WP3 - Gun and Injector

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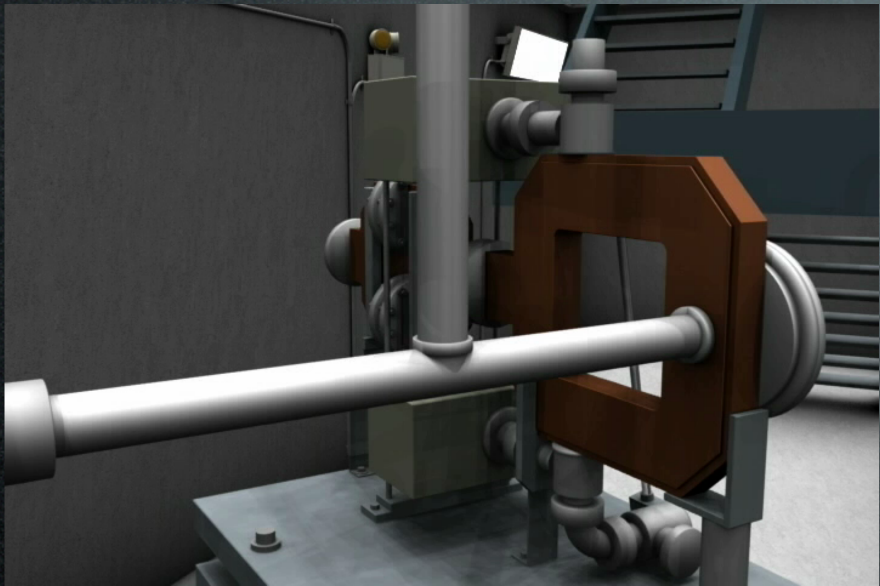


- Laser/Photocathode
- RF/DC Gun
- Solenoid
- RF Velocity Bunching

- RF Linearizer and L. Heater
- Magnetic Chicane
- Transv. RF Deflector
- Beam Diagnostics

- To design the Compact High Brightness Injector
- To design the proper matching with the X-band Linac

Swiss FEL injector design

S-band => C-band transition

Magnetic or RF Compressor for the XLS injector?

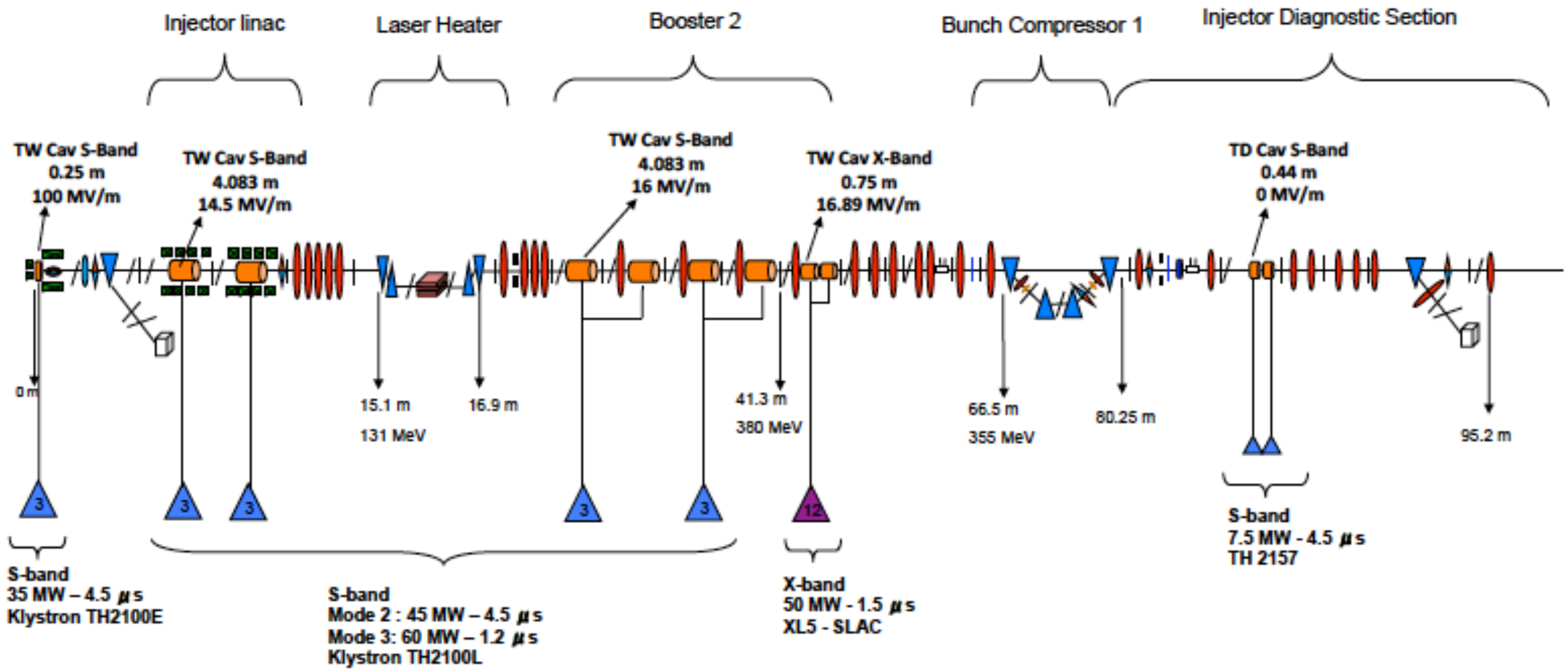
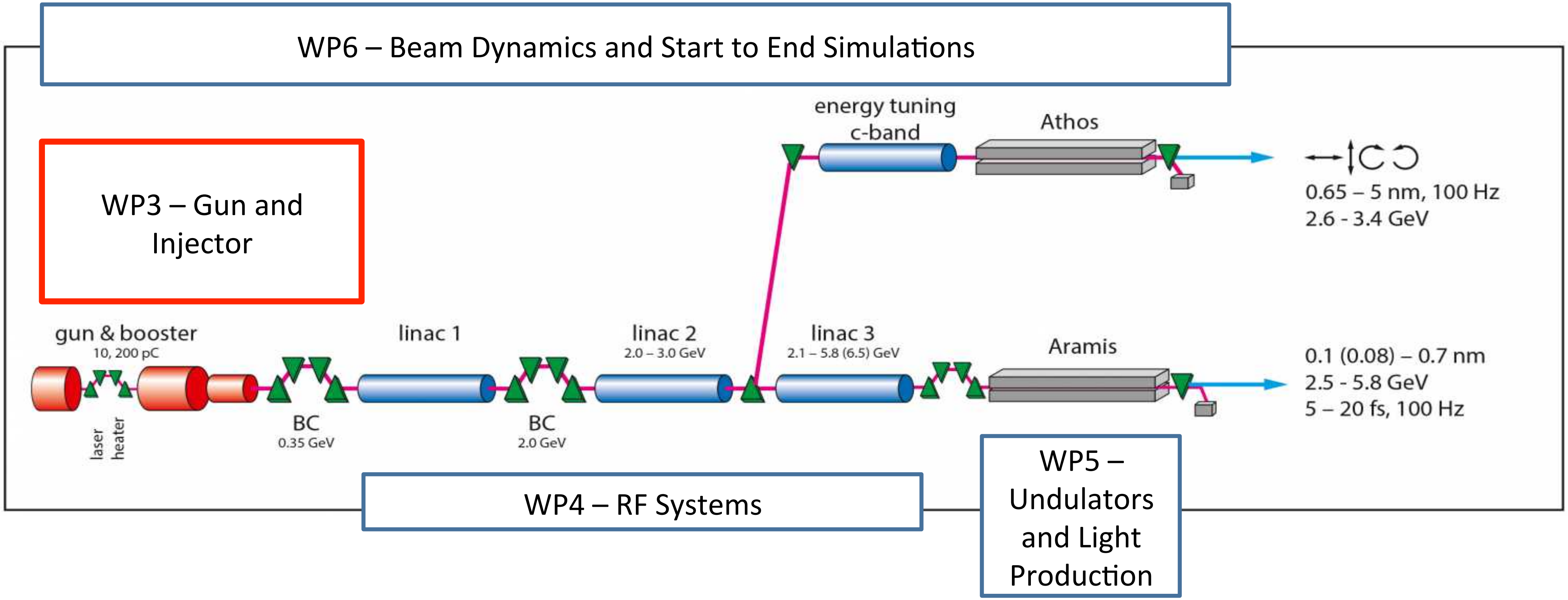


Fig. 3.2.3.1: General layout of the RF systems for the SwissFEL Injector.

Relationship to other WPs: Jim View



Deliverables

- **D3.1** - Preliminary assessments and evaluations of the optimum e-gun and injector solution for the CompactLight design, (**=>M18**).
- **D3.2** – A review report on the bunch compression techniques and phase space linearization, (**=>M18**).
- D3.3 – Design of the injector diagnostics/beam manipulations based on a X-band cavities, (=>M36).
- D3.4 - Design of the CompactLight e-gun and injector, with phase space linearizer (=>M36).

