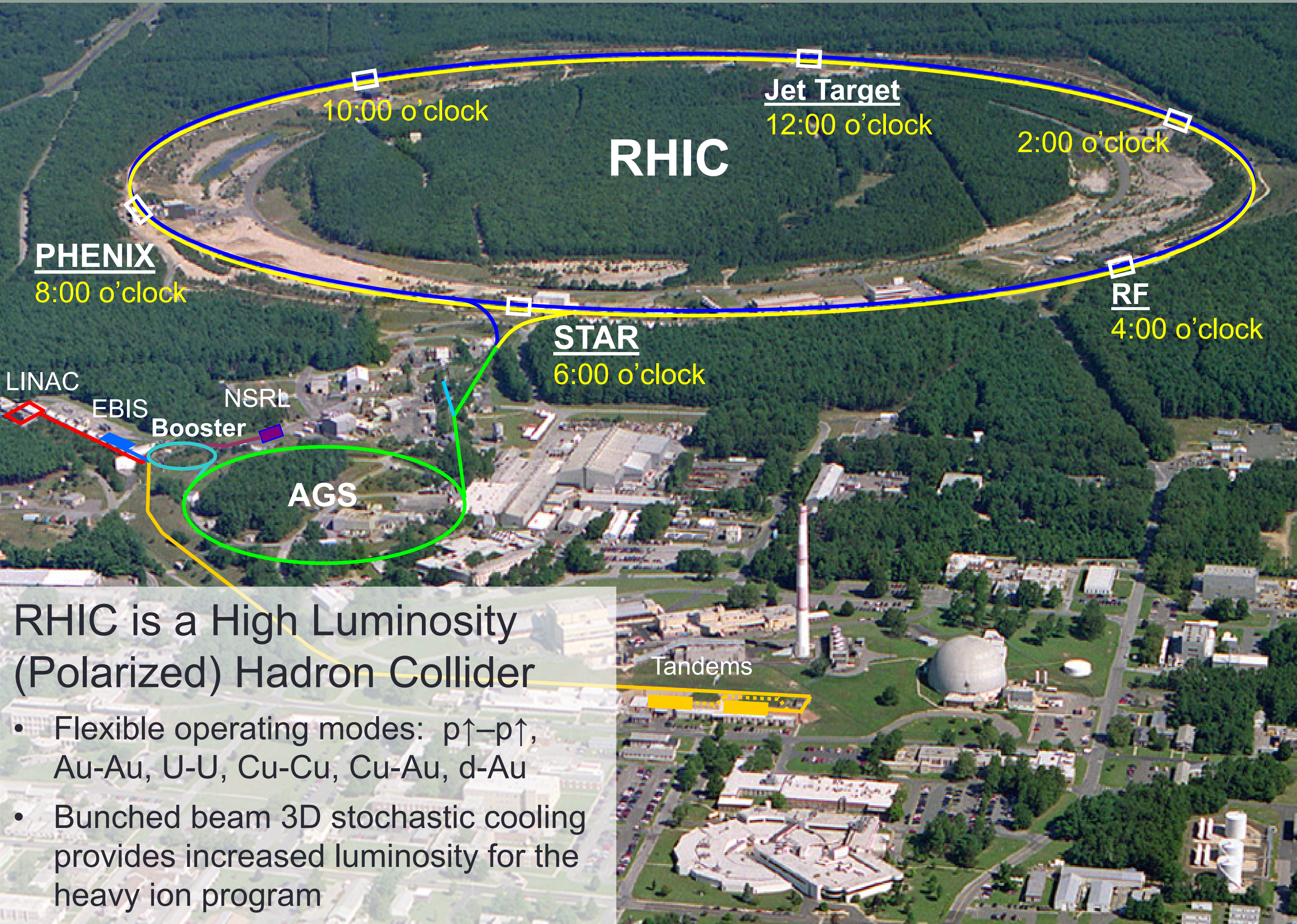
FULL 3D STOCHASTIC COOLING AT RHIC

K. Mernick, M. Blaskiewicz, J. M. Brennan

BROOKHAVEN NATIONAL LABORATORY

Outline

- Overview of the design of the RHIC stochastic cooling system
  - Pickups and kickers
  - Electronics
  - Control and Operation
- Performance of stochastic cooling during the RHIC FY12 Uranium-Uranium and Copper-Gold collider runs



RHIC is a High Luminosity (Polarized) Hadron Collider

- Flexible operating modes: p↑–p↑, Au-Au, U-U, Cu-Cu, Cu-Au, d-Au
- Bunched beam 3D stochastic cooling provides increased luminosity for the heavy ion program

Basic Idea of Stochastic Cooling

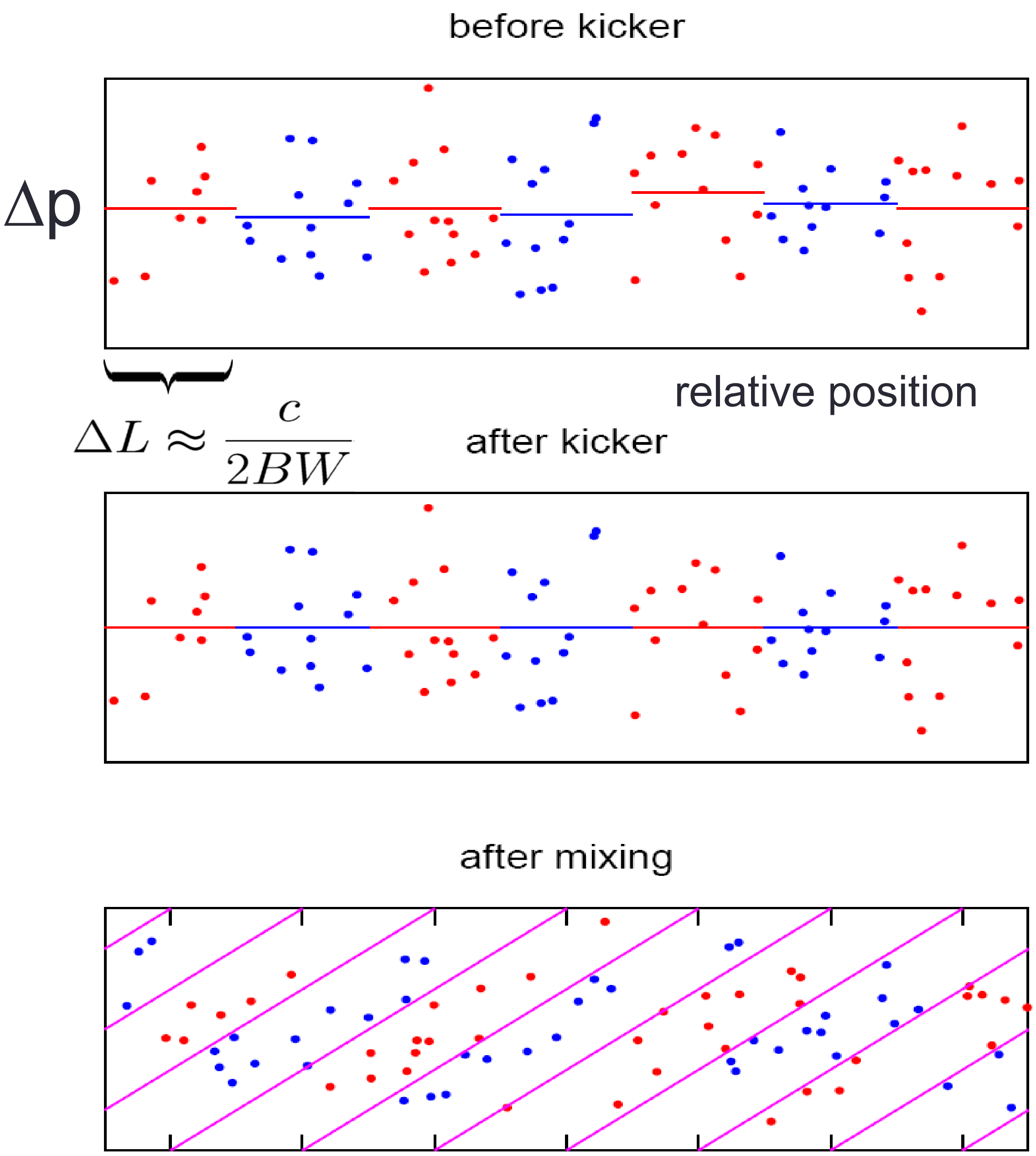
Measure average momentum error of sample with respect to the synchronous particle

Flipping a coin 100 times rarely gives exactly 50 heads – the error of the sample is (generally) non-zero

