UNIVERSITY OF LIVERPOOL

SPS Crab Cavity MDs
First results with beam

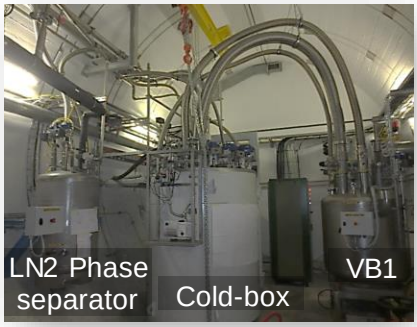
Lee Carver

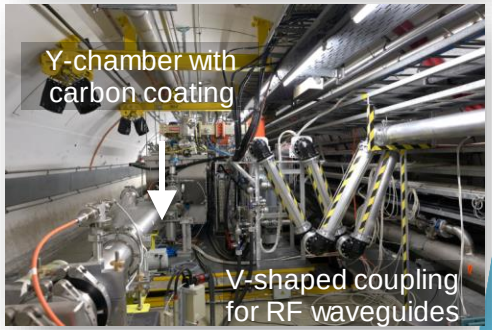
With significant input from:

H. Bartosik, P. Baudrenghien, T. Bohl, R. Calaga, T. Levens, B. Lindstrom, J. Mitchell, G. Papotti, N. Triantafyllou, E. Yamakawa & all other teams involved in the installation and support

15 June 2018 - CERN

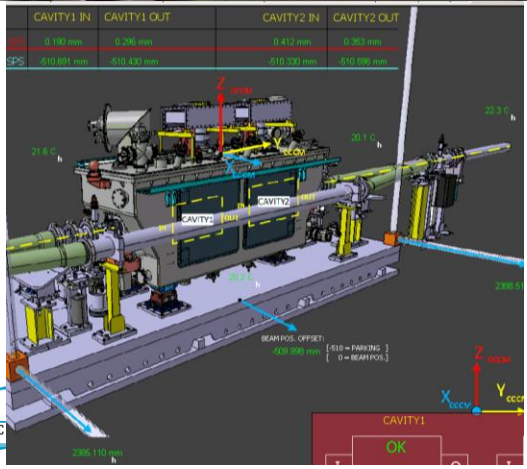
SPS-BA6 Installation



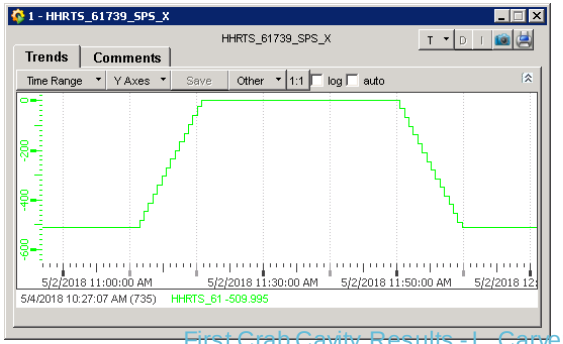


SPS-DQW Cryomodule

May 2, MD#0 for Equipment Check



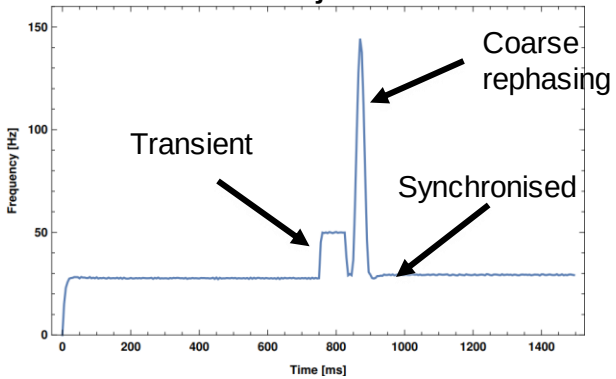
- Cavities moved with 60% LHe
- Test of interlocks: vacuum valves, access, liquid level
- Safe position table for beam confirmed by position switches (Parking, experiment)
- Absolute positions measured on line by EN Survey with FSI system, well within requirements (repeatable to within few μm)