New Description of Tasks

(sub-task leaders institutes in **bold)**

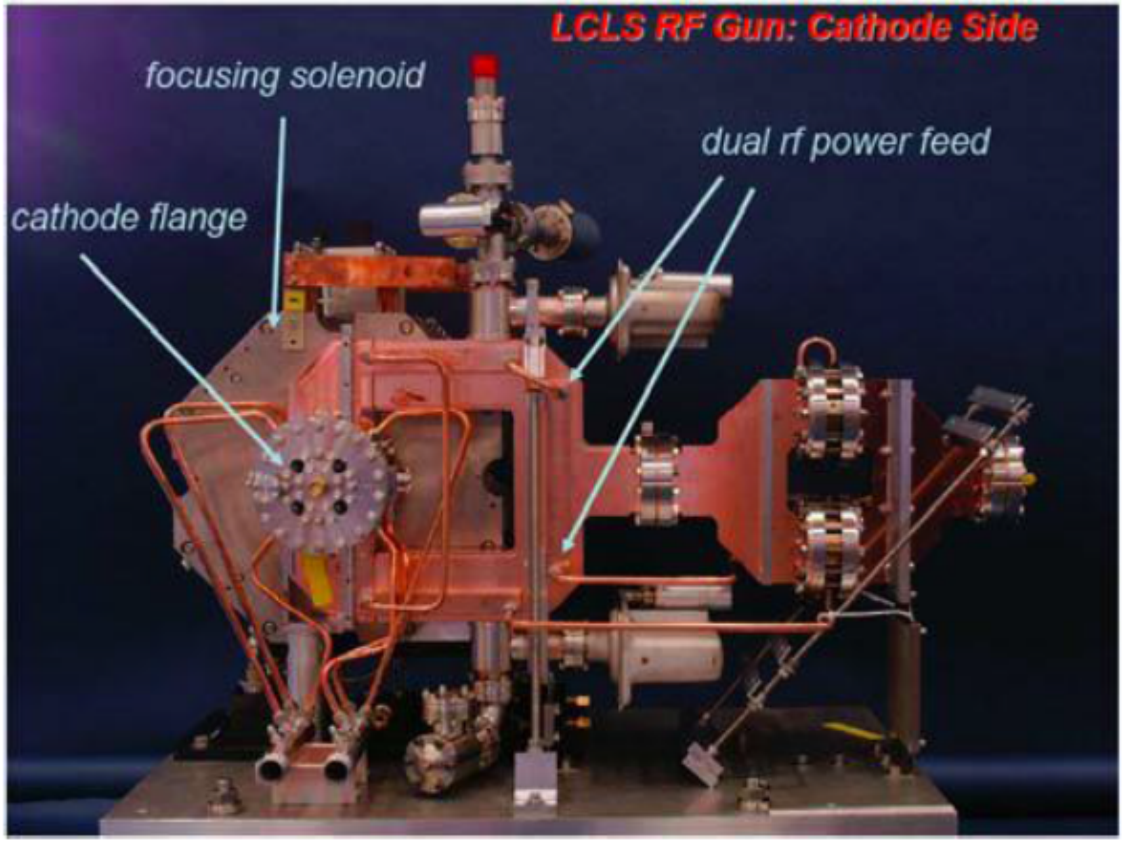
- **Task 3.1 - Gun Design** (RF, Solenoid, Cathode, Laser, Diagnostics) **=> D3.1 M18 => D3.3 M36**
  a) S-Band Gun RF Design (**CNRS** + IASA+UAIAT-INFN+ALBA)
  b) C-Band Gun RF Design (**INFN** +IASA+Sapienza)
  c) X-Band Gun RF Design (**CSIC-IFIC** + UAIAT+ Sapienza)
  d) DC Gun Design (**TU/e**)
  e) Laser/Photocathode (**IASA**+CNRS+INFN)

- **Task 3.2 - Compressor Design** (Velocity Bunching, Magnetic Chicane) **=> D3.2 M18 => D3.3 M36**
  a) S-Band Velocity Bunching (**TU/e** + IASA+ALBA)
  b) C-Band Velocity Bunching (**INFN** +IASA+TU/e)
  c) X-Band Velocity Bunching (**Sapienza**+CERN+IASA+INFN)
  d) Magnetic Compressor (**ST** + CERN+INFN+CNRS)

- **Task 3.3 – X-Band Transverse RF Deflector** (**Sapienza**+ IASA+) **=> D3.3 M36**

- **Task 3.4 - : RF Linearizer Design => D3.2 M18 => D3.3 M36**
  a) X-Band RF Linearizer Design (**Sapienza**)
  b) K-Band RF Linearizer Design (**ULANC** +Sapienza +INFN)
  c) Passive linearizer (**CNRS)**

Linac Coherent Light Source Photoemission NCRF gun at Stanford



The LCLS RF photoinjector is the state-of-the-art technology with a Cu cathode. It generates electron beam with 0.7 µm emittance.

The beam is comprised of 250pC bunches, each 2.5 ps rms, at a repetition rate of 120Hz.

The cathode peak field is ~100 MV/m

COMMISSIONING THE *LCLS INJECTOR*

R. Akre, D. Dowell, P. Emma, J. Frisch, S. Gilevich, G. Hays, Ph. Hering, R. Iverson, C. Limborg-Deprey, H. Loos, A. Miahnahri, J. Schmerge, J. Turner, J. Welch, W. White, J. Wu

SLAC, Stanford, CA 94309, USA, SLAC-PUB-13014, November 2007

Gun Design

- **Task 3.1 - Gun Design (RF, Solenoid, Cathode, Laser, Diagnostics) => D3.1 M18 => D3.3 M36**
  a) S-Band Gun RF Design (**CNRS** + IASA+UAIAT-INFN+ALBA)
  b) C-Band Gun RF Design (**INFN** +IASA+Sapienza)
  c) X-Band Gun RF Design (**CSIC-IFIC** + UAIAT+ Sapienza)
  d) DC Gun Design (**TU/e**)
  e) Laser/Photocathode (**IASA**+CNRS+INFN)

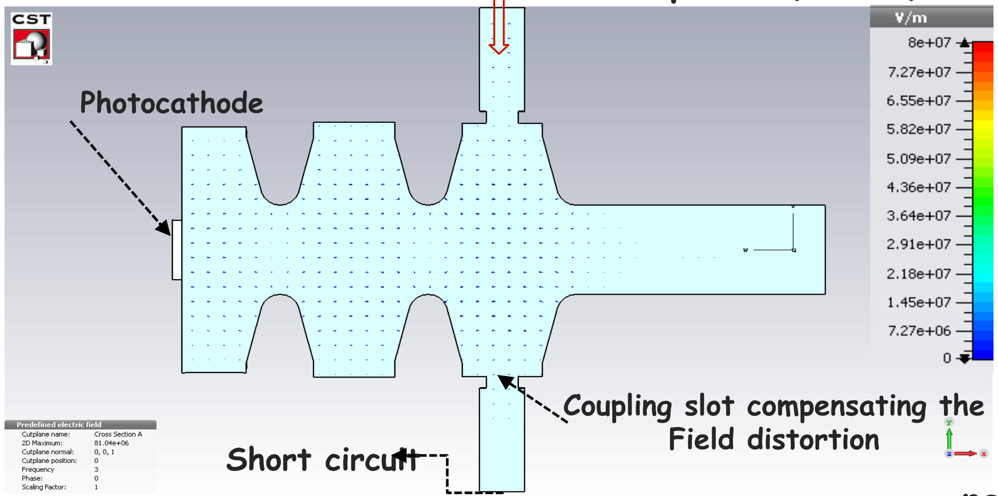
S-Band Gun

(**CNRS** + IASA+UAIAT-INFN+ALBA)

The RF gun "revisited"

Accelerating gradient (TM_{010} _ π mode): 80 MV/m at P_{in}=5 MW

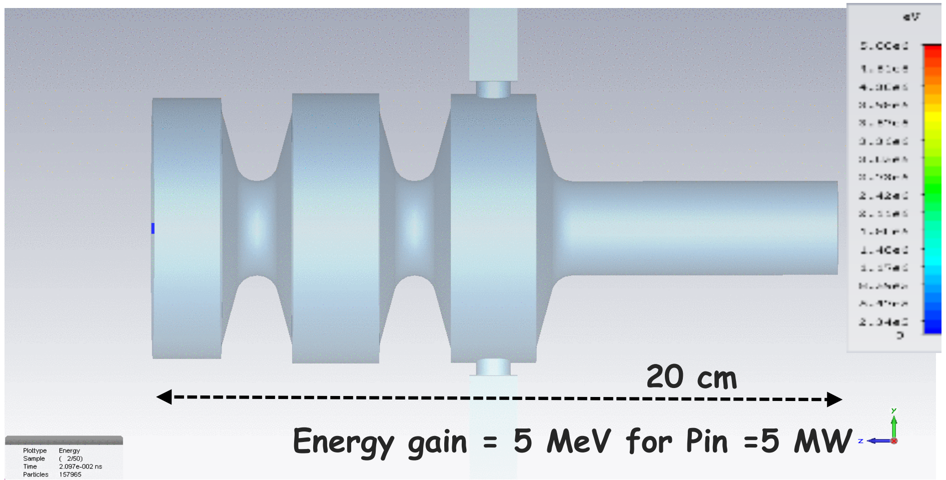
RF power (5 MW)



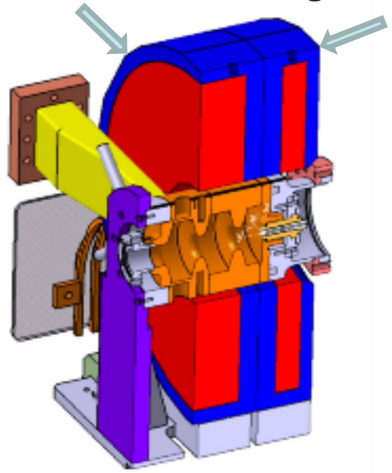
Photoinjector specification

Operation frequency	2998,55 MHz (30°C, in vacuum)
Charge	1 nC
Laser wavelength, pulse energy	266 nm, 100 µJ
RF Gun Q and Rs	14400, 49 MΩ/m
RF Gun accelerating gradient	80 MV/m @ 5 MW
Normalized emittance (rms)	4.4 π mm mrad
Energy spread	0.4 %
Bunch length (rms)	5 ps

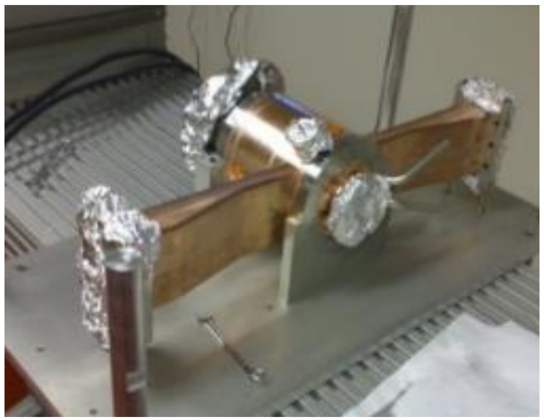
CST-Particle in cells, simulation results



new coil configurations

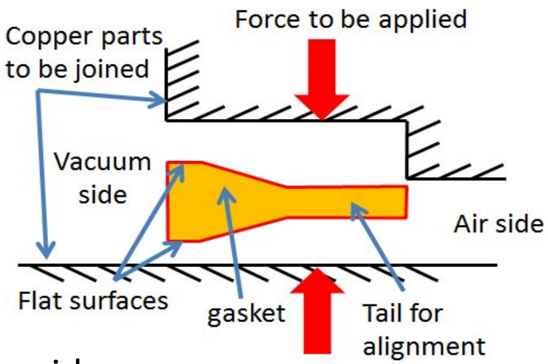


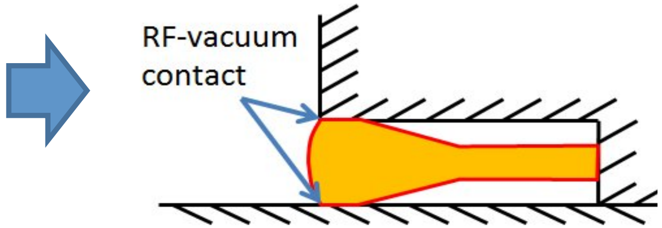
2.5 cells RF gun designed and produced at LAL for ThomX and PRAE



