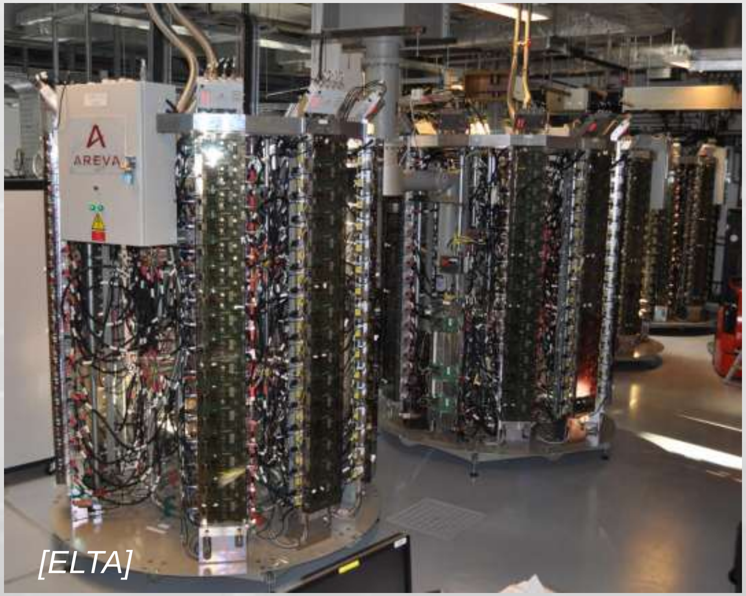


[ELTA]


[SDMS]

19th ESLS Meeting 2011

ISA, Aarhus University

23rd – 24th November

Status of ESRF RF Upgrade: HOM Damped Cavities* & Solid State Amplifiers

Jörn Jacob, Vincent Serrière, Jean-Maurice Mercier, Michel Langlois, Georges Gautier,

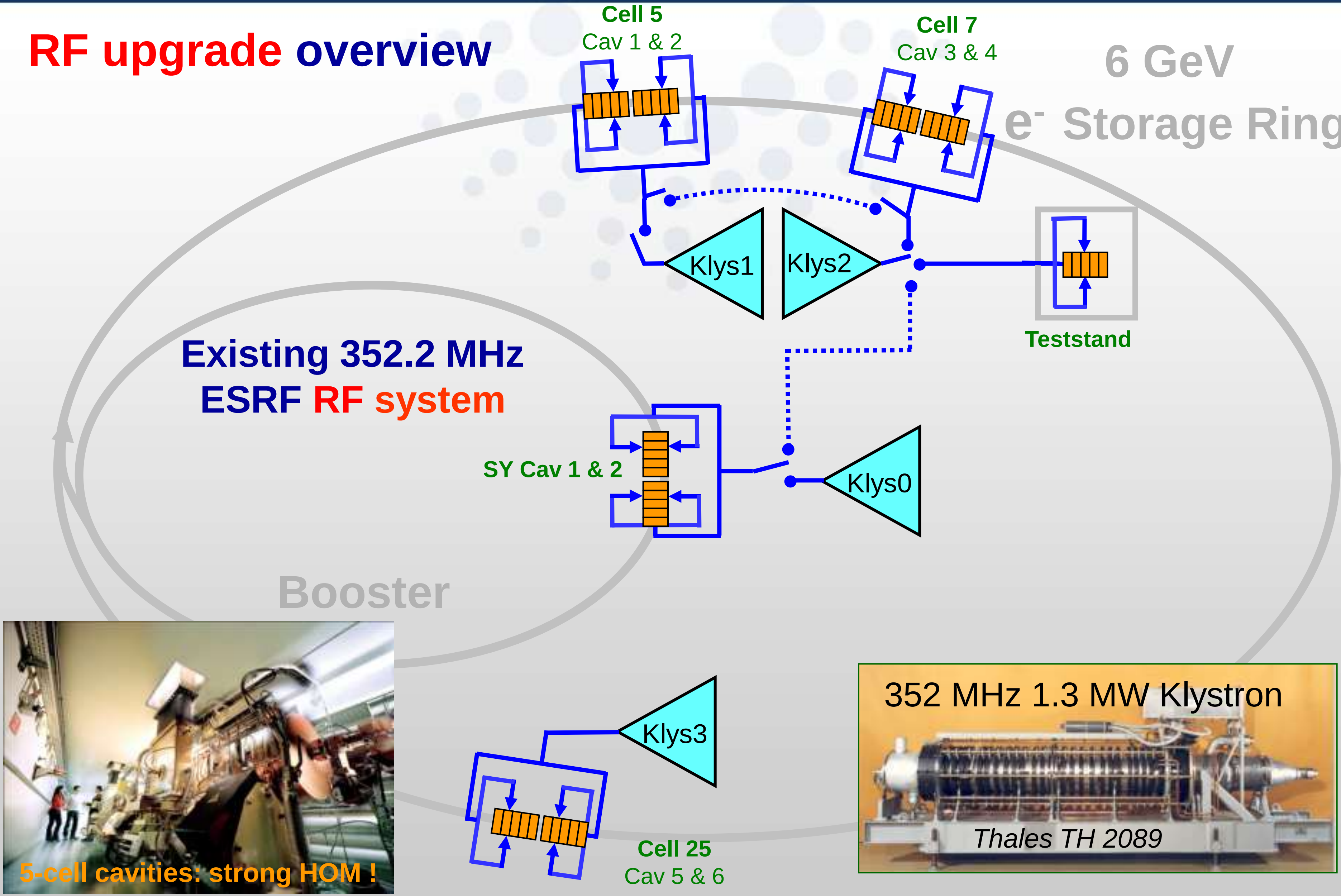
ESRF

European Synchrotron Radiation Facility

2007 - 2013

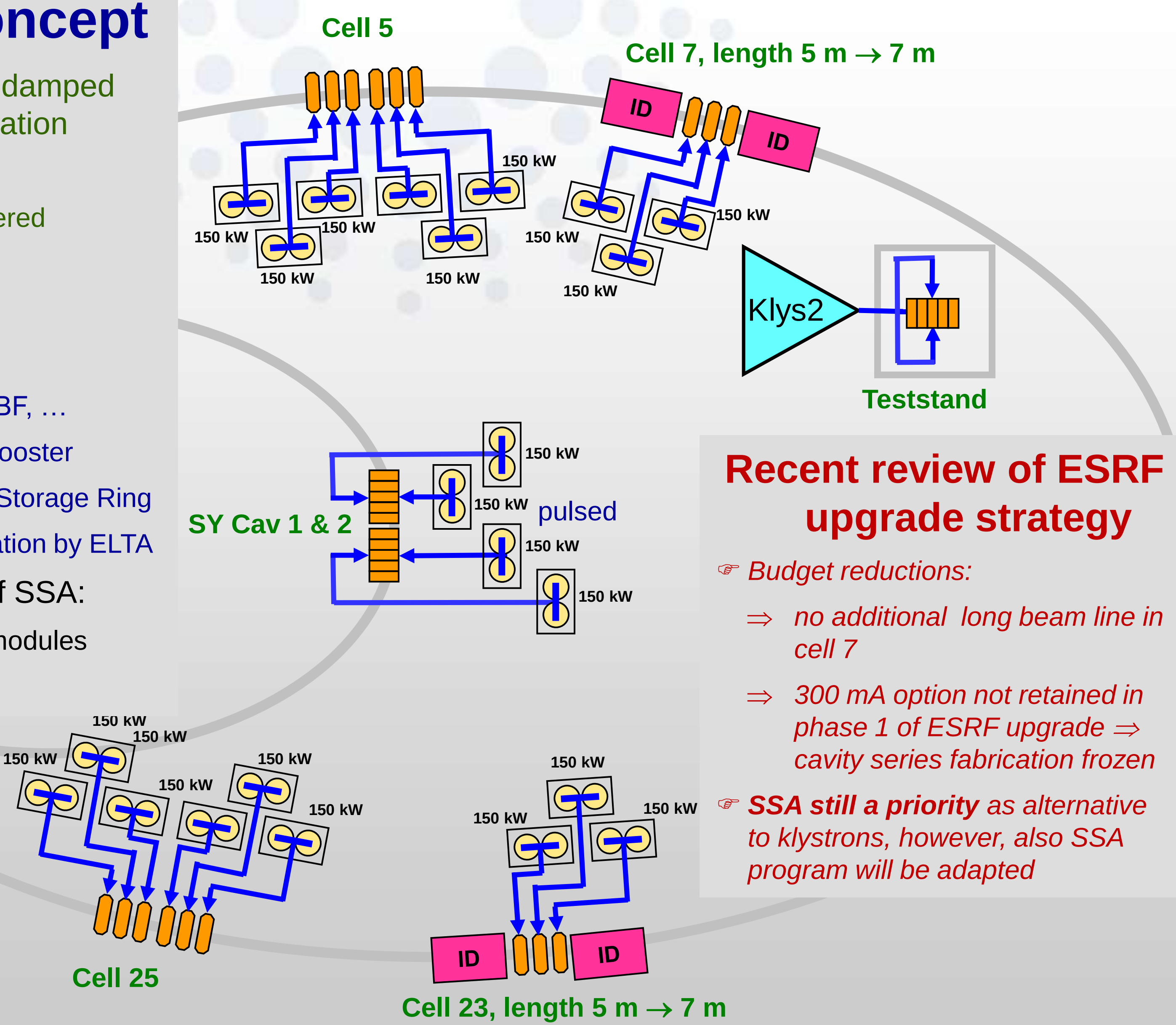
** This work, carried out within the framework of the ESRFUP project, has received research funding from the EU Seventh Framework Programme, FP7.*

