

BriXSinO: an ERL proposed facility at INFN Milan LASA Laboratory

D. Giove on behalf of the BriXSinO working group
INFN Milano - LASA

Outline

- INFN
- INFN – LASA
- A glimpse to BrisXSino
- HB²TF
 - Beam physics
 - Photocathodes
 - DC gun
 - Buncher
 - Experiments

INFN in a nutshell

- The **National Institute for Nuclear Physics (INFN)** is the Italian research agency for the **study of the fundamental constituents of matter and the laws that govern them**.
- It conducts theoretical and experimental research in **subnuclear, nuclear and astroparticle physics**.
- It was founded on **8th August 1951** to uphold and develop the scientific tradition established by **Enrico Fermi** and his school, with their theoretical and experimental research in nuclear physics.
- Today INFN is involved in all major projects related to its mission.



- Research activity is carried out mainly at two complementary facilities:
 - **19 Divisions (Sezioni)**
 - **4 National Laboratories.**
- **Each of the 19 Divisions is located at a university physics department** providing a direct connection between the Institute and the academic world.
- **The four Laboratories— Catania, Frascati, Legnaro, and Gran Sasso —** are home to major facilities, available to the national and international scientific community.
- The INFN workforce includes:
 - **about 2000 of its own employees,**
 - **almost 2000 university associated employees,**
 - **1300 young researchers,** including undergraduate and graduate students and research fellows.

What is LASA ?

The INFN laboratory **LASA** (short for Laboratorio Acceleratori e Superconduttività Applicata, i.e. **Laboratory for Accelerators and Applied Superconductivity**), in Segrate, at the outskirts of Milano, is an **internationally Excellence Particle Accelerator technology center** since nearly forty years.

The LASA develops **advanced technologies for superconductivity, cryogenics** and the productions of **high intensity DC and RF electromagnetic fields**.

As the name suggests, the **LASA** laboratory is dedicated to the **study and development of innovative acceleration schemes and applications of advanced superconductivity** both to accelerators and to other fields of physics.

The **activities carried out** since the early 90's in different sectors of accelerator physics and cryogenics applied to **both magnets and RF cavities**, have allowed the **establishment of unique skills**, which result in the possibility for **INFN to play an important rule in support of international projects** of particle physics.

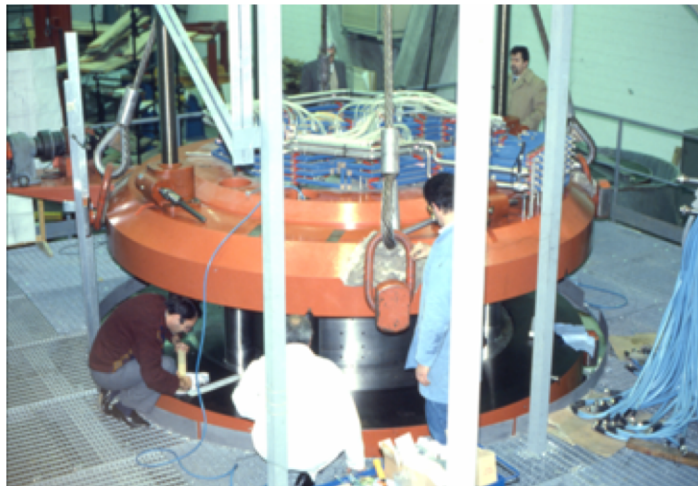
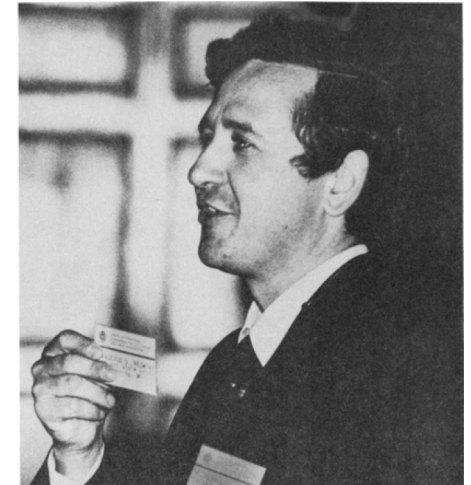


A brief history of LASA

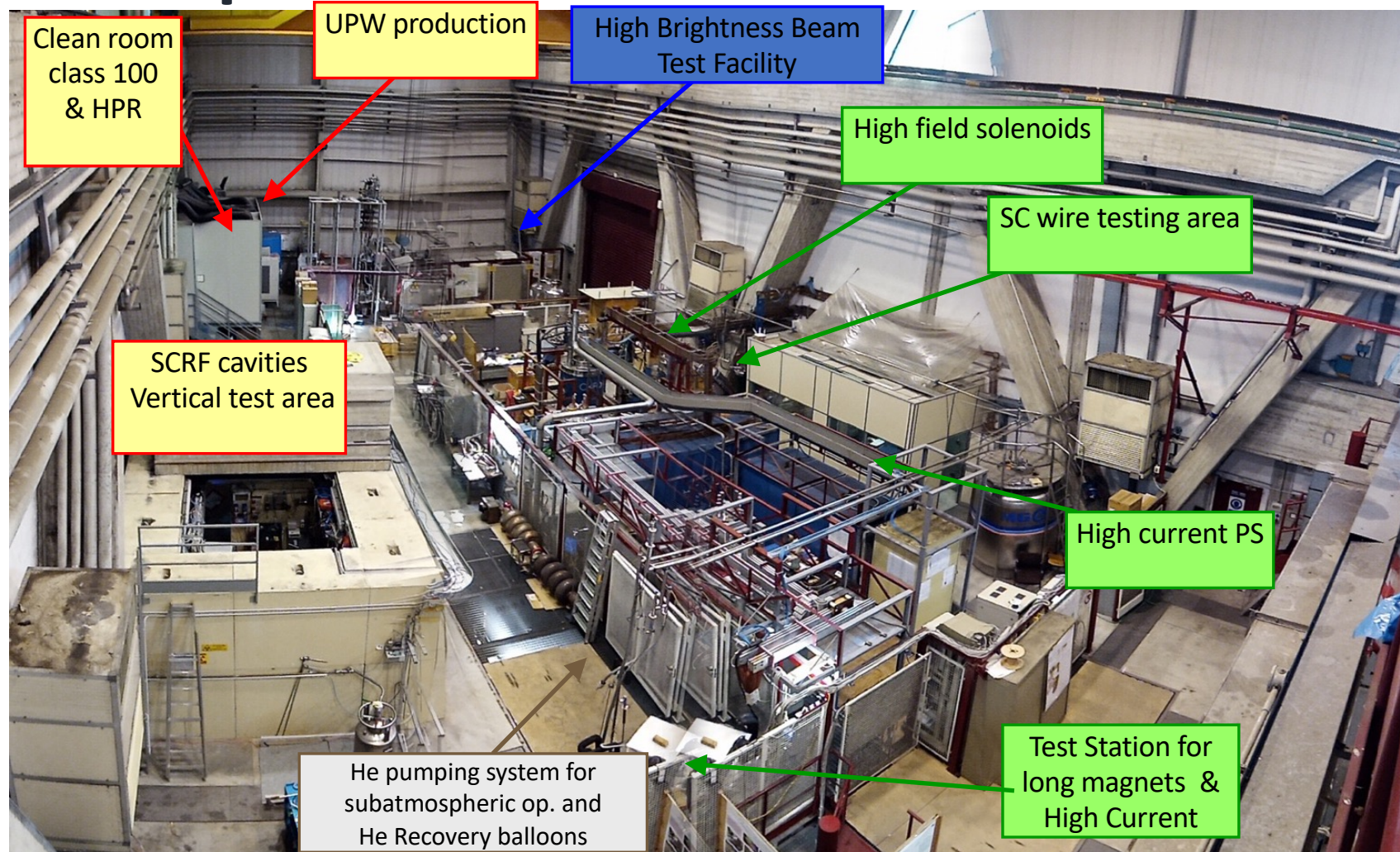
From an idea of **Prof. Francesco Resmini** (1938-1984), the third **superconducting cyclotron (CS)** ever realized worldwide (and **first in Europe**) was **designed, assembled and tested at LASA**.

The cyclotron has been in regular **operation at the INFN LNS in Catania** for nuclear physics experiments and medical applications **since 1994**.

Recently, it has been shutdown and, within the POTLNS project, will be **refurbished and upgraded**.



Main Experimental Hall

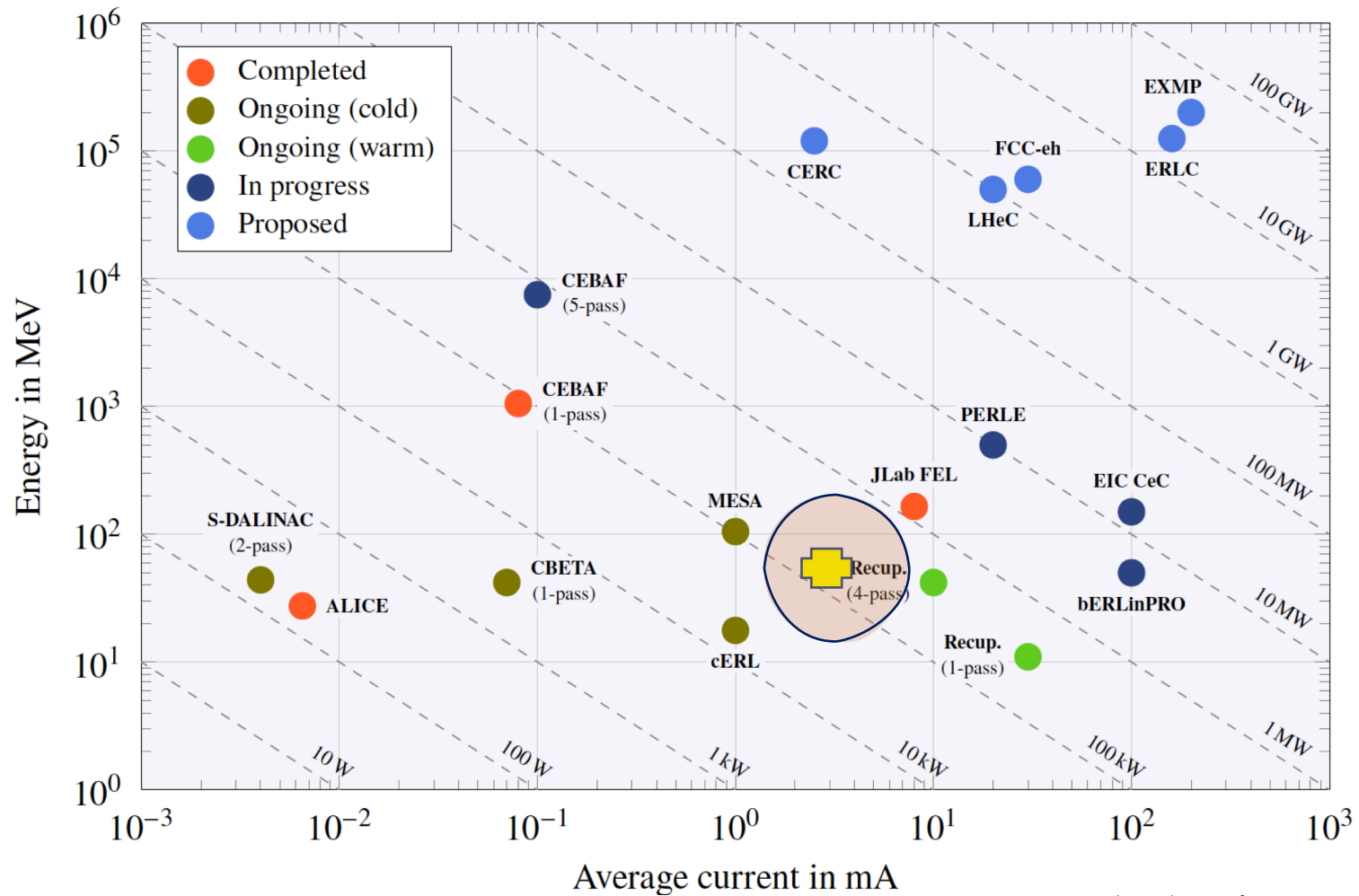




BriXSinO Project

Brilliant Source of **X**-Rays Based on **S**ustainable and **Inno**vative Accelerators

