CHARACTERIZATION OF THE VERTICAL BEAM HALO FOR REDUCED IN-VACUUM UNDULATOR GAP

9th Low Emittance Rings Workshop 2024, CERN, Geneva (Switzerland),
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Mattia Stefanelli.

The Beam Dynamics Group:
Simon White, Nicola Carmignani, Lee Carver, Simone Liuzzo, Thomas Perron, Lina Hoummi.

Kees Scheidt and the **Diagnostic Group** for the Halo Monitors material.

The **ID Group** for the help in the ID31 Scan data measurements.

All the members of the **Operation Group**.

ESRF | The European Synchrotron

OVERVIEW

- **The context**
- **Vertical Halo:**

  1. From Touschek Scattering to Resonance Crossing
  2. Resonance Crossing and Emittance Growth

- **Strategy for Vertical Halo Reduction**
- **Experiments:**

  1. Halo Monitor
  2. Validation of the Proposed Strategy
  3. Determination of a New Setup with Reduced Vertical Halo

- **Results**
- **Acknowledgements**

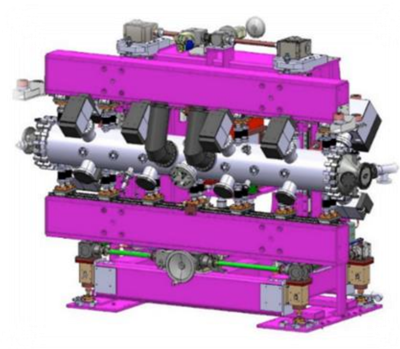
THE CONTEXT

ESRF-EBS is a fourth-generation high-energy synchrotron currently in operation.

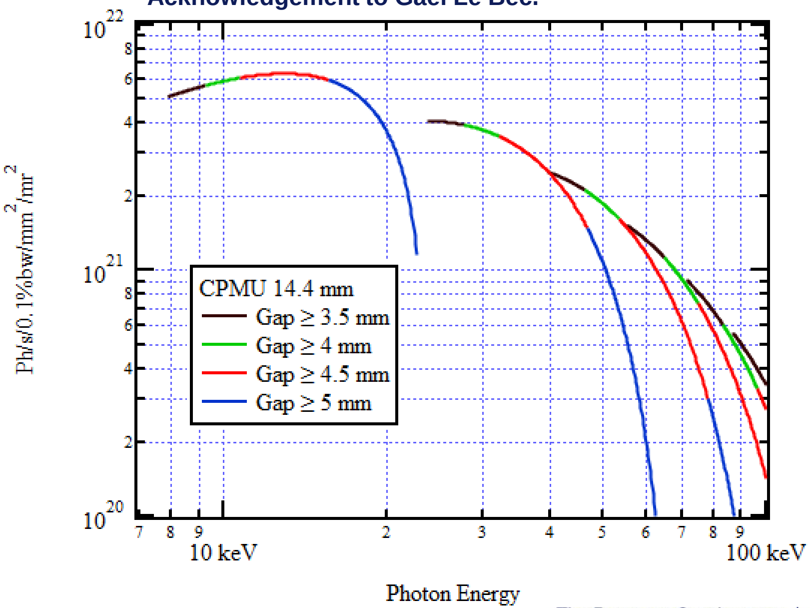
In order to exploit, at its full potential, the EBS design we aim to reduce the gap of the available In-Vacuum Undulators,
down to **4 mm**, increasing the brilliance of the radiation received by the beamlines.

Although, for gaps lower than **5 mm**, relevant losses are observed preventing small gap operation.

➡ This is due to the presence of the **VERTICAL BEAM HALO.**



Acknowledgement to Gael Le Bec.



VERTICAL HALO

From Touschek Scattering to Resonance Crossing:

- The momentum of scattered particles is transferred from the horizontal to the longitudinal plane. Particles may acquire great energy deviations ($\Delta E/E$), being lost outside the RF bucket, but, some of them could remain in within the stable region ($\Delta E/E$ in ± 4%).

- The presence of a finite dispersion and chromaticity induces, for those particles, deviations in trajectories and betatron oscillations.

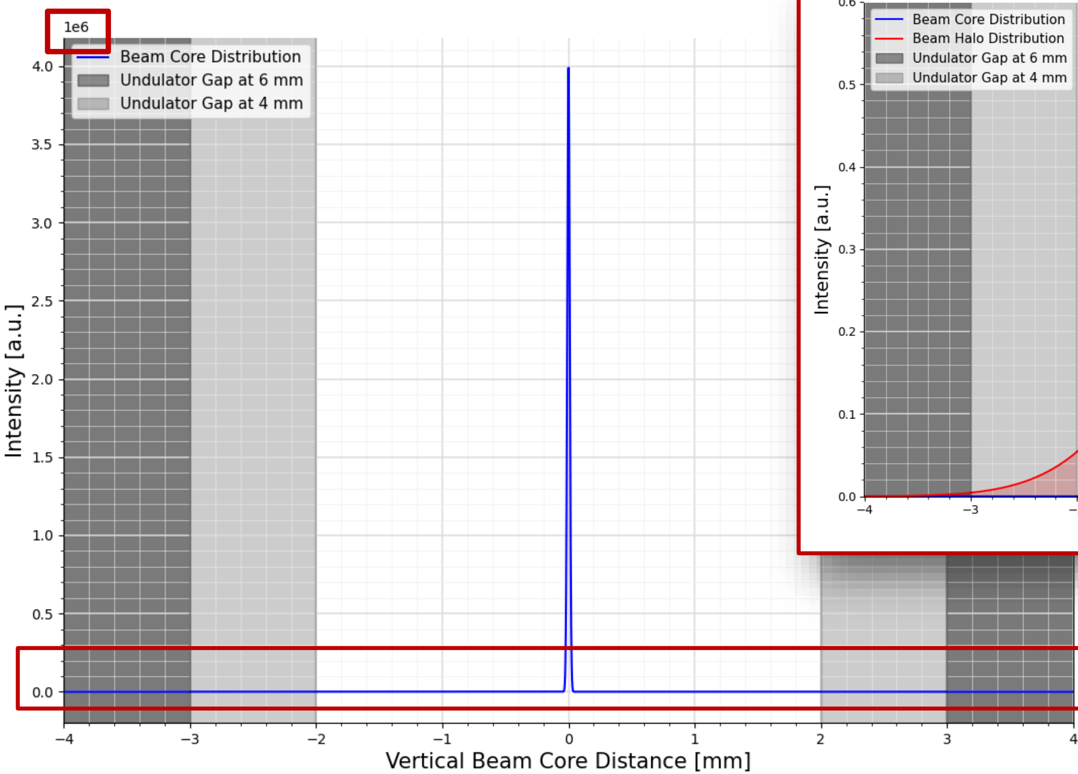
- This leads to the crossing of tune resonances, not encountered by the particles at nominal energy. In particular the sum resonance that introduces coupling in between the horizontal and the vertical oscillations.

