Transport of LWFA electron beam towards the FEL amplification at COXINEL

- Introduction
- Comparison of two different tracking codes for the COXINEL line
- Influence of the collective effects on the beam performance
- Summary and outlook

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Synchrotron SOLEIL
EAAC workshop, ELBA Island
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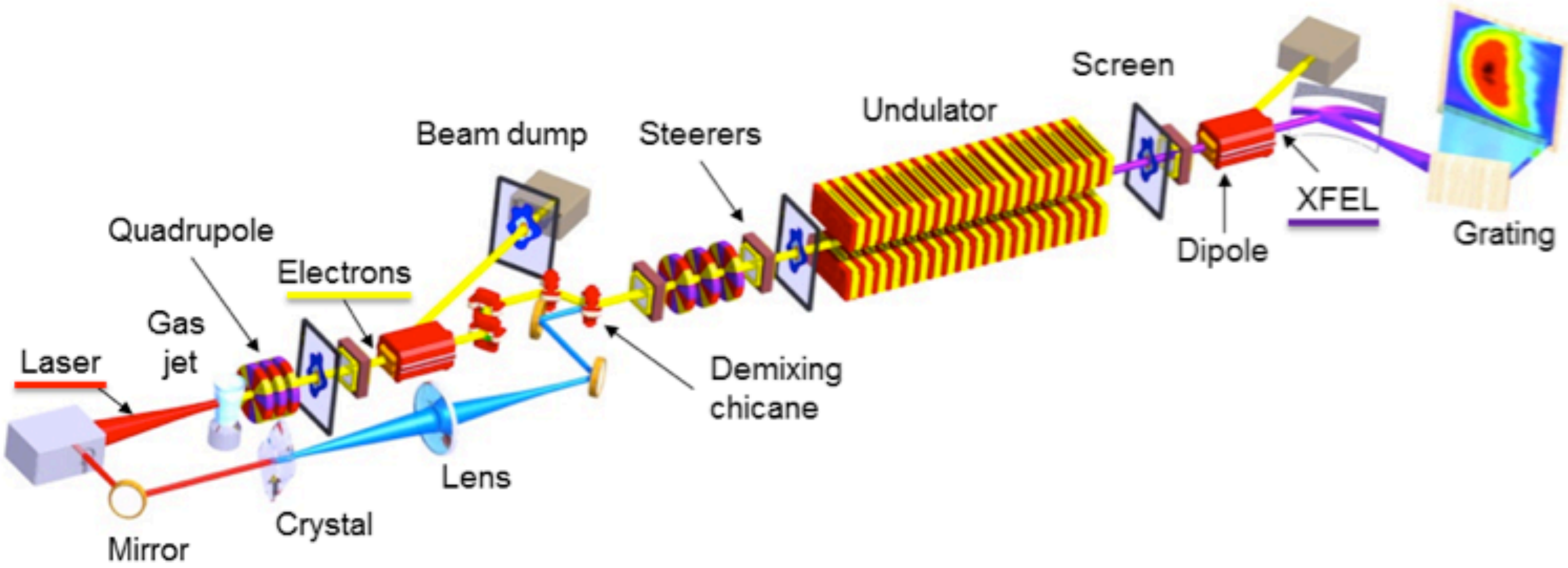
Motivation

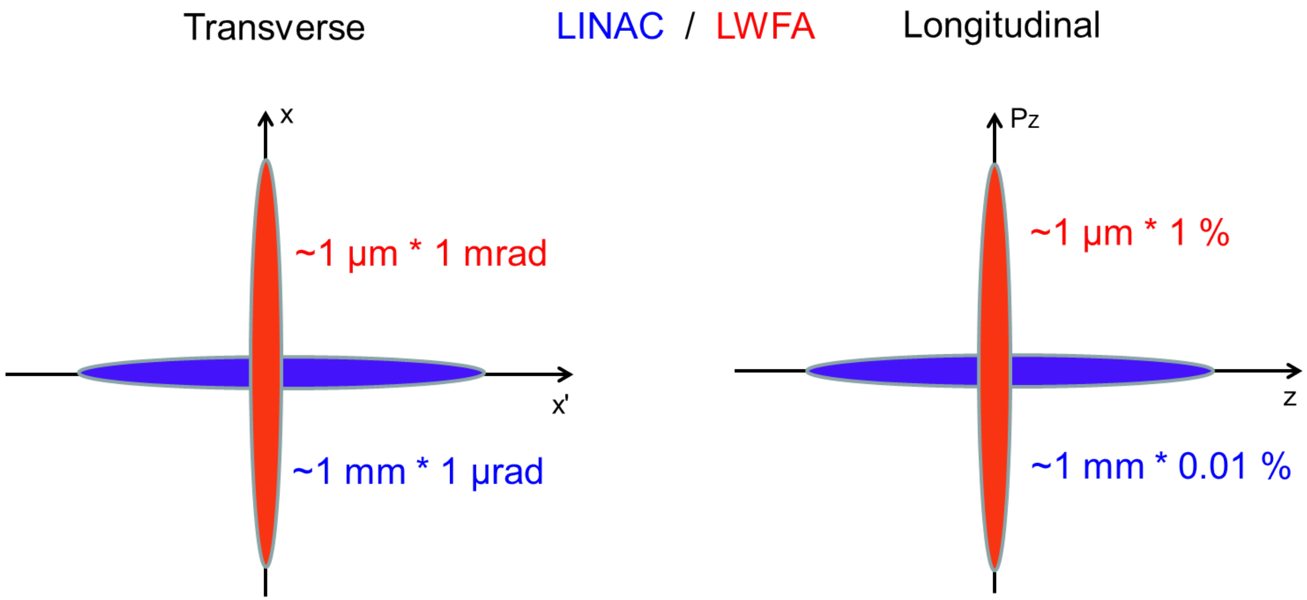
COXINEL[1]:COherent X-ray source INferred from Electrons accelerated by Laser



- COXINEL project aims at demonstrating a Free Electron Laser (FEL) amplification from a Laser Wakefield Acceleration[2] (LWFA)
- 60 TW laser provided by the Laboratoire d'optique appliquée (LOA)
- Beam transfer line under preperation at COXINEL

1. M.E. Couprie at al., Proc. of FEL 2014.
2. T. Tajima and J.M. Dawson, PRL, vol. 43, No. 4 (1979).

LWFA electron beams vs. conventional beams



LWFA beams are orthogonal to the conventional beams !

