Preliminary Results of Beam Shaping Studies for the ESS Linac

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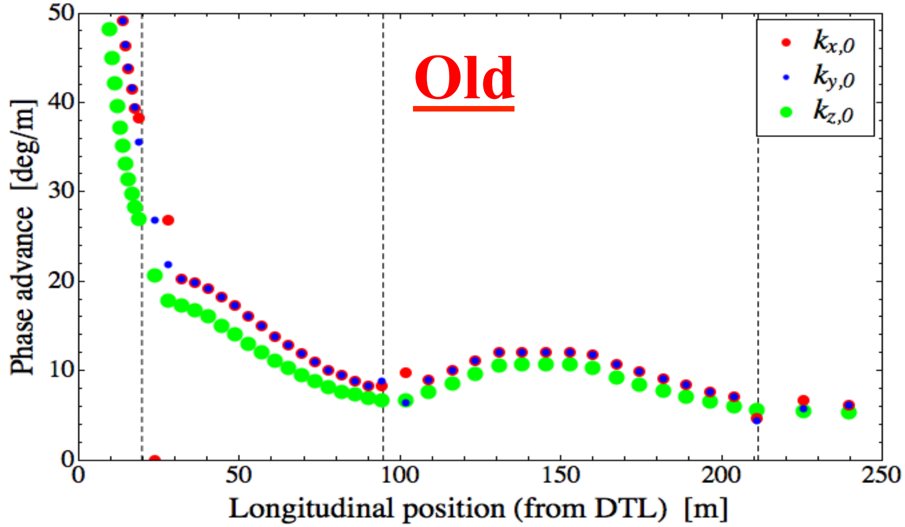
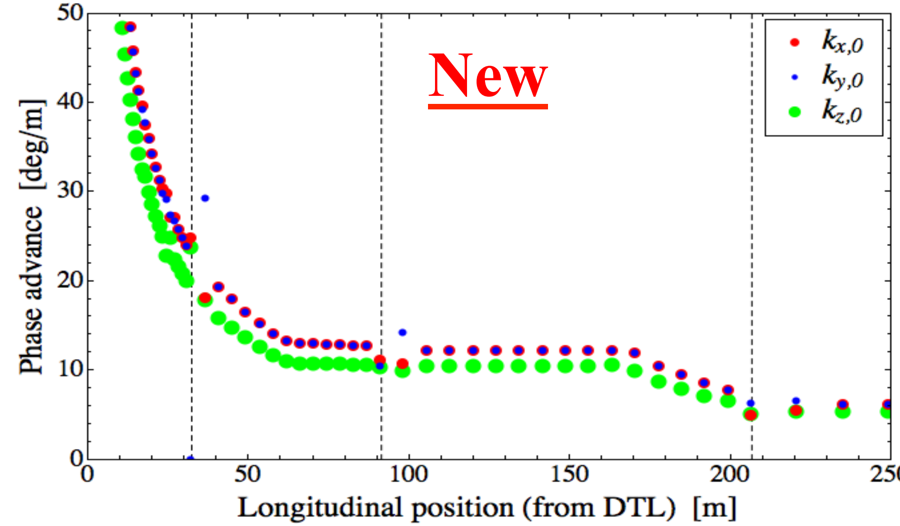
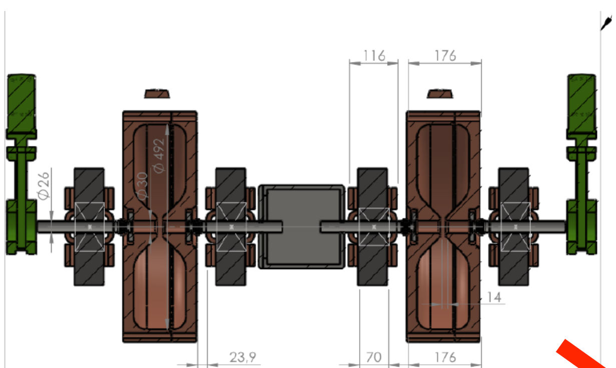
Introduction

- Control of beam losses is crucial to the operation of a high power proton linac and hence must be taken into account at the design stage.
- Obviously, a good lattice design and proper tuning (of orbit, quad, cavity) during the operation/commissioning are important.
- In addition, SNS uses collimators in the MEBT to suppress loss/halo in the downstream sections during the operation. This led us to initiate studies of the MEBT collimation scheme for the ESS linac.
- A proper collimation scheme, if there exists, depends on the lattice and the ESS linac is currently under the revision:
  - A longer MEBT including a chopper, diagnostics, collimation
  - A higher transition energy from the DTL to spokes
  - Cryomodule from 8 cavities to 4 cavities
  - …
- Hence, the study so far has been done on basic physics of the MEBT collimation scheme using the last year's lattice in CDR.

Revision of the ESS linac ongoing…

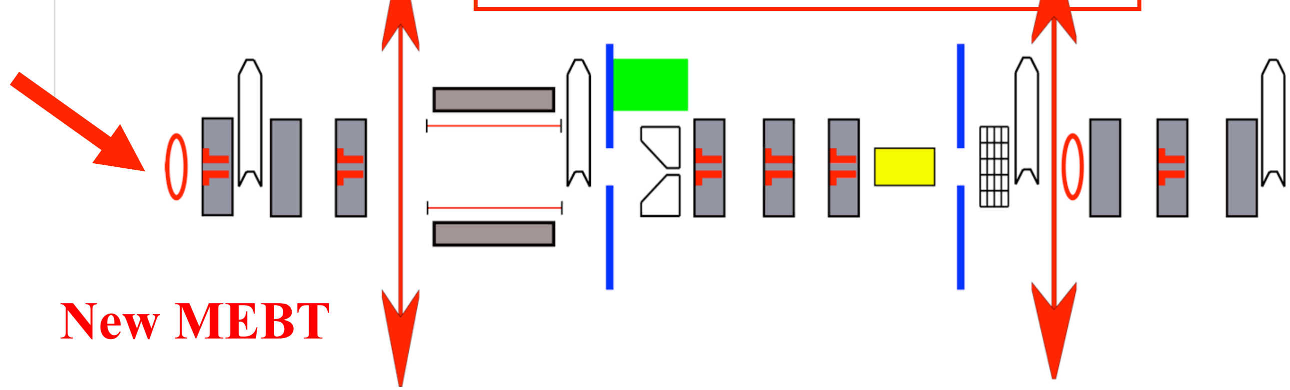






MEBT in CDR

- Matching b/w RFQ and DTL
- Chopper
- Beam instrumentation
- Collimation



New MEBT

Halo definition (Wangler's)

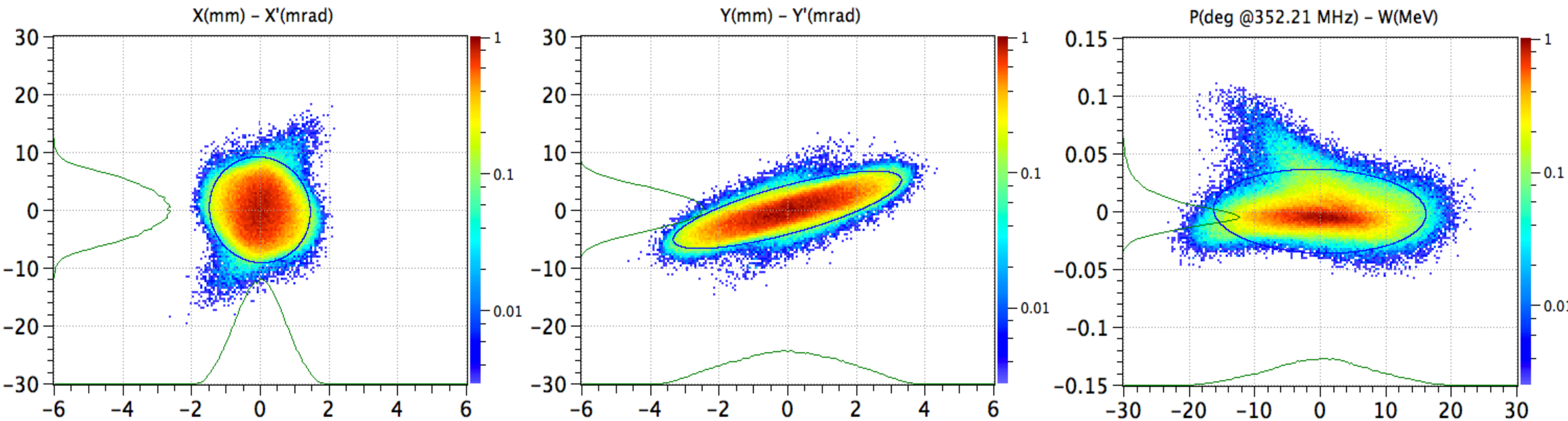
- The *spatial profile parameter* (Kurtosis):

$$h = \frac{<x^4>}{<x^2>^2} - 2$$

- The *halo intensity parameter* (extension to 2D)

