Beam Dynamics of the 13MeV/50mA Proton Linac for the Compact Pulsed Hadron Source at Tsinghua University

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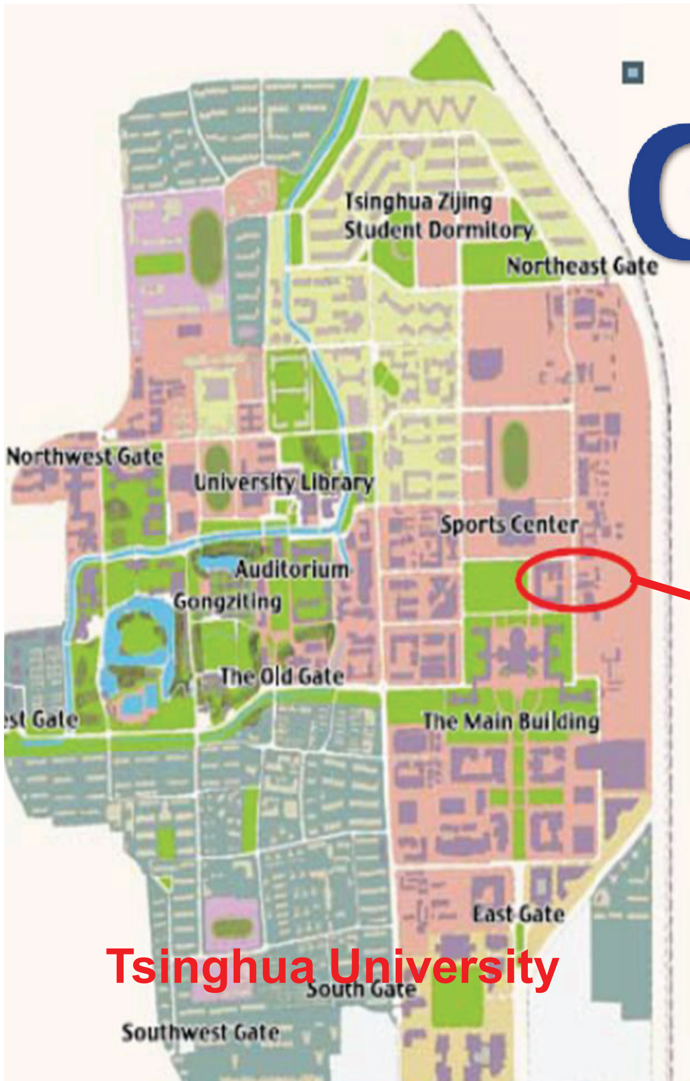
CONTENT

1. Introduction

CPHS 微型脉冲强子源
Compact Pusled Hadron Source
TSINGHUA UNIVERSITY



CPHS+TTX:

- Network of accelerator-driven proton, neutron, electrons, x-ray, and laser
- Experimental platforms for education, research, and innovative applications

