Electron Cooling of the Relativistic Heavy Ion Collider: Update

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New Challenges

The cooling time is proportional to a high power of γ. RHIC has a γ factor two orders of magnitude above any previous electron cooler.

$$\tau = \frac{A}{Z^2} \frac{\gamma^2}{4\pi r_p r_e n_e c \eta \Lambda_c} \left(\frac{\gamma \varepsilon_{in}}{\beta_{ic}} \right)^{3/2}$$

That means that we must increase the electron beam current considerably, while keeping the electron temperature down.

We cannot use conventional accelerator techniques. We require a high-energy (54 MeV), high-current (0.2 to 0.3 A) electron beam for the cooler, based on an Energy Recovery Linac.

We also need a high-field, highly precise solenoid.
We must develop reliable codes to predict the cooling rate.

Outstanding issues

1. Complete development of code and benchmarking, obtain accurate estimates for cooling times.
2. Cooling with bunched electron beam.
3. Cooling with "hot" electrons:

	RHIC	Typical coolers
transverse :	1000 eV	0.1-1 eV
longitudinal :	50 meV	0.1 meV

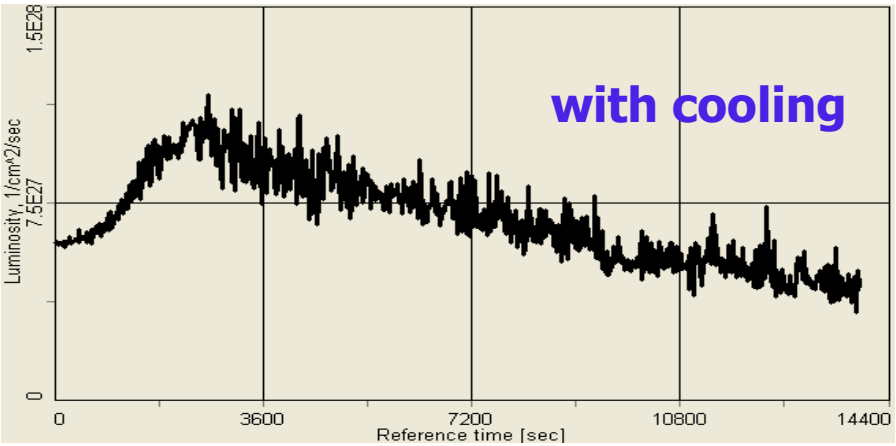
4. Do we have sufficient magnetized cooling?
5. What are the optimum parameters for electron beam?
6. Detailed IBS.
7. Dynamics of the cooled ion beam, such as the impact on threshold of collective instabilities, beam-beam limit, etc.

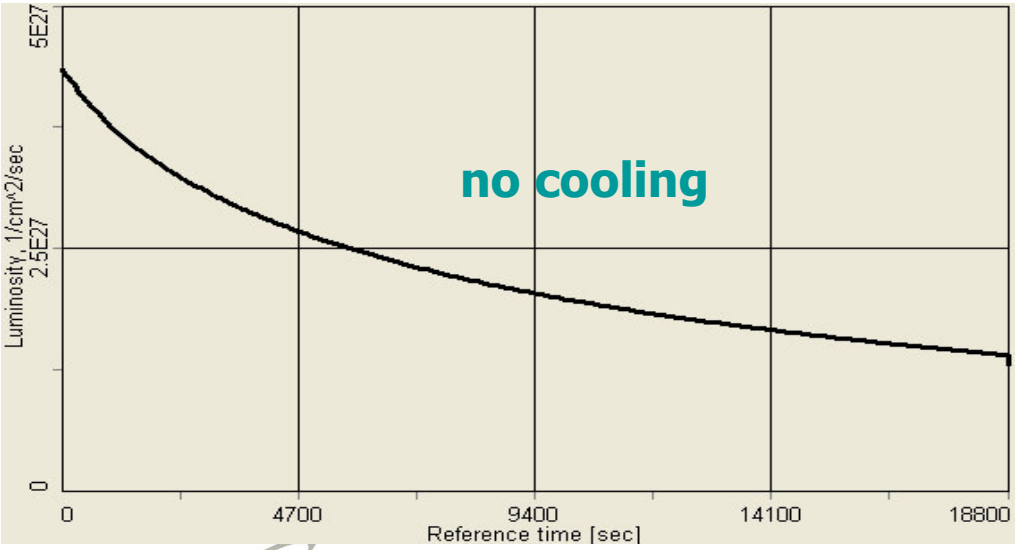
Code development

(Alexei Fedotov, Yuri Eidelman, Tech-X, JINR, BINP)

- BetaCool (cooling dynamics, in collaboration with JINR Dubna)
- Simcool (cooling dynamics, origin at BINP, local development)
- VORPAL (direct simulation of cooling force, Tech-X corporation under SBIR)
- Intensive benchmarking of all codes.

RHIC-II Luminosity with and without cooling (Au 100 GeV)





