Transverse Electron Cooling Measurements with a Kicked Pencil Beam in CELSIUS

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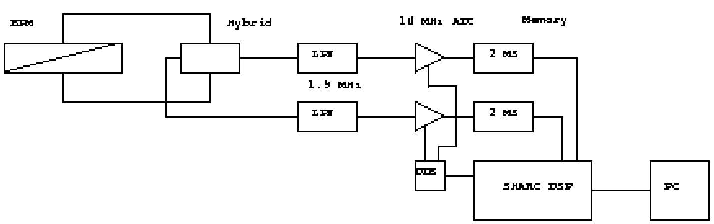
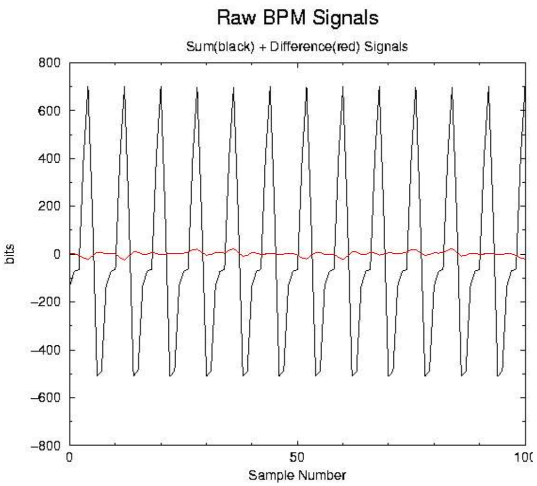
This work is performed within the framework of the INTAS collaboration on "Advanced Beam Dynamics".

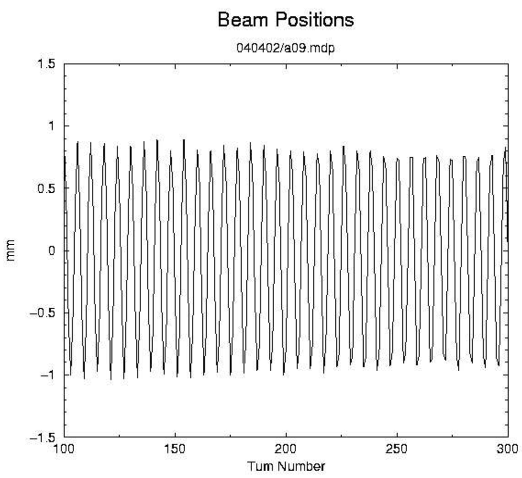
Experimental Setup

- Pilot experiment in CELSIUS (040402): Derive transverse cooling force as a function of amplitude from turn-by-turn data.
  - 48 MeV protons
  - Electron cooling at 50, 100, 150, 200 mA
  - Injection, cool for 15 s and then take data
- Experimental Setup (Homegrown)
  - Analog Devices SHARC DSP
  - Two 10 MHz 14-bit ADC
  - 8 MB Memory (2 MS/channel)
  - DDS as primary trigger
  - Parallel port interface to Linux PC
  - SHARC interrupts as secondary triggers



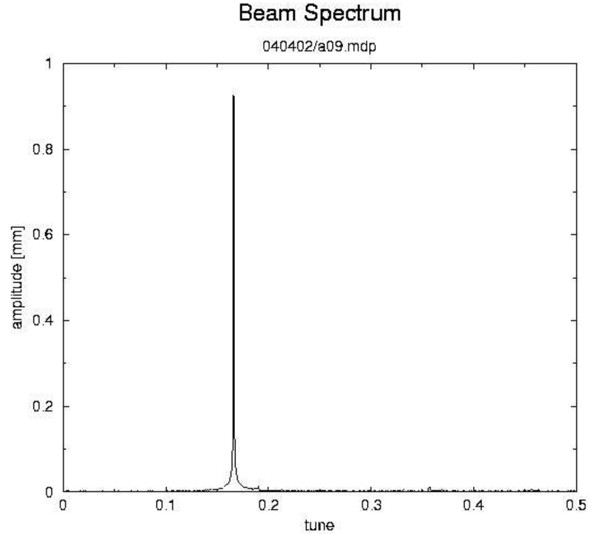
- Sophisticated triggering:
  - Set DDS to get 8 samples per turn
  - When kicking start DAQ
  - 240 x 8192 or 32 x 65536 samples with milliseconds inbetween.
- Vertical pickup and diagonal kicker



