Multiharmonic Buncher for the Isolde Superconducting Recoil Separator (ISRS) Project

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HB2023, Genève, 11-Oct-2023

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Contents

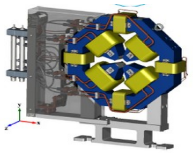
- Introduction to ESSB, ISRS and ISRS R&D program
- Multi-Harmonic Buncher concept and design
- RF power signal generation
- Plans for tests in ESS-Bilbao

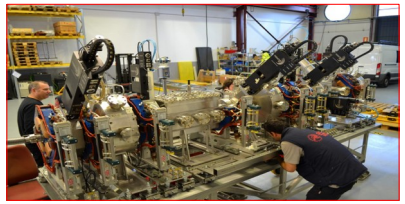
Financiado por la Unión Europea
NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
ESPAÑA PUEDE
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea
NextGenerationEU
CERN
ISOLDE

ESS-Bilbao

Public consortium of Spanish and Basque Governments, devoted to particle accelerators and neutron scattering science and technologies. Main activity: Spanish in-kind contribution to ESS project (MEBT, RF, Target station, MIRACLES instrument)

MEBT



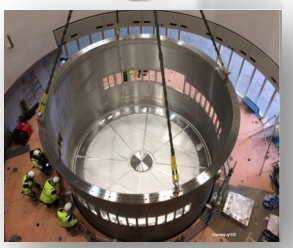


Accelerating element: complete subsystem that goes after the RFQ and integrates: design, manufacturing, diagnostics, control, assembly and testing.

RF Systems

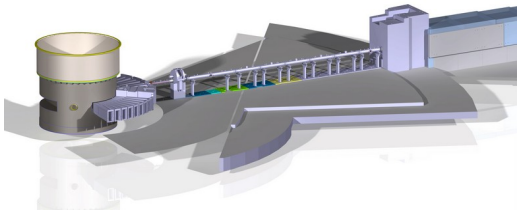
RF chains: 1 for RFQ and 5 for DTL. Composed by klystrons, modulators, loads, waveguides, interlocks and LLRF

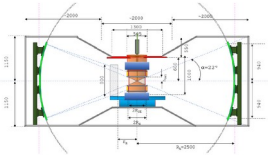
TARGET

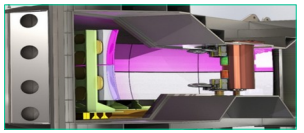


The spallation process takes place when the accelerated proton beam hits the Tungsten bricks of the 11-tonne target wheel. This will produce neutron brightness for scientific experiments across multiple disciplines.

MIRACLES INSTRUMENT







Time-of-Flight backscattering instrument for polymer science, energy materials, and magnetism studies.
Prime contractors: design, manufacturing, assembly &cold commissioning

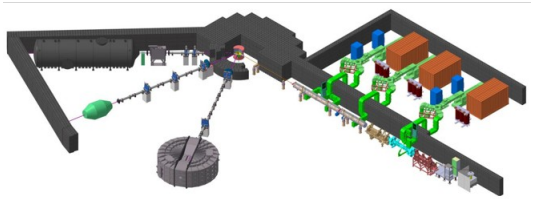
EUROPEAN SPALLATION SOURCE

ESS-Bilbao

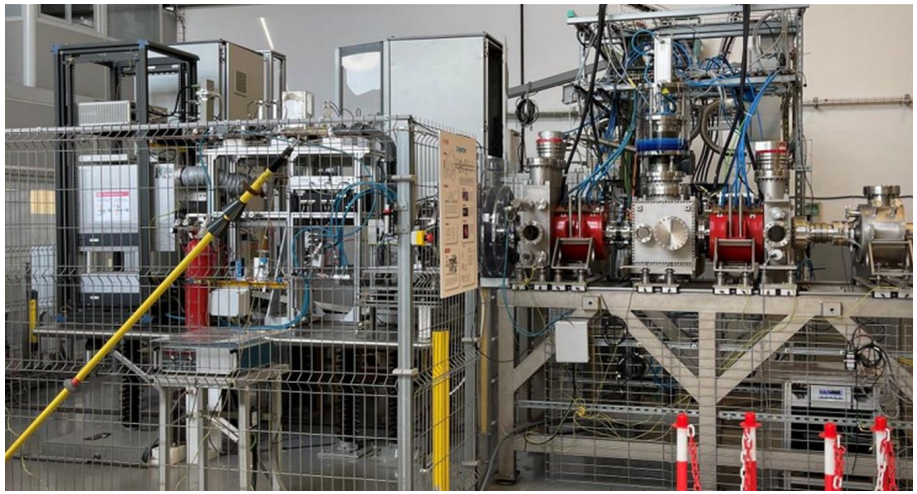
Local project: ARGITU CANS (Compact Accelerator-driven Neutron Source)

- ARGITU is part of European Low Energy accelerator-based Neutron (**ELENA**) Association.
- ARGITU Accelerator a multi-purpose machine that could provide 30 MeV proton beam.
- The proposed neutron source will have up to 4 instruments per target station, it could be possible to consider a dedicated moderator per instrument.

ELENA
European Low Energy accelerator-based Neutron facilities Association

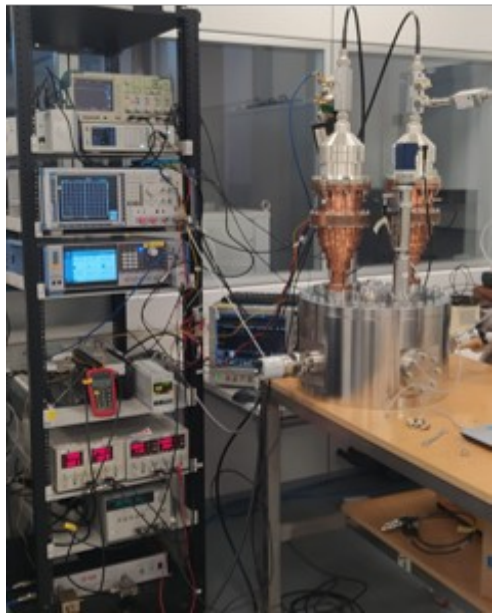


More info: M. Perez et al., "ARGITU compact accelerator neutron source: A unique infrastructure fostering R&D ecosystem in Euskadi", Neutron News, Vol. 31, issue 2-4, pp. 19-25, Dec. 2020, (https://doi.org/10.1080/10448632.2020.1819140)



Injector (H^+, He, N), ion source + LEBT (45 keV)

RFQ under fabrication (3 MeV) and testing



ISRS project

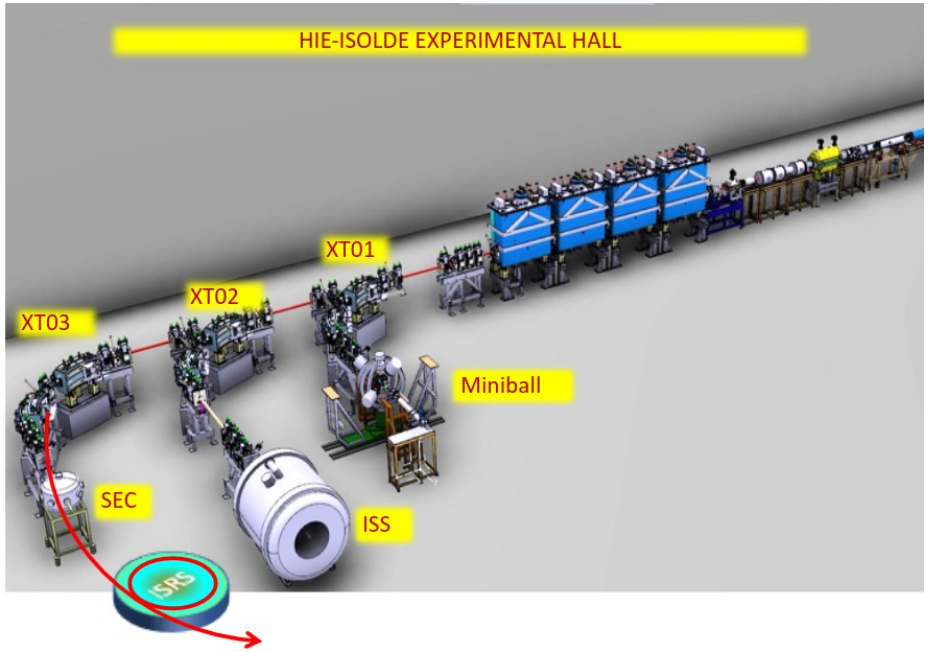
- ISOLDE Superconducting Recoil Separator

