High Luminosity LHC

Crab Cavity Status

Outcome of the last 2 days

E. Jensen

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Crab Cavity Status

- Building on A. Ratti's "Crab Cavity Progress" on Wed. – looking at the Δ.
- This really was the "Crab Cavity 12" Workshop.
- We had 17 excellent presentations and lots of constructive discussions – also jointly with other WP's.
- Some questions will be addressed in upcoming "CC Engineering Workshop" at FNAL in Dec.

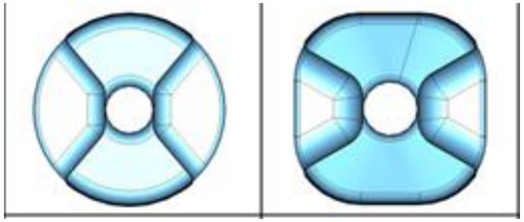
https://indico.cern.ch/conferenceDisplay.py?confId=136807

Required kick voltage

- Design kick: 10 MV /side /IP /beam – this is reached with 3 cavities. Our reference numbers!
- B. Dalena: Needed for full compensation: 11.8 MV … 13.4 MV; this could be reduced to 8.2 MV with new Q7+ .
- Our reference is compatible with the latter – but is this the overall optimum (cost!)?
- Let's see the prototype cavity performance and adapt design parameters then if needed. Keep engineering margin!.
- Even with reduced voltage, we should stay with 3 cavities (to reduce impact of single cavity trip)

Progress with Double Ridge (SLAC/ODU):

- Synergy 3 applications: 400 MHz (HL-LHC), 500 MHz (CEBAF deflector), 750 MHz (MEIC crab)
- Evolution from "round" to "squarish", field homogeneity can be optimized with electrode inner profile.

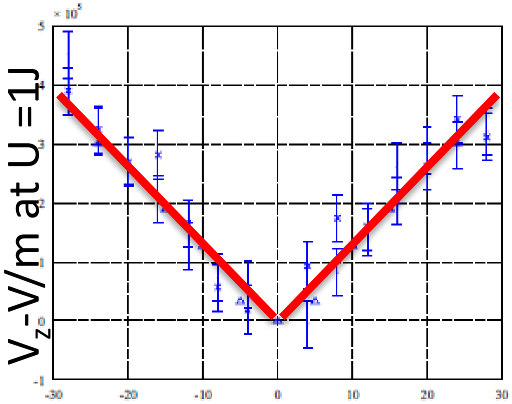


- 750 MHz prototype tested:
  MP manageable, no quench, Q_0 acceptable.
- 400 MHz prototype ready for tests at JLAB.

J. Delayen, S. Da Silva

Progress with 4-rod (ULANC):

- Field homogeneity can be optimized with electrode inner profile. Bead pull confirms field homogeneity in principle but error bars are large.



- Cavity buckling solved by stiffening ribs.
- Prototype ready, heat-treated, rinsed @ CERN, no BCP; ready for vertical test.

4-rod prepared for rinsing @ CERN

G. Burt, B. Hall

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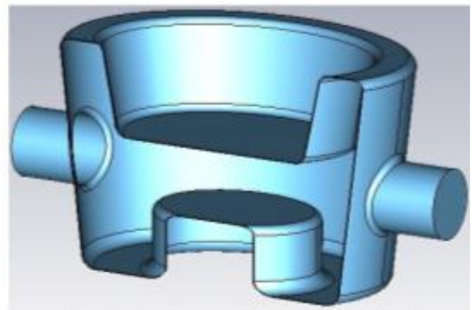
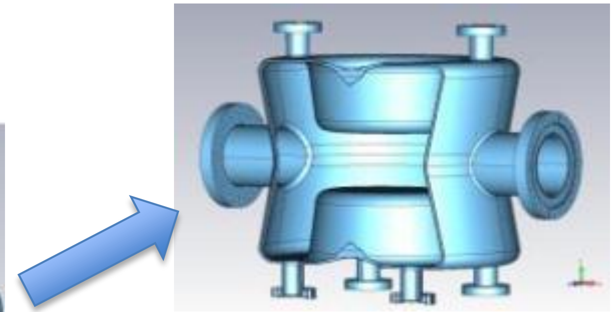
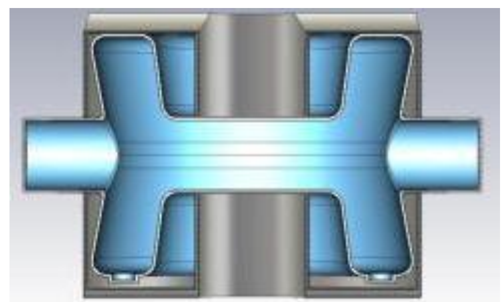
Progress with 1/4 –wave, now DQW (BNL)