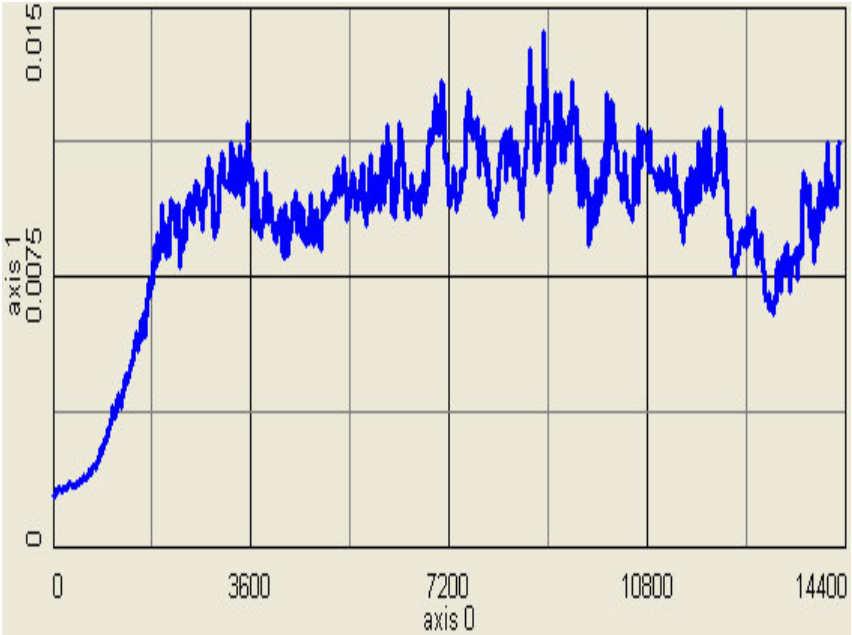
$\langle L \rangle = 7 \times 10^{27}$

E-cooling: factor of 10 increase in average luminosity per store

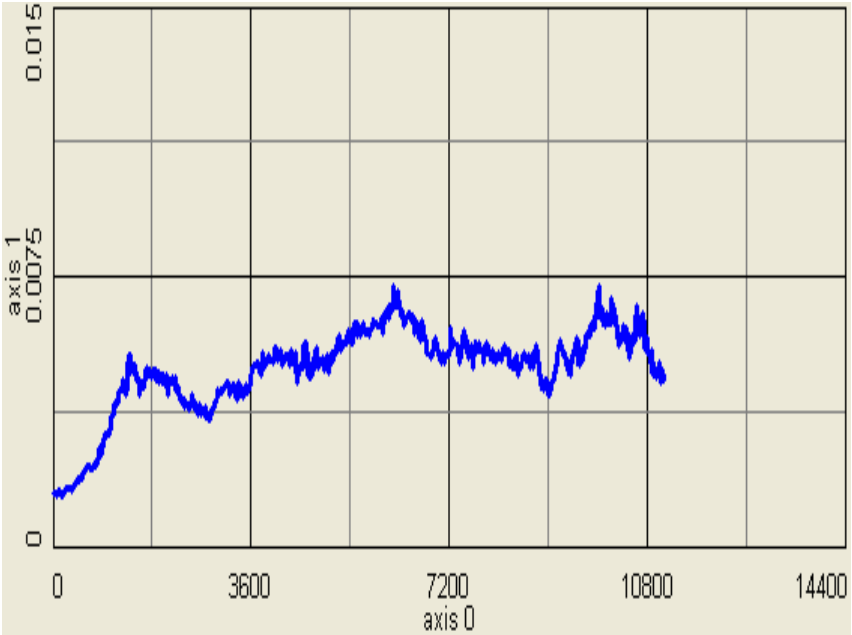
Alexei Fedotov

Beam-beam parameter

Operation near the beam-beam limit is expected



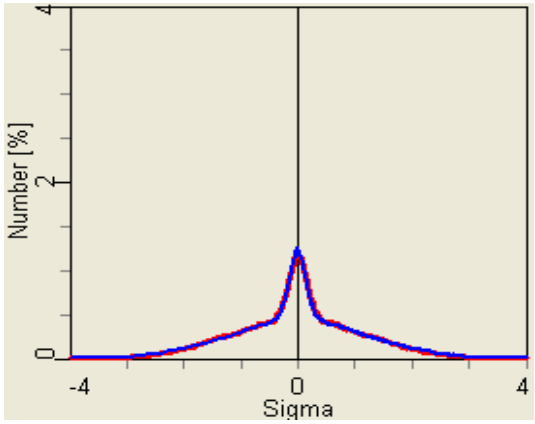
Beam-beam parameter per IP without additional optimization with e-beam

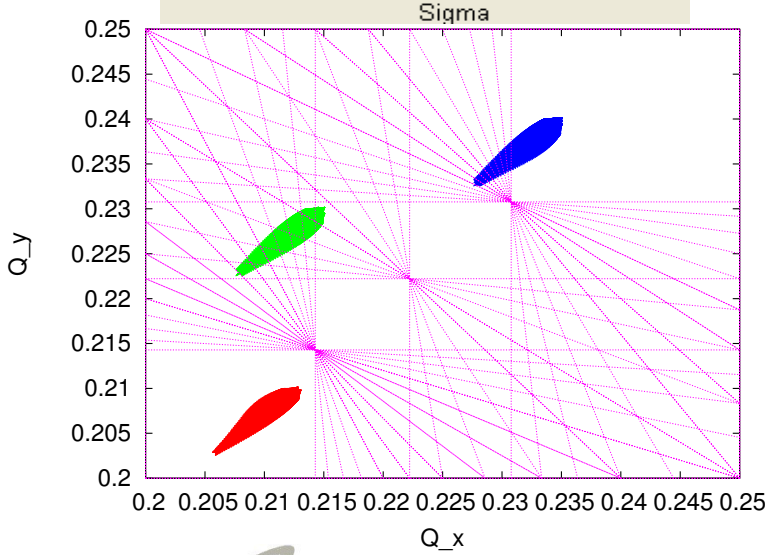


Beam-beam parameter per IP with additional optimization with e-beam

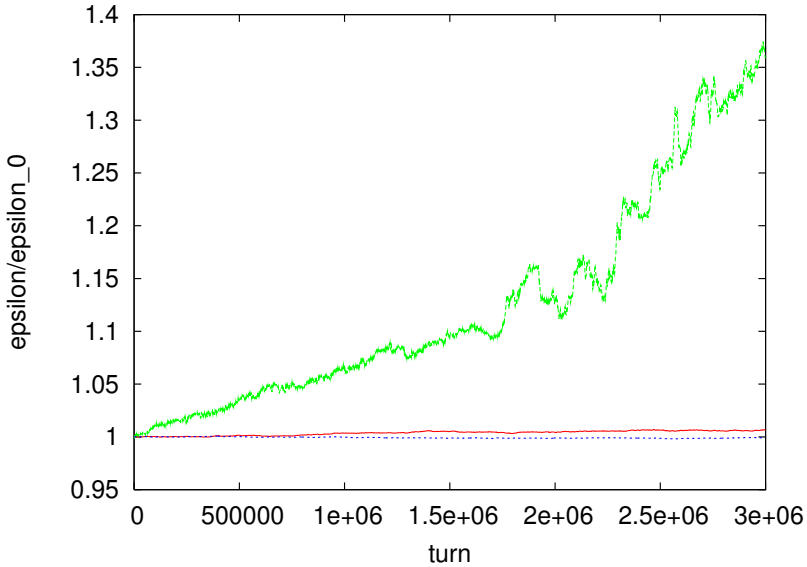
Alexei Fedotov

Beam-beam effects for cooled distribution (Christoph Montag)





Distributions resulting from cooling may produce stronger diffusion of beam tails - a careful selection of working point is required.



Beam experiments towards high-energy cooling

(Alexei Fedotov, Vladimir Litvinenko)