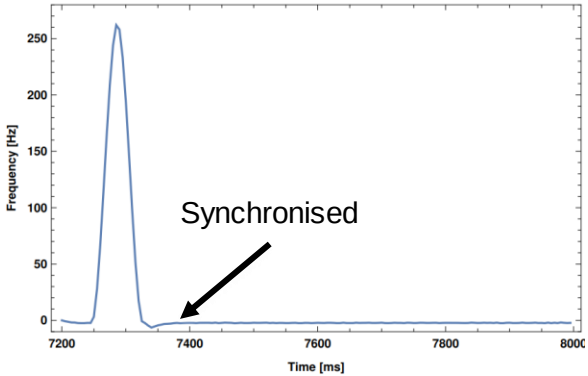
Crab-RF Sychronisation

- 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

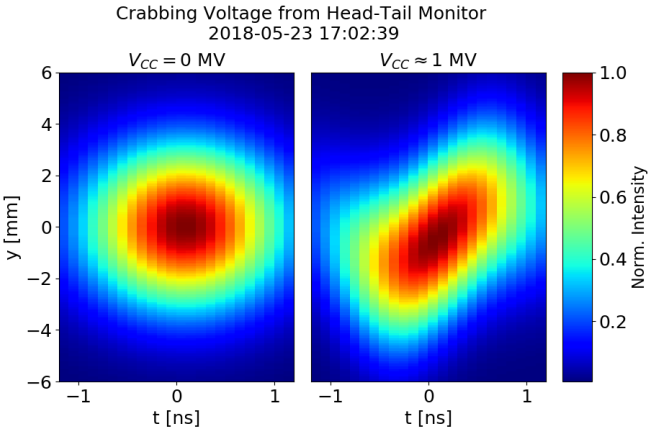
- Both cavities at 4.5K.
- Tuner loops both ok.
- No cavity feedback loop.
- Cavity 1 operated around 200-300 kV
- Cavity 2 less than 50 kV. Vaccum issues prevented going higher.
  - Not enough RF conditioning.

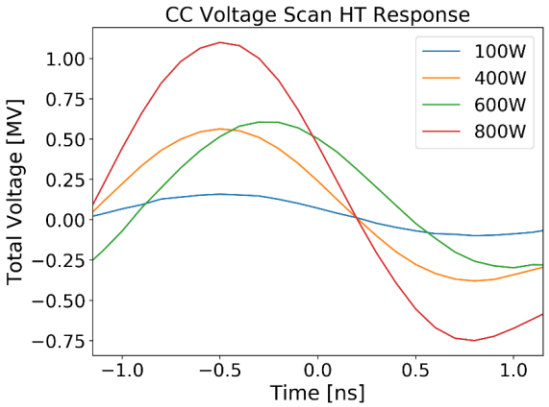
- Able to reach single bunch intensities up to 8e10 without issue.
- Performed some phase and voltage scans.

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.

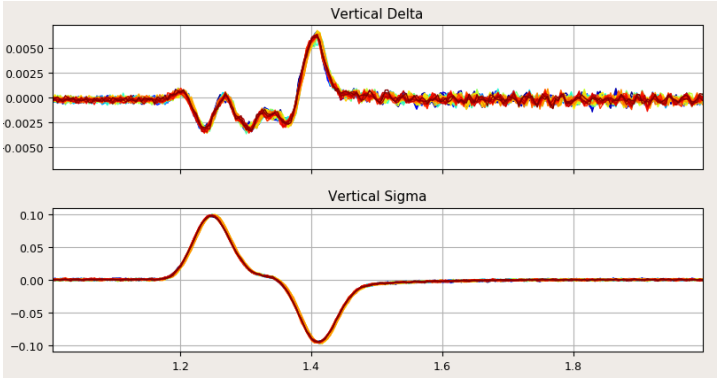
- When synchronised with the main rf, the crab signal vanishes into the baseline signal.
  - Need to remove the baseline without removing the crab signal.

- Step 1: Calculate baseline from delta signal acquired **before synchronisation**.