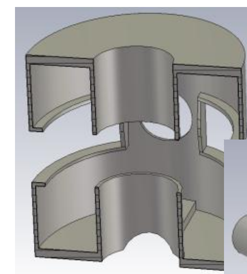
- Evolution to **symmetric**; *n*-pole error much reduced.

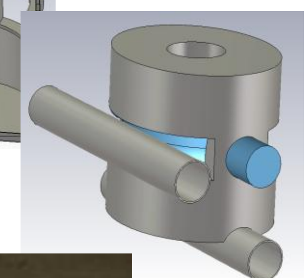




- Stiffening designed: idea to combine with He vessel







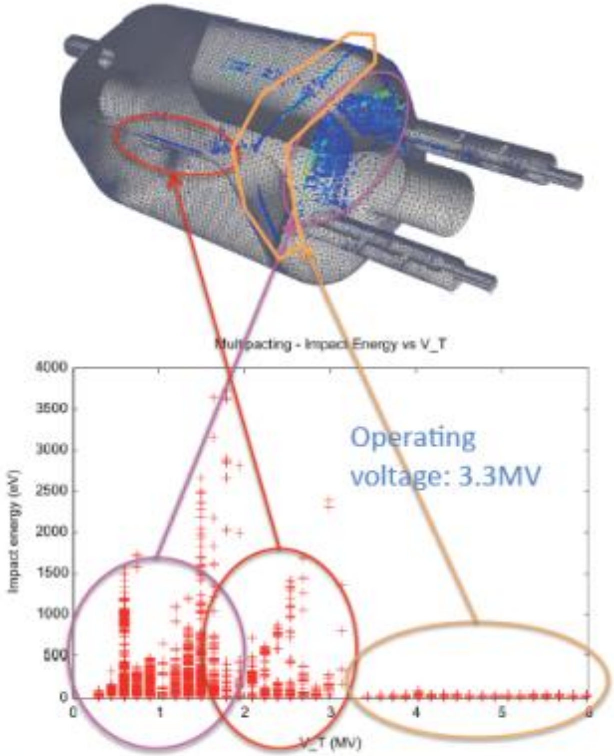
- Prototype: In fabrication; first pieces received

Pieces for QWR (cheer-up after hurricane Sandy)

Q.Wu, I. Ben-Zvi

All 3 designs:

- **<u>Common numerical tools</u>** used for comparative studies: HOMs, MP (ACE3P, Z. Li), *n*-pole (HFSS, M. Navarro-Tapia)
- HOM damping: suppression below (demanding) CM18 numbers achieved – also thanks to newly designed coaxial high-pass filters and hook-shaped couplers.
- MP simulations indicate:
  - MP at low fields is "soft" – can be conditioned;
  - MP at high fields has low impact energy.