HIE-ISOLDE FACILITY AT CERN

World-leading facility in radioisotope production and acceleration:

- Large range of radioactive beams from 6He – 234Ra
- Wide energy range 0.45 -~ 10 MeV/A

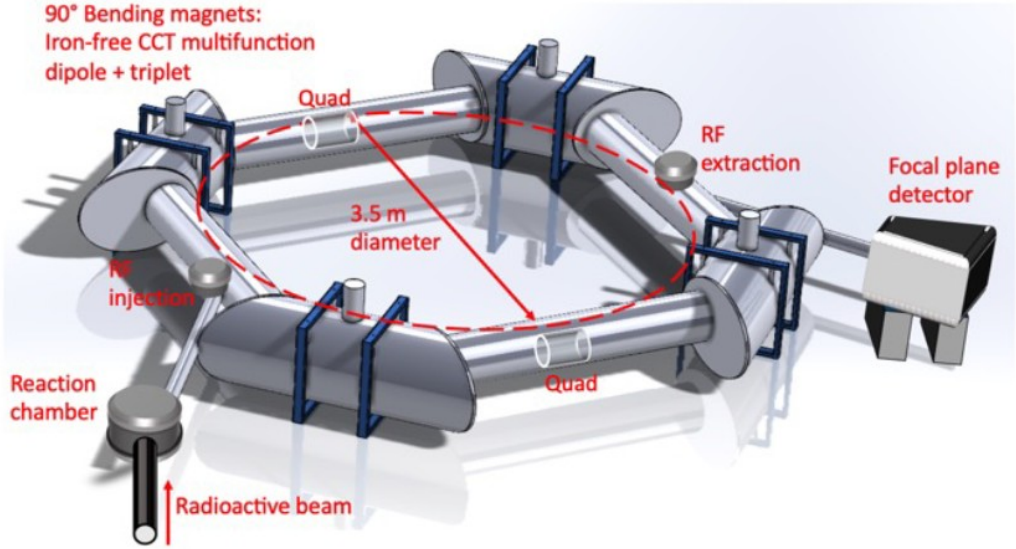
- A Recoil Separator will benefit ISOLDE physics program.

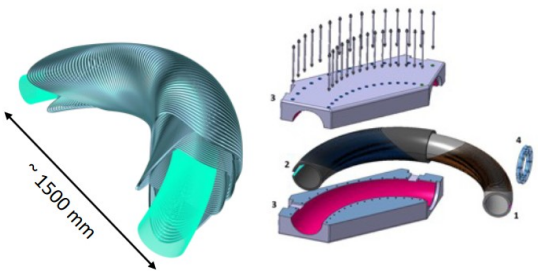


ISOLDE Superconducting Recoil Separator

ISRS project

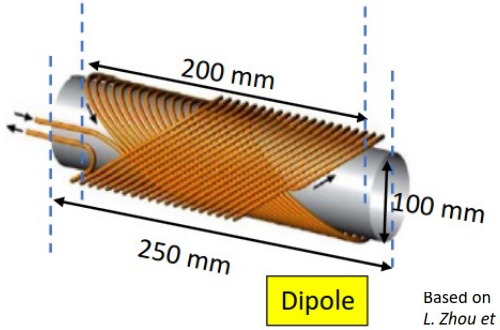
- ISRS present configuration

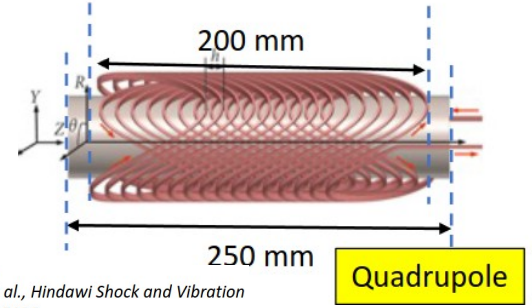




G. Kirby et al., IEEE Tran.App.Sup. 23(2022)1-5

- Fixed Field Alternating Gradient -> accepts large divergence and momentum spread
- Superconducting magnets -> reduced size, mass, large fields
- Multifunction magnets (dipole, quad., sextup.) -> compact magnets
- Canted Cosine Theta (CCT) -> reduce field errors, easier design/ fabrication
- Iron free (magnetic shield) -> reduced thermal mass, weight, non-linearities
- Cooling by cryocoolers -> easier operation, displacement (rotation)





Based on
L. Zhou et al., Hindawi Shock and Vibration 2021, 8895136

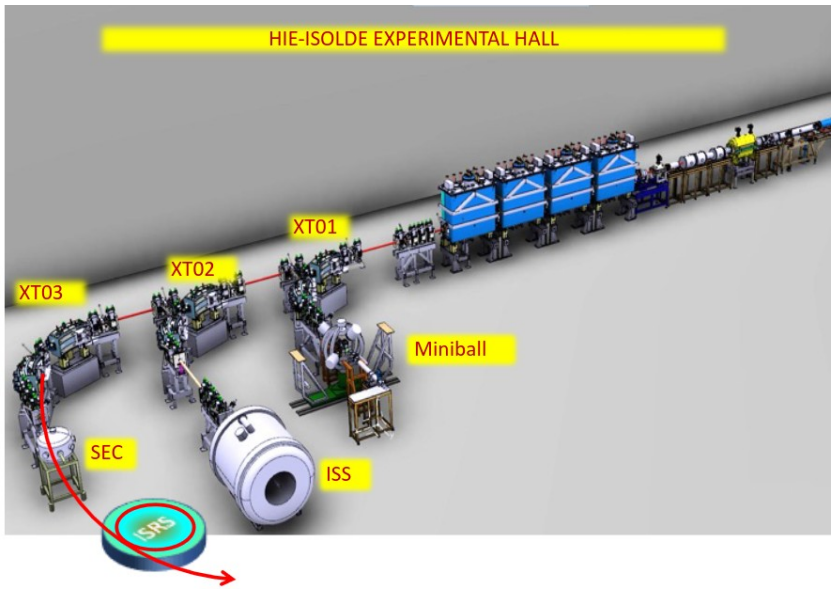
LoI INTC-I-228: Design study of a Superconducting Recoil Separator for HIE-ISOLDE.
Spokespersons: I. Martel, O. Tengblad, J. Cederkäll

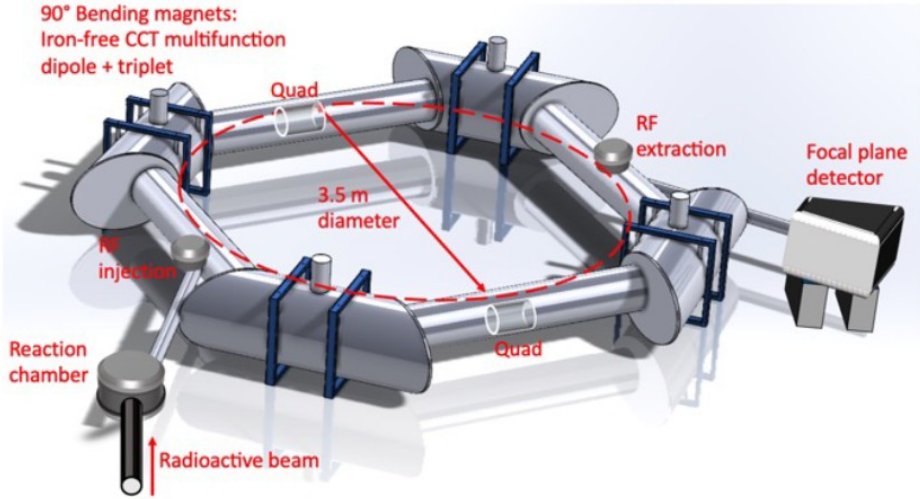
ISOLDE Superconducting Recoil Separator

ISRS – ISRS-Spain - MHB

- **ISRS project proposal** (https://www.uhu.es/isrs/)
  - ISRS R&D project (Spanish funding)
    - MHB for ISRS

