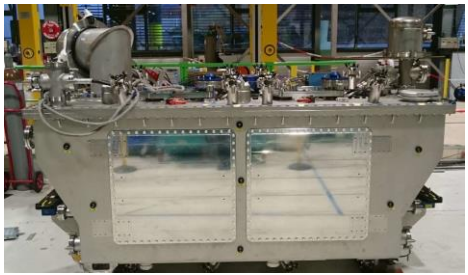
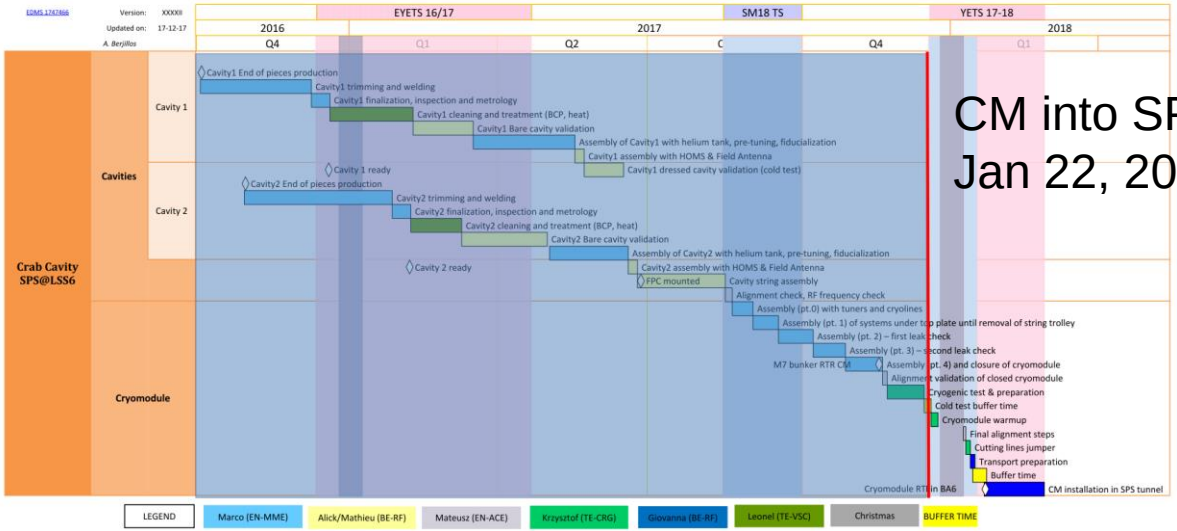
SPS Crab Cavity Tests

SPS Infrastructure & Hardware Status
Test Goals
Foreseen MD Time

On behalf of WP4
CERN

Since Chamonix 2017

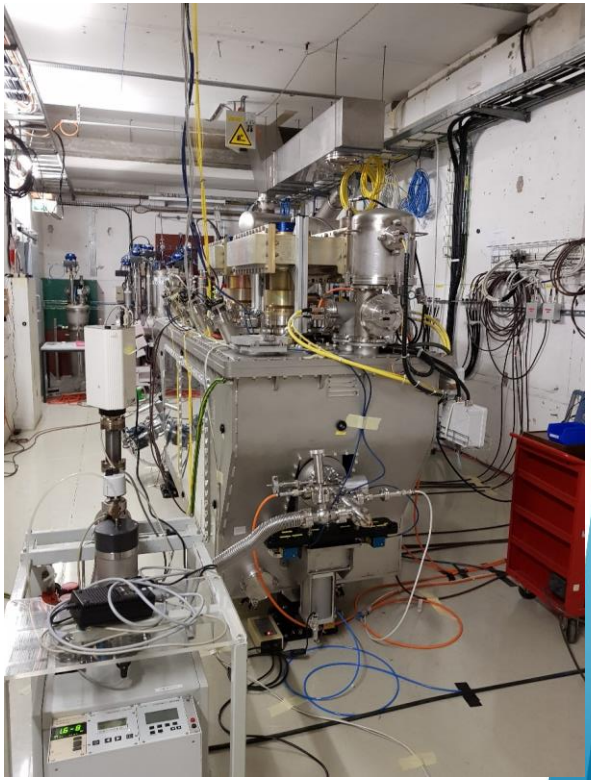




CM into SPS
Jan 22, 2017

SM18 Tests

SM18 Tests successful !



