FROM RESEARCH TO INDUSTRY

# ESS TECHNOLOGY DEVELOPMENT AT IPNO AND CEA PARIS-SACLAY

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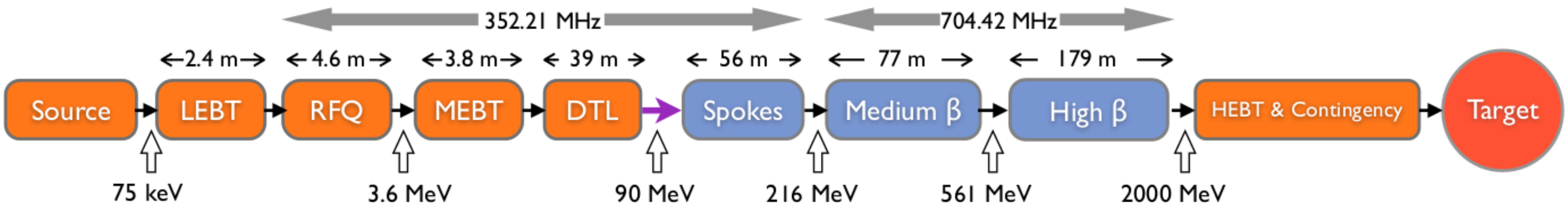
On behalf of IPN Orsay and CEA ESS team

# ESS - SRF LINAC



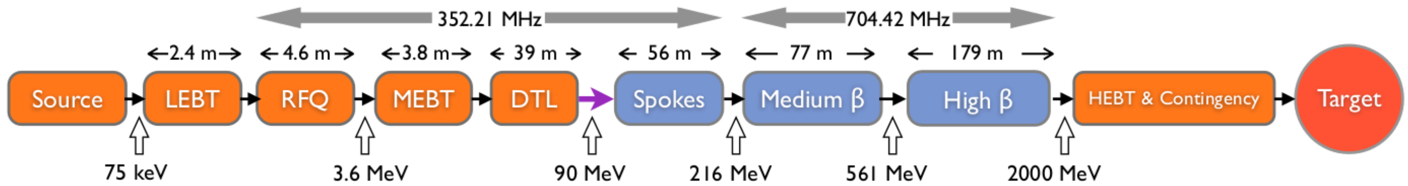

Design fixed in 2014

| Requirements | Spoke | Medium | High |
|---|---|---|---|
| Frequency (MHz) | 352.21 | 704.42 | 704.42 |
| Geometric beta | 0.50 | 0.67 | 0.86 |
| Nominal Accelerating gradient (MV/m) | 9.0 | 16.7 | 19.9 |
| Epk (MV/m) | 39 | 45 | 45 |
| Bpk/Eacc (mT/MV/m) | <8.75 | 4.79 | 4.3 |
| Epk/Eacc | <4.38 | 2.36 | 2.2 |
| Iris diameter (mm) | 50 | 94 | 120 |
| RF peak power (kW) | 335 | 1100 | 1100 |
| G (Ω) | 130 | 196.63 | 241 |
| Max R/Q (Ω) | 427 | 394 | 477 |
| Qext | $2.85\ 10^{5}$ | $7.5\ 10^{5}$ | $7.6\ 10^{5}$ |
| Q0 at nominal gradient | $1.5\ 10^{9}$ | $> 5\ 10^{9}$ | $> 5\ 10^{9}$ |

| Beam power (MW) | 5 |
|---|---|
| beam current (mA) | 62.5 |
| Linac energy (GeV) | 2 |
| Beam pulse length (ms) | 2.86 |
| Repetition rate (Hz) | 14 |

| | Num. of CMs | Num. of cavities |
|---|---|---|
| Spoke | 13 | 26 |
| 6-cell medium β | 9 | 36 |
| 5-cell high β | 21 | 84 |

# ESS - SRF LINAC




| RF performance specifications | SNS medium β 0.61 | ESS medium β 0.67 | SNS high β 0.81 | ESS high β 0.86 |
|---|---|---|---|---|
| Qo | 5e9 | 5e9 | 5e9 | 5e9 |
| Eacc [MV/m] | 10.1 | **16.7** | 15.6 | **19.9** |
| Epk [MV/m] | 27.5 | **45** | 35 | **45** |

2014

| | SNS | ESS |
|---|---|---|
| Beam power [MW] | 1.4 | **5** |
| beam current [mA] | 38 | **62.5** |
| Linac energy [GeV] | 1 | **2** |
| Beam pulse length [ms] | 0.695 | **2.86** |
| Repetition rate [Hz] | **60** | 14 |
| RF pulse length [ms] | 1.3 | **3.1** |
| Coupler peak power [kW] | 550 | **1100** |
| Coupler avg. Power [kW] | 43 | 47.7 |

ESS project decision (2012)

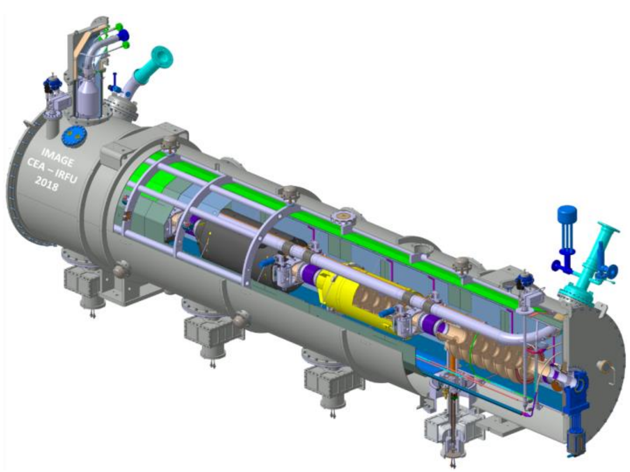
- No HOM couplers
- Instead, ensure monopole mode separation from machine lines > 5 MHz

# CRYOMODULE DESIGNS COMMON OPTIONS

Design work started with
IPNO exclusively for spoke section
CEA for ellipticals cavity package with IPNO for cryomodule

**Common options for cryomodules of all sections :**

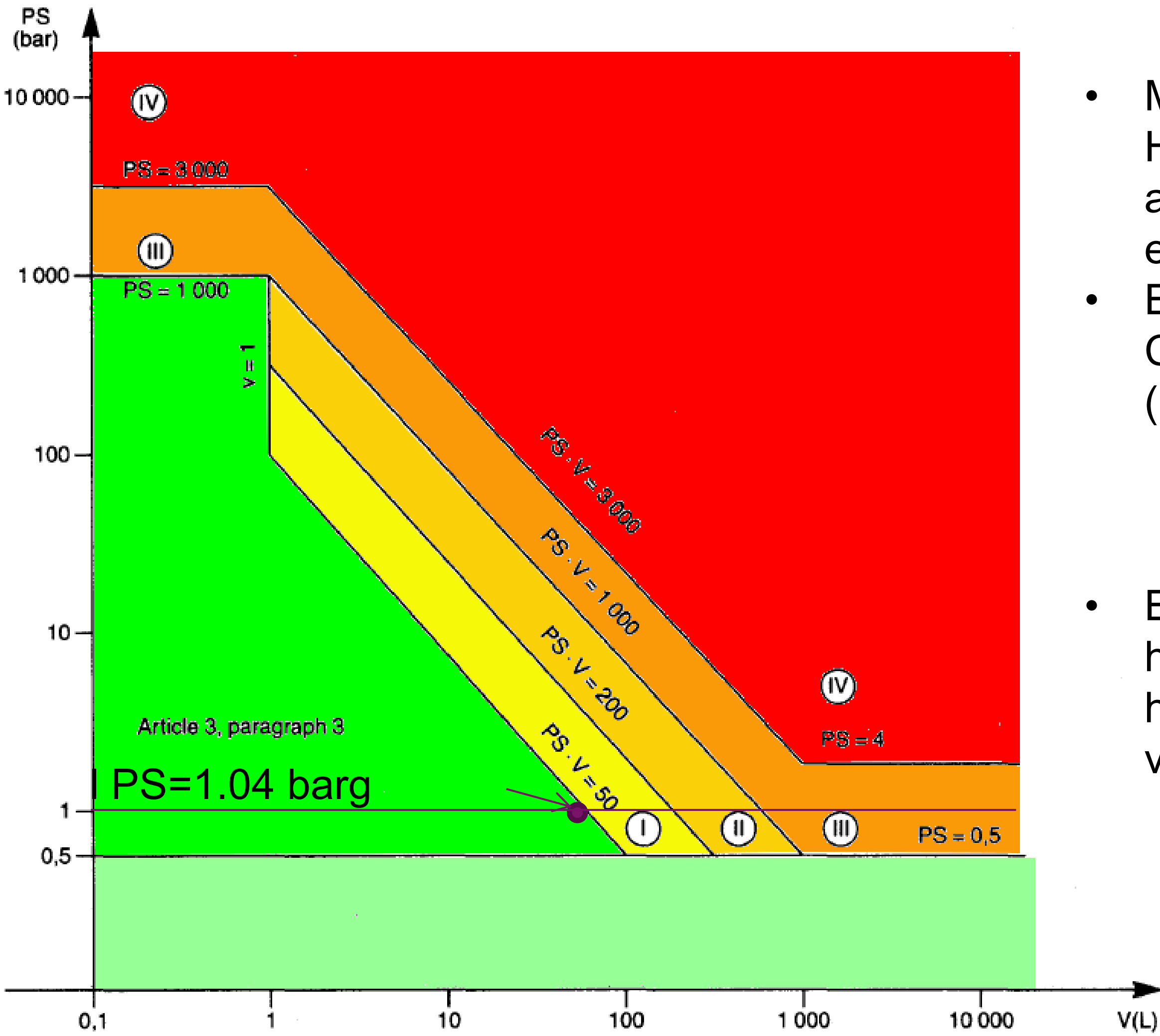
- No internal focussing elements
- cooling of He to 2 K local to each CM using a heat exchanger and Joule-Thomson valve
- Al thermal shield at 40 K (19 bar He)
- The operation pressure of 2.04 bara (→PED chapter 4.3)
- Couplers ports at the bottom of the modules
- Stainless steel vaccum vessel
- Cold magnetic shield




**At the components level :**

- Ti vessels for cavities
- Single window rigid couplers with He counterflow
- Cold tuners with cold motor/gear box and piezos

# EU PRESSURE VESSELS CATEGORY– PED




- Most critical « vessel » is the Helium volume between cavity and helium jacket (many welds, exotic materials)
- Example : XFEL cavities follow Cat. IV related verification units (B1,B,F,G modules)

  →If possible, favor lowest categories

- ESS spoke and ellipticals CM have been designed in order to have PS . V < 50 for the Helium vessel (now Art. 4 § 3)

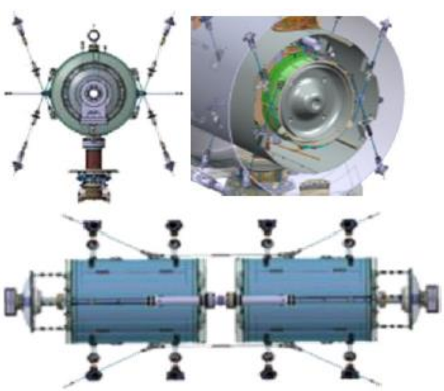
  →Design has to follow « Sound engineering practice »

PS = « Maximum Allowable Pressure », relative to atmospheric pressure (barg)

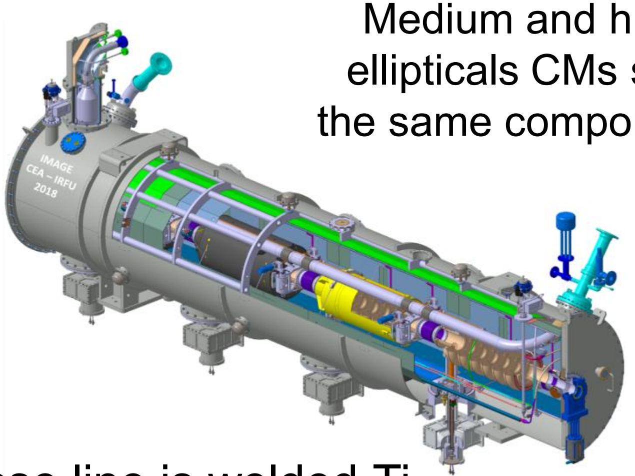
# CRYOMODULE DESIGN DIFFERENCES

Spoke

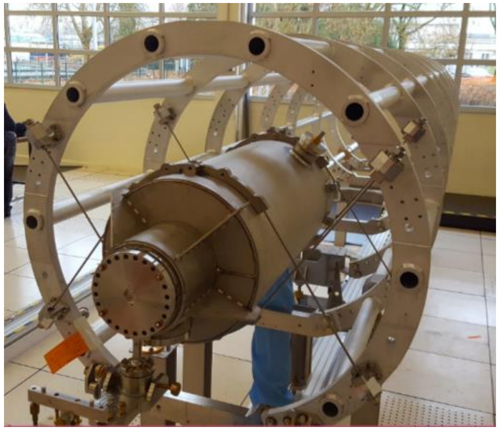
- 2-phase line includes flanges
- Cavity support using antagonist tie rods fixed on the <u>vacuum vessel</u>



Medium and high. β ellipticals CMs share the same components

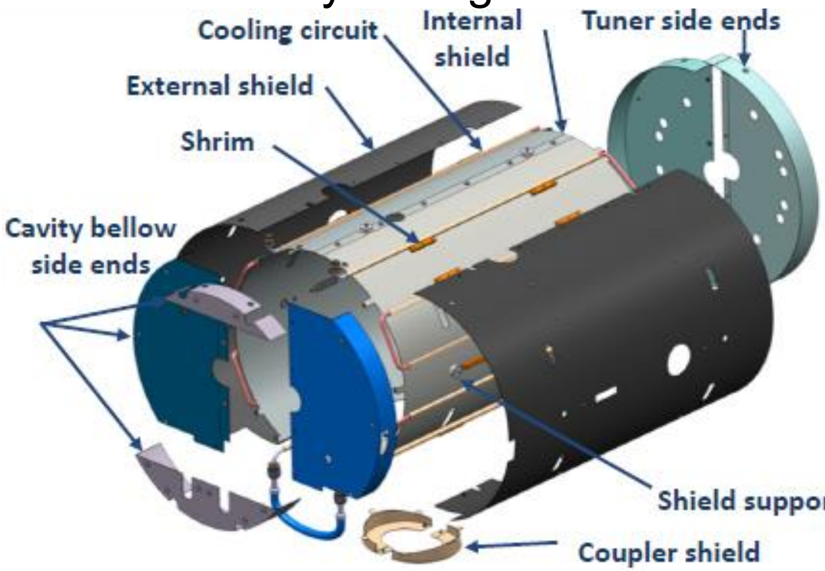


- 2-phase line is welded Ti
- Cavity support using antagonist tie rods fixed on a <u>space frame</u>

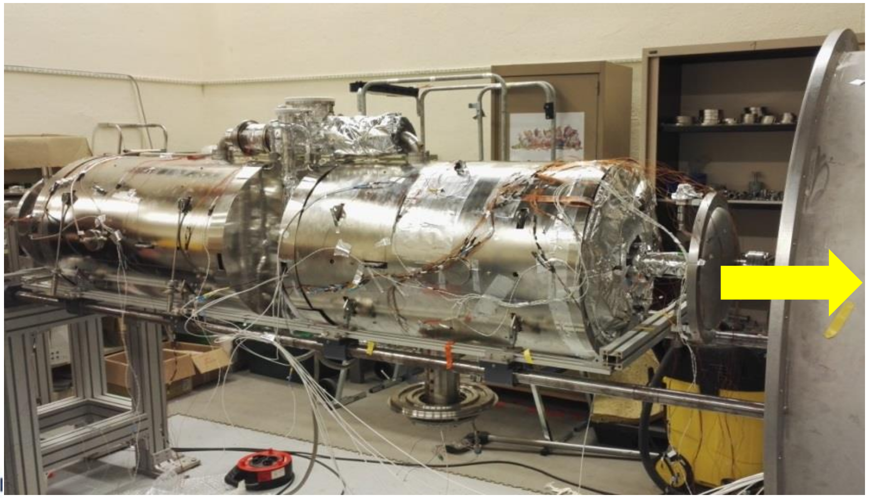


# SPOKE CRYOMODULE DESIGN

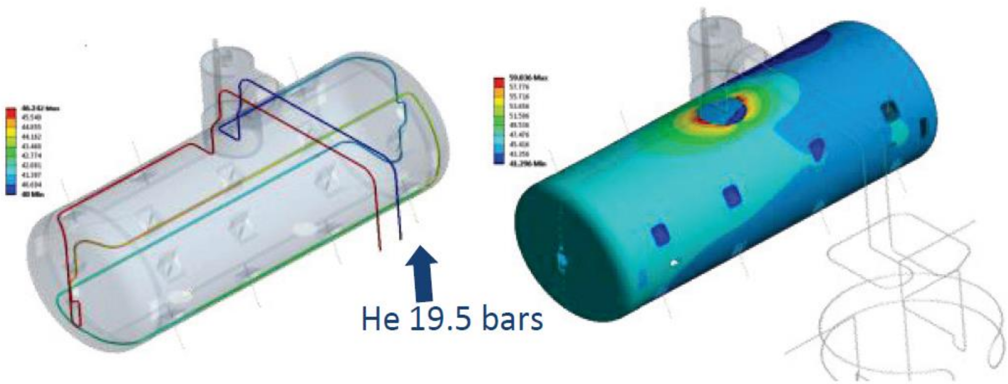
Double layer magnetic shield

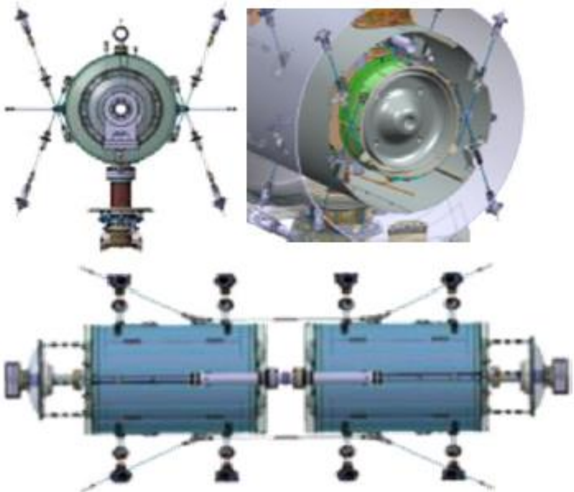


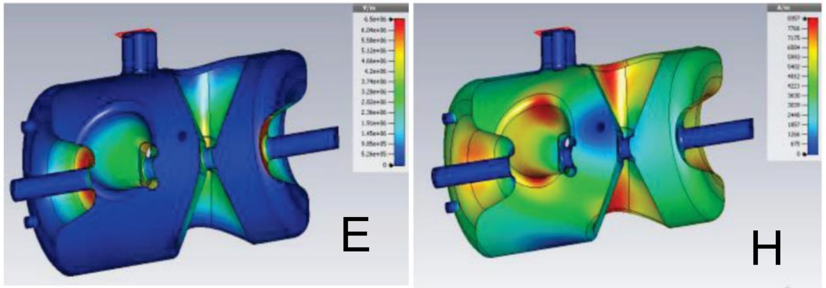

insertion by sliding of the cold mass



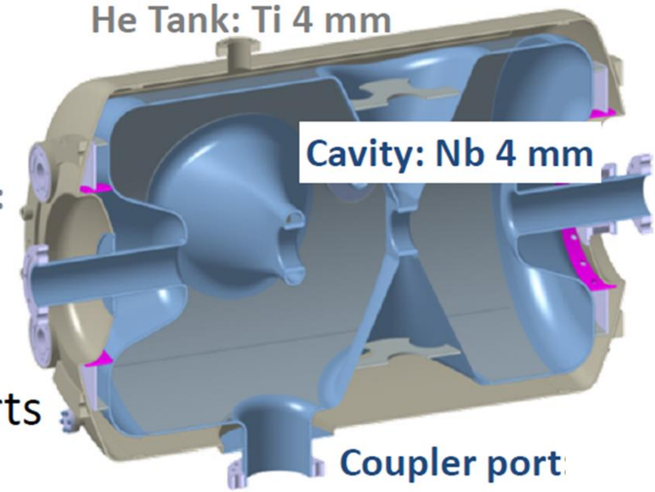
Thermal shield (ESS configuration)






| | |
|---|---|
| Frequency (MHz) | 352.21 |
| Optimum β | 0.5 |
| $E_{acc}$ (MV/m) | 9.0 |
| $B_{pk}$ (mT) | 62 |
| $E_{pk}$ (MV/m) | 39 |
| G (Ohm) | 130 |
| r/Q (Ohm) | 426 |
| $L_{acc}$ (m) | 0.639 |
| $E_{pk}/E_{acc}$ | 4.34 |
| $B_{pk}/E_{acc}$ (mT/(MV/m)) | 6.88 |
| KL (Hz/(MV/m)²) | -5.5 |
| Kp (Hz/mbar) | 15 |
| Tuning sensitivity (kHz/mm) | 130 |