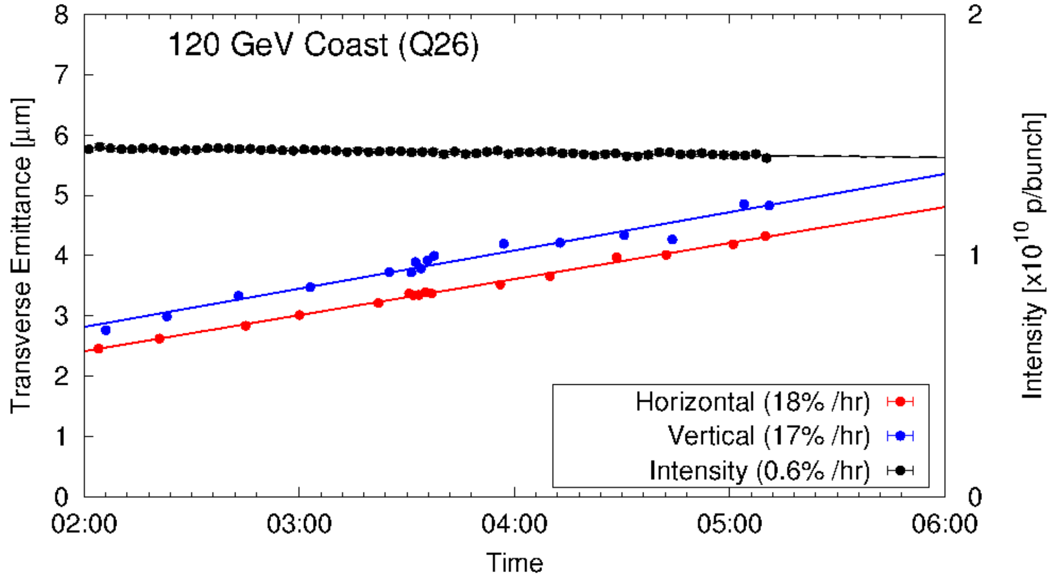


Z. Li

Getting ready for SPS tests

- SPS test is a must (LHC no best-bed!)
- Goal: Confirm that cavity can be made invisible; it would allow to try out operational scenarios.

  SPS beam may be too noisy to test additional noise injected from CCs.



R. Calaga, A. Macpherson

- Schedule: Prepare during LS1 (RF power, cryo) – install cavities X-mas break 2015/16 – perform tests in 2016

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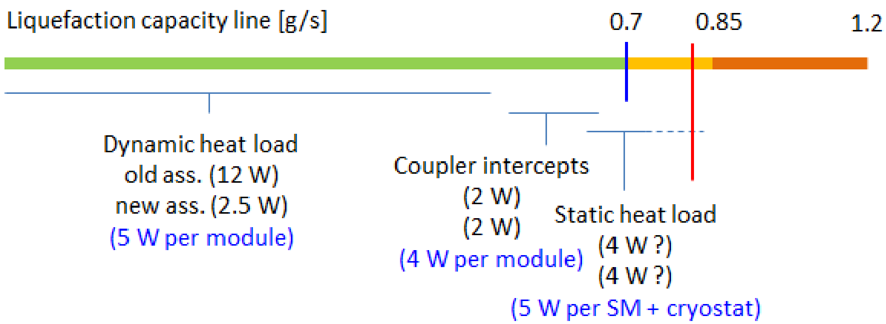
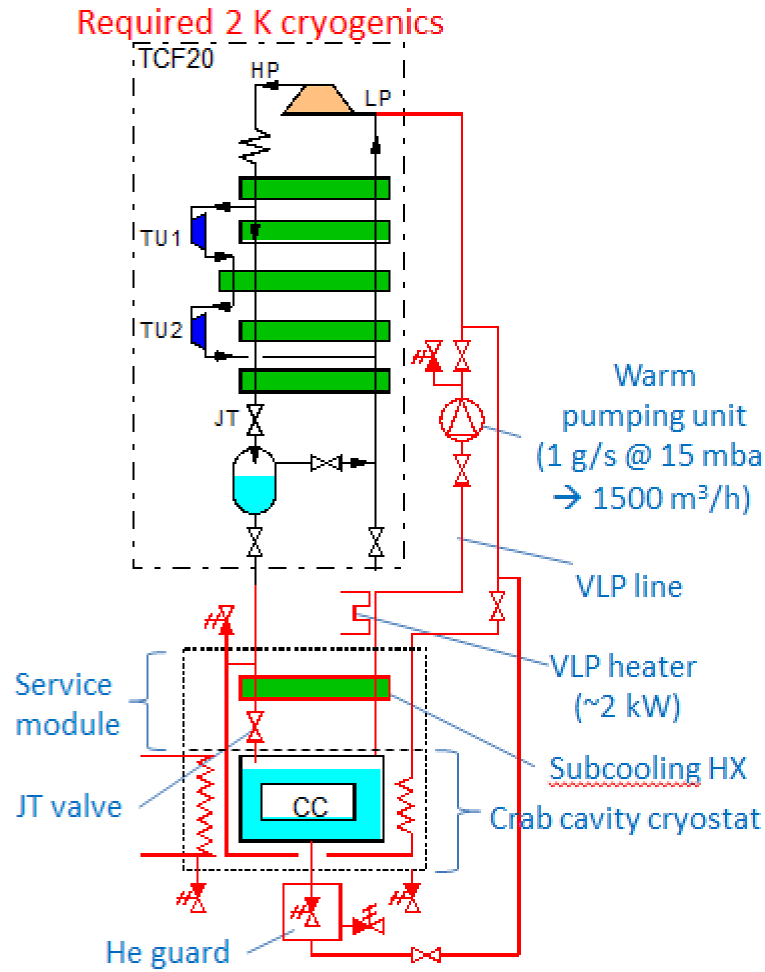
Cryo preparation for SPS tests

