High Power Test Results of the ELI-NP S-Band Gun Fabricated With the New Clamping Technology Without Brazing

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OUTLINE

1) ELI-NP Gamma Beam System and LINAC

2) Photo-Cathode RF guns

3) ELI-NP gun:

   - RF and thermo-mechanical design
   - Fabrication process with special RF-vacuum gaskets
   - Low power tests results
   - High power test results

4) Conclusions and perspectives

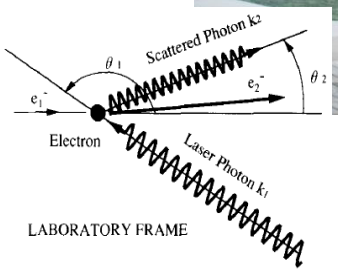
ELI-NP GAMMA BEAM SYSTEM

⇒ Advanced **source of Gamma-ray photons** in construction in Magurele (Bucharest, **Romania**) in the context of the **ELI-NP** Research Infrastructure by the "EuroGammaS" Association (composed by the INFN, the "Association leader", the University of Rome "La Sapienza", the CNRS, ACP S.A.S., Alsyom S.A.S., Comeb Srl, ScandiNova Systems AB);

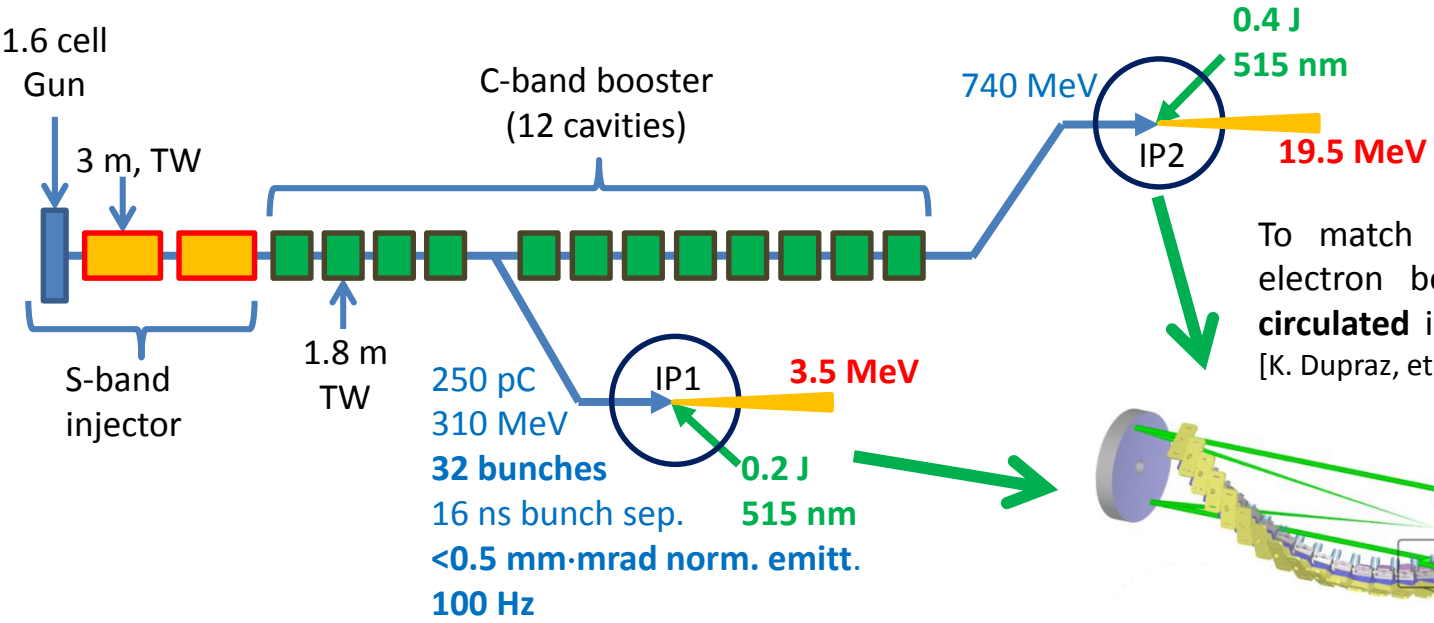
⇒ The photons will be generated by **Compton back-scattering** in the collision between a high quality electron beam and a high power laser;

⇒ The machine is expected to achieve:

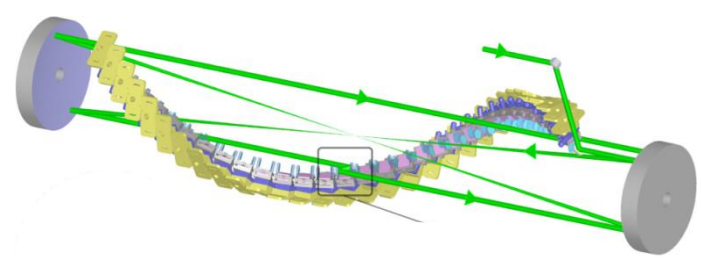
- **energy of the gamma photons tunable** 0.2-19.5 MeV
- **narrow bandwidth** (<0.5%)
- **high spectral density** (>10^4 photons/sec/eV)



[TDR ELI-NP GBS arXiv:1407.3669]
[A. Giribono, MOVA016]



To match at the IPs the multi-bunch electron beam the **laser pulse is re-circulated** in a novel optical re-circulator [K. Dupraz, et al., PRST-AB 17, 033501 (2014)]



ELI-NP LINAC

The ELI-NP LINAC operates:

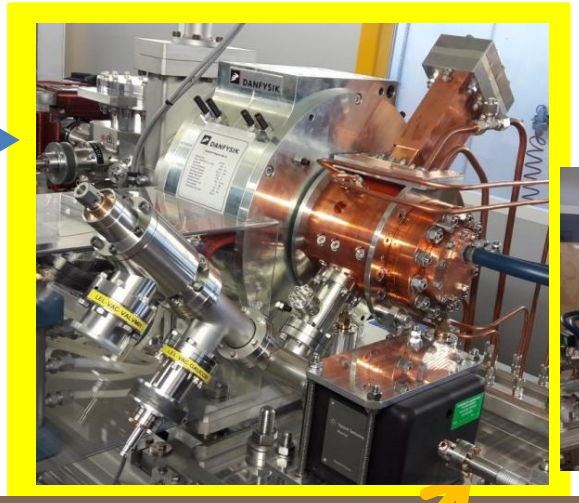
⇒ at **100 Hz**

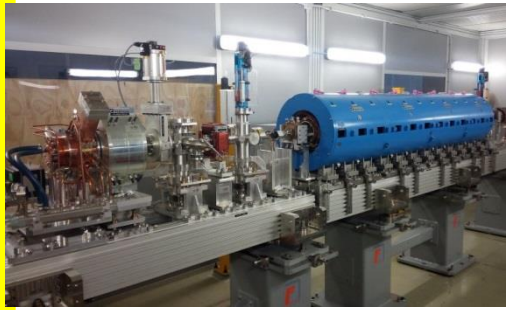
⇒ with **low emittance** (<0.5 mm mrad)

⇒at relatively **high gradient** to be compact

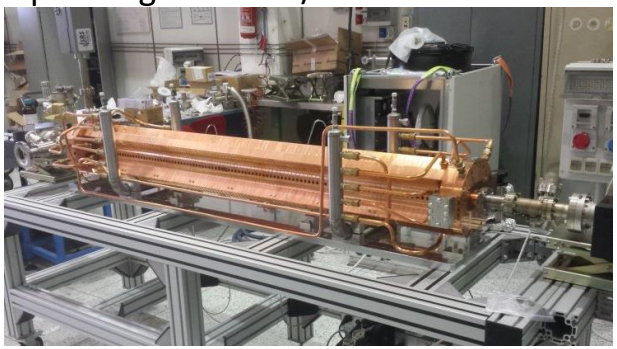
⇒in **multi bunch** (32 bunches)

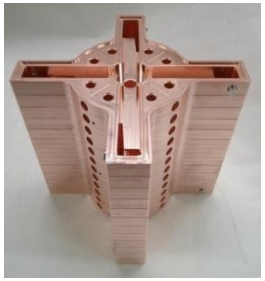
This required the development of an high gradient/high rep. rate photo-gun operating at 120 MV/m cathode peak field

