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Memo

DATE: *October 7, 2007*

TO: RHIC E-Coolers

FROM: *Ady Hershcovitch*

SUBJECT: **Minutes of the October 5, 2007 Meeting**

Present: Ilan Ben-Zvi, Eunmi Choi, Alexei Fedotov, Harald Hahn, Ady Hershcovitch, Vladimir Litvinenko, Dmitry Kayran, Jorg Kewisch, William Mackay, Damayanti Naik, Eduard Pozdeyev, Thomas Roser, Gang Wang.

Topics discussed: Low Energy Cooling

Low Energy Cooling: the meeting consisted of a presentation by Alexei Fedotov and a discussion of low energy electron beam cooling in RHIC. The reason for considering low energy electron beam cooling in RHIC is due to growing interest in RHIC heavy ion collisions with center-of-mass energy in the range of 5 - 50 GeV/nucleon. This energy range corresponds to gold energy beams with γ in the range of 2.68 to 26.8. Presently gold beams are injected with γ=10.52, which is already below design value of γ=12.6. Furthermore, as Todd Satogata et al., showed in PAC07, successful low energy runs were performed in RHIC.

Physics reason for low energy collisions in RHIC is to study and to discover the QCD critical point, where transition between bound quarks and quark-gluon plasma takes place. The critical point is predicted to be at about 3.6 GeV/nucleon. Consequently, the RHIC Program Advisory Committee recommended a 14 week run in 2010 for this study with a requested 5M events (minimum) per energy point. It requires low luminosity, which seems feasible based on present RHIC operation. However, some experiments are requesting higher statistics 50 - 500M events, which would call for electron beam cooling.

Alexei presented electron beam cooling simulation results for magnetized, non-magnetized, and AGS pre-cooling for lowest ion energies of interest (1.57 - 5.2 GeV/nucleon; corresponding electron beam energies 0.86 - 2.8 MeV), which benefit the most from electron cooling. Based on recent RHIC run at γ=4.9, scaling down to lowest energy point at γ=2.68 gives approximate conservative predictions of average luminosity of about $\langle L\rangle=1\text{-}3\times10^{22}$ $cm^{-2}s^{-1}$. Applying electron beam cooling directly in RHIC will increase integrated luminosity by at least a factor of 10 conservatively. In a more optimistic scenario, luminosity increase could be up to a factor of 100 or even higher in some very optimistic scenarios resulting in luminosity as high as resulting $\langle L\rangle=7\text{x}10^{24}$ $cm^{-2}s^{-1}$, and long stores become possible. With

additional pre-cooling in AGS, if one can inject higher intensities per bunch (of $2x10^9$ per bunch), or pre-cool transverse emittance even higher luminosities may be possible.

Electron beam parameters for cooling (assuming cooling length of 20 meter) are: 4-5nC/bunch in the case of magnetized cooling and 1-2nC/bunch for non-magnetized cooling, at electron beam energy of 0.86 - 2.8 MeV. Additionally, the cooling section can be decreased with a proportional increase electron beam current.

At these electron energies the following cooler options can easily be attained:

1. SRF ½ cell gun which is being fabricated for the ERL (though the ERL is not needed; only Gun-to-Dump setup is required).
2. DC based electron beam cooler like the FNAL Recycler.

Since there is a potential problem in a cooling system based on ½-cell 703 MHz gun in transporting short electron bunches (significant peak current at such low energy), Vladimir, Ilan, and Dima suggested to have a lower frequency gun, possibly as low as 56 MHz, which would produce long electron bunches and ease the electron beam transport at these low-energies. In this case, electron beam bunch will be comparable in length with the ion beam.

In summary, this low energy cooling can easily be implemented at a relative low cost.

Below is Alexei's presentation

Alexei's Presentation

Electron Cooling for Low-Energy RHIC Operation

Making Low-Energy RHIC a high-luminosity facility compatible with FAIR and NICA projects

October 5, 2007

Simulation of Low-Energy RHIC performance with electron cooling directly in RHIC were presented at COOL07 (Sep. 2007).

Following presentation at COOL07, more studies were done which now included loss on recombination and its compensation.

Both "Non-magnetized" and "Magnetized" approaches were considered.

