SPS Crab Cavity MDs
Beam Dynamics Results

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On behalf of the many people involved in the crab cavity project.

14 September 2018 - CERN

Overview

- MD #1: 23/05/18
  - First crabbing of protons. Some phase and voltage scans to understand measurements.
- MD #2: 30/05/18
  - First ramp to 270 GeV, some attempted studies for a3 and electrical centering but not conclusive.

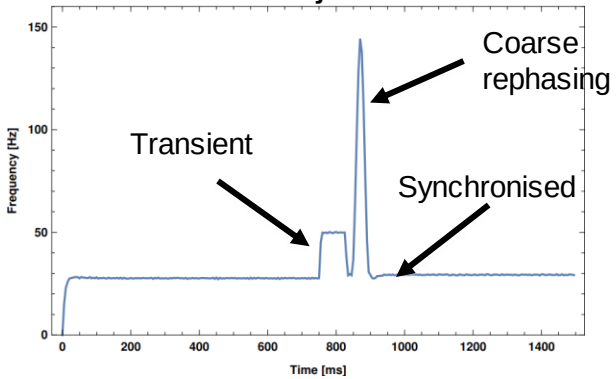
- MD slot on 11/07/18 had to be cancelled due to cavity-cryo issues
- MD #3: 18/07/18.
  - Issues with cavities meant limited performance. Performed first part of intensity ramp at 26 GeV.

- MD #4: 27/08/18
  - Focused on coast setup and first emittance growth measurements.
- MD #5: 05/09/18
  - Explored effect of LLRF noise on emittance growth.

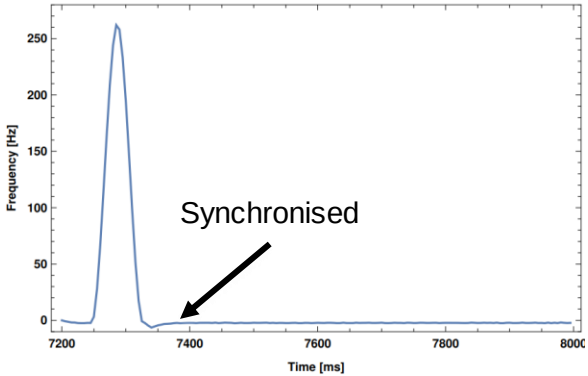
Crab-RF Sychronisation

- Crab cavity rf set point from BA6 to BA3
- CC ~400 MHz, SPS RF ~200 MHz
- Rephasing of SPS RF to become synchronous with crab signal.

26GeV rephasing
Synchronised from ~1s after injection



270GeV rephasing
Synchronised from ~7.4s i.e. 0.2s after reaching flat top



MD #1 Overview

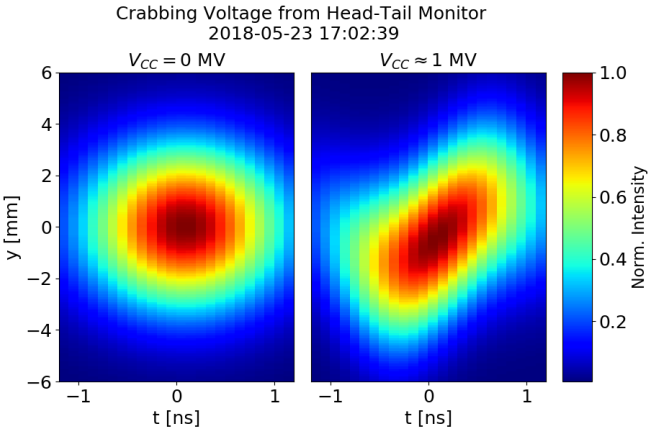
- Both cavities at 4.5K.
- Tuner loops both ok.
- No cavity feedback loop.
- Cavity 1 operated around 200-300 kV
- Cavity 2 less than 50 kV. Vaccum issues prevented going higher.
  - Not enough RF conditioning.

