FROM RESEARCH TO INDUSTRY

CAVITY DEVELOPMENT FOR THE LINEAR IFMIF PROTOTYPE ACCELERATOR

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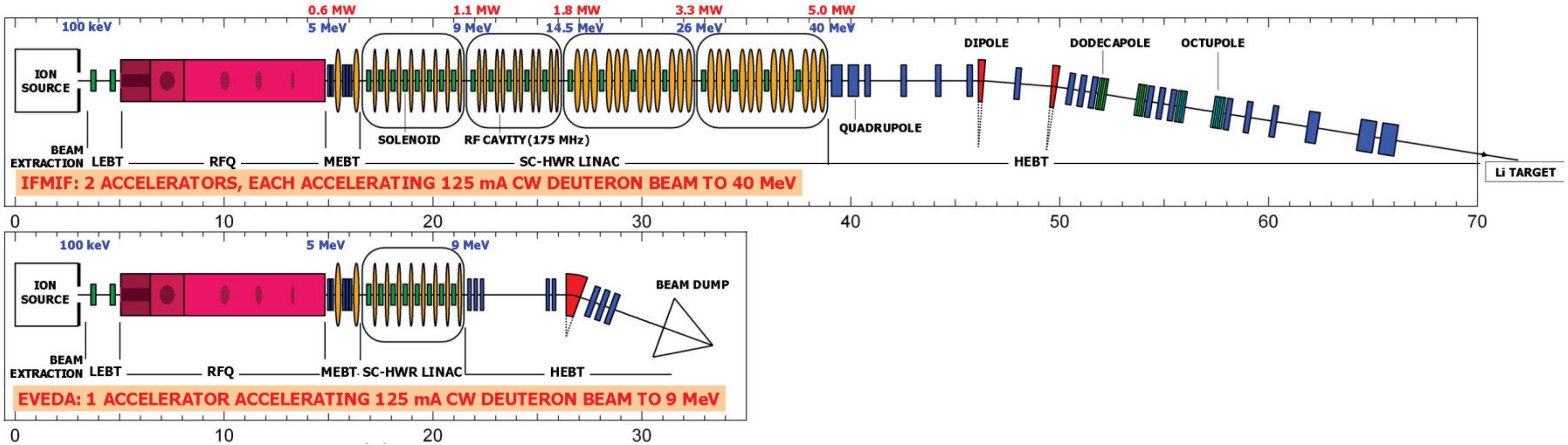
On behalf of the CEA SRF Linac Team

OUTLINE

- Overview of the Linear IFMIF Prototype Accelerator (LIPAc) and the cryomodule
- RF design and tests of the HWR prototypes
- New cavity design

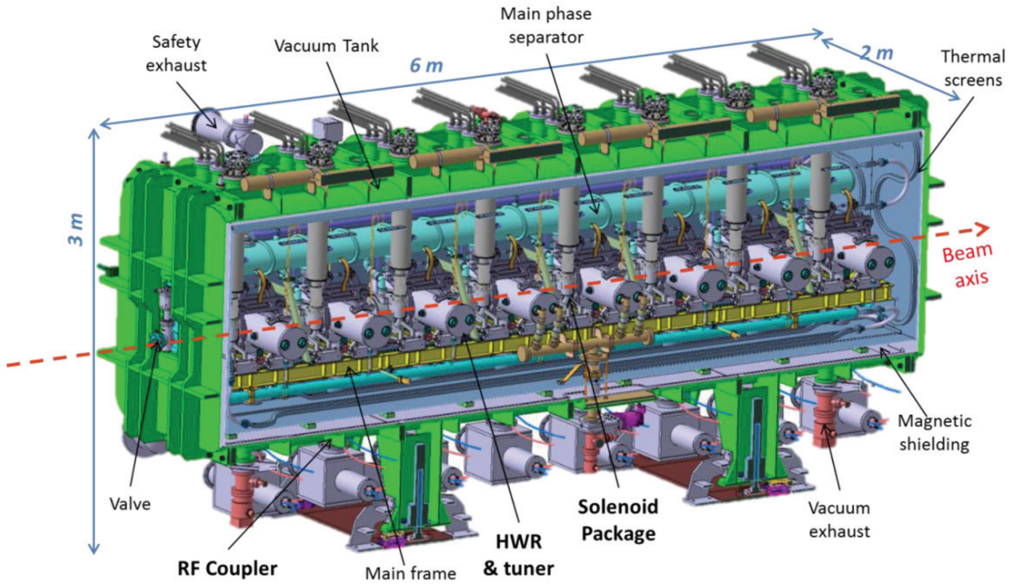
IFMIF/EVEDA: SCOPE OF THE PROJECT

- International Fusion Material Irradiation Facility (IFMIF): 2 accelerators in parallel
- Each accelerator: 125 mA deuteron beam, 40 MeV, CW
- EVEDA (Engineering Validation and Engineering Design Activities): first phase to validate the key technologies



- Linear IFMIF Prototype Accelerator (LIPAc) to be tested at Rokkasho – Japan
- International collaboration between Europe and Japan

THE LIPAC CRYOMODULE



- **8 Half Wave Resonators** (operating temperature 4.4 K)
- **8 RF Power Couplers**
  - CW operation (70 kW max)
  - Vertical position
  - One room temperature window
- **8 Superconducting Solenoid Packages**
  - Focusing solenoid with shielding
  - H & V steerers
  - Cold BPM
- **Cryostat**

See H. Jenhani, THP056

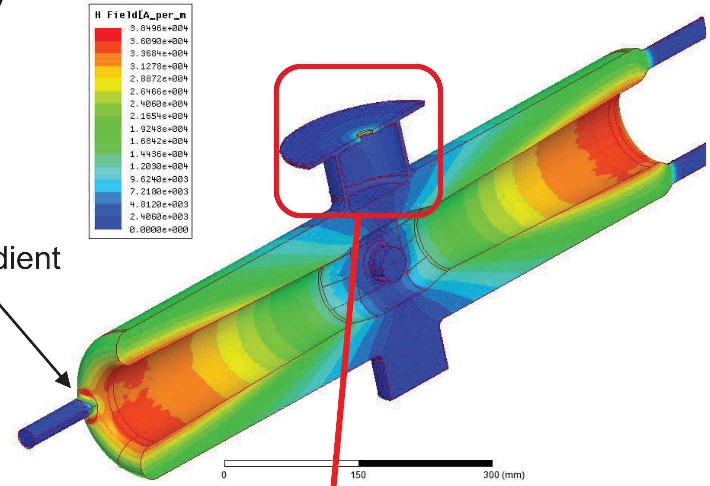
Target Values of complete Cryomodule	
Frequency	175 MHz
β value of the HWR	0.094
Accelerating field E_a	4.5 MV/m
Unloaded Quality factor Q_0 for R_s=20 nΩ at nominal field	1.4×10^9
Beam aperture HWR/SP	40 / 50 mm
Freq. range of HWR tuning syst	± 50 kHz
Freq. Resolution of tuners	200 Hz
Max. transmitted RF power by coupler in CW (for LIPAc)	70 kW
Max. reflected RF power in CW	20 kW
External quality factor Q_{ex}	6.3×10^4
Magnetic field B_z on axis max.	6 T
$\int$ B.dl on axis	1 T.m
Field at cavity flange	$\leq$ 20 mT
CBPM position meas. Accuracy	0.25 mm
CBPM phase meas. accuracy	2 deg
Total Static/Dynamic Heat losses	18 / 120 W

