Update on the Status of Linac Part of the PyORBIT Code

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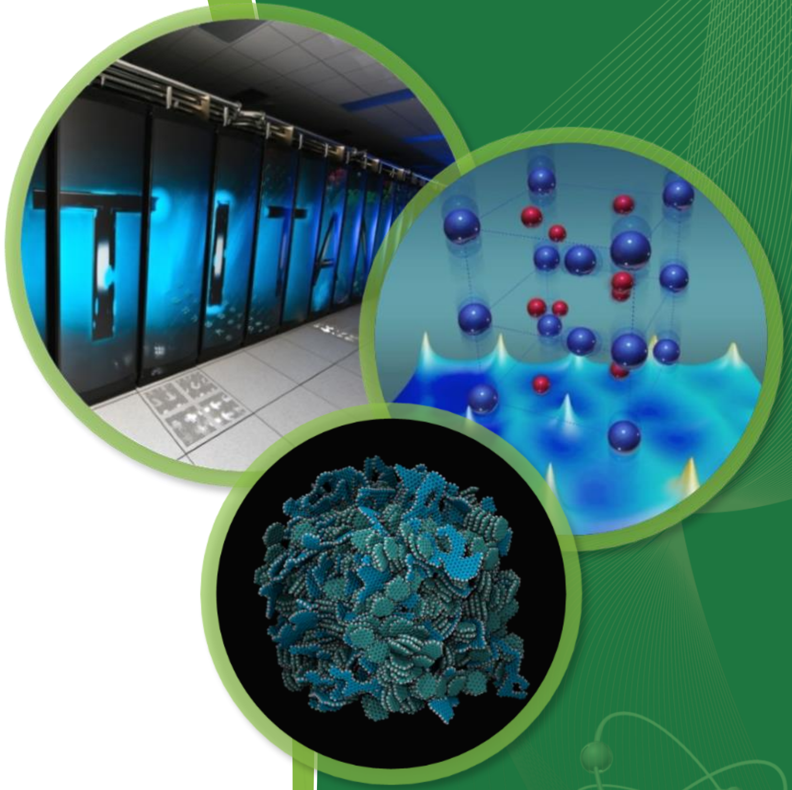


ICAP 2018, Key West, FL
October 23, 2018

Outline

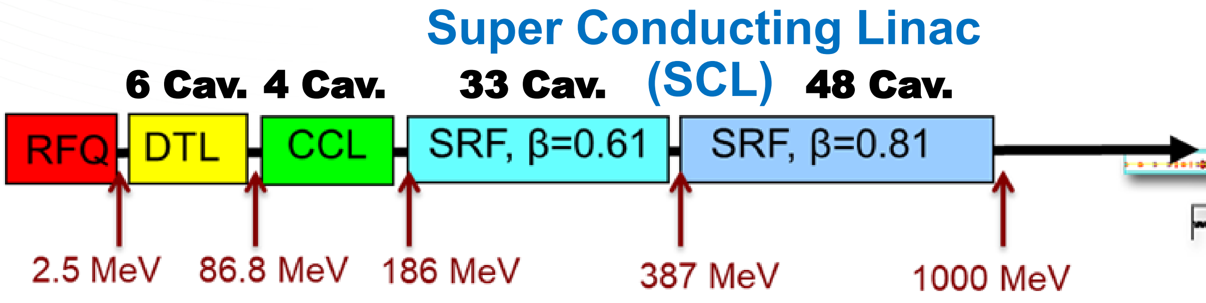
- SNS Accelerator
- PyORBIT Code
- Linac Part of PyORBIT
- RF Gap Models in PyORBIT Linac Part
- Some Benchmarks
- Summary

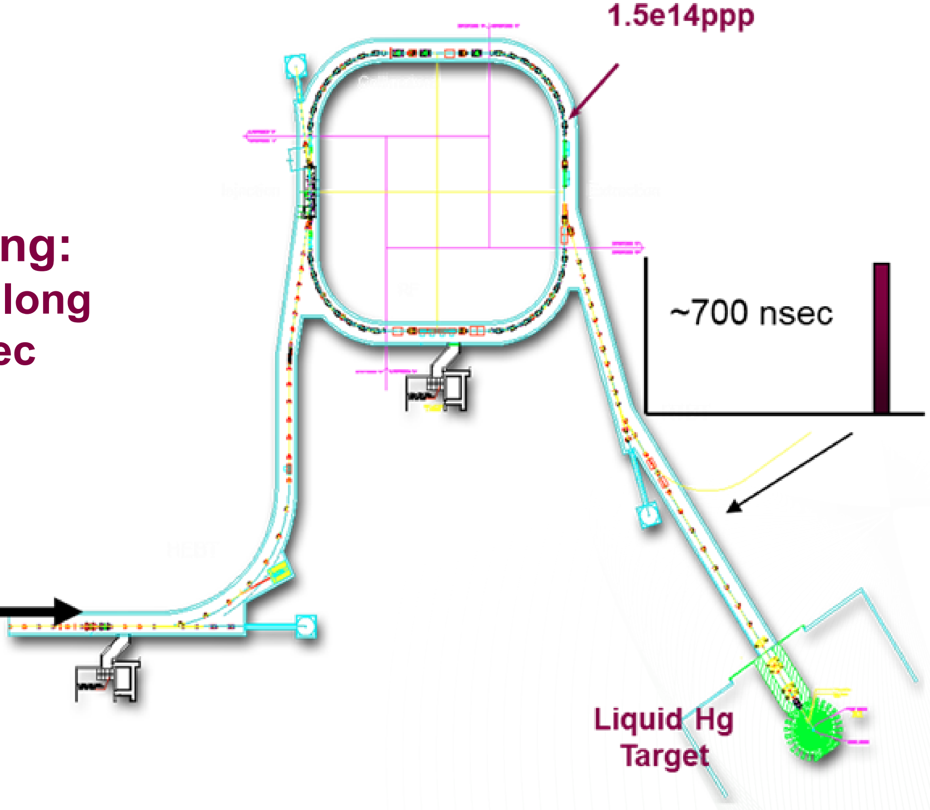
Spallation Neutron Source (SNS) Accelerator Complex

Front-End:
Produce a 1-msec long, chopped, H- beam

1 GeV LINAC

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec





Simulation Codes:
ORBIT (for ring & transport lines)
PyORBIT (for ring & recently for linac)
OpenXAL Online Model (Java, envelop code)

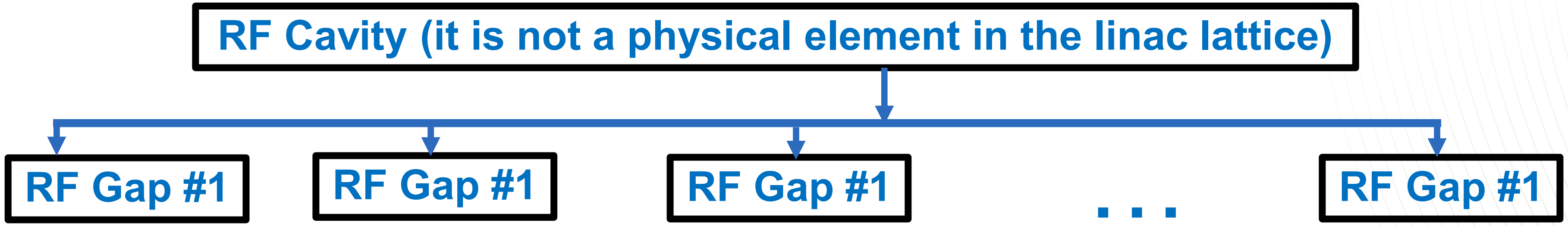
} **PIC Codes** (ORBIT and PyORBIT)

