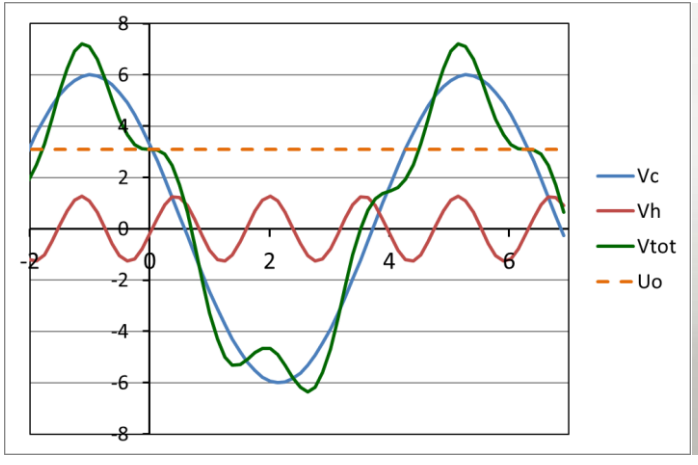
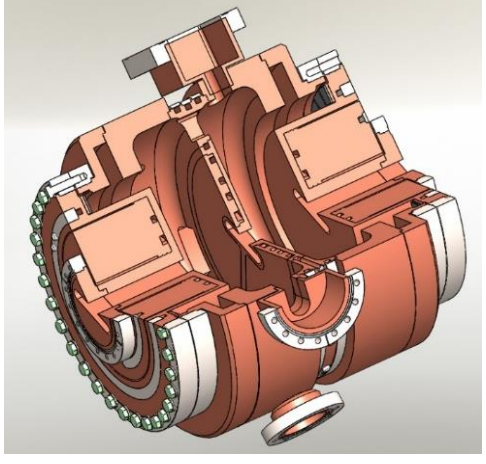
HarmonLIP Workshop

