Beam Physics Design of MEBT

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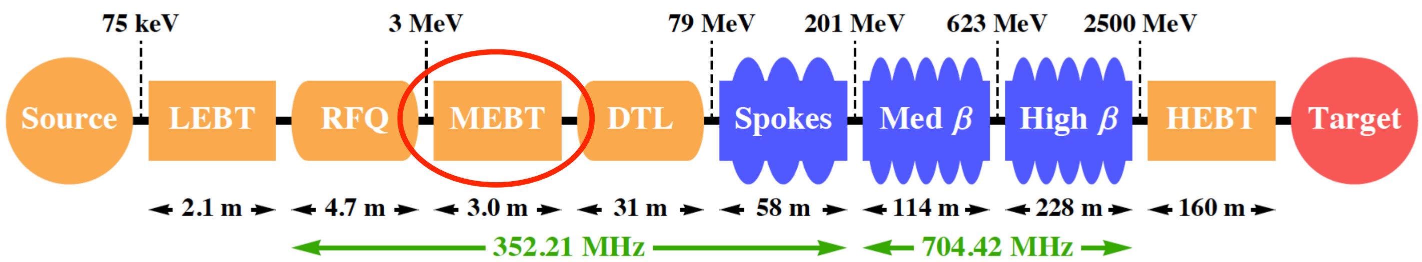
ESS AD Retreat

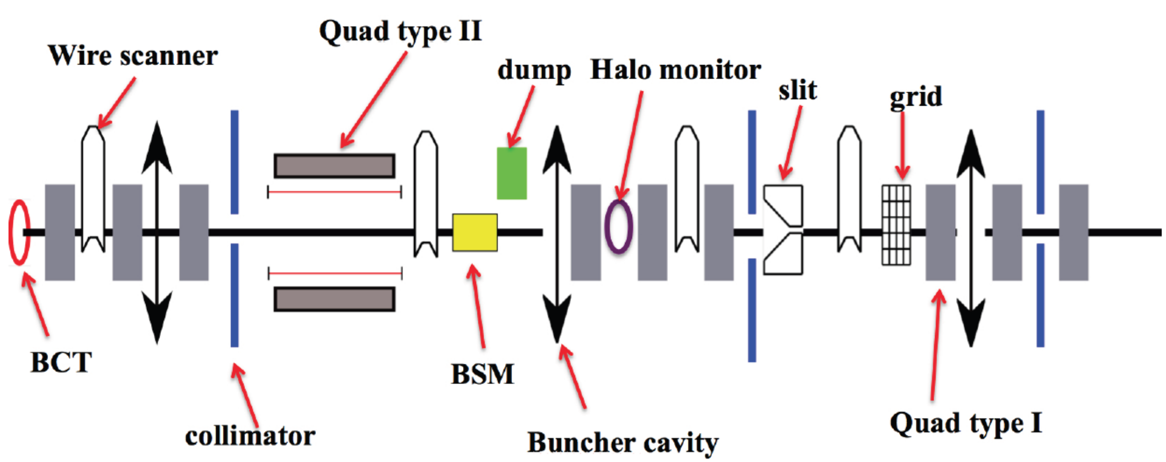
On behalf of ESS AD-BPG

& ESS Bilbao

Medium Energy Beam Transport (MEBT)

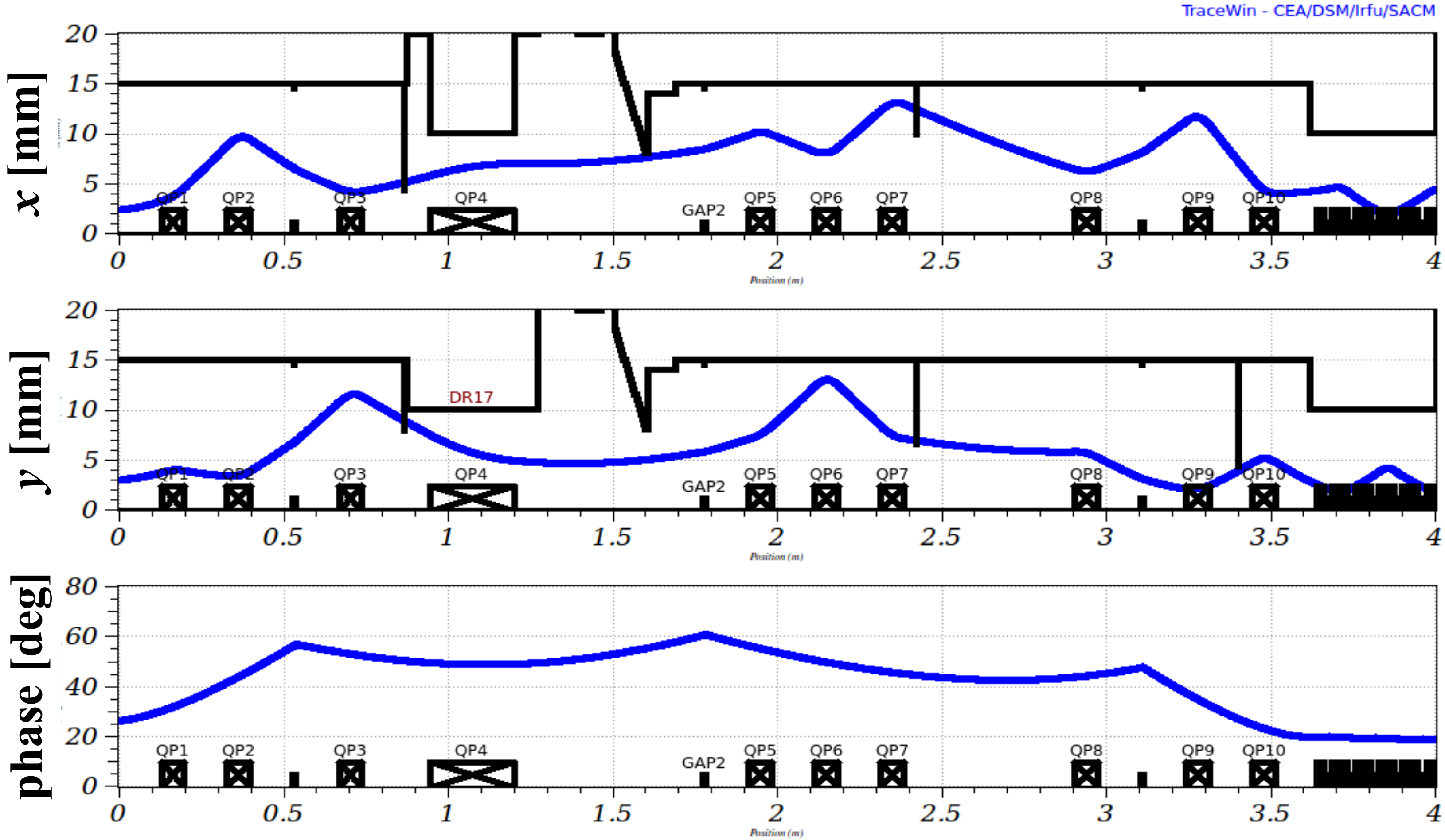


- Steering & Matching (adjust the beam from RFQ to DTL)
- Fast chopper (remove the pulse head/tail during the source transient)
- Beam instruments (measure orbit, profile, emitt, loss, …)
- Collimation (remove transverse halo)



Courtesy of B. Cheymol

Present MEBT layout & beam envelope



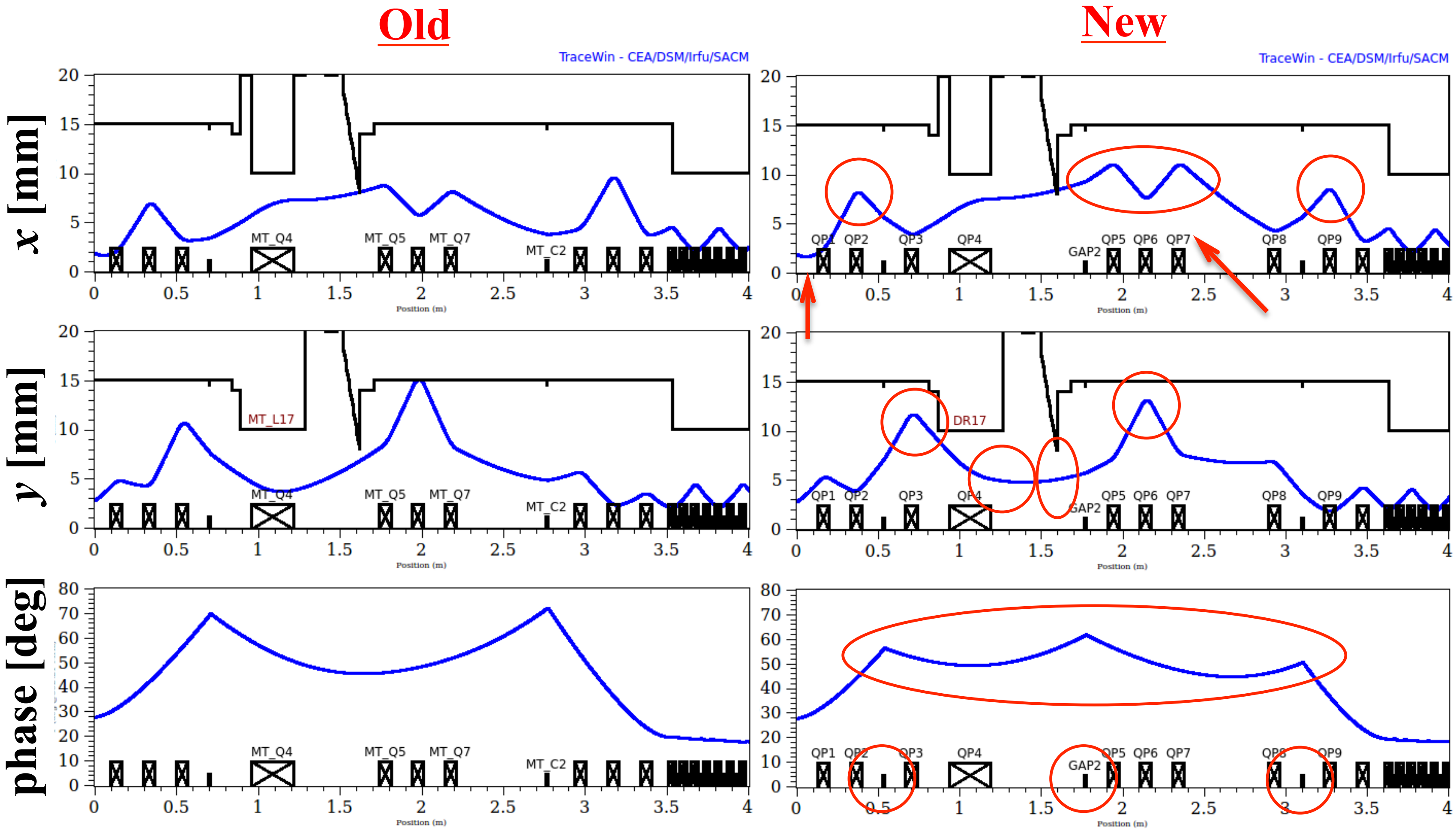
- 3 buncher cavities
- 9+1 quads
- 2 drifts: chopper & instruments
- Created from the Linac4 design but revised a lot