Few slides from presentation at COOL07

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**

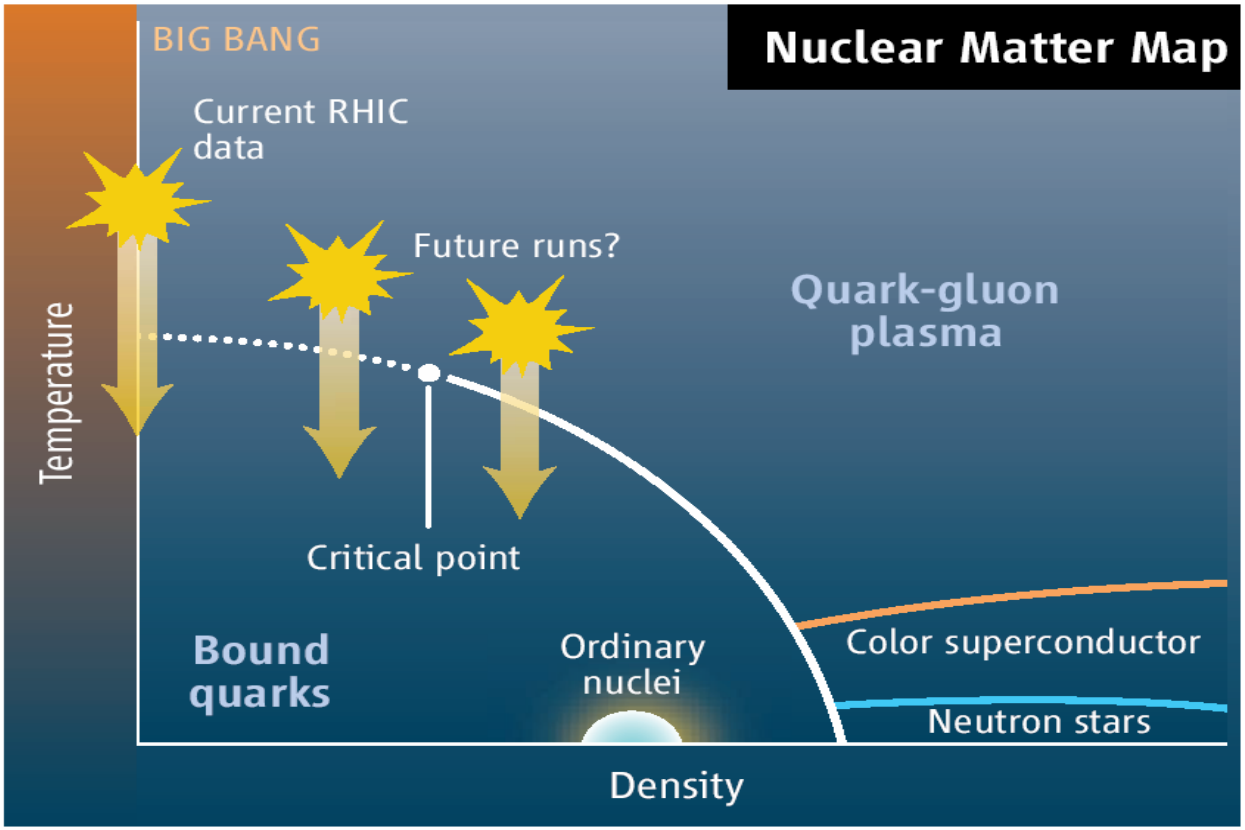
RIKEN workshop (BNL, March 9-10, 2006):

"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/n

Two 1-day test runs were done in 2006 and 2007 at low-energies to access the challenges and to make projections for low-energy operation (Todd Satogata et al., PAC07).

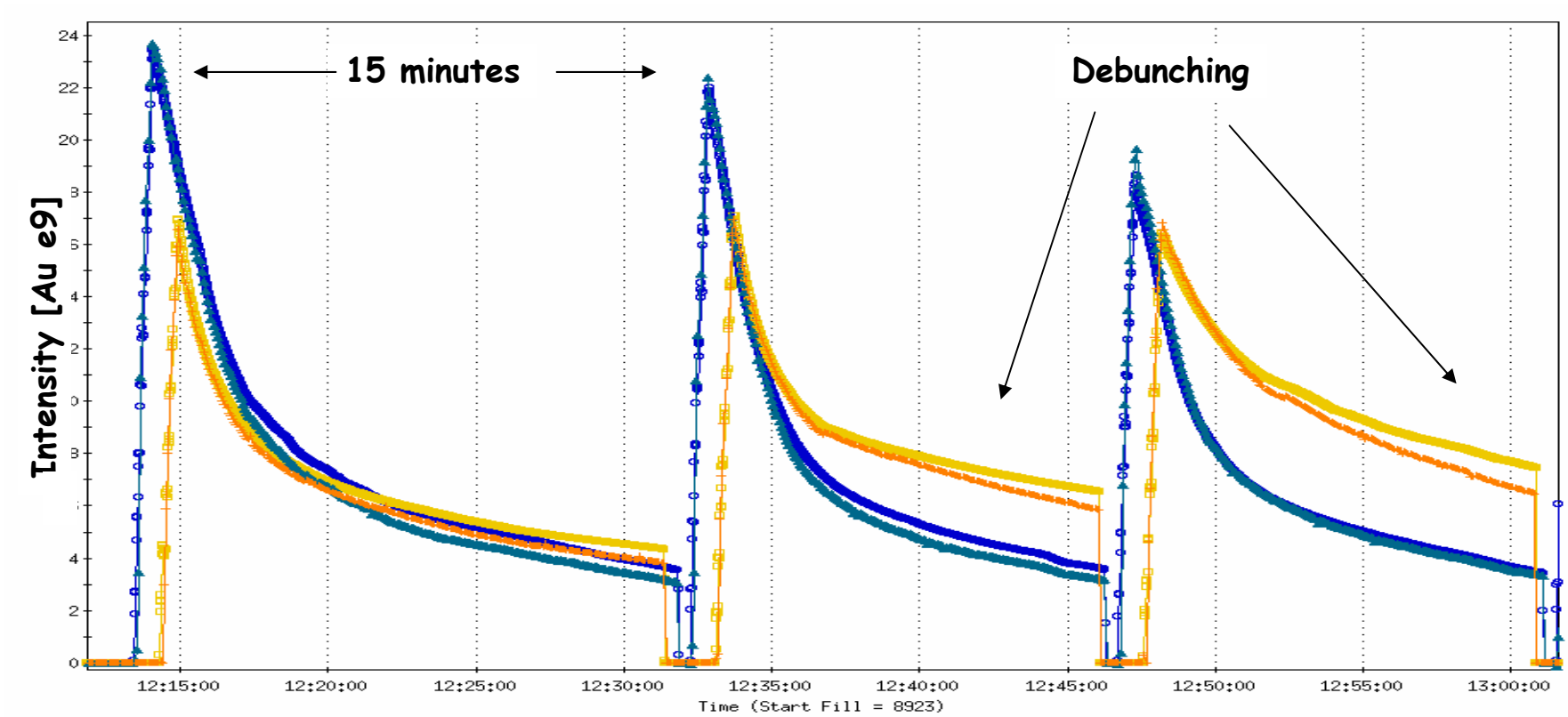
Low-energy RHIC operation: 2.5-25 GeV/n



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 $\sqrt{s}$ = 9.2 GeV/n (γ=4.93)



T. Satogata et al. PAC07

RHIC Low Energy Program Plans

- **RHIC low-energy operation is challenging**

  - RF acceptance, IBS, vertex, etc.

