RHIC plans towards higher luminosity

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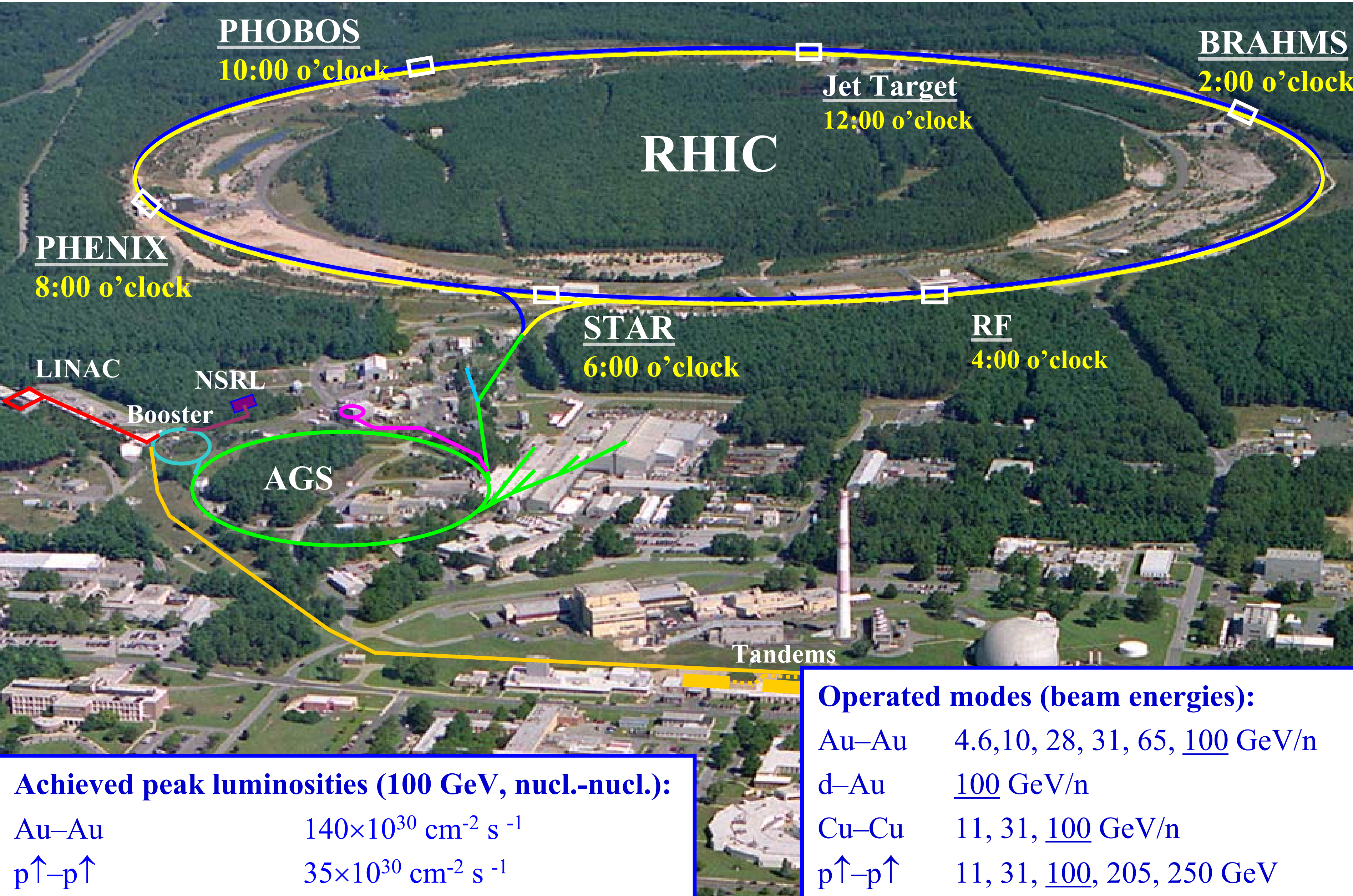
June 26, 2007

RHIC – a High Luminosity (Polarized) Hadron Collider



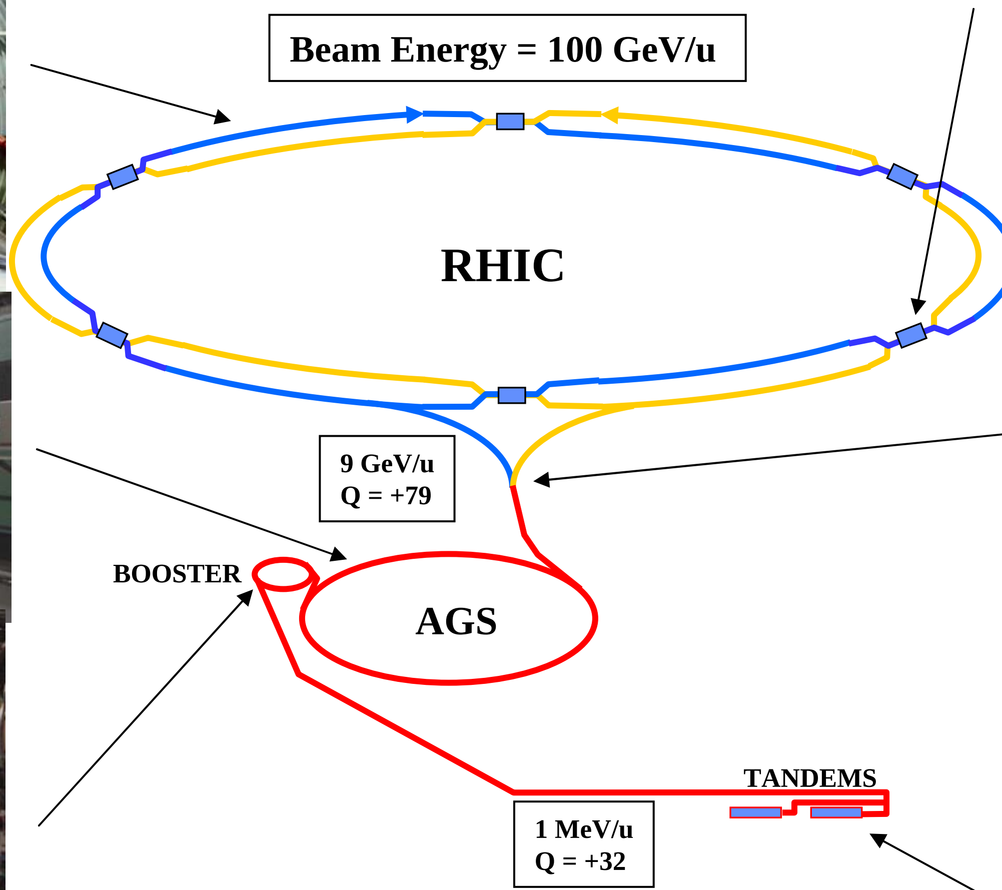
Achieved peak luminosities (100 GeV, nucl.-nucl.):

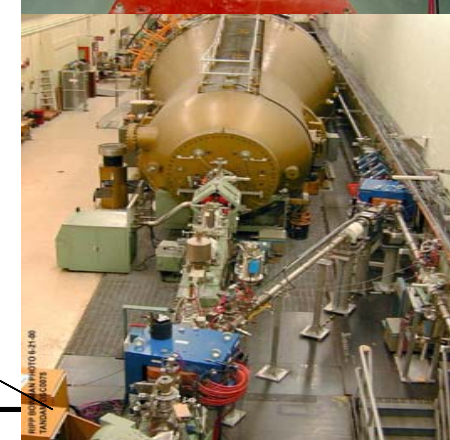
Au–Au	140×10^{30} cm^{-2} s^{-1}
p↑–p↑	35×10^{30} cm^{-2} s^{-1}

Operated modes (beam energies):

Au–Au	4.6,10, 28, 31, 65, <u>100</u> GeV/n
d–Au	<u>100</u> GeV/n
Cu–Cu	11, 31, <u>100</u> GeV/n
p↑–p↑	11, 31, <u>100</u>, 205, 250 GeV