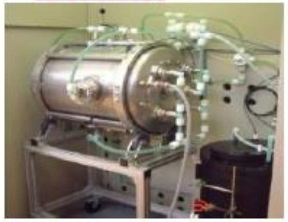

3 prototypes built with 2 vendors

# SPOKE PROTOTYPES PERFORMANCE



## Prototypes, preparations and tests

- Etching



3 positions; T < 15°C;
~ 8 hours
⇒ 200 µm

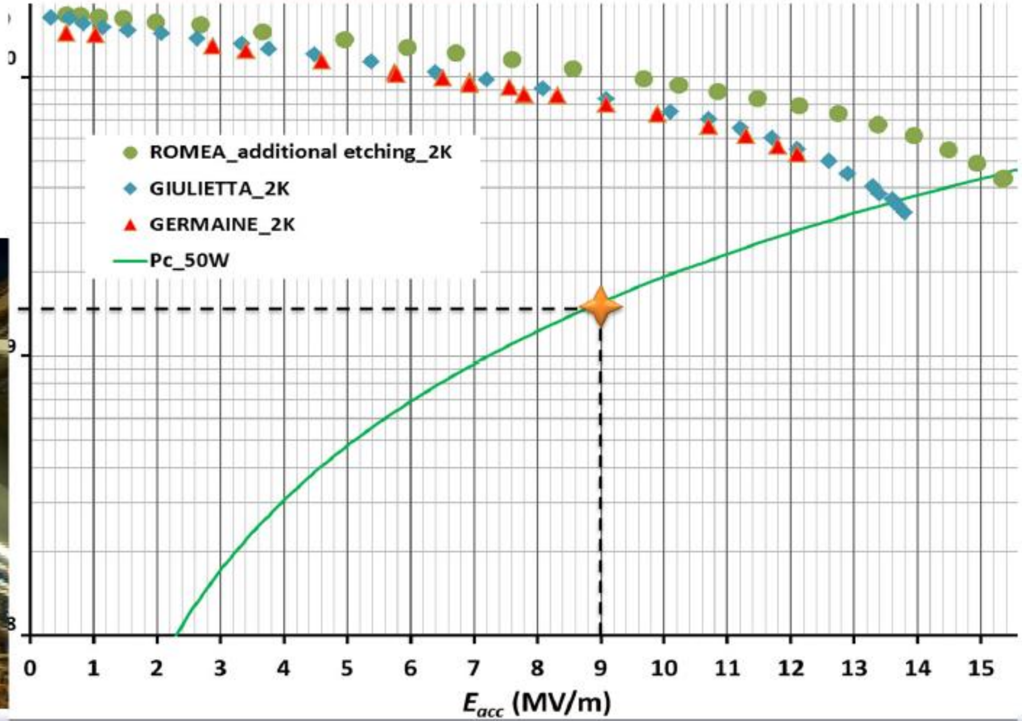
- High Pressure Rinsing

100 bars; 6 ports;
~ 12 hours

- 3 prototypes

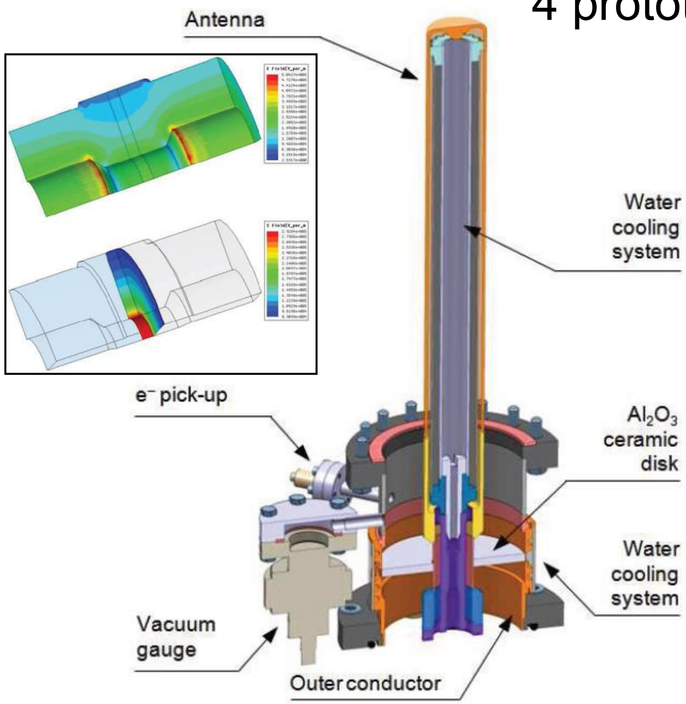


- Tests in vertical cryostat



# SPOKE FUNDAMENTAL POWER COUPLERS

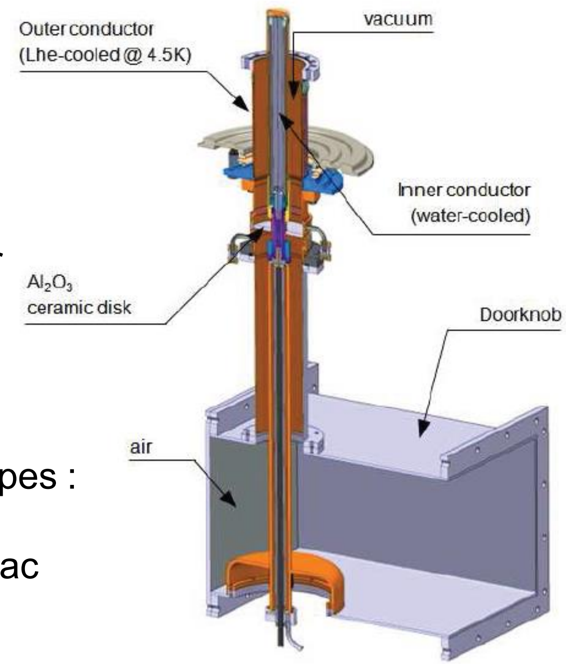
## 4 prototypes built




- Single disk window
- 100 mm 50Ω coaxial coupler
- Peak power 400 kW
- Cold connection through a He-cooled outer conductor

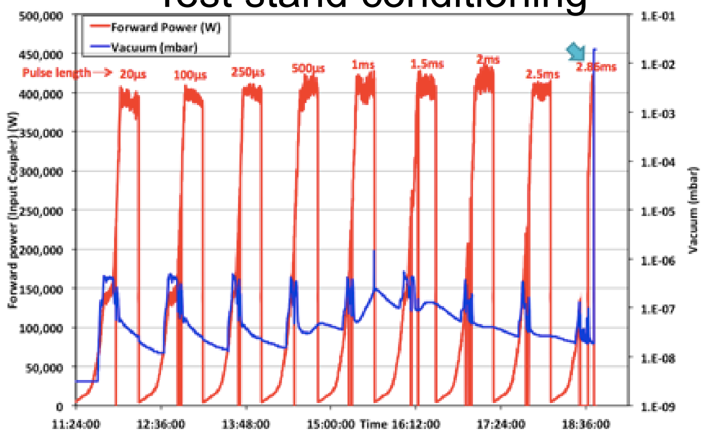
Full range operation does not require HV biasing

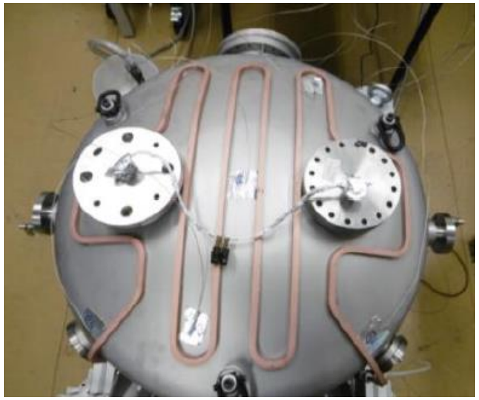
- Doorknob tested on prototypes : no bias
- New design with bias for linac being manufactured




Half height WR2300

## Test stand conditioning



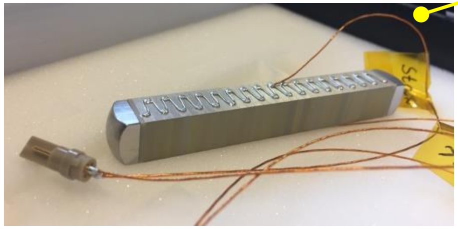
# SPOKE COLD TUNERS

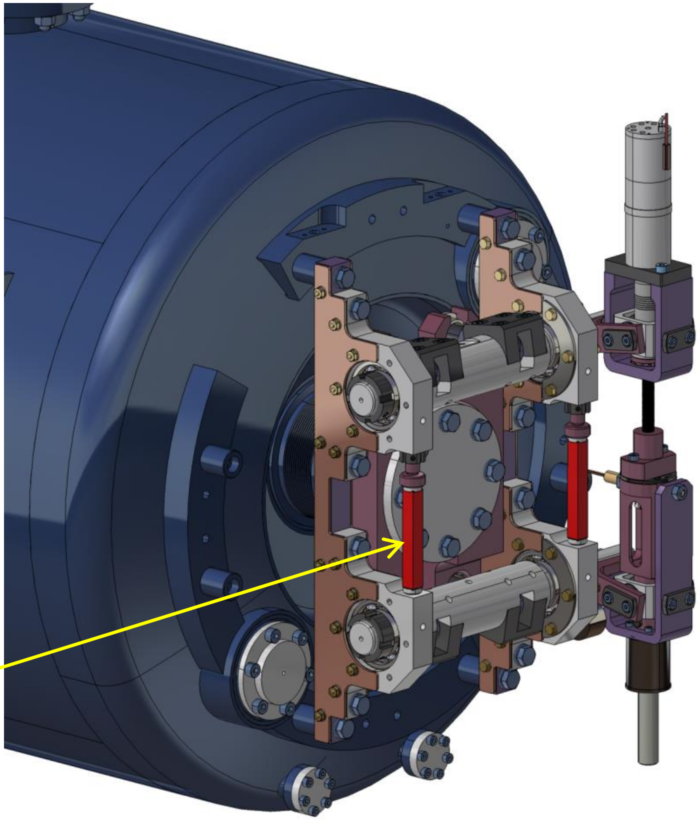
**Slow tuning**: excentric axle operated by cold motor/gearbox/screw

Stroke 1.28 mm
Range 170 kHz

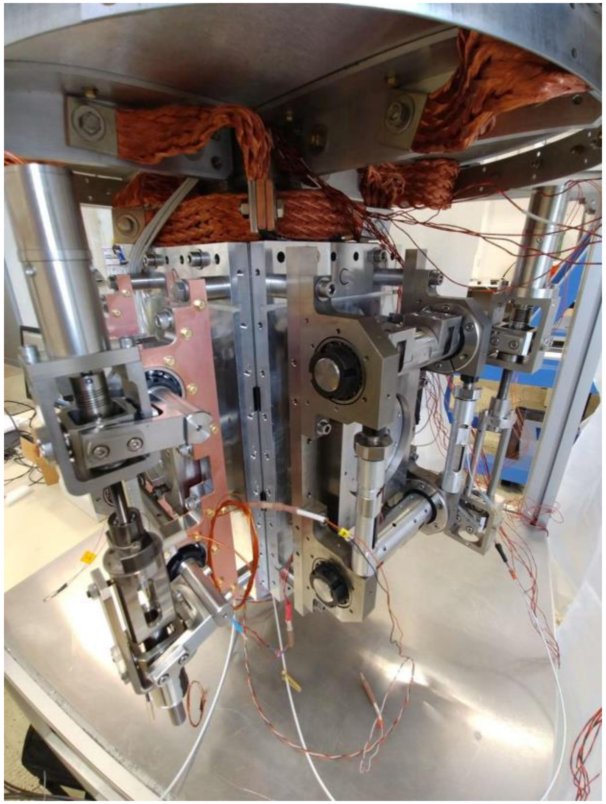
**Fast tuning**: piezo stacks bend the main vertical beams

Stroke ~800 Hz





Final design with 72 mm piezos

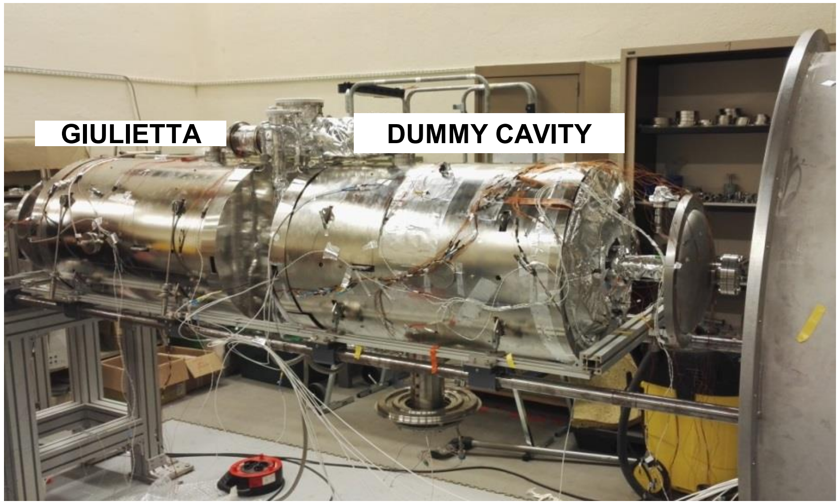


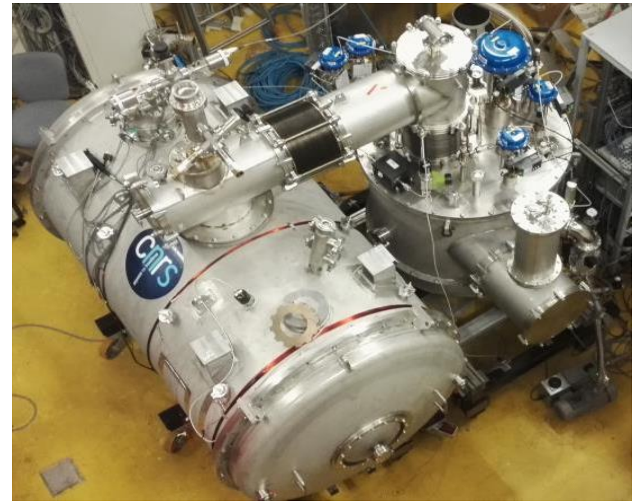
Dedicated test and qualification cryostat.
4 tuners can be tested simultaeously

Measured stiffness ~**30 kN/mm**

All components for the 26 spoke tuners delivered

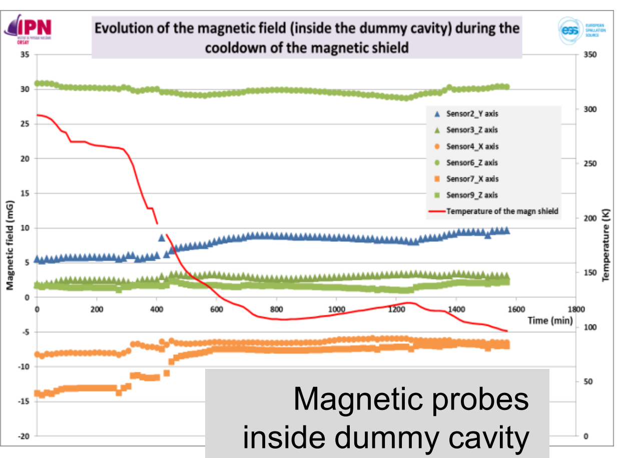
# LOW POWER TESTS AT IPNO

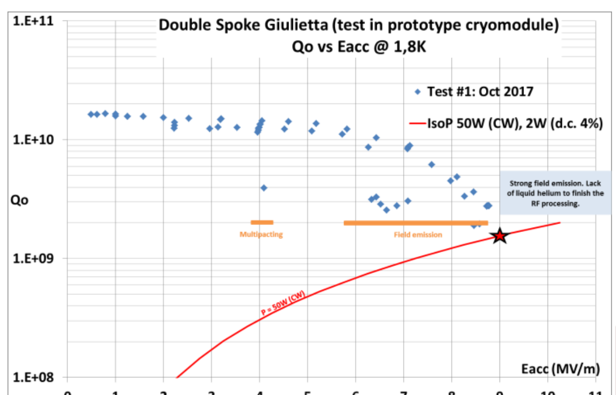


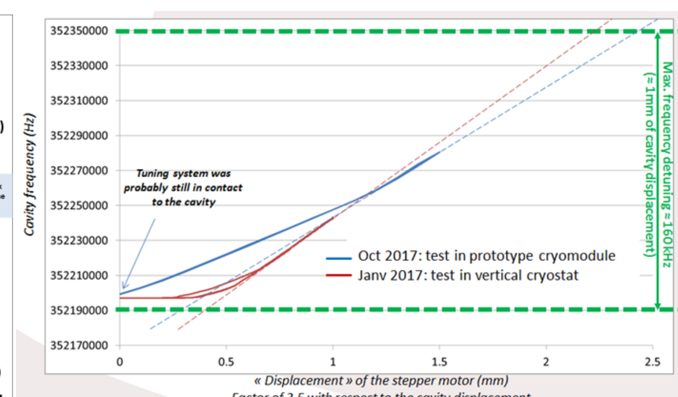



Test of the cold magnetic (cryoperm) shield efficiency with temperature : active cooling not needed