MEBT is only 3-4 m but designing it isn't so easy…

- RFQ & DTL have strong focusing
  ➔ MEBT (relatively weaker focusing) could spoil the beam quality
    ➔ Could have large influence on beam quality in downstream sections
- Short non-periodic lattice
  ➔ No "golden rules" for the design

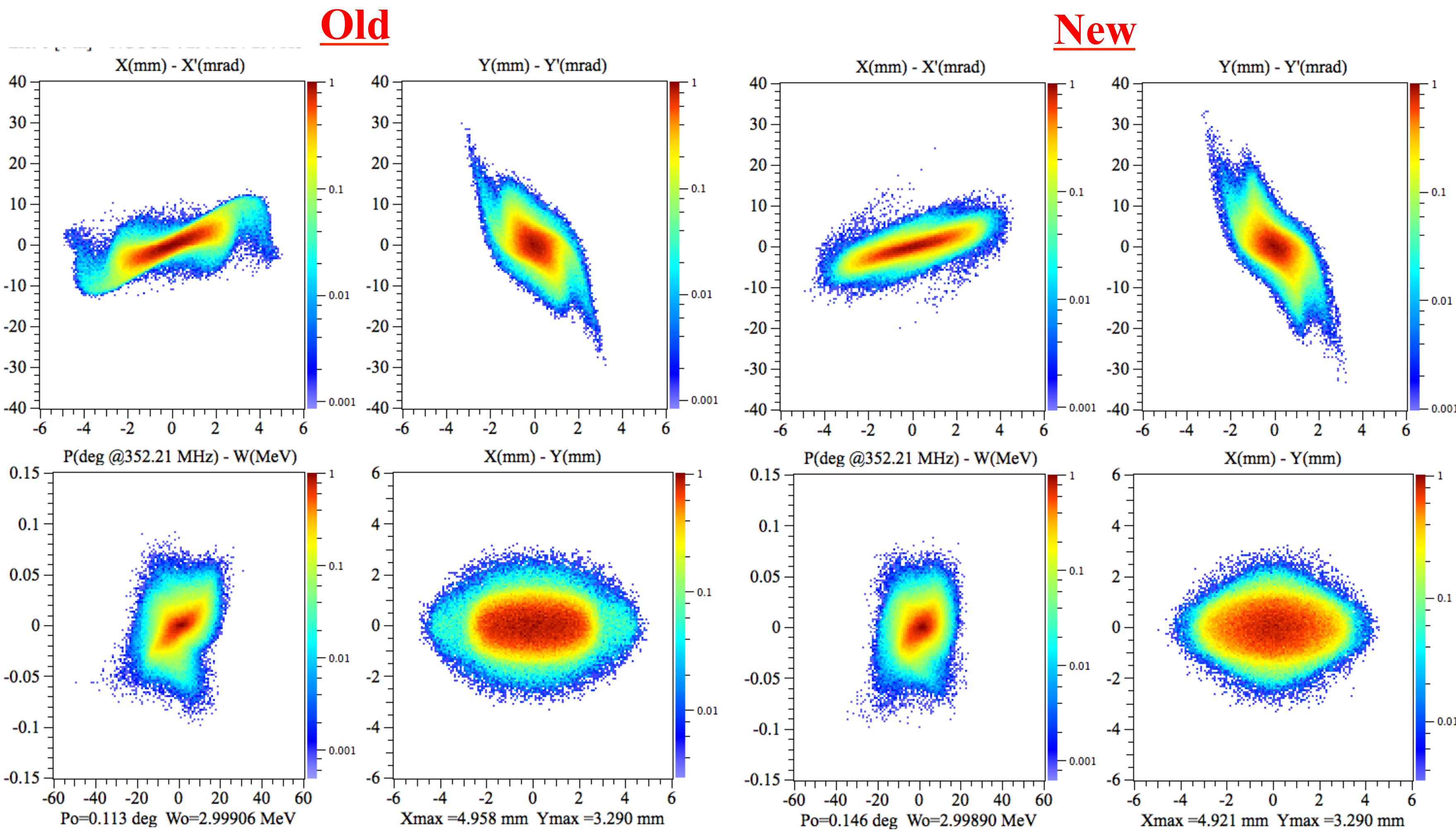
- Design is based on several guidelines with compromises.
  - Match all 6 Courant-Snyder parameters at the DTL entrance (must!)
  - Make the beam flat at the chopper target (chopper efficiency)
  - Make the beam round at buncher cavities (avoid emittance exchange)
  - Minimize losses
  - Minimize emittance and halo growths (where in the linac?)
    - Keep the beam as small as possible
      (fight with space-charge)
    - Or, keep the beam as large as possible within the aperture
      (make piece with space charge)
  - Utilize collimators
  - In addition, satisfy engineering constraints

An example: modification of the May design



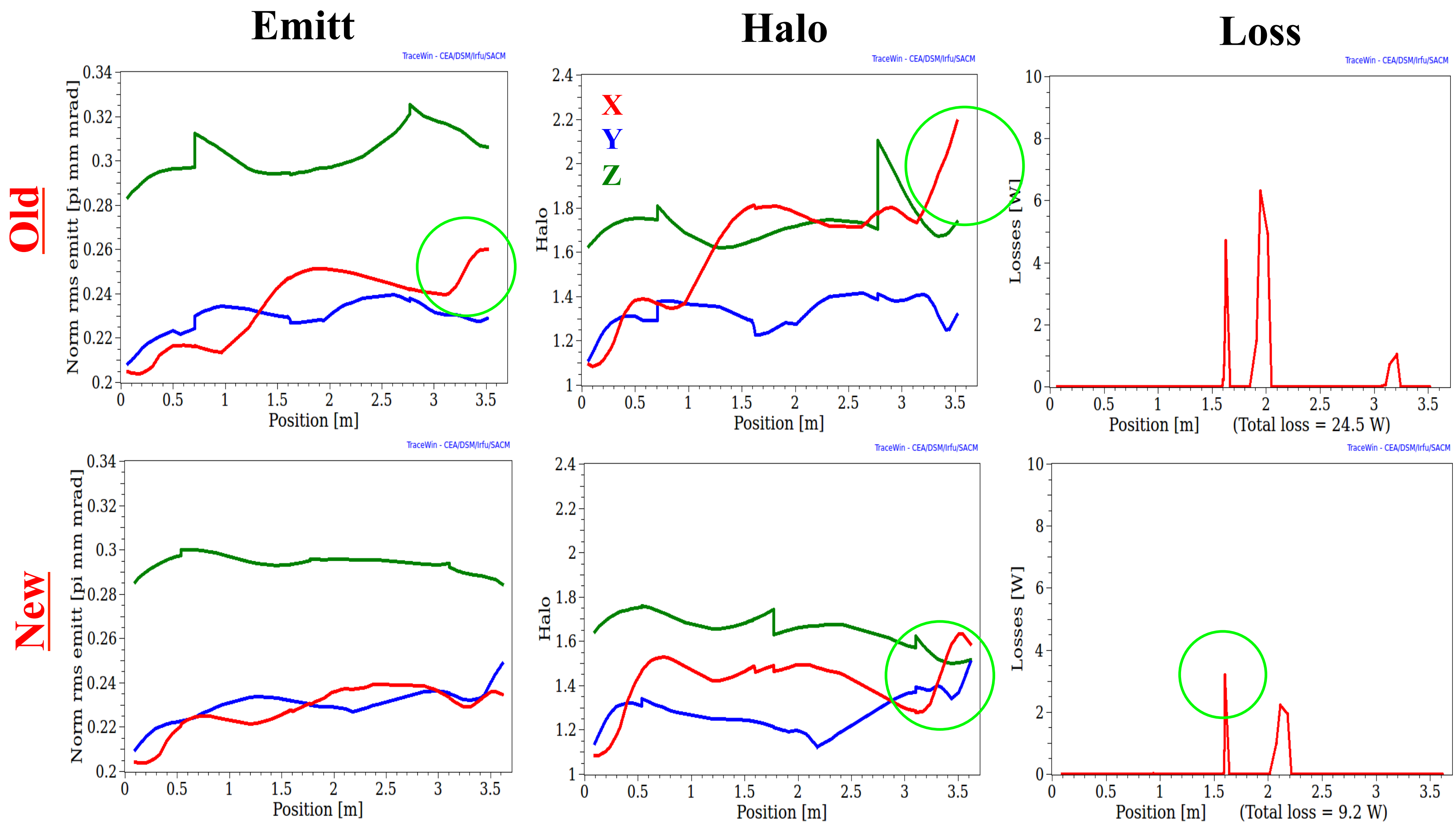
3σ (~full) envelopes in 3 planes

Is the beam quality really improved?



