M. Eshr

China

18 September 2012 —

THE ESS SC LINAC

Mamad Eshraqi
European Spallation Source

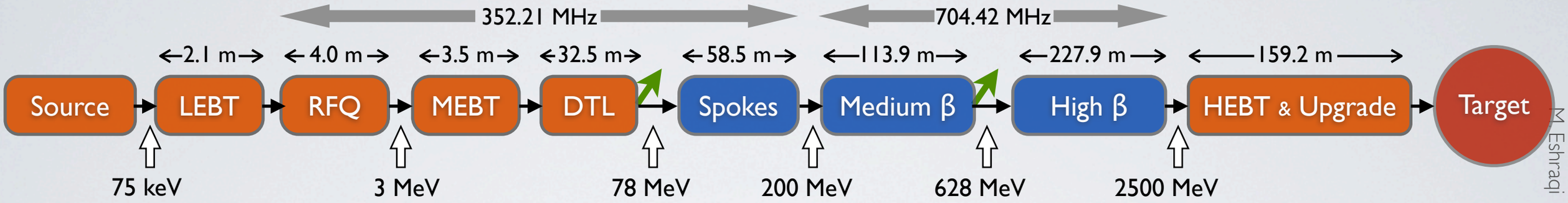
18 Sep 2012, Beijing

THE ESS LINAC

- **Power: 5 MW**
- **Energy: 2.5 GeV**
- **Current: 50 mA**
- **Repetition rate: 14 Hz**
- **Pulse length: 2.86 ms**
- **Duty cycle: 4%**
- **High reliability (>95%)**
- **Ions: p**

M. Eshraqi

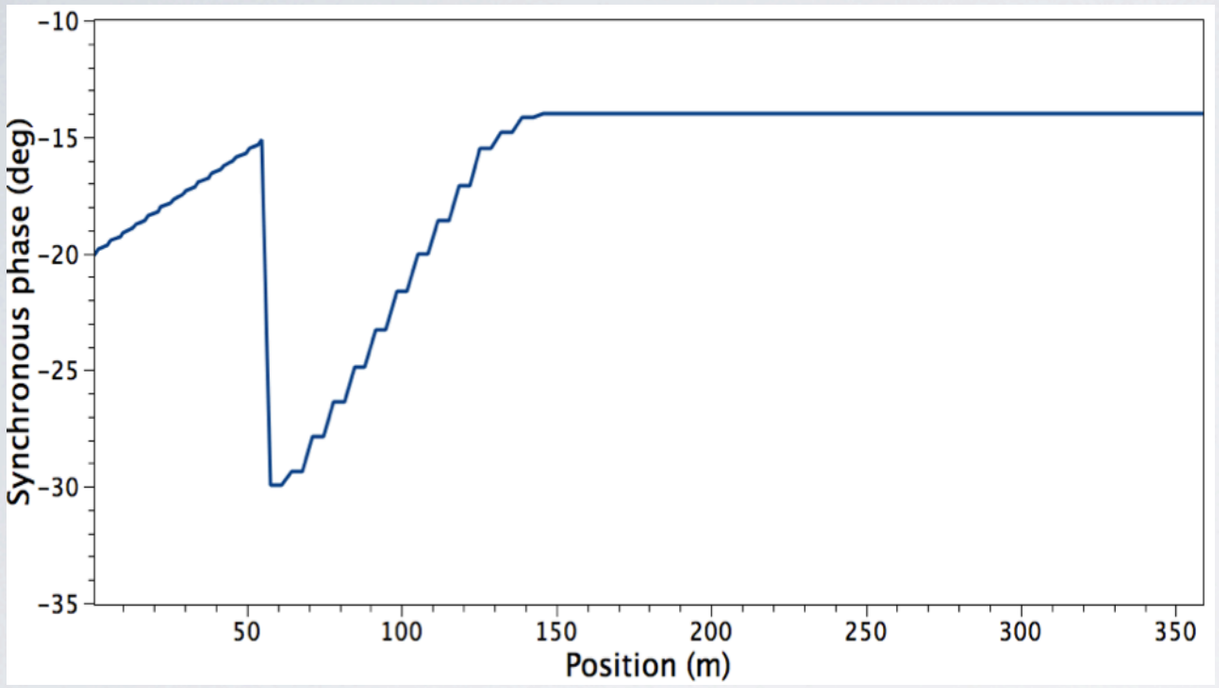
THE ESS LINAC

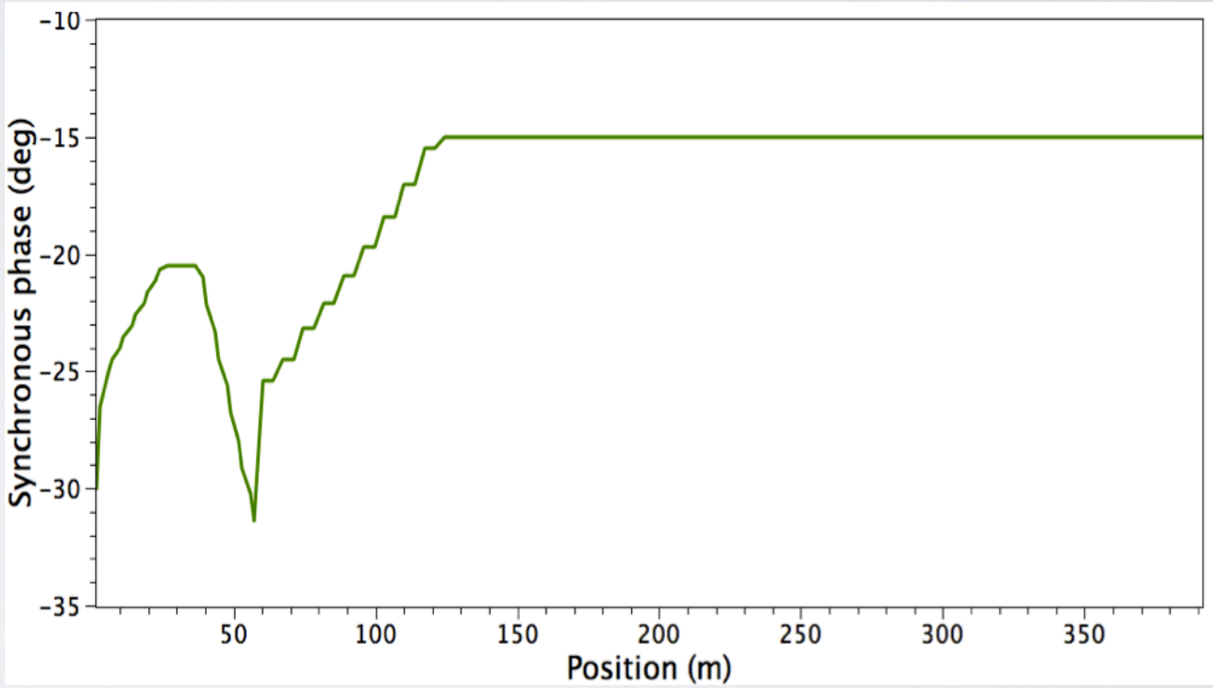


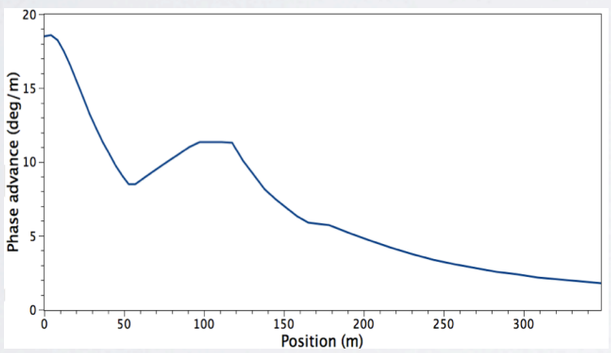
	Energy (MeV)	No. of Modules	No. of Cavities	βg	Temp (K)	Cryo Length (m)
Source	0.075	1	0	–	~300	–
LEBT	*0.075*	–	0	–	~300	–
RFQ	3	1	1	–	~300	–
MEBT	*3*	–	3	–	~300	–
DTL	77.5	4	4	–	~300	–
Spoke	200	14	2 × 14	0.5 β_{opt}	~2	2.896
Low β	628	15	4 × 15	0.67	~2	5.641
High β	2500	15 × 2	4 × 30	0.92	~2	6.705
HEBT	*2500*	–	0	–	~300	–

