Present simulations on the influence of more relaxed BSW specifications on the production of HL-LHC beams

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Outline

“The obtained result for the BSW pulse to pulse repeatability is 250 ppm (+- 125ppm), compared to the specified +-50ppm. *(See Todor’s presentation)*

Is this increased specification for the flat-top reproducibility problematic for the production of the HL-LHC beam?”

- Assumed simulation set-up for HL-LHC beams.
- Including BSW errors in simulation set-up
- Simulation results
- Outlook

Simulation set-up for HL-LHC beams

- Ekin = 160 MeV
- current: 25 mA, $\epsilon_{\mathrm{n,rms,x\,/y}} = 0.4$ mm mrad
- $\mathrm{I} = 3.5\ 10^{12}$ p+ over 37 turns
- Chopping factor = 0.62, dE_rms = 500 keV
- 200 ug/cm2 carbon foil, simple scattering model
- Working point (Qx,Qy) = (4.4, 4.45) *(see slide 4)*
- including QP errors
- including BSW fringe fields and induced sextupolar fields during chicane decay + computed compensation scheme.
- KSW ratio set for Qx = 4.4 *(see slide 5)*

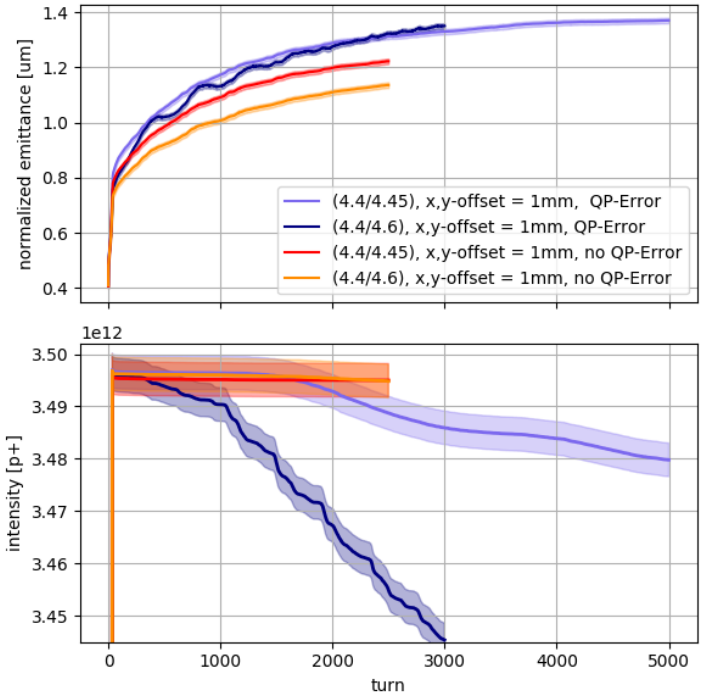
see https://indico.cern.ch/event/832290/
for descriptions of simulations set-up

- Target emittance: $\epsilon_{n,\mathrm{rms,x\,/y}} < 1.7\ \mu$m
- Target intensity: $\mathrm{I} > 3.42\ 10^{12}$ p+

Working Point

- Previous simulations conducted for (Qx,Qy) = (4.43,4.46), (V. Forte, WEP2PO007, HB2018)
  - but without quadrupole errors
- Suggestion from ABP: stay below half integer resonance in both planes.

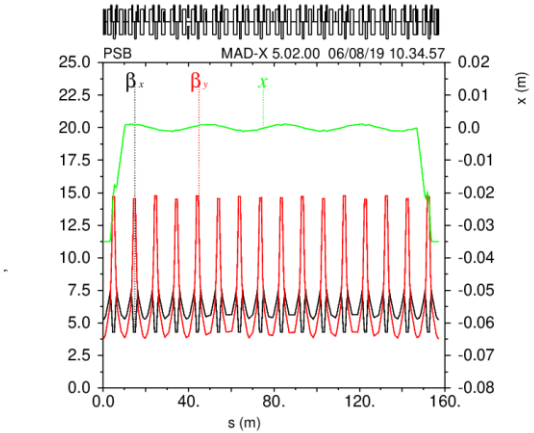
► Assumed WP for those studies: Qx,Qy = (4.4,4.45)



KSW Settings

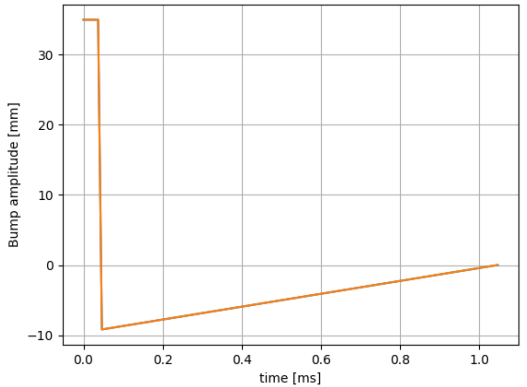
KSW ratio

- Ratio of KSW optimized for Qx = 4.4
- Considering hardware limits, orbit cannot be closed for Qx = 4.4.
- Ratio is chosen to keep closed orbit with x = 81mm, px = 0 at foil



KSW decay

- No painting, 37 turns at max. current with subsequent fast decay



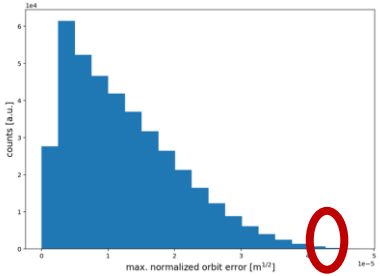
Including BSW Errors in Simulations: Present + Future Plans

For now:

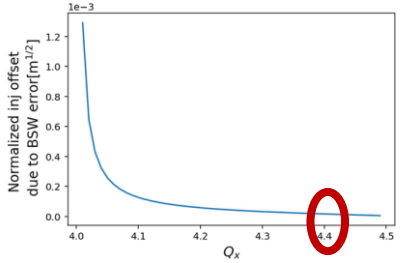
- Max. closed orbit error due to BSW flat top error is considered (very pessimistic)
  - BSW1: +125 ppm
  - BSW2: - 125 ppm
  - BSW3: -125 ppm
  - BSW4: +125 ppm
- assumed constant flat-top during injection of 1 ring
- BSW decay in 5ms, independent of varying flat top current
- additional injection offset of +-1mm considered

