ISRS proposal
ESS-Bilbao MHB-SSPA activities

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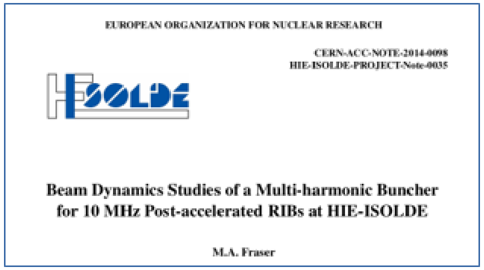
MHB intro

1. Intro
2. MHB specifications and design activities
3. RF power for the MHB R&D activities
4. Planification of tests at Bilbao

MHB intro

The purpose of the MHB is to increase the time between bunches:


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-ACC-NOTE-2014-0098
HIE-ISOLDE-PROJECT-Note-0035

Beam Dynamics Studies of a Multi-harmonic Buncher for 10 MHz Post-accelerated RIBs at HIE-ISOLDE

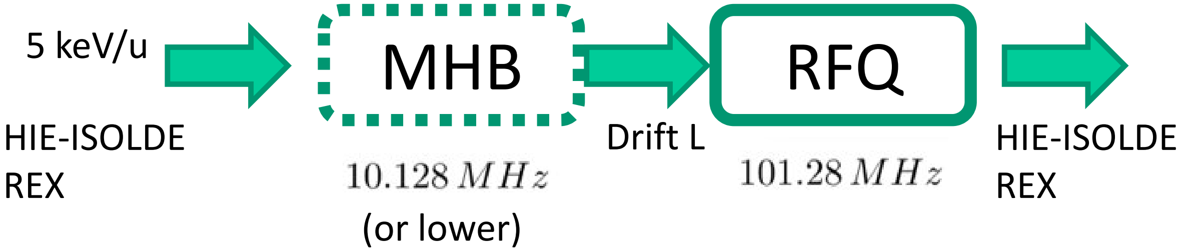
M.A. Fraser

Table 1: Comparison of the key parameters of a selection of relevant worldwide MHB-RFQ systems.

Facility	**ATLAS (ANL)**	**ISAC (TRIUMF)**	**PIAVE (LNL)**	**ISOLDE (CERN)**
RFQ frequency [MHz]	60.625	35.4	80	101.28
MHB fundamental (beam) frequency [MHz] ($h = \frac{f_{RFQ}}{f_{MHB}}$)	12.125 ($h = 5$)	11.8 ($h = 3$)	40 ($h = 2$)	10.128 ($h = 10$)
No. of MHB harmonics	4	3	3	≥ 3
RFQ structure type	multisegment split-coaxial	4-rod split-ring	superconducting	4-rod ($\lambda/2$)
MHB RF structure type	lumped circuit (resonant)	transmission line (non-resonant)	QWR (resonant)	to be defined
MHB drift-tube type	single-gap	single-gap	$2\times$ double-gap	single-gap

$$f = 101.28\,MHz \rightarrow 9.87\,ns$$

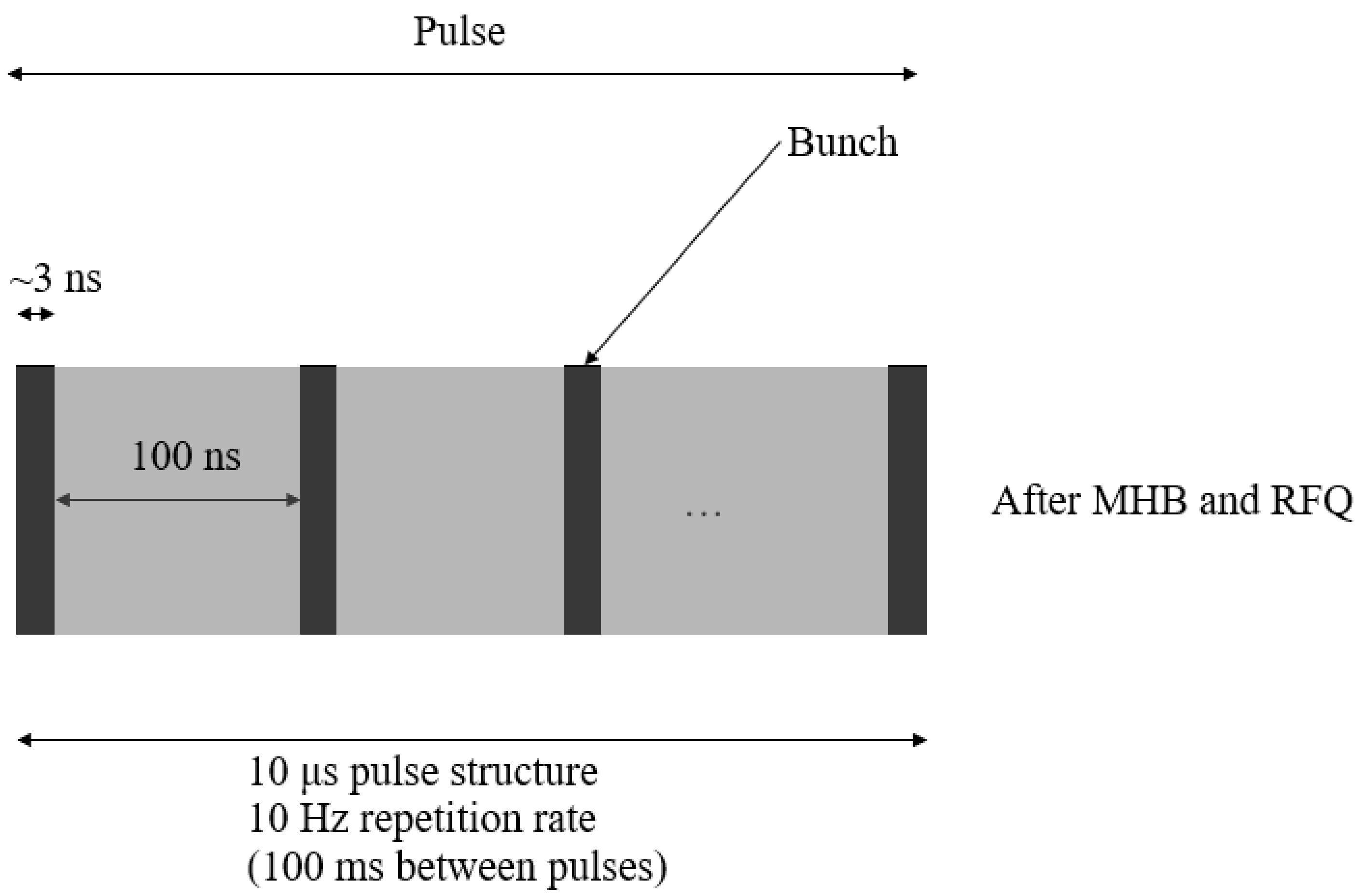
$$f = 10.128\,MHz \rightarrow 98.7\,ns$$



