XLS-WP3 Gun and Injector Meeting

X-band Gun RF design

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Summary

- It is worth to mention, our group has no previous experience in the design of RF components. Due to this, the work carried out during the past months is focused on the understanding of the RF gun structures.

- The tasks performed can be split in two categories:

1. Bibliographic review of the technical literature. The objective is become familiar with the theoretical basis that supports photoinjector design and get an insight of how they operate.

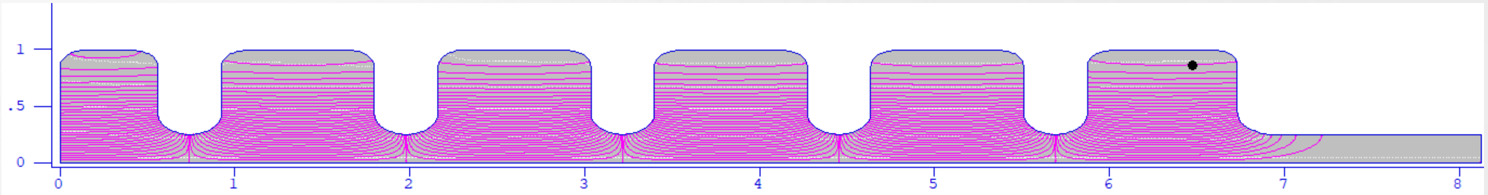
Some of the bibliography revisited:

- T. P. Wangler, "RF Linear Accelerators", ed. Wiley-VCH, 2nd edition, 2008.
- T. Rao, D. H. Dowell, "An Engineering guide to photoinjectors", 2013.
- M. Reiser, "Theory and design of Charged Particle Beams", ed. Wiley-VCH, 2nd edition, 2008.
- L. Faillace, "Innovative Radio-Frequency Linear Accelerating Structures", PhD Thesis, University La Sapienza, 2008.
- F. B. Kiewiet, "Generation of ultra-short, high brightness relativistic electron bunches", PhD Thesis, University of Eindhoven, 2003.

2. Learning to use the computational tools employed for the design of RF guns. Until now, we have focused on those related with the RF design, namely, SUPERFISH (2D) and HFSS (3D).

5.6 cell X-band RF gun

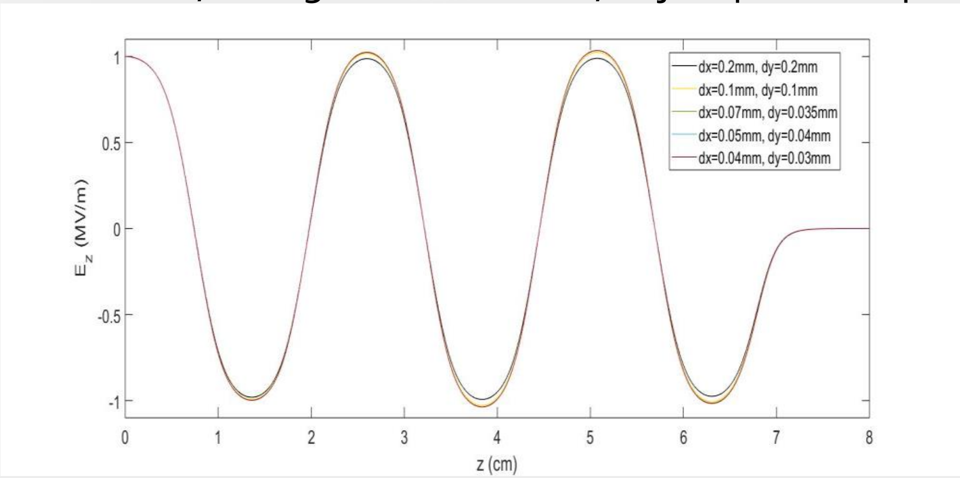
- Firstly, we have been aimed on the analysis of a 5.6 cell X-band RF gun design provided to us by the Prof. Avni Aksoy from the University of Ankara



Scheme of the 5.6 RF gun in SUPERFISH

- This design has been a very useful starting point and it has allowed us to learn about how to use the SUPERFISH software.

