# SENSITIVITY STUDY ON THE SPL : DEFINITION OF ALIGNMENT TOLERANCES, DIAGNOSTICS AND CORRECTION SYSTEMS

sLHC

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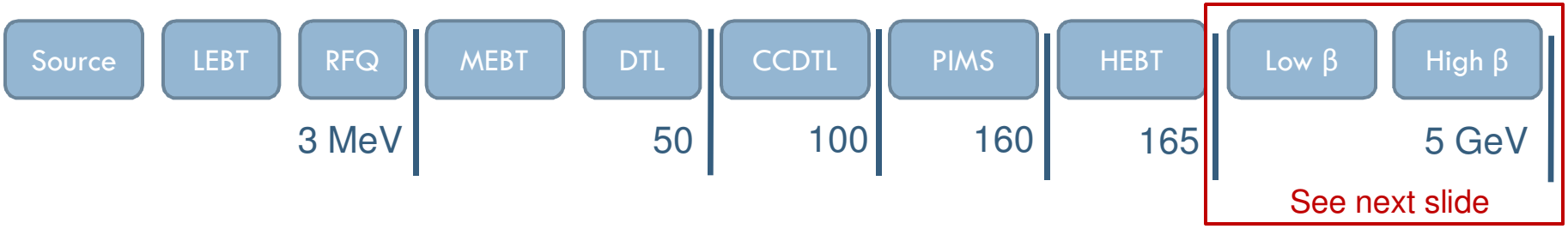
# Overview of SPL






Source: 70 mA of $H^-$ ions at 45 keV

RFQ: 60 mA, 352.2 MHz

DTL: Three tanks (FFDD+FD)

CCDTL: 7 Tanks (FD)

PIMS: 12+1 Tanks (FD)

Elliptical: 2 generations of elliptical cavities, $\beta 0$=0.65 and 1.0

(FD or F0D0) 704.4 MHz

Linac4

SPL

# SPL layout




Doublet (FD), baseline, design:

10 low beta cryomodules (780 MeV)

5 high beta cryomodules (1516 MeV)

Extraction to ISOLDE

6 high beta cryo. (2586 MeV)

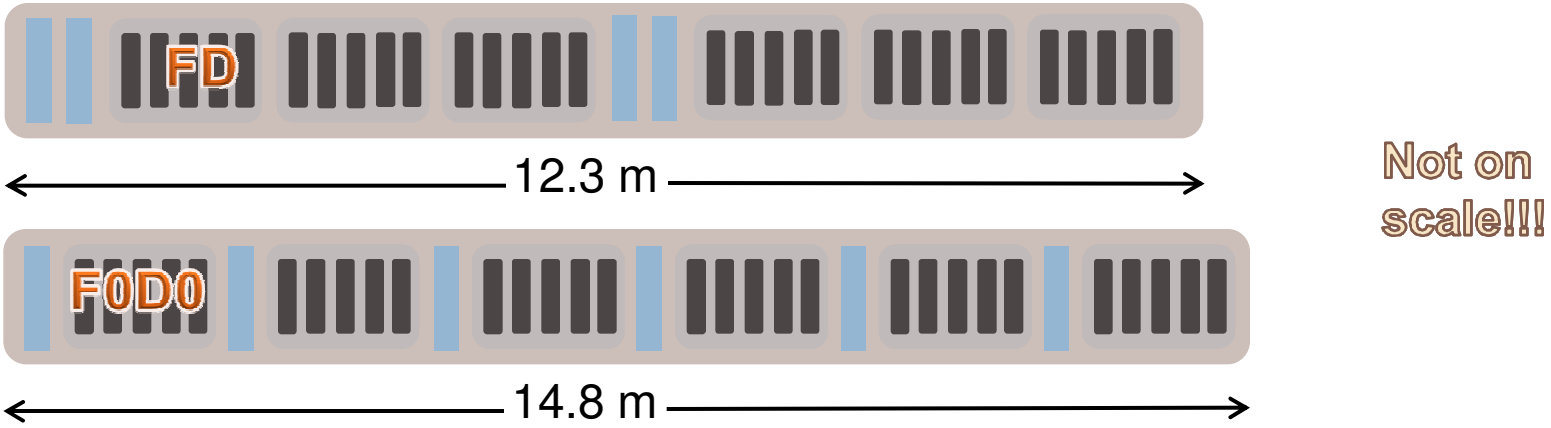
Extraction to EURISOL

→12 high beta cryomodules (Final Energy 4989 MeV)

# SPL design lattices: FD vs. FODO

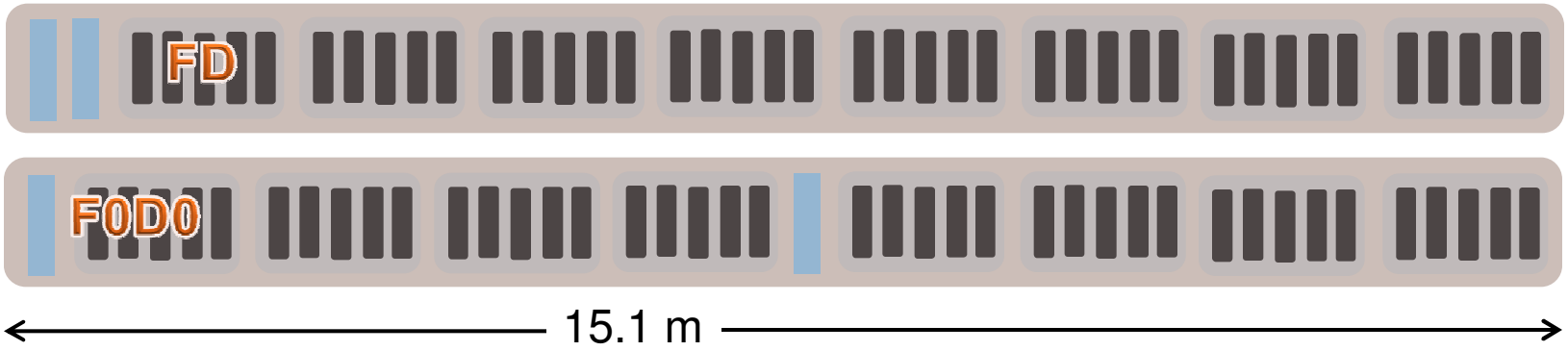


Low beta elliptical




Not on scale!!!

