Electron Cooling Simulations for Low-Energy RHIC Operation

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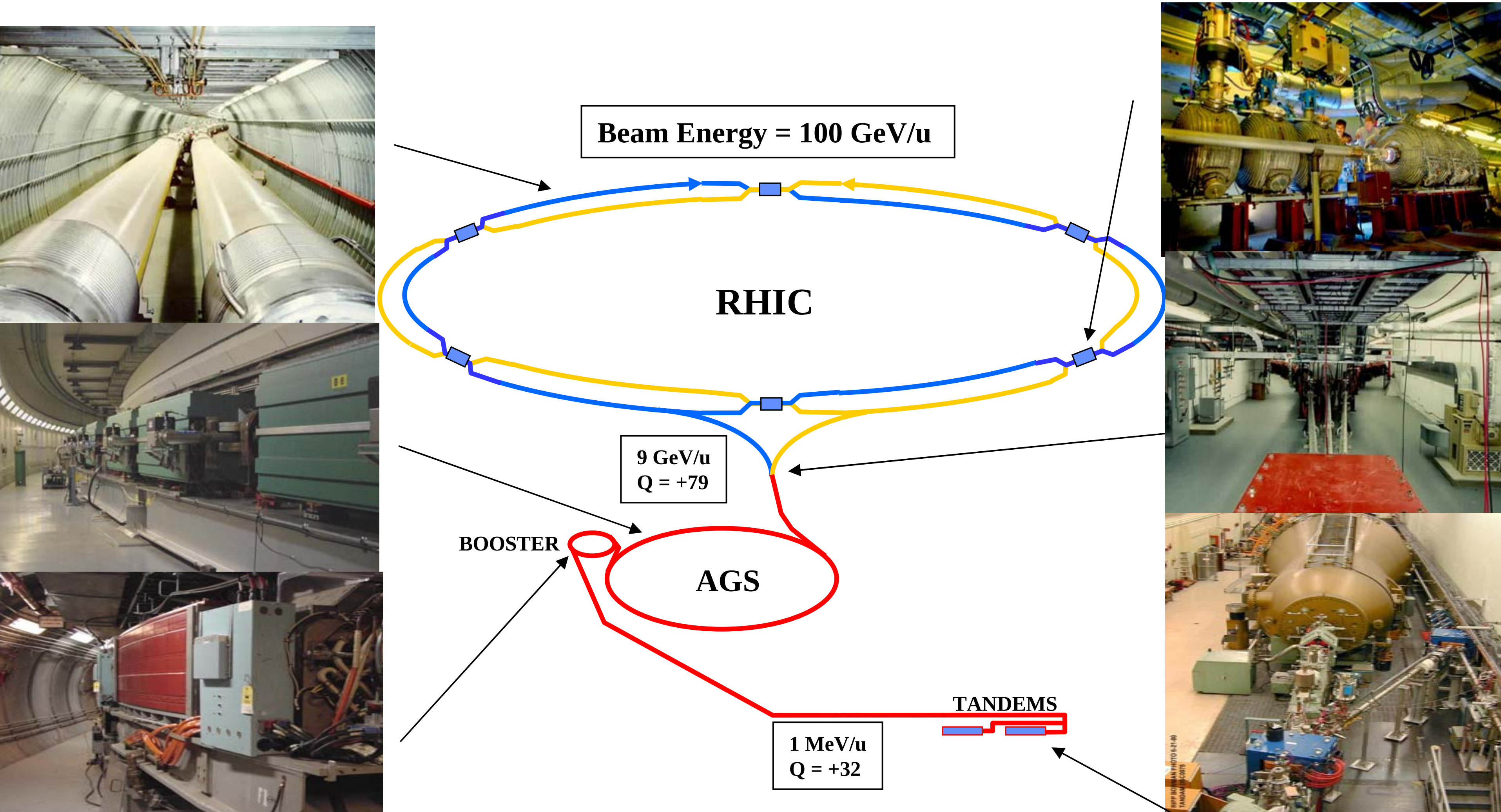
Gold Ion Collisions in RHIC



