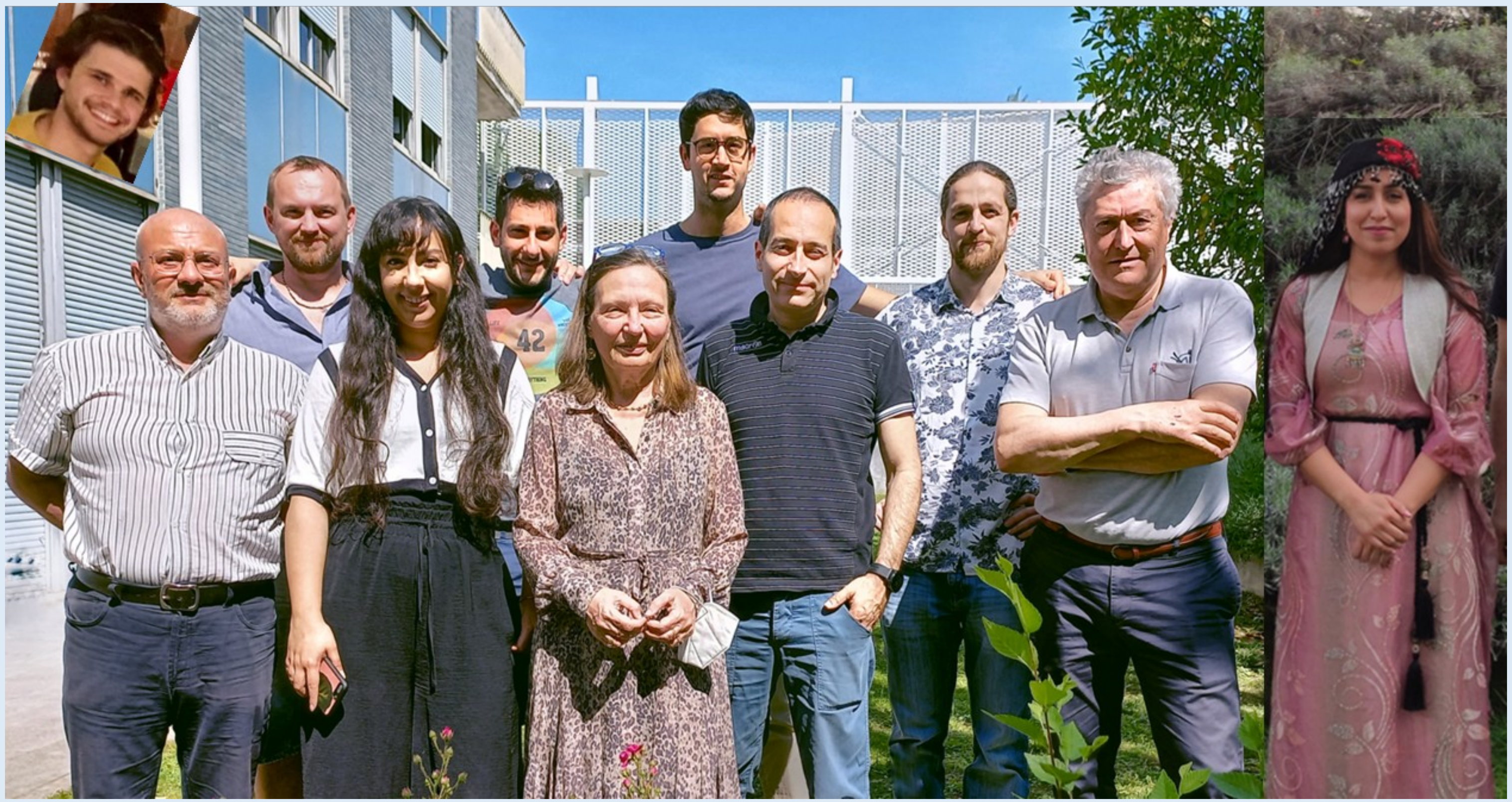
Report on BD Milano group activities

A. Bacci (INFN-MI) on behalf of Milano Group



L. Serafini, A. Bacci, I. Drebot, A. Frazzitta, G. Harki, A. R. Rossi, M. Rossetti Conti, S. Samsam, V. Petrillo

Ultrafast Beams and Applications 17-22 June 2024, CANDLE, Armenia

Main BD Milano activities & the index

- **Activities in the frame of EuPRAXIA:**
  - Plasma acceleration BD simulations [this morning – A.R. Rossi talk]
  - Plasma betatron radiation [this morning – A.R. Rossi talk]
  - Plasma based devices: bending, ion channel laser, etc … [tomorrow – A. Frazzitta talk]
  - Matching line tuning from plasma to Undulator by GIOTTO
  - EuPRAXIA injector tuning by GIOTTO (The COMB conf.)

- **GIOTTO simulations Optimizer code development** [tomorrow, M. Rossetti Conti]

- **Dielectric Laser Accelerators (DLA) (MICRON)** [this talk & tomorrow, G. S. Mauro]
  - Woodpile TW cavity simulations [this talk – index]
  - Sub-relativistic SLOT TW Cavity simulations [this talk – index]

- **Magnetic Bottle trap by Symmetric ICS &** [tomorrow, L. Serafini]

- **BriXSinO ERL – Two pass acc. test facility**
  - GIOTTO applied to BriXSinO [tomorrow, M. Rossetti Conti]
  - Low– Buncher *VS* frequency analysis [this talk – index]
  - HB$_2$TF news [this talk – index]
  - HOMEN

- **`Opt. FCC-ee positron capture line`** [this talk – index]

- **`STAR ICS machine status report`** [this talk – index]

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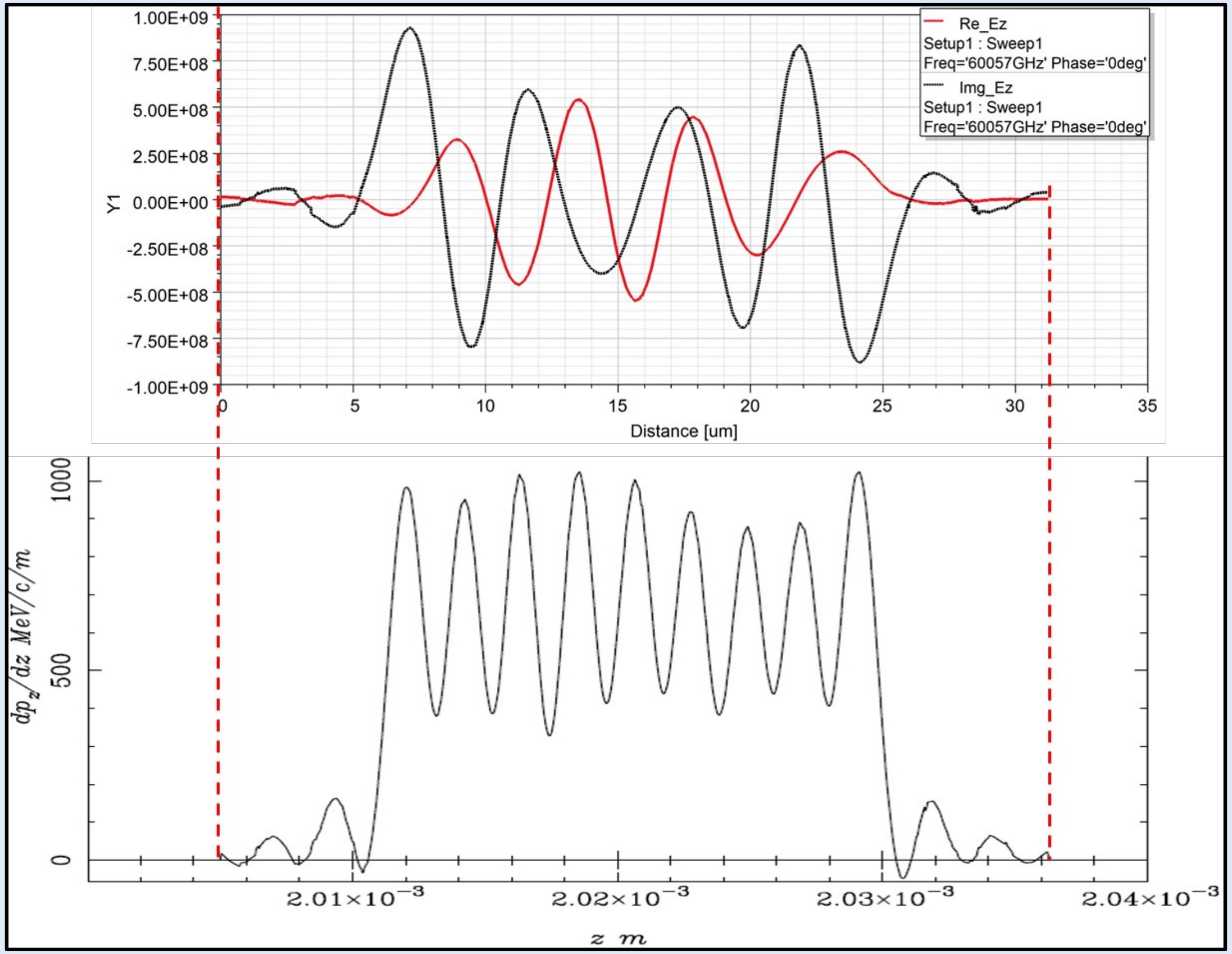
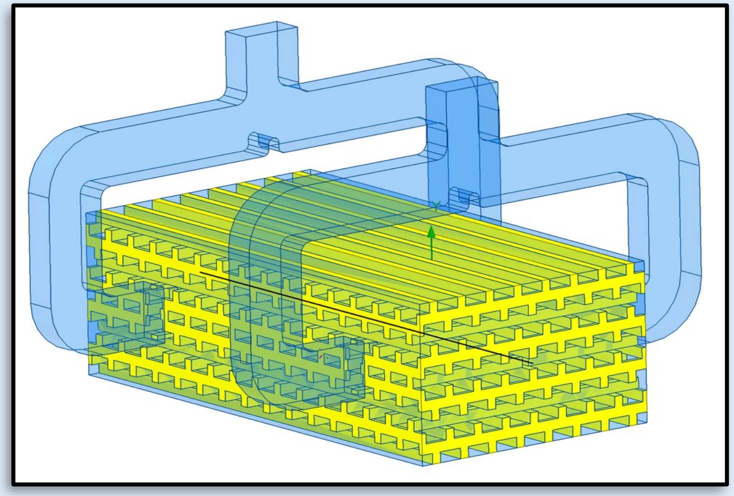
The Woodpile DLA cavity (1D fields Ez(0,0) & Full 3D)

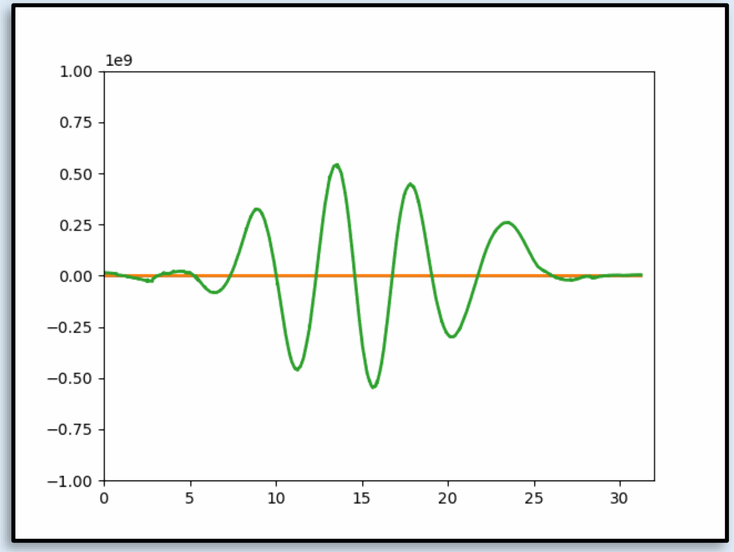
ASTRA On axis description from fields component $Ez_{0,0}$_Real and $Ez_{0,0}$_Im.

1D, the cavity doesn’t have a transversal geometry defined

$$f = 60\,TH_z$$



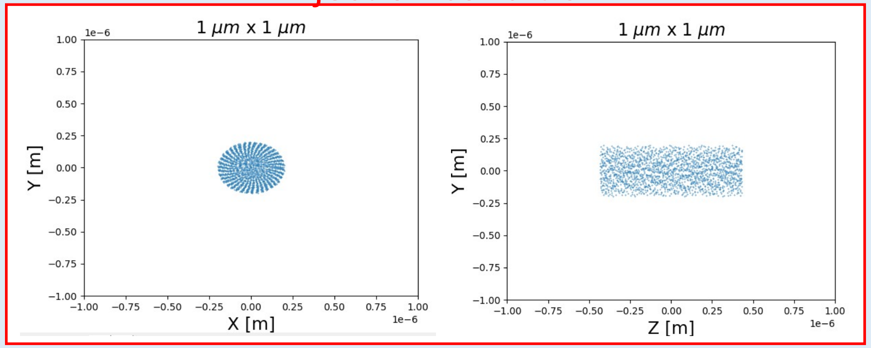


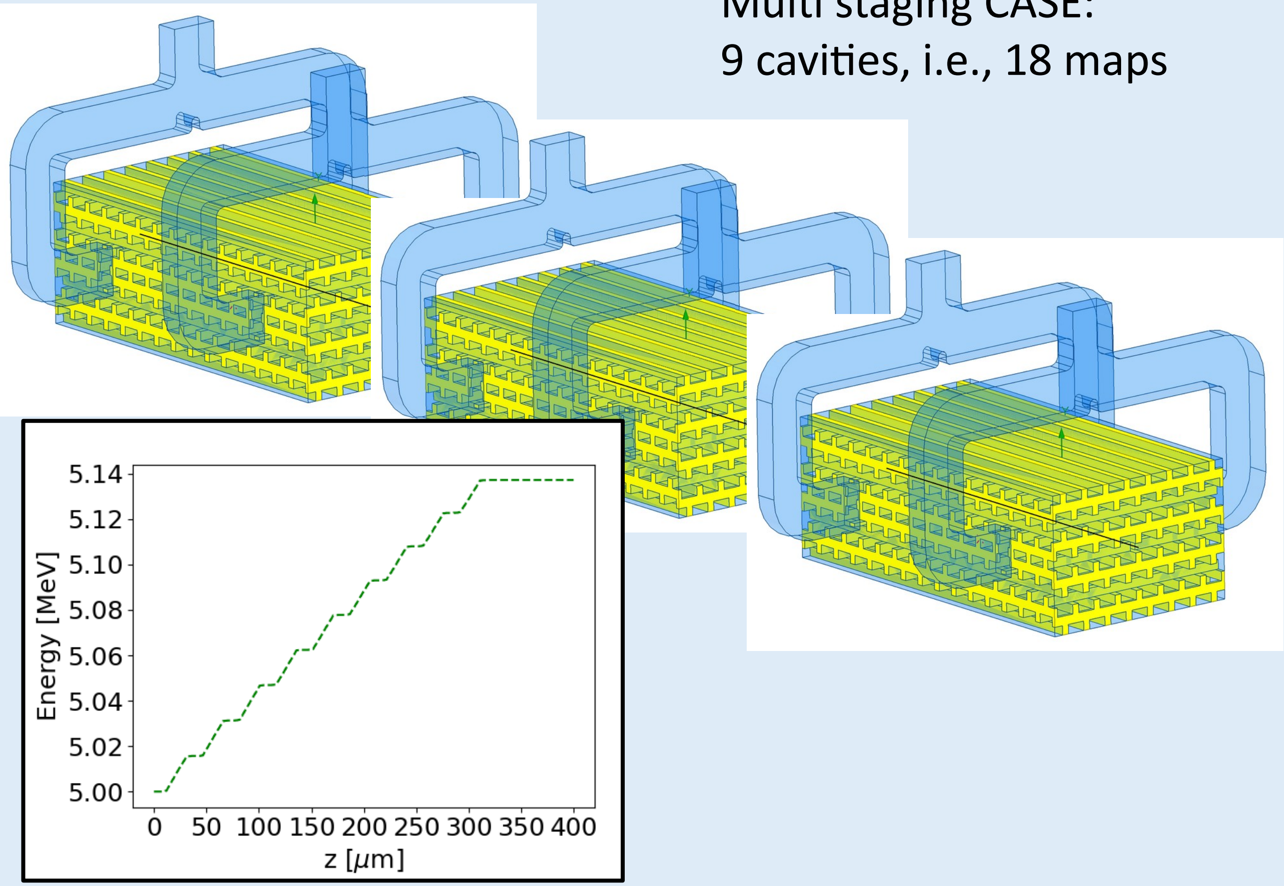


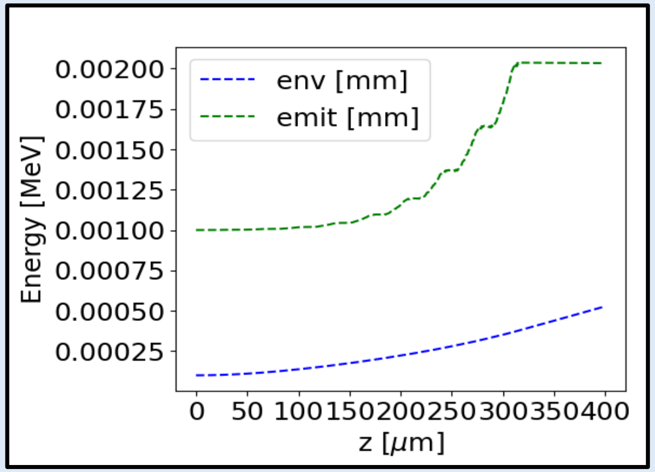
$$E_{tw} = \text{Real}(Ez) \cdot \cos(\omega t) + \text{Imag}(Ez) \cdot \cos(\omega t + 90^\circ)$$

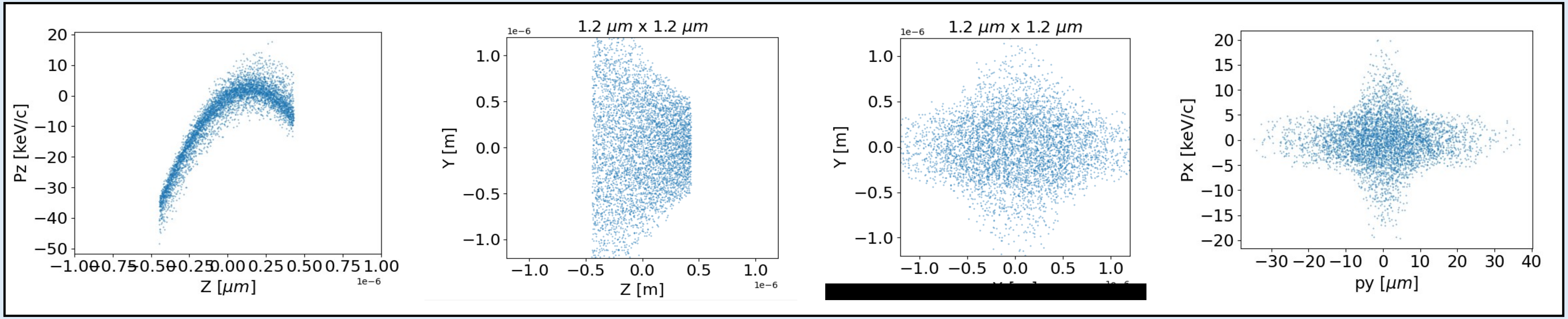
Multi staging CASE:
9 cavities, i.e., 18 maps

Injection condition



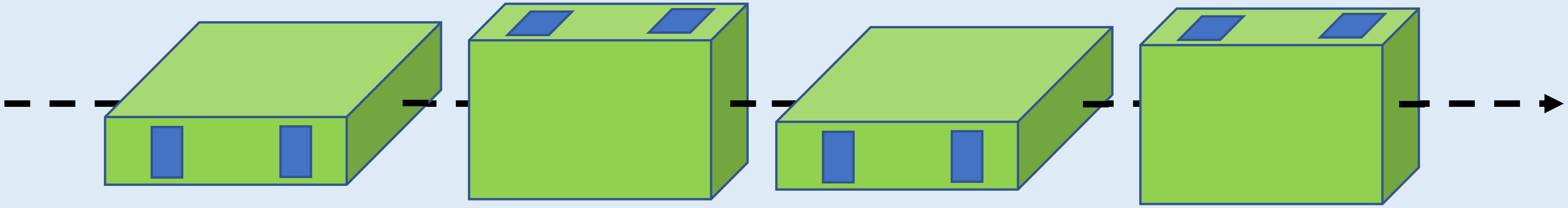


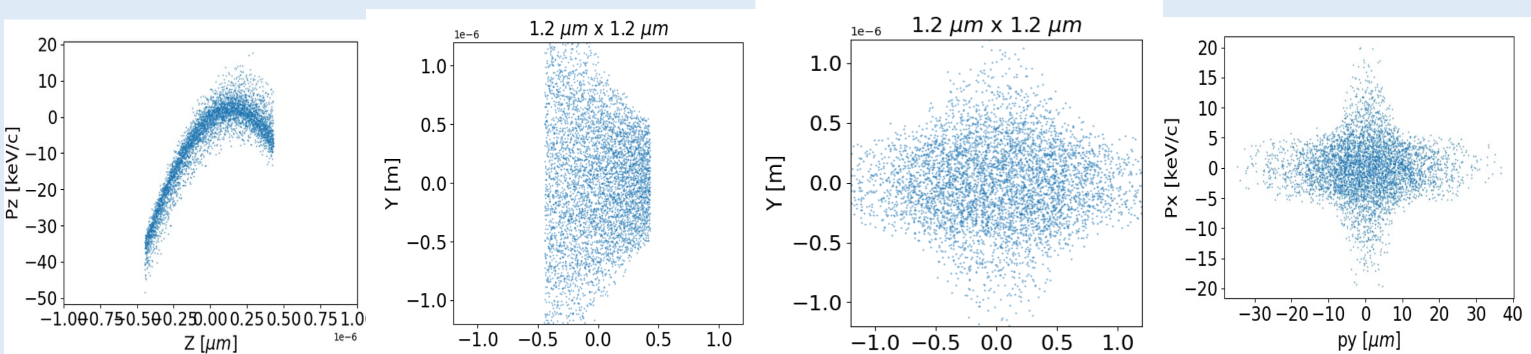




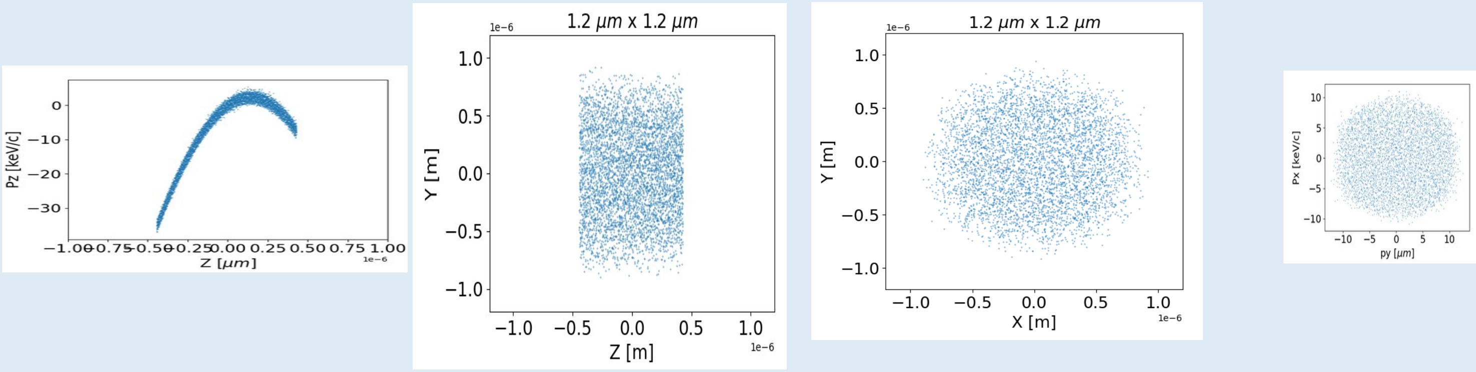
[redacted]

Multi staging CASE: 9 cavities that means 18 maps – each other rotated 0° – 90 ° – 0 ° – 90 ° …

