Overview on accelerator activities of the INFN Milano LASA SRF Group

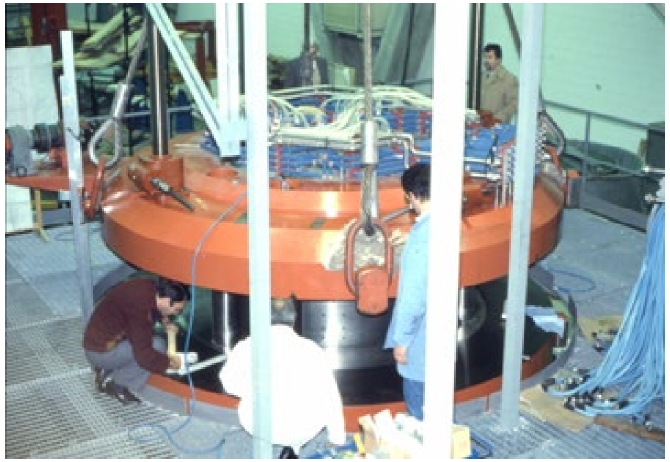
Laura Monaco
on behalf of LASA SRF group

Outline

Seminario INFN Acceleratori – 10 Novembre 2023

- **Historical intro of the SRF LASA group**
- **Cavities, cryomodules and ancillaries**
  - Expertise on prototypes and ancillaries
  - Series production (in-kind contribution)
  - Future activities
- **Photocathodes**

Path towards INFN LASA SRF experties



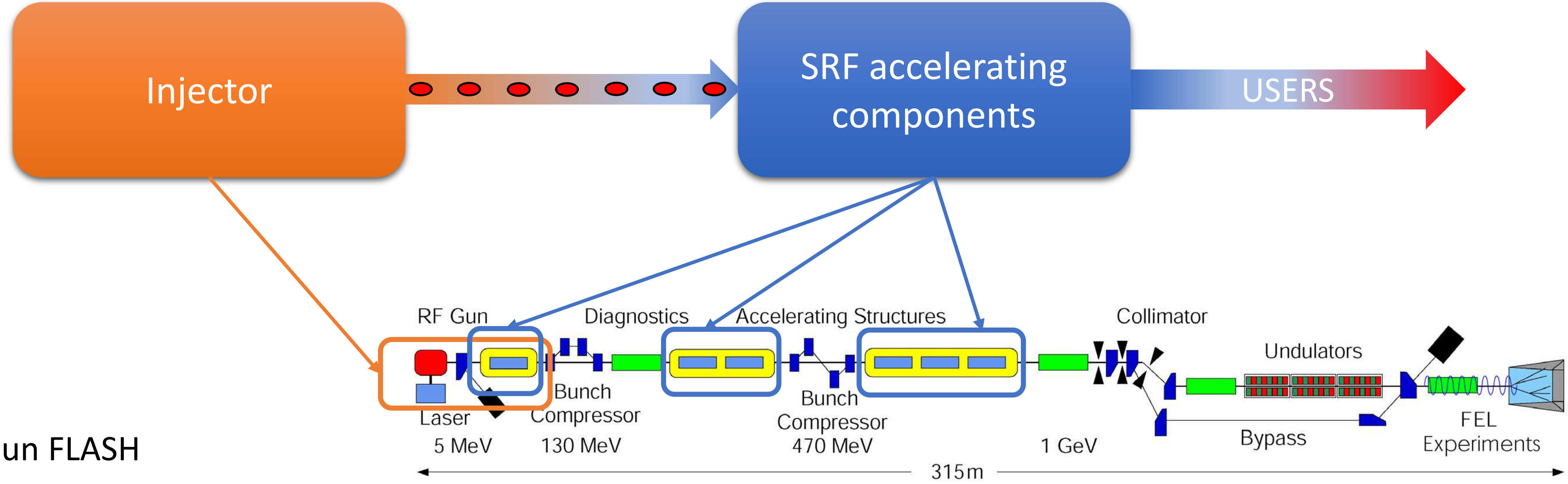
- The **First Superconducting Cyclotron** in Europe in the ‘80s, now at LNS, was realized at LASA
- **TESLA** and the **TESLA Collaboration** (90’s …)
  - TESLA, a TeV-scale electron-positron collider, was the first accelerator based on SRF.
  - As a funder of the collaboration, INFN LASA contributed to:
    - ➢ bring **SRF to be reliable and usable for acceleration application**
    - ➢ *develop **high brightness RF gun** based on **photocathodes***

TESLA TDR

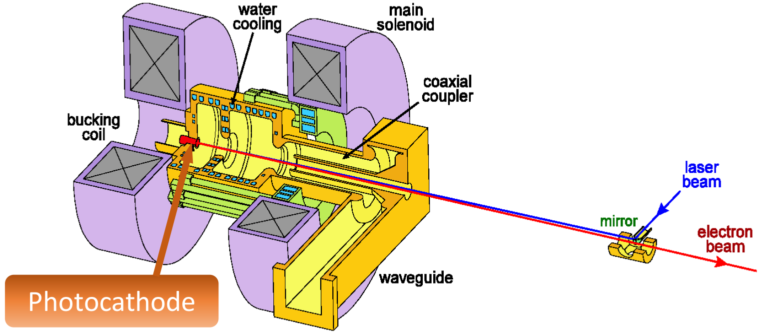
- **European XFEL** (from 2000’s …)
  - A **17.6 GeV** SRF based accelerator feeding a **X-Ray Free Electron Laser**.
    This project has succesfully demonstrated the possibility of **application of SRF to large projects**,
    paving the way to further challenging accelerators (LCLS-II, SHINE, ESS, PIP-II, ILC, FCC-ee, CEPC, etc.)

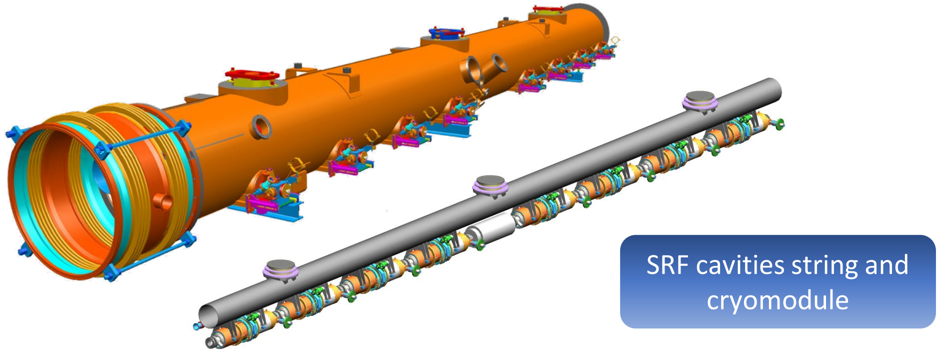
SRF and Photocathode Expertise

- Superconducting RF cavities (and ancillaries) development
- Photocathodes for high brightness injectors development



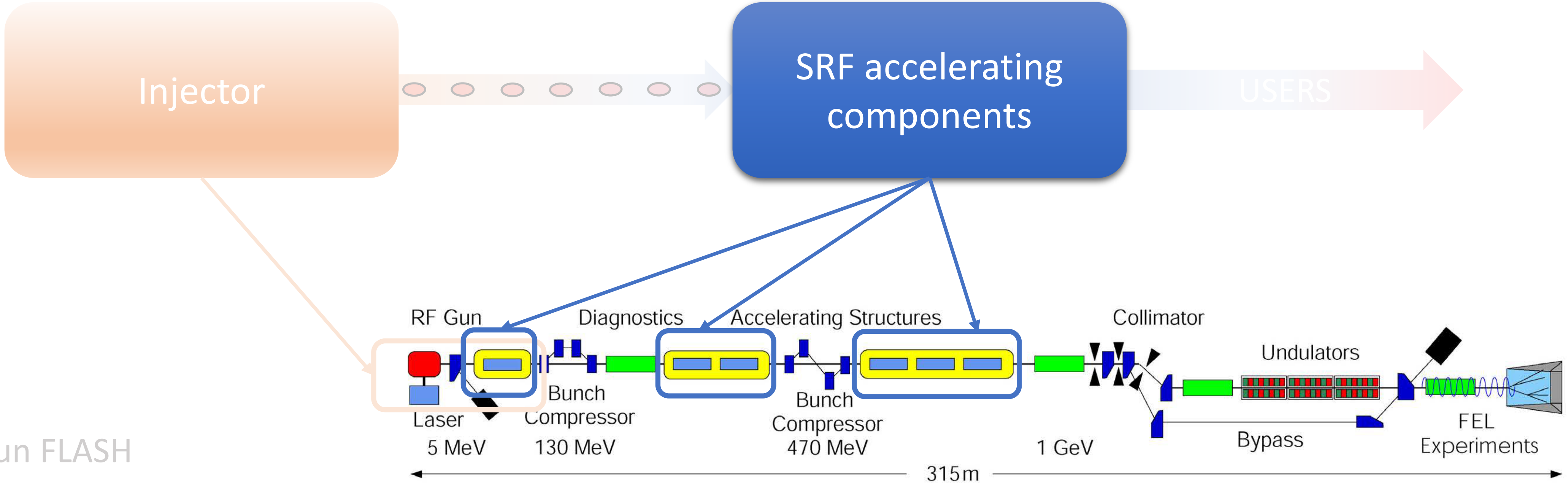
RF Gun FLASH




SRF cavities string and cryomodule

SRF and Photocathode Expertise

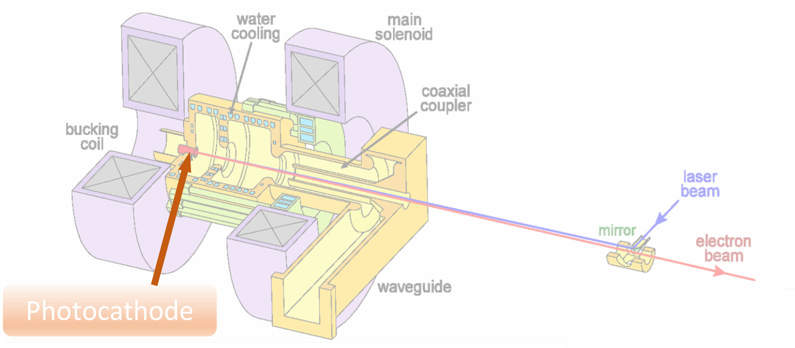
- Superconducting RF cavities (and ancillaries) development
- Photocathodes for high brightness injectors development

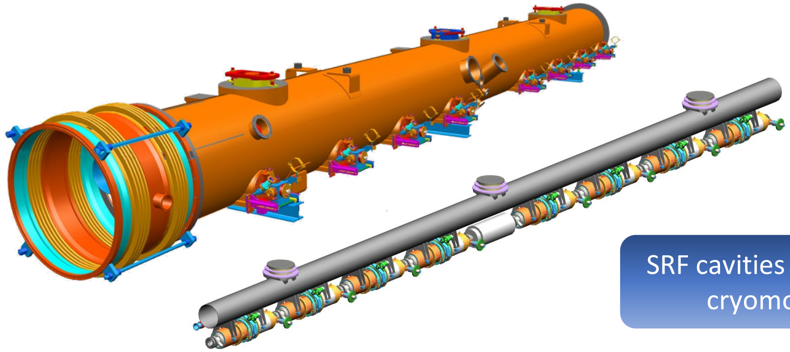


Injector

SRF accelerating components

RF Gun FLASH



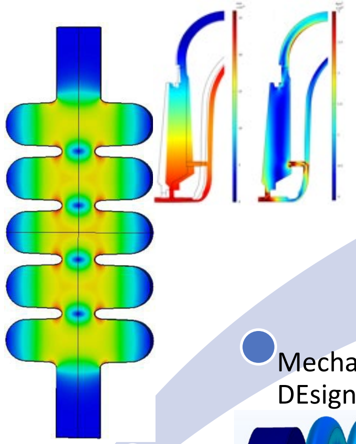


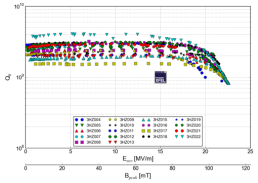
SRF cavities string and cryomodule

SRF Expertise

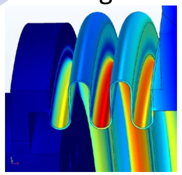
LASA SRF Group: expertise and experience in SRF

SRF cavity from design to series production

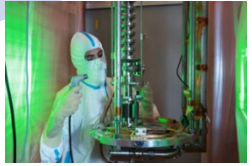




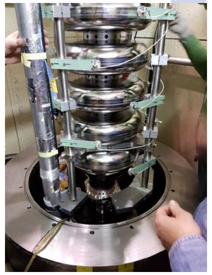
E.M. Design



Mechanical DEsign



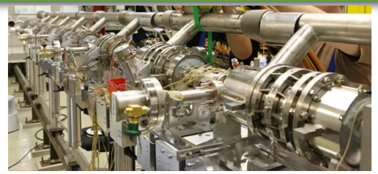
Prototypes

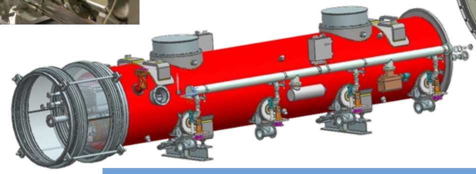


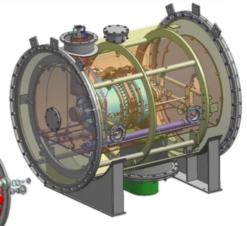
2K Vertical Test

Series Production

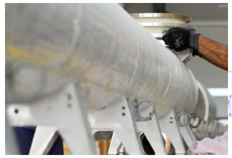
SRF cryomodule components developments

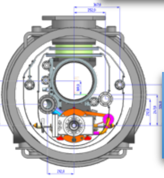




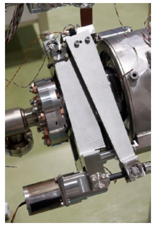


Cavity String



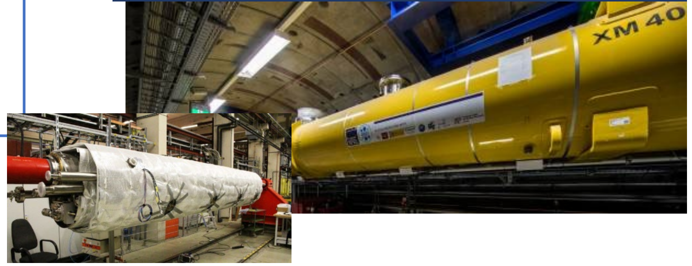


Cold Mass



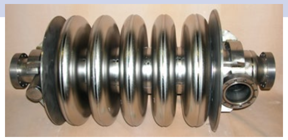
Tuner

Cryomodule



Contribution to International Projects

TRASCO
TRAsmutazione SCOrie



SNS
SPALLATION NEUTRON SOURCE

Cavity Design

TESLA TECHNOLOGY
T T C
COLLABORATION

TESLA TDR

ilc
international linear collider

S1-Global

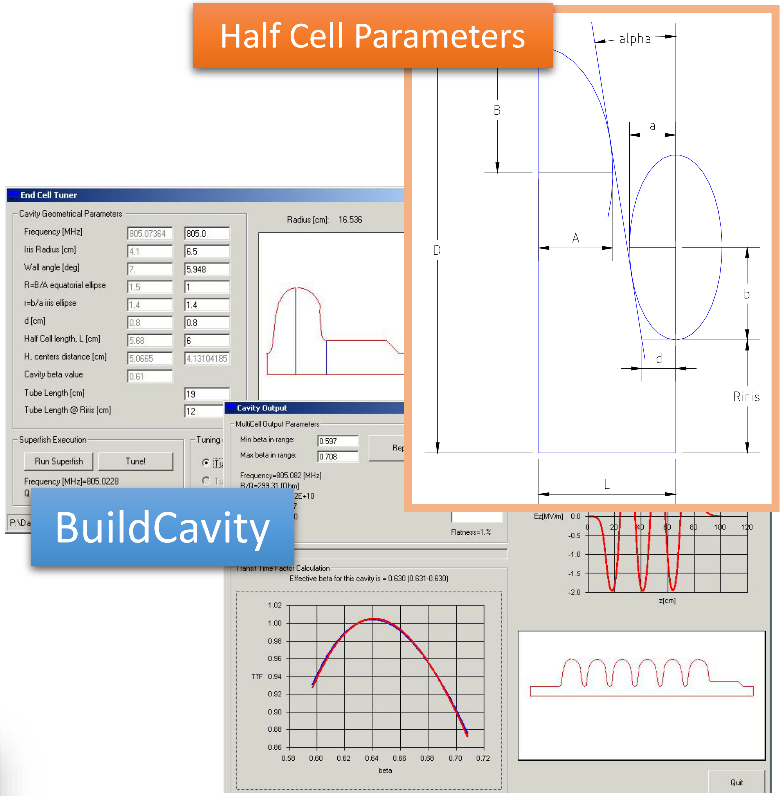
European XFEL

EUROPEAN SPALLATION SOURCE

PIP-II

Cavity – Electromagnetic Design

- Full parametric model in terms of **7 geometrical parameters**
- We built a **2D parametric tool BuildCavity** for the analysis of the cavity shape on the **electromagnetic** parameters based on SUPERFISH
- **A multicell cavity is then built** minimizing Field Flatness error, compute β and TTF as well as final performances
- The **2D model** constitutes the **basis for further 3D simulations** (HFSS, CST) for HOMs, multipacting, field emission considerations


Half Cell Parameters

BuildCavity

End Cell Tuner

Cavity Geometrical Parameters

Frequency [MHz]	805.07364	805.0
Iris Radius [cm]	4.1	6.5
Wall angle [deg]	7.	5.948
R=B/A equatorial ellipse	1.5	1
r=b/a iris ellipse	1.4	1.4
d [cm]	0.8	0.8
Half Cell length, L [cm]	5.68	6
H, centers distance [cm]	5.0665	4.13104185
Cavity beta value	0.61	
Tube Length [cm]		19
Tube Length @ Riris [cm]		12

Radius [cm]: 16.536

Superfish Execution

Frequency [MHz]=805.0228

Cavity Output

MultiCell Output Parameters

Min beta in range: 0.597

Max beta in range: 0.708

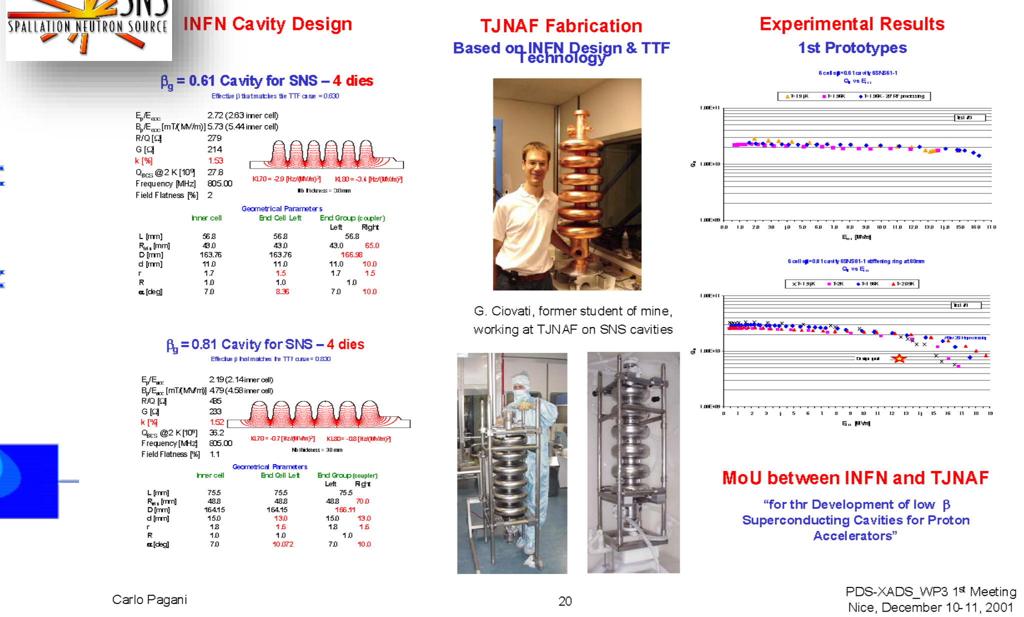
Frequency=805.082 [MHz]

R/Q=299.31 [Ohm]

Transit Time Factor Calculation

Effective beta for this cavity is = 0.630 (0.631-0.630)

Flatness=1.%


INFN Cavity Design

β_g = 0.61 Cavity for SNS – 4 dies

Effective β that matches the TTF curve = 0.630

E_p/E_{acc} 2.72 (2.63 inner cell)
B_p/E_{acc} [mT/(MV/m)] 5.73 (5.44 inner cell)
R/Q [Ω] 279
G [Ω] 214
k [%] 1.53
Q_{BCS} @2 K [10^9] 27.8
Frequency [MHz] 805.00
Field Flatness [%] 2

KL70 = -2.9 [Hz/(MV/m)^2] KL80 = -3.4 [Hz/(MV/m)^2]

Nb thickness = 3.8mm

Geometrical Parameters

	Inner cell	End Cell Left	End Group (coupler) Left	End Group (coupler) Right
L [mm]	56.8	56.8	56.8	
R_{iris} [mm]	43.0	43.0	43.0	65.0
D [mm]	163.76	163.76	166.98	
d [mm]	11.0	11.0	11.0	10.0
r	1.7	1.5	1.7	1.5
R	1.0	1.0	1.0	
α [deg]	7.0	8.36	7.0	10.0

β_g = 0.81 Cavity for SNS – 4 dies

Effective β that matches the TTF curve = 0.830

E_p/E_{acc} 2.19 (2.14 inner cell)
B_p/E_{acc} [mT/(MV/m)] 4.79 (4.58 inner cell)
R/Q [Ω] 485
G [Ω] 233
k [%] 1.52
Q_{BCS} @2 K [10^9] 36.2
Frequency [MHz] 805.00
Field Flatness [%] 1.1

KL70 = -0.7 [Hz/(MV/m)^2] KL80 = -0.8 [Hz/(MV/m)^2]

Nb thickness = 3.8 mm

Geometrical Parameters

	Inner cell	End Cell Left	End Group (coupler) Left	End Group (coupler) Right
L [mm]	75.5	75.5	75.5	
R_{iris} [mm]	48.8	48.8	48.8	70.0
D [mm]	164.15	164.15	166.11	
d [mm]	15.0	13.0	15.0	13.0
r	1.8	1.6	1.8	1.6
R	1.0	1.0	1.0	
α [deg]	7.0	10.072	7.0	10.0

TJNAF Fabrication

Based on INFN Design & TTF Technology

G. Ciovati, former student of mine, working at TJNAF on SNS cavities

Experimental Results

1st Prototypes

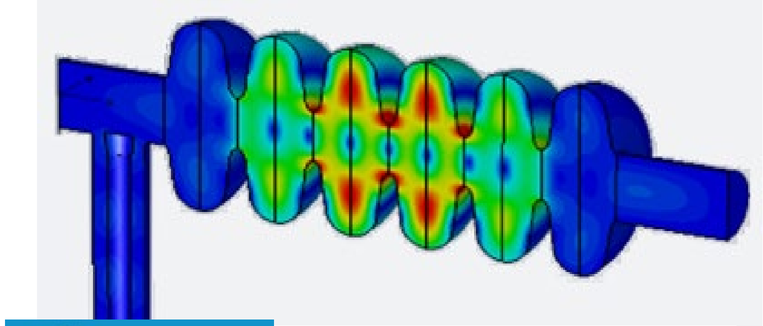
MoU between INFN and TJNAF

"for thr Development of low β Superconducting Cavities for Proton Accelerators"

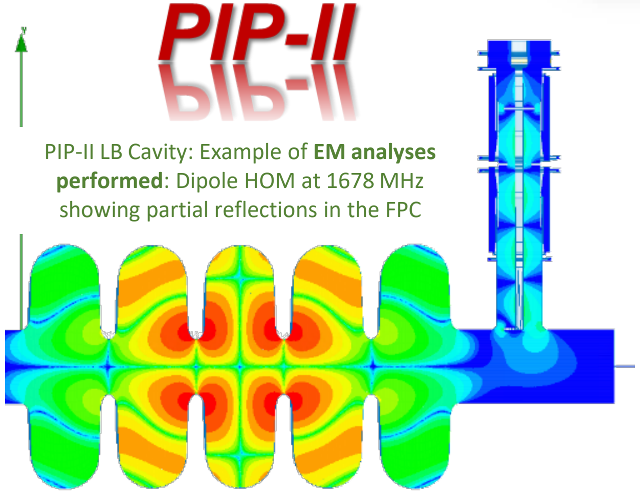
Carlo Pagani

20

PDS-XADS_WP3 1st Meeting
Nice, December 10-11, 2001



ESS MB Cavity: Example of **EM analyses performed**: Dipole HOM at 1678 MHz

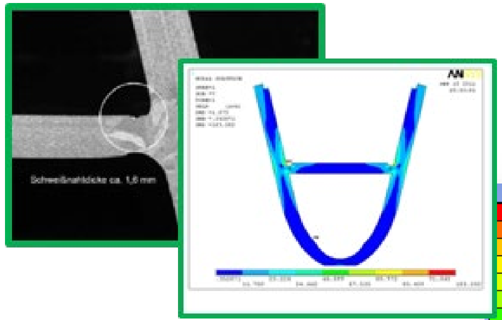


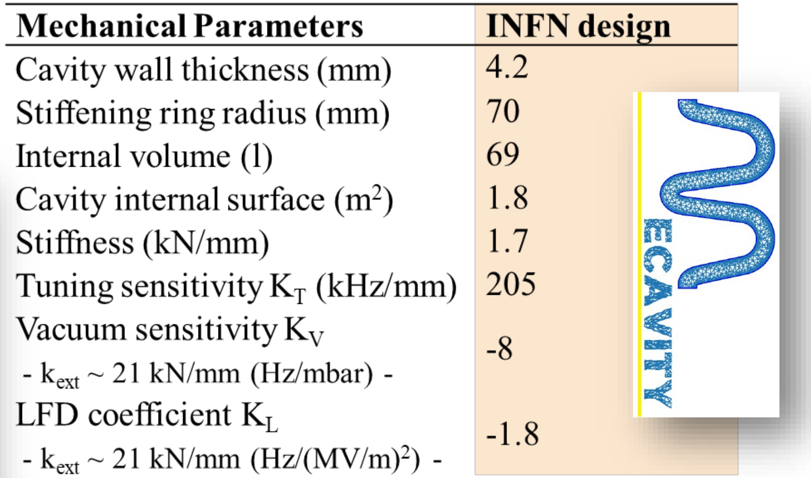
PIP-II LB Cavity: Example of **EM analyses performed**: Dipole HOM at 1678 MHz showing partial reflections in the FPC

