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The 7MeV APF DTL for Proton Therapy

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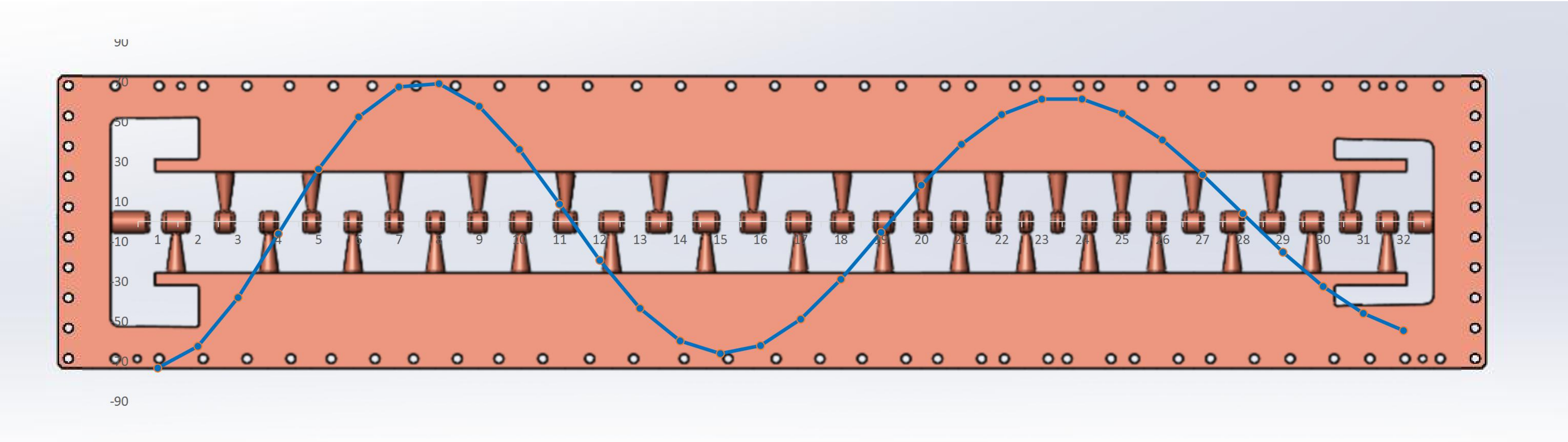
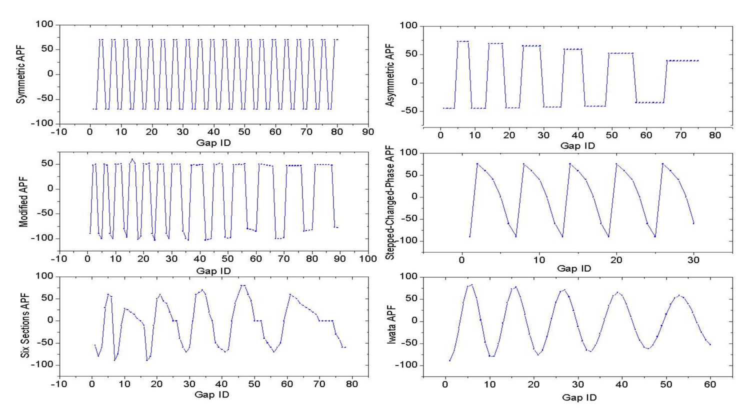
A Abstract

A design principle with robust considerations has been applied to design a new alternating phase focused (APF) drift tube linear accelerator (linac) for particle beam therapy. By assuming a sinusoidal synchronous phase formula and a linearly increasing electrode voltage scheme, the structure of the APF linac is automatically optimized with a cost function including robustness using the nonlinear correlated stacking optimization method (CSM). The design procedure includes the radio frequency quadrupole (RFQ) to drift tube linac (DTL) matching, and an end-to-end simulation of the APF acceleration beam dynamics. Moreover, the stability of the solution obtained is analyzed with respect to various independent errors as well as a number of joint errors. The designed APF DTL linac together with an already established RFQ is planned to replace the existing Alvarez-type permanent magnet focused DTL linac aiming at easier manufacturing and cost reduction.