Distributions in 3 planes at the end of the MEBT

Improvement in beam parameters

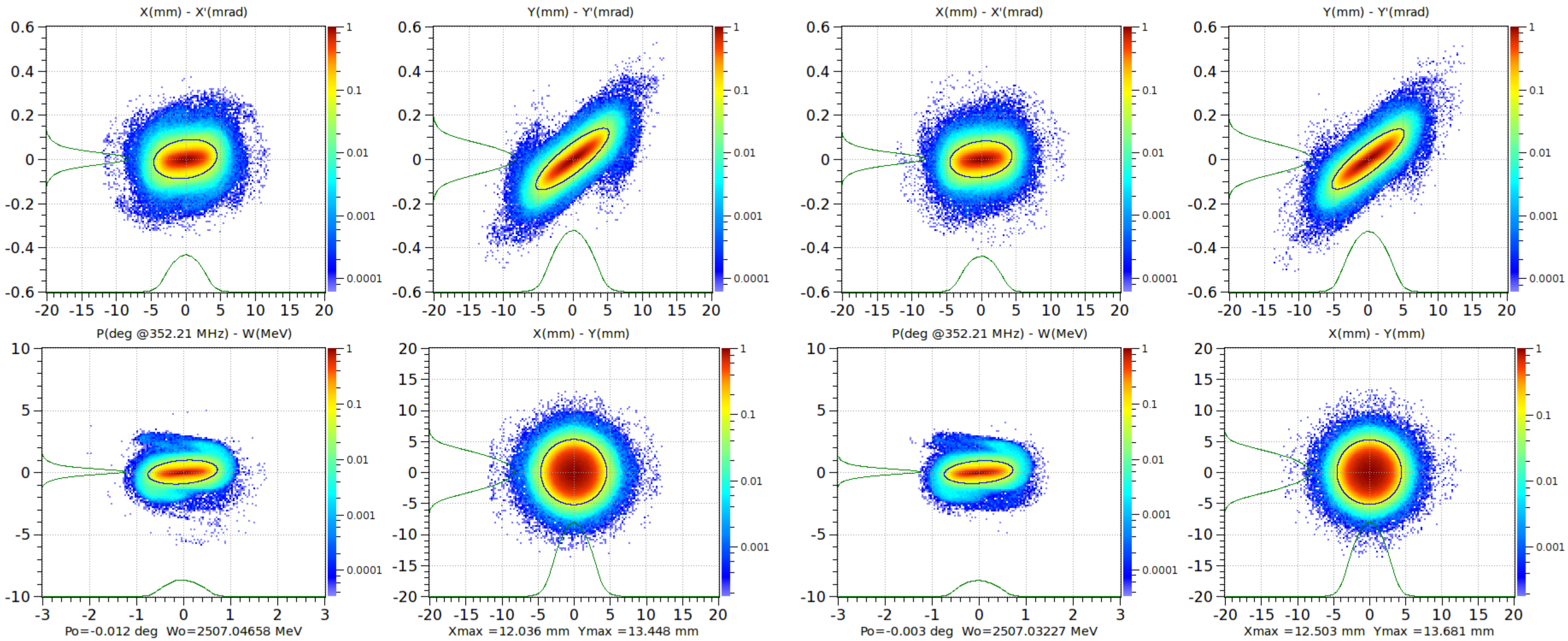


Emittance and halo growths occur at the initial and final parts

➔ Investigating reducing quad strengths in the initial part of the DTL

MEBT affects the beam quality in downstream sections

Old **New**

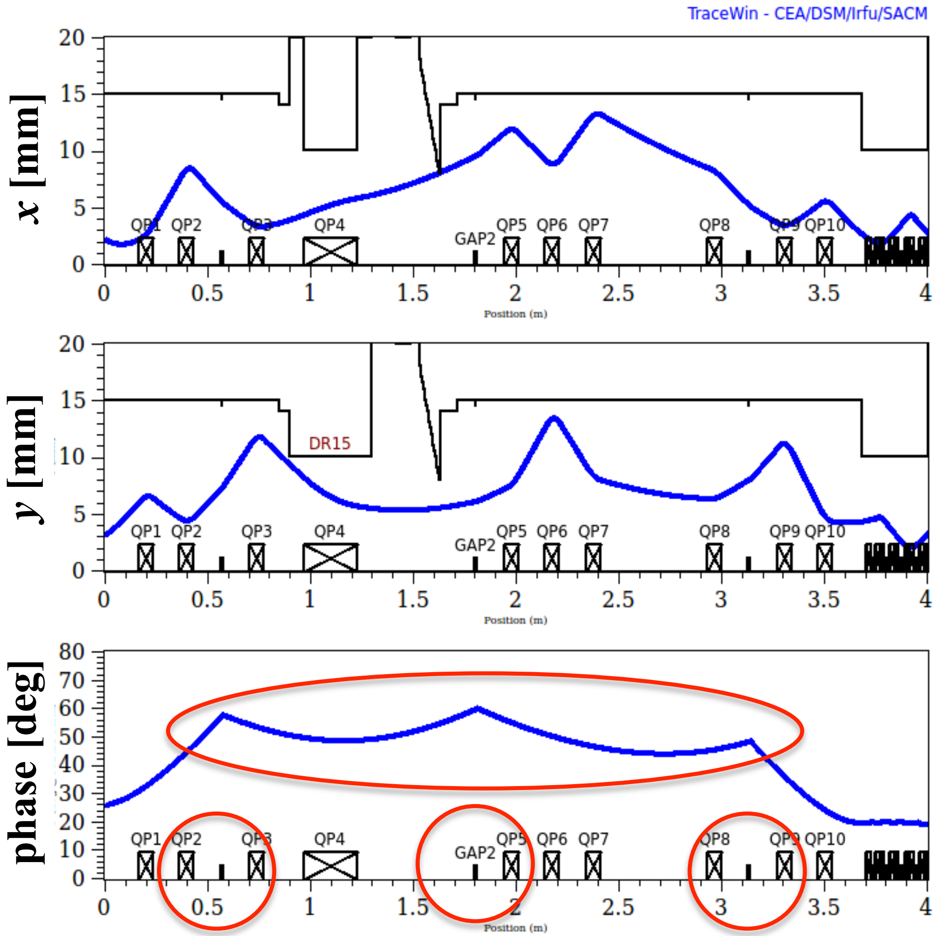


Distributions in 3 planes at the end of the High-beta section

- Both halo and emittance are improved. (Especially in the *z* plane.)
- Loss in the DTL is reduced but no loss in SC sec in both cases
- ➔ Error study needed
- 3M particles tracked.

EUROPEAN SPALLATION SOURCE

Procedure to adjust the lattice



- Matching: (Q7), Q8-10, B2-3
- Knobs: Q1-3, Q5-7, (Q4), B1

1. B1 to set the bunch lengths throughout the MEBT, B2 and B3 to match.
2. Q1-2 to set peaks (not too small/large).
3. Q2-4 to set bunch sizes inside the chopper (flat at the target for chopper efficiency, not too small, avoid loss).
4. Q5-7 to set peaks and sizes inside the 2nd drift (loss, emittance, halo).
5. Transverse match and check the result.
6. In reality, 1 and 5 in-betweens.

- JPARC adjusts only bunchers and quads are set to the design values
  ➔ Can we establish a beam based transverse tuning scheme?
- Possible to automatize? Hard with envelop calculation. Parameter scans with tracking?

