Brighter Beams for Better Physics
Stochastic Cooling in RHIC

Mike Blaskiewicz

Acknowledgements:

Mike Brennan, Freddy Severino

A. Arno, C. Biscardi, J. Brodowski, B. Brueggert, J. Butler, A. Curcio, W.C. Dawson, A. Drees, A. Etkin, S. Farooq, A. Fedotov, W. Fischer, W. Fu, D. Gassner, D. Goldberg, M. Grau, L. Hammons, M. Harvey, T. Hayes, P. Ingrassia, W. Jackson, J. Jamilkowski, F. Karl, R. Karol, N. Kling, M. Lafkey, N. Laloudakis, D. Lehn, E. Lessard, C.J. Liaw, D. Lowenstein, G. Mahler, M. Mapes, G. Marr, J. Morris, C. Naylor, T. Nehring, J. Niedziela, H. Palacios, C. Pearson, F. Pilat, D. Ravenhall, C. Rhein, T. Roser, T. Russo, J. Saetta, T. Satogata, T. Shrey, J. Tuozzolo, B. Van Kuik, J. Wei, D. Weiss, A. Zaltsman

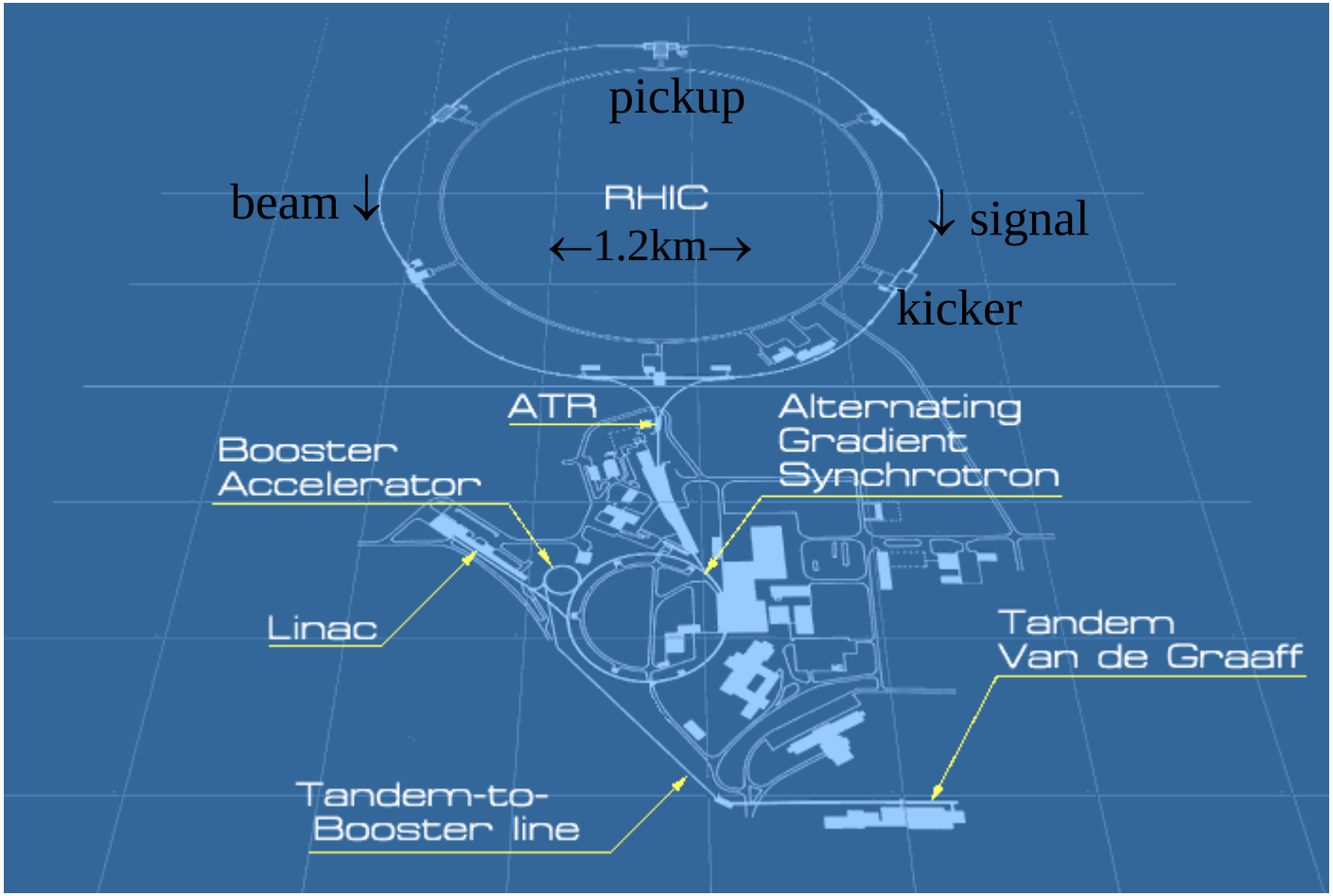
Dave McGinnis, Ralph Pasquinelli (FNAL)

Fritz Caspers, Flemming Pedersen (CERN)

Table of contents

- RHIC complex
- The reason for RHIC
- Accelerator Fundamentals
- Why we need cooling
- Principles of Cooling
- Practice of Cooling
- What's Next
- What we can Expect

The Collider Complex



Relativistic Heavy Ion Collider

Relativistic: moving at close to speed of light.

$$E = mc^2 + T$$

T is the energy of motion. For RHIC $T \approx 100mc^2$

For a rifle bullet $T < mc^2$ /billion

Heavy Ion: The dense, heavy core of atoms like gold (79p,118n).

Collisions of 200 on 200 individuals

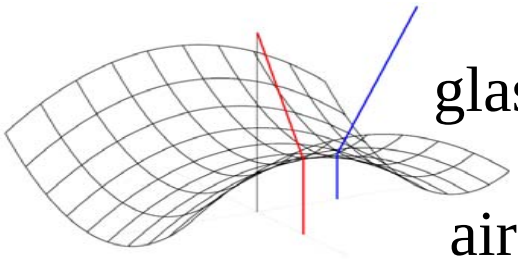
Random motions and temperature

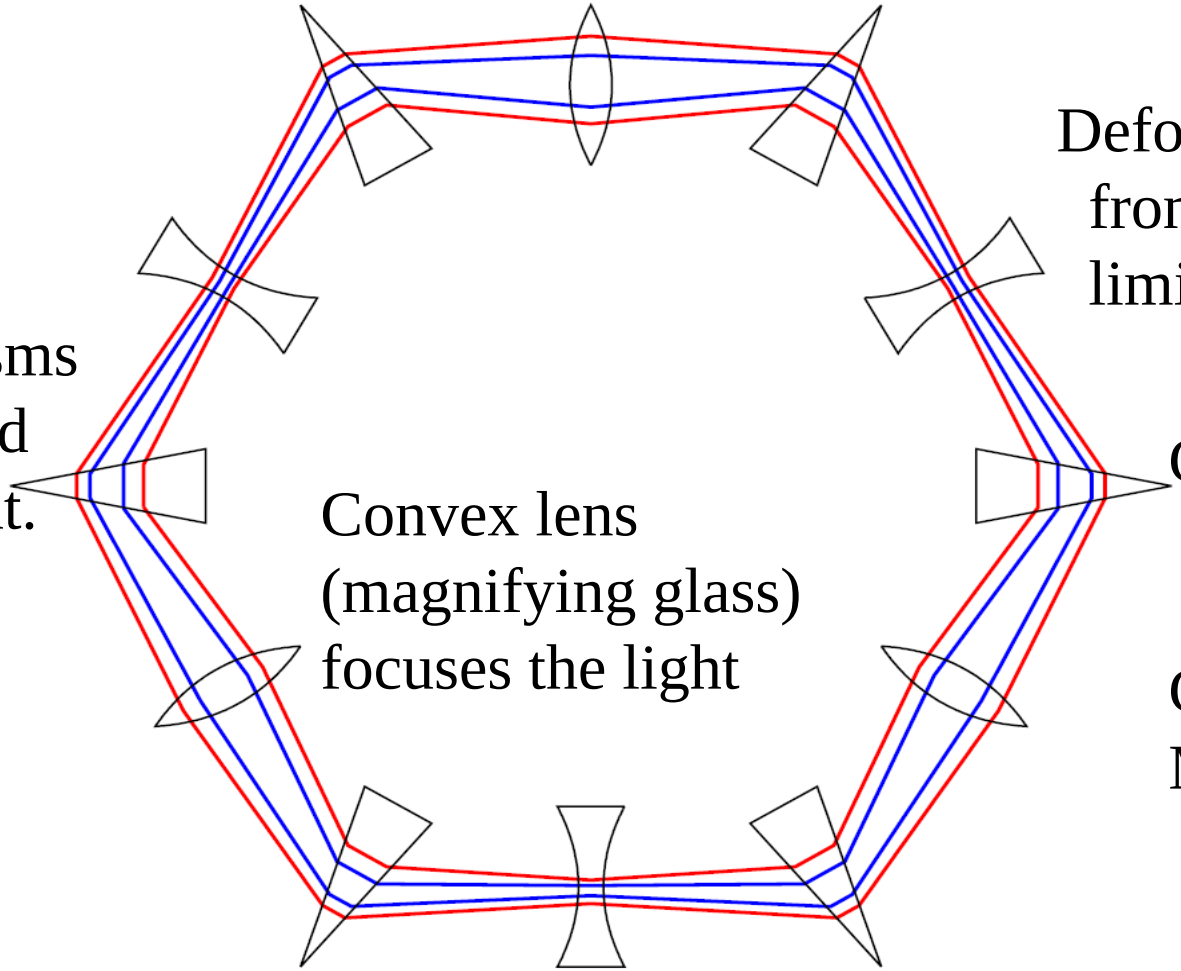
Water goes to steam…..

"steam" is a cloud of particles created from T! $100m = \frac{T}{c^2}$

Two separate rings with beams going in opposite directions.

Optical Analogy of an accelerator ring





Defocusing lenses from magnetic limitations (CS58)

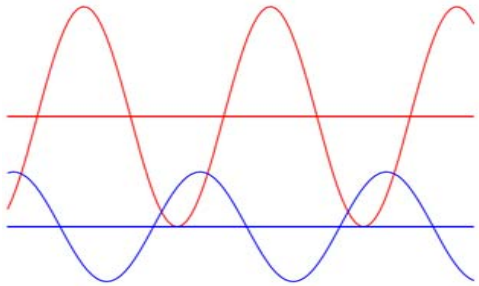
Prisms bend light.