B Iwata Synchronous Phase Formula & Two Assumptions



Alternating Phase Focusing - Drift Tube Linac (APF DTL) is a linac made up by RF gaps with alternative positive and negative synchronous phase. The beam feels longitudinal defocusing effect and transversal focusing effect when passing through positive accelerating RF gap; while the bunch feels longitudinal focusing effect but transversal defocusing effect when passing through negative accelerating RF gap. According to strong focusing principle, the whole structure could provide particle beam bunching and acceleration effect.

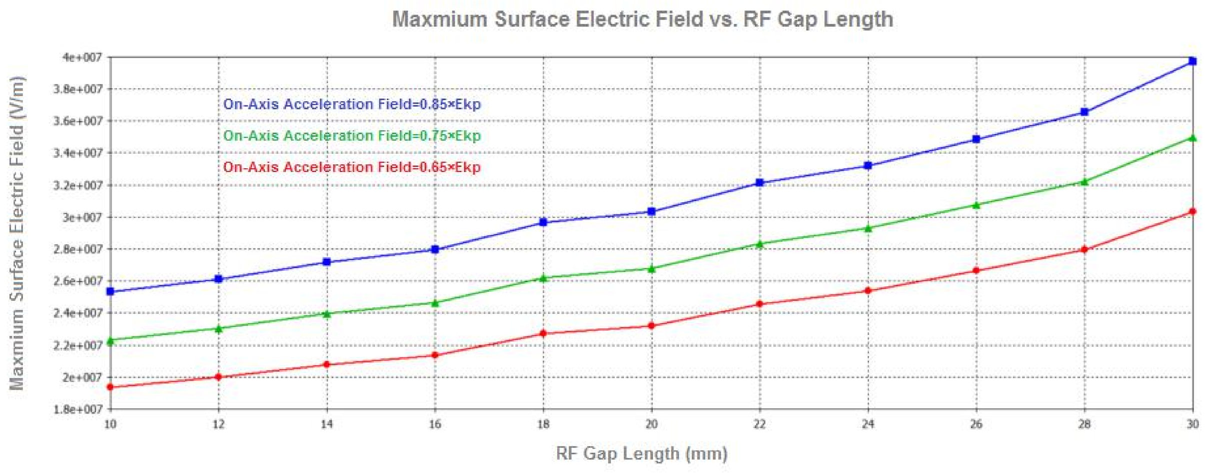


Due to APF character，beam dynamics is solely decided by the synchronous phase，therefore it is the most crucial question in the design stage.

Iwata Phase Formula

$$\phi_s(n) = \phi_0 e^{-a\cdot n}\sin\left(\frac{n-n_0}{b\cdot e^{c\cdot n}}\right)$$