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

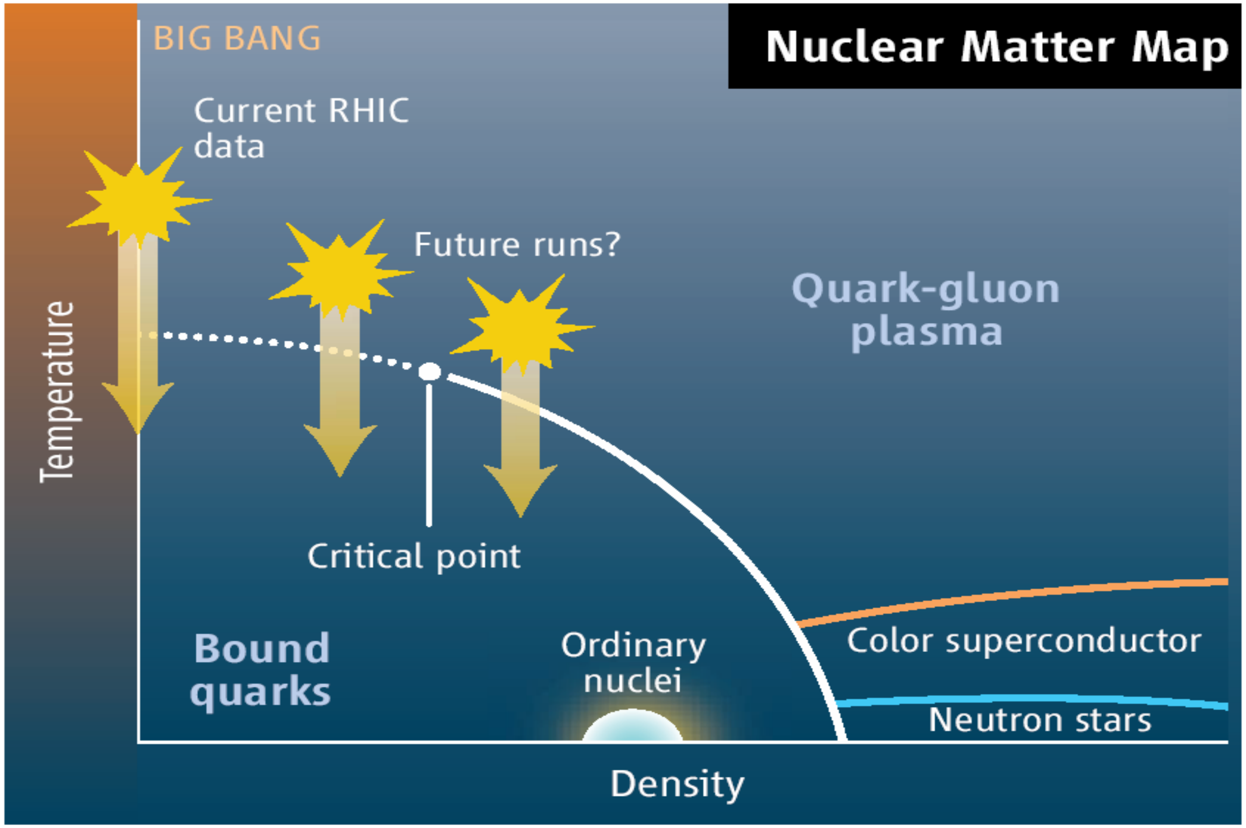
RIKEN workshop (BNL, March 9-10, 2006):

"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).

