# Some Considerations on pbar Separator Sextupoles and Steerers


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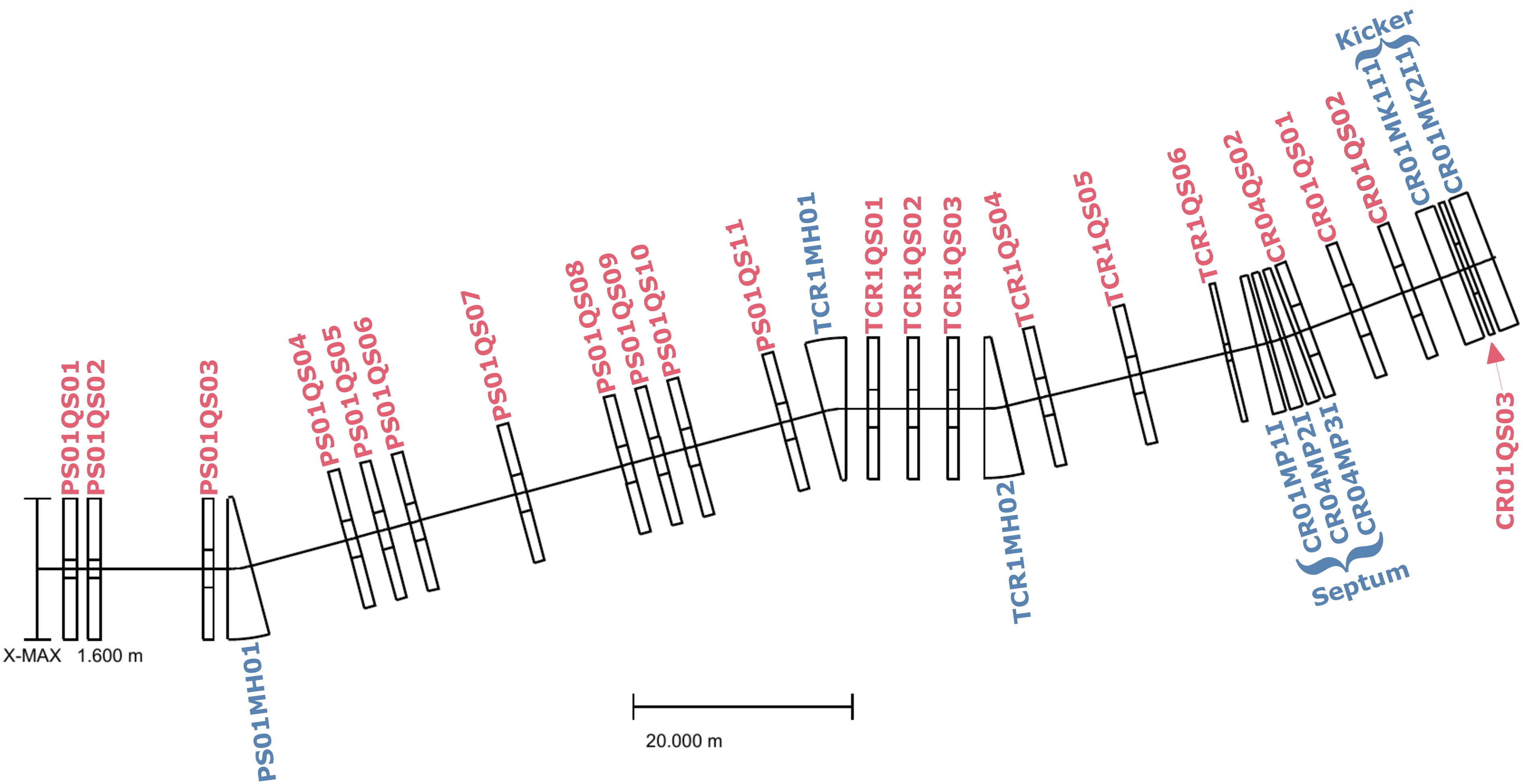
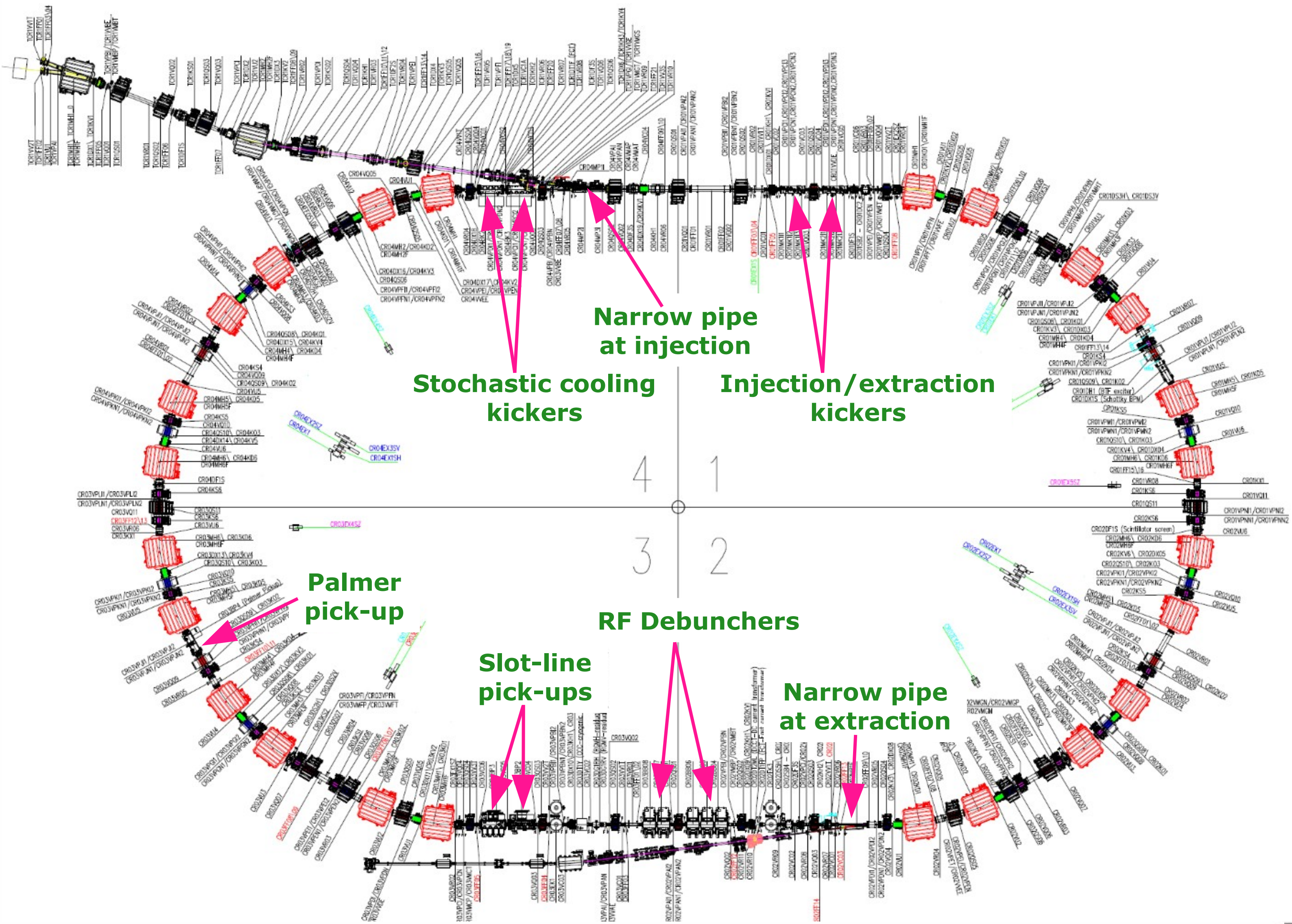
# pbar Separator and Injection Overview



# CR and Injection/Extraction Overview



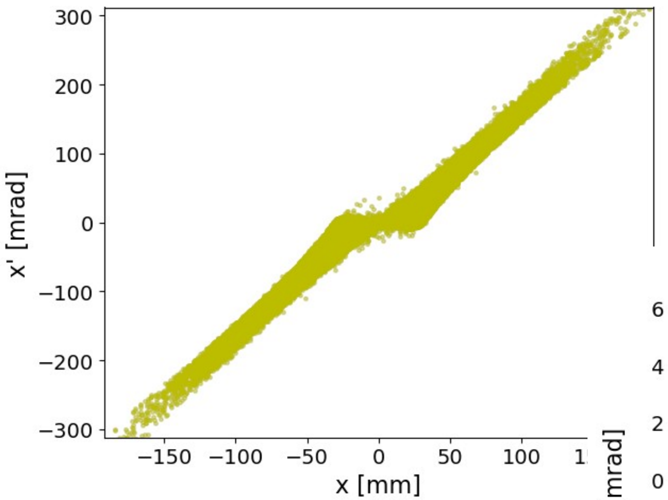
# Simulation Software

- GICOSY is an ion optics software based on COSY 5.0, developed at the University of Gießen, Germany and still maintained also at GSI (web-docs.gsi.de/~weick/gicosy/). It has been used to assess parameters such as beta and dispersion function, twiss parameters and envelopes and to generate the transfer matrices of the ion optical elements as needed by MOCADI.