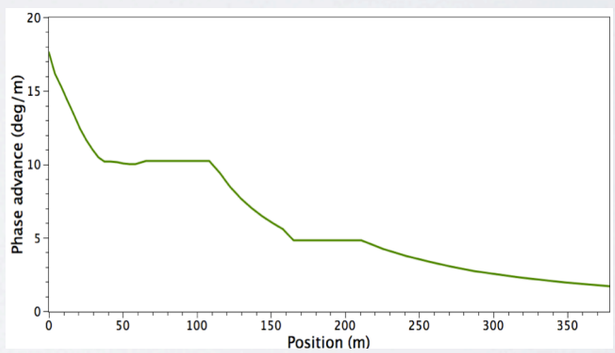
M. Eshraqi

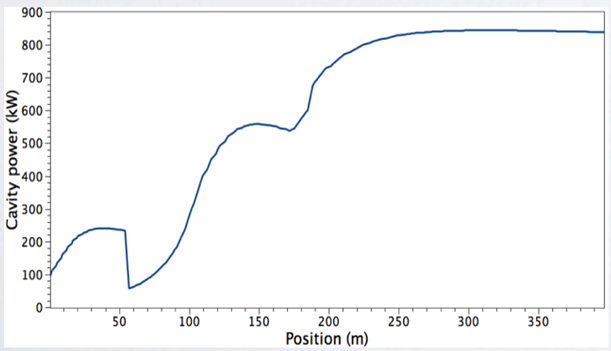
FREQUENCY JUMP

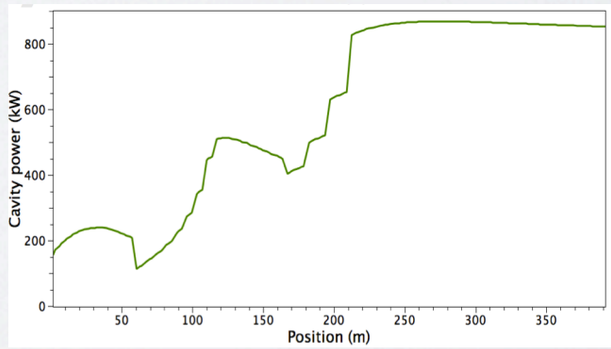




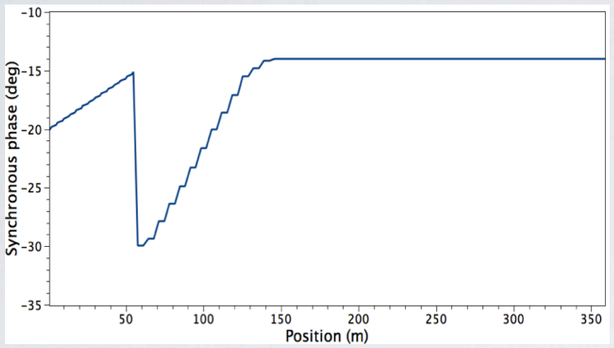


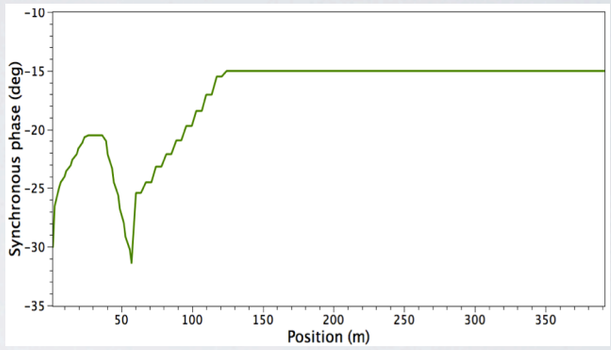


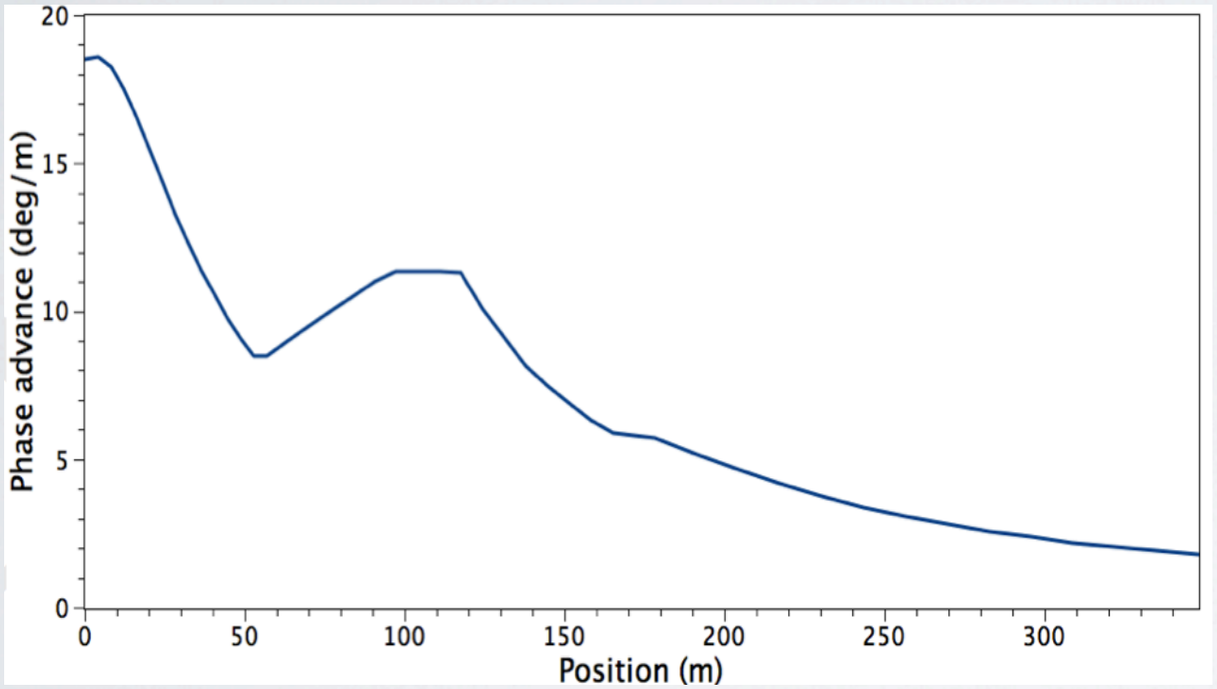


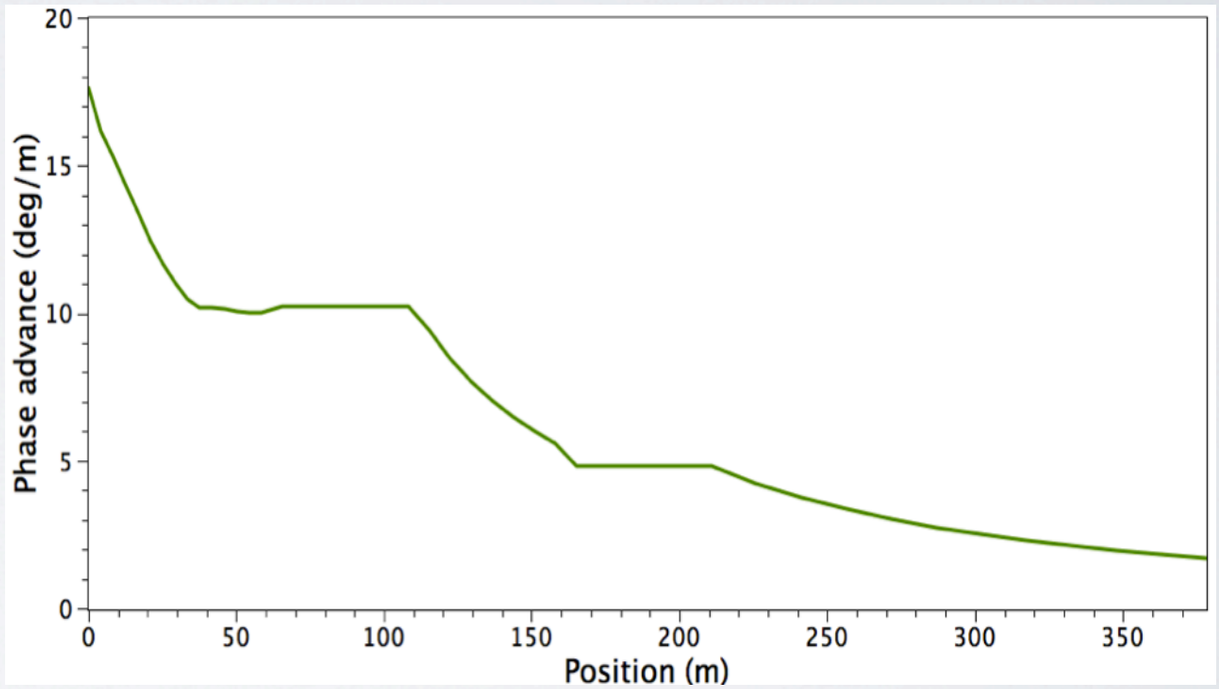


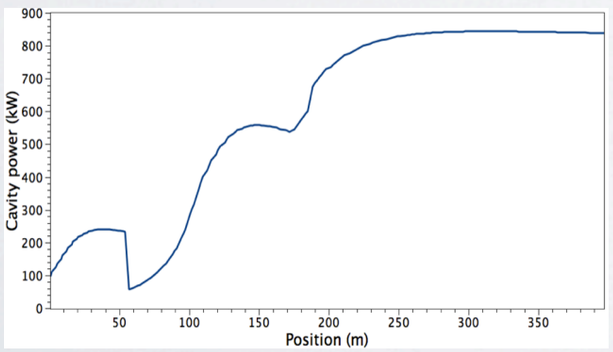
FREQUENCY JUMP

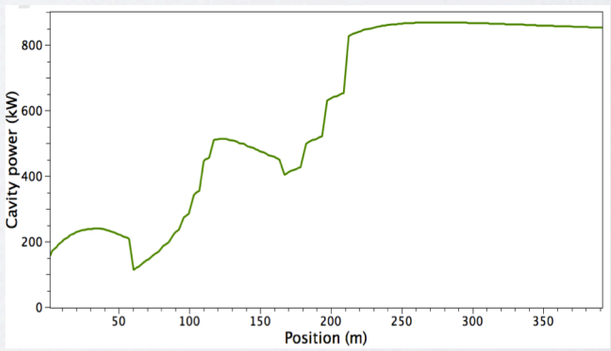




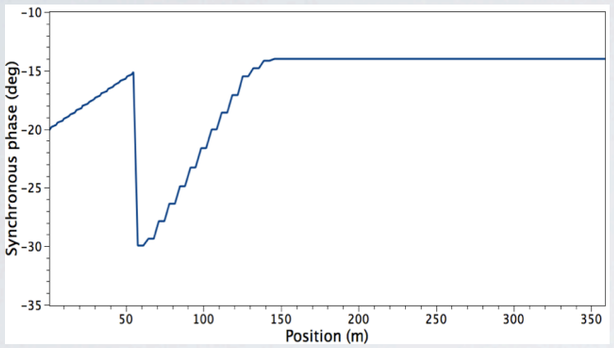


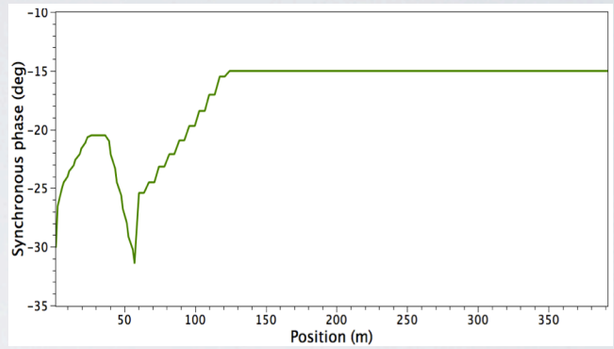


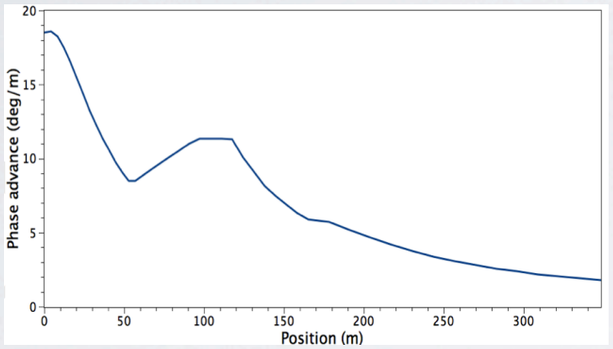


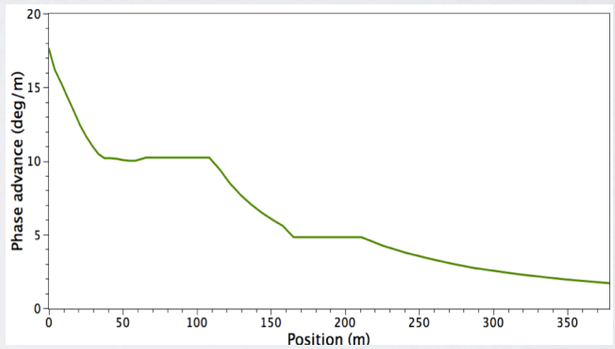


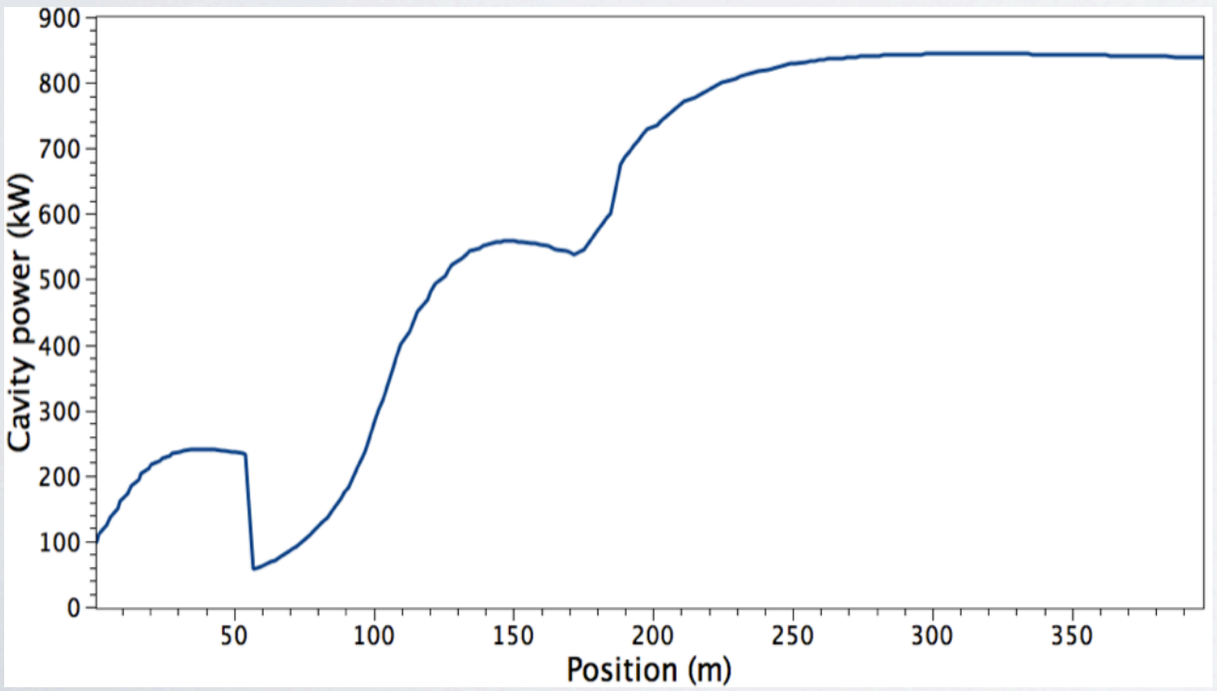
FREQUENCY JUMP