- In fact, now we are able to build new geometries, obtain and plot the RF fields, estimate ohmic losses, change the mesh size, adjust precision parameters of the RF solver, etc.



Example: Convergence analysis performed for the Avni RF gun. It is plotted the RF electric field along the gun axis, for different values of the mesh spacing.

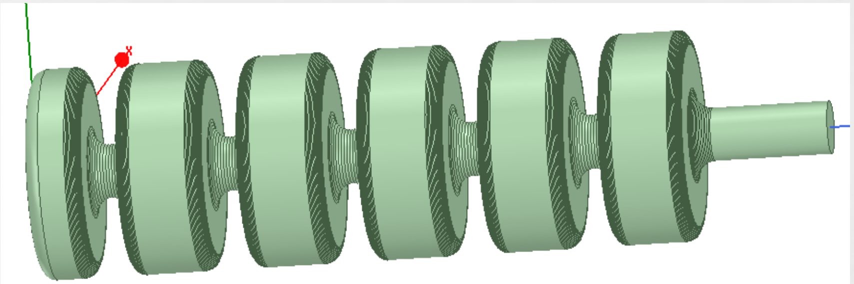
dx(mm)	0.2	0.1	0.07	0.05	0.04
f_{π} (MHz)	11991.47	11990.76	11990.080	11990.04	11989.96

dx, dy are the mesh increments along the z and r directions, respectively

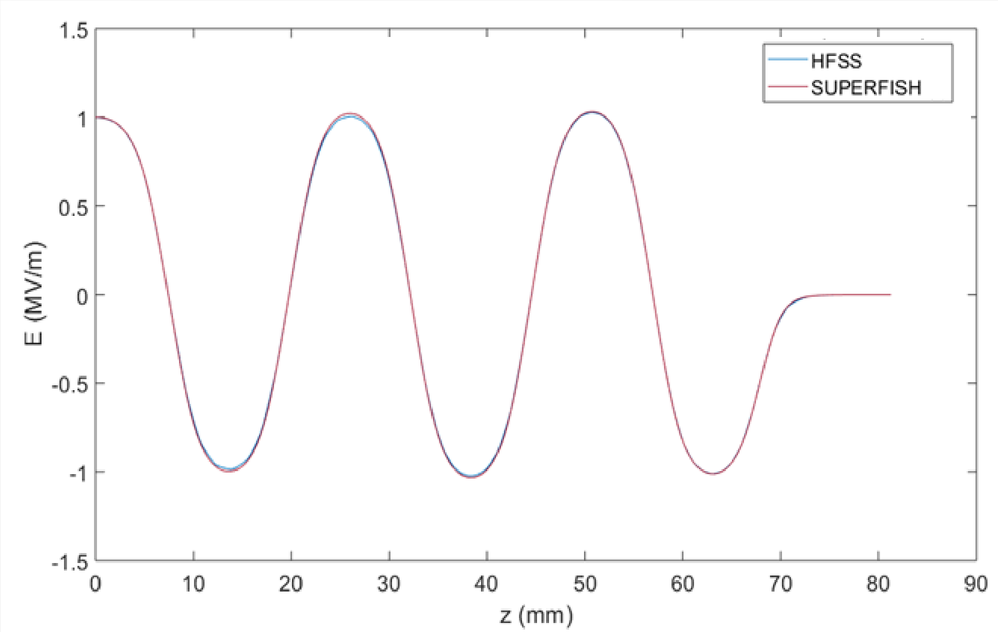
5.6 cell X-band RF gun

- In addition, the same structure was analysed using the HFSS software.

- At present, we are able to use efficiently HFSS: build and analyse RF gun structures (obtain and export RF fields, adjust precision of the solutions, etc.)



