Fermi National Accelerator Laboratory

Project X

Beam dynamic simulations in RFQ with the use of CST Studio Suite.

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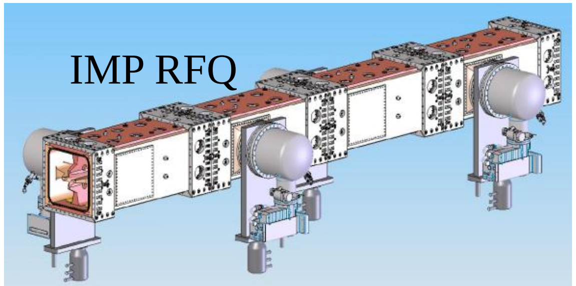
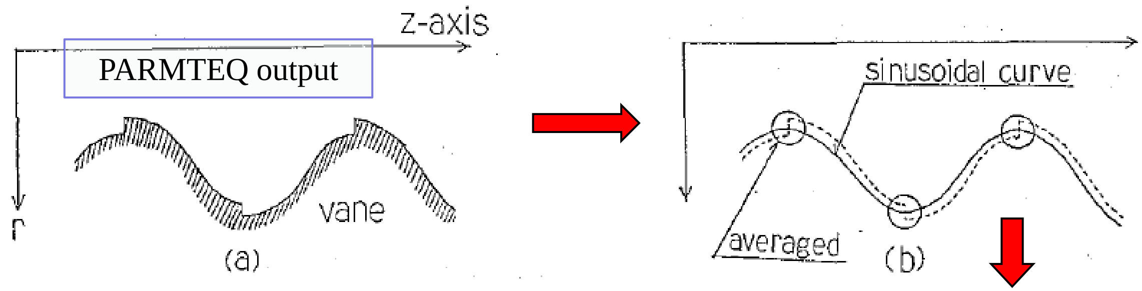
Talk Outline

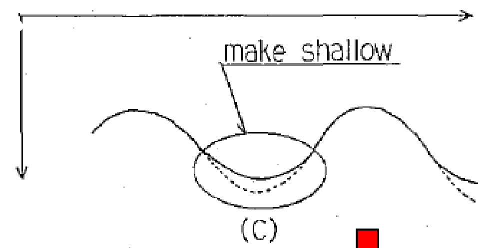
Project X

- **Preface. Motivation and workflow.**
- **Building solid models of RFQ vanes with modulation**
  - **Modulation from VANES to CST SS**
  - **Creating "modulated vane tip"**
- **Complete electrostatic RFQ model for CST ES**
  - **Building the model (electrodes)**
  - **Field simulations**
- **Complete electrodynamic RFQ model for CST MWS**
  - **Building the model**
  - **Field simulations**
- **TRACK beam dynamic simulations**
  - **Field transfer from CST SS into TRACK**
  - **Input beam parameters**
  - **Comparison of ES and RF**
- **Beam dynamic simulation with PIC solver**
  - **Preliminary results**
- **Conclusion**

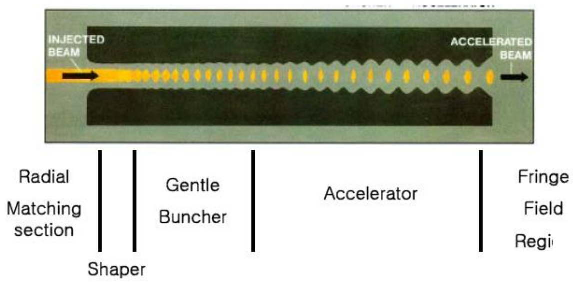
Preface. Motivation.



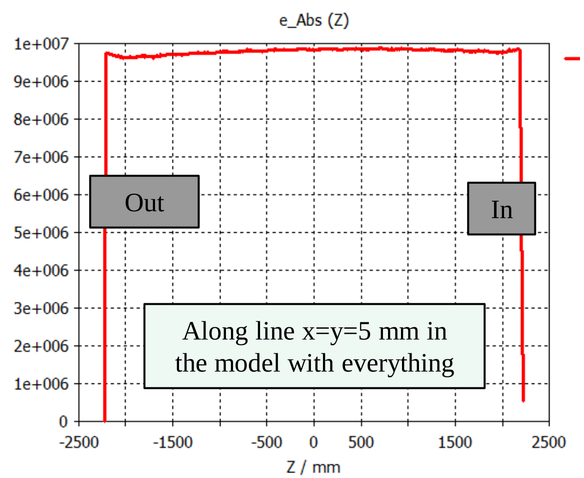




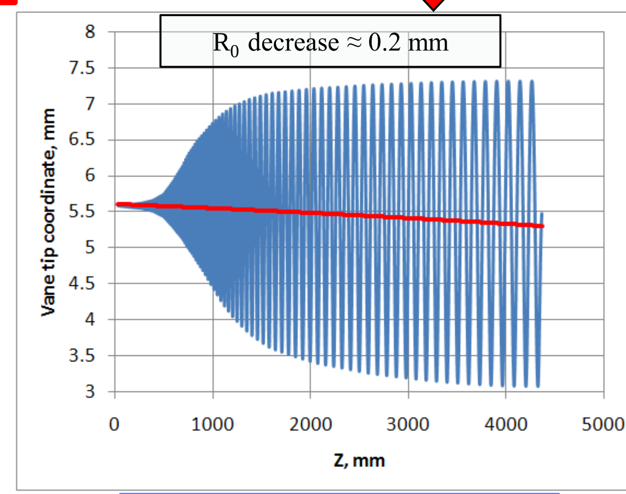
During the vane tip machinery the step-wise functions m(z), a(z) are approximated in different ways which result in a deviation of the parameters from original design.