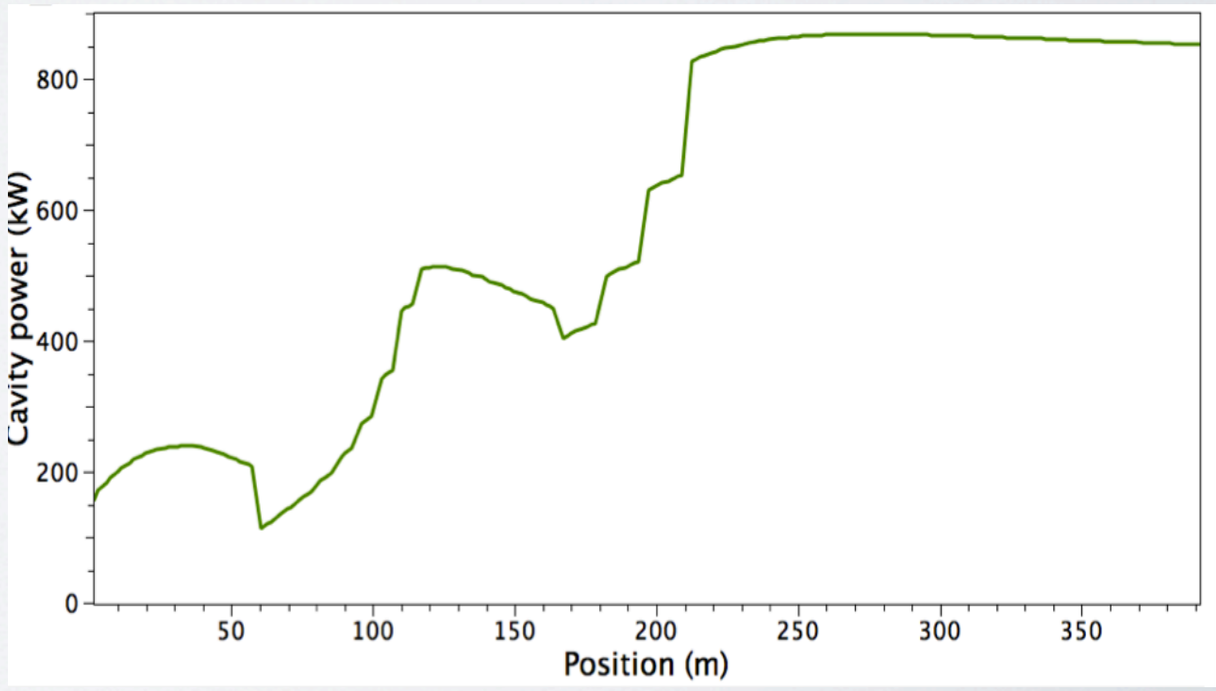












RULES OF THUMB

- Phase advance in each plane < 90°

  (When space-charge forces are not negligible) [J. Struckmeier, M. Reiser, *Particle Accelerators*, 14, p227 (1984)]

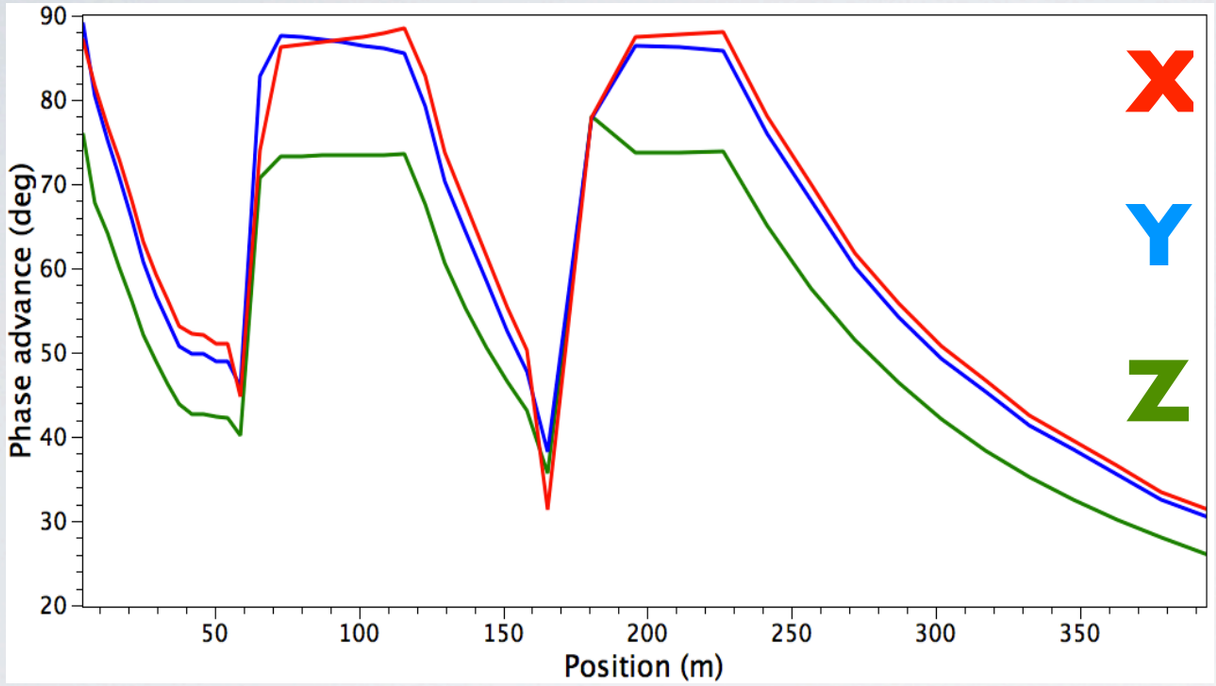
- Continuity of average phase advance

  $(\sigma_0/L)^2 \propto$ Focusing force; Avoid space-charge redistribution.

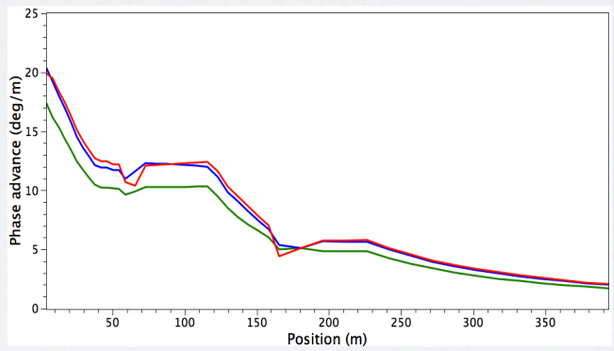
- Tune depression > 0.4

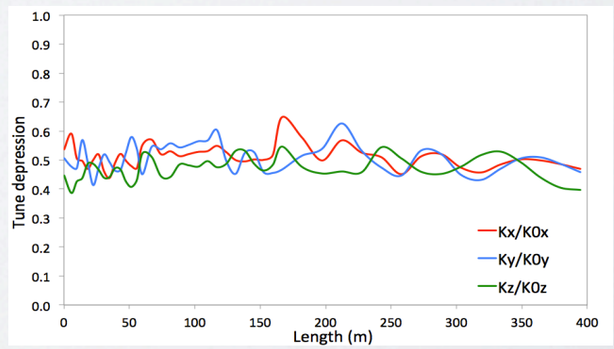
  (To avoid mismatch resonances) [J-M, Lagniel, EPAC96]

RULES OF THUMB II

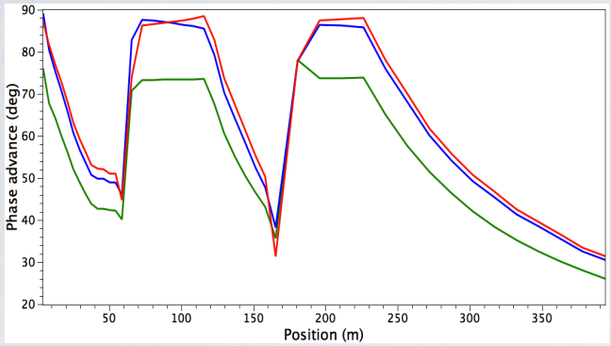


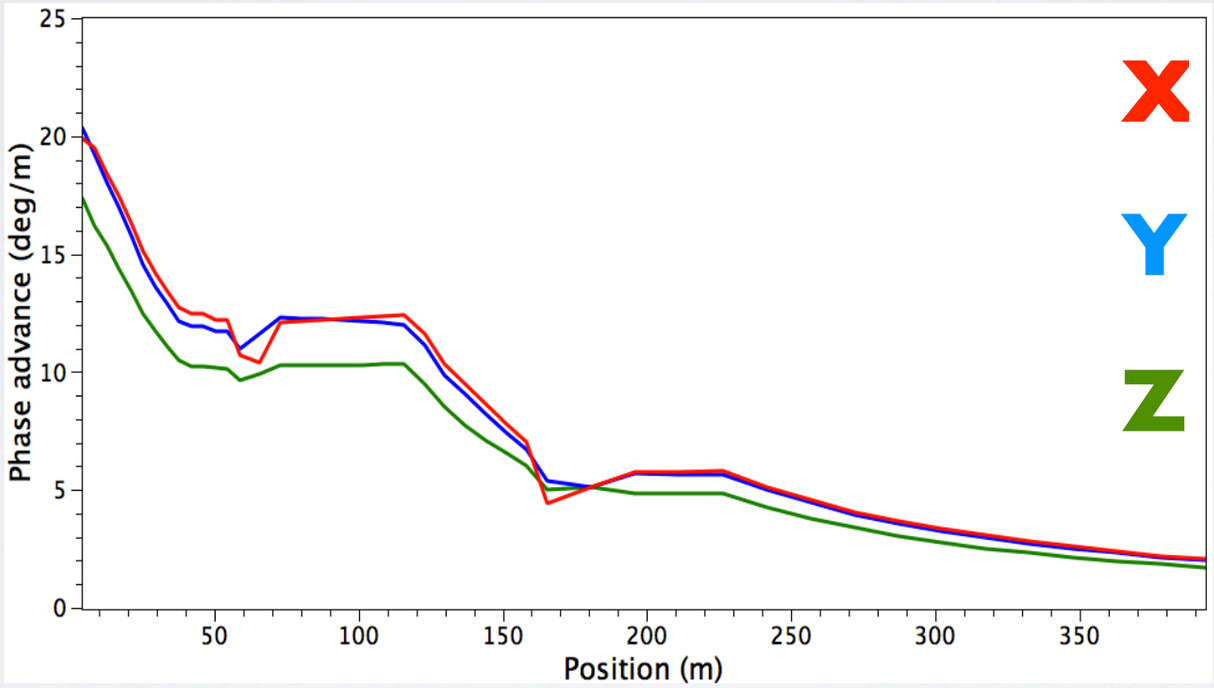
Phase advance per transverse period is limited to 87°