TSINGHUA University 清华大学

Thomson scattering X-ray source 汤姆逊散射实验平台

1. Introduction

CPHS (Compact Pulsed Hadron Source) project

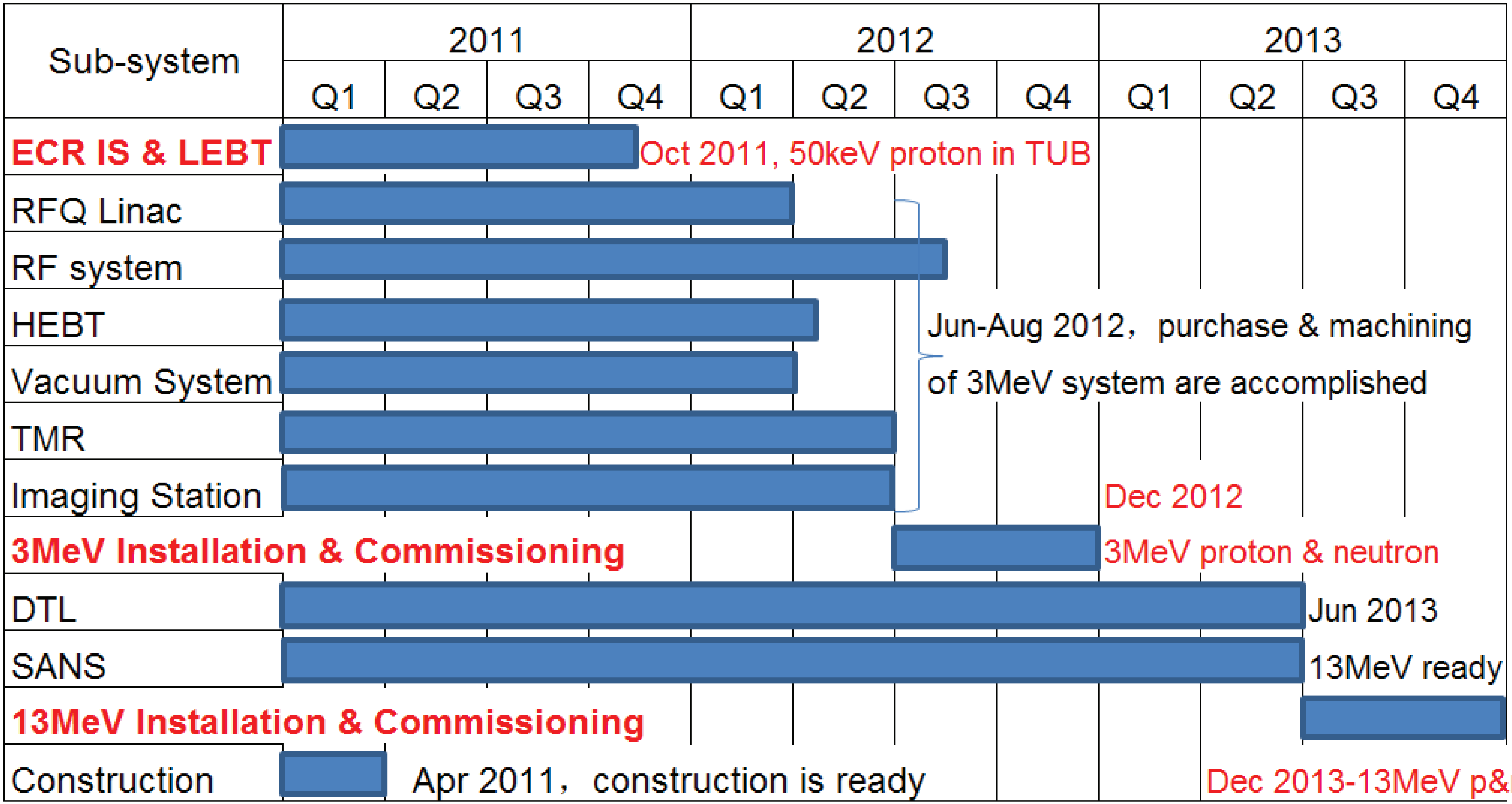
Project launched in June 2009
Four neutron beam lines planned
SANS and neutron imaging beam lines being constructed
Target station: Beryllium

