AccU-BTLBA

WBS 121.05.02

Jean-Francois Ostiguy, Placement of Collimators

BTLBA Collimators FDR Review

October 4, 2022

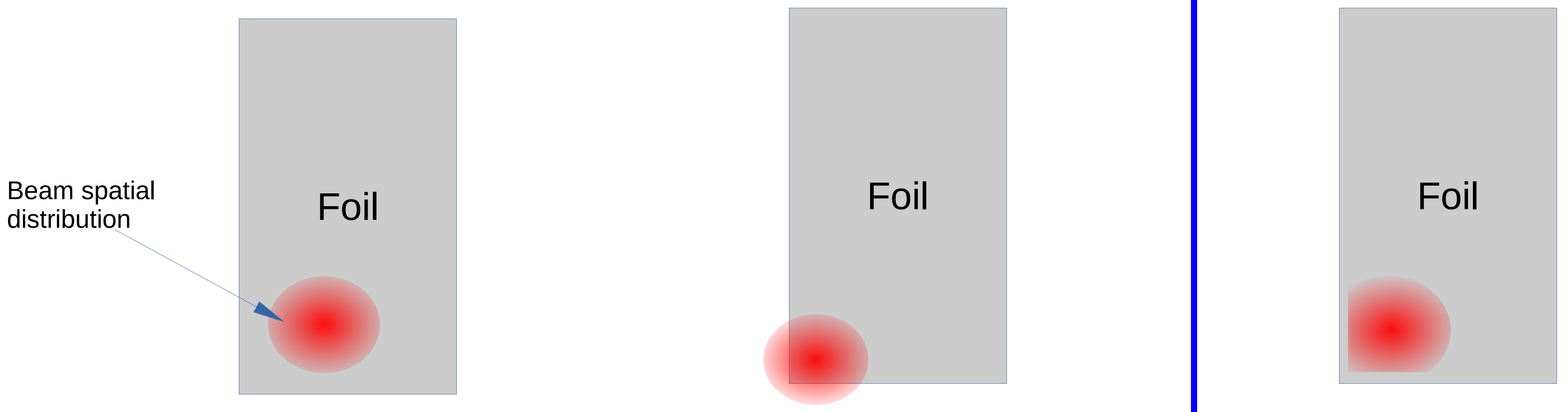
PIP-II is a partnership of:
US/DOE
India/DAE
Italy/INFN
UK/STFC-UKRI
France/CEA, CNRS/IN2P3
Poland/WUST

Outline

- Objective and Principle
- BTL layout and optical functions
- Constraints
- Simulation assumptions
- Simulation Results
- Phase Trombone
- Summary

Objective

To minimize the no of parasitic hits, the beam must be positioned as close as possible to the lower corner of the injection stripping foil. The minimal achievable distance is determined by the competing need to limit losses due to particles populating the distribution tails missing the foil. The overall function of the collimation system is to collimate in a controlled manner the far tails of the beam transverse spatial distribution so as to obtain a sharp rectangular edge at the foil.

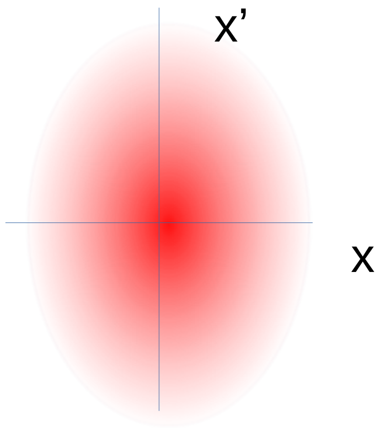


High no of parasitic hits.
No particles missing the foil.

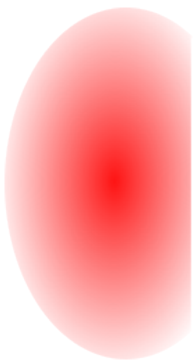
Low no of parasitic hits.
Some particles missing the foil.

Low no of parasitic hits.
No particles missing the foil.

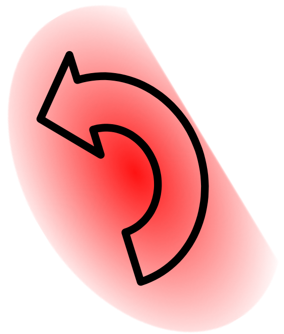
Principle



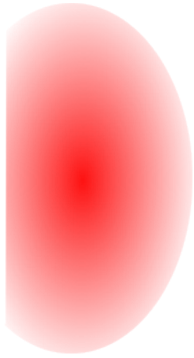
Phase space distribution
at quadrupole location



Phase space distribution
after collimation.



