Implementation of new 352 MHz RF amplifiers and cavities in the frame of a general upgrade of the ESRF

Part 1: ESRF upgrade, by Jörn Jacob

Part 2: Transmitter options, by Jean-Maurice Mercier

ESRF

5th CW and High Average Power RF Workshop

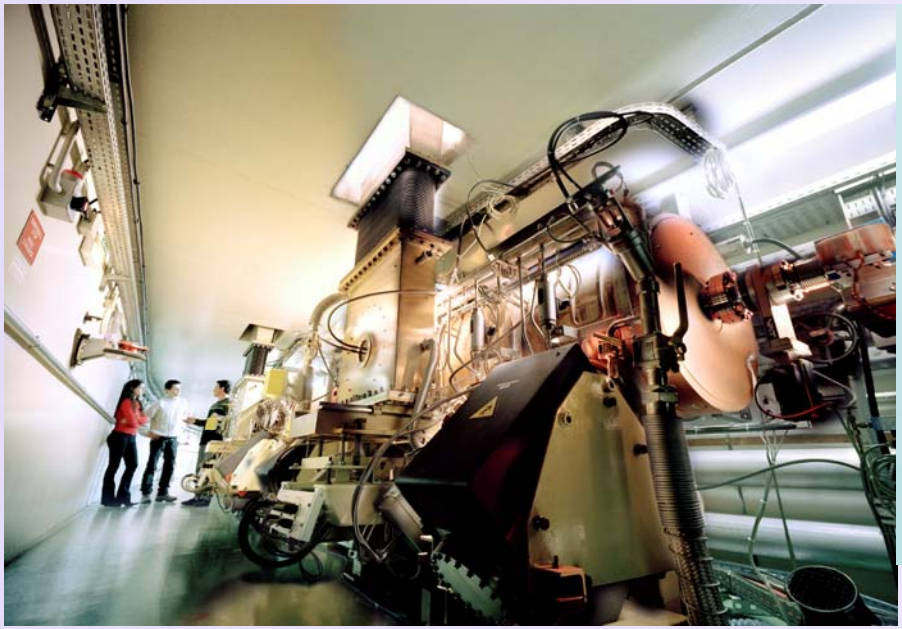
CERN – Geneva, 25 - 28 March 2008

ESRF upgrade for coming 10 years

- Science oriented ESRF upgrade
  - Reconstruction of X-ray beam lines
  - Extension of the experimental hall, new labs and offices ⇒ +30% increase in building surface
  - Nano science → creation of up to 130 m long beam lines

- Accelerator – upgrade
  - Current increase to 300 mA, R&D for 500 mA
  - Lattice modification for longer ID straights: 5 m → 7 m
  - Top up for few bunch operation / high I_{bunch} ⇔ short lifetime
  - Vertical emittance reduction ε_z : 25 → 10 pm
  - Equipment upgrade for performance increase and to strengthen durability
  - **Substantial RF upgrade for stable and safe operation at 300 mA**
    - ◊ **HOM damped cavities**
    - ◊ **Solid state amplifiers**

Existing 352.2 MHz RF system



6 five-cell cavities on the storage ring

R/Q = 139 Ω / cell *Qo = 38500*

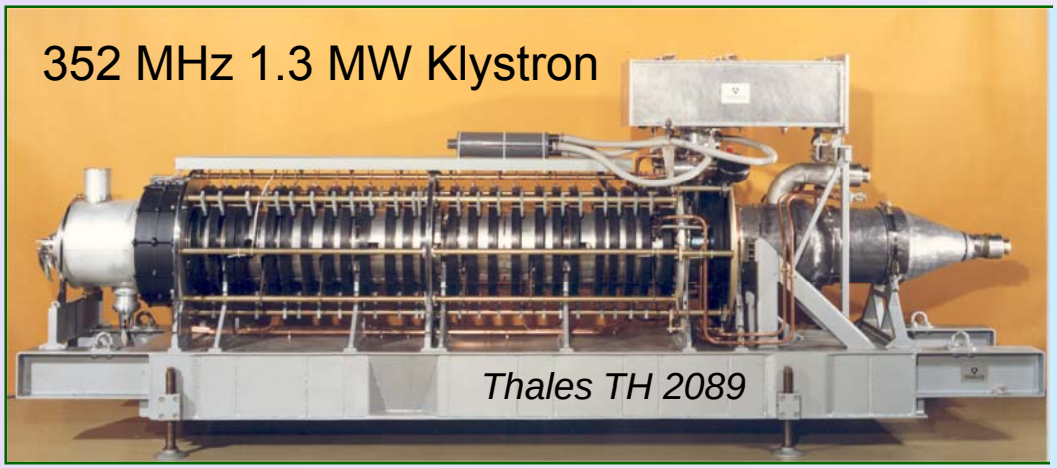
Rs = 26.8 MΩ (5 cells) f_{rf} *= 352.2 MHz*