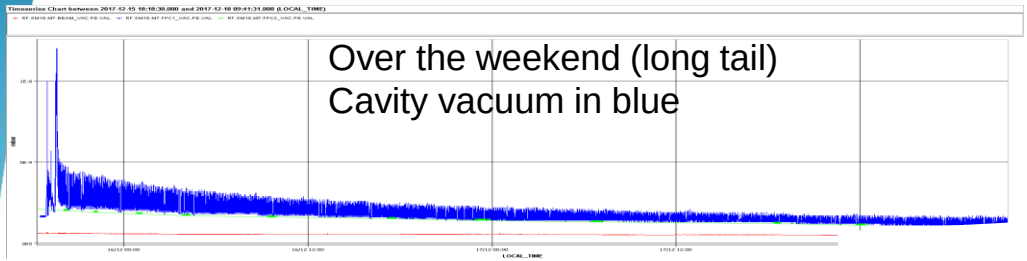
Big thanks: BE-RF, EN-MME, TE-CRG/VSC & all services

Overview SM18 Tests

Week: 47-48 SM18 Installation	Week: 49-51 SM18 Cool-down	Xmas TS	Week: 02-04 RF/Align Checks, Transport	Week: 4-7 SPS Installation	Week: 8-9 SPS Cool-down

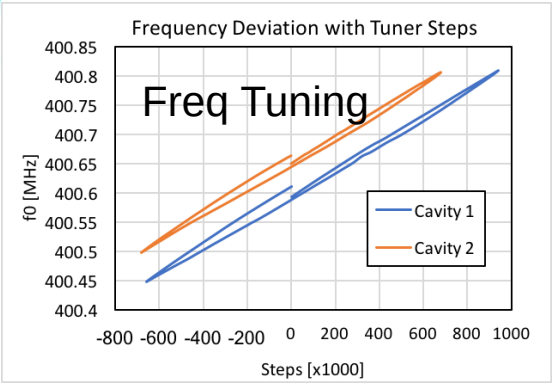
- Cryomodule tests in SM18
  - Two cool-down cycles performed (18 W static load)
  - Moderate RF conditioning, cavity tuning & LLRF tests successfully completed
- SPS installation
  - YETS activity in BA6 already began & is on schedule
  - Missing days are now gained with night shifts HC

