Electron Cooling of the Relativistic Heavy Ion Collider: Overview

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Machine Advisory Committee

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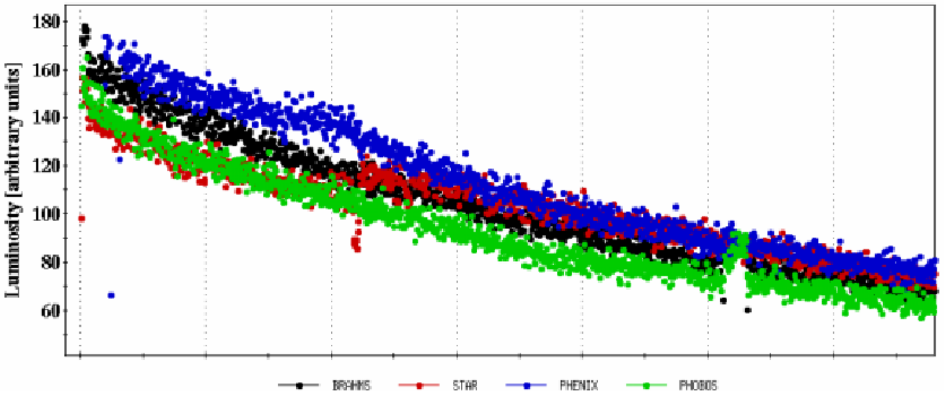
Motivation

- The motivation for electron cooling of RHIC (RHIC II) is to increase luminosity by reducing emittance and overcoming IBS.
  - Increase the integrated luminosity for gold on gold collisions by an order of magnitude, also higher P-P luminosity.
  - Increase the luminosity of protons and ions on electrons and shorten ion bunches
- Both RHIC II and eRHIC are on the DOE's 20 years facilities plan.



RHIC luminosity decay (3.5 hours)

What is special about cooling RHIC

The cooling takes place in the co-moving frame, where the ions and electrons experience only their relative motion.

RHIC ion are ~100 times more energetic than a typical cooler ring, and ~10 times higher in energy than the current record (FNAL). Relativistic factors slow the cooling by a factor of γ^2 to $\gamma^{5/2}$, depending on optimization procedure . So, first and foremost, we must provide much more cooling power than typical.

Other points: Cooling of a bunched beam, cooling of a collider, recombination and disintegration.

We cannot use conventional accelerator techniques. We require a high-energy (54 MeV), high-current (0.05 to 0.3 A) electron beam for the cooler, based on an Energy Recovery Linac.

R&D Issues

- High current, energetic, high-brightness electron beam. This in turn requires the development of:
  - Photoinjector (inc. photocathode, laser, etc.)
  - ERL, at more current than the JLAB ERL upgrade or BINP ERL.
  - Beam dynamics study (magnetized beam, space-charge and low electron temperature)
- Understanding the cooling physics in a new regime, must reduce uncertainty
  - bunched beam, recombination, IBS, disintegration
  - electron cooling simulations with some precision
  - Benchmarking experiments
- For magnetized beam, a very long, super-precise solenoid (30 m long, 2-5 Tesla, 8×10^{-6} error), wiggler for non-magnetized beam.
- Diagnostics, instabilities, RHIC lattice adaptation.

Major Developments I

- We decided to go for non-magnetized cooling.
  - Eliminates challenging superconducting solenoids
    - Technical uncertainty removed
    - Major cost saving
    - Allows longer cooling section
  - Reduces electron beam bunch charge (makes gun and cathode much easier)
  - Simplifies diagnostics
  - Eliminates certain potential instabilities
  - Was demonstrated at FNAL.

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Major Developments II

- We will use a single ERL for both RHIC rings.
  - Major cost saving.
- The ERL will be a two-pass system.
  - Cost saving in accelerator structure
  - Cost saving in conventional construction (ERL will fit into IP building).
- New cooling layout for RHIC
  - Allow very long, continuous cooling section with very large β function.