Maxmium Surface Electric Field vs. RF Gap Length



1 The voltage of the electrode is linear increasing

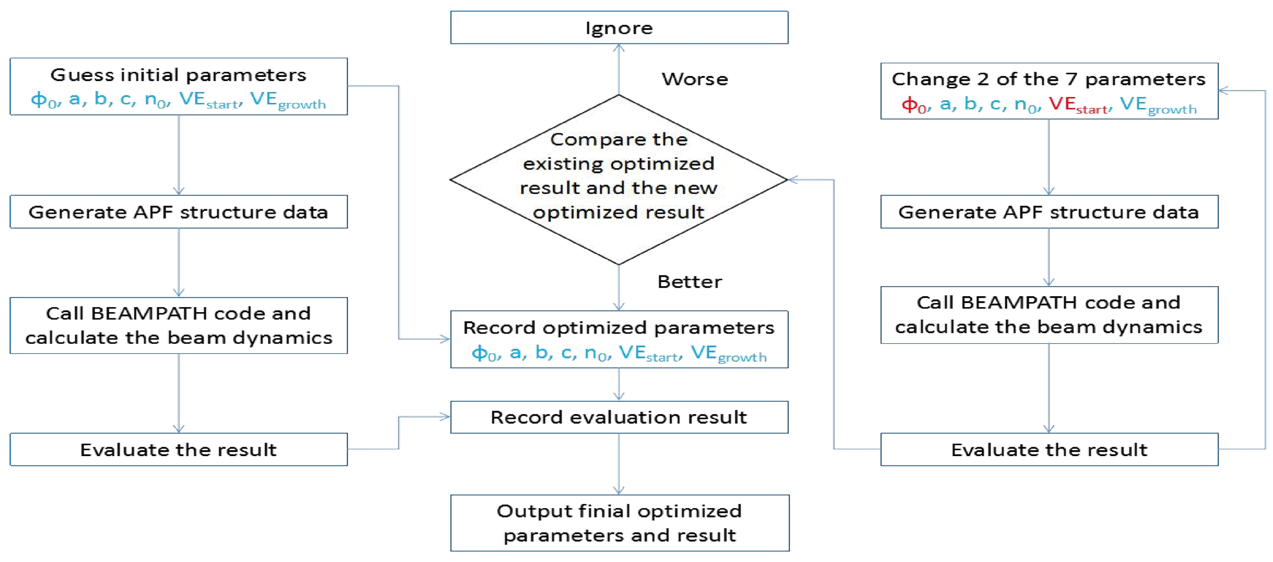
$$VE_n = VE_0 + (n-1)\cdot \Delta VE$$

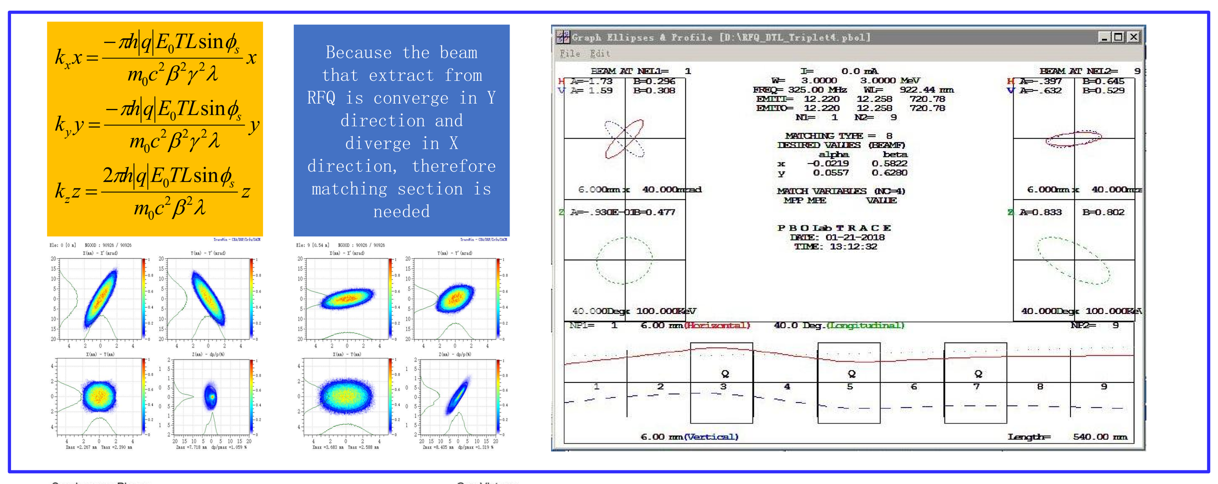
2 The electric field of the accelerating gap is an constant

