Stochastic Cooling in RHIC

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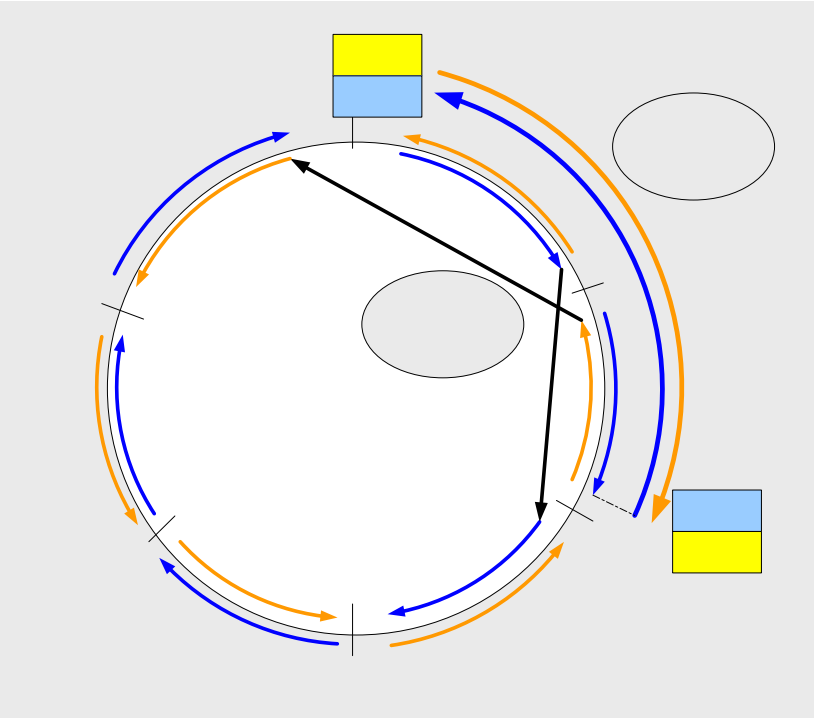
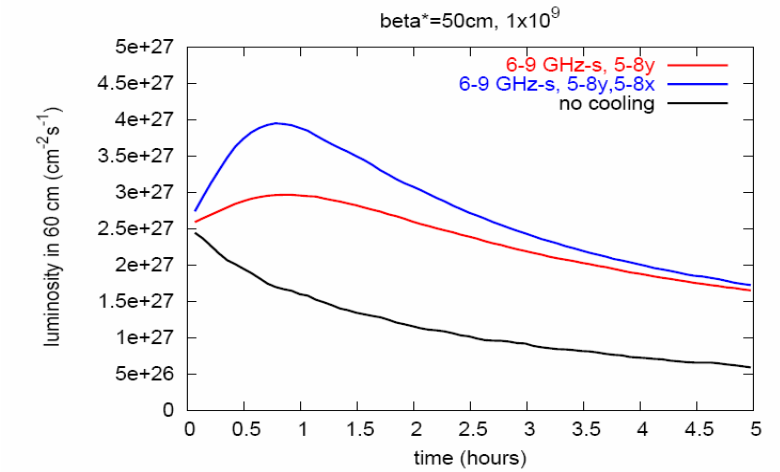
For countless gems of advice and suggestions, and for their longstanding encouragement of this project

Outline

- The overall plan for stochastic cooling at RHIC
- Motivation, to counteract IBS; Context, why we are implementing S.C. now, and not before
- Technical aspects, challenges of bunched beam, narrowband kickers, signal processing
- Results with beam, longitudinal cooling
- Simulations and luminosity projections

Overall Plan for Stochastic Cooling in RHIC





Simulation of luminosity in a 5-hour store with and without cooling

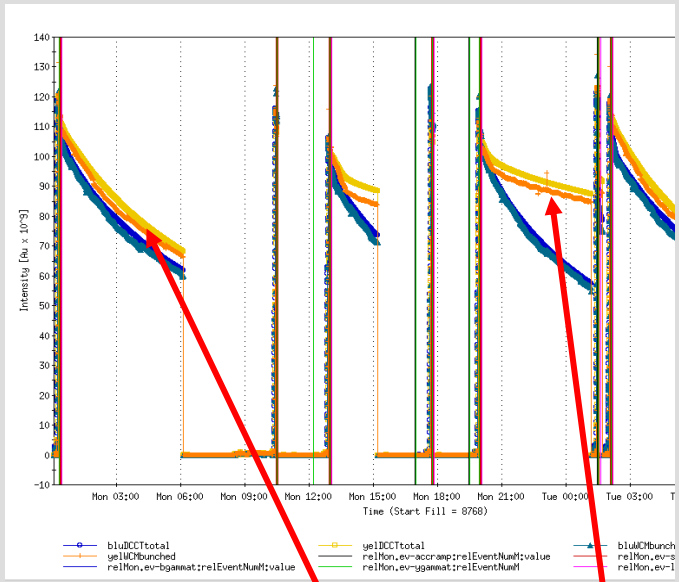
- For the two beams of RHIC we need six cooling systems
- The pickup to kicker for longitudinal and transverse systems are sent differently
- We are able to concentrate the kickers into only two IPs
- This avoids conflicts with other equipment

The purpose of Stochastic Cooling is to Counteract Intra-Beam Scattering

- The determinants of luminosity are max'ed out at the beginning of a store

$$L = \frac{N_B^2 f_B}{4\pi\varepsilon_{x,y}\beta^*}$$

- But the emittance, $\varepsilon_{x,y}$, grows because of IBS
- And the useful fraction of luminosity (± 30 cm vertex) decreases because of de-bunching
- The de-bunched beam drifts into the abort gap and has to be removed from the ring



Five hour stores; without (left) with (right) longitudinal stochastic cooling in the Yellow ring