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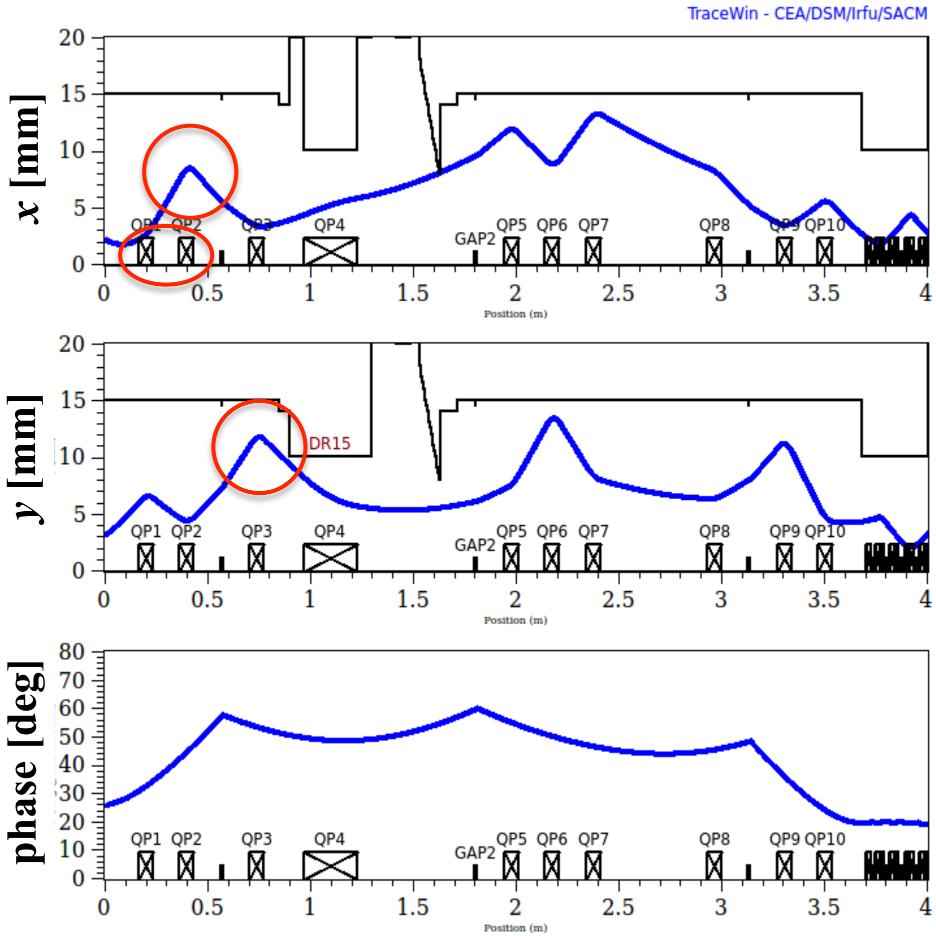

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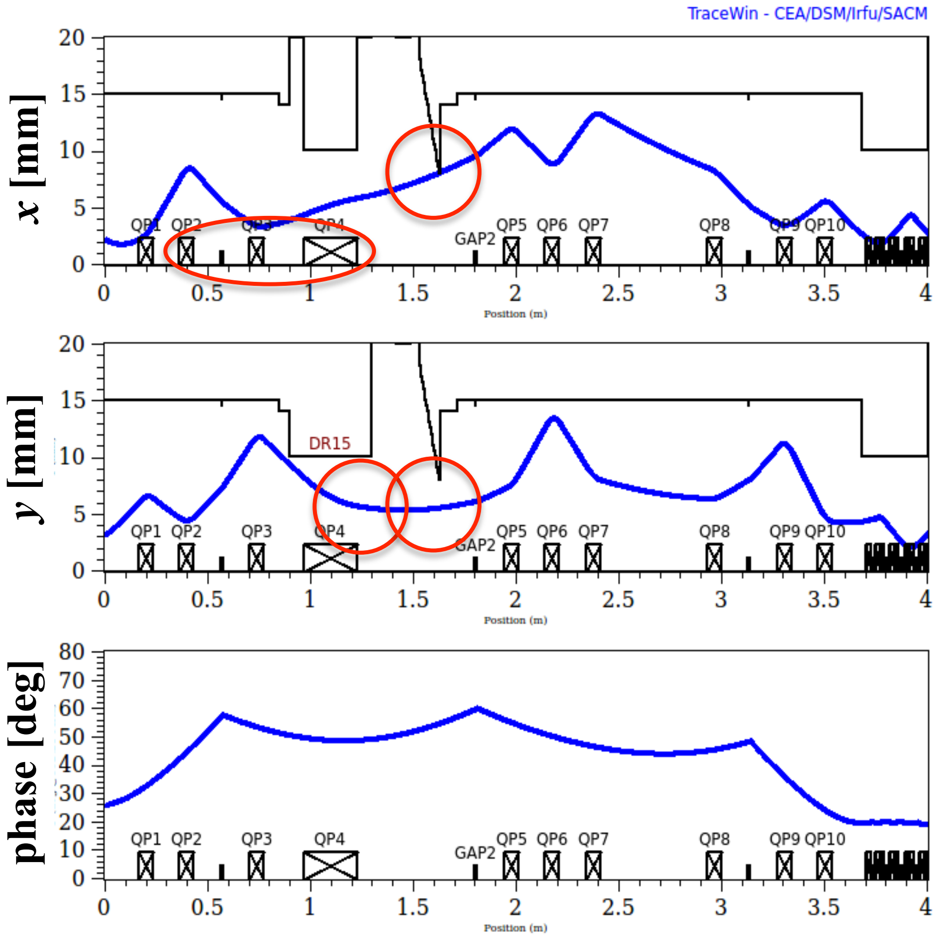

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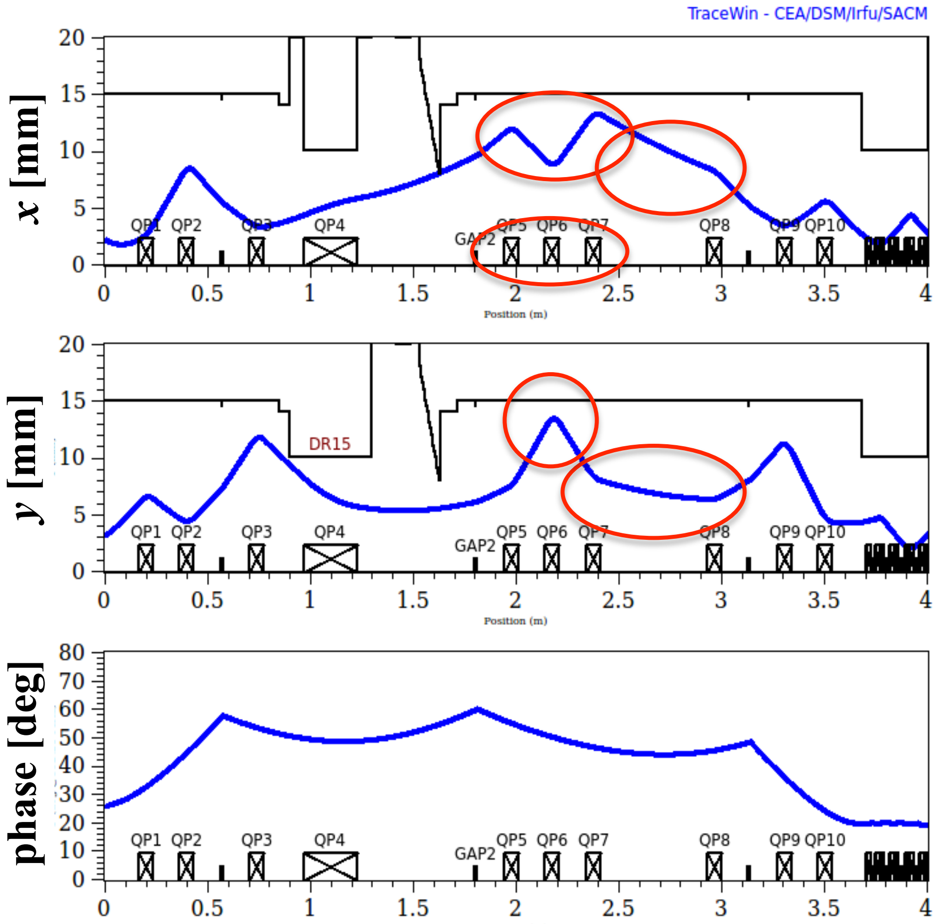

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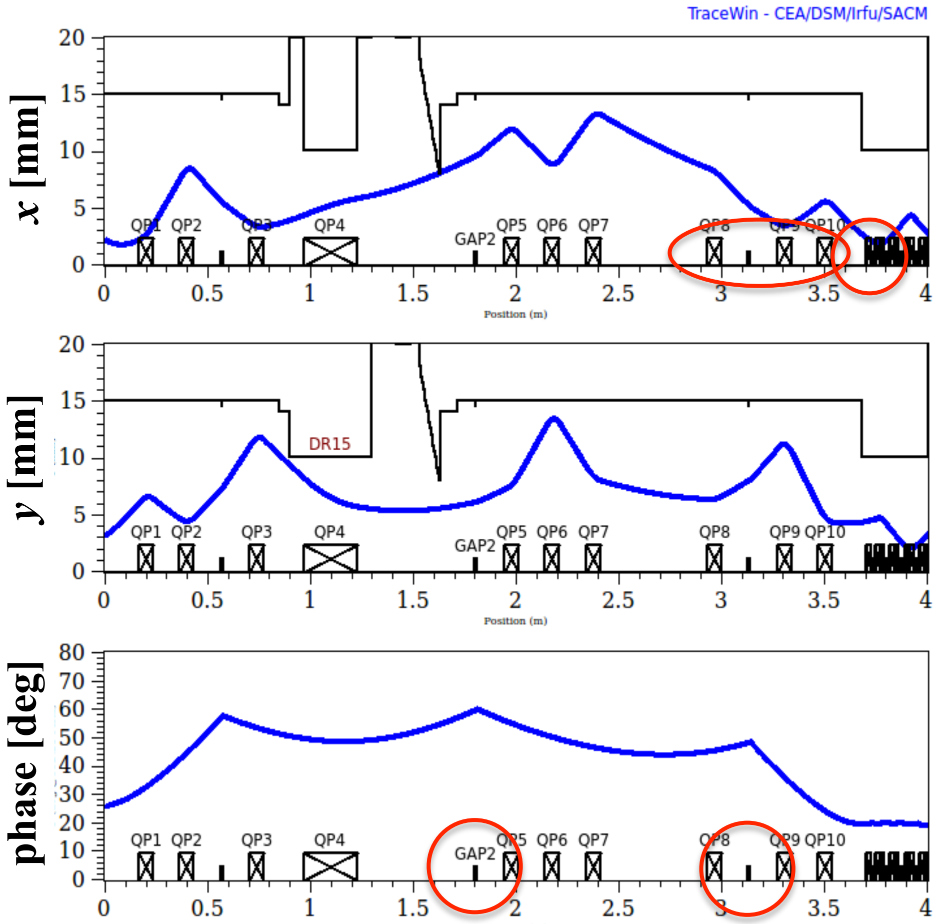