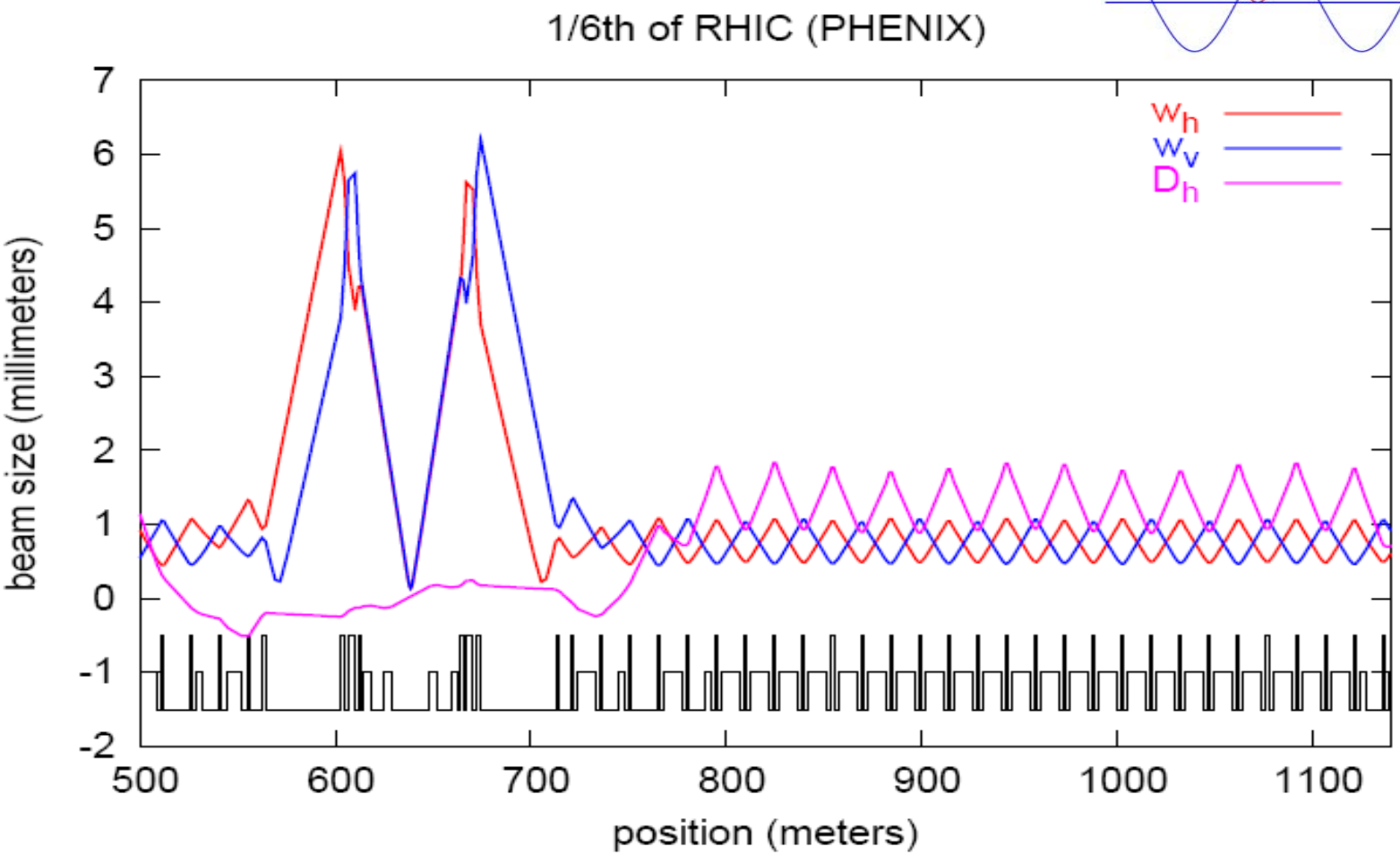
Convex lens (magnifying glass) focuses the light

Cold (blue) beam smaller than the hot (red) beam

Challenge of cooling: Make blue from red.

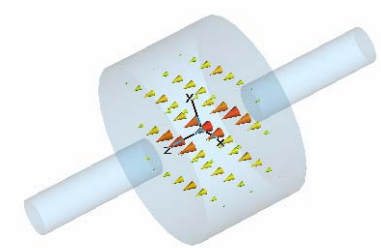
Actual Magnetic Lattice





High energy particles are bent less by magnets than low energy
Dispersion quantifies. Similar to a prism and white light.

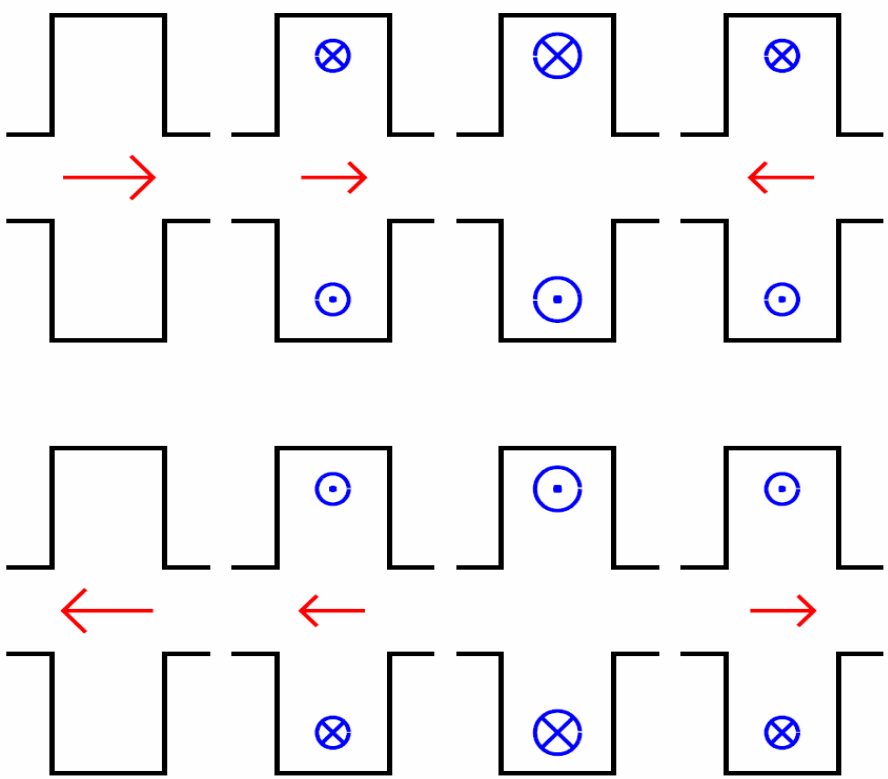
Accelerators need to accelerate

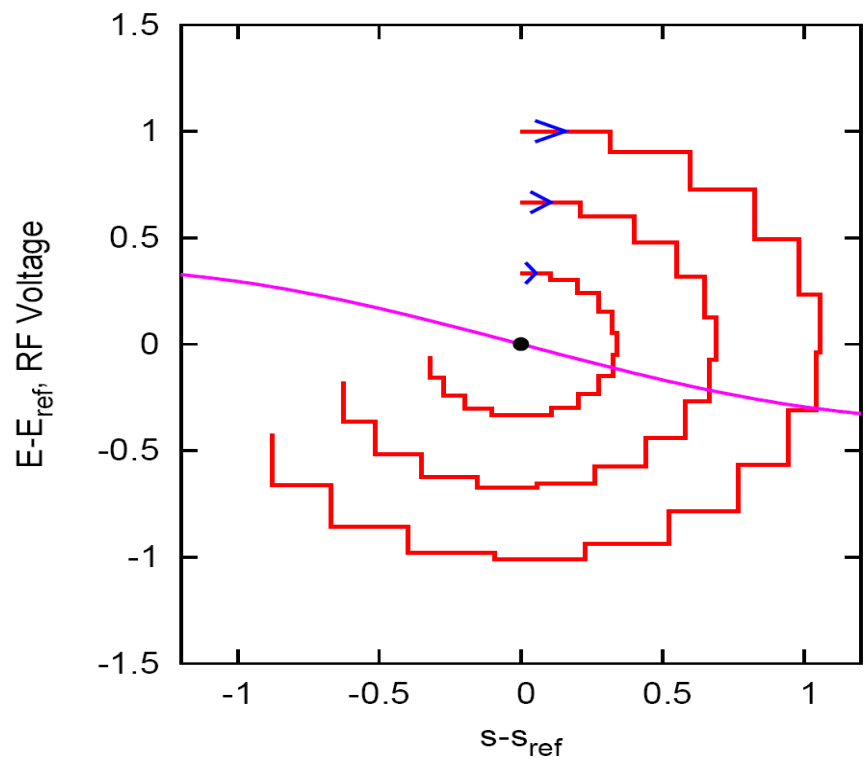


Radio frequency (RF) cavities provide electric field (E).

Energy sloshes between E and magnetic field (pendulum)

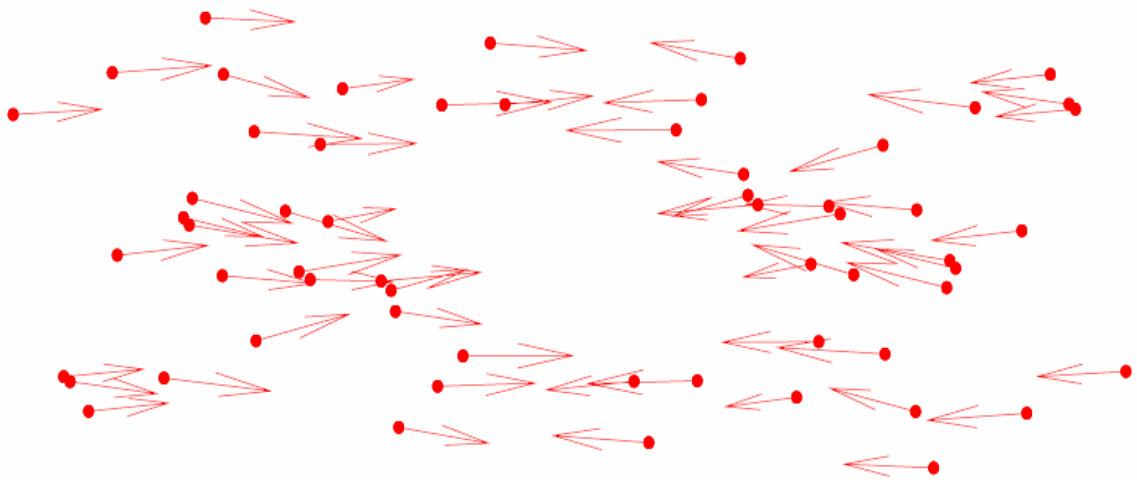
The time a particle arrives determines its kick.