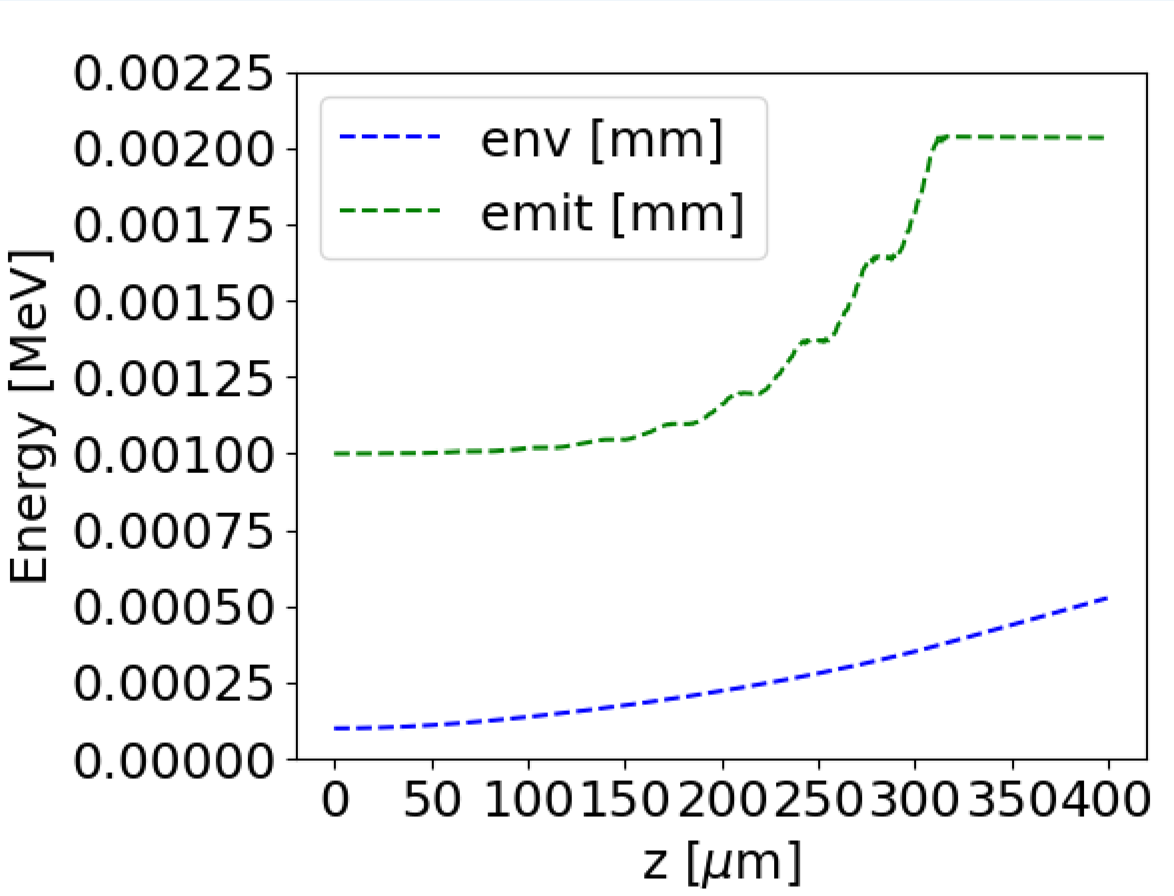




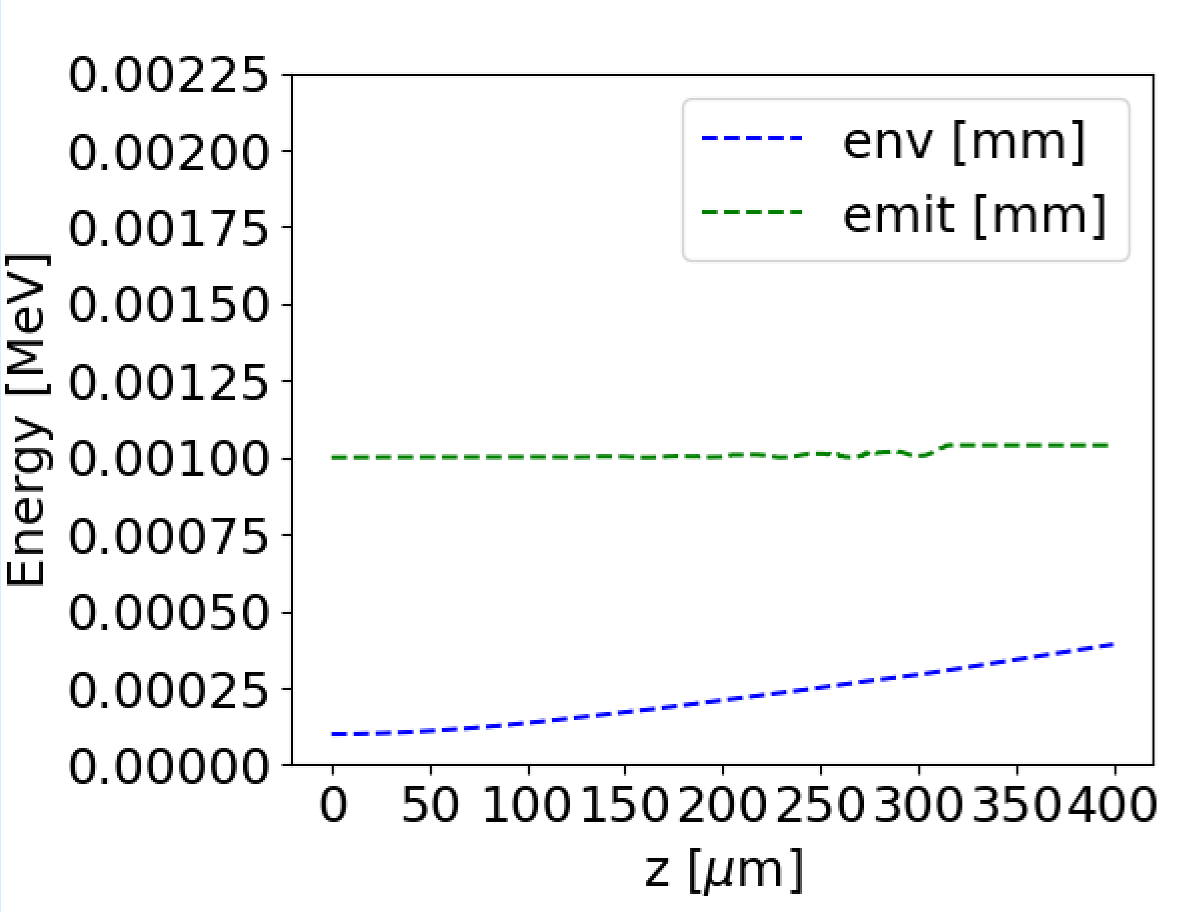
[redacted]



Multi staging CASE
Cavities not rotated



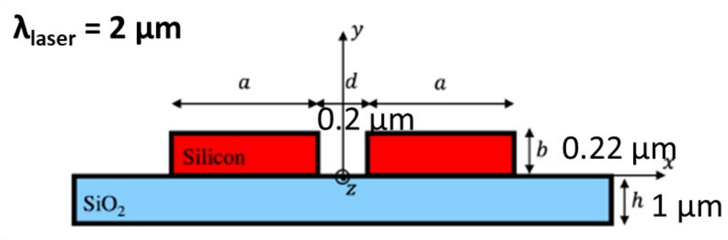
Multi staging CASE
Cavities alternated in rotation

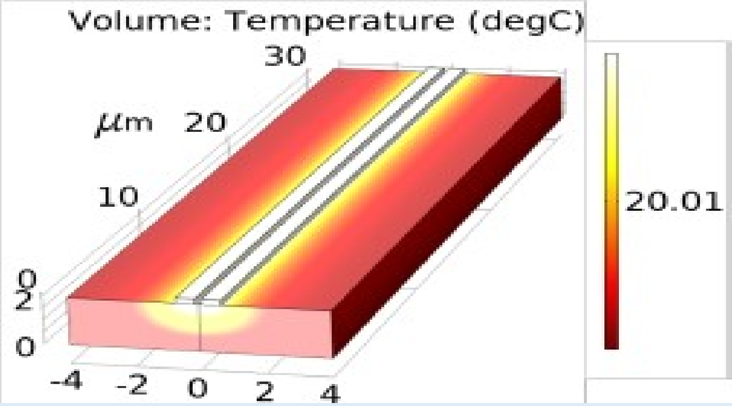


Sub-relativistic SLOT TW Cavity simulations

[this talk – index]

One-particle study

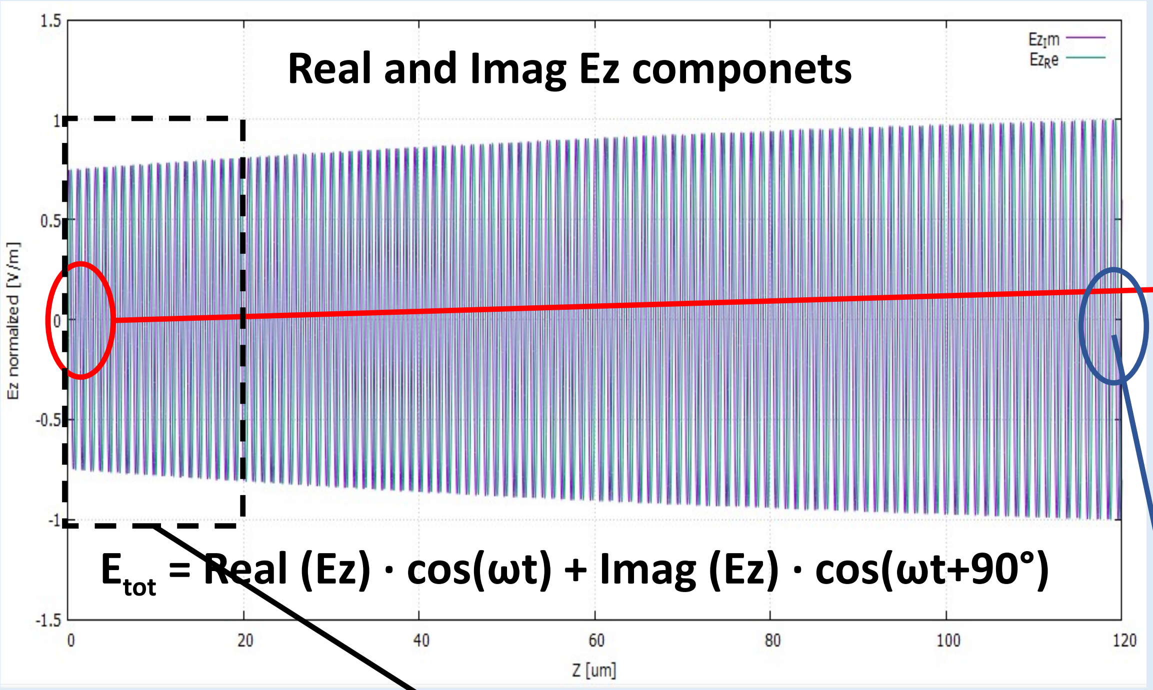




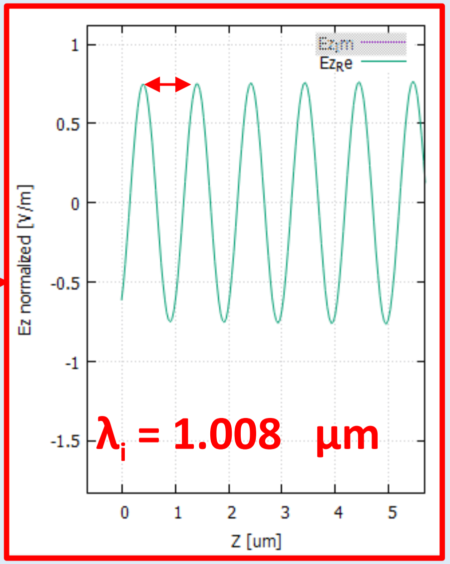
$$f = 1.49945 \cdot 10^{5} GHz$$

R. Palmeri et al., Optics Express Vol. 31, Issue 23, pp. 38891-38909 (2023) • https://doi.org/10.1364/OE.502762

Sub-relativistic co-propagating structure (slot DLA)



E_{tot} = Real (Ez) · cos(ωt) + Imag (Ez) · cos(ωt+90°)



λ_i = 1.008 μm

V_{phi} --> K_i = 80.7 keV

λ_{laser} = 2 μm

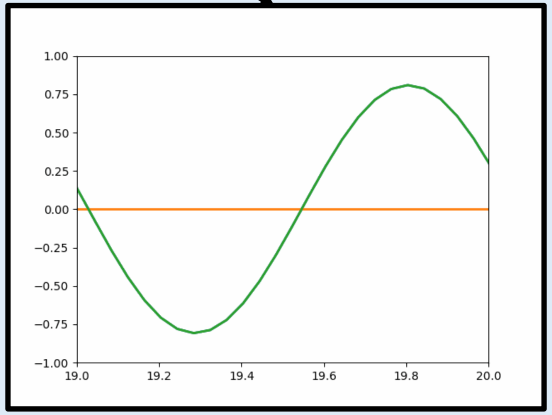
i.e. ***f*** = 1.4995 · 10^{14} [1/s]

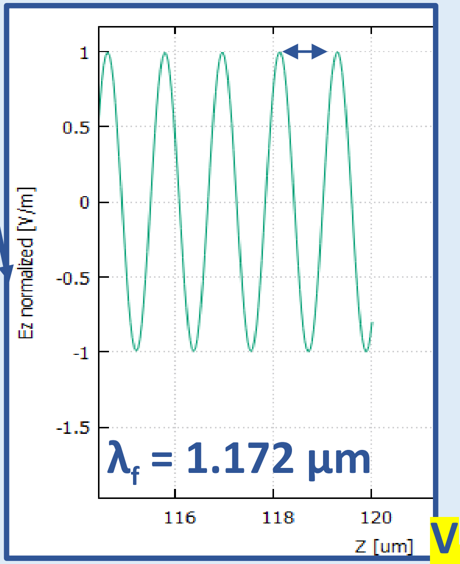
v_{ph} = ***f*** · $\lambda_c(z)$

K_z = 2 pi / $\lambda_c(z)$

From v_{ph} to e^- velocity (β) to e^- energy (K):

$$K = 0.511(1/\sqrt{1-\beta^2} - 1)$$





λ_f = 1.172 μm

V_{phi} --> $K_{ph\text{-}end}$ = 119 KeV

Fields in hard edge condition at start and end of the cavity. By the edge effect (typically focusing in acceleration), should be useful to introduce a coupling.

Normalized vector potential

The **normalized vector potential**, an important figure of merit for accelerator in non-relativistic acceleration regime is:

$$\alpha = \frac{e E_0 \lambda}{2 \pi m c^2}$$

Slot DLA, of 300-400 MV/m; about 1 um:
~1000 to reach a relativistic beam

Typical values for RF-guns is

Important implications:

1) Keep the bunch in phase with the wave: a complex trade-off of more parameters

2) Strong dependence of E_r and E_z vs r position sub-relativistic cases.

3) In FIR DLA $\mathbf{E_{z,y}}$ **vs r** dependence is large by the bad-ration vs cavity 'aperture' (compared to RF cavities)

$$E_z = E_0 I_0(r k_1) \sin(\omega t - k_z z + \psi),$$

$$E_r = \frac{E_0 k_z}{k_1} I_1(r k_1) \cos(\omega t - k_z z + \psi),$$

$$B_\phi = \frac{\omega \epsilon_0 \mu_0 E_0}{k_1} I_1(r k_1) \cos(\omega t - k_z z + \psi)$$

F. LEMERY *et al.* PHYS. REV. ACCEL. BEAMS **21**, 051302 (2018)

, an easier behaviour

$$I_0(k_1 r) = 1$$

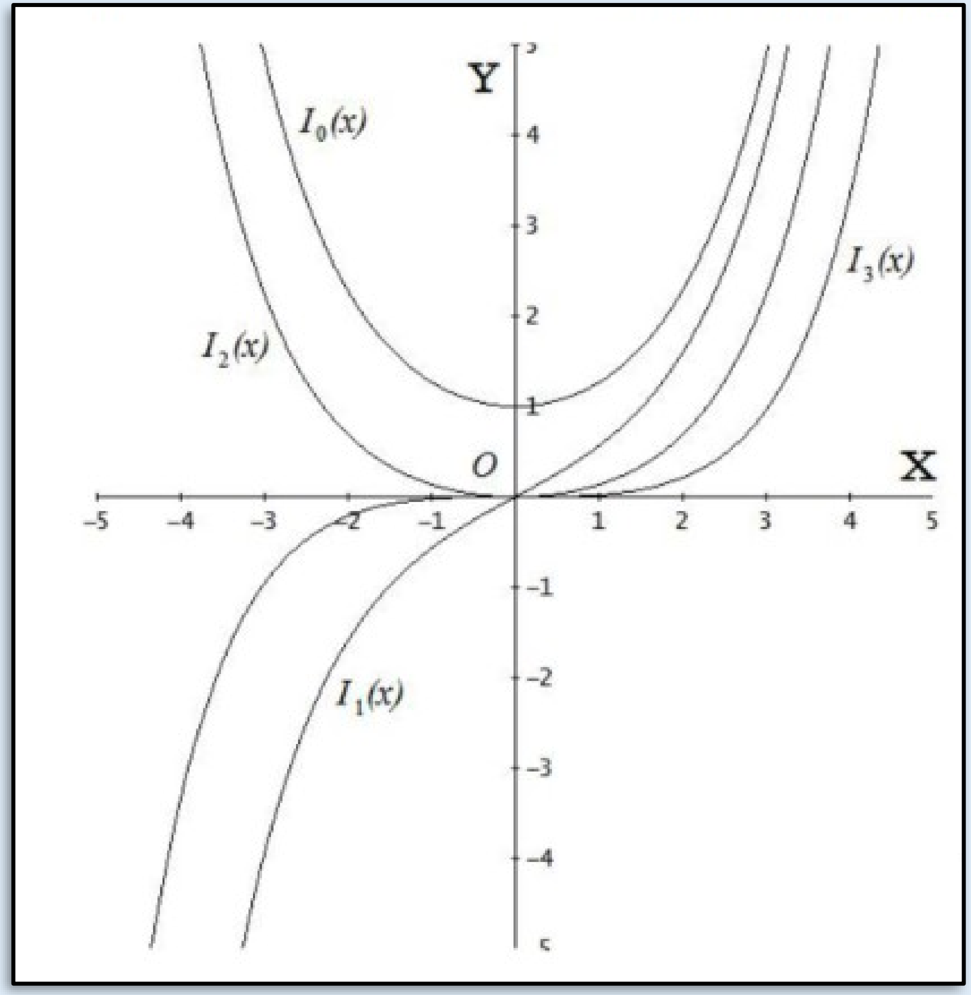
$$I_1(k_1 r)/k_1 = r/2$$

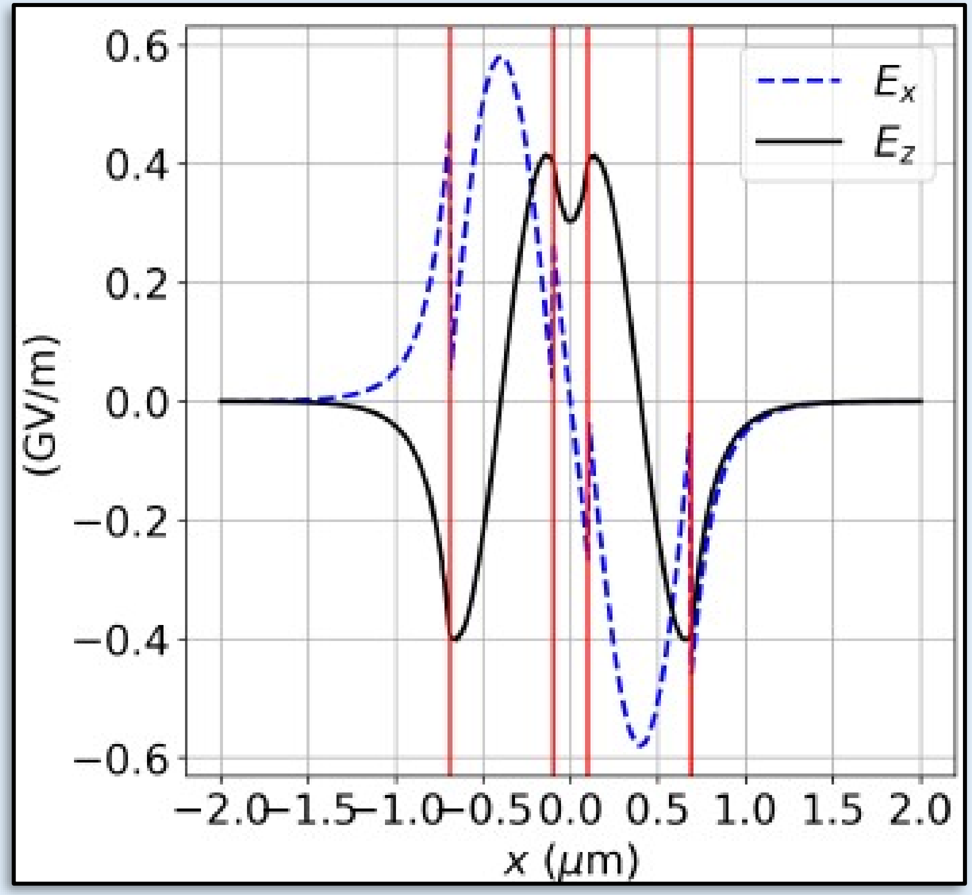
Bessel modified function ‘I’

$$E_z = E_0 I_0(rk_1)\sin(\omega t - k_z z + \psi),$$

$$E_r = \frac{E_0 k_z}{k_1} I_1(rk_1)\cos(\omega t - k_z z + \psi),$$

$$B_\phi = \frac{\omega \epsilon_0 \mu_0 E_0}{k_1} I_1(rk_1)\cos(\omega t - k_z z + \psi)$$





Keep the bunch in phase with the wave, a very complex problem

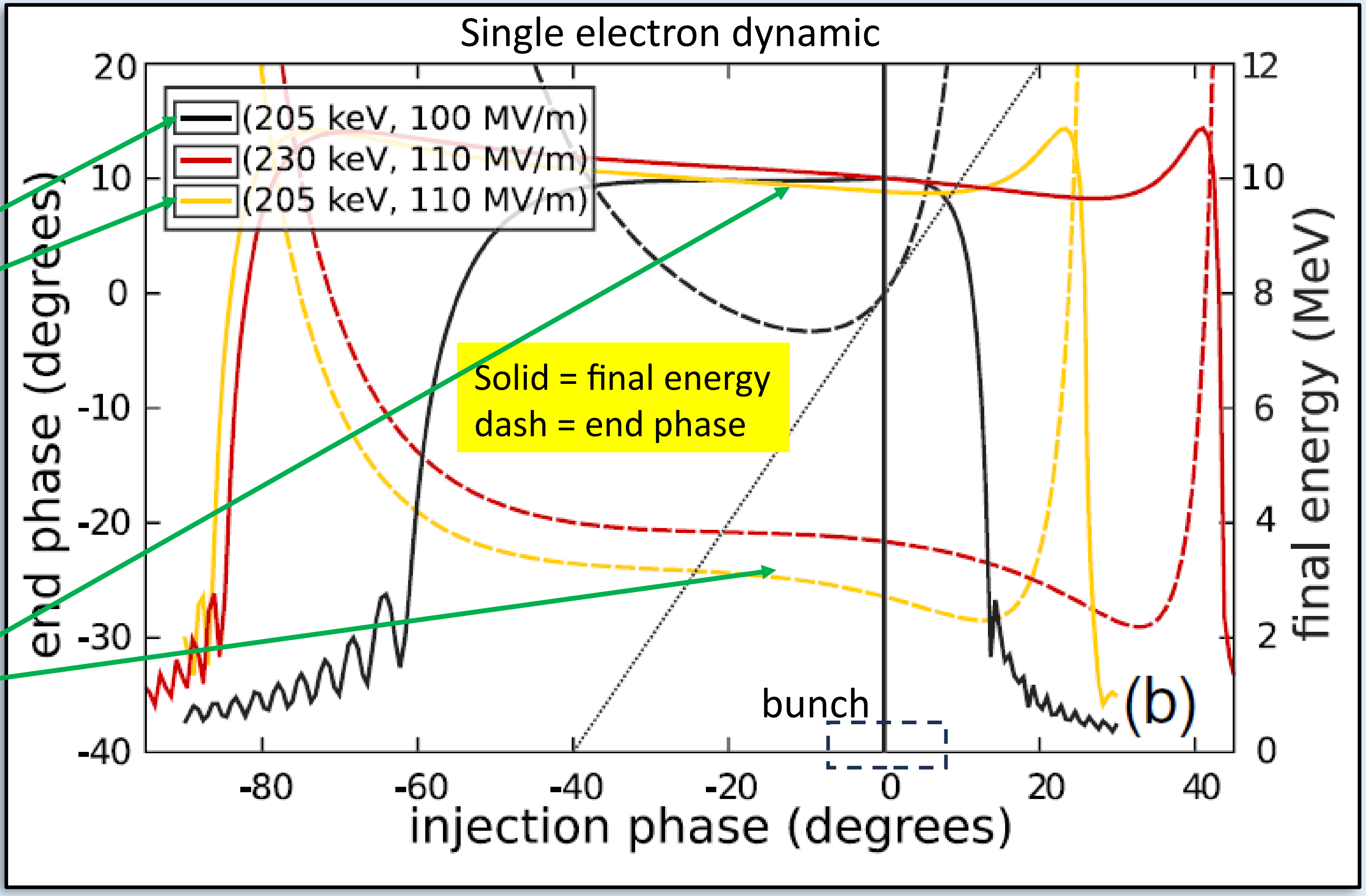
After first simulations, without success: I tried to find some good rules from the Lemery paper on DLW at 300 GHz