LWFA beam settings for COXINEL studies

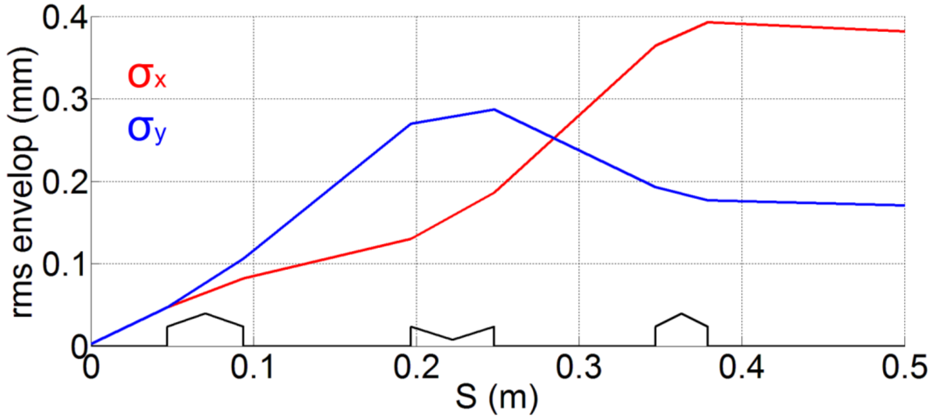
Charge: 34 pC
bunch length(rms): 1 µm
peak current: 4 kA

energy: 180 MeV
energy spread (rms): 1.8 MeV (1 %)
optimistic !

divergence (rms): 1 mrad
normalized transverse emittance: 1 mm mrad
usually an order of magnitude smaller !

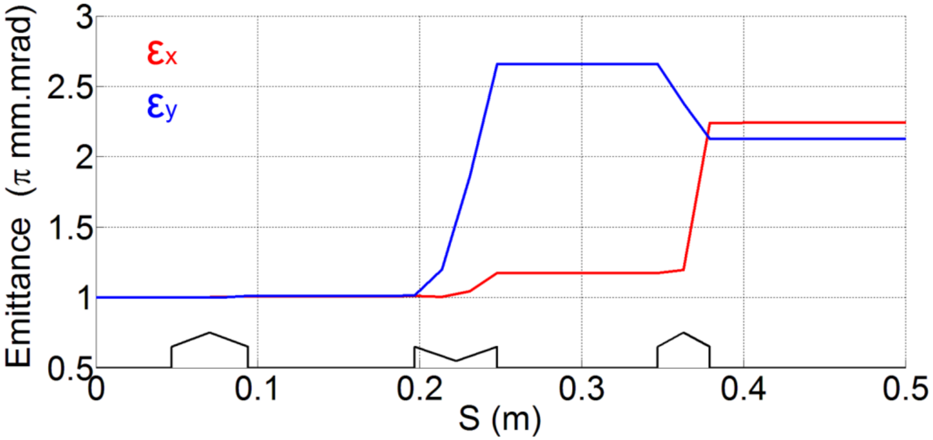
6D Gaussian beam distribution without any correlations assumed for simulations.

Capturing LWFA beams



Rapid development of transverse position – energy correlation inside the bunch along the drift

The LWFA beam has to be refocused with a strong and short quadrupoles located as close as possible to the source



LWFA beam properties in the first quadrupole triplet at COXINEL. Influence of collective effects is neglected.

Strong contribution of chromatic emittance on the total emittance in presence of magnetic fields !

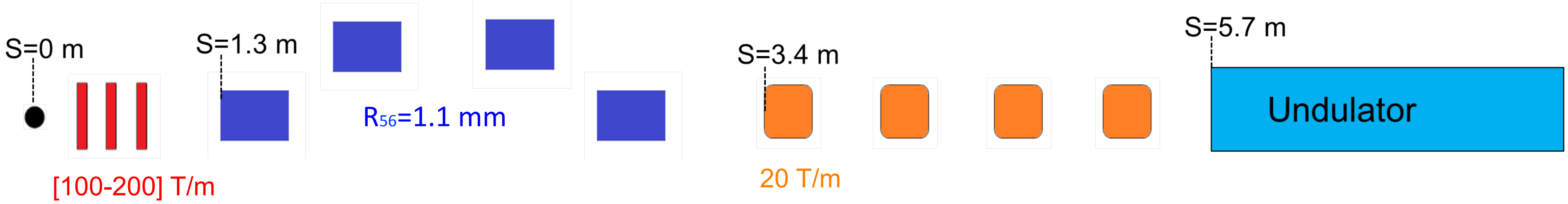
$$\varepsilon_{chrom} \sim \sigma_E \sigma_{x'}^2, \qquad \gamma\varepsilon_{total} = \sqrt{\gamma^2\varepsilon_0^2 + \gamma^2\varepsilon_{chrom}^2}$$

K. Flöttmann, PRST-AB 6, 034202 (2003).

P. Antici et al., J. Appl. Phys. 112, 044902 (2012).

M. Migliorati et al., PTST-AB 16, 011302 (2013).

COXINEL setup



- ➢ Electron beam transport from the source to the undulator for an FEL
- A permanent magnet quadrupole triplet to:

  refocus the LWFA beam (to suppress the beam divergence)

- A decompression chicane[1,2] to:

a. decrease the slice energy spread

b. make bunch longer to ease the FEL process (effective interaction of beam and FEL wave)

- Additional 4 electromagnet quadrupoles for dedicated beam matching inside the undulator[3]

(synchronization of slice e-beam waist with FEL wave propagation by adjusting the chicane strength)

Talk by A. Loulergue on Thursday.

