High Energy Booster Emittance Tuning

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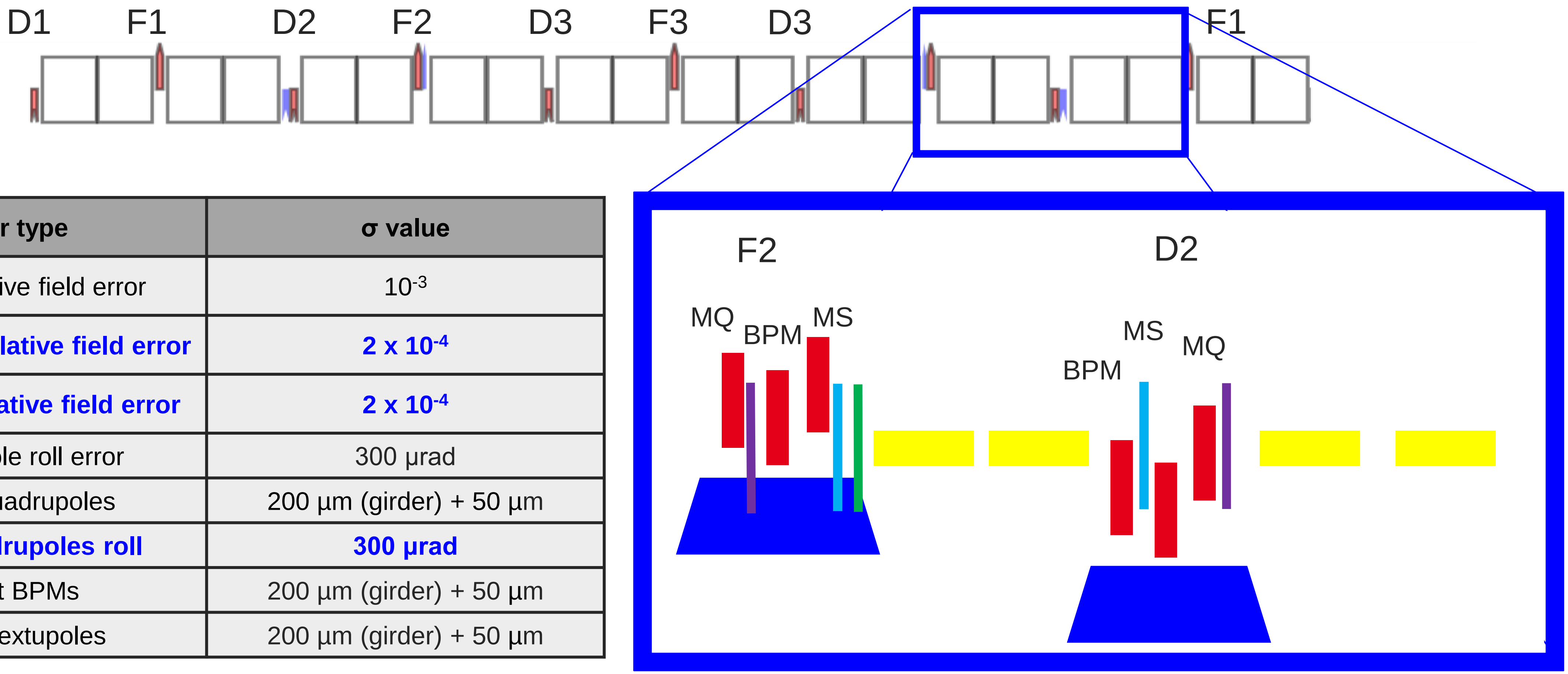
Outline

- **Errors assignments and correctors placement**
- **Emittance Tuning Strategy**
- **Results**
- **Conclusion & further steps**

Errors and Correctors

FUTURE CIRCULAR COLLIDER



Error type	σ value
Dipole relative field error	10^{-3}
Quadrupole relative field error	**2×10^{-4}**
Sextupole relative field error	**2×10^{-4}**
Main dipole roll error	300 µrad
Offset quadrupoles	200 µm (girder) + 50 µm
Main Quadrupoles roll	**300 µrad**
Offset BPMs	200 µm (girder) + 50 µm
Offset sextupoles	200 µm (girder) + 50 µm

