LAL-PMB Collaboration Status

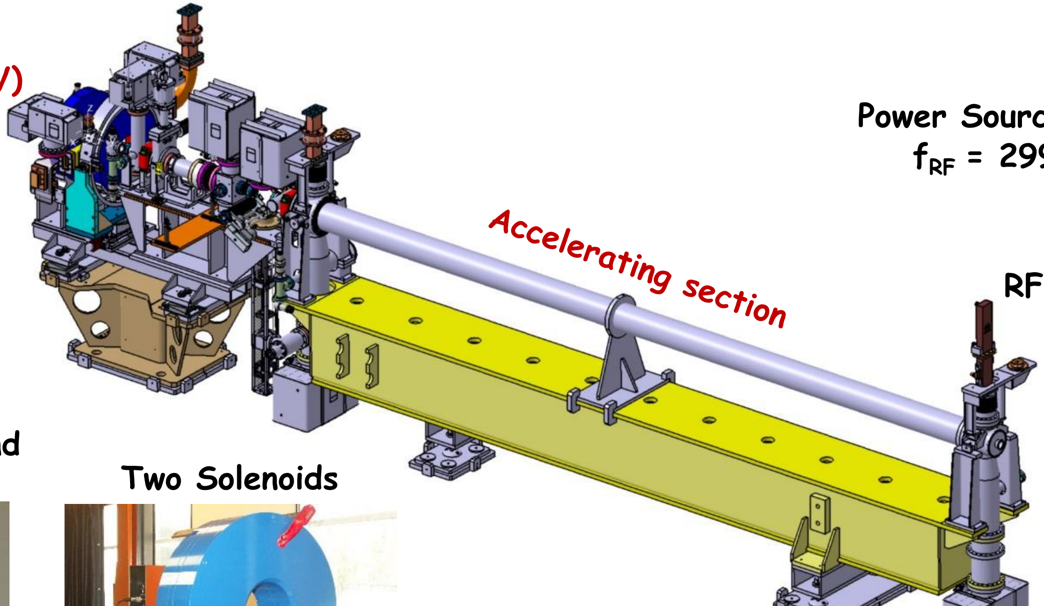
and

Alternative solution proposal

Mohamed El khaldi

ThomX Linac upgrade proposal

RF Gun
(5 MeV@ 5MW)

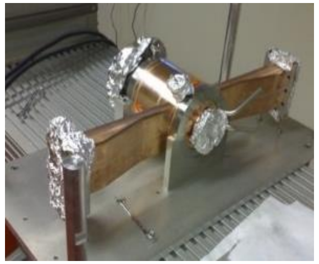


Power Sources: 35 MW peak power, Klystron
f_{RF} = 2998.55 MHz @ 30° C , in vacuum,

Repetition rate = 50 Hz,

RF pulse width (flat top)= 3 μs

RF gun designed and fabricated @LAL



Two Solenoids

LIL structure

Parameters	Commissioning phase LIL structure	Upgrade phase Compact High Gradient (HG) structure
Length flange to flange	4.8 m	3.5 m
Linac energy gain (MeV)	50 MeV	70 MeV

➡ More compactness ➡ Cathode transfer system « CTS » installation

➡ More energy gain

Direct impact on X-rays energy:
50 MeV → E_x ~ 45 keV -------▸ Medical imaging
70 MeV → E_x ~ 90 keV -------▸ Radiotherapy

Research collaboration between PMB and LAL

collaboration between PMB and LAL aiming at the development of HG compact S band accelerating structure : October 2014-September. 2018

- **Structure geometry optimisation (LAL)**
- **Fabrication process improvement (PMB)**

Reaching high gradient with minimum risks of breakdown

Development Phases

- **Prototyping:** investigating all possible issues (RF, mechanical) and improving the **cells machining** and **brazing processes**
- **Manufacturing of final accelerating section**