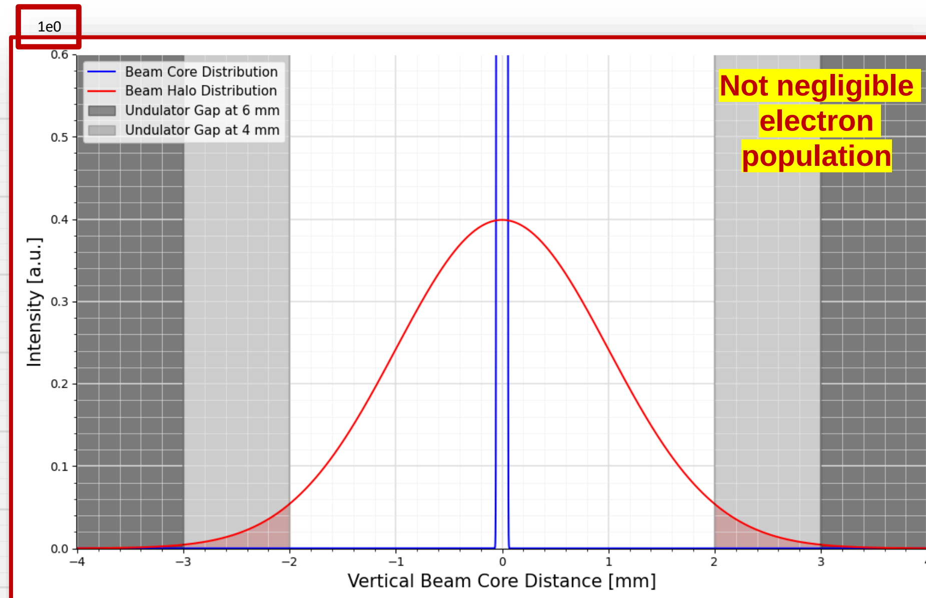
- This latter step could explain the arising of a complete unlike vertical distribution that extends for several millimeters of distance with respect the beam core.

VERTICAL HALO

Vertically, where usually the beam size is in the order of the µm, this new contribution impose a limit in the In-Vacuum Undulator gap closure, preventing the further enhancement of photon flux.

