Istituto Nazionale di Fisica Nucleare

Electron Beam Dynamics in MariX, a 2-Pass 2-Way SC Accelerator for Ultrafast, High Repetition Rate X-Ray FEL

M. Rossetti Conti

On bealf of the Beam Dynamics group, Milano

Ultrafast Beams and Applications, *03 July 2019, CANDLE, Armenia*

Synchrotron Radiation sources

500 MHz repetition

nJ pulse energy; ≈50ps

$10^{5\text{-}6}$ photons x

(5)x10^{8}pulses

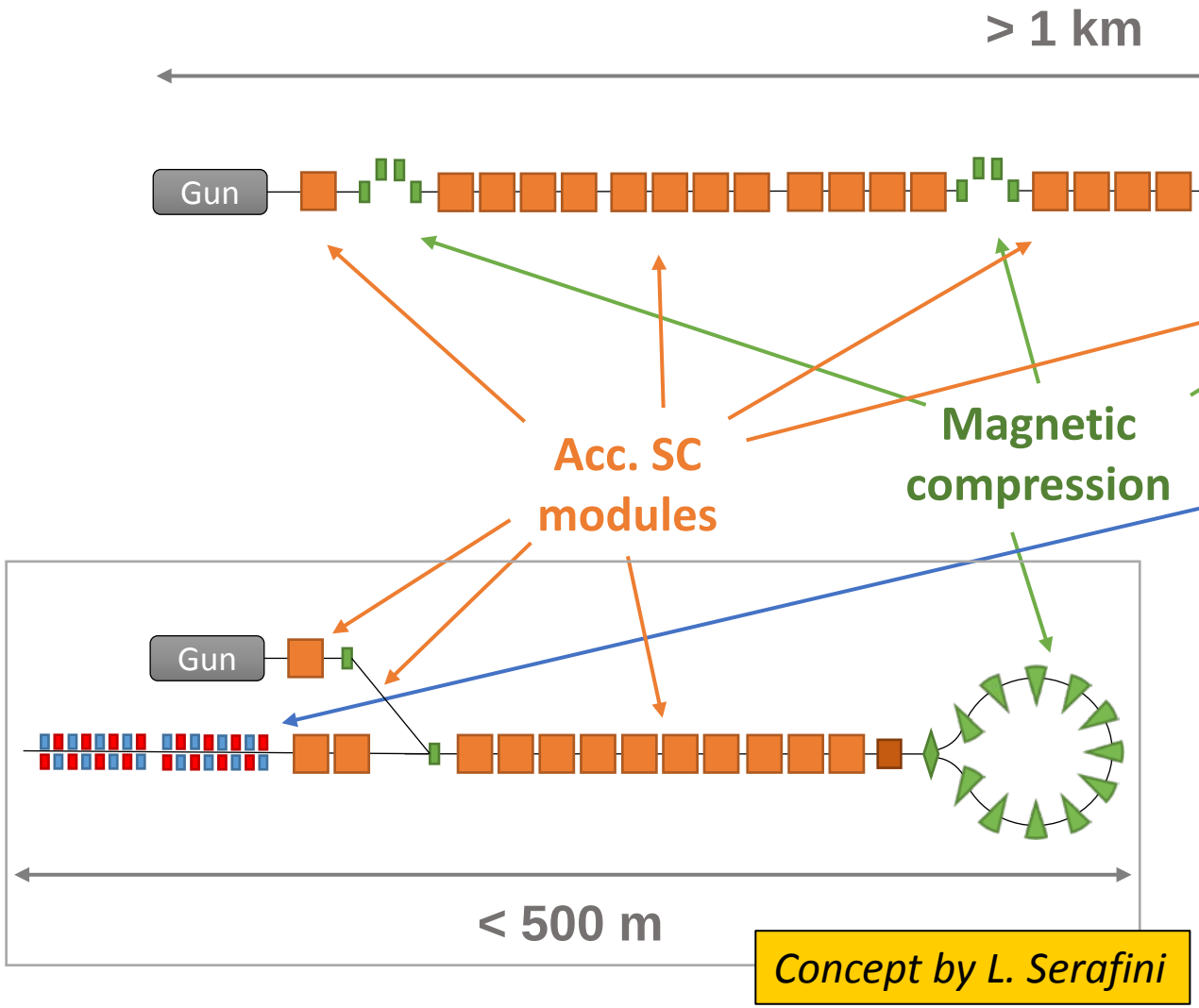
Linear response regime:

Imaging and spectroscopy (perturbation theory)

Courtesy G. Rossi

(*) **M**ulti-disciplinary **A**dvanced **R**esearch **I**nfrastructure with **X**-rays

Desiderata & Constraints



Users want:

- High rep. rate (1 MHz)
- λ_{FEL}= 1-1.5 Å ⟶ 4 GeV linac

Site constraints:

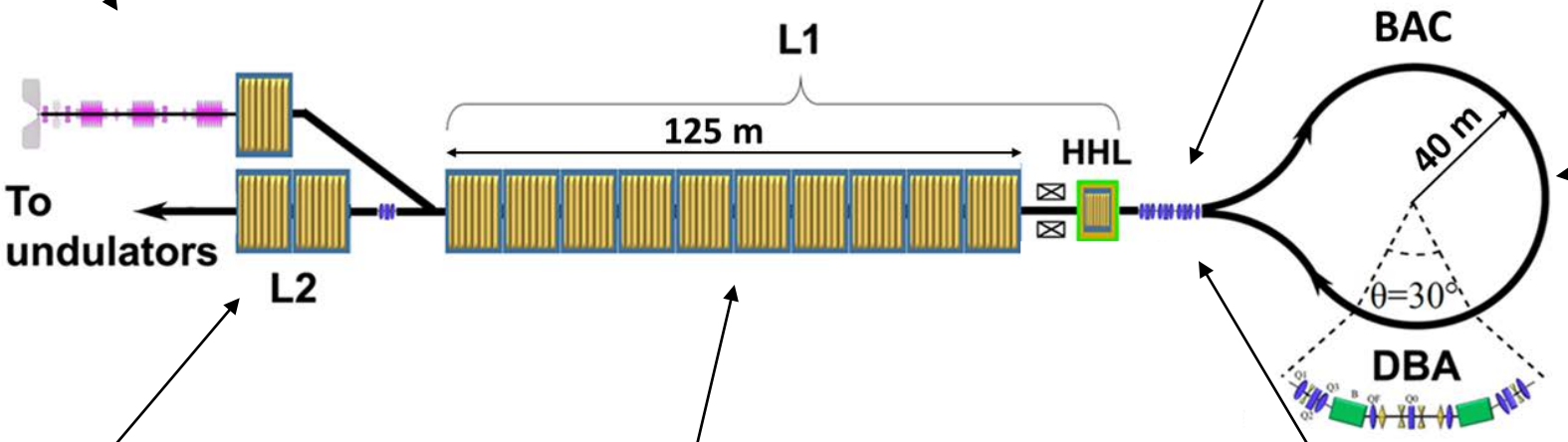
- Max length: □ 500 m

Full Beamline

Injector (1 MHz, 50 pC)
High Brightness beams
@ 130 MeV

2-way L1-Booster (0.13 → 1.6 GeV)
10 TESLA-like cryomodules
1 High Harmonic Linac (accelerates)

2-way matching line
10 quadrupoles
Match to the BAC



Bubble Arc Compressor
14 DBA
Compression and U-turn
I_{peak} : 15 A → 1.6 kA (< 100x)

2-way matching line
Reduce beam divergence

2-way L1-Booster (1.6 → 3.1 GeV)
All cavities accelerate

L2 section
(adjustment ±0.25 GeV)

Computational tools

Tracking codes

- **Astra** (**A S**pace-Charge **Tr**acking **A**lgorithm), Desy
  - **Space-charge**
- **Elegant** (**Ele**ctron **G**eneration **An**d **T**racking), APS, Argonne National Laboratory
  - **Fast** tracking
  - Good for **curvilinear** paths

