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Memo

DATE: *June 6, 2003*

TO: RHIC E-Coolers

FROM: *Ady Hershcovitch*

SUBJECT: **Minutes of the June 6, 2003 Meeting**

Present: Dan Abell (Tech-X), Michael Brennan, Rama Calaga, Alexei Fedotov, Ady Hershcovitch, Jorg Kewisch, Derek Lowenstein, William Mackay, Christoph Montag, Thomas Roser, Triveni Srinivasan-Rao, Jie Wei.

Topics discussed: Simulation & Calculations, Stochastic Cooling.

Simulation & Calculations: Alexei opened the meeting with a report on recent cooling rate and IBS calculations performed by Burov and their comparison to those presently used at BNL. Burov's calculations of IBS, cooling rates, and minimum number of electron required to compensate for IBS are based on single particle interactions. In contrast Parkhomchuk and most BNL researchers (like in SIMCOOL) use beam-averaged quantities. Accurate formulas of single particle rate are needed, since various particles are cooled at different rates. Similarly for IBS accurate formulas for IBS are needed, since cooling depends on details of the phase space. Implications of Burov's calculations are that for optimized an electron beam $1.5x10^{11}$ electrons per bunch are required to compensate longitudinal IBS growth. And, to compensate for transverse IBS $>5x10^{11}$ electrons per bunch are required. An additional factor is needed to have safety margin beyond single-particle rates.

Burov was able to reproduce the conventionally used beam-averaged values (Bjorken, Mtingwa), after averaging over distribution IBS rates. To Ady's question on whether the Tech-X calculations follow the same approach, Dan Abell replied that at Tech-X they do not want to average over information that is not understood. Alexei added that the Tech-X codes have not reached the development stage where they can be compared to Burov's calculations. Alexei's viewgraphs are the end of these minutes.

Please Note! There will be a workshop Monday (June 30) – Wednesday (July 2) to discuss this and other E-Cooling and simulations issues. The meeting will be attended by Burov (FNAL), Ya. Derbenev (JLab), A. Sidorin (Dubna), D. Bruhwiler (Tech-X), D. Abell (Tech-X) and the BNL team. Everyone interested in E-Cooling is welcome.

Jorg reported that Ilan and him are exploring a cooling scenario that employs a smaller, denser electron beam located at the edge of the ion phase space. Shorter interaction time is compensated by the higher density resulting in comparable reaction rates. However, the cooling rate for larger amplitude ions (those needed most cooling) is larger. Physically, the electron beam covers “ion turning points” where ions moves slower, hence longer interaction time.

Stochastic Cooling: Mike Brennan gave a presentation on the Cool 03 workshop. Mike’s talk focused on stochastic cooling. It is important to keep the technology and expertise alive. Mike pointed out that stochastic cooling could complement electron beam cooling in the sense that stochastic cooling works best on hot beam (tails of a distribution) whereas electron cooling works best on pre-cooled beam (the core). At the TEVATRON and SPS stochastic cooling programs were abandoned because anomalous coherent signals polluted the Schottky spectrum and saturated the electronics, killing the feedback gain and defeating the cooling. At RHIC the situation is different and stochastic cooling should work better with gold ions than with protons, as was the case at the TEVATRON and SPS. Based on Schottky signals from gold ions in RHIC, using a 4-8 GHz stochastic cooling pickup, there are essentially no problem from anomalous coherent signals. Furthermore, the signal to noise ratio for ions is high. Mike showed the Schottky signals from gold ions in RHIC, using a 4-8 GHz stochastic cooling pickup borrowed from FNL. The expense of the microwave system of 10 kW is estimated to exceed $ 2M. But, it may be reduced by new concepts in kicker design. One idea is to use pulse compression techniques to exploit the dead time between bunches to level the rf power. Another is to use the ample available insertion length to install several kickers, which would increase the effective kicker impedance. In principle, the cost can be reduced by an order of magnitude. For the future effort must be made at scoping out a stochastic cooling system that would cool in the transverse plane and be appropriate to use in conjunction with electron cooling. Mike ended his presentation with a Stochastic Cooling Development Plan. Viewgraphs presented by Mike follow Alexei’s viewgraphs.