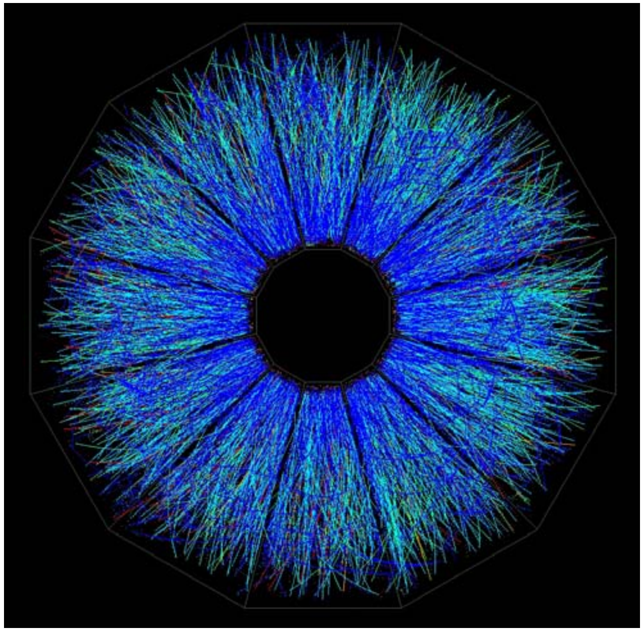
Gold Ion Collisions in RHIC





RHIC heavy ions collisions

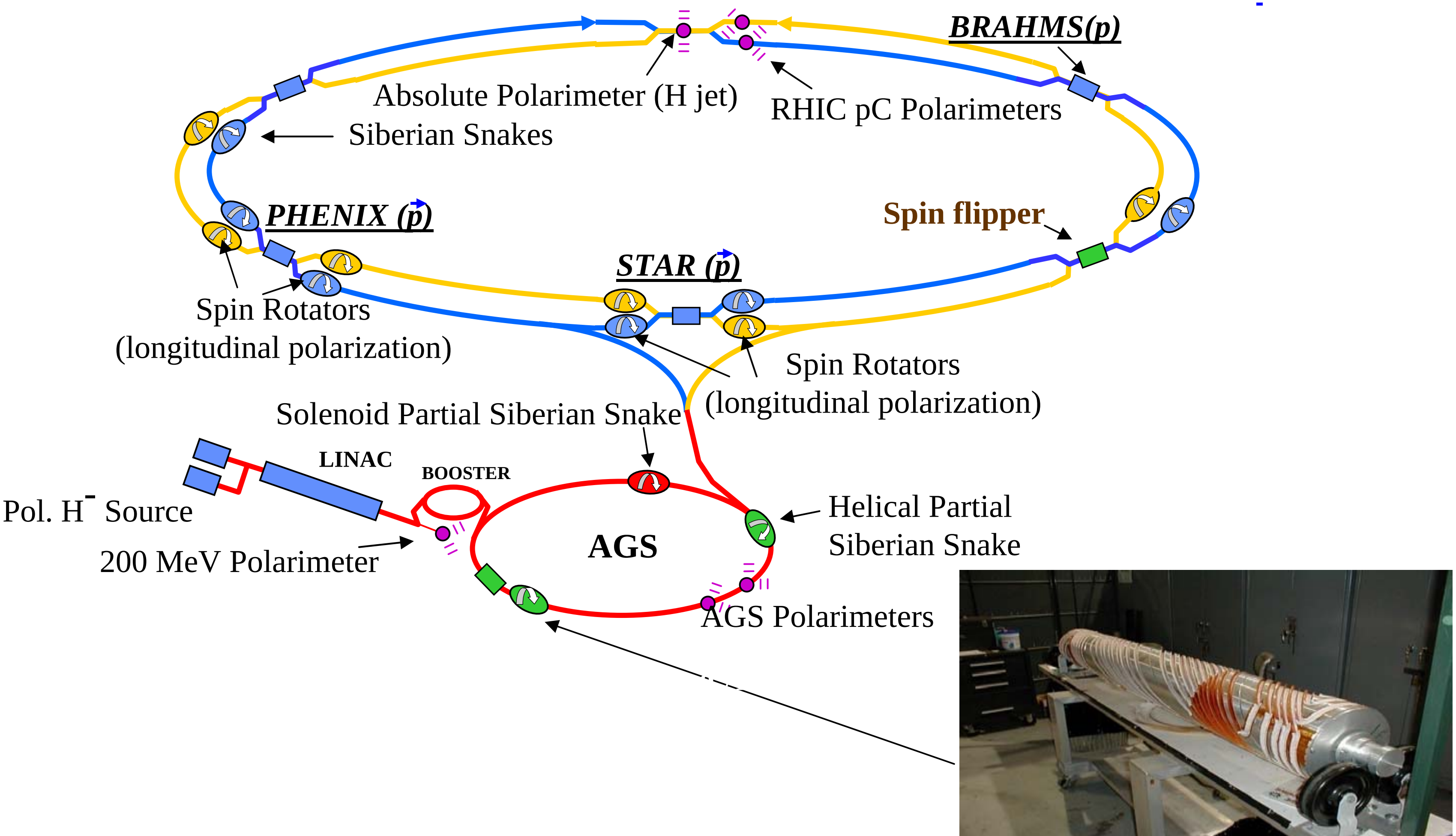
a "Mini-Bang"
Nuclear matter at extreme temperatures and density



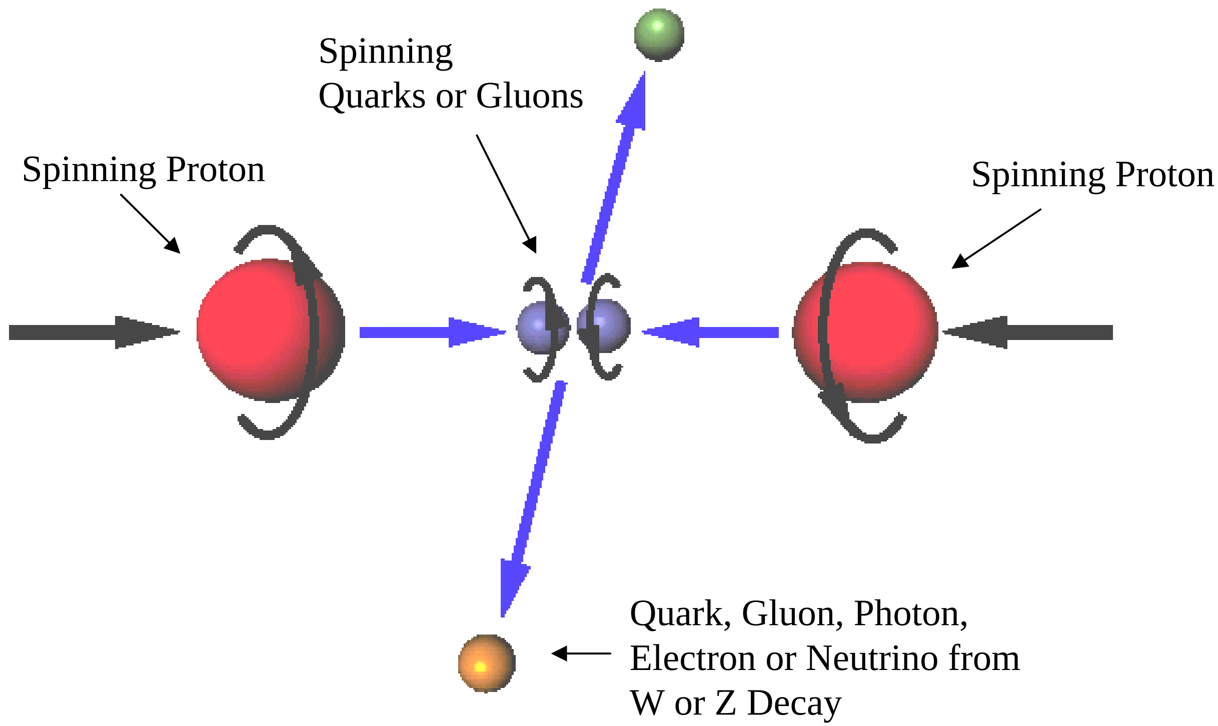
Produce and explore a new state of matter

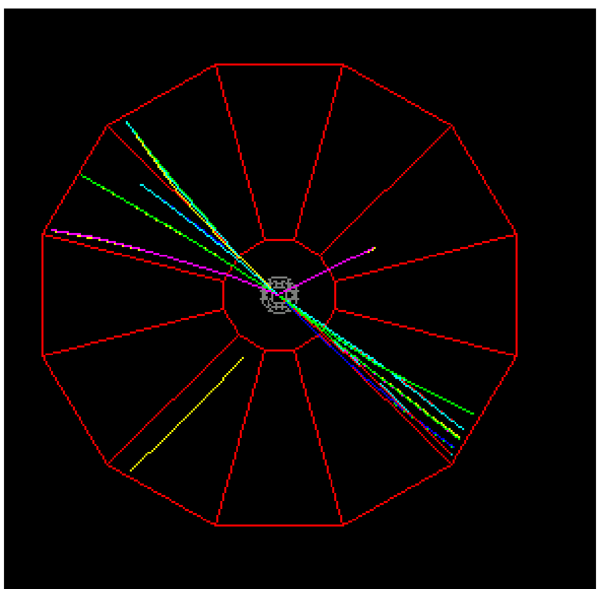
a. **Formation phase -**
   parton scattering
b. **Hot and dense phase -**
   $\rightarrow$ strongly interacting hot dense material (sQGP, "perfect liquid")
c. **Freeze-out –**
   emission of hadrons