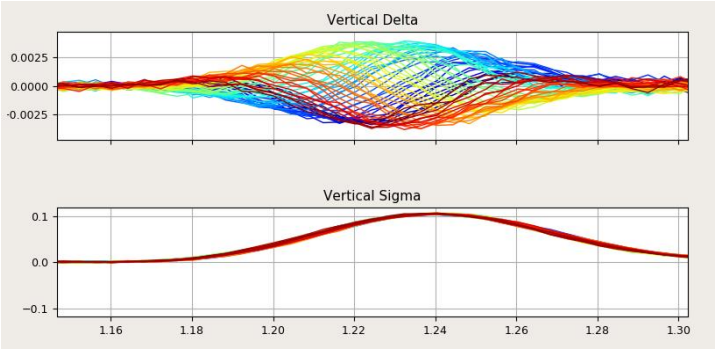
- Step 2: Take delta signal acquisitions of interest and subtract baseline. Divide by the sum signal and apply normalisation factor to acquire intra-bunch offset in mm.

Head-Tail Monitor

- Example of delta signal without baseline removal. Crabbing is in here somewhere…

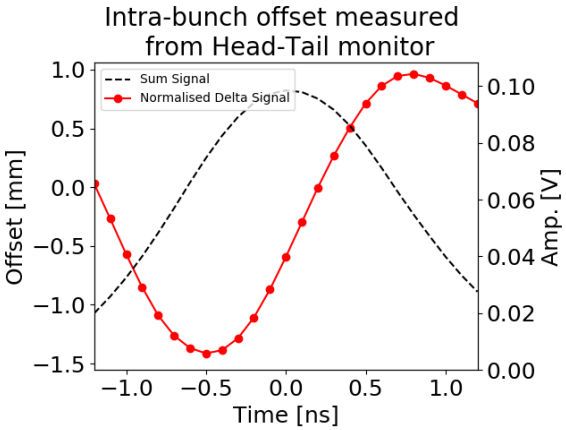


- Example of delta signal when cavity is <u>not synchronous</u> with beam. The baseline can be removed without affecting the crab signal because we only remove the average signal.

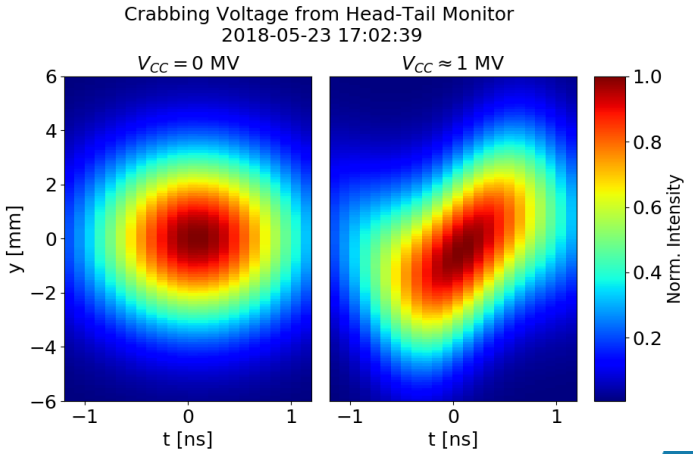


Head-Tail Monitor

- Dividing delta signal (with subtracted baseline) with sum signal gives intra-bunch offset.

