Upgrade of the RF System at the ESRF*)

J. Jacob

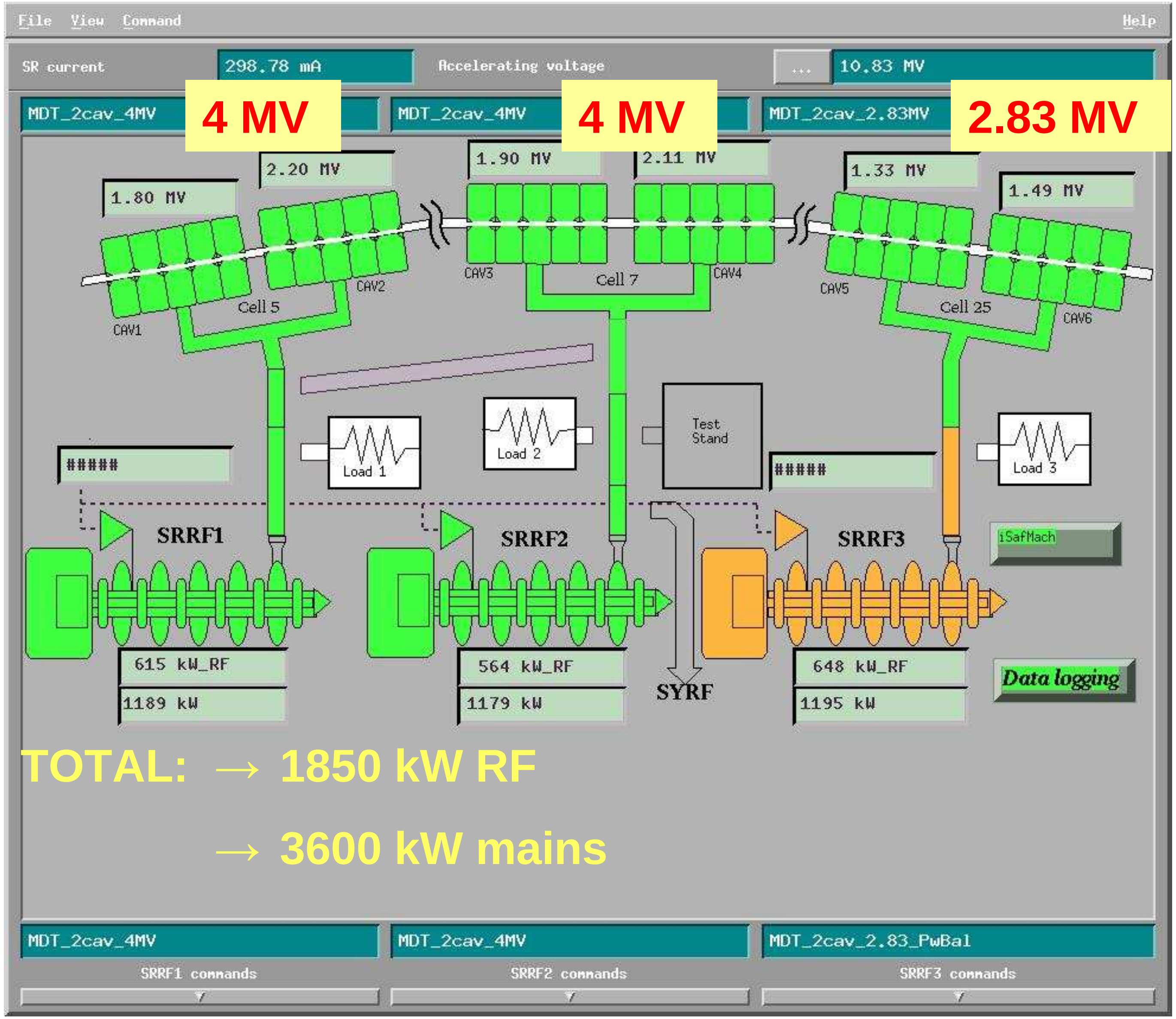
& colleagues from ESRF RF Group

**) Part of the ESRF Upgrade Program, not yet approved by the ESRF council*

Beam Current Increase ?

- 200 mA
  - Nominal current since 1997 ☞ HOM tuning / T_{cav}
- 300 mA
  - Achieved end of 2006 in MDT ☞ HOM tuning + LFB
  - Foreseen in USM for 2008/09 once replacement of all crotches will be completed
- 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

300 mA with existing RF system in MDT



Cavity Limitations (300 mA)

- Coupling already at maximum: $\beta = 4.4$
  - ⇒ RF Voltage: 9 → 11 MV against Robinson instability

- Cavity #5 break downs:
  - ⇒ Operation at reduced Voltage on SRRF3: 2.83 MV instead of 4 MV
  - ⇒ Problem linked to Voltage rather than beam current: yet a concern

- Temperature tuning of HOM:
  - → Not possible to exceed 250 mA
  - → Longitudinal Feedback necessary to reach 300 mA

- LFB limited to ≈ 1 ms damping time
  - ⇒ Combined LFB and HOM tuning still required to reach 300 mA
  - ⇒ Reliability for USM at 300 mA ?

- No further beam current increase
  - → Power per Window at maximum
  - → Robinson instability would require even higher voltage ⇒ additional window power !

☞ Maximum of 300 mA with existing cavities

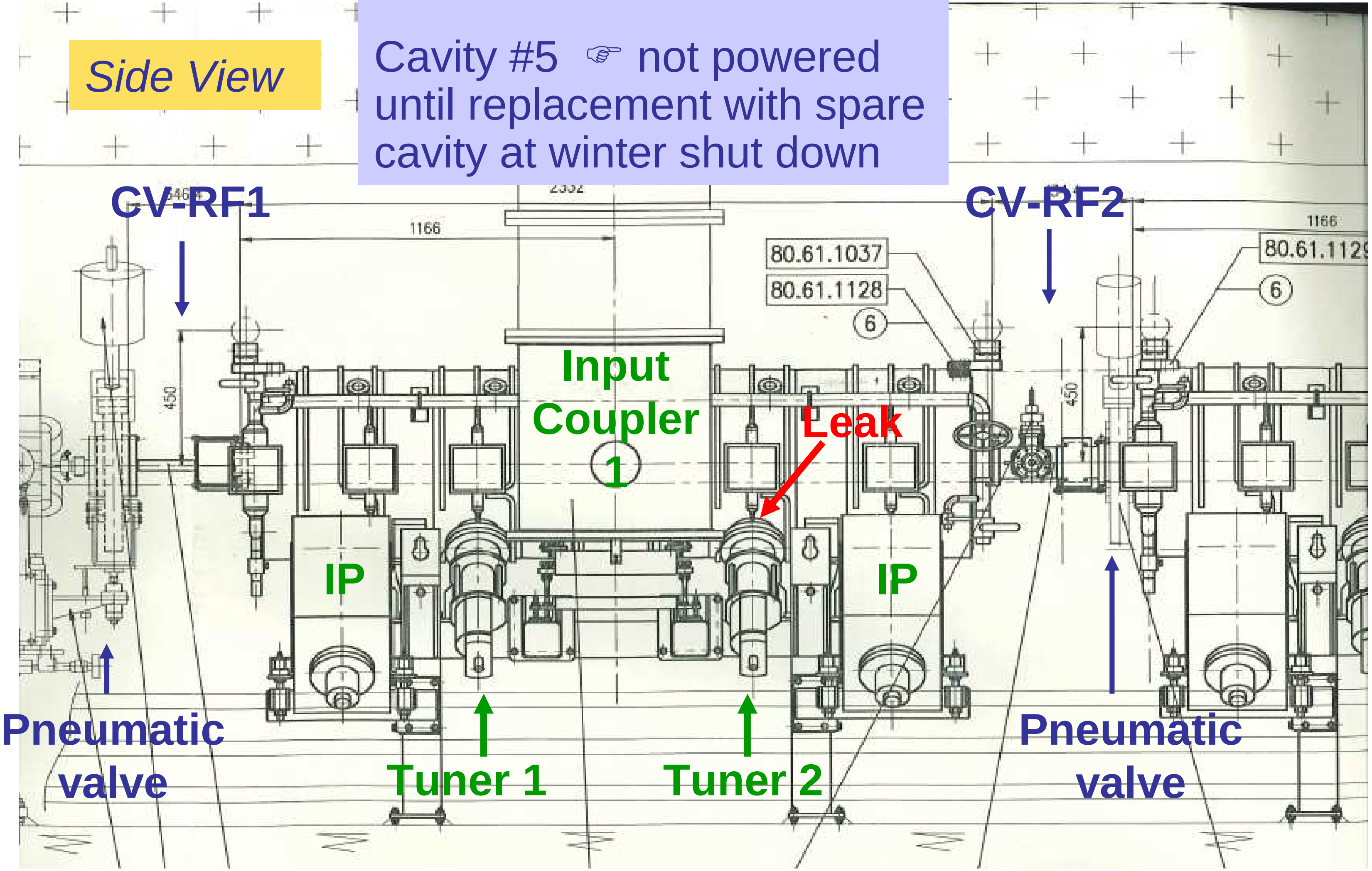
SR cell 25: Leak on Cavity #5 / Tuner port 2