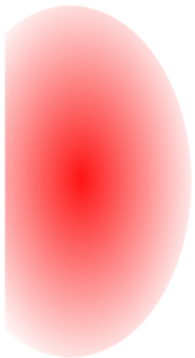
Collimated phase space
distribution at a
downstream location



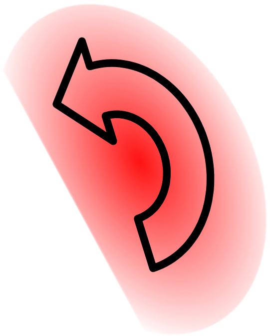
Collimated phase space
distribution at foil after (2n+1)π
phase advance accumulation

Non ideal Phase
Advance at Foil

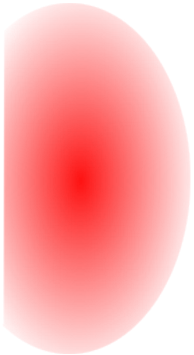
Since collimation
May be performed on either
side, locations that are π apart
in phase are equivalent.



Phase space distribution
after collimation on the left

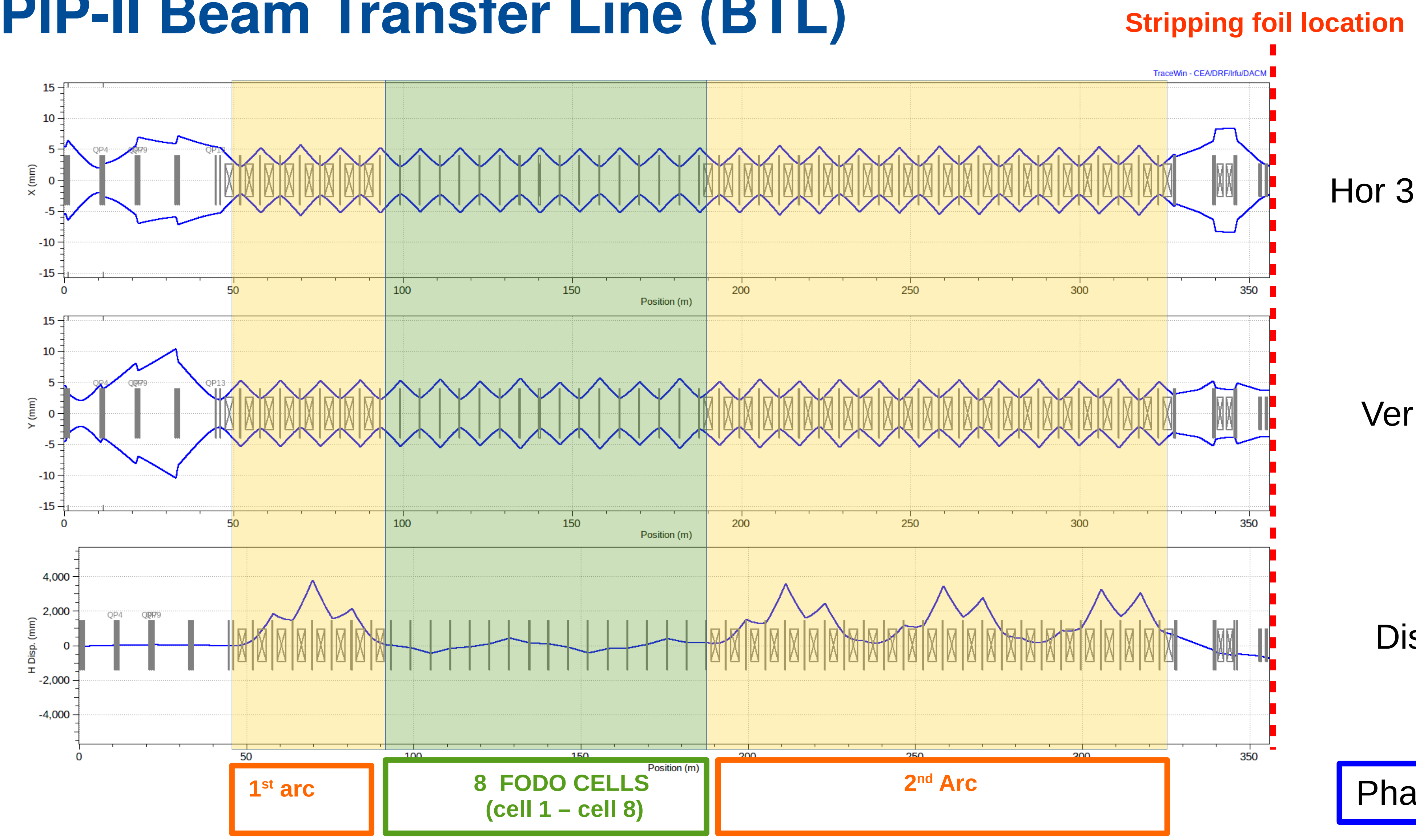


Collimated phase space
distribution at a
downstream location



Collimated phase space
distribution at foil after
2n π phase advance
accumulation.

PIP-II Beam Transfer Line (BTL)



Hor 3-sigma envelope

Ver 3-sigma envelope

Dispersion

Phase advance/cell ~ π/2

Constraints

- For maximum efficiency, collimation should take place at locations where the beam size (β function) reaches a maximum. Horizontal (vertical) collimation is therefore performed as close as possible downstream of a horizontally (vertically) focusing quadrupole.

- The dispersion at collimator locations should be small so as to minimize beam motion induced by energy jitter.

- Enough longitudinal space must be available to accomodate a collimator assembly (primary and secondary jaws inside a shielded enclosure + vacuum connections)

- The accumulated phase advance between collimator and foil should be as close as possible to an integer multiple of π. Since collimation can be performed on either side (L/R or T/B), collimator locations that are (almost) $n\pi$ apart are (almost) equivalent. In the BTL, the total accumulated phase advance between collimator H/V locations and foil are not exact multiples of π. This phase advance depends on a number of factors:

  - Accounting for the space needed for a vacuum connection and the enclosure assembly, the primary collimator jaw must be positioned at least 650 mm (25 in) downstream of a quadrupole.
  - The phase advance per cell both within the BTL and in the arcs is very nearly but not exactly $\pi/2$ (due to bending magnet edge focusing and space charge). These deviations from $\pi/2$ accumulate over many cells.
  - The H/V phase advances from the last cell of the 2nd arc to the foil are constrained by matching requirements for the Booster painting scheme.

Location Selection

- The best candidate locations are the 8 dispersion-free FODO cells (16 half-cells) in the straight section between the two arcs. The quad-to-quad separation in each half-cell is approximately 5.5 m.

- Many of the straight section half-cells are claimed for instrumentation or for a future rf deflector cavity. After careful consideration of other needs and requirements, it was determined that only the straight section cells 1,2, and 3 were available.

- It was determined from simulation that the combination cell 2 [H]/cell 1 [V] is the most favorable (provides the sharpest transverse distribution cut at the foil location). However, cell 3 is equivalent to cell 1 (almost exactly π apart in phase).

- Locating the vertical collimator in cell 1 helps keeping both collimators (radiation) as far as possible from downstream instrumentation (sensitive electronics) and other devices (e.g. a future deflector cavity).

- **Cell 1 was selected for vertical collimation**, **Cell 2 for horizontal collimation**.

