Stochastic Cooling for RHIC

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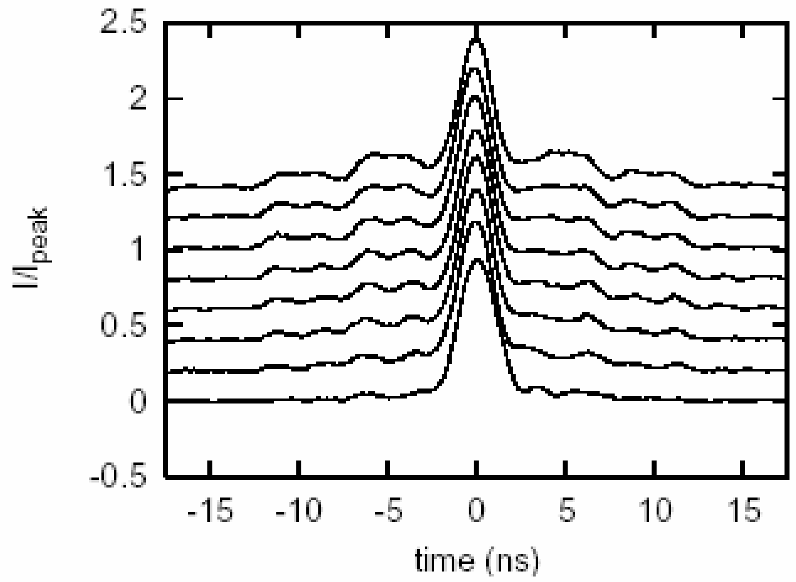
- Introduction
- Results from last year
- Coherent line problem
- Hardware for this year
- Plan for this run
- Future ideas

Introduction

We plan to implement "Halo Cooling" to counteract IBS driven debunching.

Improve integrated luminosity by a significant factor within the next few years.

Debunching reduces useful luminosity by lengthening vertex.



Bunched-beam Stochastic Cooling

- What would be required,
  - Cooling time would have to be commensurate with de-bunching time, ~ few hours
  - Cool only large ΔP particles (halo cooling)
- Consider coasting beam theory (full bucket)

$$\frac{1}{\tau} = \frac{W}{N_{eff}}\left[2g\left(1-\tilde{M}^{-2}\right) - g^2\left(M+U\right)\right] \qquad g_{optimum} = \frac{1-\tilde{M}^{-2}}{M+U} \cong \frac{1}{5}$$

$$\frac{1}{\tau_{opt}} = \frac{W}{N_{eff}}\left[\frac{\left(1-\tilde{M}^{-2}\right)^2}{M+U}\right] = \frac{1}{3000\ \text{sec}} \qquad N_{effective} = \frac{10^9}{1.5\text{m}} 3830\text{m} = 2.5\text{x}10^{12}$$

- Why wasn't stochastic cooling in the base line design for RHIC?
- High frequency bunched-beam stochastic cooling is required

