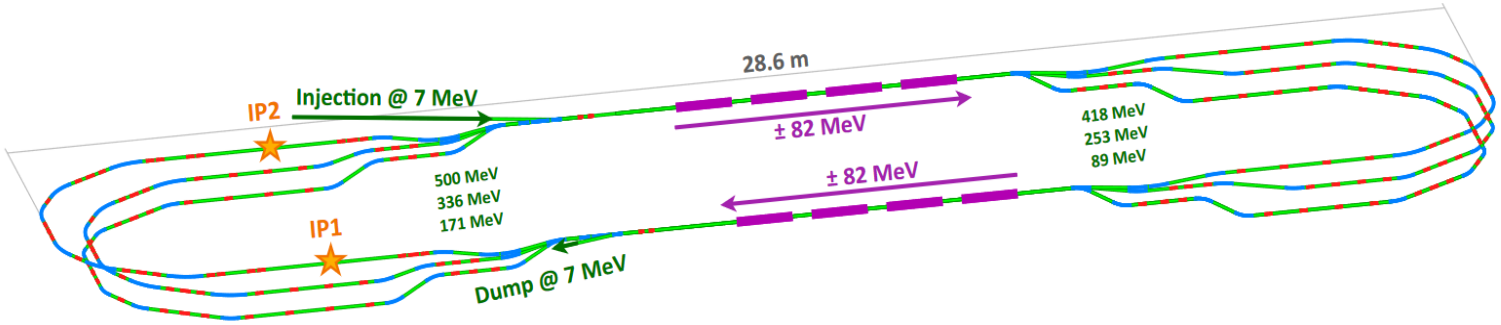
Latest and upcoming beam dynamics studies on PERLE



Speaker : Julien Michaud

Contents

BMAD simulations and benchmarking

What BMAD [1] is :

- Developed at Cornell by D. Sagan
- Already used on ERLs such as CBETA
- Object oriented
- Open source
- Subroutine library for charged-particle dynamics

What BMAD can do :

- Single and multi-particle beam dynamics
- Wakefields, radiation excitation and damping
- Transfer matrices, emittances, Twiss parameters, dispersion, coupling, etc.
- BBU analysis and more…

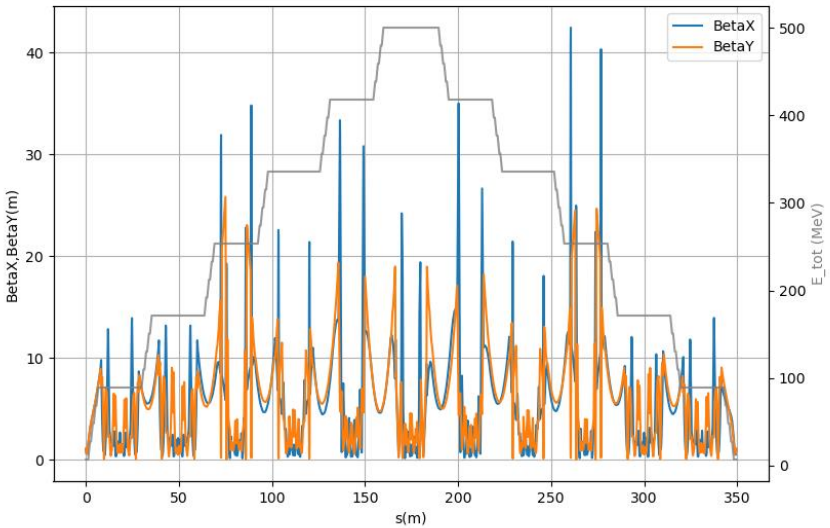
[1] D. Sagan, "Bmad: A Relativistic Charged Particle Simulation Library" Nuc. Instrum. & Methods Phys. Res. A, 558, pp 356-59 (2006).

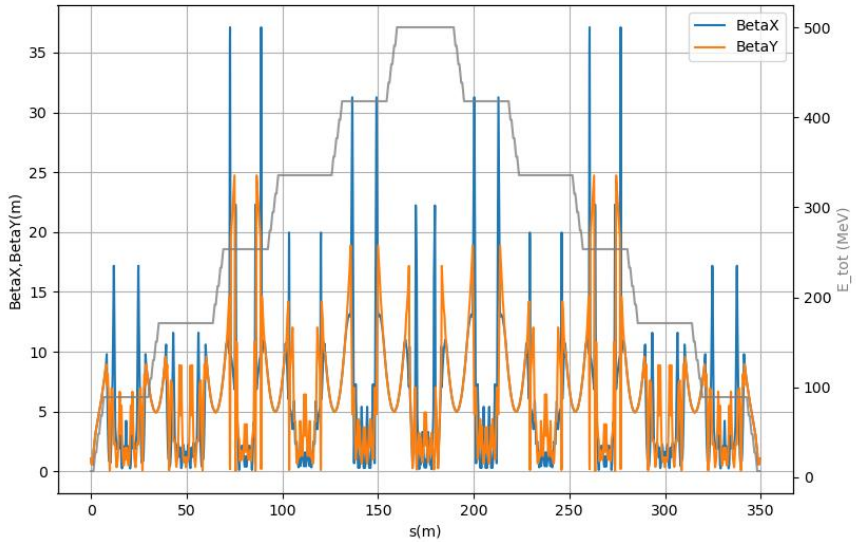
1st order tracking

Lattice imported from MADX file, with a few changes :

- Transverse dynamics in LINACS
- Higher order fringe fields

500MeV version





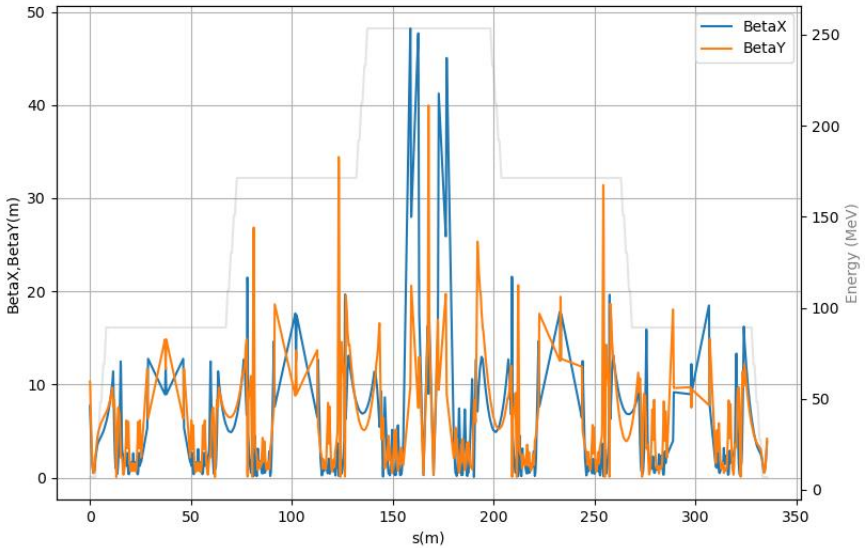
Lattice have been rematched for BMAD (500MeV and 250MeV versions)

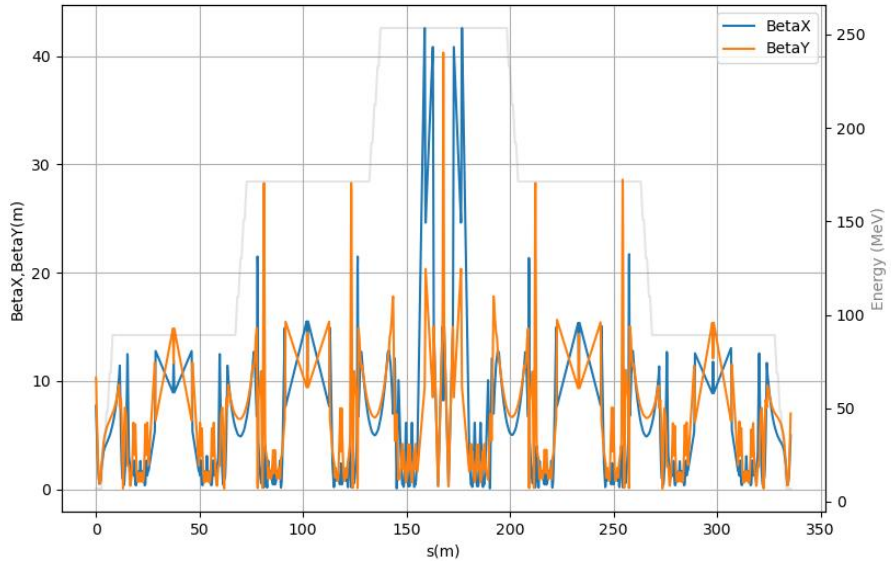
1st order tracking

Lattice imported from MADX file, with a few changes :