PyORBIT at a Glance

- PyORBIT is descendant of ORBIT code
- ORBIT is a ring and transport line code
- PyORBIT & ORBIT have the two language structure: driving scripting shell and C++ underneath
- ORBIT's Super Code shell was replaced by Python
- Recent flavor of PyORBIT was started in 2006
- PyORBIT is used and has been developing at SNS, CERN, GSI
- PyORBIT is used as a main simulation tool at SNS
- Open source: means everybody can do anything, and it is open for future collaborators (Github: PyORBIT-Collaboration)

Linac Part of PyORBIT

- Started about 10 years ago
- A part of PyORBIT, but an accelerator lattice description is different. There are RF cavities and realistic RF gaps
- XML description of a linac lattice, and a specific parser (PyORBIT ring part uses MAD and MADX parsers)
- It was used only inside SNS
- Practically no documentation, only examples
- Recent addition: realistic RF gap models



BASE, TTF, and REALISTIC RF Gap Models

1. Base model – no tricks → $\Delta W_s = W_s^{(out)} - W_s^{(in)} = q \cdot E_0 TL \cdot \cos(\phi_s)$

2. Thin RF Gap with T,S TTF → $W_{out} = W_{in} + qV_0 I_0 \left(\frac{\omega}{c \cdot (\gamma\beta)_{in}} r \right) \cdot (T(k_{in}) \cdot \cos(\phi_{in}) - S(k_{in}) \cdot \sin(\phi_{in}))$

T,S TTF functions are fitted by polynomial in a finite range of energies

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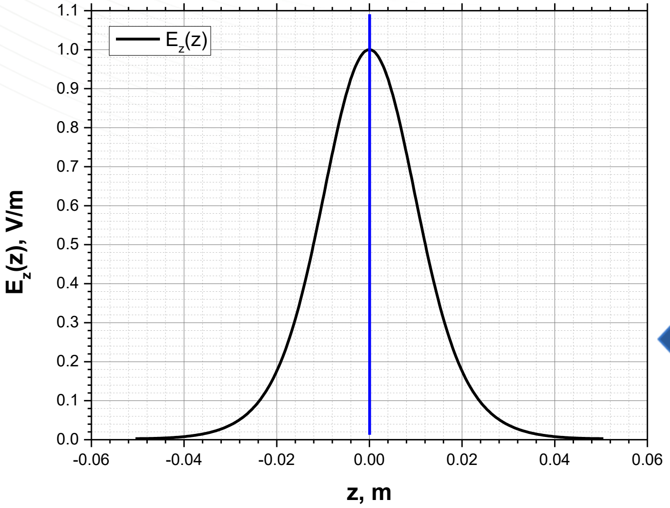
3. Realistic Model: Direct tracking through the field on the z-axis with the fixed step along z.



$$\Delta W = q \cdot \int_{-\infty}^{+\infty} E_z(z, t = \frac{z}{c \cdot \beta(z)}) \cdot dz$$

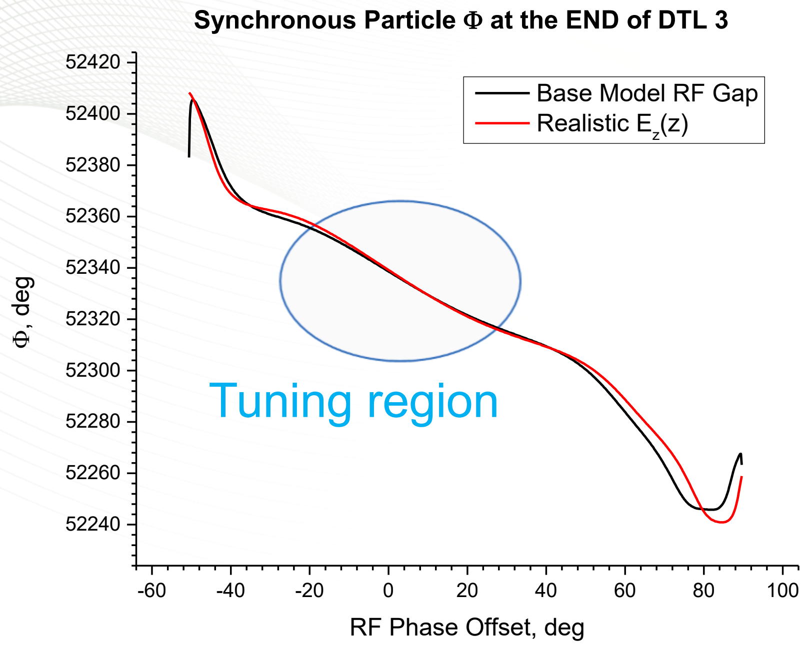
This approach implemented as a sets of 3 points longitudinal slices with analytical TTF

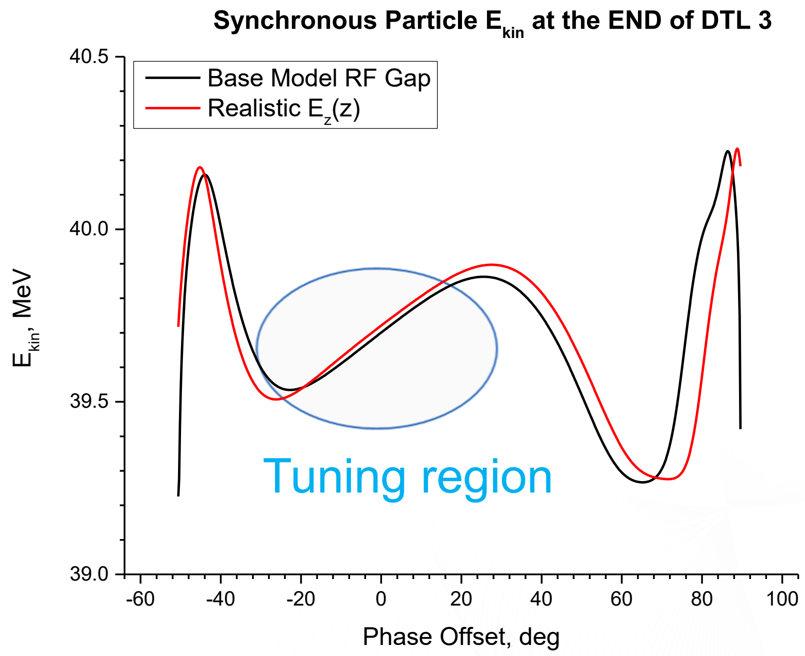
SNS MEBT RF Buncher in MEBT

Andrei Shishlo, Jeff Holmes.
Physical Models for Particle Tracking Simulations in the RF Gap
(2015) ORNL/TM-2015/247

PyORBIT Linac model includes total 5 different RF gap models at the moment (base + non-linear transverse, and full 3D RF field Runge-Kutta integration in addition to 3 shown here)

BASE and REALISTIC Models (SNS DTL1-3 Phase Tuning)