- **Tests of low-energy operation were successful**

  - At $\sqrt{s_{NN}}$=9.2 GeV/n produce 100-700 Hz BBC rates in STAR

  - Peak luminosity was about 1.5×10^{24} $cm^{-2}s^{-1}$ (for γ=4.93)

- **RHIC Program Advisory Committee recommended 14 week operation in 2010.**

  - Obtaining minimum requested 5M events per energy point seems feasible (this low luminosity run is proposed for Run-10).

  - No RHIC upgrades with e-cooler in RHIC is presently planned on this time scale.

  - Obtaining higher statistic 50-500M (already requested by some of the experiments) in the future may be produced with electron cooling in RHIC at these energies.

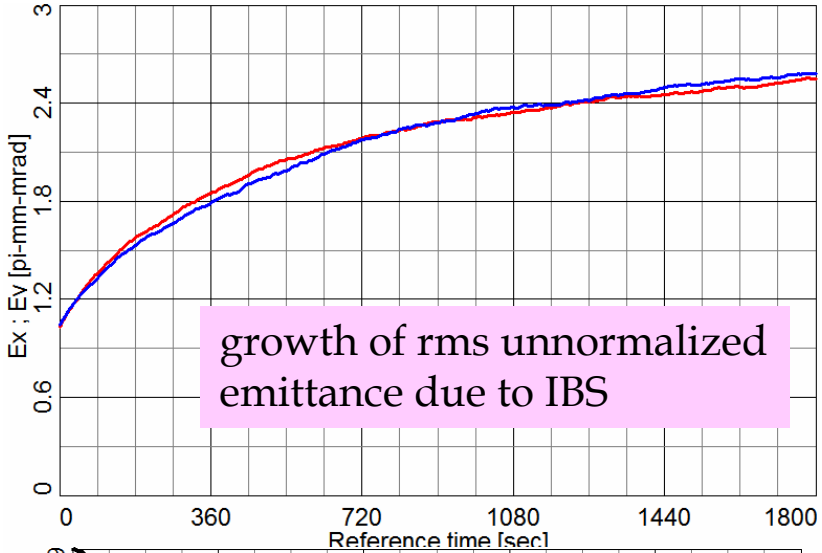
Simulations – presented at COOL07 (Sept. 2007)

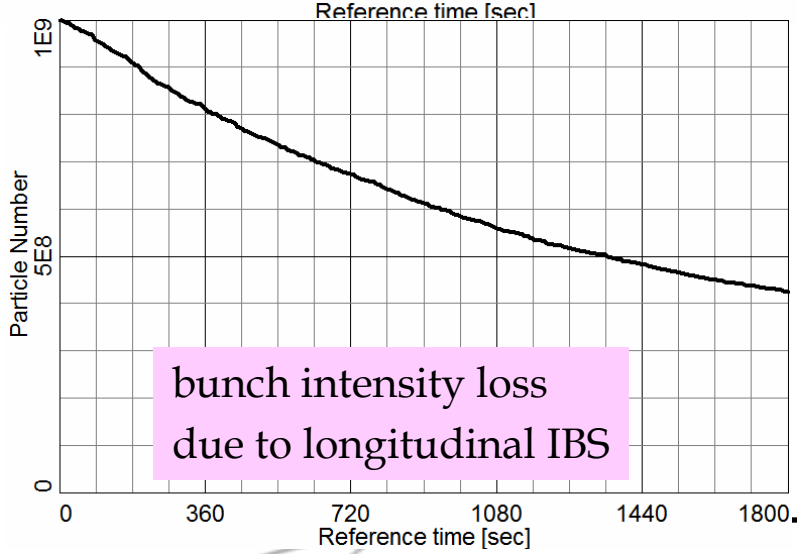
Simulations were performed:

- to evaluate limitations caused by intrabeam scattering (IBS) at low-energies
- various cooling schemes for e-cooling directly in RHIC
- pre-cooling in AGS

All simulations presented in this report were done using BETACOOL code developed by Electron Cooling Group of JINR, Dubna, Russia.

IBS for Au ions in RHIC for lowest energy point





Parameters	Value
Kinetic energy of Au ions, GeV/nucleon	1.57
Relativistic γ	2.68
Bunch intensity, 10^9	1.0
Rms momentum spread	4×10^{-4}
Rms bunch length, cm	155
Rms emittance (unnormalized), μm	1.04
RF harmonic	387
RF voltage, kV	300

RHIC low-energy electron cooler energies of interest

The lowest energy points from proposed energy scan

E_{ki}=1.57, 2.2, 2.9, 3.45, 5.2 GeV/nucleon

can benefit the most from electron cooling.

These corresponds to electron beam kinetic energies:

E_{ke}=0.86-2.8 MeV

If one wants to enhance luminosities only in the region below Critical Point (E_{ki}=3.57 GeV/n) then 2MeV e-cooler is sufficient. But uncertainty in CP location is rather big.

