PERLE Collaboration Meeting

First attempts of particle tracking

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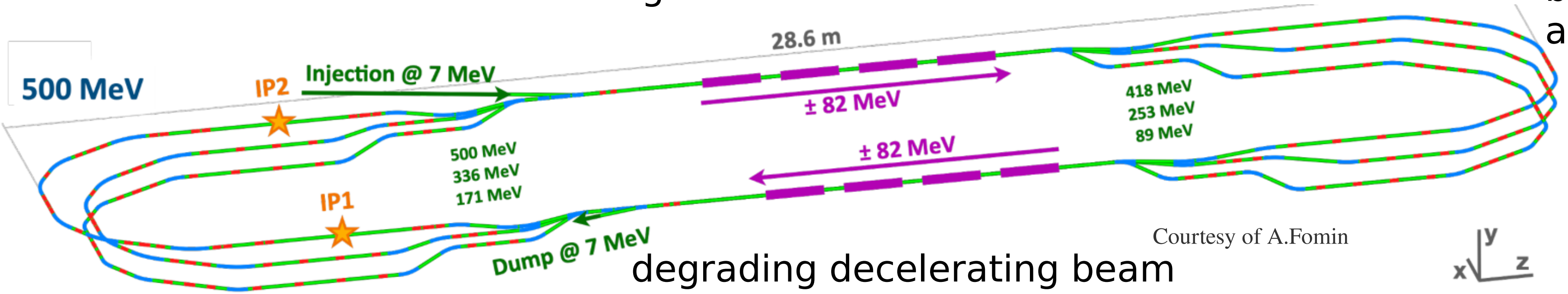
Supervision: Christelle Bruni

- Introduction
- Tracking Simulation Code
- Tracking Starting Conditions
- Chromatic Effects
- RF Cavity Dynamics
- Bunch Length : Benefits
- Other Parameters ?
- Bunch Length: Limitations ?

PERLE is a multi-turn, high current, energy recovery accelerator.

multi-energies cohabitation

beam acceptance



Courtesy of A.Fomin

degrading decelerating beam

short bunches

collective effects

beam quality & losses

ERL: Tracking Simulation Code

A large catalogue of simulations tools for accelerators → adapted for PERLE ?
Some codes used for PERLE : MAD-X, B-MAD, OPAL, PLACET2…

CODAL *(home-made code*)*

- developped for damping free ring → multi-turn without reaching steady-state
- developped for small ring → exact transverse integration of the dipoles
- short electron bunches collective effects → short range effects studies
- analytical free particle tracking → fast execution

** courtesy of A.Loulergue*

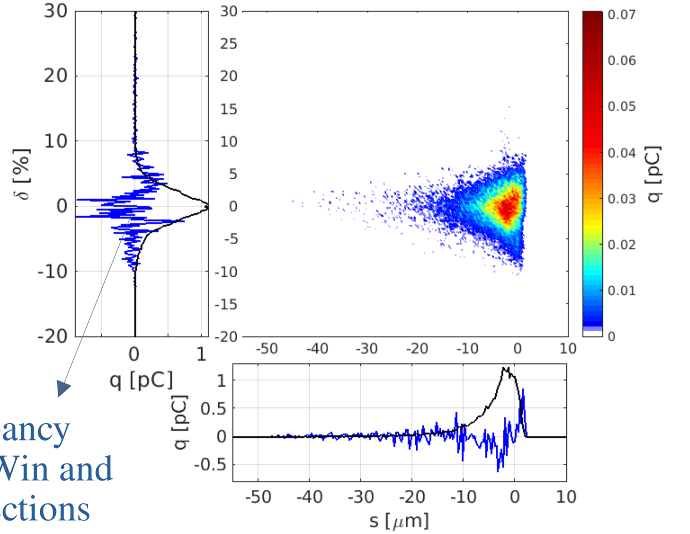
Tracking: CODAL

Several comparisons with other codes have been done, including :

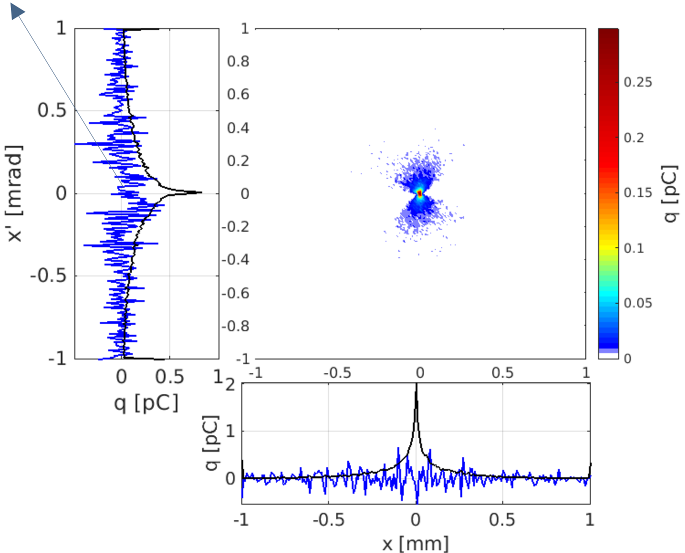
→ free particle tracking for highly off-momentum and off-axis (laser-plasma) beams compared with TraceWin [1]

→ space charge simulation for relativistic electrons benchmarked with ASTRA [2]

→ used as a comparison on LPA studies [3-4]



10 * Discrepancy between TraceWin and CODAL projections



[1] C.Guyot and al. “benchmarking for codal beam dynamics code : laser-plasma accelerator case study”, IPAC’23 proceedings (2023)

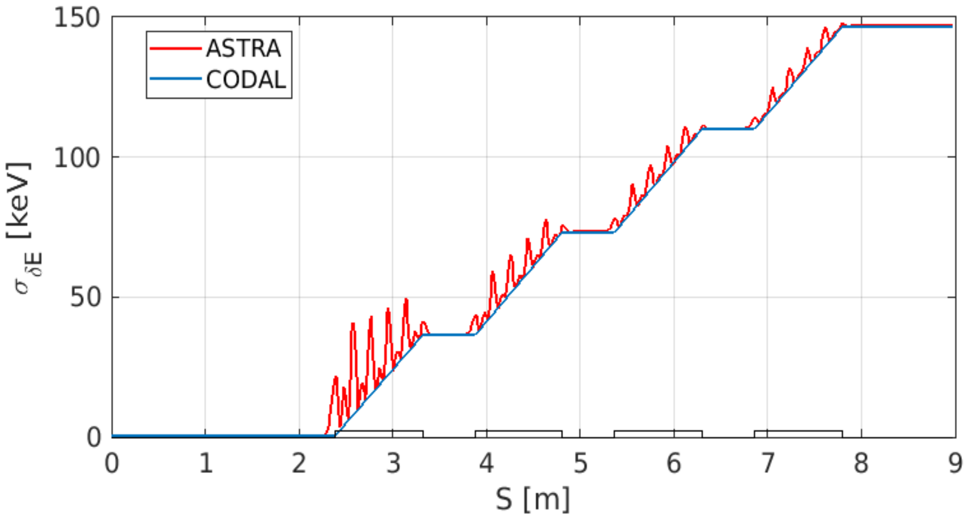
[2] Alexis Gamelin. Collective effects in a transient microbunching regime and ion cloud mitigation in ThomX. PhD Thesis, Université Paris-Saclay, September 2018