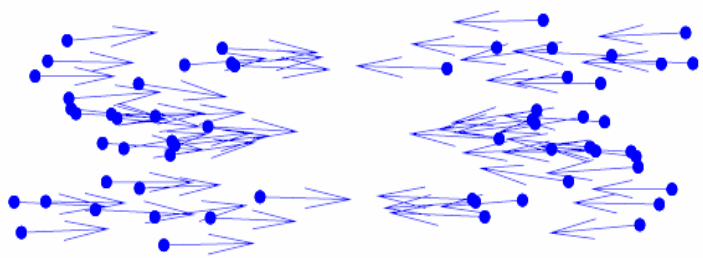


Hot versus cold beam

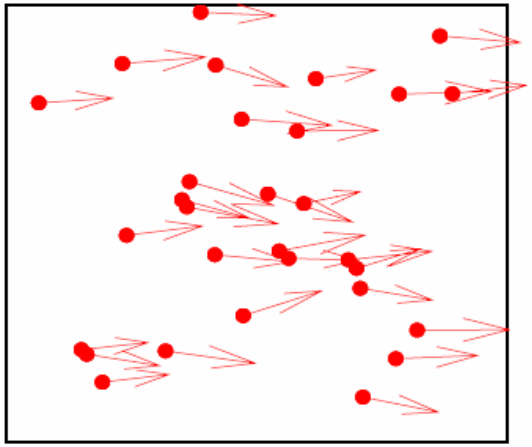
Creating collisions between particles is RHIC's purpose

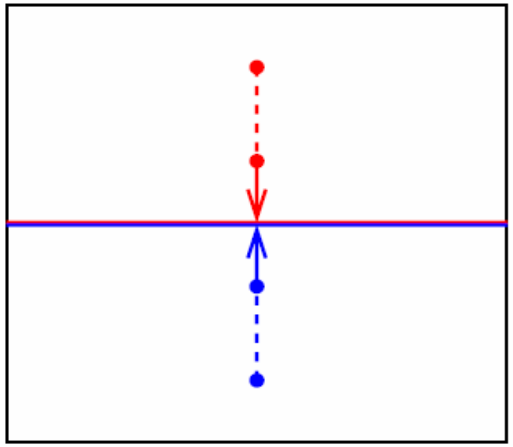


blue (cold) particles have more collisions than hot (red) ones.
Unfortunately,,,,
Cold beam warms up



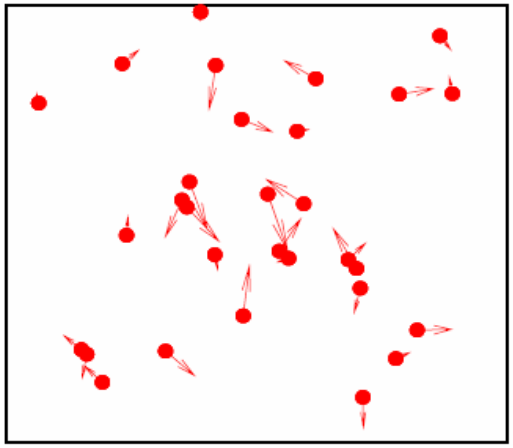
Why does the beam heat up?

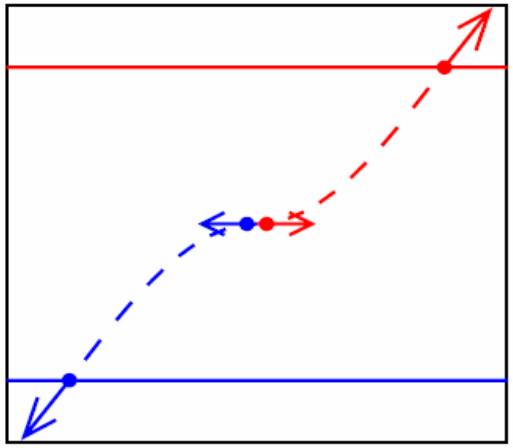




Look at 2 particles in the same beam bouncing off each other

Go to “rest frame”





Dispersion causes average orbit to change with energy.
Can get an increase in transverse speed!

Basic Idea of Longitudinal Cooling

Pickup gets average velocity error in sample with respect to synchronous particle.

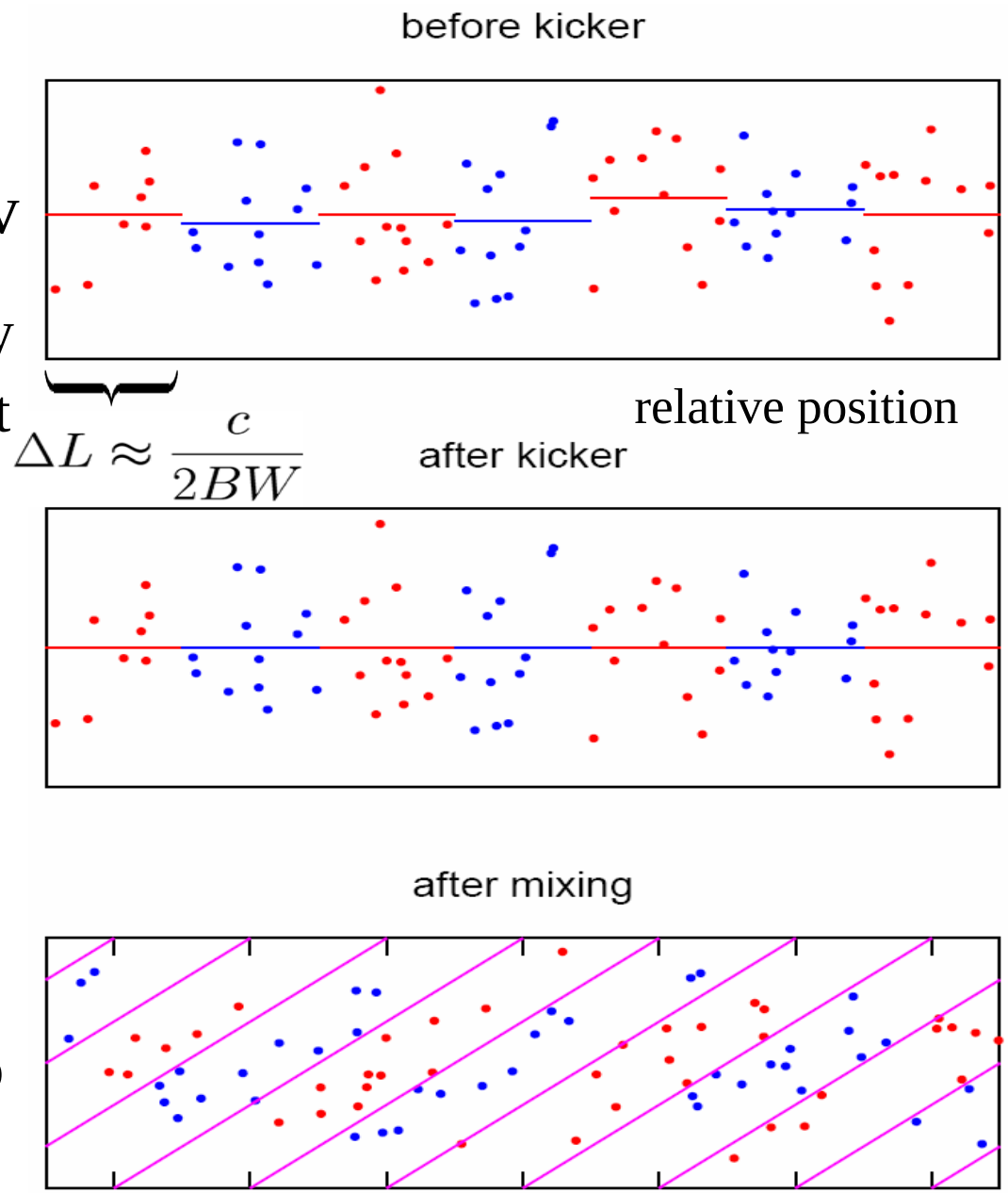
Flipping a coin 100 times rarely gives exactly 50 heads

Kicker is broad band RF

Subtracts the average from each sample.

The spread is reduced!

Longitudinal slip mixes into new samples



Longitudinal Cooling in Practice

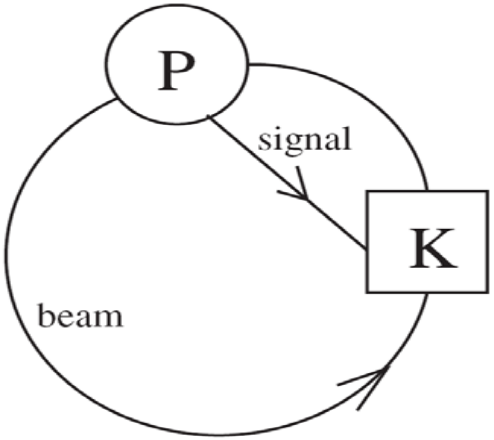
Take pickup signal from two consecutive turns.

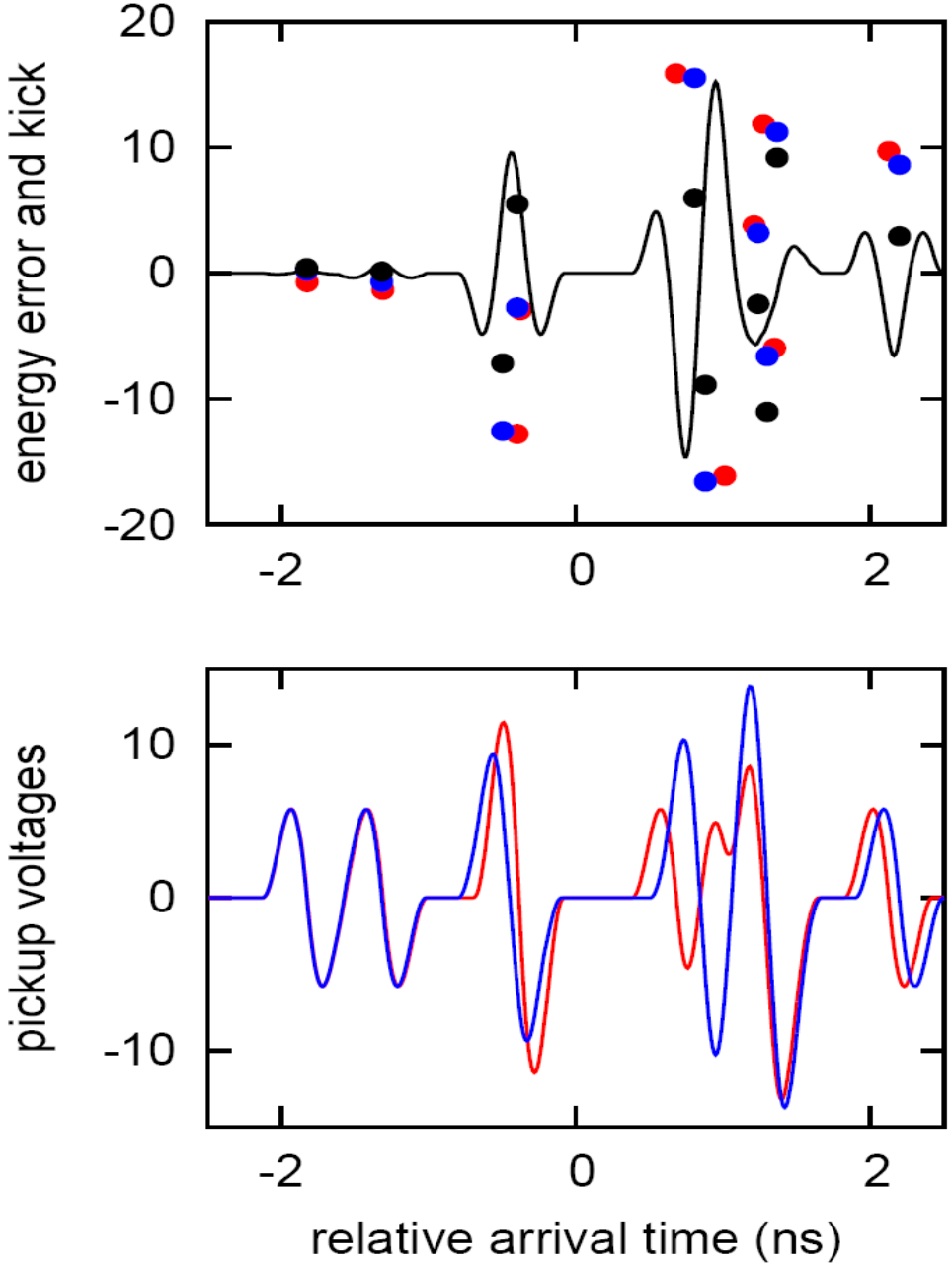
Referenced to synchronous particle.