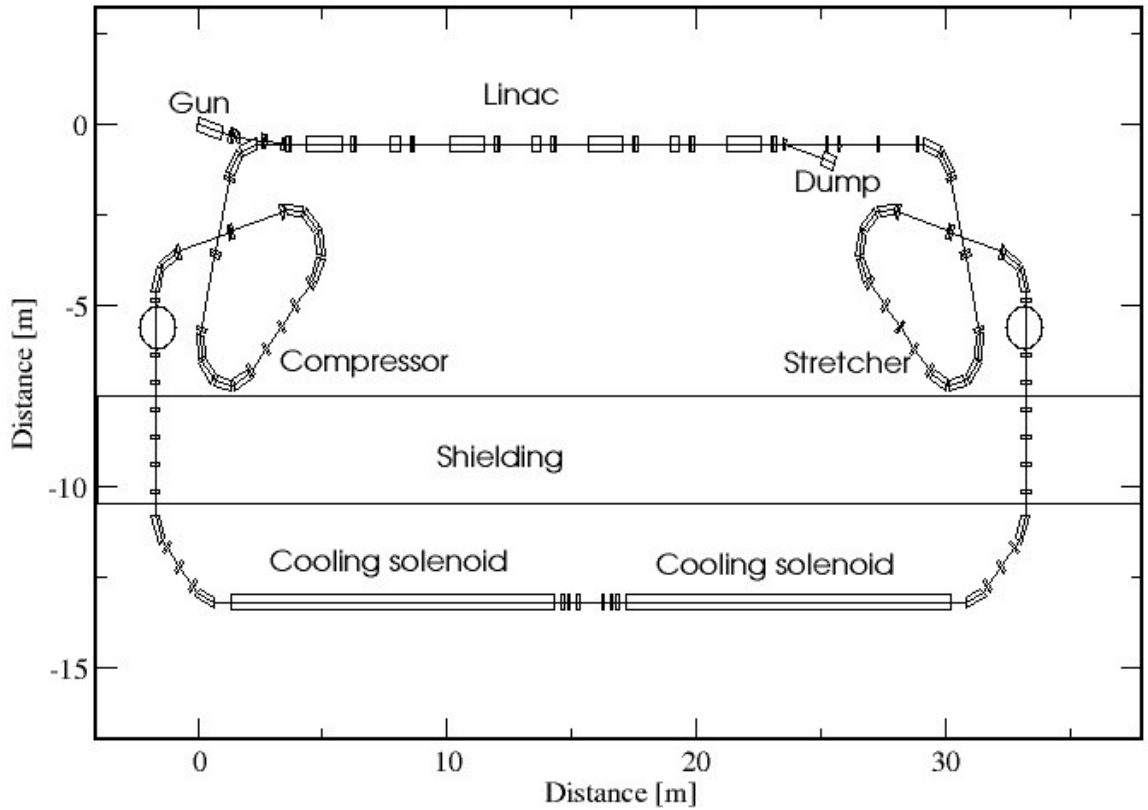
- In present coolers (Celsius, ESR, etc.):

1. Measure cooling force and benchmark codes.
2. Benchmark new models of IBS required to treat distribution shrinking under cooling.
3. Study stability of cooled distribution
4. Create conditions expected in the RHIC cooler and study some issues like magnetized cooling with small cooling logarithm, effect of solenoid errors, etc.

Experiments will start December, 2004 at Celsius

Also RHIC beam experiments (see below)

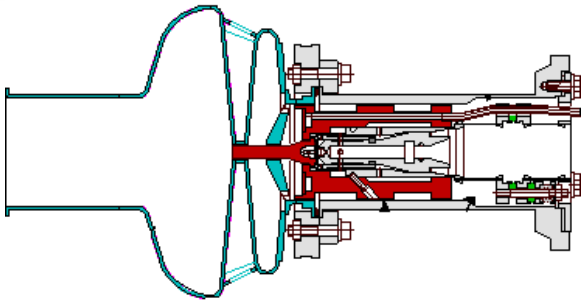
Layout of cooler



Each electron bunch is used just once.

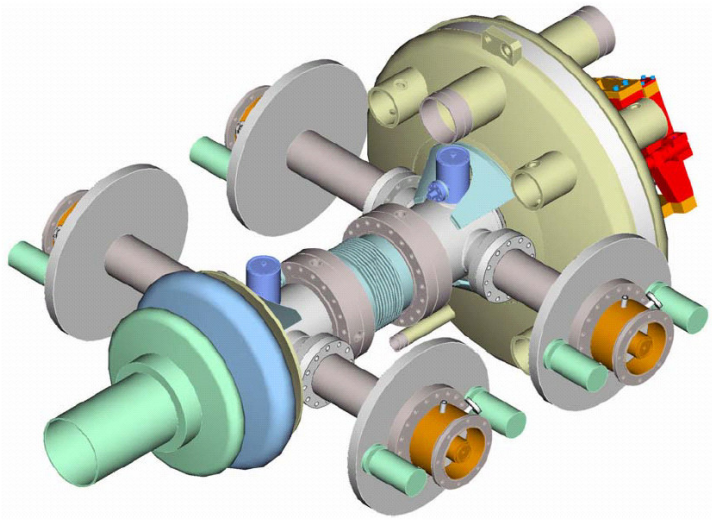
The electron gun
(A. Burrill, T. Rao)

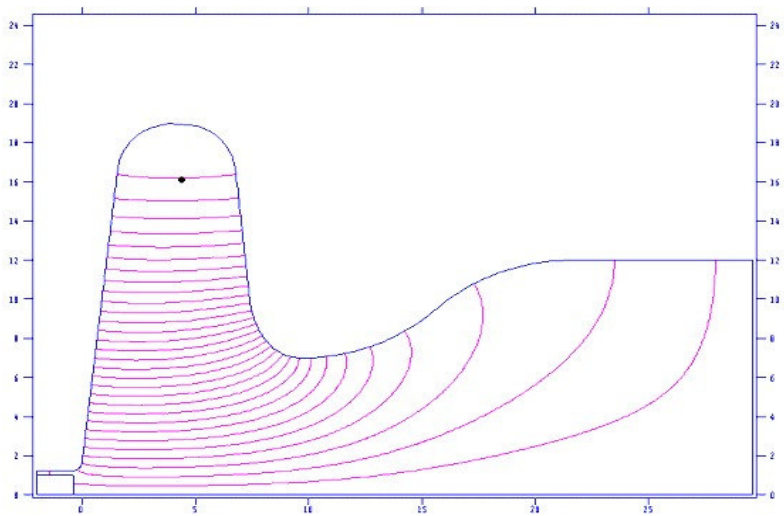
- We have an operational SRF gun, initial results gave 0.5 nC pulses.
- FZR demonstrated a gun with demountable cathode.
- The advantages of CW SRF photoinjectors are obvious.
- Question: How to provide an efficient cathode?



A New SRF Photoinjector is being designed, at 703.75 MHz by AES in collaboration with BNL

(X. Chang, R. Calaga, Y. Zhao)