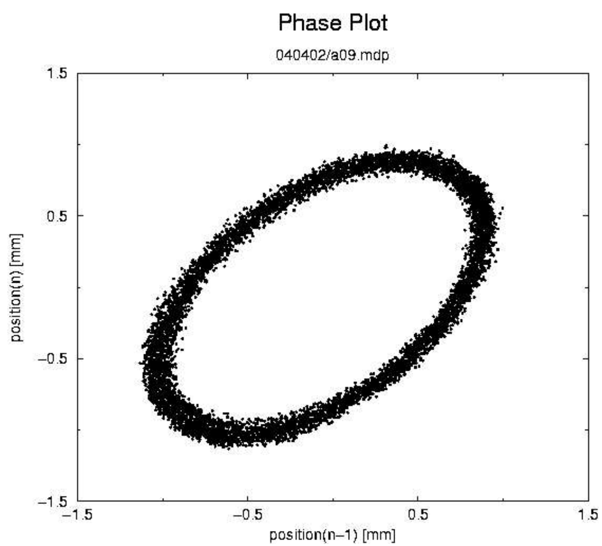


Kicked pencil beam

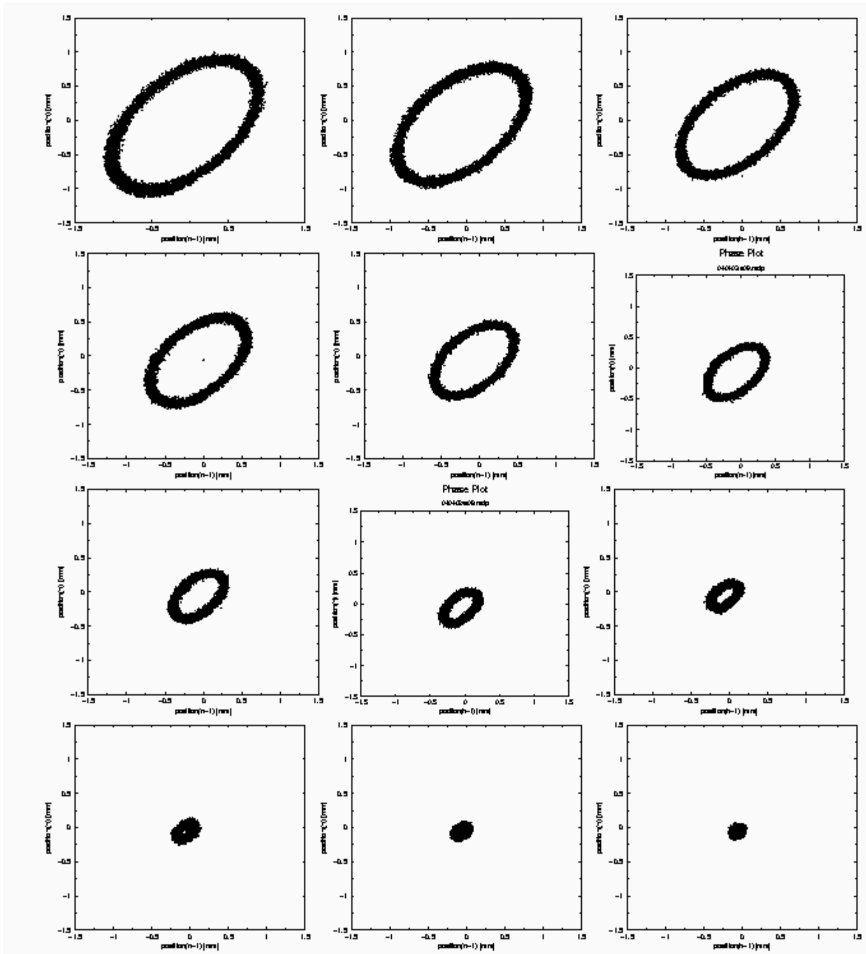
- FFT of turn-by turn data



- Plot turn n vs. n-1 for mock phase portrait