ESS MB Cavity: Example of **EM analyses performed**: Dipole HOM at 1742.47 MHz

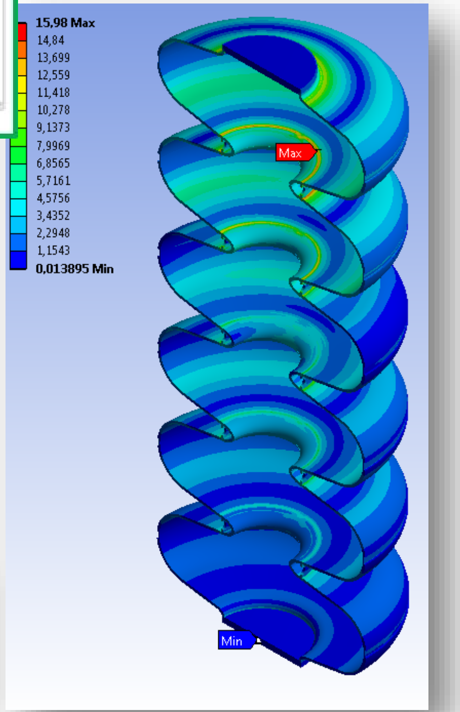
Cavity – Mechanical Design

- The **EM design** is **transferred** to **mechanical analysis** (iterative loop) for estimating critical parameters as:
  - Ring radius
  - Stiffness
  - Tuning sensitivity
  - Vacuum sensitivity
  - Lorentz Force Detuning (LFD)
  - PED, ASME compliance

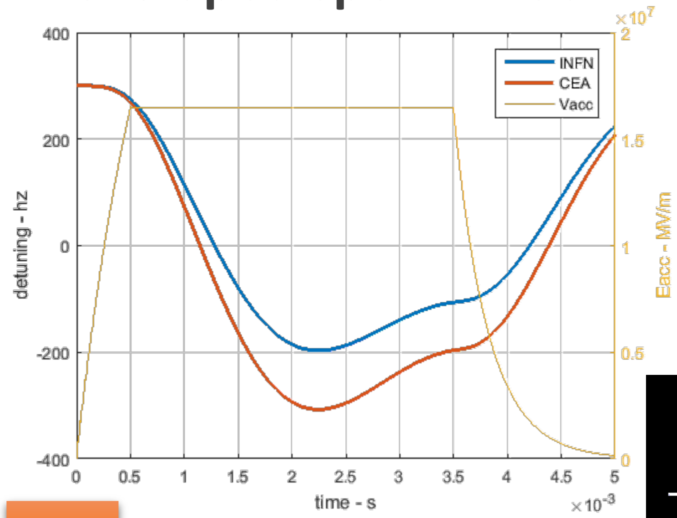




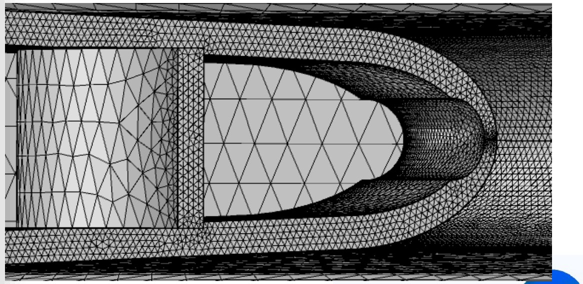
Mechanical Parameters	INFN design
Cavity wall thickness (mm)	4.2
Stiffening ring radius (mm)	70
Internal volume (l)	69
Cavity internal surface (m^2)	1.8
Stiffness (kN/mm)	1.7
Tuning sensitivity K_T (kHz/mm)	205
Vacuum sensitivity K_V - k_{ext} ~ 21 kN/mm (Hz/mbar) -	-8
LFD coefficient K_L - k_{ext} ~ 21 kN/mm (Hz/(MV/m)^2) -	-1.8

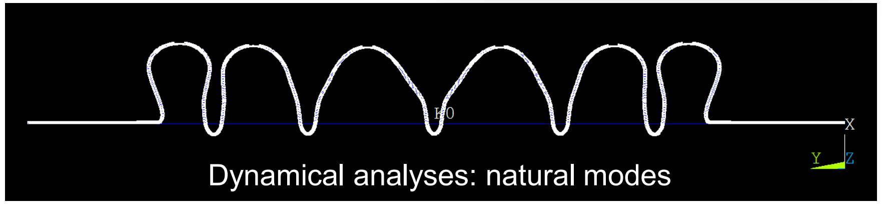


- **Developed specific tool Mecavity**

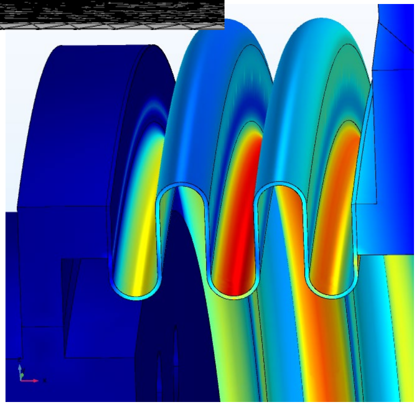


LFD



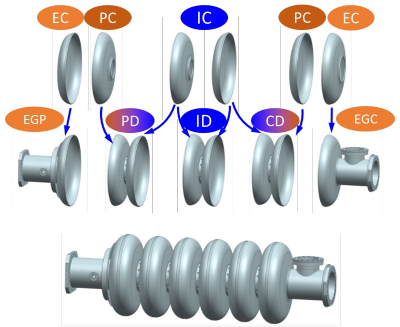


Dynamical analyses: natural modes



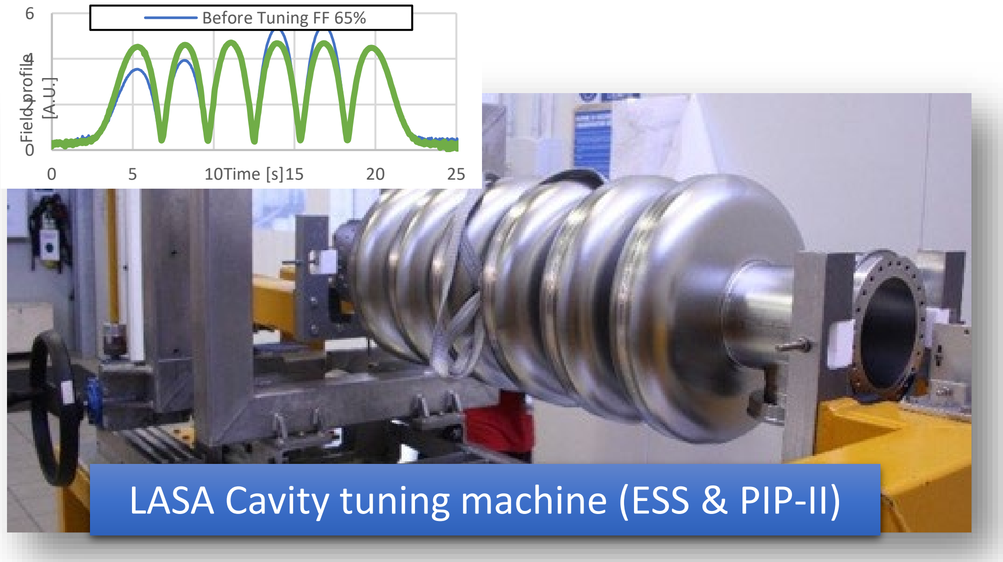
Cavity – Towards production -> Prototypes

- A key element of our expertise consists in the **transfer** of the **electromagnetic and mechanical design** to **production**:
  - Nb quality control (mech. prop., Ra, foreign inclusions, etc.)
  - RF procedures from sheets to cavity
  - Define production cycle to guarantee final length and frequency
  - Define appropriate heat and surface treatment (BCP, EP, etc.)
  - Mechanical and RF measurement and control plan
  - Test of defined scheme on prototypes
  - 2 K test for final acceptance

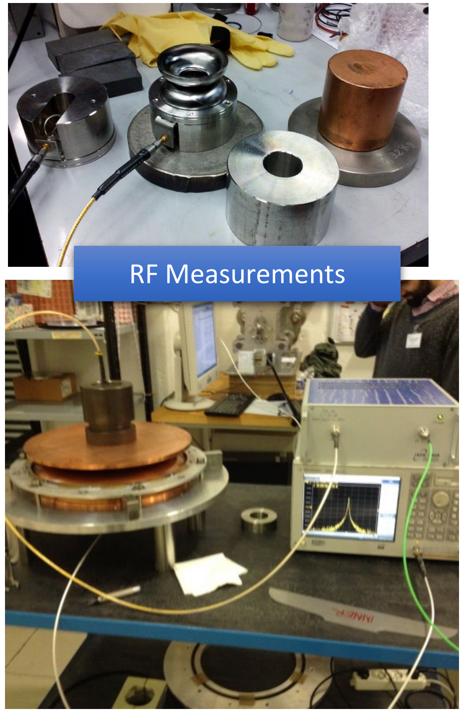


From HC to ESS CAV

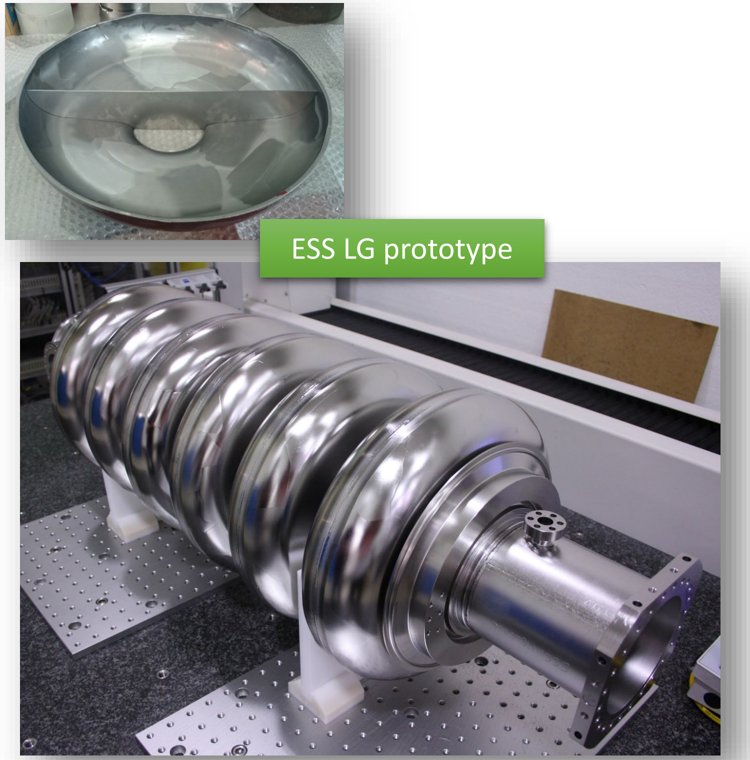
Bead pull system (3.9 GHz E-XFEL)



LASA Cavity tuning machine (ESS & PIP-II)



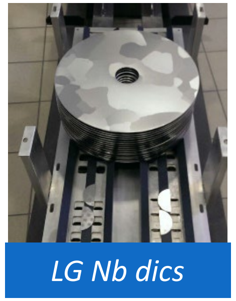
RF Measurements

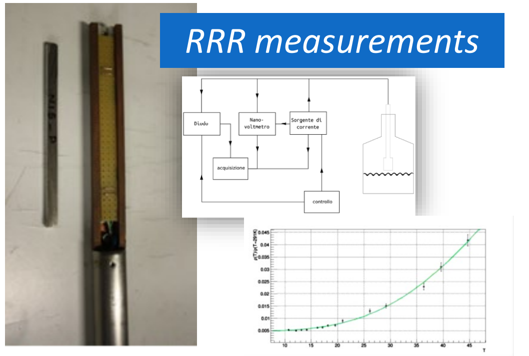


ESS LG prototype

Cavity – Nb studies and characterization

- **Nb quality is critical** for the final cavity performances:
  - **Mechanical** properties (grain size, hardness, thickness, etc.)
  - **Chemical** composition (elements and gas contents)
  - **RRR** (Residual Resistance Ratio)
  - **Surface defects** (scratches, marks, grease, etc.)
  - **Foreign materials** (ECS – Eddy Current Scanning)
  - **Traceability** (pressure vessel code)


LG Nb dics

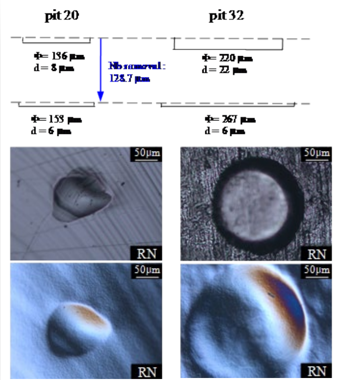

RRR measurements

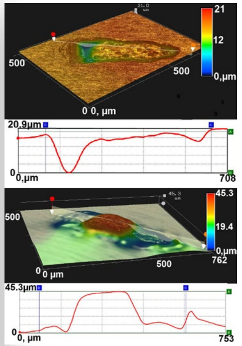

ECS at DESY

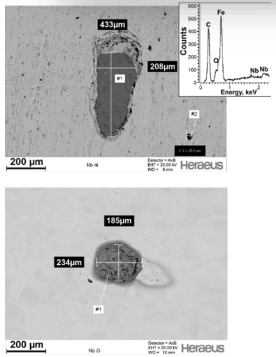

Inspection at Nb supplier

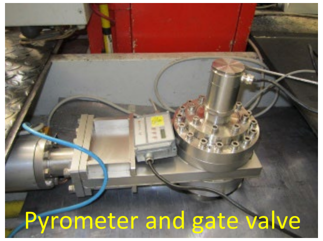
- **Studies and tools developed**:
  - Treatment studies (BCP/EP) of defect evolution on Nb samples
  - Final roughness (Ra) of Nb surface
  - RRR measurements set-up
  - Experience on FG and LG Nb
  - EBW (Electron Beam Welding) studies

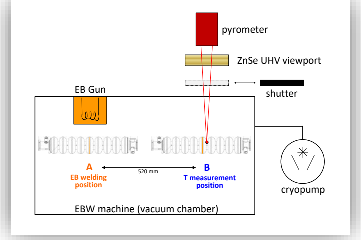

EP set-up at LASA

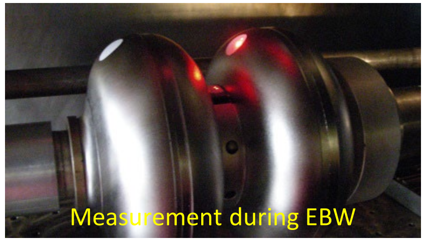


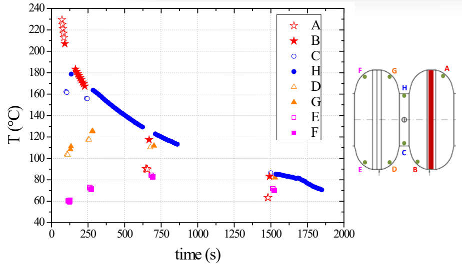


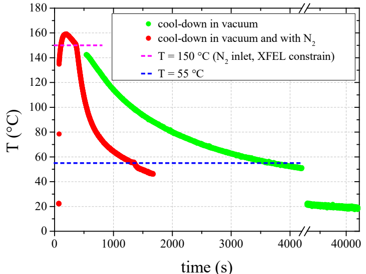



Pyrometer and gate valve




Measurement during EBW

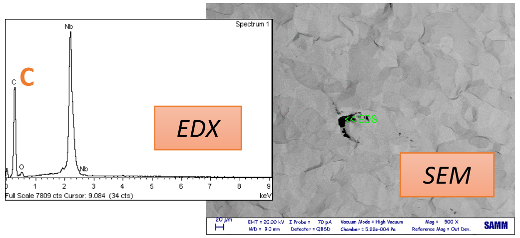


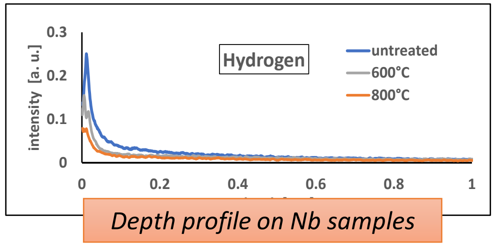


Cavity – Thermal and Surface treatments

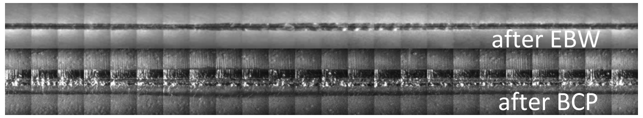
- Once the mechanical production is complete, **thermal** and **surface treatments** play a crucial role in the **cavity preparation** to reach the **final performances.**
- **Thermal treatments** for **stress release**, **de-hydrogenation**, **performance improvement:**
  - Vacuum quality (RGA - Residual Gas Analysis), pressure and temperature control, RRR
- **Surface treatments** for **proper finishing** and **cleaning** of the inner **surface exposed to RF**:
  - **BCP** (Buffered Chemical Polishing) and **EP** (Electro Polishing)
- **Studies and tools developed**:
  - **Depth profile** and SEM/EDX for process optimization and quality
  - Acid flow **simulation** and **test bench** for process improvement
  - **Temperature** and **thickness** evolution **during BCP/EP**
  - **Inner visual inspection** set-up for surface finishing check
  - **X-ray fluorescence** set-up for foreign materials analysis (non-destructive diag.)

Annealing cycle



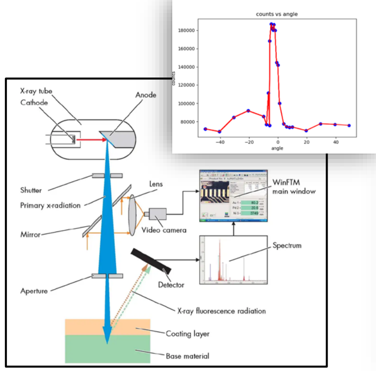


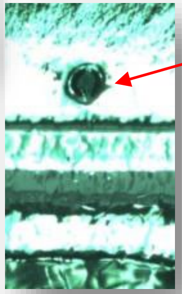
Depth profile on Nb samples

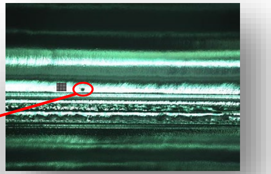


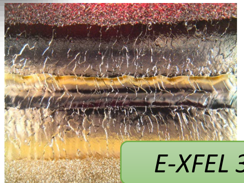
X-ray fluorescence system and Inner optical inspection

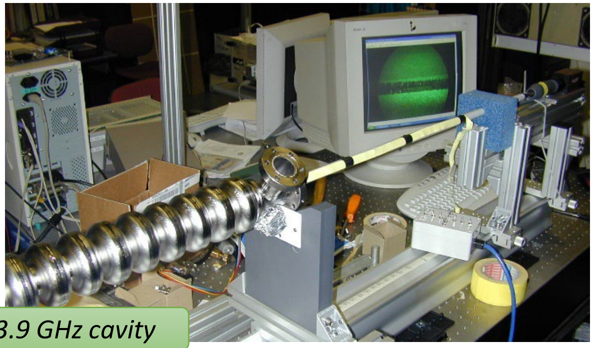
ESS cavity











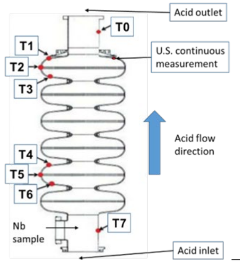
E-XFEL 3.9 GHz cavity

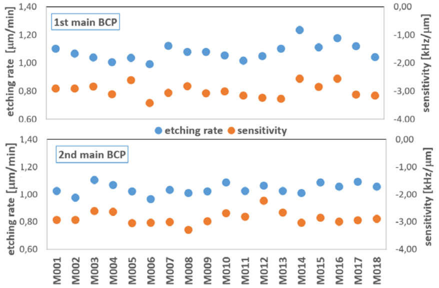
Cavity – Thermal and Surface treatments

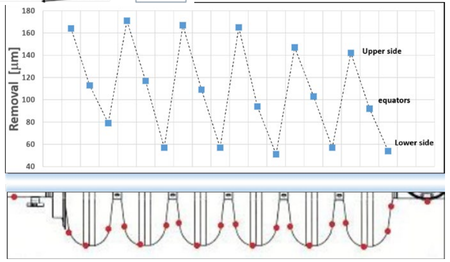
BCP treatment


ESS

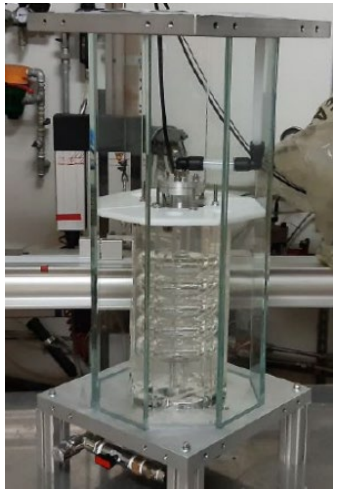

E-XFEL (3.9 GHz)

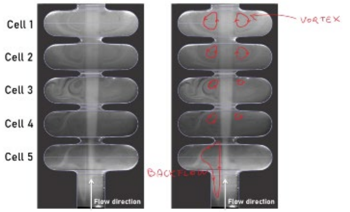


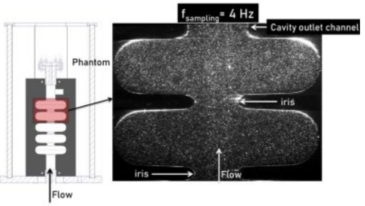


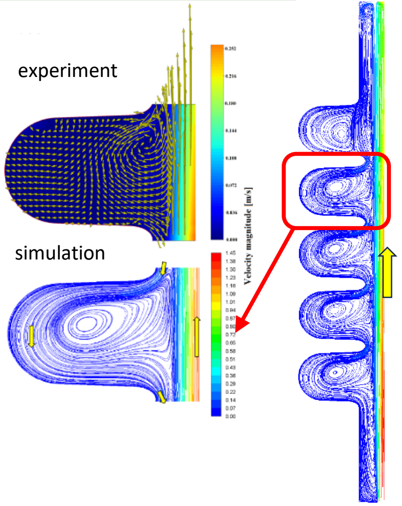


Acid-flow studies

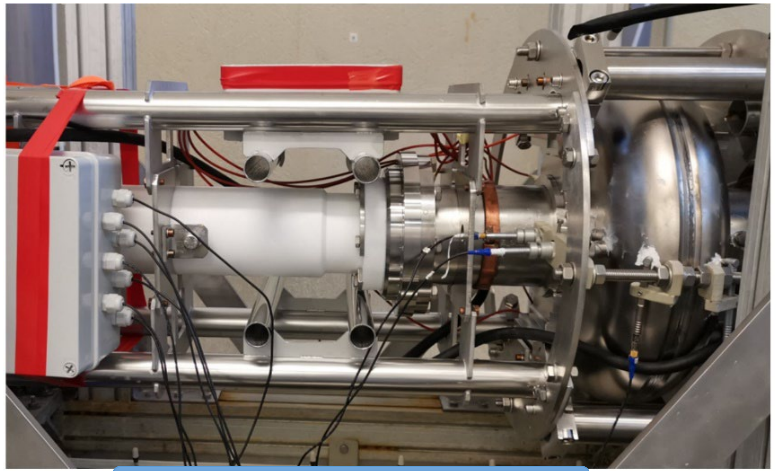


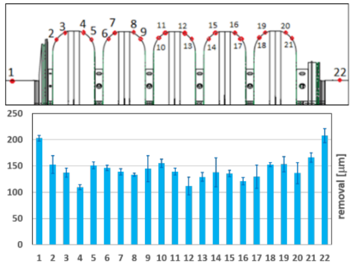




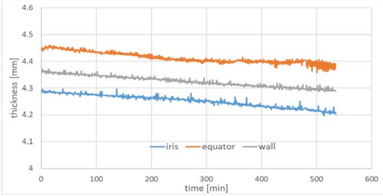


EP treatment

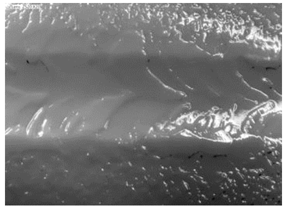

EP on-line measurements (PIP-II)

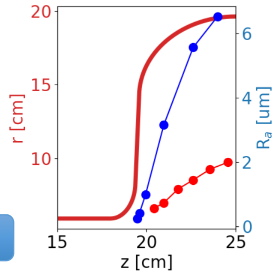


Thickness during EP (US)

