Intra-Beam Scattering Simulations for the CLIC Damping Rings

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(by Webex)

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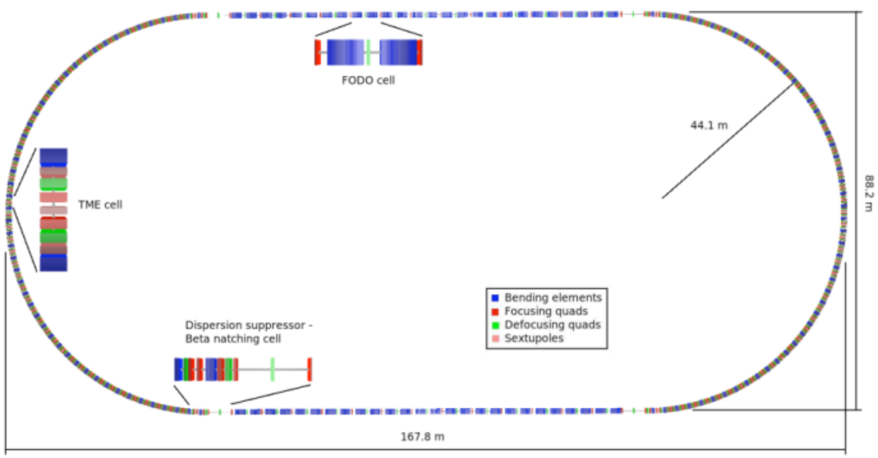
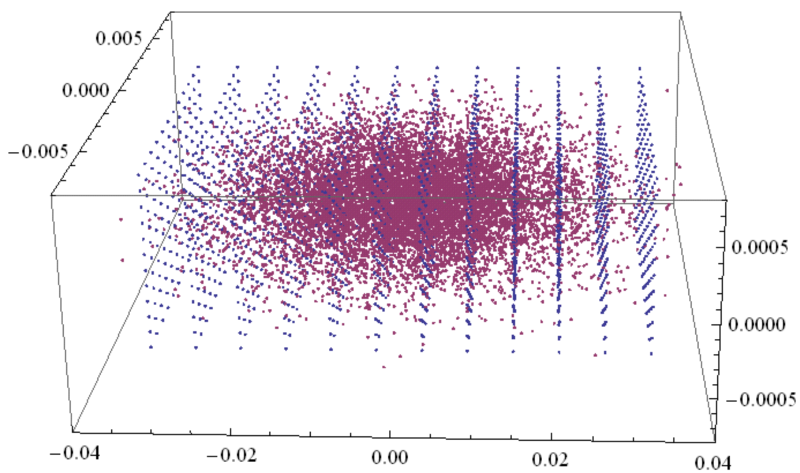
Intra-Beam Scattering (IBS) Simulation Algorithm: CMAD

IBS applied at each element of the CLIC DR





- CMAD (M. Pivi SLAC) parallel code: **C**ollective effects & **MAD.** IBS routine implemented in C-MAD with help of Theo Demma.
- Lattice read from MADX files containing Twiss functions and transport matrices
- At each element in the ring, IBS routine:
  - Particles of the beam are grouped in cells.
  - Particles inside a cell are coupled
  - Momentum of particles is changed because of scattering.
- Particles are transported to the next element.
- Radiation damping and excitation effects are evaluated at each turn.
- Vertical dispersion is included
- Code uniquelly includes: **IBS, Electron Cloud, Radiation Damping & Quantum Excitation**

M. Pivi, T. Demma (SLAC, LAL)

IBS - Zenkevich-Bolshakov Algorithm

For two particles colliding with each other, the changes in momentum for particle 1 can be expressed as:

$$\Delta P_{1x} = \frac{P}{2}\left[\zeta\sqrt{1+\frac{\xi^2}{4\alpha^2}}\sin\phi - \frac{\xi\theta}{2\alpha}\cos\phi\right]\sin\varphi + \theta(\cos\varphi - 1)$$

$$\Delta P_{1y} = \frac{P}{2}\left[\theta\sqrt{1+\frac{\xi^2}{4\alpha^2}}\sin\phi - \frac{\xi\zeta}{2\alpha}\cos\phi\right]\sin\varphi + \zeta(\cos\varphi - 1)$$

$$\Delta P_{1s} = \frac{P}{2}[2\alpha\gamma\sin\varphi\cos\phi + \gamma\xi(\cos\varphi - 1)],$$

$$\xi = \frac{P_1 - P_2}{\gamma P},\ \theta = x_1' - x_2',\ \zeta = y_1' - y_2',\ \alpha = \frac{\sqrt{\theta^2+\zeta^2}}{2}$$

with the equivalent polar angle φ_{eff} and the azimuthal angle ϕ distributing uniformly in [0; 2π], the invariant changes caused by the equivalent random process are the same as that of the IBS in the time interval Δts

$$\varphi_{\mathrm{eff}} = \frac{2r_0}{\gamma}\sqrt{\frac{\pi c\rho\Delta t_s}{\bar{\beta}^3}L_c}$$

$$\frac{dJ_{1x}}{dt} = \frac{\pi r_0^2}{4\gamma^2\bar{\beta}^3}c\rho L_c\left[-4x_1'\theta + \xi^2 + \zeta^2 + 4\frac{x_{\beta 1}D_x}{\beta_x^2}\gamma\xi + \frac{D_x^2\gamma^2}{\beta_x^2}(\theta^2+\zeta^2)\right]$$

$$\frac{dJ_{1y}}{dt} = \frac{\pi r_0^2}{4\gamma^2\bar{\beta}^3}c\rho L_c(-4y_1'\zeta + \xi^2 + \theta^2)$$

