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

David Alesini
(LNF-INFN, Frascati, Italy)

IPAC17

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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;

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- **narrow bandwidth** (<0.5%)
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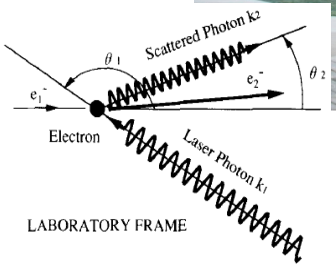

[TDR ELI-NP GBS arXiv:1407.3669]
[A. Giribono, MOVA016]

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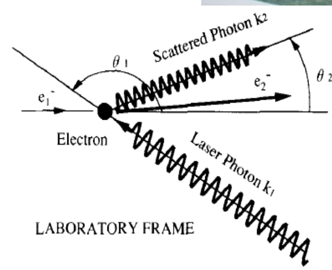

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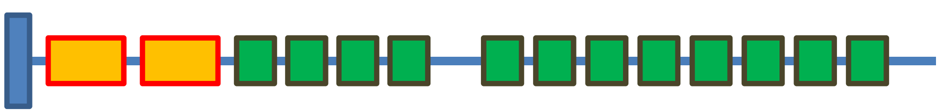

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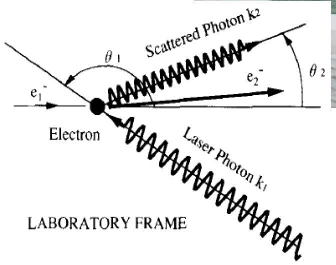

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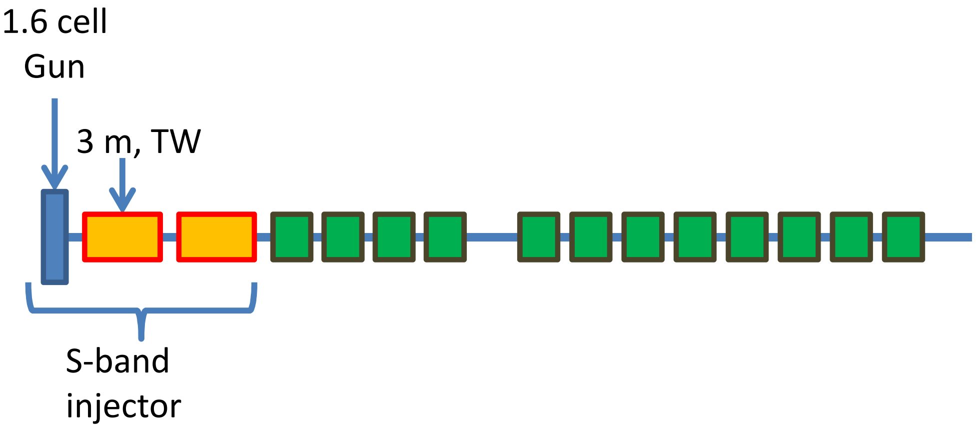

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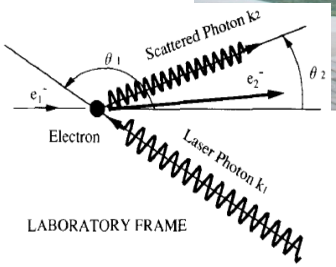

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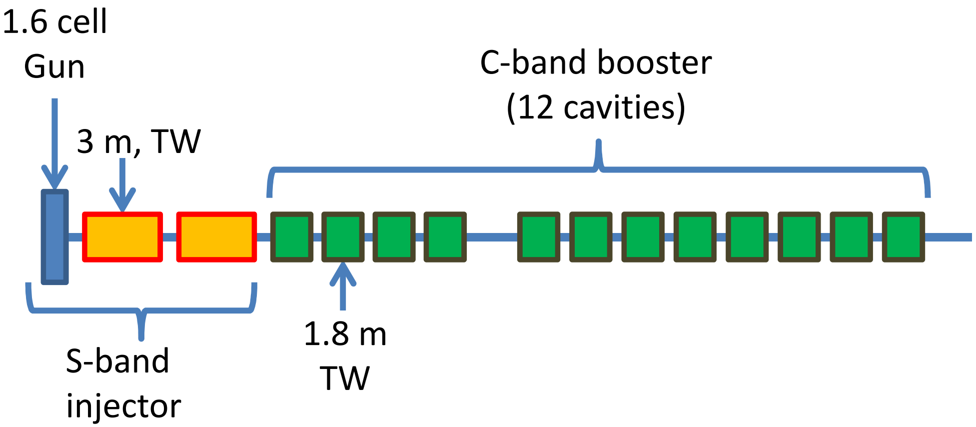

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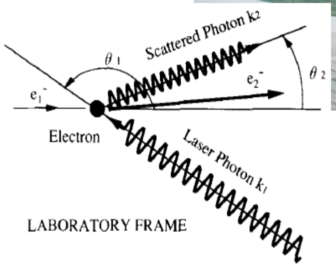

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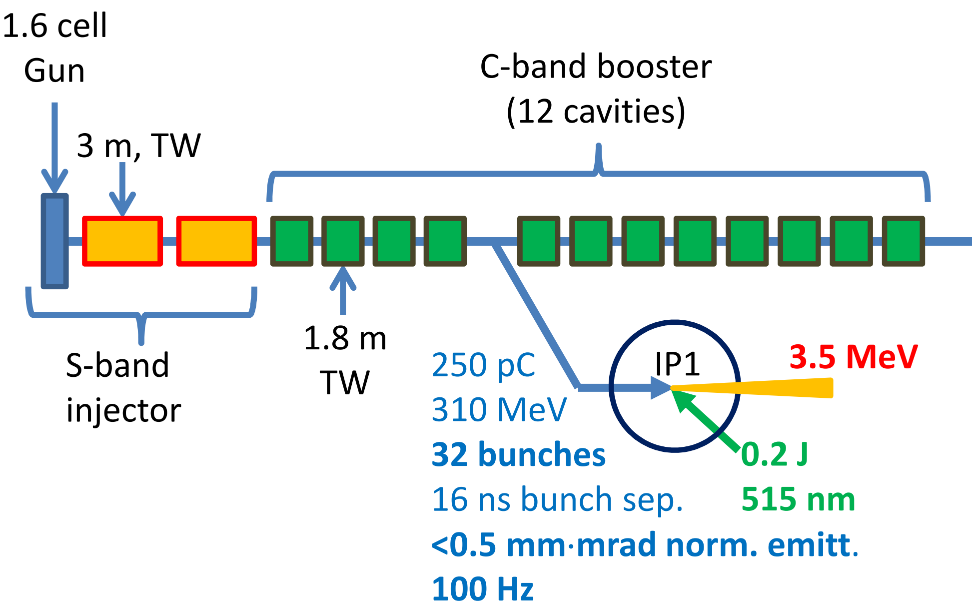

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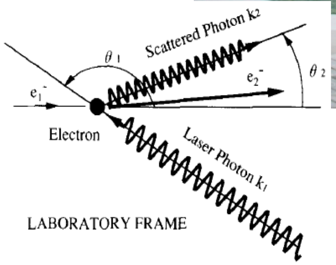

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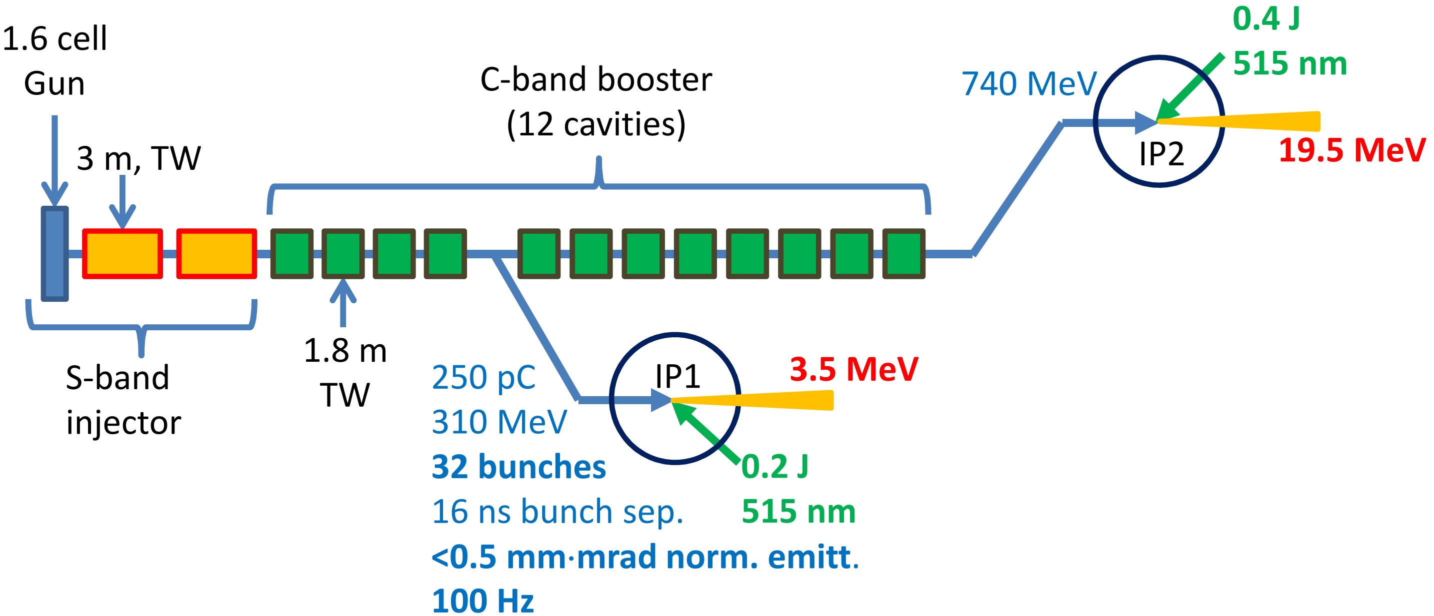

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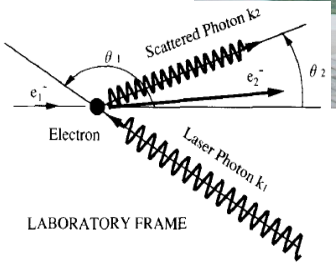

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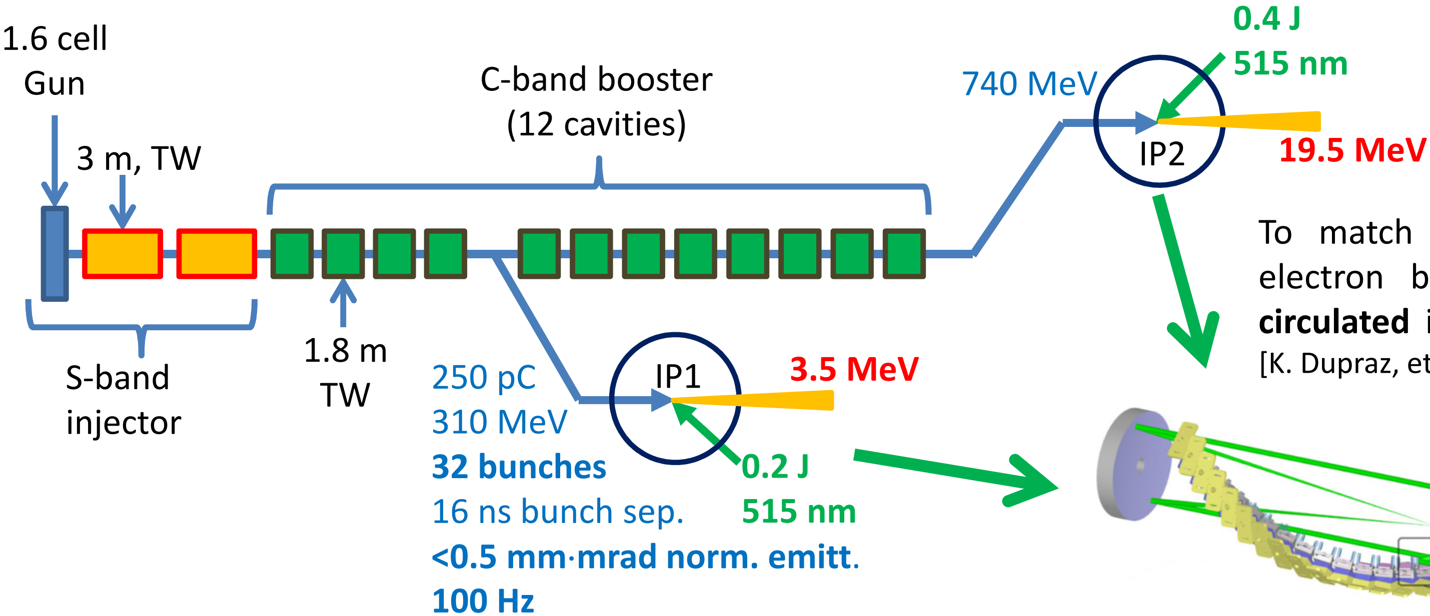
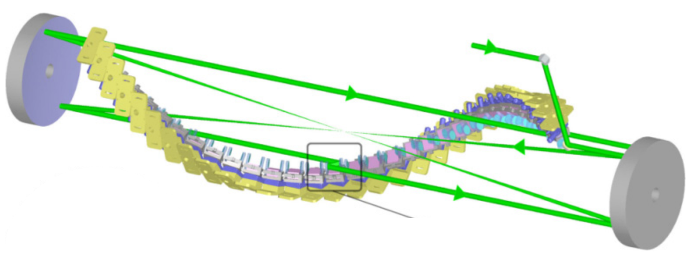


To match at the IPs the multi-bunch electron beam the **laser pulse is re-circulated** in a novel optical re-circulator [K. Dupraz, et al., PRST-AB 17, 033501 (2014)]



ELI-NP LINAC

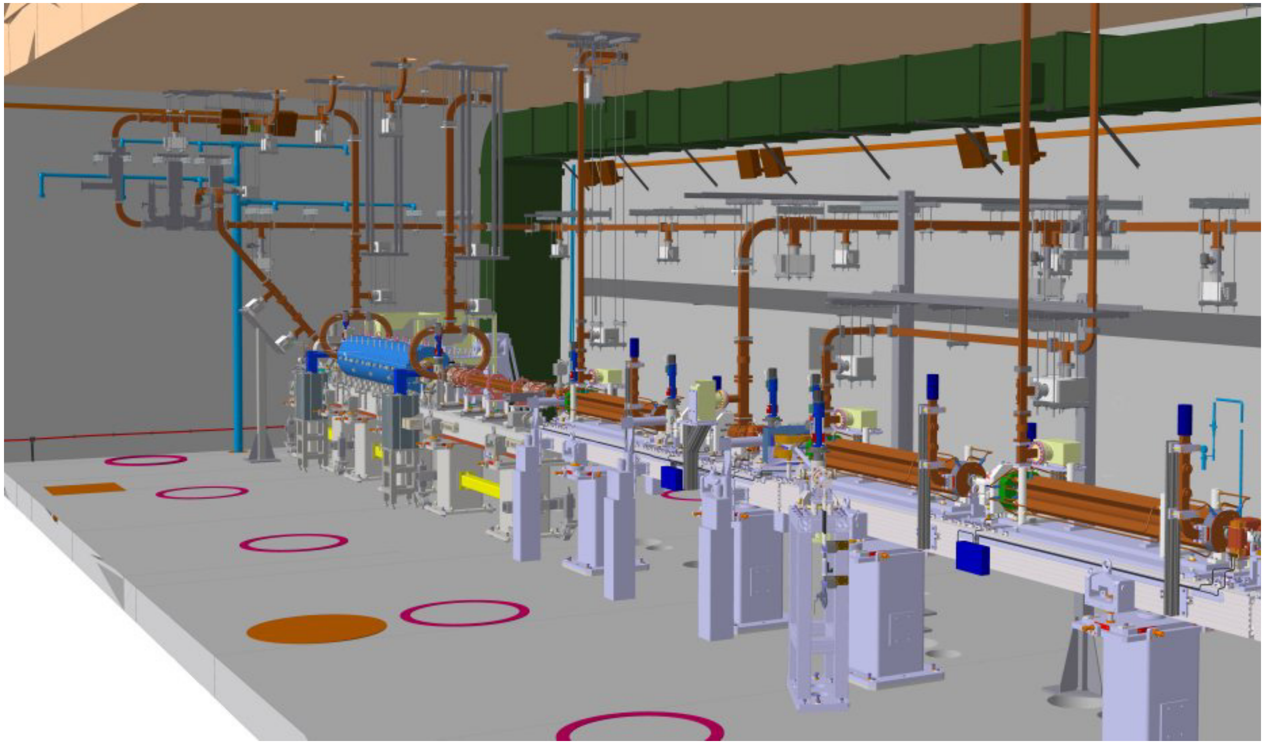
The ELI-NP LINAC operates:

⇒ at **100 Hz**

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

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

⇒in **multi bunch** (32 bunches)