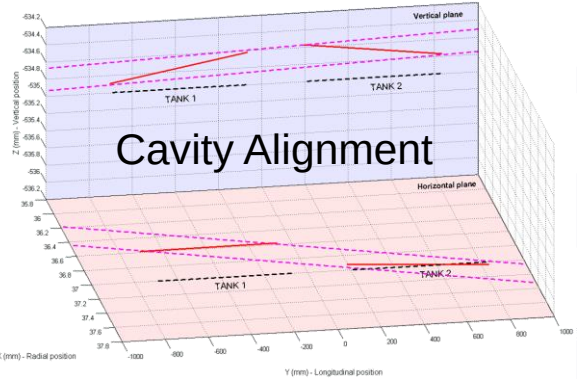
SM18 Tests, Summary

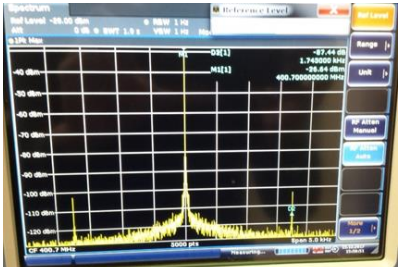


Over the weekend (long tail)
Cavity vacuum in blue

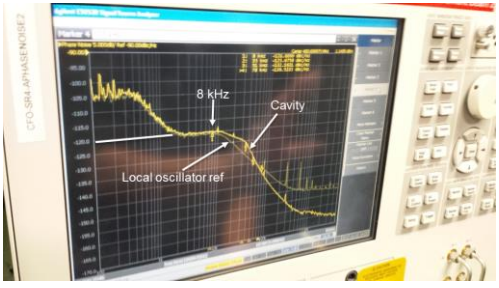
RF Conditioning



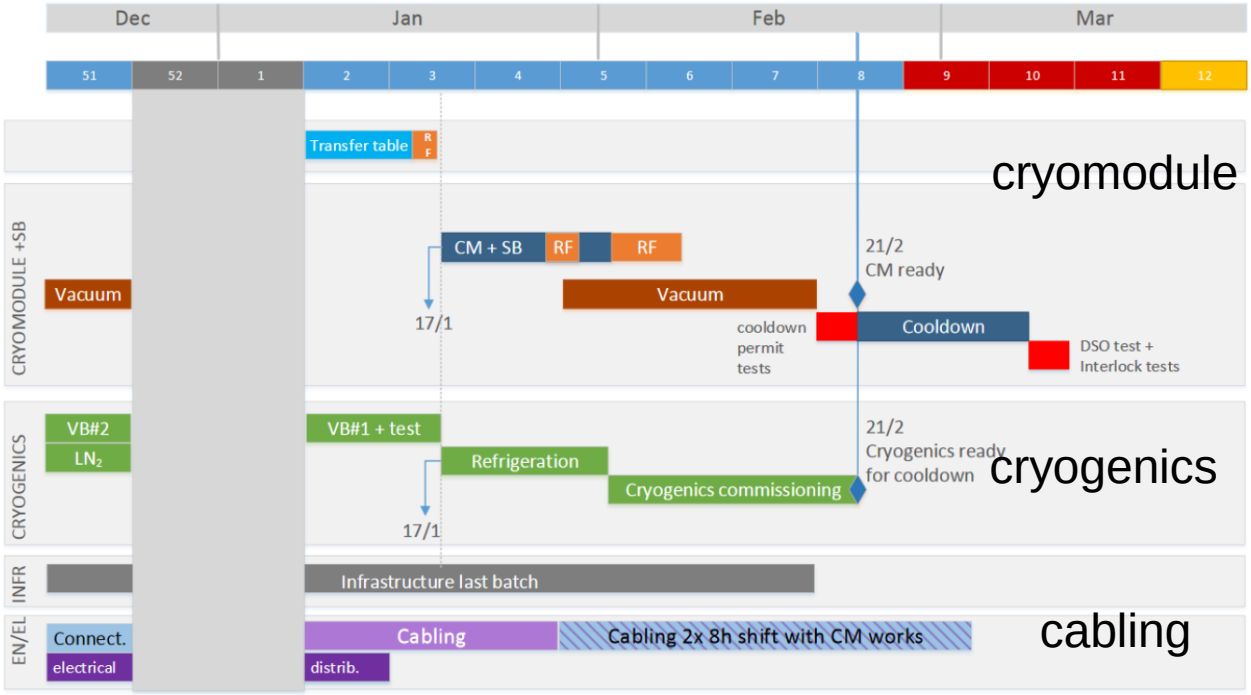




LLRF



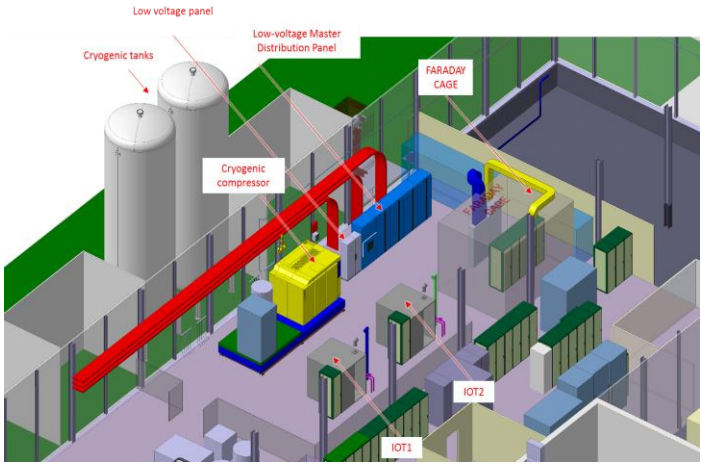
SPS Infrastructure (YETS)