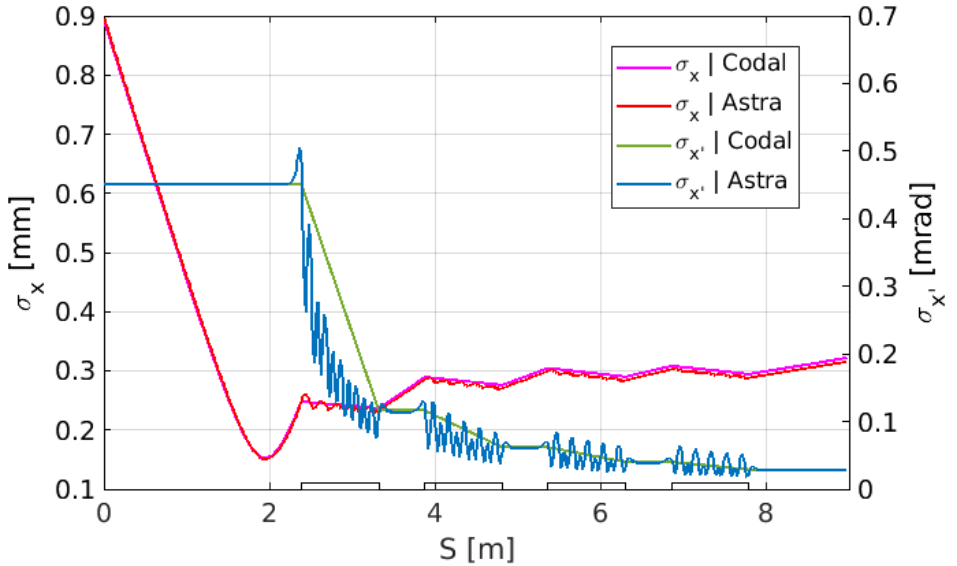
[3] T. André et al., “Control of laser plasma accelerated electrons for light sources”, Nature communications 9 (2018) 10.1038/s41467-018-03776-x

[4] M. Khojoyan et al., “Transport studies of LPA electron beam towards the FEL amplification at COXINEL”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 829 (2016) 10.1016/j.nima.2016.02.030.

Tracking: CODAL adjustements

→ vertical dispersion
→ matching routine modification to adapt for 'common' sections
→ addition of a 6D RF cavity analytic model [5,6,7]





[5] J.Rosenzweig and L.Serafini. *Transverse Particle Motion in Radio-Frequency Linear Accelerator. Phys. Rev. E*, 49:1599-1602, Feb 1994

[6] T.Vinatier, C.Bruni, P.Puzo. *Analytical modeling of longitudinal beam dynamics in an rf-gun : from almost zero to relativistiv veolcities.* Nuclear Instruments and Methods in Physics Reasearch. Section A : Accelerators, Spectrometers, Detectors and Associated Equipement, 953:162914, 2020.

[7] C.Guyot and al. "modeling of standing wave cavities for tracking through multi-pass energy recovery linac", IPAC'23 proceedings (2023)

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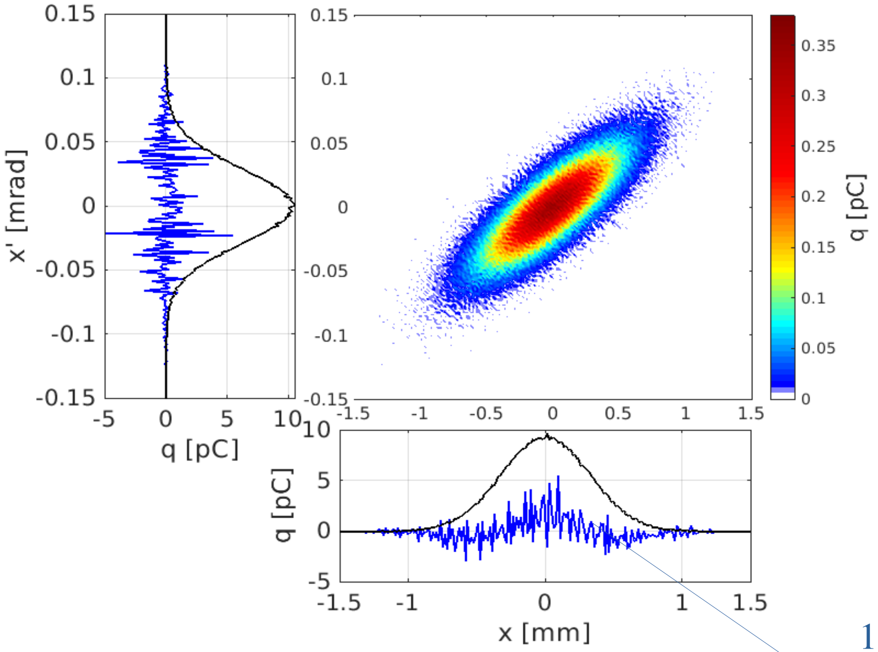

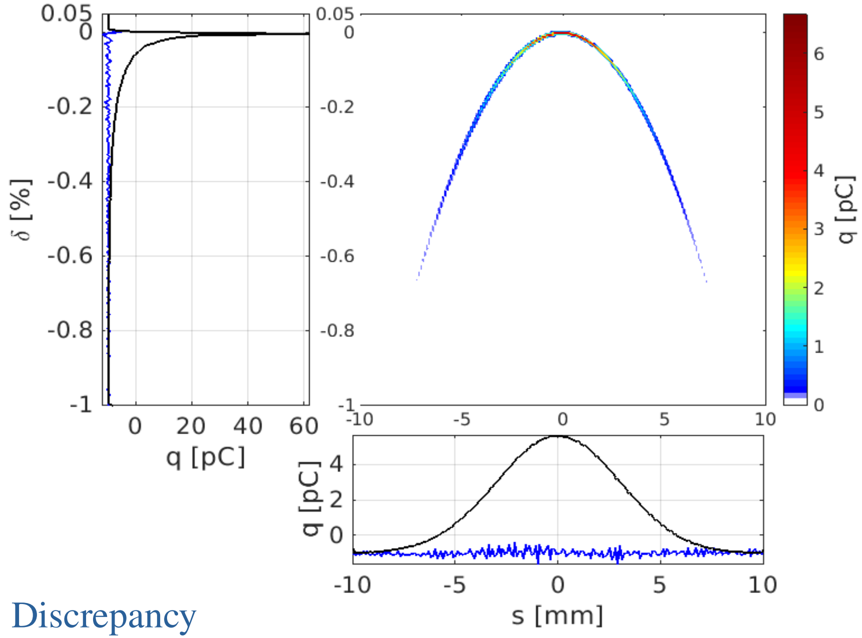

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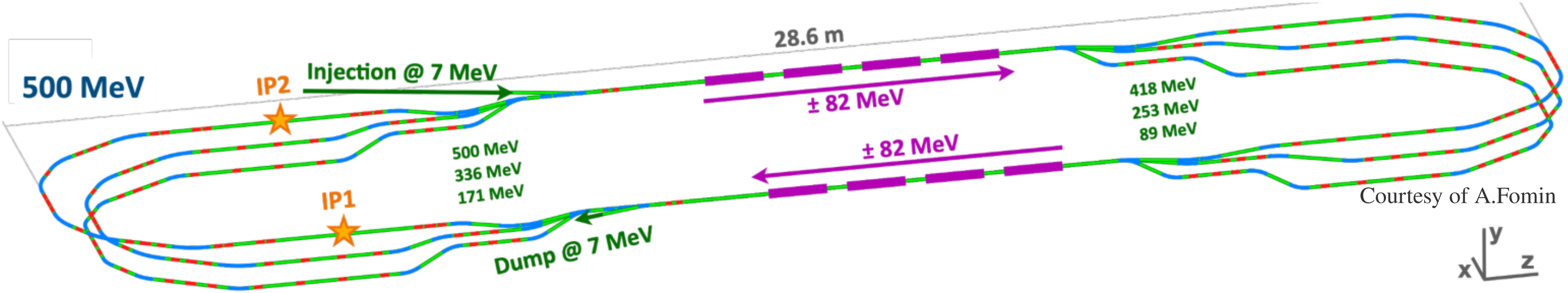
Starting Conditions for the Tracking

→ PERLE '500MeV' version

→ up to the end of the 6th arc = 3 accelerating passes (500MeV)



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Starting Conditions for the Tracking