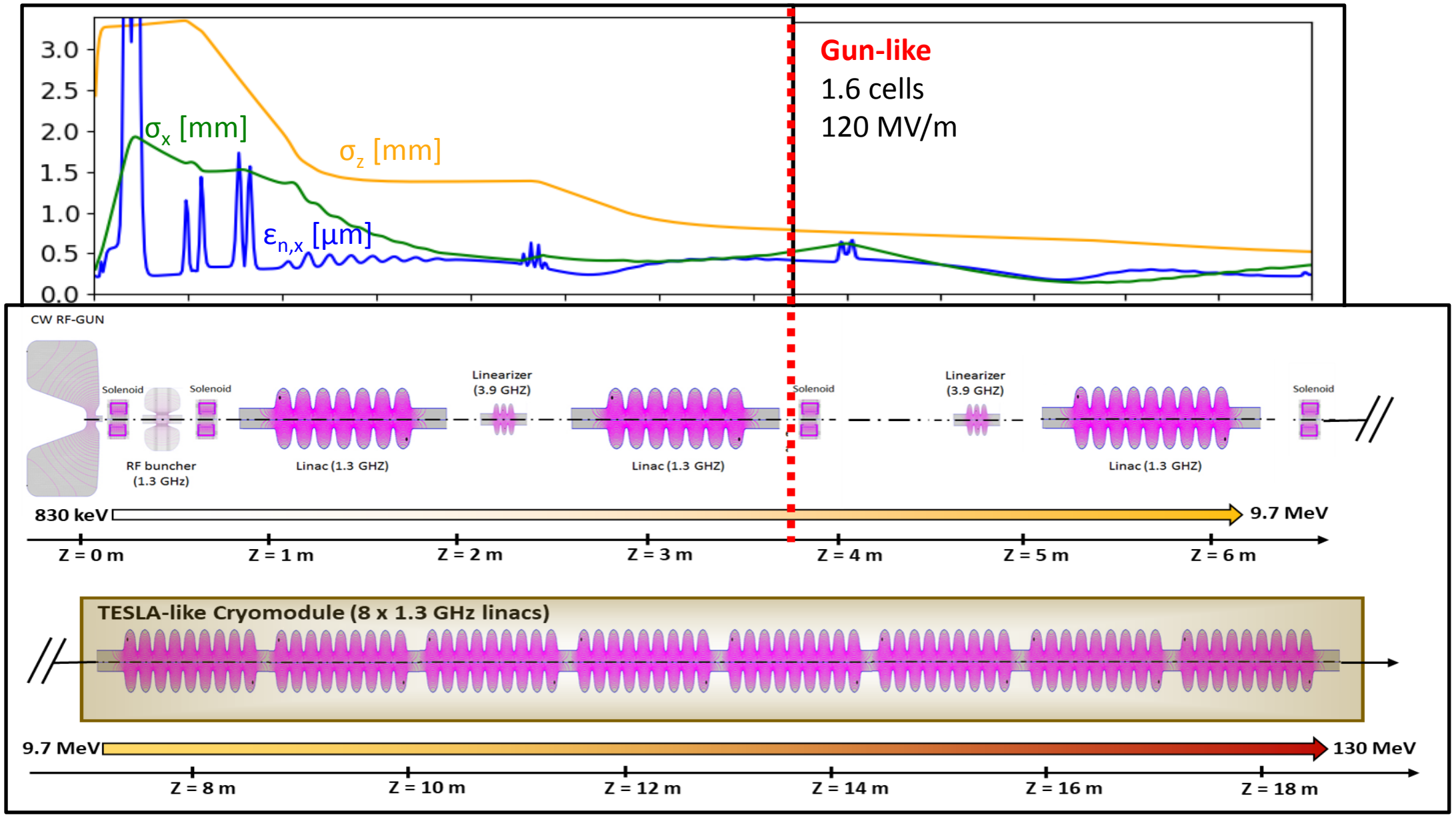
Optimizators

- **Giotto** (**G**enetic **I**nterface for **O**p**T**imizing **T**racking with **O**ptics), INFN, Milano
  - Integration with **Astra**
  - **Multi objective** opt
  - **Fast** solutions explorer
  - **Statistic** mode (jitters)
  - **Homemade** code

