DTL: Basic Considerations

Thanks to J. Stovall, for the help!

M. Comunian & F. Grespan

OutLine

- Design parameters
- Design Method
- Design of PMQ, Field Law, Lattice
- Beam dynamics optimization
- Example of a FODO and FFDD DTL
- Conclusion

DTL Parameters

- Particles is proton.
- Input energy of 3 MeV. (β=0.0798)
- Output energy of 50 MeV. (β=0.314)
- Frequency is 352.2 MHz.
- Current of 70 mA.
- Duty cycle 4%.
- Total peak power (SF*1.2+Beam) < 6 MW.
- Total DTL length <20 m (inter tanks space?).

- Input Transverse RMS emittance Norm. of 0.22 mmmrad. (output of RFQ+10% in the MEBT)
- Input Longitudinal RMS emittance Norm. of 0.32 mmmrad (output of RFQ).
- Input distribution Gaussian (5 sigma on size, i.e. a very large total emittance).
- Simulation Code: TraceWin with a minimum of 10^5 particles (i.e. 1.4 W for particle).
- Calculated matched input beam conditions.
- Constant PMQ gradient or Equipartitioning.
- PMQ size as Linac 4 PMQ tender.

Design method

- Maximum of 1.4 Ekp? -> limited By Moretti Criteria.
- Maximum of 2 MW power for Tanks. -> From Klystron limit.
- Maximum RF Tank length of 7-8 m? -> From RF tuning.
- Maximum PMQ field of 50-70 T/m? -> From manufacturing.
- Maximum output emittance? -> From SC Linac Acceptance.
- Maximum losses allowed? (1 W/m?) -> From radioprotection.
- Maximize effective shunt impedance? -> From Cell design and Field stabilization.
- Equipartitioned BD design? -> SNS design rule.
- Field E0 ramping? -> SNS yes, CERN no.
- Lattice? FFDD(CERN)? FODO? FFODDO(SNS)? O=space for steering/BPM.
- Intertank distance? 3βλ(CERN)? or 1 βλ(SNS)?
- Maximum Mechanical module length? ->2 m from manufacturing.

Moretti Criteria is more demanding respect to the Kilpatrick "Brave" factor

- sparking in the region of collinear B & E fields.

Figure 8. Linac4 PMQ prototype.

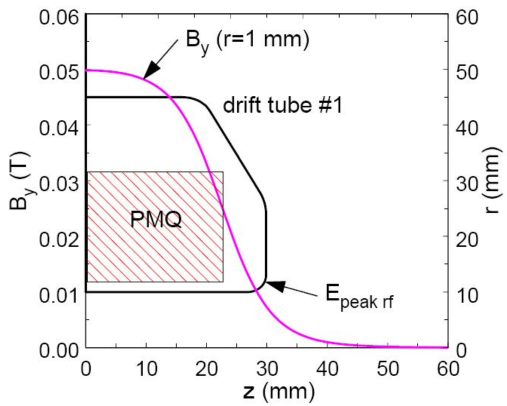
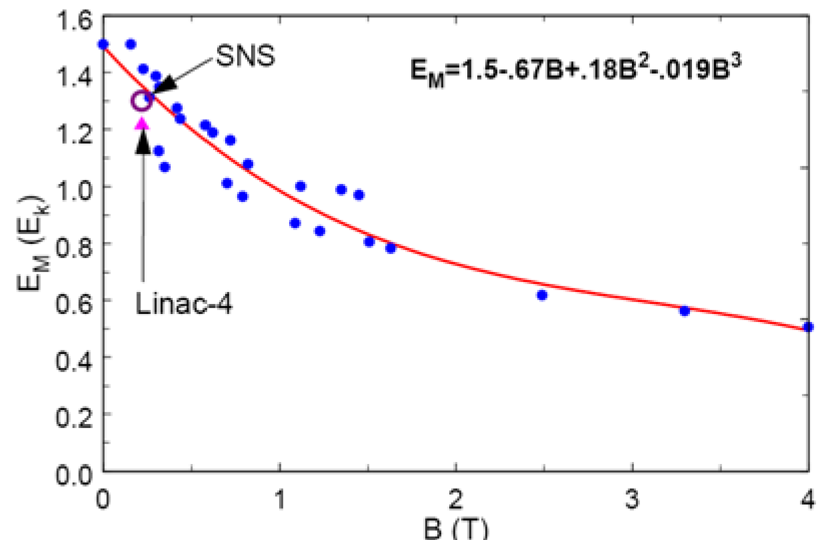
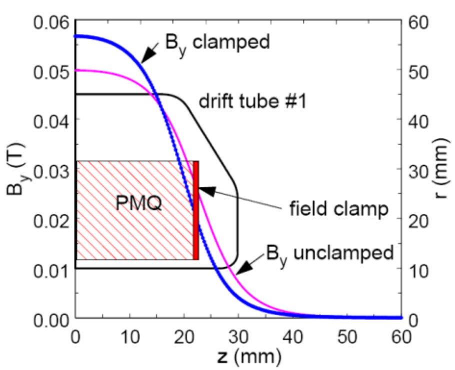


Figure 9. Axial profile of B_y at a radius of 1 mm.



Moretti Criteria

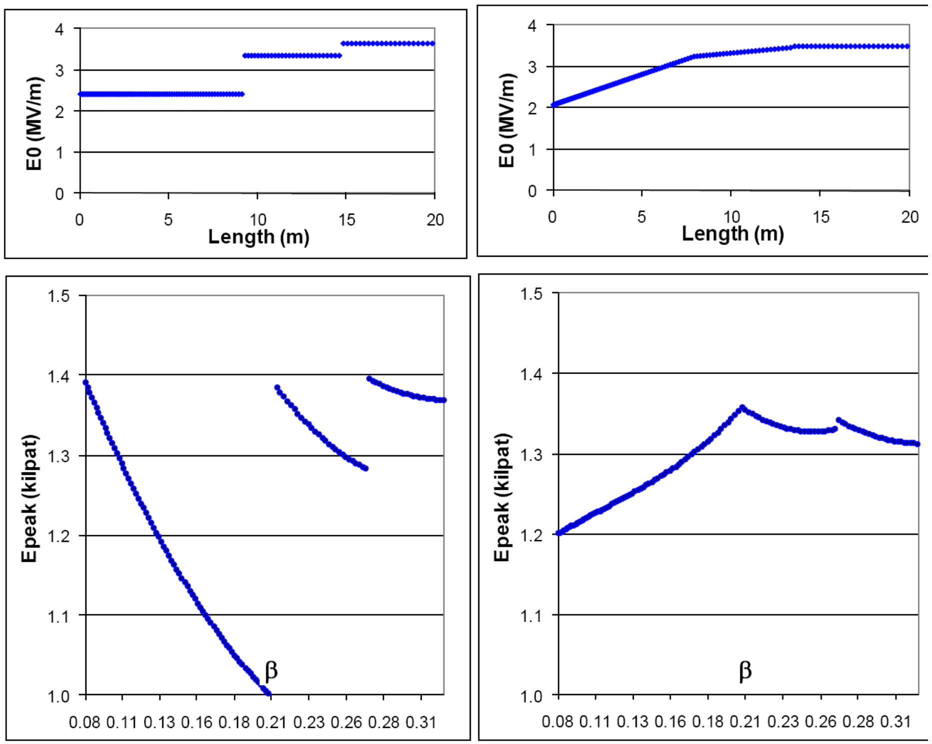
- fit to sparking threshold at 805 MHz as a function of a dc surface magnetic field
- assume data scales with Kilpatrick Criteria
- sparking threshold believed to be a surface phenomena



Clamp effects

Sparking effects (@1.7kp) on Linac4 DTL prototype

Flat or Ramped Field E0?



Flat Field design and ramped design, in the ramped design the Epeak max is 1.35.

The idea is to model the longitudinal behavior of the field distribution with the goal of determining the dimensions of perturbations applied to the tank end walls that will pre-set the longitudinal field distribution to approximately that of the design.
Shapes of the individual drift tubes are the same as the design except for the face angles.

Design Summary Flat field E0

Tank	No of Cells	Length m	Wfinal Mev	Power MW
1	76	9.16	20.83	2.047
2	27	5.49	35.96	1.955
3	20	4.98	50.19	1.977
Total	123	19.63		5.98

Design Summary Ramped field E0

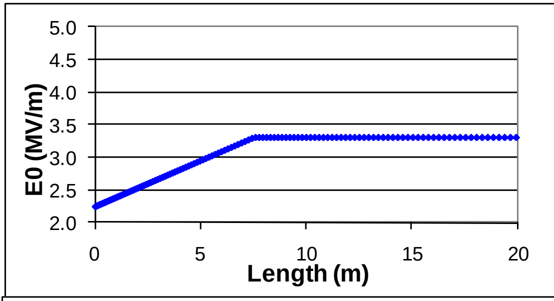
Tank	No of Cells	Length m	Wfinal Mev	Power MW
1	68	7.76	19.63	2.001
2	28	5.57	35.09	1.997
3	22	5.44	50.04	2.032
Total	118	18.78		6.03

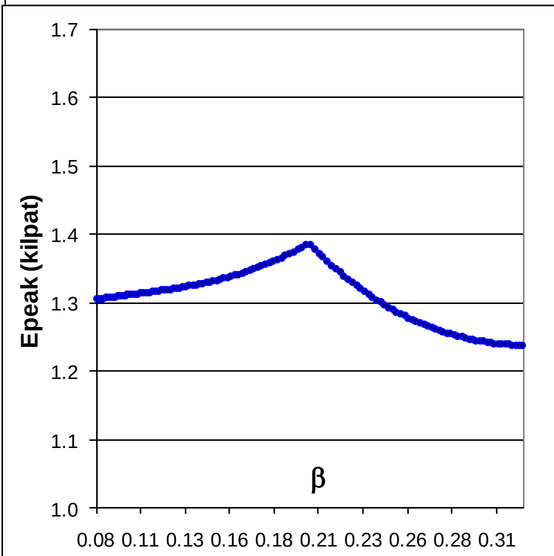
The ramped solution is better in term of performance.

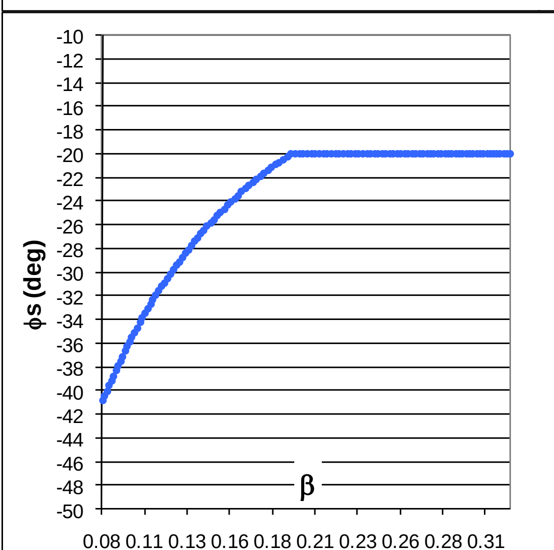
DTL Example

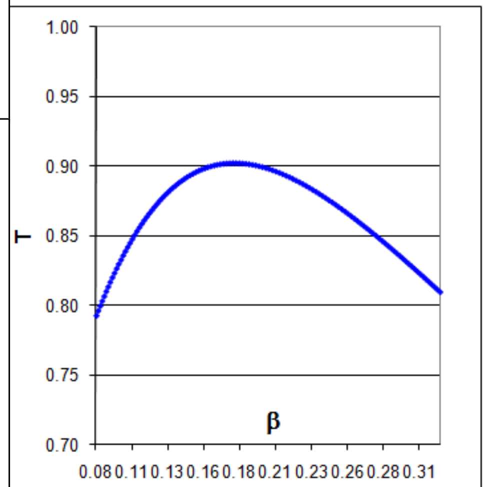
- FODO Lattice:
  - Space inside DTL for steering and BPM.
  - Optimizations of Shunt impedance by asymmetric cell.
  - Reduce number of PMQ.
  - High gradient of PMQ, from 54 T/m to 71 T/m.
- FFDD Lattice:
  - No space inside DTL.
  - Low gradient of PMQ.