Reminder: Waldo has been posting meeting minutes on the web. They can be found at http://www.rhichome.bnl.gov/RHIC/luminosity/upgrade/minutes/. Additional pages of interest are: http://www.rhichome.bnl.gov/RHIC/luminosity/ a general page for luminosity issues in RHIC; and, http://www.rhichome.bnl.gov/RHIC/luminosity/upgrade/ a page for upgrade issues.

Update on some of recent cooling issues, IBS and simulations

June 6, 2003

Recent issues brought by Alexey Burov (FNAL)

- Calculation of the cooling rate
- Calculation of IBS for cooling
- Estimates of minimum number of electrons required for cooling

Based on:

Analytic formulas of "detailed" IBS and cooling rates:

Various particles are cooled at different rates – accurate formulas of single particle rate are needed –

dependence on actions

Since cooling depends on details of the phase space – accurate formulas for IBS are needed (if applied to cooling) –

dependence on actions

Detailed formulas (A. Burov)

Cooling rate:

$$\Lambda_e^{\parallel} \equiv -\frac{1}{J_z}\frac{dJ_z}{dt} = \frac{4N_e r_e r_i c \eta_c L_e}{\gamma^2 z_m}\left\langle \frac{n_\perp}{\mathrm{v}^3}\frac{\mathrm{v}_\perp^2}{\mathrm{v}^2}\right\rangle_{x,y}$$

$$\Lambda_e^{\parallel} = \frac{4N_e r_e r_i \eta_c L_e}{3\pi\gamma^2 z_m \mathrm{v}_{zm} u_e^2 \sigma_e^2}\exp\left(-\frac{x_m^2 + y_m^2}{4\sigma_e^2} - \frac{\mathrm{v}_{xm}^2 + \mathrm{v}_{ym}^2}{4u_e^2}\right) I_0\left(\frac{x_m^2}{4\sigma_e^2} - \frac{\mathrm{v}_{xm}^2}{4u_e^2}\right) I_0\left(\frac{y_m^2}{4\sigma_e^2} - \frac{\mathrm{v}_{ym}^2}{4u_e^2}\right)$$

IBS:

$$\Lambda_i^{\parallel} \equiv \frac{1}{\mathrm{v}_{zm}^2}\frac{d}{dt}\mathrm{v}_{zm}^2 = \sqrt{\frac{2}{\pi}}\frac{N_i r_i^2 c L_i}{\gamma^2 \mathrm{v}_{zm}^2 \sigma_x^2 \sigma_z u_x}\exp\left(-\frac{z_m^2}{4\sigma_z^2}\right) I_0\left(\frac{z_m^2}{4\sigma_z^2}\right) \mathcal{G}\left(\frac{\mathrm{v}_{xm}}{u_x}, \frac{\mathrm{v}_{ym}}{u_x}\right)\left(1 - \sqrt{\frac{\mathrm{v}_{zm}}{u_x\sqrt{2}}}\right)$$

Detailed vs beam-averaged

"Detailed" rates give detailed cooling and diffusions as a function of all three particle amplitudes.

After averaging over distribution IBS rates reproduces conventionally used beam-averaged values (Bjorken,Mtingwa).

$$\frac{d}{dt}\overline{\mathrm{v}_z^2} = \frac{N_i r_i^2 c L_i}{8\gamma^2 \sigma_x^2 \sigma_z u_x}$$

Minimum Ne required to compensate longitudinal IBS

1. Detailed (Burov):

$$\frac{N_e}{N_i} = 4\frac{L_i}{L_e}\frac{r_i}{r_e}\frac{1}{\eta_c}\frac{u_x}{u_z}\left(1-\sqrt{\frac{u_z}{u_x}}\right)$$