F. LEMERY *et al.* PHYS. REV. ACCEL. BEAMS **21,** 051302 (2018)

f=300GHz & G= 100 MV/m :
(our case)

205 keV

Plateau
end-phase vs inj-phase and end-energy


Single electron dynamic

Solid = final energy
dash = end phase

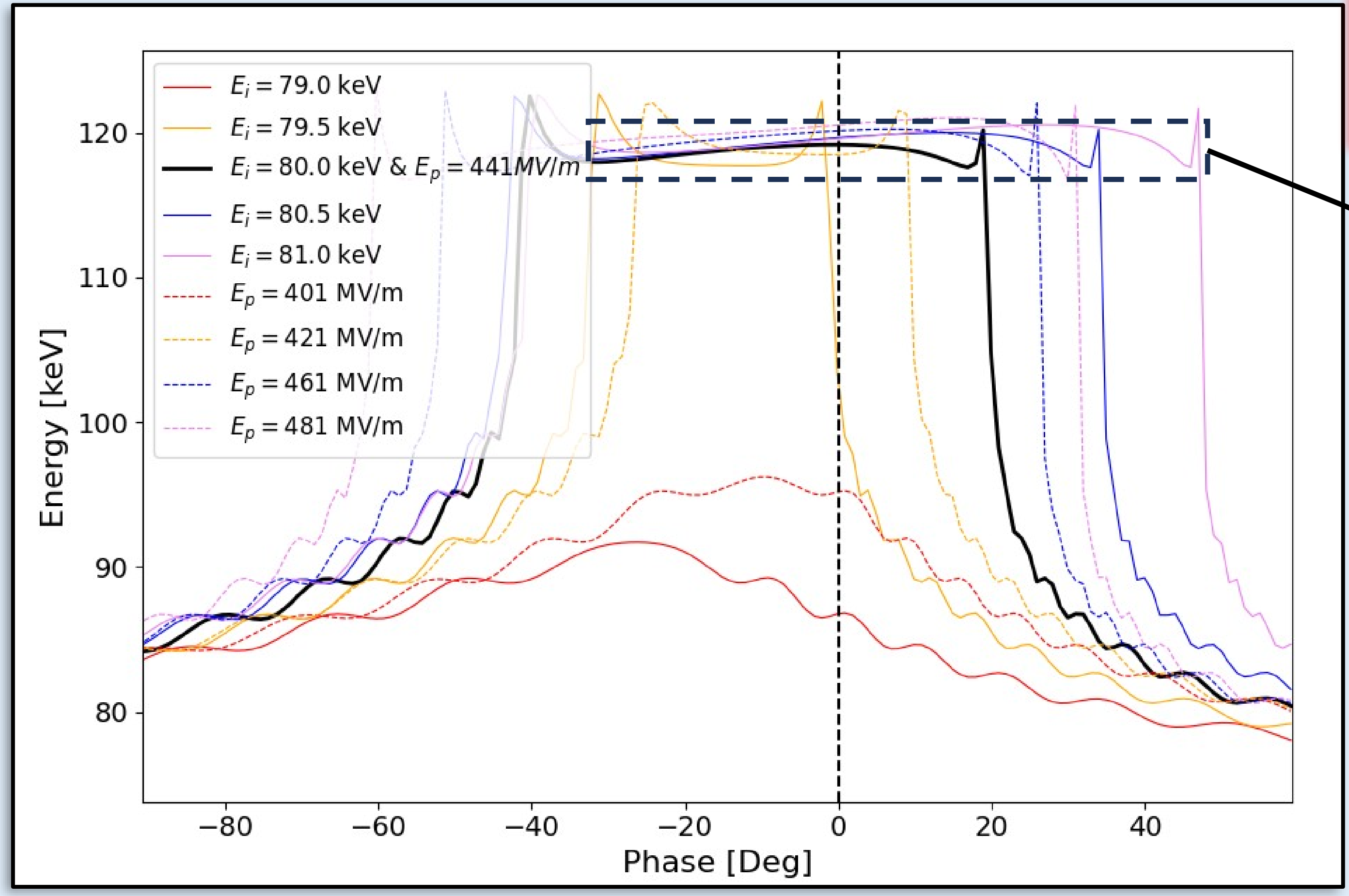
bunch

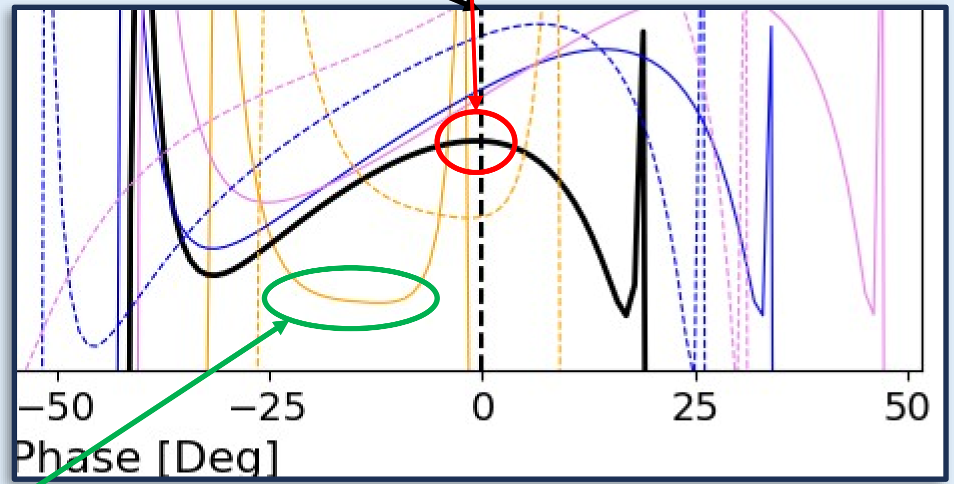
Our case: end-energy vs phase-scan for different starting conditions

Reference point. The particle:

@ 80keV = $V_{\text{ph-start}}$, and beam exit @ 119 keV = $V_{\text{ph-end}}$

Not the best working point: Using a distrib. it shows many over-focusing by synchrotron oscillations





The more stable condition than the reference one (black solid line)

The Slot waveguide accelerating structure Particle Distributions studies

$$f = 1.49945 \cdot 10^5 GH_z$$

Slot DLA – distribion simulation

2D case – bunch tracking

From numerical point of view, **we must rescale main parameters**.

Considering well known simulations set for S-band cavities (λ_{cell}=3.5 cm) witch typically drive bunch lengths ~ 10µ ÷ 1 mm

Here with λ_c = 1 µm

we can consider a roughly: 3.5 cm/1 µm ~ 3.5 · 10^4 factor.

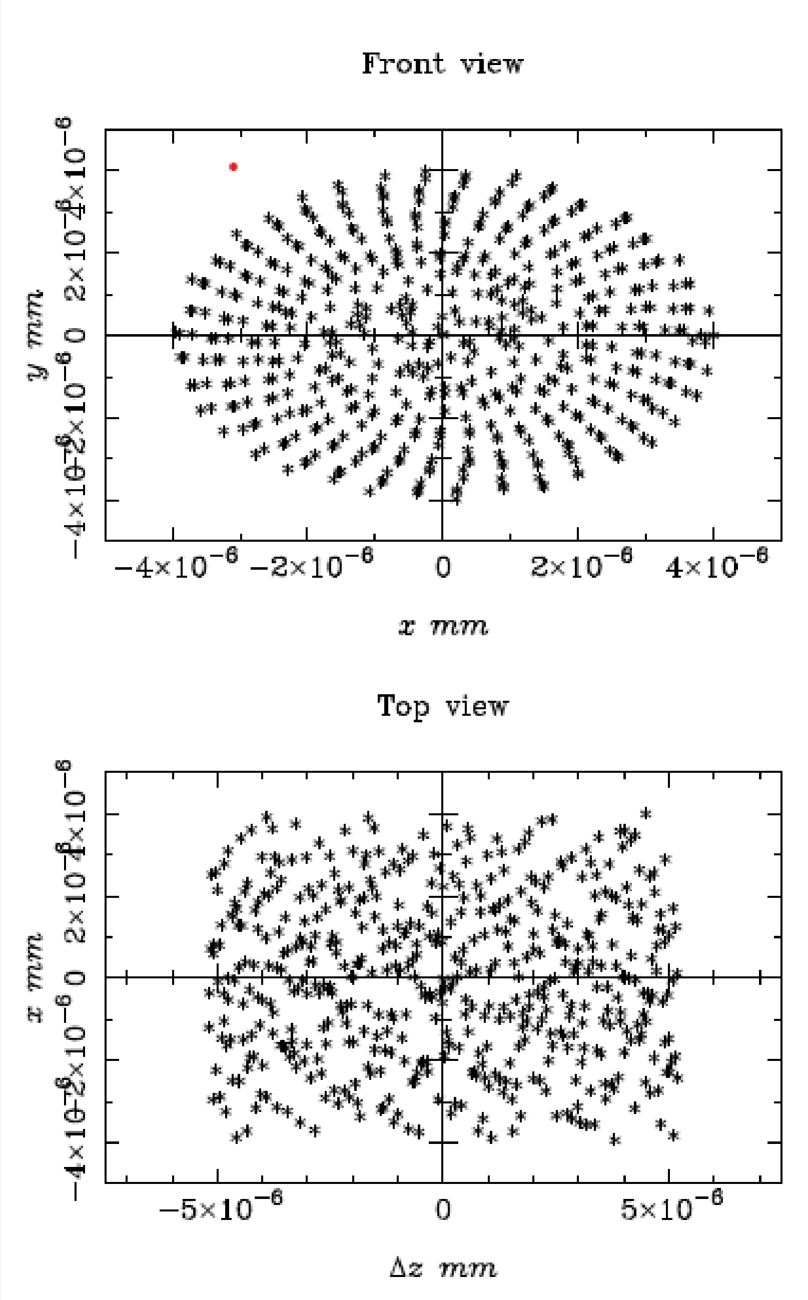
Let's do the scaling:

Bunch length:	350 µm S-band	→ 10 nm
Bunch rad:	140 µm S-band	→ 4 nm
R-K int. step	1 ps (S-band)	→ 1.5 · 10^{-8} ns (used 1 or 0.5 · 10^{-8})

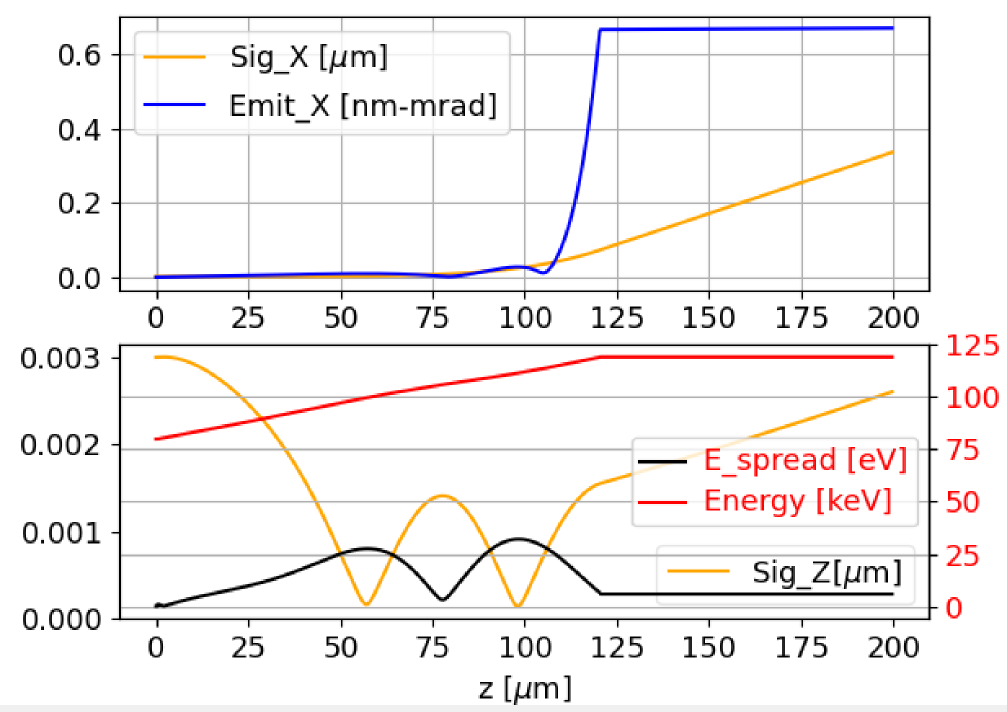
Space-charge = 0

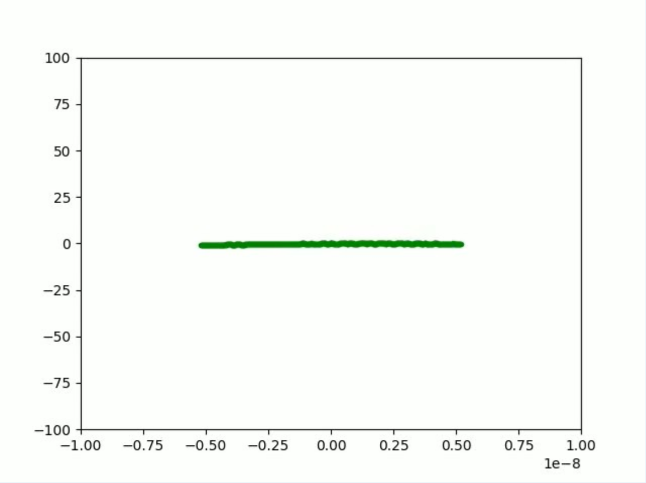
Energy spread = 0

Starting energy **80 keV** & **79.5 keV** for the plateau case

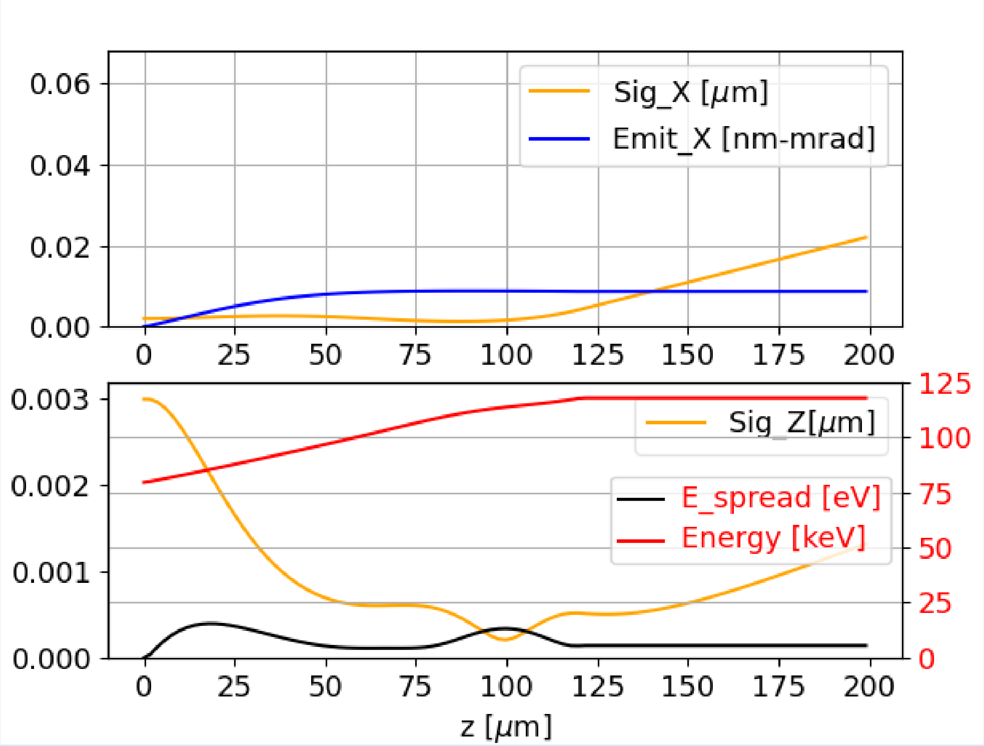


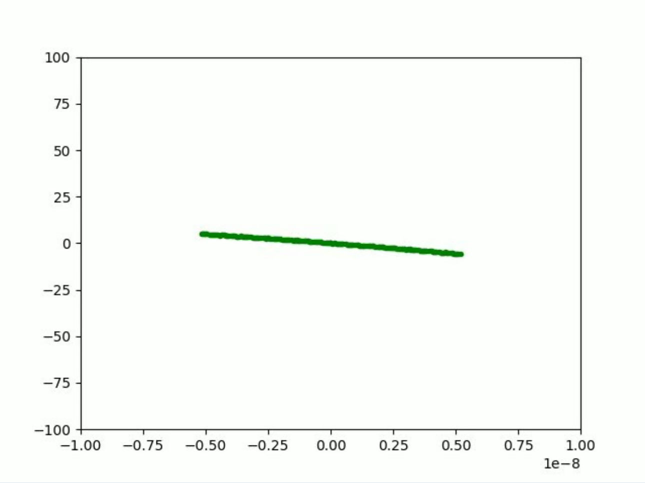
The reference case 80 keV



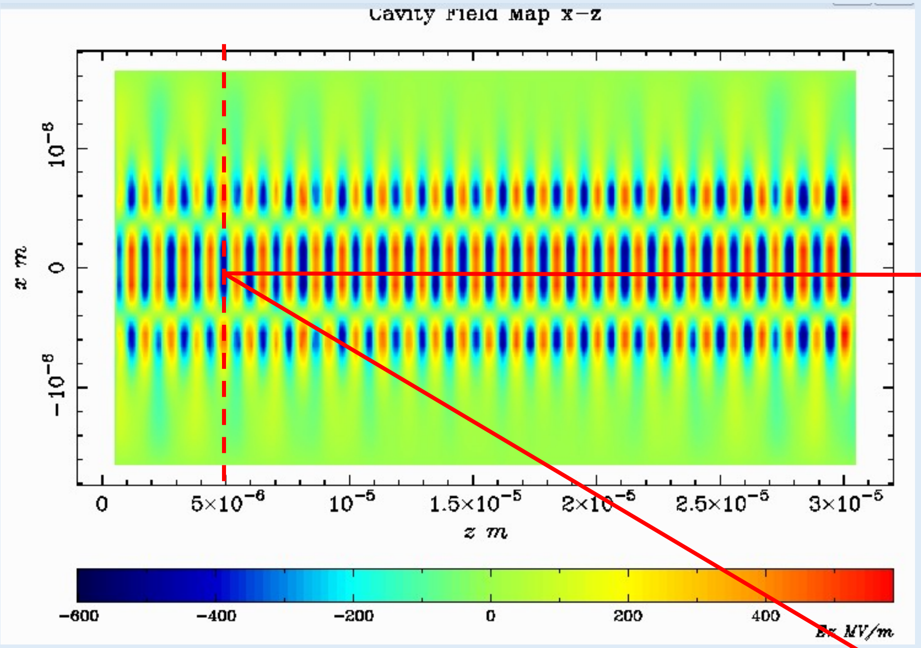


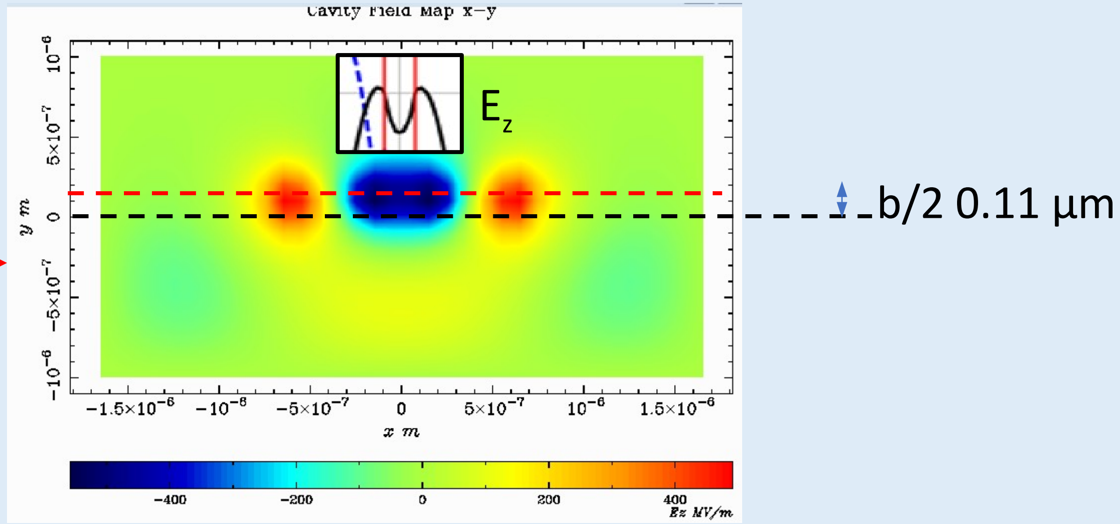
On the more stable plateau 79.5 keV

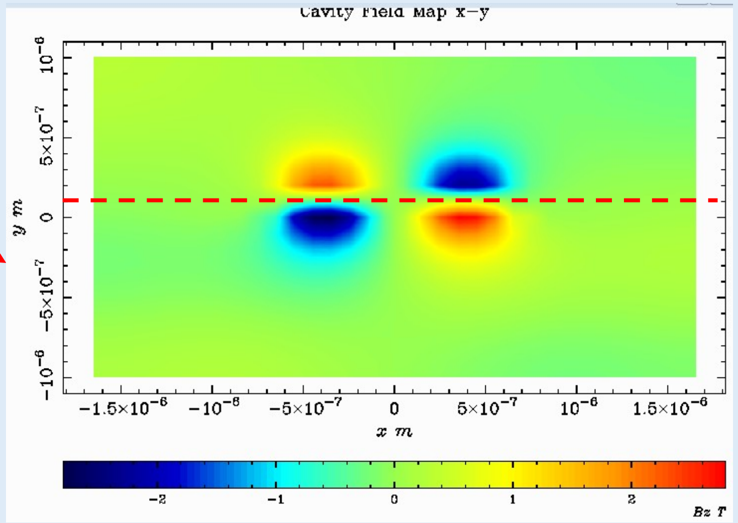




Slot DLA – Astra simulation 3D case and bunch tracking

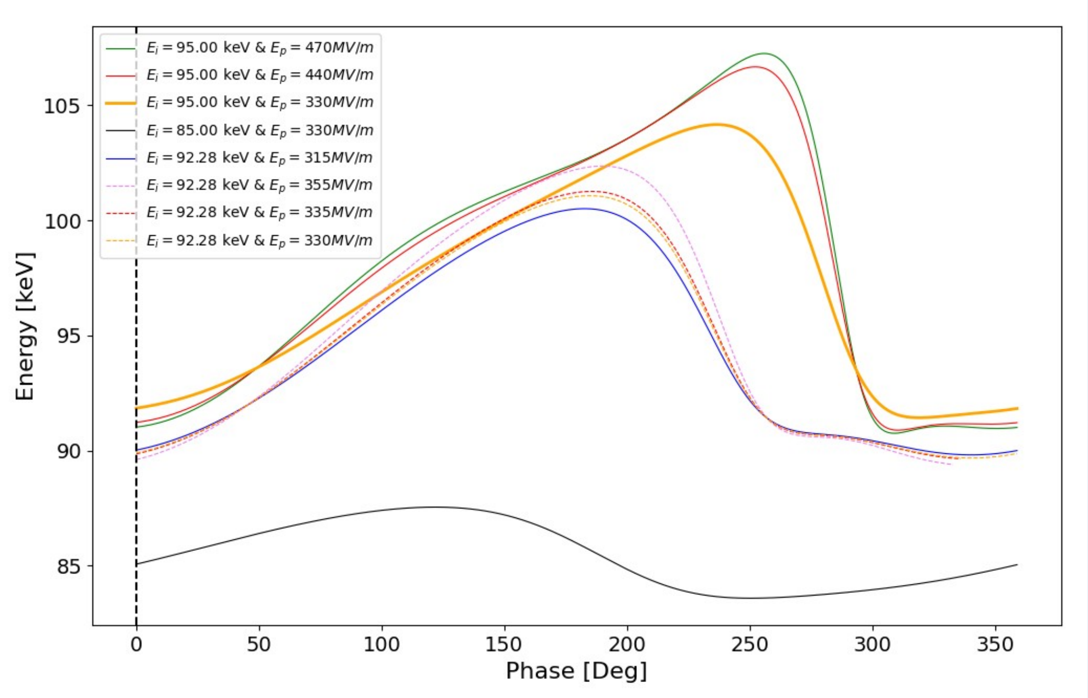






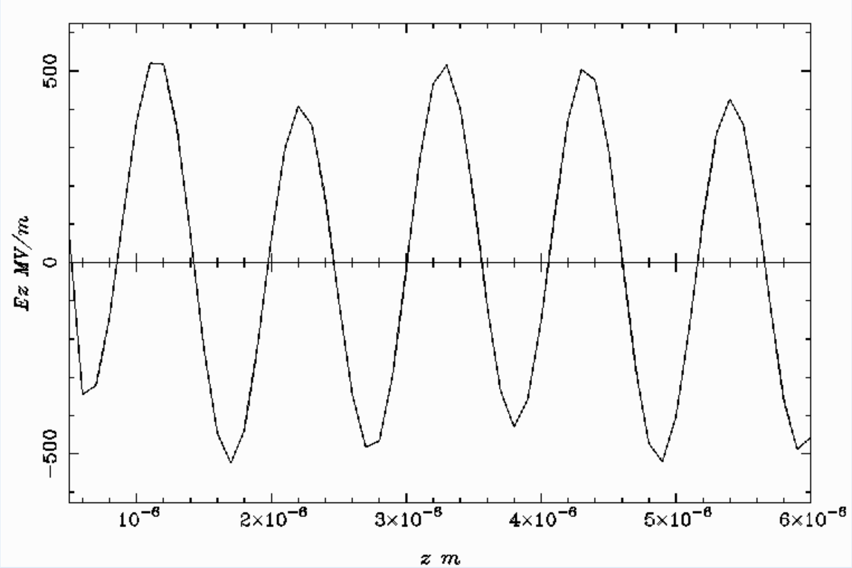
As in the paper,
the field is centered in (0,b/2), i.e. for the simulation y_{off}= 0.11E-7

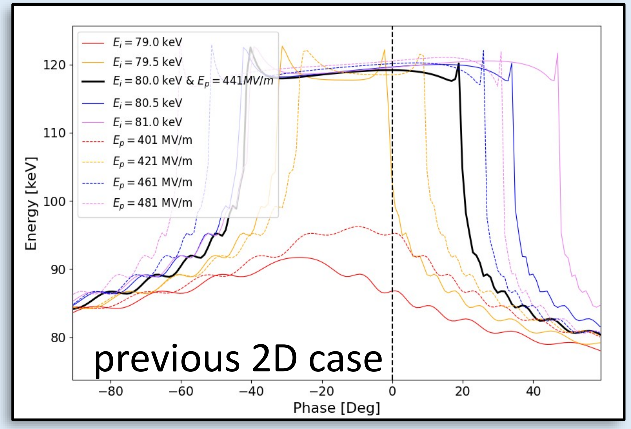
Slot DLA – Astra simulation 3D case and bunch tracking



I **tested many different Grad. and inj. E$_i$** :
it seems impossible to fined a good matching.