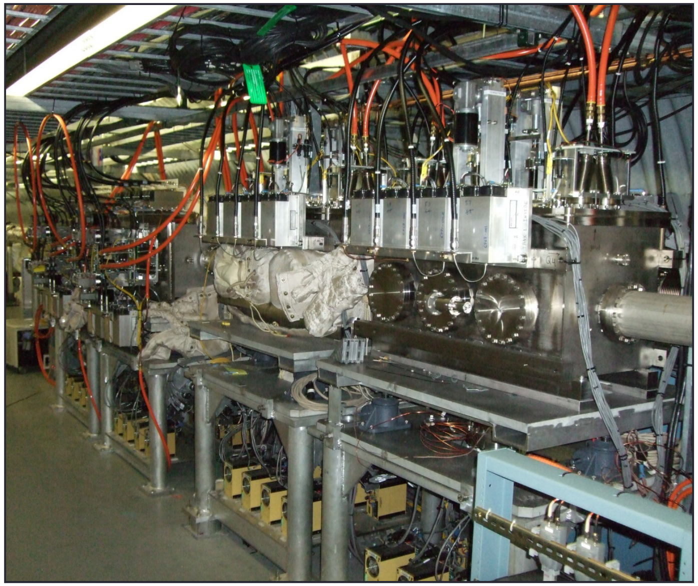
Apply a kick to each sample that subtracts its average error

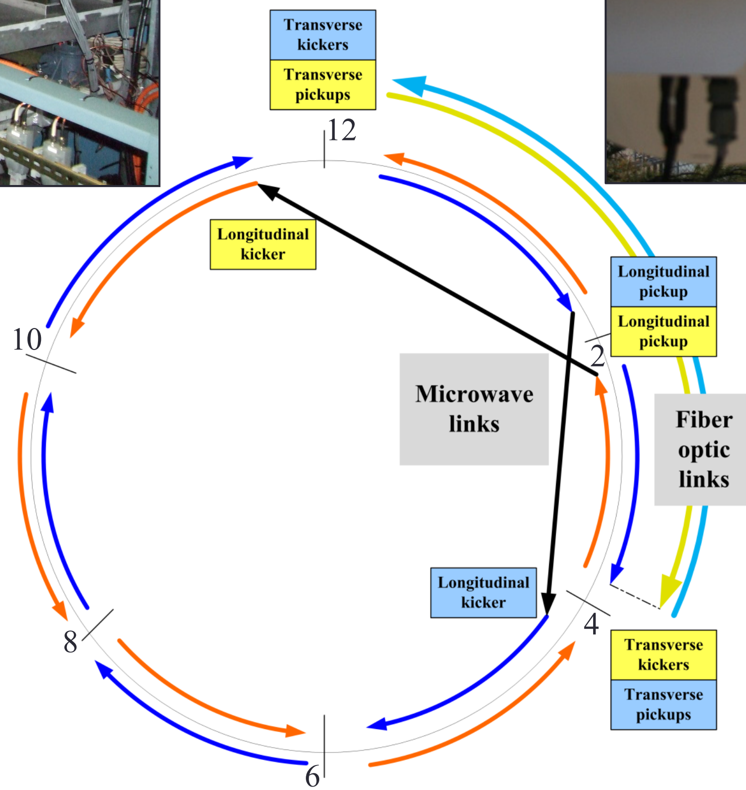
The spread is reduced!

Longitudinal slip mixes into new samples



System Layout





Longitudinal Pickups

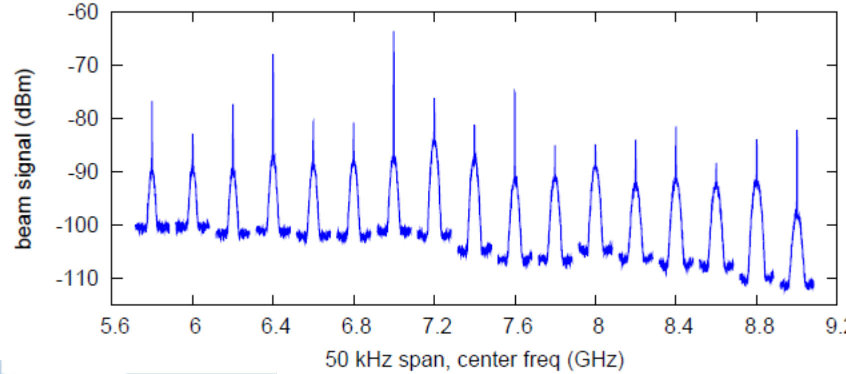
We have two types of pickups – one for the longitudinal systems, and the other for transverse

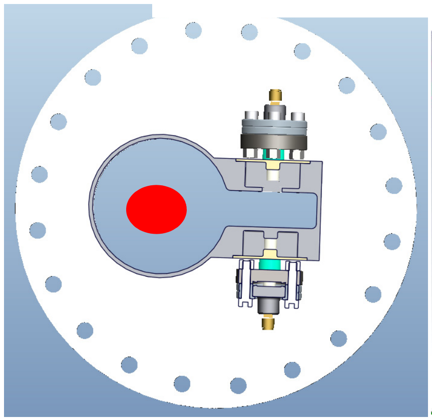
The longitudinal “keyhole” pickup has a large (7 cm) aperture for beam at injection and a small (2 cm) aperture when operating

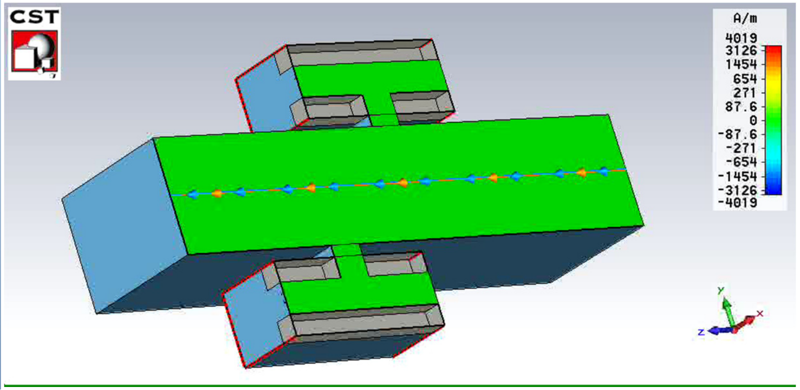
The beam couples to top and bottom waveguides through slots – these signals are summed together for the longitudinal pickup

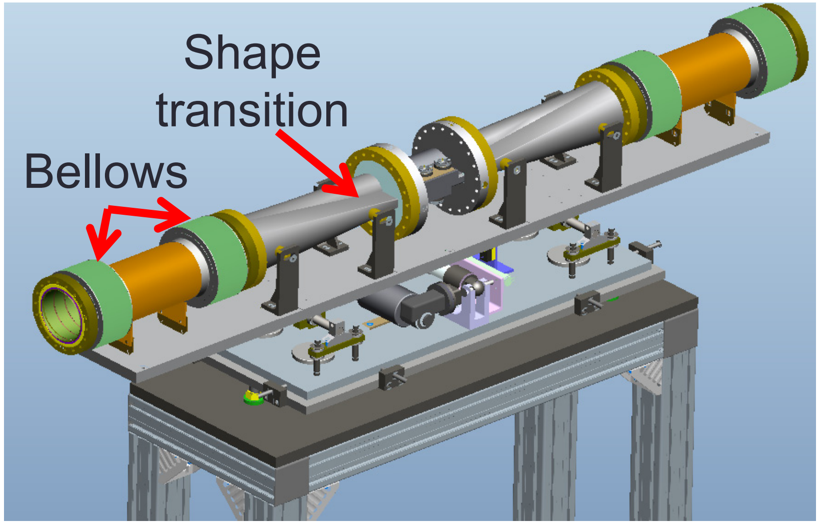
No moving parts inside the vacuum chamber

Frequency response across the 6 – 9 GHz band is much flatter than previous pickup design









