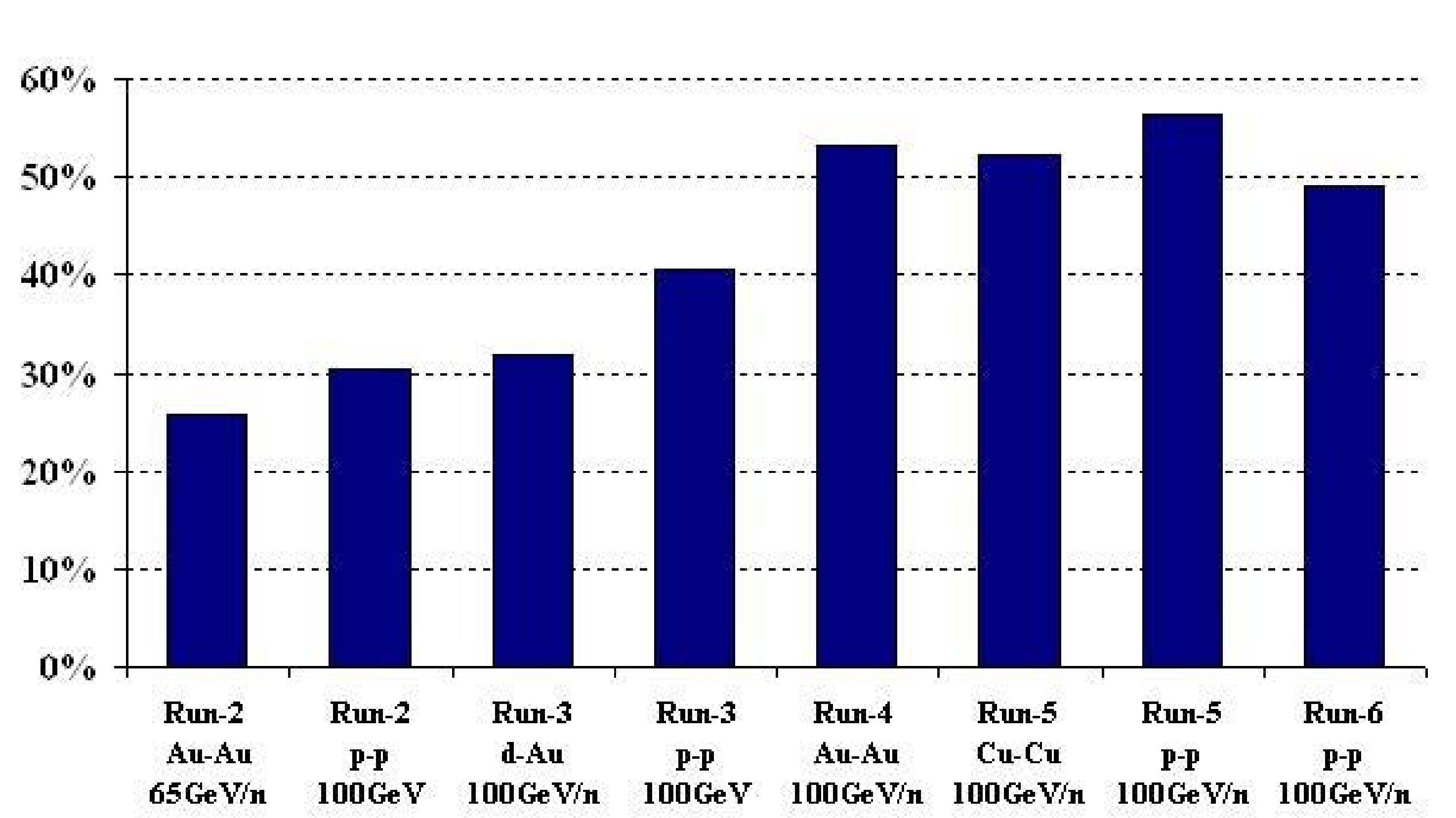
(can compare different ion species, including protons)

Typical year (Run)

~30 weeks of cryo operation



Calendar time in store after setup



goal 100h/week

Rest of the time:

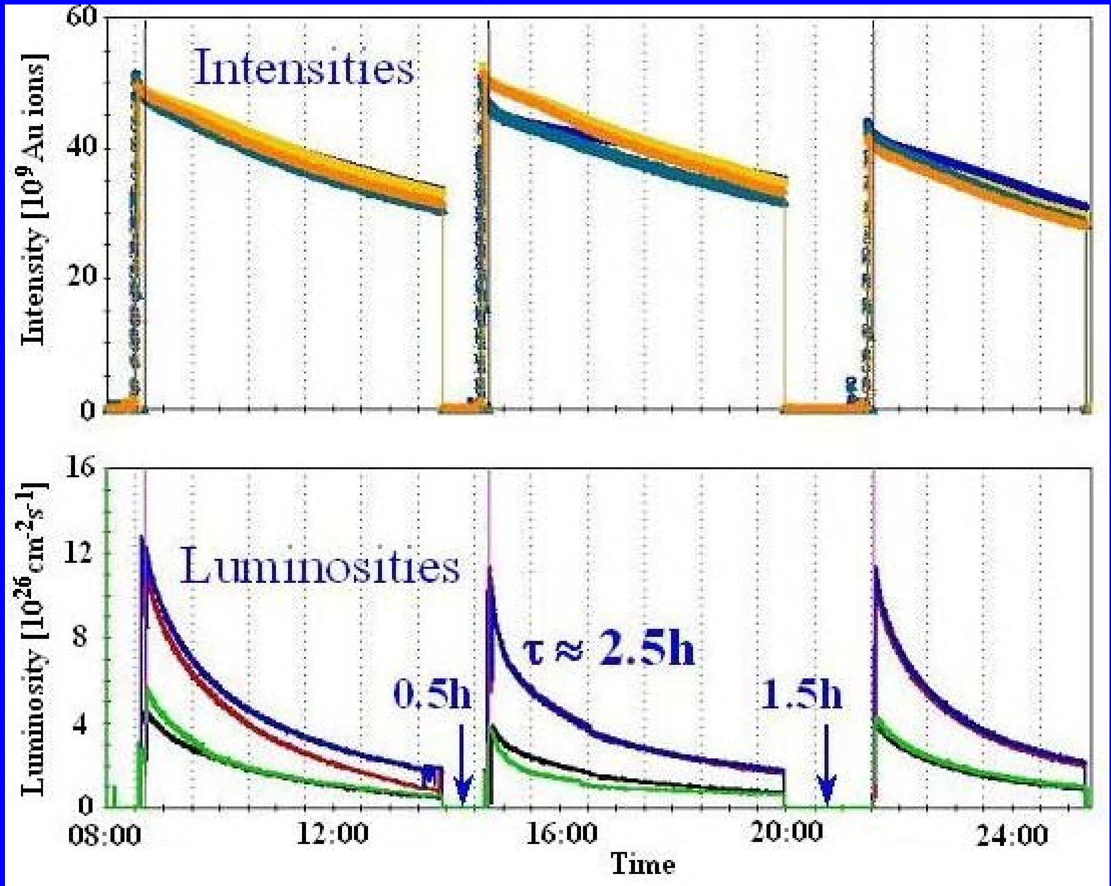
~20% machine tuning/ramping

~15% failures

~10% machine development and accelerator physics experiments

F. Pilat et al., THPCH197

Performance limit: IBS for heavy ions



Beam and luminosity lifetime for Au – Au dominated by IBS

$$\tau^{-1} \propto \frac{Z^4}{A^2} N_b$$

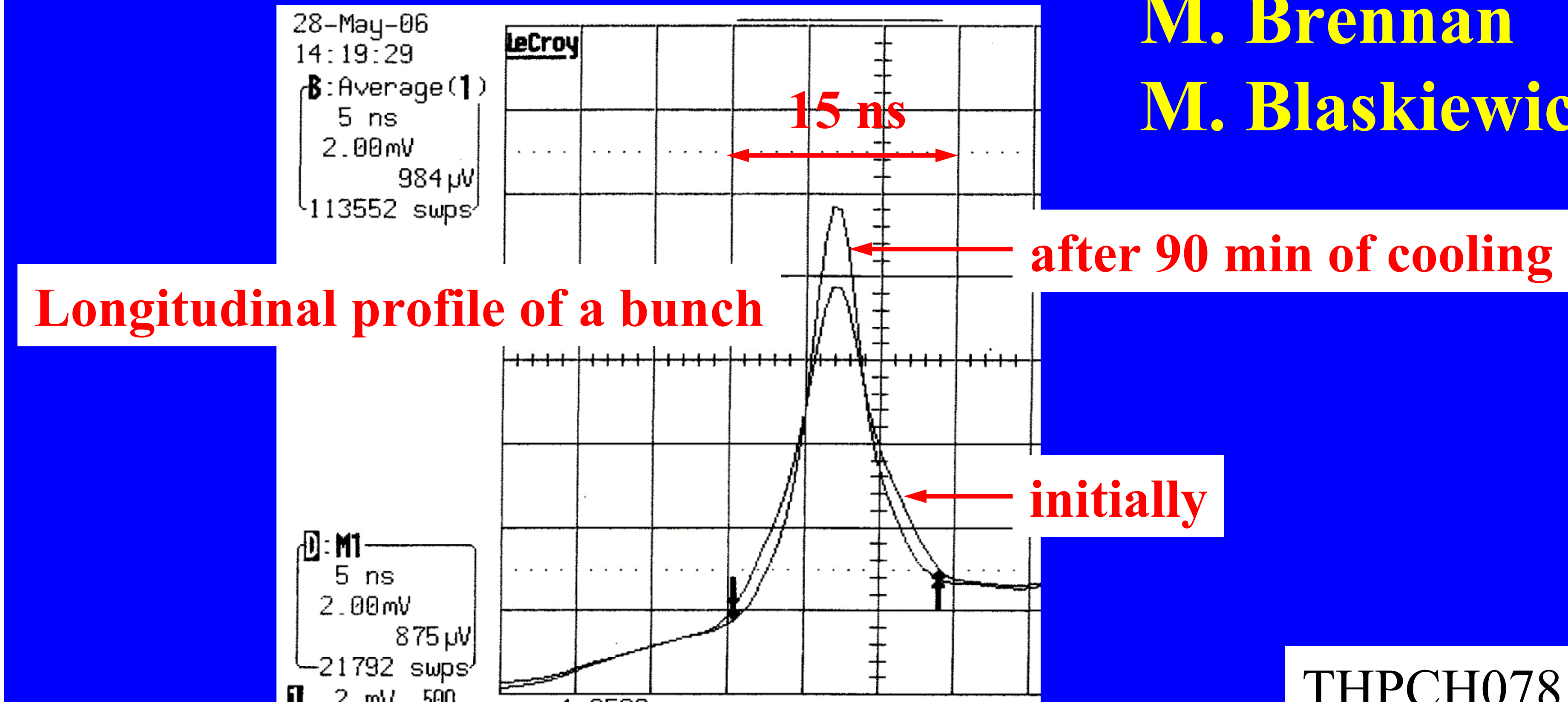
[Factor 10 between Au an p]

- Debunching requires continuous abort gap cleaning
- Luminosity lifetime requires frequent refills
- Ultimately need cooling at full energy

Recently demonstrated longitudinal stochastic cooling in bunch of 2×10^9 protons at 100 GeV

(~1% of normal p intensity, ~ normal Au intensity)

M. Brennan
M. Blaskiewicz



THPCH078

Expect to stop debunching of Au beams → 20-50% more luminosity

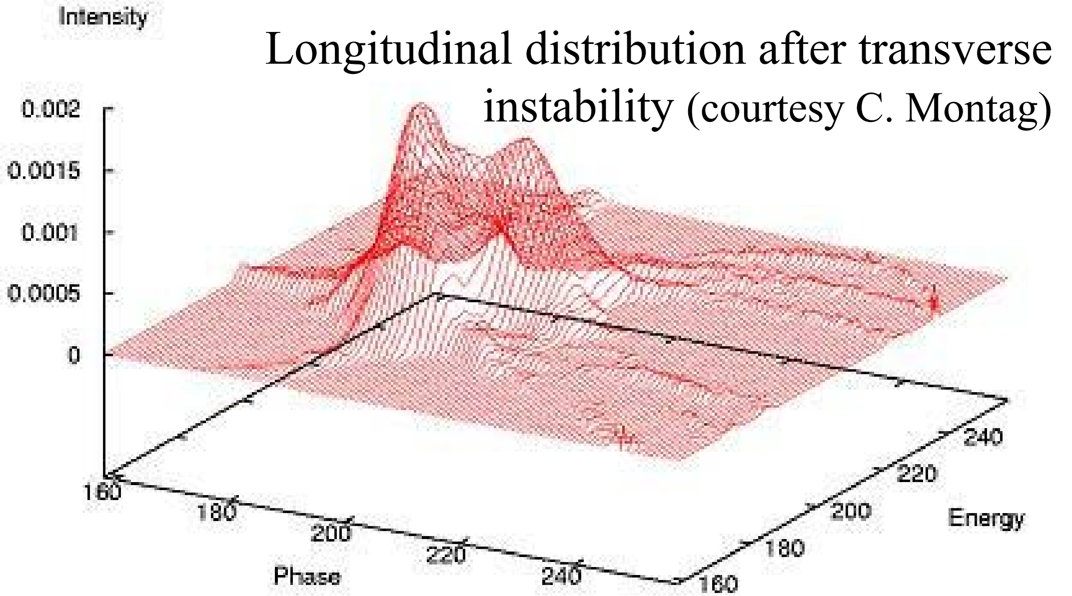
Performance limit: transition crossing

Crossing transition with slowly ramping sc. Magnets
(all ions except protons)

→ Instability limits bunch intensities for ions (~1.5 – 2.0×10^{11} e)

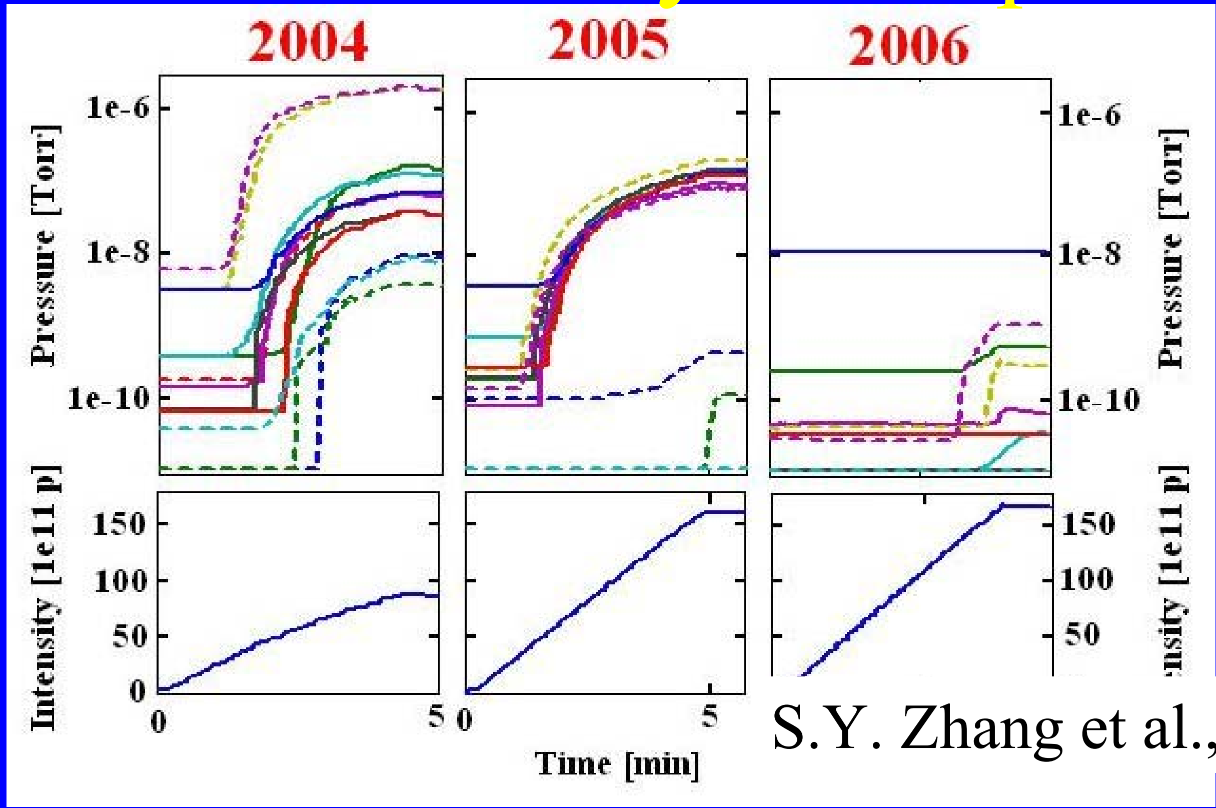
→ Instability is fast (τ =15 ms), transverse, single bunch
(electron clouds can lower stability threshold)