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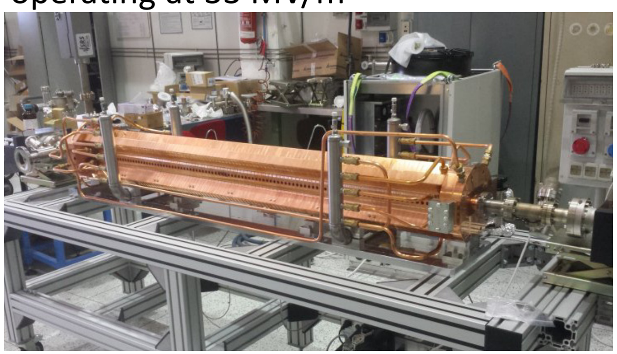
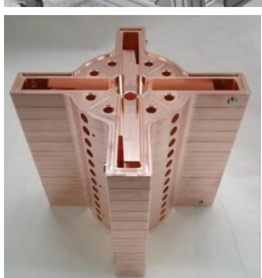
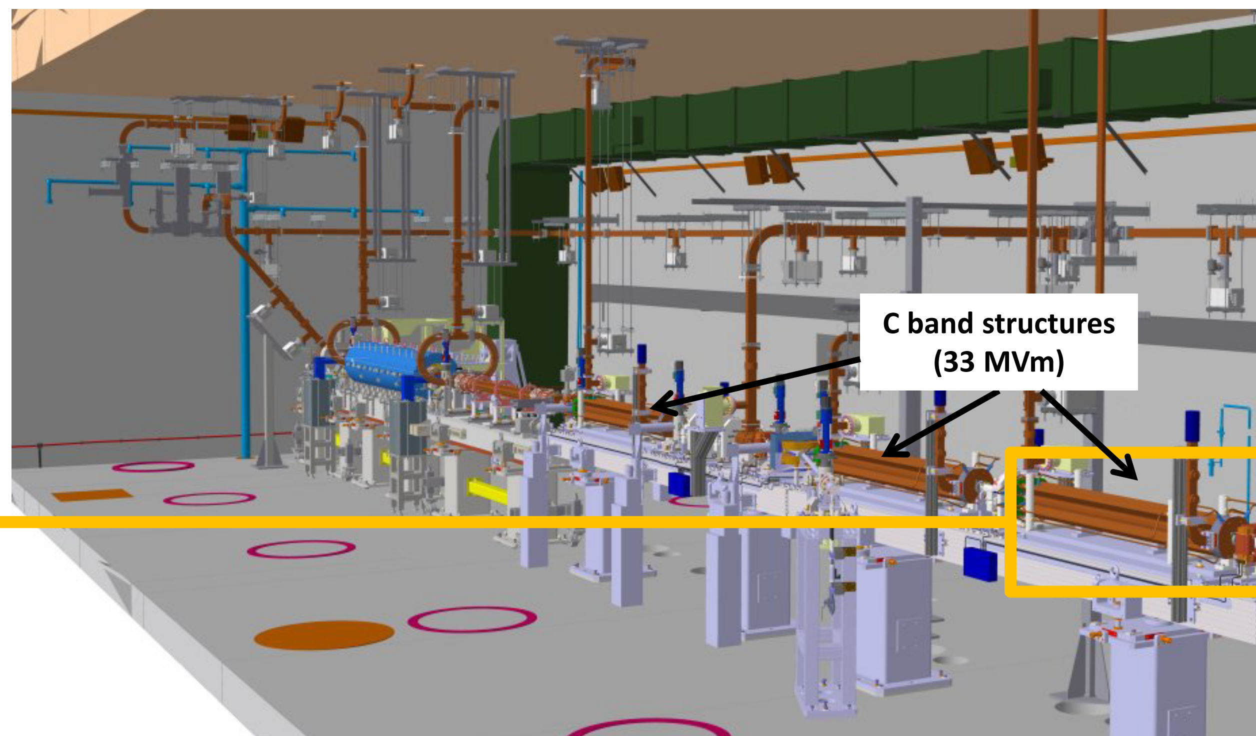




[D. Alesini et al., PR AB 20, 032004 (2017)]



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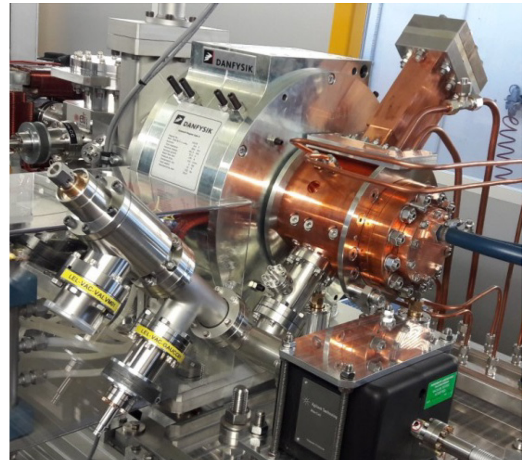

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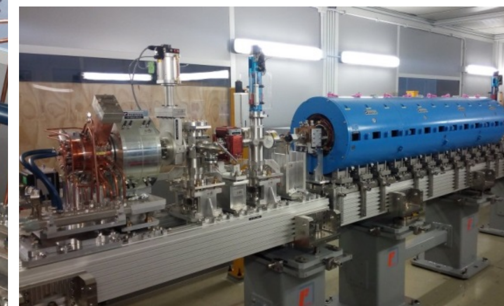

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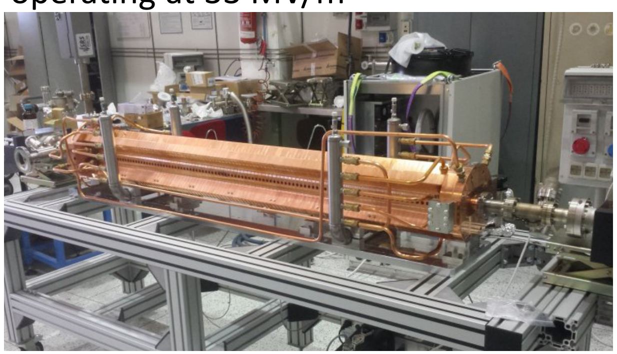

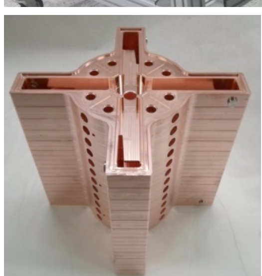

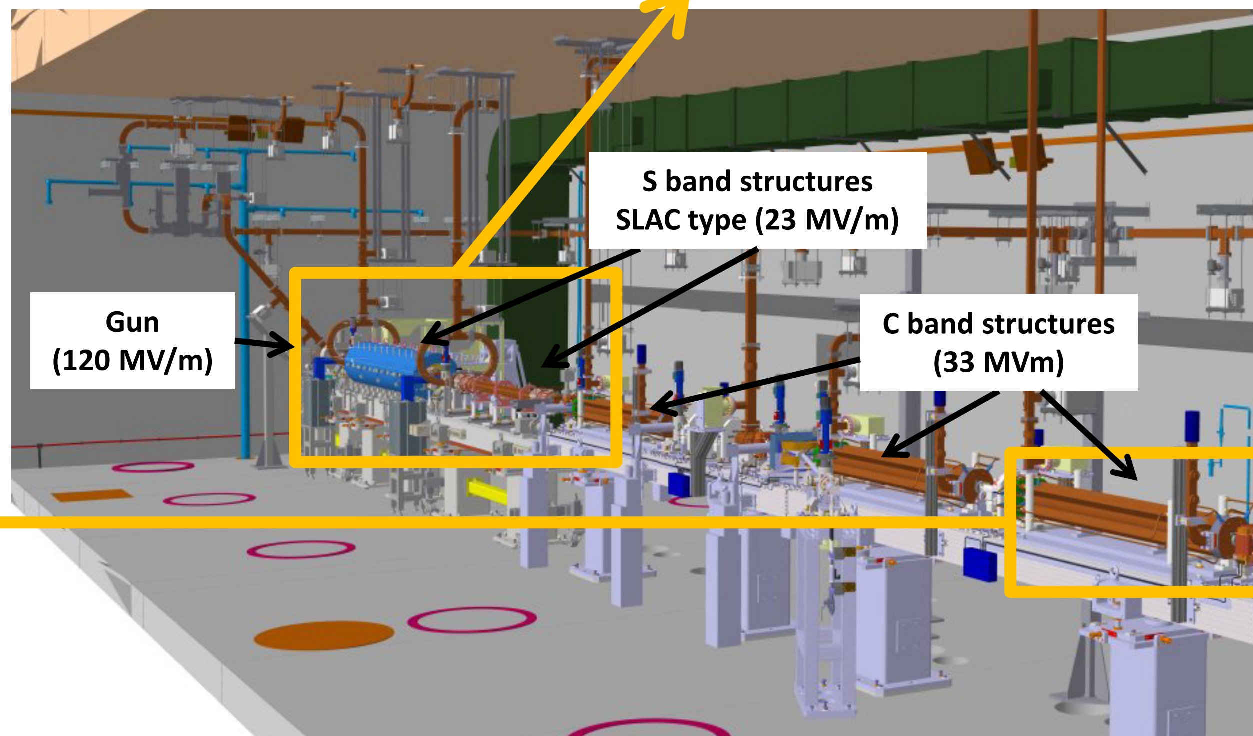

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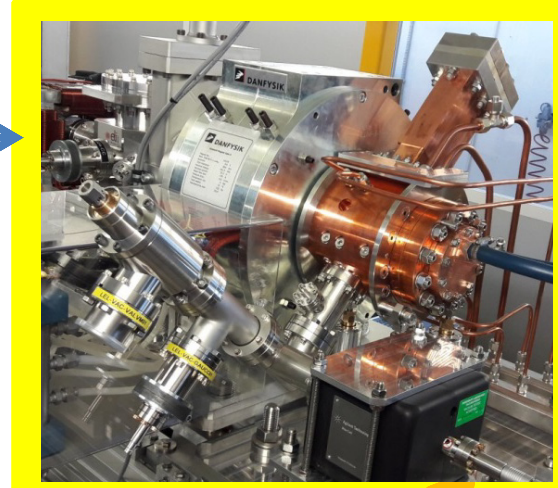

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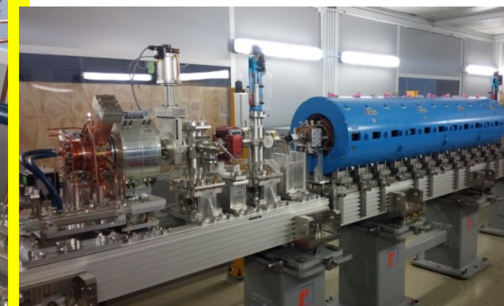

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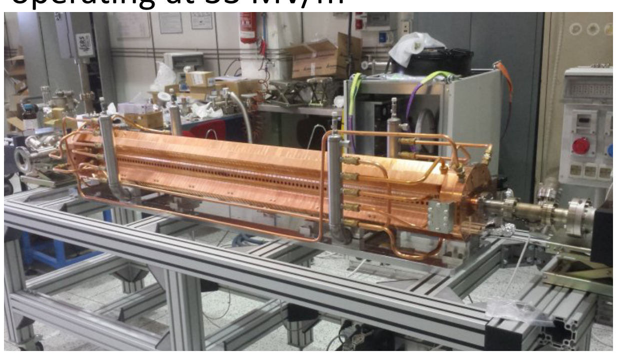

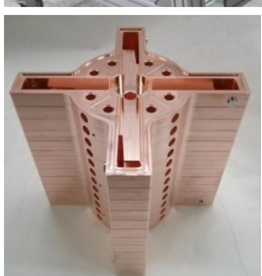

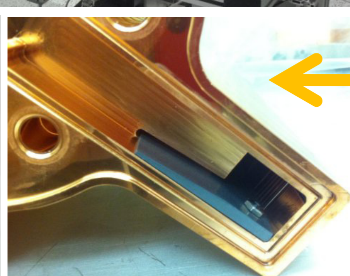

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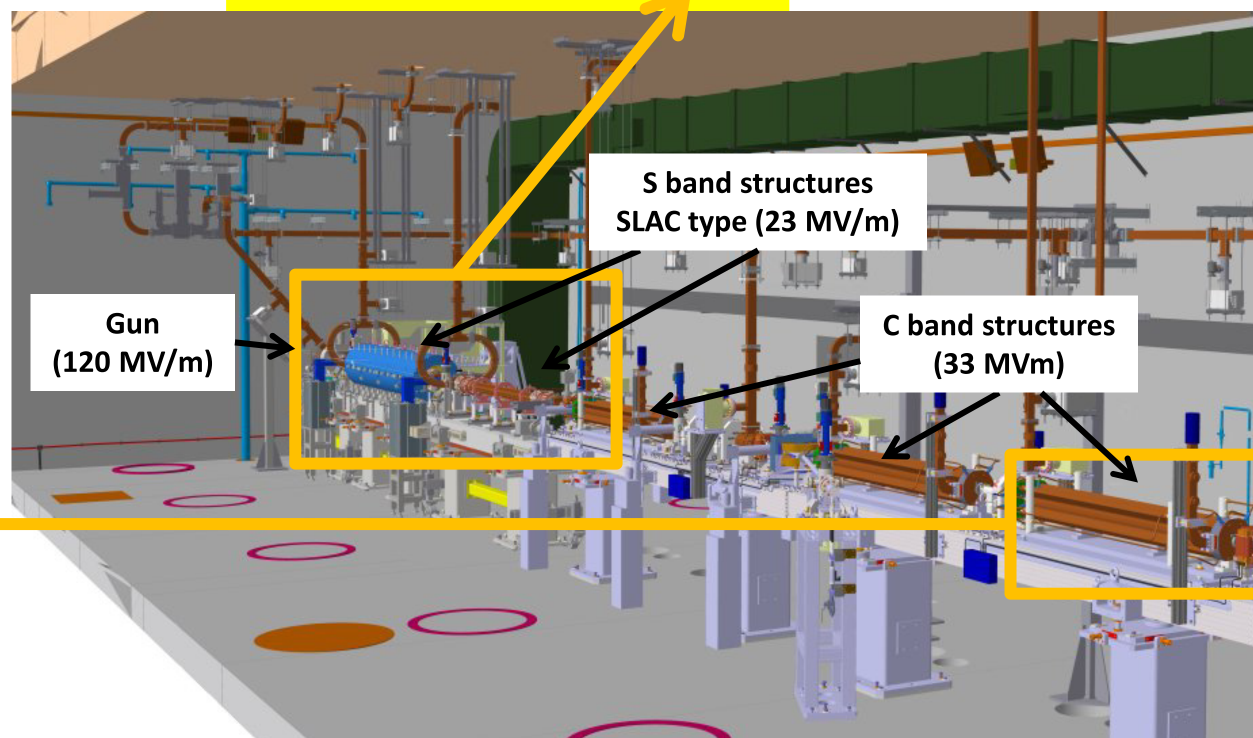

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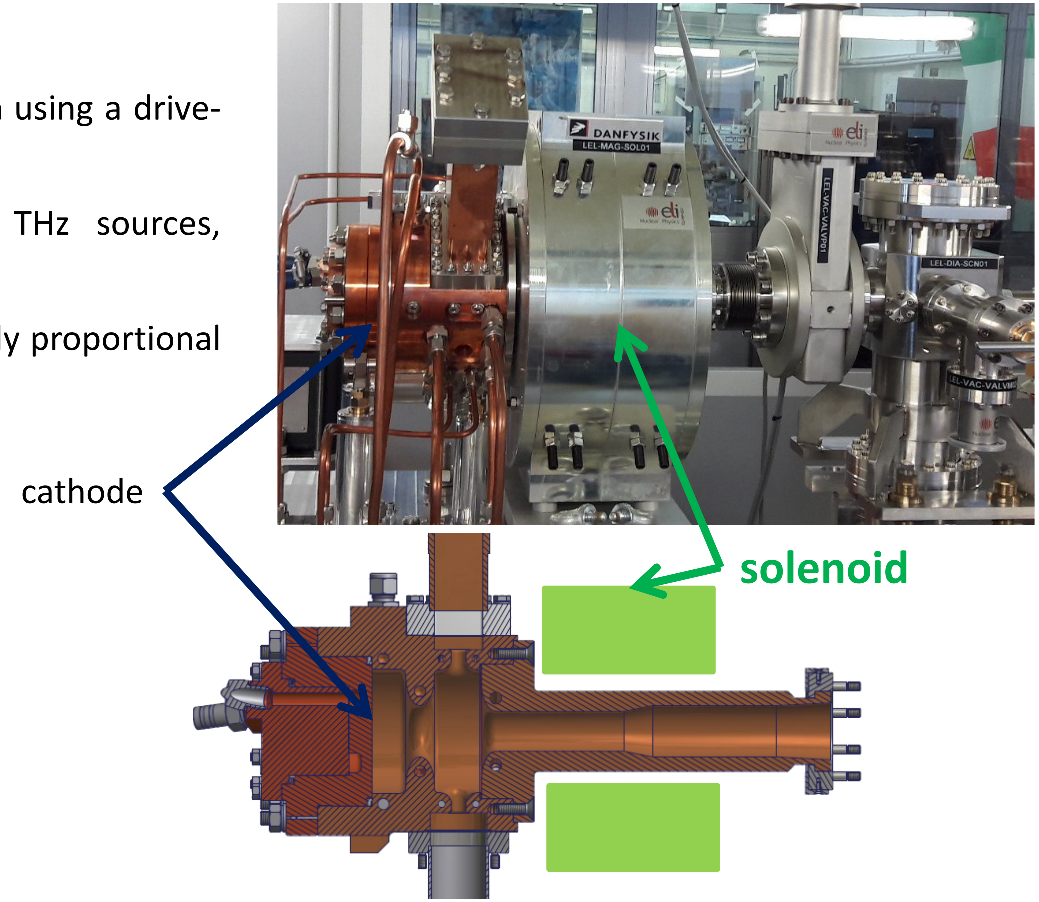
PHOTO-CATHODE RF GUNS

⇒ 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).