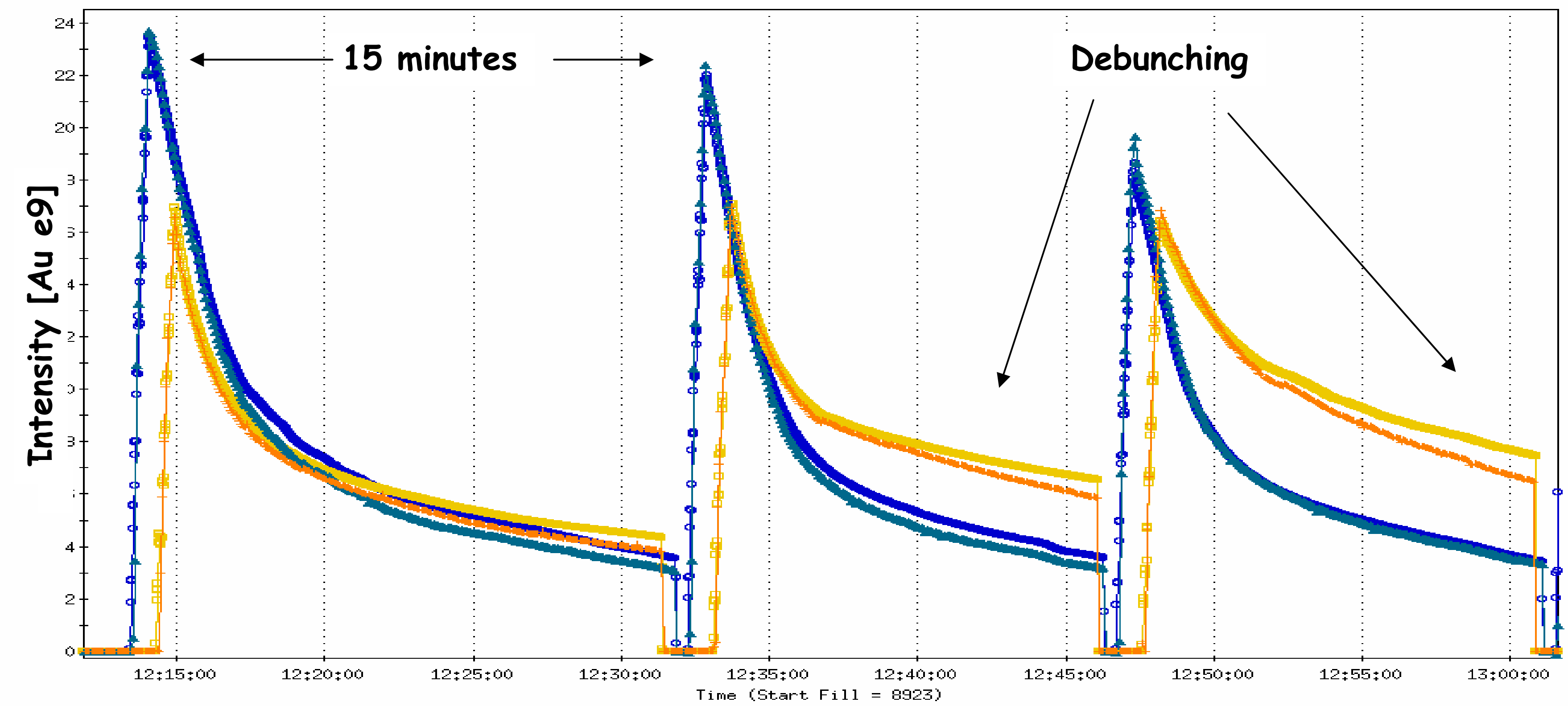
Low-energy RHIC operation: 2.5-25 GeV/n



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} $cm^{-2}s^{-1}$

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

  - Obtaining minimum requested 5M events per energy point seems feasible.

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

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

Simulations

Simulations were performed:

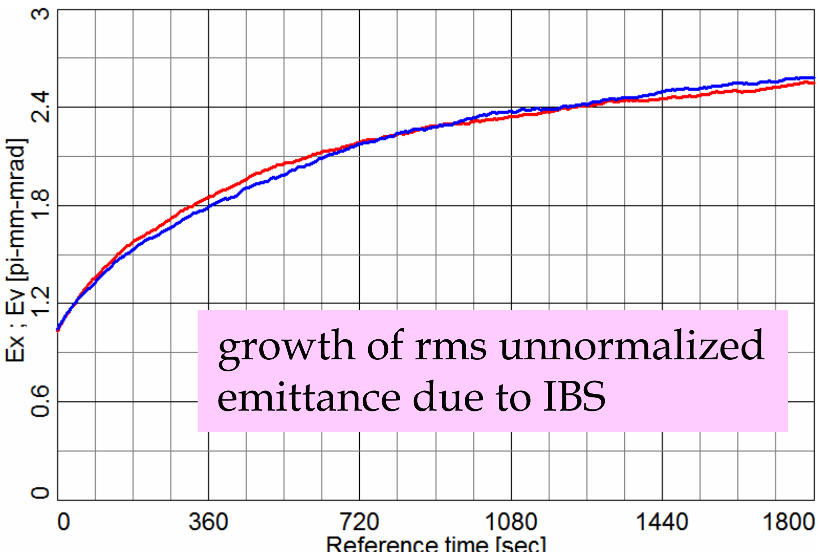
- to evaluate limitations caused by intrabeam scattering (IBS) at low-energies

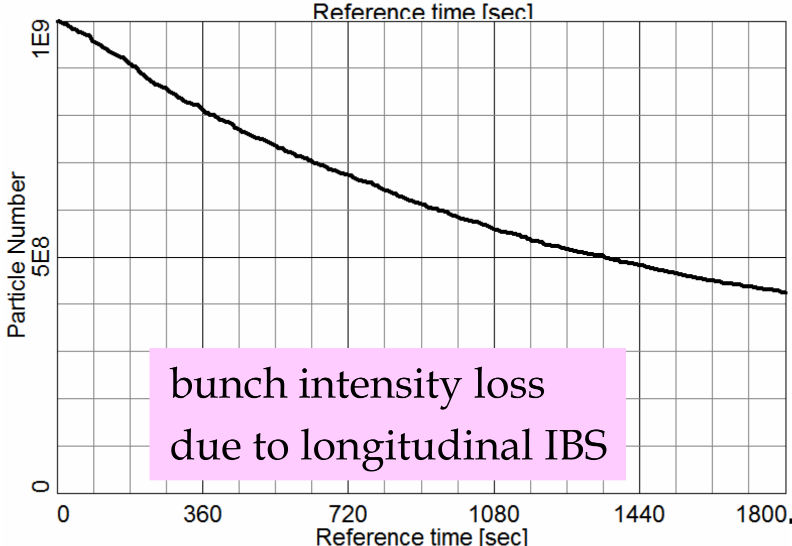
- various cooling schemes for e-cooling directly in RHIC