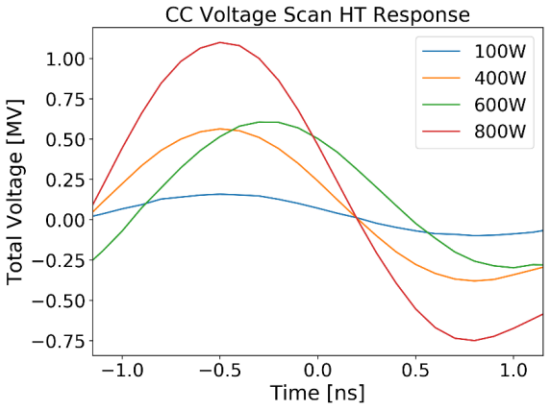
- Able to reach single bunch intensities up to 8e10 without issue.
- Performed some phase and voltage scans.

MD #1 – Protons meet Crabs

First injection – 12:55, May 23

Worked w/o RF feedback
$0.2 - 0.8 \times 10^{11}$p/b





Head-Tail Monitor

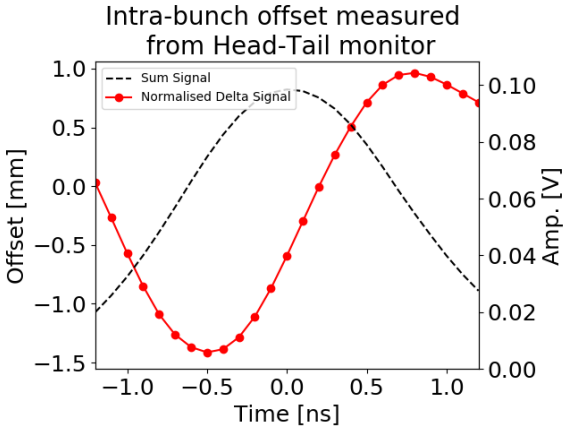
- The Head-Tail monitor gives two data sets
  - A sigma (or sum) signal, which is the longitudinal line density for a given window (often ~10,000 turns with 100ps sampling)
  - A delta (or difference) signal, which is a measure of the transverse offset within the bunch.

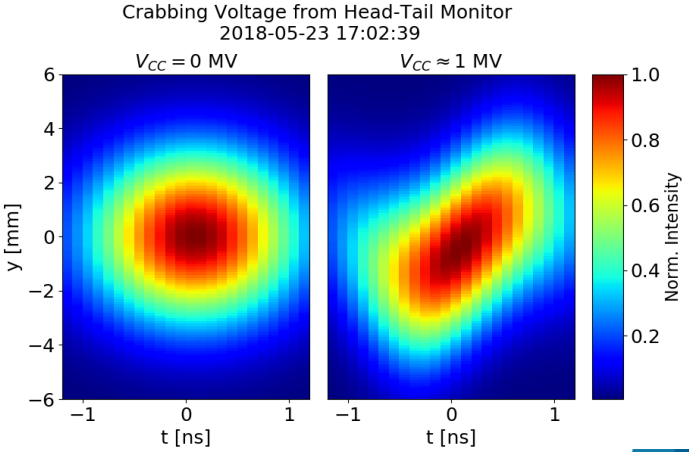
- When synchronised with the main rf, the crab signal vanishes into the baseline signal.
  - Need to remove the baseline without removing the crab signal.

- 1. Calculate baseline from delta signal acquired before synchronisation. This gives the background signal without the crab cavity signal.

Head-Tail Monitor

- 2. Take delta signal acquisitions of interest and subtract baseline. Divide by the sum signal and apply normalisation factor to acquire intra-bunch offset in mm.
- 3. Take the measured profile in z. Assume a Gaussian profile in y with sigma taken from wirescan.
- 4. Modulate in z with intra-bunch offset.
- Make plot of reconstruction o crabbing!