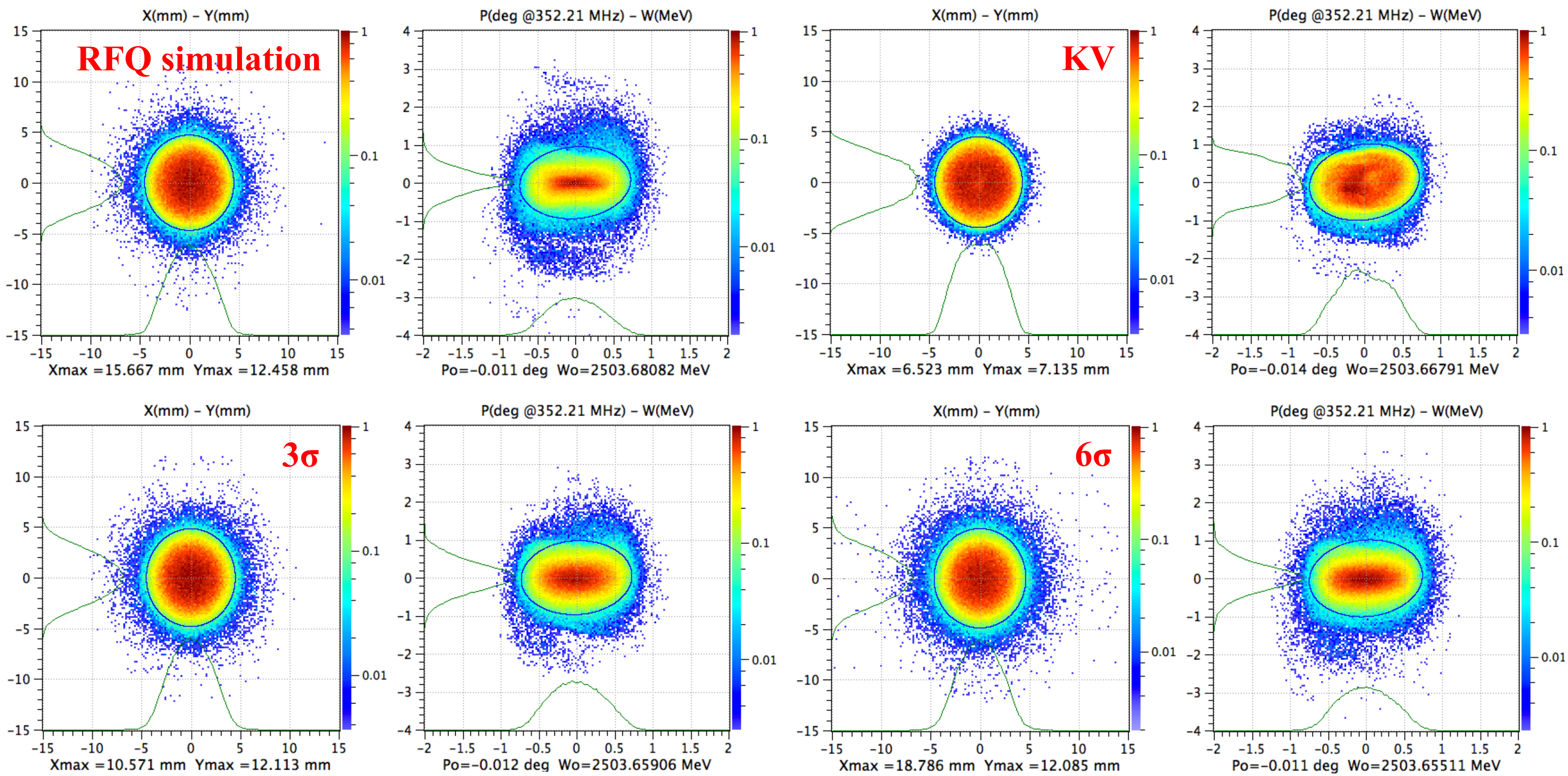
$$H = \frac{\sqrt{3}}{2}\frac{\sqrt{<x^4><x'^4> + 3<x^2x'^2>^2 - 4<x^3x'><xx'^3>}}{<x^2><x'^2> - <xx'>^2} - 2$$

- The normalization "2" to make the "KV" = 0 and "Gaussian" = 1.



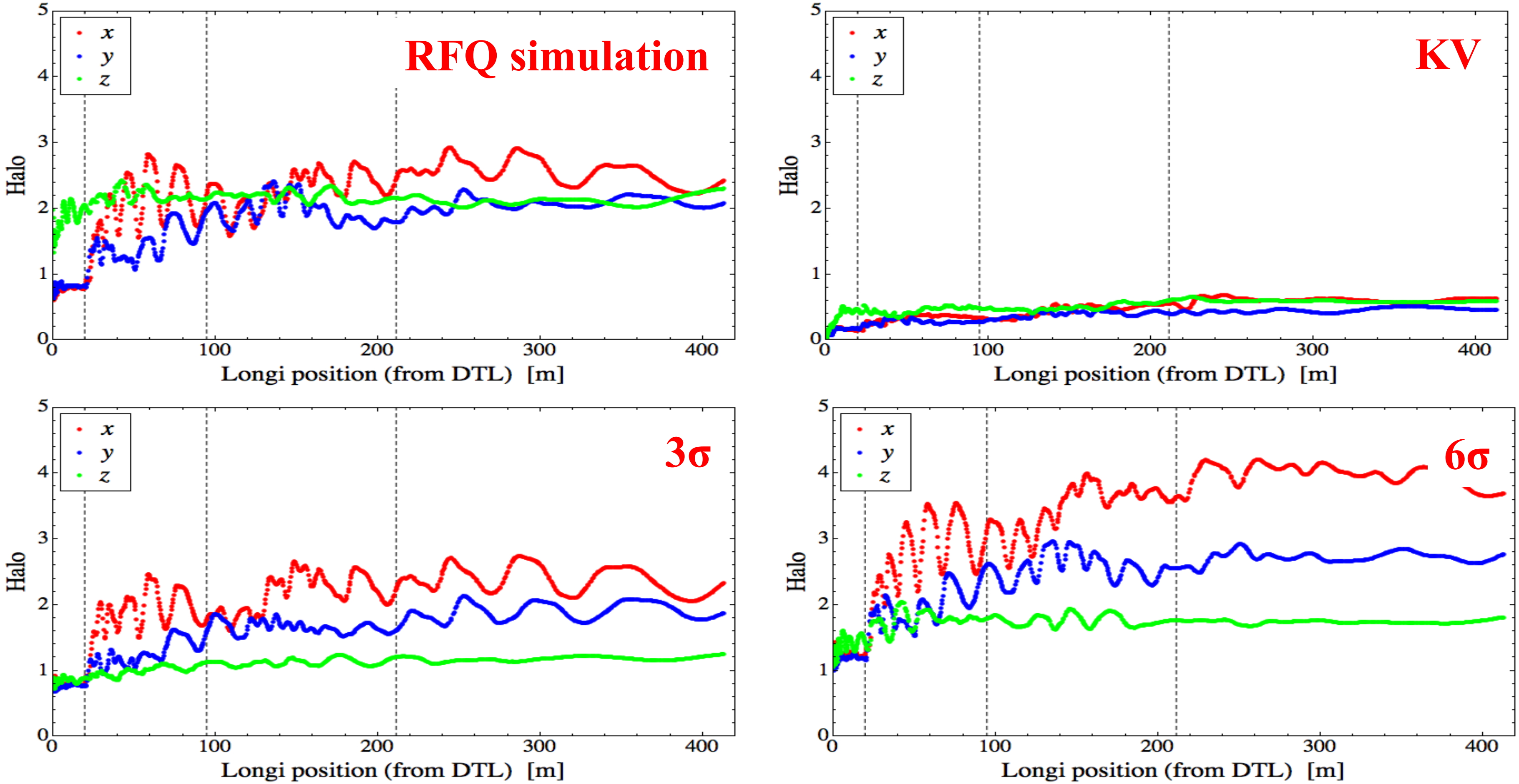
Distribution into the DTL (from a simulation of the RFQ by A. Ponton)

How does the input distribution affects the output?



