Very high gradient RF Guns operating in the C-band RF technology (Task 7.4)

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On behalf of the INFN-PSI Very High Gradient C band gun group

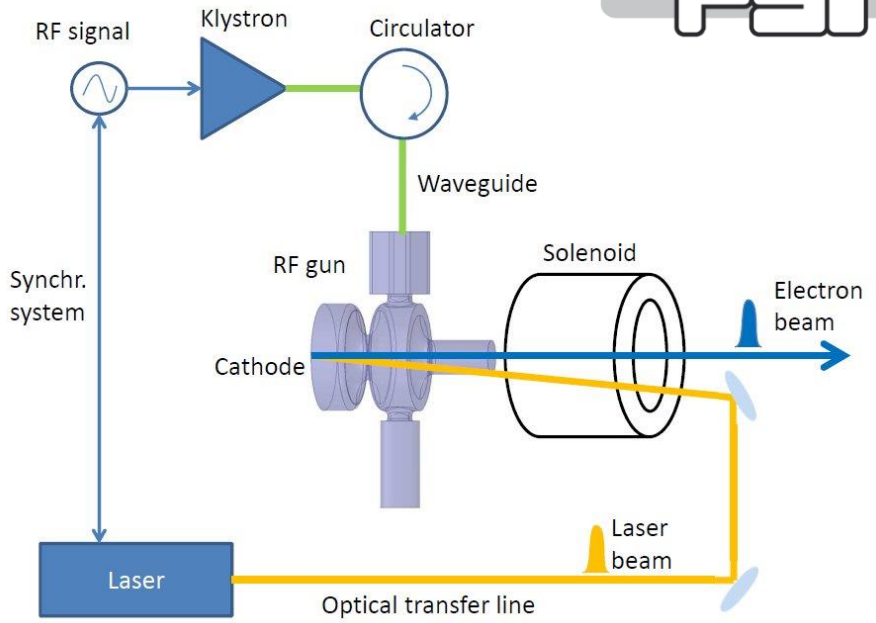
OUTLINE

1. Recap. on Goals and Responsibilities
2. Update on **SW GUN Activities and High power test**
3. Update on **TW GUN Activities**

TASK 7.4 STRUCTURE AND OBJECTIVES

- **Design, realization and high power test of two different C-band (5.712 GHz) RF electron photo-guns** operating at very high gradient cathode peak field (>160 MV/m):
  - ⇒ Standing Wave (**SW**) gun (**INFN** (IT), **COMEB** (IT))
  - ⇒ Travelling Wave (**TW**) gun (**PSI** (SW); **VLD** (NE))

- **Comparison** of the performances, **beam dynamics** simulations to exploit the device potentialities
- **Research Institutions** involved: **INFN** (IT), **PSI** (SW);
- **Private Companies** involved: **VLD** (NE), **COMEB** (IT)



SW GUN

- Coordination
- Design and low power test of the SW Gun
- Solenoid design and procurement
- RF circulator procurement

- mechanical construction and assembly of the SW gun

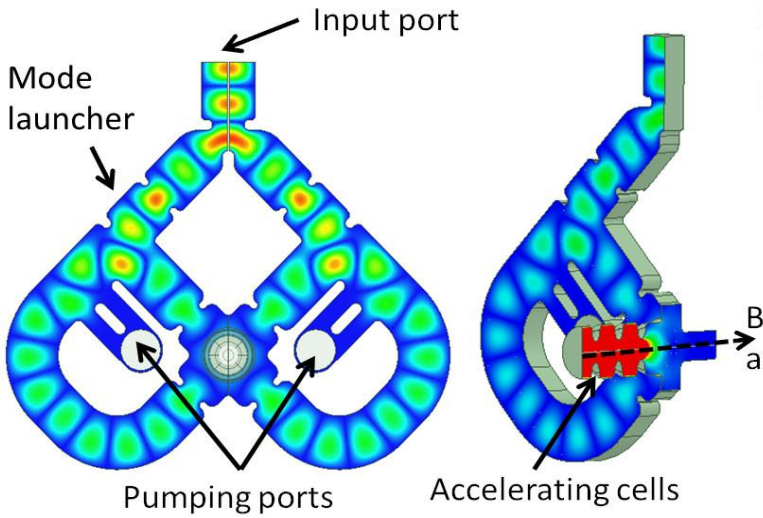
TW GUN

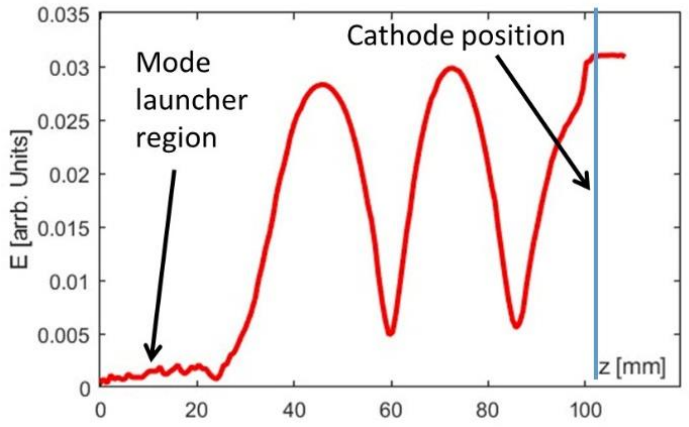
- design, brazing and low power characterization of the TW Gun
- hosting and setting up the facility to perform the high-power test