High beta elliptical



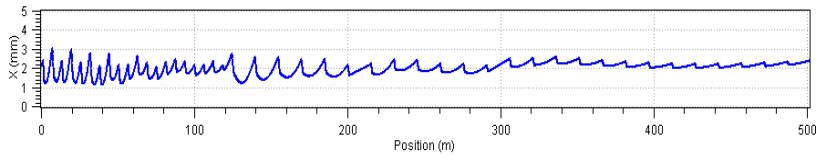
# SPL Beam dynamics (1/2)

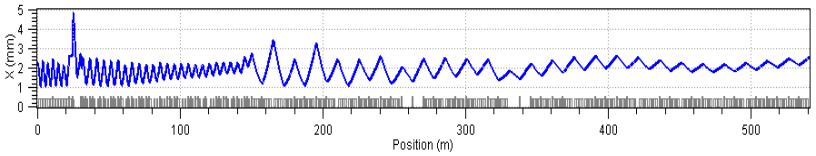


**RMS beam envelopes for a beam generated at PIMS input for the FD option**

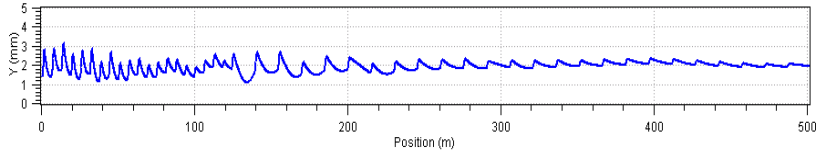
**RMS beam envelopes for a beam generated at PIMS input for the FODO option**

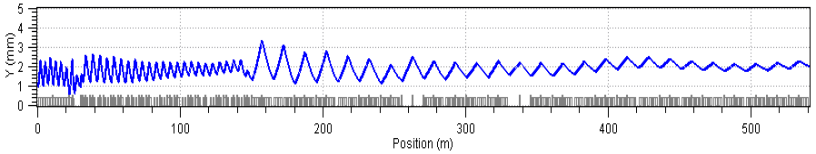
X



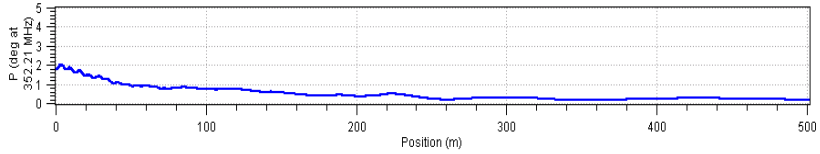



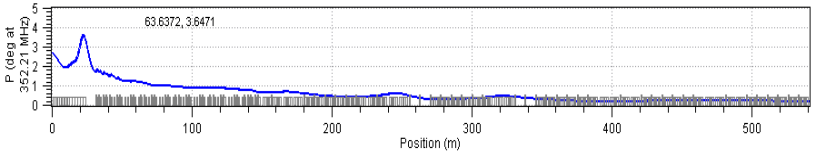

Y



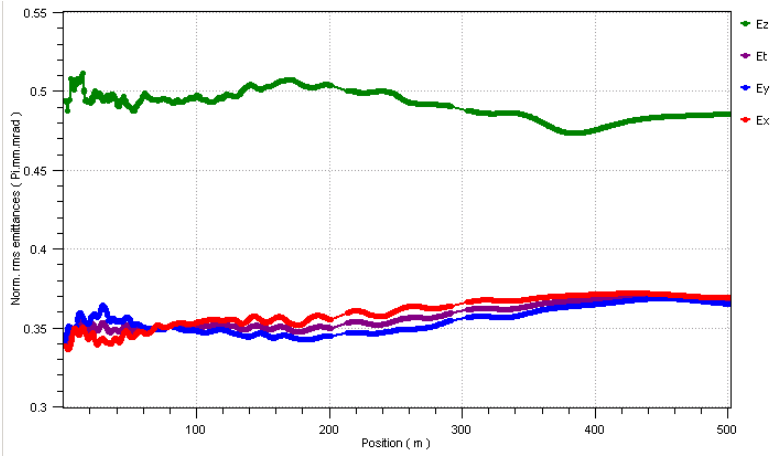

Z

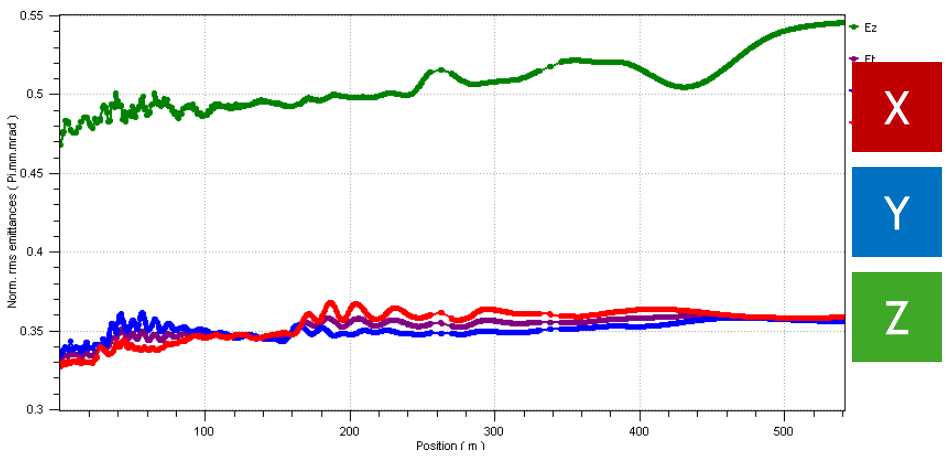


# SPL Beam dynamics (2/2)






| FD | x | y | z |
|---|---|---|---|
| Initial ε | 0.328 | 0.334 | 0.468 |
| Final ε | 0.369 | 0.365 | 0.486 |
| Δε% | 12.5 | 9.4 | 3.8 |

| FODO | x | y | z |
|---|---|---|---|
| Initial ε | 0.328 | 0.334 | 0.468 |
| Final ε | 0.359 | 0.356 | 0.546 |
| Δε% | 9.5 | 6.5 | 16.6 |

unit: π mm mrad (RMS)