RF DESIGN AND TESTS OF THE HWR PROTOTYPES

HALF-WAVE RESONATOR RF DESIGN

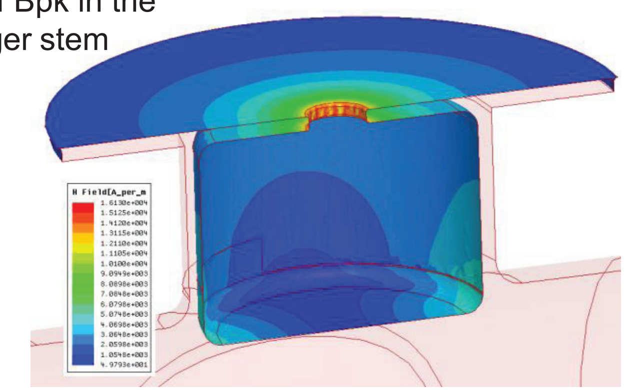
Original design includes a capacitive plunger tuner (2009)

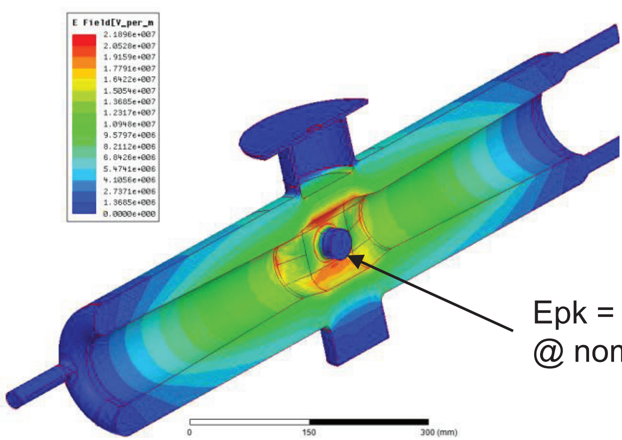
Parameter	Value	Unit
Frequency	175.366	MHz
Maximum r/Q	150	Ohm
Optimum beta	0.11	
Design beta	0.094	
r/Q @ design beta	140	Ohm
Epk/Eacc	4.8	
Bpk/Eacc	11	mT/(MV/m)



Bpk = 49.5 mT
@ nominal gradient

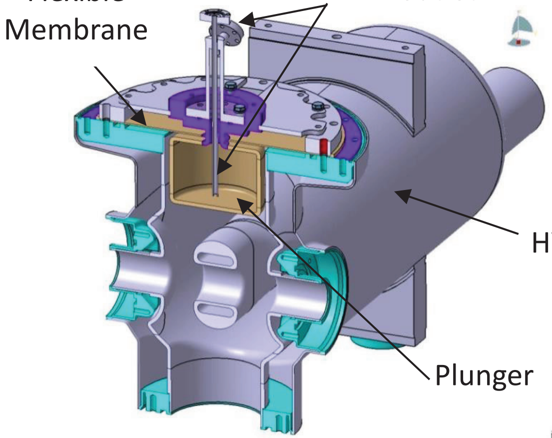
0.4 of Bpk in the
plunger stem



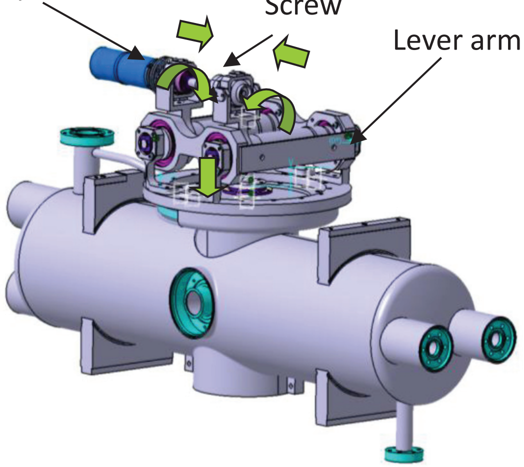


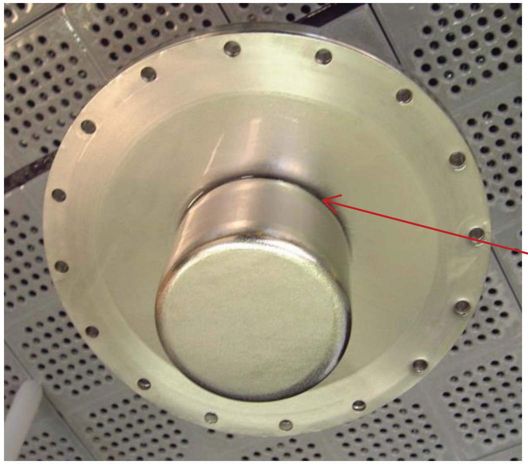
Epk = 21.6 MV/m
@ nominal gradient

PLUNGER AS TUNING SYSTEM

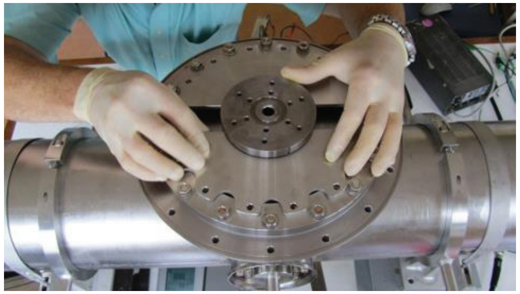


- Deformation of a thin NbTi membrane
- Tuning range: ± 50 kHz -> membrane deformation: ± 1 mm
- Lever-arm system based on Saclay type tuners
- Plunger cooled with liquid helium