Polarized Hadron collider



RHIC Spin Physics





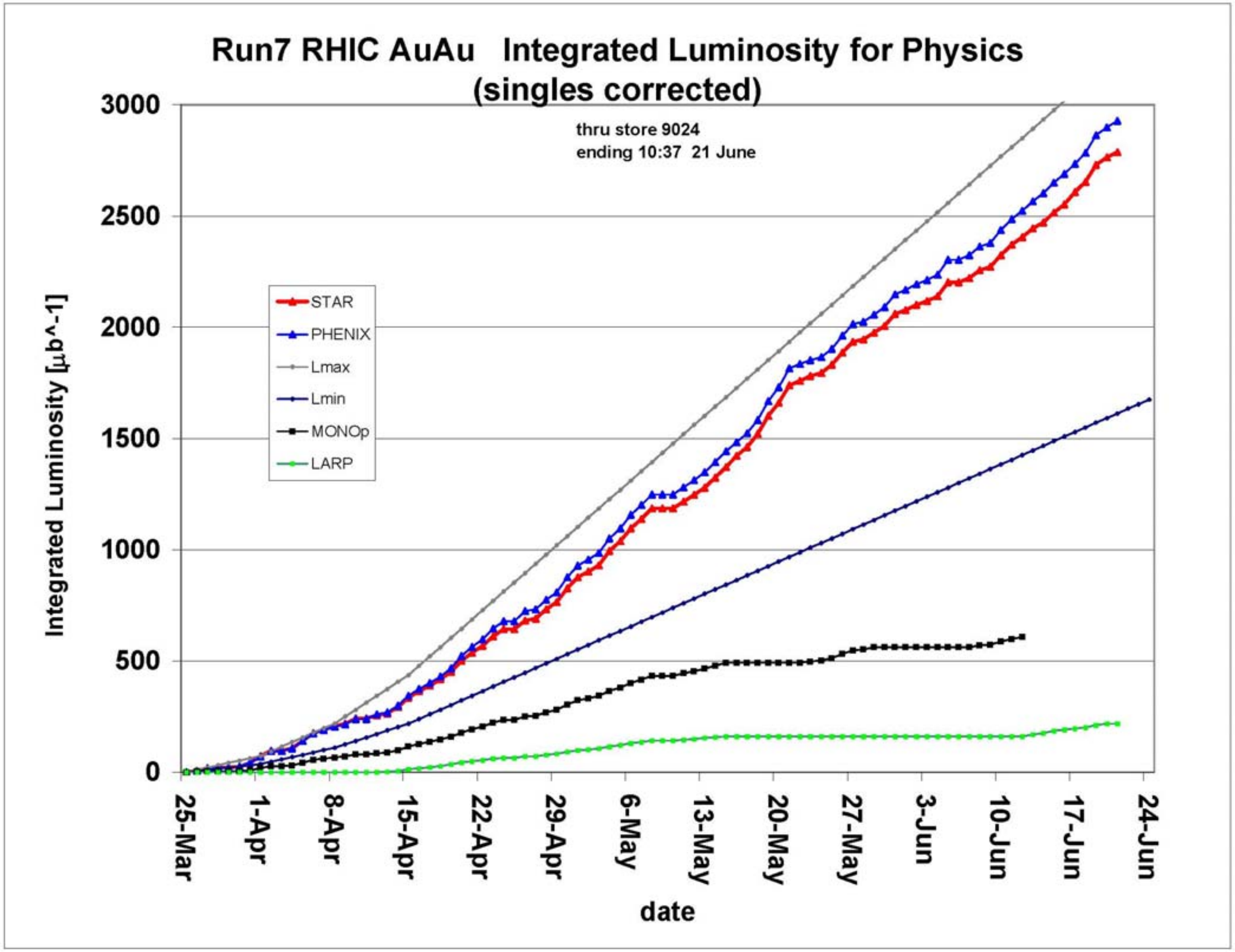
- Spin structure functions of gluon and anti-quarks
- Parity violation in parton-parton scattering
- Requires high beam polarization and high luminosity

RHIC design and achieved parameters for 100 GeV/n

(A_1 and A_2 are the number of nucleons in the ions of colliding beams)

species	No of bunches	Ions/ bunch [10^9]	β* [m]	Polarization, average	$L_{store,avg}$ [$cm^{-2}s^{-1}$]	$A_1A_2L_{store, avg}$ [$cm^{-2}s^{-1}$]	$A_1A_2L_{peak}$ [$cm^{-2}s^{-1}$]
Design Parameters (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}
Enhanced Design Parameters (by 2009)							
Au-Au	111	1.0	0.9		8×10^{26}	31×10^{30}	140×10^{30}
p↑-p↑	111	200	0.9	70%	60×10^{30}	60×10^{30}	90×10^{30}
Achieved operational values (as of 2007)							
Au-Au	103	1.1	0.8		14×10^{26}	54×10^{30}	140×10^{30}
p↑-p↑	111	130	1	60%	20×10^{30}	20×10^{30}	35×10^{30}
d-Au	55	120/.7	2		2×10^{28}	8×10^{30}	28×10^{30}
Cu-Cu	37	4.5	0.9		80×10^{26}	32×10^{30}	79×10^{30}

2007 RHIC run with Au ions



A. Drees
TUOCKI02

Major upgrades

1. Electron Beam Ion Source (EBIS)
2. Stochastic cooling
3. Electron cooling for RHIC-II
4. Low-energy RHIC operation
5. eRHIC

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

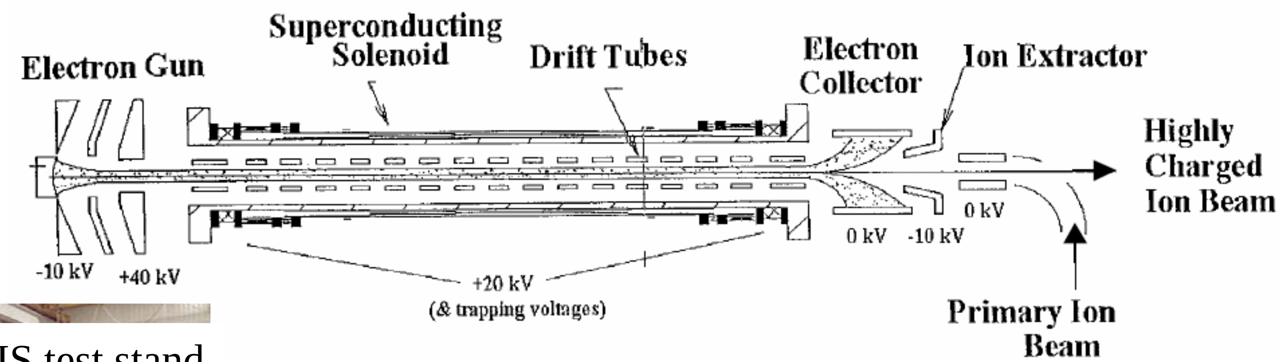
→ Can avoid reliability upgrade of Tandem

→ Expect improved reliability at lower cost

→ New species: U, $^{3}He\uparrow$

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)
- Construction schedule: FY2006 – 09