V_{nom} *= 1.4 … 2.5 MV*

2 couplers: β_{max} *= 4.4*

Max 170 kW / coupler

☞ *Undamped HOM*



- 2 out of 3 installed klystrons needed to feed the 6 cavities at 200 mA

⇒ 1 klystron available for the cavity power test stand or to back up operation for any bunch filling mode

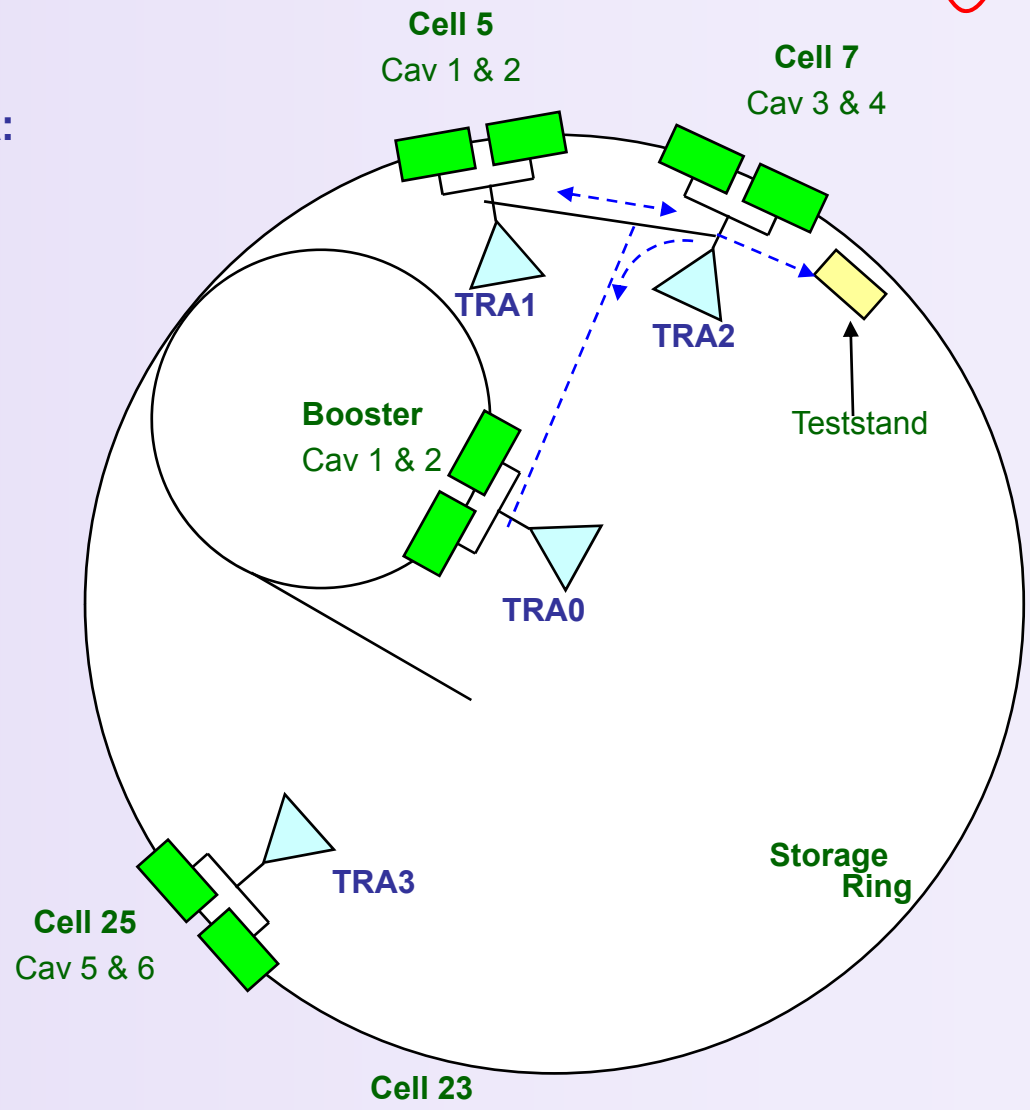
RF operation at 200 mA with safety margin