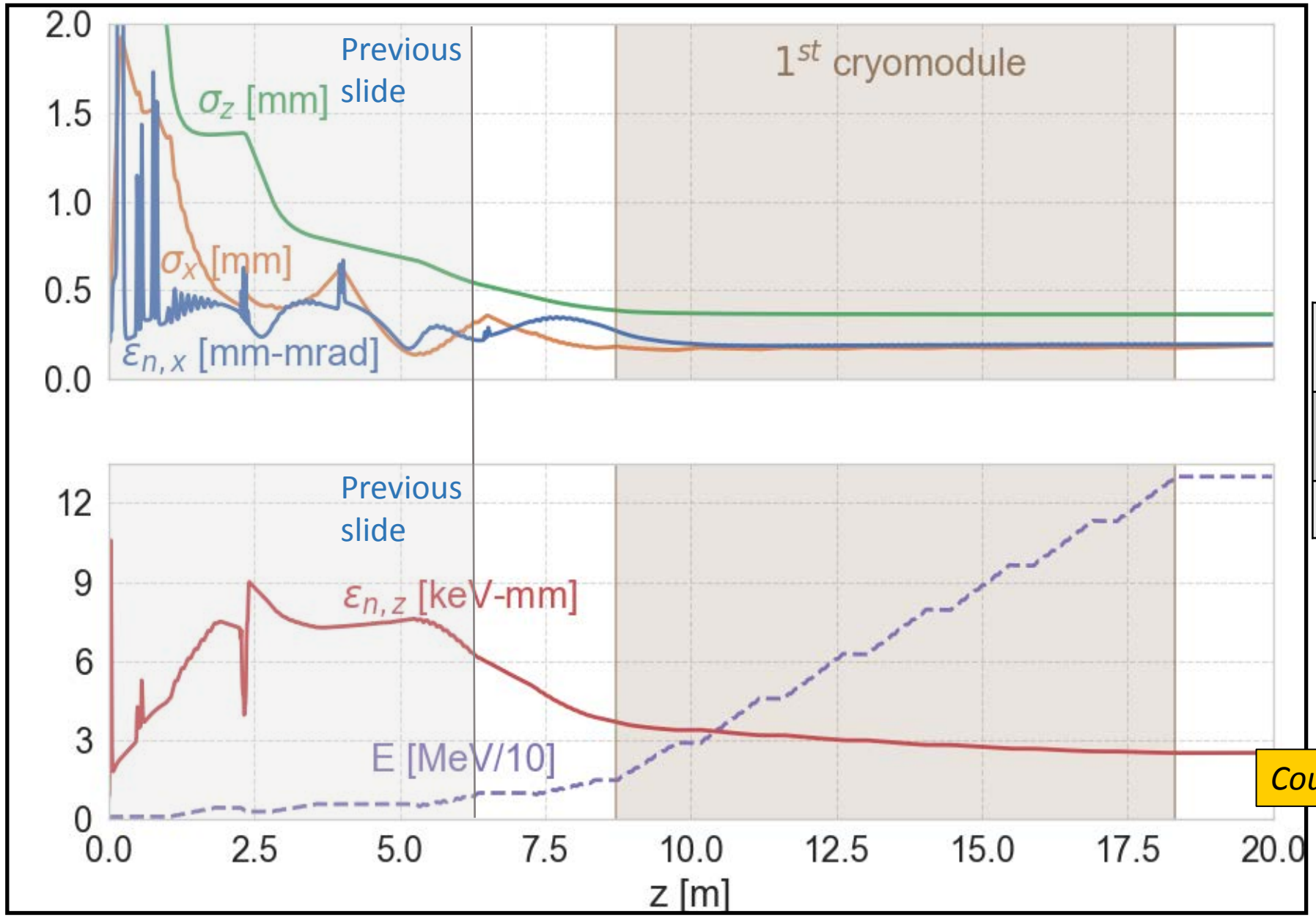
Simulations

Main Beam Dynamics results

The MariX injector



The MariX injector

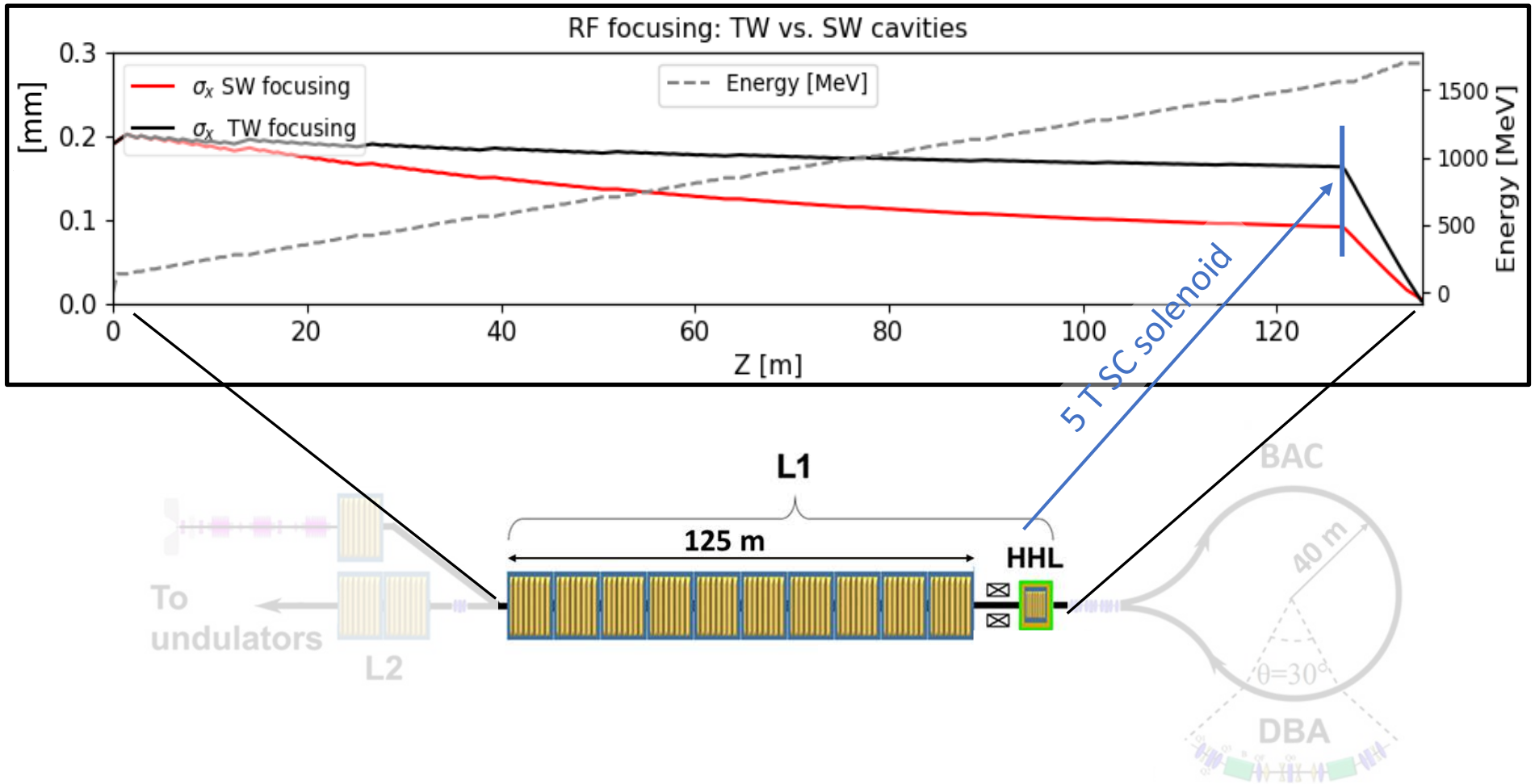


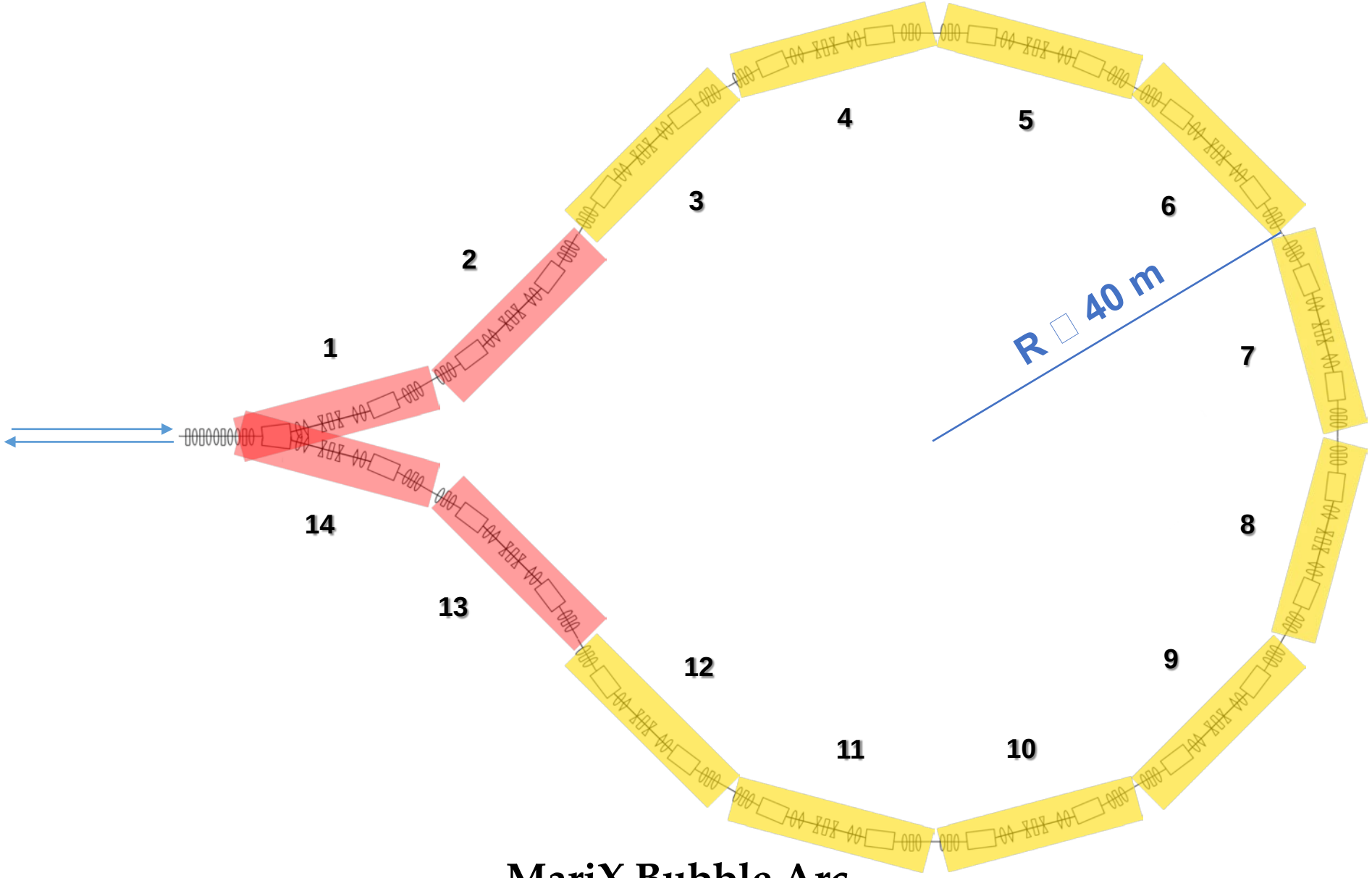
injector opt. beam-line by GIOTTO (@ 20 m)				
ε_z [keV-mm]	ε_x [μm]	σ_x [μm]	σ_z [μm]	E [MeV]
2.5	**0.2**	190	365	130

Courtesy A. Bacci

The Super Conductive Booster L1

- 10 TESLA-like cryom. : max grad 16 MV/m, 8 cavities per cryomodule
- **Chirp** for compression given injecting @ **+ 6°** from RF crest.