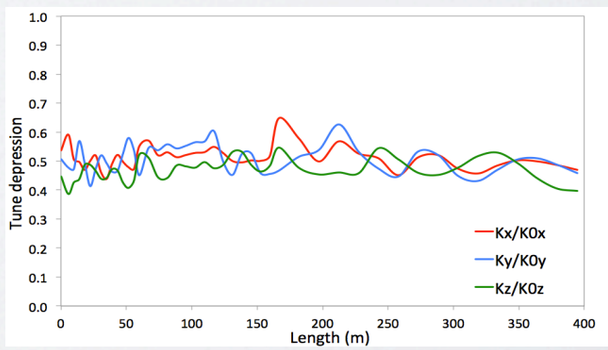


RULES OF THUMB II

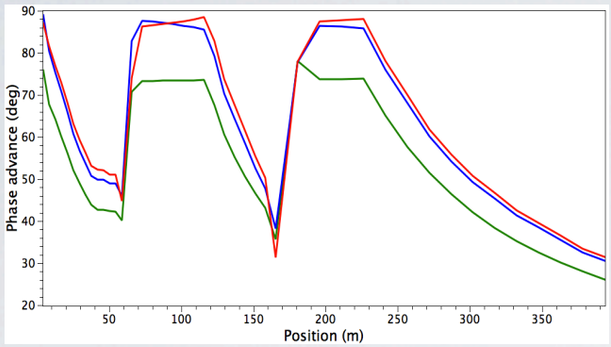


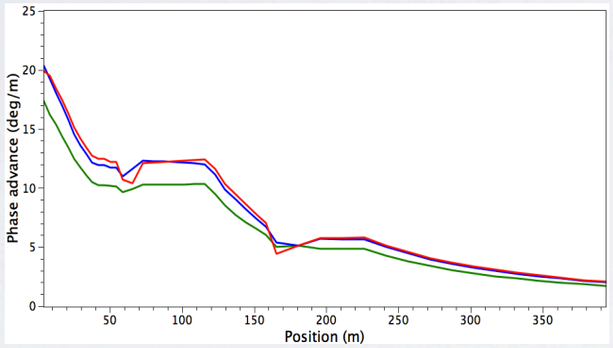


Phase advance per meter is smooth and monotonic

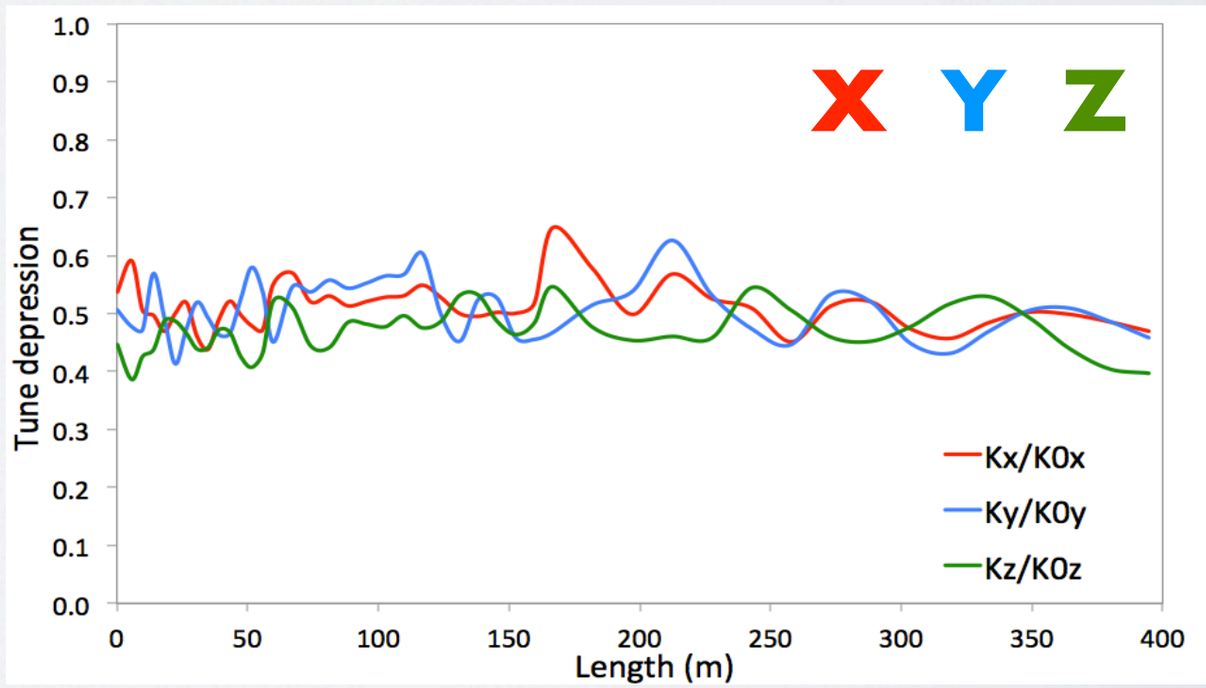


RULES OF THUMB II

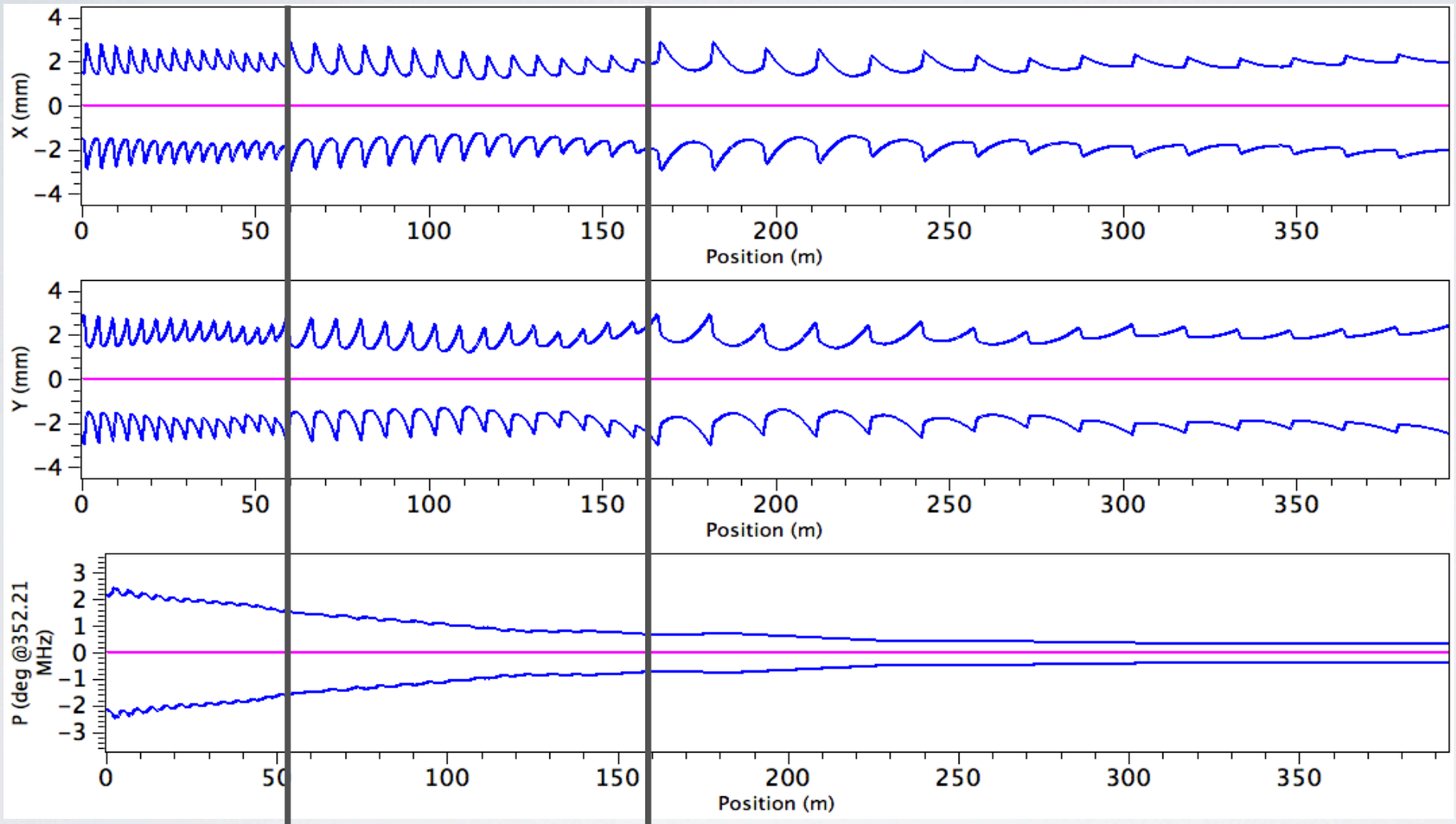




Tune depression stays right above 0.4 along the linac



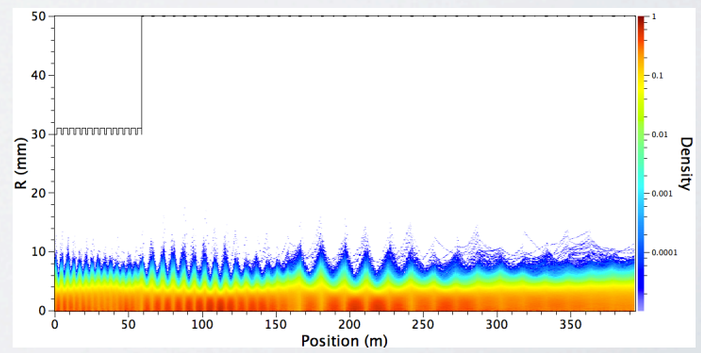
ENVELOPE / DENSITY



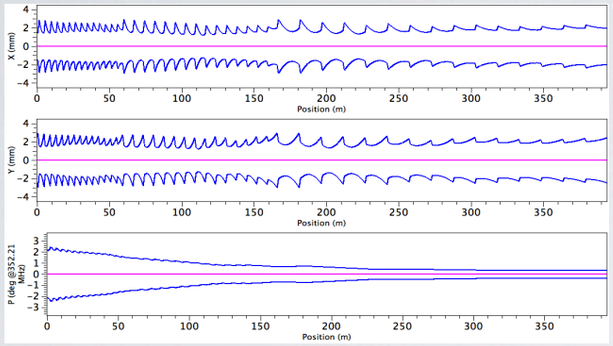
Spokes

Medium β

High β



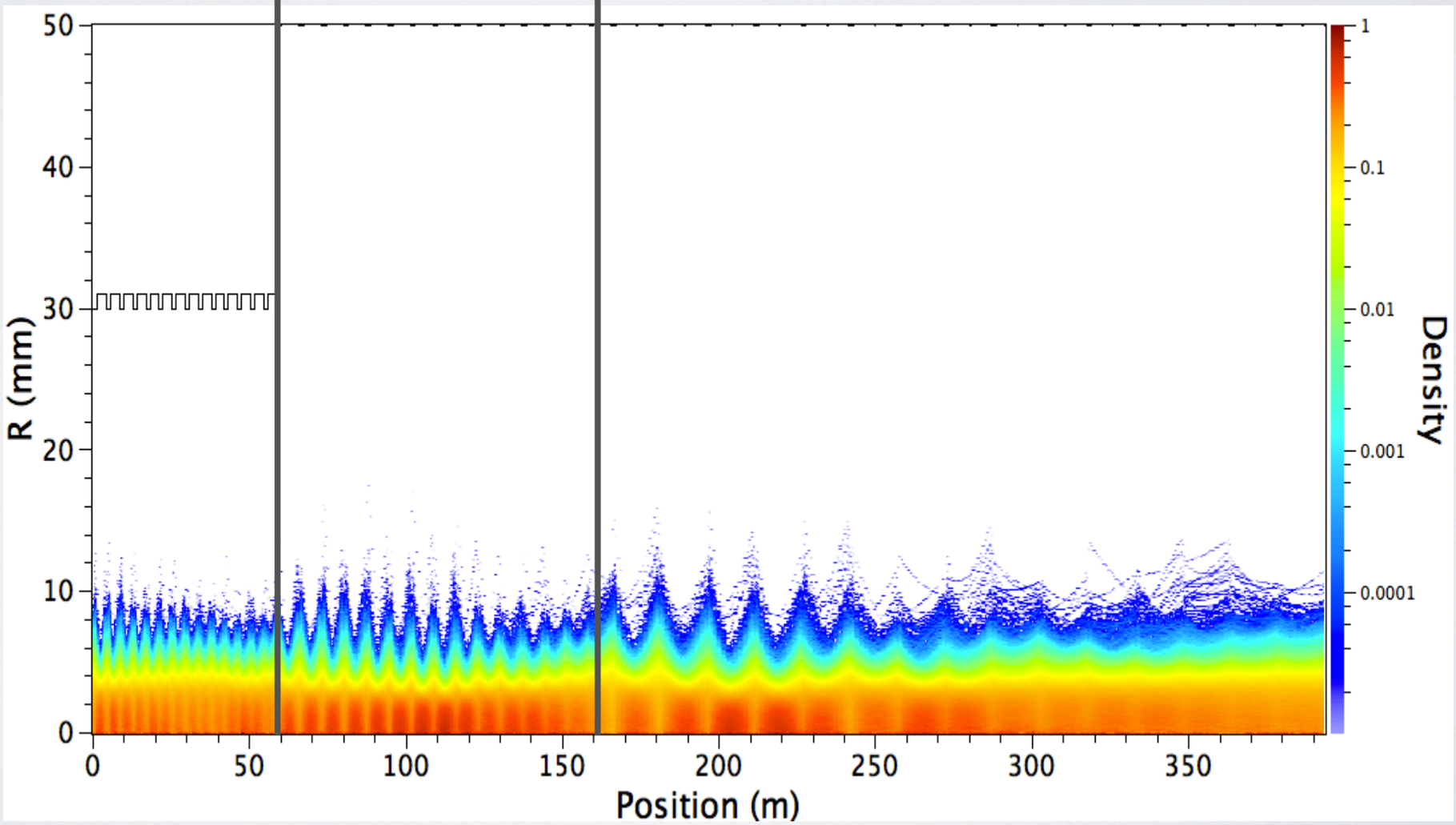
ENVELOPE / DENSITY



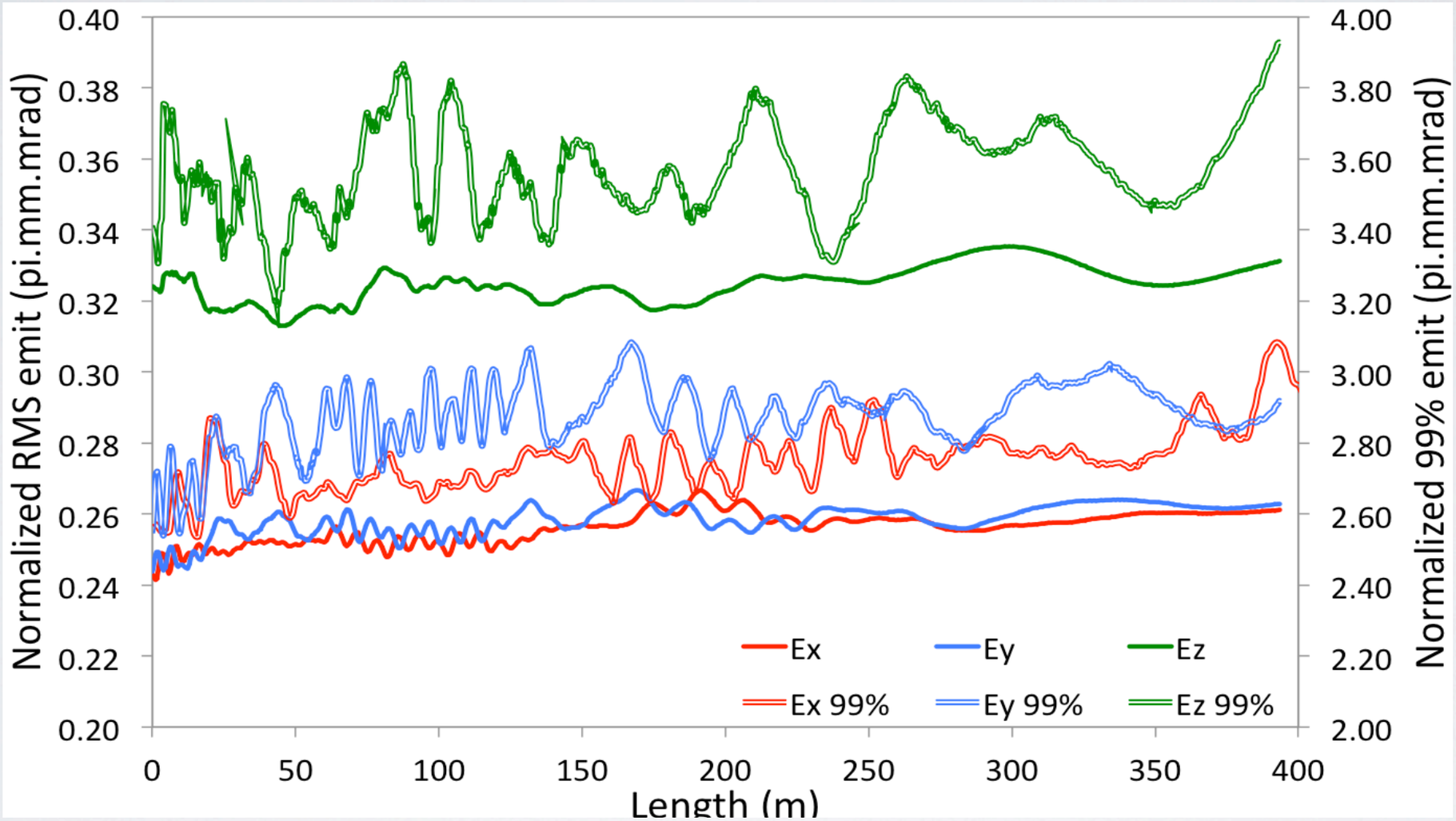
Spokes

High β

Medium β



EMITTANCES

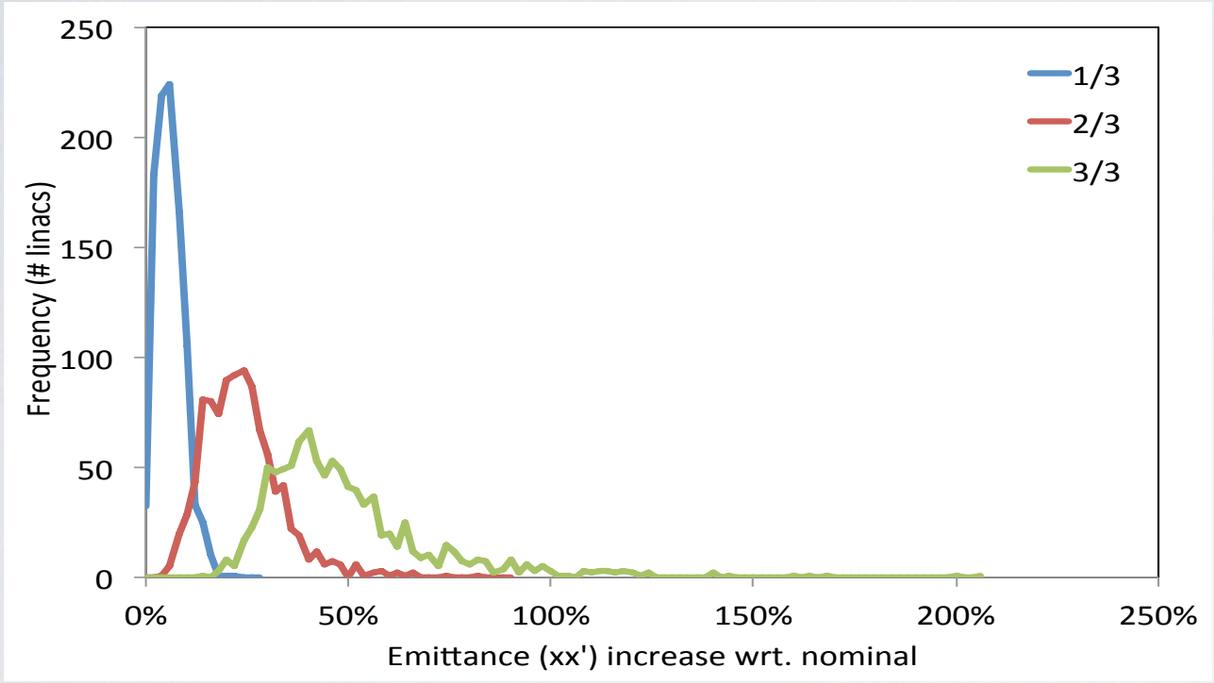

Normalized RMS emit (pi.mm.mrad)
Normalized 99% emit (pi.mm.mrad)