RF upgrade overview



RF upgrade concept

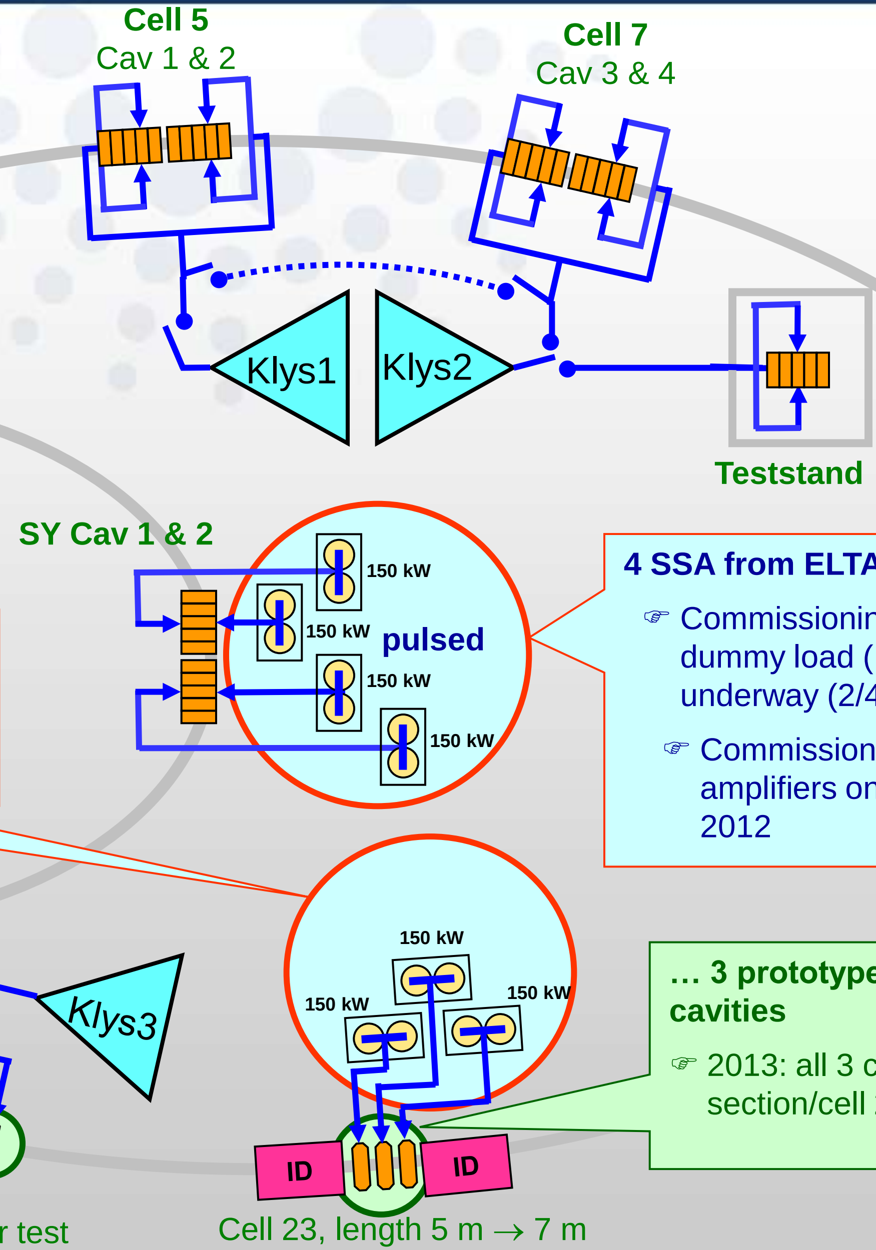
1. 18 new single cell HOM damped cavities for 300 mA operation
   - ☞ End of 2004 start R&D
   - ☞ Today: 2 prototypes delivered
2. Solid State Amplifiers
   - ☞ Extremely Modular,
   - ☞ Intrinsic redundancy,
   - ☞ High global operation MTBF, …
   - ◊ 4 x 150 kW SSA for the Booster
   - ◊ 18 x 150 kW SSA for the Storage Ring
   - ◊ 1st batch: 7 SSA in fabrication by ELTA
3. In house development of SSA:
   - ☞ Cavity combiner for 132 modules
   - ☞ Planar balun transformer



Recent review of ESRF upgrade strategy

- ☞ *Budget reductions:*
  - ⇒ *no additional long beam line in cell 7*
  - ⇒ *300 mA option not retained in phase 1 of ESRF upgrade ⇒ cavity series fabrication frozen*
- ☞ ***SSA still a priority** as alternative to klystrons, however, also SSA program will be adapted*

RF upgrade phase 1
well in progress !



3 SSA from ELTA for SR:

- Powering 3 new HOM damped cavities on the storage ring

4 SSA from ELTA for the booster:

- Commissioning on variable dummy load (EH tuner) underway (2/4 tested)
- Commissioning of all 4 amplifiers on the ring in March 2012

3 prototype HOM damped cavities …

- Test with beam one by one on cell 25 with klystron transmitter TRA3:
- **RI cavity installed in October:** excellent behaviour with beam