- MOCADI is a Monte Carlo simulation software developed and maintained at GSI (web-docs.gsi.de/~weick/mocadi/) which has been used to assess losses using realistic aperture shapes and an initial pbar distribution due to a MARS simulation of pbar generation through proton-target interaction followed by magnetic horn focusing*.

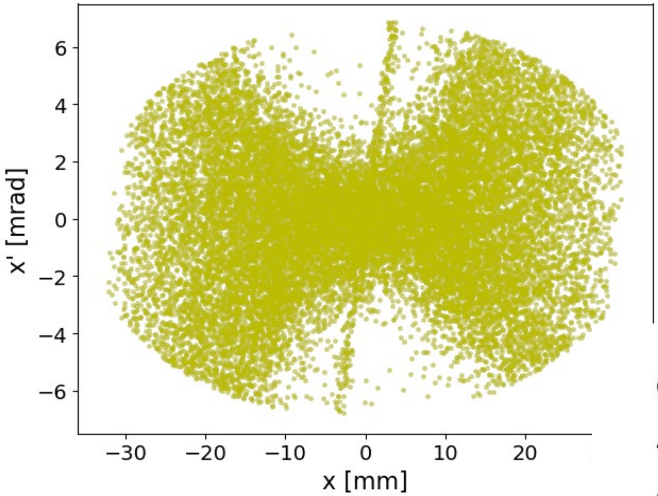
* horn focusing simulated by dedicated software

# Input Beam Distributions used with MOCADI

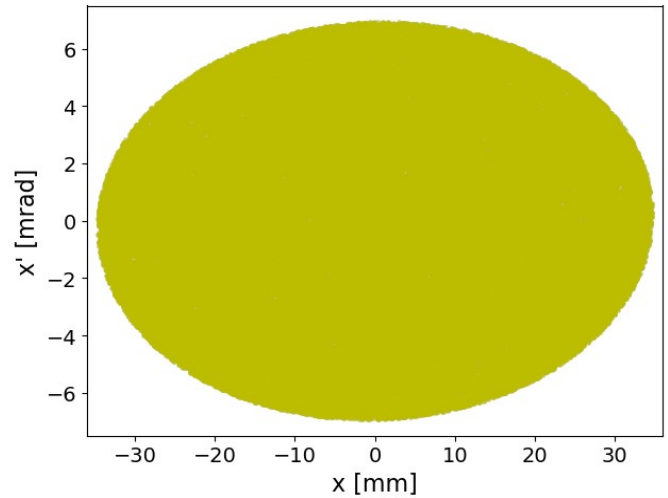



13 Tm ± 10% or 13 Tm ± 3% selection from a MARS generated beam, no acceptance limitation

Acceptance limited, 13 Tm ± 3% selection from a MARS generated beam; in some cases 13 Tm sharp were set for all particles




Uniformly distributed, acceptance limited 13 Tm sharp or 13 Tm ± 3% beam



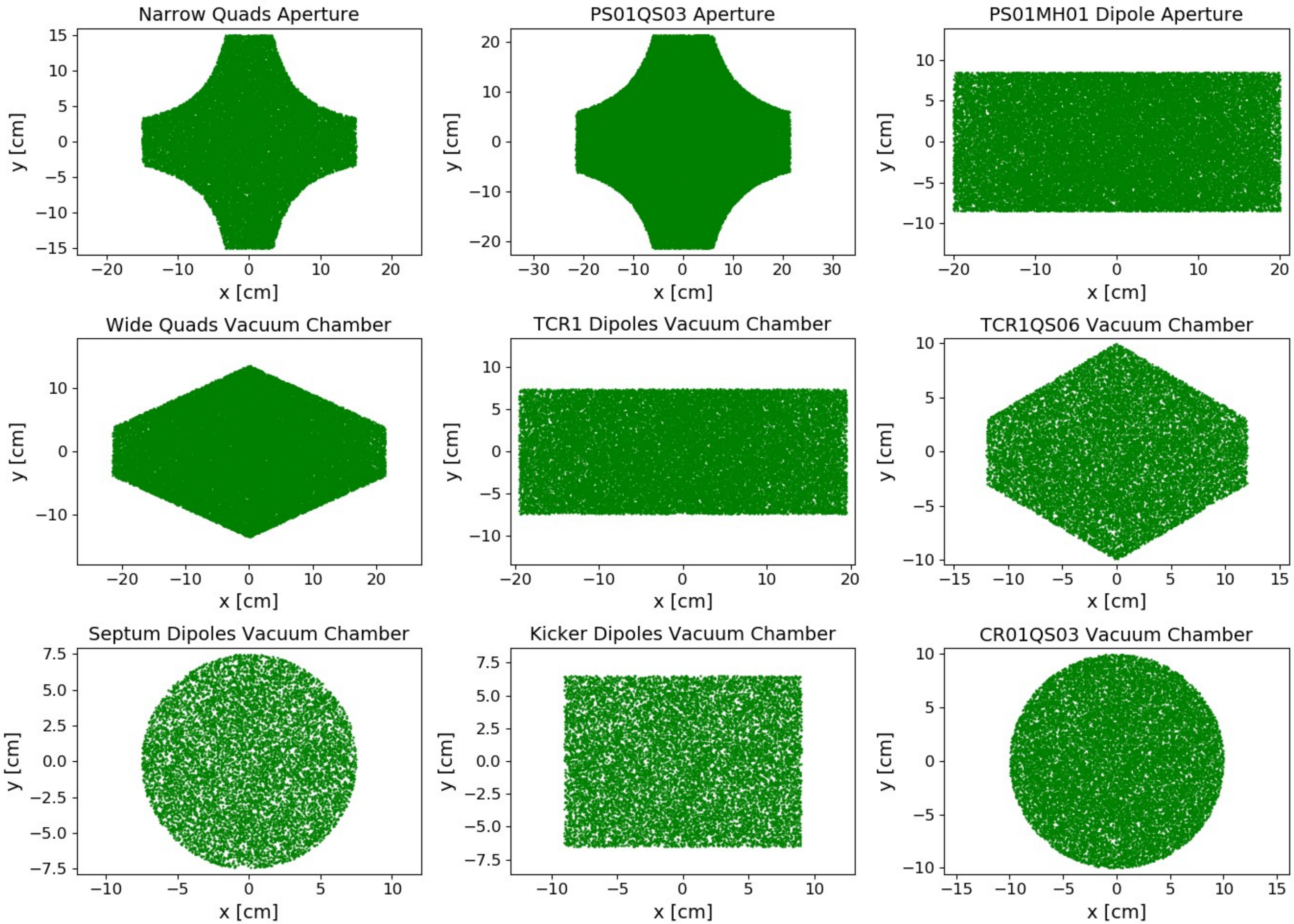

**Note:** Here acceptance is to be understood as purely geometrical, i.e. as defined by the x-x' and y-y' phase space ellipses. The ellipses used for the acceptance limited beams depend on the quad settings and position of the horn's exit plane, since they have to be imaged onto those defining the CR's acceptance.

# Remarks on Collimators used in MOCADI

- Collimators are either elementary, i.e. fully absorbing and infinitesimally thin, or composed of elementary ones.
- The horizontal-vertical (HV) collimator placed between the magnetic horn and PS01QS01, the beamline's first quadrupole, is simulated by two identical elementary collimators in 1.6 m distance from each other. The reference HV-collimator has a circular aperture with a 70 mm diameter.
- The horizontal and vertical collimators between PS01QS02 and PS01QS03 and the momentum collimator between PS01QS04 and PS01QS06 are each elementary ones.
- Quadrupole apertures* are simulated as three subsequent elementary collimators: at entrance, in the middle and at exit.
- Dipole apertures* are simulated as two subsequent elementary collimators: at entrance and at exit. **Exception:** the septum dipoles, where there are five elementary collimators per dipole.
- A special phase space collimator is used for assessing losses to be expected due to particles not within the ring's (geometric) acceptance.

