Electron Cooling for Low-Energy RHIC Operation

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RHIC Retreat July 1-2, 2010

Expected beam dynamics luminosity limits for RHIC operation at low energies

2008:

The beam lifetime observed during lower energy test runs (2007-8) was limited by machine nonlinearities – this performance may be improved provided sufficient time is given for machine development. ? 2010

Other, more fundamental, limitations come from:

Intra-beam Scattering (IBS):

- **IBS growth at lowest energies - Electron Cooling was proposed to counteract IBS**

Beam-beam:

- **Becomes dominant limitation for RHIC parameters 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.**

In Run-10, we were able to reach space-charge tune shifts up to 0.1

Electron Cooler for Low-E RHIC

Present baseline:

Recycler's Pelletron (FNAL) – 6 MV electrostatic electron accelerator

main components:

1) pressure vessel

2) high-voltage insulating support structure

3) charging system

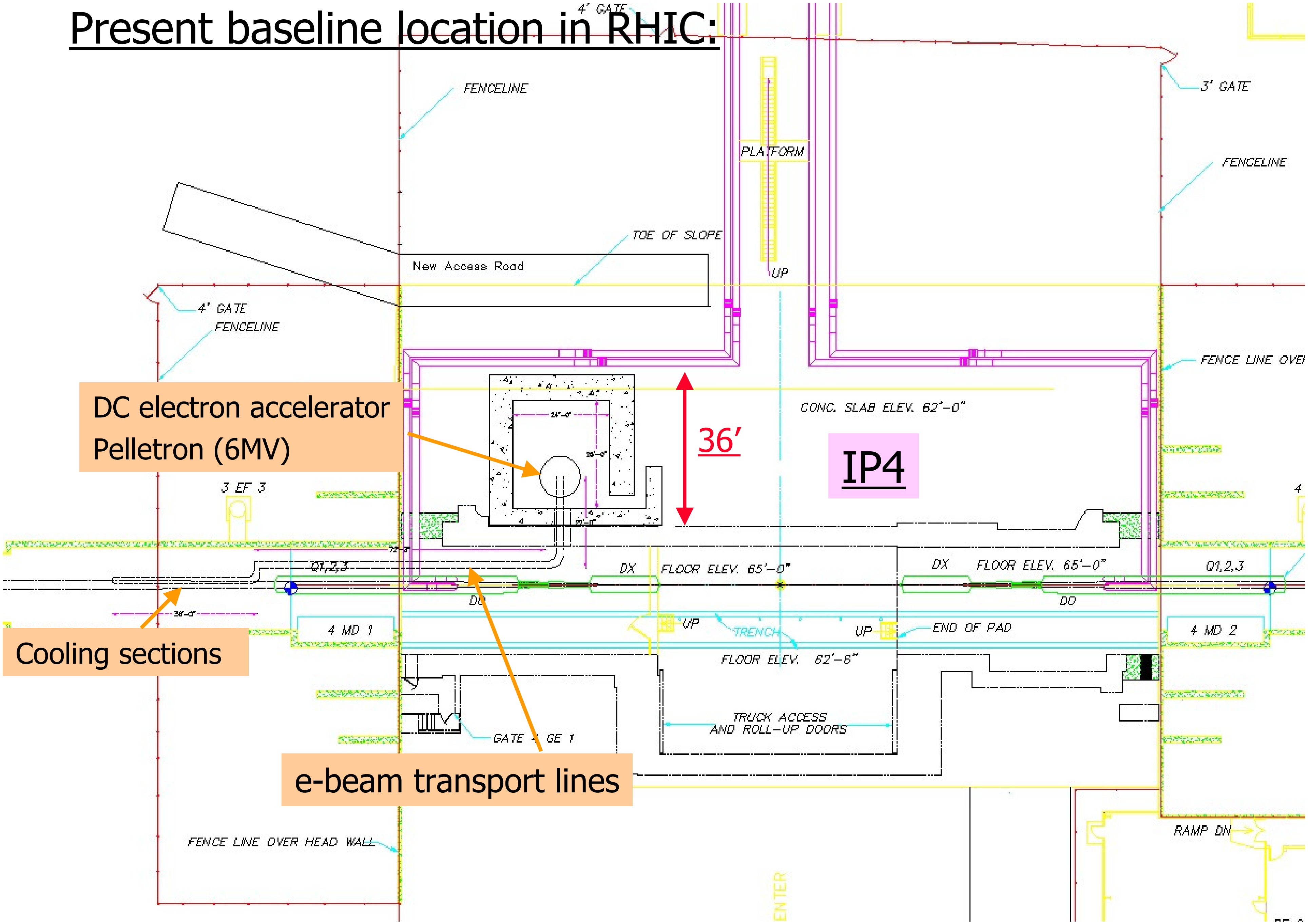
4) accelerating/decelerating tubes

Covers full energy range of interest:

Electron kinetic energies

0.9-5 MeV (for ion beam energies 2.5 – 10 GeV/n)

Present baseline location in RHIC:



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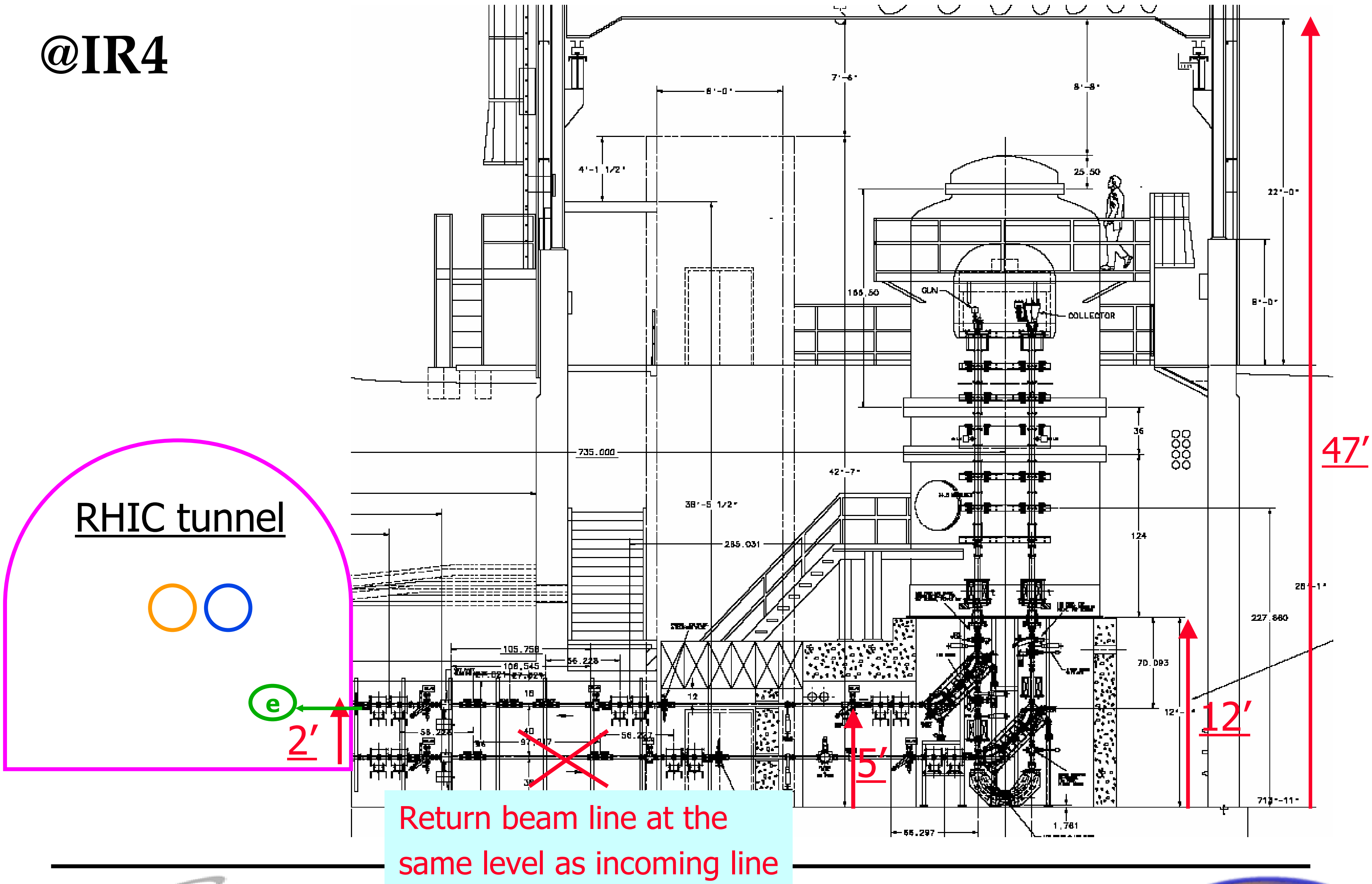