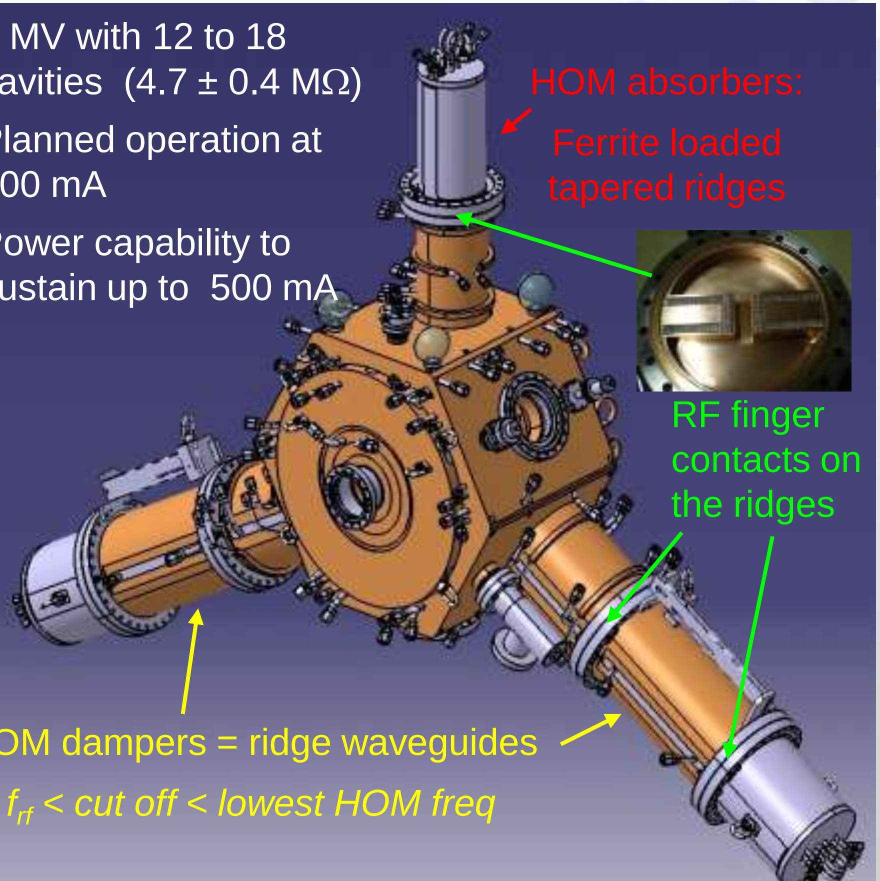
… 3 prototype HOM damped cavities

- 2013: all 3 cavities in new 7 m section/cell 23 with 3 SSA

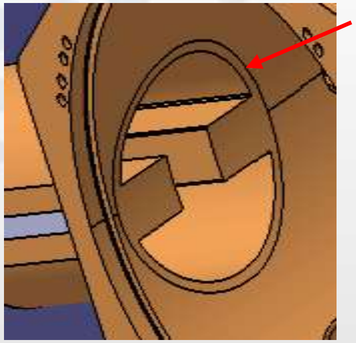
352.2 MHz Single cell NC HOM damped cavity

[ESRF project leader: Vincent Serrière]

- 9 MV with 12 to 18 cavities (4.7 ± 0.4 MΩ)
- Planned operation at 300 mA
- Power capability to sustain up to 500 mA



Based on 500 MHz BESSY, MLS, ALBA design [E. Weihreter et al.]



E-beam welding of HOM coupling sections to the body

⇒ to avoid the gap between ridges and cavity body

⇒ to suppress residual HOM and flange over- heating (observed on BESSY/ALBA cavity)

3 power prototypes in fabrication:

- validate the design
- validate 2 different manufacturing procedures
- qualify 3 companies: RI, SDMS, CINEL
- obtain 3 operational cavities for cell 23 according to initial upgrade concept

2007 - 2013

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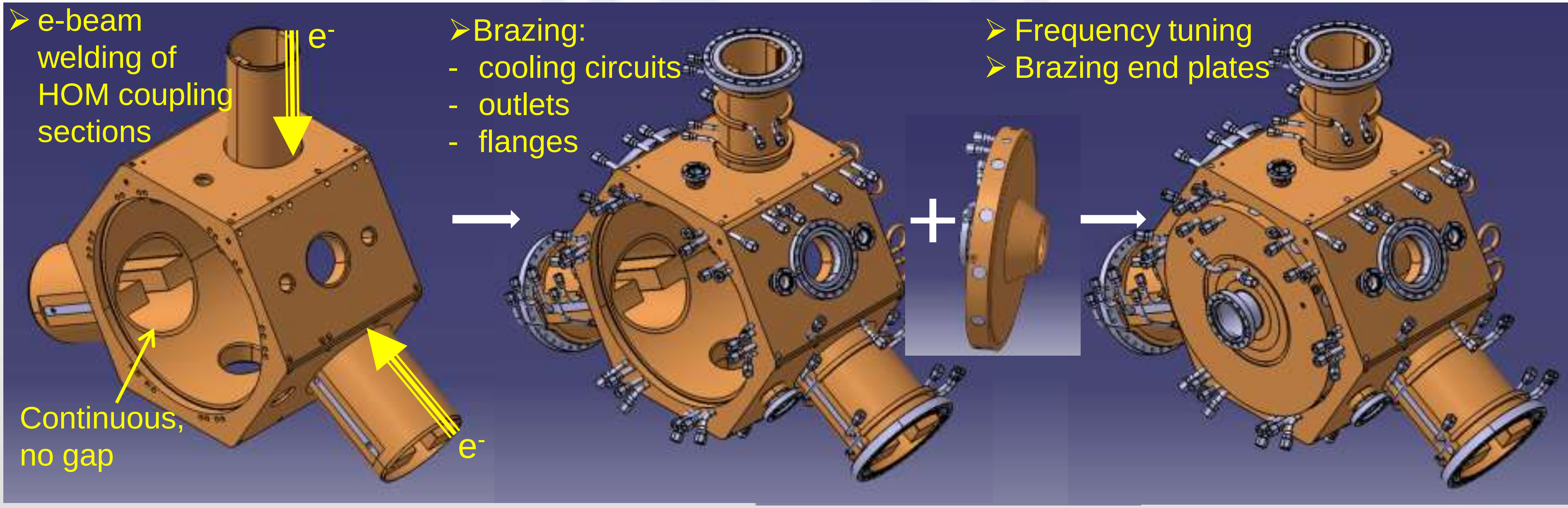
Initially specified mechanical design & manufacturing procedure *applied by RI - Research Instruments (photos)*

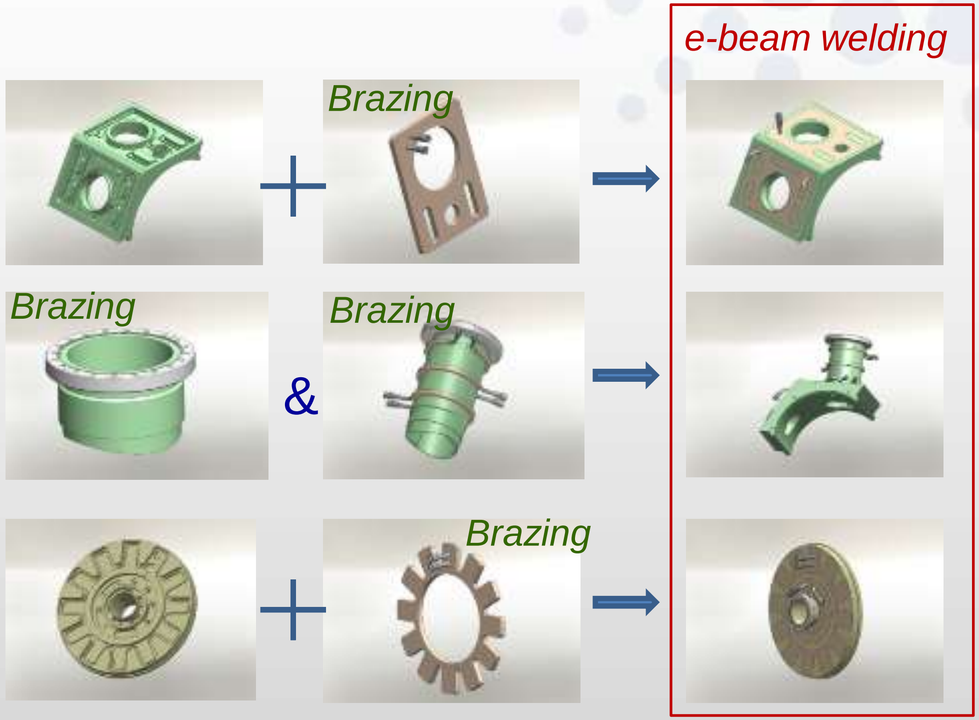


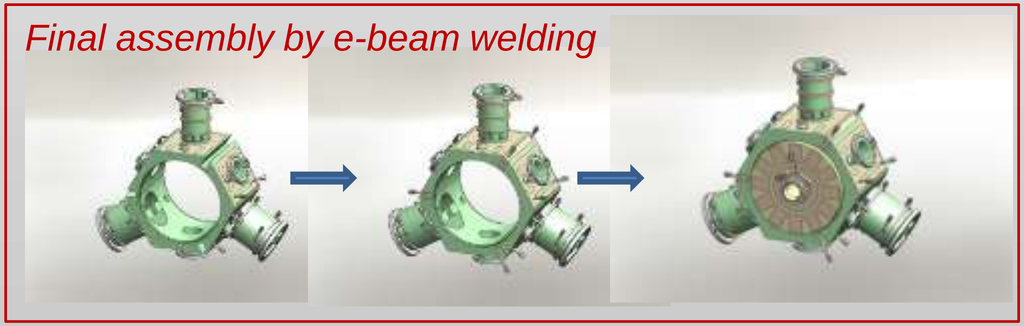

After e beam welding

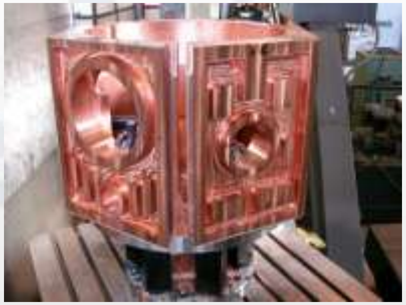

Laser smoothing of pores


After brazing / body & 1st end disc

Alternative design proposed by SDMS, engineered by V. Serrière / ESRF
applied by SDMS and CINEL





