The 7MeV APF DTL for Proton Therapy

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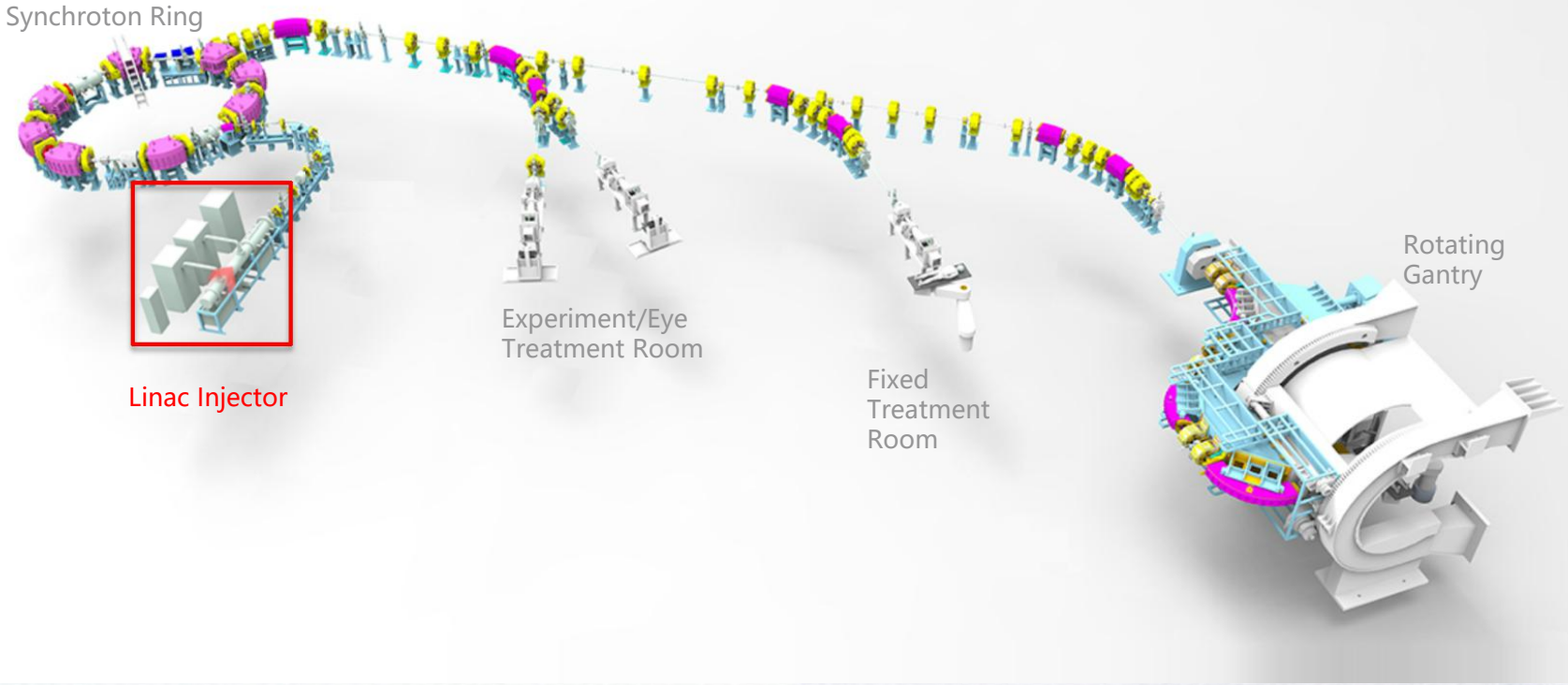
1.1 The Proton Therapy Facility in Rui-Jin Hospital, Shanghai

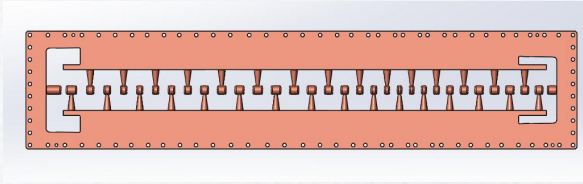
APTRON--Advance Proton Therapy Facility



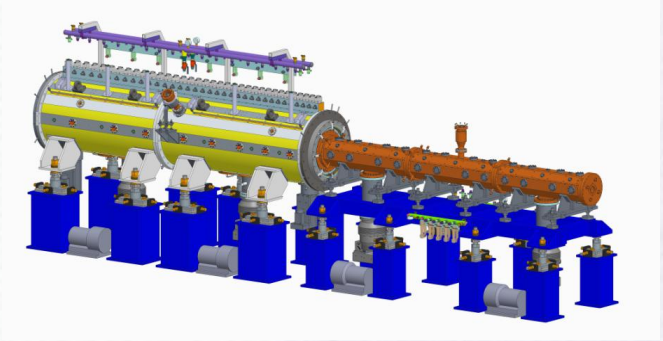
1.2 Road Map of Injector Project

The injector buy from ACCSYS (Hitachi)