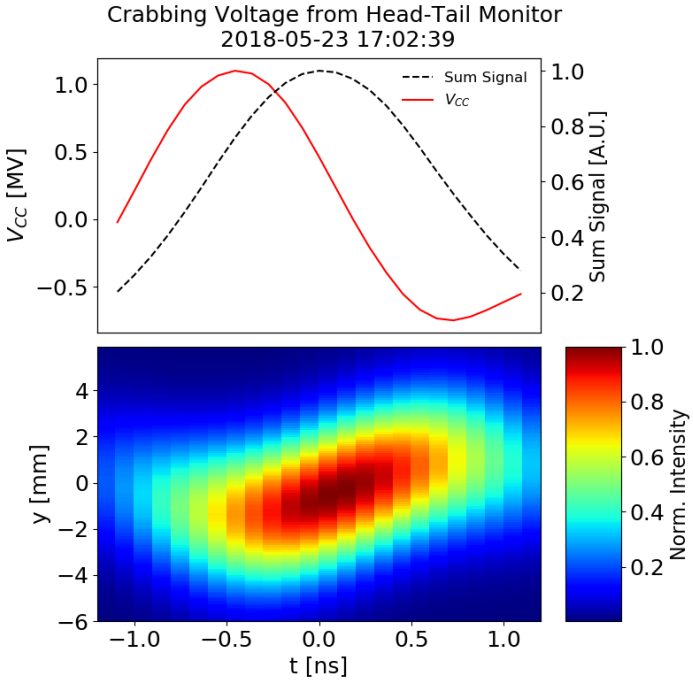


- Take the measured profile in z. Assume a Gaussian profile in y with sigma taken from wirescan.
- Modulate in z with intra-bunch offset.
- Make plot of reconstruction of crabbing!



Head-Tail Monitor

- Step 3: Using twiss parameters from MAD-X, calculate the orbit response bringing in phase advance, beta-functions and beam energy to convert mm to voltage.



Asymmetry in total voltage could be HT systematic.

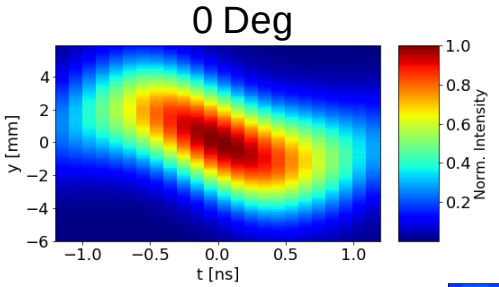
Cable transfer functions will be measured and corrections applied.

MD #2 Overview

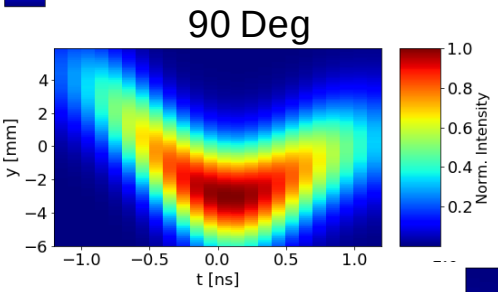
- Both cavities at 4.5K.
- Cavity loop working for cavity 1
- Cavity 2 minimal voltage due to vacuum limitation
- Independent cavity phase control possible.

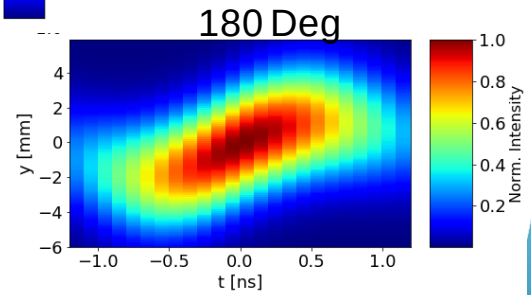
- Immediately performed an intensity ramp to nominal intensity.
  - No issues seen. Spent most of MD operating with Nb=1.1e11p.
- Performed orbit scans for electrical centering.
- Performed closest tune approach measurements to help setup for future measurements.
- Successfully ramped to 270GeV, first 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