Probably the filed **map is too poor**, and we **see only a field envelop**





previous 2D case

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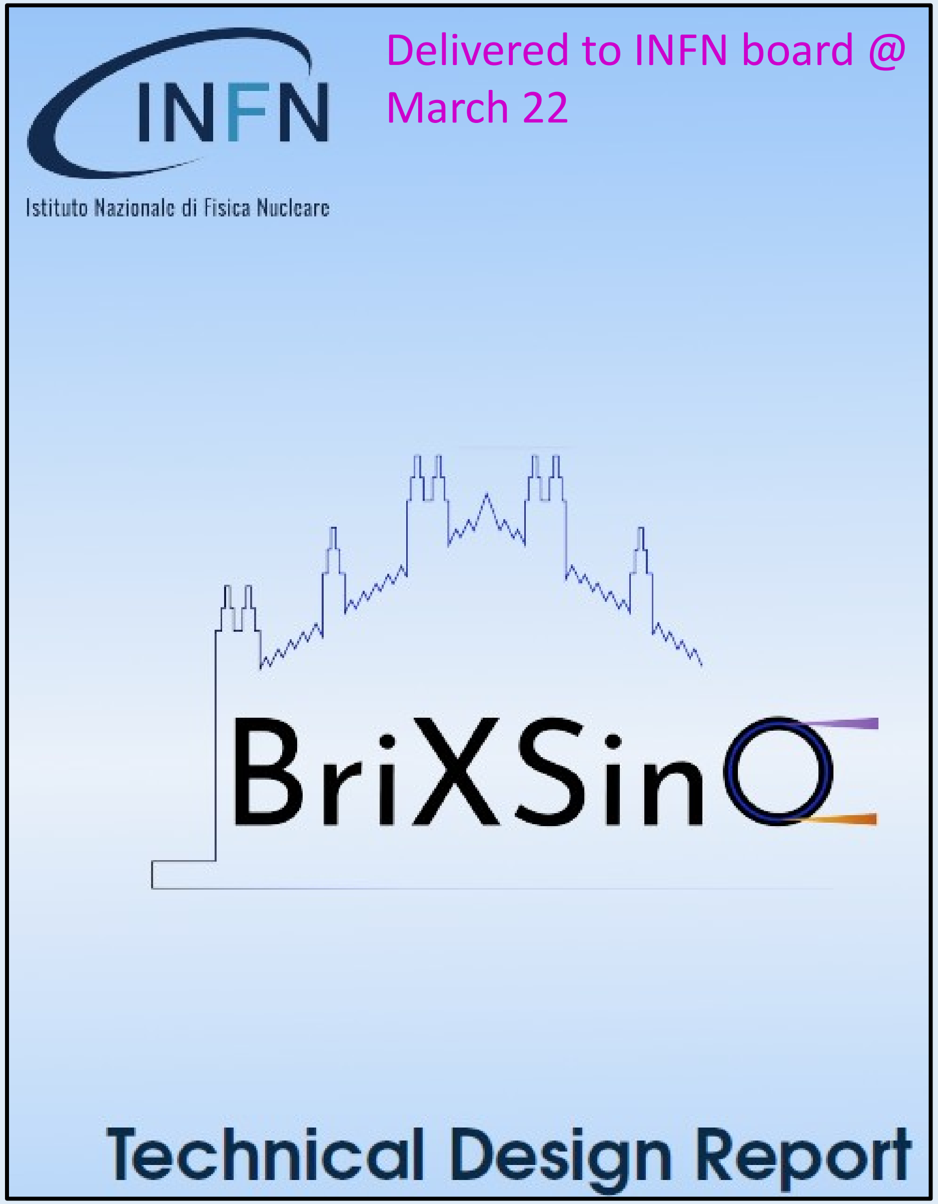
BriXSinO ERL project, the origin

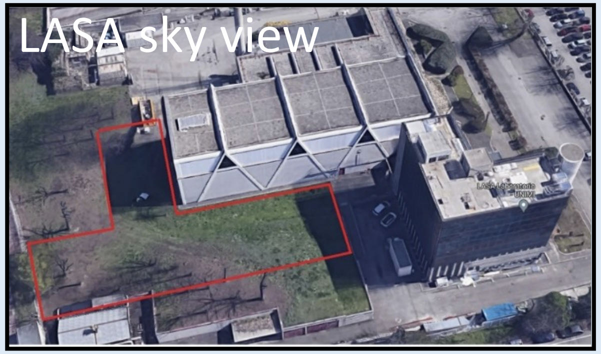

Istituto Nazionale di Fisica Nucleare

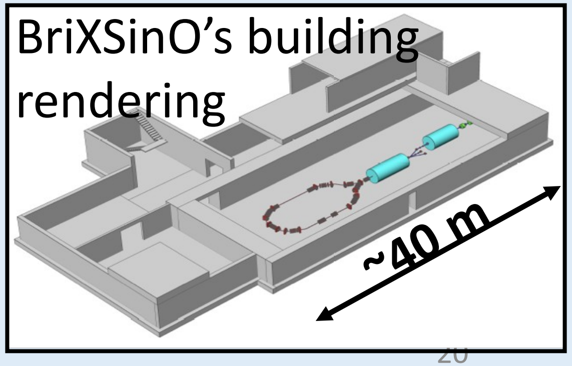
BriXSinO

Technical Design Report

Delivered to INFN board @ March 22

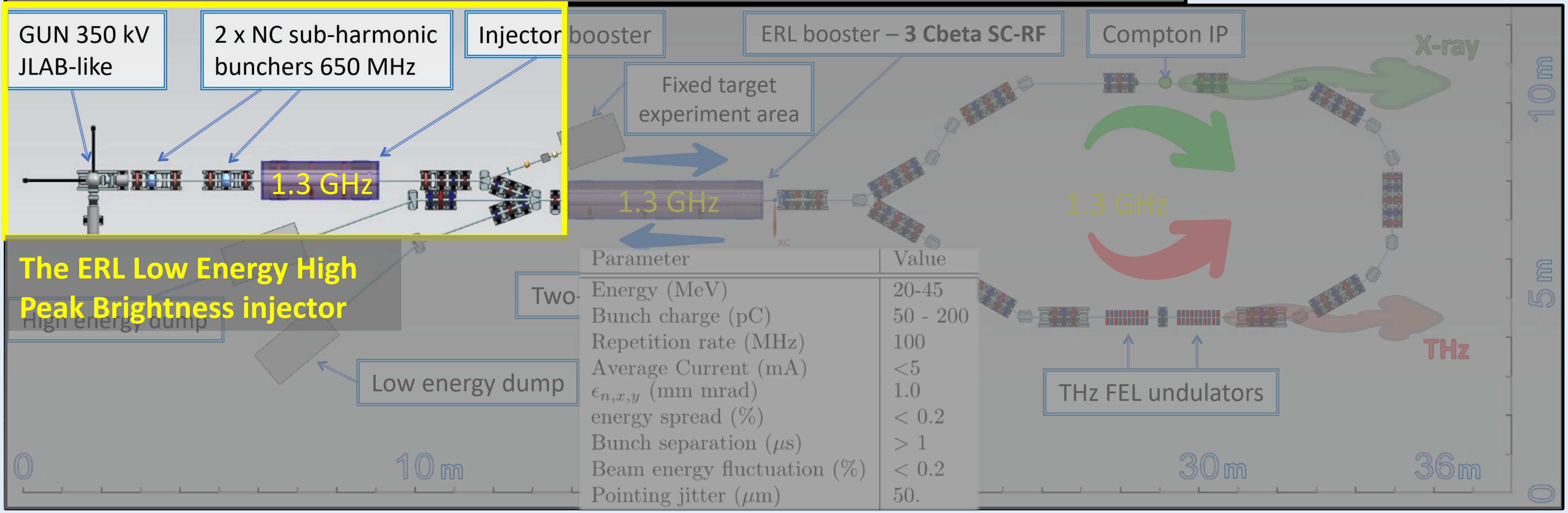
L.A.S.A. - Laboratorio Acceleratori e Superconduttività Applicata
→ Accelerator Laboratory and Applied Superconductivities


LASA sky view


BriXSinO’s building rendering

The BriXSinO Layout

***Bri**lliant source of **X**-rays based on **S**ustainable and **in**n**O**vative accelerators*



The ERL Low Energy High Peak Brightness injector

Parameter	Value
Energy (MeV)	20-45
Bunch charge (pC)	50 - 200
Repetition rate (MHz)	100
Average Current (mA)	<5
$\epsilon_{n,x,y}$ (mm mrad)	1.0
energy spread (%)	< 0.2
Bunch separation (μs)	> 1
Beam energy fluctuation (%)	< 0.2
Pointing jitter (μm)	50.

A recent study on bunchers performances:

Lower *f* is better

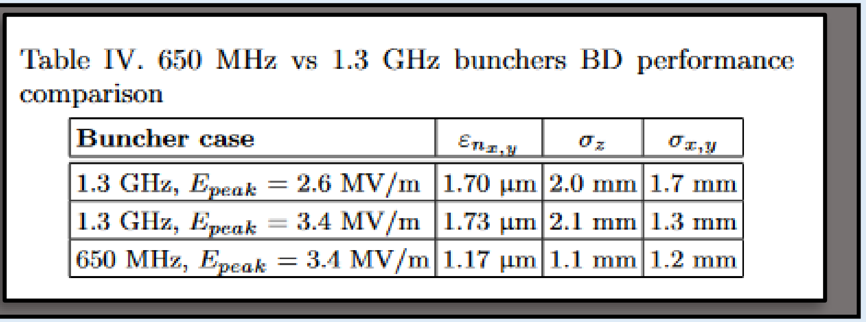


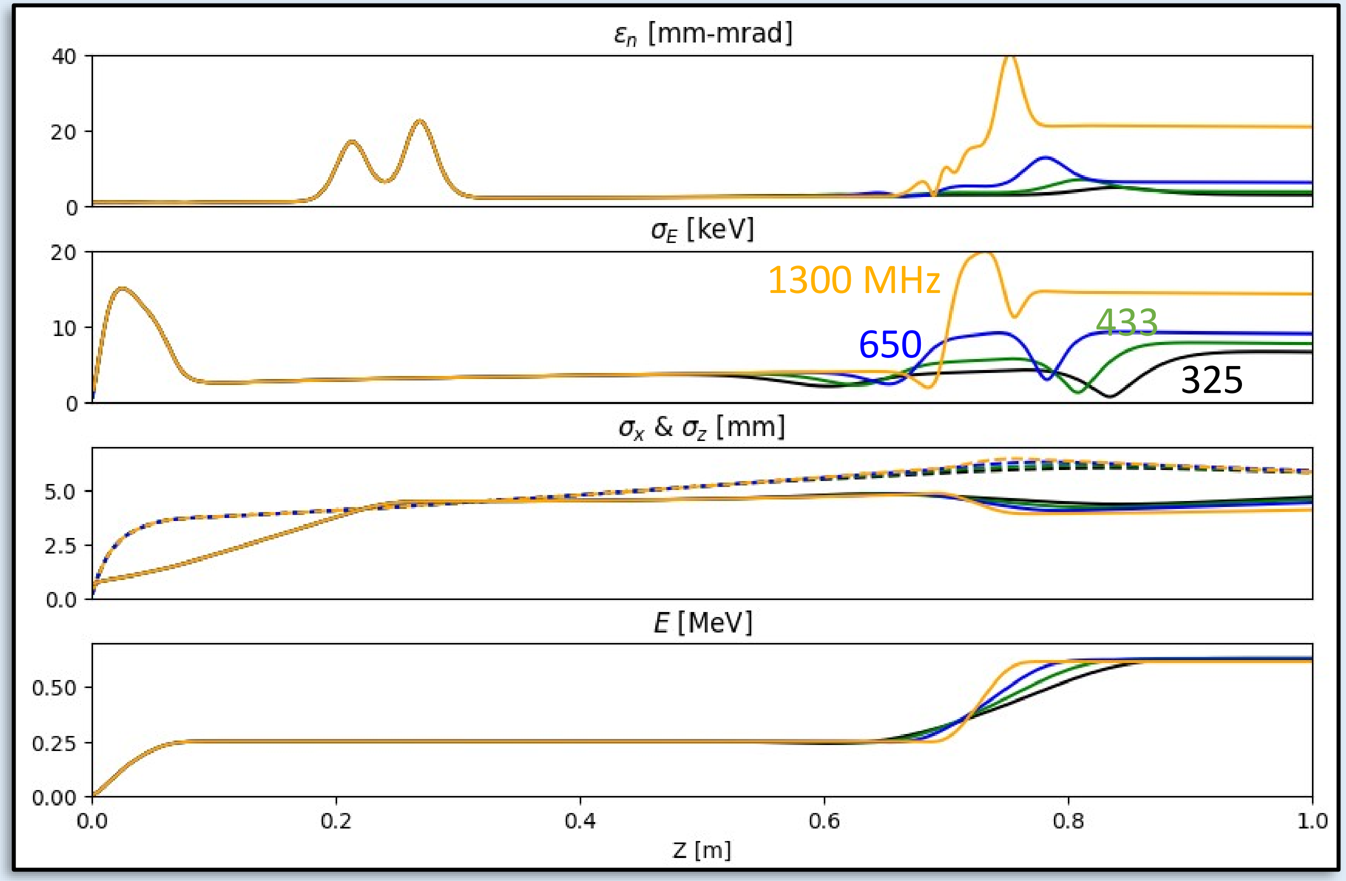
Table IV. 650 MHz vs 1.3 GHz bunchers BD performance comparison

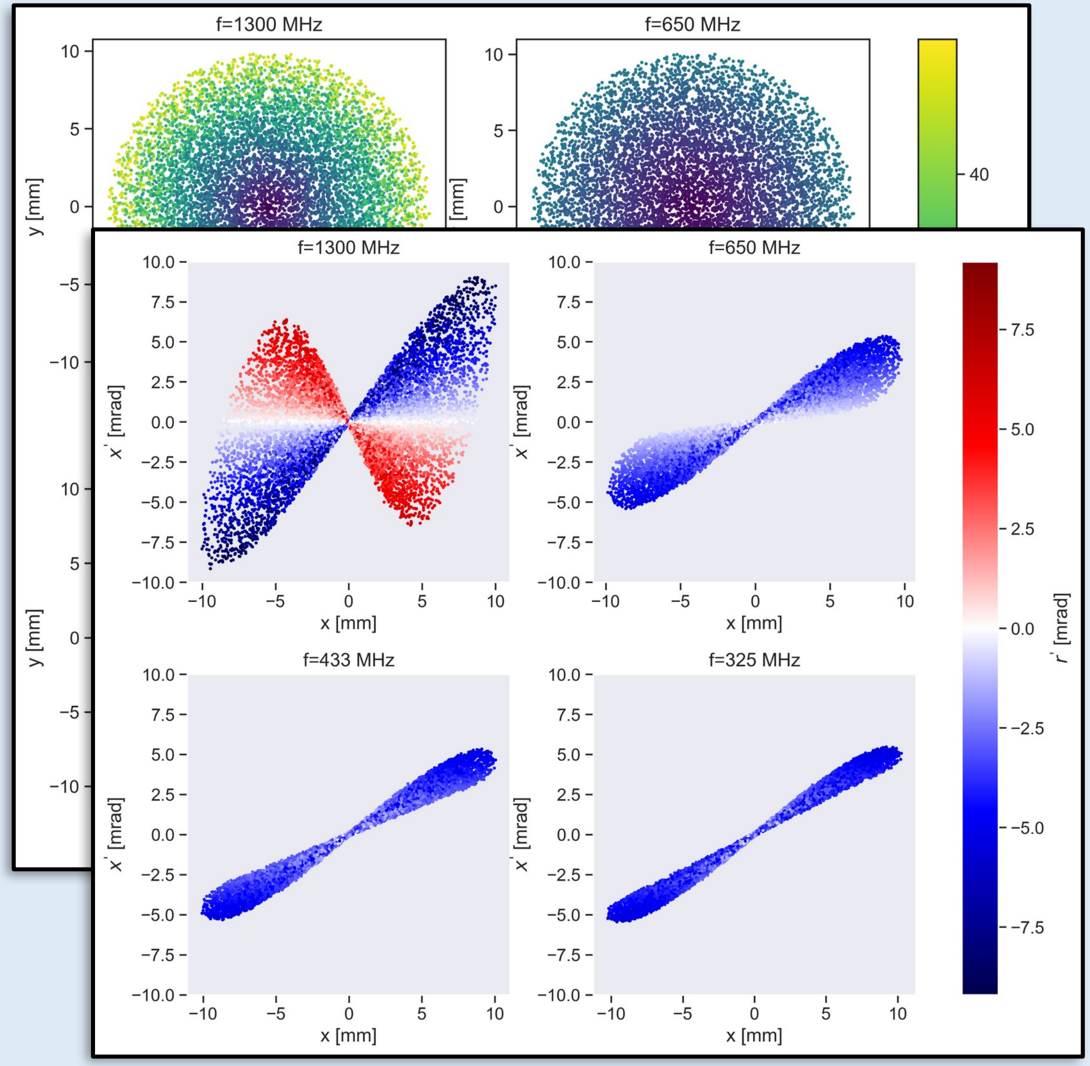
Buncher case	$\varepsilon_{n_{x,y}}$	σ_z	$\sigma_{x,y}$
1.3 GHz, E_{peak} = 2.6 MV/m	1.70 µm	2.0 mm	1.7 mm
1.3 GHz, E_{peak} = 3.4 MV/m	1.73 µm	2.1 mm	1.3 mm
650 MHz, E_{peak} = 3.4 MV/m	1.17 µm	1.1 mm	1.2 mm

Maximum Energies:
ERL WP up to 45 MeV
TPTW acceleration up to 80 MeV

BriXSinO Bunchers: *performances* VS *frequencies*

1.3 GHz vs 650 MHz vs 433 MHz vs 325 MHz





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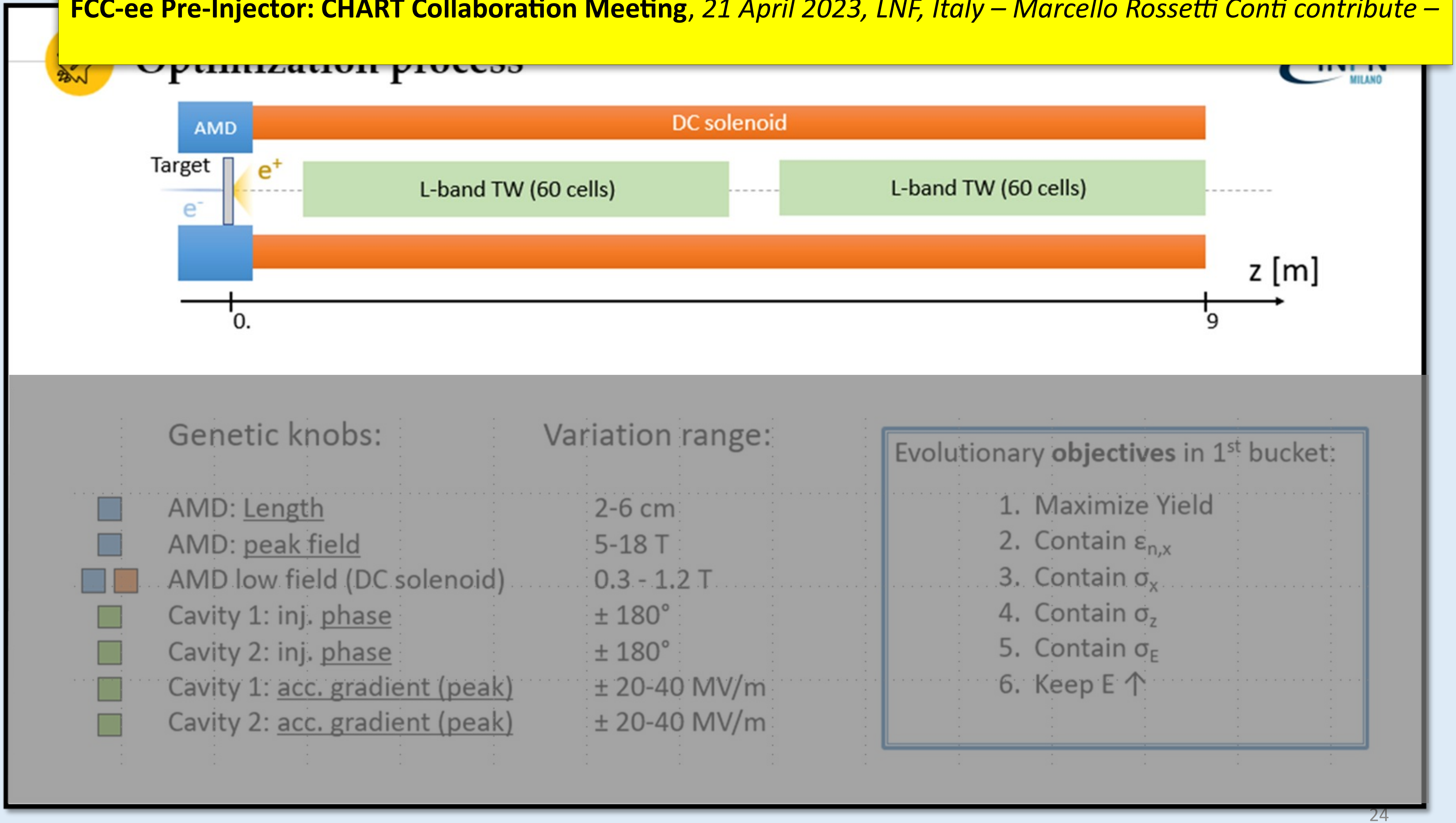
- **`STAR ICS machine status report`** [this talk – index]

FCC-ee Pre-Injector: CHART Collaboration Meeting, *21 April 2023, LNF, Italy – Marcello Rossetti Conti contribute –*



