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

David Alesini, task coord.
INFN-LNF (Frascati, Italy)

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**

3. Update on **TW GUN Activities**

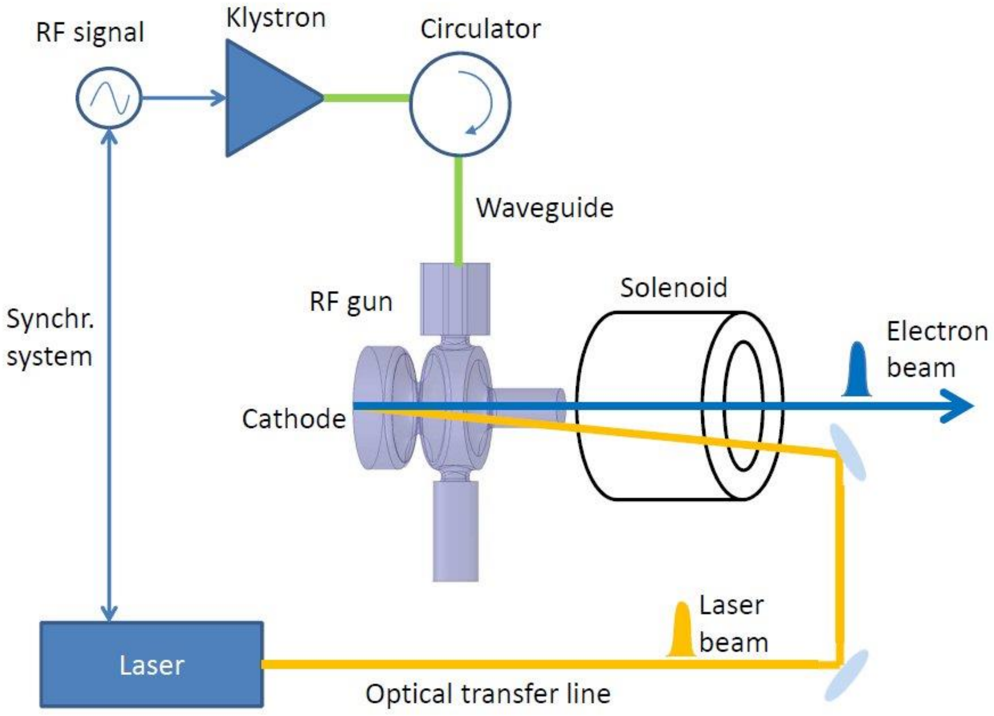
4. **Bunker Status@PSI for high power test**

C BAND RF PHOTO-GUNS

Istituto Nazionale di Fisica Nucleare

PAUL SCHERRER INSTITUT

- **RF Photo-injectors** are widely used in **FEL**, as very low-emittance and high-brightness electron sources.
- A **laser pulse** hits a cathode and the electrons are immediately accelerated by an intense RF E field (60-120 MV/m)
- **RF technology mostly used is the L or S-band** (f=1.3 or 3 GHz).
- The higher the **peak electric field on the cathode**, the better the quality of the beam emerging from the Gun.



- The frequency step-up from L/S-band to C-band can provide **higher achievable cathode peak field as high as 160-180 MV/m**.
- Because of its higher efficiency a C-band RF Gun is also suitable for **application requiring repetition rates in the 200 Hz÷1 kHz range**.

- The availability of a new state-of-the-art, electron injector would **bring benefits to a large accelerator user community, (FEL radiation sources, Thomson/Compton photon sources and plasma based accelerators)**

iFAST

GOALS AND TIMSCHEDULE OF TASK 7.4

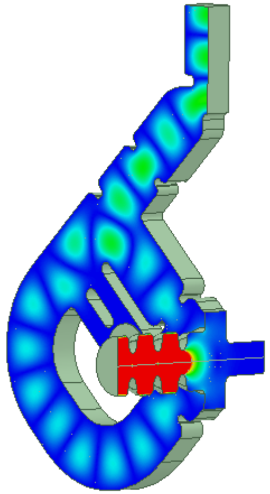
- **Design, realization and high power test of two different C-band (5.712 GHz) RF electron guns** operating at very high gradient cathode peak field (>160 MV/m): a Standing Wave (**SW**) gun and a Travelling Wave (**TW**) gun.

- **Comparison** of the performances.

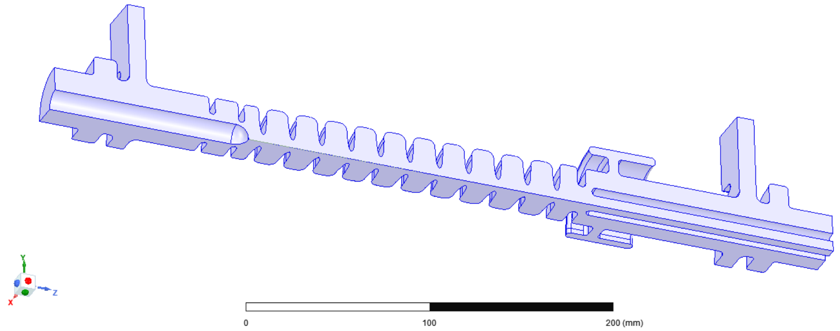
- **Beam dynamics** simulations to exploit the device potentialities