Future studies:

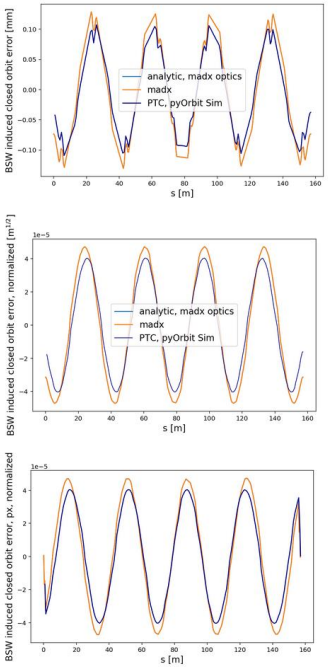
- Create model with randomized errors from various sources, including BSW (distribution?)
- Note: Impact of BSW2 error on injected beam not yet considered in presented results



Histogram of max. closed orbit deviation (normalized phase space), considering uniformly distributed errors between +-125 ppm for all 4 BSW

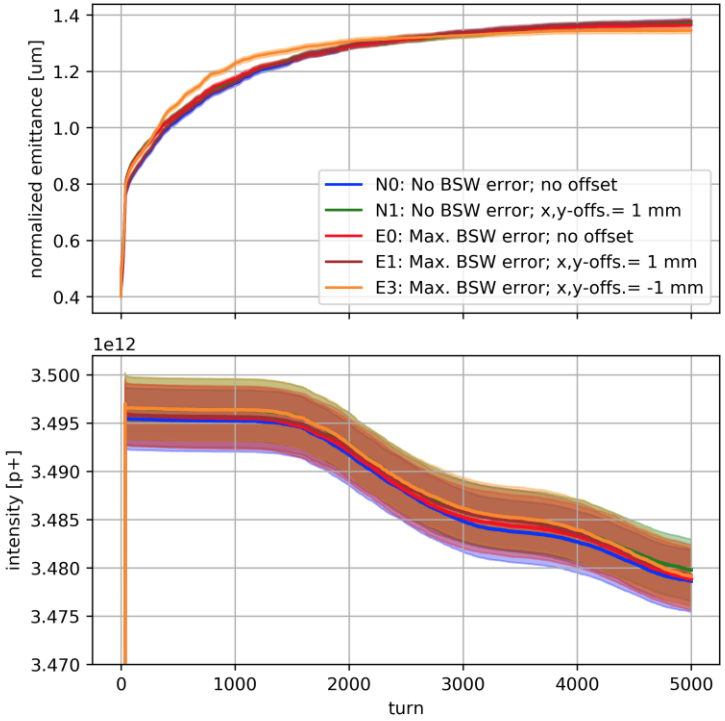


Normalized max. closed orbit error depending on tune



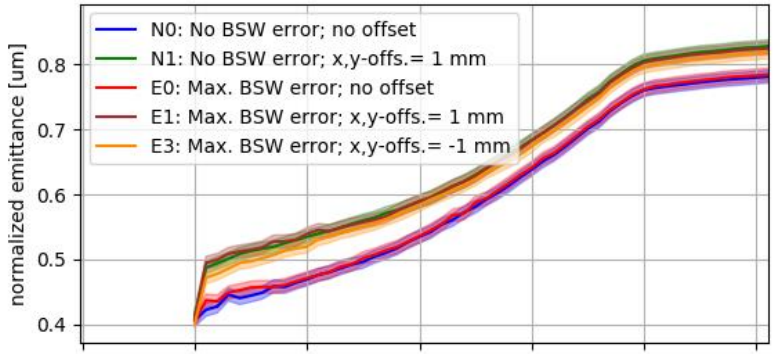
Induced orbit error. Mad-x vs. pyOrbit

Simulation results I – average rms emittance



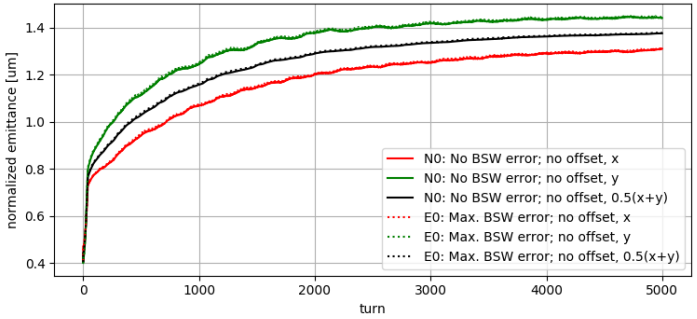
No significant emittance increase due to BSW shot-to-shot reproducibility of +- 125 ppm

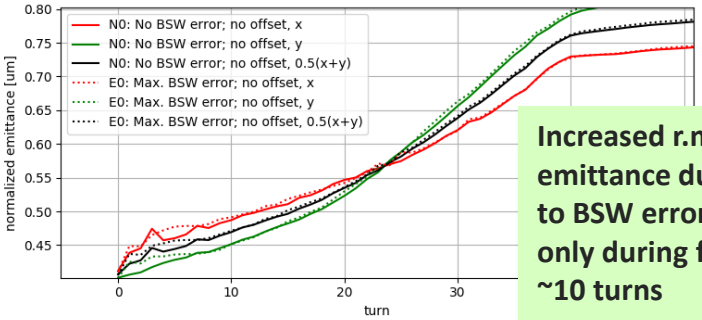
✓ **+- 125 ppm shot-to-shot error acceptable**



Simulation results II

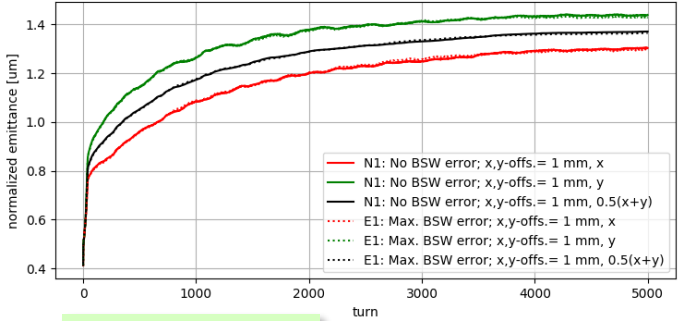
BSW error with no additional injection offset