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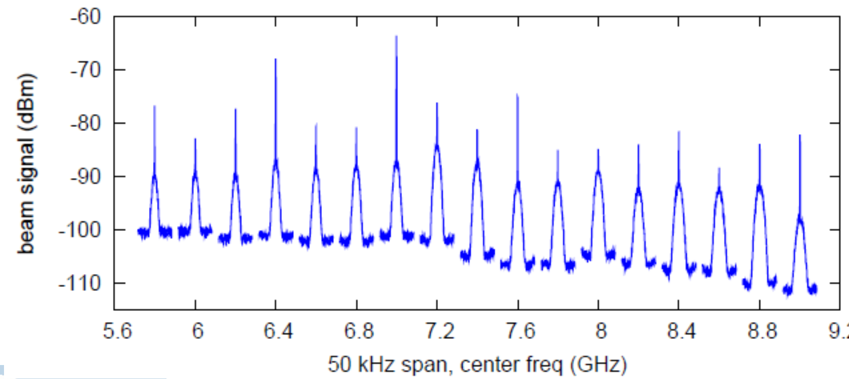
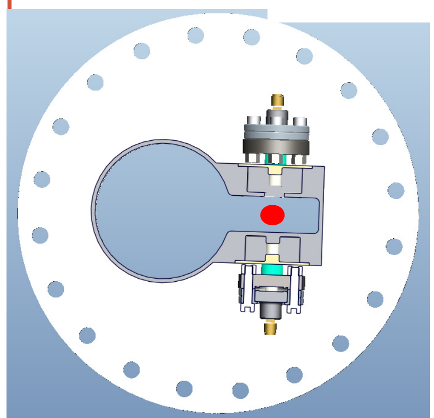
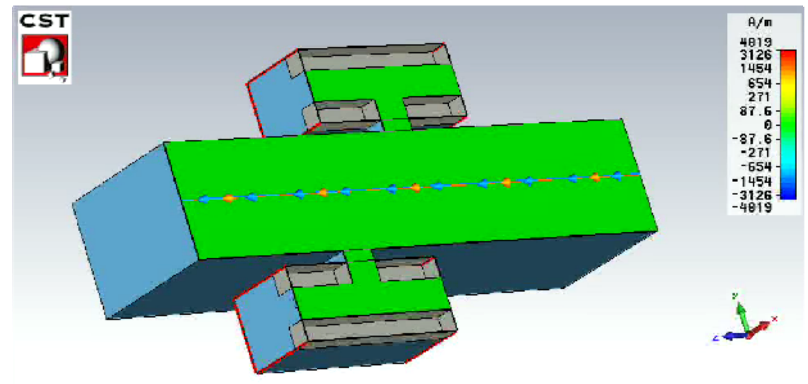
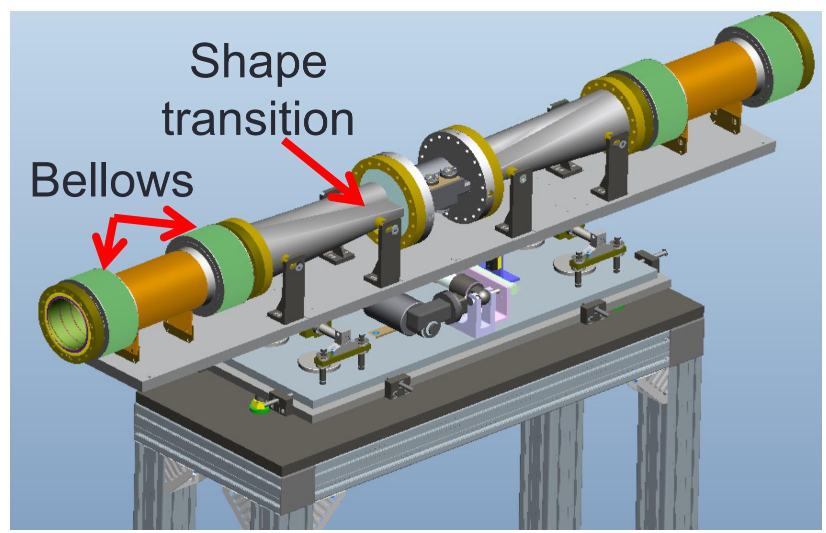








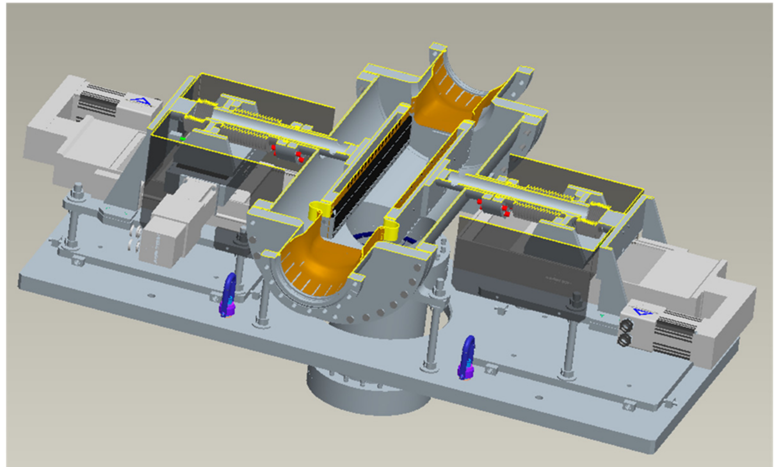
Transverse Pickups

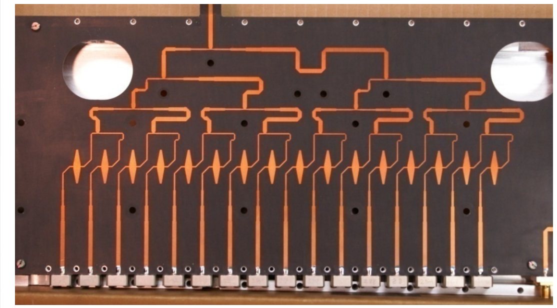
Each transverse pickup uses two planar loop arrays designed at Fermilab

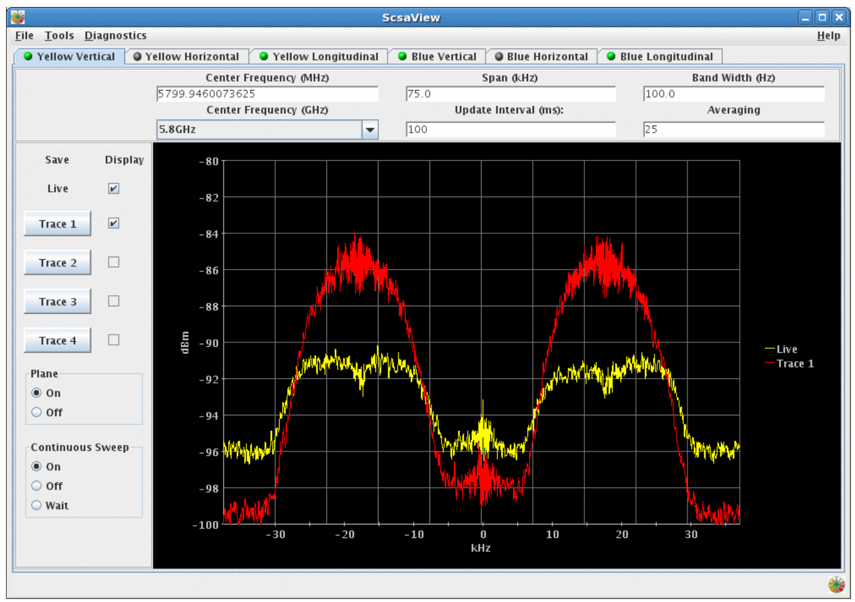
The pickup array is supported by a cantilever connected to a precision linear motor stage

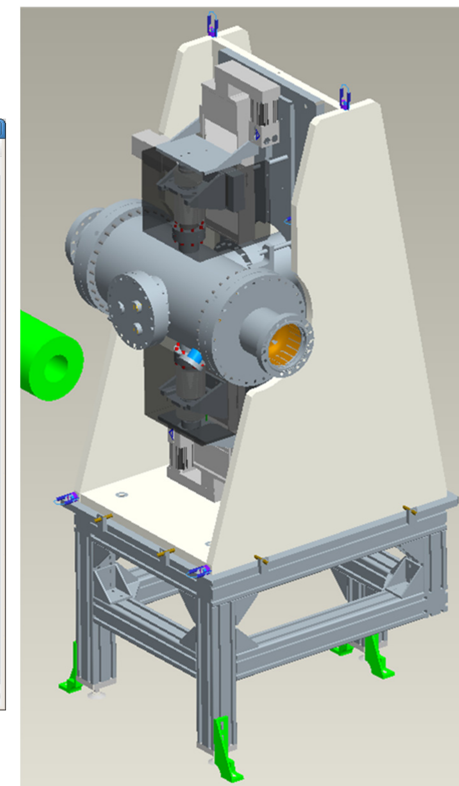
This allows opening to a maximum aperture of 8 cm for beam injection and ramping and closing to a minimum aperture of 2 cm for operation the pickup while maintaining precise alignment

The difference signal from an external hybrid is used









See poster THPH008, Liaw, et al

Kickers

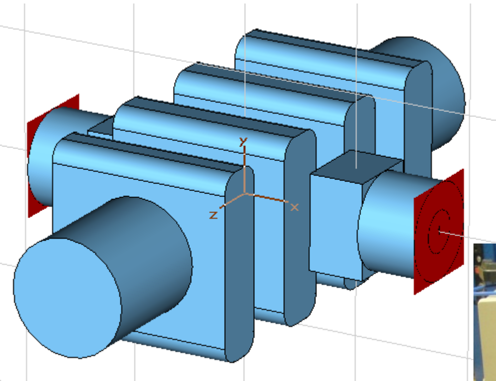
The bandwidth of the system is an important factor in the cooling rate