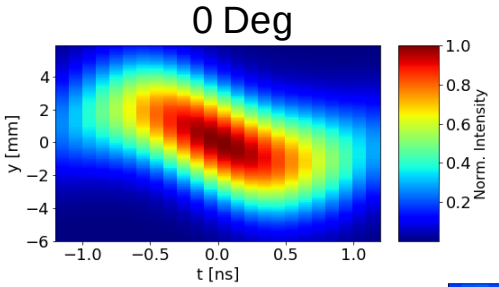


MD #2 Overview

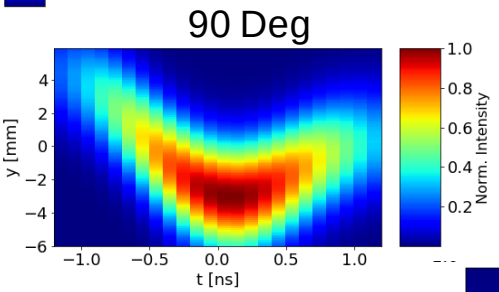
- Both cavities at 4.5K.
- Cavity loop working for cavity 1
- Cavity 2 minimal voltage due to vacuum limitation
- Independent cavity phase control possible.

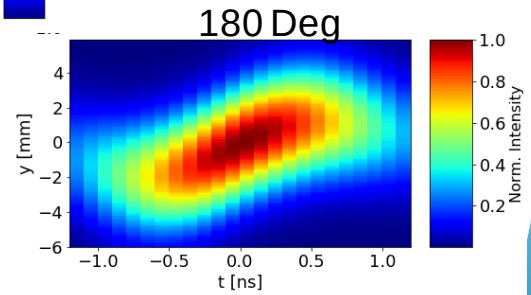
- Immediately performed an intensity ramp to nominal intensity.
  - No issues seen. Spent most of MD operating with Nb=1.1e11p.
- Performed orbit scans for electrical centering.
- Performed closest tune approach measurements to help setup for future measurements.
- Successfully ramped to 270GeV, first with 2e10 then with 1e11. Some problems in the beginning but were quickly overcome.

MD #2: Phase Scan



RF phase scan w.r.t the beam phase with cavity 1

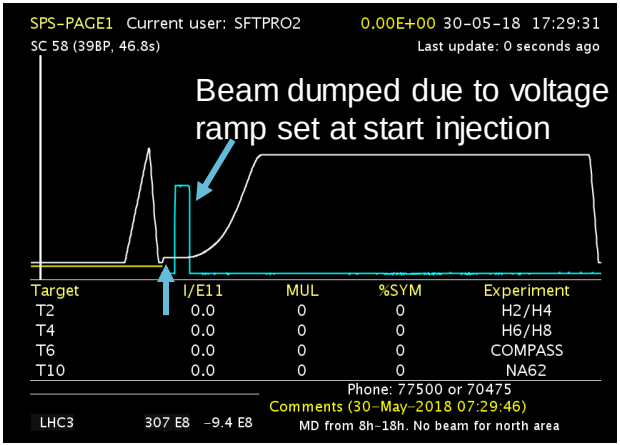


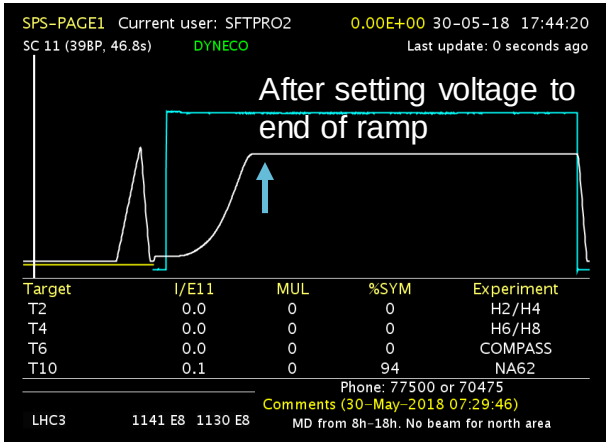


1 MV in cavity 1 (up to 2MV in some cases)
~50 kV in cavity 2, limited by cavity vacuum

MD #2: 270 GeV Ramp

Cav1 ~1MV (400.787 MHZ), Cav2 off (400.528 MHz)