To Beat IBS the Cooling Time Must be Less Than 1 Hour

- To a good approximation coasting beam theory gives the cooling time, (full bucket)
- If N_{eff} is the number of particles that would be in a coasting beam of equivalent density, 2.5 x 10^{12}
- M is mixing factor, ≈ 4 turns
- BW is bandwidth, 5-8 and 6-9 GHz

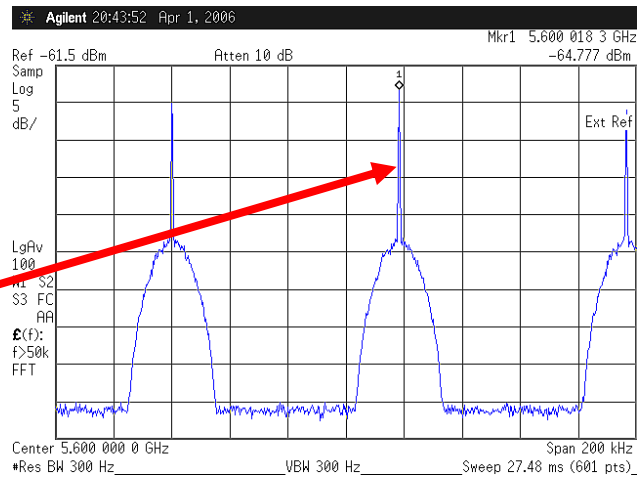
$$\tau = \left(\frac{N_{eff}}{BW} \right) \frac{1}{M}$$

$$\cong 50 \text{ minutes}$$

Noise is negligible for ions

So why are we doing stochastic cooling now and not years before?

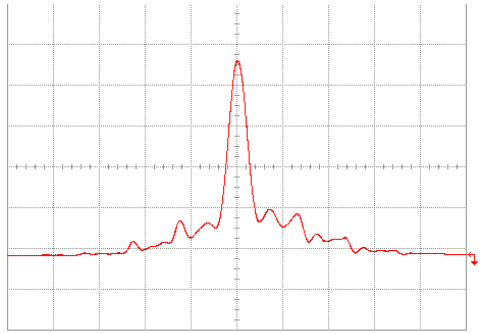
- The technical obstacles for bunched beam cooling were an unresolved issue
- Schottky signals for bunched beam are mixed with a coherent component
- Much R & D went into coping with the coherent components

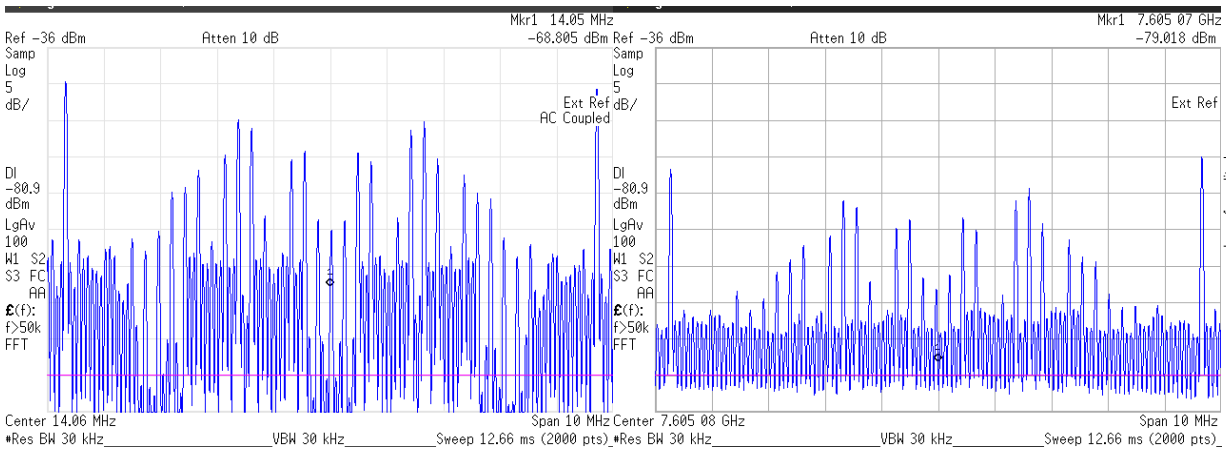


Pickup signal with coherent component mixed with Schottky

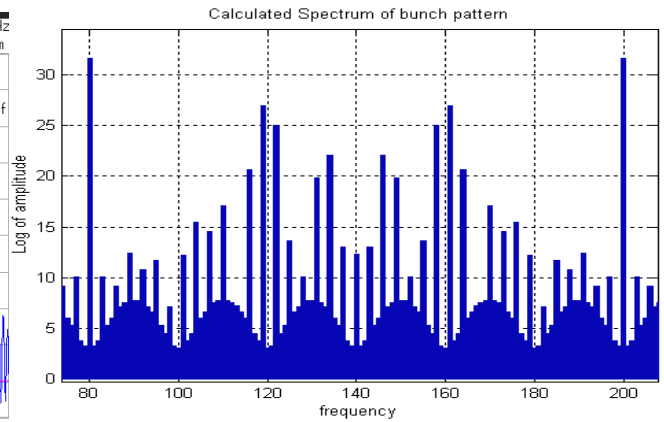
The coherent components are not anomalous

- They are much stronger than what would be expected from a Gaussian bunch with $\sigma = 1$ ns
- For ions the bunch shape is far from Gaussian because of the double harmonic storage rf
- The bunch shape has strong Fourier strength at 8 GHz
- All the bunches have the same shape