ISOLDE Superconducting Recoil Separator





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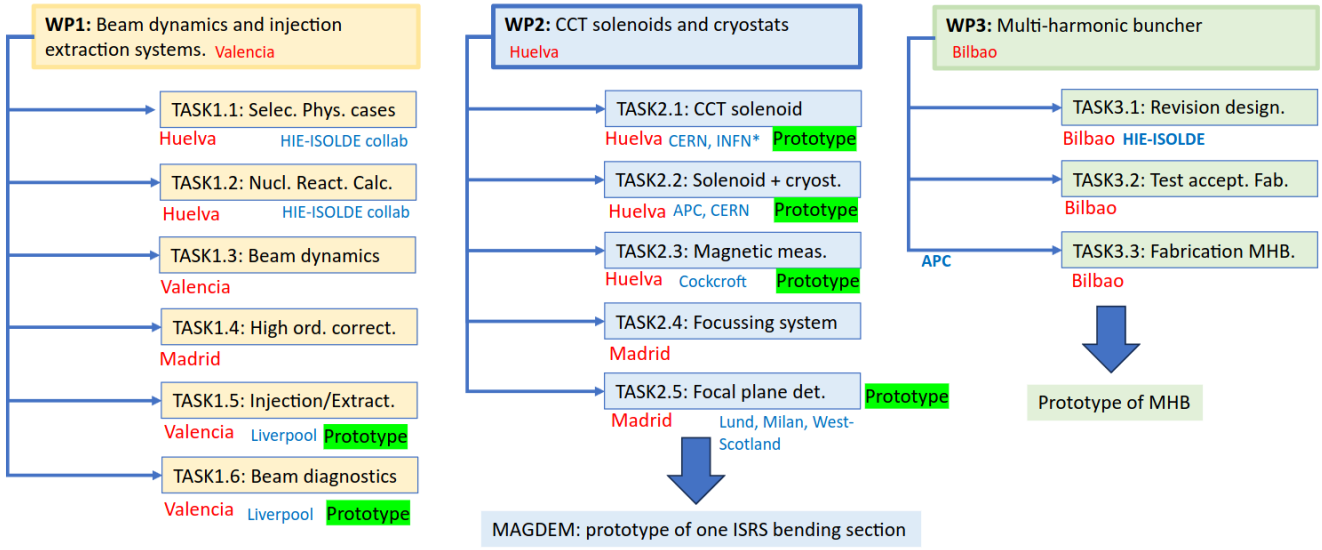
WORK PACKAGE BREAKDOWN

- Reordering of LOI WPs in only three: WP1, WP2 and WP3
- In RED, Spanish institutions receiving funding and responsible of deliverables



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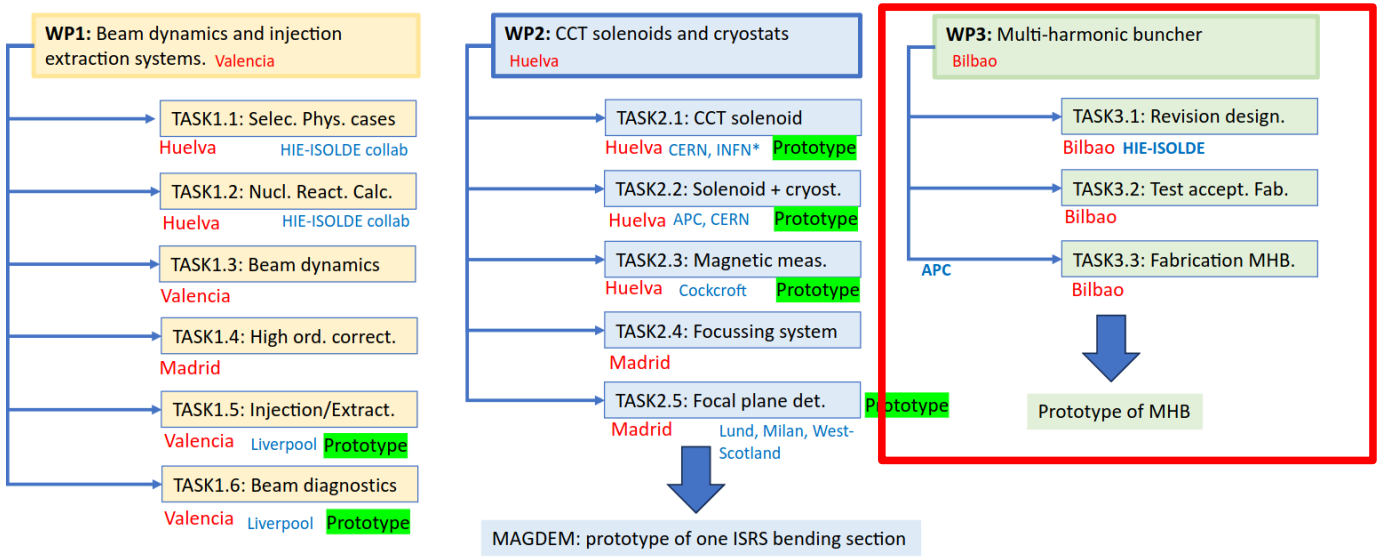

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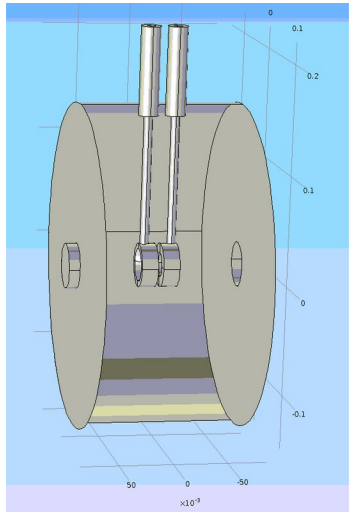
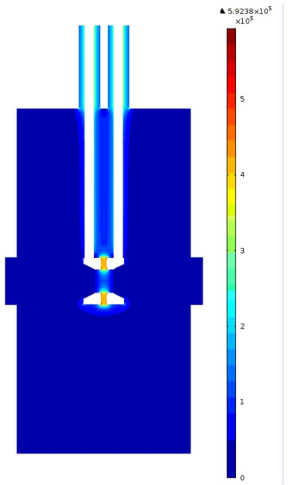




WP3: Multi-harmonic buncher
Bilbao

TASK3.1: Revision design.
Bilbao **HIE-ISOLDE**

TASK3.2: Test accept. Fab.
Bilbao

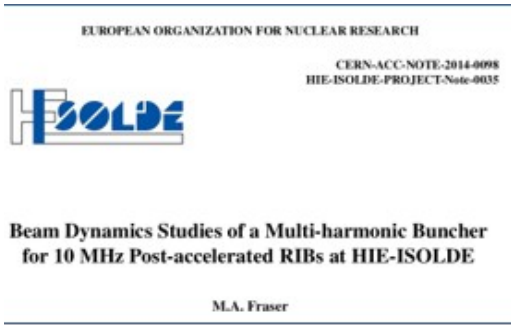
TASK3.3: Fabrication MHB.
Bilbao

APC

Prototype of MHB

Multi-Harmonic Buncher (MHB)

- 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

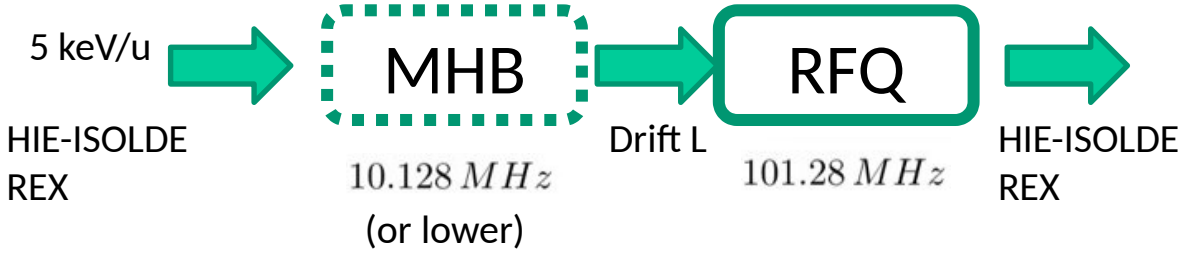
Beam Dynamics Studies of a Multi-harmonic Buncher for 10 MHz Post-accelerated RIBs at HIE-ISOLDE