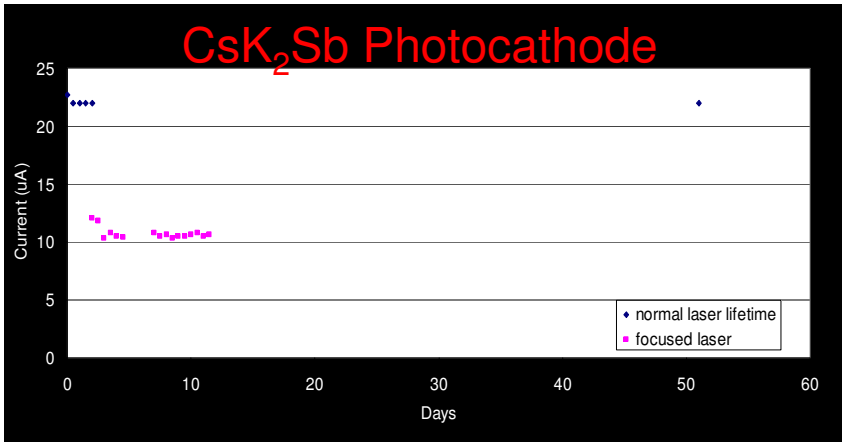


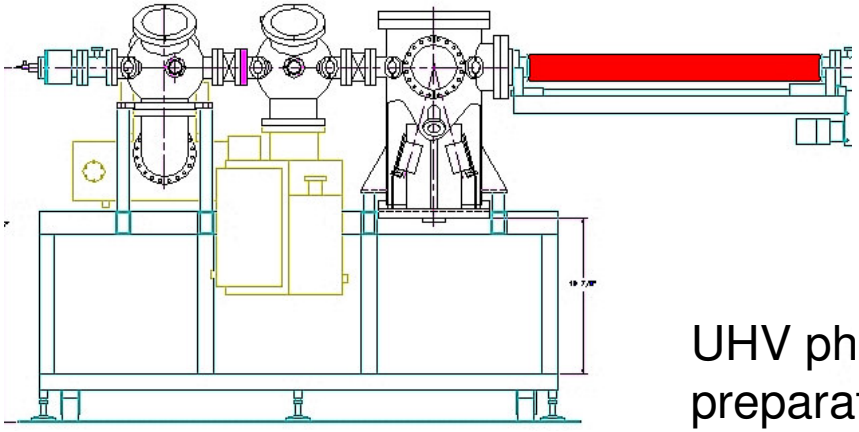


Photocathode and laser system

(T. Rao, A. Burrill, D. Kayran, X. Chang)

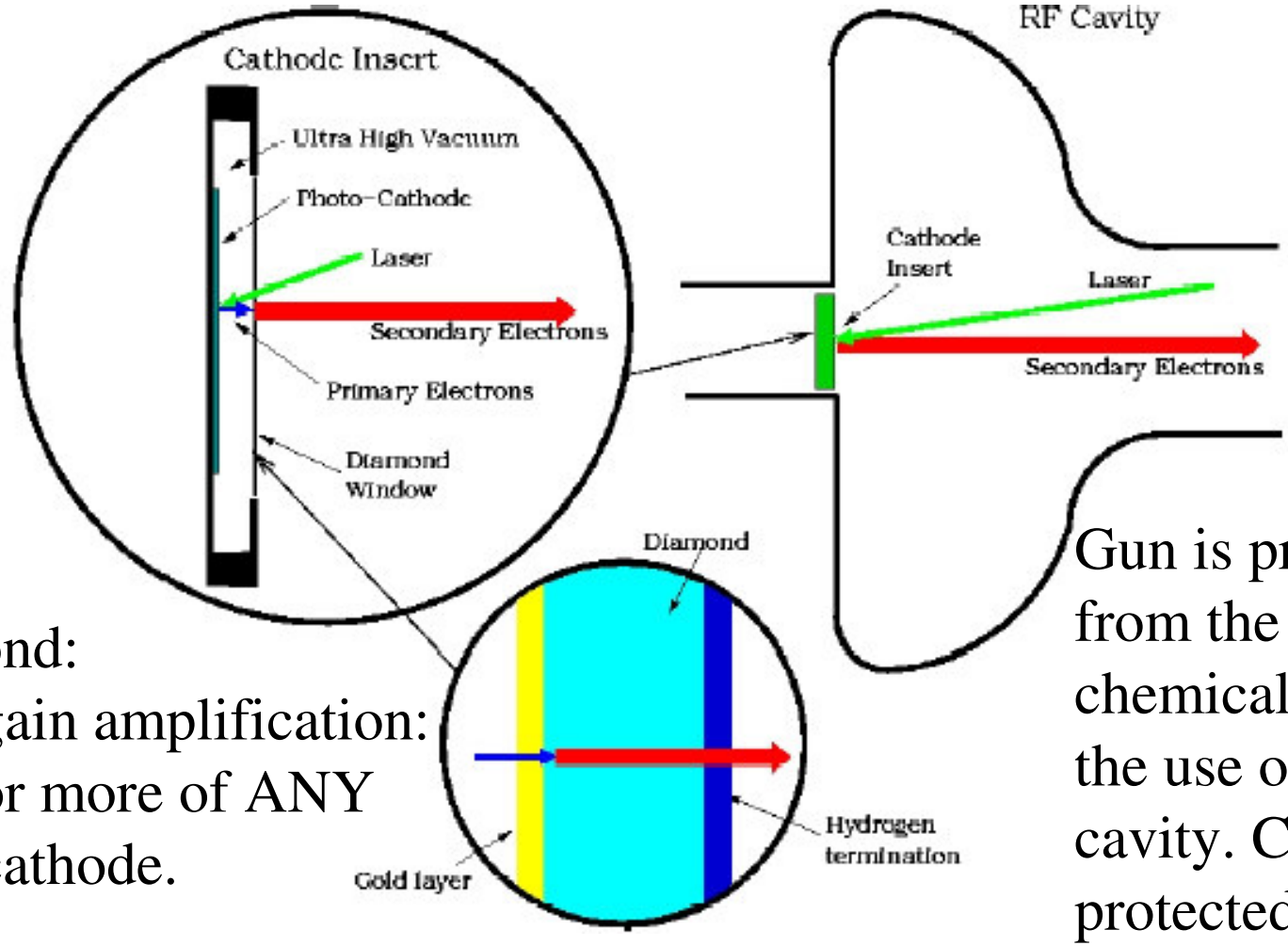
- Cathode quantum efficiency – tied to the laser size and complexity.
- Cathode lifetime (contamination) and vacuum requirements.
- Gun contamination by cathode materials.
- Complicated load-lock mechanisms.
- Thermal emittance, promptness.





UHV photocathode preparation system

Schematic Arrangement of the System

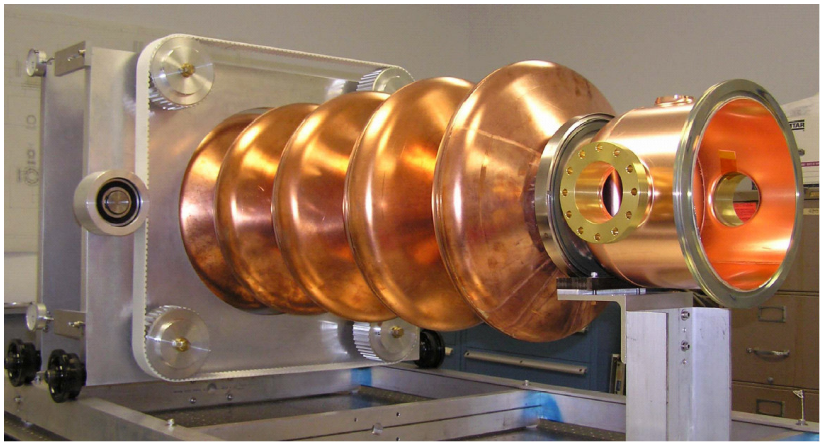


Diamond:
High gain amplification: x100 or more of ANY photocathode.

Gun is protected from the cathode chemicals, enabling the use of an SRF cavity. Cathode is protected from gun.

