BENCHMARKING OF PATH AND RF-TRACK IN THE SIMULATION OF LINAC4

G Bellodi, J-B Lallement, A Latina, A M Lombardi, CERN

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A campaign started a few months ago to apply RF-Track to Linac4 modelling and compare with official simulation results obtained with PATH.

Main motivations:

1. Extend RF-Track functionalities and bridge the gap between electrons and ions ;
2. Make Linac4 simulations available with a modern code, easily accessible from Octave/Python user interface.

Adopted test-cases: Linac4 RFQ and accelerating cavities , comparing RF-Track to PATH simulation results which were reference for the design and commissioning of Linac4

LINAC4 machine layout- 352MHz				
Pre-injector (9m)		DTL (19m)	CCDTL (25m)	Π-mode (23m)
3MeV		50 MeV	100 MeV	160 MeV
SOURCE Plasma Generator Extraction e-Dump LEBT 2 solenoids Pre chopper	RFQ CHOPPER LINE 11 EMQ 3 Cavitis 2 Chopper units In-line dump	3 Tanks 3 Klystrons : 5 MW 1 EMQ 114 PMQ 2 steerers	7 Modules 7 Klystrons : 7 MW 7 EMQ + 14 PMQ 7 steerers	12 Modules 8 Klystrons: 12MW 12 EMQ 12 steerer

PATH/Travel

Tracking in *space*.

SCHEFF algorithm for space charge calculations in 2D rings of charge approximation, with linear interpolation of the electric field calculated at the 4 adjacent mesh vertices (radial and longitudinal mesh mapping the beam ellipsoid with user defined step sizes). The force acting on the particle is then transformed back to lab frame.

RF-Track (A. Latina→ WEA3C1)

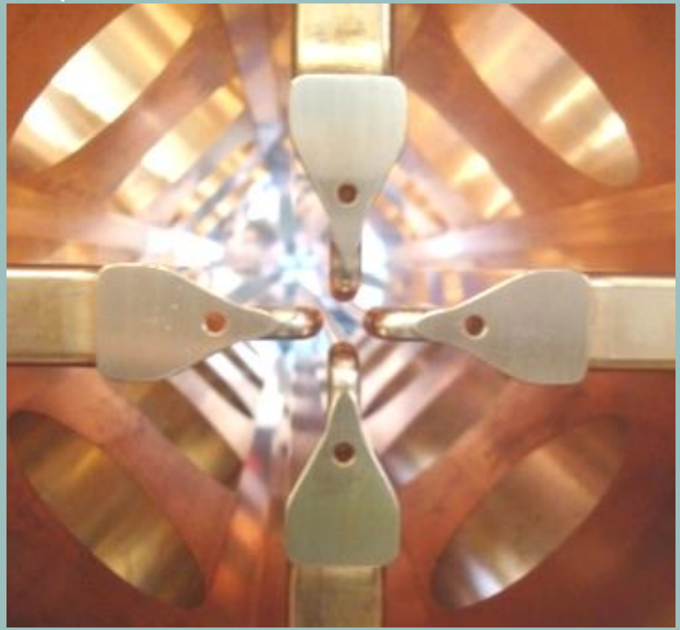
Tracking in *space* and *time*, the latter preferred in high space charge regimes.

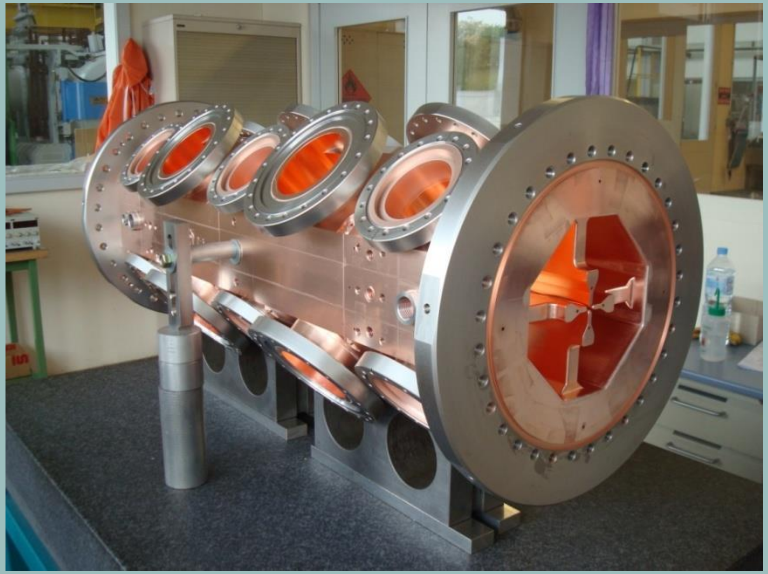
Solves 3D Maxwell's equations for electric-scalar and magnetic-vector potentials via cloud-on-cell method based on integrated Green's functions. No particular beam symmetry is assumed.