Highlights from last year

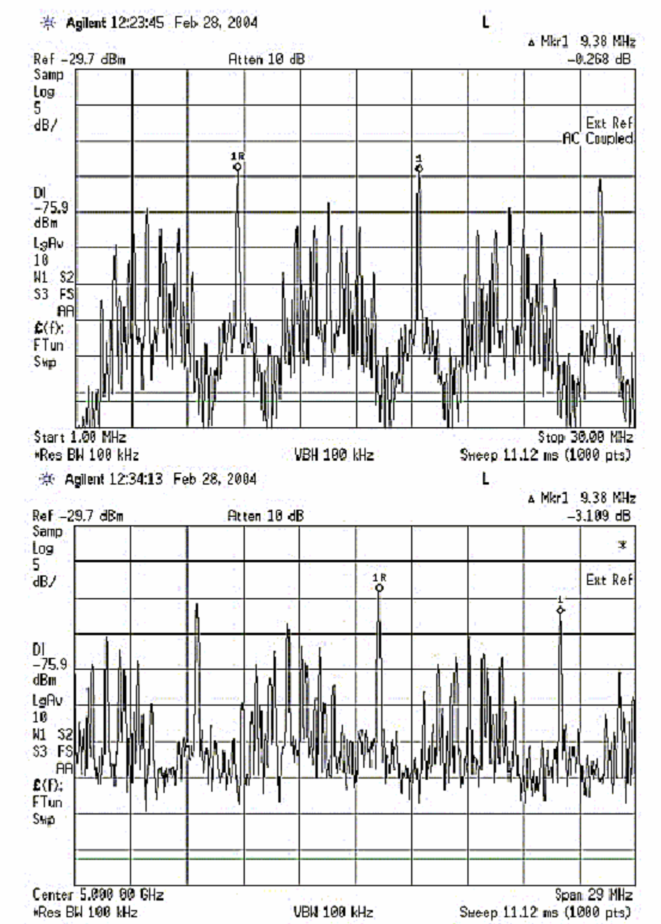


Figure 2: High and low frequency gold spectra with a span 29 MHz and a resolution bandwidth of 100 kHz. The generic features of the spectrum do not change between baseband and 5 GHz.

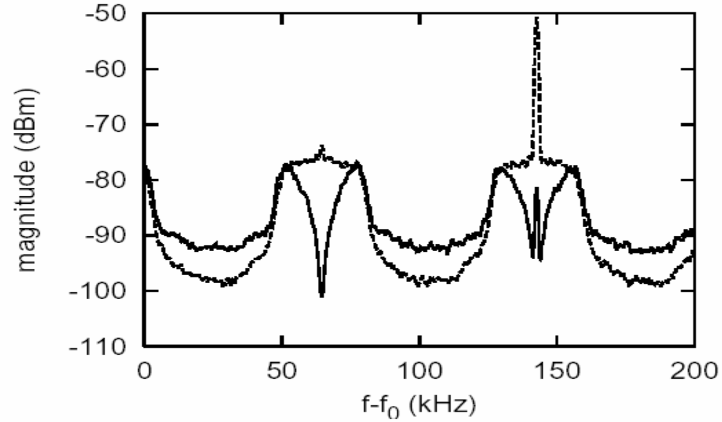
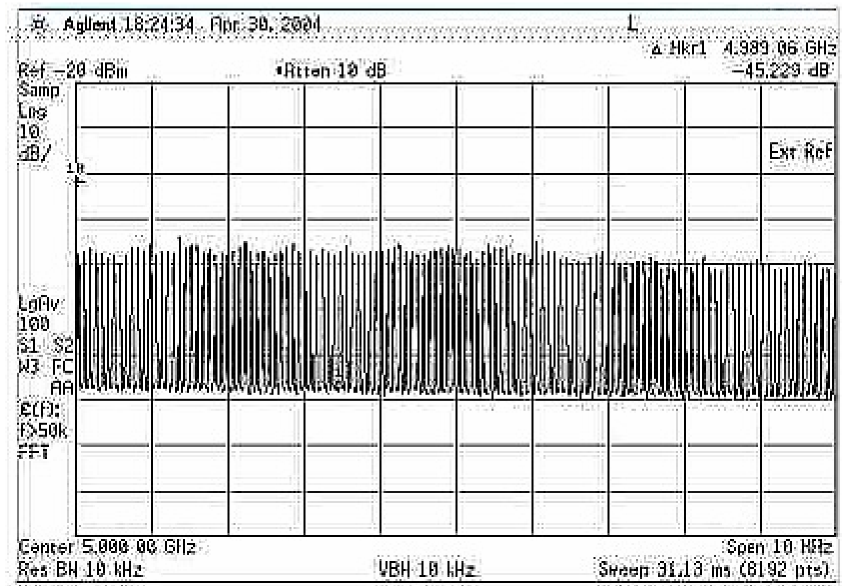
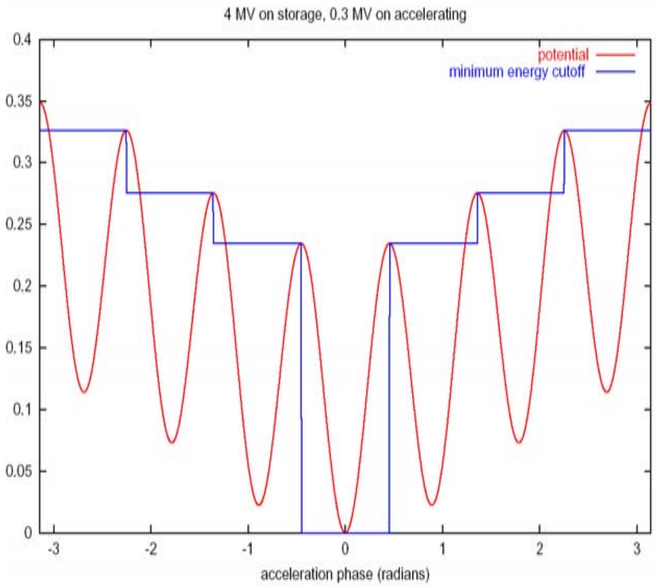