← Quadruple

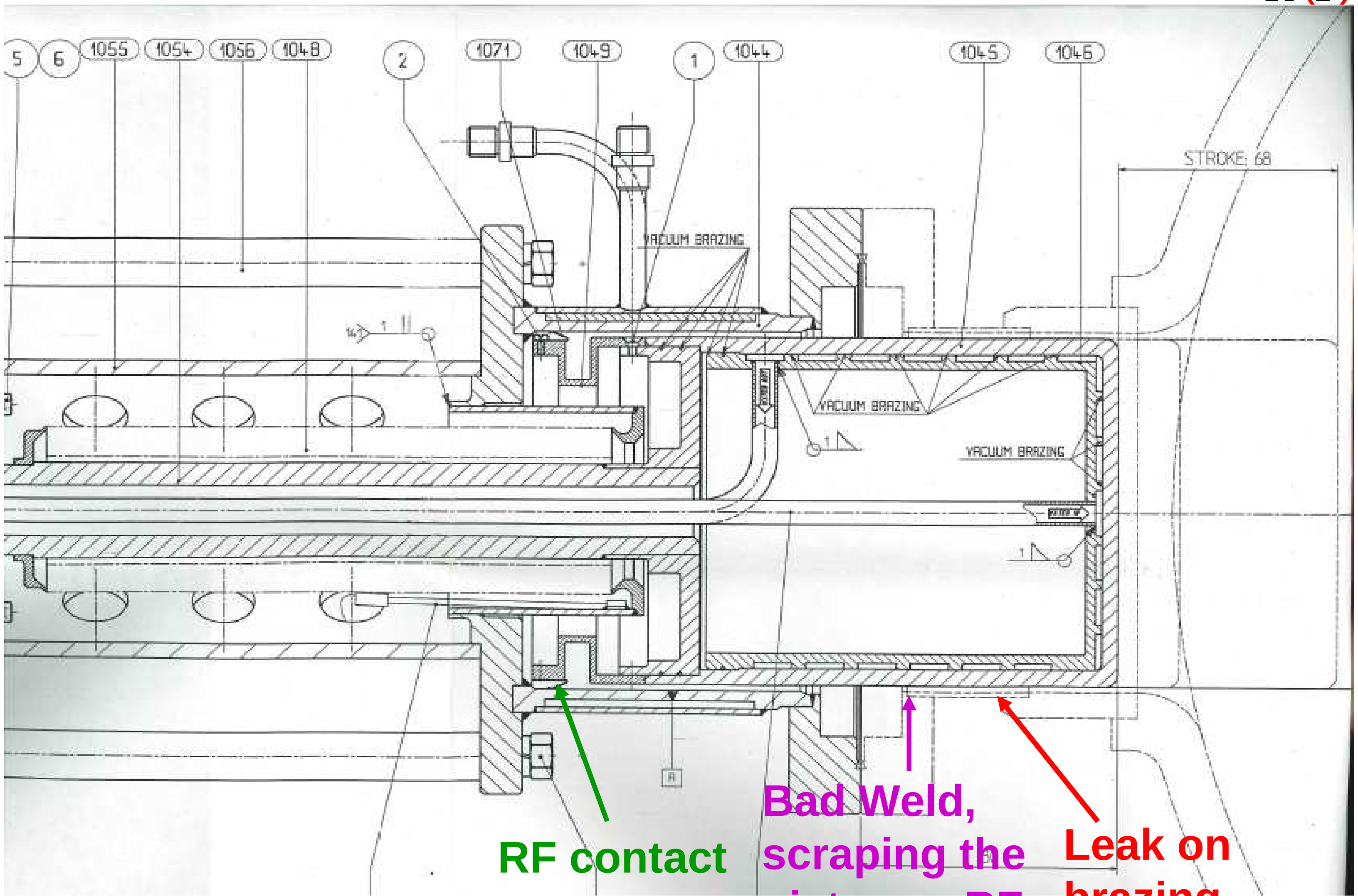
Cav #6 →

⇒ June – December 2007: no 300 mA in MDT

Cavity #5 ☞ not powered until replacement with spare cavity at winter shut down



Piston Tuner



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

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

Cavity comparison

HOM damped alternatives to existing ESRF 5-cell cavity:

- EU type NC HOM damped cavity: preferred solution for ESRF upgrade
- SOLEIL type SC HOM damped cavity: beam power ⇒ 2 couplers per cell

Vnom = 9 MV									300 mA, Pbeam = 1500 kW					*500 mA, Pbeam = 2500 kW*				
Cavity type		**R/Q** [Ω]	**Qo**	**β**	**Qext**	**price** [k€/unit]	**Nb**	**Pc-tot** [kW]	**Pfw** [kW]	**Pwind** [kW]	**Costs** **Capital** M€	**Electr.** M€, 10y	**Total** M€, 10y	*β*	*Pfw [kW]*	*Pwind [kW]*	*Costs Electr. M€, 10y*	*Total M€, 10y*
five-cell	NC	696	38500	4.4	8750	0	6	376	1900	158	0	14.8	14.8		*not possible*			
(2 couplers)	*-> Robinson imposes Vacc = 11 MV at 300 mA*																	
EU type	NC	140	30000	3.8	7895	400	18	536	2050	114	7.2	16.0	23.2	*6*	*3036*	*169*	*23.7*	*30.9*
HOM damped							15	643	2150	143		16.8			*3161*	*211*	*24.7*	
(1 coupler)							12	804	2350	196		18.3			*3393*	*283*	*26.5*	
SOLEIL type	SC	45	2.0E+09		80000	1000	6	0	1500	125	6	11.7	22.5		*2500*	*208*	*19.5*	*30.3*
HOM damped		*1 LHe liquifier / 2 cavities:*				1000	3	450			3	1.8		*Robinson: 11.4 MV*			*1.8*	
(2 couplers)																		

Electr. Cost 60 € / MWh, mains price in 2006
390 k€/MW year
7.80 k€ / kW-rf assuming 50% efficiency, 10 years of operation and 6500 hours/year

Single cell NC HOM damped cavity

New 352 MHz Cavities for ESRF

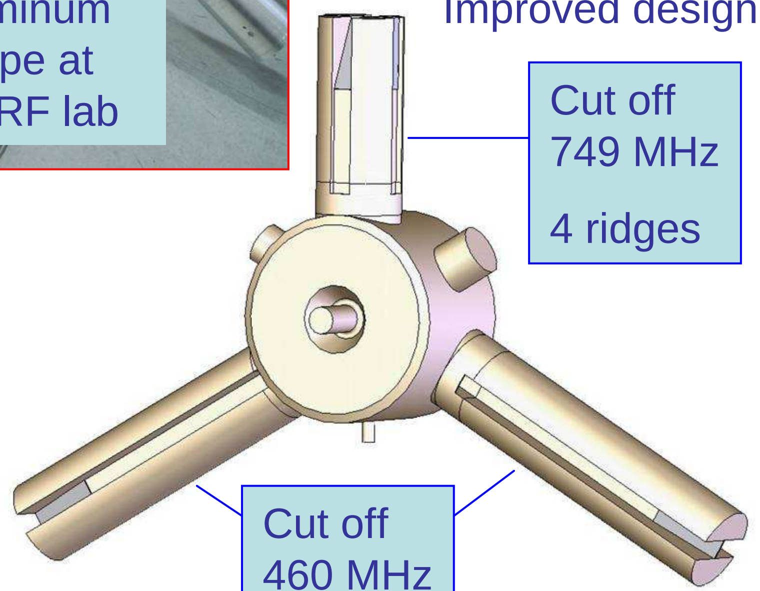
- Unconditional stability & higher current:

  400…500 mA

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

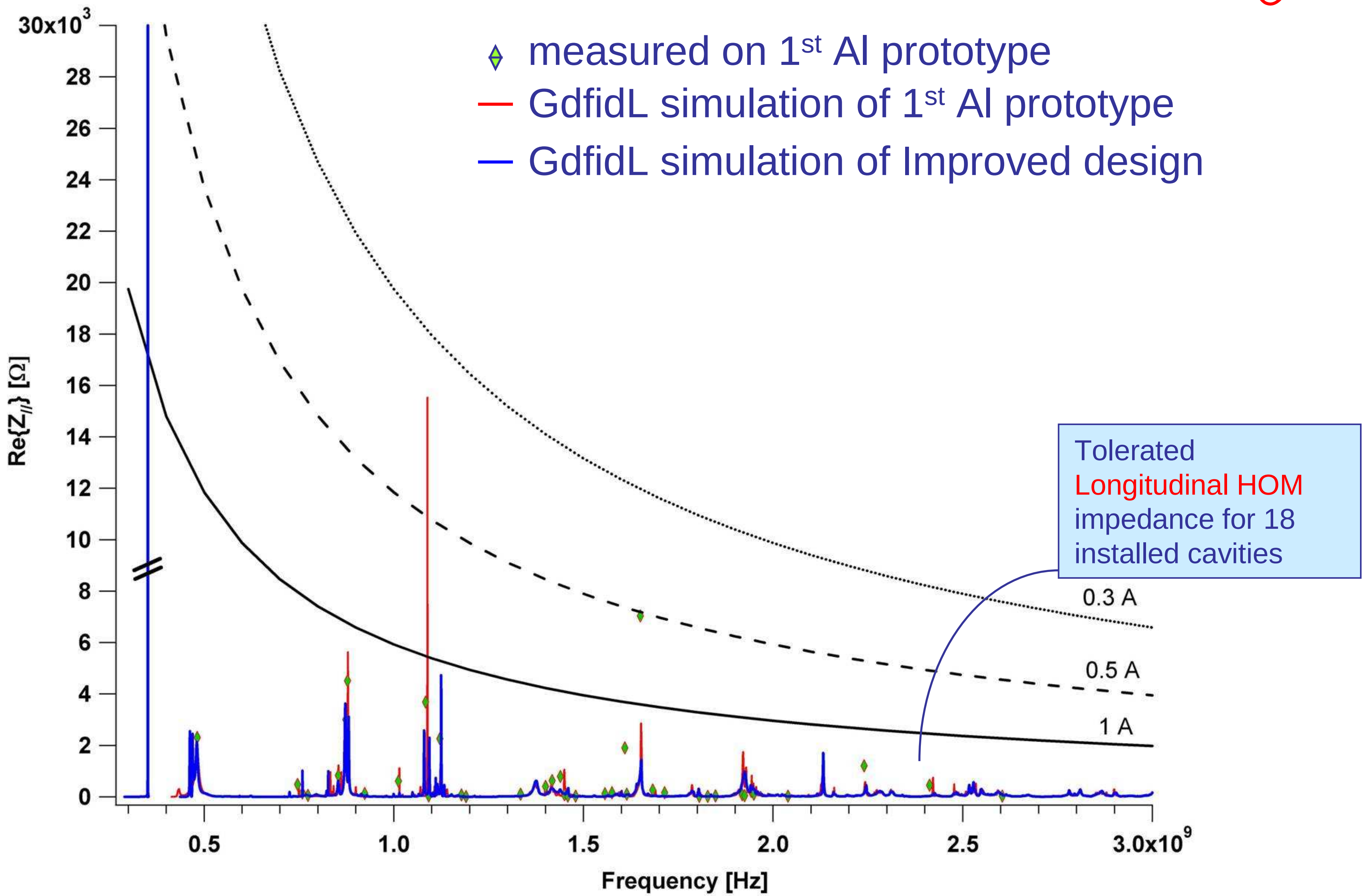
[E. Weihreter, F. Marhauser]

Improved design



☞ Nicolas Guillotin's presentation this afternoon
[N. Guillotin, V. Serrière, P. Roussely, J. Jacob]

Multibunch – HOM driven LCBI



Existing RF configuration

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

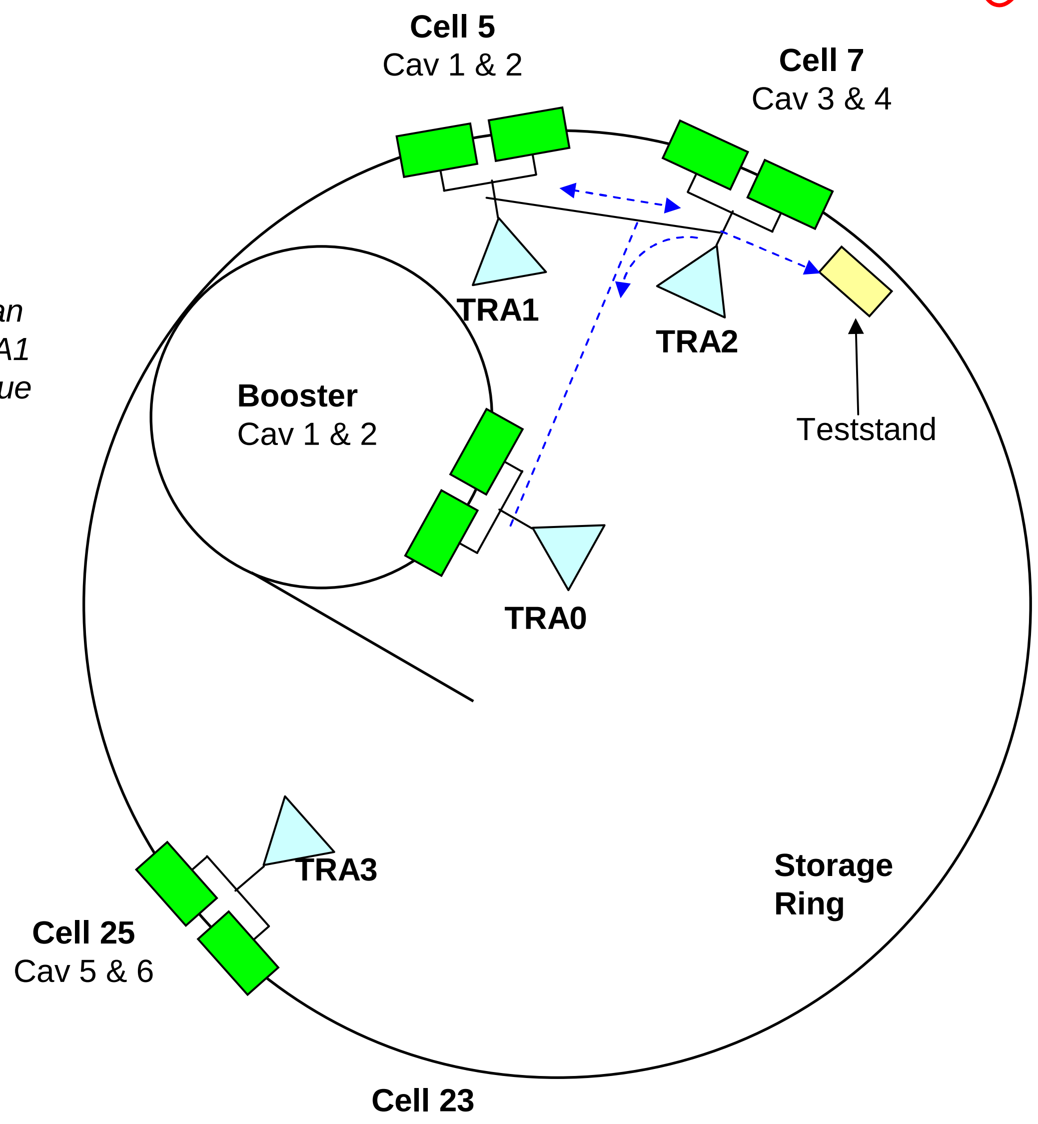
TRA2 available for the teststand; can be switched to replace TRA0 or TRA1 when they have to be shut down (blue dashed lines, arrows)

200 mA in case of TRA3 fault:

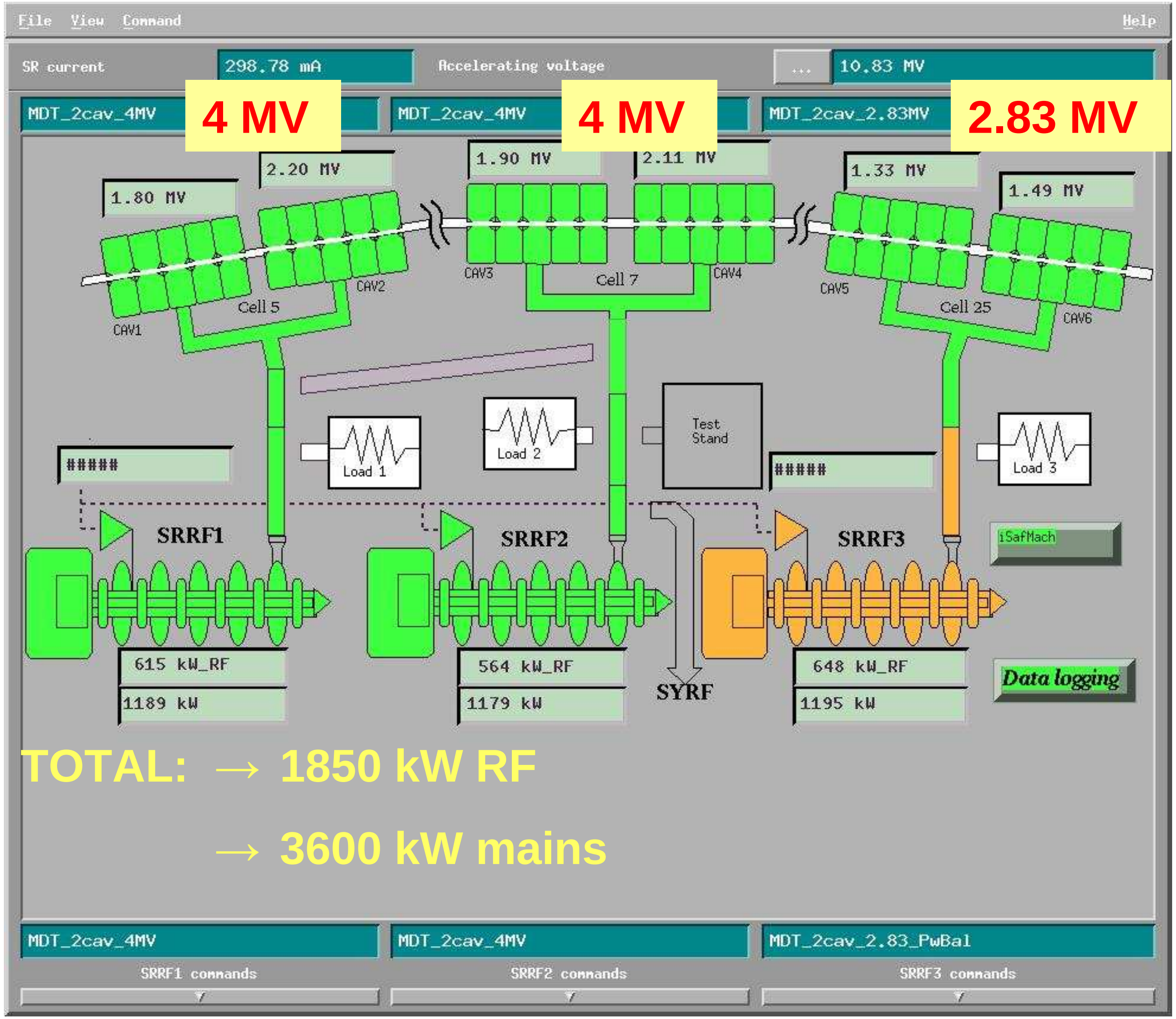
TRA1 on SR cavities 1,2

TRA2 on SR cavities 3,4

Cavities 5,6 not powered



Existing transmitter configuration for 300 mA



RF Transmitter upgrade

- 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

☞ Remark: existing transmitters provide enough power for 500 mA

RF Transmitter upgrade

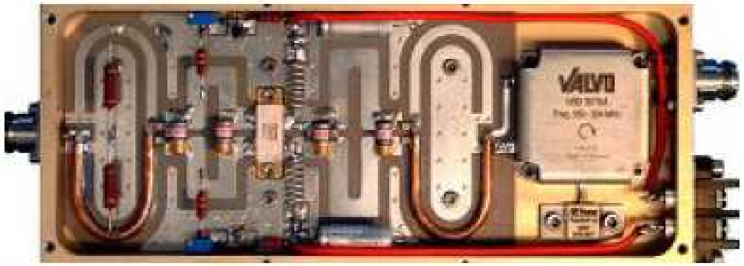
- Klystron transmitters
  1. Safety margin would require 2 more 1.3 MW transmitters:
     - → One to back up TRA0, TRA1 and TRA2
     - → One to back up TRA3
  2. Are Klystrons still a good choice for new transmitters?
     - → Stability problem, difficulty in finding working point without :
       - Multipactor
       - Sidebands
     - → Monopoly situation with only one supplier left
       - Risk of strong price increases
       - Risk of obsolescence
     - → ESRF burning about 0.5 klystron / year:
       - Difficulty to motivate supplier to invest for more stability
  3. TED in principle ready to develop a 300 … 400 kW klystron
     - → Better in terms of modularity with respect to point 1 above
     - → But arguments under point 2 in principle still apply

Alternatives to Klystrons

- IOTs: not for ESRF
  - Examples: ELETTRA, DIAMOND, ALBA
    - Still some problems at high power
  - Anyhow: no existing IOT at 352 MHz

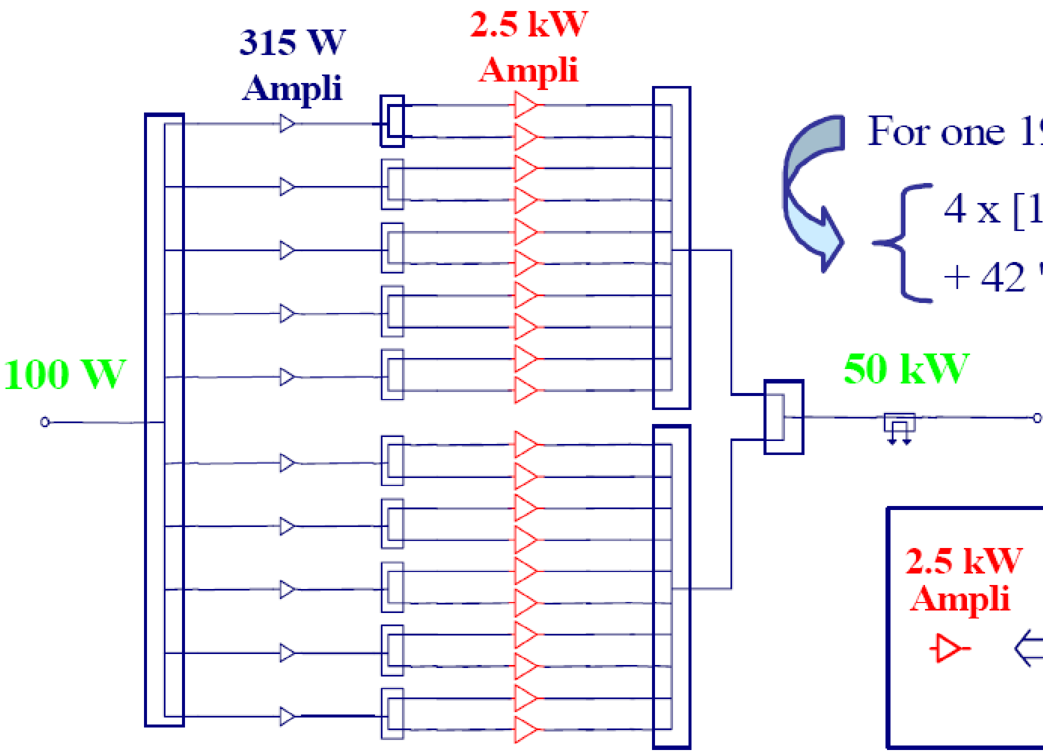
- Solid State Amplifiers: PROPOSED for the ESRF upgrade
  - Successfully designed, implemented and commissioned at SOLEIL
  - Intrinsically redundant, no interruption in case of failure of an output amplifier module:
    - Not a single beam trip after 1500 hours with beam
    - Only 20 / 1400 modules broken after 1500 hours
    - ☞ Fresh statistics expected from P. Marchand in Session 2
  - Extremely modular
  - 20 dB less phase noise
  - No High Voltage
  - No Radiation
  - Note that it requires:
    - Good Quality Assurance policy at manufacturing
    - Good procurement strategy for transistors, in particular for later spare procurement