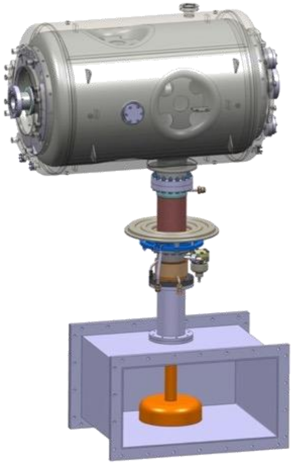
Test of the cold tuner:
- no hysteresis,
- tuning range 160 kHz

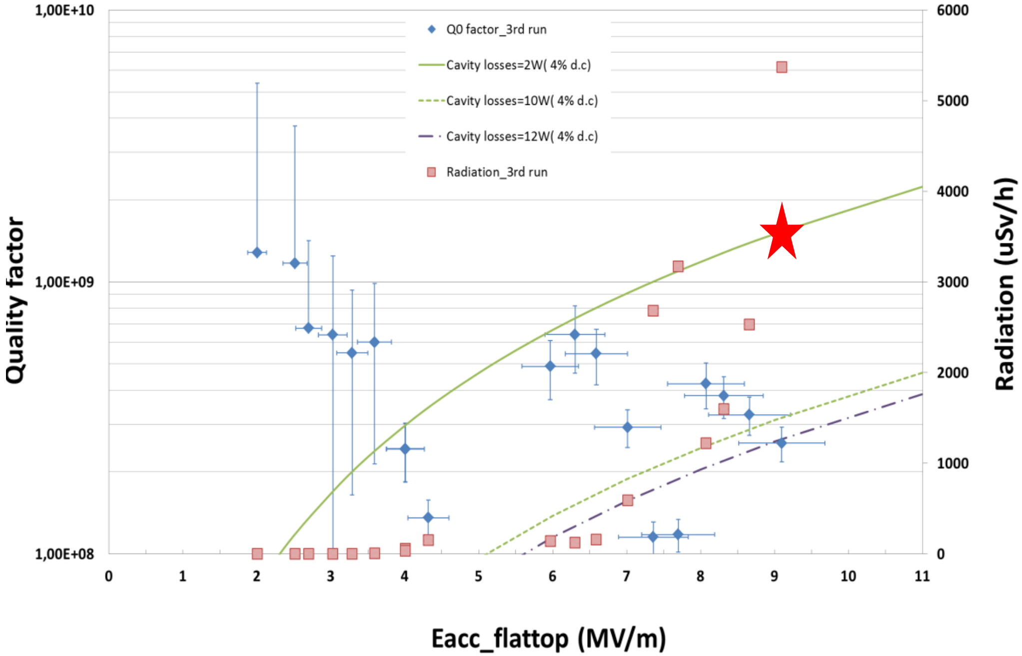


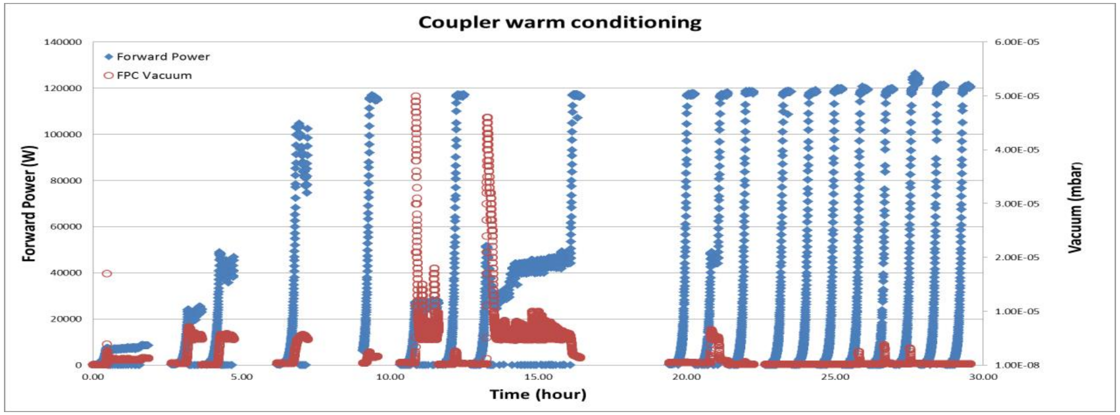



# TEST OF SPOKE CAVITY PACKAGE AT UPPSALA



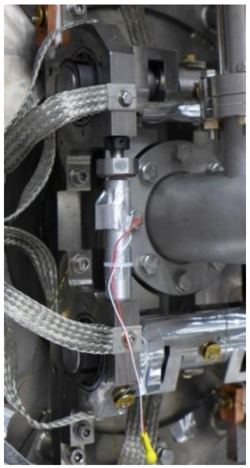


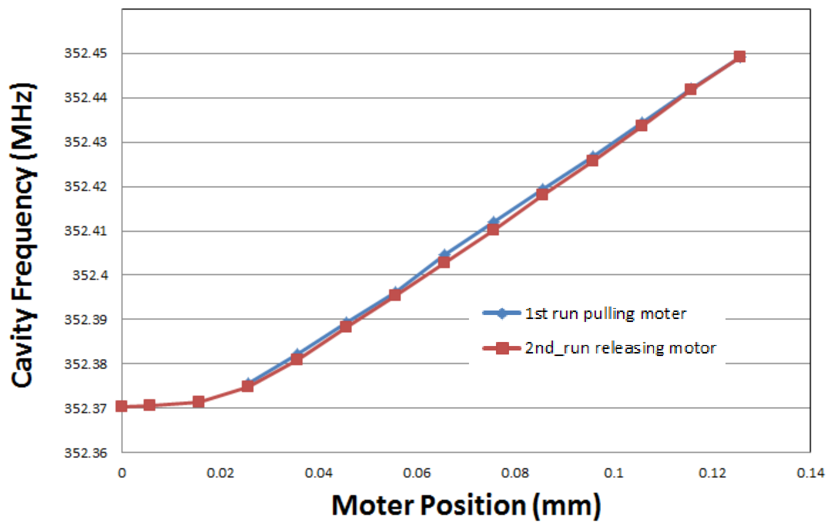

- Low-field $Q_0$ factor of $1.4\times10^9$@ 2 K
- Q factor of $2.8\times10^8$@ $E_{acc}$ = 9 MV/m (FE)
- 3 major multipacting regions found

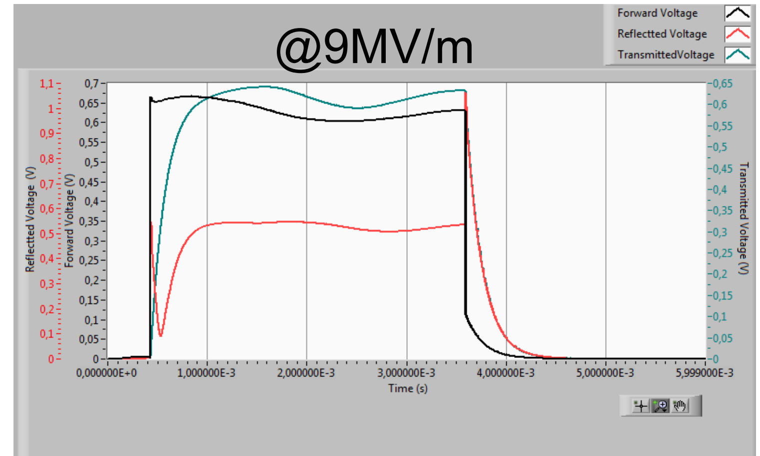


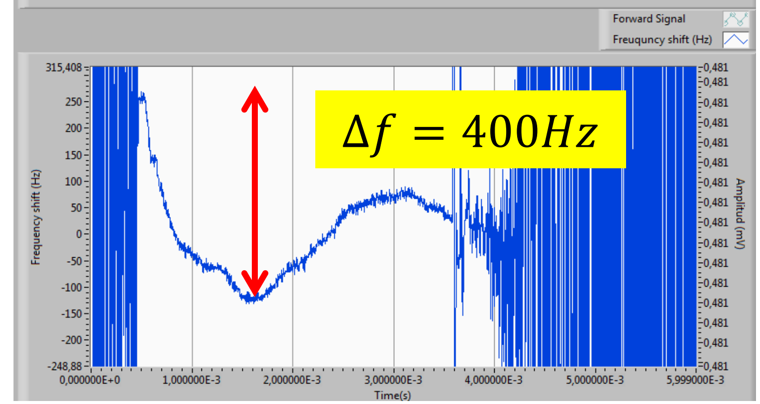

Conditioning time 30h @ 300K, 14h@2K, 30h with cavity@2K

Tuning sensitivity: 150Hz/mm

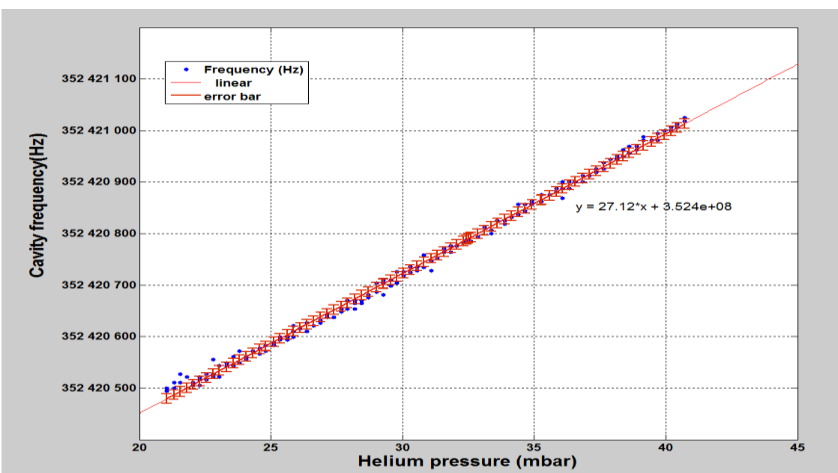




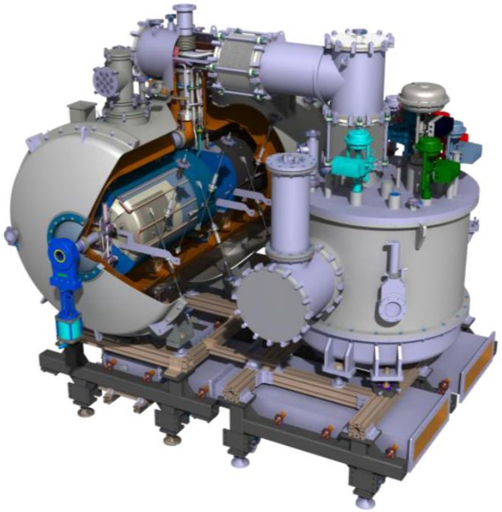




Lorentz Force Detuning in pulsed mode




Pressure sensitivity: $K_P$= +27.1 Hz/mbar

# TEST OF PROTOTYPE CM AT UPPSALA



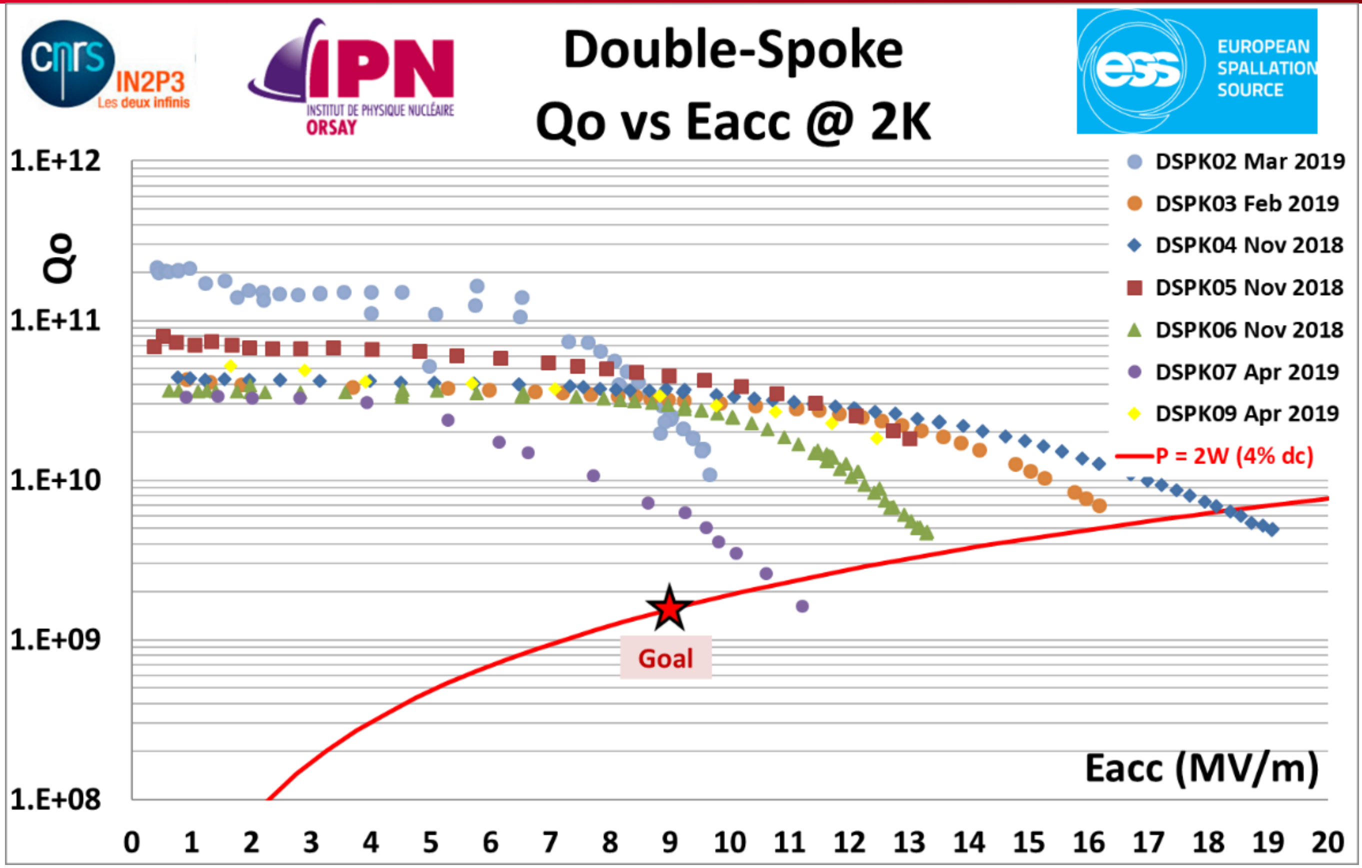
First test without quench detection : burst disk opened on cavity quench

Preliminary results of second test with quench detection installed:

- Static losses :**10 W**
- Cavity 1 reached 15 MV/m, No FE
- Cavity 2 reached 10.5 MV/m (Quench)
- Dynamic load per cavity < 1W

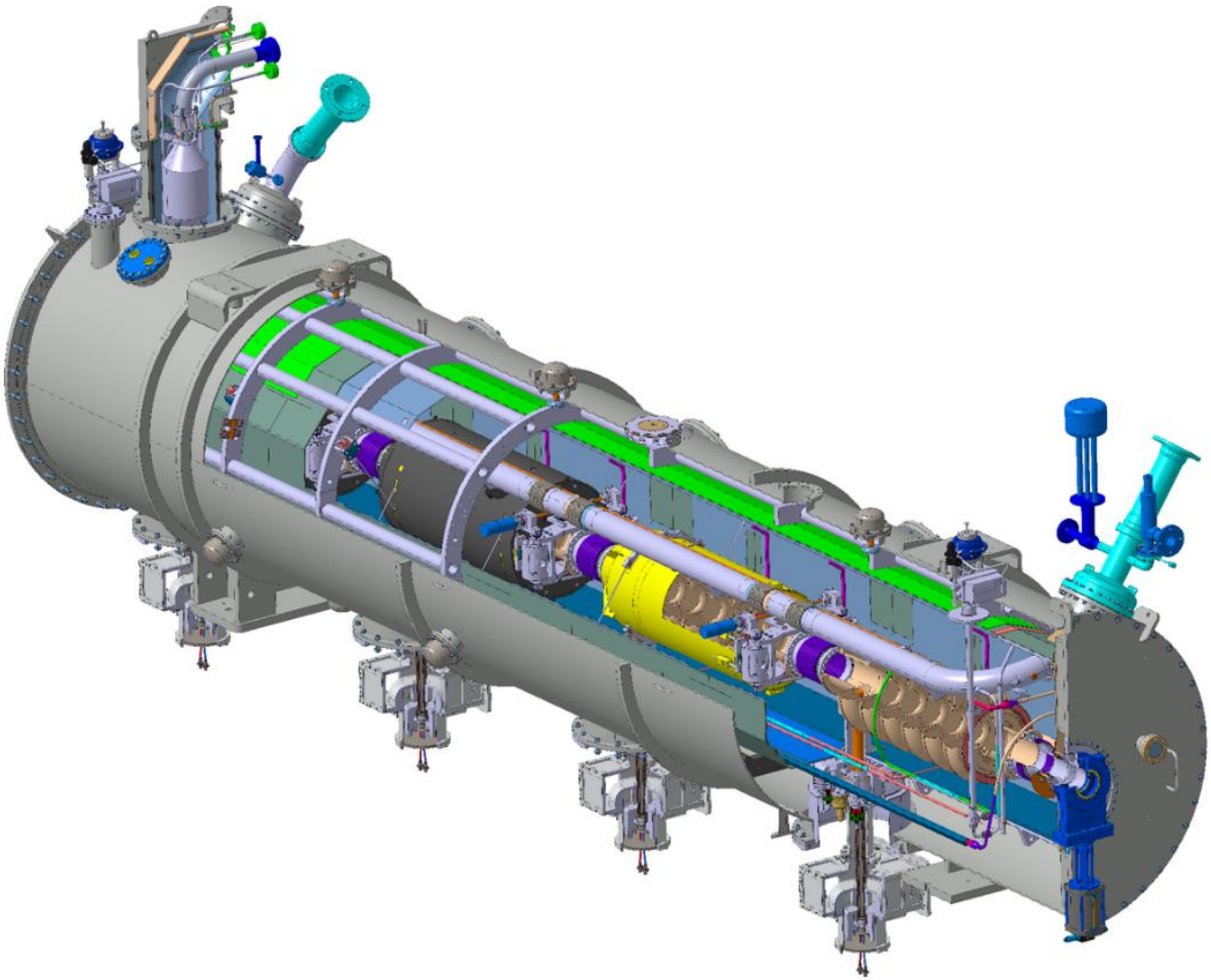
POSTERS tomorrow
THP057 & THP058

# SERIES SPOKE CAVITIES

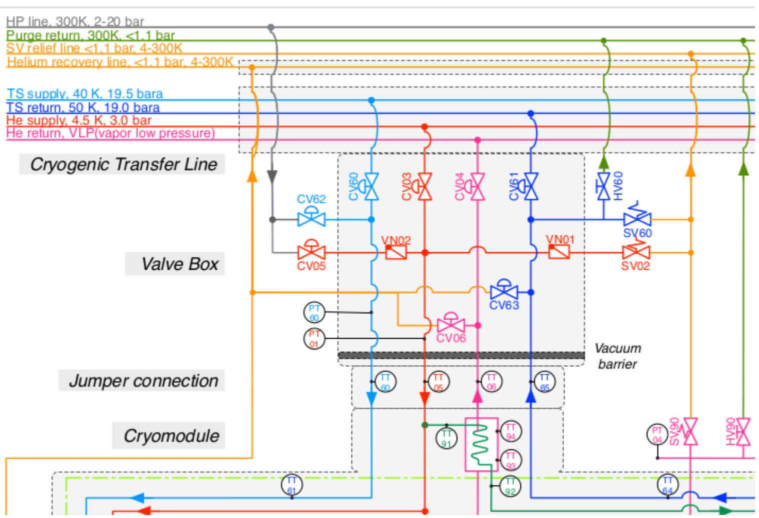



- **10 resonators built, 7 cavities tested @ 2K**
- **2 cavities within the specs** (ie. Eacc > 9MV/m, Qo> 1.5 10E+09 and 352.089 MHz < Freq < 352.175 MHz)
- **1 cavity with thermal quench limitation at 19MV/m**. For all other ones, limitation comes from **field emission**.