# Error study philosophy (1/3)



1. Test the line from PIMS to 5 GeV with errors on magnets (misalignment and gradient):
   - Check how the lattices (PIMS, HEBT, SPL) "amplify" the errors
   - Look for beam losses, emittance increase, output beam misalignment
   - Find the tolerance range and foresee different alignment tolerances for PIMS and SPL

# Error study philosophy (2/3)



2. Test the PIMS and HEBT line with errors on magnets (misalignment and gradient) and with a residual beam misalignment:
   - Define the alignment tolerances for PIMS
   - Switch on the steerers and see how good the beam out of HEBT can be centered
   - Define a residual beam misalignment as input for the SPL alone

# Error study philosophy (3/3)



3. Test the SPL alone with the residual steering from HEBT:
   - Check the tolerances without correction
   - Find the limit for magnet misalignment
   - Switch on the steerers and correct it
4. Check the differences between the doublet (FD) layout and the F0D0 layout for SPL
   - Different tolerances?
   - Different correction strategy?

# Criterion of tolerances



- 100% transmission
  - Correction system not be used to correct structure misalignment but input beam misalignment
- Emittance growth less than 20% (3 sigma)

# Error study resume



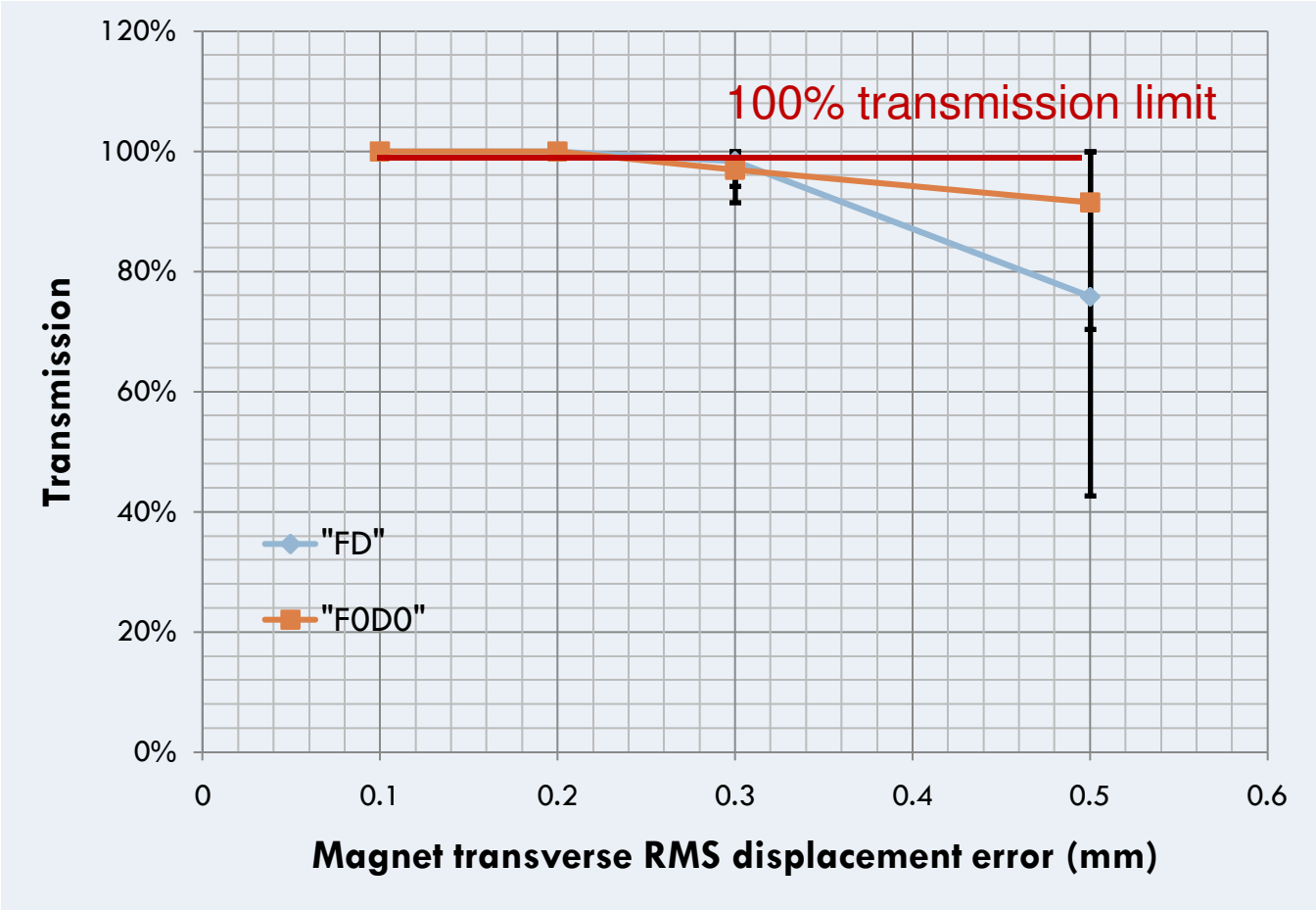
| | STEP I | STEP II | STEP III |
|---|---|---|---|
| *50k particles from RFQ to PIMS, 500 runs each error configuration, TraceWin (CEA)* | | | |
| *SPL design* | FD and F0D0 | common | FD and F0D0 |
| *Input beam misalignment* | none | ±0.2mm<br>±0.2mrad | ±0.2mm<br>±0.2mrad |
| Magnet errors: | | | |
| *Gradient* | ±0.5% | ±0.5% | ±0.5% |
| *Displacement* | ±0.1mm<br>±0.2mm<br>±0.3mm<br>±0.5mm | ±0.1mm | ±0.1mm<br>±0.2mm<br>±0.3mm |
| Discovered tolerances: | | | |
| | ±0.1mm for PIMS<br>±0.2mm for SPL | ±0.1mm ±0.1mrad<br>residual beam mis. | ±0.2mm for SPL |

# STEP I: From PIMS to 5GeV (1/3)



Comparison between the doublet (FD) and the F0D0 solutions.