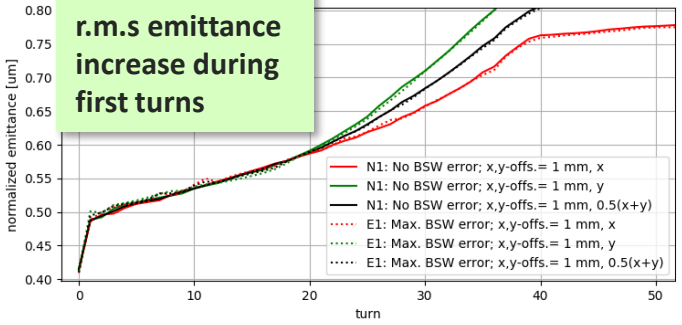


Increased r.m.s emittance due to BSW error only during first ~10 turns

BSW error with additional injection offset of 1 mm in x and y.



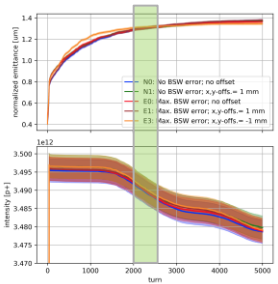
No additional r.m.s emittance increase during first turns

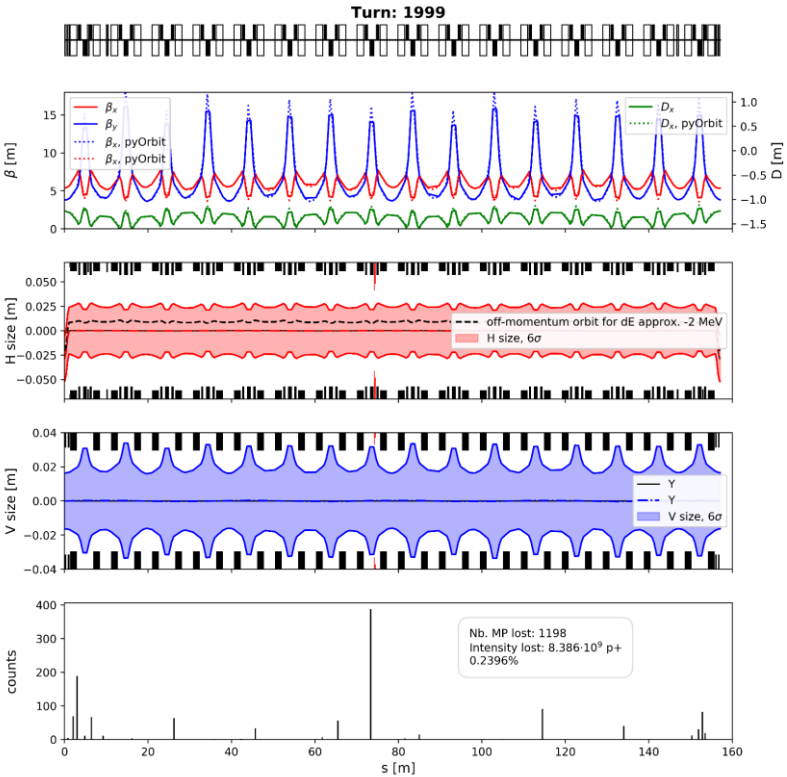


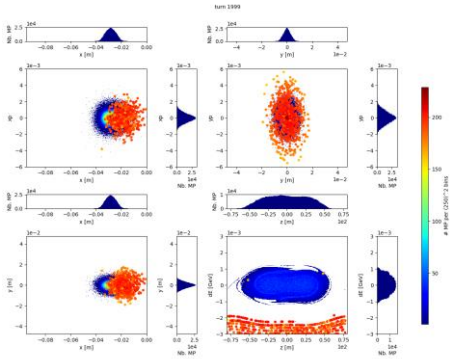
Simulation results III - Losses HL-LHC Beam

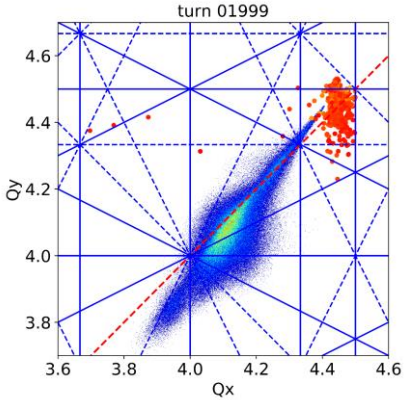
Total losses after turn 5000 ~ 0.6%

Obviously, no difference due to +- 125 BSW flat top reproducibility







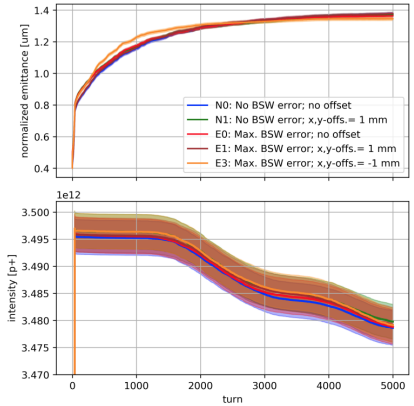


Going beyond +-125 ppm?

- No simulations for BSW errors > +-125 ppm conducted
- First, other error sources have to be included in simulation set-up.
- Further margin required for unforeseen error sources, to stay below $\epsilon_{\mathrm{rms,x\,/y}} = 1.7\ \mu\mathrm{m}$

► **The specs should not be increased to > +-125ppm shot to shot reproducibility, as margin needs to be kept for other error sources.**

V. Forte, Multi-particle Simulations of the future CERN PSB Injection Process with updated LINAC4 Beam Performance, WEP2PO007, HB2018



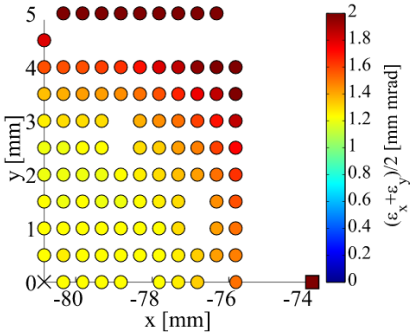


Figure 4: The final emittances 10 ms after injection for $I_{\mathrm{peak}} = 40$ mA and $\epsilon_{x,y,n,0} = 0.4$ µm and different transverse offsets [10].