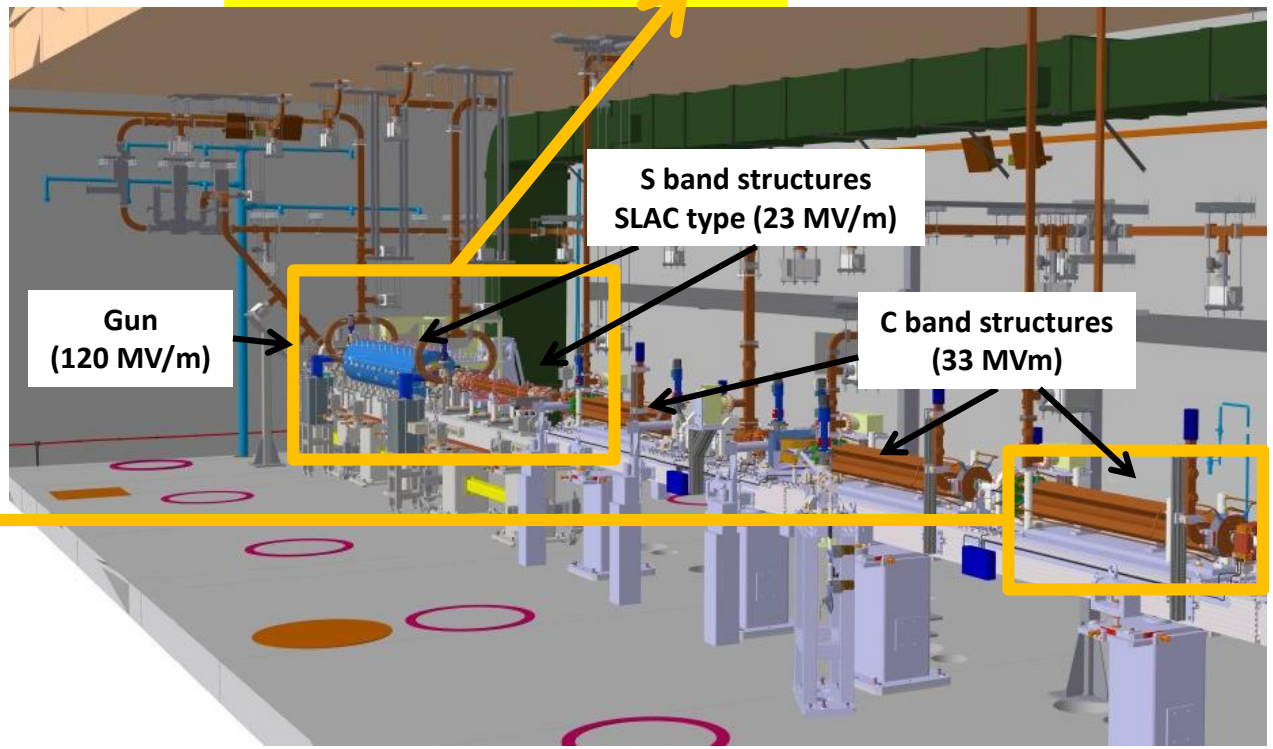




This required the development of **special damped C band cavities** operating at 33 MV/m







[D. Alesini et al., PR AB 20, 032004 (2017)]

3D V. Pettinacci

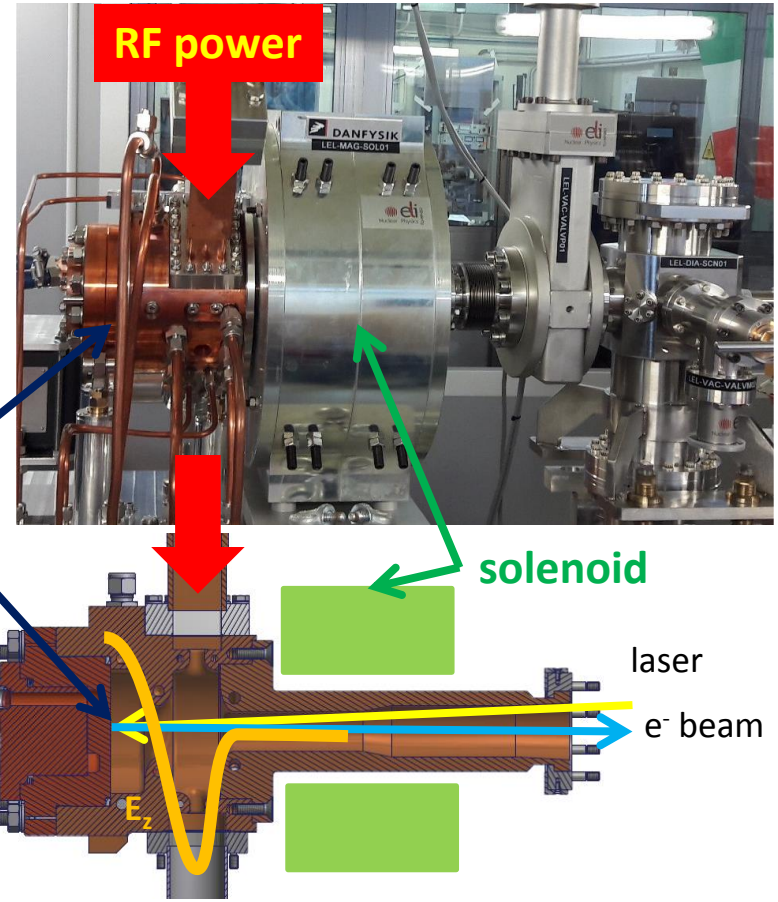
PHOTO-CATHODE RF GUNS

⇒ Photocathode RF guns are **multi-cell SW structures**.

⇒ The **electron beam is generated by photo-emission** using a drive-laser pulse to illuminate the cathode.

⇒ They are used for **several applications** (FELs, THz sources, Compton sources…).

⇒ The maximum achievable beam **brightness** is directly proportional to the **peak field** at the cathode (50-120 MV/m).



In the last generation of RF guns much effort has been spent to:

Increase the peak E field amplitude at the cathode

Increase the rep. rate (av. diss. power)

Reduce the realization cost

RF and thermo-mechanical design

⇒ Rounded **couplers** to reduce pulsed heating

⇒ **irises** profiles with low peak surface electric field

⇒ Cooling system design integrated with RF design

Realization processes

⇒ Milling machines and lathes to achieve roughness <150 nm

⇒ Cleaning procedures for **high gradient technology**

RF guns are fabricated by a **brazing process:**

⇒ requires large vacuum furnaces

⇒ are expensive

⇒ poses a not negligible risk of failure.

⇒ at the end of the process copper is "soft", annealed (lost the hardness of forged one)

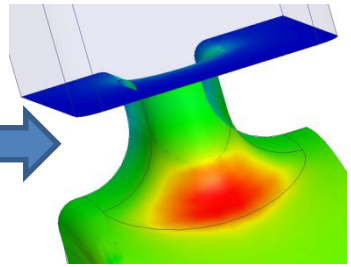
RF AND THERMO-MECHANICAL DESIGN OF ELI-NP GUN

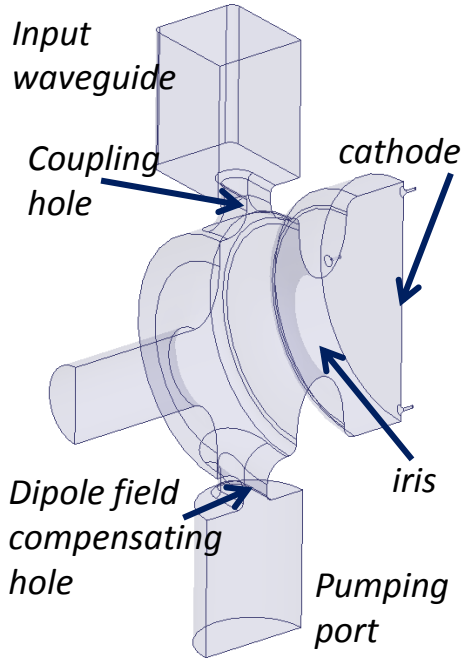
RF design

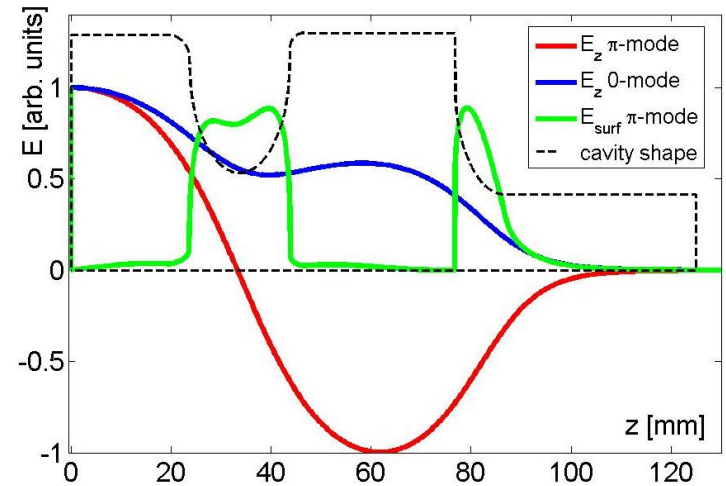
⇒**iris profile** with an **elliptical shape** and a **large aperture** to:

- reduce the peak **surface electric** field;
- increase the **pumping speed** on the half-cell;
- increase the **frequency separation** between the two gun RF modes: in pulsed regime this allow using short (<1μs) RF pulses w/o affecting the BD.

⇒The **coupling window strongly rounded** to reduce the peak **surface magnetic** field and, as a consequence, the **pulsed heating**.