Overview of ERL Facilities



 Brixsino: 45 MeV@5 mA- 225 KW 50% efficiency

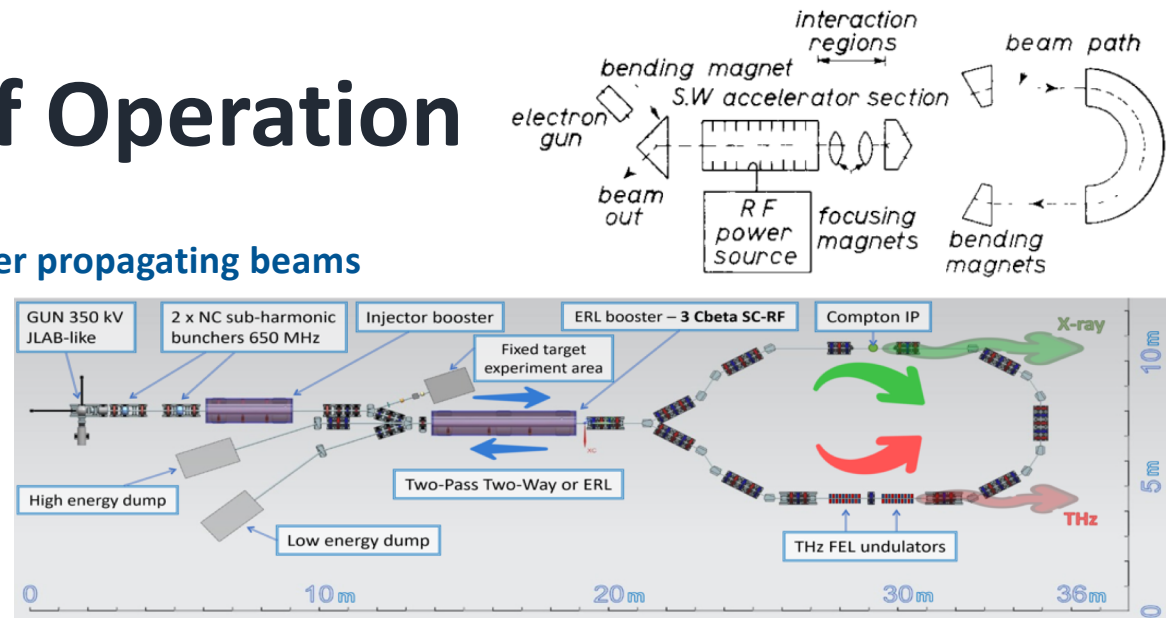
Technology

The Development of Energy-Recovery Linacs – C. Adolphsen et al.

Costs

BriXSinO Principle of Operation

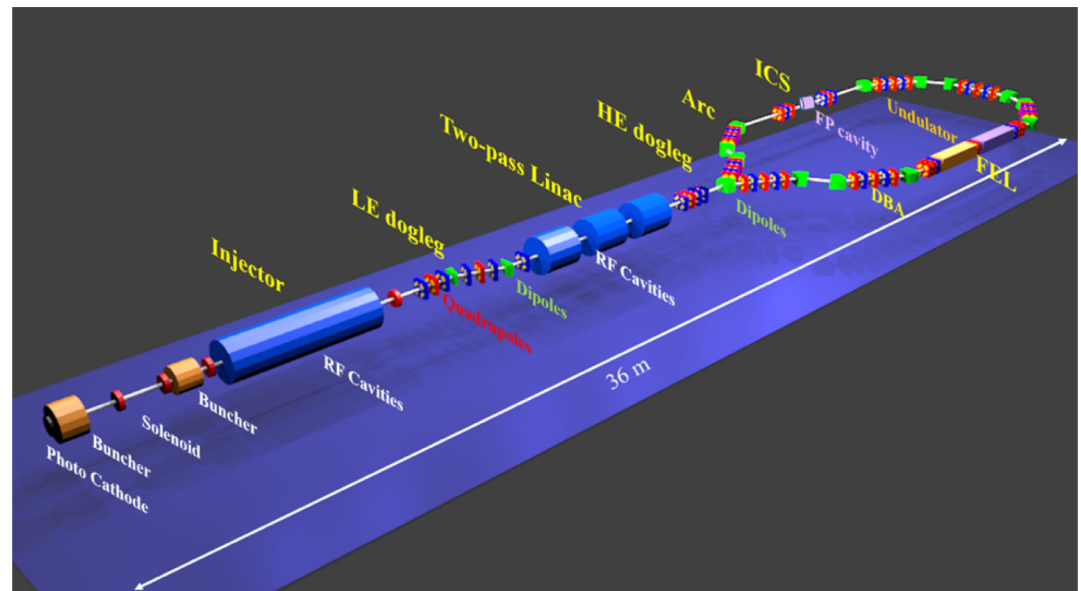
- A “**newly**” conceived scheme of ERL with **counter propagating beams** is proposed in BriXSinO.
- This **scheme allows** to explore not only the **ERL operation** but also the **two-pass operation** where the beam is reaccelerated when reinjected in the accelerating module at reduced current.
- A further operation mode for BriXSinO is the use of its **injector for fixed target experiments** performed with maximum electron energy of 10 MeV and 5 mA average current. This high intensity beam enables both **experiments of flash therapy** (total charge in a 200 ms time interval up to 1 mC), as well as converting the electron beam into **bremsstrahlung photons with energy peaked at 7 - 8 MeV at an impressive flux of 10^{16} photons/s** (i.e. up to 30 kW X-Ray beam).
- Also experiments of **positronium generation** for fundamental studies of matter-antimatter asymmetry can be conducted at this test station.



Parameter	two-pass acc.	ERL
Energy (MeV)	80	45
Bunch charge (pC)	100	100
Repetition rate (MHz)	0.9286	92.86
Average Current (mA)	$5 \cdot 10^{-3}$	5
Beam power @ dump (W)	$22.5 \cdot 10^3$	400
$\varepsilon_{x,y}^n$ (mm – mrad)	< 1.6	< 1.6
Energy spread (%)	< 0.2	< 0.2

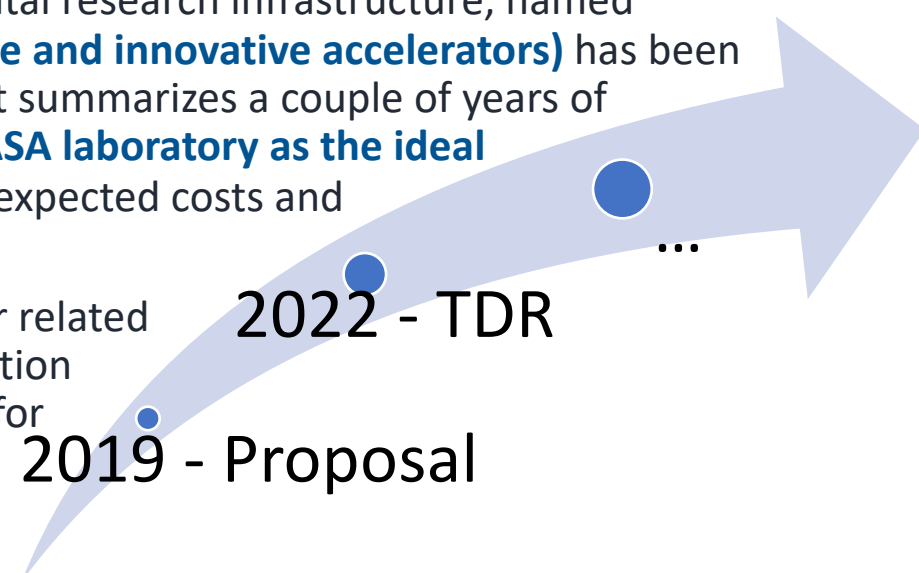
BriXSinO Principle of Operation

- In the ERL operation mode, two experiments are envisioned: **Inverted Compton Scattering (ICS)** and a **THz FEL**.
- **The importance of the full BriXSinO is then twofold.**
- From one hand, it will act as test facility for **fundamental questions of accelerator physics and strategies of Dynamics and Energetic** by hosting experiments for maximizing the energy sustainability and minimizing the AC power consumption.
- From the other hand, **it will work as user facility by providing large quality coherent THz and X-Rays emission** from its high brightness accelerated electron beam, enabling important and advanced applications.



Relevant Milestones for BriXSinO

- ✓ Starting from 2019 a group of researchers from INFN LASA, expert in superconducting technology and accelerator design, and from the Università degli Studi of Milan, expert in radiation, has been the core element of a larger collaboration (other INFN groups, INFN-Ferrara, INFN-Napoli, LNF, Universities as Naples, Ferrara, Politecnico of Milan, Institutions as the CNR and hospitals like San Raffaele), aimed to **propose and design a test-facility addressing the physics and technology challenges posed by the ERL generation, hoping to make in a short-to-mid-term scenario a significant advance in the Italian and INFN contest.**
- ✓ In **June 2022 a Technical Design Report** of an experimental research infrastructure, named **BriXSinO (Brilliant source of X-rays based on Sustainable and innovative accelerators)** has been submitted to the INFN Executive Council. The document summarizes a couple of years of research activities and included the proposal of **INFN-LASA laboratory as the ideal site** to install this facility. A detailed plan, related to the expected costs and time scale, was included too.
- ✓ The project foresees the development of the accelerator related elements typical of an ERL-based facility and the installation of a couple of experiments related to Compton sources for high flux X-rays and high power coherent Terahertz radiation.