- MHB bunching and RF
- SSPA
- Propagation of beam through RFQ
- Position of MHB in line and additional elements

MHB intro

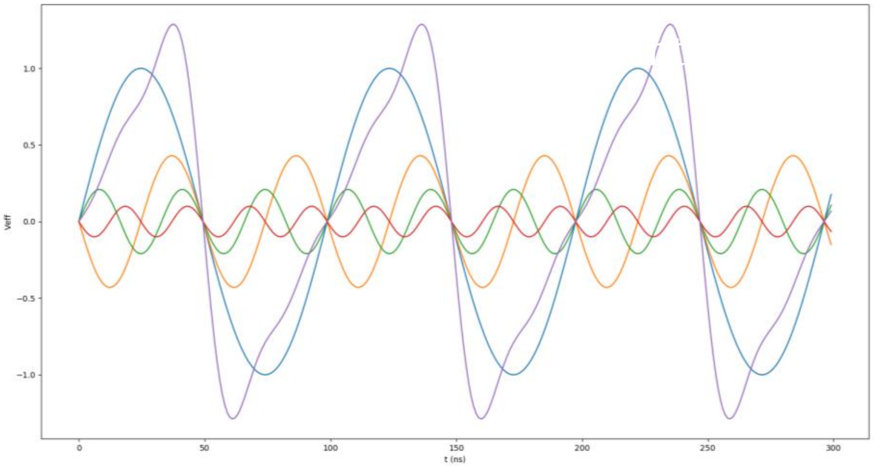
Pulse structure



MHB intro

- Multi-Harmonic Buncher

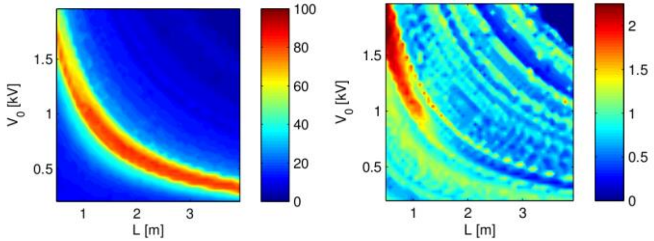
  The optimum field profile for bunching is a saw-tooth profile, that can be achieved by adding-up several harmonic components of the base frequency



$$V_{\text{eff}}(\tau) = V_0 \left(\sin \omega_0 \tau - 0.43 \sin 2\omega_0 \tau + 0.21 \sin 3\omega_0 \tau - 0.10 \sin 4\omega_0 \tau\right) .$$

$$V_0 = 840\, V\ (520\, V),\ \text{for}\ L = 1.4\, m\ (2.4\, m)$$

V0 is the effective voltage (including transit time effects through gap *g*), and depends on the postion *L* of the MHB upstream the RFQ.



(HIE-ISOLDE-PROJECT-Note-0035.pdf)

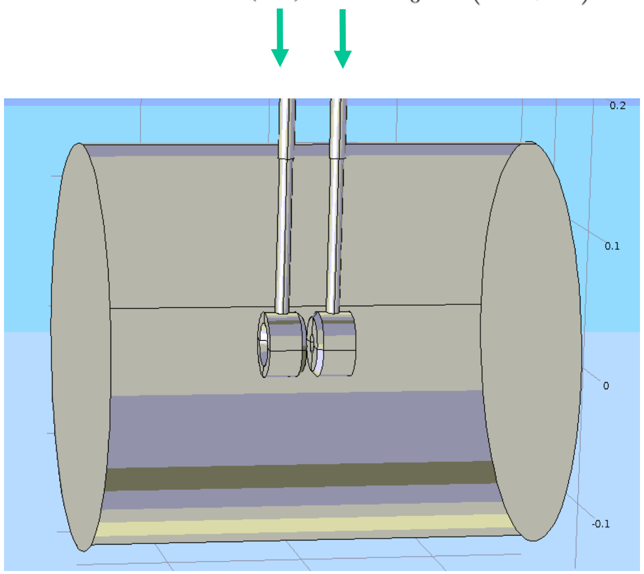
(a) Transmission [%] through RFQ and bunched at 10.128 MHz.

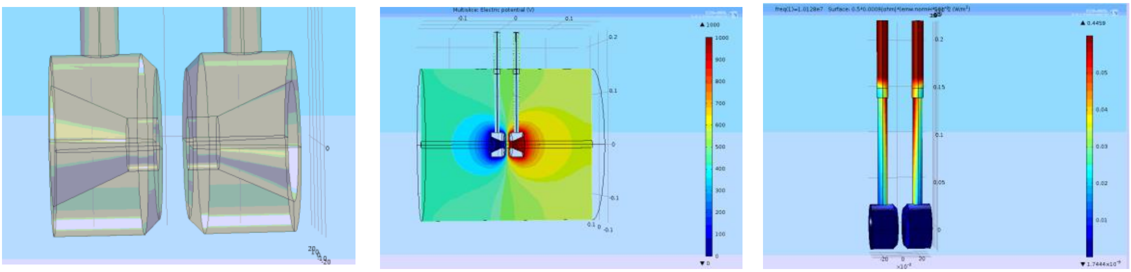
(b) Longitudinal emittance: ratio with dc injection, $\epsilon^{rms}_{MHB}/\epsilon^{rms}_{dc}$.