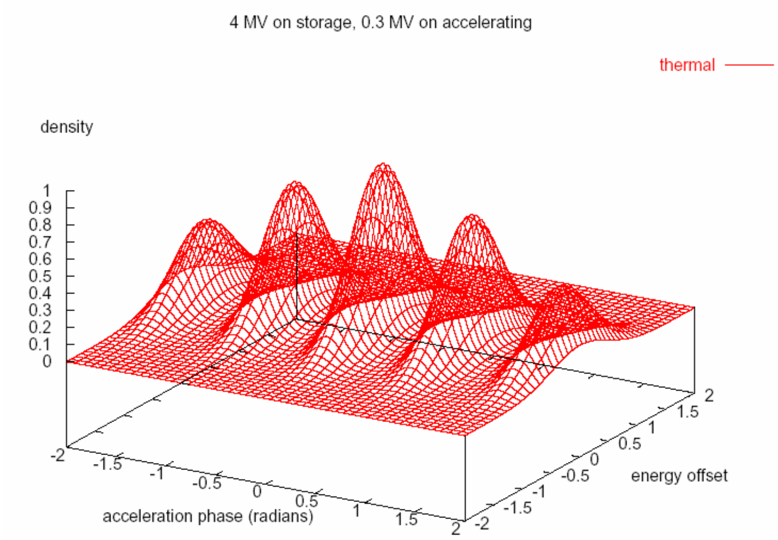
Figure 1: Gold Schottky spectra with (solid) and without (dashed) the one turn delay notch filter, $f_0 = 4.77$ GHz.

