LASA -Status for Medium-beta cavity fabrication & testing and open issues

Paolo Michelato
INFN – LASA

10° ESS SRF Collaboration Meeting, 25 - 26 June 2019

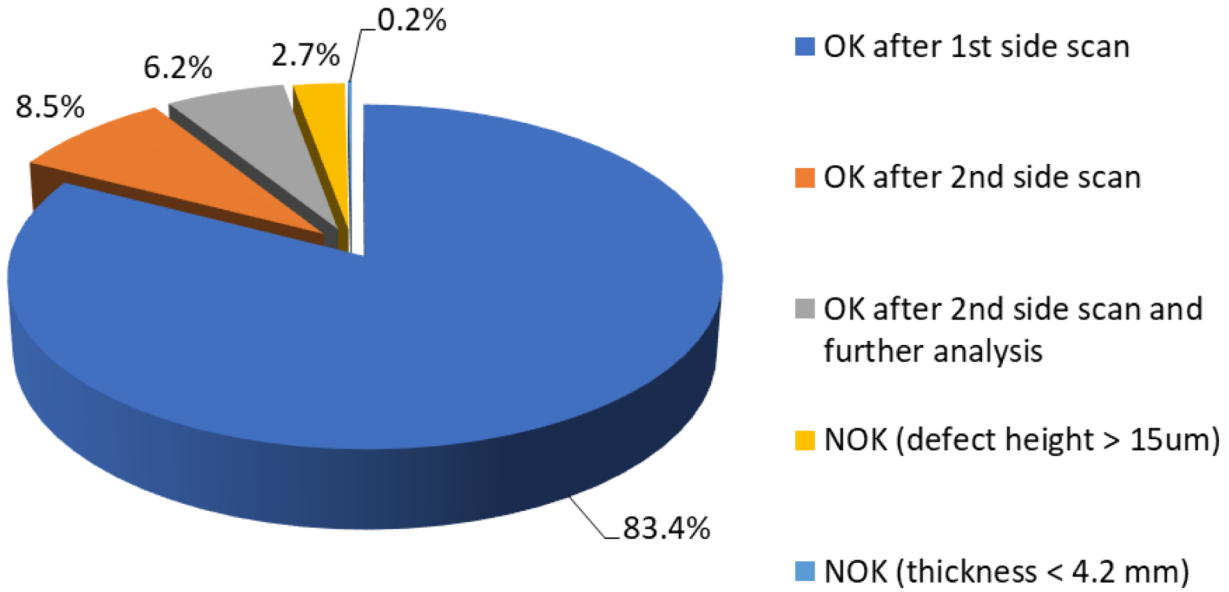
Outlook

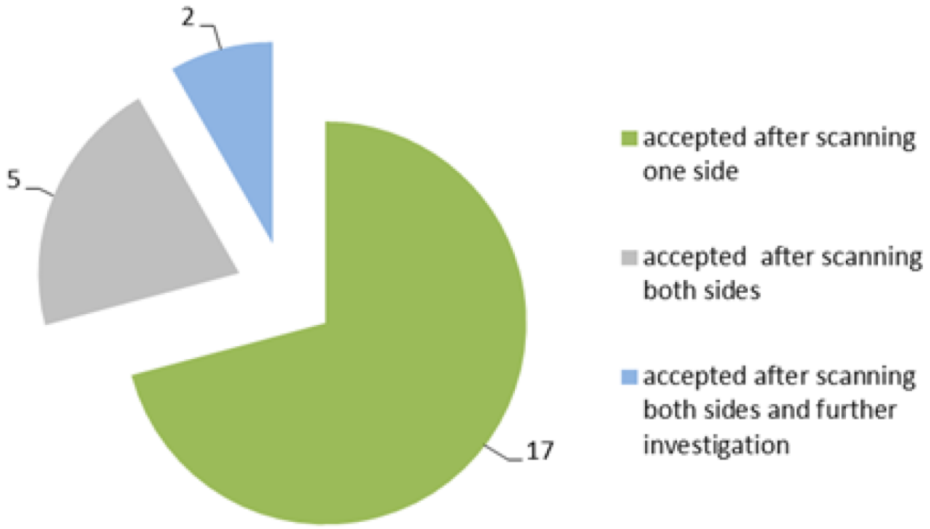
- Niobium scanning for series and spare cavities
- Subcomponent status and statistics
- Transportation and boxes
- Vertical test of dressed cavities
- Vertical test of undressed cavities
- RF acceptance criteria for next cavities
- Defect (pit) analysis and corrective strategy
- EZ oven re-qualification
- Status of production and next deliveries
- P05

Niobium scanning summary

Series sheets

- **All** 4xx sheets have been **scanned**.
- 83.4 % accepted after first scan.
- Only **1 sheet rejected** due to **thickness below specs**.
- **Sheets** with **geometrical** defects are all **recoverable**





Spare sheets

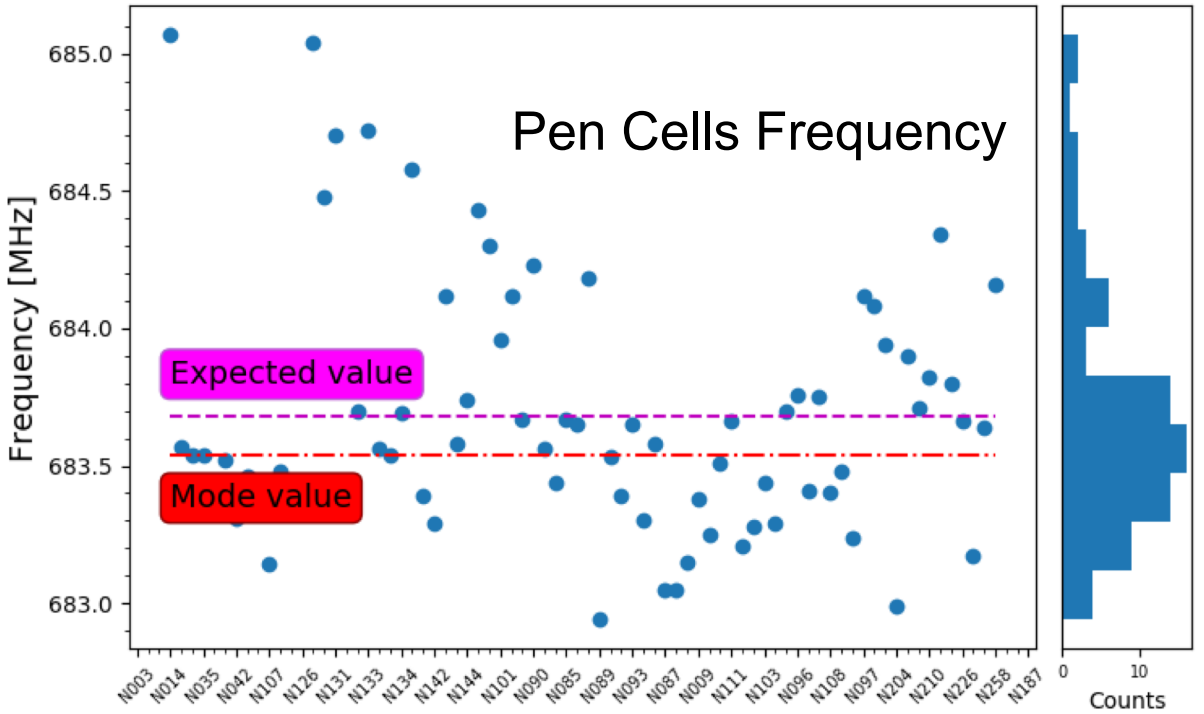
- **All 24** sheets have been scanned.
- 70.8 % accepted after first scan
- **All sheets accepted**

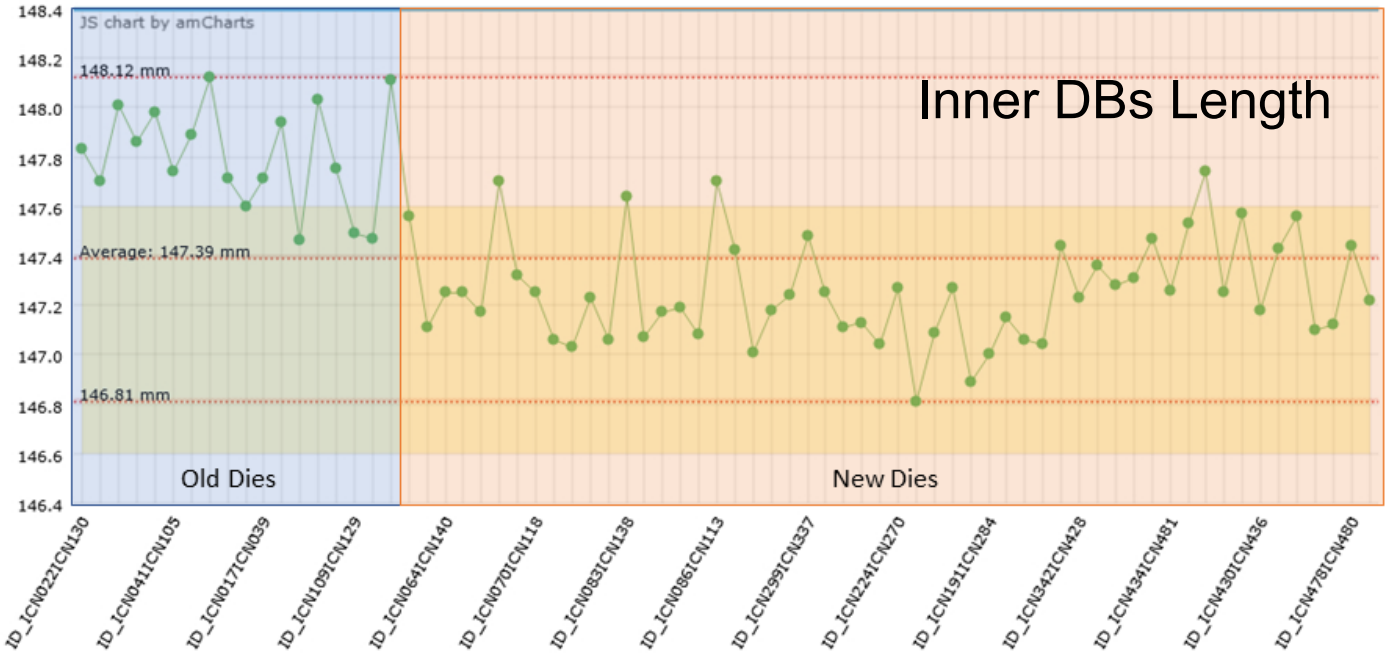
Subcomponents Status

Component	Produced	Expected	Percentage
Inner Half Cell	304	304	100
Penultimate Half Cell	76	76	100
End Half Cell	76	76	100
Inner Dumbbells	72	114	50
Terminal Dumbbells	48	76	63
End Groups	61	76	80
Cavities	21	38	55

Statistics on production

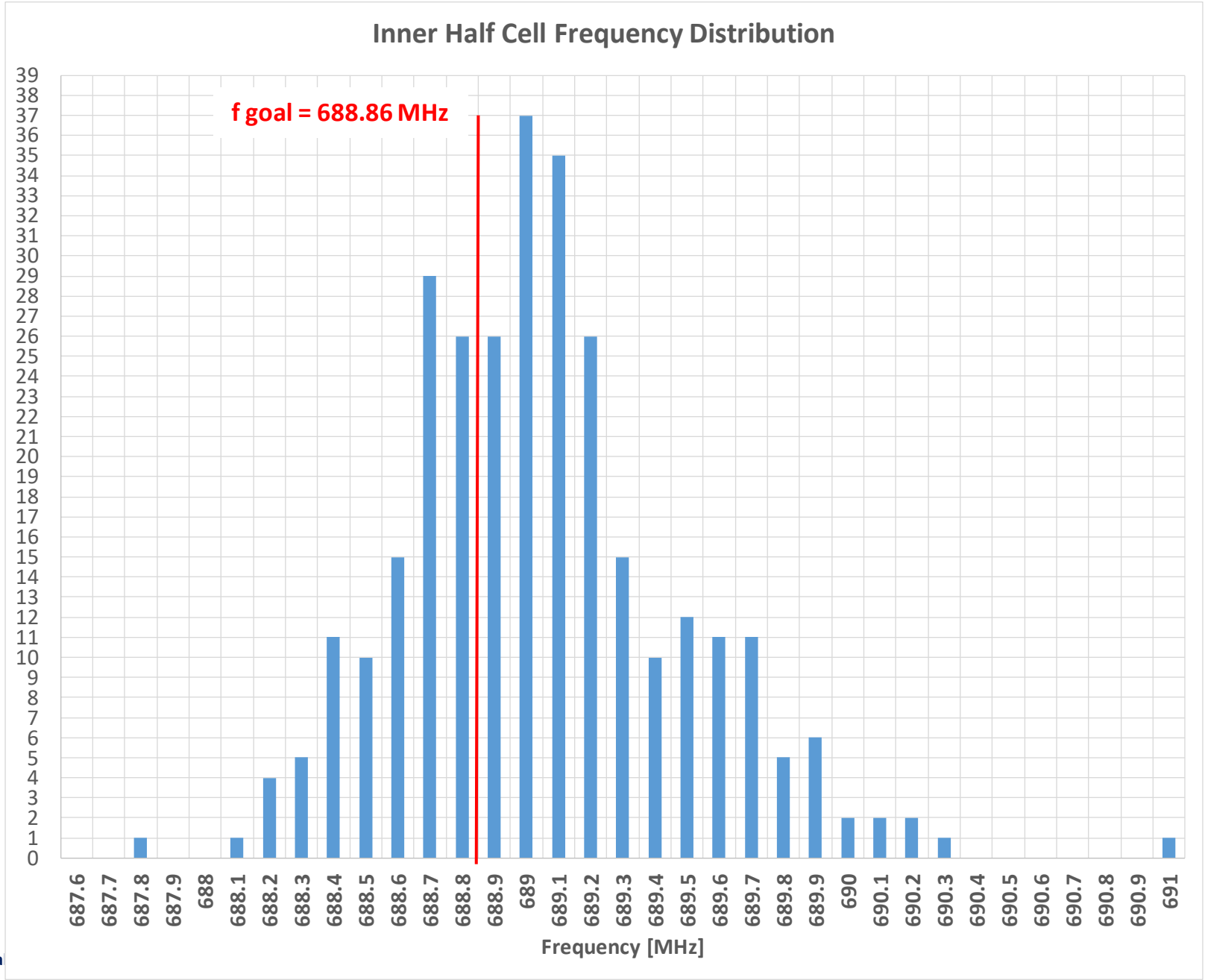
- **Pen Cells for 38 cavities** are available.
- The **mode value** of the frequency distribution is about **150 kHz** below the **target value**.