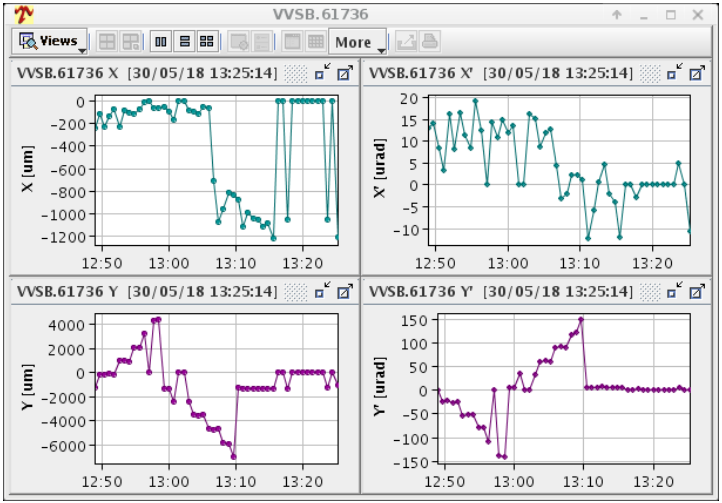




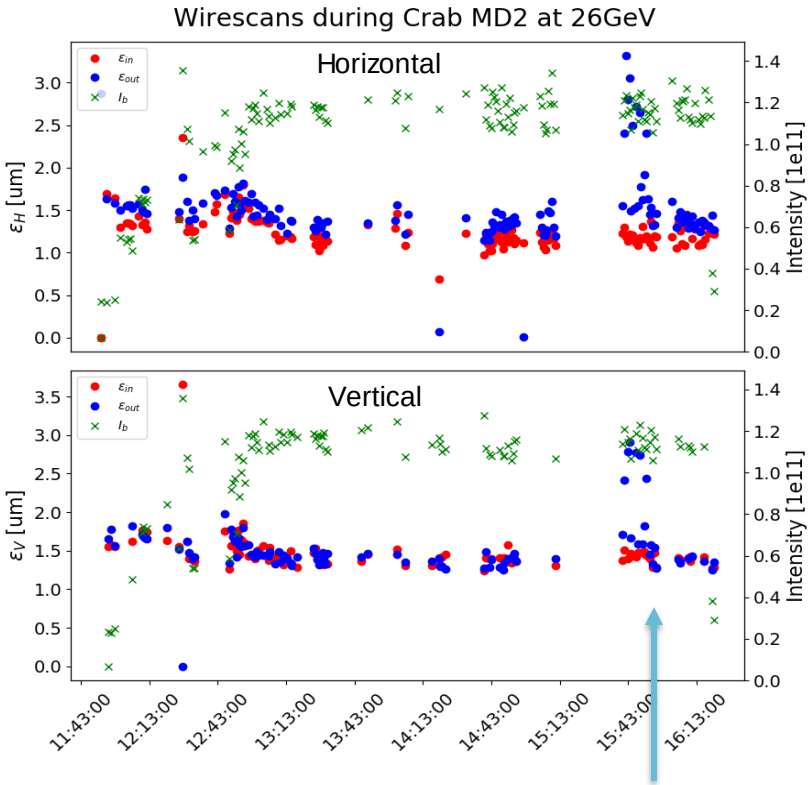
1 MV in cavity 1 (up to 2MV in some cases)
~50 kV in cavity 2, limited by cavity vacuum

MD #2: Orbit Bump for Electrical Centering

- First attempt at finding electrical center of fundamental mode.
- Some difficulty with measurement on the fundamental, parasitically measuring centering of HOMs.
- Data analysis ongoing, will repeat detailed orbit scans in MD3.



MD #2: Emittance Measurements



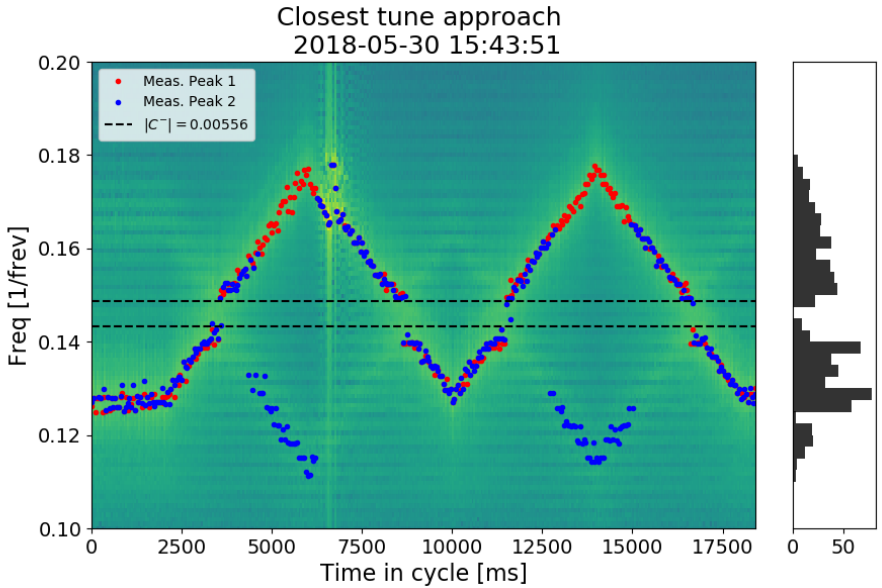
Start Cycle, ϵ_{in} (red)
End Cycle, ϵ_{out} (blue)
Vertical crabbing

Nothing systematic (in V) during 20 sec
Few percent increase expected.