EBIS test stand

J. Alessi et al. FRYAB02

Microwave stochastic cooling

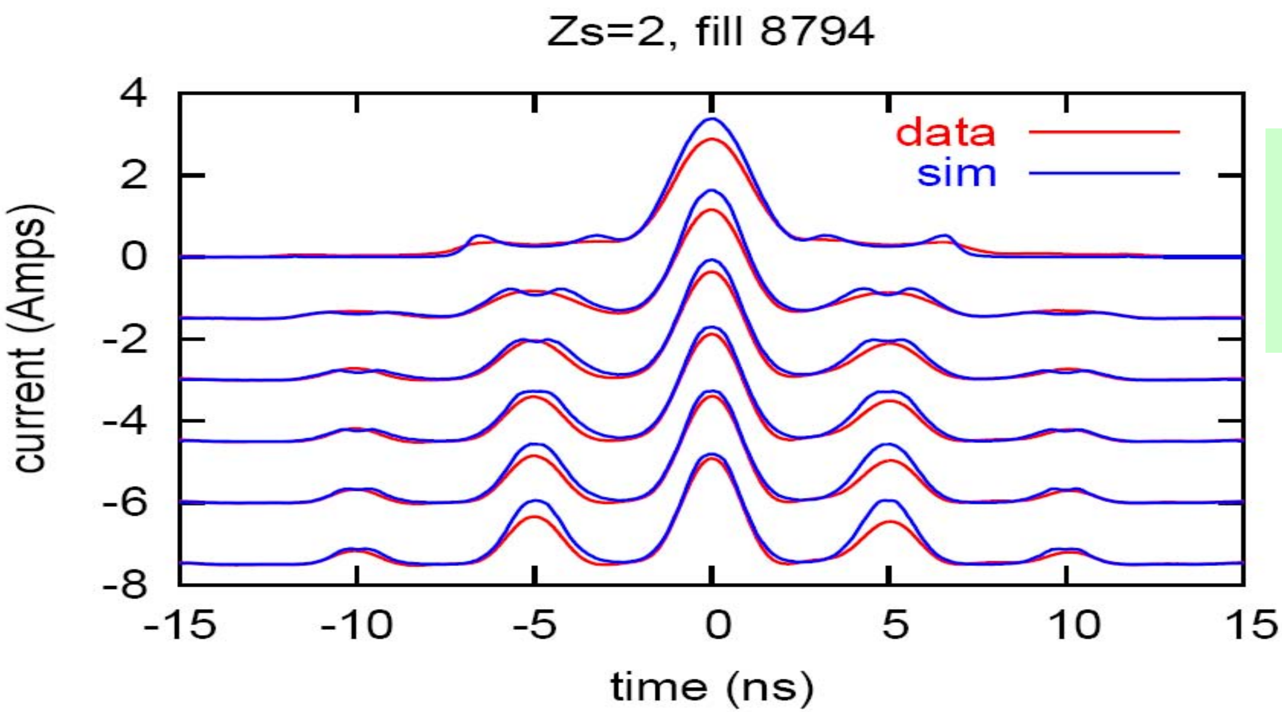
M. Blaskiewicz, M. Brennan et al.

- **Longitudinal cooling of low intensity proton bunch at 100 GeV was first demonstrated in 2006.**
- **Longitudinal cooling for Au ions was made operational in Yellow ring in 2007.**
- **Longitudinal cooling in Blue ring – under development.**
- **Design work started on transverse cooling.**

Longitudinal stochastic cooling in Yellow ring

M. Blaskiewicz et al., WEYC02

Cooling ON



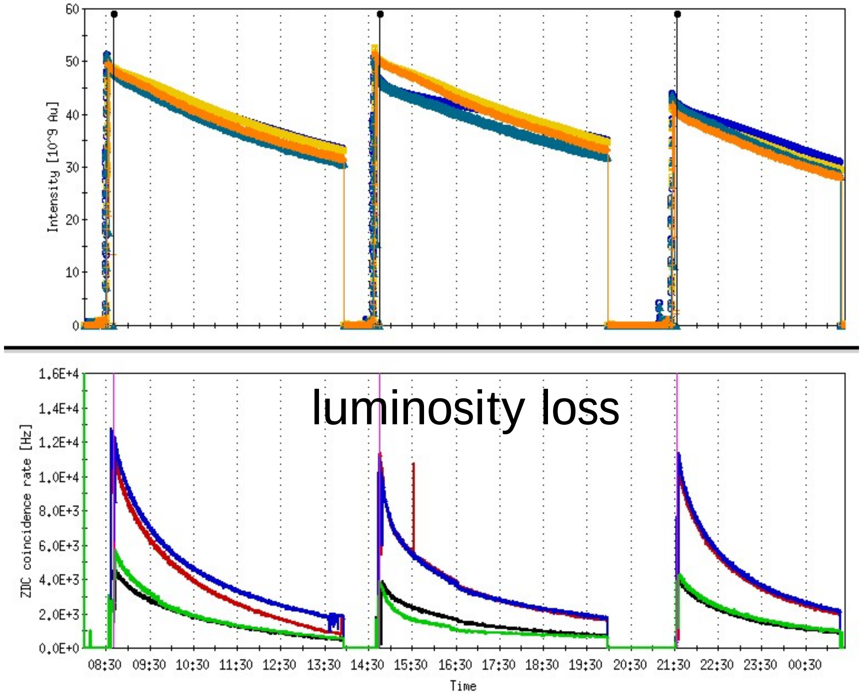
Longitudinal beam profile from

Wall Current Monitor

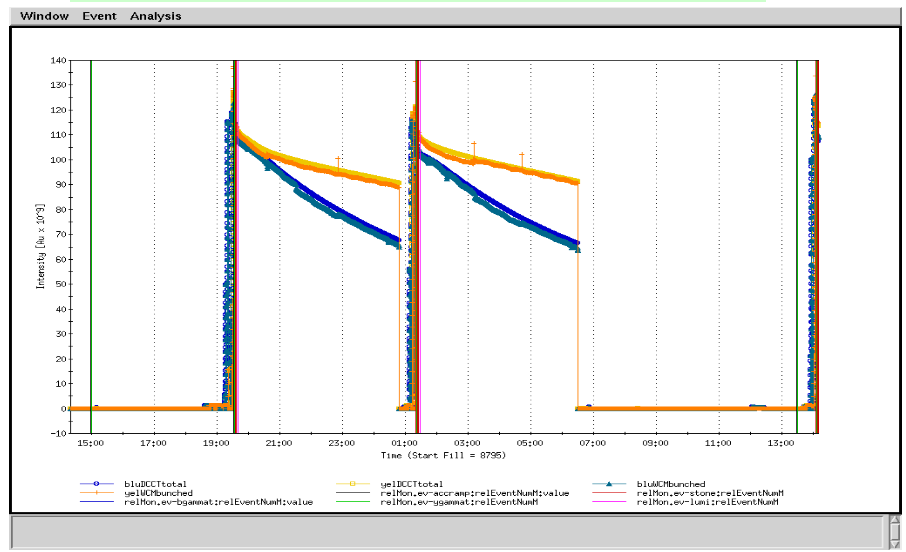
RHIC performance for Au ions

2004 run

intensity loss



2007 run
(with longitudinal stochastic cooling in Yellow ring)