1. A. Maier et al., PR X 2, 031019 (2012).

2. M.E. Couprie et al., J. Physics B: At., Mol., Opt. Phys. 47 234001 (2014).

3. A. Loulergue et al., New J. Phys. 17, 023028 (2015).

Tools for electron beam transport

Goal

- ➢ Study the beam dynamics by comparing two different tracking softwares
- ➢ Study the influence of collective effects on the beam performance

Home-made code

- ❑ Beam matching inside the undulator using BETA[1] code
- ❑ Tracking based on symplectic mapping through each magnetic element (assuming hard edge field profile)
- ❑ Includes collective effects such as 3D space charge (SC), coherent synchrotron radiation (CSR[2]) and Wakefields
- ❑ Estimated calculation time including space charge (1Mp): ~ 10 minutes

Astra[3] (<u>A</u> <u>S</u>pace charge <u>TR</u>acking <u>A</u>lgorithm)

- ❑ Tracking based on 4th order Runge-Kutta integration to solve the equation of motion through the magnetic fields
- ❑ Well established algorithm for the space charge field calculation
- ❑ Estimated calculation time including space charge (1Mp): ~ 3 hours

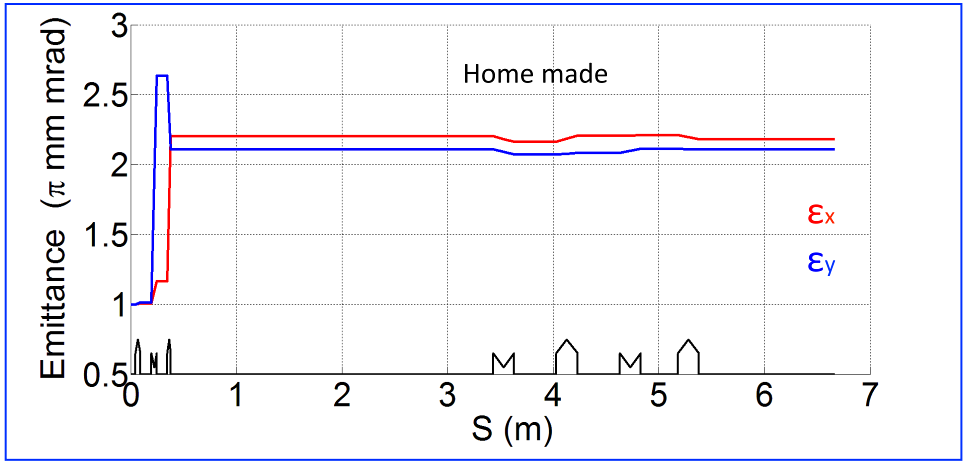
1. J. Payet, Beta Code, CEA, SACLAY.

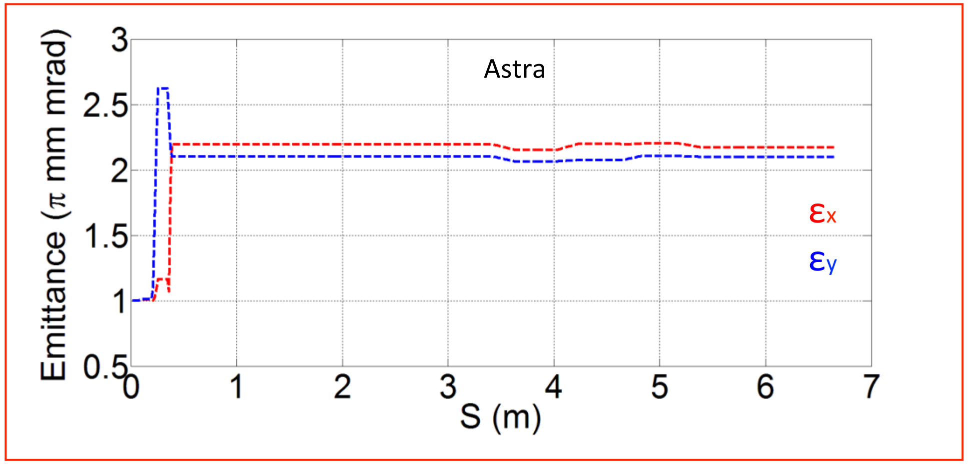
2. E. Saldin et al., NIM A 398, 1997.

3. K. Flöttmann, ASTRA, http://www.desy.de/mpyflo

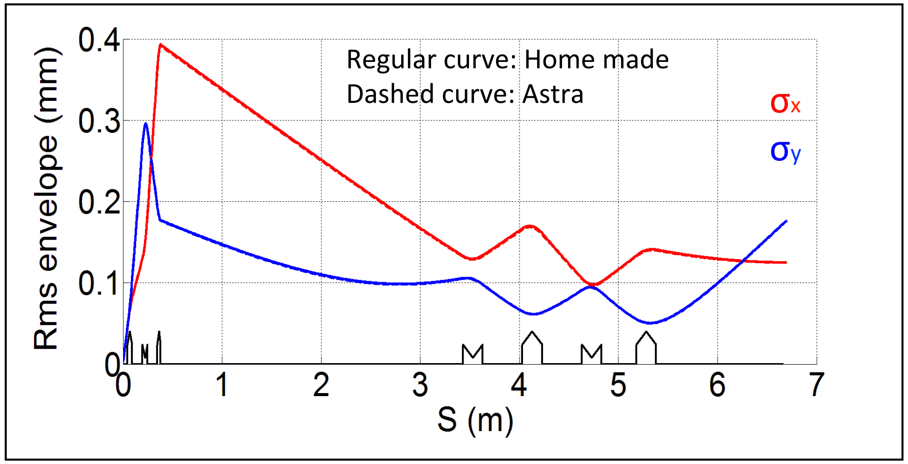
Beam properties without space charge and without chicane