RFQ: first accelerating structure (45keV→ 3MeV)

4 vanes, 3m length (3x1m modules)
Entire in-house fabrication (2009-2012)

Parameter	Value	Unit
Operating frequency	352.2	MHz
Inter-vane Voltage	78	kV
Kilpatrick factor	1.84	-
Unloaded Quality factor	6700	-
Cavity Coupling factor □□□without beam)	1.59	-
Total dissipated RF Power (without beam)	390	kW

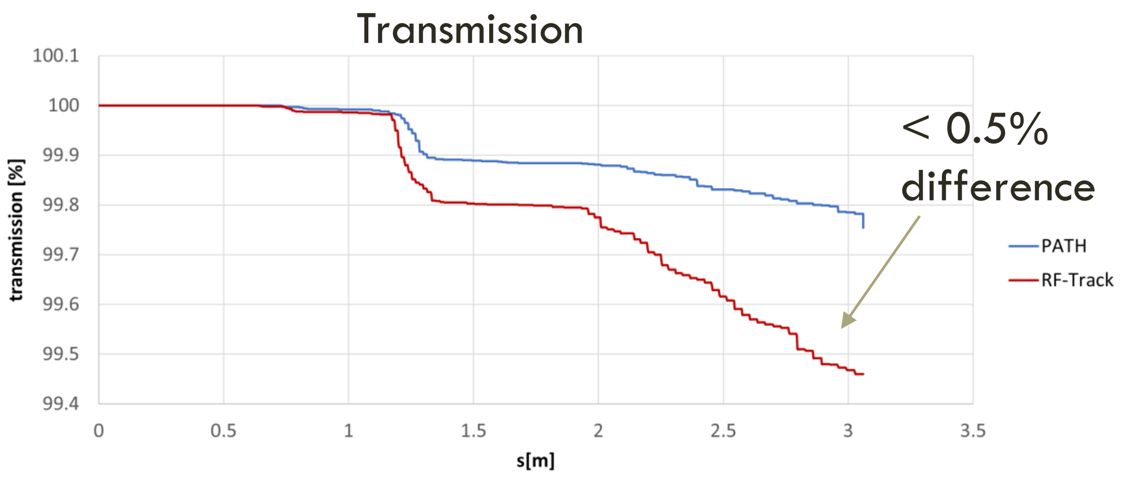




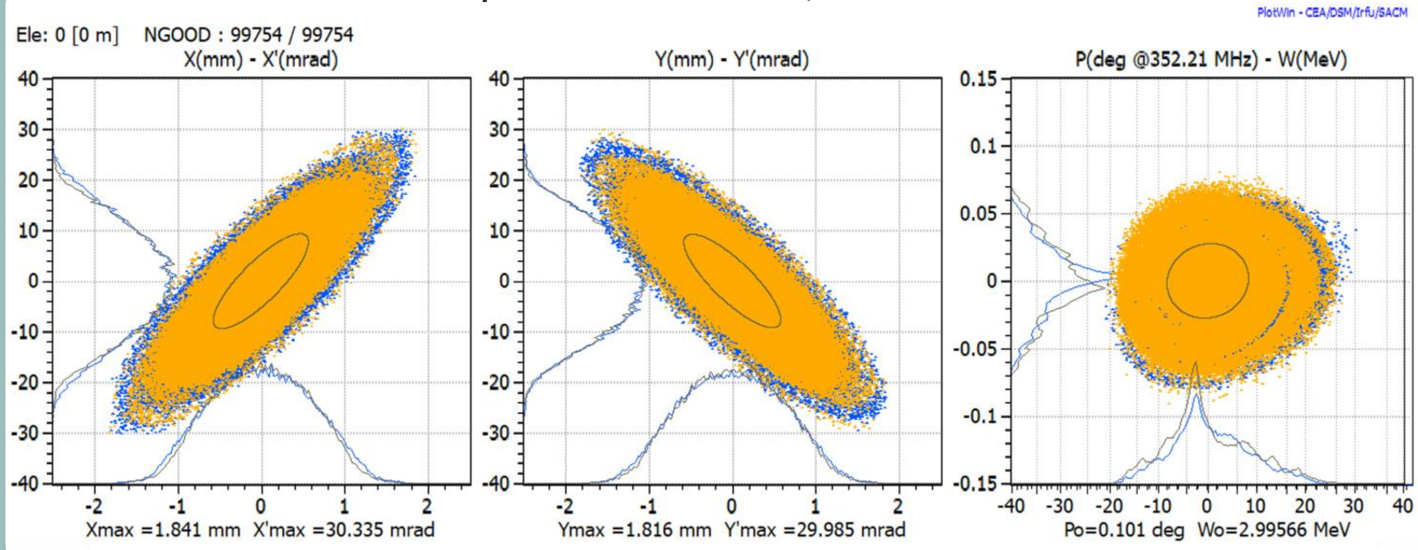
RFQ, zero space charge

The Linac4 RFQ is described by a field map built out of FEM electrostatic simulations performed with COMSOL with 0.2mm step size. The physical vane geometry is used to define the apertures.

The same field map is used in both codes.