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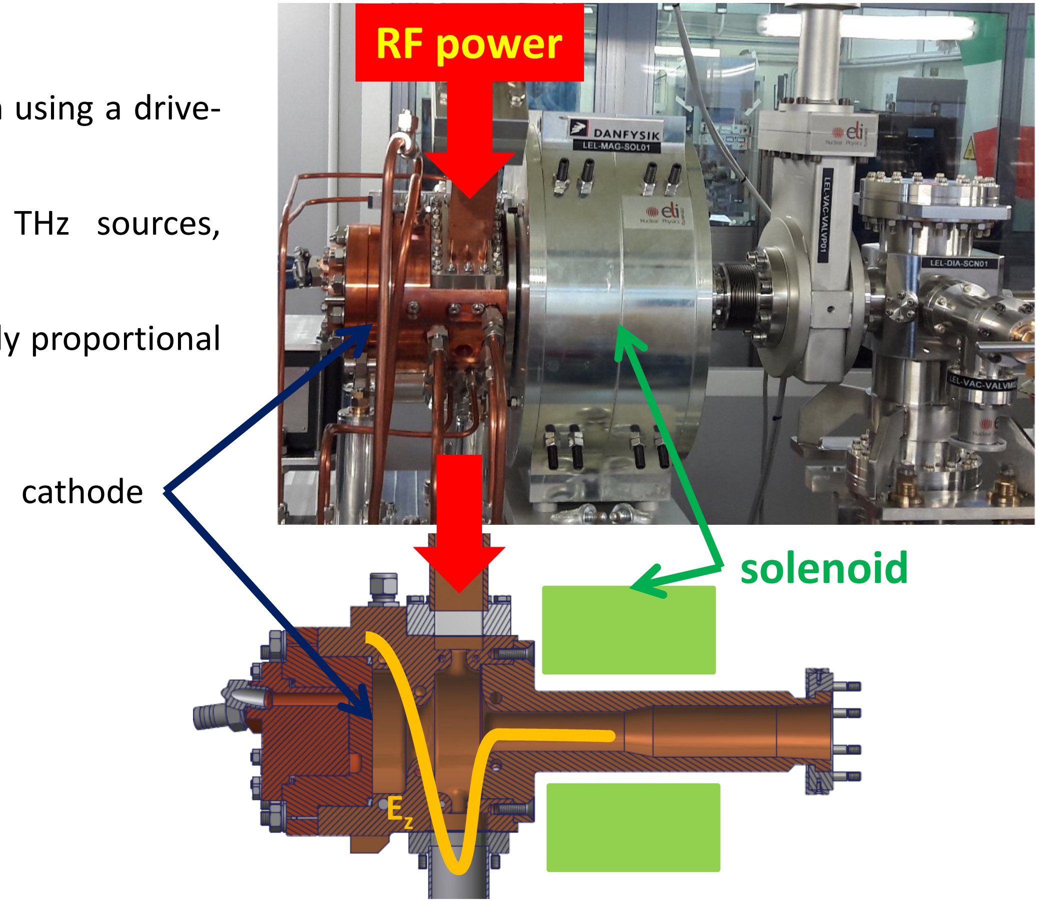

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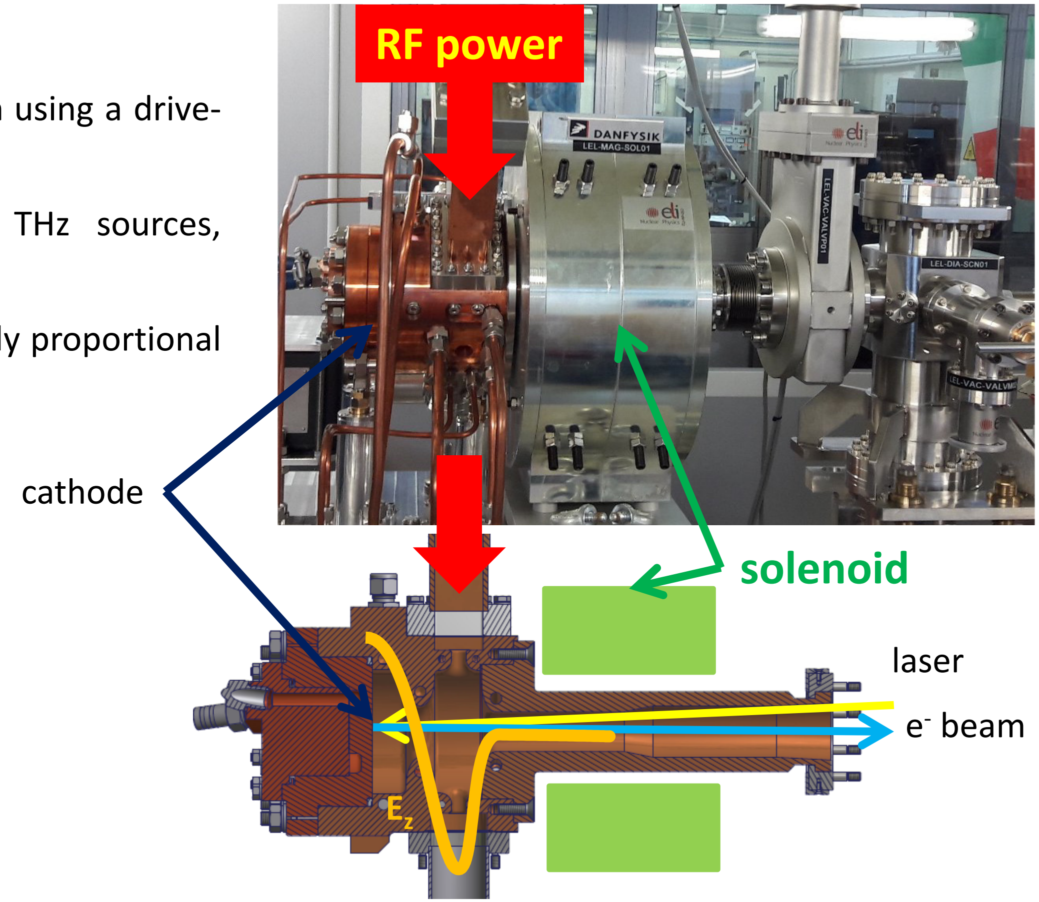

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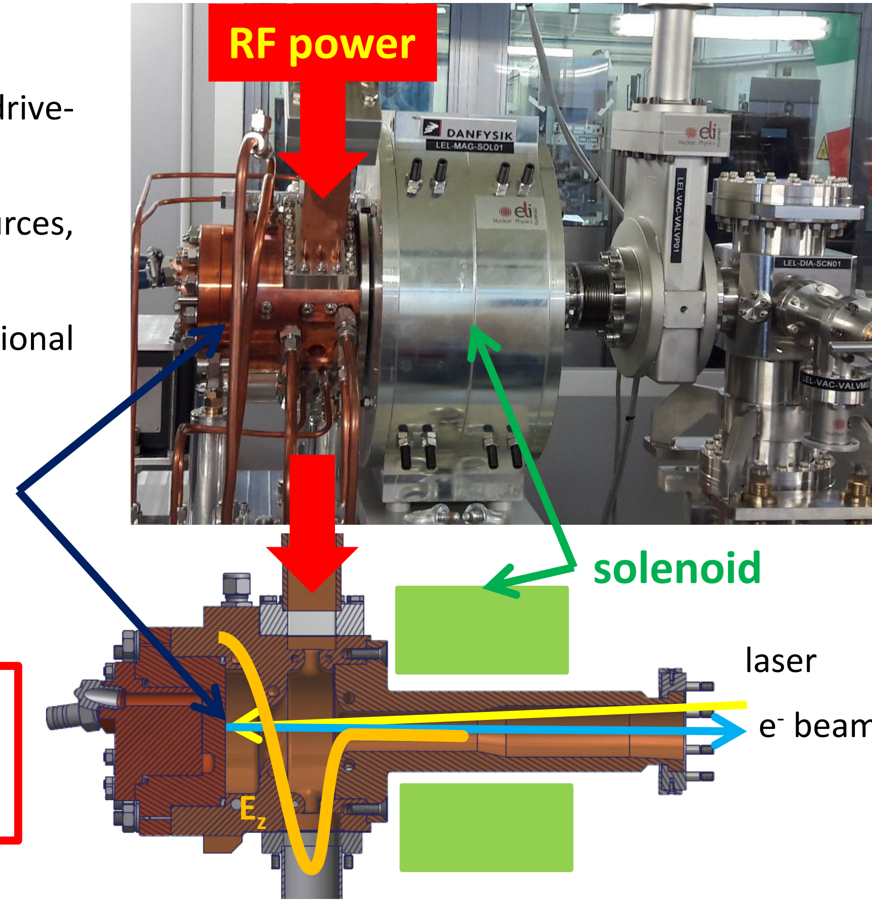

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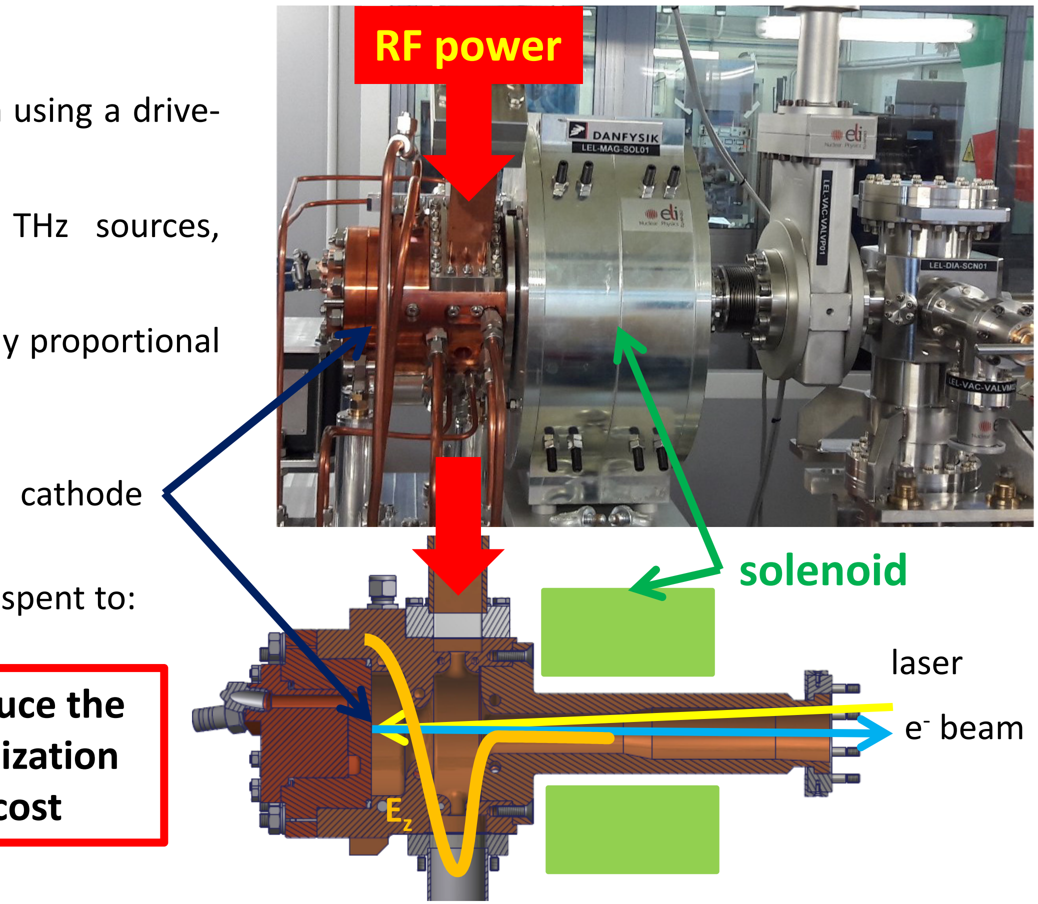

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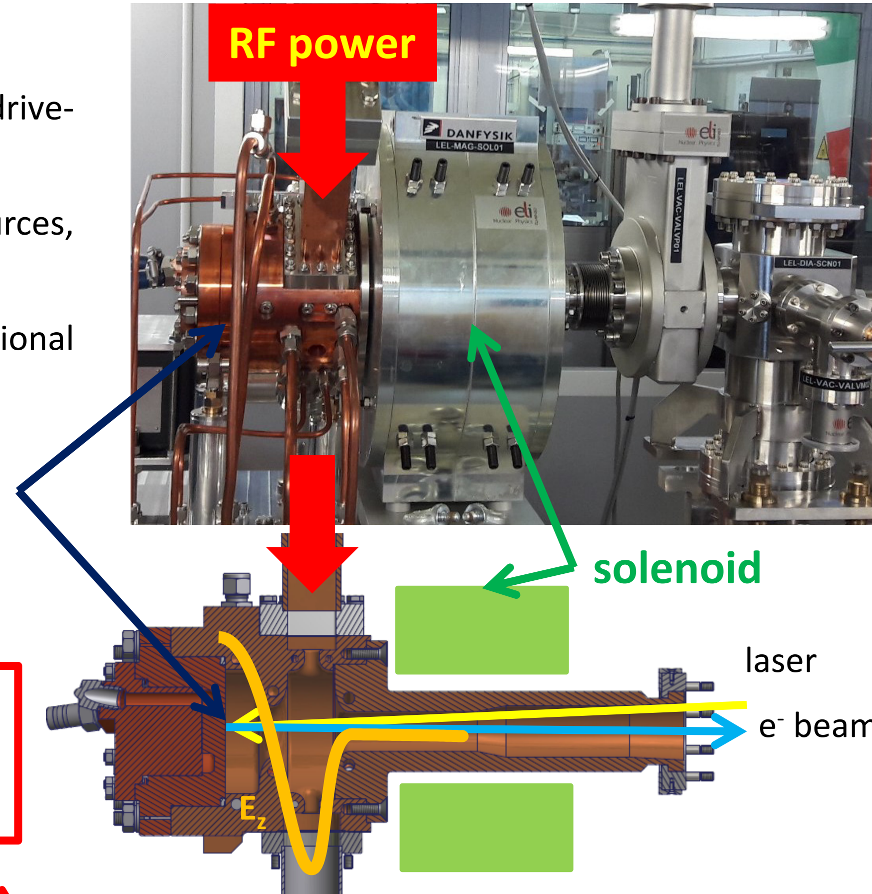

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Realization processes

⇒ 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)

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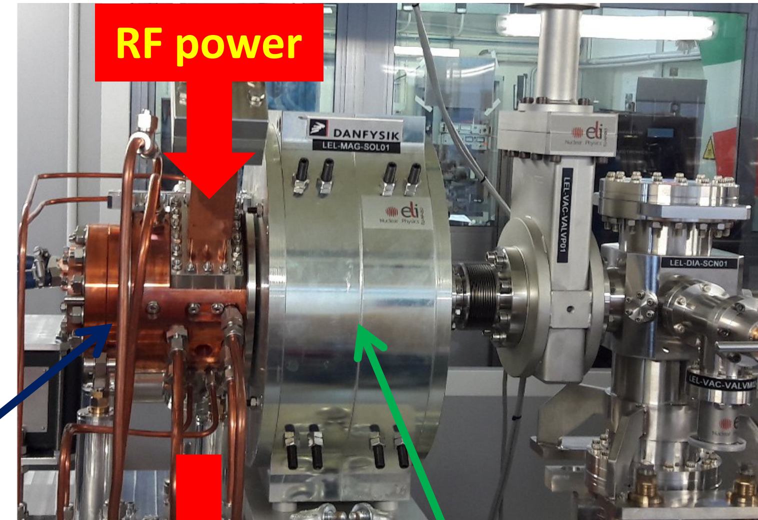

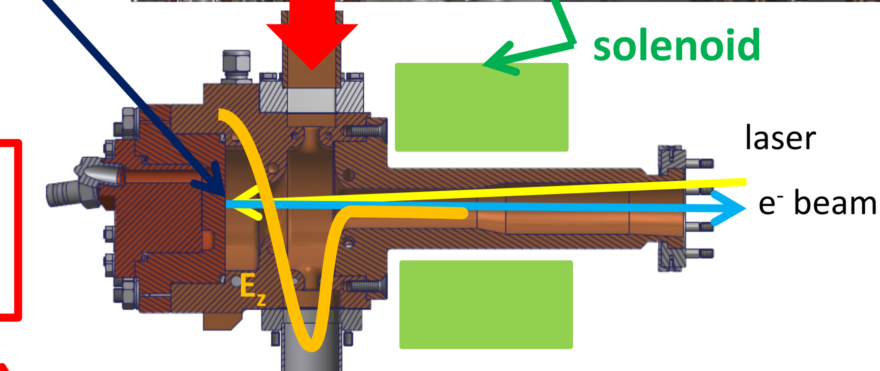

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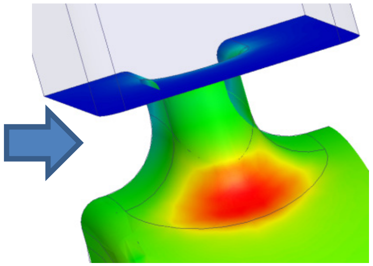
RF AND THERMO-MECHANICAL DESIGN OF ELI-NP GUN

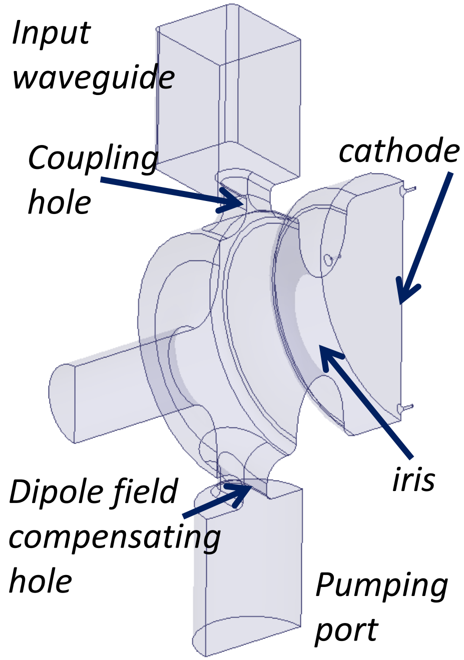
RF design

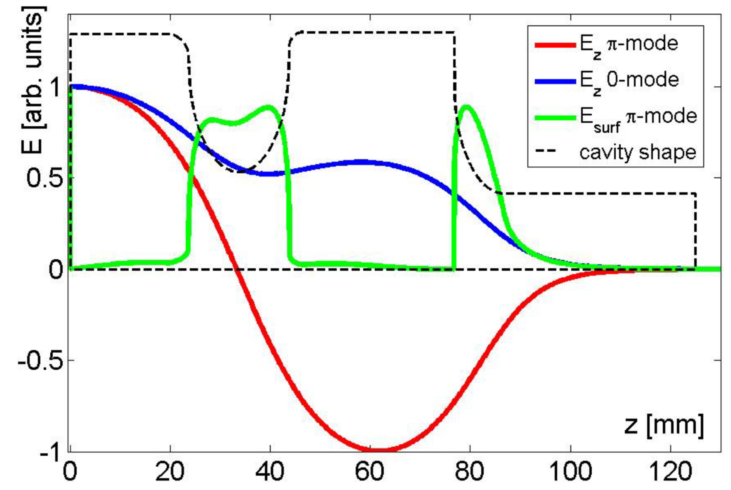
⇒**iris profile** with an **elliptical shape** and a **large aperture** to:

- 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**.