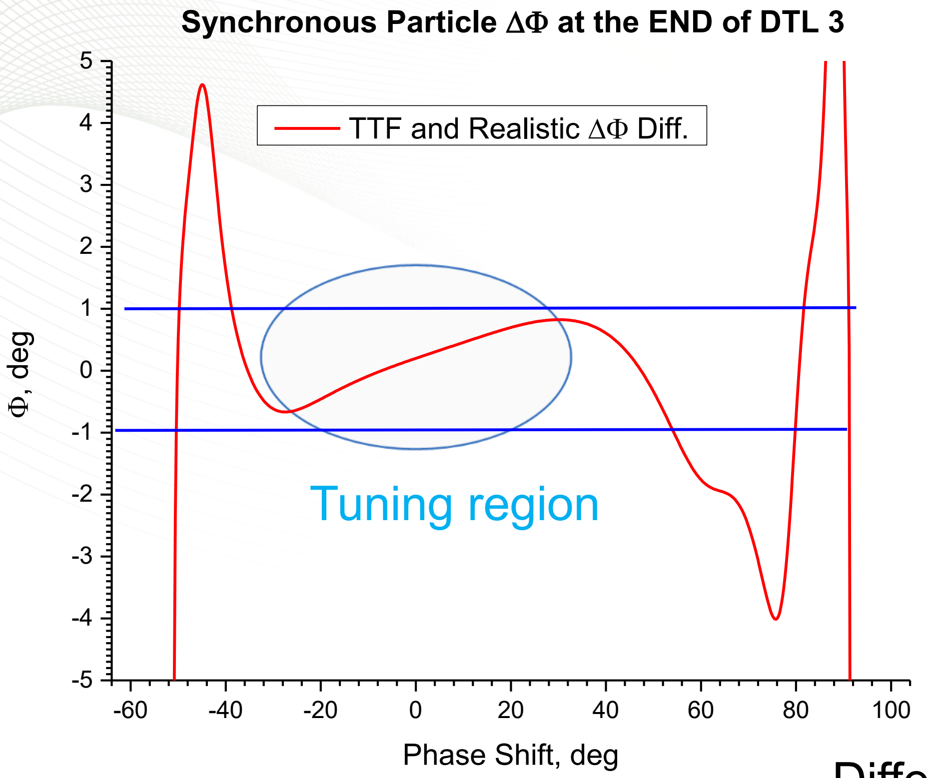


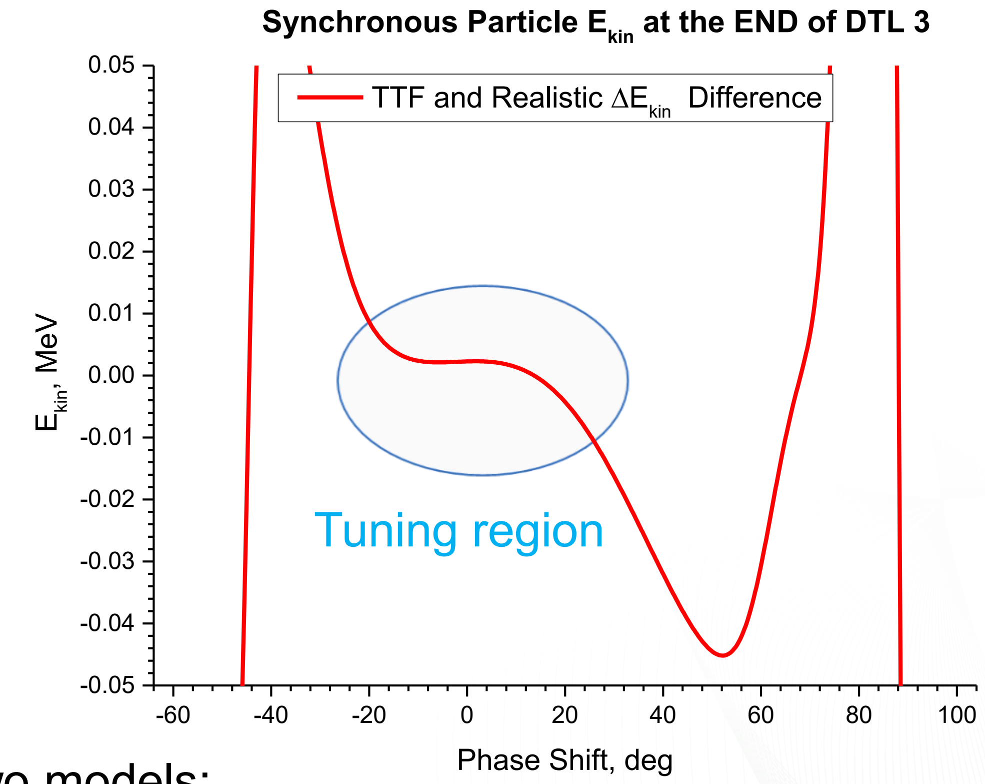


Final Phase and Energy for DTL1-3 Phase Shifting.

Results are not bad.
Phase Signature Fitting Tuning approach should work for both models.

TTF and REALISTIC Models (DTL1-3 Phase Tuning)



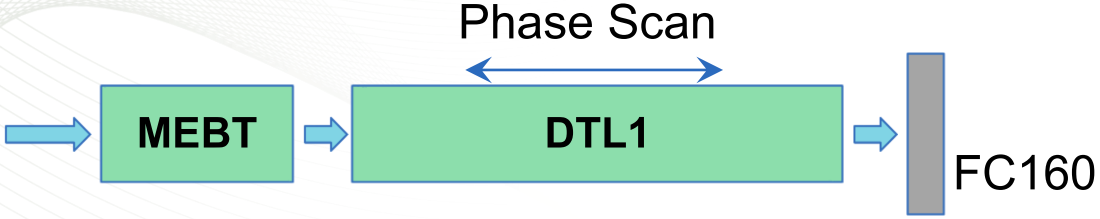


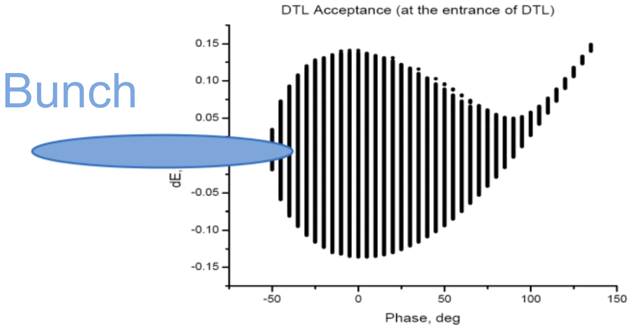
Differences for two models:
Final Phase and Energy for DTL1-3 Phase Shifting.

The difference is less than 1 deg and 10 keV which are higher than our accuracy during the tuning!

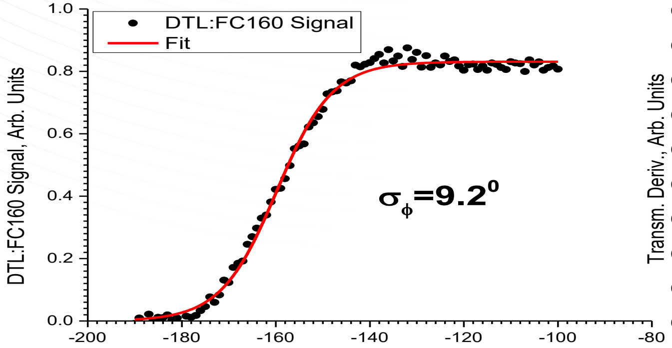
Phase Signature Fitting Tuning approach should work for both models.