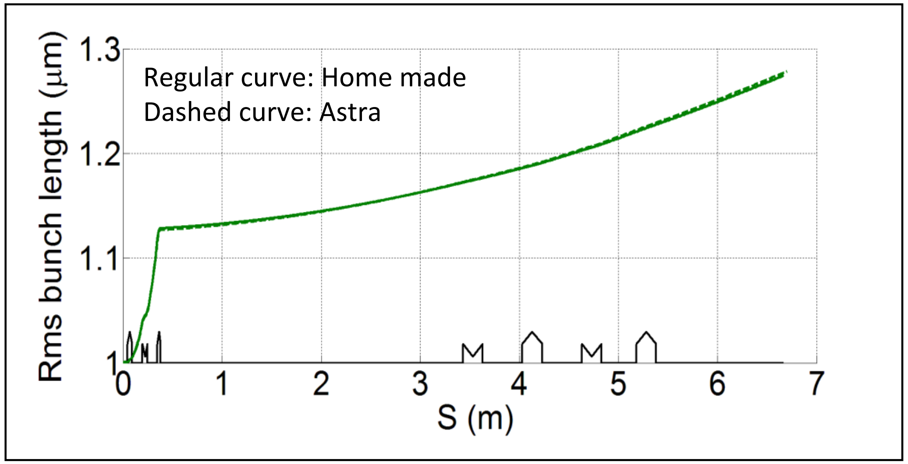
Normalized rms emittance from two codes





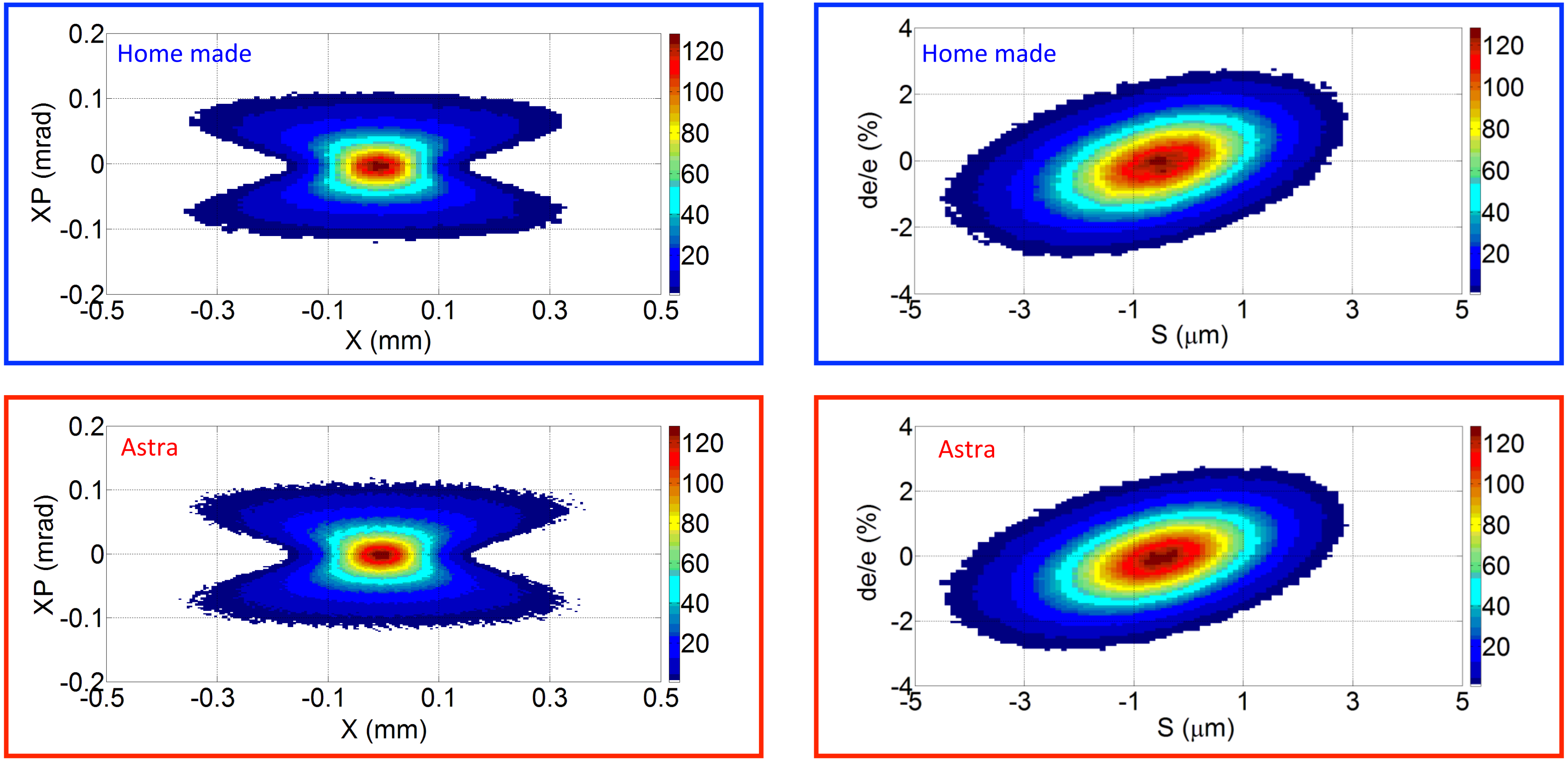
Beam envelope and bunch length from two codes





Evolution of beam properties along the COXINEL line from the electron source up to the undulator center.