- 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}=1.6, 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}=0.9-2.8 MeV

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.

Electron cooling at low energy

Electron cooling for low-energy RHIC operation was initially considered using parameters of high-energy cooler (A. Fedotov, in Proceed. of Workshop "Can we discover QCD critical point in RHIC?" (March, 2006), BNL RIKEN Report No. BNL-75692-2006).

However, assumptions of using high charge 5nC electron bunches and long cooling sections (up to 80 m) are very challenging at such low energies.

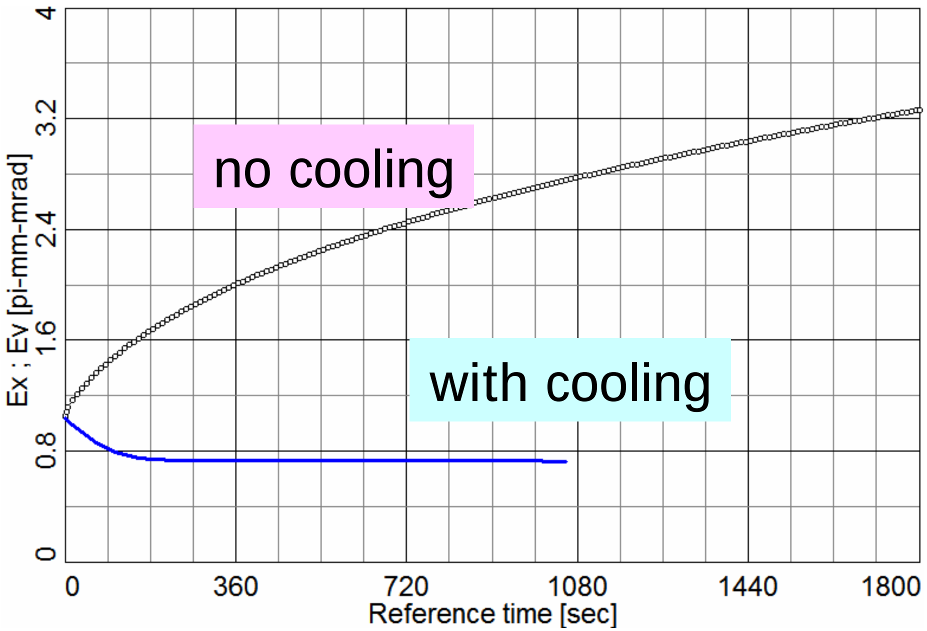
On the other hand, since there is no requirement on strong cooling – just to stop IBS and prevent intensity loss, less demanding cooling scenarios are presented in this report.

Parameters of SRF gun based cooler used in present simulations

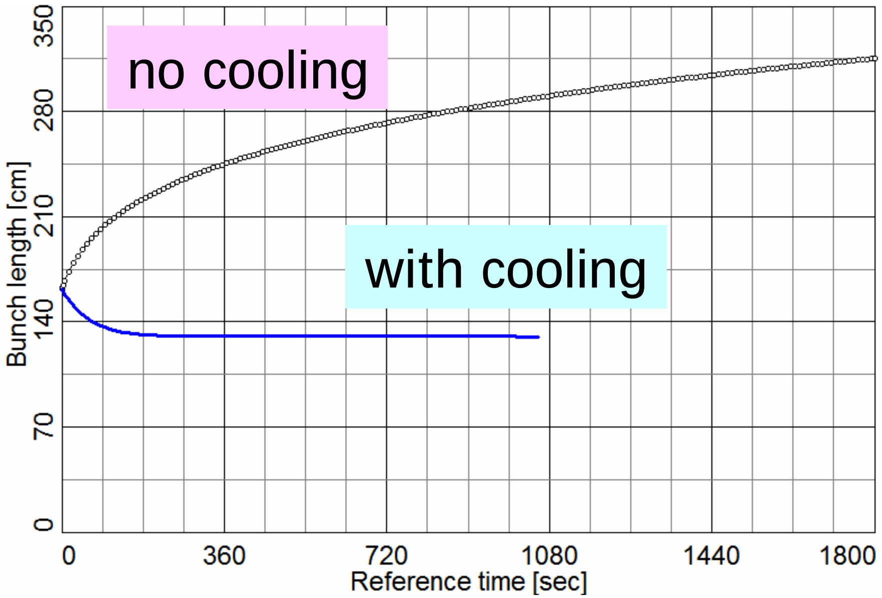
Table 1.