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
0
50
100
150
200
250
300
350
400
Length (m)
Ex
Ey
Ez
Ex 99%
Ey 99%
Ez 99%

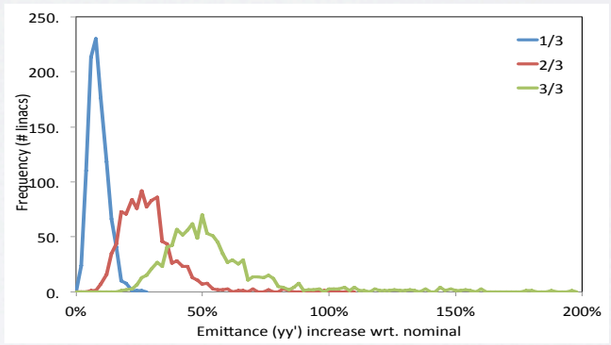
ERROR STRATEGY

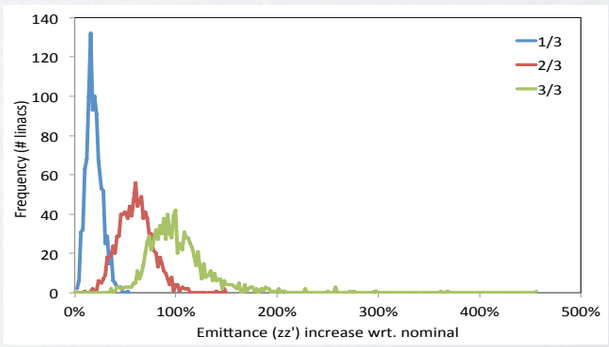
- Step 1:
  - Apply error to one variable (e.g. Δx, or $\Delta\varphi$, …)
  - Find individual tolerances
- Step 2:
  - Apply weighted errors to all variables
  - Find sensitivity

	$\Delta x, \Delta y$ (mm)	$\Delta\varphi_z$ (mrad)	ΔG (%)	$\Delta\varphi_x, \Delta\varphi_y$ (mrad)	$\Delta\varphi_s$ (°)	ΔE_{acc} (%)
QUAD	0.3	1	0.75	0*	N/A	N/A
CAVITY	3	0	N/A	3	1.5	1.5

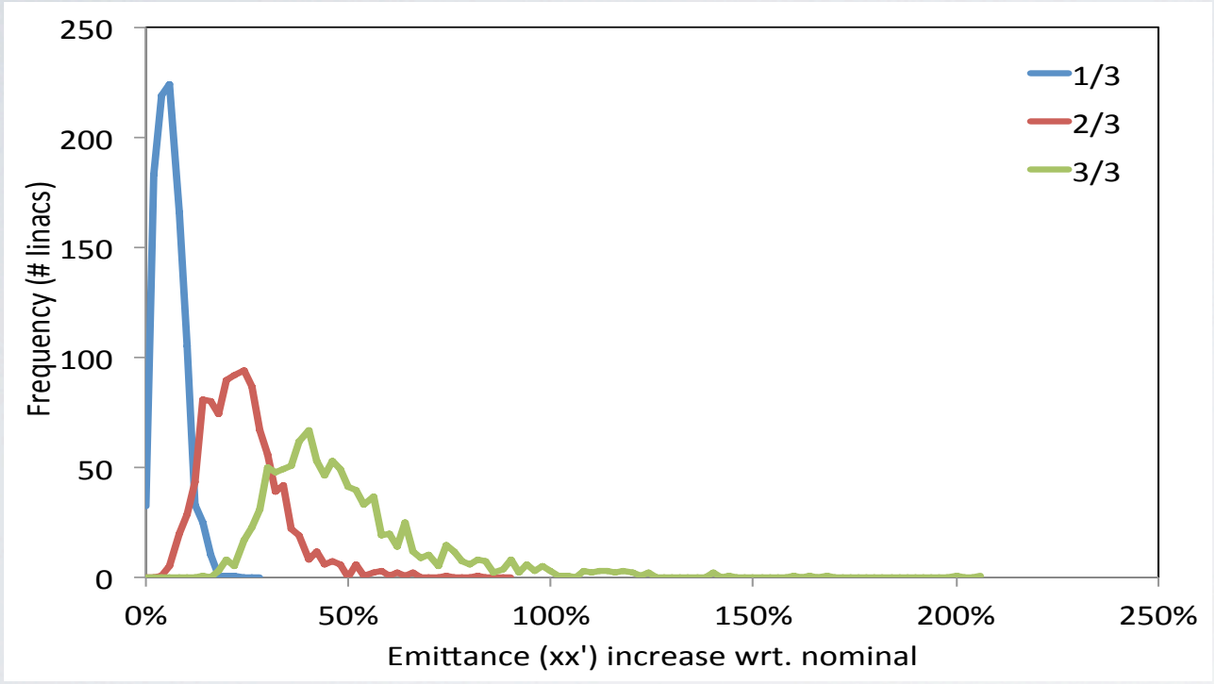
ERRORS


250
200
150
100
50
0
Frequency (# linacs)
1/3
2/3
3/3
0%
50%
100%
150%
200%
250%
Emittance (xx') increase wrt. nominal