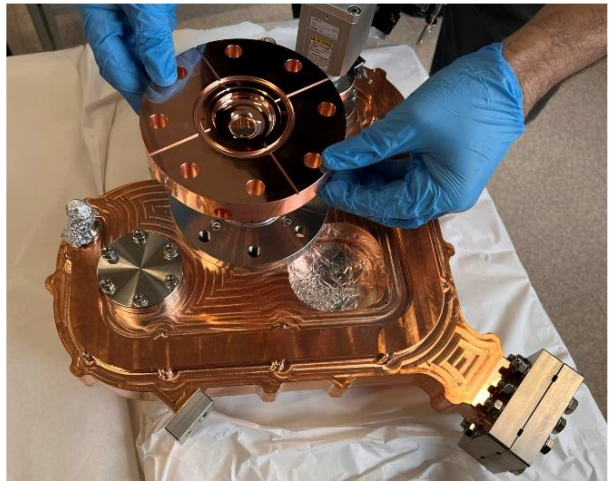
- mechanical construction of the TW gun components

SW GUN FINAL ASSEMBLY

- The new C-Band RF gun, developed in the context of the INFN Commission V and European I.FAST projects, has been realized and **is now under high power test**.
- It is a **2.6 cell standing wave cavity** with a four-port **mode launcher**, designed to operate with short rf pulses (300 ns) and **cathode peak field larger than 160 MV/m**.
- It is fabricated using the **brazed-free technology** developed @INFN.
- It allows to operate at **very high repetition rate** (up to 1 kHz).