Parameters	Value
Kinetic energy, MeV	0.87
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

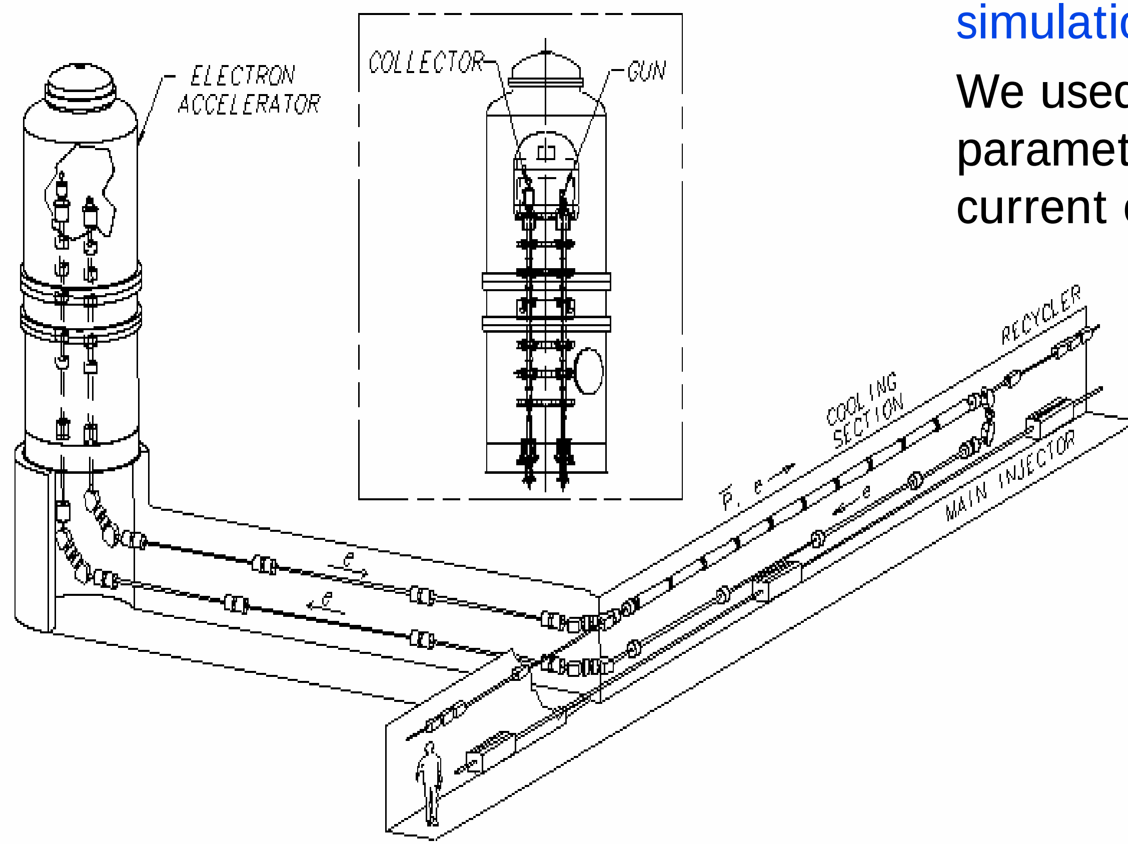
SRF gun cooler simulations for E_{ki}=1.6 GeV/nucleon



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.