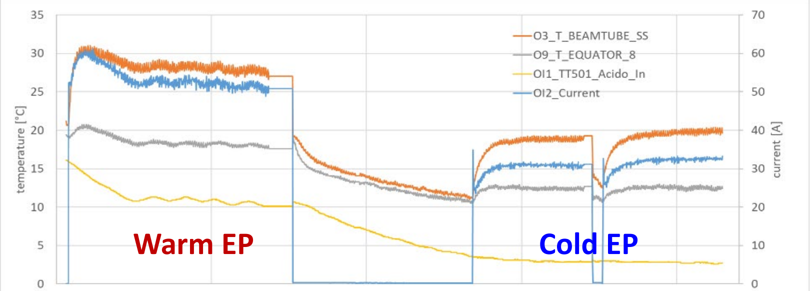



US probe





Ra before/after 40 um EP

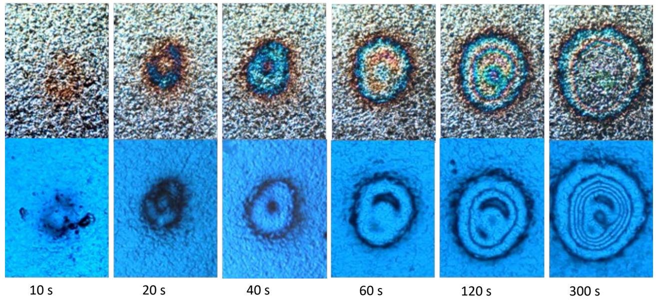


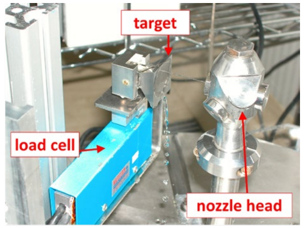
T control during EP

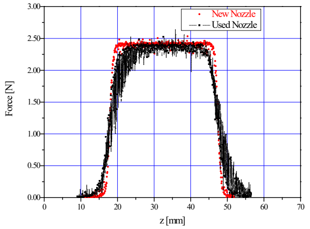
Cavity – Final assembly before cold VT

- **Final assembly** operations are crucial to reach **good final performances** of the cavity, done in **Clean Room** (ISO4-7):
  - **Final surface treatments: BCP/EP** and **heat treatments**
  - **Cleaning** and **rinsing procedure**, **HPR** (High Pressure Rinsing), **UPW** (Ultra Pure Water) system
  - **Accessories assembly** (antennas, flanges, etc.)
  - **Pumping to low pressure** (10^{-10} mbar) with **SPSV** (Slow pump/Slow vent), **leak check** and **RGA**
  - **RF Final check** before delivery

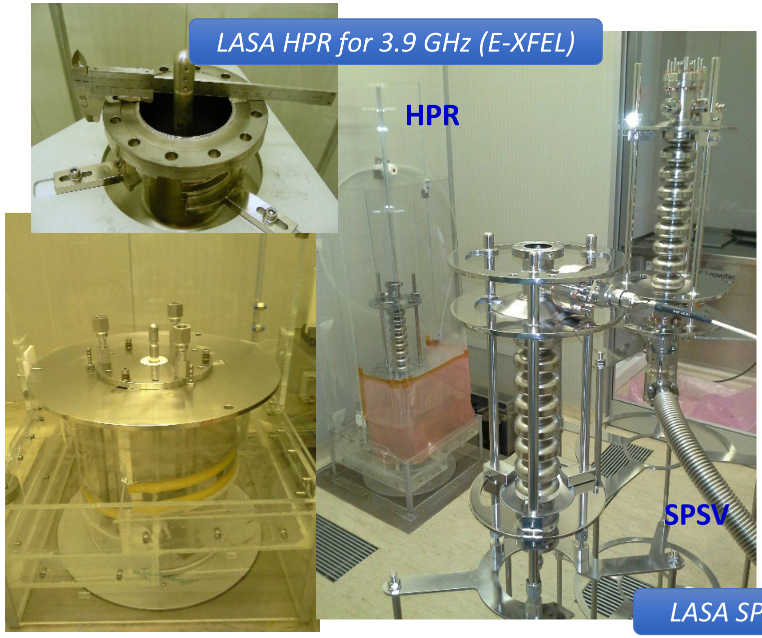
LASA tool for HPR studies





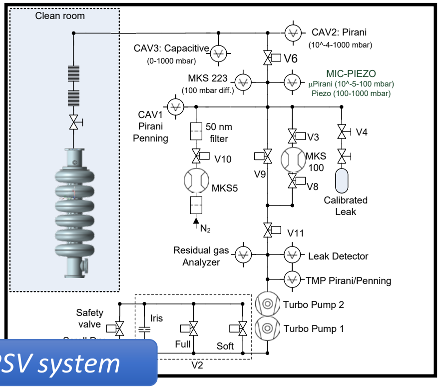


The LASA Clean Room activities for cavity VT preparation

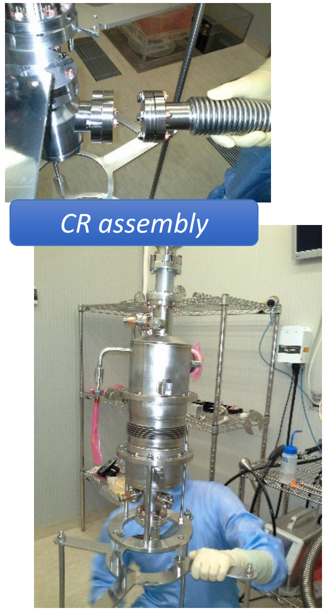


LASA HPR for 3.9 GHz (E-XFEL)

Accessories preparation



LASA SPSV system



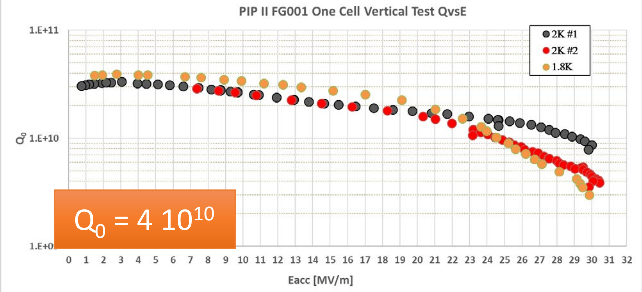
CR assembly

RF final measurements

US Cleaning and rinsing

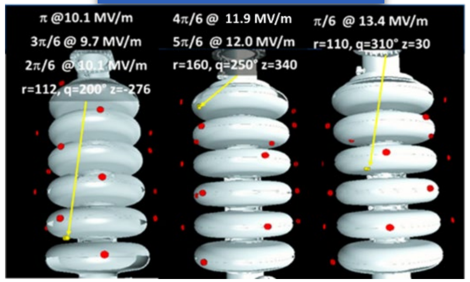
Cavity – Cold VT at LASA

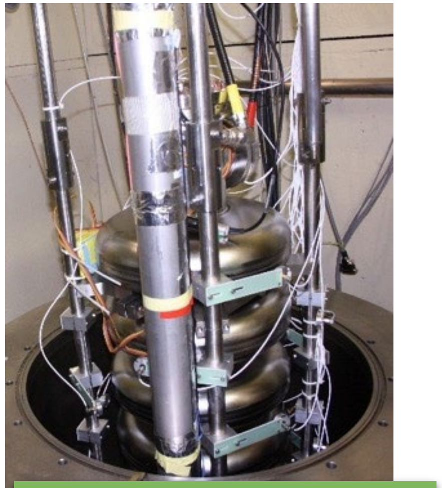
- **Clean Room and UPW**
  - Ultra-Pure Water plant
  - ISO4-7 clean room, HPR system
  - Qualified Slow Pumping Slow Venting system
- **Cryostat**: ϕ 700 mm, 4.5 m length, losses ~ 1 W @ 2 K
- **Residual magnetic field**: < 8 mGauss (single shield)
  - Single μmetal external shield and, second cryogenic shield (Cryoperm) installed
- **Sub-cooling system**:
  - Cooling power: ~ 70 W @ 2 K
  - Lowest temperature 1.5 K.
  - Direct filling at 2 K
- **RF capability:** 500 to 3900 MHz
- **Dedicated inserts with several diagnostics**:
  - 2nd sound detectors for quench localization
  - cryogenic photodiodes
  - fast thermometry
  - flux gate
- **X-ray counter and X-ray NaI spectrometer**



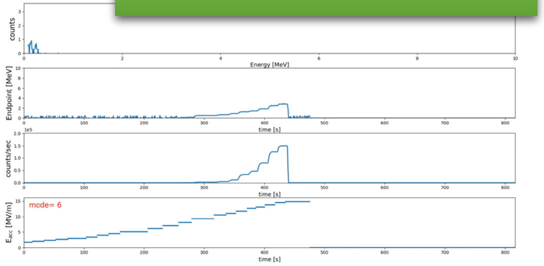
$Q_0 = 4\ 10^{10}$

Second Sound





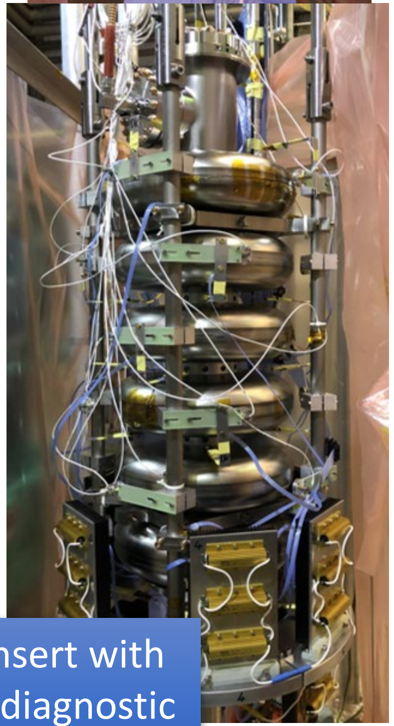
Real-time Scintillator



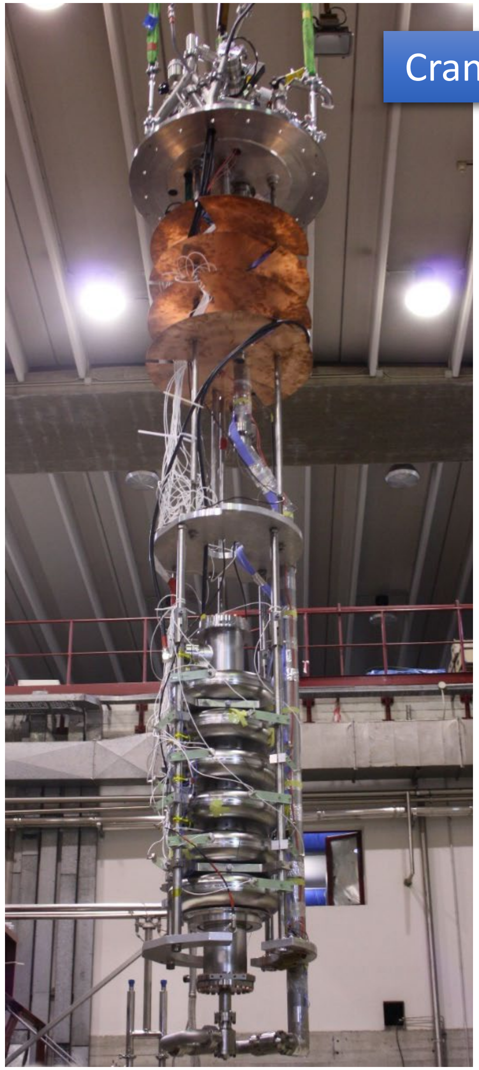
Internal Magnetic Shield

Cavity – Insert installation

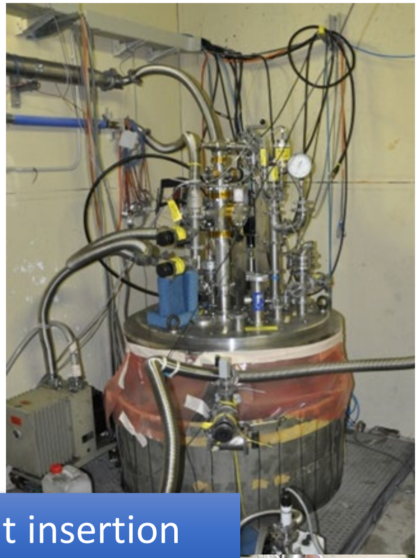
Connection to SPSV



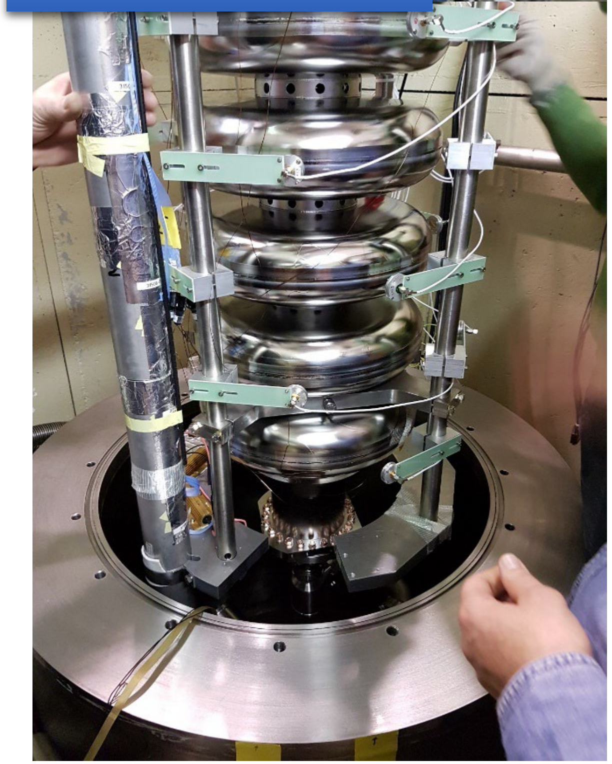
Cavity on insert with sensos and diagnostic installed



Craning to test bunker



Cryostat insertion



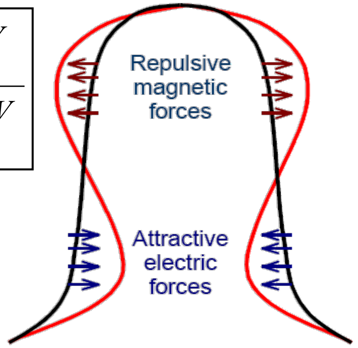
Cavity ancillaries - Frequency tuners

- Each SRF cavity must be equipped with a cryogenic tuning device, **Cold Tuner**, to keep its resonant frequency as close as possible to the project value and thus **compensate detuning**.
- Many possible detuning sources:
  - **Lorentz forces** on cavity walls shielding currents induced by electromagnetic fields
  - **Microphonics** and stochastic noise, strongly correlated to helium bath pressure fluctuations
- Tuners control **static frequency value** (slow action, scale of second to minutes) and suppress dynamic detuning (fast action, scale of milliseconds).
- At INFN LASA we designed, developed and experimentally qualified tuners and their control systems in many international projects

Cavity *Detuning*: $\Delta\omega \equiv \omega_{RF} - \omega_0$

$$\frac{\Delta f}{f} \propto \frac{\int_{\Delta V} (\varepsilon_0 E^2 - \mu_0 H^2) dV}{\int_{V_{CAVITA'}} (\varepsilon_0 E^2 + \mu_0 H^2) dV}$$

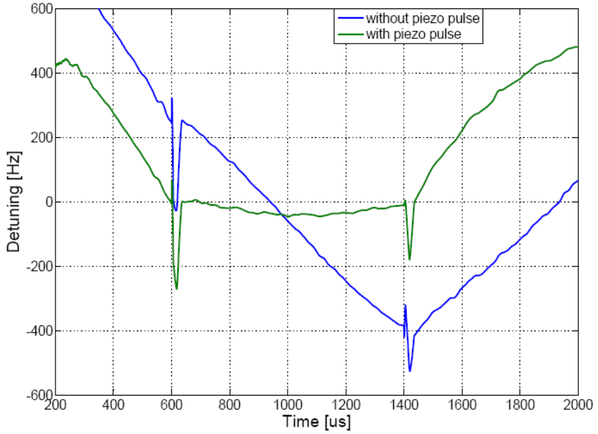
Slater's theorem:
detuning rises with the square of field



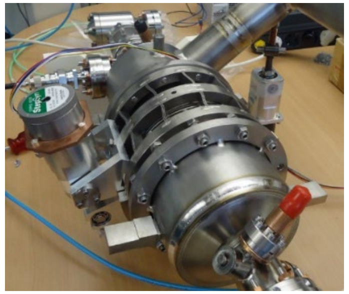
Lorentz Force detuning

$$P = V_{acc} I_b \left(1 + \frac{1}{4} \left(\frac{\Delta f}{f_{FWHM}} \right)^2 \right)$$

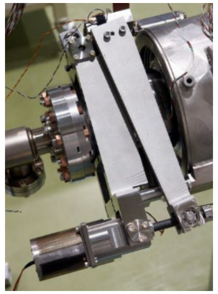
Required power rises with the square of detuning!



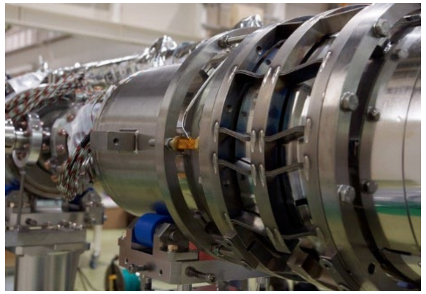
INFN Blade Tuner for
E-XFEL, DESY, **Germany**



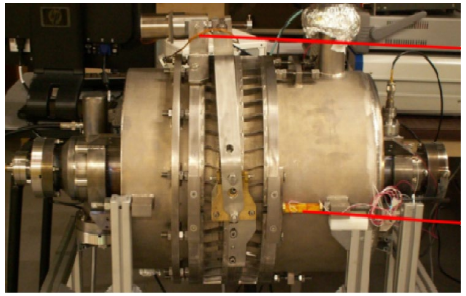
E-XFEL Main
Linac Tuner



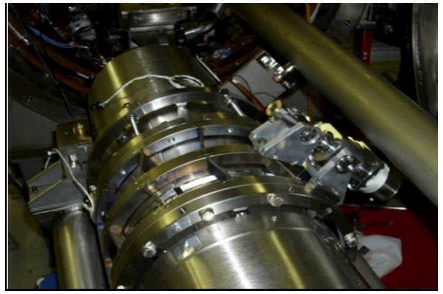
INFN Blade Tuner at S1-Global
KEK, **Japan**



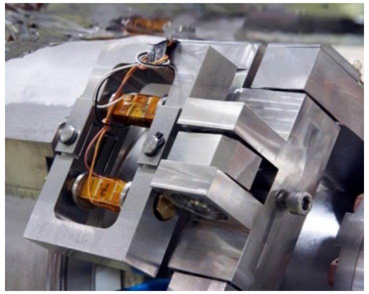
INFN Tuner for the ADS cryomodule
at IPN-Orsay, **France**



INFN Tuner for the ILC cryomodule
at Fermilab, **USA**

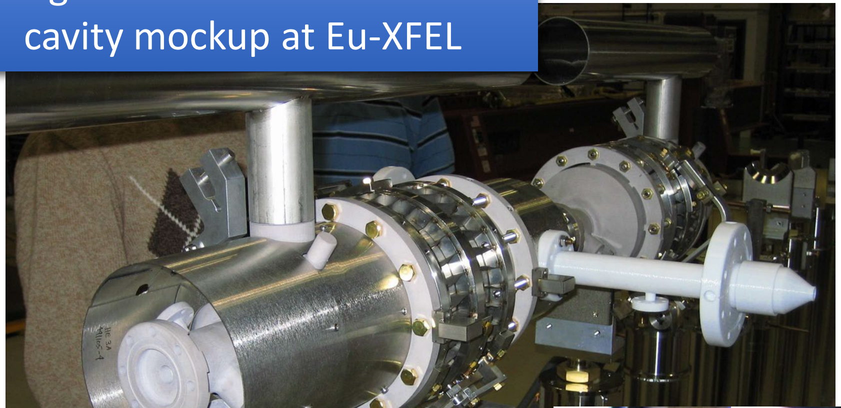


Piezoelectric actuators for
fast tuning, E-XFEL, DESY

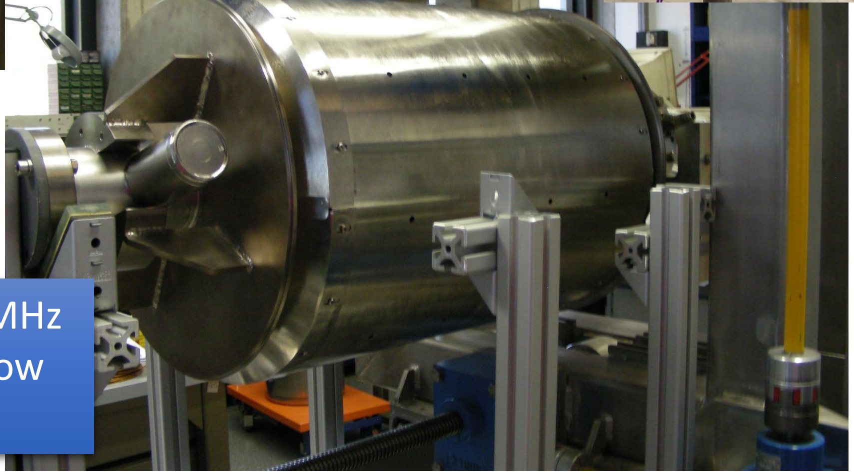


Cavity ancillaries - Magnetic shielding and compensation coils

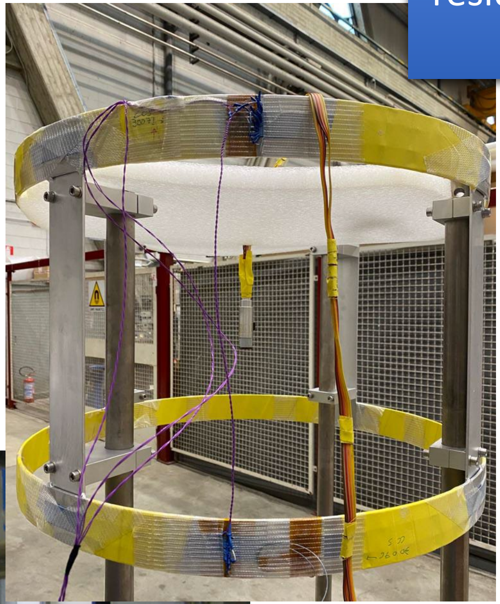
We have design and experimentally qualified cryogenic magnetic shielding solutions for different cavities, for cryomodule as well as for cryostats.