Difference is amplified and sent to the kicker.

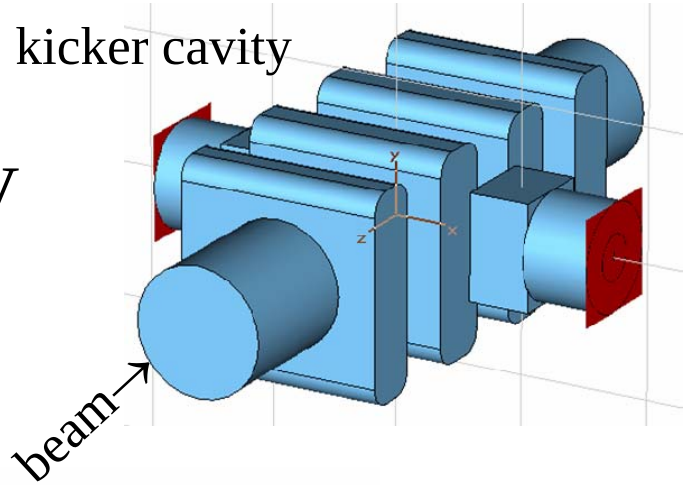
Energy spread drops.

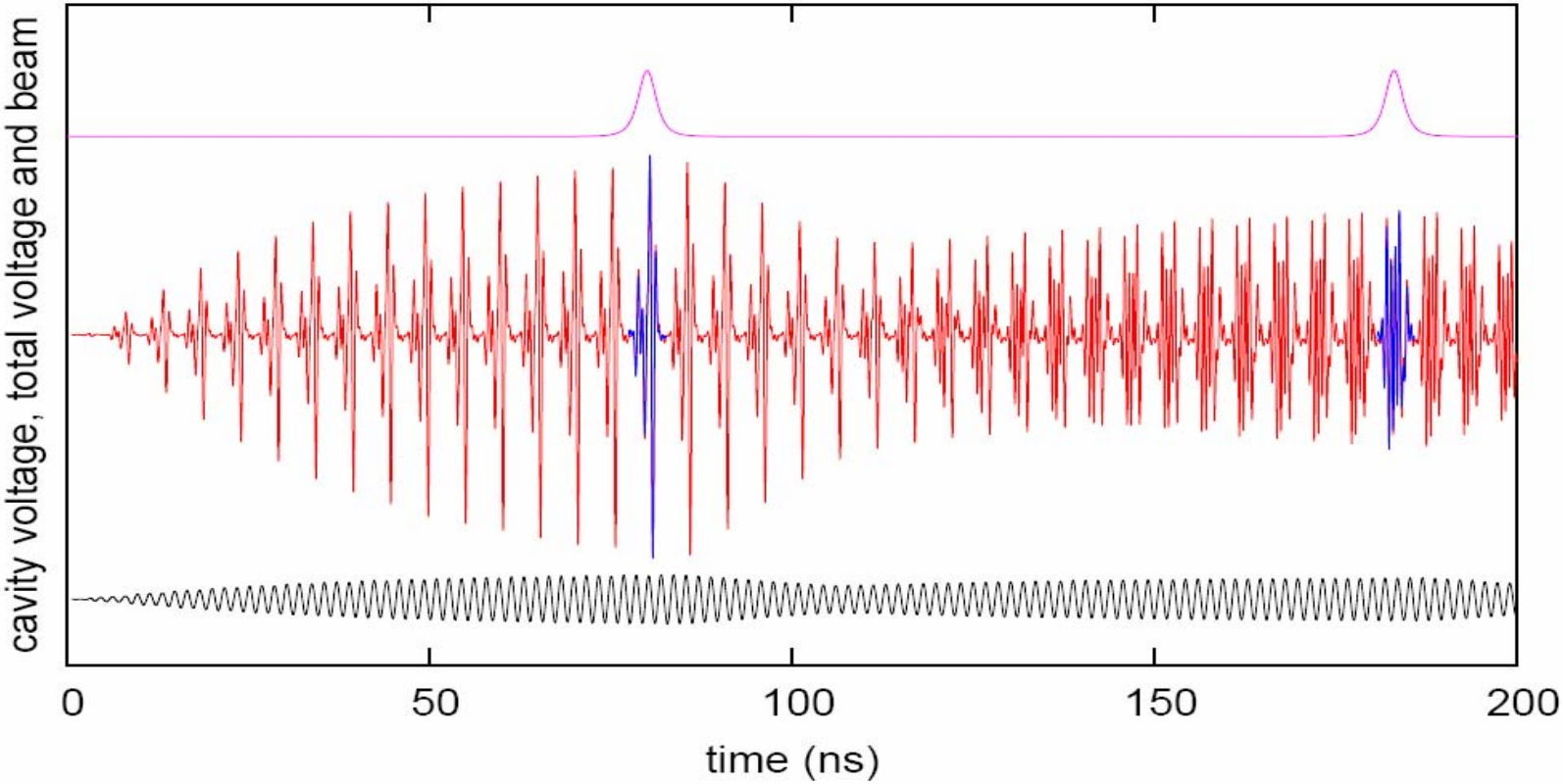
3 turns of data in real system.



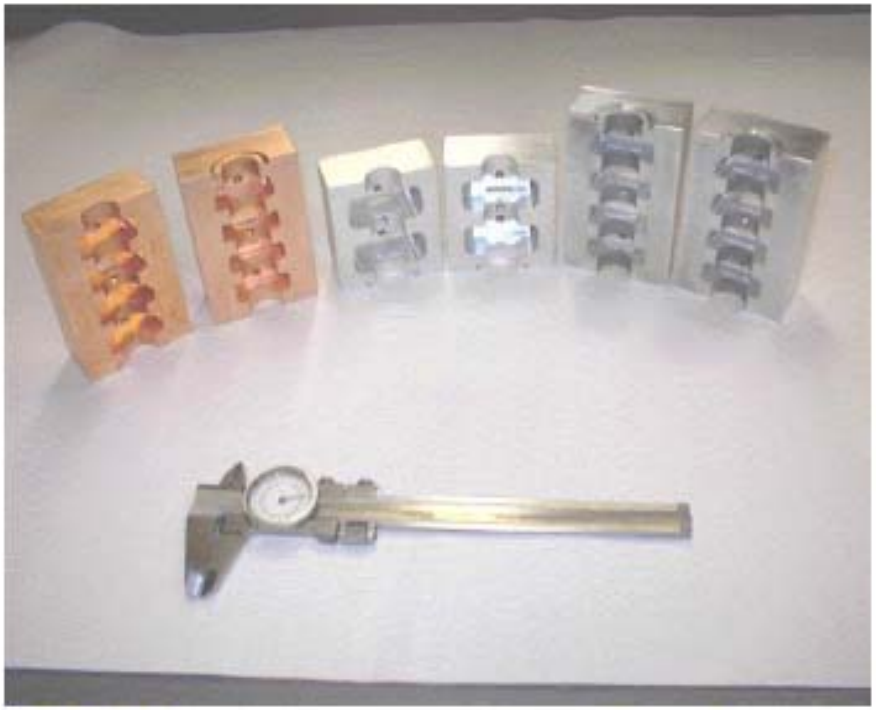


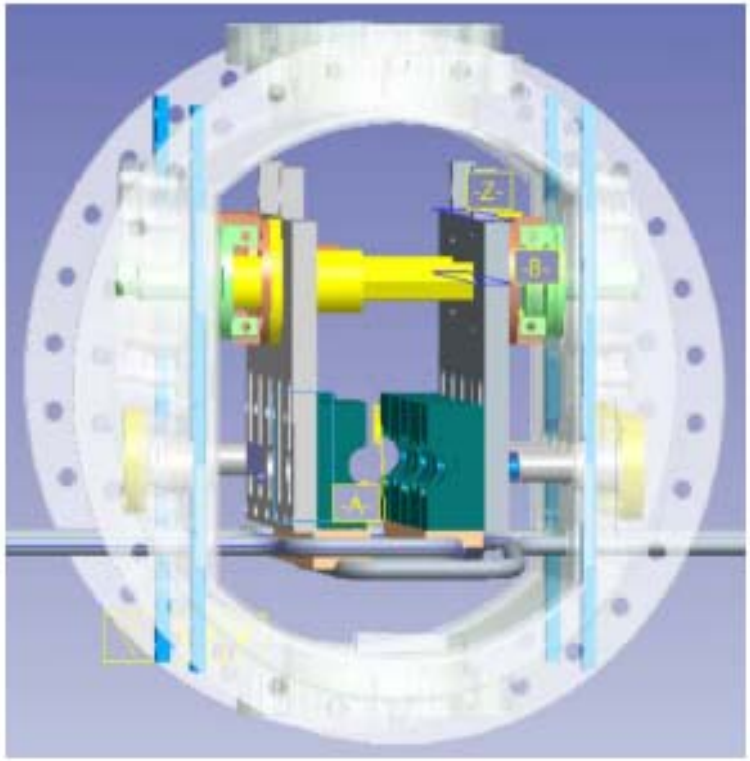
It takes kilovolts to cool a 100 GeV/nucleon beam σ(E)/q ~100MV





Longitudinal kicker needs to open during the ramp





Tolerance for closing is 0.002”
Individual cavities driven by 40 Watt amplifiers
(90,000 W for 50 Ohm kicker).
Amplitude and delay are corrected every 5 minutes.