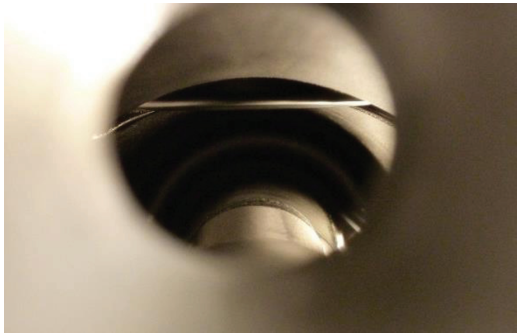




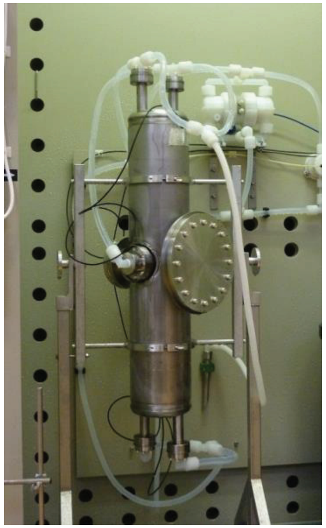
Problems during manufacturing:
- Break of NbTi thin layer during rolling procedure
- Flatness of membrane
- Breakdown of the welding (plunger-membrane)



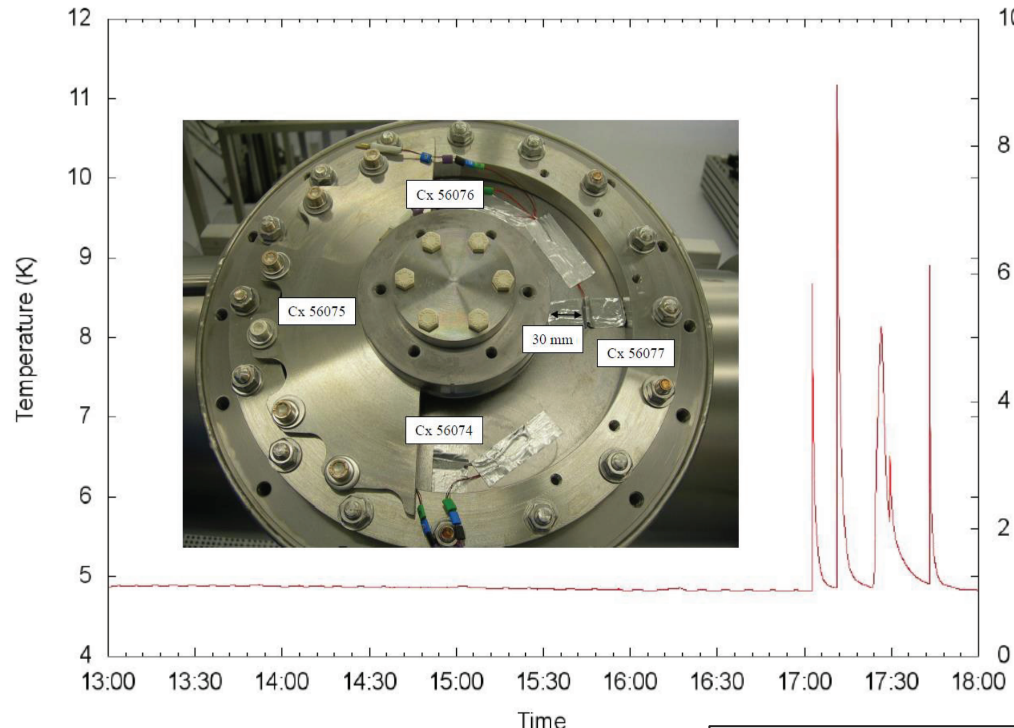
Butt fits correctly when installed on the cavity



VERTICAL TEST WITH THE PLUNGER



- Test with one of the two HWR prototypes
- Standard surface treatment (BCP, HPR), assembly and test @ IPN Orsay



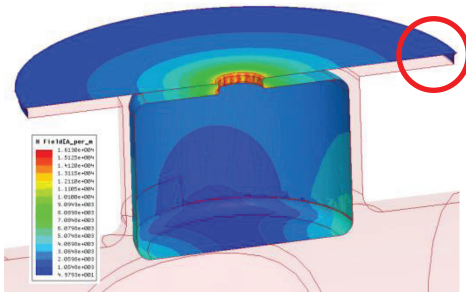
F. Orsini et al., SRF 2011, THIOB02

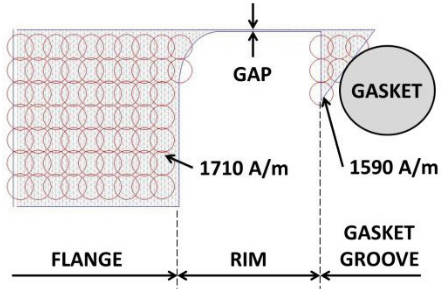
- Quench events at 1 MV/m on the plunger
- Measured Q_o at low field 1.7×10^8 (10 times lower than expected)

ANALYSIS OF THE VERTICAL TESTS RESULTS

RF dissipation breakdown

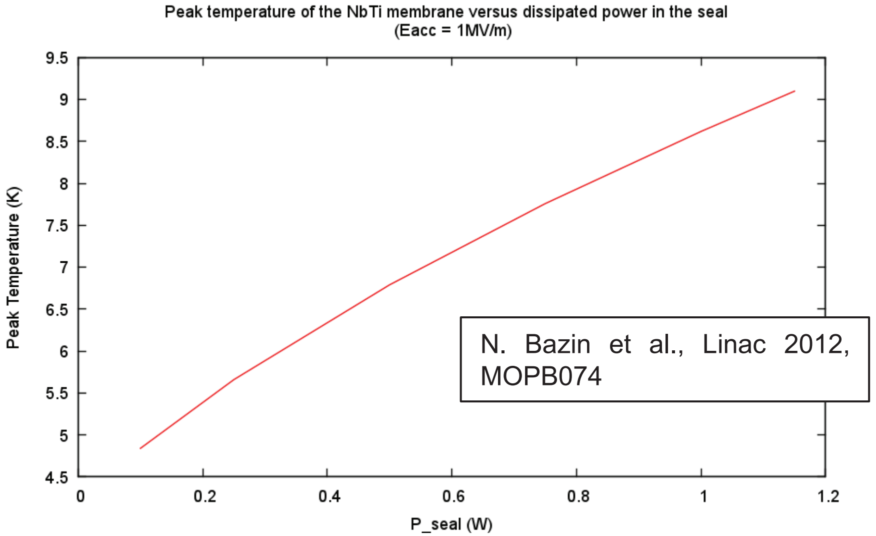
Cavity areas	1/2 Integral(H_{surf}^2) dS (1/2 cav)	RF dissipation (W)
Membrane (Nb)	7,58E+02	3,41E-04
gasket (Sn)	5,61E+01	**9,98E-01**
Plunger outer cylinder (Nb)	1,75E+03	7,00E-05
Plunger facing cavity (Nb)	5,55E+02	2,22E-05
Tuner flange (NbTi) vert.	5,96E+01	5,72E-06
Tuner flange (NbTi) horiz	6,50E+02	6,24E-05
Tuner port (Nb)	1,85E+03	7,38E-05
Coupler port and cap (Nb)	1,84E+01	7,35E-07
Cavite excluding all of the above (Nb)	3,49E+06	**1,39E-01**
TOTAL		1,14E+00
Q0		**1,61E+08**





