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Mode launcher impact on the beam dynamics

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On behalf of the WP3 XLS team

Outline

- The 2.5 cell C-band gun
- Building up the 3D gun model in ASTRA
- ASTRA-HFSS interfacing
- Beam dynamics considerations
- WP validation with ASTRA
- Conclusions and hints for next future

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The 2.5 cell C-band gun

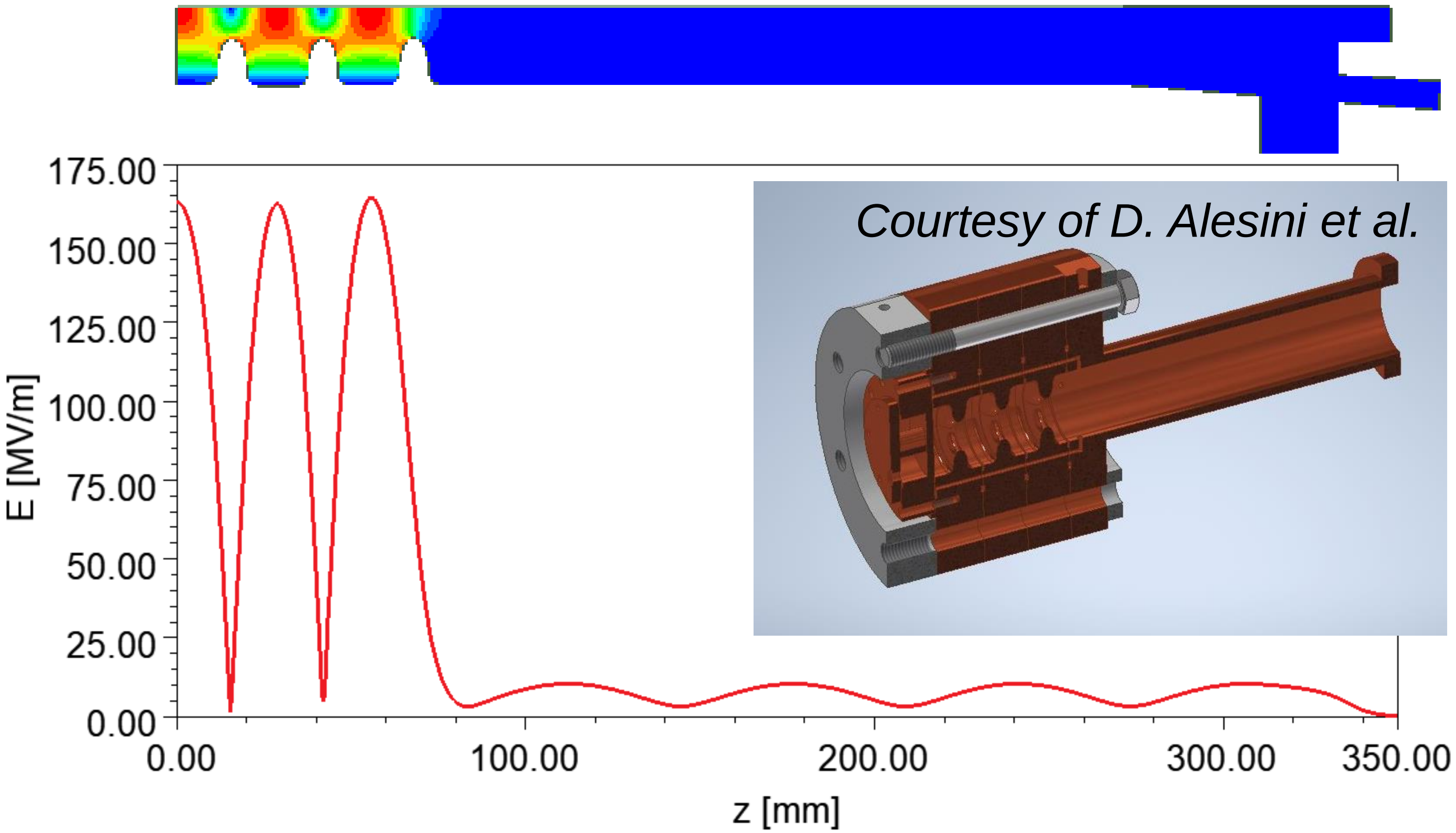
- The XLS photoinjector proposal relies on a **2.5 cell C-band gun** followed by *n* 2 m long C-band TW structures
- The **2.5 cell gun** has been chosen because it allows higher energy gain and so to double the distance between the cathode and the first TW cavity useful for the *beam characterization before entering the linac.*
- The gun will be powered using a mode launcher

Advantages:

- Increased flexibility in positioning the input waveguide relative to the gun body → more powerfull cooling capability of the accelerating cells especially usefull for the high repetition rate operation
- Lowered pulsed heating on the gun cell surface

Disadvantages:

- Field tails in the mode launcher region that can affect the beam quality
- Bigger pipe radius that impacts on the gun solenoid design requiring a bigger bore and the introduction of a bucking coil to zero the field at the cathode