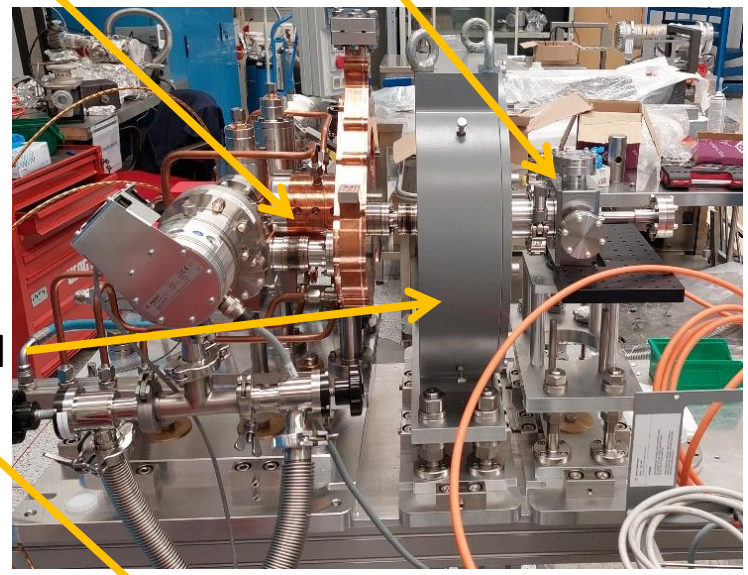




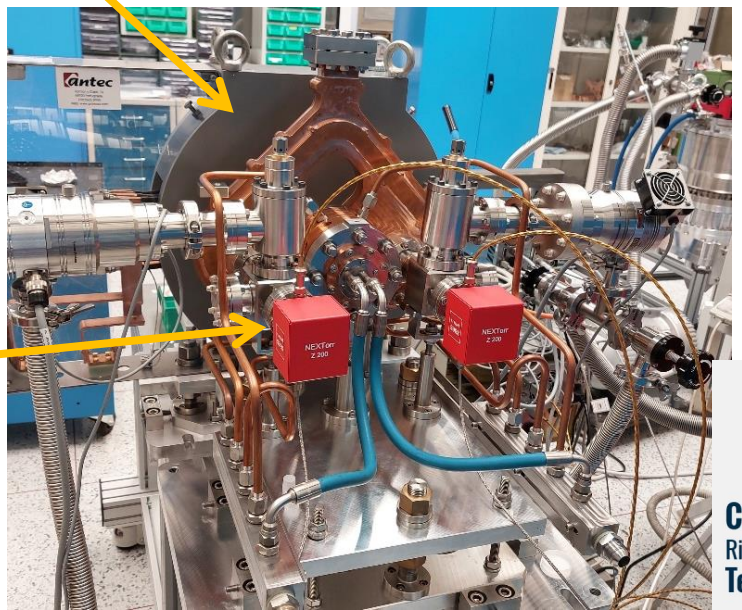
gun

Laser injection chamber

solenoid



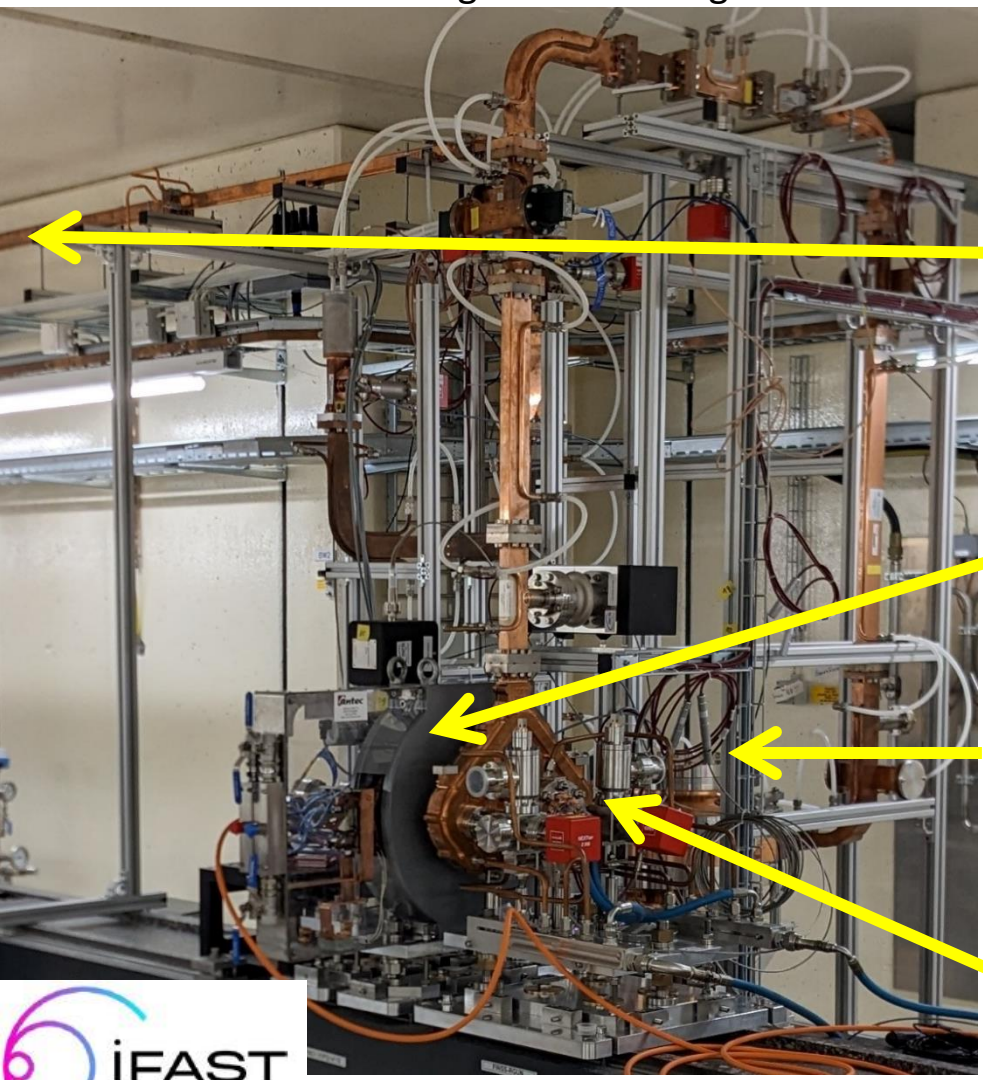
Pumping system

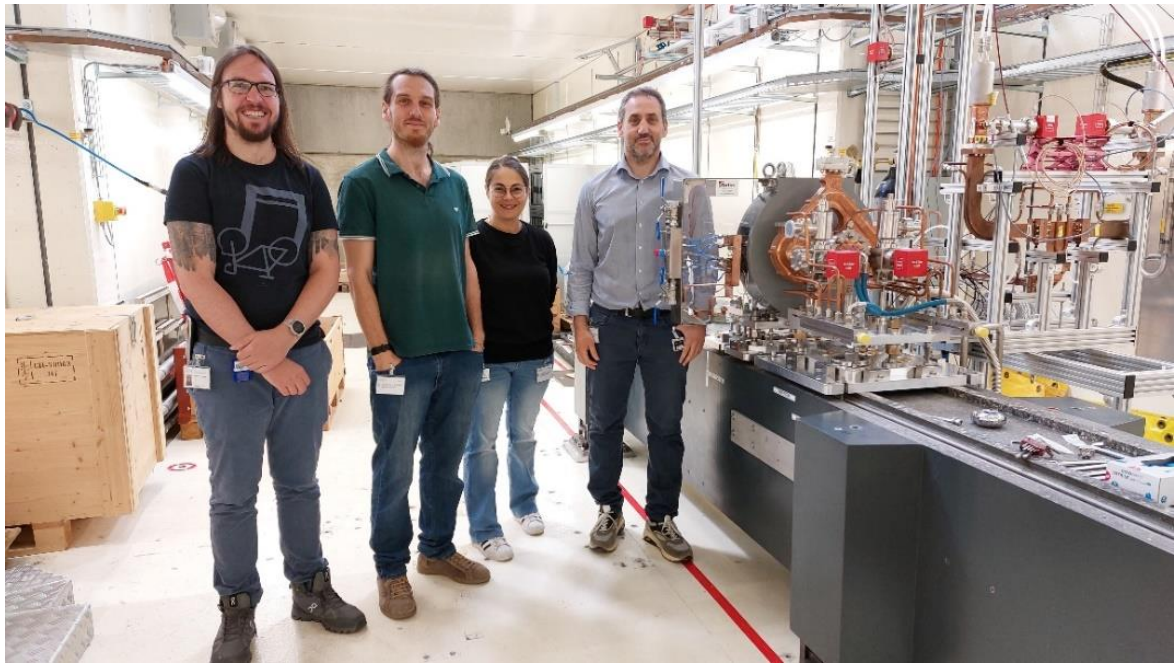


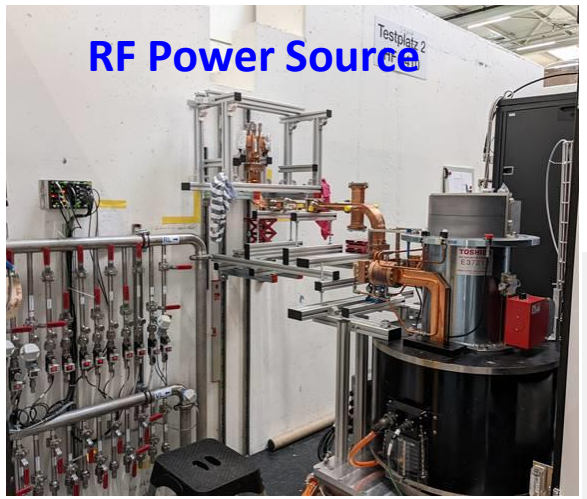
SW GUN INSTALLATION AT PSI

⇒ High power test stand and **bunker implemented by PSI**.