H-field @4.5 M/m

- Enhancement of magnetic field near central stem
- Rf losses in the gasket extremely difficult to predict
- Depend on the seal surface seen by the RF
- Estimation: up to 25W @ 4.5 MV/m for Helicoflex HN200

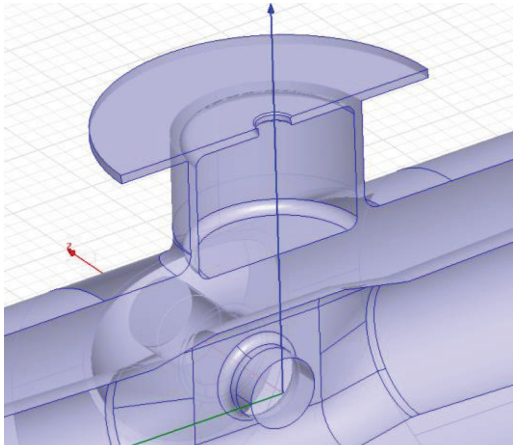


<u>Explanations of the tests results:</u>

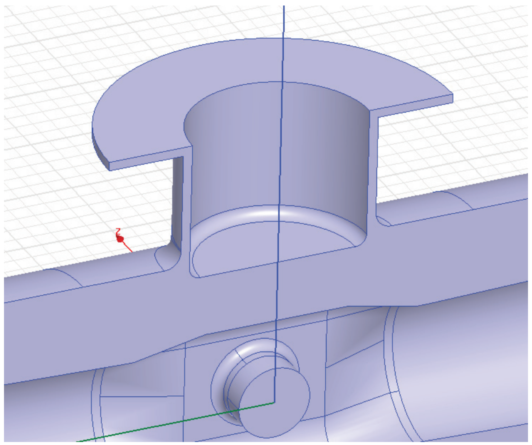
Combination of seal dissipation and bad thermal conductivity of the niobium-titanium membrane

PROOF-OF-PRINCIPLE NIOBIUM PLUNGER

Original niobium plunger with NbTi membrane



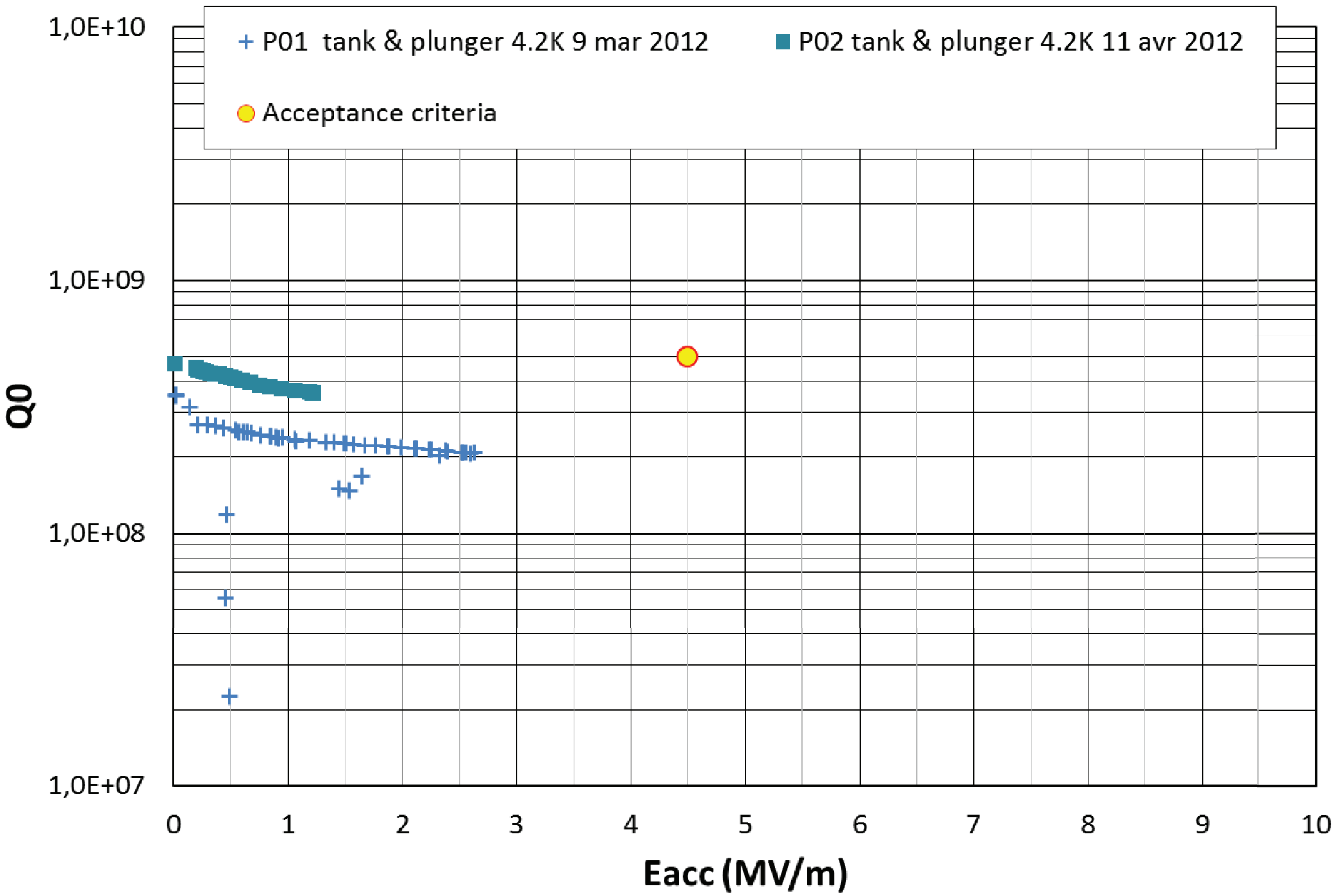
All-niobium plunger



Basically no change in RF properties

- Manufacturing of a proof-of-principle simple fixed-position plunger out of high RRR niobium only
- Use of an indium seal to minimize the surface of non superconducting material exposed to RF

VERTICAL TESTS RESULTS



- Q_0 still lower than expected
- Prototype 1: quench at 2.6 MV/m (4.5 W in the cavity)
- Prototype 2: quench at 1.23 MV/m