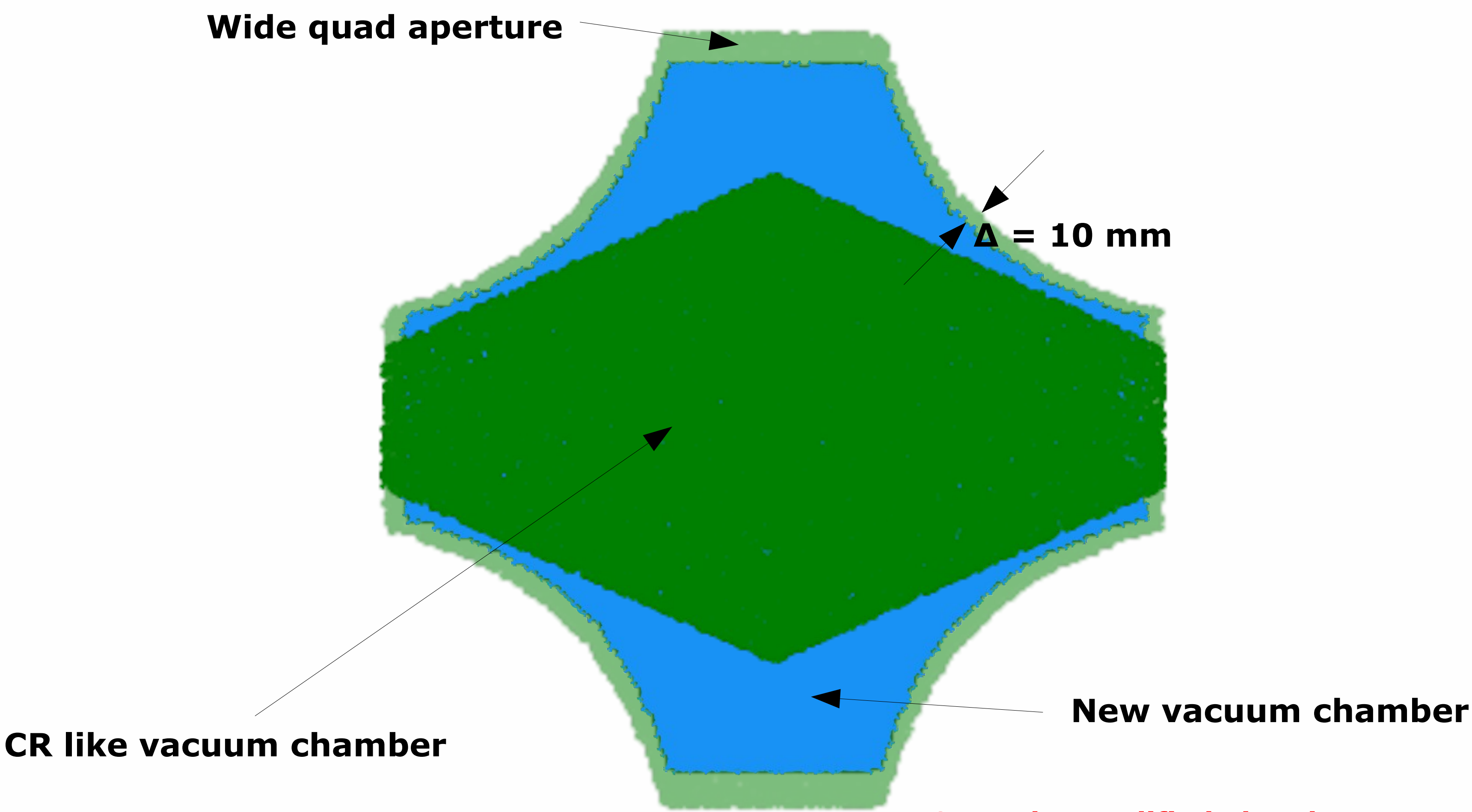
* due to yoke or vacuum chambers

# Reference Apertures used with MOCADI




**Note:** CR01QS03 has an associated aperture of 200 mm diameter in all simulations!

# Reducing Losses by Chamber Modification

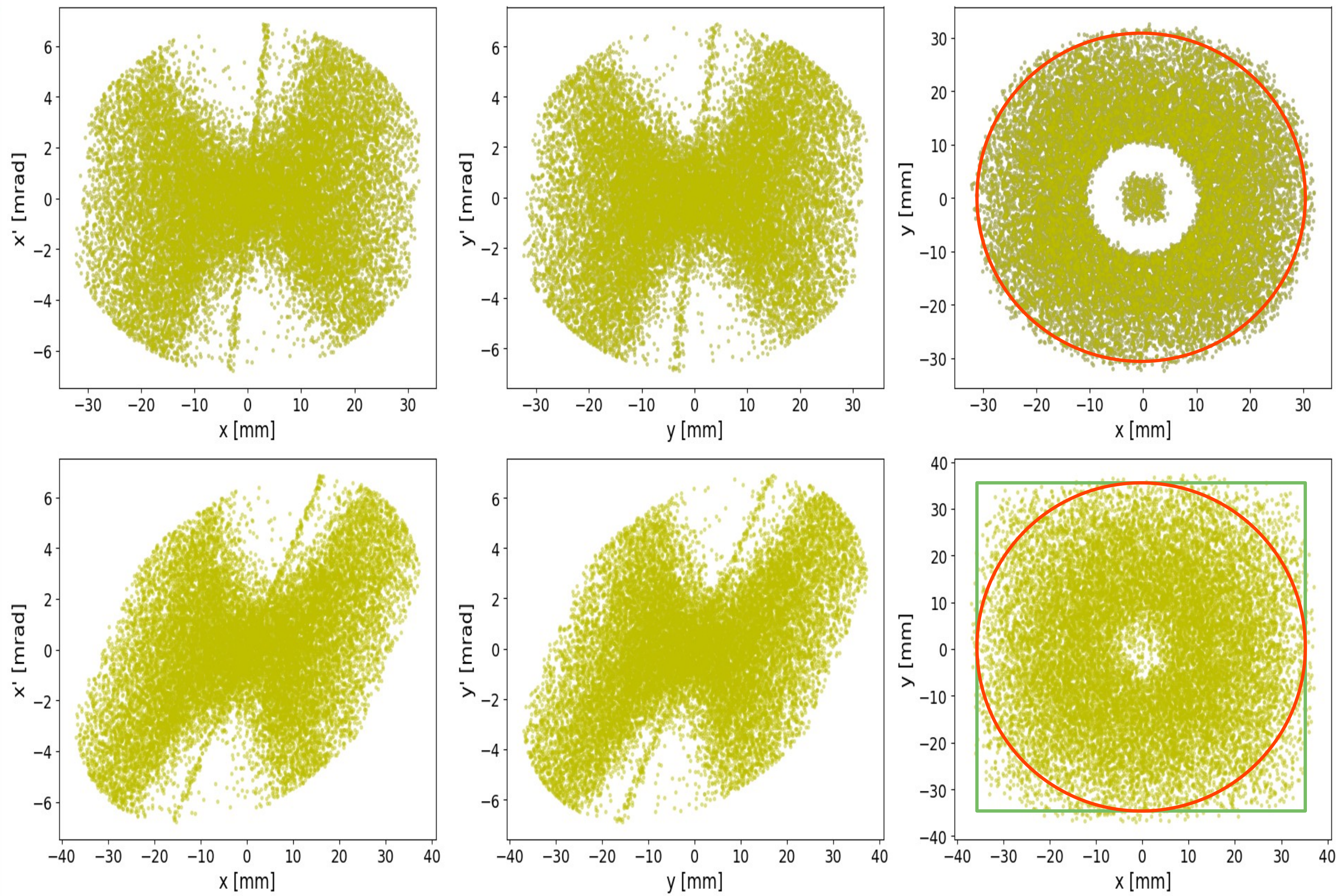



**NOTE: The modified chambers are used in the simulations only for the PS01QS04-06 quadrupole triplet.**

# Specific CR Apertures*

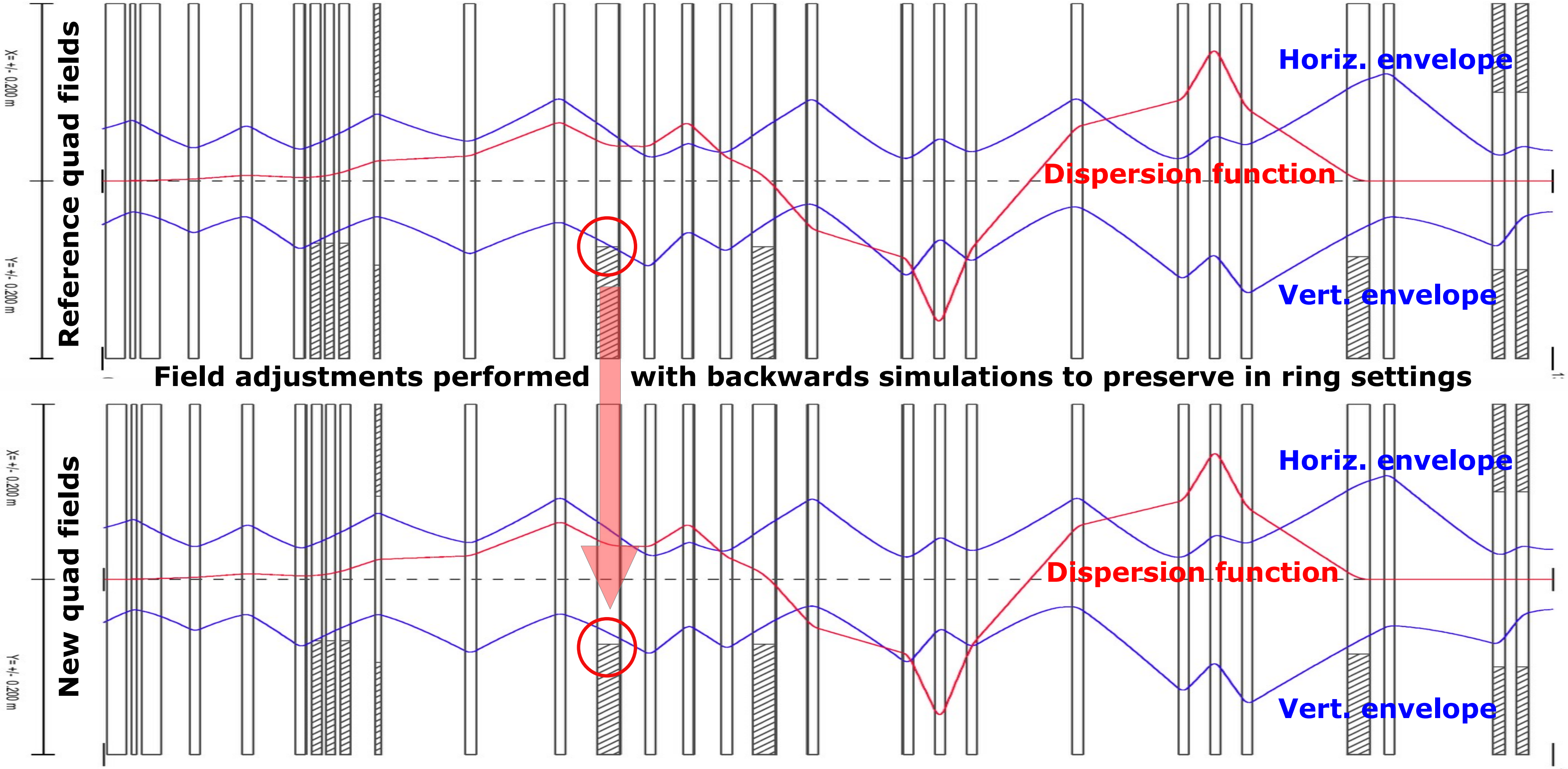
- 175 mm diameter for all narrow quads except CR01QS03, which has a 200 mm diameter aperture
- WxH = 136 mm x 170 mm for the narrow, 2.66 m long pipes at injection and extraction
- 150 mm diameter for the RF debunchers
- ±80 mm vertical and horizontal limitations respectively for the two stochastic cooling slot-line pick-ups (vertical limitation upstream of the horizontal one)
- WxH = 400 mm x 132 mm for the stochastic cooling palmer pick-up
- 140 mm diameter for the slot-ring electrodes of the stochastic cooling kickers
- The diamond shaped apertures specific to the wide CR quadrupoles have also been used for the associated sextupoles

* not included on slide 7




**Note:** Particle distributions at horn's exit plane (upper graphs) and after a drift to the position of the collimator's exit plane. No collimator used for this simulation!