Nominal configuration at 200 mA:

- TRA0 on booster cavities 1,2
- TRA1 on SR cavities 1,2,3,4
- TRA3 on SR cavities 5,6
- TRA2:
  - available for the teststand
  - can be switched to replace TRA0 or TRA1 when they have to be shut down

200 mA in case of TRA3 fault:

- TRA1 on SR cavities 1,2
- TRA2 on SR cavities 3,4
- Cavities 5,6 not powered



Mastering instabilities at 200 mA

- TCBI – Transverse Coupled Bunch Instabilities
  - ➢ Resistive wall instability
  - ➢ Ion trapping
  - → Mastered by an increased **chromaticity**
  - ➢ Transverse cavity HOM are masked

- LCBI – Longitudinal Coupled Bunch Instabilities
  - ➢ Instabilities driven by longitudinal **HOM from 6 five-cell Cu cavities** for I_{beam} > 50 … 130 mA, depending on T_{cav}
  - → Stabilisation by **Landau damping** thanks to transient beam loading from non-symmetric **fractional filling → 200 mA in 1/3 et 2/3 filling**
  - → 1998: Improved **Cavity temperature regulation $T_{cav} = T_{set}$ ± 0.05ºC,** for a precise control of the HOM frequencies

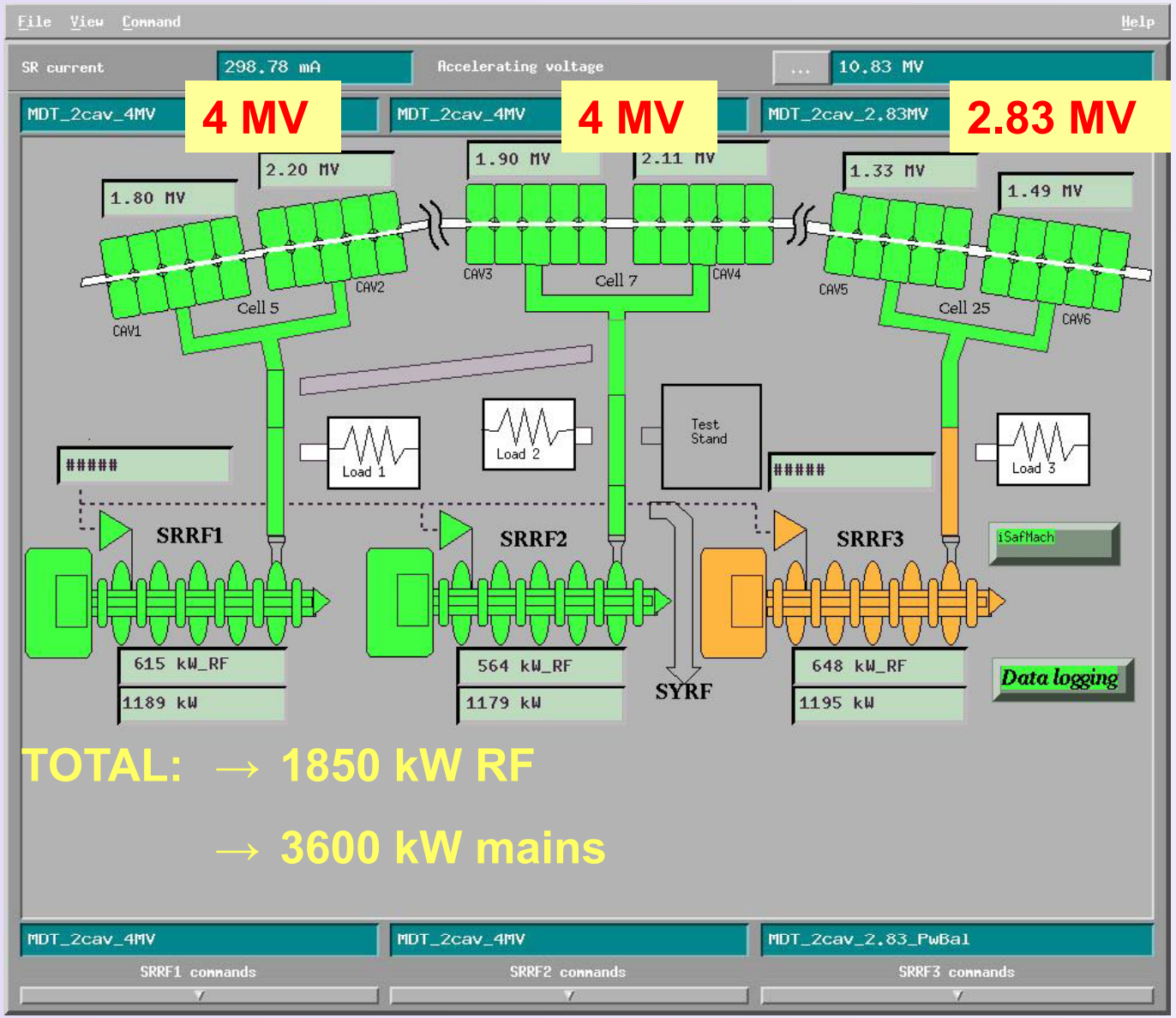
    ⇒ Stable beam at **200 mA** in **uniform** and symmetrical 2 x 1/3 filling