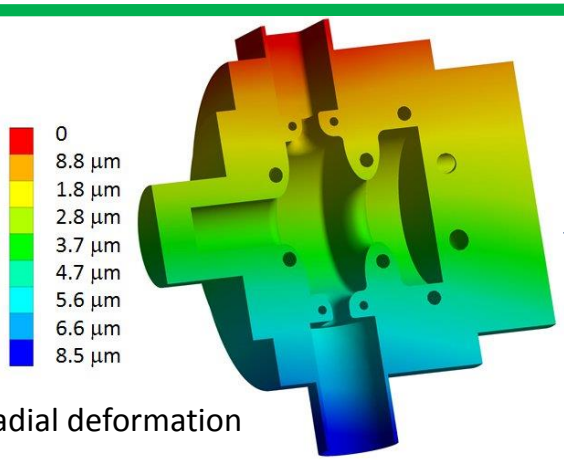
Thermo-mechanical design

⇒**100 Hz and long RF pulses** for MB ⇒ av. diss. power **> 1kW**

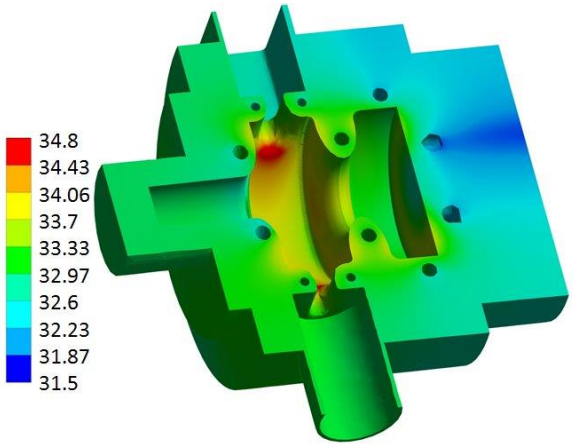
⇒**6 cool. channels** (incl. cathode) with total water flow of **30 liter/min**

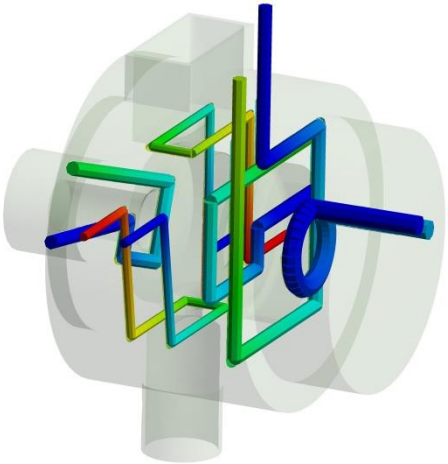
⇒full coupled thermal-structural analysis (Ansys Workbench)

⇒**detuning of the gun under power <100 KHz** (<2 deg temp.) w/o affecting the field flatness



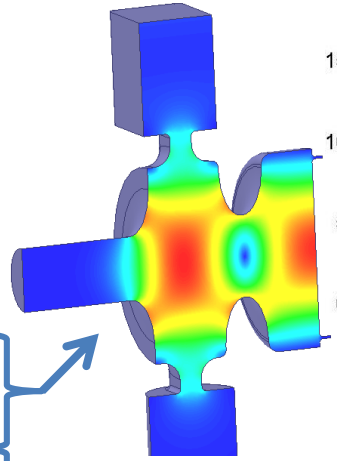
Radial deformation

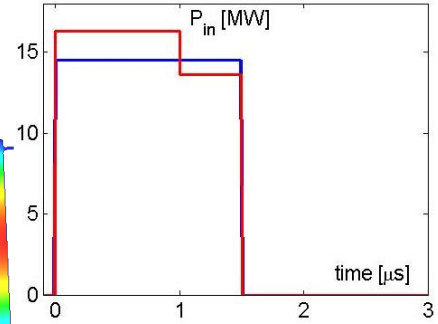


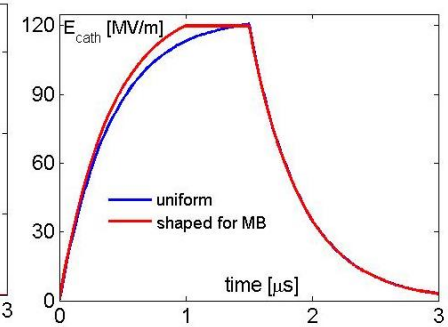


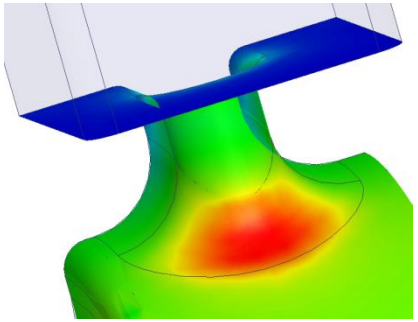
FINAL GUN PARAMETERS

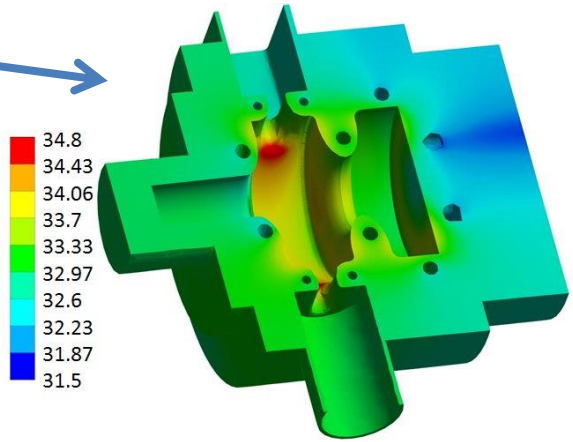
Parameters	Value
f_{res}	2.856 [GHz]
Q_0	14600
Cath. peak field	120 MV/m
$E_{cathode}/\sqrt{(P_{diss})}$	37.5 [MV/(mMW$^{0.5}$)]
E_{surf}/E_{cath}	0.9
Δfreq. 0 /π-mode	41.3
RF input power	14.5 MW (shaped)
RF pulse length	1.5 μs
Coupling β	3
H_{surf}	350 [kA/m]
Pulsed heating	<35 [°C]
Repetition rate	100 [Hz]
Av. Diss. power	1.2 [W]
Working temp.	30 [°C]
Δf under power	<100kHz
Fill. Time (τ)	400 ns











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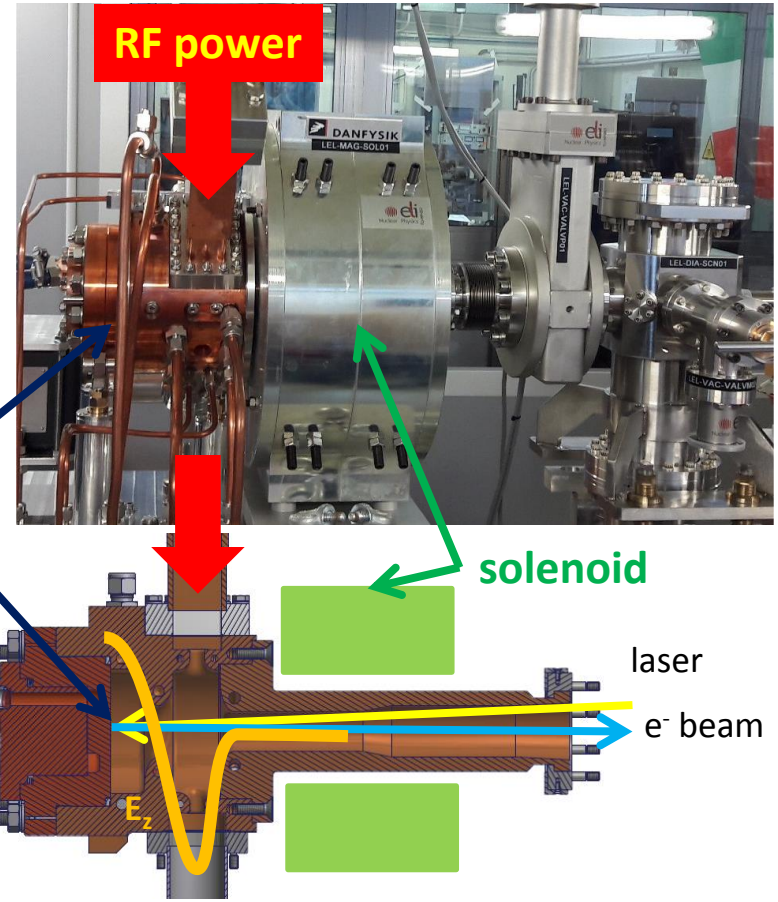

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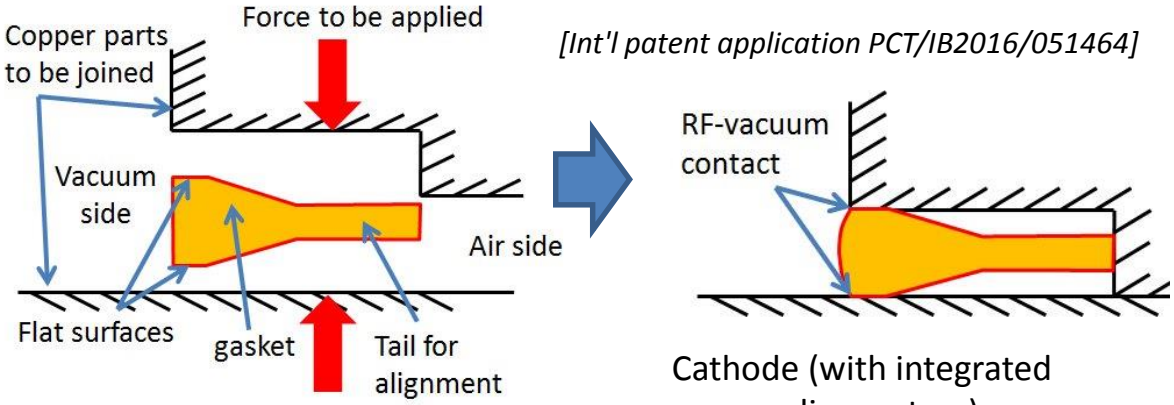
FABRICATION PROCESS: SPECIAL RF-VACUUM GASKETS