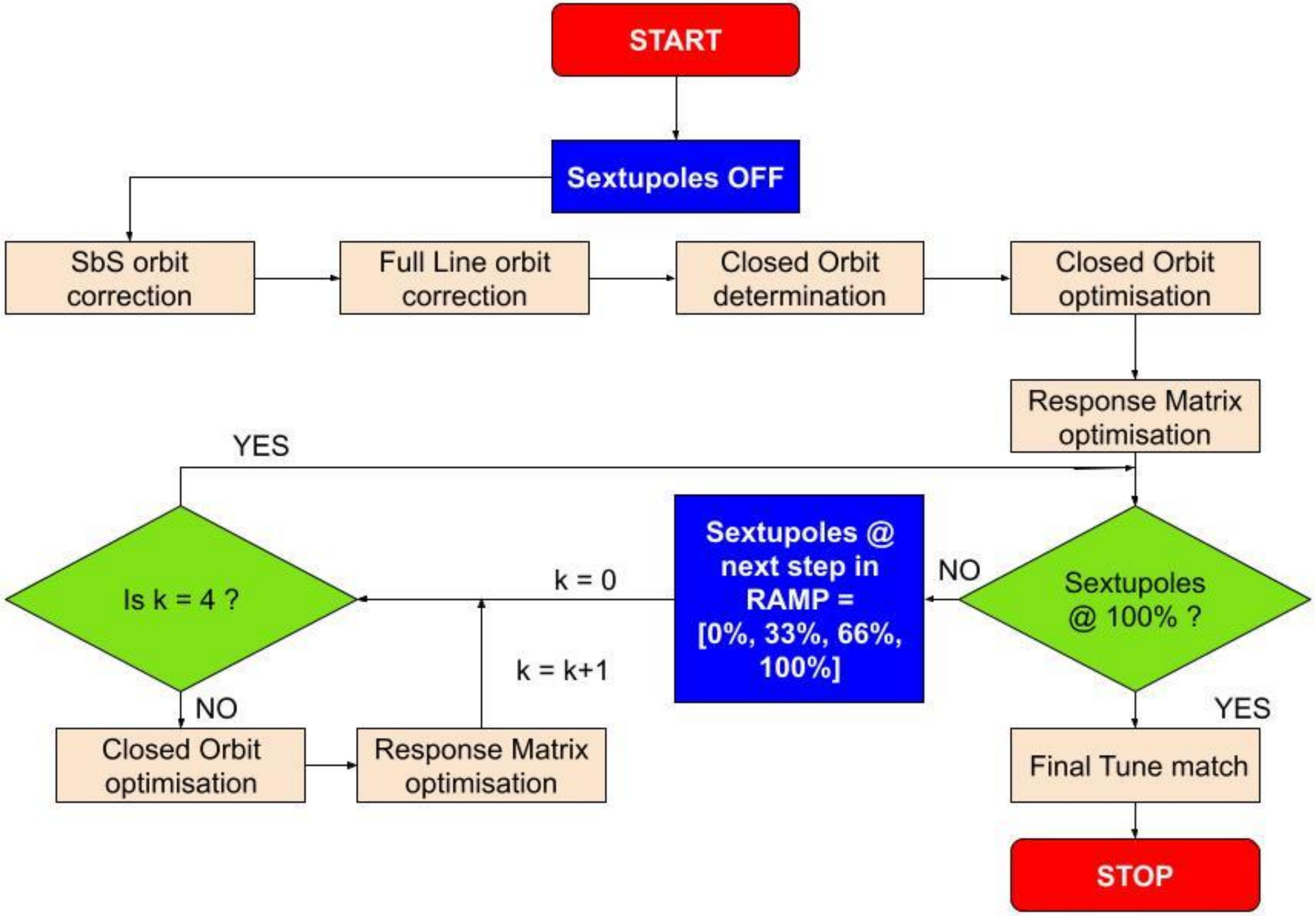
Errors are randomly distributed in arcs (PDF=Truncated gaussian @3σ).

= skew quad corrector (568)

= normal quad corrector (560)