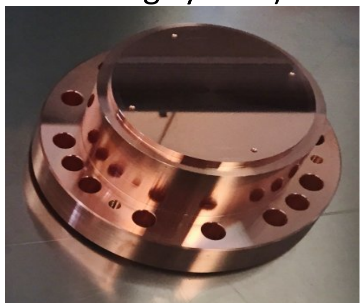
NEW FABRICATION TECHNIQUE W/O BRAZING

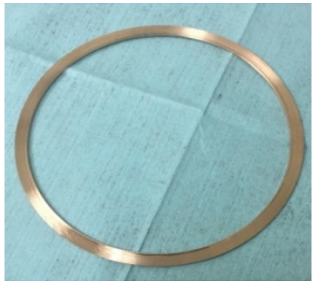
The ELI-NP gun and the first prototype of the new SPARC_LAB gun (now in operation at UCLA) have been fabricated w/o brazing using a novel process recently developed at LNF-INFN involving the use of **special RF-vacuum gaskets** (same Cu material of gun) that guarantee (simultaneously) the vacuum seal and a perfect RF contact when the structure is clamped.

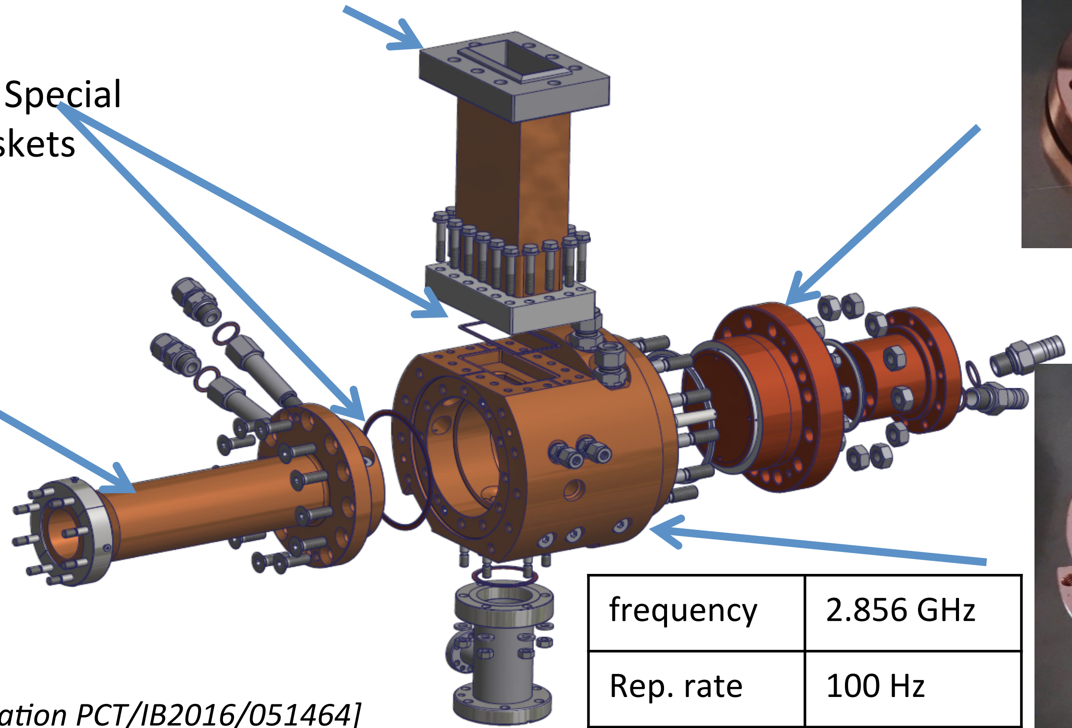




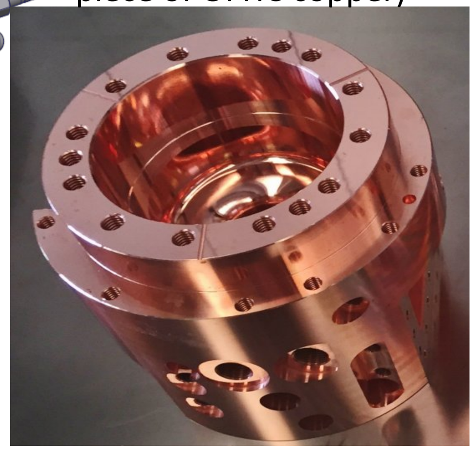
Cathode (with integrated cooling system)

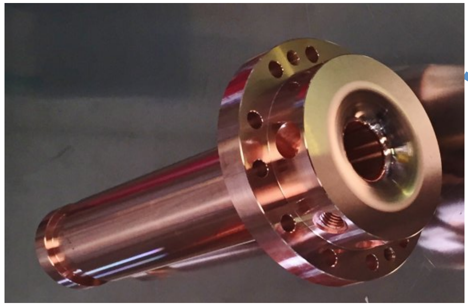






Body of the gun (single piece of OFHC copper)





Closing cup and pipe

[D. Alesini et al., Int'l patent application PCT/IB2016/051464]

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

frequency	2.856 GHz
Rep. rate	100 Hz
Cath. field	120 MV/m

C-Band Gun

(**INFN** +IASA+Sapienza)

	Charge	Wavelength
Q		$\propto \lambda$
$\sigma_x, \sigma_y, \sigma_z$	$\propto Q^{1/3}$	$\propto \lambda$
E_o		$\propto \lambda^{-1}$
B		$\propto \lambda^{-1}$
ε_{sc}	$\propto Q^{2/3}$	$\propto \lambda$
ε_{th}	$\propto Q^{1/3}$	$\propto \lambda$
ε_{rf}	$\propto Q^{4/3}$	$\propto \lambda$

ORGANIZATION OF THE ACTIVITY ON C-BAND INJECTOR

1) **C-Band gun design** to reach the 240 MV/m peak field level

1a) Optimum **2D profile** to minimize mod. Poy. Vector, peak field etc... and to increase the gun mode separation for short RF pulses (*F. Cardelli, D. Alesini, G. Castorina*)

1b) **Powering schemes** with RF pulse compressors and optimum coupling coefficient (*D. Alesini, F. Cardelli*)

1c) **Coupler design** options:

magnetic (*F. Cardelli, D. Alesini*)
mode launcher (*G. Castorina, B. Spataro*)
alternative schemes (*F. Cardelli, D. Alesini*)

2) **C-Band TW accelerating structures** design for the velocity bunching and acceleration: optimum irises tapering, structure length,... *(M. Diomede, D. Alesini)*

3) **Beam dynamics simulations** of the injector to reach the XLS requirements: gun gradient, TW structures accelerating field, solenoids strength, half cell length optimization...*(M. Croia, M. Ferrario,...)*

4) **Solenoids** design *(C. Kourkoutis, N. Gazis)*

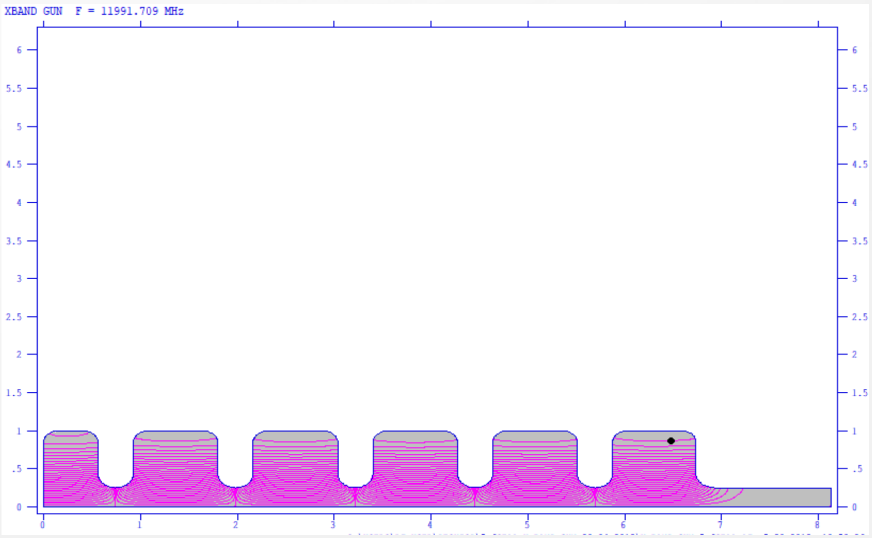
5) **Mechanical drawings** of the injector module *(N. Gazis)*

X-Band Gun

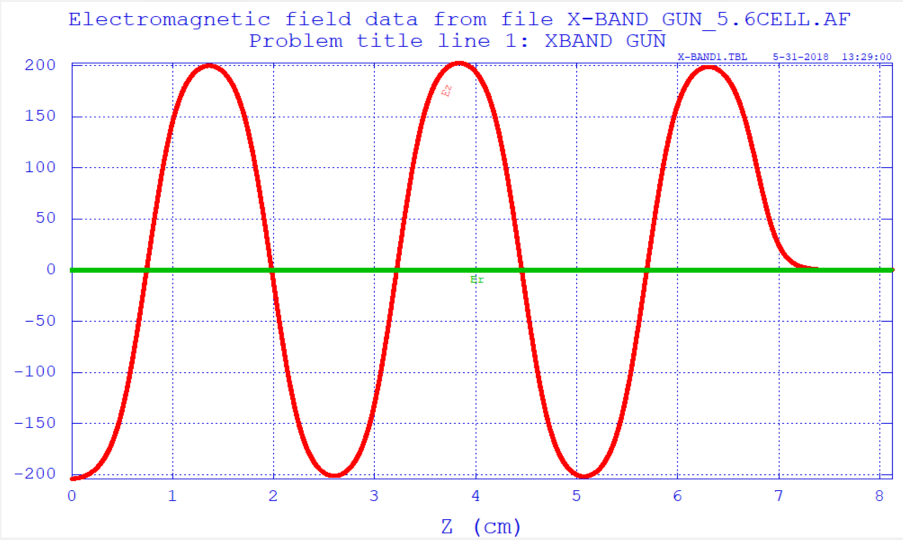
(**CSIC-IFIC** + UAIAT+ Sapienza)