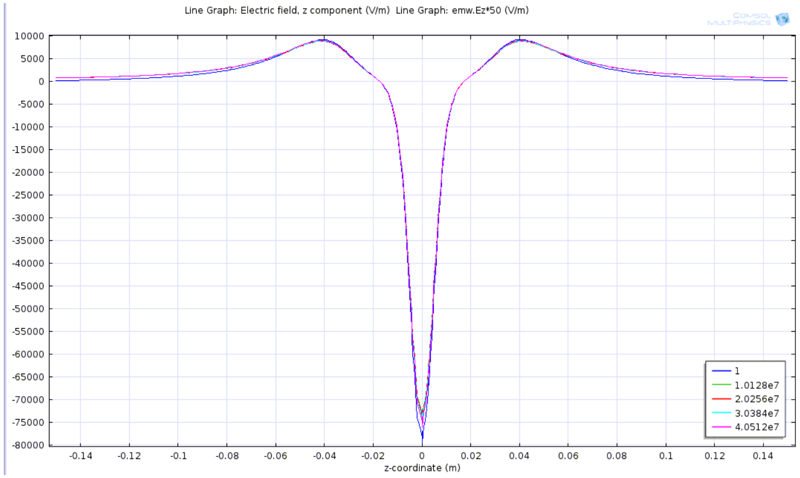
MHB design

RF voltage through internal conductor of coaxial line

$E = E_0 \cos(\omega t)$ $E = E_0 \cos(\omega t + \pi)$



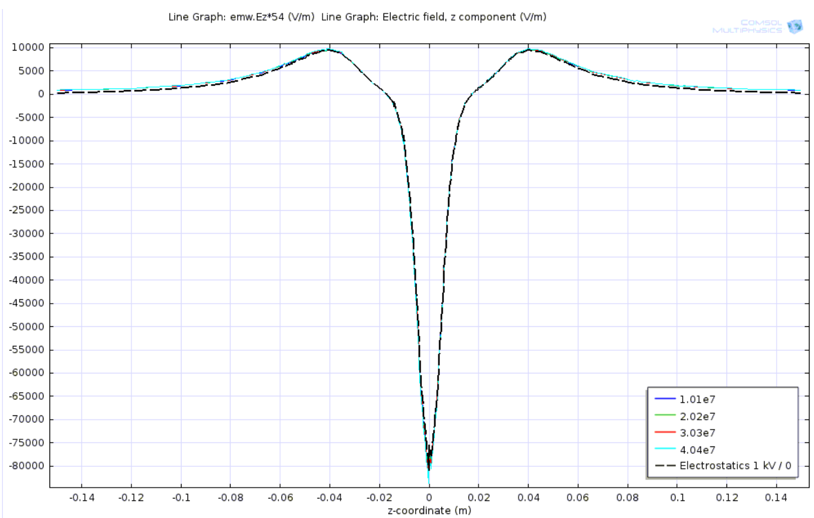




Electric field profile, modulated by the saw-tooth wave.

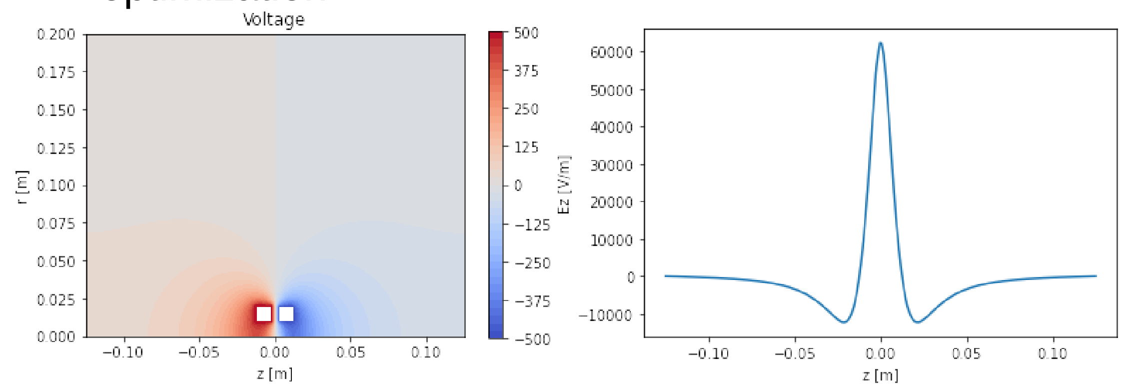
MHB design

- Different electrodes geometries have been explored.
- Integrated computational framework (geometry+mesh+electromagnetic+beam dynamics)



Field profile is the same for EM or ES simulations, so ES are used for quick batch calculation.

Python scripting for quick parametrization and optimization




```
def calculate_MHB_all_z (mhb, gpt, results='', mhb_voltage=1000.0):
    rz_field_name_txt = mhb.model_name + '.txt'
    rz_field_name_gdf = mhb.model_name + '.gdf'
    # geometry, mesh, and finite elements
    create_model=True
    if hasattr (mhb, 'create_model') and not mhb.create_model:
        create_model=False

    if create_model:
        mhb.build_mesh()
        mhb.solve_for_field()
        R = np.arange(0, mhb.R0, 0.0001)
        Z = np.arange(-0.5 * mhb.Lcav, 0.5 * mhb.Lcav, 0.0001)
        rz = mhb.export_grid_rz(R, Z, rz_field_name_txt, magnetic_field=True)
        pygpt.gpt_asci2gdf(rz_field_name_txt, rz_field_name_gdf)
```

MHB design

- Integrated computational framework (geometry + mesh + electromagnetic + beam dynamics)

pygpt is a homemade python wrapper for GPT beam dynamics code

```
f0=10.128e6

mhb_run_voltage=520.0
mhb_ratios=[1.0,-0.428,0.215,-0.101]

# beam dynamics parameters, in a dictionary for pygpt
p=dict()
p['AoQ']=4.5 # A over Q. Default=1
p['Q']=1 # gpt charge will be QIon=-Q*qe , qe is negative. Default=1
p['Ku']=5e3 # Kinetic energy per nucleon eV
p['I']=1e-3 # beam intensity in A
p['initial_beam_radius']=2.219e-3 # Beam radius, m
p['emittance_xy']=0.806e-6/cte.pi # in pi m mrad
#p['emittance_z']=12.41*1e-9*1e3
p['f']=f0 # RF base frequency in Hz
p['z_MHB']=0.5*mhb.Lcav # center of MHB electrodes
p['harmonics']=mhb_ratios
p['comment']='MHB test gpt simulation'
p['phase']=0
p['nmacro']=1000

p['t_end']=0.5e-5
p['delta_t']=1.0e-9

# field factor
mhb_run_voltage=520.0

p['fe']=mhb_run_voltage/1000.0
p['efield_2da']='mhb_conical_1000V.gdf'
#
p['phase']=4.71
name_gpt_in='temp/mhb_cone_plot.in'
pygpt.MHB_create_gpt_infile (name_gpt_in, p)
data=[]
data.append (p['efield_2da'])

pygpt.gpt_server_run (name_gpt_in, results_file='results/result_conical.gdf',data=data)
#
```