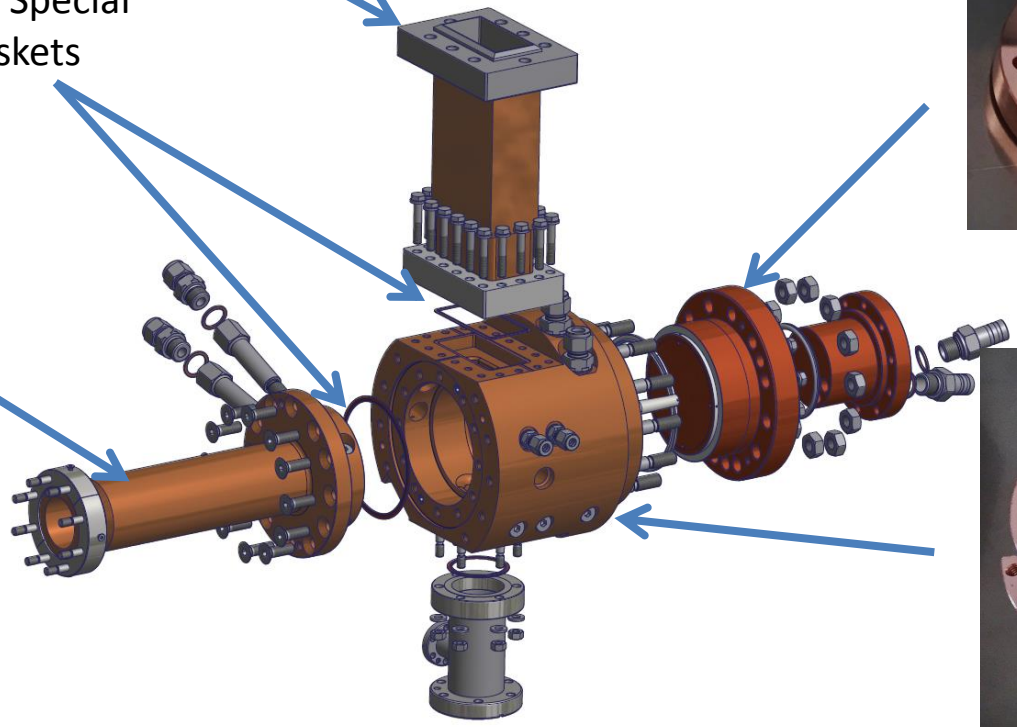
The gun has been fabricated w/o brazing using a novel process recently developed at LNF-INFN involving the use of **special RF-vacuum gaskets** (same Cu material of gun) that guarantee (simultaneously) the vacuum seal and a perfect RF contact when the structure is clamped.



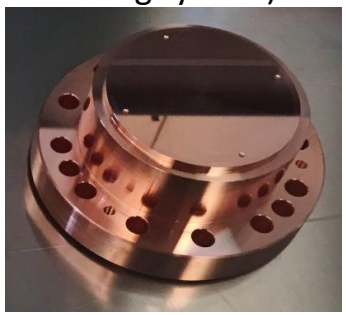
[Int'l patent application PCT/IB2016/051464]

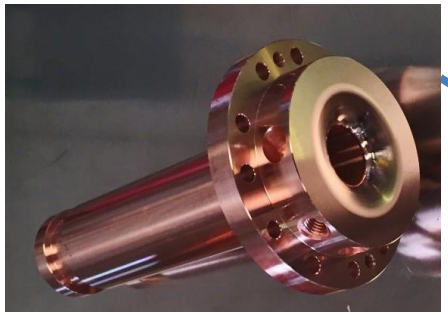
Cu Special gaskets

waveguide



Cathode (with integrated cooling system)





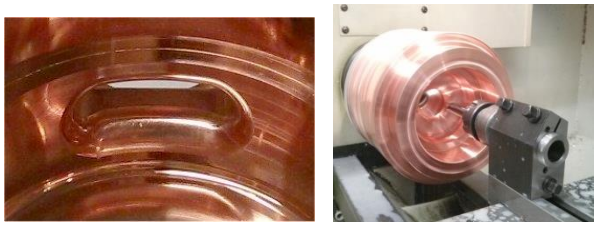
Closing cup and pipe

Body of the gun (single piece of OFHC copper)

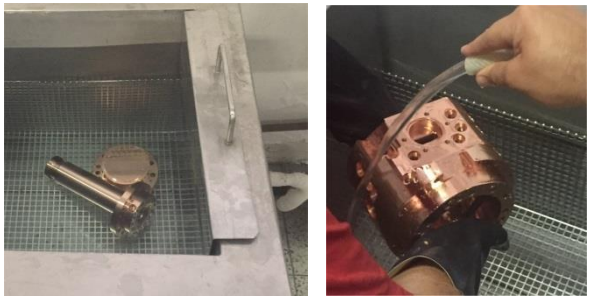
[D. Alesini, et al., PRST- AB 18, 092001 (2015)]

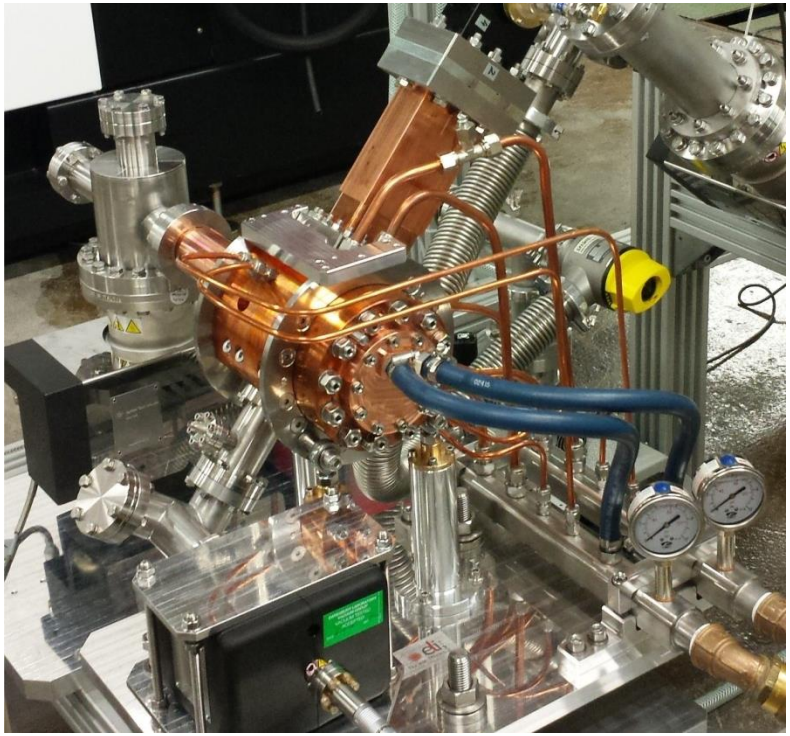
GUN FABRICATION AND ASSEMBLY

All parts fabricated with a **precision of ±10 μm** and surface **roughness <150 nm**. Rounded coupling hole machined with a **5 axis milling machine (@ COMEB company partner of Eurogammas)**.

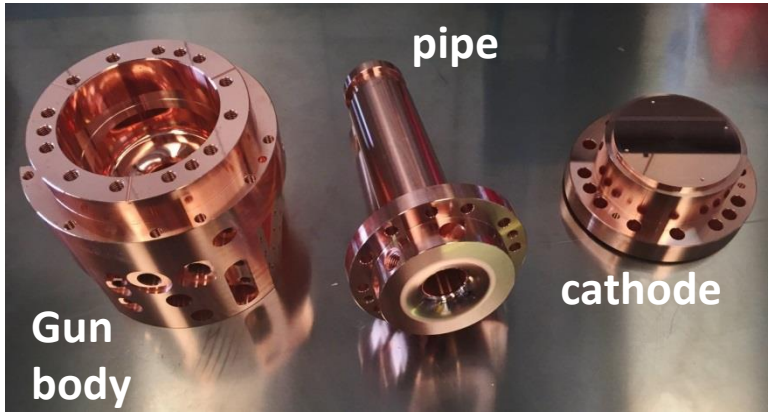


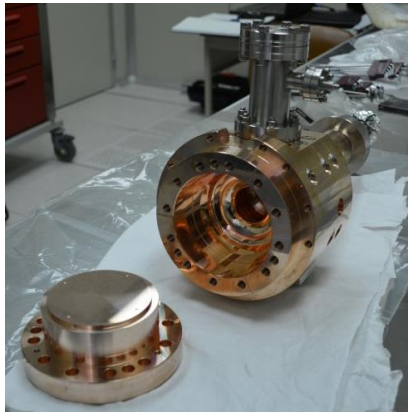
All parts **cleaned** with a detergent, followed by a ultra-sound bath of organic acid (citric) in distilled water. Dried with N_2 flux and, finally, in vacuum.

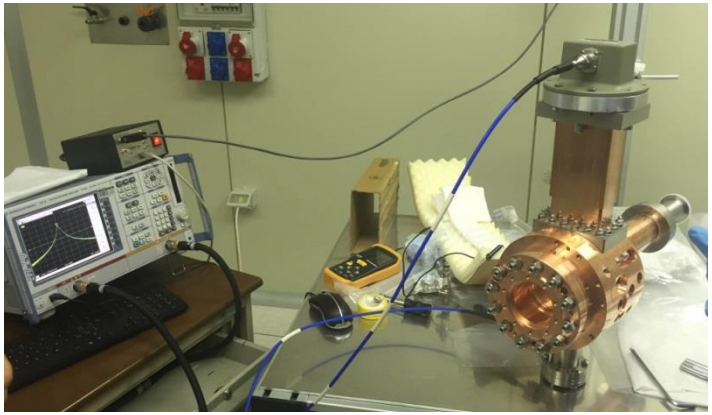




Final assembly in **clean room**. The gun has been vacuum **leak tested**, then **measured at RF and tuned** (acting on deformation tuners) at low power. Finally, assembled with **cooling system and support**.