Summary

➤ Work in progress in collaboration with Prof. Avni Aksoy from the University of Ankara, who has provided us the SUPERFISH files for an X-band 5.6 Cell RF gun



Scheme of the 5.6 RF gun



Electric field along the axis of the RF gun

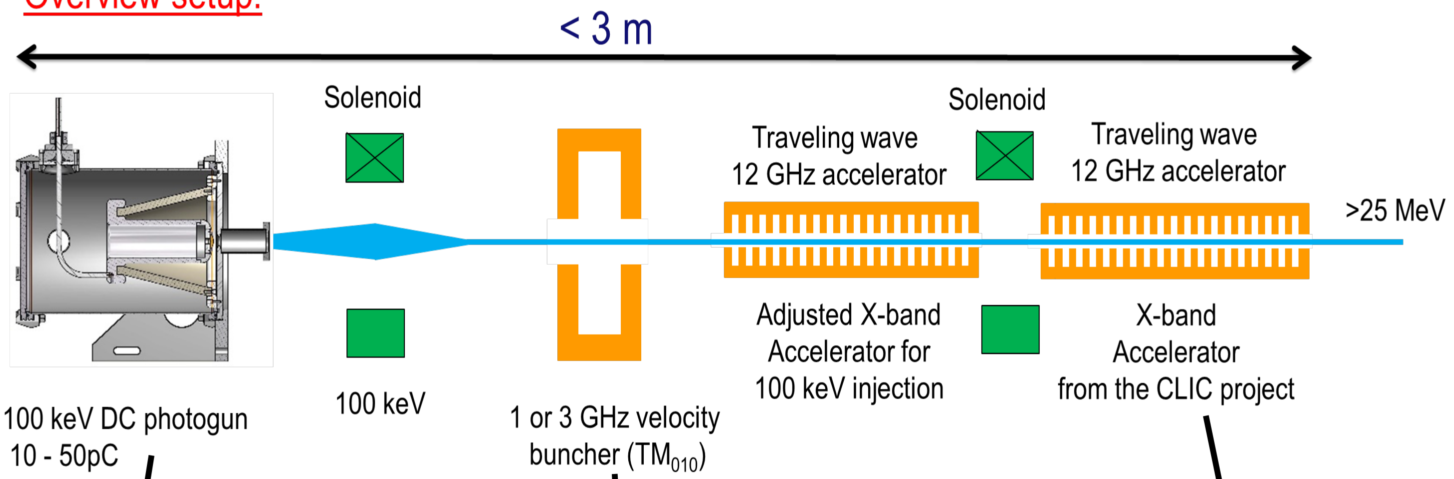
➤ We are studying this design in order to get a better understanding of realistic photinjector structures and how to analyse them using SUPERFISH.

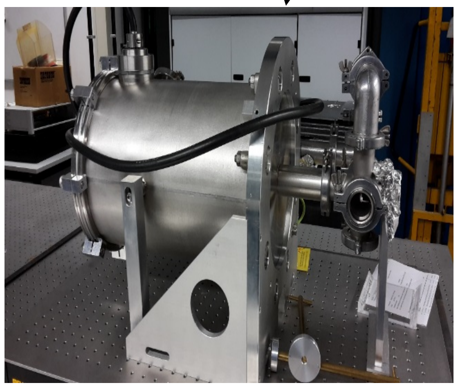
DC- Gun

(TU/e)

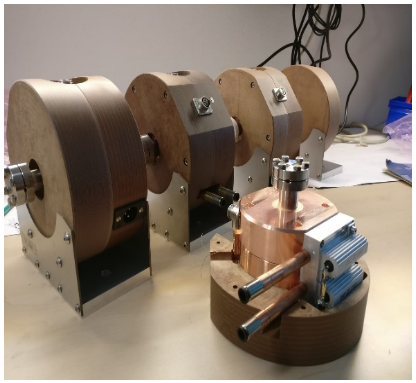
Already developed and available material

Overview setup:

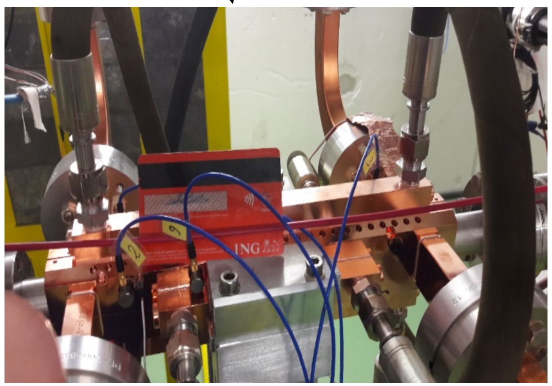




Made by ACCTEC



Made by ACCTEC



CLIC accelerator

Technische Universiteit Eindhoven University of Technology

Laser/Photocathode

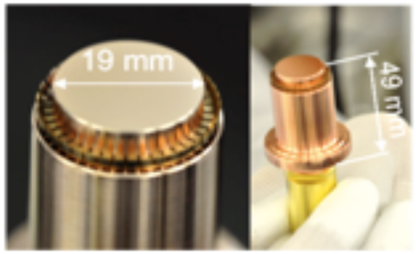
(**IASA**+CNRS+INFN)

Current photocathode materials

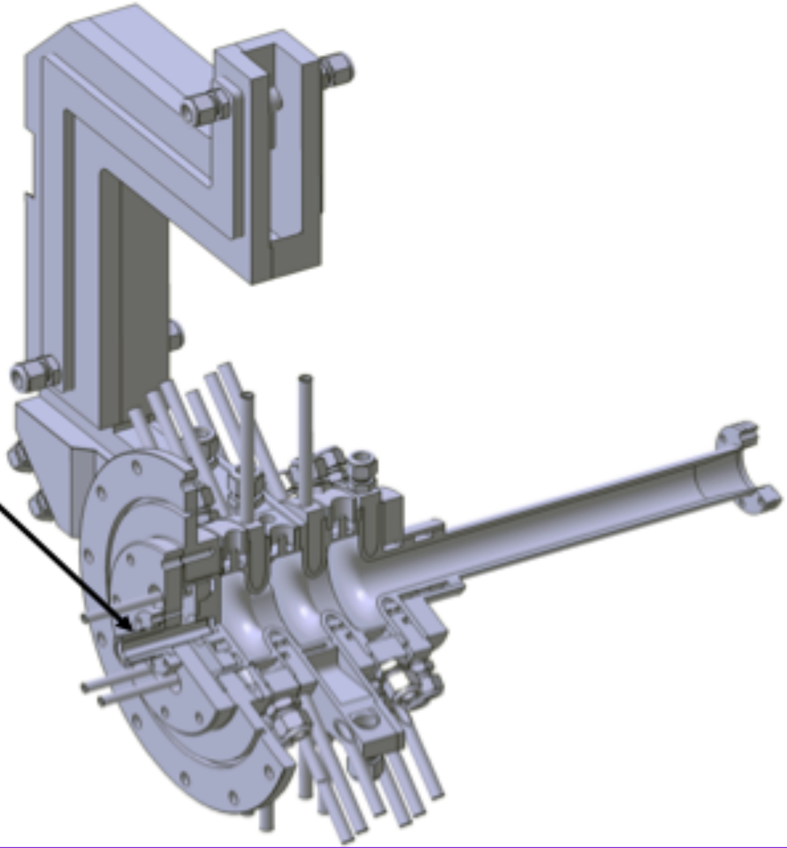
Class	Material	QE	Response time	Intrinsic Energy	Wave Length	Gun	Application
Normally conducting metals	Cu, Mg	10^{-5}-10^{-4}	10's fs	100's mV – 1's V	UV	NC-RF, VHF	Low rep rate FELs
Super conducting metals	Nb, Pb	10^{-5}-10^{-4}	10's fs	100's mV – 1's V	UV	SC-RF	High rep rate FELs
Positive e^- affinity Te-based	Cs_2Te	0.1-0.2	ps's	100's mV	UV	NC-RF, SC-RF VHF DC	High rep rate FELs
Positive e^- affinity Sb-based	Cs_3Sb etc	0.1-0.2	ps's	100's mV	Visible	DC VHF, SCRF(?) NCRF(???)	ERLs, High rep rate FELs
Negative e^- affinity semiconductor	GaAs, etc	0.1-0.35	1's ps – 100's ps	10's mV – 100's mV	IR- Visible	DC (XHV)	Polarized sources, ERLs

SWISS FEL RF Photoinjector

SwissFEL RF Photoinjector:
S band, 2.5 Cell; 7 MeV; 100 MV/m; 100 Hz; 10 - 200 pC