time step output (general calculation) or fixed z calculation

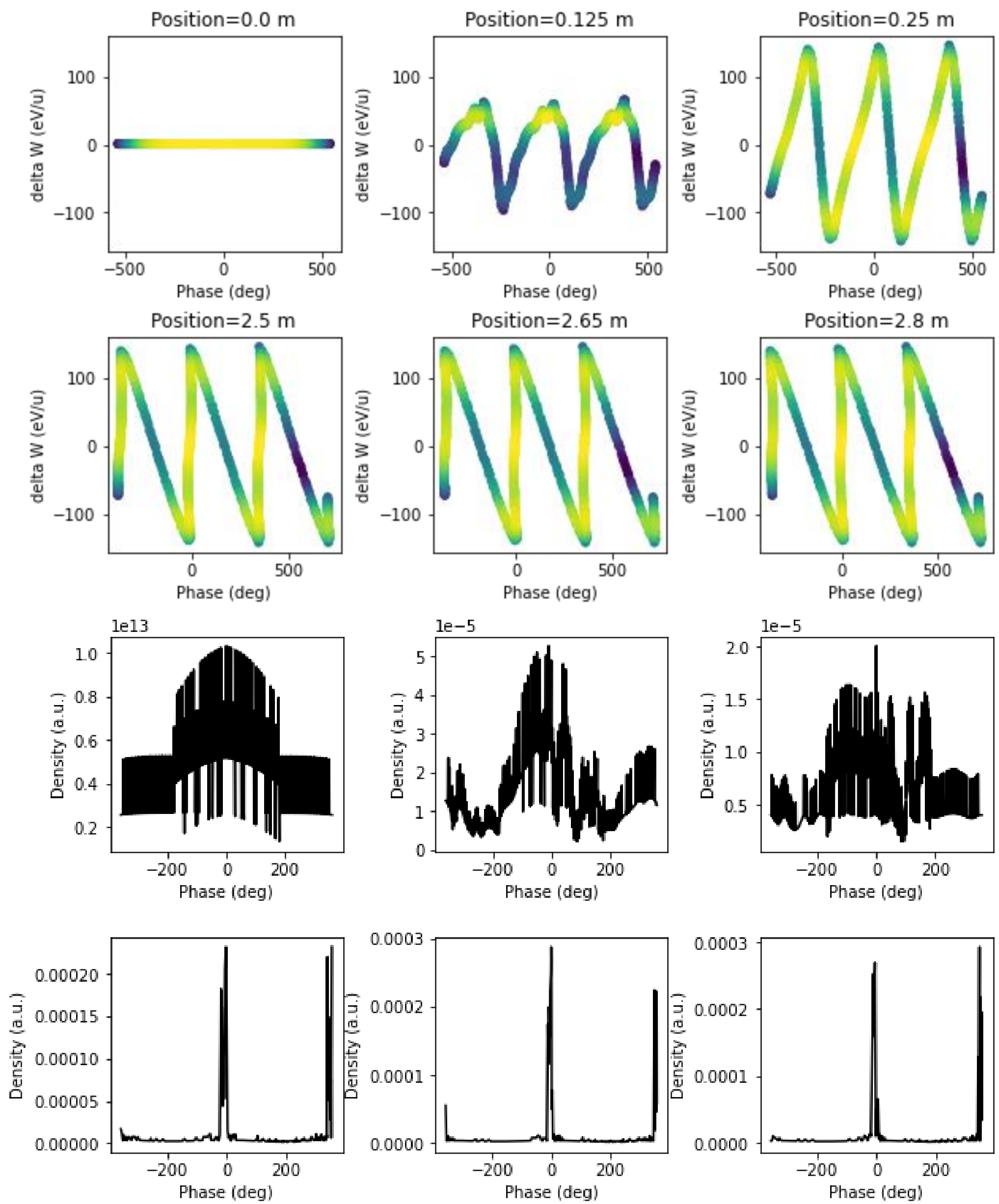
```
p['screen']=[0,0.125,0.25,2.5,2.65,2.80]
```

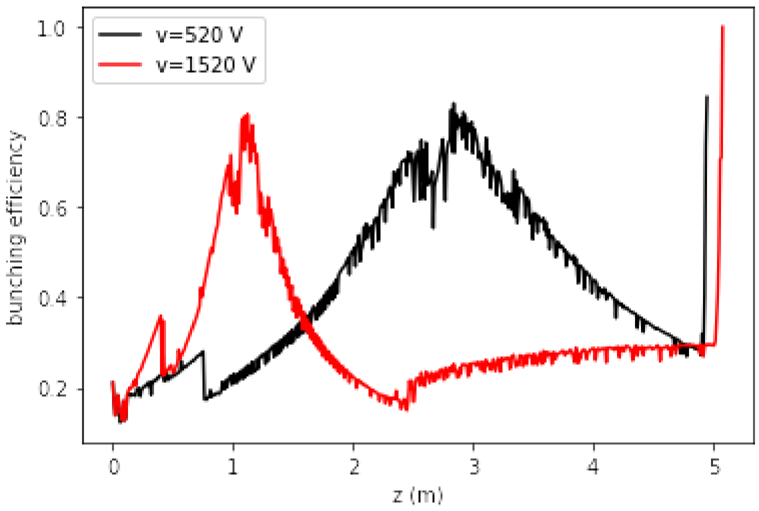
Field factor scale for actual voltage

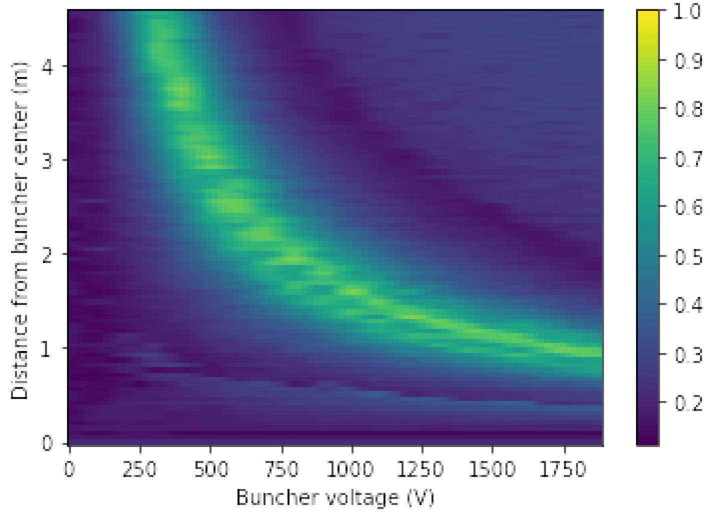
.in

MHB design

(Example of results)