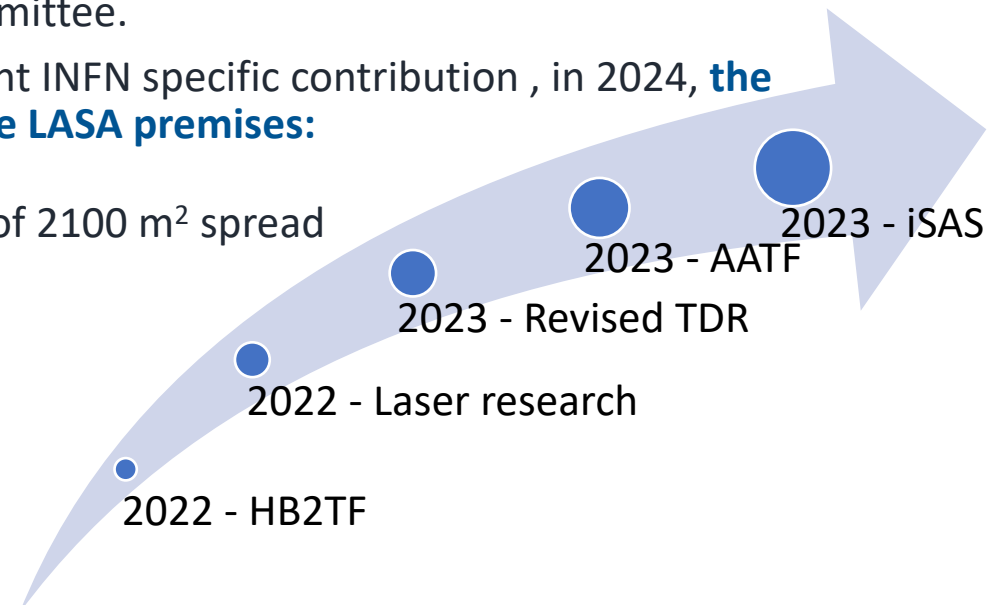
2019 - Proposal

2022 - TDR

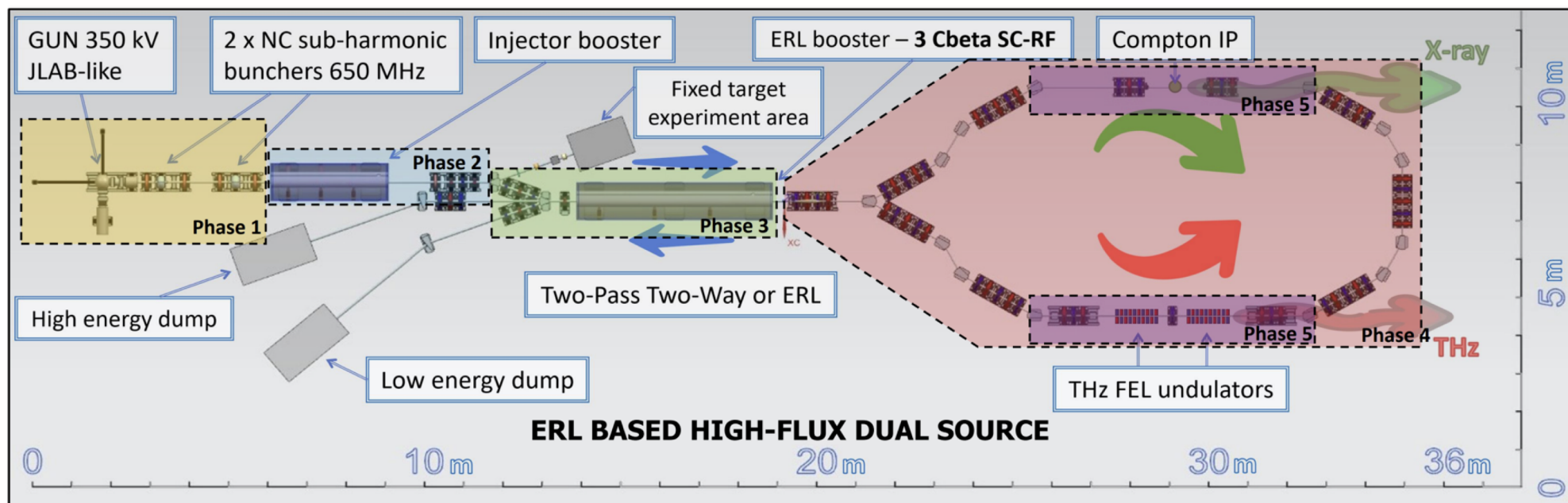
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Relevant Milestones for BriXSinO

- ✓ In September 2022, the first part of the accelerator, a **High Voltage photoinjector DC operated** followed by a couple of room temperature cavities, has been partly funded by INFN under the supervision of the **CSN5 Committee (HB2TF project)**.
- ✓ In October 2022, an additional funding was granted by INFN to complement an allocation made in 2021 for establishing **a dedicated test stand for BriXSinO laser related research**. Within this R&D, we obtained a maximum power of 30 kW in air in the Fabry-Perot prototype cavity.
- ✓ In March 2023, a **revised version of the original Technical Design Report** of BriXSinO has been discussed by the proposers and the INFN Milano Director with the INFN Executive Council, the chair of the INFN MAC and the INFN-Accelerator committee.
- ✓ As part of the PNRR-IRIS program and with a significant INFN specific contribution , in 2024, **the construction of two laboratories will begin within the LASA premises: SML (Superconducting Magnet Laboratory) and AATF (Advanced Accelerator Test Facility)** for a total of 2100 m² spread over an underground bunker and two external floors.
- ✓ In July 2023, a **Horizon Europe application** named “Innovate for Sustainable Accelerating Systems with Energy Recovery” (**iSAS**) has been approved and a specific item is the development of an **innovative RF power coupler** for the superconductive linac foreseen in BriXSinO.

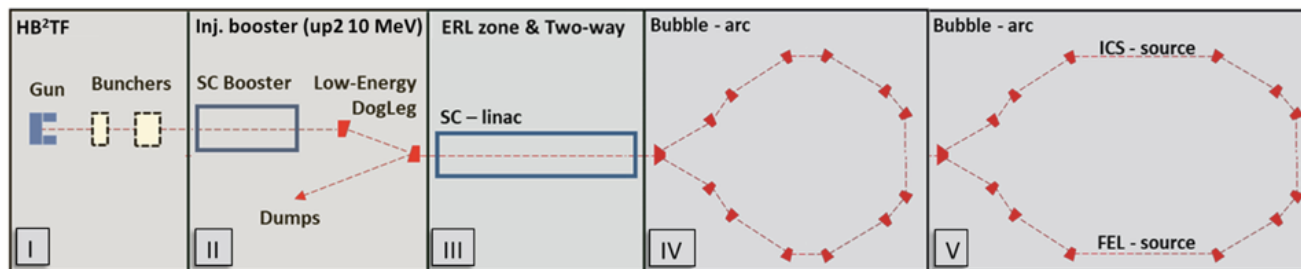


BriXSinO foreseen Schedule



BriXSinO foreseen Schedule

1. Development and construction of the **injector and first beam line transport based on 2 RF bunchers and few magnetic elements to allow the injection in a SC booster**. The final beam will have an energy of the order of 1 MeV.
2. Development and construction of a **beam line which foreseen an acceleration process of the electron beam up to 10 MeV**. At the end of this phase a beam suitable to be injected in a SC linac will be available and, at the same time, an experimental line at the maximum energy and current of 5 mA will permit experimental runs.
3. Development and construction of a **SC linac able to accelerate the beam up to 45 MeV at the maximum current of 5 mA** with beam parameters suitable for the ERL process or for the reacceleration to double the energy.
4. Development and construction of a **minimal recirculating arc coupled to the Linac** of phase 3 to test the Energy Recovery and the the double-accelerating way. A suitable beam dump to fit the requirements in terms of power will be included in this phase.
5. Development and construction of an **experimental set-up for one of the two experiments foreseen** in the original report of BriXSinO.

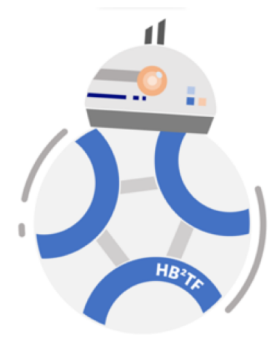


BriXSinO at LASA

SML



AATF
BriXSinO

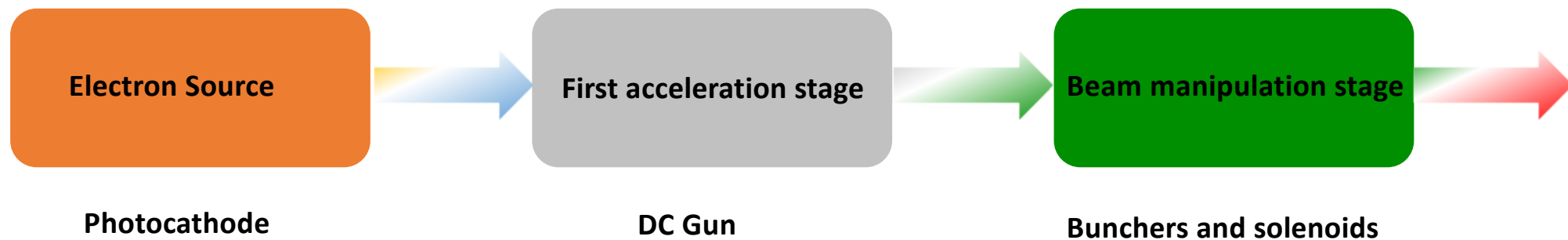


HB²TF : BriXSinO Phase One

High Brightness Beam Test Facility

HB²TF in a nutshell

- The HB²TF project aims to provide a **high power and high brightness CW beam**. The beam will provide different bunch charges at different repetition rate and energies.
- **This impressive flexibility** is part of the originality of the facility and will allow the usage of the beam for some advanced experiments.
- To achieve these parameters, we have done an **extensive simulation activity to select optimal components and their characteristics** to get the design goals.
- Under these assumptions, the facility is composed of different elements that can be grouped into the following sections:

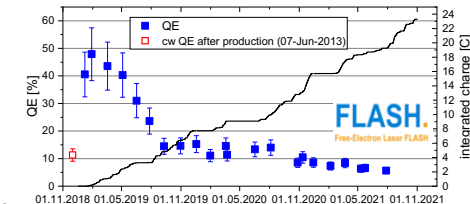


Photocathode

INFN LASA Cs₂Te Photocathodes

Extracted charge: ~ 23 C
1063 days of oper. until now

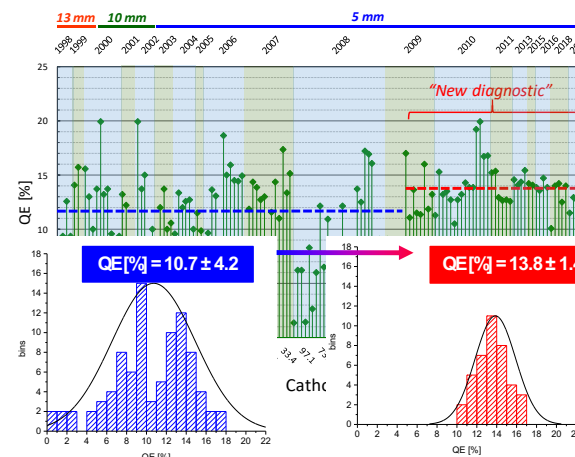
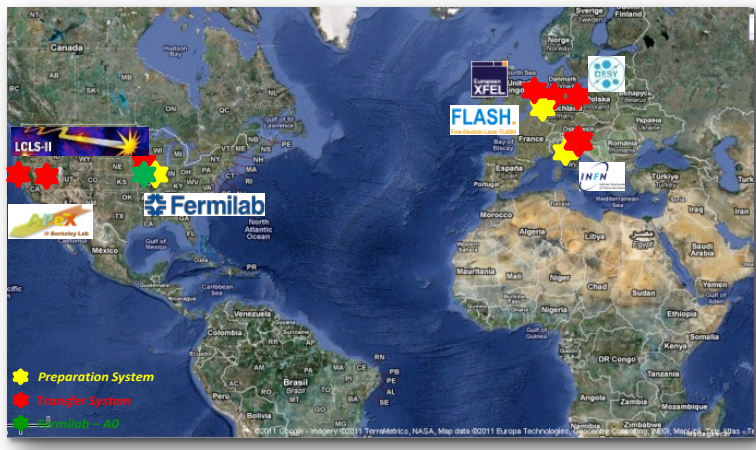
- INFN LASA produces Cs₂Te photocathode since 90s and it's a reference lab
- With a continuous interplay between collaborators and R&D, we today growth cathodes with an **operational lifetime (24/7) in the user facilities increased from few months to few years**, that are a **reference for many accelerator complex**
- More than **150 photocathodes** delivered up to now
- Cs₂Te photocathodes have been demonstrated **usable** also for **CW operation**
- Facilities/injectors: **FLASH** and **PITZ** (DESY), **FAST** (FNAL), **APEX** (LBNL), **LCLS-II** (SLAC)
- **INFN Mo plug** is now a “**standard**” allowing exchange of photocathodes between facilities: **EU** (DESY, STFC), **US** (FNAL, LBNL, BNL, SLAC, UCLA, Cornell), **China** (IHEP, SHINE, Dalian)



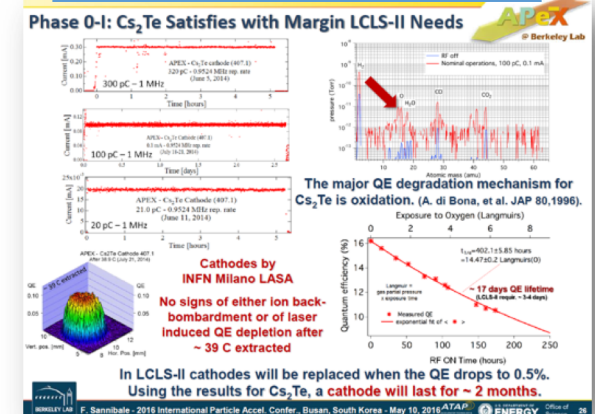
QE and integrated charge for cathode #105.2, cw QE measured by Hg-lamp at 254 nm after production June 2013 at LASA.