- Transverse dynamics in LINACS
- Higher order fringe fields

250MeV version





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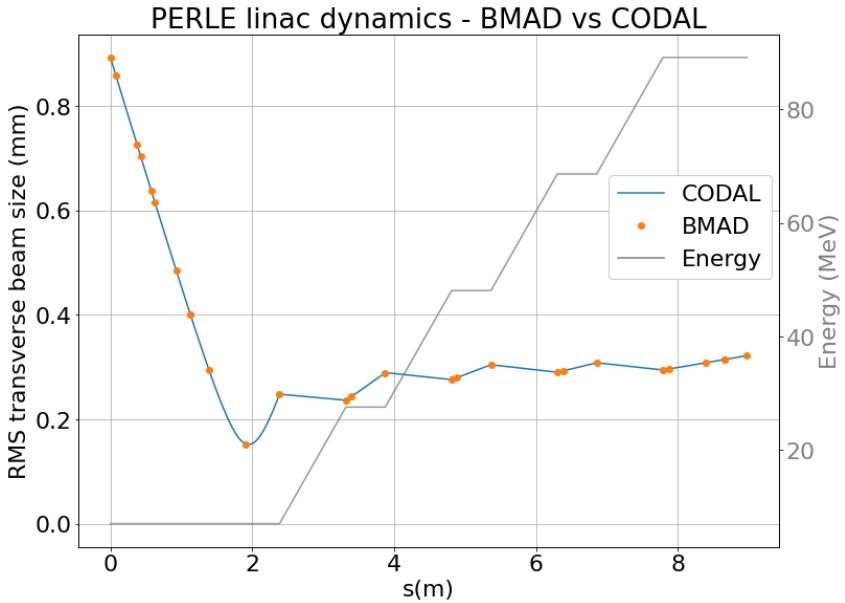
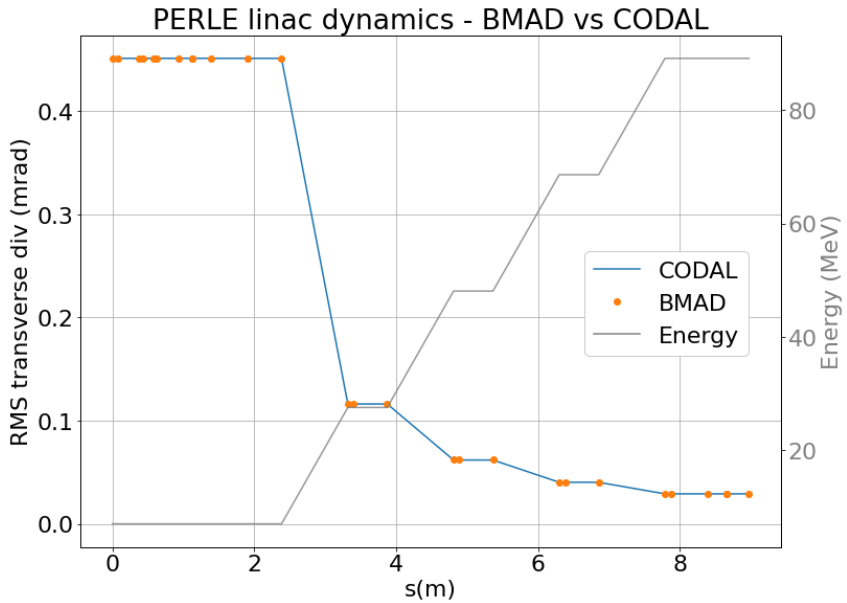
Transverse position



Transverse divergence



BMAD crosschecked with CODAL and ASTRA (see Coline's talk)

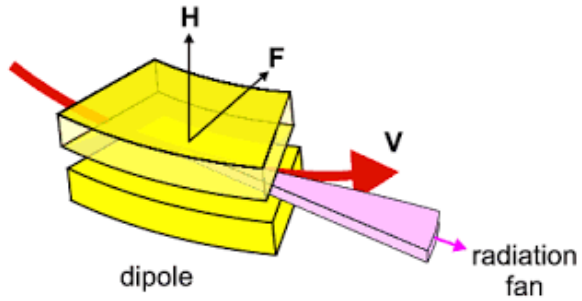
- Energy
- Transverse envelope
- Longitudinal and transverse emittance distributions

Equations (CODAL&BMAD) from the same publication [2]

[2] Rosenzweig, J, and Serafini, L. 1994. "Transverse particle motion in radio-frequency linear accelerators". United States

Collective effects : space charge and CSR

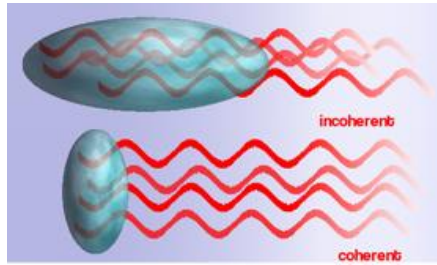
- Particles (electrons) emit synchrotron radiation when they are subject to centripetal acceleration
  - ➔ Typically the case for dipoles



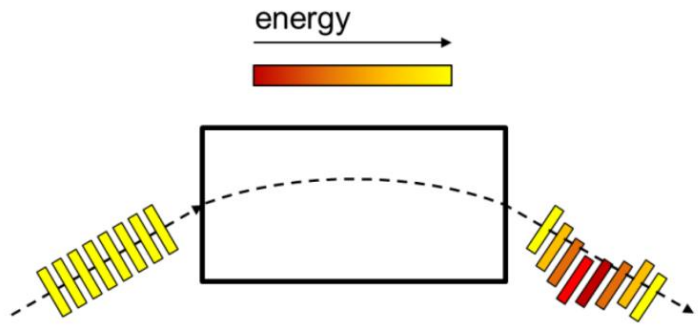
- We can observe 2 regimes for these radiations :
  - i. Incoherent regime : SR
  - ii. Coherent regime : CSR

$$P_{SR} \equiv N_{part}$$

$$P_{CSR} \equiv N_{part}{}^{2}$$



- Radiation emission will affect the bunch energy distribution
- Energy spread will translate to spatial bunch spread in dipoles
- ➔ Longitudinal and transverse emittance growth



Simulations with BMAD

BMAD CSR calculation methods :

1-Dim CSR calculation :

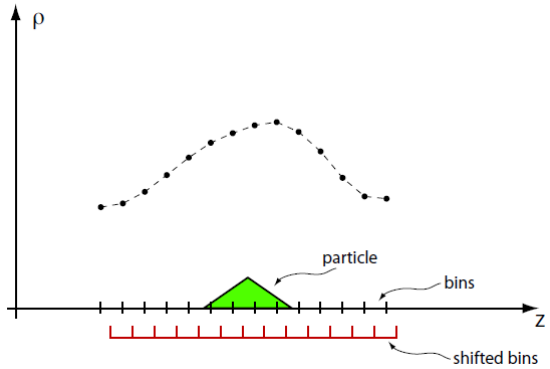
- The particle-particle CSR kick is calculated by dividing the bunch longitudinally into a number of bins
- Triangular densities distributions

Slice Space Charge calculation :

- The particle-particle CSR kick is calculated by dividing the bunch longitudinally into a number of bins
- Longitudinal + transverse kick

FFT_3D Space Charge Calculation:

- Uses OpenSC package from someone else
- 3D grid with FFTs
- Slower method, but handles low energy space charge



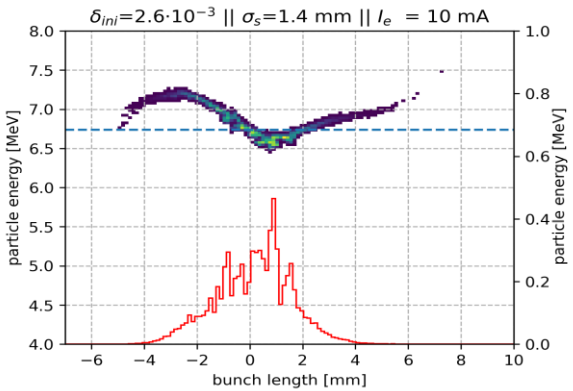
High Energy Space Charge :

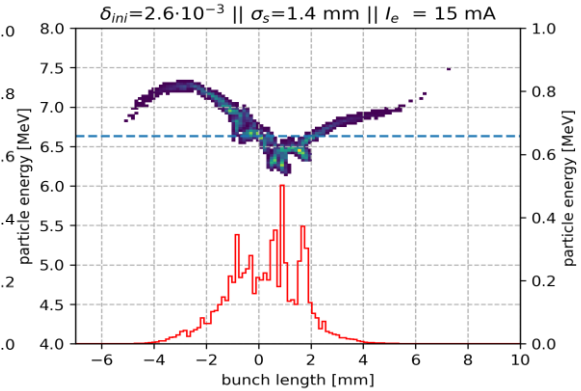
- Totally different formalism that other methods
- Very fast as more statistical
- Acceptable for storage rings at relatively high energy but not accurate in other situations

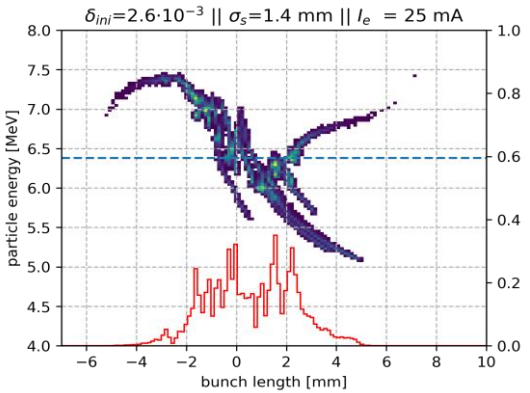
Collective effects benchmarking

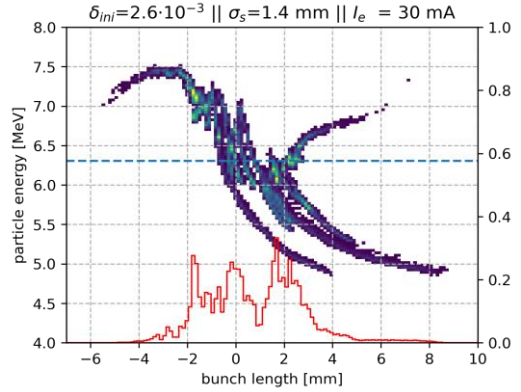
Initial distribution : 3x2D gaussian distribution at the beginning of the first linac
Tracking : from first linac to dump

