Crab Cavity MD Proposals - Preliminary

Proposal for MD1&2:

Main tasks:

- Beam capture
  - Check synchronisation between main RF and CC's without beam.
  - With cavities at ~10% of max voltage (300kV), inject a single low intensity bunch. Set tunes and chromaticity. Verify the orbit around the table.
  - Find minimum cavity voltage where all signals are measurable.
  - Check feedback RF loop (losses, emittance, lifetimes). Feedback transients during injection oscillations. Cross talk between feedback and crab cavity.
  - Vary cavity voltage and check behaviour of IOT supply to cavities with injection oscillations.
- Beam centering
  - Inject and dump cycle at 26 GeV.
  - Both cavities on with medium voltage (~750kV-1MV per cavity).
  - Scan orbit vertically and observe power output from IOT. 3-4 cycles per step.
  - Orbit steps can be found in Tab 1. Intentionally made to coincide with existing offsets used in bead pull measurements for easier comparisons.
  - Scan orbit horizontally to check field asymmetry.
- Check aperture in region of crab cavity
  - Not aggressive. Can be done in vertical using orbit bumps as vertical aperture is smaller.
  - Maximum offset in H < 20mm, V < 12mm
- Calibrate crab cavity phases and increase voltage.
  - Crabbing signal vs cavity voltage. What is the output from the Headtail Monitor or the WBFB pickups? See Tab. 2.
  - Scan phase of cavities and check orbit. Create a plot of rms closed orbit vs cavity phase.
  - Calculate the crab dispersion.
  - Increase bunch length from 1ns to 2ns and check impact w.r.t. RF non-linearities.
  - Is there a certain phase between the crab cavities that gives better signals than others?
- Ramp to coast energies
  - At the end of an MD, session, perform a quick check of a ramp to 270 GeV. Can the beam survive or is it lost in the process? Gives time to analyse results before next MD.
  - Crab as master, SPS RF as slave.
  - Cavity frequency set for synchronisation at 270 GeV. Cavities in transparent mode.
  - Ramp to the defined energy.
  - Cog the main RF to resynchronise the beam with the crab cavity.

Duration: 10-20 hours
Beam Requirements: Single low intensity bunch Nb=2e10.
Beam Settings: Qx, Qy= 26.13, 26.18, Q'x, Q'y = 1,1

To be filled	Orbit	Bump	Information

Table 1: Lookup table for some easy to implement orbit bumps. The step size and numbers used are to intentionally replicate bead pull measurements.

Energy	Voltage [MV]	Phase	HT [V] (Peak)	WBFB [V] (Peak)
26	1	0		

Table 2: Lookup table for determination of crabbing parameters by computing expected voltages at different diagnostics.

Energy	RF Trim	CC Freq	Tuner Setting

Table 3 Lookup table for some values relating to the RF trims applied to the main to bring it into synchronicity with the CCs.

Post MD1&2

It is proposed that, after the successful setting up of the crab cavities, failure scenarios can be studied in parallel with other tasks.

Failure scenarios can be driven (voltage drop, change of phase reference or detuning) and the beam position, crabbing and BLM signals can be synchronously triggered with high resolution.

The table below shows a checklist to be filled out (as best as possible) while progressing with other tasks. This will provide important information on the criticality of the tested failure cases for the SPS and the HL-LHC

Failure (right) Mode (below)	Voltage drop with LLRF*	Phase jump with LLRF*	Phase jump	Voltage drop	Detuning High voltage	Detuning on resonance
Priority**	1	1	2	2	2	3
Phased 55, (120), 270 GeV						
Transparent (26), 55, (120), 270 GeV						

*With the LLRF trying to compensate for the failure by matching the voltage/phase of the other cavity
** Priority 1 tests are considered realistic failures, whereas priority 2 are considered less realistic but would allow cleaner tests with fewer parameters to better validate the models. Priority 3 is considered improbable.