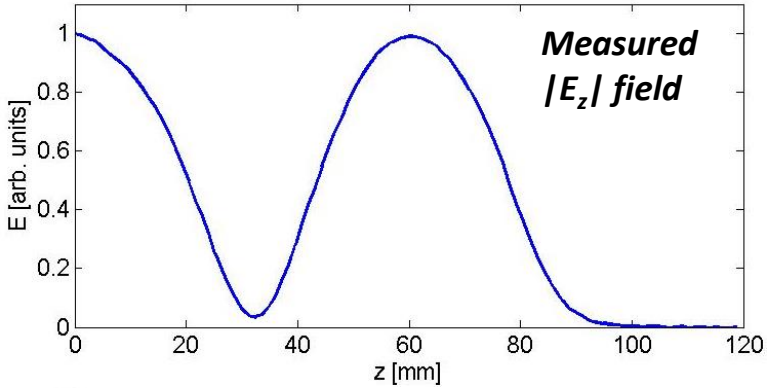


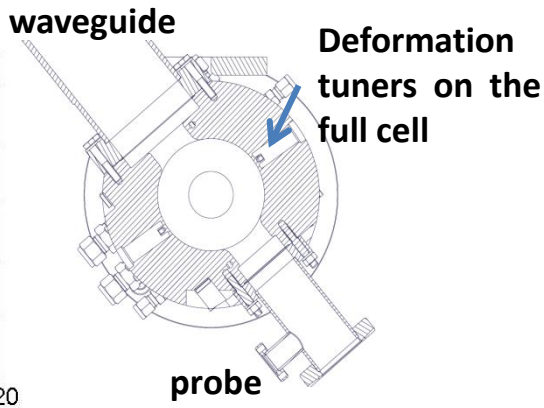


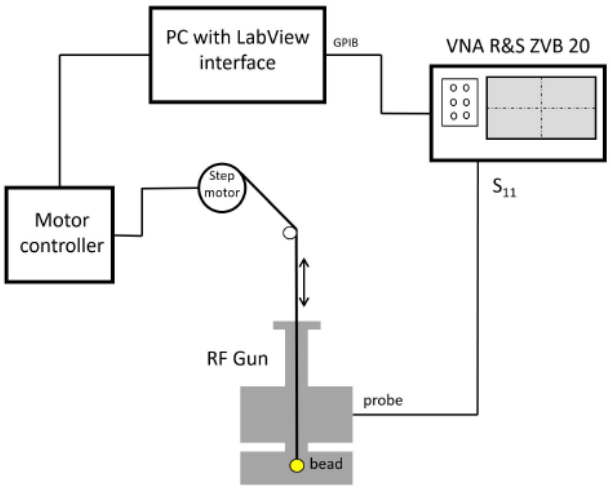


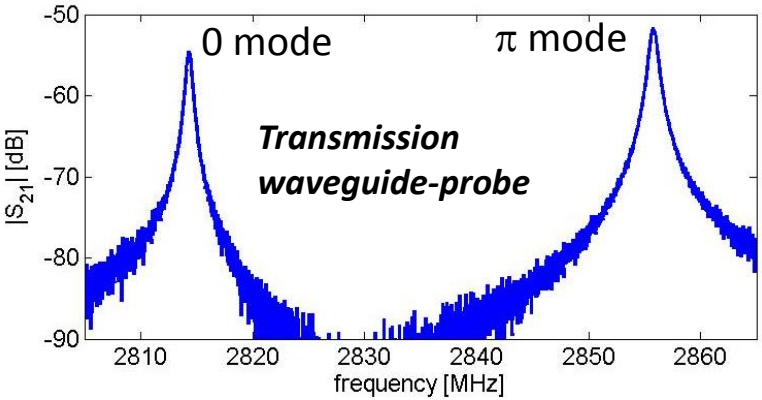
RESULTS OF THE LOW POWER RF MEASUREMENTS

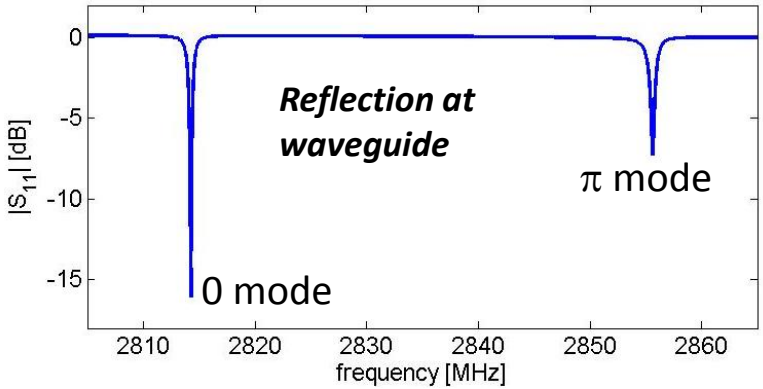
Field profile has been measured by **bead drop technique** (Slater theorem). Tuning of the field flatness has been done acting on two deformation tuners on the full cell.