- γ_t-jump implemented
- Octupoles near transition
- Chromaticity control
(need ξ-jump for higher bunch intensities)



Longitudinal distribution after transverse instability (courtesy C. Montag)

Performance limit: dynamic pressure rise



S.Y. Zhang et al., MOPLS025

Dynamic pressure rise caused by electron clouds

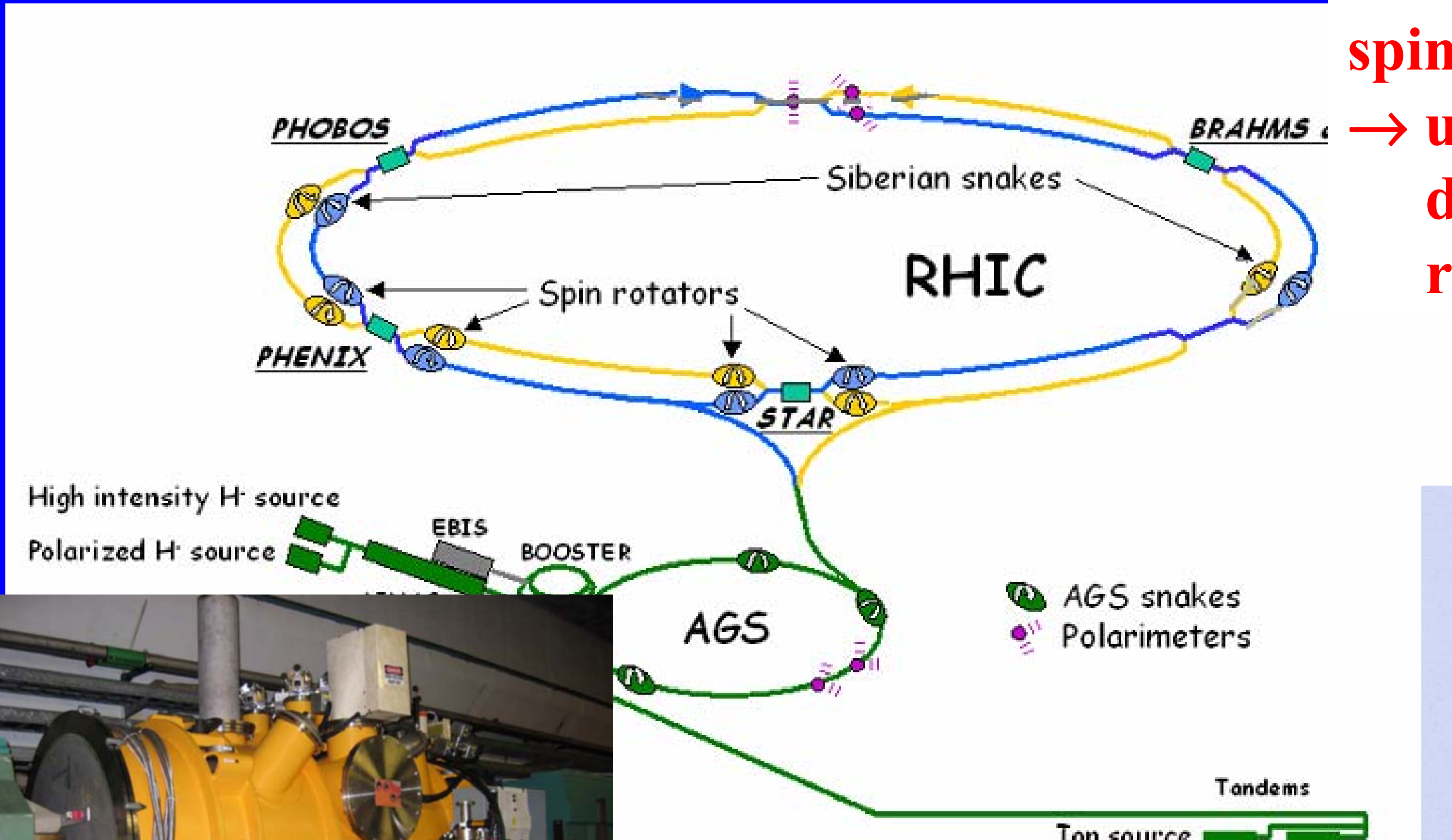
Upgraded warm and cold vacuum system:

- installed 430m of NEG pipes (~700m warm sections)
- reduced pressure in cold section to 1e-7 Torr before cool-down

Dynamic pressure currently not a concern in operation

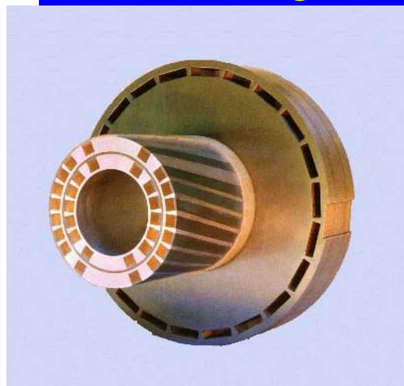
Performance limit: polarization of protons

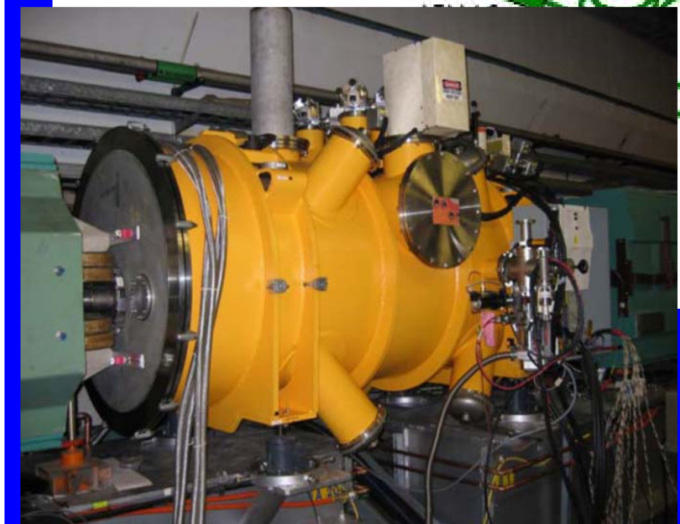
Equipment for polarized beam



Snakes change spin direction → used to avoid depolarizing resonances

RHIC helical magnet





Superconducting helical magnet in AGS – most complex magnet ever built by Superconducting Magnet Division

Performance limit: polarization of protons

First operational use of AGS cold snake in 2006

- Raised AGS polarization from 60% to 65%
- Removed intensity dependence of polarization