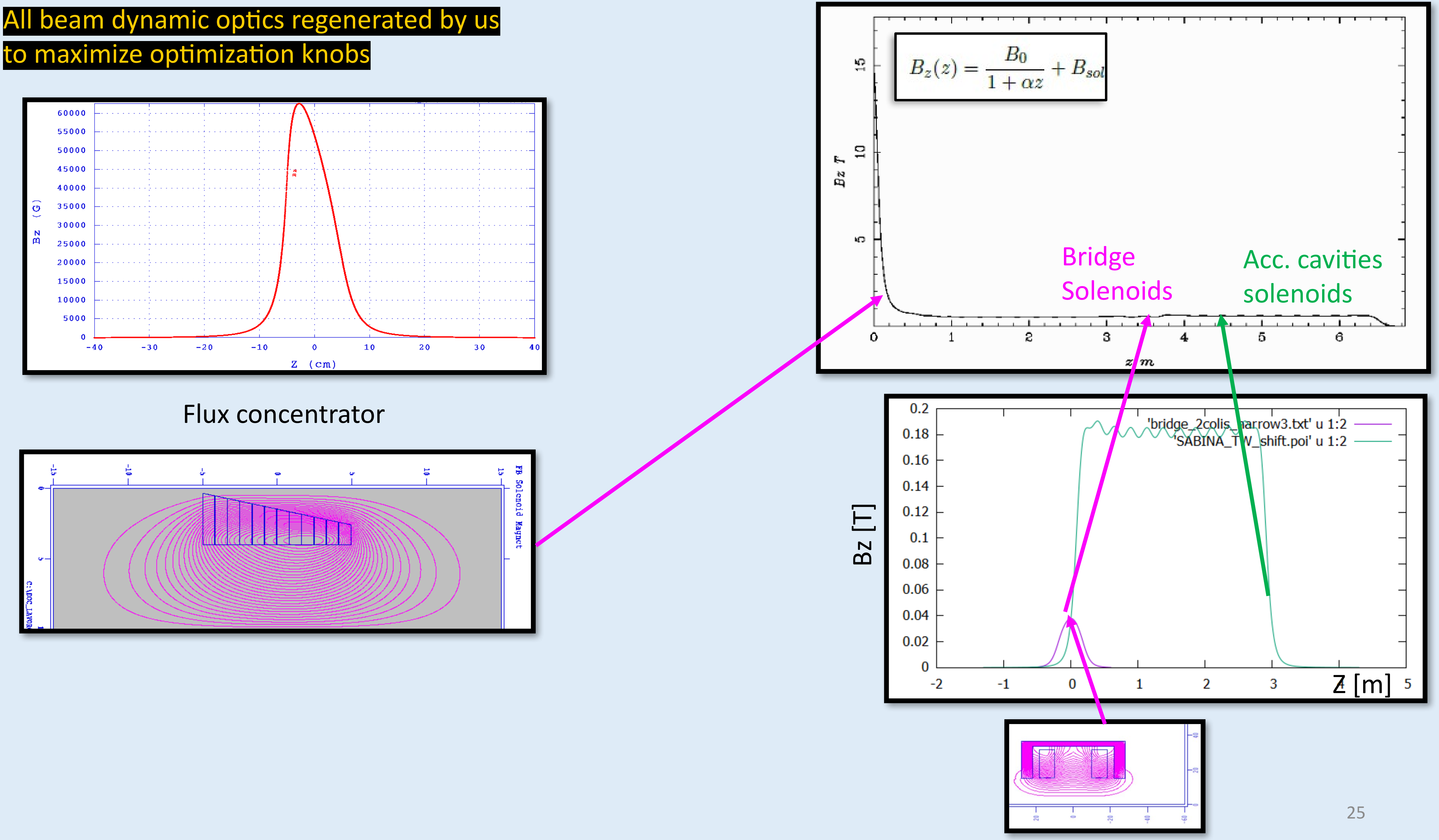
Optimization process

	Genetic knobs:	Variation range:
🟦	AMD: Length	2-6 cm
🟦	AMD: peak field	5-18 T
🟦 🟧	AMD low field (DC solenoid)	0.3 - 1.2 T
🟩	Cavity 1: inj. phase	± 180°
🟩	Cavity 2: inj. phase	± 180°
🟩	Cavity 1: acc. gradient (peak)	± 20-40 MV/m
🟩	Cavity 2: acc. gradient (peak)	± 20-40 MV/m

Evolutionary **objectives** in 1st bucket:

1. Maximize Yield
2. Contain $\varepsilon_{n,x}$
3. Contain σ_x
4. Contain σ_z
5. Contain σ_E
6. Keep E ↑

All beam dynamic optics regenerated by us to maximize optimization knobs

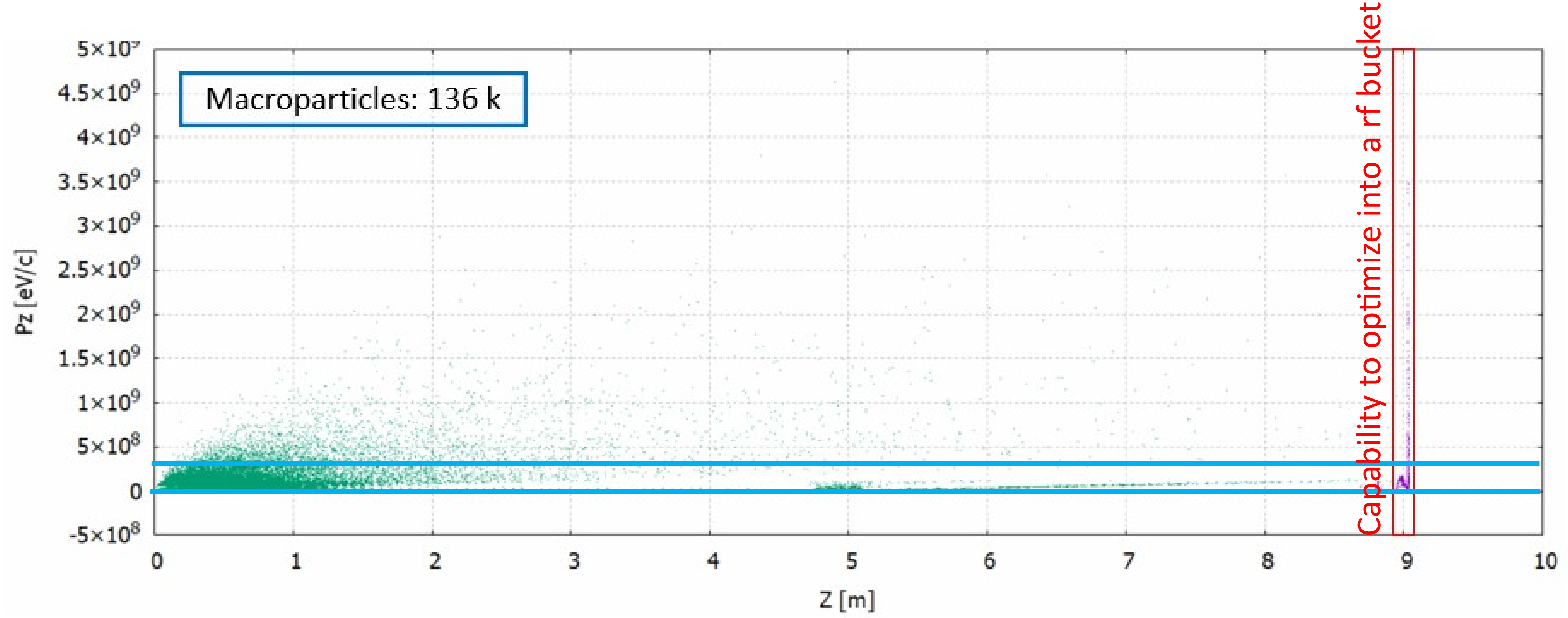


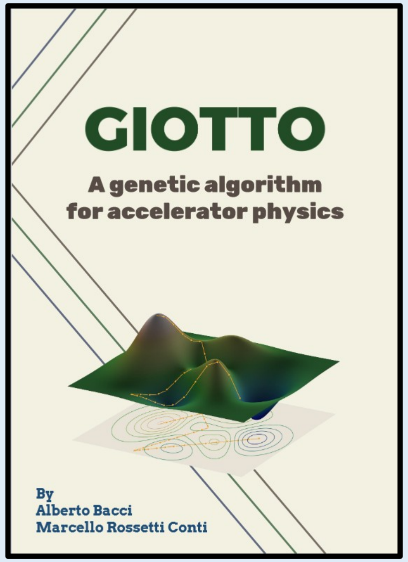
$$B_z(z) = \frac{B_0}{1+\alpha z} + B_{sol}$$

Flux concentrator

Window optimization

- GIOTTO now optimizes particle distribution subsets within **specific windows**, now **enhancing first bucket** optimization (z-cut).
- It could optimize potentially **in-acceptance window** particles.





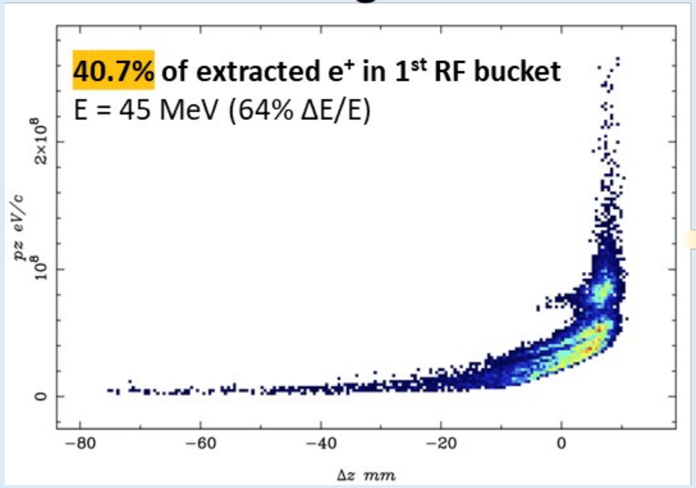
GIOTTO

A genetic algorithm
for accelerator physics

By
Alberto Bacci
Marcello Rossetti Conti

@ FCC-ee – prelaminar GIOTTO optimization

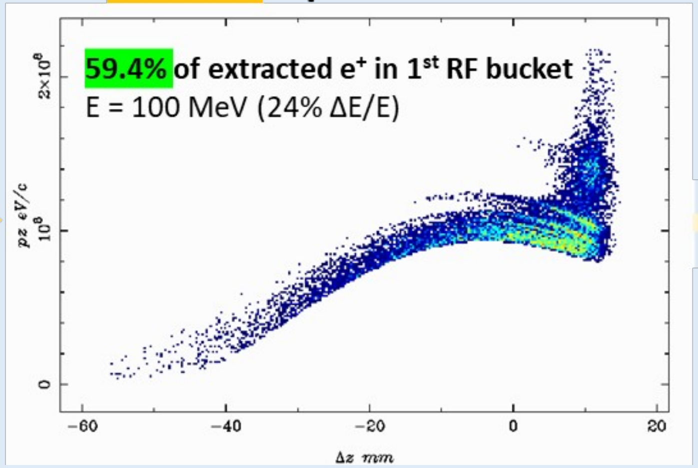
Starting Point



40.7% of extracted e$^+$ in 1st RF bucket

E = 45 MeV (64% ΔE/E)

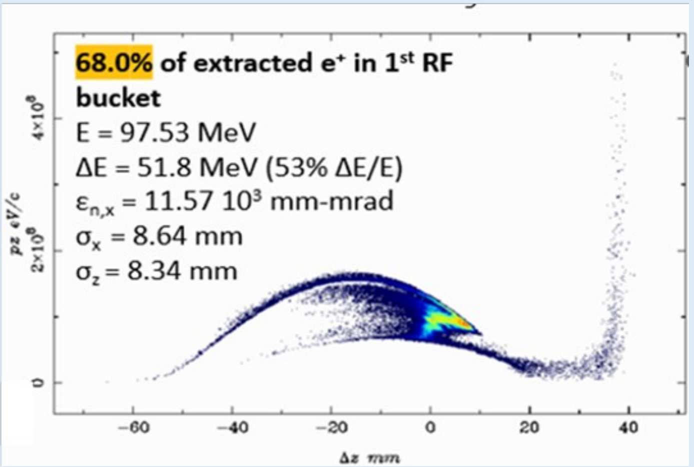
GIOTTO Optimized Point



59.4% of extracted e$^+$ in 1st RF bucket

E = 100 MeV (24% ΔE/E)

GIOTTO windows opt.



68.0% of extracted e$^+$ in 1st RF bucket

E = 97.53 MeV

ΔE = 51.8 MeV (53% ΔE/E)

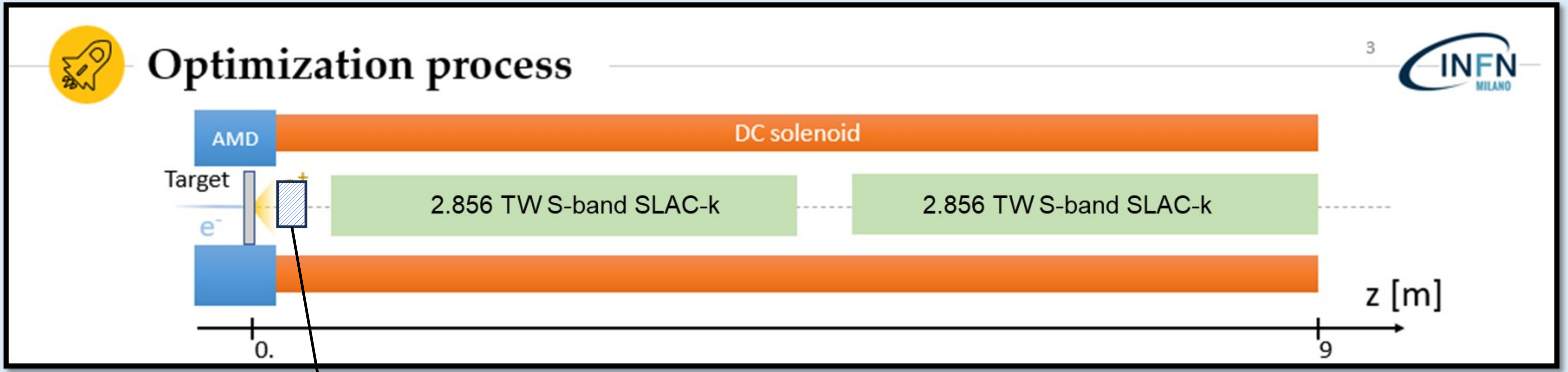
$\varepsilon_{n,x}$ = 11.57 10^3 mm-mrad

σ_x = 8.64 mm

σ_z = 8.34 mm

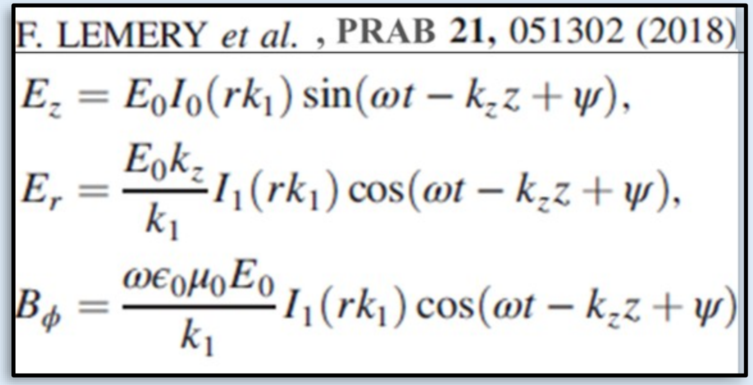
Recent tests

1- Use of a low-β bucher as first trapping device
2- Use of a more standard TW S-band SLAC cavity with a larger airis (r = 16.5 mm) *VS* 2.0 GHz TW mode (r = 30.0 mm)



Optimization process

325 MHz Buncher



F. LEMERY *et al.* , PRAB **21**, 051302 (2018)

$$E_z = E_0 I_0(rk_1)\sin(\omega t - k_z z + \psi),$$

$$E_r = \frac{E_0 k_z}{k_1} I_1(rk_1)\cos(\omega t - k_z z + \psi),$$

$$B_\phi = \frac{\omega\epsilon_0\mu_0 E_0}{k_1} I_1(rk_1)\cos(\omega t - k_z z + \psi)$$

- **Activities in the frame of EuPRAXIA:**
  - Plasma acceleration BD simulations [this morning – A.R. Rossi talk]
  - Plasma betatron radiation [this morning – A.R. Rossi talk]
  - Plasma based devices: bending, ion channel laser, etc … [tomorrow – A. Frazzitta talk]
  - Matching line tuning from plasma to Undulator by GIOTTO
  - EuPRAXIA injector tuning by GIOTTO

- **GIOTTO simulations Optimizer code development** [tomorrow, M. Rossetti Conti]

- **Dielectric Laser Accelerators (DLA)** [this talk & tomorrow, G. S. Mauro]
  - Woodpile TW cavity simulations [this talk – index]
  - Sub-relativistic SLOT TW Cavity simulations [this talk – index]

- **Magnetic Bottle trap by Symmetric ICS**

- **BriXSinO ERL – Two pass acc. test facility**
  - GIOTTO applied to BriXSinO [tomorrow, M. Rossetti Conti]
  - Low– Buncher *VS* frequency analysis [this talk – index]
  - HB_2TF news [this talk – index]

- `Opt. FCC-ee positron capture line` [this talk – index]

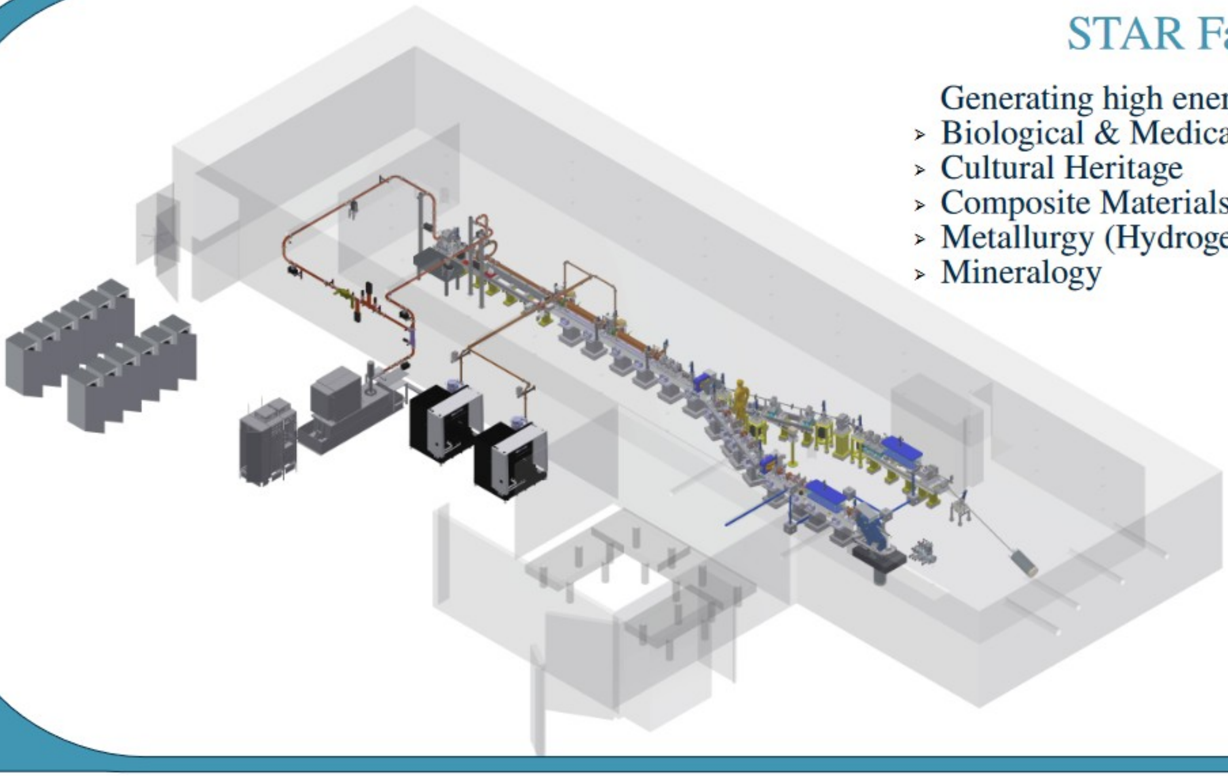
- **`STAR ICS machine status report`** [this talk – index]


INFN
Istituto Nazionale di Fisica Nucleare

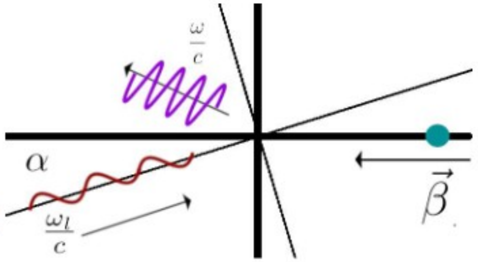
STAR HE-Linac

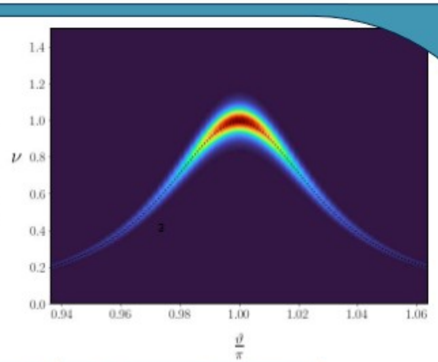

ReStarting @ 2021
missing cables,
cooling pipes ☹

STAR Facility



Generating high energy radiation for
- Biological & Medical Imaging
- Cultural Heritage
- Composite Materials
- Metallurgy (Hydrogen embrittlement)
- Mineralogy

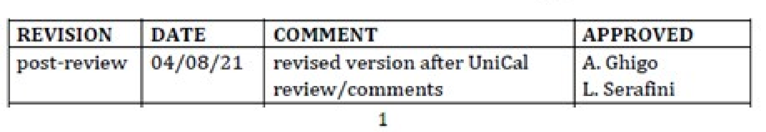




	Electron [Mev]	Photon [keV]
LE – line	23 -65	40 - 150
HE – line	40-150	25 - 350

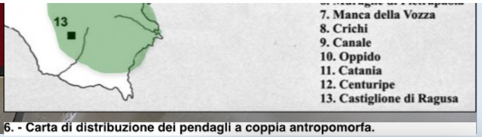
Electrons
- Emittance : 1 [mm mrad]
- Charge : 100 – 500 [pC]
- Bunch length : < 0.7 [mm]
- Energy spread : 0.1 %, 0.05%

(CPA) Laser
- Energy : > 0.5 [Joule]
- Wavelength : 1030 [nm]
- Bandwidth : 1 [nm]



REVISION	DATE	COMMENT	APPROVED
post-review	04/08/21	revised version after UniCal review/comments	A. Ghigo L. Serafini

1

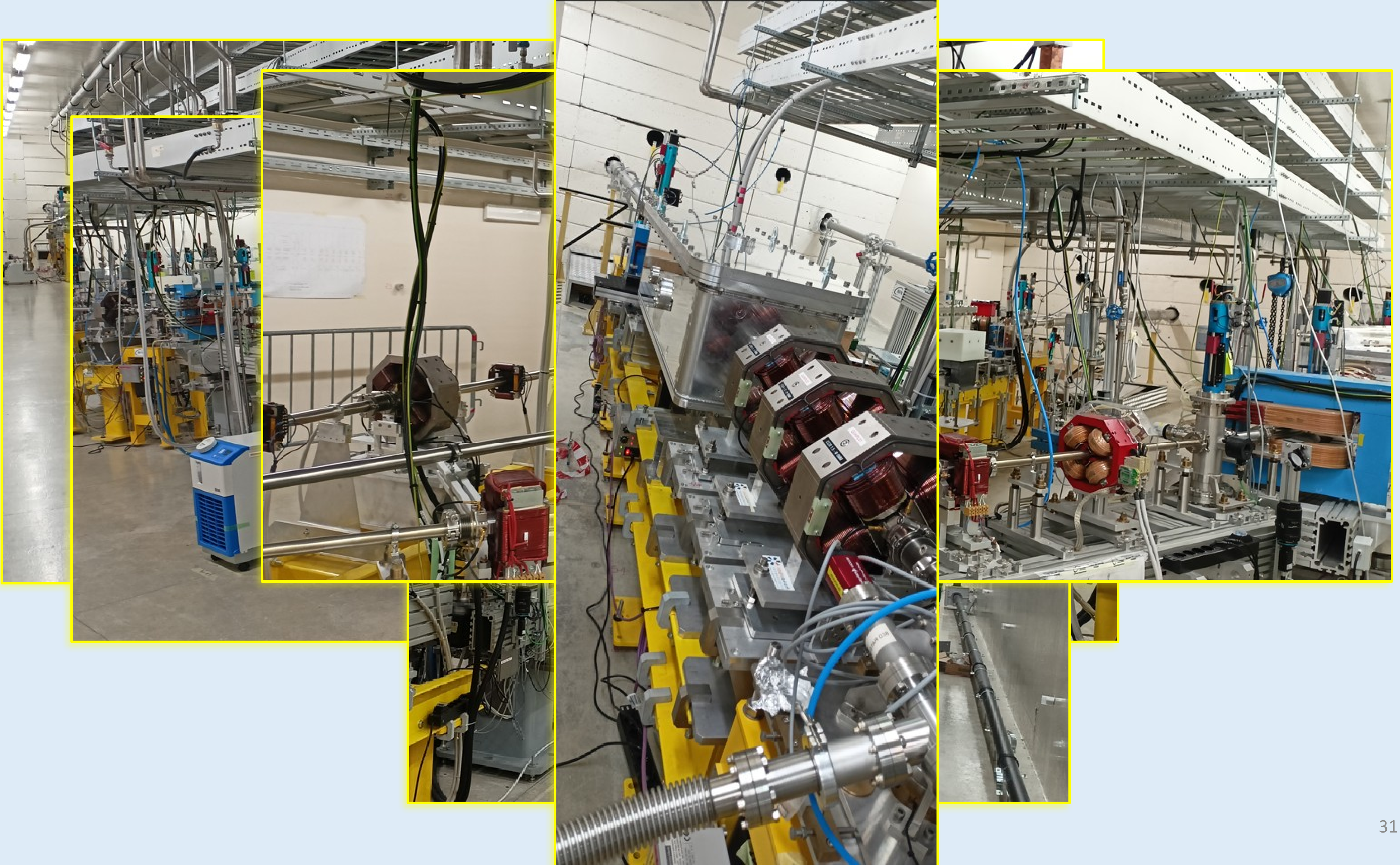


7. Manca della Vozza
8. Crichi
9. Canale
10. Oppido
11. Catania
12. Centuripe
13. Castiglione di Ragusa

6. - Carta di distribuzione dei pendagli a coppia antropomorfa.