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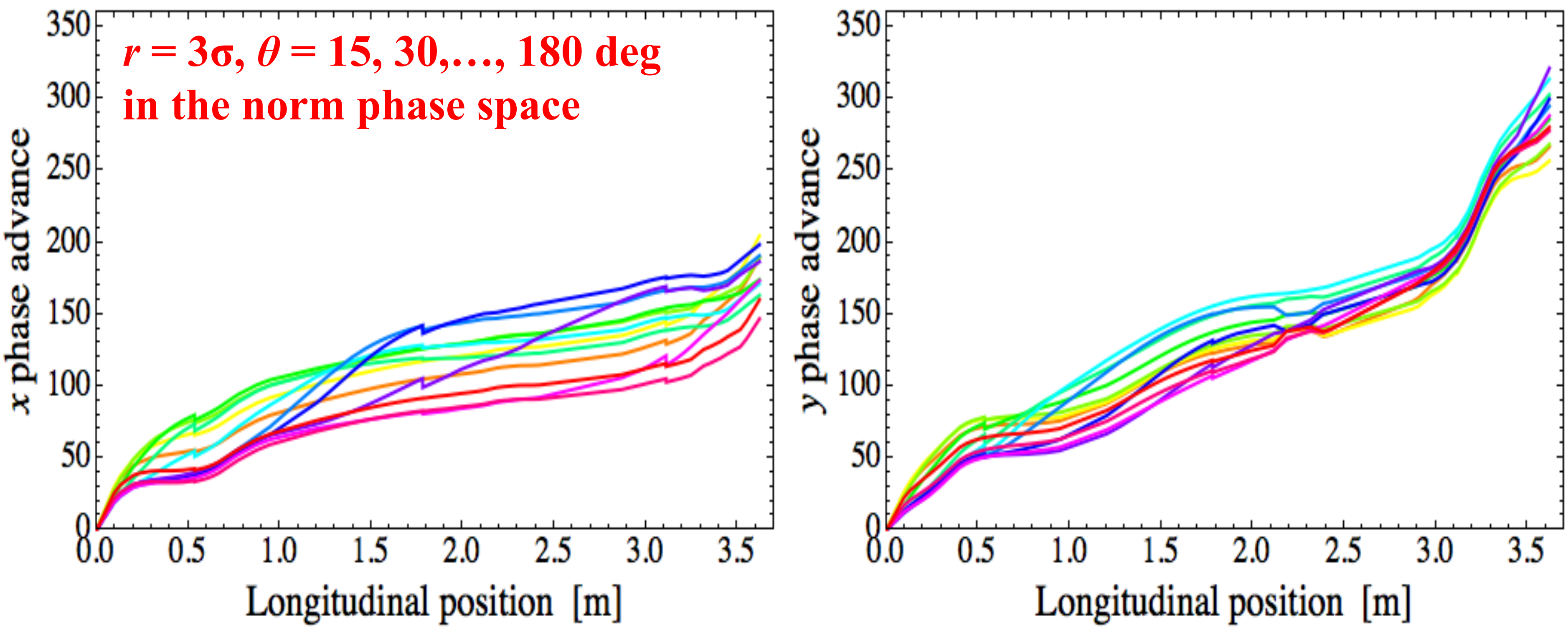
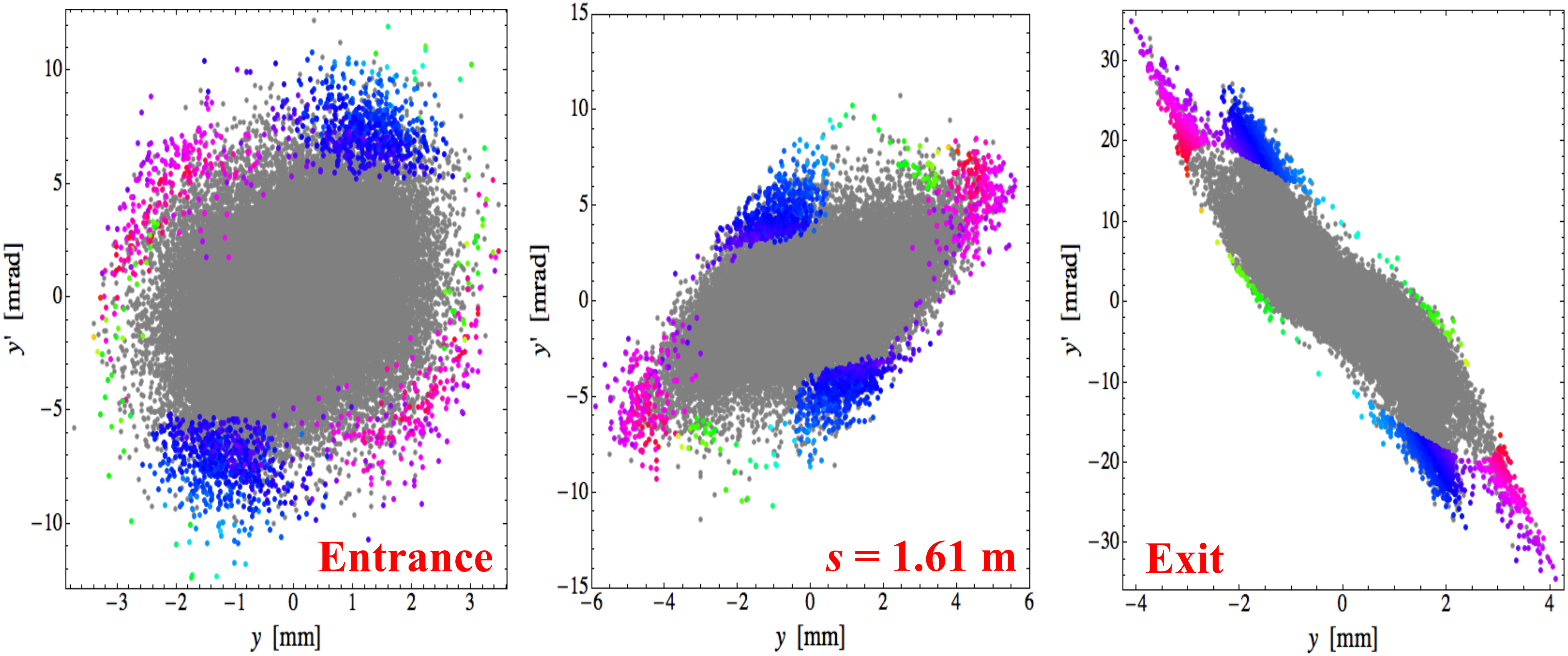
Standard collimation scheme not effective for MEBT



- SNS uses MEBT collimators in the operation (remove 2-3% of the beam!) but how they work hasn't been well re-produced in simulations.
- Due to space charge, phase advance of a particle depends on its initial position

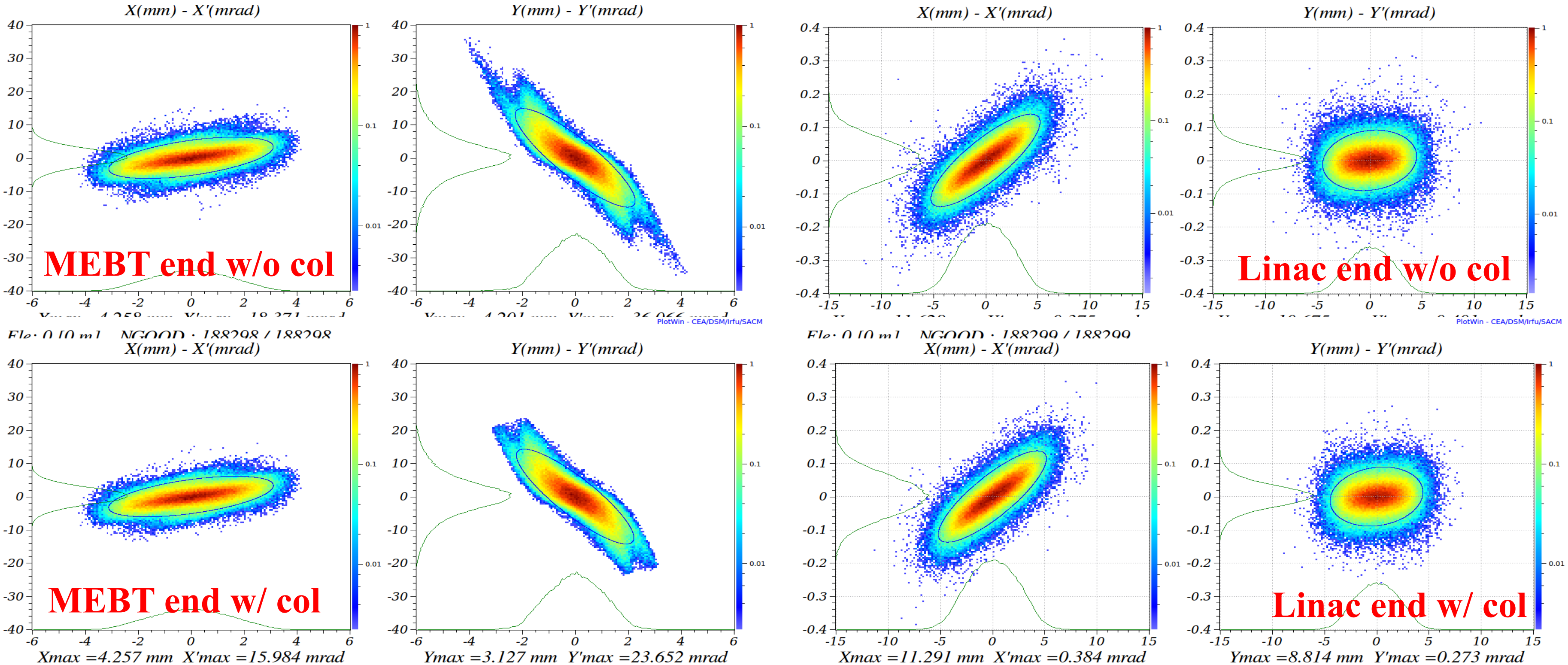
  ➔ standard collimation schemes (3 collimators separated by 90 deg, 3 separated by 60 deg, …) are not optimum for the MEBT.
- Angular distribution of halo particles is not uniform.