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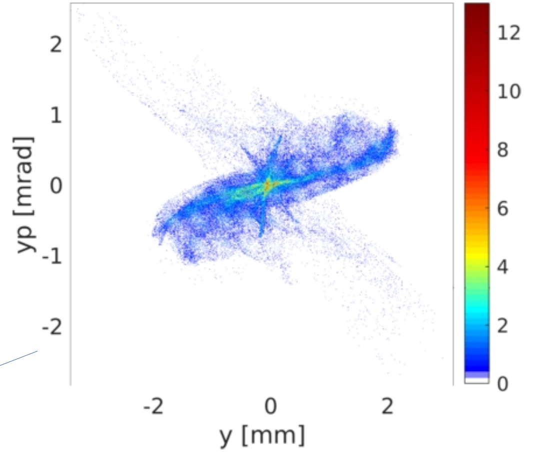
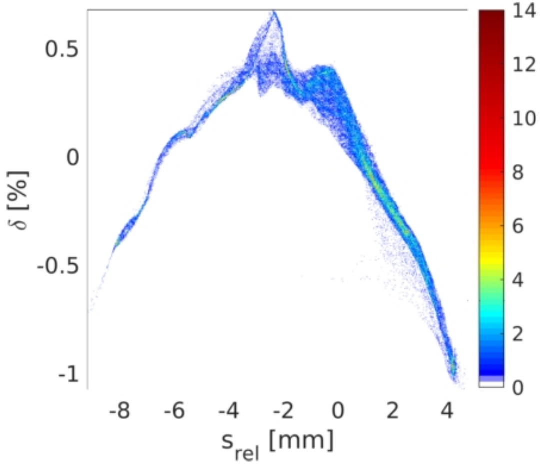
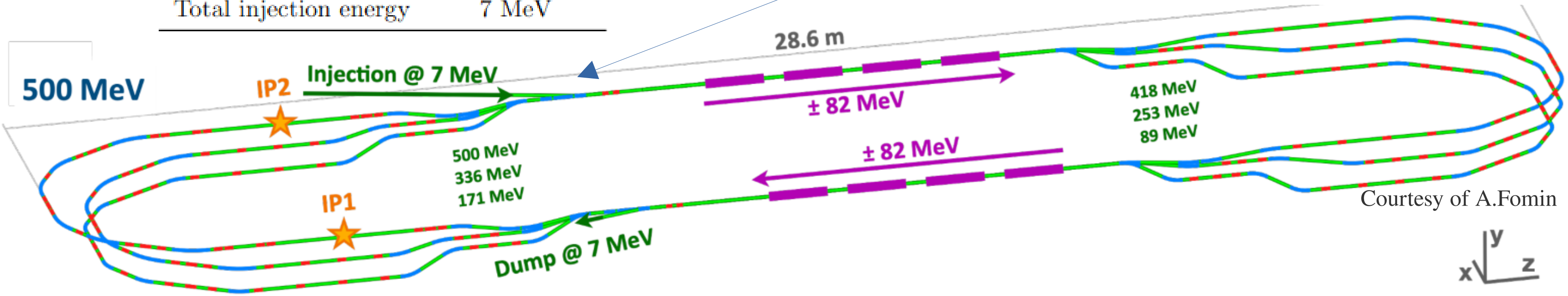
→ approximated post-injector simulated beam distributions





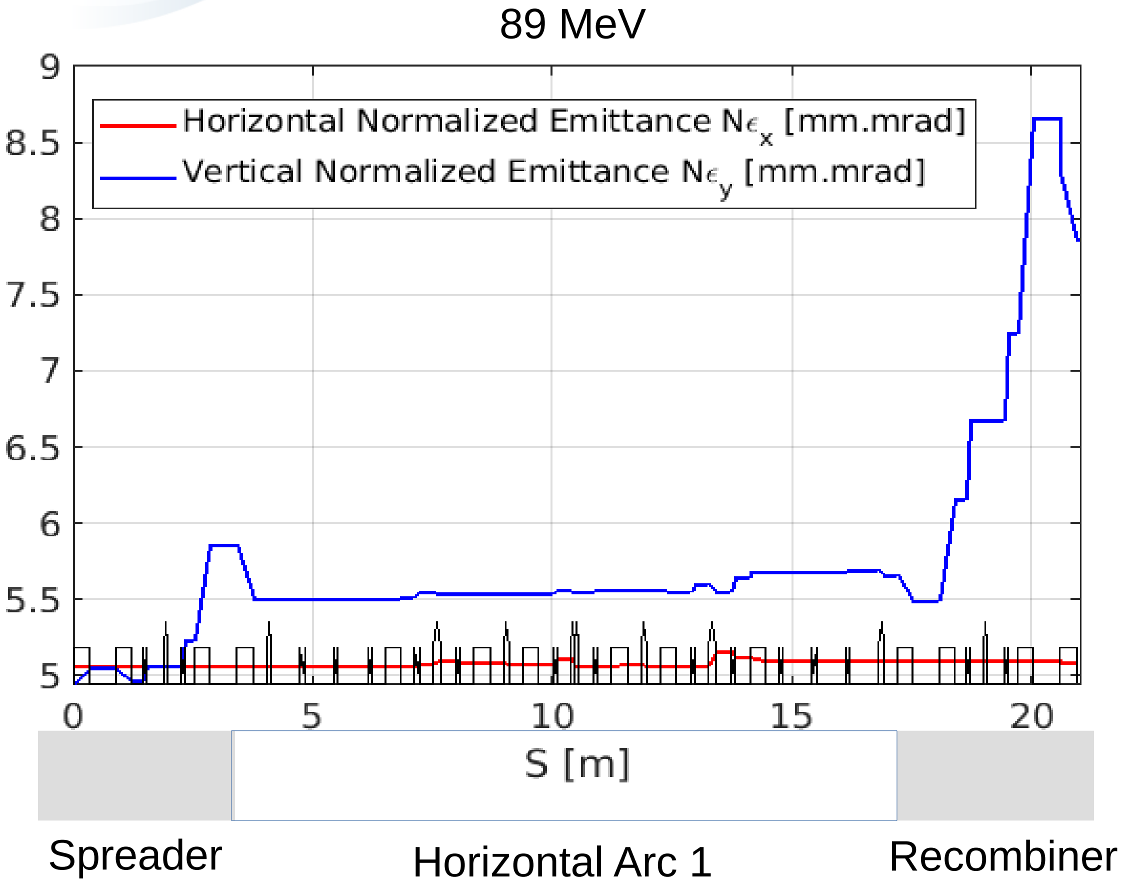
First specifications for the PERLE injector

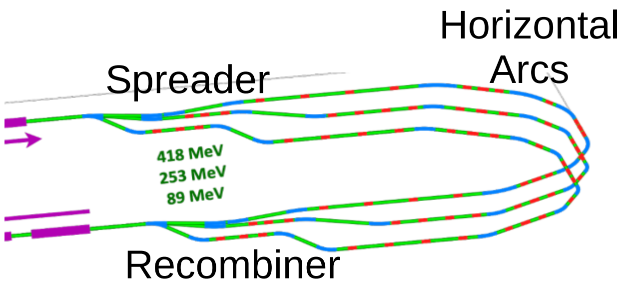
Parameter	Values
Emittance	< 6 mm·mrad
Bunch charge	500 pC
Repetition rate	40.1 MHz
Current	20 mA
RMS bunch length	3 mm
Total injection energy	7 MeV