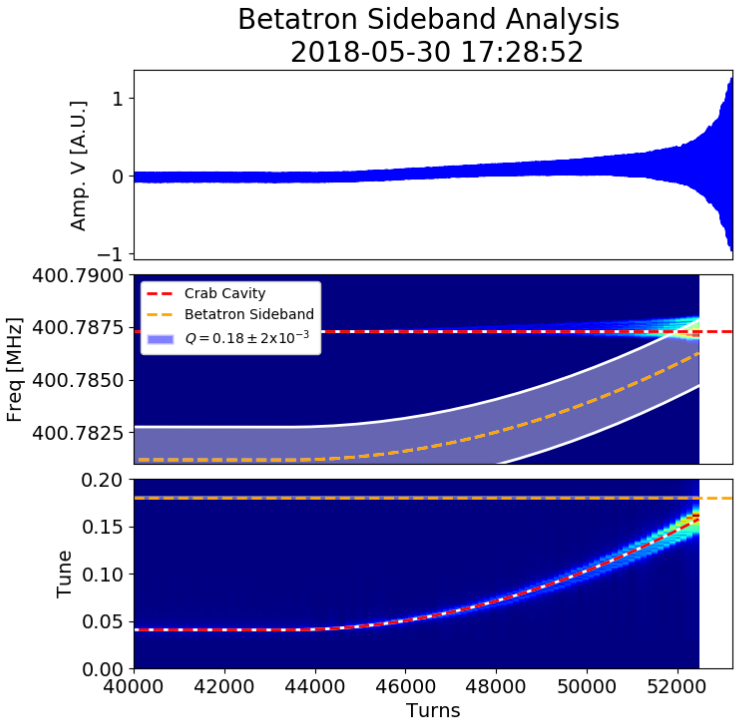




- Successfully reached 270 GeV with no CCs powered during the ramp.
- Checked with and w/o transverse feedback for nominal bunch intensities.
- Longitudinally unstable w/o 800 MHz

MD #2: Ramp to 270 GeV

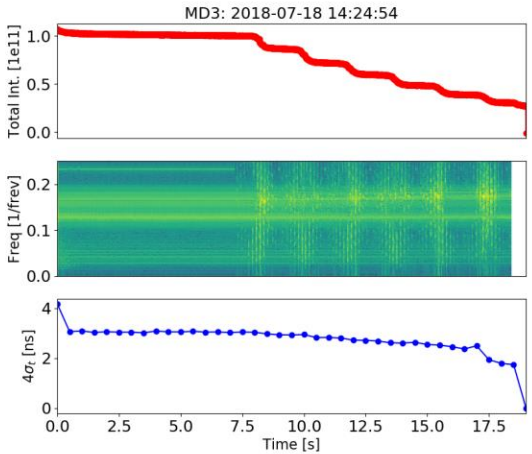
- Vertical tune: $Q_y = 0.18$
- For 270 GeV, crab cavities not synchronized until flat top (~7s).
- Cavities wrongly powered to ~1MV from start of the cycle.
- Resonant excitation observed as the betatron sideband is crossed.
- Rise time ~800 turns.



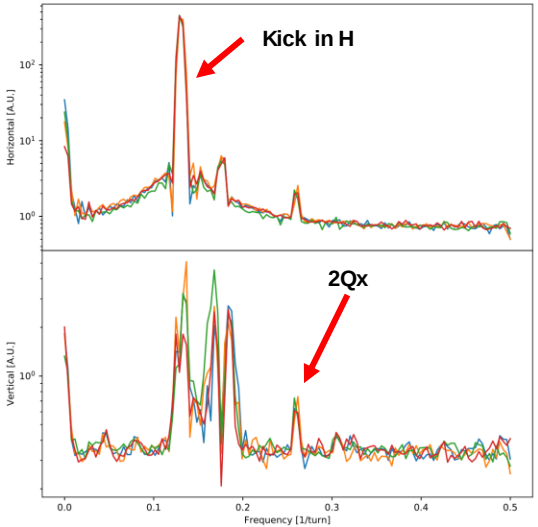
MD #3

- Cavities at 4.5K but several issues strongly inhibit MD plan
  - No RF feedback due to large frequency fluctuations
  - Issues setting up BA3-BA6 synchronisation.
- Performed some basic voltage scans with the cavity performance we had (but nothing new).
- Observed interesting losses while cavity feedback was setup.
- **Increased intensity up to 72*2e10**.