- Existing TCF20 should do, but liquefaction test must be done before 15-Jun-2013.
- Dynamic heat load assumed: 2.5 W/module.



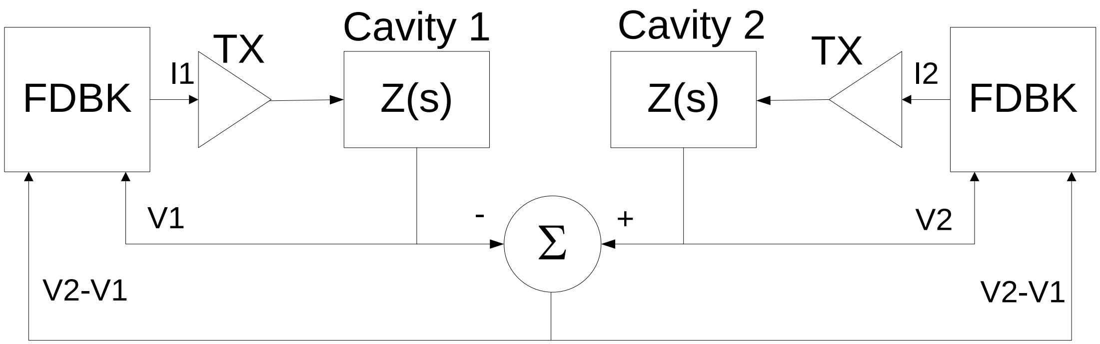
- Upgrade to 2 K during LS1.



K. Brodzinski

LLRF

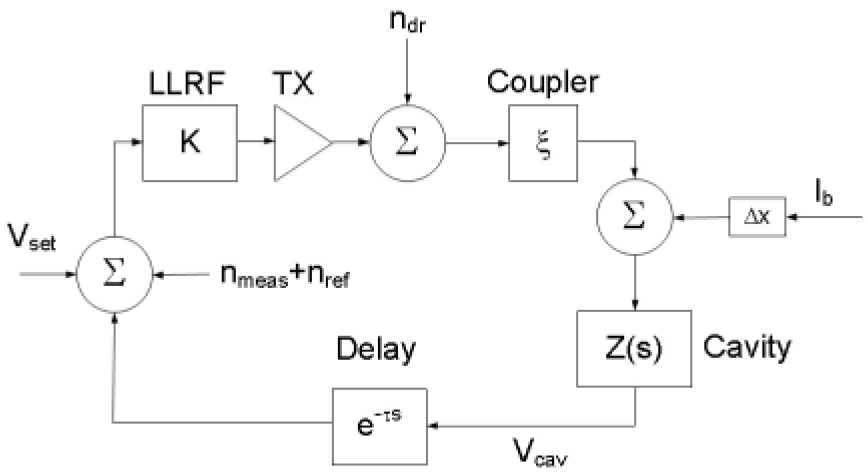
- Active feedback (as used in many modern RF systems) is key. It can reduce Z by loop gain. Limit: $R_{min} = \frac{R}{Q}\omega_0\tau_g$. For CCs approx. 50 dB.
- Large feedback gain increases BW. Trade off against noise!
- Coupled feedback interesting and challenging – required to minimize impact of single cavity failure.