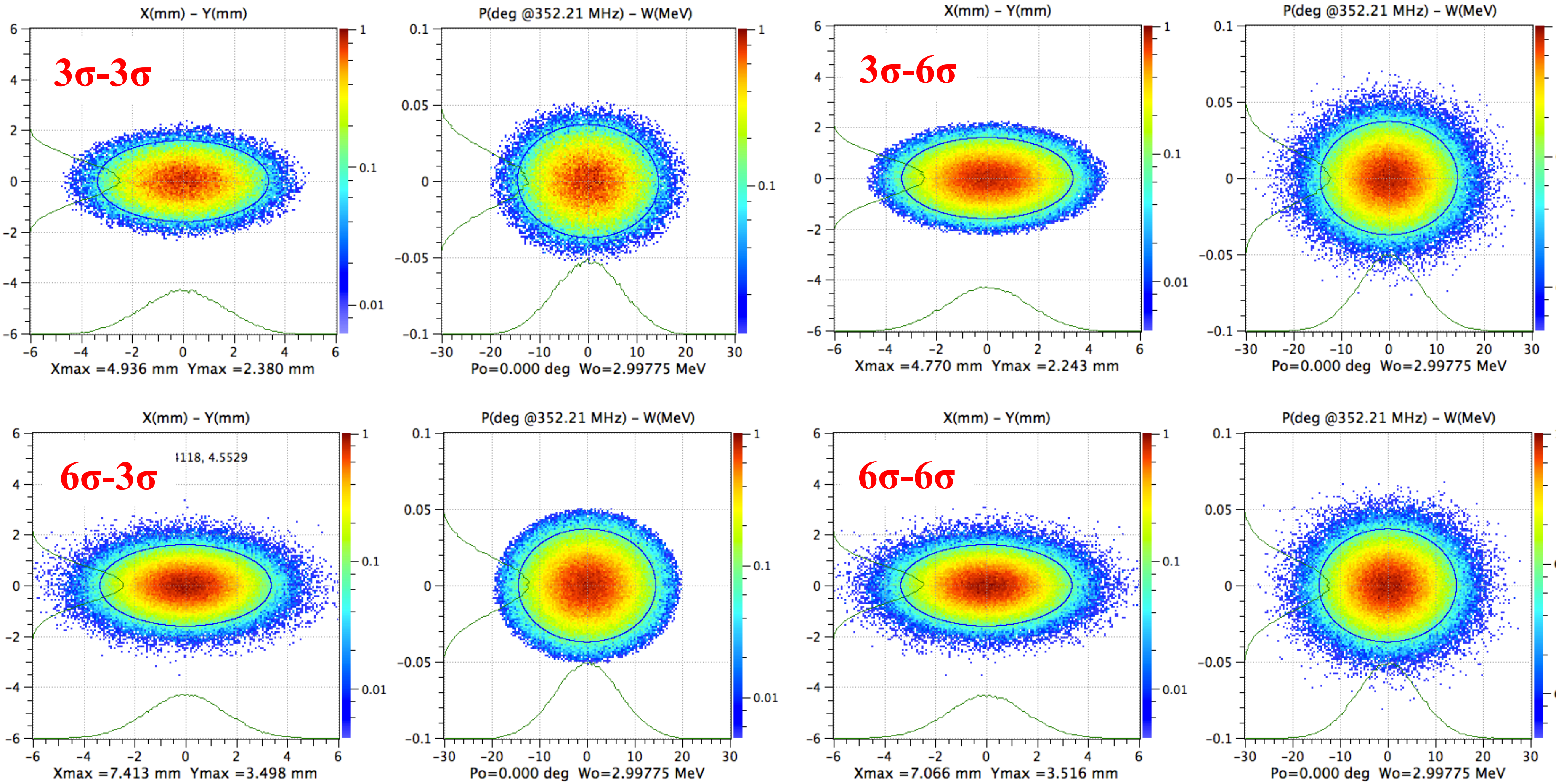
- Particles are transported from the DTL entrance to the HEBT entrance.
- Input distribution types are changed while emittances and optics parameters are kept.
- Clearly, the output is sensitive to the input distribution.

Halo evolution vs. initial distribution types



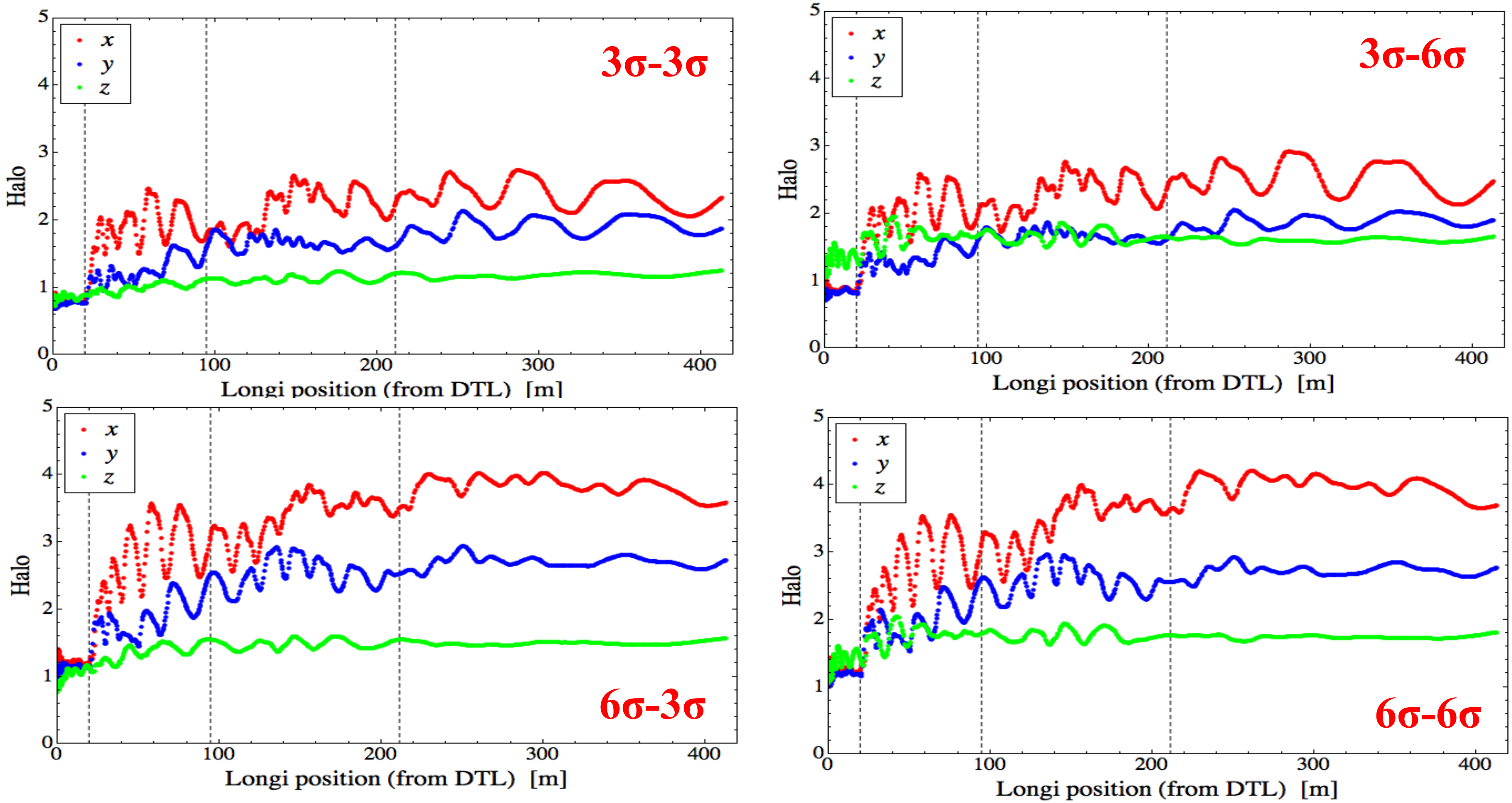
- Again, clear dependence on the initial distribution.
- Almost no halo growth if starting from the KV distribution, as expected.
- "Jumps" at the transition from the DTL to spokes. (Improved for the new lattice)
- The result based on the RFQ simulation is close to the case of 3σ.

Correlation between transverse and longitudinal?