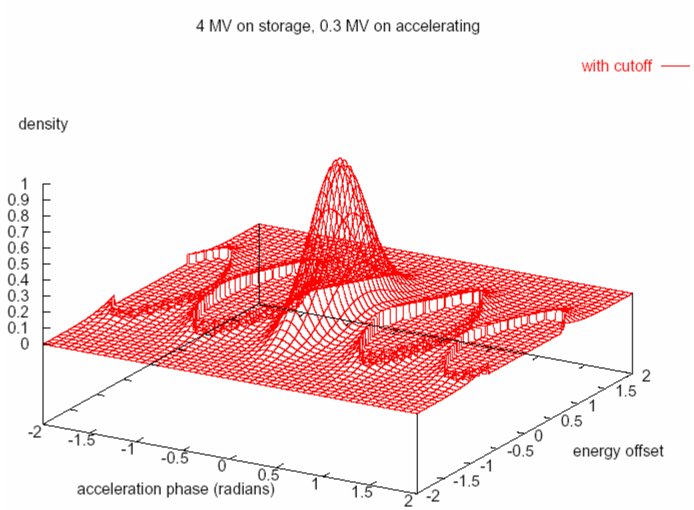


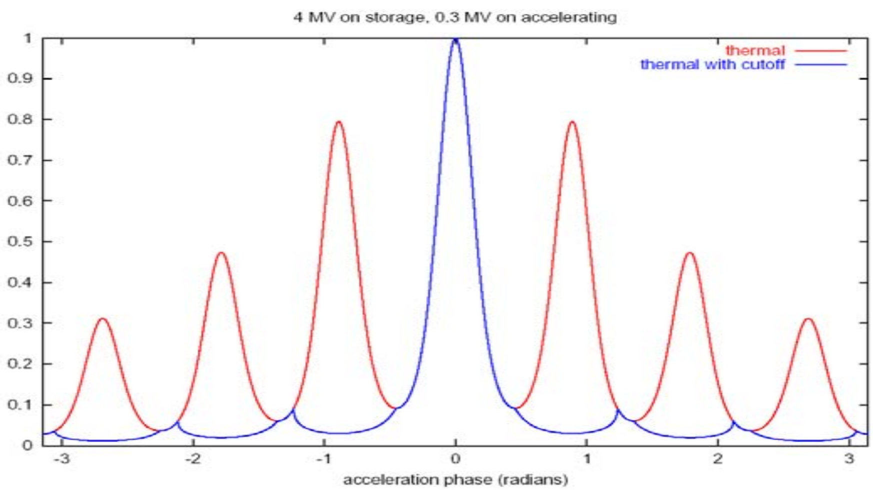
High frequency proton spectra

Coherent Line Problem with Gold



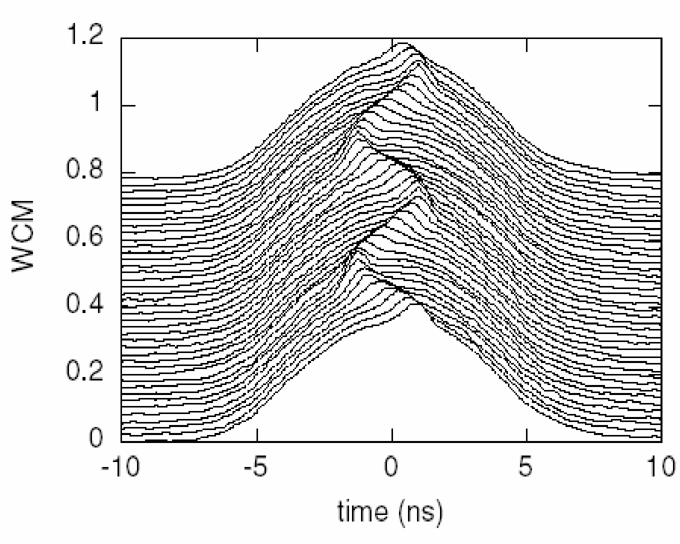






Coherent Line Problem with Protons

Long lived coherent oscillations produce strong, narrow band spectra.



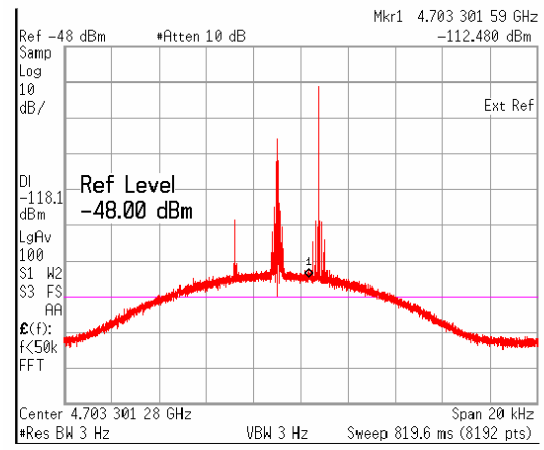


Figure 3: High resolution proton Schottky spectrum.

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **7**, 044402 (2004)

$$H(\phi, p, s) = p^2/2 + 1 - \cos\phi + \ell\rho(\phi, s). \qquad (4)$$

$$p = \sqrt{2J}\cos(\Psi + s), \qquad \phi = \sqrt{2J}\sin(\Psi + s).$$

$$-\frac{2a^3\lambda}{\ell} = G_b(r)/r^2 - G_a(r) \approx -0.77r\ln(r)/(1 + r), \qquad (32)$$

If we take a simple diffusion model, the rate at which a soliton dissipates will scale as $\nu_{\rm coll}/a^2$, with a being a typical dimension of the soliton. With this extra factor, the dissipation rate for solitons in a gold bunch is about 50 times faster than the dissipation rate for a comparable soliton in a proton bunch.