ANALYSIS FOR PROTOTYPE 1

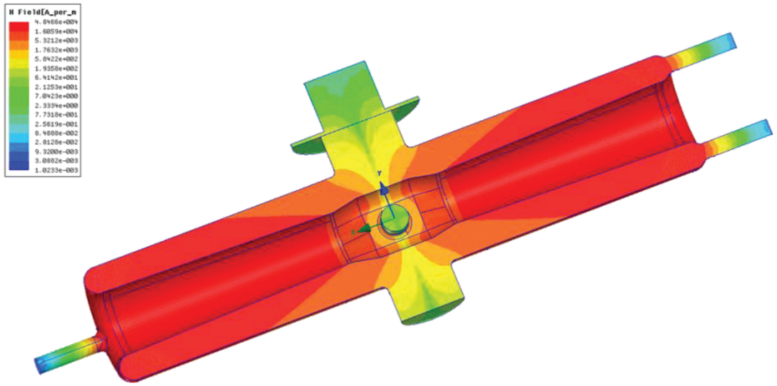
RF dissipation breakdown

Cavity areas	RF dissipation (W)
Membrane (Nb)	2,02E-04
Seal (Indium)	**6,03E-01**
Plunger outer cylinder (Nb)	4,66E-04
Plunger facing cavity (Nb)	1,48E-04
Tuner flange (NbTi) vert.	3,81E-05
Tuner flange (NbTi) horiz	4,15E-04
Tuner port (Nb)	4,91E-04
Coupler port and cap (Nb)	4,89E-06
Cavite excluding all of the above (Nb)	9,28E-01
TOTAL	1,53E+00
Q0	**7,97E+08**

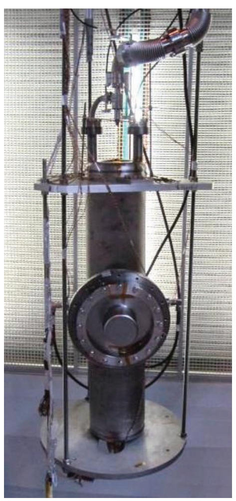
Indium seal measured at 0.5 mm thickness after vertical test- > gain of a factor 11 on the seal losses with respect to the previous test configuration for a given E_{acc} value

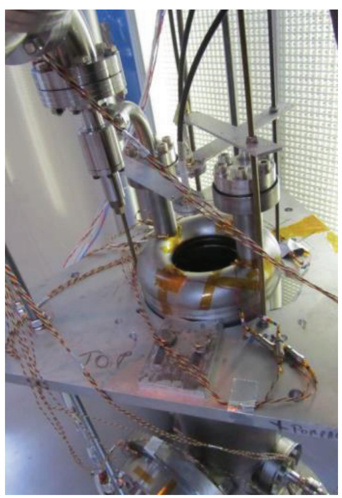
- Measured Q_0 between $2x10^8$ and $3x10^8$ is not explained by this analysis. 3W are missing at E_{acc}=2.6 MV/m
- Changing the membrane material from NbTi to Nb prevents heat build-up or low field quench but does not improve Q_0
- Overall less power dissipated in the plunger seal than in previous test : the quench must originate from another area of the cavity

TEST OF P01 WITH INVERTED PLUNGER

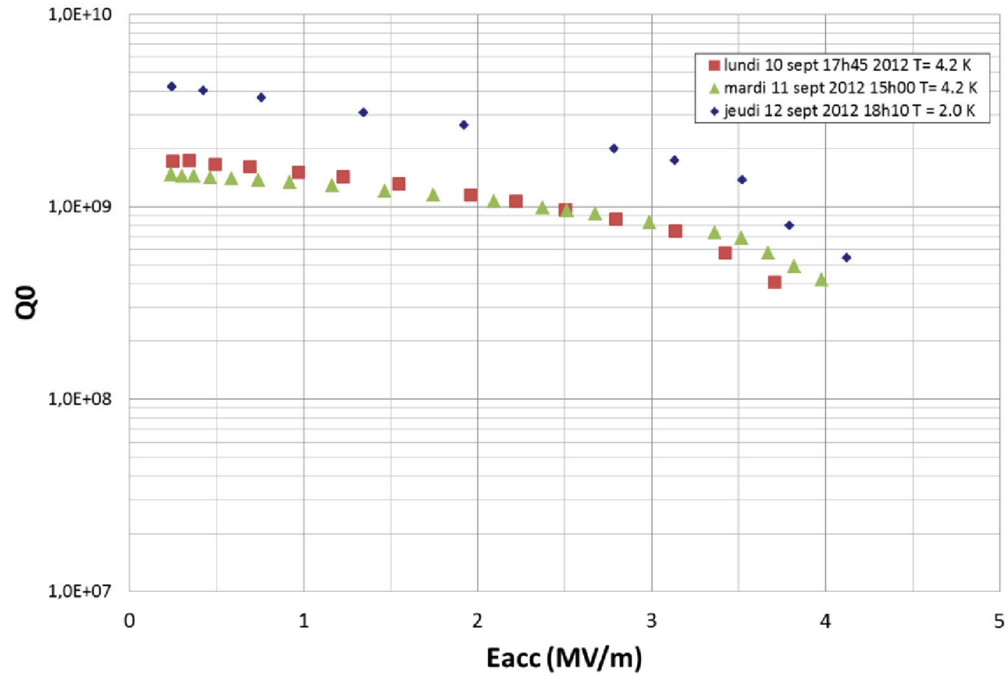


H is reduced by a factor of 25 on the NbTi tuner flange with respect to the previous situation





- He tank removed
- 18 CERNOX T-sensors on critical areas



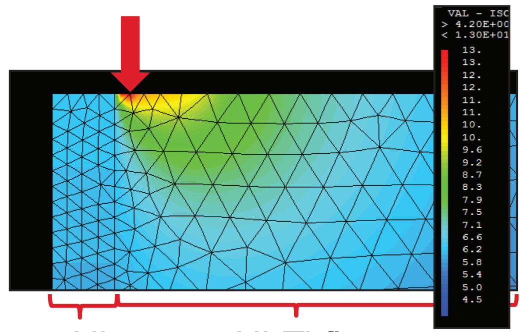
- Q_0 recovered
- Quench occurring on one HPR port

POSSIBLE SOURCE OF DISSIPATION: THE NB / NBTI WELD

The weld between the plunger NbTi flange and the Nb cavity body, which is exposed to RF, could be the source of dissipation.