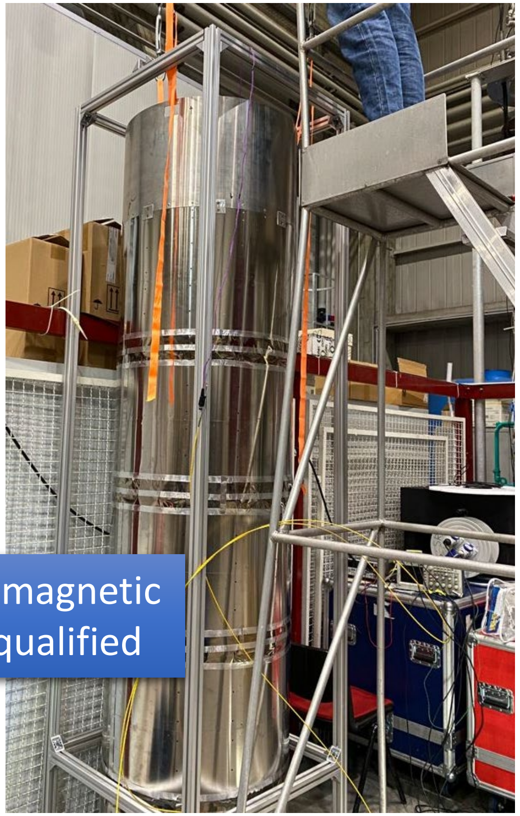
Magnetic shield on a 3.9 GHz cavity mockup at Eu-XFEL



Magnetic shield on a 704.4 MHz TRASCO cavity installed below the helium vessel



Helholtz coils setup for residual field compensation during SC transition

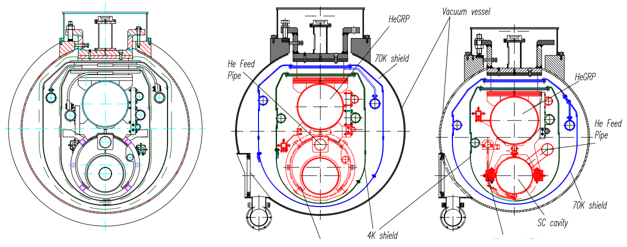


LASA cryostat magnetic shield being qualified

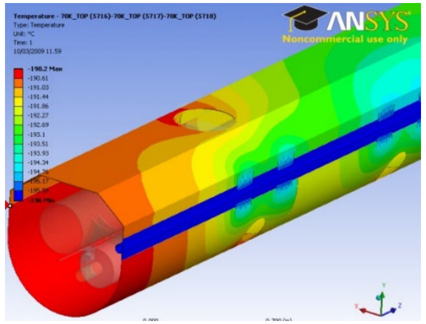
Cryomodules for SC cavities

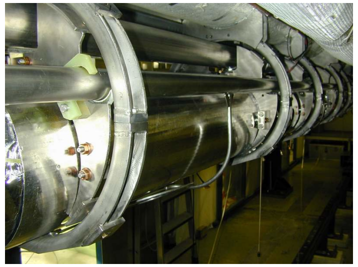
Since TESLA we are collaborating to the R&D on **cryomodule design,** toward:

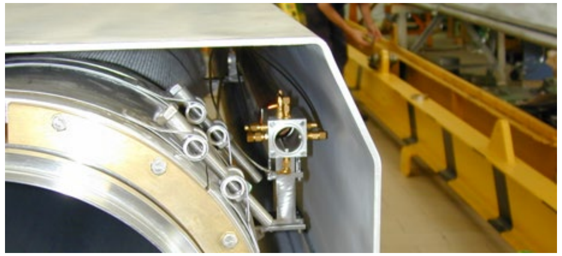
- **High filling factor:** maximize real estate gradient/cavity gradient
- **Moderate cost per unit length** with simple design, based on reliable technologies and with low static heat losses
- **Effective cold mass alignment strategy with** room temperature alignment preserved at cold
  - Wire Position Monitors designed and demonstrated
- **Effective, optimized and reproducible assembling procedures**



Module 1 Module 2 Module 3



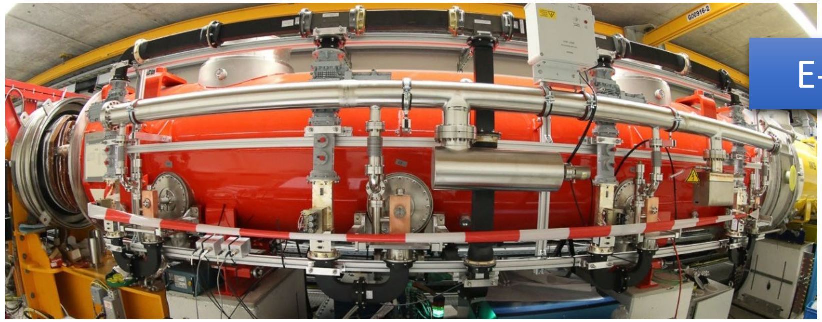




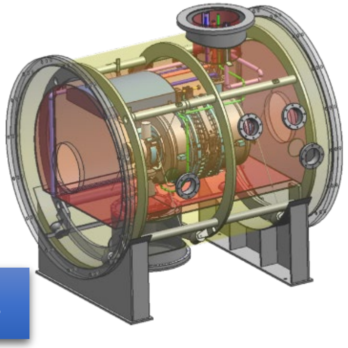
As well as cryomodule production:

- **EUROTRANS / MYRRHA** demonstrator module
- **TESLA Test Facility** at DESY
- XFEL 3rd harmonic modules for the **E-XFEL**

S1-Global



E-XFEL 3H



Eurotrans

From prototypes to series production

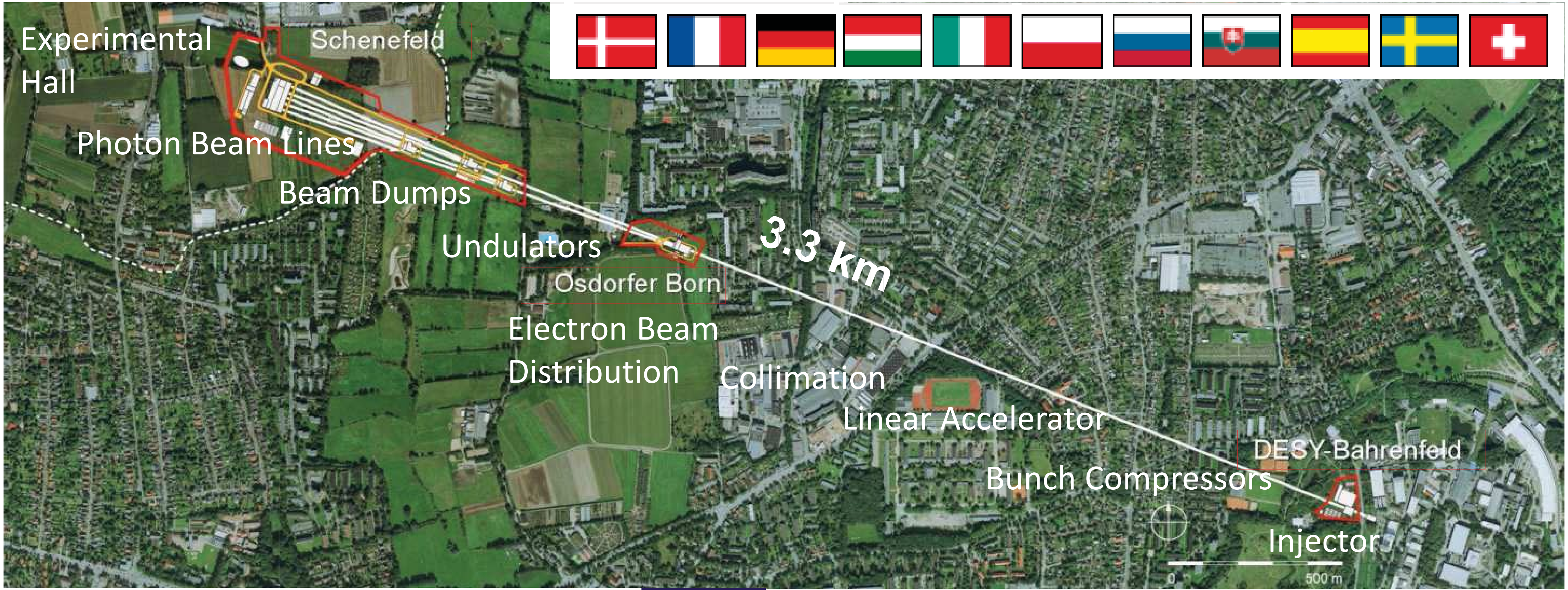
- **Large projects requirements**:
  - **Large number** of **components** (cavities, cryomodule, ancillaries), **massive number** of **high quality Nb** sheets
  - **Process optimization** (**industrialization**) for **high reproducibility** and **reliability**
  - **High production rate**

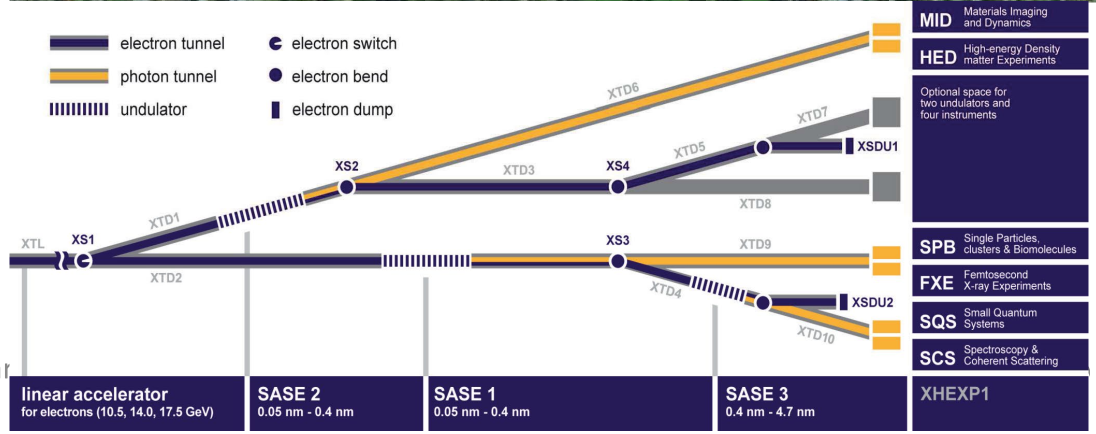
- **Laboratory resources**:
  - **not able to manage** large numbers in term of quality, man-power, optimized cost, scheduling respect, infrastructures, etc.

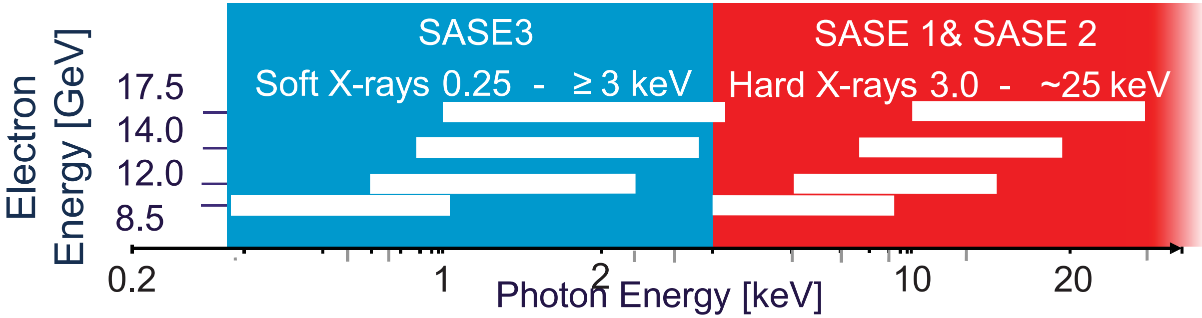
- **Criticalities**, **warnings** **(mainly for cavities):**
  - **Optimization of components design**: feasible for the production and for repairing action
  - **Stable and feasible preparation process**: **no R&D** during series production -> **high risk of delays!**
  - **Long production cycle**: from mechanical production to final steps some months -> **risk** of several **defective cavities** and a **long and expensive recovery process**
  - **High Quality Control (QA/QC plan) is a must**: diagnostic of large number of parameters during all production steps (failures mitigation)
  - **Preventive maintenance on plants**: mitigation of possible faults

European-XFEL 1.3 GHz Cavities

European XFEL





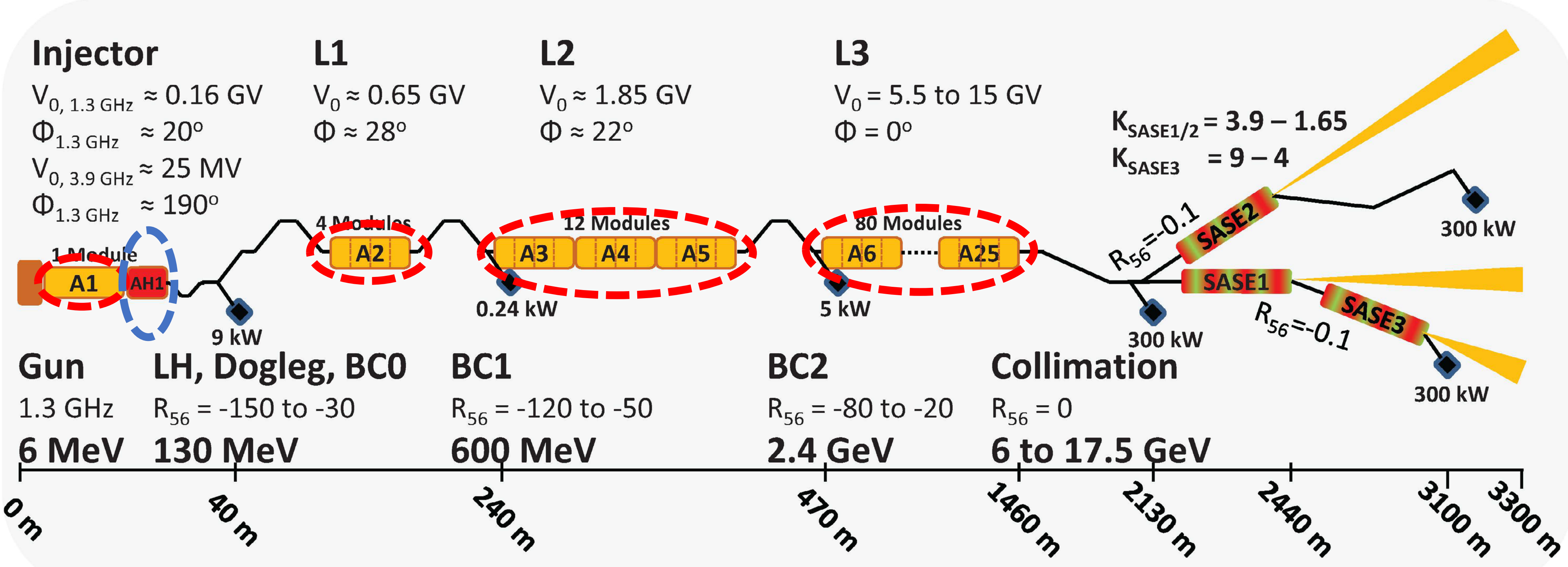


Mar

European XFEL

Italian in-kind contribution:

- 1.3 GHz: 320 cavities, 42 cryomodules, QC 800 tuners
- 3.9 GHz: 1 cryomodule, 20 cavities (blade tuners, He-tanks, magnetic shields)



Injector
$V_{0,\,1.3\ GHz} \approx 0.16$ GV
$\Phi_{1.3\ GHz} \approx 20^o$
$V_{0,\,3.9\ GHz} \approx 25$ MV
$\Phi_{1.3\ GHz} \approx 190^o$

L1
$V_0 \approx 0.65$ GV
$\Phi \approx 28^o$

L2
$V_0 \approx 1.85$ GV
$\Phi \approx 22^o$

L3
$V_0 = 5.5$ to 15 GV
$\Phi = 0^o$

$K_{SASE1/2} = 3.9 – 1.65$
$K_{SASE3} = 9 – 4$

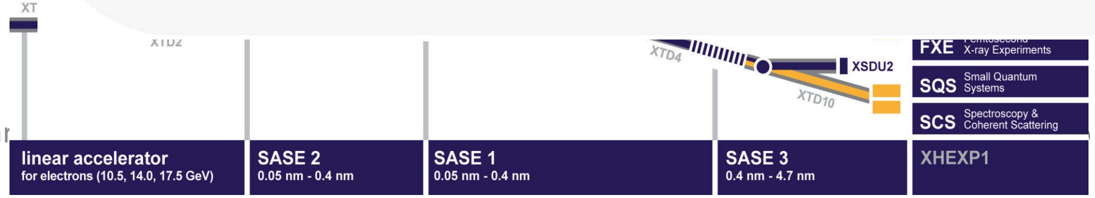
Gun
1.3 GHz
6 MeV

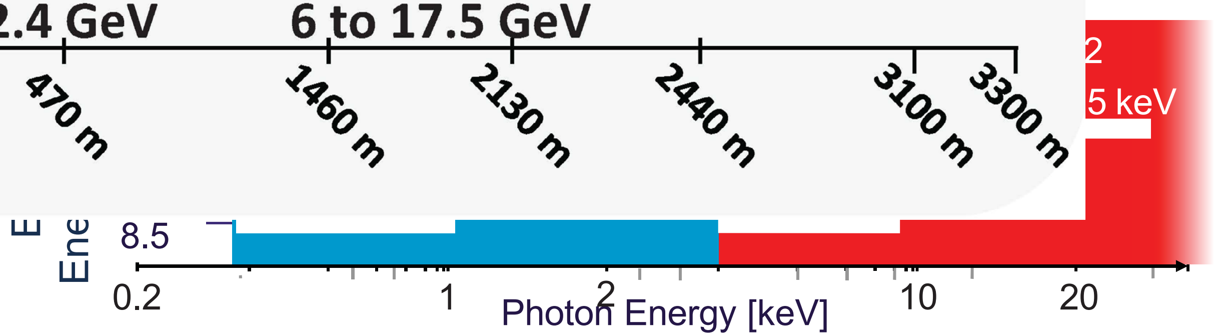
LH, Dogleg, BC0
$R_{56} = -150$ to -30
130 MeV

BC1
$R_{56} = -120$ to -50
600 MeV

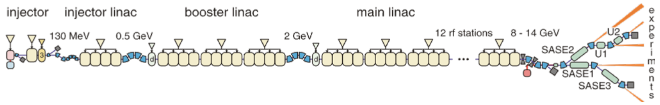
BC2
$R_{56} = -80$ to -20
2.4 GeV

Collimation
$R_{56} = 0$
6 to 17.5 GeV





European XFEL: 1.3 GHz series cavity



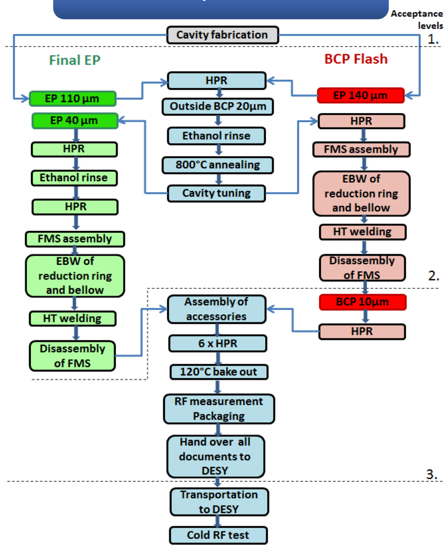
Purposes:

- **800** SC cavities, **3 Nb suppliers**, **2 industries**, **2 recipes** (**Final EP**/ **Flash BCP**)
- Average usable E-XFEL gradient
  - **23.6 MV/m @ Q_0=1x10^{10}, X-Rays <1x10^{-2} mGy/min**
- Delivery rate about **8 CVs/week**

How it worked:

- **Materials** and **vendors qualification** (Nb)
- **Definition of detailed production specs** (2 recipes), **PED 4.3** compliant (prototypes, TESLA experience)
- **Cavity producers qualification** (mechanical)
- **Technology transfer to industries**
- **Grown** and **qualification of insfrastrucutes**
- **Qualification of the transferred technology**
- **Set-up** of the «external**» QA/QC at industries**
- **Series cavities production: continuos monitoring of key parameters**
- **Prompt feedback of the running production quality** (analysis of VT vs. key parameters)

Final EP / Flash BCP


Acceptance levels

Cavity fabrication

1.

Final EP

EP 110 µm

EP 40 µm

HPR

Ethanol rinse

HPR

FMS assembly

EBW of reduction ring and bellow

HT welding

Disassembly of FMS

HPR

Outside BCP 20µm

Ethanol rinse

800°C annealing

Cavity tuning

BCP Flash

EP 140 µm

HPR

FMS assembly

EBW of reduction ring and bellow

HT welding

Disassembly of FMS

2.

BCP 10µm

HPR

Assembly of accessories

6 x HPR

120°C bake out

RF measurement Packaging

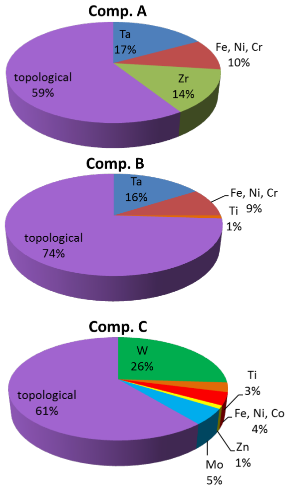
Hand over all documents to DESY

3.

Transportation to DESY

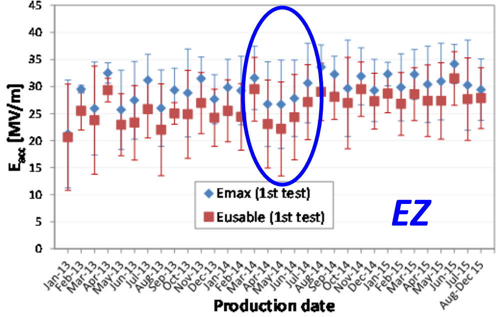
Cold RF test

Inclusions in Nb sheets

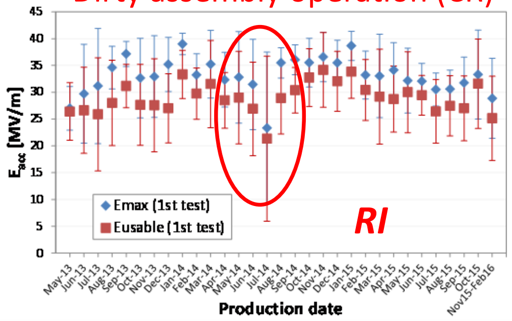


Analysis VT @ 2 K vs. running production quality

Mechanical defects



Dirty assembly operation (CR)




120 °C baking system (EZ)

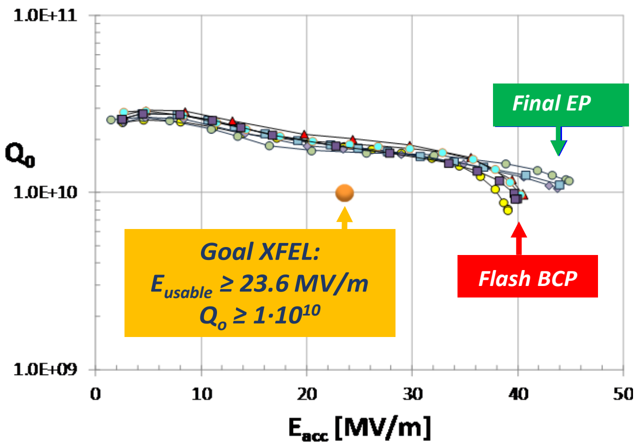

HPR cabinet (RI)


EBW (EZ)

European XFEL: 1.3 GHz series cavity results

Results:

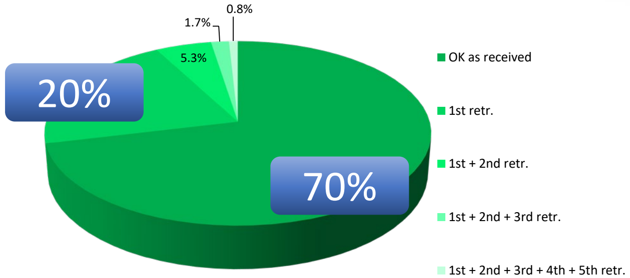
- **Accepted Cavities as Delivered: ≈ 70% (over 800)**
- After Additional Treatments (**mainly HPR**): **all cavities accepted**
- **Rejected Cavities** (replaced by companies)**: 8 (1%)**
- In total **3 years** (2013-2015)

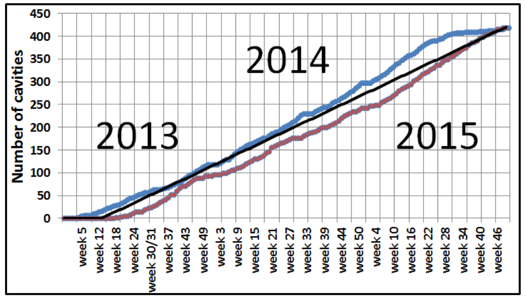


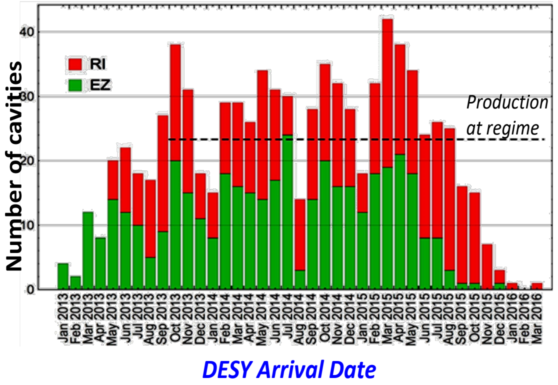
Goal XFEL:
E_{usable} ≥ 23.6 MV/m
$Q_o \geq 1\cdot10^{10}$

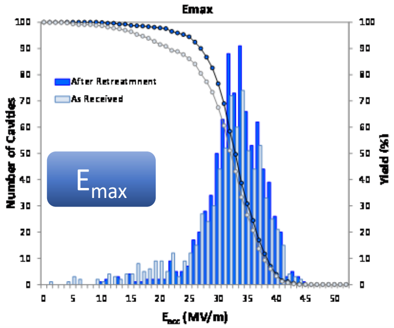
Cavities ready for the cold test at AMTF (DESY)

Cavity recovery history

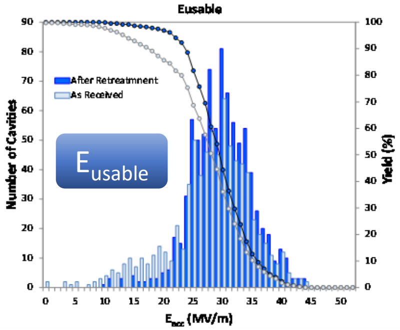




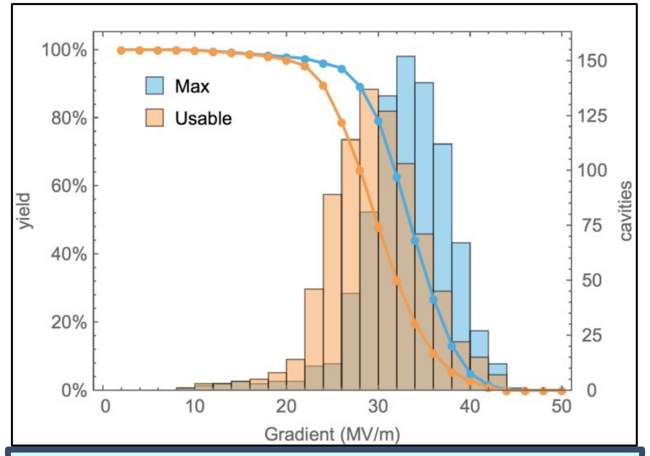




After 33.0 ± 4.8 [MV/m]
Before 31.4 ± 6.8 [MV/m]



After 29.8 ± 5.1 [MV/m]
Before 27.7 ± 7.2 [MV/m]

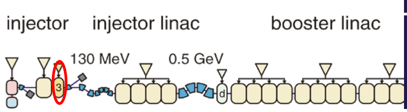


Final Performances

E_{max} = 33.0 ±4.8 [MV/m]
E_{usable} = 29.8 ±5.1 [MV/m]
Q_0 (23.6MV/m) = 1.4 ±0.2 [10^{10}]
(E_{goal} = 23.6 [MV/m], $Q_0 \geq 1\cdot10^{10}$)

European-XFEL 3.9 GHz Module

European XFEL: 3.9 GHz complete Cryomodule



European XFEL

Purposes:

- **10+10 Cavities, 1 Nb supplier, 1 industry, 1 recipe (BCP)**
- **3.9 GHz** E-XFEL **gradient 15 MV/m @ Q_0=1x10^9**
- **Cavity ancillaries:** Blade Tuners, magnetic shields, He-tank, etc.
- **Cryomodule:** cold mass, thermal shielding, etc.