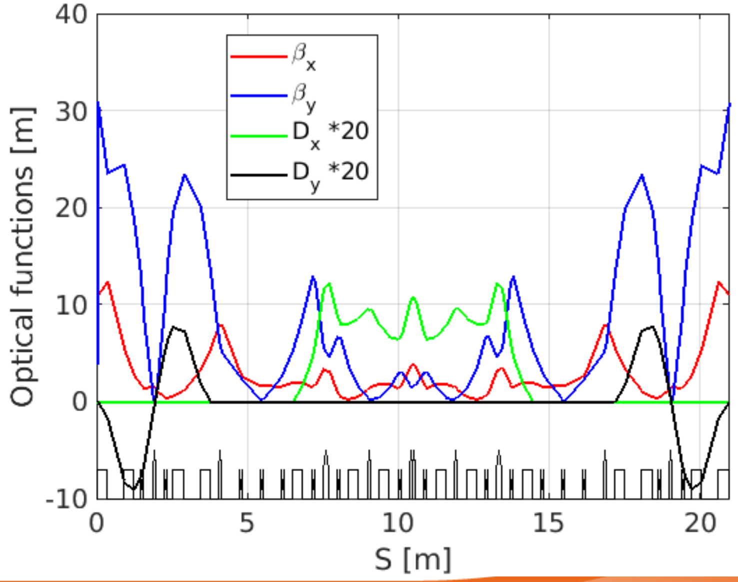


Courtesy of A.Fomin

Chromatic Emittance Growth: Arcs

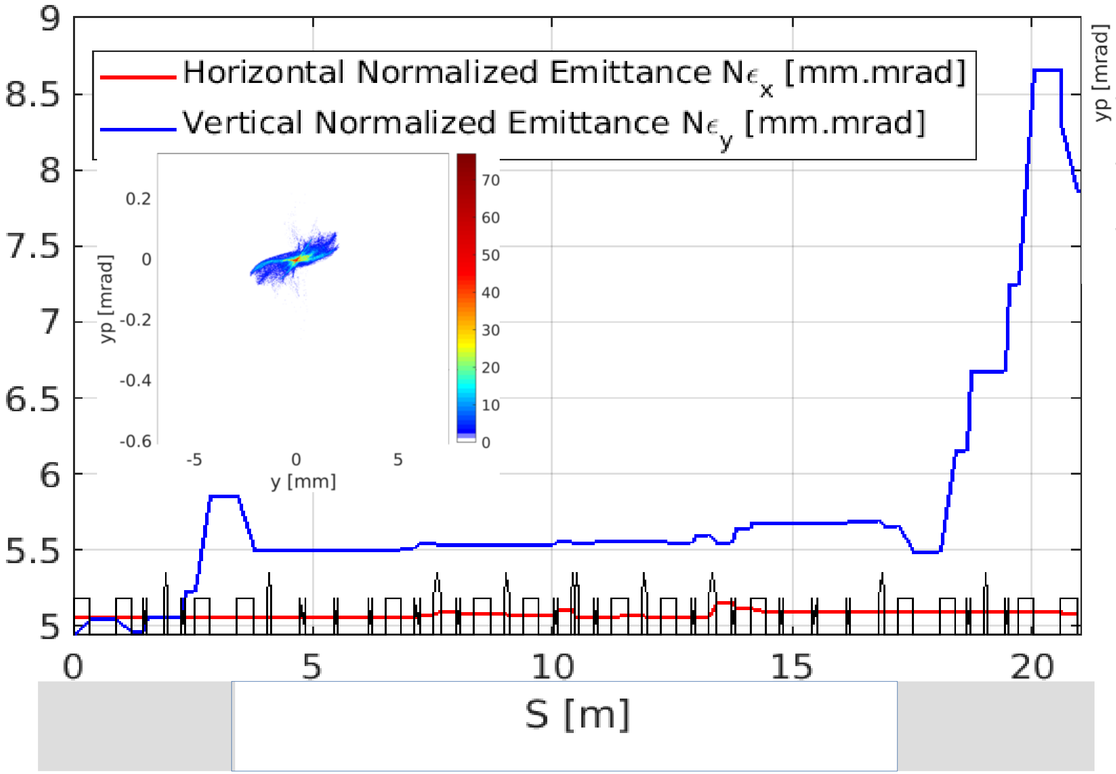




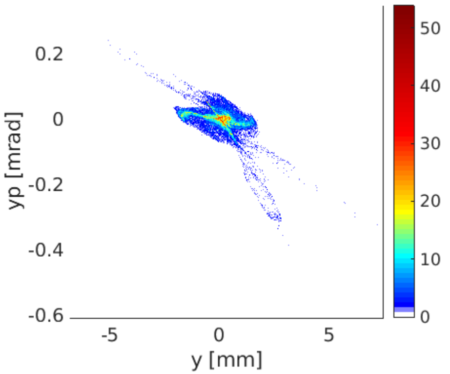


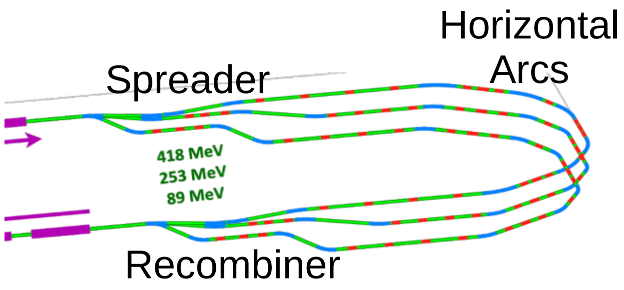
Chromatic Emittance Growth: Arcs

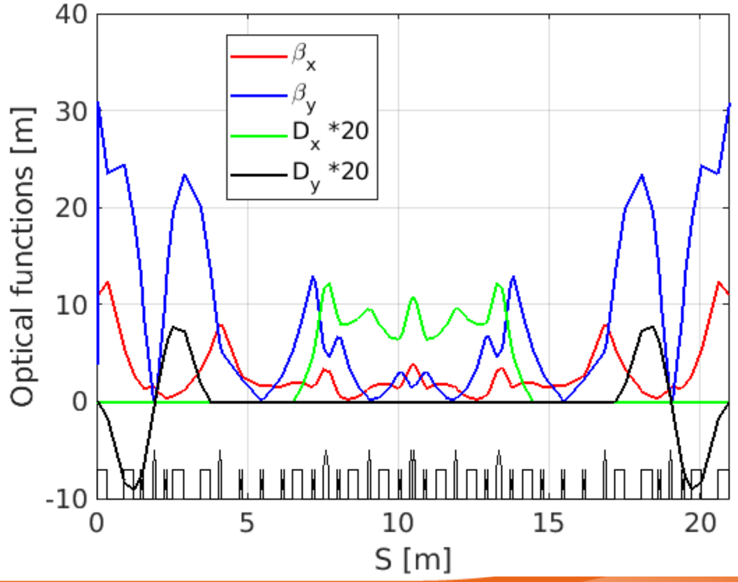
89 MeV



Spreader
Horizontal Arc 1
Recombiner







Need to limit the chromatic effects

→ potential solution: energy spread reduction

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→ energy spread dynamics mainly dominated by the RF cavities

$$\Delta E = \pi f e \beta_L c E_m \left(\cos(\phi) L - \frac{1}{k} \cos(kL + \phi) \sin(kL)\right) \Delta s$$

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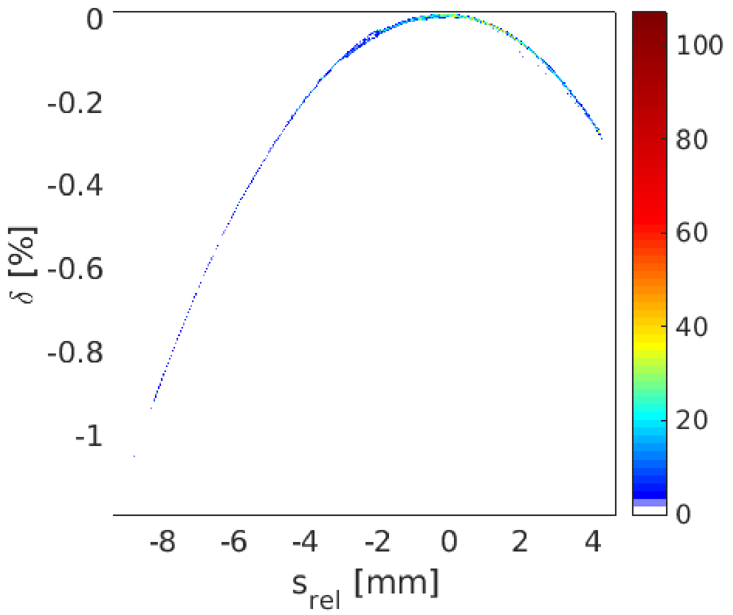

Chromatic Emittance Growth: RF Cavity Dynamics

Need to limit the chromatic effects
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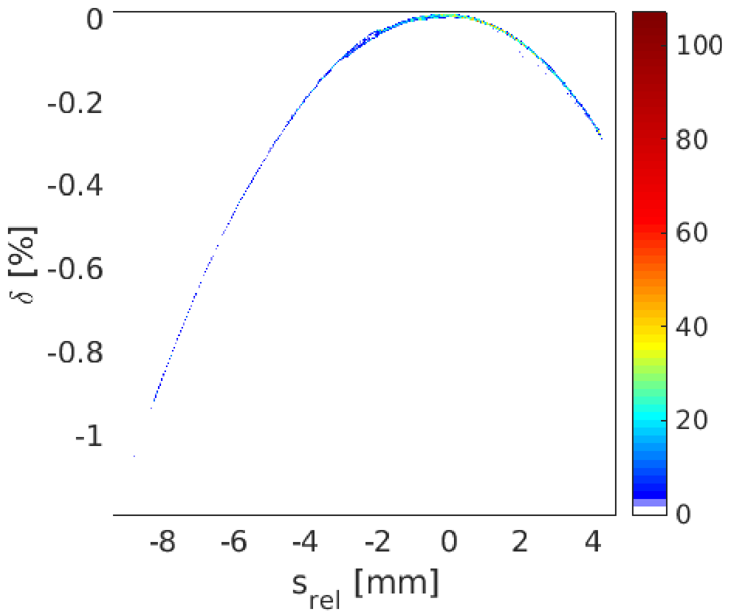