- The **Inner DB length** changed noticeably by changing from the old (M001-M006) to **the new dies.**
- This is clearly visible on the ESS **Dashboard**

Statistics on production for IC



Acceptance criteria for frequency: past and future

We are proposing to continue with the same criteria for the next cavities.
From lot 2 we are more to the nominal frequency value: 704.150 MHz

	ESS Specs	M001	M002	M003	M005
f_π [MHz]	$704.15\ ^{+0.10}_{-0.15}$	704.216	704.187	704.223	704.211
f_π closest f [MHz]	$f_\pi \pm 0.45$	703.442	703.459	703.462	703.487
Max E_{acc} [MV/m]	> 16.7	23.7	23.8	23.6	24.5
Q_0 @ ESS E_{acc}	$> 5\cdot10^{9}$	$1.8\cdot10^{10}$	$1.6\cdot10^{10}$	$1.8\cdot10^{10}$	$2\cdot10^{10}$
Q_0 @ Max E_{acc}		$7.8\cdot10^{9}$	$6.3\cdot10^{9}$	$8\cdot10^{9}$	$6.8\cdot10^{9}$
Q_I (input Q_{EXT})		$5.7\cdot10^{9}$	$5.7\cdot10^{9}$	$6.4\cdot10^{9}$	$5.6\cdot10^{9}$
Q_T (PU Q_{EXT})	$2\cdot10^{11}$	$3.5\cdot10^{11}$	$3.5\cdot10^{11}$	$4.8\cdot10^{11}$	$4.5\cdot10^{11}$
F.E. [mGray/min]		$3.5\cdot10^{-4}$	$8.4\cdot10^{-4}$	$7\cdot10^{-5}$	0

Transportation and its acceptance criteria

INFN Milano - LASA
20057 Segrate (Mi)
Italy

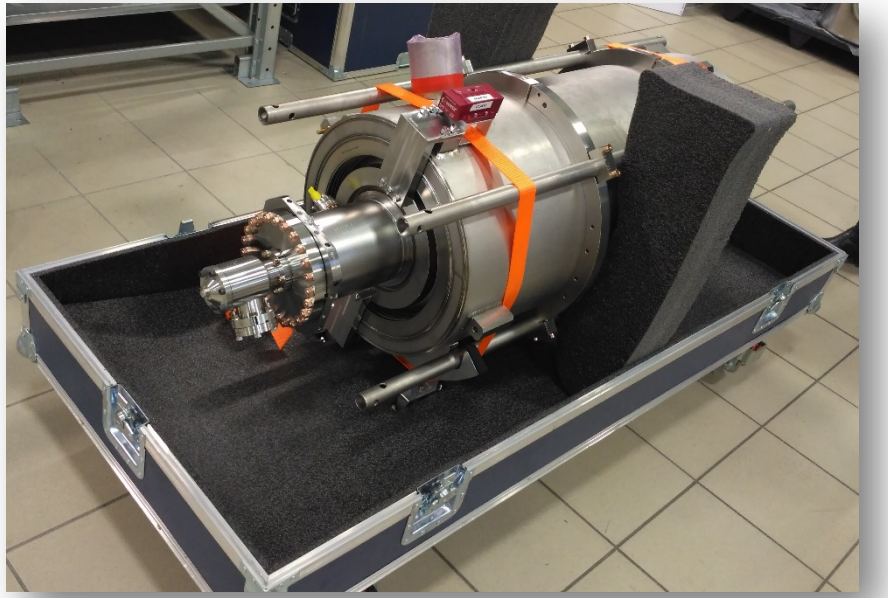
DESY
22607 Hamburg
Germany

EUROPEAN SPALLATION SOURCE

Document No.
M002_AL4_Y_INC01

Cavity ID
M002

Incoming Inspection of the fully equipped cavity



RF Transportation Acceptance Criteria	
Max p mode frequency difference	± 0.1 MHz
Max p mode RF power transmission	-100 dB
Min p mode RF power transmission	-130 dB
Max Mean Spectrum Frequency Deviation	10 kHz

Acceleration	< 3 g

INFN Milano - LASA
20057 Segrate (Mi)
Italy

DESY
22607 Hamburg
Germany

EUROPEAN SPALLATION SOURCE

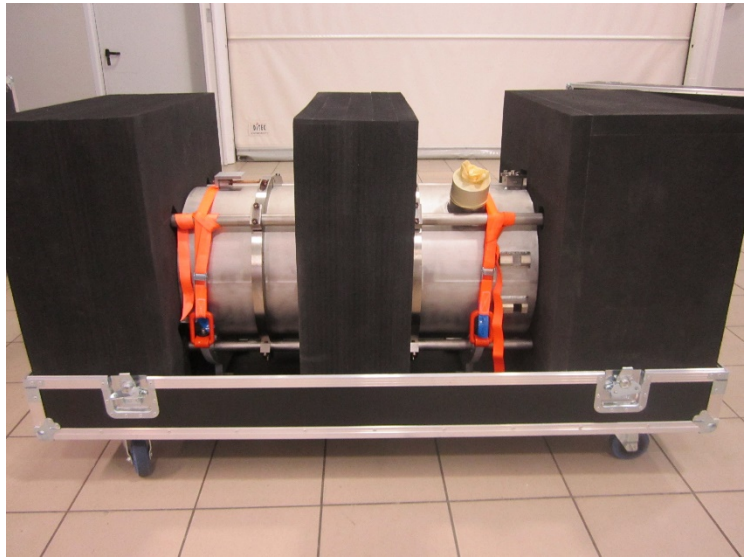
Document No.
M002_AI4_Y_OUT02

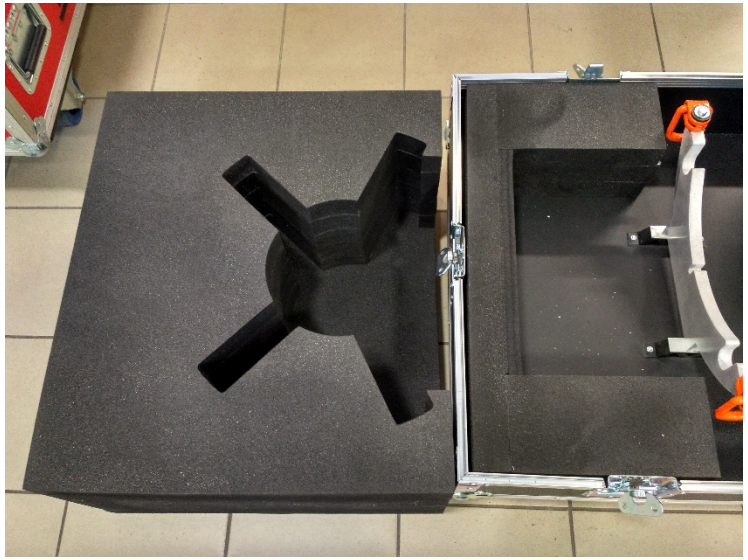
Cavity ID
M002

Outgoing Inspection of the vertically tested cavity

ESS transports

- **30 cavities transported** so far, different configurations:
  - 4 prototype boxes (blue ones), 20 series boxes (black ones)
  - Naked cavity (with frame) w or w/o foam cushions
  - Dressed cavity w or w/o frame, w or w/o foam cushions
- **EZ-DESY route**: EZ responsibility, done using always the same company used for E-XFEL.
- **DESY-CEA route** on few different dealers from Germany (**dedicated transport**, point to point, no intermediate storage during transportation). Dealer choice not possible.
- Hopefully, **cavity configuration** for transport should be now **assessed.**





ESS transports

- **Series boxes** tested on a **vibrating platform**
  - **Cavity: CEA cavity mockup**
  - **2 h** duration **equivalent to 1600 km** road transpor
  - Spectral analysis before and after, **single impulse test up to 6 g**
  - Ended OK:
    - Modal frequency lowered to **7 Hz** (10-15 Hz for E-XFEL)
    - 6-8 shock damping factor (2-3 for E-XFEL)
    - **Identical before/after spectra**