INFN Mo plug



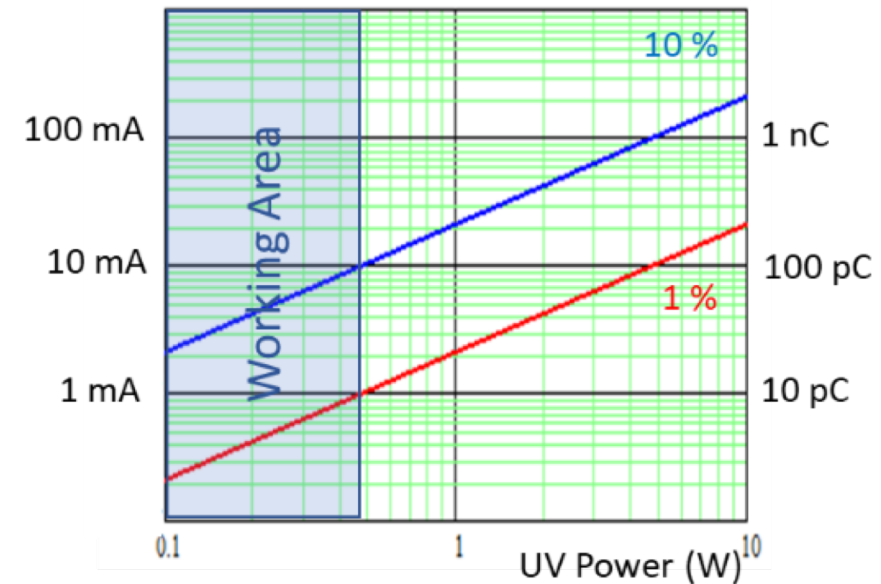
CW (1 MHz) operation in APEX gun



Photocathodes for HB2TF

- For HB²TF **Cs₂Te photocathodes** will be used as electron sources
 - Average QE at the production $\geq 10\%$ in UV range, in operation typically used until QE 0.5%
 - Vacuum quality: low 10^{-10} mbar (in the production stage), low 10^{-9} mbar (in operation mode)
- Laser system (**Yb laser**, $\lambda_{\text{fund}} = 1035$ nm, $P = 10$ W, rep. rate $1 \div 93$ MHz, 190 fs):
 - **UV is needed** for the photocathode operation:
 $\lambda^{4\text{th}} = 258.75$ nm, $P = 0.5$ W

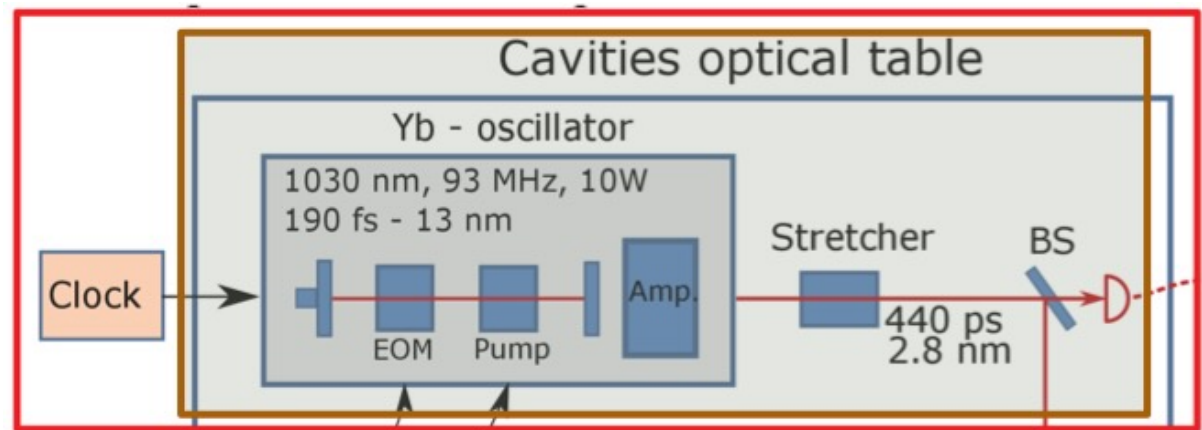
- **Photocathode requirements** in operation:
 - Q: **up to 50 pC**; I_{ave} up to 5 mA
 - **Lifetime**: as long as possible
 - **On-line measurement**: QE and reflectivity characterization
 - Post-usage analysis: after operation, photocathodes will be analyzed in the production system



Laser System

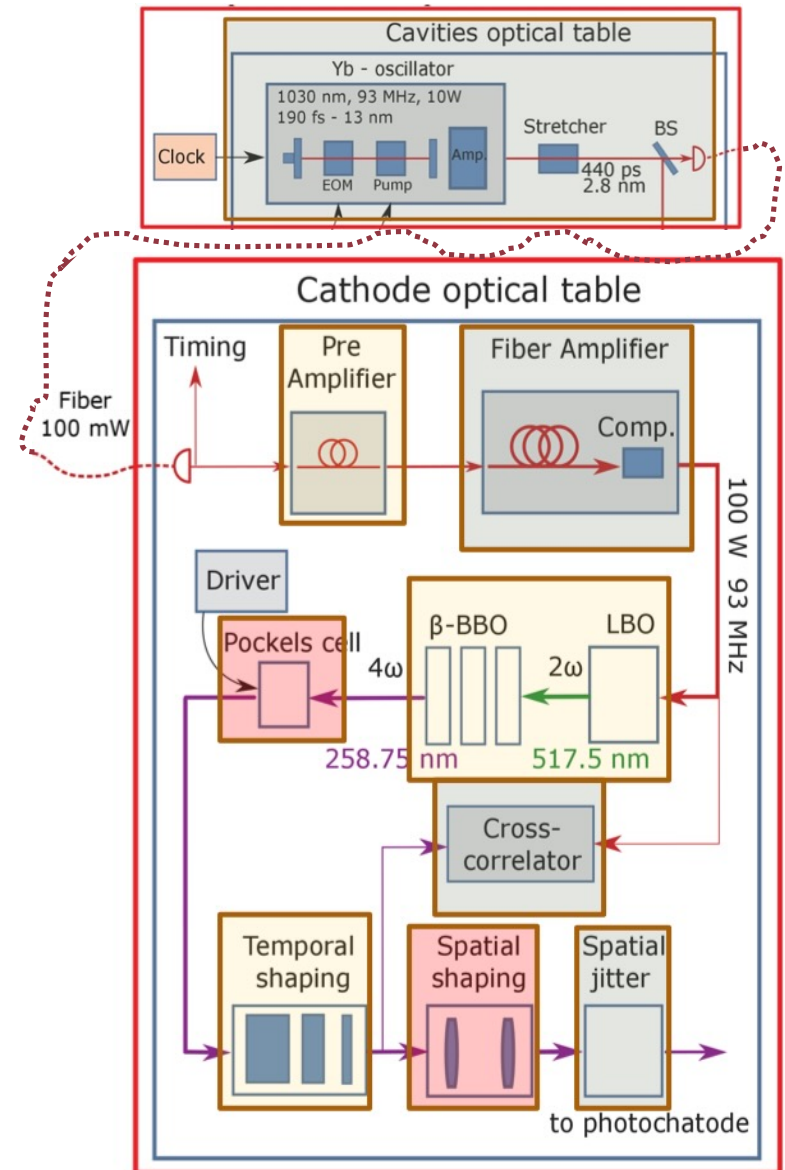
Laser scheme

- The **aim** of the optical system is to **excite the photocathode** for the generation of the electron bunches.
- The **main oscillator** is a **1035 nm** mode-locked Yb laser with a **92.857 MHz** repetition frequency (7th sub-harm of 1.3 GHz).
- An internal amplification system guarantees a **maximum output power of 10 W**, with a spectral width of 13 nm and a pulse duration of **190 fs**.
- The **pulses** from the oscillator are temporally **stretched** by a Chirped Volume Bragg Grating (CVBG) up to **440 ps**, with a spectral width of 2.8 nm.
- **After this stretching** stage, a **100 mW** laser power is **coupled into a fiber** (about 30m long) and then used for the photoemission process.



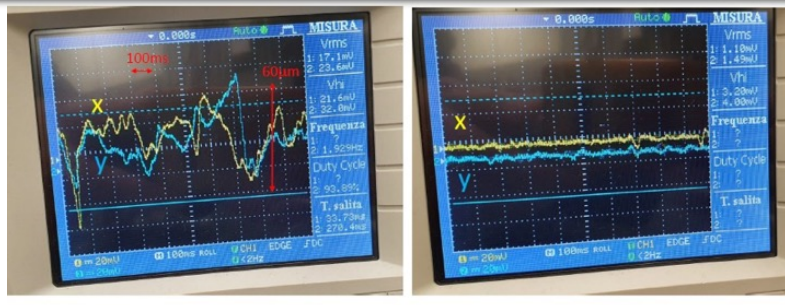
Laser scheme

- The **100 mW** laser pulses are amplified using a **2 stage** process **up to 60 W**.
- The high power pulses are **converted from IR to the 4th harmonic** at 258.75 nm to obtain pulses suitable for the Cathode Material.
- The **repetition rate** of the laser pulses is **controlled by a Pockels cell** from kHz up to the repetition rate of the oscillator.
- Subsequently, the 4th harmonic pulses undergo an intensity **profile shaping, both in temporal and spatial domains**.



Laser scheme & results

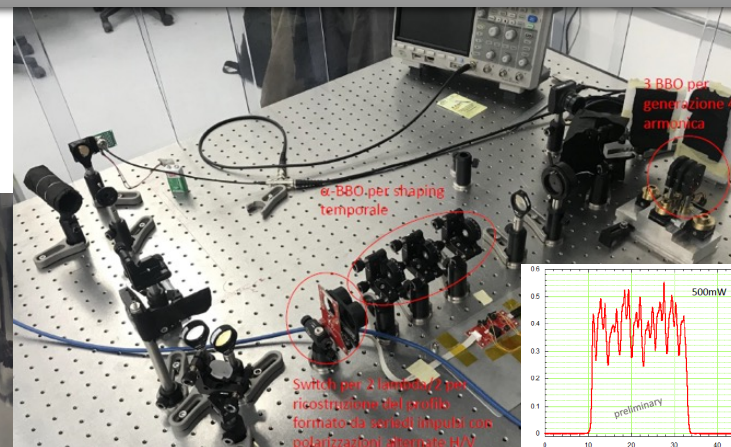
Spatial stabilization of the laser on the photocathode



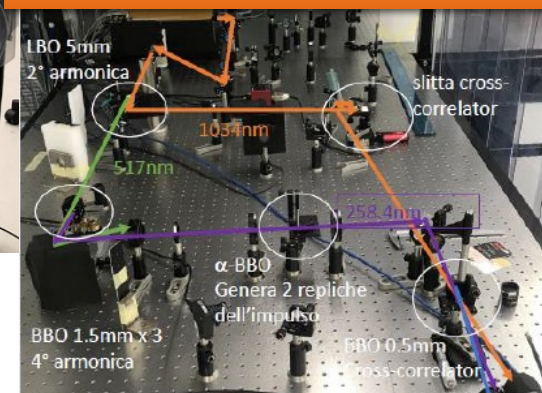
Stabilization of the laser rep-rate referenced to external RF



Temporal pulse shaping stacking (3 crystals alpha-BBO)



2nd and 4th armonics generation



Photocathode Stress Test

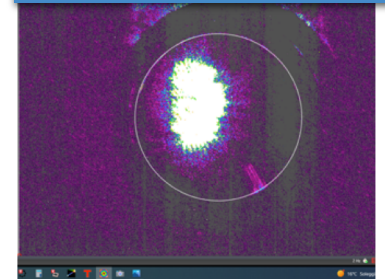
- To test the laser and photocathodes in operation at 100 MHz we have assembled a small test facility based on a 60 kV DC gun able to accept INFN plug.