Real physical vane modulation is not the same that is used for beam dynamic simulation in PARMTEQ. Furthermore the real end terminations, PISLs, tuners, couplers, different ports, RFQ segmentation etc. don't allow achieving a flat field distribution along RFQ even with perfectly machined parts.



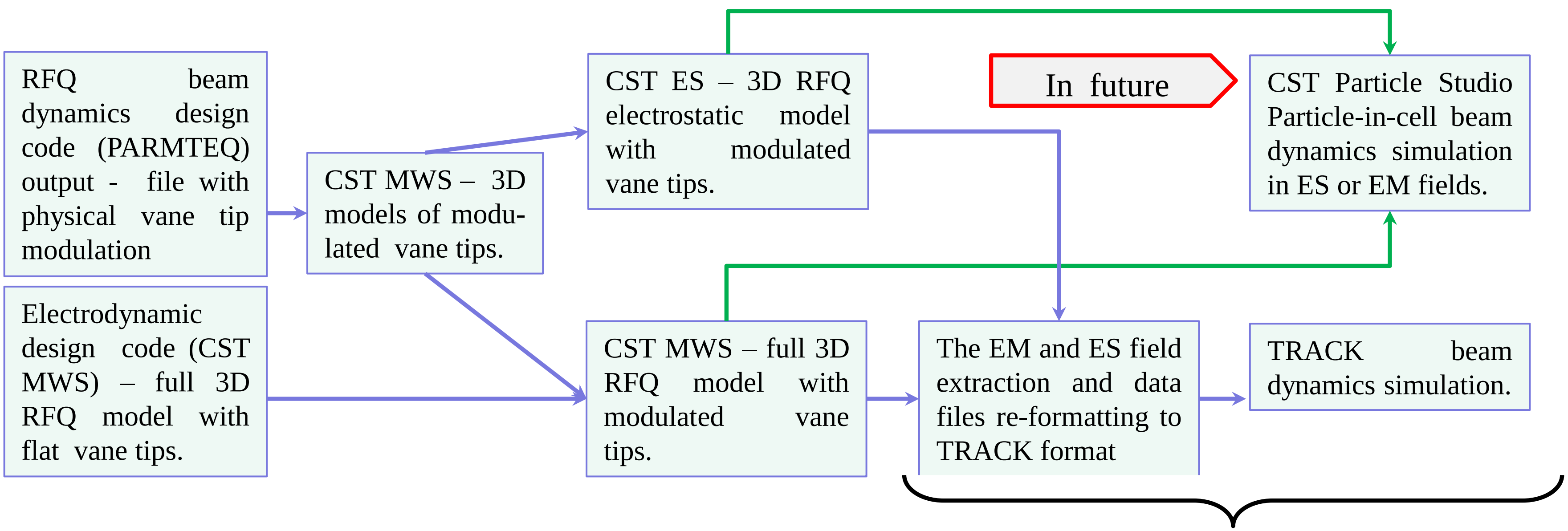
Simulated field distribution in the gap



Subroutine VANES output

Preface. Workflow.

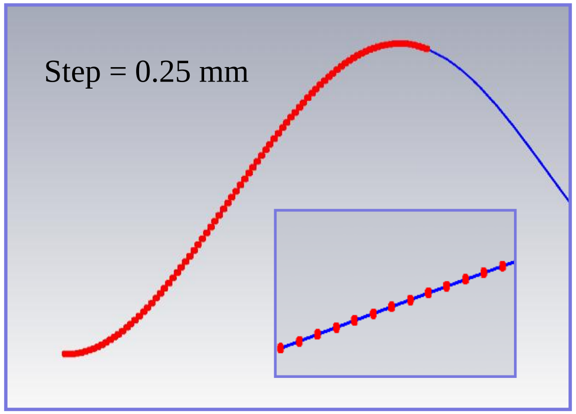
The beam dynamics and the electromagnetic design of an RFQ are usually done separately using different tools. A RFQ design code such as PARMTEQ uses analytical description of the fields in electrostatic approach for the beam dynamics simulations. To obtain more accurate RFQ output parameters the fields simulated with a electromagnetic model, which takes into account as many physical features of the RFQ as possible, must be used. Else this is the most adequate way to study impact of manufacturing and tuning errors on the RFQ's output beam parameters. Eventual integrating the electromagnetic and beam dynamics simulations in one software seems to be the most consistent way for design evaluation.