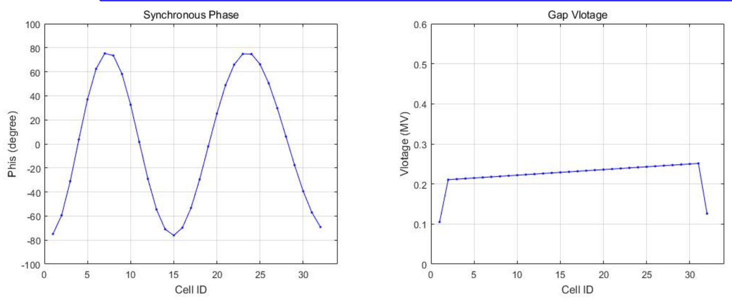
$$L_n = V_n / E$$

C The Automatic Optimization Code and Design Result

Seven Variables：ϕ_0, a, b, c, n_0, VE_0, ΔVE

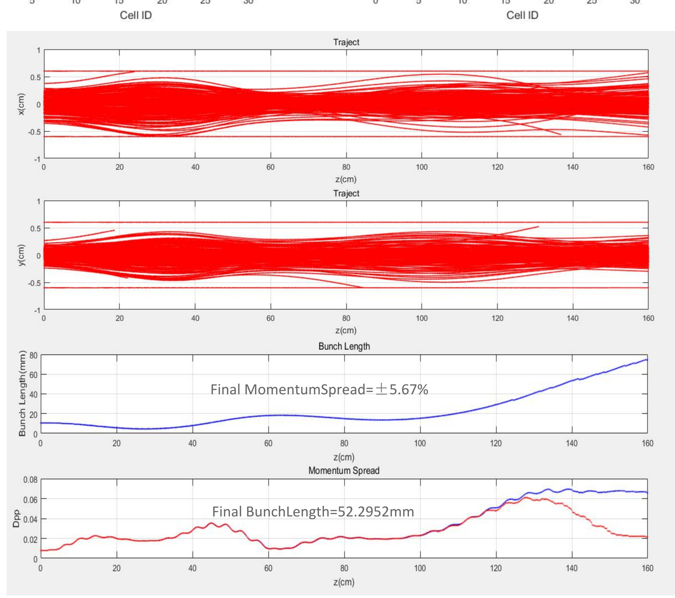




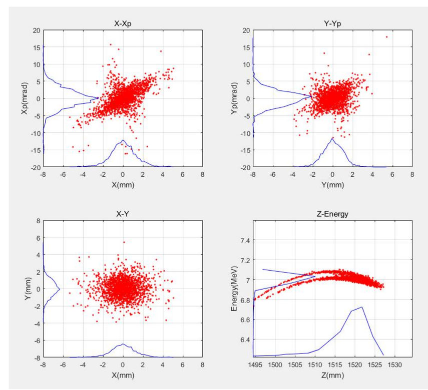


- ϕ_0=74
- a=0.007375
- b=1.925
- c=0.006625
- n_0=-8.25
- VE0=0.0805 (MV)
- ΔVE=0.00165 (MV)

Item	Value	Unit
Particle	H^+	/
Cell Number	32	/
Injection Energy	3	MeV
Extraction Energy	7	MeV
Operation Frequency	325	MHz
On Axis Acceleration Field	8.9 (0.5×EKp)	MV/m
Drift Tube Radius	6	mm



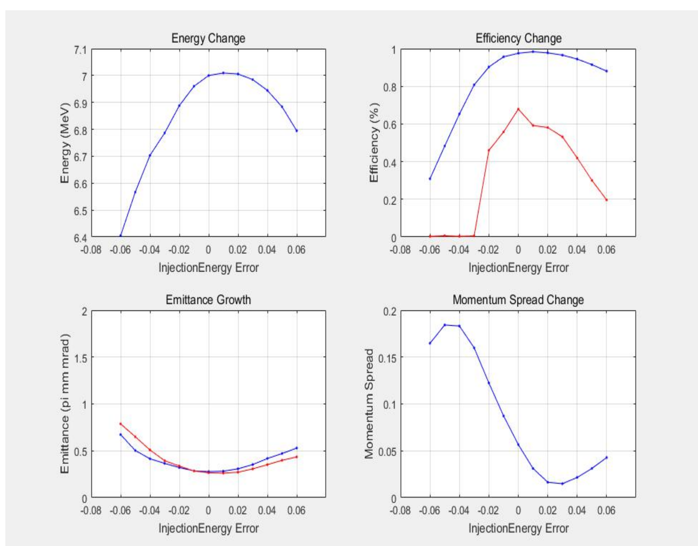
Item	Value	Unit
Final Energy	7.0000/7.0428	MeV
Total Length	1.5056	m
Total Transmission	97.55	%
Effective Transmission	67.9	%
Final Emittance X	0.2777	π·mm·mrad
Final Emittance Y	0.2660	π·mm·mrad
Final Bunch Length	52.2952	mm
Final Momentum Spread	0.0567	/
Maximum Surface Field	26.0739(1.46Ekp)	MV/m