Laser vacuum cross



Reflected laser from Mo photocathode



Recent achievements:

- **Transport** of the beam over **140 m of fiber**
- Reached **45 kV in Gun** with some FE (conditioning in progress)
- **Extracted about 150 nA from Mo** (first try, optimizations are on-going)

DC Gun

DC Gun

- For the DC gun we have adopted a robust and already well-developed solution with proven and well documented successful operations at high repetition rate. Our reference solution is the “**inverted insulator**” design developed at **JLAB**.
- A user agreement has been signed in the past years with JLAB to take advantage of their experience in this component.
- The collaboration is quite active and an open exchange of tech documents, tech solutions, and supplier companies is well established.

Non-Proprietary User Agreement

No. 21-TOO1

Between

JEFFERSON SCIENCE ASSOCIATES, LLC
“CONTRACTOR”
Operator of Thomas Jefferson National Accelerator Facility (hereinafter “Jefferson Lab” or “Laboratory”) under Prime Contract No. DE-AC05-06OR23177 with the United States Government (hereinafter “U.S. Government” or “Government”), as represented by the United States Department of Energy (hereinafter “DOE”),

AND

Istituto Nazionale di Fisica Nucleare (INFN)
“USER”

(Collectively, “the Parties”)

The obligations of the above-identified DOE CONTRACTOR may be transferred to and shall apply to any successor in interest to said CONTRACTOR continuing the operation of the Laboratory.

ARTICLE I. FACILITIES AND SCOPE OF WORK

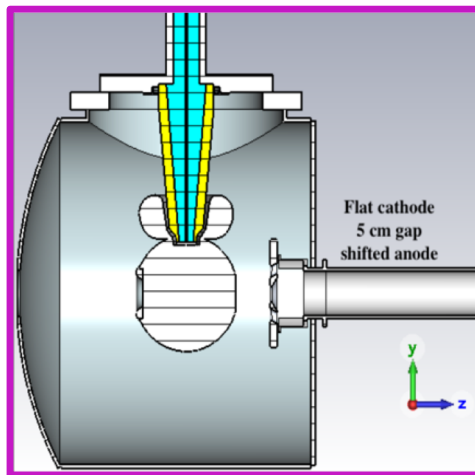
CONTRACTOR will make available to duly authorized employees, consultants and/or representatives of USER (hereinafter called “Participants”) certain Laboratory Non-Proprietary User Facilities, which may include equipment, services, information and other material, with or without Laboratory scientist collaboration, for purposes as described in individual proposals approved by said User Facilities, as attached in Appendix A, and made a part of this Agreement.

HB2TF Current Activities – DC Gun cathode

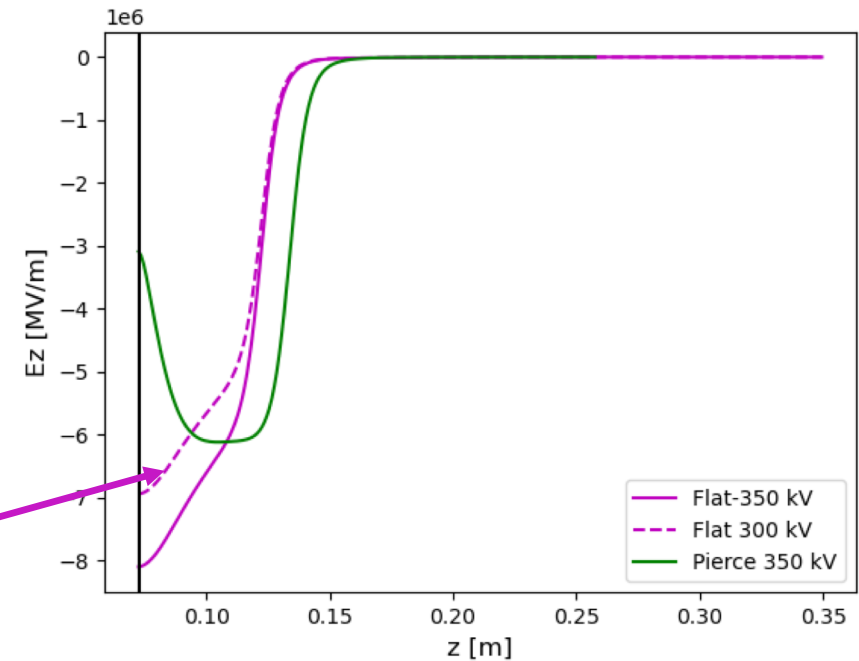
The **flat-cathode geometry** works very well.

We tested some different cases:

- $\Delta V = 250$ kV (an option for BriXSinO) not shown
- $\Delta V = 350$ kV (maximum gain case)
- $\Delta V = 300$ kV (most reasonable operative case)

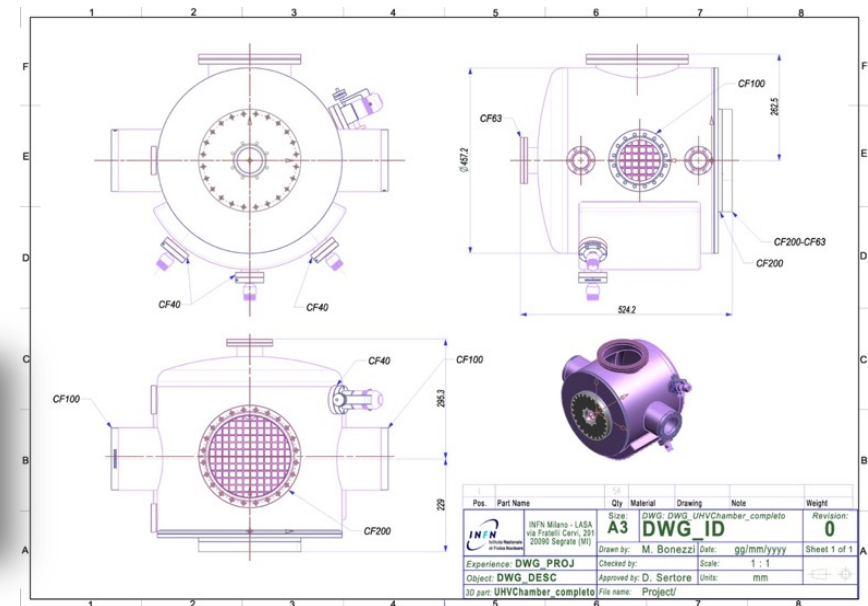
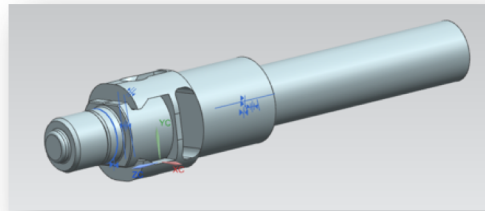
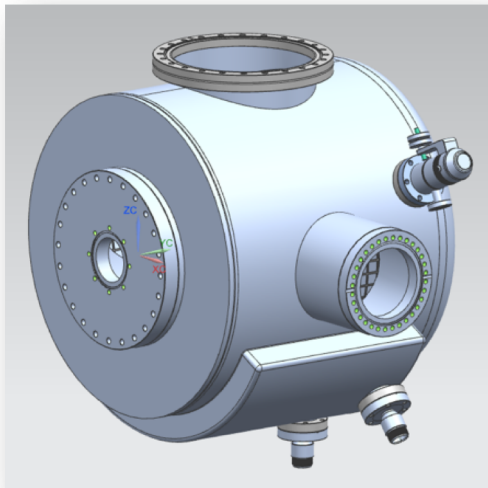


Flat-cathode
300 kV



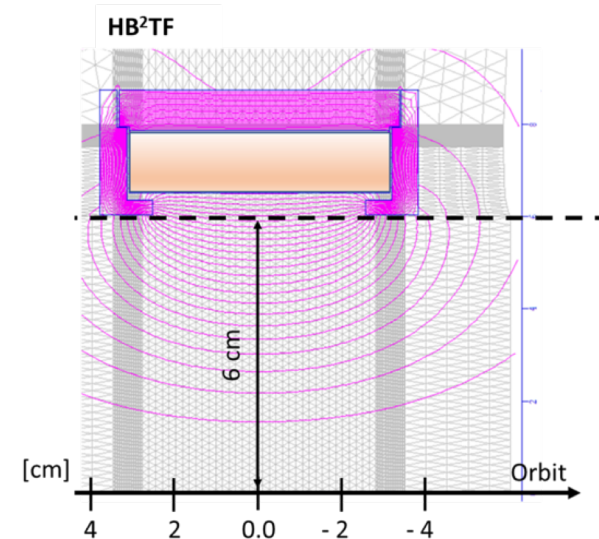
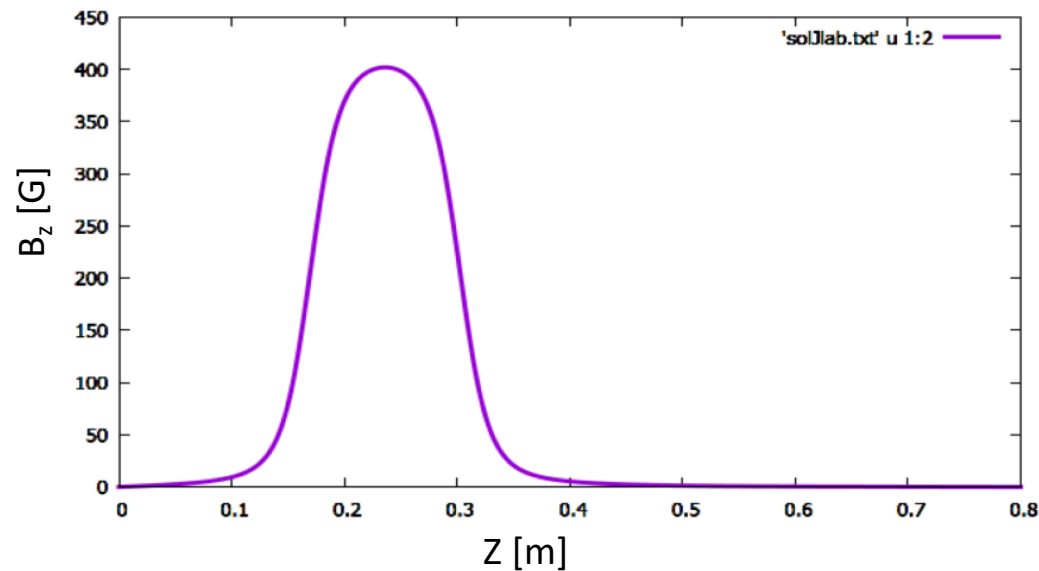
DC Gun Vacuum Chamber

- We have taken the opportunity to improve the symmetric of the chamber by design a new vacuum chamber.
- The vacuum system has been modified adding two NexTORR to the NEG modules.
- Adapt cathode insertion system to hold INFN plugs.



HB2TF Current Activities – Focusing Solenoid

- The DC Gun Solenoid Magnetic is at the closest distance from the cathode i.e. 270 mm.