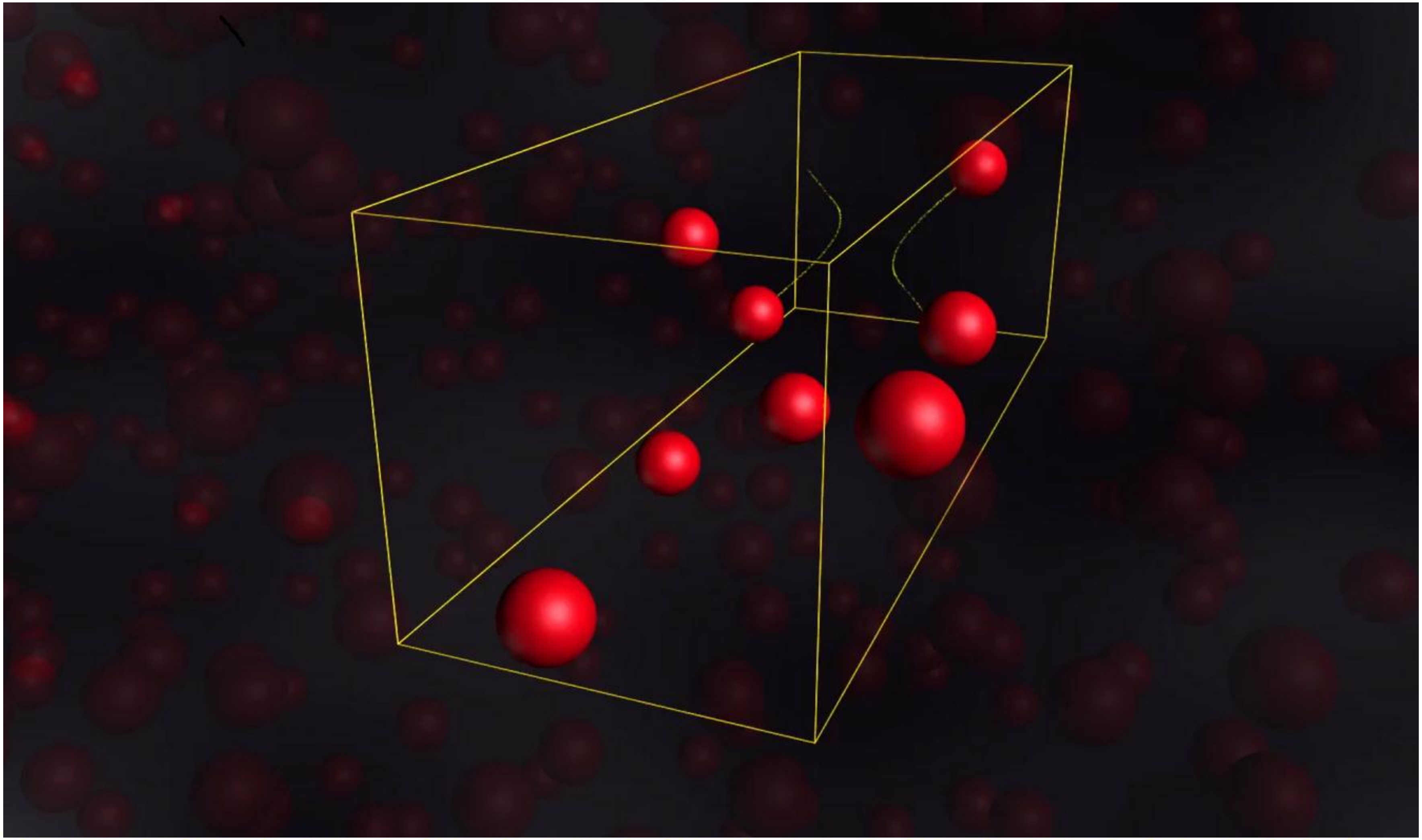
$$\frac{dJ_{1s}}{dt} = \frac{\pi r_0^2}{4\gamma^2\bar{\beta}^3}c\rho L_c\left(-4\frac{\delta_1}{\gamma}\xi + \zeta^2 + \theta^2\right),$$

SIRE code uses similar implementation (A. Vivoli Fermilab, Y. Papaphilippou CERN)

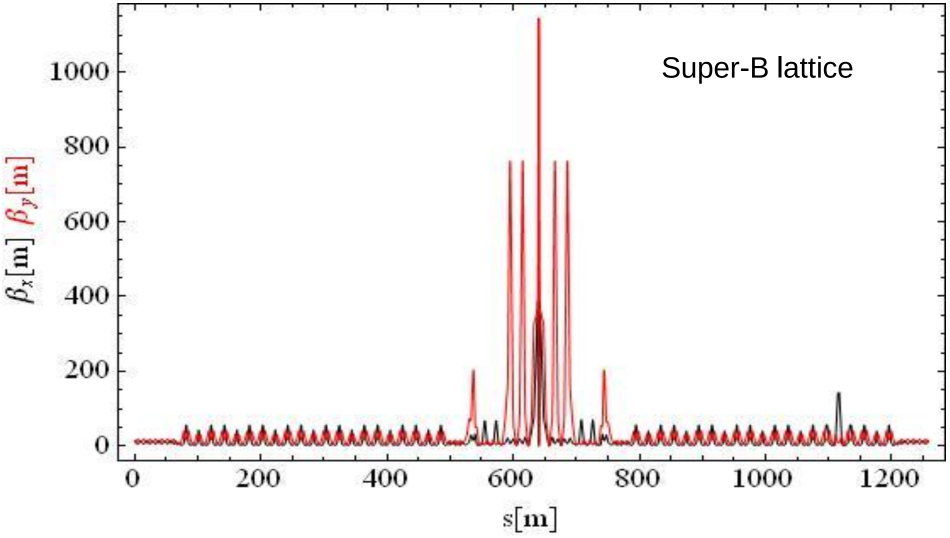
IBS modeling: animation

- http://www-user.slac.stanford.edu/gstewart/movies/particlesimulation_animation/