Further Current Upgrade

- 300 mA
  - → HOM driven LCBI above 200 … 250 mA for any T_{cav}
  - ⇒ **End of 2004: Decision to implement a digital bunch-by-bunch feedback system** (already reported at last 3 WM in June 2006)
    - ◊ LFB (Longitudinal Feedback): to damp HOM driven LCBI
    - ◊ TFB (Transverse Feedback): allows operation at zero chromaticity and to damp ion instability at 300 mA
  - ➢ 300 mA achieved in Machine Physics test in December 2006
  - ➢ Foreseen in USM after tests with individual beam lines in 2008/2009

- 500 mA
  - ➢ Not scheduled for the coming accelerator upgrade
  - ➢ Subject to R&D for the coming 10 years, in preparation of a possible later upgrade
  - ➢ Any new RF design will have to be compatible with a possible increase to 500 mA

Summary / tests with 300 mA at ESRF



RF:

- 11 MV necessary for Robinson stability
- All 3 transmitters in operation ⇒ no margin for test stand or in case of equipment failure

LFB:

- Stabilisation of HOM up to 300 mA

TFB vertical

- Needed to control beam blow up due to ion trapping

Existing system

- At 300 mA: all SR transmitters are needed
  - TRA1 → Cavities 1 & 2
  - TRA2 → Cavities 3 & 4
  - TRA3 → Cavities 5 & 6

  ⇒ No spare transmitter = no safety margin

- Re-establishing a safety margin at 300 mA would require 2 more 1.3 MW transmitters:

  → One to back up TRA0 (booster), TRA1 and TRA2 (SR)

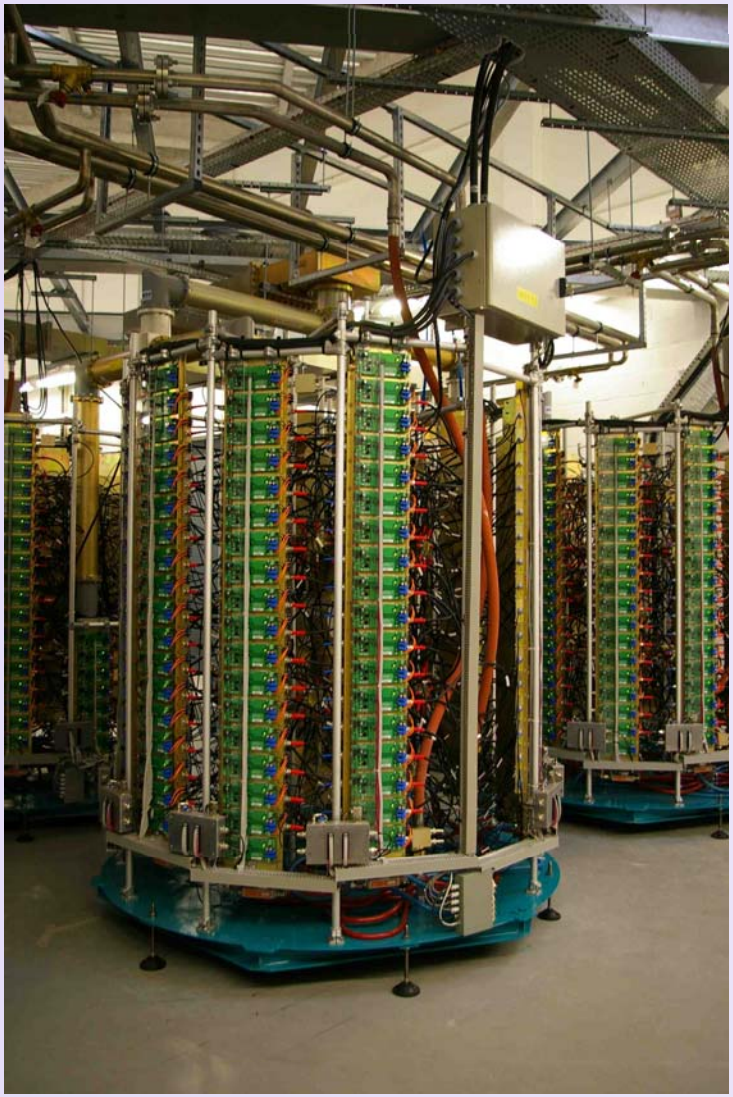
  → One to back up TRA3 (SR)