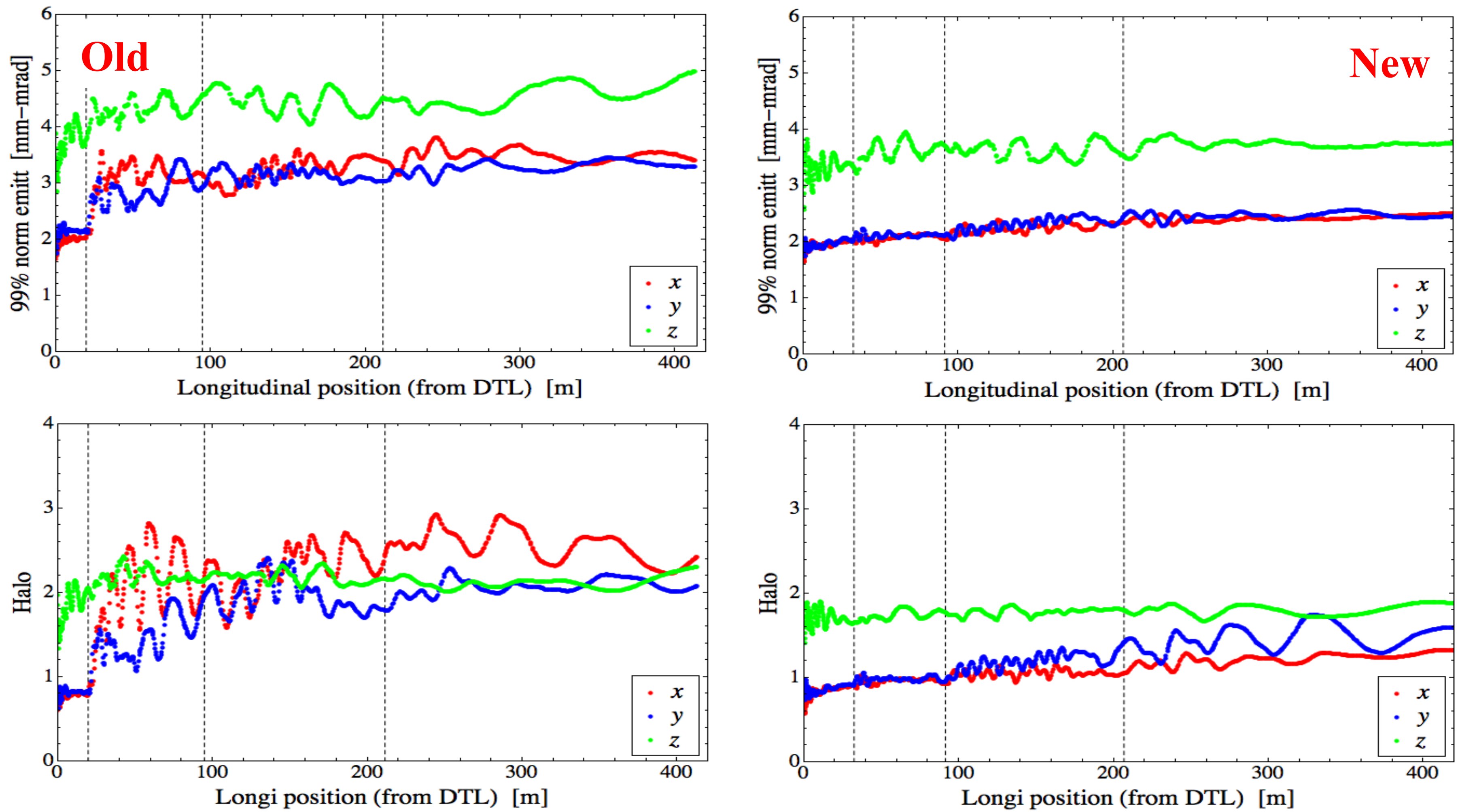
Repeat with 6D Gaussian inputs with different cuts for the transverse and longitudinal planes.

Transverse and longitudinal fairly well decoupled



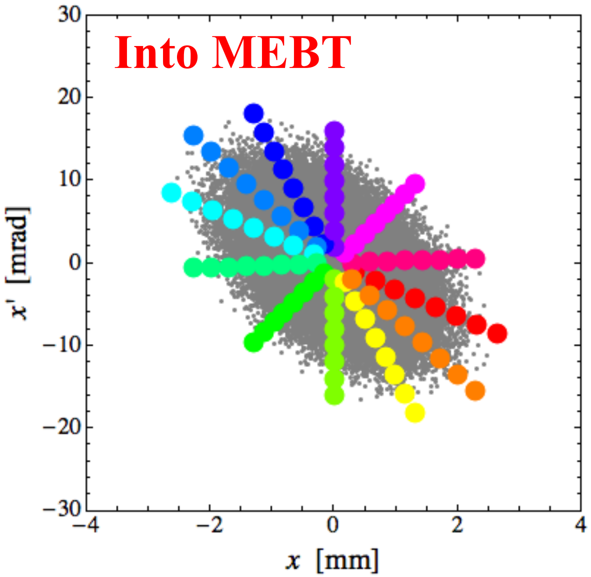
Based on these simple studies, shaping the transverse distribution into the DTL with the MEBT collimators may be able to reduce the transverse halo and hence the loss in the downstream. (Note: lattice errors not considered)

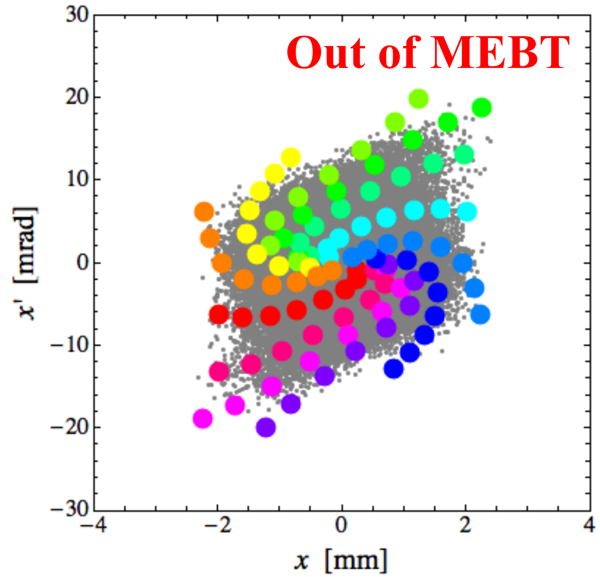
Emittance & halo: old vs. “new” lattices



- Emittances and halos quite different in the old and “new” lattices. The new lattice has them under much better control.
- A proper collimation scheme, if there exists, depends on the lattice.

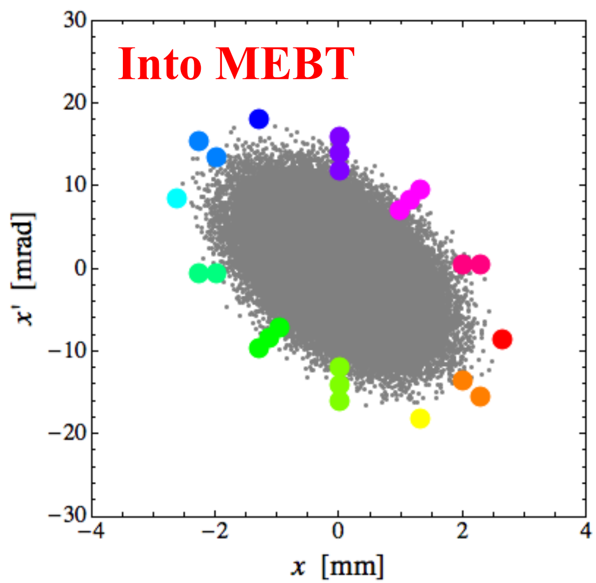
Distribution evolution in the MEBT (H)

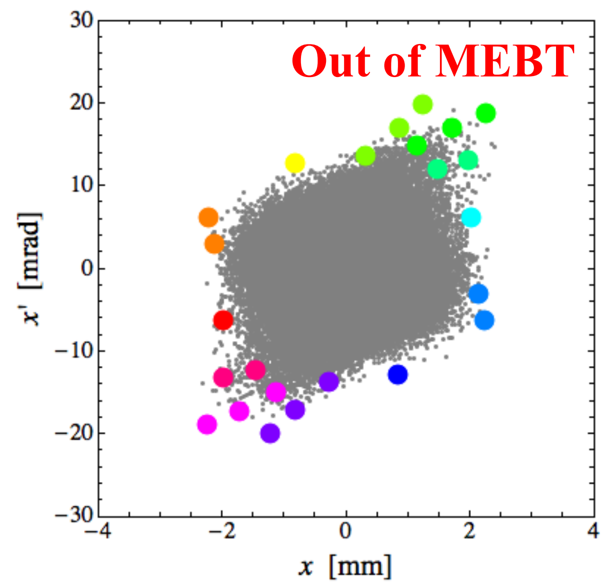




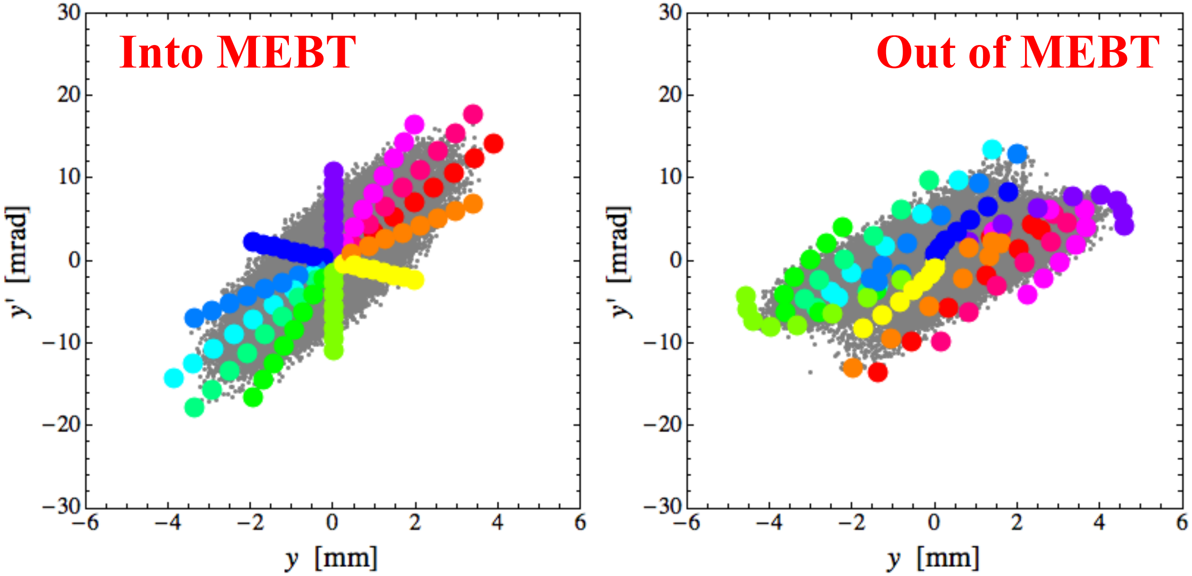
- Sample particles in the normalized phase space:
  - 0.5σ, 1.0σ, …, 4.0σ
  - 30°, 60°, …, 360°
- Space charge deforms the distribution