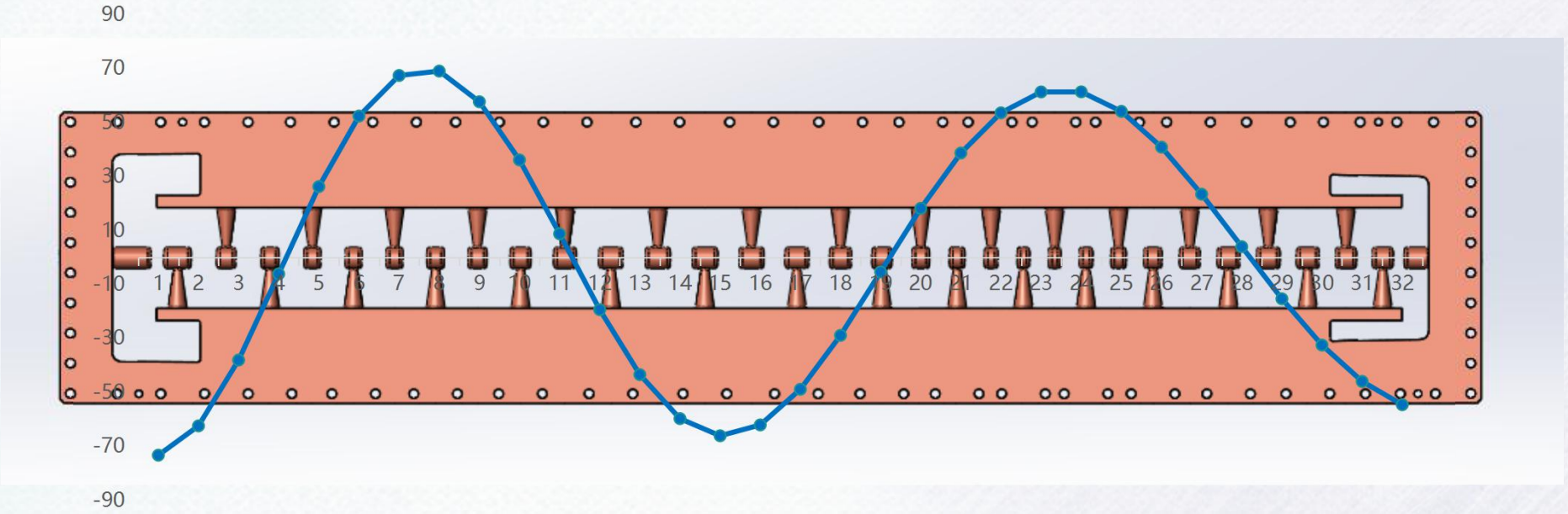
The RFQ+APF DTL developed by SINAP



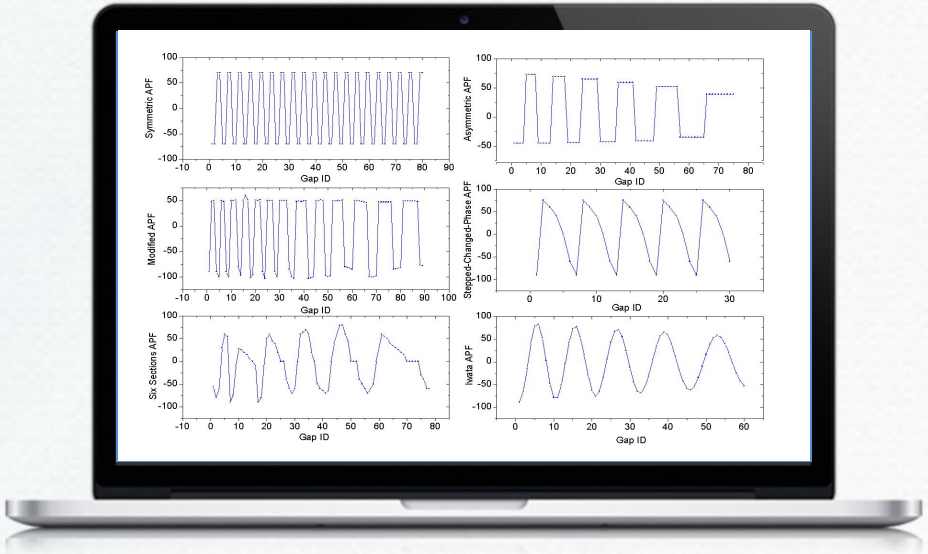
The RFQ+Alvarez DTL cooperate with Tsinghua University