3-D view in HFSS of the 5.6 cell X-band gun



Comparison between the results provided by SUPERFISH and HFSS for the 5.6 cell X-band gun

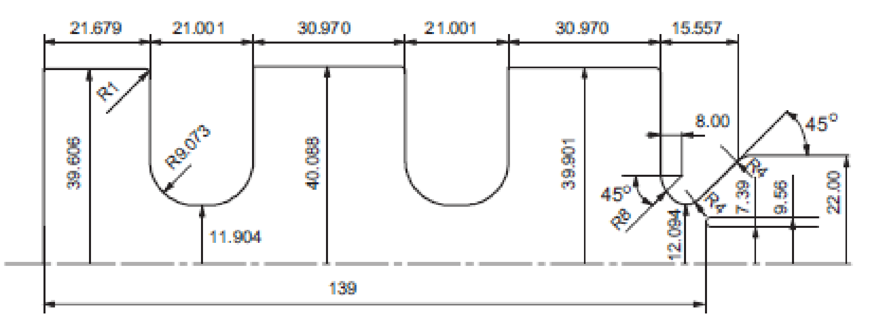
In order to check that we are employing correctly both electromagnetic solvers, it was performed a comparison between the results provided with HFSS and SUPERFISH.

As it is observed in the left figure, there is a very good concordance between them, thus it is demonstrated the accuracy of our analysis.

RF coupler

- Once understood the basic structure of a RF gun, the next step we performed is to acquire some knowledge about the RF coupler that feeds the gun.

- To reach this aim, the following structure extracted from the literature[1] has been considered for the analysis of a coaxial coupler scheme.



Scheme of the 2.6 cell RF gun photoinjector

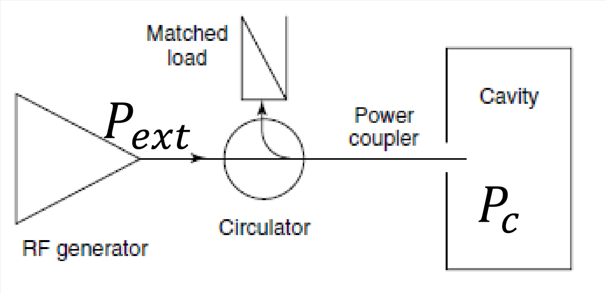
- The main concern is the calculus of the coupling factor, β

$$P_{ext} \equiv Power\ consumed\ by\ the\ external\ circuit$$

$$P_c \equiv Power\ disipated\ in\ the\ cavity\ (RF\ gun)$$

$$\text{Coupling factor}\ \ \beta = \frac{P_{ext}}{P_c}$$

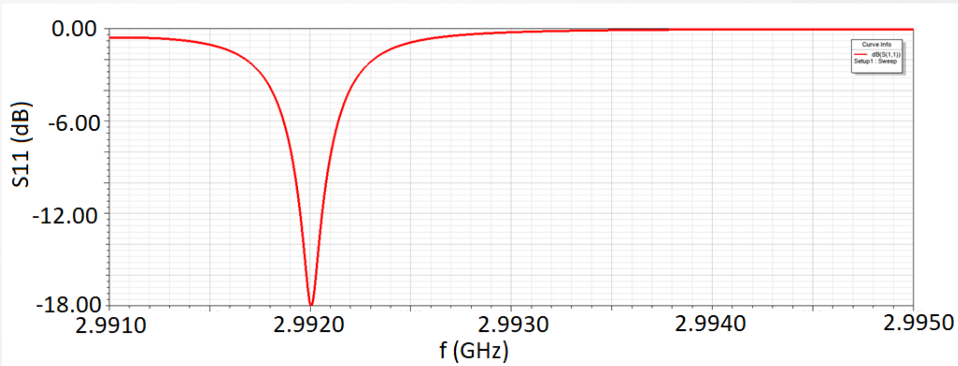
At resonant frequency, it can be shown that $\beta = \frac{1+|S_{11}|}{1-|S_{11}|}$



(1) F. B. Kiewiet, "Generation of ultra-short, high brightness relativistic electron bunches", PhD Thesis, University of Eindhoven, 2003.