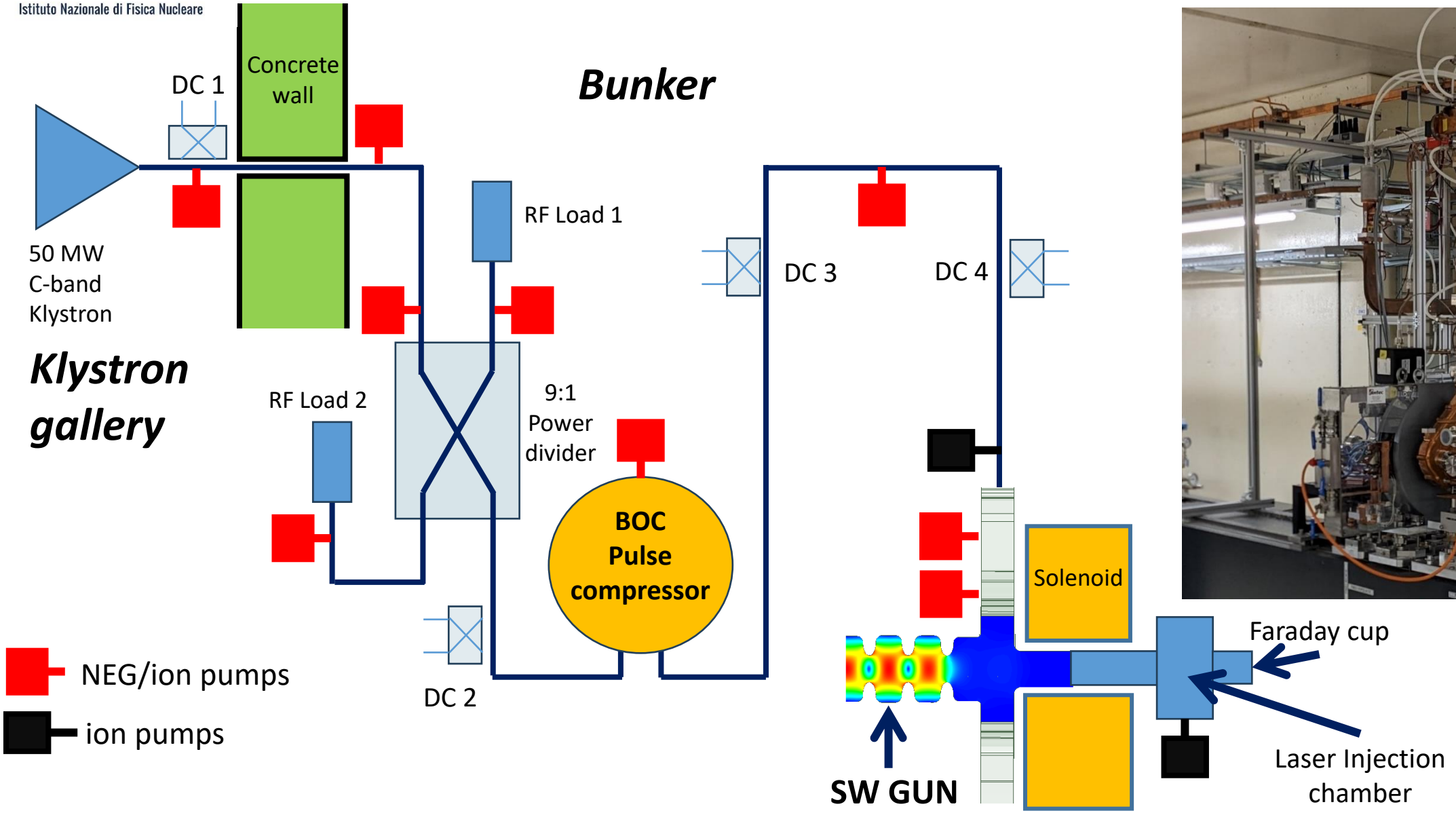
⇒ Installation of the SW gun with waveguides done in collaboration INFN-PSI