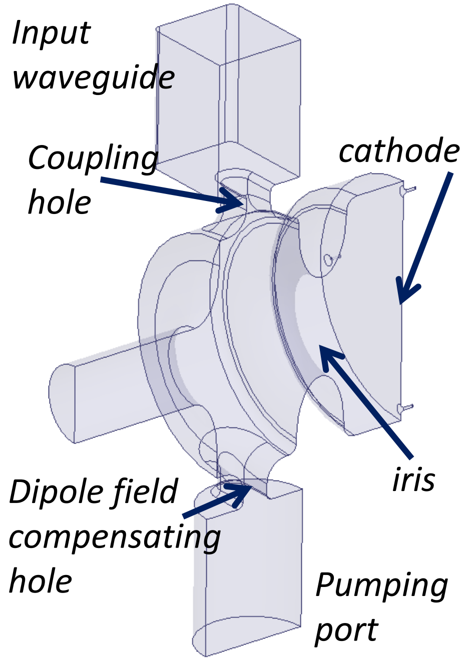


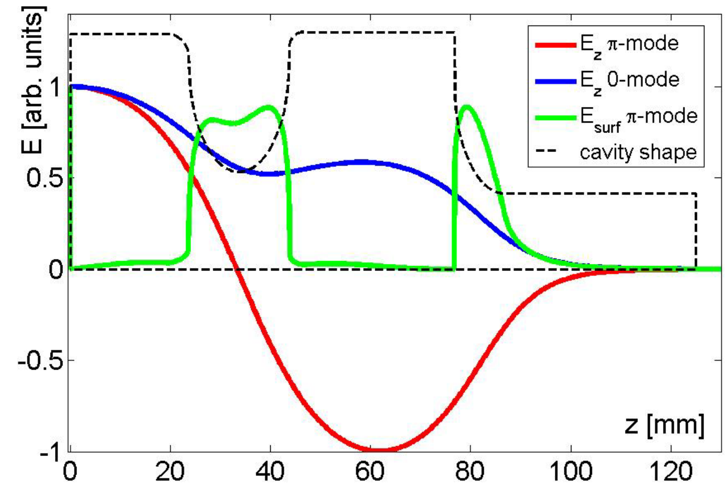
RF AND THERMO-MECHANICAL DESIGN OF ELI-NP GUN

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.





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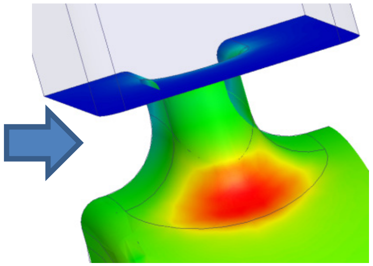


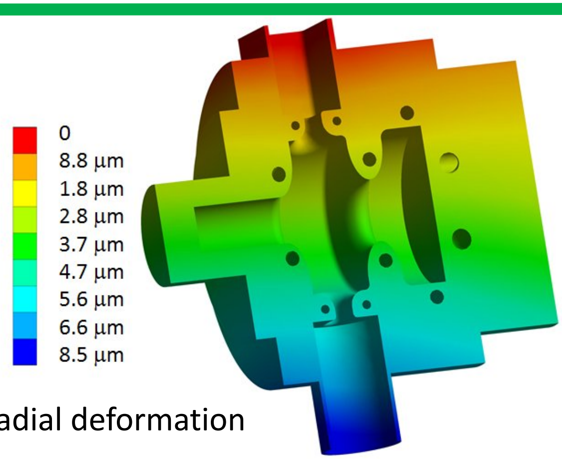
Thermo-mechanical design

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

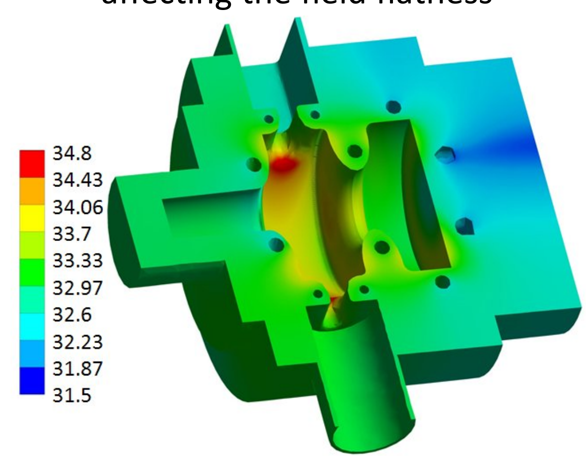
⇒**6 cool. channels** (incl. cathode) with total water flow of **30 liter/min**

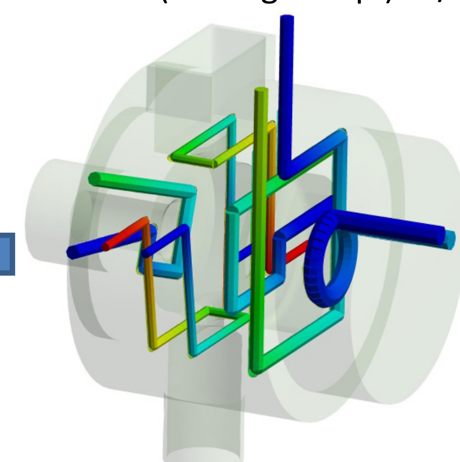
⇒full coupled thermal-structural analysis (Ansys Workbench)

⇒**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]
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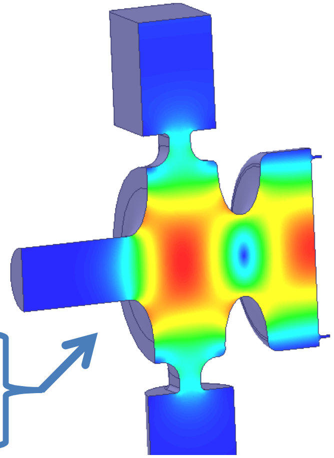

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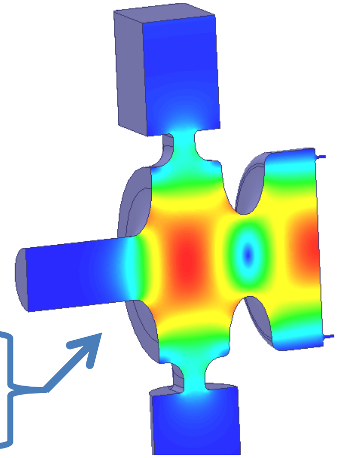

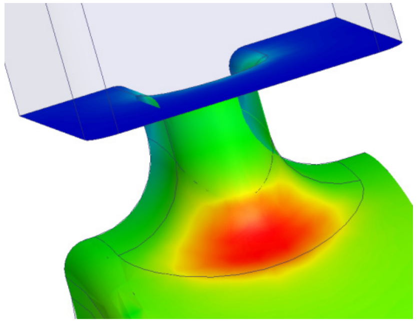

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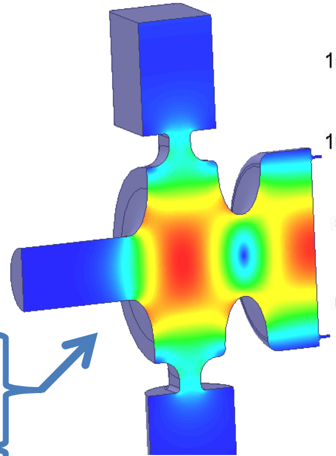

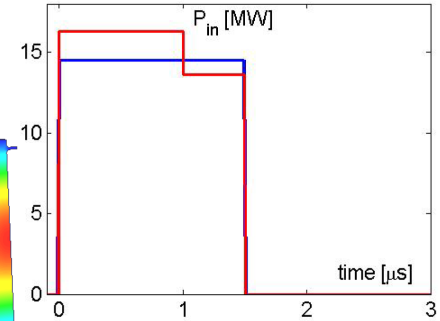

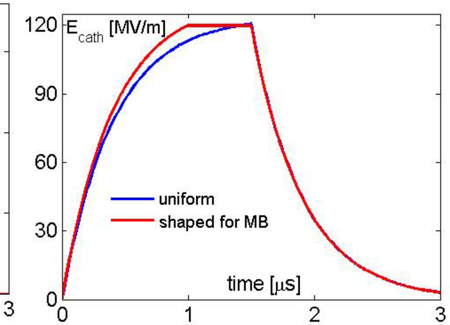

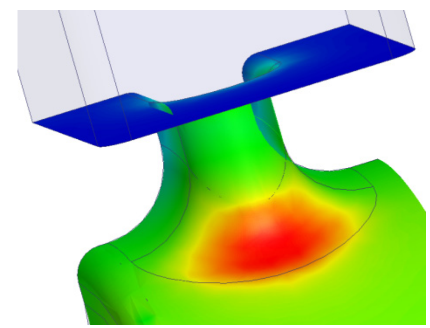

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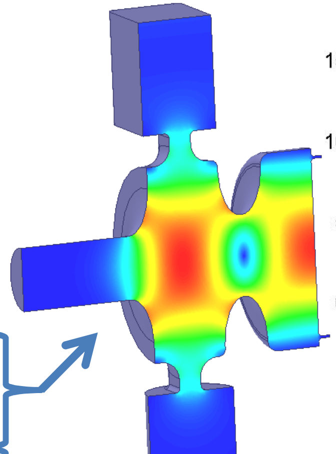
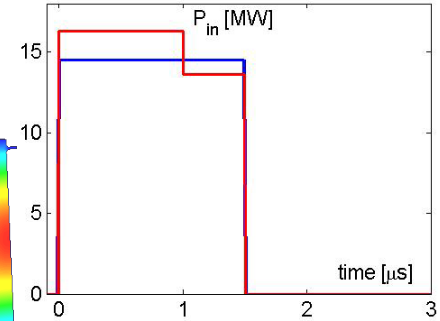
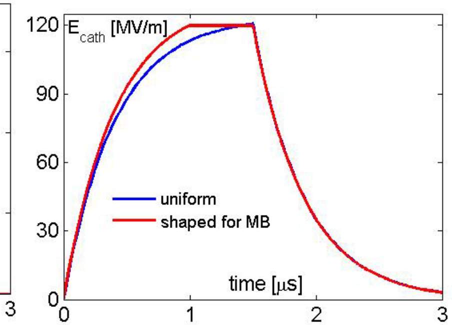
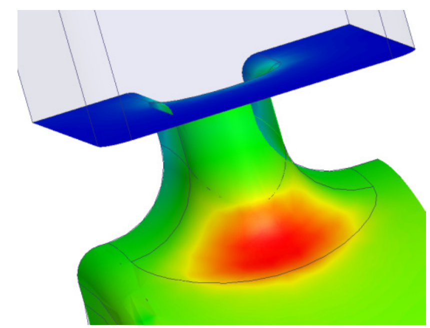








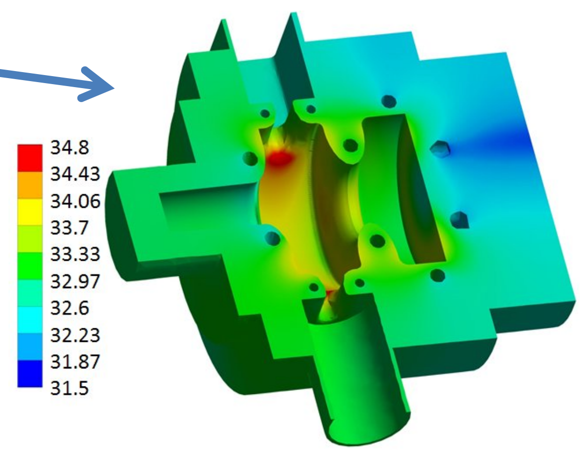


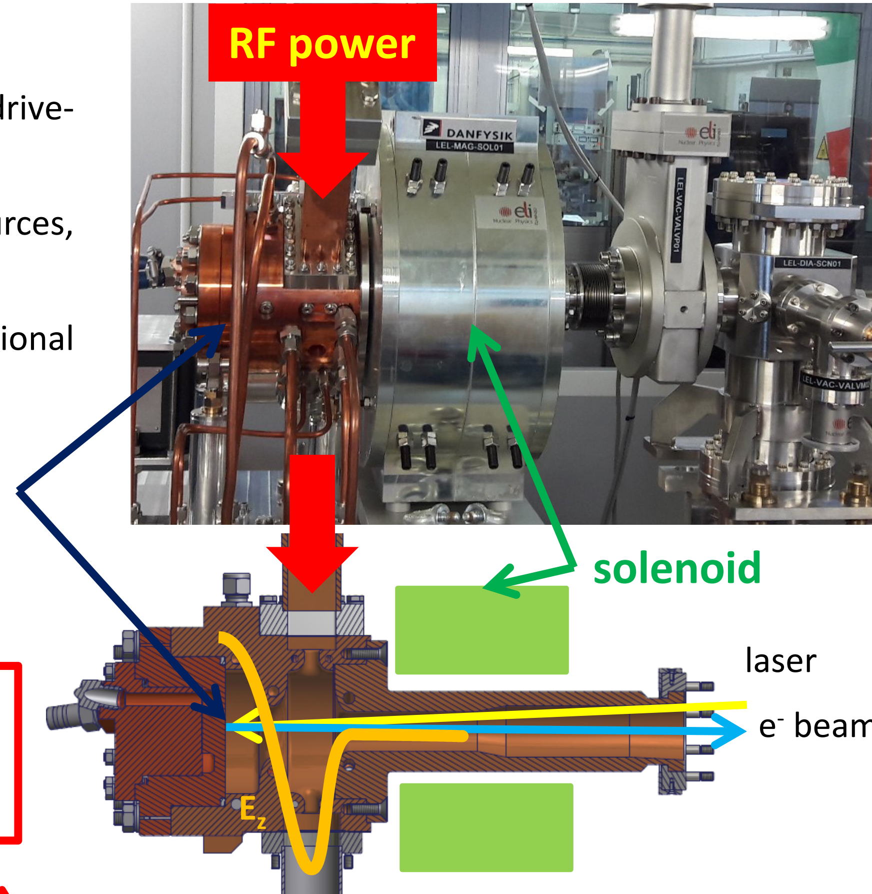
PHOTO-CATHODE RF GUNS

⇒ 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).



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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)

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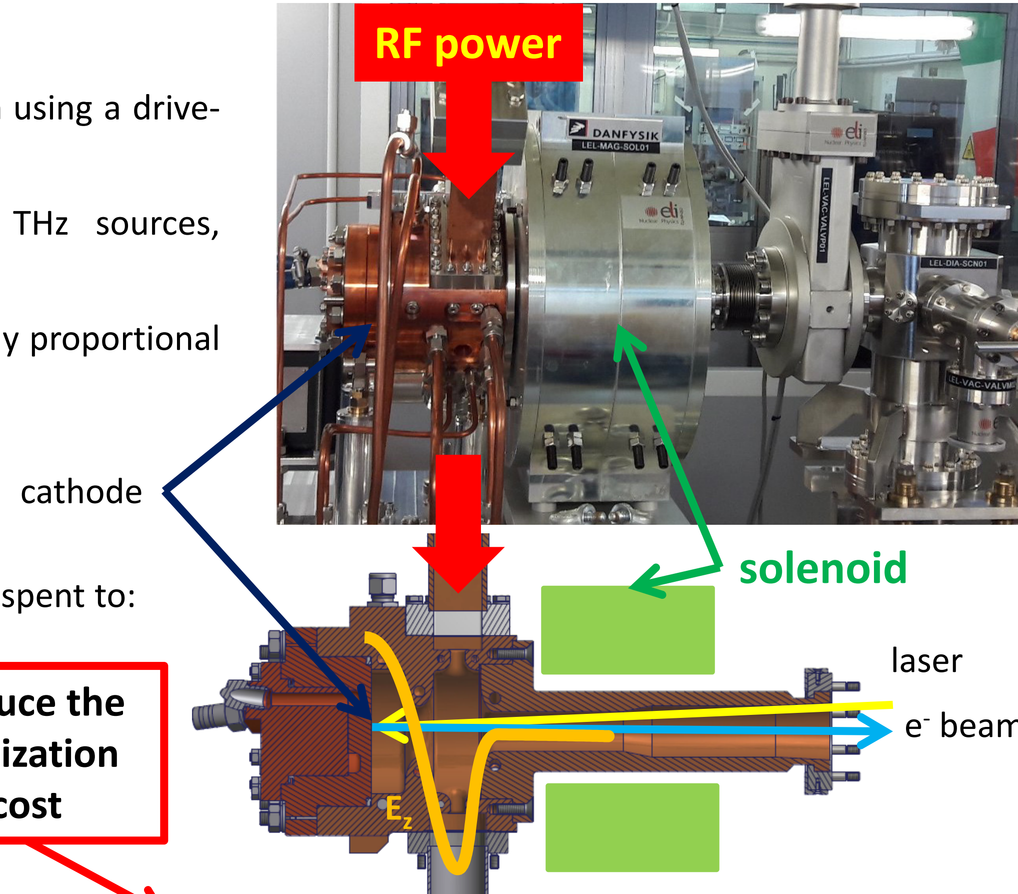

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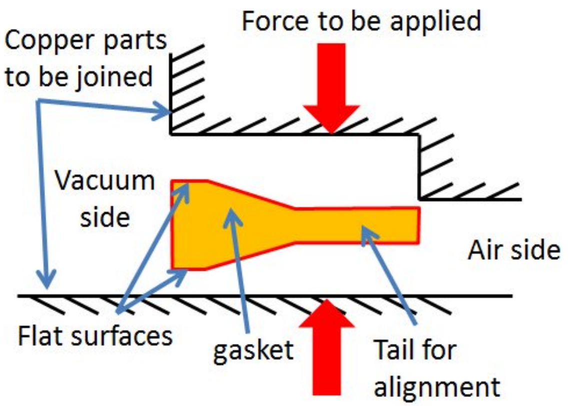

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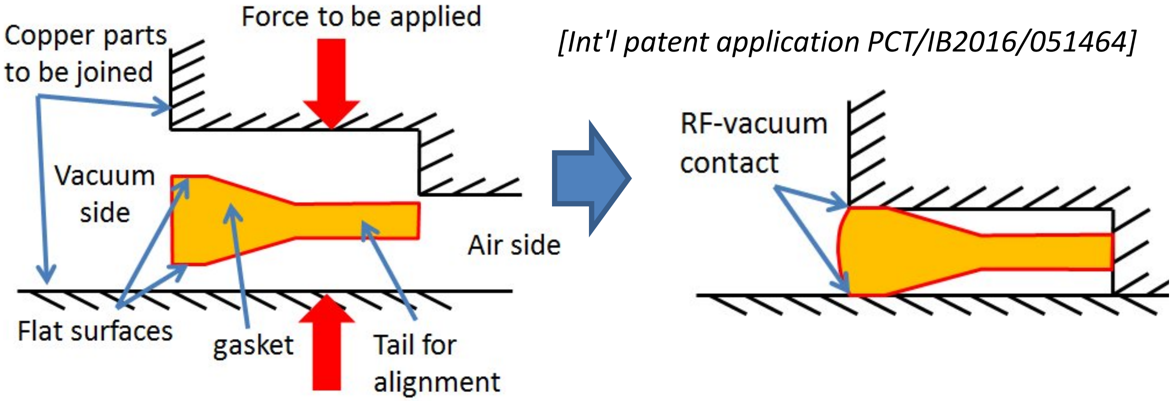