MAX IV / Lund, 10-12 October 2022

Harmonic RF project for ESRF-EBS

Lee Carver, Alessandro D'Elia, Jörn Jacob, Vincent Serrière, Simon White

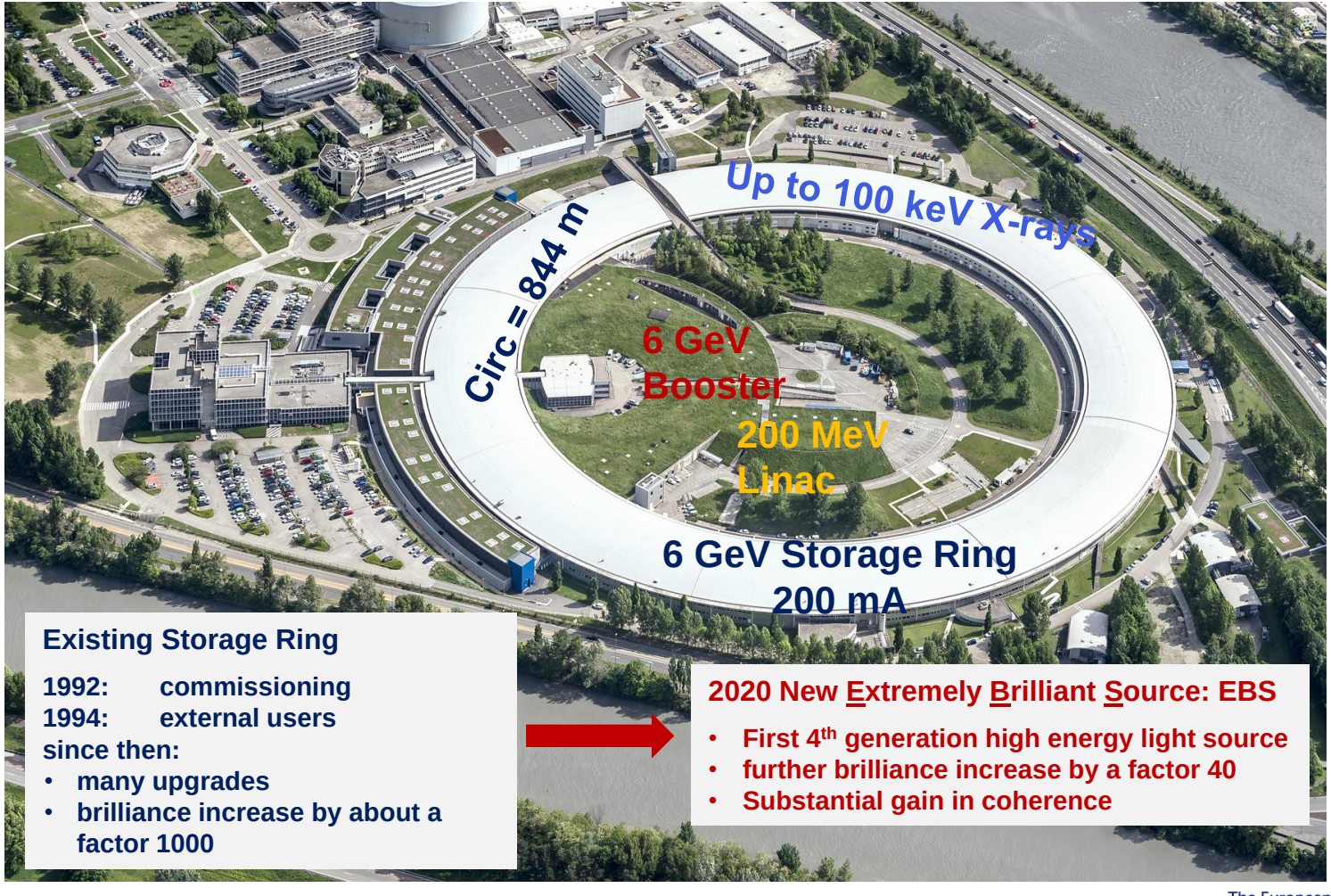




ESRF | The European Synchrotron

→ Part of this work has been performed within the frame of the WP2 collaboration among ESRF, HZB, KEK, PSI & SOLEIL

ESRF 1992: FIRST 3rd GENERATION SYNCHROTRON LIGHT SOURCE



Existing Storage Ring

1992: commissioning
1994: external users
since then:

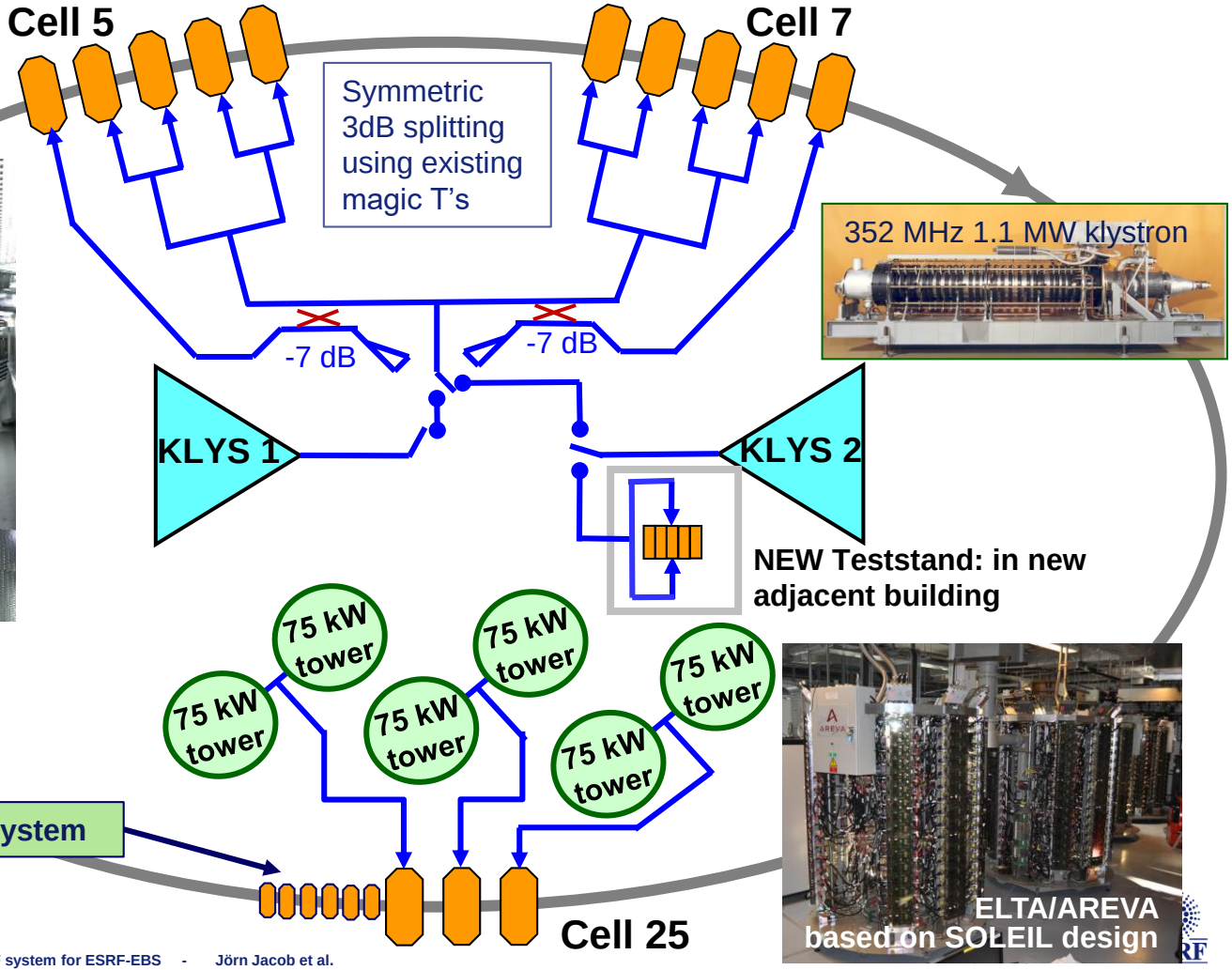
- many upgrades
- brilliance increase by about a factor 1000