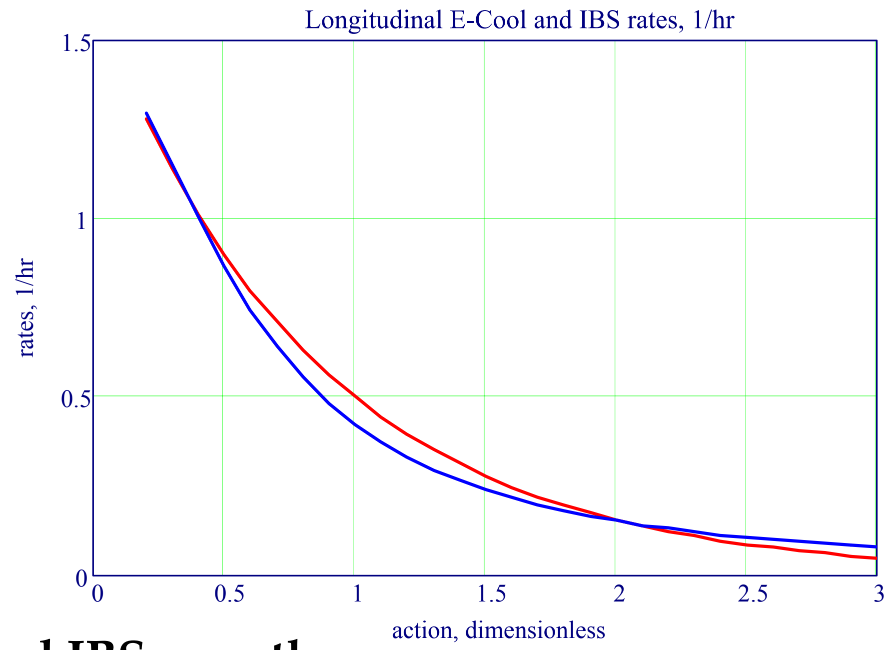
- Already optimized $\sigma_e = 1.3\sigma_x \; u_e = 1.3u_x$ (otherwise, even bigger)

2. Beam-averaged (Parkhomchuk): SimCool – used for RHIC

$$\frac{N_e}{N_i} = (2/\pi)\frac{L_i}{L_e}\frac{r_i}{r_e}\frac{1}{\eta_c}$$

Additional factor 2.5 from ratio of L : Burov - 19/2 vs SimCool - 10/2.5

Estimates (Burov)



- **For optimized electron beam:**

$$N_e = 1.5 \cdot 10^{11}$$

is required to compensate longitudinal IBS growth.

$$N_e \geq 5 \cdot 10^{11}$$

to compensate transverse IBS.

Need additional factor to have safety margin beyond single-particle rates

Summary (Burov)

- **Conventionally used beam-averaged IBS formulas are good to describe beam-averaged parameters: emittance growth, bunch lengthening.**

- **They are not good enough for the cooling process which requires detailed description in the phase-space – may be off by a large factor.**

summary

- This topic generated discussions on various issues:

  accuracy of beam-averaged formulas

  accuracy of detailed formulas

  values for Coulomb logs

  magnetization vs no magnetization (requires less Ne !)

  optimized electron beam, etc.

We plan to study this effect of "detailed" formulas further – implement in SimCool and/or BETACOOL, other updates for codes are discussed.

Working meeting

We will have working meeting:

Monday (June 30) – Wednesday (July 2)

to discuss this and other *issues of e-cooling and simulations.*

- **Burov (FNAL), Ya. Derbenev (JLab), A. Sidorin (Dubna),**

D. Bruhwiler (Tech-X), D. Abell (Tech-X) and BNL's team

+ everyone is welcome.