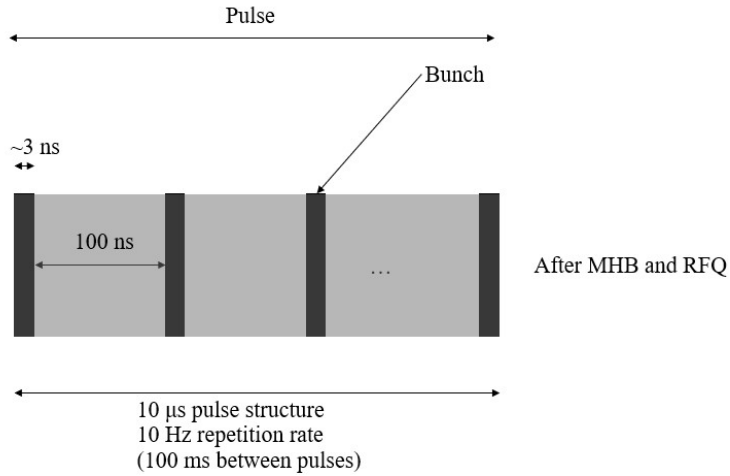
M.A. Fraser

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× double-gap	single-gap

$$f = 101.28\,MHz \rightarrow 9.87\,ns$$
$$f = 10.128\,MHz \rightarrow 98.7\,ns$$

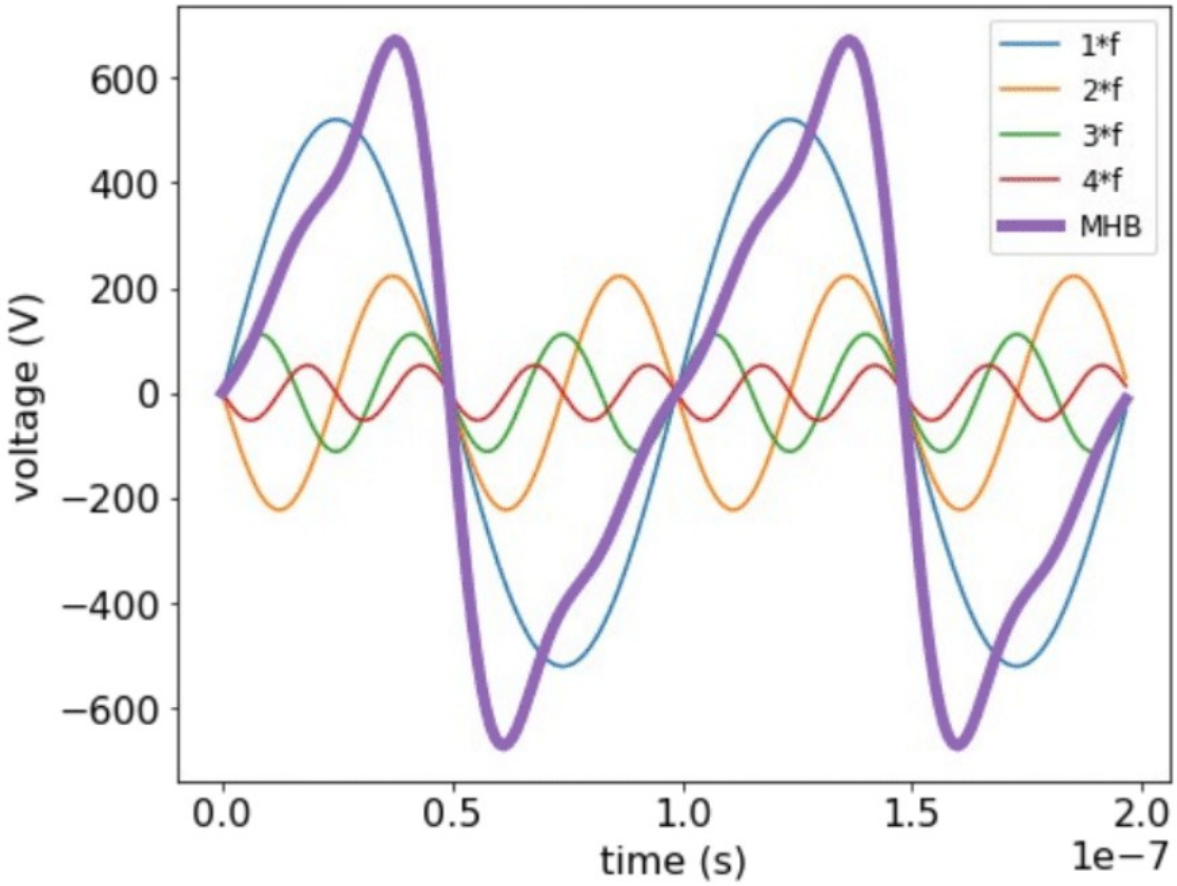




Multi-Harmonic Buncher (MHB)