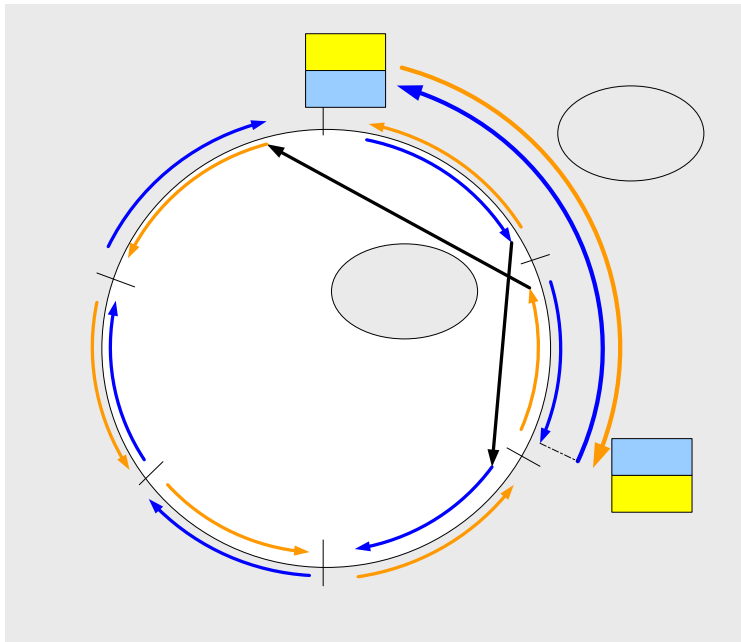
Low frequency spectrum, 14 MHz **High frequency spectrum, 7.6 GHz**



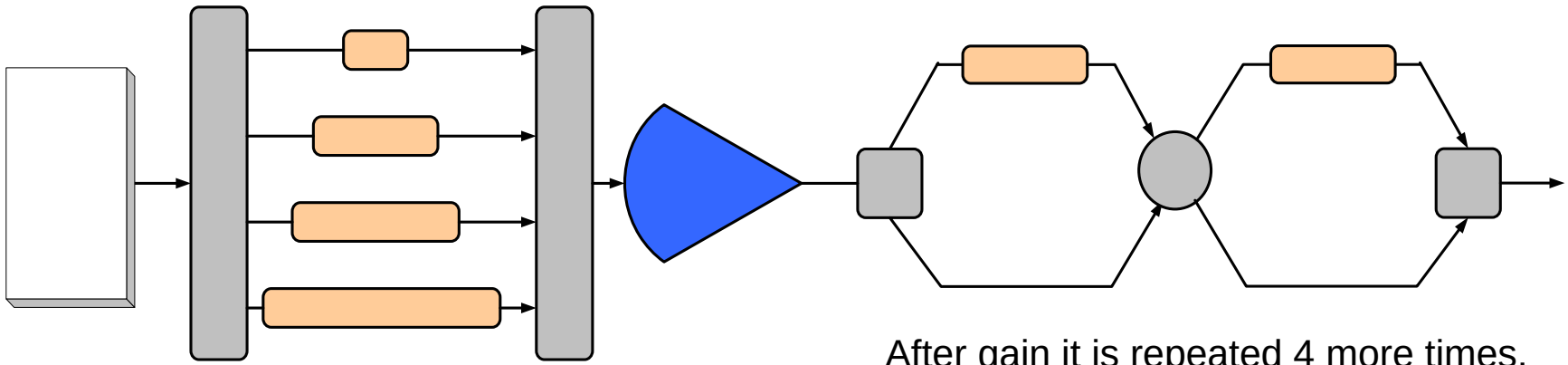
Calculated spectrum for delta function bunches

The hardware is built to cope with the coherent components

- The low-noise amplifier at the pickup is vulnerable to inter-modulation distortion from high peak voltage
- Also transmission of the signal from the pickup to kicker can become distorted, for example by dispersion in the long fiber optic cable
- The distortions cannot be filtered out

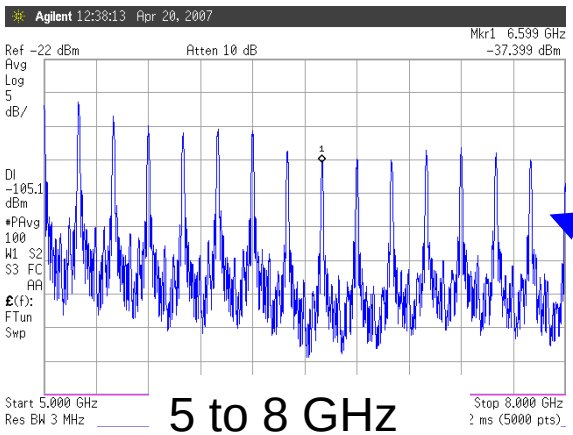


The signal from the pickup is filtered before gain is applied



The 5 ns bunch signal is split and delayed 4 times, reducing the peak by ¼, 20 ns out

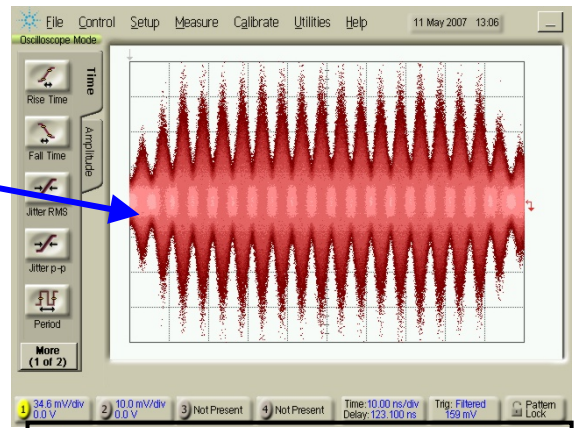
After gain it is repeated 4 more times, to 80 ns. The time between bunches.