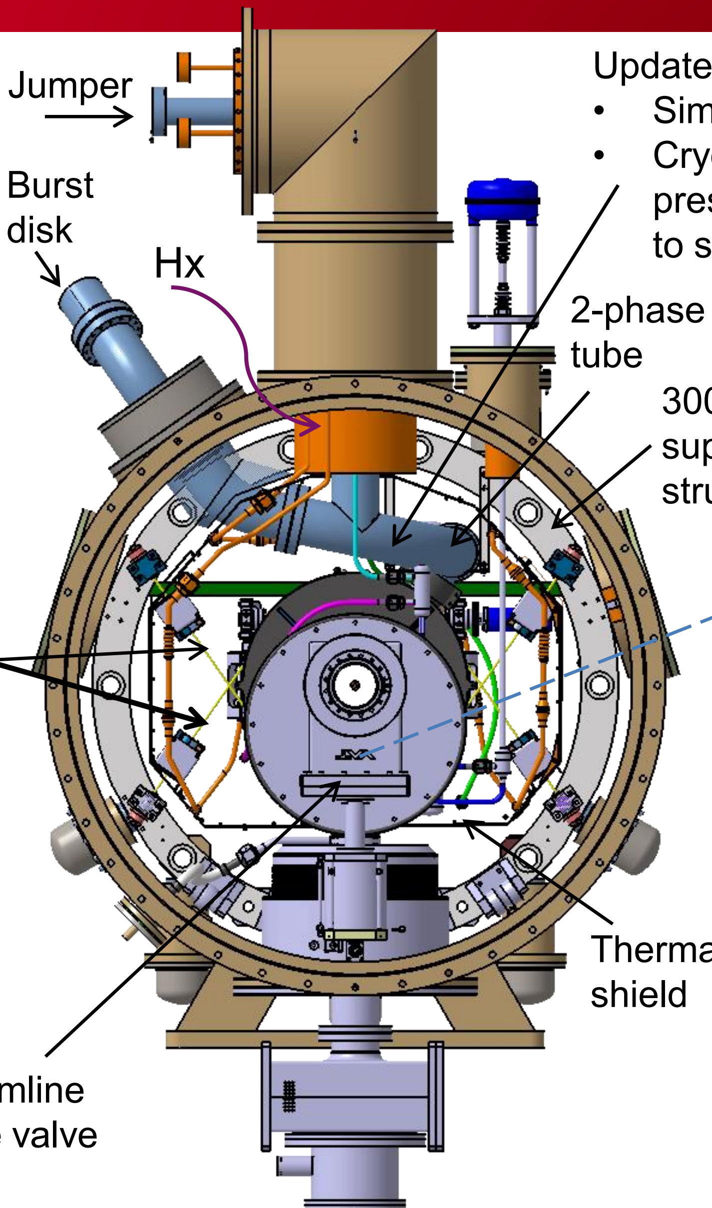
# ELLIPTICAL CAVITY CRYOMODULES



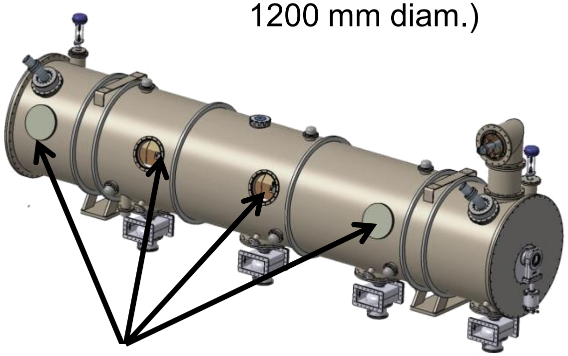
# ELLIPTICAL SECTION CRYOMODULE



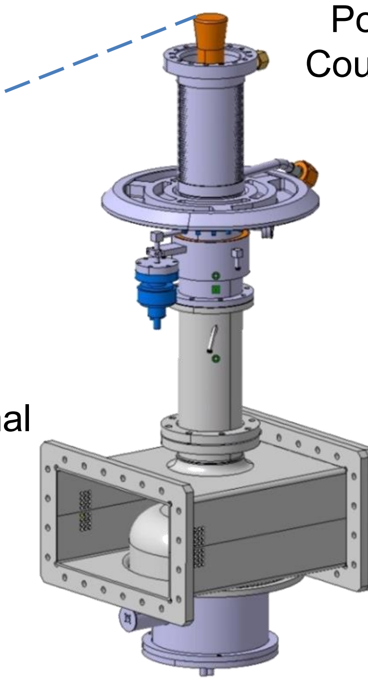

Updated design
- Simpler 40 K thermal shield
- Cryogenics and PED: lower pressure drop from He vessel to safety devices




Vacuum vessel (stainless steel, 1200 mm diam.)

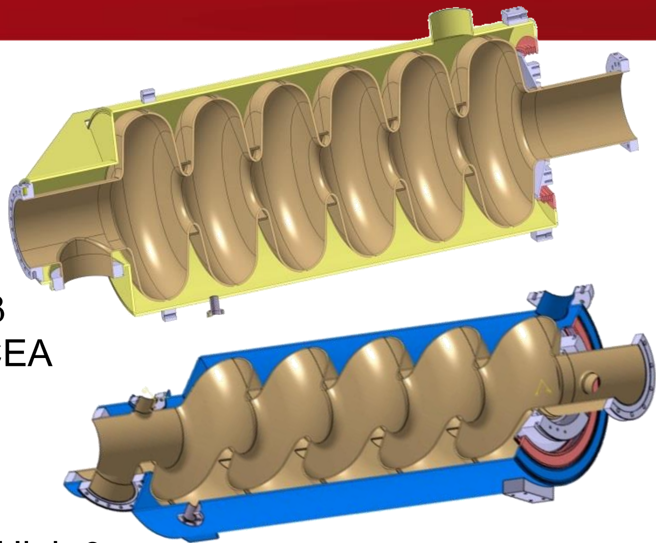



Fundamental Power Coupler



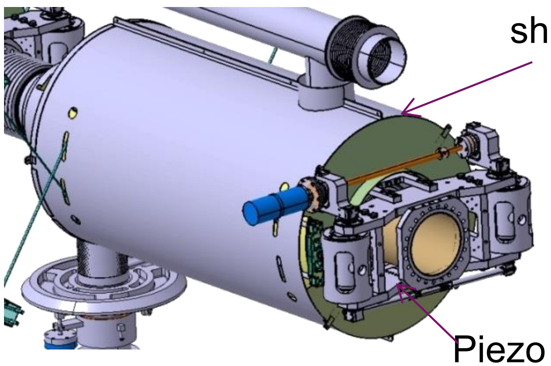
# 704.42 MHZ ELLIPTICAL CAVITIES - PROTOTYPES

| | Medium | High |
|---|---|---|
| Geometrical beta | 0.67 | 0.86 |
| Number of cells | 6 | 5 |
| Length (mm) | 1259 | 1316 |
| Nominal Accelerating gradient (MV/m) | 16.7 | 19.9 |
| Nominal Accelerating Voltage (MV) | 14.3 | 18.2 |
| $Q_0$ at nominal gradient | > 5e9 | |
| Cavity dynamic heat load (W) | 4.9 | 6.5 |
| $Q_{ext}$ | $7.5\ 10^5$ | $7.6\ 10^5$ |
| Iris diameter (mm) | 94 | 120 |
| Cell to cell coupling k (%) | 1.2 | 1.8 |
| $\pi$ and $5\pi/6$ (or $4\pi/5$) mode separation (MHz) | 0.53 | 1.2 |
| $E_{pk}/E_{acc}$ | 2.35 | 2.2 |
| $B_{pk}/E_{acc}$ (mT/(MV/m)) | 4.78 | 4.3 |
| Maximum. r/Q ($\Omega$) | 397 | 477 |
| Optimum $\beta$ | 0.705 | 0.92 |
| G ($\Omega$) | 197 | 241 |
| Static KL (Hz/(MV/m)²) with tuner | -2 | -1 |

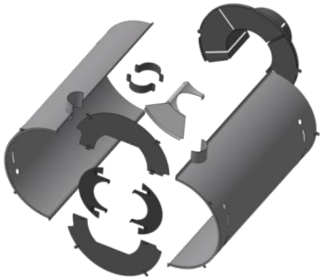


Medium $\beta$
U-Lund/CEA

High $\beta$



Mag.
shield



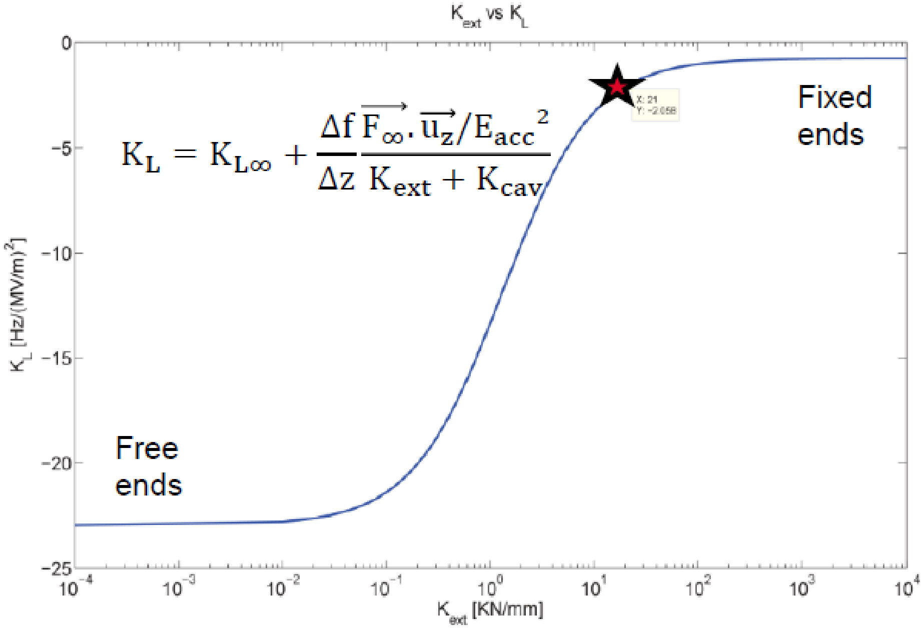
Piezo
tuner

- No HOM couplers
- Cold magnetic shield over the He jacket (target 1.4 $\mu$T)
- Use as far as possible tesla technology material (Ti tank, Al gaskets)

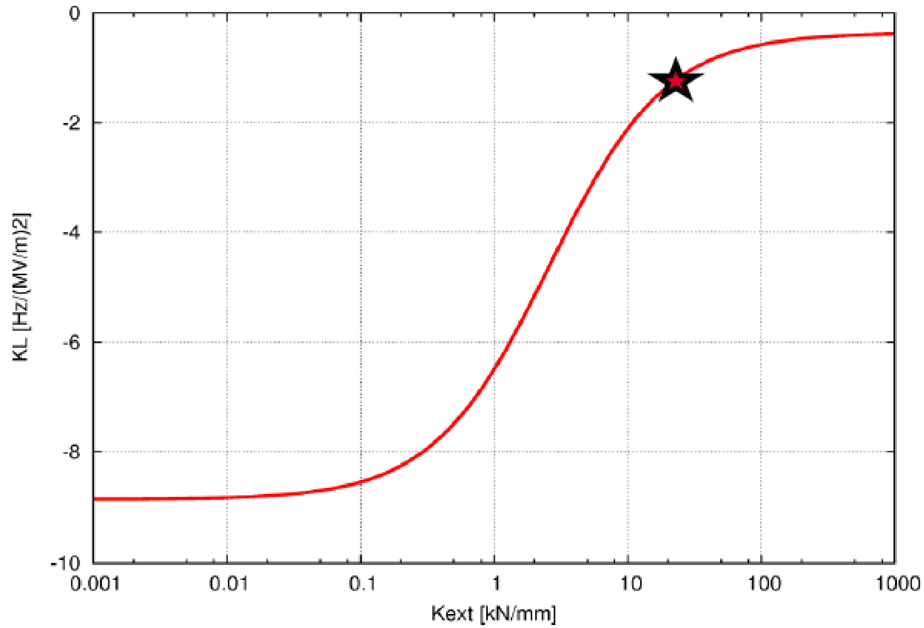
# LORENTZ FORCE DETUNING

| | |
|---|---|
| Designed stiffness of the tank: | $K_{tank}$ = 75 kN/mm |
| Measured stiffness of the tuner: | $K_{tuner}$ = 30 kN/mm |
| Total external stiffness (tank + tuner): | $\underline{K_{ext} = 21\ \text{kN/mm}}$ |

Medium beta




High beta

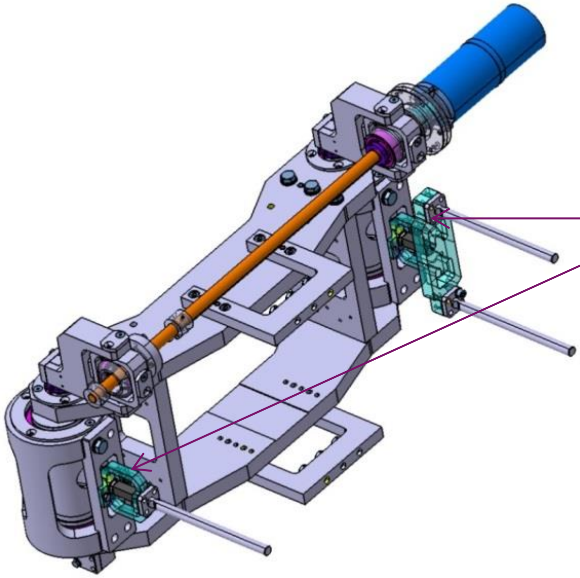


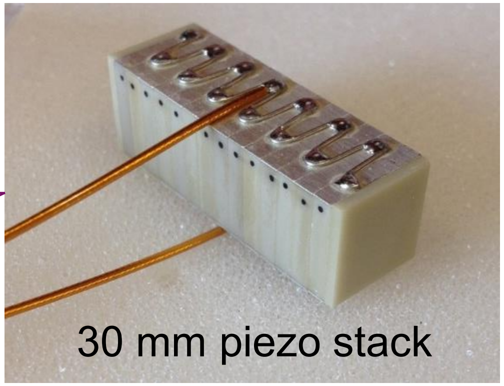

**For $K_{ext}$ = 21 kN/mm**
**→ $K_L$ = -2 Hz/(MV/m)²**
**→ ΔF = -557 Hz @ 16.7 MV/m**
**→ $\Delta L_{piezo}$ = - 2.6 µm**

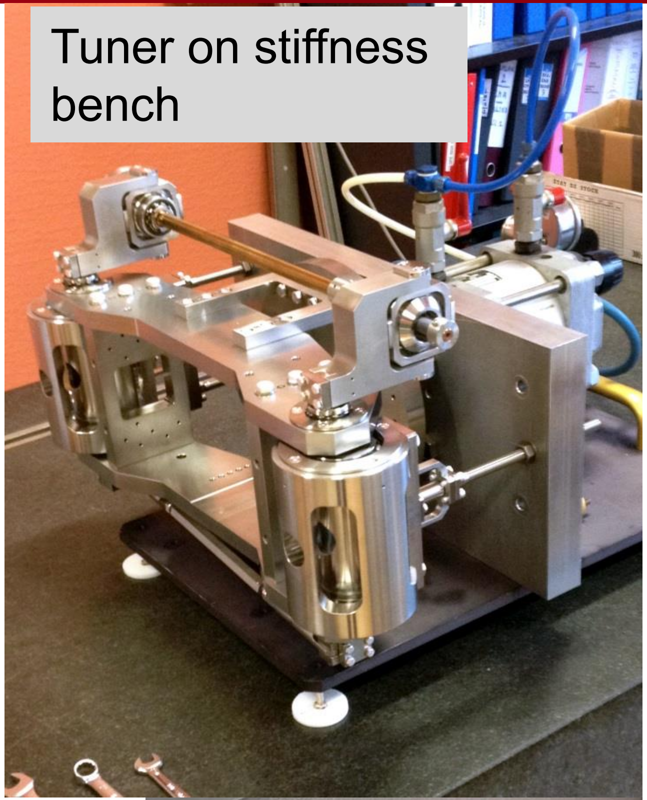
**For $K_{ext}$ = 21 kN/mm**
**→ $K_L$ = -1 Hz/(MV/m)²**
**→ ΔF = -396 Hz @ 19.9 MV/m**
**→ $\Delta L_{piezo}$ = - 2 µm**