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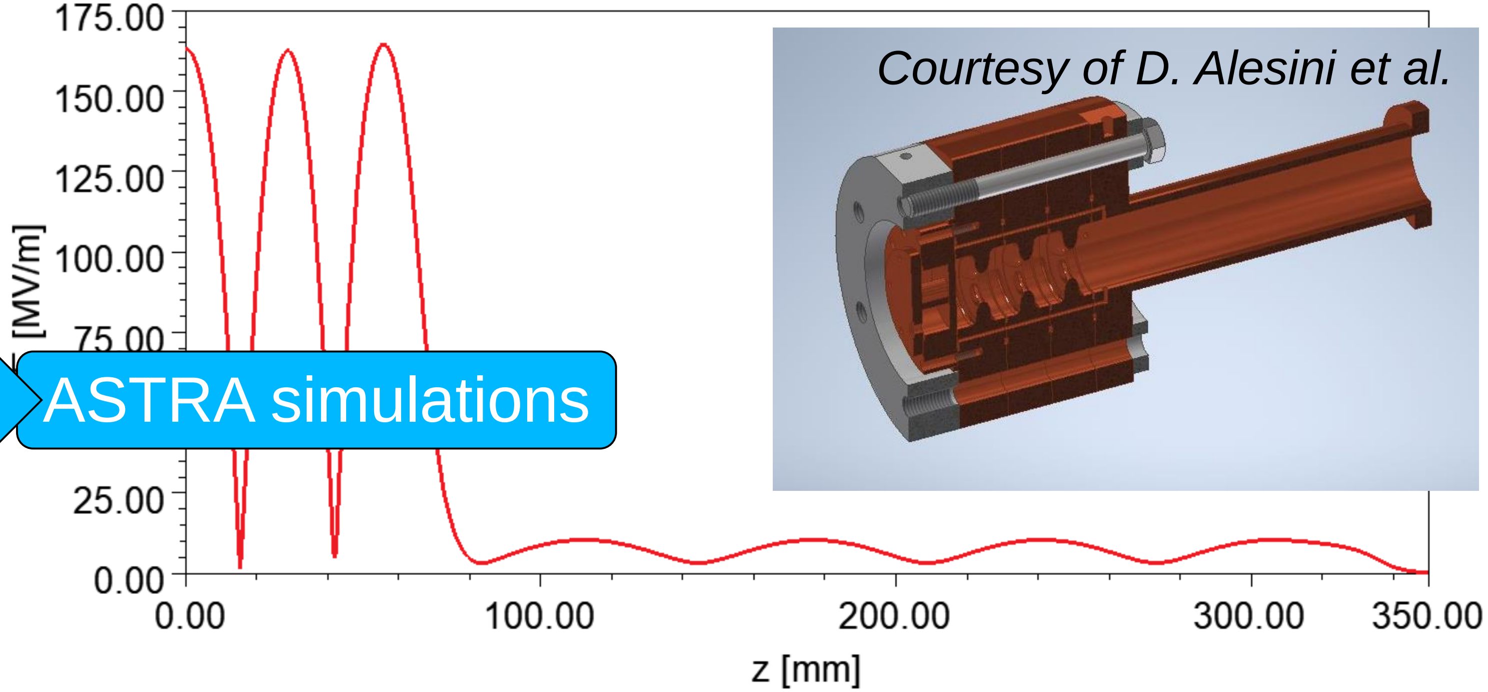
ASTRA simulations



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Compact

Building up the 3D gun model in ASTRA

- ASTRA supports both 3D space charge tracking and 3D modeling of static and EM elements
- In particular for accelerating cavities the ASTRA manual says:

A field can be represented in complex form as:

$$V = A \cdot \exp i\left(\omega \frac{z}{c} + \alpha + \varphi\right)$$

with: $A^2 = Re^2 + Im^2$

$$\cos\alpha = \frac{Re}{A}; \quad \sin\alpha = \frac{Im}{A}$$

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An equivalent representation can be formulated by superimposing a standing wave with $\varphi = 0$ (index $c1$) with a second standing wave with $\varphi = \pi/2$ (index $c2$):

$$E_{c1}\ cos\left(\omega\frac{z}{c}\right); \quad -B_{c1}\ sin\left(\omega\frac{z}{c}\right)$$

$$E_{c2}\ cos\left(\omega\frac{z}{c} + \frac{\pi}{2}\right); \quad -B_{c2}\ sin\left(\omega\frac{z}{c} + \frac{\pi}{2}\right)$$

$$= -E_{c2}\ sin\left(\omega\frac{z}{c}\right); \quad -B_{c2}\ cos\left(\omega\frac{z}{c}\right)$$

With the following identification both representations are identical:

$$E_{c1} = E_r; \quad B_{c1} = B_i$$

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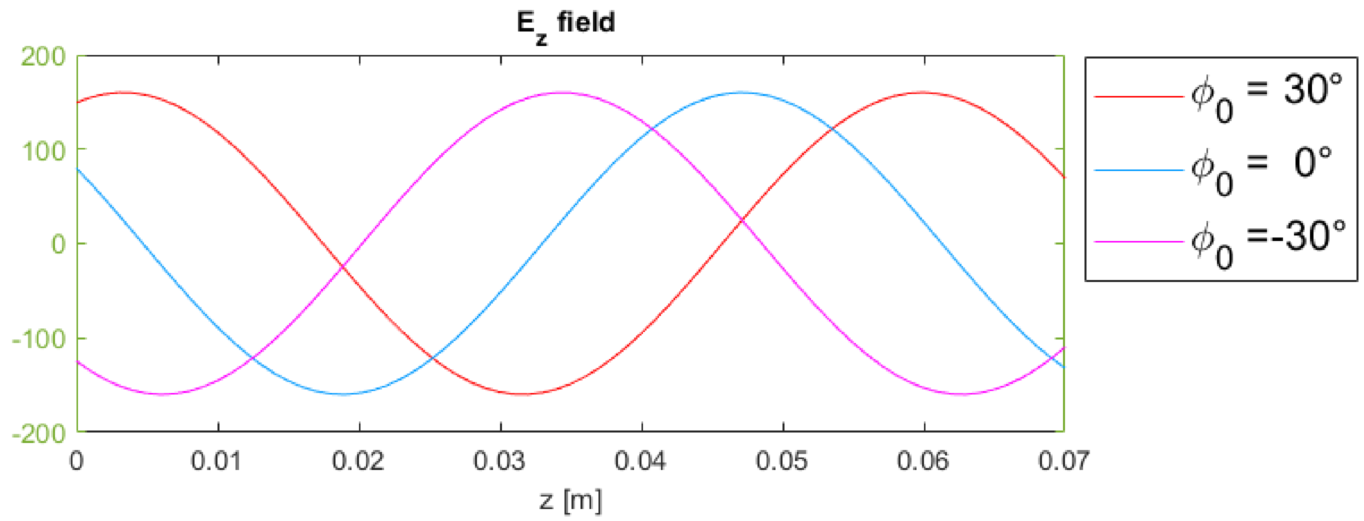
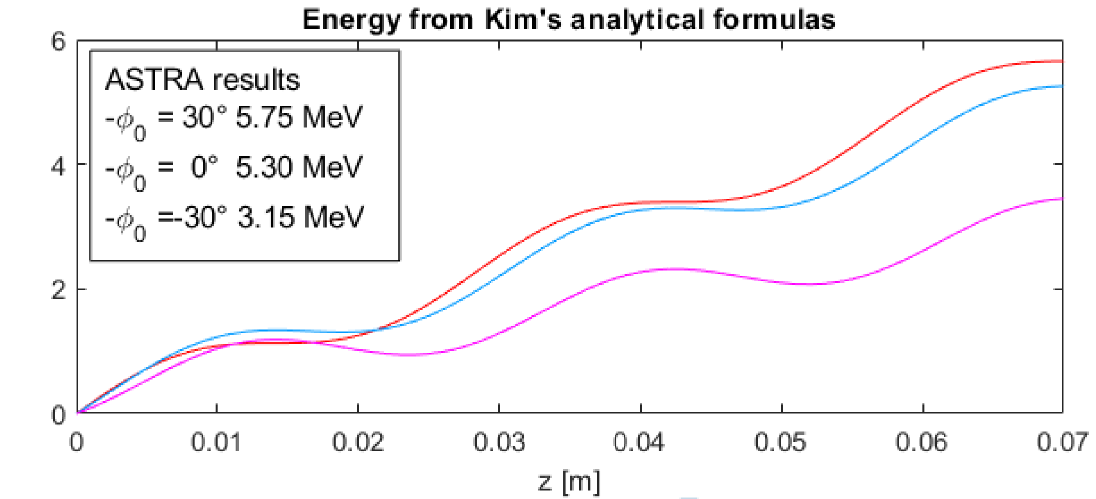
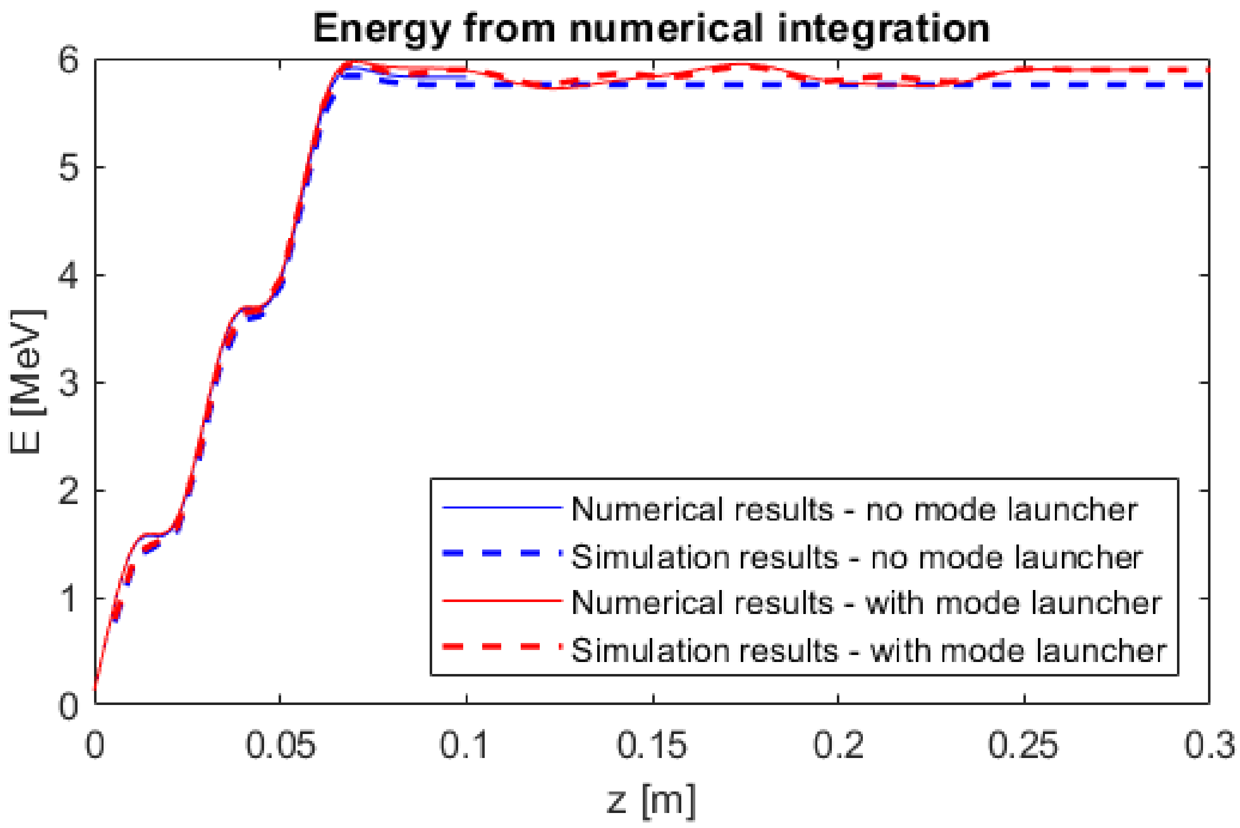
I wrote a Matlab routine that reads HFSS files provided by D. Alesini and converts them to ASTRA formalism