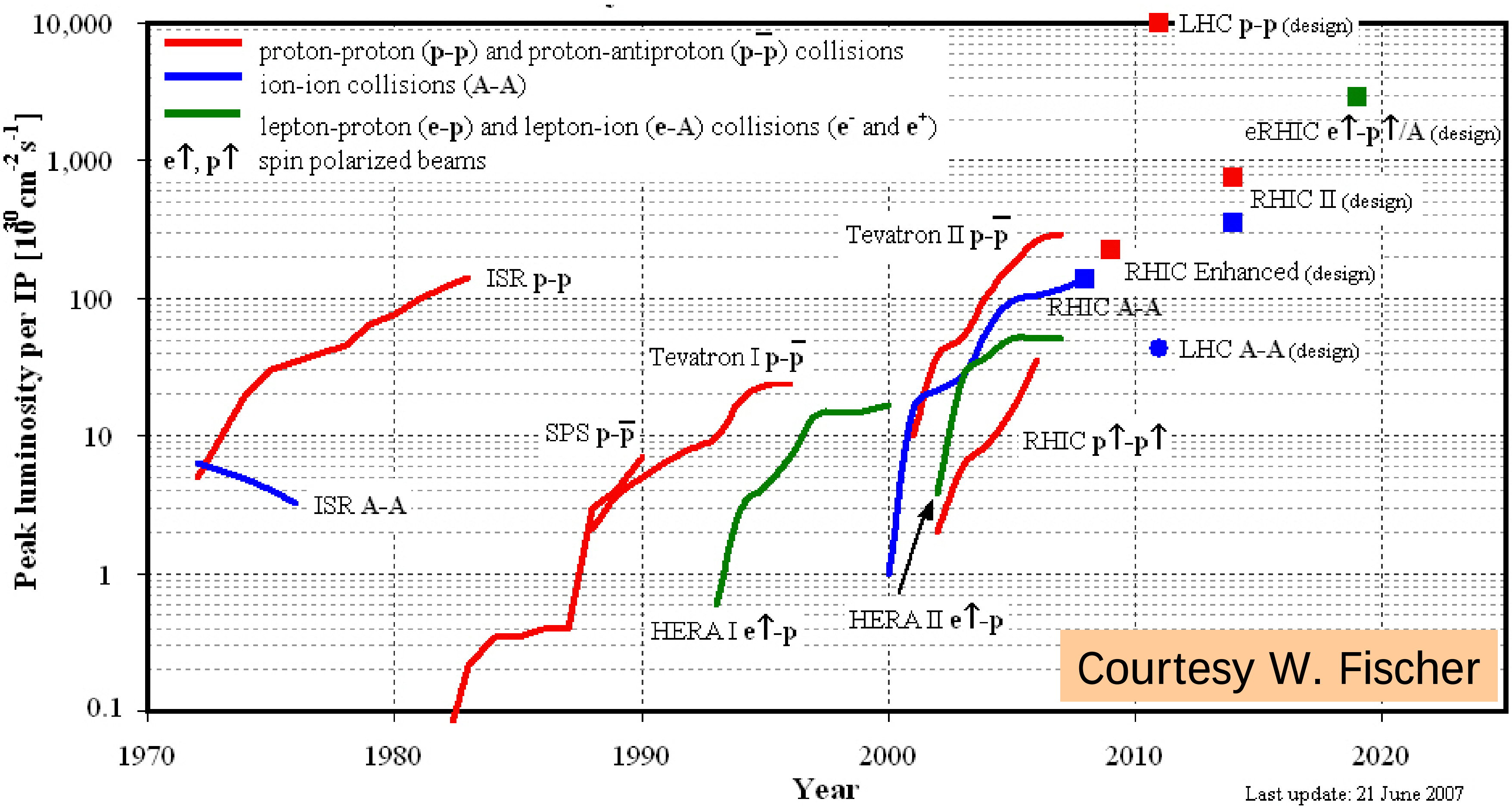


RHIC II – major luminosity upgrade

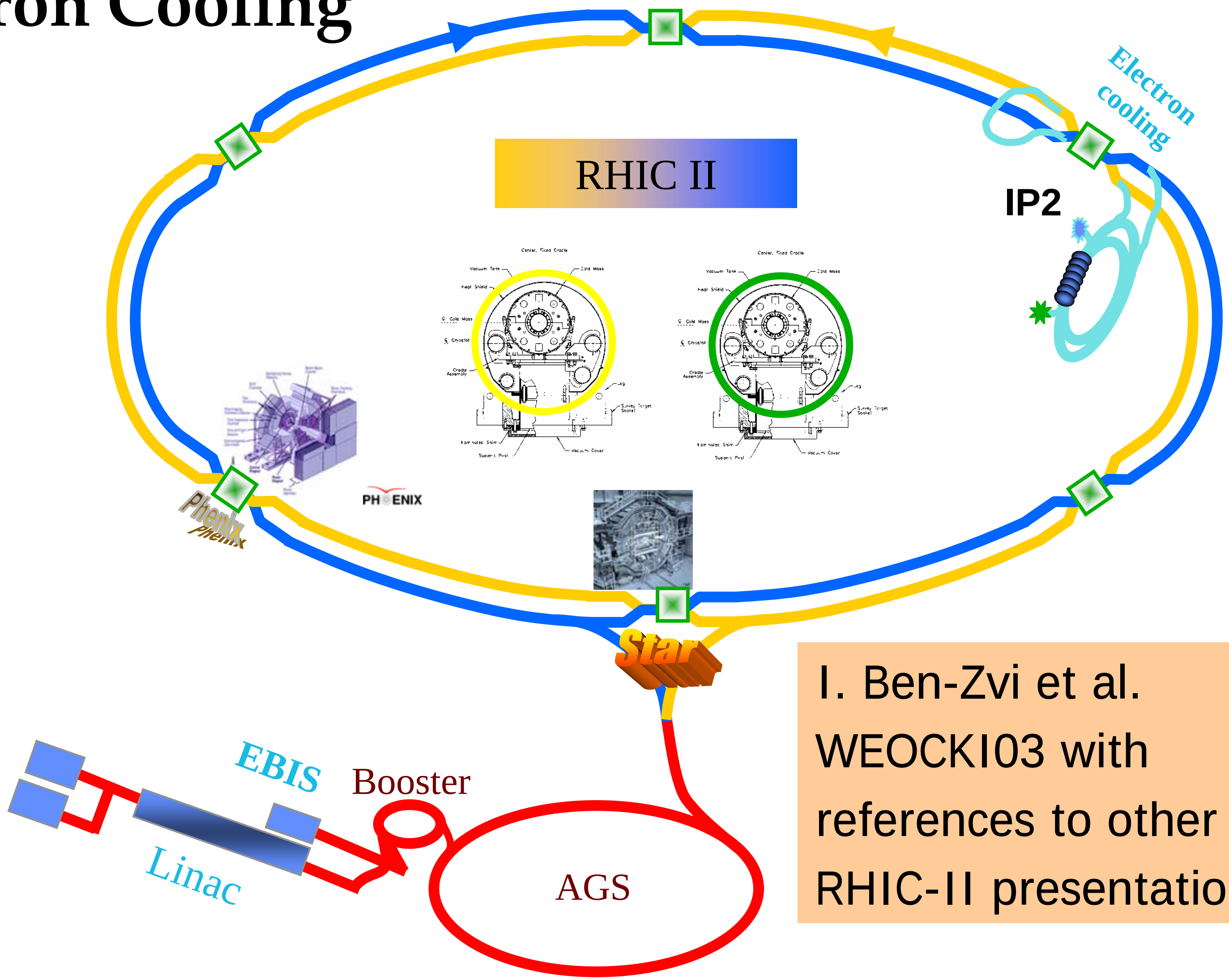
Parameter	unit	Enhanced design	RHIC II
Au-Au operation			
Energy	GeV/n	100	100
No of bunches	…	111	111
Bunch intensity	10^9	1.0	1.0
Average $\mathcal{L}$	$10^{26}cm^{-2}s^{-1}$	8	70
p↑- p↑ operation			
Energy	GeV	250	250
No of bunches	…	111	111
Bunch intensity	10^{11}	2.0	2.0
Average $\mathcal{L}$	$10^{30}cm^{-2}s^{-1}$	150	400
Polarization $\mathcal{P}$	%	70	70