1. - Pendaglio a coppia antropomorfa da Francavilla Marittima tipo A (lato 1 e 2).

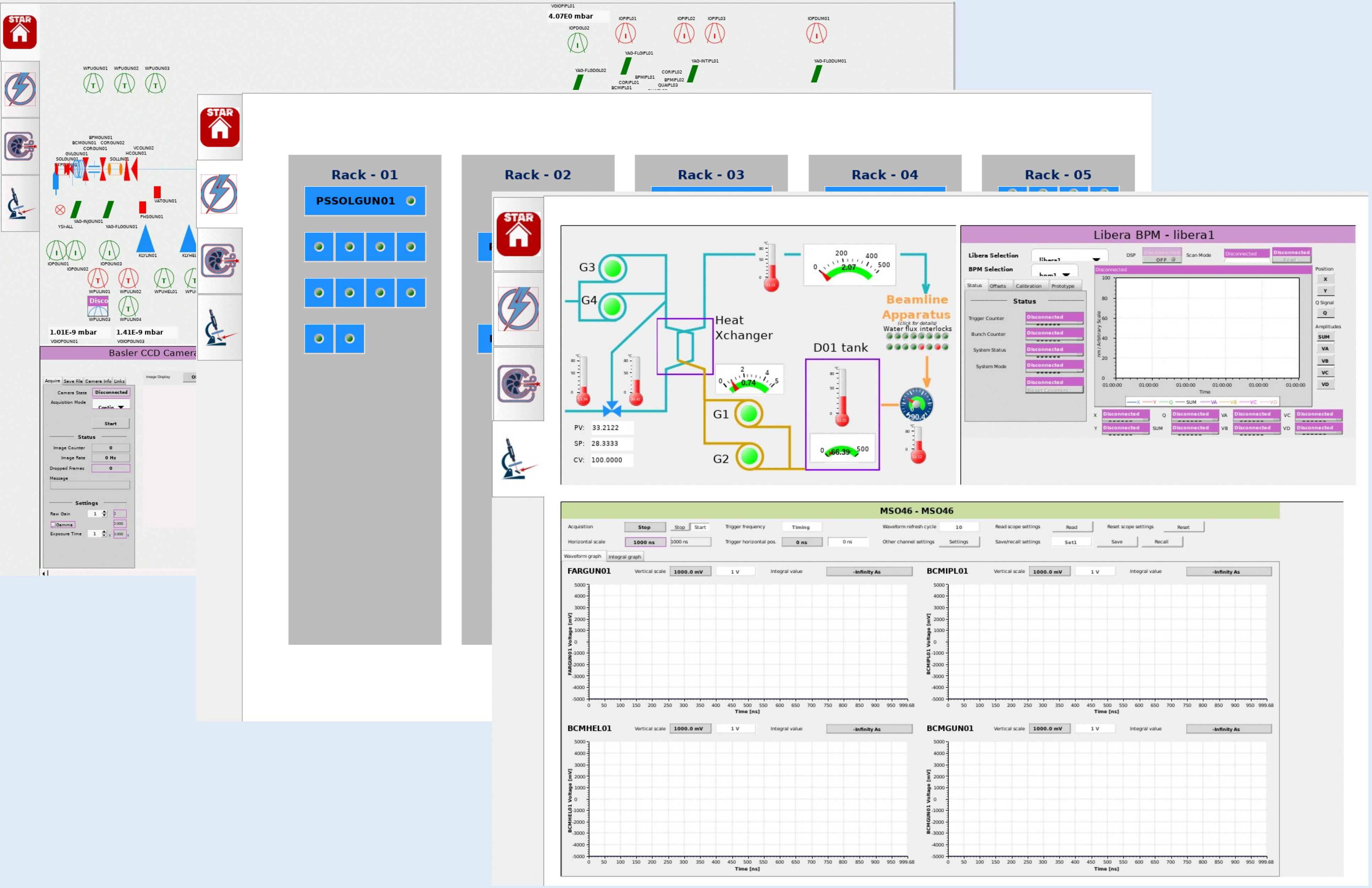

2. - Pendaglio a coppia antropomorfa da Francavilla Marittima tipo B (lato 1 e 2).



The hangar

The Laser

The user hatch



PV: 33.2122
SP: 28.3333
CV: 100.0000

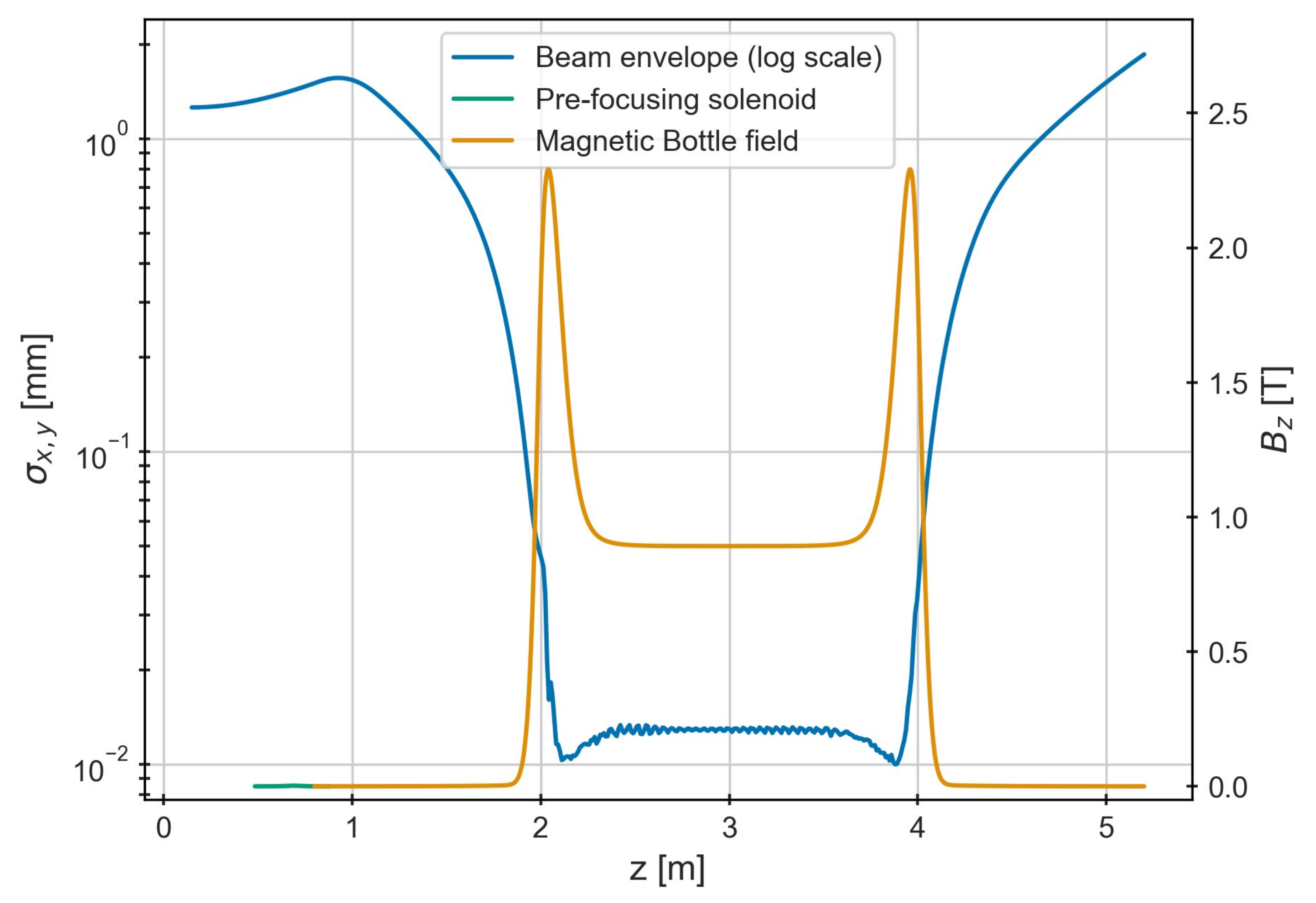
Sample

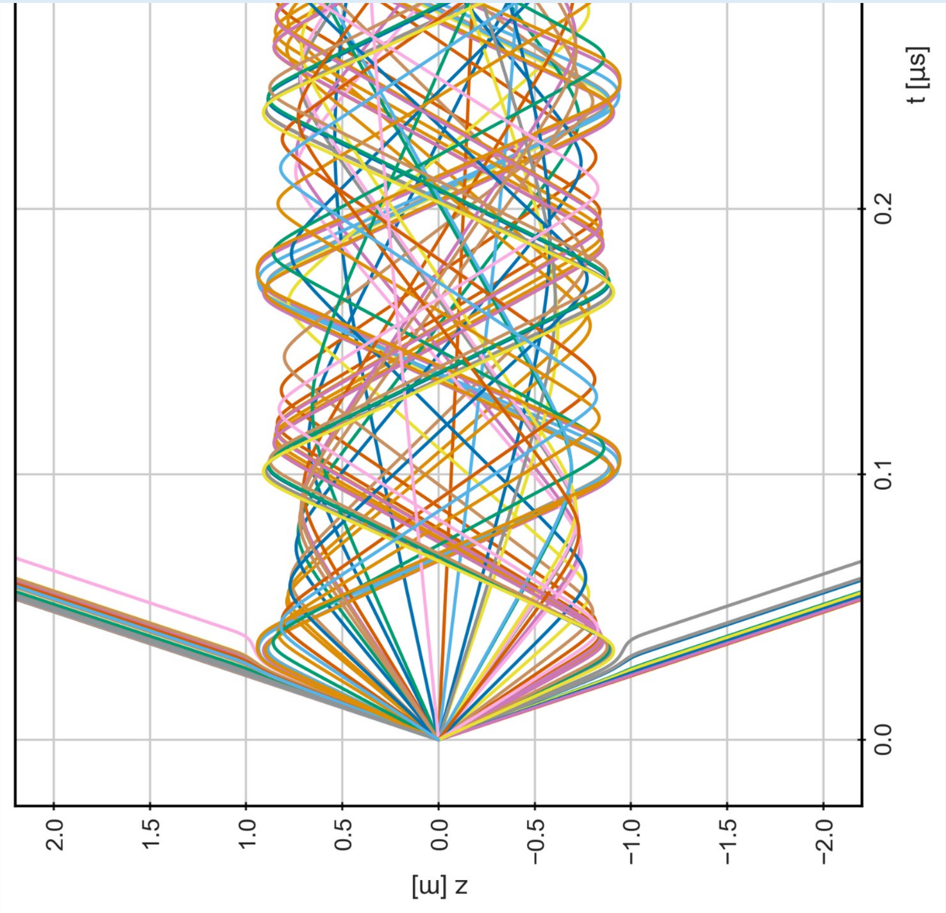
@ moment,
we are waiting for:

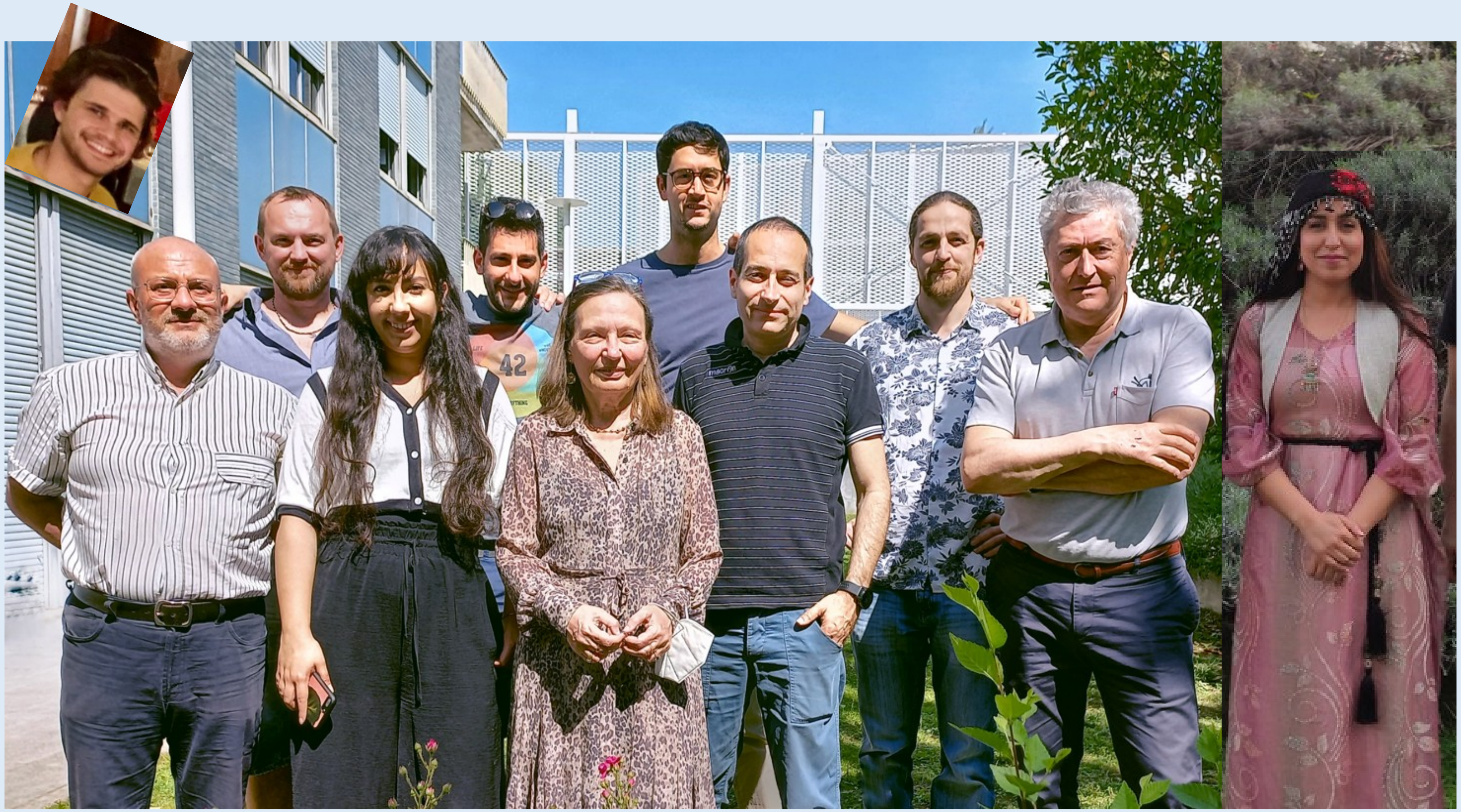
Radioprotection
Authorizations

Tomography

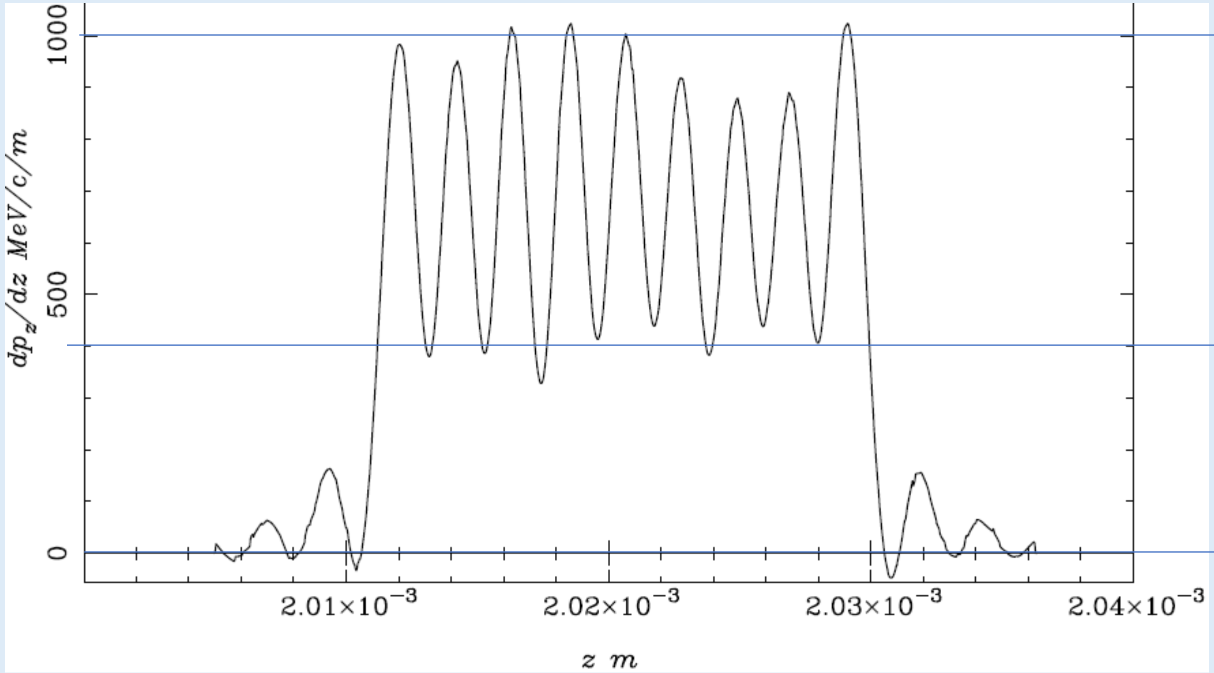
Thanks for your attention!

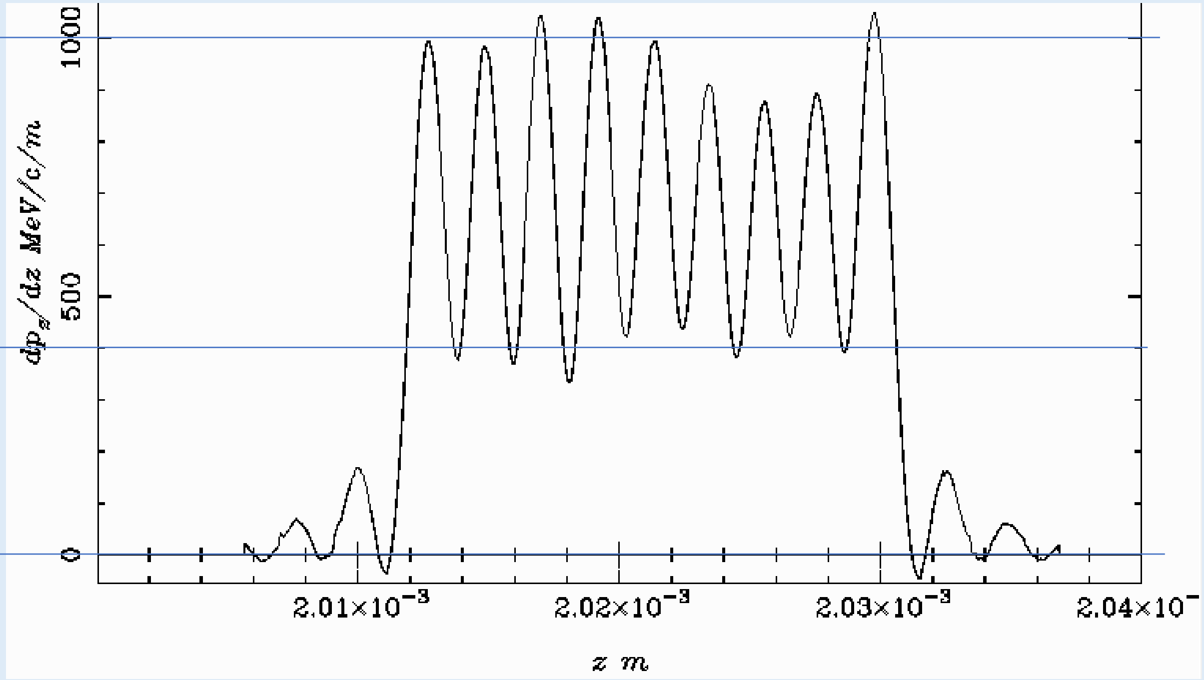

Beam envelope (log scale)
Pre-focusing solenoid
Magnetic Bottle field
$\sigma_{x,y}$ [mm]
10^0
10^{-1}
10^{-2}
B_z [T]
2.5
2.0
1.5
1.0
0.5
0.0
z [m]
0
1
2
3
4
5


t [μs]
0.0
0.1
0.2
z [m]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0



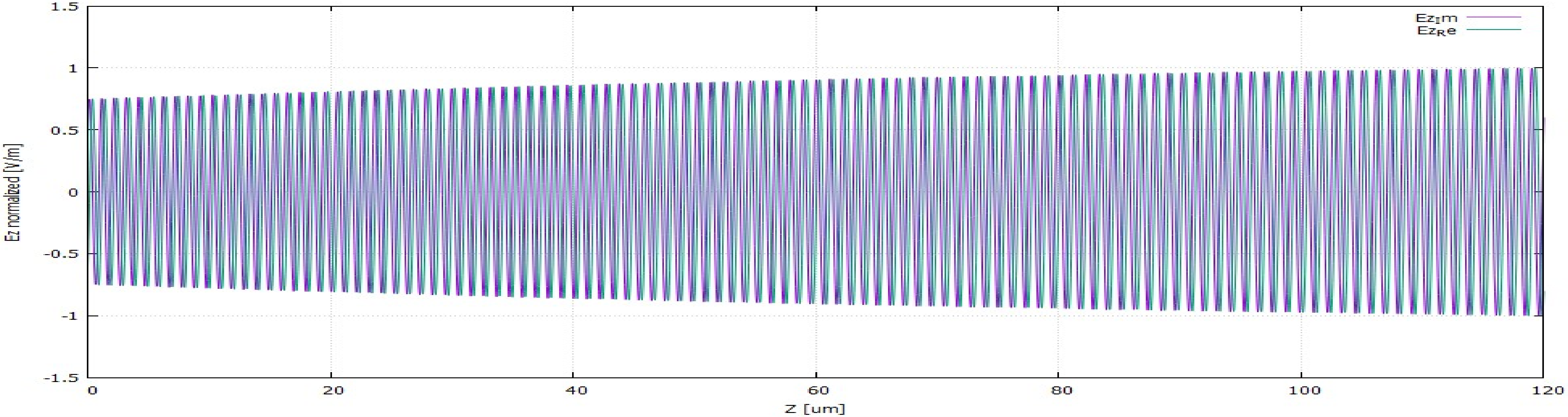
1D vs 3D case: Field seen by one particle:





Fields are very similar.
The one particle beam-dynamic is equal, clearly it **is not visible the non-cylindrical transversal geometry**

Sub-relativistic co-propagating structure (slot DLA)



In the next slides we will see:

Beam “dancing” on the wave crest.