MariX Bubble Arc

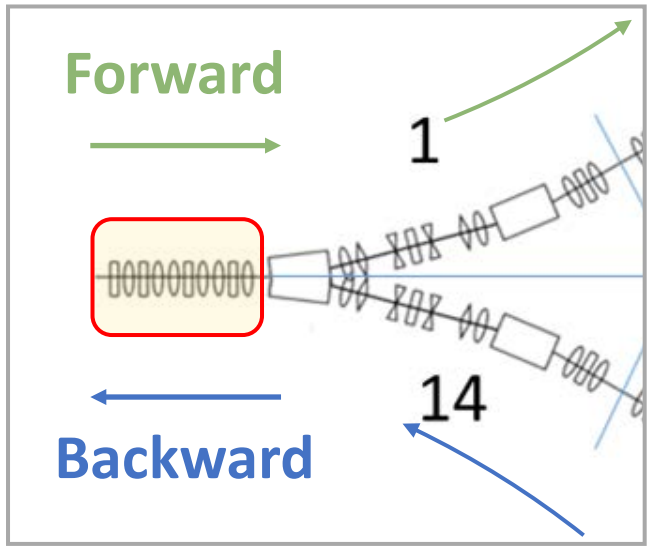
Bubble Arc matching line

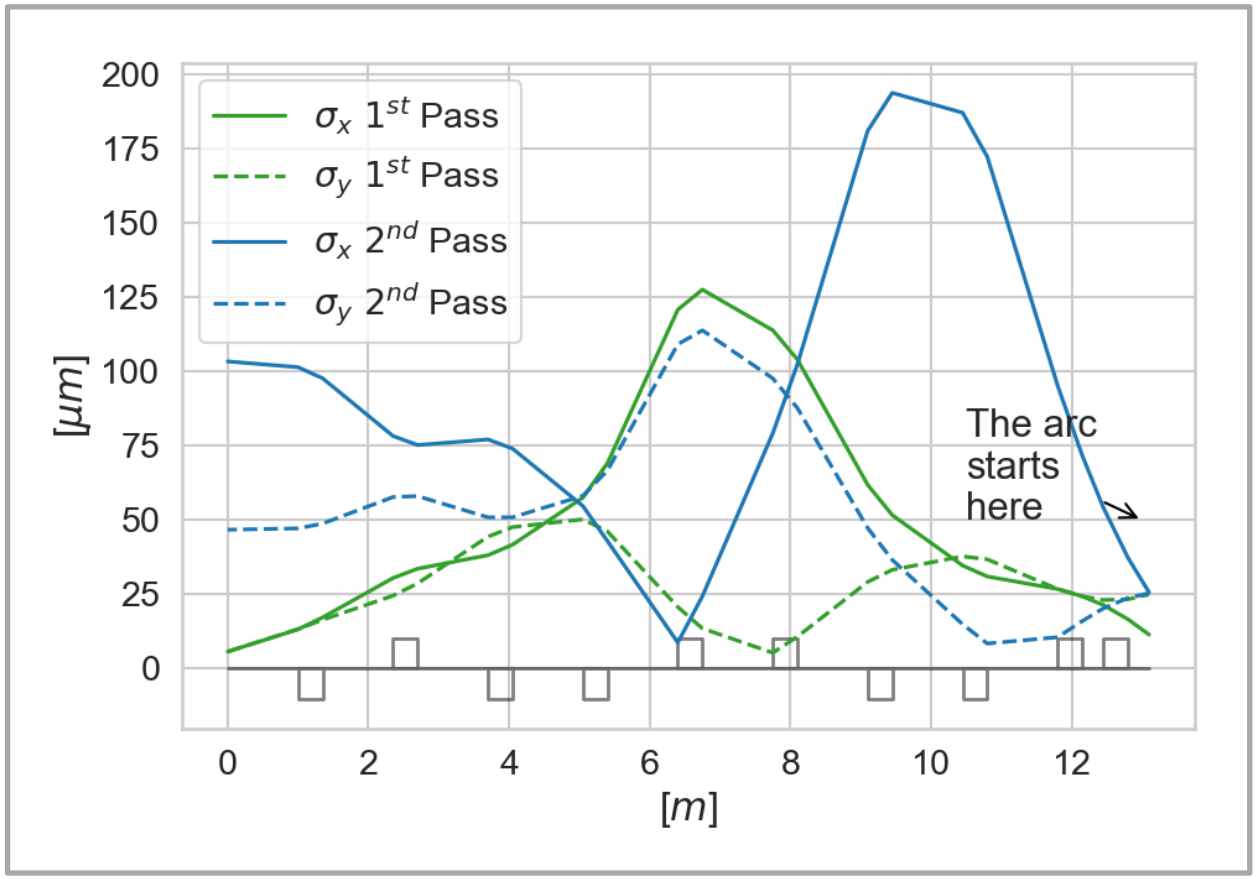
10 quads matching line with two different objectives:

- The **forward traveling bunch** is **matched** to the BAC (in first DBA bending).
- The **bunch traveling back** divergence is controlled to avoid **strong $\varepsilon_{n,x-y}$ degradation**

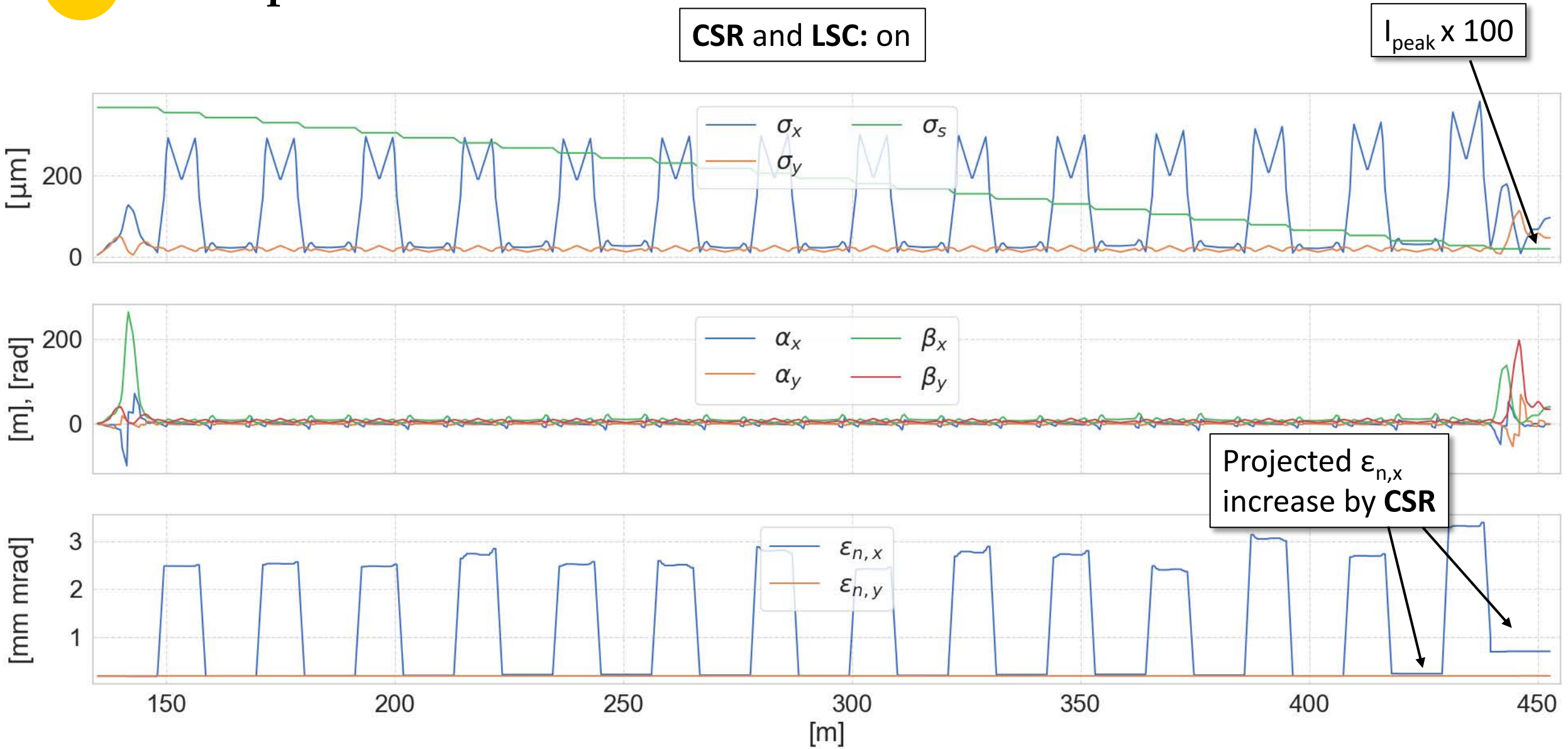
by chromatic effects in the SC solenoid.

$$\epsilon_{n,chromatic} = \beta\gamma K\sigma_x^2(\sin KL + KL\cos KL)\frac{\sigma_p}{p}$$