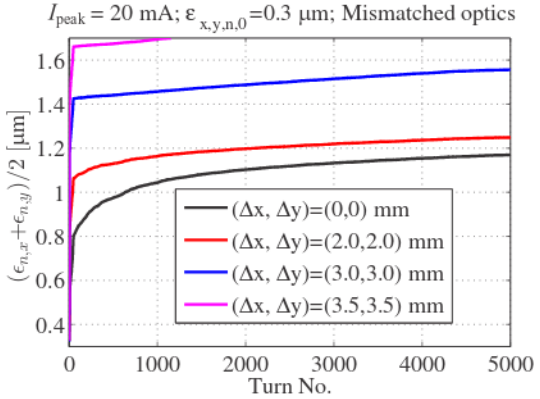


Figure 8: Average transverse emittances for different injection offsets.

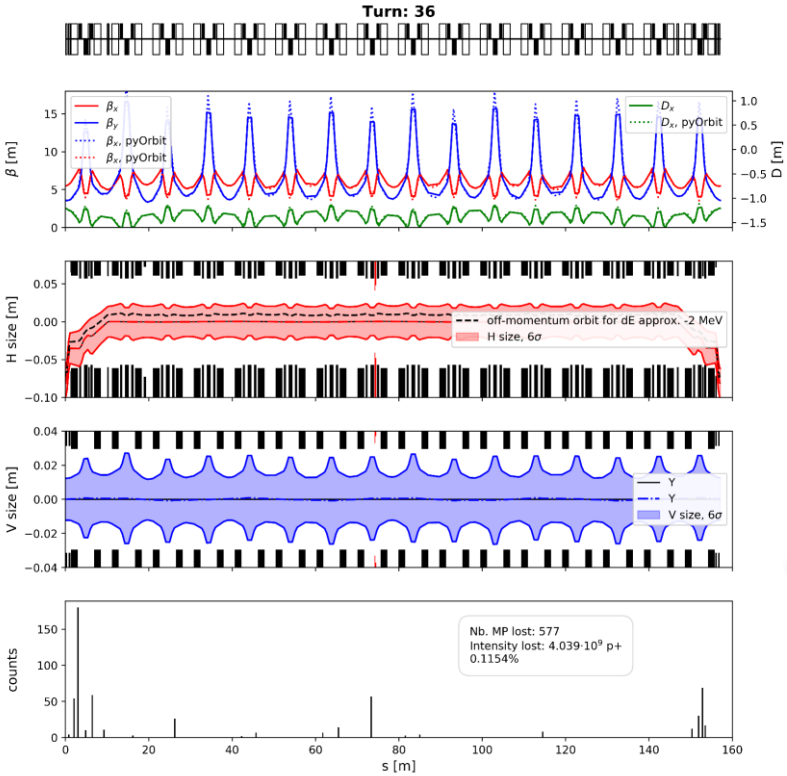
Plans and conclusion

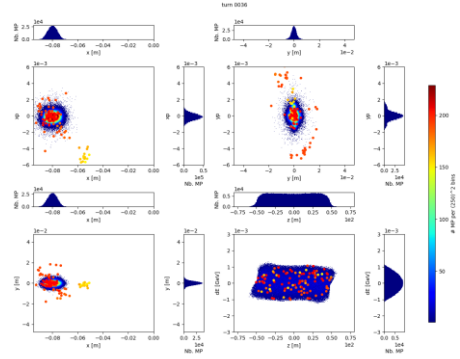
- The most pessimistic combination of BSW errors (+,-,-,+ 125 ppm) was considered to estimate the impact of a **worst case scenario for the emittance of the HL-LHC beam.**
- Future studies will include randomized BSW errors
- **From current point of view, a shot to shot reproducibility of +-125 ppm is acceptable for achieving the brightness targets of the HL-LHC beam.**
- Other error sources need to be estimated and included before theoretical impact of BSW reproducibility > +- 125ppm could be looked at.
- **The specs should not be increased to > +-125ppm shot to shot reproducibility, as margin needs to be kept for other error sources.**

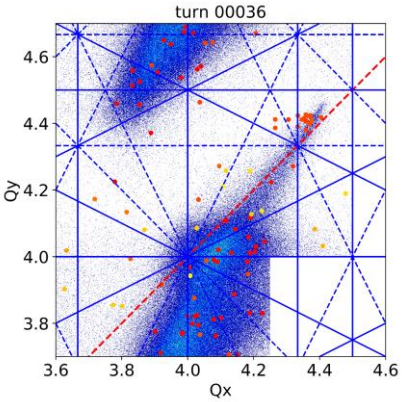
Appendix

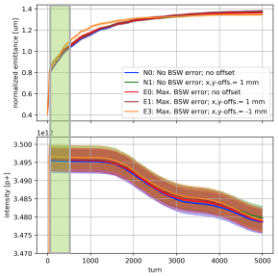
Simulation results III - Losses HL-LHC Beam