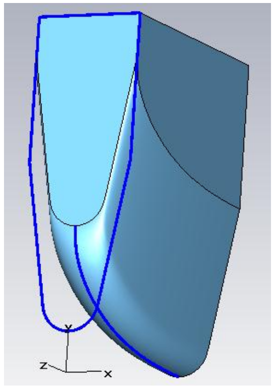
Special thanks to Brahim Mustapha

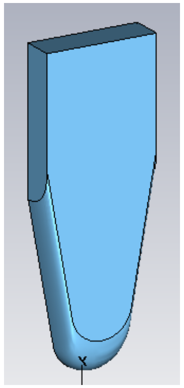
Creating “modulated vane tip”

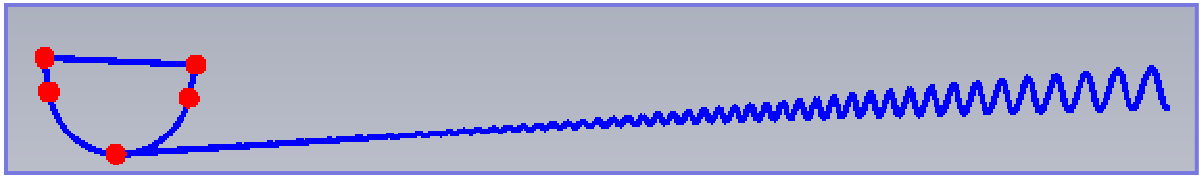
Project X



The tables of vane tip profiles from VANES output file are imported into CST MWS, and the points are interpolated with splines.

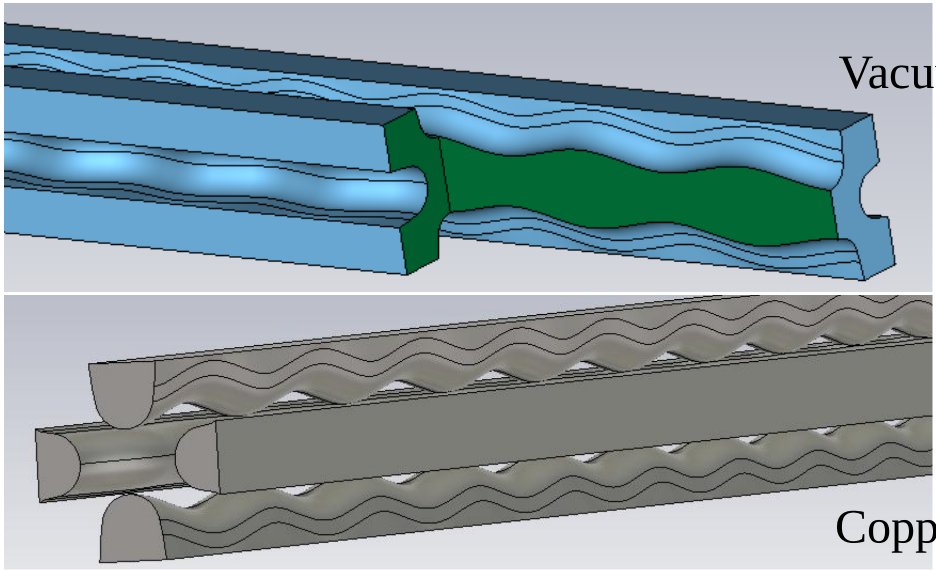






The vane tip profile is swept along the modulation curve and the vane profile solid model is created.

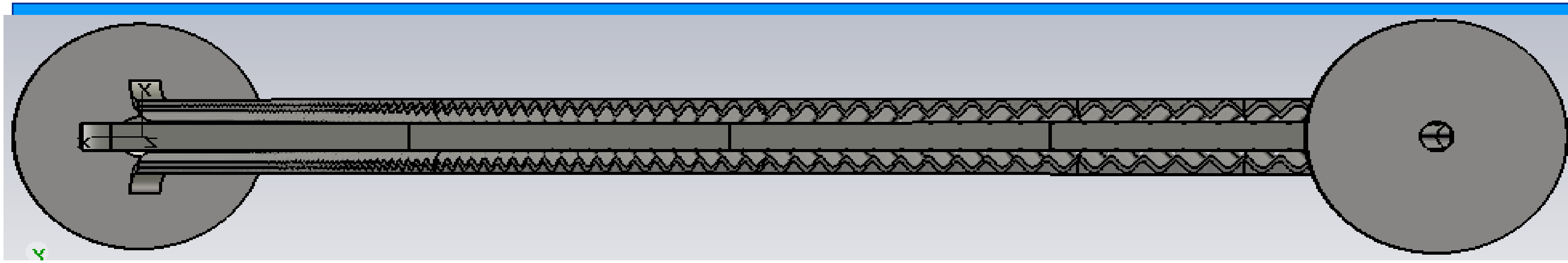
4 vertical and 4 horizontal ≈ 1m long profiles (two per RFQ module) were prepared. They have been combined to build two final 3D modulated vane tip solid models for RF and ES problems.