2020 New Extremely Brilliant Source: EBS

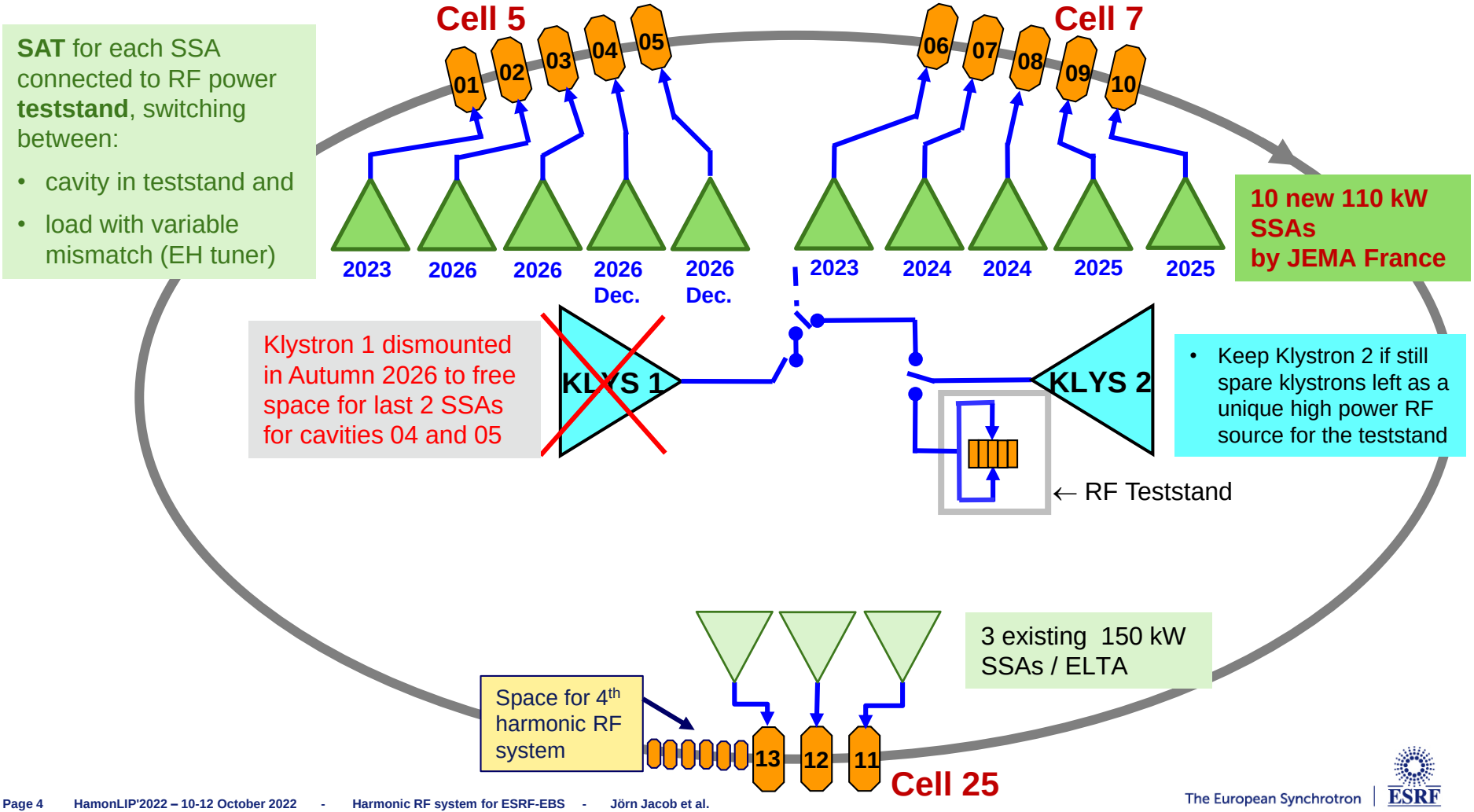
- First 4th generation high energy light source
- further brilliance increase by a factor 40
- Substantial gain in coherence