Several order of magnitude of difference

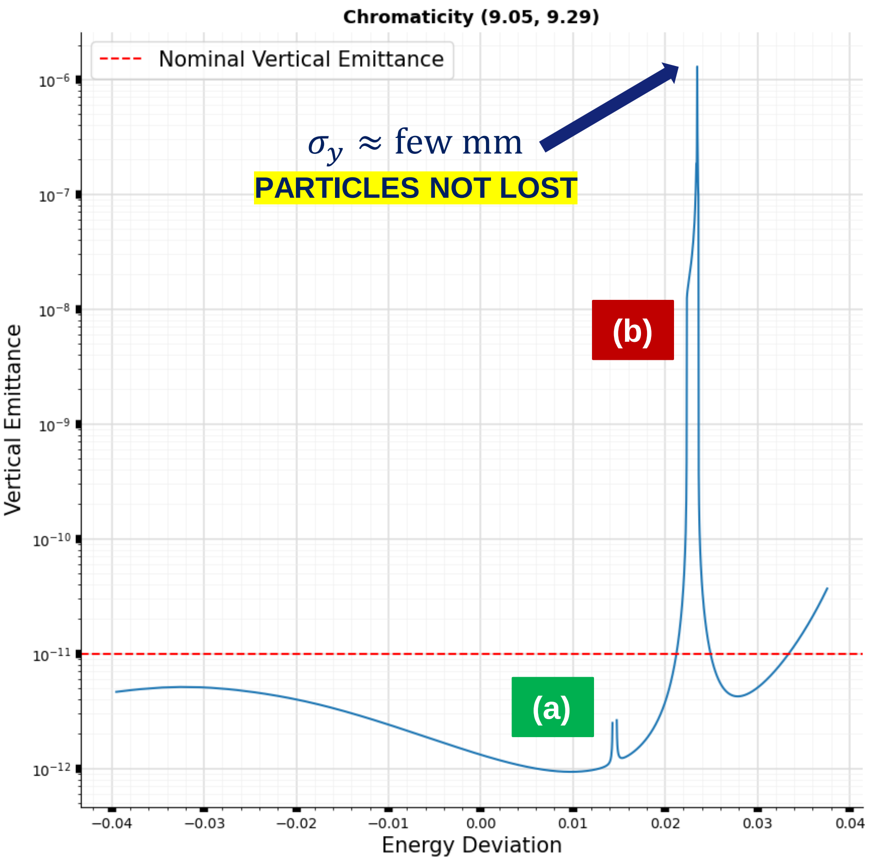


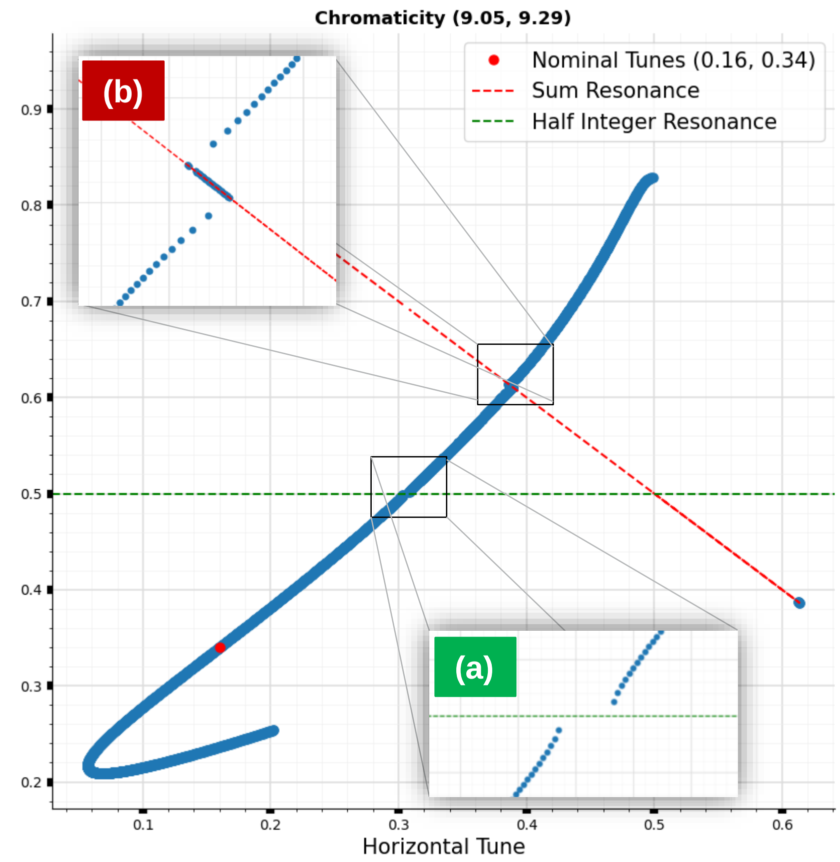


$\sigma_{y\,beamcore}$ enlarged by a factor 10 for the clarity of the plot.

$\sigma_{y\,halo}$ approximated as 1 mm.

Resonance Crossing and Emittance Growth: simulation carried on in pyAT with a set of quadrupole errors satisfying the following criteria, vertical emittance = 1 pm, horizontal and vertical beta-beating = 1%, horizontal and vertical orbit distortion = 50 µm.



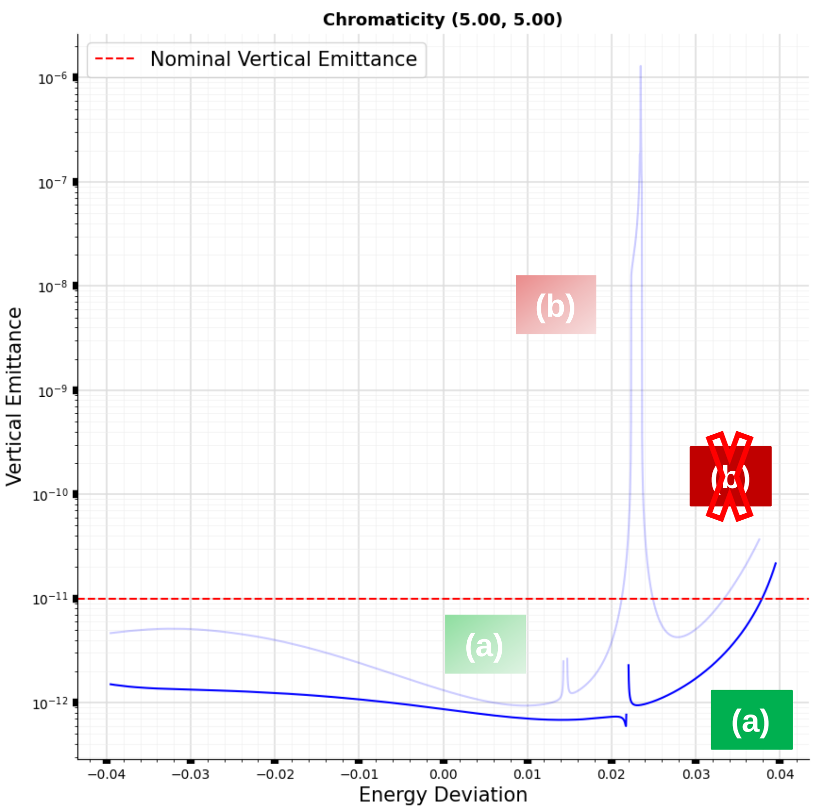


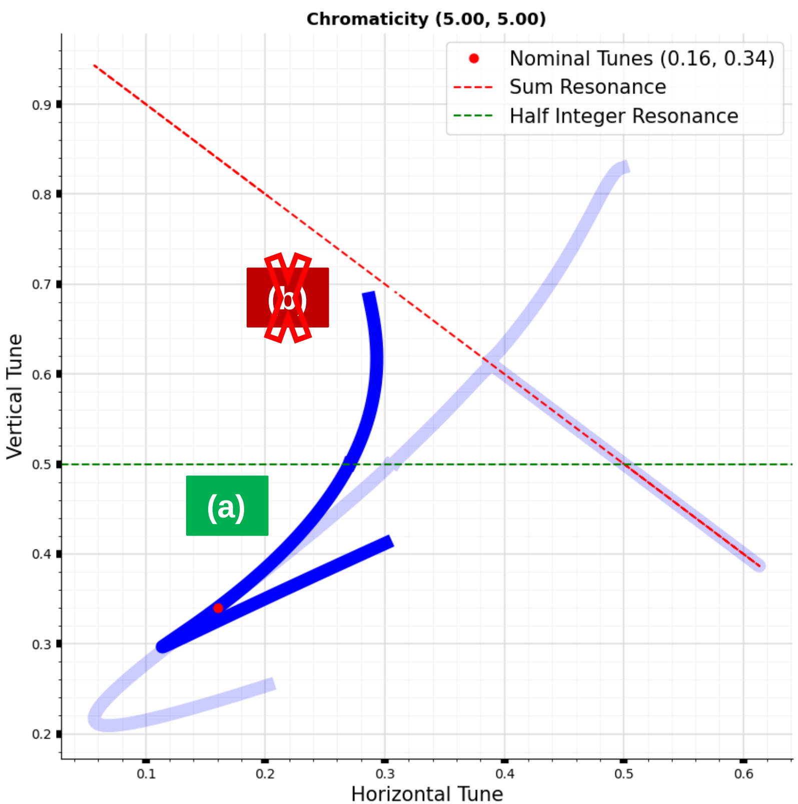
The approach is based on the reduction of the chromaticities Q' :

The dependence of the betatron oscillation tunes on the energy deviation is decreased.