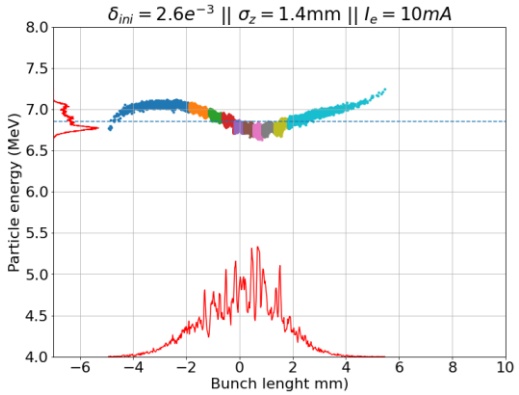
PLACET2 (K. Andre)

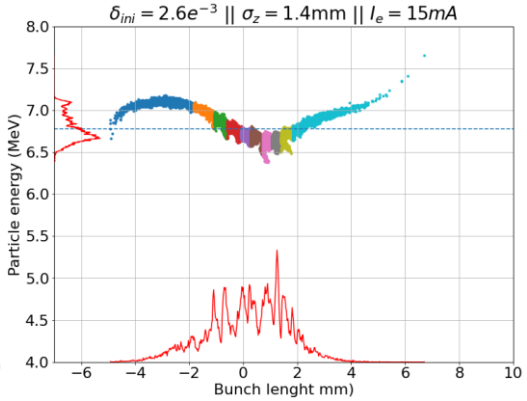


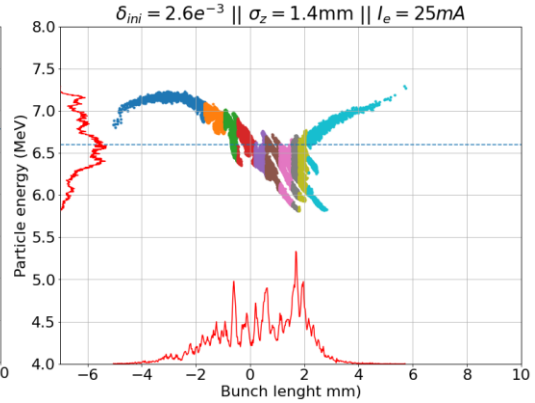


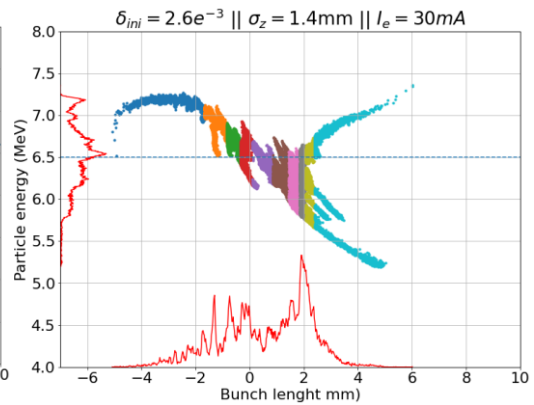












BMAD

Conclusion about BMAD

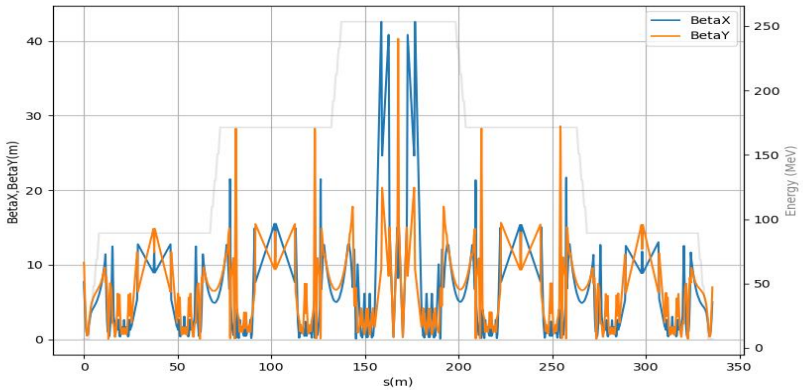
Versatility

- Good option for start-to-end tracking
- High order tracking
- CSR and space charge
- Wakefields, BBU…

Accuracy

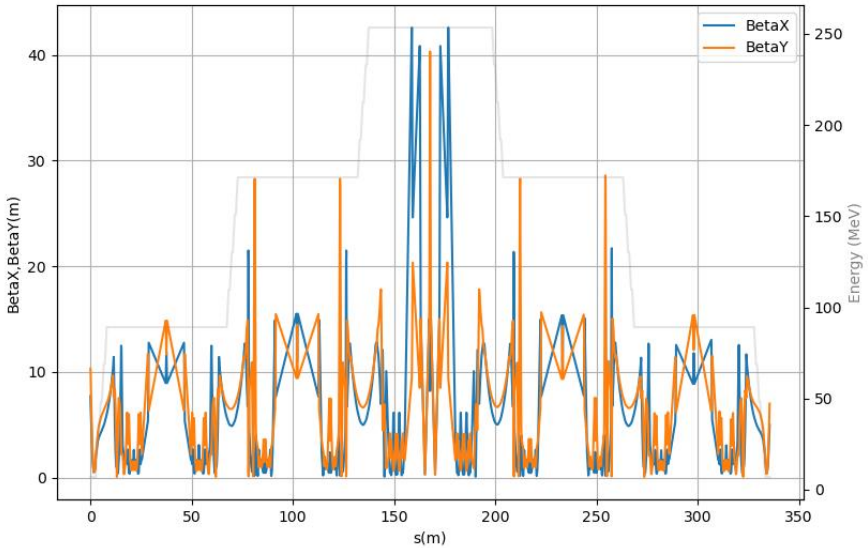
- Linacs dynamics verified
- CSR effect benchmarked
- Can include field maps

Contents



Linear matching

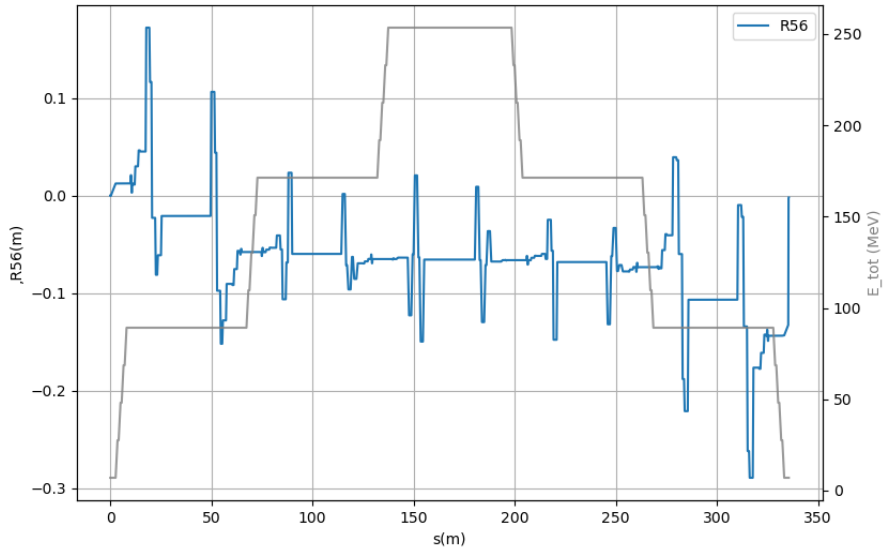
Twiss parameters



Objectives :

- Symetry accel/decel
- Minimum beta in spreaders
- Dispersion closed

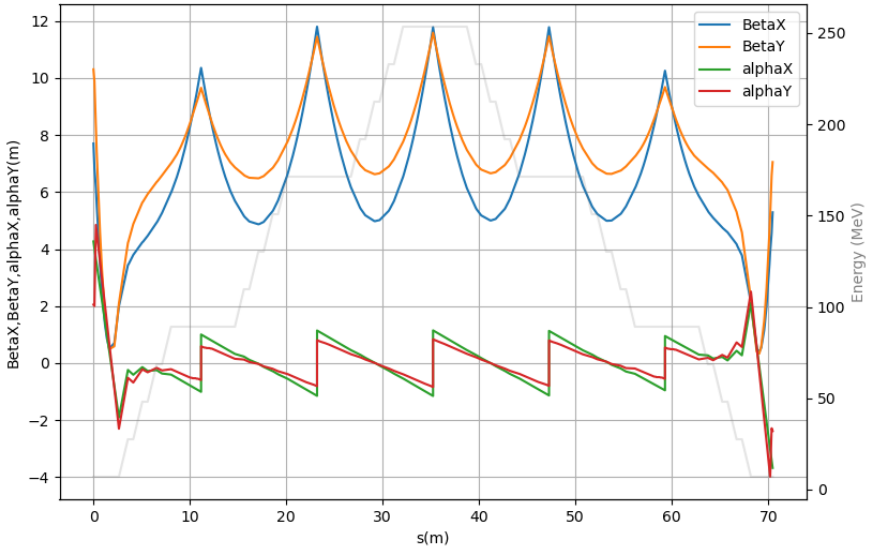
Momentum compaction factor



Trajectories are longer in dipoles for different energies
Ends up with bunch length changes
Term M56 must be cancelled at the end of arcs