Tasks shared between LAL and PMB

LAL	PMB
Electromagnetic and thermal studies, RF design Beam dynamics study	Mechanical drawings
Fabrication follow up	Fabrication
High power test (RF conditioning)	Tuning and lower power tests

Development Phases

Phase 1:

- 7-cell Aluminium prototype
  - Machining process validation
  - Tuning and low power tests validation

Phase 2:

- 16-cell Copper prototype can be used as a booster on PHIL
  - Brazing process validation
  - High power RF tests validation

Phase 3:

- 3.2 m long S band constant gradient (CG) Copper final structure
  - High power RF tests validation
  - ThomX Linac energy upgrade

The last planning proposed by PMB: Fabrication of Aluminium and copper prototypes

- Second 7 cell Aluminium prototype
  - Design review: January 2017
  - Machining and fabrication: May 2017
  - Assembly, RF tuning and low power test: June-July 2017

- Copper prototype
  - 3D Mechanical drawings: january 2017
  - Milestone (depending on aluminium prototype results)
  - Machining and fabrication: June 2017
  - Assembly and cleaning: August 2017
  - RF tuning and low power test before brazing: August 2017
  - Brazing, chemistry, etc : September 2017
  - RF tuning and low power RF test: Octobre 2017

these steps have not been addressed

Problems related to manufacturing processes

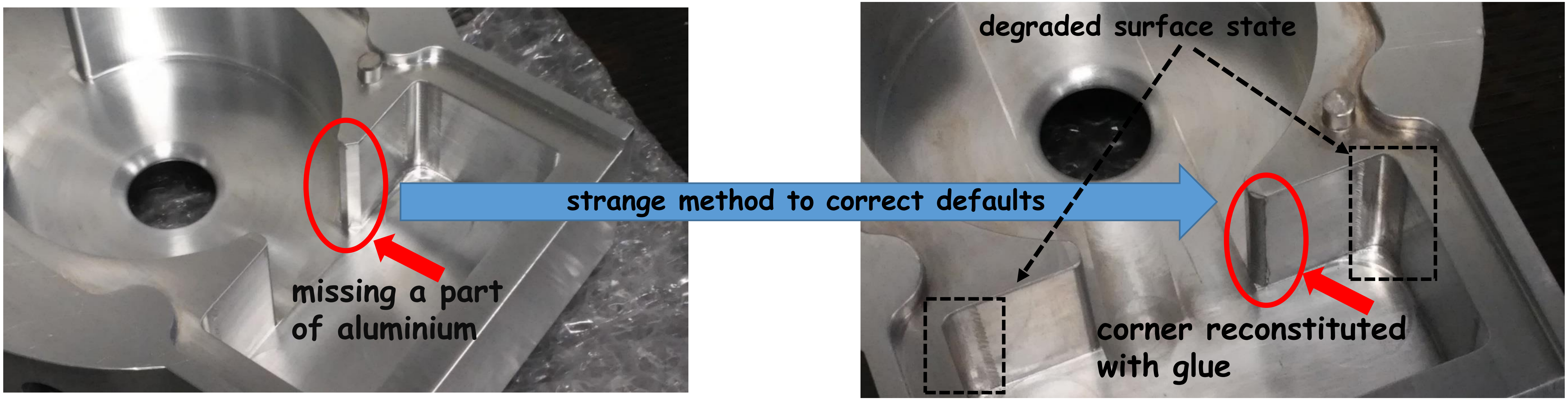
Two aluminium prototypes have been developped by PMB with difficulties : 2015-2017

Problems related to manufacturing processes: PMB uses a standard machining process

- Mechanical tolerances not respected
- Presence of Manufacturing defaults
- Surface flatness problems (problems of electrical contact)