Detailed Timeschedule well defined

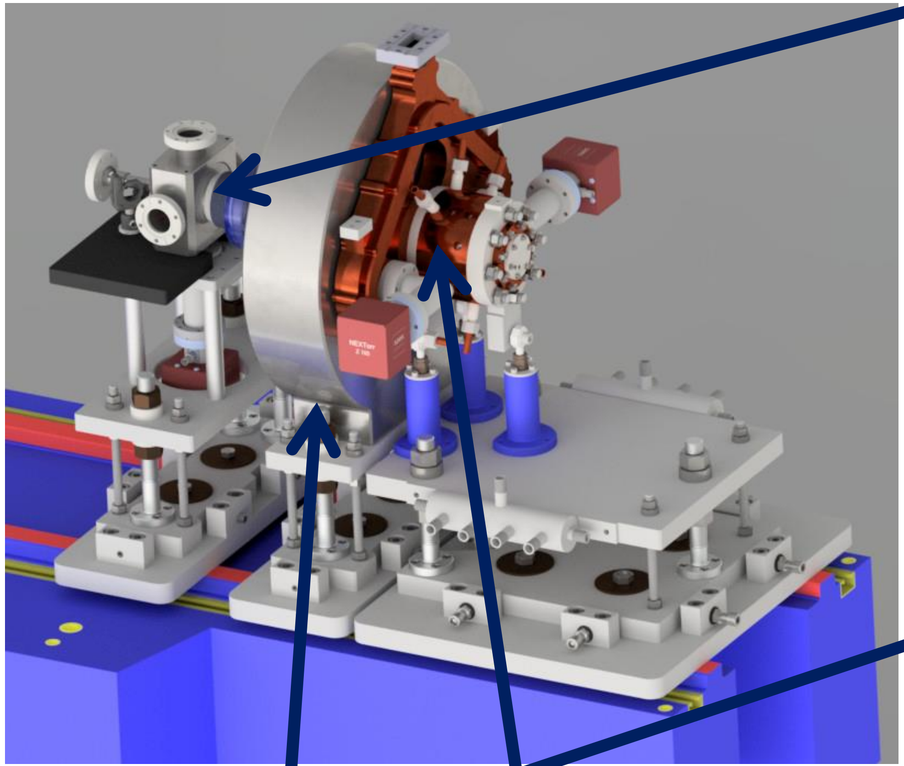
SW GUN

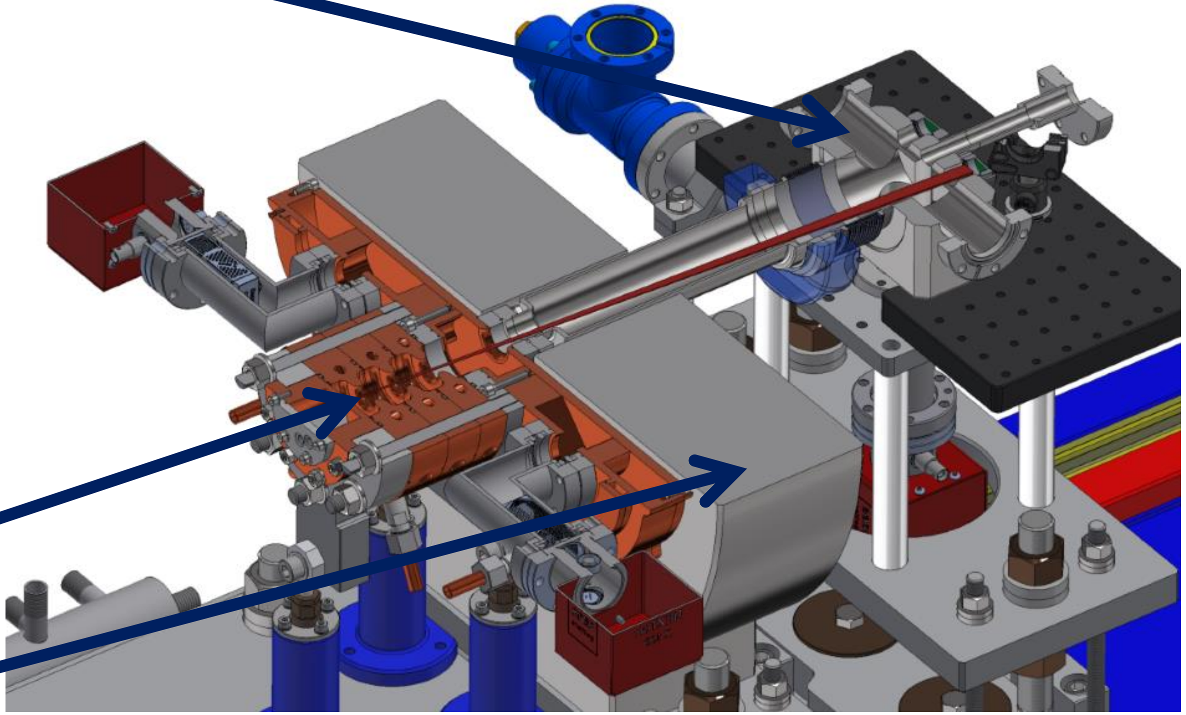


TW GUN



SW GUN STATUS





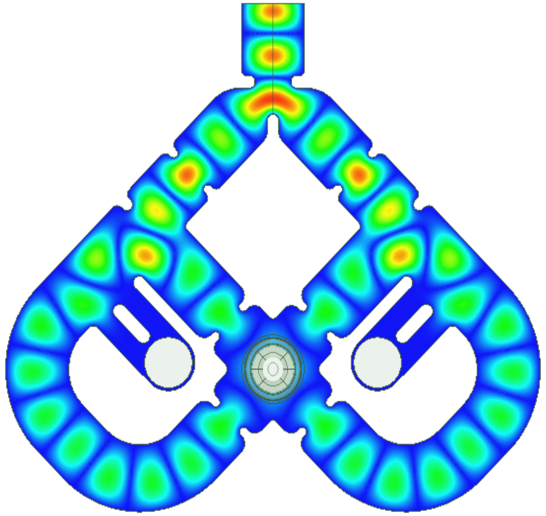
⇒ **e.m. design** completed

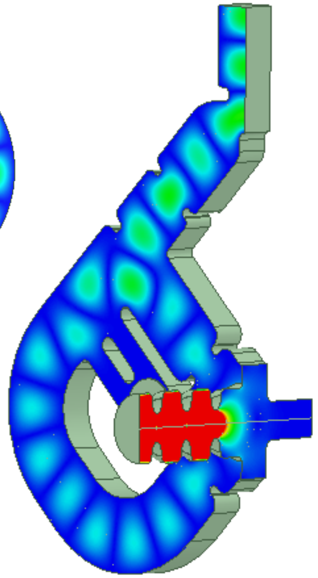
⇒ **Mechanical design:** completed

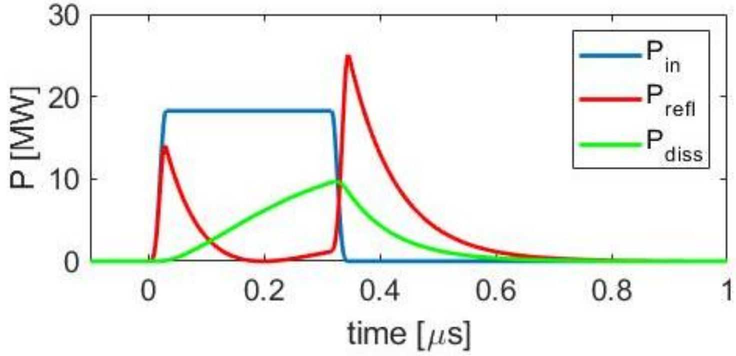
⇒ **Alluminum prototype built and now under RF characterization**

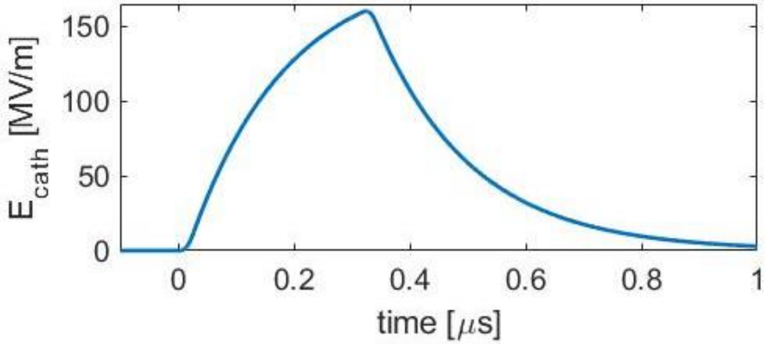
SW GUN: MAIN FEATURES AND PARAMETERS

- **Sort RF pulses (~300 ns) to reduce BDR**
- **4-port mode launcher** for quadrupole compensation and low pulsed heating
- **Hard copper and clamping technology**









Parameter	value	
Frequency [GHz]	5.712	
Number of cells	2.5	
$E_{cath}/\sqrt{P_{diss}}$ [MV/(m·MW$^{0.5}$)]	51.4	
Peak input power [MW]	18	23
Cathode field [MV/m]	160	180
Cathode type	copper	
Rep. rate [Hz]	1000	100
Quality factor	11900	
Filling time [ns]	166	
Coupling coefficient	3	
RF pulse length [ns]	300	
E_{surf}/E_{cath}	0.96	
Mod. Poy. Vect. [W/μm^2]	2.5	3.1
Pulsed heating [^{o}C]	16	20
Av.diss. Power [W]	2300	300