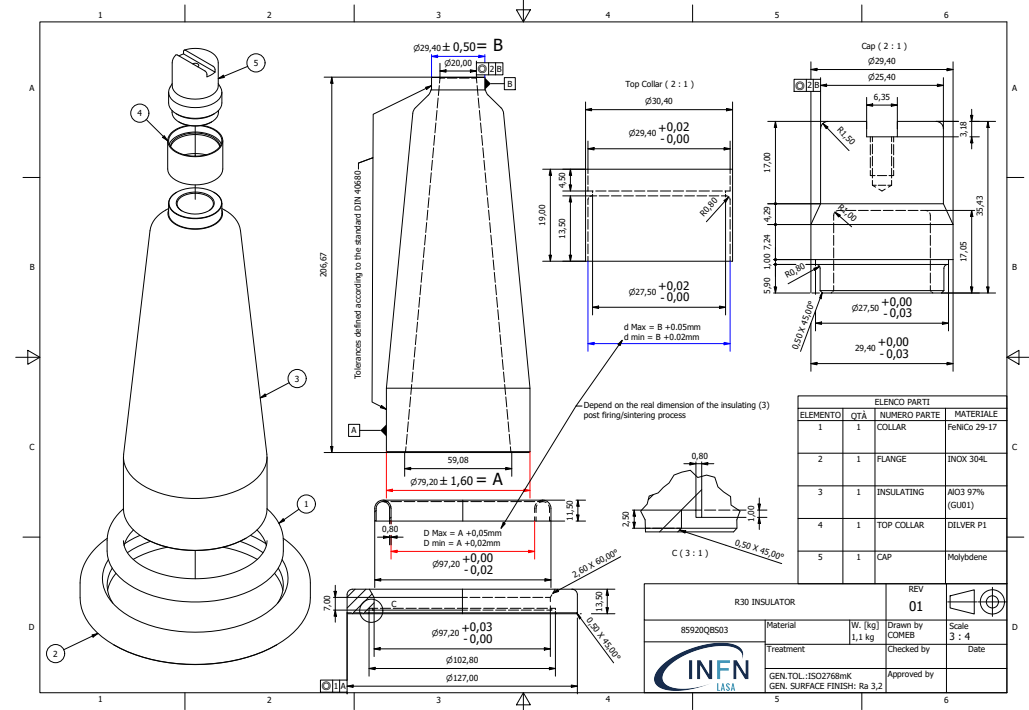
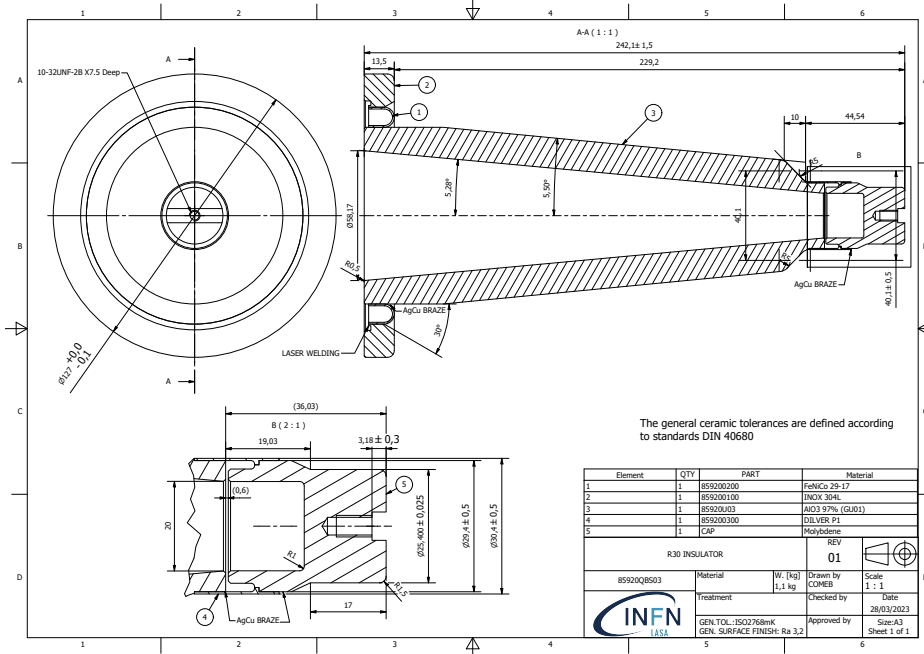
A prototype of the solenoid will be built “in house” to verify this design

HB2TF Current Status DC Gun Inverted Insulator

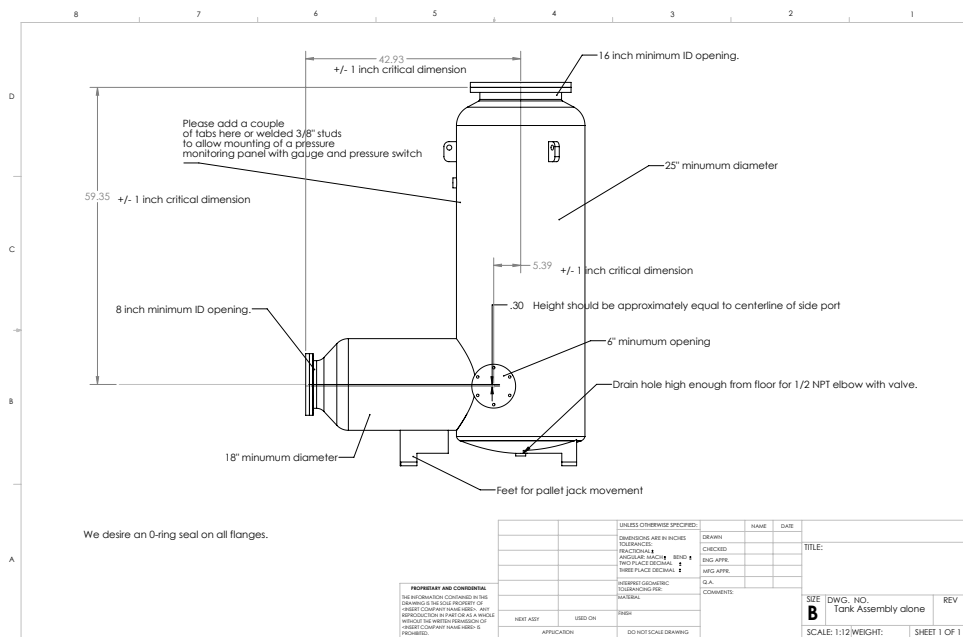
- The DC Gun **Inverted Insulator** is one of the most **critical components** of the Injector. It is dedicated to provide the input path for the HV Voltage.
- Jlab uses components from a small **supplier in France** BUT immediately when we asked a quote for more identical elements it results that the company **has been closed** or, at least, was no more involved in this business.
- We contacted **a lot of companies** in Europe and in the US but it was quite **impossible to get an involvement** in the subject.
- We **got interest** from the Company **HME-Tech GmbH**– Germany and after a short iteration we provide them an engineering drawing of the insulator and they **quoted the realization of a first set of units**.

HB2TF Current Status DC Gun Inverted Insulator

ERL 2024 – Tsukuba 24.9.2024



HB2TF Current Activities – HV, SF6 tank and Limiting Resistor



High Voltage Resistor

High Voltage Power Resistor Series 500
Precision, Non-Inductive

High Voltage Power Resistor Series 500 combines proprietary non-inductive resistor technology and design to achieve low temperature coefficient, low voltage coefficient, high stability, excellent high operating voltage and high power ratings.

These Precision High Voltage Power Resistors are designed to meet the demanding requirements of high voltage testing, including: electrostatic, X-ray, synchrotron, and particle accelerators.

NON INDUCTIVE

Model	Wattage	Max. Operating Voltage	Dimensions in millimeters ± 1.00	Dimensions in inches ± 0.040	C	D	G
500.10	15.00	35/000	81 x 1.5 (3.19 x 0.04)	14.00 (0.55)	13.50 (0.53)	10.00 (0.40)	AA
500.20	25.00	80/000	106 x 1.5 (4.17 x 0.04)	14.00 (0.55)	13.50 (0.53)	10.00 (0.40)	AA
500.50	50.00	70/000	136 x 1.5 (5.35 x 0.04)	21.50 (0.85)	20.50 (0.81)	17.00 (0.67)	BB
500.75	75.00	100/000	204 x 2.0 (8.03 x 0.08)	31.50 (1.24)	30.50 (1.20)	26.00 (1.02)	BB
500.100	100.00	150/000	308 x 3.0 (12.12 x 0.12)	31.50 (1.24)	30.50 (1.20)	26.00 (1.02)	BB

* 1/2 of 100 power in dry air.



HV PS @ LASA
-450 kV – 3 mA

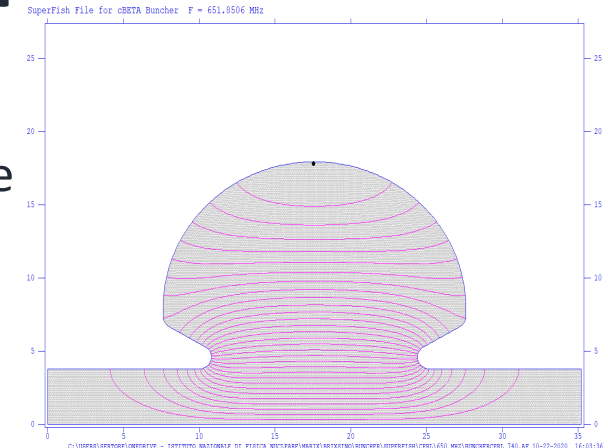
Buncher

Bunchers

- The **electron bunches** generated by the DC Gun have **long longitudinal profile** so to avoid emittance dilution.
- But, in order to **minimize nonlinear energy spreading** due to RF waveform in the foreseen booster, **bunches** need to be **compressed** to shorter length after the gun.
- As the beam is still non-relativistic at this point, the **simplest method** of bunch compression is the **velocity bunching**. To this end, we choose the **sub-harmonic bunching** solution, employing **two $\beta < 1$, 650 MHz spherical re-entrant shape copper cavities**. The **beam energy before entering** the first and second cavity are assumed to be **300 keV** and **638 keV**, respectively.
- The specific frequency of the **buncher** has been chosen as a **subharmonic** of a foreseen **1.3 GHz** SC booster. This makes the HB²TF buncher quite unique, along with the requirement to accelerate the beam.

Buncher cavities and RF power requirements

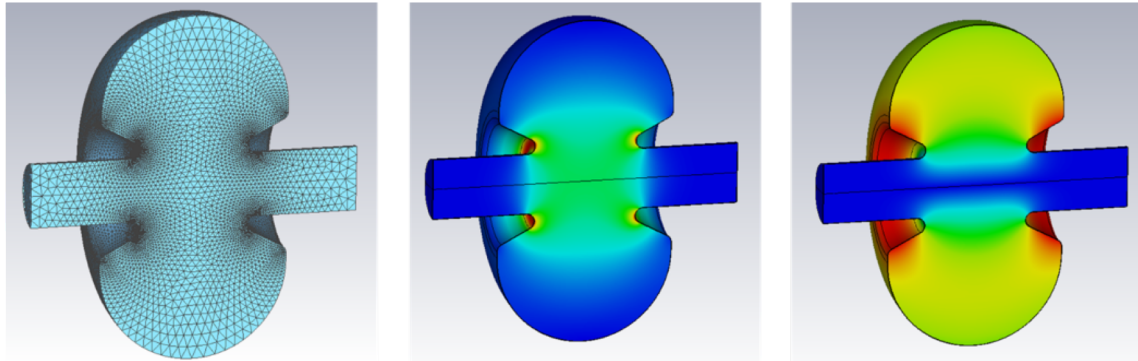
- The **buncher cavity geometries** have been designed using **Superfish** and **CST** simulations, using as a reference cavity and scaling to the requested frequency.
- We have **completed the electromagnetic, mechanical and thermal design** of the low beta buncher in **ANSYS**.
- Concerning the choice of **RF power amplifiers**, we are looking to the market of **solid-state amplifiers (SSA)**.