Already achieved and exceeded

RHIC II – luminosity (nucleon-pair) projection

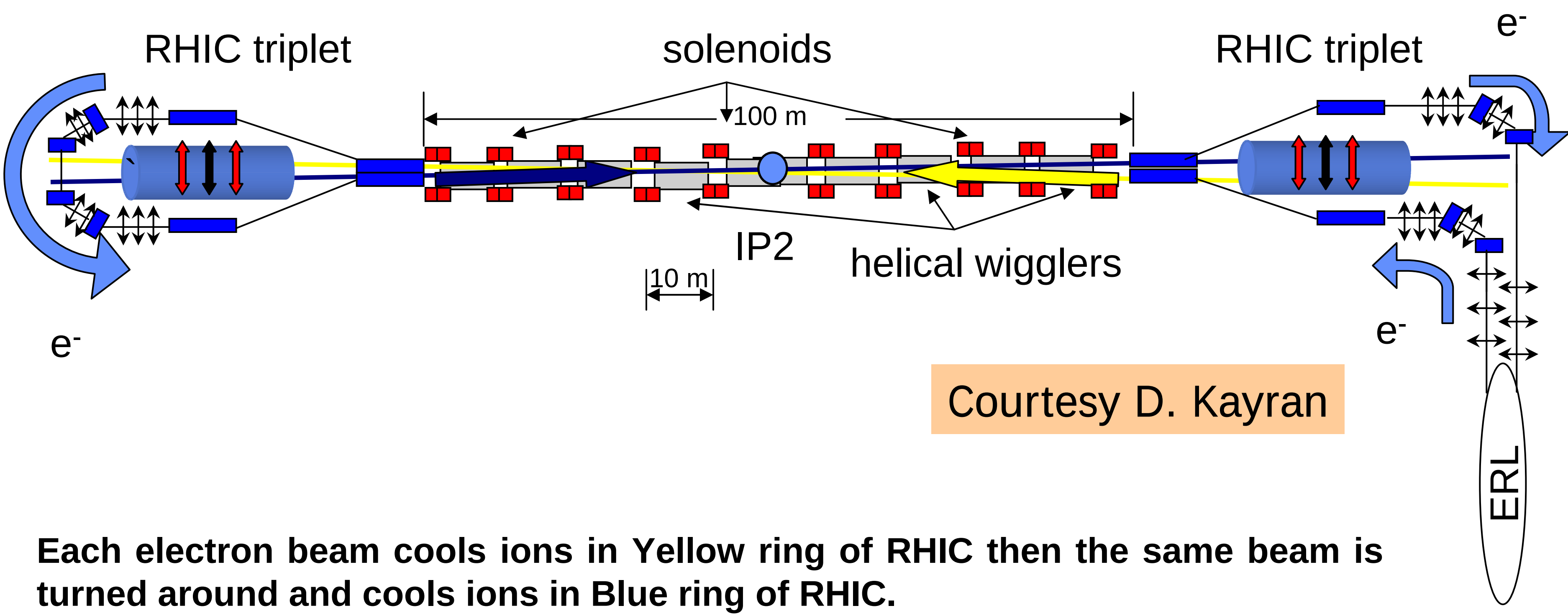


Electron Cooling



I. Ben-Zvi et al. WEOCKI03 with references to other RHIC-II presentations

Electron cooling section at RHIC 2 o'clock IP



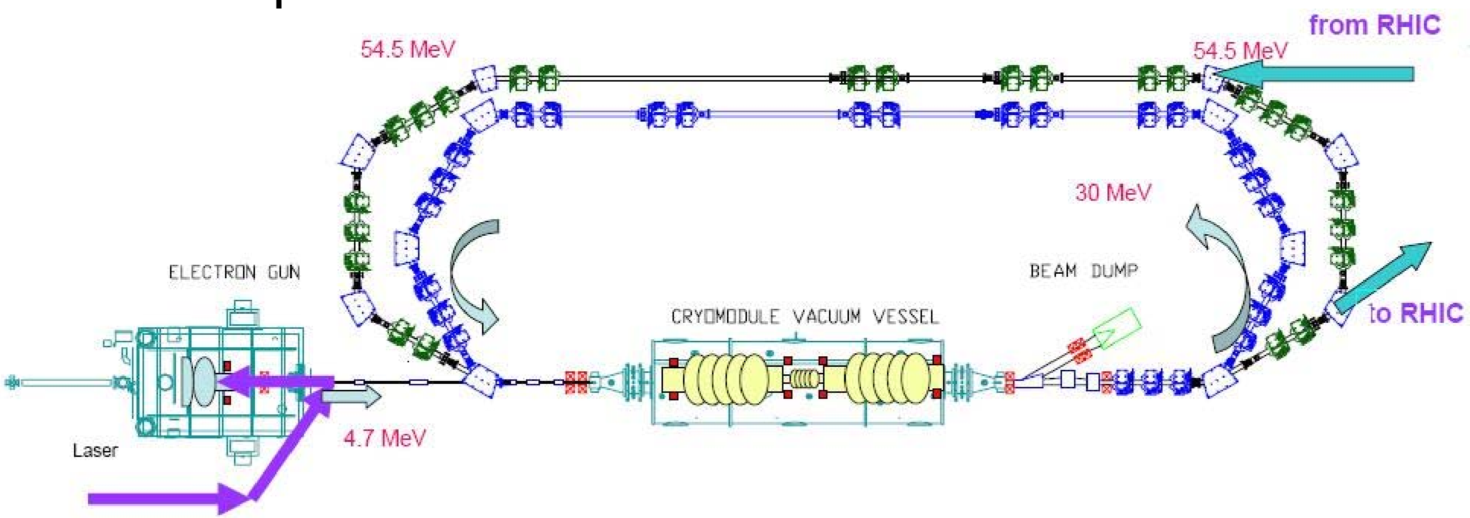
Each electron beam cools ions in Yellow ring of RHIC then the same beam is turned around and cools ions in Blue ring of RHIC.

Energy Recovery Linac (ERL) for RHIC-II

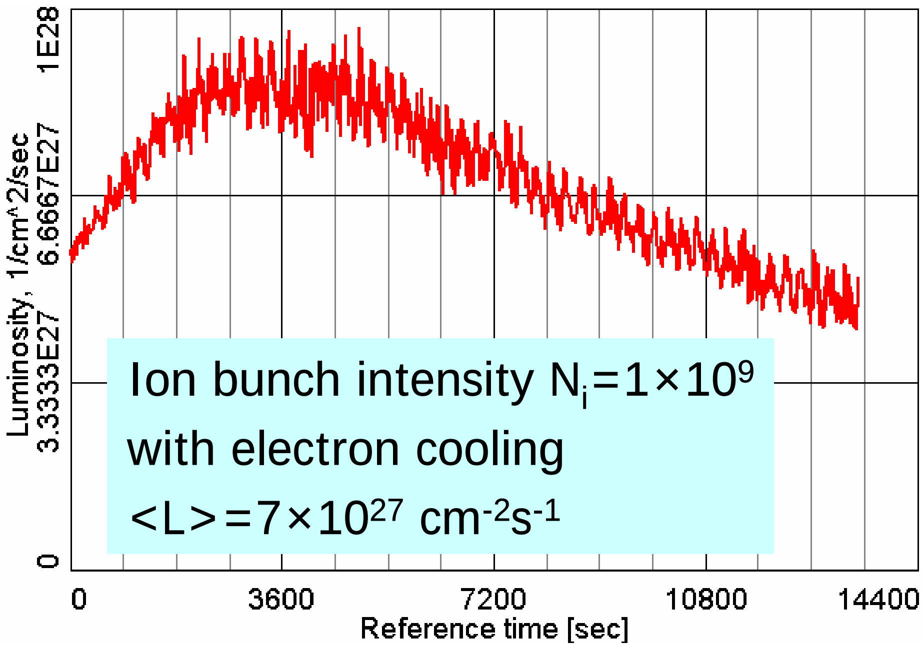
Cooling of Au ions at 100 GeV/n:

- 54.3 MeV electron beam
- 5nC per bunch
- rms emittance < 4 μm
- rms momentum spread < 5×10^{-4}

D. Kayran, THPAS096



Cooling of Au ions for RHIC-II (simulations)

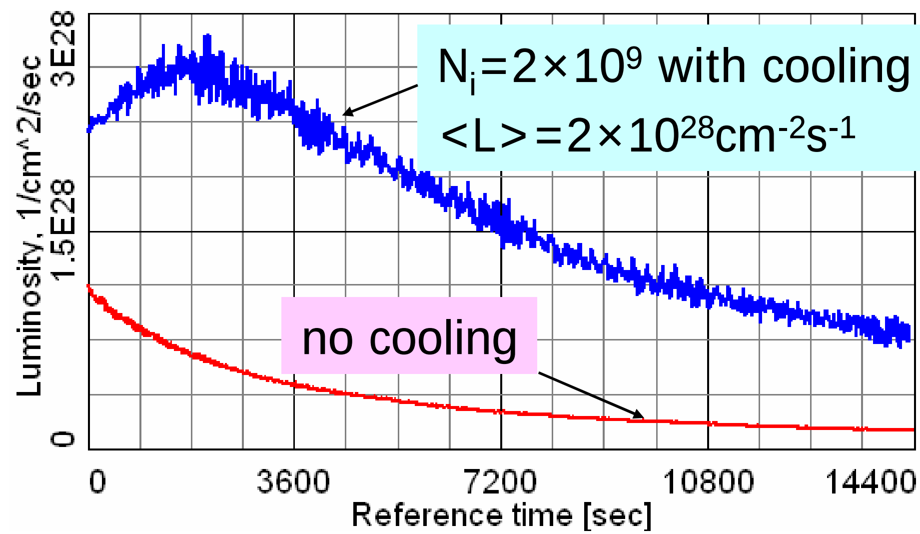


number of bunches: 111

initial $\varepsilon_{95\%,n}$ =15 μm

rms momentum spread 5×10^{-4}

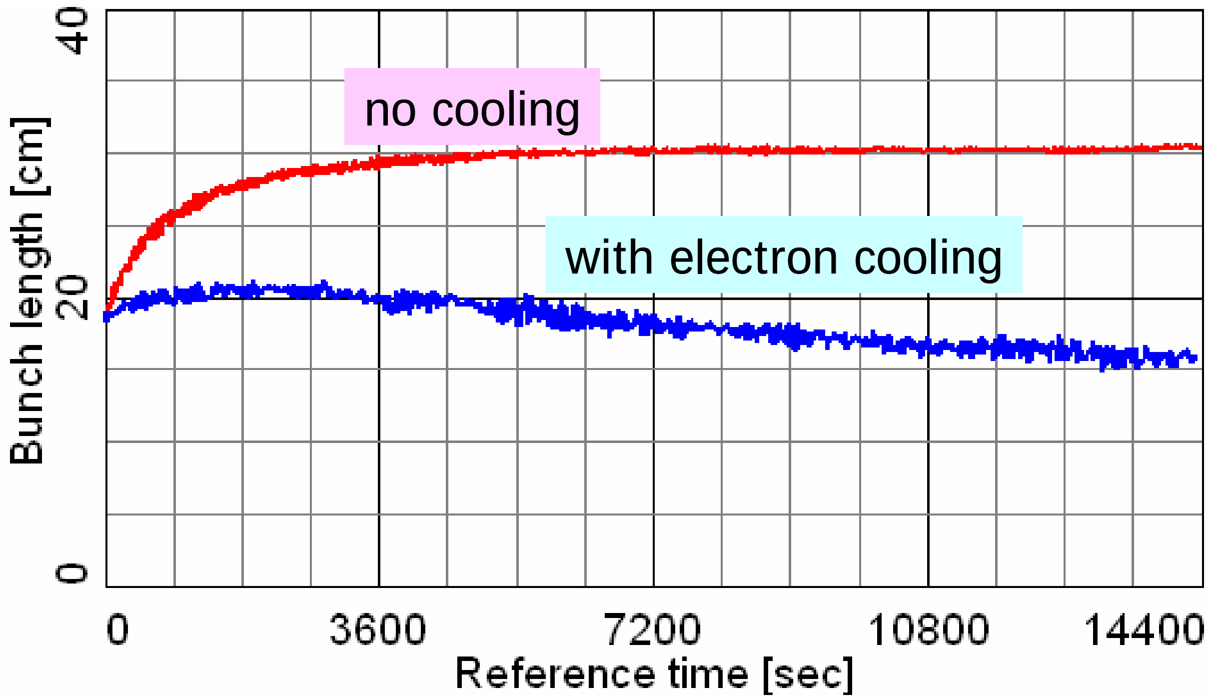
$\beta^*=0.5$m



BETACOOL (JINR, Russia) simulation.

included effects: intra-beam scattering, electron cooling, particle loss in collisions ("burn-off"), loss from rf bucket.