Transmitter upgrade

- Existing RF transmitters:
  - Only one klystron supplier left
  - These klystrons are particularly subject to instabilities and not optimized for light sources
  - RF upgrade = time to implement an alternative for 352 MHz

- Proposed upgrade with Solid State Amplifiers (SSA):
  - Replace klystron transmitters with SSA
  - SSA highly modular $\Rightarrow$ redundant $\Rightarrow$ intrinsically reliable
  - Good experience at SOLEIL, yet still R&D to find even better transistors
  - 20 dB less phase noise
  - No HV
  - No X rays
  - Easy maintenance
  - Likely to become the new standard for high power CW RF applications

Solid State Amplifiers at SOLEIL



← 50 kW tower:
- tested at 45 kW
- normally operated up to 40 kW

↓ 8 towers operated at 2 x [150 to 160 kW]

Photos: Courtesy SOLEIL

Further development of SSA

- Collaboration with SOLEIL:
  - GOAL: raise the operation power from 40 to 45 kW/tower
  - SOLEIL booster: SEMELAB transistors VDMOS D1029UK05
  - SOLEIL SR: Improved performance with POLYFET LDMOS LR301 (V4)
  - Prototype tests under way at SOLEIL with other transistors to optimize:
    - Robustness
    - Output power
    - Efficiency
- Some companies already interested in supplying complete SSA systems

New Cavities for the ESRF

- Optimized for high beam current

  - At least 1 coupler per cell
    (instead of existing 2 couplers / 5-cell-cavity)

    ⇒ Single cell cavities

  - Strong HOM damping for unconditional stability at 300 mA without active HOM damping

  - Design goal including necessary margins:
    - 500 mA in terms of power
    - 1000 mA in terms of HOM damping

Single cell NC HOM damped cavity

New 352 MHz Cavities for ESRF

⇒ R&D based on BESSY design with ferrite loaded ridge waveguides for selective HOM damping

[E. Weihreter, F. Marhauser]

- Cavity project partly funded from the EU as work package WP13 of the ESRFUP project within the FP7 grant agreement
- Goal: produce a power prototype within 3.5 years