Polarization by machine

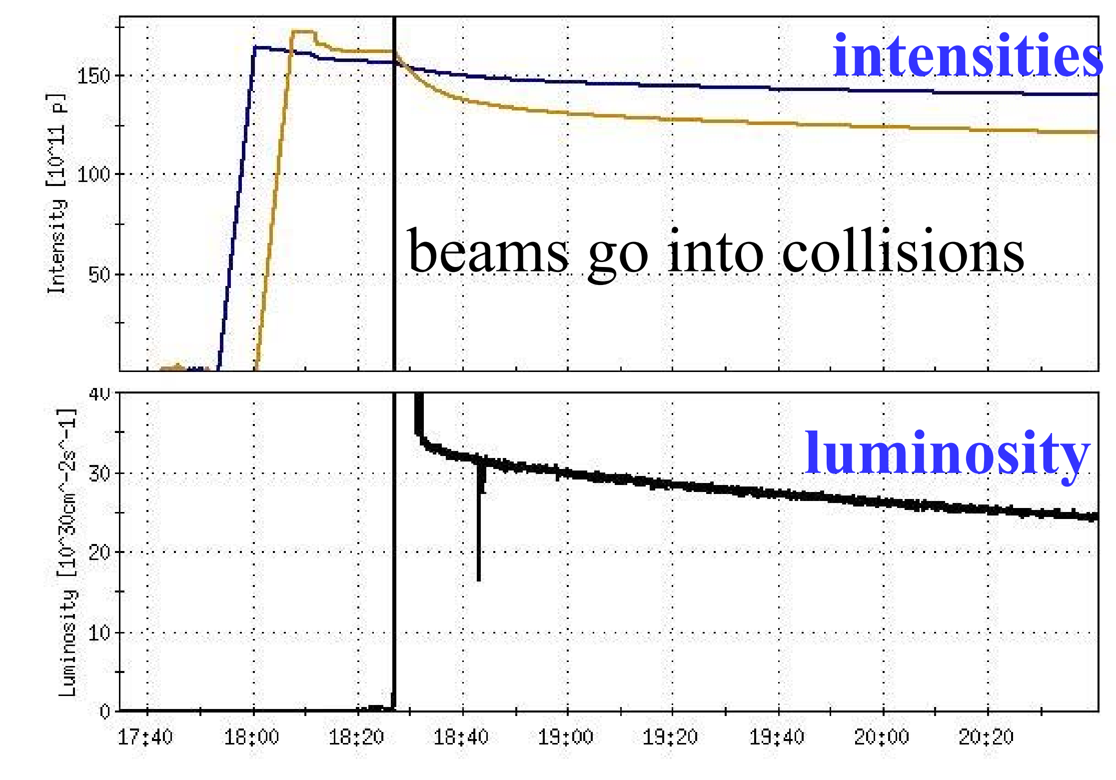
- Source → 85%
- AGS extraction → 65%
- RHIC store
  - 100 GeV (no loss) → 65%
  - 205 GeV (in 2005) → 30%
  - 250 GeV (yesterday!) → 47%

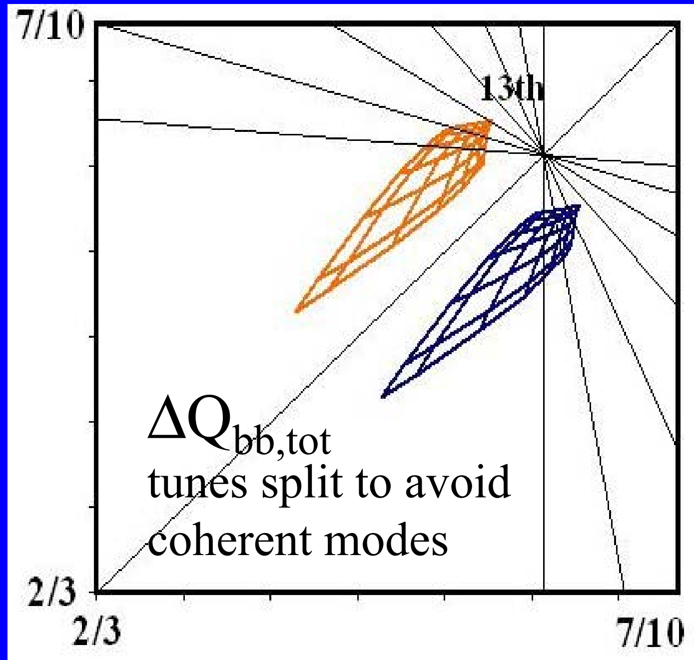
H. Huang et al. MOPCH100

M. Bai et al., PRL 96 174801 (2006).

Blue only, current record energy for p↑

Performance limit: beam-beam for p↑- p↑





- Total beam-beam induced tune spread reached $\Delta Q_{bb,tot} = 0.012$
- Other sources of tune spread: $\Delta Q \approx 0.005$
  - nonlinear chromaticity (correction planned for next year)
  - triplet errors (locally corrected)
- Sources for orbit and tune modulation

RHIC upgrades

Upgrade goals

- More luminosity and polarization
- More flexibility and reliability

Four main upgrades planned:

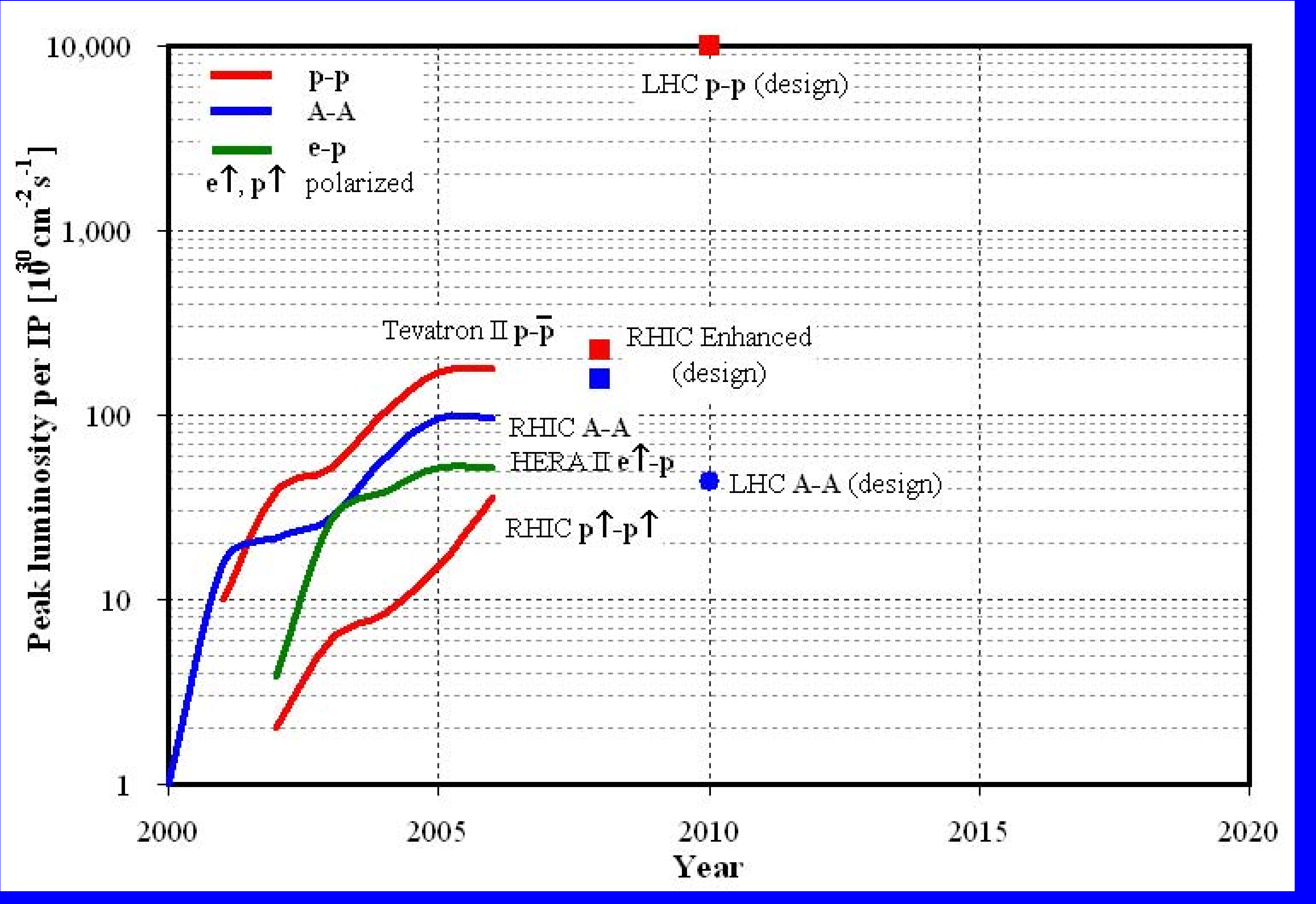
1. Enhanced Design parameters
2. Electron Beam Ion Source (EBIS)
3. RHIC II (electron cooling)
4. eRHIC

Upgrade 1: Enhanced Design (~2008*)

Parameter	unit	**Achieved**	**Enhanced design**	
Au-Au operation				
Energy	GeV/n	100	100	
No of bunches	…	45	111	
Bunch intensity	10^9	1.1	1.0	
Average $\mathcal{L}$	**10^{26}cm^{-2}s^{-1}**	**5**	**8**	← **1.6×** Should be possible in next Au-Au run
p↑- p↑ operation				
Energy	GeV	100	250	
No of bunches	…	111	111	
Bunch intensity	10^{11}	1.4	2.0	
Average $\mathcal{L}$	**10^{30}cm^{-2}s^{-1}**	**20**	**150**	← **7.5×**
Polarization $\mathcal{P}$	**%**	**65**	**70**	← **+5%**