Scattering losses during first ~50 turns in injection region



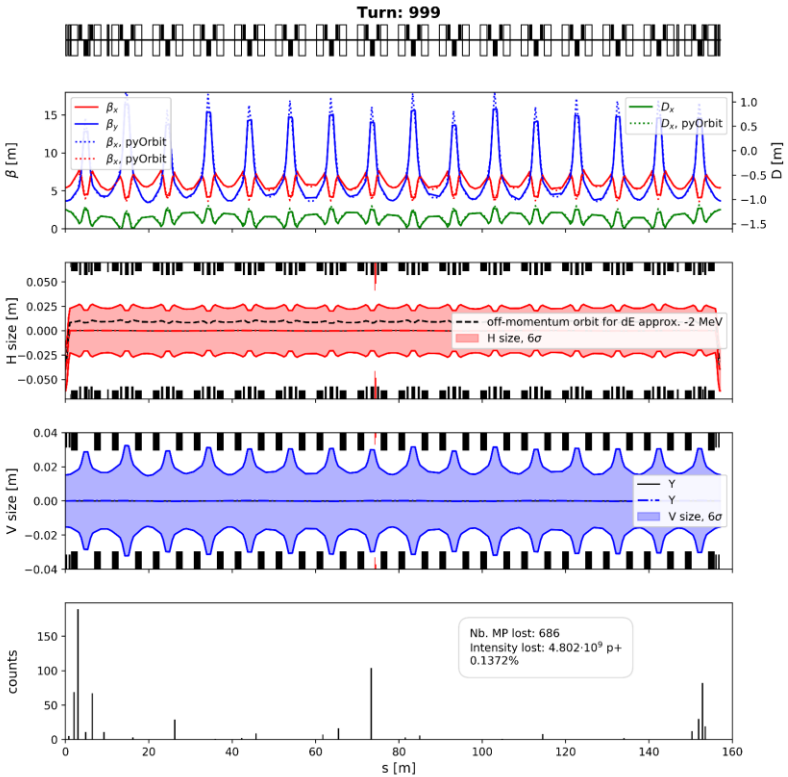


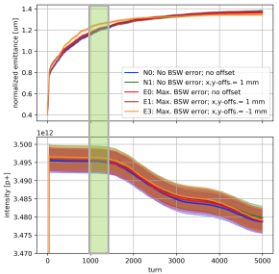


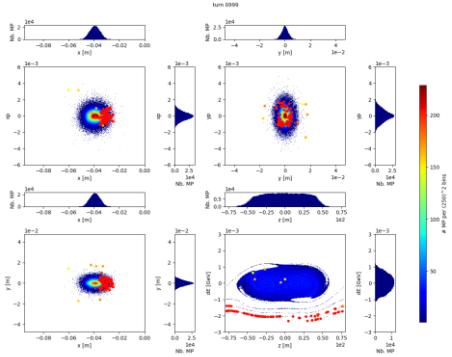


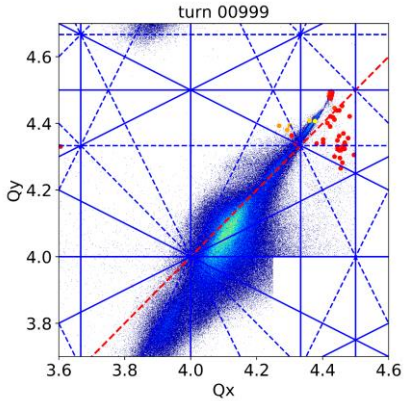
Simulation results III - Losses HL-LHC Beam

After turn 1000: off momentum losses at absorber









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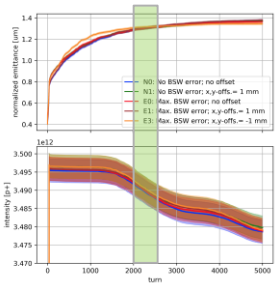
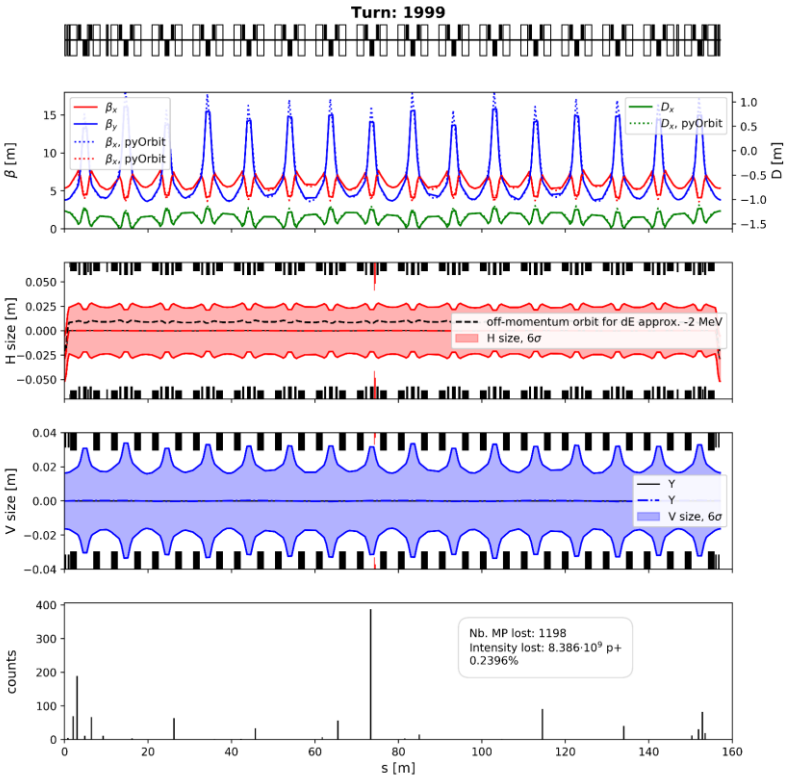
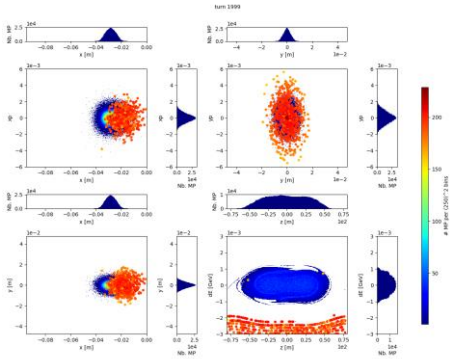
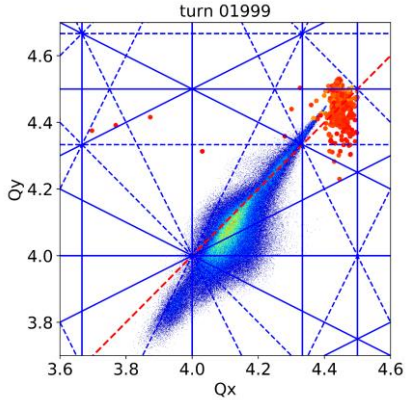