NB**: Isolator is needed** and has been ordered by a private company

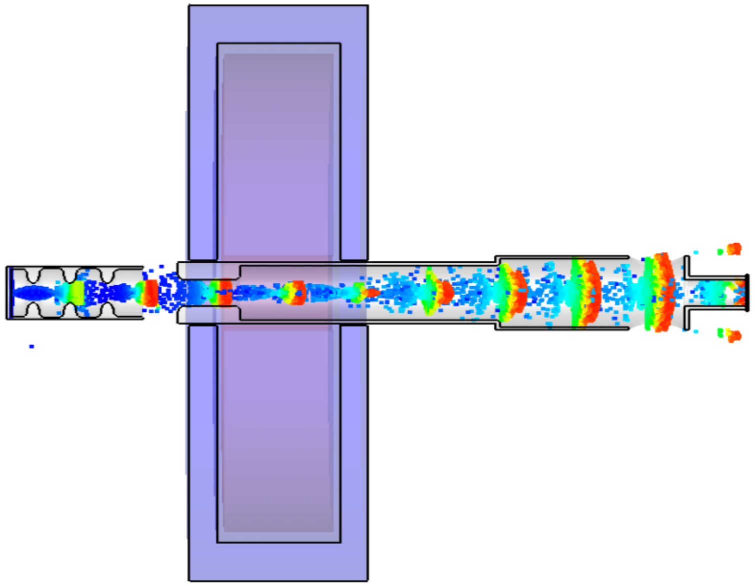
SW GUN: DARK CURRENT

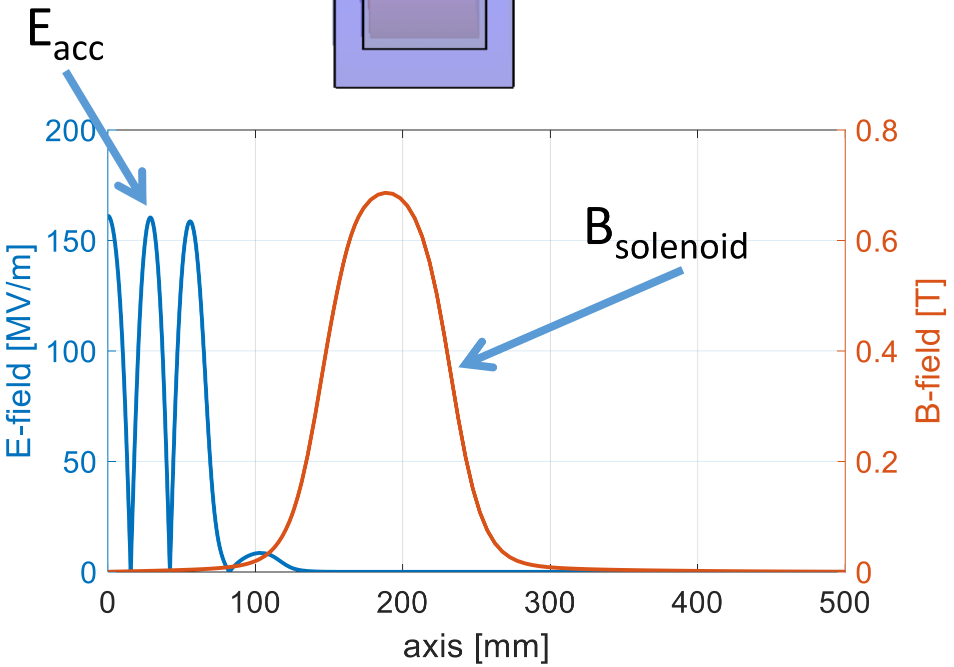
- Dark current simulations have been performed using **CST with and w/o solenoid**
- Current transported up to the laser injection chamber has been calculated

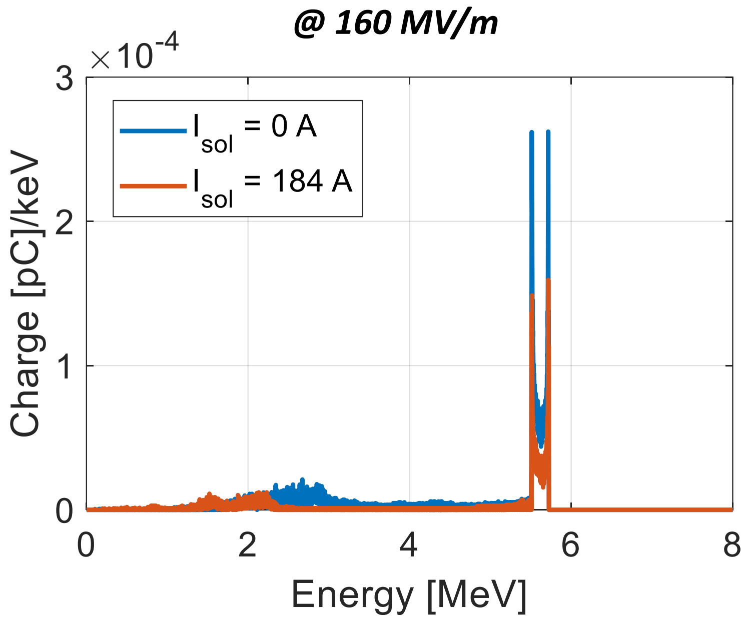
Input parameters:
$\beta = 70$
$\Phi = 4.65$ eV
$A_e = 0.01$ um^2
$A_{cathode} = 1520$ mm^2
$E_{cathode}$=160 MV/m

$I_{solenoid}$ **= 184 A**

Courtesy of F. Cardelli



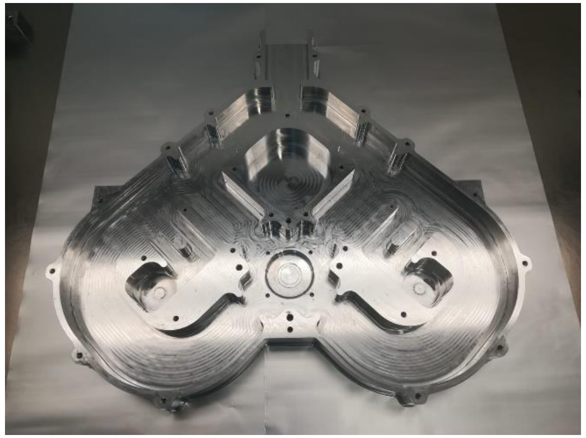




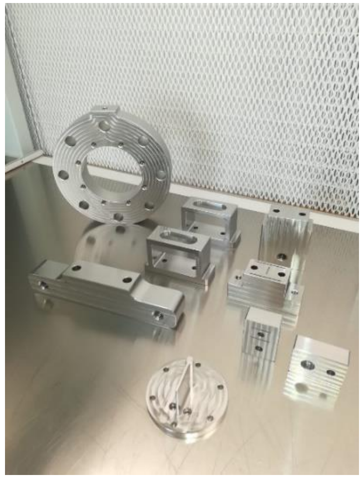
	Unit	160 MV/m	
Solenoid Current	A	0	184
Q_{period} emitted	fC	360	
Q_{period} transported	fC	33	15
Charge transport factor	%	9.1	4.2
Maximum energy	MeV	5.7	