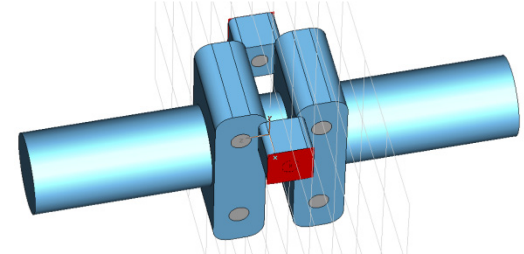
But a broadband kicker (and power amplifier) is expensive – instead we synthesize the kick from an array of narrowband (~10 MHz BW) cavities

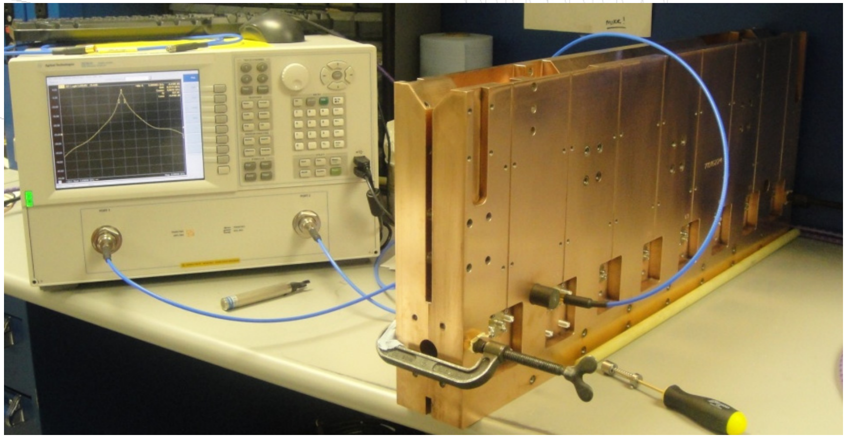
The RHIC bunches are ~5 ns long and separated by ~100 ns and the kicker voltage only matters when the bunch is present