40

# COLD TUNING SYSTEM



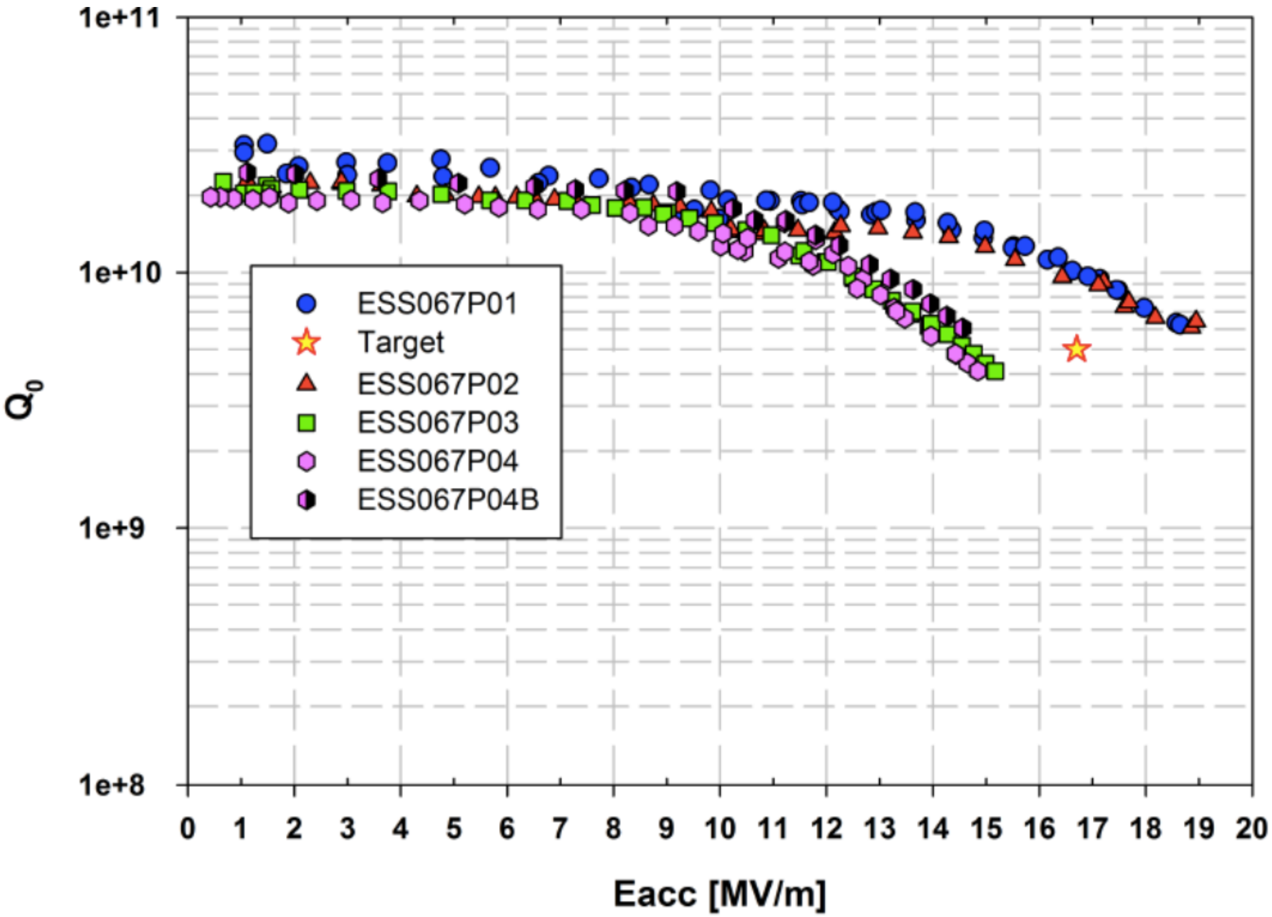


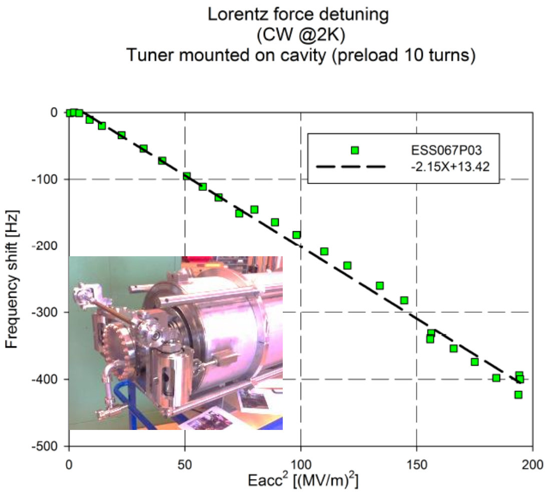

Stiffness of 30 kN/mm obtained on test bench for pre-series production

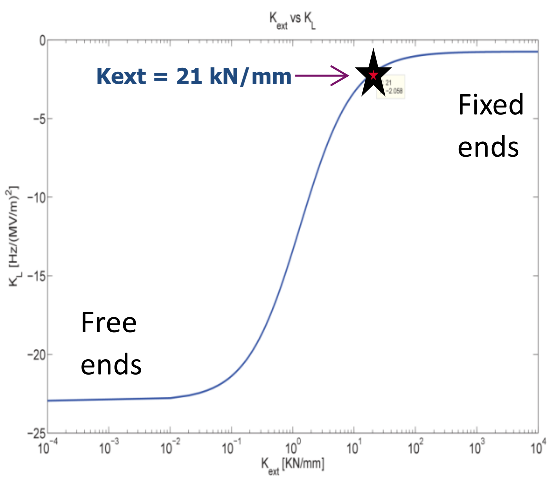
- Saclay V type adapted for ESS cavities
- Cold motor and planetary gearbox (1/100)
- +/- 3 mm range
- Theroretical resolution ~1Hz
- 1+1 piezo symmetrical arrangement
- Piezo support has a stiffness 10 times higher than the cavity ⇨ piezo preload at 2K is independant of the cavity springback force
- Good linearity due to high stiffness, proven on many previous Saclay designs (Soleil, Super-3HC, TTF/X-FEL, HIPPI)

# FIRST BATCH OF MEDIUM BETA CEA/U-LUND PROTOTYPES




$K_L$ measured at -2.15 Hz/(MV/m)²
(-2.04 computed)
with tuner attached in VT



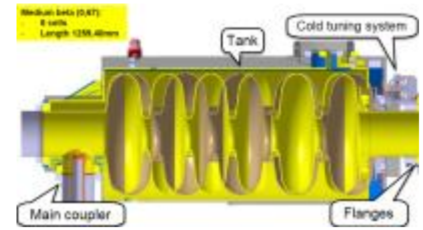
# NEW DESIGN OF MEDIUM BETA BY INFN

## Design goal

- Plug-compatible
- Larger cell-to-cell coupling factor, k>1.5%
- Allowing for a slight modest sacrifice on $E_{peak}$ and R/Q

| Mechanical parameter | INFN Design |
|---|---|
| Cavity wall thickness (mm) | 4.5 |
| Stiffening ring radius (mm) | 70 |
| Cavity Internal volume (l) | 69 |
| Cavity internal surface ($m^2$) | 1.8 |
| Stiffness (kN/mm) | 1.7 |
| Tuning sensitivity $K_T$ (kHz/mm) | -210 |
| Vacuum sensitivity $K_V$ for $K_{ext}$ ~ 21 kN/mm (Hz/mbar) | 31 |
| LFD coefficient $K_L$ for $K_{ext}$ ~ 21 kN/mm (Hz/(MV/m)$^2$) | -1.7 |

S. Pirani 2016




Plug-compatible

| RF Parameters | INFN design | ESS spec. |
|---|---|---|
| $R_{iris}$ (mm) | 50 | ≥47 |
| Geometrical beta | 0.67 | 0.67 |
| Frequency (MHz) | 704.42 | 704.42 |
| Acc. length (m) | 0.855 | 0.855 |
| Cell to cell coupling k | 1.55%↗ (+26%) | |
| $\pi$-5$\pi$/6 mode sep.(MHz) | 0.70↗ (+30%) | >0.45 |
| G ($\Omega$) | 198.8 | |
| Optimum beta, $\beta_{opt}$ | 0.705 | 0.705 |
| Max R/Q at $\beta_{opt}$ ($\Omega$) | 374 | |
| $E_{acc}$ at $\beta_{opt}$ (MV/m) | 16.7 | 16.7 |
| $E_{peak}/E_{acc}$ | 2.55 ↗ (+7%) | |
| $E_{peak}$ (MV/m) | 42.6 ↘ (-6%) | < 45 |
| $B_{peak}/E_{acc}$(mT/MV/m) | 4.95 ↗ (+3%) | |
| $Q_0$ at nominal gradient | $>5\times10^9$ | $>5\times10^9$ |
| $Q_{ext}$ | $7.8\times10^5$ | $5.9\sim8\times10^5$ |

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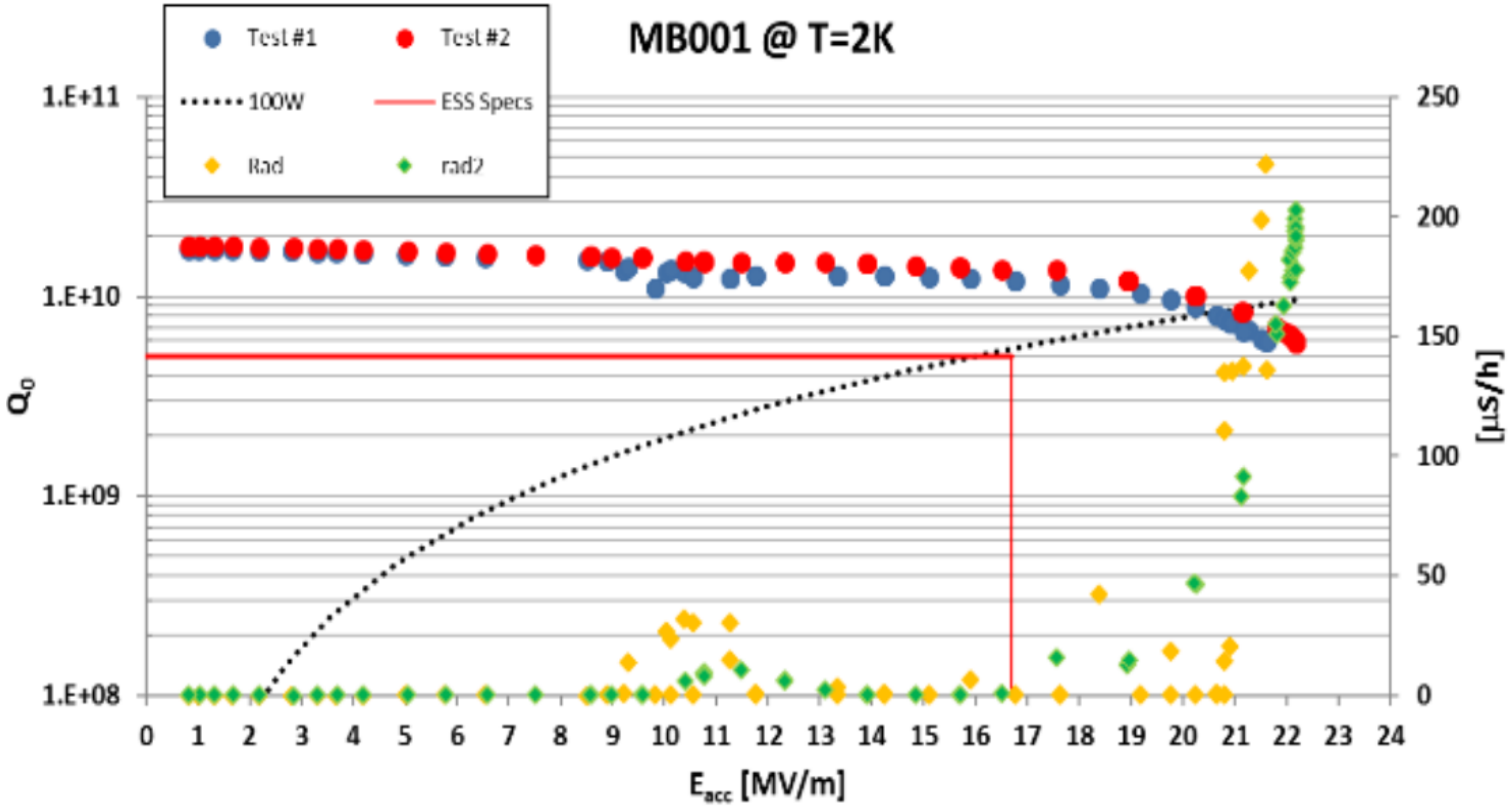
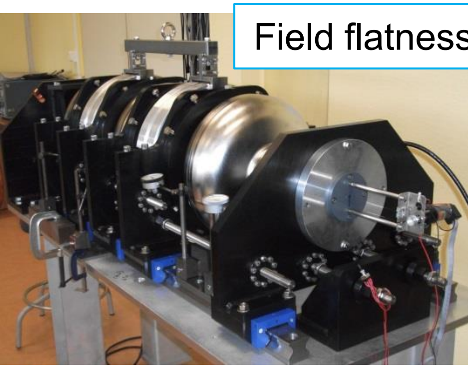
# FIRST LASA MEDIUM BETA PERFORMANCE

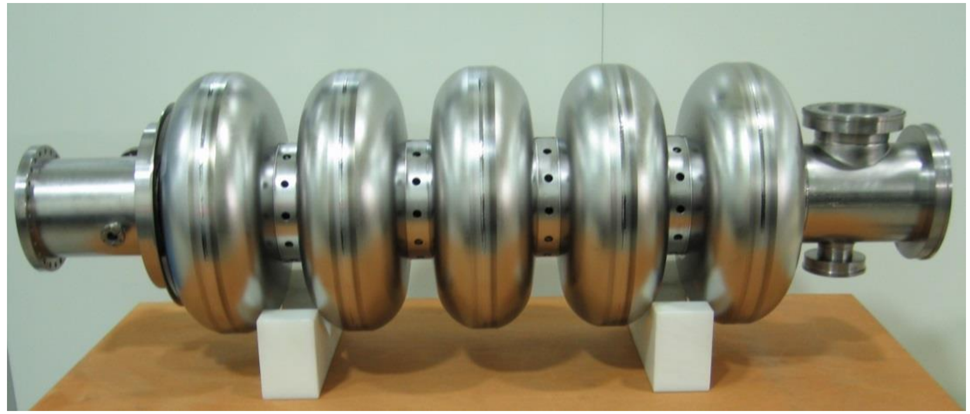


# FIRST TWO HIGH BETA PROTOTYPES



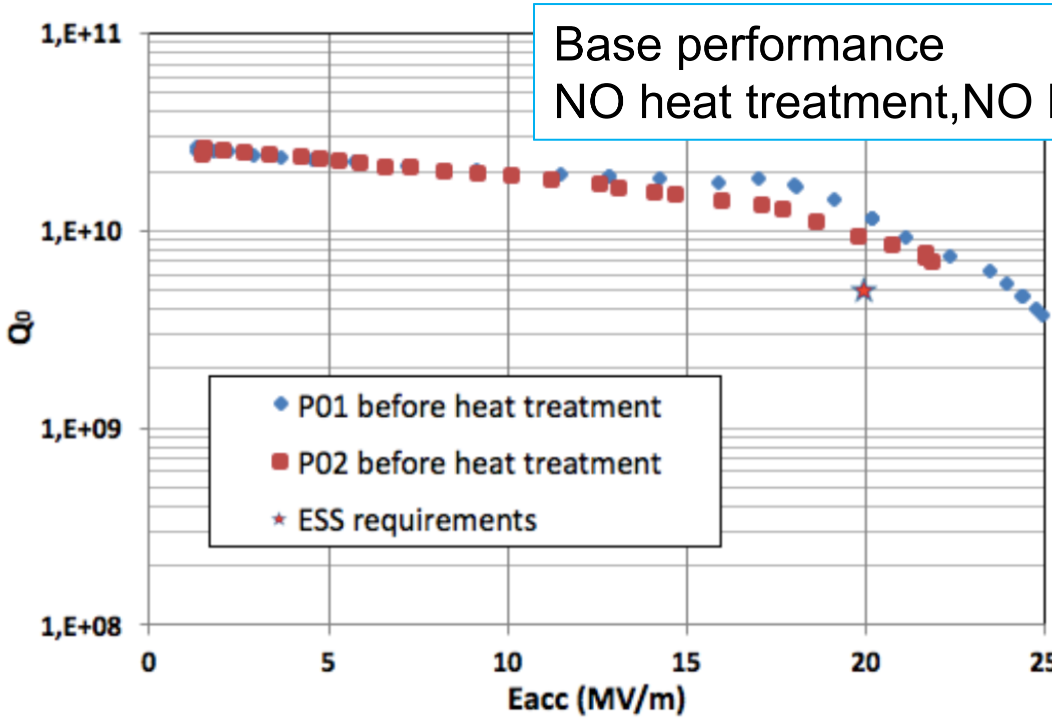
Field flatness:92%

FNP 1-1-2.4 etching performed on BCP/EP cabinet



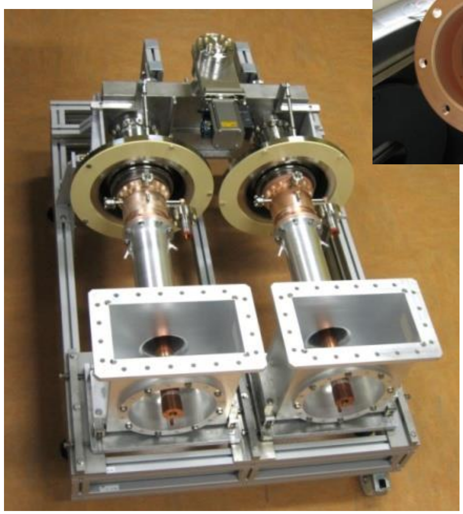
With HOM ports

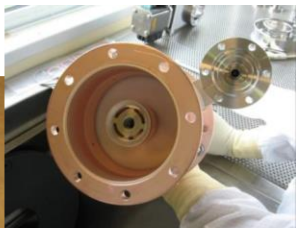
Base performance
NO heat treatment,NO baking yet



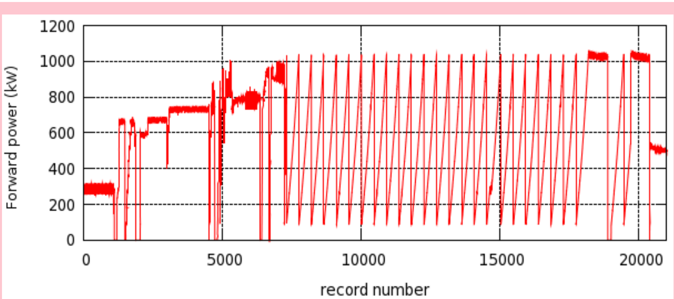
# FUNDAMENTAL POWER COUPLERS - ELLIPTICALS

CEA «HIPPI» coupler (2009)
- Peak power 1.2 MW
- Avg. power 120 kW



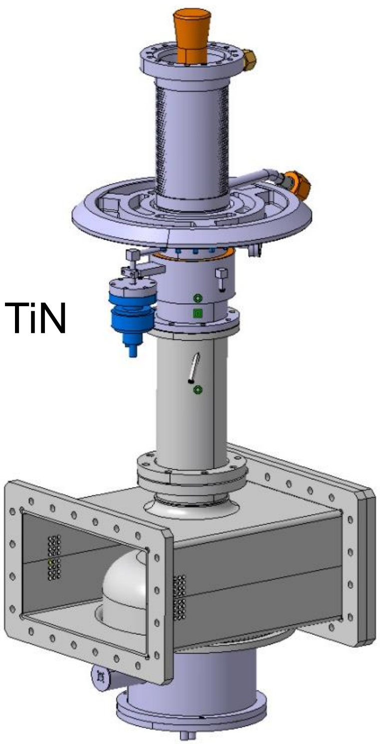


KEK-SNS type
- 100 mm 50 Ω
- single disk window w/ TiN
- Water cooled antenna
- He cooled double wall tube