Dinosaur Losses



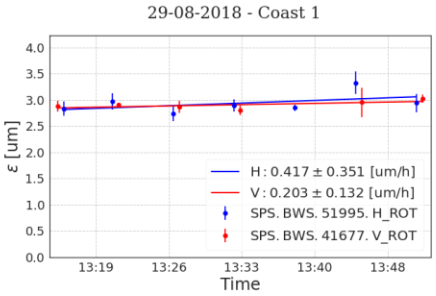
Preliminary a3 measurement



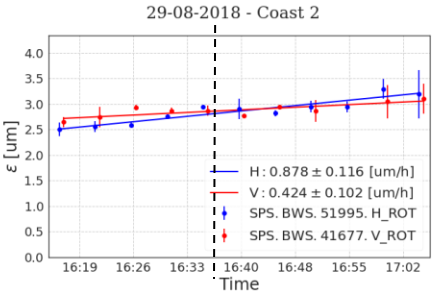
MD #4

- The cavities are at 2K for both MD4 and MD5!
- Emittance growth in coast measurements.
- After some setup of crabs with coast cycle, 2 short coasts and 1 long coast were achieved.

Crabs off

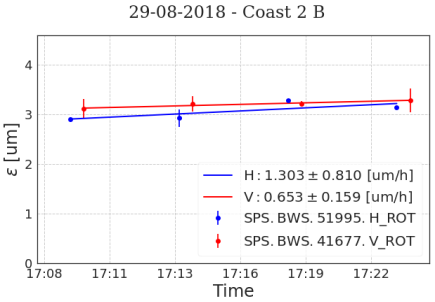


1.5MV -> 1MV



Prediction: 0.2um/h from crabs

Increased noise via RF feedback gain

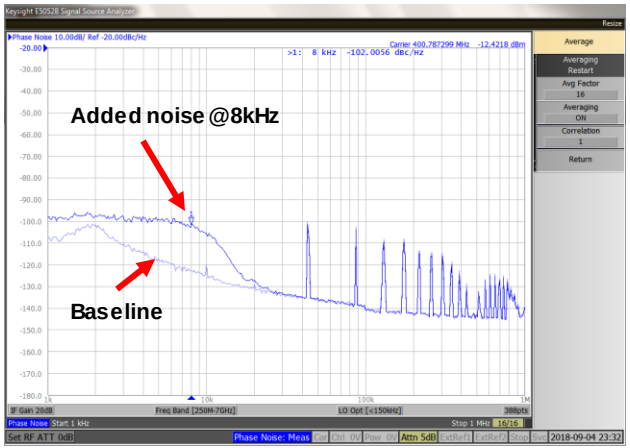


Prediction: 0.6um/h from crabs

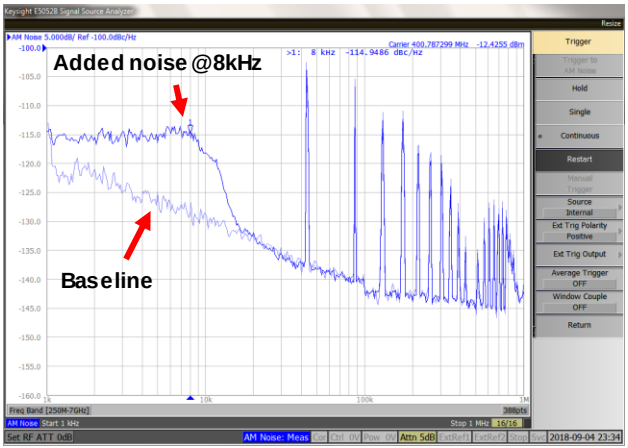
MD #5

- More measurements of emittance growth in coast.
- Phase and amplitude noise added up to 10kHz.
- Below is the power density squared of the signal sent to the cavity feedback.
  - The power is artificially increased around the first betatron sideband @8kHz.