Beam parameters in BAC

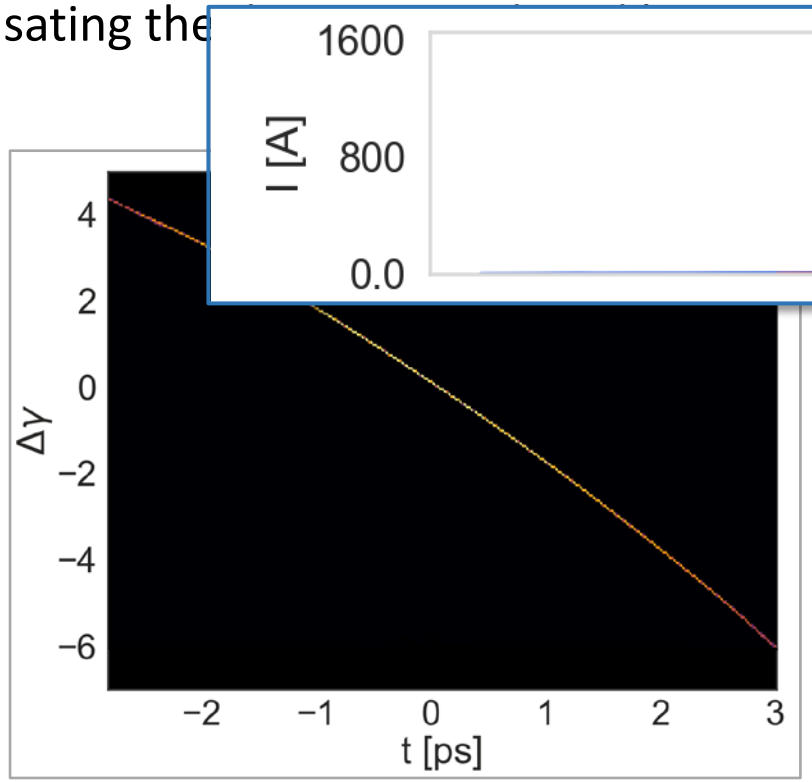


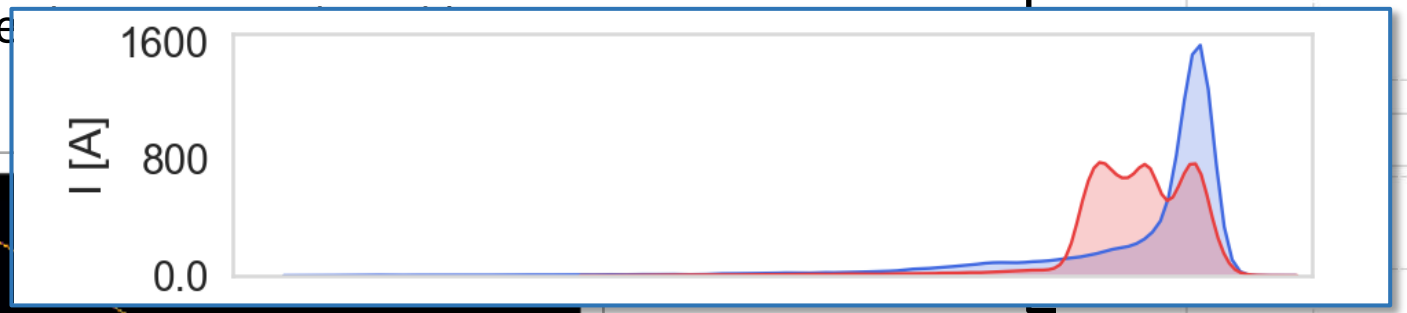
CSR compensation

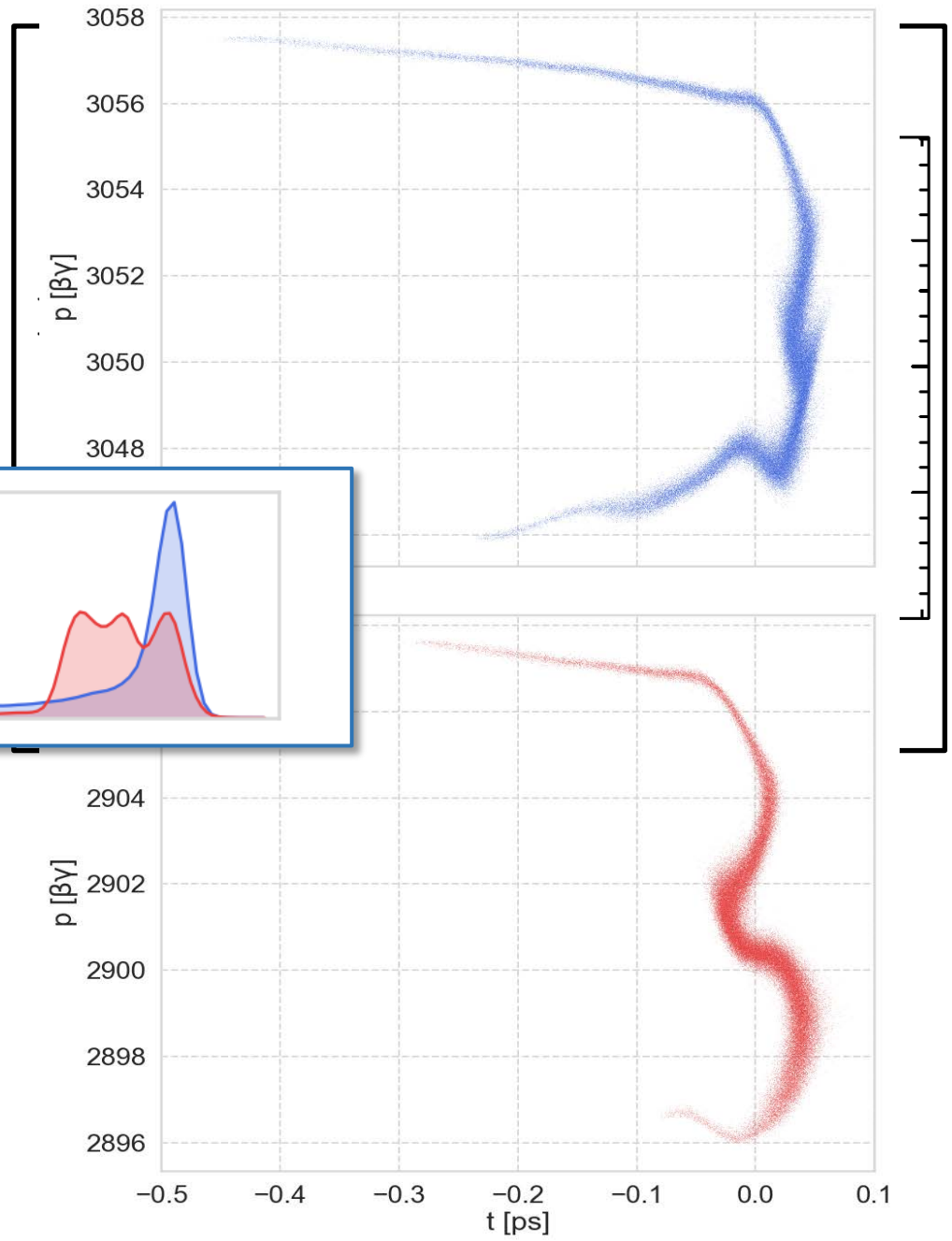
Two main factors contribute in CSR compensation:

- **Current** profile **shaping** (injector) reduce CSR kick.
- The **HHL** in acc. phase (+100 MeV) increases LPS curvature

compensating the







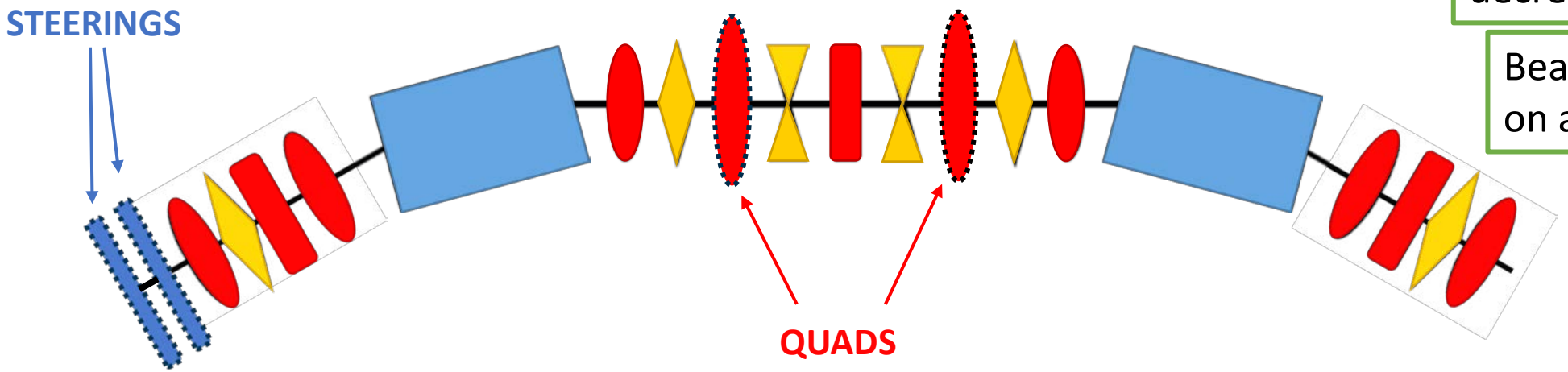
Beam dispersion damping

The CSR kick induces **residual dispersive effects** on the beam: increase η and η', <x> and <x'> and **spoils FEL emission**