Cross-checking with Kim's analytical formulas and numerical method







ASTRA-HFSS interfacing

- First, we worked with a 3D map version of the gun without any mode launcher and we used it as reference for other cases
  - We worked on the field maps in order to control numerical effects that corrupt beam dynamics simulation results
  - We identified to numerical effect sources:
    - map discontinuities rising from HFSS resolution routine → step size, tetrahedra edge
    - map numerical noise → HFSS functions that help in suppressing the noise
- Then we proceeded with the 3D map of a gun with cylindrical waveguide → indeed introducing 3D maps we have anymore pure cylindrical beam dynamics and so we need to separate physical from numerical noise beam dynamics effects.
- Finally we studied the case of the gun with the mode launcher as it comes from EM and mechanical drawings

	tetrahedra edge size Δ [mm]	**(x,y) step size ε [mm]**	**z step size [mm]**	**Smooth Function**
2D		ASTRA routine	0.9773	
3D w/o ML	0.5 – 1.0 – 2.0	0.5	1	ON - OFF
3D with cylindrical ML	1.0 – 2.0	0.5	1	ON - OFF
3D with ML	1.0	0.5	1	ON

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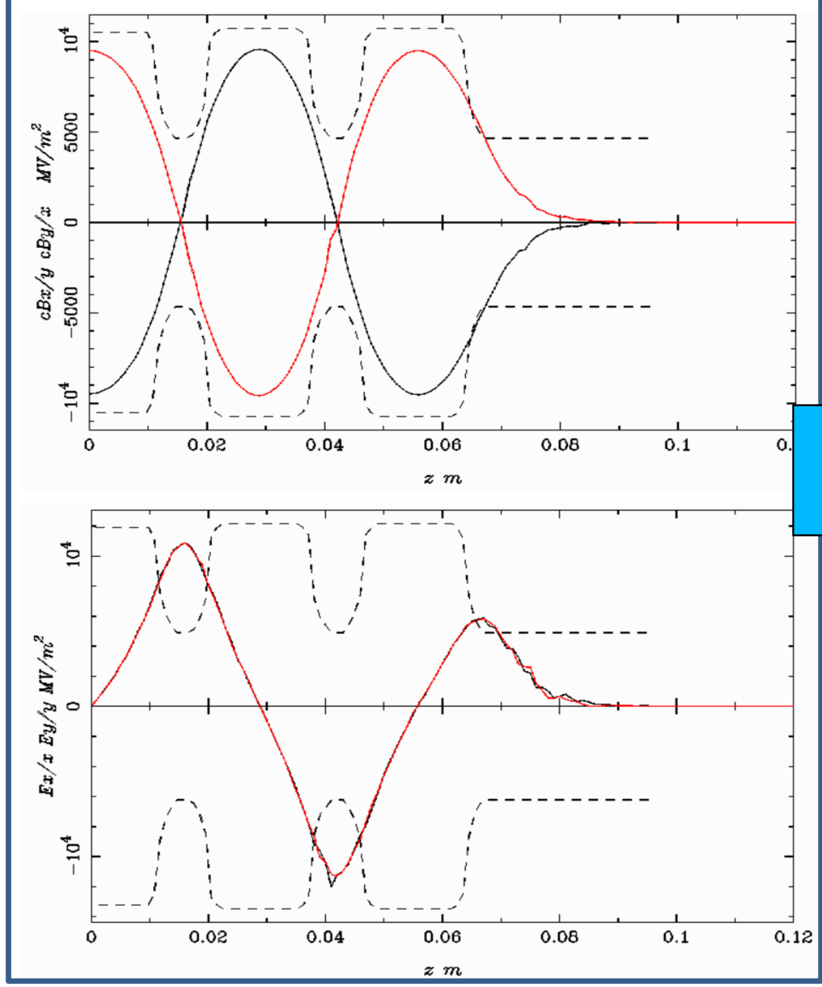
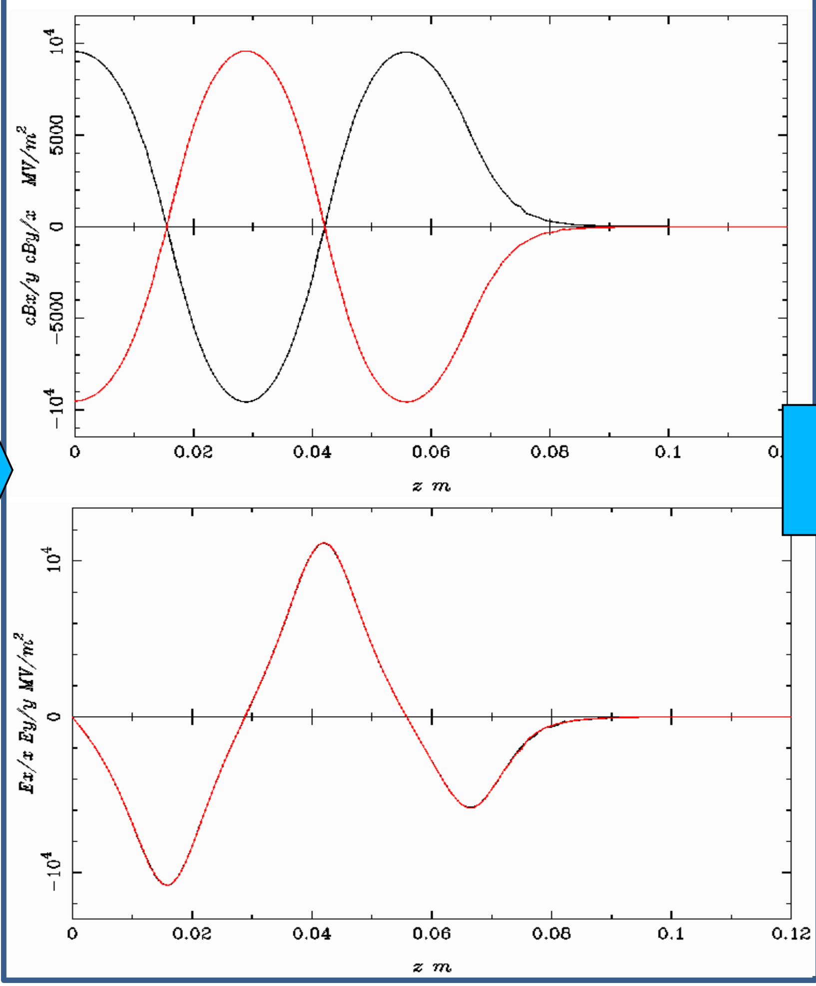
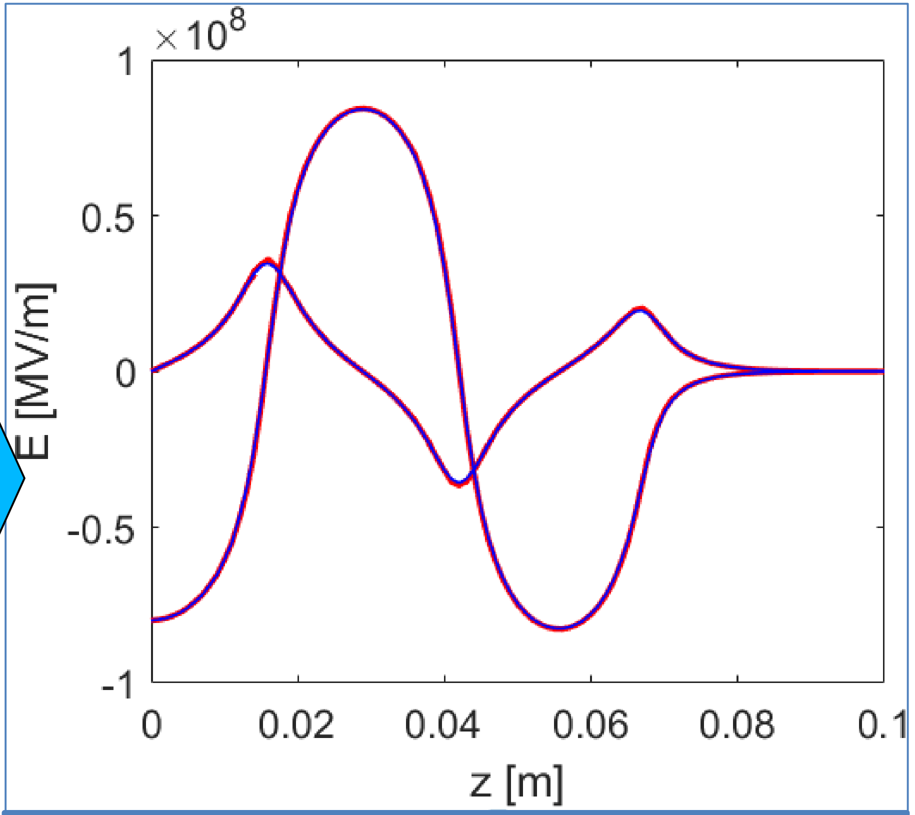
ASTRA-HFSS interfacing – Suppressing the noise