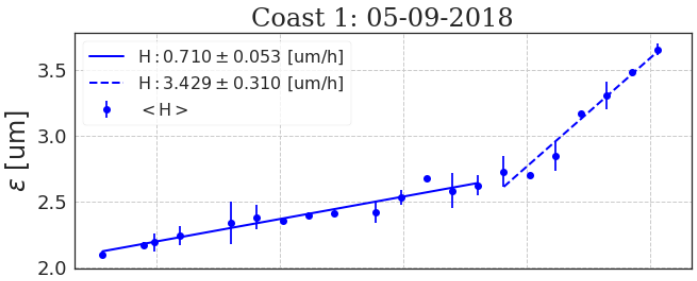
Phase

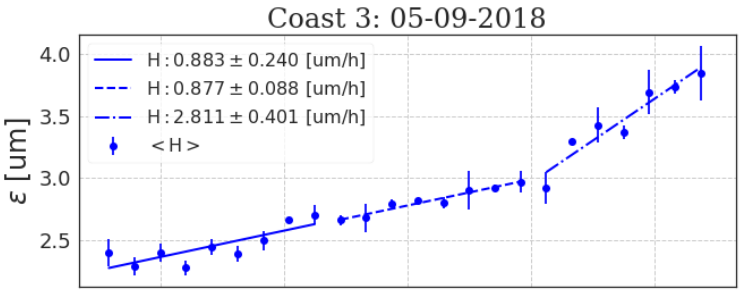


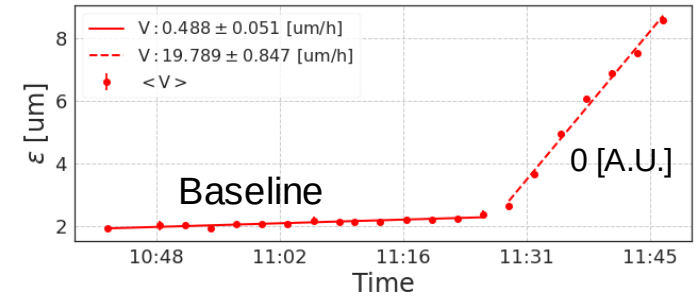
Amplitude

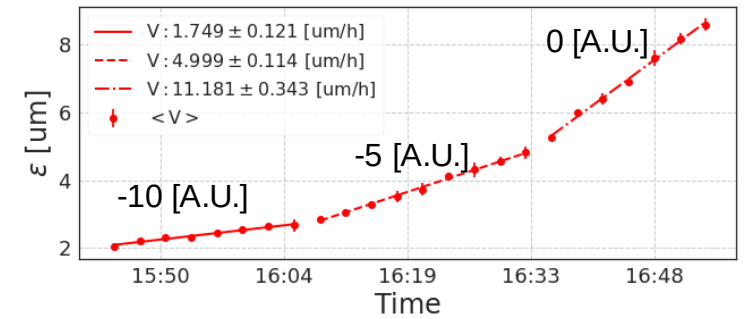


MD5: Summary of Coasts

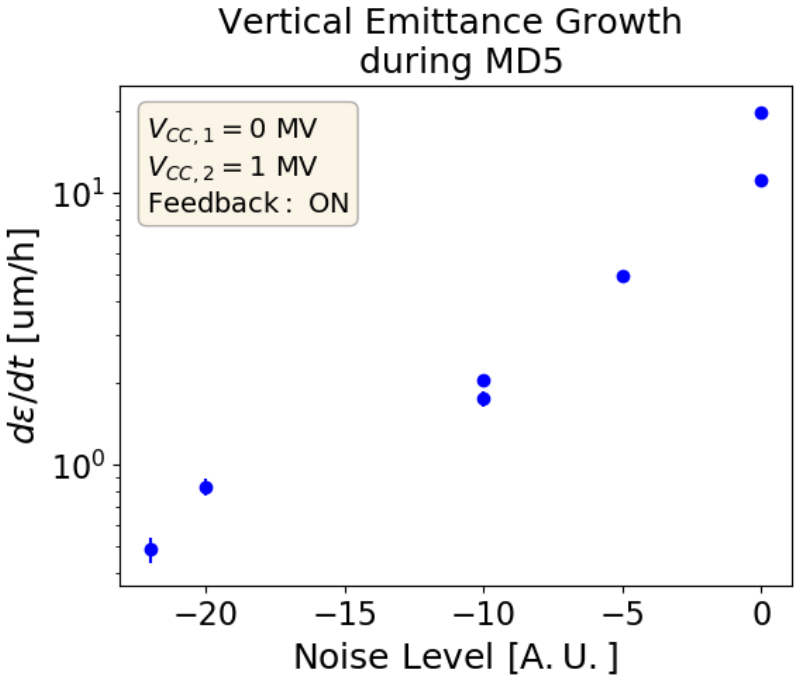








MD5: Summary of Coasts



Overview

MD#	Highlights	C1 Peak Volt. [MV]	C2 Peak Volt. [MV]	CM Temp. [K]
1	First crabbing, phase and voltage scan.	0.2-0.3	<0.05	4.5
2	Ramp to 270 GeV, betatron excitation, interesting loss cases.	1-2	<0.05	4.5