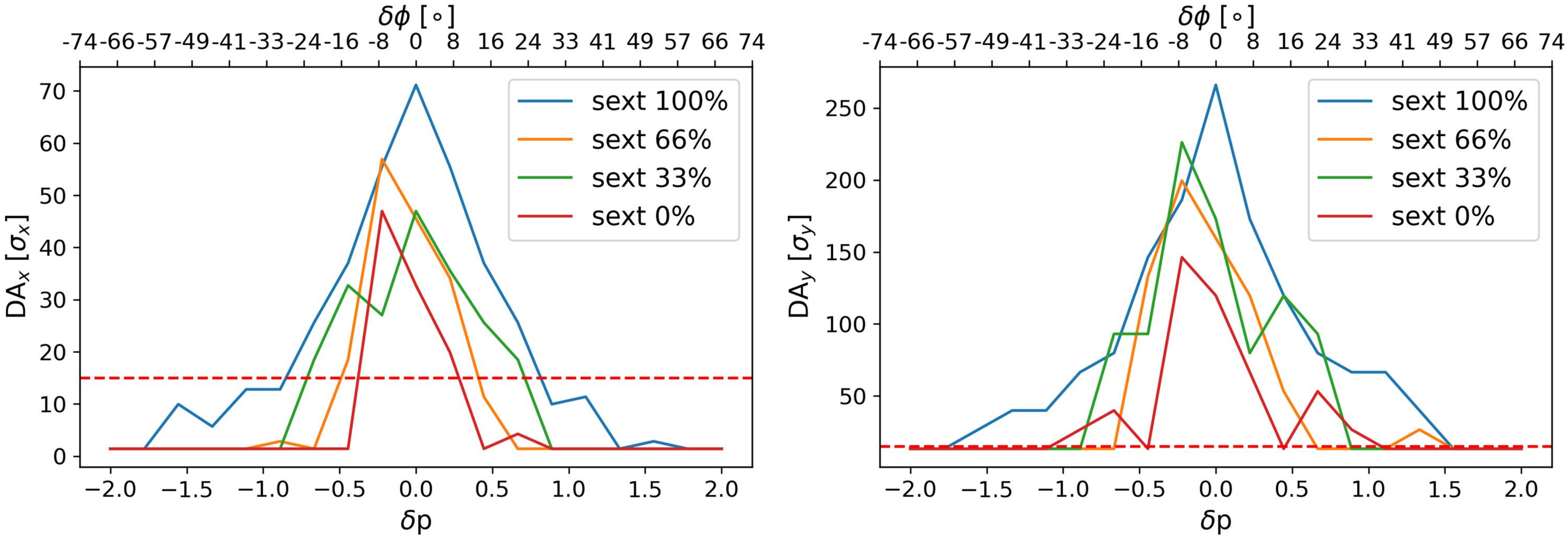
= orbit corrector (~2800)

Correction Strategy



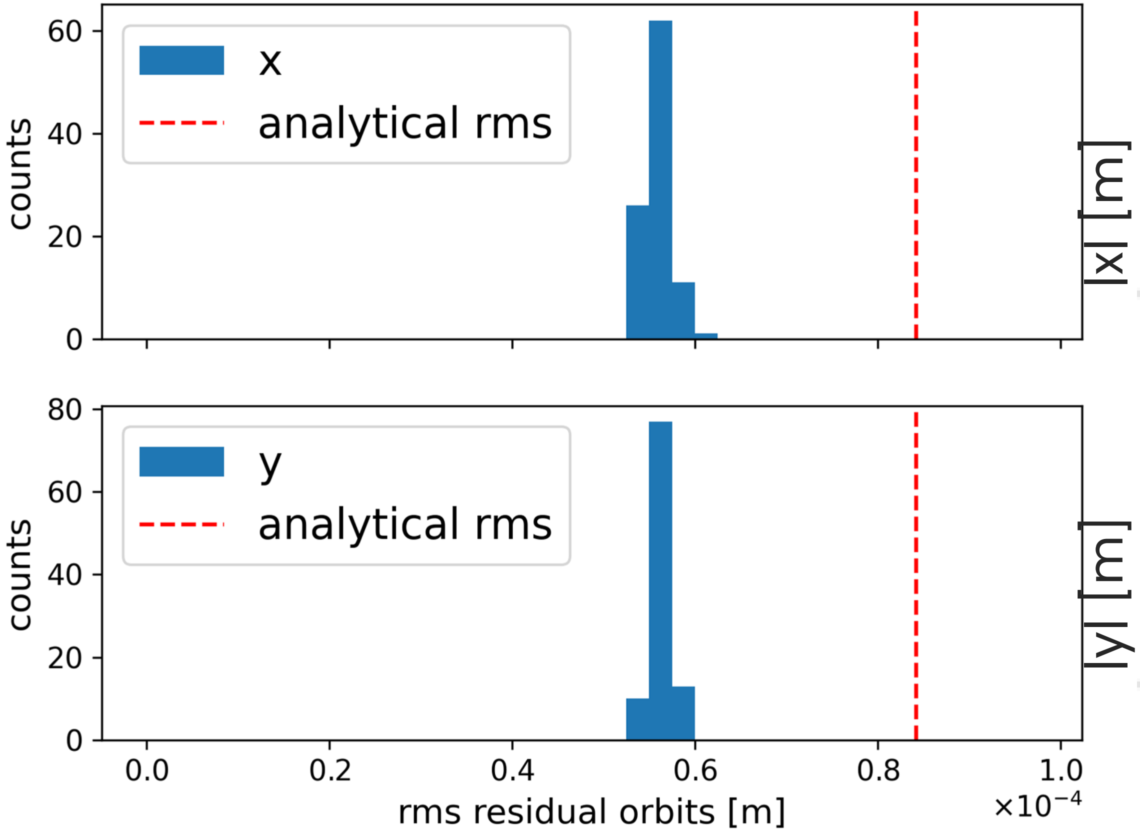
- Response matrix divided in two matrices :
  - normal quads
    - μ_x, μ_y, Q_x, Q_y, D_x
  - skew quads
    - $\mathbb{R}e\{f_{1001}\}$, $\mathbb{R}e\{f_{1010}\}$, $\mathbb{I}m\{f_{1001}\}$, $\mathbb{I}m\{f_{1010}\}$, D_y
- Sextupole RAMP ensure limited effect due to interplay between sextupole strength and imperfections
- 100 seeds simulated