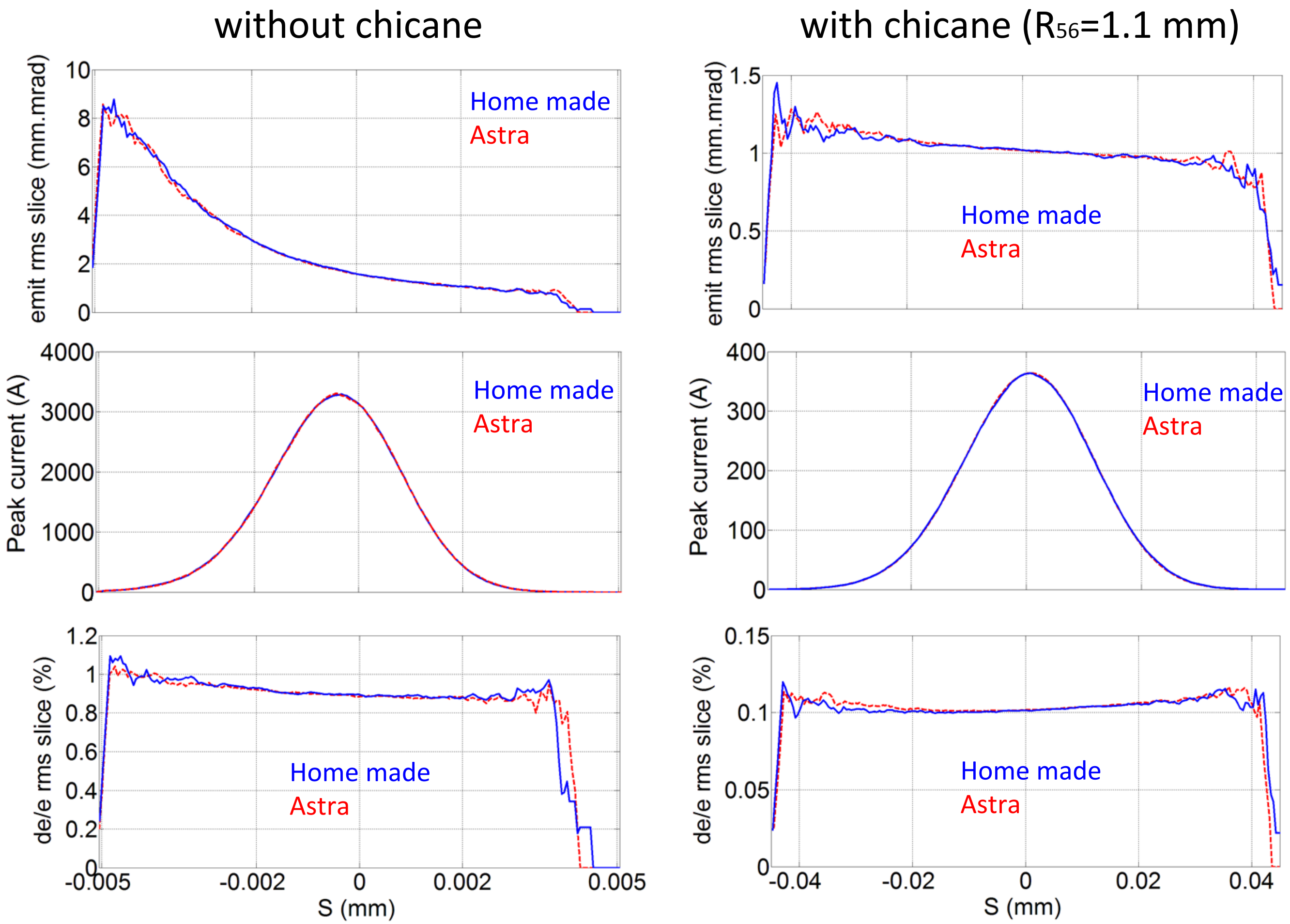
Electron beam phase space at the undulator center



Beam distribution in transverse and longitudinal phase spaces at s=6.7 m.

Consistent results from both codes !

