Electron Cooling for Low-Energy RHIC Operation

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Low-energy RHIC operation (critRHIC project)

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

- **Present injection of Au ions in RHIC is at γ=10.5**

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, 16, 20 GeV/n

Luminosity projections are relatively low for the lowest energy points of interest. However, significant luminosity improvement can be provided with electron cooling applied directly in RHIC at low energies (BNL Tech. Note C-A/AP/307, April 2008).

To cover all these energies with cooling requires electron beam with kinetic energies: 0.8-5 MeV.

For more details on physics at low-energies in RHIC see CPOD workshop (BNL, June 2009).

Beam dynamics luminosity limits for RHIC operation at low energies

The beam lifetime observed during lower energy test runs (T. Satogata et al.) was limited by machine nonlinearities – this performance can be improved provided sufficient time is given for machine development.

Other, more fundamental, limitations come from:

Intra-beam Scattering (IBS):

- Strong IBS growth - can be counteracted by Electron Cooling.

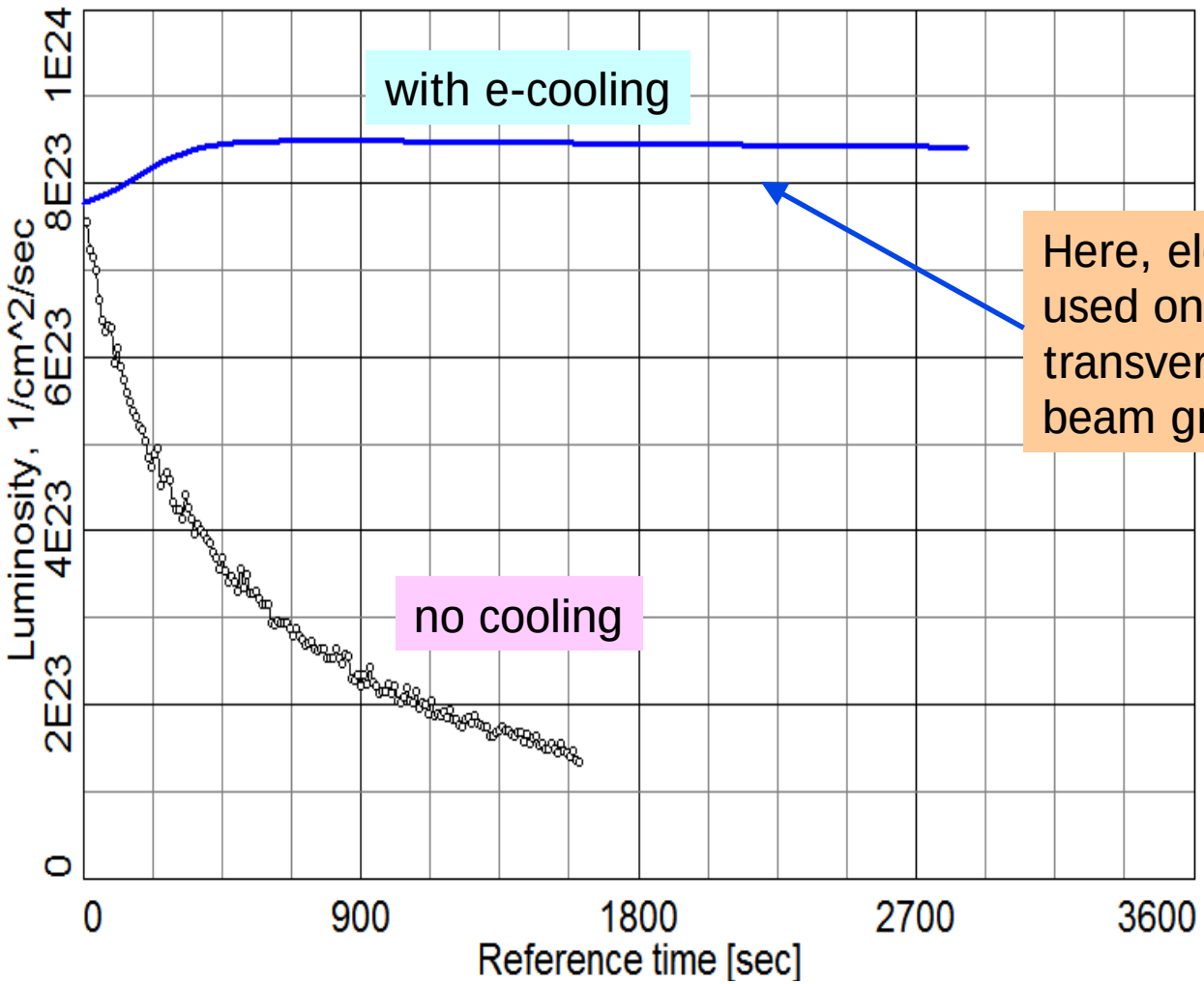
Beam-beam:

- Becomes significant limitation for RHIC parameters only at $\gamma > 10$.

Space-charge:

- At lowest energies, ultimate limitation on achievable ion beam peak current is expected to be given by space-charge effects.

γ=2.7 – lowest energy point. Simulations (BETACOOL) of luminosity with and without electron cooling.



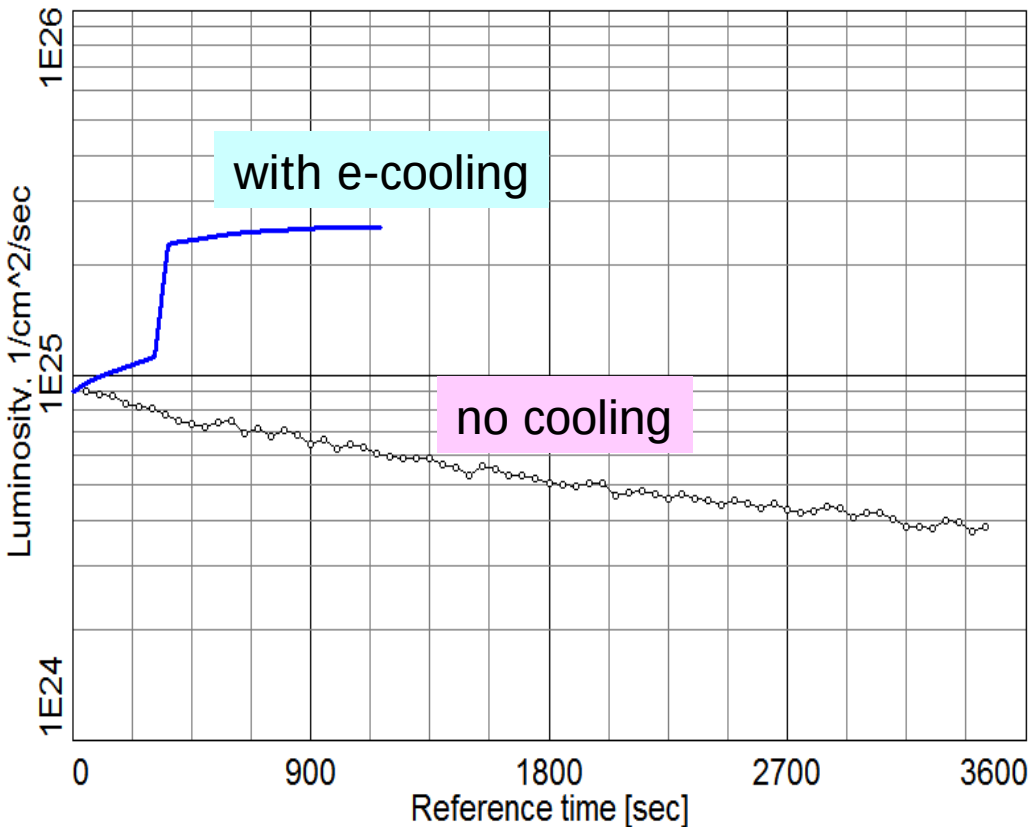
Here, electron cooling was used only to counteract transverse and longitudinal beam growth due to IBS.