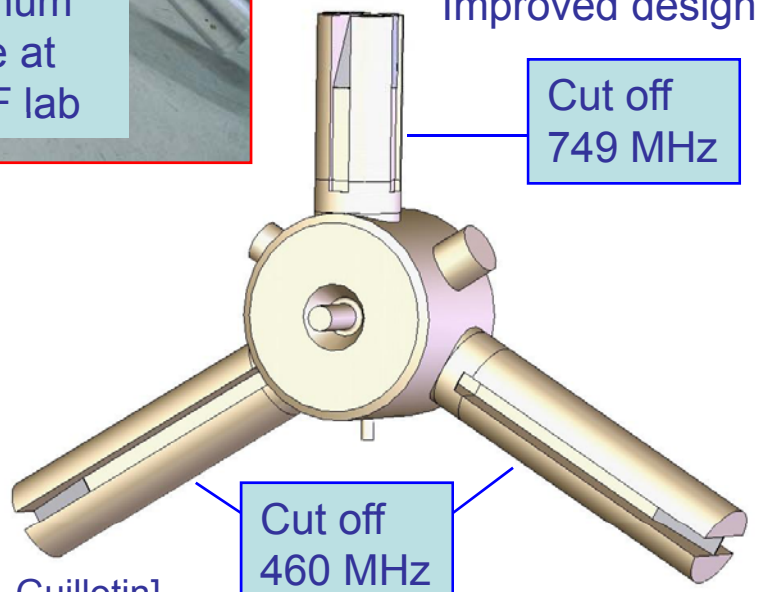
Qo = 30000
R/Q = 140 Ω

9 MV / 18 cavities:
→ P_{dissip} = 540 kW
= 30 kW/Cavity

300 mA: P_{beam} = 1.5 MW
→ P_{tot} = 114 kW / cavity