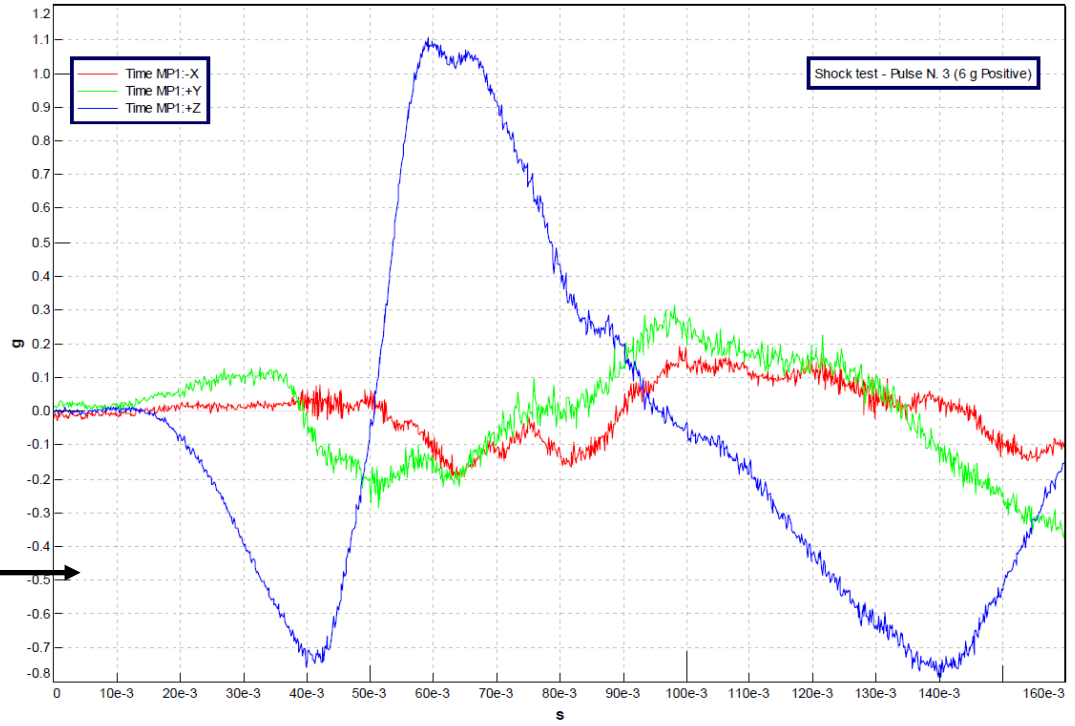


Photo 1: Vibration test mounting techniques

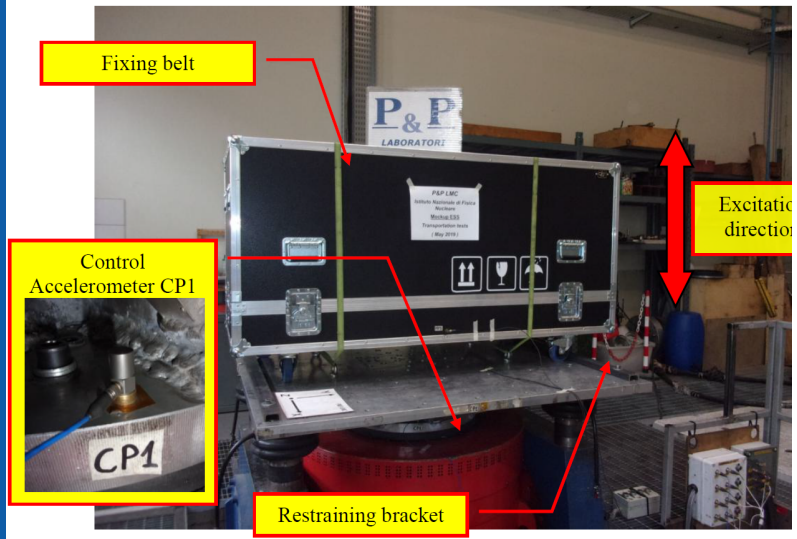
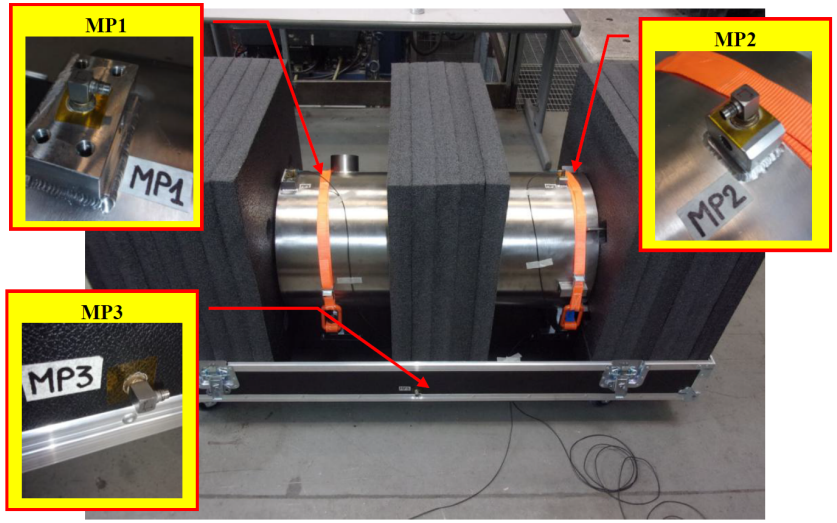
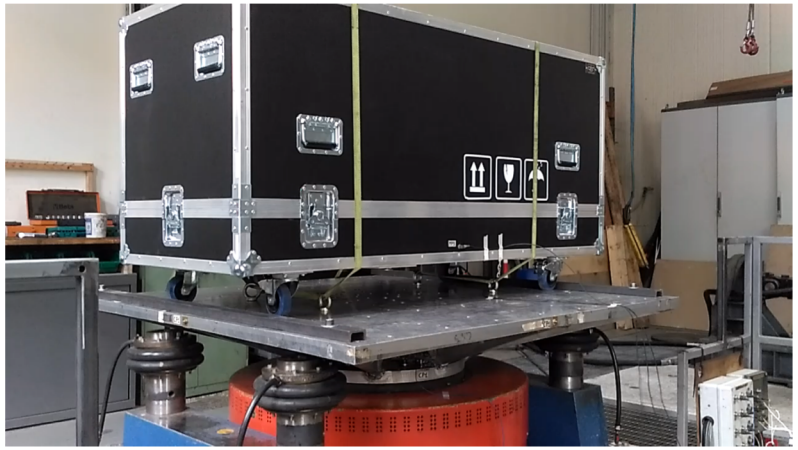


Photo 2: Measuring positions





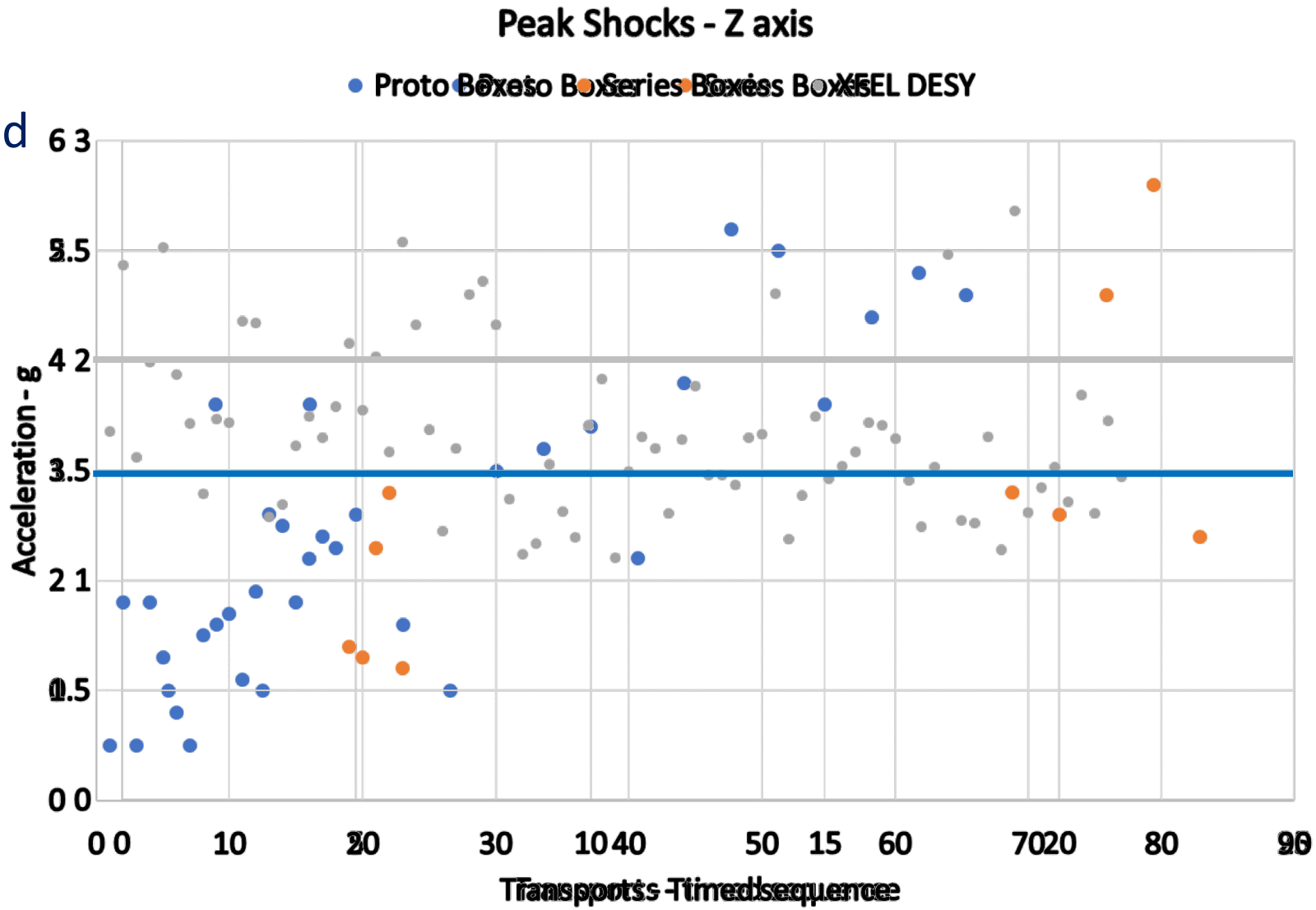
ESS transports

SENSR SL setup for EXFEL was auto-unbiasing:
- By subtracting 1 g to vector magnitude
- **With AC coupling: low frequency shocks lowered by 1 g!**

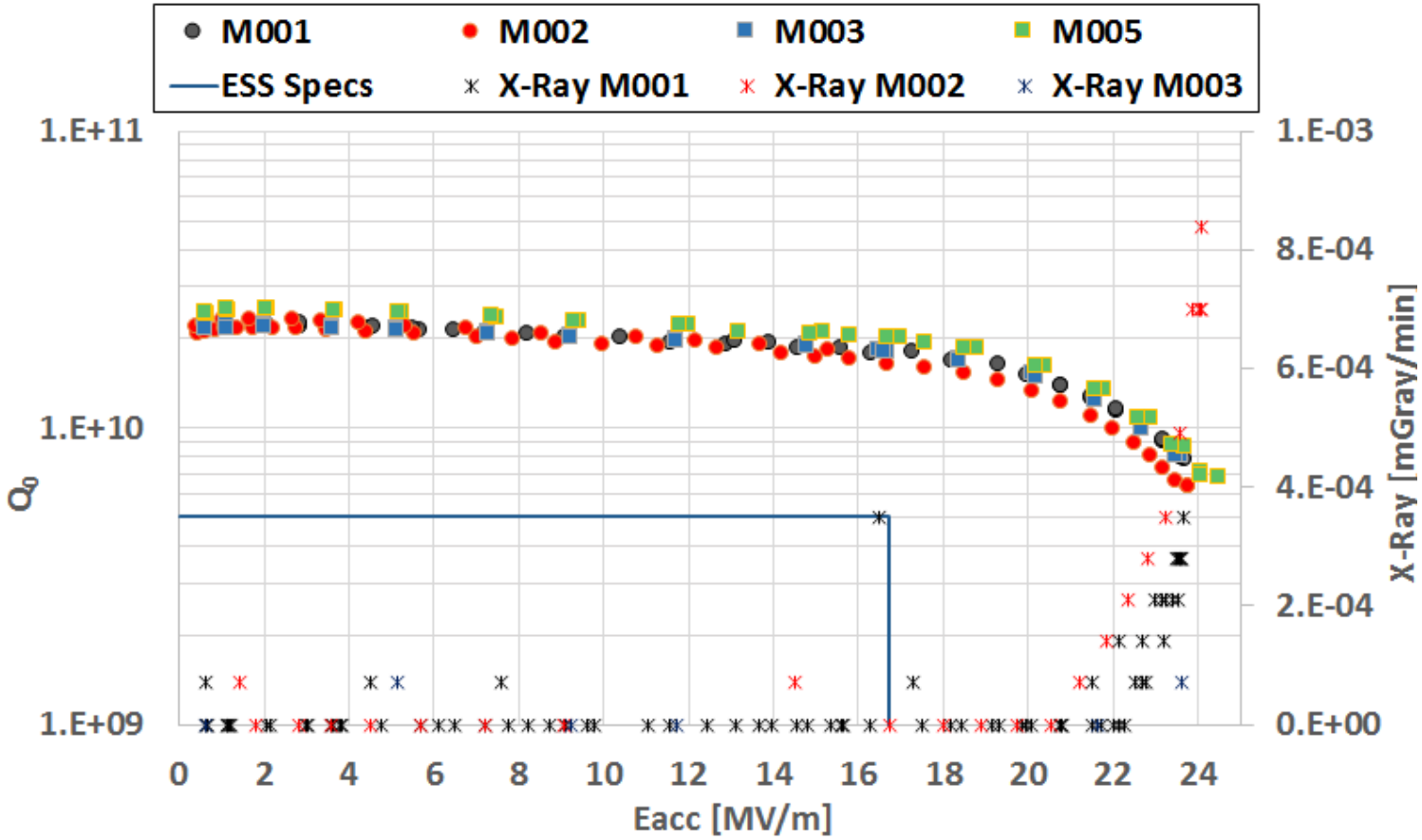
- **30 cavities transported so far**
  - 2 with old SL
  - 2 SL data missing
  - 3 SL data not yet received (M004, 6 and 9 at DESY)