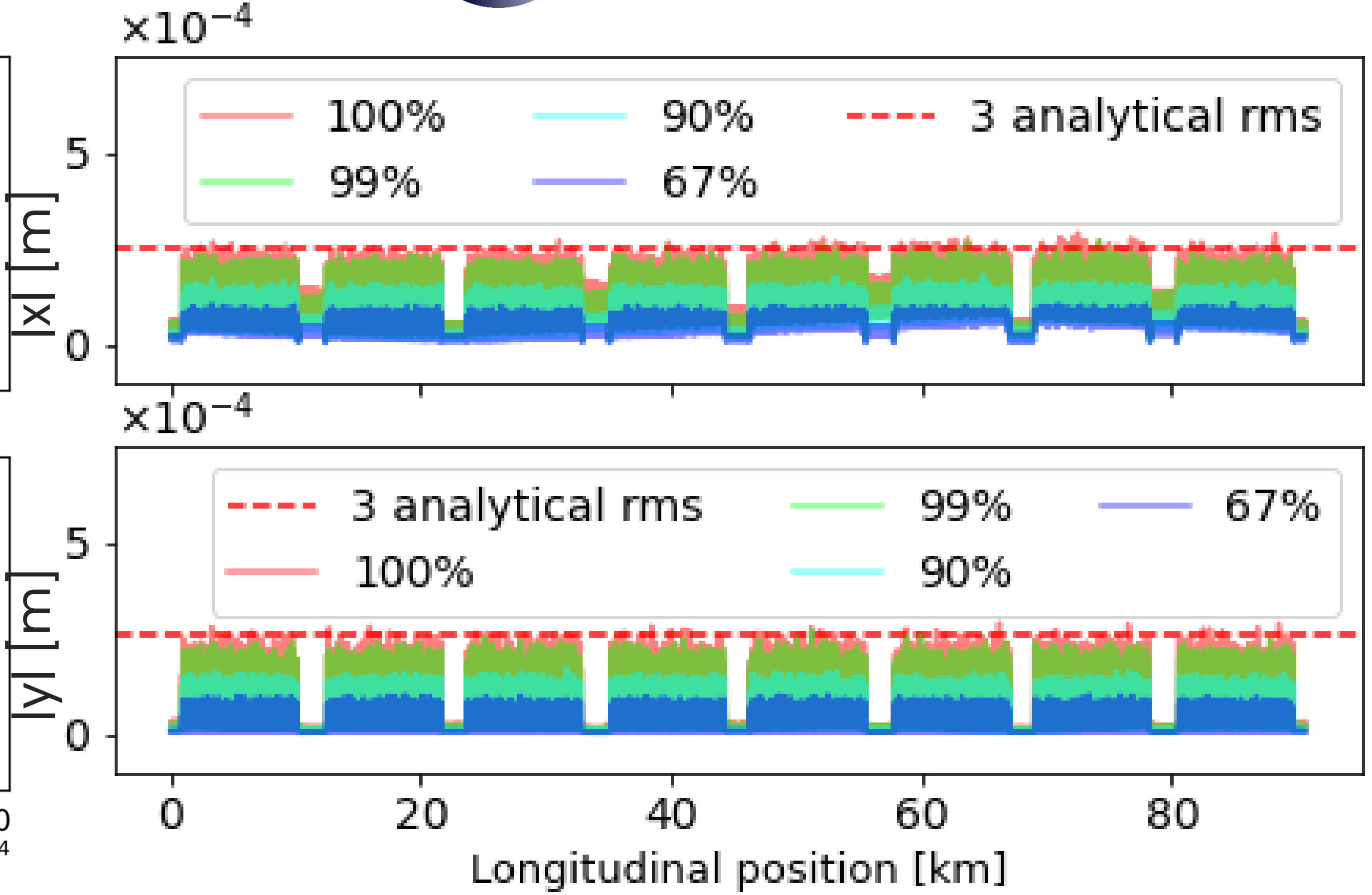
MA wrt sextupole ramp



- **MA seems to be large enough at each step of the ramp.**
- **High Energy LINAC can provide dedicated single bunches with .05% energy spread.**