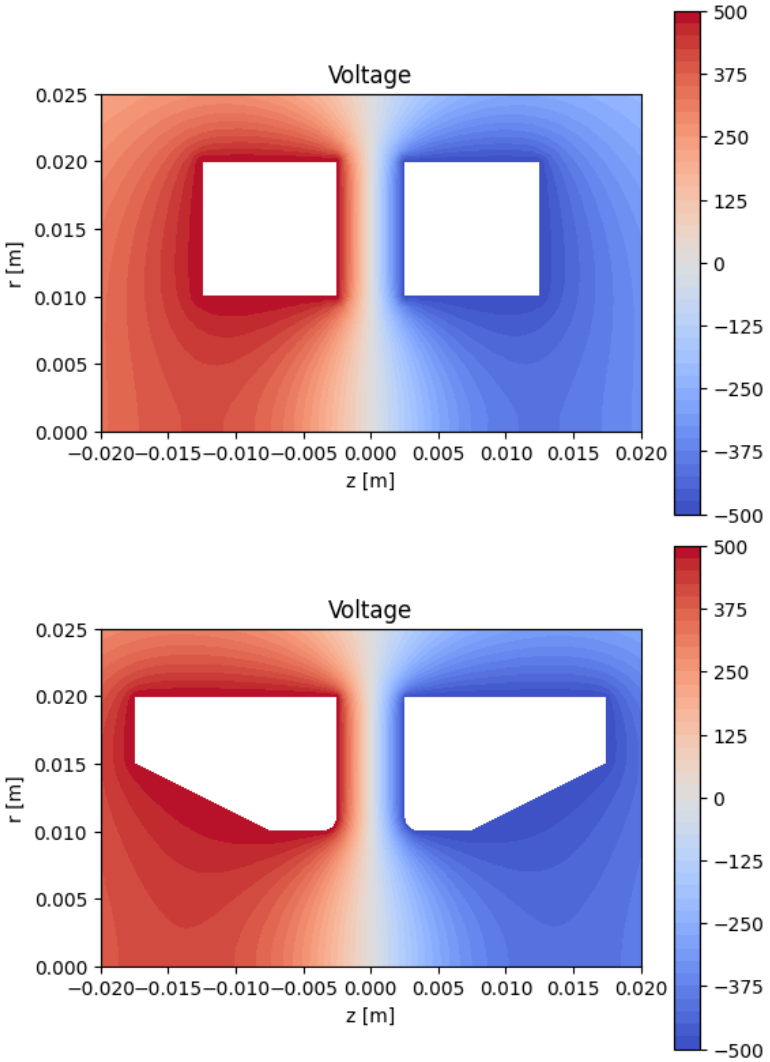
- Multi-Harmonic Buncher

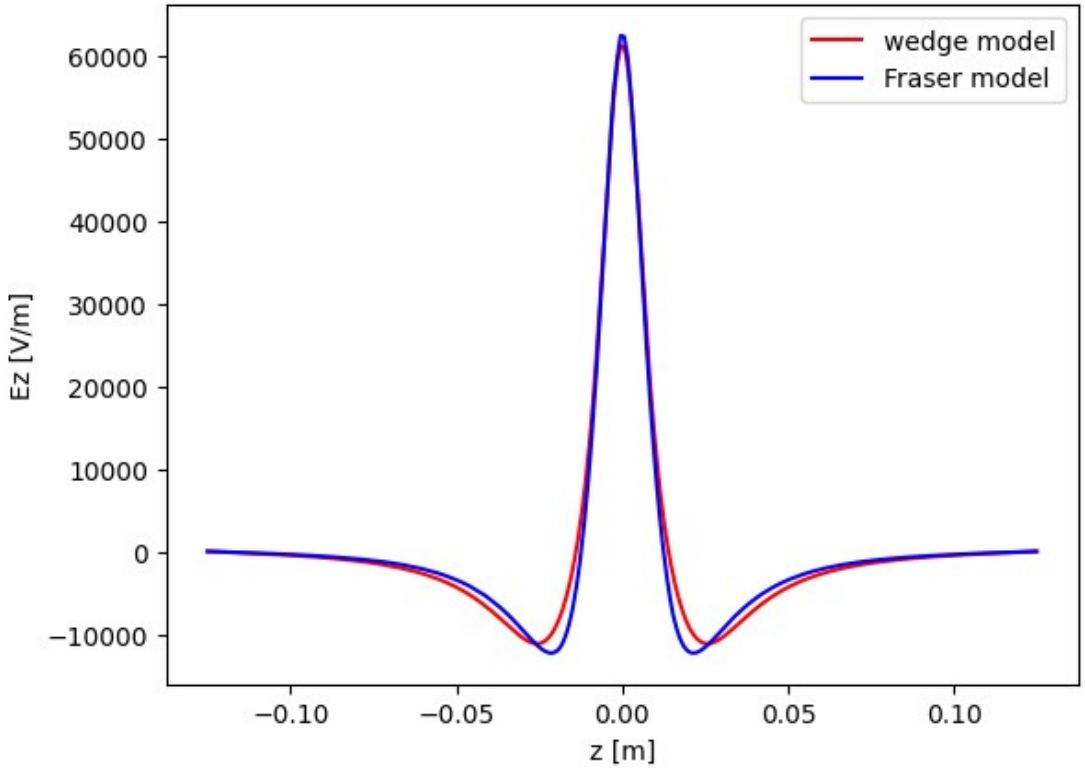
  The optimum field profile for bunching is a saw-tooth profile, that can be achieved by adding-up several harmonic components of the base frequency



Multi-Harmonic Buncher (MHB)

- Electrode design (2D-axisymmetric models)





Multi-Harmonic Buncher (MHB)

- Integrated computational framework (geometry + mesh + electromagnetic + beam dynamics). ELCANO electromagnetic solver linked with GPT.

```
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)
#
```

pygpt is a homemade python wrapper for GPT beam dynamics code

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

Multi-Harmonic Buncher (MHB)

- Quick calculation for comparing electrode geometry models.
- Electric field computed for electrostatics model is then modulated according to:

$$E_{MHB}(r,z) = (\frac{V_0}{1000})E_0(r,z)\sum_{n=1}^{4}(a_n \sin n\omega t)$$

a_0=1, a_1=-0.428, a_2=0.215, a_4=-0.101

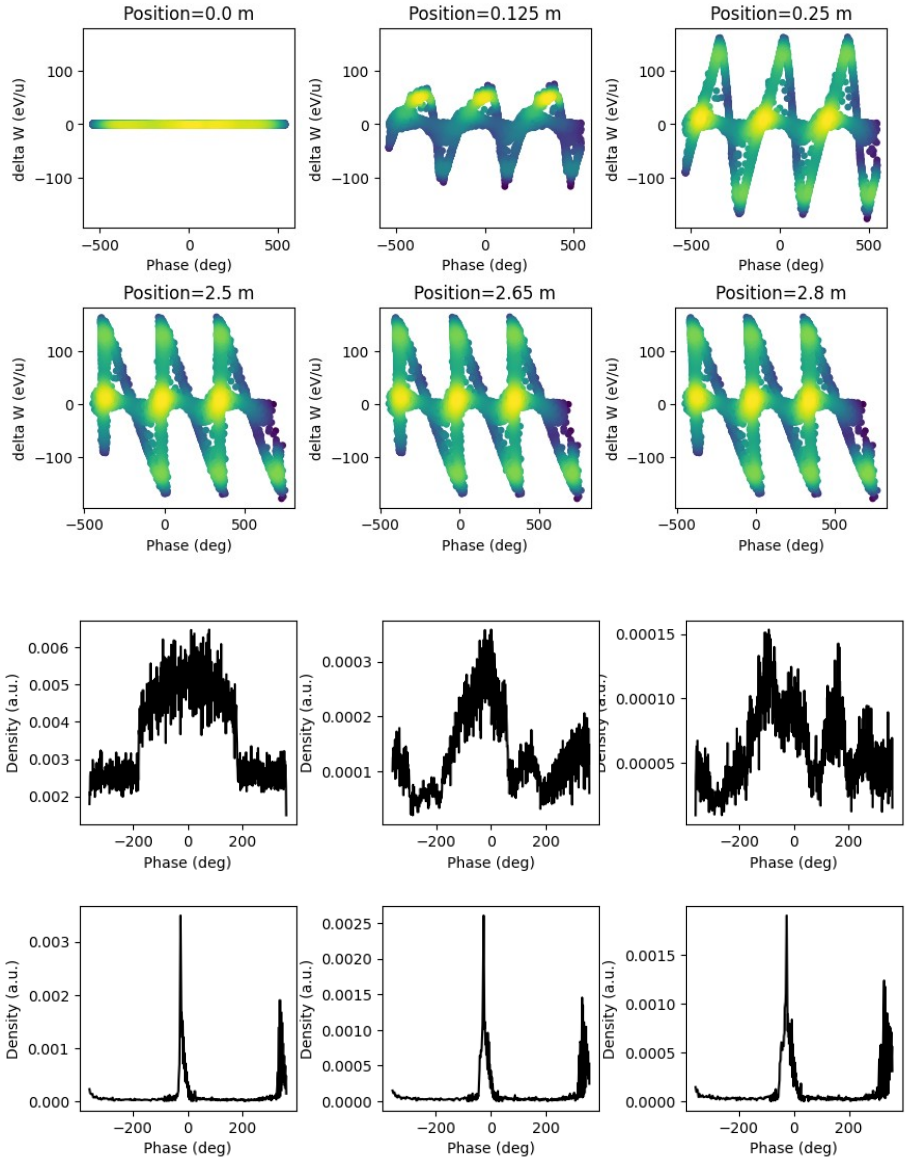
- Input beam characteristics for this preliminar study:

  A/q=4.5, β=0.00328

  ϵ_x, ϵ_y=0.62 mm mrad

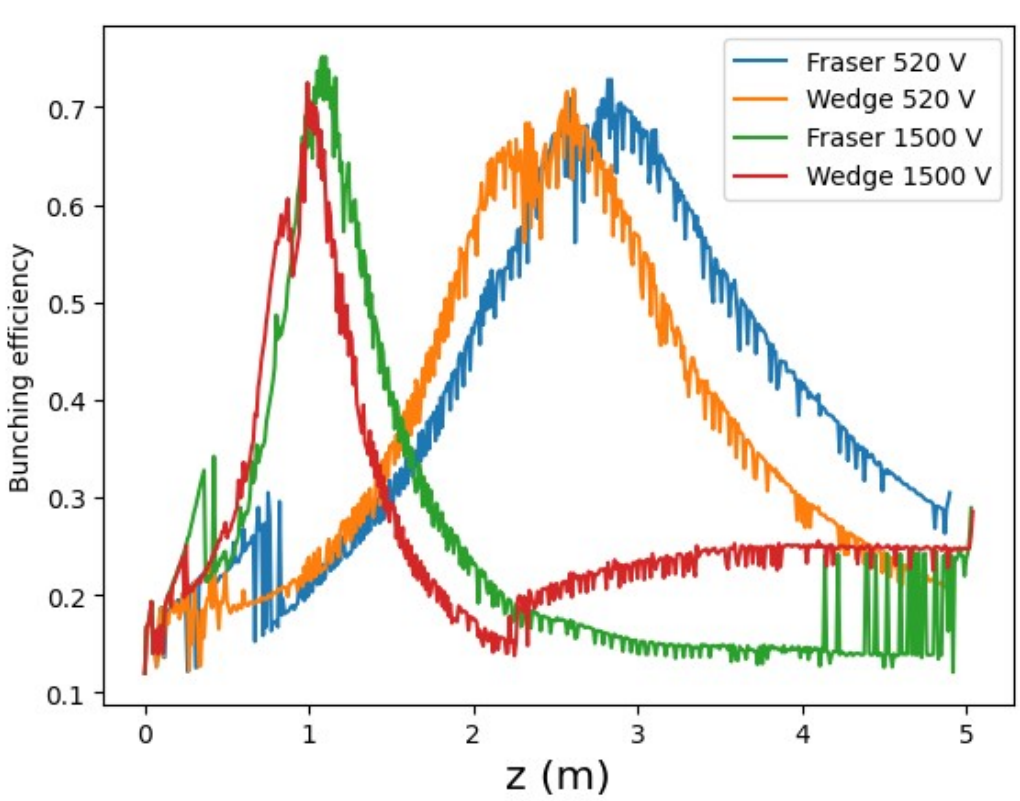
  I = 1 nA (no space charge)