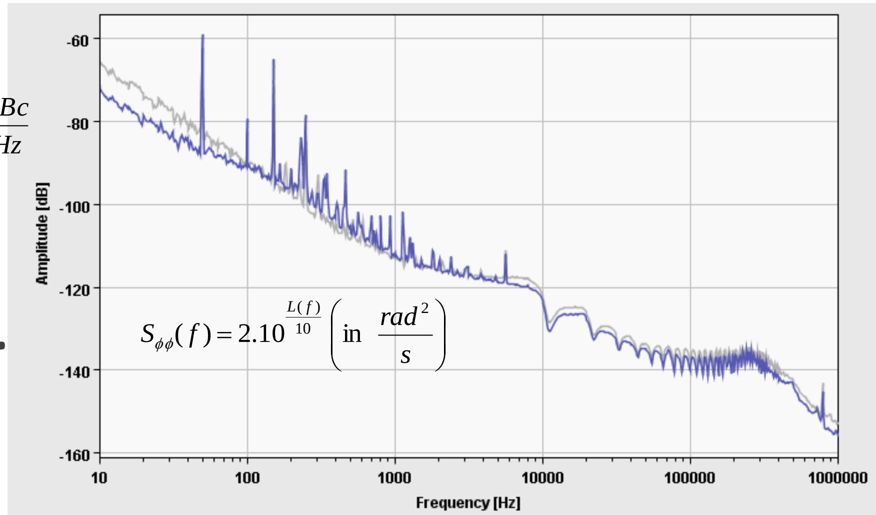
P. Baudrenghien

RF Noise

- Different noise sources have different spectra;
- 1st betatron SB 3 kHz off – dominated by TX noise.
- Tetrode/IOT advantageous.
- Scaling from ACS: expected 0.01 ° rms φ noise @ 400 MHz. This looks OK.



$L(f)$ in $\frac{dBc}{Hz}$



- Idea for noise measurement: excite on betatron SB.

Operational scenario revisited

- Strong RF feedback on at all times
- To keep CCs invisible during fill & ramp, detune but keep small voltage (active tuning) – dephase 3 cavities 120 ° to cancel. RF feedback provides add’l stability.
- On flat top, reduce detuning keeping V set-point small – RF feedback compensates BL. Once detuning is zero, synchronously change voltage on all CCs to desired kick.

- Much of this can be tried out, commissioned and verified in SPS tests!

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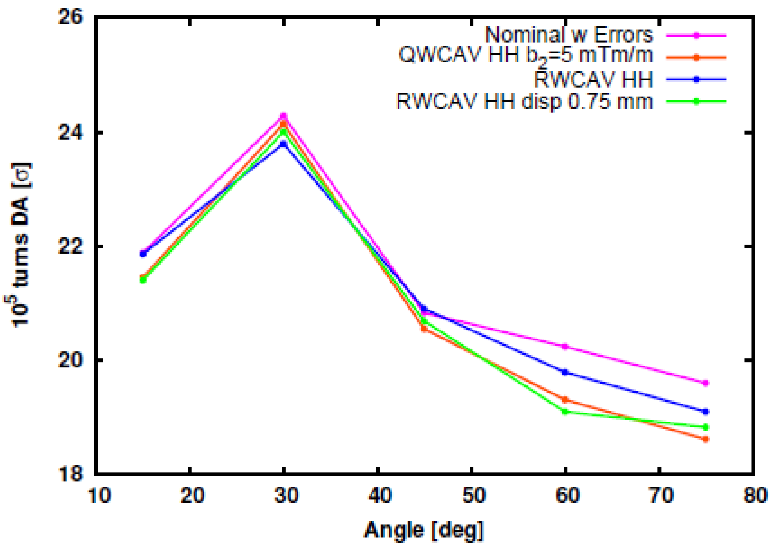
LLRF studies

- ULANC developed time-domain model so study LLRF behaviour including noise propagation
- Power requirement/position alignment:
  Assuming $\Delta y = 0.2\ \sigma_y$ results in 250 µm. RF power to compensate for this: 16 kW.
- Simulation result: assuming instantaneous quench: amplitude reduces to small levels before phase change significant.