The Ampere-Class ERL Cavity

(BNL-AES-JLAB, G. McIntyre, R. Calaga)



Copper model of the 703.75 MHz high-current ERL cavity.
The niobium cavity is under construction

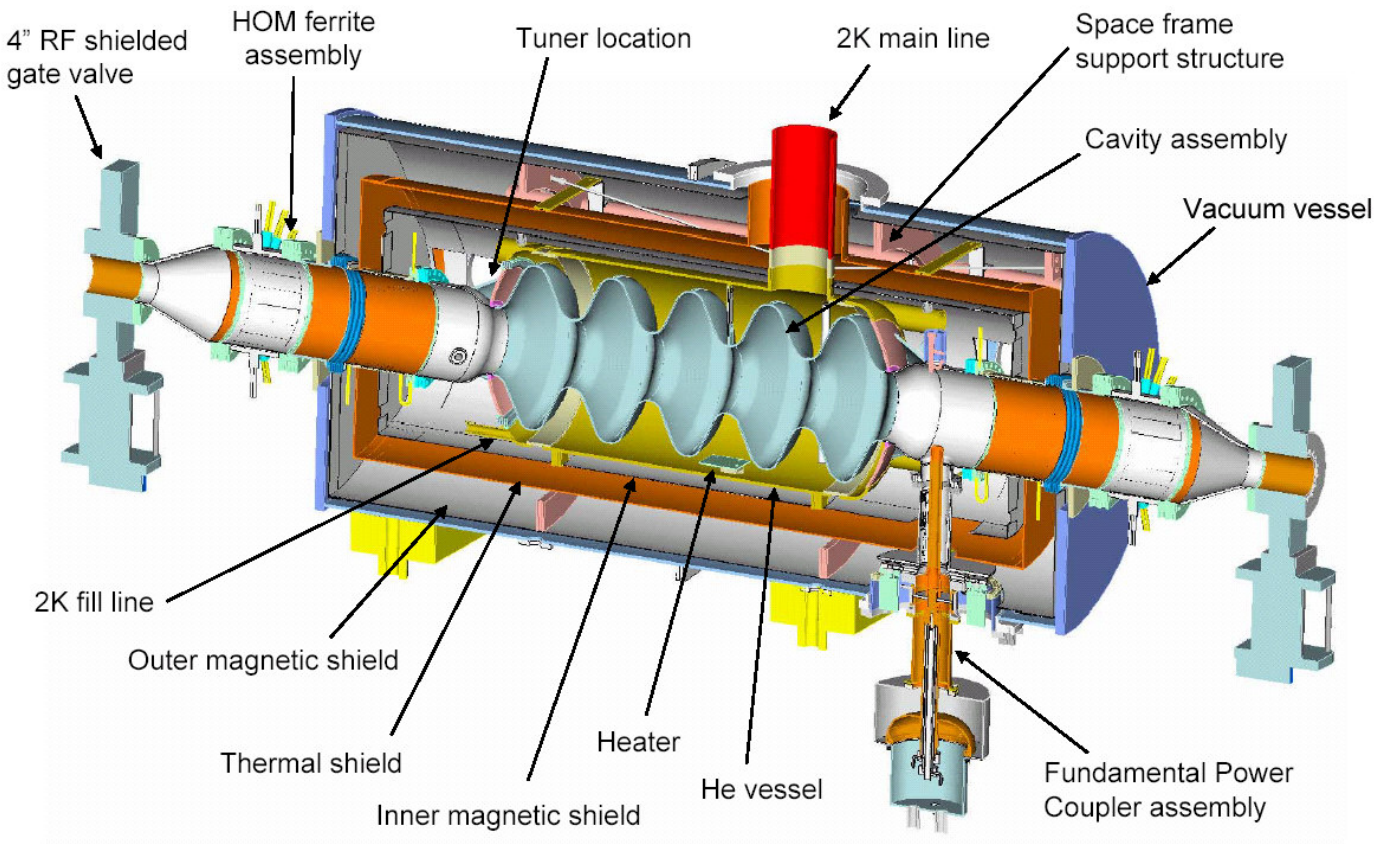
Objectives:

1. Low loss factor
2. High BBU threshold

Principles:

1. Low frequency elliptical cavity
2. Large iris (17 cm diameter)
3. Huge beam tube (24 cm dia.)
4. External ferrite HOM dampers

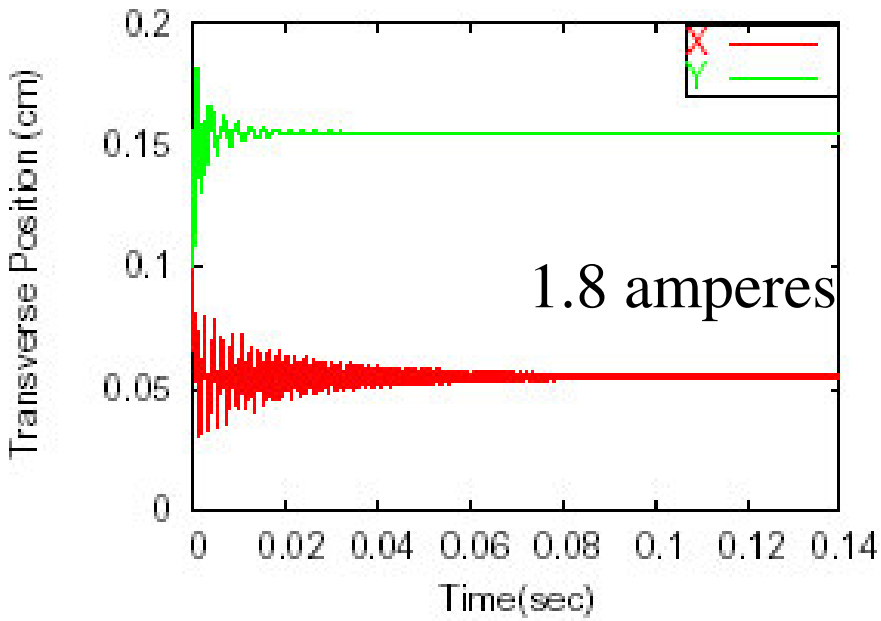
Cryomodule: design passed Final Design Review



How to make a linac cavity capable of over 1 ampere?