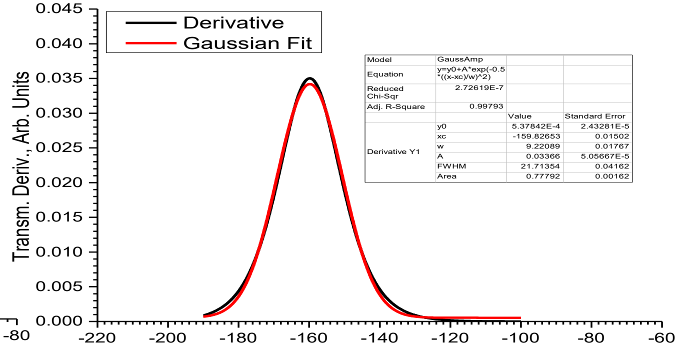
DTL1 Transmission Scan and Analysis
Done in 2015.11.15





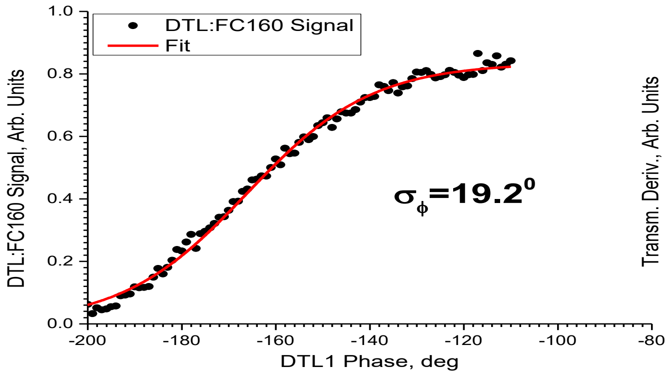
Rb04 On

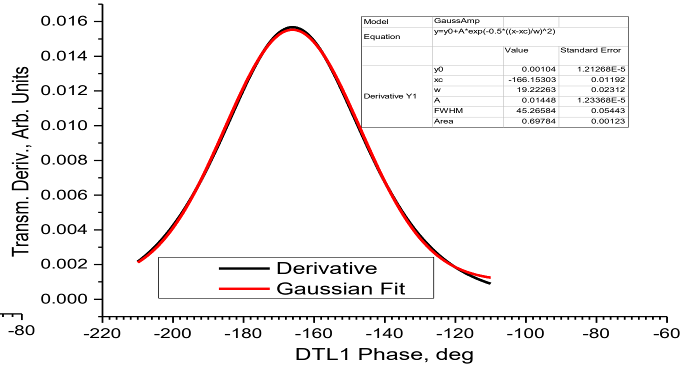




Model	GaussAmp		
Equation	y=y0+A*exp(-0.5 *((x-xc)/w)^2)		
Reduced Chi-Sqr	2.72619E-7		
Adj. R-Square	0.99793		
		Value	Standard Error
Derivative Y1	y0	5.37842E-4	2.43281E-5
	xc	-159.82653	0.01502
	w	9.22089	0.01767
	A	0.03366	5.05667E-5
	FWHM	21.71354	0.04162
	Area	0.77792	0.00162

Rb04 OFF





Model	GaussAmp		
Equation	y=y0+A*exp(-0.5*((x-xc)/w)^2)		
		Value	Standard Error
Derivative Y1	y0	0.00104	1.21268E-5
	xc	-166.15303	0.01192
	w	19.22263	0.02312
	A	0.01448	1.23368E-5
	FWHM	45.26584	0.05443
	Area	0.69784	0.00123

Design tracking:
8.5 deg
and
21 deg

Thanks to A. Zhukov

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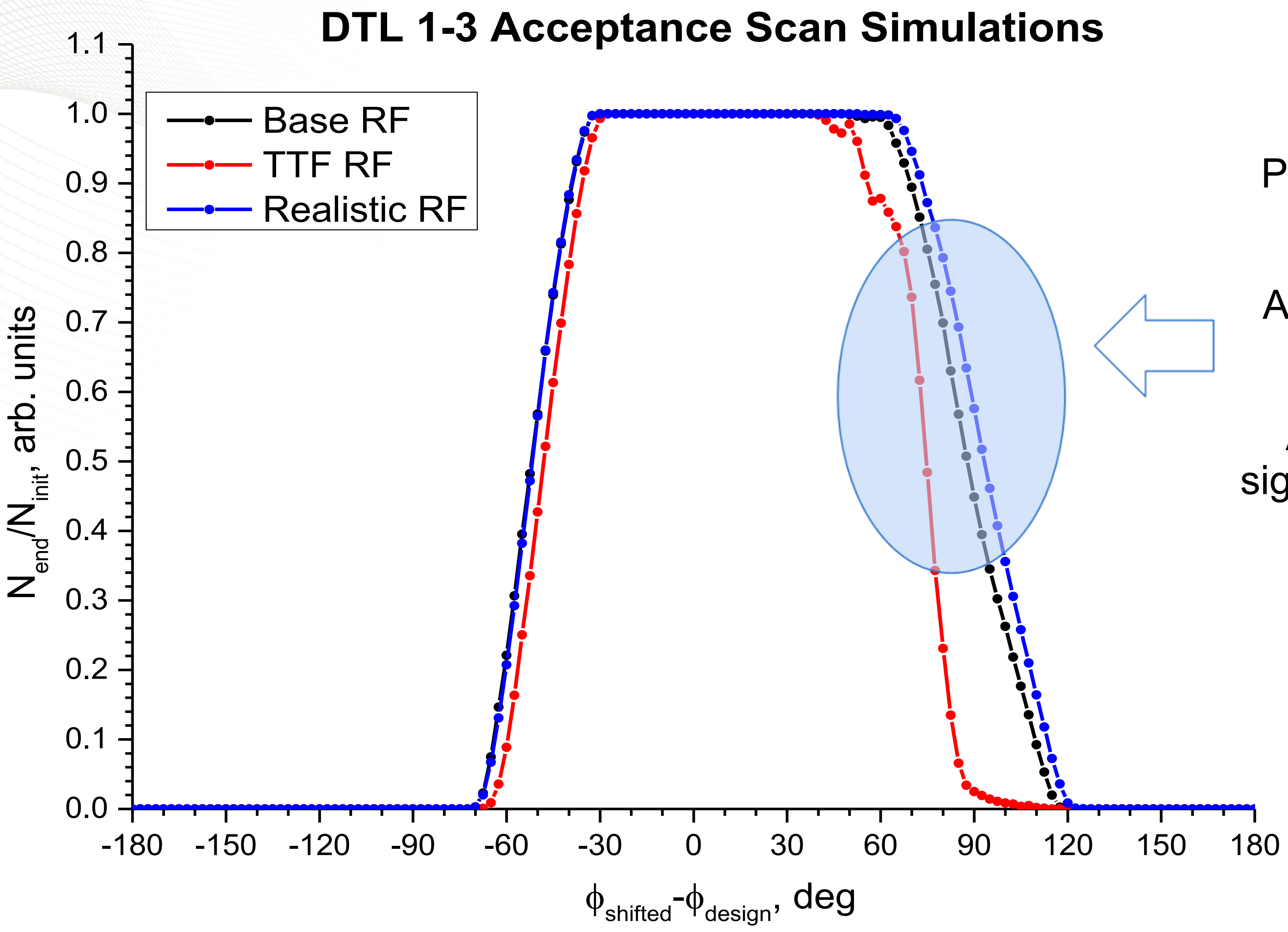
DTL 1-3 Acceptance Scan Simulations