Especially true in 250MeV lattice (lack of spreader/recombiner in straight section)

Linacs dynamics



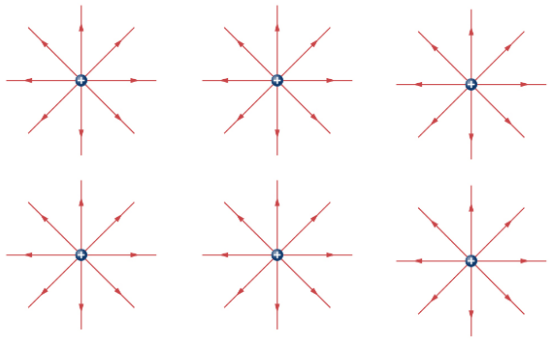
Twiss functions must be stable over all successive linacs (see A. Fomin talk)

Fringe fields

- MADX : fringe field order 1
- BMAD : fringe field order 2

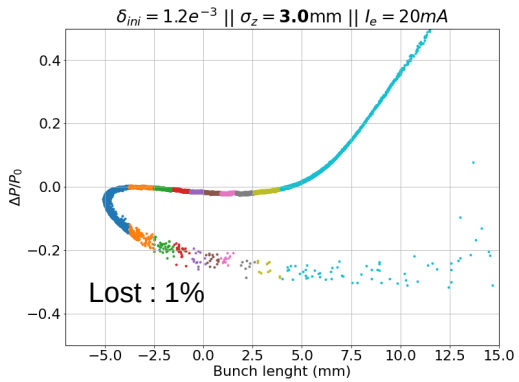
- Forced BMAD FF to order 1 and simulations matched
- Need to re-tune the lattice

Contents

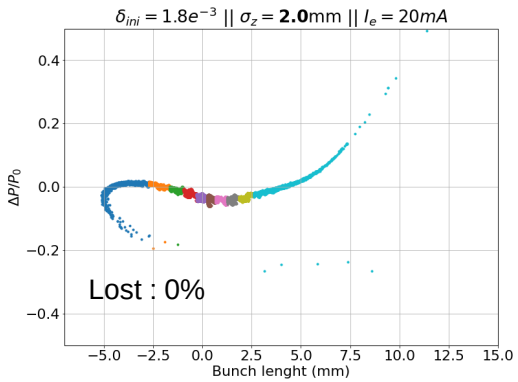


RF curvature VS CSR

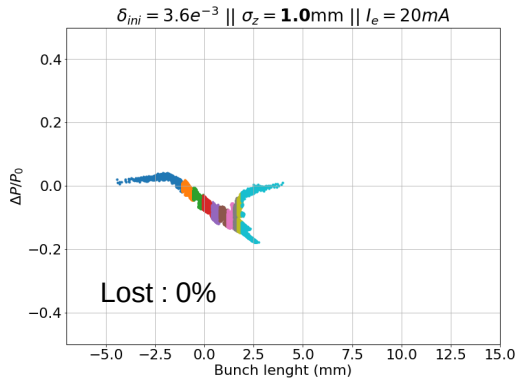
3 mm bunch length



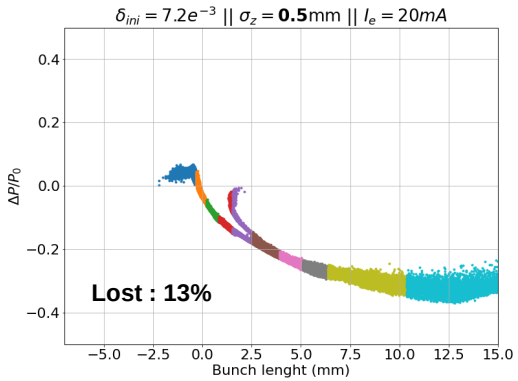
2 mm bunch length



1 mm bunch length



0,5 mm bunch length



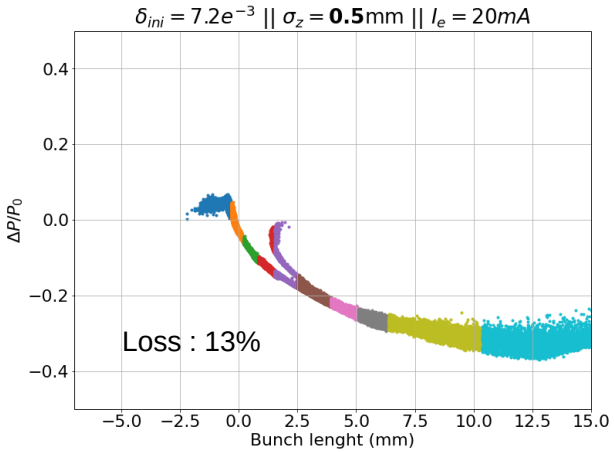
RF curvature dominated

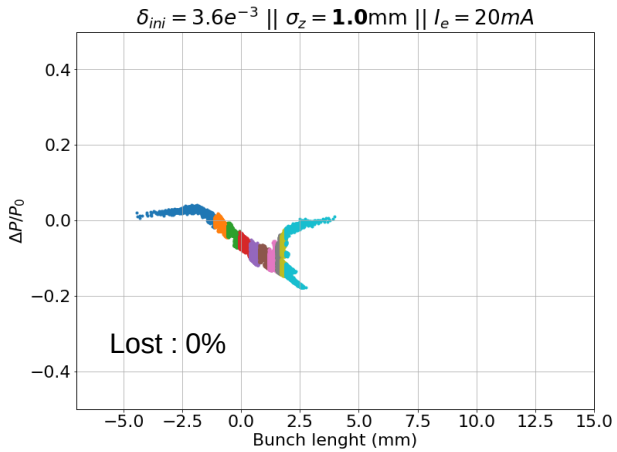
CSR dominated

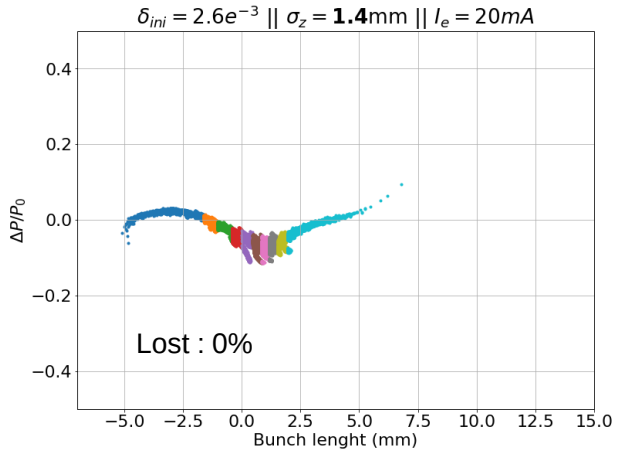
Need to specify an optimum bunch length for simulations and injector

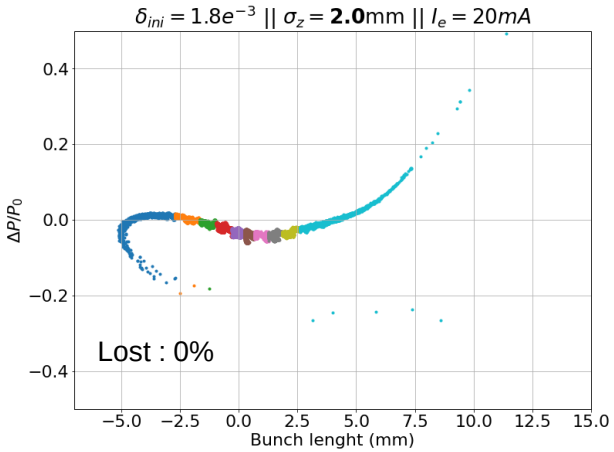
1,4mm optimal value from K. Andre simulations

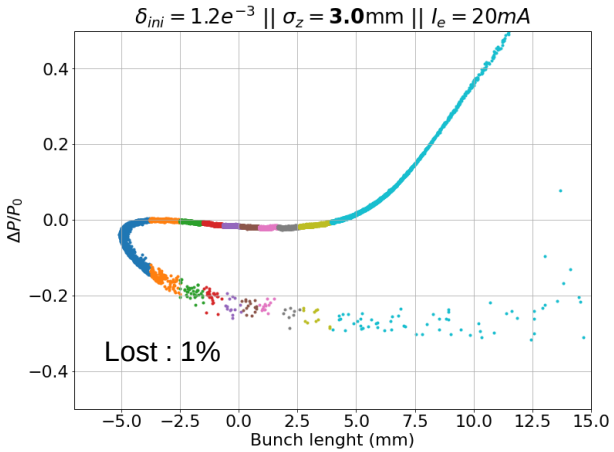
Beam long. emittance different bunch lengths (50 000 particles)