3	Prelim. a3 measurements, dinosaur losses, intensity ramp, HOM signals	1	~0.3	4.5
4	Setup of crabs for coast cycle. Initial emittance growth coasts.	1.0	0.5	2
5	Emittance growth in coast with and without noise.	0	1	2

Still To Do

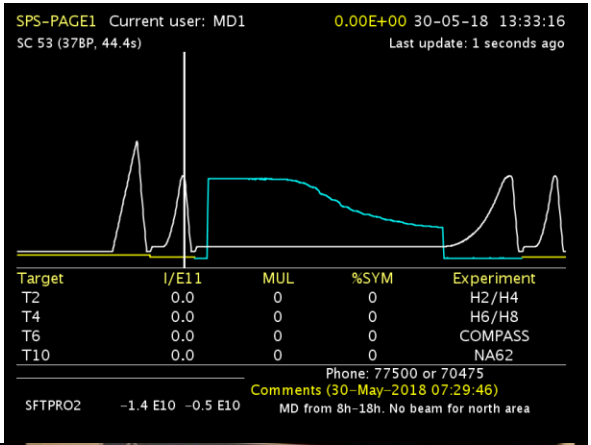
- Transparency checks
- Crab dispersion
- Electrical Centering

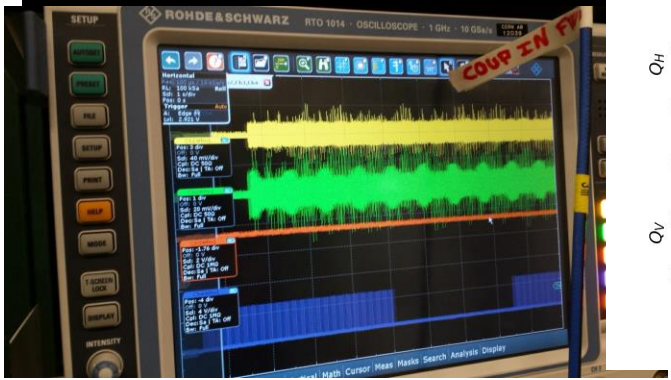
- Transverse Feedback Studies
- Measurement of a3
- Loss maps with crab cavities
- AC Dipole like excitation with BA3-BA6 desynchronisation