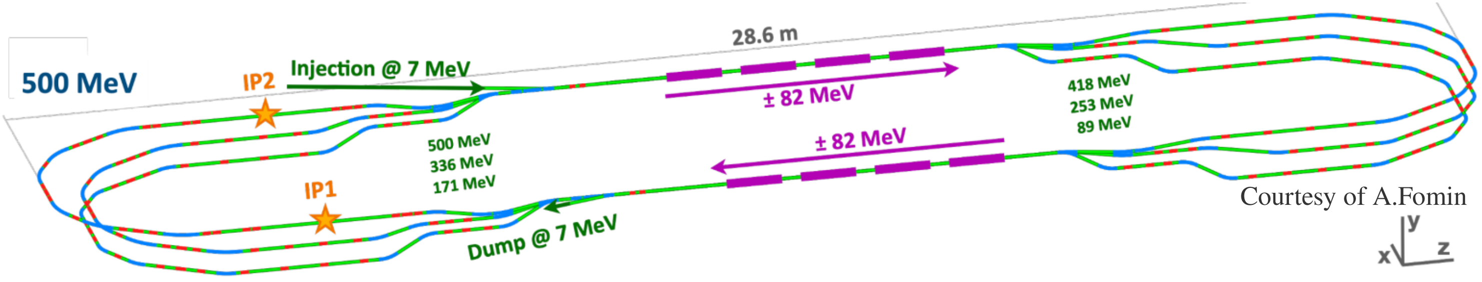

Courtesy of A.Fomin

Cumulated effect : up to 3 passes → up to 500MeV

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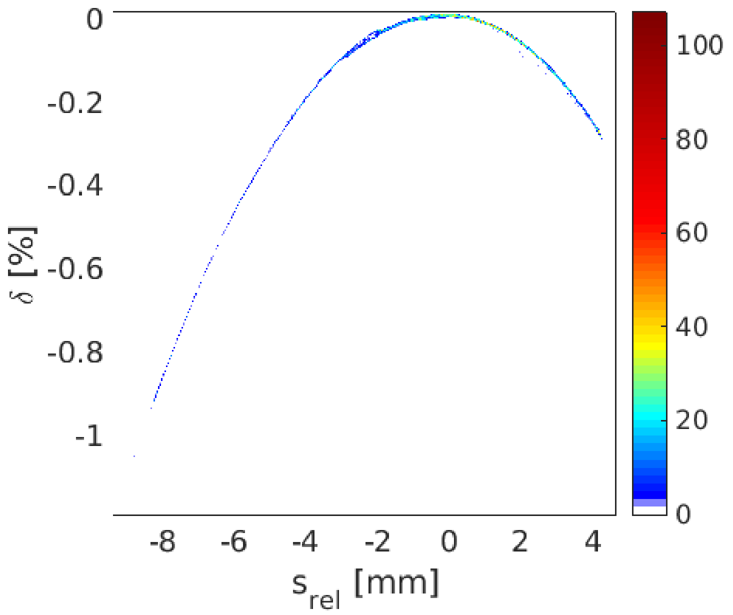

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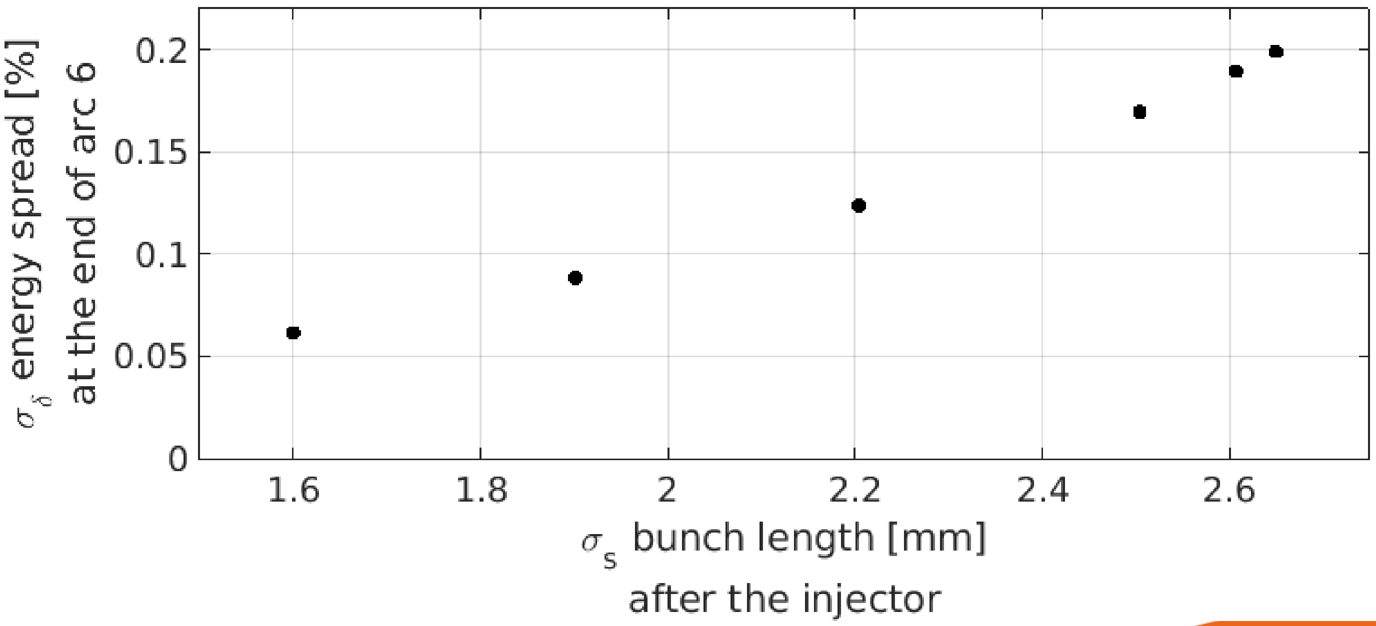

Emittance Chromatic Growth: Bunch Length

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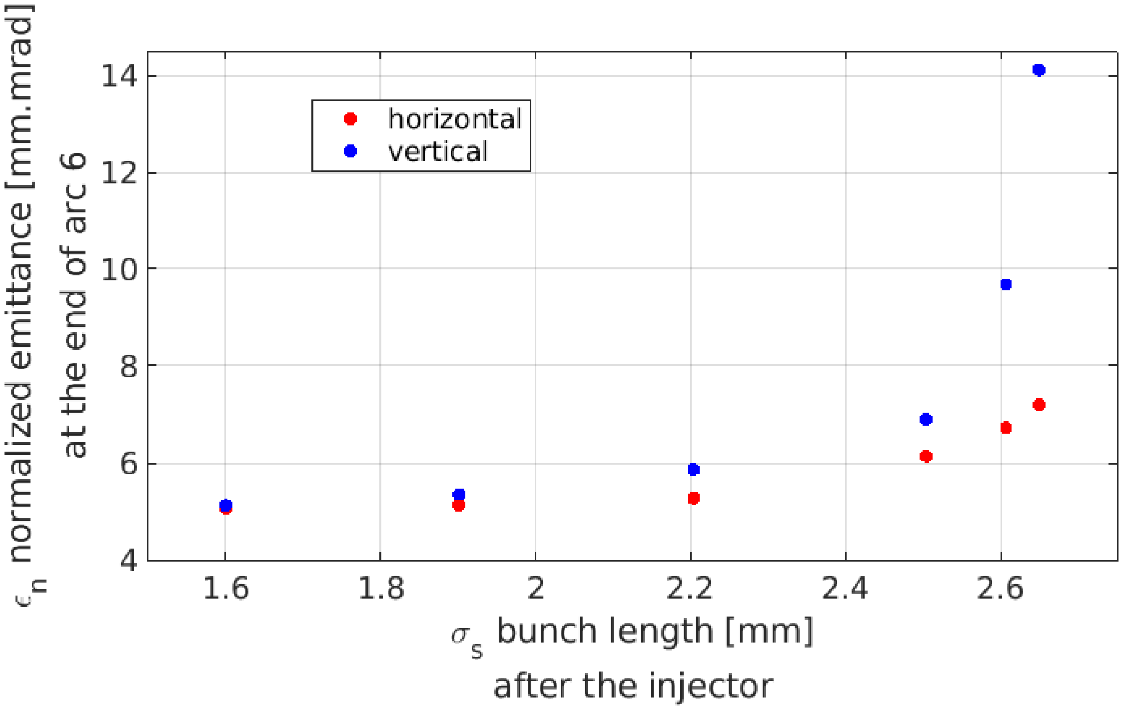