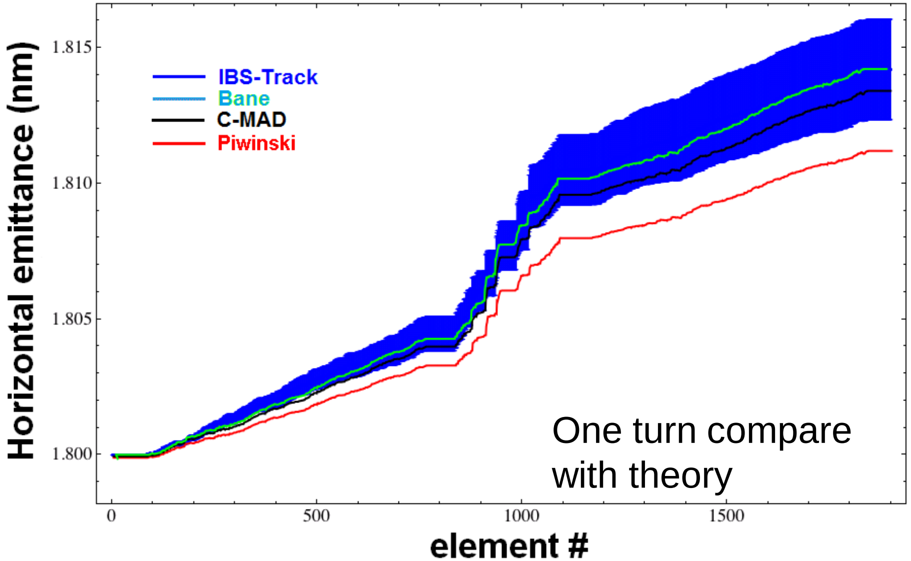
Modelling Intra-beam Scattering



IBS evaluation in Super-B



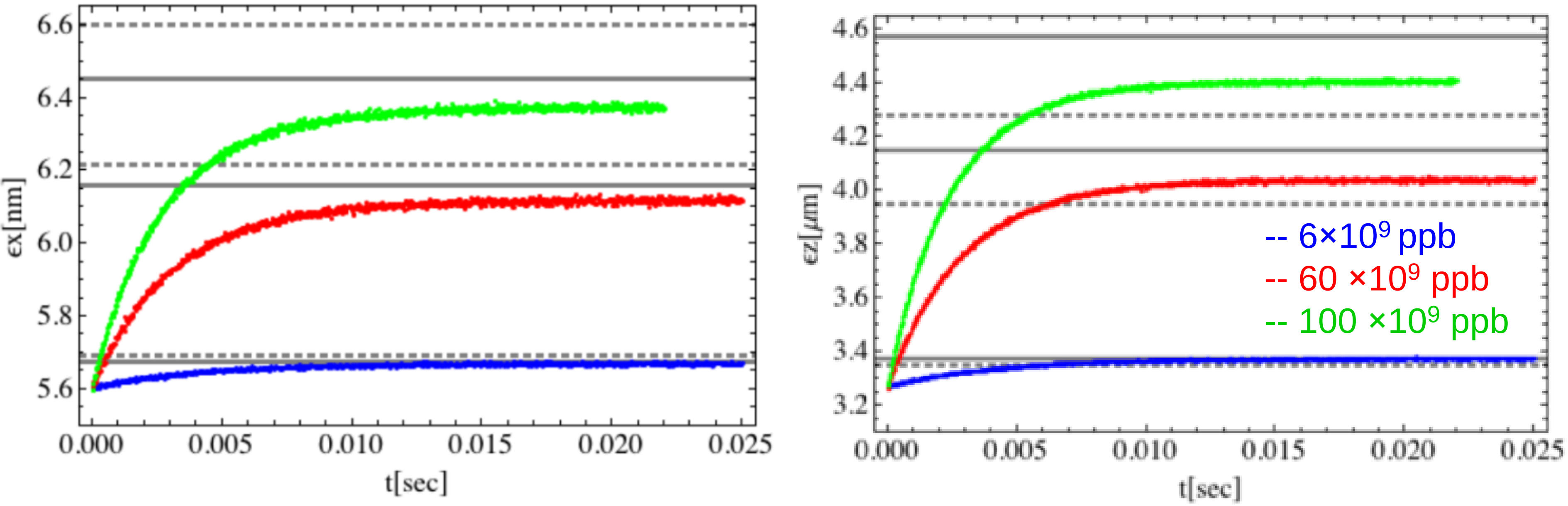
Parameter	Unit	Value
Energy	GeV	4.18
Bunch population	10^{10}	6.5
Circumference	m	1257
Emittances (H/V)	nm/pm	1.8/4.5
Bunch Length	mm	3.99
Momentum spread	%	0.0667
Damping times (H/V/L)	ms	40/40/20
N. of macroparticles	-	10^5
N. of grid cells	-	64x64x64



Theoretical models compared with simulations for Super-B, using IBS-Track and C-MAD codes: one turn evolution of emittance with Intra-beam scattering.

M. Pivi, T. Demma

IBS evaluation for Swiss Light Source (SLS)



IBS_Track (T. Demma)

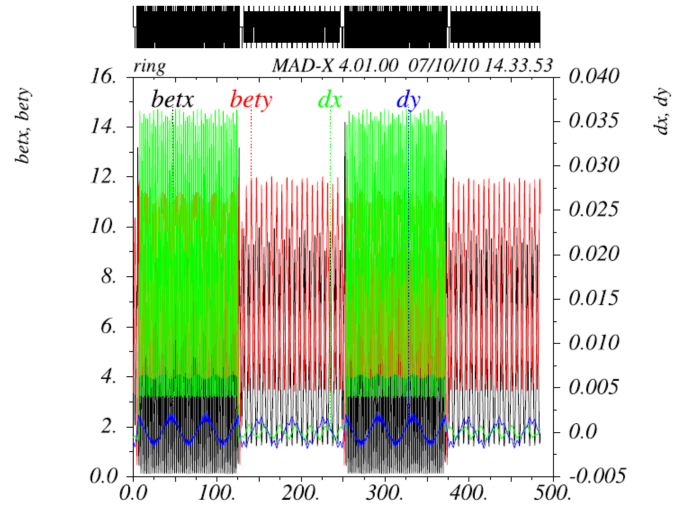
Evolution of the emittances obtained by tracking with IBS for different bunch populations. Horizontal lines: Piwinski (full) and Bane (dashed) models for the considered bunch populations.

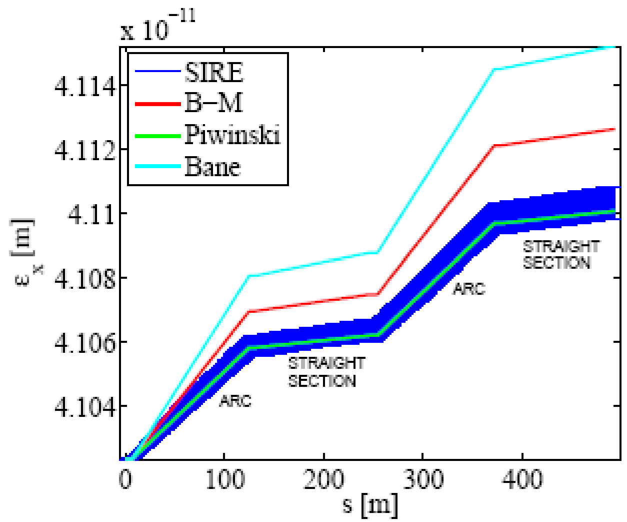
See more in Fanouria Antoniou talk for SLS experimental results

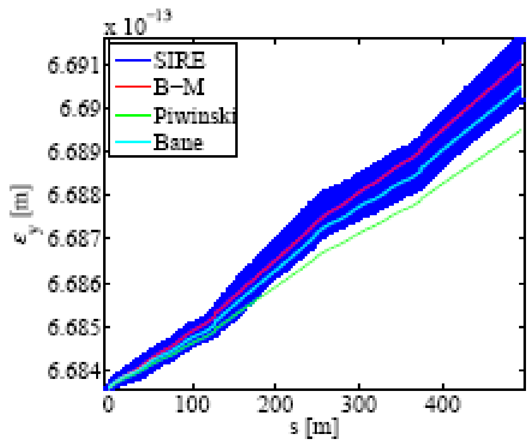
IBS evaluation for CLIC DR. Previous work: SIRE code