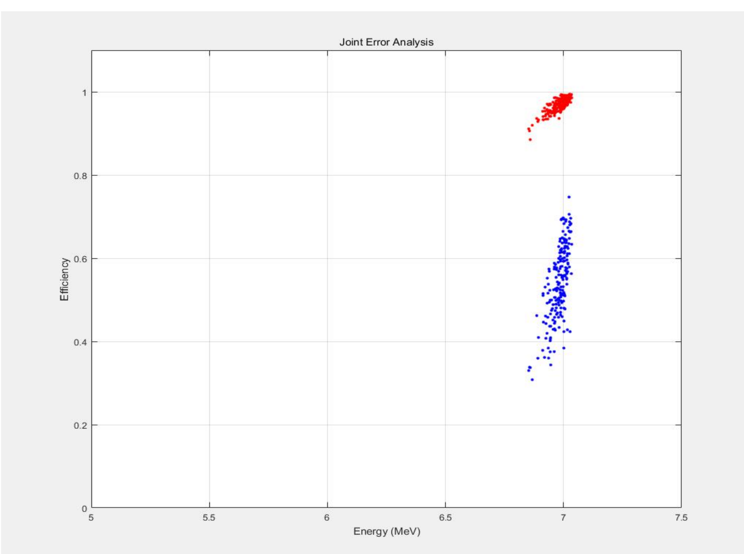


D Error Analysis & End-to-end Simulation

The APF DTL is very sensitive to Injection Energy Error and RF Amplitude Error

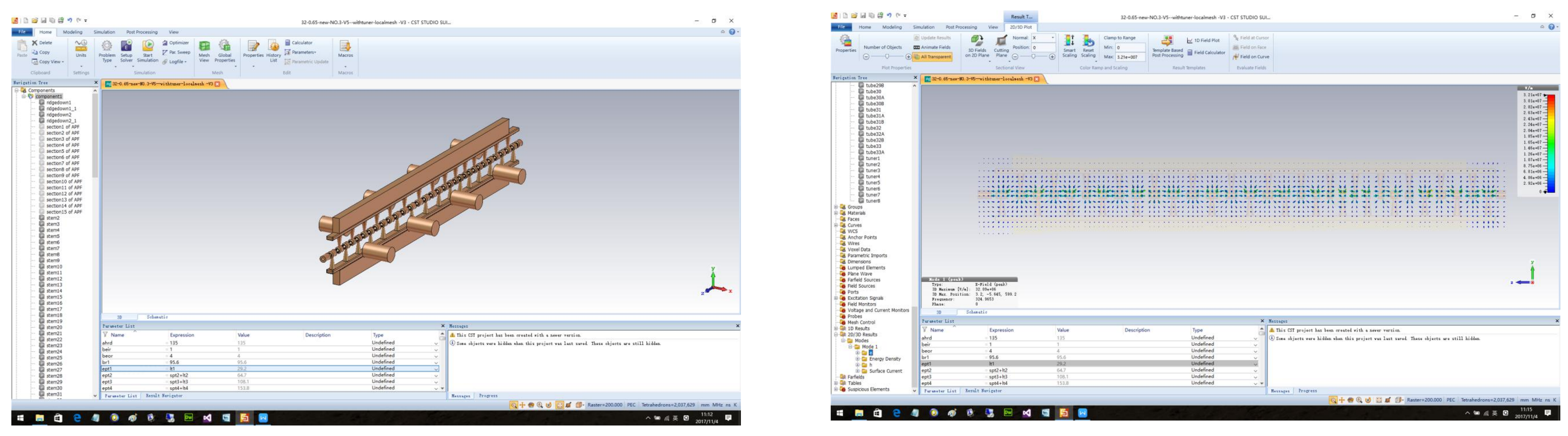
- Beam Center Error X/Y
- Injection Emittance Error X/Y
- Injection Phase/Time Error
- Bunch Length Error
- Injection Energy Error
- Momentum Spread Error
- Acceleration Field Error
- Mechanical Error