Simulation Assumptions

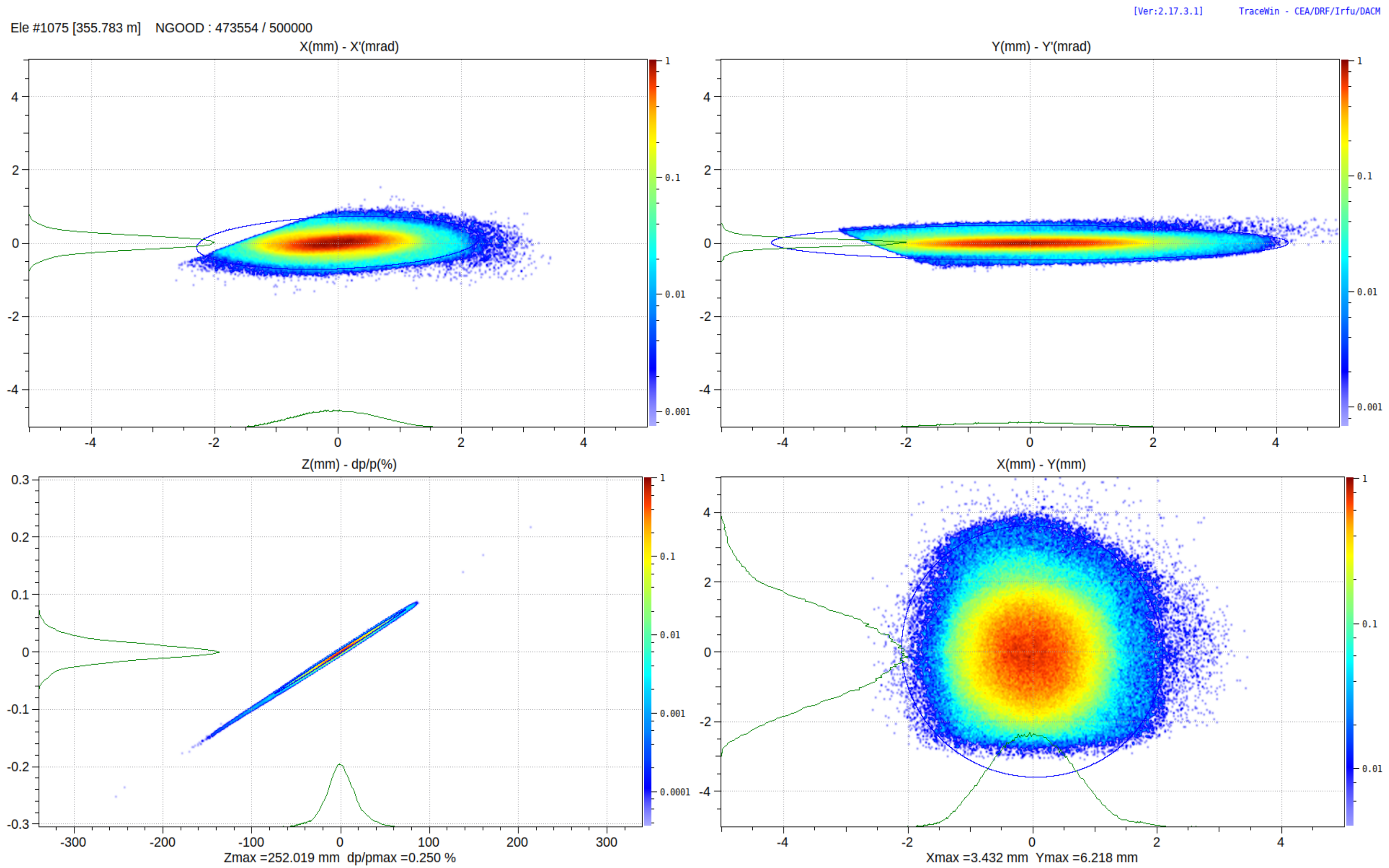
- Collimator jaws are located approximately 635 mm (~ 25 in) downstream of the nearest upstream quadrupole

- Horizontal collimator is located in cell 2 (1st ½ cell)
- Vertical collimator is located in cell 1 (2nd ½ cell)

- Collimator jaw position is set at ~2.5 sigma

- The particle distribution used is a “realistic” (and probably pessimistic) distribution that has a somewhat larger emittances and dp/p than the nominal specification. It was obtained by start-to-end tracking in a linac with errors.