Thermal simulation:

The missing 3 W to explain the value of Q_0 @ E_{acc}=2.6 MV/m are seeded in the weld

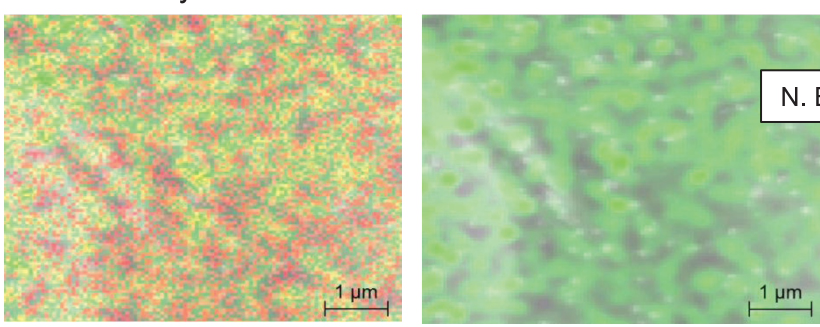


Nb NbTi flange

NbTi is heated over the standard Tc of 9.3 K

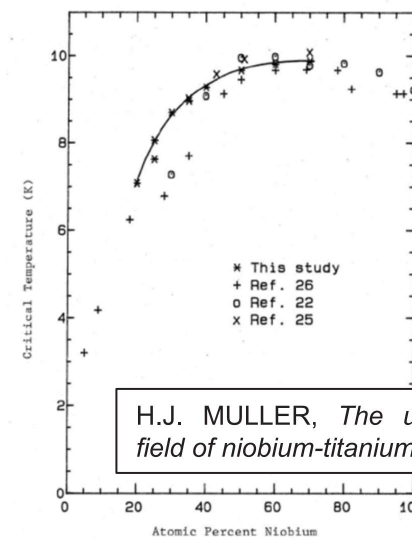
Material analysis: preliminary results

- ❑ LIBS measurements: small variations of Ti and Nb concentrations in the weld seam
- ❑ EDX analysis: Ti enriched area