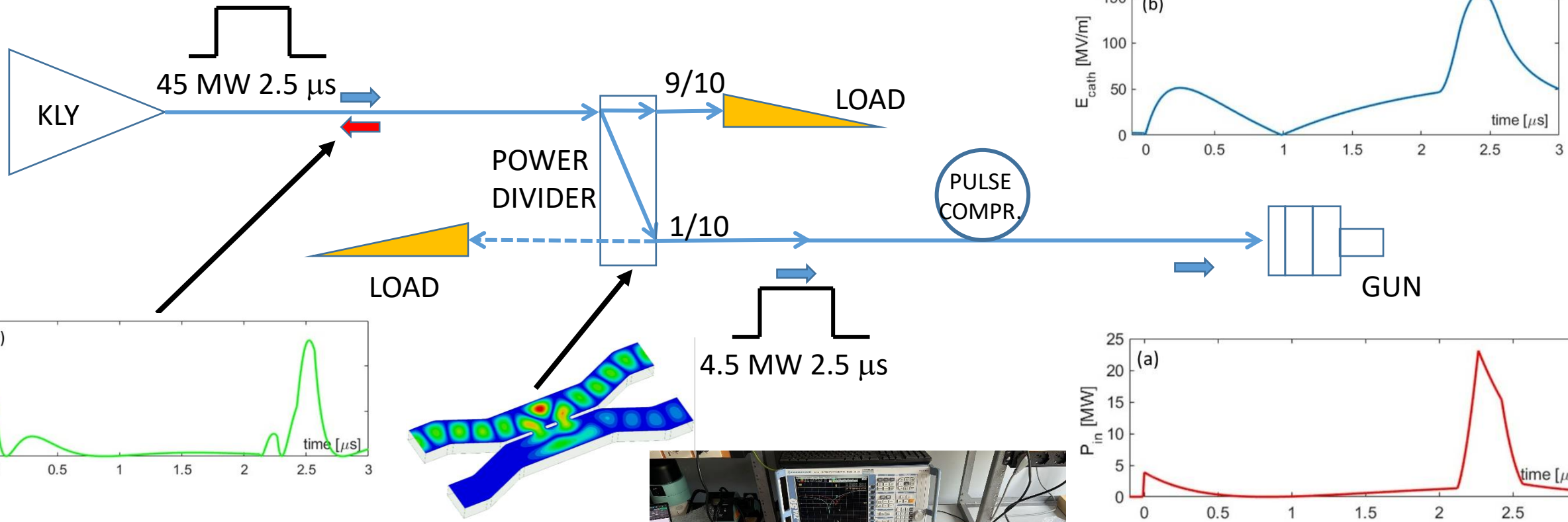


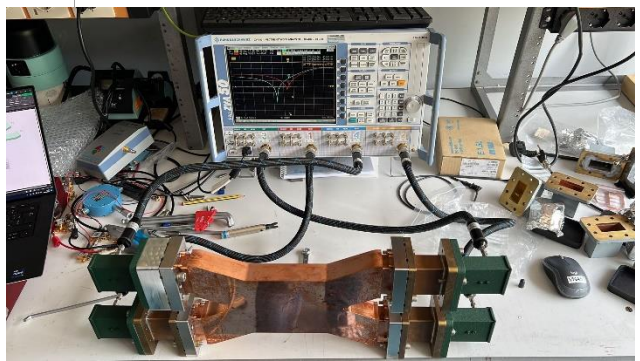
HIGH POWER TEST SCHEMATIC LAYOUT



ALTERNATIVE FEEDING SCHEME W/O ISOLATOR

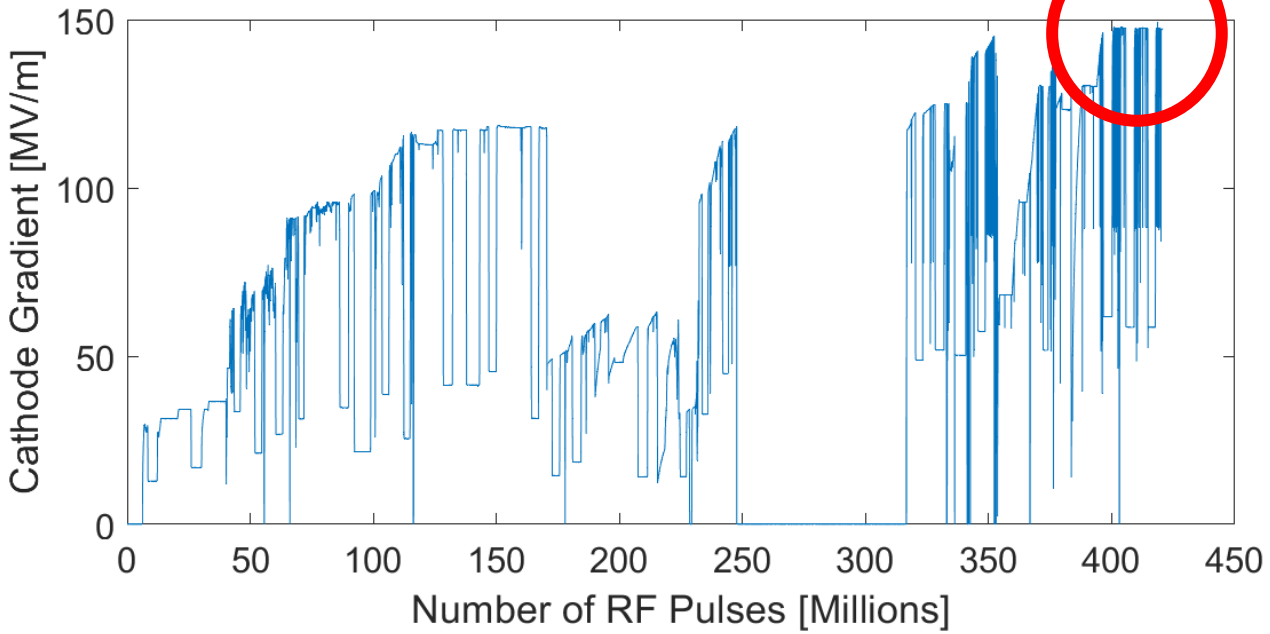
The original gun feeding scheme foresaw the use of a **new in-vacuum isolator**. The delivery of the isolator from the Company experienced some **delays** due to the difficulties that have been encountered in its realization. For this reason and also to have a backup solution in case of difficulties in reaching, with this new device, the required performances in term of power, **we have developed an alternative scheme using power dividers and a BOC-type pulse compressor** already available at PSI for the test of the travelling wave gun in the context of the I.FAST project.