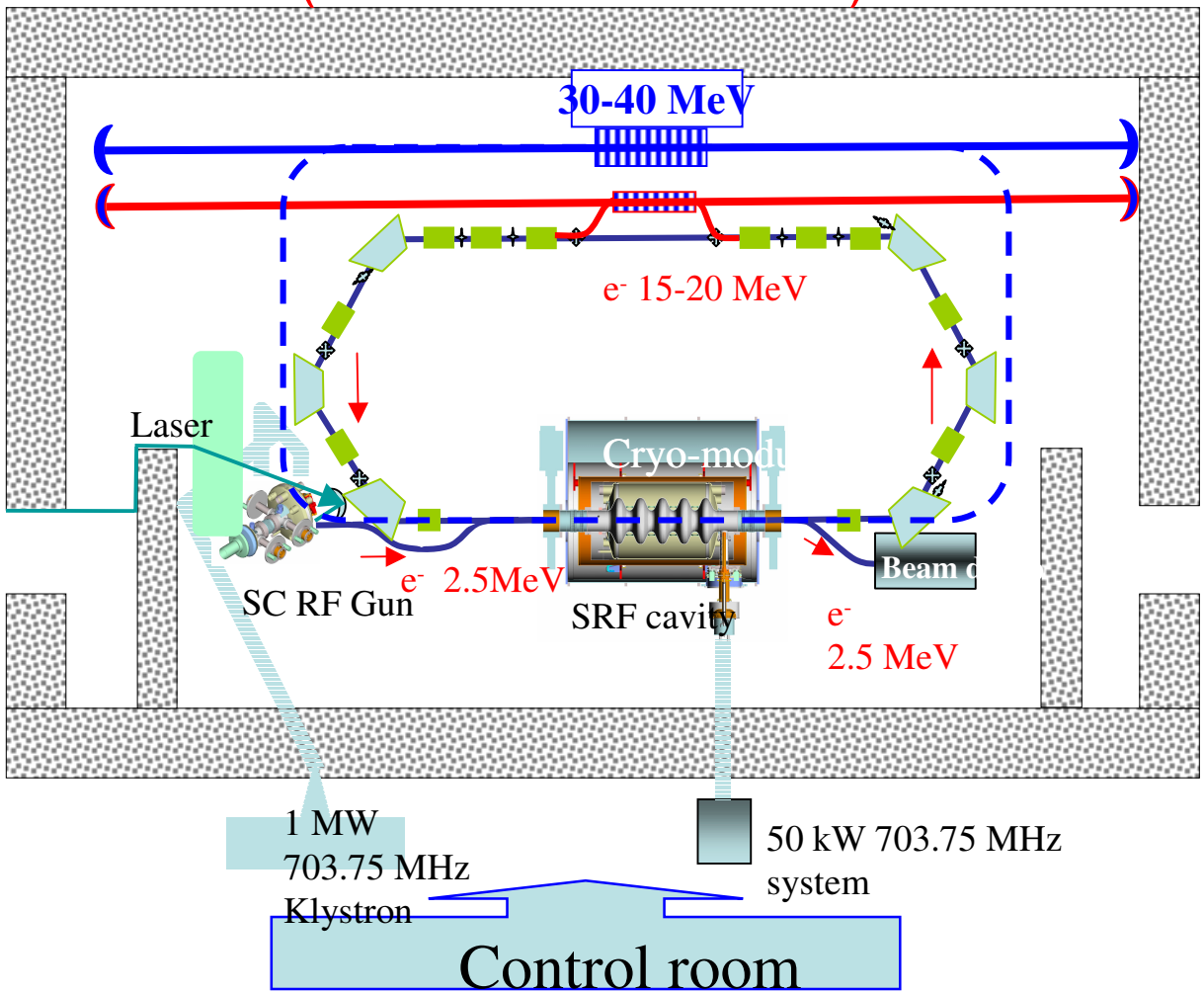
- Good cavity / HOM design, using very large beam ports to guide HOM to ferrite absorbers.
- Design has excellent SRF cavity properties, low loss factor and high BBU threshold

TDBBU:



ERL to test it all!

(Vladimir Litvinenko)

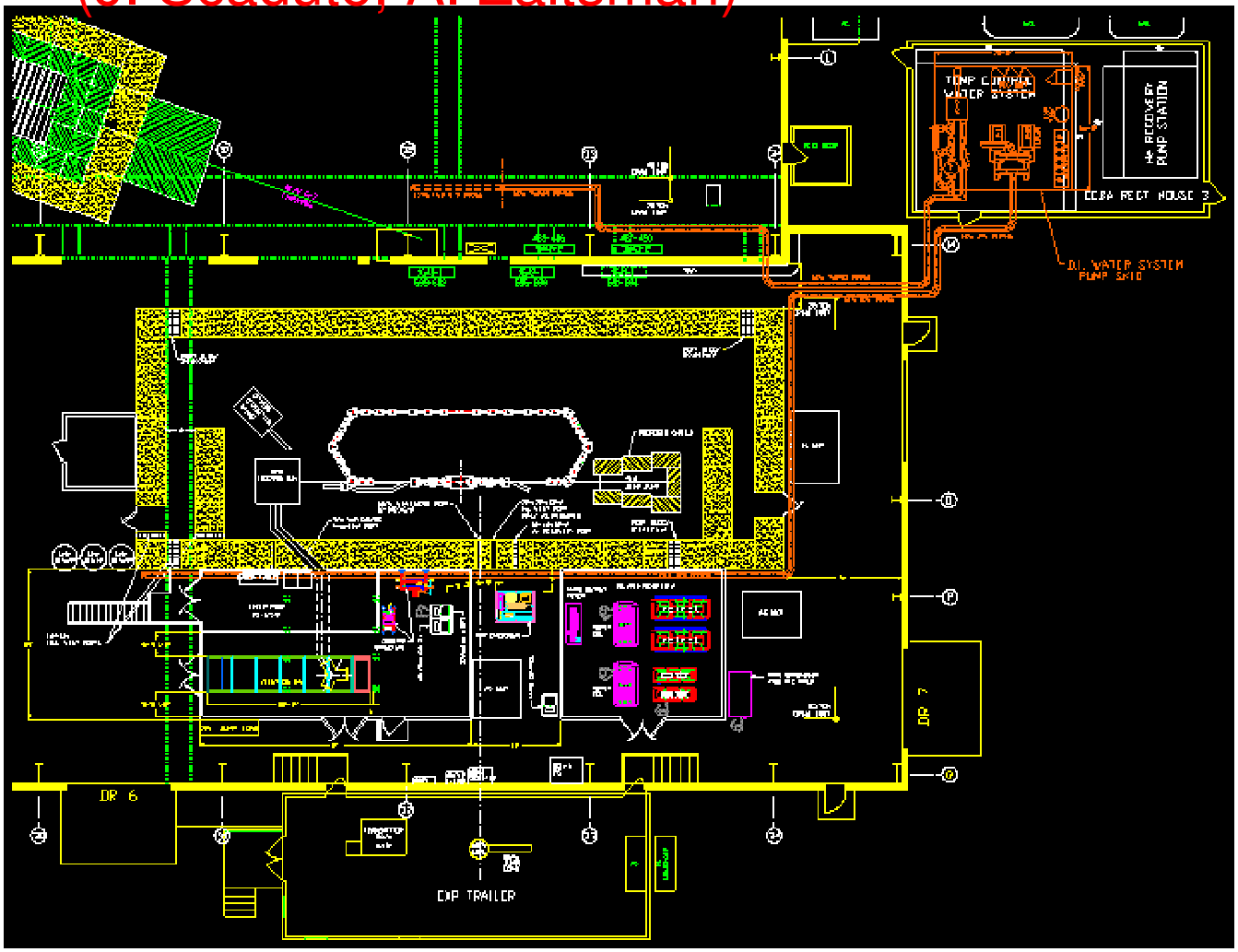


Infrastructure Building 912

(J. Scaduto, A. Zaltsman)