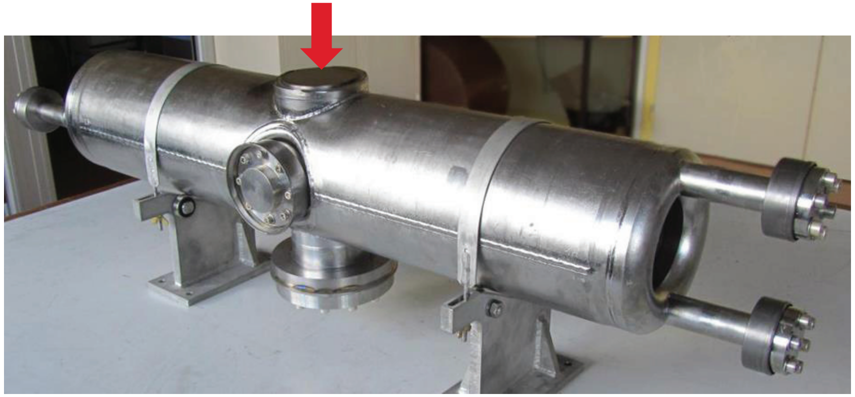
N. Bazin et al., TUP085

part of the weld may have a low Tc

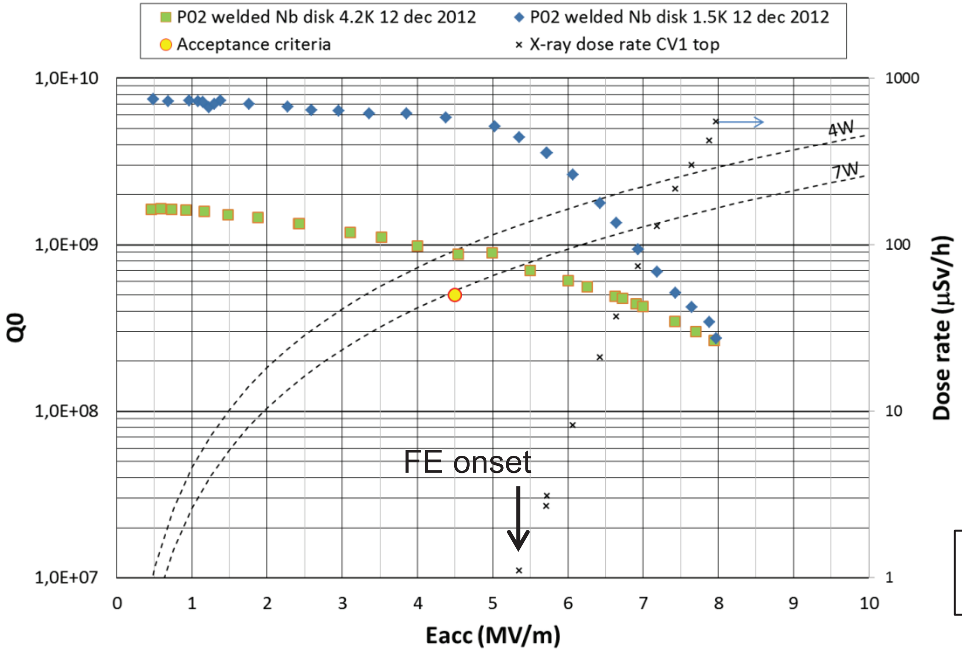


H.J. MULLER, *The upper critical field of niobium-titanium*, PhD thesis

PROTOTYPE 2



NbTi plunger flange removed and port closed with Nb disk



- ❑ HWR prototype qualified
- ❑ RF design validated

F. Orsini et al., IPAC 2013, THPFI004

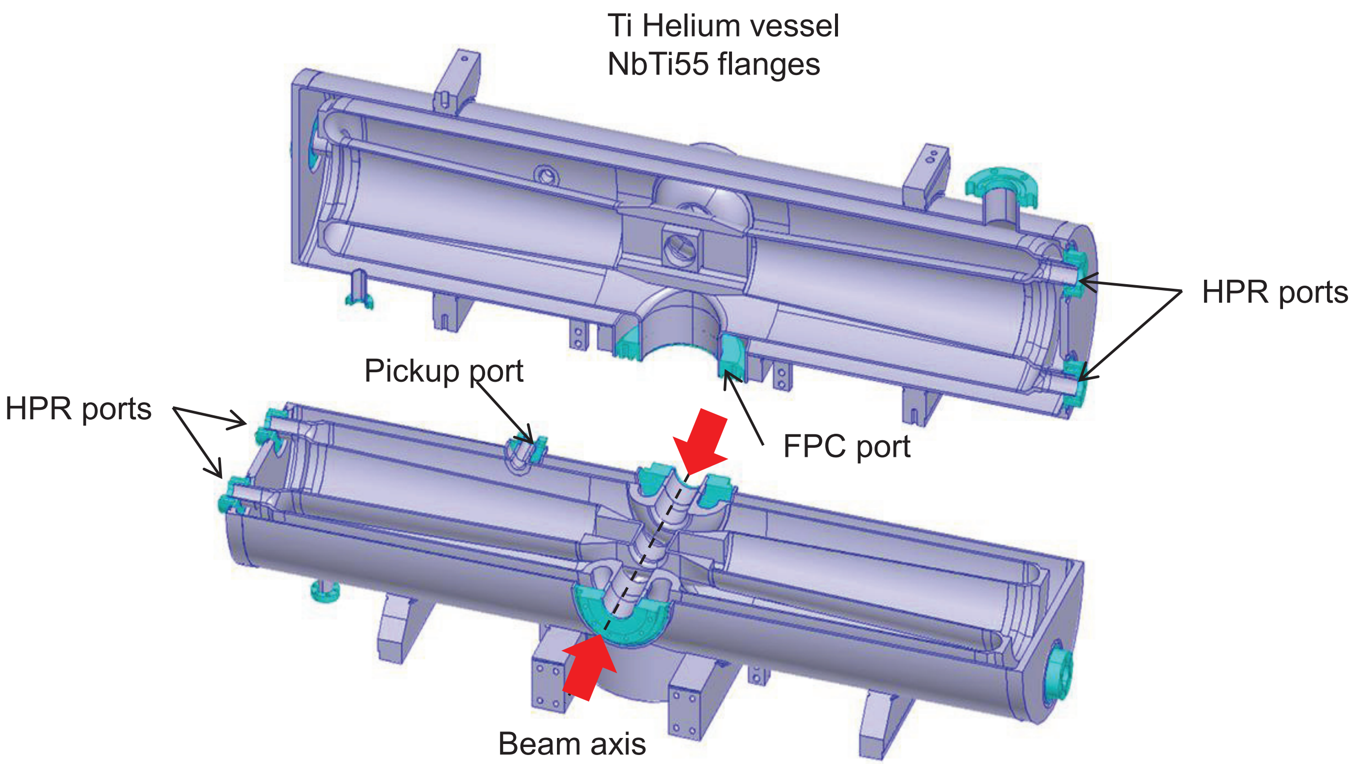
NEW CAVITY DESIGN

HWR DESIGN

- RF properties similar to the ones for the prototypes
- Capacitive tuner abandoned and replaced by an external mechanical tuner

-> HWR wall deformation on beam axis

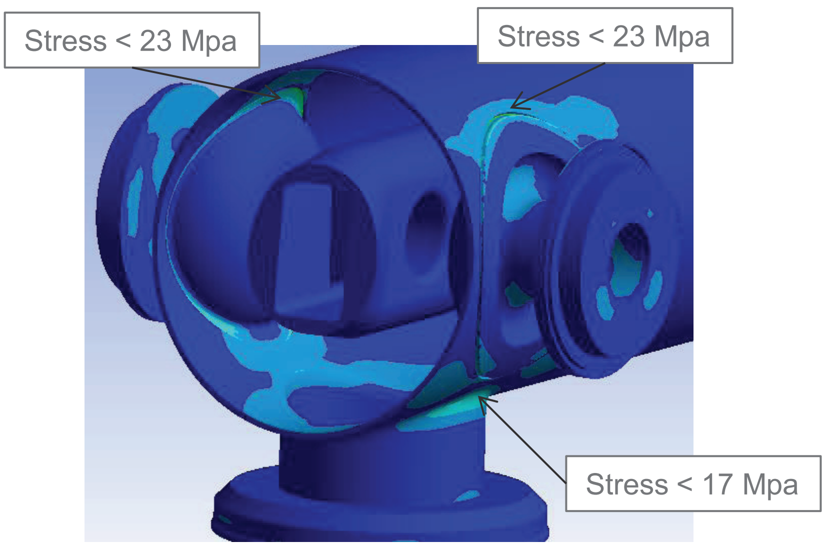
- He tank simplified



MECHANICAL DESIGN: STRESS ANALYSIS

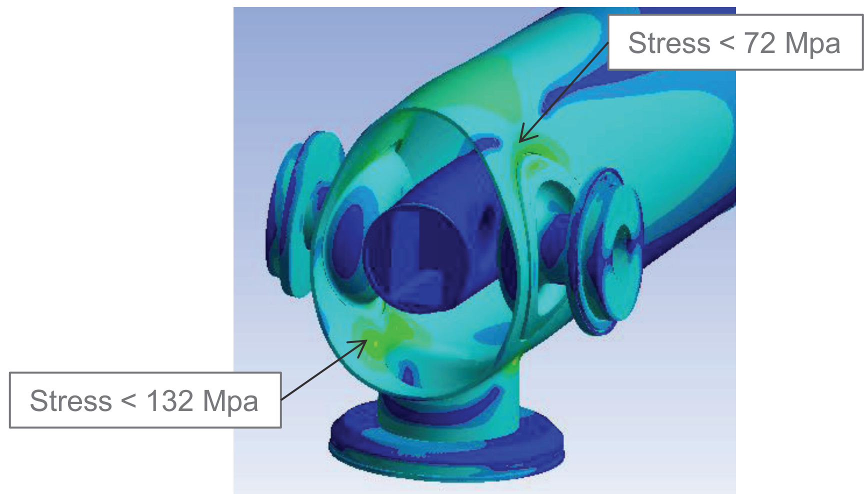
- Load case :
  - 1.5 bar pressure in He vessel at 300K
  - Allowable stress = 23.7 Mpa

- On niobium cavity :
  VM stress < 23 MPa



- Load case :
  - 1.5 bar pressure in He vessel at 4.45K
  - Tuning force : 8000 N/beam port, equivalent to displacement by 0.3 mm
  - Allowable stress = 150 MPa