SOLEIL 352 MHz Solid State Amplifier



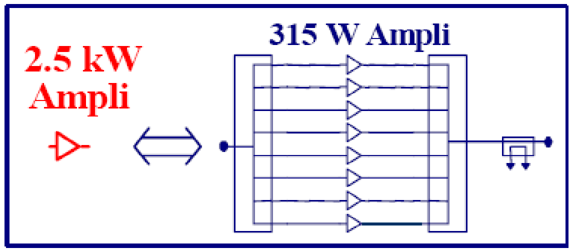
315 W module

300 V / 30 V dc-dc converter



For one 190 kW ampli → x 4

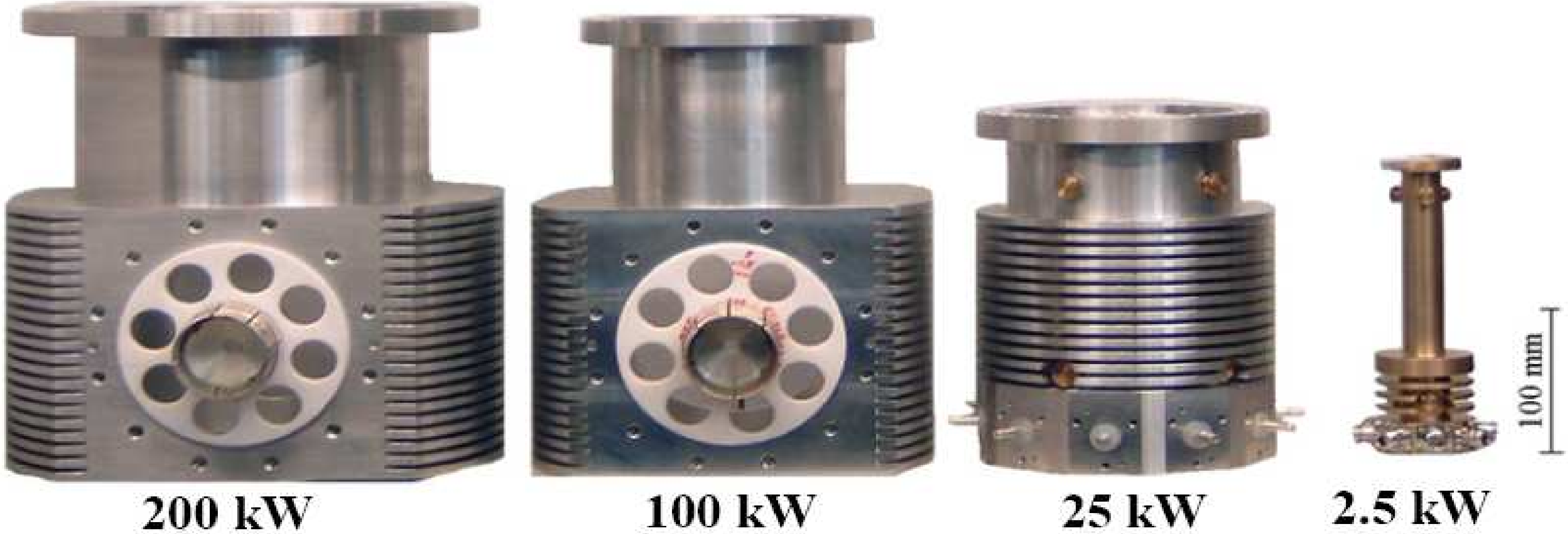
4 x [10 + (20 x 8)] + 2
+ 42 "stand-by" = 724



[P. Marchand, Ti Ruan et al.]