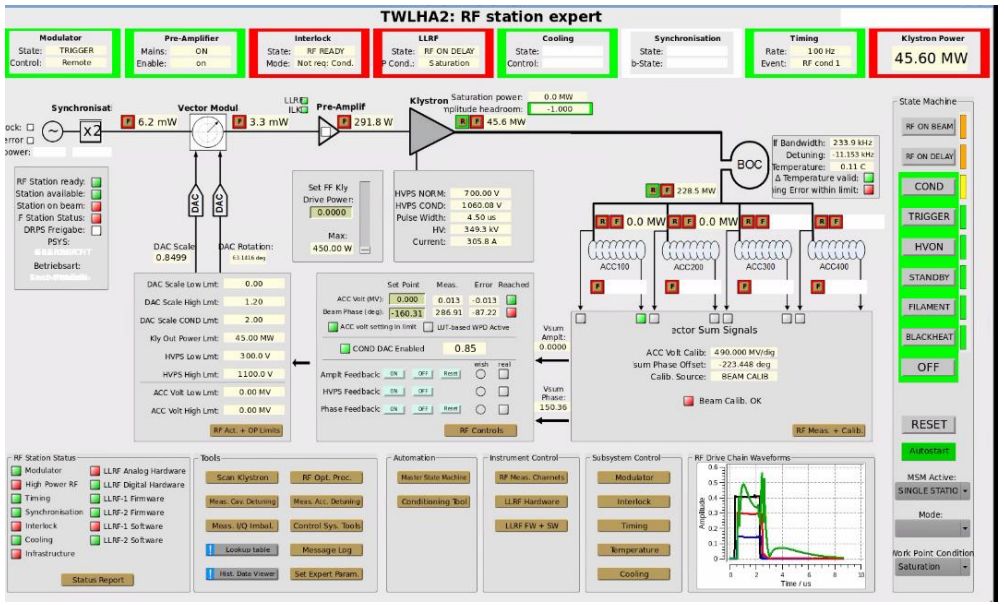




HIGH POWER TEST RESULTS (SO FAR)

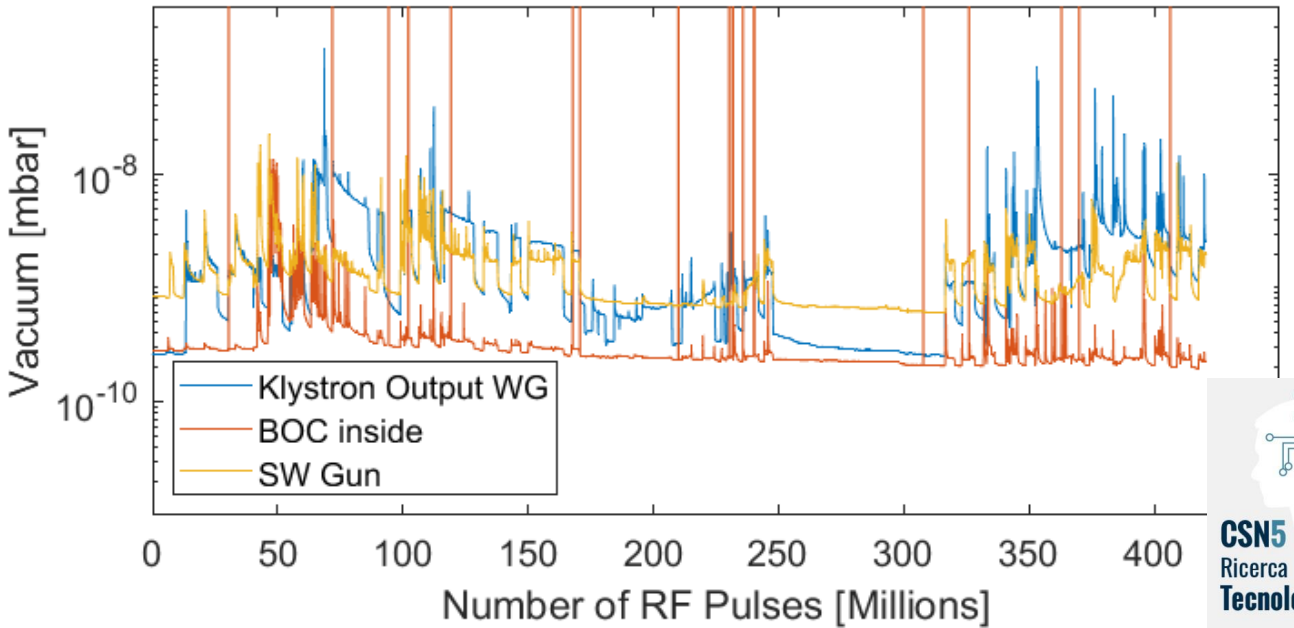
~150 MV/m





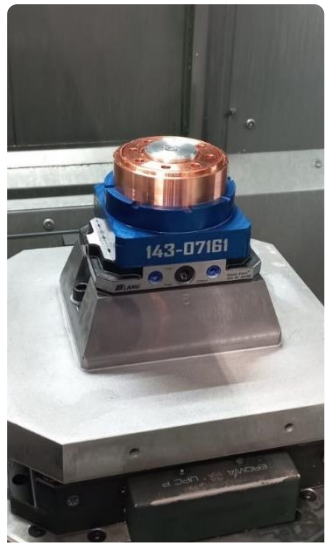
Very low number of RF gun breakdown (to be precisely calculated <5x10^{-7}bpp)

Oral IPAC 24



SUMMARY OF ACTIVITIES: TW GUN

Preturning



Pre-milling

Flycutting

Precision turning

Ultra precision Milling

⇒ TW gun components have been machined
⇒ Delivery of the TW gun parts occurred on the 7th March 2024.
⇒ **Brazing to occur within few weeks @ PSI**
⇒ Final cathode design with VDL.