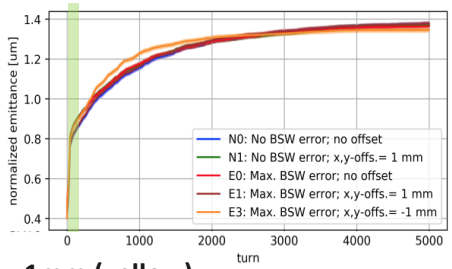




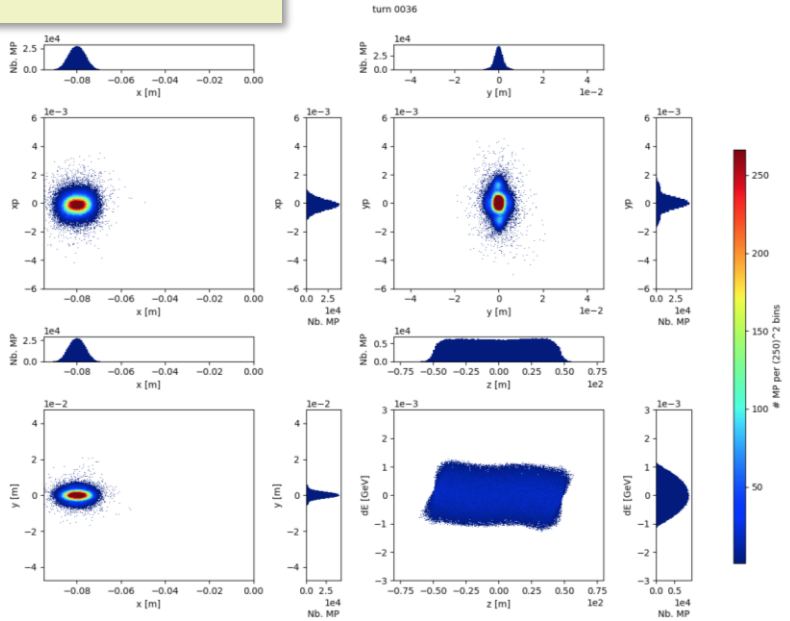
Simulation results III - Open points + Discussion

Open:

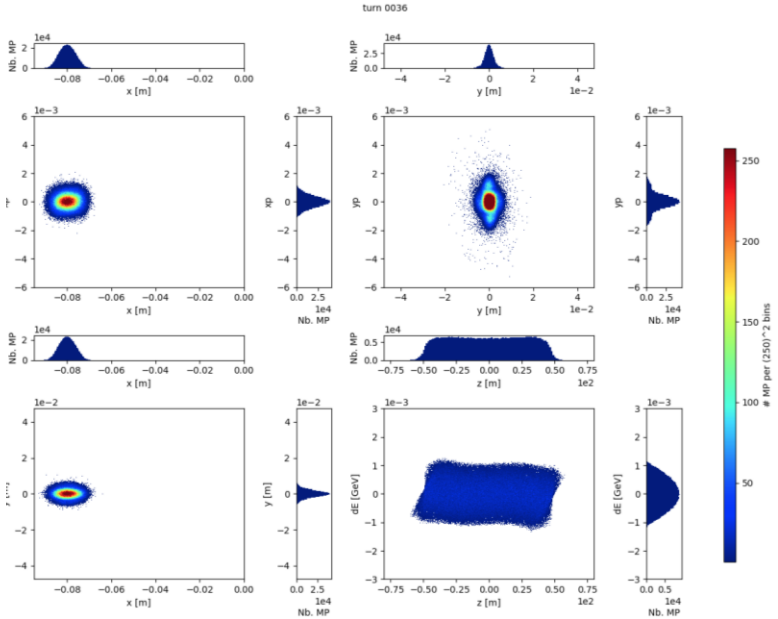
Emittance increase in x and y between turn 500 and 2000 for BSW error and x / y offset + -1mm?



BSW error, no offset (red)



BSW error, x- / y-offset = -1mm (yellow)



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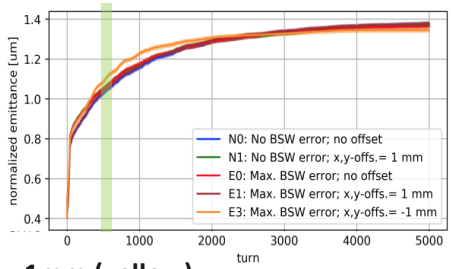

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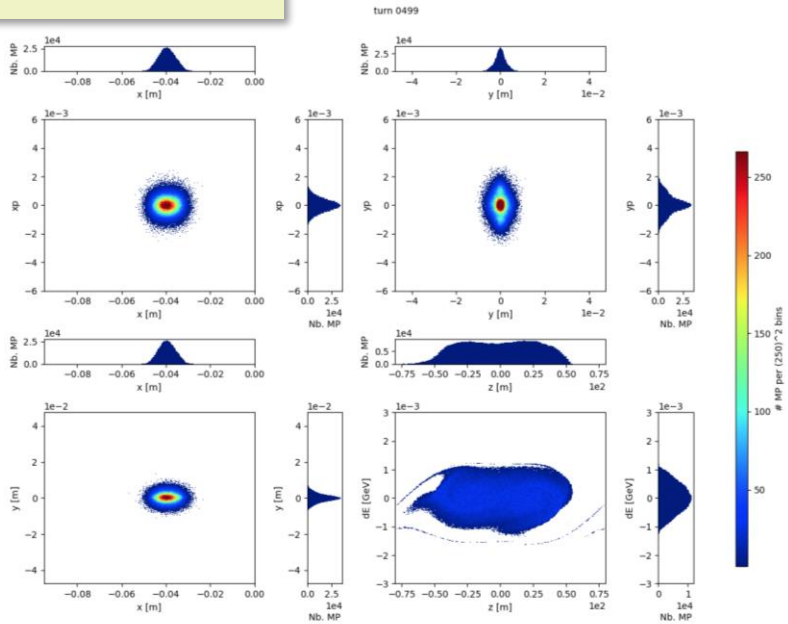