RF coupler

- Firstly, the analysis is performed using HFSS. Obtaining β is straightforward:

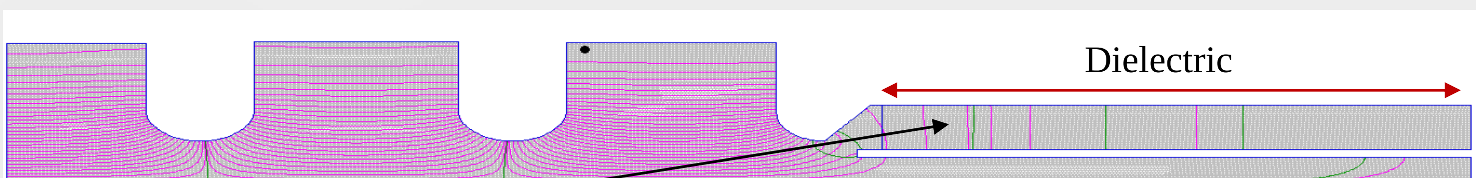


$$|S_{11}| = -17.984\ dB$$

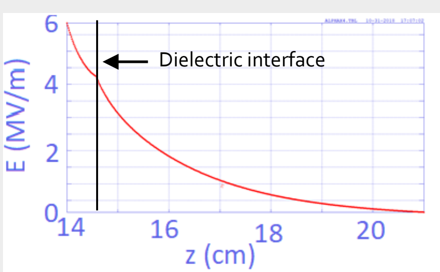
$$\beta = \frac{1 + |S_{11}|}{1 - |S_{11}|}$$

$$\beta_{hfss} = 1.29$$

- Secondly, the analysis is carried out with SUPERFISH. For obtaining β, it must be defined a fictitious dielectric lossy material with properties: $\varepsilon_r = 0.6 + 0.8j$ $\mu_r = 0.6 + 0.8j$



Scheme of the 2.6 cell RF gun with coupler in SUPERFISH



RF electric field along the coupler

If the dielectric length is enough to ensure all the RF power is absorbed, then the coupling factor can be calculated in the following way:

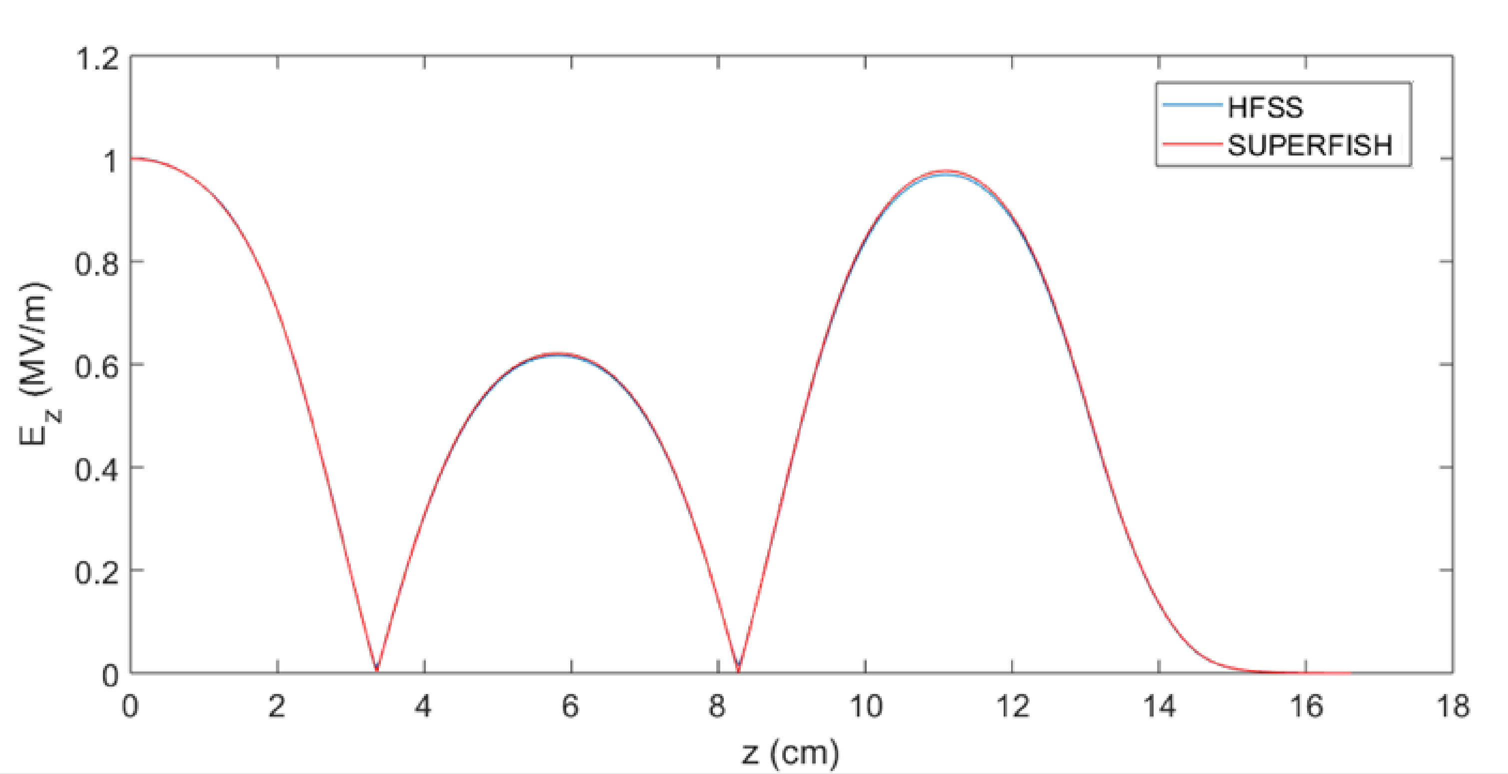
$$P_{diel} = P_{ext} \qquad \beta = \frac{P_{ext}}{P_c} \qquad P_{diel} = 19.346\ MW \qquad P_c = 15.09\ MW$$

$$\beta_{superfish} = 1.28$$

P_{diel} is the power absorbed by the dielectric

RF coupler

- Finally, we compare the axial electric field and the resonant RF frequency for the sake of completeness:



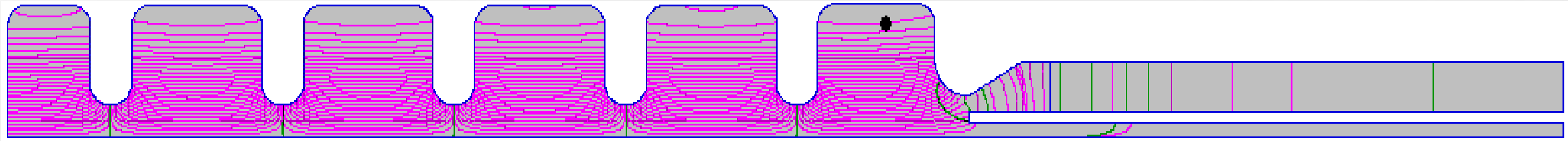
$f_{superfish} = 2992.6\ MHz \qquad f_{hfss} = 2992.0\ MHz$