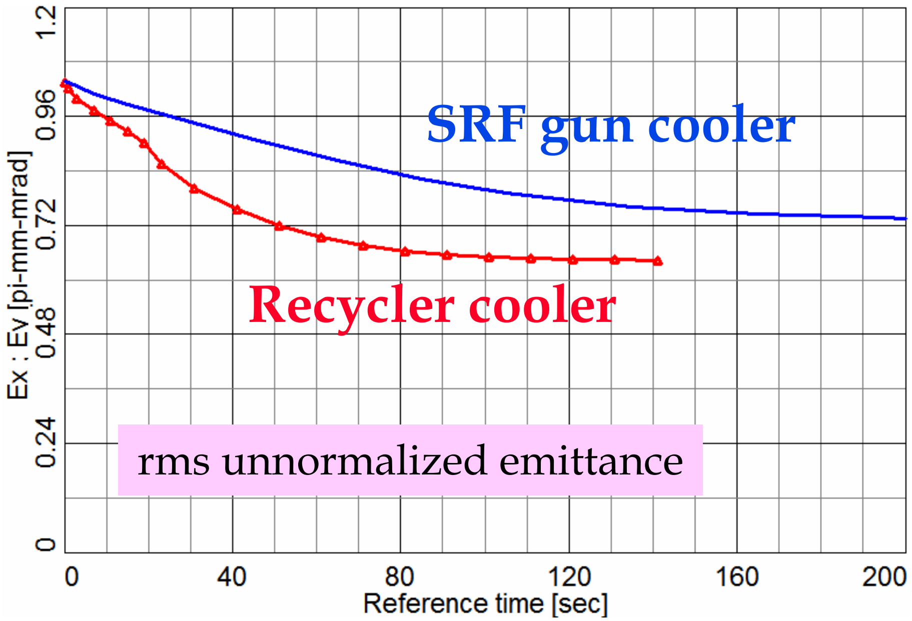
Cooling of Au ions at E_{ki}=1.6 GeV/n using Recycler FNAL cooler

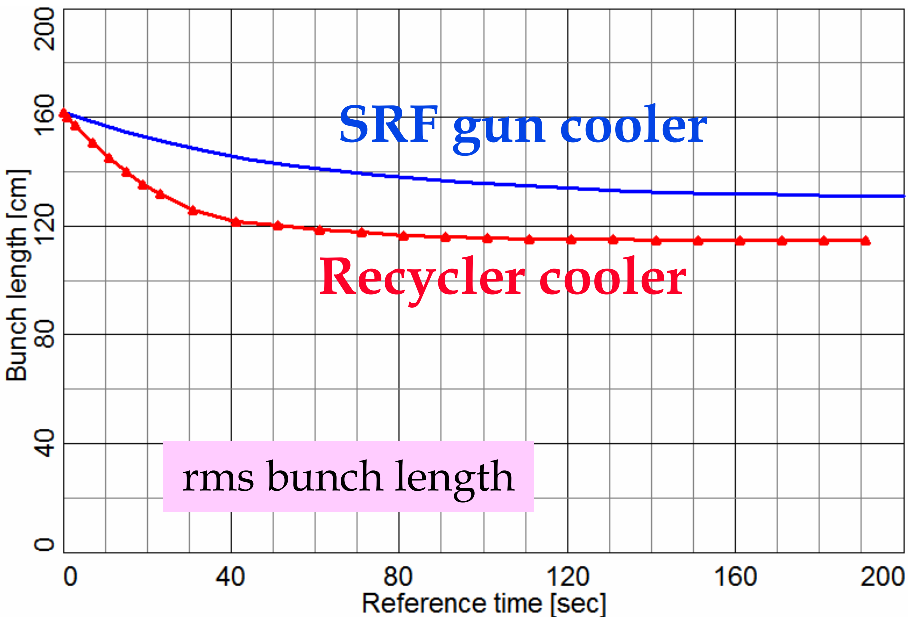


Parameters of electron cooler used in simulations:

We used typical Recycler e-cooler parameters with electron beam current of 0.2A (L. Prost, MOA2I06).

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 predictions of peak luminosity of about:

$L_{peak}=5\times10^{22}$ 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:

$\langle L\rangle=1\times10^{22}$ 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 10.

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

AGS pre-cooling

- Luminosities which were used in the estimates for 2010 low-energy RHIC operation assume almost perfect longitudinal injection into the RF bucket.

- However, for typical RHIC operation longitudinal emittance of Au ion beam injected in RHIC is 0.2-0.3 eV-s.

- For lowest energy point and RF bucket acceptance is only 0.08 eV-s (at 300 kV). Injecting large emittance in such a bucket would result in a dramatic loss in peak luminosity.

- For June 2007 test run, injected longitudinal emittance was estimated to be only 0.14 eV-s (T. Satogata et al., PAC07) which resulted in nearly perfect longitudinal injection at γ=4.9.

- The source of emittance growth in AGS is presently under investigation (E. Pozdeyev et al.).

- If found necessary, longitudinal emittance of Au beam can be cooled in AGS before injecting into RHIC. AGS pre-cooling was studied in simulations.