Voltage considerations

For 4-8 GHz need 3.6 kV rms, large by stochastic cooling standards

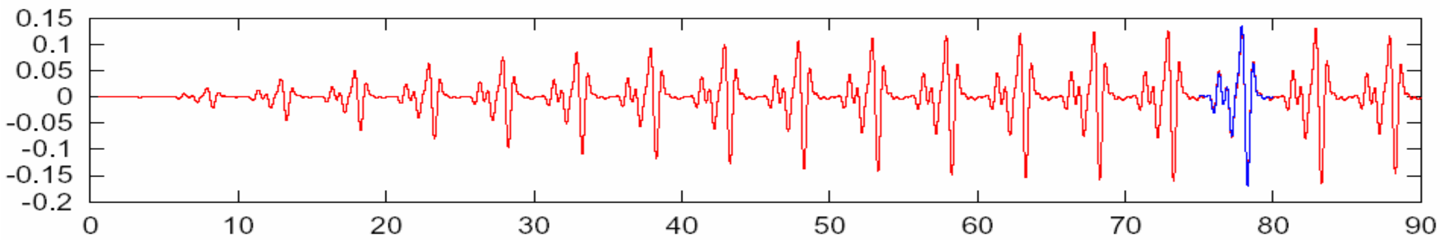
Bandwidth-Voltage product sets the cost scale

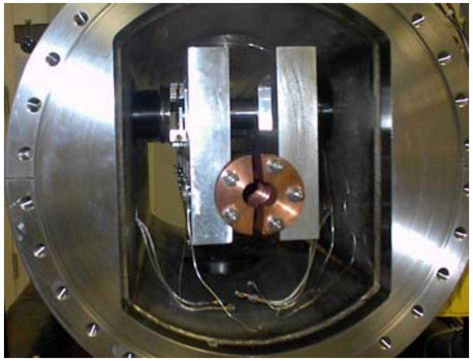
Bunches are $\tau_b = 5$ ns long spaced by at least $T_b =$ 100 ns

The value of the kicker voltage matters only when the bunch is present

$$V(t) = \sum_n A_n \sin(2\pi n t / \tau_b + \theta_n)$$

A_n and θ_n vary smoothly





Voltage and Power part 2

Take 21 cavities, 4-8 GHz bandwidth 40 Watts/cavity (10 K each)

R/Q=100Ω, 10 MHz FWHP bandwidth, R ≥ 40 kilo-Ohm

gives 1 to 1.4 kV rms per cavity, or 5.6 kV total

Cavity drive signal needs to be roughly sinusoidal for R (not R/Q) to matter

Suppose $S_0(t)$ is the drive signal for a broad band kicker (like a resistor).

Periodically extend $$S(t) = \sum_{k=0}^{N} S_0(t - k\tau_b)$$

This creates a signal with 10 MHz $(1/T_b)$wide peaks,

spaced by 200 MHz $(1/\tau_b)$.

Split and pass through 100 MHz filters, centered on cavity resonance, before power amps. In this way each amplifier sees a piecewise sinusoidal input.

Plan to use fiber optic technology for the delay line filter.