Courtesy T. Lucas, P. Craievich

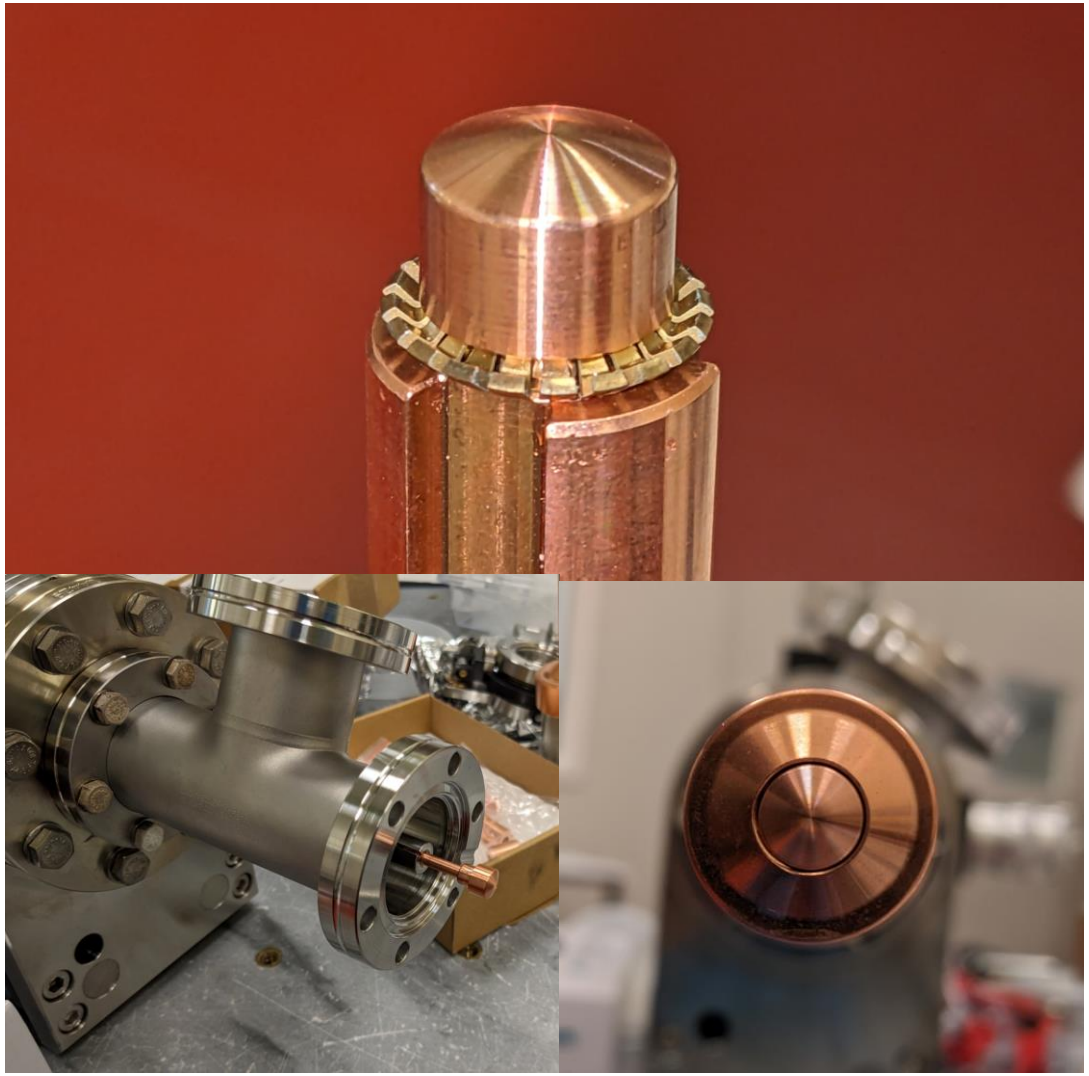
CATHODE FOR TW GUN DEVELOPMENT

⇒ A dummy inner-conductor was made to test the concept for the cathode.

⇒ The findings led to the development of a new cathode concept where the cathode was made in two pieces.

⇒ Furthermore, the spring was found to **plastically deform** with only a small force (compared to that observed in SwissFEL). This is under investigation.

⇒ Gap between cathode and wall increased from 230um to 480um for mechanical tolerances.