Such energies can be covered with the following cooler:

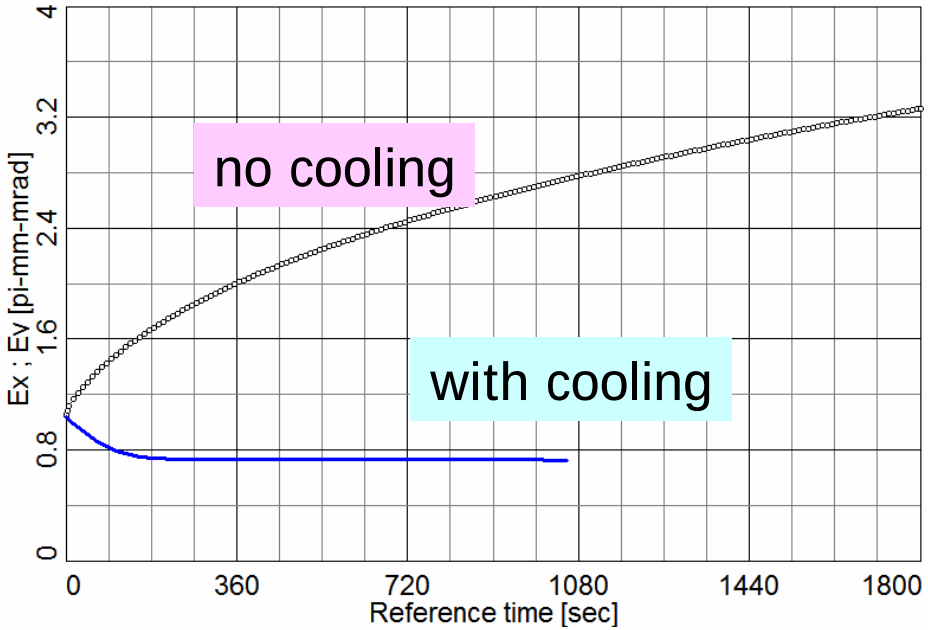
1. **SRF ½ cell gun which is under construction for R&D ERL at BNL. Note that all is needed for such cooler is Gun-to-Dump setup – no actual ERL.**
2. **Recycler (FNAL) based cooler – performance of DC cooler was discussed/shown at COOL07.**

Parameters of SRF gun based cooler used in present simulations

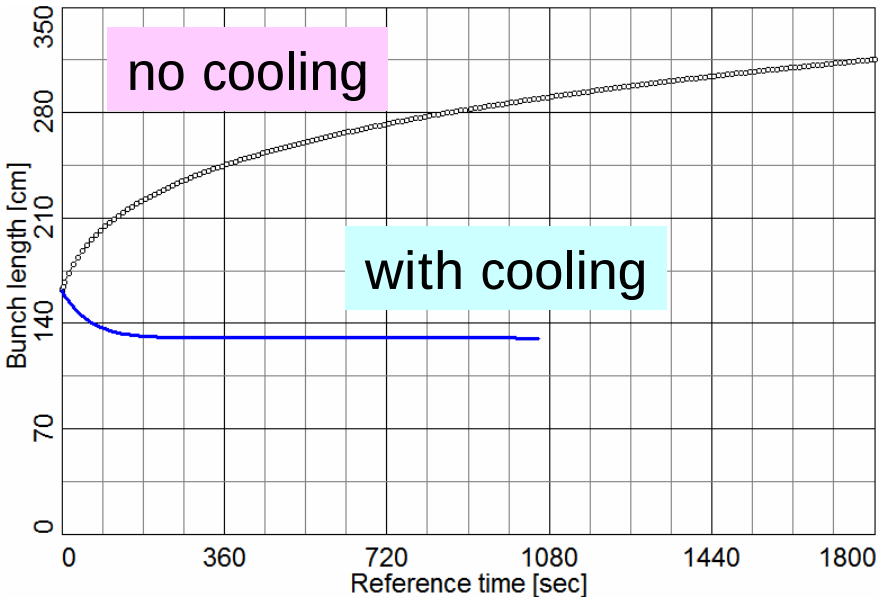
Table 1.

Parameters	Value
Kinetic energy, MeV	0.86
Charge per bunch, nC	1
Cooling length L, m	20
Normalized rms emittance, μm	2
Rms momentum spread	3×10^{-4}
Rms beam radius, mm	5
Rms bunch length, mm	8

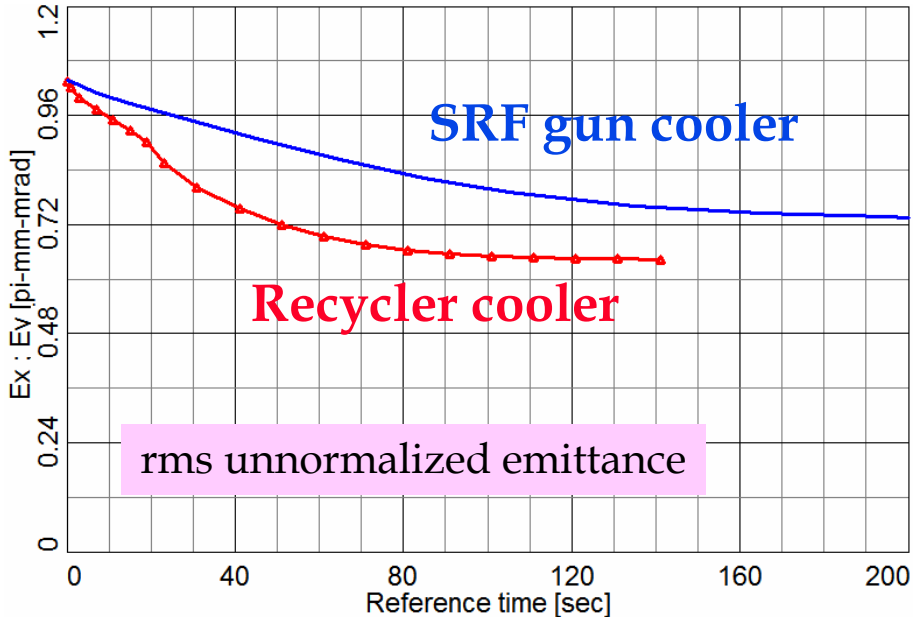
SRF gun cooler simulations for E_{ki}=1.57 GeV/nucleon (from COOL07; no recombination was included)