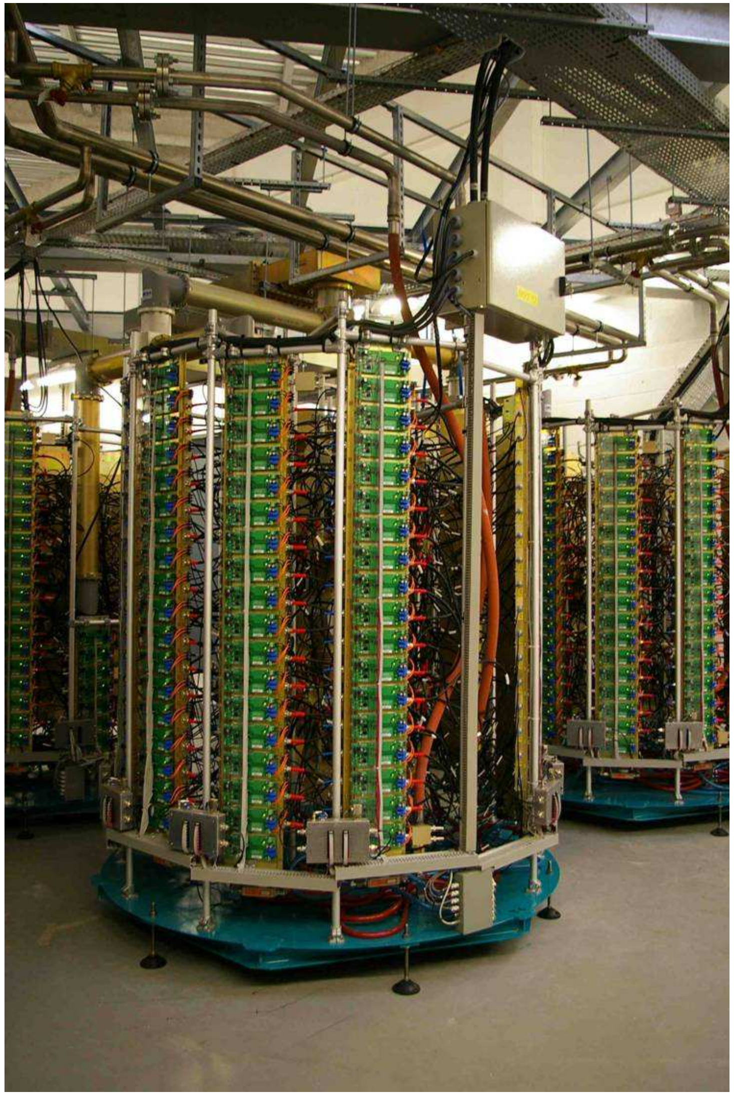
RF Power Combiners and Splitters

Power Combiner



Power Splitter

Solid State Amplifiers at SOLEIL

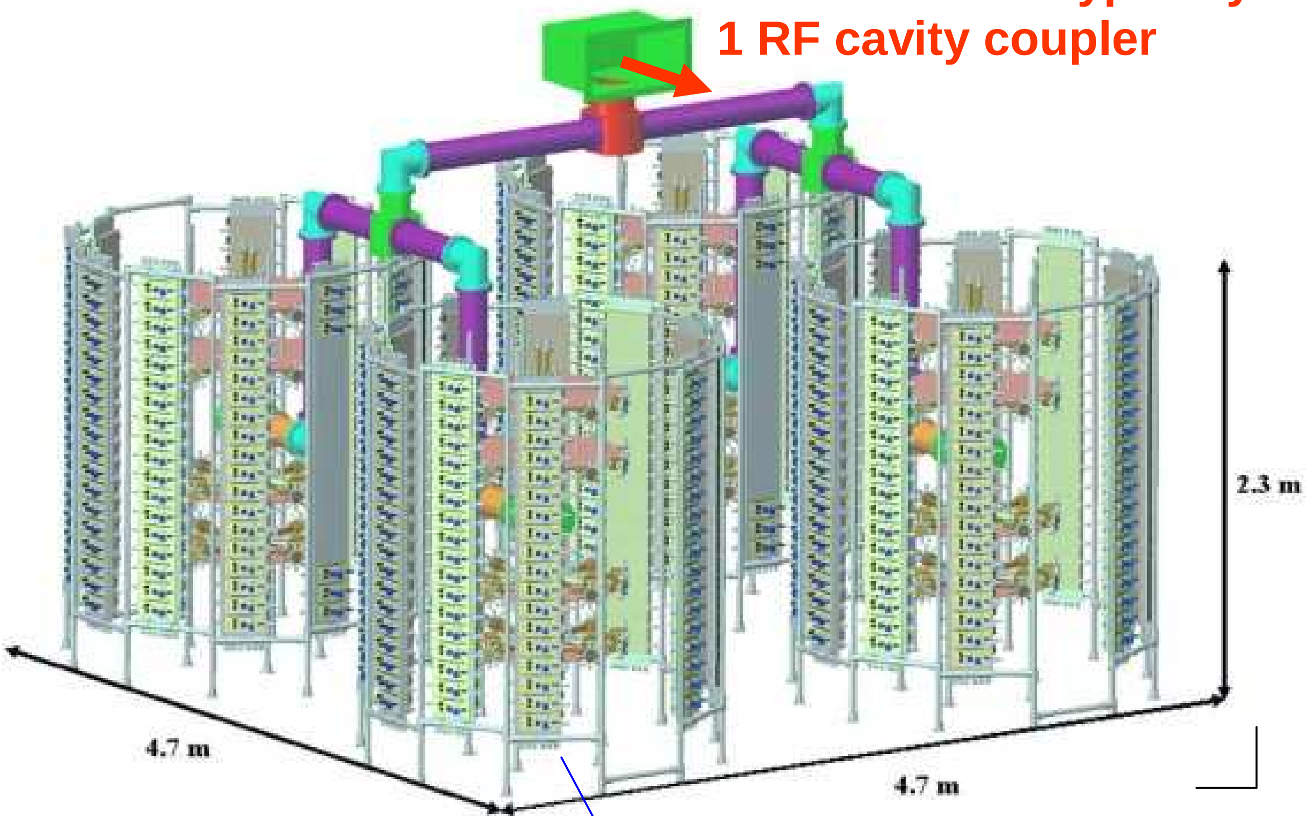


← 50 kW tower

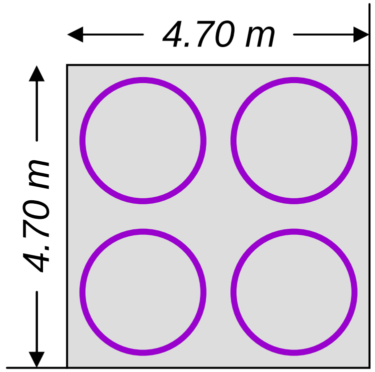
↓ 8 towers delivering 2 x 190 kW

Solid State Amplifiers at SOLEIL

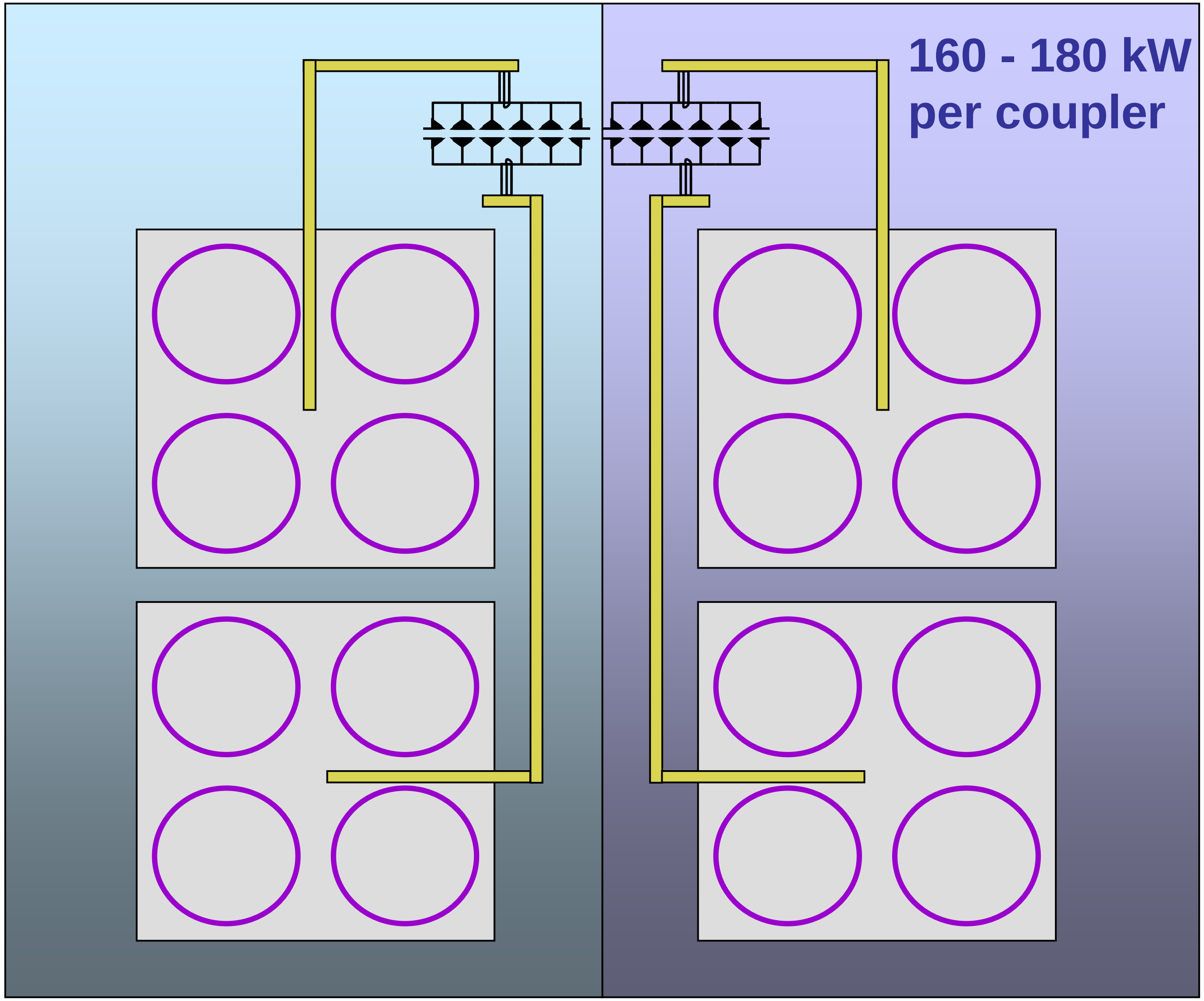
Max 190 kW ☞ typically
1 RF cavity coupler