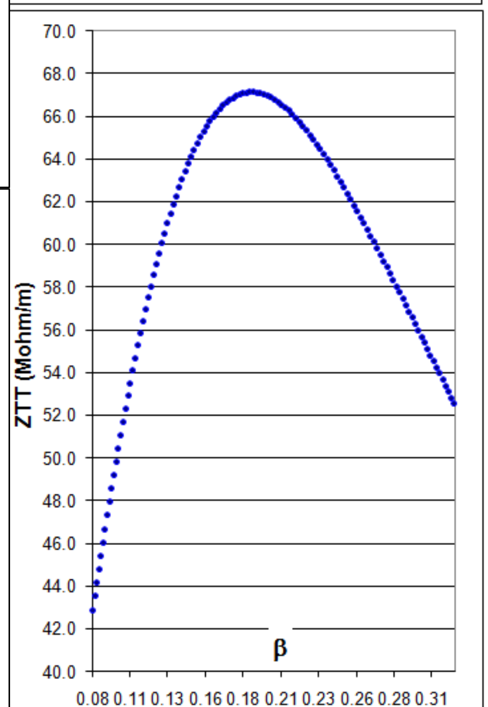
DTL Example

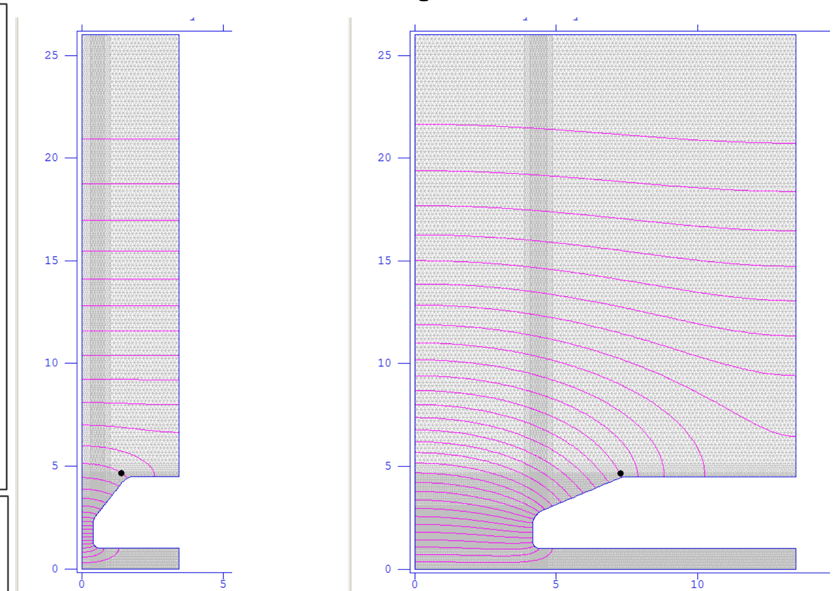












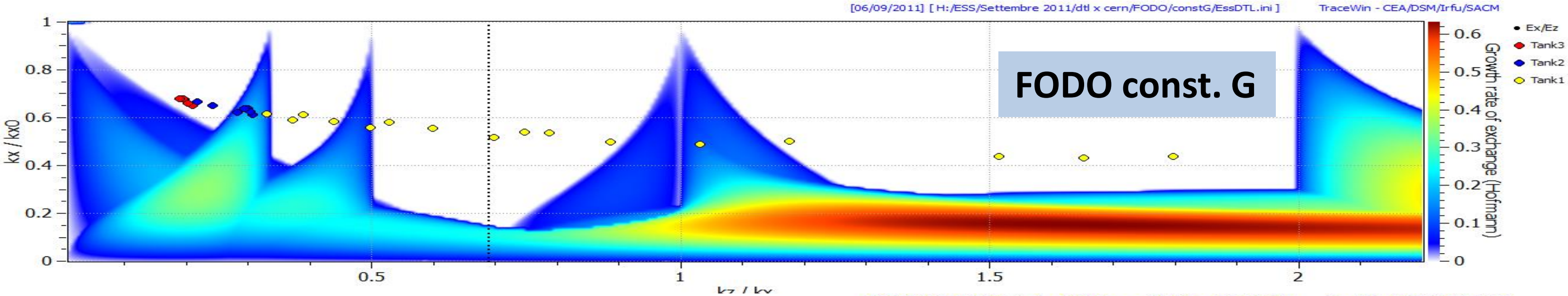
SF runs from 3 to 50 MeV

Data collect and analysis on Excel

Power by SF*1.25

Design Summary

Tank	No of Cells	Length m	Wfinal Mev	Power MW
1	66	7.47	19.20	2.050
2	29	5.75	34.88	2.045
3	24	5.93	50.26	2.072
Total	119	19.15		6.17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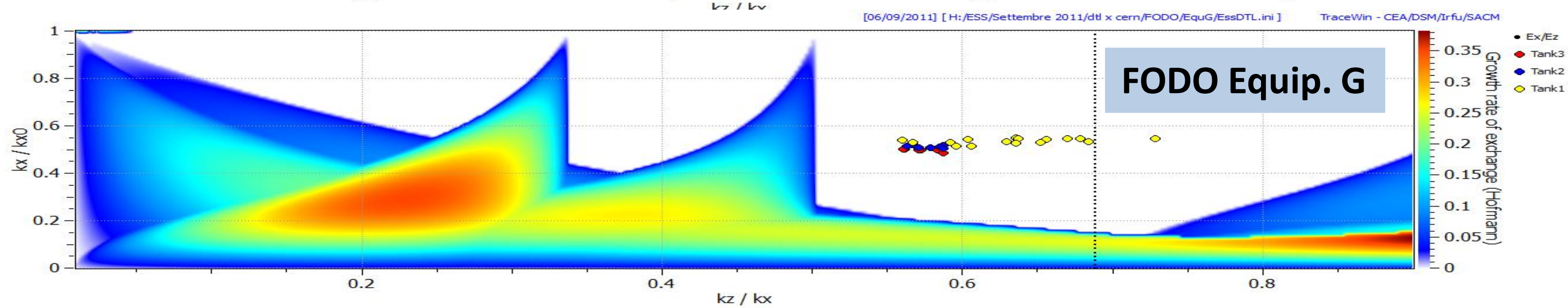
TraceWin - CEA/DSM/Irfu/SACM
FODO const. G
kx / kx0
kz / kx
Growth rate of exchange (Hofmann)
Ex/Ez
Tank3
Tank2
Tank1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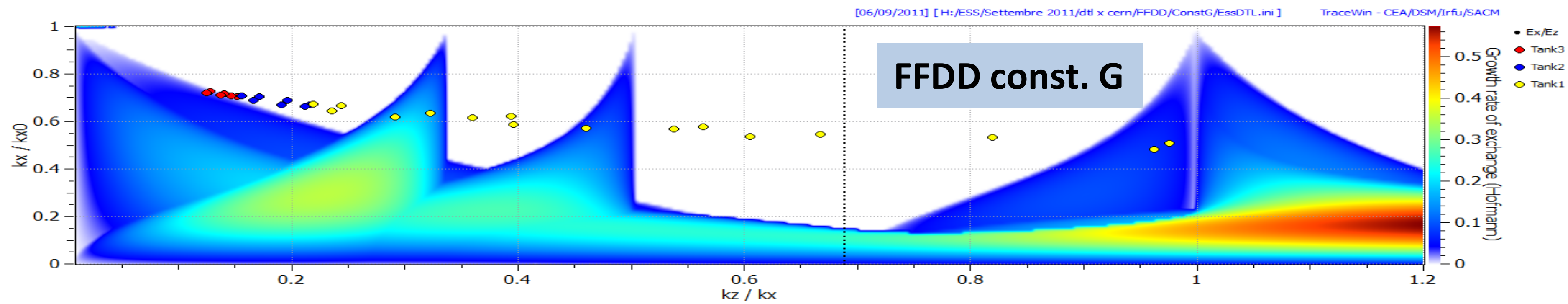
kx / kx0
kz / kx
Growth rate of exchange (Hofmann)
Ex/Ez
Tank3
Tank2
Tank1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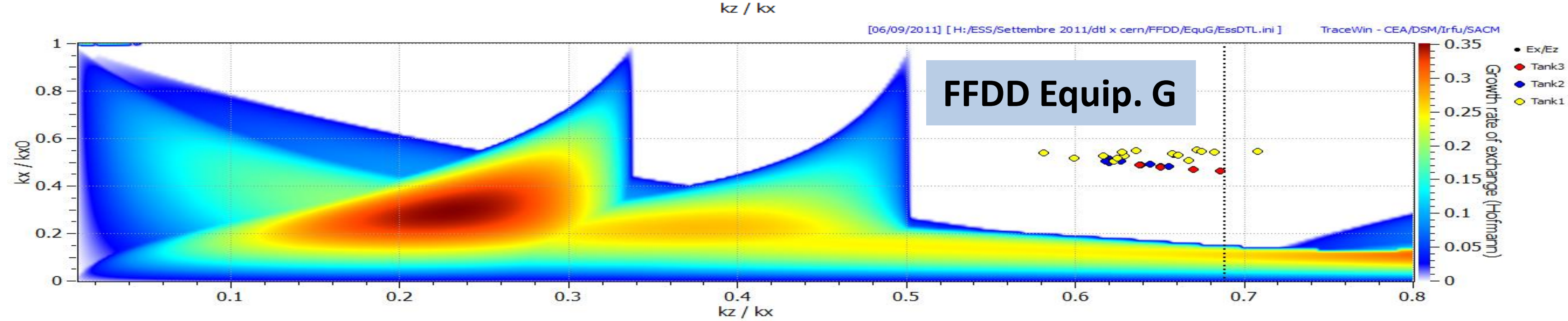
kx / kx0
kz / kx
Growth rate of exchange (Hofmann)
Ex/Ez
Tank3
Tank2
Tank1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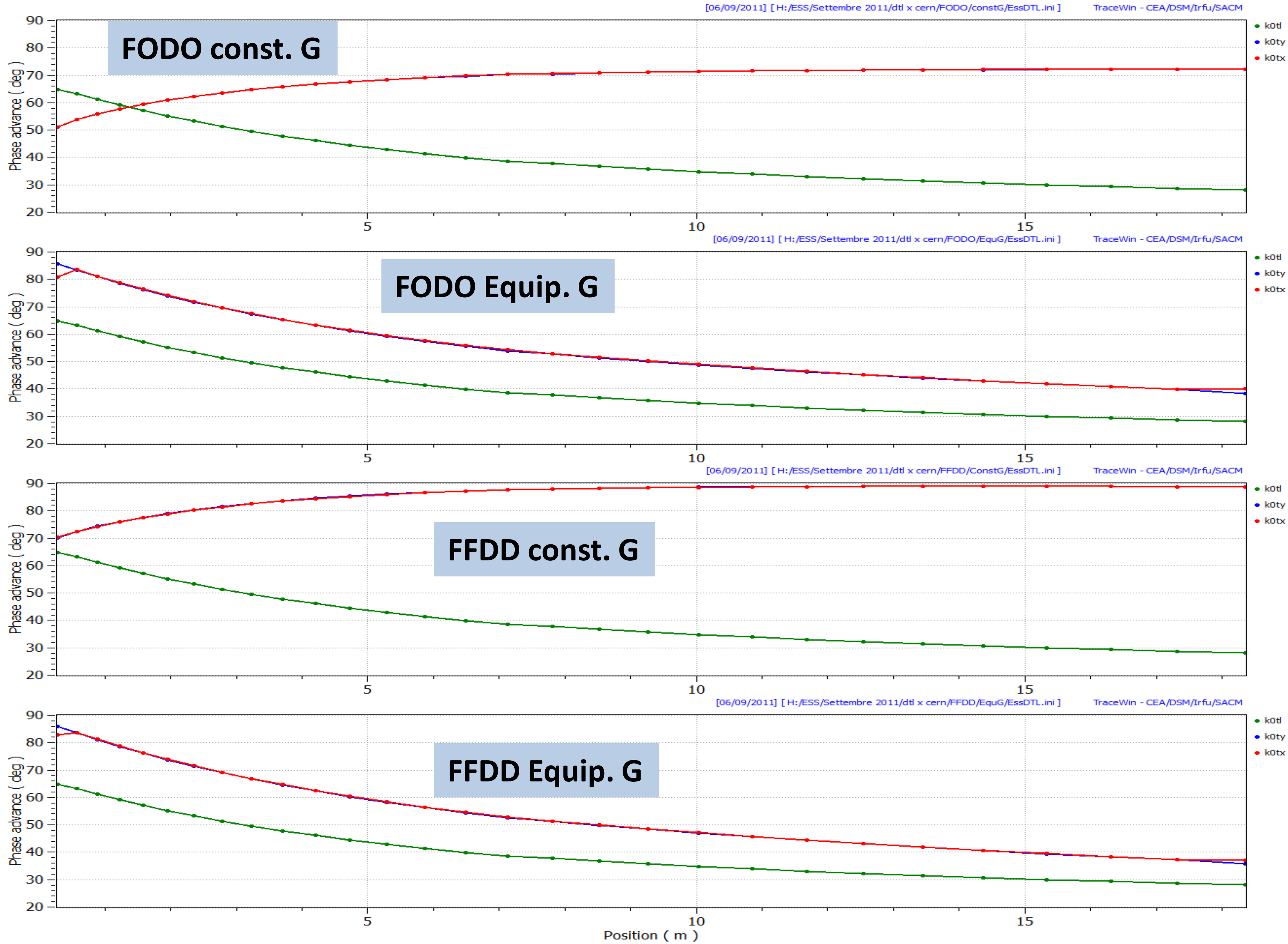
kx / kx0
kz / kx
Growth rate of exchange (Hofmann)
Ex/Ez
Tank3
Tank2
Tank1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FODO Equip. G
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FFDD const. G
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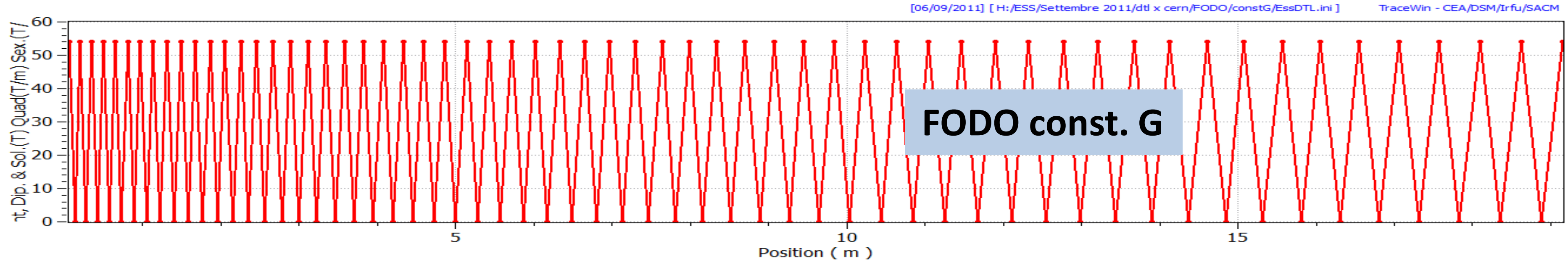
TraceWin - CEA/DSM/Irfu/SACM
FFDD Equip. G
k0tl
k0ty
k0tx
Phase advance (deg)
Position (m)
20
30
40
50
60
70
80
90
5
10
15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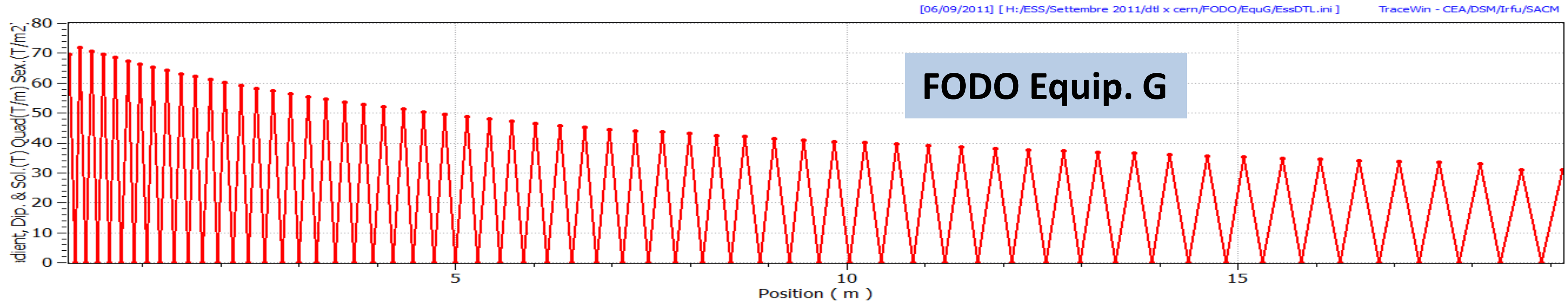
FODO const. G
Position (m)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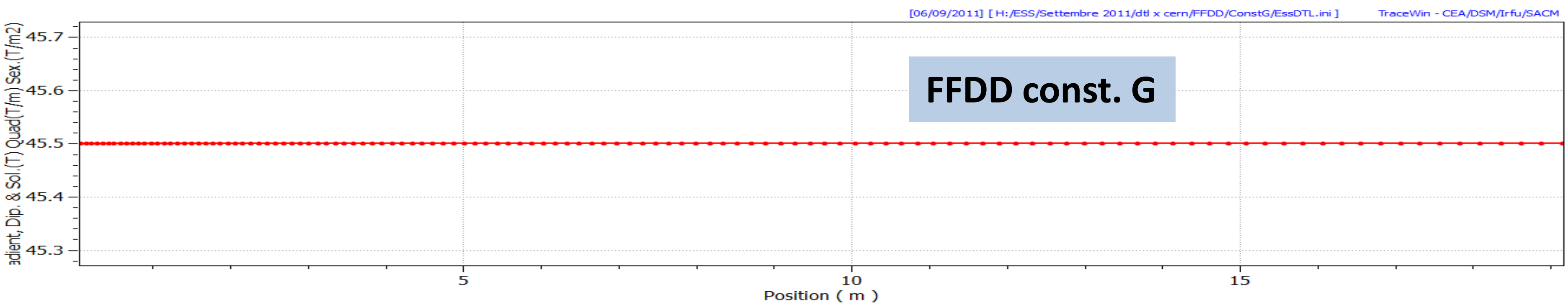
FODO Equip. G
Position (m)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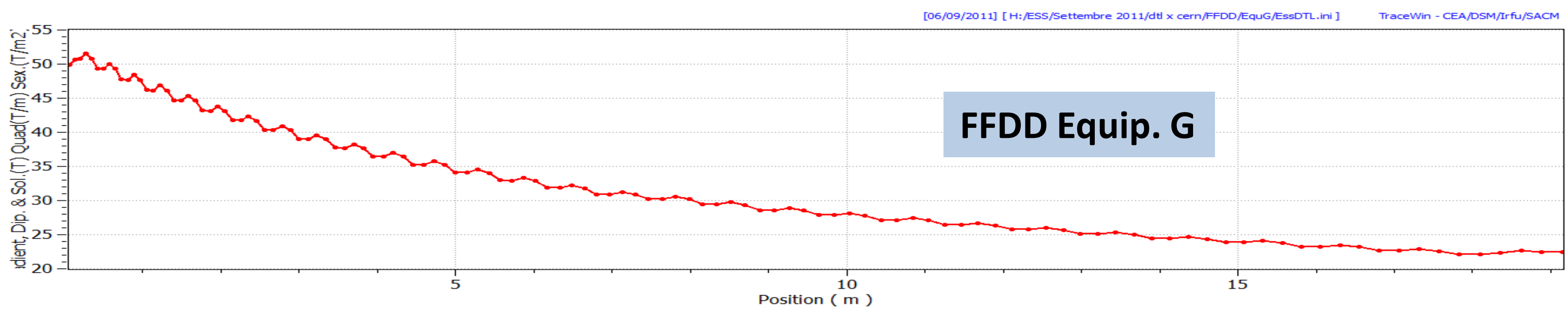
FFDD const. G
Position (m)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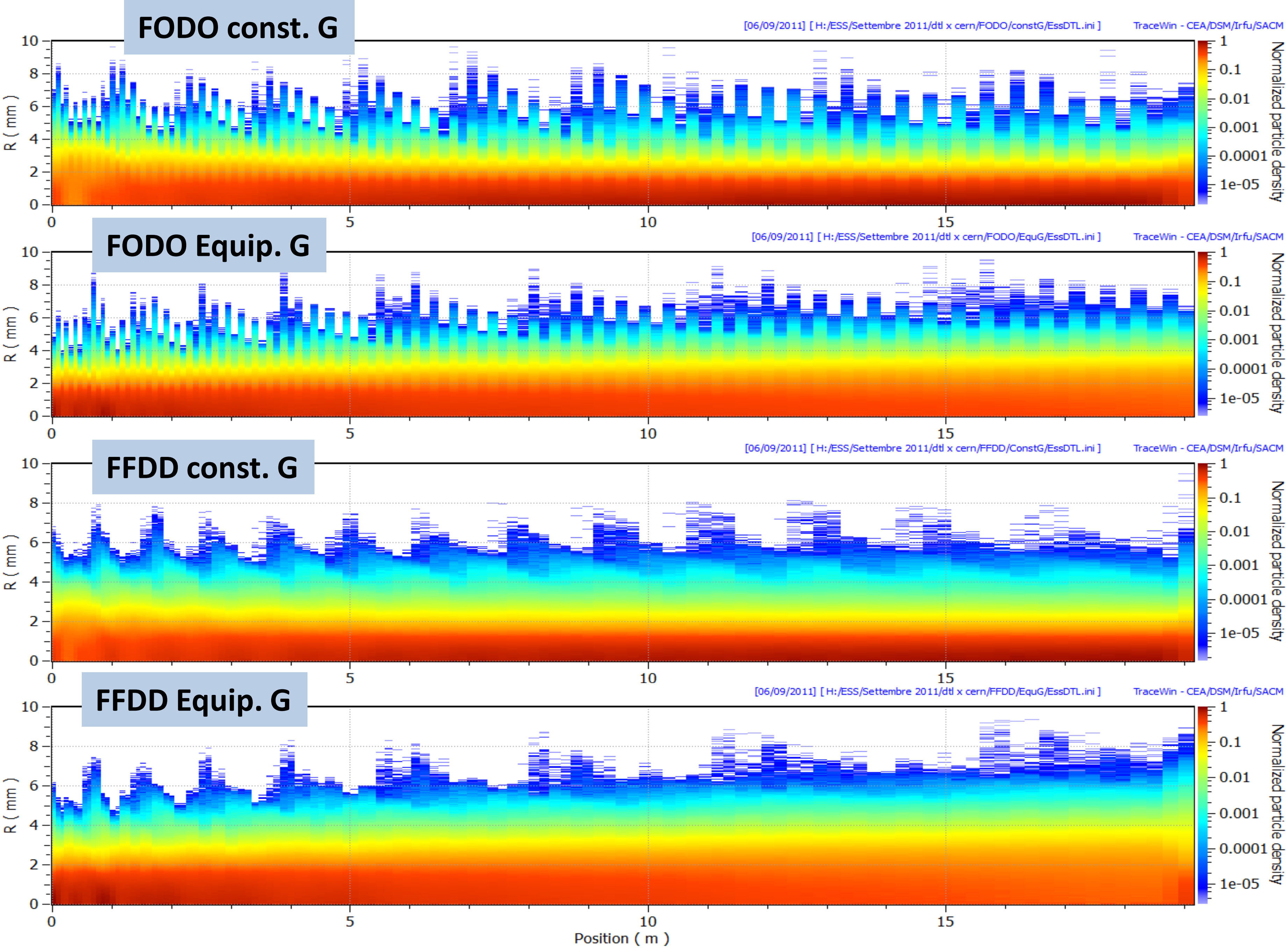
FFDD Equip. G
Position (m)