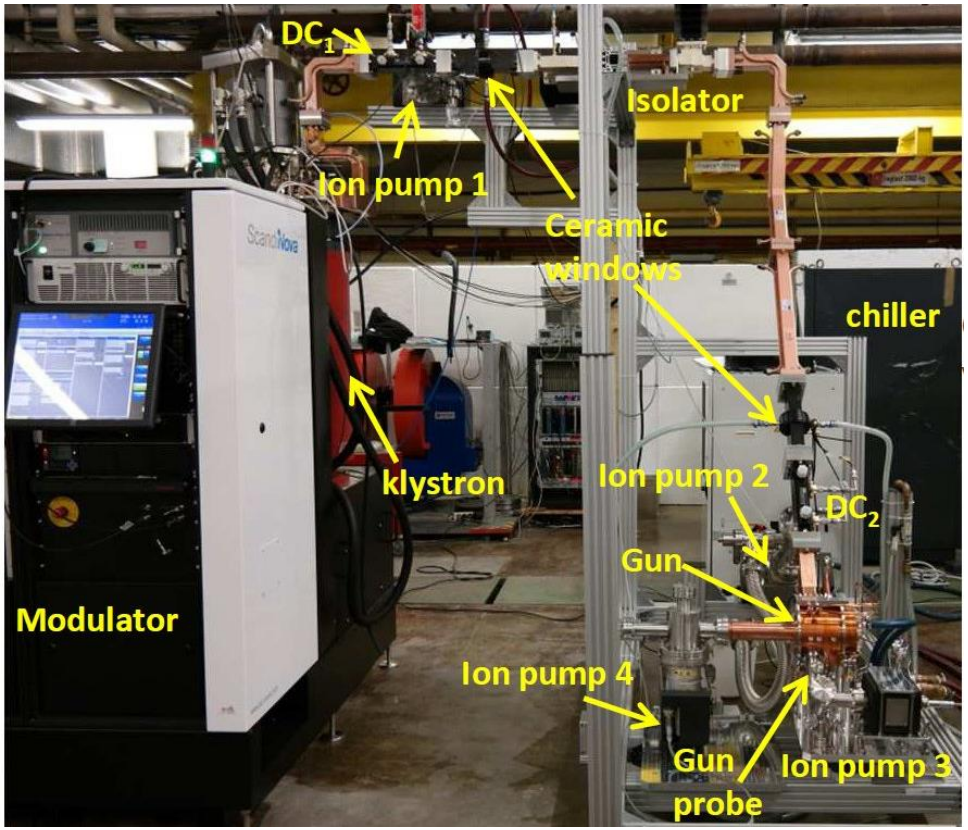




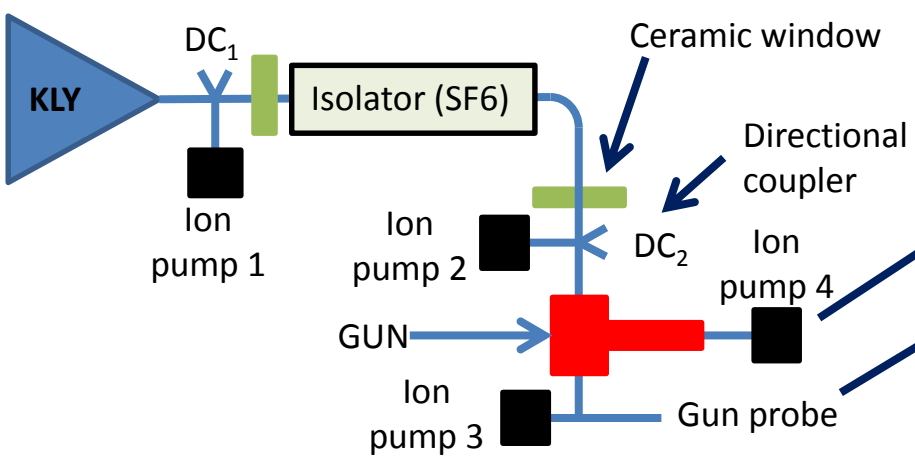


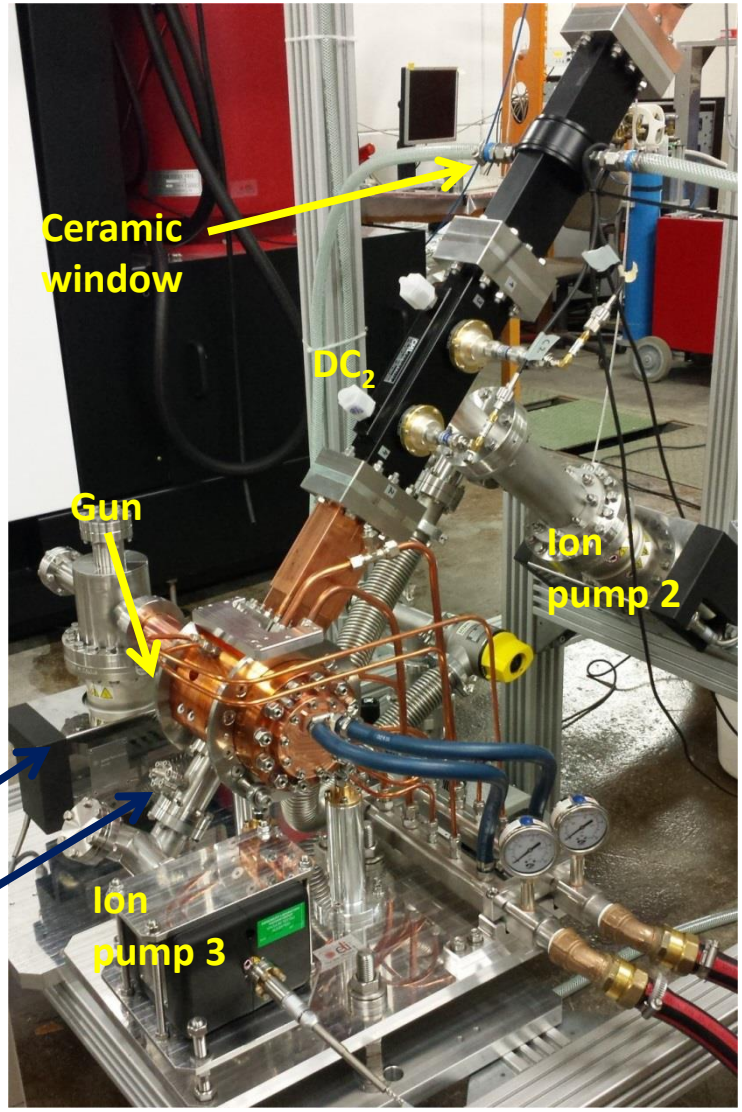
Parameter	Measured value (sim.)
resonant frequency (f_{res})	2.856 GHz @34 deg
coupling coeff. (β)	2.64 (3)
unloaded Q	14980 (14600)
0/π mode separation (Δf)	41.3 MHz

HIGH POWER RF TEST: SETUP



High power RF tests have been performed at the Bonn University under the Research Instruments responsibility. The power source was the ELI-NP Scandinova RF Unit based on Solid State modulator K2-3 and 60MW S-band Toshiba klystron.





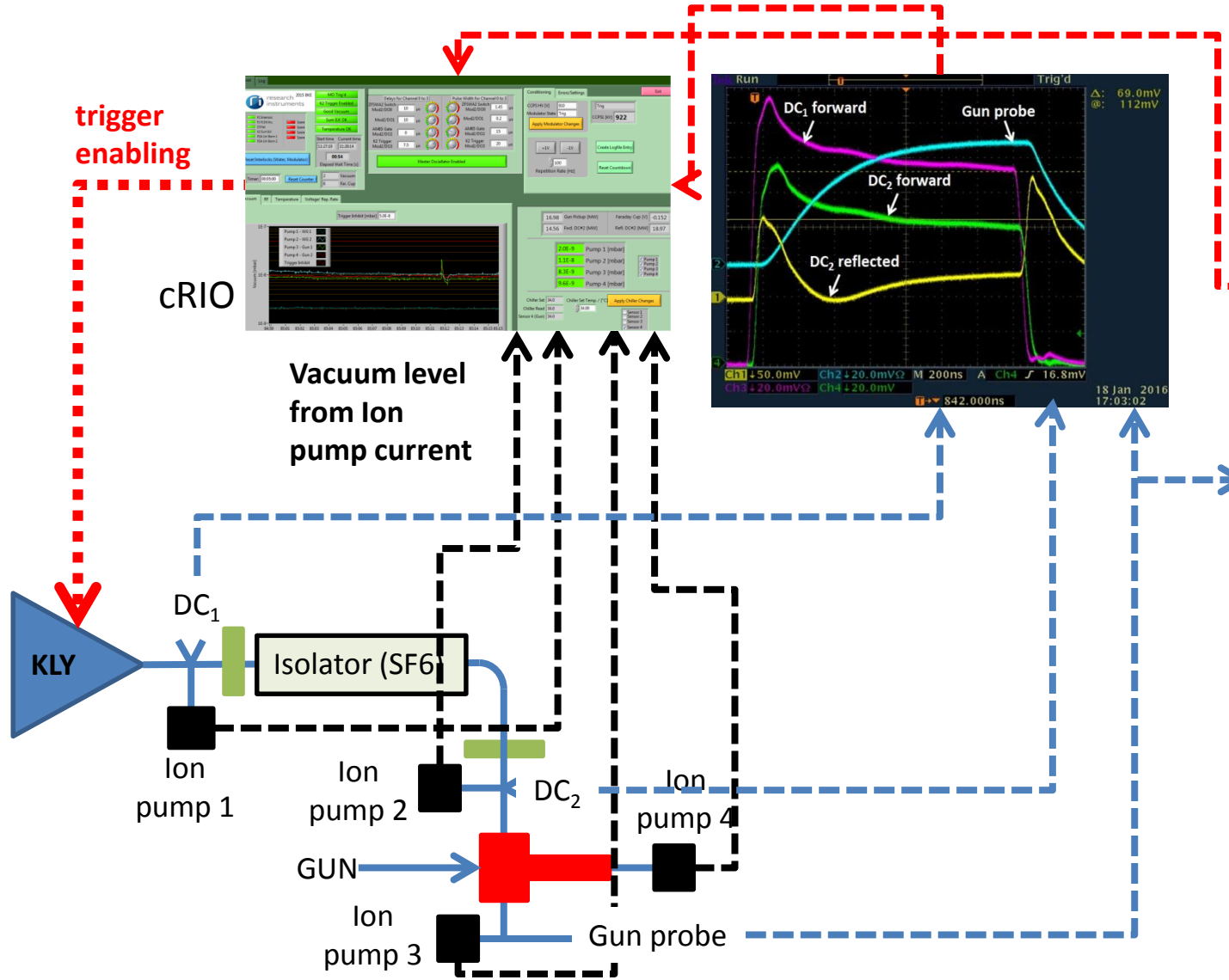
HIGH POWER RF TEST: CONDITIONING CONTROL SYSTEM

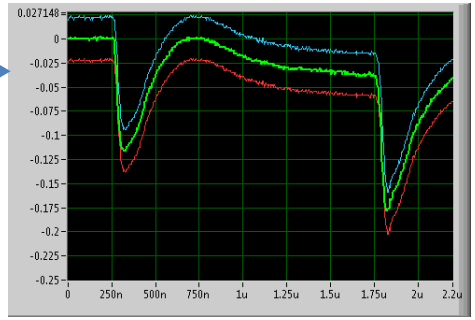
The klystron power, rep. rate and pulse length were progressively increased. The trigger of the modulator was enabled by:

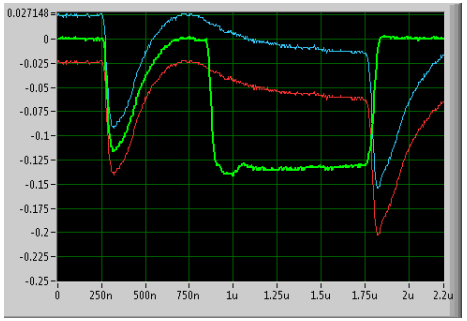
(a) **ion pumps current** absorption exceeding a certain threshold;

(b) **distortions of the reflected signal** due to breakdown phenomena.

The waveform at each pulse was compared with the previous one within a **mask** of tolerance and, in case of pulse distortions due to a discharge, the modulator was switched off immediately.[S. Pioli, TUPIK057]