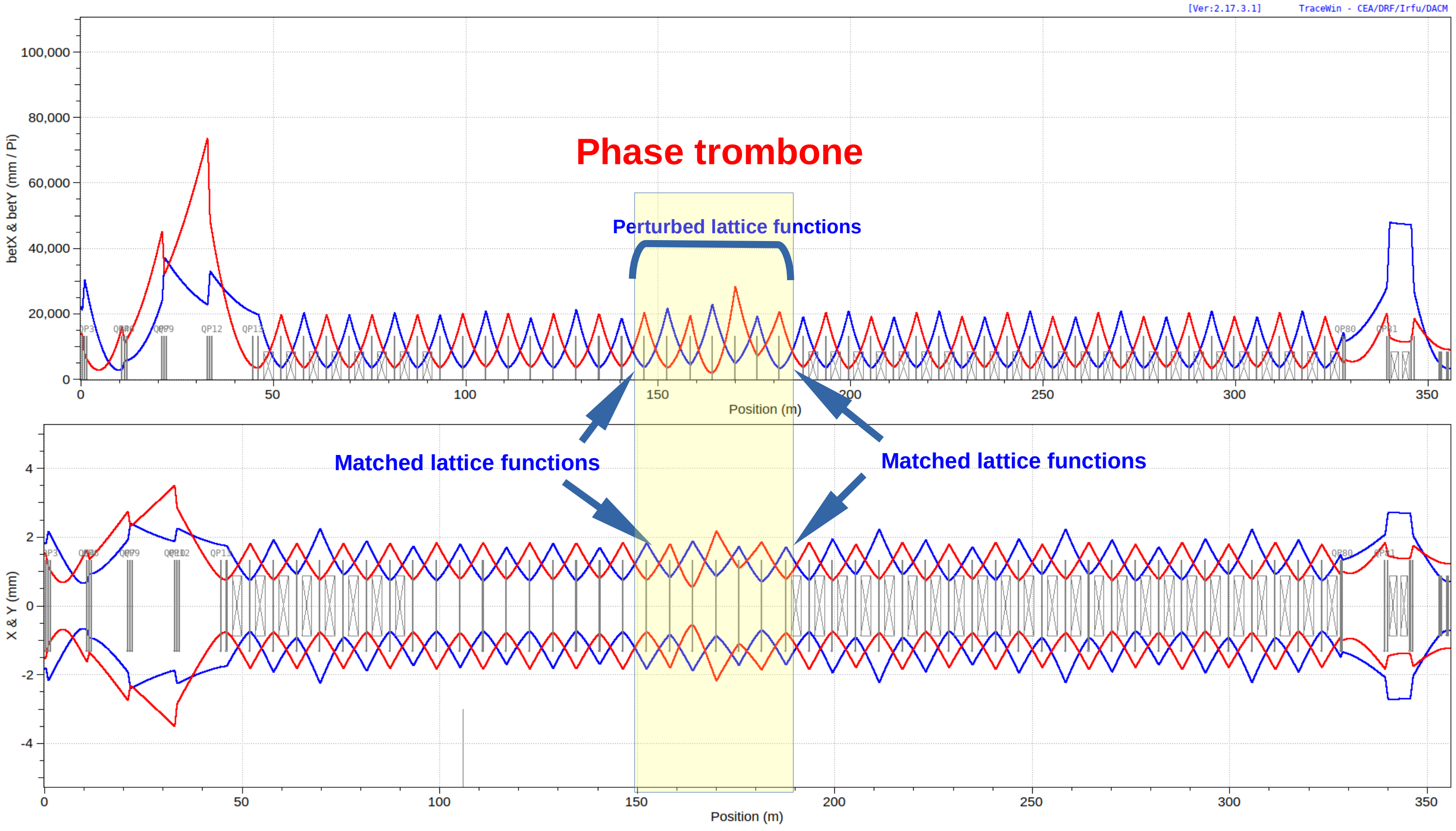
Collimation Cell 2 [H] and Cell 1 [V]



No phase advance correction.