FODO const. G
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FODO Equip. G
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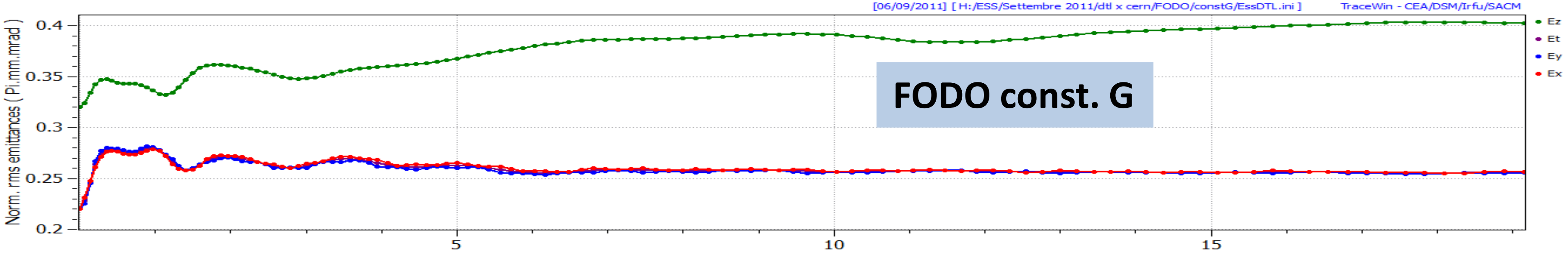
TraceWin - CEA/DSM/Irfu/SACM
FFDD const. G
[06/09/2011] [H:/ESS/Settembre 2011/dtl x cern/FFDD/ConstG/EssDTL.ini]
TraceWin - CEA/DSM/Irfu/SACM
FFDD Equip. G
[06/09/2011] [H:/ESS/Settembre 2011/dtl x cern/FFDD/EquG/EssDTL.ini]
TraceWin - CEA/DSM/Irfu/SACM
R (mm)
Position (m)
Normalized particle density
1
0.1
0.01
0.001
0.0001
1e-05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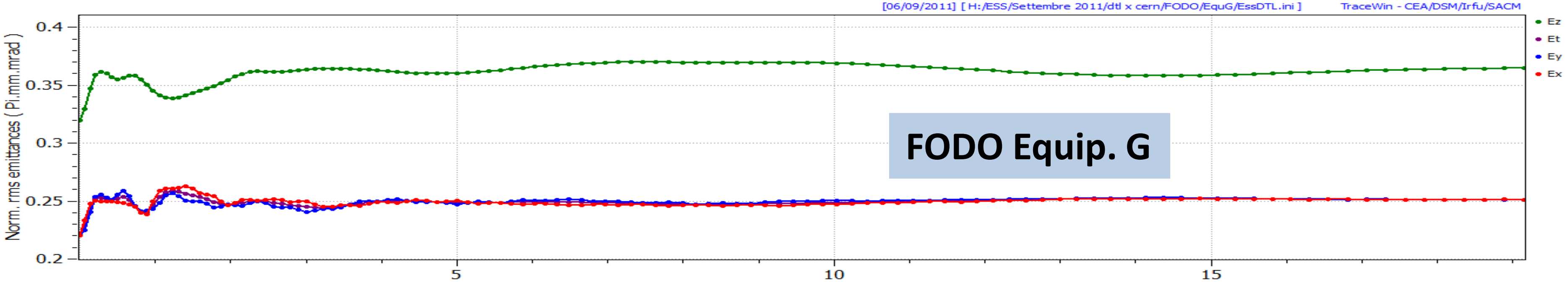
TraceWin - CEA/DSM/Irfu/SACM
Norm. rms emittances (Pi.mm.mrad)
Ez
Et
Ey
Ex
FODO const. G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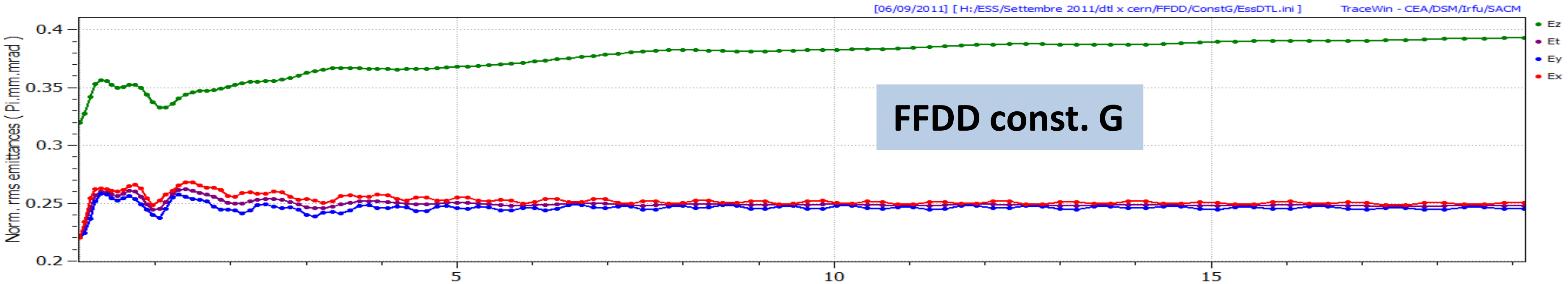
Norm. rms emittances (Pi.mm.mrad)
Ez
Et
Ey
Ex
FODO Equip. G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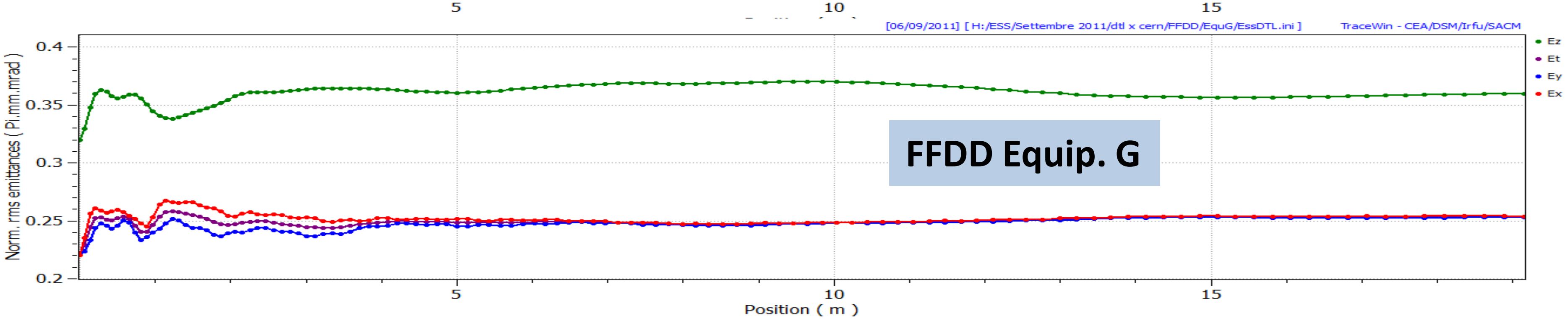
Ez
Et
Ey
Ex
FFDD const. G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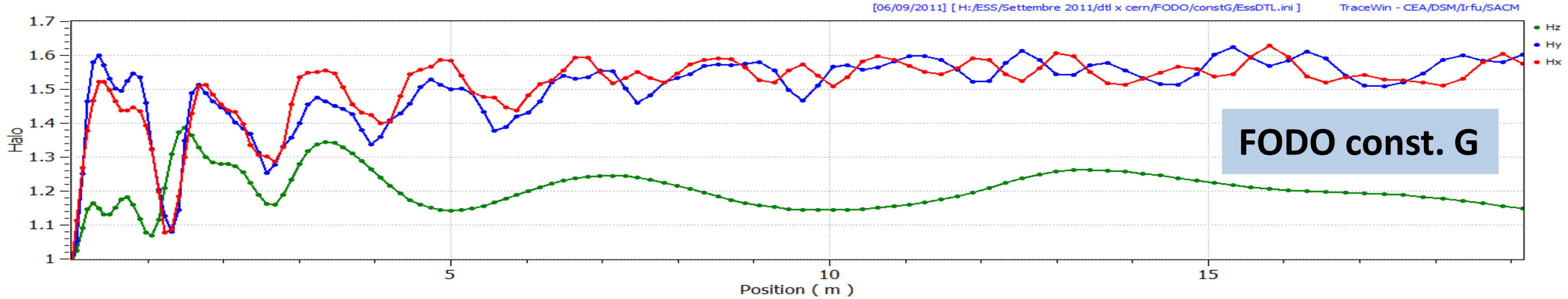
Ez
Et
Ey
Ex
FFDD Equip. G
Position (m)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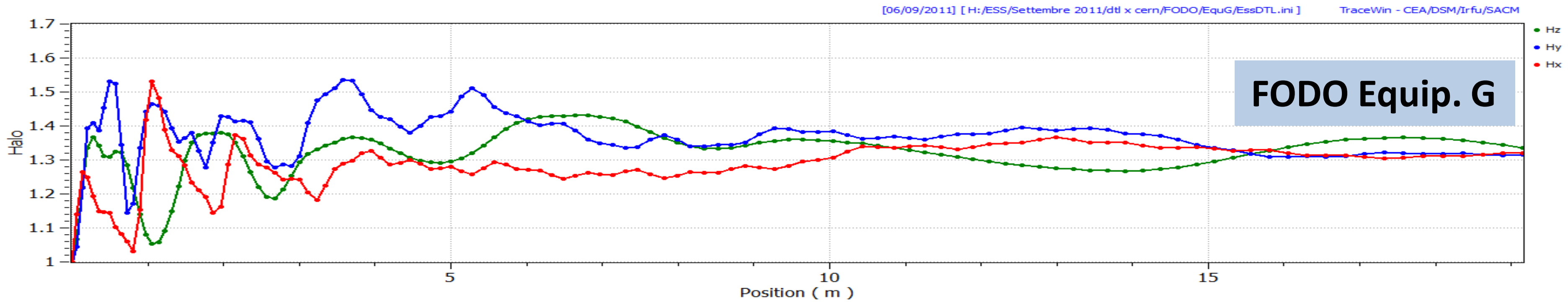
TraceWin - CEA/DSM/Irfu/SACM
FODO const. G
Halo
Position (m)
Hz
Hy
Hx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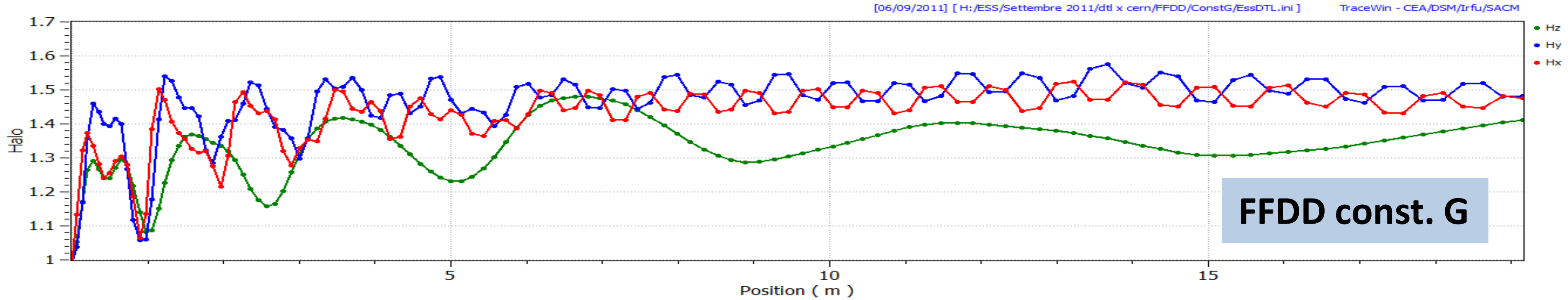
Halo
Position (m)
Hz
Hy
Hx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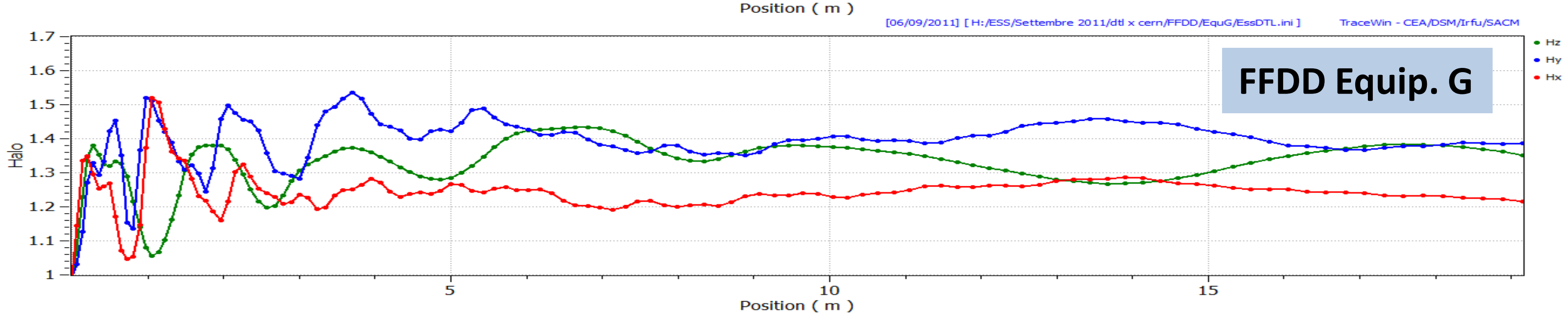
Halo
Position (m)
Hz
Hy
Hx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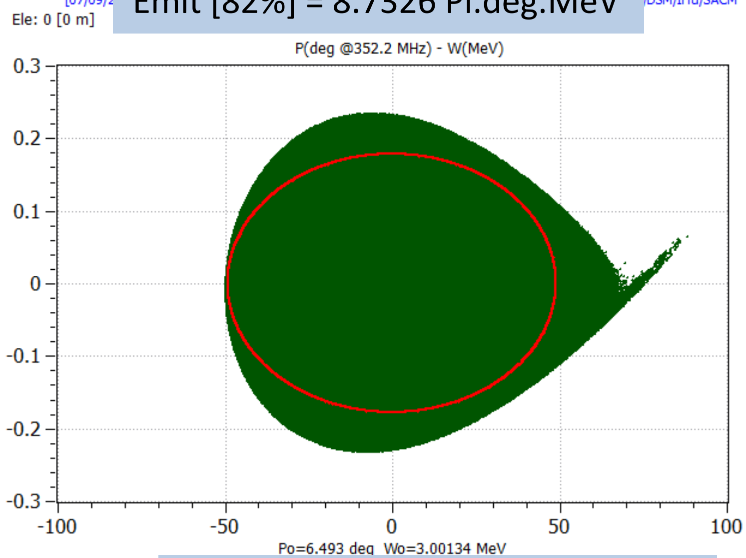
TraceWin - CEA/DSM/Irfu/SACM
FFDD Equip. G
Halo
Position (m)
Hz
Hy
Hx