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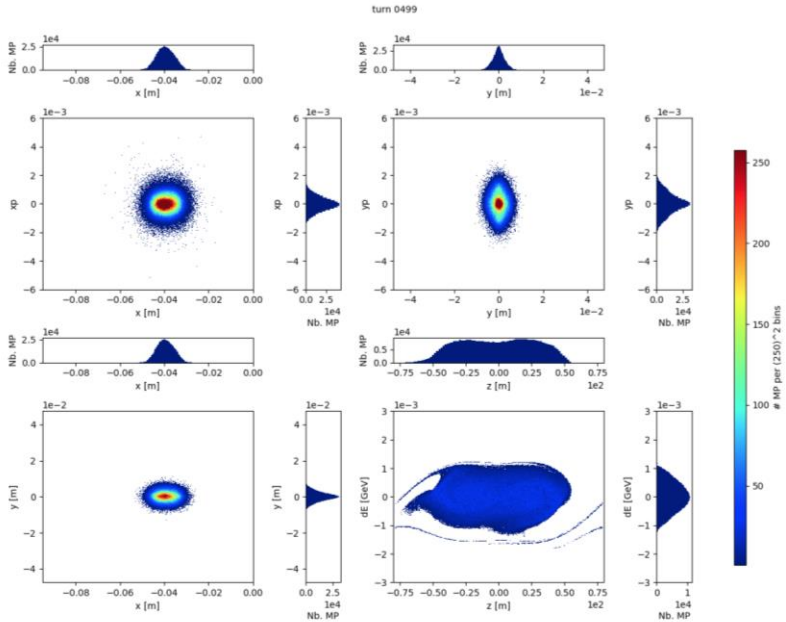

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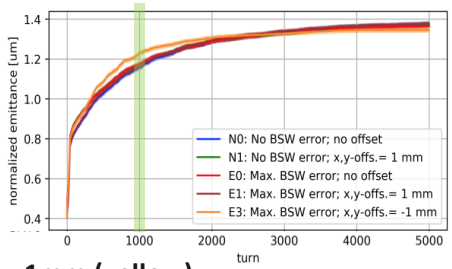
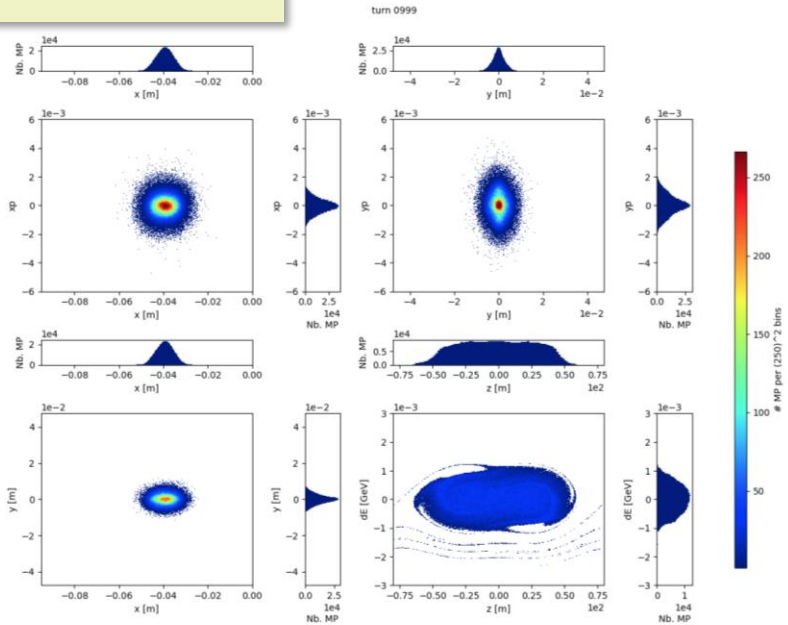
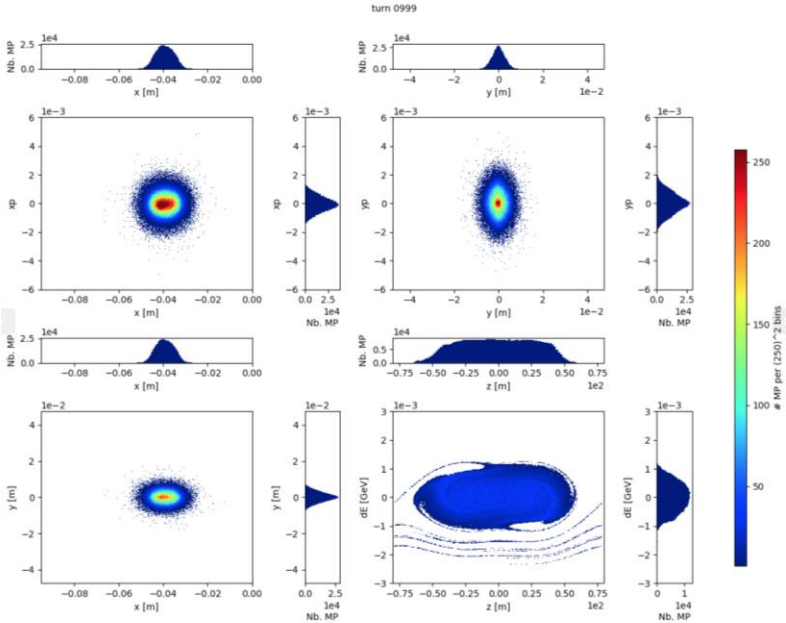


BSW error, no offset (red)



BSW error, x- / y-offset = -1mm (yellow)



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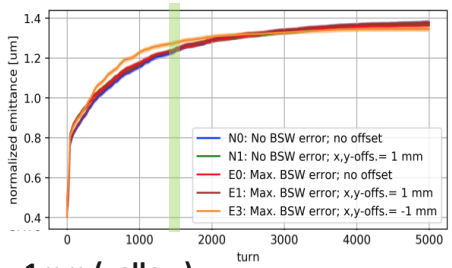

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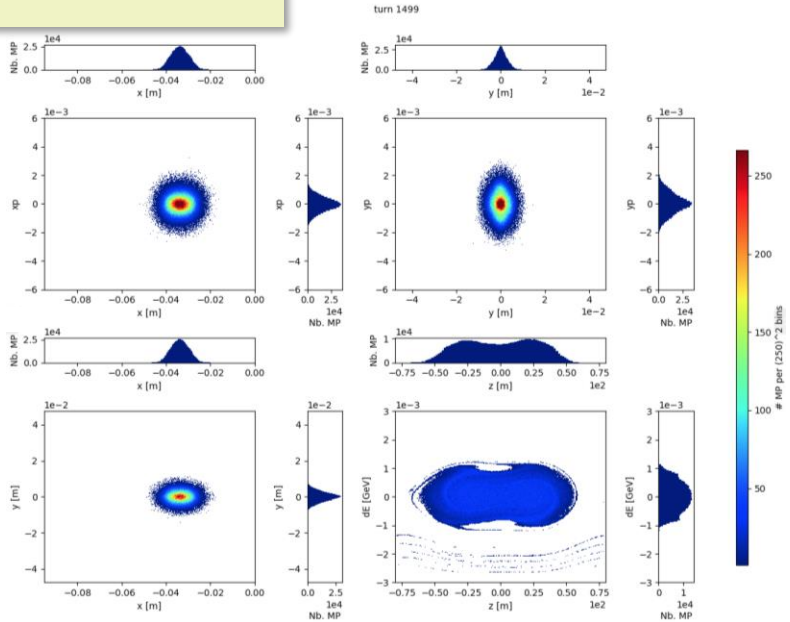