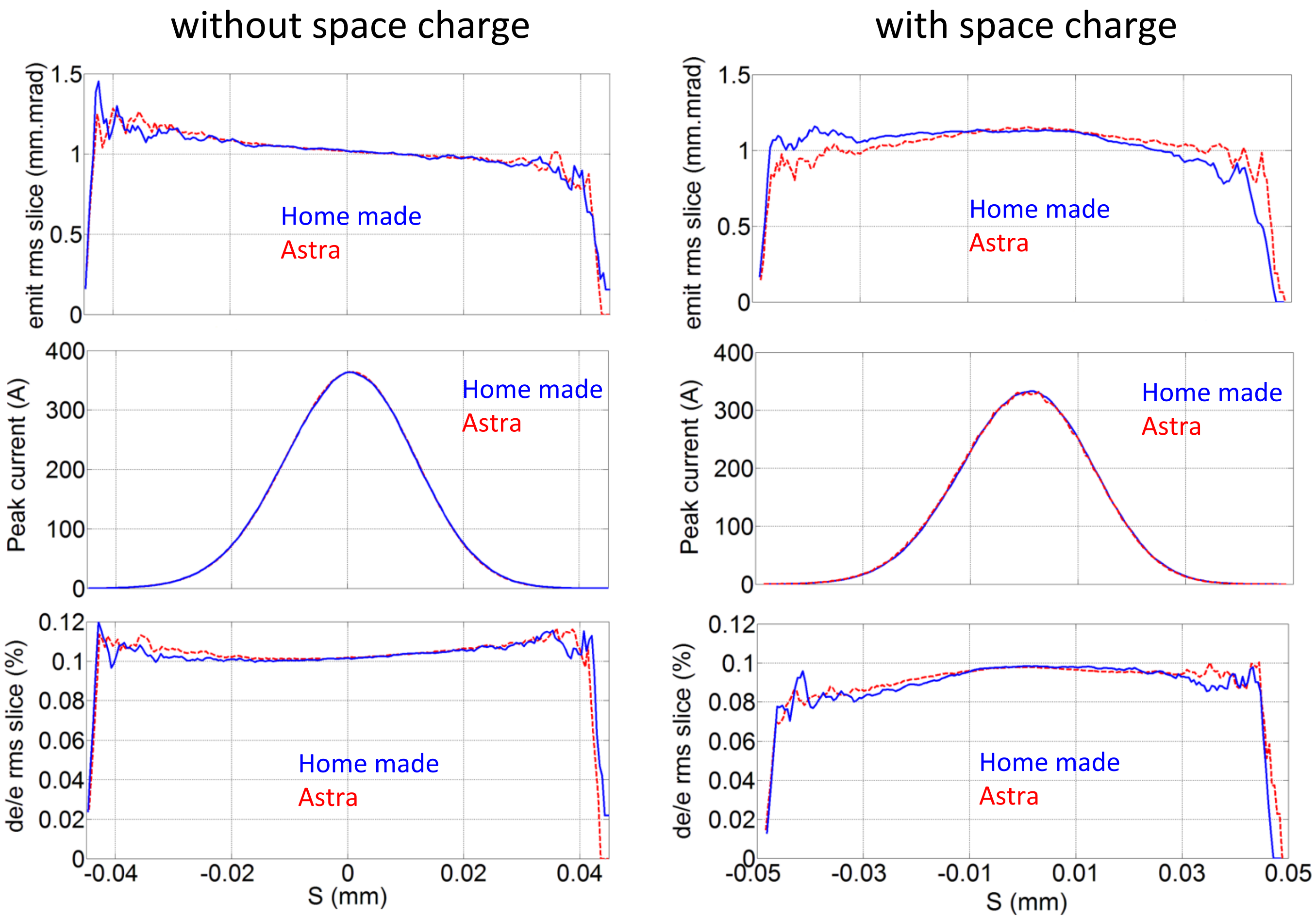
Slice beam output without space charge



- ✓ Demixed slice emittance after the chicane
- ✓ ~ 10 times less peak current due to decompression
- ✓ ~ 10 times less slice energy spread
- ✓ Reproducible results from both codes !

Slice beam properties at s=6.7m (undulator center). Influence of SC is neglected.

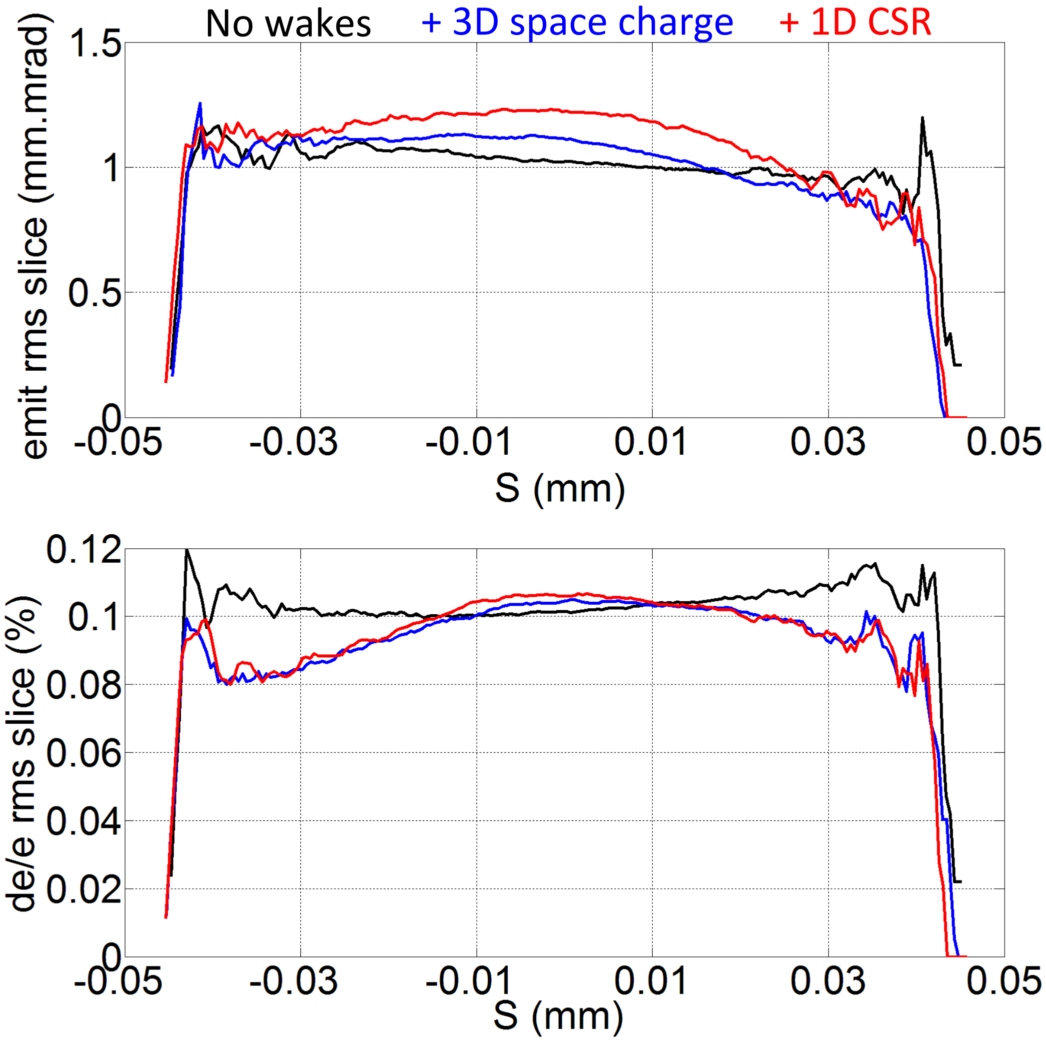
Slice beam output with chicane



- ✓ Increased emittance (~ 10 %) in the central part with SC
- ✓ Additional bunch lengthening due to space charge
- ✓ Consistent results from two codes

Slice beam properties at undulator center. 3D SC calculation algorithm is applied.
Chicane strength fixed to 1.1 mm.