Lattice	FODO Const. G	FODO Equip. G	FFDD Const. G	FFDD Equip. G
# PMQ	62	62	119	119
G PMQ [T/m]	54	72 - 31	45.5	51.5 - 22.5
Emit(x,y) increase [%]	16	14	13	15
Emit(z) increase [%]	26	14	23	13
Halo(x,y) increase [%]	59	32	48	30
Halo(z) increase [%]	14	34	41	35

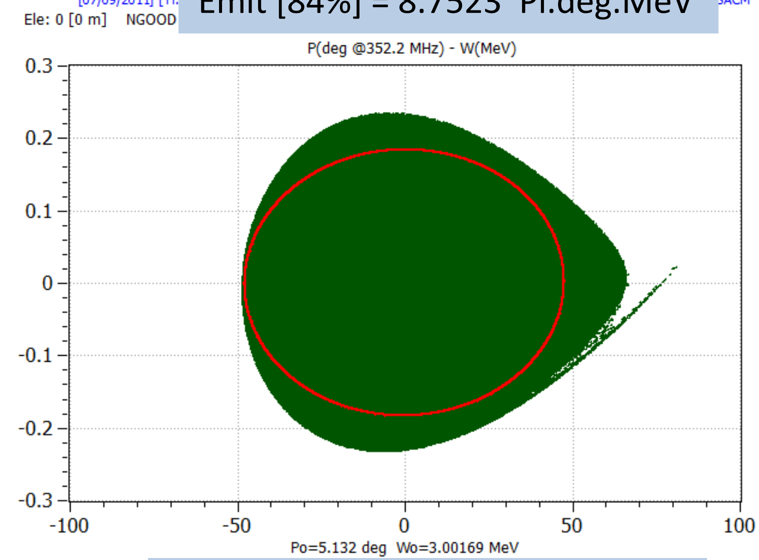
The Equipartitioned design show less emittance and halo increase.

Longitudinal Acceptance of the DTL

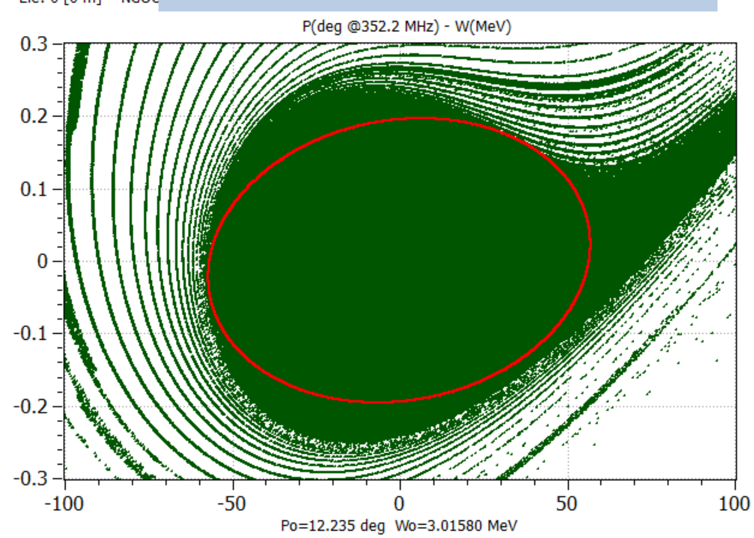
FODO const. G
Emit [82%] = 8.7326 Pi.deg.MeV



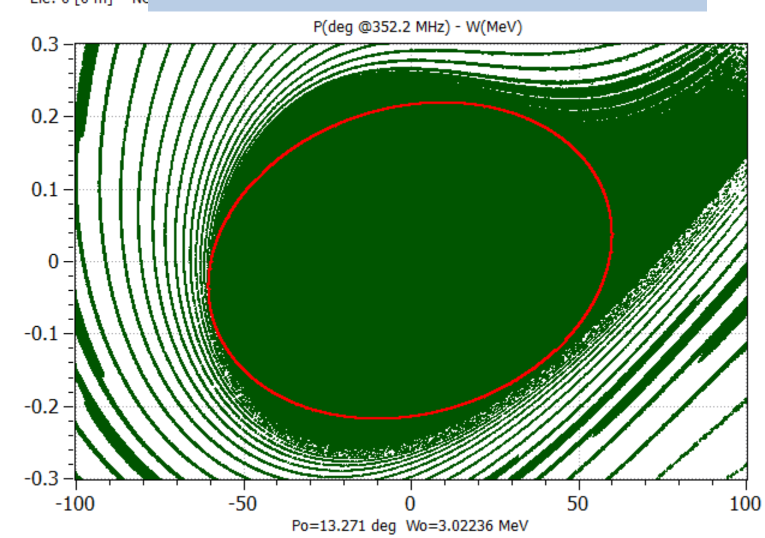
FFDD const. G
Emit [84%] = 8.7523 Pi.deg.MeV



FODO Equip. G
Emit [78%] = 11.1151 Pi.deg.MeV

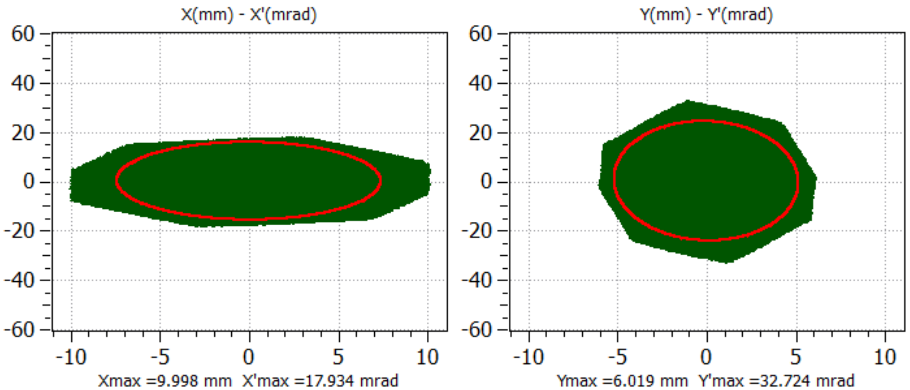


FFDD Equip. G
Emit [73%] = 12.9853 Pi.deg.MeV

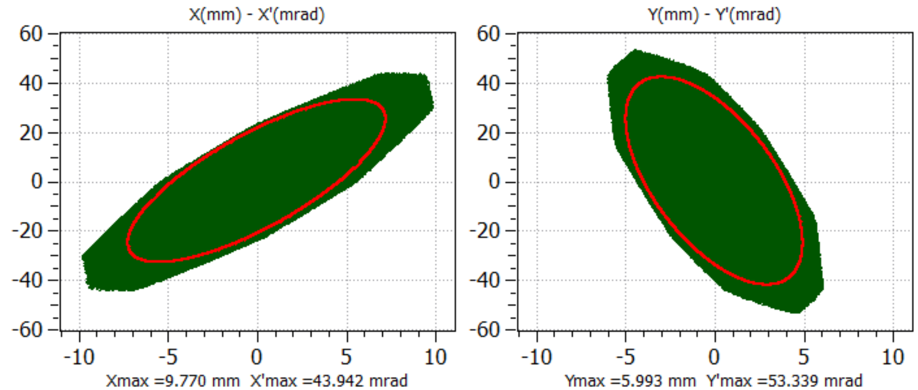


Transverse Acceptance of the DTL

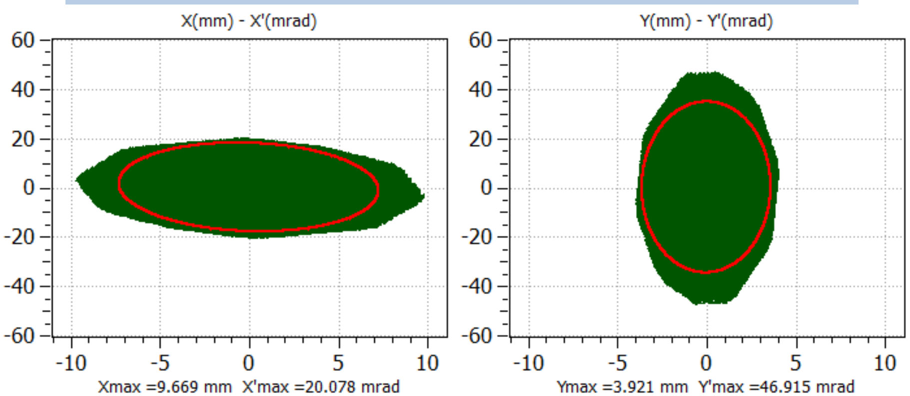
FODO Const. G
X-Xp Emit [82%] = 9.2989 Pi.mm.mrad [Norm.]