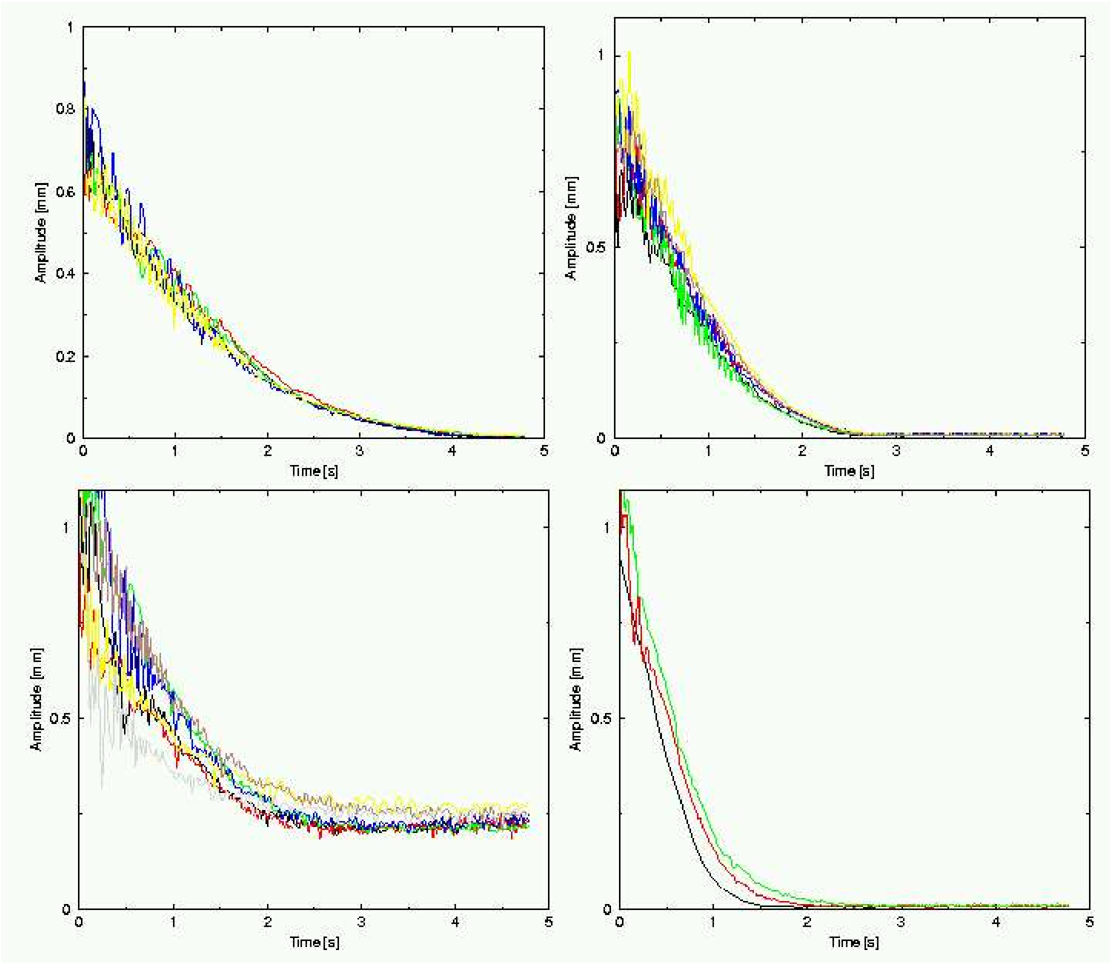
- Cooling sequence
  - 200 mA cooler current
  - 100 ms between pictures



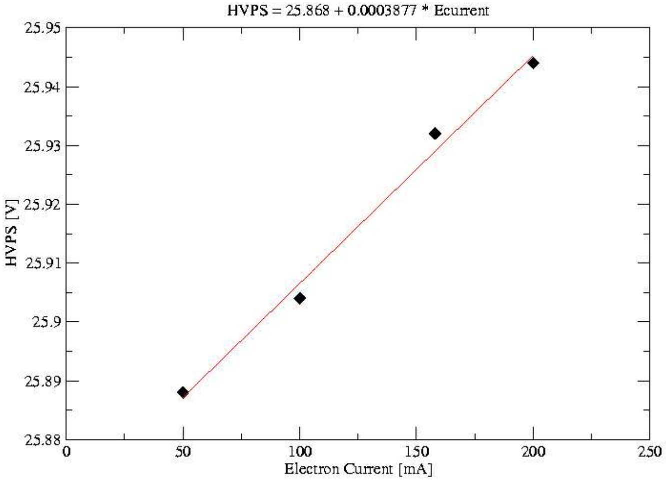
- Use Fourier amplitude instead of ellipse area.