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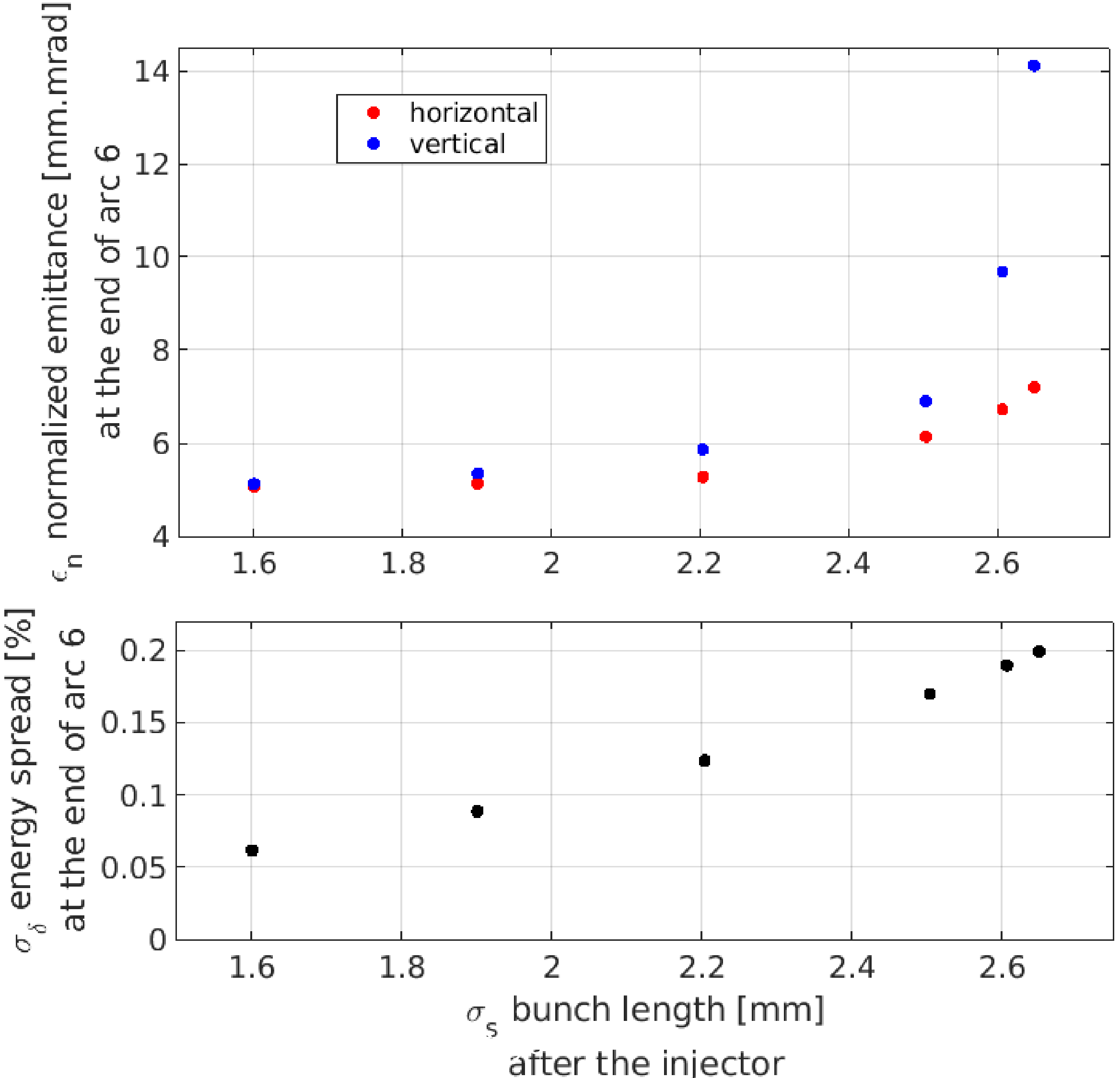

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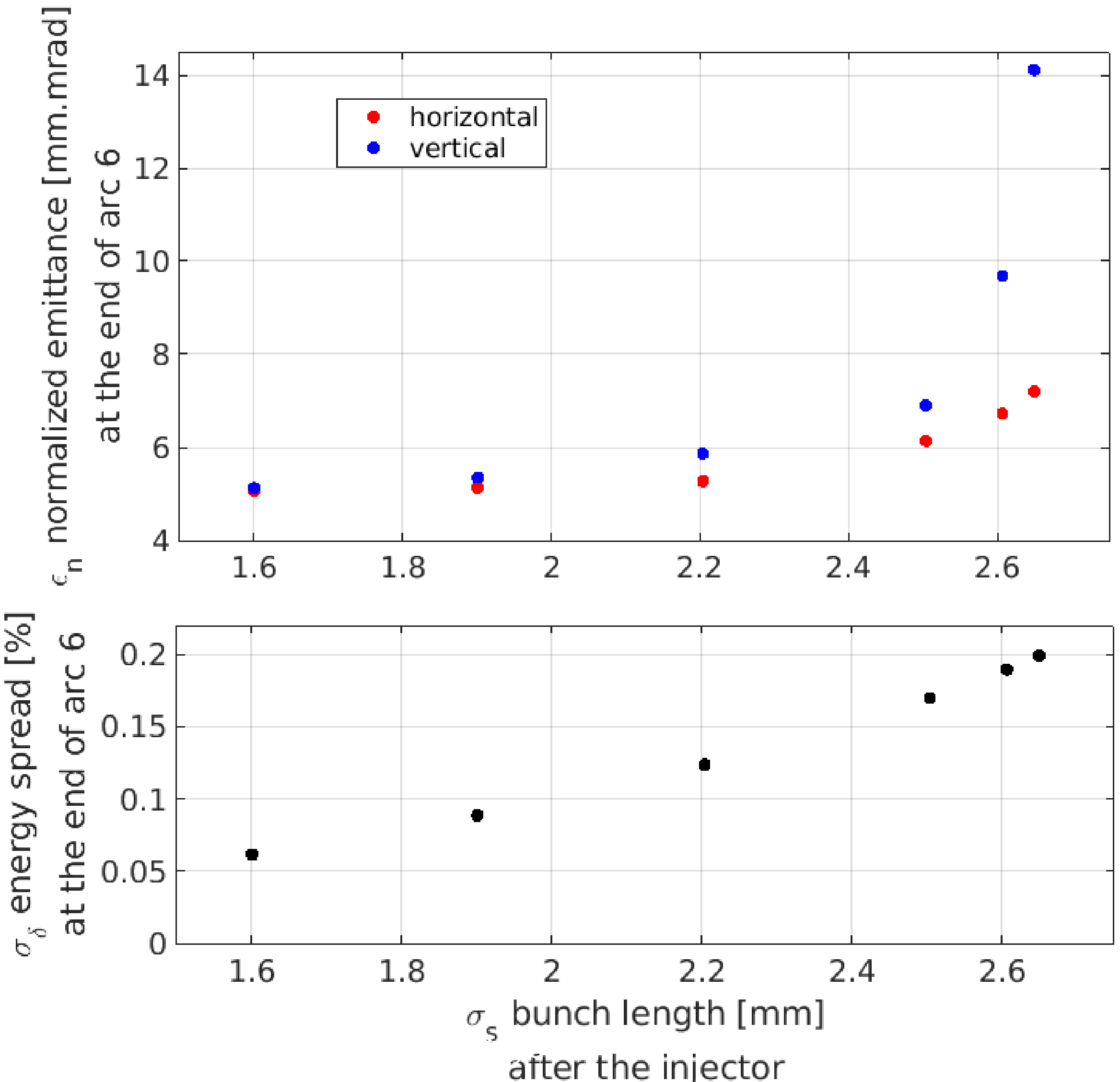


Potential Favorable option
→ Bunch length closer to 2mm
→ ~ 0.1 % energy spread

Chromatic Emittance Growth: Other Parameters ?