EBS RF SYSTEM LAYOUT

EBS Storage Ring



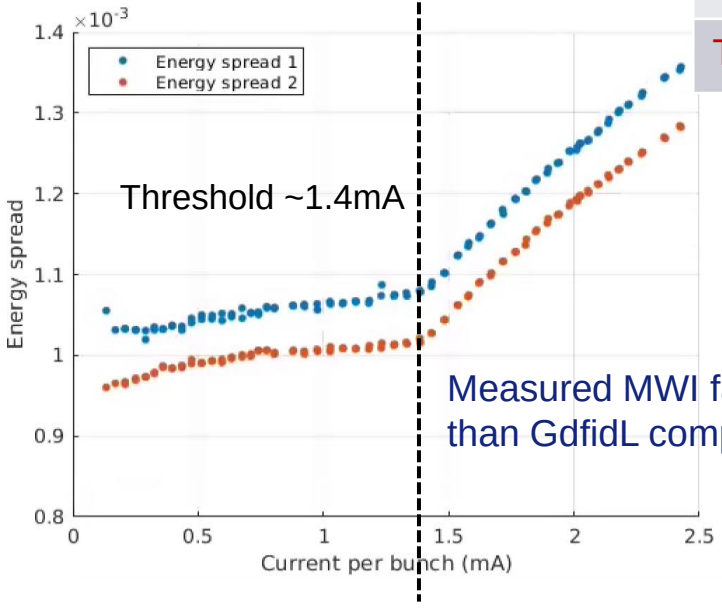
GRADUAL IMPLEMENTATION OF 10 SSA (EACH 110 KW RF, MAX 250 KW AC)



LIFETIME IN EBS

For all modes: Hor. Emit. ε_z = 135 pm	Multibunch 7/8 filling	16-bunches	4-bunches
Total current	200 mA	92 mA	40 mA
Current per bunch	0.23 mA	5.75 mA	10 mA
Bunch length (calc.)	13 ps	31 ps	37 ps
Vert. Emit. ε_z set at	10 pm	20 pm	20 pm
Touschek Lifetime	33 h	3.5 h	2.5 h

computed, not measured



Measured MWI factor 2 lower than GdfidL computation

[S. White, N. Carmignani et al.]

4TH HARMONIC RF SYSTEM FOR BUNCH LENGTHENING

Harmonic RF system at 1.41 GHz

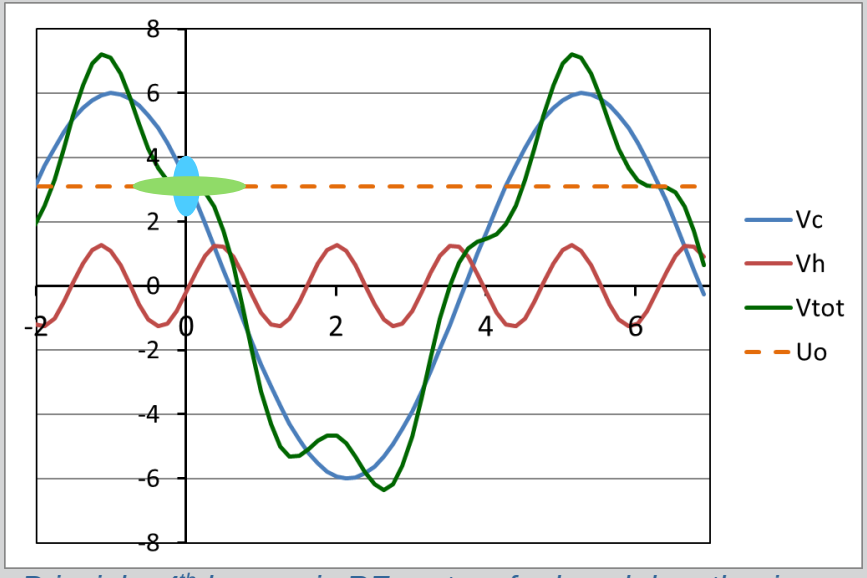
- Bunch lengthening by a factor 2.5 to 3

1st Priority for high I / bunch (16b and 4 x 10 mA)

- Reduced Touschek scattering, IBS and microwave instability:
  - Increased lifetime → less frequent injections, reduced loss rate and radiation load
  - Improved overall stability
  - Room for smaller In-Vacuum ID gaps
  - alleviate possible impact from future lattice developments like mini-beta straights
  - Reduced emittance and energy blow up
- Reduced heat-load and stress of critical chambers, like ceramic chambers or In-Vacuum IDs
  - → Today maximum 35 mA in 16 bunch and 20 mA in 4 bunch operation until installation of new ceramic Kicker chambers