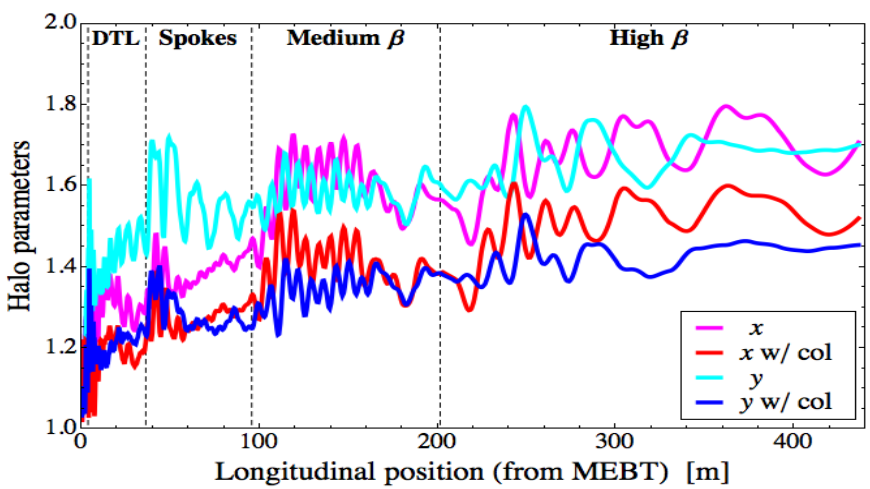
Primitive way to determine collimator locations



- Mechanical constraints ➔ a collimator placed only between quads.
- Identify halo particles (beyond 3σ) at the end of the MEBT.
- Stick to ~15 W and avoid where the beam is smaller than $\sigma_x \sim \sigma_y \sim 1$ mm.
- Trace back the distribution of the halo particles at possible collimator locations and identify the optimum set of locations.
- Chaotic behavior? Also indicate collimation effective in the later part.

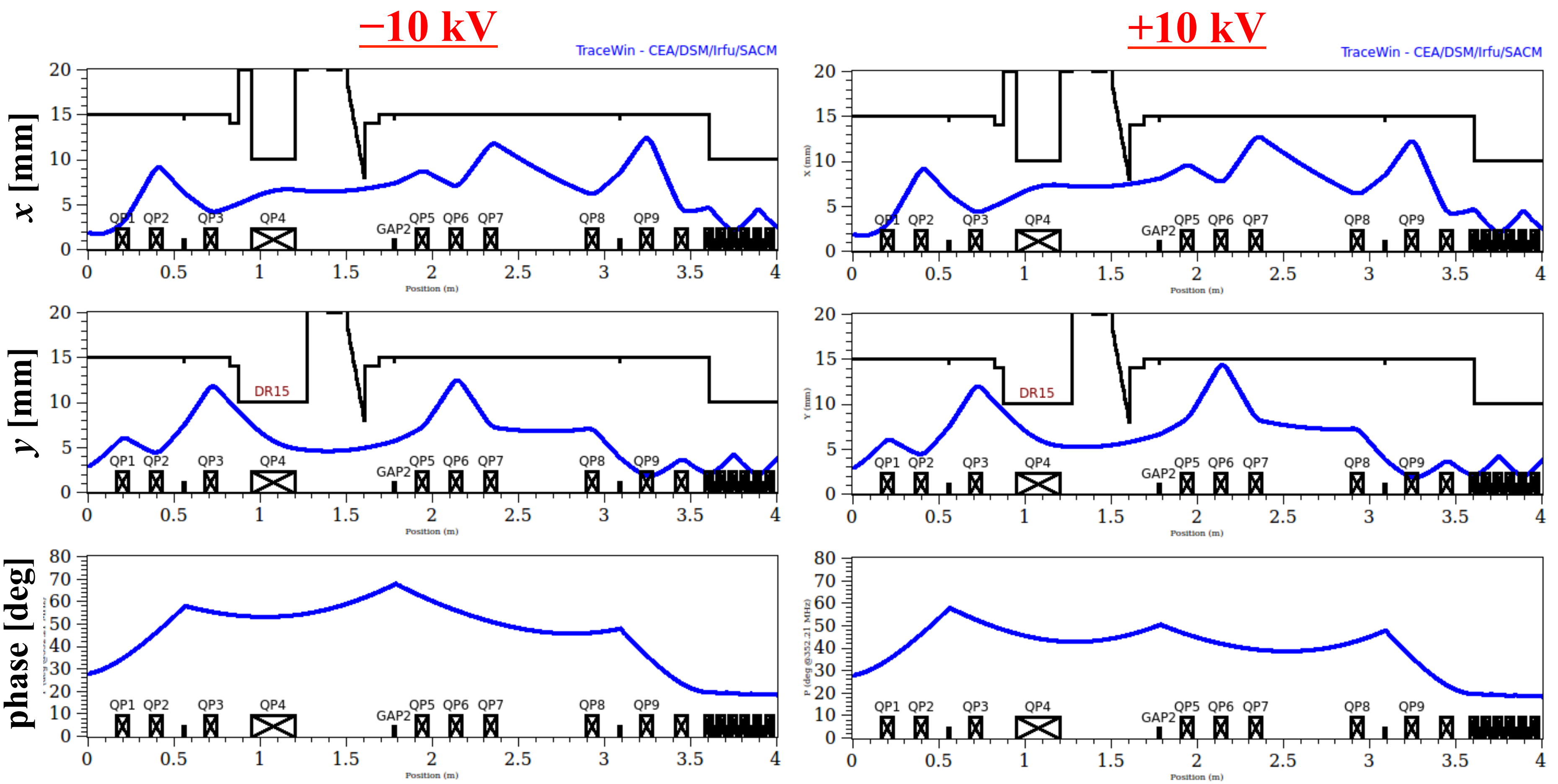
Improvement with collimators





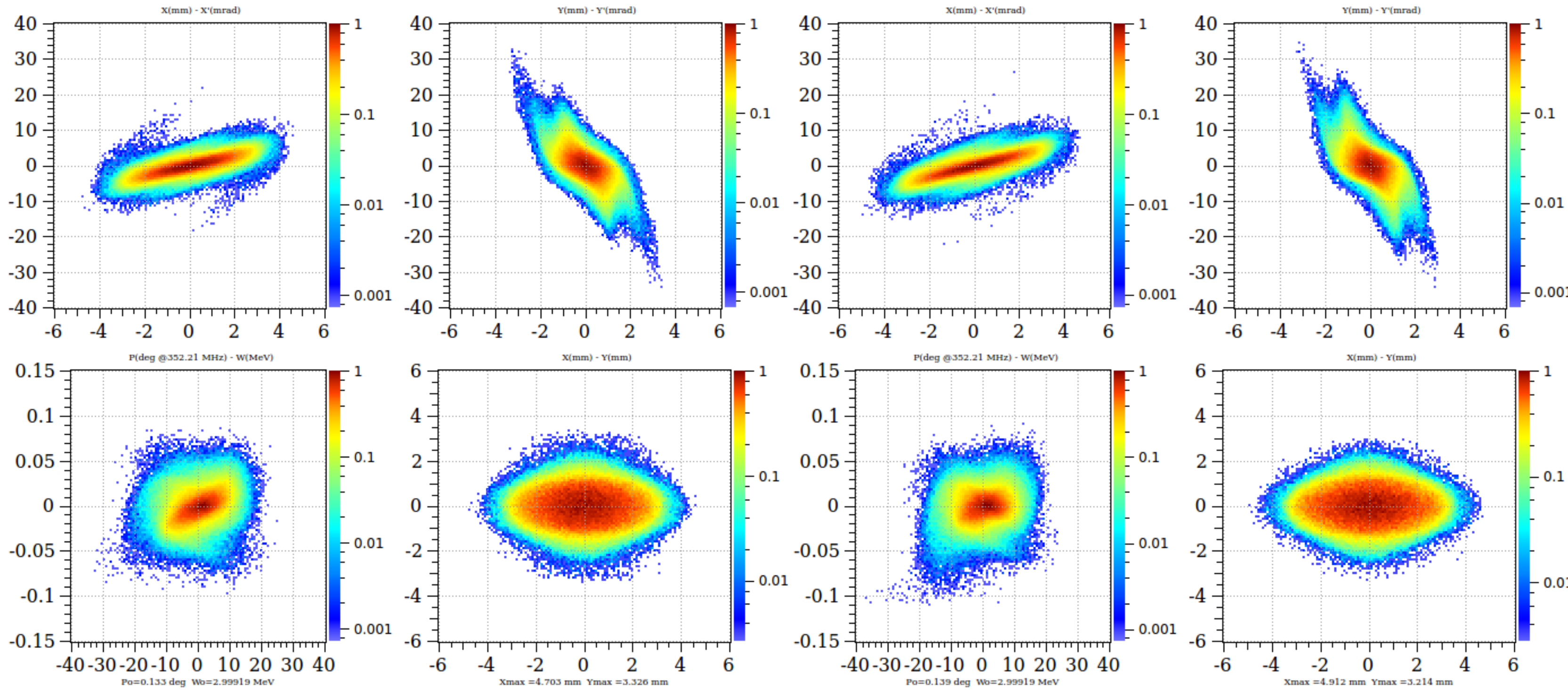
- The beam quality can be improved at the end of MEBT and the end of linac.
- The present MEBT output is already good enough for a perfect linac. Error studies will be done.