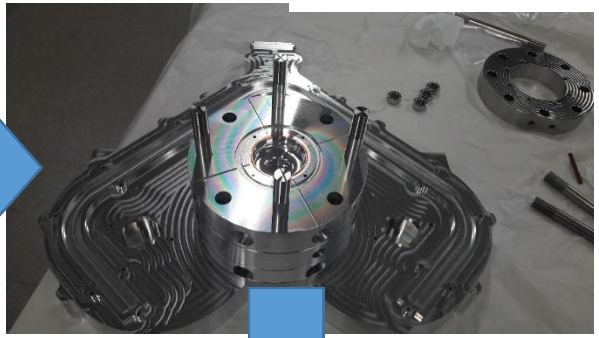
SW GUN: ALLUMINUM PROTOTYPE ASSEMBLY

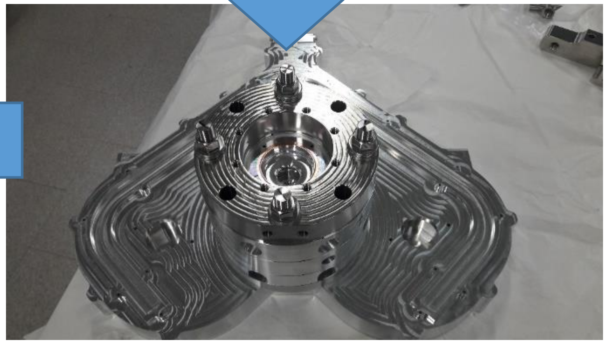
Mode launcher

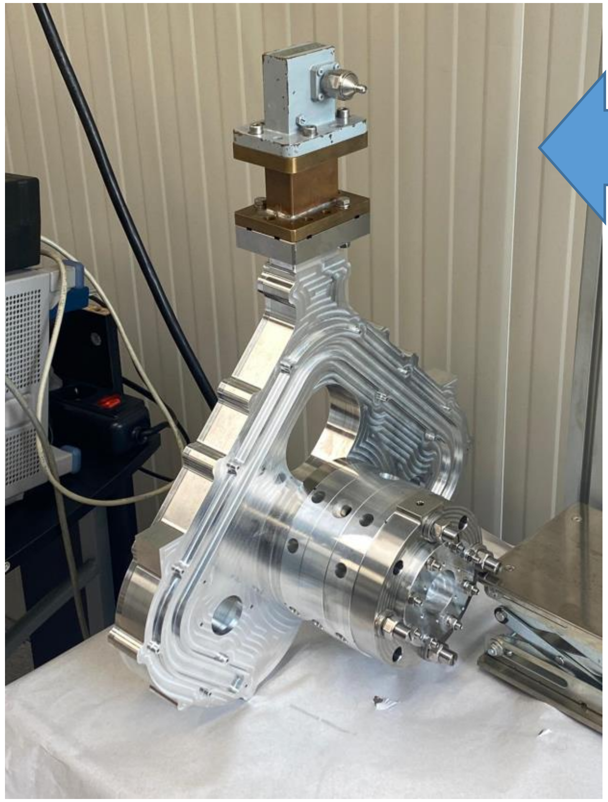


cells

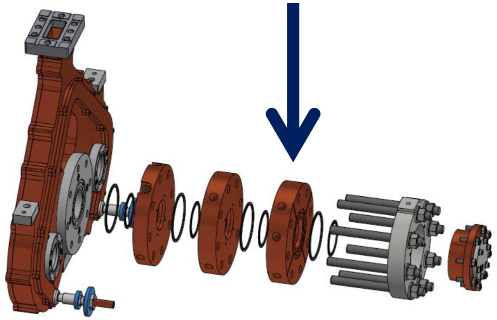






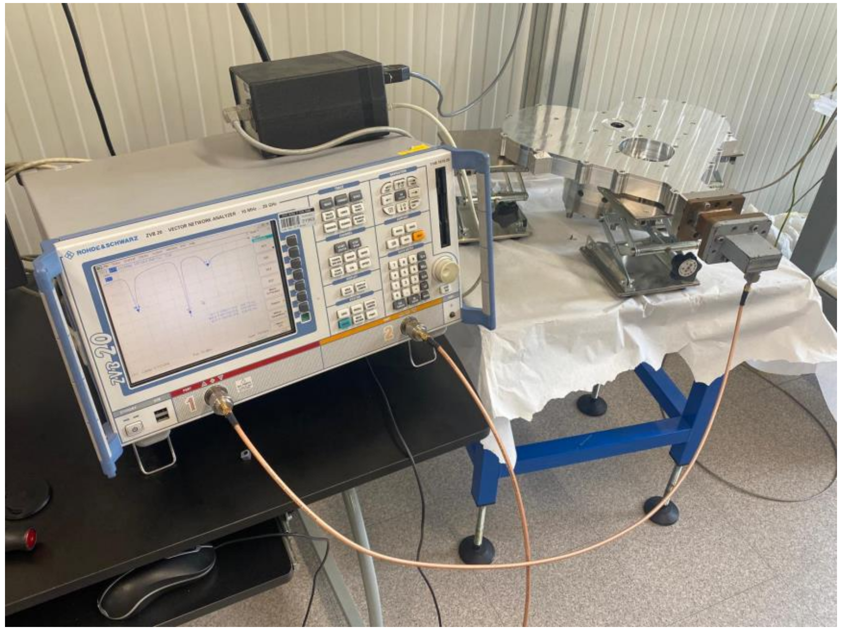


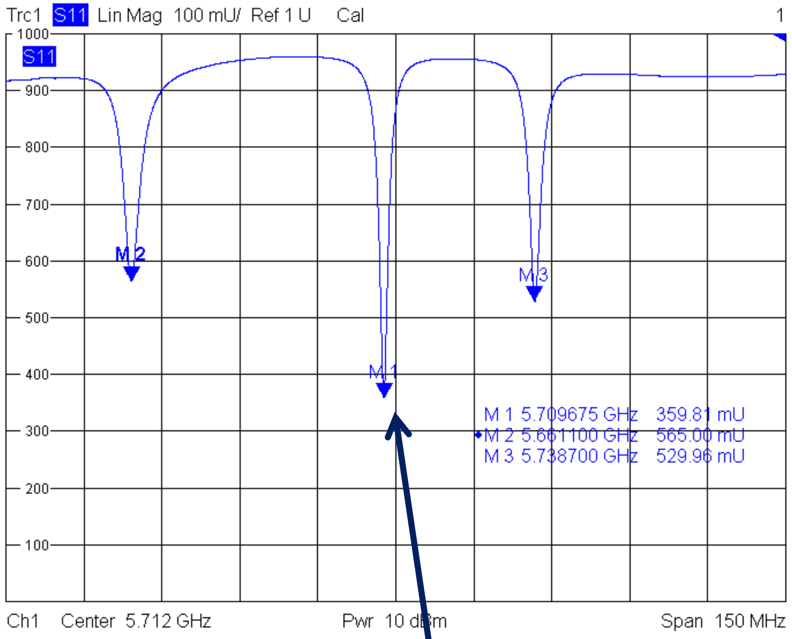
New technology *w/o brazing for RF gun realization (clamping and special gaskets)*

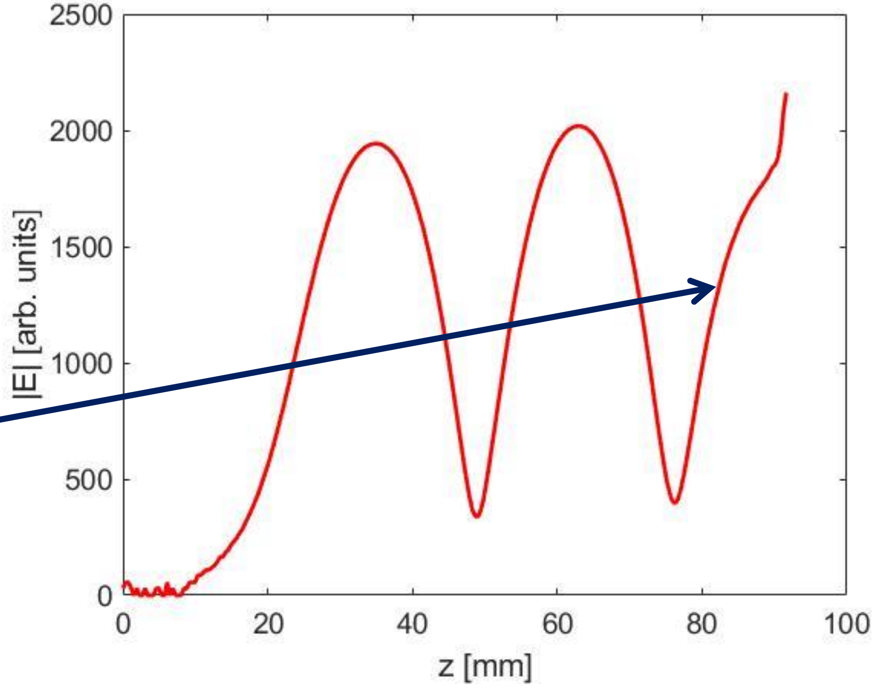


SW GUN: ALLUMINUM PROTOTYPE RF MEASUREMENT

Bead drop measurements







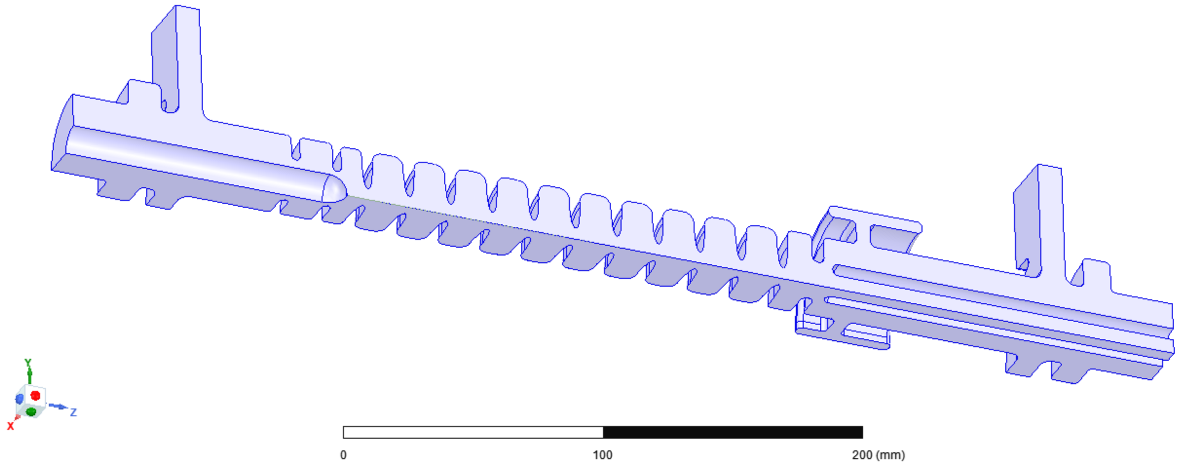
Δf=~500 kHz due to a non complete compression of the cathode gasket