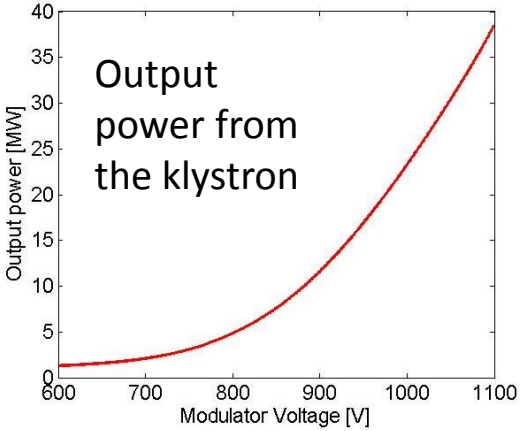




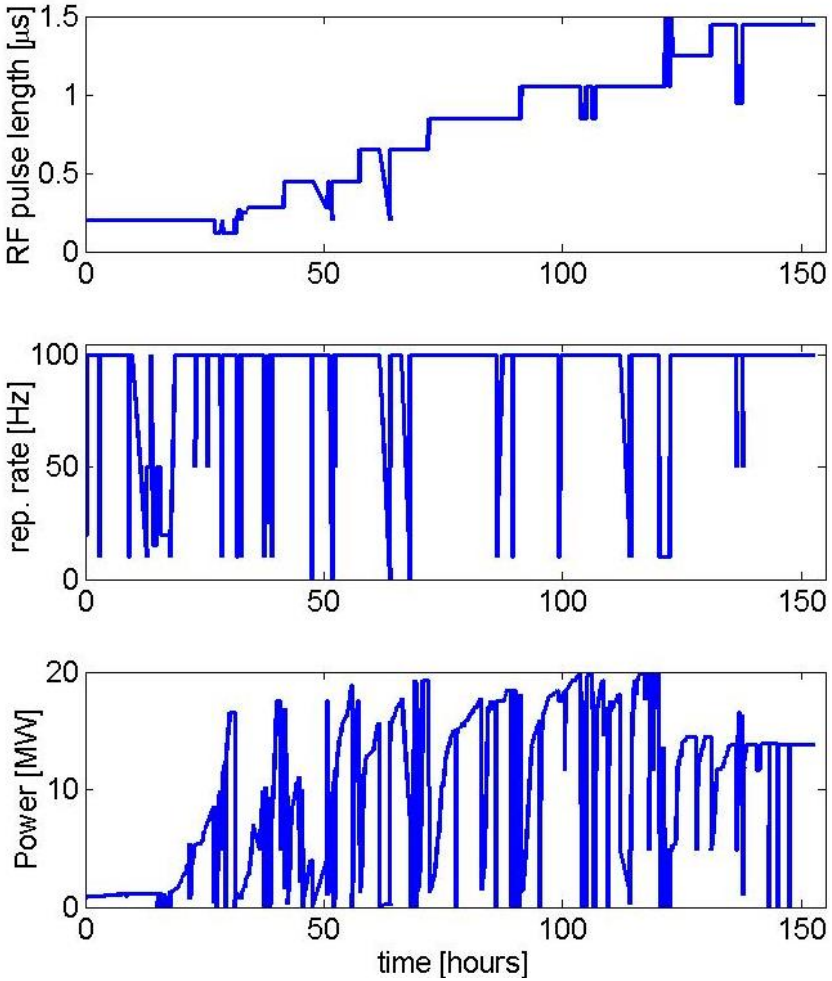


HIGH POWER RF TEST: CONDITIONING RESULTS

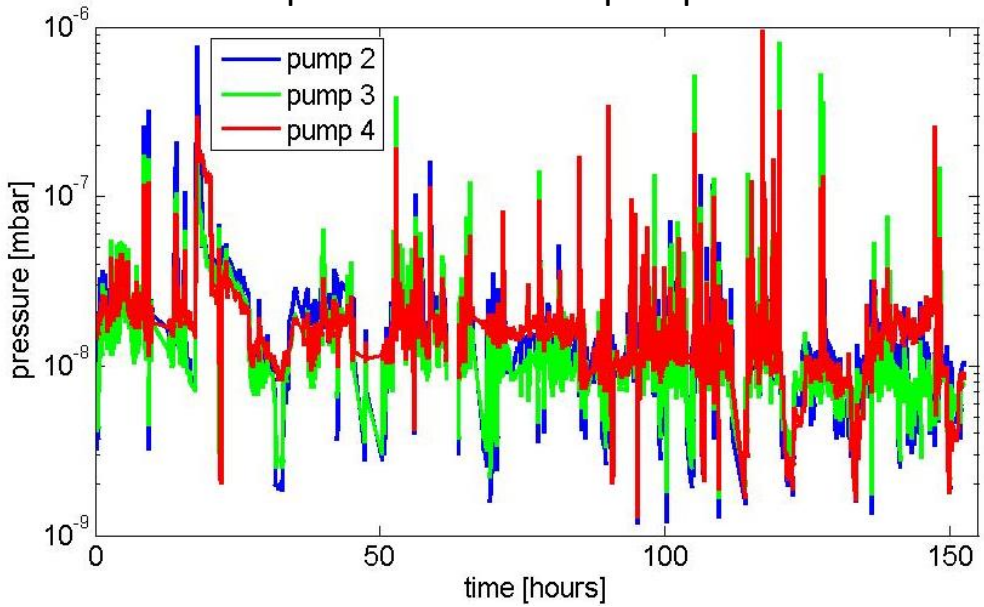
The RF conditioning lasted about **160 hours** and the gun finally reached the nominal parameters with a break down rate of few 10^{-5} bpp. The **vacuum pressure** was measured by the ion pumps current during the whole process. It was of the order of $1x10^{-8}$ mbar at full power and always maintained a **decreasing trend**. At the end of conditioning and without power the vacuum pressure in the gun was lower than **$5x10^{-10}$ mbar.**



Conditioning history

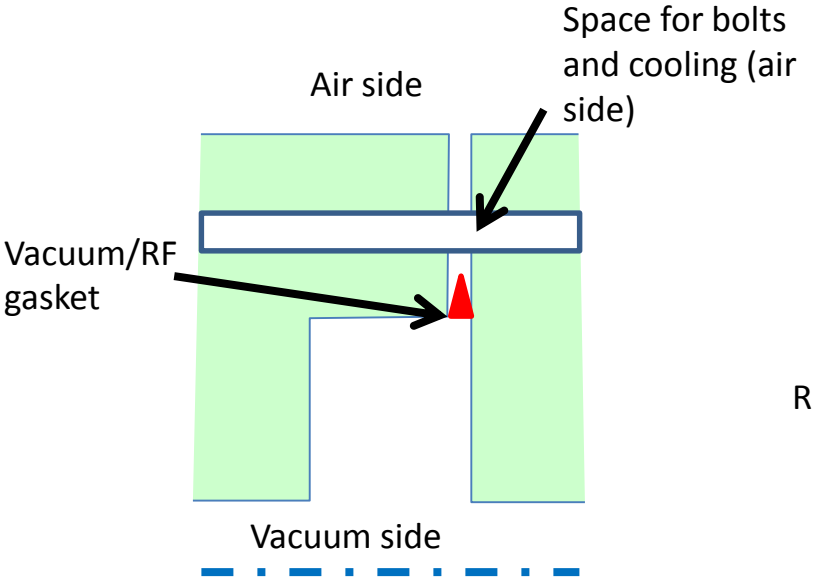


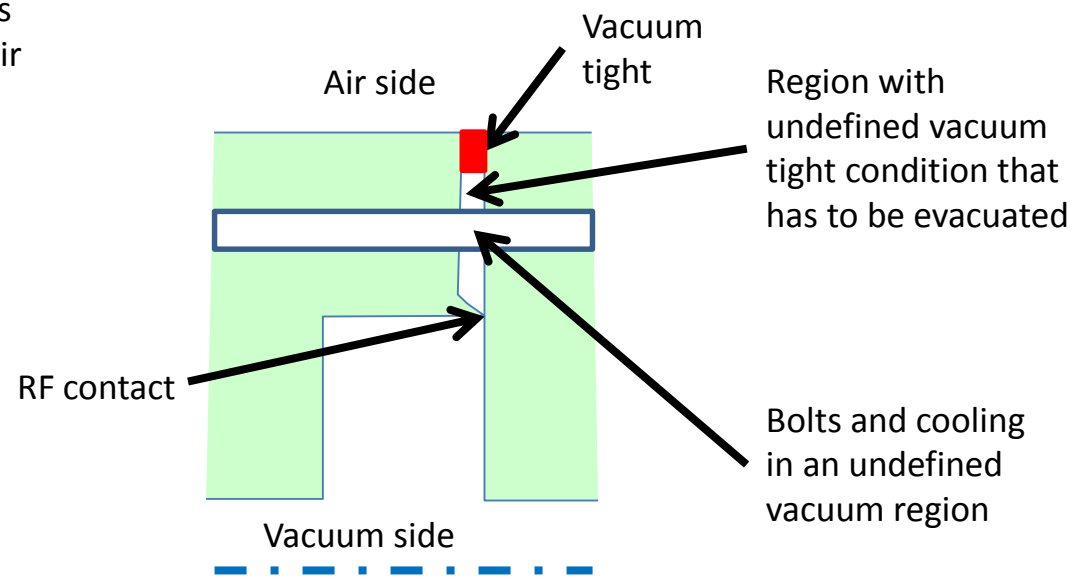
Vacuum pressure from ion pumps current

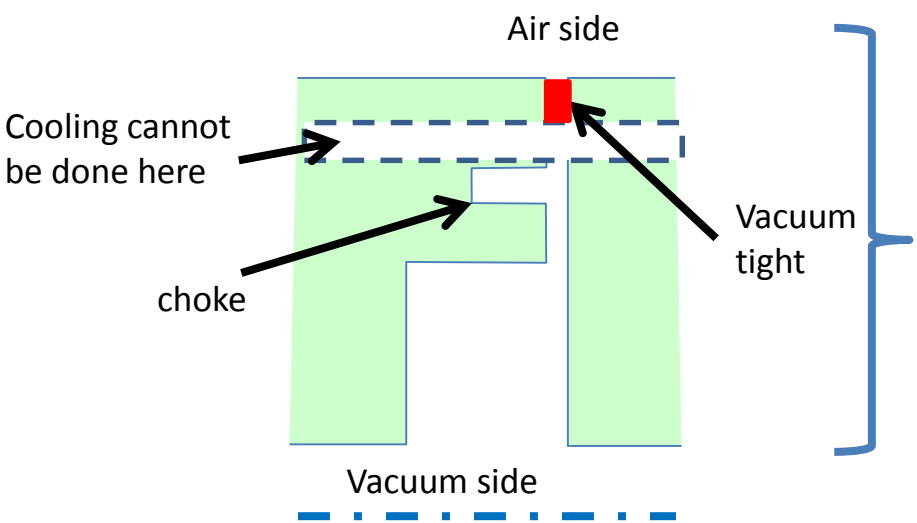


VACUUM-RF GASKET CONSIDERATIONS

The **proposed RF/vacuum gasket realizes in the same point (line) the vacuum and RF contact**. There are **other possibilities** in which the RF contact are separated with respect to the vacuum tight.







Designed based on choke modes, different Q factor, BDR, etc…

Reliability of the design. Micro-discharges that can deteriorate the quality of the junction. **Stress tests have to be done**. For the moment the RF gun in operation at UCLA is routinely working since 3 years.