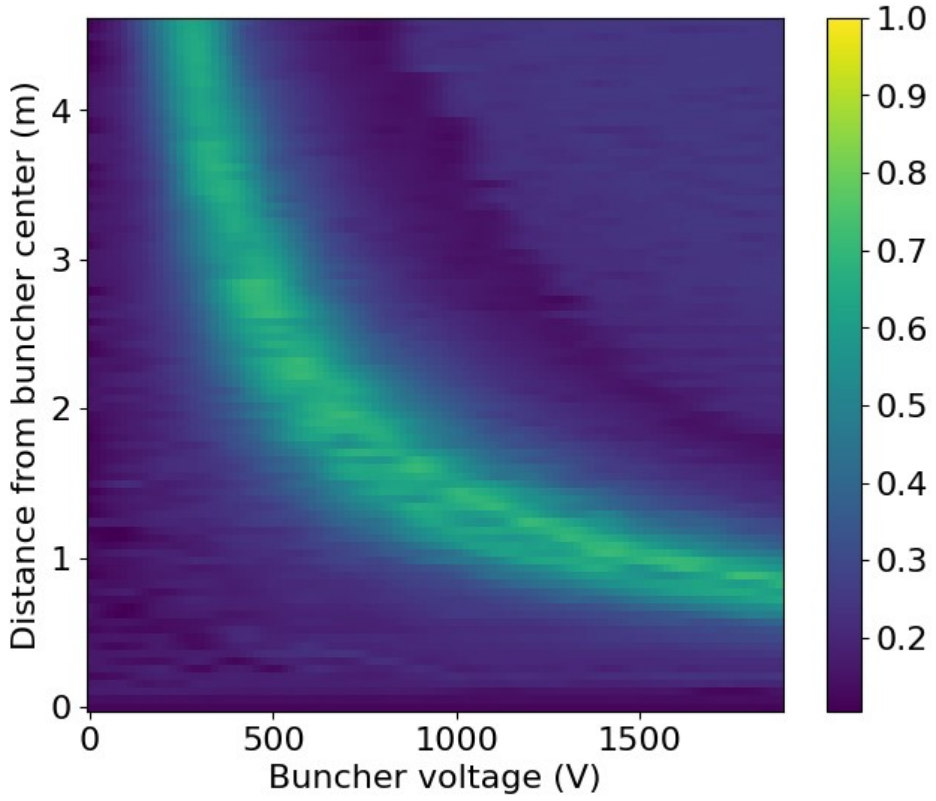
- Final design (for PDR) will be carried out after iterations with ISOLDE team.



Multi-Harmonic Buncher (MHB)

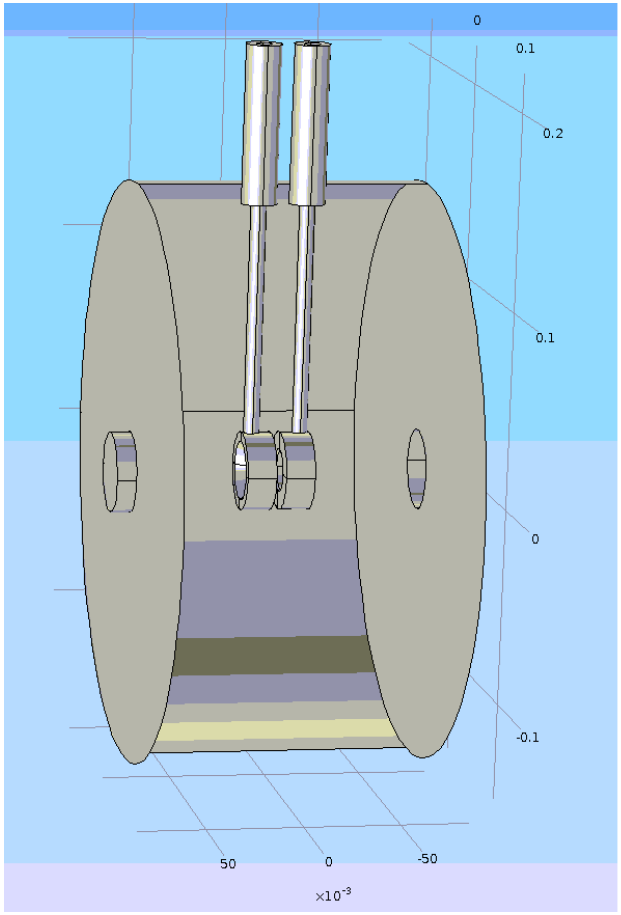
- Bunching as a function of electrode voltage and distance, different geometries.

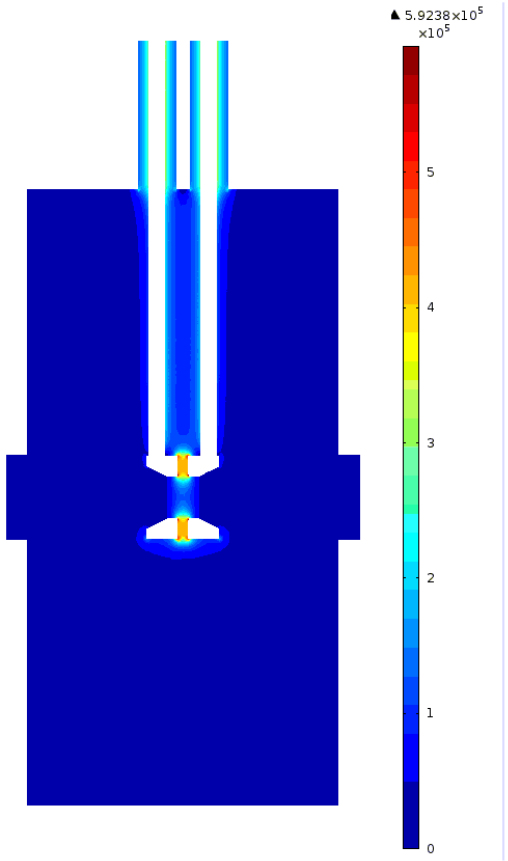


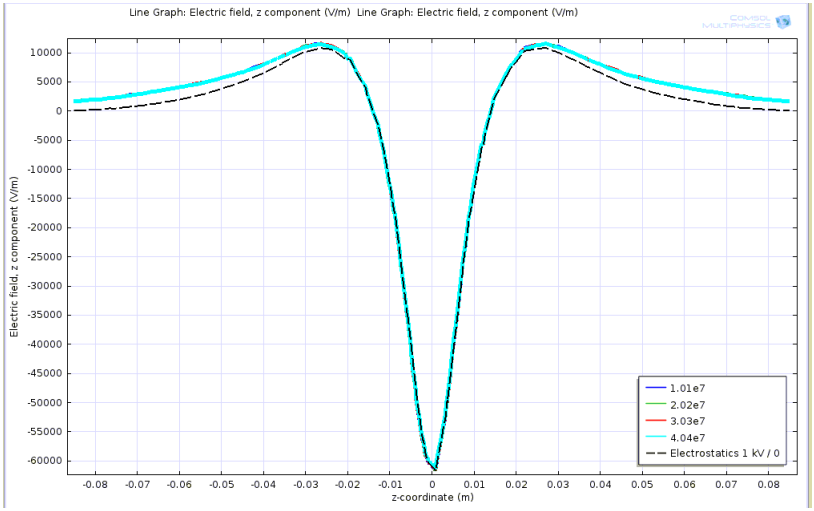


Multi-Harmonic Buncher (MHB)