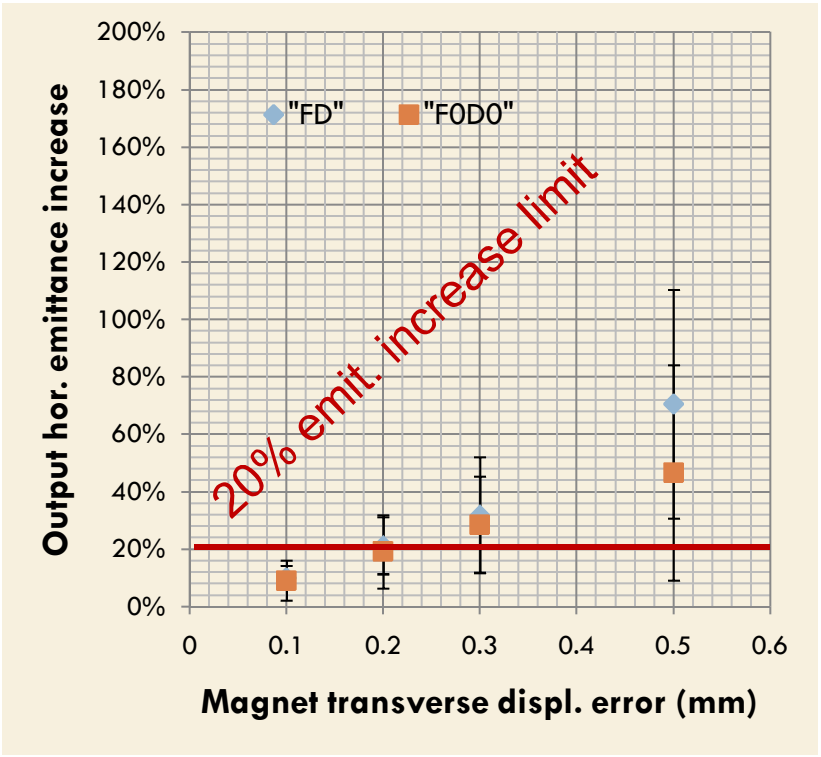
*All the line magnets are "Gaussian" randomly displaced and an error of 0.5% on the gradient is added.*



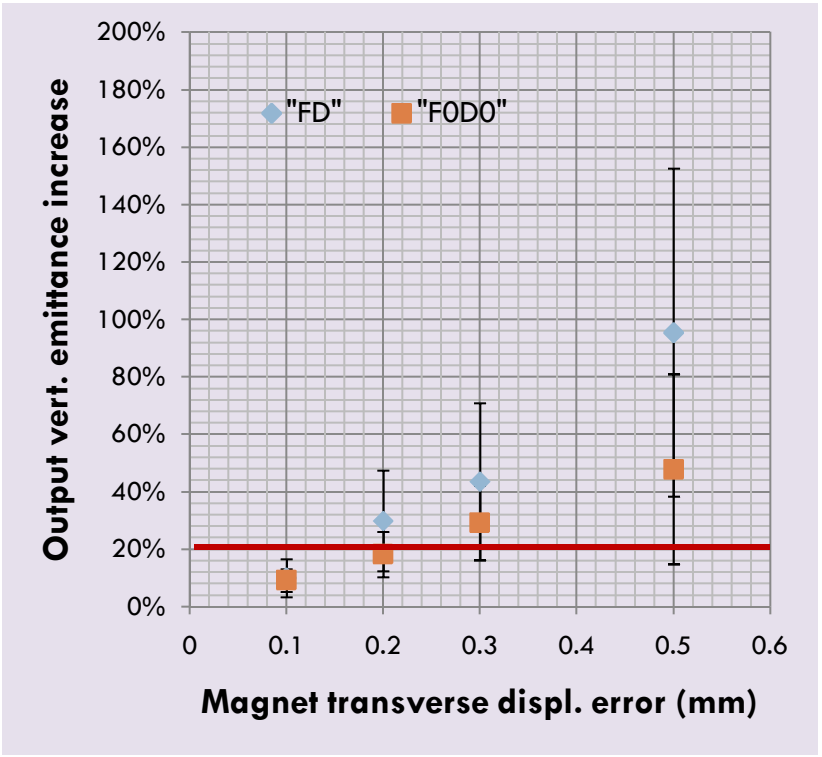
# STEP I: From PIMS to 5GeV (2/3)