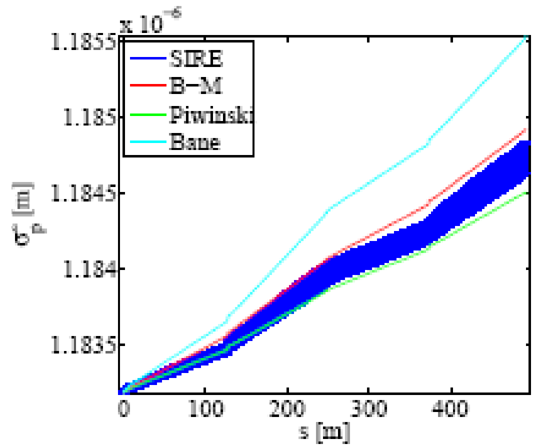
Table 1: Parameters for validation

Parameter	Unit	Value
Energy	GeV	2.86
Bunch Population	10^9	4.07
Circumference	m	493.16
Norm. Emittance H,V	nm	229.6 , 3.74
Momentum Spread	%	0.109
Bunch Length	mm	0.922
N. macro-particles	10^3	200
N. cells	10^3	200
ΔT	μs	1.645





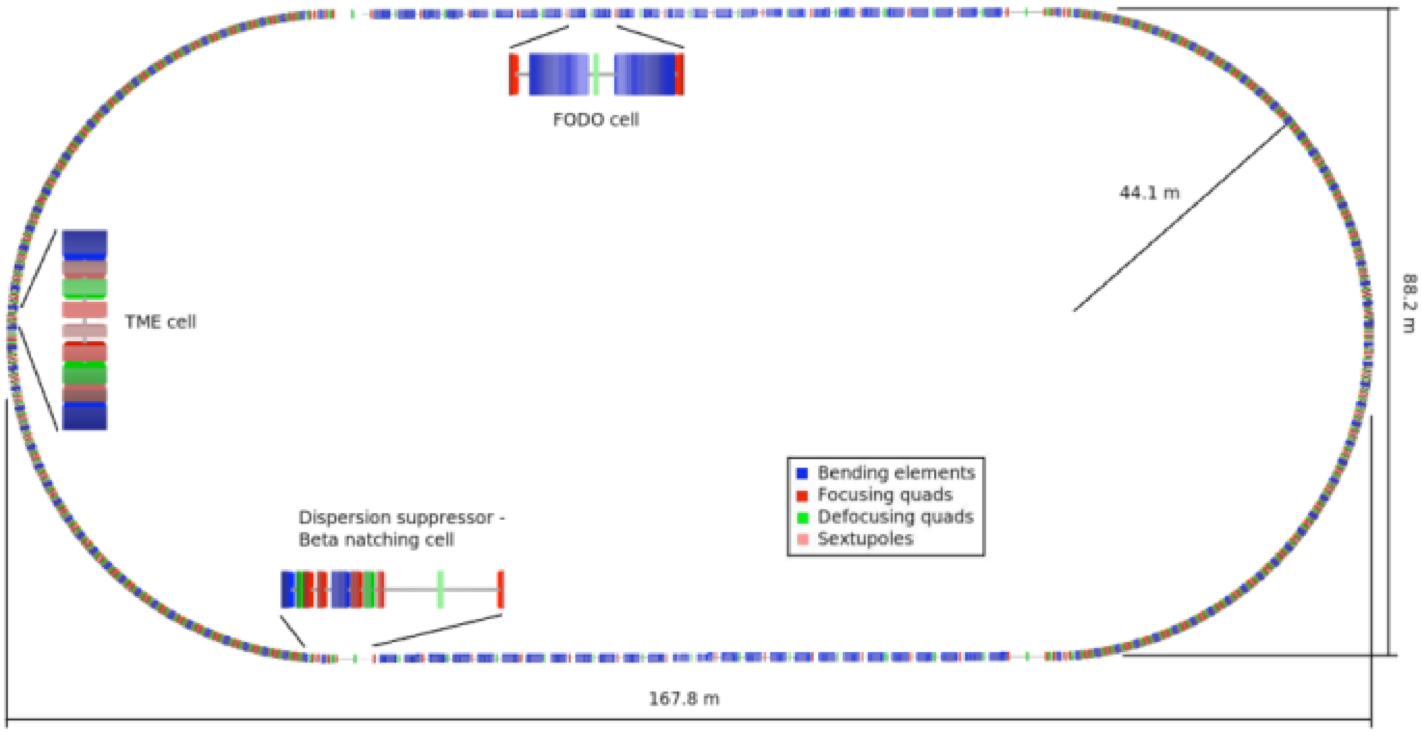




F. Antoniou, IPAC10

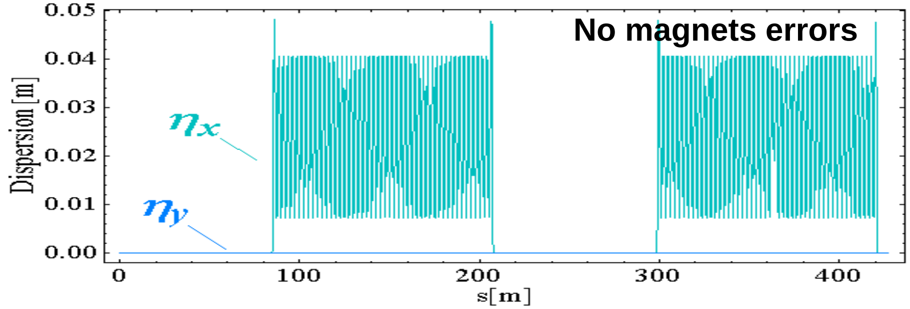