Residual Orbit

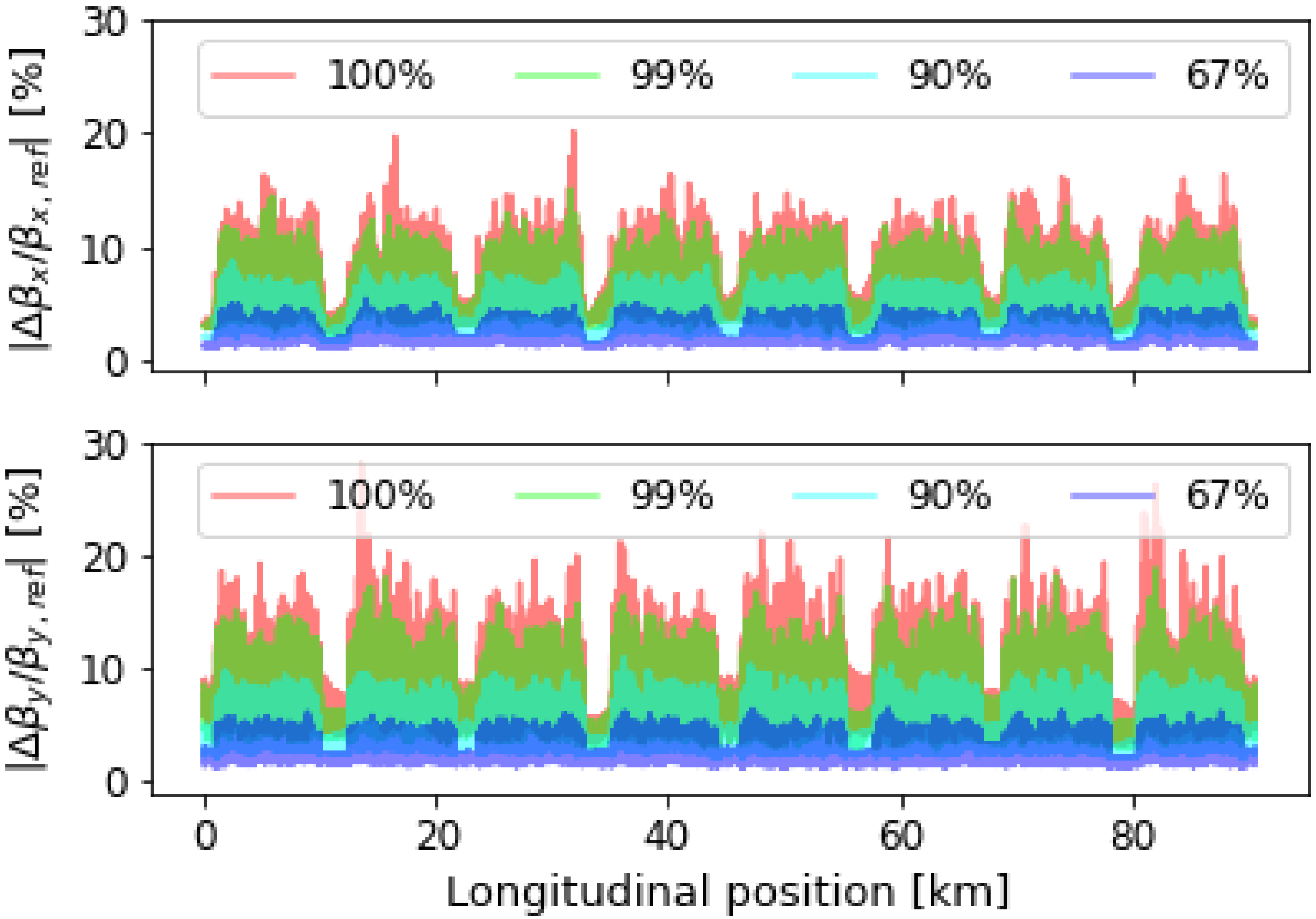




- RMS residual orbits below analytical value
- Absolute orbit excursion below .3mm