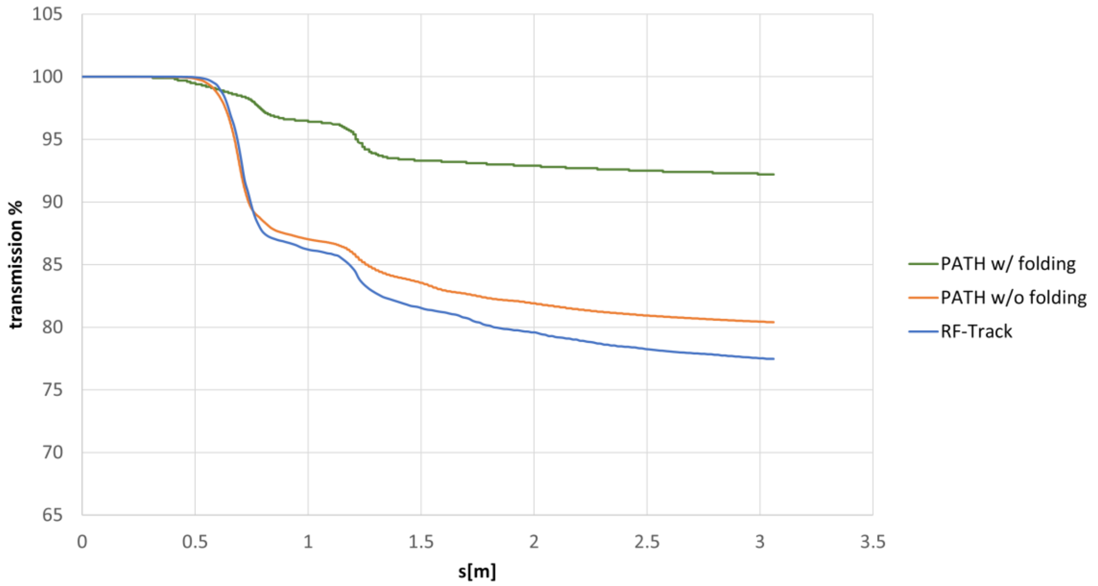


Output 3 MeV beam, **PATH** vs **RF-Track**

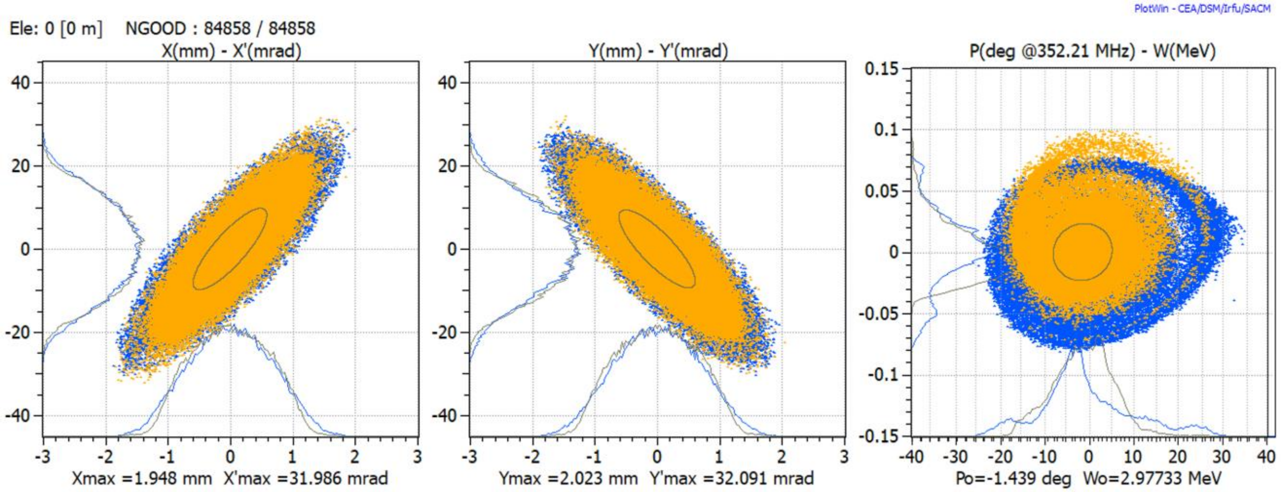


RFQ, 70mA space charge study case

PATH: space charge model for bunched beams is normally used for tracking through RFQs, assuming 5 adjacent bunches for calculating longitudinal effects. Particles' folding is activated (= particles falling outside the 360° bucket are folded back in) at every calculation step (this is not yet implemented in RF-Track).
Better agreement in final results is reached when disactivating the folding procedure in PATH while tracking an input beam that extends longitudinally over five consecutive RF buckets (with 5 times the number of charges).