Leading to

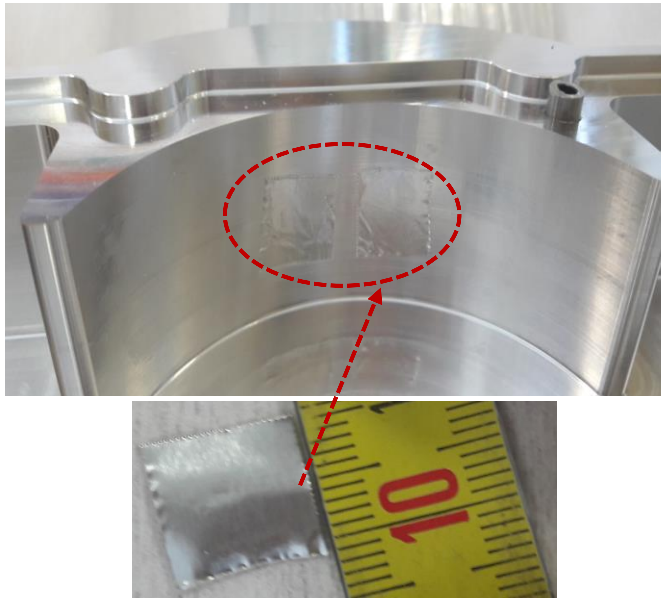
- Resonant frequency shifiting
- Phase advance per cell error
- Quality factor reduction => increasing RF losses



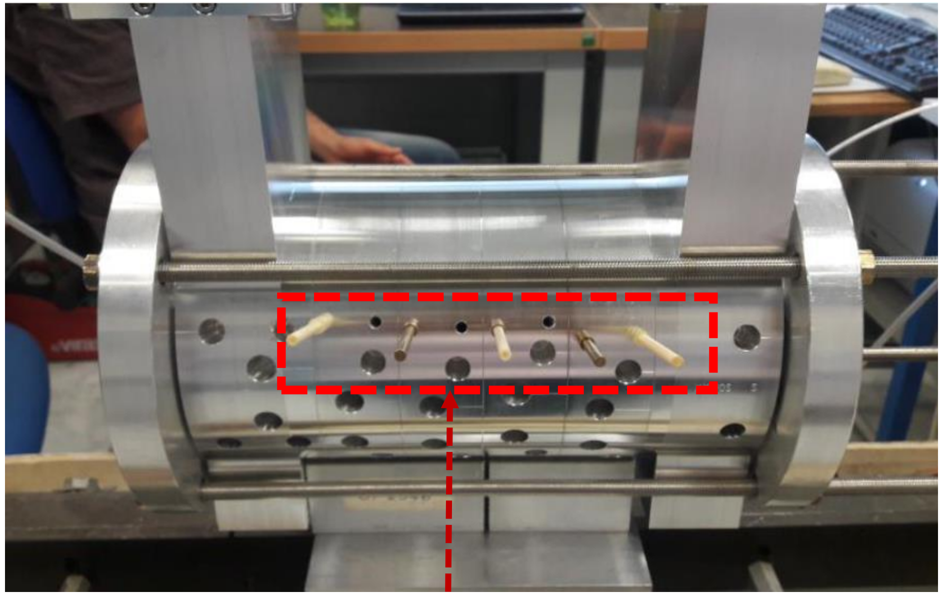
Problems related to the RF tuning and low power tests

PMB uses a manual RF tuning method : the process is not efficient and very time-consuming

- Tuning of coupling cells using aluminium **scotch** tapes Or a screw wrapped in aluminum foil to decrease the internal volume of the cell



- Tuning of regular cells using dielectric and conductor rods



Dielectric and conducting rods

- **The Insertion of scotch tapes and rods increase internal cavity losses and perturbate the EM field**

- **Tuning rods method is not appropriate for high performance structures since rods behaves as coaxial conductors and may induce multipacting between the tuner and the cell walls spoiling the cavity performance**