Av. Z peak 1.6 ± 0.7 g

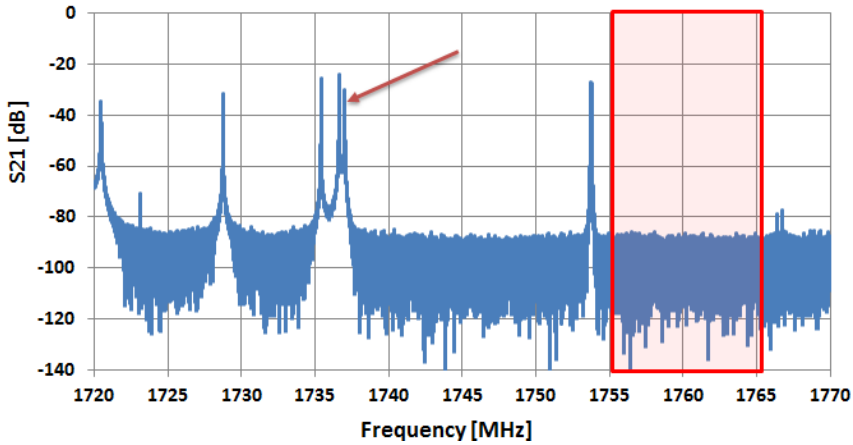
Av. X,Y peak 1.0 ± 0.5 g



VT at DESY-AMTF of dressed cavities

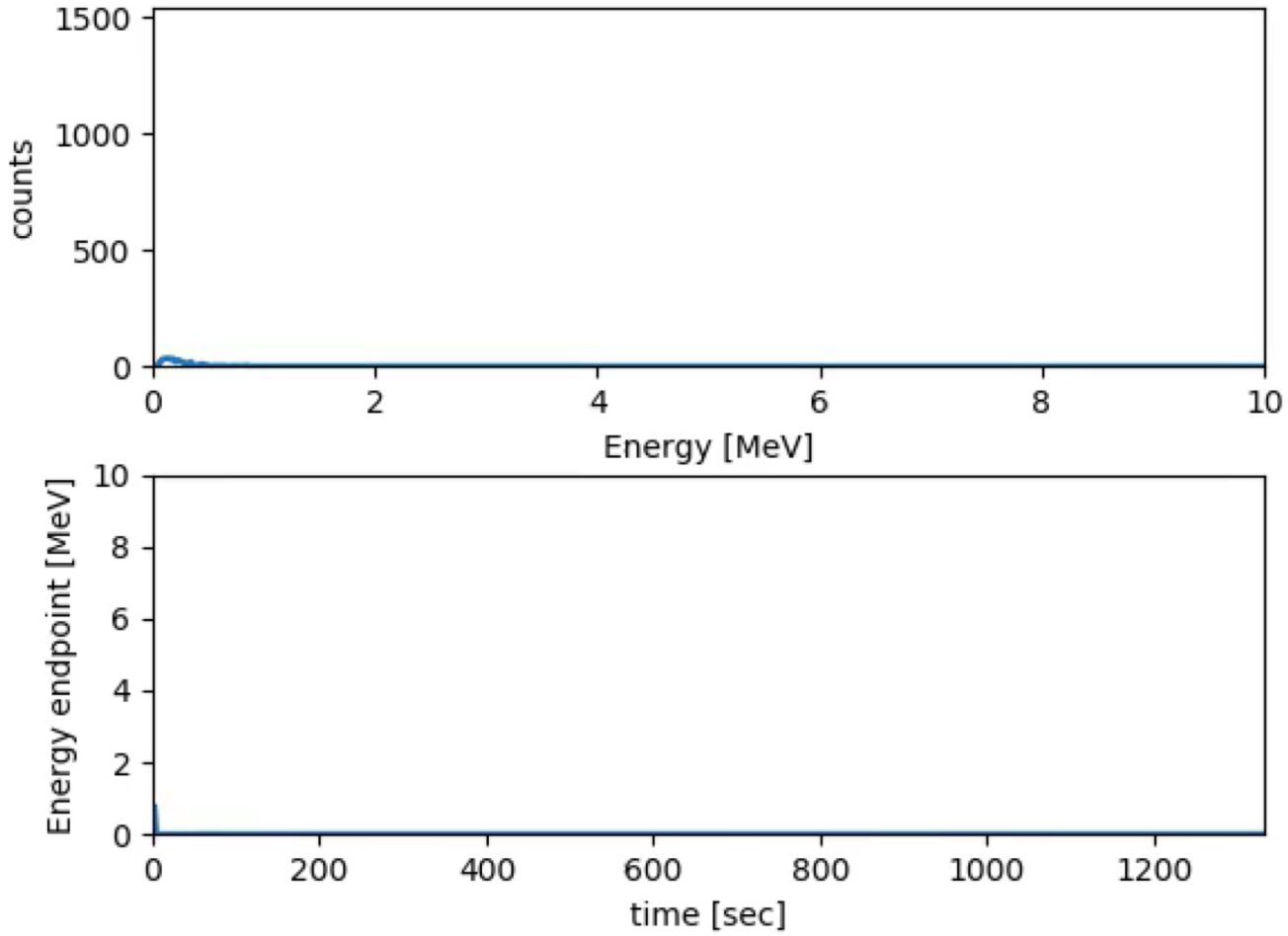


- **4 cavities tested up to now, all above ESS specs**
- **2 cavities** in test **this week**
- **2 cavities** in test in **three weeks** from now
- **No HOM in the "forbidden" area**

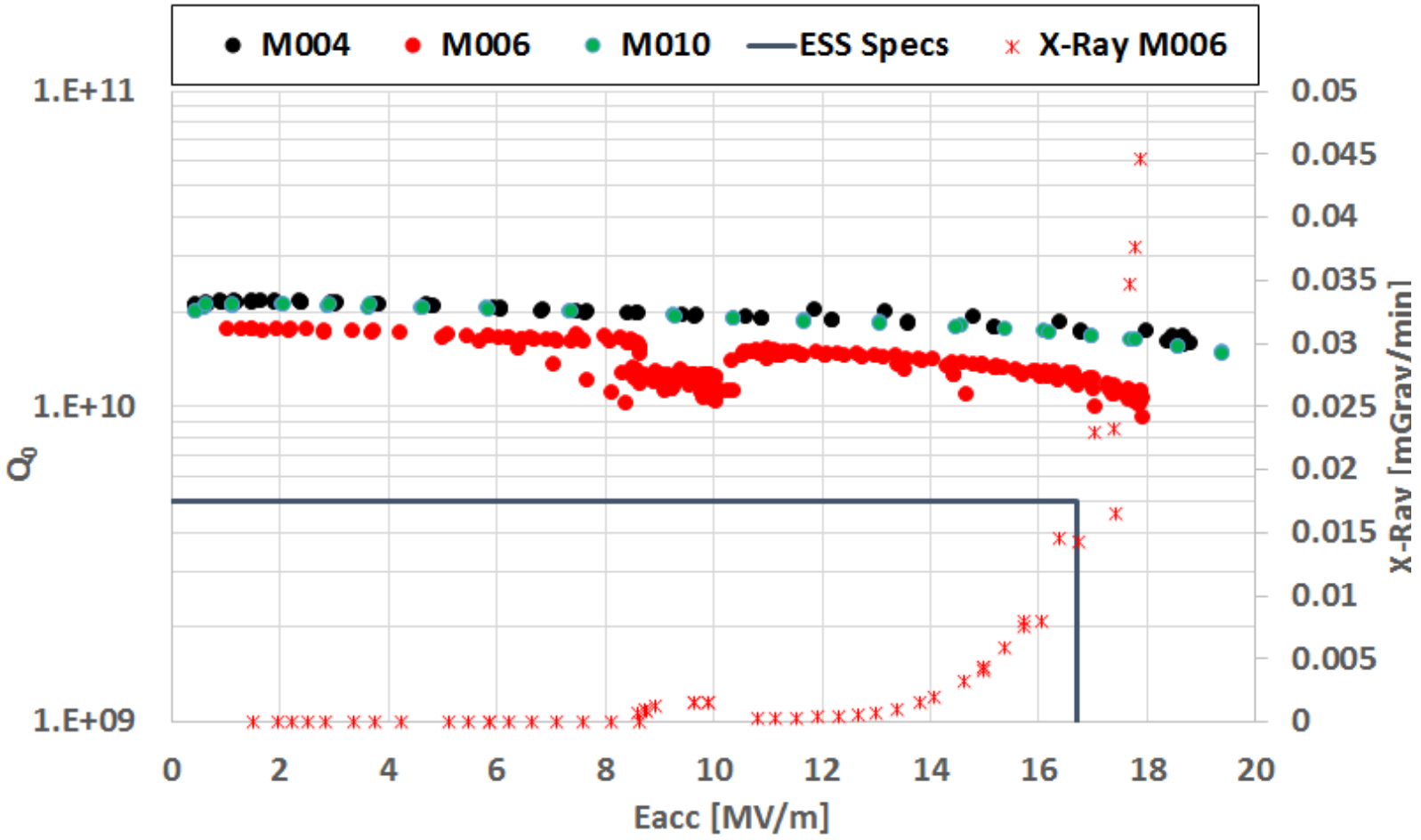


X-ray emission energy spectrum

- Continuous registration of X-ray spectrum vs time cavity M001 (Test at DESY)



VT at DESY-AMTF and LASA of undressed cavities



- M004 tested at DESY after grinding for not fully penetrated equatorial welding
- M006 tested at LASA after grinding of defects
- M010 test at DESY w/out grinding but with defects

Defect (pits)

Pitting (spherical / round shape) on the equator area (**HAZ boundary**) found during optical inspection **after the bulk BCP** (≈200 μm) on a few cavities.

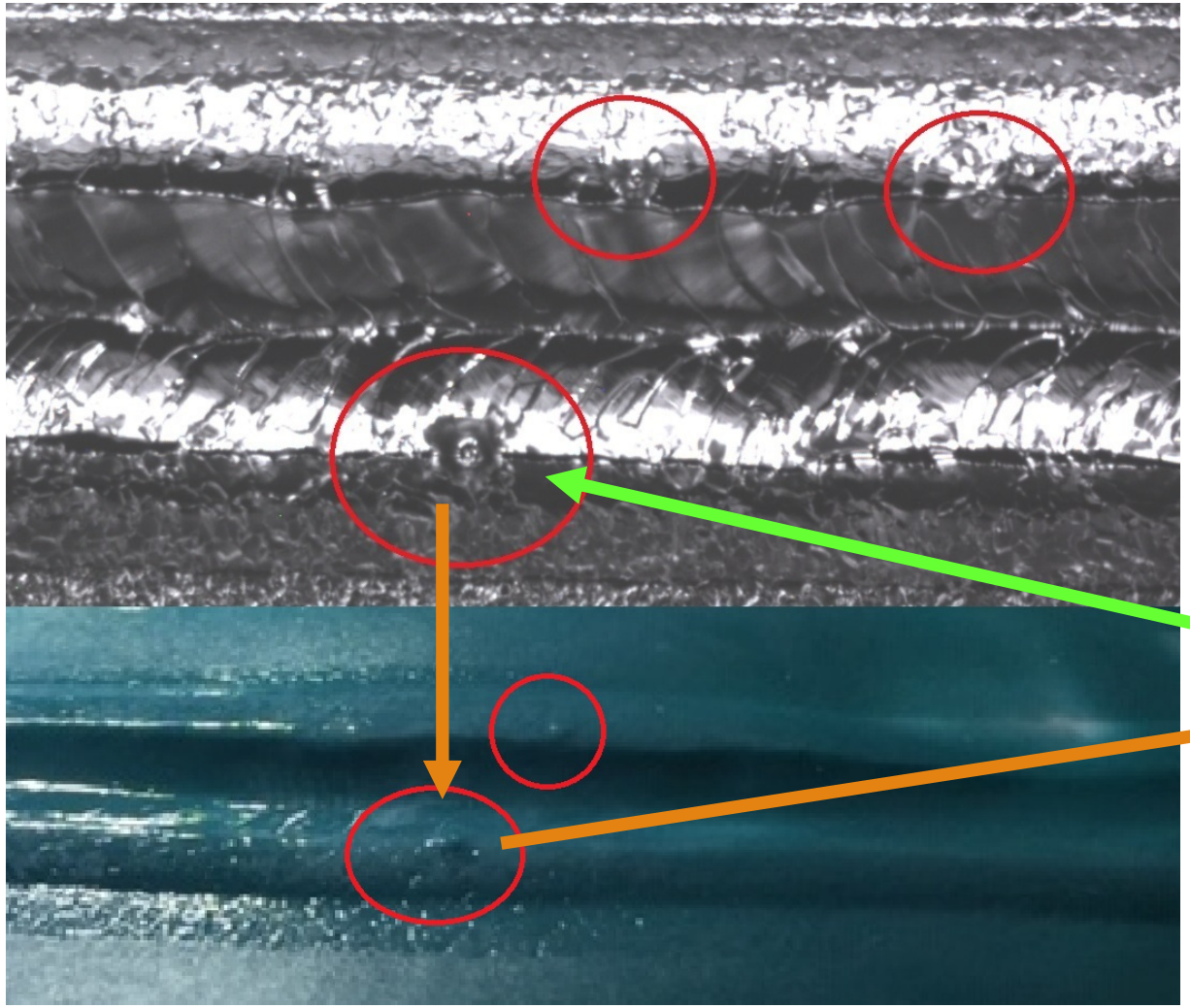
L. D. Cooley, E. Hahn, D. Hicks, A. Romanenko, R. Schuessler, and C. Thompson, ANNEALING TO MITIGATE PITTING IN ELECTROPOLISHED NIOBIUM COUPONS AND SRF CAVITIES, FERMILAB-CONF-11-264-TD

- **Bubbles of trapped gas** might occur when **small defects are vaporized** by the electron beam, or possibly when **hydrogen incorporated during pre-weld etching** becomes accumulated. Such bubbles would be consistent with the spherical shape noted for many pits
- **… interstitial contaminants** also diffuse along the thermal gradient and accumulate at the HAZ boundary.
- Likewise, **dislocations can be concentrated** at the HAZ border, making **those regions susceptible** to dislocation-assisted pitting, as is well known for niobium.