Damping of Fourier Amplitude

- Fourier amplitude vs. time (50, 100 150, 200 mA)
  - Several data sets each agree fairly well
  - all are 240 x 8192 data, except one with 32 x 65536

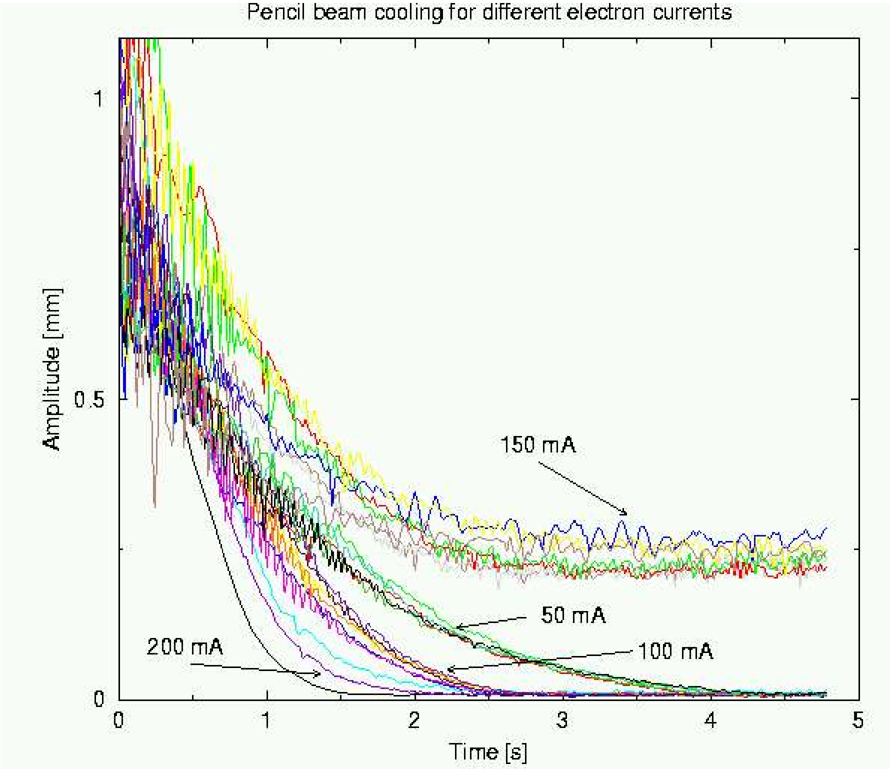


- Increasing the cooler current causes faster cooling.
- Anomaly at 150 mA, persistent oscillations.
- Need to adjust HVPS to keep revolution frequency constant and compensate space charge.



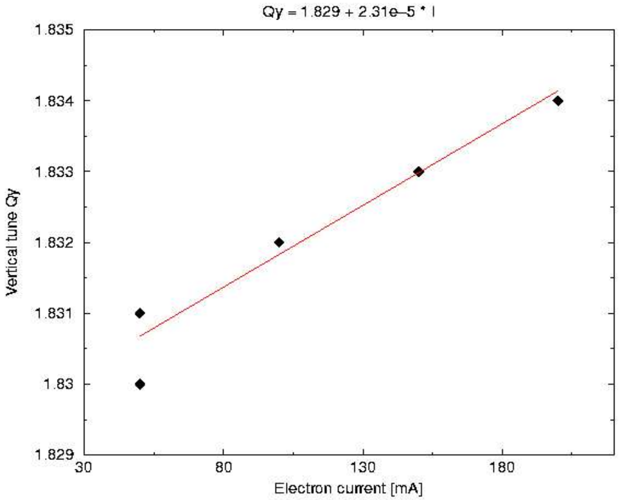
All plots superimposed

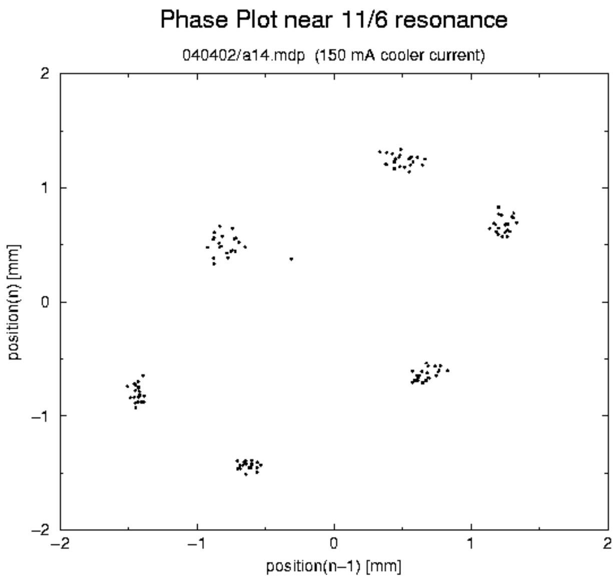
- Something is wrong with the 150 mA data.
  - Tune is near 11/6 (see mock-phaseplot).
  - A little noise can keep the oscillation going.



- Surprisingly long coherence.
  - If dominated by decoherence increasing the electron current should make the oscillation last longer because the beam gets more mono-chromatic.
  - If dominated by electron cooling, increasing the electron current should make the oscillation die out faster.