For baseline beam parameters:

BNL Tech. Note C-A/AP/307, April 2008

- Apart from preventing emittance and bunch length from growing due to IBS, electron cooling can also cool beam emittance and/or bunch length to smaller values – this can result in substantial luminosity increase.
- However, for lowest energy points in RHIC, the limitation which will prohibit reaching high peak currents with electron cooling is space-charge ($\sim 1/\beta^2\gamma^3$).
- Presently, we do not know exact number for space-charge limit in RHIC. We have just started to explore this question in Accelerator Physics Experiments (APEX).
- In principle, one can attempt to provide some space-charge compensation in RHIC. For example, with E-lenses which are presently being designed for beam-beam space-charge compensation in RHIC. Then electron cooling could provide even further luminosity increase.
- Electron cooling may also allow to operate with larger space-charge tune shift parameter.
- At this point, we have chosen conservative estimate for luminosity improvement with e-cooling assuming operation with space-charge tune shift of about $\Delta Q=0.05$.

γ=6.6 ($\sqrt{s_{NN}}$ = 12 GeV/n)– (higher energy allows to cool beam emittance keeping the same space-charge tune shift)



At higher energies, by providing sufficient cooling we can cool emittance of ion beam until space-charge limit, which in turn allows to decrease β^*.

In example shown, electron cooling provides a factor of 6 improvement in integrated luminosity.

E-cooling benefits

1. Electron cooling can provide significant luminosity improvement for low-energy RHIC operation (factor 3-6 assuming modest space-charge tune shift).
2. Electron cooling offers longer stores with relatively constant luminosity.
3. Additional improvement with cooling might be possible if one can operate with larger space-charge tune shifts (>0.05) or apply space-charge compensation.
4. If significant luminosity increase for low-energy RHIC operation is requested in the future (after first low-energy runs), acquisition of high statistics is impractical without electron cooling.
5. Present choice of the cooler with electron energy up to 5MeV will extend cooling all the way up to present injection energy with heavy ions. As such, if needed, pre-cooling of transverse and/or longitudinal emittance can be done for high-energy program as well.

Electron Cooler

Present baseline option:

DC electron beam - Recyler's Pelletron (FNAL)

Possible timeline:

Based on assumption of Recycler's cooler availability at the end of 2011:

1) Transport and installation in RHIC in 2012.

2) Commissioning in 2012-13.

3) Ready for physics running in 2013-2014.

Other, options are also being considered (BNL TN C-A/AP/307, April 2008).

Electron cooler parameters

Baseline approach:

Non-magnetized with undulators for recombination suppression:

1) Present FNAL's set-up with small magnetic field on the cathode and cooling section + undulators.

2) No magnetic field on the cathode, short solenoids to counteract space-charge defocusing +undulators.

Electron kinetic energy, MeV	0.86-4.9
γ	2.7-10.6
DC current, mA	50-100
Undulator field B_u, G	3
Undulator period: λ_u, cm	8
Length of cooling section L_{cool} per ring, m	10