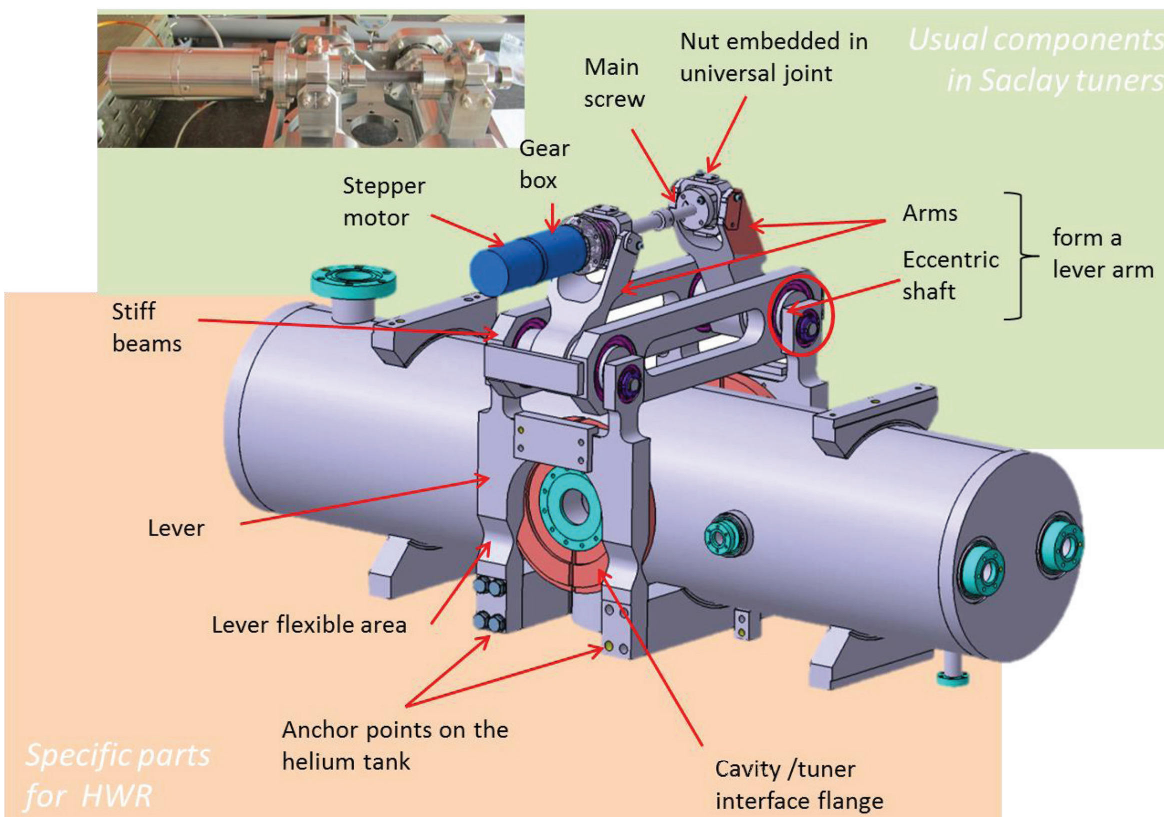
- On Nb cavity
  VM stress <132 MPa



Stress level acceptable in both cases for a 3 mm thick cavity

HWR TUNER

- The full tuning range can be obtained by compressing the cavity only (requirements: 60 kHz)
- The HWR must not be mechanically stressed due to the tuner during cooldown and warmup phases -> disengagement system mandatory
- The amplitude of the displacement needed on each beam port is 0.3 mm, which corresponds to a 8000 N compressive force and a HWR detuning of -78 kHz

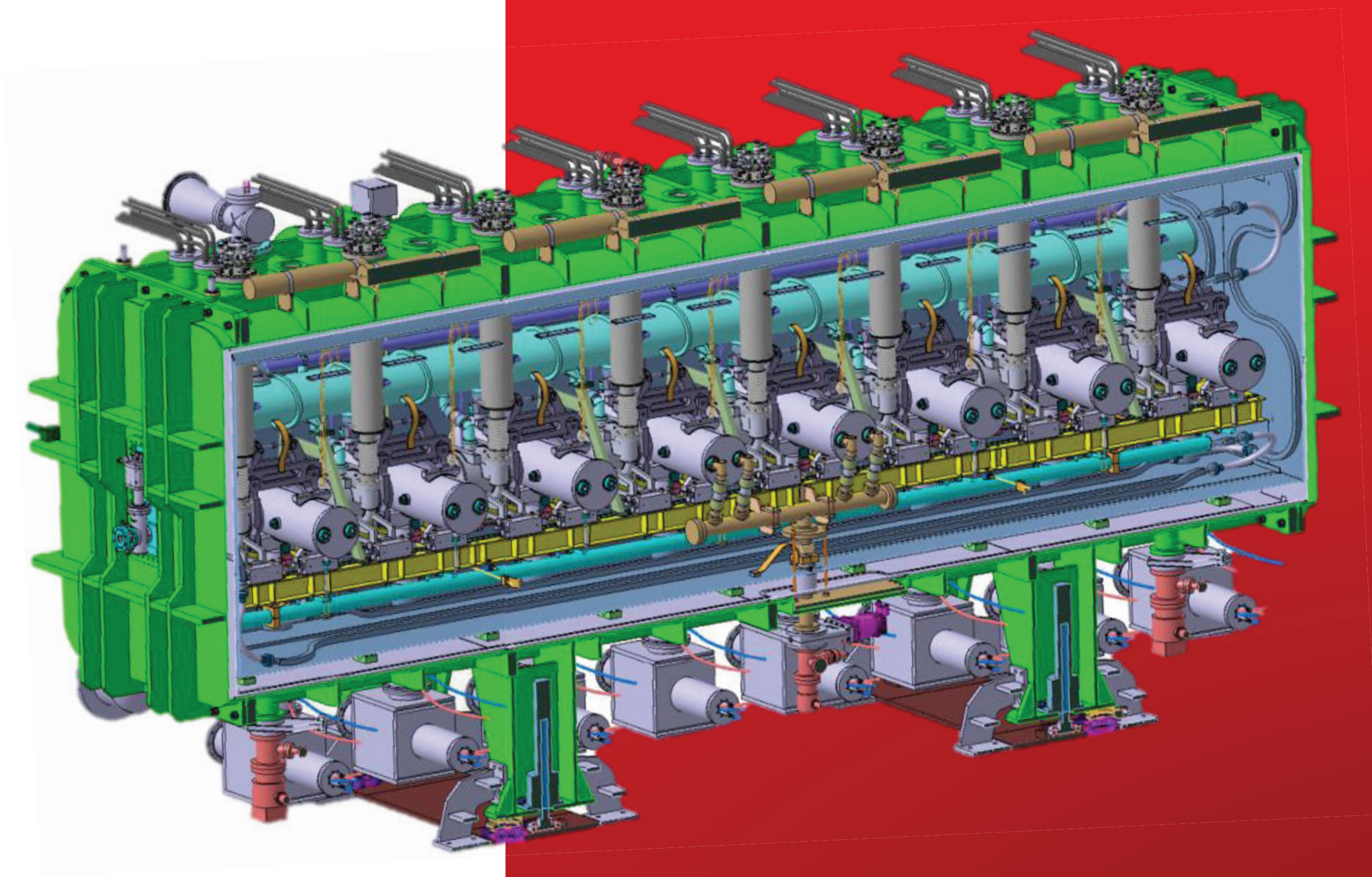


SUMMARY

- Original tuner design: capacitive plunger
  - Quench at low field, poor Q_0
  - RF and thermal models developed to understand the phenomena
  - NbTi flange and / or NbTi – Nb weld could be the cause of the problem
  - Proposal for a future capacitive plunger: avoid NbTi in moderate field area

    => Nb flange and Nb plunger

- New cavity design
  - External mechanical tuner based on Saclay-type system
  - Stress level in materials acceptable in regards to pressure vessel regulation
  - Production of the cavities for the cryomodule will be launched in next few weeks



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