Mike's Presentation

STOCHASTIC COOLING @ COOL03

- Why consider s.c. at rhic?
  - Debunched beam
  - Future
- Will it work?
  - Schottky signals
  - Coherence
  - Proton BTF/solitons
- How to do it?
  - Frequency range
  - Palmer cooling
  - Filters

- How much will it cost?
  - Microwave power is expensive, 10 kW > 2M$
  - Kicker impedance
  - Pulse expansion/compression
- Future
  - Expand to transverse plane
  - Complement e-cooling/collect the tails

The Problem

- IBS
  - Emittance growth drives beam out of the bucket
    - Diminishes effective luminosity
    - Creates de-bunched beam, > dirty dumps
  - Can't FIX the problem (atomic scale)
    - Mitigate with bigger buckets (momentum aperture)
    - Emittance blowup strategies
    - Gap cleaning
  - Not a surprise
- Cooling can counteract IBS
  - So why wasn't cooling part of the original project scope?

RHIC Design Manual

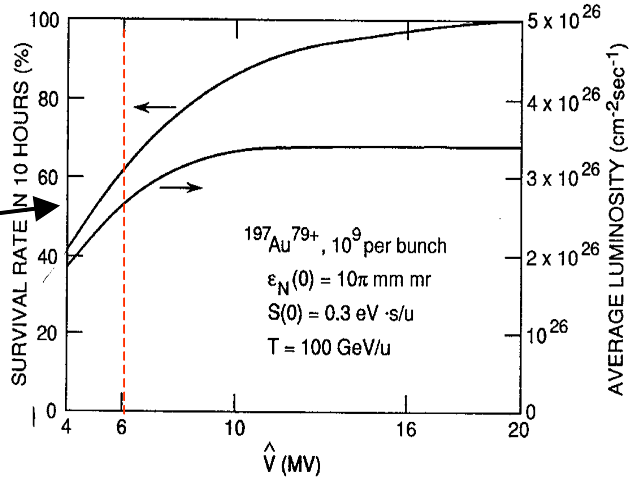
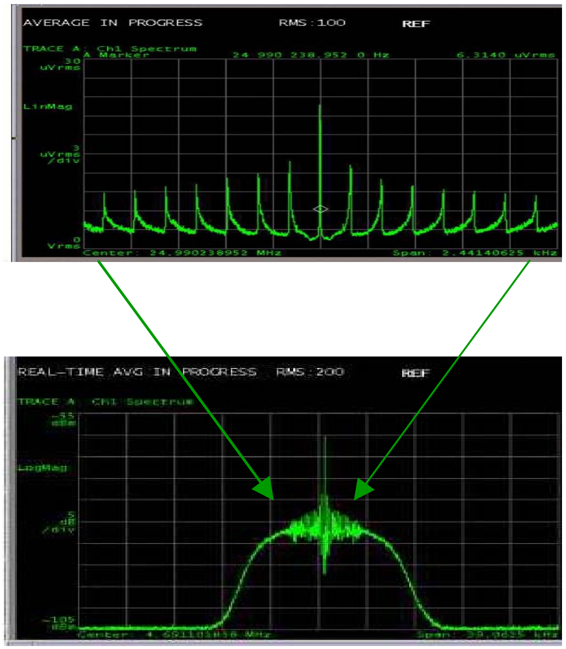


Fig. 7-3. Dependence of final beam survival rate and average luminosity on storage rf voltage after 10-hour operation, "constant voltage" scenario (courtesy J. Wei).

Schottky Spectra

- *"if you want to find out if cooling can work look at the Schottky signals"* (consensus of experts)
  - Signal to noise ratio
  - Mixing situation
  - Anomalous coherence