- 3D electromagnetic model in COMSOL

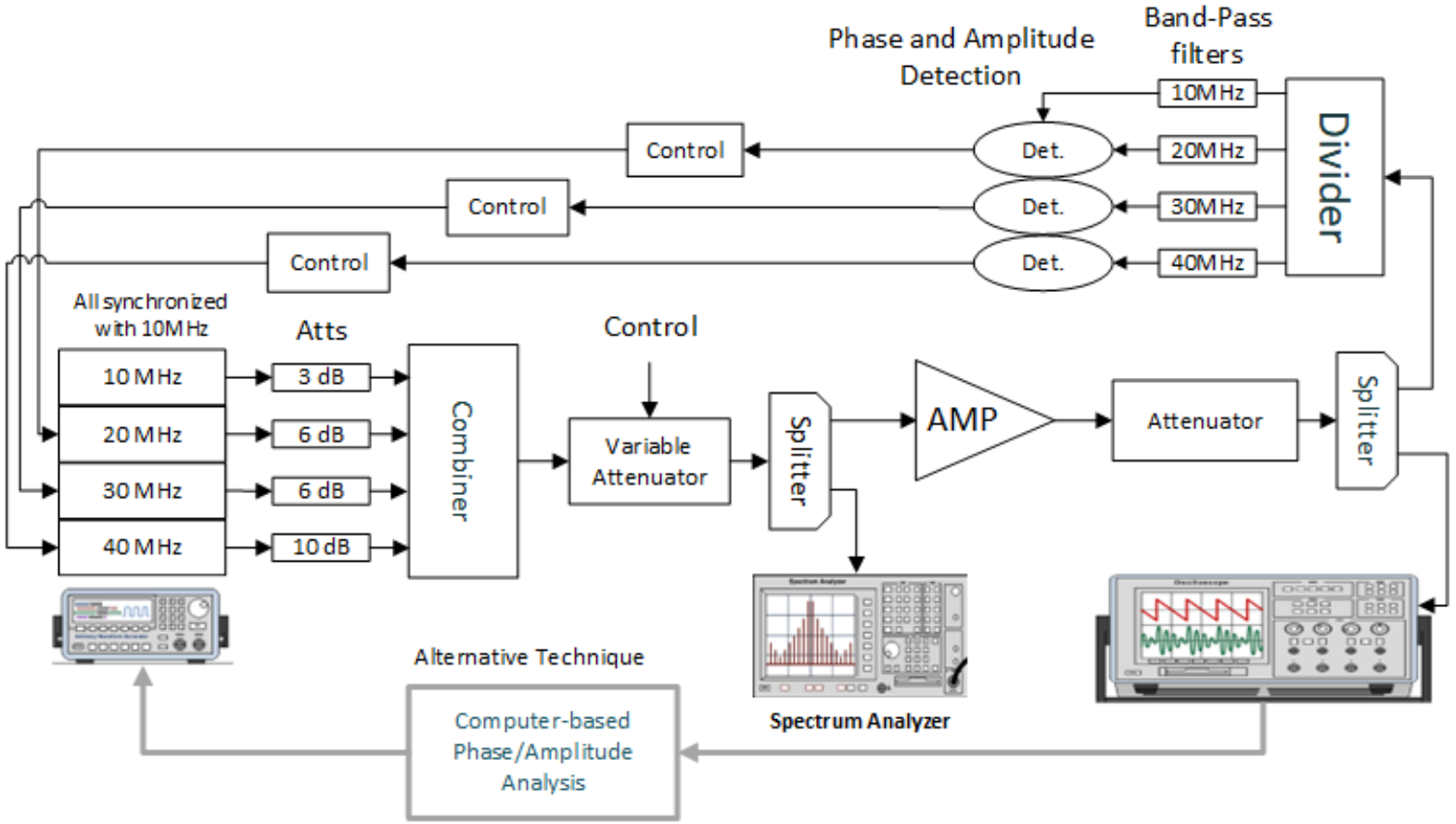






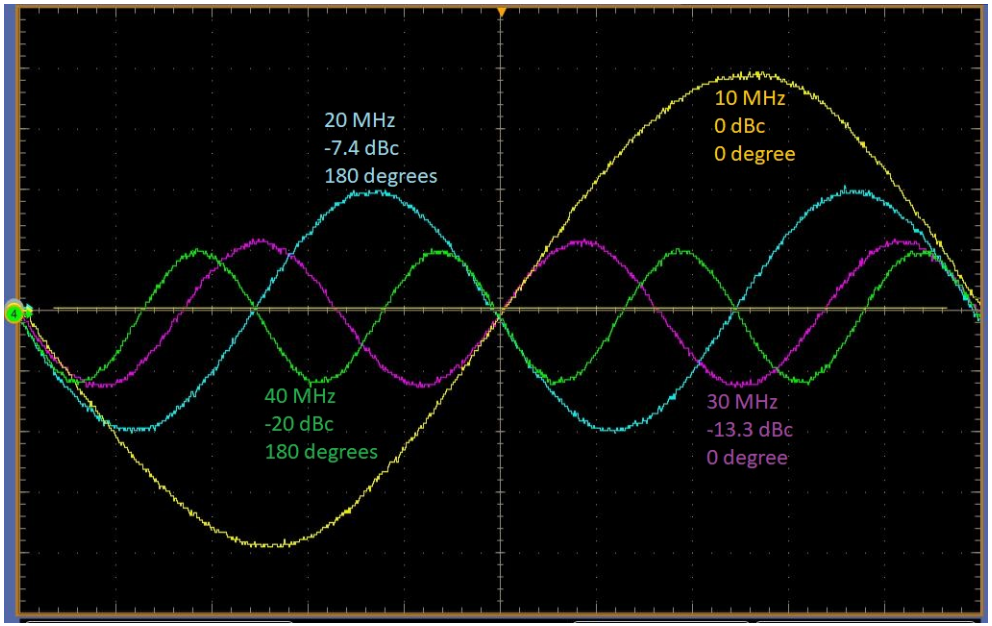
Signal generation

- MHB signal generation and combination



Signal generation

- MHB signal generation and combination
- Combined signal at the test-bench



Tests at ESS-Bilbao

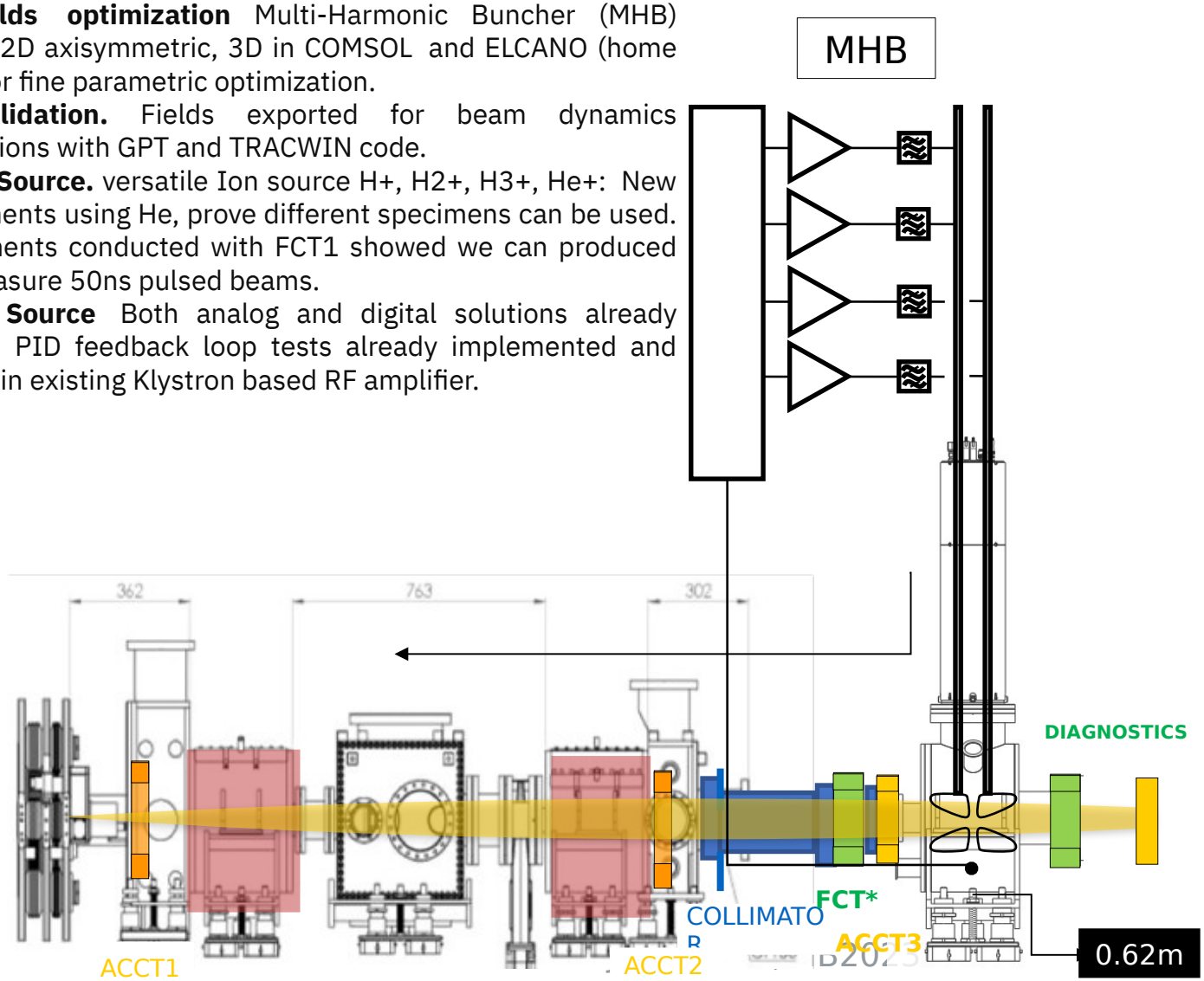
- ESS-Bilbao injector

- Nominal:
  - Proton injector
  - 45 keV
  - 30 mA
- Tests are on-going with lower extraction voltage (Ioert beta), other species (He,N) to test the MHB

Tests at ESS-Bilbao

- ESS-Bilbao injector

[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.



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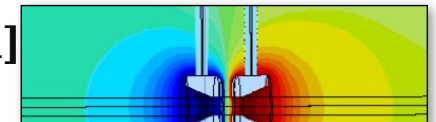
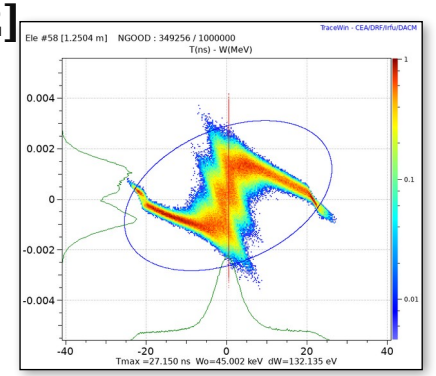


[2]



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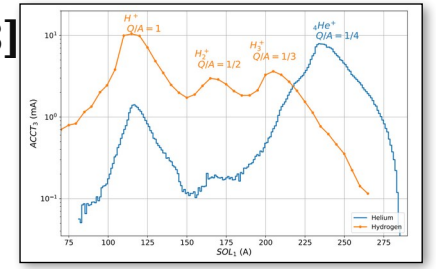
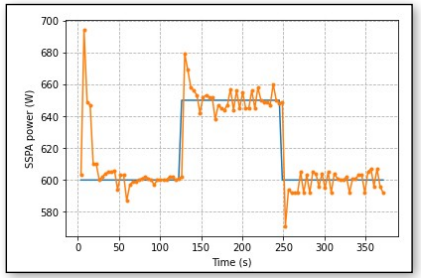