Lessons learned from this collaboration

- PMB uses standard fabrication processes (machining errors ⇨ tolerance design not respected; Surface flatness problem leading to HF contact problem) ⇨ Realisation of the high gradient accelerating section would not be acheived with respect to the required specifications
- PMB has never developped before high gradient accelerating sections
- PMB doesn't have a high temperature brazing furnace for long accelerating sections (> 2,5 m)
- PMB RF tuning and measurement procedures are manual and not efficient
- Manual stacking: Mechanical alignment of disks and couplers (the specified straightness tolerance ≤ 150 μm for the final structure not sure to be respected)

Conclusions and perspectives

Ph D thesis of Luca Garolfi under my supervision *defended* on 12 *January* 2018:

- Electromagnetic design (regular cell, couplers, prototypes and final accelerating section), thermal studies and cooling system design have been performed
- Beam dynamics studies using ASTRA code of the whole ThomX Linac have been performed in order to validate the Linac design and find an optimised working point delivering a beam with high charge, low emittance, low energy spread, small transverse beam size,
- Aluminum prototypes have been realized with difficulties by PMB ➔ These prototypes are not validated by LAL

Future actions:

- Fabrication of a copper prototype with a reduced number of cells

  The goals of this prototype are:
    - ❖ ***test the fabrication procedure***
    - ❖ ***test the structure at high power***
- Fabrication of 3.2 m long high-gradient S-band accelerating section

We are looking for collaborators with an extensive experience in the development of HG accelerating sections,

Plan B

Alternative solution proposal

Development of a high gradient accelerating section: 3 years min

A plan B is being considered to replace PMB company by academic partners **with an extensive experience in the development of HG accelerating sections** such as **Paul Scherrer Insitute** (PSI)

Positive and constructive collaboration between PSI and ELETTRA

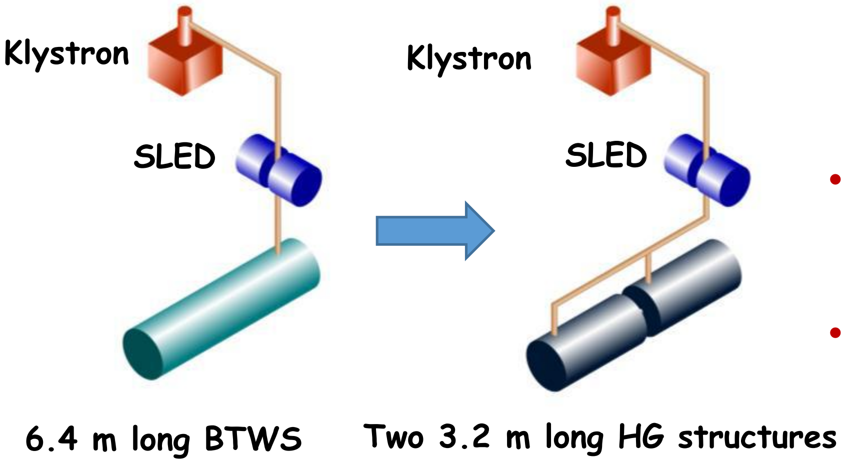
We have organized a Skype meeting with a responsible of the FERMI free electron laser linac upgrade. Elettra collaborates with PSI to produce a high gradient accelerating structure for the Fermi feel.

THE FERMI UPGRADE PROPOSAL

ACTUAL LINAC ENERGY: 1.5 GeV @ 10 Hz → TARGET LINAC ENERGY: **1.8 GeV @ 50 Hz**

The actual Linac energy is limited by the **breakdown rate** of the **BTW structures.**

Courtesy Claudio Serpico (ELETTRA)