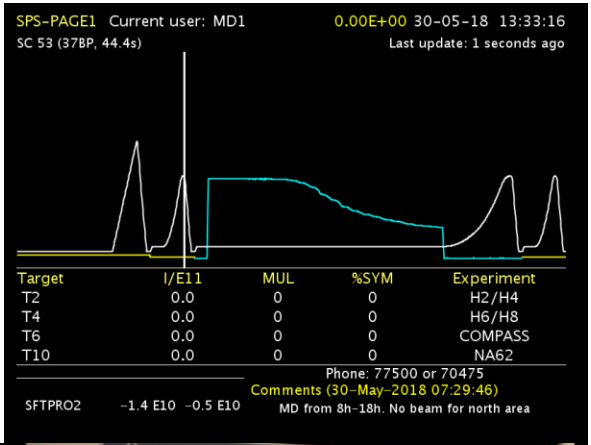
Tune crossing for $a3$

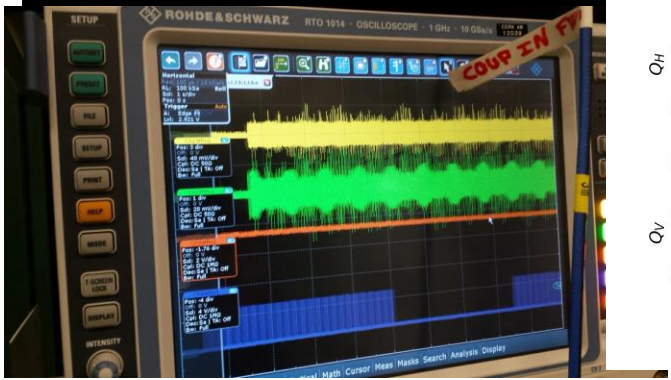
MD #2: Tune Crossing for a3 Measurements

- First attempt to determine the $a3$ multipolar component of CCs using closest tune approach.
- Better setup required for measurements.