ASTRA: W/o HFSS smoothing



ASTRA: with HFSS smoothing

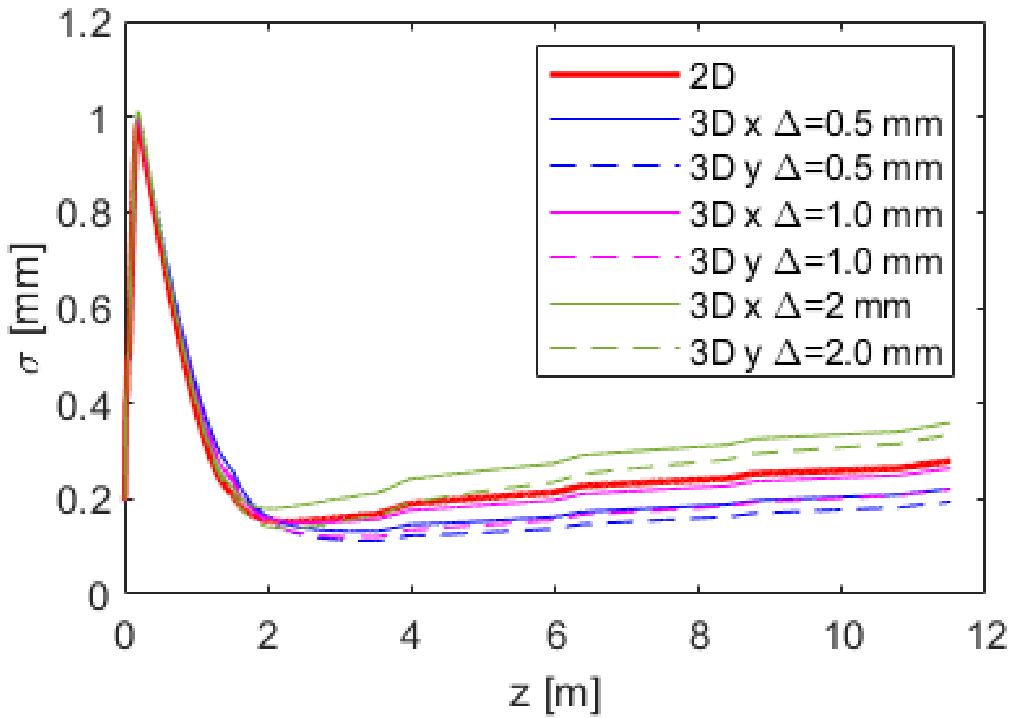


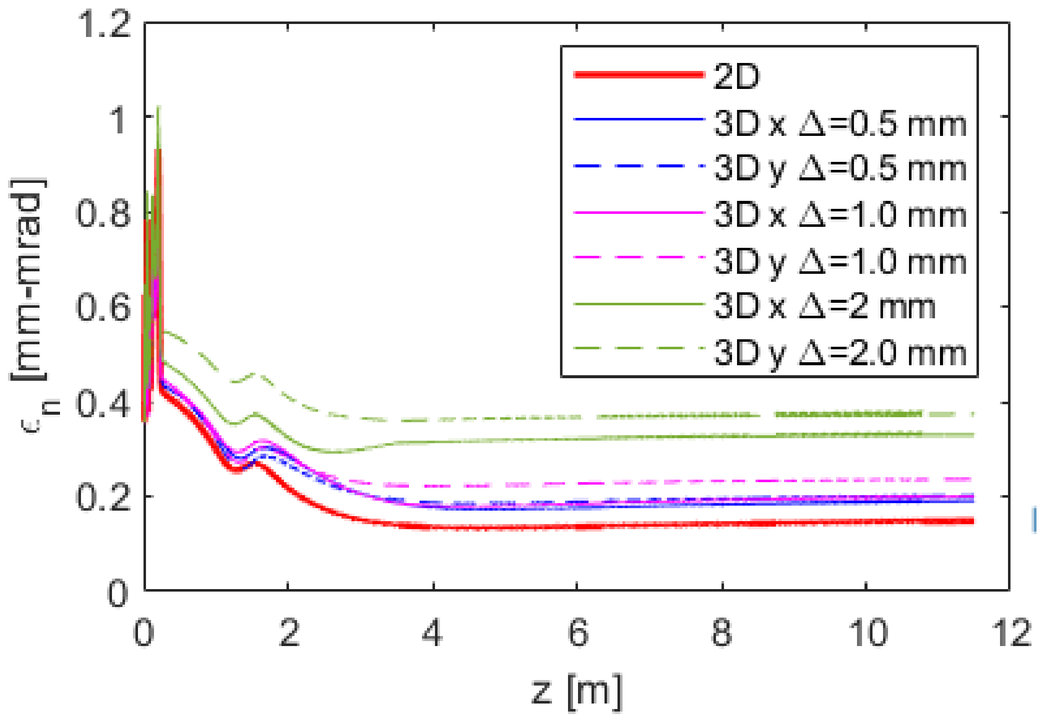


Plus Matlab smoothing

Beam dynamics simulations – Gun w/o mode launcher

- In order to distinguish physical by fictitious contribution to the beam quality we studied the case of a *cylindrical symmetric gun without mode launcher described by a 3D field map*

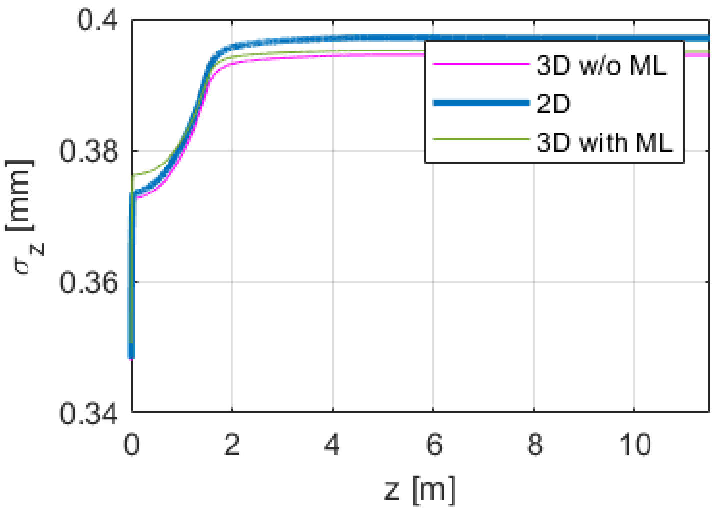


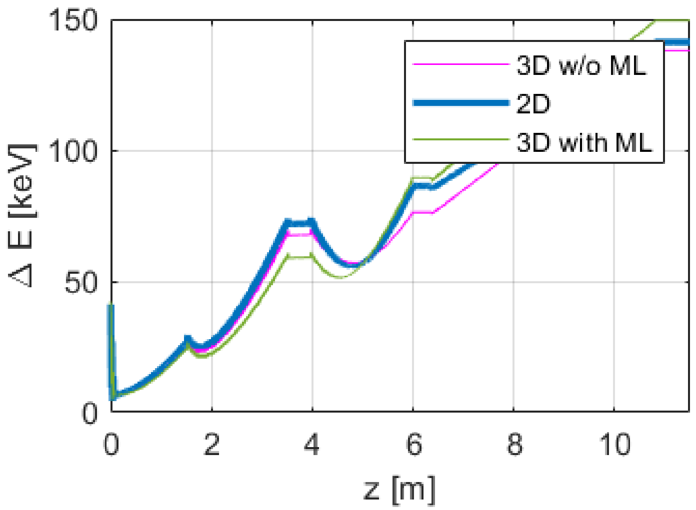


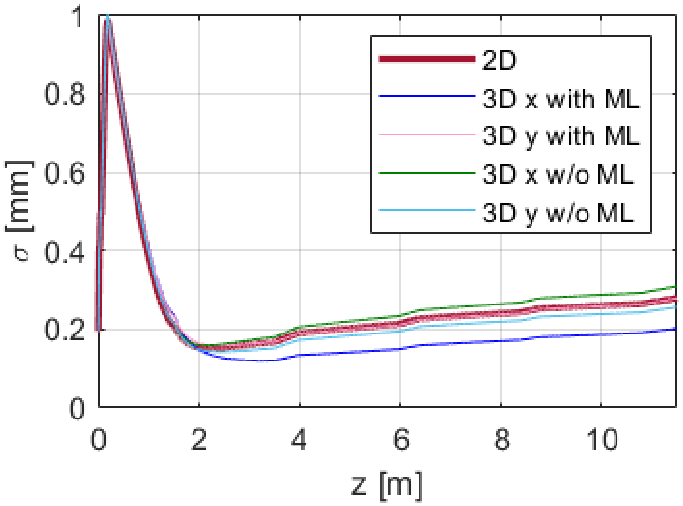
- The simulation is very sensitive to field map numerical noise. Indeed there is any physical explanation for the observed emittance increase, while acting on the tetrahedra edge size Δ in HFSS helps in reducing artificial asymmetry
- The case Δ = 1.0 mm is chosen as reference for further studies