## Horizontal emittance



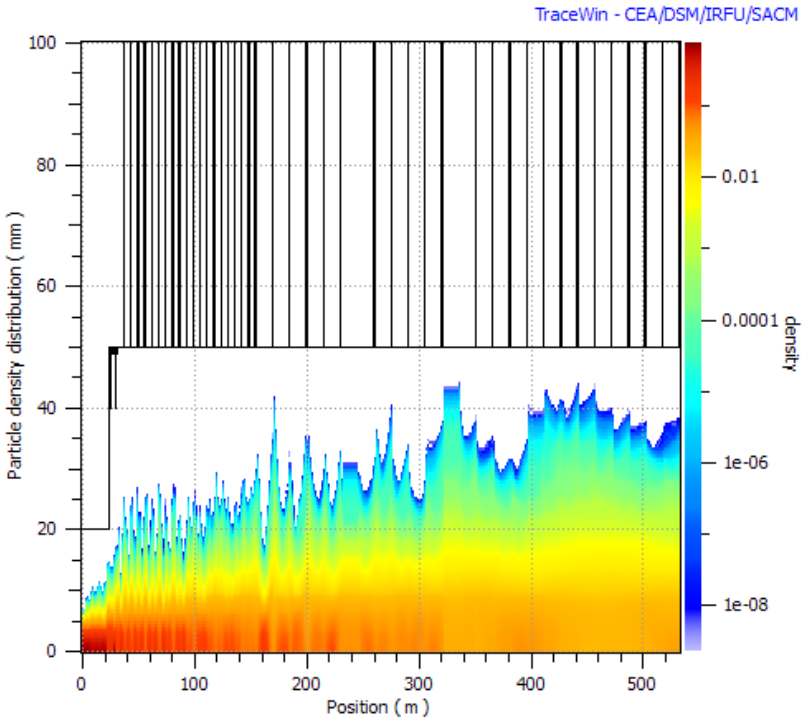

## Vertical emittance



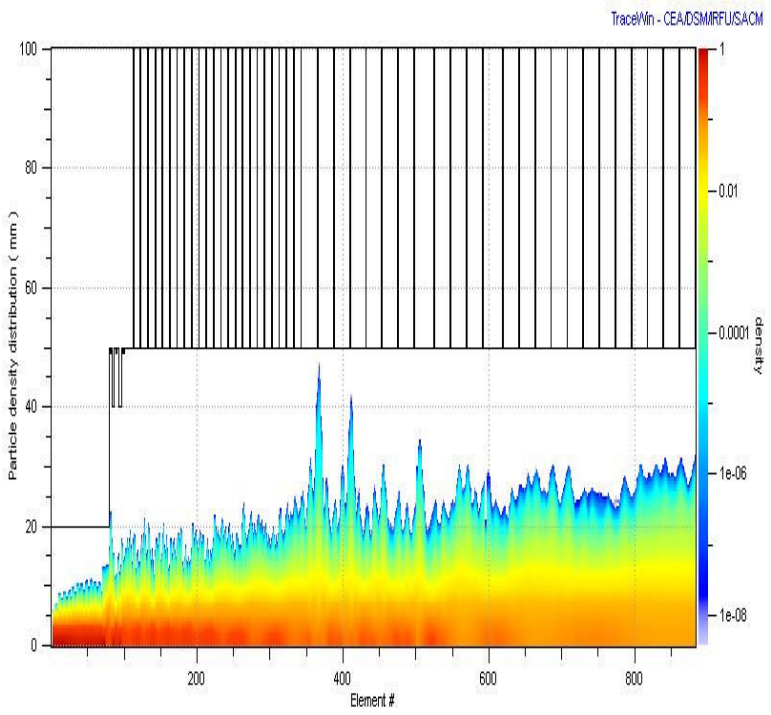
# STEP I: From PIMS to 5GeV (3/3)



**FD configuration (0.2 mm magnet displacement)**




**FODO configuration (0.2 mm magnet displacement)**



# STEP II: From PIMS to SPL



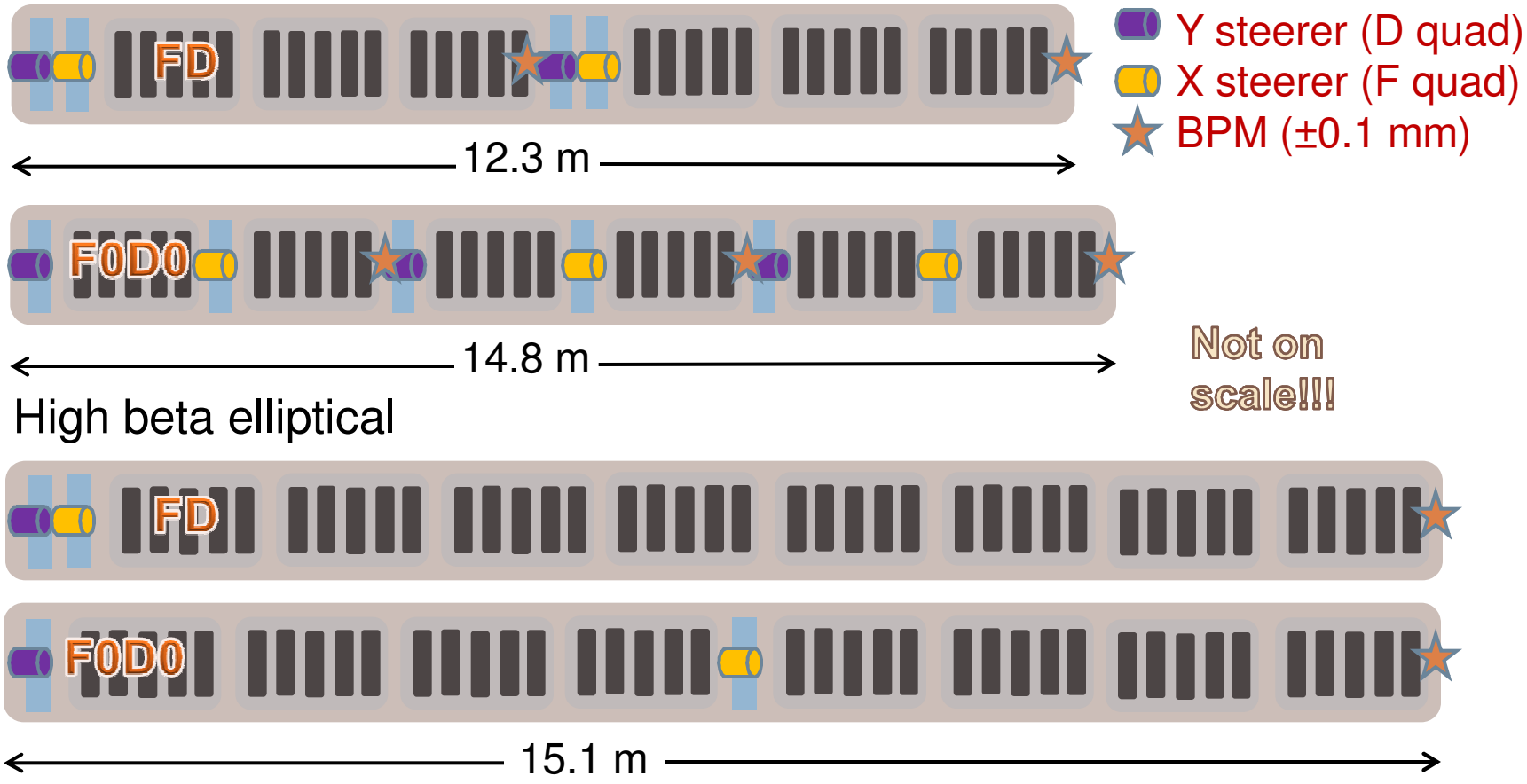
| ±0.2 mm ±0.2 mrad input beam misalignment<br>±0.1 mm quad misalignment (±0.5% on gradient)<br>*AFTER CORRECTION* | |
|---|---|
| ***Δε horizontal*** | (0.013±0.003) % |
| ***Δε vertical*** | (0.017±0.001) % |
| ***Δε longitudinal*** | (0.016±0.001) % |
| ***X center*** | (0.096±0.003) mm |
| ***Y center*** | (0.103±0.001) mm |
| ***X' center*** | (0.038±0.040) mrad |
| ***Y' center*** | (-0.070±0.067) mrad |