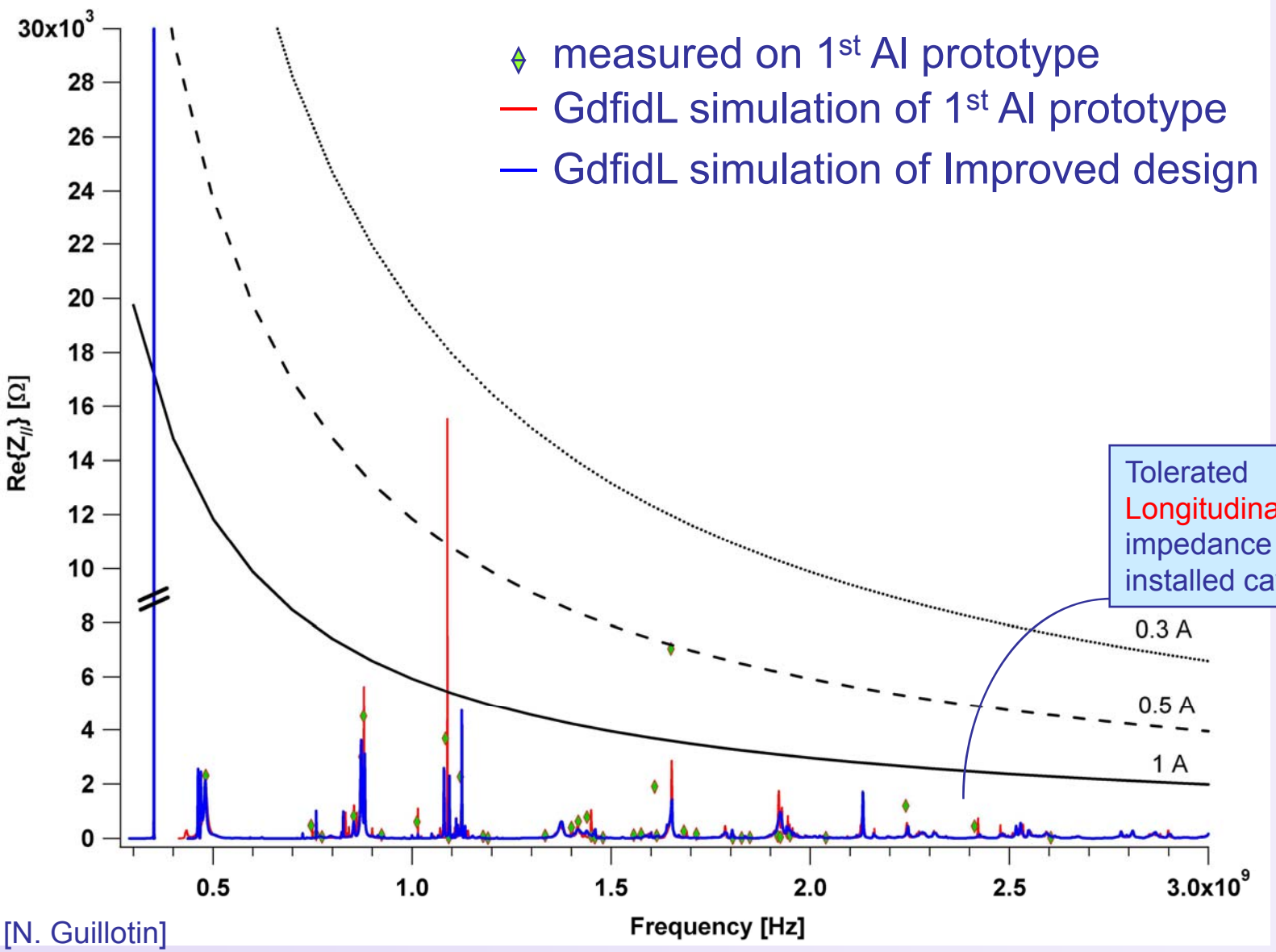
500 mA → 169 kW / cavity

Improved design



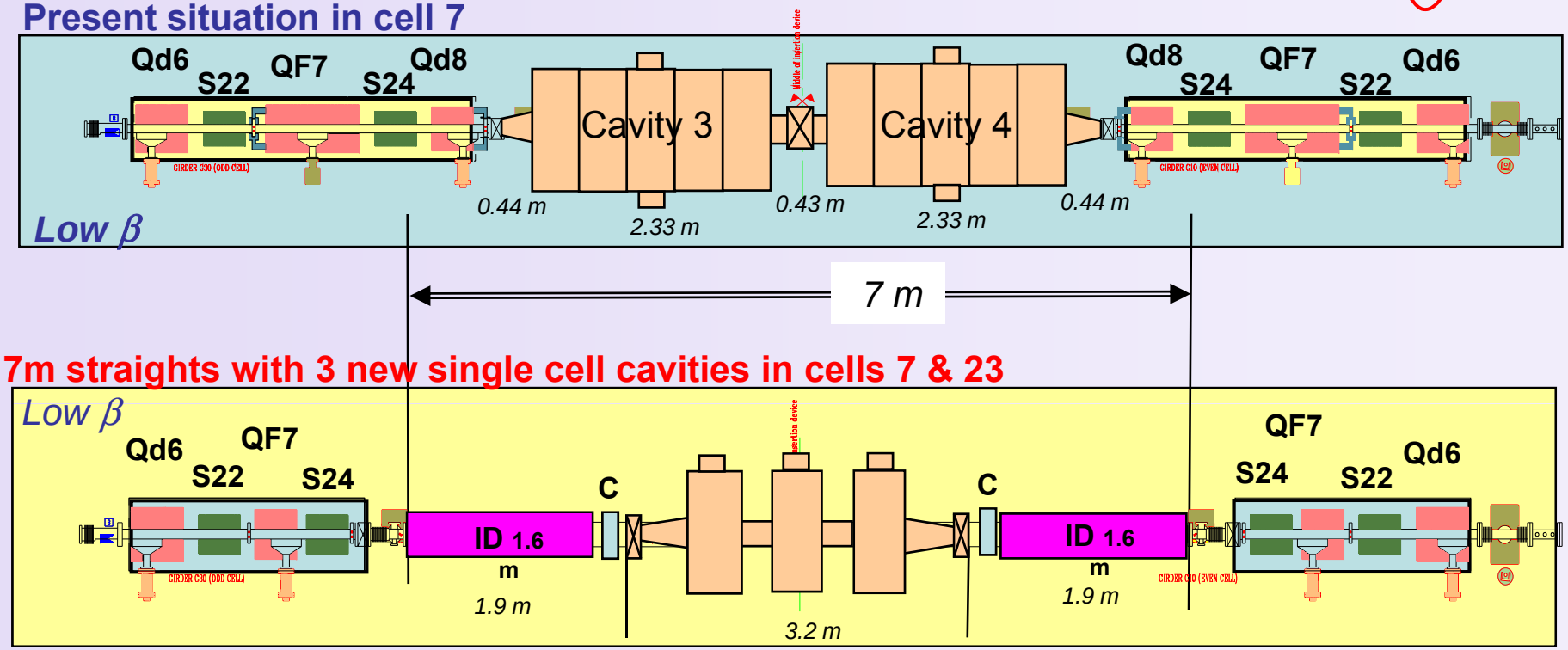
[N. Guillotin]

Multibunch – HOM driven LCBI



[N. Guillotin]