2.1 The Alternating Phase Focusing (APF) Principle



2.2 APF Synchronous Phase Formula

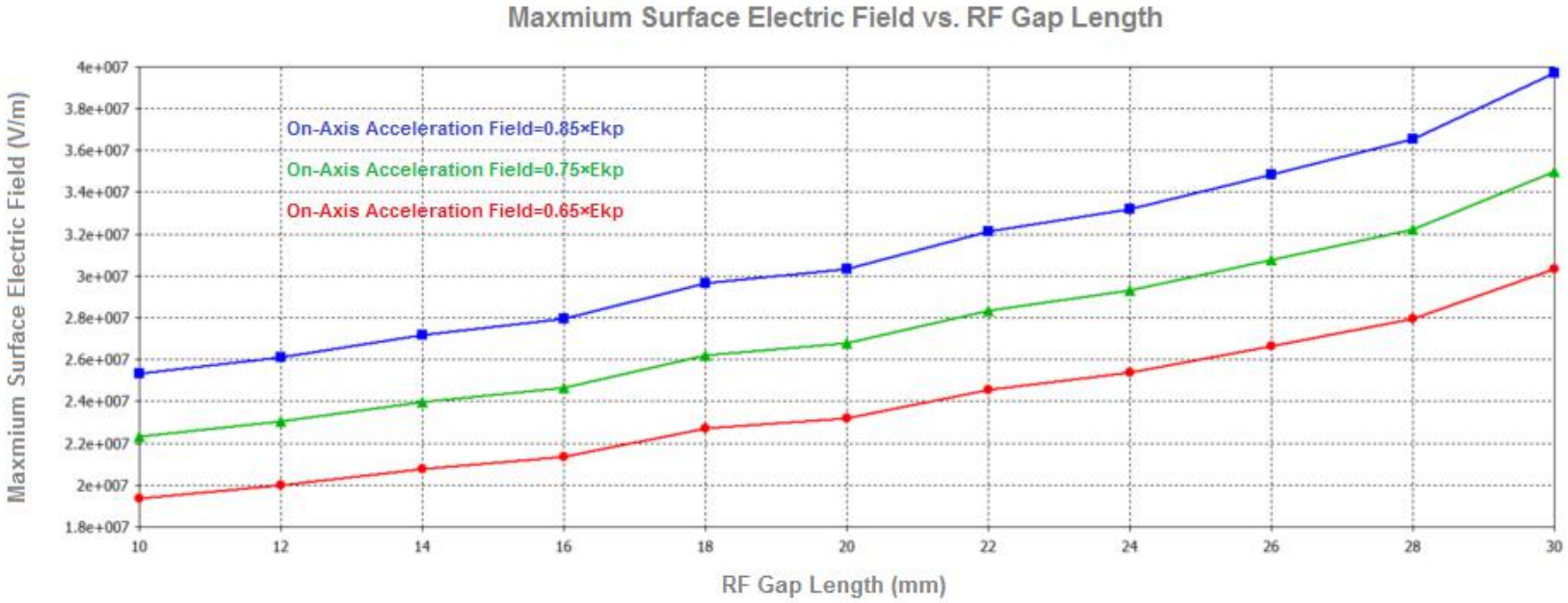


The synchronous phase sequence is the crucial question in APF design.