- Samples particles of 3σ and above at the end of the MEBT are left.
- Not all samples above 3σ at the entrance ends at above 3σ at the end.
- An effective collimation requires weights on specific angles even for a Gaussian distribution.

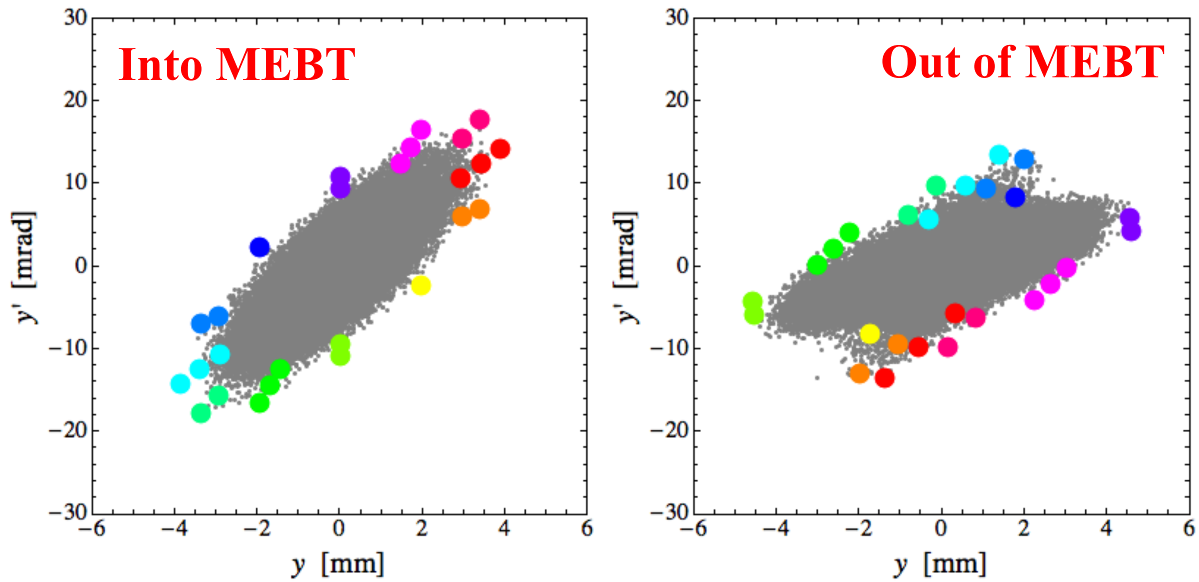




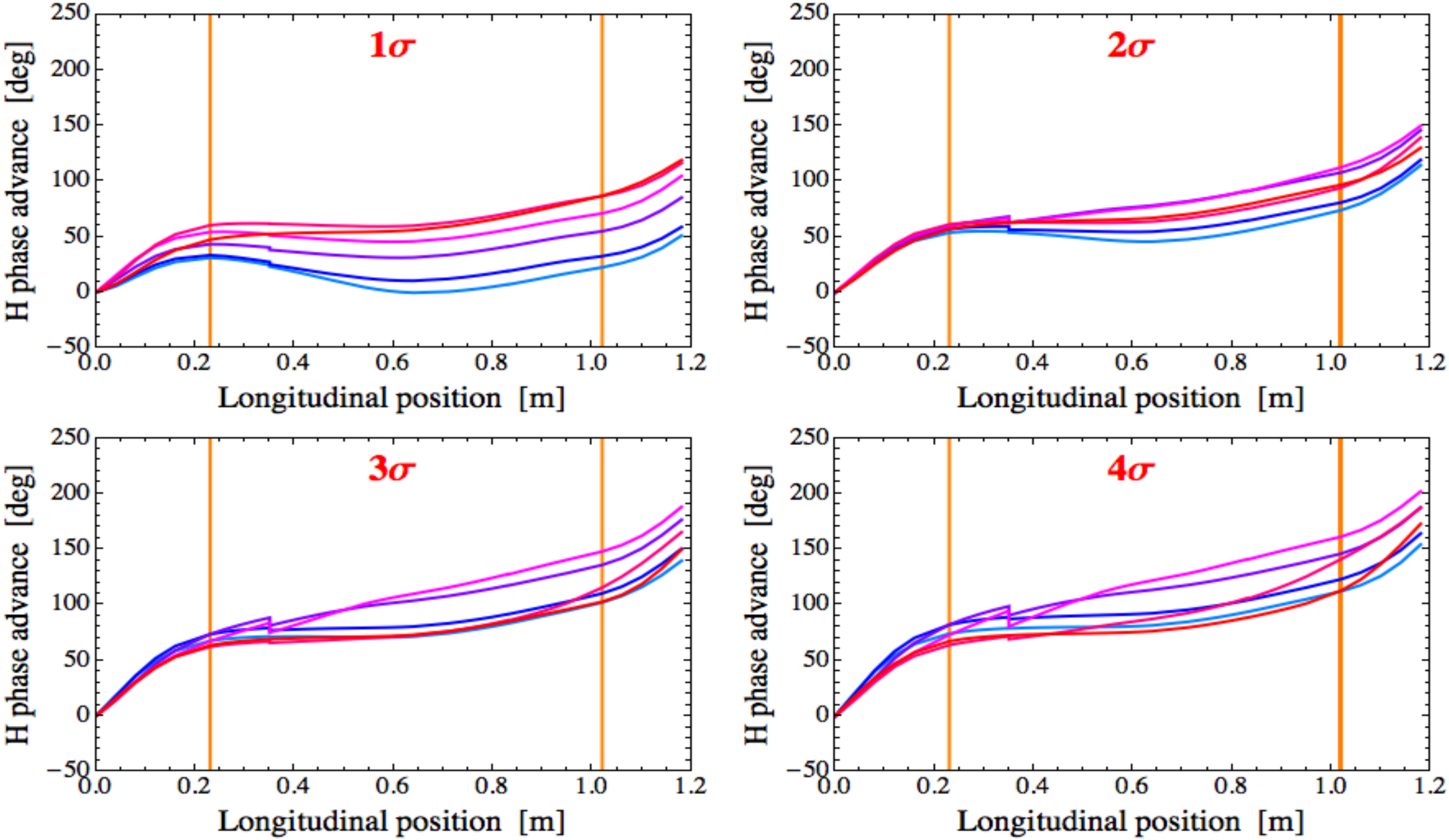
Distribution evolution in the MEBT (V)