100 successful seeds

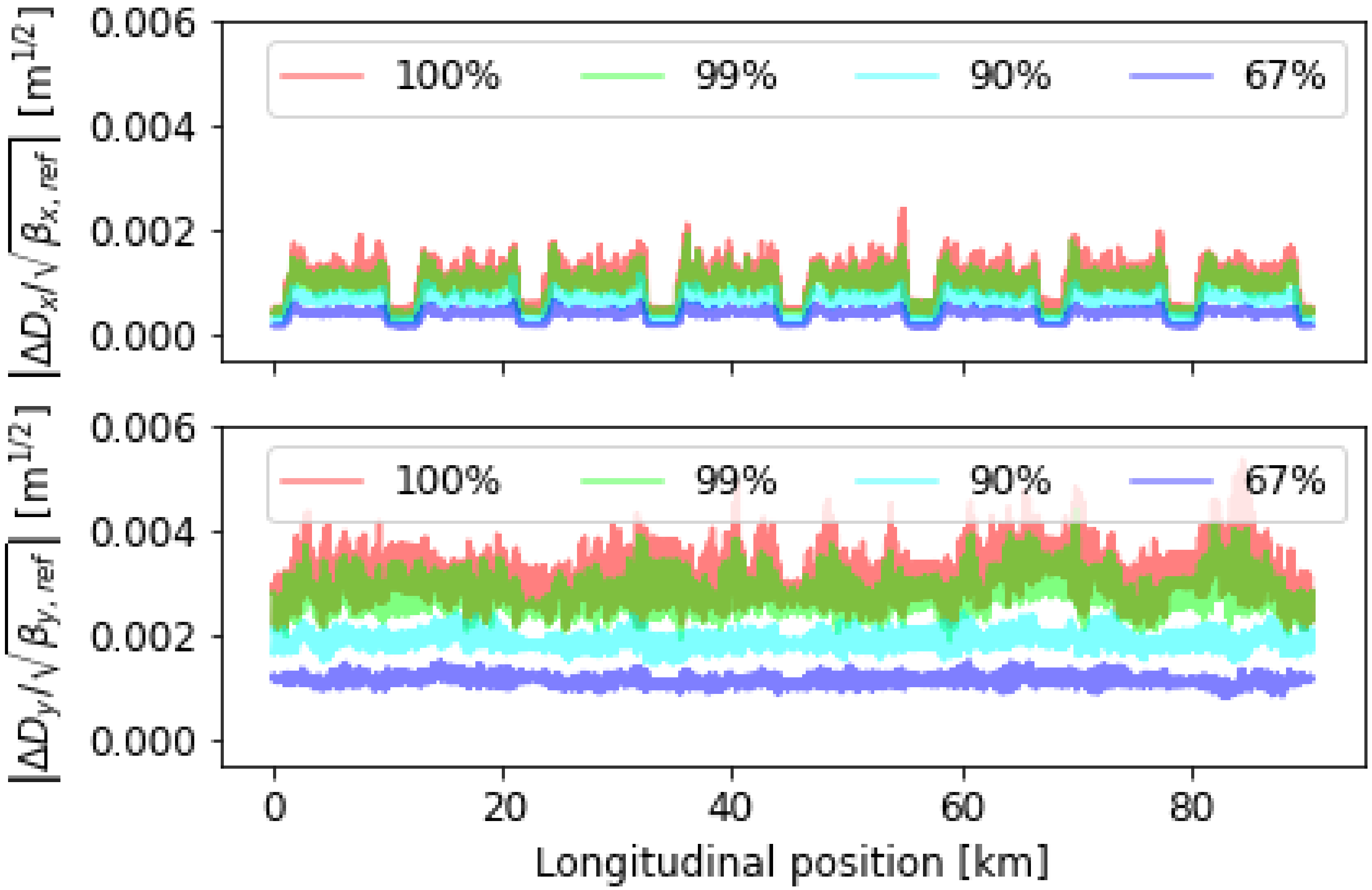
Beta-beating



- ➢ **Limitation of Beta-beating under 20% for 99% of seeds**
- ➢ **⅔ of the seeds show Beta-beating below 5% in both planes**
- ➢ **Vertical plane seems higher than horizontal**
  - **add quad correctors?**