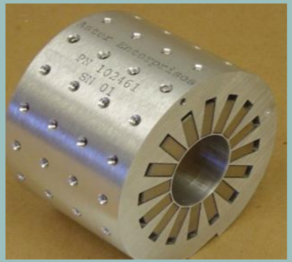


Output 3 MeV beam, **PATH** vs **RF-Track**



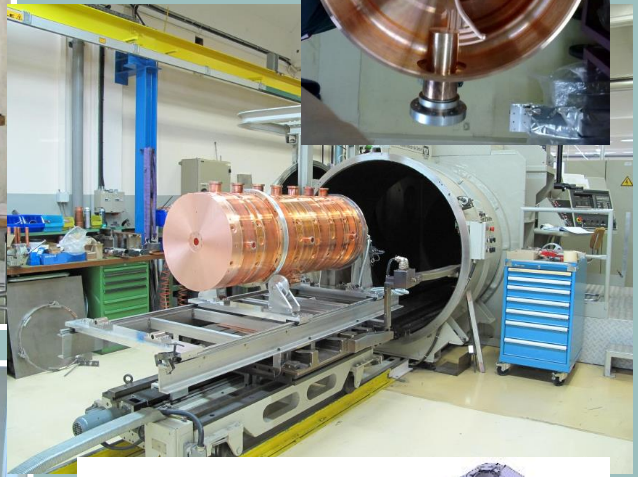
LINAC4

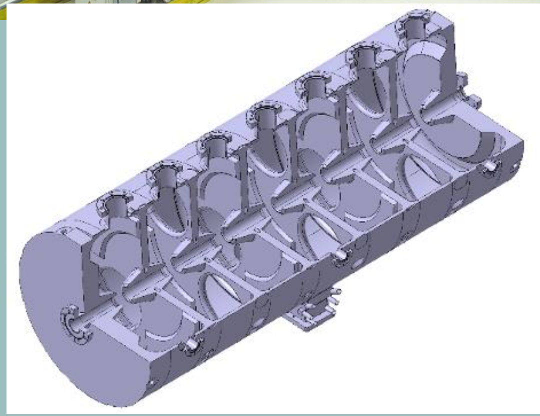
DTL: 3→ 50 MeV
3 tanks in Cu-plated StSt
120 drift tubes with PMQs
FFDD system
ESS-Bilbao collaboration



CCDTL: 50→100 MeV
7 modules of 3 tanks each
DTL-like tanks w/ coupling cells
PMQs+ EMQs (external cells)