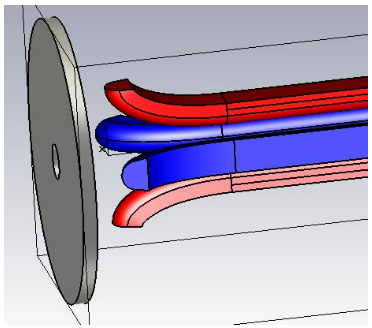


Vacuum for RF

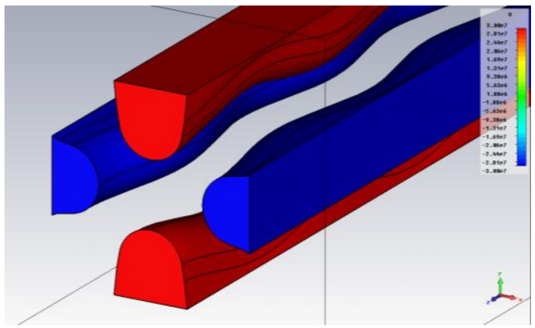
Copper for ES

Electrostatic RFQ model

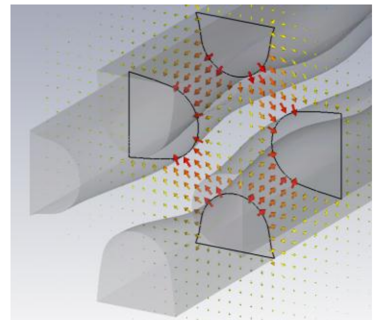




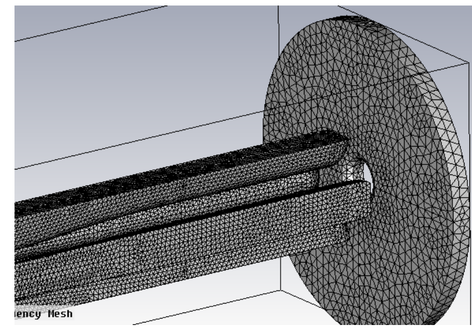
Input matcher with end-wall.



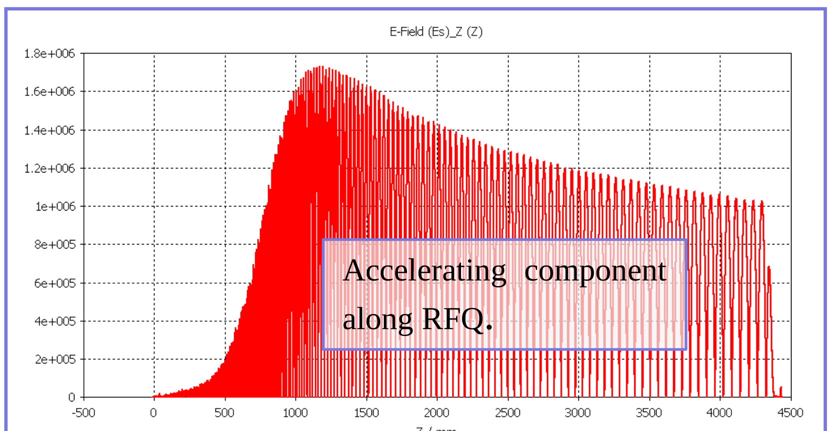
Potentials of ± 30 kV assigned to the electrodes.



Electrostatic field

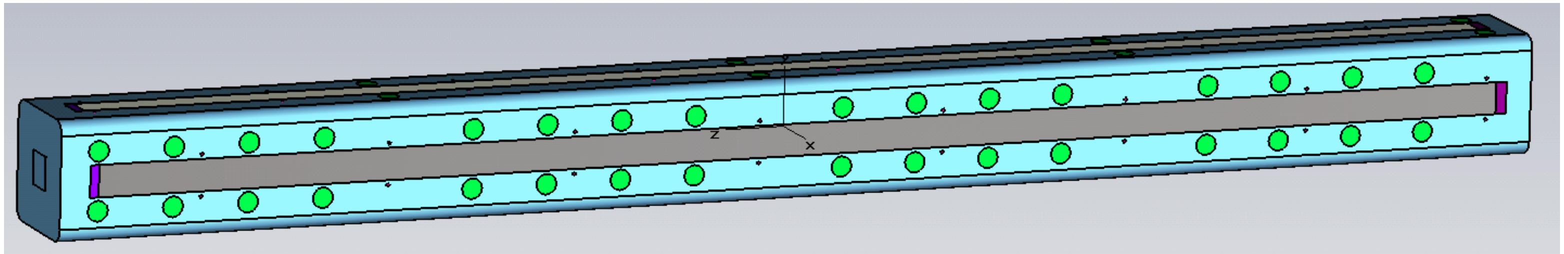


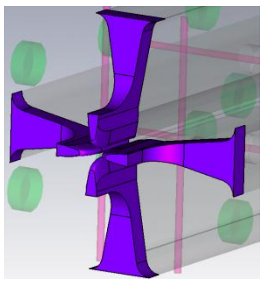
Meshed output termination with end-wall.