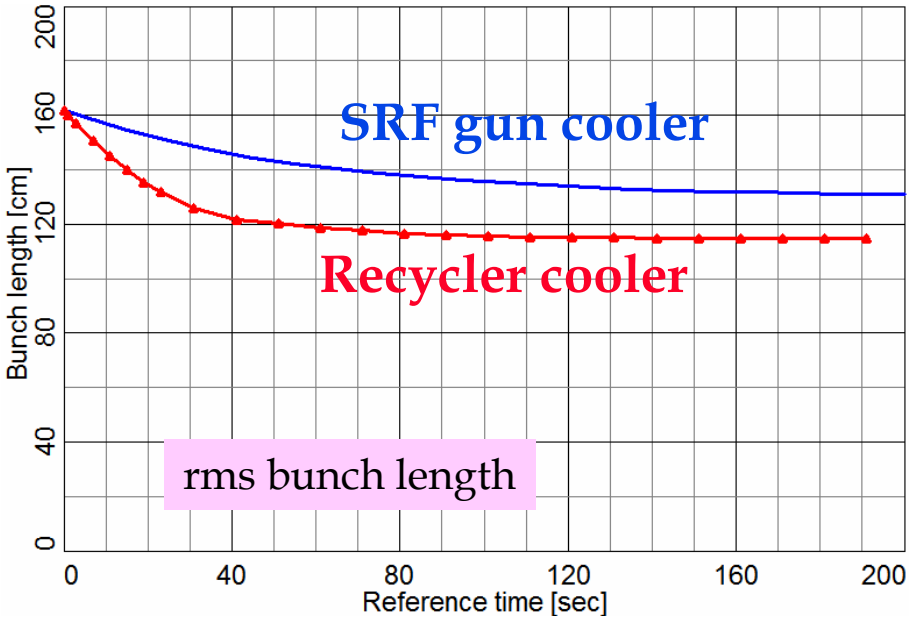


Note, that if rms emittance of 1nC electron beam is as big as 4 μm, IBS growth is just compensated, which may be already sufficient cooling performance.



Cooling simulations for Au ions at E_{ki}=1.6 GeV/nucleon





Luminosities with and without cooling

Based on recent test run at γ=4.9, scaling to lowest energy point at γ=2.68 gives approximate conservative predictions of peak luminosity of about:

$L_{peak}=0.5\text{-}1\times10^{23}\ cm^{-2}s^{-1}$

However, due to rapid debunching and strong transverse emittance growth, the store length will be just a few minutes with an average luminosity of about:

$\langle L\rangle=1\text{-}3\times10^{22}\ cm^{-2}s^{-1}$ ←

Such average luminosities were used for estimates of proposed run in 2010.

Applying electron cooling directly in RHIC will increase integrated luminosity by at least a factor of 10 – in fact, it could be up to a factor of 100 or even higher in some optimistic scenarios!!!

The need of electron cooling becomes critical if high statistics is requested in the future.

Follow-up after COOL07

Other projects: NICA and FAIR (SIS300)

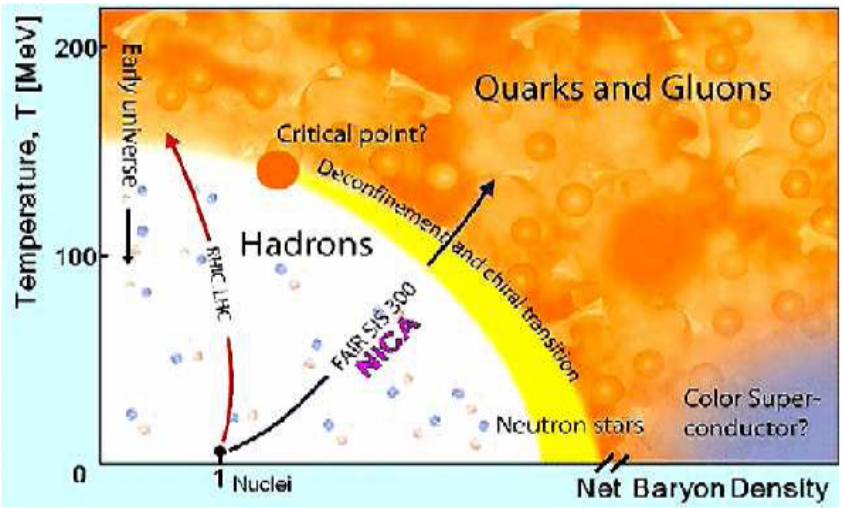
NICA project (Dubna, Russia) – Au-Au collisions in the range of kinetic energies of ions 1.0-3.5 GeV/nucleon. Very high luminosities are essential for physics program. With present (optimistic) design parameters, maybe able to get to luminosities of 10^{27} for highest energy point (3.5 GeV/n).

E-cooling: 1) pre-cooling at injector energy is required (AGS-type) 2) E-cooling (up to 2 MeV) of ions 1.0-3.5 GeV in collider is being considered.

(Design: 2007-09; Construction of components: 2008-11; Assembling: 2011-12; Commissioning: 2013)

At RHIC, for lowest energy point (1.57 GeV/n) without electron cooling one may expect to have average luminosities in the range of $3*10^{22}$.

With direct electron cooling in RHIC, significant boost in luminosity is expected.