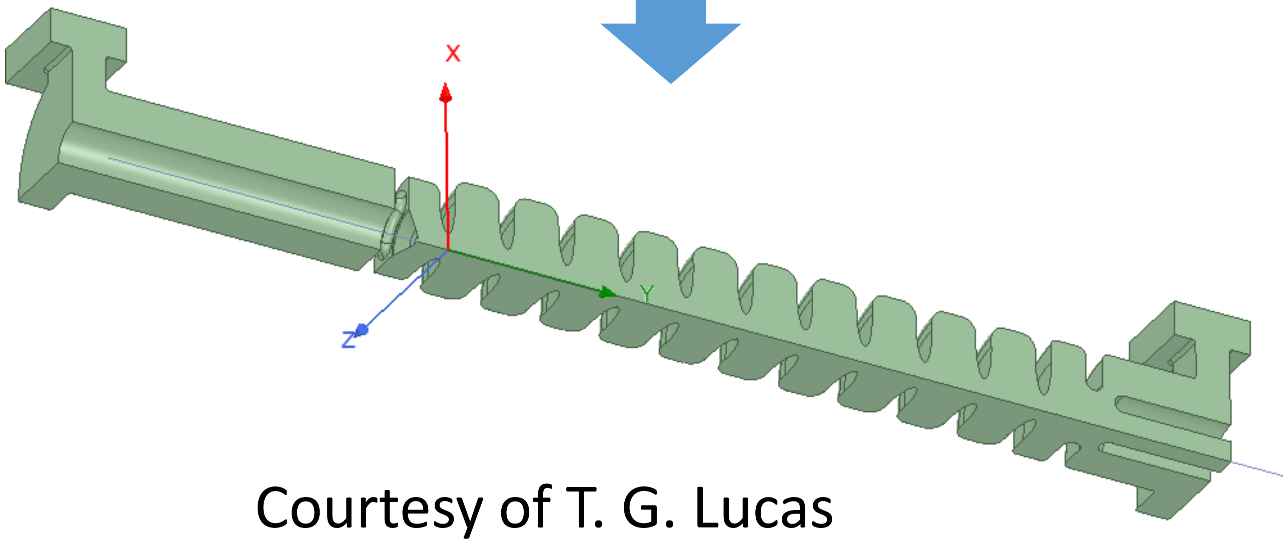
TW GUN: NEW RF DESIGN

- TW gun RF design adapted from M. Schaer's Thesis work.

- **Magnetically coupled input coupler**: tolerance studies demonstrated that the electrically coupled input coupler would suffer significantly from small misalignment.

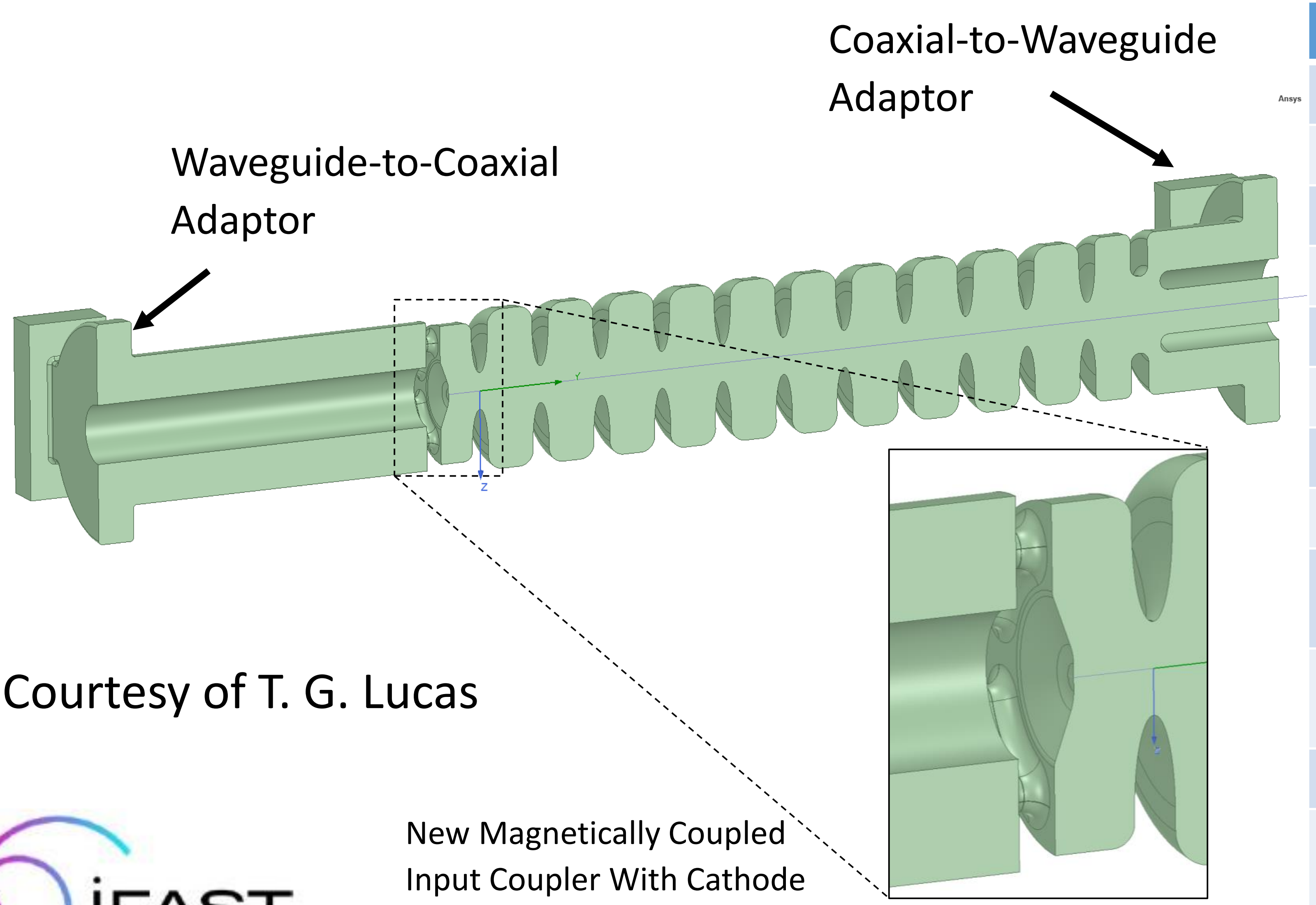
- **Removed the choke filters** and new waveguide-to-coaxial adaptors: these were no longer needed as the new compact waveguide-to-coaxial adaptors would allow for the magnet to be slide over the entire design.