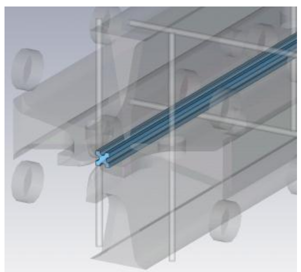
The main advantage of the electrostatic model is a designed field distribution – only electrode geometry in paraxial area and electrode potentials matter. And an exact operating frequency can be assigned. But the ES solver uses low frequency mesh which is not very advanced. So, a huge mesh up to 10 M tetrahedrons is needed, and mesh building is very time consuming. The solver itself is very fast though.

Electrodynamic RFQ model

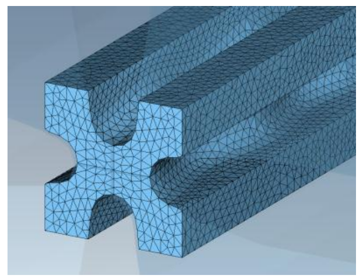




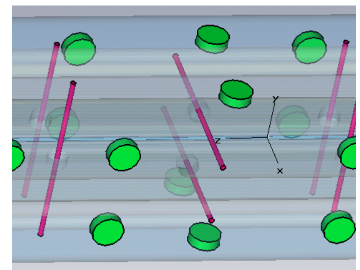
Input matcher.



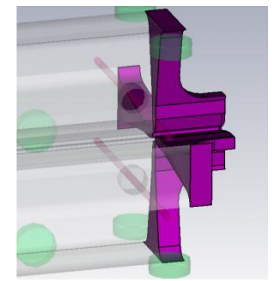
Modulated vane tip.



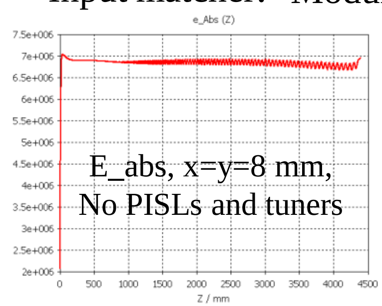
Mesh. 600,000 tets

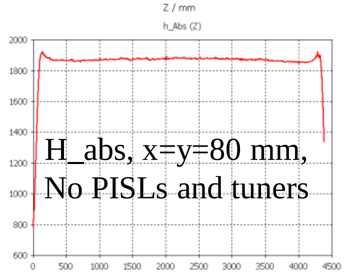


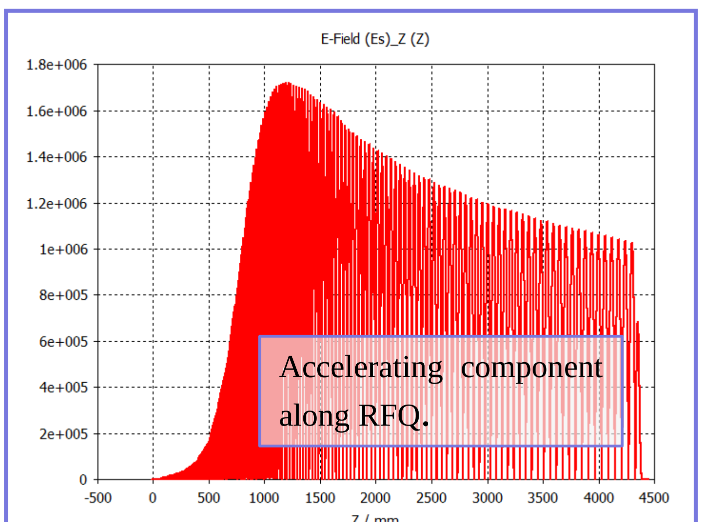
PISLs and tuners



Output termination







Field distribution in this model reflects influence of many factors – neighboring modes, tuning, stabilizers etc., so the result is never theoretical and may be confusing. On the other hand this is the only approach to analyze real mechanical and tuning errors.

Field map transfer. Input beam.

Project X

3D field map.

The 3D field distribution is exported from CST projects in plain text format. The field grid has 25x25x4001 points uniformly distributed over 11 mm x 11 mm x 4380 mm rectangular box. That corresponds about 7 points per shortest cell in z direction. Then the extracted files for E and H fields are reformatted and combined by special code in one file in binary format that is used in TRACK.

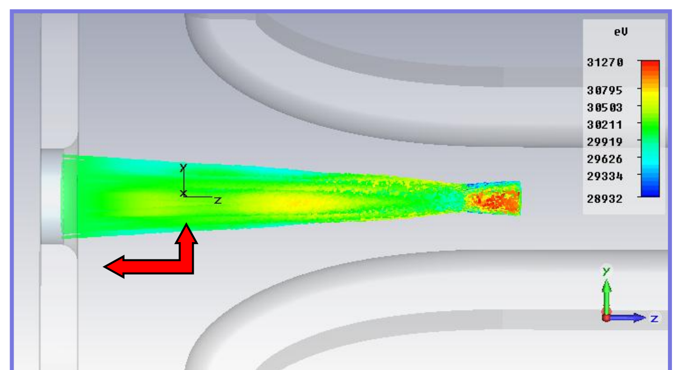
The overall procedure is not very convenient and optimized. It takes several hours to extract the field distribution in text format from CST. The final binary file eh_MWS.#xx is about 360 MB and it is difficult to move it around. But the worst thing is that there many places where you can make an error which is hard to catch.