1 tower = 50 kW

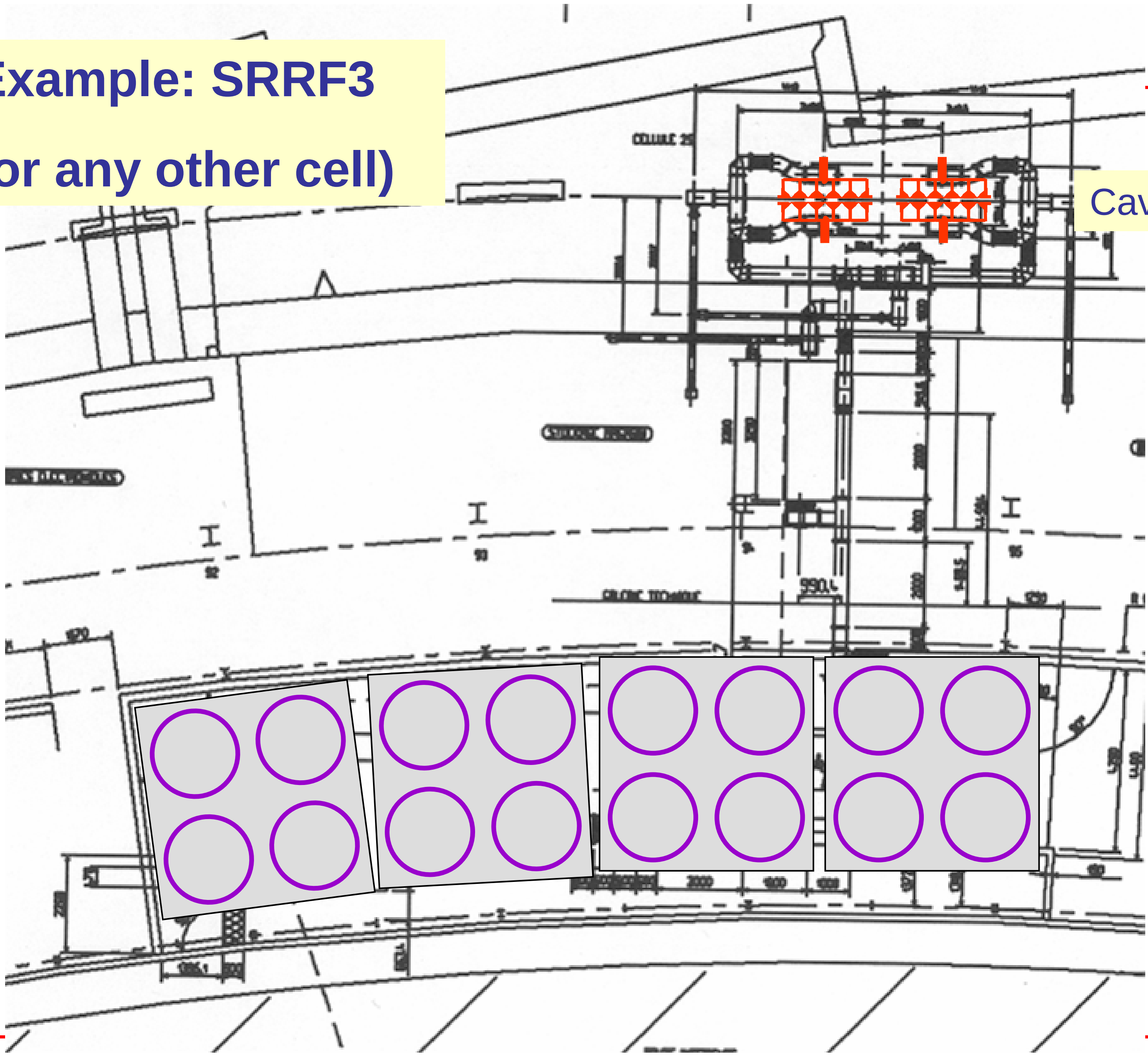


ESRF: for 300 mA with existing 5-cell-cavities

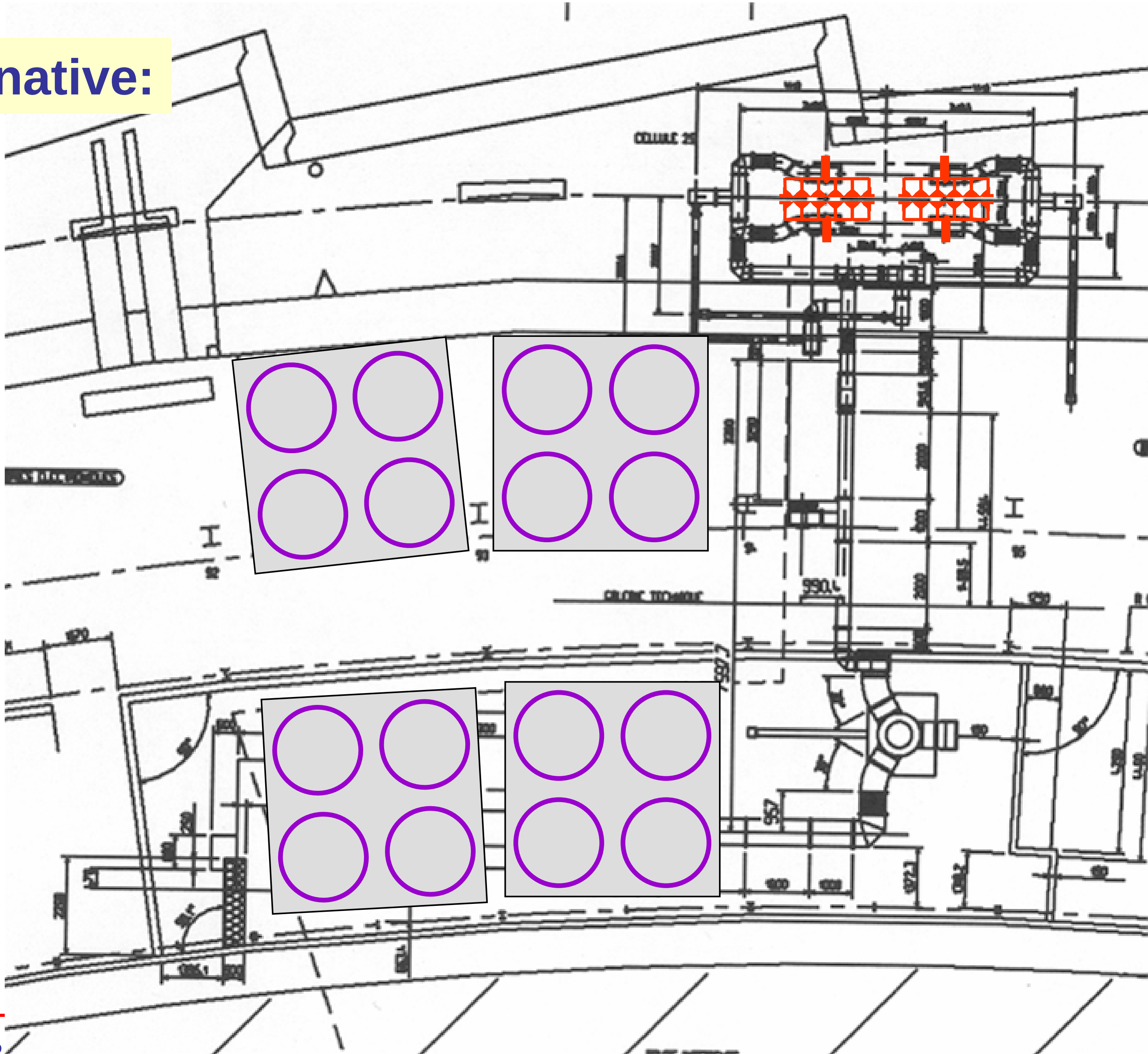


Example: SRRF3

(or any other cell)



Alternative:



Solid State Amplifiers with existing cavities

- 300 mA with 5-cell cavities
  - 160 - 180 kW per coupler $\Rightarrow$ 4 towers (dimensioning being checked with SOLEIL)
  - 4 couplers = 16 towers per straight section
  - Replace TRA1, TRA2 and TRA3: **48 towers**

- Booster
  - Replace TRA0: **12 to 16 towers**

Solid State Amplifiers with 18 new cavities

- 300 mA with 18 single cell HOM damped cavities:
  - ◊ 120 kW per cavity $\Rightarrow$ 3 towers
    (dimensioning being checked with SOLEIL)
  - ◊ 6 cavities/cell $\Rightarrow$ 18 towers on a cell
  - ◊ TOTAL of 18 cavities $\Rightarrow$ **54 towers**

- 500 mA upgrade by adding 18 towers:
  - ◊ 18 x 170 kW $\Rightarrow$ 18 x 4 towers
  - ◊ 24 towers on a cell
  - ◊ TOTAL of **72 towers**

- Replace TRA0

18 / 24 towers/cell for 300 / 500 mA with new cavities

Final layout

- Smooth RF Upgrade without interruption of ESRF operation:
  - ➢ Additional space required for solid state amplifiers
  - ➢ Already existing infrastructure in the technical zones around the ring
  - ⇒ Probably new satellite buildings necessary to house additional ☞ will be defined in the coming months

Distributed RF for more beamlines

- Planned ESRF lattice upgrade:
  - 5 m straight sections → increased to 7 m
  - More space for ID's
  - Possible implementation of canted IDs → additional beam lines, however, separated only by small angle