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R&D Program

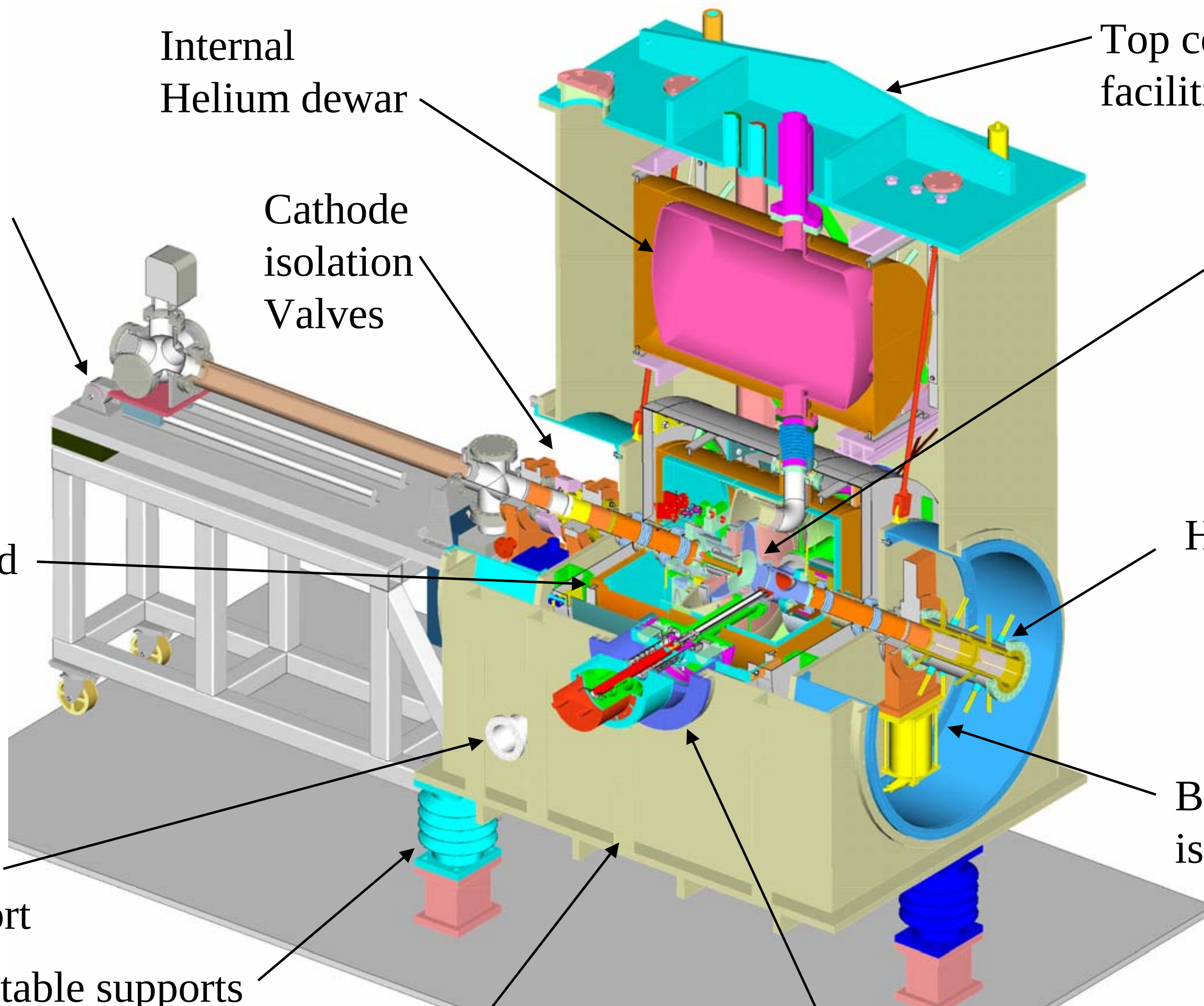
In response to the R&D issues, a program, has been put in place:

- Development of a high-current, high-energy, low emittance ERL and all its associated components: Cathode, gun, linac structure, electronics, high RF power, beam dynamics, diagnostics etc.
- Development of theory, software and experiments to provide accurate, benchmarked predictions of cooling. Studies of stability issues.
- R&D on solenoid, now to replaced by wiggler.