Courtesy of T. G. Lucas

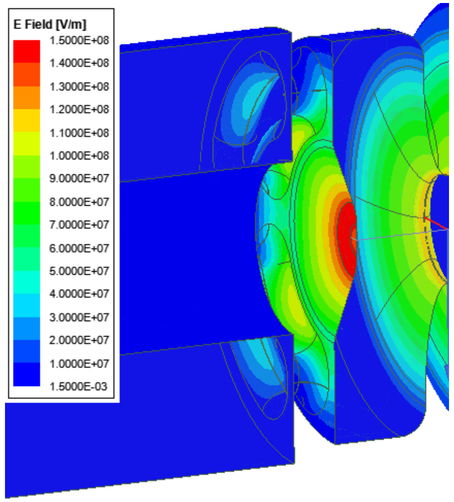
TW GUN: RF DESIGN DETAILS AND PARAMETERS

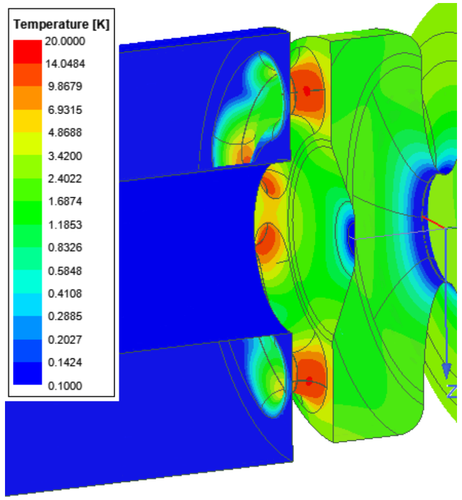


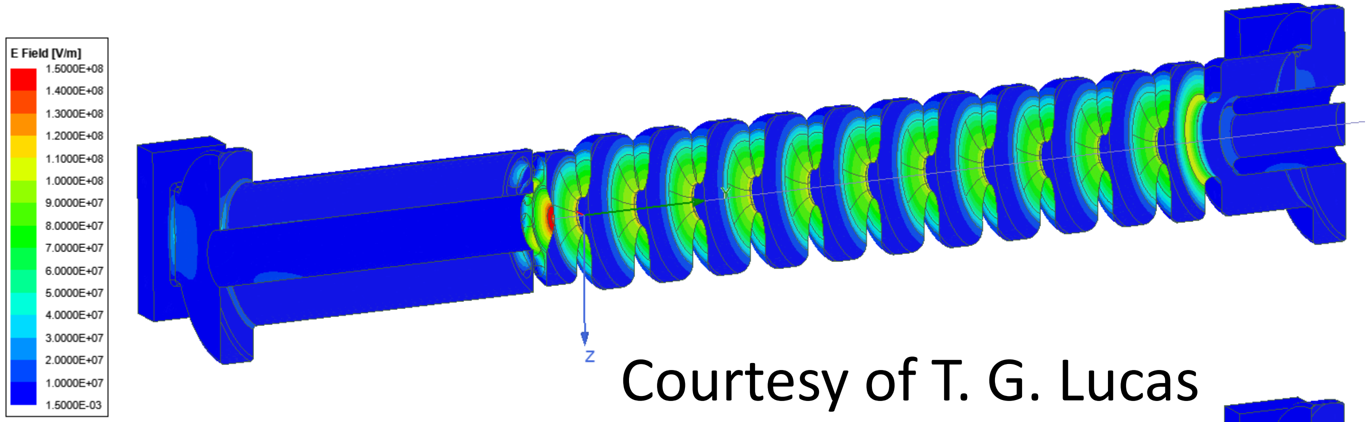
Parameter	Value	Units
Accelerating Cells	10 (+2 coupling cells)	
Cell Length	17.495	mm
Total RF Length	229	mm
Phase Advance	120	deg
Attenuation	1.4	dB
Group velocity	0.0079	c
Fill Time	90	ns
Input Power	37.5	MW
Cathode Field	138	MV/m
Extracted Field	95	MV/m
Energy	13.1	MeV
Pulsed Surface Heating	14	K