Iwata Phase Formula

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

2.3 Maxmium Surface Electric Field & Electrode Assumptions



Two Assumptions

1 The voltage of the electrode is linear increasing

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

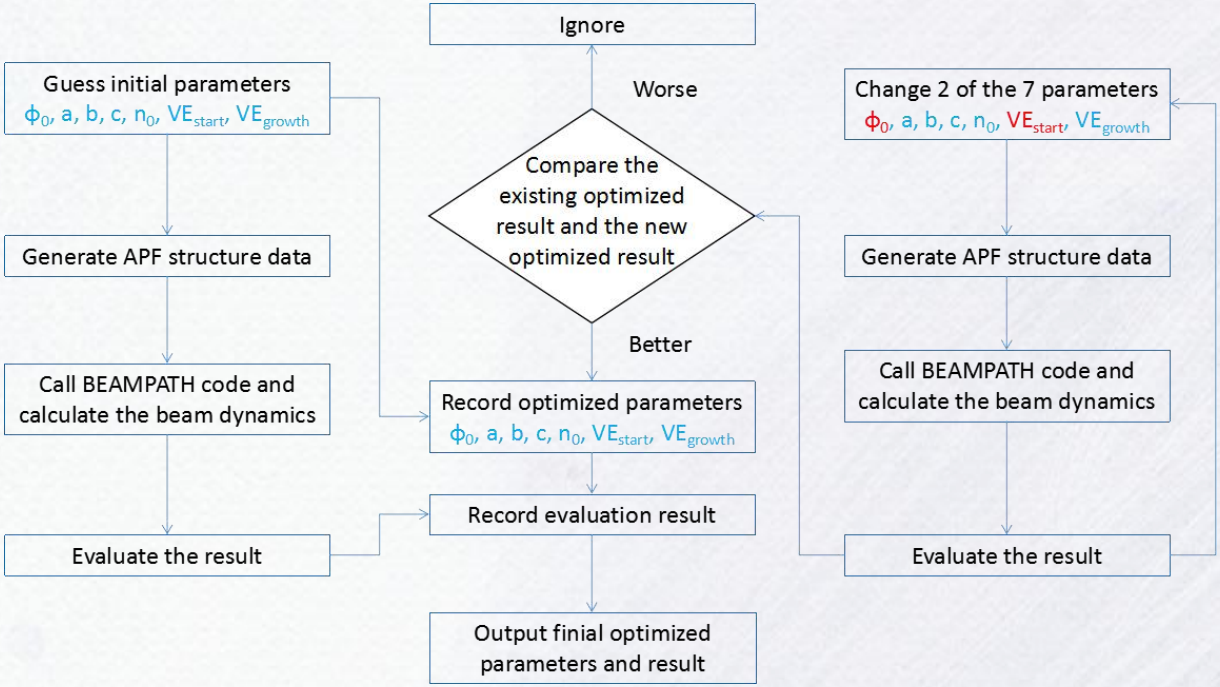
2 The electric field of the accelerating gap keep constant