Electron cooling for RHIC-II: bunch length control (simulations)



Maintaining short bunch length.

Also, shaping of the longitudinal distribution is possible.

High-energy Electron Cooling system for RHIC-II

1. Provides cooling of various ion species at 100 GeV/nucleon.
2. Delivers luminosity required by RHIC-II upgrade.
3. Maintains short bunch length which is important for detectors.
4. Provides pre-cooling of protons (above transition energy) to required transverse and longitudinal emittances.
5. Provides cooling of various ion species at other collisions energies in the range of 25-100 GeV/nucleon.

Low-energy RHIC operation

There is substantial and growing interest in RHIC heavy ion collisions with c.m. energy in the range $\sqrt{s_{NN}}$= 5-50 GeV/nucleon

- Corresponds to Au beams in RHIC of γ=2.68 to 26.8
- Nominal Au injection is γ=10.52, already below design γ=12.6

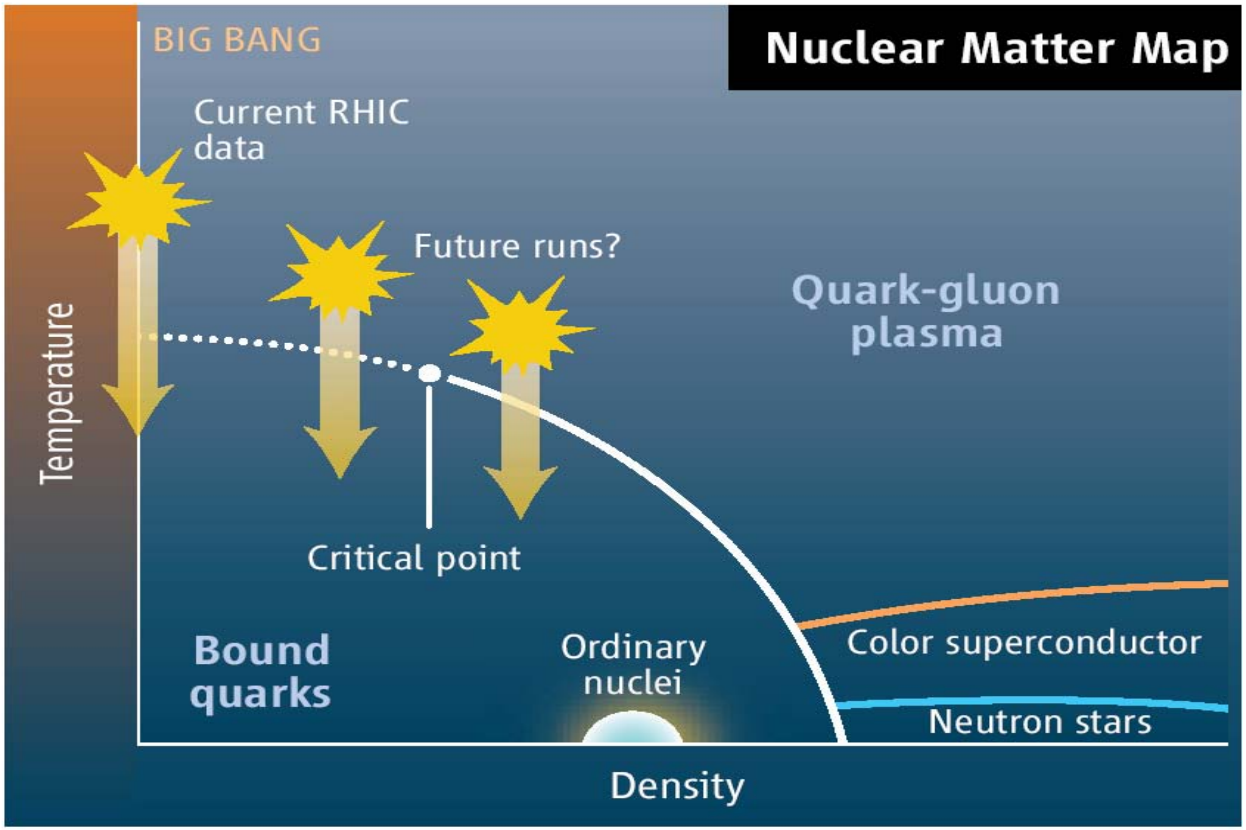
RIKEN workshop (BNL, March 9-10, 2006):
"Can we discover the QCD critical point at RHIC?"

Suggested energy scan: $\sqrt{s_{NN}}$ = 5, 6.3, 7.6, 8.8, 12.3, 18, 28 GeV/nucleon

Test runs at low energies were done (T. Satogata et al.).

- Pre-cooling of ion beam in AGS for efficient injection into RHIC at lowest energies (with significant potential for luminosity gain) is under investigation.

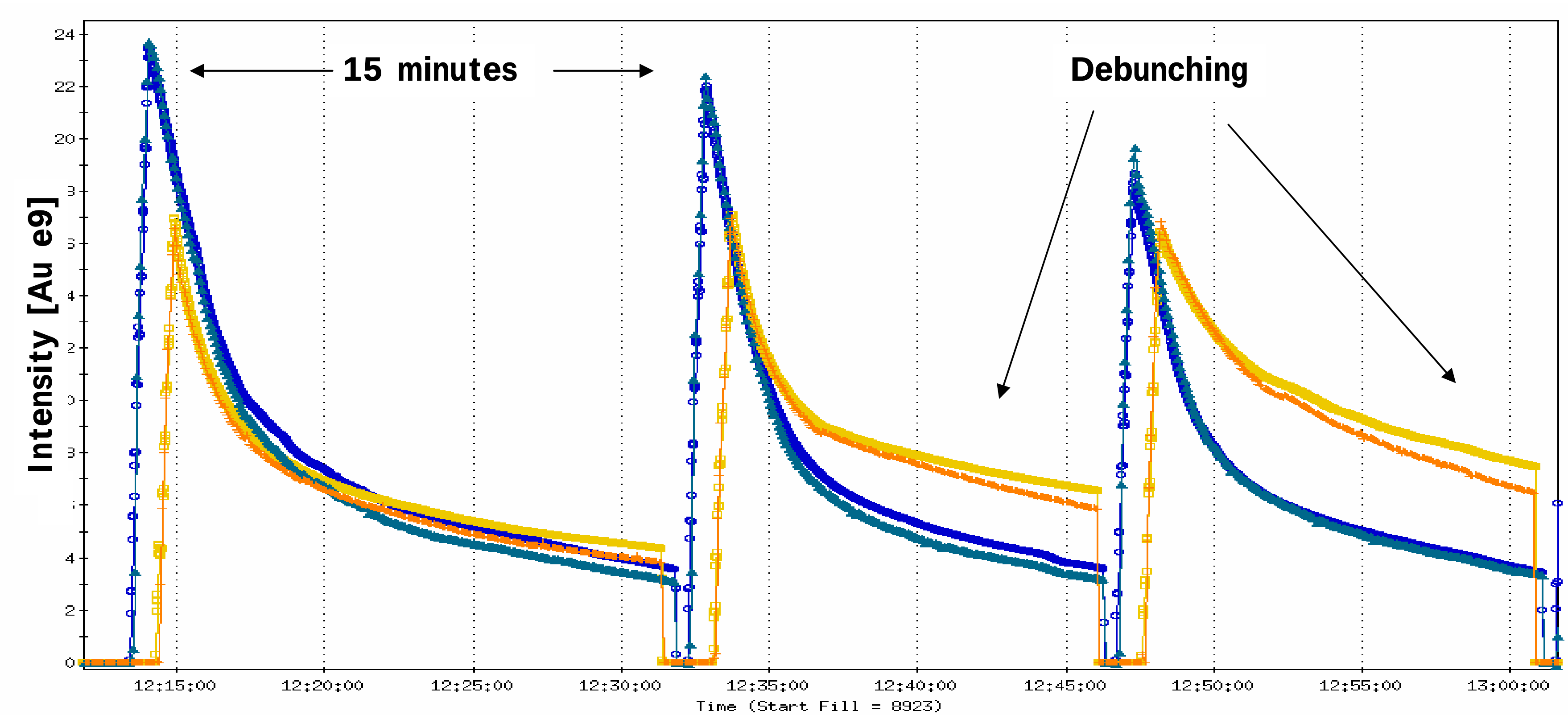
Low-energy RHIC operation: 2.5-25 GeV/n



Landmark study. Physicists have seen a smooth transition from bound quarks to quark-gluon plasma (dotted line). They now hope to find the point beyond which the transition becomes violent (white line).