It's not enough to look at just MEBT…

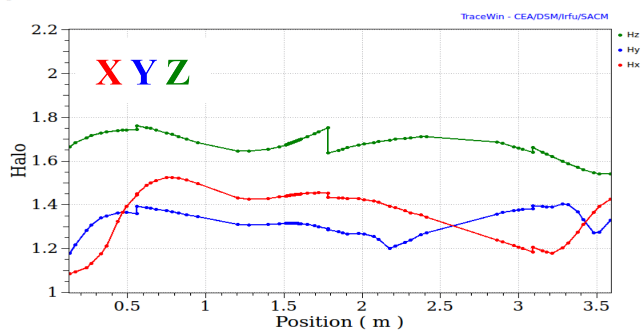


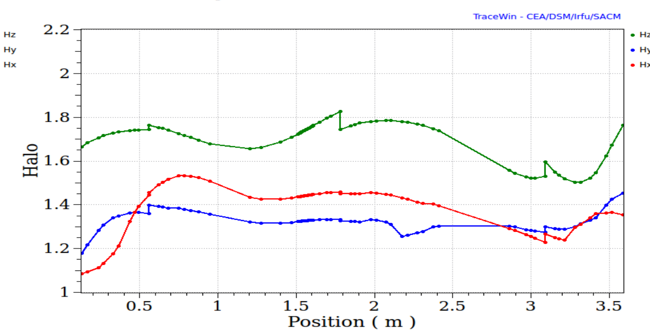
As an demonstrative example, consider to change E0TL of B1 by ±10 kV (~8%)

The situation at the end of the MEBT



−10 kV

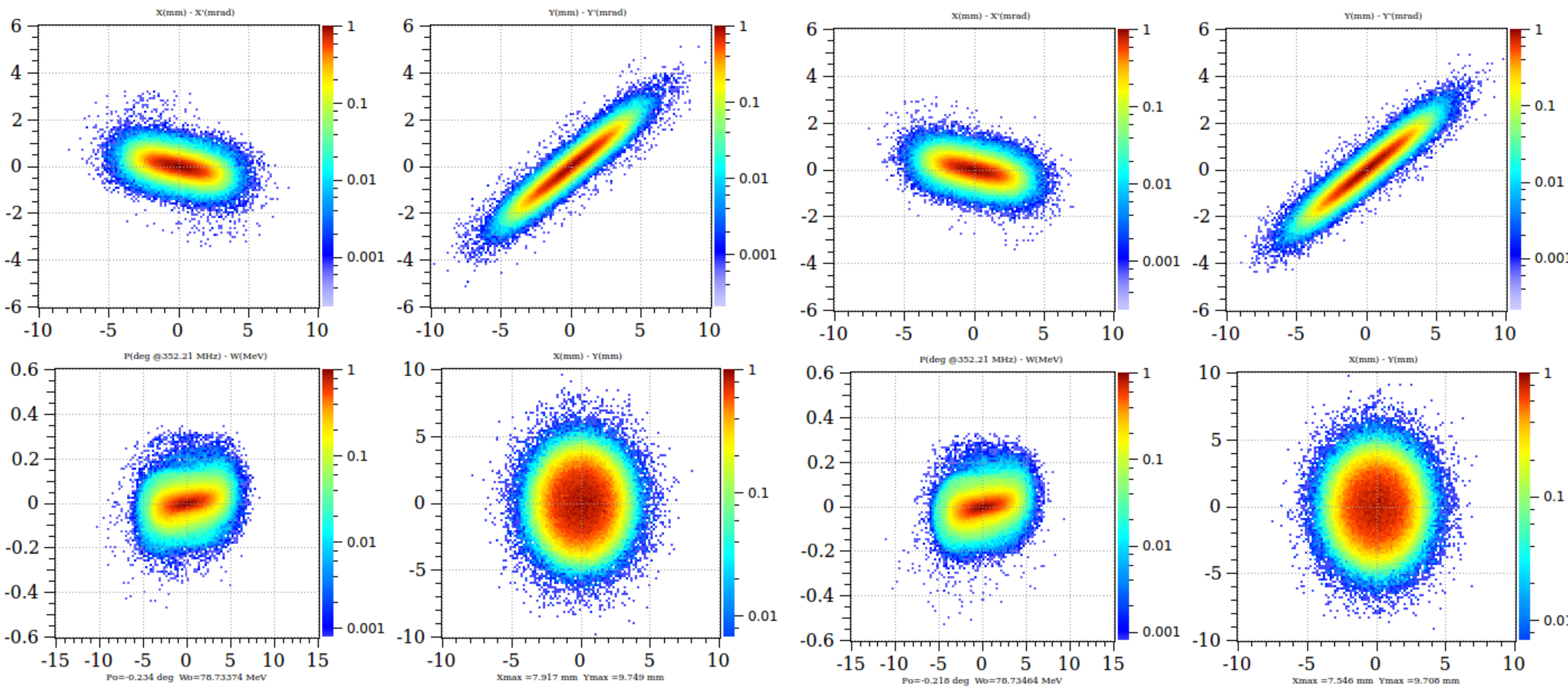




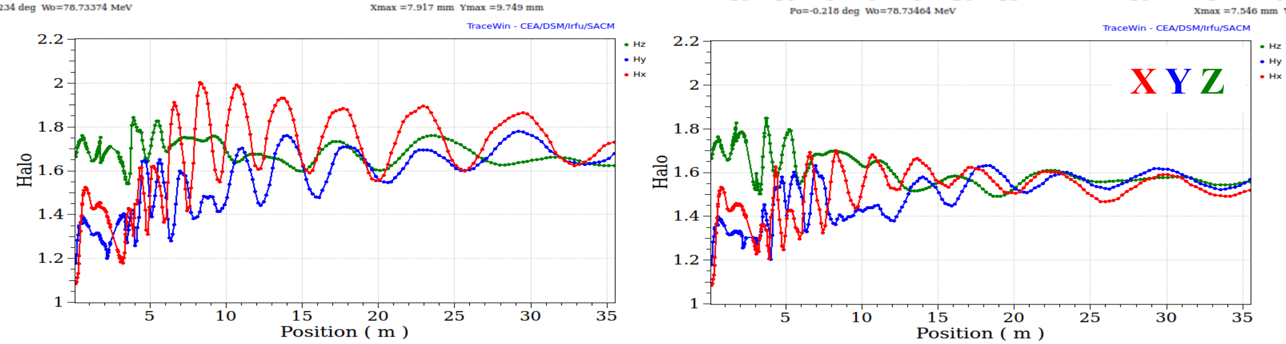
+10 kV

- Longitudinal quality visibly worse for the “tight” setting (+10 kV).
- Transverse quality is about the same for both.

The situation at the end of the DTL



−10 kV



+10 kV

- Now, the beam quality is better for the "tight" setting (+10 kV)! Internal Mismatch?
- Loss near the end of DLT is also reduced to 1/3.
- Should re-think the buncher setting? (Worth to try to weaken initial quads in DTL.)
- **Must consider the downstream sections!**

EUROPEAN SPALLATION SOURCE

Conclusions

- The MEBT lattice in the May baseline has been revised based on detailed studies of influences of each component on the beam. An unsystematic procedure of lattice optimization has been established.
- Schemes of collimation in the MEBT have been studied and a (manual) procedure of setting up collimators have been established.
- The story is far from over as everything else with the linac. The overwhelming) list to do includes
  - Error studies: input beam, lattice components
  - Optimizing the interfaces, done with RFQ on some level, studying reduction of quad strengths in the initial part of DTL
  - Optimization based on beam quality in downstream sections
  - Establishing transverse tuning procedure
  - Automatizing the optimization procedure, if possible

Thanks for your attention!