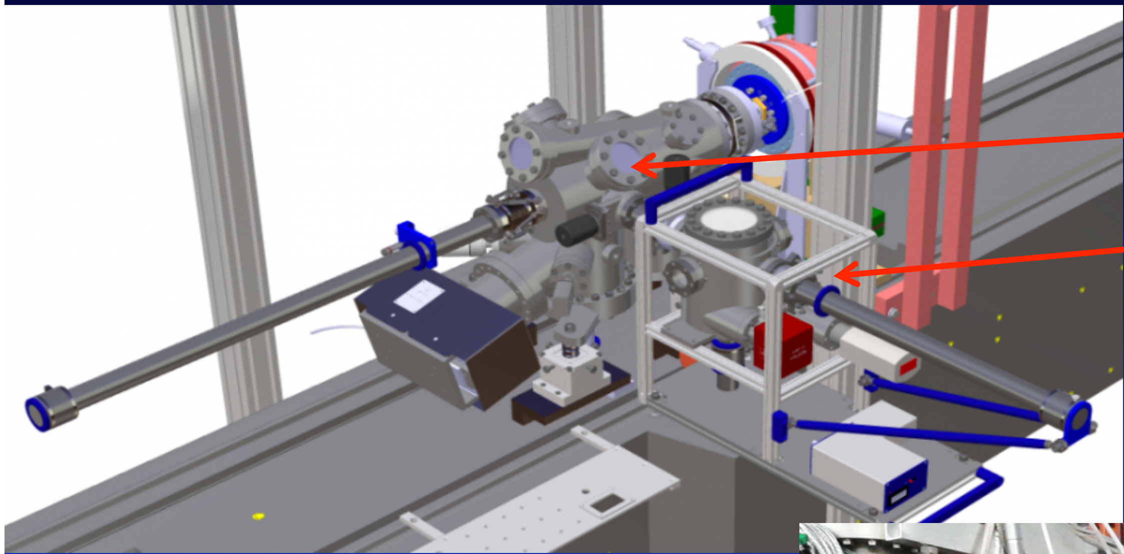
Exchangeable cathode plug (*)



(*) CERN design: CLIC Note 303 (1996)

SWISS FEL RF Photoinjector

Load Lock Chamber behind RF Gun

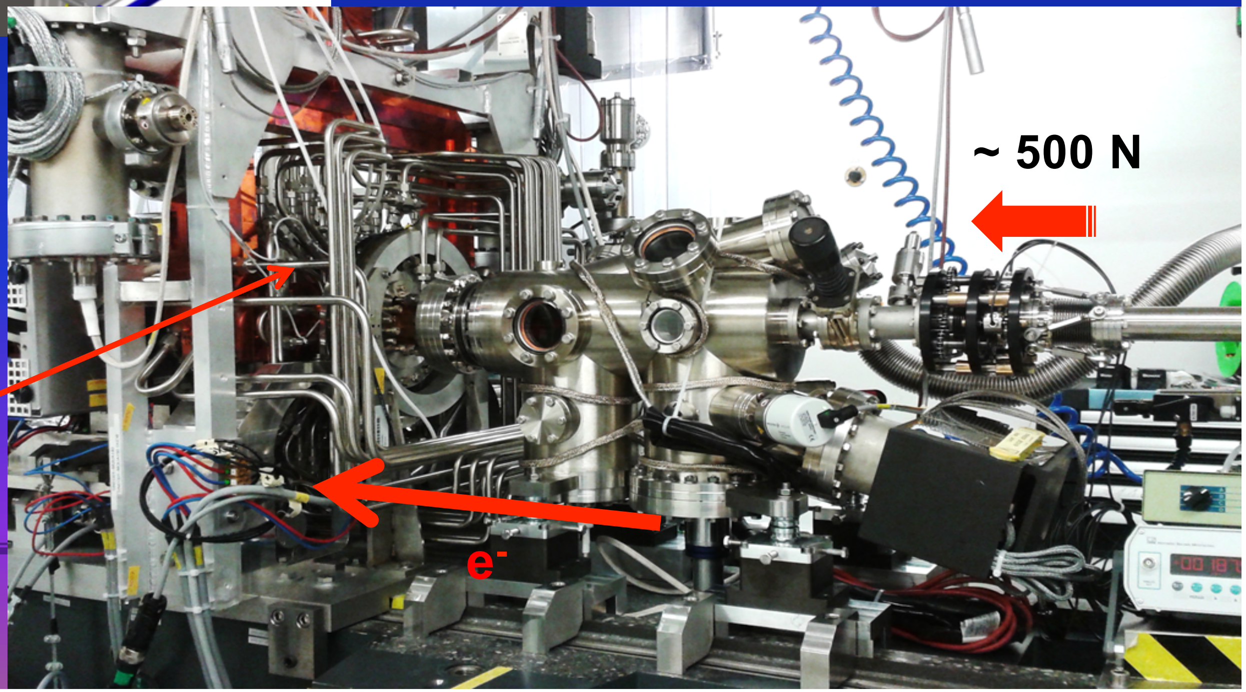


Load lock chamber

Vacuum suitcase

Cathode is pushed against RF gun with ~500 N mechanical force

RF Photoinjector:
2.5 Cell; 7 MeV;
100 MV/m peak field

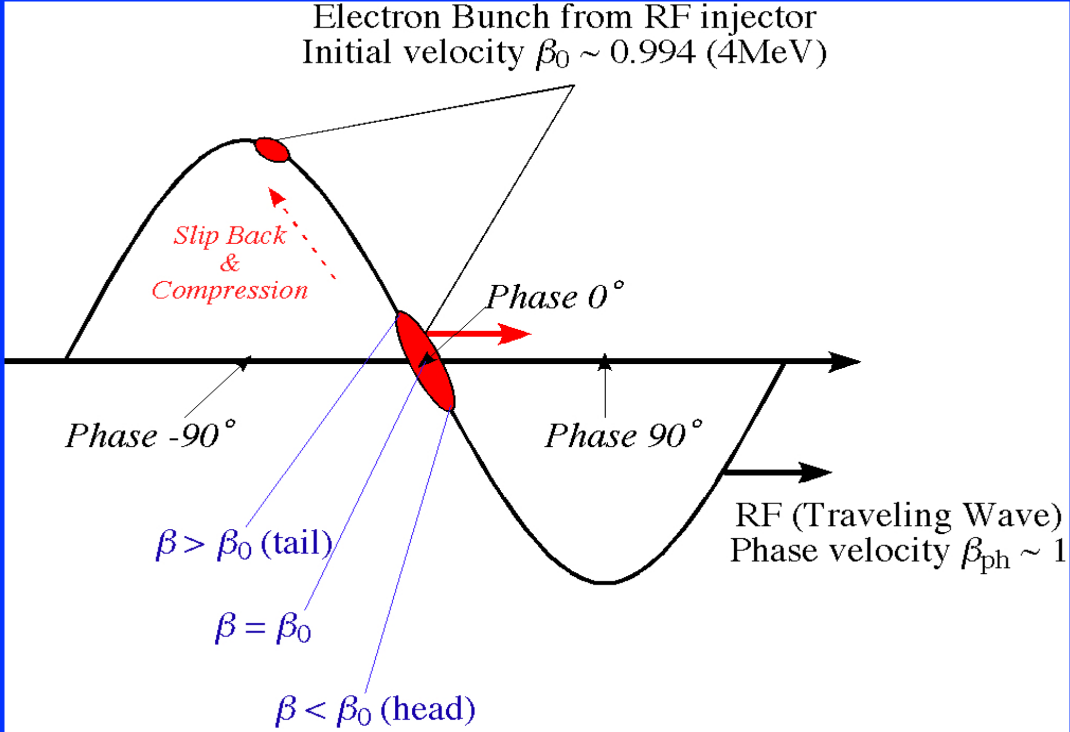


Bunch Compressor Design

- **Task 3.2 - Compressor Design (Velocity Bunching, Magnetic Chicane)) => D3.2 M18 => D3.3 M36**
  a) S-Band Velocity Bunching (**TU/e** + IASA+ALBA)
  b) C-Band Velocity Bunching (**INFN** +IASA+TU/e)
  c) X-Band Velocity Bunching (**Sapienza**+CERN+IASA+INFN)
  d) Magnetic Compressor (**ST** + CERN+INFN+CNRS)

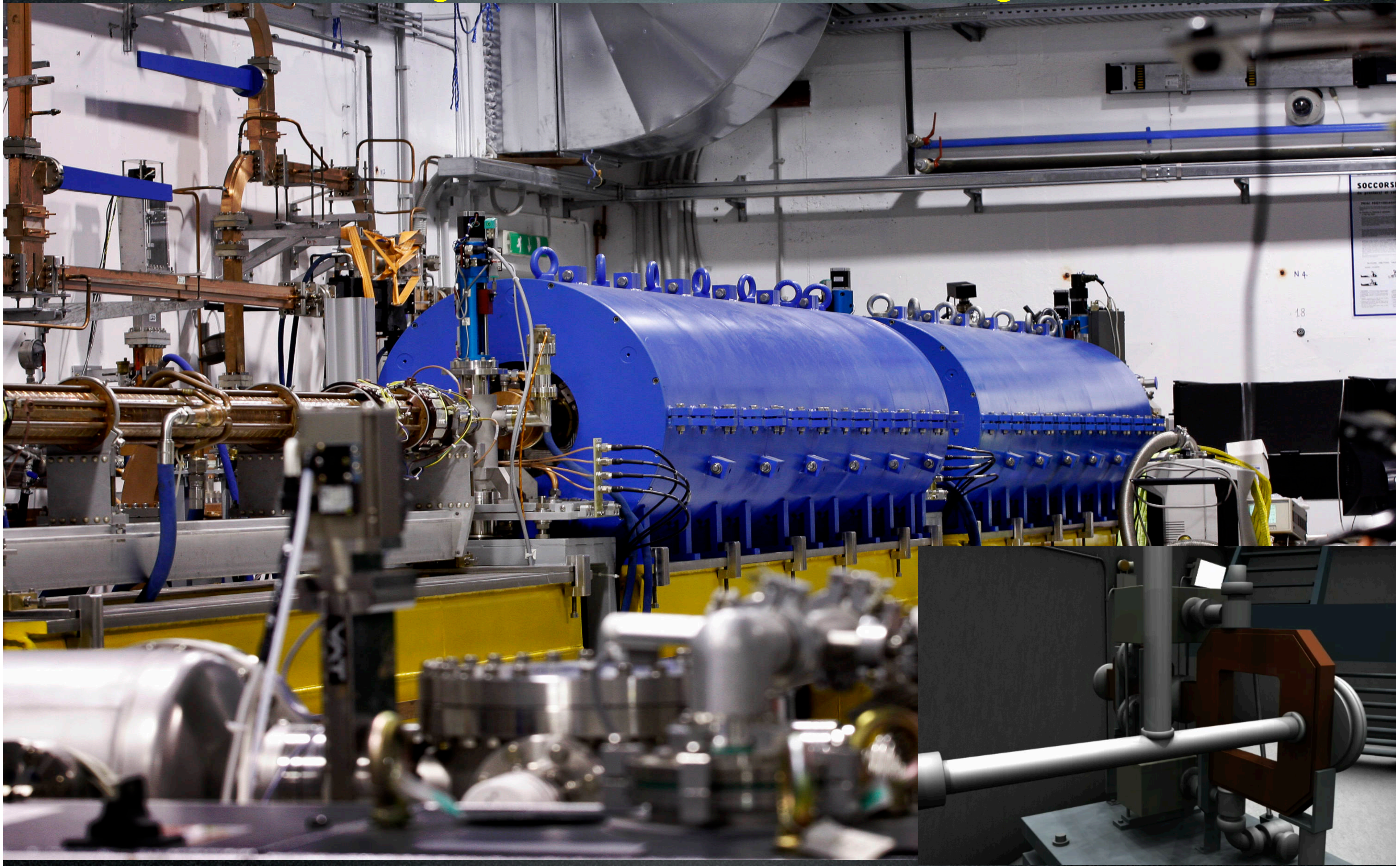
Velocity bunching concept (RF Compressor)

If the beam injected in a long accelerating structure at the crossing field phase and it is slightly slower than the phase velocity of the RF wave , it will slip back to phases where the field is accelerating, but at the same time it will be chirped and compressed.