RHIC RF

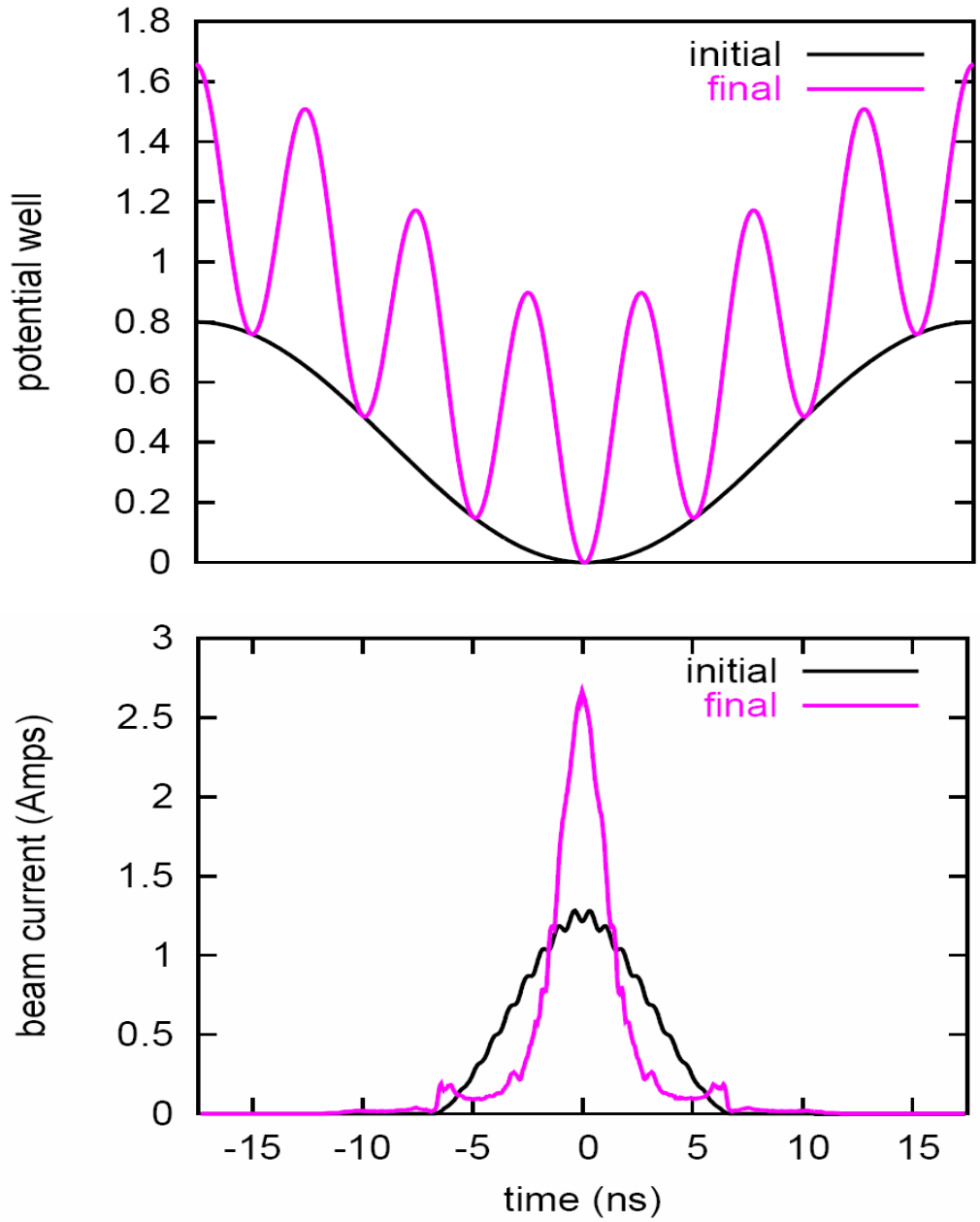
Heavy ions are "rebucketed"

Initially the bunch is in a 35 ns long potential well (black)

Particles are like beads on a wire

After some RF gymnastics most of it ends up in the 5 ns central well (magenta)

We usually spill a little.

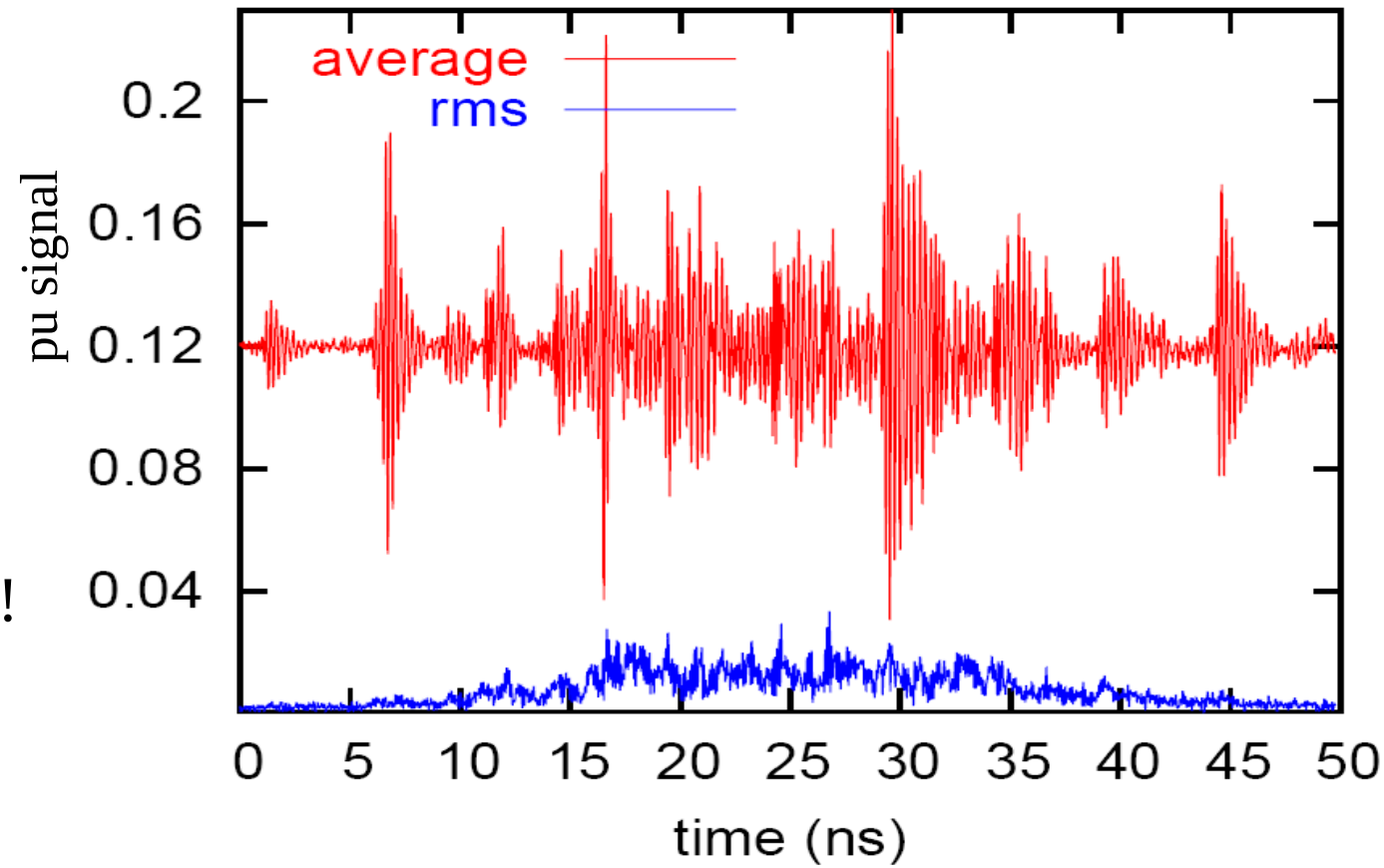


Things look different around 5 GHz!

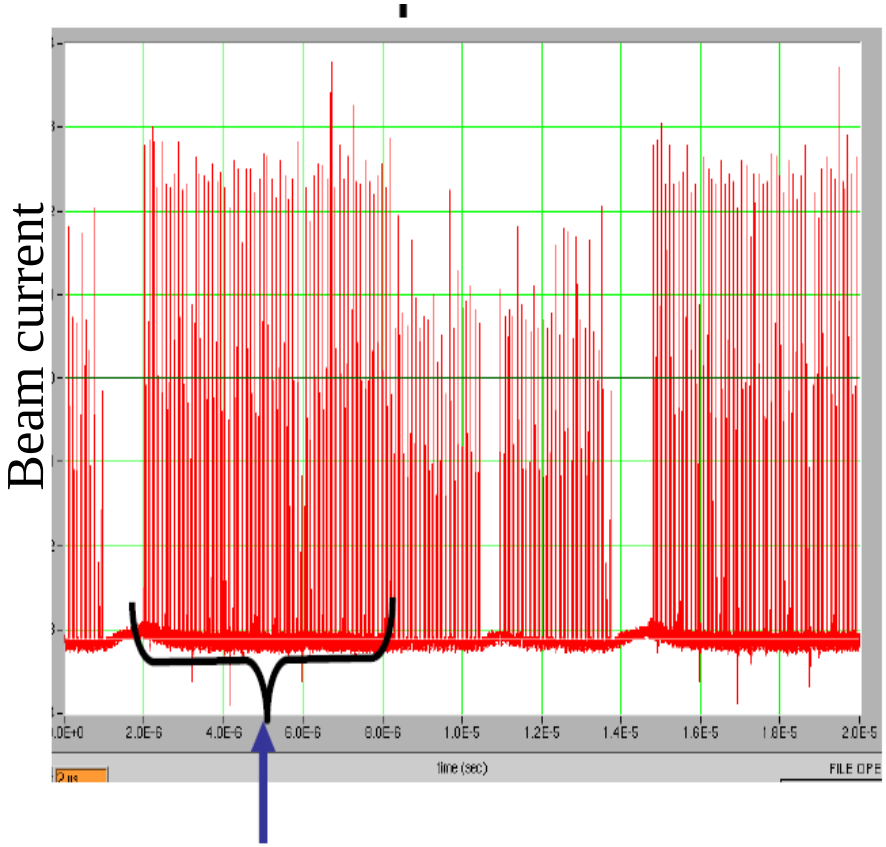
Fluctuations (rms) have all the cooling information.