A. Vivoli, Y. Papaphilippou

IBS evaluation for CLIC DR

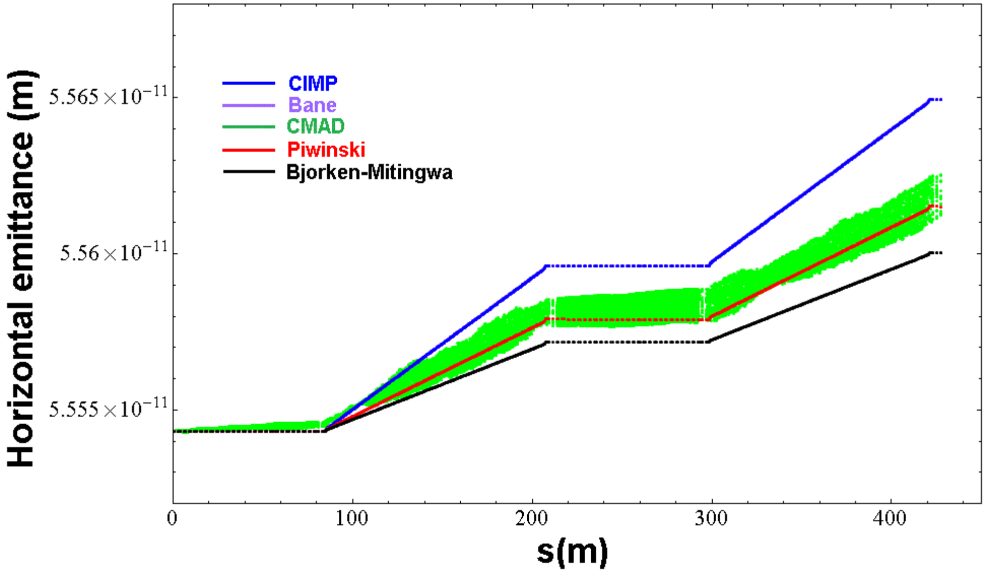


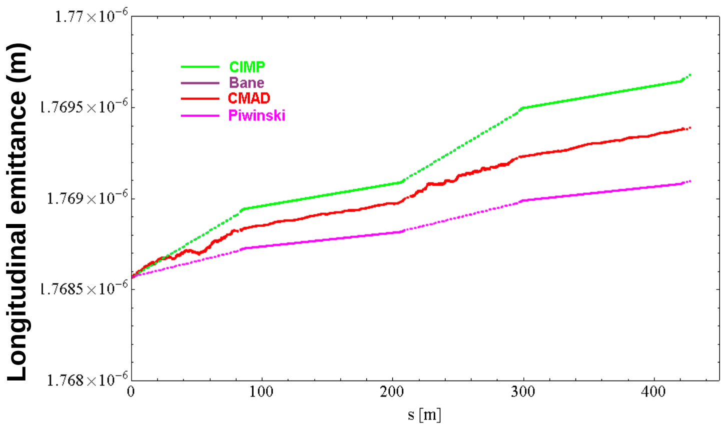
Evaluate Intra-beam Scattering in CLIC DR lattice by tracking the beam and applying IBS at every element in the ring.

IBS evaluation for CLIC DR



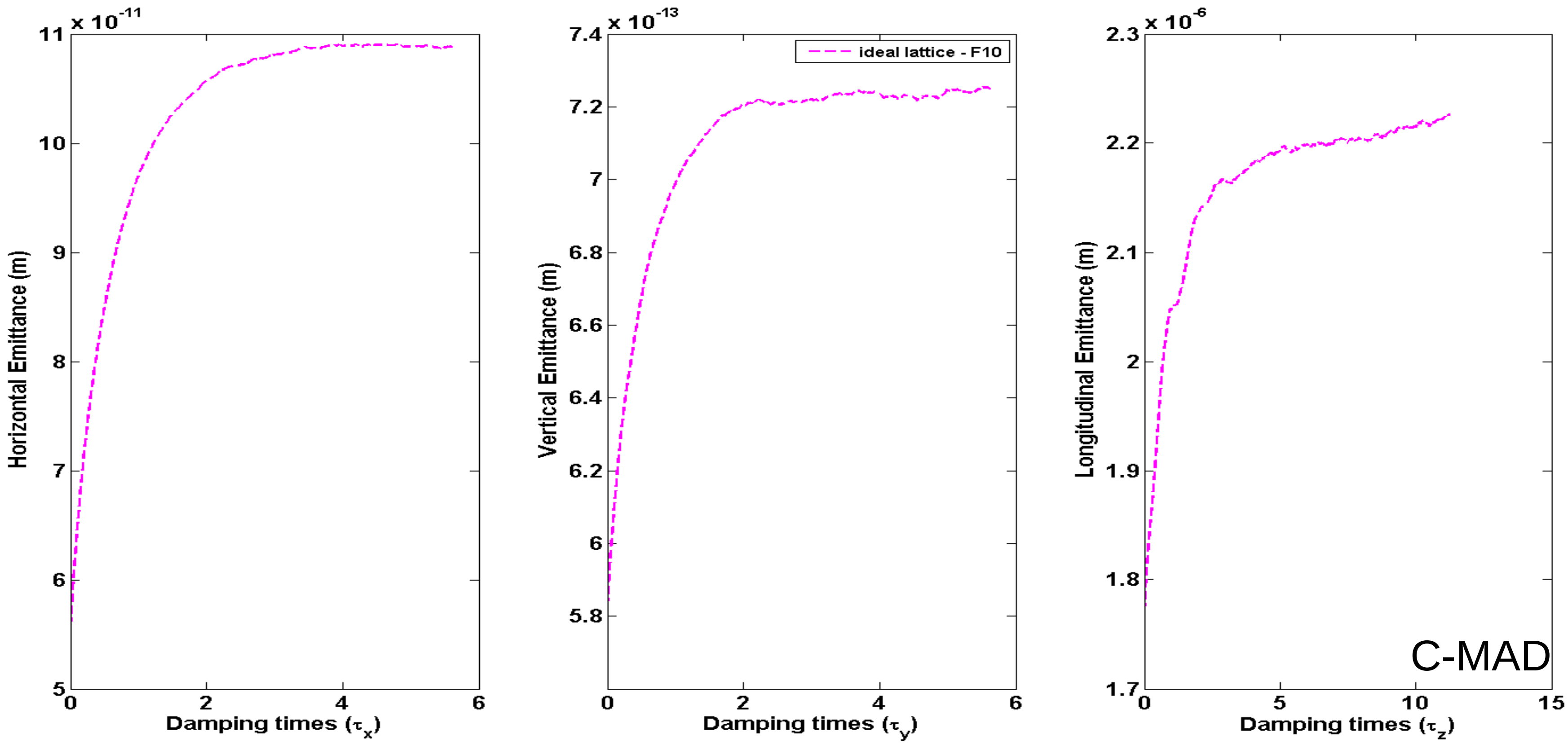
CLIC DR	parameter
Energy (GeV)	2.86
epsx (m)	5.55e-11
epsy (m)	5.82 e-13
Deltap	1.2e-3
sigmaz (m)	1.46e-3