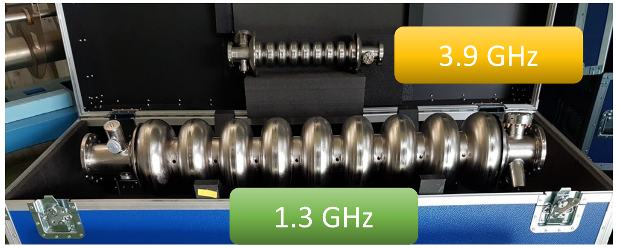
How it worked:

- **RF and mechanical design** of cavity
- **Recipe** developed also in collaboration with industry using **three prototypes, PED 4.3** compliant
- Industry and LASA **infrastructures adapted to 3.9 GHz geometry** (smaller) and **qualified** (BCP treatment, new HPR set-up, inner optical inspection system)
- **QC at industry and at LASA -> QC improved** (based on 1.3 GHz experience)
- **Production shared between Industry and LASA** (final steps in LASA clean room)
- **Cold VT (performance qualification) all done at LASA**


Mechanical production


BCP EZ


LASA clean room



PED Qualification

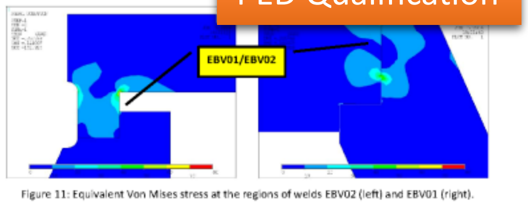


Figure 11: Equivalent Von Mises stress at the regions of welds EBV02 (left) and EBV01 (right).

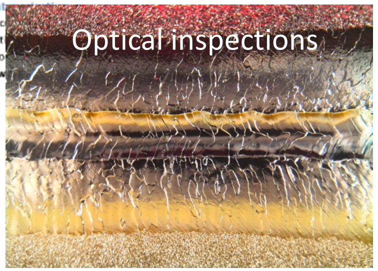
1.2.3 Stress linearization and stress cat

Since the most stressed regions are the Ti1 c

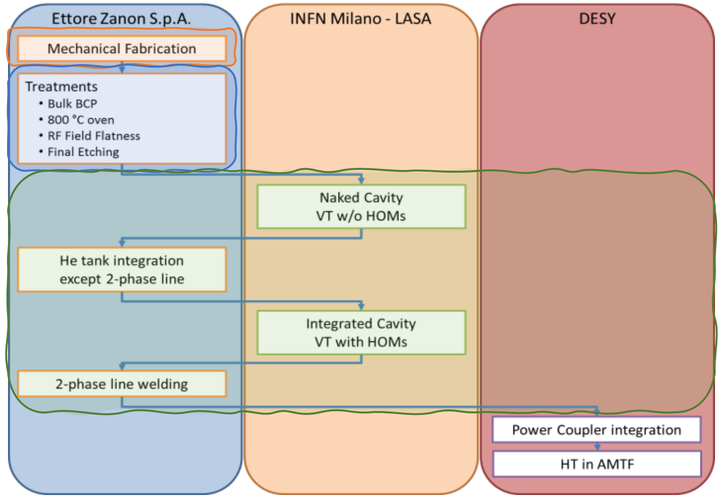
sections the stress linearization, categorizat

EN13445-3 will be performed only in the two

and in particular T04/T05 and EBV02, it w


Optical inspections

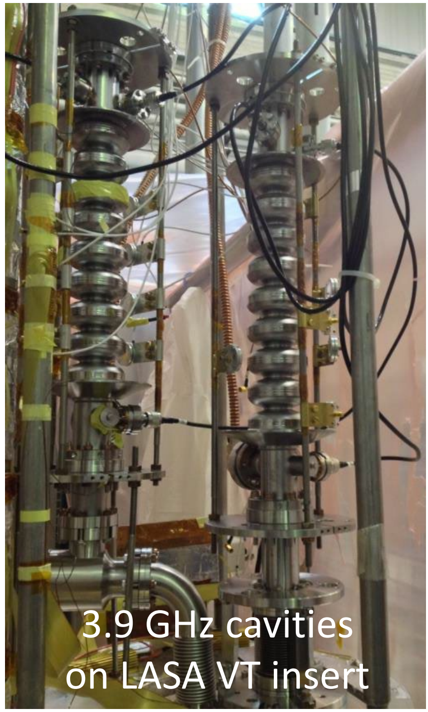
Production Cycle (3 acceptance levels)

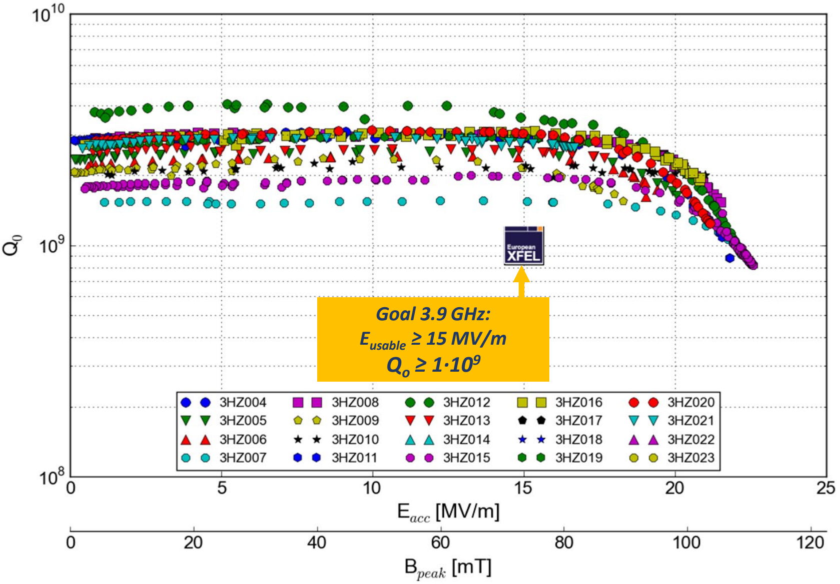


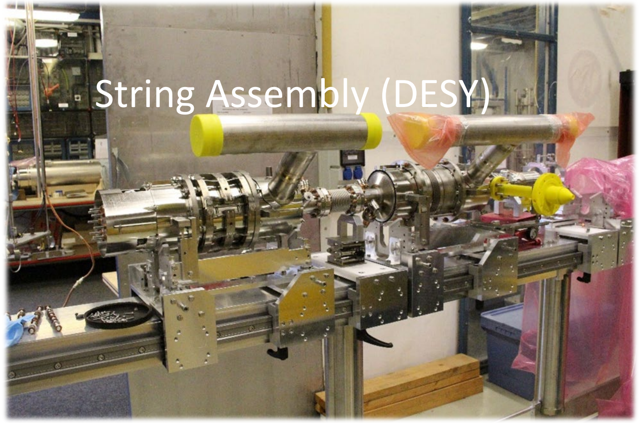
European XFEL: 3.9 GHz cavity and cryomodule results

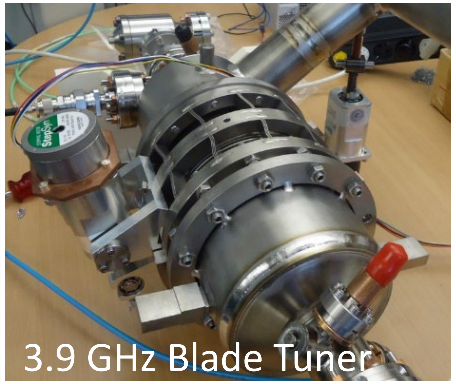
Results:

- **Accepted Cavities as Delivered: 85% of 20 overall**
- After Additional Treatments (**only HPR**): **all accepted**
- **Rejected Cavities: none**
- Delivery rate: **2 cavs/3 weeks**

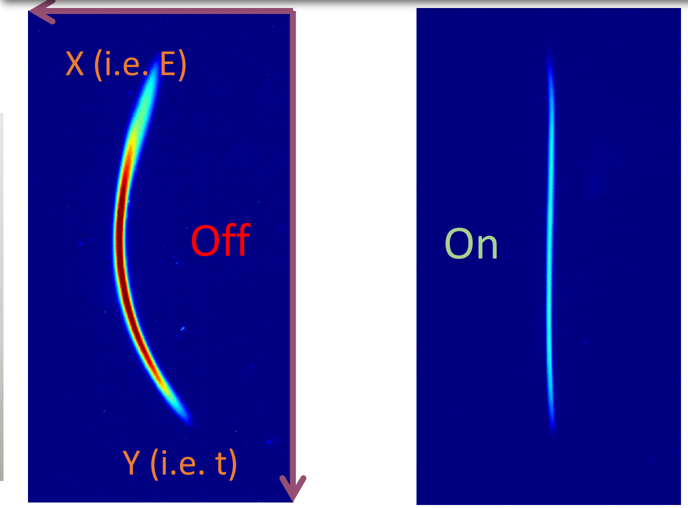

3.9 GHz cavities on LASA VT insert

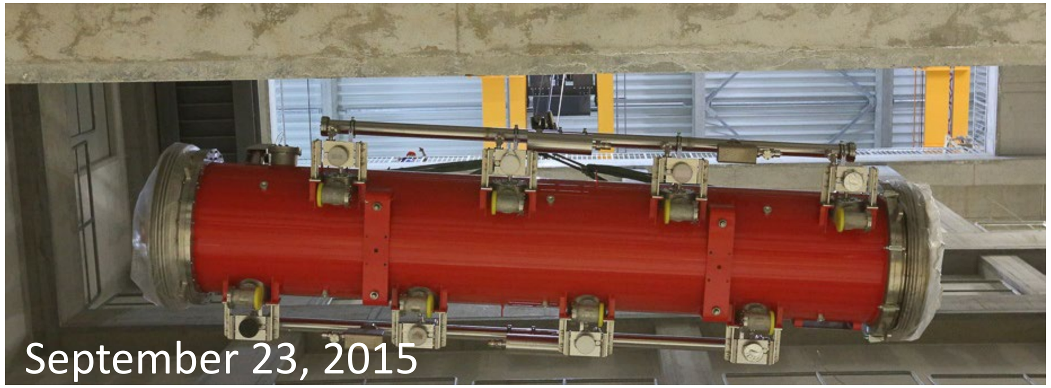



String Assembly (DESY)


3.9 GHz Blade Tuner

RF Curvature Linearization by AH1




September 23, 2015


3.9 GHz cavity ancillaries

ESS Medium Beta Cavities

European Spallation Source

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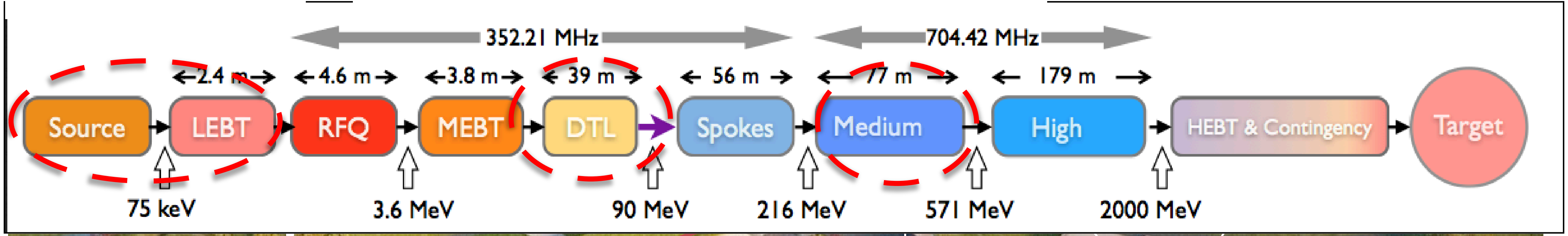


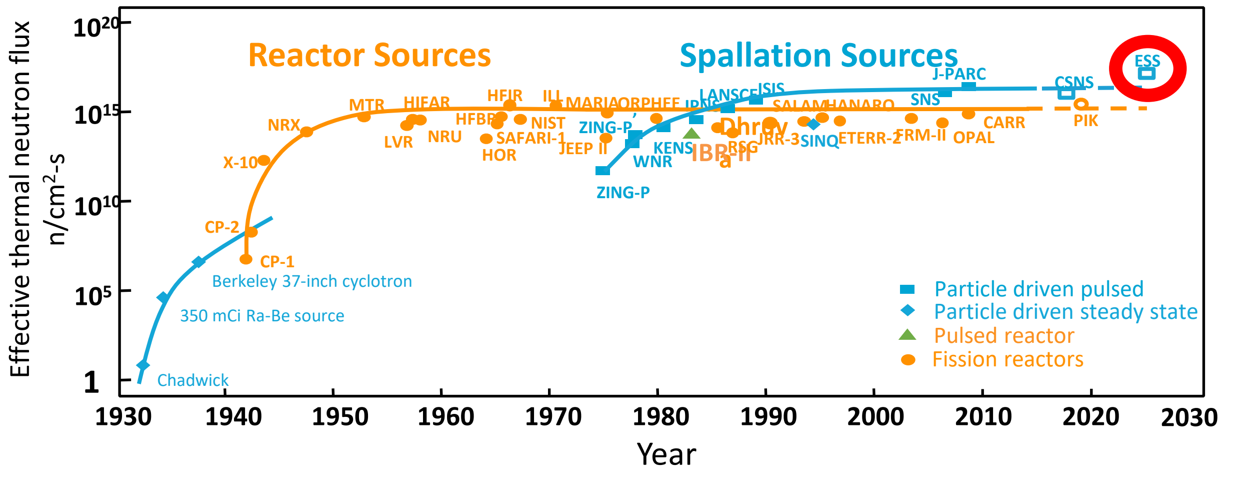
INFN - LNS **INFN – LNL&TO** **INFN - MI**

352.21 MHz 704.42 MHz

2.4 m 4.6 m 3.8 m 39 m 56 m 77 m 179 m

Source → LEBT → RFQ → MEBT → DTL → Spokes → Medium → High → HEBT & Contingency → Target

75 keV 3.6 MeV 90 MeV 216 MeV 571 MeV 2000 MeV



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

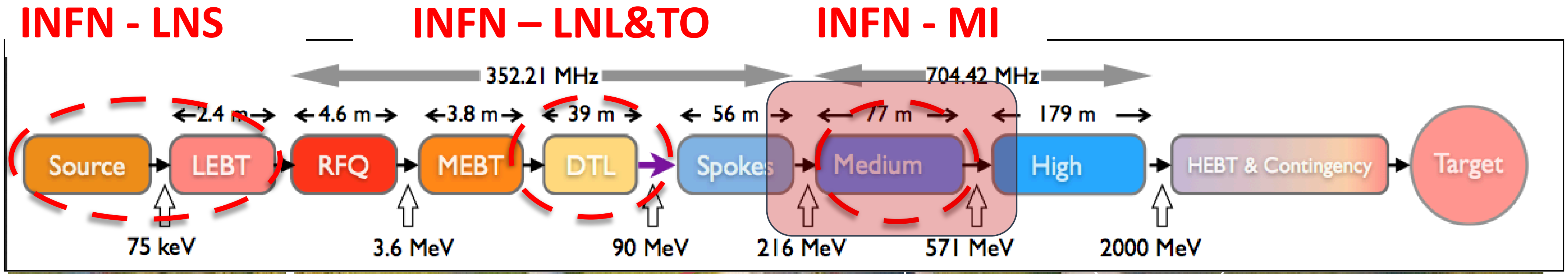
16 Instruments in Construction budget

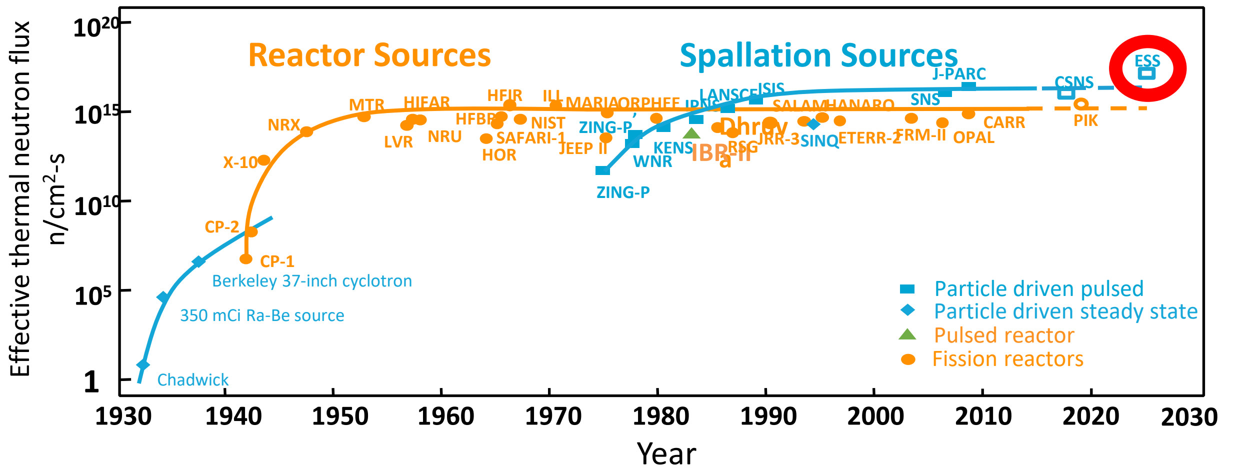
Committed to deliver 22 instruments by 2028

Peak flux ~30-100 brighter than the Institute Laue-Langevin

Total cost: 1843 MEuros$_{2013}$

European Spallation Source





(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

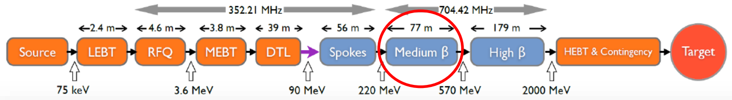
Total cost: 1843 MEuros$_{2013}$

16 Instruments in Construction budget

Committed to deliver 22 instruments by 2028

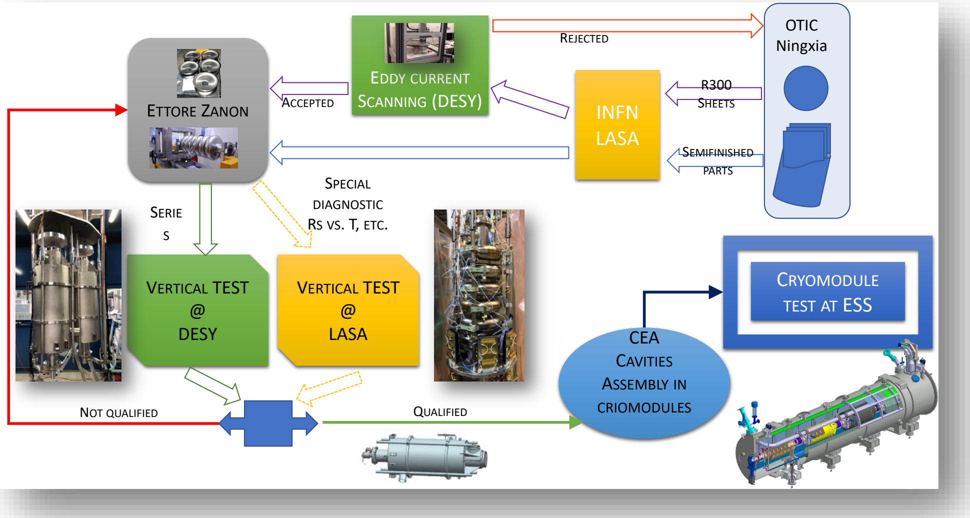
Peak flux ~30-100 brighter than the Institute Laue-Langevin

ESS: 704.4 MHz series cavity



Purposes:

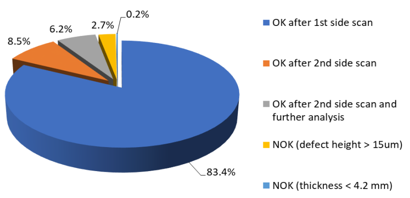
- **36** (+2) SC cavities, **1 Nb suppliers**, **1 industry**, **1 recipe** (BCP)
- ESS medium β (0.67) **E_{acc} ≥ 16.7 MV/m @ Q_0 ≥ $5 \cdot 10^9$**

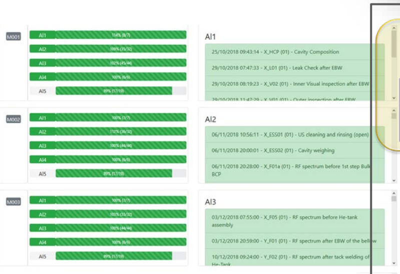


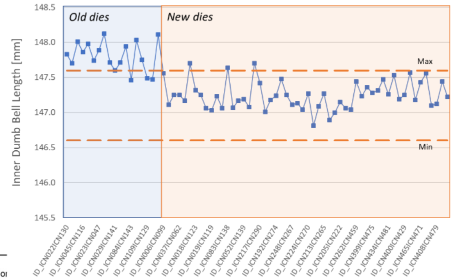
How it is working:

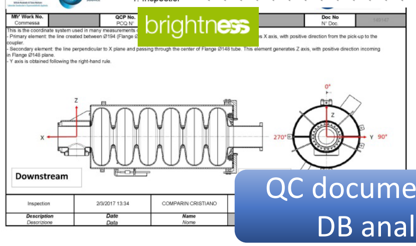
- **Definition of Nb specs** and **QC** (inspection at **Nb** vendor, **ECS** at **DESY)**
- **Optimization** of the **RF** and **mechanical design**
- **Definition of detailed production specs** (1 recipe), **PED sound engineering practice** compliant (3 prototypes)
- **Infrastructures adapted** to **704.4 MHz larger geometry** and **qualified** (BCP treatment, new HPR head geometry, new inner inspection system, EP treatment, tuning machine)
- **Definition of the QC plan** -> **QC improved** for the **interfaces between all partners** (INFN-Industry-DESY-CEA-ESS)
- **Management** of all documentation (INFN Alfresco based) and **database** developed for **analysis of key production parameters**
- **Cold VT at LASA** for «special» cavities (more diagnostics available)

ECS Nb sheets (DESY)









1. Inspectio

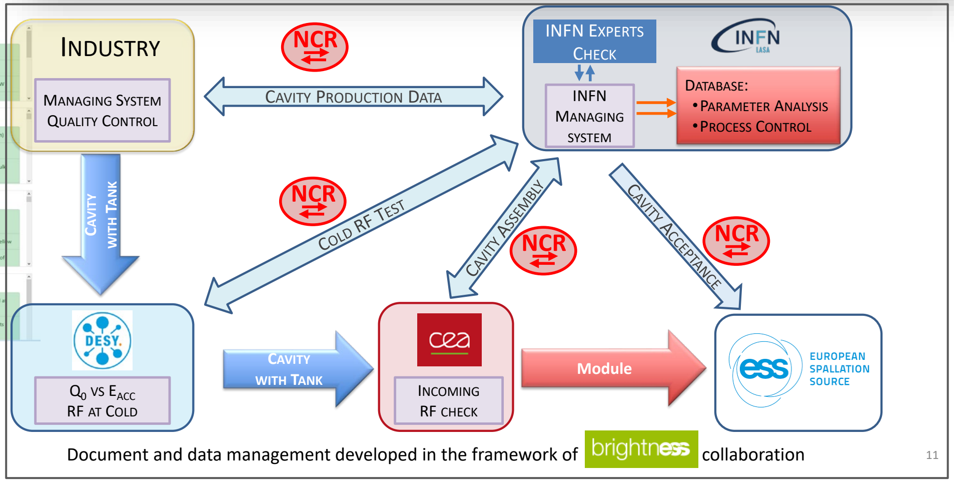
Mfr' Work No. Commessa		QCP No. PCQ N°		Doc No N° Doc.	

This is the coordinate system used in many measurements

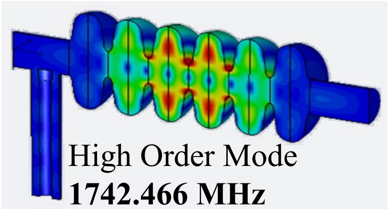
- Primary element: the line created between Ø194 (Flange Ø … s X axis, with positive direction from the pick-up to the coupler.
- Secondary element: the line perpendicular to X plane and passing through the center of Flange Ø148 tube. This element generates Z axis, with positive direction incoming in Flange Ø148 plane.
- Y axis is obtained following the right-hand rule.