$$L_n = V_n / E$$

2.4 Automatic Optimization Code

7 Variables :
ϕ0, a, b, c, n0,
VE0, ΔVE

Non-Linear
Correlated
Stacking
Optimization
Method

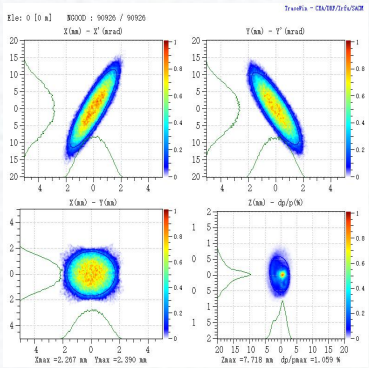


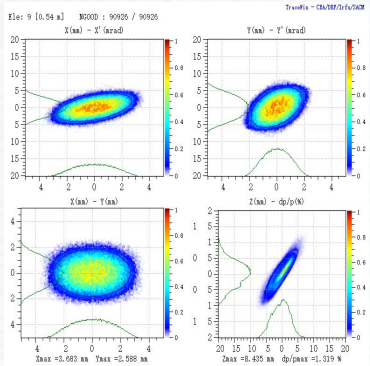
3.1 RFQ to DTL Matching

$$k_x x = \frac{-\pi h|q|E_0 TL\sin\phi_s}{m_0 c^2 \beta^2 \gamma^2 \lambda} x$$

$$k_y y = \frac{-\pi h|q|E_0 TL\sin\phi_s}{m_0 c^2 \beta^2 \gamma^2 \lambda} y$$

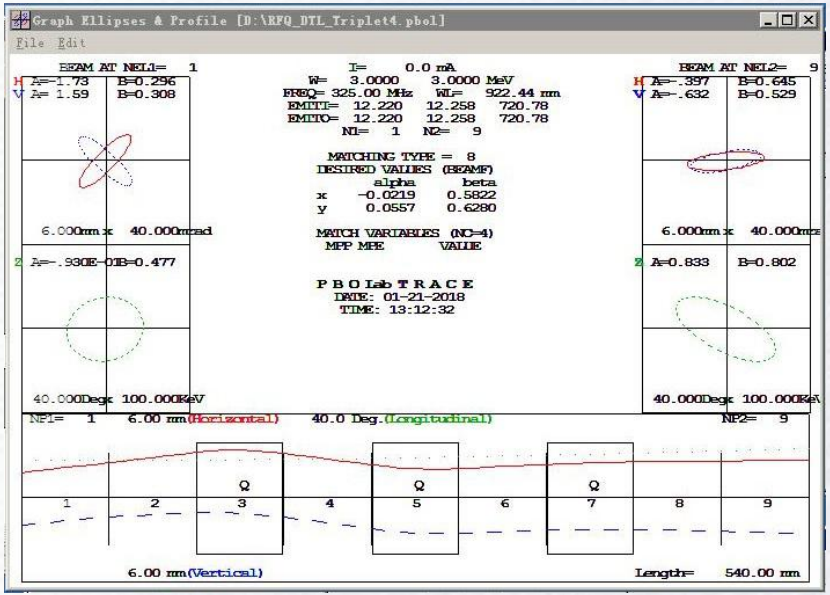
$$k_z z = \frac{2\pi h|q|E_0 TL\sin\phi_s}{m_0 c^2 \beta^2 \lambda} z$$



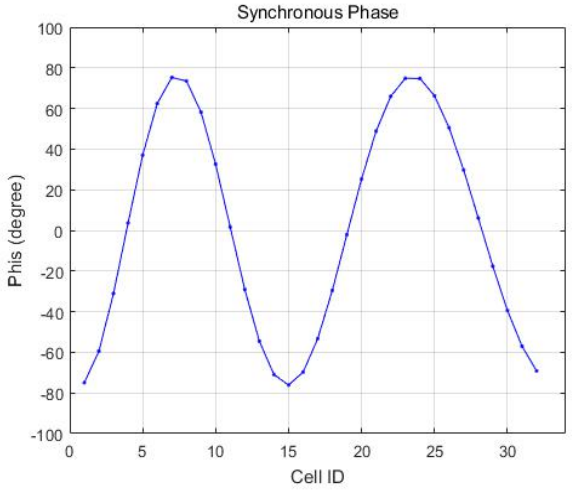


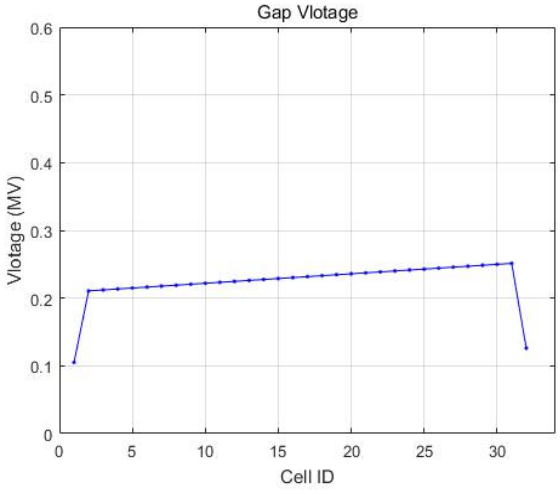
Because the beam that extract from RFQ is converge in Y direction and diverge in X direction, therefore matching section is needed