Effective duration now 7 weeks

First week (51) only partial access, extra cabling

BA6-Surface Installation



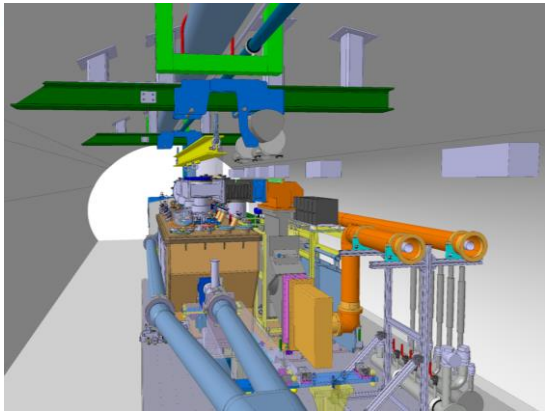
Transformer and GHe tanks

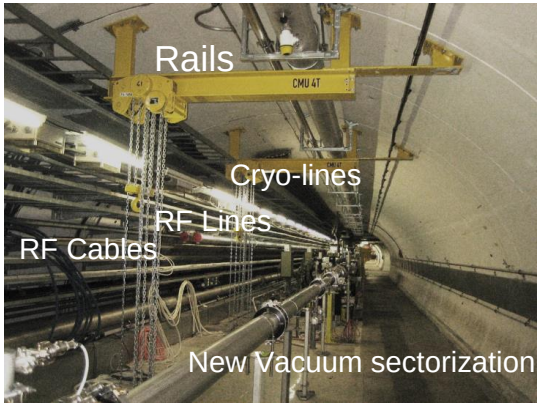
Low Voltage distribution

IOT RF Amplifier

Faraday cage

SPS-LLS6 Tunnel Installation





Transfer Table

Cryogenic distribution line

Valve Box

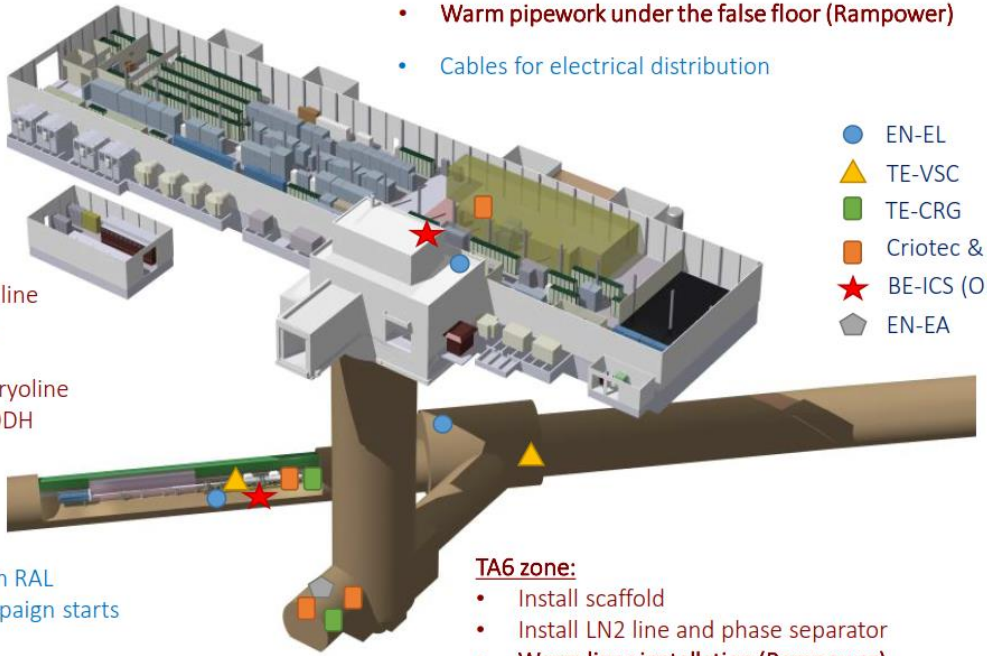
Week 51

DAY

DAY/ NIGHT

BA6 zone:

- Install ODH racks
- Drilling of wall for cryolines
- **Warm pipework under the false floor (Rampower)**
- Cables for electrical distribution



LSS6 CC zone:

- Dismount vacuum line
- Install heater tank
- Position VB#2
- Connect VB#2 to cryoline
- Install cameras + ODH

- Cable connectors in RAL
- Cables – 2018 campaign starts

TA6 zone:

- Install scaffold
- Install LN2 line and phase separator