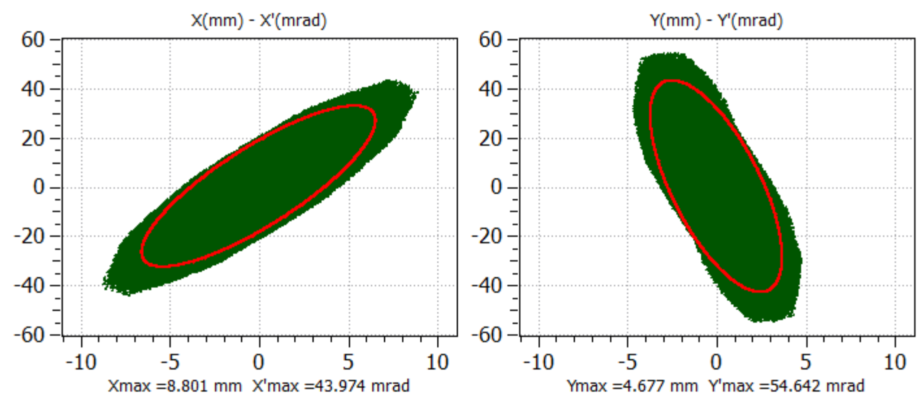
FFDD Const. G
X-Xp Emit [83%] = 12.3347 Pi.mm.mrad [Norm.]



FODO Equip. G
Y-Yp Emit [87%] = 10.0178 Pi.mm.mrad [Norm.]

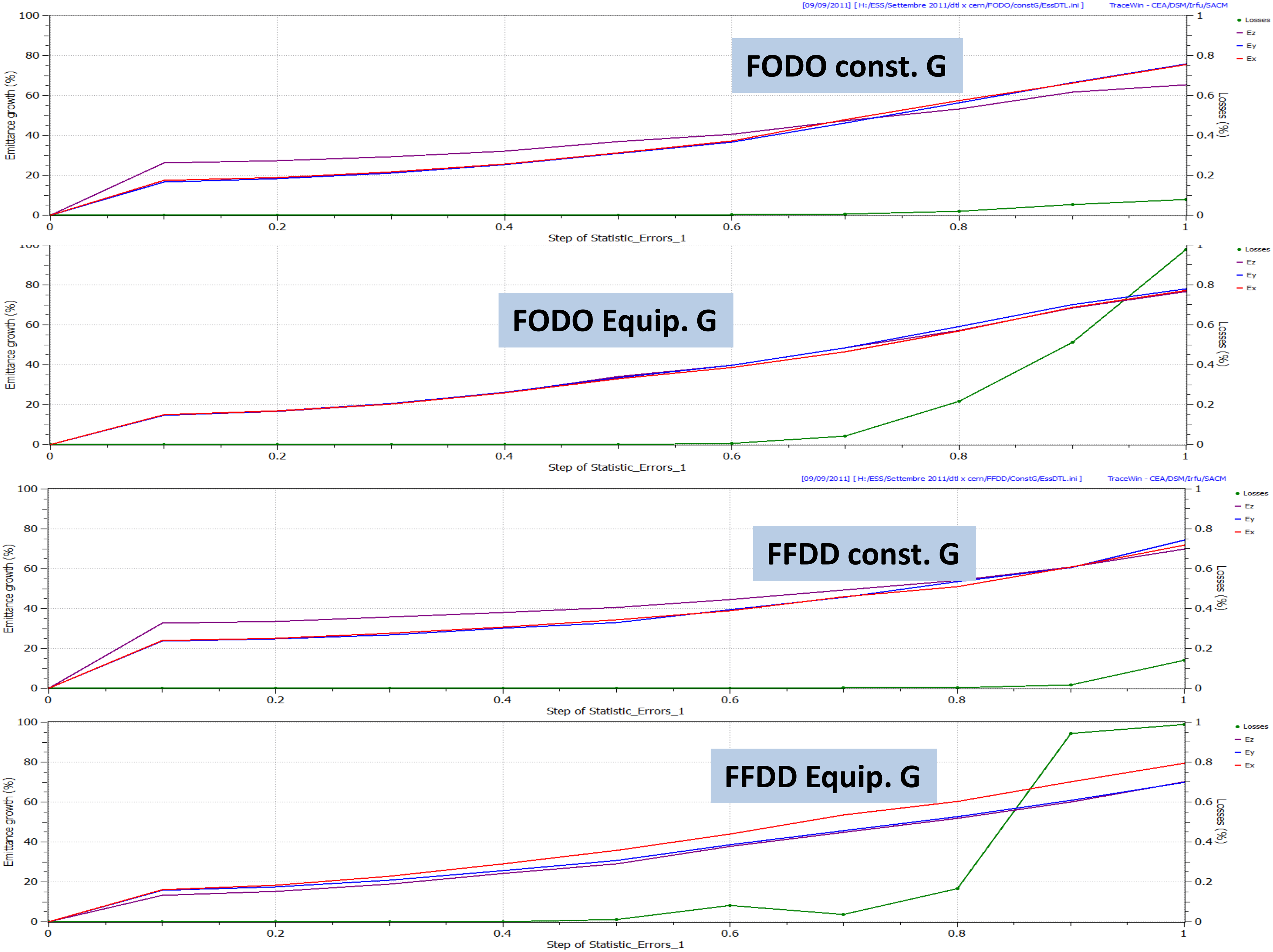


FFDD Equip. G
Y-Yp Emit [82%] = 9.4390 Pi.mm.mrad [Norm.]

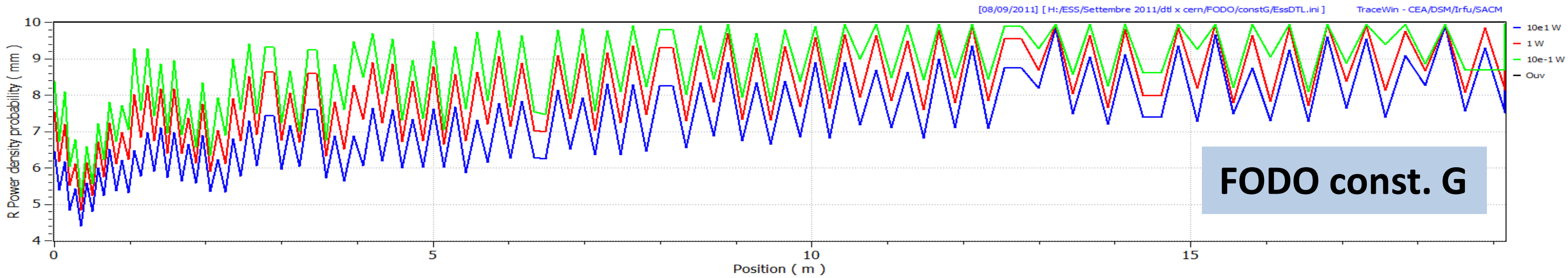


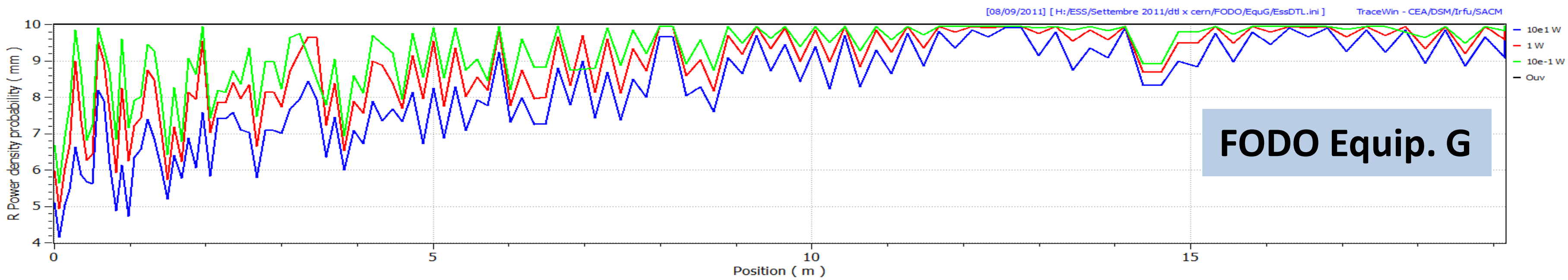
Errors study on the DTL example

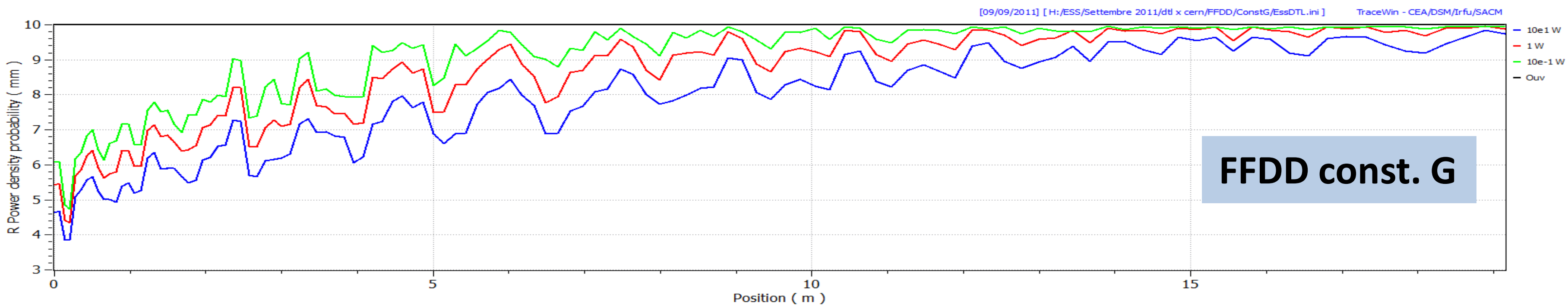
- Magnetic center respect the geometrical center shake of +/- 0.2 mm
- Yaw/pitch/Roll of +/-1°=17mrad
- Gradient error of +/-1%
- All errors apply together with a Gaussian input beam distribution
- 100 DTL generated.
- 10^5 particles i.e. 1.4 W for particles.