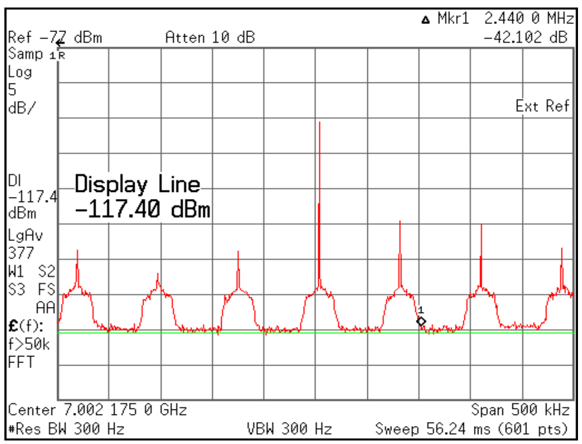
- The signal to noise ratio is high for ions
  - For the same number of charges in the ring the Schottky power from ions is Q times larger than from protons

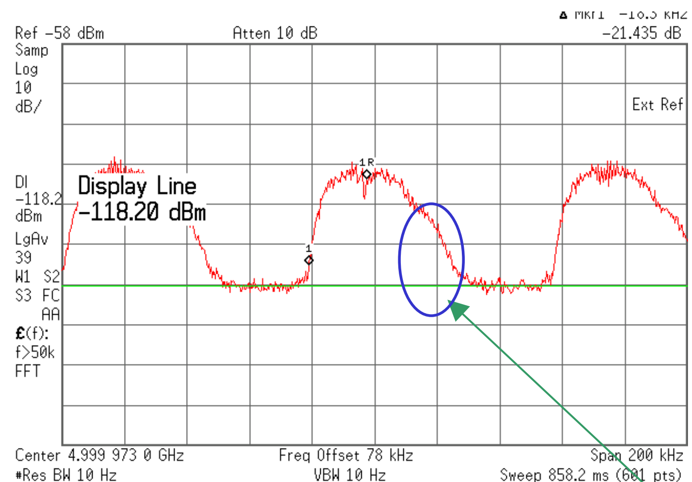


Schottky signals from 2.7 GHz narrowband pickup. Many synchrotron sidebands are resolved. Signal to noise ration > 25 dB.

Schottky signals in the 4-8 GHz band

- Fermilab loaned to RHIC a pickup and kicker pair at 4-8 GHz
- Looking at the gold beam



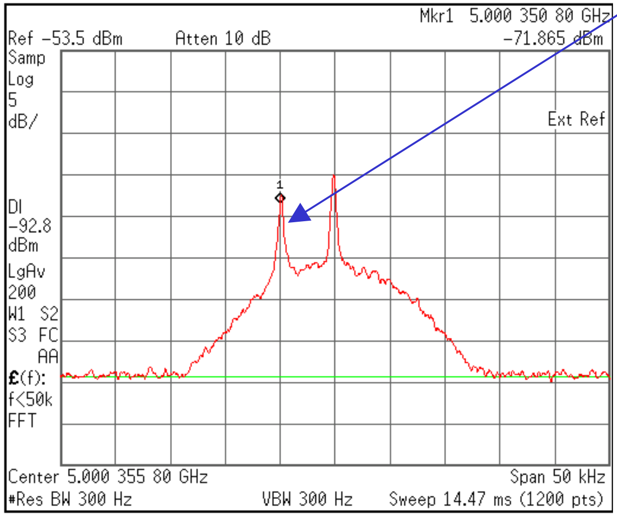


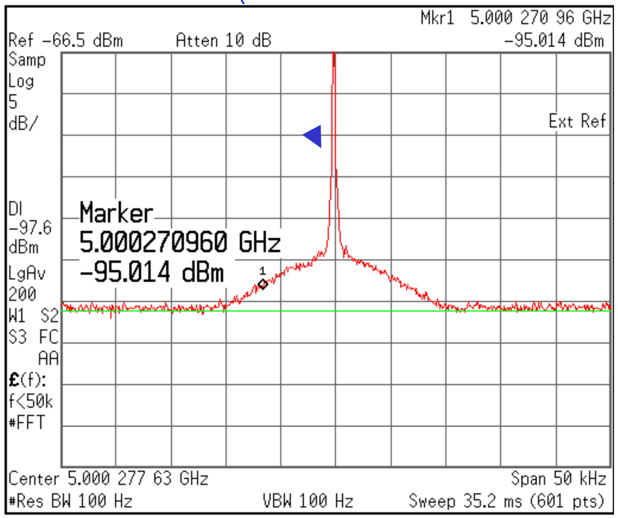
1. At 7 GHz early in a store, via 150 m cable
2. Coherence lines show up at harmonics of the bunch frequency
3. Even at 7 GHz the Schottky bands do not overlap,⇒ poor mixing