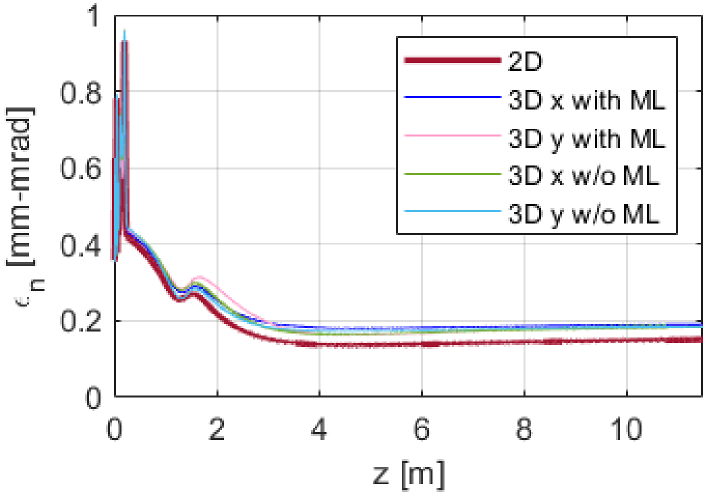
Beam dynamics simulations – Gun with mode launcher

- A *cylindrical symmetric gun with coaxial mode launcher is described by a 3D field map*









Field tails of the mode launcher for the C-band gun don't affect the beam quality

Next step would be considering various configurations for the mode launcher

WP validation with ASTRA

Courtesy of J. Scifo

- The studies related to the mode launcher started from a WP optimised with TStep → *J. Scifo* worked on the ASTRA input files to reproduce it with ASTRA
- The main difference between ASTRA and TStep regards the photo-emission process treatment *: ASTRA implements the photo-emission process from the cathode when a Fermi-Dirac beam distribution impinges on the cathode and it is the only code that explicitly foresees the treatment of the Schottky effect

The photo-emission process determines the beam intrinsic emittance at the cathode, a key parameter that represents the lowest emittance value one can get at the FEL injection

FERMI-DIRAC distribution

The particles emerging from the cathode at room temperature have an intrinsic velocity spread and so an intrinsic emittance described as:

$$\varepsilon_{x,y}^{\text{intrinsic}} = \sigma_{x,y}\sqrt{\frac{E_{\text{phot}} - \Phi_{\text{eff}}}{3m_0c^2}}$$

where $\sigma_{x,y}$ is the rms laser beam size, Φe_{ff} is the effective work function and E_{phot} is the photon energy.

ISOTROPIC distribution

The beam distribution emerges from the cathode with isotropic emission angles into a half sphere over the cathode according to with the intrinsic emittance being:

$$\varepsilon_{x,y}^{\text{intrinsic}} = \sigma_{x,y}\sqrt{\frac{2E_{\text{kin}}}{3m_0c^2}}$$

where $\sigma_{x,y}$ is the rms laser beam size and E_{kin} represents the beam kinetic energy.