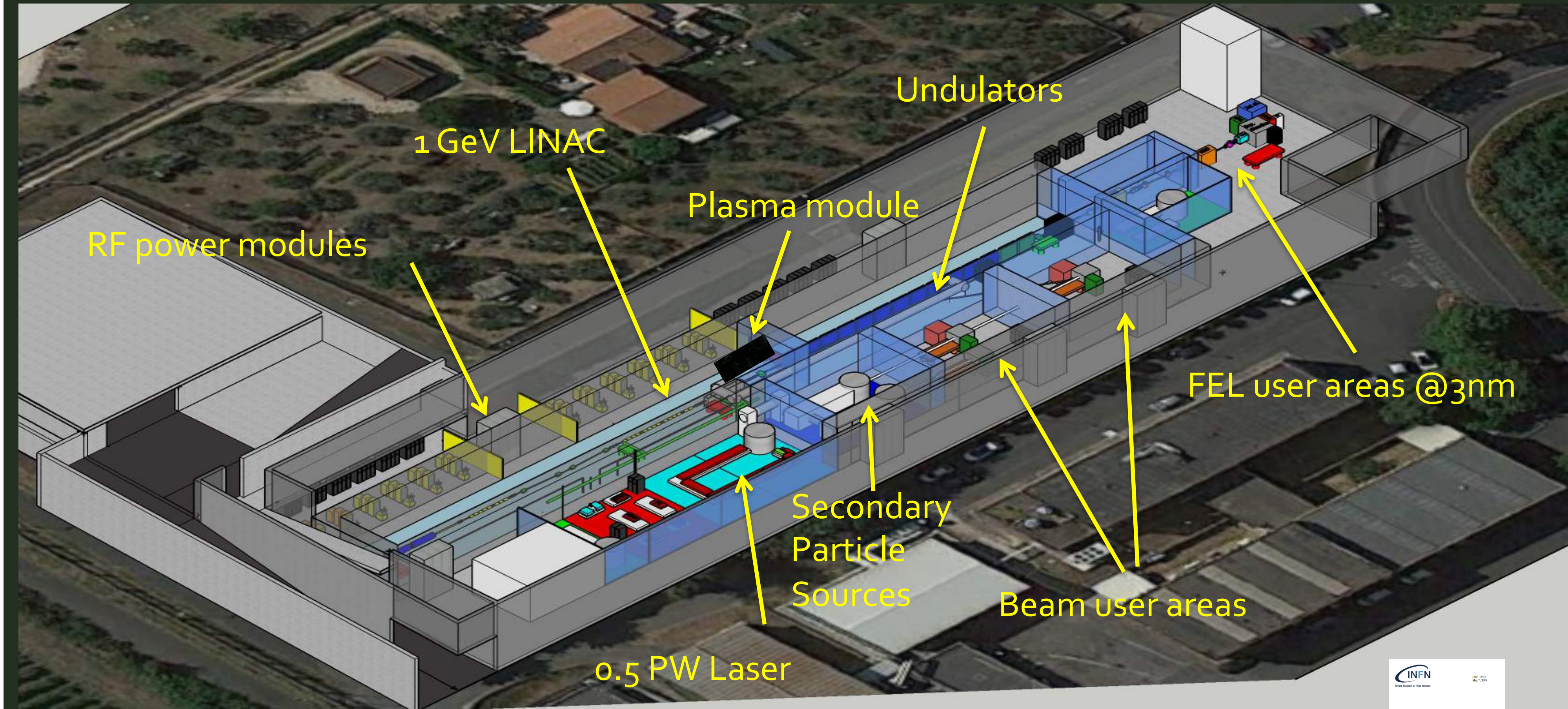


The key point is that compression and acceleration take place at the same time within the same linac section, actually the first section following the gun, that typically accelerates the beam, under these conditions, from a few MeV (> 4) up to 25-35 MeV.

HB photo- injector with Velocity Bunching



EuPRAXIA@SPARC_LAB



http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

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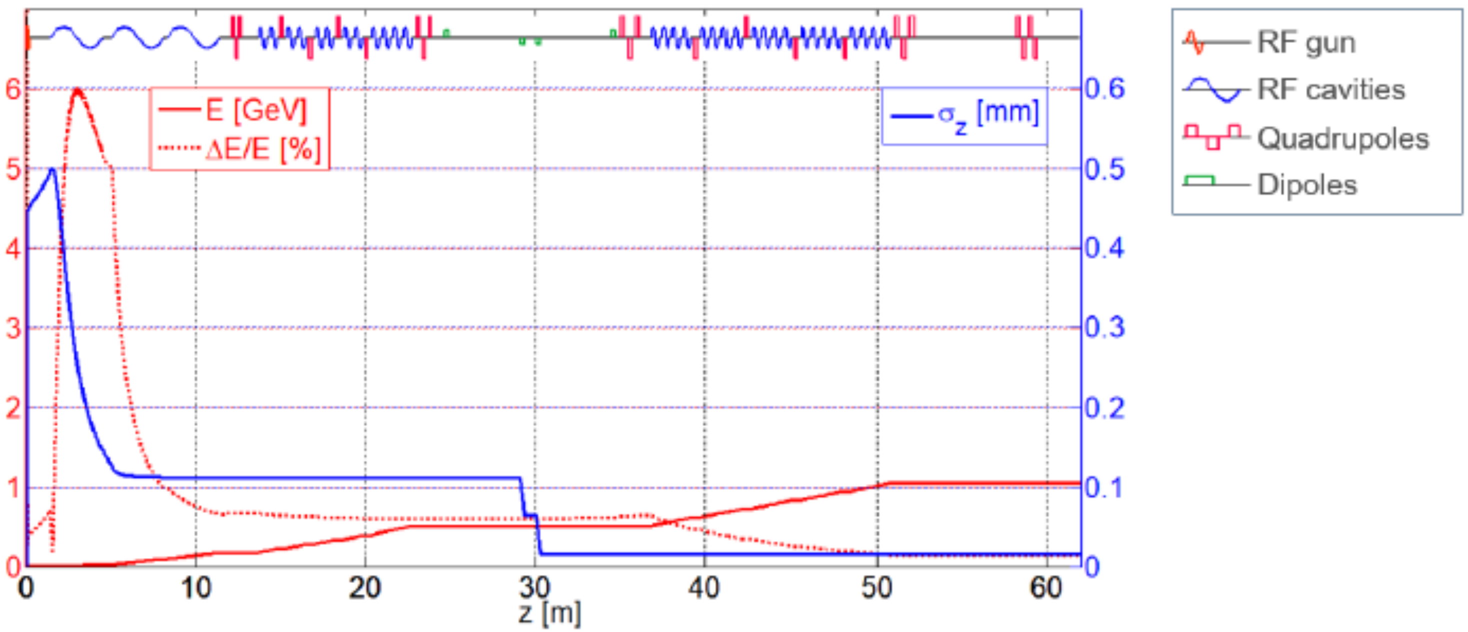
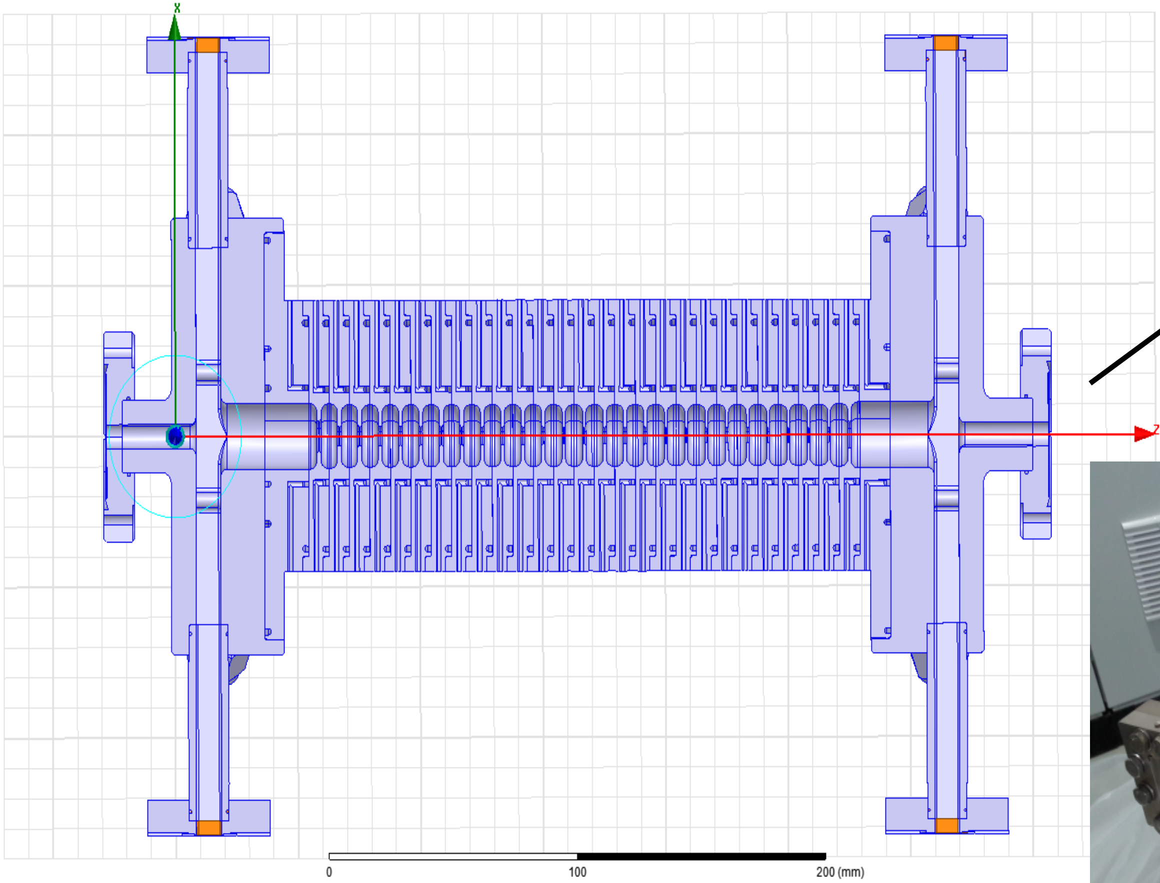
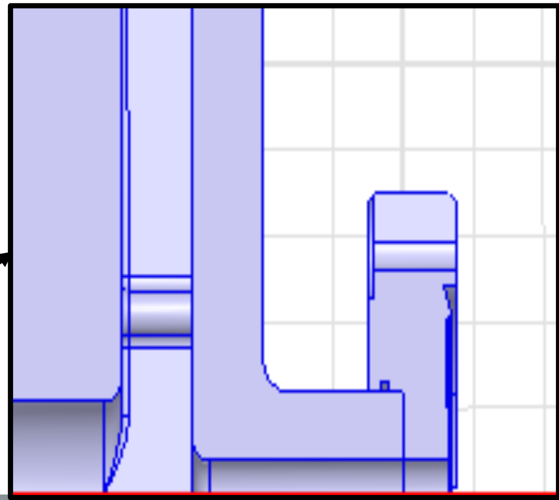