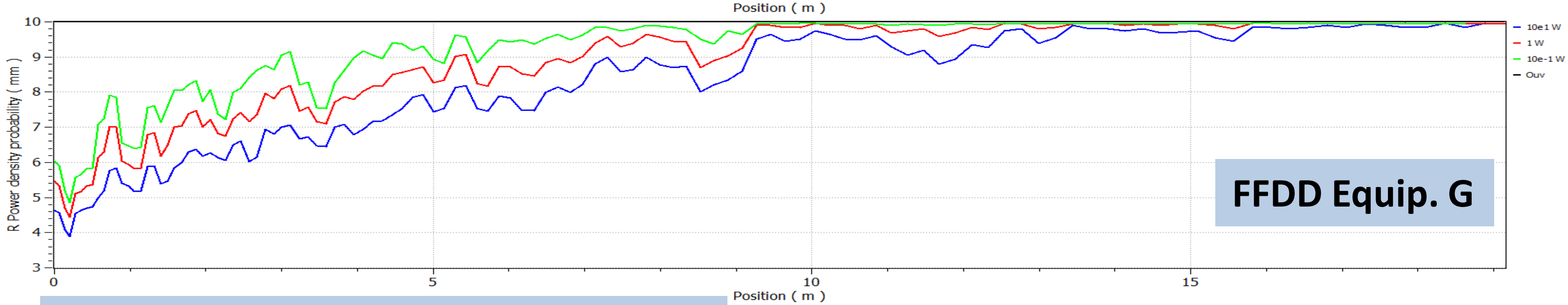


10^5 particles;10^2 DTL; Max Quad shake of X,Y ±0.2 mm; ±1°; ±1%

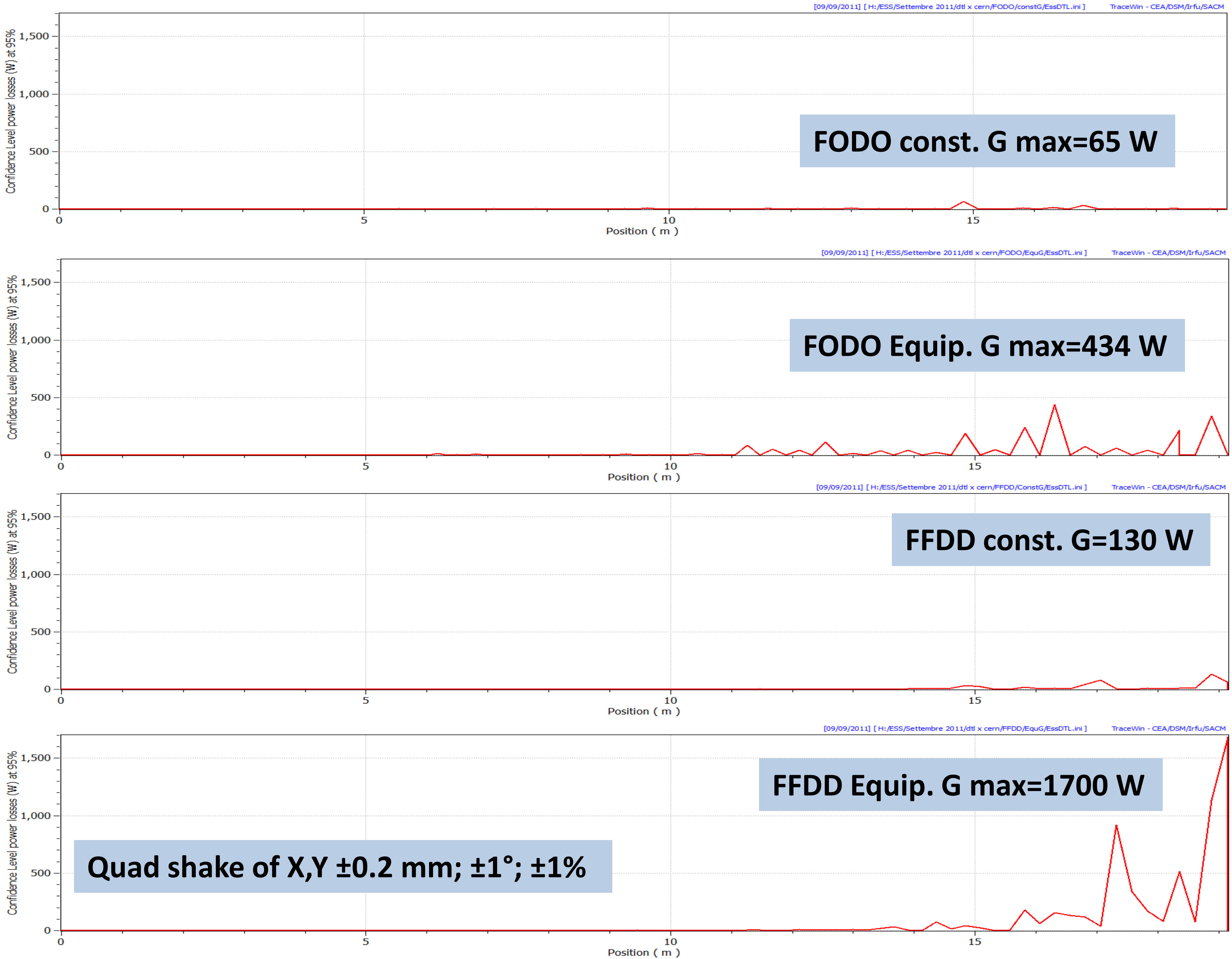








Quad shake of X,Y ±0.2 mm; ±1°; ±1%


[09/09/2011] [H:/ESS/Settembre 2011/dtl x cern/FODO/constG/EssDTL.ini]
TraceWin - CEA/DSM/Irfu/SACM
Confidence Level power losses (W) at 95%
Position (m)
FODO const. G max=65 W
[09/09/2011] [H:/ESS/Settembre 2011/dtl x cern/FODO/EquG/EssDTL.ini]
FODO Equip. G max=434 W
[09/09/2011] [H:/ESS/Settembre 2011/dtl x cern/FFDD/ConstG/EssDTL.ini]
FFDD const. G=130 W
[09/09/2011] [H:/ESS/Settembre 2011/dtl x cern/FFDD/EquG/EssDTL.ini]
FFDD Equip. G max=1700 W
Quad shake of X,Y ±0.2 mm; ±1°; ±1%

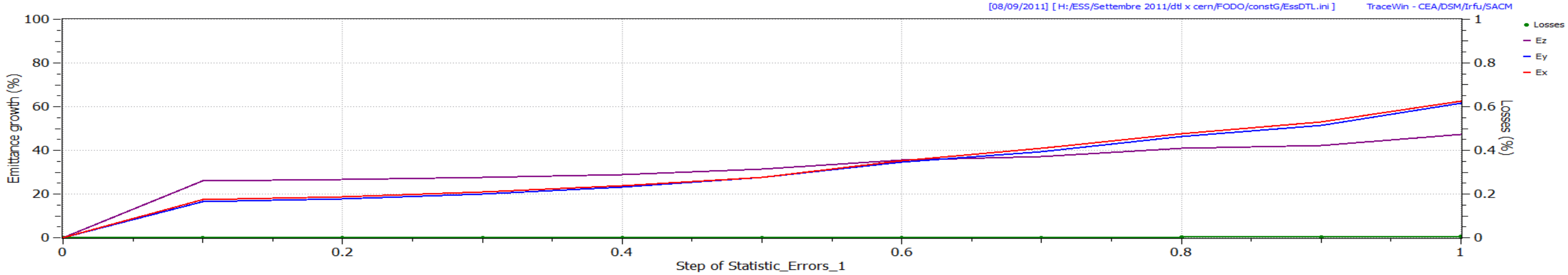
Steerers on FODO Lattice

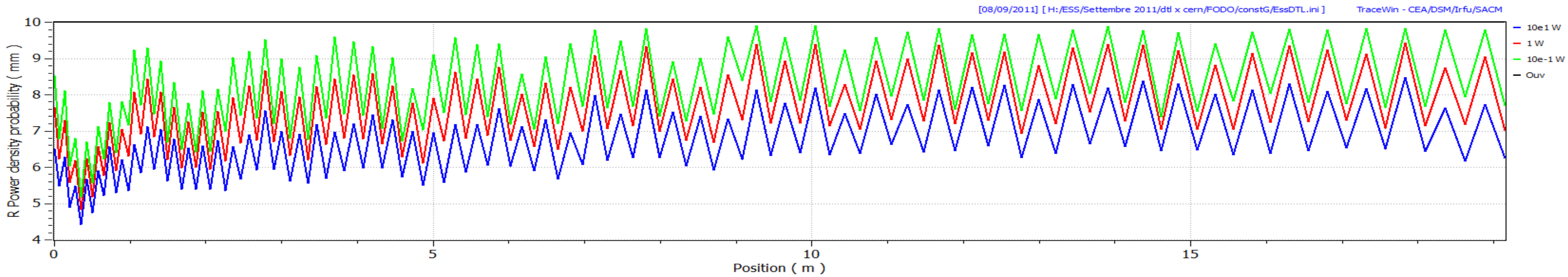
- Using the empty space it has been put steerers X;Y almost at 90° phase advance apart for tank and 2 BPMs.

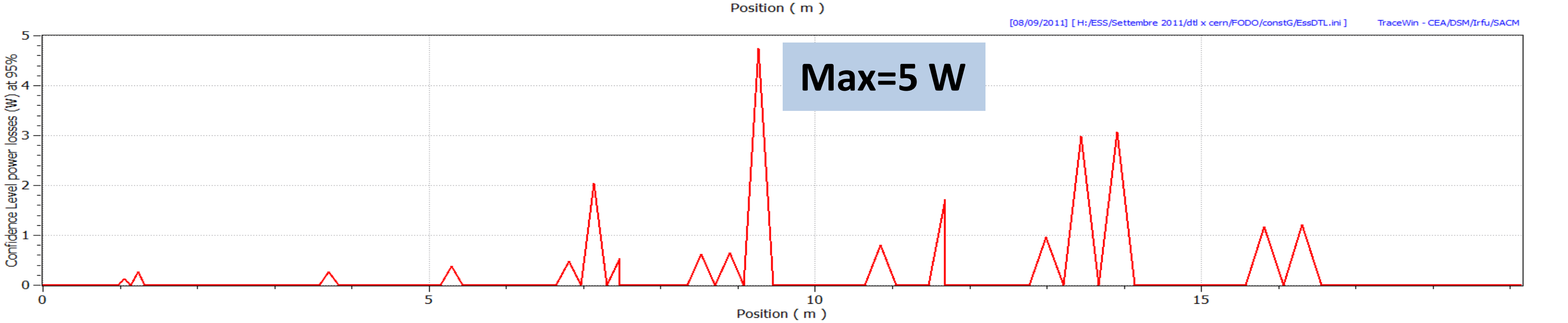
8 Steerers for tank1

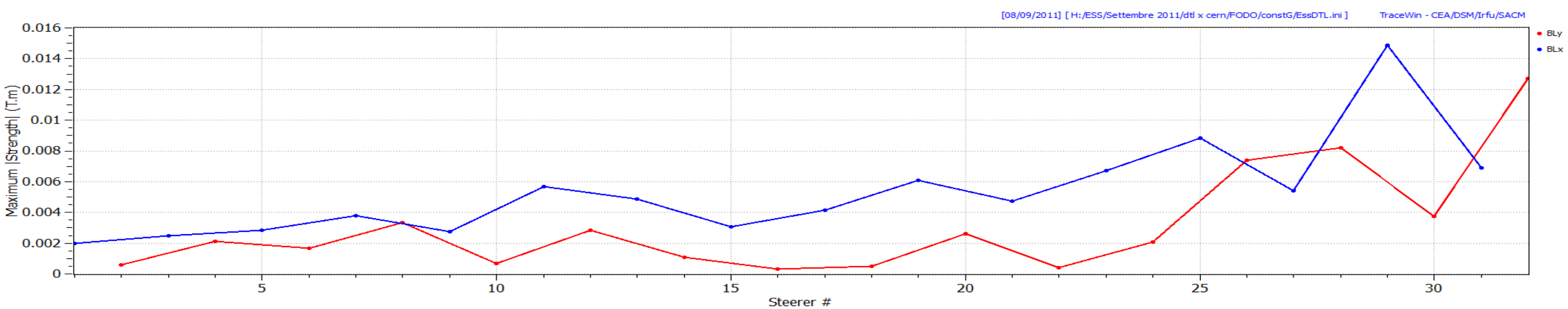
4 steerers for tank 2 and 3

```
adjust_steerer 1
steerer 0 0
DTL_CEL 69.538  22.5  22.5 0  0 -54 124959.2 -40.47  10 0 0.08099 0.79522 -0.35473 -0.15947
DTL_CEL 70.592  22.5  22.5 0 -54  0 127928.9 -40.04  10 0 0.08221 0.79848 -0.34964 -0.15932
DTL_CEL 71.661  22.5  22.5 0  0  54 130968.8 -39.62  10 0 0.08346 0.80172 -0.34458 -0.15917
DTL_CEL 72.745  22.5  22.5 0  54  0 134080.2 -39.20  10 0 0.08472 0.80494 -0.33954 -0.15901
adjust_steerer 1
steerer 0 0
DTL_CEL 73.845  22.5  22.5 0  0 -54 137264.3 -38.78  10 0 0.08601 0.80814 -0.33454 -0.15884
DTL_CEL 74.960  22.5  22.5 0 -54  0 140522.2 -38.36  10 0 0.08730 0.81132 -0.32957 -0.15868
DTL_CEL 76.091  22.5  22.5 0  0  54 143855.3 -37.94  10 0 0.08862 0.81447 -0.32465 -0.15850
DTL_CEL 77.237  22.5  22.5 0  54  0 147264.7 -37.53  10 0 0.08996 0.81759 -0.31976 -0.15833
adjust_steerer 1
steerer 0 0
DTL_CEL 78.399  22.5  22.5 0  0 -54 150751.5 -37.11  10 0 0.09131 0.82069 -0.31491 -0.15815
DTL_CEL 79.577  22.5  22.5 0 -54  0 154317.1 -36.70  10 0 0.09269 0.82375 -0.31012 -0.15796
DTL_CEL 80.771  22.5  22.5 0  0  54 157962.5 -36.29  10 0 0.09408 0.82678 -0.30537 -0.15777
DTL_CEL 81.980  22.5  22.5 0  54  0 161689.0 -35.89  10 0 0.09549 0.82978 -0.30067 -0.15758
adjust_steerer 1
steerer 0 0
DTL_CEL 83.206  22.5  22.5 0  0 -54 165497.7 -35.49  10 0 0.09692 0.83274 -0.29604 -0.15739
DTL_CEL 84.447  22.5  22.5 0 -54  0 169389.7 -35.09  10 0 0.09837 0.83566 -0.29146 -0.15720
DTL_CEL 85.705  22.5  22.5 0  0  54 173366.2 -34.69  10 0 0.09984 0.83854 -0.28694 -0.15700
DTL_CEL 86.979  22.5  22.5 0  54  0 177428.2 -34.29  10 0 0.10132 0.84137 -0.28249 -0.15680
DTL_CEL 88.269  22.5  22.5 0  0 -54 181577.0 -33.90  10 0 0.10283 0.84417 -0.27811 -0.15660
DTL_CEL 89.575  22.5  22.5 0 -54  0 185813.5 -33.51  10 0 0.10435 0.84691 -0.27380 -0.15641
DTL_CEL 90.897  22.5  22.5 0  0  54 190138.9 -33.13  10 0 0.10589 0.84961 -0.26956 -0.15621
DTL_CEL 92.235  22.5  22.5 0  54  0 194554.1 -32.74  10 0 0.10746 0.85226 -0.26541 -0.15601
DTL_CEL 93.590  22.5  22.5 0  0 -54 199060.2 -32.37  10 0 0.10904 0.85486 -0.26133 -0.15582
DTL_CEL 94.961  22.5  22.5 0 -54  0 203658.2 -31.99  10 0 0.11064 0.85740 -0.25733 -0.15563
DTL_CEL 96.348  22.5  22.5 0  0  54 208349.1 -31.62  10 0 0.11226 0.85989 -0.25343 -0.15544
DTL_CEL 97.752  22.5  22.5 0  54  0 213133.8 -31.25  10 0 0.11390 0.86232 -0.24961 -0.15525
DTL_CEL 99.171  22.5  22.5 0  0 -54 218013.3 -30.88  10 0 0.11555 0.86469 -0.24588 -0.15507
DTL_CEL 100.607  22.5  22.5 0 -54  0 222988.5 -30.52  10 0 0.11723 0.86700 -0.24225 -0.15490
DTL_CEL 102.060  22.5  22.5 0  0  54 228060.3 -30.16  10 0 0.11893 0.86925 -0.23872 -0.15473
DTL_CEL 103.528  22.5  22.5 0  54  0 233229.5 -29.81  10 0 0.12064 0.87143 -0.23529 -0.15457
diag_position 1 0 0 0.05
DTL_CEL 105.013  22.5  22.5 0  0 -54 238496.9 -29.46  10 0 0.12238 0.87355 -0.23196 -0.15442
DTL_CEL 106.513  22.5  22.5 0 -54  0 243863.4 -29.11  10 0 0.12413 0.87561 -0.22873 -0.15427
DTL_CEL 108.030  22.5  22.5 0  0  54 249329.8 -28.77  10 0 0.12590 0.87759 -0.22561 -0.15414
DTL_CEL 109.563  22.5  22.5 0  54  0 254896.7 -28.43  10 0 0.12769 0.87951 -0.22261 -0.15402
DTL_CEL 111.113  22.5  22.5 0  0 -54 260564.9 -28.09  10 0 0.12950 0.88135 -0.21971 -0.15391
DTL_CEL 112.678  22.5  22.5 0 -54  0 266335.1 -27.76  10 0 0.13133 0.88312 -0.21693 -0.15381
DTL_CEL 114.259  22.5  22.5 0  0  54 272208.0 -27.43  10 0 0.13318 0.88482 -0.21427 -0.15373
DTL_CEL 115.856  22.5  22.5 0  54  0 278184.1 -27.11  10 0 0.13505 0.88645 -0.21173 -0.15366
diag_position 1 0 0 0.05
DTL_CEL 117.469  22.5  22.5 0  0 -54 284264.2 -26.79  10 0 0.13693 0.88800 -0.20930 -0.15361
DTL_CEL 119.098  22.5  22.5 0 -54  0 290448.7 -26.47  10 0 0.13884 0.88947 -0.20700 -0.15358
DTL_CEL 120.743  22.5  22.5 0  0  54 296738.2 -26.16  10 0 0.14076 0.89087 -0.20483 -0.15357
```