	$E_z \text{ max} = 2.7 \text{ [MV/m]}$	
	Buncher 1	Buncher 2
Beam power [kW]	2	2
Cavity power [kW]	11	14
Total power [kW]	13	16
+15% margin	15	18.4
FW power – 4 kW SSA [kW]	16	20
FW power – 5 kW SSA [kW]	20	20

	Buncher 1	Buncher 2
f^0 (π -mode) [MHz]	650	
β (v/c)	0.74	0.906
Input beam energy [MeV]	0.3	0.638
E-field ampl. [MV/m]	2.7	
Cell per cavity	1.0	
Active cavity length [m]	0.171	0.209
Cavity quality factor Q^0	$3.2 \cdot 10^4$	$3.67 \cdot 10^4$
Ext. quality factor Q^{ext}	$3.02 \cdot 10^4$	$3.24 \cdot 10^4$
R/Q [Ω]	195.7	223
Geometry factor G [Ω]	211	244
$E_{\text{pk}}/E_{\text{acc}}$	3.07	3.88
$B_{\text{peak}}/E_{\text{peak}}$ [mT/(MV/m)]	0.96	0.96
$B_{\text{peak}}/E_{\text{acc}}$ [mT/(MV/m)]	2.94	3.73

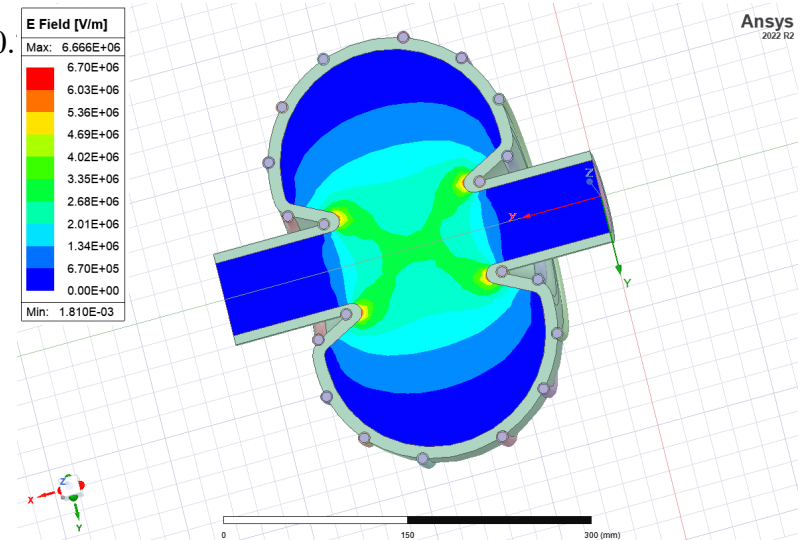
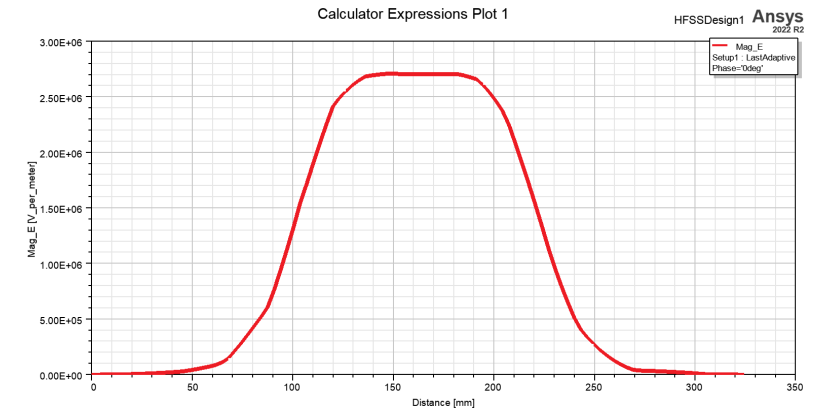
Buncher – Electromagnetic design



3D mesh and profile for E and H field in Buncher 1.

Parameter “g” is the effective gap length that is 17 cm corresponding to a cavity beta 0.

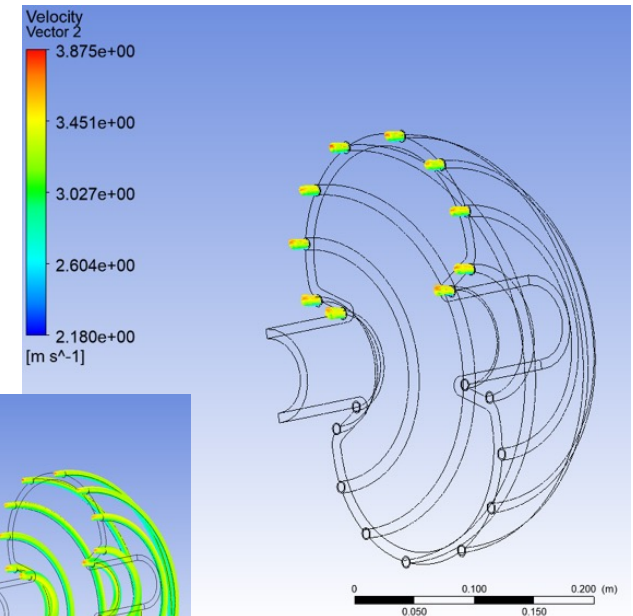
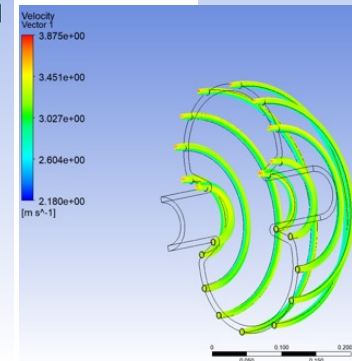
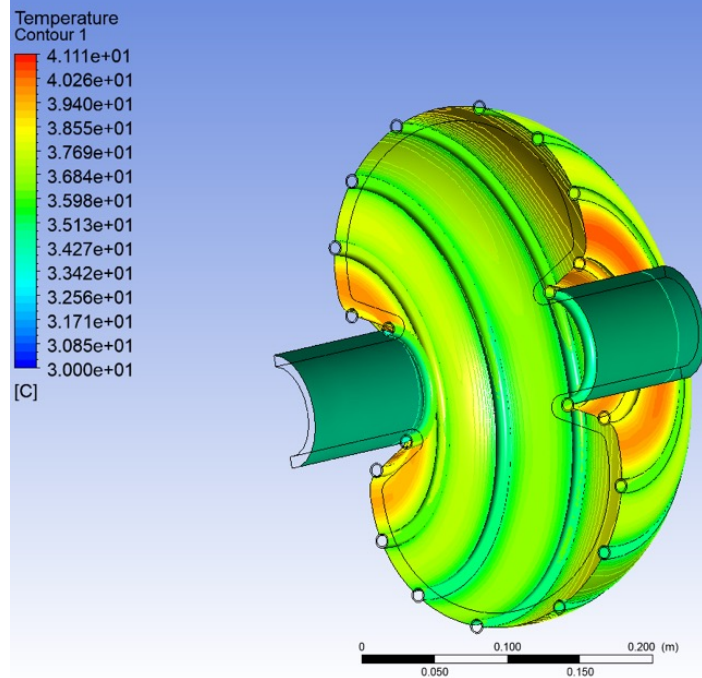
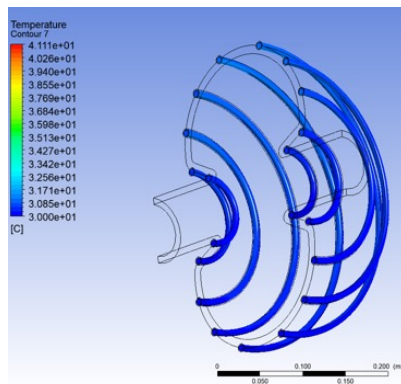
	Buncher 1	Buncher 2
f_0 (π -mode) [MHz]	650	
β (v/c)	0.74	0.906
Input beam energy [MeV]	0.3	0.638
E-field ampl. [MV/m]	2.7	
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Active cavity length [m]	0.171	0.209
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Ext. quality factor Q_{ext}	$3.02 \cdot 10^4$	$3.24 \cdot 10^4$
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Geometry factor G [Ω]	211	244
E_{pk}/E_{acc}	3.07	3.88
B_{peak}/E_{peak} [mT/(MV/m)]	0.96	0.96
B_{peak}/E_{acc} [mT/(MV/m)]	2.94	3.73



Buncher – Mechanical/Thermal design

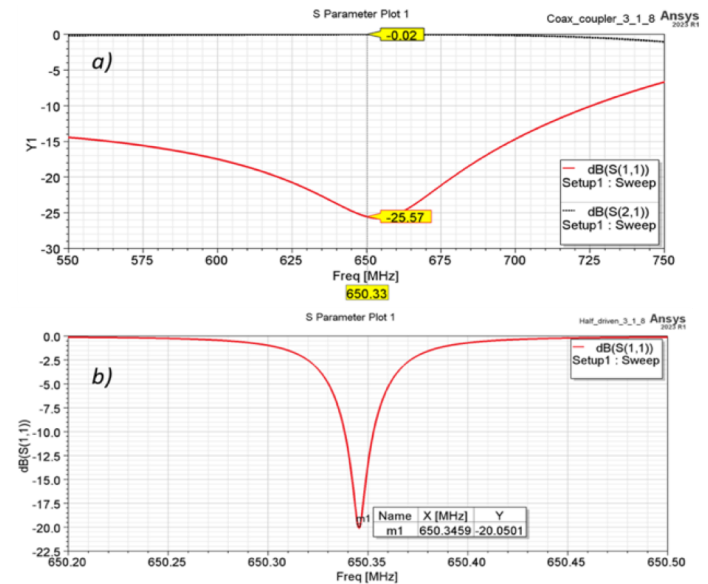
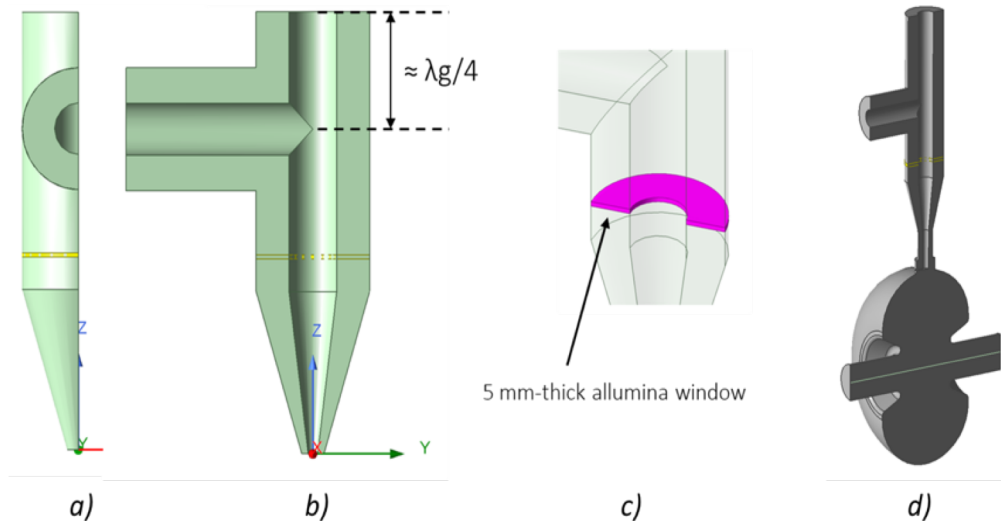
- We closed the loop EM – mechanical – thermal/fluid design to estimate major effects.

Example of em/Thermal/Fluid design



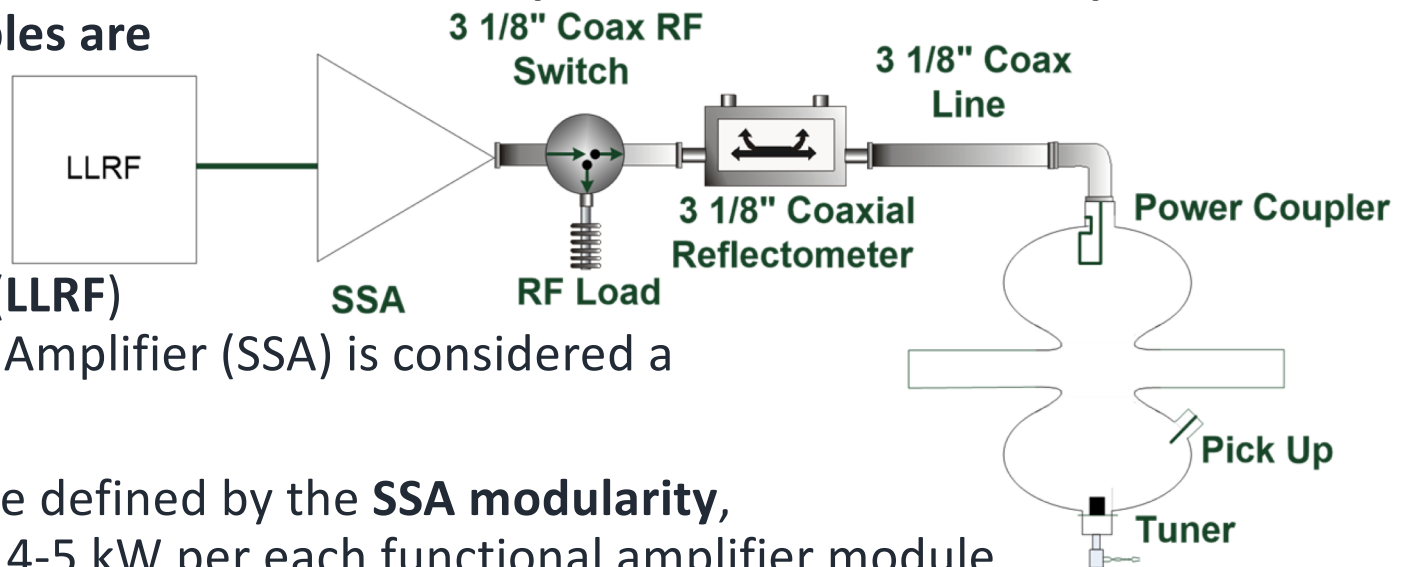
Buncher – Fundamental Power Coupler Concept

- A **coaxial line coupler**, tapered and tuned through a $\lambda_g/4$ section, has been designed to feed the cavity via the 3 1/8" standard line.
- The **ceramic thin window** used as **vacuum boundary**.
- The **coupling is magnetically performed** through a loop, that extends from the coupler inner conductor, which could be rotated (with respect to the cavity axis) to obtain the desired coupling factor.