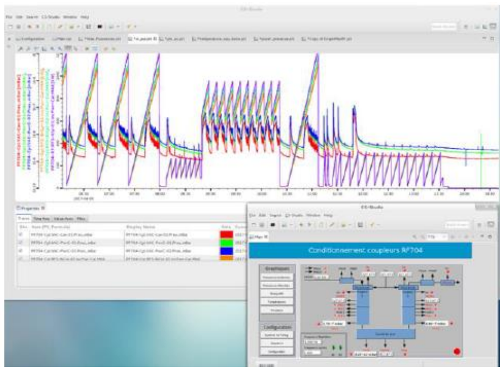

Test of the HIPPI power coupler a b=0.5 5-cell cavity at 1.8 K, full reflection, horizontal cryostat

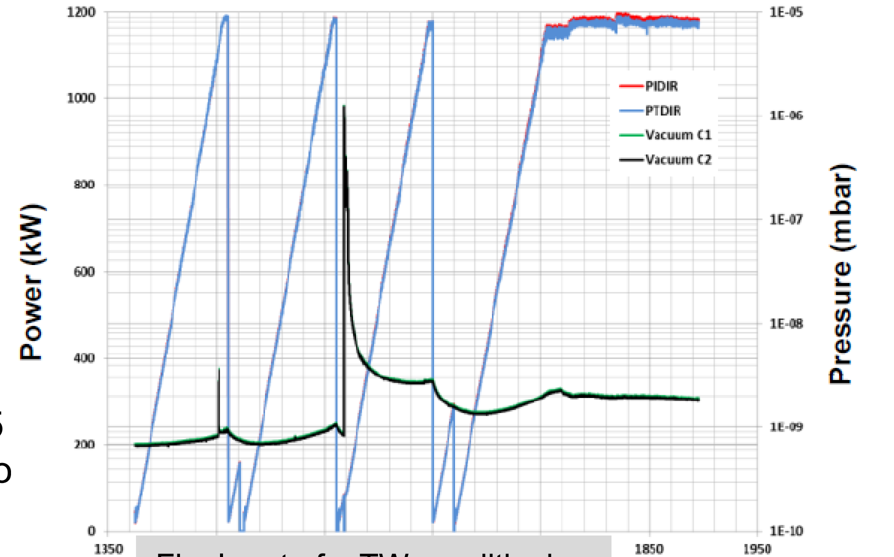
ESS coupler (2013)
- Peak power 1.1 MW
- Avg. Power 50 kW
- Antenna HV bias

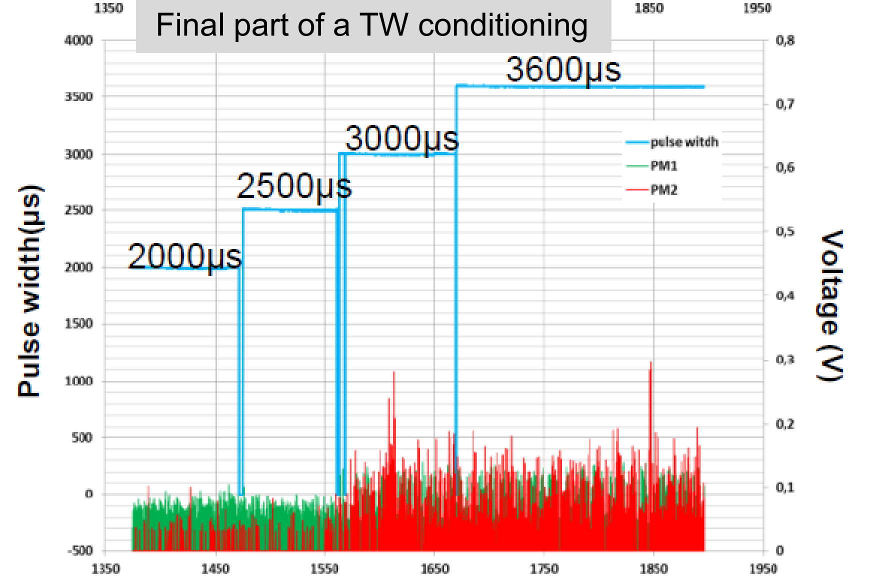


ESS prototypes (2016)

# FPC PROTOTYPES RF CONDITIONING






Conditioning is performed on a FPC pair assembled in ISO5 clean room on a coupling cavity , the baked at 170°C for 3 to days

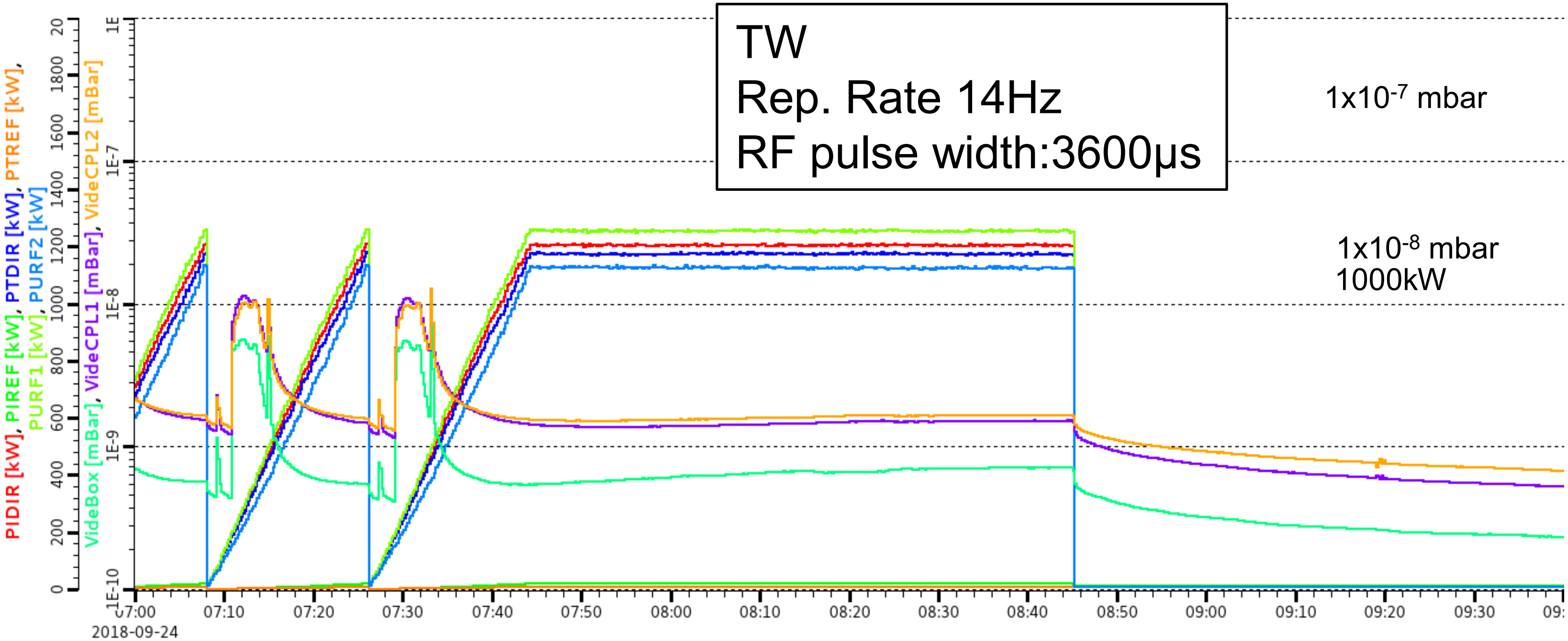
- with power ramps, increasing RF pulse duration
- Power increase is controled by pressure, interlocked by vacuum, arc detectors, electron pickups
- 2 runs in TW: 1Hz rep. Rate, 14Hz Rate
- 2 runs in SW : 1Hz rep. Rate, 14Hz Rate
- 1hr TW @ maximum power, nominal ESS pulse

3 pairs of prototype FPC:

- Mixed components from 2 window providers, 2 doorknob manufacturers, 2 double-wall tube manufacturers
- Total RF-on time for conditioning for those 3 pairs : 82 hrs, 88 hrs, 106 hrs

# PRE-SERIES FPCS

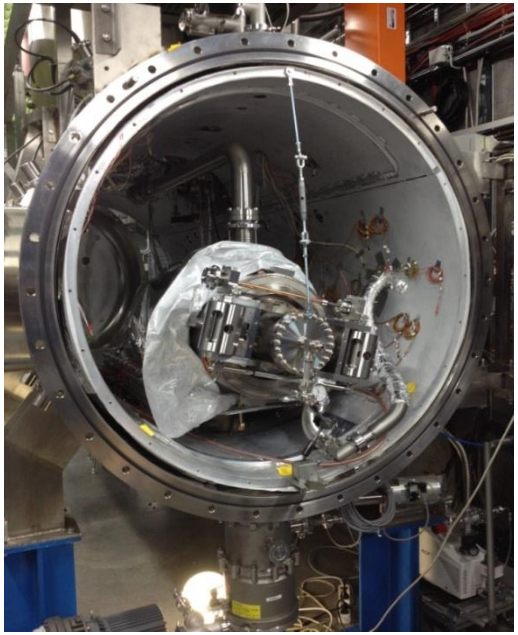
- 3 FPC pairs delivered as a pre-series by the 120-coupler manufacturer.
- RF conditioning performed to specs




Up to now : 14 FPCs have been qualified to specs

See Poster MOP086

# HB CAVITY PACKAGE TESTS AT UPPSALA

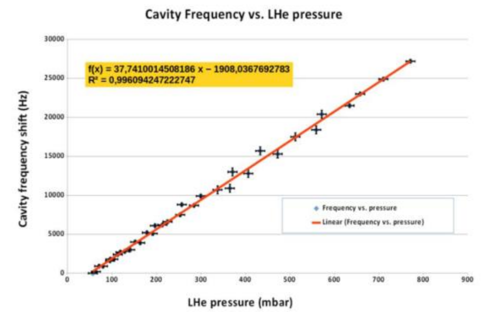


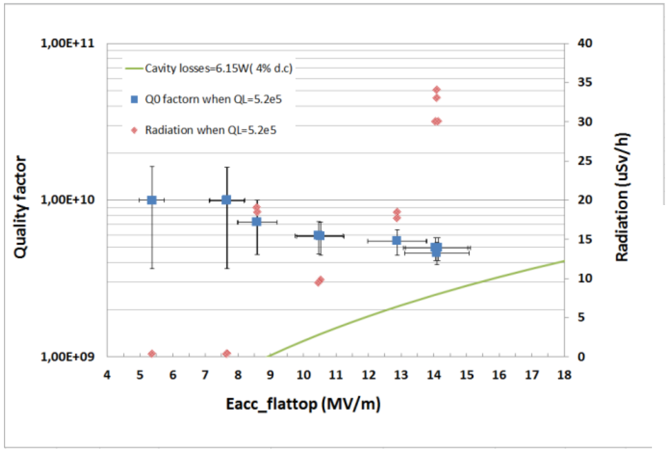
First cold test of elliptical FPC and tuner on Prototype High beta cavity package

Cavity measurements :

$K_P$ = +37 Hz/mbar (tuner at home position)

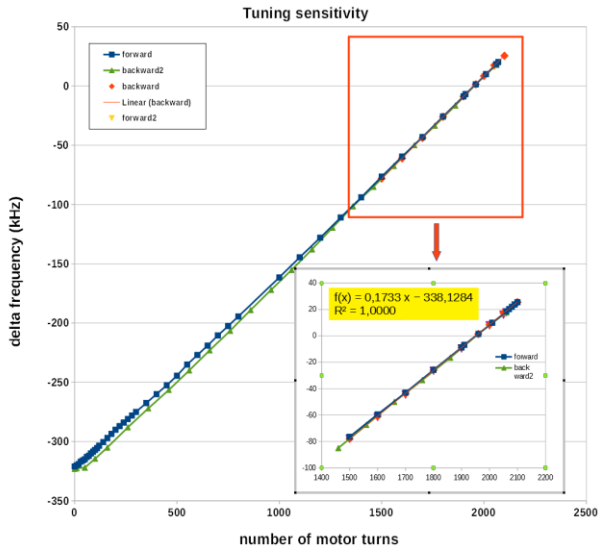
$K_L$ =-1.3 Hz/(MV/m)²




## Test Plan:

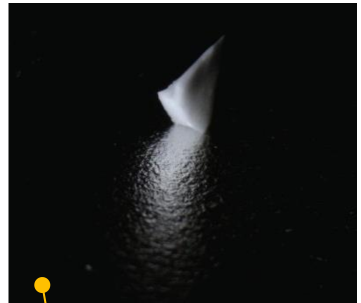
- RT FPC conditioning
- Cooldown
- RF conditioning at cold
- measurement
  - $Q_0$ preliminary result >$10^9$
    - not much multipacting, cavity and coupler very quiet during last tests
  - Lorenz force detuning, cavity tuning sensitivity
    - lost some motor steps during 1st movement, others ok
- Cold tuner test

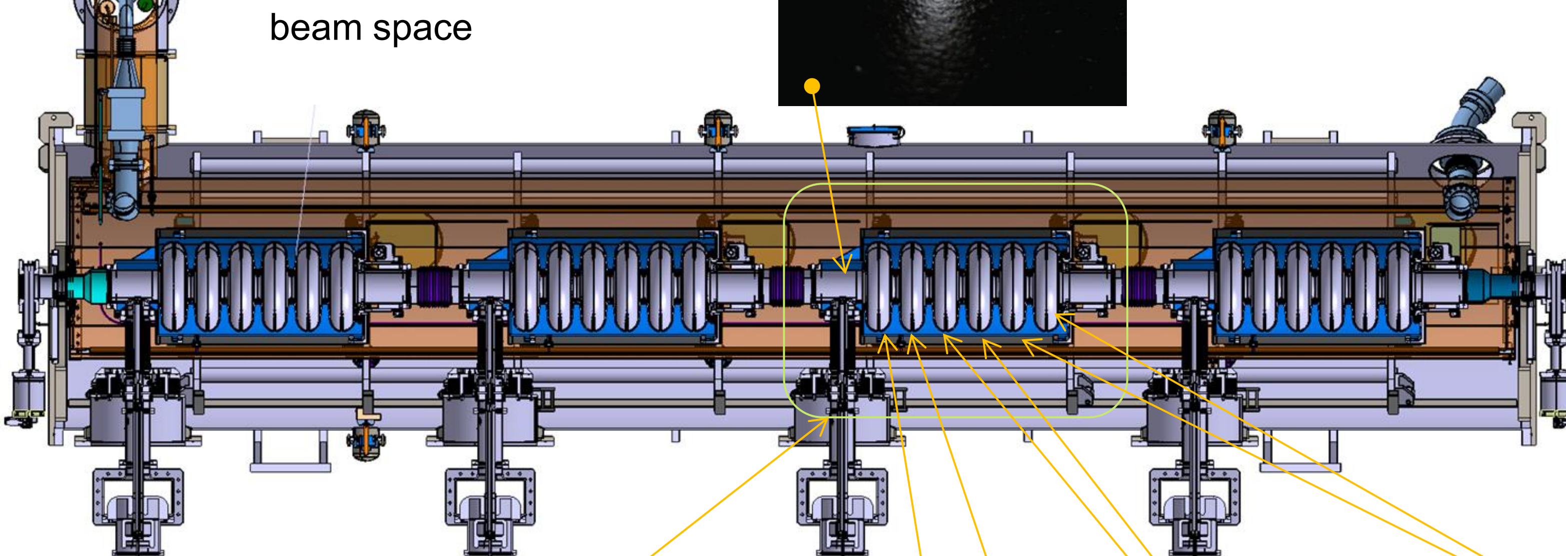


# CAVITY STRING WITH PROTOTYPE FPCS

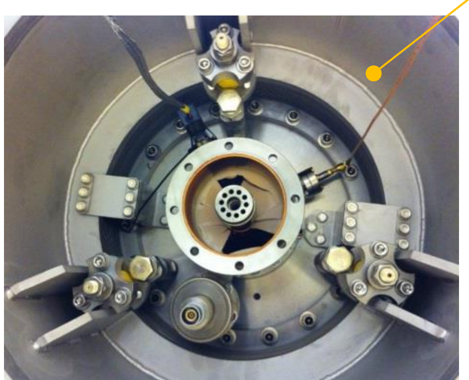
# FIRST ASSEMBLY – DOORKNOB ASSEMBLY WITH LOSS-OF-VACUUM ACCIDENT

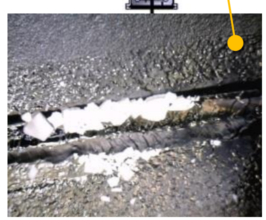
Alumina dust was found in the whole beam space

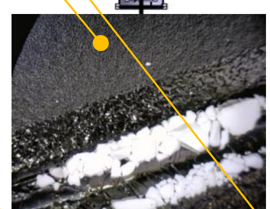


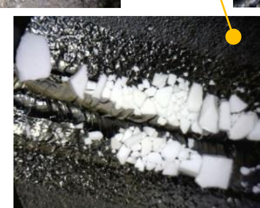


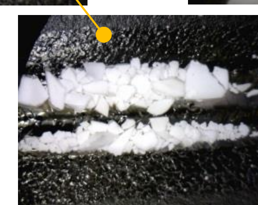
An dedicated assembly tool has been designed to perform doorknob assembly safely