Proton linac requirement

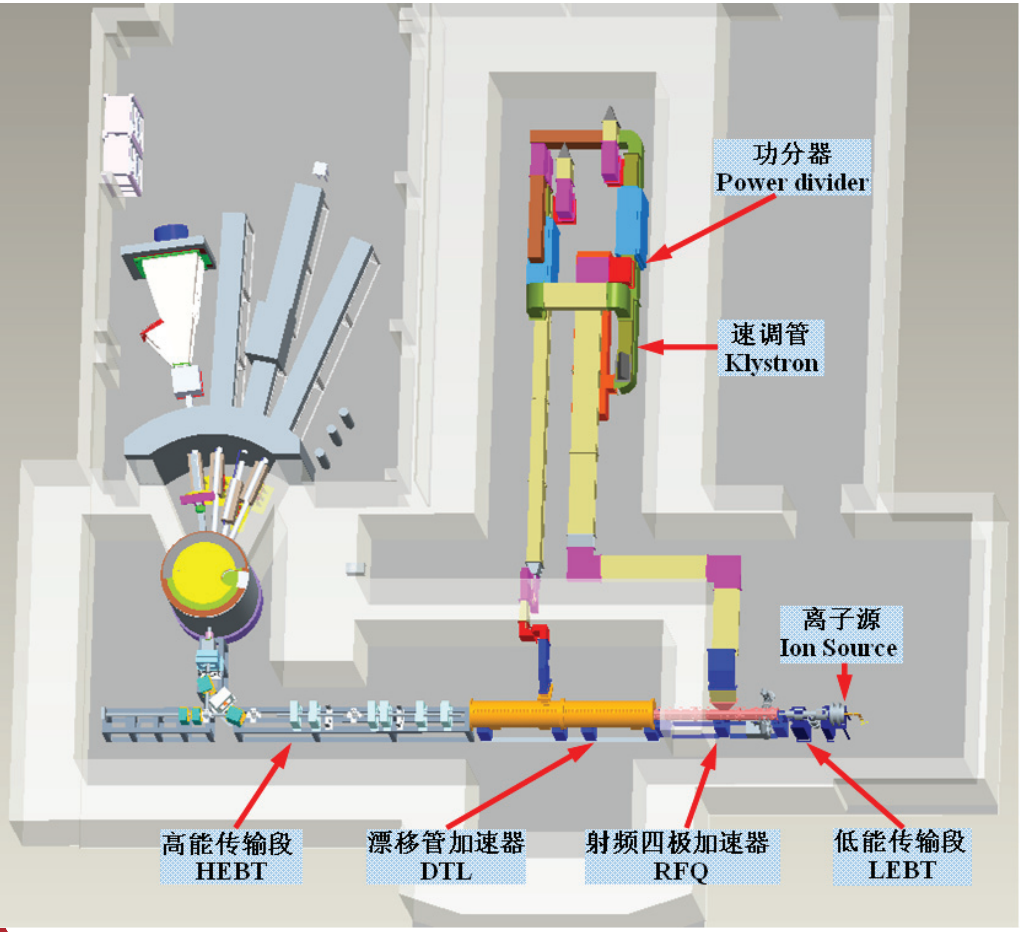
Ion type	Proton	
Beam power	16	kW
Beam energy	13	MeV
Average current	1.25	mA
Pulse repetition rate	50	Hz
Uniform beam diameter on the target	5	cm

1. Introduction

CPHS project schedule



Main parameters of the CPHS accelerator system



Ion type	Proton	
Beam power	16	kW
Beam energy	13	MeV
Average current	1.25	mA
Pulse repetition rate	50	Hz
Protons per pulse	1.56×10^{14}	
Charges per pulse	2.5×10^{-5}	C
Pulse energy	0.325	kJ
Pulse length	500	μs
Peak current	**50**	**mA**
Beam duty factor	2.5	%
RF frequency	325	MHz
Output energy of the ion source	**50**	**keV**
Output energy of the RFQ	**3**	**MeV**
Output energy of the DTL	**13**	**MeV**

● ECR source and LEBT

ECR source

Four-electrode extraction

LEBT

Two glaser lens each with two steering magnets inside

One cone structure (the cone, ACCT and electronic trap)

Space charge neutralization rate ~ 97%

Design and simulation

PBGUNS for ECR source extraction and LEBT

TRACK for LEBT

Designed parameters for the ECR source and LEBT

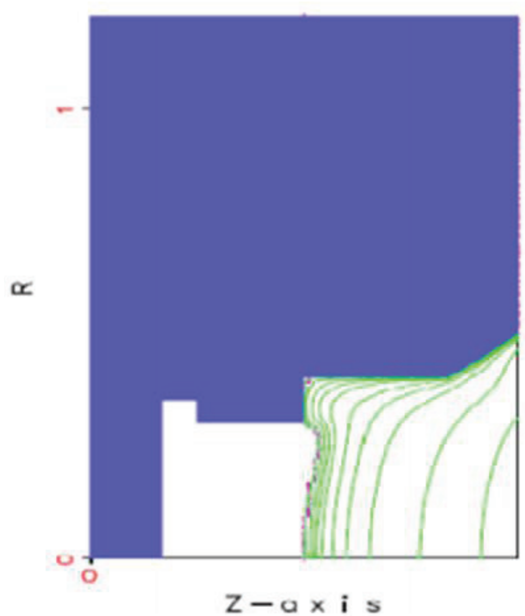
Output energy	50	keV
Output current	60	mA
Microwave frequency	2.45	GHz
Microwave average power	1.5~2.0	kW
Normalized RMS emittance	0.2	π mm·mrad
Reliability	120	hour