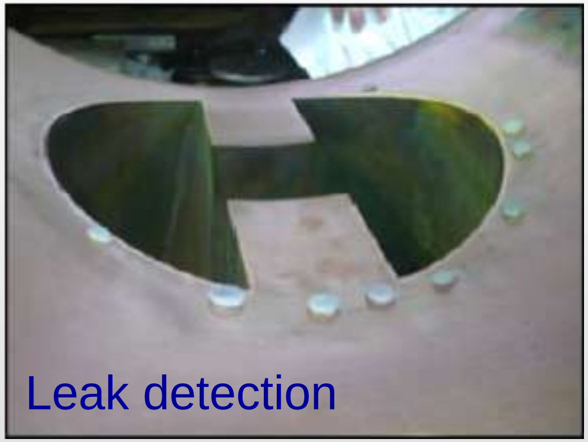


CINEL: 3 body sectors after machining of the water cooling channels, September 2010

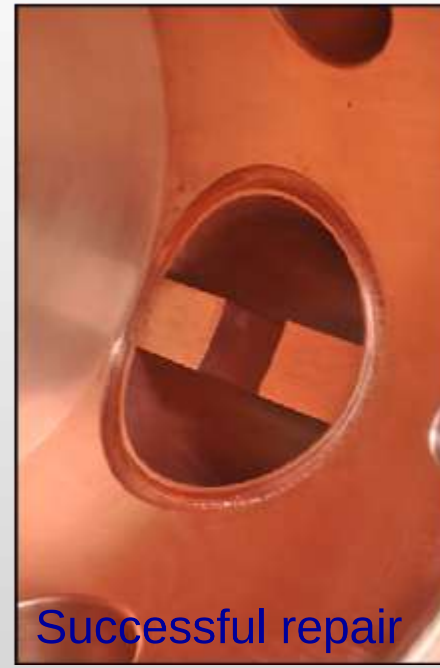
SDMS parts of end discs ready for e-beam welding

SDMS: Body after e-beam assembly of the 3 sectors, November 2010

SMDS cavity: one e-beam weld / HOM coupling section leaky → successful repair


Leak detection


Difficult e-beam welding operation


Successful repair

SDMS proposed to solve the problem:

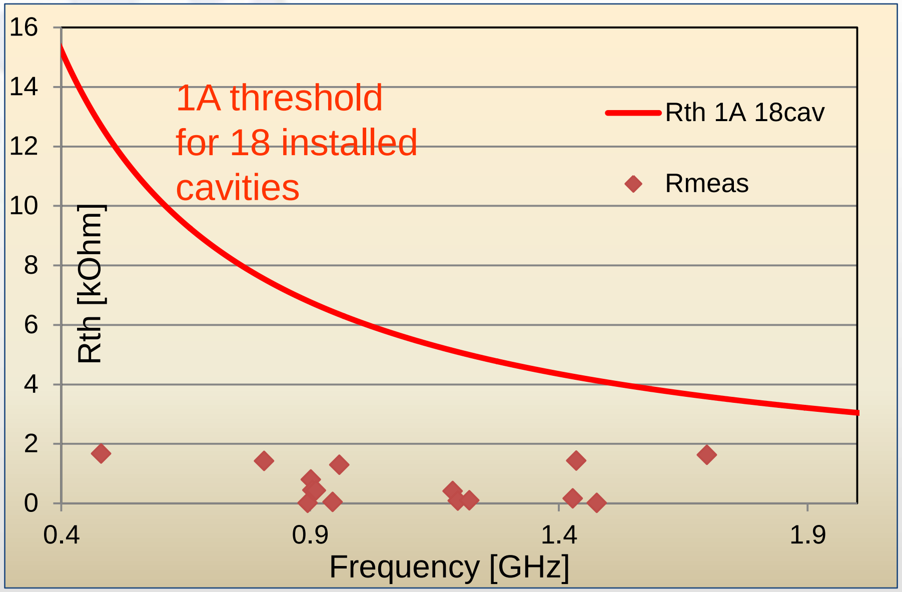
1) MIG welding: not successful and after several attempts the coupling section fell off
2) by a further e-beam weld from inside with an intermediate copper ring

Status of HOM Damped Cavities

RI – Research Instruments

- Delivered 15 June 2011
- Excellent fundamental mode impedance:

  R_s = 4.9 MΩ,
  Q_0 = 33800 (expected 30000 to 35000)
- HOM spectrum a factor two lower than design goal
- **600 kV obtained in CW** on RF power test stand
  - RF fingers between HOM coupling section and damper: no sign of degradation ⇒ **1st successful step in validating our approach**



- October: Installation on Storage Ring cell 25
- Passive operation with excellent vacuum behaviour at
  - ✓ 200 mA in mutlibunch fillings (a few hours after machine restart)
  - ✓ 95 mA in 16 bunch filling: obtained within 10 min, with $p < 5.10^{-9}$ mbar (most demanding for HOM dampers)
- Active operation - first tests with beam acceleration
  - ✓ Vacc = 0.4 MV with 20 kW
  - ✓ Ibeam = 168 mA with total of 63 kW into new cavity

Status of HOM Damped Cavities

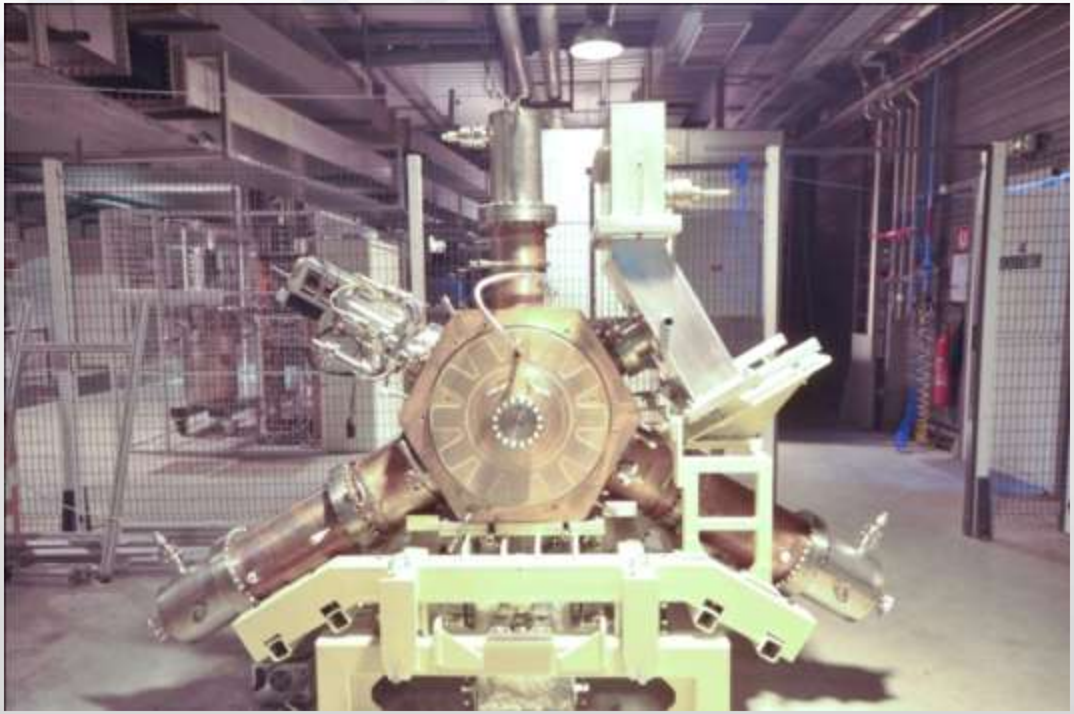
SDMS cavity:

- Delivered on 20 July 2011
- Installation on cell 25 in summer 2012

CINEL

- Still in fabrication: delivery in 2012
- Tests on cell 25 early 2013

☞ Summer 2013: Installation of all 3 cavities on cell 23 lengthened to 7 m



SDMS cavity

Status of SSA from ELTA

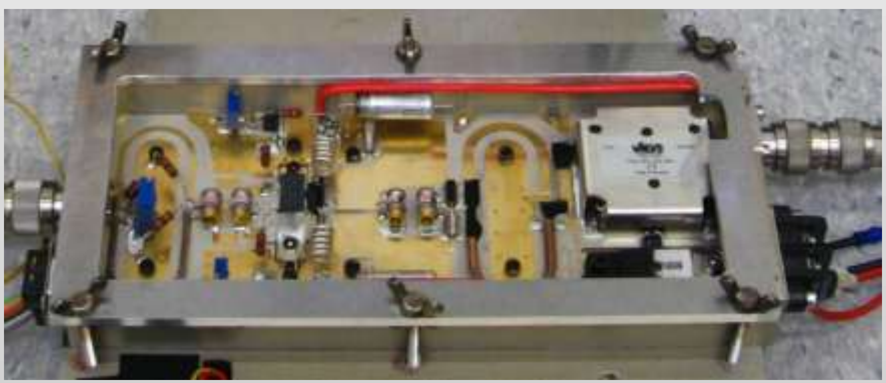
[ESRF project leader: J.-M. Mercier]

Order 7 x 150 kW SSA from ELTA / AREVA:

- Qualifying SSA as alternative to high power klystrons to guarantee long term operation of ESRF→ preparing possible replacement of other klystrons in further upgrade phases.
- Saving electrical power on the booster thanks to the anti flicker system needed for the cycling at 10 Hz.
- Qualifying with beam a new storage ring RF unit comprising 3 HOM damped cavities powered by 3 SSA, which could replace one klystron powered five-cell copper cavity.

ELTA design based on SOLEIL SSA:

(Transfer of technology from SOLEIL)



650 W – 352.2 MHz RF module

- developed by SOLEIL
- 6th generation LDMOSFET = BLF 578 / NXP
- V_{ds} = 50 V
- Gain: 20.3 ± 0.2 dB
- Efficiency: 68 to 70 %
- Low transistor & circuit temperature: < 60 °C
- Circulator: Insertion loss < 0.2 dB, Isolation > 26 dB

Summer 2010:

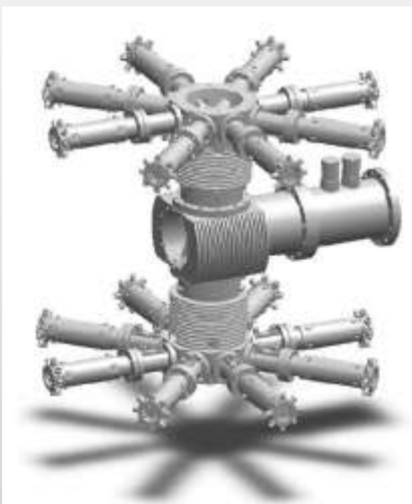
- 500 hours fatigue test with 7500 ON/OFF cycles
- 16 RF modules at 10 kW: without any detected degradation

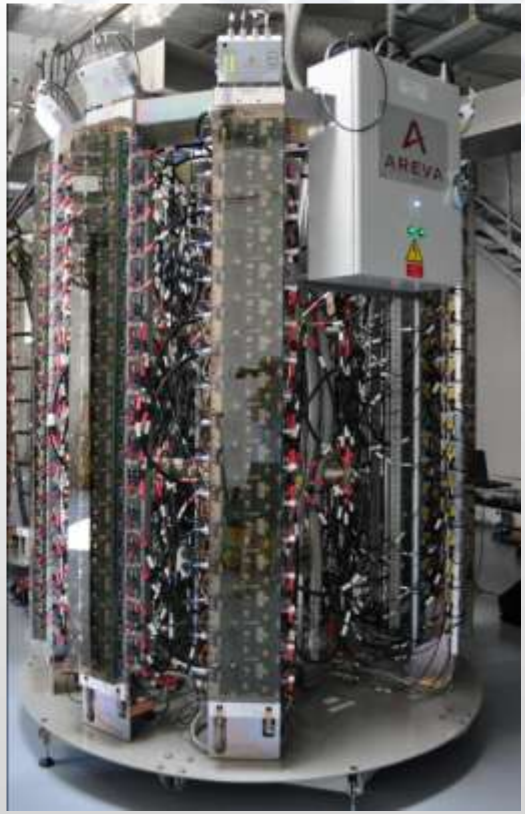
Status of SSA from ELTA, followed

75 kW tower →

- 128 RF modules
- Coaxial combiner tree with $\lambda/4$ transformers

↓





150 kW amplifier = 2 towers

Spec: η > 55 % at 150 kW

η > 45 % at 100 kW

150 kW / full reflection for 20 μs

150 kW / 50 kW reflection permanently

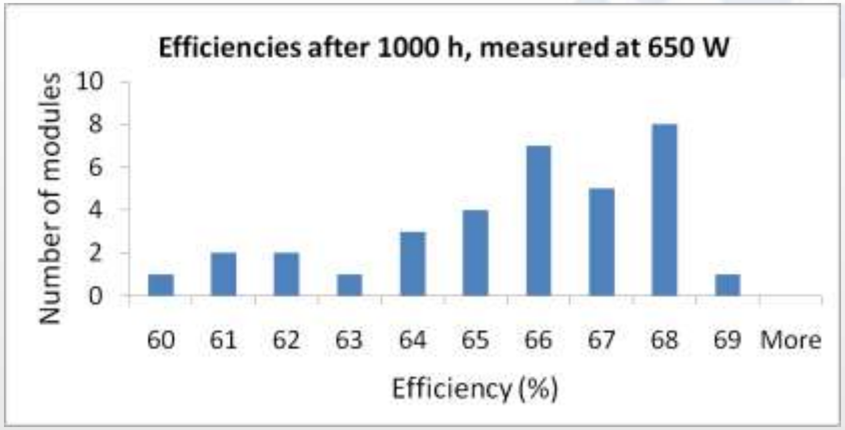
80 kW / full reflection permanently

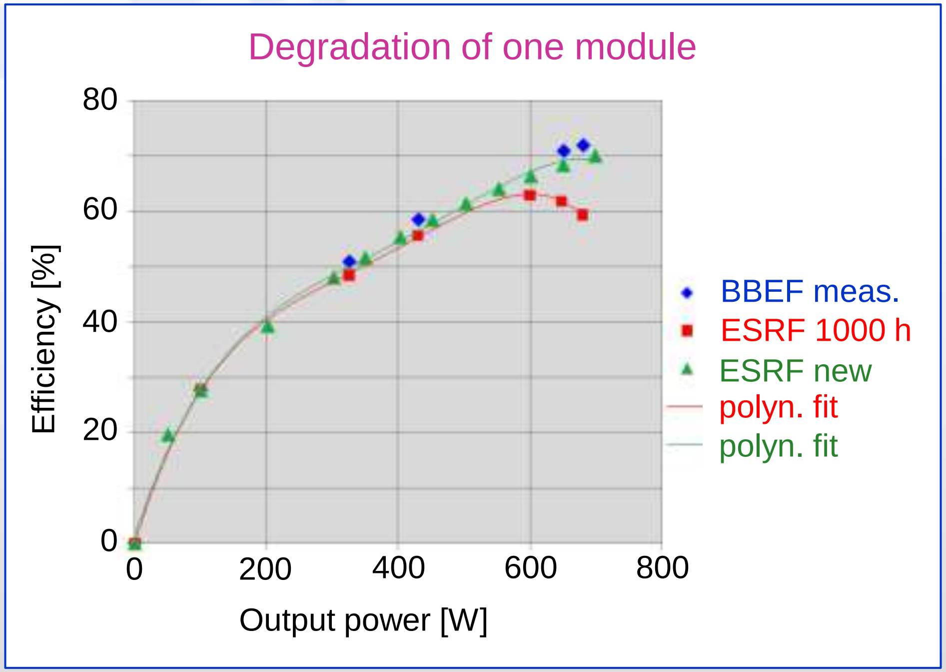
Guarantee extension ⇒ 5 years in total !