CONCLUSIONS

The use of special RF-vacuum gaskets technology:

1) allows avoiding **brazing processes**, **reducing the cost**, **realization time** and the **risk of failure**;

2) The technique has been **successfully applied for the realization of the ELI-NP GUN** and, previously, to the realization of a first gun now installed at **UCLA Pegasus** lab producing beams for electron microscopy and electron diffraction experiments;

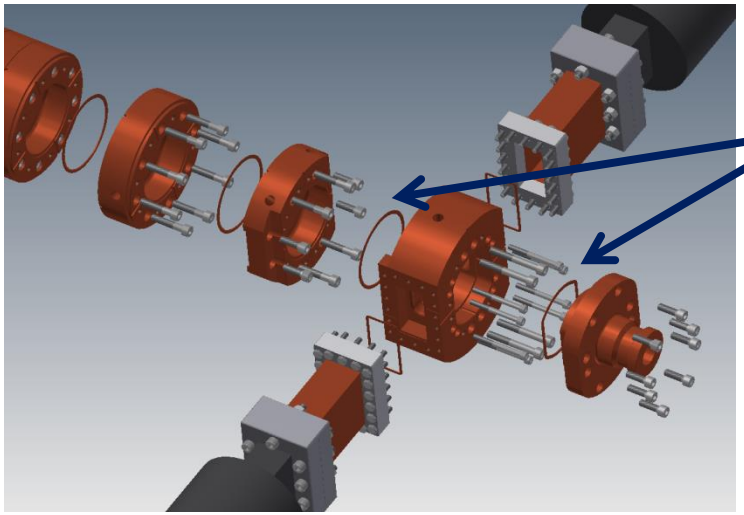
3) **without copper annealing** due to the brazing process, it is possible to reduce also the conditioning time (X band experience, CERN) and further investigations have to be done to see if it is also possible to reduce the BDR (X band experience, SLAC);

UCLA Pegasus lab with clamped RF gun in operation (90 M/m 5 Hz)

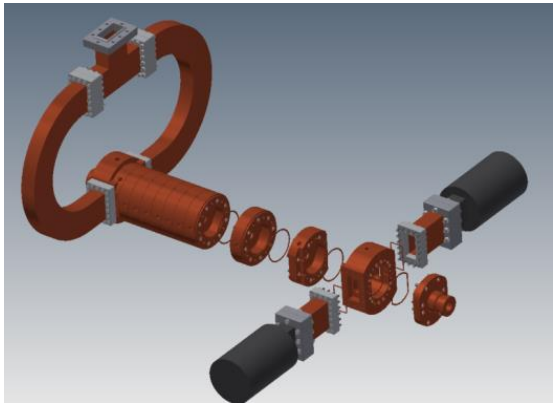
[D. Alesini, et al., PRST- AB 18, 092001 (2015)
D. Cesar, et al., PRL 117, 024801 2016
J. Maxson, et al., PRL 118, 154802 (2017)
D Cesar et al., JAP 118, 234506 (2015)]

PERSPECTIVES AND FUTURE APPLICATIONS

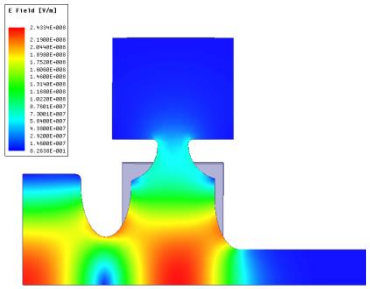
The **extension of this new fabrication process to complex (long) LINAC structures** is the next step on the application of this new technique for particle accelerators. **A strong impact in the accelerator market** is also expected because in principle all industries that are able to do precise and clean machining of components can produce accelerating structures.



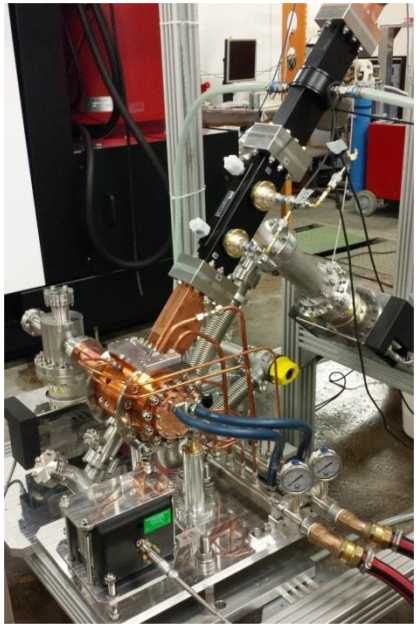
[F. Cardelli et al., IPAC2016, p. 403, 2016]



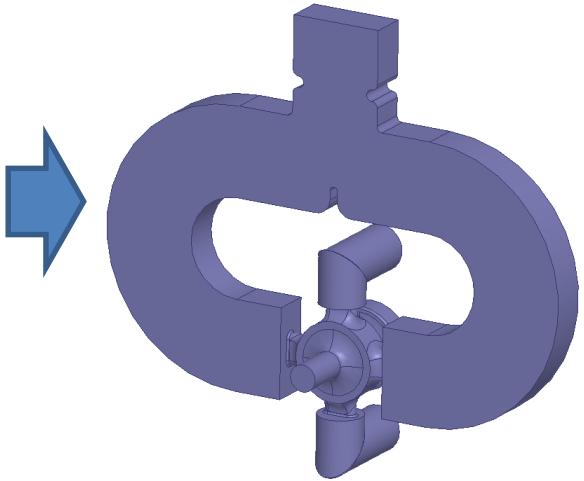
C-band Ultra fast (<50ns) RF Gun



120 MV/m S-Band



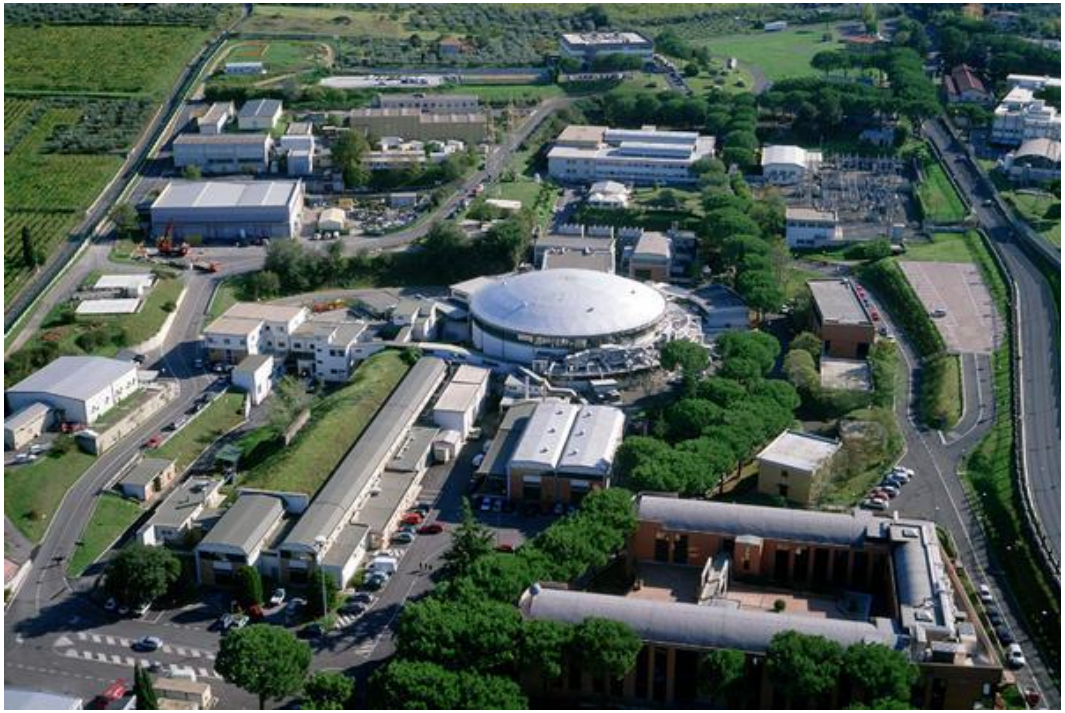
240 MV/m C-Band

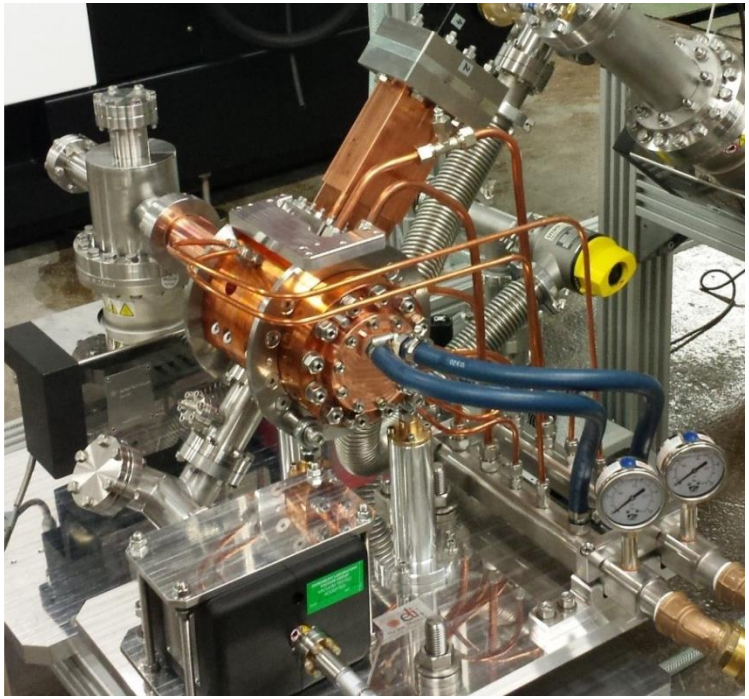


THANK YOU FOR YOUR ATTENTION!

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

eli
extreme light infrastructure





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