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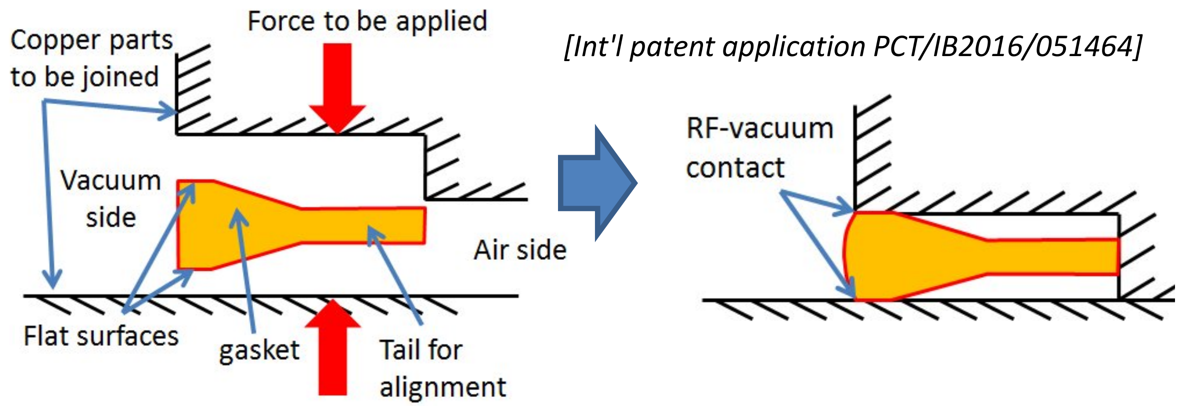

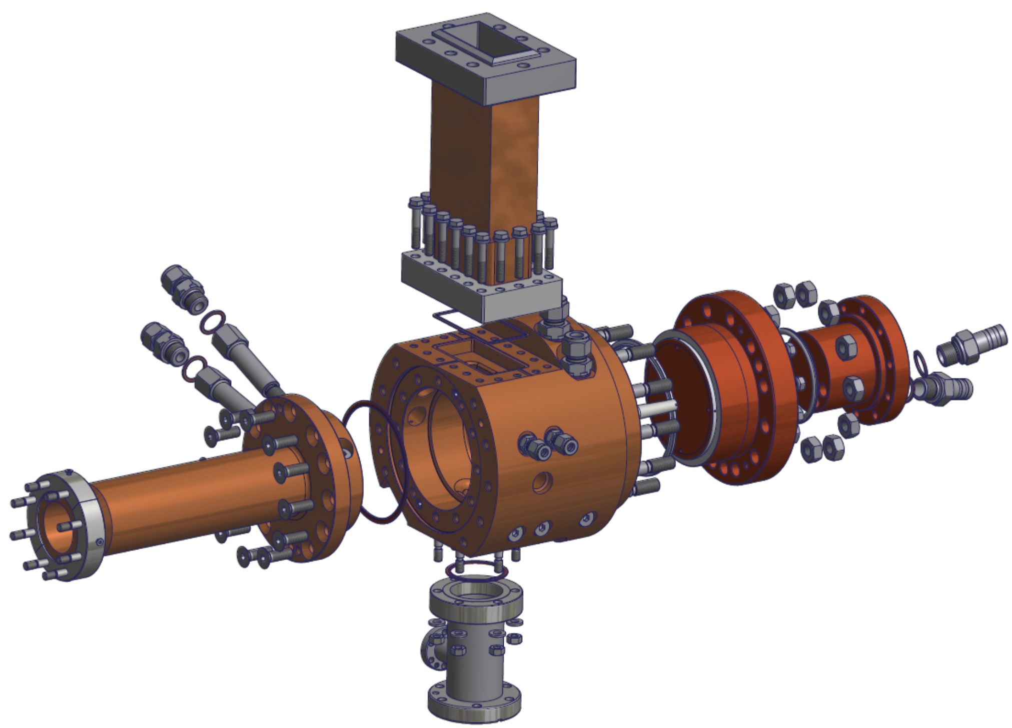

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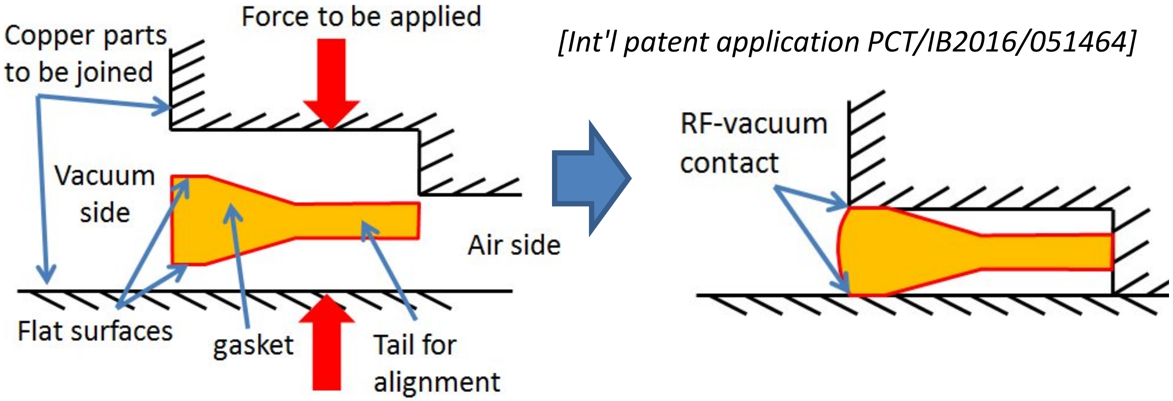
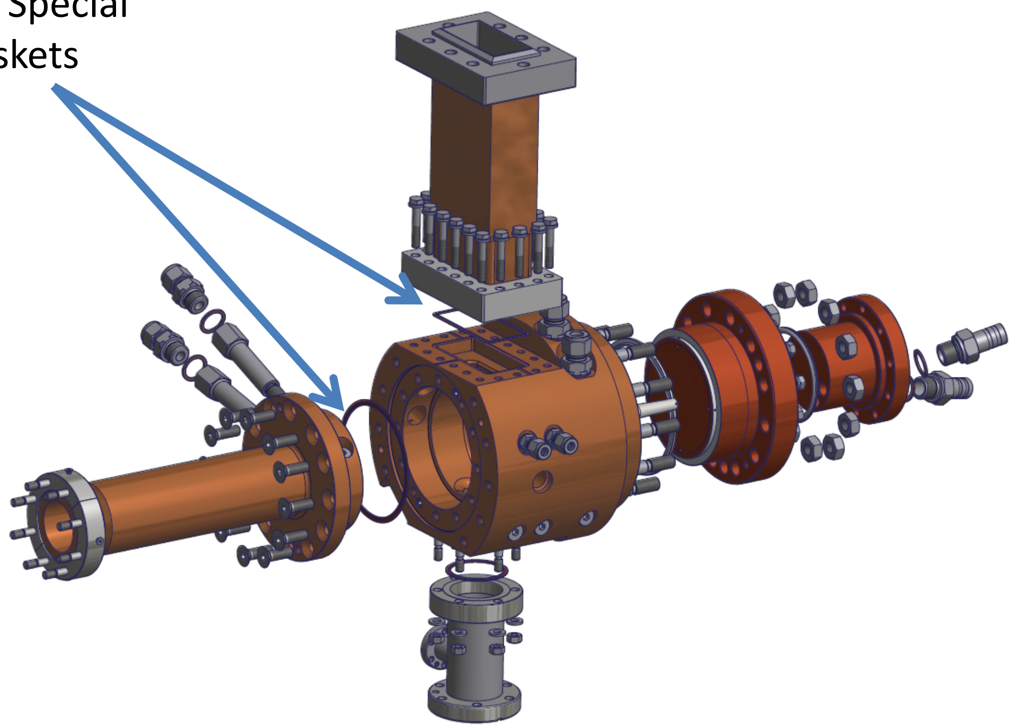


Cu Special
gaskets



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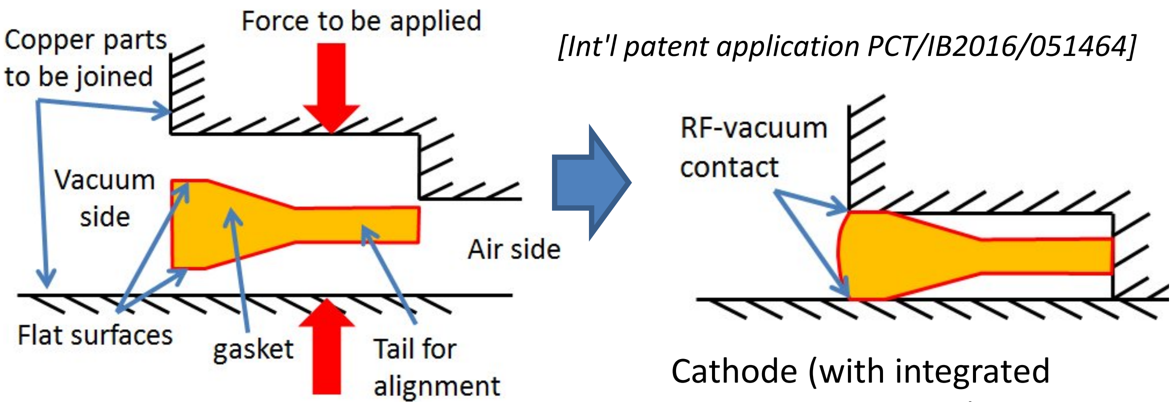

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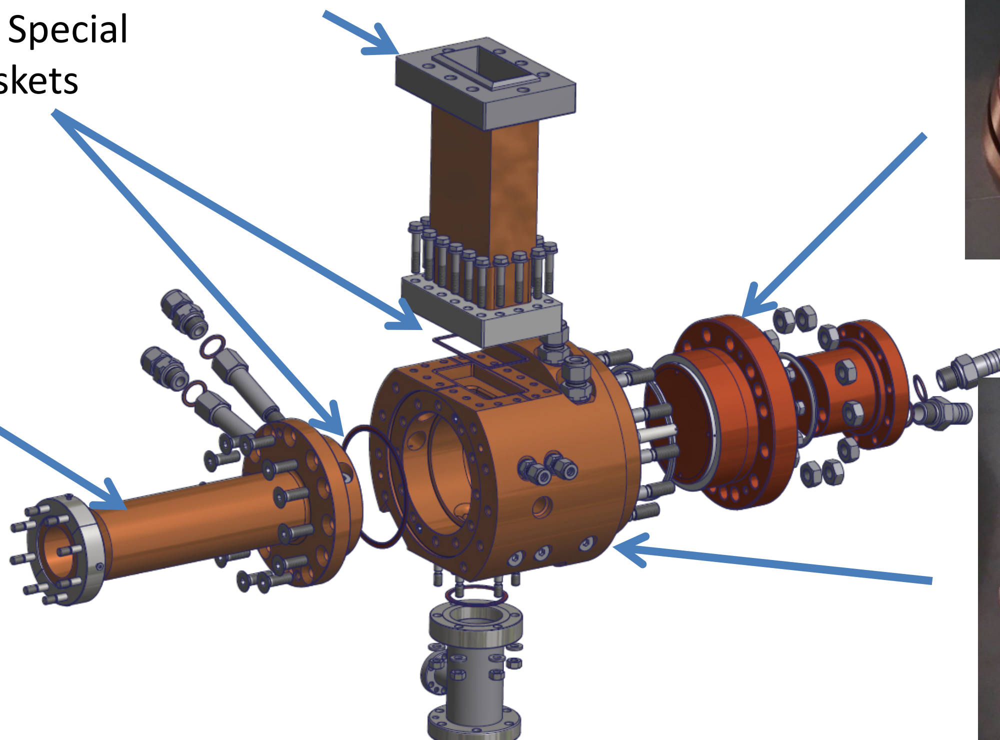
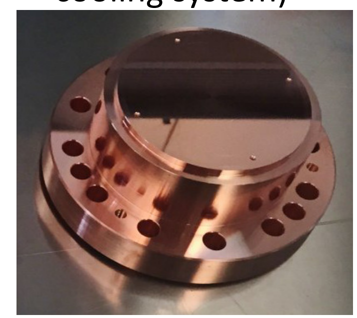
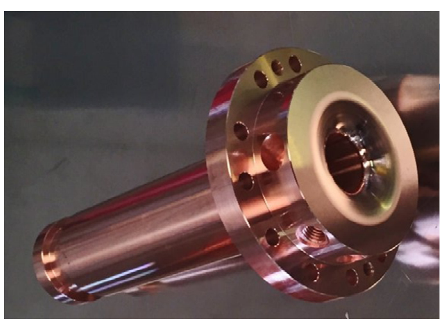
Cu Special gaskets

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

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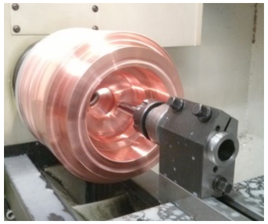

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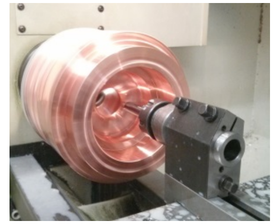

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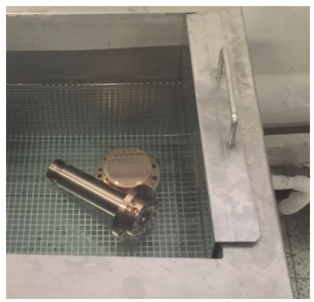

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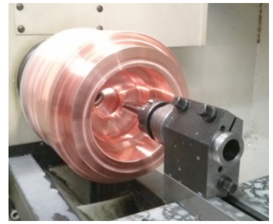

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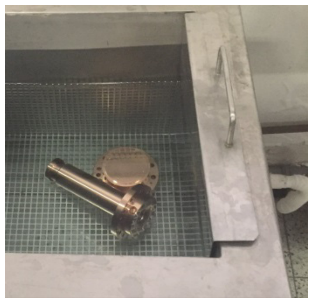


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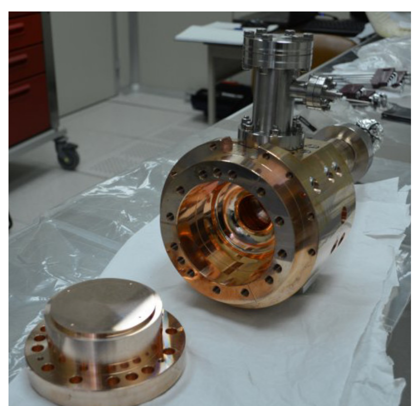
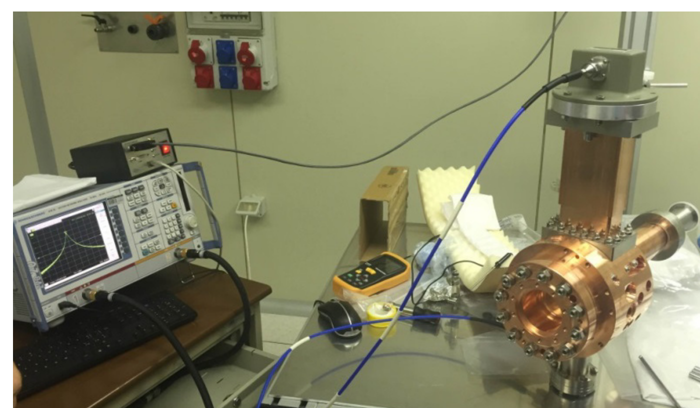

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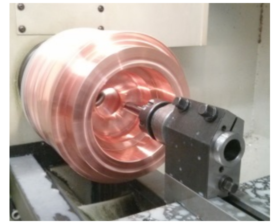

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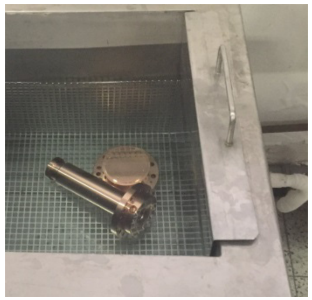

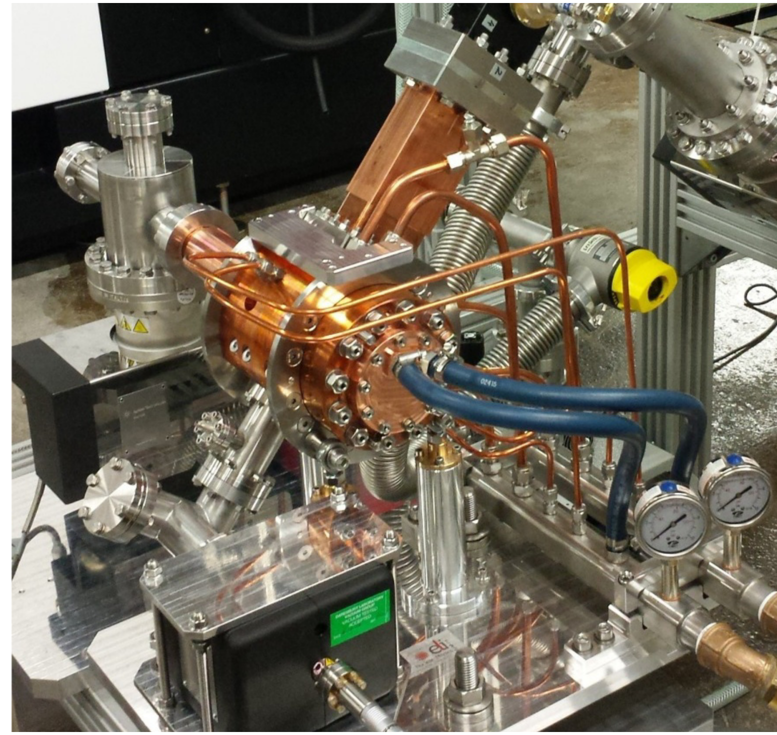

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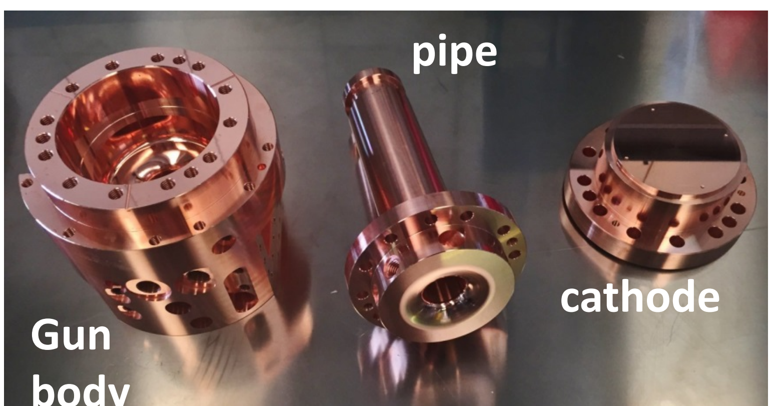
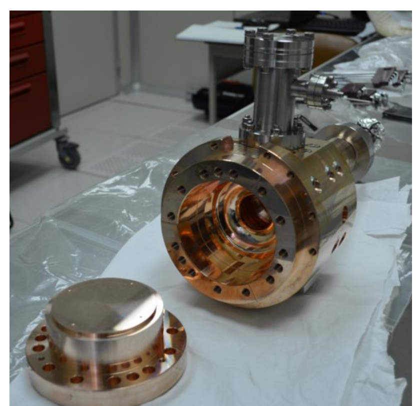
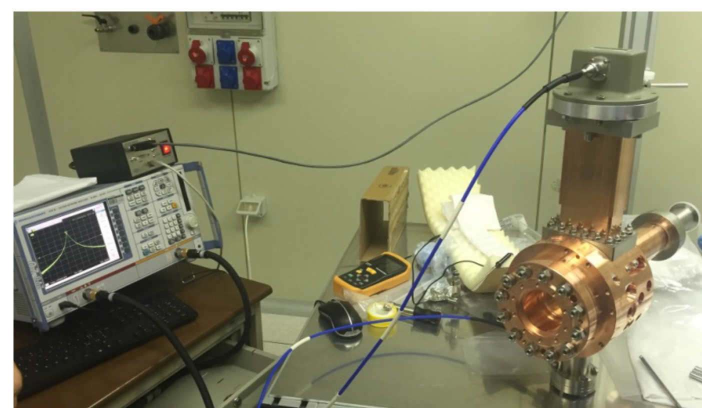
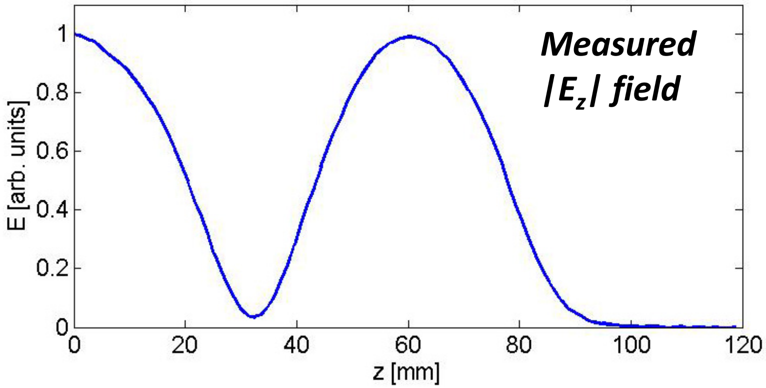