Need to limit the chromatic effects

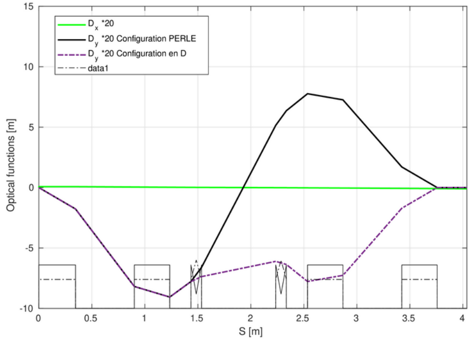
→ potential solution: energy spread **reduction**

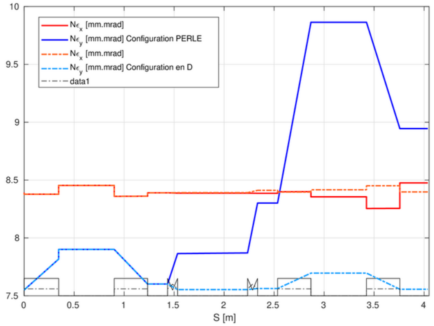
→ energy spread dynamics mainly dominated by the RF cavities

$$\Delta E = \pi f e \beta_L c E_m \left(\cos(\phi) L - \frac{1}{k} \cos(kL + \phi) \sin(kL)\right) \Delta_s$$

→ potential solution: energy spread **'acceptance / sensitivity'**

→ geometries more or less sensitive to the energy spread



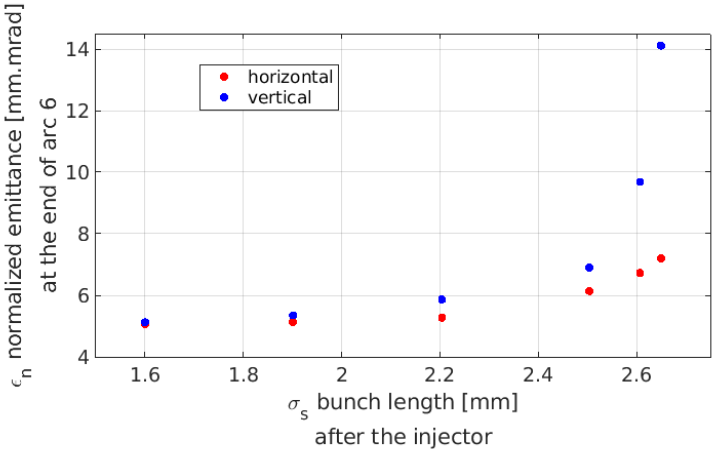


→ potential solution: **correction**

→ higher order effect correction (ex : sextupoles)

Bunch length: Limitations & Compromise

However :
→depth gun / injector studies regarding the feasibility



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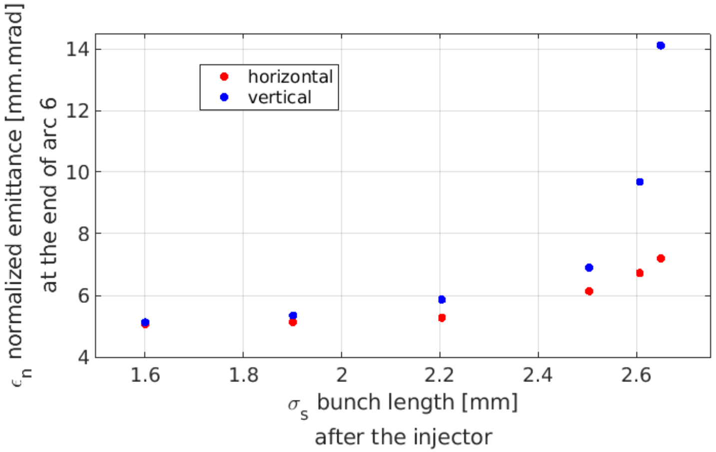

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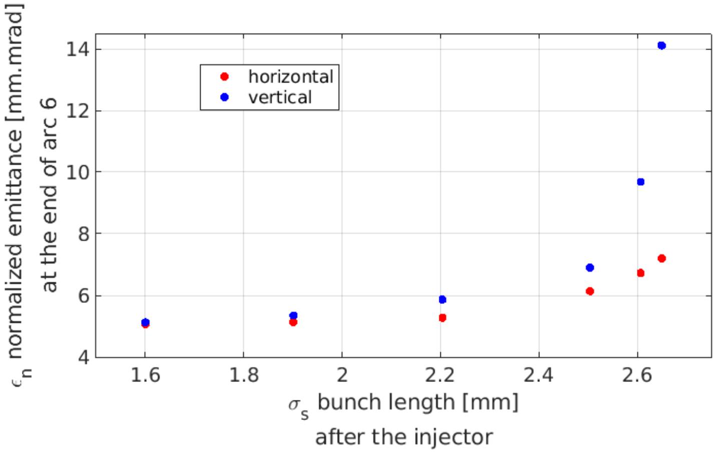

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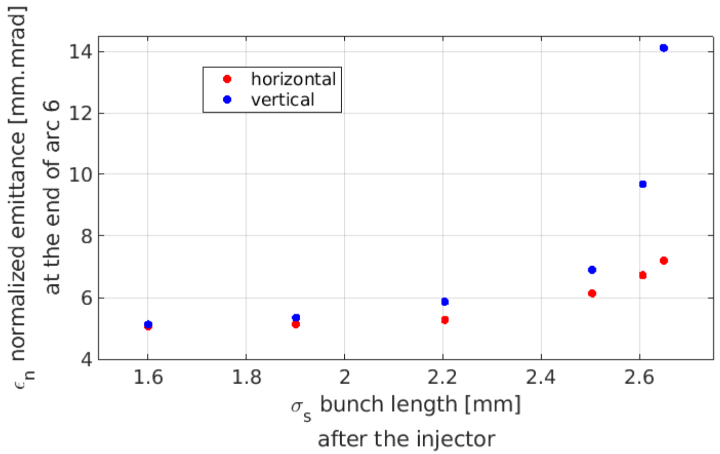

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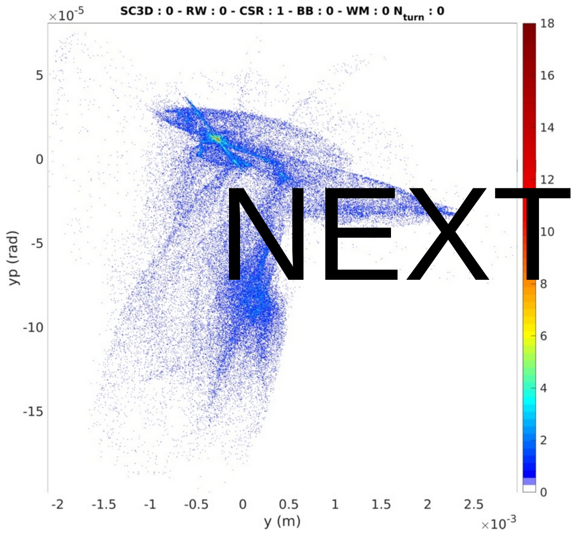