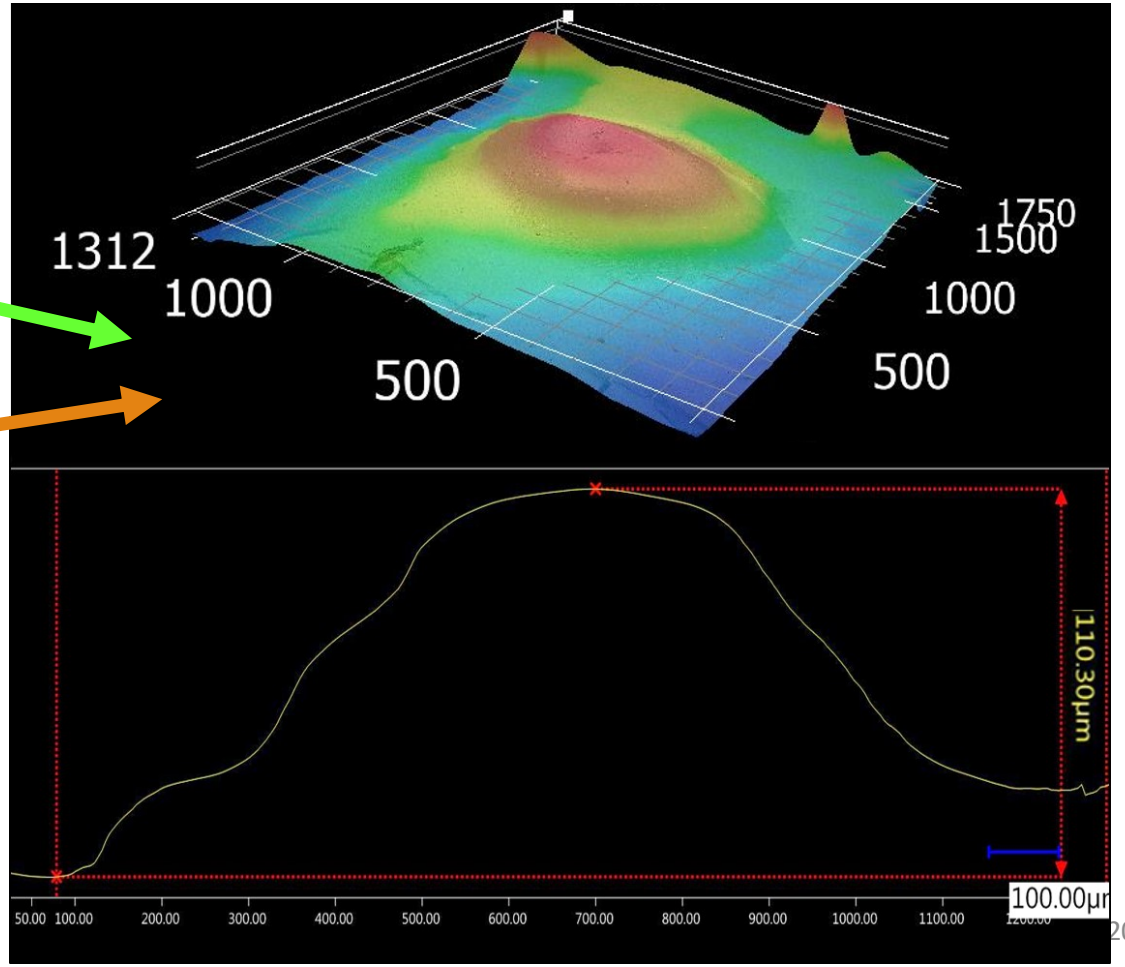
Defect (pits) analysis

- **No defect or any kind of foreign structure visible** before the bulk BCP during the optical inspection..
- Strategy pursued
  - **Analysis of the geometry** of defect from the recorded images during optical inspection. Camera resolution: better than 50 μm.
  - **Replica of defect** (Provilnovo).
  - **Analysis of the replica** for a more accurate evaluation of defect geometry.
  - **Decision** grind / no grind, based also on the results of test of cavities 6 and 10, both with pits.
    - **6: deeply grinded**. ~ 17 MV/m, high field emission at high accelerating field.
    - **10: no grinding**. ~ 19 MV/m, low field emission.
  - In parallel **successfully actions** done by EZ for the reduction of number of defects

Defect analysis on cav. M008



≈ 1.5 mm length, 1.0 mm wide, 110 μm depth

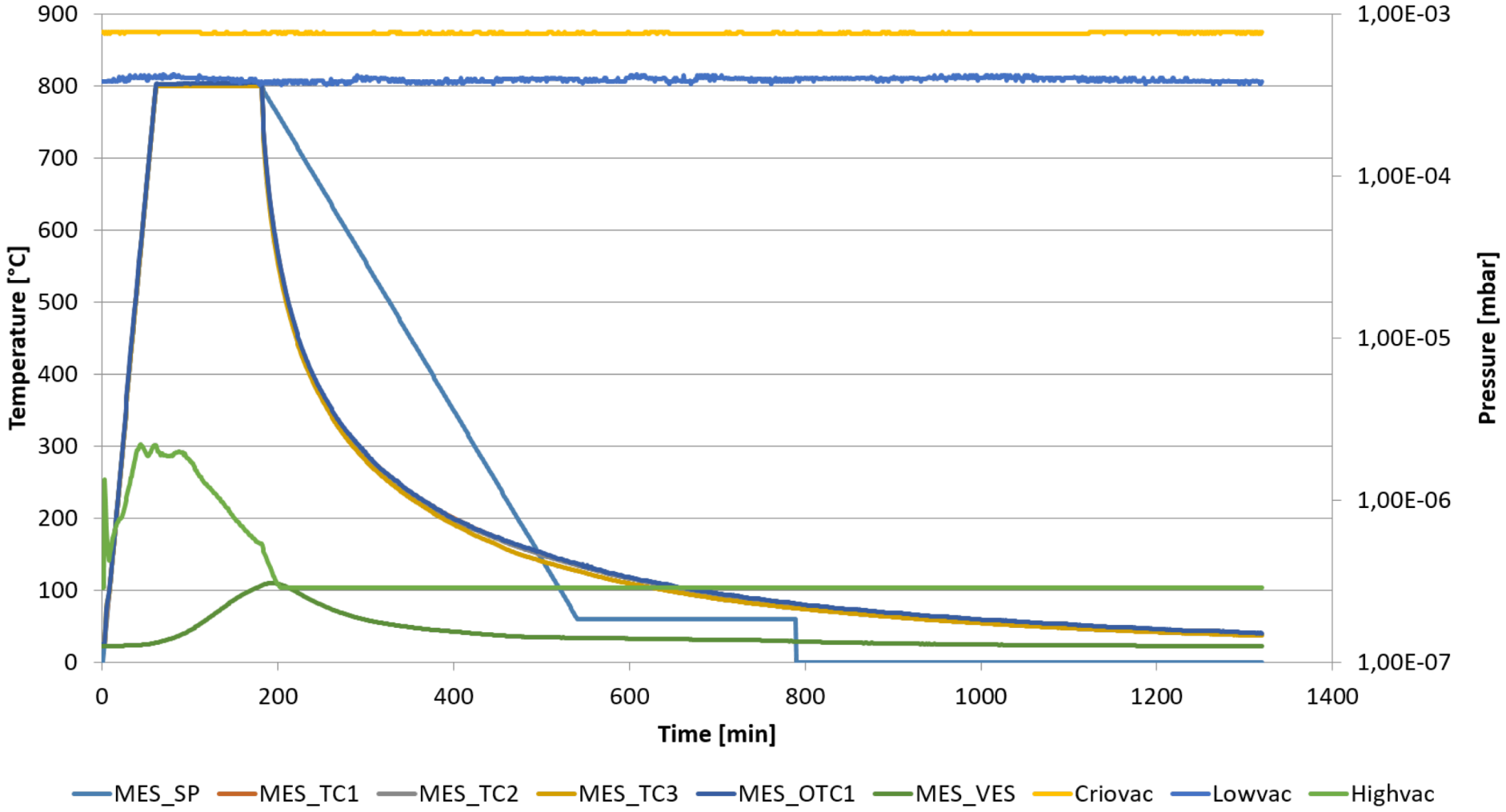


EZ oven requalification

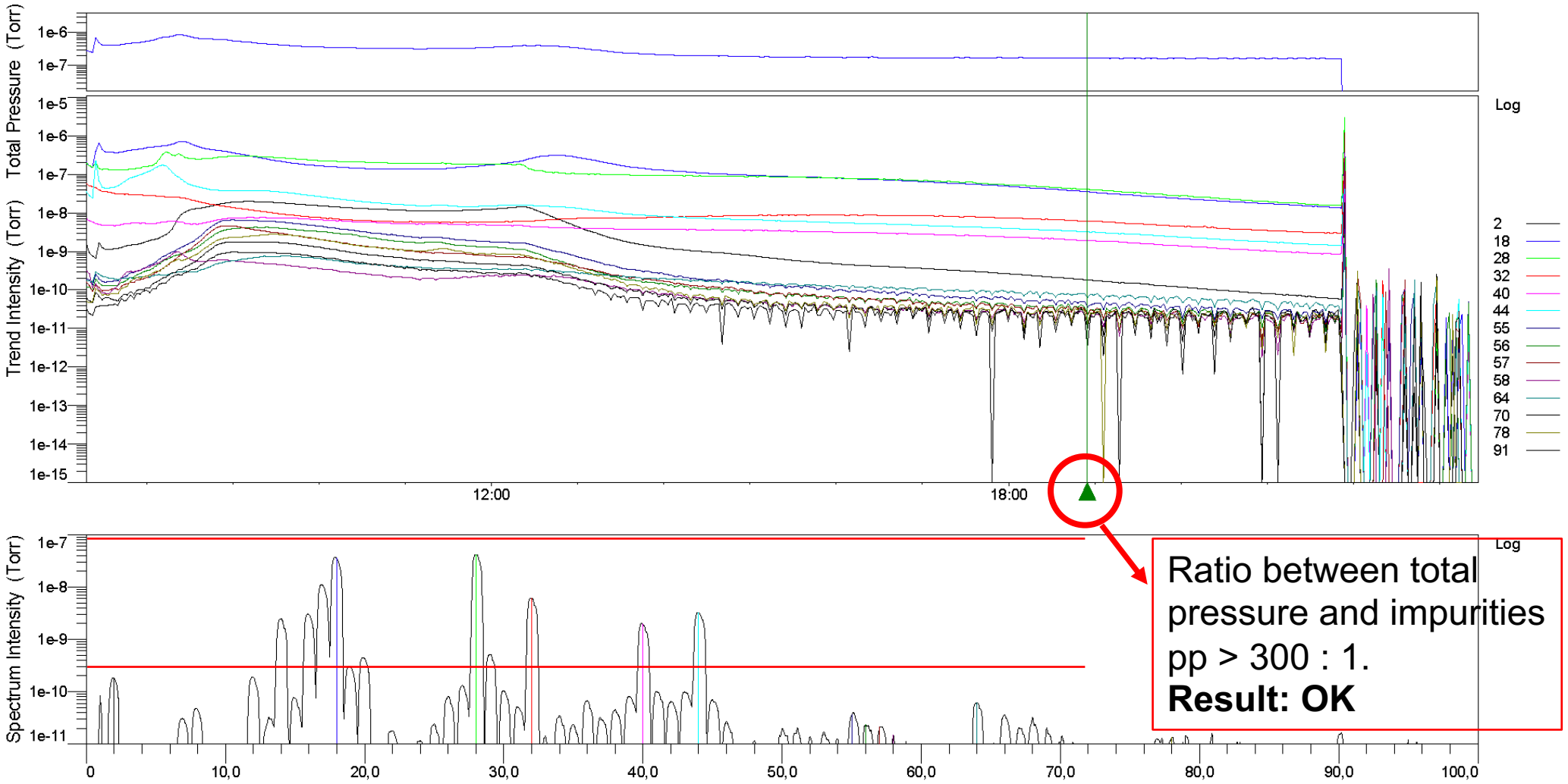
- EZ oven **accidental venting** with air at high temperature.
- Oven internal structure **oxidation** forced the complete disassembly of the oven.
- **Requalification needed** before SC cavities heat treatment, after several cleaning cycles at 1100 °C.
- **Qualification done at 800 °C, 2 h**. We used the standard **E-XFEL cycle** (800 °C, 2 h) on samples, to compare results of past experience.
  - The test is **more severe** due to the **physics of the diffusion** process for impurities.
    - Diffusivity increase **exponentially with temperature**, therefore between 600°C and 800 °C there are 2 or more order of magnitude.
    - **The effect of time** (2 h / 10 h) is less severe (**factor 2 – 4**).
    - Therefore 2 h 800 °C is much more severe w.r.t. 600 °C, 10 h used for the ESS cavities treatment.

1) **RGA status must be ok**: hydrocarbon free (300:1 ratio for mass > 45) must be fulfilled .
2) **RRR of Nb sample** no/limited change during the heat treatment.
3) **Nb samples** exposed at the treatment must show **no surface and impurities** contamination for Mo and Ti oxides, Sulfur, etc. Analysis done with GDOES and SEM.