The cavity is driven with a periodic extension of the broadband signal

16 cavities spaced 200 MHz apart give a system bandwidth of 3 GHz



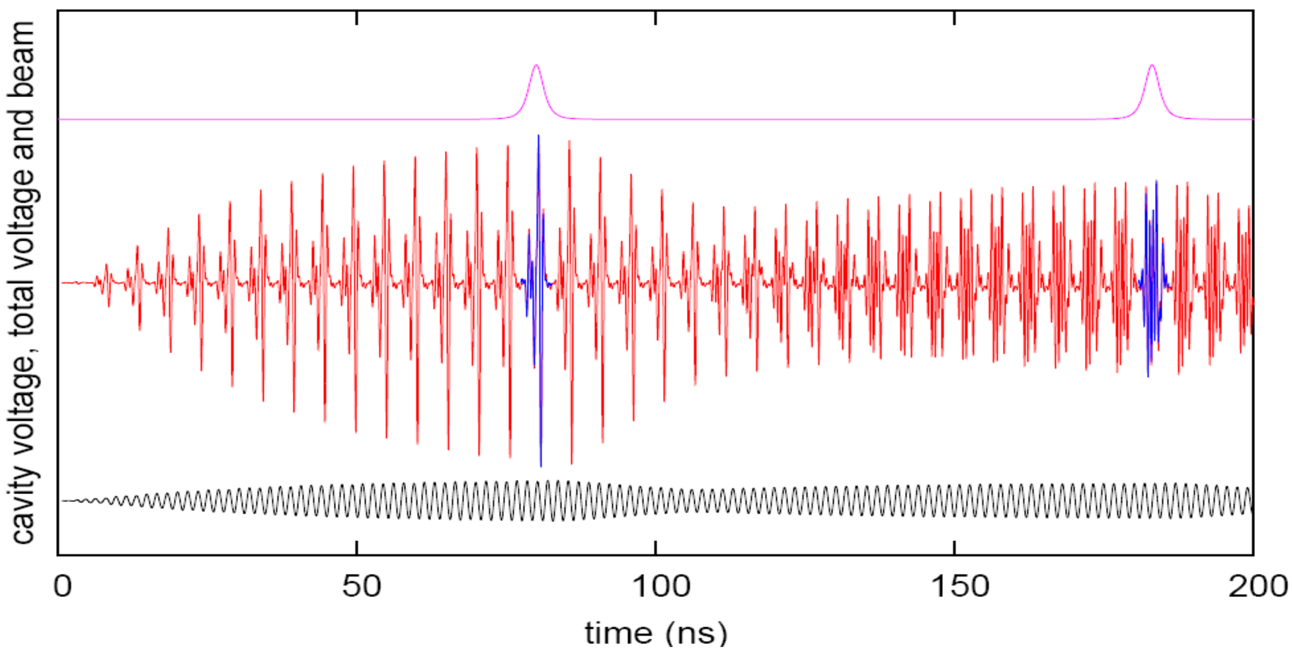




$$y(t) = \sum_{n=0}^{15} u(t - n\tau) \qquad \tau = 5\,\text{ns}$$

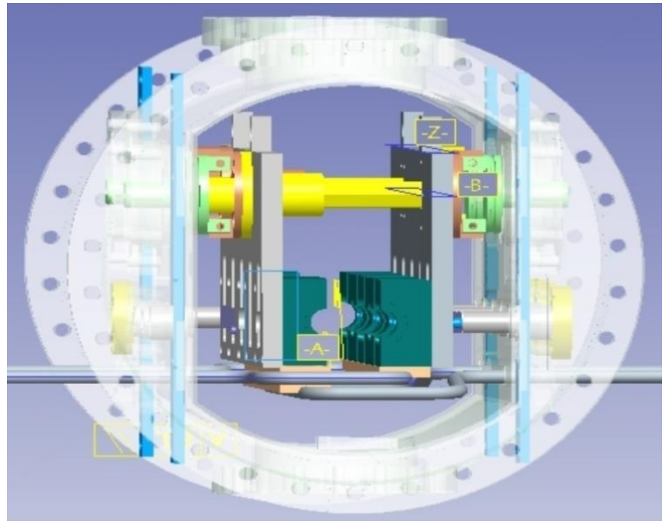
or

$$y(t) = \sum_{n=0}^{15} (-1)^n u(t - n\tau)$$

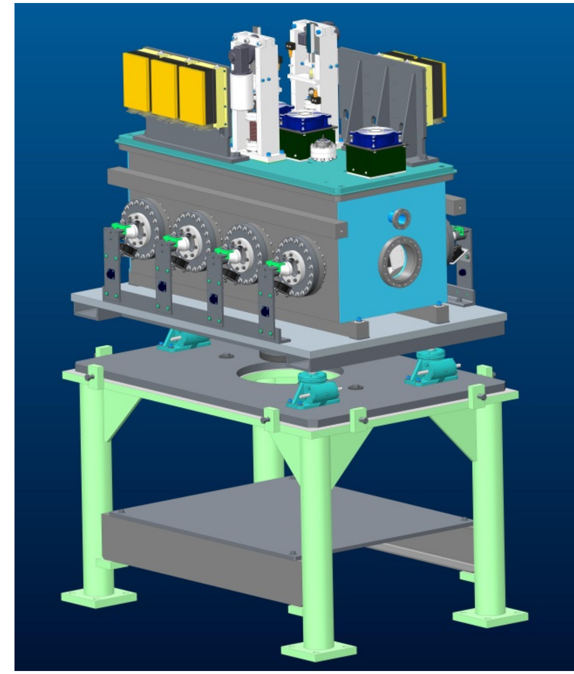


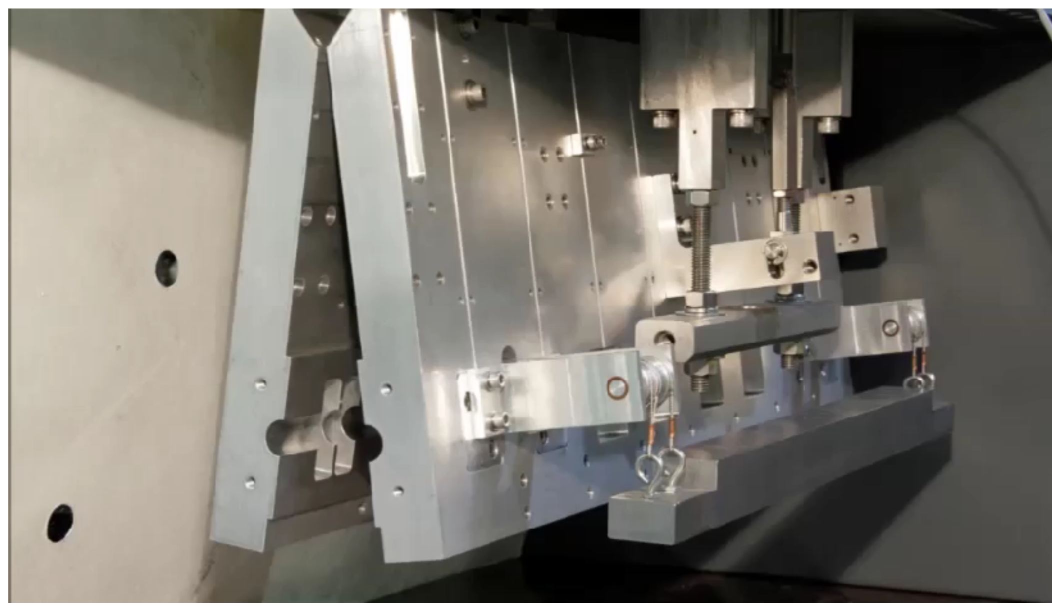
Kickers

- 3 types of kicker vacuum chambers
- Cavities are split to open and close
- Initial longitudinal kickers were built using Fermilab tanks – sliding parts in vacuum
- First vertical kicker used a new design – difficult assembly tolerances
- Subsequent kickers were built using a “flexi-hinge” – they open and close in a scissor motion with no sliding parts
- Simplified motion control, “positive stop” gives repeatable motion
- Longitudinal kickers are being upgraded with the new design (and RF improvements)



See poster THPH007, Liaw, et al





Transverse Electronics

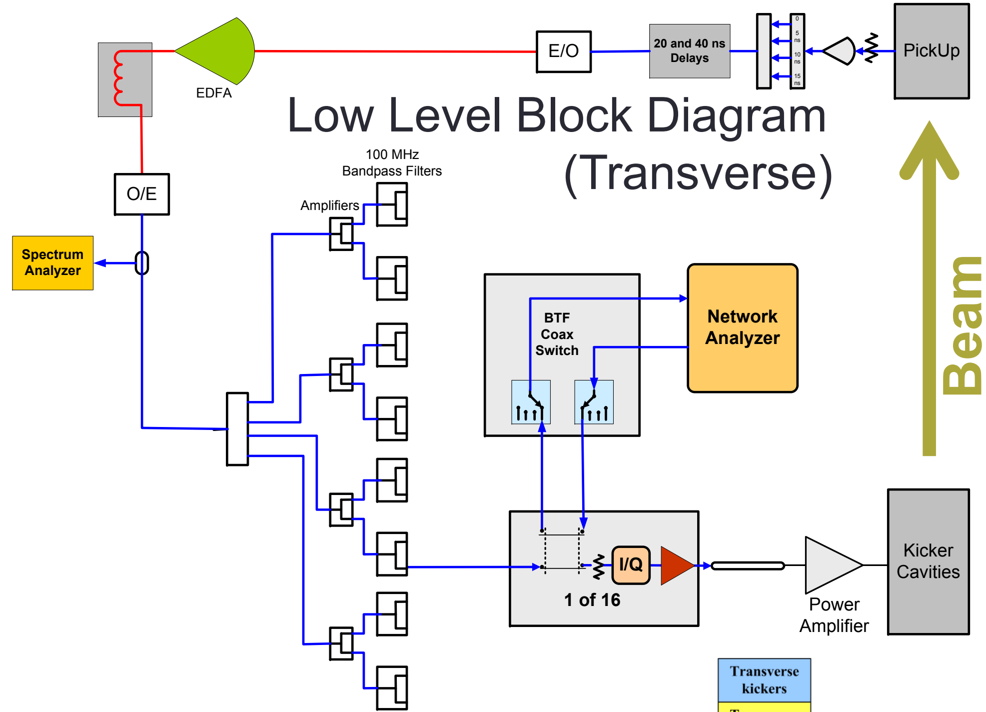
Pickup: hybrids, gain, traversal filter, BPF, fiber optic transmitter

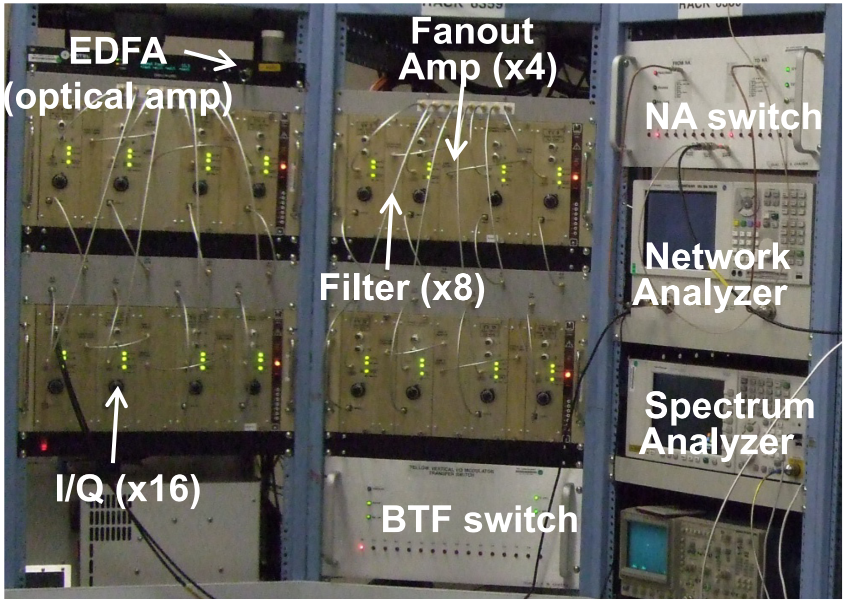
Service building: fiber optic amplifier, delay matching and fiber receiver, fanout & filters, I/Q modulators

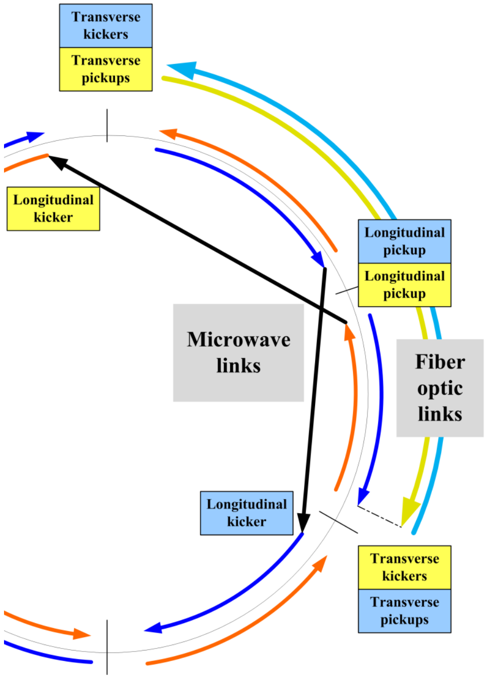
Kicker: power amplifiers

Transfer switches in the I/Q modulators and coax relay-based multiplexers allow measurement of the system transfer functions and monitoring of signals

I/Q and switch modules are controlled with a locally broadcast serial “NIM link” – similar to the Real Time Data Link used throughout RHIC







Longitudinal Electronics

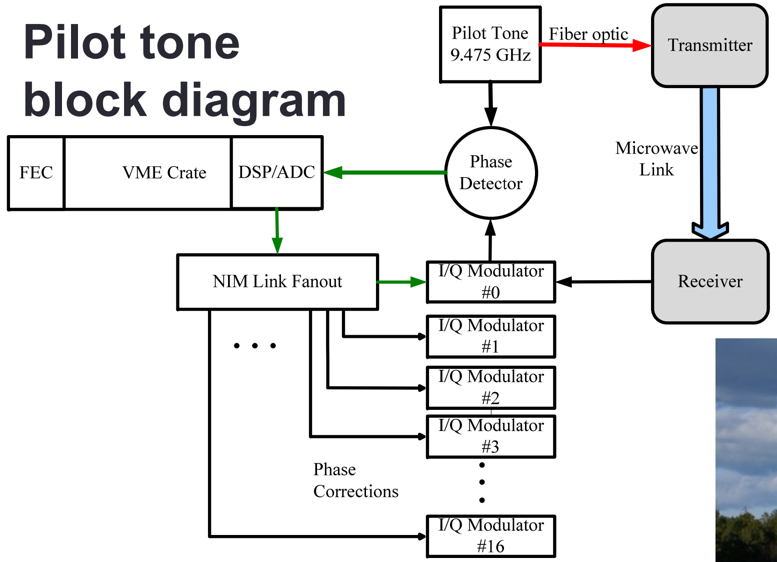
The electronics for the longitudinal systems are similar to the transverse