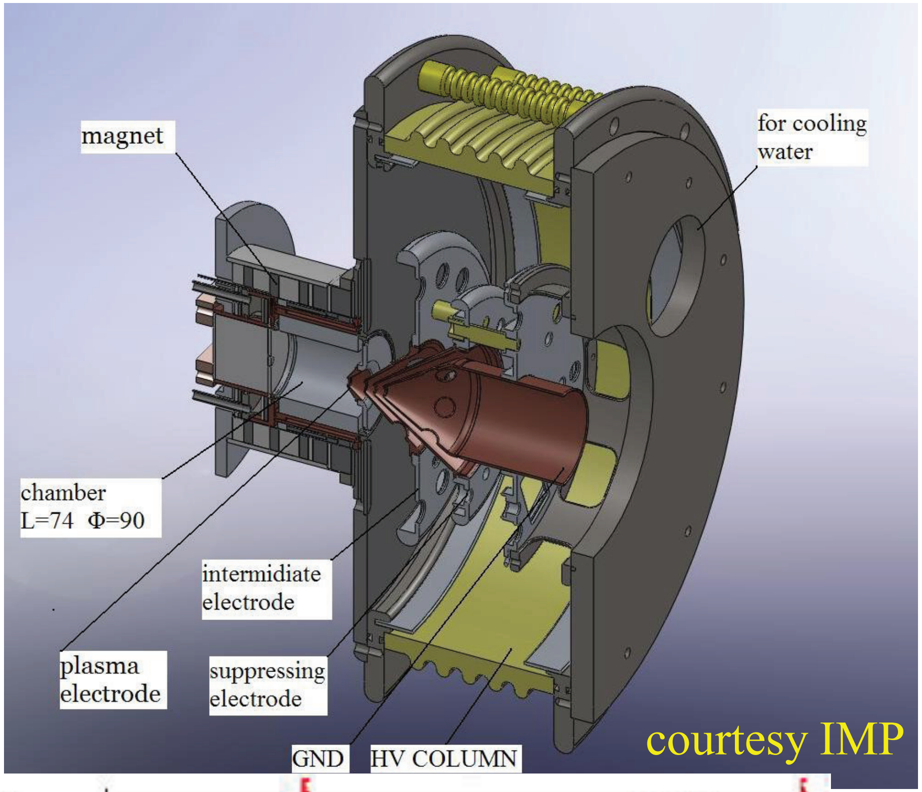
Required Twiss parameters at the entrance of RFQ