5 to 8 GHz

Time domain

Frequency domain

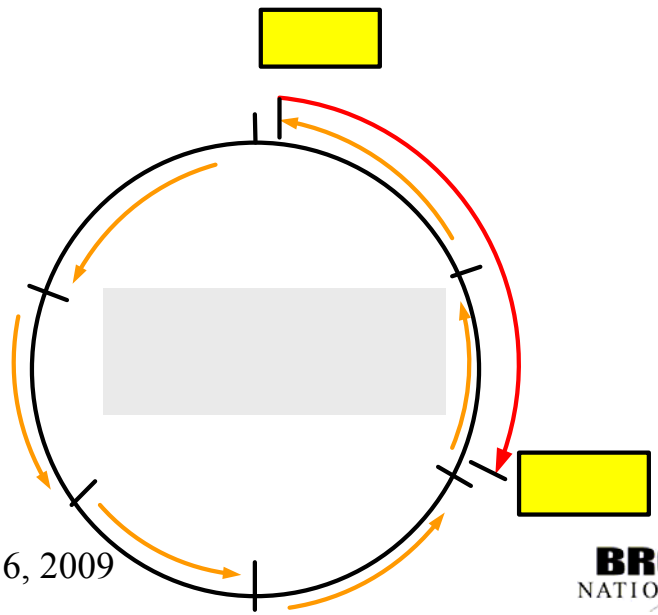


Output of traversal filter for 5 ns bunch, 10 ns/Div

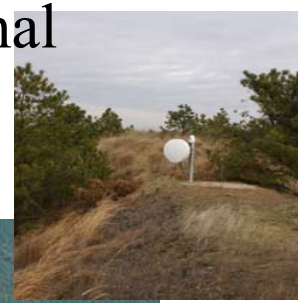
0 ns

Pickup to Kicker Signal Transmission

- An analog fiber optic link is used for transverse
- Electro-Absorption Modulator is used with 1550 nm DFB laser



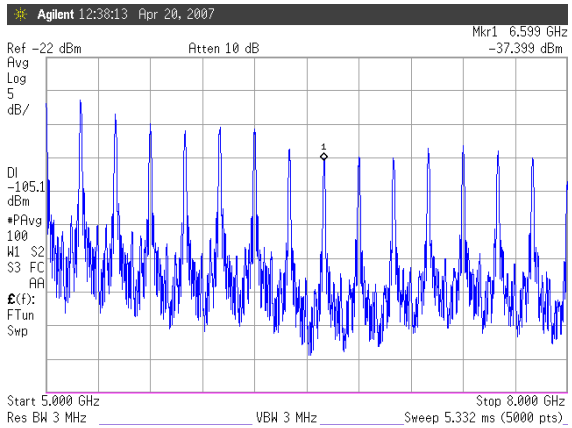
- A 70 GHz microwave link is used for longitudinal (proposed by F. Caspers)

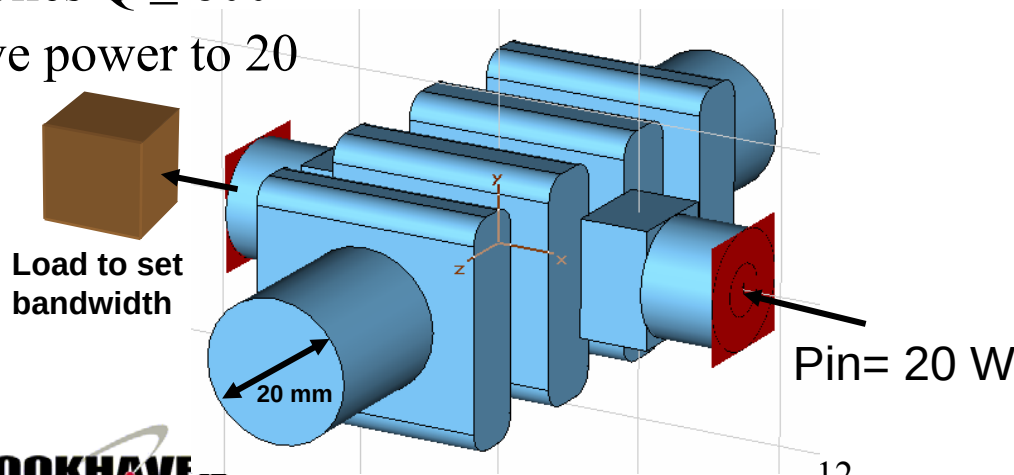


- Arrives 200 ns
- before the beam

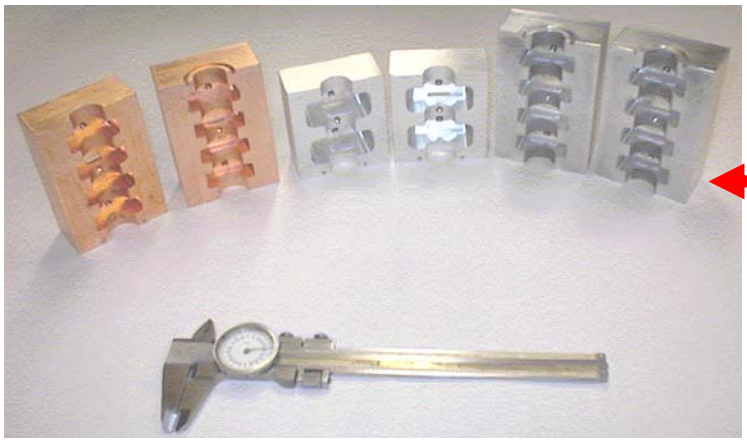
The kicker is made from microwave cavities

- Because the beam is 5 ns bunches we can synthesize the kick with a Fourier series of 200 MHz harmonics
- There are 16 terms between 5 and 8 GHz so we have 16 microwave cavities
  - Their Q is only limited by the filling time between bunches, 100 ns, implies $Q \leq 800$
  - This reduces the required drive power to 20 Watts (solid state linear)