Inspection	2/3/2017 13:34	COMPARIN CRISTIANO
Description *Descrizione*	***Date*** *Data*	***Name*** *Nome*

QC documents and DB analysis



Document and data management developed in the framework of brightness collaboration



High Order Mode 1742.466 MHz

He tank integration

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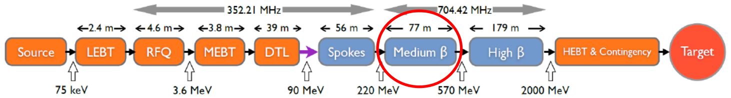
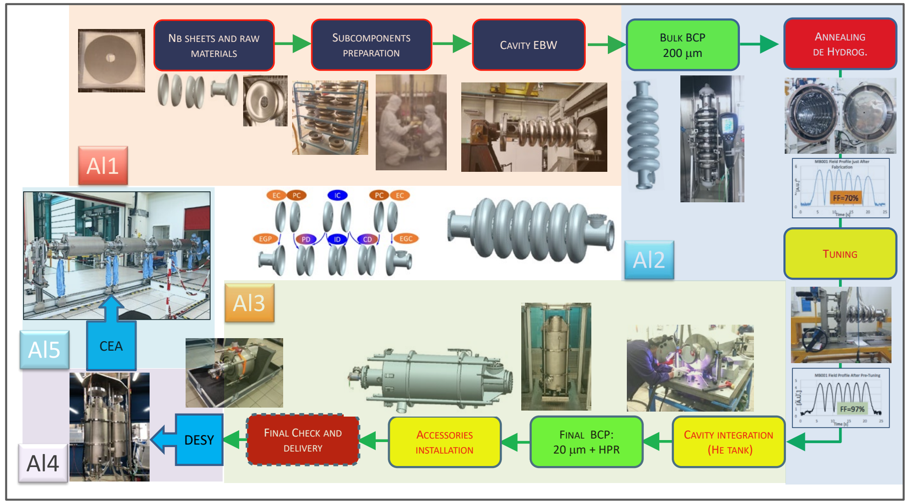
ESS: 704.4 MHz series cavity results



Results:

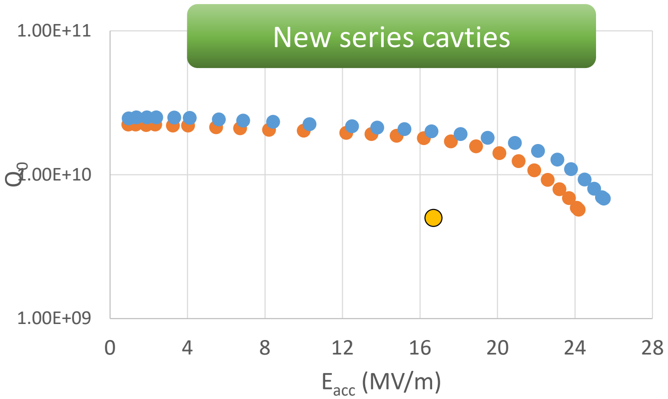
- **Cavities at CEA for string assembly (cryomodule): 34 (+1 spare)**
- **Accepted Cavities as Delivered: 27**
- Recovered after Additional Treatments
  - **HPR**: **3**; **EP**: **3**
- Further 4 cavities produced (**EP cycle**):
  - **2 at CEA** for string assembly, **2 qualified** (VT)
- **Cavities in quarantine: 5**

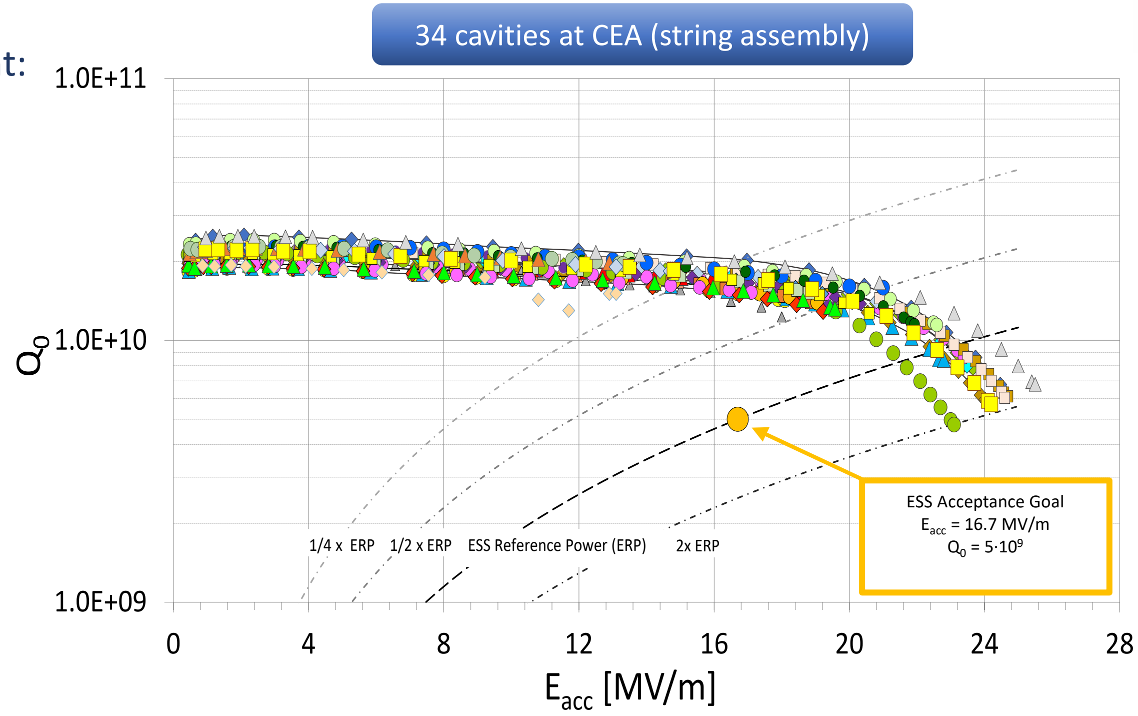



ESS cavity on LASA insert

Recovery strategy:

- **HPR improved** to better fit the **cell shape** (new head), **EP** adapted to ESS shape for surface treatment: -> **performance improvement of poor cavities**
- **rotating BCP:** -> **some performance improvement**
- **Risk mitigation with 4 new cavities** produced: -> **all** cavities **overcome ESS goal** (EP process)

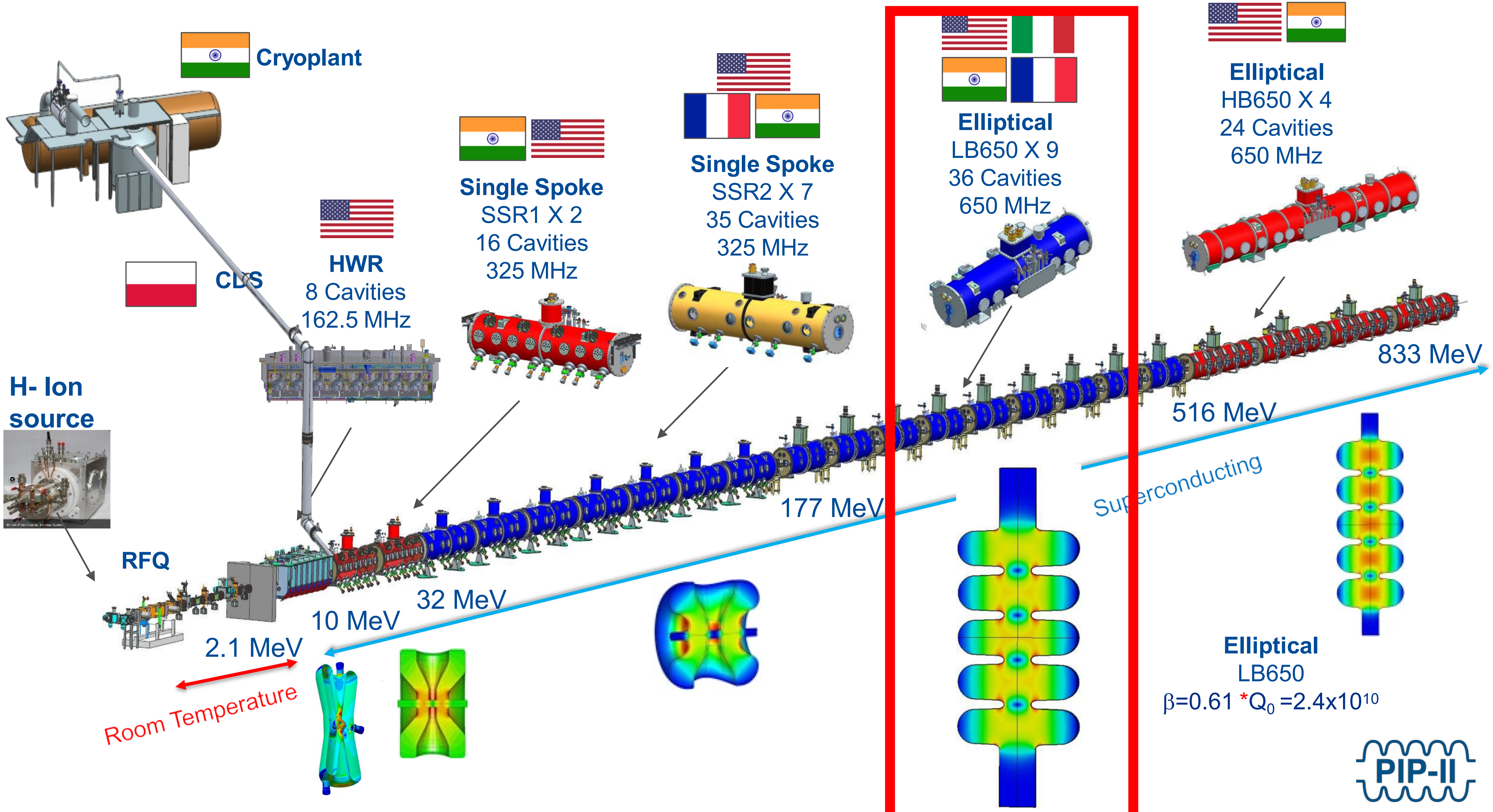




ESS Acceptance Goal
E_{acc} = 16.7 MV/m
$Q_0 = 5\cdot10^9$

PIP-II LB650 MHz

PIP-II: SC RF CW linac, 2mA, 800 MeV



Cryoplant

CDS

H- Ion source

RFQ

HWR
8 Cavities
162.5 MHz

Single Spoke
SSR1 X 2
16 Cavities
325 MHz

Single Spoke
SSR2 X 7
35 Cavities
325 MHz

Elliptical
LB650 X 9
36 Cavities
650 MHz

Elliptical
HB650 X 4
24 Cavities
650 MHz

2.1 MeV

10 MeV

32 MeV

177 MeV

516 MeV

833 MeV

Room Temperature

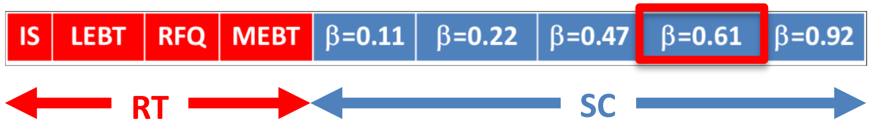
Superconducting

Elliptical
LB650
$\beta=0.61$ *$Q_0=2.4\times10^{10}$

PIP-II

Seminario INFN Acceleratori – 10 Novembre 2023

PIP-II: INFN in-kind contribution

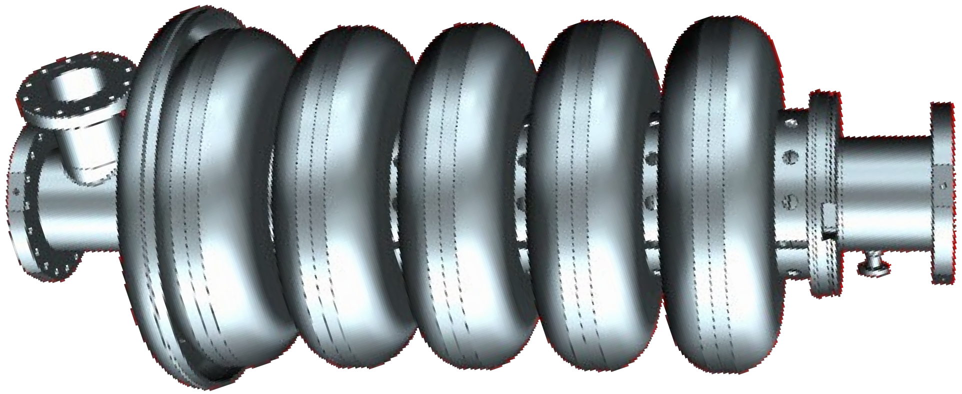


PIP-II LB650 Project Specifications	
Acc. Gradient	**16.9 MV/m**
Q_0	**$2.4\ 10^{10}$**
RF rep rate	20 Hz to CW
Beta	0.61

INFN LASA firstly provided a ***novel RF design for the LB650 cavities***, compatible with the Fermilab technical interfaces and performances specifications.

INFN-LASA contribution will cover the needs of LB650 section, and this includes:

- **38 SC cavities** required to equip **9 cryomodules** with 2 spares, delivered **as ready for string assembly**.
- **Qualification** via vertical cold-test provided by INFN through a **qualified cold-testing infrastructure** acting as a subcontractor
- **Compliance** to the **PIP-II System Engineering Plan**



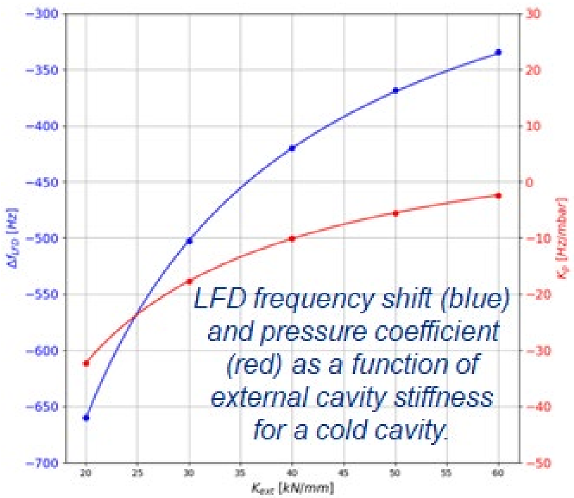
INFN Deliverable Components	Acceptance Early Date
LB Jacketed Cavities (Batch 1 - Qty 4) and Pre-Series (Qty 2)	May-2025
LB Jacketed Cavities (Batch 2 - Qty 4)	Jun-2025
LB Jacketed Cavities (Batch 3 - Qty 4)	Aug-2025
LB Jacketed Cavities (Batch 4 - Qty 4)	Oct-2025
LB Jacketed Cavities (Batch 5 - Qty 4)	Dec-2025
LB Jacketed Cavities (Batch 6 - Qty 4)	Feb-2026
LB Jacketed Cavities (Batch 7 - Qty 4)	Apr-2026
LB Jacketed Cavities (Batch 8 - Qty 4)	Jun-2026
LB Jacketed Cavities (Batch 9 - Qty 4)	Aug-2026

PIP-II: LB650 cavity challenges

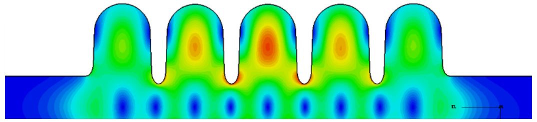
PIP-II **LB650 cavities** are among the key scientific **challenges** of the project:

- an **unprecedented quality factor** is required for these resonators.
- Accelerating and **High-Order Modes** must be assessed so that neither instabilities nor additional cryogenic losses are posing critical issues.
- PIP-II operational scenario is **an uncharted territory in terms of detuning control**
  - Requires deep understanding of Lorentz Force detuning, pressure sensitivity and mechanical leading parameters as rigidities, yield limits, stresses.
- Detailed finite element analysis to ensure **compliancy to ASME codes**.

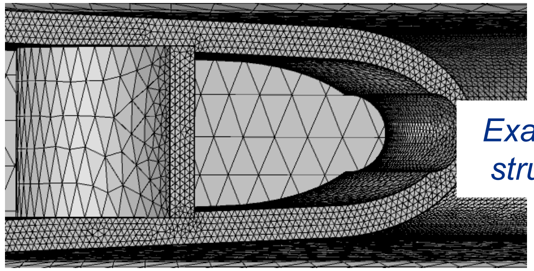
INFN LB650 for PIP-II, cold cavity	
$\beta_{geometric}$	0.61
Frequency	650 MHz
Number of cells	5
Iris diameter	88 mm
Cell-to-cell coupling, k_{cc}	0.95 %
Frequency separation π-4π/5	0.57 MHz
Eq. diameter - IC	389.8 mm
Eq. diameter - EC	392.1 mm
Wall angle – Inner-End cells	2 °
Effective length (10*L_{hc})	704 mm
Optimum beta β_{opt}	0.65
E_{peak}/E_{acc} @ β_{opt}	2.40
B_{peak}/E_{acc} @ β_{opt}	4.48 mT/(MV/m)
R/Q @ β_{opt}	340 Ω
G @ β_{opt}	193 Ω
Inner cells stiffening radius	90 mm
External cells stiffening radius	90 mm
Wall thickness	4.2 mm
Longitudinal stiffness	1.8 kN/mm
Longitudinal frequency sensitivity	250 kHz/mm
LFD coefficient *k_{ext} at 40 kN/mm*	-1.4 Hz/(MV/m)^2
Pressure sensitivity *k_{ext} at 40 kN/mm*	-11 Hz/mbar
Maximum Pressure *VM stress at 50 MPa*	2.9 bar
Maximum Displacement *VM stress at 50 MPa*	1.5 mm

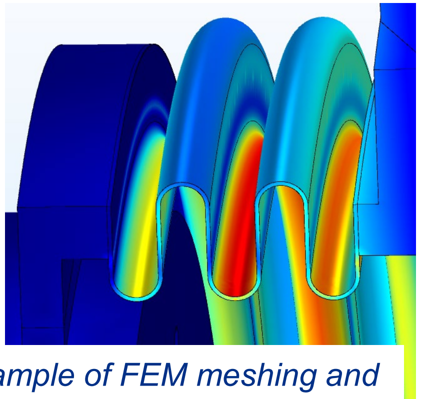


LFD frequency shift (blue) and pressure coefficient (red) as a function of external cavity stiffness for a cold cavity.



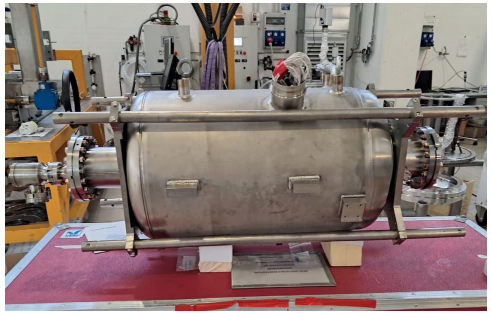
Last HOM in 3rd monopole passband





Example of FEM meshing and structural analyses on LB650

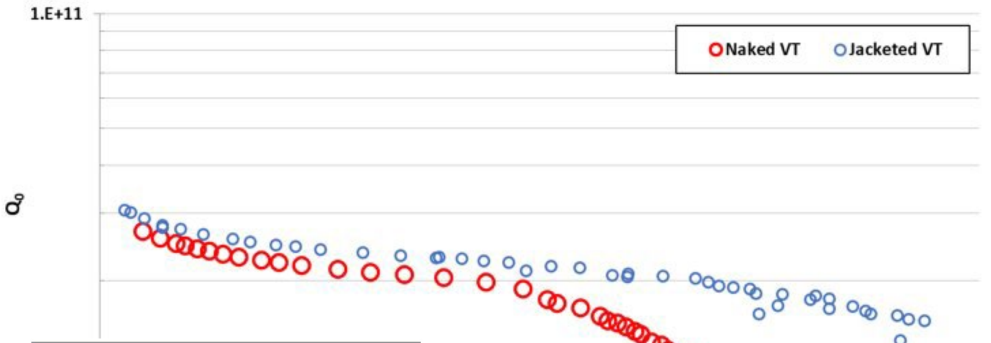
PIP-II: LB650 cavity on-going activities

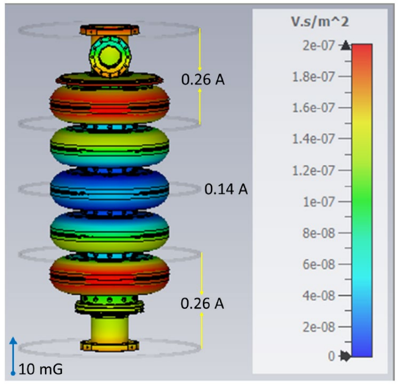


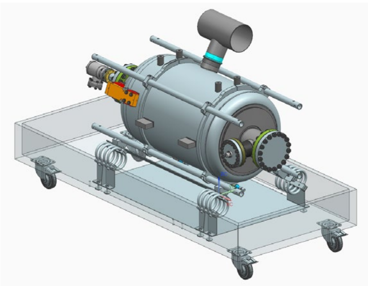
R&D towards high Q_0 and **preparation for transfer to industry**

- Prototypes to **develop proper surface treatments**
    - B61-EZ-001 jacketed and tested at FNAL
    - B61-EZ-002 jacketed and tested at LASA
    - B61S-EZ-001 single cell treated and tested at FNAL
    - B61S-EZ-002 treated, jacketed and tested at LASA
    - B61S-EZ-003 single cell to be processed
- **Develop diagnostic** for process control
- Analytical Field-Emission model
- **Cavity transport boxes** developed, prototypes built
- Prepare **LASA test station** for **high Q_0** measurements
    - Lower residual magnetic field, Helmholtz coils
    - Faster cool-down rate across SC transition

B61-EZ-002 - Naked vs. Jacketed VT







Main procurements in view of the series production

- **RRR300 Nb tender:** 1st batch inspected in Oct. 23, delivery in one month than ECS
- Agreement with DESY in progress for **Eddy current scanning** and **series cavity vertical tests**
- **Cavity manufacturing, treatment and preparation**: CFT open, then selection and awarding

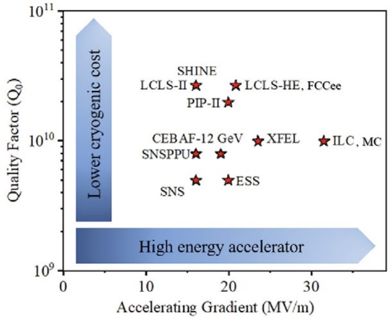
SRF Future activities

- **Future activities** on SRF cavities:
  - **PIP-II series production:**
    - **QC** on **material** for cavity production
    - continue **R&D with prototypes** (single and multicell) to **improve process parameters** for the **series production**
    - Work on the **QC measurements and checks** and definition of the **“external” QC**
  - **R&D towards European Strategy:**
    - HighQ/HighG cavity performances R&D in view of the EU Strategy (**ILC Technical Network**, **muon collider**)
    - Tuner studies (muon collider)
    - Staff exchange between Eu, Japan and US for SRF experience sharing (**EAJADE**)
  - **BriXSinO:**
    - An ERL technology demonstrator that see our group involved for the SRF sections (Buncher and linac)
    - Call HB^{2}TF already funded and under construction at LASA for the BriXSinO injector

INFN High-Q / High-G R&D activities

Cost reduction & sustainability for future machine

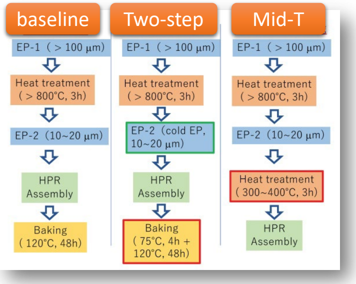
- ➢HighQ -> power saving
- ➢HighG -> shorter machine



R&D on High-Q/High-G cavities (ILC and muon collider):

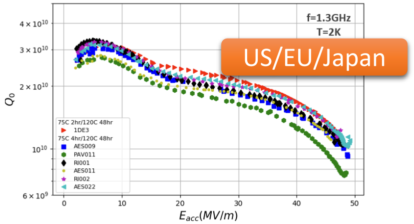
- 1-cells 1.3 GHz: **surface** and **thermal treatments** development & qualification
- 9-cells 1.3 GHz: **industrialization** (9-cells)
- **Cold frequency tuners**
- **FG** and **MG Nb**
- **Synergies:**
  - ITN (ILC Technology Network) & EAJADE

ILC goal: E_{acc} = 35 MV/m @ $Q_0 \geq 1 \cdot 10^{10}$

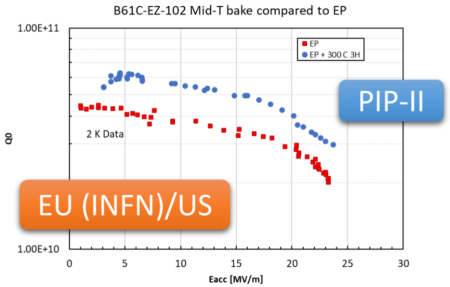


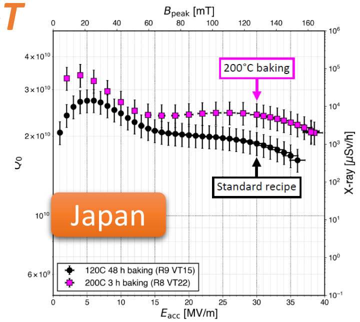
baseline	Two-step	Mid-T
EP-1 (> 100 μm)	EP-1 (> 100 μm)	EP-1 (> 100 μm)
Heat treatment (> 800°C, 3h)	Heat treatment (> 800°C, 3h)	Heat treatment (> 800°C, 3h)
EP-2 (10~20 μm)	EP-2 (cold EP, 10~20 μm)	EP-2 (10~20 μm)
HPR Assembly	HPR Assembly	Heat treatment (300~400°C, 3h)
Baking (120°C, 48h)	Baking (75°C, 4h + 120°C, 48h)	HPR Assembly

Two-step



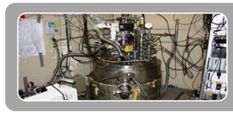
Mid-T





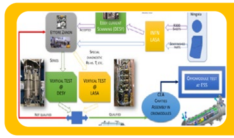
Development of production processes for the SRF cavities

- Cavity Surface treatments on single-cells: etching, annealing and rinsing
- From the E-XFEL like baseline to current state-of-the art (e.g. *Two-step* and *Mid-T* baking)



Cavity vertical cold-tests

- Qualification of surface treatments
- Consistency between results from different labs and testing infrastructures



Industrialization process

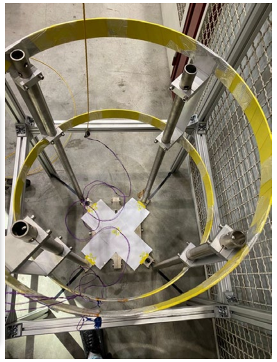
- Knowhow transfer to vendor
- High Pressure Gas Safety (HPGS) compliant design
- External Quality Control and Quality Acceptance system

Cold Frequency Tuners

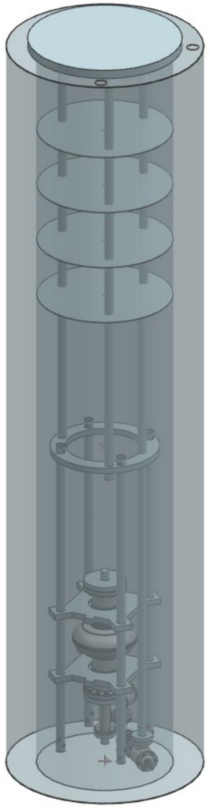
- Design and development of prototypes
- Large scale production

New cryostat dedicated to R&D:

- Design specifically for R&D on TESLA type single- and multi-cell cavities
- Much faster overall work cycle compared to main cryostat
  - Optimized insert installation and removal process
  - Liquid Helium inventory needed for a test down by almost 4 times
  - Active B-field compensation by design
- Procurement in progress, detailed technical design soon released.