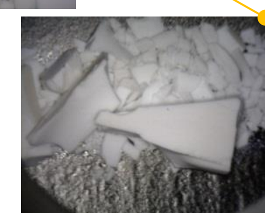






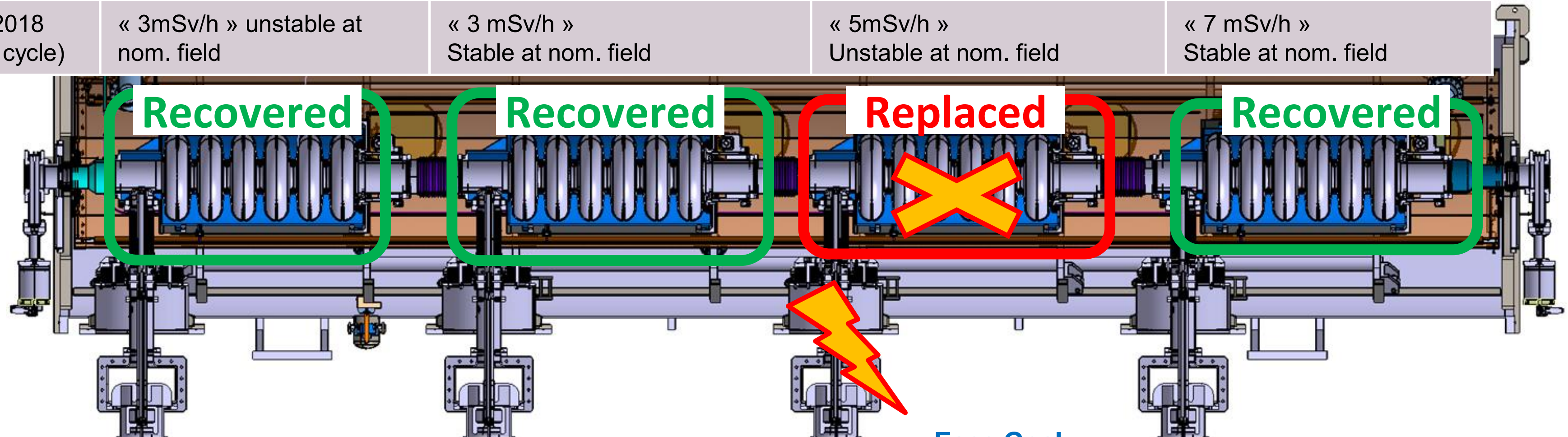


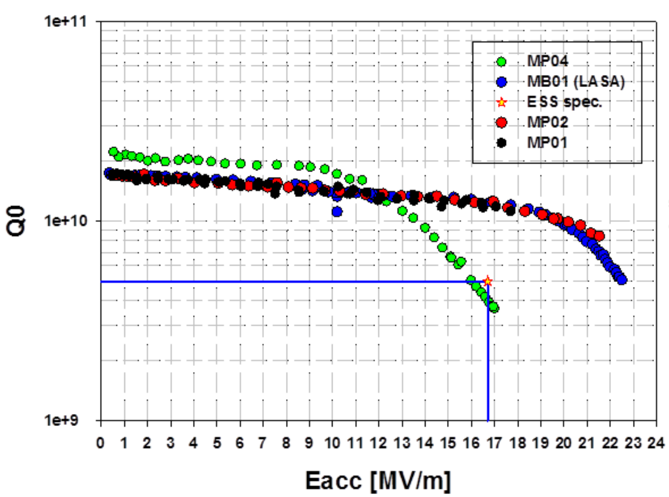


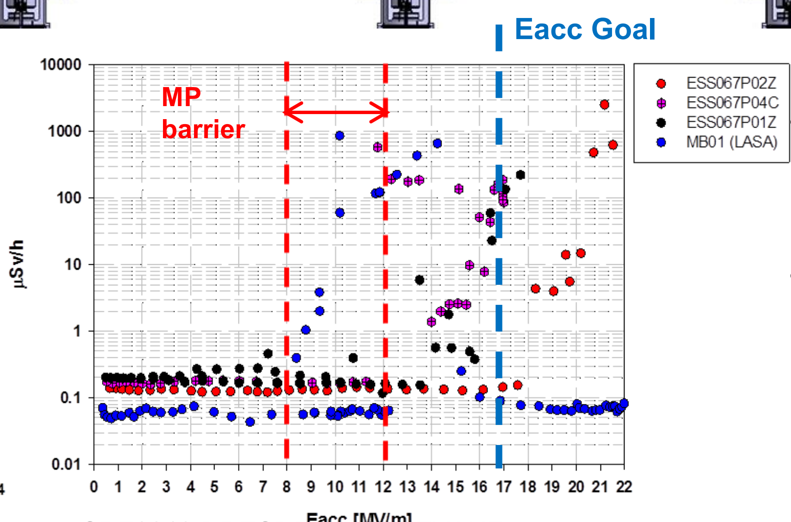


# REFURBISHED M-ECCTD (PHOENIX)

| CAVITIES | MP02 | MP01 | MP04 | MB01-LASA |
|---|---|---|---|---|
| FE in VT before accident (CW) | no | Yes, onset 8 MV/m | Yes, onset 11 MV/m | no |
| FE in VT After refurbish (CW) | Yes, onset 8 MV/m | Yes, onset 11 MV/m | Yes, onset 11 MV/m | no |
| CM test 2018 (4% duty cycle) | « 3mSv/h » unstable at nom. field | « 3 mSv/h » Stable at nom. field | « 5mSv/h » Unstable at nom. field | « 7 mSv/h » Stable at nom. field |



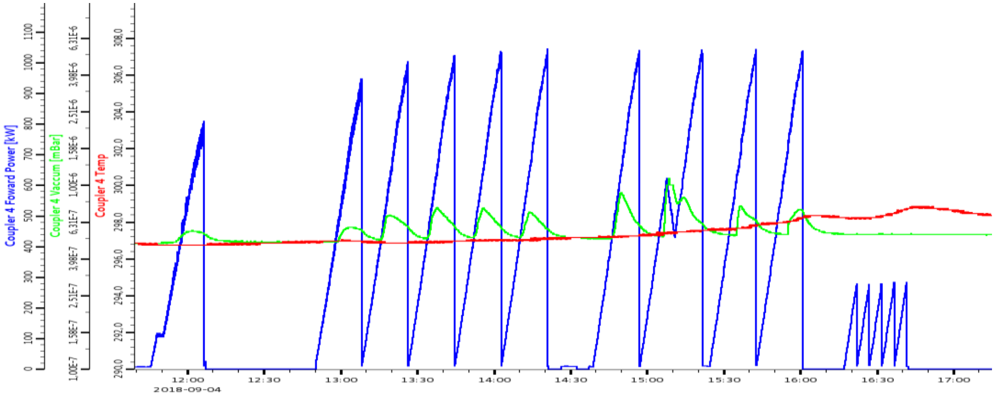



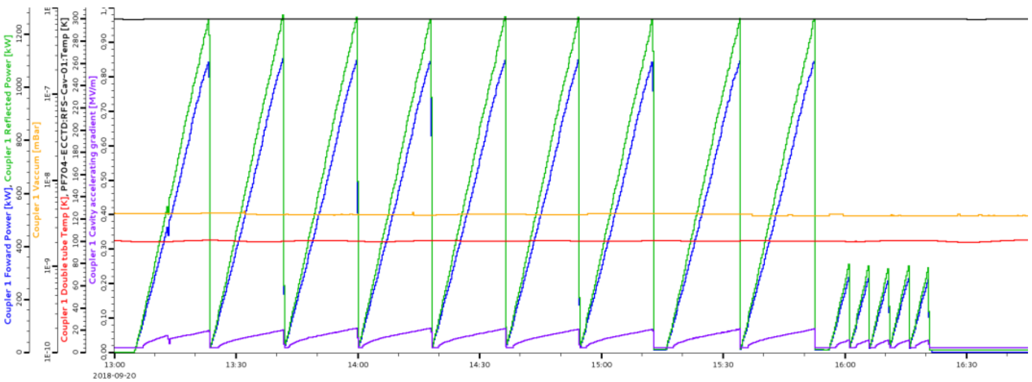

- 3 Cavities reprocessed with 25-30 $\mu$m BCP, HPR
- 3 FPCs have been cleaned and fully re-conditionned along with a 4th one

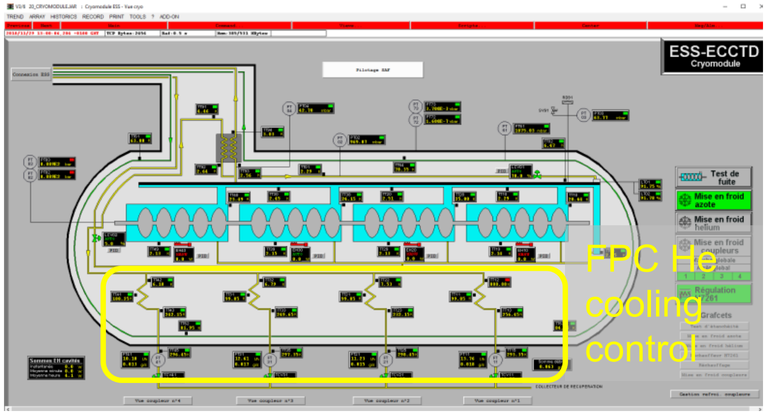
# FPC CONDITIONING ON CRYOMODULE

Room temperature :



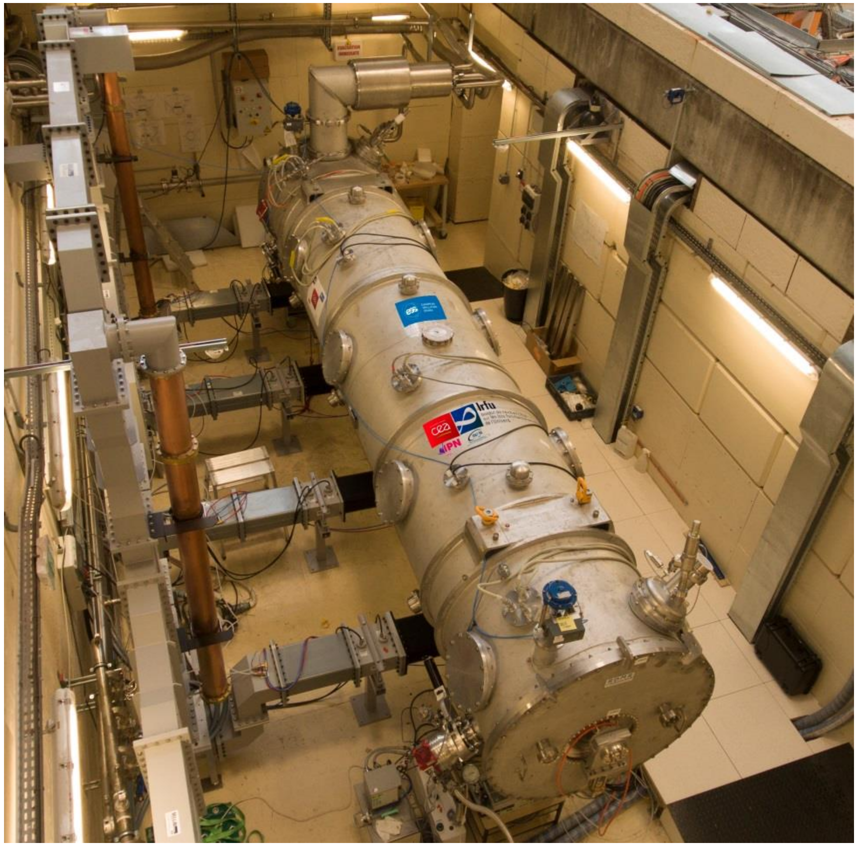

After cryomodule cooldown :



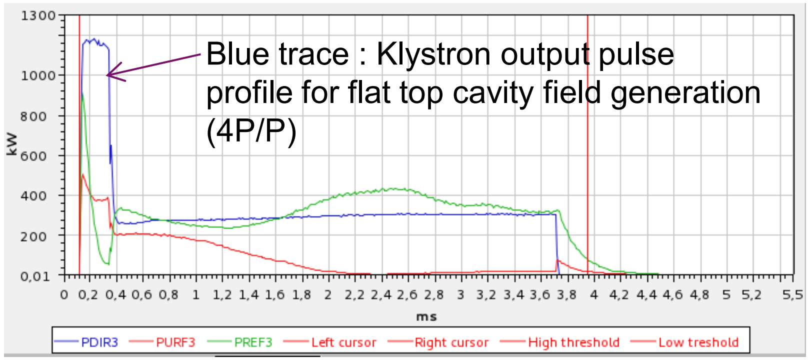



Same logic is followed as on FPC conditioning stand
avg. duration ~4 hours for both warm and cold conditioning

# 2018 HIGH POWER TEST OF ESS MEDIUM BETA ECCTD CRYOMODULE



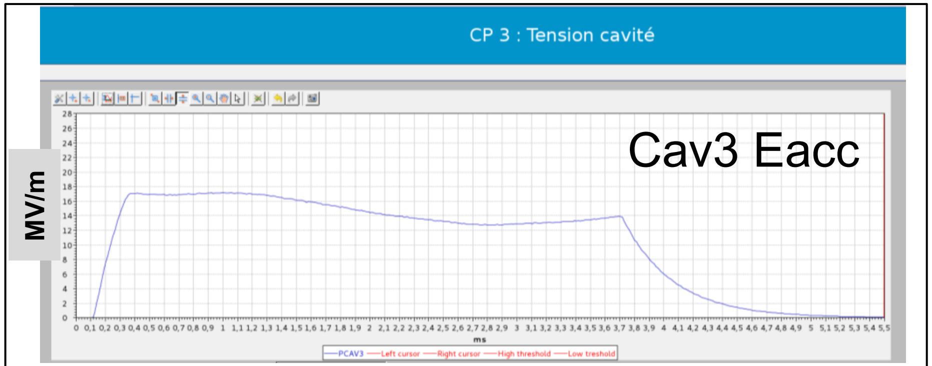
- 3 CEA cavities, 1 INFN cavity
- Operated at 2K
- All 4 beta=0.67 cavities connected to a single RF source
- Only single cavity high power operation with 4P/P pulse is possible with the current setup
- Fundamental Power Couplers (FPC) are conditionned at room temperature first, then at 2K up to 1.2 MW peak power



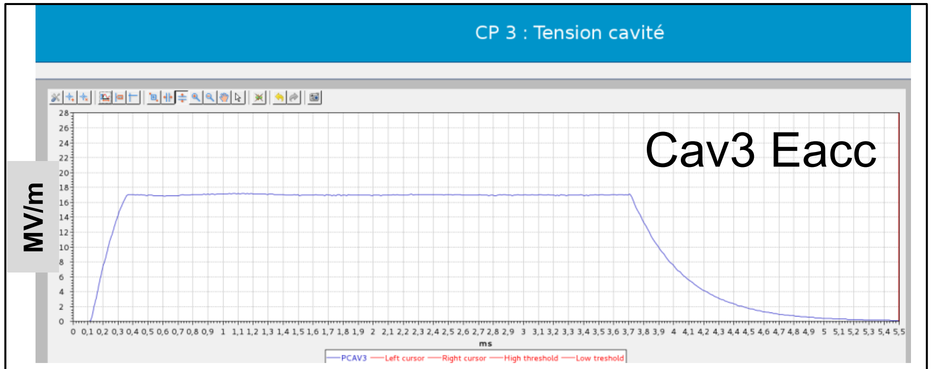

**RESULTS:**

- 4 FPCs pass all conditionning stages (full reflection)
- All cavities tuned to nominal frequency at 704.42 MHz and run with high power
- 3 cavities operated at 2 K above nominal gradient of 16.7 MV/m , RF pulse of 3.6 ms total, @14 Hz, with LFD piezo compensation
- 1 cavity with field limitation at 16 MV/m

# ESS M-ECCTD CAVITY #3 4P/P FLAT TOP LFD PIEZO COMPENSATION AT NOMINAL GRADIENT

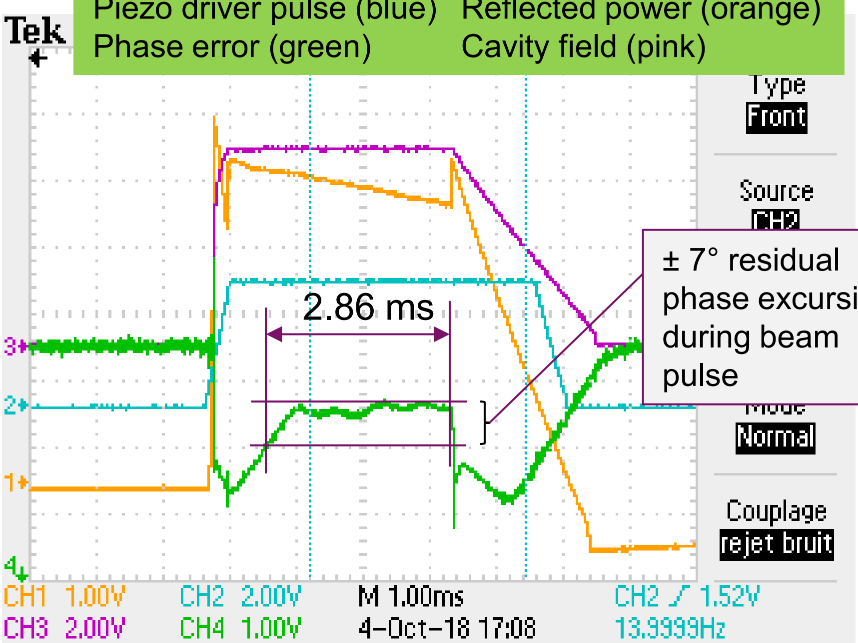



Cavity with static pre-tuning *without* piezo compensation

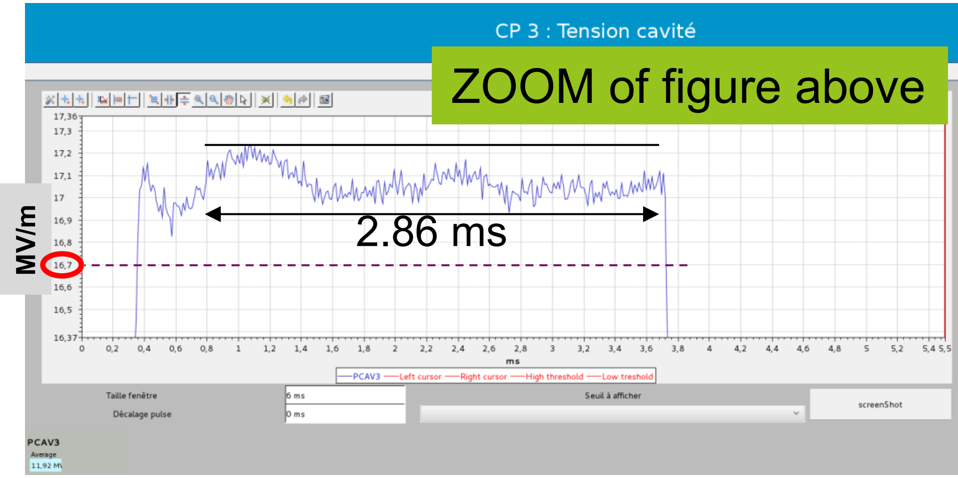



Cavity with static pre-tuning *with* piezo compensation with simple trapezoidal pulse

Piezo driver pulse (blue) Reflected power (orange)
Phase error (green) Cavity field (pink)