* First 250 GeV p↑-p↑ physics run currently scheduled for 2009

Upgrade 1: Enhanced Design (~2008)



Upgrade 2: Electron Beam Ion Source (EBIS)

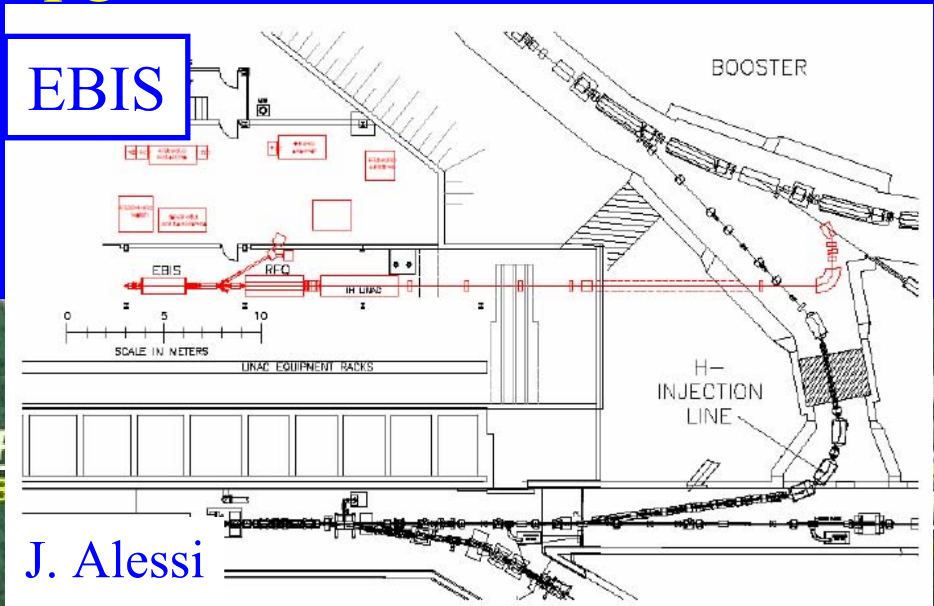
- Current ion pre-injector:
  upgraded Model MP Tandem (electrostatic)
- Plan to replace with:
  Electron Beam Ion Source, RFQ,
  and short linac

→ Can avoid reliability upgrade of Tandem

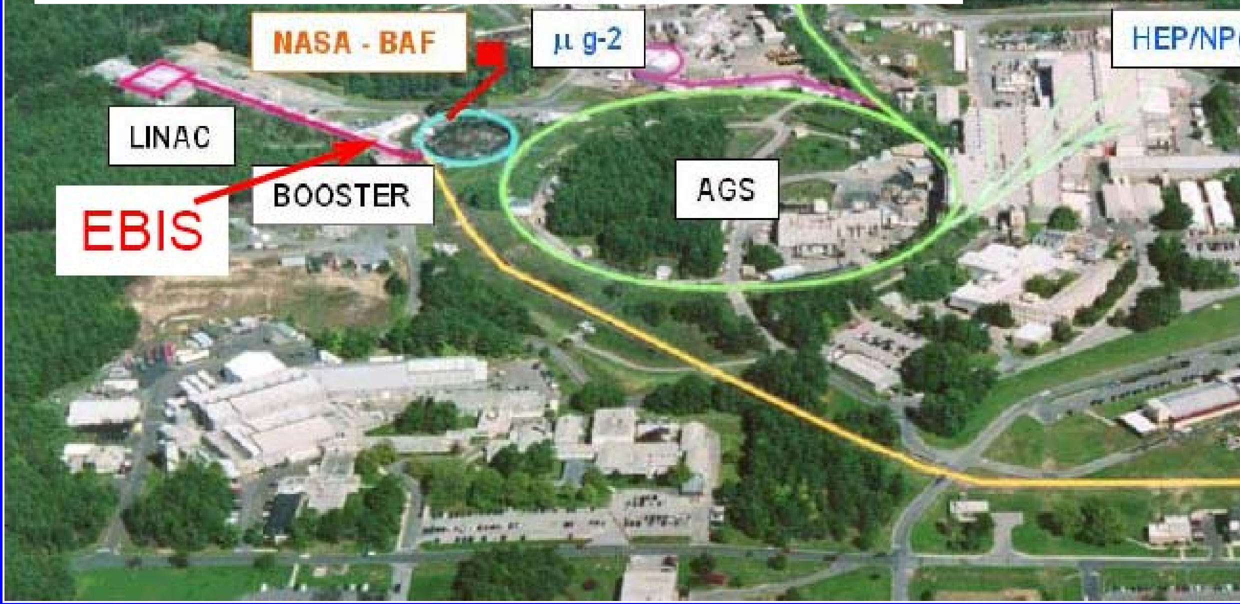
→ Expect improved reliability at lower cost

→ New species: U, ^{3}He↑

Upgrade 2: Electron Beam Ion Source (EBIS)

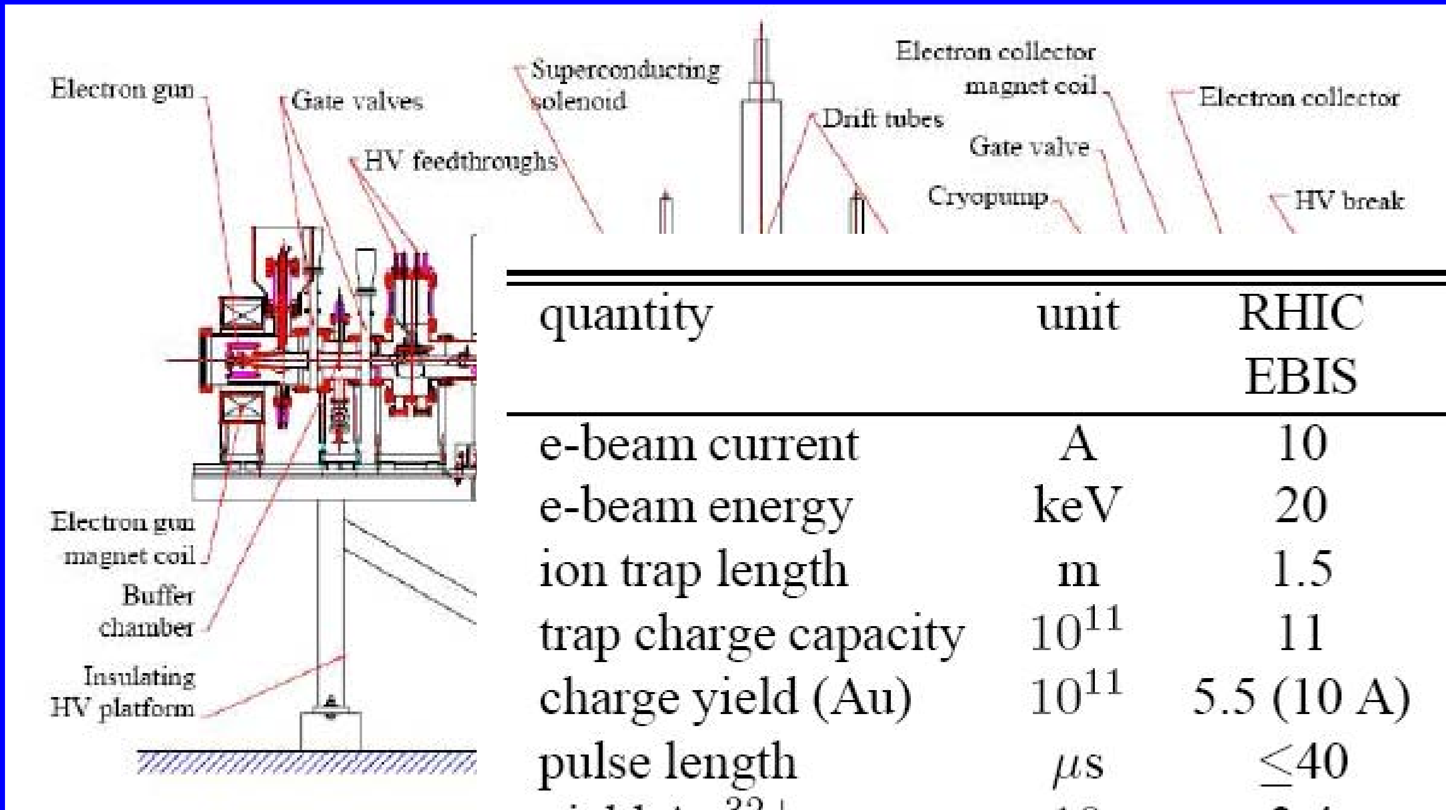


Tandem-to-Booster: 840m
EBIS-to-Booster : 30m



Upgrade 2: Electron Beam Ion Source (2009)