Since no significant emittance increase, used the nominal HEBT out distribution displaced (±0.2 mm ±0.2 mrad) for SPL alone simulations

# SPL design and diagnostics



Low beta elliptical



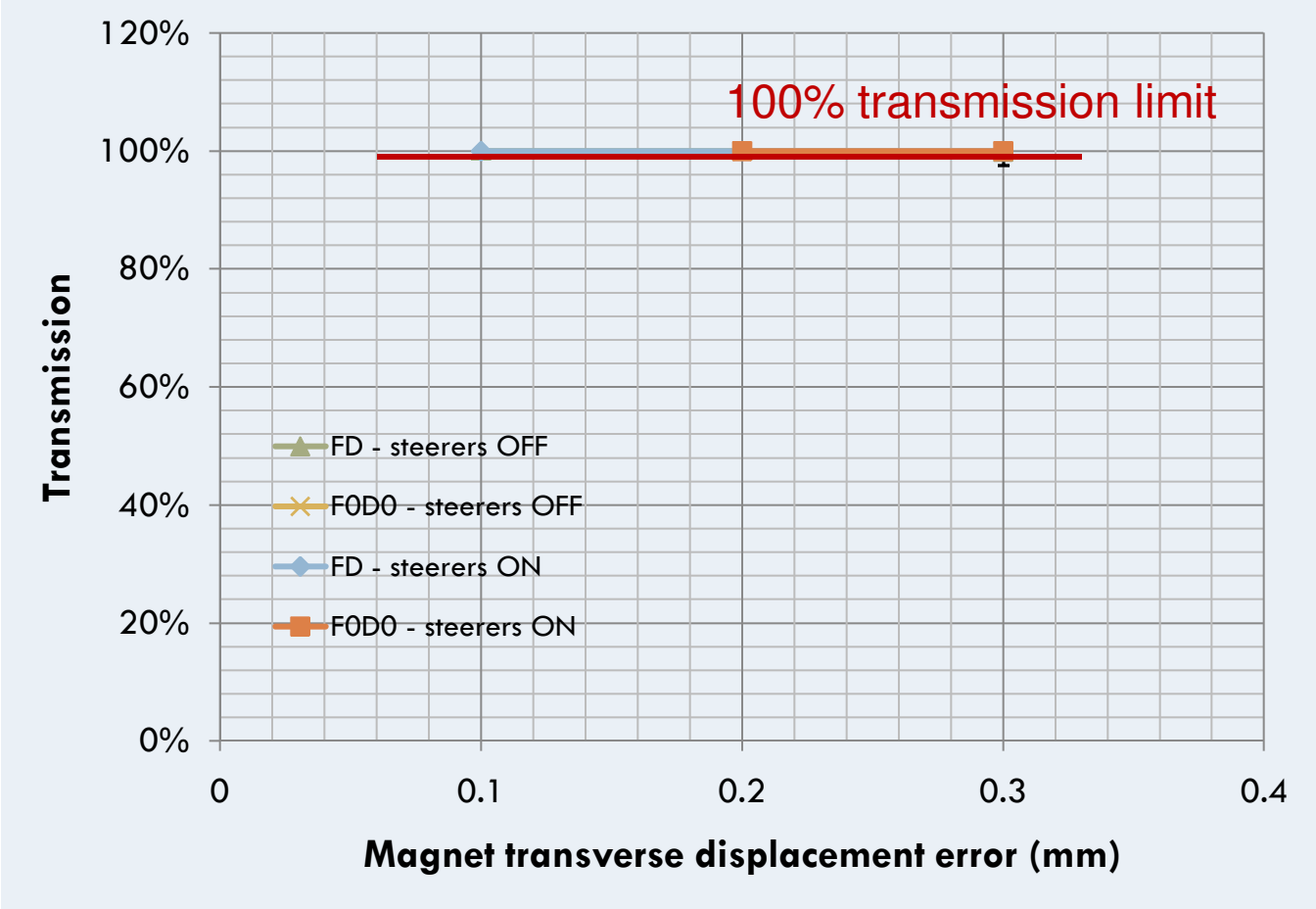
# STEP III: SPL alone (1/4)



Comparison between the doublet (FD) and the F0D0 solutions.

*All the line magnets are "Gaussian" randomly displaced and an error of 0.5% on the gradient is added.*