RHIC tunnel
e
2′
5′
12′
47′
GUN
COLLECTOR
Return beam line at the same level as incoming line

Some recent work

Completed:

- Evaluation of what modifications for FNAL cooler will be needed to adopt it to RHIC
- Location in RHIC tunnel
- Choice of cooling section design (with weak solenoids)
- Vacuum chamber size
- RHIC optics for e-cooler
- Effect of undulators
- Most physics questions were addressed
- Simulations of electron beam transport started.
- Cost estimate updated.

To be done:

- Design of realistic beam transport
- Design of new bending magnets
- Start architectural design for Pelletron Bldg. (blockhouse)
- Start electrical design
- Start mechanical design

Aggressive schedule is required to meet timeline of 2015 for Physics

Preliminary cost estimate of the project	November 2009 (done)
Estimate of C-AD manpower	November 2009 (done)
Physics design complete	December 2010
Updated cost estimate of the project	June 2010 (done)
Architectural design & layout	July 2010 - June 2011
Electrical design & layout	November 2010 - November 2011
Mechanical design & layout	November 2010 - November 2011
Site preparation (requires first AIP funds)	June 2011 - March 2012 (10 month)
Recycler's cooler disassembly and transport	October 2011-February 2012 (5 month)
Electron cooler installation	March 2012 –January 2013 (10 month)
Commissioning	February 2013 -October 2013 (9 month)