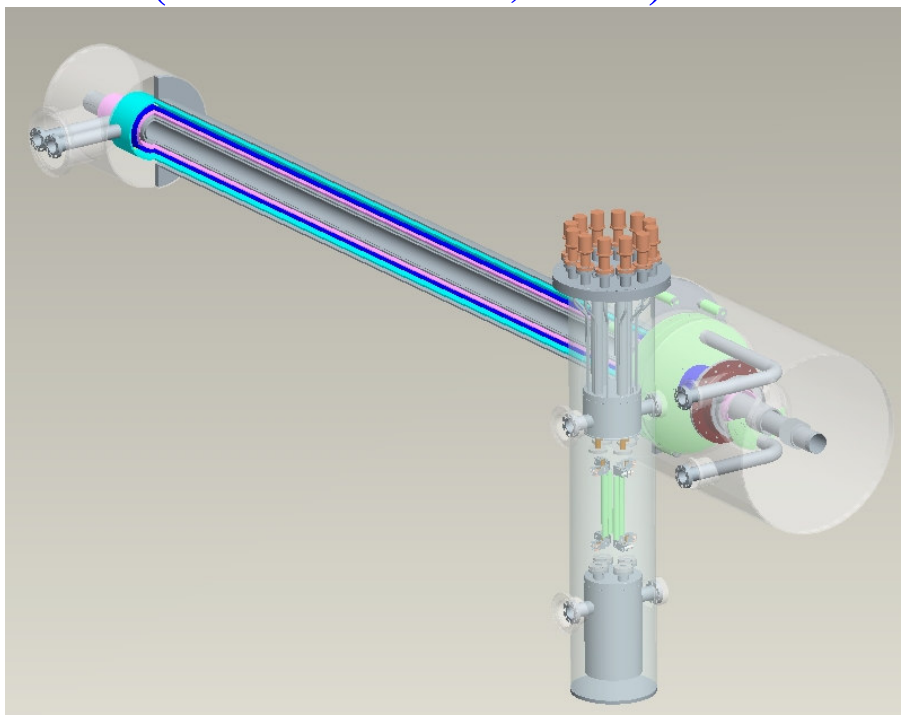
Shielding

50 kW amplifier

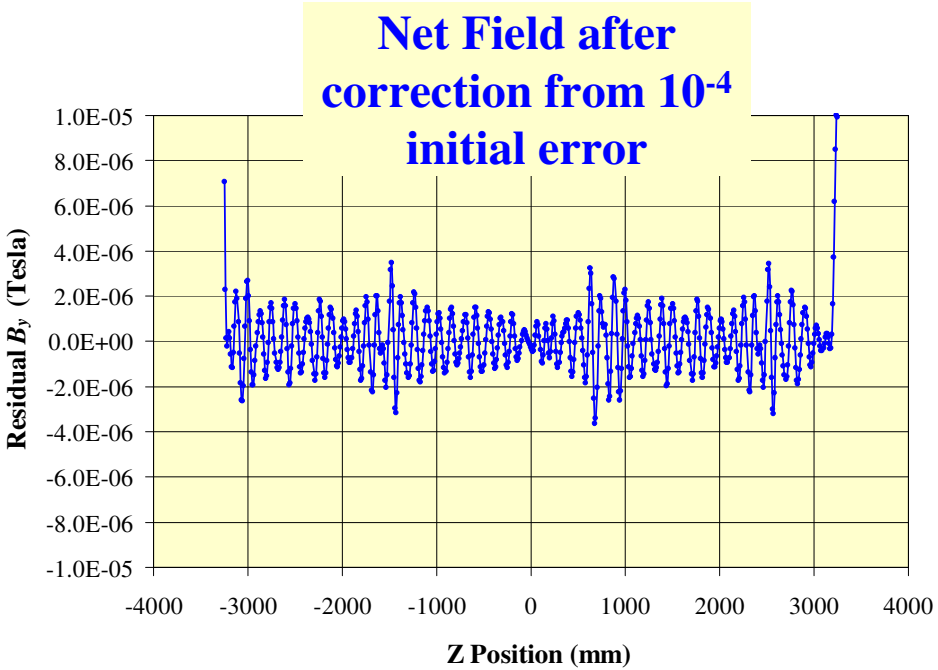


Conceptual Design of Solenoid
(SMD, Animesh Jain)

(from *A. Marone, SMD*)

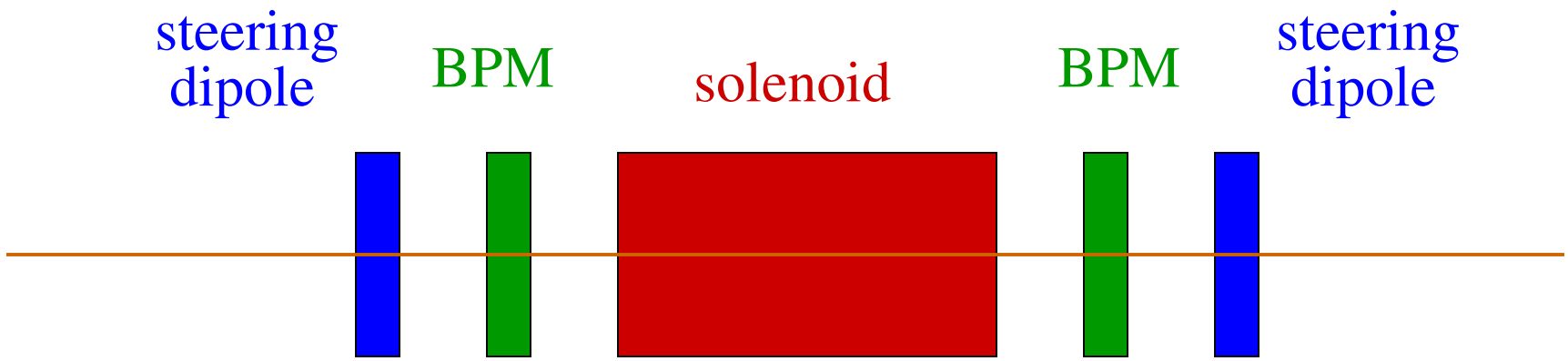


Required precision:
8×10^{-6} radians, or
8 micrometers every meter, over 2x13 meters.