Beam Requirements: Preferably higher than 2e10, 1e10 could suffice if HT monitor signal is satisfactory.
Diagnostic Requirements: Synchronous triggering of BLMs, HT, and BPMs with cavity failure. (Preparation needed)

Proposal for MD3&4

Main tasks:

- Inject and then ramp multi-bunches with low intensities (1b, 6b, 12b, 48b) and set up cogging for desired energies
  - Cavities will be at 10% max voltage.
- Operate the cavities in transparent mode
  - Verify from beam diagnostics that no crabbing is detected (first record BPM orbit w/o CCs, and WS, and HT)
  - Ensure transparency for several single bunches (well separated).
- Move from transparent mode to phased mode adiabatically.
  - How many turns is needed to be truly adiabatic?
- Start increasing beam current
  - Nb=1e10 can go to Nb=1e11
  - Single bunch to several multi-bunches (still low bunch intensities).
  - Ensure transparency in each case.
- Compare cavity and cryo performance with beam vs beam intensity
  - Find minimum stable voltage and maximum stable voltage with beam of different intensities.
  - Cryogenic heat load
- RF gymnastics
  - Adiabatic ramping of voltage
  - Phase manipulation (anti-phasing, re-phasing...)
  - Long term stability - Coast MDs with several bunches and maximum voltage
- Measurement of a3 from crab cavity
  - Single nominal bunch at 26 GeV. Cycling mode.
  - Scan tune through third order tune resonance and observe losses.
  - Perform tune crossing to measure |C-| with both dp=0 and an offset dp using the rf trims.
- Tune shift with intensity
  - 26 GeV. Cycling mode.
  - Take many scans (10-20 per intensity point) and cycle through the intensities between 1e10 and 1.5e11.
  - Tune shift vs intensity can be compared for case with crabs in vs crabs out (crabs out will be measured in parallel MD).
- Failure Tests
  - Voltage drop and phase jumps with LLRF compensating with other CC
  - Voltage drop and phase jumpy without compensation
  - Continuous change of phase on and off betatron resonance

Duration: 10-20 hours
Beam Requirements: Single bunches with Nb=1e10 increasing to Nb=1e11. Short bunch trains, is it possible with bunches of 1e10 or do they need to be nominal?
Beam Settings: Qx, Qy= 26.13, 26.18, Q'x, Q'y = 1,1

Proposal for MD5

Main tasks:

- Emittance growth in coast at 270 GeV
  - Inject bunch with 2e10.
  - Set crab cavity up in coast at 270 GeV.
  - Operate cavity in phased mode and transparent mode and measure the emittance growth with the available diagnostics. Following an identical situation to the that used in previous MDs.

Energy: 270 GeV
Beam Requirements: Single bunch, Nb=2e10.
Crab Cavity Requirements: Phased mode and transparent mode.
Diagnostic Requirements: Wirescanners, headtail monitor, BSRT.

MPP Review Pre-MD6

Before commencing with MD6, a special MPP will be organised to review the experience gained with crab cavities before moving to higher intensities.

The following items will be reviewed:

- Measurements from cavities used to update the failure models
- Failure experiments compared with simulations
- Operational experience: failure rates, severity, time scales of failures etc
- Available mitigations and necessity of interlocking RF signals.

Proposal for MD6&7

Main tasks:

- Cavity stability with trains
  - Trip rate
  - What beam current can create a field strong enough to quench?
  - Effect of fast transients on the beam .
- Beam loading and coupled bunch effect with growing 4 corrector bumps at the cavity location.
- Phase shift
  - Fast operator request to shift phase of crab cavity.
- Cryo heating
  - Invoke a quench and observe transient behaviour of phase / amplitude.
- Exciting different HOMs with different filling schemes.
  - Inject different beam variants (1b, 12b, 48b, 72b) at 26GeV. (Individually, not all at once).
  - Information from HOM couplers can be used to calibrate HOM power with beam.
  - Will also attempt to strongly excite a particular HOM at 960MHz by potentially using a more exotic filling scheme (if needed. Will be confirmed in the future).

Duration: 10-20 hours
Beam Requirements: To be defined.