The same analysis for the vertical plane

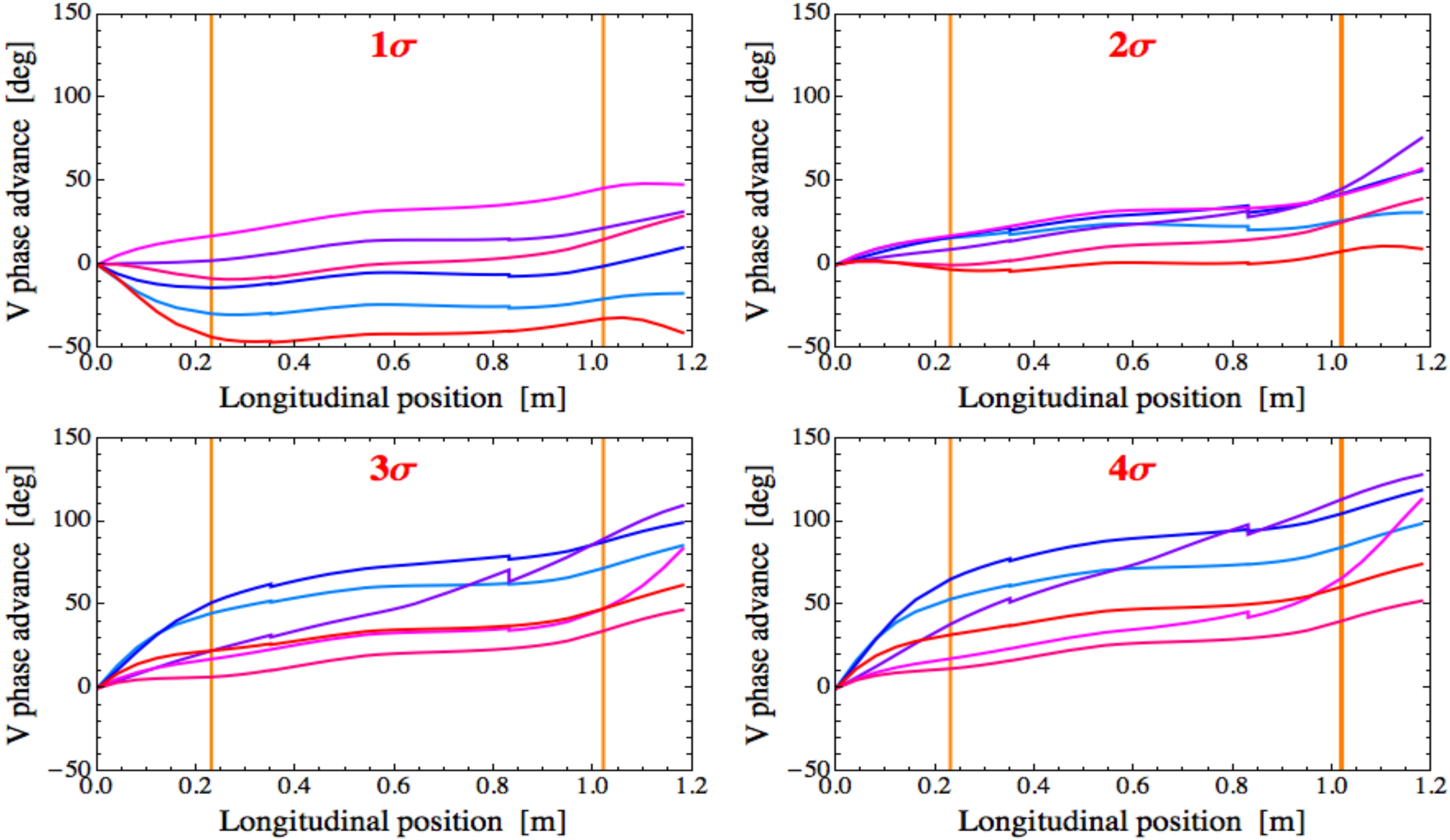


“Phase advances” of each sample particle (H)



A simple scheme of two collimators separated by 90 deg phase advance of zero current didn’t work well.

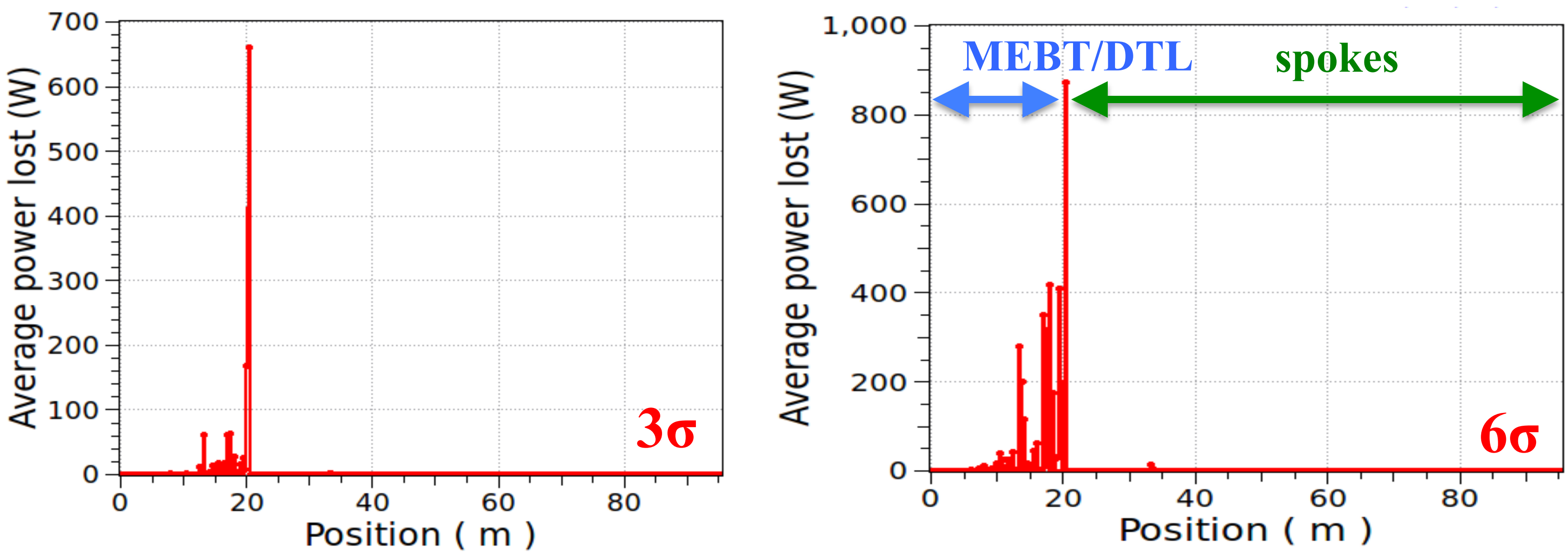
"Phase advances" of each sample particle (V)



The difference among particles is larger on the vertical plane in this specific case.

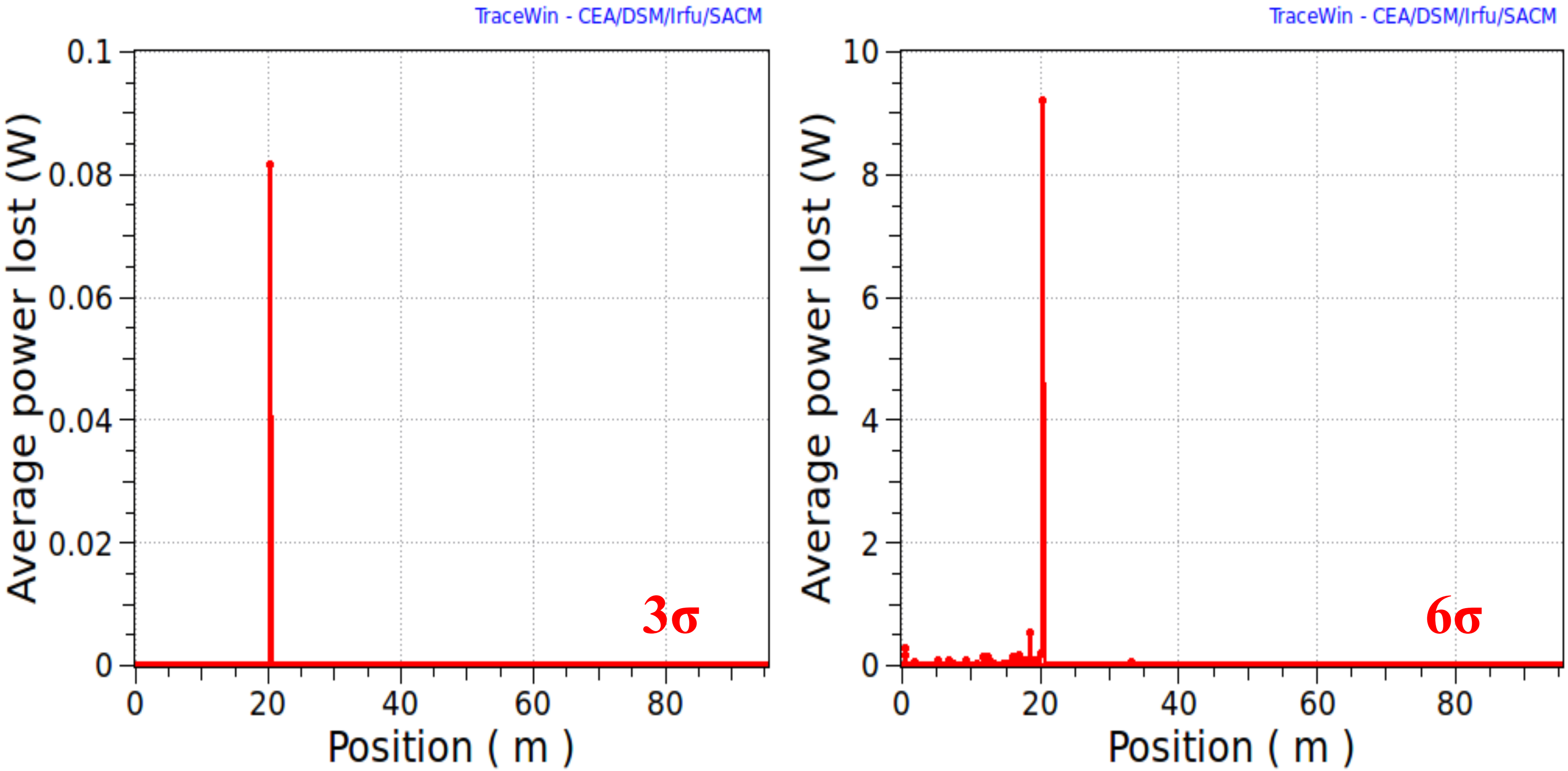
Beam losses due to quad errors

- Quad errors: 0.2 mm in *x*/*y* alignment, 0.5% in gradient. (Cavity errors of 0.5 mm in alignment, 0.5% in amp, and 0.5 deg in phase were also tried but the induced losses were much smaller.)
- Uniform error distribution.
- Input distribution: 6D Gaussian w/ 3σ and 6σ cuts.