Physics:

deconfinement and/or chiral symmetry restoration phase transitions

the first stage

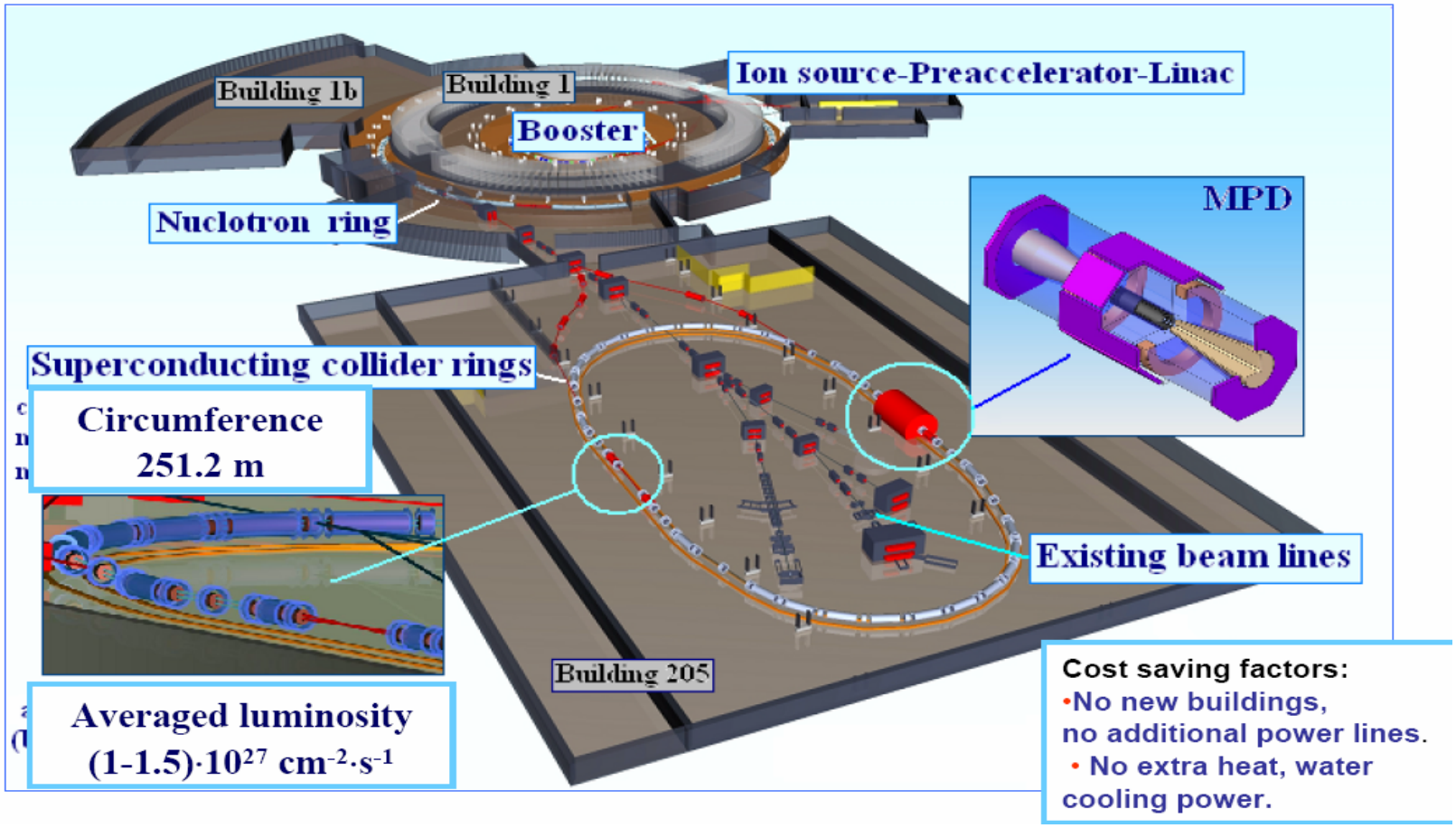
- Multiplicity and global characteristics of identified hadrons including multi-strange particles
- Fluctuations in multiplicity and transverse momenta
- Directed and elliptic flows for various hadrons
- HBT and particle correlations

the second stage

- **Electromagnetic probes (photons and dileptons)**

V. Toneev et al. (GSI workshop, July 2007)

NICA general layout



Cost saving factors:
- No new buildings, no additional power lines.
- No extra heat, water cooling power.

Two approaches of RHIC Low-Energy Cooler were considered which should take care of recombination.

1. **Magnetized:**

   require high electron charge (4-5nC), require large electron emittance to control recombination, require strong solenoid to control recombination.

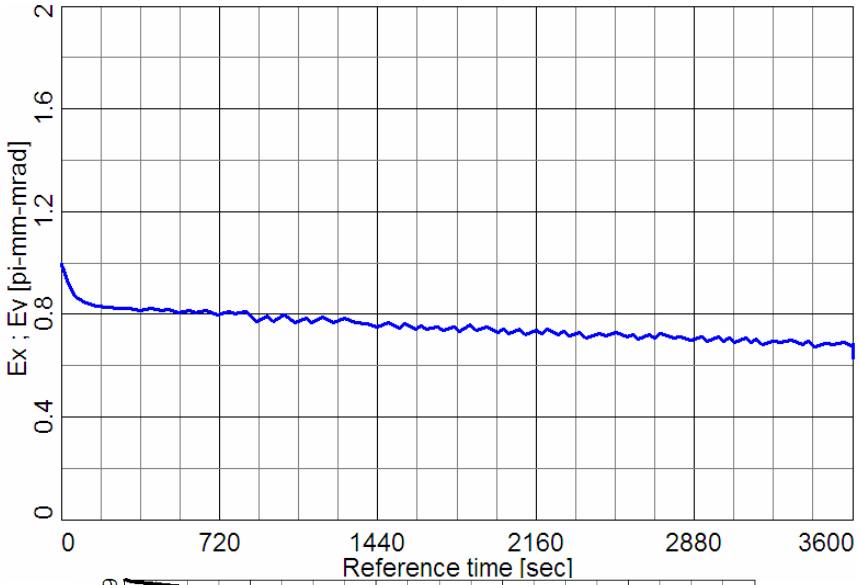
   Simulation are shown for q=5nC, ε=20 μm, B=0.5T, L=20m