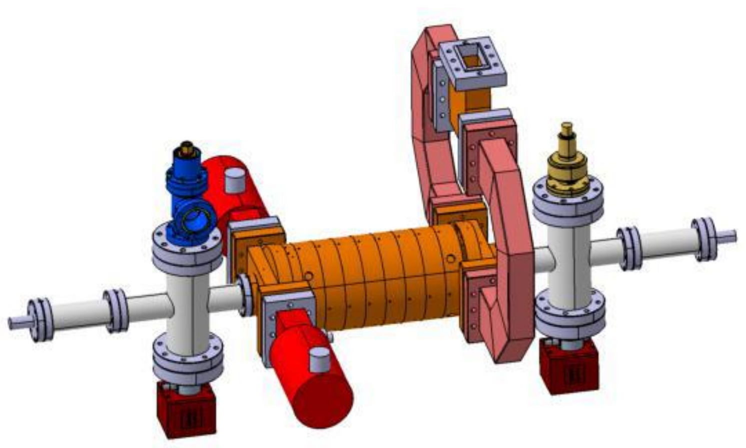


- **Two 3,2 m long HG structures will be installed in place of each backward traveling wave type accelerating structures (BTWS)**
- **The HG structure will guarantee reliable operation at 30 MV/m at 50 Hz repetition at full gradient, operating the RF plants at full power,**

PSI-ELETTRA collaboration

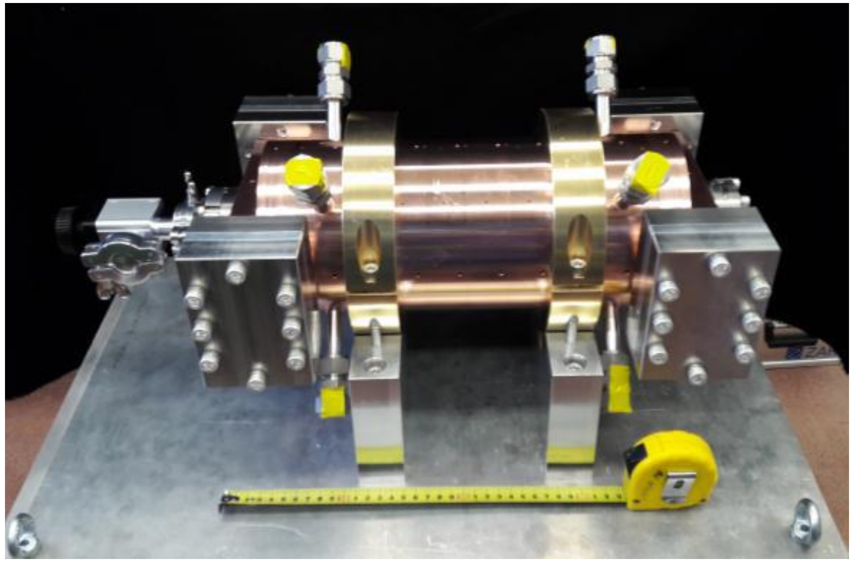
To prove the **reliability** and the **feasibility** of the upgrade proposal at an accelerating gradient of 30 MV/m, a **first (short) prototype** has been built in collaboration with Paul Scherrer Institute (PSI, Zurich).