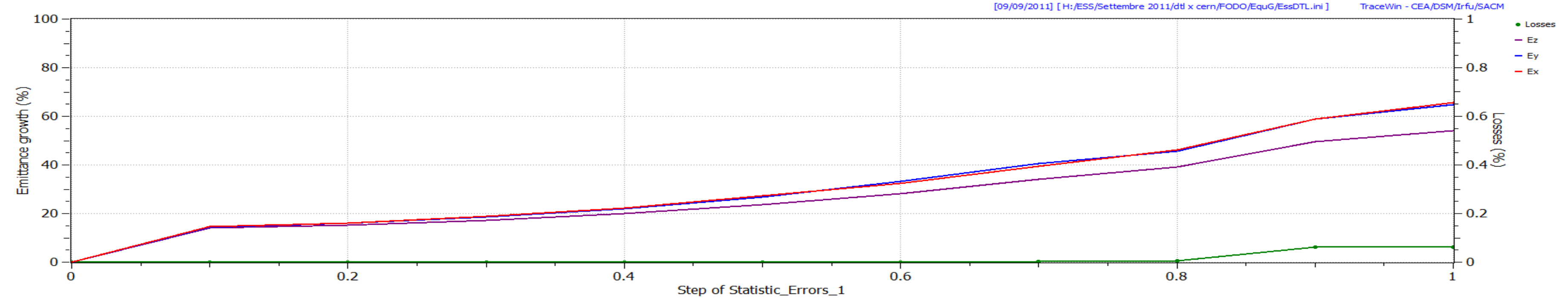


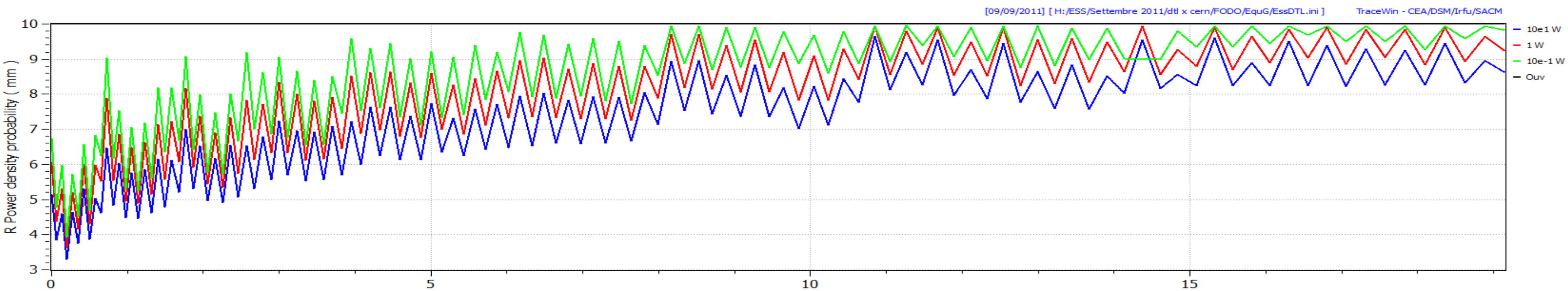


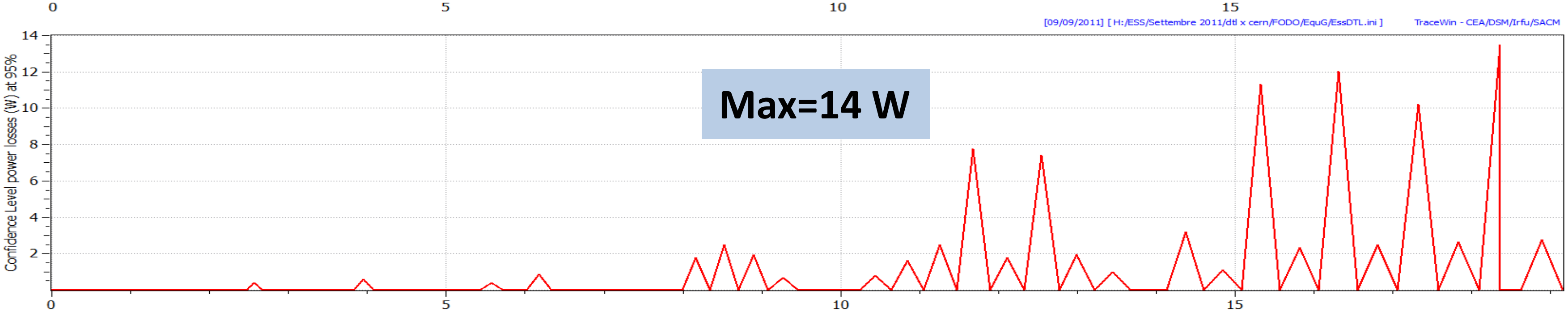


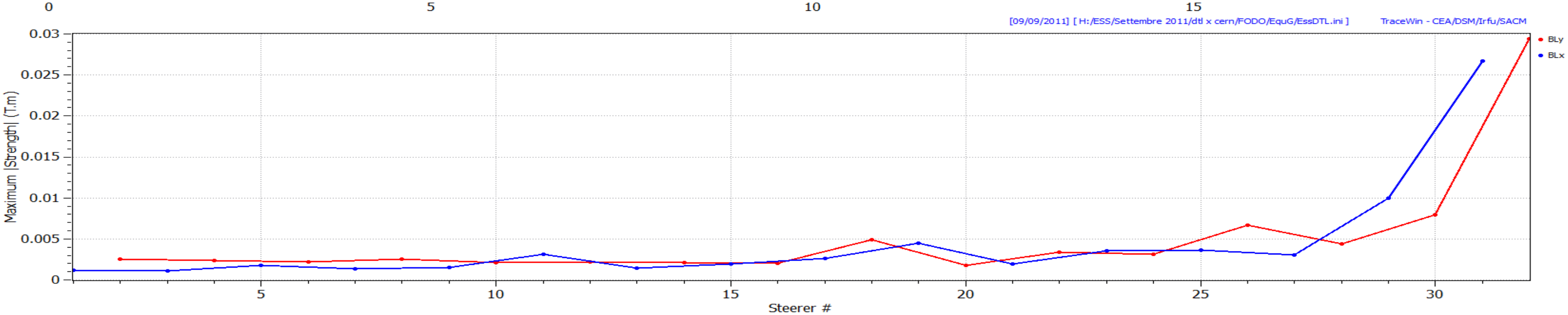


FODO const. G with 32 steerers









FODO Equip. G with 32 steerers

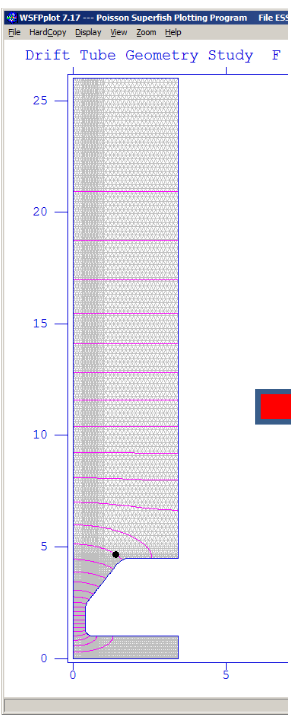
Conclusion on DTL example

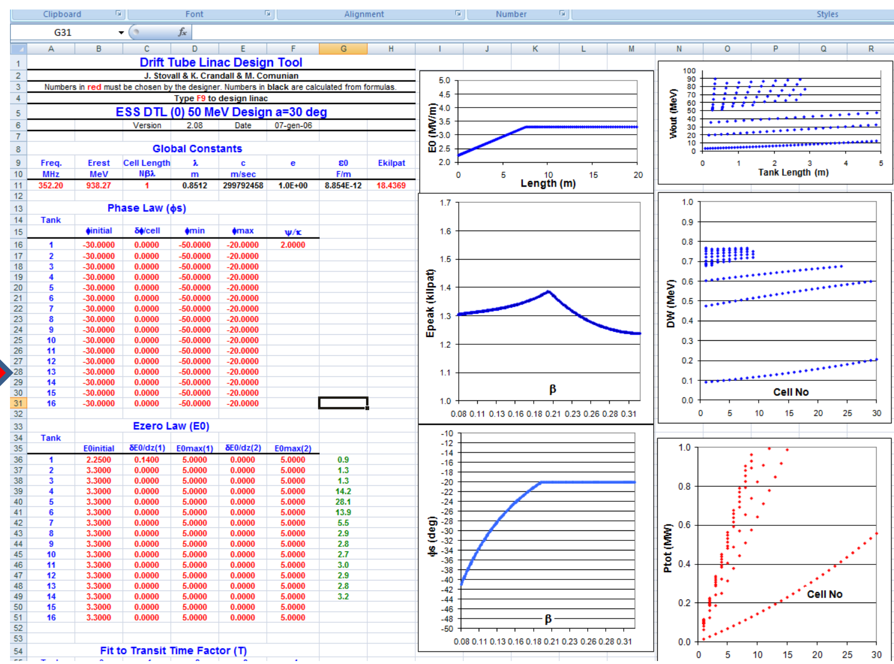
- FFDD and FODO almost same PMQ grad.
- FFDD better output emittance.
- Constant Grad. more “robust” respects to errors.
- FODO more flexible and at lower cost.
- Steerers on FODO reduce the losses by 1 order of magnitude.
- A possible solution with PMQ G=54 T/m -> as Linac4 DTL tender.
- Space for steerers and BPM -> low tolerance on PMQ and reduced intertank distance.
- No problem by losses -> low tolerance on PMQ.

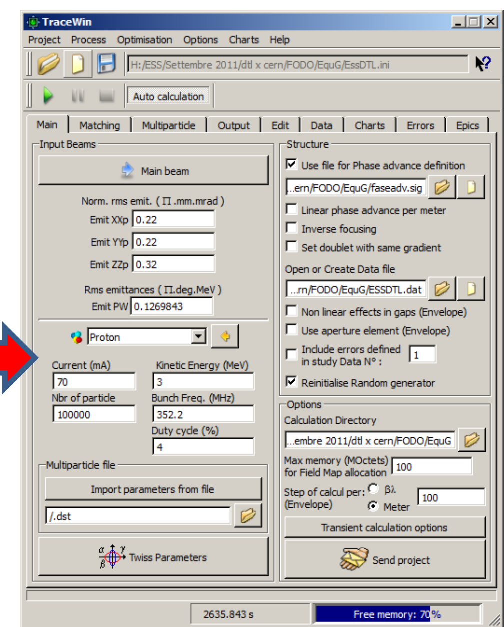
Thank you!

Design Method

- **DTLFISH**: design and optimization of the DTL shape from 3 to 50 MeV.
- **Worksheet**: import of DTLFISH data and fit cell by cell.
- **Worksheet** : Synch. Phase, PMQ, Lattice and E0, Es Fields design.
- **Worksheet** : data for TraceWin cell by cell, including TTF' and TTF''.
- **TraceWin**: Phase advance design and input matched conditions.
- **TraceWin**: Errors study.

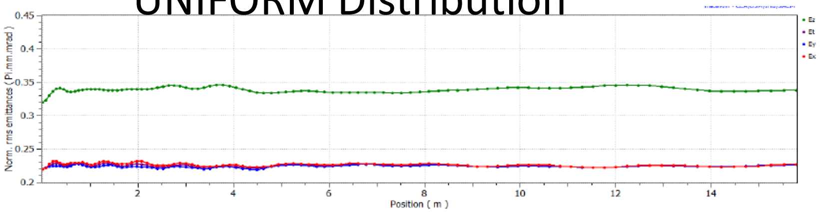




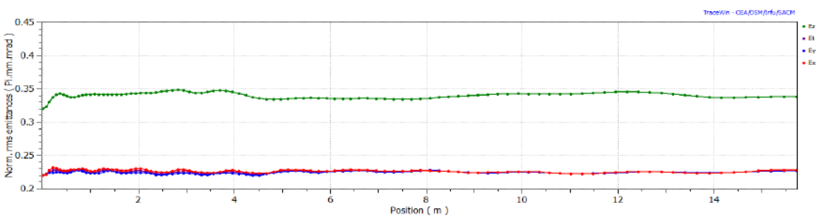


Emittance evolution on the DTL

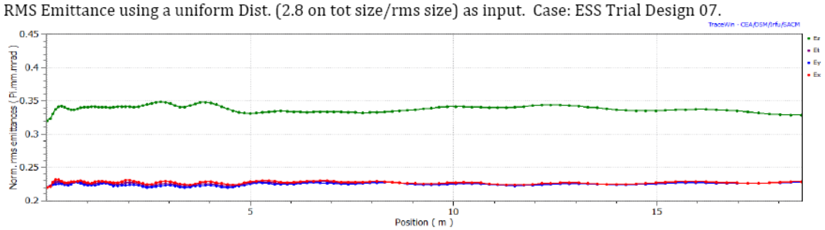
UNIFORM Distribution



RMS Emittance using a uniform Dist. (2.8 on tot size/rms size) as input. Case: ESS Trial Design 05.