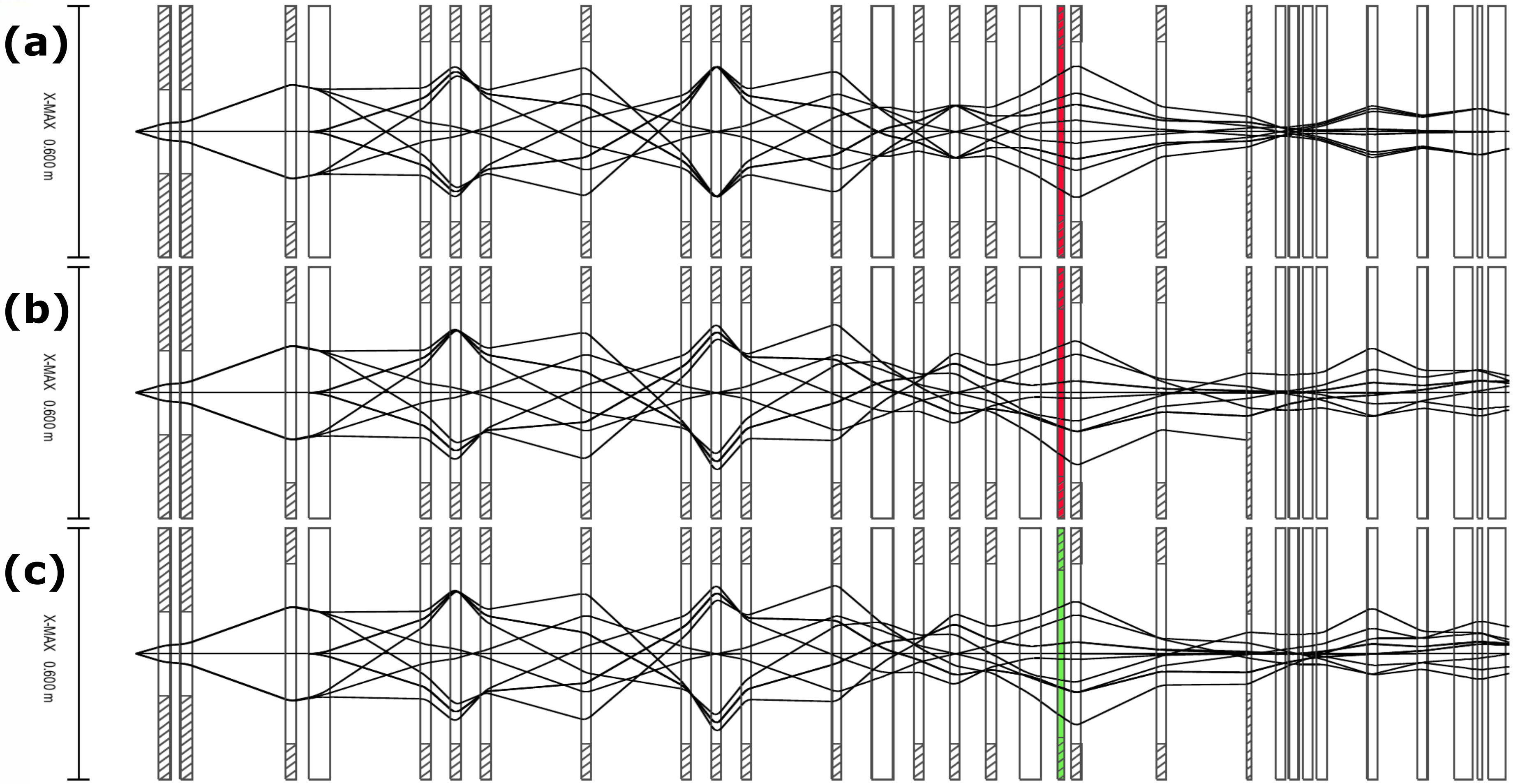
# Reducing the Beam Envelope @ TCR1MH02




**Field gradients in T/m – only for quads with changes**

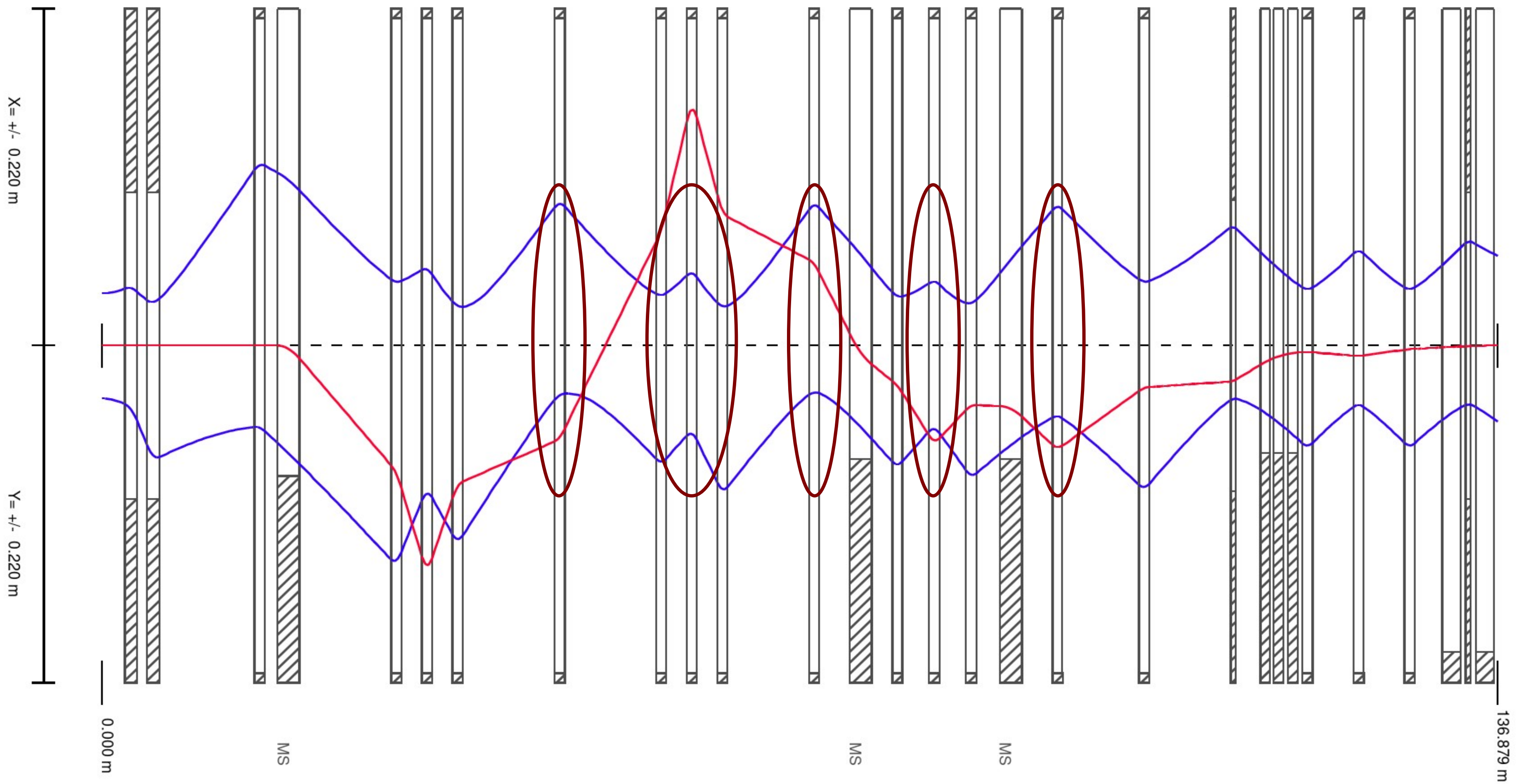
| | PS01QS02 | PS01QS04 | PS01QS05 | TCR1QS04 | TCR1QS05 | TCR1QS06 |
|---|---|---|---|---|---|---|
| Reference | -3.24821 | -2.40617 | 3.90601 | 2.10321 | -1.79760 | 3.93614 |
| New | -2.97 | -2.23857 | 3.84080 | 2.16377 | -1.97023 | 4.09569 |

# Adding a Sextupole to Reduce Losses in Septum




Ray tracing simulations performed with GICOSY. A point source emits along three different directions respectively three rays of different energies, including the reference one. **a)** 1st order simulation, sextupole is **off** (but also irrelevant); **b)** 3rd order simulation, sextupole is **off**; **c)** 3rd order simulation, sextupole is **on**.

# Adding more Sextupoles: Where to Place Them?




Beam envelopes (in blue) and horizontal dispersion function (in red) along the pbar separator beam line. A rule of thumb for placing sextupoles is: large horizontal dispersion (at best a maximum) and low vertical beta function (lower than the horizontal one is better). Some options are indicated on the image above. However, there are no obviously ideal positions. Several configurations have been tested.