Prototype 3D model



Prototype ready for Vacuum Brazing

Prototype after brazing



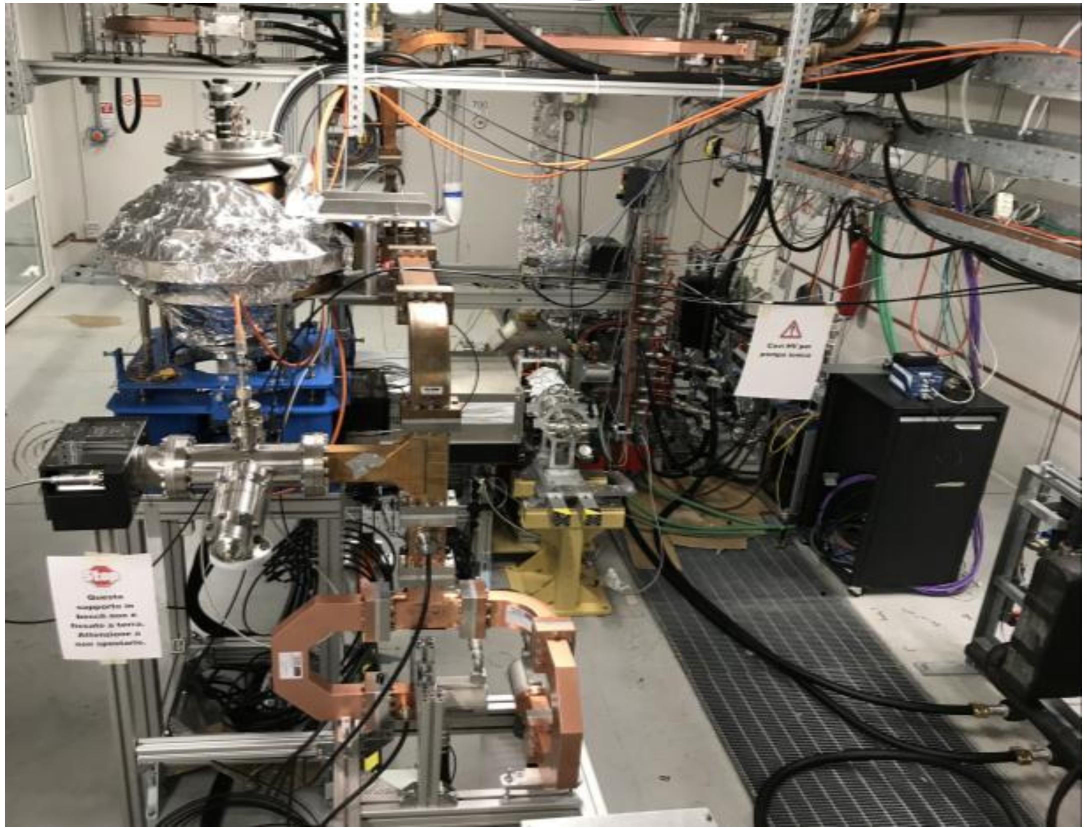
- **The prototype is made by 7 regular cells and 2 EC-couplers.**
- **Cells and couplers are realized with Ultra-high precision machining (specified tolerances of +/- 4 μm and measured tolerances +/- 2 μm by VDL).** ***ultra-precise*** **cup** ***machining*** **to avoid dimple** ***tuning.***

Courtesy Claudio Serpico (ELETTRA)

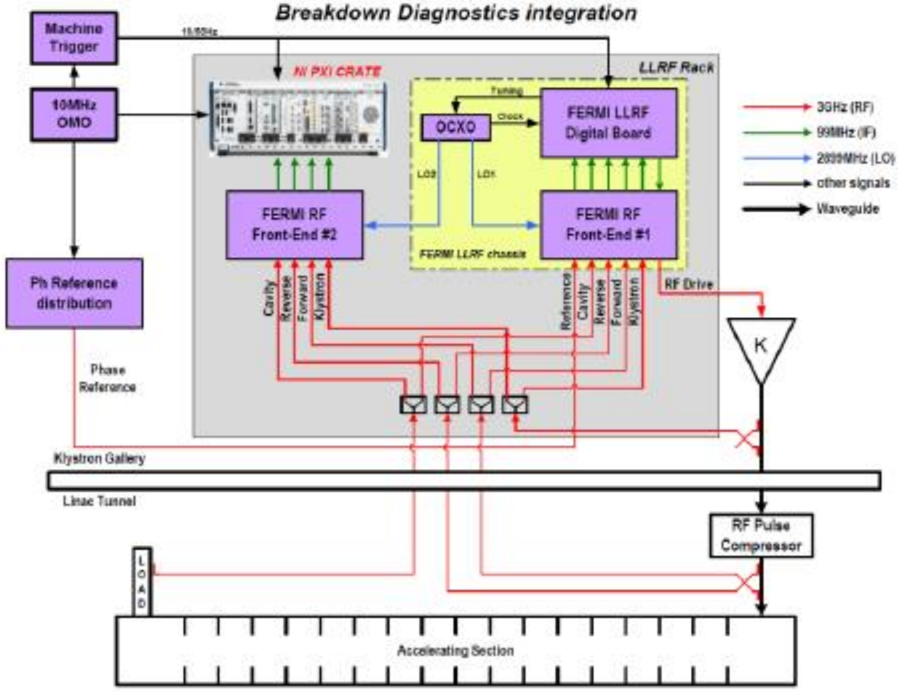
HIGH POWER TESTS FACILITY AT ELETTRA

In order to perform a high power test on the first prototype, a Test Facility has been built at Elettra, in the FERMI tunnel.