2nd step: for multibunch operation

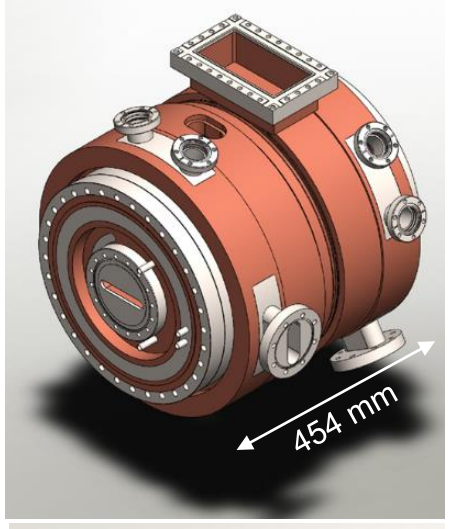
- Intrinsically less Touschek scattering, very low IBS, no MWI
- 7/8 filling → strong transient beam loading (TBL) almost impossible to avoid
  - Phase transients partly spoil bunch lengthening
  - ⇒ Minimize R/Q of harmonic cavities ⇒ E020 mode cavity

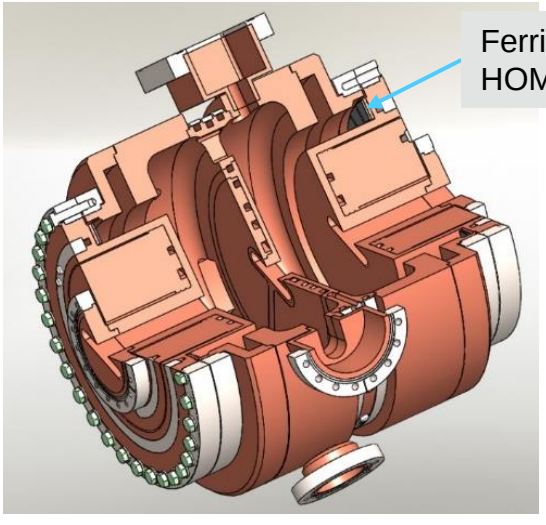


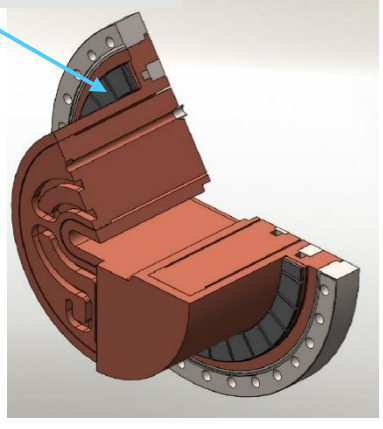
Principle: 4th harmonic RF system for bunch lengthening

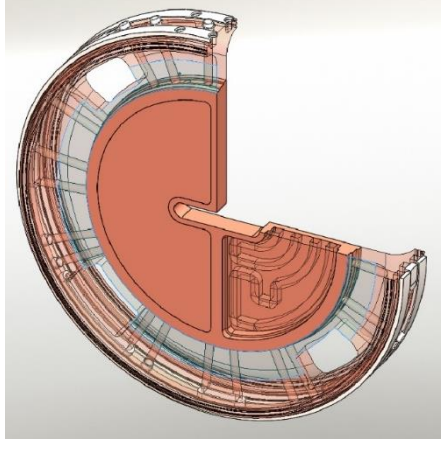
→ E020 mode cavity initially proposed by Naoto Yamamoto / KEK

4TH HARMONIC 2-CELL E020 MODE CAVITY – IN HOUSE DEVELOPMENT





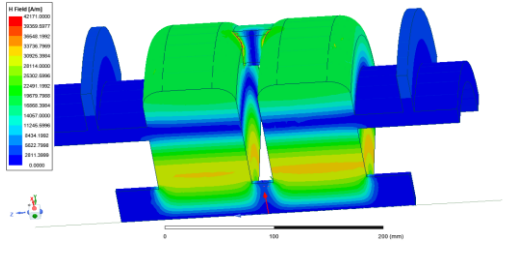




Active NC cavity design well advanced:

- ✓ 2 coupled and 2 uncoupled cells considered
- ✓ Freq = 1.409 GHz
- ✓ R/Q = 44.5 ohm/cell
- ✓ Q0 = 30500
- ✓ Smart HOM & LOM dampers almost not affecting Q0 of E020 mode
- ✓ Elaborate water cooling
- ✓ Aperture coupler: coupling $\beta = 1$
- ✓ Vacuum ports on HOM dampers also preserving Q0