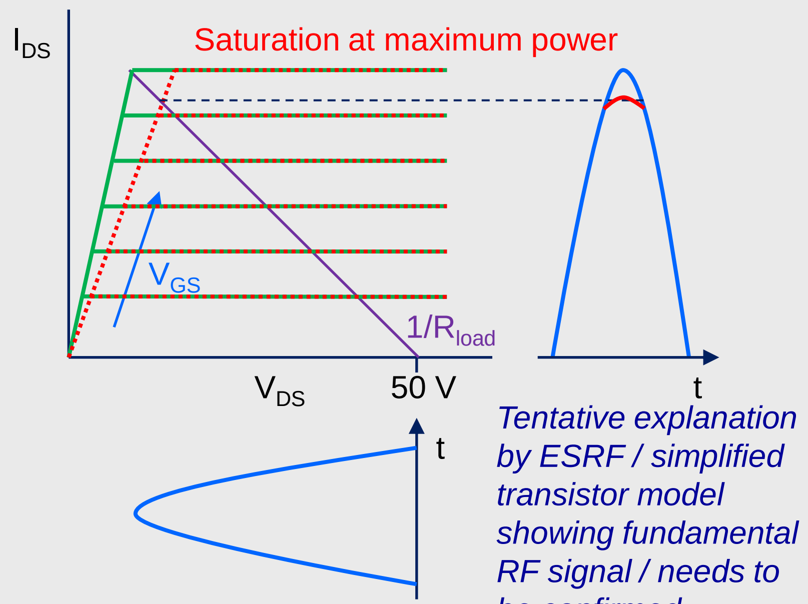
April 2011:

- **First 75 kW tower at the ESRF, tested at full power on load**
- **Mismatch checked for all phases with E/H tuner**
- **Initially $\eta \approx$ 59 %** → degradation after 1000 h run test → **$\eta \approx$ 57 %** (still above spec)

Status of SSA from ELTA, followed



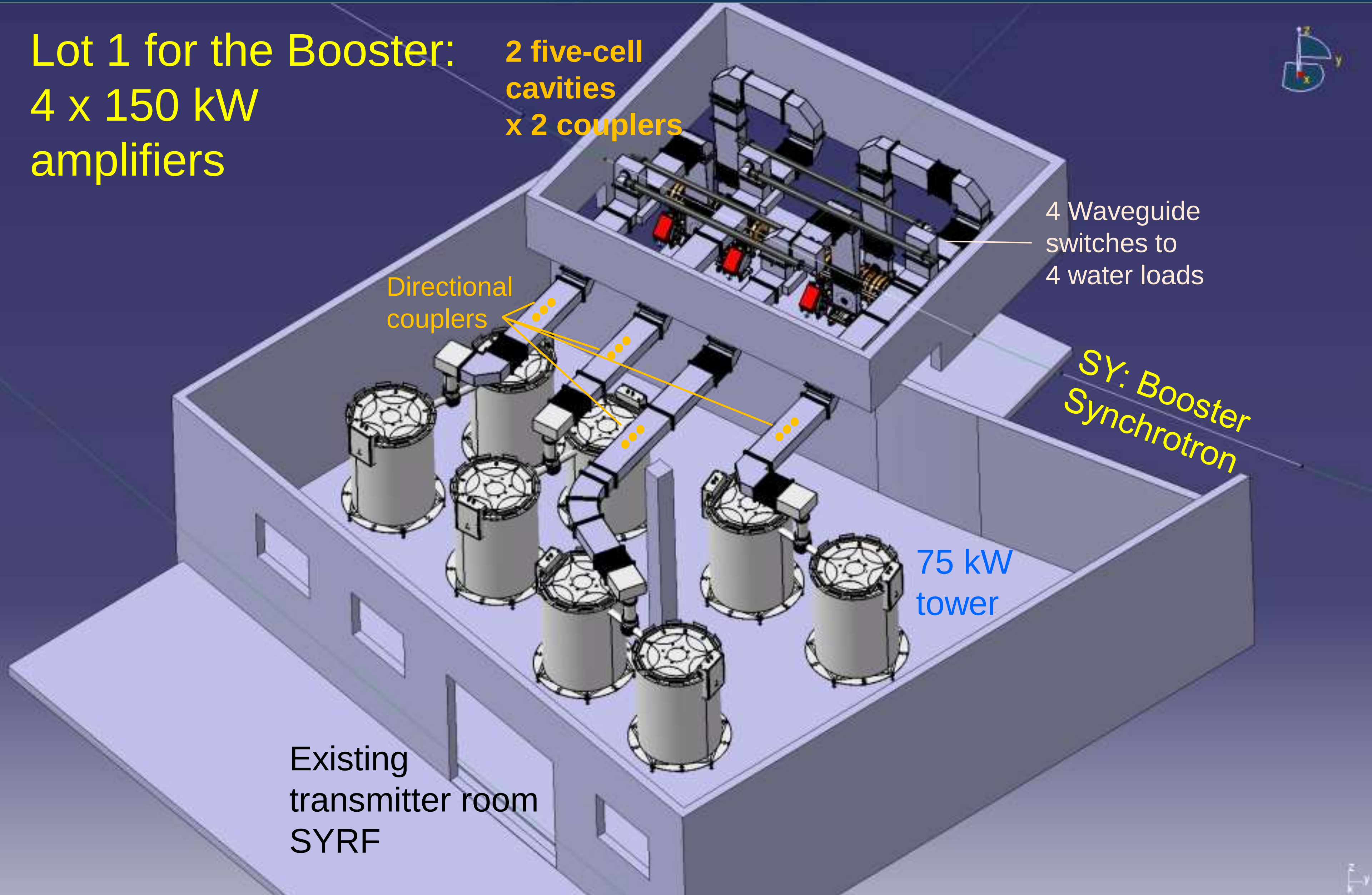




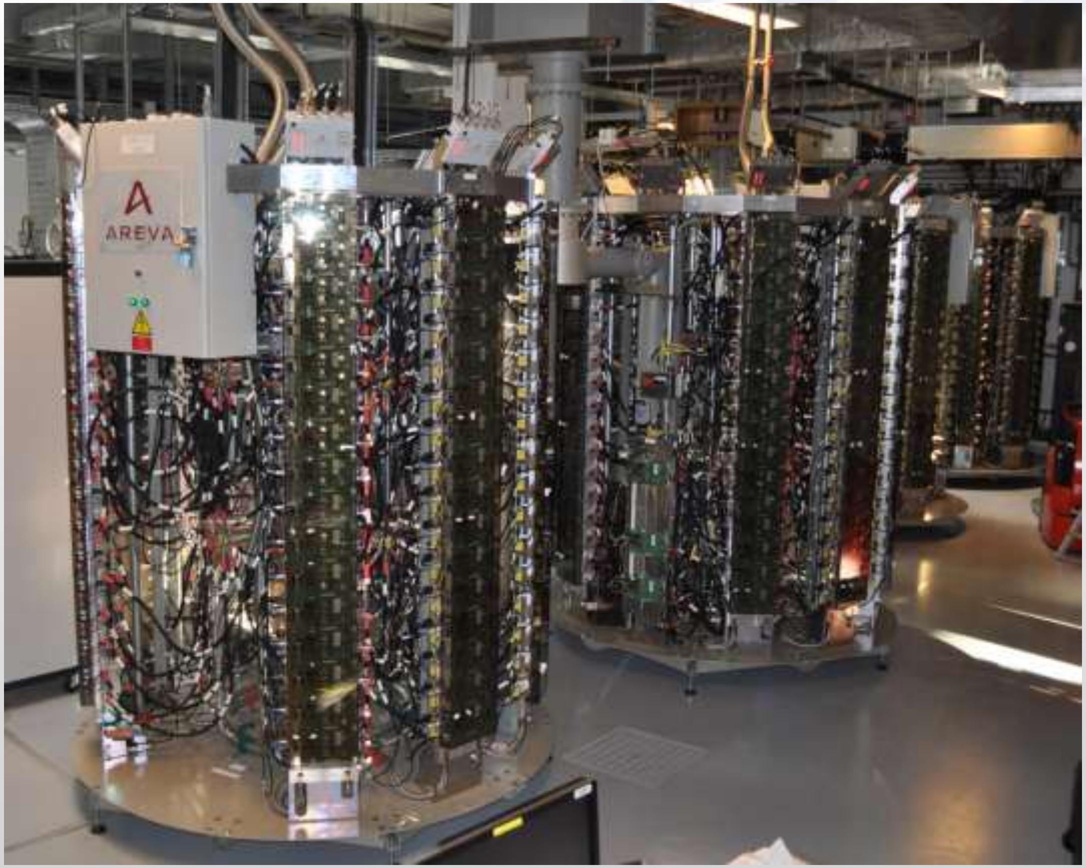
Tentative explanation by ESRF / simplified transistor model showing fundamental RF signal / needs to be confirmed