$$\eta_x = \frac{\langle x\, p_r \rangle}{\sigma_{p_r}^2} \qquad \eta'_x = \frac{\langle x'\, p_r \rangle}{\sigma_{p_r}^2}$$

$$with: \quad p_r = \frac{p - \langle p \rangle}{\langle p \rangle}$$

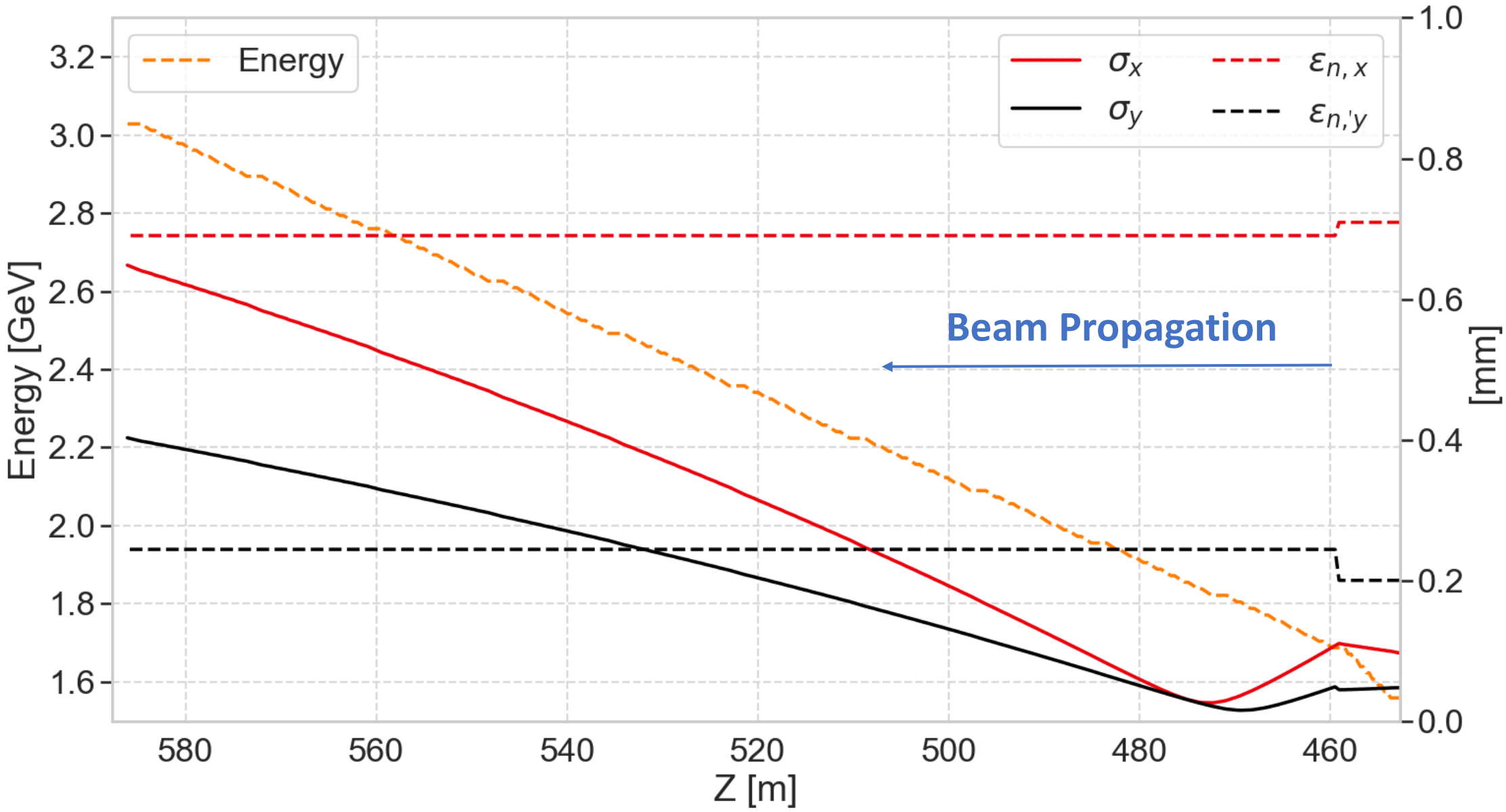
Modified last DBA



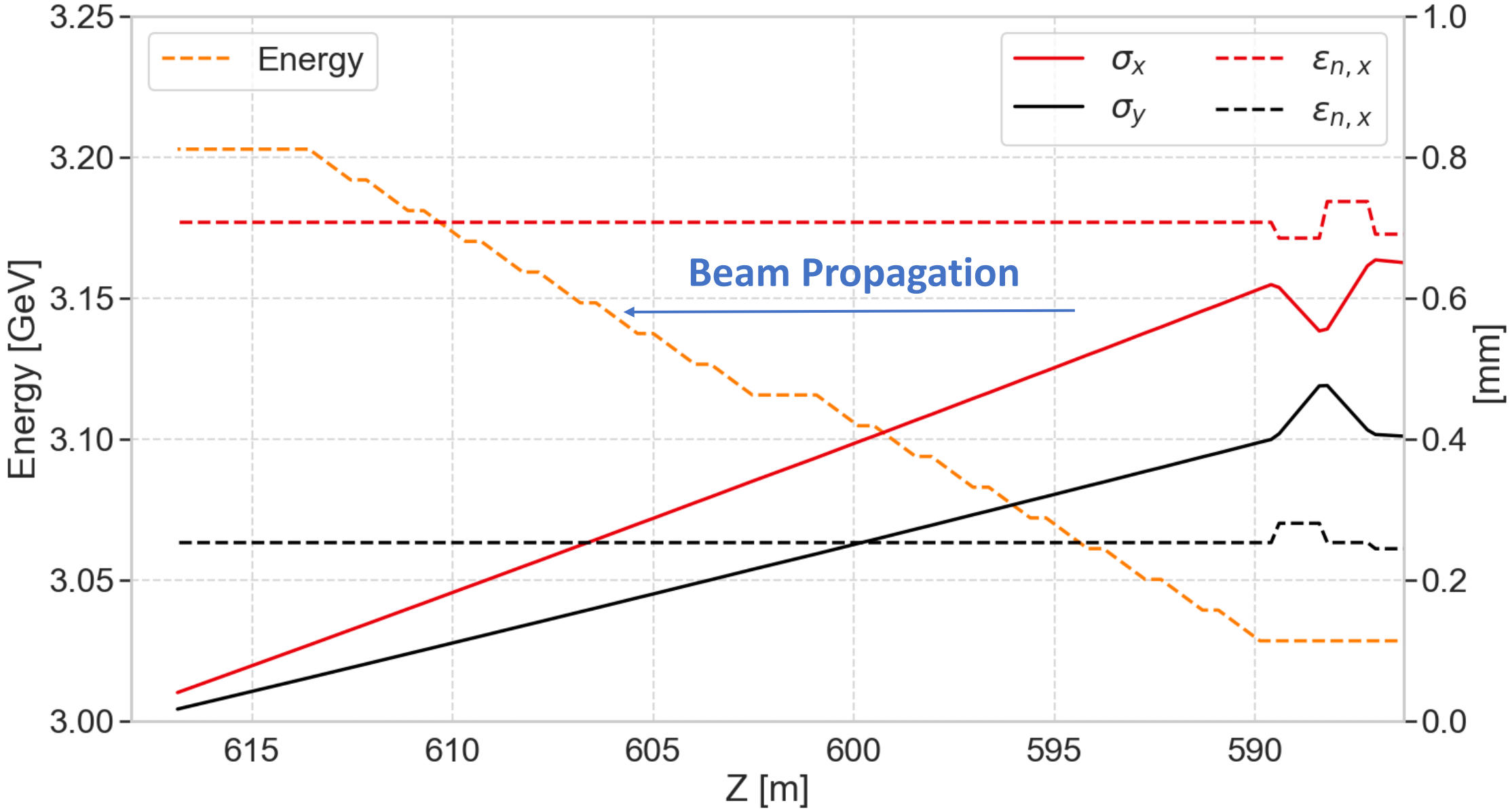
Projected $\varepsilon_{n,x}$ decreased by 30%