- **Warm lines installation (Rampower)**
- Position VB#1 if possible (anyway before mid wk2)

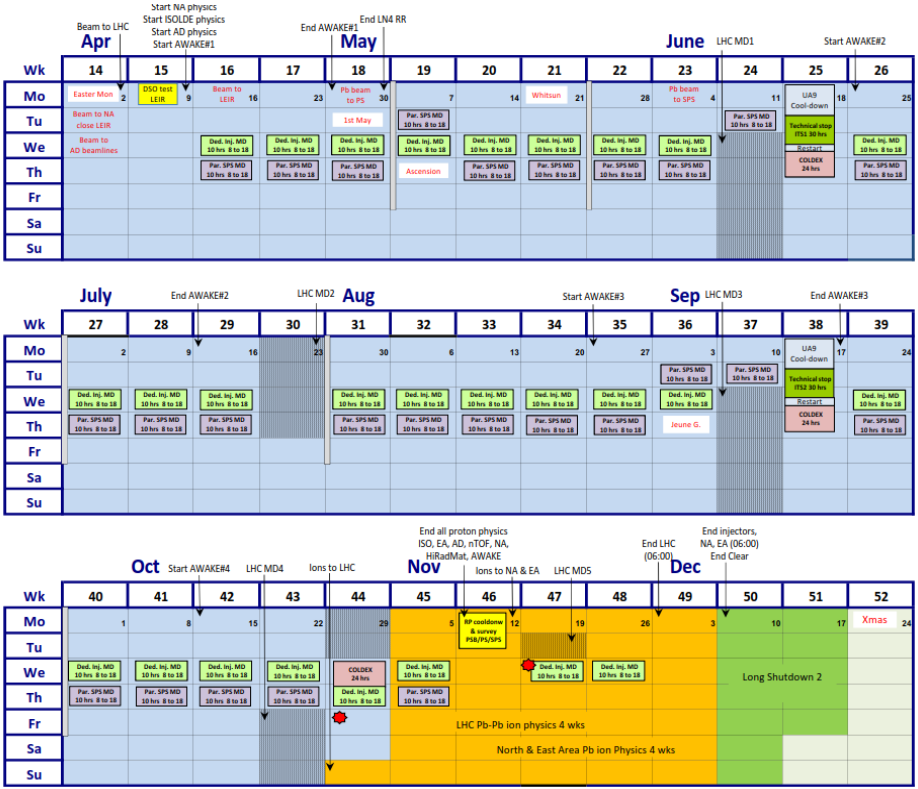
Expected SPS Test Sequence

	What	When	MD slots
0	RF commissioning (no-beam)	Mar-Apr	~ 4 weeks
1	RF-beam synchronization	Apr-May	2-4 x 10h
2	Transparency to beam	Jun-Jul	2-4 x 10h
3	Performance & Stability	Aug-Sep	4 x 10h
4	High intensity RF operation	October	2 x 10h

- Steps 1) & 2) mandatory to declare success for the 2018 SPS tests (will be dedicated MDs)
- Due to the complex movement of “cold” cryomodule in the bypass and hardware setup, early beam commissioning is essential for MD program into 2018
- Crab-bypass is designed for full remote control: **no need for access** for MDs

SPS 2018 (Draft) Schedule

- First MD slots in Apr 18 & May 2 foreseen



How to synchronize Crab-RF ?