VNIITF/BINP collaboration

PIMS: 100-160 MeV
12 tanks of 7 pi-mode cells each
External EMQs
Soltan Institute/FZ Juelich coll.



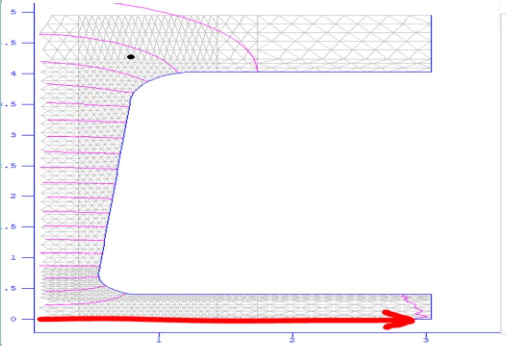


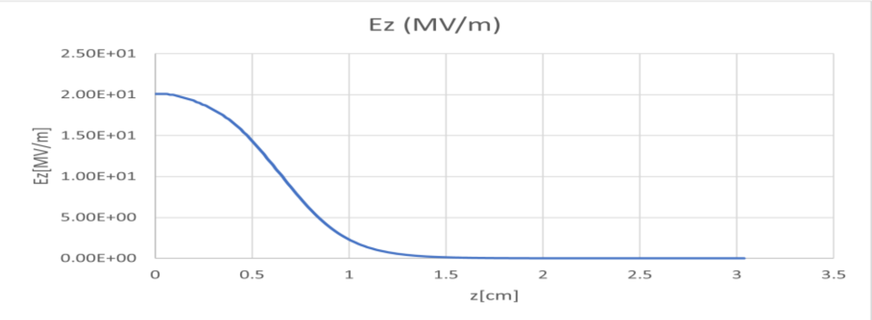
Linac4 cavities

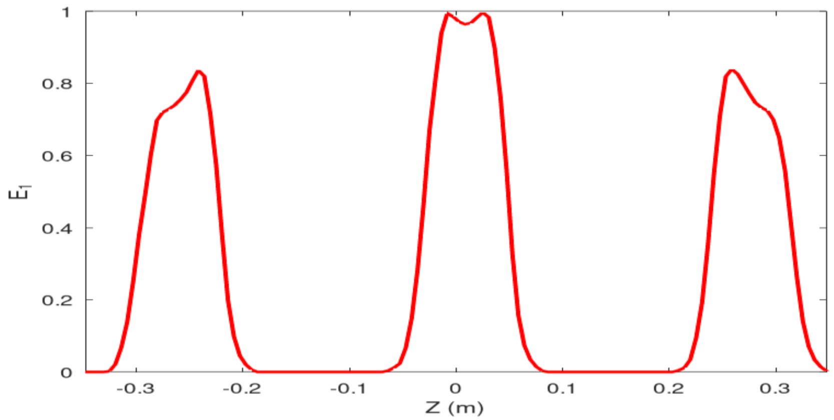
PATH : sequence of drifts and zero-length RF gaps giving acceleration kicks (thin gap model).