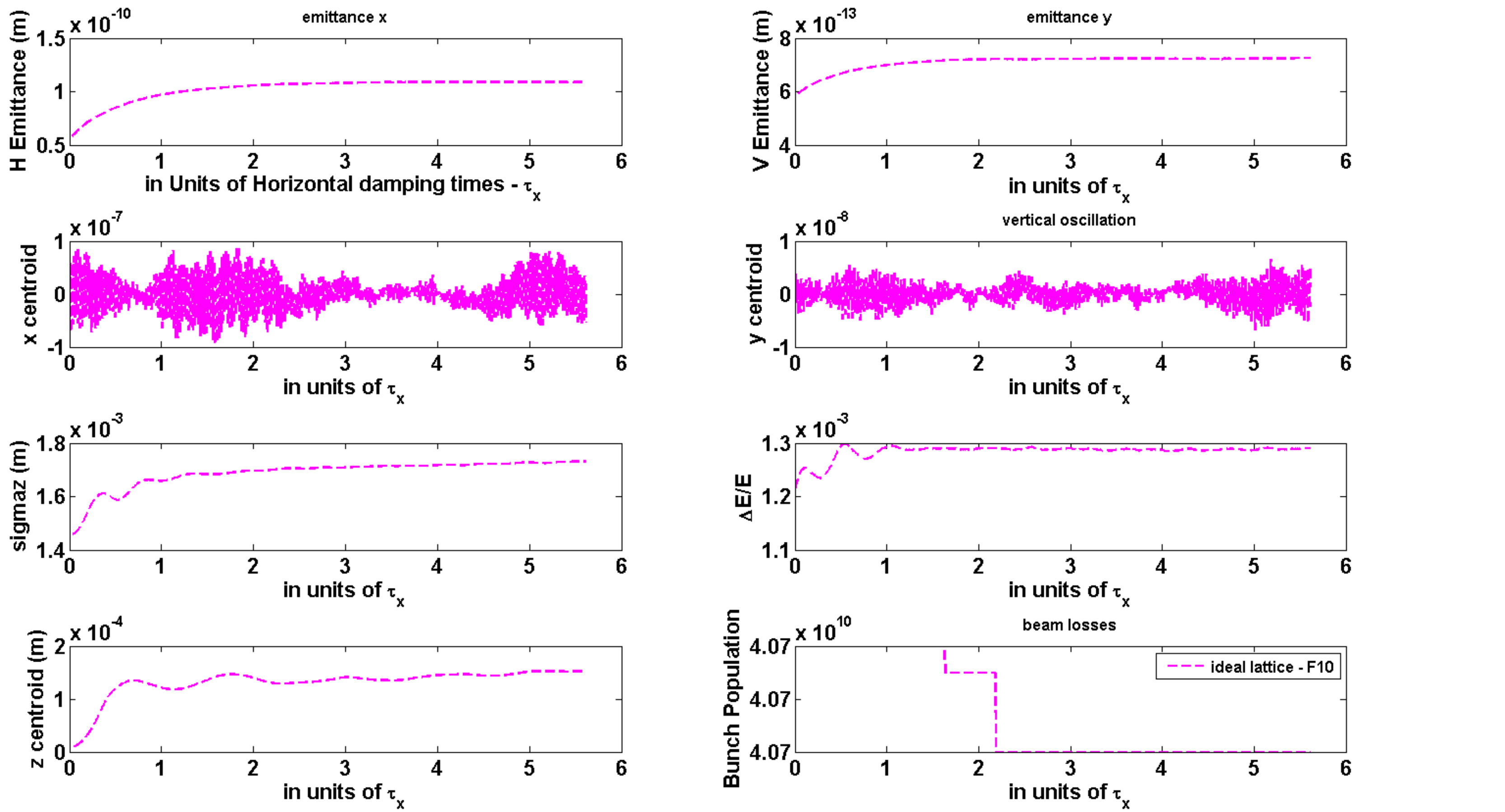
Theoretical models and C-MAD simulations for CLIC DR: one turn evolution of emittance with Intra-beam scattering.

IBS evaluation for CLIC DR



Emittance growth in the CLIC DR lattice with no magnet errors, using C-MAD.
("Factor10" simulations: 10 time larger beam intensity and 10 time faster damping times)

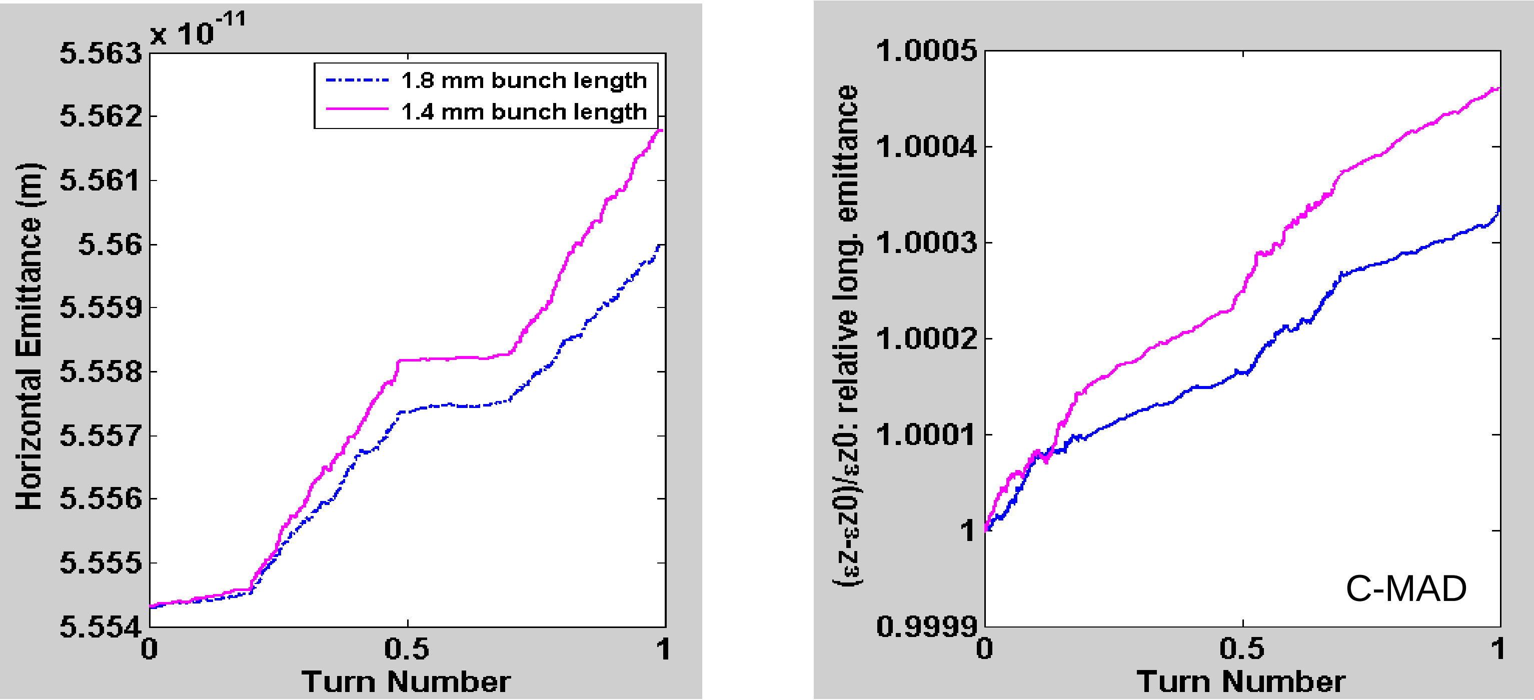
IBS evaluation for CLIC DR



CLIC DR lattice with no magnet errors, using C-MAD.
(“Factor10” simulations: 10 time larger beam intensity and 10 time faster damping times)

CLIC DR parameters optimization: IBS and bunch length

Lattice with no magnet errors



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One turn emittance evolution for different bunch lengths.