Influence of collective effects on beam performance



Slice properties at undulator center for nominal COXINEL beam parameters.

180 MeV, 1 mm mrad, 4kA, 1 mrad, 1 %

- ✓ ~ 10 % slice emittance increase (in central part) due to space charge effects
- ✓ ~ 25 % slice emittance increase (in central part) including space charge and CSR
- ✓ ~ 5 % increase of slice energy spread (in central part) including SC and CSR

Summary

- Overall reproducible beam output results from two different tracking codes
- Chicane decompression reduces the space charge influence on the beam performance
- About 10 % slice emittance growth for the nominal COXINEL beam parameters due to space charge contribution, additional 15 % increase because of CSR
- Sensitivity studies to the initial beam parameters has been started
- Start to end (PIC+home made+FEL+Optics) simulation for the Coxinel setup
- Experimental test under preparation

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Thanks to:

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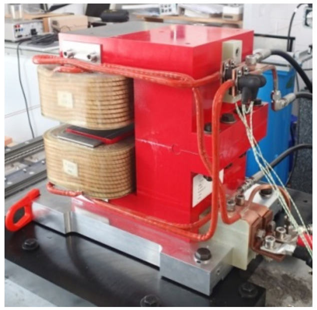
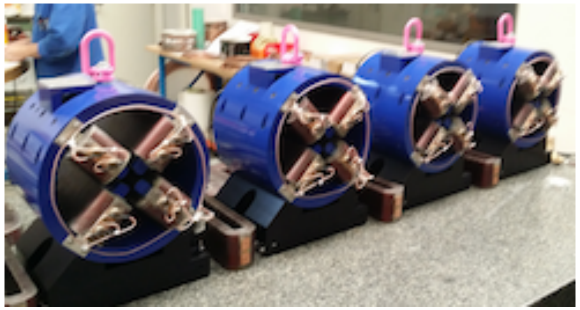
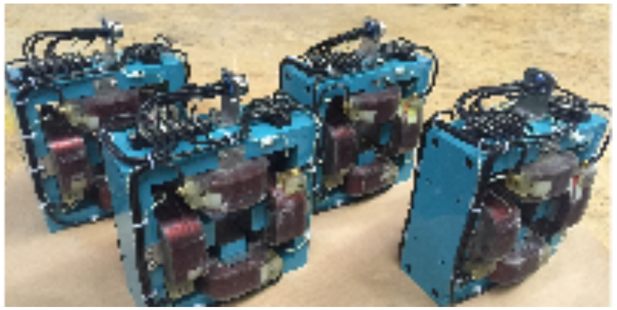