A lower limit is set by the arising of strong collective effects for great values of current / bunch.

$$Q'_{x,y} = \frac{\Delta\nu_{x,y}}{\Delta\delta}$$





MATTIA STEFANELLI

EXPERIMENTS

Experiments carried on have been divided in 2 steps:

1. Validation of the proposed strategy.

2. Determination of a new setup with reduced vertical halo (Low Chromaticity Setup).

Three different signals have been used for the halo detection:

1. **HALO MONITOR SIGNAL**

2. **LIFETIME**
   Lifetime reduction associated with vertical scrapers closure.

3. **LOCALIZED LOSSES**
   Localized losses increase with ID31 In-Vacuum Undulator gap reduction.

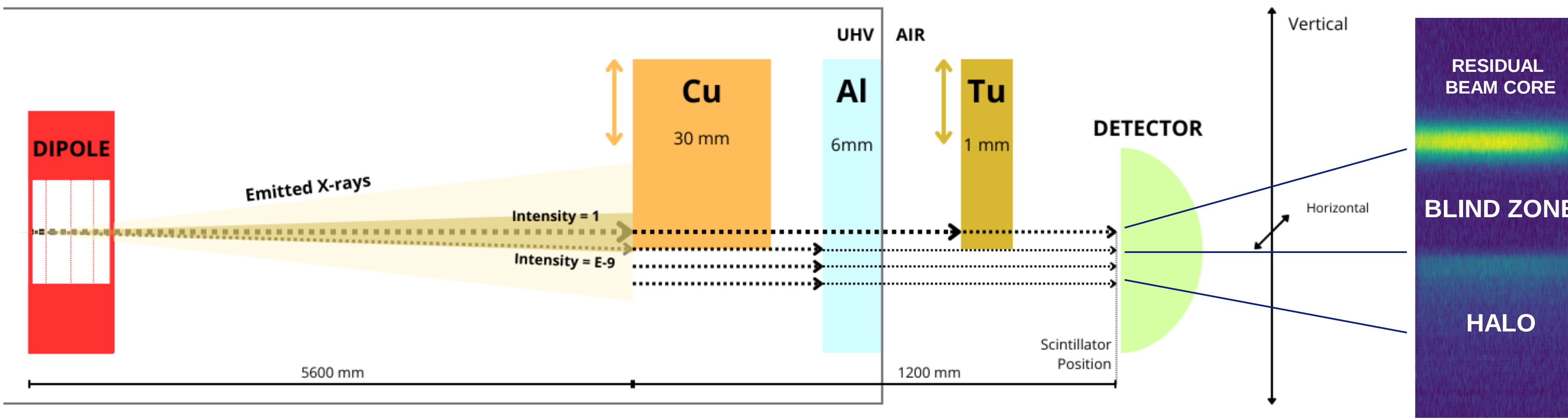
Non-destructive measurement. (1)

Destructive measurement. (2, 3)

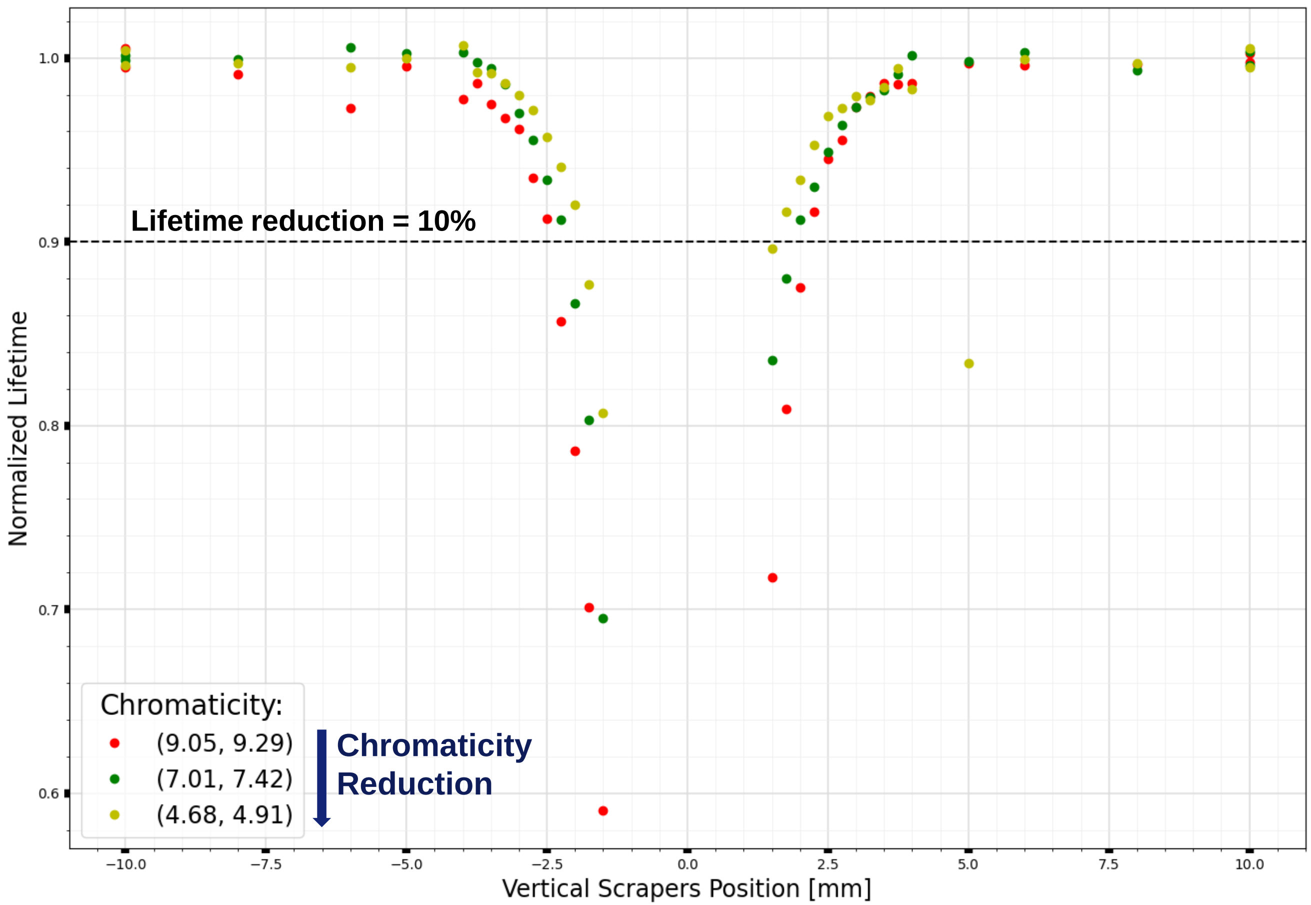
Halo Monitors:

X-rays emitted in DQ1D dipole in cell-10 and cell-11 are collected by an optical detector. Radiation emitted by the beam core is shielded in order to make it comparable with the halo contribution, several order of magnitude lower.

Acknowledgement to Kees Scheidt.



EXPERIMENTS



Validation of the proposed strategy:

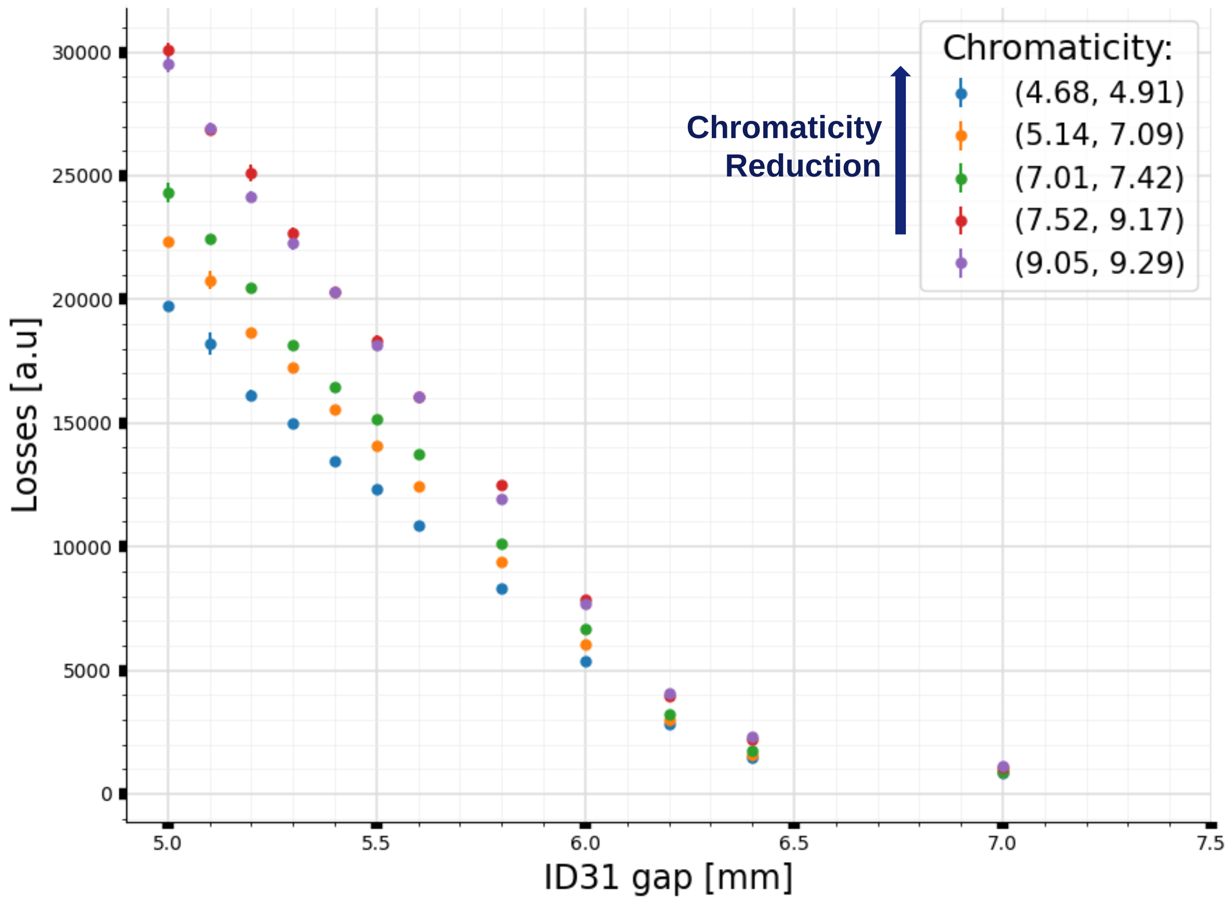
Normalized Lifetime with the vertical scrapers gap for different chromaticities.

Ex. Accepting a lifetime reduction of 10%:

- **Nominal Setup:**
Aperture ≈ 5 mm

- **(4.68, 4.91) Setup:**
Aperture ≈ 4 mm

Gap gain ≈ 1 mm



Validation of the proposed strategy:

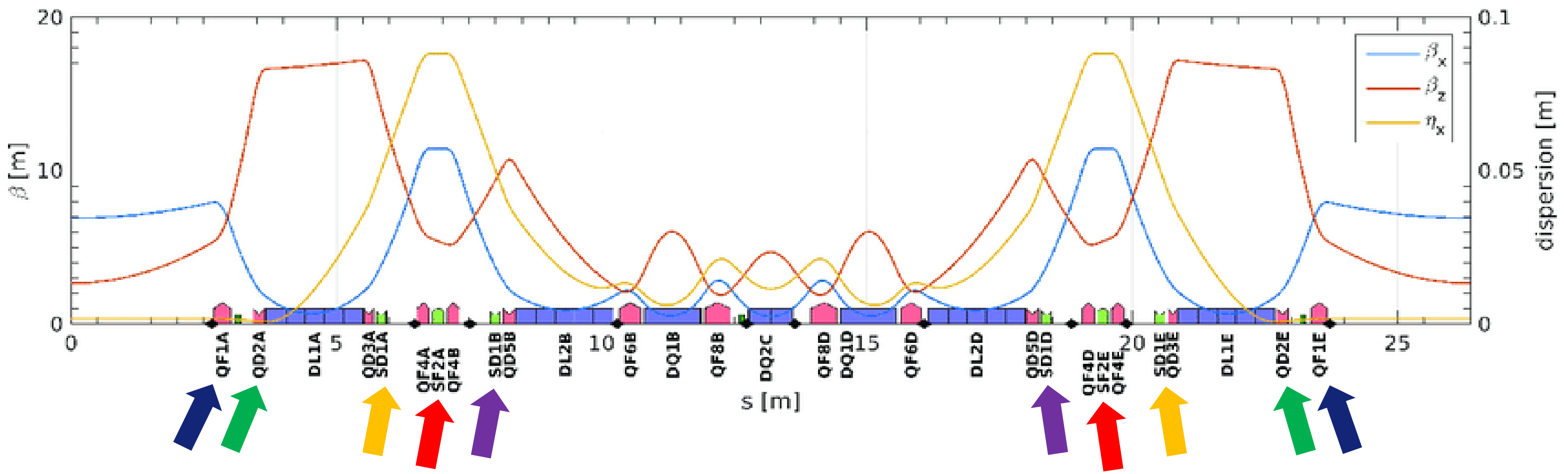
Localized Losses at ID31 with the ID31 gap for different chromaticities.

Losses reduction at minimum gap ≈ factor 1.5

Determination of a new setup with reduced vertical halo (Low Chromaticity Setup):

BADGER, a software designed to access several optimizers, is run with the Xopt Trust Region Bayesian Optimization (TuRBO) algorithm, developed at SLAC, in order to find a better setup:

- The signal detected by the halo monitors is used as reference for the optimization process while 5 families of knobs are used as observable for tune and chromaticity corrections.



Tunes correction:

- QF1
- QD2

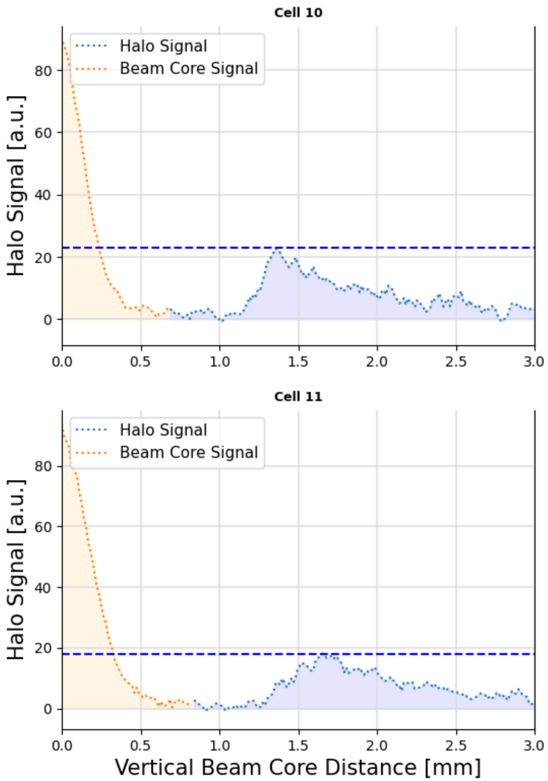
Chromaticity correction:

- SD1A – SD1E
- SF2
- SD1B – SD1D

EXPERIMENTS

- The new setup has been chosen as a compromise between halo signal reduction and high enough chromaticity to avoid too strict limitations on the possible current per bunch.

Halo Signal Nominal Setup at 100mA and 5pm



Nominal Starting Condition:

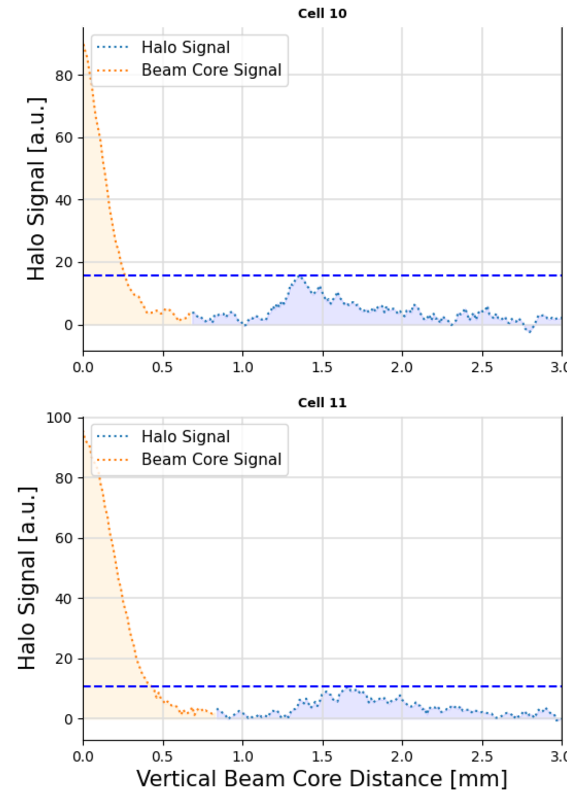
Chromaticity = (9.05, 9.29)
Tune = (0.16, 0.34)