Schematic of RHIC EBIS



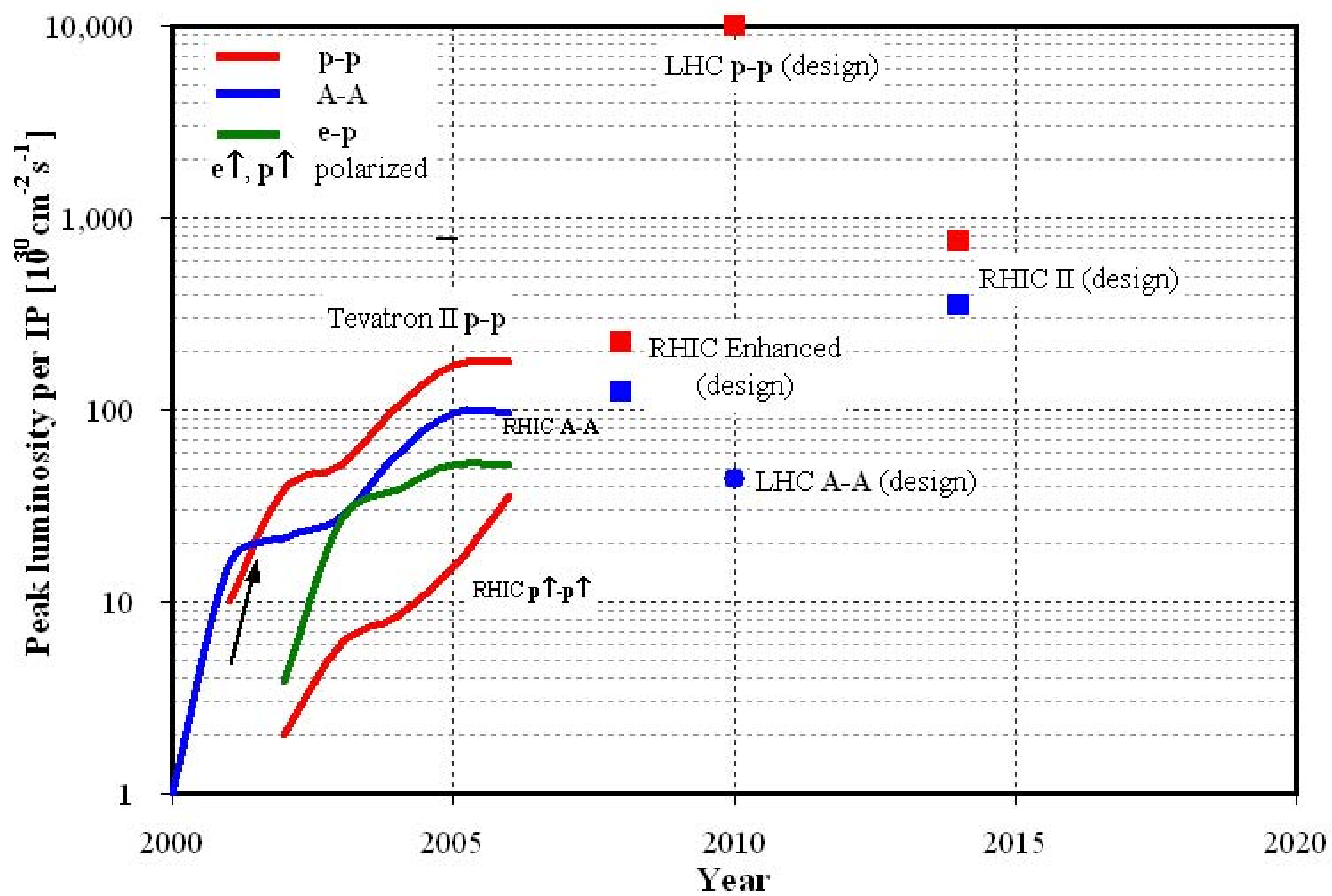
quantity	unit	RHIC EBIS	Test EBIS achieved
e-beam current	A	10	10
e-beam energy	keV	20	20
ion trap length	m	1.5	0.7
trap charge capacity	10^{11}	11	5.1
charge yield (Au)	10^{11}	5.5 (10 A)	3.4 (8 A)
pulse length	μs	≤ 40	20
yield Au^{32+}	10	3.4	> 1.5

Test EBIS of ½ length achieved ½ of required yield, yield scales with trap length

Upgrade 3: RHIC II – electron cooling (≥ 2012)

Parameter	unit	**Enhanced design**	**RHIC II**	
Au-Au operation				
Energy	GeV/n	100	100	
No of bunches	…	111	111	
Bunch intensity	10^9	1.0	1.0	
Average ℒ	**10^{26}cm^{-2}s^{-1}**	**8**	**70**	9×
p↑- p↑ operation				
Energy	GeV	250	250	
No of bunches	…	111	111	
Bunch intensity	10^{11}	2.0	2.0	
Average ℒ	**10^{30}cm^{-2}s^{-1}**	**150**	**500**	3×
Polarization 𝒫	**%**	**70**	**70**	

Upgrade 3: RHIC II – electron cooling (≥ 2012)



Upgrade 3: RHIC II – electron cooling (≥ 2012)

Use non-magnetized cooling (no solenoidal field)

(demonstrated with 8.9 GeV antiprotons in Fermilab Recycler – Nagaitsev et al.)

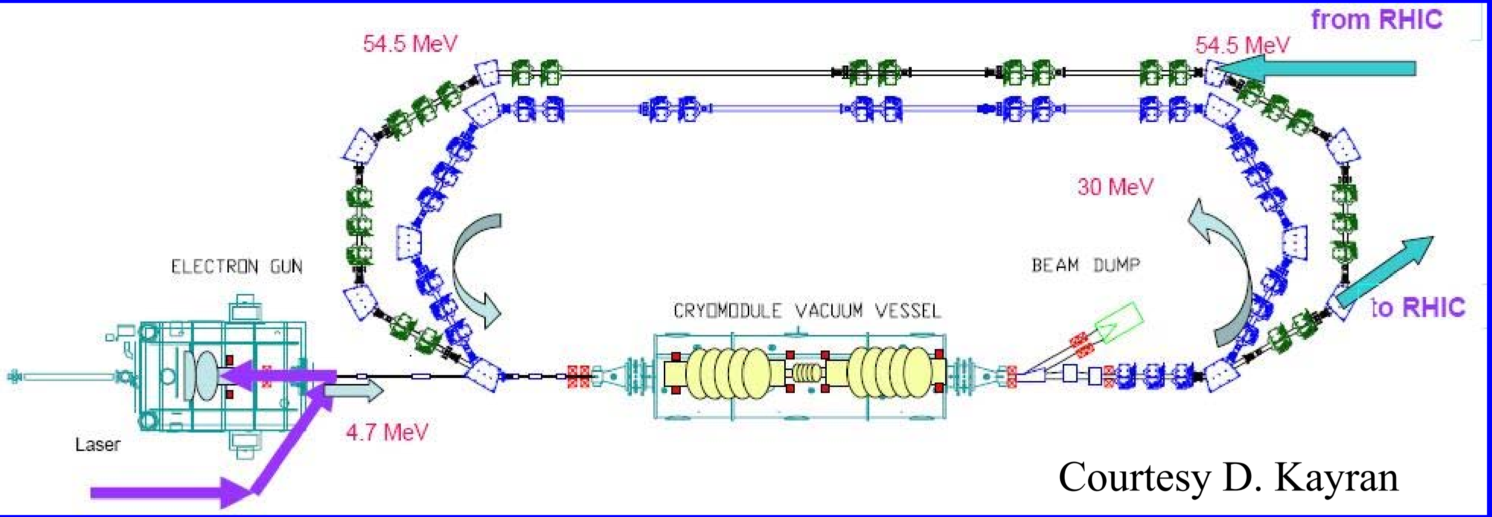
I. Ben-Zvi et al. TUZBPA01

For 100 GeV Au beams need:

- 54 MeV electron beam
- 5nC per bunch
- rms emittance < 4 μm

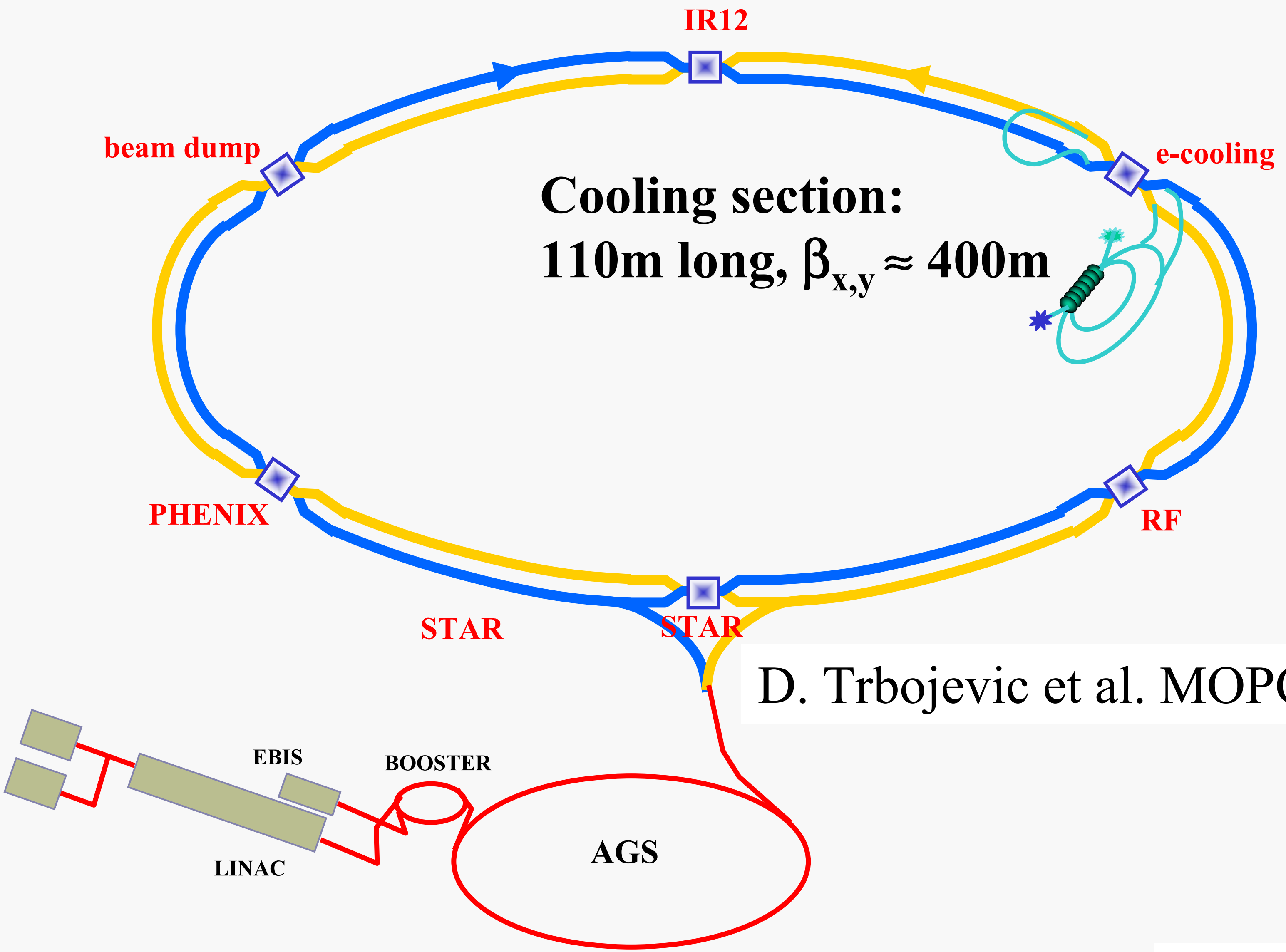
→ 2.7 MW beam power

→ need Energy Recovery Linac (ERL)



Courtesy D. Kayran

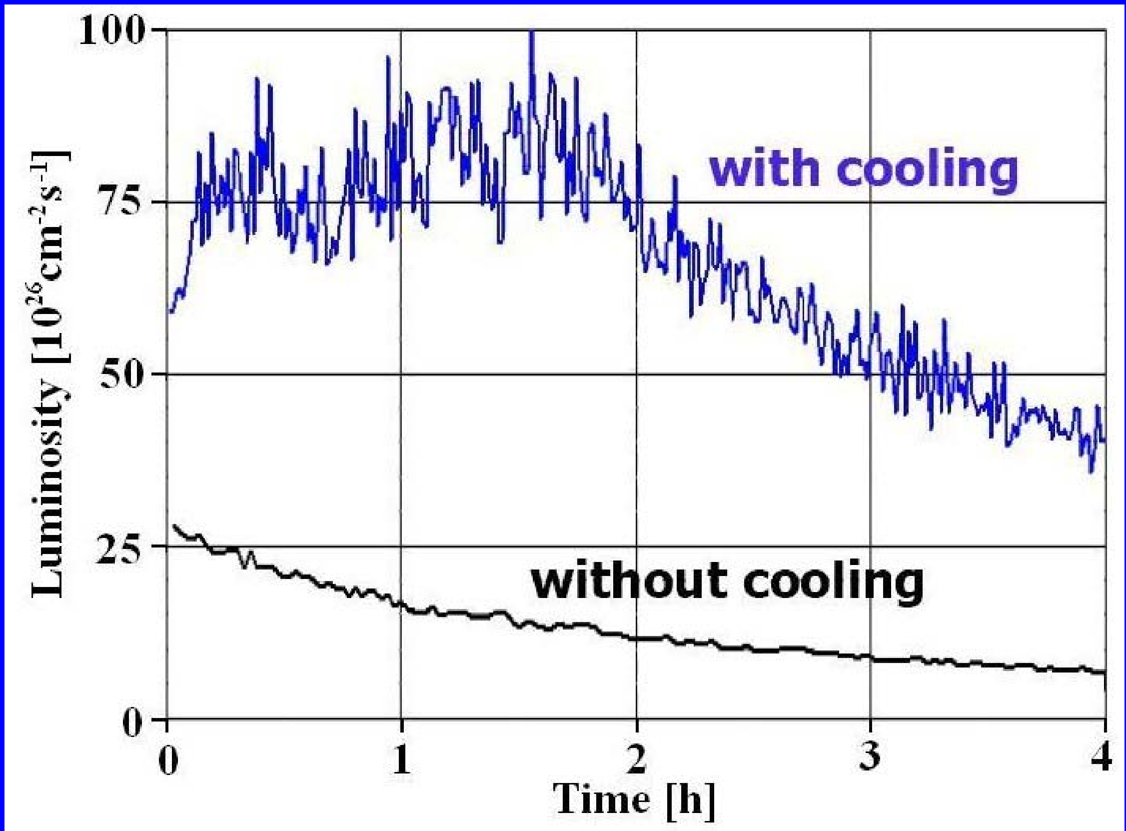
Upgrade 3: RHIC II – electron cooling (≥ 2012)



D. Trbojevic et al. MOPCH102

Upgrade 3: RHIC II – electron cooling (≥ 2012)

Simulated luminosities (A. Fedotov)



For:

- Beam-loss only from burn-off (luminosity)
- Constant emittance (cooling)

$$\mathcal{L}(t) = \frac{\mathcal{L}(0)}{(1+t/\tau)^2}$$

$\rightarrow\ \tau \approx 5$ h for Au-Au

Store length limited by burn-off

Upgrade 4: eRHIC (≥ 2014)