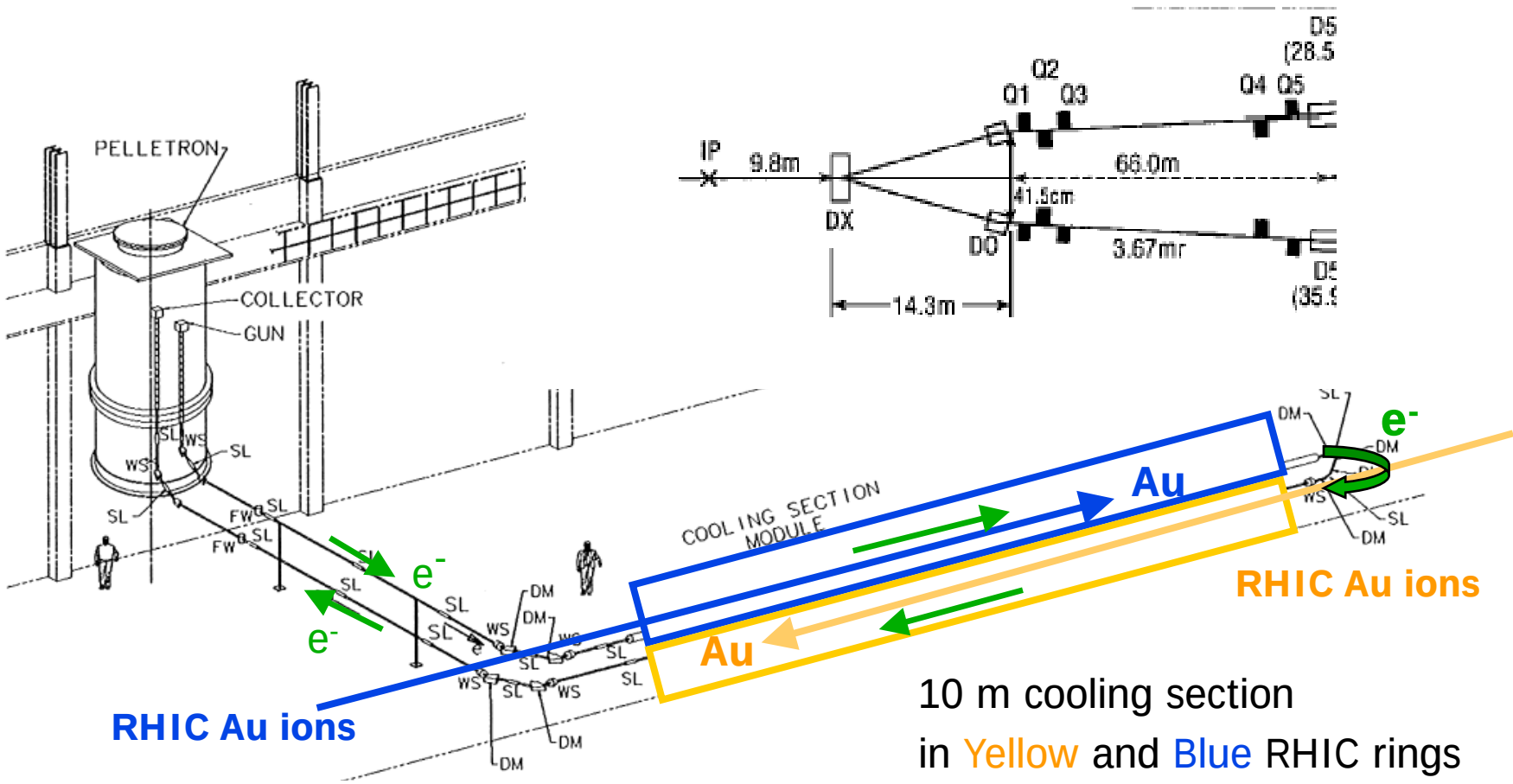
FNAL e-cooler

Pelletron

Cooling section solenoids

(MI-30 straight section)

E-cooler schematics (@ RHIC)



10 m cooling section

in Yellow and Blue RHIC rings

Near-term goals

Remaining of FY09:

- **Produce white-paper/short design report.**
- **Evaluation of needed modifications of Pelletron EC for RHIC.**
- **Selection of cooler location in RHIC complex.**
- **Detailed cost estimate.**

FY10: engineering/drawings, Technical design, evaluation of needed construction in Bldg. which will host Pelletron, design of transport lines, cooling section, safety, etc.

FY11: start to order hardware; needed constructions, etc. (AIP funds).

FY12: installation

Thank you