Matching Section



3.2 Basic Parameters

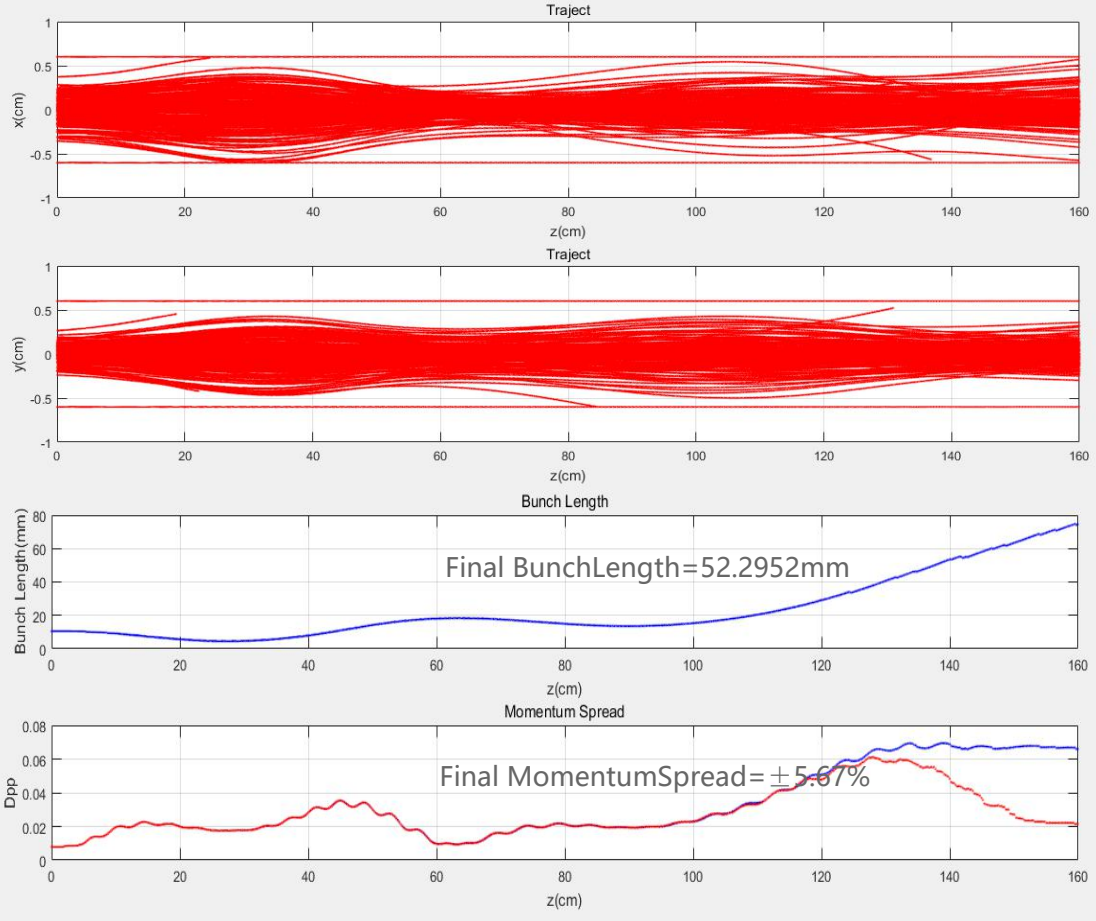


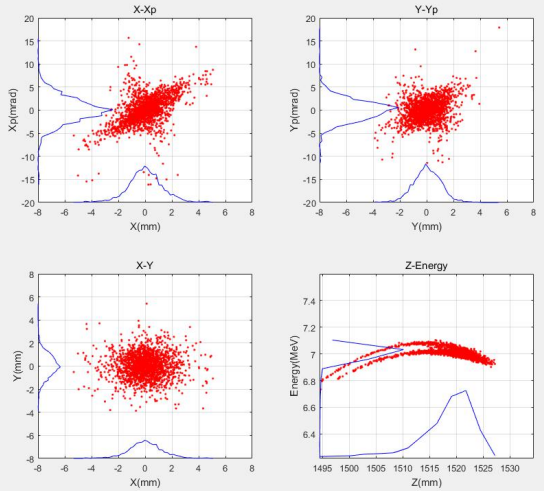


- ϕ_0=74
- a=0.007375
- b=1.925
- c=0.006625
- n_0=-8.25
- VE0=0.0805 (MV)
- ΔVE=0.00165 (MV)

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

3.3 Beam Envelop and Ellipse



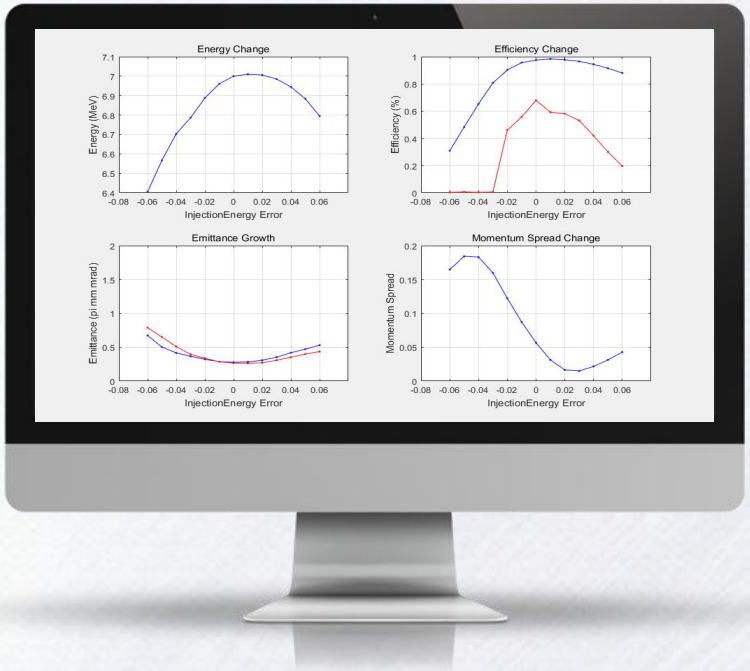


Item	Value	Unit
Final Energy	7.0000/7.0428	MeV
Total Length	1.5056	m
Total Transmission	97.55	%
Effective Transmission	67.9	%
Final Emittance X	0.2777	π·mm·mrad
Final Emittance Y	0.2660	π·mm·mrad
Final Bunch Length	52.2952	mm
Final Momentum Spread	0.0567	/
Maximum Surface Field	26.0739(1.46Ekp)	MV/m