Parameters of AGS cooling used in simulations shown

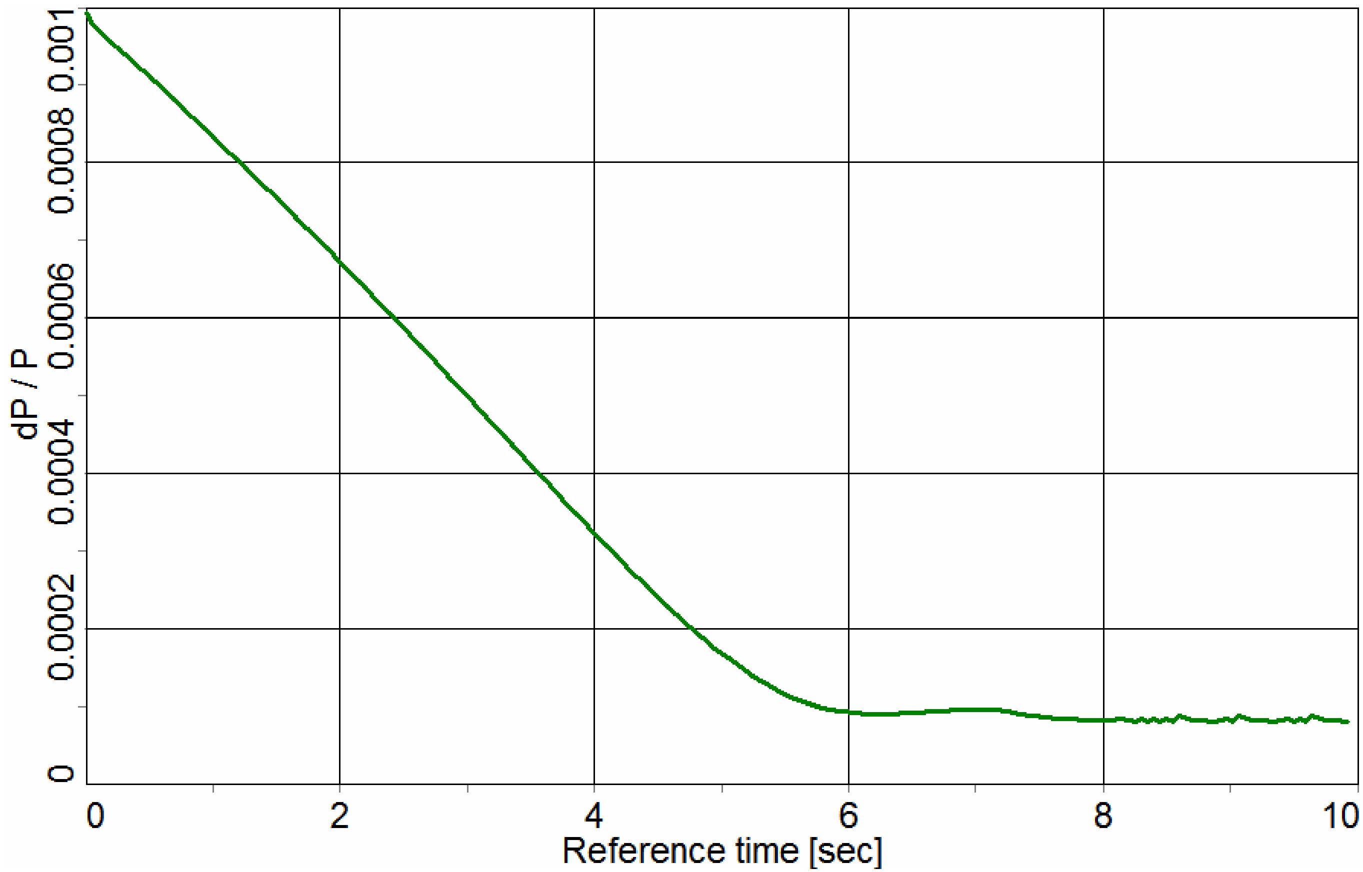
Table 2.

Parameter	Value
Electron kinetic energy, keV	53
Relativistic γ	1.1
Relativistic β	0.42
Effective cooling length, m	1.0
Solenoidal magnetic field, T	0.1
Electron beam current, A	1.0
Ion rms momentum spread	1×10^{-3}
Ion rms unnormalized emittance, μm	3.6
Number of ions	1×10^{9}