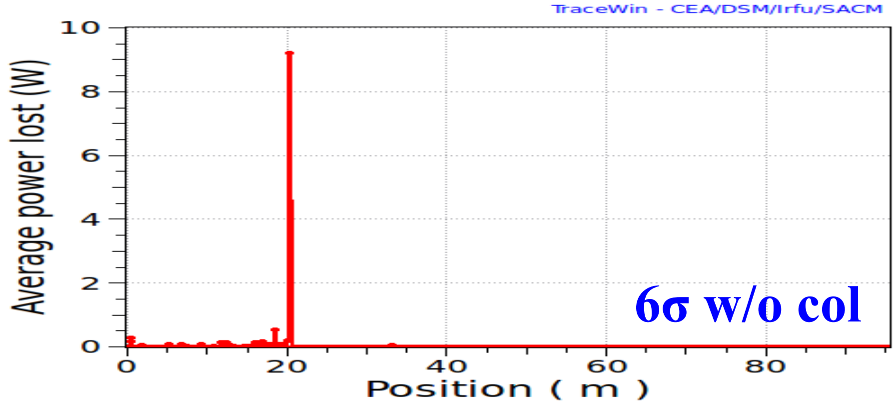
- Clearly, this magnitude is too large for the last year's lattice.
- Large losses in the DTL before starting see the loss in spokes due to the tight aperture in the DTL. Should the collimation focus only on the DTL??

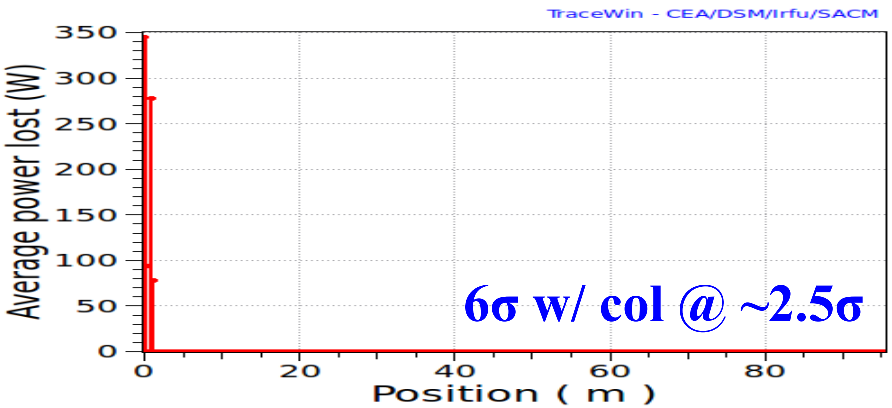
What if the errors are half?

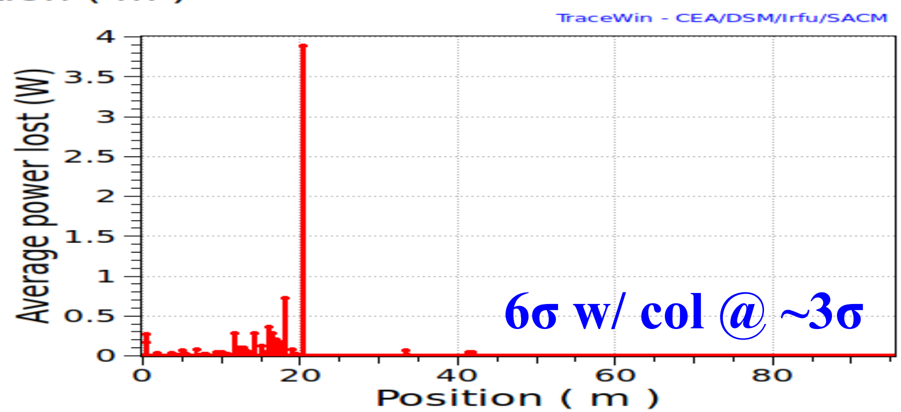


- With 2 times better alignment and gradient errors, the loss looks acceptable except at the transition. (JPARC DTL alignment is ~50 microns. The loss at the transition better for the new lattice?)

Collimation exercises







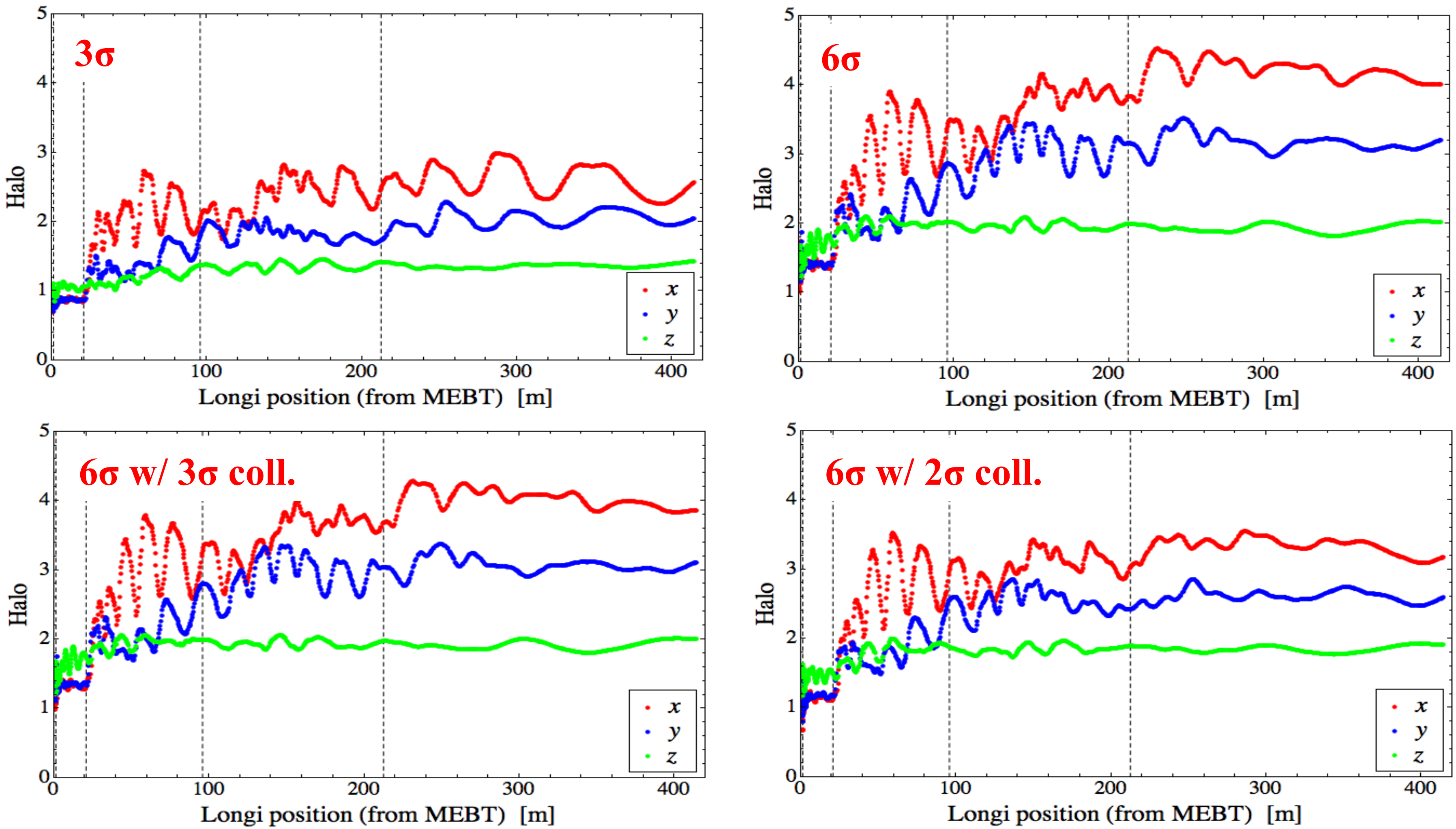
- 2 horizontal and 2 vertical collimators with locations based on the evolution of the distribution (not based on the phase advance).
- [# of particles (100k)] × [random seed (40)] probably not enough.
- The detailed numbers not important at this stage, but the trend is that to "shave" the halo in the DTL I must deeply "cut" the beam in the MEBT. (Also true for the halo.)
- We must also consider how much heat a collimator can tolerate.