The beam will be never full relativistic

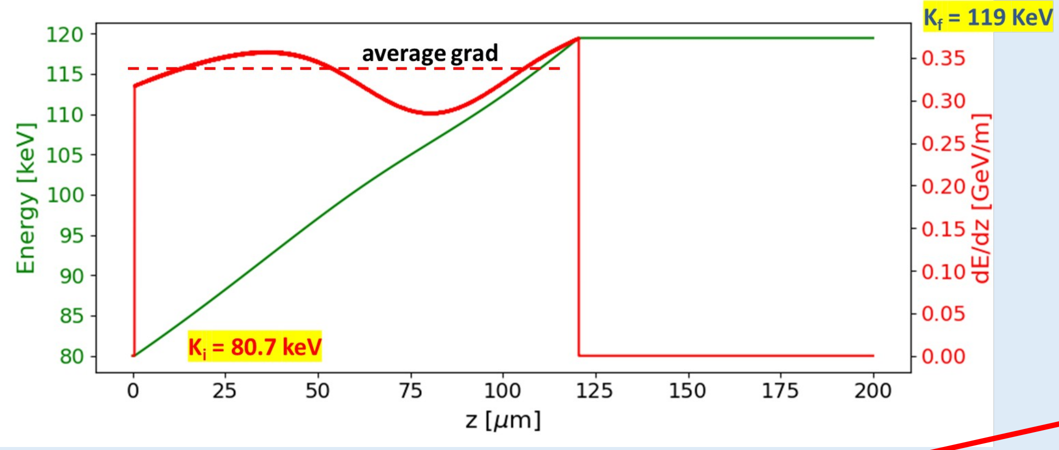
The field curvature is very strong. E_p = 400 MV/m & ‘**λ-cell**’ = 1 um

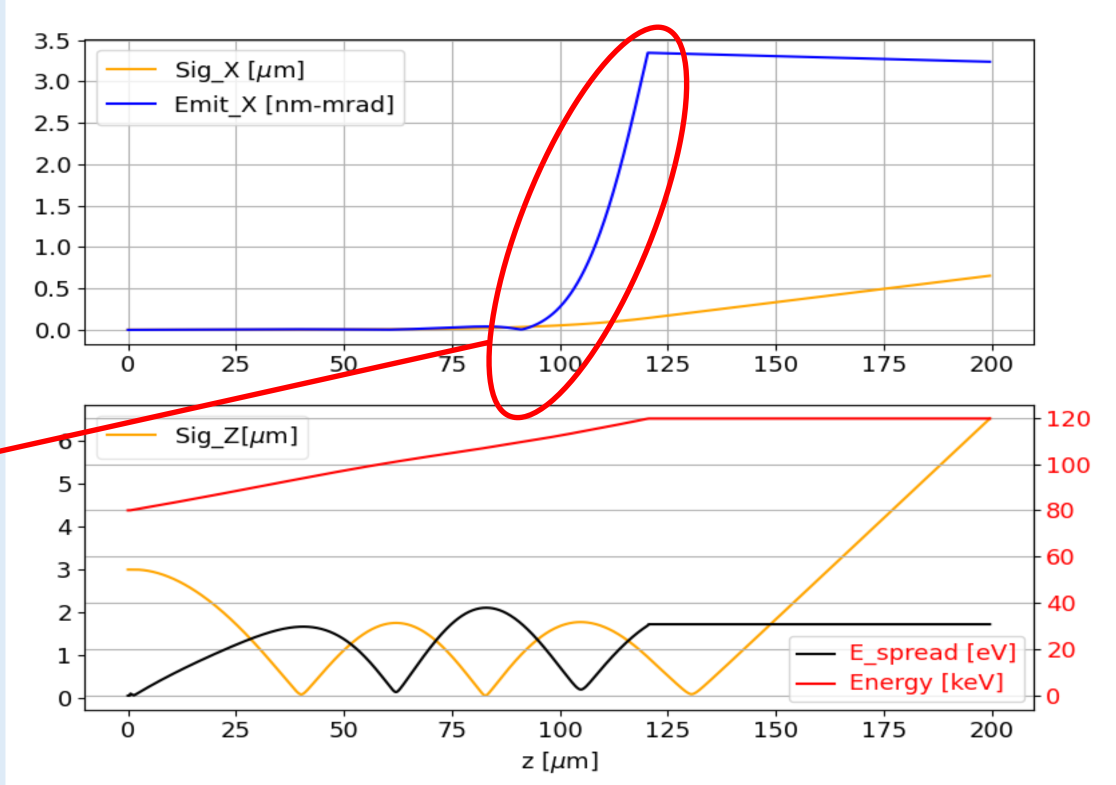
To consider: 2D maps **with 25 points for λ could be not enough** for a best description **“Astra’s smoothing used”**

Soon, let’s test a much denser maps (1D case and 3D case)

Slot DLA – Astra simulation   2D map – bunch tracking

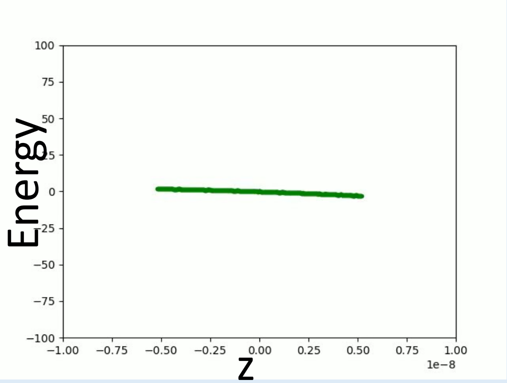
From theory reference case





Unphysical result,
to mitigate numerical problem let's test the Astra field smoothing routine as anticipated previously.

Long. Phase-space

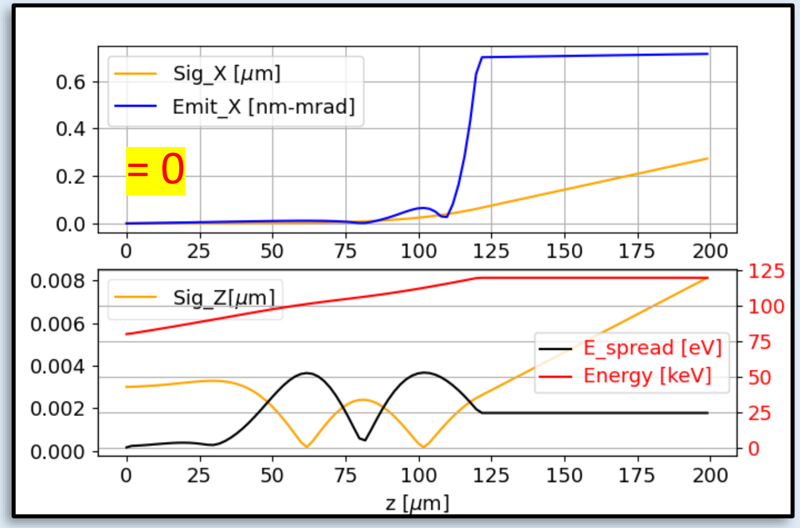


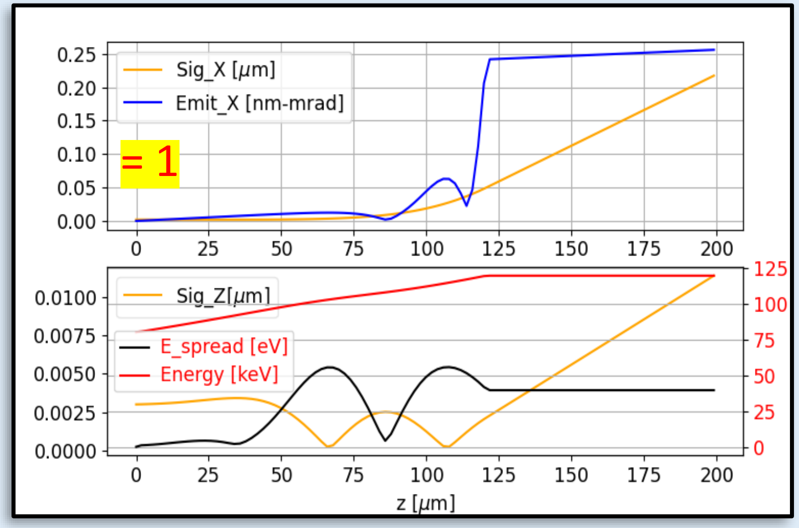
Slot DLA – Astra simulation 2D case – bunch tracking

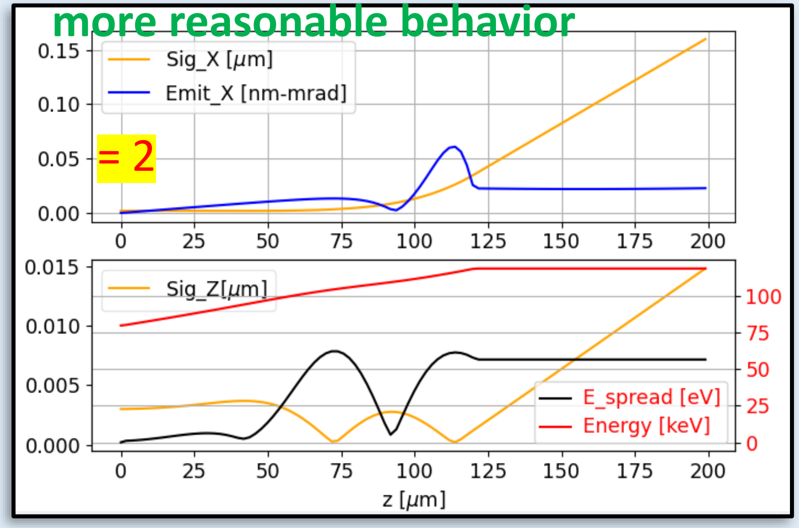
It sounds that 25 points for λ are not enough – we have stron numerical noise

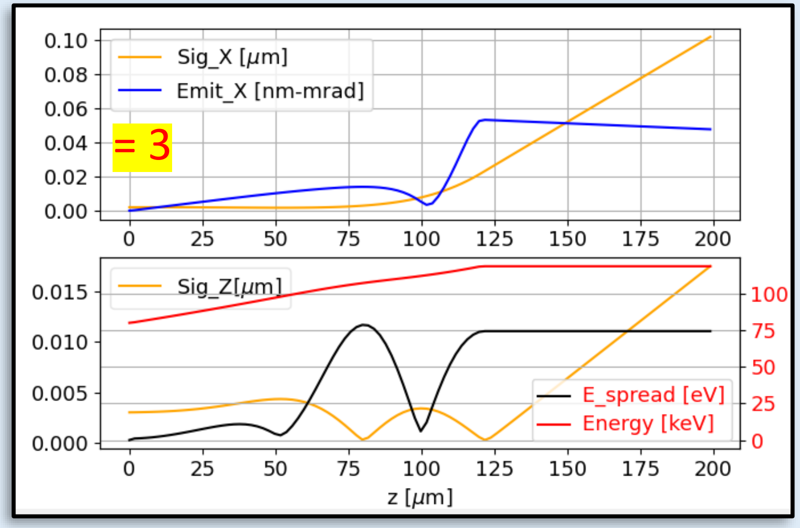
test **Astra field smoothing** algorithm with different weights

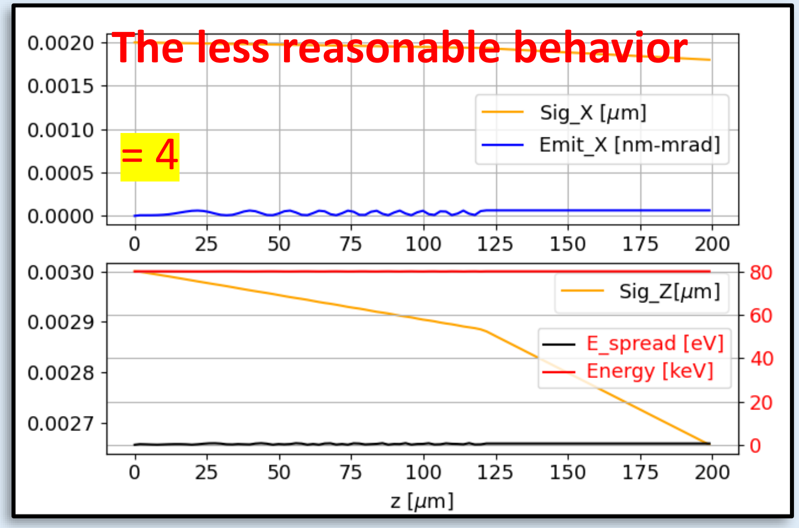
Analysis reused for the single particle tracking seen previously






more reasonable behavior

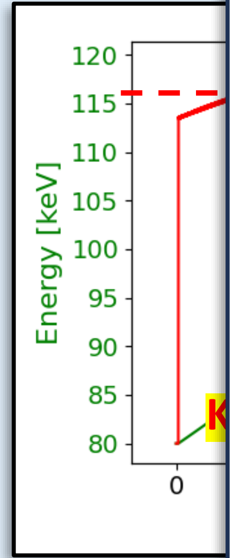


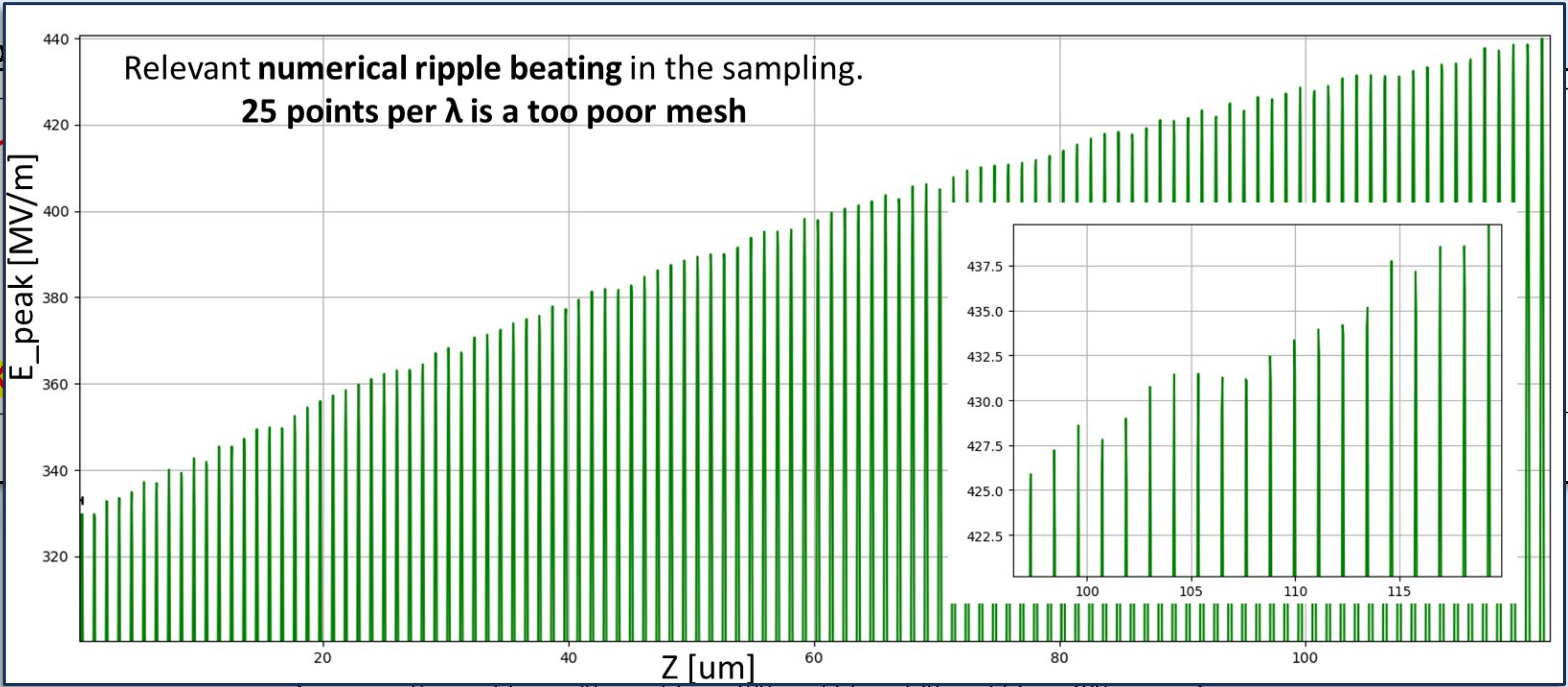

The less reasonable behavior

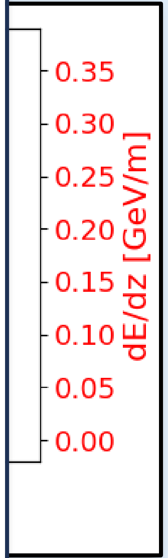
Slot DLA – Astra simulation single particle tracking

The field bump comes from synchrotron oscillations (is the effect given by maps resolutions? …)
A further investigation is required.

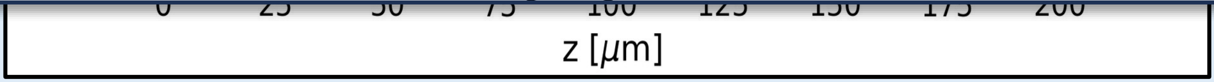
From theo

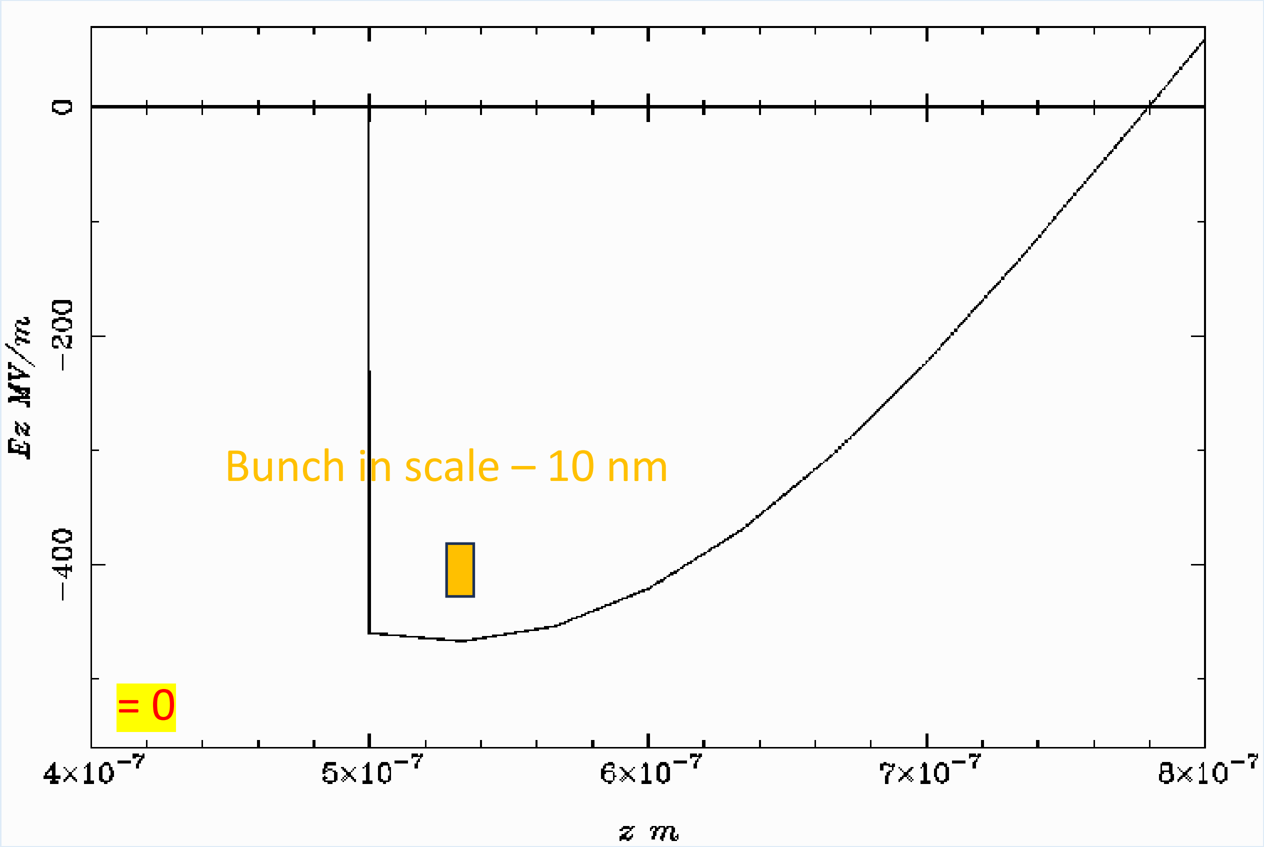



Relevant **numerical ripple beating** in the sampling.
25 points per λ is a too poor mesh