1. Late in the store at 5 GHz we see de-bunched beam, coasting on the low-energy side
2. The coherence has dissipated
3. The signal to noise ~ 30 dB

Protons (polarized)

- Looking at the proton beam
- The significant difference in that the coherence lines do not dissipate
- This is consistent with experience at TEVATRON and SPS
- We also measured the longitudinal Beam Transfer Function by driving the kicker (5 Watts) at a single frequency within the distribution



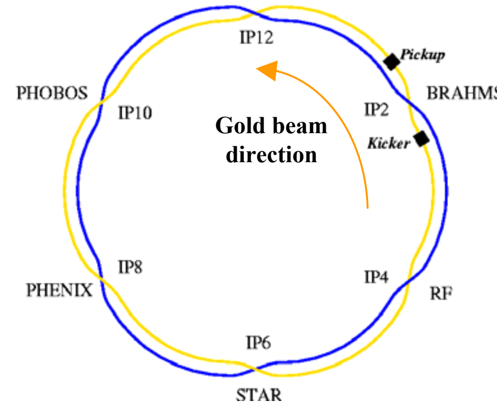


Longitudinal Beam Transfer Function

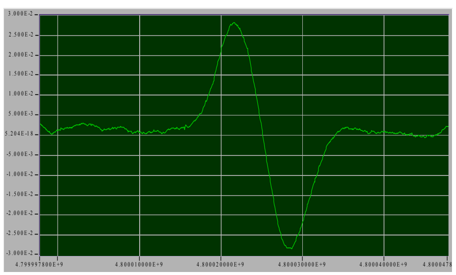
- The beam transfer function represents the beam's response to stimulus of the kicker
- It is a key part of feedback loop of a cooling system
- For a coasting beam it is given by the dispersion integral,

$$B(\omega) \propto j \int \frac{\frac{d\psi_0}{dE}}{\omega - n\omega_0 - nkE} dE$$

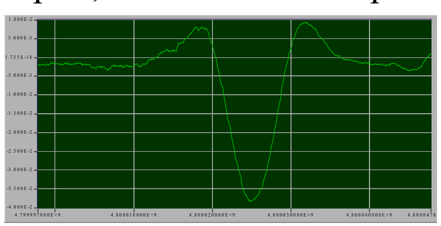
1. **Real part is anti-symmetric and proportional to the derivative of the energy distribution function**
2. **The imaginary part is symmetric and extends beyond the zero of the real part, where the interaction is pure reactive**
3. **The magnitude calibrates the impedance of the pickup and kicker**