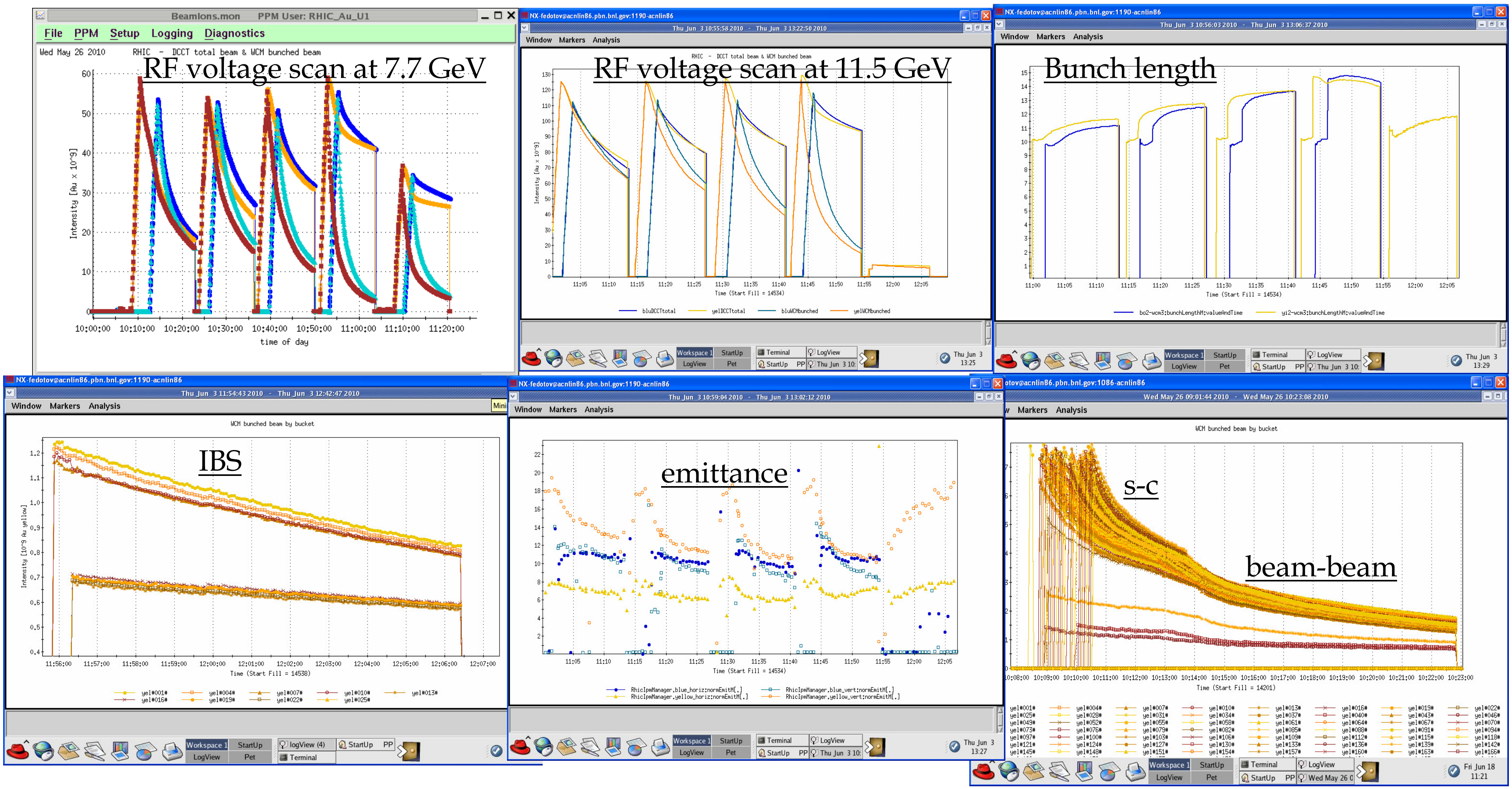
GOAL:

-2014 run: should expect luminosity optimization (cooling commissioning run)

-starting 2015 – can expect full luminosity improvement

2010 Low-E RHIC runs (sqrt[s]=7.7 & 11.5 GeV/n) and beam studies

- Series of APEX studies were done to understand beam lifetime at low energies. Available data was analyzed – **machine set-up which would allow full benefit from electron cooling upgrade was not achieved yet.**



Beam lifetime at sqrt[s]=7.7 GeV/n (γ=4.1)

Beam lifetime limitation at 7.7 GeV/n:

- **Large b2 (sextupole errors) in dipoles, other nonlinearities**
- **Octupoles which are introduced to compensate for tune spread by sextupoles and space charge**
- **Space charge**
- **Beam-beam**
- **Collimators**

All of these effects seems to contribute to lifetime in some way.

Low-E RHIC γ=4.1 (sqrt[s]=7.7 GeV/n)

Space charge up to ΔQ_{sc}=0.1 !

beam-beam ΔQ_{bb}=0.0014

At 7.7 GeV/n beam lifetime was limited by fast component of about 100 sec

Much better at 11.5 GeV/n

Based on analysis of beam lifetime in Run-10, projection of luminosity improvement with cooling were revised.

Projected improvement from cooling – after 2010 Low-E RHIC run

1. **Au+Au=11.5 GeV/n and up:**

   Improvement of about factor of 6 may be possible

2. **Au+Au=7.7 GeV/n:**

   Not conclusive since we do not know whether with retracted collimators we can achieve better lifetime or operate with larger emittance and reduced tune shifts.

Three possible scenarios:

- **Most optimistic (dynamic aperture problem is resolved by finding appropriate magnetic cycle, etc.): up to a factor of 6 improvement**
- **Somewhat optimistic (dynamics aperture problem is not solved, but we can run with low RF and compensate debunching with cooling or we found better regime with retracted collimators) – about factor of 2 improvement**
- **Pessimistic (only slow component can be compensated with cooling) – about 20% improvement**

3. **Au+Au=5 GeV/n:**

   We were not able yet to achieve machine performance needed for physics. E-cooling cannot help unless significant machine improvement is achieved.