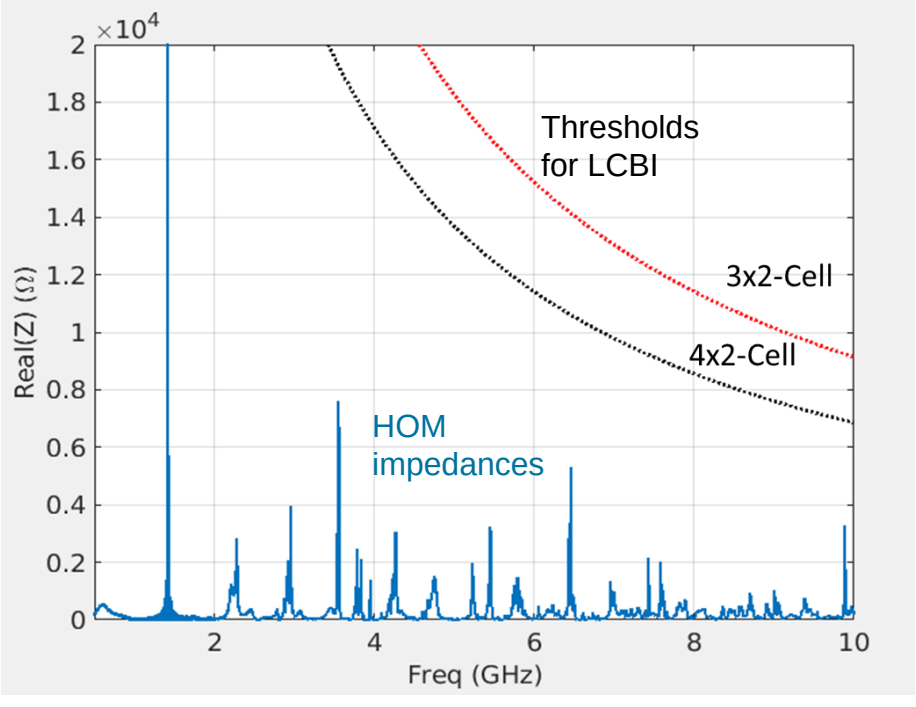
H-Field



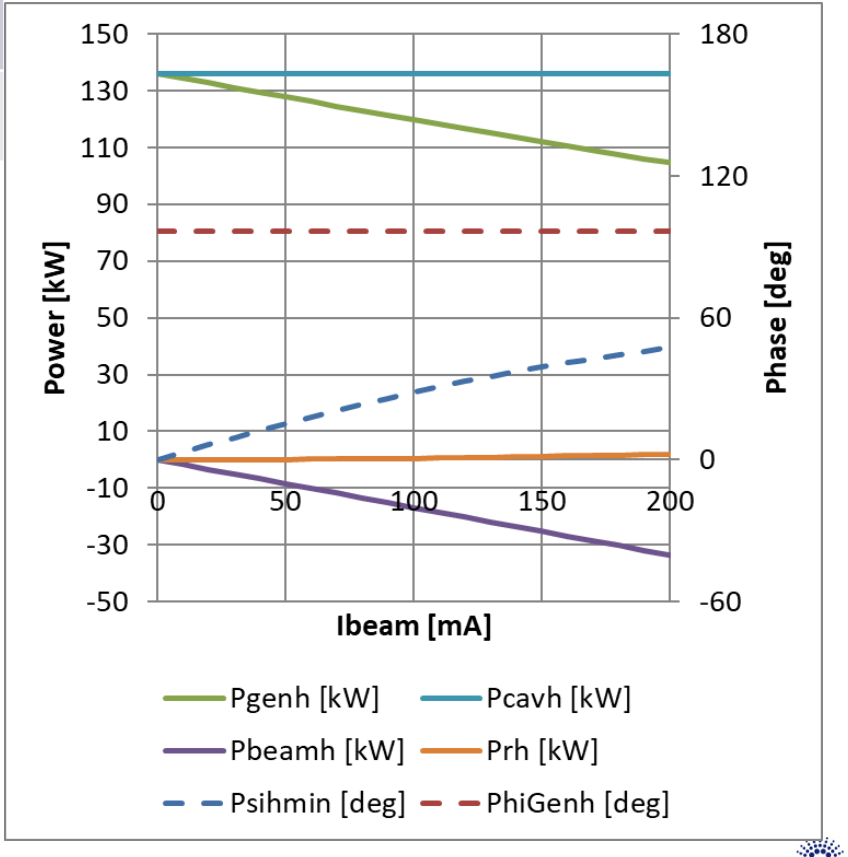
[Alex D'Elia, Vincent Serrière]