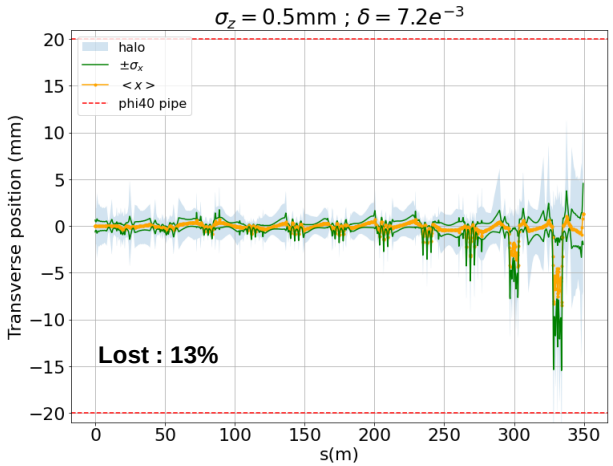


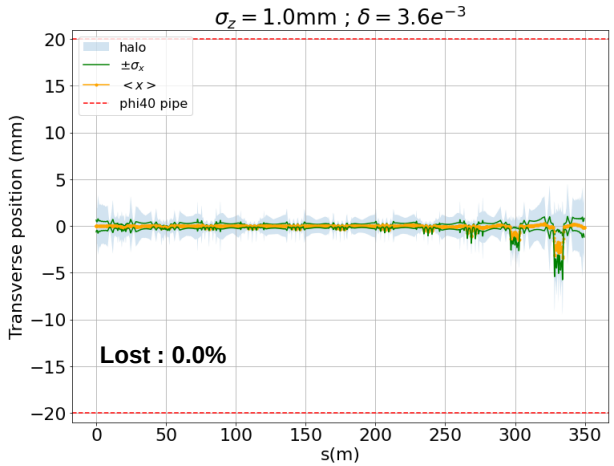
- We observe CSR vs RF curvature effects
- No loss range : [1mm ; 2mm] bunch length
- Best result around 1.4mm

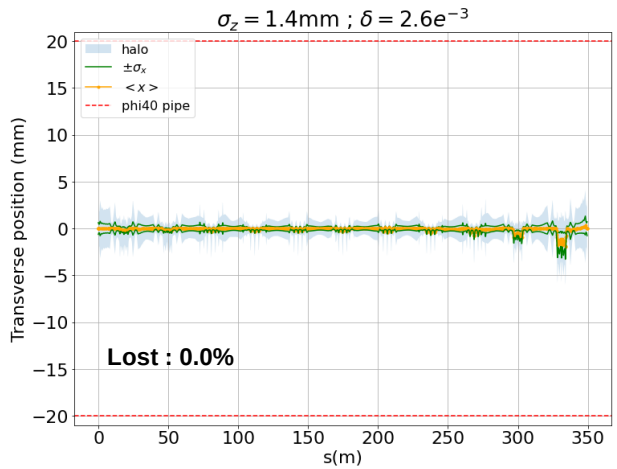
➔ Longer bunch length are easier to achieve with the injector

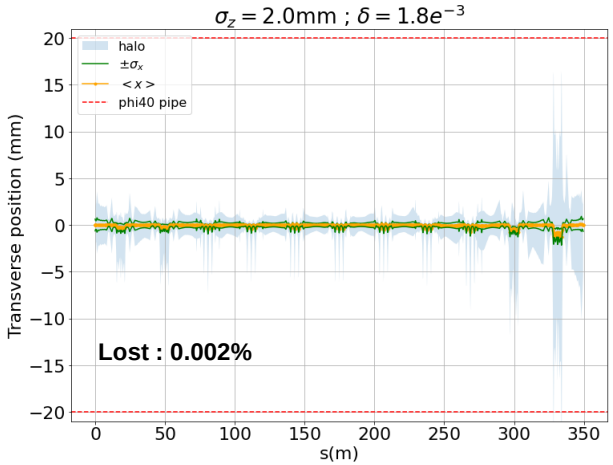
Q : Possible corrections of RF curvature effects ?

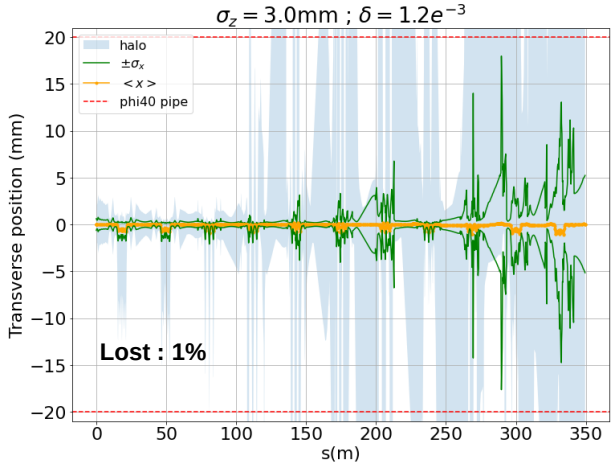
Beam X envelop for different bunch lengths (50 000 particles)











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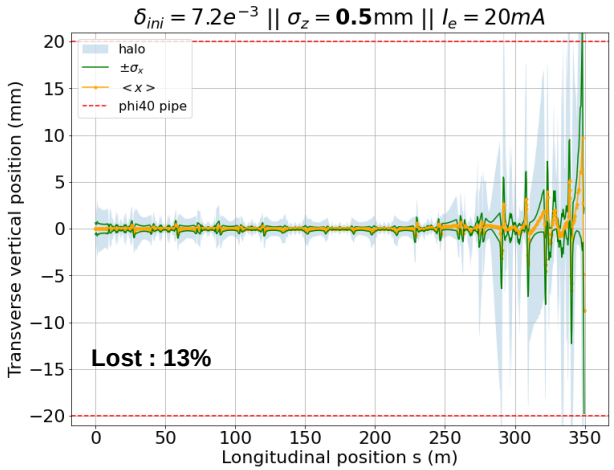

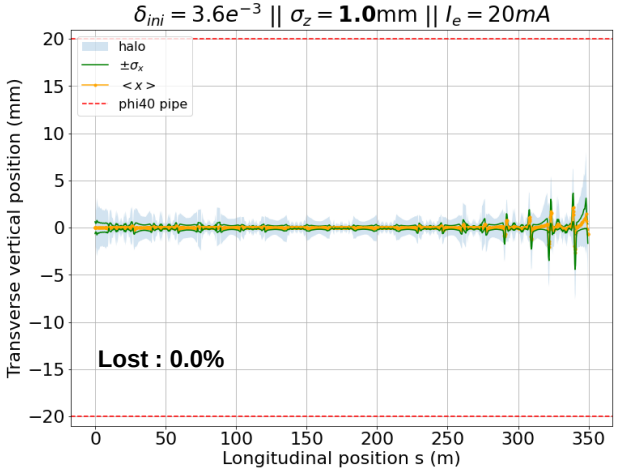

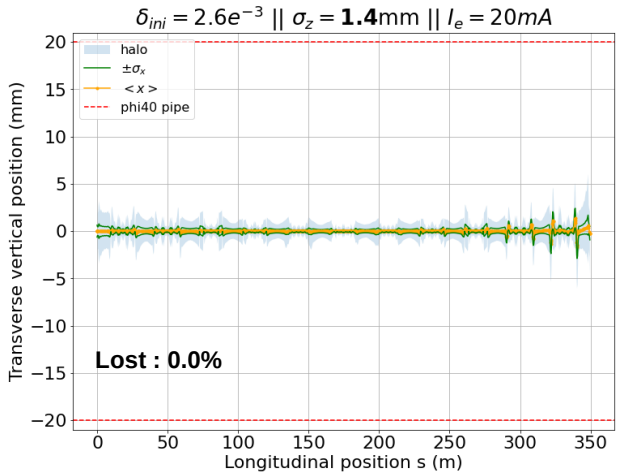

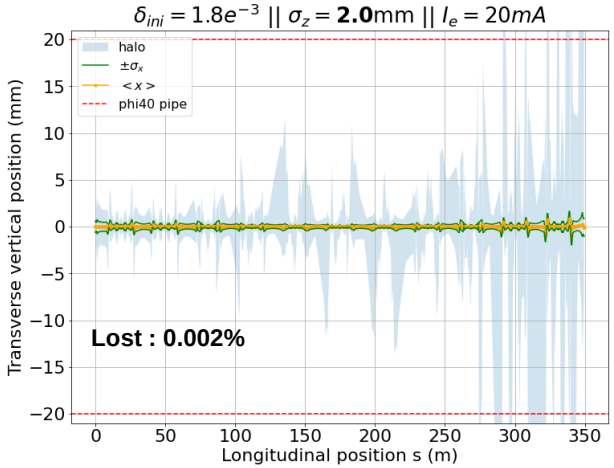

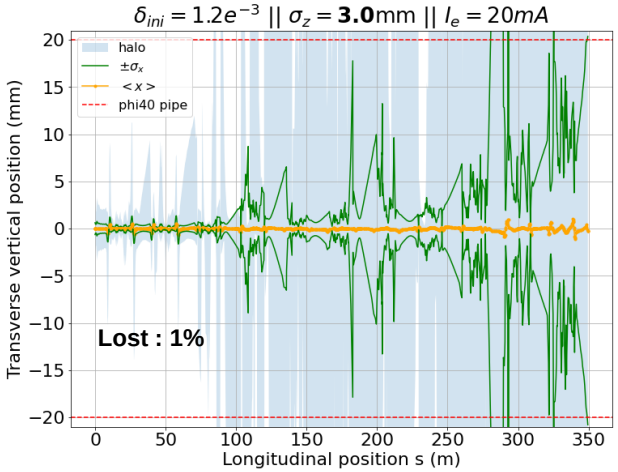

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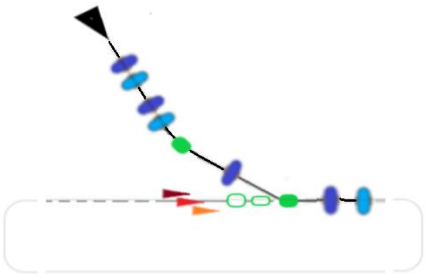
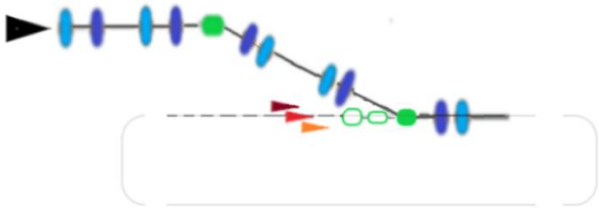
Merger : Matching the injector beam to the eigen-ellipse of PERLE