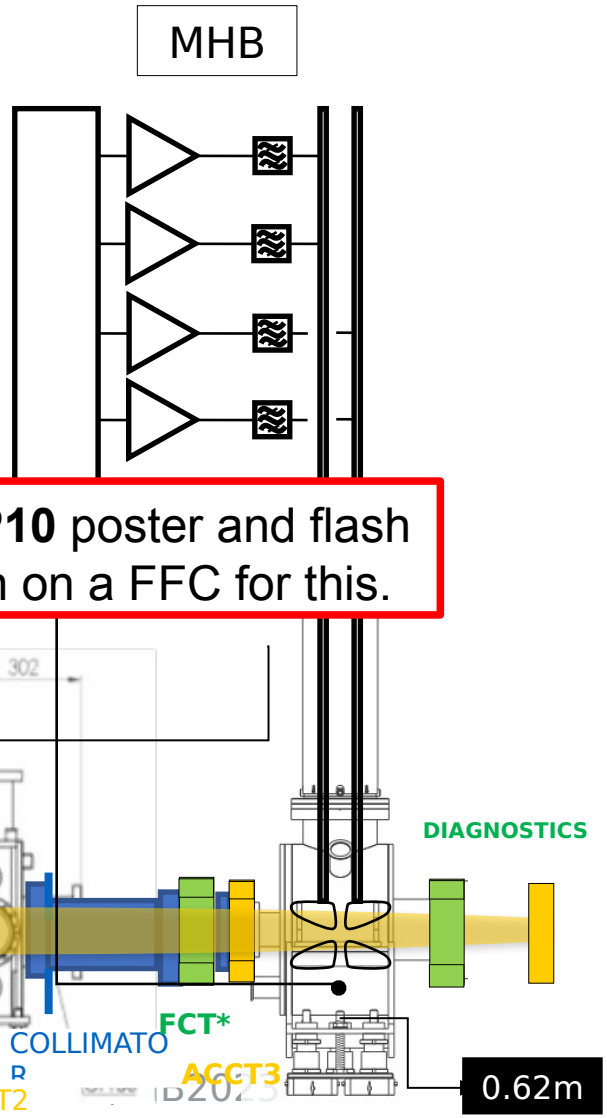
[4]



Tests at ESS-Bilbao

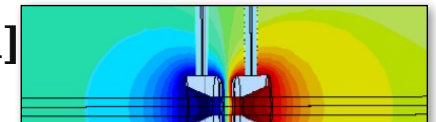
- ESS-Bilbao injector

[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.

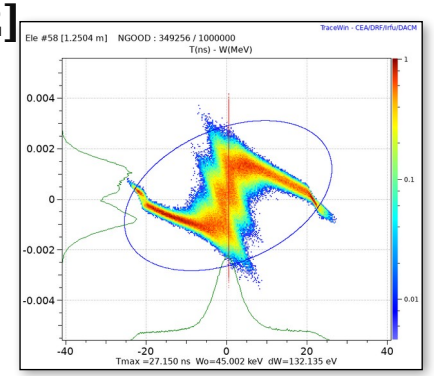


See **THAFP10** poster and flash presentation on a FFC for this.

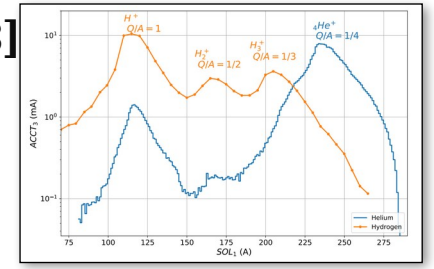
[1]



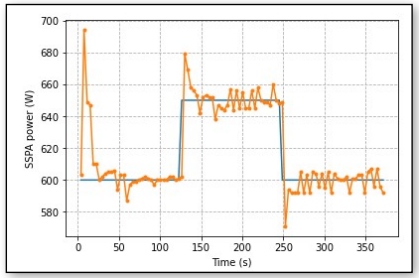
[2]



[3]



[4]



Conclusions

- ESS-Bilbao participates in the ISRS project initiative
- As a part of the work, a Multi Harmonic Buncher device will be designed, and a prototype will be built and a tested
- The MHB will comply with HIE-ISOLDE specifications, so the prototype could be installed or being replicated there
- A SSPA RF signal generation is proposed to power up the MHB with the combined harmonic signal
- Tests will be carried out at ESS-Bilbao injector.

Thanks for your attention!!

ISOLDE Superconducting Recoil Separator