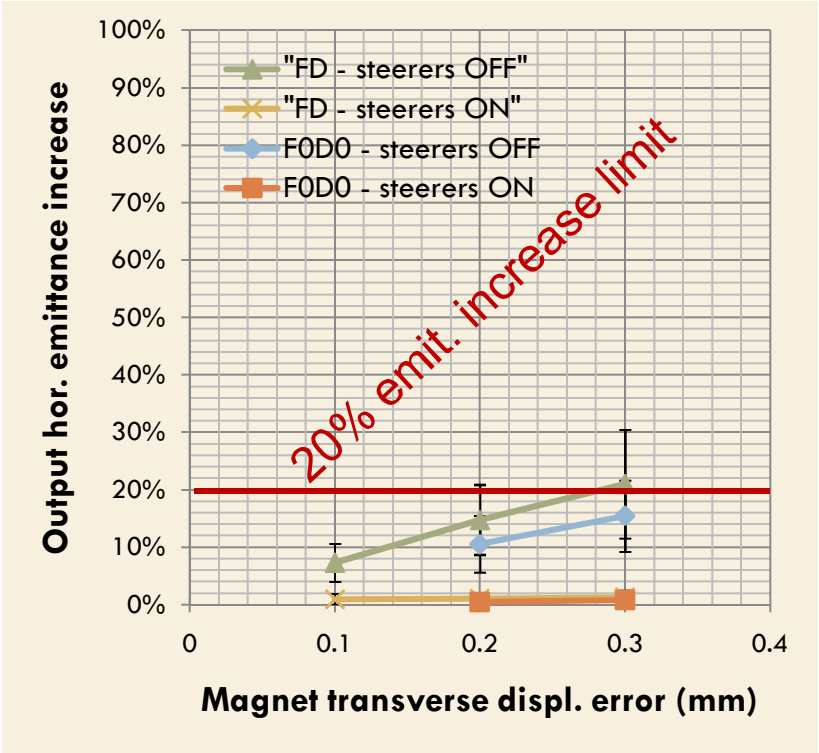
*For all cases: ±0.2 mm ±0.2 mrad input beam misalignment.*



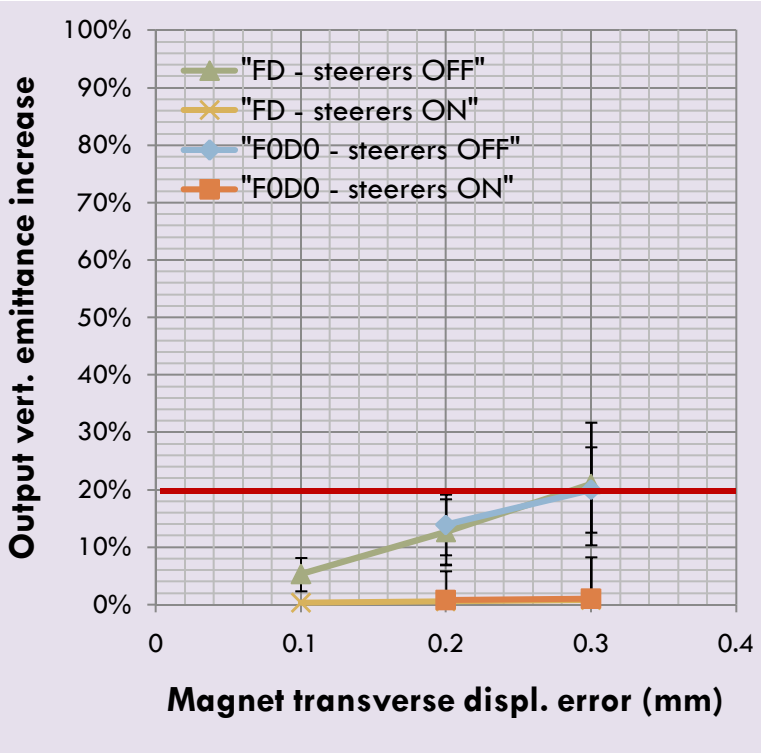
# STEP III: SPL alone (2/4)