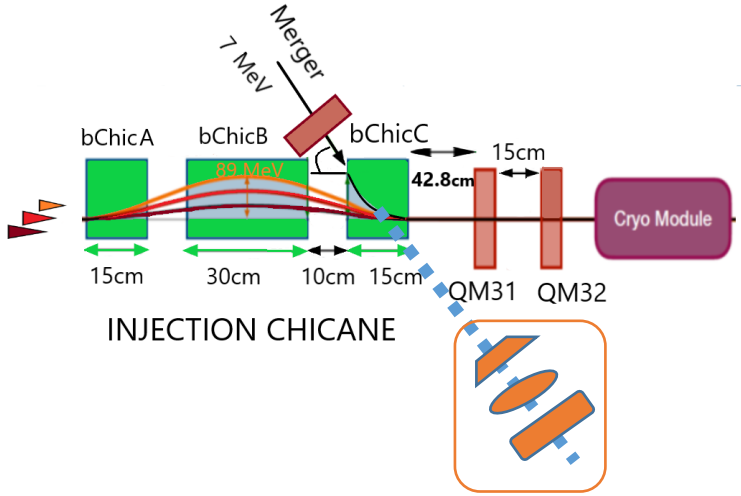
New studies by B. Jacquot (GANIL)
From initial studies by B. Hounsell

Ubend



Sbend (Dogleg)





Ubend : Shorter (less expensive) but perpendicular to ERL
Sbend : A few more elements, but more compact (parallel to the ERL)

Need for a diagnostics station after merger

<u>Both options fulfill the requirements for PERLE</u>

Diagnostics under study/evaluation

Other studies ongoing or planed

Beam dynamics effects

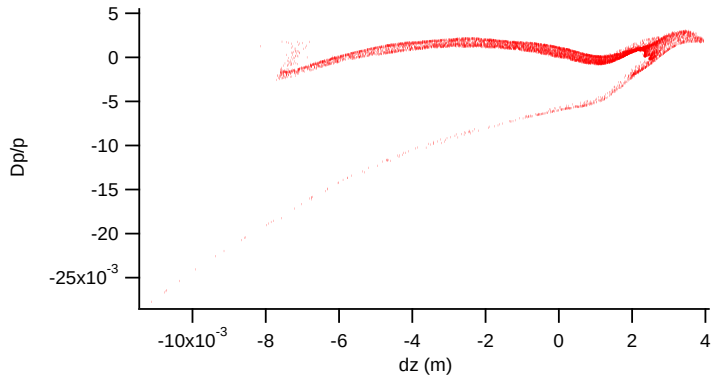
- BBU threshold
- Wakefields
- High order tracking and corrections (sextupoles, octupoles)
- Misaligmnents & corrections

Work in close collaboration with diagnostics team

➔ See M. Abdillah talk tomorrow

Start to end simulations

- Add Merger to full simulations
- Inject output distribution from injector
- Beam losses and halos



Injector longitudinal output (for illustration)

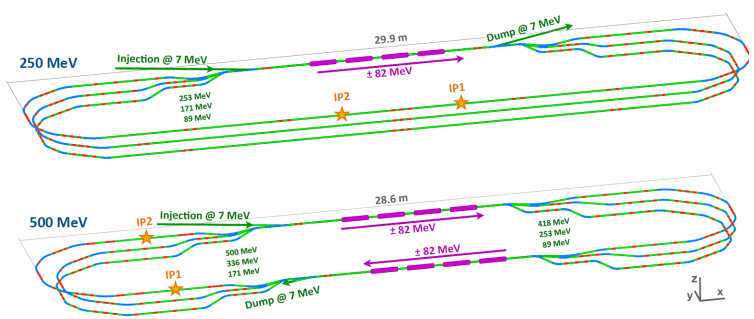
➔ See Raphael's talk this afternoon

Contents

Next talks

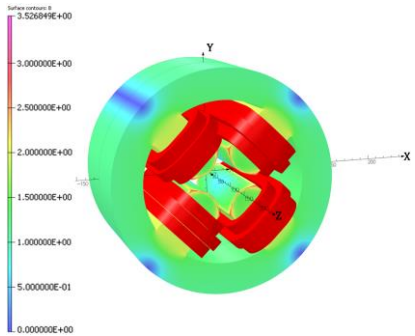
Alex Fomin

- PERLE 250 MeV version
- MADX matching
- Optimisation
- Filling patterns



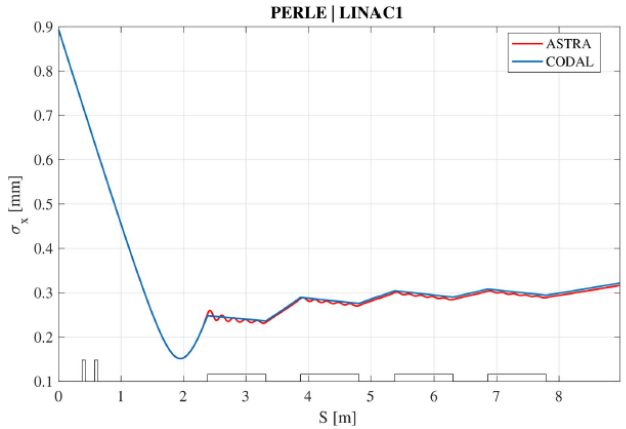
Rasha Abukeshek

- Magnets
- Misalignment studies



Coline Guyot

- Collective effects
- Linac dynamics



Thank you for listening !

References :

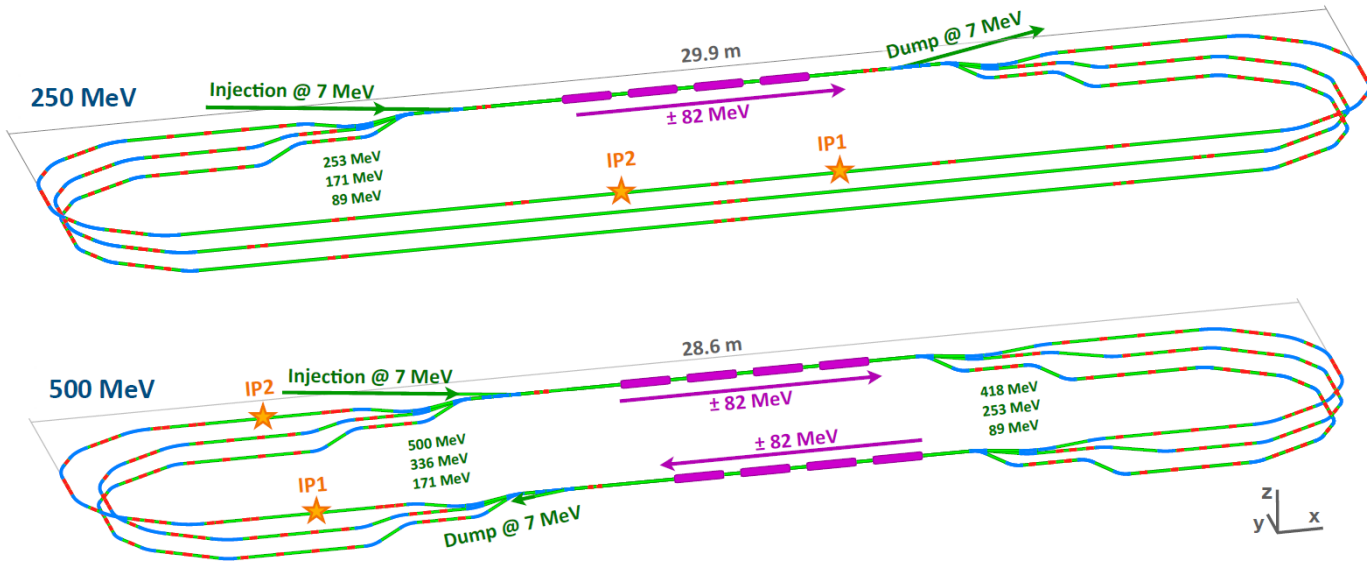
[1] D. Sagan, "Bmad: A Relativistic Charged Particle Simulation Library" Nuc. Instrum. & Methods Phys. Res. A, 558, pp 356-59 (2006)

[2] Rosenzweig, J, and Serafini, L. 1994. "Transverse particle motion in radio-frequency linear accelerators". United States

Two models studied

Arcs are identical : reduction of immediate expenses and construction time :
1 (of 2) cryomodules, 60 (78) dipoles and 136 (148) quads)

Fields in quads are consistant with current design (no saturation)



Images and design (250MeV) by Alex Fomin

<u>250 MeV version</u> :

- 3 energies -> 6 arcs
- 1 linac
- 1 spreader ; 1 merger
- 3 straight sections

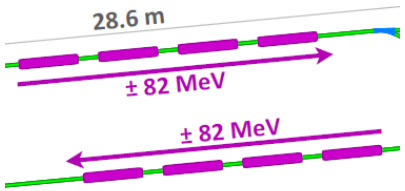
<u>500 MeV version</u> :