- ✓ NXP: checked transistors are still in spec
- ✓ ESRF experiment: Partial cure by UV radiation ☞ indicates electron trapping in crystal defects of LDMOSFET channel, but not only explanation
- ✓ ELTA is currently investigating this phenomenon
- ✓ Only little degradation on SSA efficiency, since nominal module power around 610 W, i.e. at the limit of the observed effect

Lot 1 for the Booster: 4 x 150 kW amplifiers



Status of SSA from ELTA, followed



Three 150 kW SSA already installed in SYRF

- Delivery of first 150 kW SSA for the booster on 2 September 2011 (late by 2 months)
- 3rd SSA delivered last week
- Preliminary acceptance tests on adjustable load (E/H tuner) completed on SSA 1 and SSA 2
  - SSA1: $\eta = 59 \pm 1\%$
  - SSA 2: $\eta = 58 \pm 1\%$
  - Some reservations to be released at the final acceptance tests on booster cavities
- No significant gain & efficiency degradation after 200 hours run test on SSA 1: however, this needs to be monitored carefully during coming 1000's hours of operation
- Tests of booster SSA 3 and SSA 4 still foreseen this year, before 18th December
  - then electricity and water cut for long ESRF shut down ☞ tight schedule
- Connection to booster cavities foreseen during long winter shut down
- Final acceptance tests on booster cavities in March 2011 ☞ intermediate accelerator restart during ESRF shut down

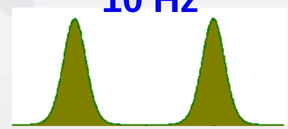
400 V ac / 280 V dc power supply for the booster SSA

Constant power
300…400 kW

Reduced power consumption

Peak DC power
1000…1200 kW

10 Hz



Mains 400 V ac

280 V dc

600 kW RF

In house built capacitor cabinets

- One 280 V dc / 400 kW PS for the booster SSA
- Four 280 V dc / 360 kW PS: 3 for the 3 SR SSA and 1 as “hot spare “ for the booster SSA (slightly reduced power for normal injection use of the booster)

Developed by ESRF Power Supply Group

SSA control

SSA - monitoring of:

- For each RF module:
  - DC Current
  - Transistor socket and circulator load temperatures
- RF forward and reflected power at each 5 kW combination and each 75 kW tower
- Cooling water flow and temperature interlocks
- "Muxboxes" interconnected via RS485

4 control racks:

(1 per SSA)

- LLRF & Driver crate with RS232 communication
- Hardwired Fast Interlock crate with RS232 communication
- PLC crate / slow interlocks with TCP/IP communication
- RF amplitude & phase measurement crate with RS232 communication

FPGA rack for booster waveform control

1 common rack:

- Transmitter control computer (PCI Express)
- PCI Rocket ports (RS 232/422/485) communication with local control racks and ELTA "muxboxes"
- LLRF crate with FPGA based IQ regulation loop for the 10 Hz / 50 ms booster pulse

→ modulated RF signal distributed to 4 individual SSA

IQ modulator / demodulator LLRF rack
[ESRF project leader: G. Gautier]

In house R&D of SSA

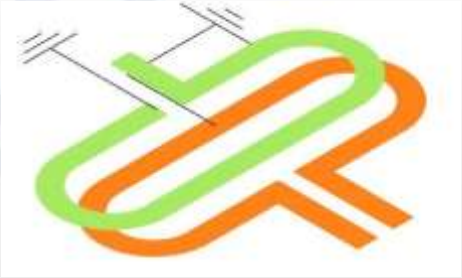
[ESRF project leader: Michel Langlois]

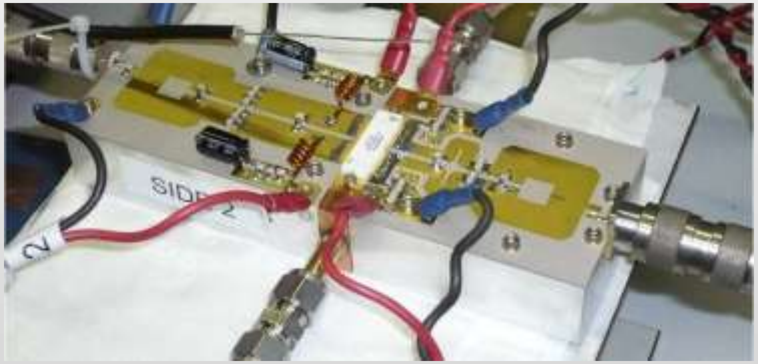
Objectives

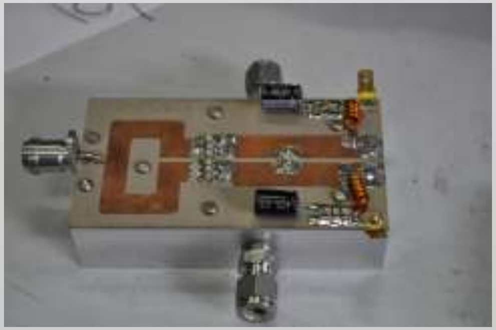
- develop the required internal expertise for the follow up of more than 1 MW of SSA
- further develop this technology to reduce size & costs and to increase the efficiency

1. RF module with planar balun

- ✓ Both sides of the transformer are printed on the PCB
- ✓ No coaxial for the balun transformer:
  - ⇒ easier mass production,
  - ⇒ reduced fabrication costs
- ✓ 1st version limited to ≈ 400 W by component temperature
- ✓ 2nd improved version:
  - ⇒ no matching capacitor on balun – at the price of some extra length
  - ⇒ **650 W already obtained**
  - ⇒ ultimately: use of high thermal conductivity substrate





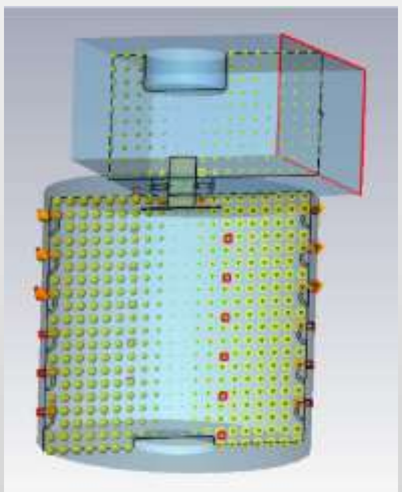


In house R&D of SSA

2. Cavity Combiner

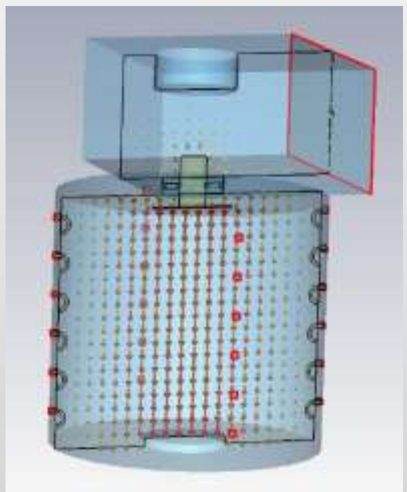
Strongly loaded E_{010} resonance

- Modest field strength
- Cavity at atmospheric pressure
- 1 dB - Bandwidth ≈ 500 kHz