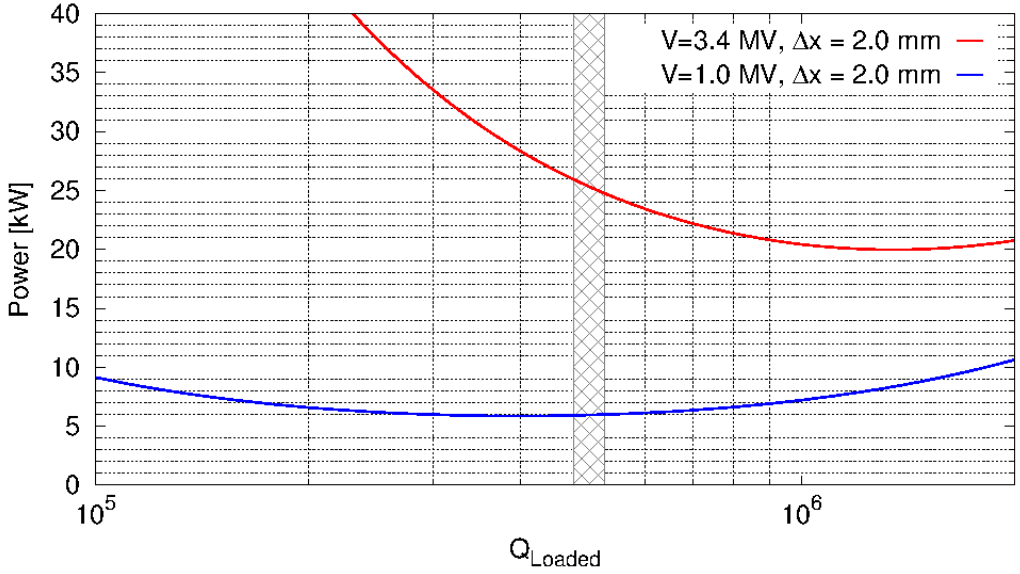
- Tuning range verification at $2\mathrm{K}$
  - Freq $(400.53 - 400.78\ \mathrm{MHz})$: $26 - 450\ \mathrm{GeV}$

- At Injection: LSS6 – LSS3 RF synchronization
  - Beam capture with at ~10% of the voltage $(26\ \mathrm{GeV})$
  - Closing of RF loops at injection plateau
  - Beam centering, crab-RF phase & RF power calibration

Cavity Parameter	Units	Value
Resonance frequency	MHz	$400.6 \pm 200\ \mathrm{kHz}$
V_T/ cavity (cw)	MV	$\mathbf{2.5}$
R/Q	Ω	420
Low field Q_0	-	4×10^9
Dynamic Load at 2.5 MV (3.4 MV)	W	$5\ (12)$

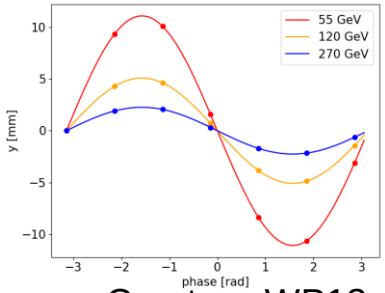
Sizing of RF Power (in SPS)

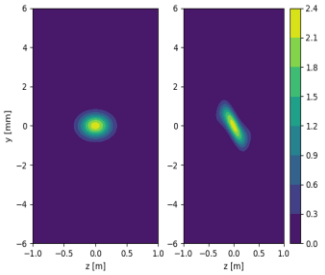
- Maximum required power with $I_b = 350$ mA (200 bunches, $N_b = 1.7 \times 10^{11}$p/b)
- Available maximum is 40 kW including in LHC



Is the Instrumentation Sufficient ?