# Adding more Sextupoles: Strengths and Solution*

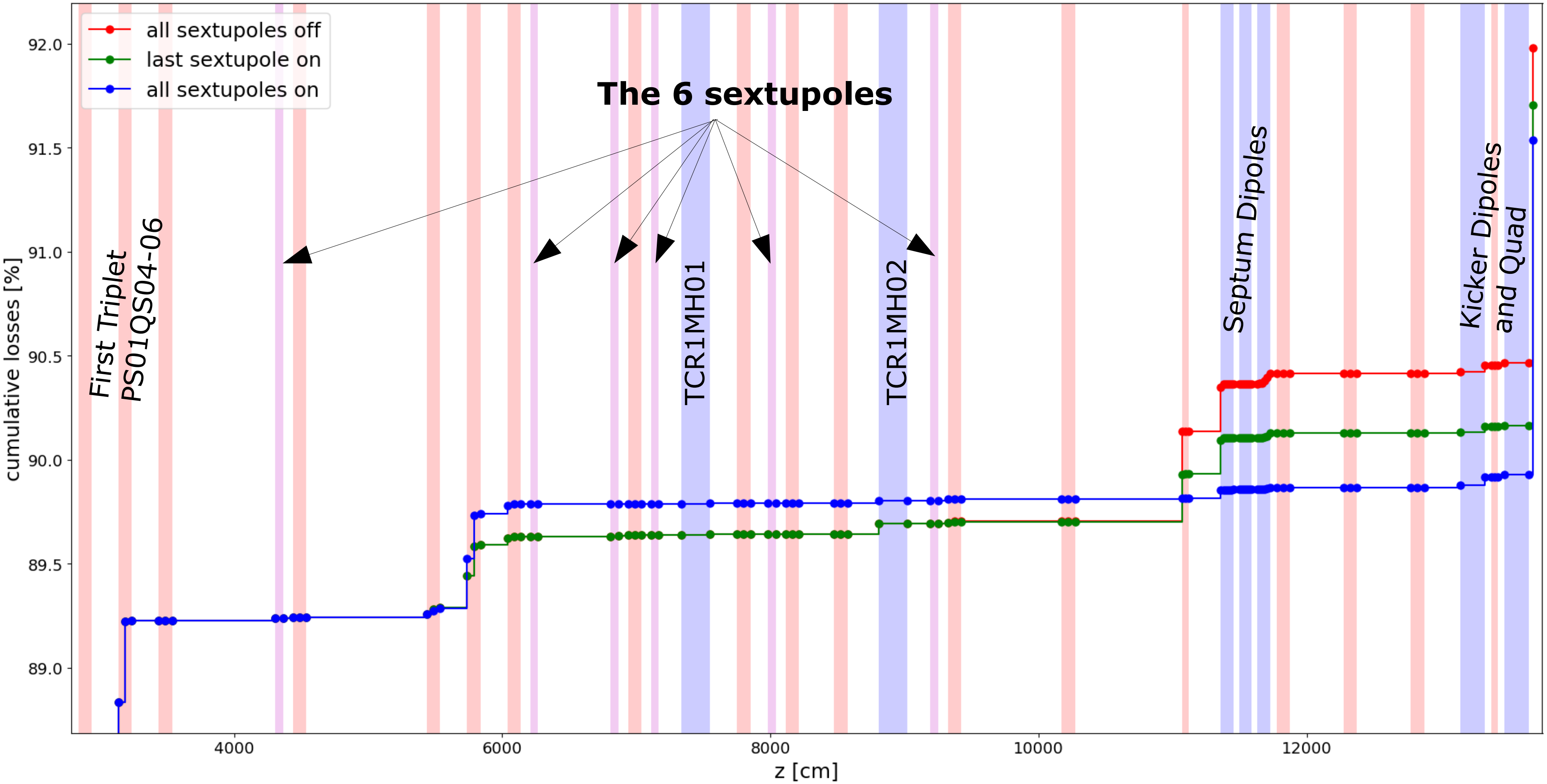
GICOSY offers the possibility to automatically search for the optimum of a configuration by varying given parameters such as to zero a target function depending on them. The target function used for optimizing the sextupole strengths for each of the tested configurations achieved zero if for a test particle the non-linear contributions were a small fraction of the linear ones (ideally zero).

Present solution:

| Name | Position | Strength [T/m$^2$] |
|---|---|---|
| PS01KS01 | 0.7m upstream of PS01QS07 | -2.60875 |
| PS01KS02 | 0.7m downstream of PS01QS10 | -1.28035 |
| PS01KS03 | 0.7m upstream of PS01QS11 | 3.57125 |
| PS01KS04 | 0.7m downstream of PS01QS11 | -4.25000 |
| TCR1KS01 | 0.7m upstream of TCR1QS02 | -0.10861 |
| TCR1KS02 | 0.7m upstream of TCR1QS04 | -1.02500 |

* as good as I could get it

# Losses Comparison: Full Beam, Zoom In




**Note:** The large cumulative losses are due to the fact that the simulations have been performed with an initial beam (at the magnetic horn's exit plane) having a momentum spread of ±10% and an angular spread of ±300 mrad. Thus a factor of about 10 losses (approx. 3 respectively because of the momentum and angular spreads) is expected and confirmed by the simulations.