- 6 energies -> 6 arcs
- 2 linac
- 2 spreader ; 2 merger

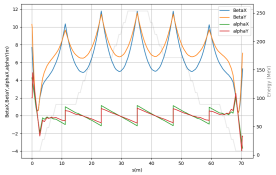
Optimization objectives

What needs to be tuned :

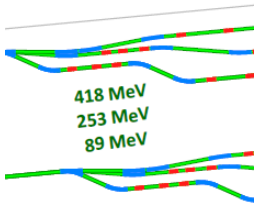
What can we play on :



Twiss functions
stable over all linacs



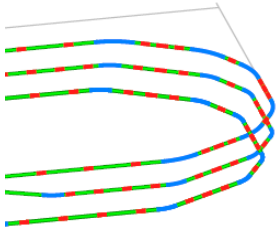
Merger output :
initial twiss functions



$3\sigma_{y,x} < 2{,}2\ mm$

$D_y = D'_y = 0$

- K1 gradient of quads in spreader
(7 quads families)



$\beta_{start} = \beta_{end}$

$\alpha_{center} = 0$

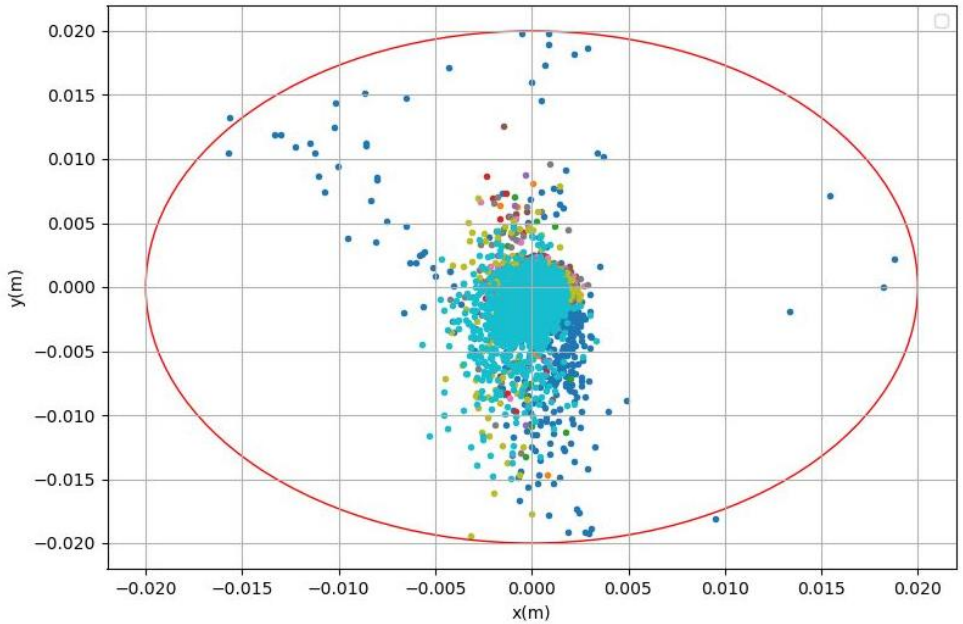
$D_x = D'_x = 0$

$M_{56} = 0$

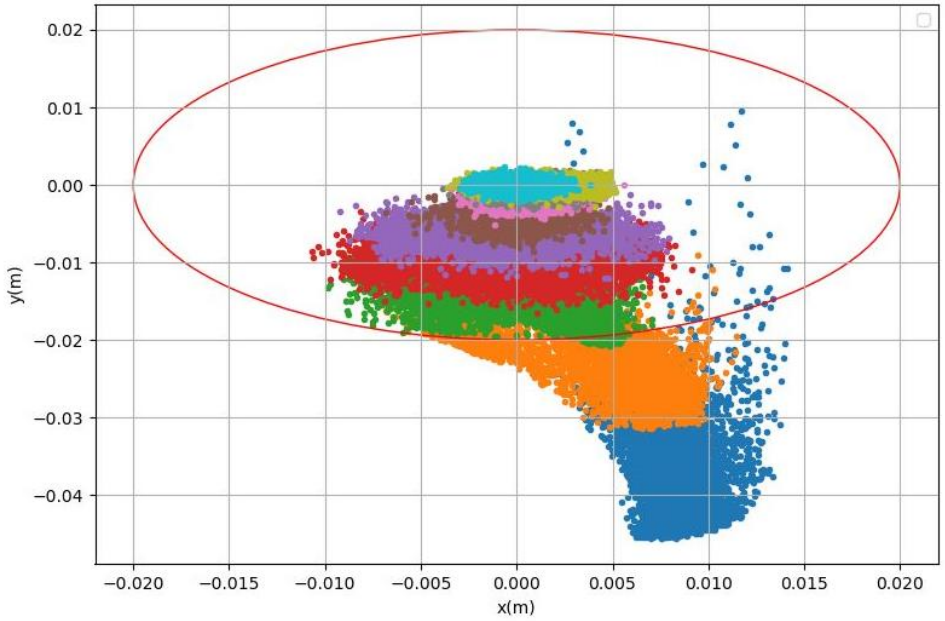
- K1 gradient of quads in arcs
(11 quads families)