Input beam.

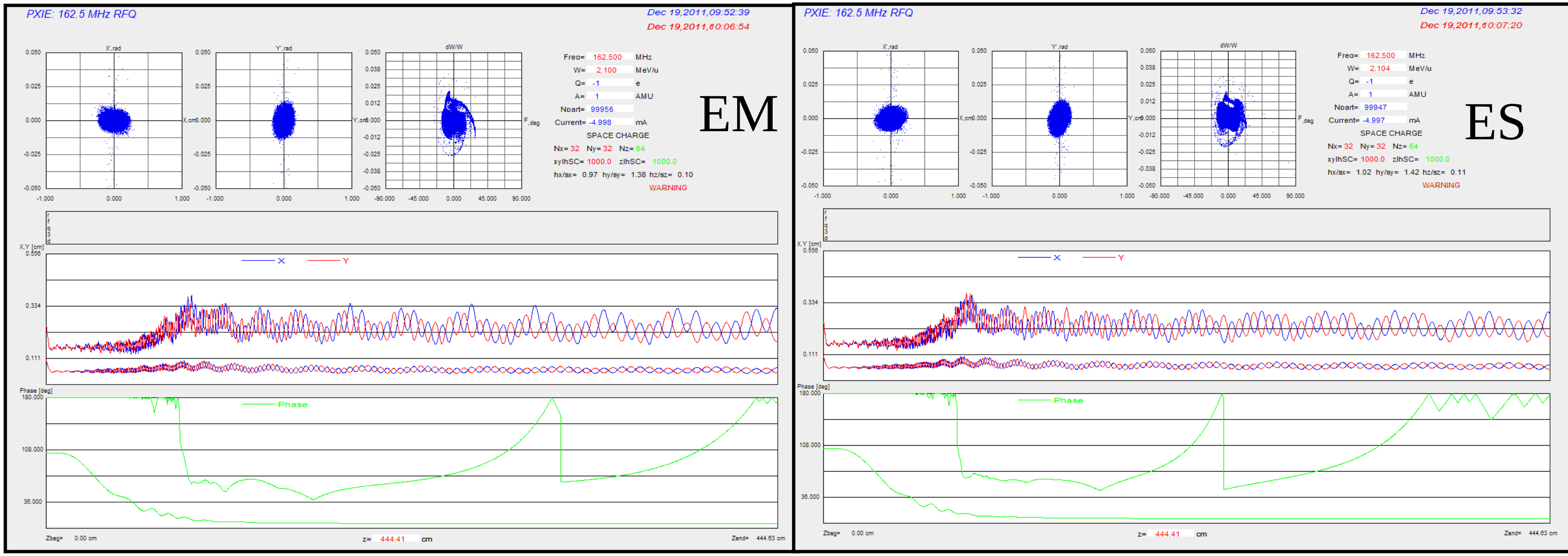
The beam parameters were taken from PARMTEQ output file from 9/11/2011 (version 4). Since these parameters correspond to the tip of matcher, the beam has been transported back outside RFQ and slightly adjusted for better matching.