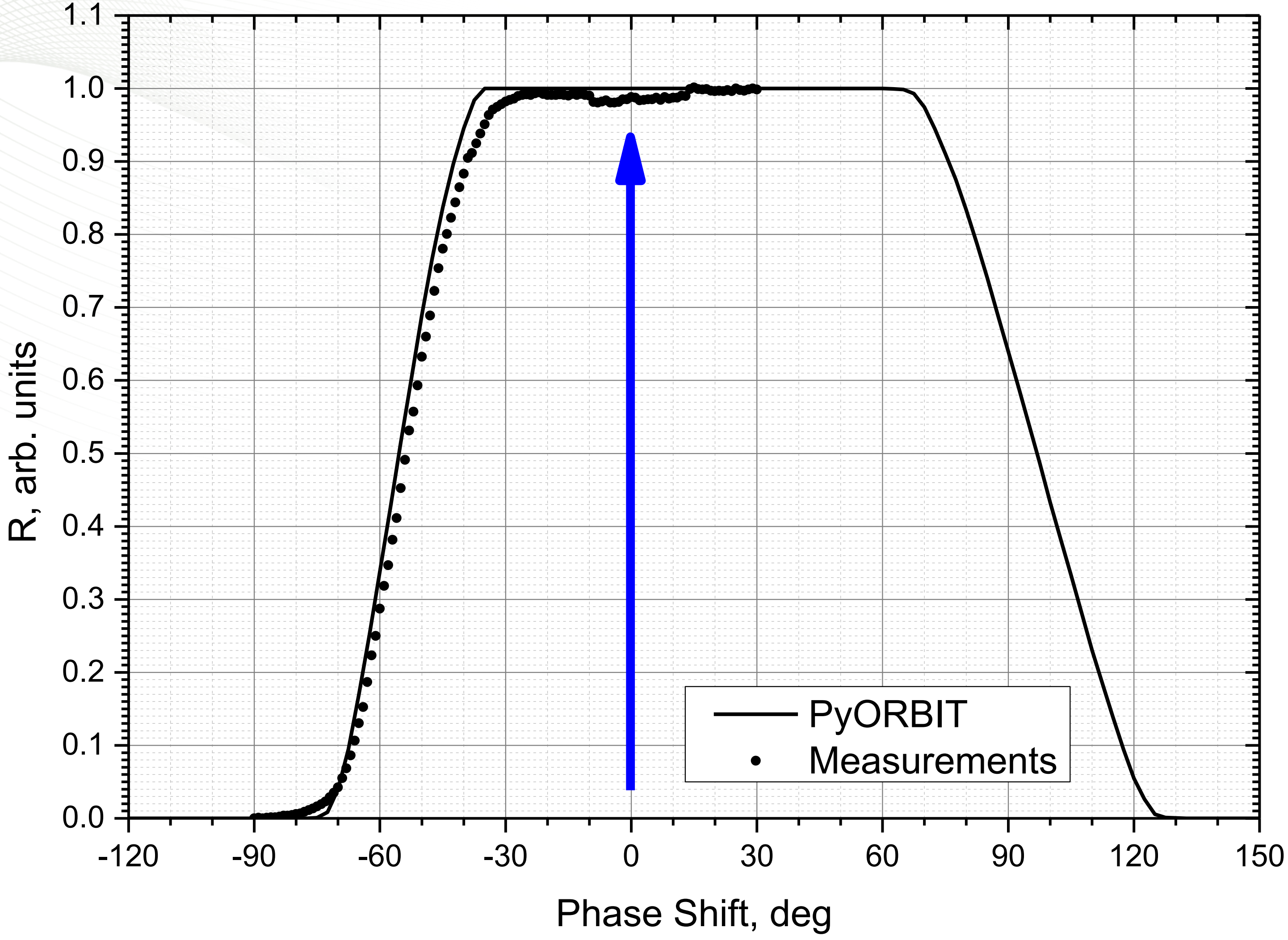
TTF Model is different.

Possible reason – limited range of the TTF polynomial representation.

Anyway, TTF model is not suitable for simulations far from the design.

All this could be checked later after significant PyORBIT code modifications.

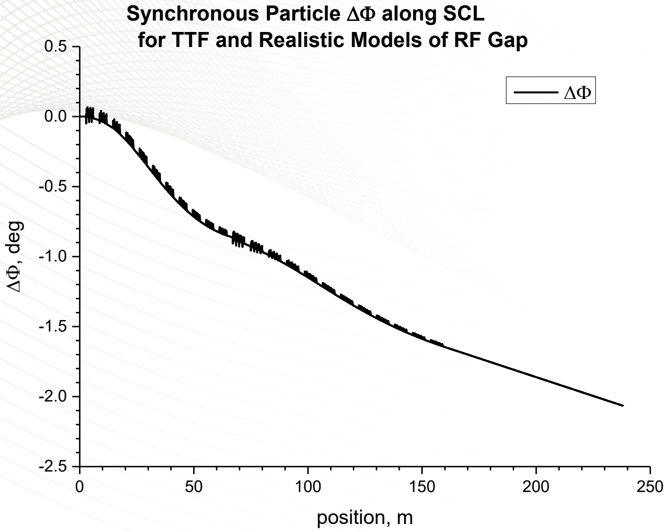
DTL 1-3 Acceptance Scan: Model vs. Experiment

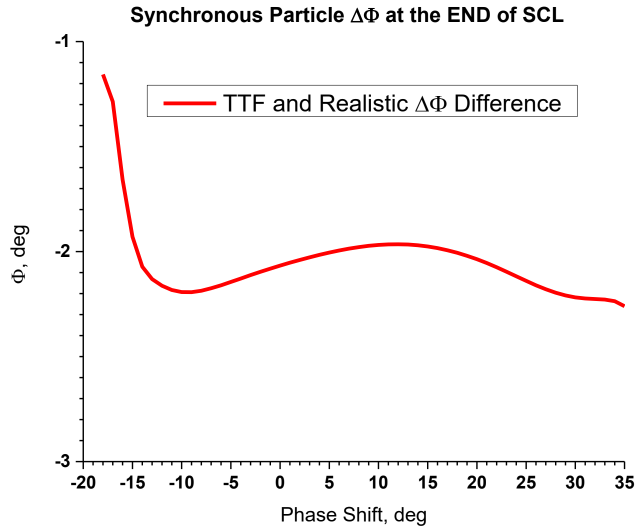


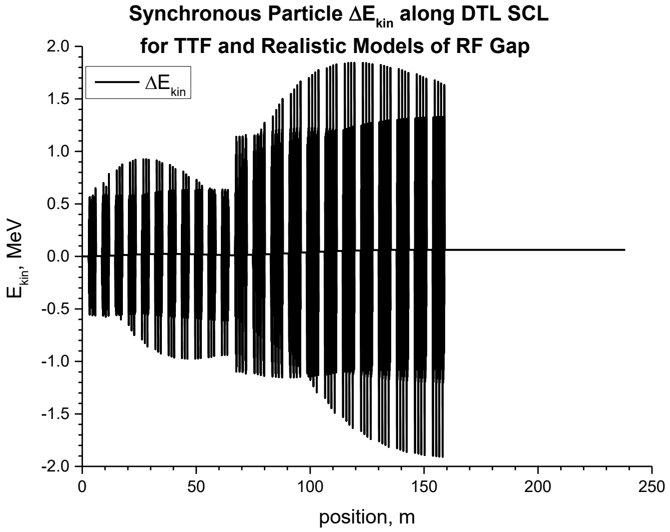
The realistic RF gap model showed not bad results for DTL 1-3 acceptance scan.