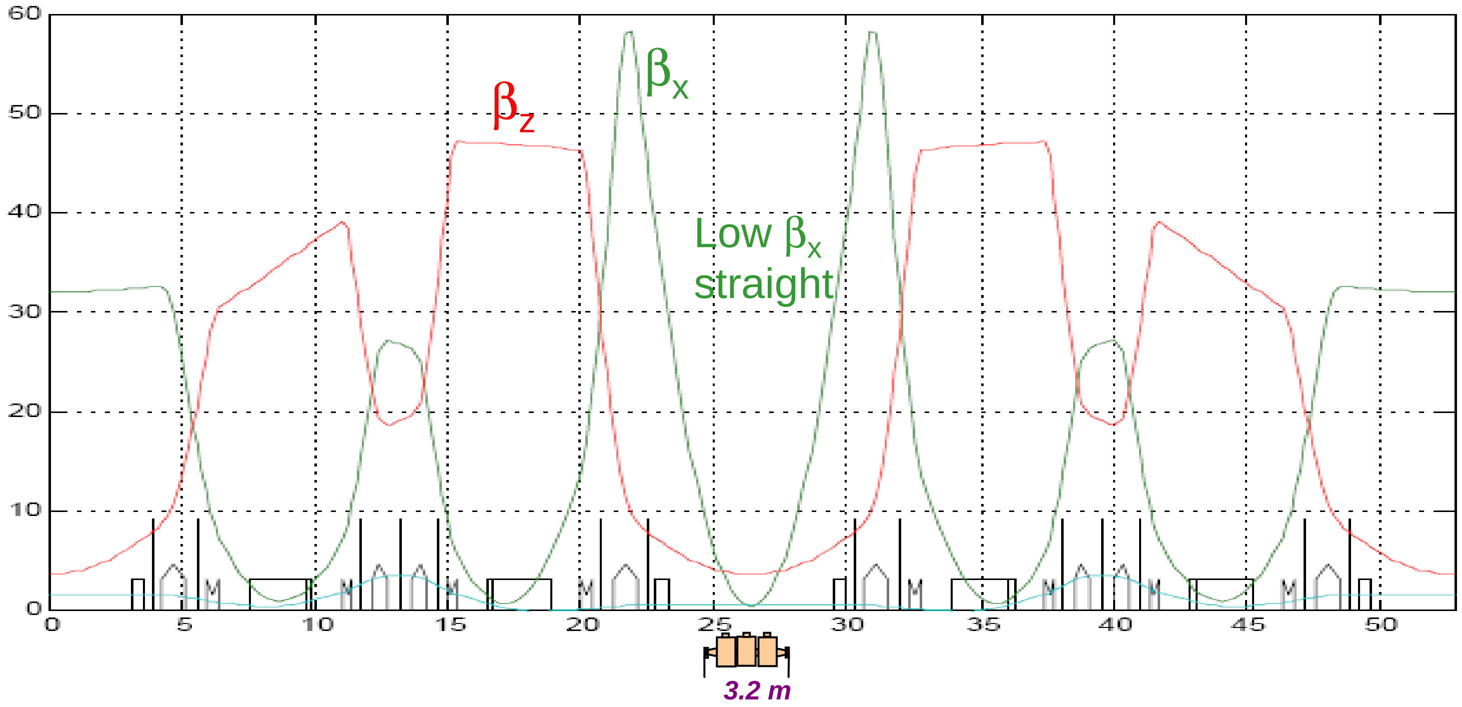
- Extensions of experimental hall for long beam lines to develop nanoscience
  - Possible at some portions of the ring, including existing RF section in cell 7

- RF upgrade would allow
  - Distributed RF Layout
  - Space for additional long beam line in planned building extension at existing RF section
  - No problem with small canting angle

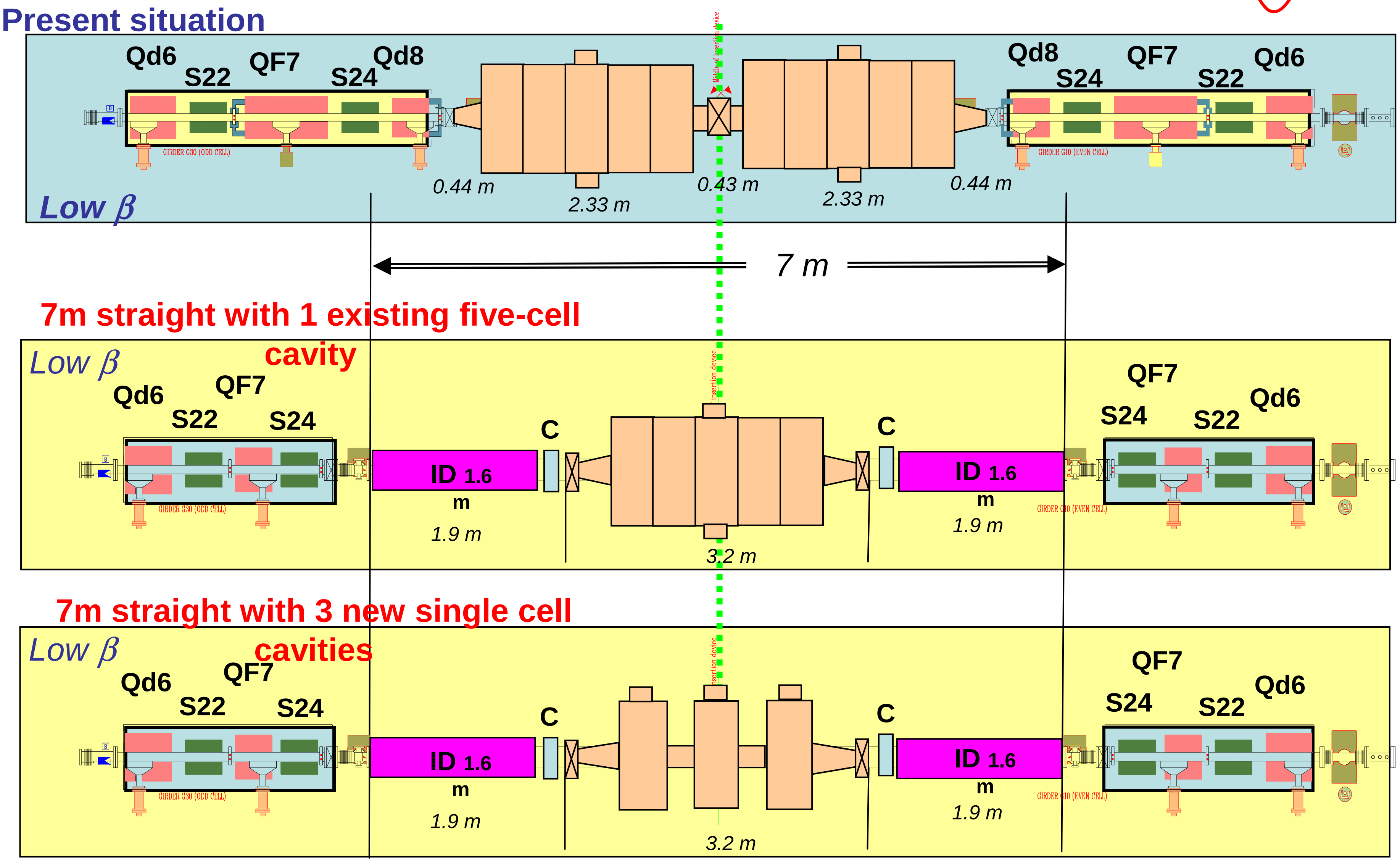
Distributed RF for more beamlines

RF cavities at low β:

- To avoid transverse instabilities from transverse cavity HOMs
- Low beta straight sections (odd numbers)
- Best: in the middle of a straight section



Distributed RF for more beamlines



Application – under discussion at ESRF

Now:

- Cell 7:
  - full with RF, no ID
- Cell 23 (symmetric position):
  - 2 canted IDs

In future:

- Cell 7
  - 7 m long
  - **2 additional IDs** + ½ RF
  - **Possible long beam line !**
- Cell 23:
  - 7 m long
  - **Keep same 2 canted IDs** + ½ RF

- Allows prototyping RF upgrade on ID 23
  - Solid state amplifier on 1 existing five-cell cavity moved from cell 7
  - 3 new single cell HOM free cavities, replacing five-cell cavity
  - Smooth and non-disruptive implementation of RF upgrade
- Could also be envisaged for other pairs of straight sections at symmetric positions:
  - RF cell 5 / ID21
  - RF cell 25 / ID9

Major upgrade steps

- Goal for 2008: test one 50 kW tower
  - Collaboration contract with SOLEIL
  - Implementation and large scale test of new generation of transistors (e.g. BLF369, …)

- 2009, if ESRF upgrade program is approved: start building up 1 prototype RF unit
  - 1 five cell cavity

    fed by 320 to 360 kW ☞ 8 towers of SSA

  or

  - 3 new HOM damped cavities

    fed by 360 to 400 kW ☞ 9 towers of SSA

- Then steadily implement the full upgrade