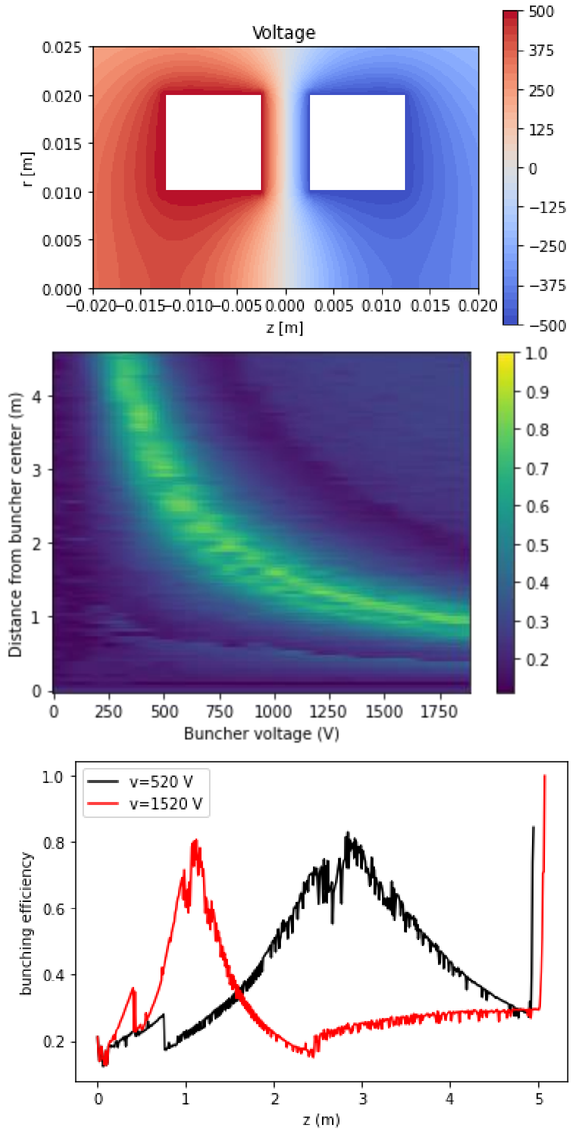




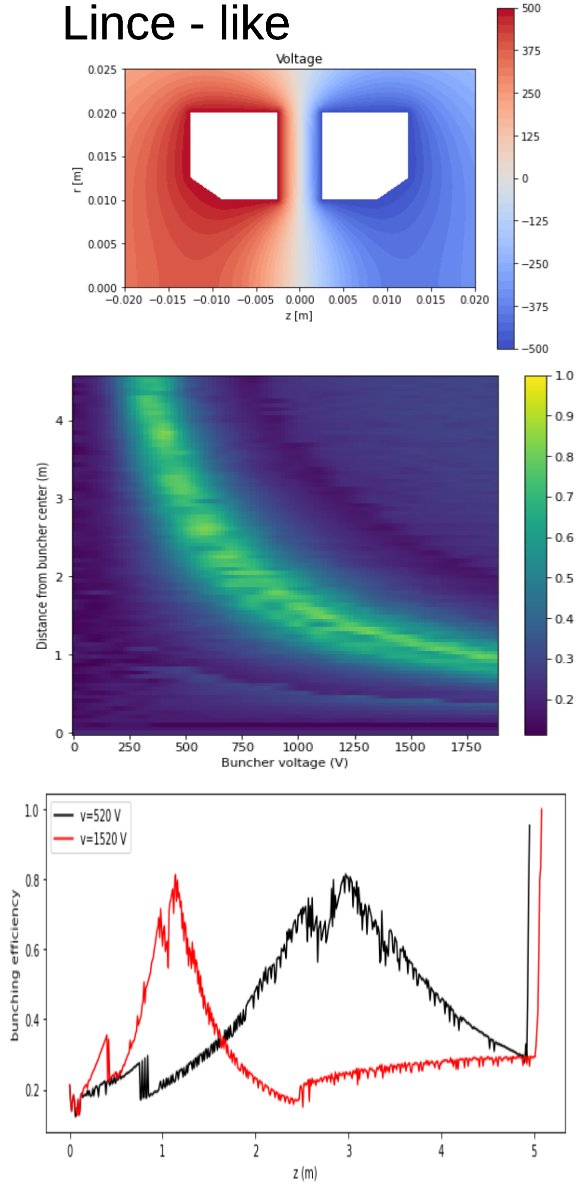
MHB design

Different geometries explored in parametrized models

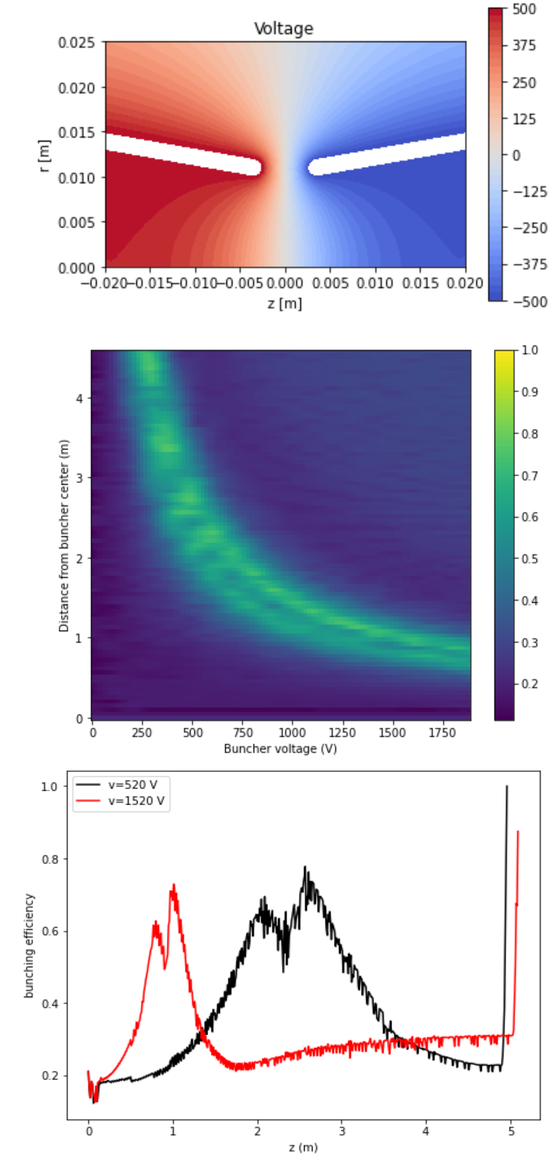
Fraser - like



Lince - like



FRIB-like (conical)



MHB RF power R&D

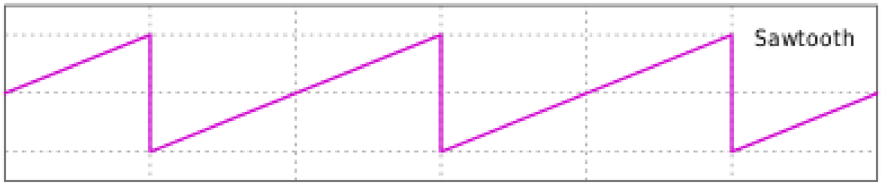
- Generation of Multi-Harmonic power signal with SSPA technology

Based on Fourier Series (decomposition of a periodic function into an infinite sum of sinusoidal functions).

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos \frac{2n\pi}{T} t + \sum_{n=1}^{\infty} b_n \sin \frac{2n\pi}{T} t$$

Sawtooth: linear ramp with instant return at the beginning of each period.