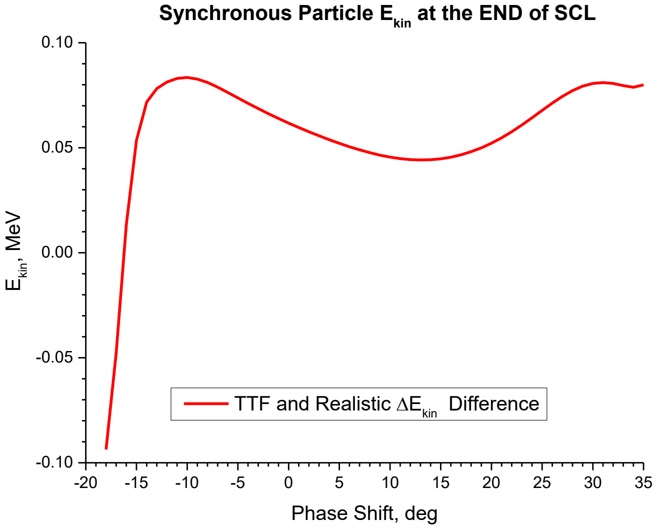
The longitudinal Twiss fitting was not used.

TTF and Realistic Model for SCL



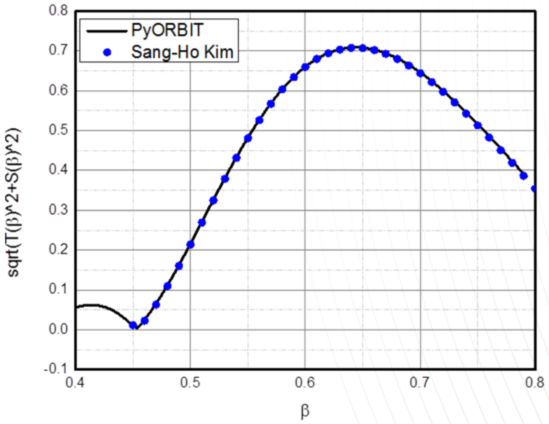






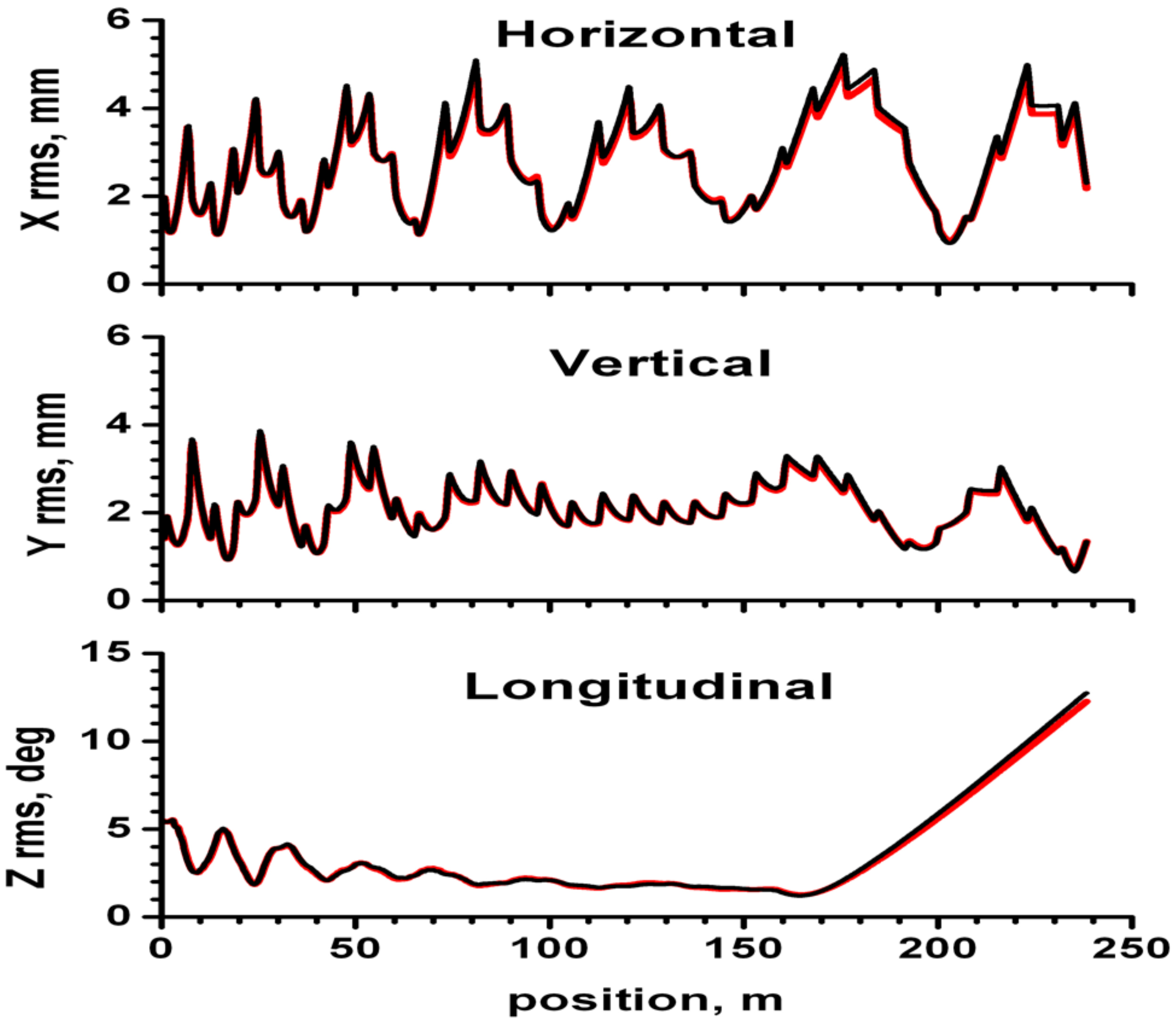
At the end of SCL: phase is 150000 deg, and energy is 1 GeV

- **TTF and Realistic models are practically indistinguishable in SCL: 0.06 MeV energy difference on the top of 1 GeV, and 2 deg particle phase difference in 150000 deg.**
- **The limits in the polynomial representation of TTFs are still there. It means that we cannot use the TTF model for extreme scenarios for SCL (like slow down H- along SCL).**



TTF for the SCL cavity. It is hard to use polynomial fit in the full range of beta.