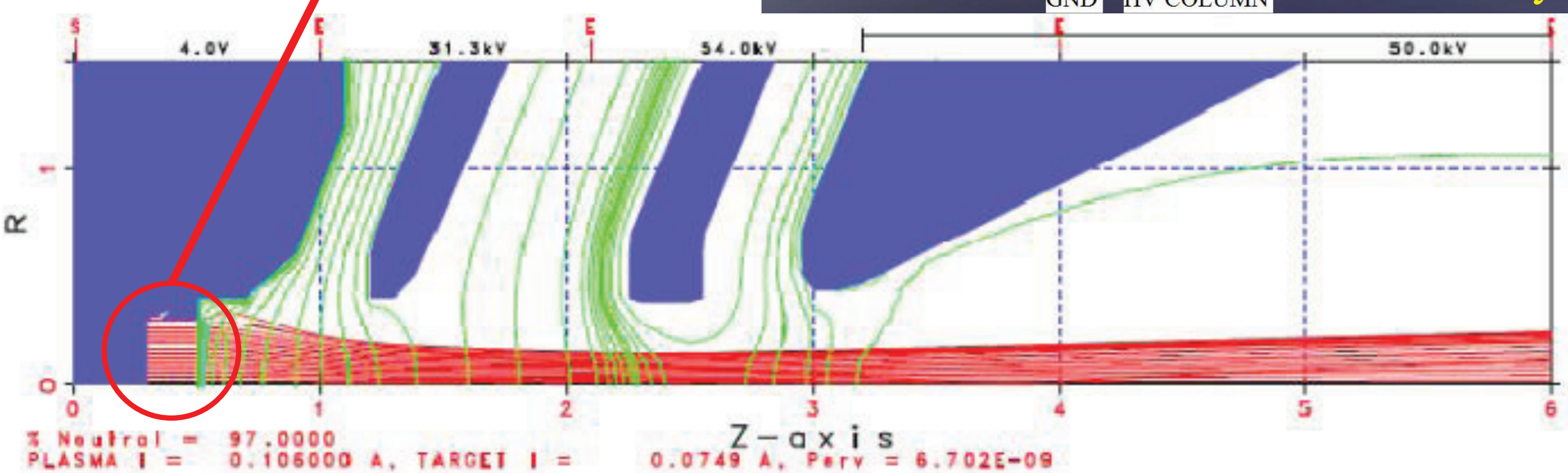
α	1.35	
β	7.73	cm/rad

ECR source

ECR extraction region

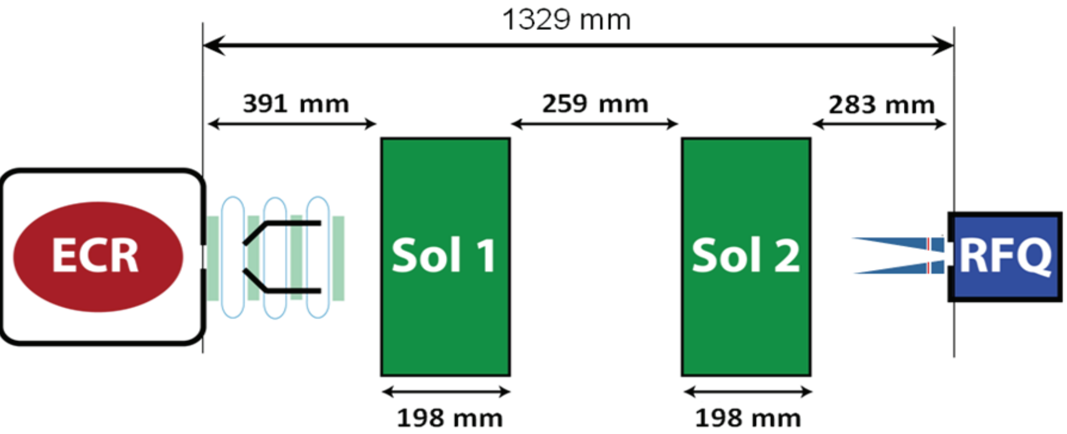


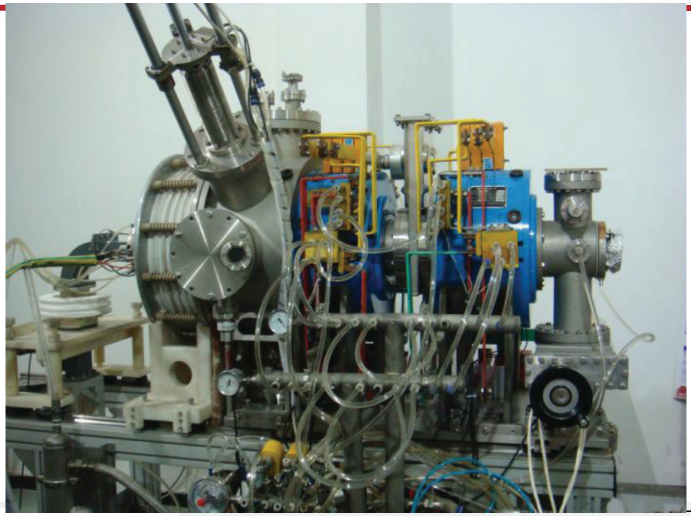


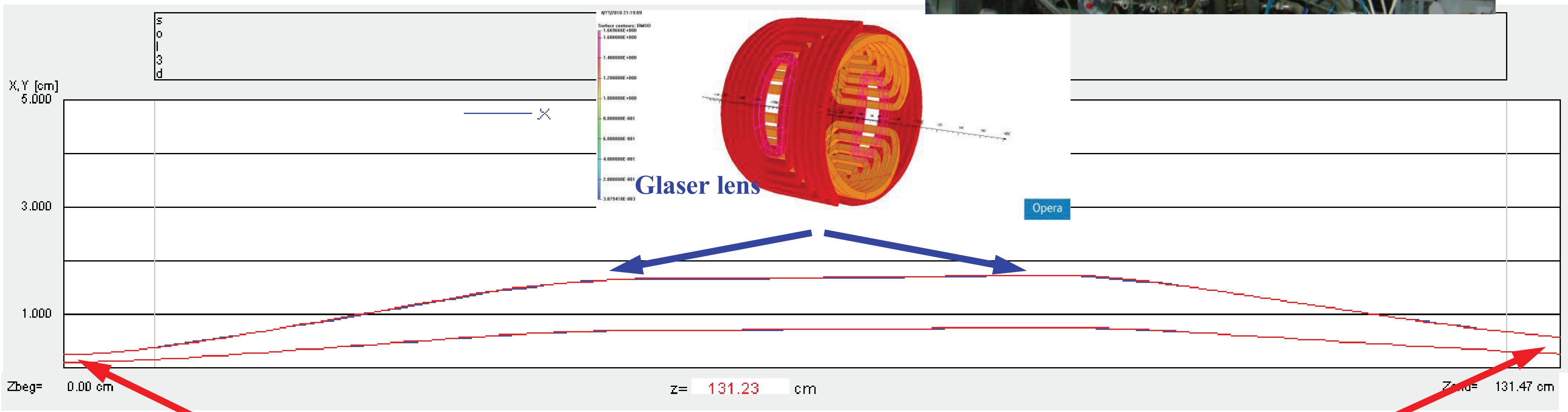


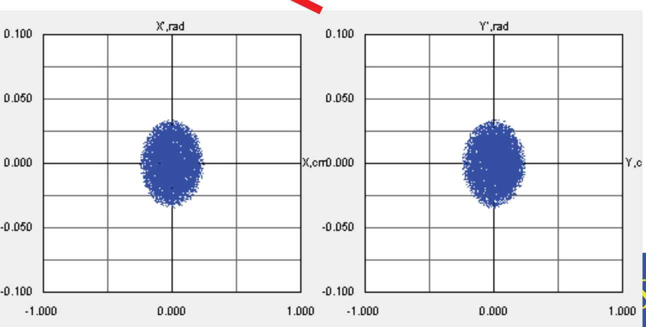
ECR extraction simulation by PBGUNS

LEBT