250.
200.
150.
100.
50.
0.
Frequency (# linacs)
1/3
2/3
3/3
0%
50%
100%
150%
200%
Emittance (yy') increase wrt. nominal


140
120
100
80
60
40
20
0
Frequency (# linacs)
1/3
2/3
3/3
0%
100%
200%
300%
400%
500%
Emittance (zz') increase wrt. nominal

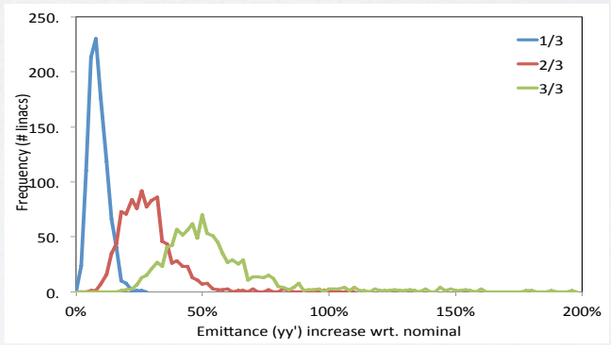
ERRORS

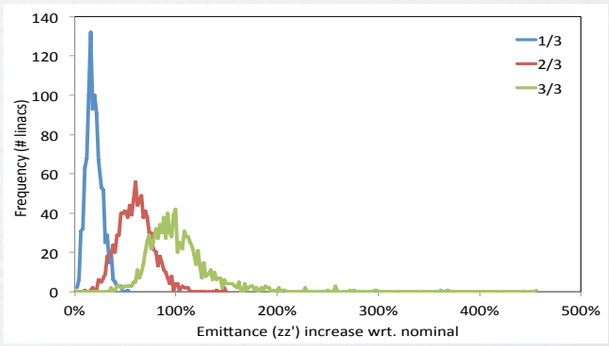


6.90±3.39

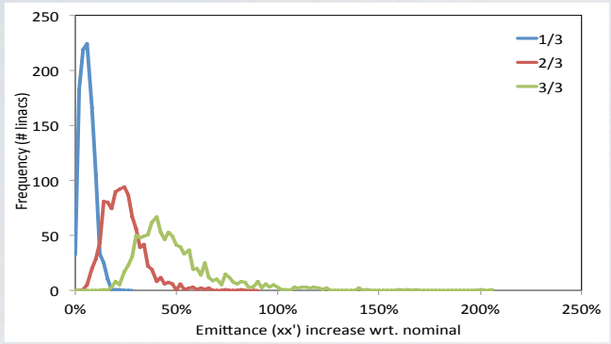
24.70±9.75

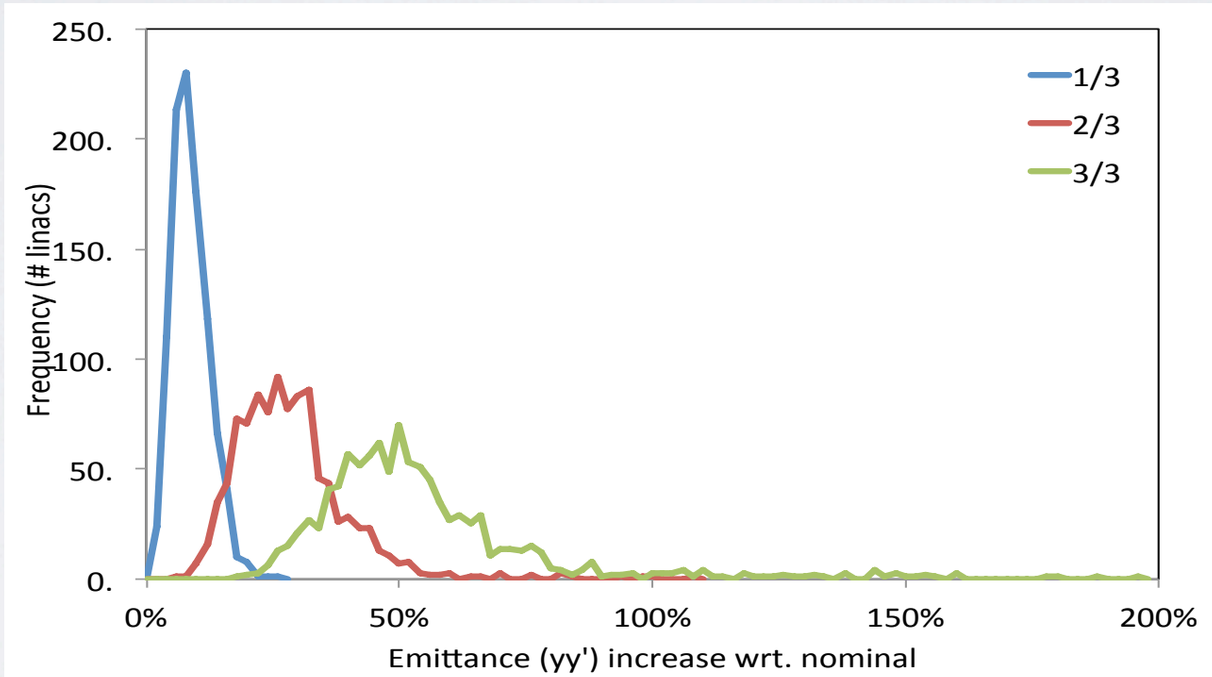
50.33±21.72





ERRORS

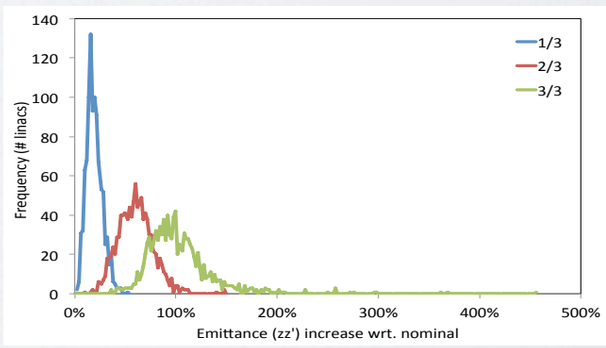




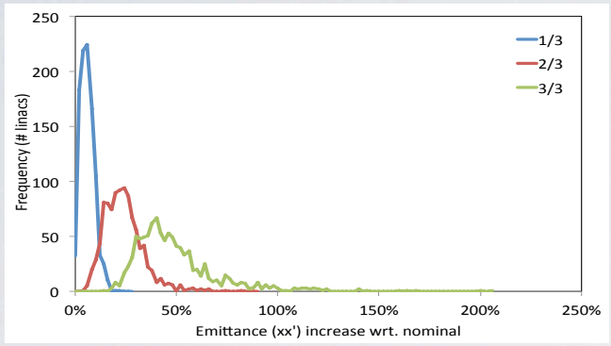
7.75±3.62

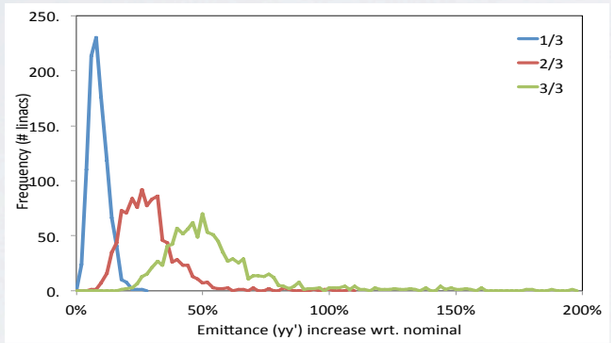
27.60±11.39