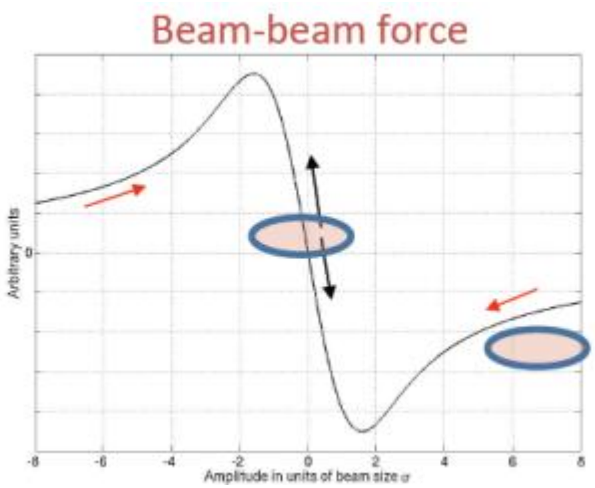
n-pole errors

- For the first time, SixTrack simulations could study the effect of *n*-pole errors on beam. Results can give also tolerable misalignments:
  - QWCAV (only HV) $|d_{x,y}| < 2$ mm
  - RWCAV (HH or HV) $|d_{x,y}| < 0.75$ mm
  - 4RCAV (HH or HV) $|d_{x,y}| < 2.7$ mm
- These studies were done with older versions of the cavities.
- n-pole fields with latest versions of cavities indicate globally even smaller errors.



J. Barranco, M. Navarro-Tapia

Luminosity Levelling



- Offset levelling successfully used for LHCb, but beam-beam forces may exclude this for high intensity.
- Crab cavities allow levelling, but CCs alone may result in inacceptable pile-up density
- β^* levelling alone is less interesting, but combining β^* levelling with CC levelling looks attractive.

T. Pieloni

Machine Protection

- One beam off – missing LRBB perturbs remaining beam $0.2\ \sigma$.

  Classification: slow | 1 s | fast | 10 ms | very fast | 0.3 ms | ultra fast

- Up to very fast (dominated by external Q) – there seem to be solutions. Most worrying: ultra fast (< 3 turns).
- Ultra-fast quench would lead to inacceptable displacement of $5\ \sigma$ with one and $1.7\ \sigma$ with 3 (decoupled) cavities.
- Can the “coupled feedback” be made reliable enough?
- Better control of transverse bunch population would help.

	Scenario 1: 3 CCs	Scenario 2: $\beta^* = 25cm$	Scenario 3: 800 MHz
CC frequency (f)	400 MHz	400 MHz	**800 MHz**
Number of independant CCs (n_{cc})	**3**	3	3
Q_{ext}	1’250’000	1’250’000	1’250’000
β^*	15 cm	**25 cm**	15 cm
Distance from collimators to be depleted below 1MJ.	1.7σ	1.0 σ	0.9 σ

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T. Baer, B.Y. Rendón

Discussions/brain storming

- Lots of productive/critical discussion throughout – this was really a "work"-shop.
- What instrumentation do we need for CCs – head-tail monitors, streak camera to measure remaining non-closure? What instrumentation do we need to make the SPS test a success?
- We need fast BLMs for MP (diamond?)
- We still need better understanding of possible (ultra) fast failure modes – cavity tests and in particular SPS tests will help this understanding.

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Summary – Crab Cavity Status

- This was a very productive workshop – I have learned a lot.
- Progress over the year and also during the last days was remarkable.
- I see improved co-ordination of activities and true collaboration between international partners.
- Thank you all for this effort.
- There remain challenges, but really interesting ones!

Thank you!

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