500 k Particles

Phase Advance Adjustment using Trombone



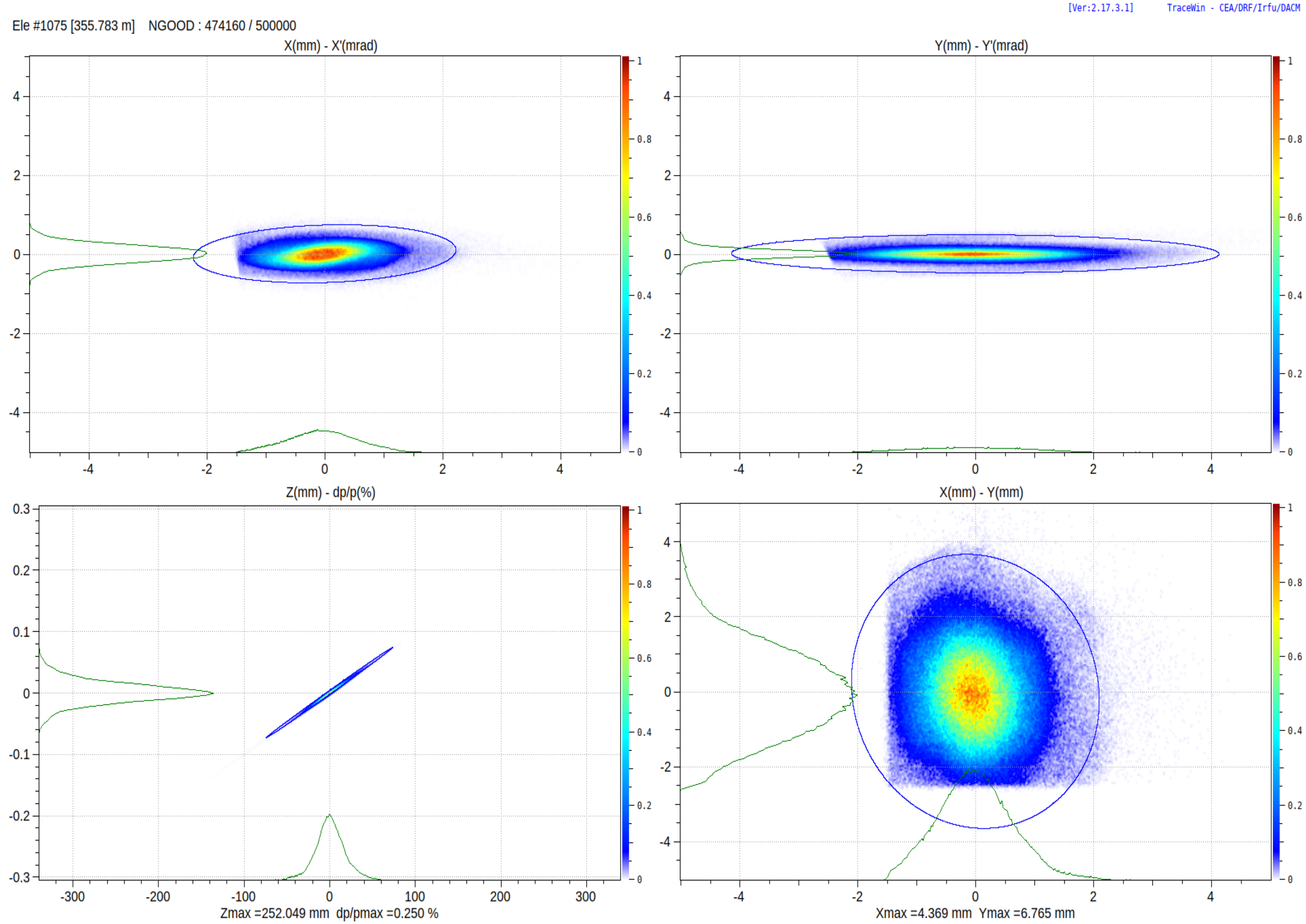
Rms transverse beam sizes shown

The phase trombone encompasses 3 FODO cells (cells 6,7,8). 6 individually powered quadrupoles allow the lattice functions to remain matched to their nominal design values at both upstream and downstream boundaries (cell 5 2nd half and 2nd arc entrance). Within the trombone region the β-functions may vary, to allow adjusting the phase advance accumulated between each collimator location and the foil.

The accumulated phase advance determines the orientation of the collimator cut in the phase space plane at the foil location.

The phase trombone does not perturb the downstream lattice functions. The lattice functions at the foil are set by the phase space painting procedure.

Distribution at Foil after Phase Advance Adjustment



Correction applied
H = -30 deg, V= + 30 deg

Summary

- The main function of the BTL collimators is to sharpen the edges of the transverse spatial distribution so as to allow the beam to be positioned as close as possible to the foil corner. The beam position is a trade-off between losses due to particles missing the foil and losses due to parasitic foil hits.
- Ideally, collimation should be performed at a location where the β-function reaches a maximum i.e. at a quadrupole location. This is only approximately achievable, because the primary collimator jaw must be located dowwnstream inside a rather substantial shielded enclosure.
- To get the sharpest possible spatial distribution edges, the phase advance between collimator and foil must as close as possible to an integer multiple of π. In the base PIP-II BTL lattice this is only loosely realized.
- Using a phase trombone to adjust the accumulated phase advance, a near ideal edge orientation in phase space can be achieved without perturbing the lattice functions at the foil.