- Intensity ramp-up

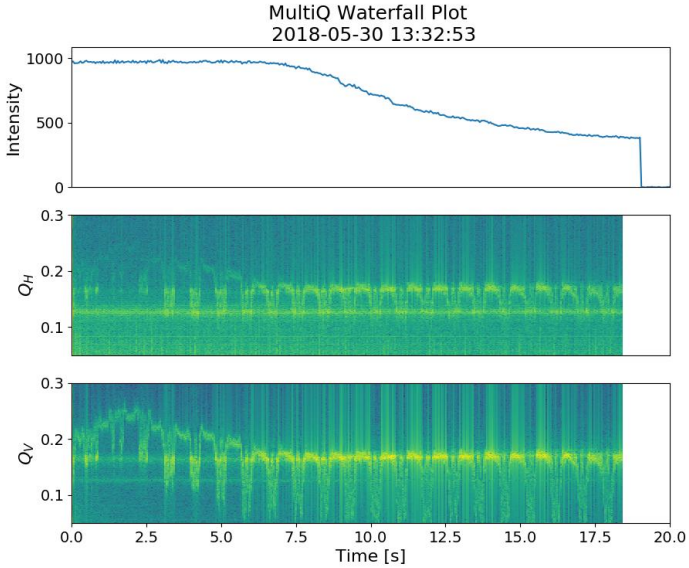
Thank you

MD #2: 26 GeV Losses



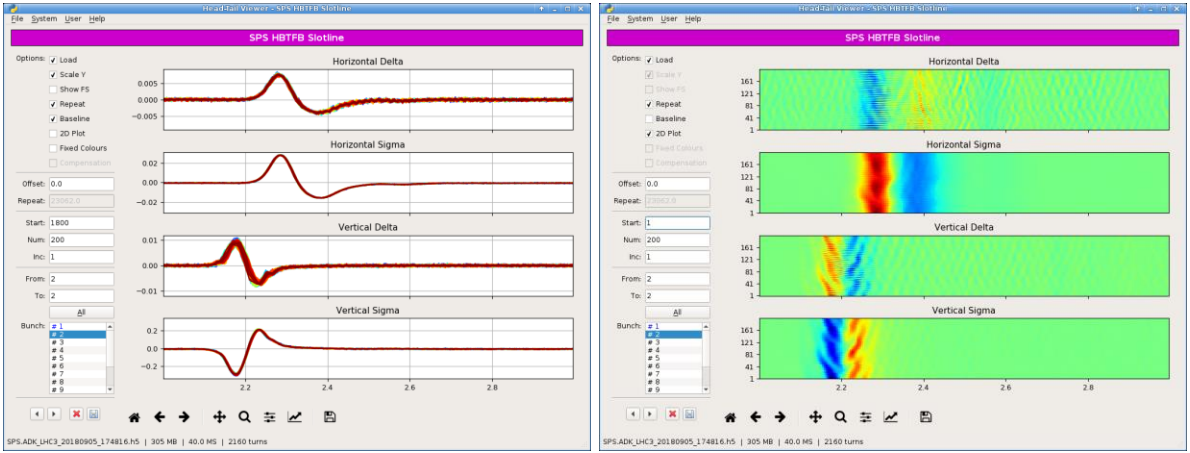


- Slow losses seen during one cycle.
- Investigations ongoing.
- Cavity tuner was being setup during this period.



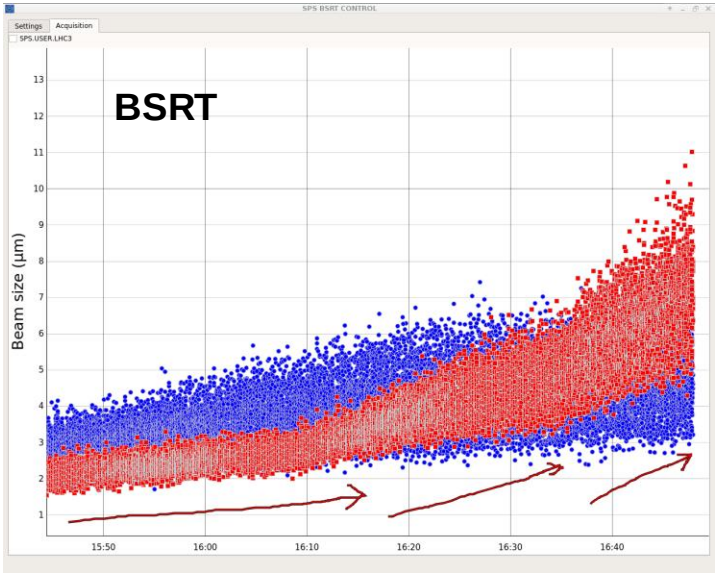
Slotted Waveguide Pickup

- Big effort by W. Hofle and T. Levens to setup the slotted waveguide as an intra bunch pickup.
- Using the same scope as the HT monitor allowed an easy copy of all HT software.
- Identical triggering times for SW and HT monitor. Will attempt to reconstruct crabbing signal from this data.
- Available for MD4 and MD5 which was entirely at 270 GeV.



BSRT & BGI

- BSRT profiles also logged for 270 GeV, big thanks to G. Trad for his effort.
- Analysis still to be done for a thorough comparison to wirescan results.
- Some issues with setting up BGI for the coast cycle, unfortunately data not useable but ready for any future coasts.



Misc. Figures