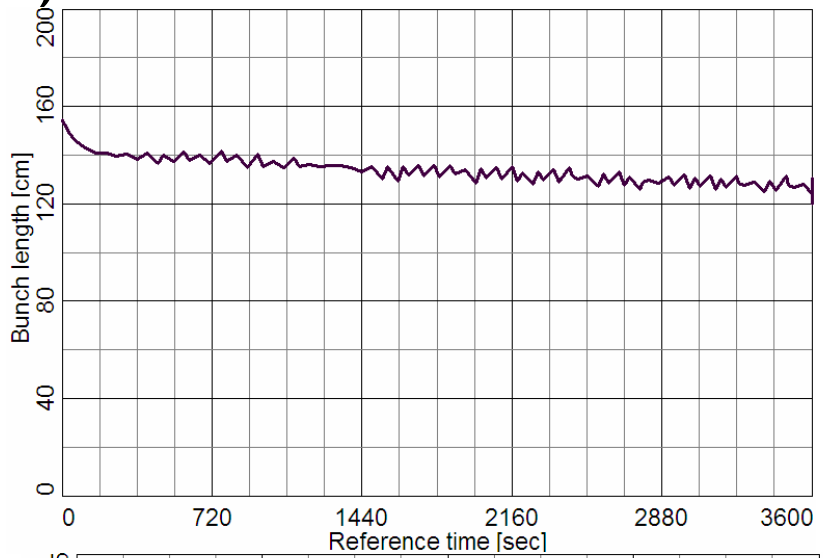
2. **Non-magnetized (1-2nC):**

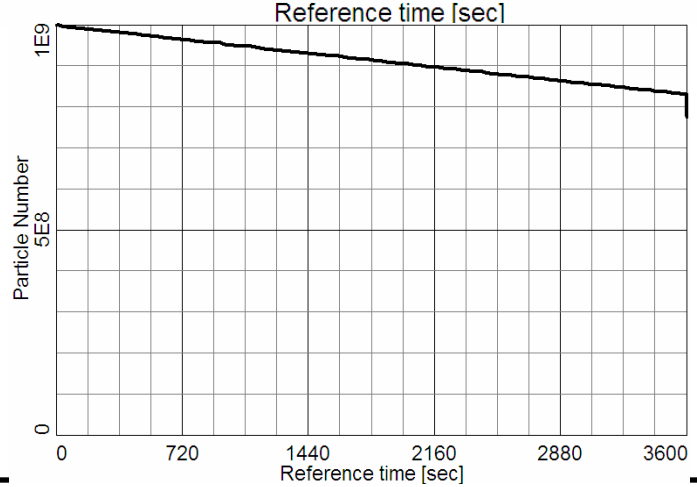
   Simulations are shown for q=2nC, ε=2μm, B=3G, λ=8cm, L=20m

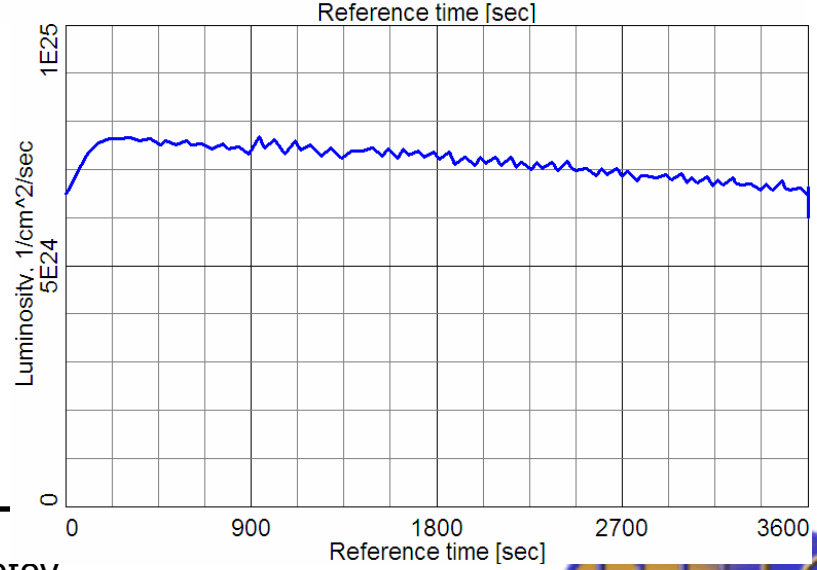
Note, that length of cooling section L=20m is not a requirement because electron beam current can be increased as well as specific luminosity requirement does not exist yet (cooling section length can be decreased).

Magnetized cooling approach (L=20m, B=0.5T, q=5nC, electron rms normalized ε=20 μm)