4.1 Individual Error Analysis

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

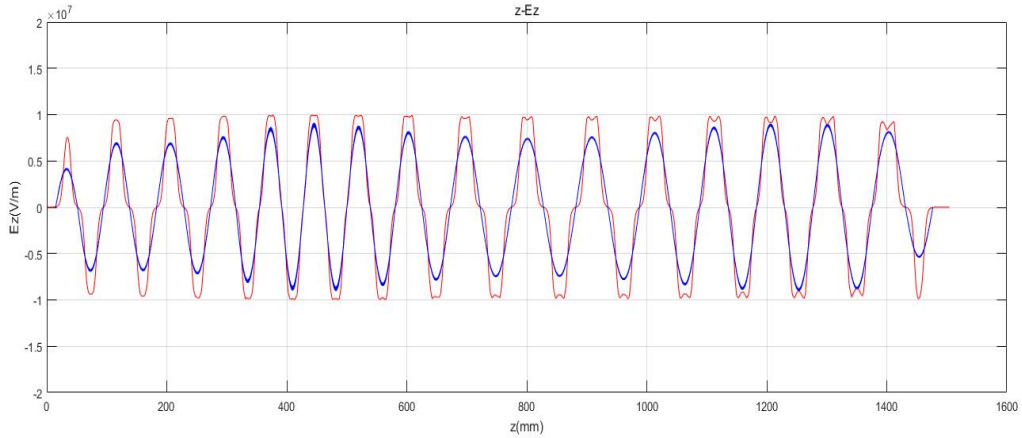
- Beam Center Error X/Y
- Injection Emittance Error X/Y
- Injection Phase/ Time Error
- Bunch Length Error
- Injection Energy Error
- Momentum Spread Error
- Acceleration Field Error
- Mechanical Error