- Again, good concordance is obtained between HFSS and SUPERFISH

Design of a RF gun with coupler

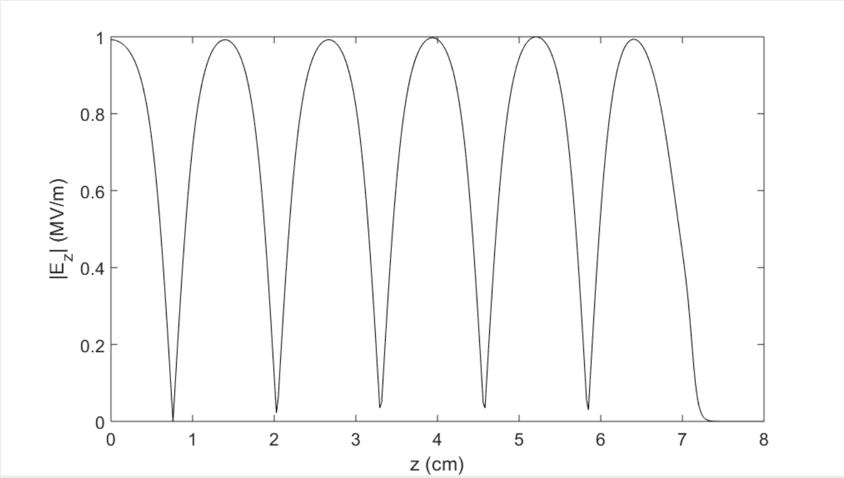
- In order to learn a bit more about photoinjectors and couplers, we tried to design a 5.6 cell RF gun with a coaxial coupler using the Avni gun as the reference model.
- To do this, SUPERFISH software (which is much faster than HFSS) was employed
- The final objective was to design a gun with the following optimized magnitudes:

$$f_\pi = 11.8\ GHz,\ same\ peak\ value\ of\ the\ Ez\ in\ all\ cavities, \beta = 1$$



Scheme of the 5.6 cell RF gun with coaxial coupler

- After some attempts we reached a prototype that presents the following characteristics:

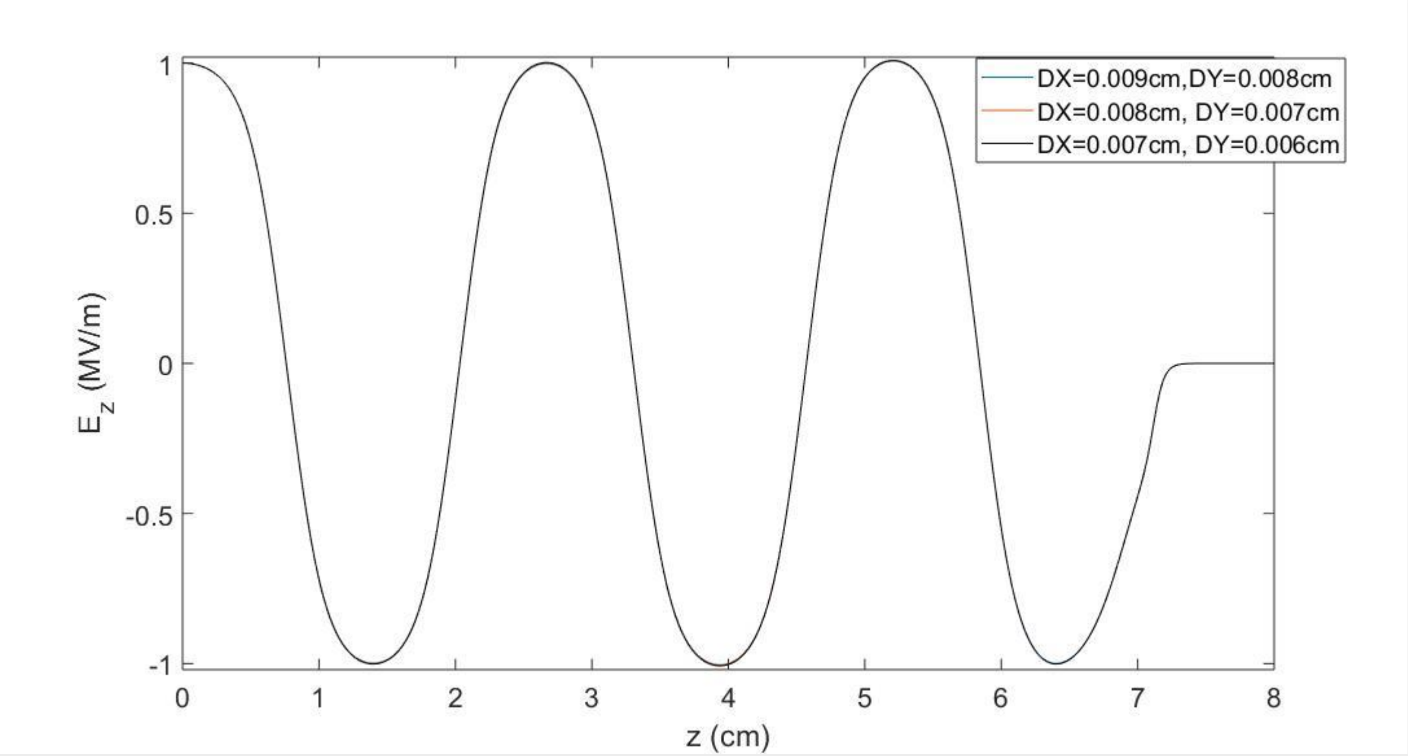


$$f = 11.799912\ GHz$$
$$\beta = 1.015$$

RF electric field maximum flatness is better than 99%

Design of a RF gun with coupler

- Finally, it is checked the convergence of the solution by essaying different mesh size increments



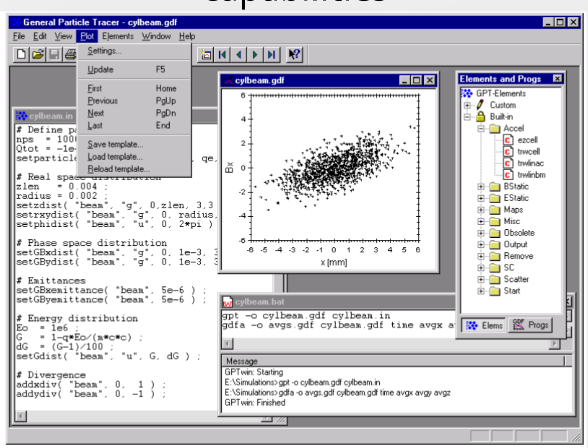
These are the mesh values employed in the design process

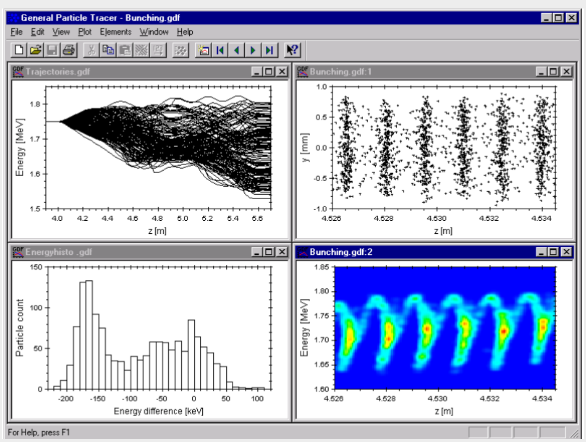
DX(cm), DY(cm)	f (MHz)	β
0.009, 0.008	11800.05	1.014
0.008, 0.007	11799.91	1.015
0.007, 0.006	11799.80	1.013

DX, DY are the mesh increments along the z and r directions, respectively

Future work

- For the previous designed 5.6 cell RF gun with coupler, it is expected to optimize other parameters such as the mode separation and the RF electric field intensity at cavity surfaces
- We plan to learn the *General Particle Tracer*[1] (GPT) software, which is a commercial code able to simulate the electron beam dynamics along the RF photoinjector. To reach this aim, the following steps will be given*:
    - Read carefully the GPT manual (currently in progress)
    - Run the examples included with the GPT manual
    - Try to build some basic scenarios which might be checked with analytical expressions (e.g., one single electron in a pillbox)
    - Simulations of an electron beam through a realistic RF gun, exploring all the GPT capabilities





Some GPT screenshots

*A physics degree student will be helping us with GPT simulations

[1] http://www.pulsar.nl/gpt/

Thank you!