Scheme for additional long beamline ID7

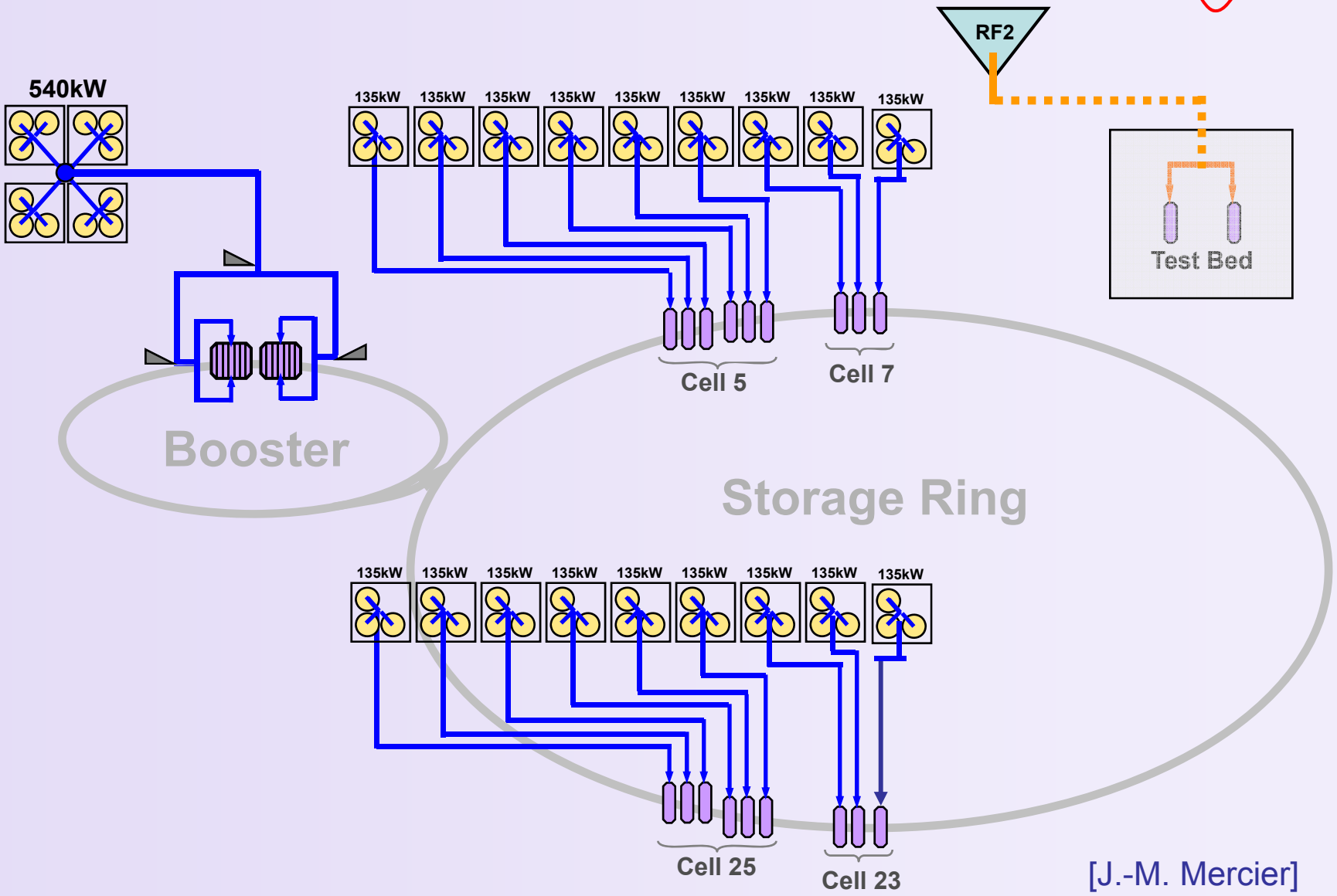


- Transform Cells 7 and 23 into long straights
- Replace SR cavity 3 with 3 single cell cavities in the middle of cell 7
  - Creates new space for a long beam line ID7 with 2 ID's
- Replace SR cavity 4 with 3 single cell cavities in the middle of cell 23
  - Keeping existing 2 canted undulators in ID23: just insert 3.2 m of RF
- Scheme could also be applied to cells 5 / 21 and cells 9 / 25

Planned RF upgrade / coming 8 years

- Replacement of all 6 SR five-cell cavities with 6 x 3 new single cell HOM damped cavities
- 9 MV / 300 mA: 18 cavities at 114 kW
- 18 solid state amplifiers
  - ◊ 3 towers x 45 kW = 135 kW: sufficient margin
  - ◊ R&D for improved transistors therefore essential
  - ◊ Note that currents above 300 mA will be possible by adding a 4th tower to each SR amplifier
- 4 amplifiers x 3 towers for the booster cavities
  - ◊ Can be switched ON/OFF within 10 seconds: better adapted to frequent top up operation than klystrons

Overview RF upgrade – new cavities and SSA



[J.-M. Mercier]