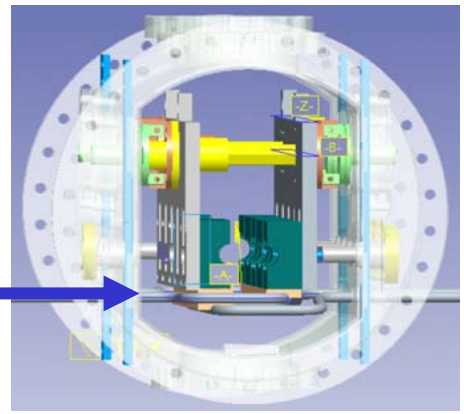


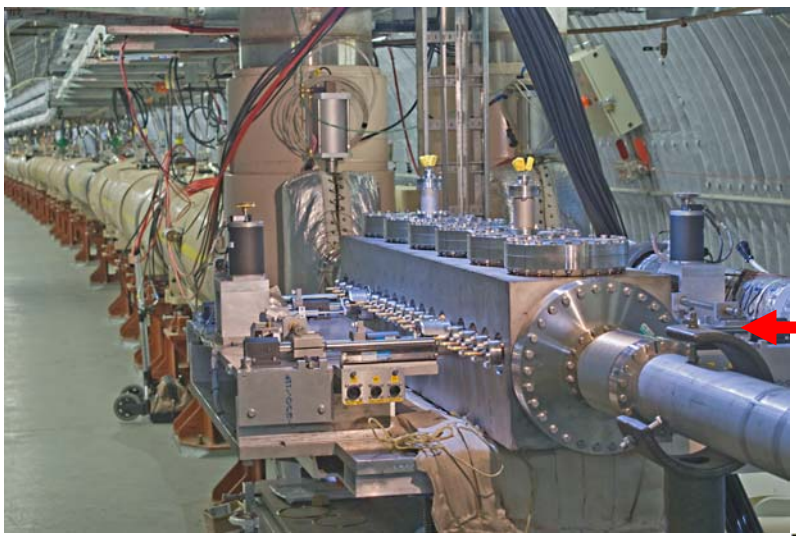
The microwave cavities need to open when not in use. Injection and ramping