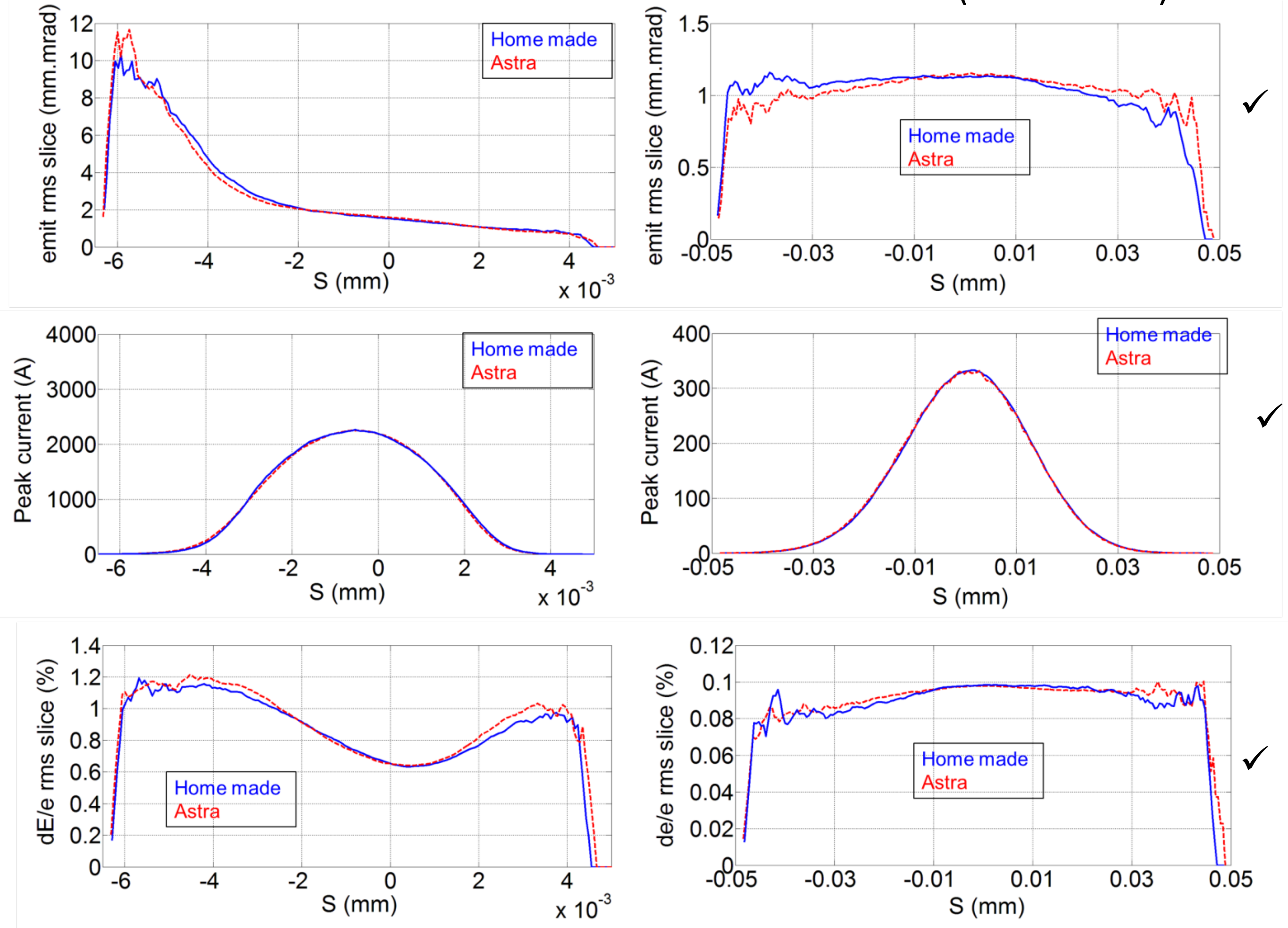




Thank you for your attention !

Slice beam output with space charge

without chicane | with chicane (R_{56}=1.1 mm)



- ✓ Strong space charge influence on the beam without chicane
- ✓ 10-15 % emittance increase in the central slice due to space charge (with chicane)
- ✓ Consistent results with space charge from both tracking codes

Slice beam properties at undulator center. 3D SC calculation algorithm is applied.

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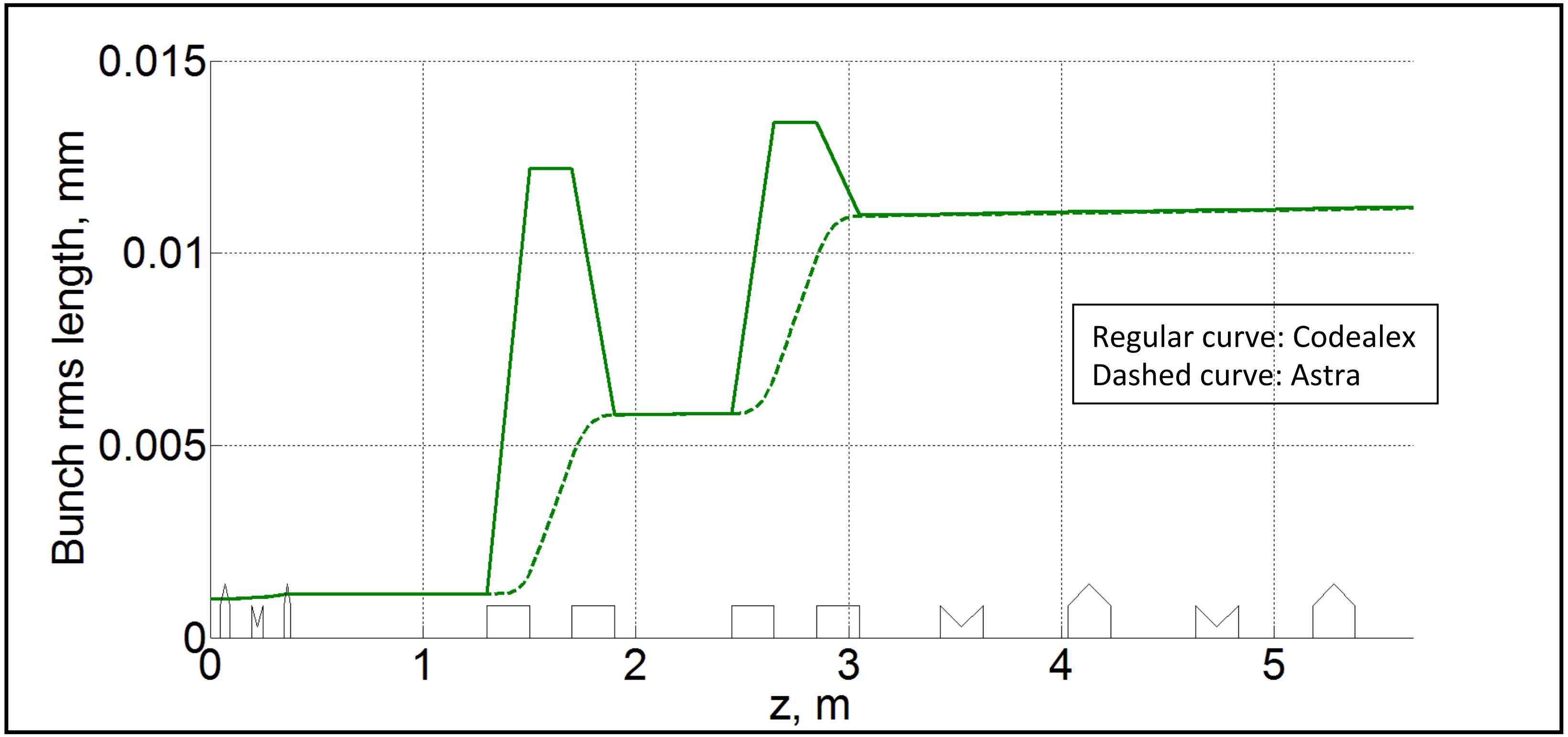
Bunch length inside the chicane: Codealex and Astra



Evolution of bunch (rms) length inside the chicane for two tracking codes.