RF-Track: choice to use 1D field maps of on-axis longitudinal electric field obtained with Poisson-Superfish. The longitudinal electric field is modelled with a generalized Gaussian function whose main parameters are fitted case by case to reproduce the different geometry and match the specified TTF (*ad-hoc* fitting procedure). The transverse field is calculated from derivatives of the on-axis field with 3rd order polynomial expansion.
The same procedure is applied to all types of Linac4 cavities (DTL, CCDTL, PIMS).

DTL-type gap

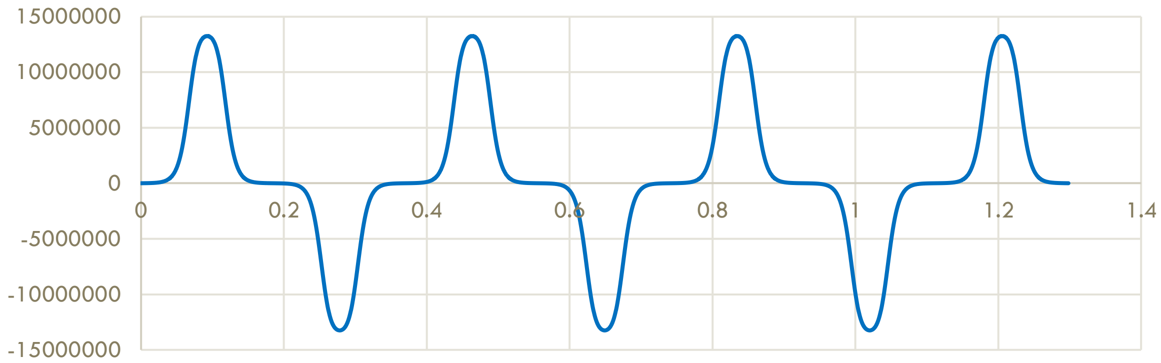