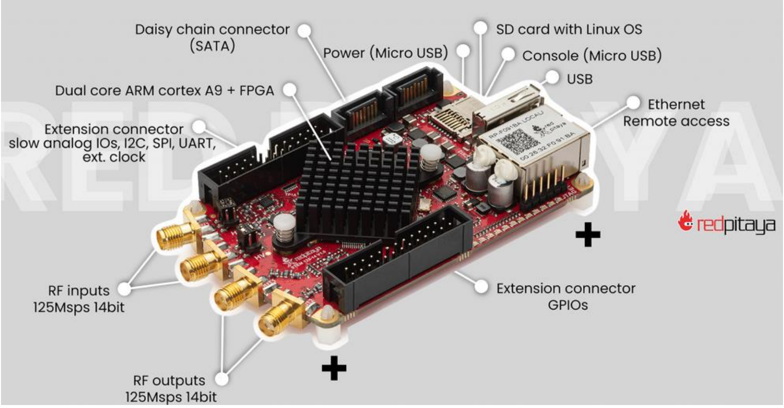
$$f(t) = -\frac{a}{\pi} \sum_{k=1}^{\infty} \frac{(-1)^k}{k} \sin k\omega t$$

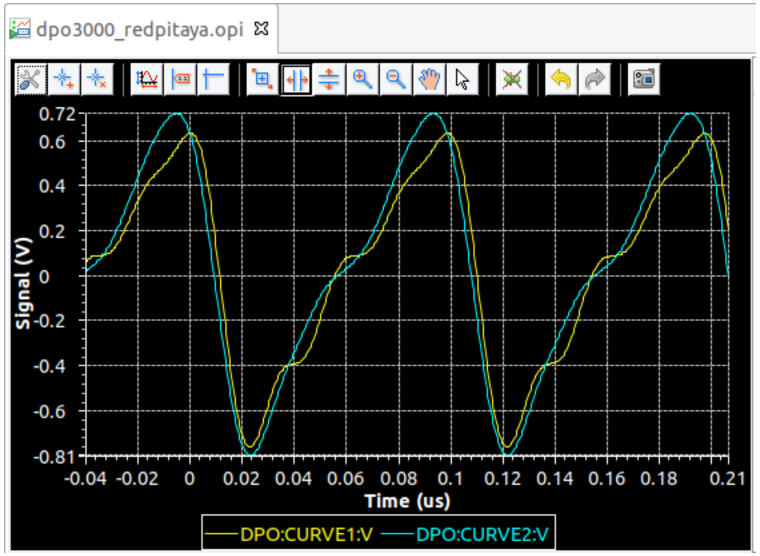


MHB RF power R&D

- Generation of Multi-Harmonic power signal with SSPA technology

$$V_{eff}(t) = V_0\left(\sin(\omega_0 t) - 0.43\sin\left(2\omega_0 t\right) + 0.21\sin\left(3\omega_0 t\right) - 0.10\sin\left(4\omega_0 t\right)\right)$$



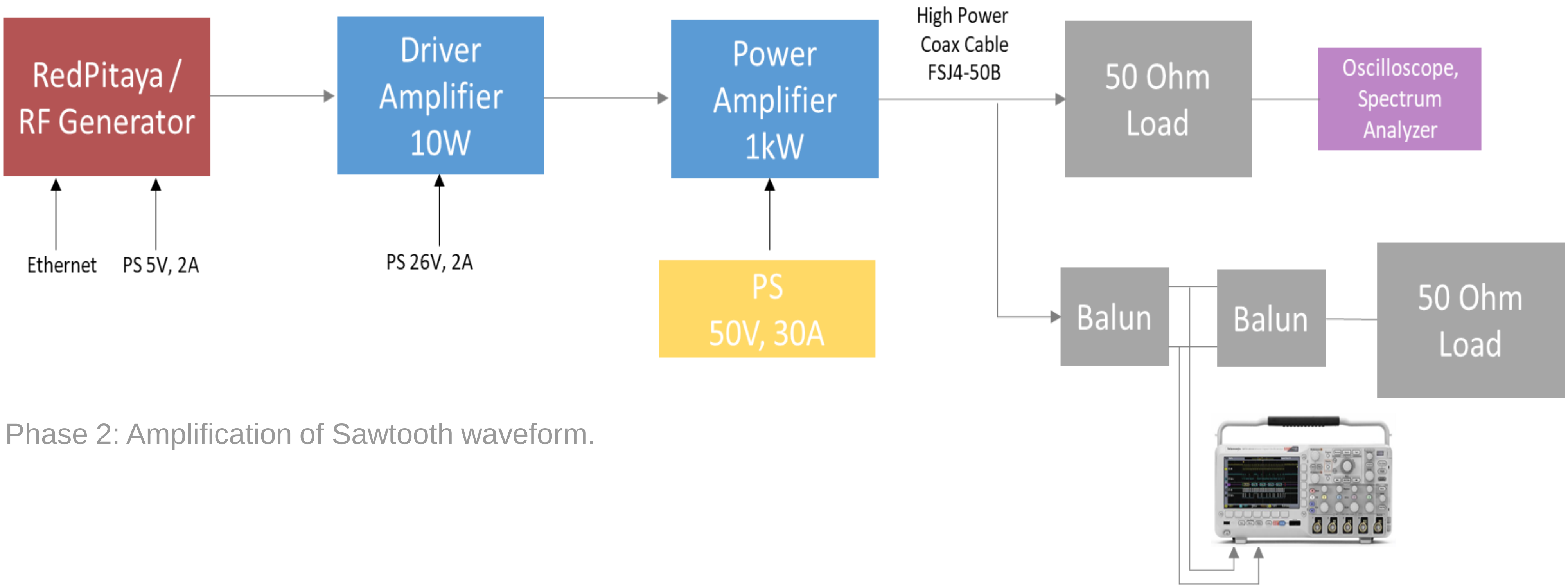


RED PITAYA STEMlab 125-14

- ❖2 RF Inputs (14 bit, DC-60MHz)
- ❖2 RF Outputs (14 bit, DC-60MHz)
- ❖FPGA Xilinx Zynq 7010

RF power test stand

- Test stand schematics:

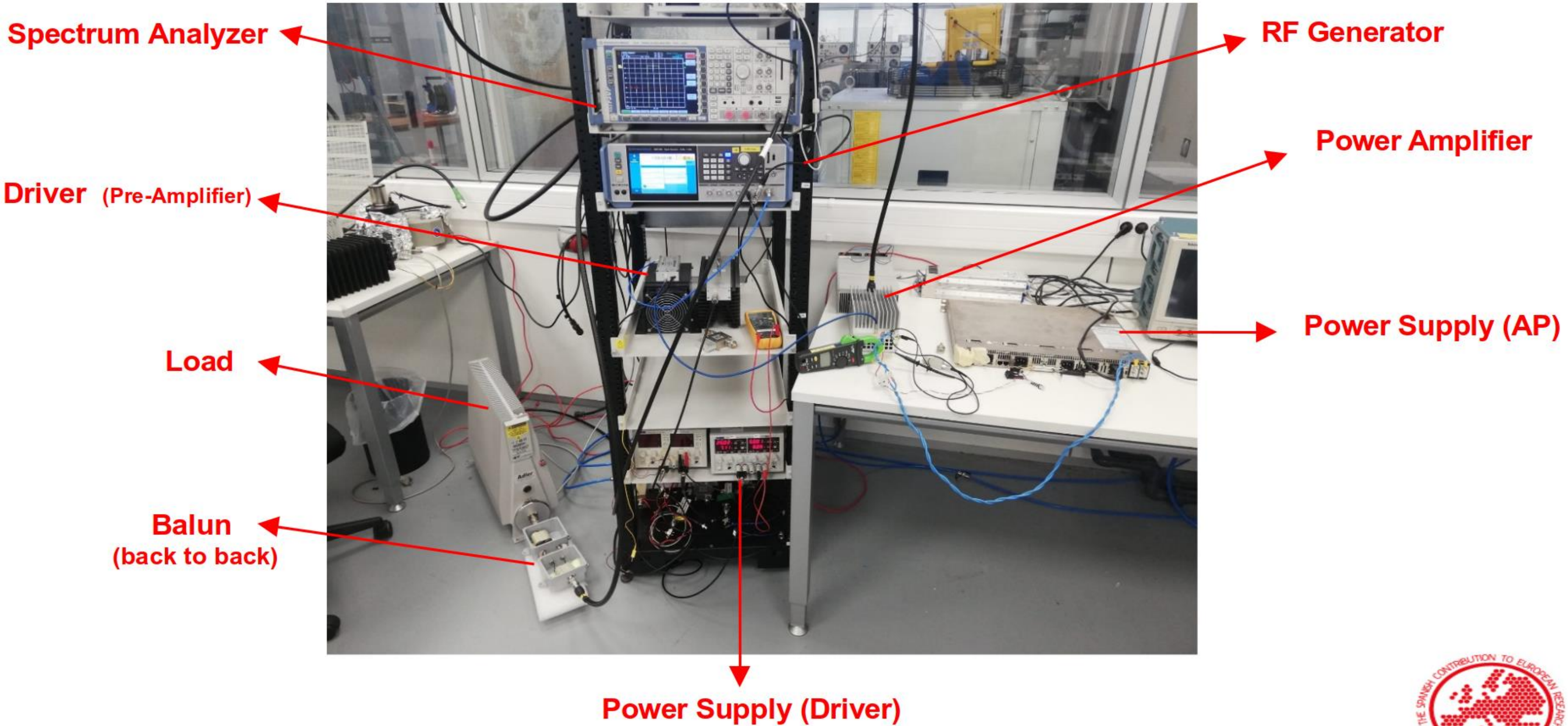


Phase 2: Amplification of Sawtooth waveform.

RF power test stand

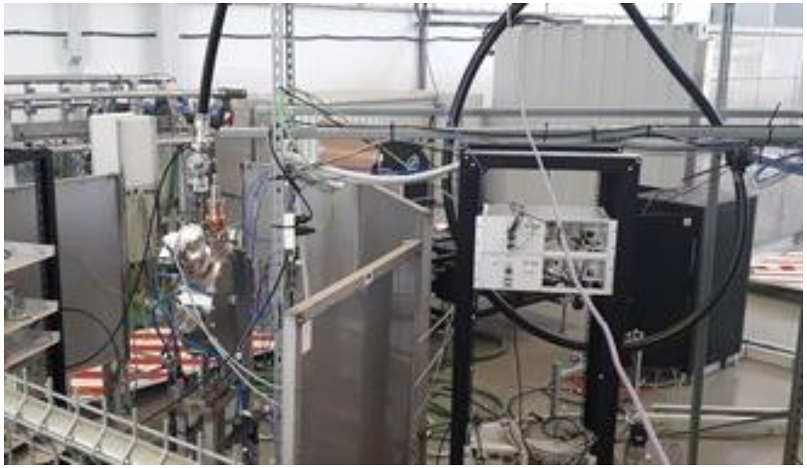
Test Stand

Balun- Balun Configuration



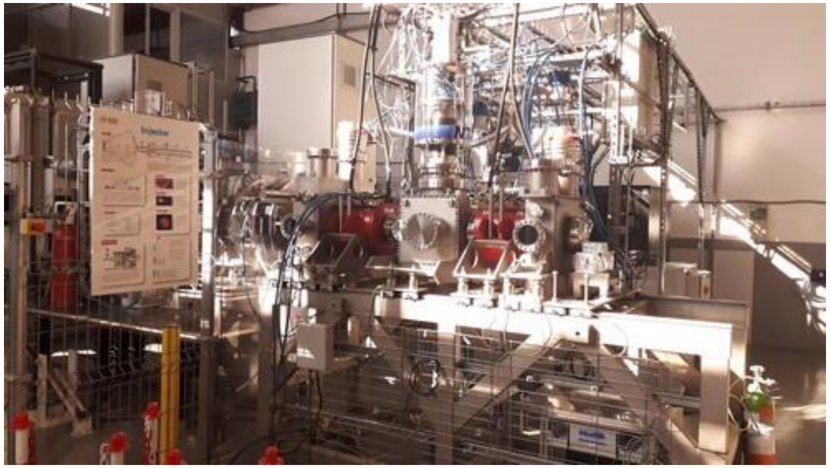
Testing @ ESS-Bilbao

Status during 2021 (previous ISRS meeting)



(Conditioning of ESS-MEBT buncher cavities)

RF Test Stand ready for testing of devices
Possibility of MHB testing with beam



ESS-Bilbao ion source + LEBT

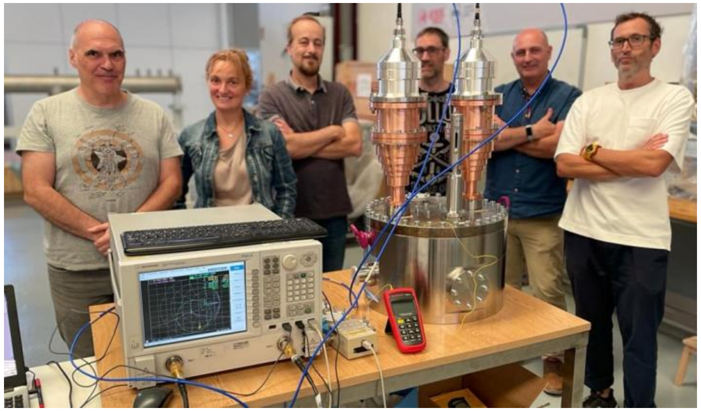
(waiting for RFQ ~2022)

Testing @ ESS-Bilbao

- ESS-Bilbao injector

Testing @ ESS-Bilbao

- ESS-Bilbao injector, waiting for RFQ (expected installation end of 2024-2025).