Backup Slides

Halo definition (Wangler's)

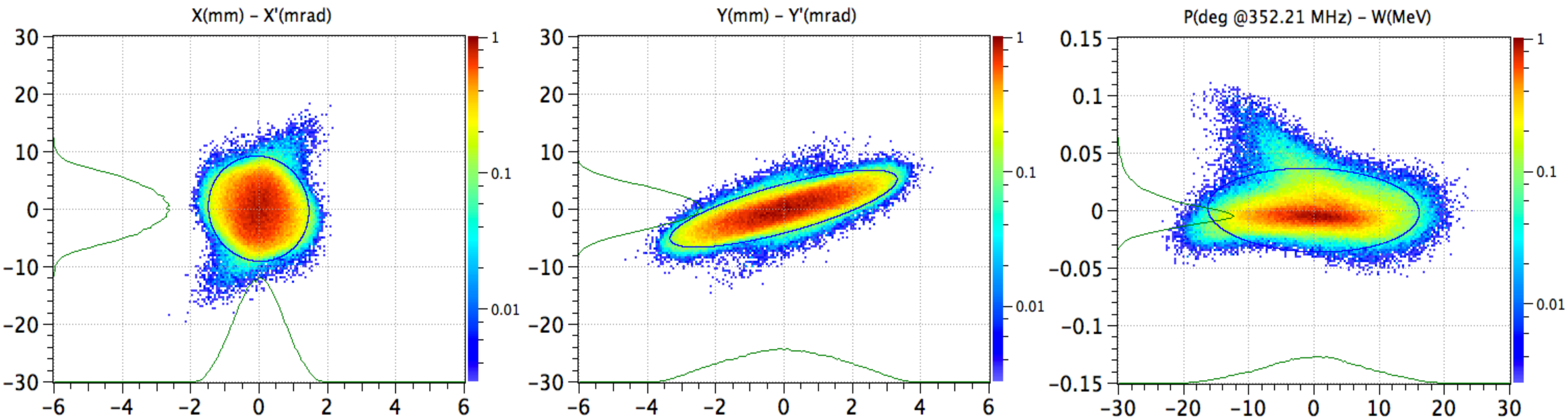
- The *spatial profile parameter* (Kurtosis):

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

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

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

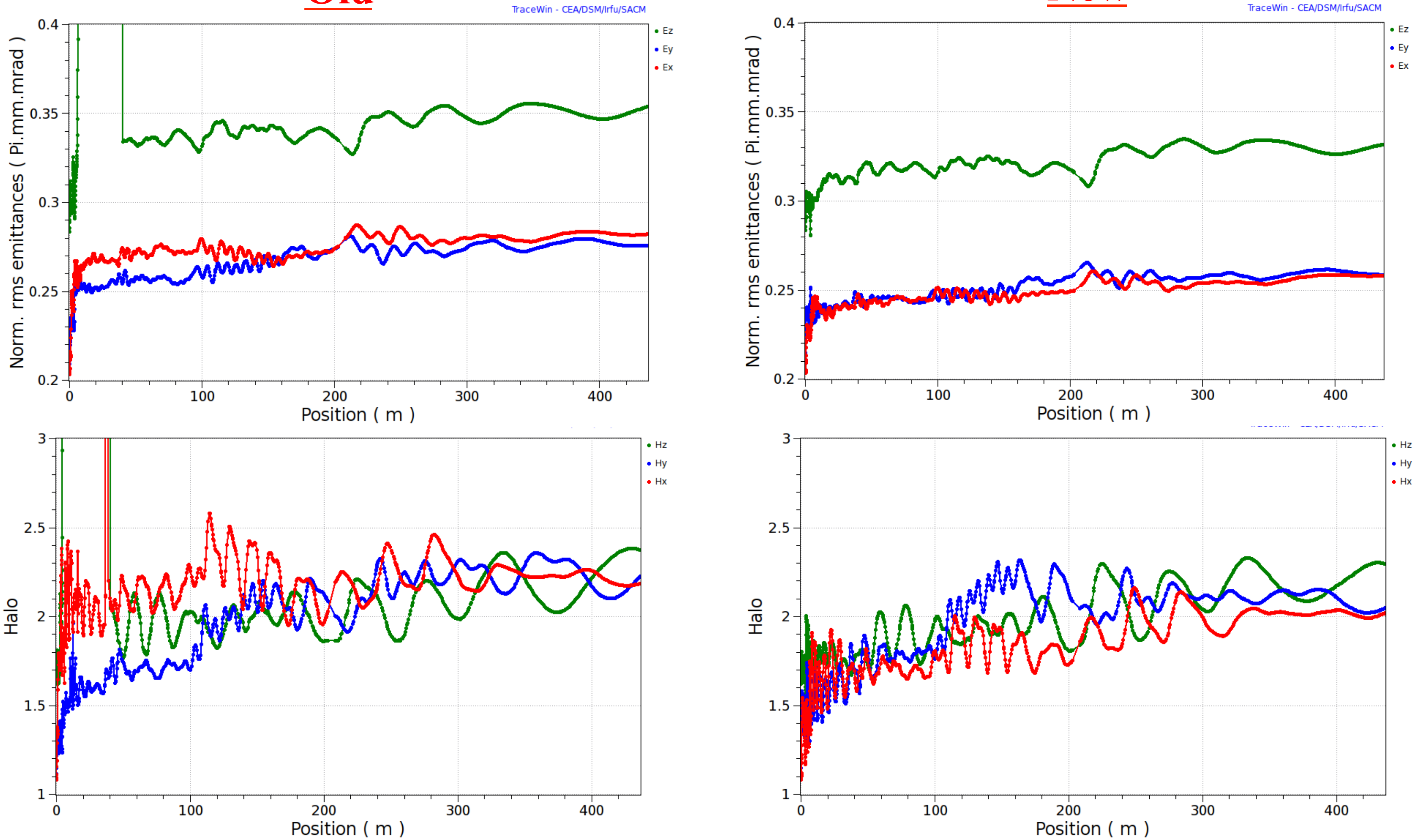
- The normalization "2" to make the "KV" = 0 and "Gaussian" = 1.



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

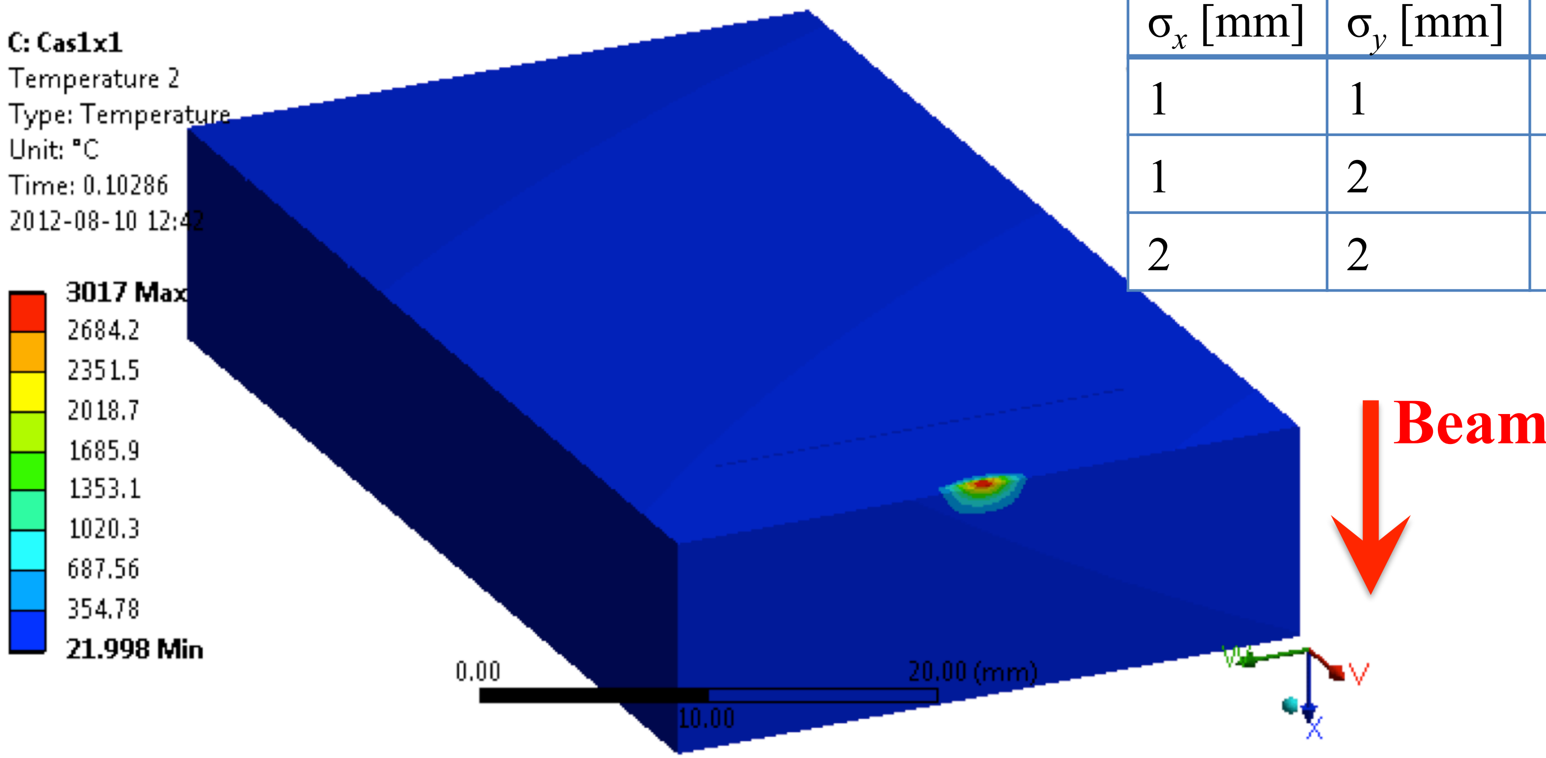
New vs. old long MEBTs: emittances and halos

Old | **New**



Loss in the DTL is also improved but no loss in the SC sections in both cases.

Loss limit of a MEBT collimator?



σ_x [mm]	σ_y [mm]	Temp [C°]
1	1	3017
1	2	1430
2	2	1178

- Assumptions: graphite jaw, Gaussian beam, remove beyond 3σ (~0.25%, ~15 W)
- Graphite may suffer mechanical damages beyond ~1500 C°.
- **In the simulation, stick to ~15 W and avoid where $\sigma_x \sim \sigma_y \sim 1$ mm.**
- Better to know the beam size vs. loss limit in detail.
- Other materials planned to be studied.