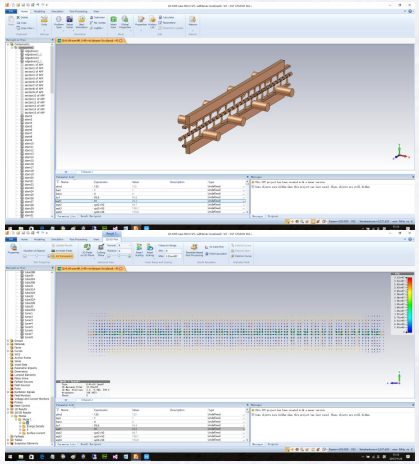


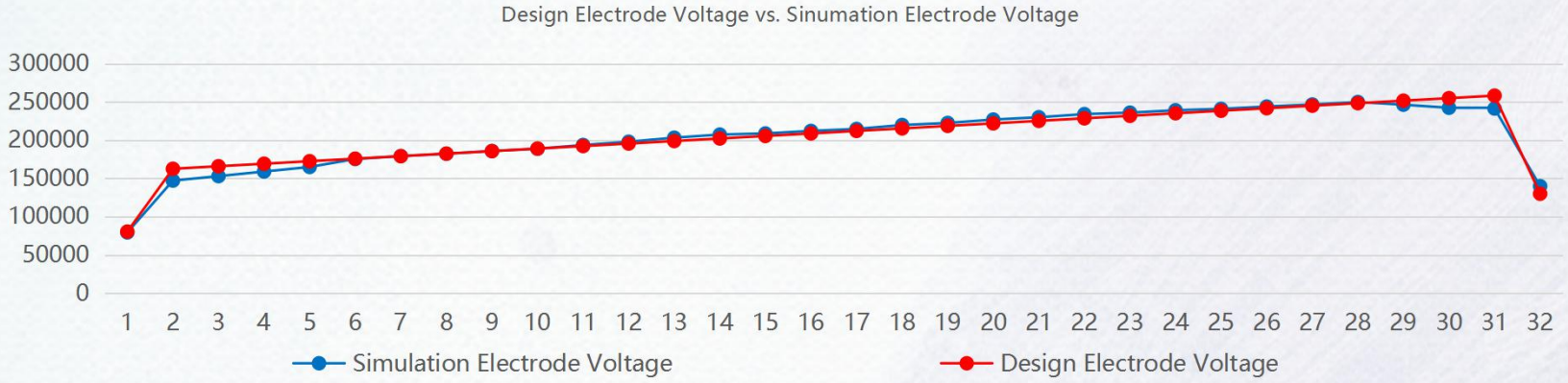
4.2 Joint Error Analysis

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

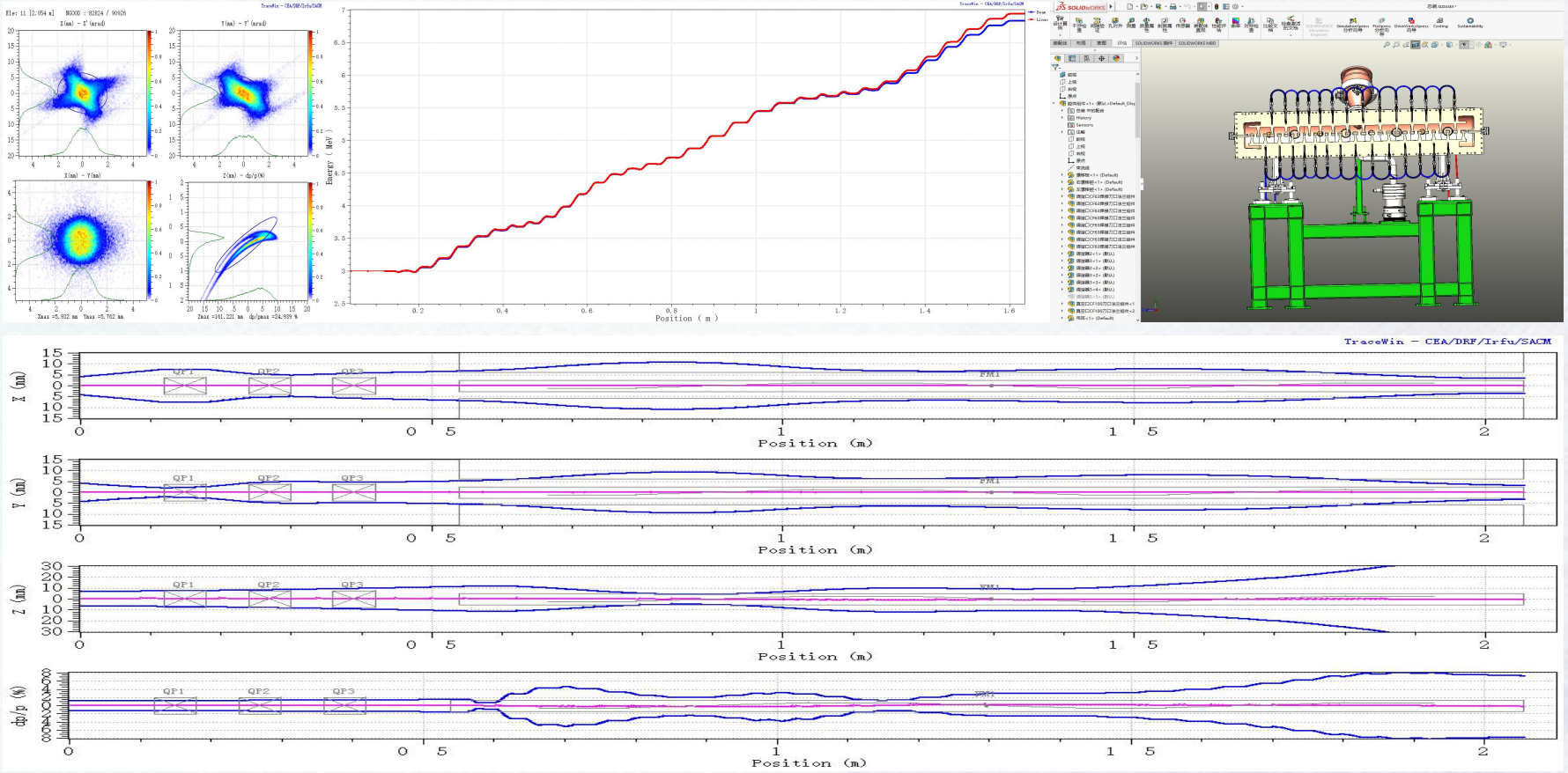
5.1 Electromagnetic Design







5.2 End-to-end Simulation




Thank you !