Major subsystems

- Photocathode
- Laser
- SRF gun
- ERL cavity
- ERL lattice
- Diagnostics
- High-power RF
- Lots of infrastructure

SRF Gun – critical element



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MAC Review of 3/10-11, 2004

MAC input	**C-AD action**
Improve agreement between calculated and measured cooling rates	Enormous progress in this area as will be reported [Fedotov].
Strengthen the effort in the laboratory to support the activities	We enjoy top support in C-AD, BNL Director's Office and DOE
Further collaboration with other electron cooling laboratories	MOUs with GSI, JLab. Work w/ Svedberg, FNAL, BINP and JINR Dubna. Industry: AES, Tech-X

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Continued 1

MAC input	**C-AD action**
Sensitivity to errors and on required tolerances.	To be done when final lattice is in place.
The (BD) results should be checked using another computer code.	Work is being done to introduce IMPACT-T and MaryLie [Kewisch].
Proof-of-principle demonstration (magnetized emittance compensation)	Insufficient resources so far, perhaps will not be necessary.

Continued 2

MAC input	**C-AD action**
Studies of the effect of transverse kicks from RF cavities on emittance.	Done, to be presented today [Calaga].
Interplay of IBS, beam-beam, wake fields and bunched beam cooling.	Some elements done, more is planned.
Systematic comparison of theoretical models with experimental results	Results will be presented. More work is under way [Fedotov].

Continued 3

MAC input	C-AD action
Collective instabilities in the cooled beam.	Work under way, some results will be presented [Wang].
Electron beam diagnostic systems, diagnostics of the cooled ion beam.	Work is under way, some results will be presented [Cameron].
A study plan for the ERL prototype.	Made, to be presented [Litvinenko].

Continued 4

MAC input	**C-AD action**
Human resources appear to be quite small.	Limited by budget constraints. Some persons added, soon some more.
Alternative designs should be considered to the CsK2Sb cathode.	A new approach started (diamond amplifier) and will be presented [Rao].
Perform measurements on a prototype RF cavity with HOM dampers.	Done, results will be presented [Calaga].

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Purpose for this meeting

- We would like to get your advice on the recent changes which we made, in particular taking non-magnetized electron cooling as the approach for electron cooling of RHIC.
- Presentations will be made both for magnetized and non-magnetized electron cooling
  - on the technology underlying the system
  - cooling rate and resulting luminosity calculations

Meeting agenda

• Photocathode	A. Burrill & T. Rao
• Electron gun, ERL cavity	R. Calaga
• Diagnostics	P. Cameron
• Solenoid/wiggler	A. Jain
• Tour (Bldg. 912, ERL site)	J. Scaduto
• Stability	G. Wang
• Magnetized beam dynamics	J. Kewisch
• Magnetized cooling	A. Fedotov
• Non-magnetized beam dynamics	D. Kayran & X. Chang
• Non-magnetized cooling	A. Fedotov
• RHIC lattice for cooling	S. Tepikian
• RHIC IBS Experiments and summary	V. Litvinenko

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Parameters

RHIC Electron Cooling Parameters

Remark: Parameters are given per ring.