# CR Losses Assertion

Each simulation has been performed for 200 turns.

To assert the effect of different apertures placed along the CR a synthetic beam has been used with the following parameters: 2500 particles, uniform distribution within the phase space projections x-x’ and y-y’ respectively, uniform energy distribution of ±3.71% around the reference value corresponding to a stiffness of 13 T·m. This synthetic beam has always been generated at the position of CR’s symmetry point (center of CR01QS01).

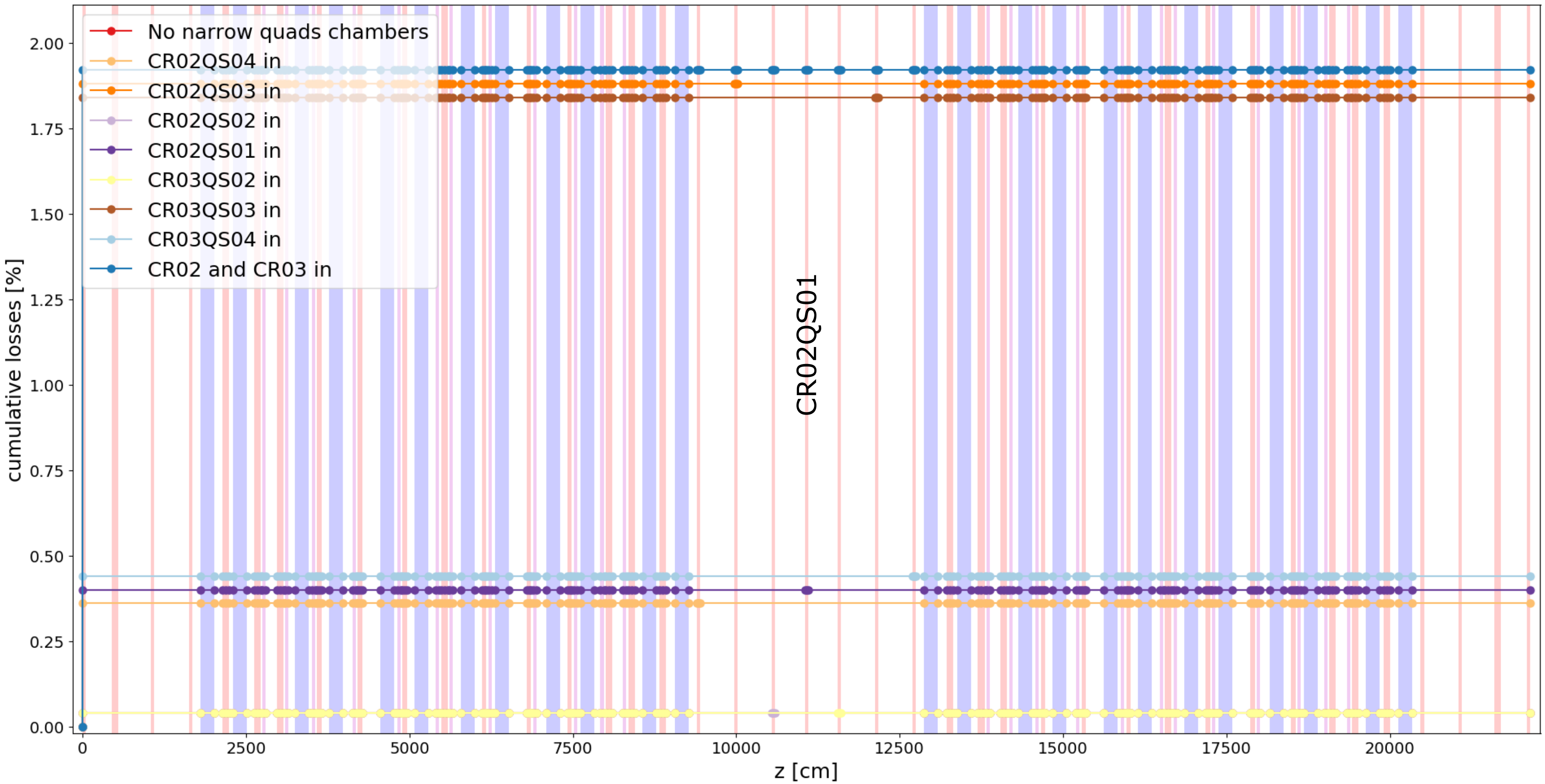
After asserting the effect of different apertures, simulations have been performed with the three different beams injected from the pbar separator respectively, i.e.: transported to the CR with no use of sextupoles, with the use of a single sextupole and with the use of six sextupoles.

First simulations performed with the synthetic beam showed that there are no losses* in the two arches of the CR as long as the CR sextupoles are switched on and only apertures are used which correspond to the vacuum chambers of the magnets along the arches. Furthermore, inclusion of the apertures corresponding to the two injection/extraction kickers did not produce any extra losses. Thus on the following slides just simulations performed by adding further relevant apertures are shown.

**IMPORTANT:** Keep in mind that the collimators used to simulate apertures along the CR are fully absorbing the particles not within their respective openings.

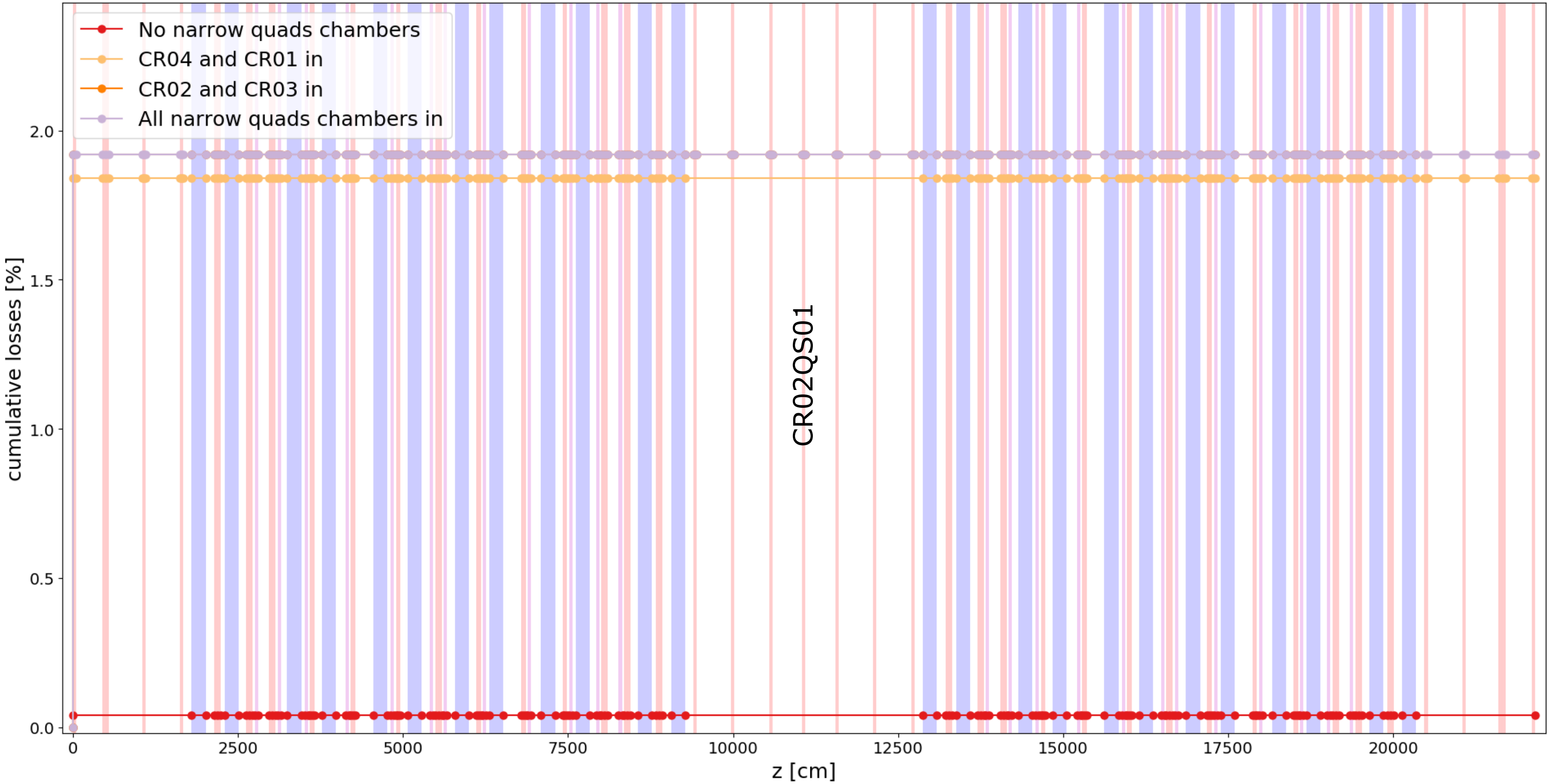
* exactly one particle gets lost systematically, this appears to be a not yet clarified software bug