	α	β, cm/rad	ε, norm rms, cm·mrad
x	1.331	7.414	0.0115
y	1.336	7.455	0.0113

Twiss parameters at the tip of input matcher



TRACK simulations



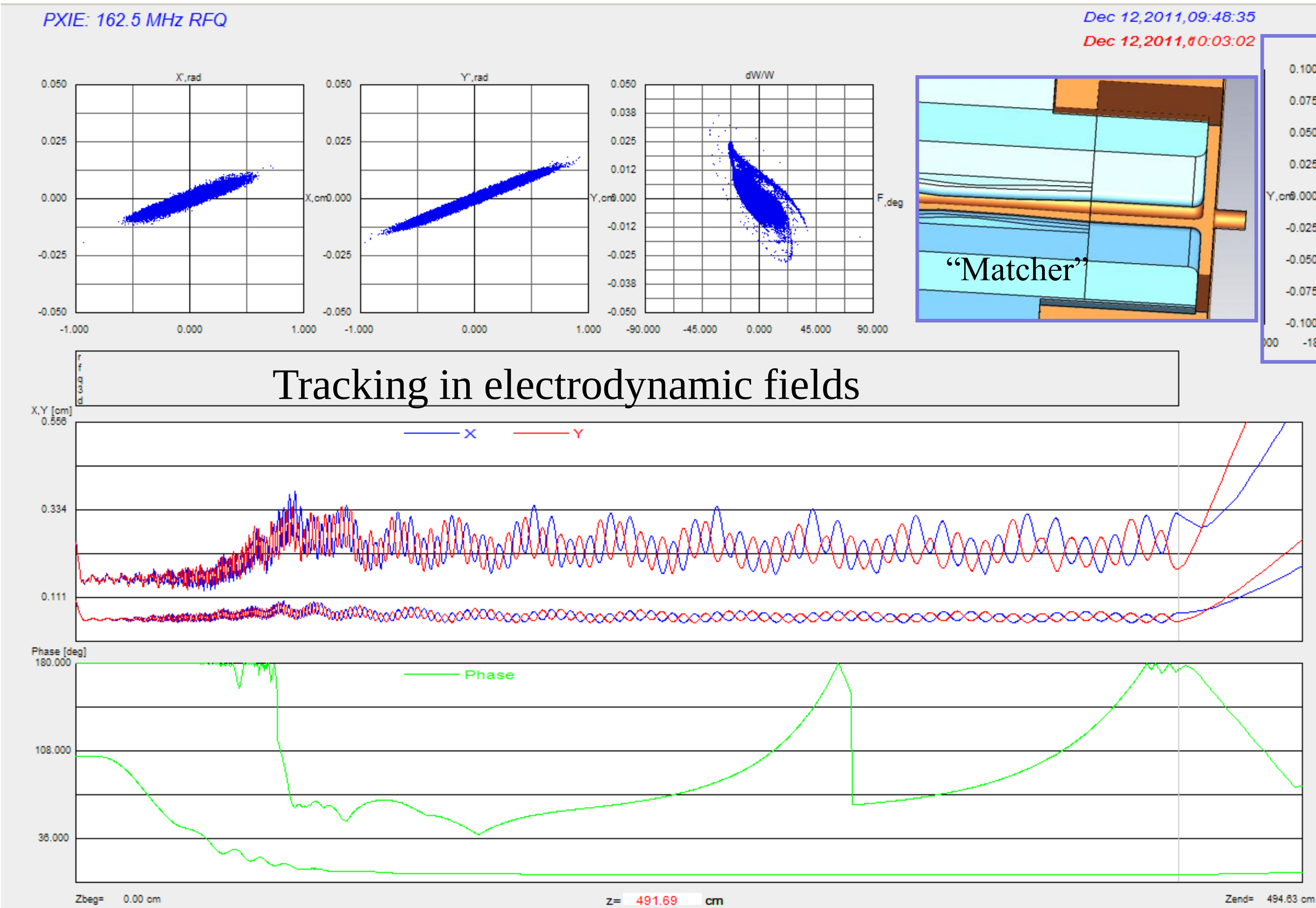
	α	β	4 ε n_rms	Coord.
EM	0.02	0.025	0.054	x
	-0.55	0.012	0.054	y
	0.2	18.35	3.25	z
ES	0.028	0.023	0.054	x
	-0.1	0.012	0.054	y
	0.209	18.99	3.25	z

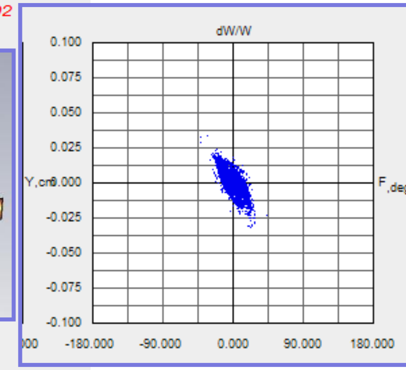
TRACK units in xy plane: β[cm/mrad], ε[cm·mrad]
TRACK units in z coordinate: β[°·(% of ΔW/W)], ε[keV·ns]

The Twiss parameters at the RFQ exit are close for electrodynamic and electrostatic fields. But detailed particle distribution seems to be different. Transverse emittance growth is 17-19%.

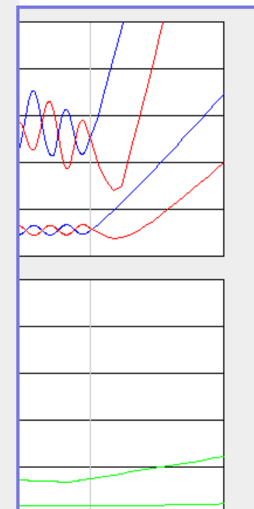
Output "matcher"