ACTIVE HARMONIC SYSTEM - POWER REQUIREMENTS

Main RF Voltage	Harmonic RF Voltage	3 x 2 Harm Cav cells	4 x 2 Harm Cav cells
6.5 MV	1.49 MV	46 kW	26 kW
6.0 MV (nominal)	1.35 MV	38 kW	22 kW



Optimum harmonic cavity tuning: **Load angle = 0** (exactly as for main RF)



SIMULATION WITH FERRITE INSTEAD OF PML REVEALED NEW CHALLENGE

Replacing PML with real ferrites in the 3D model:

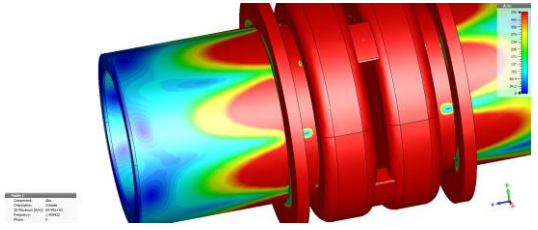
- revealed small azimuthal modulation of fields of TM020 / π-mode of coupled cells

→ coupling to higher order waveguide TE mode in coaxial HOM/LOM damper reaching ferrite ring

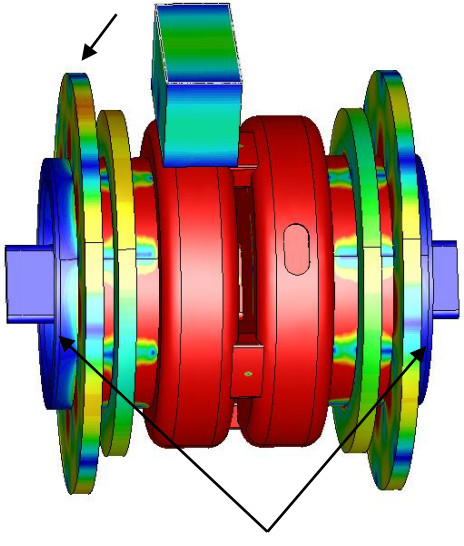
→ Reduction of Q by a factor 2 !

2 investigated possibilities to mitigate this problem:

H-Field penetration in the original structure



Additional choke



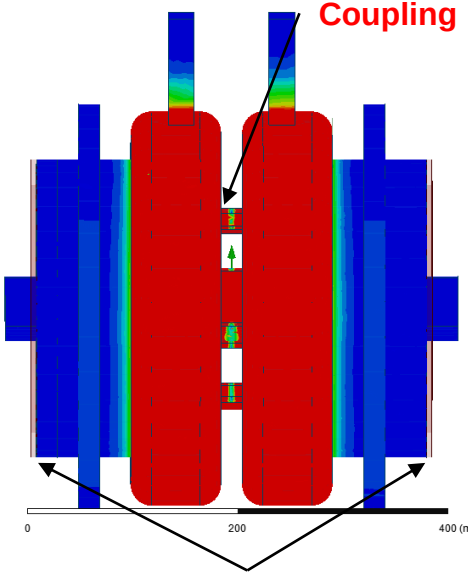
Ferrite Loads

Remarks:

1. Additional choke to stop TE propagation
2. Initial RF performances recovered
3. Power density at the ferrite after optimization ~10W/cm^2 (15W/cm^2 is the limit given by the manufacturer: being checked on teststand);
4. Cavity slightly longer (by ~80mm in total).