A. Cho, Science, 312 (14 Apr 2006)

Low–energy RHIC operation: June 11, 2007 test Run at √s = 9.1 GeV/n (γ=4.93)

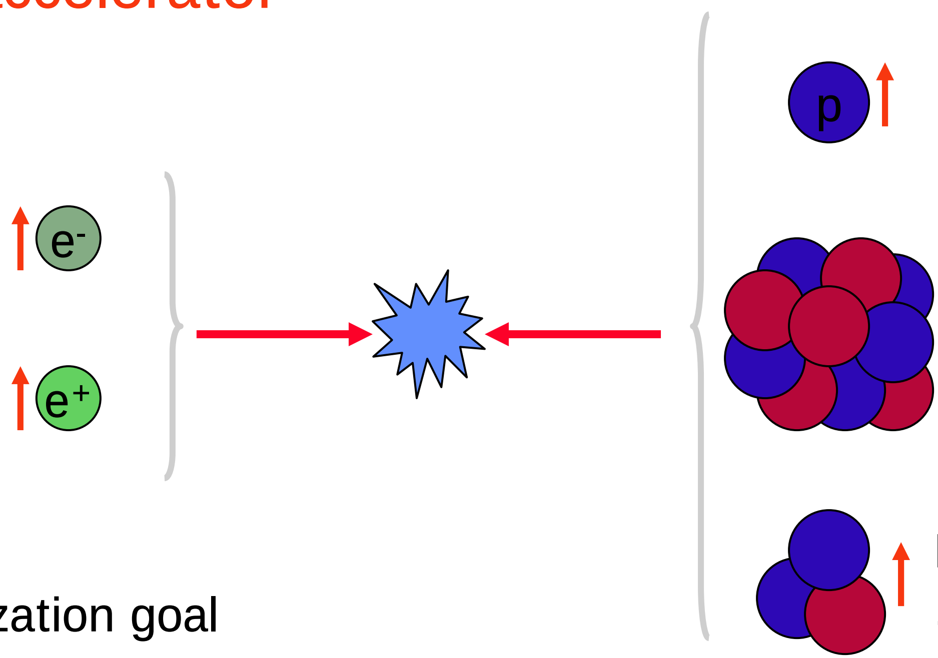


T. Satogata et al. TUPAS103

Electron-Ion collider (eRHIC)

Electron accelerator

Polarized leptons
3-20 GeV



70% beam polarization goal

RHIC

Polarized protons
50-250 GeV

Heavy ions (Au)
50-100 GeV/n

Polarized light ions (He^3)
167 GeV/n

eRHIC

Two accelerator design options developed in parallel (2004 Zeroth-Order Design Report):

1. ERL-based design "Linac-Ring":

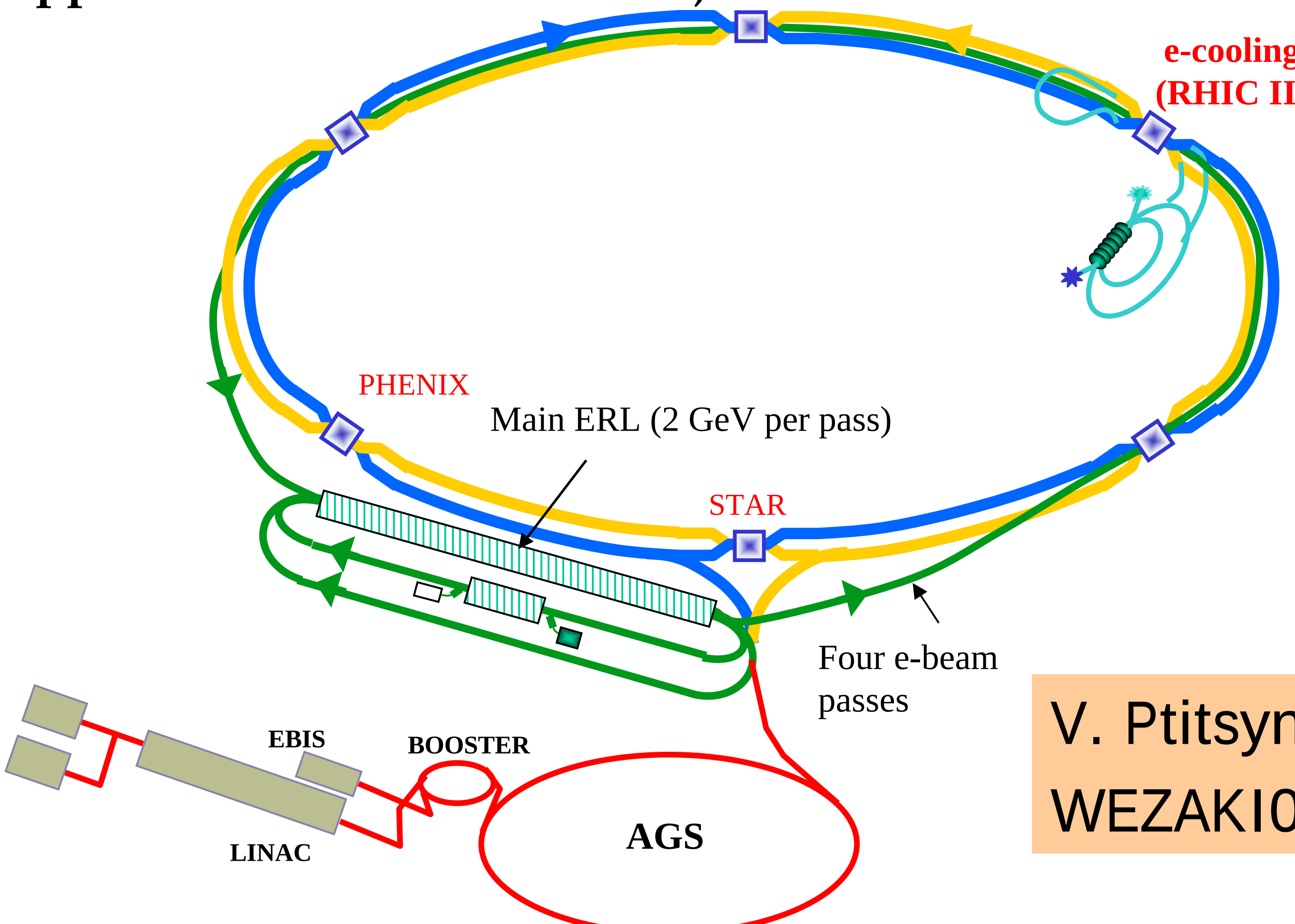
- Superconducting energy recovery linac (ERL) for the polarized electron beam.
- Peak luminosity of 2.6×10^{33} $cm^{-2}s^{-1}$ with potential for even higher luminosities.
- Uses electron cooling to pre-cool heavy ions and protons.
- R&D for a high-current polarized electron source needed to achieve the design goals.

2. "Ring-Ring" option:

- Electron storage ring for polarized electron or positron beam.
- Technologically more mature with peak luminosity of 0.47×10^{33} $cm^{-2}s^{-1}$

eRHIC

(Linac-ring approach: V. Litvinenko et al.)



V. Ptitsyn
WEZAKI02

Summary

RHIC upgrades are designed to provide

a comprehensive "QCD Laboratory"

to study

- the nature of quark-gluon matter
- the detailed properties of the "glue" that binds matter in these various forms
- the full understanding of how complex QCD structures combine to form the observed properties of the proton

Acknowledgements

We are grateful to the members of Brookhaven's Collider-Accelerator Department whose work is summarized in this presentation.

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