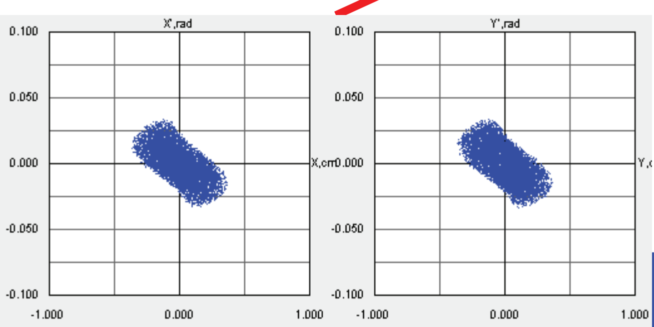




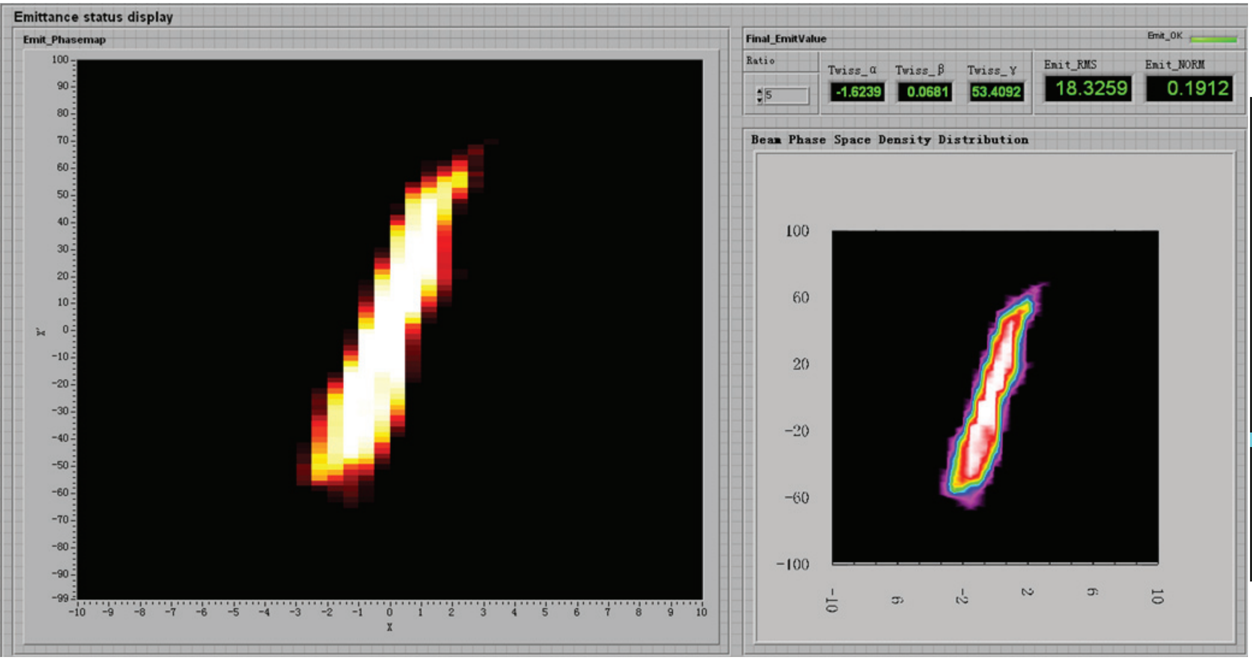


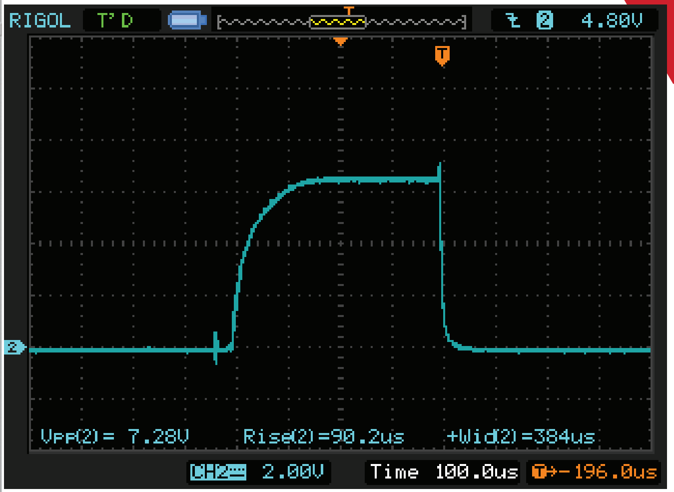


LEBT simulation by Track code



ECR source and LEBT --- Measurement result





Measurement result in the second chamber (Sep. 2012)

Proton current	60	mA
Normalized RMS emittance	0.19	π mm·mrad