Summary

- Following the SNS experience, studies of the MEBT collimation scheme have been initiated.
- The transverse halo is affected by the transverse distribution going into the DTL so, in principle, the MEBT collimators should be able to improve the loss and halo in the downstream.
- The evolution of the beam distribution in the MEBT is complex due to the strong space charge so the optimum locations of the collimators are not very trivial.
- Alignment and gradient errors of quads could produced losses (in the last year's lattice) but the most losses are in DLT due to its tight aperture.
- Exercises of the MEBT collimations have been performed with the last year's lattice. There are cases where we could shift the loss from the DTL to the MEBT collimators but such cases require large cuts of the beam (not just the halo but even the core).
- The further error studies w/ (and w/o) the MEBT collimator will be performed: the new lattice, separate and combined errors, more realistic input distribution.
- Any comments/suggestions are welcome.

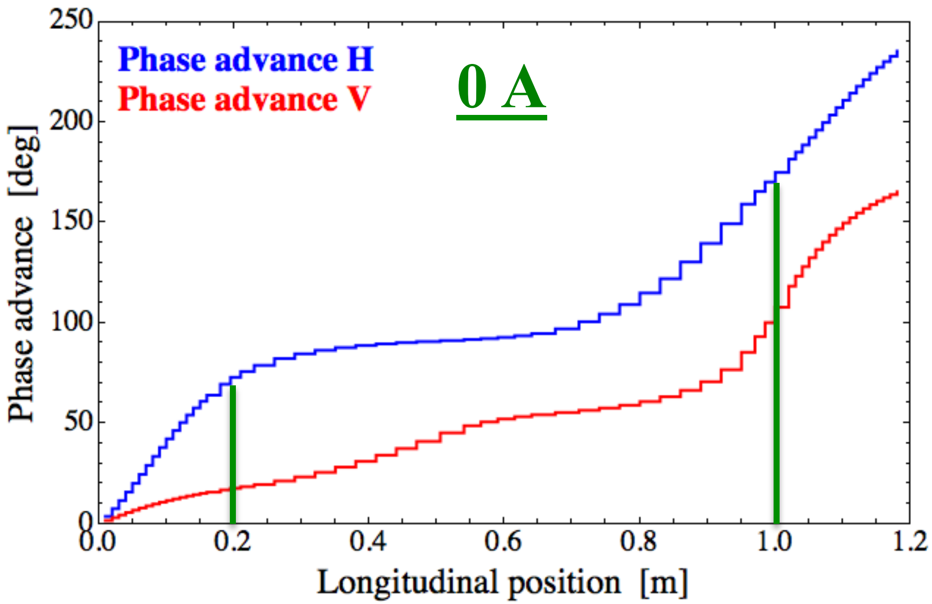
Thank you for your attention!

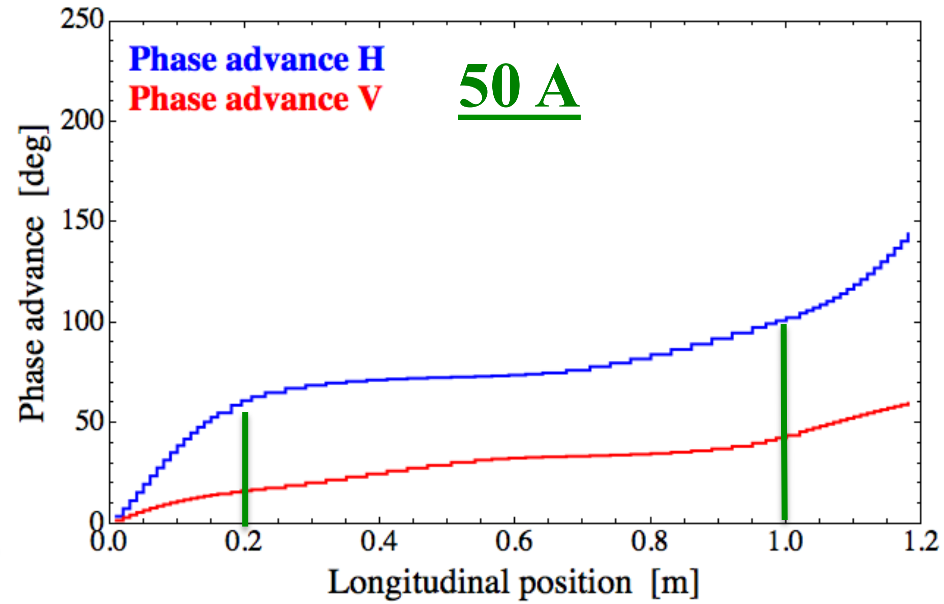
Collimators in the short MEBT of the old lattice



Collimators made almost no difference in this particular case, unless we largely scrape the core of the beam.

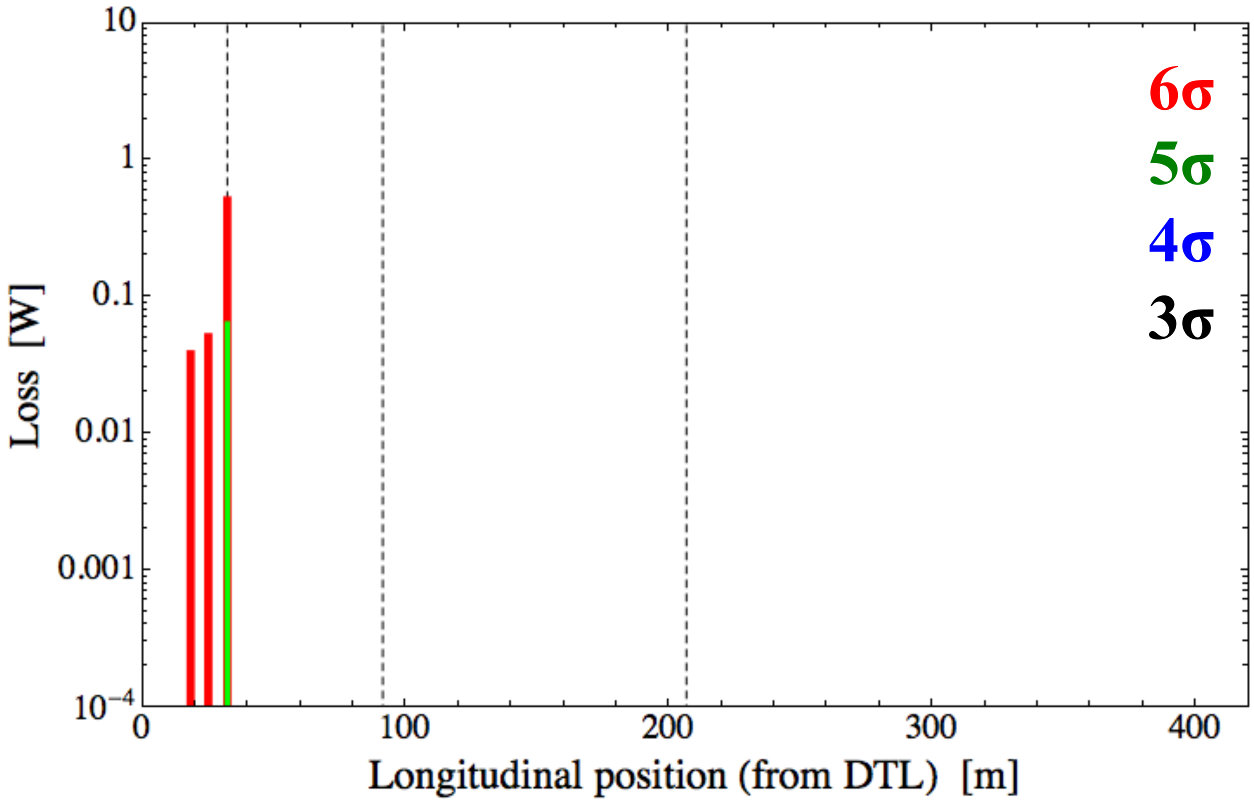
Collimators in the short MEBT





- Two square apertures are placed at the ends of the first (~0.2 m) and last (~1.0 m) quads.
- The distance between two collimators are too far?
- The collimators too close to the beam and the halo particles no longer follow the zero-current phase advance?
- Alpha-function?
- ….

We should study the loss studies as well…



- Tried with 2.5M particles for the new lattice but this is too small. (If we have 50M macro particles, loss of a single 2.5 GeV macro particle corresponds to ~0.1W.)
- Correlation with halo? (The MEBT collimators help?)