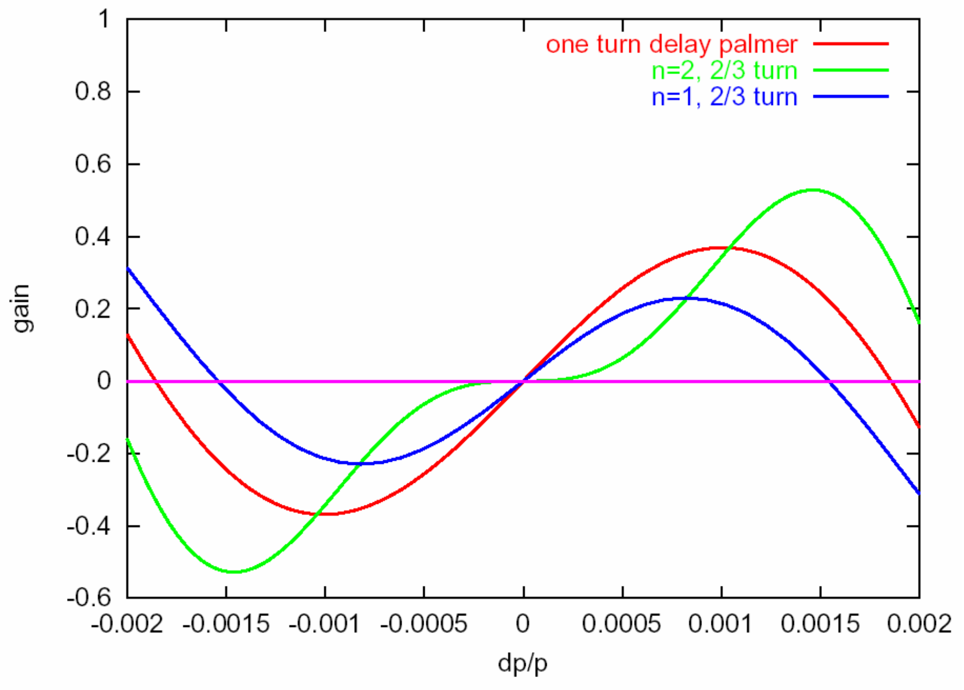
Low Level Drive for Halo Cooling

For cooling we need a force in reverse to the energy error.

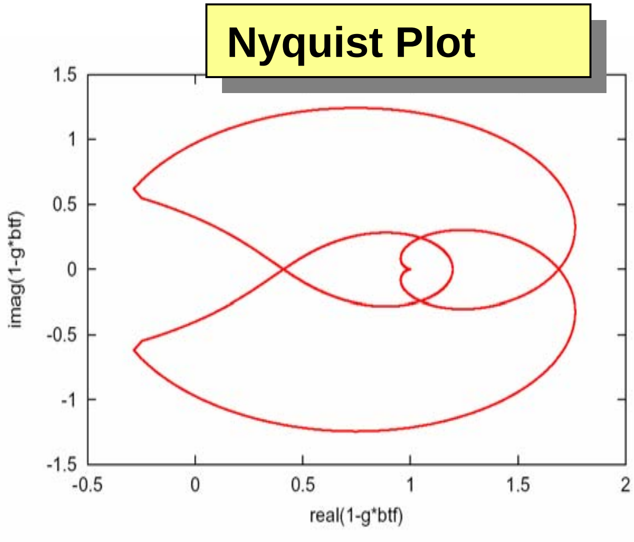
For 4-8 GHz we can use filter cooling

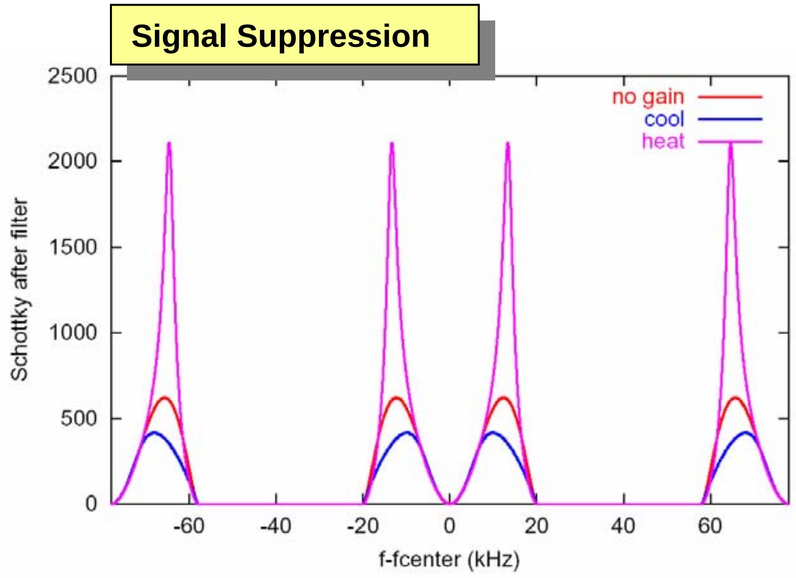
$$S(t) = G(1 - e^{-j\omega T_{rev}})^n I_b e^{j\omega(t - T_d)}$$