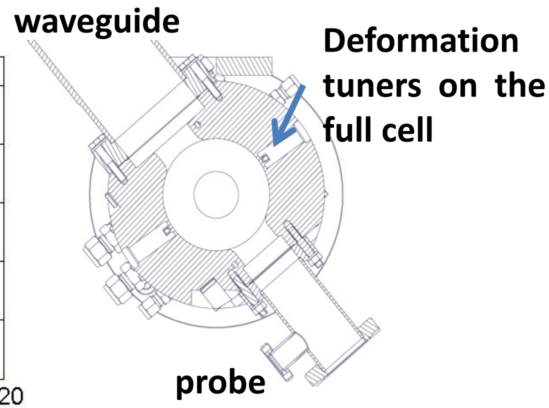


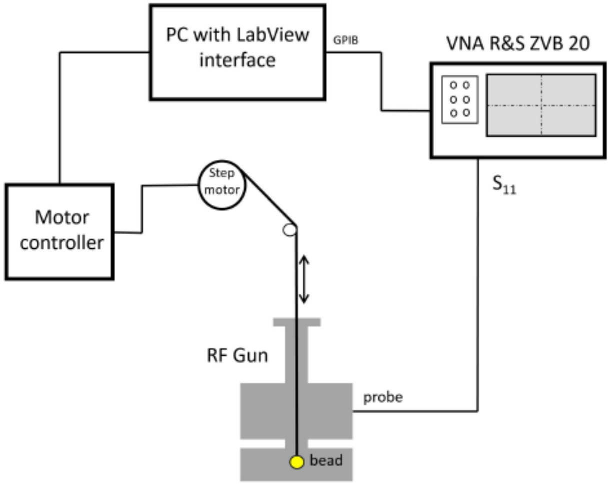


RESULTS OF THE LOW POWER RF MEASUREMENTS

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.







RESULTS OF THE LOW POWER RF MEASUREMENTS

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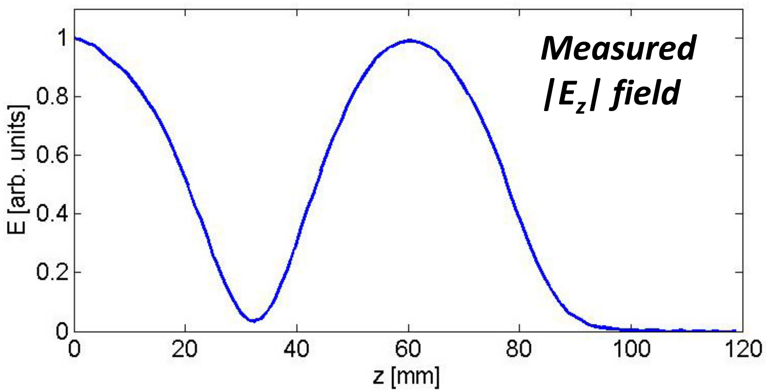

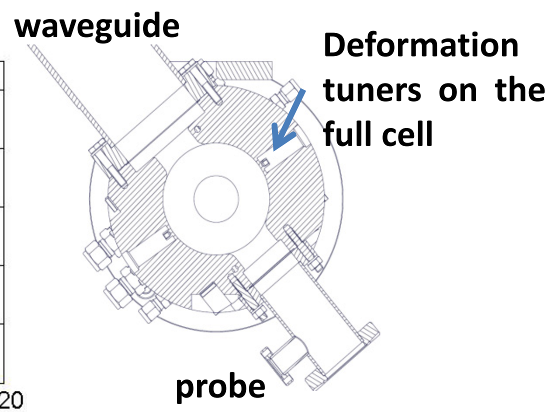

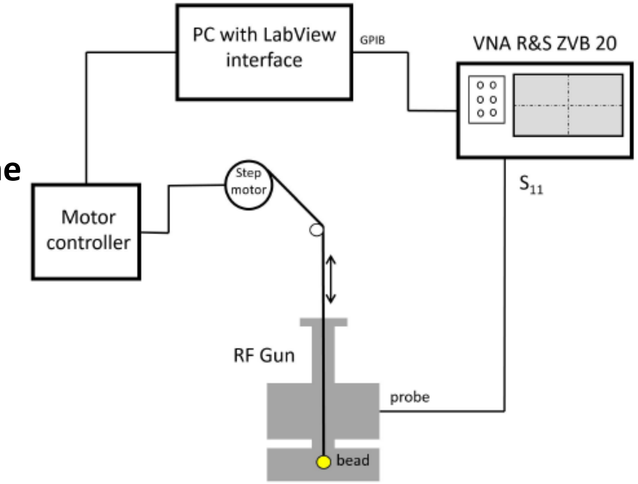

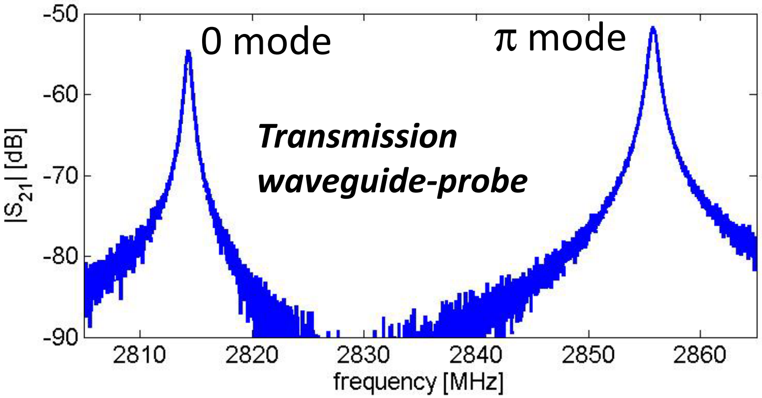

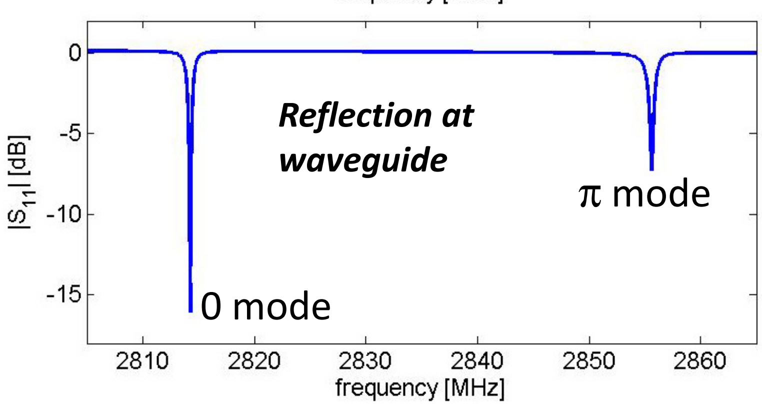

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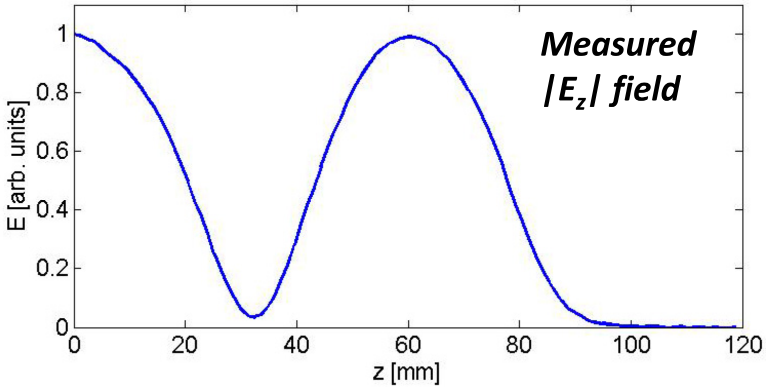
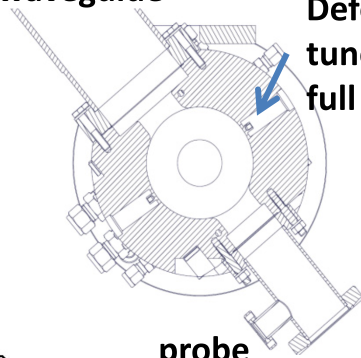
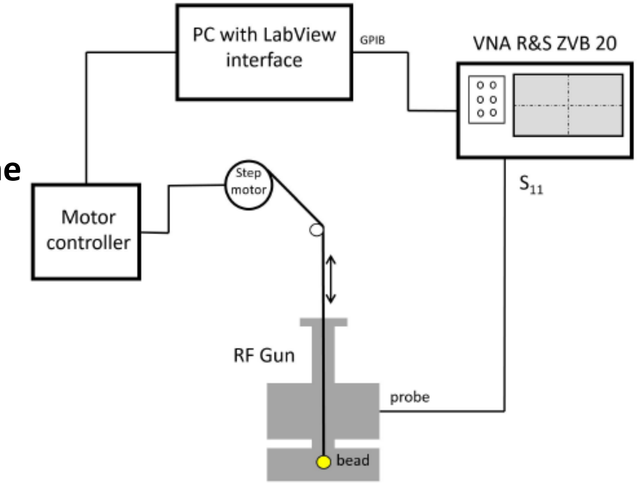
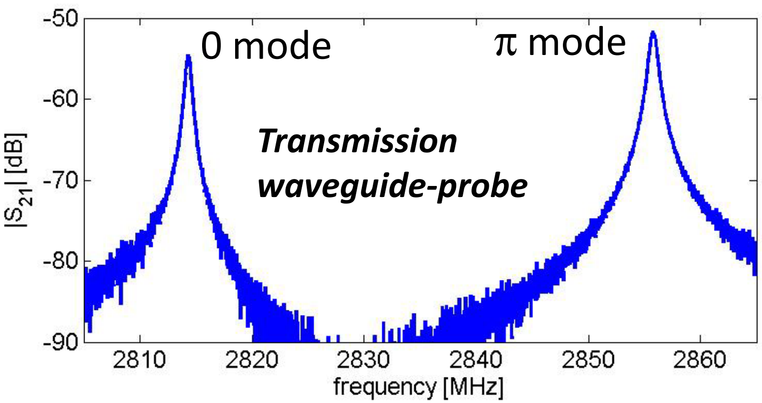
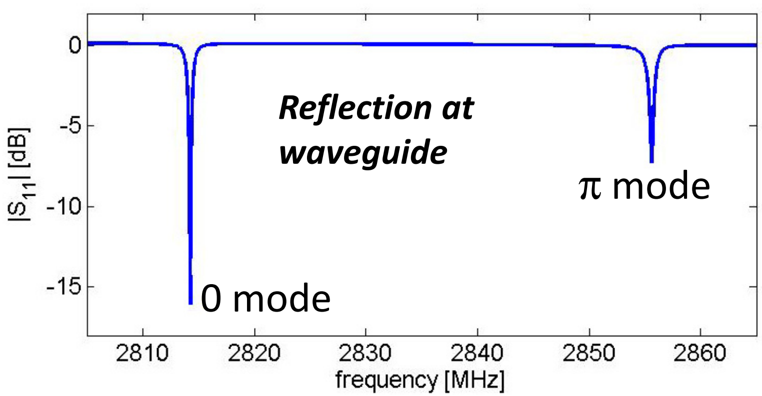


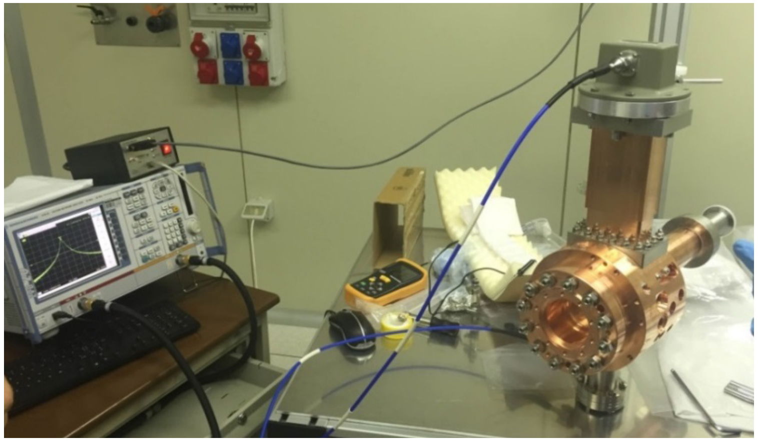






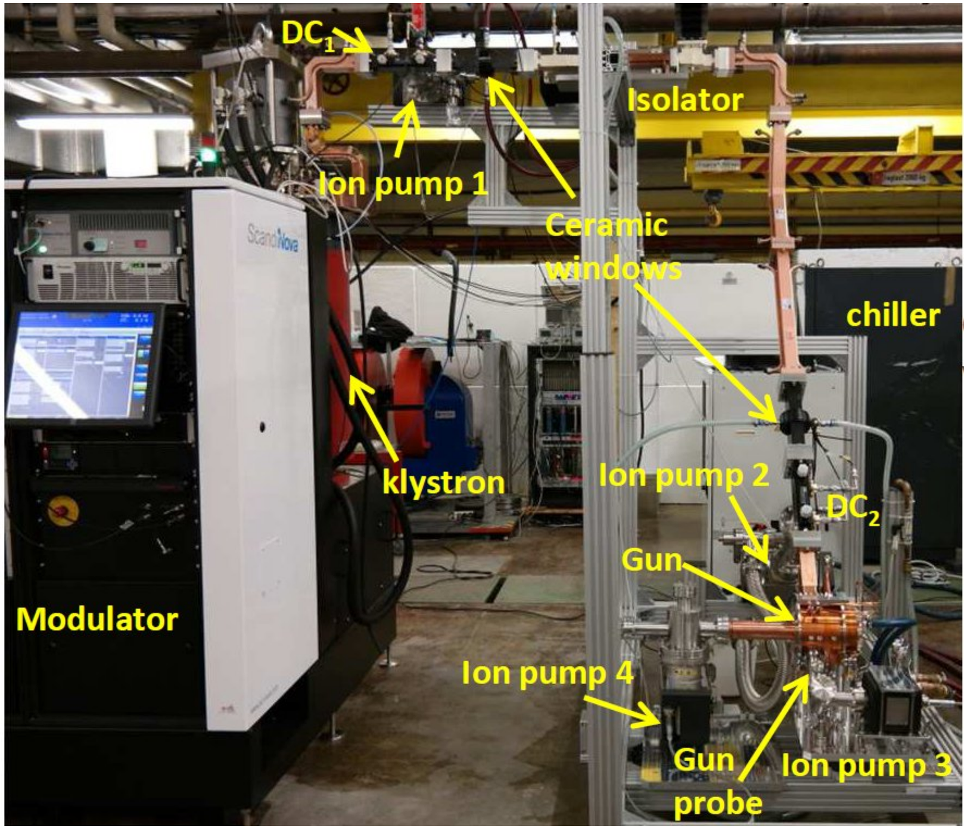


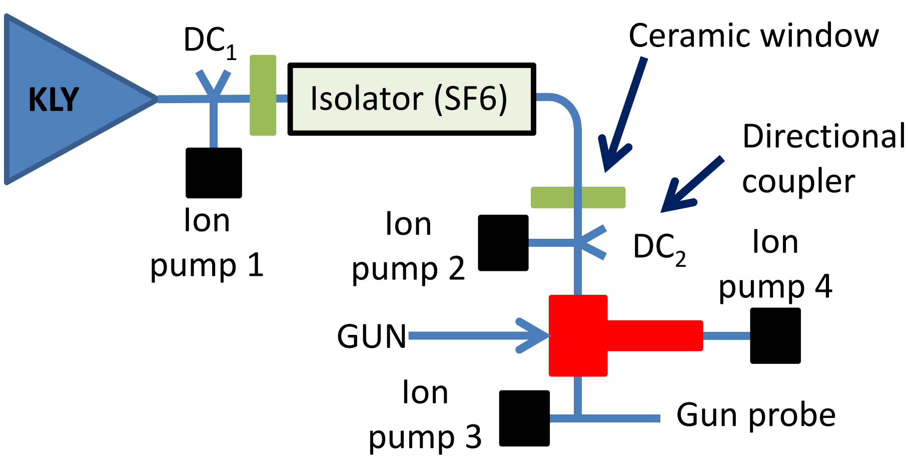
Parameter	Measured value (sim.)
resonant frequency (f_{res})	2.856 GHz @34 deg
coupling coeff. (β)	2.64 (3)
unloaded Q	14980 (14600)
0/π mode separation (Δf)	41.3 MHz