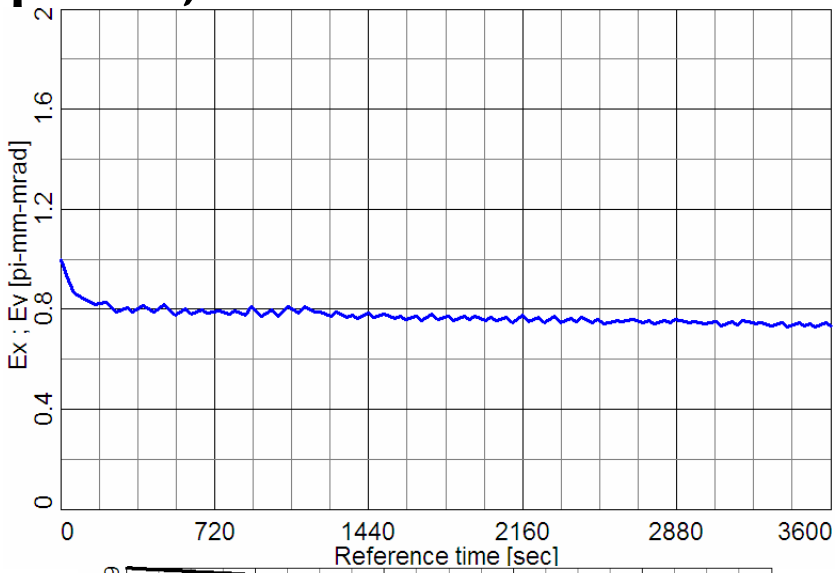


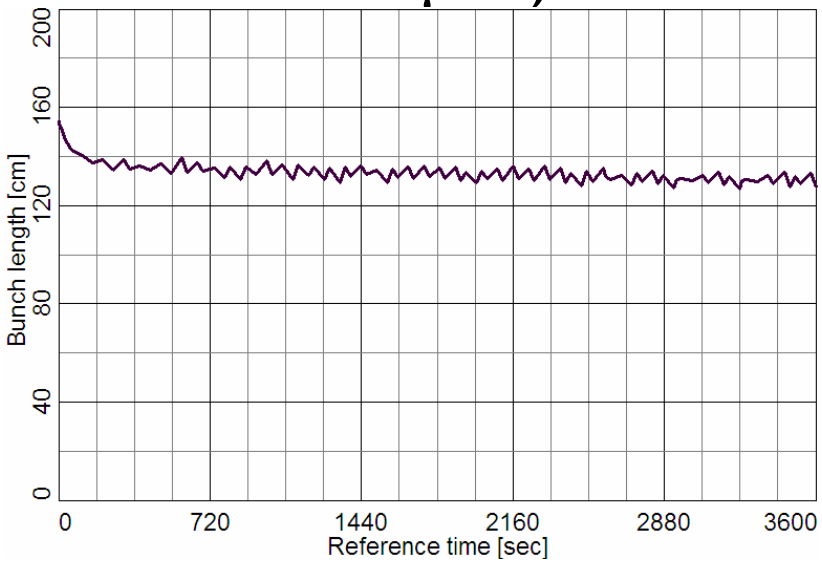


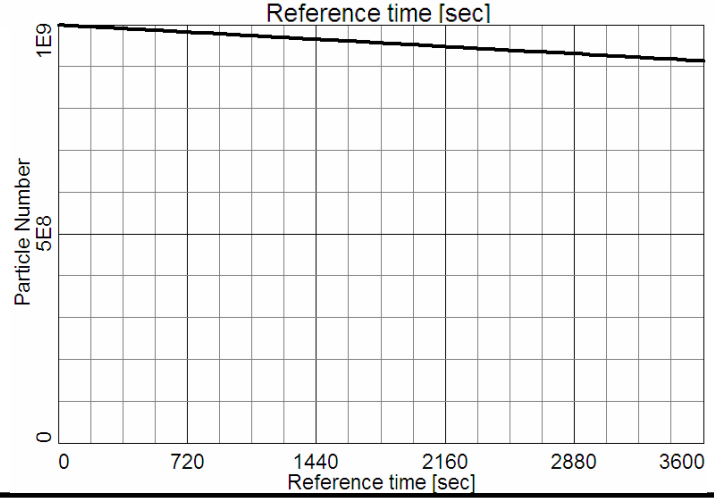


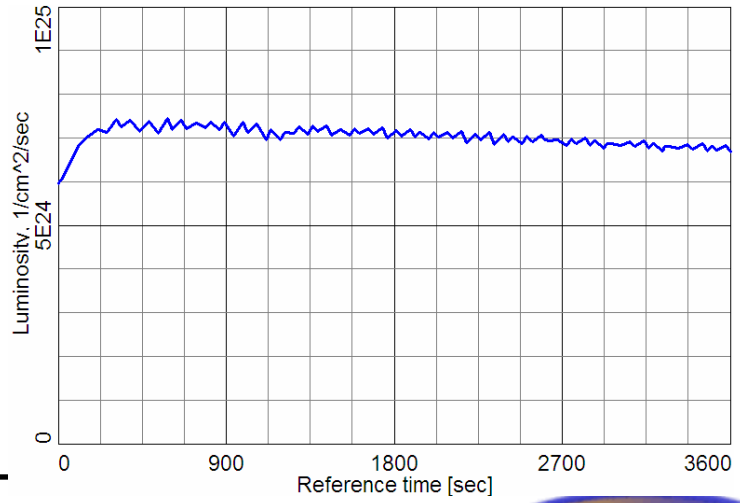


Non-magnetized cooling approach (L=20m, B=3G, q=2nC, electron rms normalized emittance ε=2 μm)









Low-energy RHIC luminosity estimate (given for lowest energy point with γ=2.6)

1. Conservative (no-cooling): beta*=10m, large emittance due to strong transverse IBS, strong intensity due to longitudinal IBS and loss from RF bucket, reduced bunch intensity, reduced number of bunches – overall, about $<L>=1\text{-}3*10^{22}$ may be expected. But stores are very short – just few minutes.
2. Optimistic (with cooling in RHIC): beta*=10m, small emittance (15 pi initial), full intensity of 1e9 per bunch, full number of bunches (112) – resulting $<L>=7*10^{24}$ - long stores become possible.

This factor of > 100 in improvement may be on an optimistic side.

On the other hand, using cooling in RHIC together with additional pre-cooling in AGS, if one can inject higher intensities per bunch (2e9?), or pre-cool transverse emittance even higher luminosities may be possible.

Since no design of such cooling systems exists, cooling performance presented here should be treated as a rough estimate only!

Potential problem of cooling system based on ½-cell 703 MHz gun is transport of short electron bunch (significant peak current at such low energy).

It was suggested (Vladimir, Ilan, Dima) to have gun with 56 MHz cavity which would produce long electron bunches and remove question of difficult electron beam transport at these low-energies. In this case, electron beam will be comparable in length with the ion beam.

Required parameters on electron beam, for RF gun and non-magnetized approach:

Kinetic energies: 0.86 – about 2.8 MeV (upper energy is not set)

Charge per bunch 2nC

Rms normalized emittance < 2.5 μm

Rms momentum spread < 0.0004