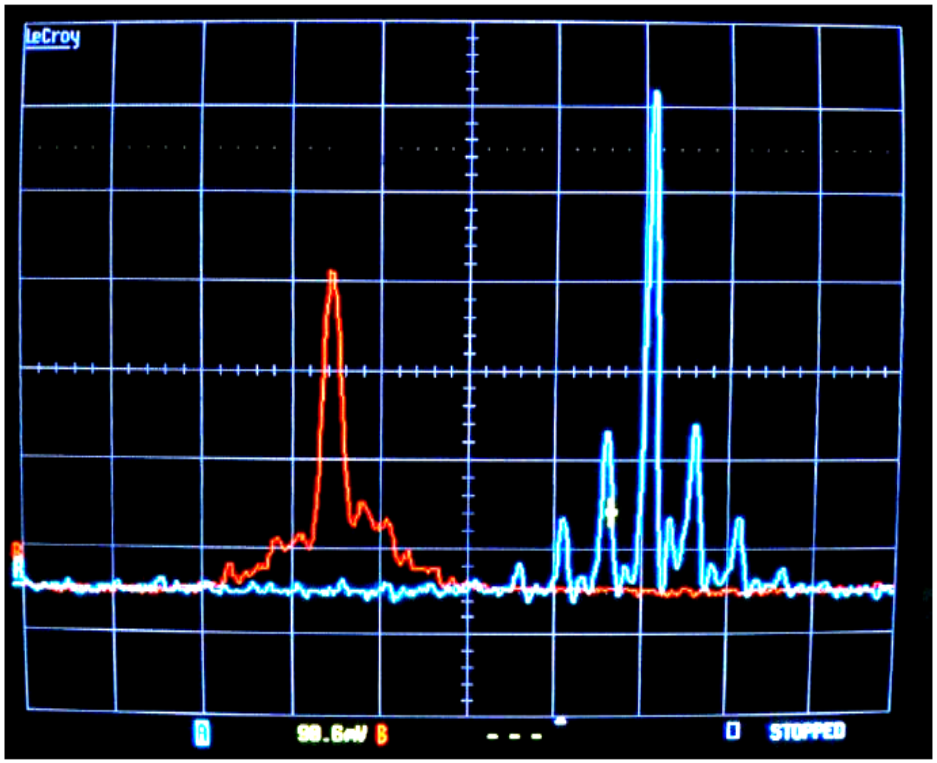
Average is Filtered Out.

Real amps don't just multiply Dynamic range!!



The first time we cooled half the ring

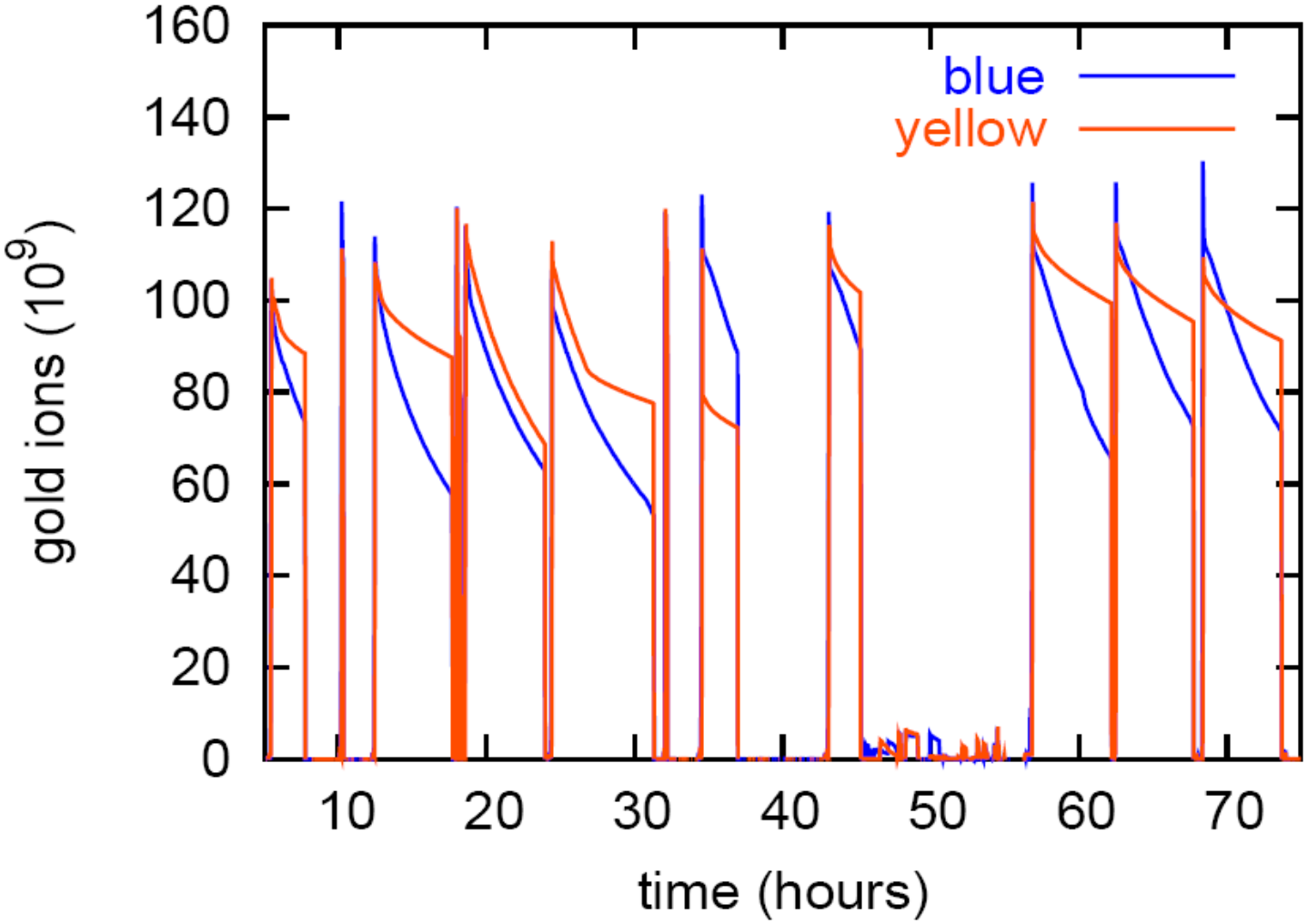




Cooling was applied to half of the bunches

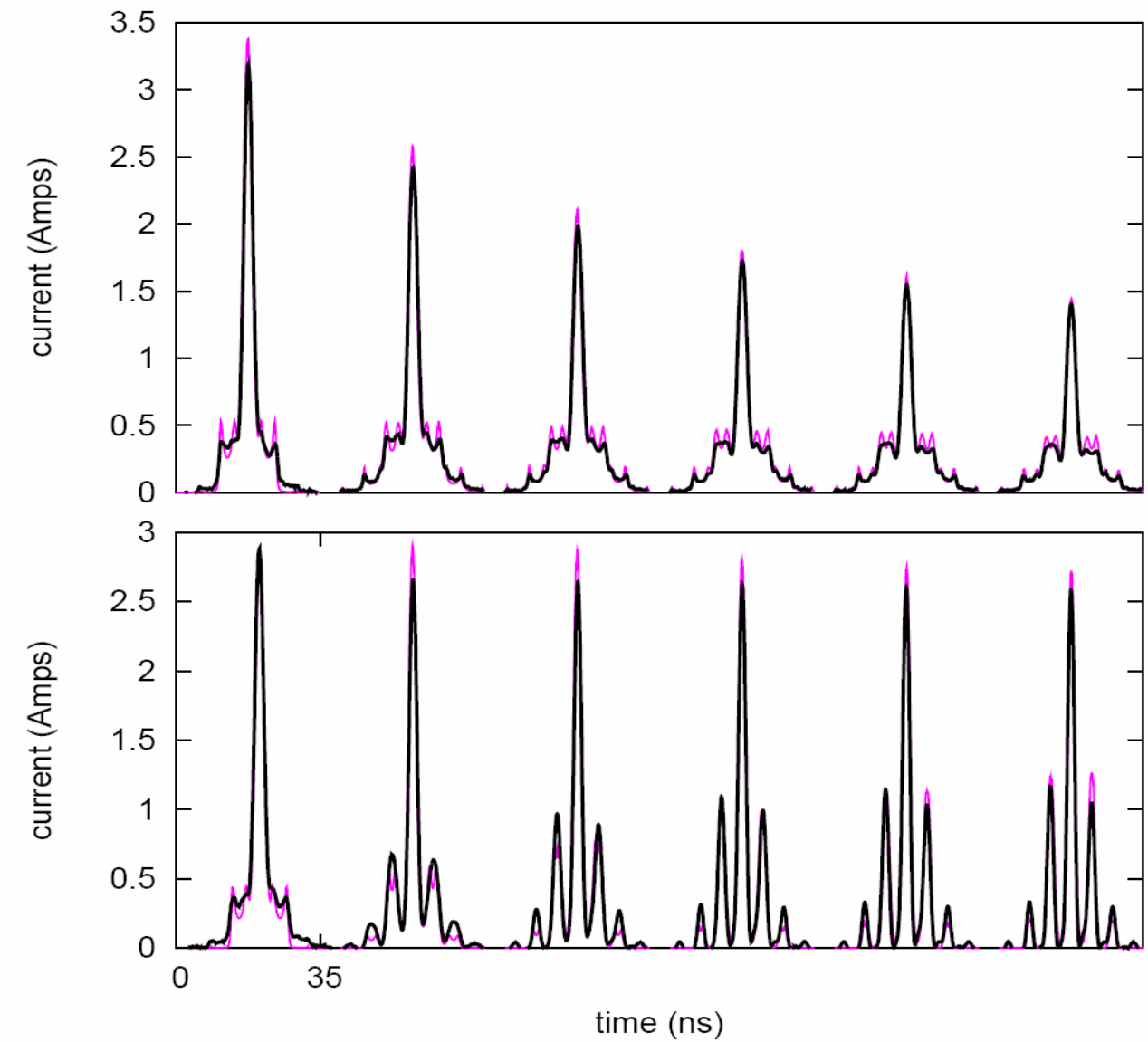
The peak current increased. Beam in the satellites was cooled

Pretty soon it was routine



Calculations compared well with reality

- Data (black)
- Simulation (magenta)
- Good agreement
- Believe the simulations.
- Extend to include transverse cooling.