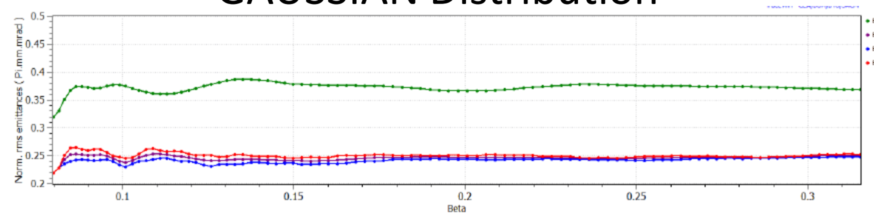


RMS Emittance using a uniform Dist. (2.8 on tot size/rms size) as input. Case: ESS Trial Design 07.

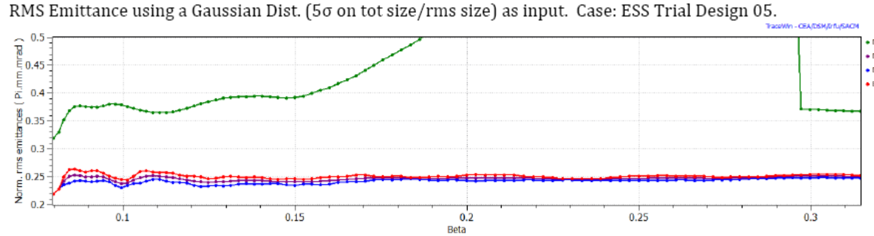


RMS Emittance using a uniform Dist. (2.8 on tot size/rms size) as input. Case: ESS Trial Design 08.

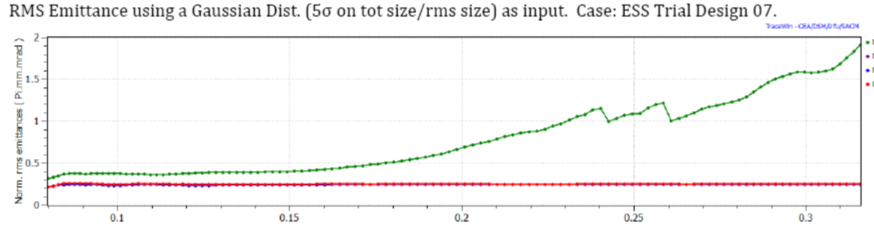
GAUSSIAN Distribution



RMS Emittance using a Gaussian Dist. (5σ on tot size/rms size) as input. Case: ESS Trial Design 05.



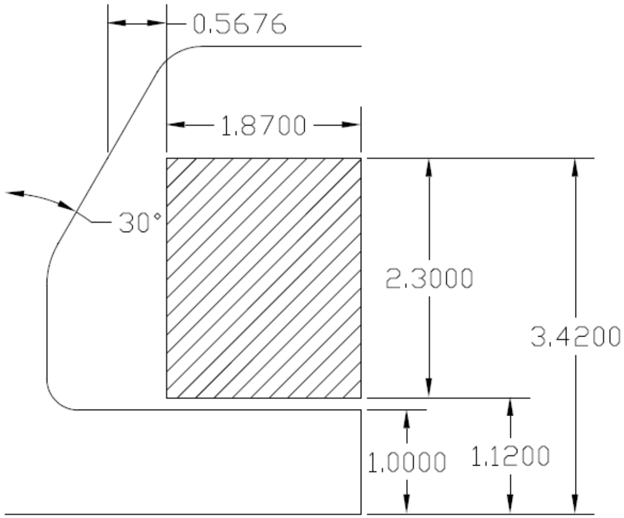
RMS Emittance using a Gaussian Dist. (5σ on tot size/rms size) as input. Case: ESS Trial Design 07.



RMS Emittance using a Gaussian Dist. (5σ on tot size/rms size) as input. Case: ESS Trial Design 08.

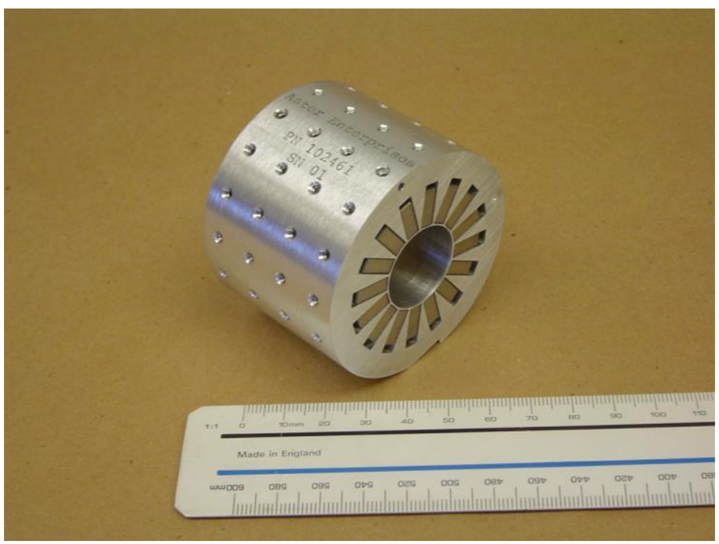
The emittance increase depend from the input beam distribution

PMQ



First DTL Cell

- Difficult to housing the Quad on the first DTL cell.
- The least expensive type has rectangular PM pieces.
- The most performing is the Bullet shape.
- Field clamp?
- Bore aperture ID?
- PMQ tolerance!!!

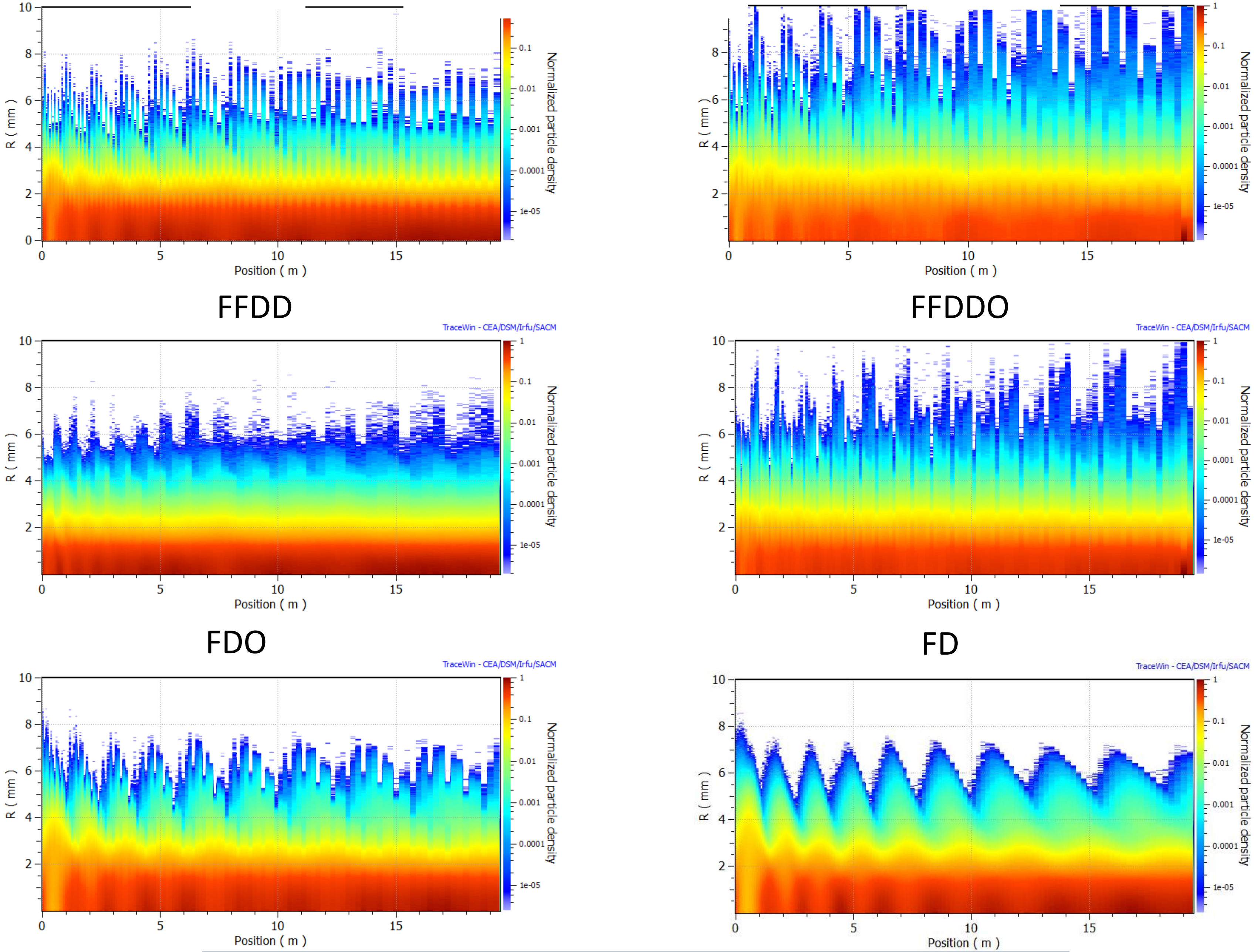


CERN Linac4
ID=22 mm
L=45 mm
Gmax=54 T/m

SNS	**PL-7**
ID=25.4 mm	ID=12.7 mm
L =35 mm	L =25.4 mm
G =36 T/m	G =175 T/m

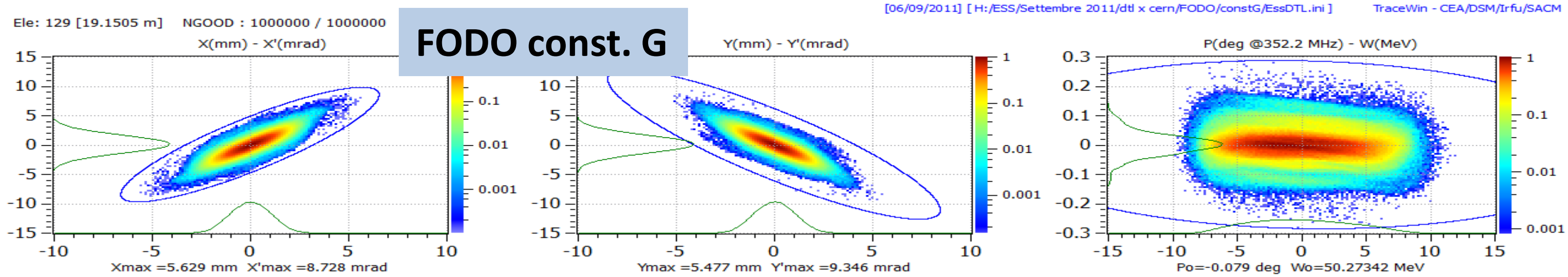
LATTICE DESIGN

FODO FFODDO

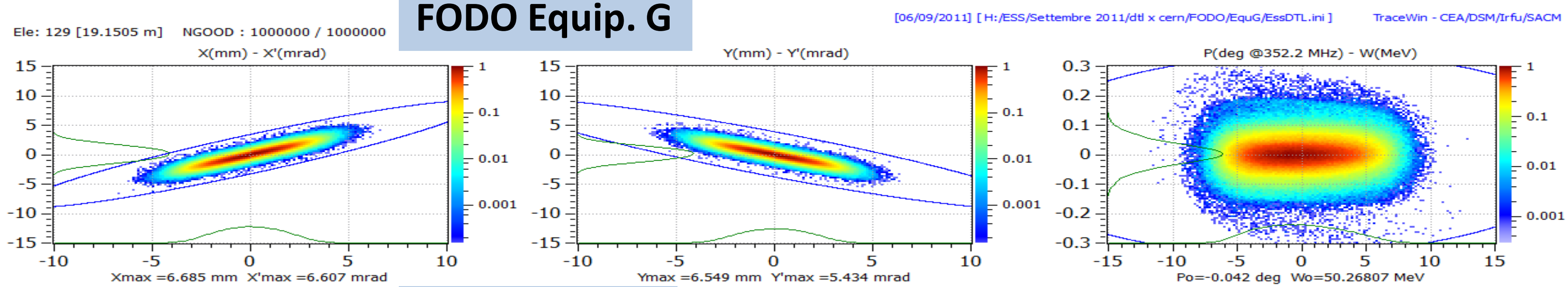


Particles density plot for different focusing scheme along the DTL

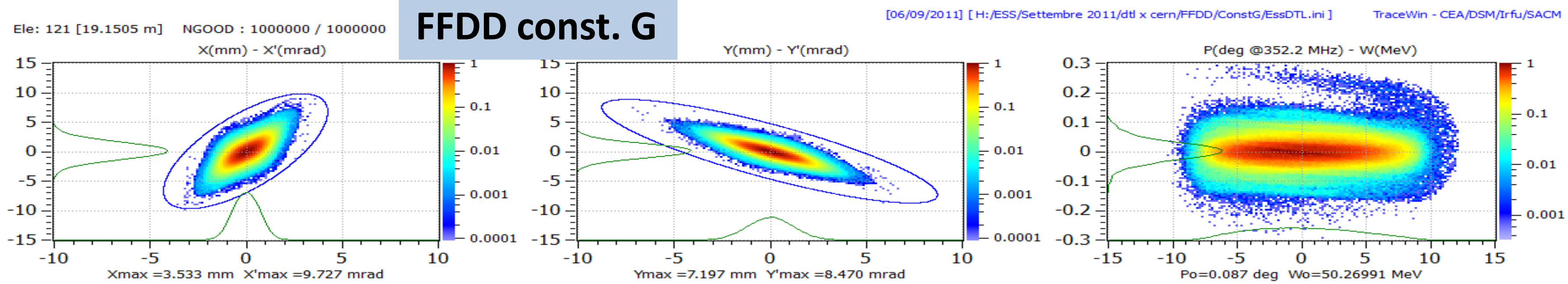
FODO const. G



FODO Equip. G



FFDD const. G



FFDD Equip. G