Project X



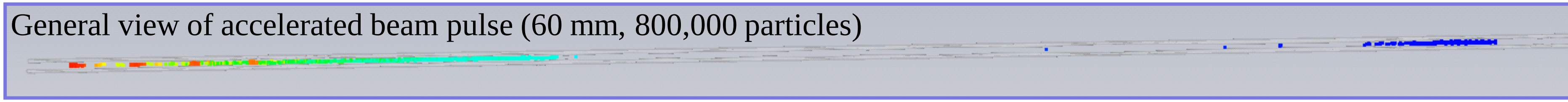


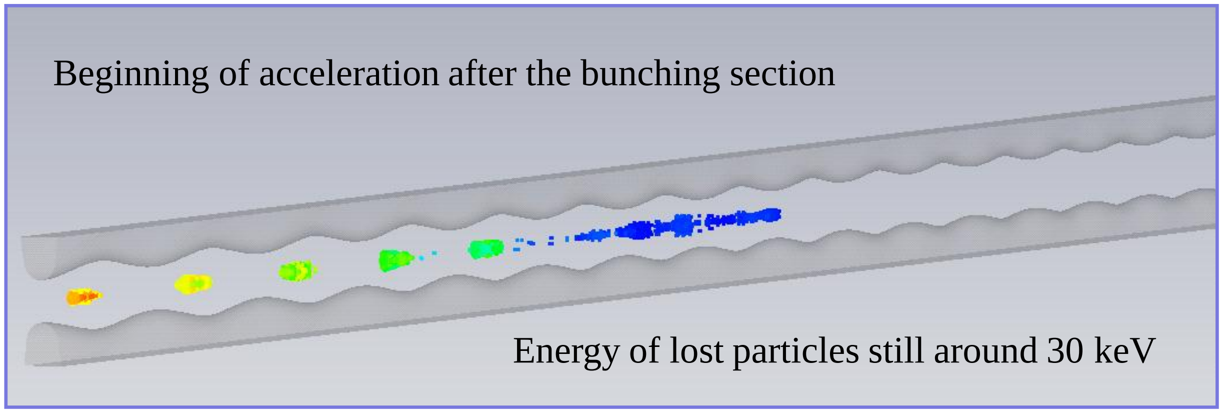
Without "matcher"



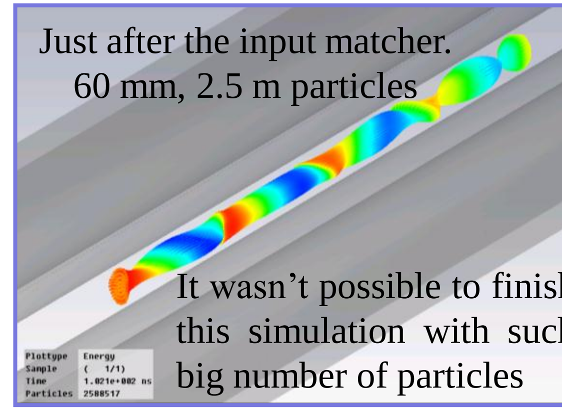
Again, a more detailed study of particle distributions is needed to make a certain conclusion on the "matcher" effect.

Particle-in-cell simulations

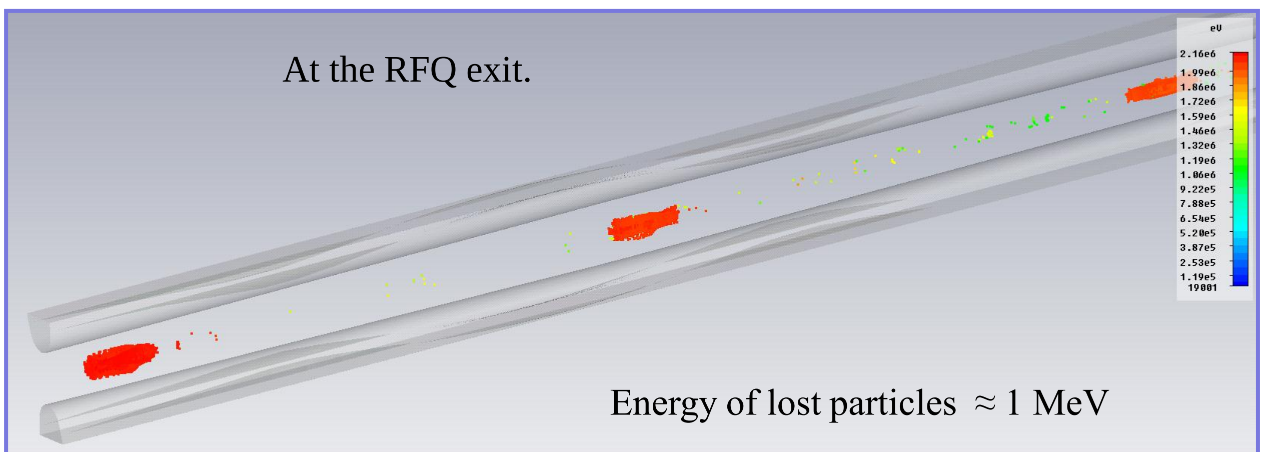

General view of accelerated beam pulse (60 mm, 800,000 particles)


Beginning of acceleration after the bunching section

Energy of lost particles still around 30 keV


Just after the input matcher.
60 mm, 2.5 m particles

It wasn't possible to finish this simulation with such big number of particles


At the RFQ exit.

Energy of lost particles ≈ 1 MeV

Total losses is only 0.4 %.
Simulation time > 48 h

Conclusion

Project X

- **The possibility to create high quality 3D field maps with CST SS open the way to end-to-end beam dynamics simulation in “real” fields.**
- **The electrodynamic RFQ model allows detailed studying of manufacturing and tuning errors impact on beam dynamic.**
- **Particle-in-cell solver delivers very interesting results, but it is not an effective tool for big models yet. Distributed computation or use of GPU may improve the situation.**