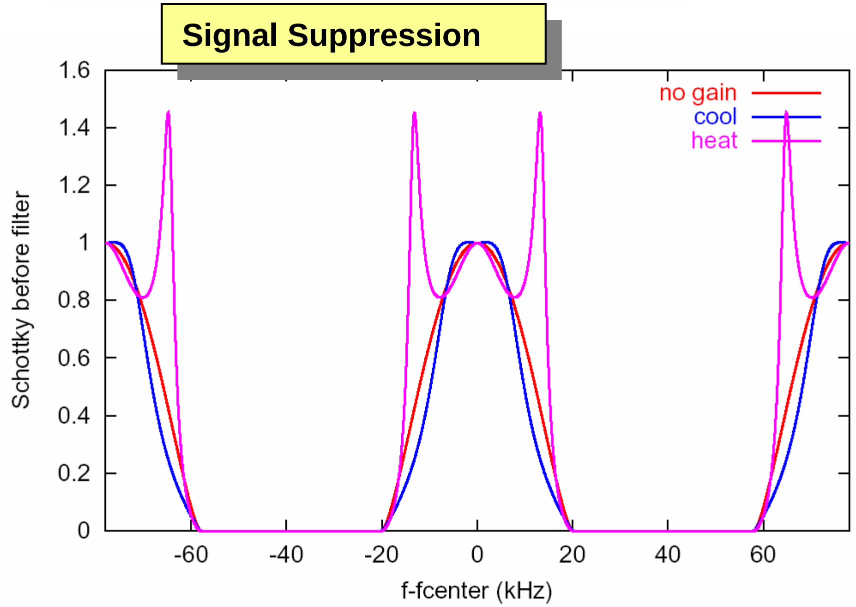
For n=2 we cool the full halo.