800 °C thermal cycle on samples for oven qualification



RGA during 800 °C.



Ratio between total pressure and impurities pp > 300 : 1.
Result: OK

Sod File Name: C:\Users\bertucci\Documents\RGA\qualifica fornace\2019_05_30 dopo 800C alto vuoto (1).sod
Recipe: Monitor (2).rcp
Date: Wednesday, May 29, 2019

RRR sample measurements

4 wire I vs V curve with bipolar current ramp (delta mode).

- Measurement precision: +/- 5%
- Repeatability is better.

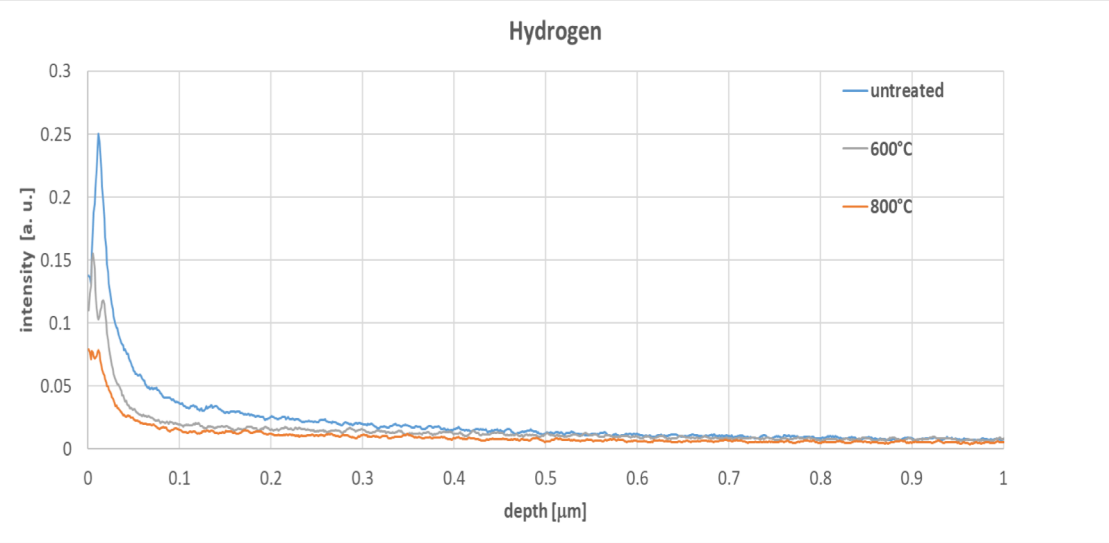
	RRR pre HT	RRR post HT	Variation (%)
Sample 1	385	383	1
Sample 2	383	335	13

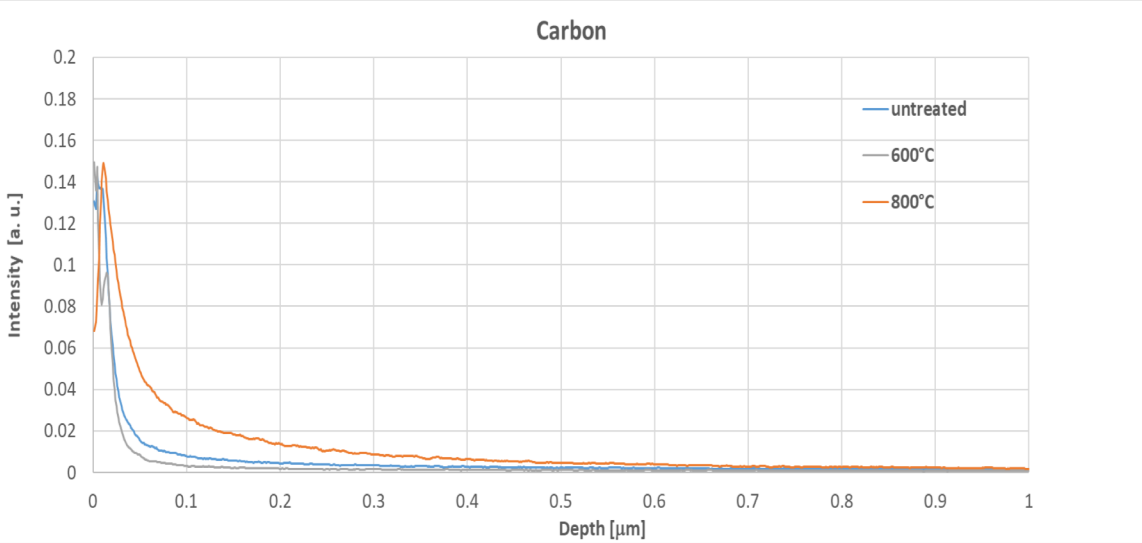
No substantial variation of RRR after the heat treatment.
Independent measurement on the same samples done at DESY with similar results.
The 13% variation of second sample is in line with typical variations registered after heat treaments in other furnace.

Result: OK

GDOES results

- Some samples of high purity Nb treated in the oven (800°C and 600 °C)
  - **GDOES depth profile** before and after 800°C and 600 °C heat treatment

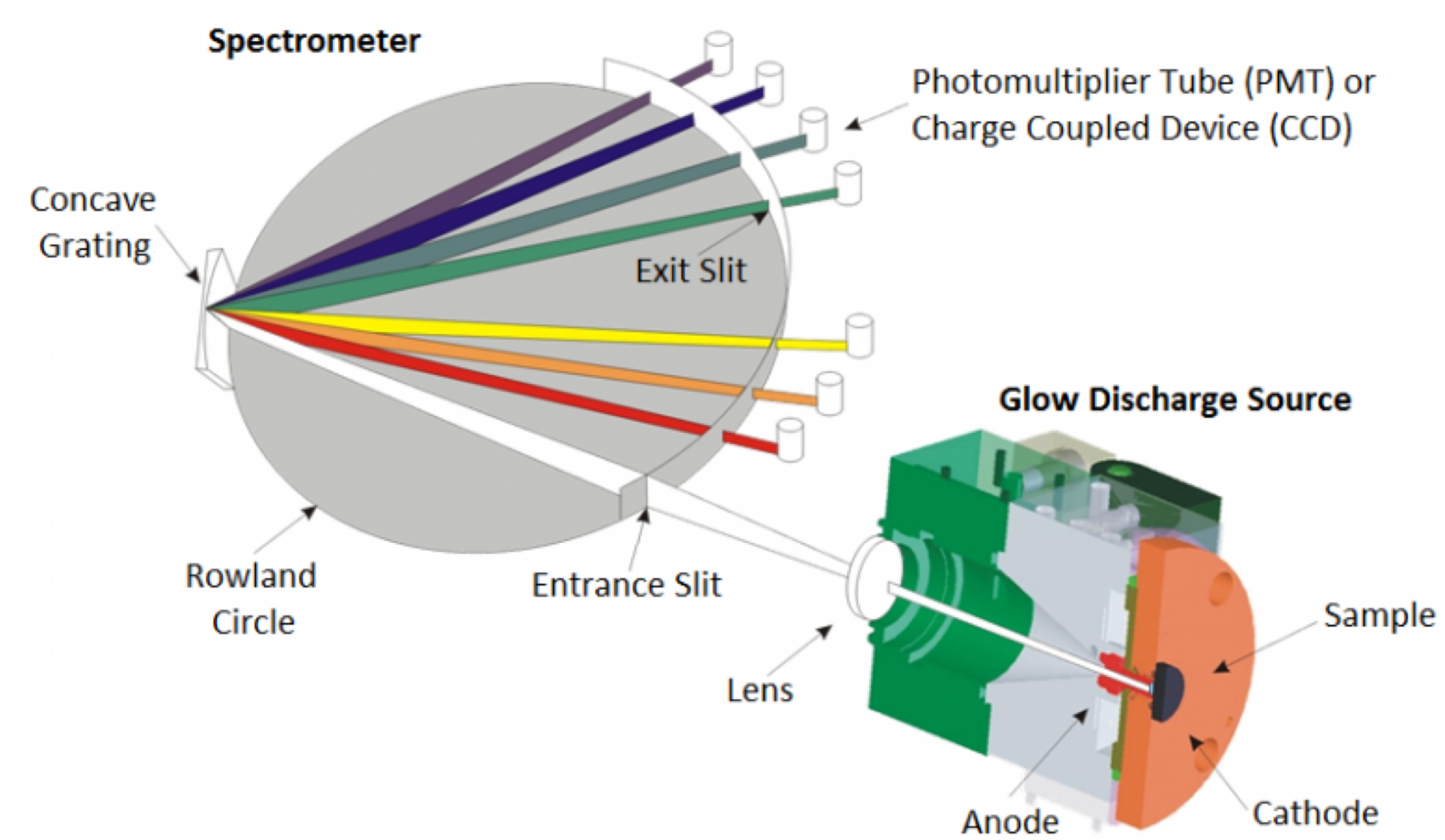




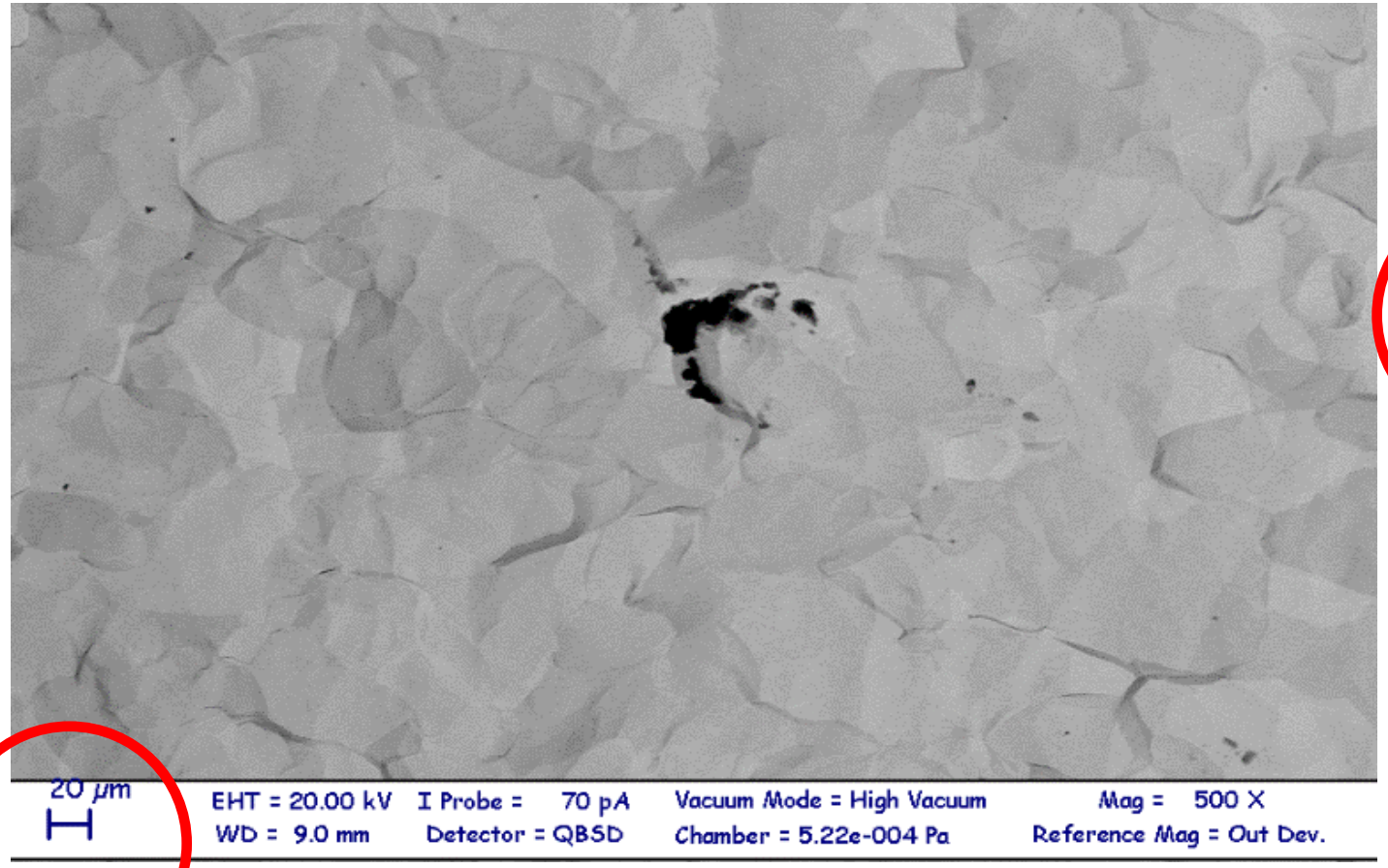
- H_2 decrease (as foreseen). Higher is the temperature, lower is the H_2 concentration.
- Carbon diffusion length is of the order of 1 µm. One can therefore assume that, after final removal (flash BCP or EP), the optimal surface condition is again restored.
- **Result: OK**