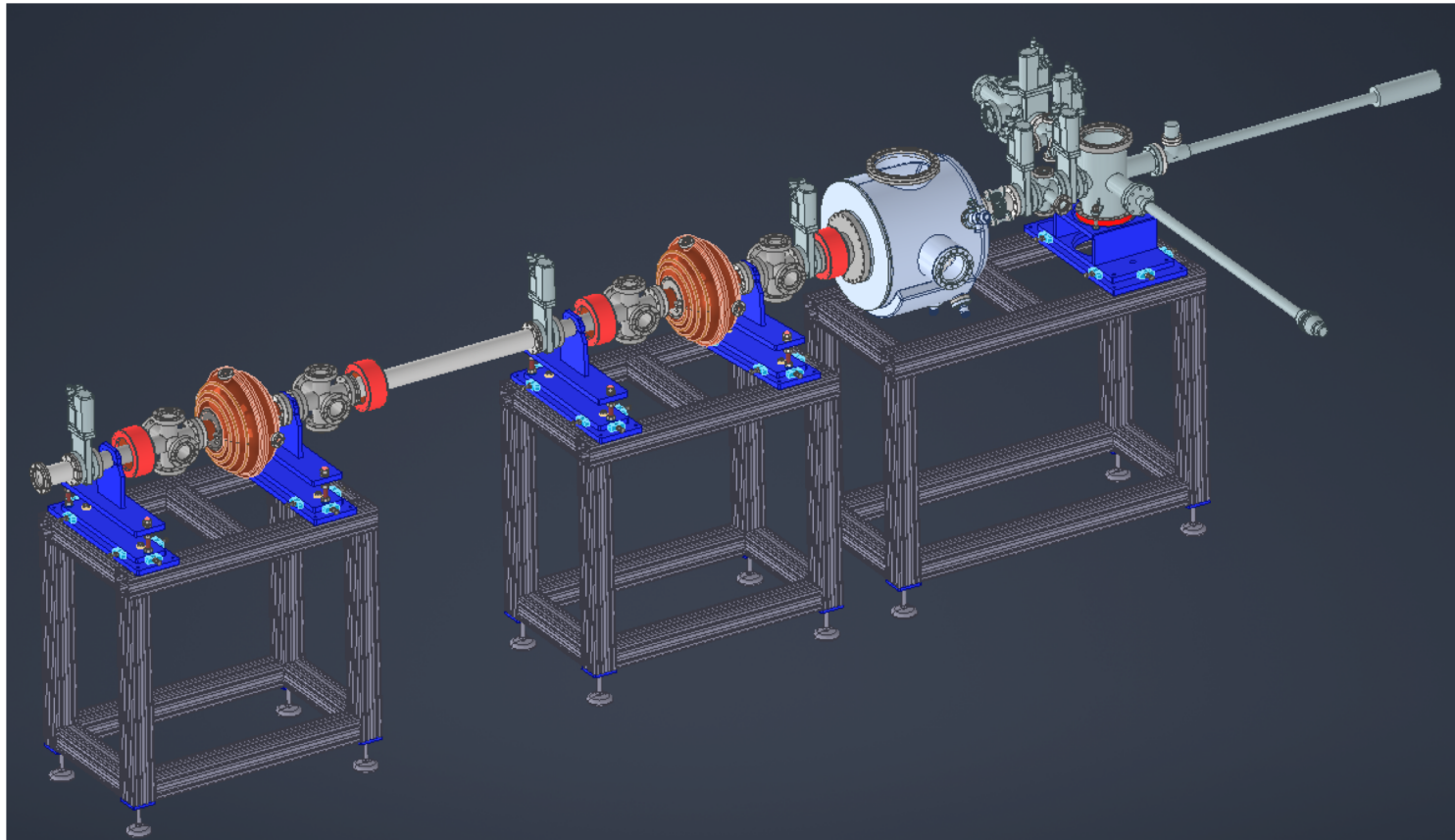


Buncher – RF power

- The **beam loading** of the buncher cavities is **negligible**, as the **RF power** is almost all **dissipated in the cavity walls**. We **foresee** power supplies of **20 kW** each to provide **2.7 MV/m** of accelerating gradient.
- For the power amplifier we envision a modular, **expandable Solid-State Amplifier (SSA)** solution. Coaxial **cables are preferred over waveguides**.
- The possibility to **embed the Low-Level RF (LLRF)** controls in the Solid-State Amplifier (SSA) is considered a viable solution
- Final forward power will be defined by the **SSA modularity**, tentatively in the range of 4-5 kW per each functional amplifier module.



HB²TF Layout



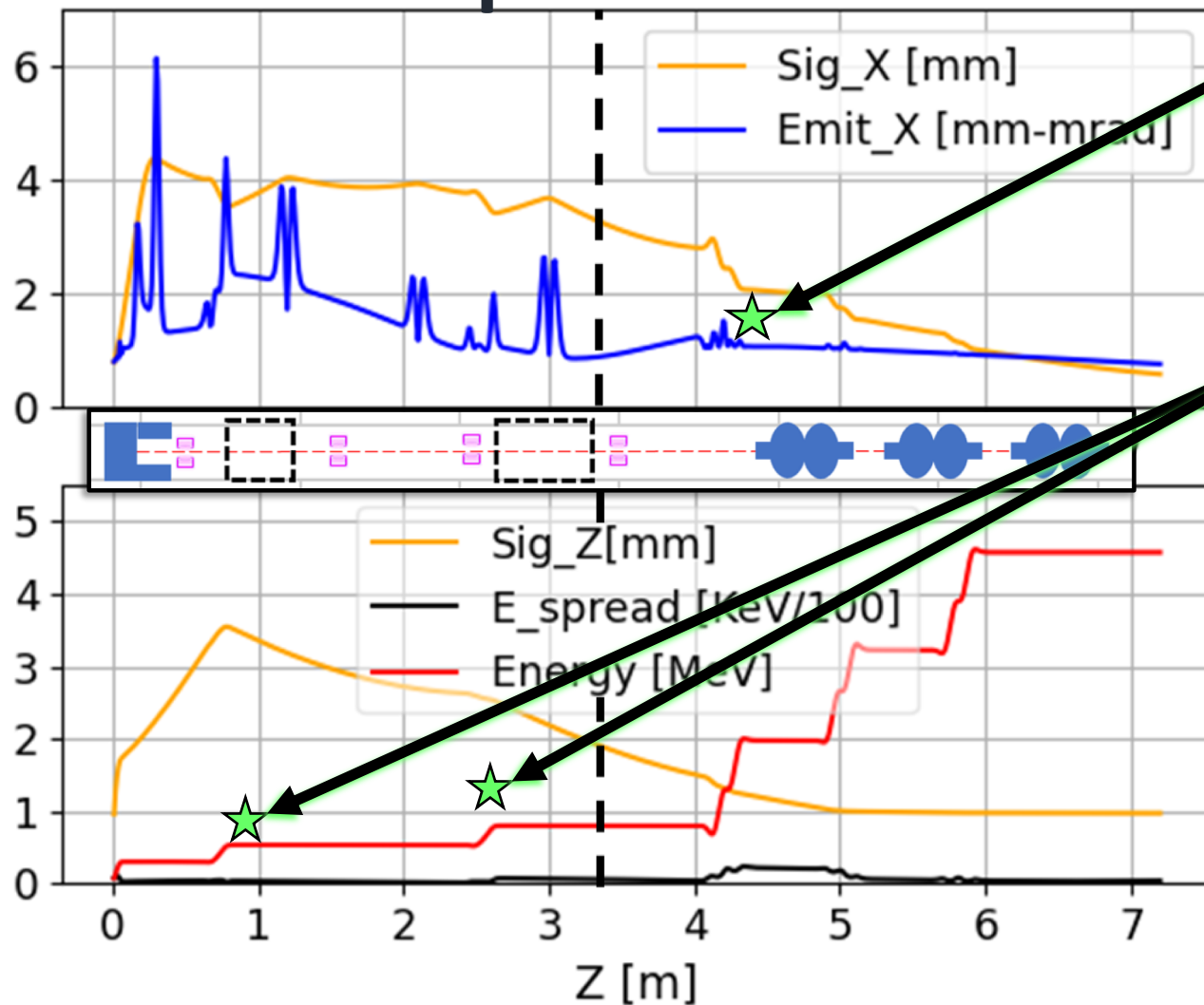
Beam Physics

- The beam dynamics study developed for this project aims **to design an injector** that in a near future **will be used for an ERL**.
- This concept can be made explicit as follows: **beam energies as low as possible** (they will never be recovered) compatible with a **beam brightness high** enough to drives experiments.
- In this view, the beam dynamics studies carried out aimed to **couple the injector of HB²TF to a SC booster** to produce a beam with energy of 4.5 MeV, an emittance of about 1.2 mm- mrad and a rms bunch length of about 1.2 mm.
- To obtain **high brightness beam** it is of paramount importance to keep **emittance growth under control**.
- **Low energy and high brightness results into a BD space charge dominated that is one of the points of interest of this proposal.**

Beam Manipulation

- This design is **innovative** because it uses **two bunchers instead of one** and employs a **650 MHz** rf frequency **instead** of the commonly used **1.3 GHz**.
- The choice to use a **longer rf bucket** allows for the trapping of **longer cigar-like electron bunches** having lower emittances. Additionally, the use of **two bunchers** provides **better control** over **longitudinal bunch compression**.
- The **injection phases** of the two bunchers are not at the rf zero-crossing, allowing for **acceleration** while mitigating space-charge effects and bunching to increase the final beam brightness.
- The whole HB²TF **beamline** has been **studied** using the tracking code **Astra** that is designed to consider space-charge collective effects, a key point for HB²TF beam dynamics, further the beam line working point (WP) has been **optimized using an AI** code already developed in our group named **GIOTTO**.

Beam Manipulation



SC booster
emit-compensation in
space charge regime:
 σ_x & ϵ_n behaviour well
tuned

Bunchers
compression &
acceleration

Bunch extraction:

$Q_b = 50$ [pC]; $\sigma_{x,y} = 650$ [μm]; $\tau_{\text{laser}} = 18$ [ps] (rise-time = 1 ps)

DC-gun:

$\Delta V = 300$ kV

The two Bunchers:

$E_p = 2.7$ MV/m $\Phi_{\text{inj}_1} = -31^\circ$, $\Phi_{\text{inj}_2} = -35^\circ$

SC inj. booster (three two-cells):

$E_p = 11.5$ MV/m $\Phi_{\text{inj}_1} = -25^\circ$, $\Phi_{\text{inj}_2} = 21^\circ$, $\Phi_{\text{inj}_3} = 0.0^\circ$

beam-line solenoids peak fields [T]:

$B_{z_1} = 0.0276$, $B_{z_2} = 0.0172$, $B_{z_3} = 0.0128$, $B_{z_4} = 0.0246$

Thanks for your attention