53.84±23.84



ERRORS

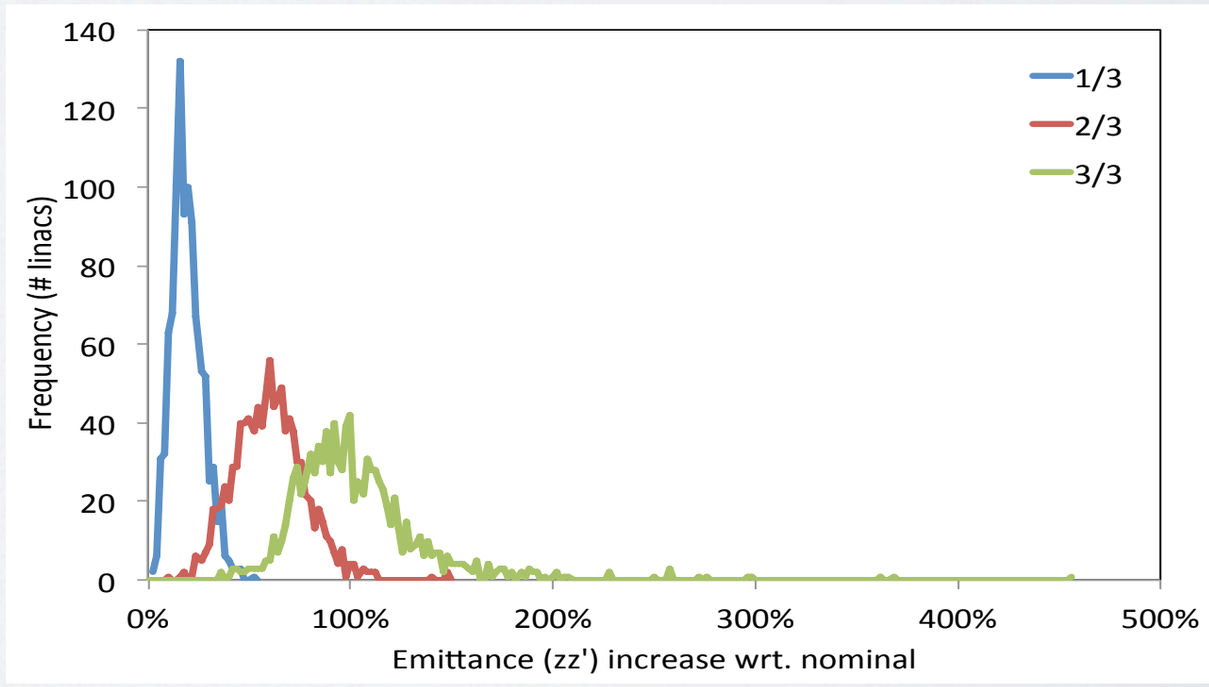




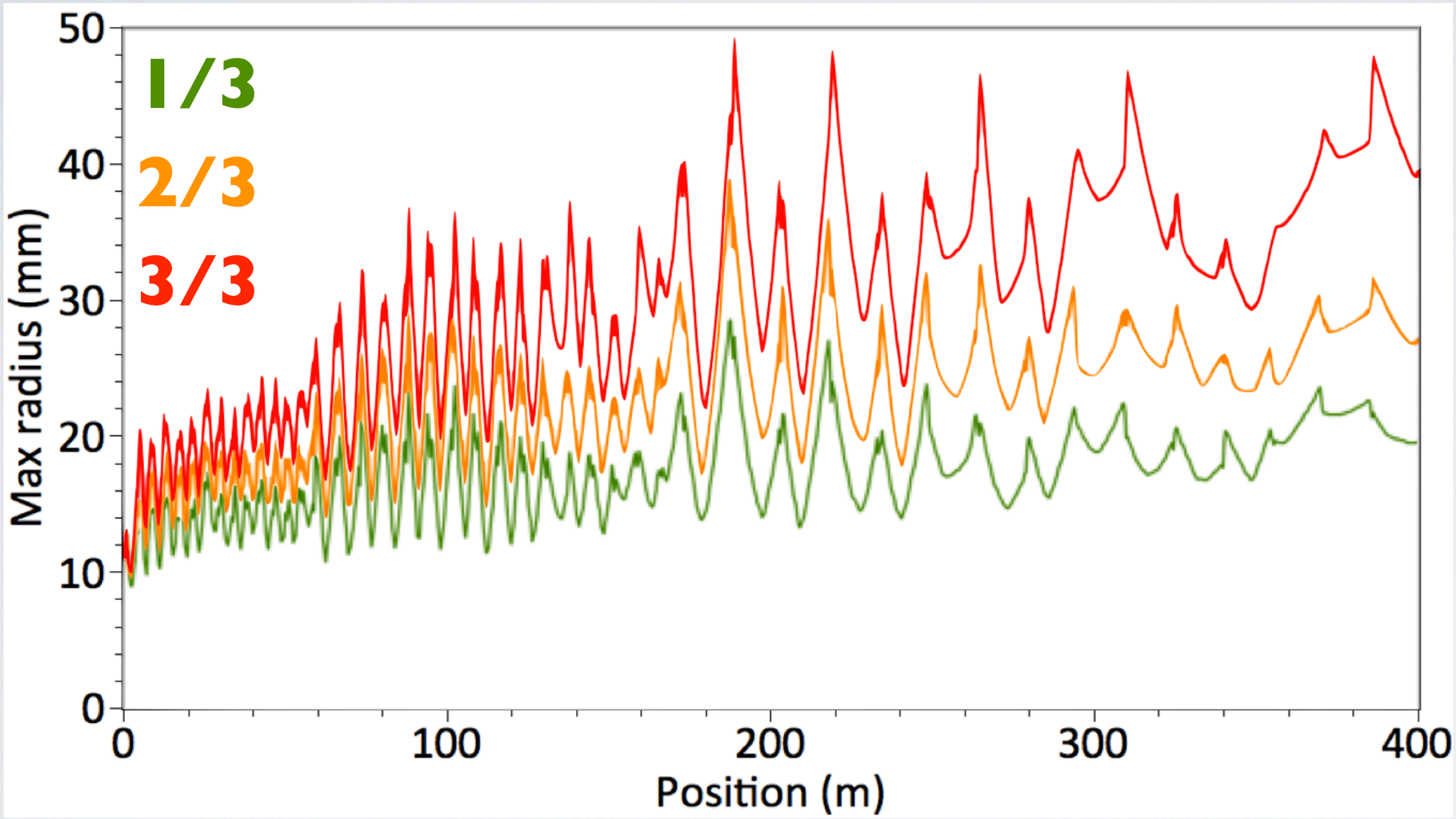
18.31±7.74

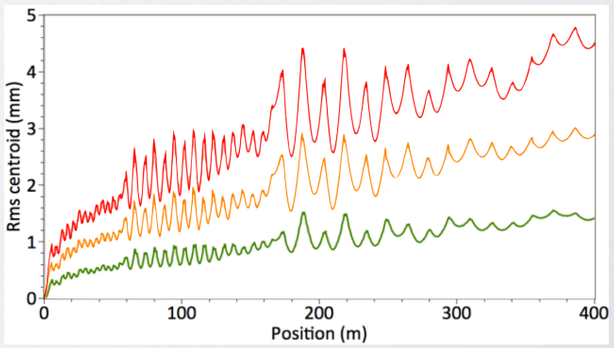
59.17±17.36

102.33±35.70

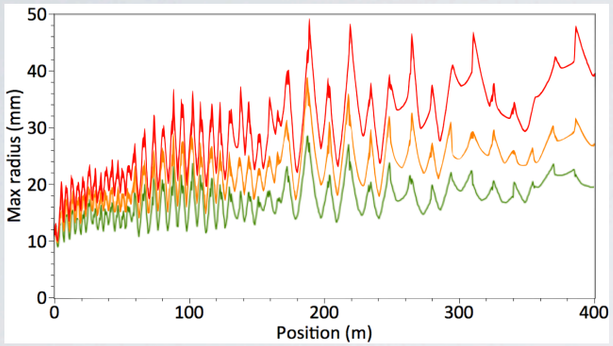


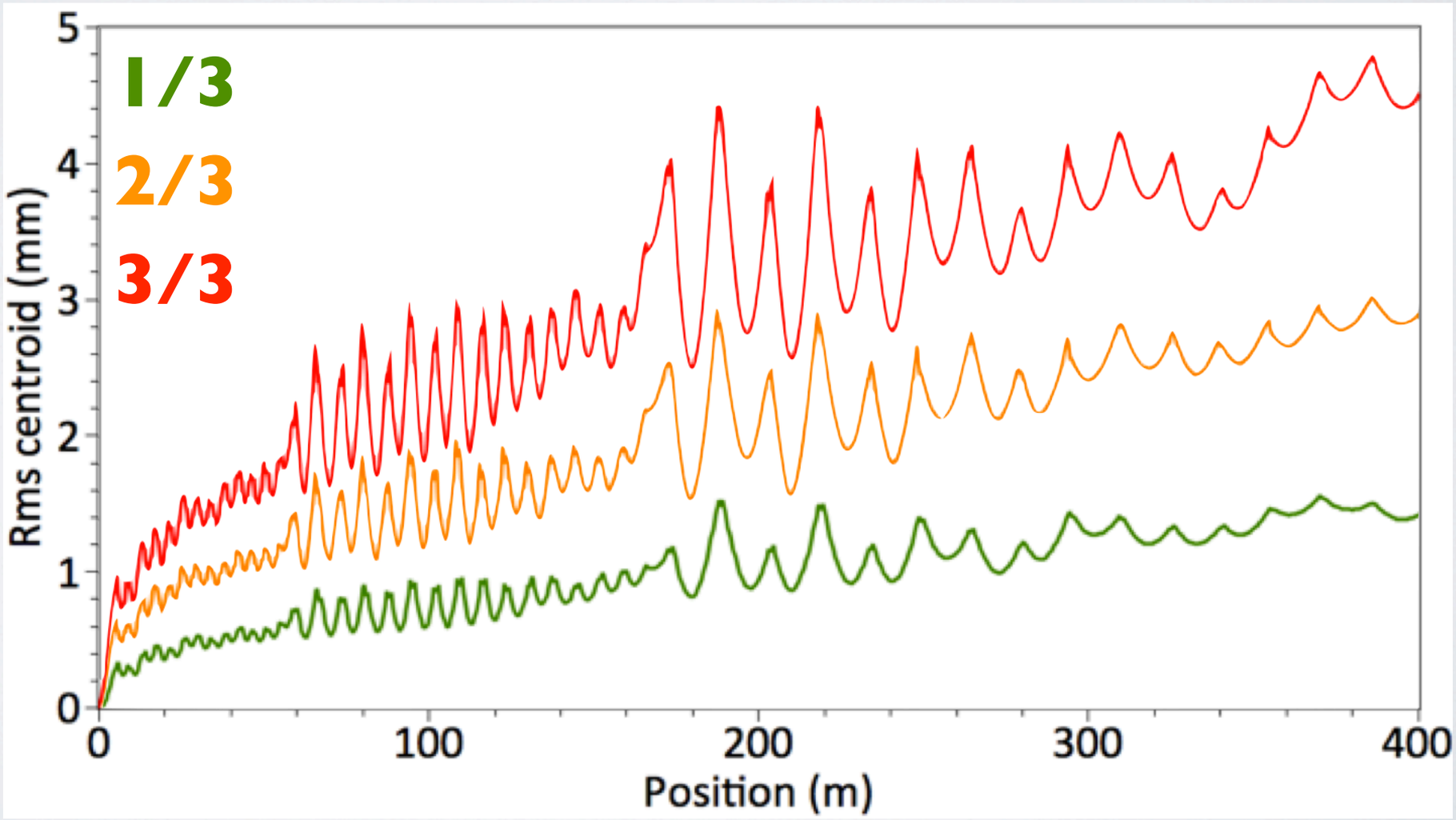
ERRORS


1/3
2/3
3/3
Max radius (mm)
Position (m)
0
10
20
30
40
50
0
100
200
300
400

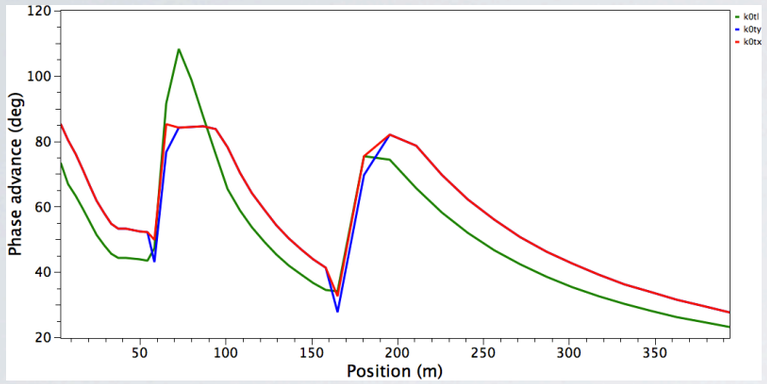

Rms centroid (mm)
Position (m)
0
1
2
3
4
5
0
100
200
300
400

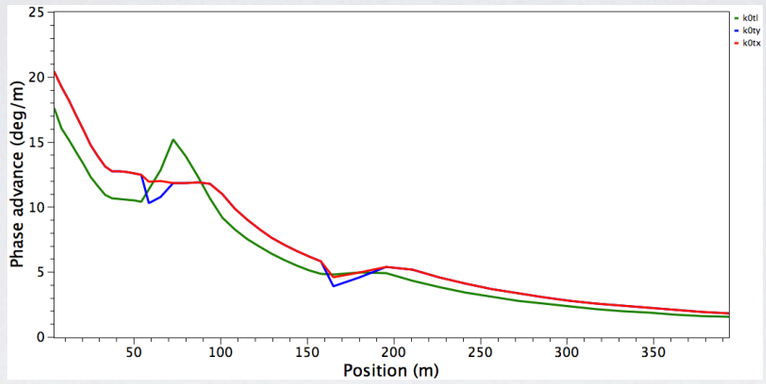
ERRORS

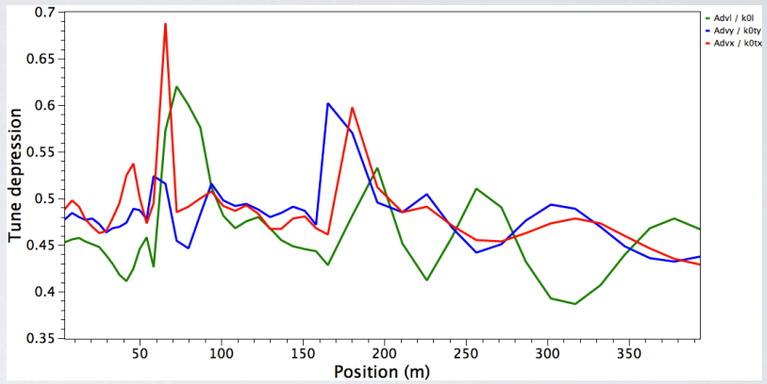

Max radius (mm)
Position (m)
0
10
20
30
40
50
0
100
200
300
400