SCL: PyORBIT – XAL Online Model Benchmark



XAL Online Model is an envelop tracking code

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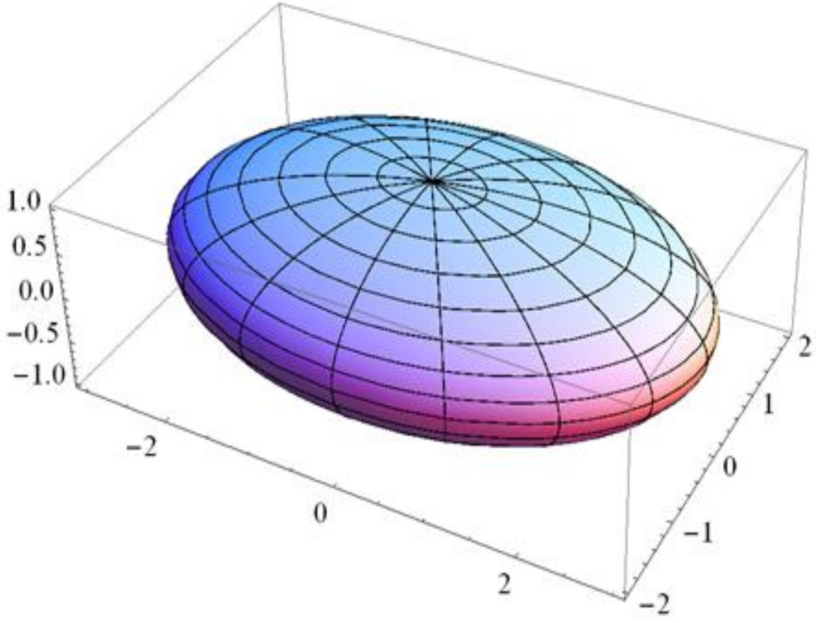
Summary

- **The "thin RF gap with TTFs" model is working well in the region not so far from the design amplitude and phases of the RF cavities. It will work for our warm and cold linacs tuning without any dissections of the RF gaps and iteration schemes.**
- **When we need to simulate the beam far from the design RF parameters (like acceptance scans) we have to use the more realistic model which is much slower.**
- **In the future it will be interesting to replace the polynomial representation of the TTFs by the general functions and to benchmark them against the realistic model again. For envelop models it is not necessary, because we do not trust them anyway when we far from the linear region (design).**

Backup slides

Uniformly Charged Ellipse Solver



$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$

$$\phi(\mathbf{x}) \equiv \int_{V_0} \frac{\rho}{|\mathbf{x} - \mathbf{x}'|} \, dV(\mathbf{x}')$$

$$\phi(x,y,z) = \pi\, abc\, \rho \int_0^\infty \left[1 - \frac{x^2}{a^2+s} - \frac{y^2}{b^2+s} - \frac{z^2}{c^2+s}\right] \frac{ds}{\sqrt{\varphi(s)}}$$ inside

$$\phi(x,y,z) = \pi\, abc\, \rho \int_\lambda^\infty \left[1 - \frac{x^2}{a^2+s} - \frac{y^2}{b^2+s} - \frac{z^2}{c^2+s}\right] \frac{ds}{\sqrt{\varphi(s)}}$$ outside

$$\varphi(s) \equiv (a^2+s)(b^2+s)(c^2+s) \qquad f(s) \equiv \frac{x^2}{a^2+s} + \frac{y^2}{b^2+s} + \frac{z^2}{c^2+s} - 1$$

where λ is the greatest root of the equation $f(s) = 0$

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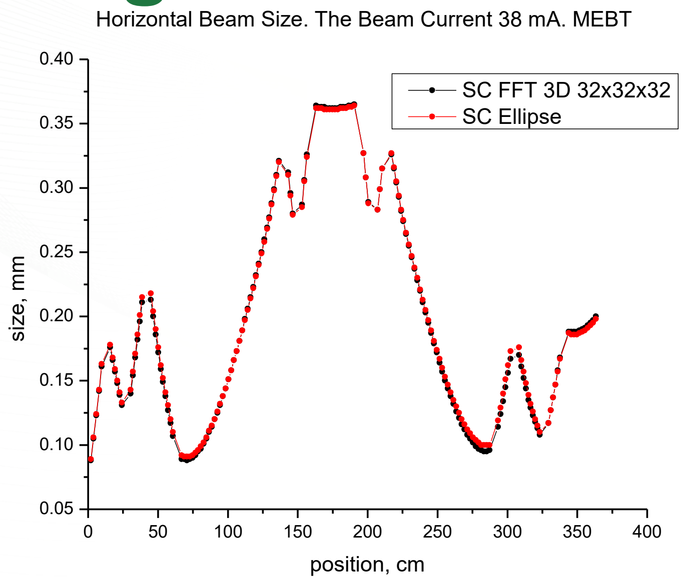
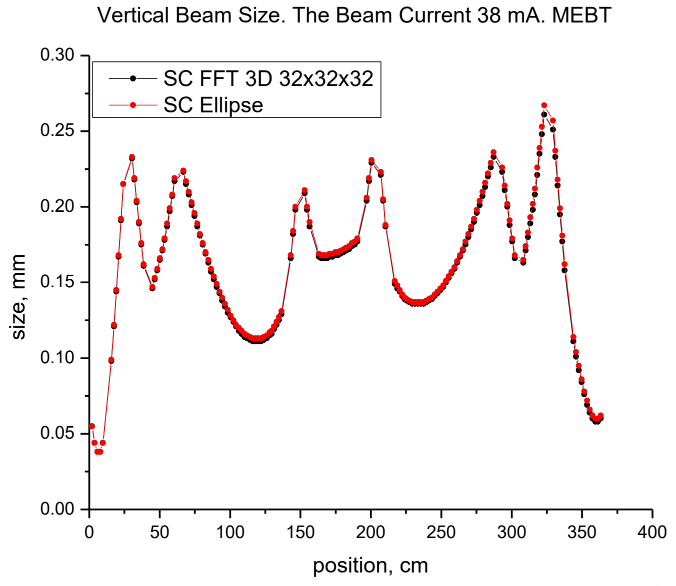
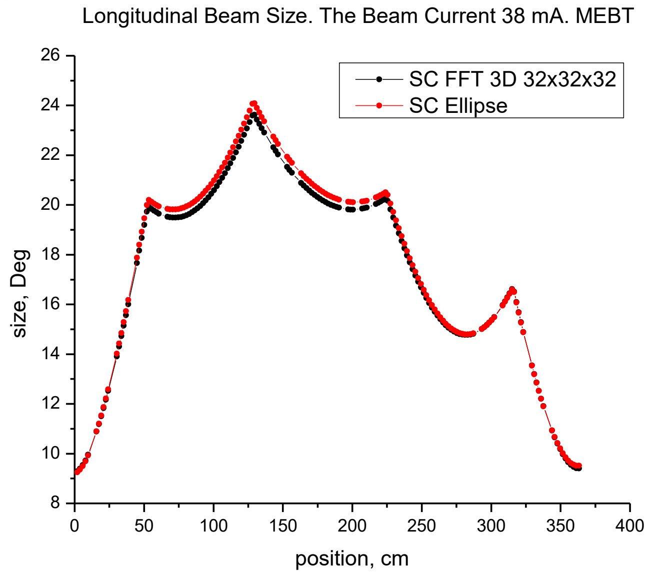
Space Charge: 3D FFT & Ellipsoid - MEBT