Helmholtz coils for the new cryostat (based on PIP-II experience)

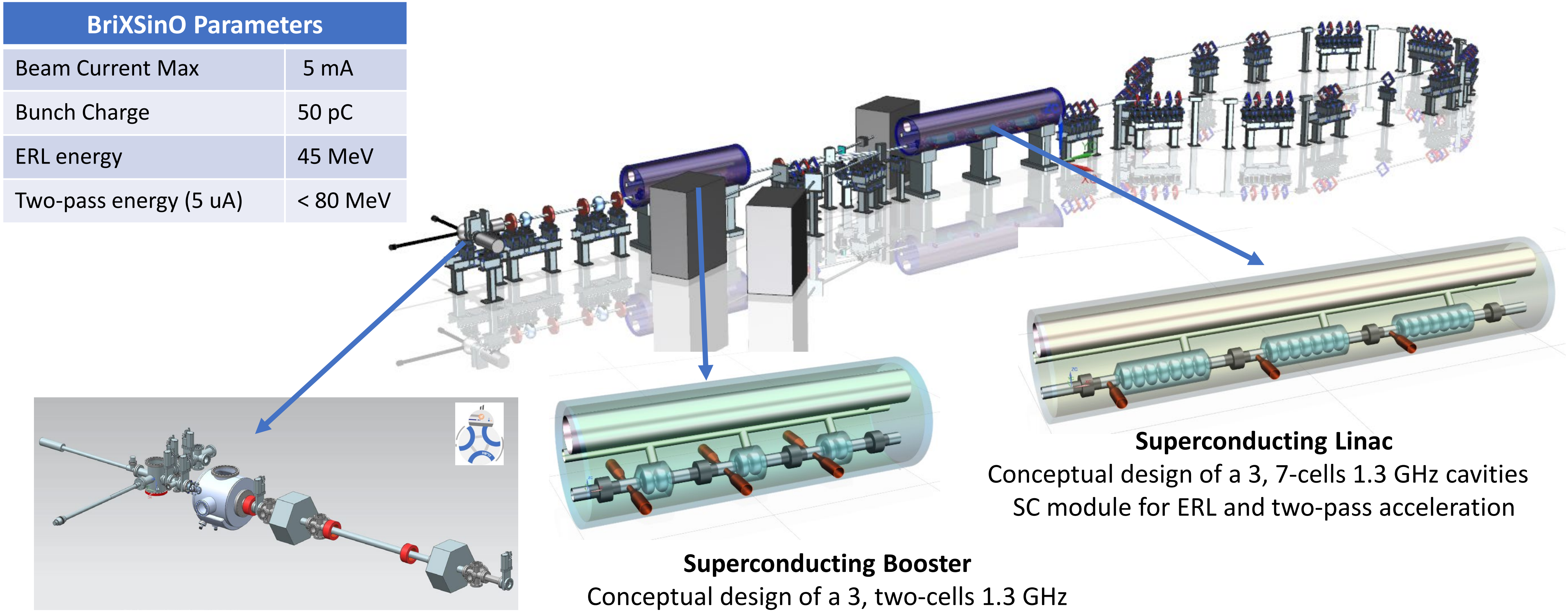


Draft sketch of R&D cryostat and insert

Activities for BriXSinO

... **BriXSinO** aims at developing at INFN LASA laboratory **a test-facility** that would enable **addressing the physics and technology challenges posed by the ERL generation** ...

BriXSinO Parameters	
Beam Current Max	5 mA
Bunch Charge	50 pC
ERL energy	45 MeV
Two-pass energy (5 uA)	< 80 MeV



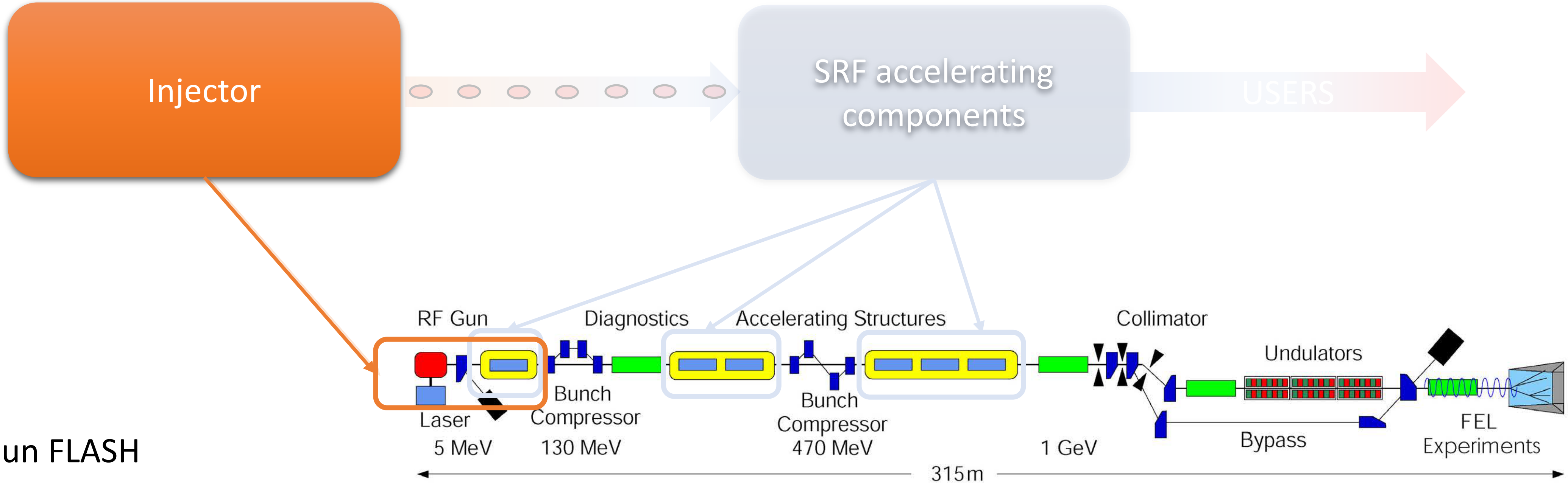
Superconducting Linac
Conceptual design of a 3, 7-cells 1.3 GHz cavities SC module for ERL and two-pass acceleration

Superconducting Booster
Conceptual design of a 3, two-cells 1.3 GHz cavities Superconducting module

HB^{2}TF – A 5mA 300 kV **DC gun injector** with photocathode and bunchers
2023-2025

SRF and Photocathode Expertise

- Superconducting RF cavities (and ancillaries) development
- Photocathodes for high brightness injectors development

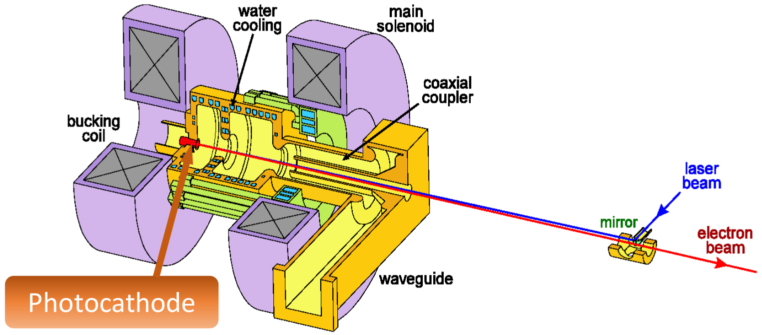


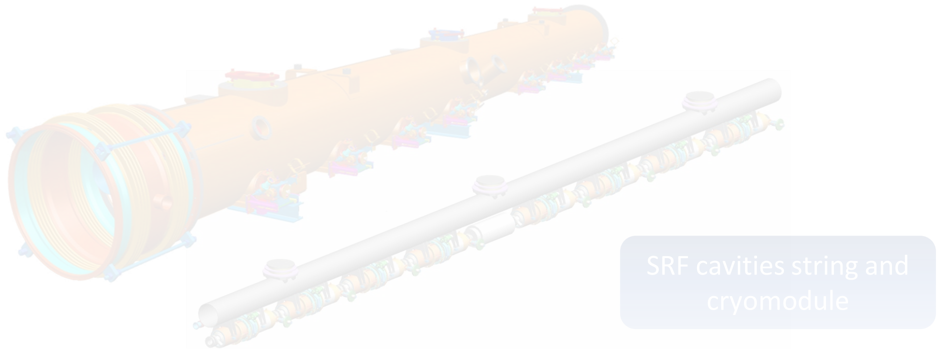
Injector

SRF accelerating components

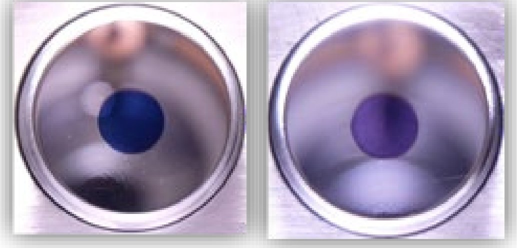
USERS

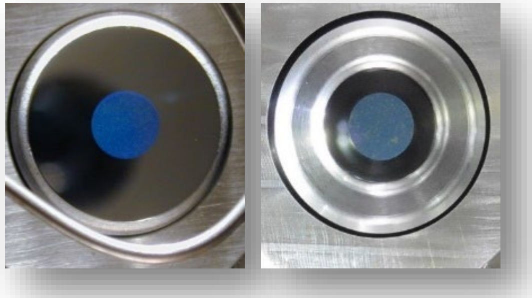
RF Gun FLASH

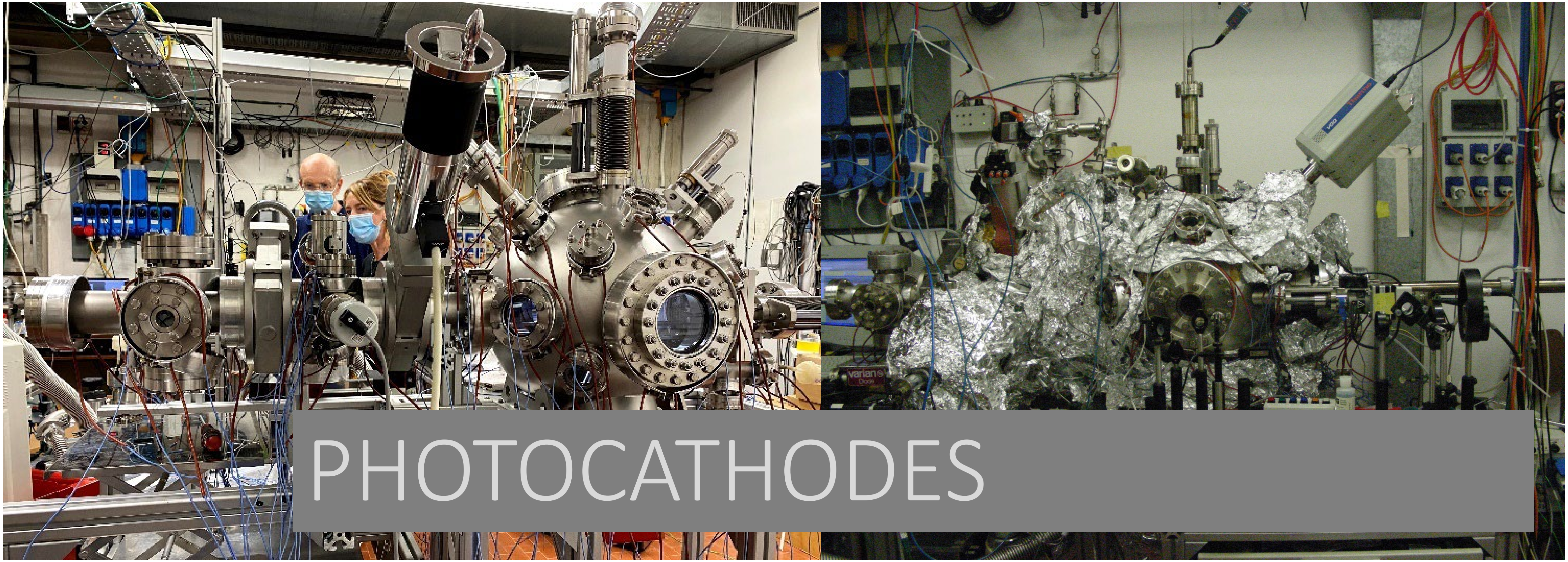




SRF cavities string and cryomodule



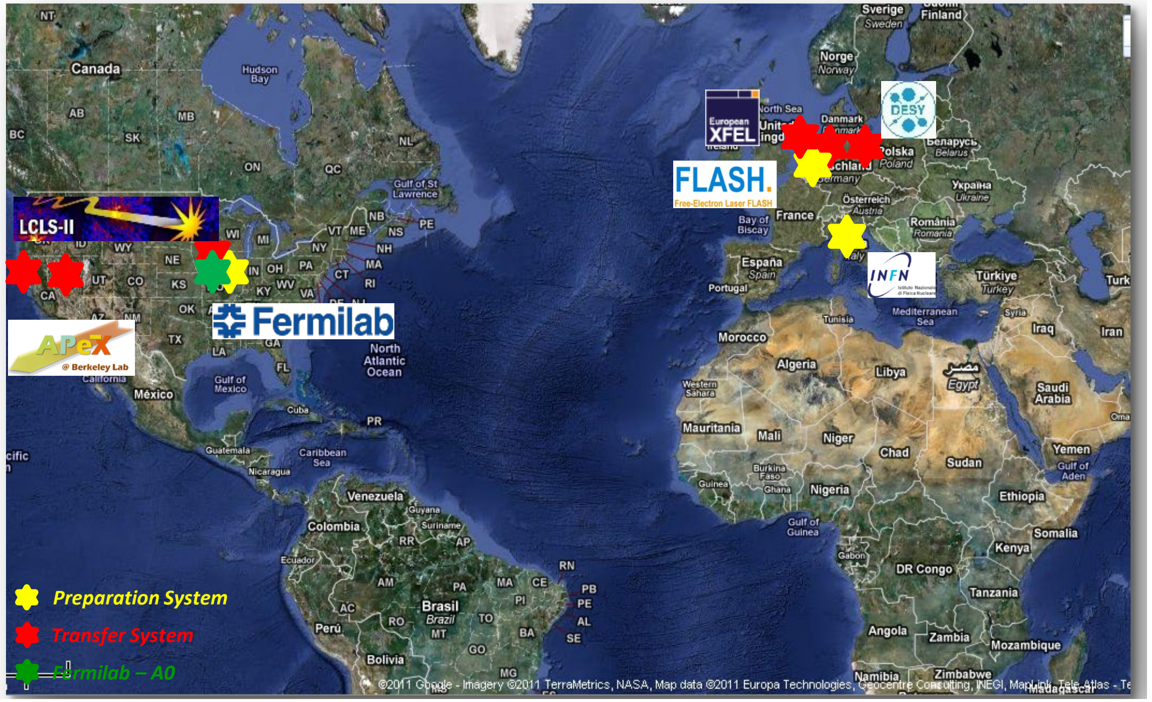


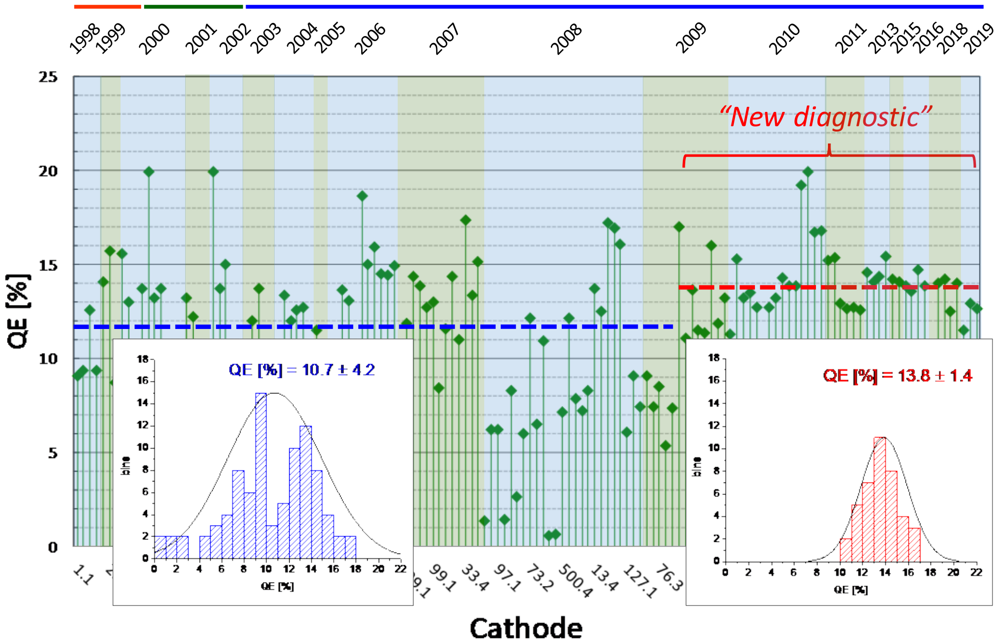


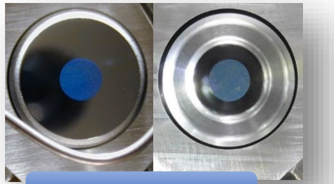
PHOTOCATHODES

Photocathodes for High Brightness Photoinjectors

- INFN LASA photocathode lab is providing high QE **Cs_2Te photocathodes** since '90s (more than **150** photocathode produced) to different labs for **high brightness** RF electron gun operation, representing the **state of the art** in this field.
  - DESY (FLASH, PITZ, REGAE)
  - E-XFEL
  - APEX (LBNL)
  - FAST (FNAL)
  - LBNL for the LCLS II commissioning (SLAC)
- We have also produced **preparation systems** for **DESY Hamburg** and **FNAL** and **Gun transfer systems**

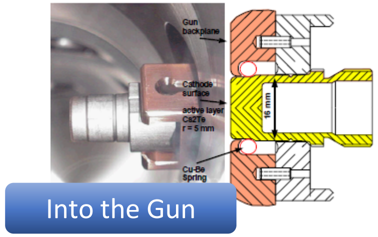






Film in Cs_2Te

INFN plug



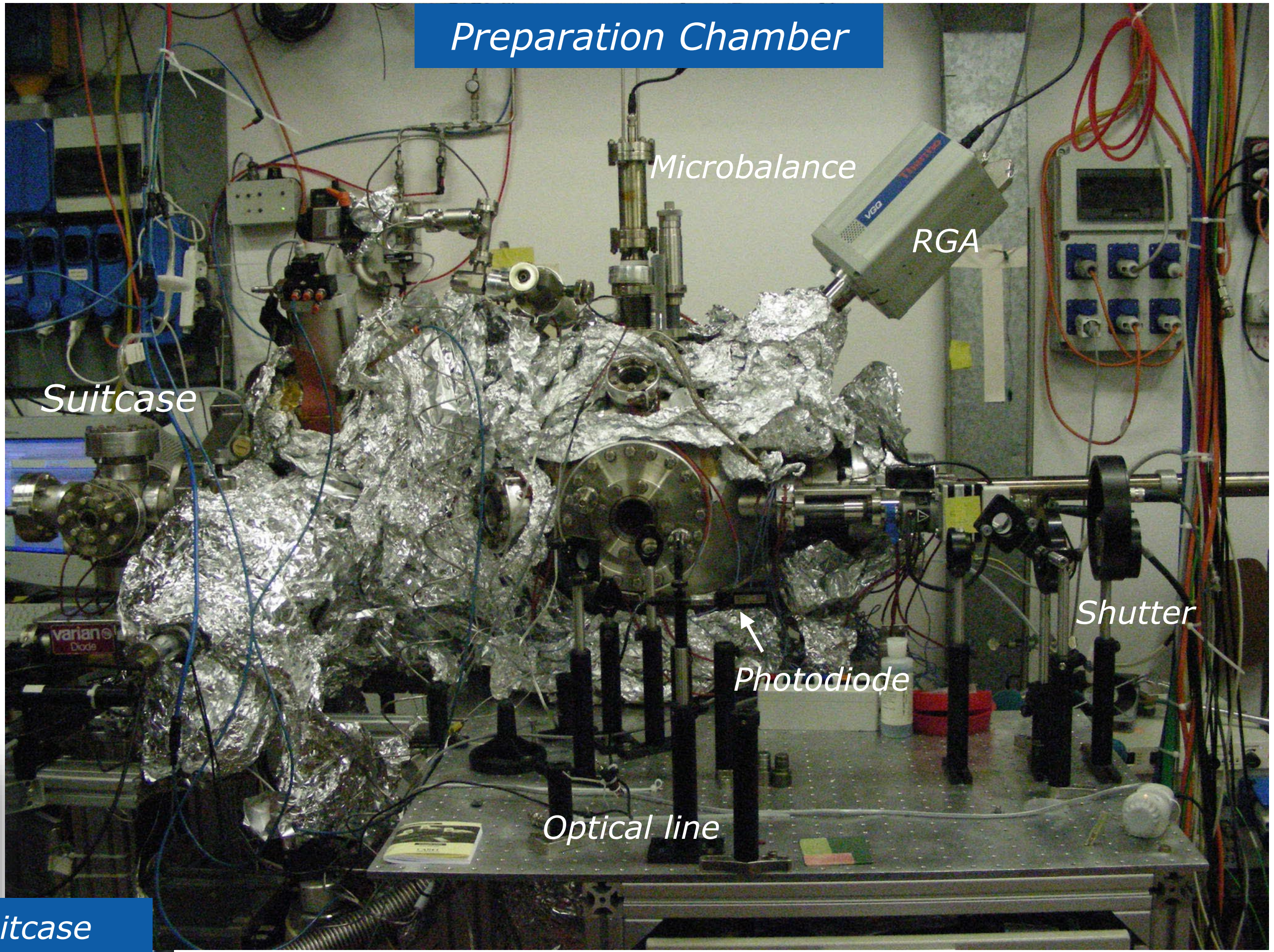
Into the Gun

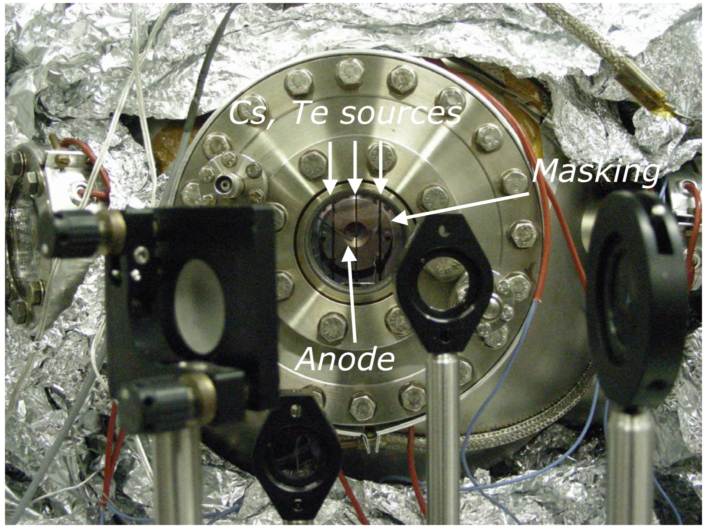
INFN LASA photocathode system:

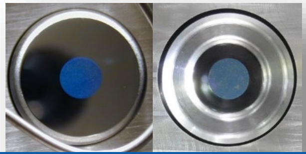
- p ≈ 10^{-10} mbar (deposition chamber, suitcase, gun transfer system)
- R&D is always running to satisfy coming user/facility requests

Photocathodes Production: How it works

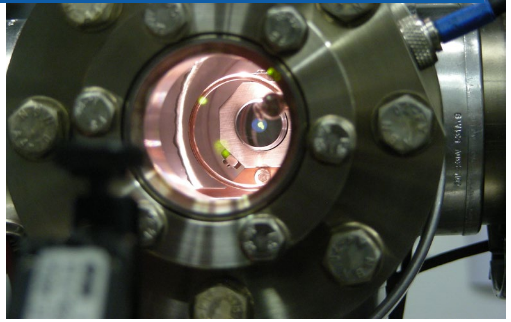
- **System**:
  - **Preparation** chamber (base pressure 10^{-10} mbar)
  - Transport box «**suitcase**» (base pressure 10^{-10} mbar)
  - **Transfer chamber to RF Gun** (base pressure 10^{-10} mbar)
  - **Carrier** to hold and exchange plugs
- **Diagnostic** for growing and characterization:
  - Hg-Xe lamp: filters (239 nm ÷ 436 nm), main λ = 254 nm
  - Reflectivity (power meter) and QE (picoammeter)
  - Microbalance for thickness measurement
  - RGA for vacuum quality control
- **Masking system:** 5 mm (changeable)
- **Mo plugs shapes:** compatible with all systems


Preparation Chamber



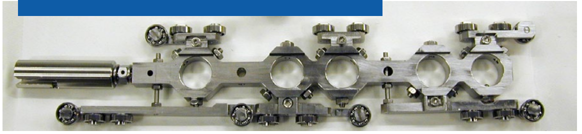


Cathode in the suitcase

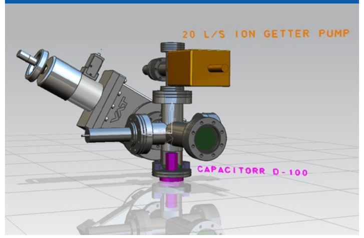


INFN Mo plugs

Cathode carrier



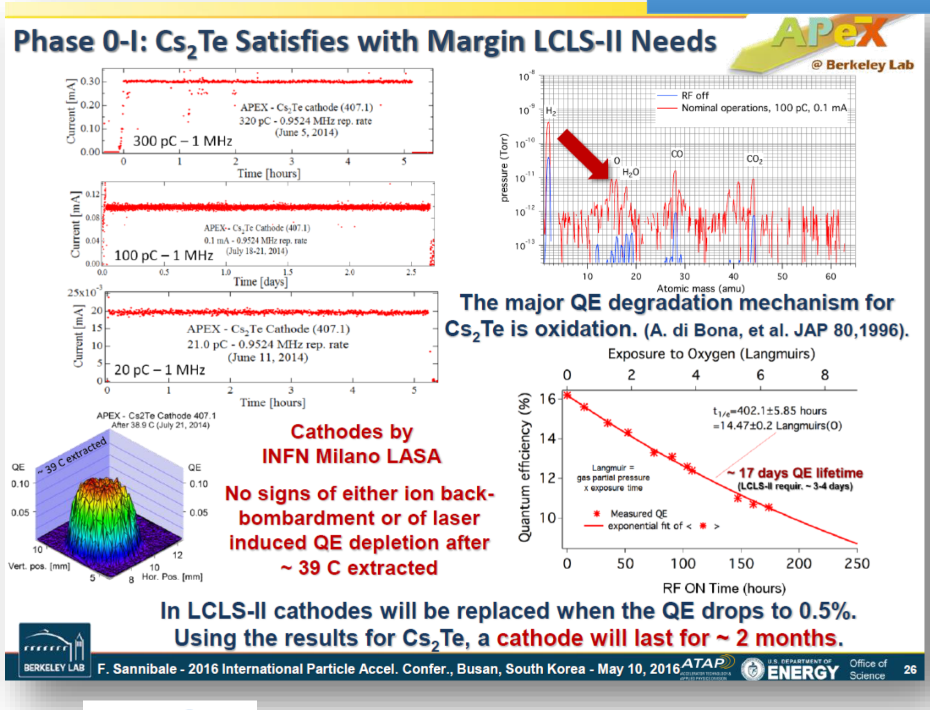
Cathode suitcase



Photocathode: Requirements and Performances

- **High QE** (at the reference at the laser wavelength)
  - **Average QE (%)** @ 254 nm (all films): **11.7 ± 3.9**
- **Spatial uniform QE** of the photoemissive film
  - **> 95 %** over the whole photoemissive area
- **Low dark current** during operation
  - **Negligible** (plug optical surface polishing mandatory)
- **Long operative lifetime**
  - **Improved from 4 months to 4 years**
- **Reproducible growing process**
  - **Stable responses at laser wavelength** (multiwavelenghts diagnostic)

CW operation – 1 MHz



Phase 0-I: Cs_2Te Satisfies with Margin LCLS-II Needs

The major QE degradation mechanism for Cs_2Te is oxidation. (A. di Bona, et al. JAP 80,1996).