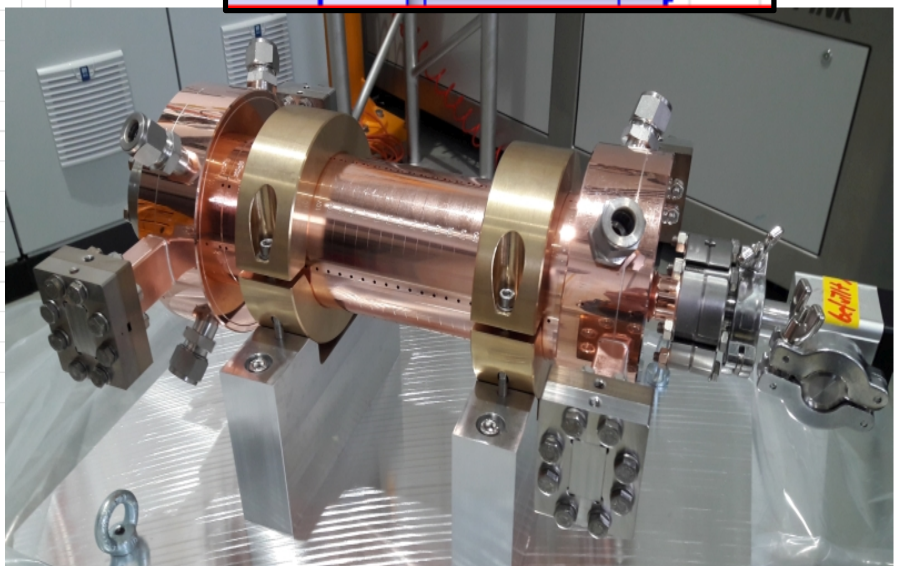
Figure 4.1: Start to end simulation results for the 200 pC bunch for the X-band case: evolution along the injector of the energy (E red line) and energy spread ($\Delta E/E$ red dotted-line) and longitudinal bunch length (σ_z blue line).

Courtesy A. Giribono, C. Vaccarezza

Starting point for X-band Velocity bunching T24_PSI X-band accelerating structure







Elettra Sincrotrone Trieste

Magnetic Compressor Report Contents

Number of pages: in the range 10 – 50 (single column)

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1 Theoretical Background

- 1.1 Motivation of bunch length compressors for x-ray FELs **(SDM)**
- 1.2 Theory of magnetic compression and phase space linearization
  - 1.2.1 Linearization with active RF **(SDM)**
  - 1.2.2 Linearization with passive devices **(AFG)**
  - 1.2.3 Linearization with magnetic multipoles **(SDM)**
- 1.3 Magnetic Compressor Geometries **(SDM)**

Essential theoretical background, state-of-the-art linearized magnetic compression schemes and R&Ds.

2 Beam Quality Preservation and Degradation

- 2.1 Static and dynamic magnetic imperfections **(AL)**
- 2.2 CSR modeling and shielding **(AL)**
  - 2.2.1 Theory of CSR instability (transverse and longitudinal) **(CV)**
  - 2.2.2 Options for minimization of CSR effects **(CV)**

Single-particle dynamics and collective effects

- 2.3 Microbunching instability
  - 2.3.1 Theory of MBI instability **(SDM)**
  - 2.3.2 Options for minimization of MBI **(SDM)**

Microbunching instability and suppression schemes

3 State-of-the-Art and Beyond

- 3.1 Comparison table of magnetic compression schemes at existing FELs **(AFG)**
- 3.2 Outlook of compressor options for CompactLight **(AFG)**

Overview & Comparison tables. Indications for CL.

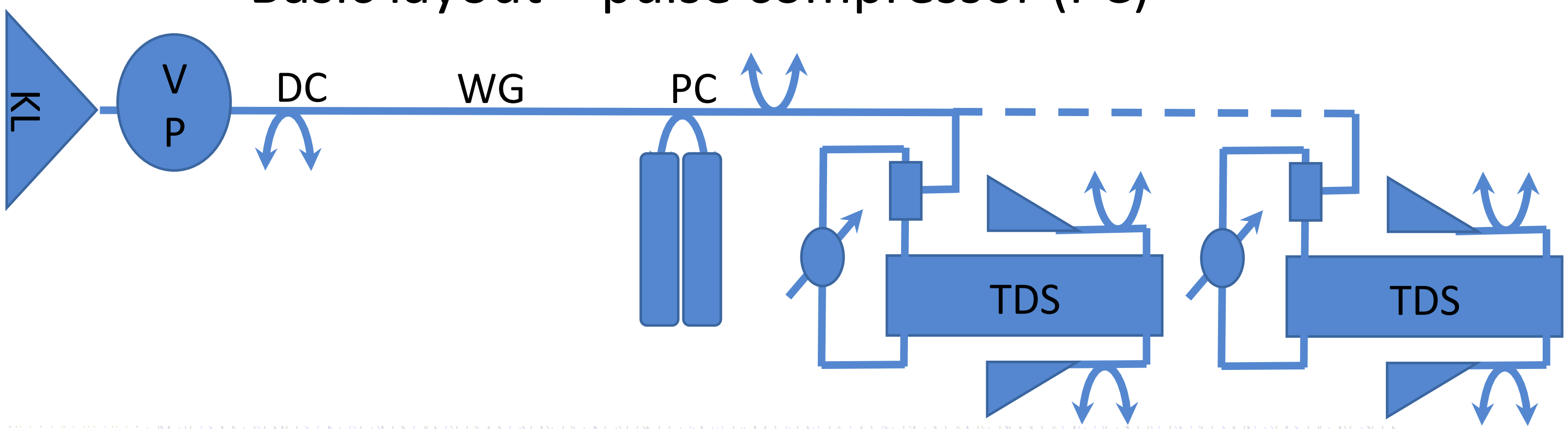
Beam Diagnostics and Manipulation

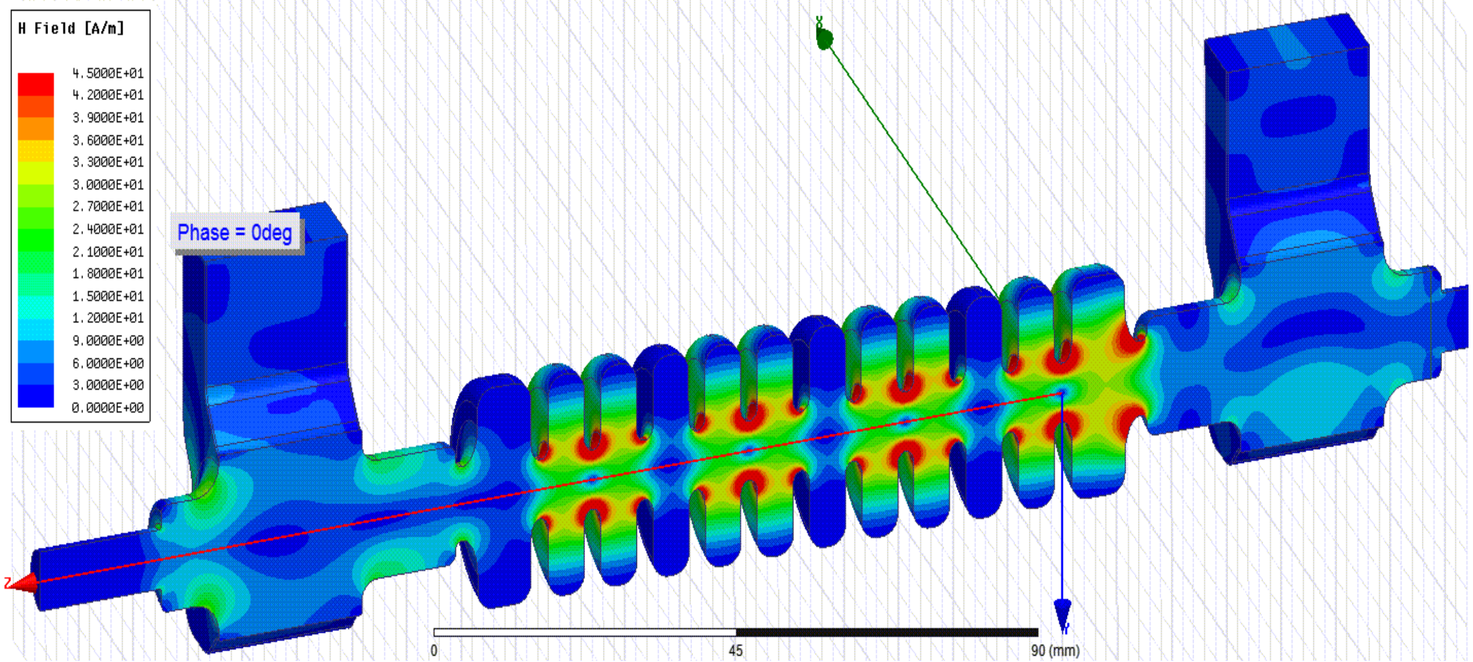
- **Task 3.3 – X-Band Transverse RF Deflector** (**Sapienza**+ IASA+) **=> D3.3 M36**