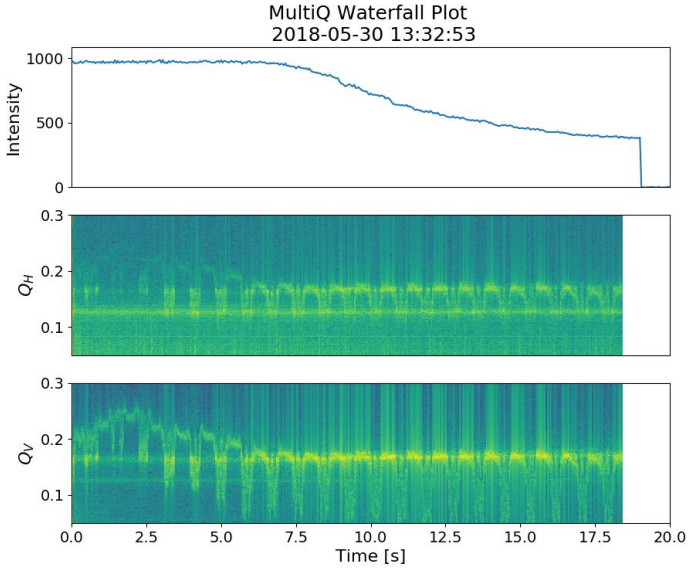


MD #2: 26 GeV Losses



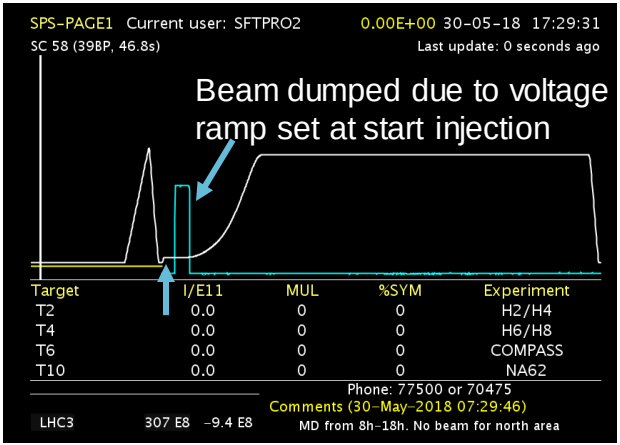


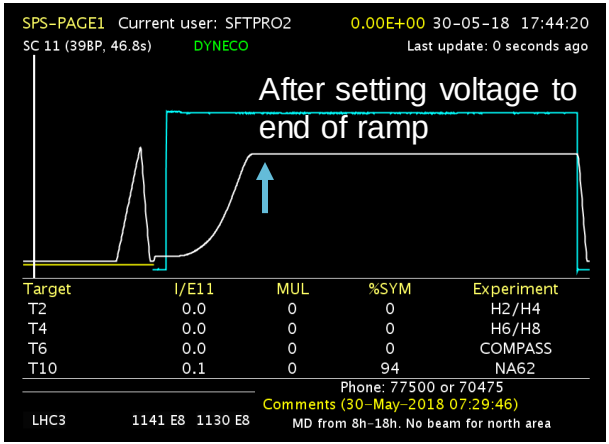
- Slow losses seen during one cycle.
- Investigations ongoing.
- Cavity tuner was being setup during this period.



MD #2: 270 GeV Ramp

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

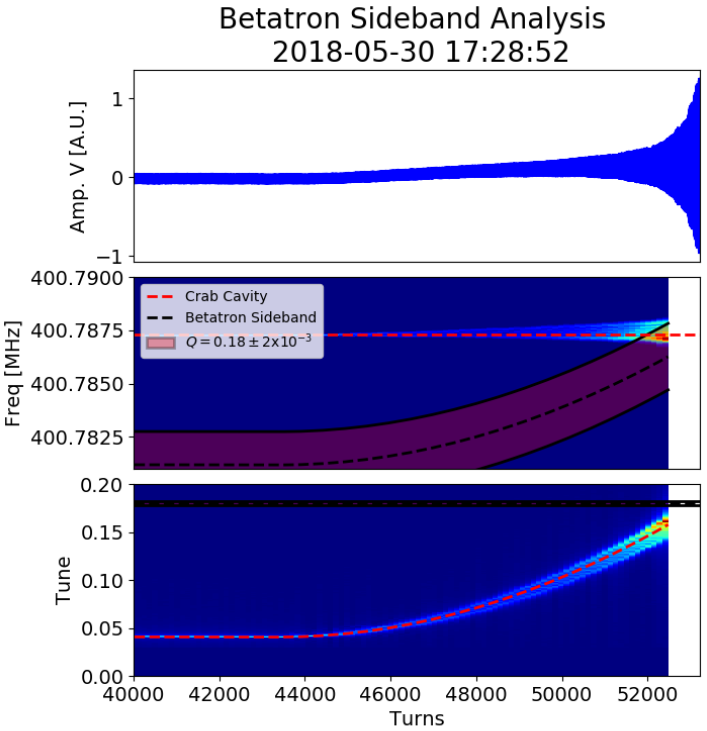




- Successfully reached 270 GeV with no CCs powered during the ramp.
- Checked with and w/o transverse feedback for nominal bunch intensities.
- Longitudinally unstable w/o 800 MHz

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.



Conclusions

- Crabbing seen in protons for the first time.
- Headtail monitor performance exceeding expectations, will be further improved with cable transfer function measurement.
- MDs so far have made the best use of the SPS time considering the status of the cavities.

Next Steps

- No MDs in June. Will attempt to establish 2K in the CCs ready for July MDs with increased performance.
- Further improvement of online analysis tools is underway.
- Cavity transparency and targeting higher intensities / multi-bunch are current priorities. Possibility for July?

Thank you