Solenoid Center Location

(Peter Cameron)

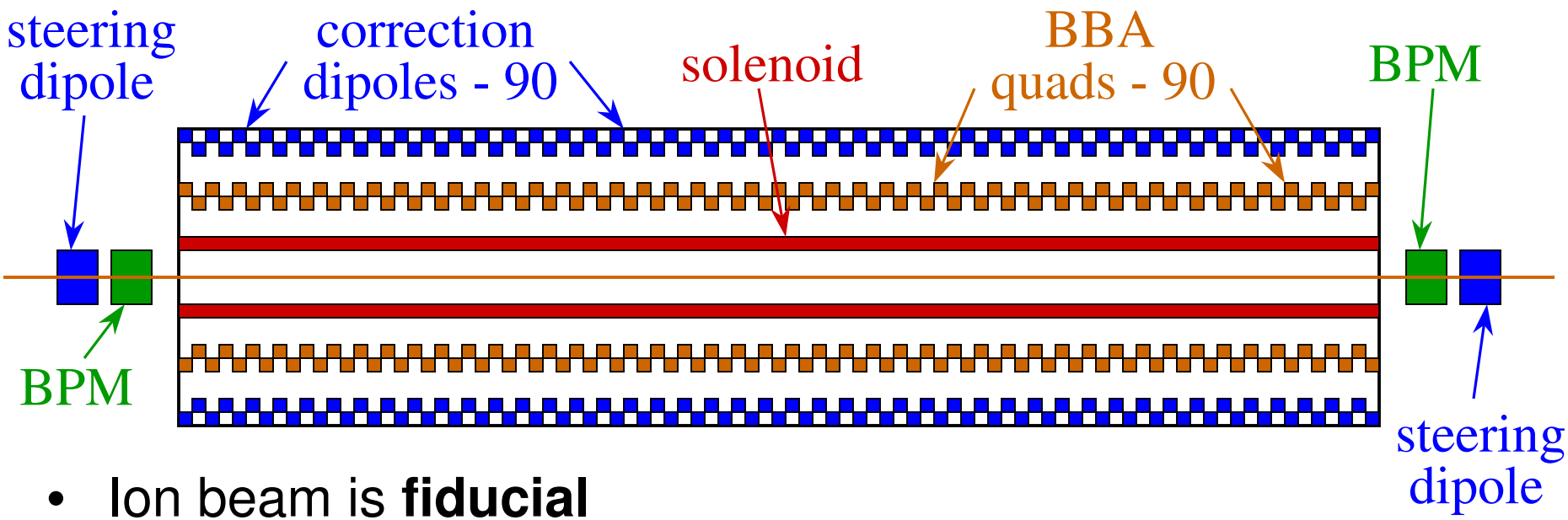


transverse component of fringe field imparts kick, increases transverse temperature of electron beam

- Modulate e-beam position with steering dipole (few Hz)
- Adjust solenoid field (1% ~ 1λ) to half-integer λ_{larmor}
- lockin downstream orthogonal electron BPM plane
- null gives entrance center

electron-Ion Beam Alignment

(Peter Cameron)



- Ion beam is **fiducial**
  - modulate quad (few Hz), sweep Ion beam steering dipole
  - lockin RHIC BPM to modulation, **find quad position**
- Knowing quad position relative to Ion beam **fiducial**
  - modulate quad (few Hz), sweep e-beam steering dipole
  - lockin electron BPM to modulation, **find e-beam position**

ZDR status

- Comprehensive document (currently 230 pages long) with contributions from many in the department.
- ZDR covers cooling theory and simulations, electron machine design and dynamics and interaction with RHIC.
- WBS, schedule and cost estimate for R&D part nearly finished.
- WBS, schedule and cost estimate for RHIC electron cooler about to begin.

Beam Experiments and eCooling

- We must benchmark some of the RHIC parameters that are critical for electron cooling:
  - IBS rate
  - Beam-beam limit
  - Beam based alignment of solenoid
- A number of relevant experiments are being proposed.

RHIC beam experiments towards high-energy cooling

1. Further studies of IBS –
   a) predict emittance growth for some conditions and then confirm experimentally
   b) measure IBS for uncoupled beam, etc.
2. Study beam-beam and benchmark with models – effects of nonlinearities and choice of working points
3. Study beam-beam diffusion for possible distributions under cooling – colliding big and small beams.

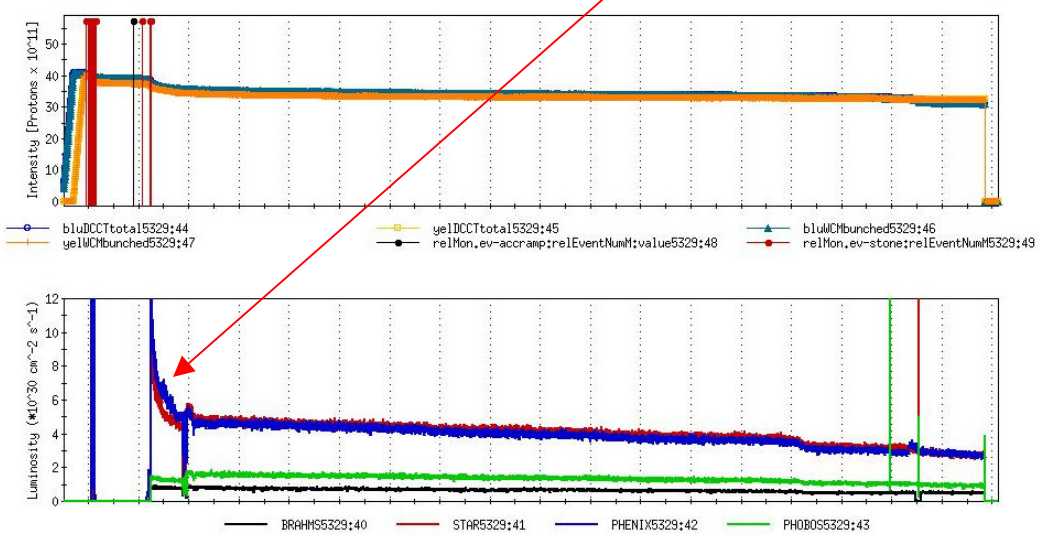
Plan and objectives of beam-beam studies

(A. Fedotov, W. Fisher, N. Malitsky, C. Montag, R.Talman, R. Tomas)

1. Build an efficient composite model using RHIC non-linear maps and strong-weak beam-beam approaches (C. Montag, R.Talman):

With the 5th order one-turn map one can track a single particle for 45 μs which is comparable with the RHIC revolution period of 12.5 μs !

It means we can deal with slow (20 min.) processes. We probably need QCDOC for a large bunch.



M. Bai. RHIC Retreat 2004

2. Propose beam experiments (TBD) motivated by the RHIC operational data (December).

3. Do model benchmarking experiment (Spring 2005)

4. Reuse the beam-beam model(s) in electron cooling beam studies.

Proposal for related beam experiment (Peter Cameron)

- Beam position relative to quad center
  - Modulate RHIC quad at ~few Hz
  - Sweep steering dipole
  - Lock in on modulation with BPM
  - Determine sensitivity, repeatability
- Beam position relative to solenoid center
  - Use Physics experiment solenoid
  - Modulate beam position/angle at ~few Hz
  - Lock in on modulation with orthogonal BPM
  - Determine sensitivity, repeatability
  - Scale to e-Cooling

Conclusions

- High energy electron cooling looks feasible, but requires R&D.
- An aggressive and comprehensive R&D program is in place.
- RHIC Beam Experiments play a critical role in our program.
- In about three years we expect to resolve all outstanding R&D issues.