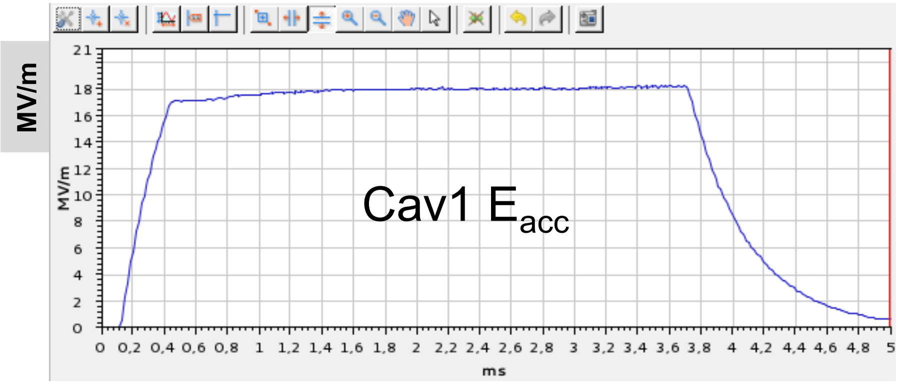

ZOOM of figure above

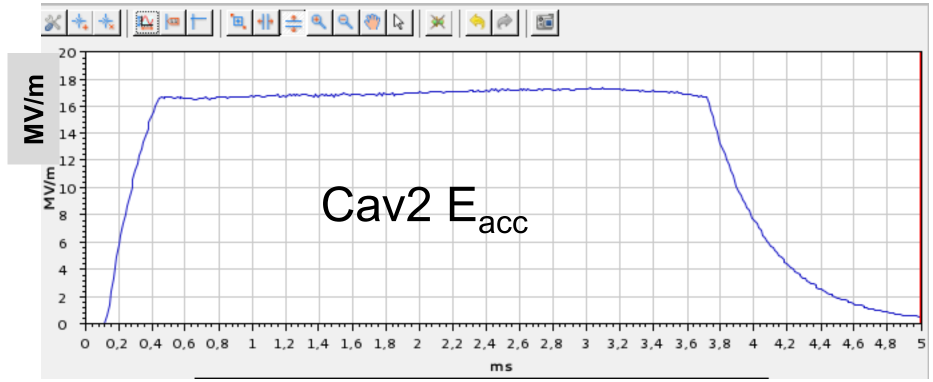


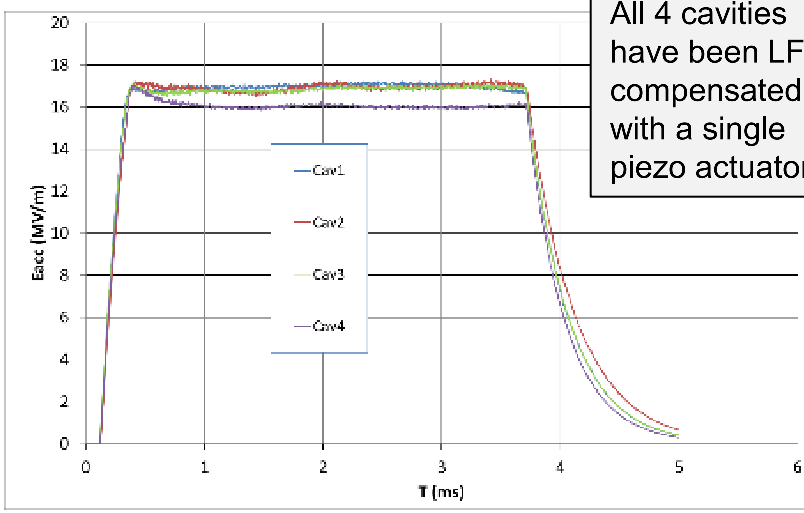

$E_{acc}$ =17.07± 0.15 MV/m during beam pulse : $E_{acc}$ is stabilized within +/- 0.9% with 1 piezo only (No LLRF)

# M-ECCTD 4P/P FLAT TOP LFD PIEZO COMPENSATION AT NOMINAL GRADIENT

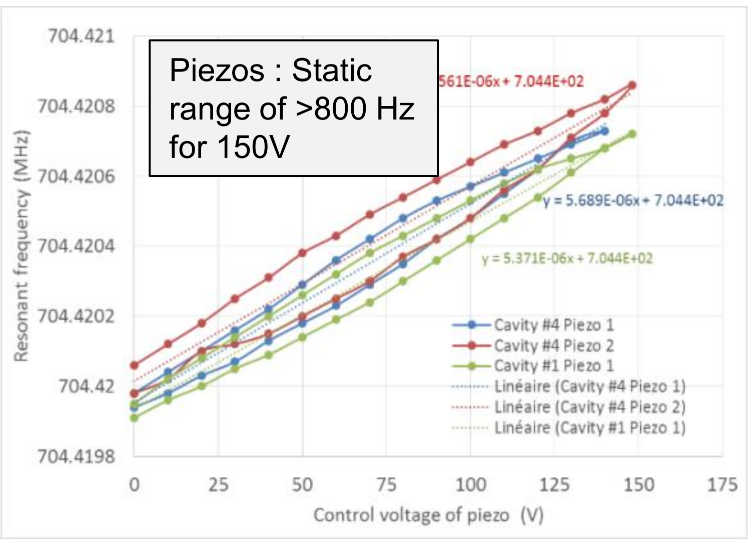
## Piezo LFD compensation simultaneously on 2 neighbour cavities



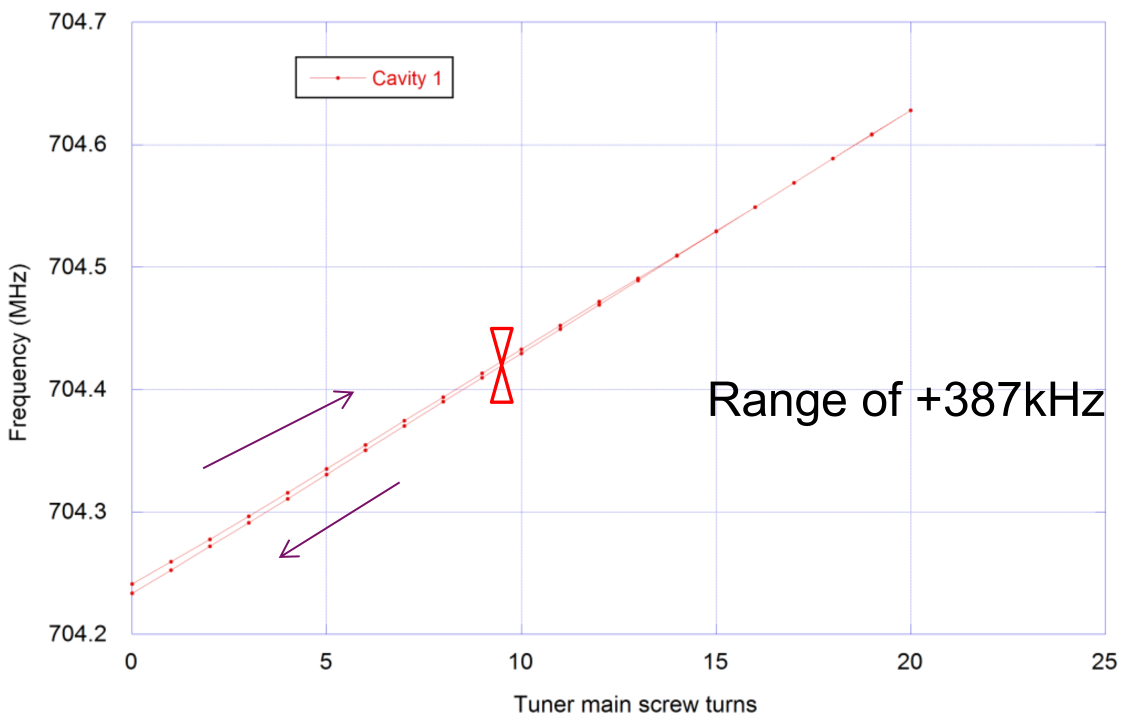



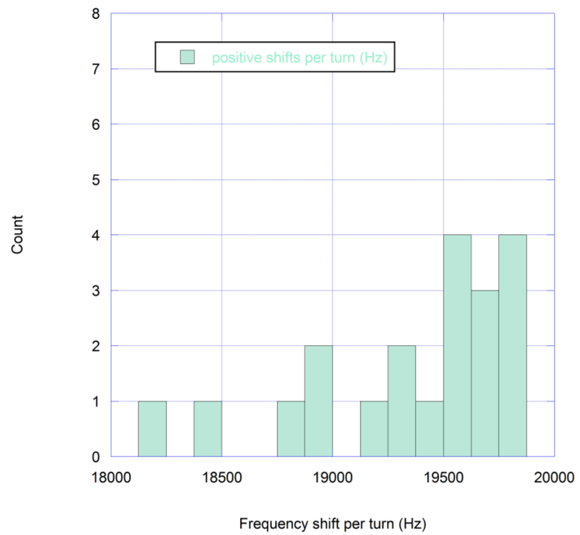

All 4 cavities have been LFD compensated with a single piezo actuator

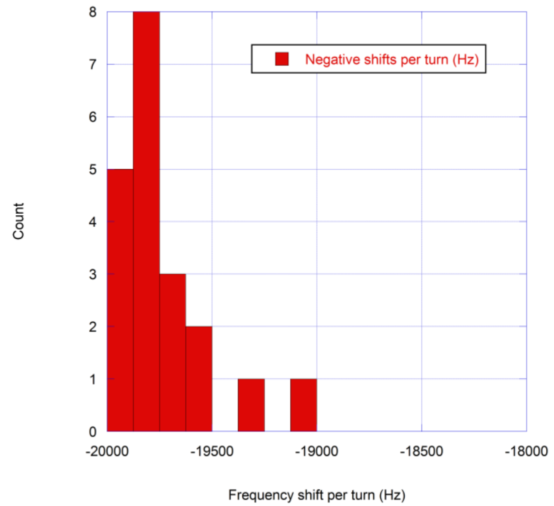



Piezos : Static range of >800 Hz for 150V

# CAVITY 1 TUNER – WIDE RANGE SCAN




Pretuning of cavities done initially at RT at 703.000 Mhz corresponds to 704.240 MHz at 2 K

Ultimate range is limited by mechanical stop around 22 turns
Sensitivity is slightly asymetric (the tuner needs initial loading) :
+19.35 kHz/turn for positive shifts
- 19.81 kHz/turn for negative shifts

# CRYOGENIC MEASUREMENTS

Test conditions differ from ESS site:

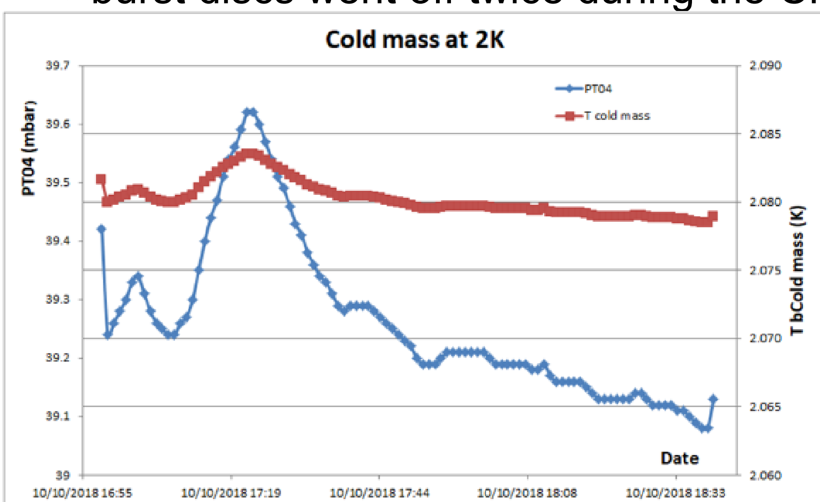
- 1.1 bar saturated He instead of 3 bar supercritical He
- thermal shield cooled with Liquid $N_2$, at 80 K instead of 19.5 bar He (TS@40K)

Issues during tests:

- Instabilities due to the diphasic helium and the Hampson heat exchanger ⇨ Phase separator will be installed for next tests
- Issue with the initial design of piping for the He level gauge : the gauge is blind above 92%, corresponding to the bottom of the 2-phase pipe ⇨ corrected for next modules

Consequences:

- Difficulties to get stable levels for periods longer than ~1 hour
- Lhe could overflow without a warning and reach warm areas of the piping
  → burst discs went off twice during the CM test period

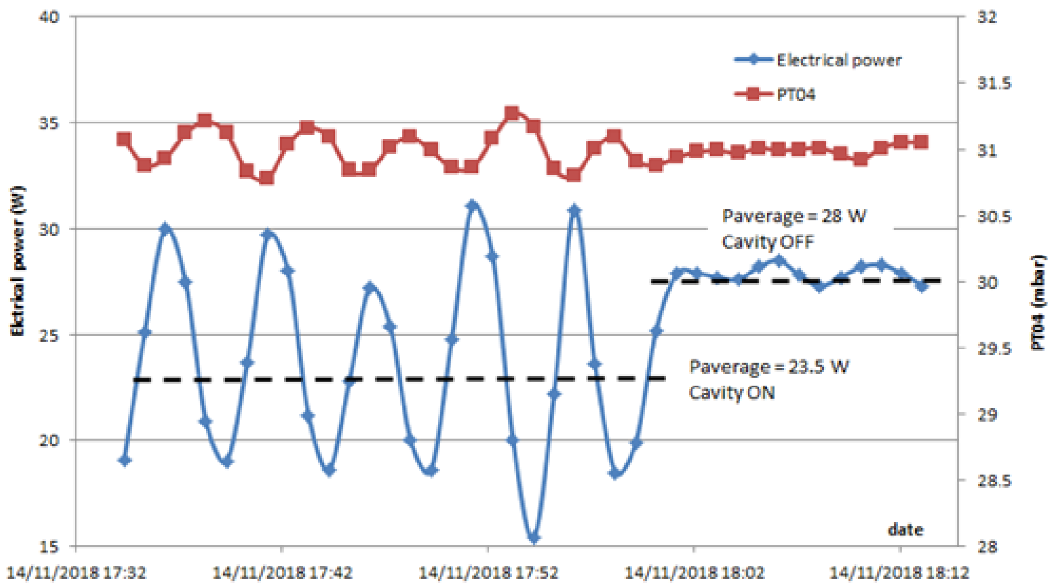



Measured static heat load at 2K:
**19.5 to 19.7 W**

Measured static heat load at 4.2K:
**20.4W**
(calculated: 19.6W)

# CAVITY RF DISSIPATION

Measured RF dissipation of the cavity MB01 at ESS nominal field: **4.5 W** (requirements : < 5W)




Electrical heaters power and helium bath pressure variations at the stop of the RF power in the cavity MB01.

Other measurements that were performed were not reliable enough.

# IMPROVEMENTS FOR NEXT MODULES AND TESTS

Tests have been strongly perturbed by:

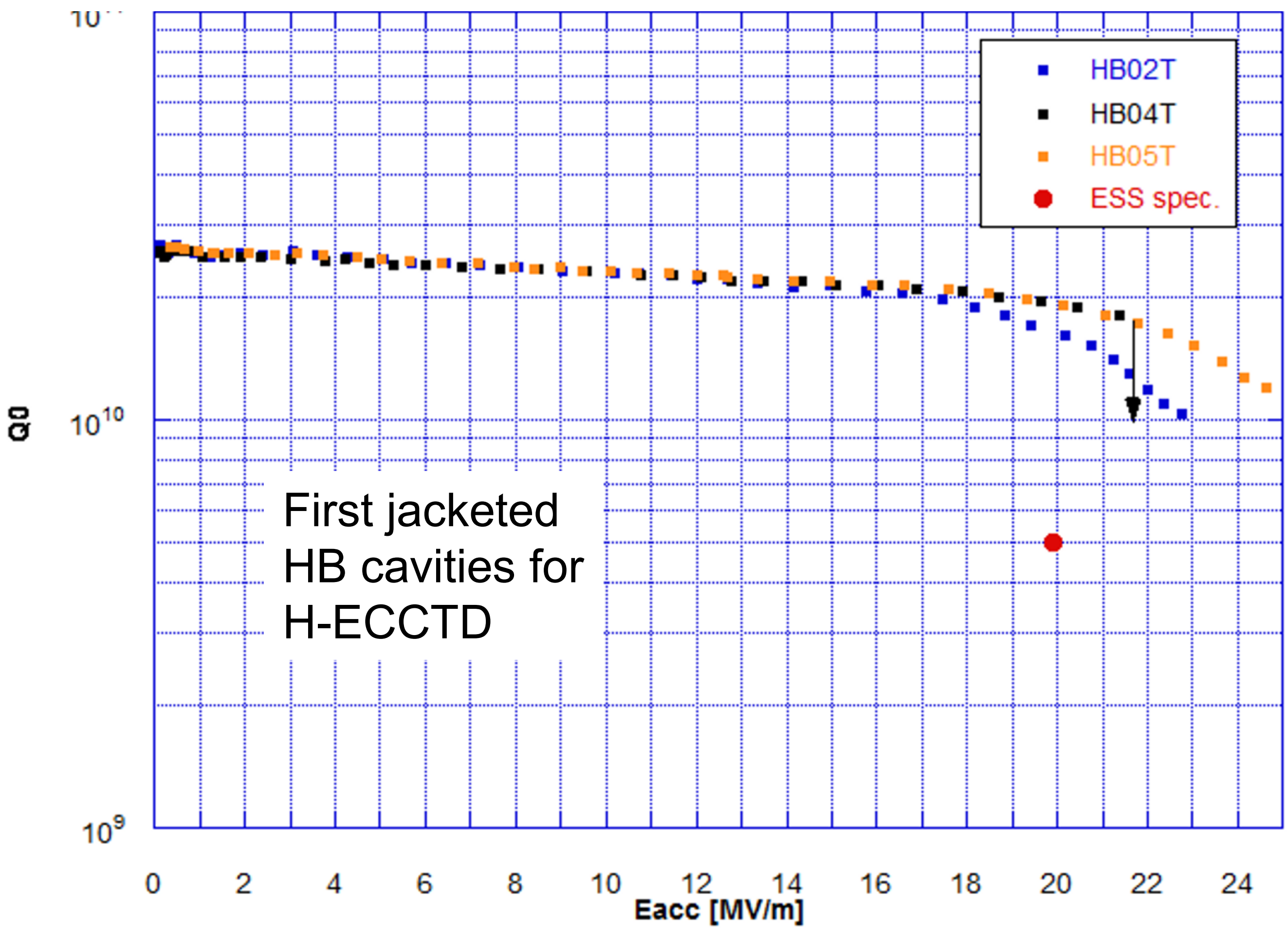
- unstable behavior of heat exchanger due to diphasic He feed
  → phase separator will be added to mitigate this issue

- FE in all cavities
  → review of potential cavity contamination in order to improve procedures
  → use ion or getter pump when cold (used pumping station failed during cooldown!)
  → setup a 6+ radiation monitor set in the test bunker for repeatable measurements in a known spatial distribution, so successive tests can be compared, and possibly locate the origin of emission by combining data with simulation

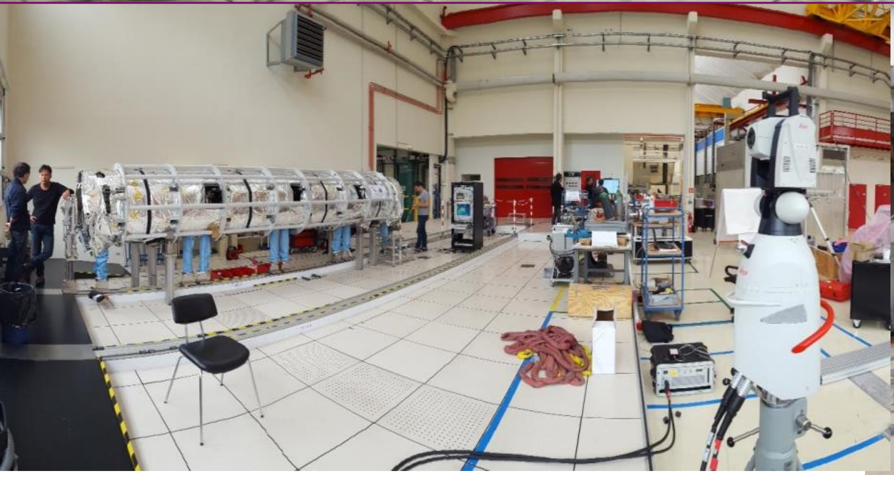
see poster THP097

# NEXT STEPS

- FIRST series cryomodule is under construction
- ISO4 assembly of H-ECCTD cavity string components is on-going



# SETTING THE STAGE FOR THE SERIES



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