A one-turn delay notch filter is used to generate the kicker signal from the time of arrival on consecutive turns

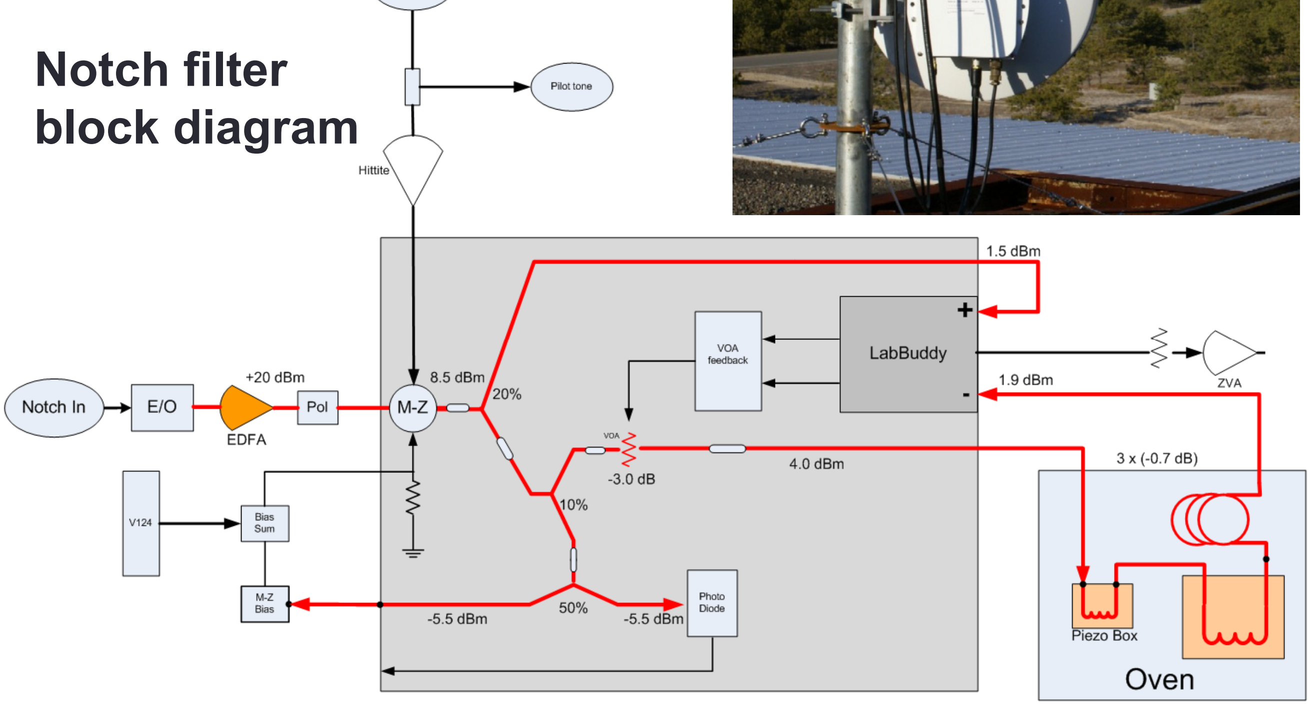
The fiber optic link is replaced with a microwave link that "cuts the chord" between the pickup and kicker

A pilot tone is transmitted over the microwave link and used to correct phase modulation introduced by the link

Pilot tone block diagram



Notch filter block diagram

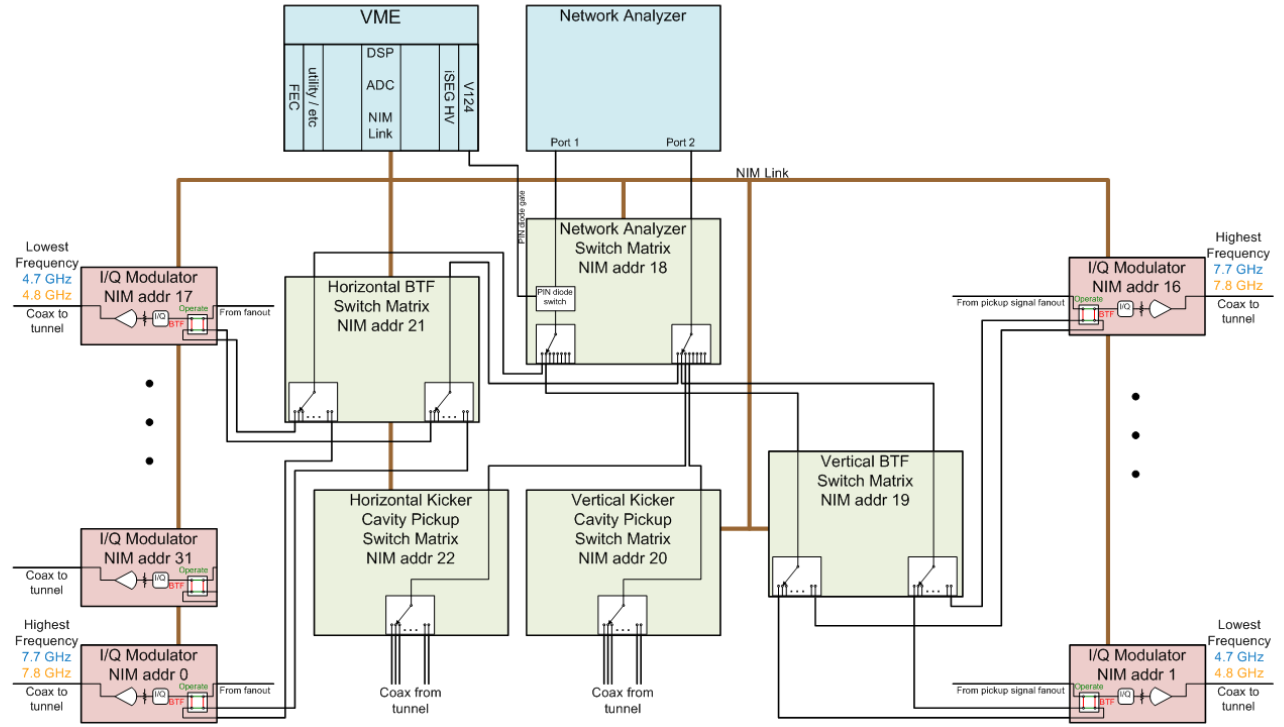


Control and Operation

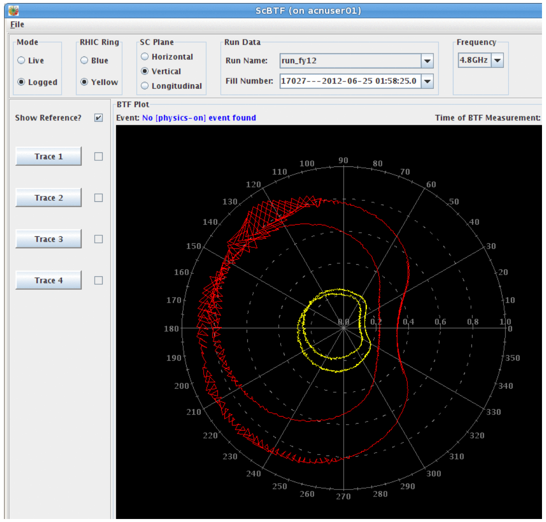
Routine operation of the stochastic cooling systems is fully automated with "tape" sequences

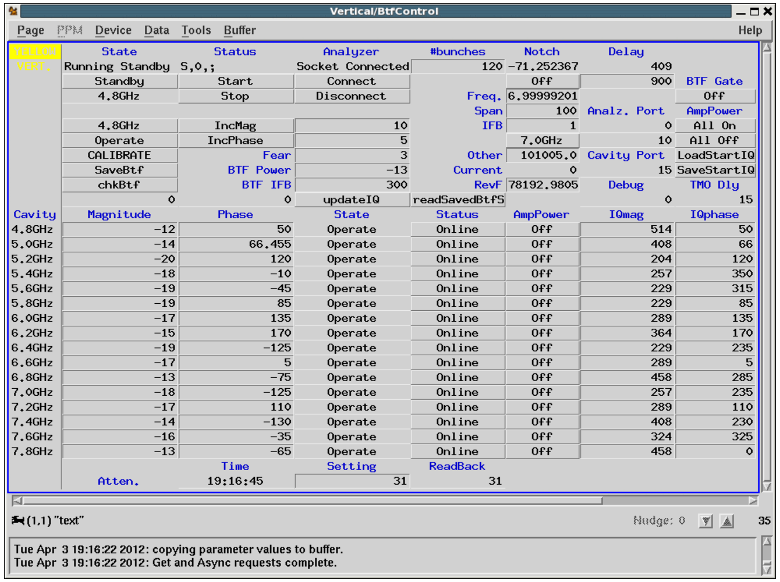
Control system managers handle closing and opening of the pickups and kickers with loss monitor interlocks