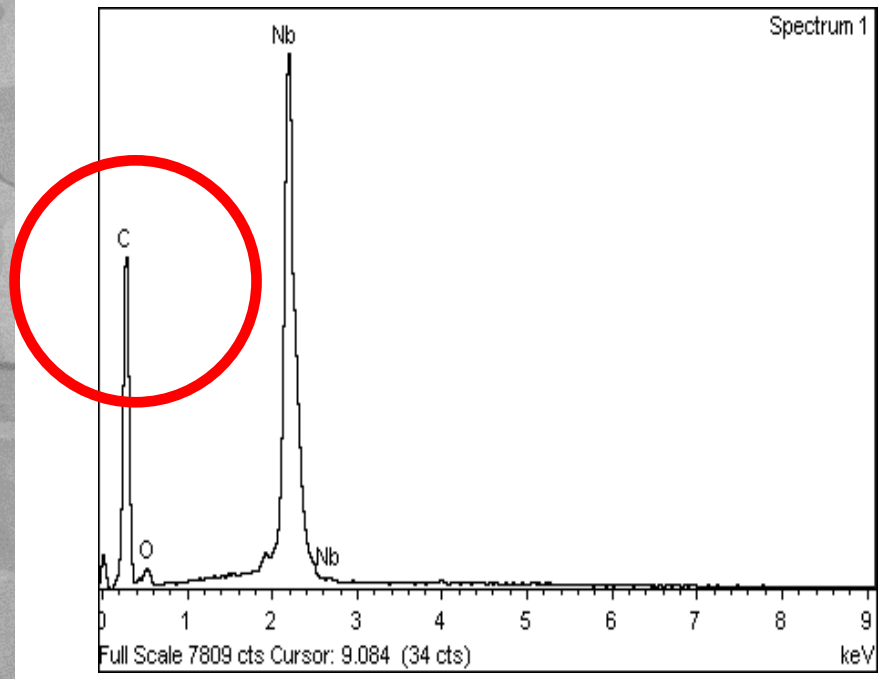
GDOES tecnique

GDOES: Glow-discharge optical emission spectroscopy
Able to measure also light ions.



SEM analysis of a local defect





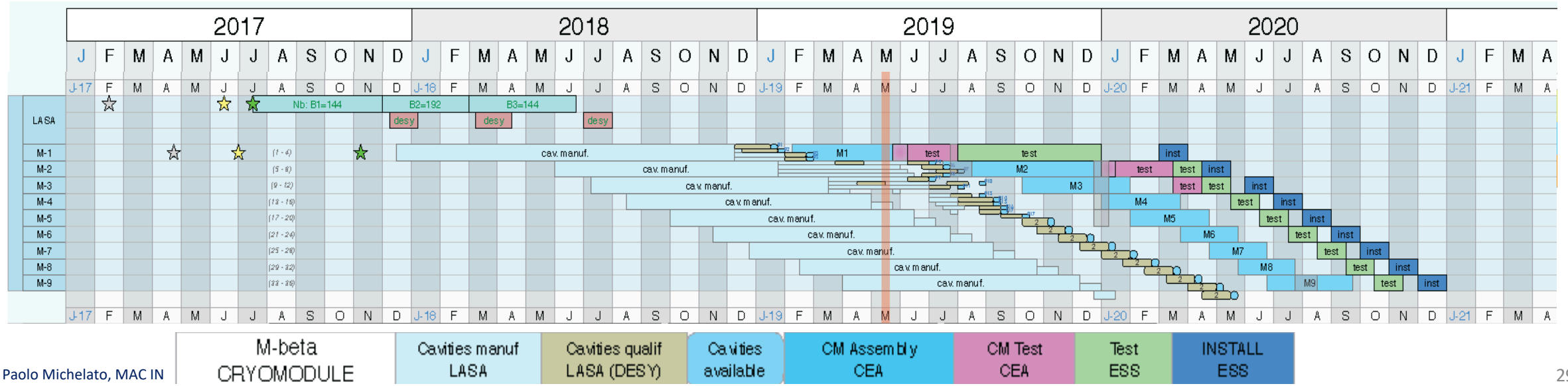
Limited local small C contamination. **Result: OK.**

EZ oven requalification

- All measurement done indicates that the oven atmosphere and contaminants are OK.
- Therefore we decided to do the heat treatment of cavity M013.
- Heat treatment done in the past days.
- Cavity test (undressed) will be done at LASA before the end of July
  - If successful, this result will give the green light for the heat treatment of other cavities already treated with bulk BCP during summer.

Status and time schedule of the INFN-LASA series cavities for ESS

- **4 cavities successfully tested**, delivered at CEA, Module M-1
- **2 cavities under test at DESY**, to be sent at CEA within **mid of July** for module M-**1.**
- **One more cavity already available** at DESY. A **second one** available soon (W28). These cavities in test in 3/4 weeks. **These two cavities for assembly of M-2**.
- **3 cavities will be additionally delivered to DESY within July end (W29 and 30) to be tested in August.**
- **2 cavities delivered to LASA** for additional cold test in the next 2 months (13 and 12)
- **A total of 21 cavities** welded at Ettore Zanon, under processing for surface treatment.
- **All subcomponents** (half cells, terminal cell, etc.) already deep drawn



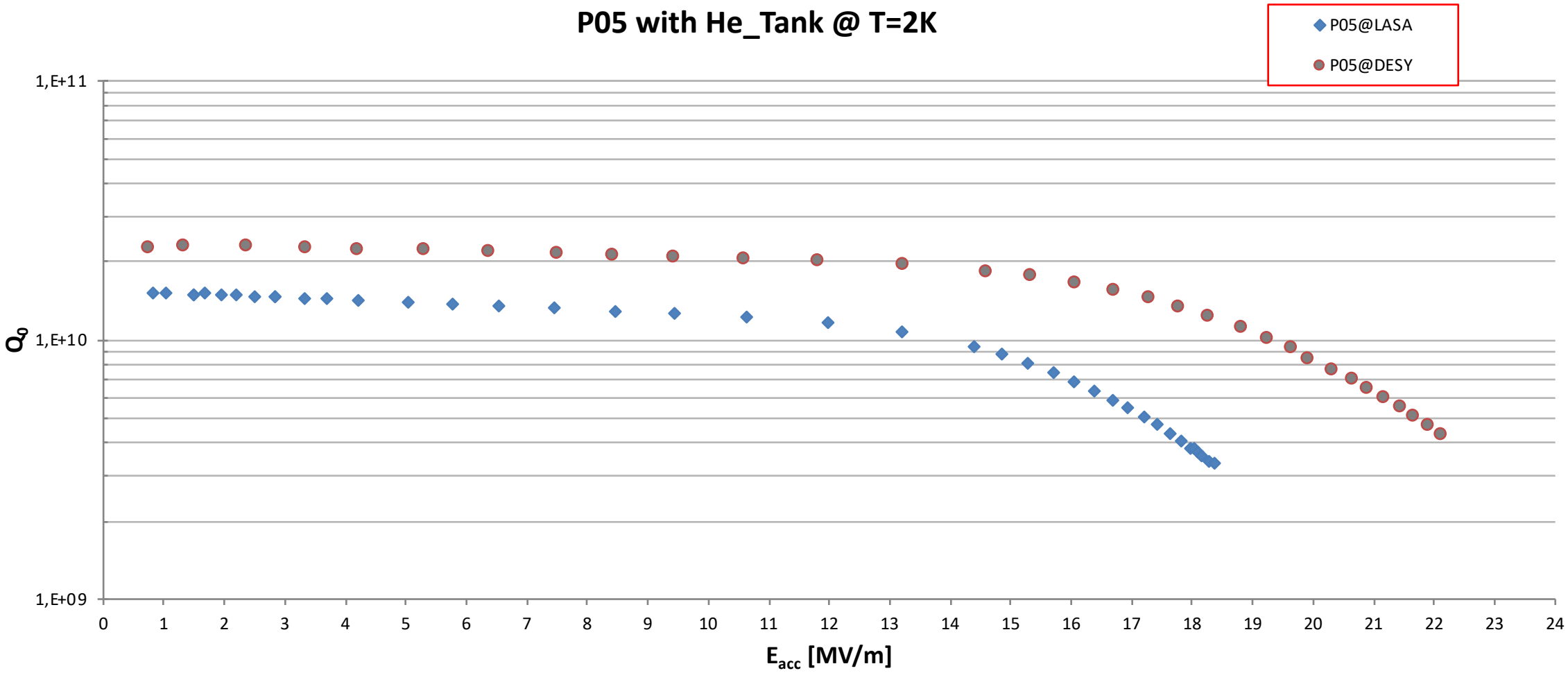
Cavities production status

Cavity	Al1	Al2	Al3	Al4	Al5	E_{acc}^{Max} [MV/m]	Q_0 @ E_{acc}^{max}	Q_0@E_{acc}^{ESS}
M001						23.7	7.9e9	1.7e10
M002						24.1	5.7e9	1.6e10
M003						23.5	8.0e9	1.8e10
M004								
M005						24.5	6.8e9	2.0e10
M006								
M007								
M008								
M009								
M010								
M011								
M012								
M013								
M014								
M015								
M016								
M017								
M018								
M019								
M020								
M021								

The Acceptance Levels

Level	Cavity status	Needed documents	If Level reached
AI1	Cavity after mechanical fabrication	Mechanical, RF, vacuum, visual documents	Proceed to Level Two
AI2	Cavity before He-tank integration	Mechanical, RF, vacuum, Treatment documents (bulk BCP, annealing)	Proceed to Level Three
AI3	He-tank integration, Final BCP and surface treatments, assembly of accessories for the cold RF test	He-tank integration and pressure tests (mechanical, RF, vacuum, visual documents, transfer measurements), last surface treatments, final vacuum and RF checks, outgoing inspection	Integrated cavity ready to be cold RF tested
AI4	Cavity cold RF tested	Documents of the cold RF test, incoming/outgoing checks	Cavity can be sent to CEA for string assembly
AI5	Cavity accepted for string assembly	Documents with incoming inspection at CEA	Cavity final approval

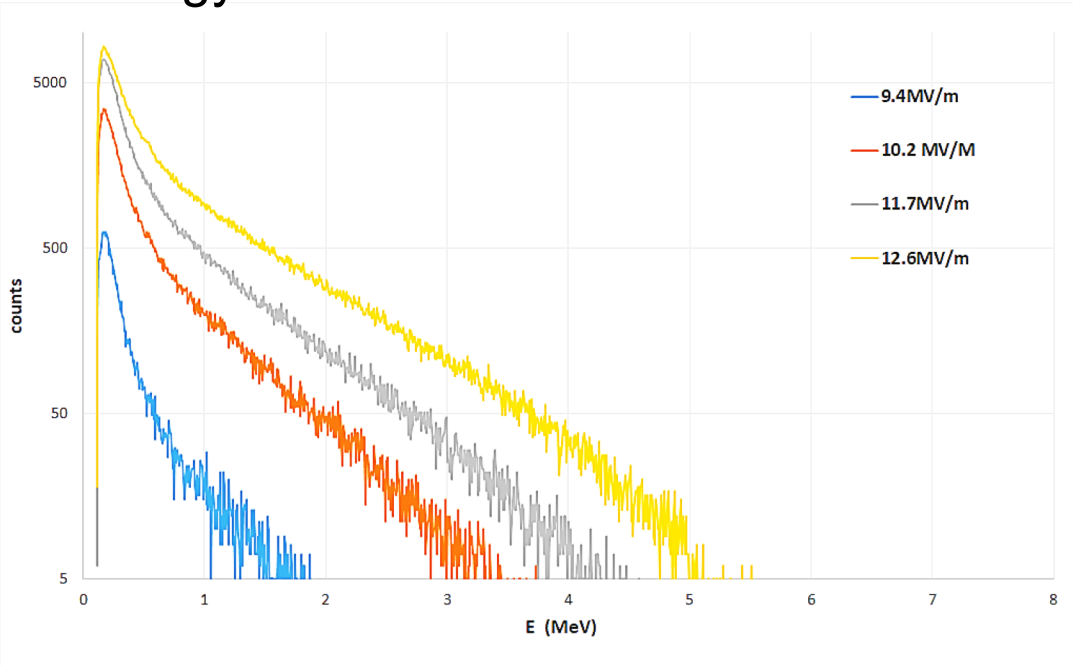
P05 test at DESY and at LASA



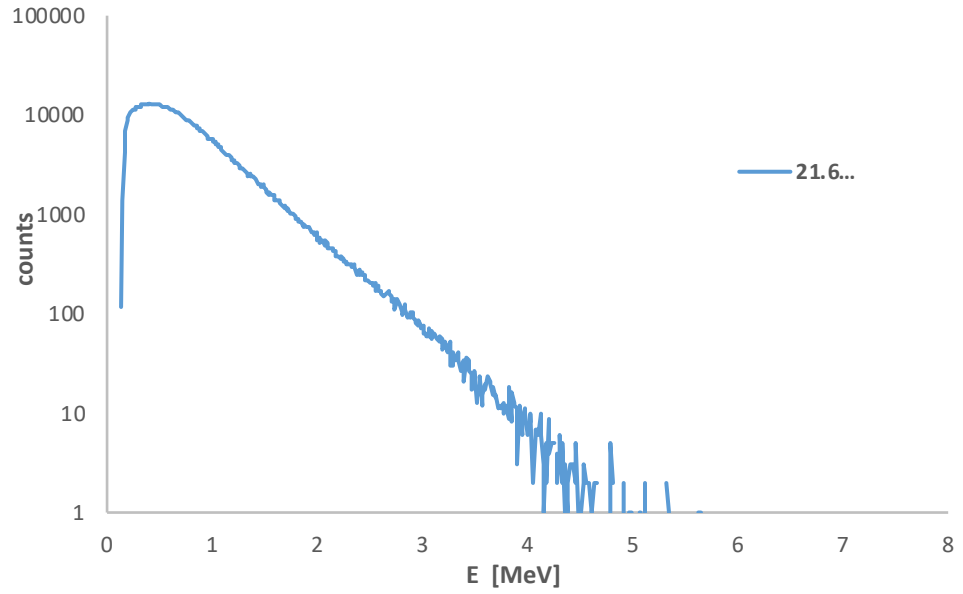
Spare slides

Field emission diagnostic on MB001: energy spectrum from NaI scintillator

MP barrier (9-13 MV/m): low count rate, no saturation. 5 sec. Acquisition. Endpoint energy increases rapidly while reaching the resonance for maximum impact energy