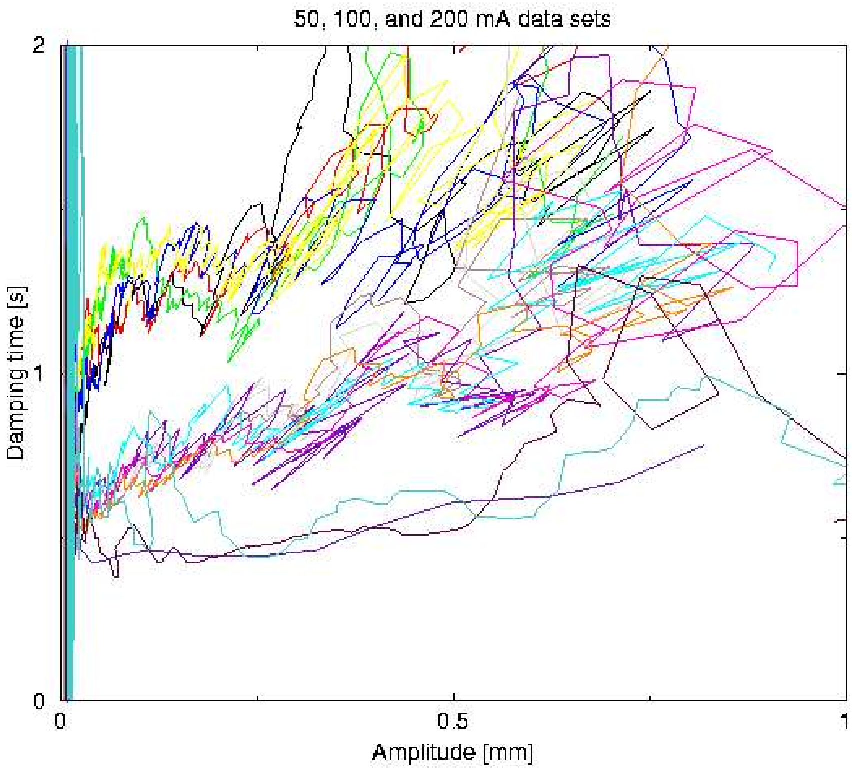
- Tune vs. electron current



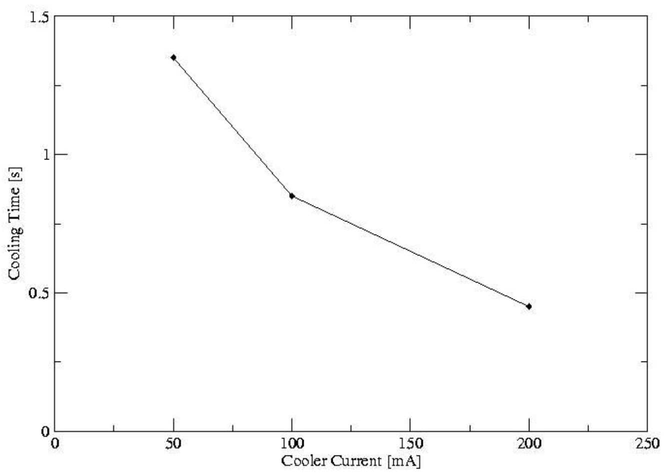


Damping times as function of Amplitude

- Extract damping times
- $$\frac{dA}{dt} = -\frac{1}{\tau}A \quad \longrightarrow \quad \tau = -\frac{A}{dA/dt}$$
- Amplitude scale drops out
- Derivative from straight line fit over ≈0.4 s.



- The data sets per current cluster together.
- The 32 x 65536 data set is cleanest.
- Cooling time at 0.3 mm.



Improvements for the Future

- Carefully calibrate BPM scale.
- Use fewer but longer measurement batches 32 x 65536, 64 x 32768.
- Beside HVPS also correct tune when changing the cooler current.
- Make simultaneous measurements of the horizontal beam profiles with the MGPM.
- Use a kicker that kicks vertically only (new hardware at TSL).
- Measure bunch length with fast oscilloscope to determine the momentum spread. Repeat with different RF amplitude settings.
- Need to deconvolute the effect of tune spread.
- Use damping decrement $\alpha=1/\tau$ as fit variable.
  - *Should result in high precision transverse cooling measurements. Planned for next CELSIUS runs.*

Conclusions

- Could observe long coherent oscillations after transversely kicking a well-cooled beam...
- ...using a home-grown data-acquisition system.
- Damping time (inversely) scales with electron current.
- Chromaticity and Decoherence needs to be investigated.
- Will continue to develop this method until the demise of CELSIUS in the summer of 2005.