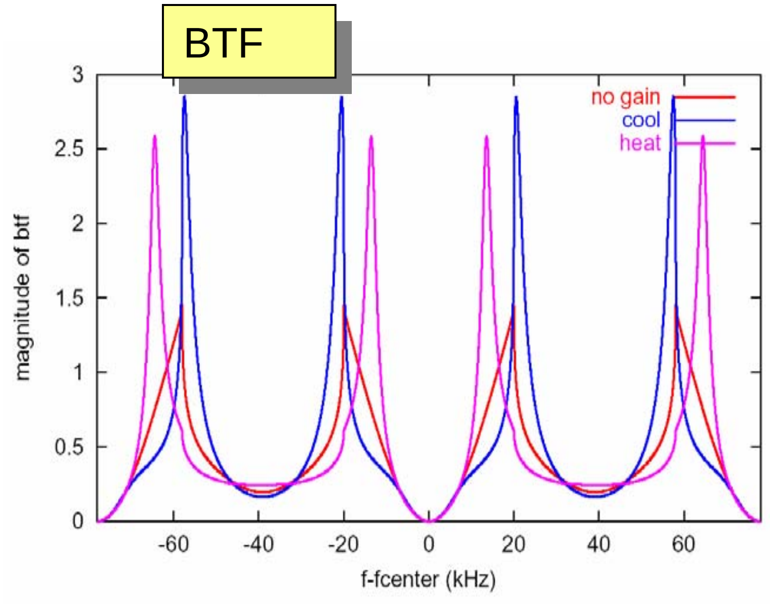


System Stability, n=2









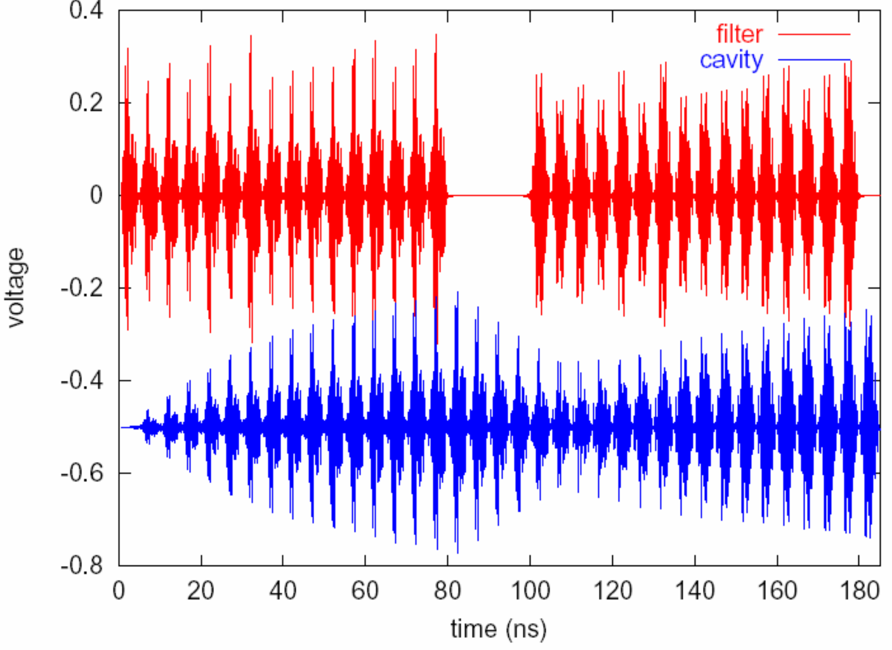
Error Limit Simulations

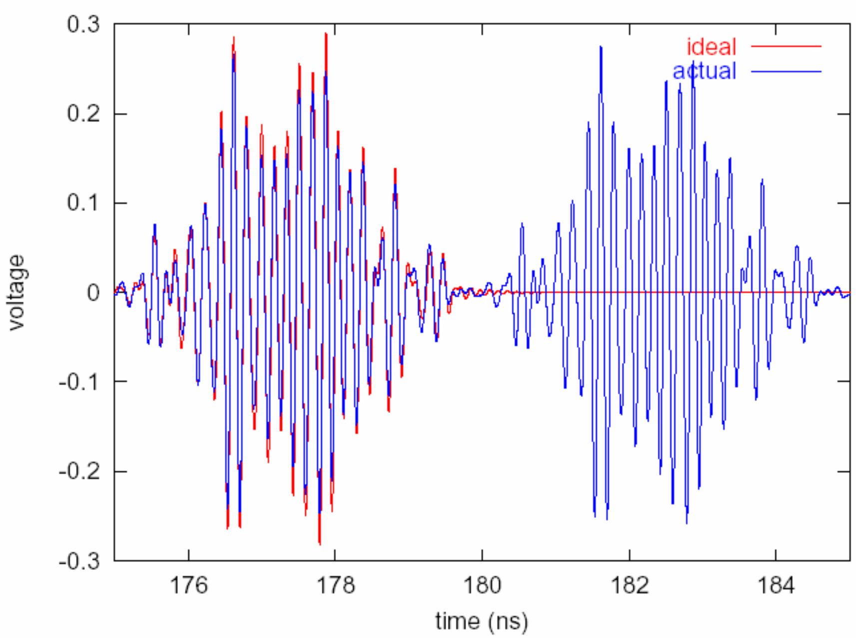
Took conservative errors.

- 2 ps timing error
- 20% amplitude errors
- 2 MHz cavity frequency errors

Desired cooling voltage is modeled as band limited noise.

System is well behaved with these errors.





Plan for this run

- Installing 7-8 GHz and 4-5 GHz kickers in yellow 4 o'clock
- Build 16 channel delay line and full turn delays.
- Have 5 amplifiers so far
- For full comparison with Au beams need 1.e9 ions in a witness bunch
- We should get a clean cooling signal albeit at about ½ the expected rate for the full system.
- Required voltage/cavity very similar to that needed for Au.
- All this assumes rebucketed beam. An experiment without rebucketed beam would be worthwhile.

Future Plans and Ideas

- Install full 4-8 GHz systems in both rings
- Study interaction with electron cooling
- Consider a wider bandwidth.
  - Cut a chord
  - Use a transverse pickup (dispersion).
  - New kicker technology needed.
- Transverse Cooling