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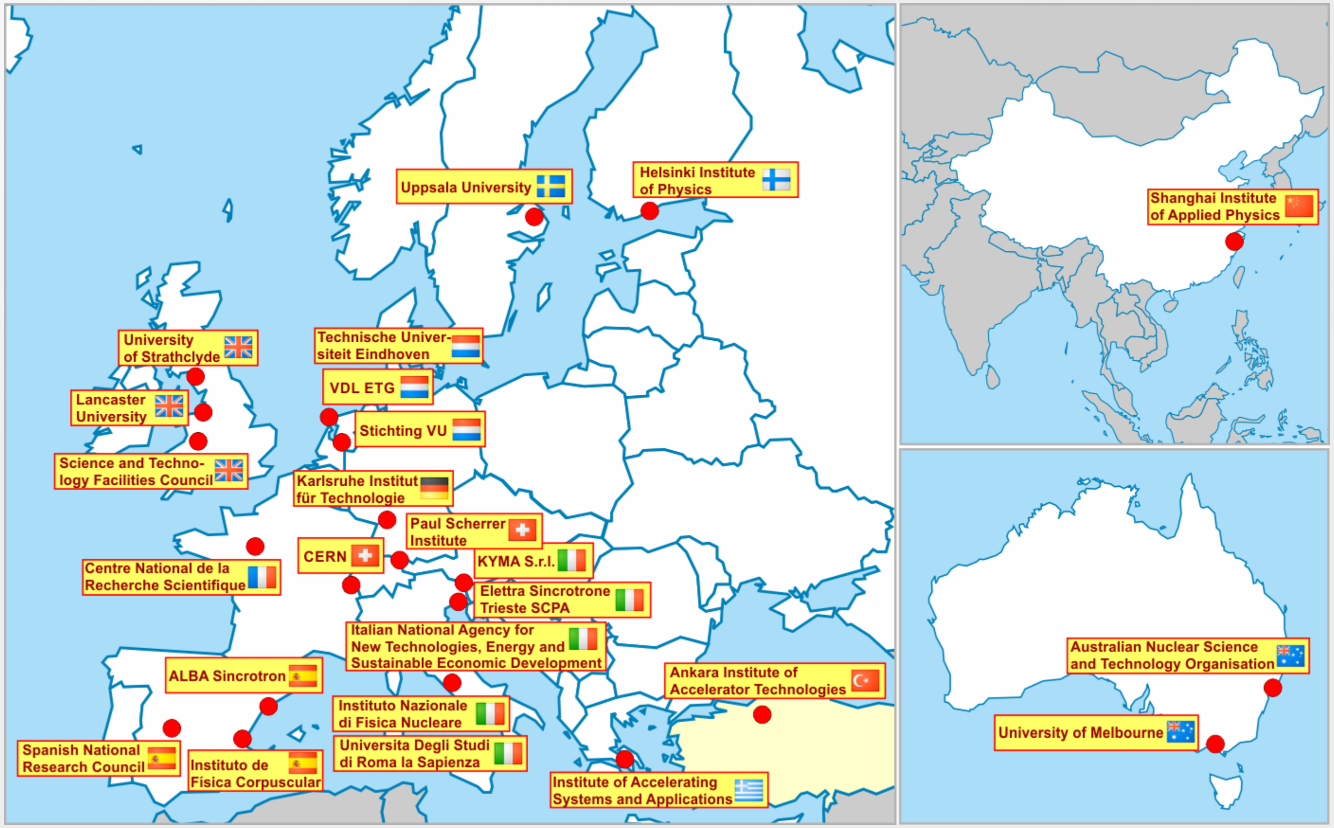

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