* XLS Deliverable D6.1 3

WP validation with ASTRA

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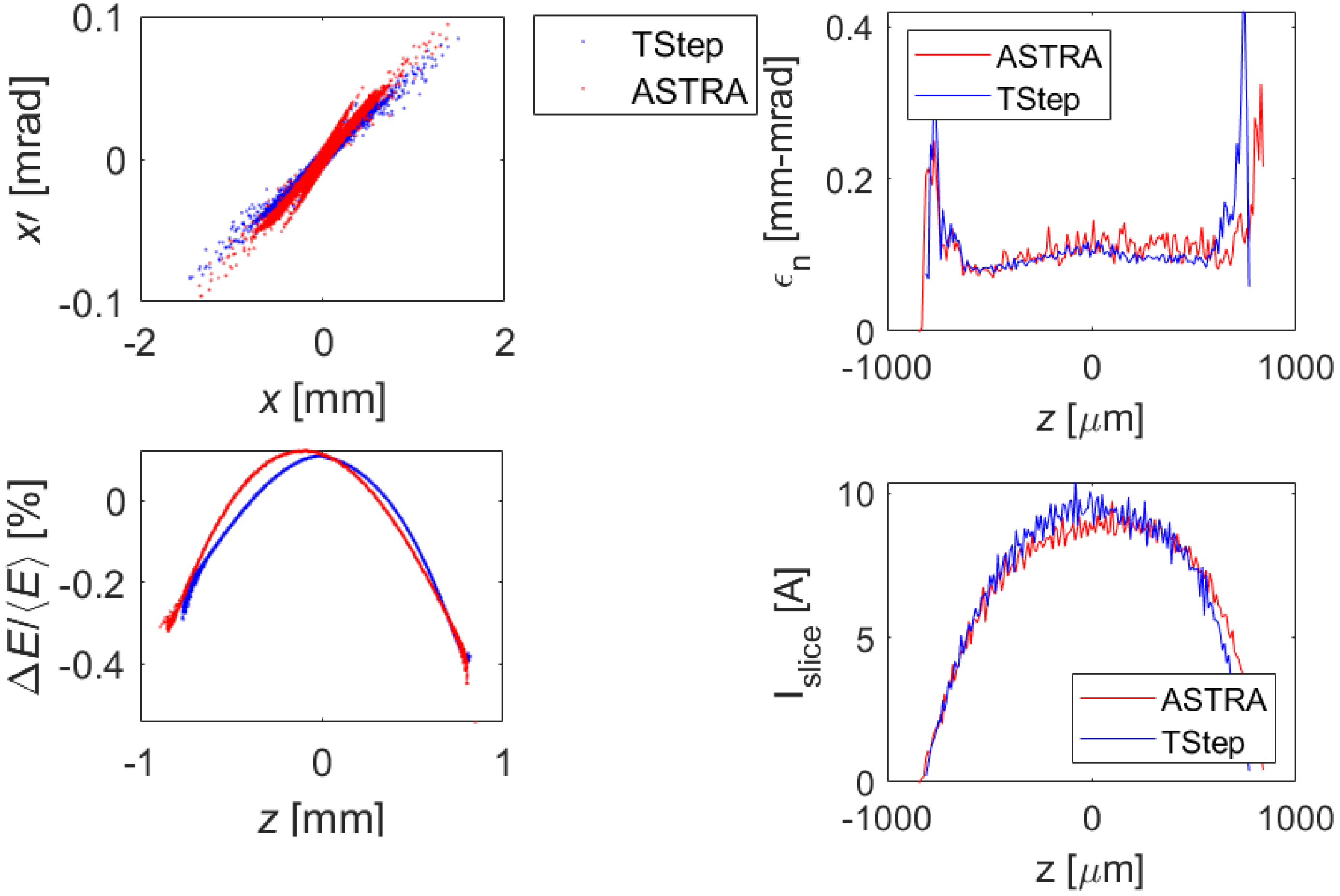
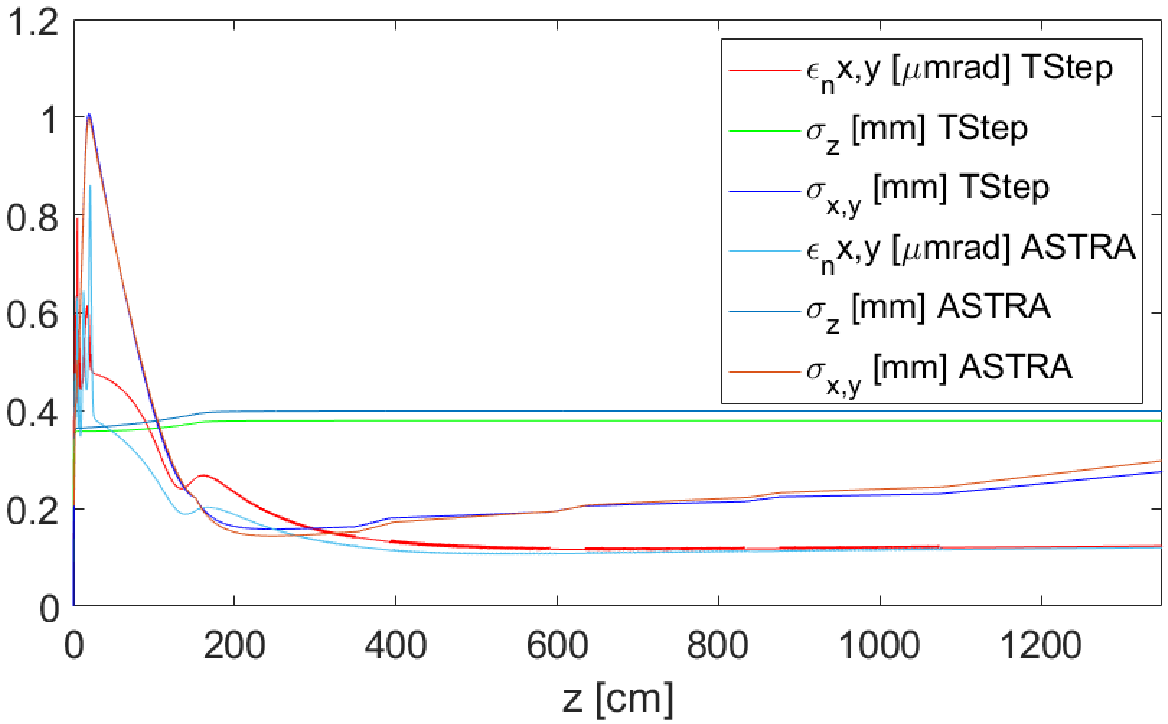
Parameters before BC1	Sim. results	Target	units
Q	75		pC
Rep. rate	1000		Hz
E	126	125	MeV
σ_E/E	0.11	0.5	%
$\epsilon_{n,rms}$	0.12	0.15	µm





Conclusions

- *The mode launcher for the C-band gun presents "field tails" whose effect on the beam dynamics has been studied*
- *Further beam dynamics study are ongoing to evaluate the effect of non cylindrically symmetric waveguide for the mode launcher (2 or 4 ports).*
- *The WP proposed in Glasgow meeting (June2020) has been validated with ASTRA and a more accurate treatment for the photo-emission has been introduced and discussed.*

The C-band photoinjector proposal

- We propose a **C-band** photoinjector relying on a **2.5 cell gun** followed by *n* 2 m long TW structures
- The **C-band technology** could represent a good compromise between the S and X-band ones

✓ it still allows for exploring a wide range in terms of beam charge and length

✓ it allows for a more compact beamline compared to S-band solution

✓ it enables high repetition rate operation with higher field compered to S-band solution

→ up to 160 MV/m peak field on cathode in the gun

→15 MV/m average field in TW sections

- The **2.5 cell gun** allows to at least double the space for *beam characterization after the gun* → *150 cm drift from WP8*