↓

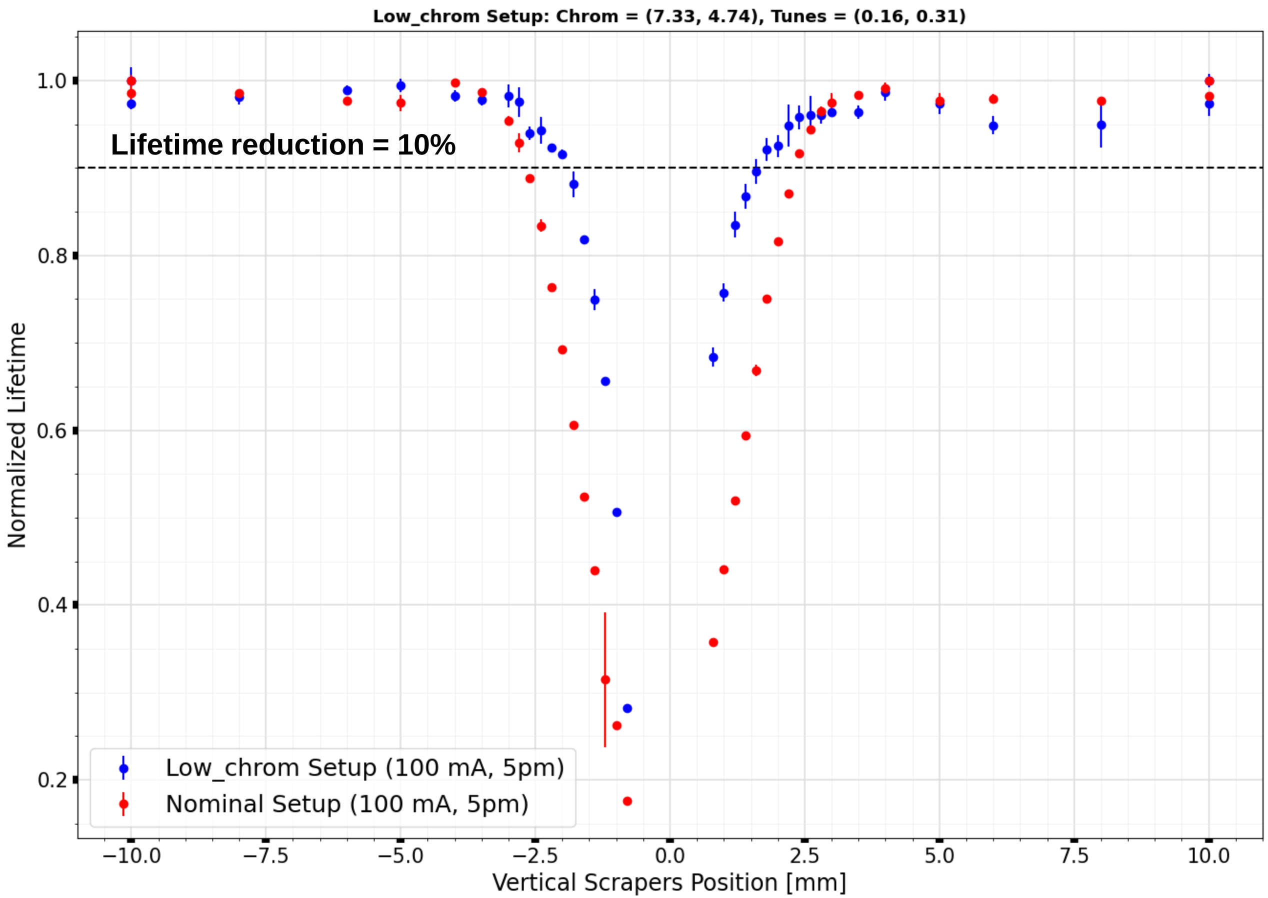
New Low Chromaticity Setup:

Chromaticity = (7.33, 4.74)
Tune = (0.16, 0.31)

Halo Signal Low Chrom. Setup at 100mA and 5pm



RESULTS



Validation of the proposed strategy:

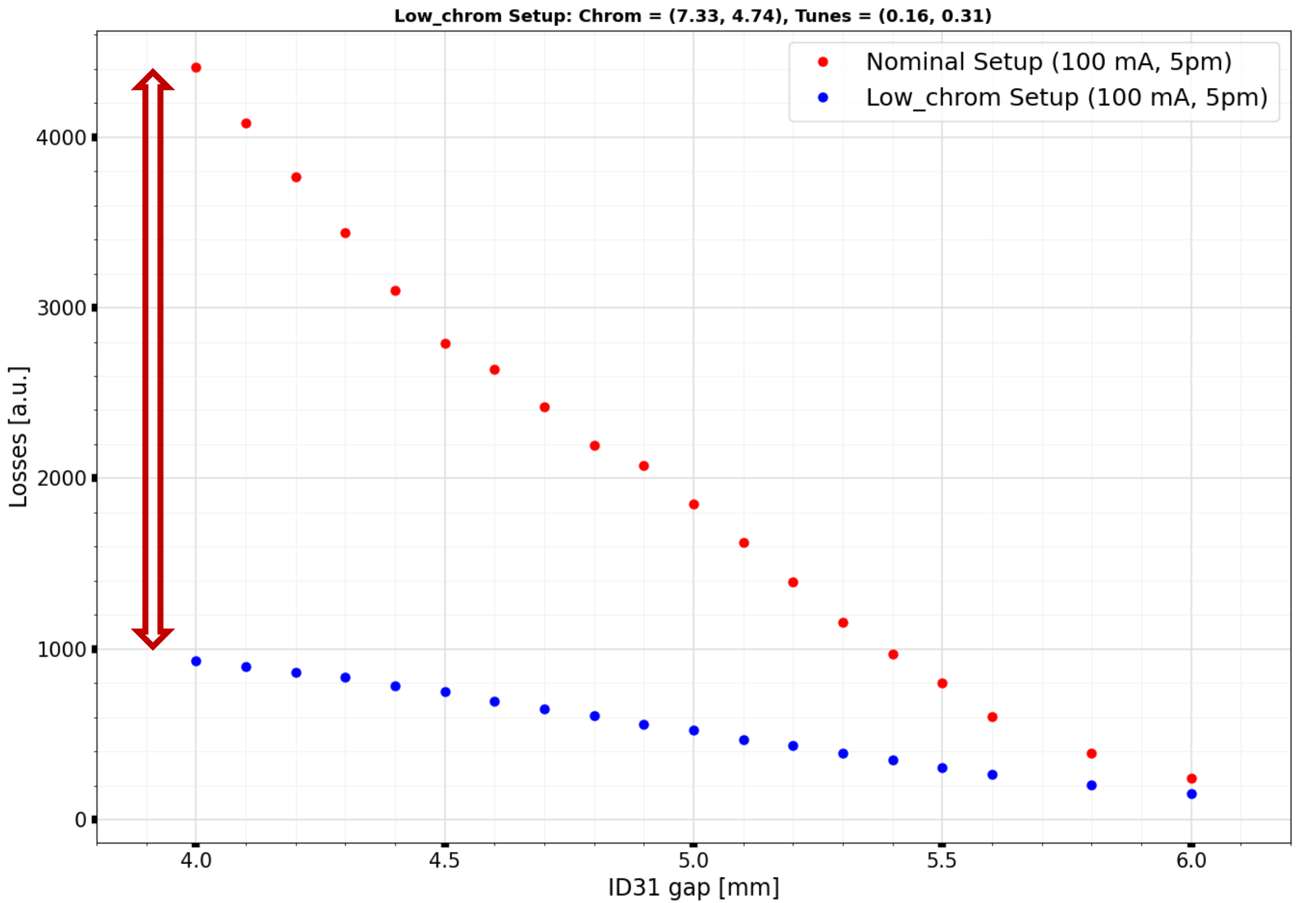
Normalized Lifetime with the vertical scrapers gap for different chromaticities.