Include Vertical Dispersion in CLIC DR

In the vertical plane, IBS is much stronger in the presence of vertical dispersion. Then, it is crucial to include vertical dispersion in simulations to estimate the evolution of vertical emittance.

We wish to generate a lattice with Vertical Dispersion but no Coupling to benchmark theoretical models that include the 1st but not the 2nd.

Thus, in MADX we create quadrupole misalignments to generate vertical dispersion.

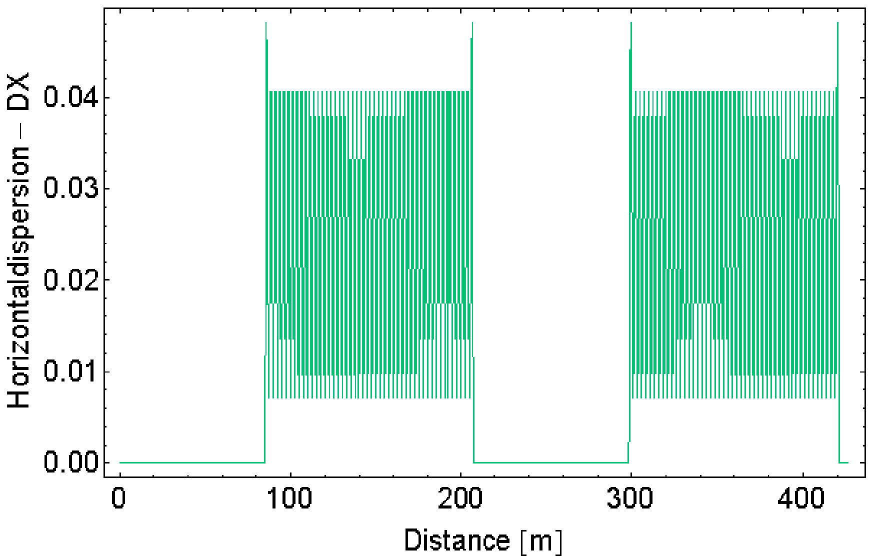
In the CLIC DR (not in SLS), this generates also coupling due to Sextupoles. Then for now, turned off Sextupoles.

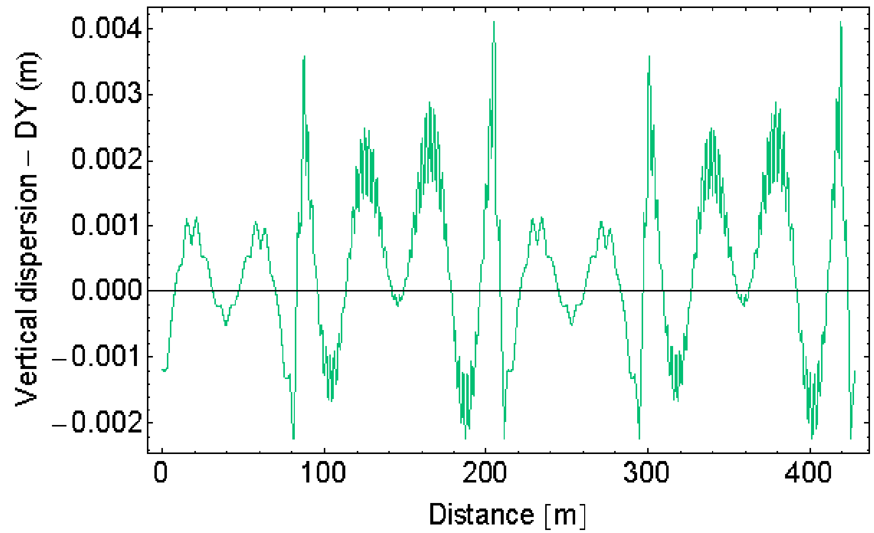
Lattice with vertical quadrupole misalignments

$$\begin{pmatrix} -0.580314 & 6.42681 & -0.0223792 & -0.125682 & 1.38662\times10^{-6} & -2.87752\times10^{-6} \\ -0.103166 & -0.580275 & 0.00108029 & -0.00433313 & 5.12858\times10^{-8} & 4.85299\times10^{-6} \\ -0.0182548 & -0.0987152 & -0.771129 & 3.4715 & 7.08986\times10^{-6} & -0.00279715 \\ 0.00121189 & -0.00619628 & -0.109623 & -0.802995 & 0.0000120084 & 0.000224278 \\ 3.81557\times10^{-6} & 9.93192\times10^{-6} & 0.000479168 & 0.00146256 & 0.997959 & -0.054539 \\ 2.80518\times10^{-8} & 3.64453\times10^{-7} & 9.42958\times10^{-6} & 0.000102212 & 0.0373476 & 1. \end{pmatrix}$$