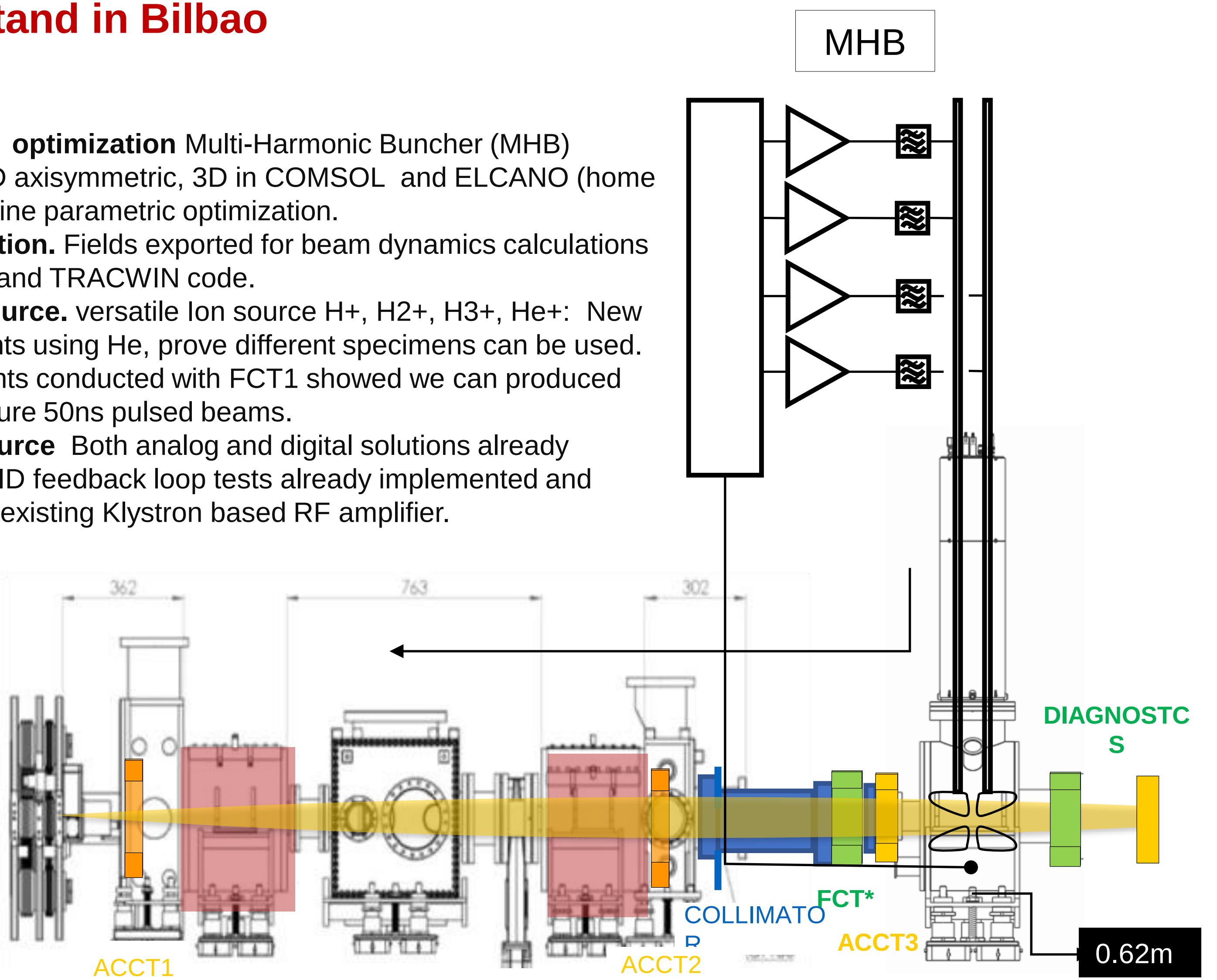


Testing @ ESS-Bilbao

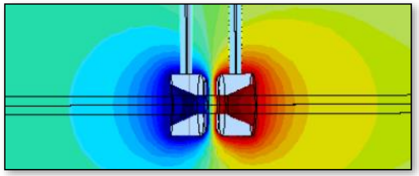
Summary

Test stand in Bilbao

[1] Fields optimization Multi-Harmonic Buncher (MHB) design, 2D axisymmetric, 3D in COMSOL and ELCANO (home code) for fine parametric optimization.
[2] Validation. Fields exported for beam dynamics calculations with GPT and TRACWIN code.
[3] Ion Source. versatile Ion source H+, H2+, H3+, He+: New experiments using He, prove different specimens can be used. Experiments conducted with FCT1 showed we can produced and measure 50ns pulsed beams.
[4] RF Source Both analog and digital solutions already studied, PID feedback loop tests already implemented and verified in existing Klystron based RF amplifier.



[1]



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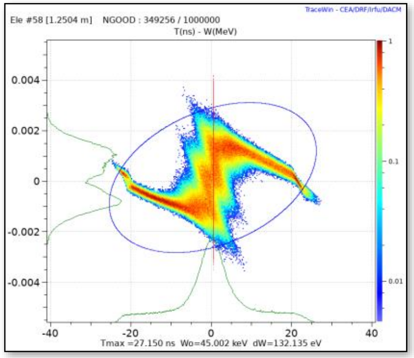
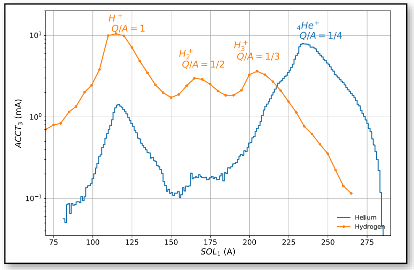
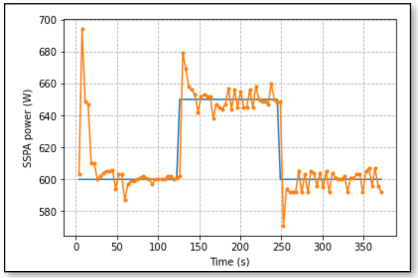


[3]



[4]



MHB

Thank you for your attention!