Courtesy of T. G. Lucas

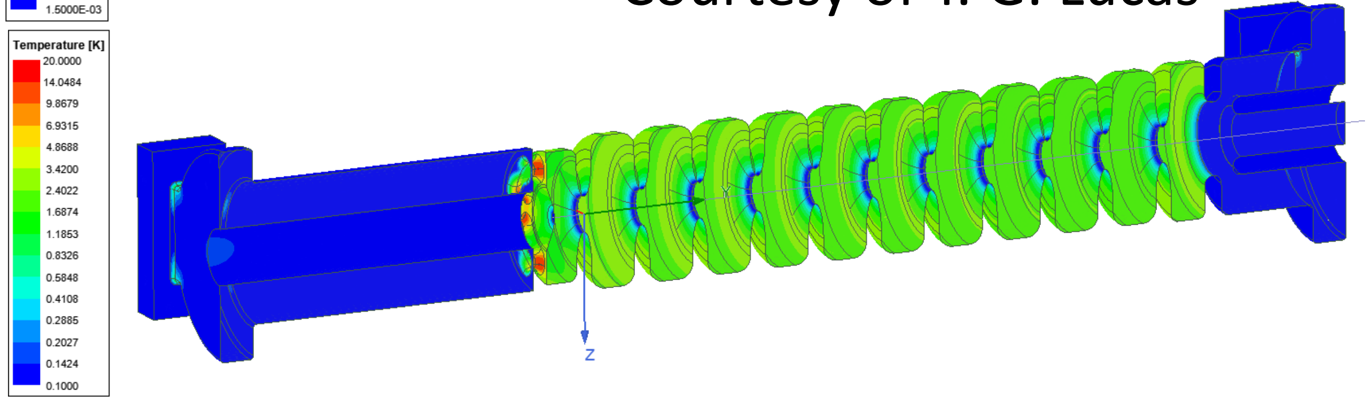
TW GUN: E.M. FIELD DISTRIBUTION

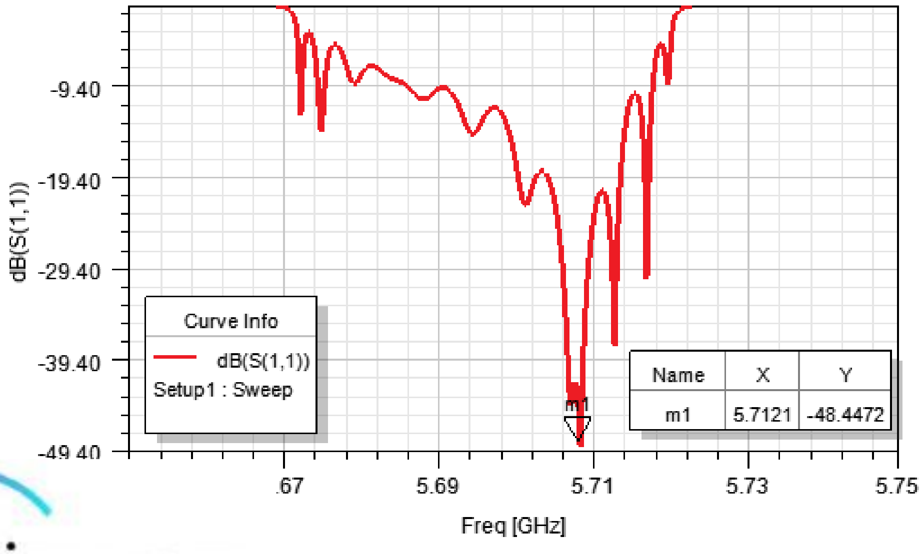


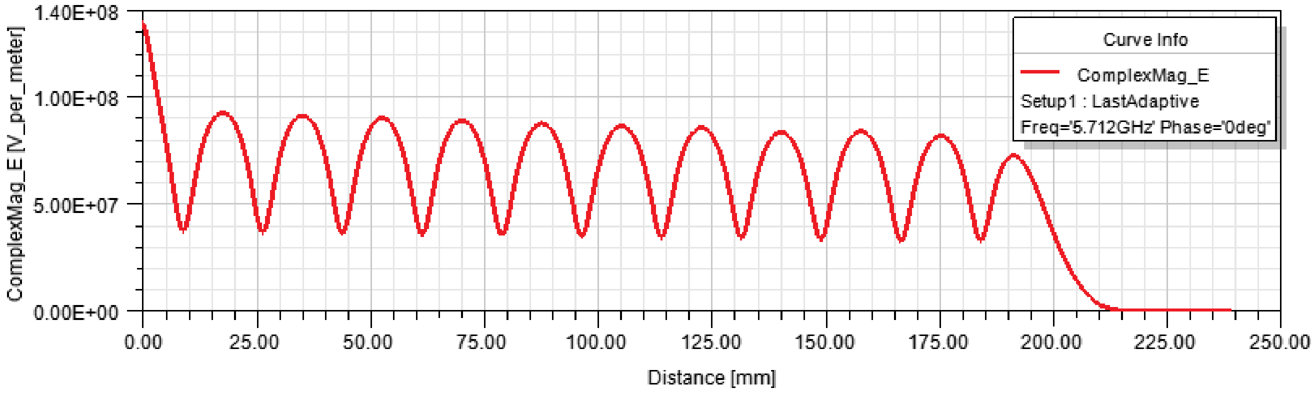




Courtesy of T. G. Lucas



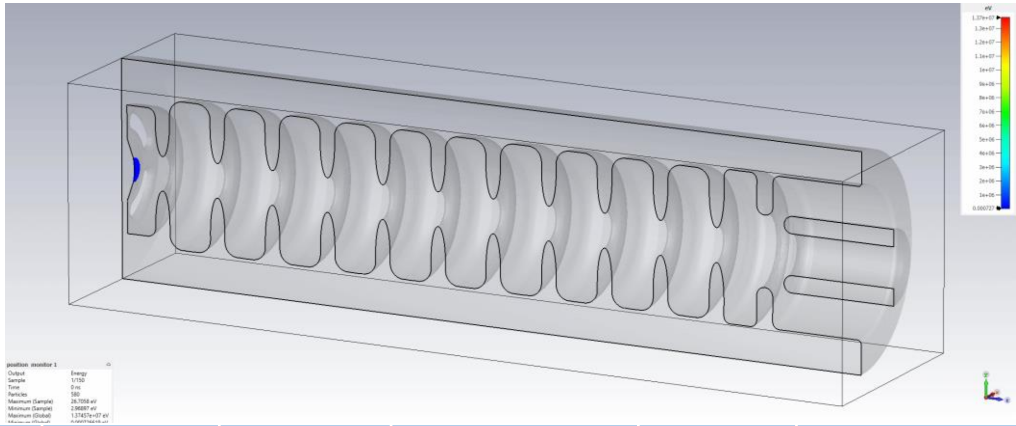




TW GUN: PIC SIMULATIONS OF PERFORMANCE LIMITING PHENOMENA

Dark Current

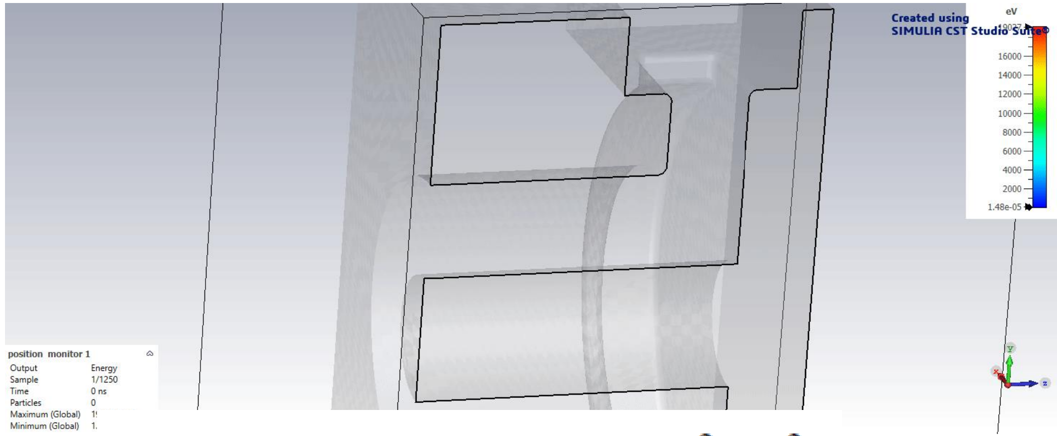
- Simulations technique described in: T. G. Lucas, *Dependency of the capture of field emitted electron on the phase velocity of a high-frequency accelerating structure Nucl. Instrum. Meth. A 914 (2019) 46-52*



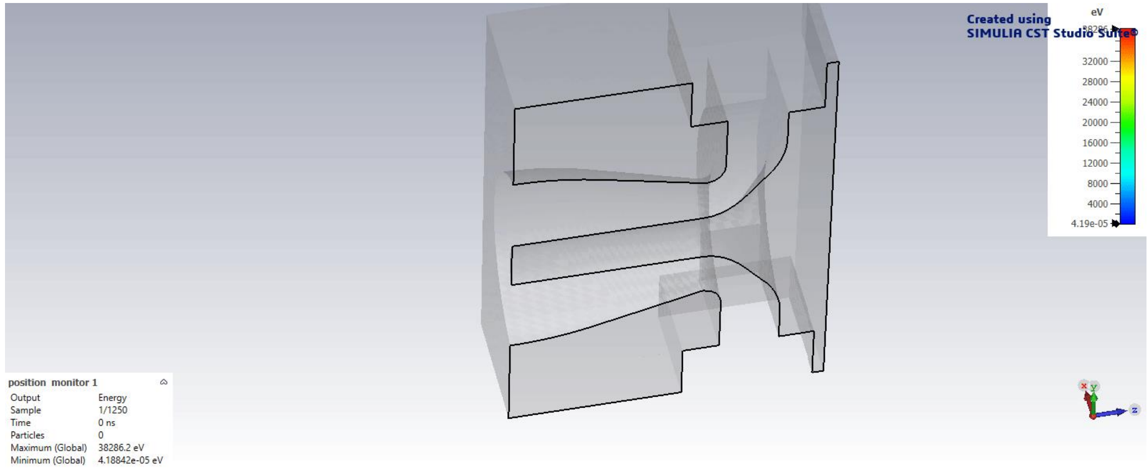
Field Enhancement Factor (β)	Effective area (A_e) [um^2]	Cathode Gradient [MV/m]	Charge arriving downstream (per 90ns RF pulse) [pC]	Capture Ratio	Total Field emitted charge (per RF pulse) [pC]	Peak Energy [MeV]
70	0.01	135	5.9	0.31	19.0	13.0
70	0.01	200	160.3	0.29	552.8	19.2

Courtesy of T. G. Lucas

Multipacting



$$\ddot{\mathbf{r}}_0 = -\nabla\Phi, \quad \Phi = (\eta/2\omega)^2|\mathbf{E}|^2,$$

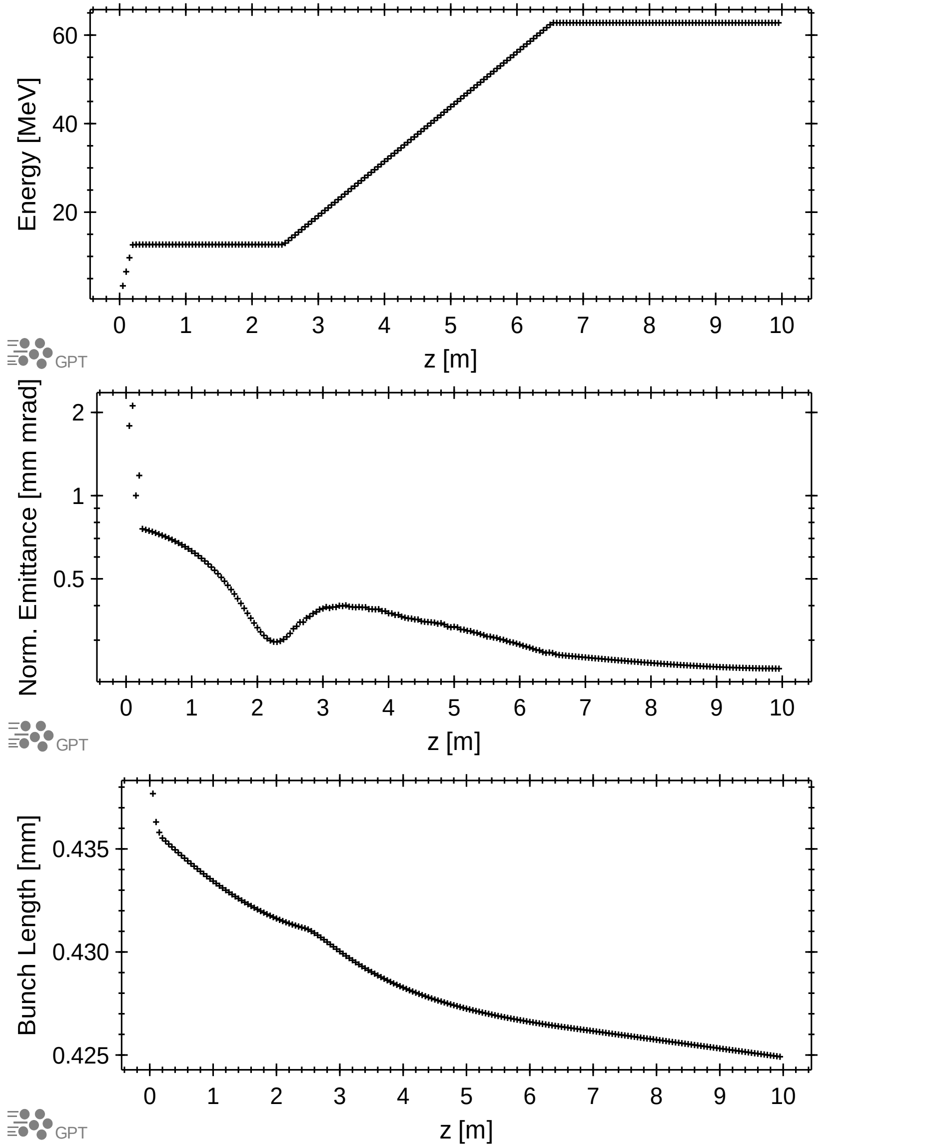


Ref: A.V. Gaponov, M.A. Miller, Potential wells for charged particles in a high-frequency electromagnetic field. Sov. Phys. JETP 7, 168 (1958)