One turn matrix: large coupling terms are present

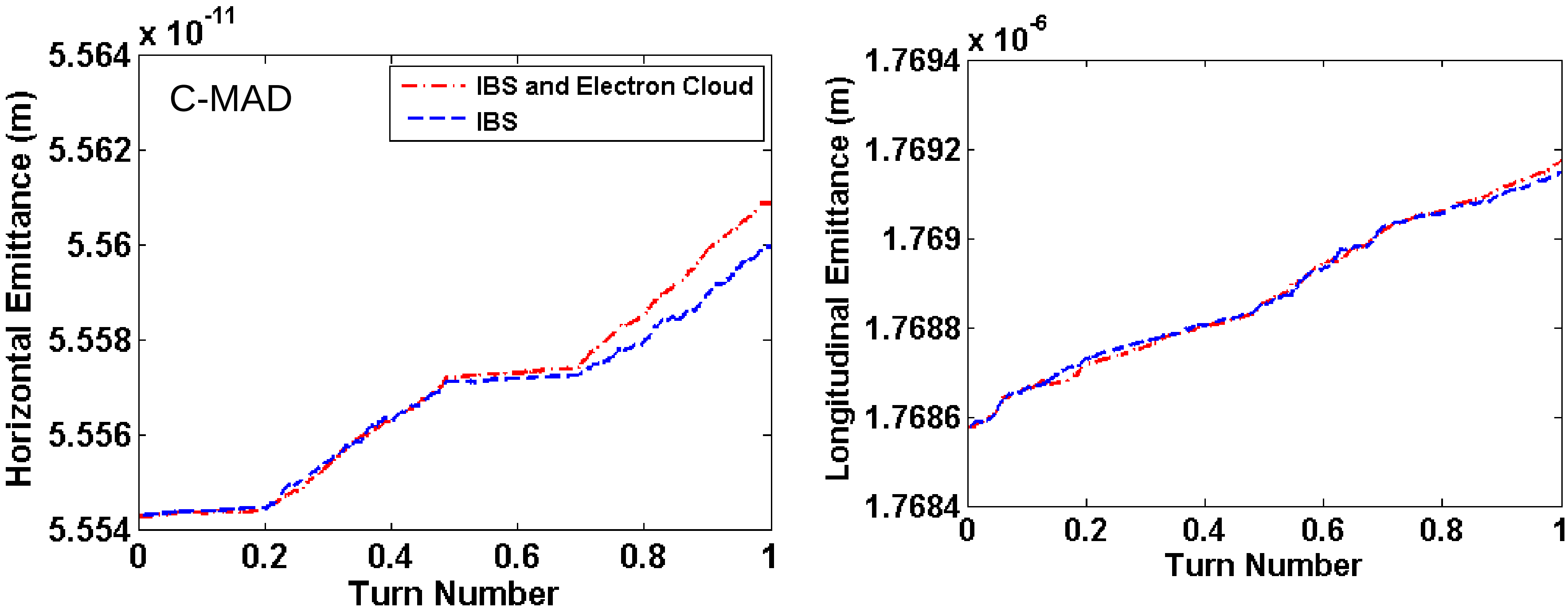
MADX





Vertical dispersions in DR lattice with misaligned quadrupoles dy=4.5um

IBS evaluation for CLIC DR



CLIC DR lattice **with** magnet misalignments and **vertical dispersion**, Effects: IBS and Electron Cloud effects + Radiation damping and Quantum excitation. Using C-MAD.

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IBS evaluation: 2012-2016 Plans

- Code validation: benchmark recent experiments made at CesrTA and SLS with simulations
- Code predictions: long term beam evolution in CLIC Damping Rings
  - Fix RF system
  - Use MAD lattice with no magnet errors
  - Include magnet vertical misalignments and vertical dispersion
  - Include magnet rotation and coupling also to closely benchmark experimental data (CesrTA, SLS)

M. Pivi, F. Anotniou, Y. Papaphilippou (CERN)

IBS evaluation: 2012-2016 Plans

- Code use to optimize CLIC DRs:
  - Optimize ring parameters and IBS: beam energy, bunch length, optics
- Improve code speed: Merge wiggler elements in simulations
- Study the evolution of the bunch shape during IBS: generation of non-Gaussian tails
- IBS theoretical models: include betatron coupling

M. Pivi, F. Anotniou, Y. Papaphilippou (CERN)

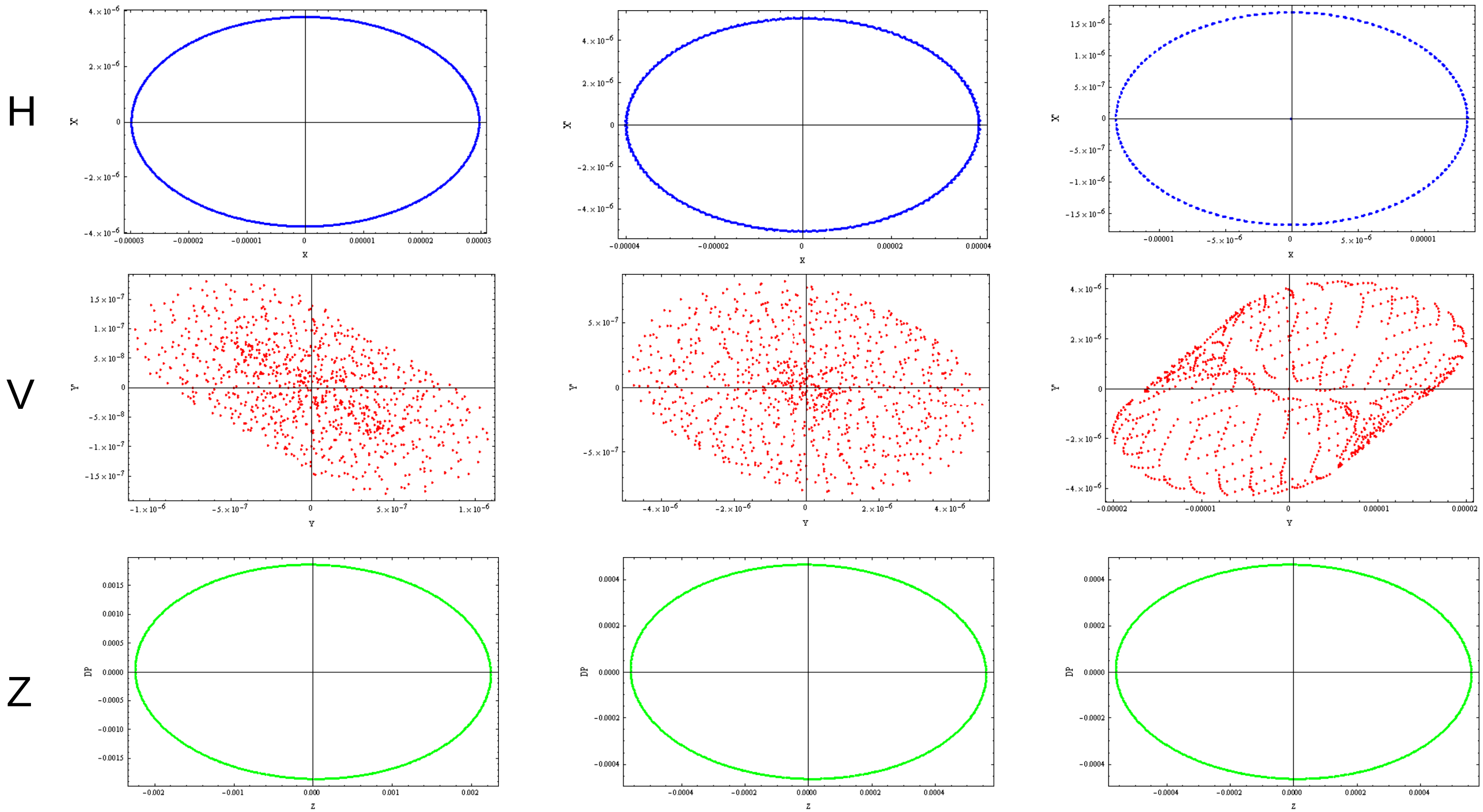
Summary

- Intra-Beam Scattering codes in agreement with theoretical models
- Estimations for Super-B and SLS, CesrTA
- Evaluation of IBS in CLIC DR on-going
- Plans for methodical evaluation of IBS in CLIC Damping Rings.

Single particle tracking in lattice with misaligned quadrupoles

Phase spaces of single particle CLIC DR, 1000 turns

CMAD



Quad misalignment: **dy=1um** **dy=4.5um** **dy=1um** and sextupole off