- **Task 3.4 - : RF Linearizer Design => D3.2 M18 => D3.3 M36**
  a) X-Band RF Linearizer Design (**Sapienza**)
  b) K-Band RF Linearizer Design (**ULANC** +Sapienza)
  c) Passive linearizer (**CNRS**)

X-band TDS with variable polarization @ CERN

Basic layout + pulse compressor (PC)





Cell Parameters	
$a[mm]$	4
$\Delta\phi_0[degree]$	120
Q	6490
$v_g/c[\%]$	-2.666
$R_x[M\Omega/m]$	50
TDS Parameters	
Number of regular cells	96
Active length [m]	0.8
Filling time [ns]	104.5
Transverse Shunt Impedance $[M\Omega]$	27.3
V_d *TDS at* $P_k = 6MW$ [MV]	12.8
V_d *TDS + PC at* $P_k = 6MW$ [MV]	29.5

Alexej Grudiev, CERN

RF – linearizer

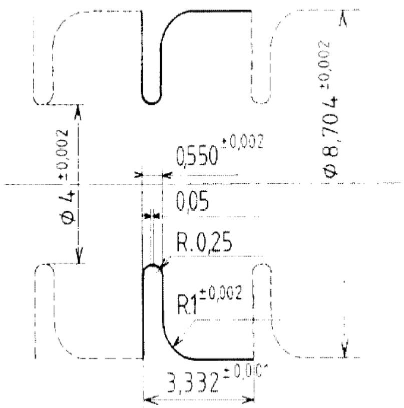
(**ULANC** +Sapienza)

CLIC 30 GHz structure scaled to 36 GHz

- Shunt impedance ~170 Mohm/m, aperture scaled for 36 GHz is 3.3 mm.
- Group velocity is very high at 7.4% c so the gradient is much lower than one would expect from the shunt impedance unless the structure is very long.
- 3.6mm aperture 130 Mohm/m and vg is even higher
- 4mm aperture 104 Mohm/m and vg is even higher still
- 5mm is 85 Mohm/m and vg is higher even than that.

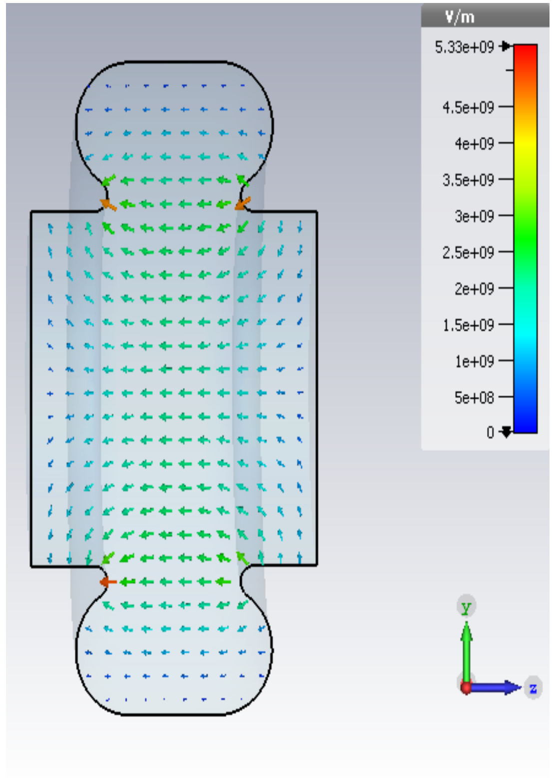
Table 1: Main structure and linac parameters

Shunt impedance	109 MΩ/m
Quality factor	4112
R′/Q	26.5 kΩ/m
Group velocity (v_g/c)	7.4%
Field attenuation	0.25 Nepers/section
Gradient	80 MV/m
Section length	25.8 cm
Fill time and pulse length	11.3 ns
Cells per section	72
Sections per linac	50′000
Ratio output/input power	0.61
Total peak input power	1.875 TW/linac 150 MW/m
Repetition rate	1.69 kHz
Total average input power	35.75 MW/linac 2.86 kW/m
Average dissipated power	1.125 kW/m



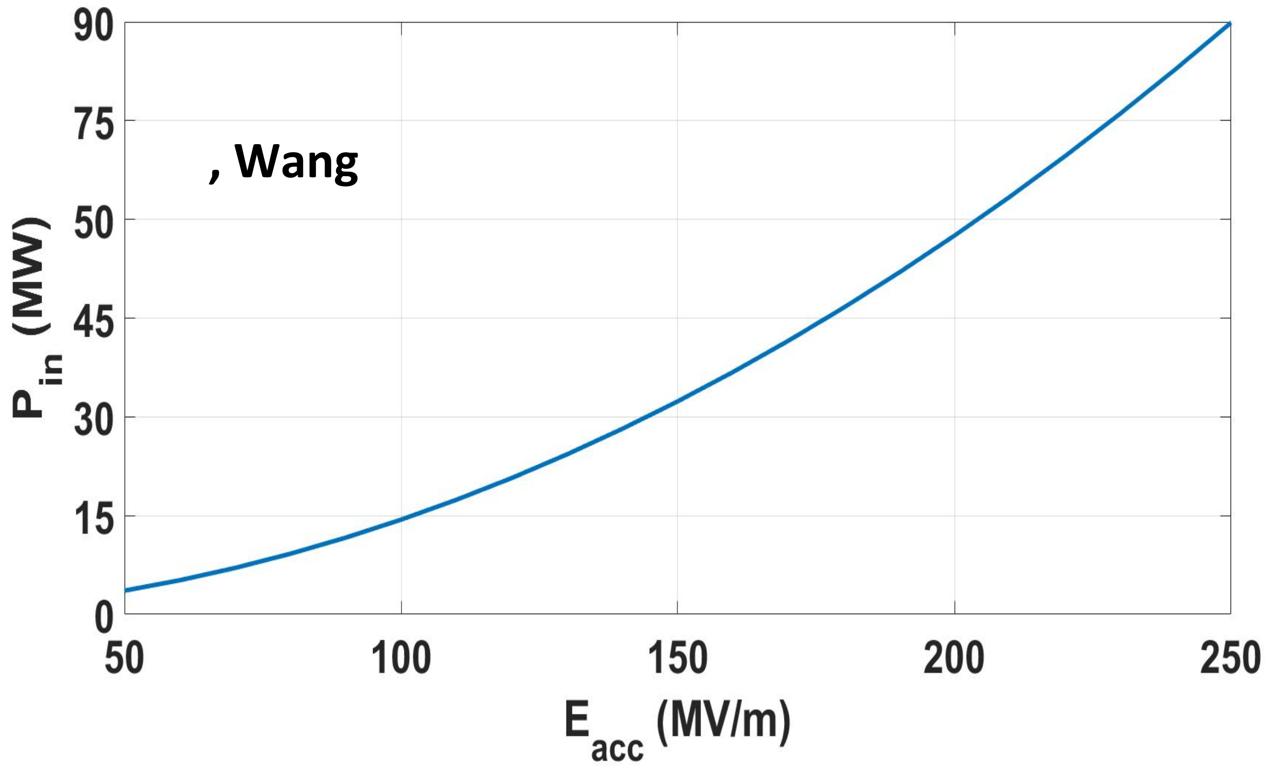
36 GHz Re-entrant travelling wave

- Shunt impedance 415 kOhm, cell length=3.6 mm hence shunt impedance per unit length is ~114 Mohm/m (note using a thicker wall than CLIC hence the drop).
- A 2 MW supply will give 15.5 MV kick in a 1 metre structure.
- Aperture is 3.6 mm
- Shunt impedance is around the same but group velocity can be lowered to 1% the speed of light without reducing aperture or reducing shunt impedance



Input RF power for different gradients

Assuming a structure length L = 21 cm ,T_f = 20 ns (filling time) and τ = 0.65 (attenuation)



Parameter	Value
Filling Time, Tf	20 ns
L, length	21 cm
w, frequency	2pi*35.982 GHz
R/Q	57.7 kΩ/m
τ	0.65

For a CG structure: **input group velocity v_{gr_in}/c =6.2%, output group velocity v_{gr_out}/c=1.7%,**
For a CI structure : **v_{gr} = 0.035 c**

Luigi Faillace checked these estimations by using a different approach (normalized electric field m

Institute of Accelerating Systems and Applications

EUROPEAN SPALLATION SOURCE

XLS – WP3 – Gun & Injector

Mechanical Engineering Design

Trieste 19-20 June 2018

Dr. Eng. Nick Gazis
European Spallation Source ERIC – EIS/D&E/MET section leader,
on behalf of the mechanical engineering design team

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** Photo courtesy from mass spectrometer*

XLS | CompactLight Midterm Review

Triest, 19th-20th June 2018

[state: 17/05/2018]

Tuesday, 19th June 2018	
Time	Session
09:00	Welcome
09:10	Project status
09:30	WP2 and task leaders reports
10:00	WP3 and task leaders reports
10:45	Coffee Break
11:00	WP4 and task leaders reports
11:45	WP5 and task leaders reports
12:30	WP6 and task leaders reports
13:15	Lunch
14:30	WP2-WP5 joint meeting
16:30	Coffee break
16:45	WP3-WP4-WP6 joint meeting
18:30	End first day
20:00	Dinner

1. C Band Gun- David
2. DC Gun - Jom

Preliminary Workshop announcement:
"High Brightness Beam Physics"
7-11 April 2019
Crete – Greece

Thanks for your attention

Compact