TEST FACILITY @ ELETTRA



TEST FACILITY DIAGNOSTIC



CERN-like breakdown diagnostic is being developed at Elettra.

- Test of Standing Wave structures/RF Guns up to 25 MW peak power.
- Test of Traveling Wave structures and RF components up to 150 MW peak power.
- Breakdown rate measurements and breakdown localization

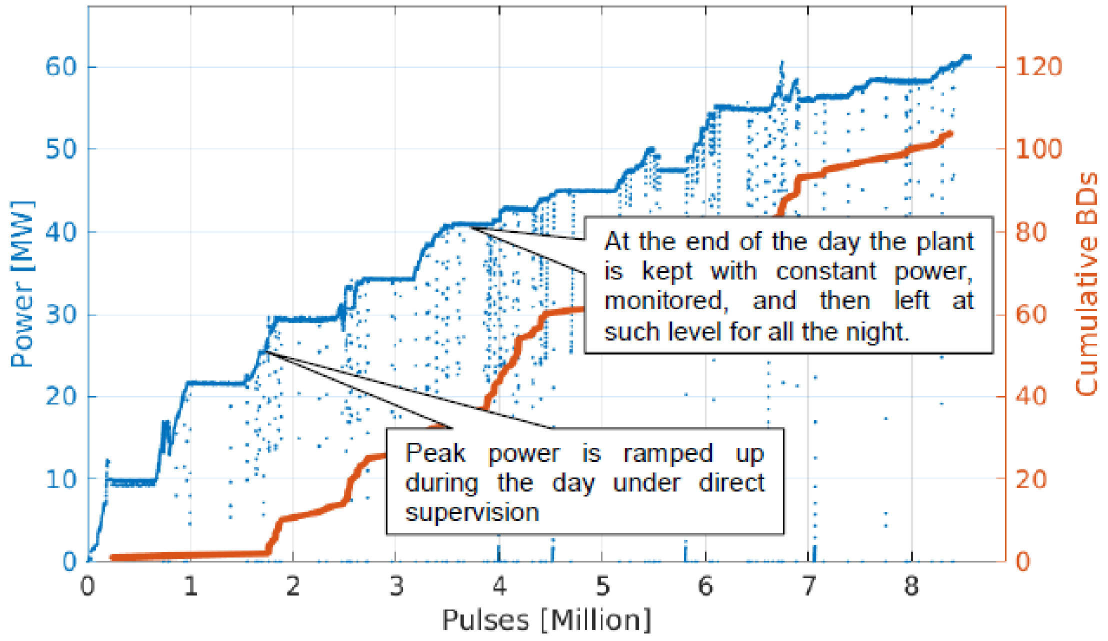
Courtesy Claudio Serpico (ELETTRA)

Elettra SHORT PROTOTYPE : RF CONDITIONING

RF Conditioning started on May 30. So far....

- 64 MW peak power, corresponding to an accelerating gradient of 27.5 MV/m.
- 200 ns RF pulse after Pulse Compressor (goal is 30 MV/m @ RF pulse 650 ns & repetition rate 50 Hz)

History Plot



Courtesy Claudio Serpico (ELETTRA)

NEXT STEPS AND TIME SCHEDULE

- Prove the **reliability** and of operating a **30 MV/m** with a **50 Hz** repetition rate.

- In collatoration with **Paul Scherrer Institute**, address all the technical issues related to the brazing of a 3 meter long accelerating structure.