Common Parameters

Gold ions at 100 GeV/A
Ion number per bunch 10^9
Ion charge 79
Initial normalized rms emittance 2.5 μm
(in both transverse planes)
Initial momentum spread 10^{-3}
Initial rms bunch length 37 cm
110 stored bunches
RF frequency (store) 197.043
Bunch frequency 9.383 MHz
ERL RF frequency 703.75 MHz
h=2520
V=3 MV

Magnetized Cooling

Cooling section

Solenoid length 60 meters (in two separate sections of 30meters, each consisting of two 15 m long units).
Magnetic field range 2-5 Tesla
Rms magnetic error $\leq 10^{-5}$
Ions β function in solenoid 60 m

Electron beam

Energy 54 MeV
Bunch charge 20 nC
Bunch rms length 5 cm (at solenoid)
rms normalized emittance 50μm (at solenoid)
rms relative momentum spread <0.001

Non-Magnetized Cooling

Cooling section

Wiggler, helical, length 60 meters
Magnetic field range 0.001 Tesla
Rms magnetic error $\leq 0.5\ 10^{-5}$
Ions β function in wiggler ≥200 m

Electron beam

Energy 54 MeV
Bunch charge 5 nC
rms bunch length 30 ps
rms normalized emittance ≤4 μm
rms relative momentum spread <0.001

Average luminosity over a 4 hour store:
Without cooling (β^*=1m) $7 \cdot 10^{26}$
With cooling (β^*=0.5m) 6~7 10^{27}.

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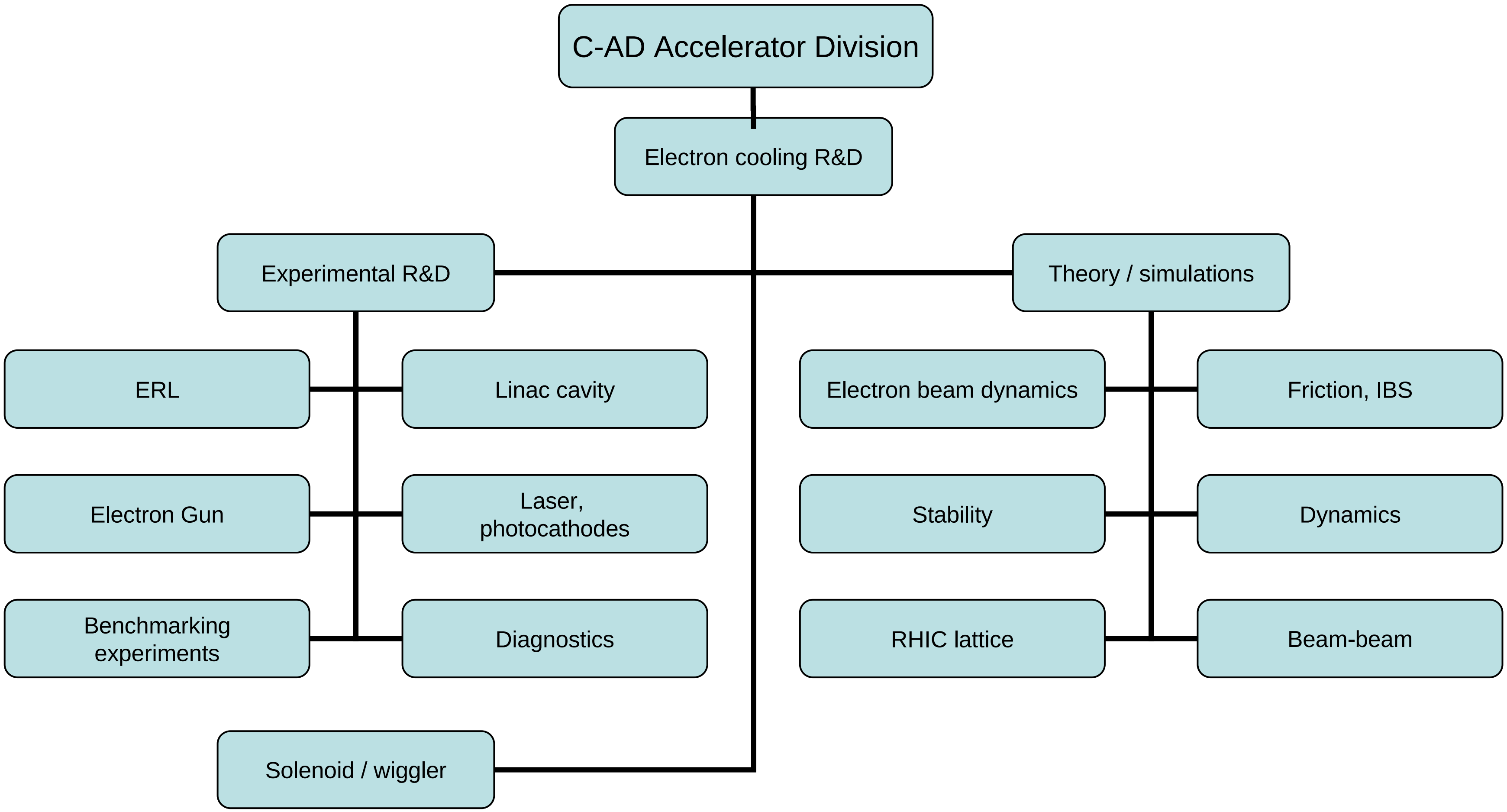
RHIC Electron Cooling R&D