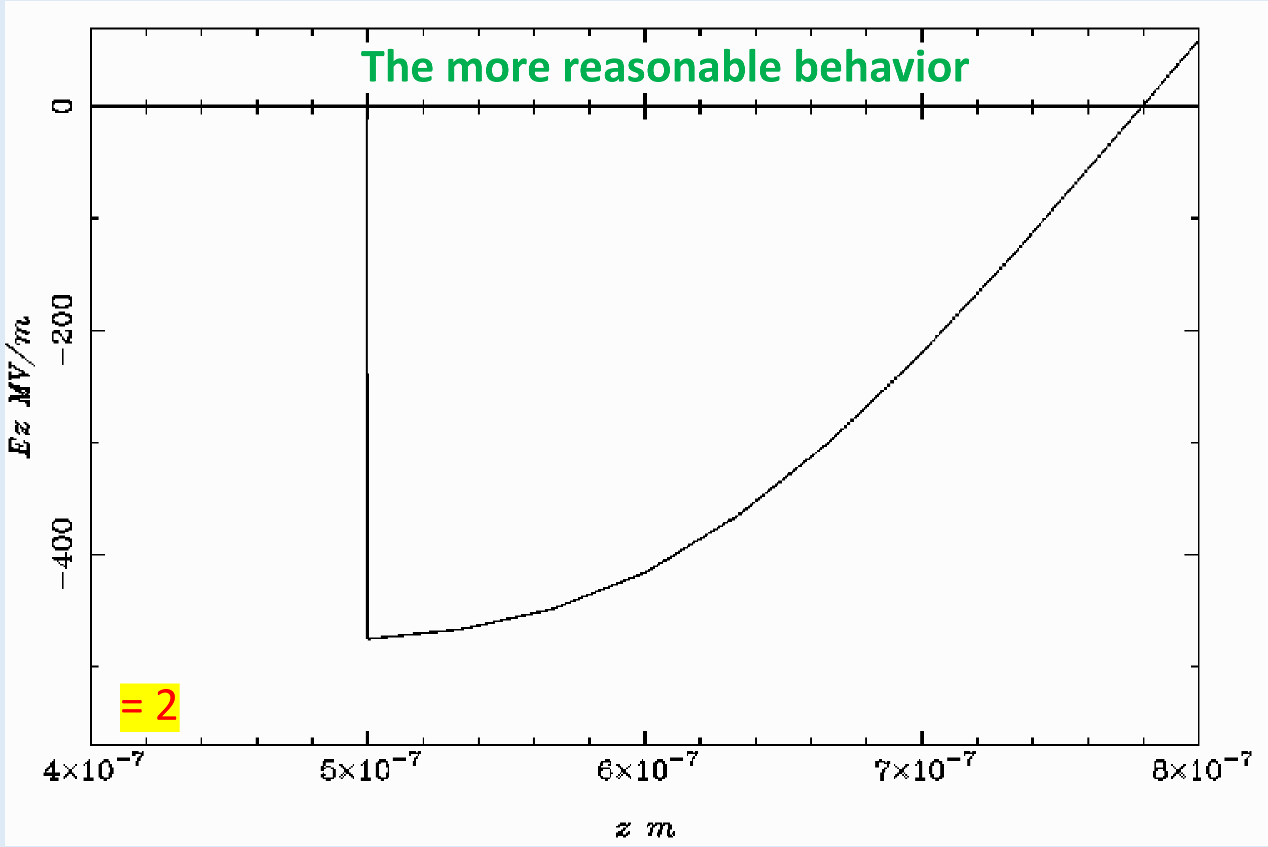
Ez peak fiel





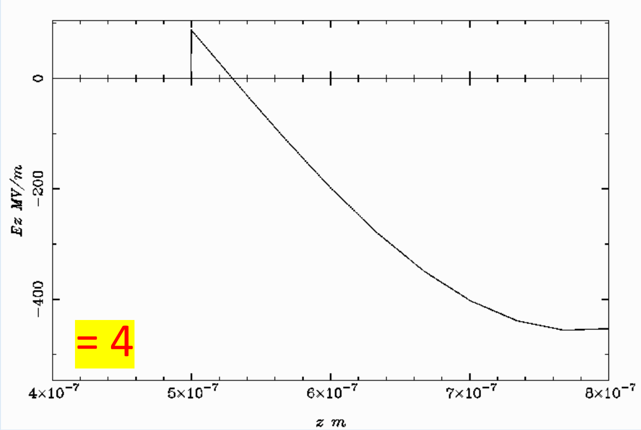
Bunch in scale – 10 nm

= 0

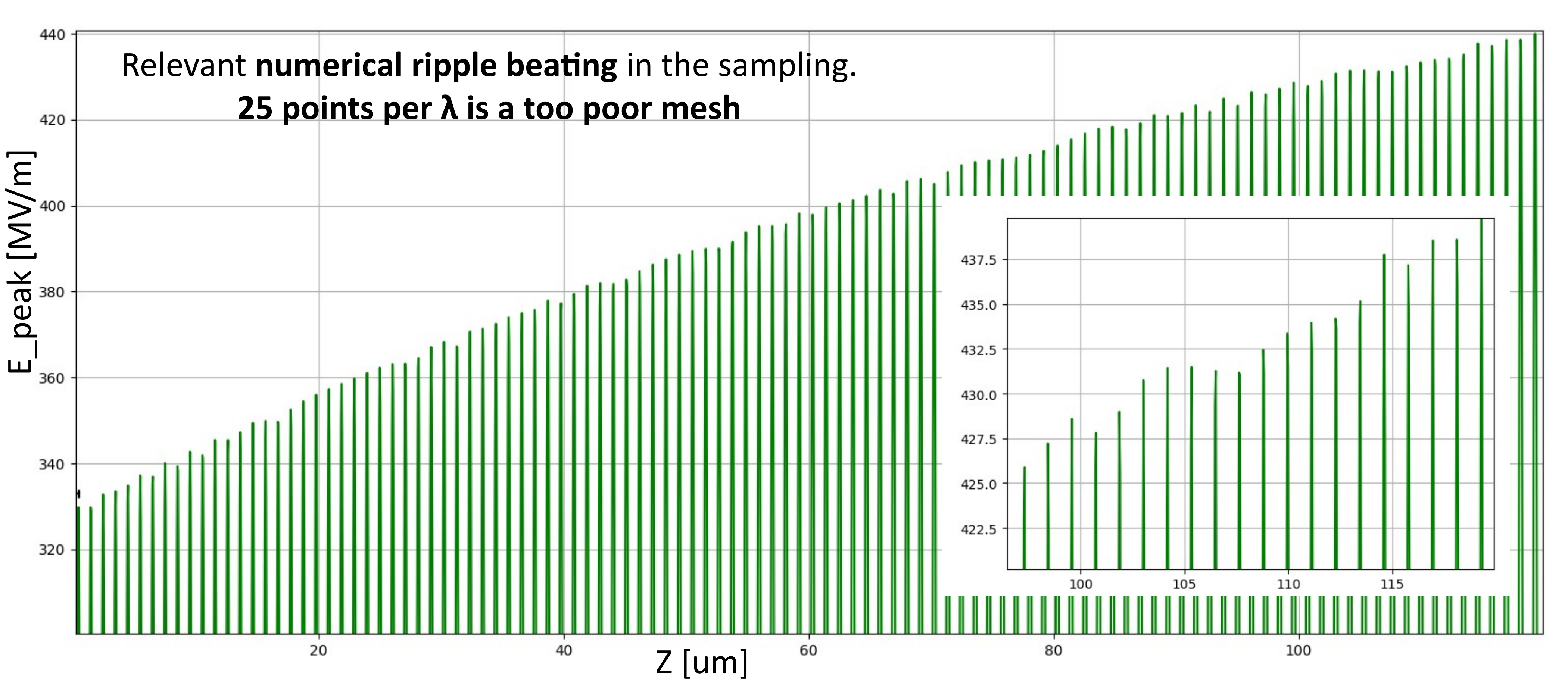


The more reasonable behavior

= 2



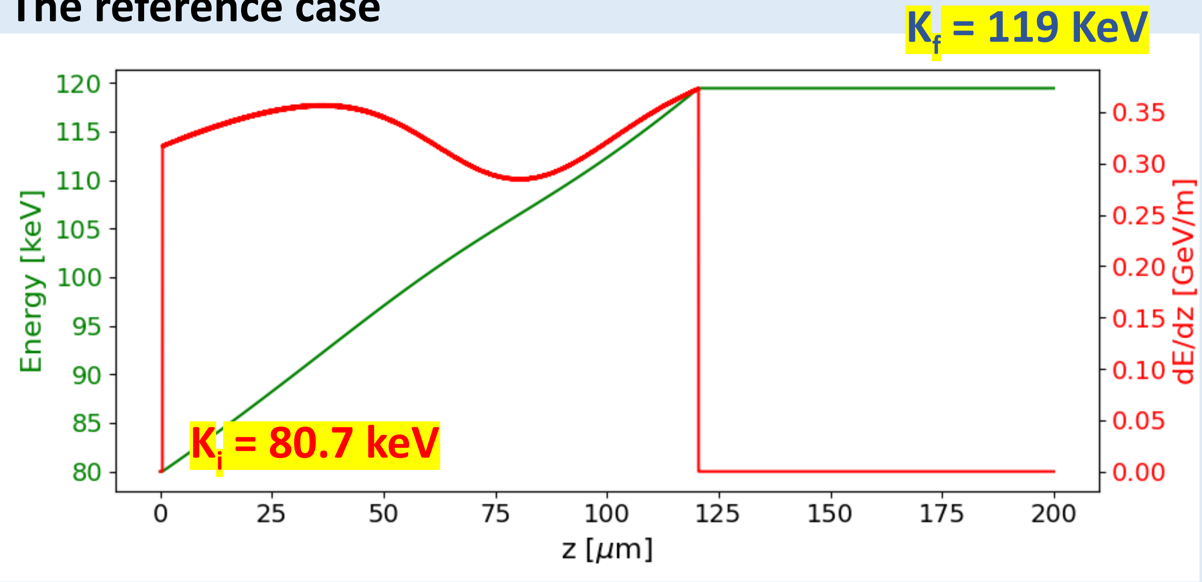
= 4



Relevant **numerical ripple beating** in the sampling.

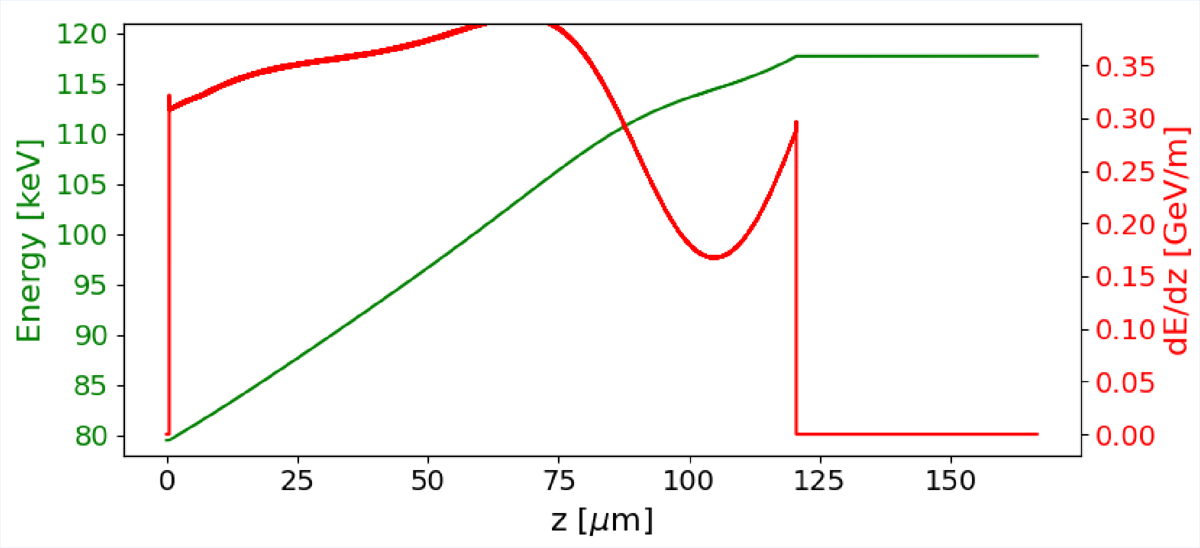
25 points per λ is a too poor mesh

The reference case


K_f = 119 KeV

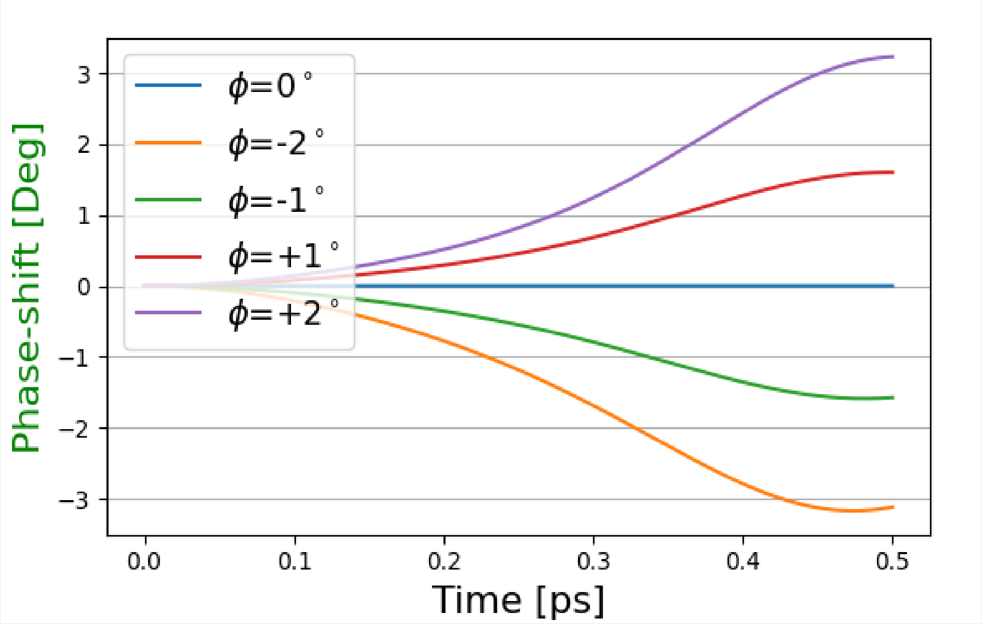
K_i = 80.7 keV

On the more stable plateau



end-phase =

Position shift injecting -2,-1,0,+1,+2 deg

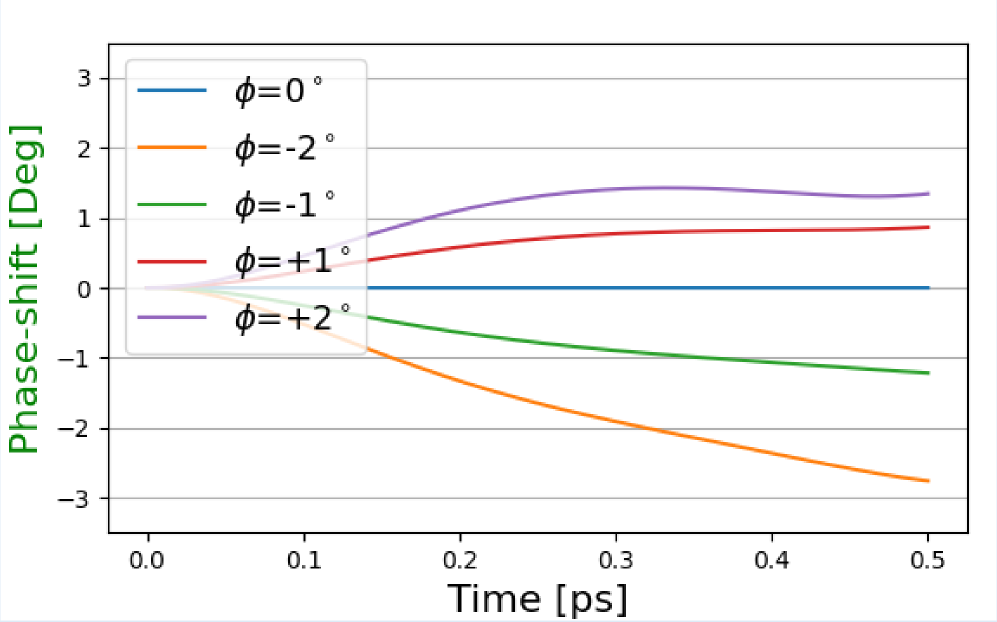


= 440 MV/m

=

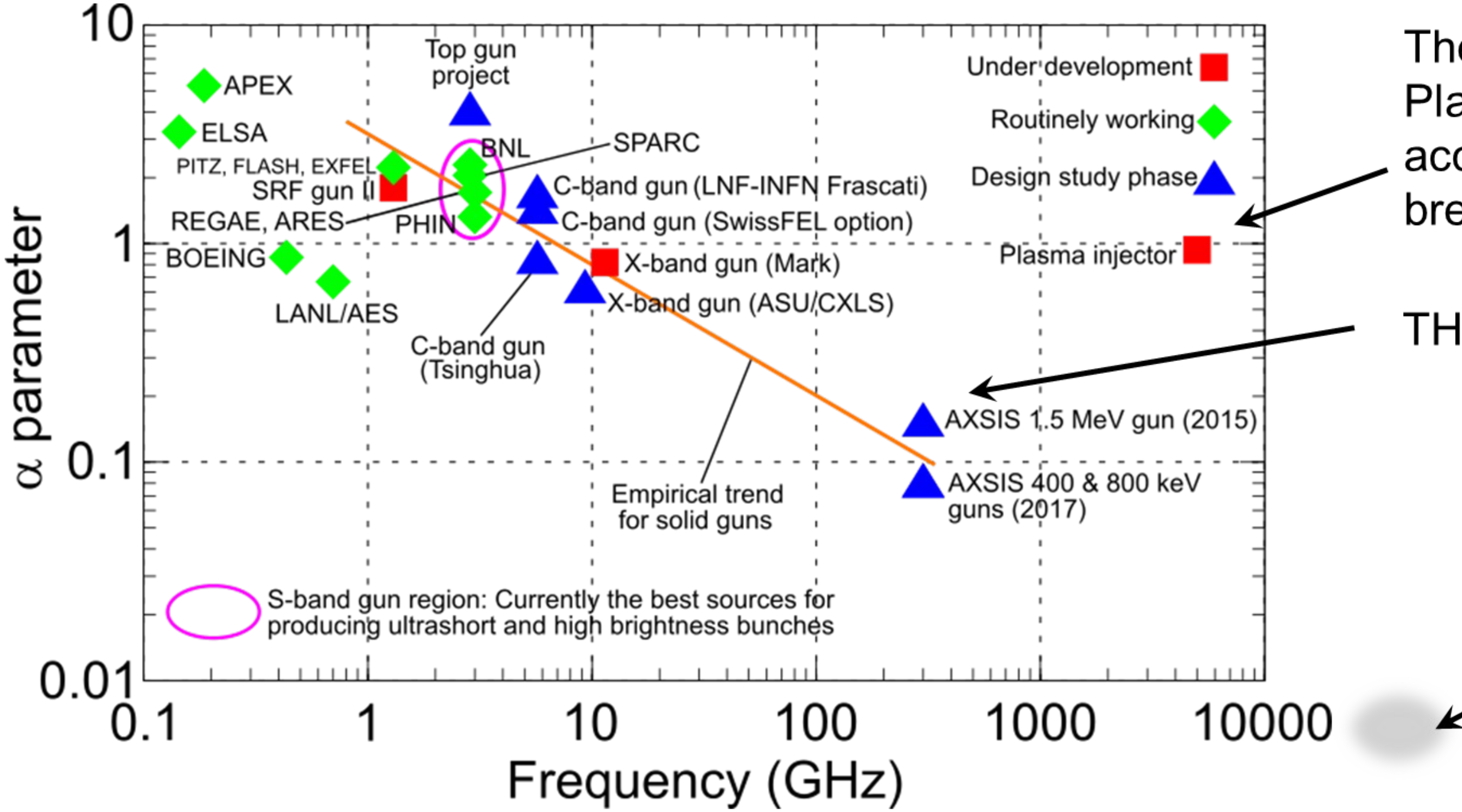
=

end-phase



The normalized vector potential shrinks with increasing frequency

…because the gradient is not increased as much as the wavelength decrease



The exception:
Plasma
accelerators
break the trend

THz-Projects

optical
wavelength
(ACHIP)

Th. Vinatier et al. EAAC 2017, NIM A 909 (2018) 185–192

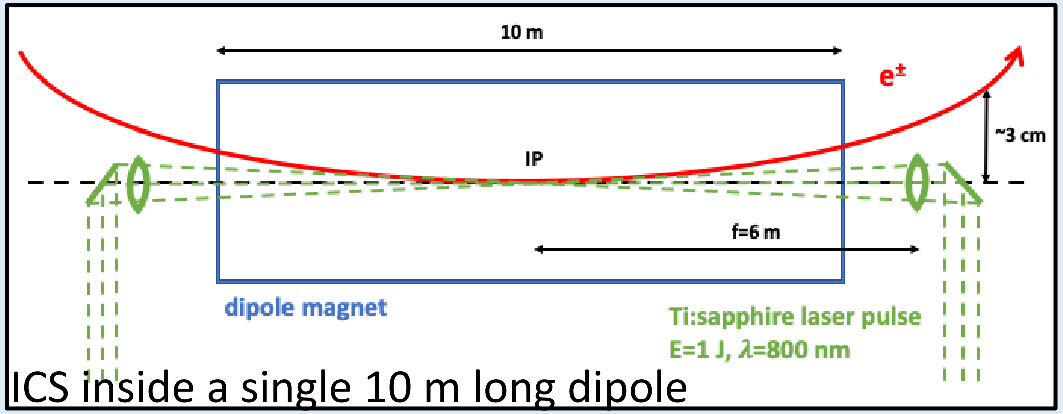
UBA17,K. Floettmann talk

Diagnostics and bunch intensity control via Compton scattering

I. Drebot, **S. Cialdi**[2], INFN-Milano & Univ. degli Studi di Milano (Italy)
A. Abramov, **M. Hofer**, **F. Zimmermann** (CERN)

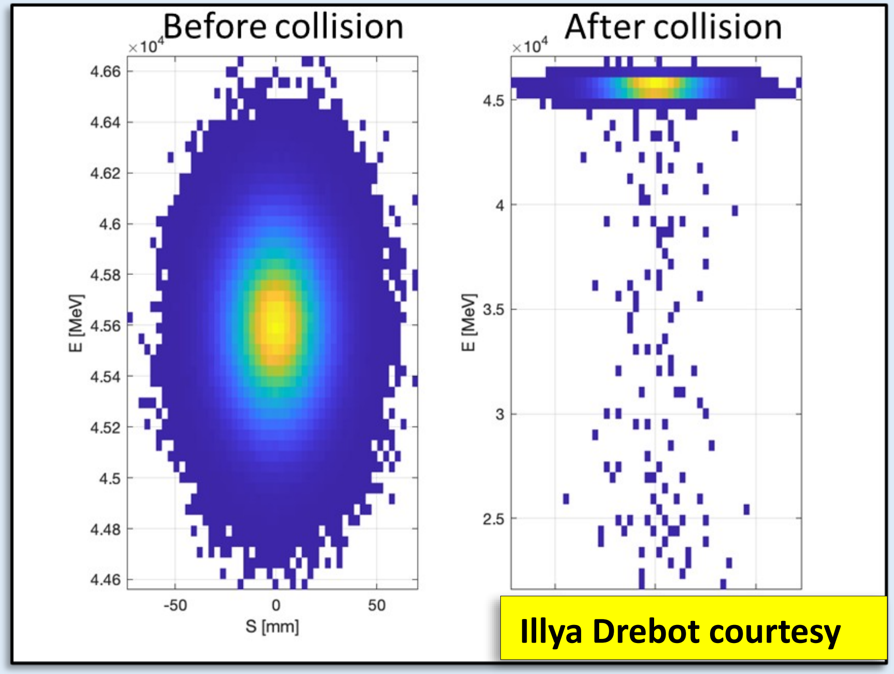
In FCC-ee colliding bunches **intensity must be tightly controlled**: 3–5% as maximum charge imbalance flip-flop instability

Laser Inverse Compton Scattering (ICS) could be used to adjust and fine-tune the bunch intensity.



ICS inside a single 10 m long dipole

Ne_{tot}=2.68e+11; Ne_{scat}=3.45e+07;

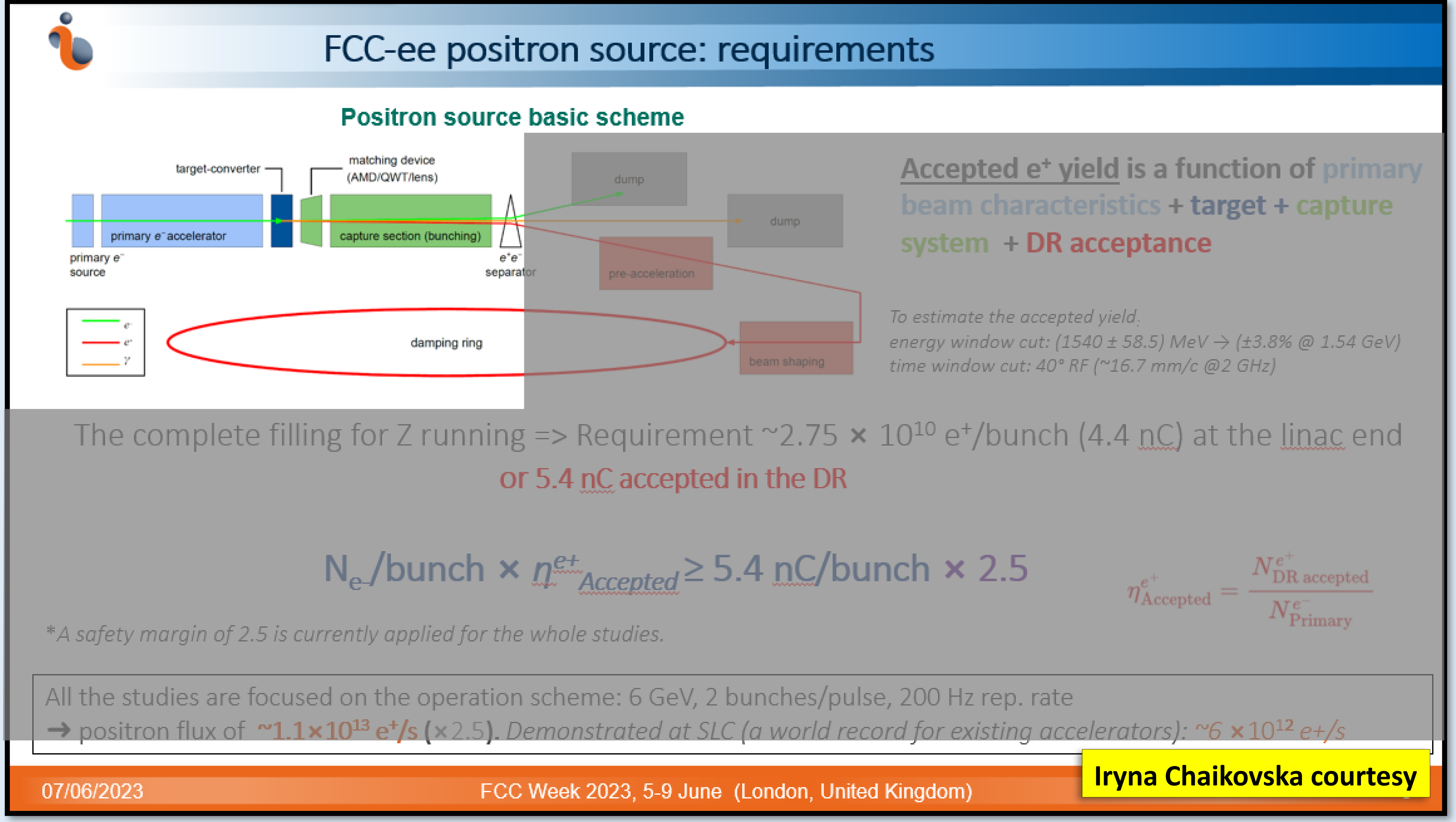


Illya Drebot courtesy

Activities under study:

(1) Optimum between flip-flop instability and emittance growing. (2) Bunch Energy distribution optimization (ICS in dispersive regions). (3) Beam halo reduction with Donuts-shaped laser beam. (4) Scattered photons for diagnostic. (5) Find applications and users for 25 and 150 GeV photon beam

FCC Week 2023 – London



FCC-ee positron source: requirements

Positron source basic scheme

Accepted e⁺ yield is a function of primary beam characteristics + target + capture system + DR acceptance

To estimate the accepted yield:
energy window cut: (1540 ± 58.5) MeV → (±3.8% @ 1.54 GeV)
time window cut: 40° RF (~16.7 mm/c @2 GHz)

The complete filling for Z running => Requirement ~2.75×10^{10} e⁺/bunch (4.4 nC) at the linac end or 5.4 nC accepted in the DR

$$N_{e-}/\text{bunch} \times \eta^{e+}_{Accepted} \geq 5.4\ \text{nC/bunch} \times 2.5$$

$$\eta^{e^+}_{\text{Accepted}} = \frac{N^{e^+}_{\text{DR accepted}}}{N^{e^-}_{\text{Primary}}}$$

**A safety margin of 2.5 is currently applied for the whole studies.*

All the studies are focused on the operation scheme: 6 GeV, 2 bunches/pulse, 200 Hz rep. rate
➜ positron flux of ~1.1×10^{13} e⁺/s (×2.5). *Demonstrated at SLC (a world record for existing accelerators): ~6×10^{12} e+/s*

07/06/2023 FCC Week 2023, 5-9 June (London, United Kingdom)

Iryna Chaikovska courtesy