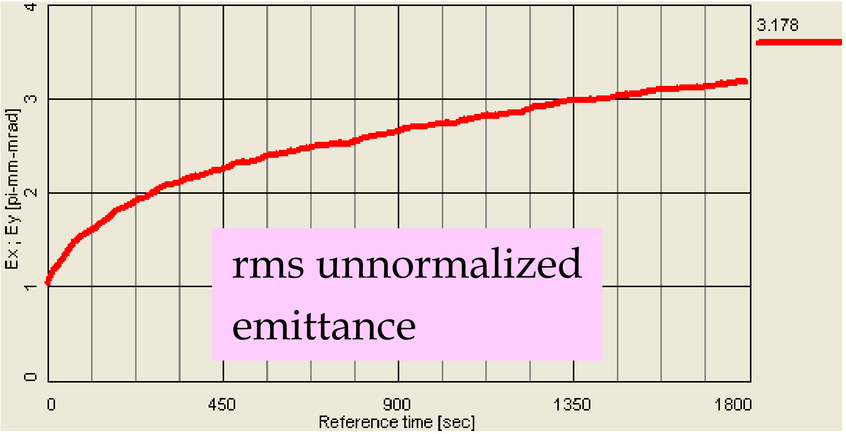
Two major constraints on the cooler:

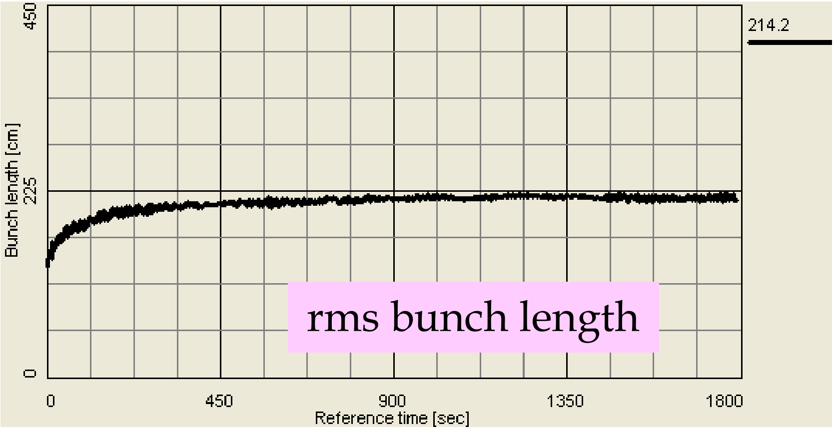
1. Physical length of the cooler including toroids is limited to 2.6m.
2. Cooling should be very fast not to impact AGS cycle significantly.

Longitudinal cooling of rms momentum spread with parameters from Table 2.



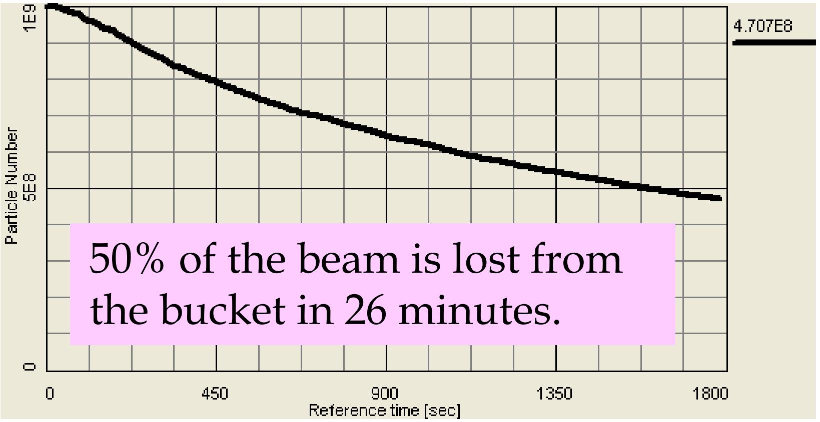
RHIC performance (kinetic energy of E_k=1.5 GeV/n γ=2.61) with injected Au ions longitudinal emittance of 0.055 eVs/n (pre-cooled in AGS).





Initial injected longitudinal emittance 0.055 eVs/n (full bucket area 0.08 (300kV))

If initial longitudinal emittance of injected beam is significantly larger than RF bucket acceptance – then there is a significant luminosity drop due to strong initial intensity loss.



Future Plans

1. A low-energy run in RHIC which should scan 6-7 energies was proposed for 2009-2010 run.
2. Feasibility of pre-cooling in AGS is presently under investigation (E. Pozdeyev et al.).
3. A test of gold collisions at lowest energy of interest 1.6 GeV/n kinetic beam energy has been proposed for 2007-2008 run. It will help to determine luminosity lifetime, and to evaluate requirements for potential AGS pre-cooling.
4. R&D ERL is scheduled for commissioning in early 2009. SRF gun may be available for direct cooling in RHIC in 2010.

Acknowledgements

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Simulations were done using BETACOOL code.

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