# Hierarchy of Losses Along the Second Straight



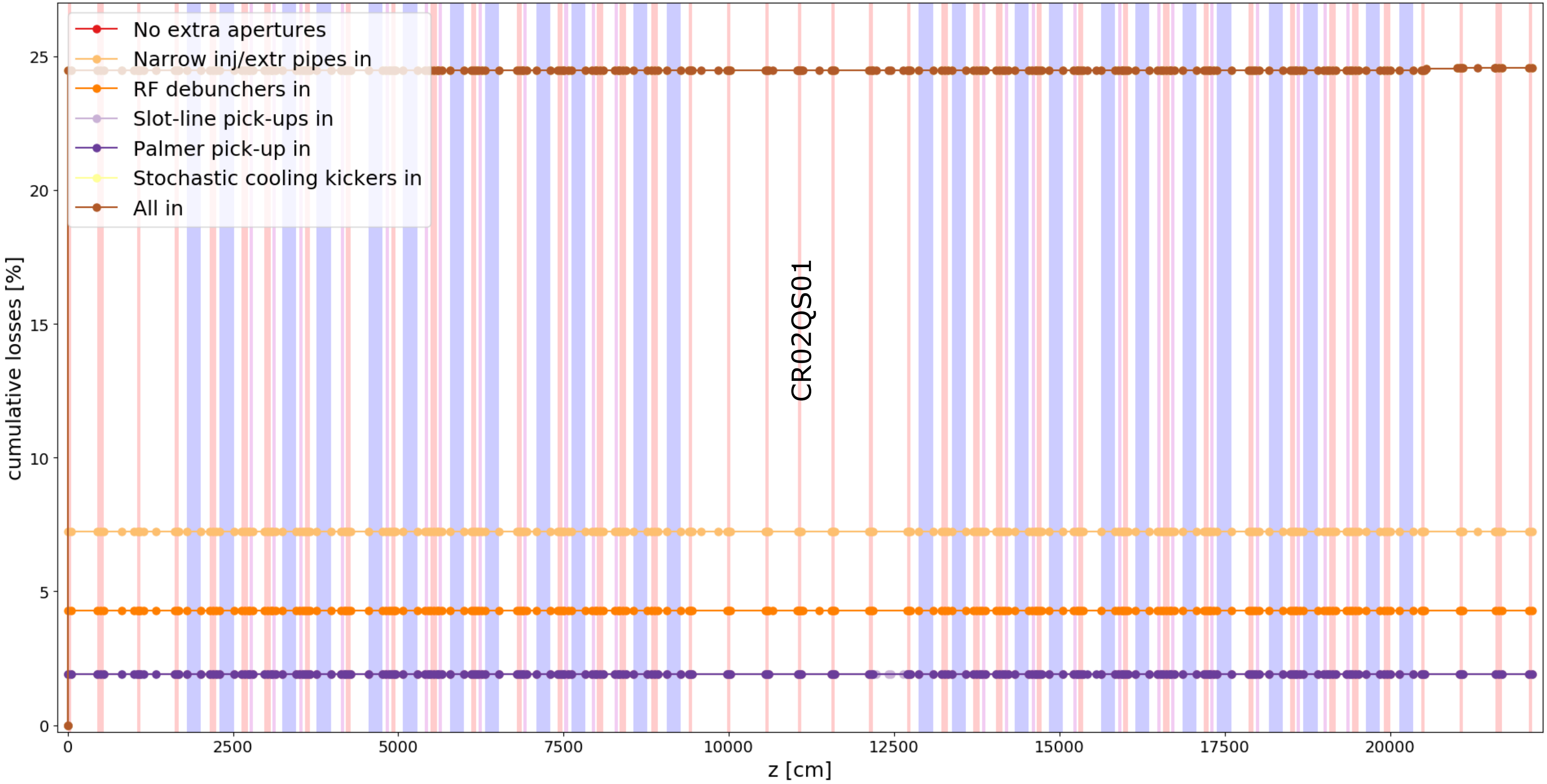

**Note:** Losses are dominated by those in CR02QS03 and CR03QS03. No extra losses are induced in CR02QS02 and CR03QS02.

# Hierarchy of Losses Along Both Straights



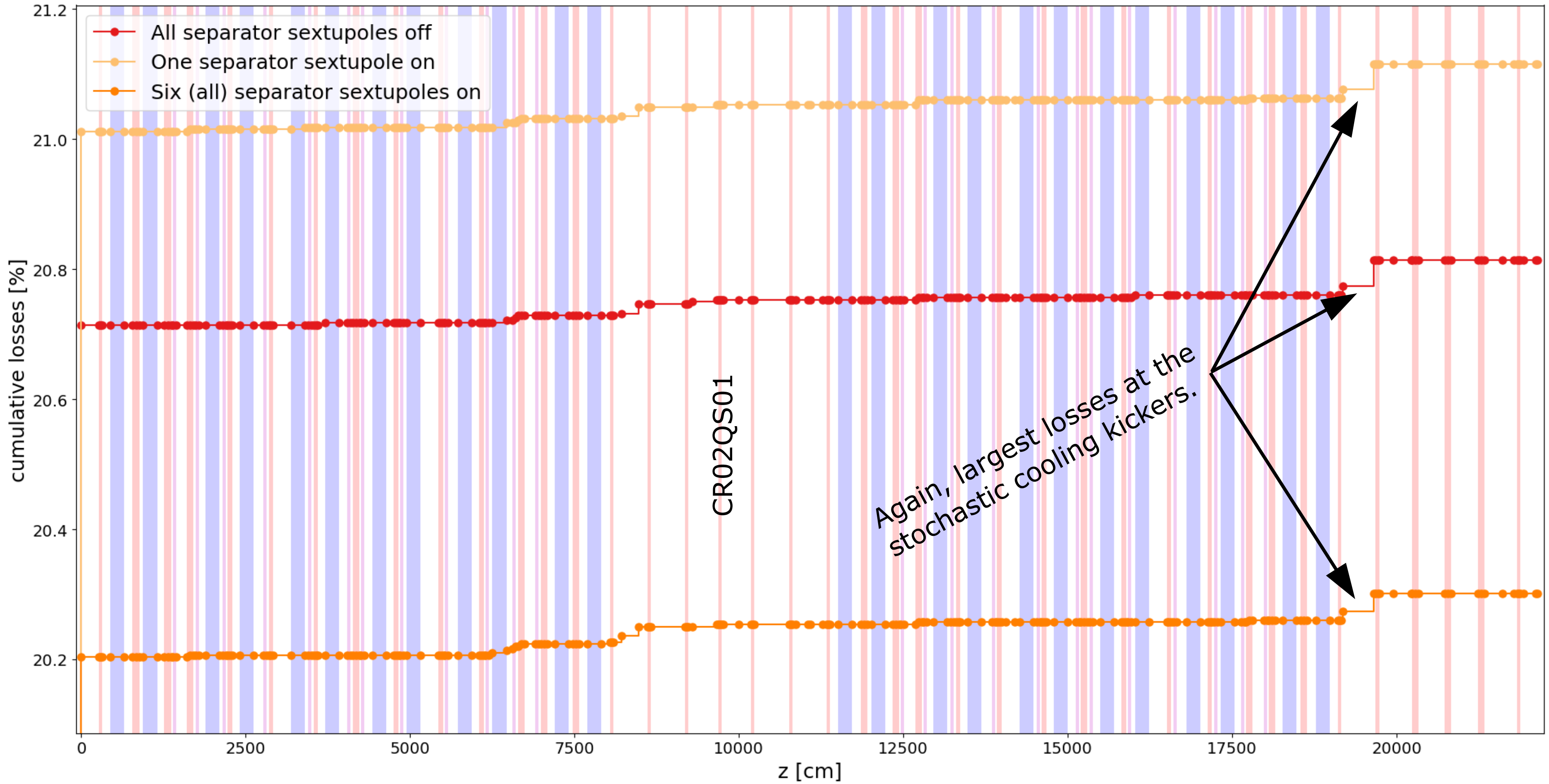

**Note:** The losses are slightly lower in the CR04-CR01 straight and finally determined by those in the CR02-CR03 straight.