100 successful seeds

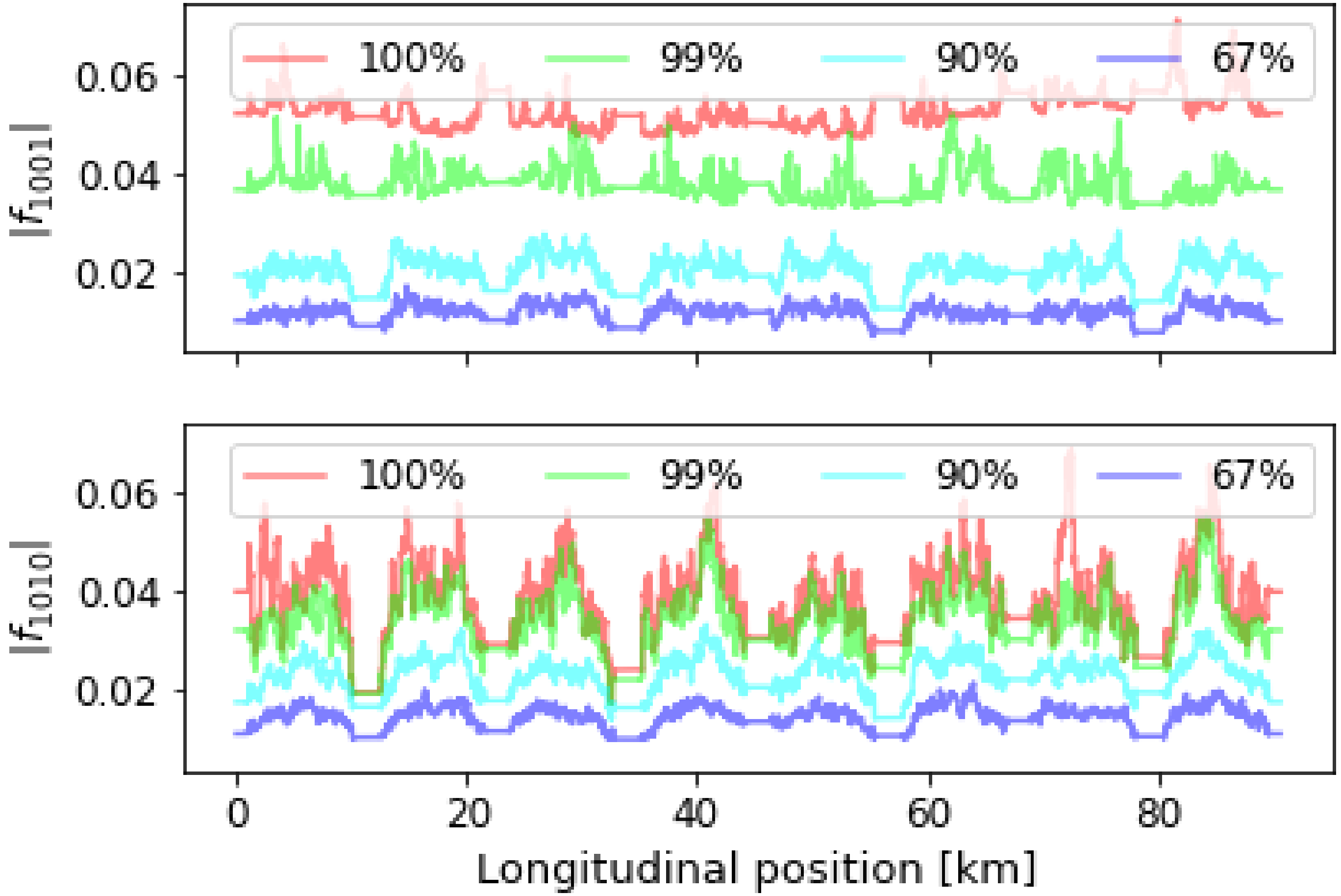
Normalized dispersion



- ➢ **Horizontal normalized dispersion kept under $2x10^{-3}$ $m^{1/2}$**
- ➢ **Vertical normalized dispersion twice as high as horizontal**
  - ○ **add some skew correctors in straight sections ?**
  - ○ **Use full response matrix instead of two separated matrices ?**