Cavities split on median plane

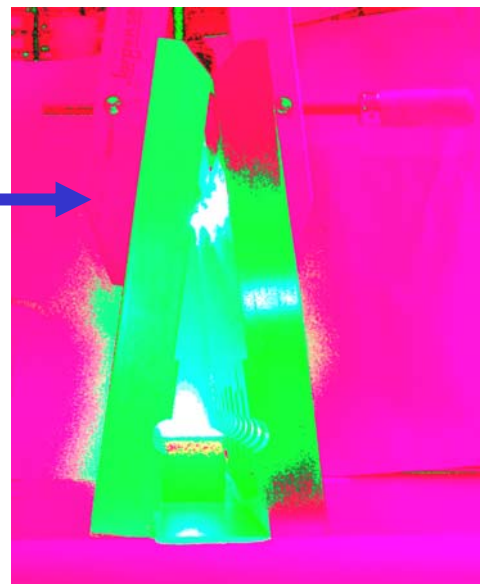
Open for clear aperture



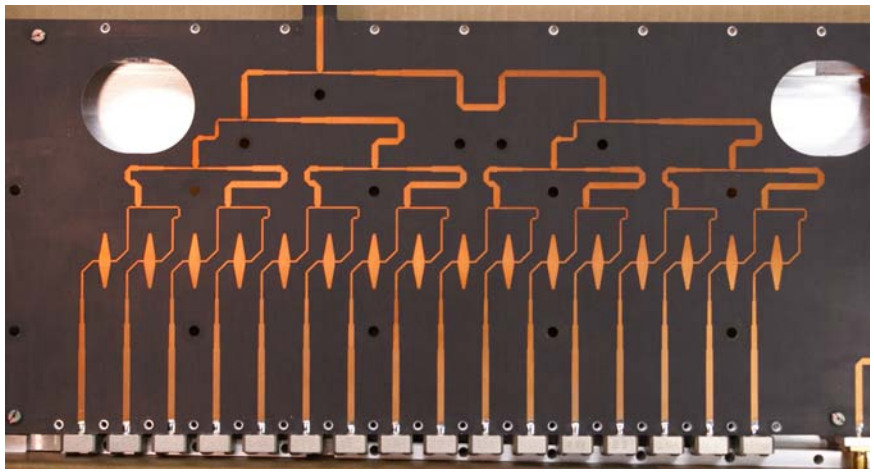


New mechanical concept for next system

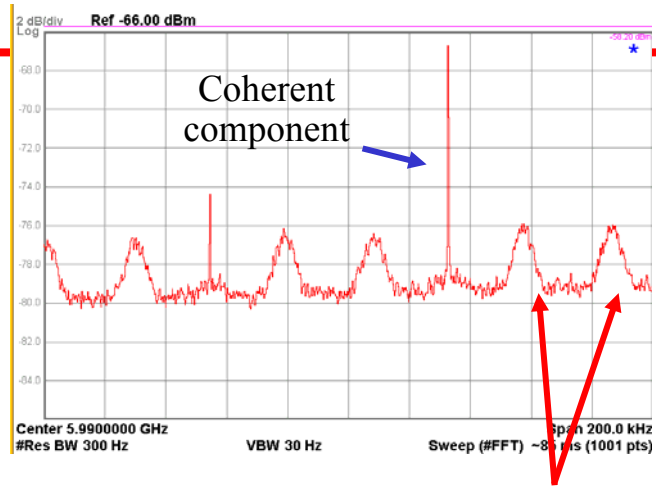
Installed in vacuum vessel



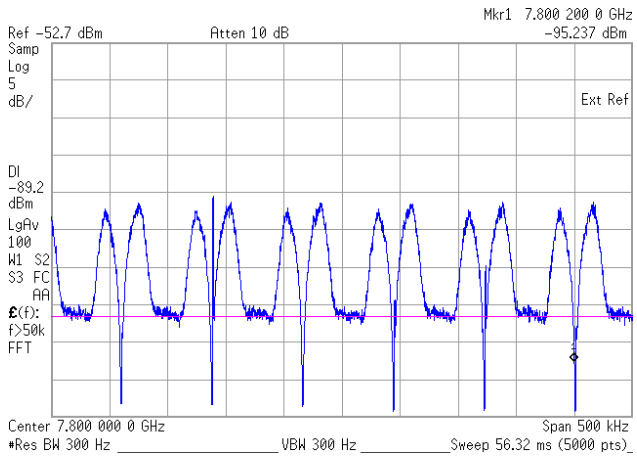
Signal Processing



- The pickup are the planar arrays, donated to RHIC by Fermilab

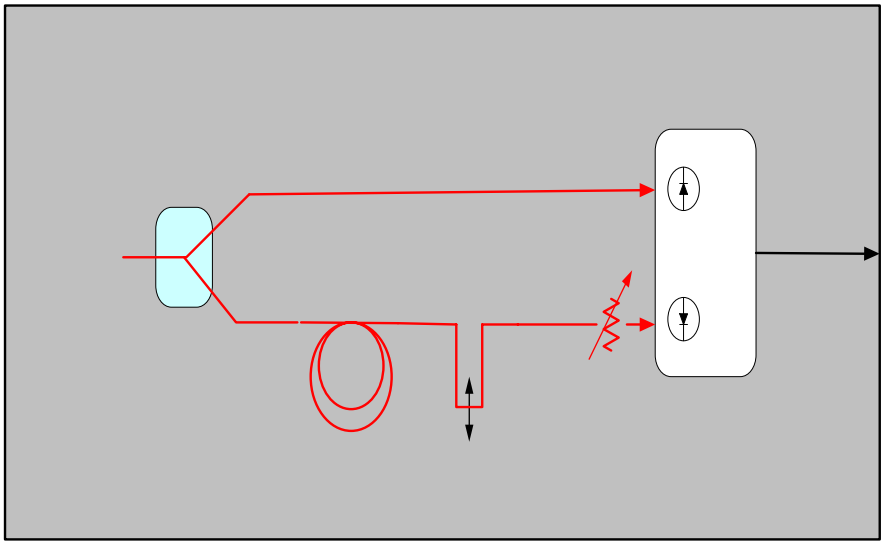


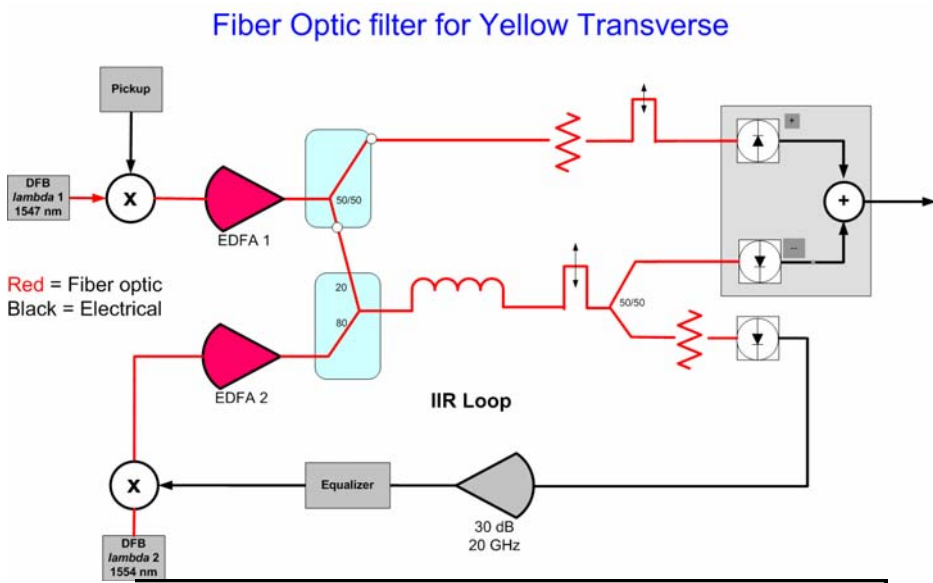
Transverse pickup signal with Betatron lines