Courtesy T. Lucas, P. Craievich

COMPARISON OF THE TWO GUN PERFORMANCES

PHYSICAL REVIEW ACCELERATORS AND BEAMS **26,** 103401 (2023)

Toward a brightness upgrade to the SwissFEL: A high gradient traveling-wave rf photogun

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PHYSICAL REVIEW ACCELERATORS AND BEAMS **26,** 083402 (2023)

Dynamics studies of high brightness electron beams in a normal conducting, high repetition rate *C*-band injector

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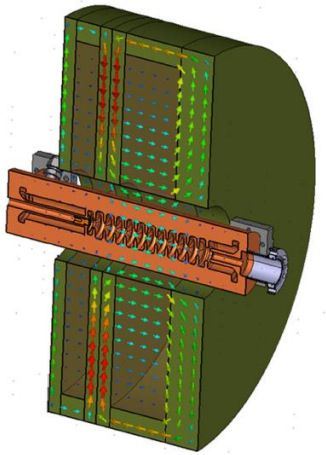
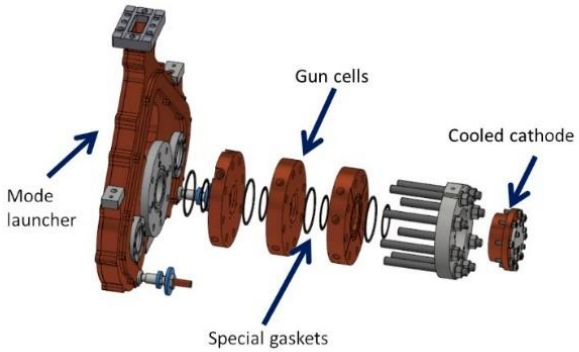
	SW gun	TW gun
Cathode field	160-180 MV/m	200 MV/m
Required RF power	19-23 MW/300 ns with isolator	82 MW/ 90 ns (with BOC, w/o isolator)
Technology	2.5 cells brazed free with mode launch.	12 cells, brazed, coaxial mode launcher
Solenoid	Single coil, after the gun	Around the structure with bucking coil





COMPARISON OF THE TWO GUN PERFORMANCES

TW GUN

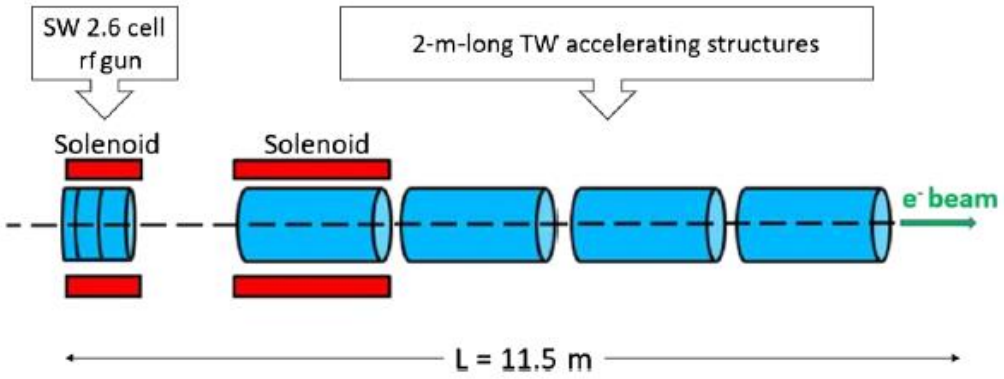
TABLE II. Summary of the beam dynamics performance of the current SwissFEL injector compared to the proposed injector upgrade.

Parameter	S-band SW gun [12,14]	TW rf photogun
Cathode gradient (MV/m)	100	200
Bunch charge (pC)	200	200
Extraction field strength (MV/m)	75.3	173.8
Transverse laser profile	Uniform	Uniform
Longitudinal laser profile	Uniform	Uniform
Laser beam radius (μm)	342	322
Thermal emittance (mm mrad/mm)	0.55	0.55
Laser pulse width (FWHM) (ps)	9.9	2.83
Laser pulse energy (nJ)	200	200
Energy (after gun) (MeV)	7.1	18.3
Energy (end of injector) (MeV)	130	130
Correlated energy spread (%)	0.22	0.16
Bunch length (μm)	931	326
Projected emittance (mm mrad)	0.221	0.185
Sliced emittance (mm mrad)	[illegible]	[illegible]
Peak current (A)	19.74	55.5
Central 5D brightness (TA/m^2)	905	5155

SW GUN

TABLE I. List of the working points described in this paper.

	Low charge		Medium charge			High charge		Units
Charge	75	75	200	200	200	500	500	pC
Average energy	125	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	125	MeV
Transverse normalized emittance (100%—rms)	0.15	0.18	0.25	0.25	0.37–0.69	1.3	0.65	mm mrad
Transverse normalized emittance (95%—rms)	0.11	0.13	0.18	0.16	0.25–0.45	0.80	0.44	mm mrad
Length (rms)	380	100	[illegible]	[illegible]	[illegible]	55	720	μm
Peak current	20	85	40	40	70–500	1000	70	Ampere
rf compression	off	on	off	off	on	on	off	
Repetition Rate	high	high	high	low	low	low	high	
Peak field @cathode	160	160	160	180	180	180	160	MV/m
TW structure accelerating field	15	15	15	31	31	31	15	MV/m



CONCLUSIONS

- **SW GUN has been realized and is now under high power test at PSI.**
- **TW GUN: design activity** concluded, fabrication of the components by VDL has been done. Brazing under way.

Deliverable D.7.4: mechanical realization and low power rf tests of the two guns (M38)

THANK YOU FOR YOUR ATTENTION

MAIN CONTRIBUTORS

INFN-LNF: F. Cardelli, G. Di Raddo, A. Vannozzi, A. Giribono, L. Faillace, A.Gallo, L. Pellegrino, M. Ferrario, A. Liedl, L. Spallino, S. Lauciani, C. Vaccarezza, V. Lollo, S. Pioli.
INFN-ROMA1: L. Ficcadenti, G. Pedrocchi, G. Castorina
PSI: T. Lucas, P. Craievich, R. Fortunati, R. Zennaro, M. Pedrozzi, F. Marcellini, J-Y Raguin, M. Schaer, C. Beard

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