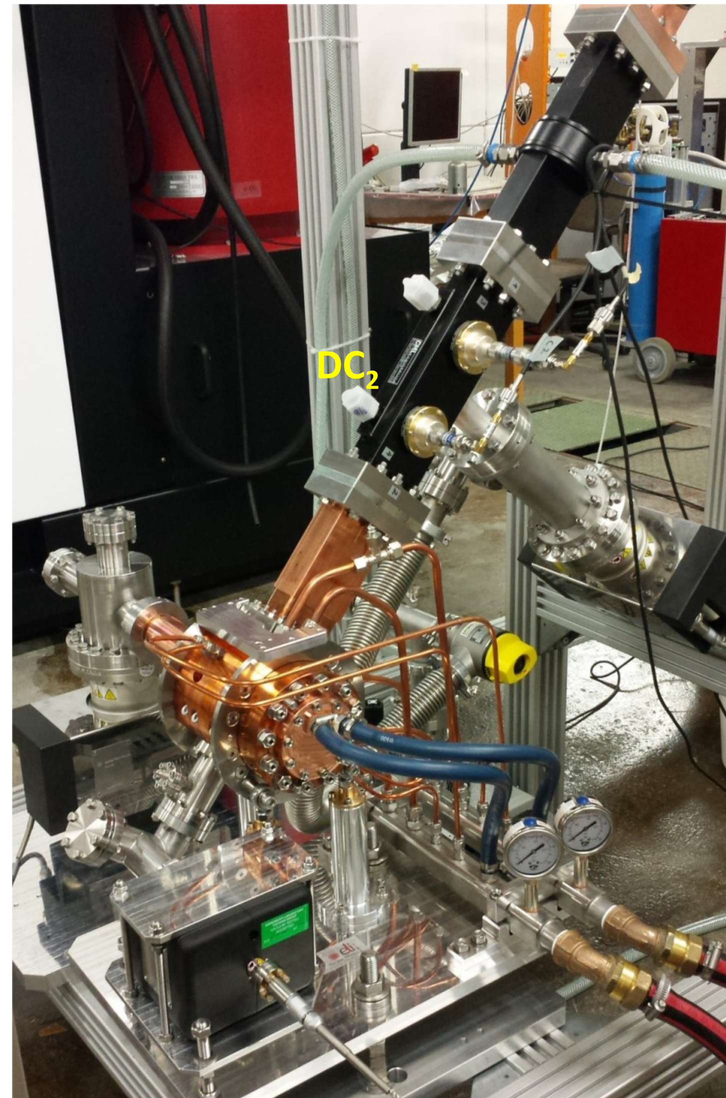


HIGH POWER RF TEST: SETUP

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.







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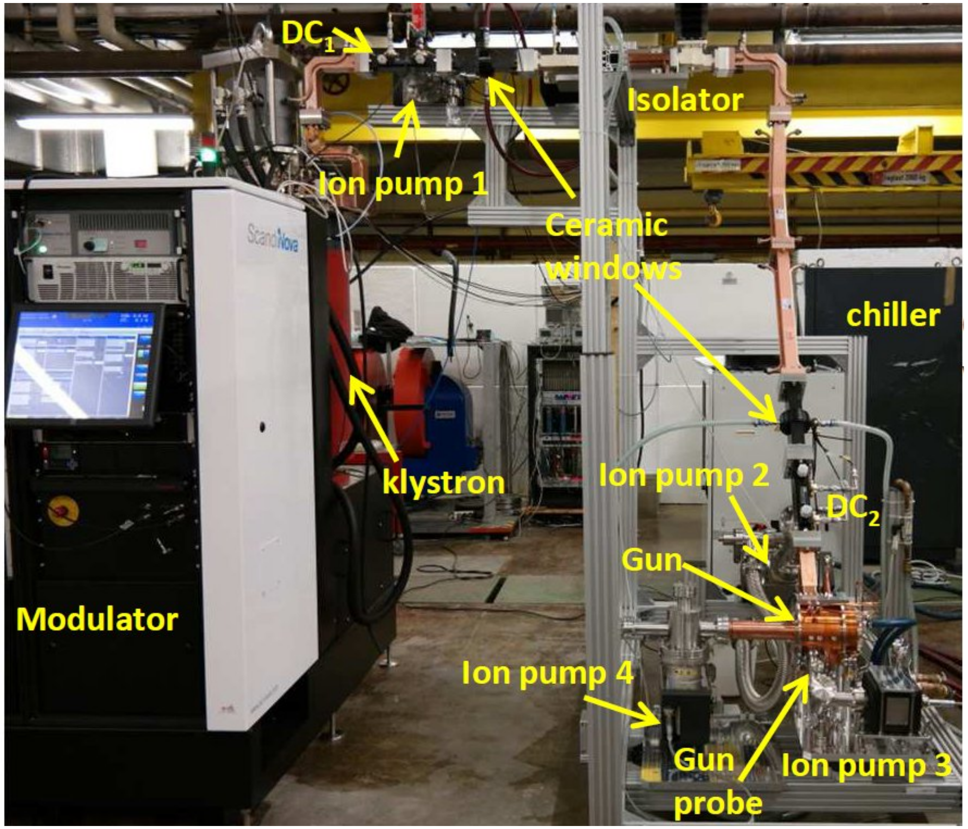
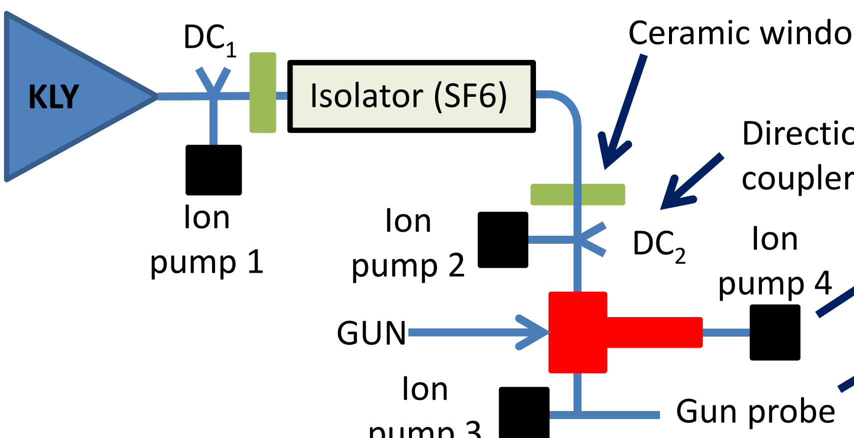
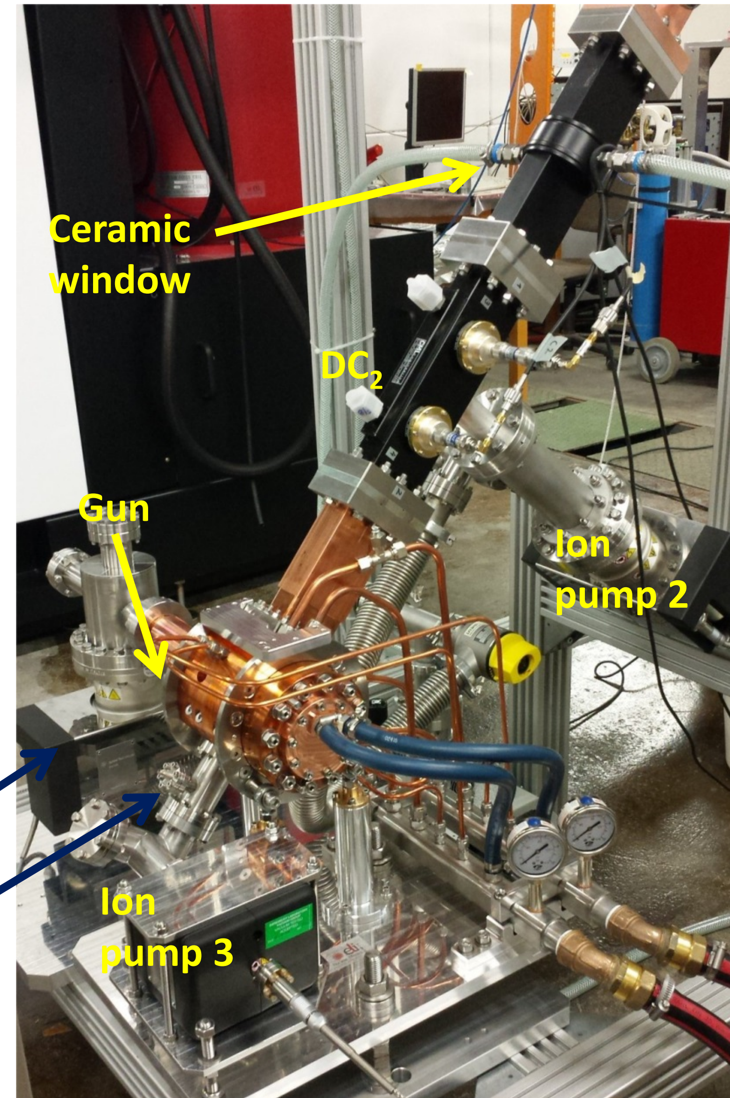




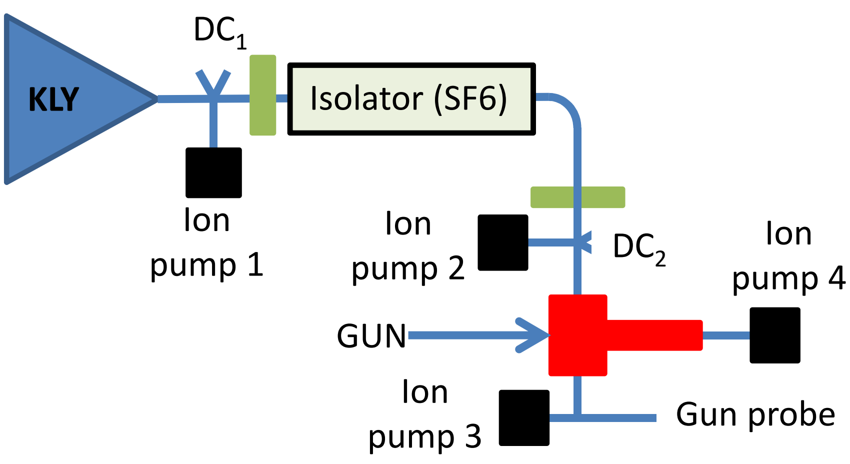


HIGH POWER RF TEST: CONDITIONING CONTROL SYSTEM

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.



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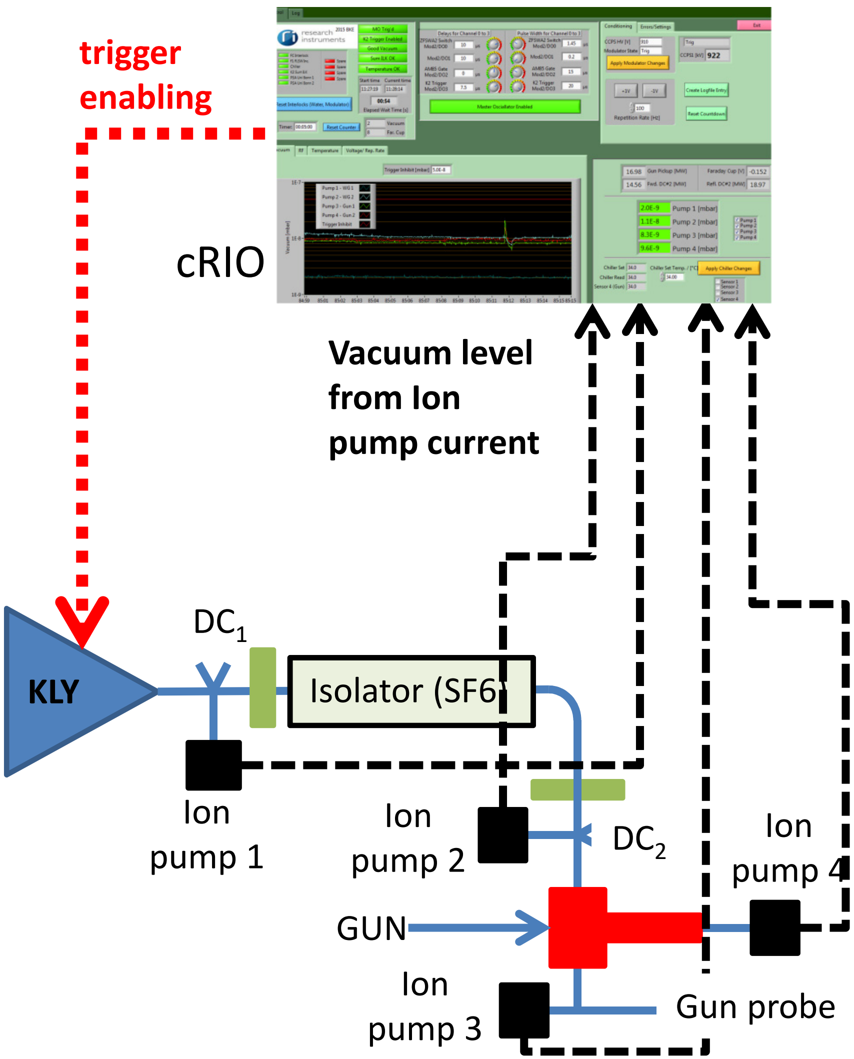

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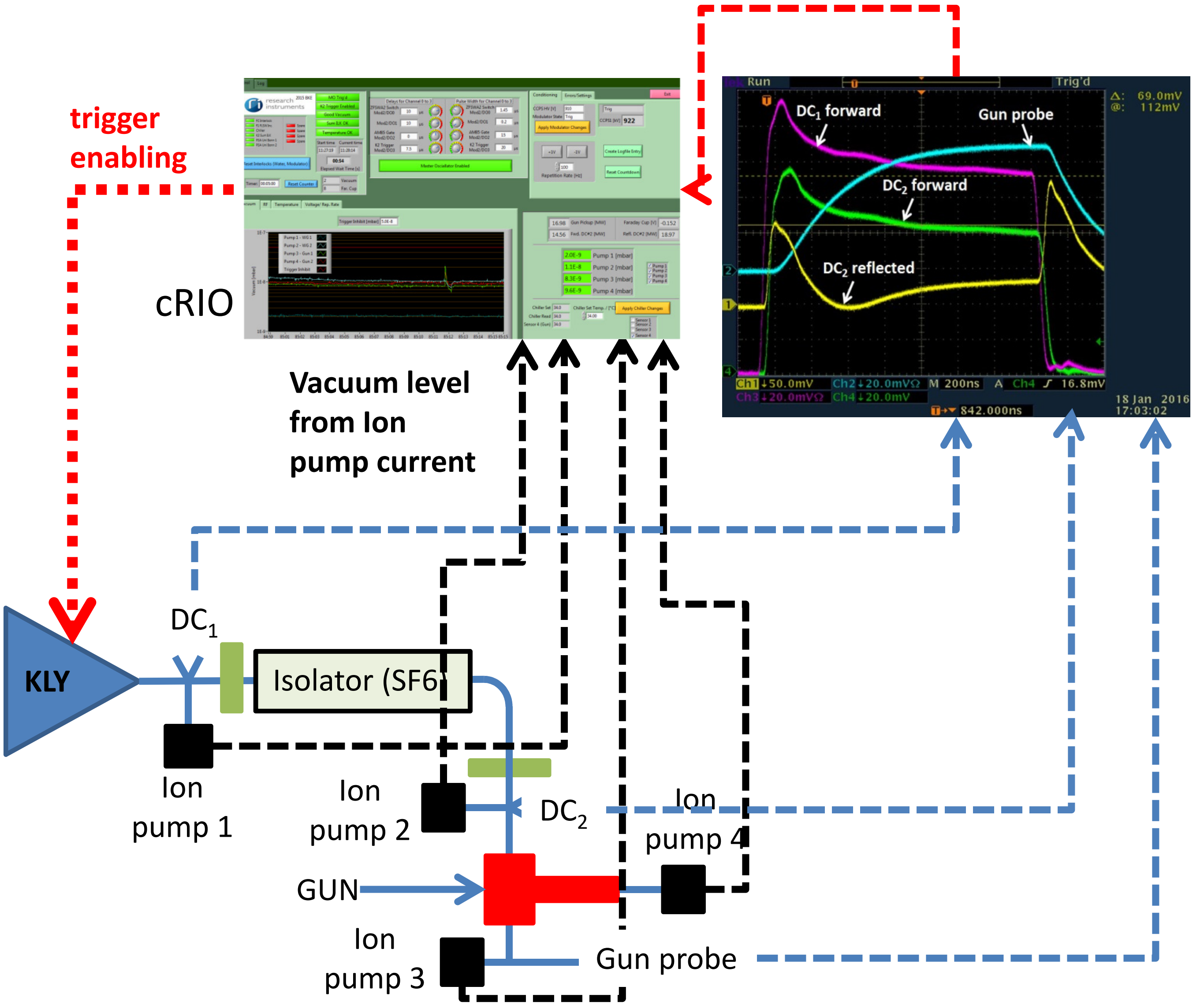