Projections were scaled down not because of cooling but because of present RHIC performance

Projection for 50M event Low-E RHIC program

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	<Event rate> [Hz]	Mevent /day	# events	# days	#days with cooling
5.0	535	0.5 unknown	0.035	50M	1440	depends on RHIC
6.1	470	2.0 unknown	0.138	50M	360	depends on RHIC
7.7	405	6.0	0.414	50M	120	20 (60)
8.6	370	8.0	0.552	50M	90	15 (45)
11.5	290	12	0.83	50M	60	10
18	210	>30	2.07	50M	24	2.4

} Need machine time to have more definite projections

- pre-cooling at γ=9-10 for High-Energy RHIC program?

Some caveats of projected luminosity improvement with e-cooling

- **Recycler electron cooler is a well-working machine. However, making this machine work in RHIC will be much more challenging:**

- **Recycler cooler – 1) cools in a single ring 2) at fixed energy 3) with minimum bends in beam transport.**
- **In RHIC – 1) will require cooling in 2 rings with the same electron beam 2) more bends and more complicated beam transport 3) everything from Pelletron to cooling sections should be working "at best performance" for different energies 4) recombination**

Finally, this will be the first e-cooling in a collider: ANY luminosity improvement will require careful cooling optimization not to overcool beam distribution and produce acceptable beam lifetime.

To what extent electron cooling can be effective in compensating diffusion not associated with IBS? Cooling with off-centered beam to compensated diffusion of large-amplitude particles?

Possible approach to improve beam lifetime?

- **Effect of space-charge and beam-beam can be reduced by running at slightly large emittances (at least for higher energy points when there is enough acceptance)**

$$L = \frac{A}{Z^2 r_p} \frac{N_1 c}{\beta^*} \frac{\sqrt{2\pi}\sigma_s}{C^2} \gamma^3 \beta^2 f\left(\frac{\sigma_s}{\beta^*}\right) \Delta Q$$

$$\Delta Q_{sc} = -\frac{Z^2 r_p}{A} \frac{N_1}{4\pi\beta^2\gamma^3\varepsilon_1} \frac{C}{\sqrt{2\pi}\sigma_s}$$

- This should improve beam lifetime.

- It should make easier to find better tune space.

- Peak luminosity is not necessarily reduced.

$$L \propto \sqrt{2} N_1 \frac{\sqrt{2} N_1}{2\varepsilon_1}$$

This was tried during last day of Run-10 on June 7. Unfortunately, it did not work because of strong acceptance limitation due to collimators, which was not realized until the end of the run. Should be repeated without collimators.

Steps towards machine improvement at lowest energy points: for sqrt[s]=7.7 GeV/n and below

Some machine improvement may be still possible:

1. **Studies of magnet cycles can be done on the test bench to see what improvement should be expected. Such studies are needed anyway to make operation below γ=4.1 feasible.**

2. **DA tracking to see whether some configuration of correctors can be found to improve lifetime.**

3. **RHIC test run at sqrt[s]=7.7 GeV (12 hours shift) to test above items and perform series of dedicated measurements without collimators.**

Short (8-12h) dedicated test run at sqrt[s]=7.7 GeV/n is needed to have a definite conclusion whether better than a factor of 2 improvement from e-cooling may be expected for lowest energy points (<=7.7 GeV/n).
Can it be done at the start of Run-11?

Near-term plans

August 2010:

- **Experiments at FNAL Pelletron at low energies needed for RHIC**

July 2010-June 2011:

Electron cooling project is now at the stage when it is ready for C-AD engineering support:

- engineering/drawings, blockhouse design which will host Pelletron,

-design of transport lines, magnets, cooling section, instrumentation, etc.

Need decisions how to proceed with the project!

End of FY11: first AIP funds needed to meet the timeline of 2015 for physics.

FY11-FY14: – project phase which will require significant C-AD manpower.

Thank you