TW GUN: BD SIMULATIONS

- **Simulations performed in G**PT with Mesh Space-charge.
- Increase in brightness achieved through increase in peak current.
- Ongoing investigations on increasing 6D brightness.

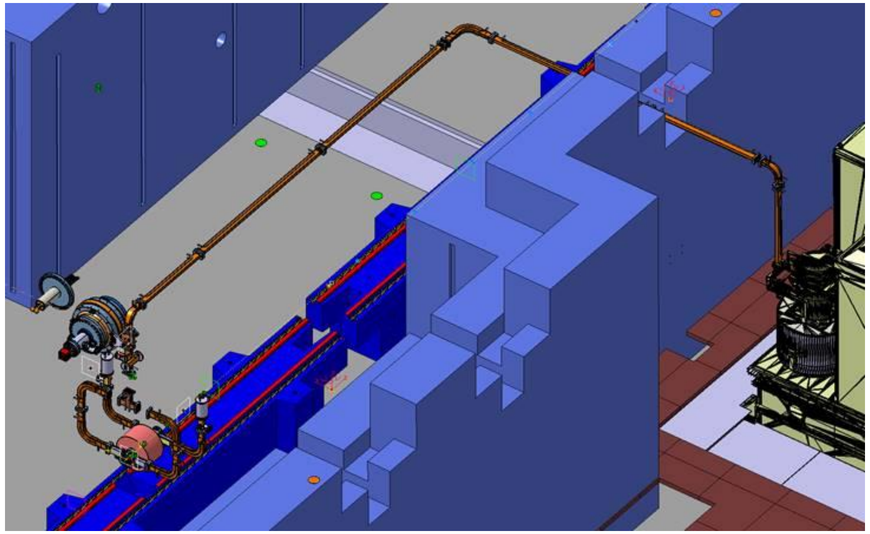
Parameter	TW RF Photogun		SwissFEL Nominal	Units
Peak Cathode Field	135	200	100	MV/m
Bunch Charge	200	200	200	pC
Energy	13.1	18.8	6.6	MeV
Projected Emittance	0.23	0.155	0.21	mm mrad
Bunch Length	0.425	308	0.933	mm
Peak Current ($Q/\sqrt{12}t$)	41	56	19	A



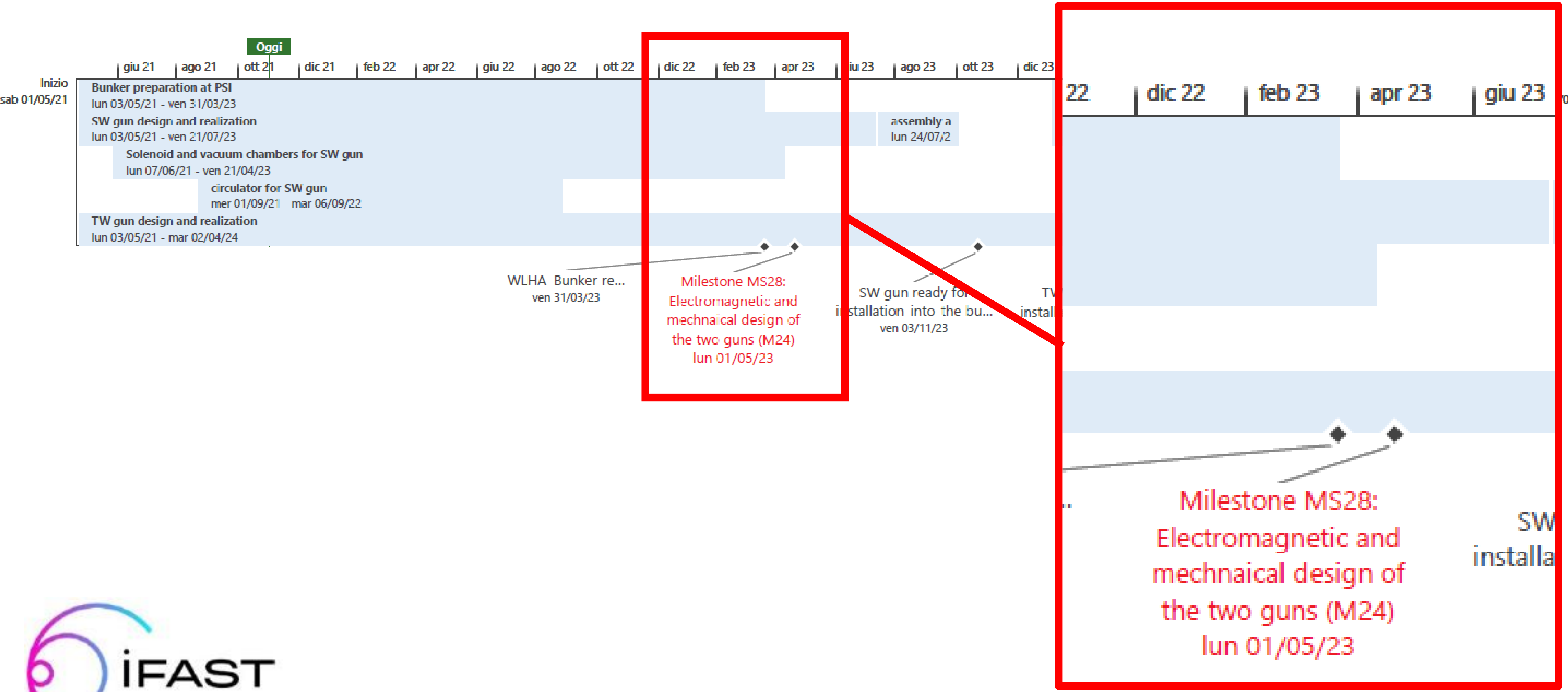
Courtesy of T. G. Lucas

BUNKER@PSI: STATUS

- **Waveguide network** drawn with some small WG sections to fabricate.
- **Radiation simulations** started and will determine shielding requirements particularly thickness of new wall.
- Waveguide from klystron extended in preparation for IFAST.
- **Setup ready for isolator testing** (SW gun).
- Once we have the radiation simulations done we’ll proceed with the **BAG application**.



MILESTONES AND DELIVERABLES



CONCLUSIONS

- **TIMESCHEDULE for SW, TW and BUNKER preparation well defined**
- **SW GUN: design activity** concluded, we are now in the prototyping phase
- **TW GUN: design activity almost** concluded
- **NEXT STEPS**:
    - SW GUN: solenoid design and its order
    - TW GUN: Concluding the e.m. design and proceed with the mechanical one
    - BUNKER: waiting for the authorizations (BAG) and work in parallel on control access, waveguides, etc…

THANK YOU FOR YOUR ATTENTION

MAIN CONTRIBUTORS

INFN-LNF: F. Cardelli, G. Di Raddo, A. Vannozzi, A. Giribono, L. Faillace, A.Gallo, L. Pellegrino (support on project management tools)
INFN-ROMA1: L. Ficcadenti, G. Pedrocchi, G. Castorina
PSI: P. Craievich, T. Lucas, R. Fortunati, R. Zennaro, M. Pedrozzi, F. Marcellini, W. Tron

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No101004730.