Transfer function measurement is automated and I/Q gain/phase settings are optimized via a least squares fit to a reference



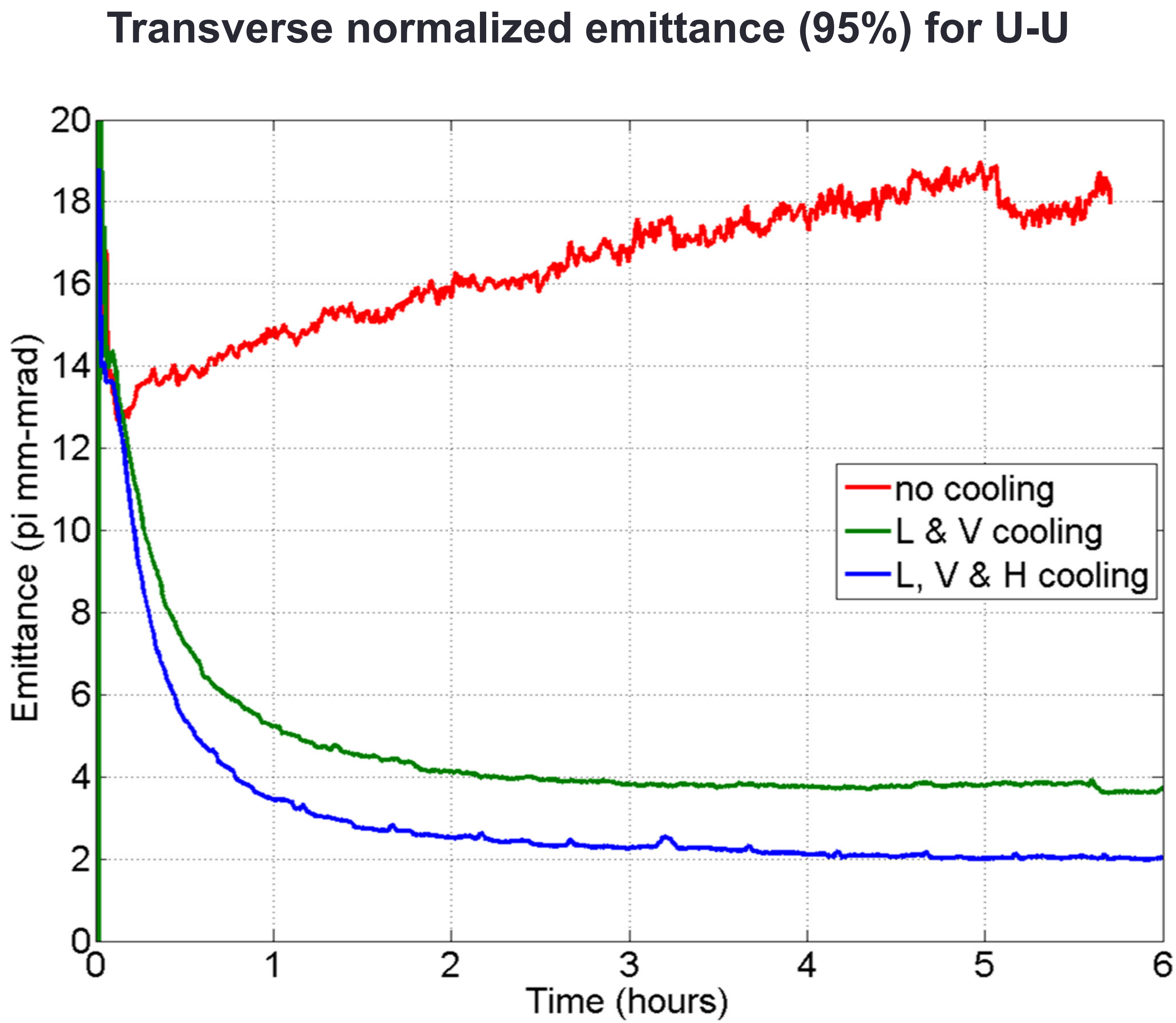
Stochastic Cooling Horizontal & Vertical LLRF Functional Block Diagram





2012 Uranium Results

- Run12 was the first RHIC run with uranium-uranium collisions at 96.4 GeV/nucleon
- Per bunch intensity was ~0.3 x 10^9 ions
- With the full 3D stochastic cooling system running, the beam was cooled from an initial emittance of 14π mm-mrad to 2.5π mm-mrad

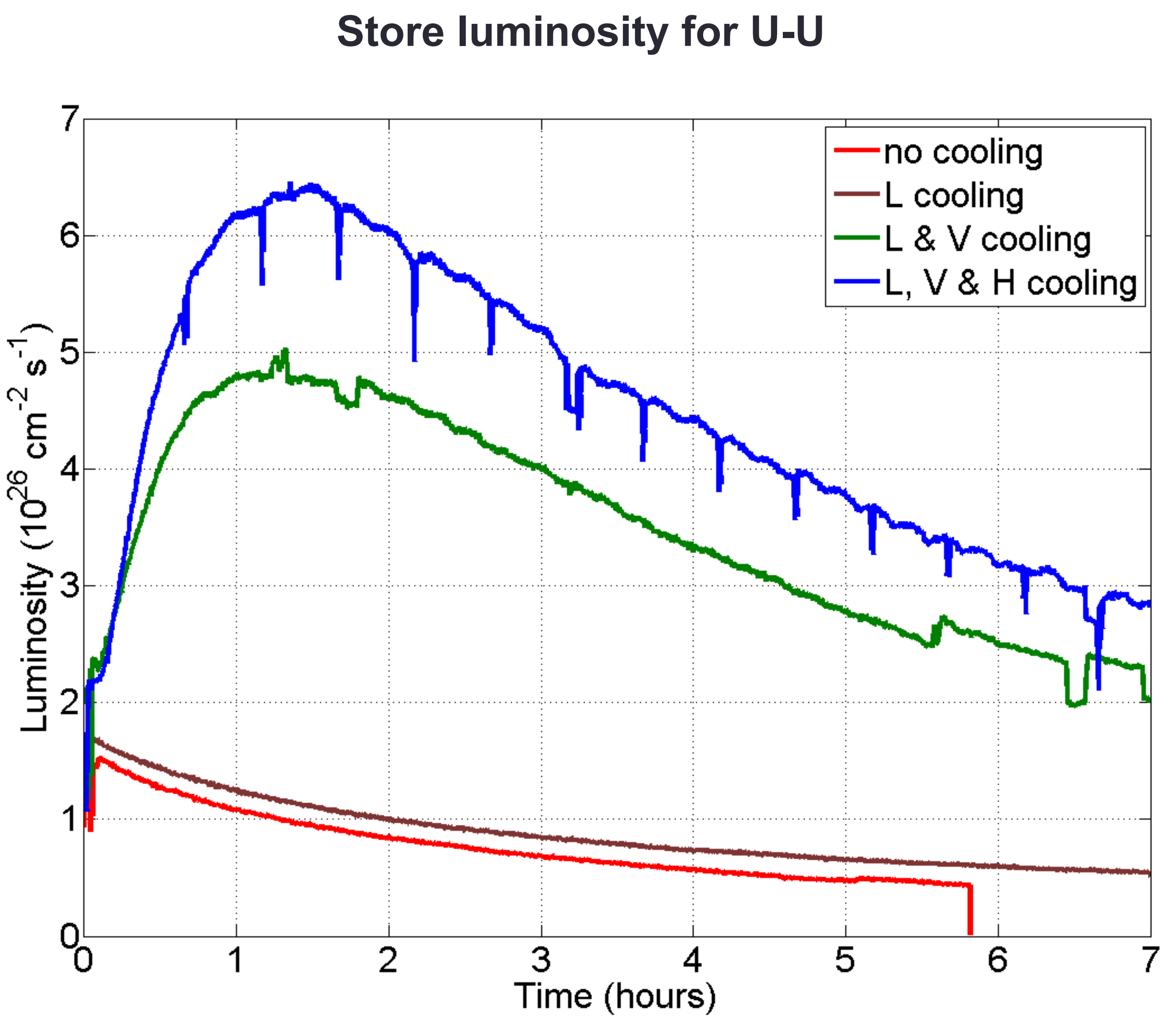


2012 Uranium Results

Peak luminosity with 3D cooling is increased 3x from stores with no cooling

Integrated luminosity with 3D cooling is increased 5x from stores with no cooling