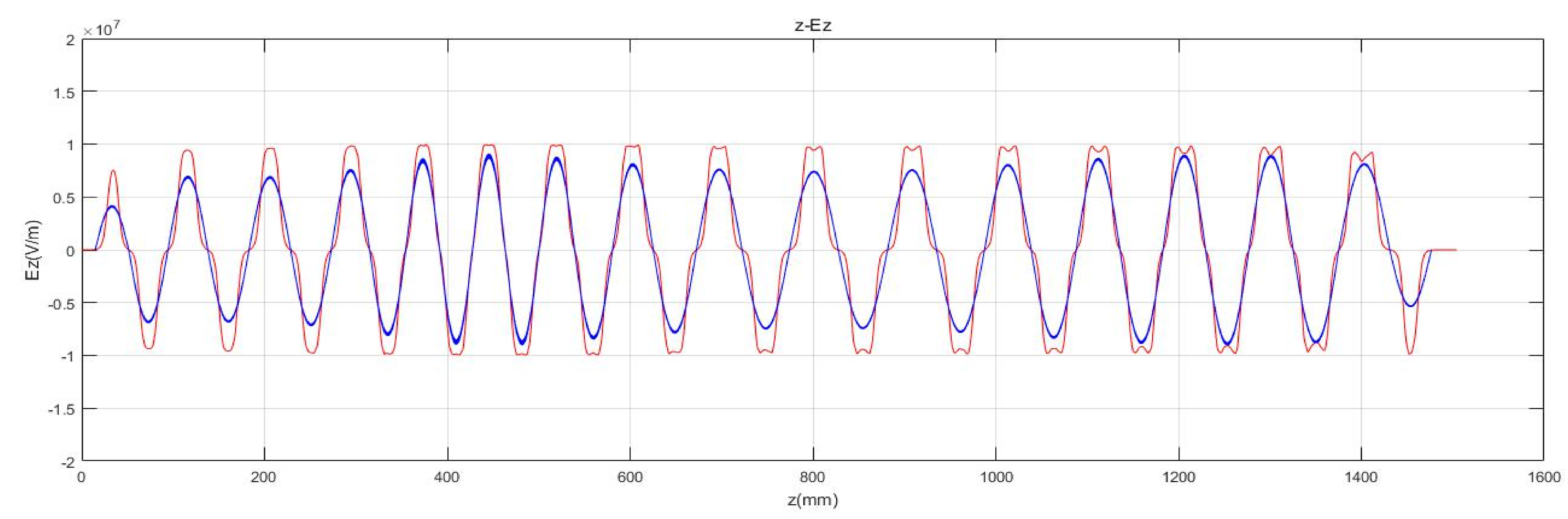


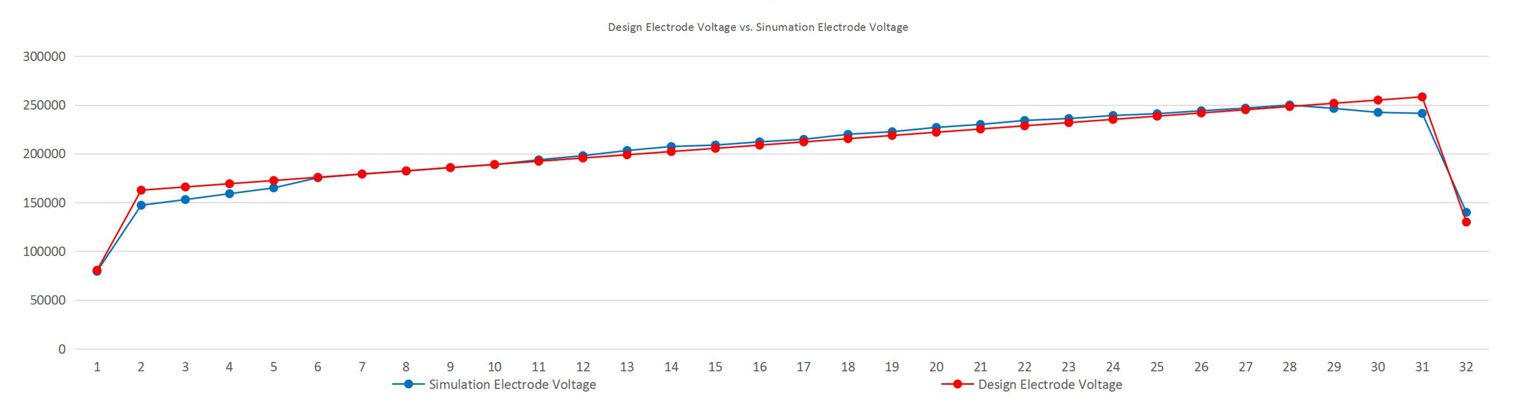


Error type	Error Range	Error type	Error Range
X position	±0.01mm	X Emittance	±20%
Y position	±0.01mm	Y Emittance	±20%
X angle	±0.01mrad	Bunch Length	±20%
X angle	±0.01mrad	Momentum Spread	±20%
Phase	±1degree	Cavity Field	±1%
Injection Energy	±0.01MeV	Mechanical	±50um

Electromagnetic design with Microwave Studio CST







End-to-end Simulation with Tracewin