XY space at dump

- 3mm bunch lenght

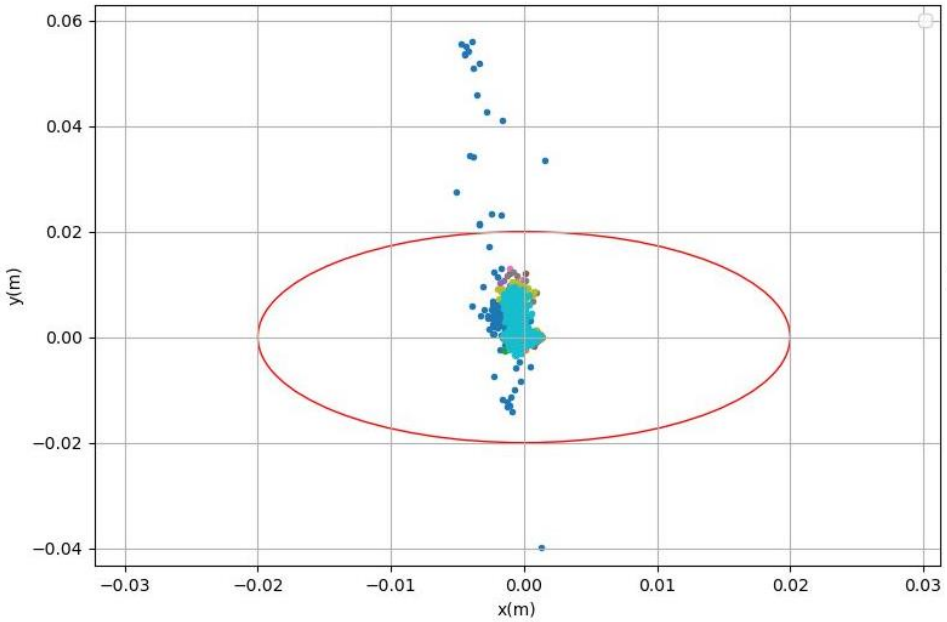


- 0,5 mm bunch lenght

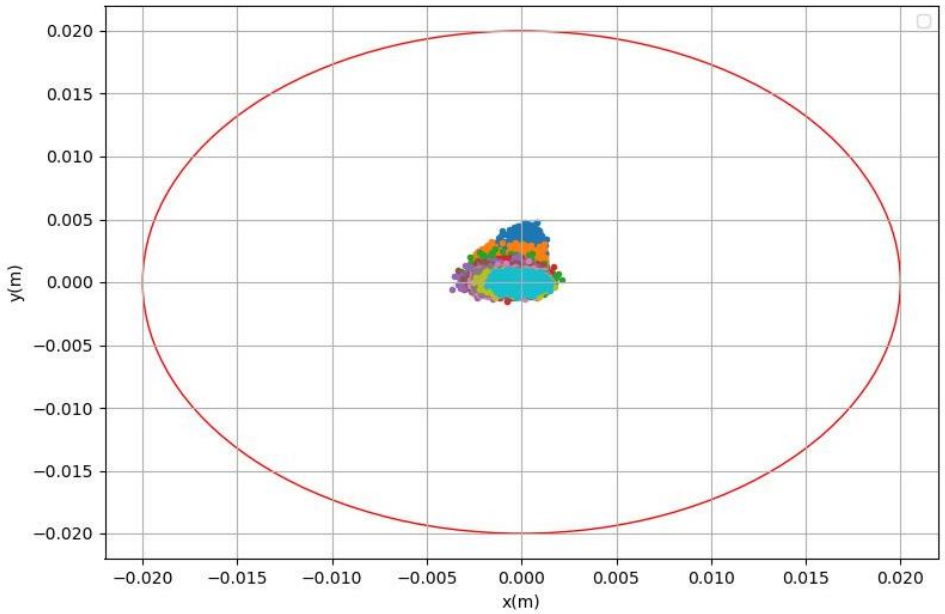


XY space at iENDARC6

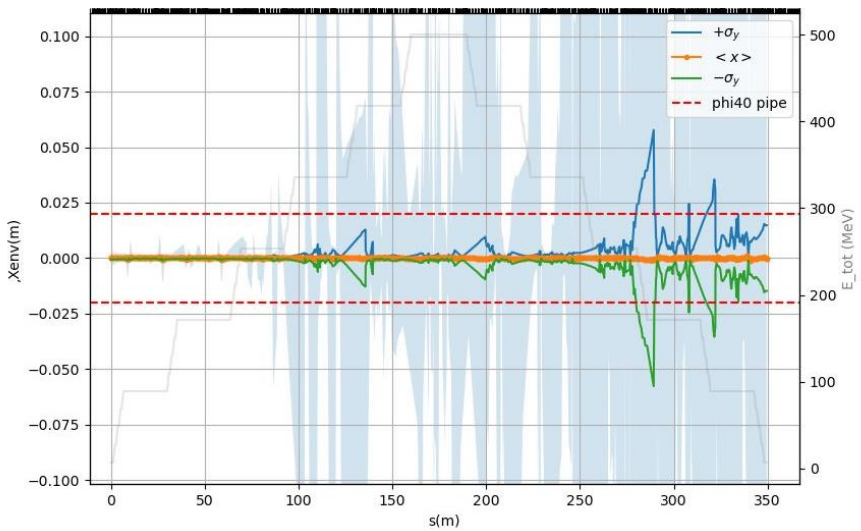
- 3mm bunch lenght



- 0,5 mm bunch lenght

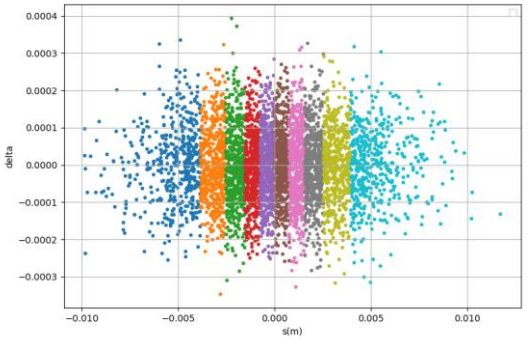


- 3mm bunch lenght

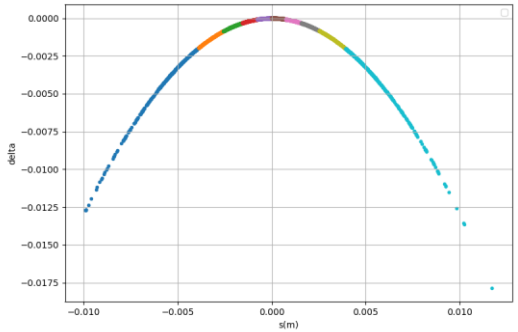


- 0,5 mm bunch lenght

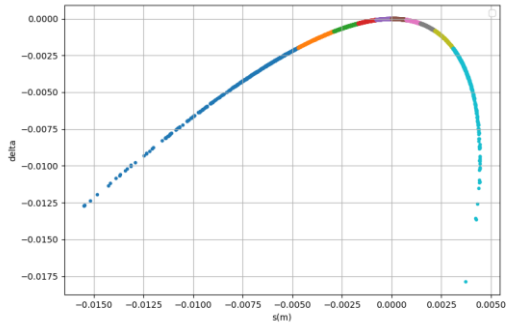
Stacking effect on 250 MeV lattice



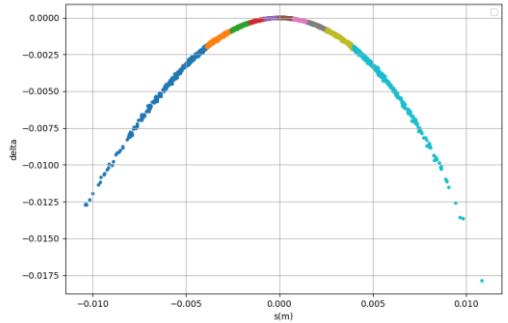
Injection



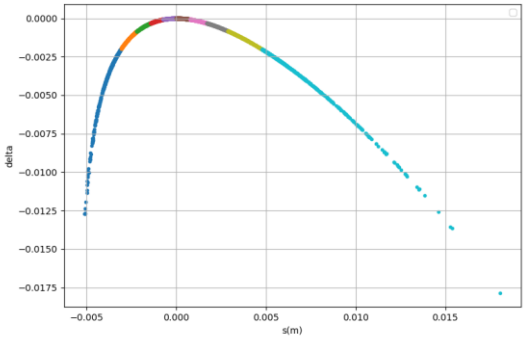
Post-linac



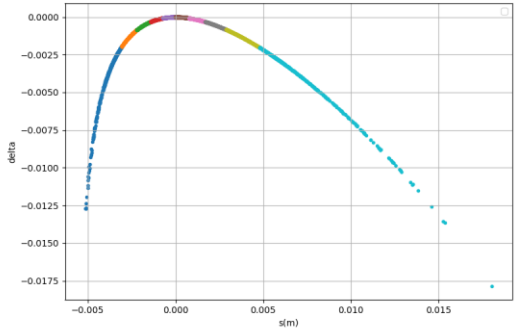
Spreader



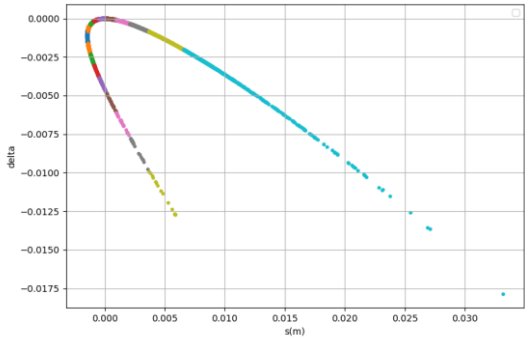
Middle arc1



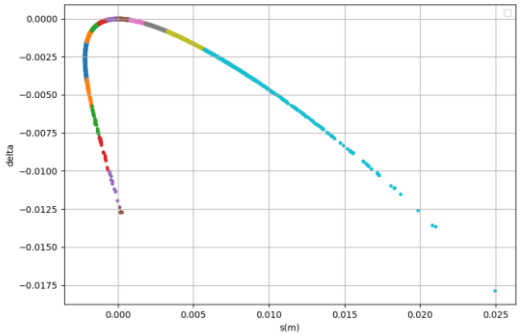
End arc 1



Str section

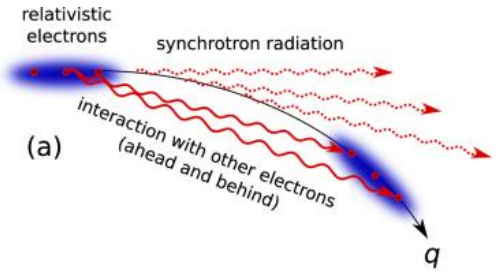


Arc 2



Merger

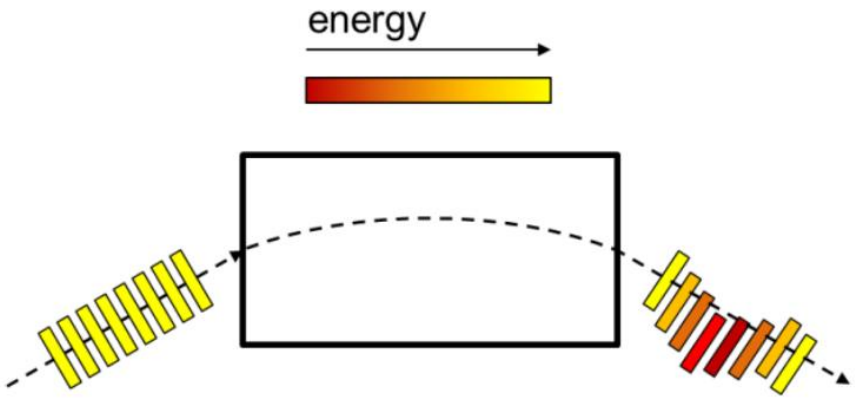
Effect of CSR on the beam

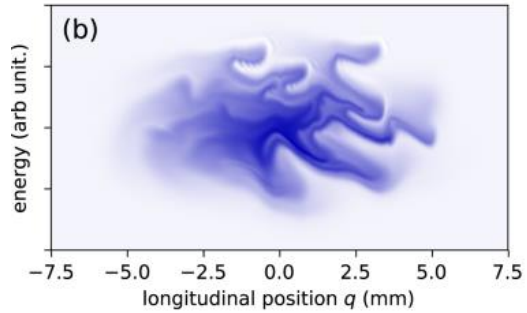


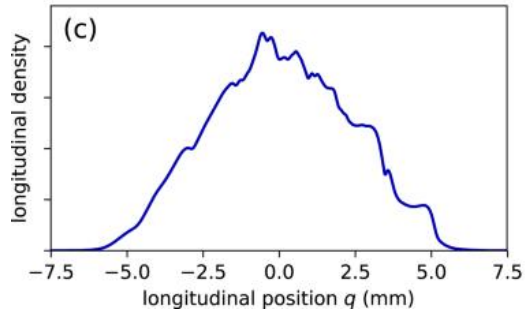
If we slice a bunch in longitudinal bins, we can observe a change in energy of each bin.
This is linked to the z position of the bin wrt the coherent SR wavelength.

This effect, mixed with dispersion, causes transverse shifts of the particles in the dipoles.

$$\Delta x \sim \eta_x \delta \, , \Delta x' \sim \eta'_x \delta \;\; ...$$







For PERLE, for 1 dipole :

$$\delta \sim 3e^{-4} \, ; \eta_x \sim 0{,}1 \, ; \eta'_x \sim 0{,}5 \Rightarrow \Delta x \sim 0{,}03mm \, ; \boldsymbol{\Delta x' \sim 0{,}1mrad}$$

Not cancelled, even if dispersion closed, because energy spread introduced within the arc