Beam centered on axis

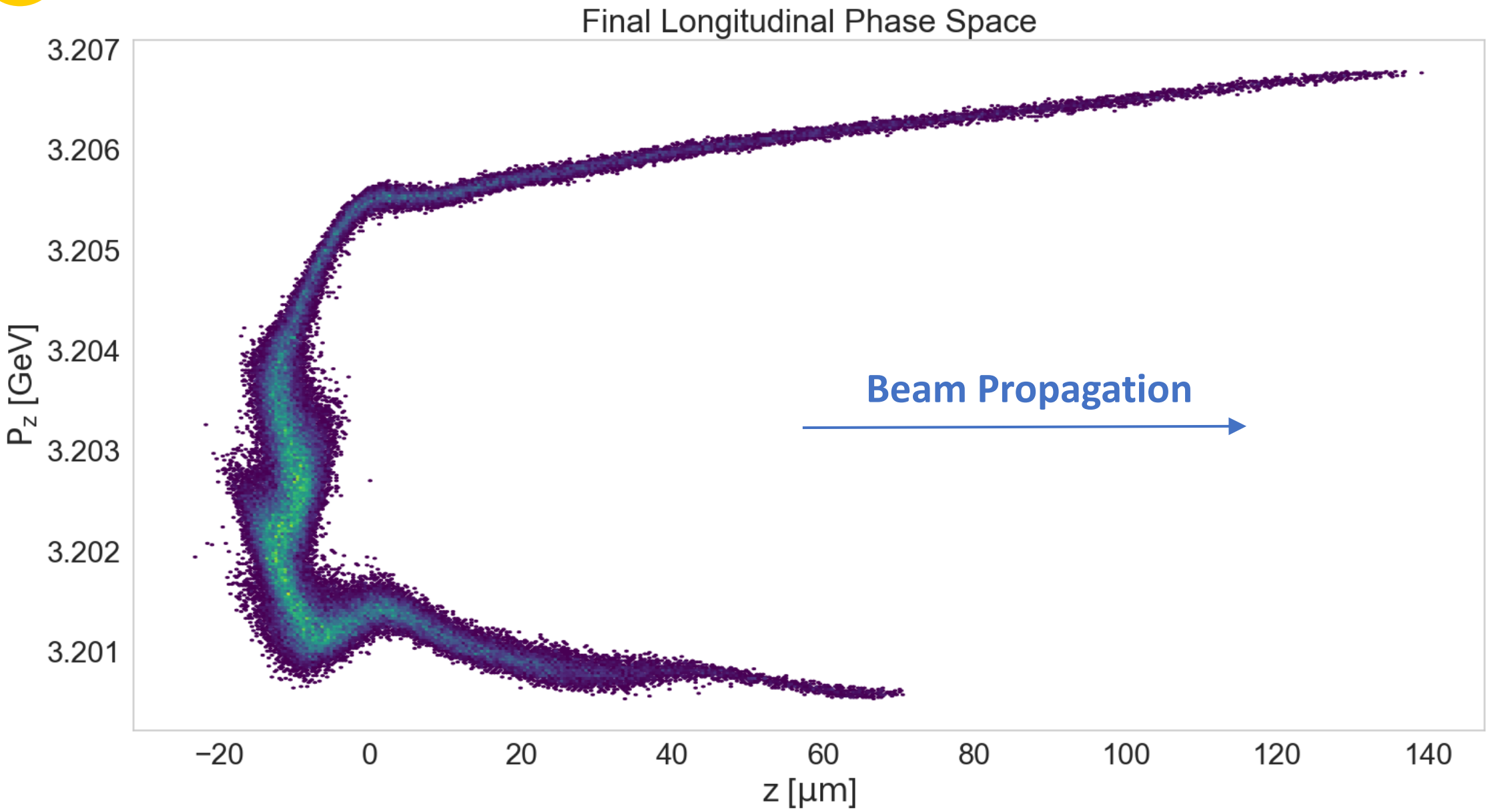
The way back in the L1 Booster



Energy adjustment in L2

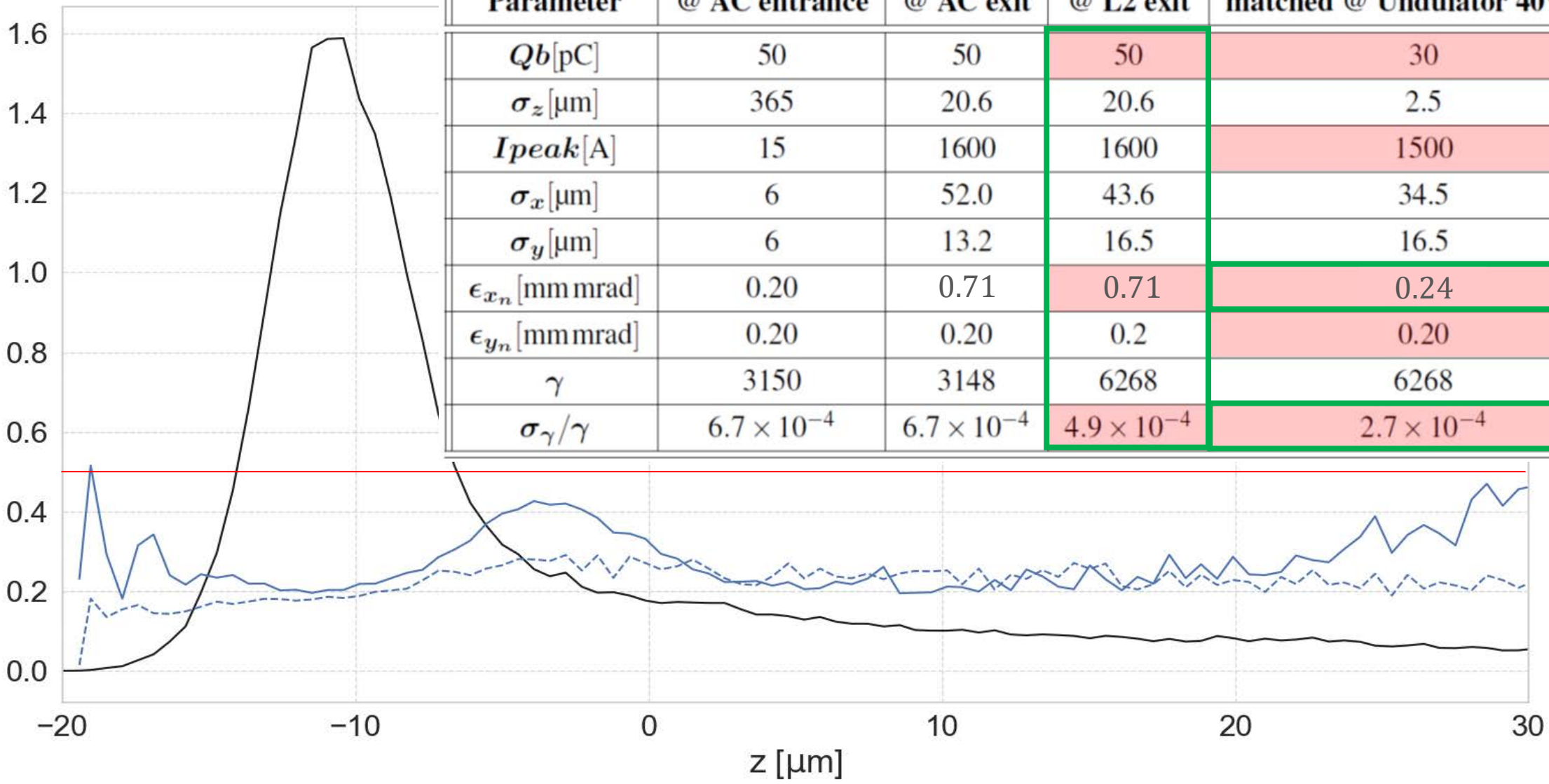


The Bunch

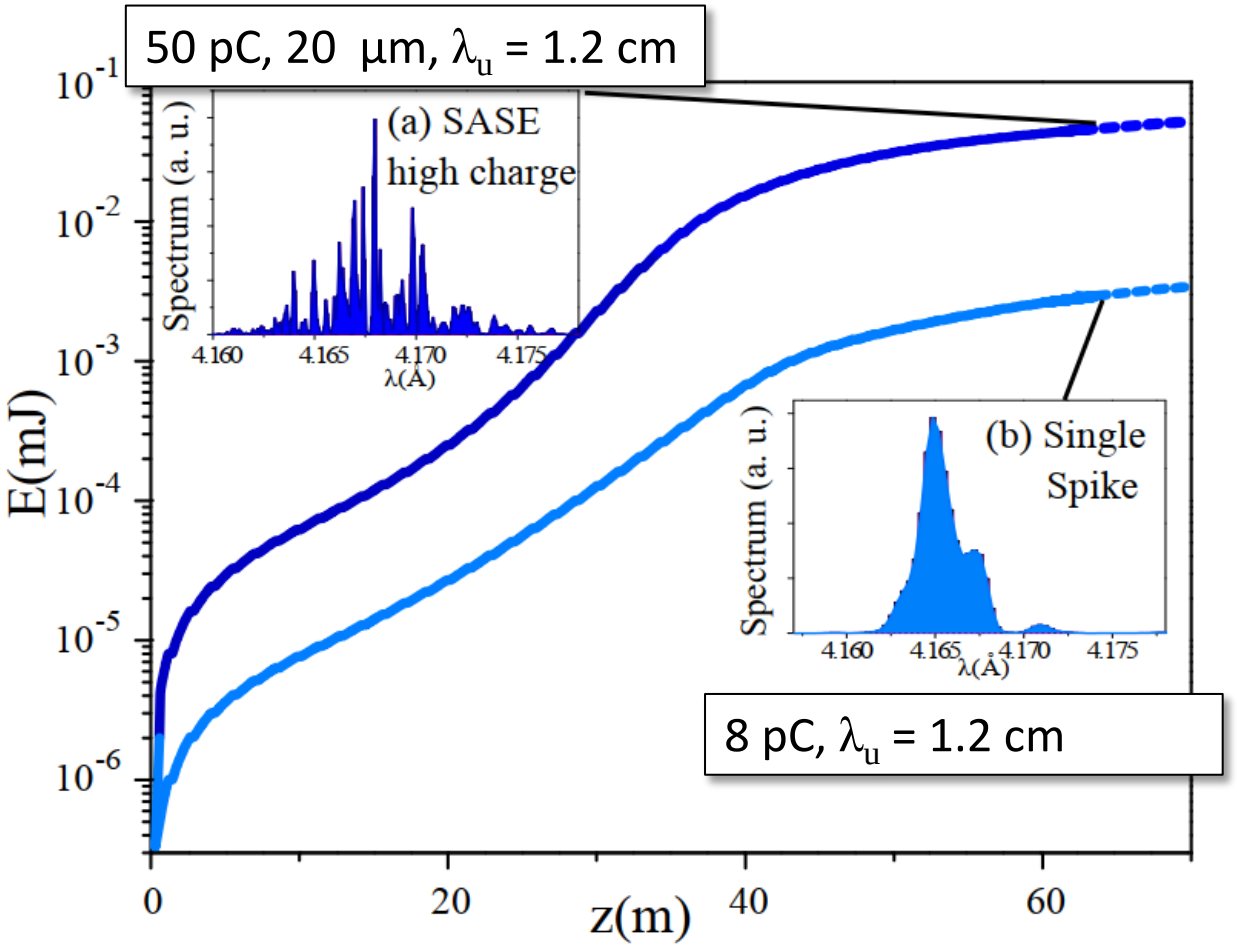

Final Longitudinal Phase Space
3.207
3.206
3.205
3.204
3.203
3.202
3.201
P_z [GeV]
Beam Propagation
−20
0
20
40
60
80
100
120
140
z [μm]

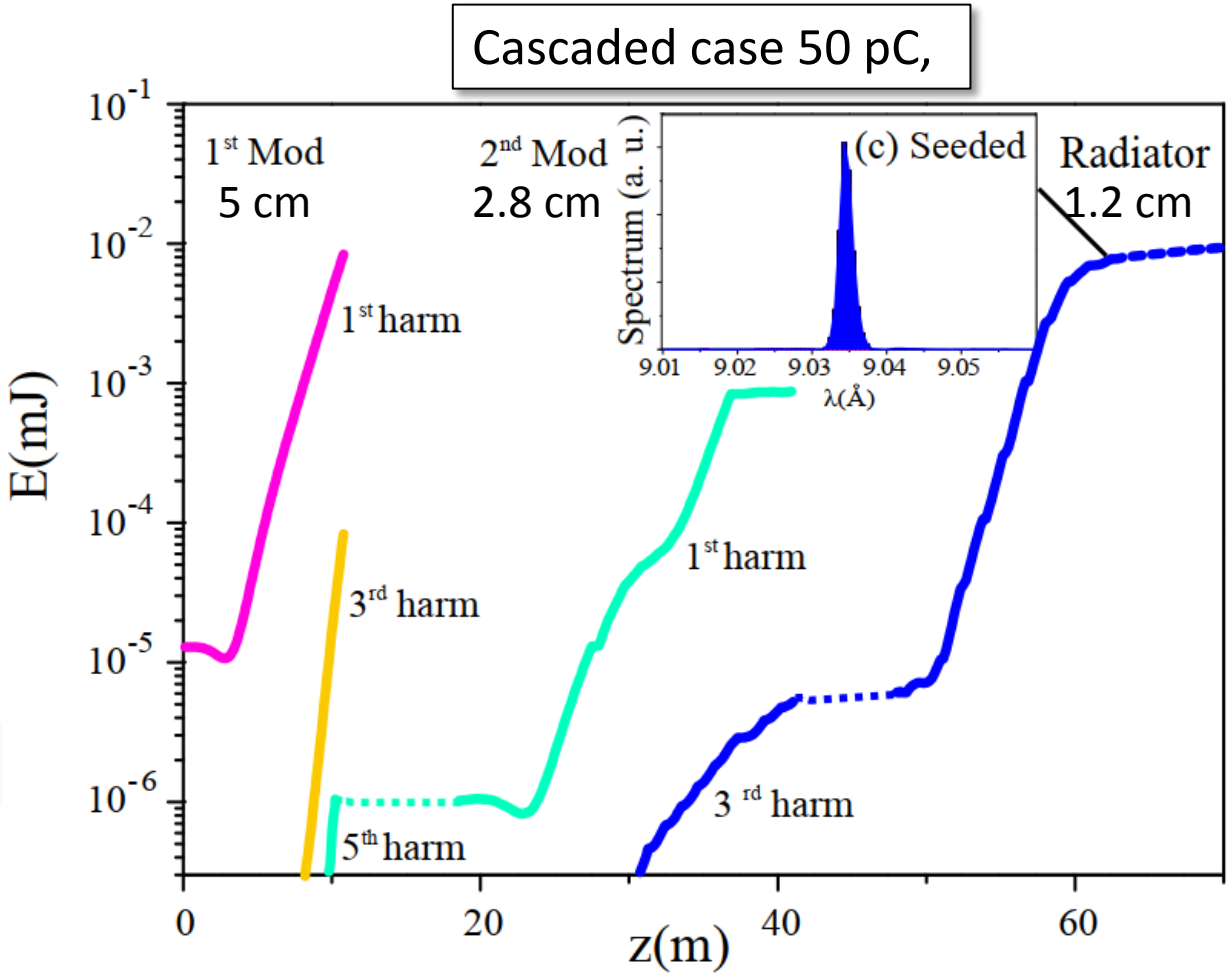
The Bunch

Parameter	@ AC entrance	@ AC exit	@ L2 exit	matched @ Undulator 40% cut
Qb[pC]	50	50	50	30
σ_z[µm]	365	20.6	20.6	2.5
$Ipeak$[A]	15	1600	1600	1500
σ_x[µm]	6	52.0	43.6	34.5
σ_y[µm]	6	13.2	16.5	16.5
ϵ_{x_n}[mm mrad]	0.20	0.71	0.71	0.24
ϵ_{y_n}[mm mrad]	0.20	0.20	0.2	0.20
γ	3150	3148	6268	6268
σ_γ/γ	6.7×10^{-4}	6.7×10^{-4}	4.9×10^{-4}	2.7×10^{-4}



FEL Performance





Courtesy V. Petrillo & M. Opromolla

Conclusion

- A new acceleration scheme has been presented with TWO remarkable benefits:
  1. More **sustainable** layout with **foot print** about two times **shorter.**
- F
- C that:
  - The layout can host a laser heater.
  - Preliminary evaluation with **CSR** and **LSC** give indication of moderate µBI gain (not a showstopper)

Thanks!

Project **website**: www.marix.eu

- Conceptual Design Report
- Articles and other material
- News
- Contacts

Credits

Special thanks to all the people who made and released these awesome resources for free:

- Presentation template by SlidesCarnival
- Icon made by Freepik from www.flaticon.com