By the end of 2018 Elettra expect to have a set of data from the ongoing tests and experiments which will allow Elettra to draft a detailed and complete upgrade proposal.

Courtesy Claudio Serpico (ELETTRA)

PSI's Know How: C-BAND STRUCTURES REALIZATION

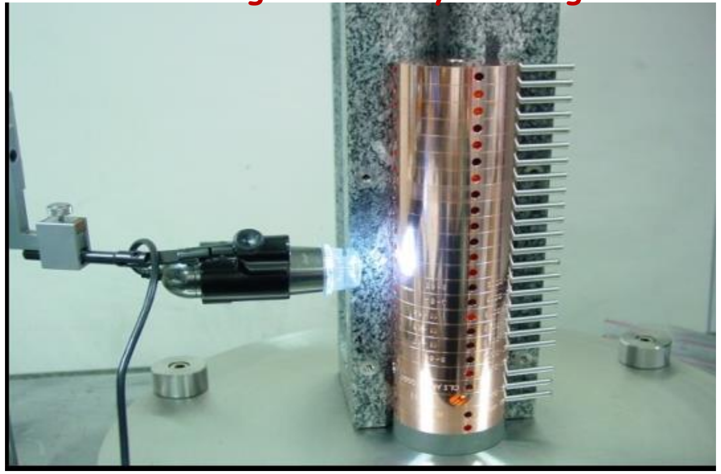
- PSI designed & developed C-Band accelerating structure, 2m long; 104 pcs for SwissFEL
- Technology/production process development at PSI's central technical unit
- Diamond machining, robotic stacking, cleaning/heating/multiple brazing procedures, extended survey, vacuum and RF testing…

C-band technology:

✓In house development of ultra-precise machined accelerating structure ***without tuning*** (short structure program and 2m nominal structure)

✓In house development of the brazing technique for the 2m structure

Robotic stacking : Assembly and alignment of stack.



Specifications:

Phase adv. 2π/3

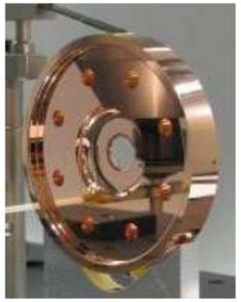
Filling Time: 329 ns (th.)

vg/c: 3.1% - 1.2% (th.)

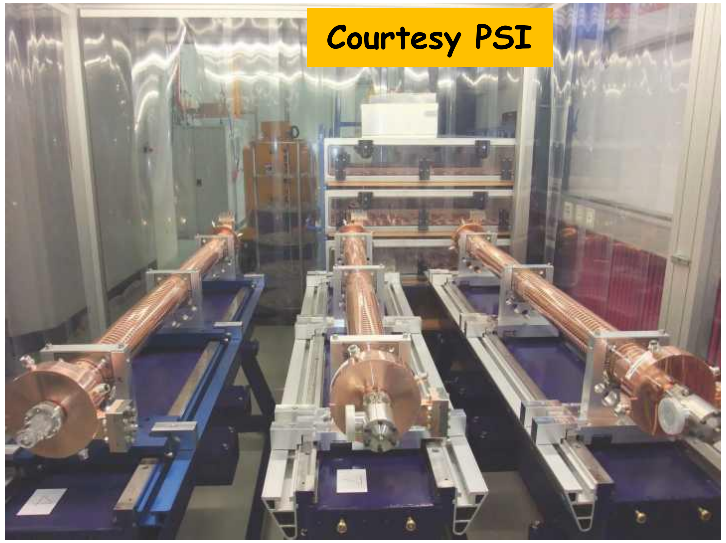
Iris radius (20°C): 7.238 mm – 5.447 mm

Length : 2 m

Accelerating gradient 28 MV/m



Courtesy PSI



Perspectives

- Invitation of Claudio Serpico from Elettra to give a seminar at LAL
- Visite of PSI and Elettra to talk about our future collaboration