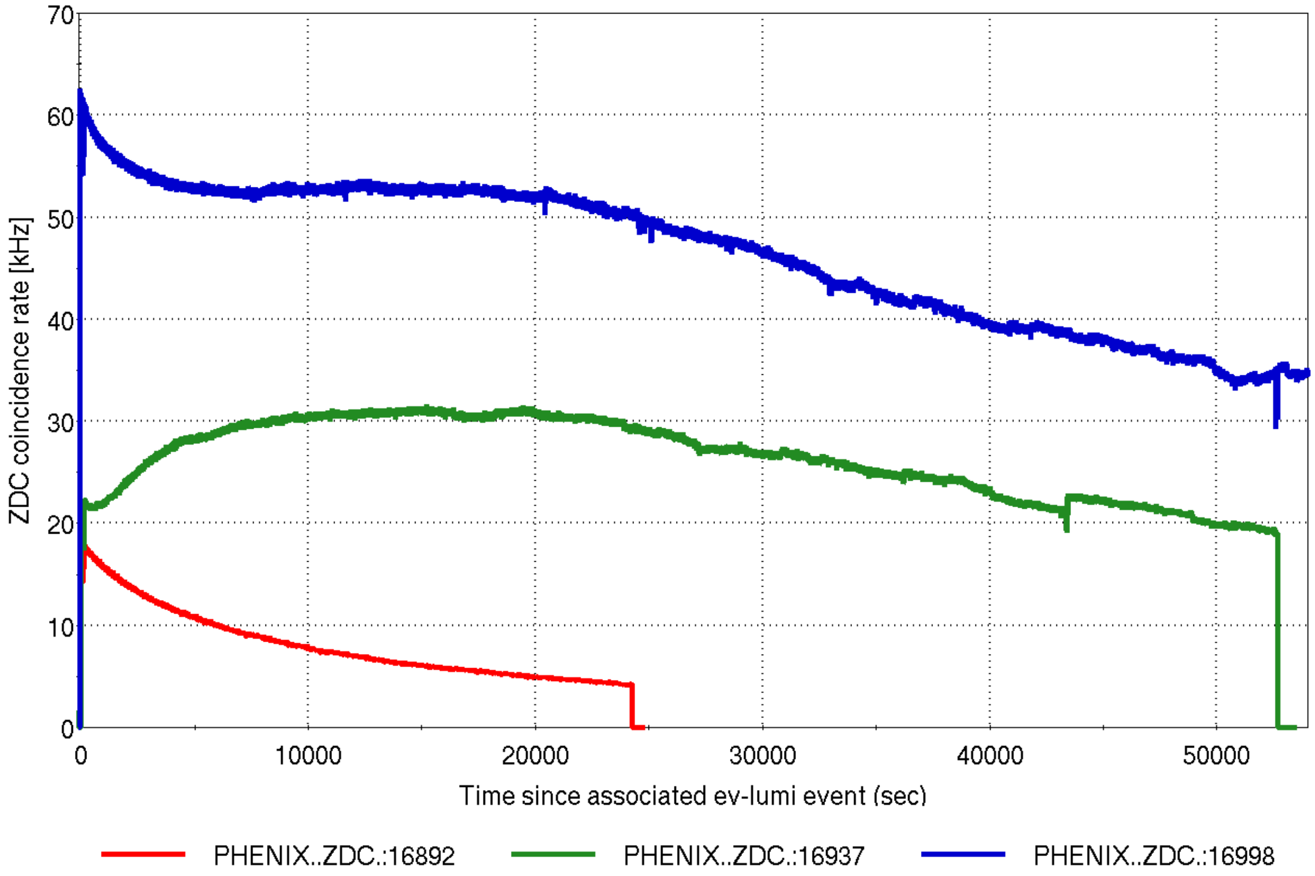
For the first time in a hadron collider, the peak luminosity exceeded the initial luminosity



2012 Copper-Gold Results

- Run12 was also the first RHIC run with copper-gold collisions at 100 GeV/nucleon
- Significant improvements with the EBIS source and the injectors during the run make store-to-store comparisons difficult, but cooling was effective and increased integrated luminosity
- Blue and green lines both have 3D cooling, red has no cooling; blue has 2x Cu ions, 1.5x Au ions

Store luminosity for Cu-Au



2012 Copper-Gold Results

The major operational challenge for stochastic cooling in the Cu-Au run was the asymmetric cooling rates

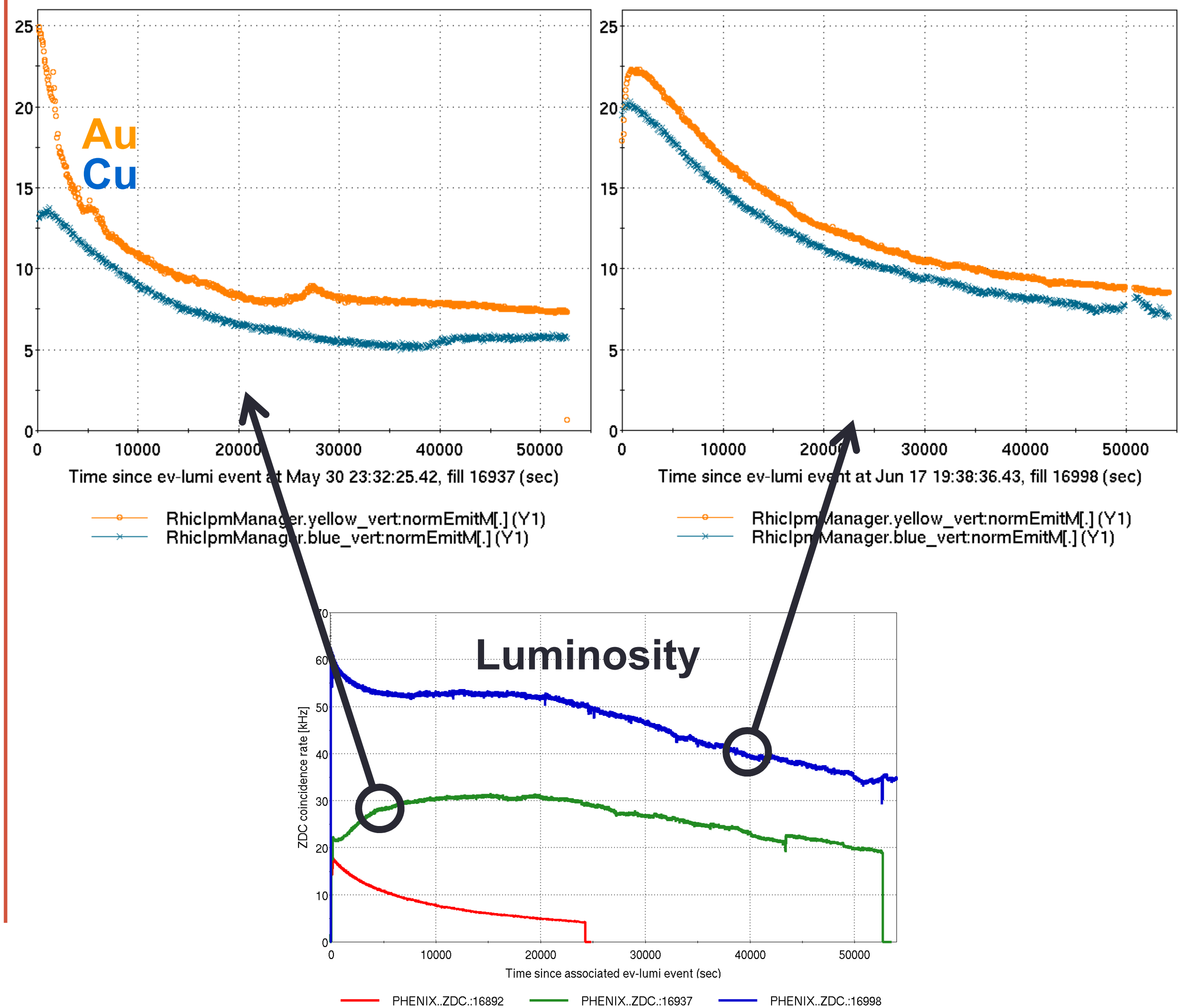
Cu beam had ~3x ions per bunch → 1/3 cooling rate

If Au emittance was much smaller than Cu, the Cu beam lifetime suffered due to beam-beam interaction

To avoid this, we ran the Au transverse cooling systems at reduced gain to slow the cooling to match the Cu rate

See talk TUXA1, Yun Luo

Transverse normalized emittance (95%)



Summary

- The installation and commissioning of the full 3D bunched beam stochastic cooling system in RHIC is complete
- Incremental upgrades targeting improved reliability and performance are ongoing
- System performance is good, matching the expectations from simulations
- Due to 3D stochastic cooling, peak luminosity exceeded initial luminosity for first time in a hadron collider

We thank the members of the C-AD Accelerator Components & Instrumentation, Controls, Mechanical Systems, Operations, and RF groups for their work implementing these designs.