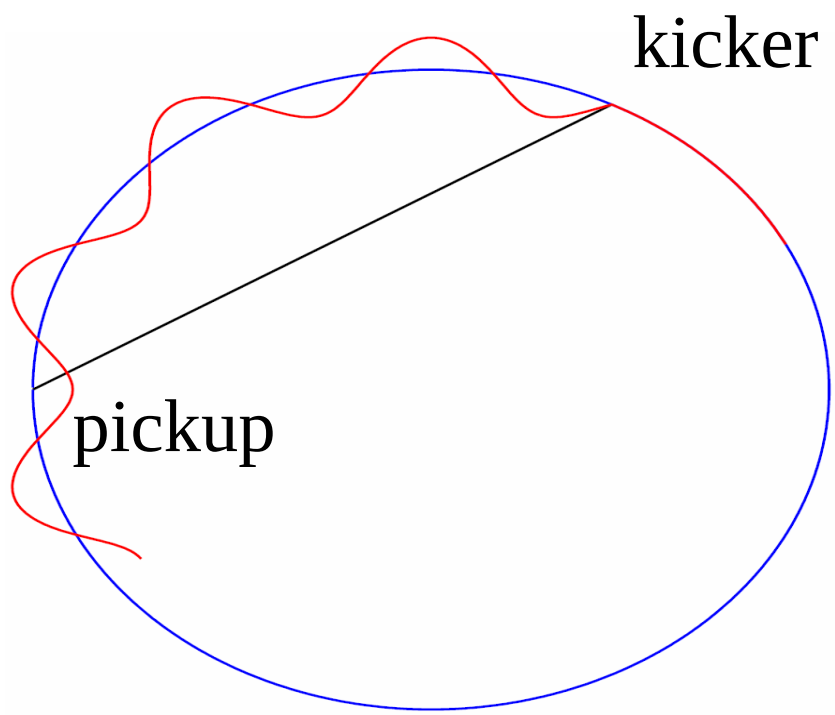


Transverse Cooling Scenario

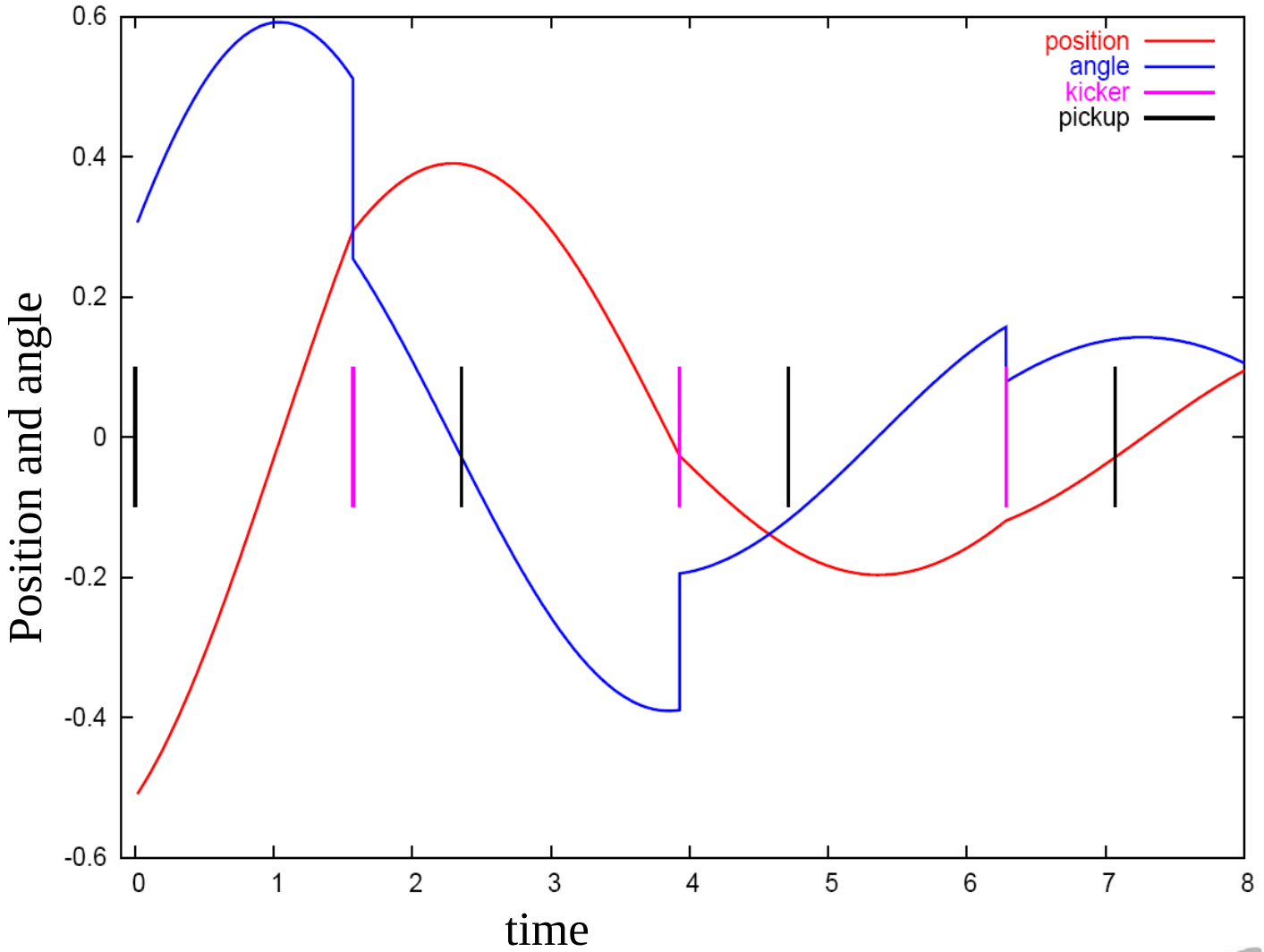
Signal from a transverse pickup

Amplify and send to kicker.

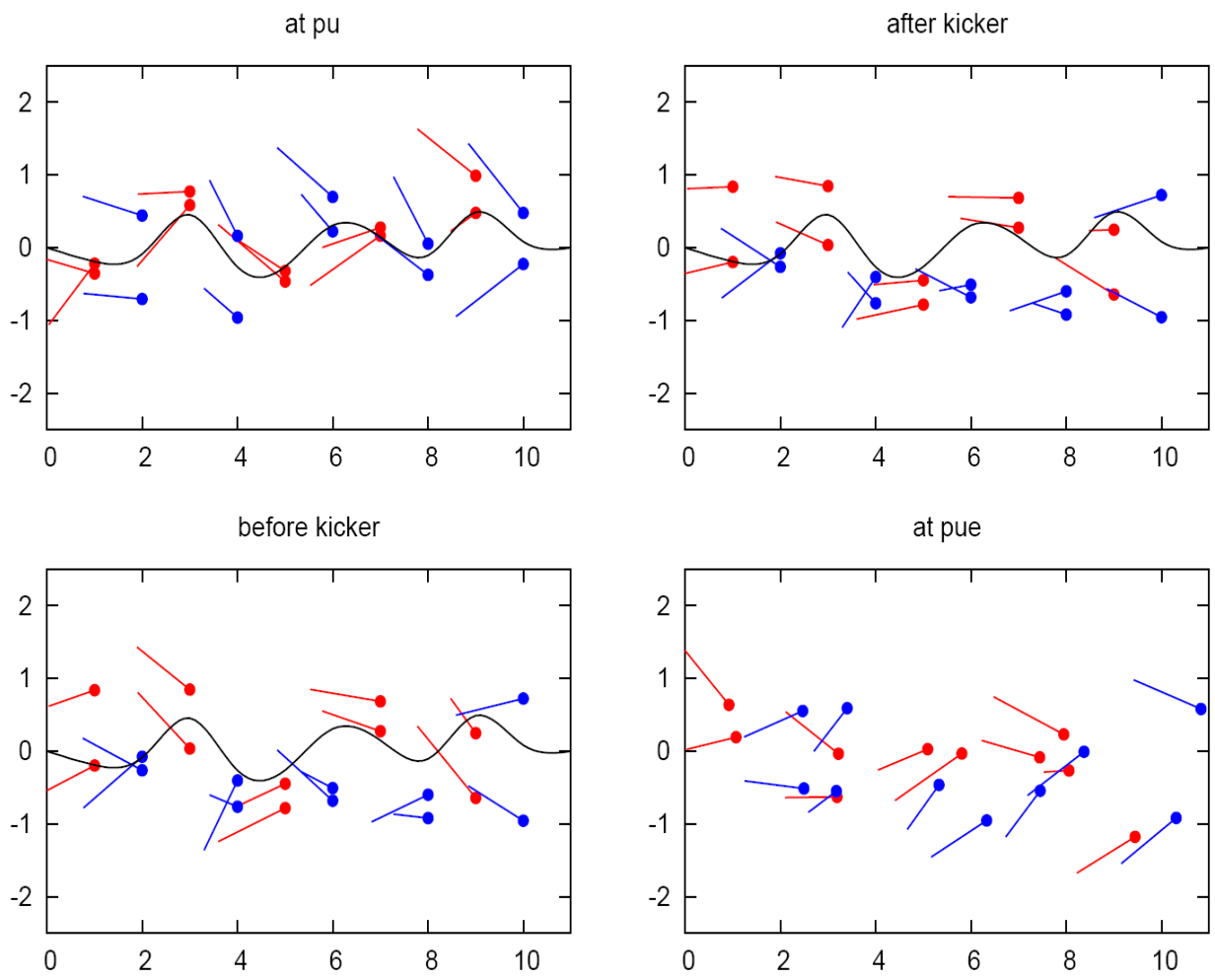
Transverse kicker changes direction of motion



Cooling one particle



Cooling with several particles



Notice flattened velocities. Compared with before kicker

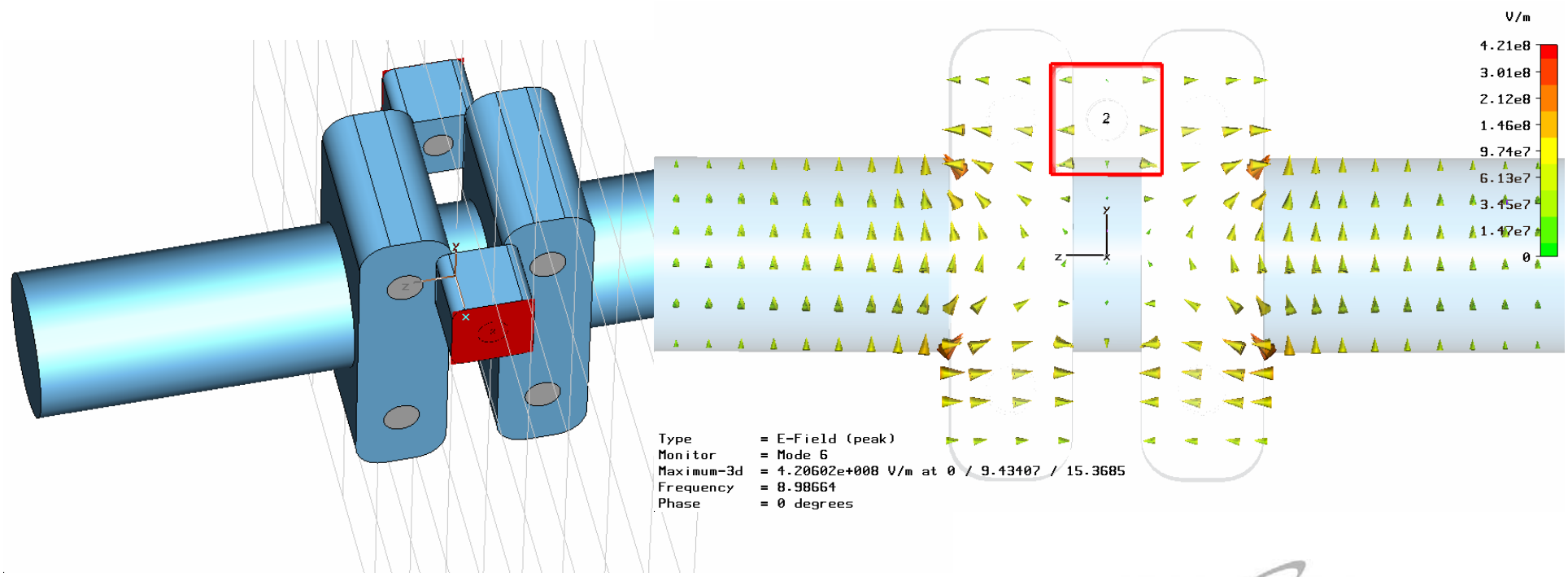
Longitudinal slip creates new groups. Randomizes things so that each kick cools.