100 successful seeds

RDTs



- ➢ **90% of coupling RDTs below .04**

100 successful seeds

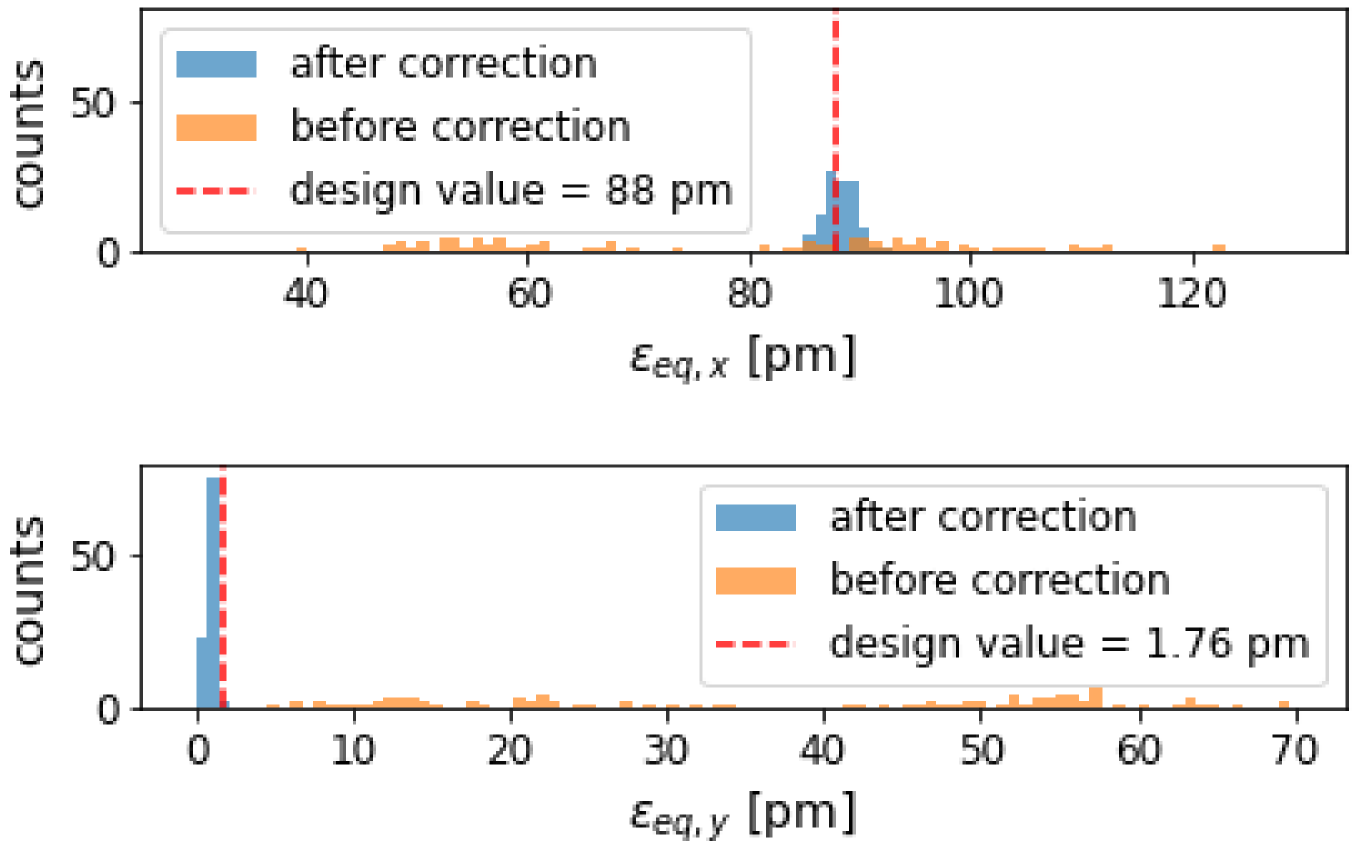
Correctors integrated strength

Corrector type	E [GeV]	3 x RMS
Orbit X	20 (inj)	2.5 mT.m
	182.5 (ttbar)	23 mT.m
Orbit Y	20 (inj)	2.6 mT.m
	182.5 (ttbar)	24 mT.m
Normal Quad	20 (inj)	0.11 $T.m^{-1}.m$
	182.5 (ttbar)	0.96 $T.m^{-1}.m$
Skew Quad	20 (inj)	0.05 $T.m^{-1}.m$
	182.5 (ttbar)	0.39 $T.m^{-1}.m$

100 successful seeds

Equilibrium Emittance

- ➢ **Emittance in both planes are centered around the design values**
- ➢ **100% stability, all seeds converging**



Recap

- **Orbit excursion kept below $3{\times}10^{-4}$ m in both plane**
- **Beta-beating:**
  - **below 20% in both planes for 99% of seeds**
  - **below 5% in both planes for 67%**
- **Normalized dispersion:**
  - **horizontal: below $2{\times}10^{-3}$ $m^{1/2}$**
  - **vertical: twice as high**
- **90% of coupling RDTs below .04**
- **Correctors integrated strength:**
  - **dipoles: 3×RMS below 25mT.m**
  - **quadrupoles: 3×RMS below $1T.m^{-1}m$**
- **Final emittance close to target values**

Perspectives

1. **Introduce longitudinal misalignment**
2. **Introduce tapering at ttbar energy to correct distortion due to SR**
3. **Compute DA with errors and corrections**
4. **Further optimisation of correction scheme:**
    a. **Correctors position and number,**
    b. **Study of correctors correlation, non-linear approach**

THANK YOU

Annex

Analytical computation

The following formulas from *LHC Project Note 43* and *LHC Project Note 501* are used for the rms orbit estimation:

- For random dipole field error: $\Delta x_{rms} = \frac{\pi}{\sqrt{2}\,sin(\pi Q)} \frac{\bar{\beta}}{\sqrt{N_d}} \left(\frac{\Delta B}{B}\right)_{rms}$
- For dipole roll errors: $\Delta y_{rms} = \frac{\pi}{\sqrt{2}\,sin(\pi Q)} \frac{\bar{\beta}}{\sqrt{N_d}} (\Delta\theta)_{rms}$
- For quadrupole alignment errors: $\Delta(x, y)_{rms} = \frac{\sqrt{N_q}}{\sqrt{2}\,sin(\pi Q)\cos(\mu/2)} \left(\Delta q_{x,y}\right)_{rms}$
- For BPM alignment errors: $\Delta(x, y)^2_{rms} = \frac{1/2}{[1+sin\left(\frac{\mu}{2}\right)]^2} \left(\Delta\sigma_{x,y}\right)^2_{rms}$