Possibility 1

Coupling lots moved towards cav' axis



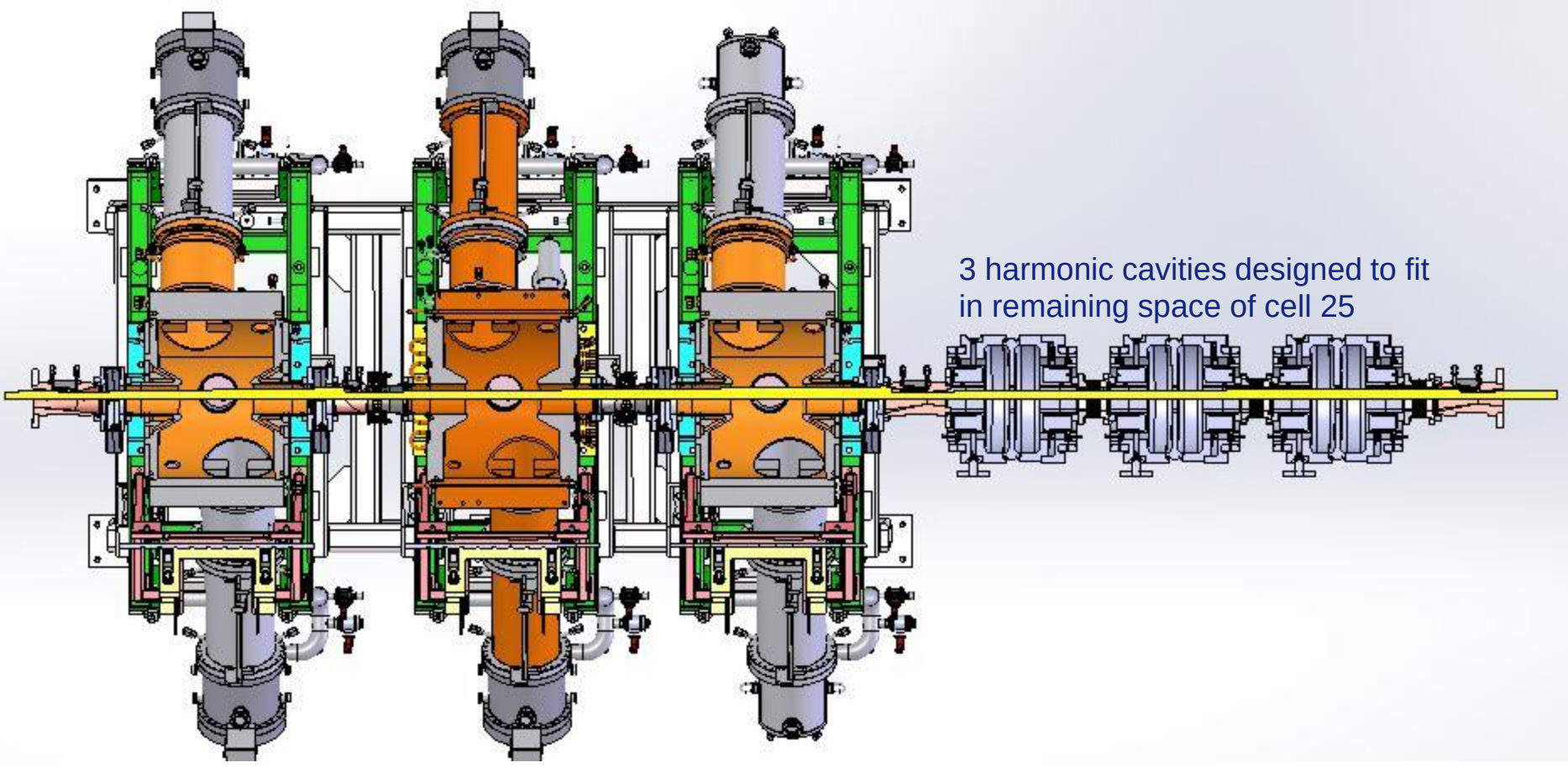
Ferrite Loads

Remarks:

1. 1 additional HOM damper per cell to stay within LCBI threshold
2. Q factor ~5% lower because of the HOM dampers
3. Power density at the ferrite ~15W/cm^2 (no optimizations done yet);
4. Review of mechanical integration of the disk needed
5. Cavity length does not change

Possibility 2

CELL 25 WITH 3 MAIN RF AND 3 HARMONIC RF CAVITIES



3 harmonic cavities designed to fit
in remaining space of cell 25

STATUS

Status and objectives:

- Challenging design of 4th harmonic cavity goes on: → Vincent Serrière's presentation of latest findings
- Launch procurement of cavity and 1.4 GHz SSA hopfully early 2023, including prototype phases
- Why not 3rd harmonic at 1.057 GHz ?
  - Existing 1.3…1.4 GHz SSAs was the main reason to go to 1.4 GHz fro an active system, now also high power transistors around 1 GHz
  - As suggested by Patrick Marchand: we could now also envisage a 3HC system
  - We would need 1.6 to 1.8 MV at 1057.11 MHz for 5.5 to 6.0 MV at 352.37 MHz,
  - Cavities expected to have R/Q = 44 Ohm, Qo ≈ 40000
- Collaborations :
  - Particle tracking simulations under way in a collaboration of ESRF RF and Beam Dynamics groups: → Lee Carvers's presentation
  - International exchange and bench marking → WP2 collaboration ESRF, HZB, KEK, PSI & SOLEIL, HarmonLIP
  - Planned collaboration with ESRF Detector & Electronics group for the development of a fast digital RF feedback system built with ESRF FPGA controllers
- Remarks on Active vs Passive and Robinson DC → J. Jacob's dedicated presentation
- Implementation on EBS possibly in about 3 years

MANY THANKS FOR YOUR ATTENTION