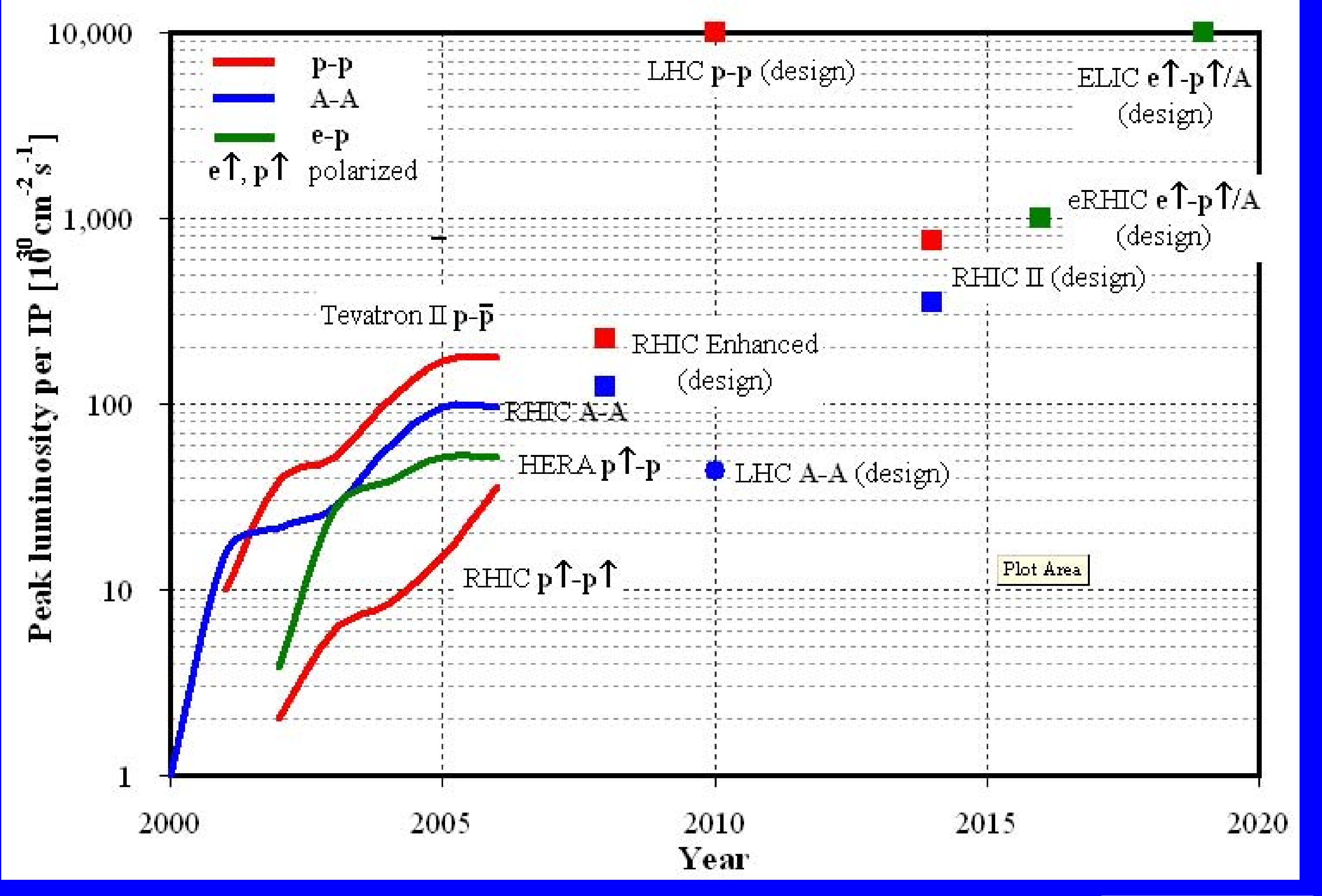
Main features:

- High-luminosity electron-ion collider
  - 10^{32}-10^{34} cm^{-2}s^{-1} for e↑-p↑
  - 10^{30}-10^{32} cm^{-2}s^{-1} for e↑-A(↑)
- 30-100 GeV center-of-mass energy
- Longitudinally polarized electrons, protons, possibly light ions

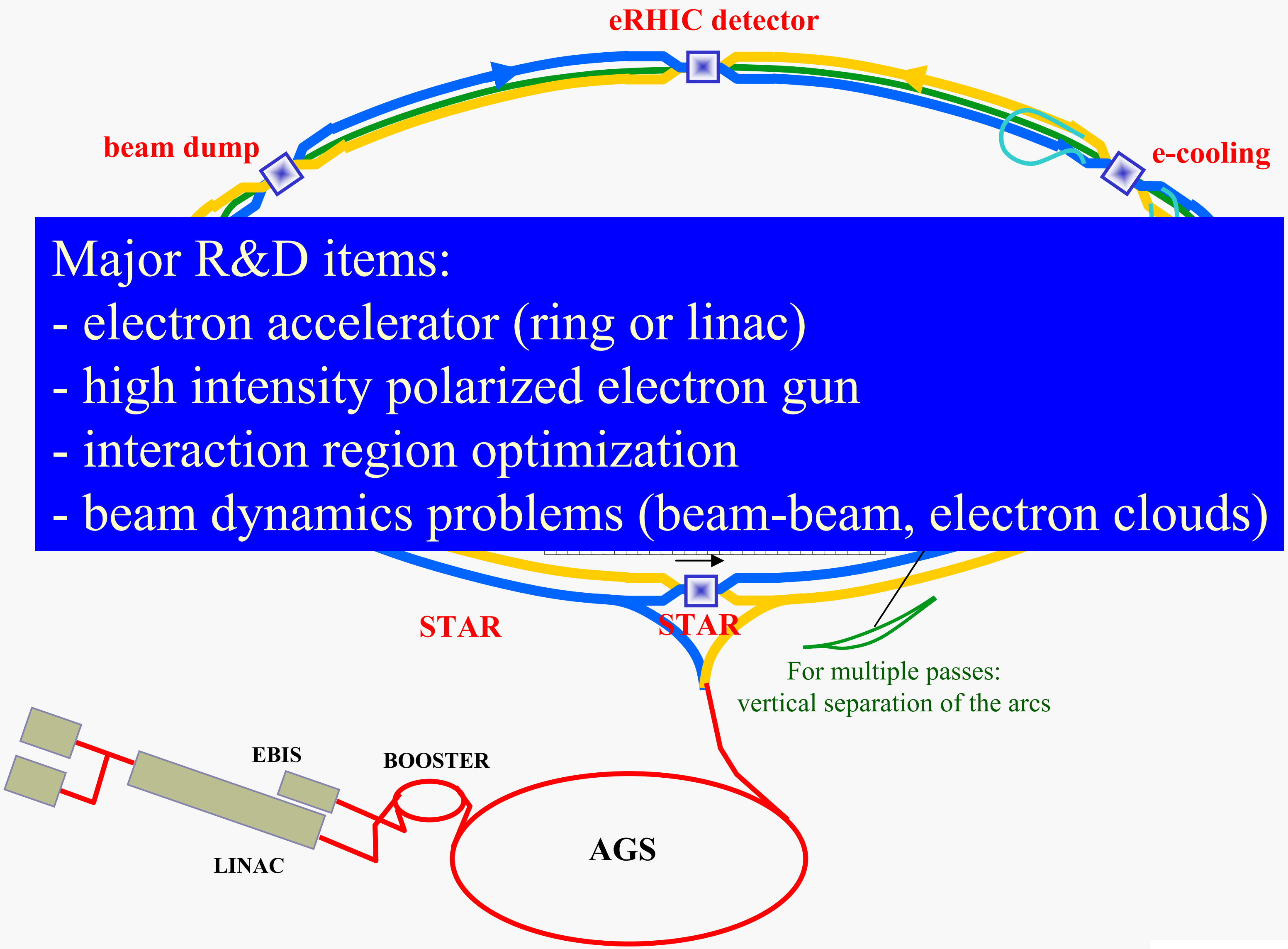
V. Ptitsyn et al. MOPLS058

- Currently working on
  - Ring-ring option (B-factory like e-ring)
  - Linac-ring option (higher luminosity potential)

Upgrade 4: eRHIC ($\geq$ 2014)



Upgrade 4: eRHIC (≥ 2014)



Major R&D items:
- electron accelerator (ring or linac)
- high intensity polarized electron gun
- interaction region optimization
- beam dynamics problems (beam-beam, electron clouds)

Summary RHIC

Status:

- Since 2000, 4 ion combinations, 8 energies
- Luminosity/year increased by 2 orders of magnitude
- Protons with 65% polarization at 100 GeV

Planned upgrades:

1. Enhanced Design parameters (~2008)
2. EBIS (modern pre-injector, U and ^{3}H↑ – 2009)
3. RHIC II (order of magnitude increase in Au-Au $\mathcal{L}$ – ≥2012)
4. eRHIC (high luminosity electron-ion collider – ≥2014)