Ex. Accepting a lifetime reduction of 10%:

- **Nominal Setup:** Aperture ≈ 5 mm
- **Low_chrom Setup:** Aperture ≈ 3.5 mm

Gap gain ≈ 1.5 mm

RESULTS



Validation of the proposed strategy:

Localized Losses at ID31 with the ID31 gap for different chromaticities.

Losses reduction at minimum gap ≈ factor 4

Previous result of ≈ factor 1,5
Obtained with lower horizontal chromaticity and larger gap (5 mm)

RESULTS

The Low Chromaticity setup was finally tested also at 200mA and 10pm of vertical emittance in **7/8** filling mode with injection efficiency and lifetime comparable with the operation file used in USM (User Service Mode).

We then inject current in the single bunch to approach the **7/8+1** USM and test the maximum current/bunch achievable without bunch-by-bunch feedback:

- Max. Current/Bunch = 4.6 mA (8 mA in USM).

✓ **Uniform filling mode.**

○ Other filling modes currently under investigation.

ACKNOWLEDGEMENTS

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THANKS FOR YOUR ATTENTION

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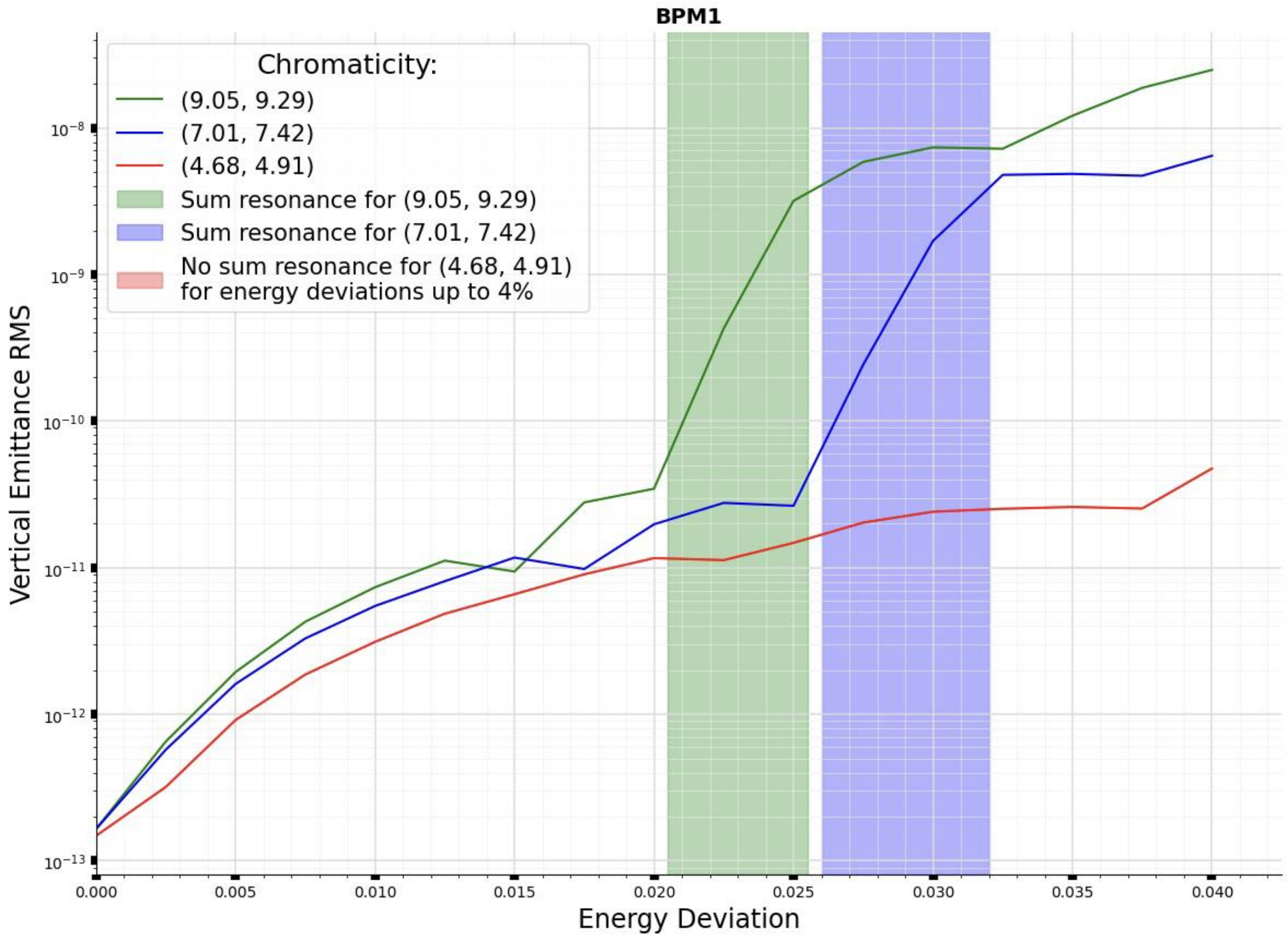
BACKUP SLIDES



BACKUP SLIDES