~ 17 days QE lifetime (LCLS-II requir. ~ 3-4 days)

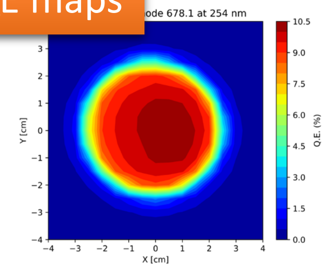
Cathodes by INFN Milano LASA

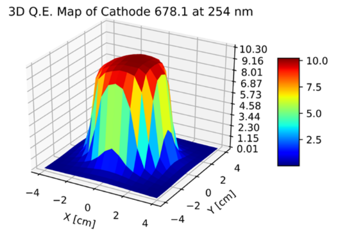
No signs of either ion back-bombardment or of laser induced QE depletion after ~ 39 C extracted

In LCLS-II cathodes will be replaced when the QE drops to 0.5%.
Using the results for Cs_2Te, a cathode will last for ~ 2 months.

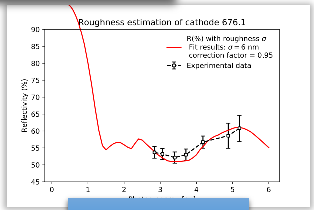
BERKELEY LAB F. Sannibale - 2016 International Particle Accel. Confer., Busan, South Korea - May 10, 2016 ATAP U.S. DEPARTMENT OF ENERGY Office of Science 26

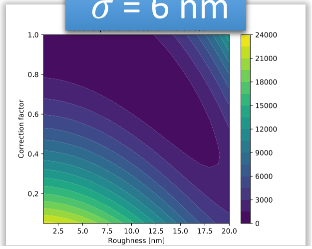
QE maps





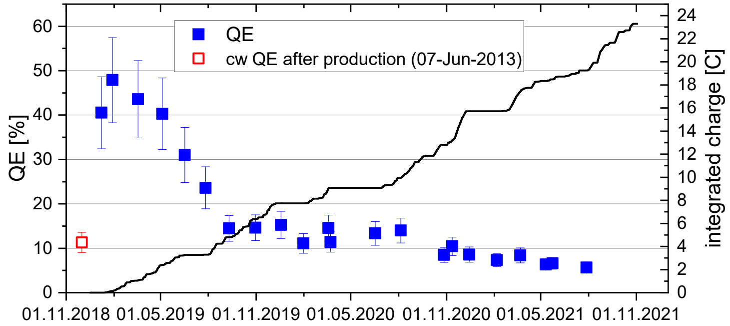
Roughness





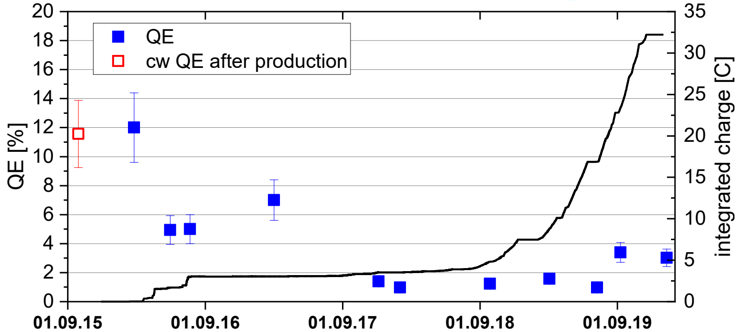
$\sigma = 6$ nm

Extracted charge: ~ 23 C
1063 days of oper. until 2019



QE and integrated charge for cathode #105.2, cw QE measured by Hg-lamp at 254 nm after production June 2013 at LASA..

Extracted charge: 32.2 C
1452 days of operation

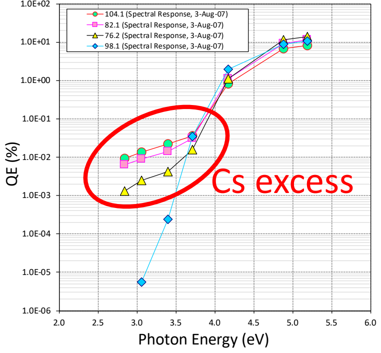


QE and integrated charge for cathode #680.1, cw QE measured by Hg-lamp @ 254 nm after production September 2015 at DESY

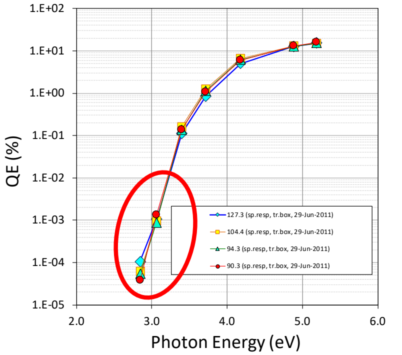
Photocathode Production: the Multiwavelenghts diagnostic

- Since 2009, we introduced a **new diagnostic** system mainly used for the production phase called **“multiwavelenghts diagnostic”** obtaining:
  - **Optimization of the deposition recipe**
    - Better control on final spectral responses (no Cs excess -> lower “low energy” threshold)
    - Improved control of the Te deposition thickness
    - Spectral responses of produced cathodes very similar and reproducible
    - Higher final QE (at 254 nm)
    - Less consumption of the sources
  - **Diagnostic** (i and R) **at all λs during production**

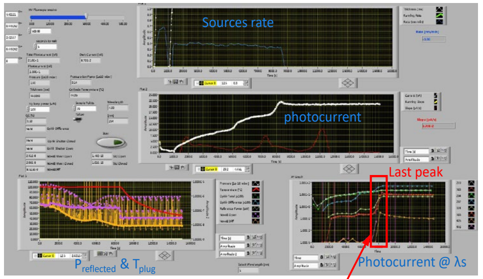
Old diagnostic



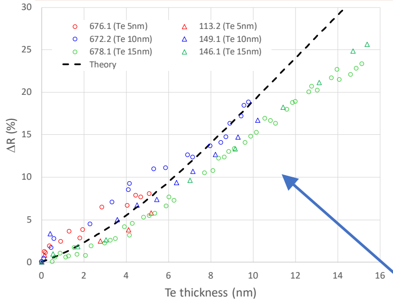
Multiwavelenghts diagnostic

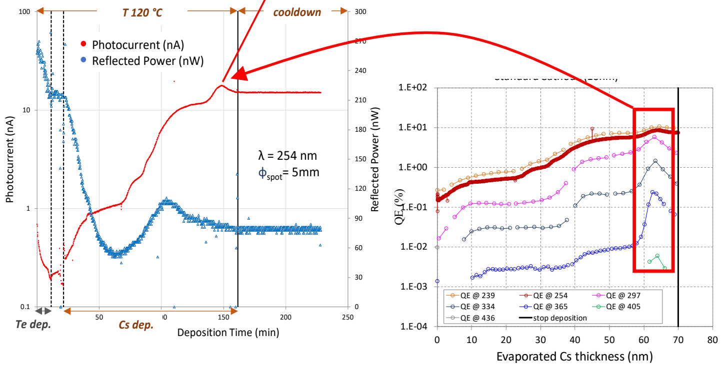


i and R duirng flm growth

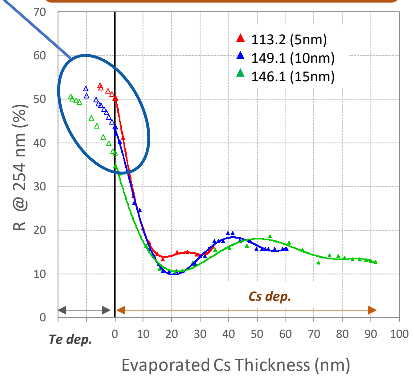


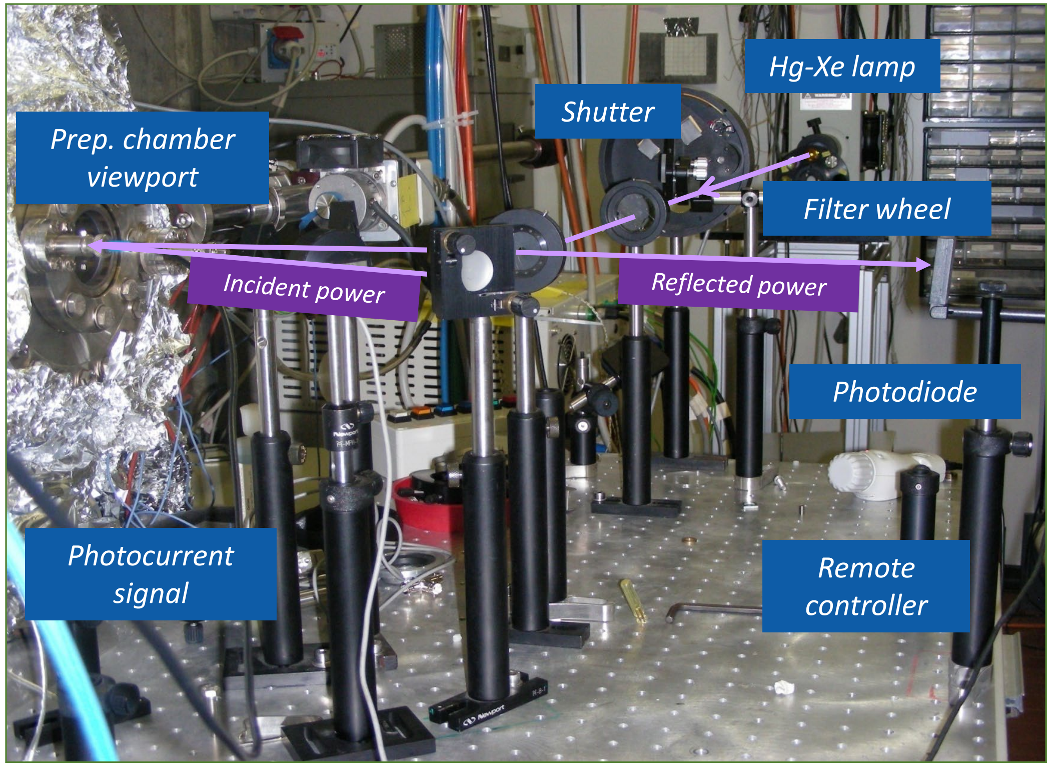
R decrese vs. Te deposition





R vs. Te and Cs deposition





Photocatodes: thermal emittance

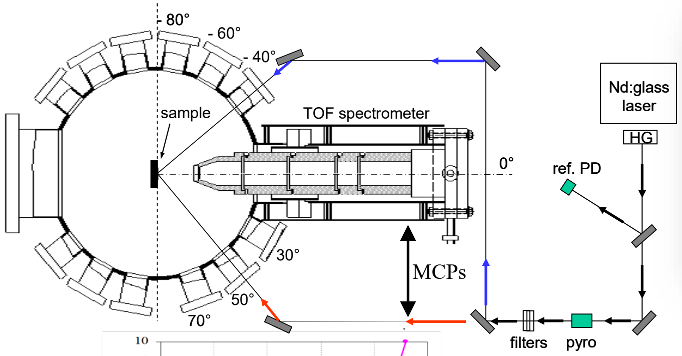
Cs_2Te Thermal emittance measurement:

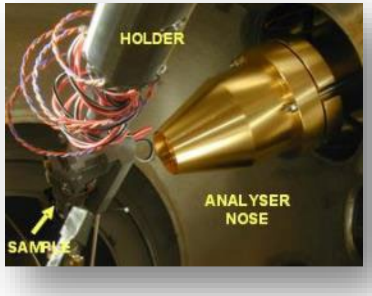
- **Time-of-flight (TOF) spectrometer** (low energy electrons, <5 eV):
  - UHV μ-metal chamber ($p \sim 1 \cdot 10^{-10}$ mbar)
  - UV viewport [5° ÷ 80°]
  - MCPs detector (1850 V)
  - Nd:glass laser (λ = 1055nm), UV: 4th 264nm, 5th 211nm, 0.5 ps
  - Resolution: $\Delta E/E$ = 15meV @ 1.9eV (25meV @ 0.4eV), Δt = 2ns
- **LASA TOF design, characterization, calibration**
- **Simulations** and **perturbations reduction**:
  - Contact potential (gold-plated, V_{bias})
  - Space charge ($J < 50 mA/cm^2$)
  - Magnetic shield: **8mG max** -> *poisson simulation e new external shield installation*

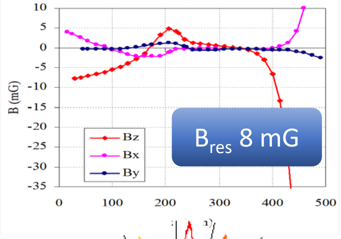
➢ ***First measurments with this technique of the Cs_2Te thermal emittance (4th and 5th harmonics)***

4th harmonic (λ = 264 nm)
ε_{th} = 0.5 ± 0.1 mm mrad
for 1 mm rms spot radius

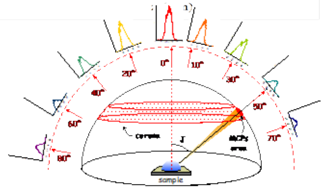
5th harmonic (λ = 211 nm)
ε_{th} = 0.7 ± 0.1 mm mrad
for 1 mm rms spot radius

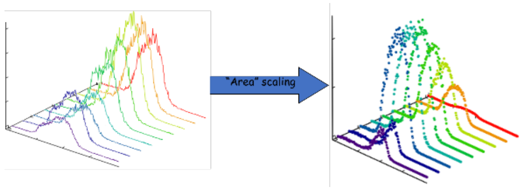


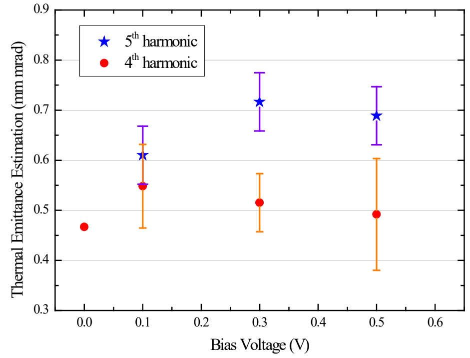




$$\varepsilon_x = \sigma \cdot \sqrt{\frac{\langle E_{kin}(\theta) \cdot \cos^2(\theta)\rangle_{E_{kin},\theta}}{2 \cdot E_0}}$$

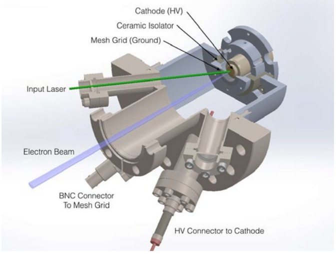


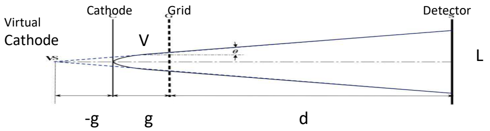


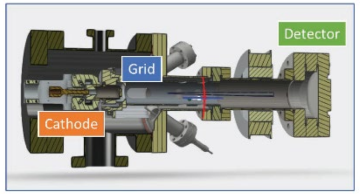


TRAMM (TRAnsverse Momentum Measurement):

- **Thermal emittance measurement system in the deposition chamber during the film growth:**
  - From transverse momentum to position displacement
  - Fast response during growth process
  - Further improvement of recipe deposition





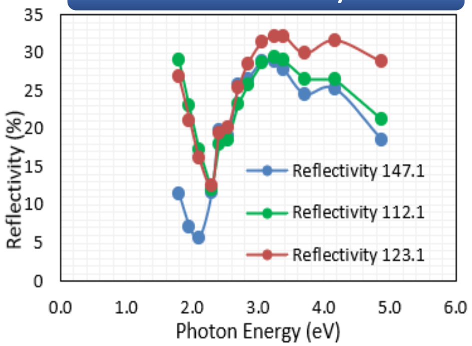


$$\frac{p_x}{mc} = \frac{L}{2g+d}\sqrt{\frac{2eV}{mc^2}}$$

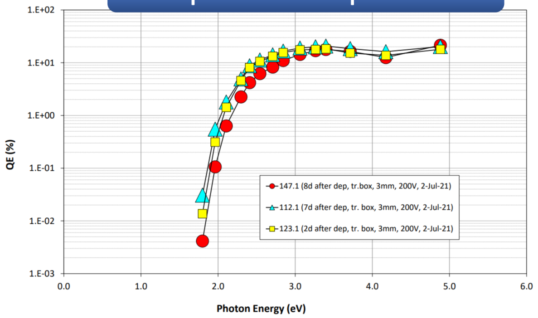
The “Green” Photocathodes (INFN – DESY)

- **CW machine** operation requires photocathode:
  - sensitive to visible light to relax requests on lasers.
  - smaller thermal emittances $\epsilon_{th} \approx 0.3$ mm mrad to improve machine performances
- **Requires XUHV** (≈ 10^{-11} mbar) since more sensitive than Cs_2Te
- **New LASA deposition system** for “green” films (DESY-PITZ collaboration)
  - collaboration with DESY-PITZ

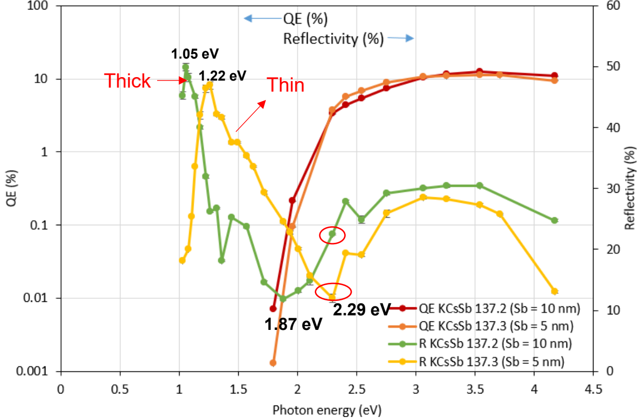
Reflectivity



Spectral response

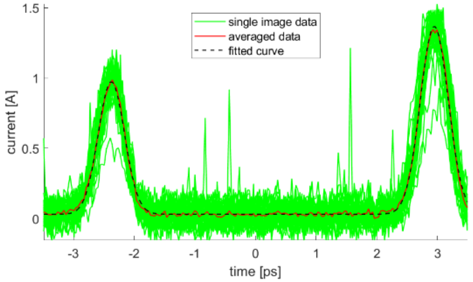


thin & thick films studies

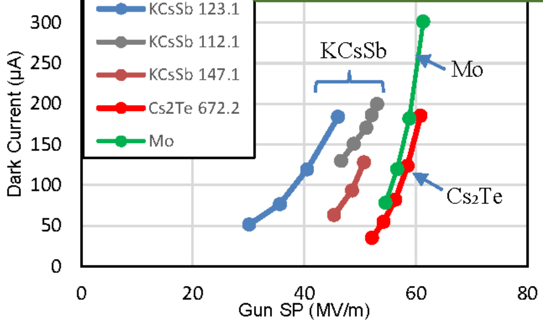


- **Photocathode tested in PITZ RF gun**

Response time



Dark Current



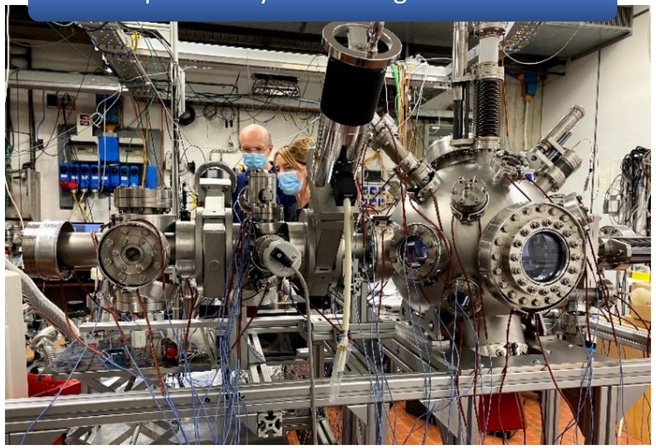
#123.1 QE@2.4 eV

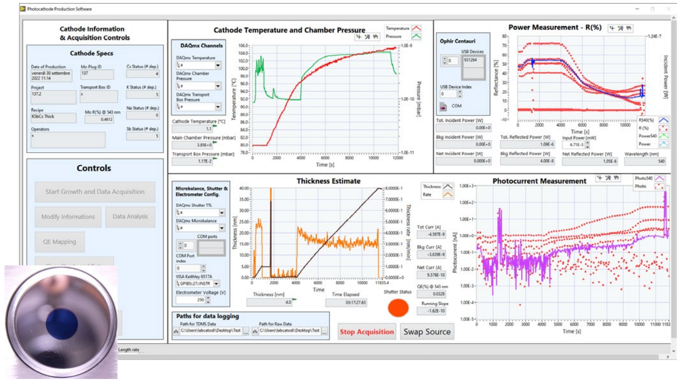
~8% (At INFN)

~4% (In PITZ loadlock)

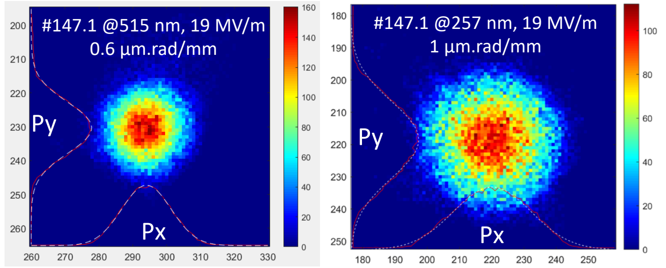
~5.6% (In PITZ gun)

New deposition system for «green» cathodes





Emittance



2D distribution of photoemission transverse momentum

Photocathodes future activities

- **Continue with R&D and test in RF guns of “green” photocathodes**
  - New compounds
  - Different growing processes (T, thickness, etc.)
  - Sequential vs. co-deposition
- **Continue R&D and RF guns operation of Cs_2Te photocathodes**
  - R&D
    - Sequential vs. co-deposition
    - Deposition on graphene layers
    - TRAMM in the production system
  - Stress test photocathodes (DC gun at LASA)
    - Operation at 100 MHz
  - HB^2TF activity on new DC Gun:
    - Transfer system and suitcase realization
    - Design of Photocathode insertion into the DC Gun
    - DC gun vacuum chamber
    - DC gun vacuum system

Thanks for your attention!

If you need more info or if you want to collaborate with us, here our contacts (daniele.sertore@mi.infn.it; laura.monaco@mi.infn.it)