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Electron cooling group.
Reporting to Thomas Roser

Ilan Ben-Zvi, Group Leader.
Vladimir Litvinenko, Deputy Group Leader.
Andrew Burrill, RF gun, photocathode and laser.
Rama Calaga, graduate student, SRF cavity, ERL.
Xiangyun Chang, beam dynamics, photocathode.
Alexei Fedotov, cooling simulations, benchmarking experiments.
Harald Hahn, Superconducting RF and HOMs.
Dmitry Kayran, RF gun and ERL.
Joerg Kewisch, beam dynamics and simulations.
David Pate, technician.
Gang Wang, graduate student, instabilities.

- Oversight weekly meeting headed by Thomas Roser.

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Other C-AD Participants

Donald Barton, computer control
Mike Blaskiewicz, stability, RF systems
Brian Boyle, financial management
Peter Cameron, diagnostics.
Wolfram Fischer, Dep. Head, Acc. Division
David Gassner, diagnostics
Ady Hershcovitch, plasma, beam dump
Dick Hseuh, vacuum.
Gary McIntyre, E-Cooling Project Engineer
Robert Lambiase, power supplies
Kerry Mirabella, project management

Anthony Nicoletti, cryogenics
Brian Oerter, computer hardware
George Parzen, IBS and cooling theory
James Rank, mechanical engineer
Thomas Roser, Head, Accel. Division
Joseph Scaduto, conventional facility
Karl Schultheiss, RF control system
Kevin Smith, RF control system
Jonathan Reich, interlocks
Alex Zaltsman, high-power RF

Many more than space allows to enumerate in
design, technical support, safety, administration and services!

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Other Participants / collaborators

Animesh Jain (BNL Superconducting Magnet Div.), solenoid, wiggler.
Ramesh Gupta (BNL Superconducting Magnet Div.), HTS, wiggler.
Triveni Rao (BNL Instrumentation Div.), photocathode and laser, SRF gun.
John Smedley (BNL Instrumentation Division), photocathode
GSI/INTAS collaboration: O. Boine-Frankenheim, others.
JLAB: J. Delayen, Ya. Derbenev, P. Kneisel, L. Merminga.
JINR (Dubna), Russia: I. Meshkov, A. Sidorin, A. Smirnov, G. Trubnikov
BINP, Russia: V. Parkhomchuk, A. Skrinsky, many others.
FNAL: A. Burov, S. Nagaitsev, A. Shemyakin, L. Prost.
The Svedberg Laboratory: V. Ziemann, B. Galnander, T. Lofnes, D. Reistad.
SLAC: D. Dowell.
Advanced Energy Systems: M. Cole, A. Burger, A. Favale, D. Holmes,
A. Todd, J. Rathke, T. Schultheiss.
Tech-X, Colorado: D. Abell, D. Bruhwiler, R. Busby, J. Cary.

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