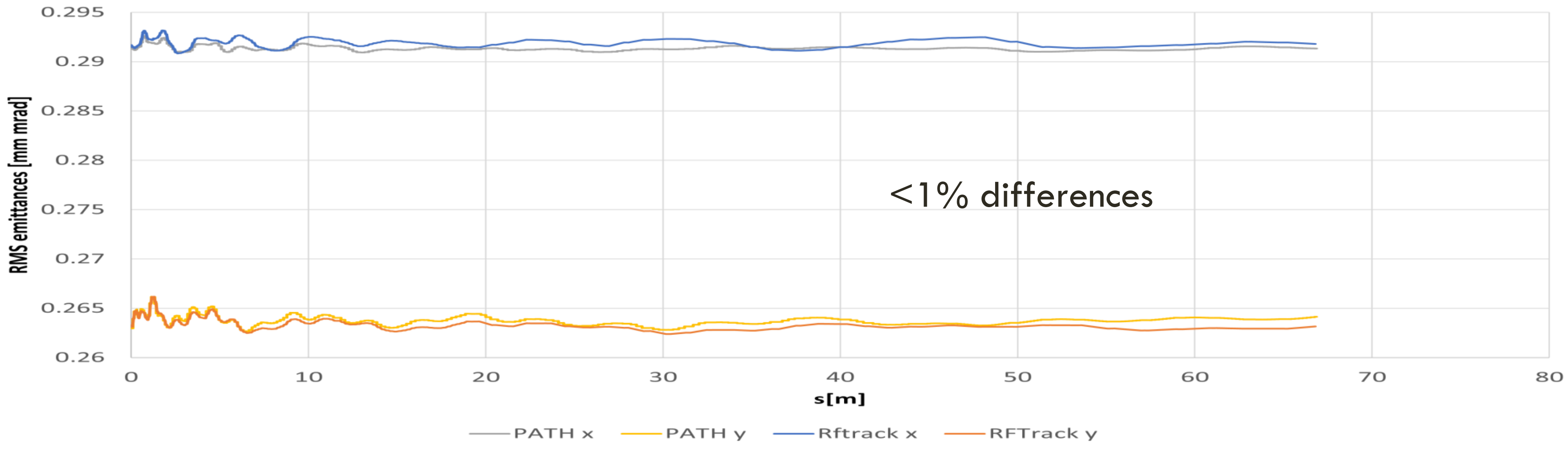




CCDTL tank

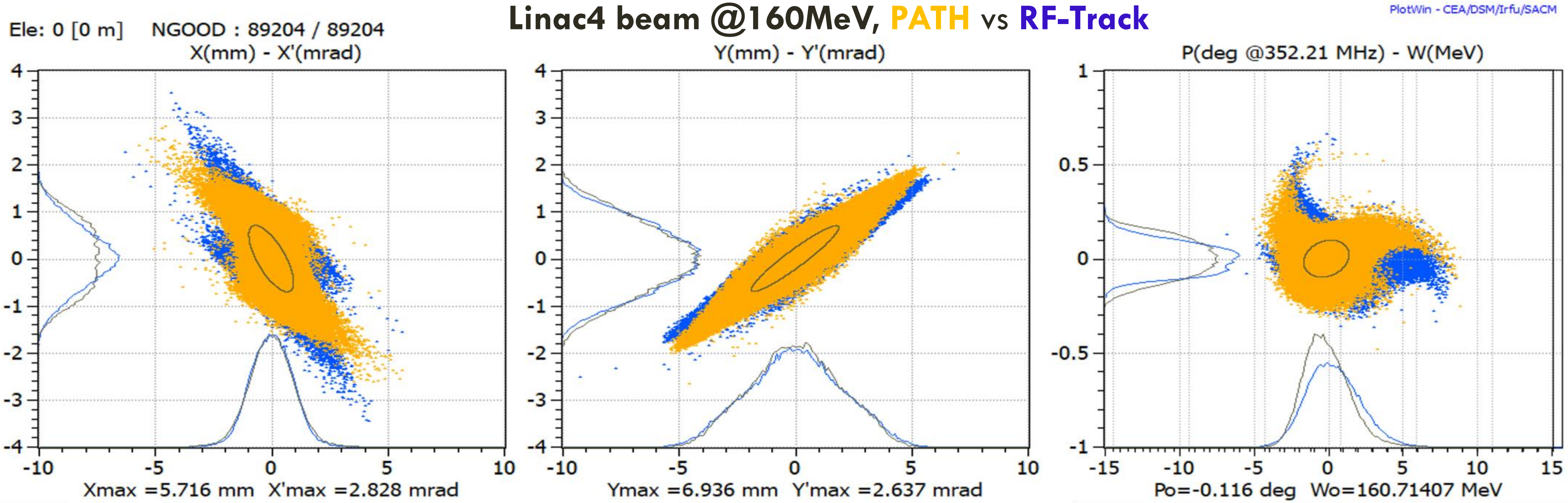
PIMS cavity

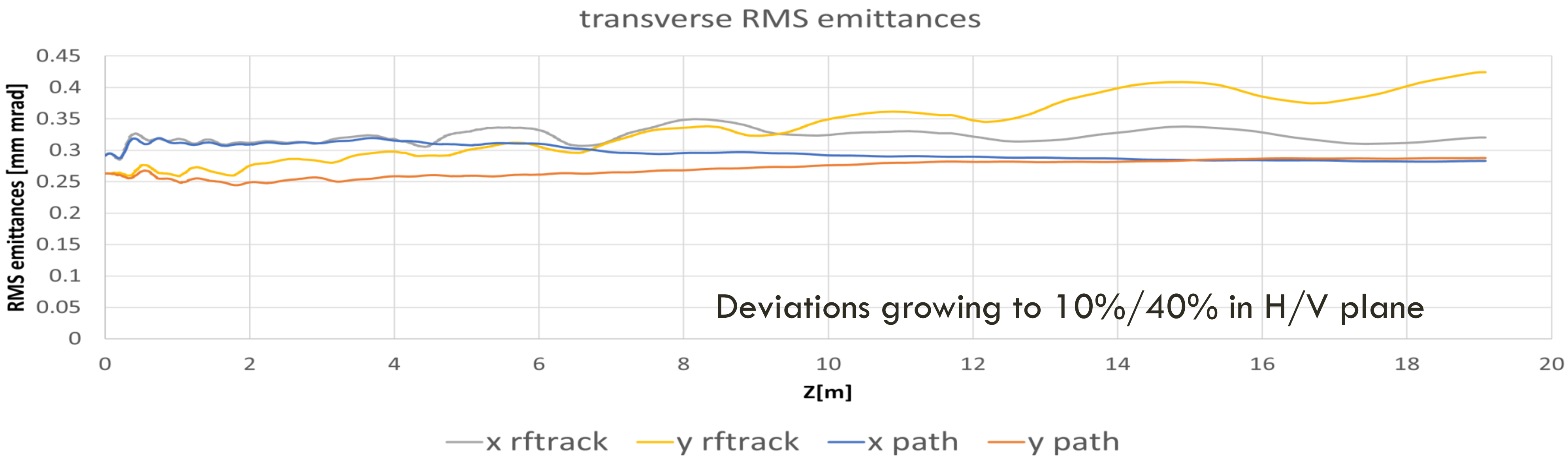




Linac4 with zero space charge

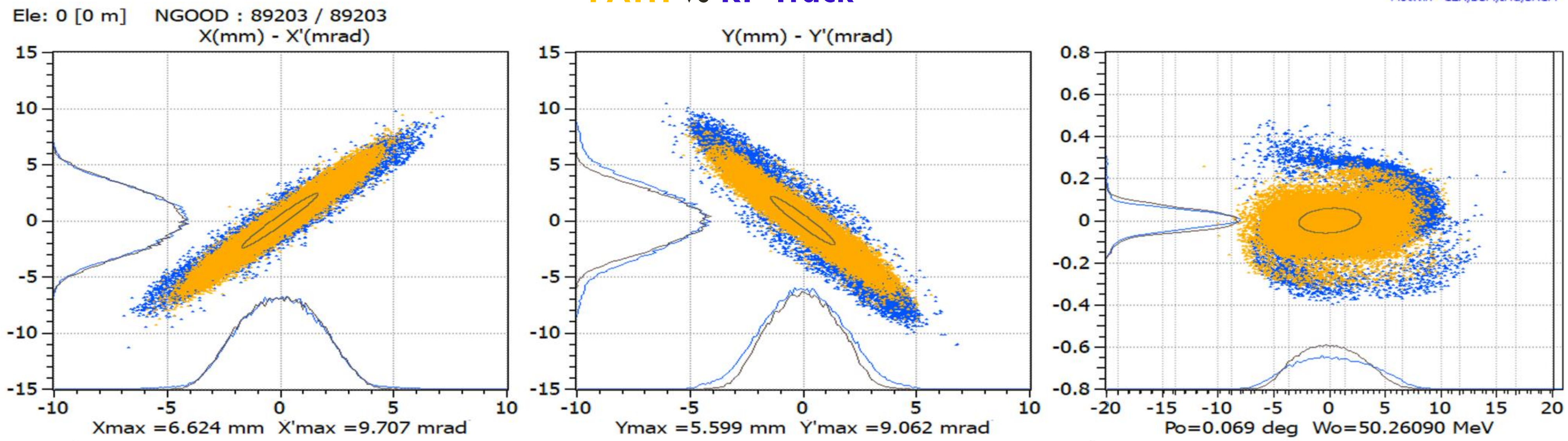
Linac4 beam @160MeV, PATH vs RF-Track





DTL with 60mA space charge

PATH vs **RF-Track**



Conclusions

Very encouraging results of the code benchmarking with zero space charge, with discrepancies <1% in transverse emittance values and transmission.

Space charge introduces differences in the results obtained with the two codes, to be further understood.

Possible causes:

- Significantly different space charge modelling
- Thin gap kicks vs 1D field maps of all RF elements in lattice
- RF phases in RF-Track not yet optimized

Next steps

Test different space charge setups, time integration vs space integration and optimise attribution of RF phases.

Once a full validation is achieved and the differences are smoothed out, next goal will be to complete the end-to-end modelling of Linac4 starting from the beam extraction from the source.

Thank you for your attention