**Horizontal emittance**
**(±0.2 mm ±0.2 mrad input beam mis.)**



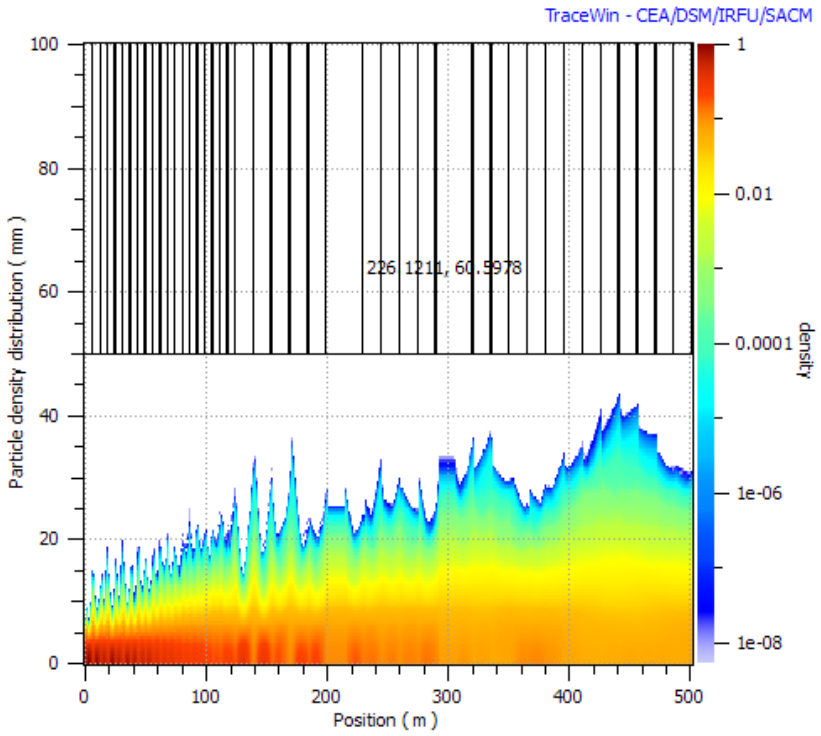

**Vertical emittance**
**(±0.2 mm ±0.2 mrad input beam mis.)**



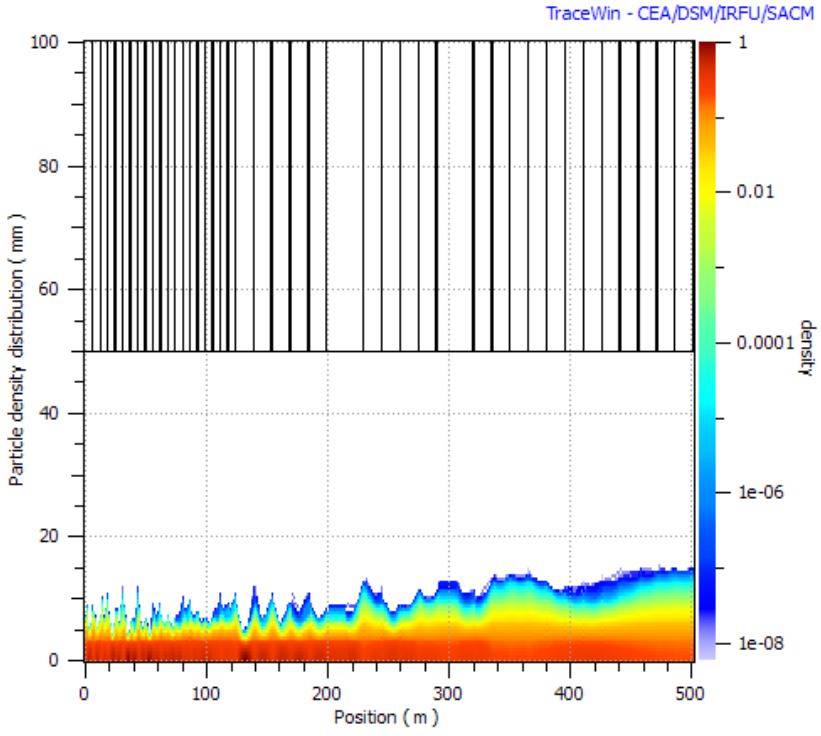
# STEP III: SPL alone (3/4)



**±0.2 mm ±0.2 mrad input beam mis.**
**±0.2 mm quad misal. not corrected (FD)**



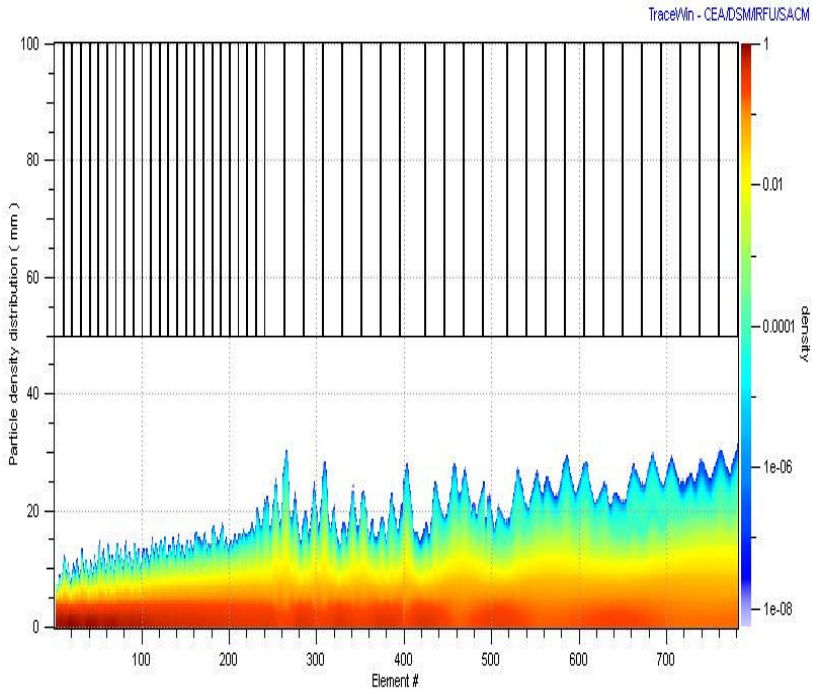

**±0.2 mm ±0.2 mrad input beam mis.**
**±0.2 mm quad misal. corrected (FD)**



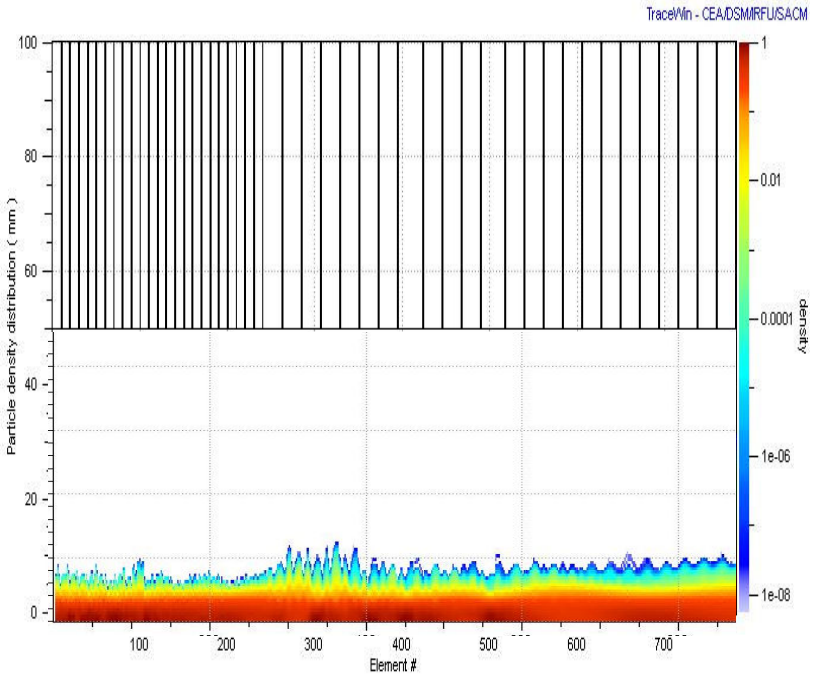
# STEP III: SPL alone (4/4)



**±0.2 mm ±0.2 mrad input beam mis.**
**±0.2 mm quad misal. not corrected (FODO)**




**±0.2 mm ±0.2 mrad input beam mis.**
**±0.2 mm quad misal. corrected (FODO)**



# Conclusions on alignment



- PIMS and HEBT must be aligned within ±0.1mm (LINAC4 tolerance)
- SPL, due to the larger bore and the different lattice, requires a slightly more relaxed limit (±0.2mm)
- The correction system foresees at the moment:
  - 1 steerer for each quad (strength less than 0.02 Tm)
  - 1 BPM after 2 quads (just before the following quad)
- Further diagnostics still in progress