Beam Transfer Function, 2×10^{12} protons



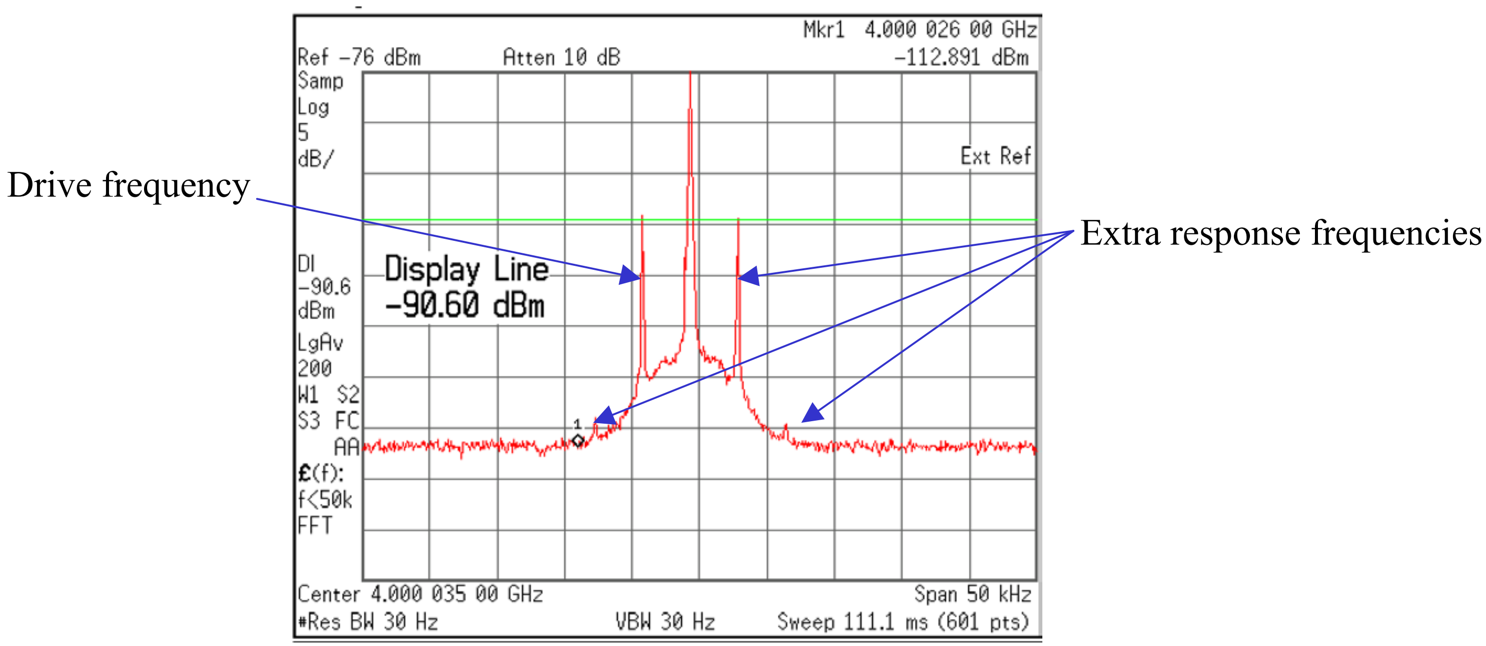
Real part, 5 GHz center frequency



Imaginary part, 50 kHz span

The BTF in not always so straightforward

- Sometimes the response resembles low-frequency bunched beam BTF
- Generating mirror image frequencies at ±Δf, ±2Δf,…
- Indicates creation of some long-lived (>>$\tau_{synchrotron}$) structures, eg: solitons
- This seems to be the key difference between protons and ions



Stochastic Cooling Development Plans

1. Examine Schottky signals…..
2. Measure Beam Transfer Function….
3. Demonstrate some cooling…….FY04
4. Design a practical momentum cooling system
    a. Filter method/Palmer cooling (halo cooling)
    b. Frequency band
        i. 4-8 GHz implies a 2/3 turn delay is OK
        ii. 6-12 GHz better mixing, ½ the cooling time, 1/6 turn delay
    c. Kicker power requirements
        i. 10 kW = 2 M$
        ii. Higher impedance kickers (slotted waveguide) [McGinnis at FNAL]
        iii. Power leveling (pulse expansion/compression) [proposed by F. Caspers]
        iv. Fourier decomposition (only 20 lines are relevant) [proposed by Boussard for SPS]

5. In the long range, when RHIC is equipped with e-cooling, stochastic cooling would be a natural complement
    a. E-cooling works best on a cool beam. It tends to collect beam into a dense core
    b. Stochastic cooling works best on a hot beam. It could capture beam in the tails and contribute to the effective luminosity

Two-Turn delay filter

- Filter emphasizes high momentum deviation particles
- Extends deltaP reach
- Saves power