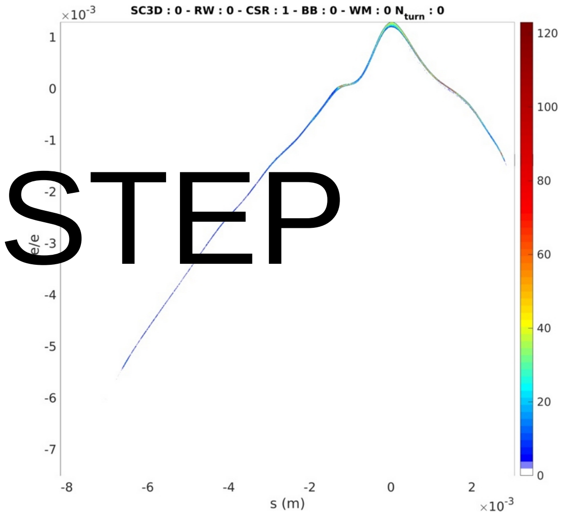

NEXT STEP

Thank you for your attention

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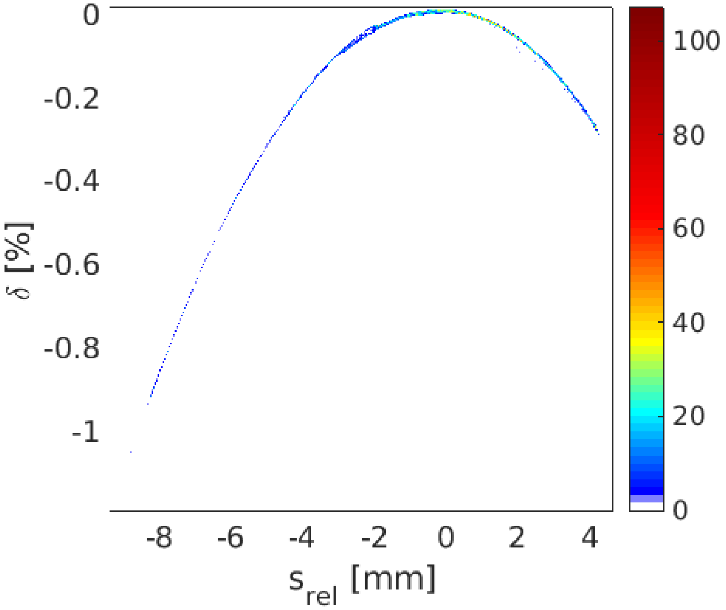

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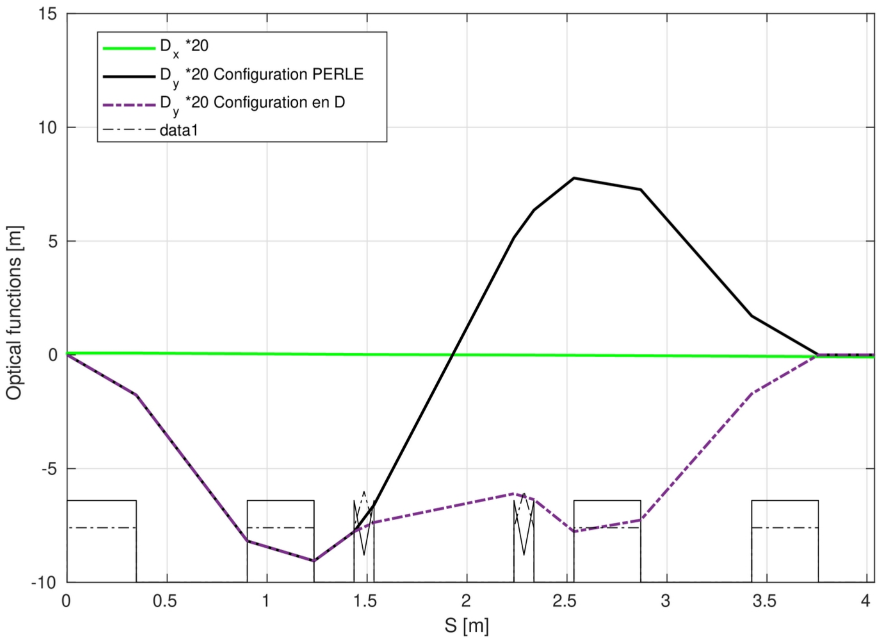

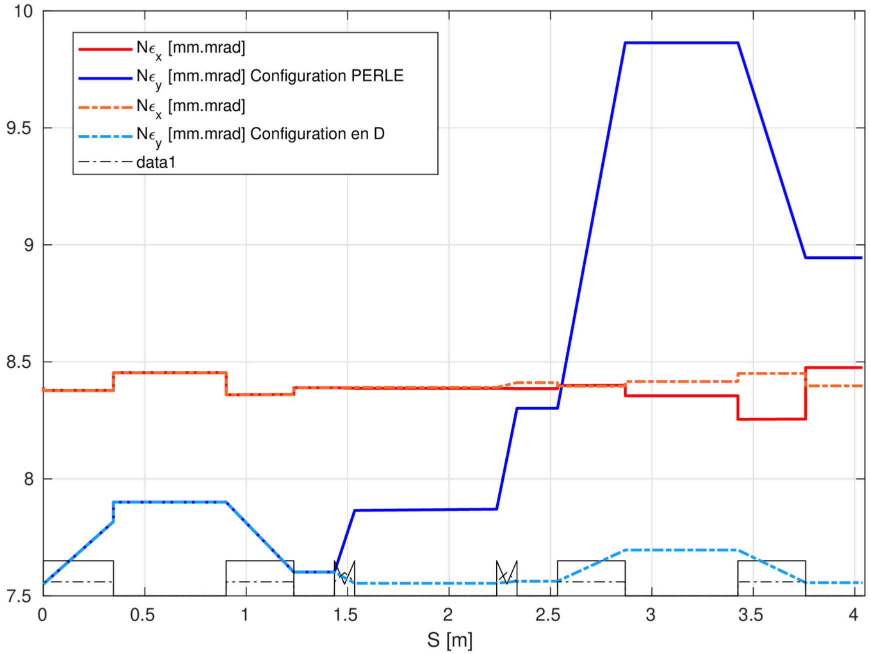

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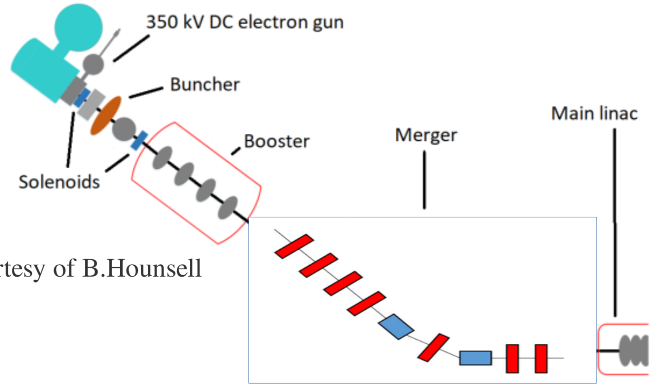
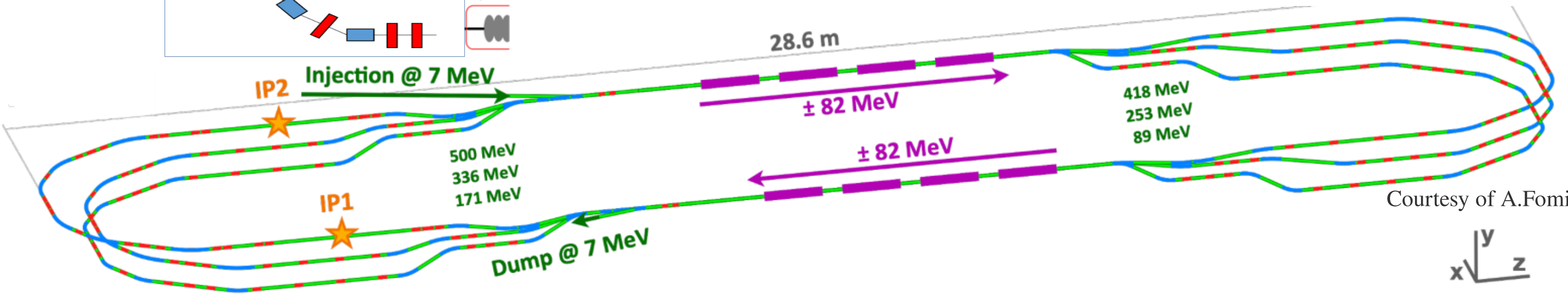


Courtesy of B.Hounsell



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