- At 26 GeV, orbit response of ± 20 mm and implies ± 2 mm at 270 GeV (2.5 + 2.5 MV)
  - **BPMs**: Orbit mode resolution ± 0.1 mm, and trajectory mode $\pm$ 0.4 mm. Effect of RF non-linearity under investigation
  - **Head-tail monitor**: $\pm 100\ \mu m$ orbit resolution, we can observe a pk-to-pk $\pm 600\ \mu m$ oscillation at 270 GeV
  - **Wire-scanners**: Change in the projected emittance from 1 μm to 1.5 μm should be easily seen
  - **Synchrotron light monitor**: Non-destructively measure the projected emittance as a function cavity voltage





Courtesy WP13, Simulations: A. Alekou

What is the preferred Energy ?

- Available “coast” energies (55, 120, 270 GeV)
- SPS energy ramp ($26 - 450$ GeV):
  - Time for Energy ramp ~ 2 s → 250 kHz in freq. swing
  - Fixed crab cavity freq with beam re-tuning

- The crab kick (or tilt) inversely proportional to γ
- Effect more visible at injection, but beam better behaved at higher energies (shorter bunches & natural emittance)
- Beam-crab commissioning majority at **injection** and use **270 GeV** coast for long term stability

*LHC ramp: ~20min, 1kHz

Transient Effects ?

- Injection & beam centering
  - Injection oscillations (mm over ? turns)
  - RF power calibration between the two cavities
- Cavity alignment strategy for LHC (+ FSI)
  - Realize (measure) the $\pm 0.5\ \mathrm{mm}$ cavity-to-cavity offset
  - Implication of large orbit shifts in LHC ($\sim 5\ \mathrm{mm}$)
- Counter-phasing & re-phasing
  - The fastest feedback is limited to RF roundtrip delay ($1.3\ \mu s$ loop delay with $R_{\mathrm{min}} = 1\ \mathrm{M}\Omega$)
  - Counter-phasing for a “invisibility” (ex: $\pm 90^0$) including transient phase of energy ramp & squeeze
  - Re-phase the cavities adiabatically

Where are we with Emittance Growth ?

- After numerous MDs over the last years
  - The sweet spot for long term behavior is 270 GeV (or 120 GeV)
  - IBS explains only part of the growth, there is a natural residual growth similar in both planes ($\leq 0.5\ \mu/\mathrm{hr}$) – reproducible!
  - Chromaticity plays an important role, especially in the vertical plane
  - Identified source of de-bunching from RF feedback with low intensities

- Growth sensitive to beam energy but not to intensity, optics & initial conditions
  - A good candidate for the natural vertical emittance growth is the residual gas scattering
- Present estimate from existing crab electronics in SM18 (very noisy!)
  - Phase noise: $2 - 8\ \mu\mathrm{m/hr}$ (bunch length: 1.0-2.0 ns)
  - Amplitude noise: $0.8 - 1.4\ \mu\mathrm{m/hr}$ (bunch length: 1.0-2.0 ns)
  - From SM18 measurements, we expect noise to be visible

4) High Intensity Operation

- Beam induced failure scenarios as a function of bunch high intensity and number of bunches
  - Beam aperture near crabs needs some special attention (i.e. LHC extraction not possible)
- Cavity stability, trip rate, cavity quenches including fast transients to the beam
  - Trip scenarios are difficult to foresee, no obvious signs from SM18 until “quench field” ~ 3.3 MV
- Special attention to injection & ramp (parasitic impedance to beam)
- HOM power interlock at 200 W from any of the 6 couplers (RF feedthrough limit)