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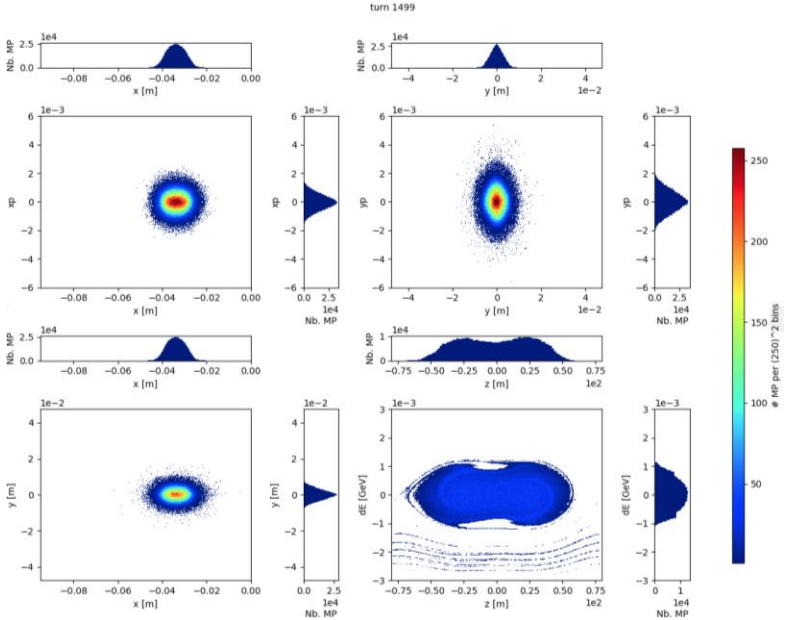

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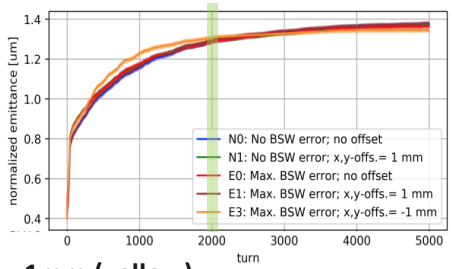

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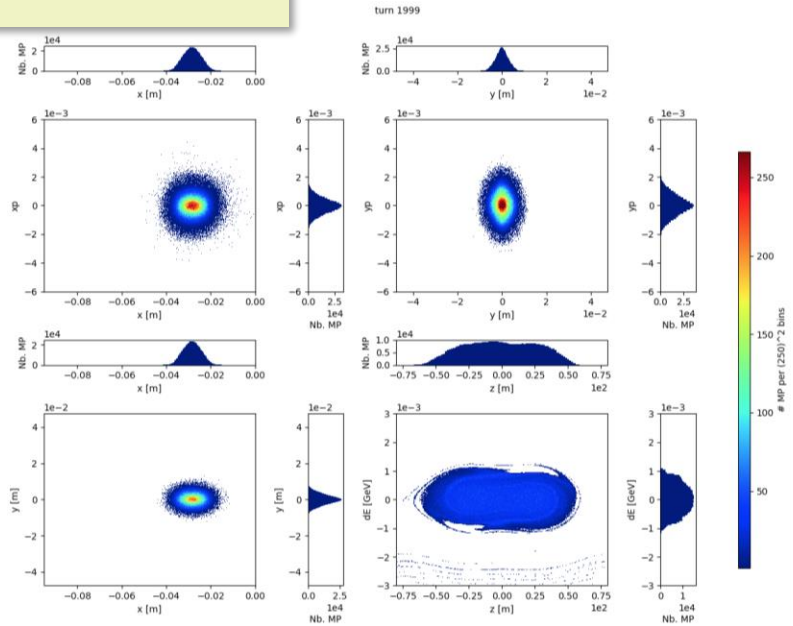

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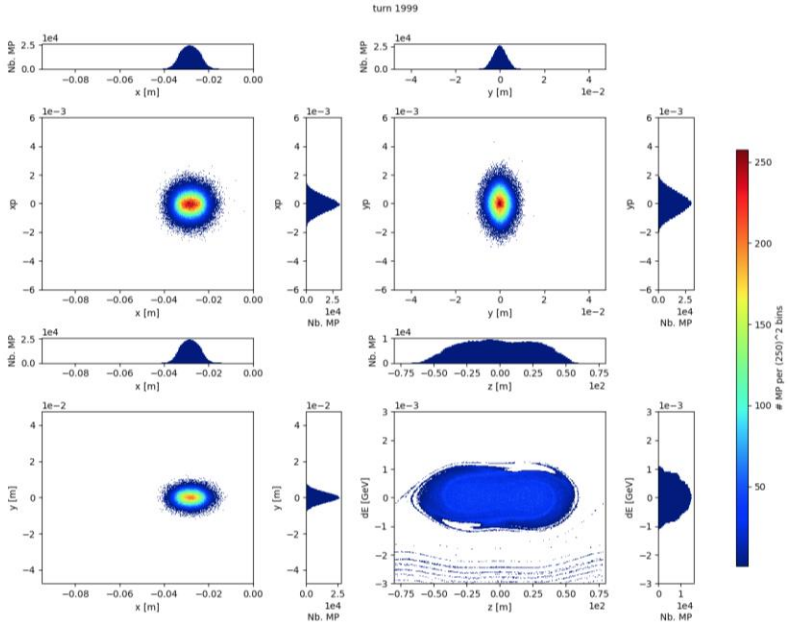

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