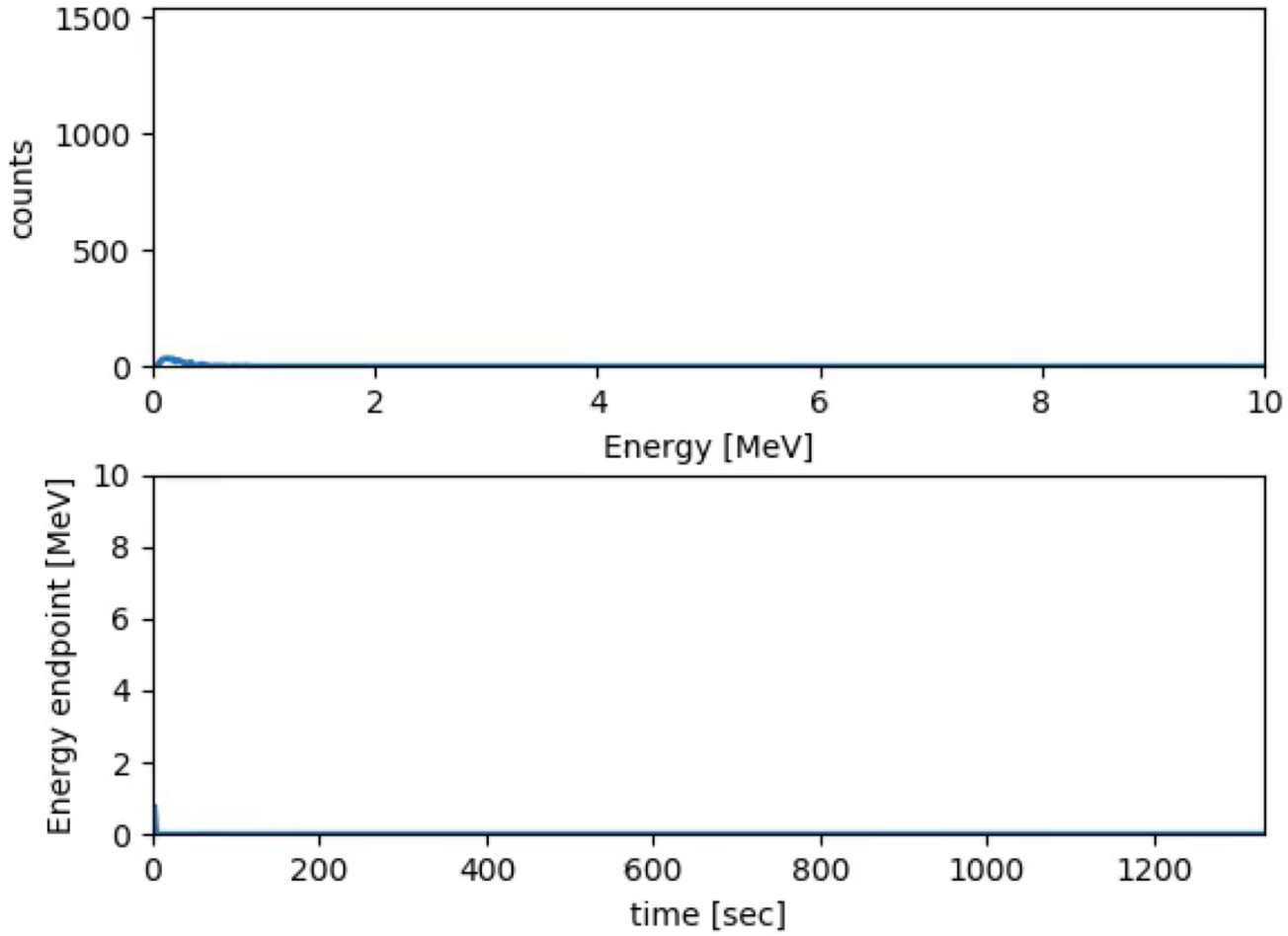


Field emission at high field (21.6 MV/M): high count rate (>10^6 cps), detectors saturates and Endpoint determination is affected by count pile up. A lead screen (10 cm thick) is added so to mitigate saturation.
A nearly 5 MeV endpoint is calculated



X-ray emission energy spectrum

- Continuous registration of X-ray spectrum vs time cavity M001



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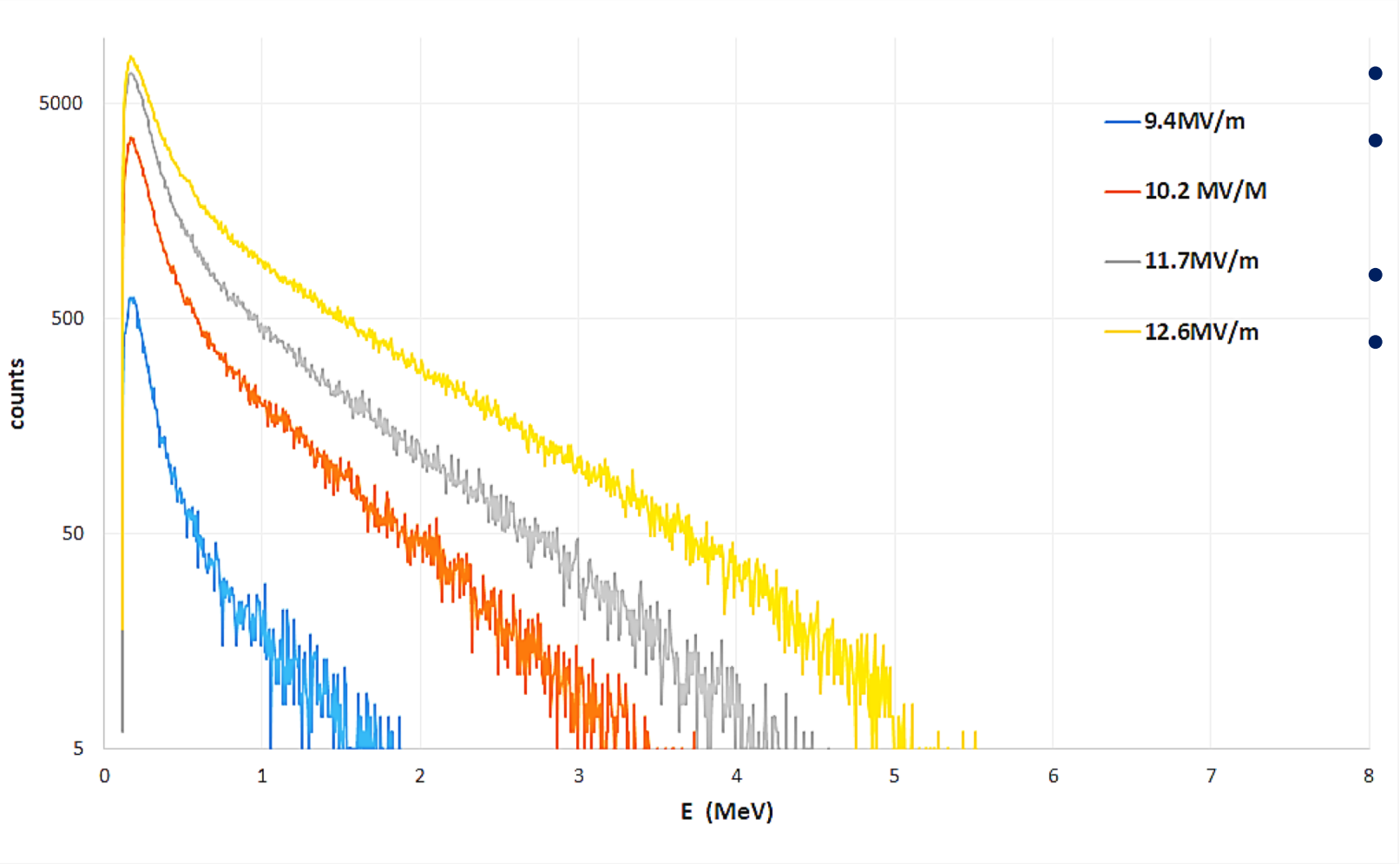
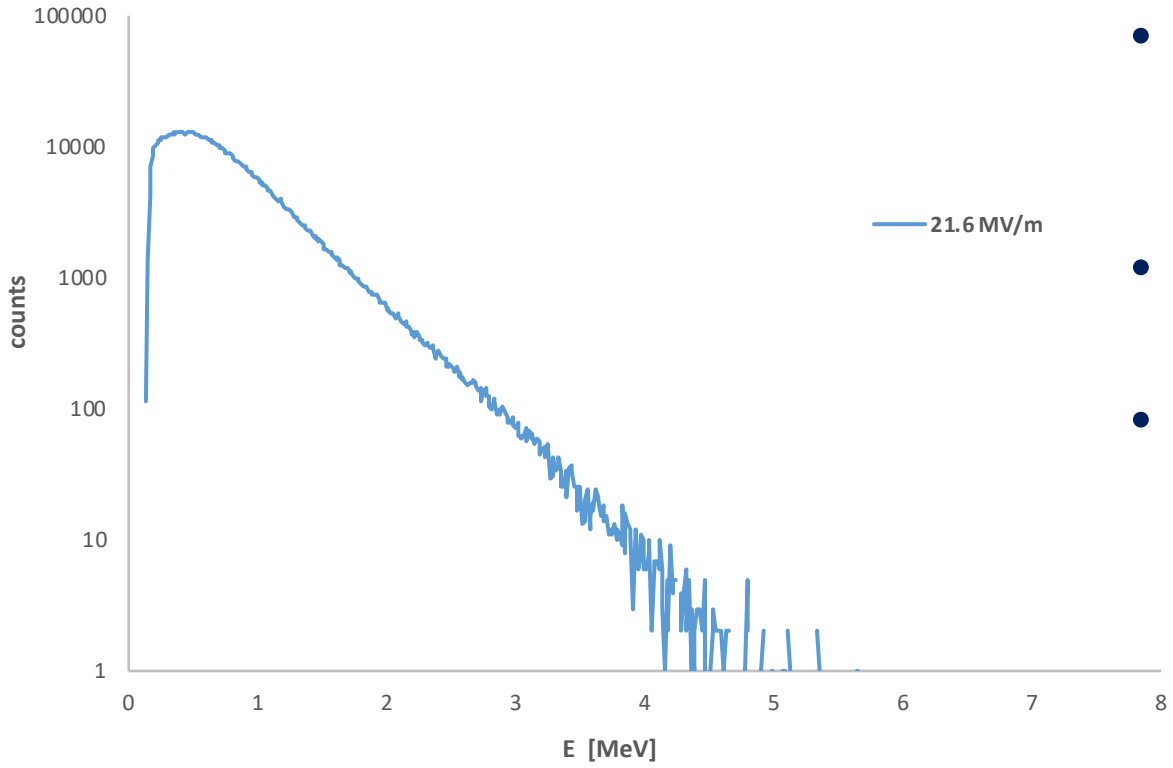


- **MP barrier (9-13 MV/m)**
- low count rate, no saturation.
- 5 s acquisition.
- Endpoint energy increases rapidly while reaching the resonance for maximum impact energy

X-ray emission energy spectrum

Field emission diagnostic on MB001: energy spectrum from NaI scintillator



- **Field emission at high field (21.6 MV/M)**
- high count rate (>10^6 cps), detectors saturates and Endpoint determination is affected by count pile up.
- A lead screen (10 cm thick) is added so to mitigate saturation.
- A nearly 5 MeV endpoint is calculated