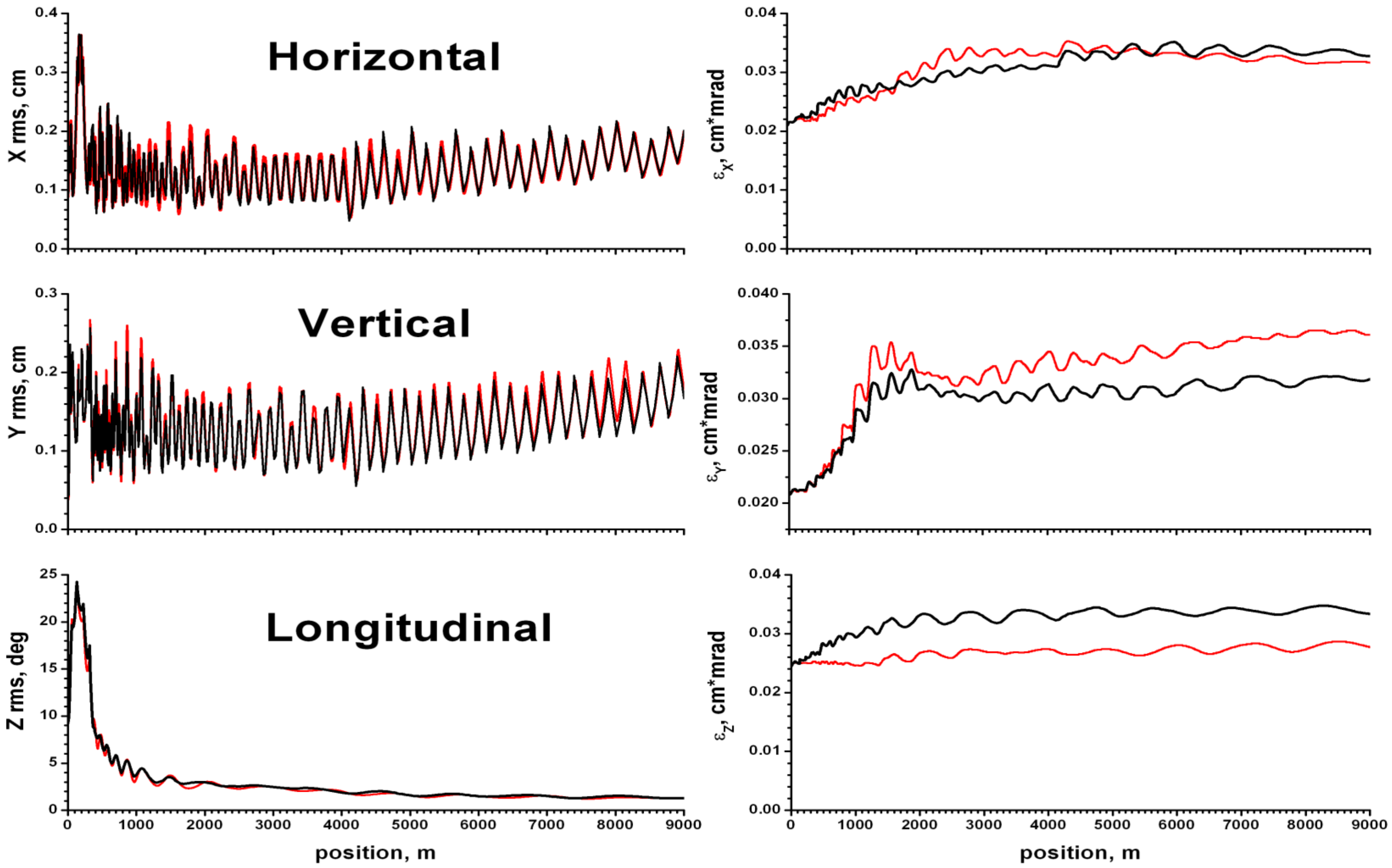






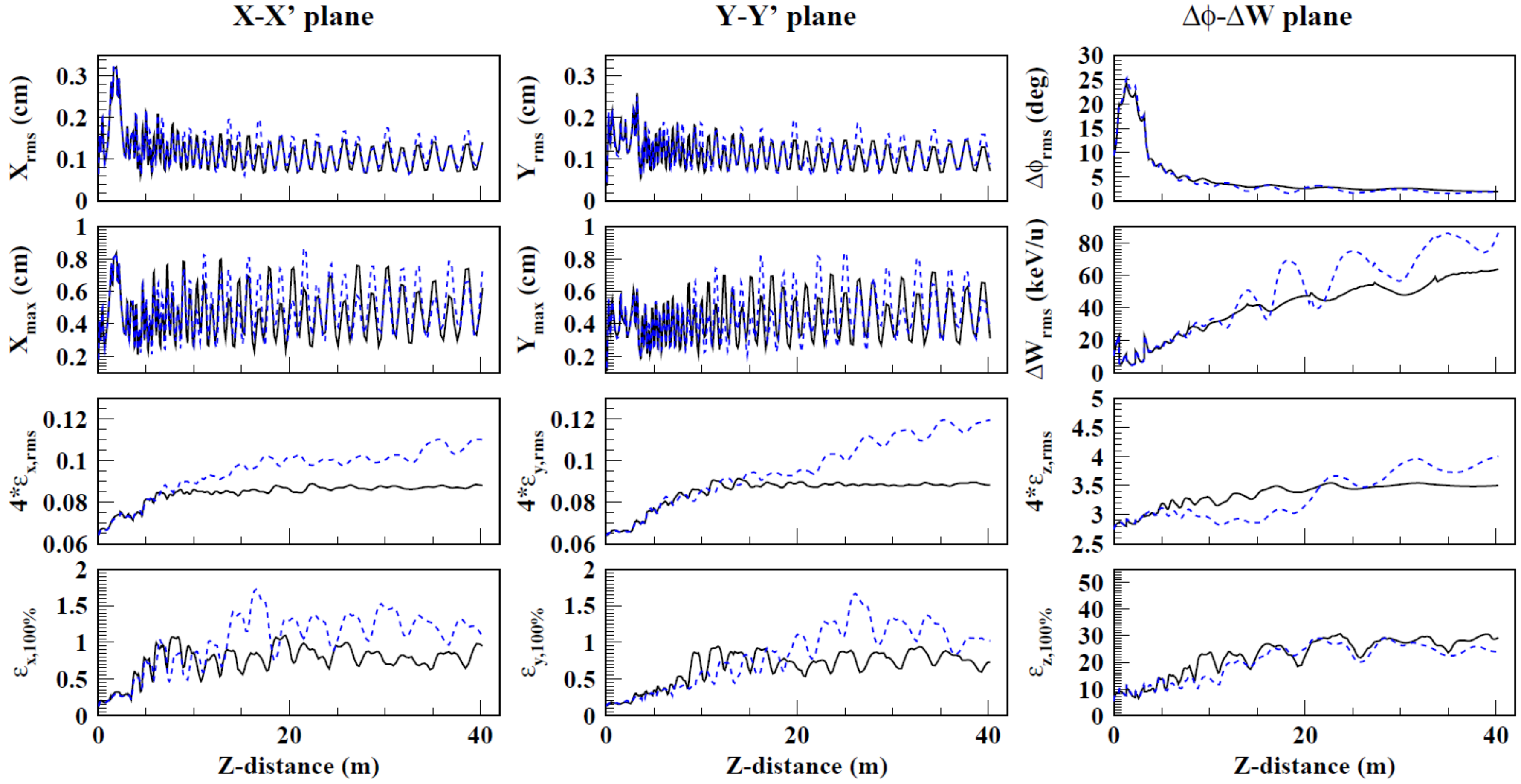
Water Bag 3D, 38 mA
2,000 macro-particles for Ellipse SC
20,000 macro-particles for 3D FFT
32 x 32 x 32 grids
1.3 sec for Ellipse SC
4.6 sec for FFT 3D

PyORBIT–Parmila Benchmark – MEBT-DTL-CCL



MEBT-DTL-CCL = 90 meters, PyORBIT (red)   Parmila (black)

Track-Parmila Benchmark – LINAC'06



DTL only - 40 meters, Blue – Track code

B. Mustapha, "First Track Simulation of the SNS Linac," LINAC'06, Knoxville, TN 2006, TUP076, p. 432 (2006); http://www.JACoW.org