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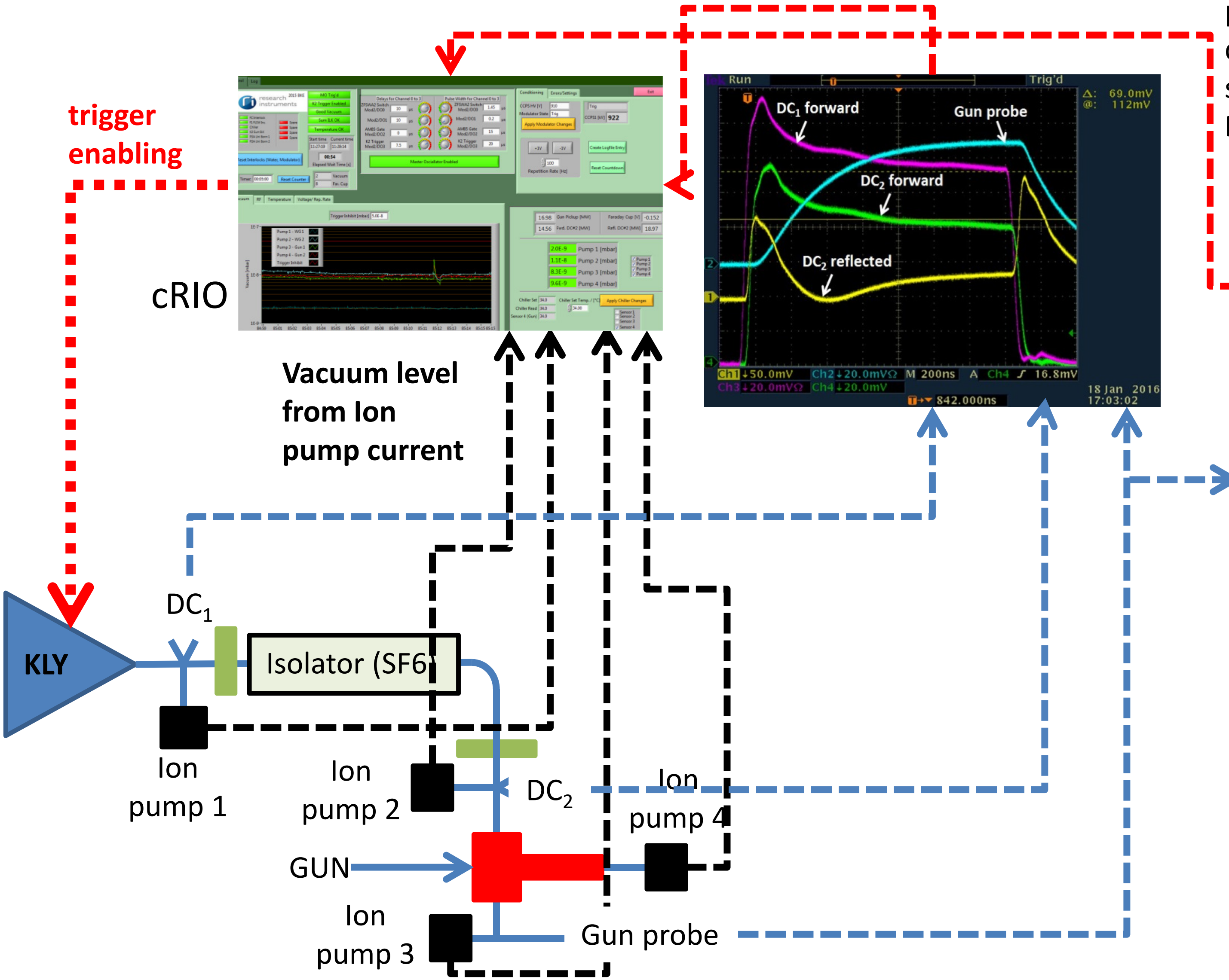
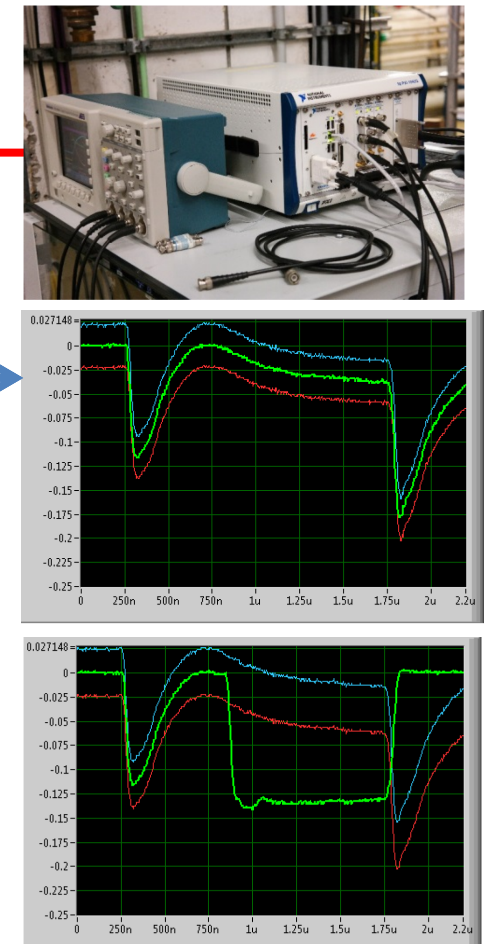
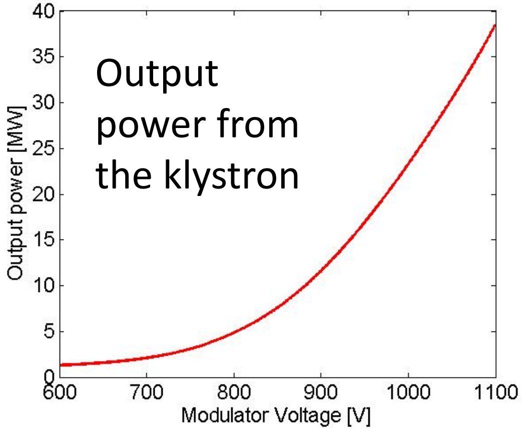
The waveform at each pulse was compared with the previous one within a **mask** of tolerance and, in case of pulse distortions due to a discharge, the modulator was switched off immediately.[S. Pioli, TUPIK057]



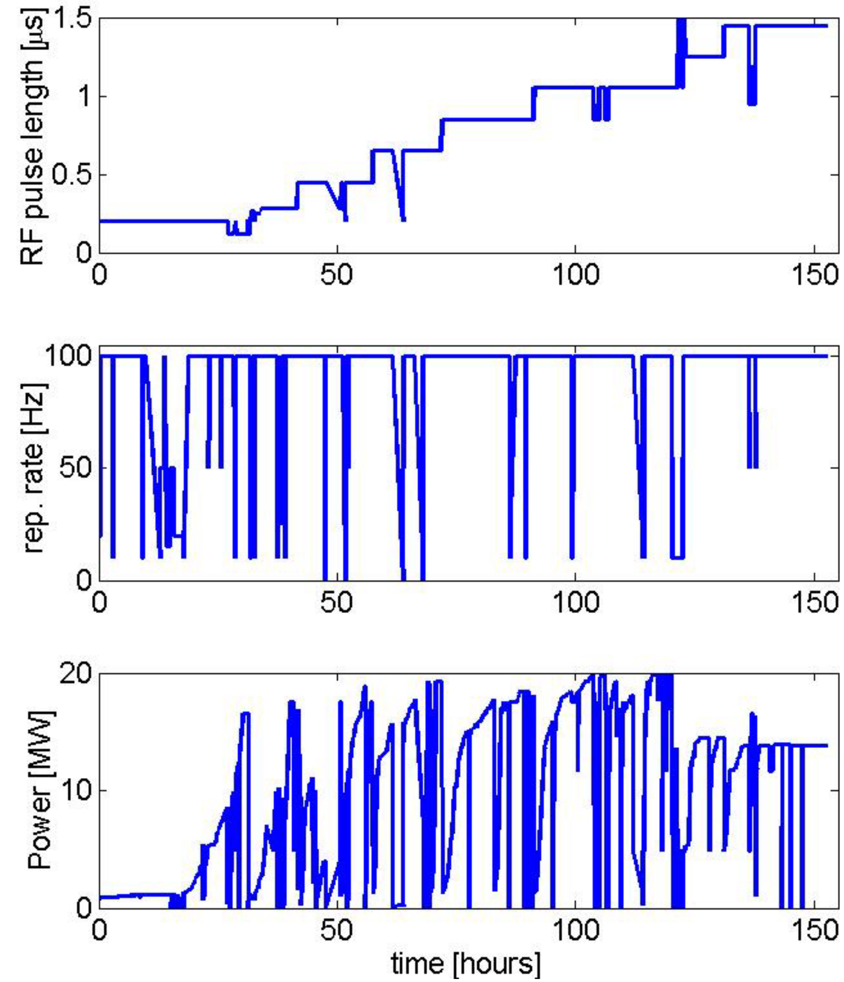


HIGH POWER RF TEST: CONDITIONING RESULTS

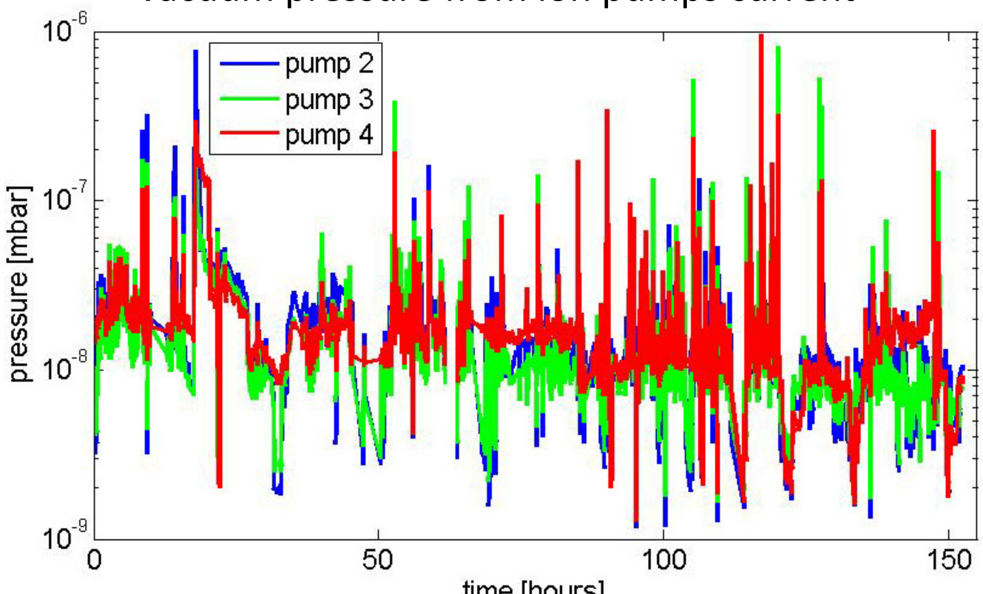
The RF conditioning lasted about **160 hours** and the gun finally reached the nominal parameters with a break down rate of few 10^{-5} bpp. The **vacuum pressure** was measured by the ion pumps current during the whole process. It was of the order of 1×10^{-8} mbar at full power and always maintained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



Conditioning history



Vacuum pressure from ion pumps current



CONCLUSIONS AND PERSPECTIVES

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);

4) 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.

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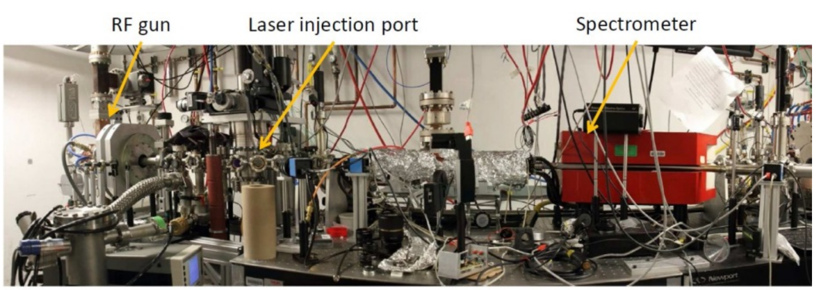

UCLA Pegasus lab with clamped RF gun in operation (90 M/m 5 Hz)

[D. Alesini, et al., PRST- AB 18, 092001 (2015)
D. Cesar, et al., PRL 117, 024801 2016
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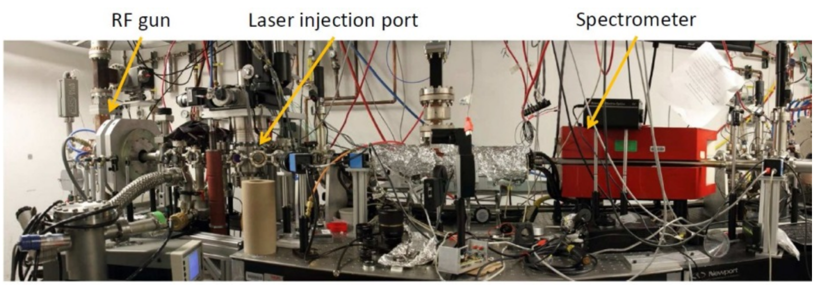

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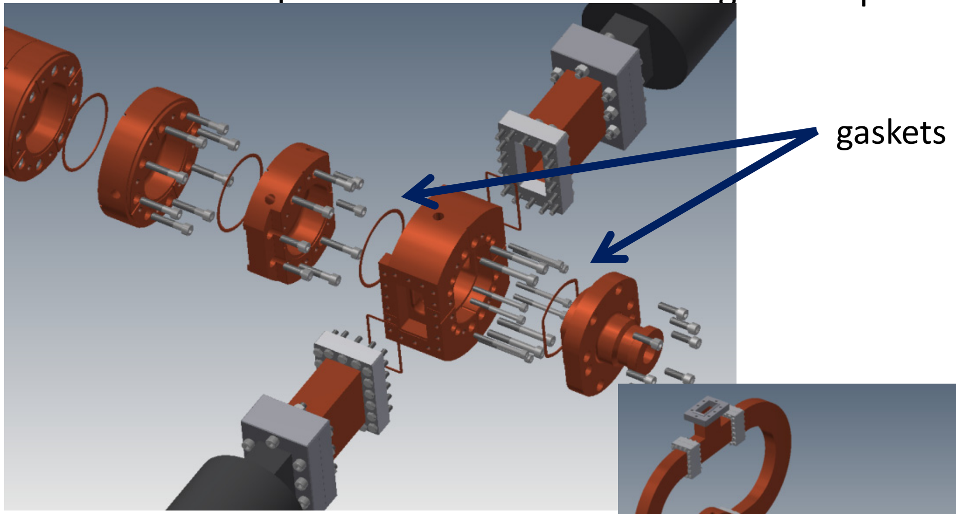
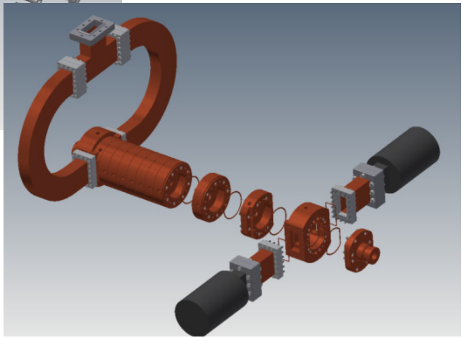
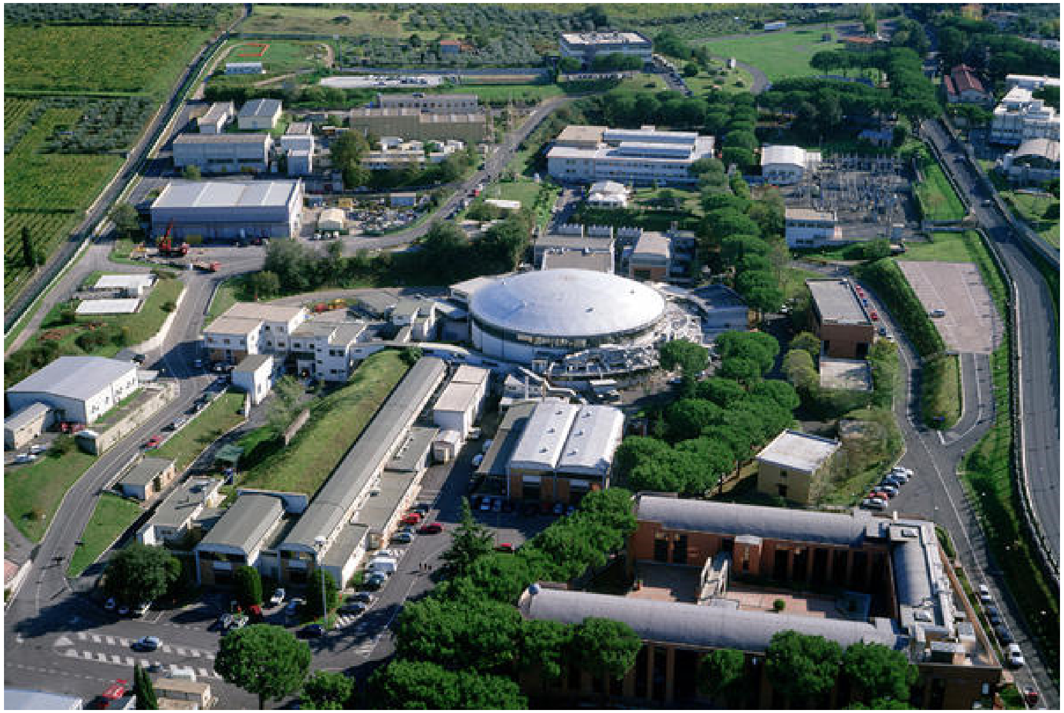
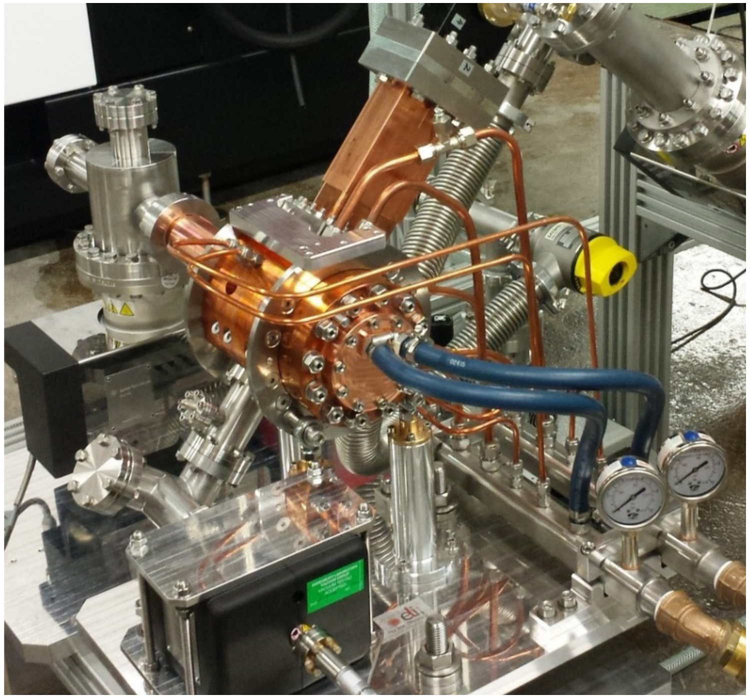


[F. Cardelli et al., IPAC2016, p. 403, 2016]



THANK YOU FOR YOUR ATTENTION!





I would like also to thank A. Ghigo, L. Serafini, P. Chimenti and R. Di Raddo