H field

Homogenous magnetic coupling of all input loops



E field

Strong capacitive coupling to **the output waveguide**

For ESRF application:

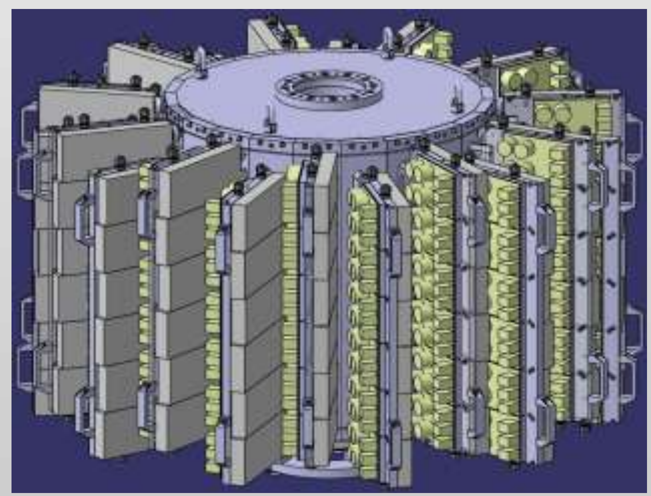
- **6** rows x **22** Columns x **600 … 800 W** per transistor module

  ⇒ 75 … 100 kW

- More compact than coaxial combiners

  $\beta_{waveguide} \approx n_{module} \times \beta_{module} >> 1$

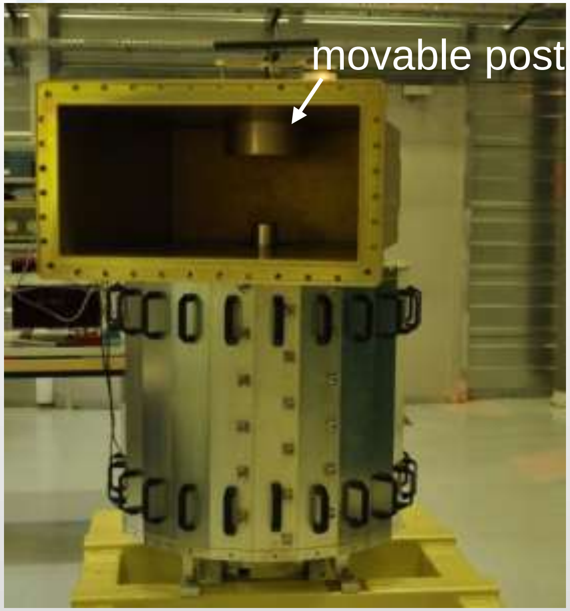
- Easy to tune if n_{module} is varied
- Substantial reduction of losses ⇒ higher η



In house R&D of SSA

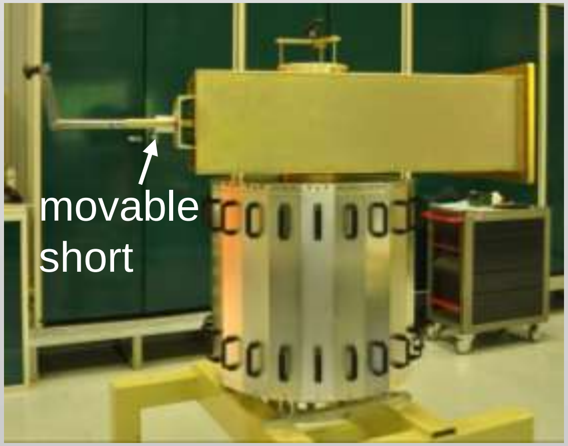
Lab prototype with 18 inputs

- ✓ Versatility already checked: matching with 6 to 18 modules in place by moving post and short
- ✓ Next step: build 3 wings with 6 RF power modules each to obtain 10 to 12 kW

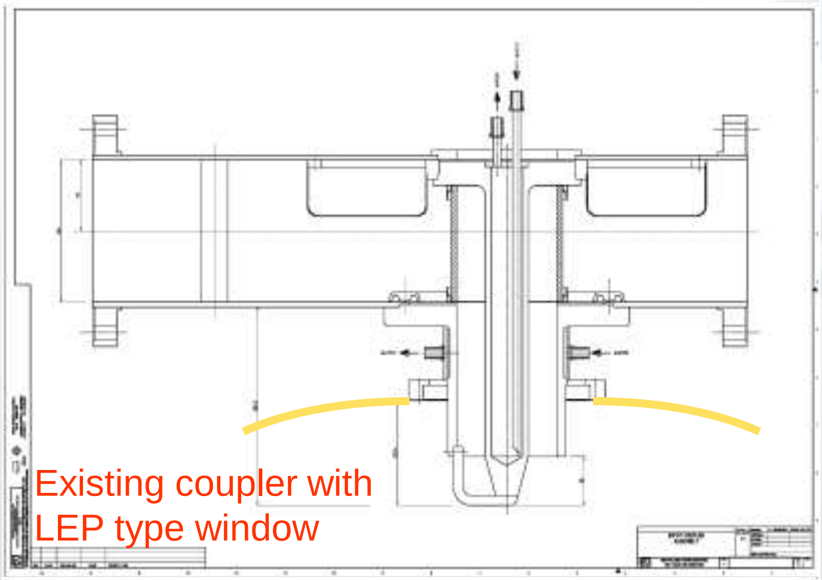


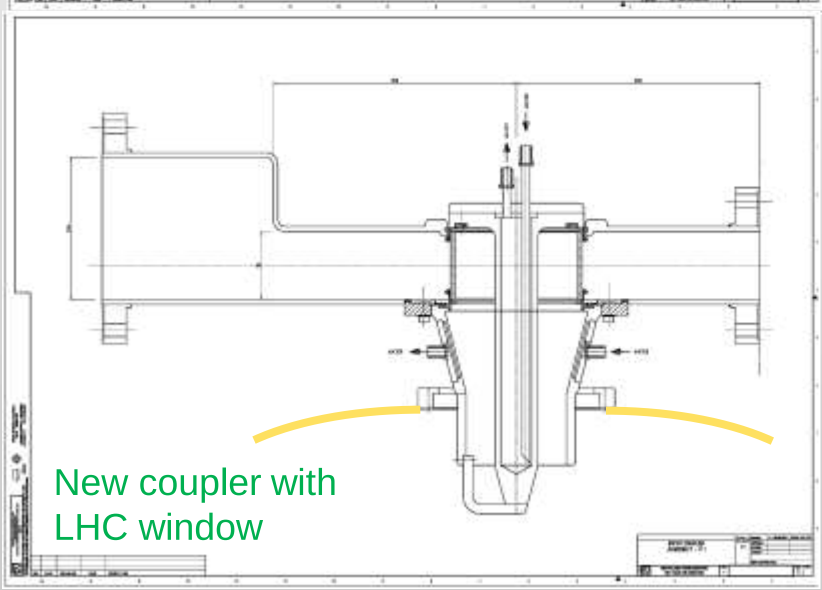
Project within FP7/ESFRI/CRISP:

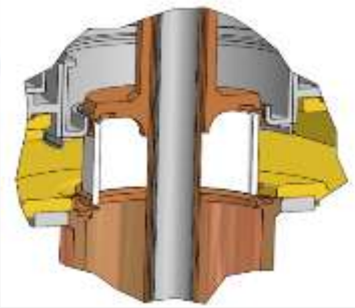
- ➢ 75 kW prototype for ESRF
- ➢ Feasibility studies for CERN, ESS and FAIR at other frequencies



New cavity high power coupler using LHC window







- Collaboration contract CERN / ESRF / SOLEIL
- First prototype coupler:
  - Conditioning at ESRF since 1 week: already 200 kW CW and 300 kW in 80 μs pulses !
- Prototype coupler for SOLEIL cavity will be tested later at ESRF using a dedicated warm cavity from CERN
- Furthermore, fabrication of
  - 2 series couplers for ESRF
  - 2 series couplers for SOLEIL
  - 1 prototype to be tested this autumn + possibly several series couplers for APS (extra contract)
  - 4 prototypes for SPL

☞Many thanks to Eric Montesinos / CERN for his great involvement and for leading this project !

Thank you for your attention !

ESRF Linac / Injection-Extraction / RF Group