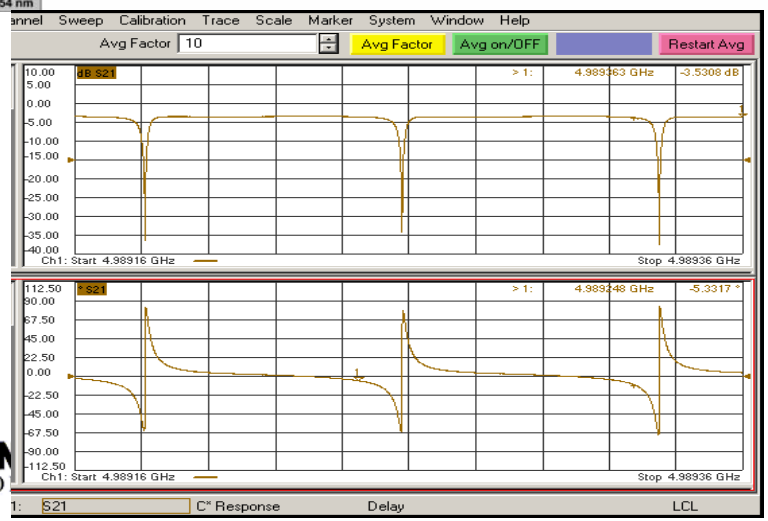


Longitudinal signal with notches of cooling filter

One-turn Delay Filters with Fiber Optics





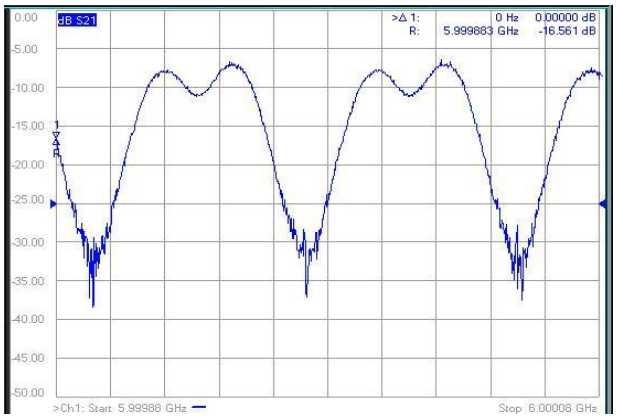


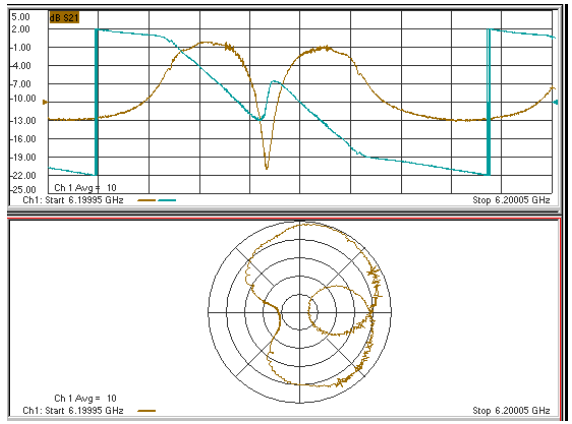
- For longitudinal the cooling filter is a one-turn delay correlator filter
- For transverse the filter uses an IIR loop in the delay path. Note the phase of the transverse filter

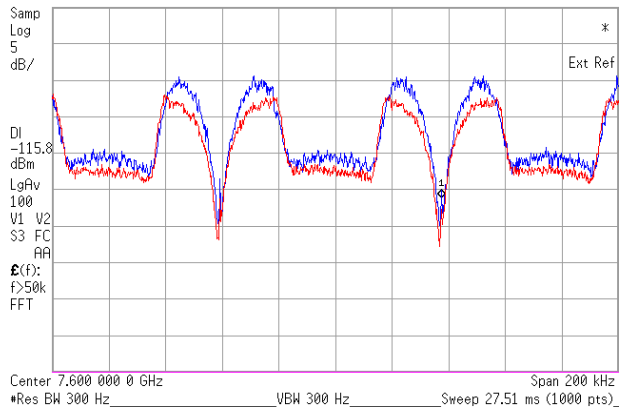
Each channel (cavity) is adjusted independently for phase and amplitude

Open-loop transfer functions

Signal suppression







Transverse

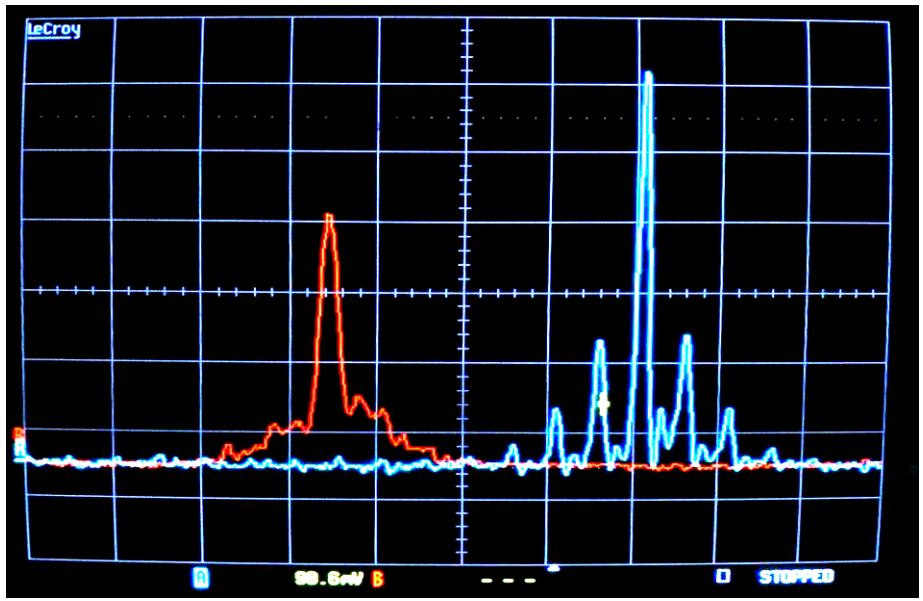
Longitudinal

With cooling filter

- First the system open-loop transfer function is measured for each cavity, to set the gain and phase
- The settings are checked by observing signal suppression for that frequency
- This optimizes the gain versus frequency
- The settings are automatically monitored and updated periodically during the store