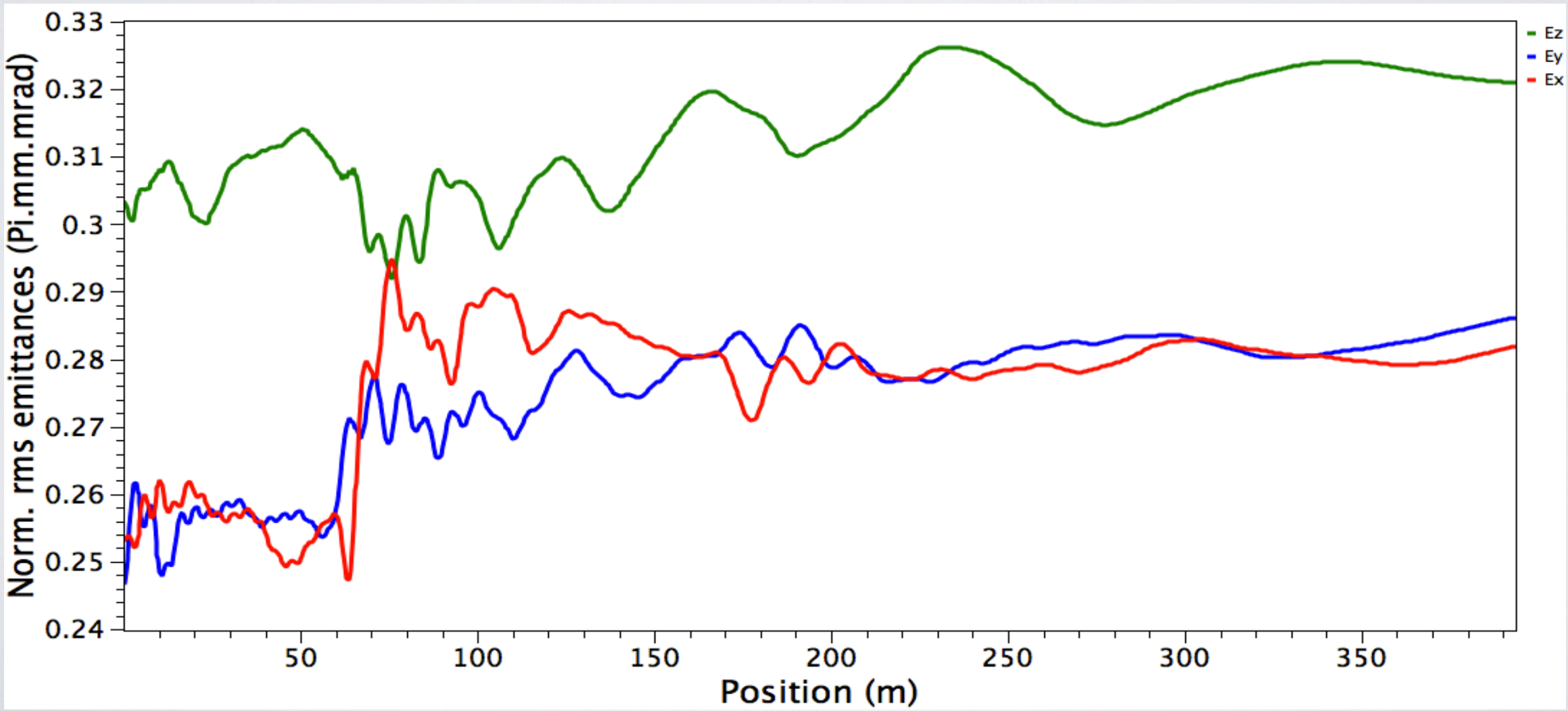

1/3
2/3
3/3
Rms centroid (mm)
Position (m)
0
1
2
3
4
5
0
100
200
300
400

BREAKING THE RULES









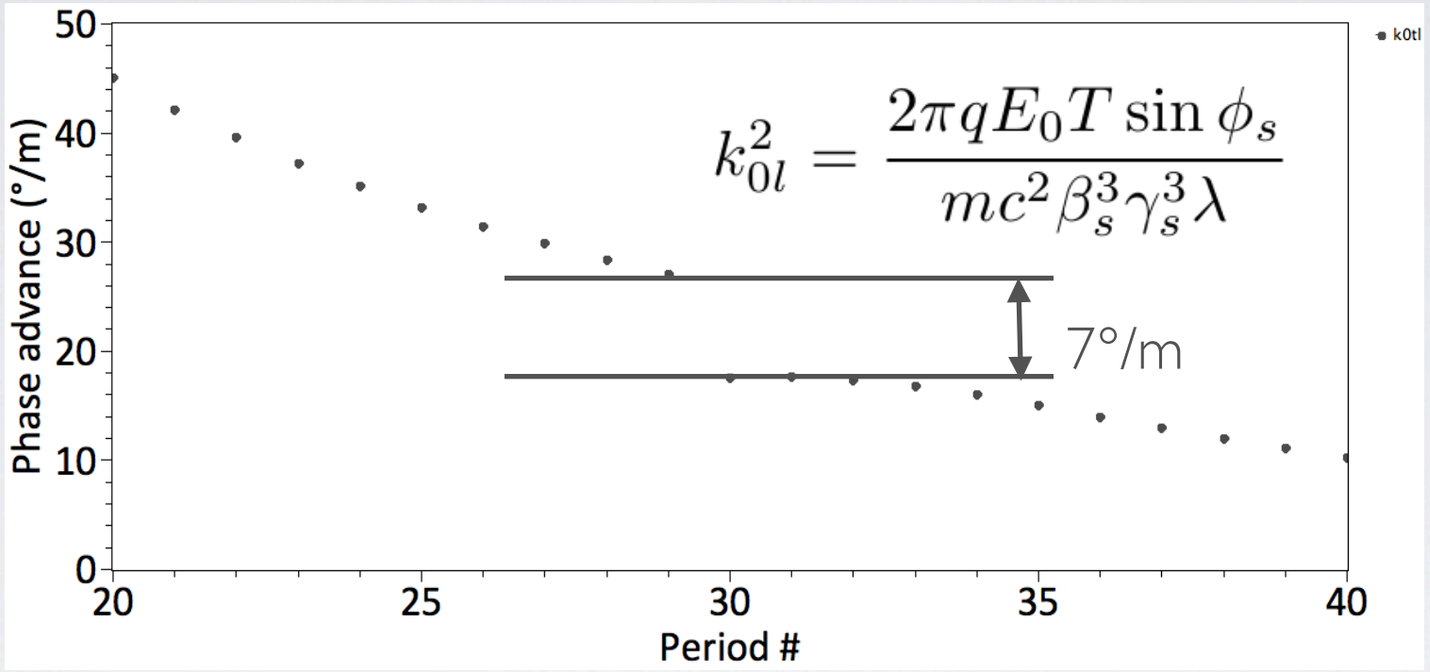
SUMMARY

- A linac respecting known rules of thumb is designed and simulations do not show any sign of beam quality degradation.
- Statistical runs are performed to check the sensitivity of the linac to real life errors
- How important is the emittance?

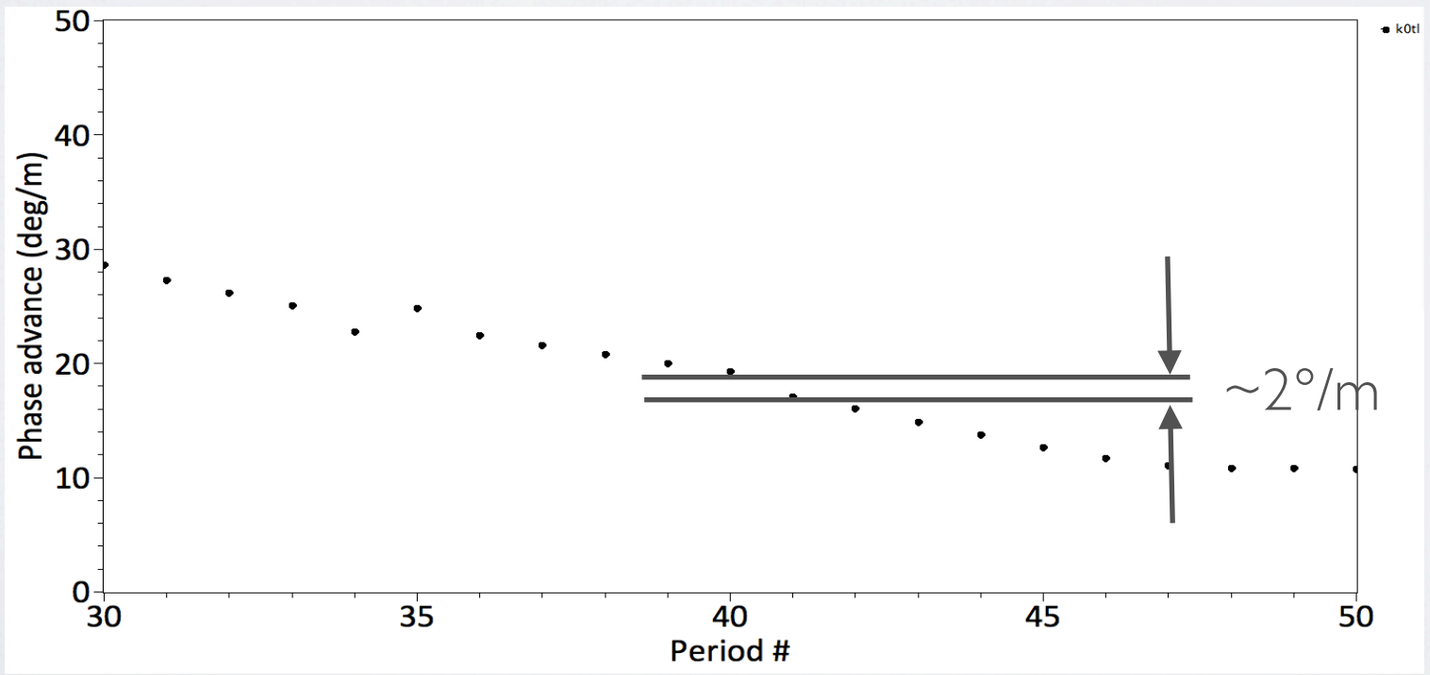
THANK YOU FOR YOUR ATTENTION!

HIGHER DTL ENERGY I

Before

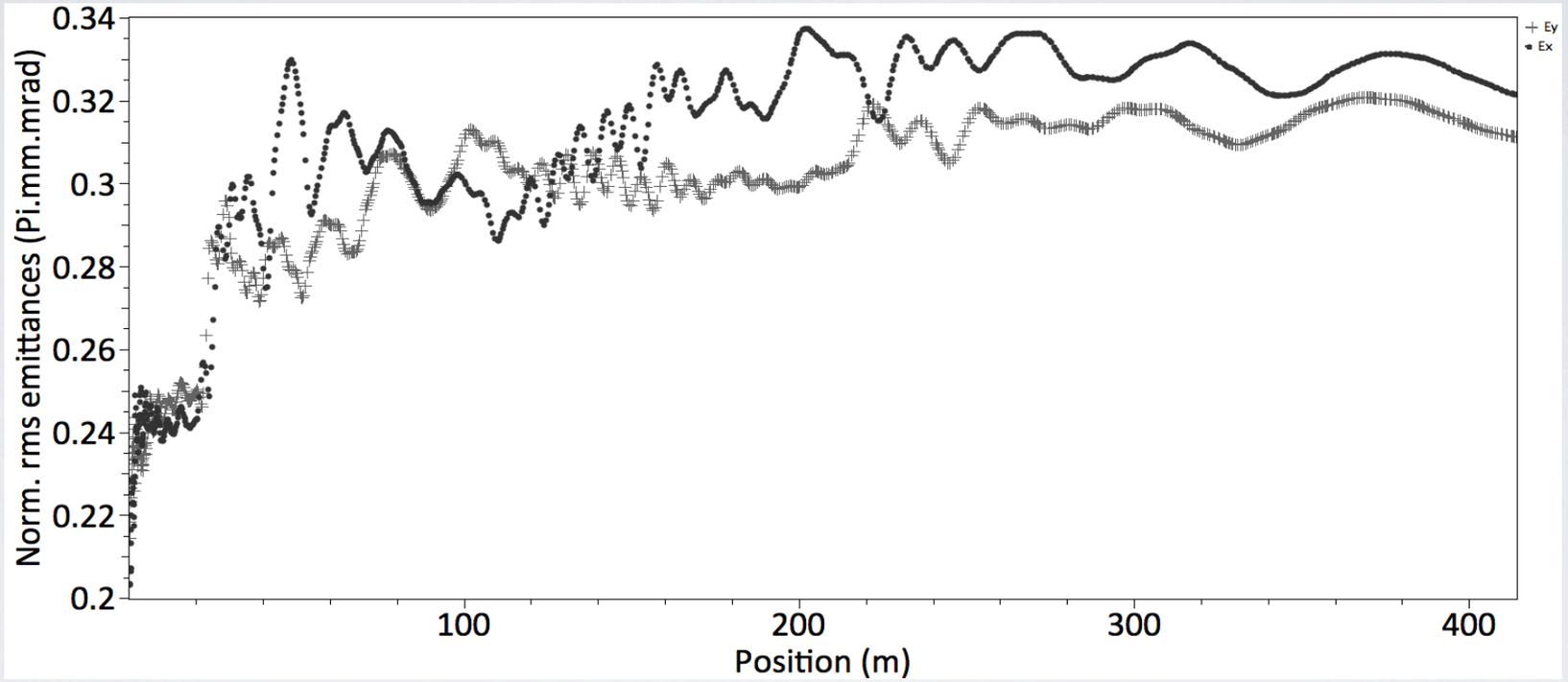


After



HIGHER DTL ENERGY II

Before



After