# Hierarchy of Losses due to Extra Apertures



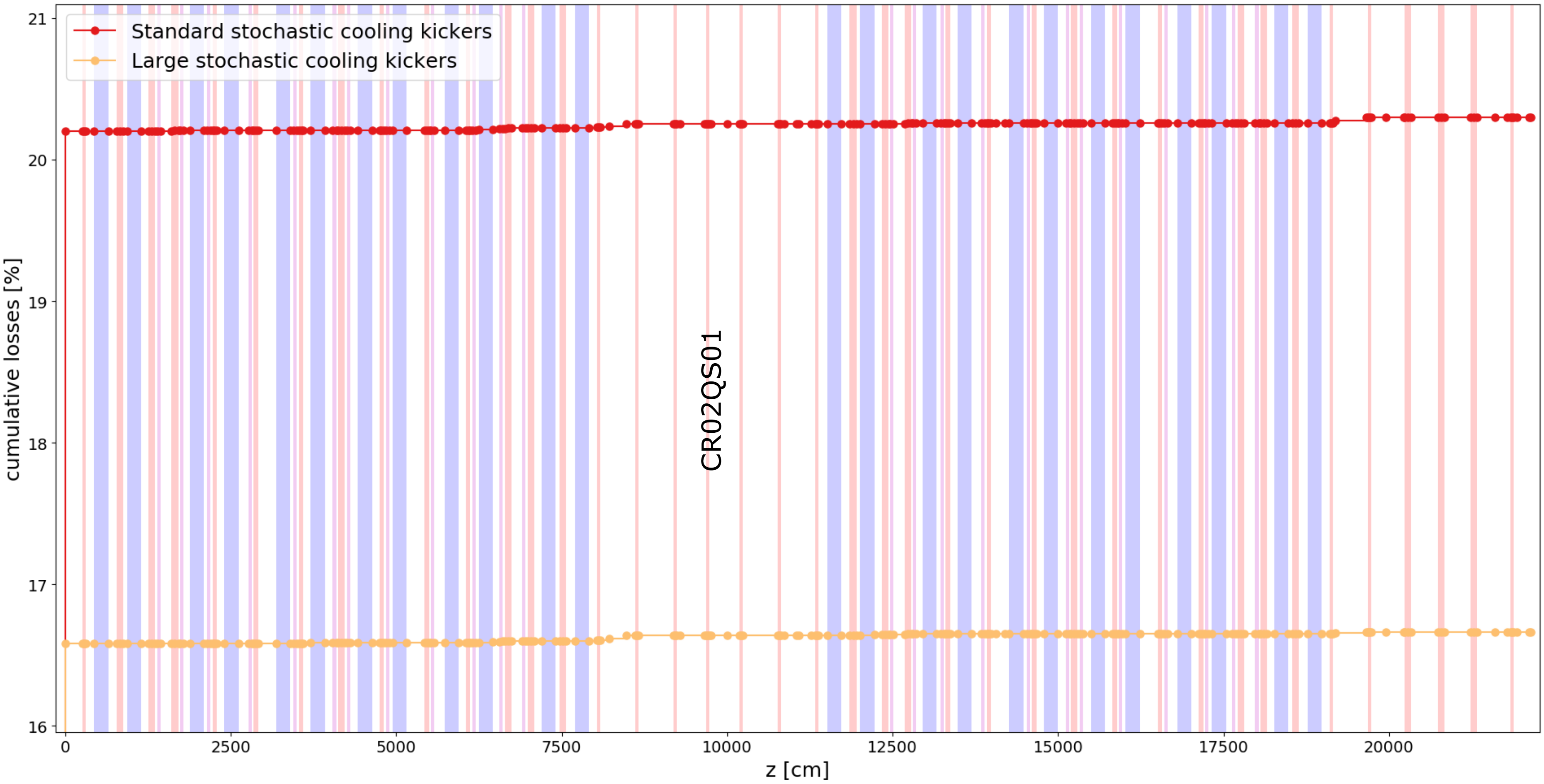

**Note:** Losses are strongly dominated by those in the stochastic cooling kickers, which even when used alone produces the same losses as observed with all relevant apertures taken into account. No losses are observed at the stochastic cooling pick-ups.

# Losses with All Extra Apertures, Realistic Beams



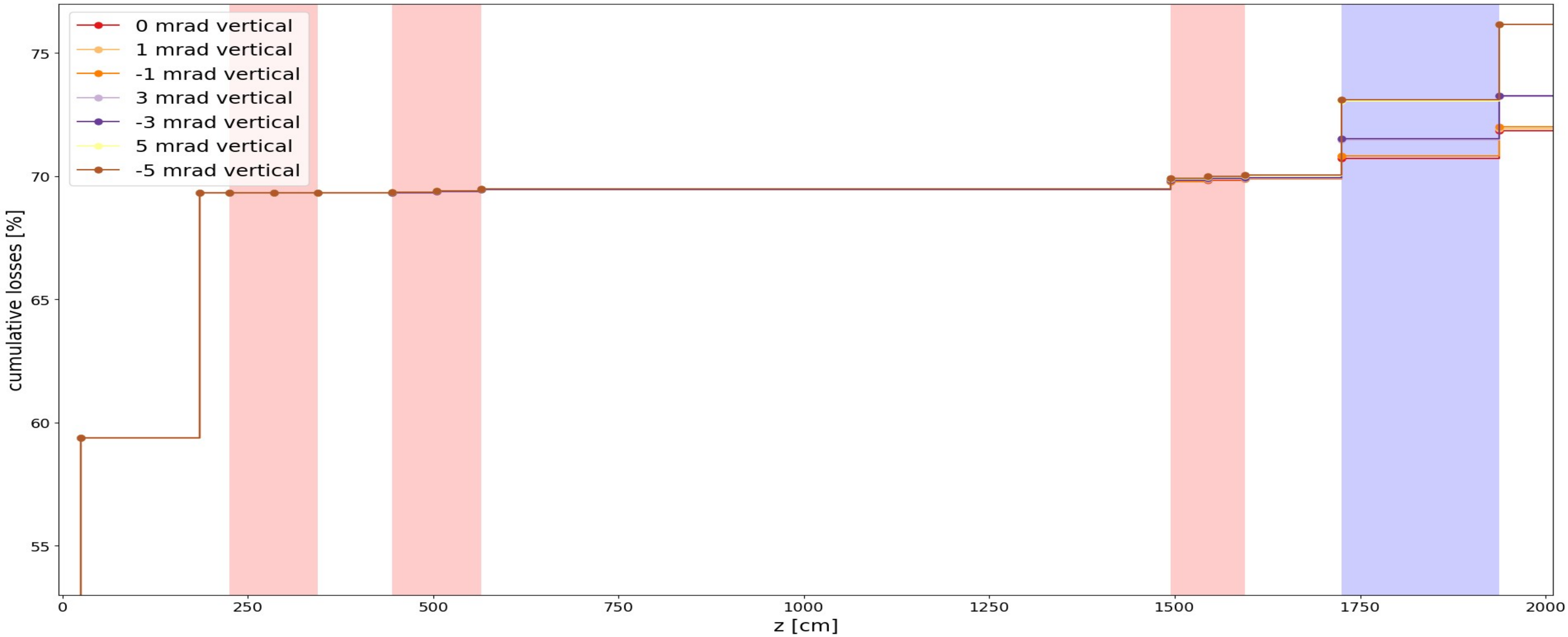

**Note:** The amount of injected particles is different for the three realistic beams. It is highest for the one injected with all pbar sextupoles on. Therefore approx. 6.3% more particles survive the 200 turns in this case as compared with the one with all pbar sextupoles off. There are approx. 2.7% more for one sextupole on, in spite of larger losses. No losses observed at the pick-ups.

# Losses Comparison for Two Types of STC-kickers




**Note:** The large stochastic cooling kicker has an inner diameter of the slot-ring electrode of 150 mm instead of 140 mm.

# About pbar Separator Steerers




To simulate the effect of vertical angular displacements in the first section of the pbar separator (i.e. up to the first dipole) the beam got kicked vertically just after the HV-collimator by different angles. Losses of a few percent have been observed for angles within ±3 mrad. These happen mostly at the dipole itself. Thus it has been decided to not install a radiation hard vertical steerer within this section.

| Vertical angular displacement | Extra losses |
|---|---|
| ±1 mrad | 0.7% |
| ±3 mrad | 5.0% |
| ±5 mrad | 15.3% |

# Final Remarks

- No losses have been observed at the slot-line and palmer pick-ups in the CR under the conditions of the performed simulations.
- Losses in the CR are dominated by those in the stochastic cooling kickers. A slight increase of the inner diameter of its electrodes definitely improves the situation.
- The beam injected when all six sextupoles are in use along the pbar separator leads to the largest amount of particles completing 200 turns in the CR. It also has the lowest amount of losses at the injection septum.
- There is no need for a vertical radiation hard steerer in the first section of the pbar separator.