Test of longitudinal stochastic cooling with gold beam

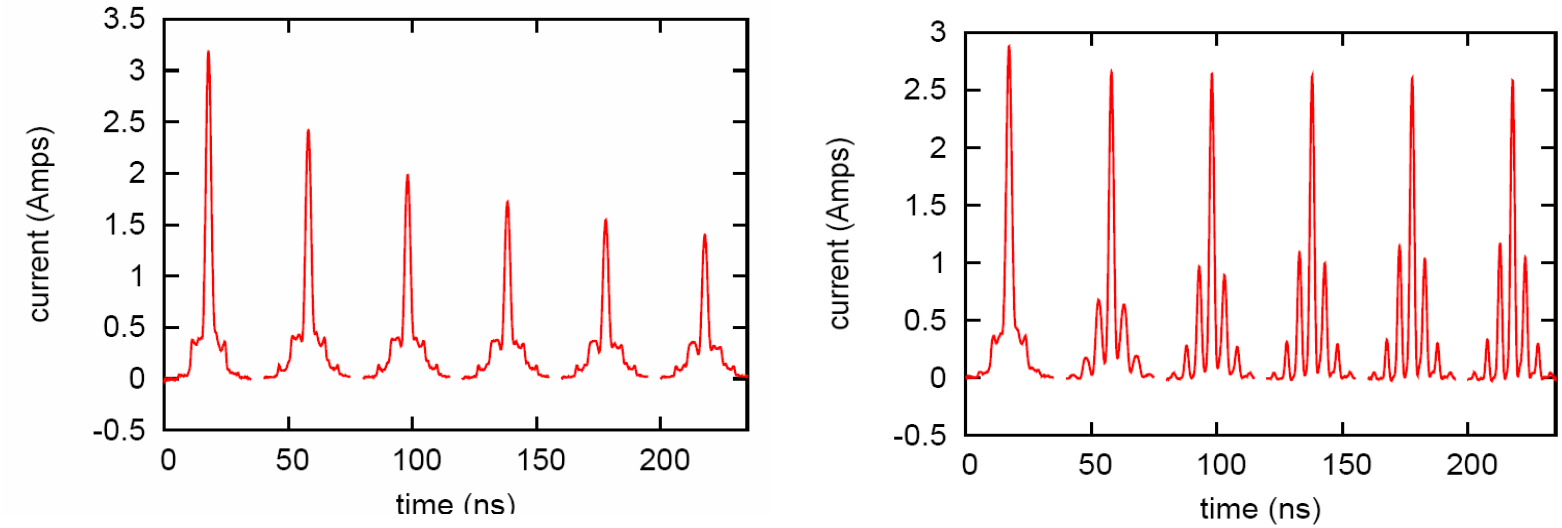
Cooling was applied to half of the bunches



The peak current increased. Beam in the satellites was cooled

- The longitudinal emittance is **reduced**
- Compare cooled and un-cooled bunches

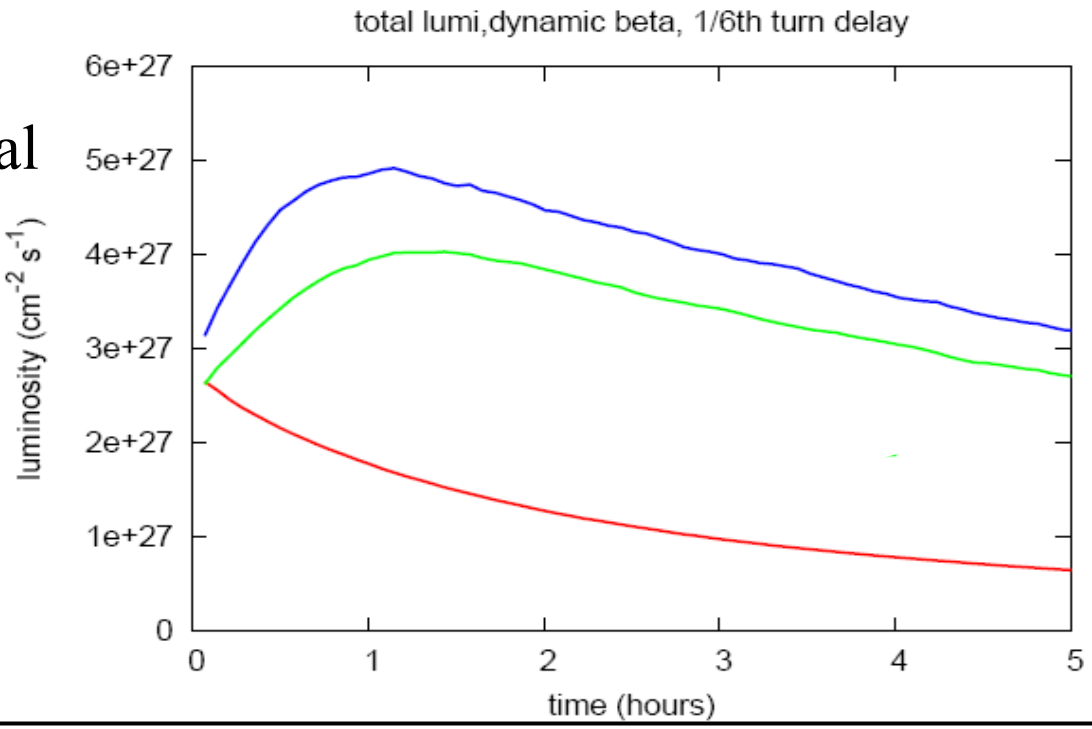
A simulation program was written to aid design and predict luminosity



- The program was benchmarked against these data. Un-cooled on left, cooled on right
- Each profile to the right is one hour later
- Used to balance gains between longitudinal and transverse (IBS)
- Beam in the satellite buckets will be there until we upgrade the rf system with the new SRF 56 MHz cavity (Fedotov, WE6PFP004)

Projected Luminosity Improvement with Transverse and Longitudinal Cooling

- Transverse and longitudinal interact via IBS
- Shortening the bunch increases transverse IBS
- X 4 increase in integrated luminosity is expected



Simulations of luminosity for a 5 hour store with; red=no cooling, green=cooling, blue=56 MHz SRF harmonic cavity

Status and Plans

- Now we have three of the six phase space planes ready
  - Longitudinal, Yellow(1) and Blue(2) (with microwave link)
  - Transverse, Vertical(3) in Yellow ring
- Shutdown of 2009 we add Vertical in Blue(4), the microwave link in Yellow longitudinal
- Shutdown of 2010 we add Horizontal(5+6) to complete
- Only Yellow longitudinal has seen ions so far
- In the future (?) we would like to upgrade the longitudinal to 12 GHz

Summary

- Cooling of bunched beam ions in RHIC has been accomplished
- It has been used operationally for two runs with gold ions in one ring
- We are about half way complete on a full six plane system
- We expect stochastic cooling to increase the integrated luminosity of gold collisions by approximately a factor of 4 over no cooling