Transverse Cooling system

Similar cavities. Low level requires a notch filter (R&D)

40 Watt amplifiers are sufficient.

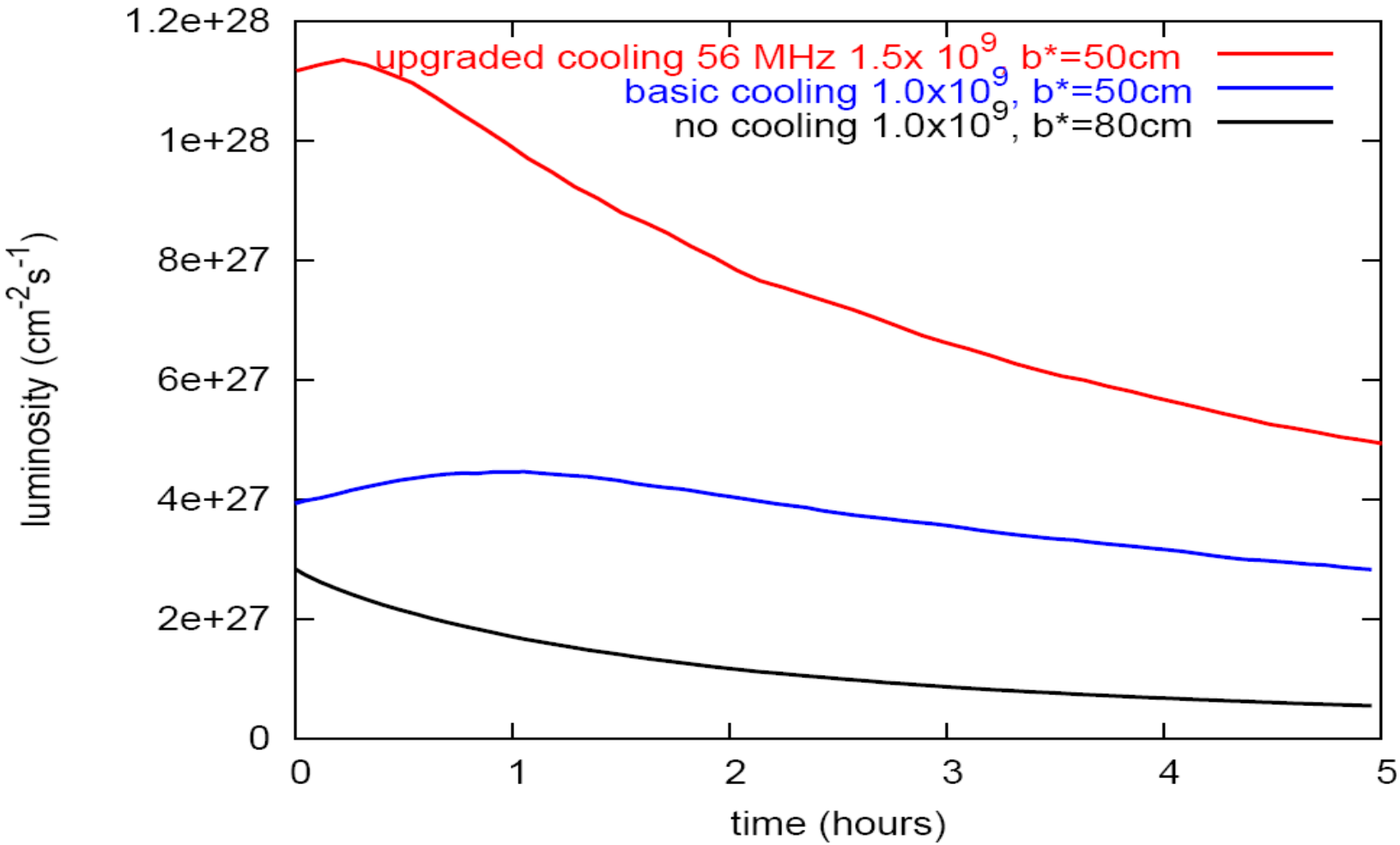
5-8 GHz keeps aperture reasonable.



Expected improvement

Basic stochastic cooling is pretty good.

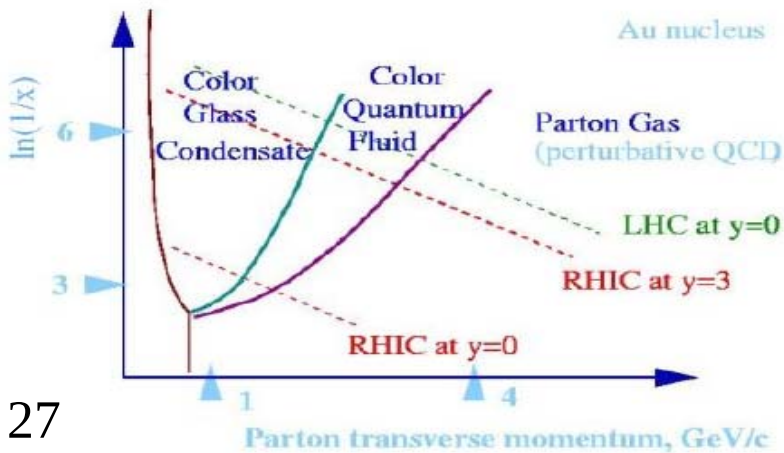
More beam can be stored with upgraded cooling.



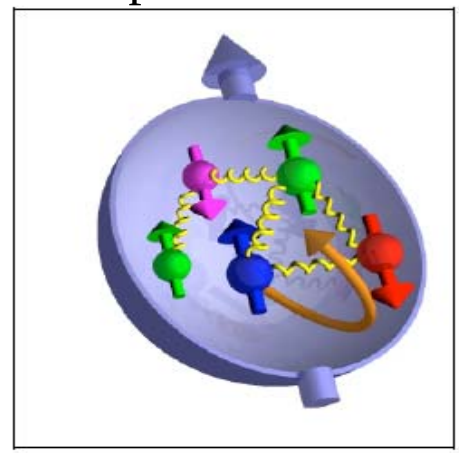
RHIC II

Gold-Gold requirement

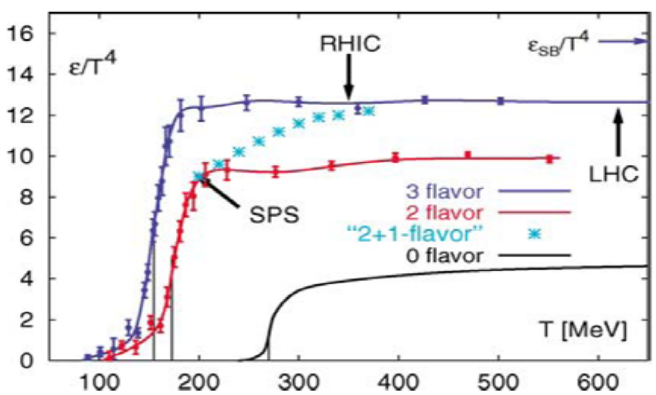
$$L = 8 \times 10^{27}$$

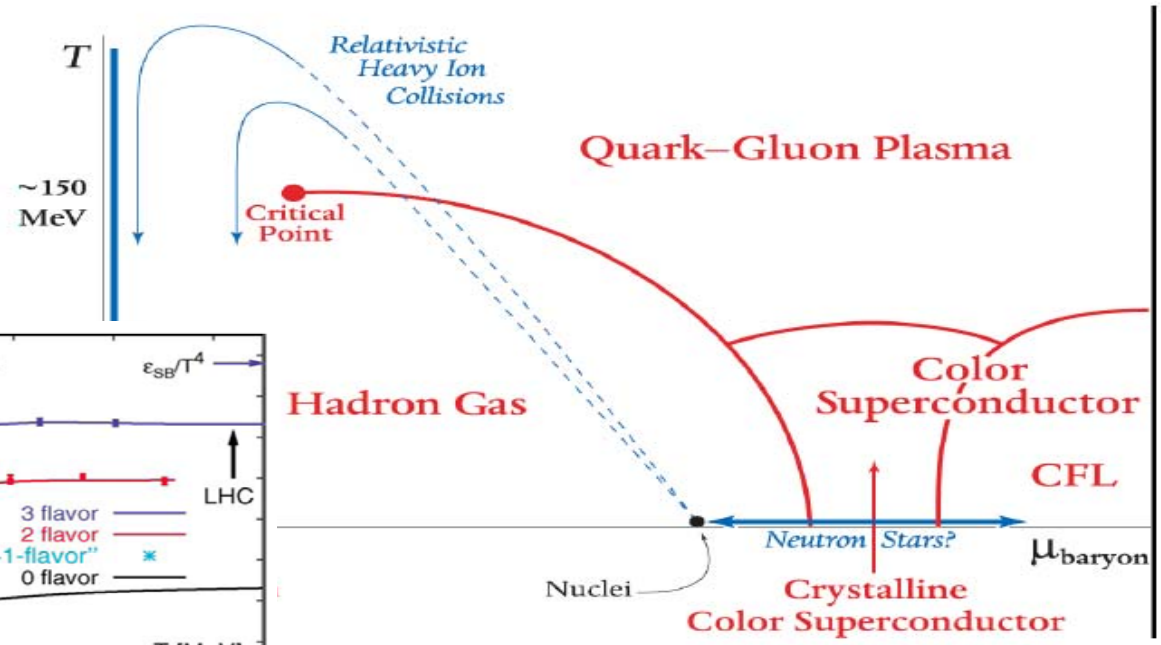


proton



Coherent electron cooling?





Conclusions

For ion beams in RHIC:

1) Longitudinal stochastic cooling worked.
2) Lifetime was improved.
3) Simulations show good agreement with data.
4) Transverse cooling looks straightforward.
5) Expect a big payoff from transverse cooling.