α	-1.62	
β	6.81	cm/rad

- RFQ

Configuration

Shorter length: coupling plates are not necessary

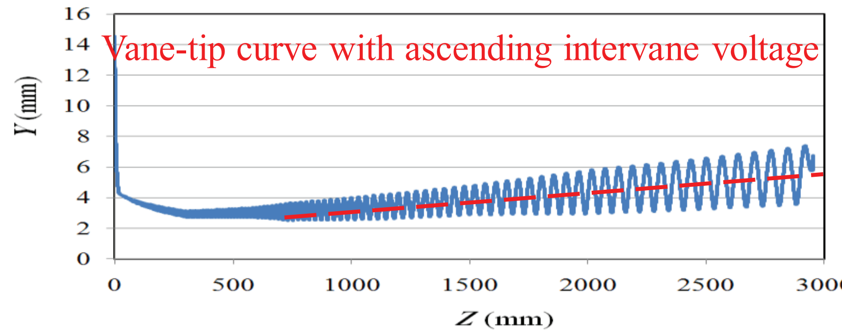
Optimization design of the peak field and the multipole field: vane-tip geometry are tailored as a function of longitudinal position

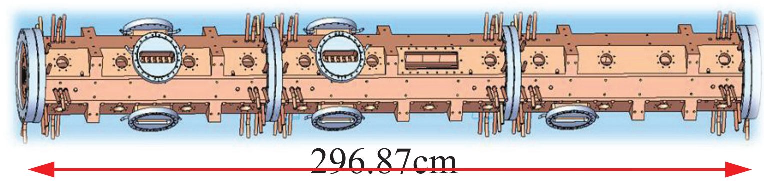
No MEBT

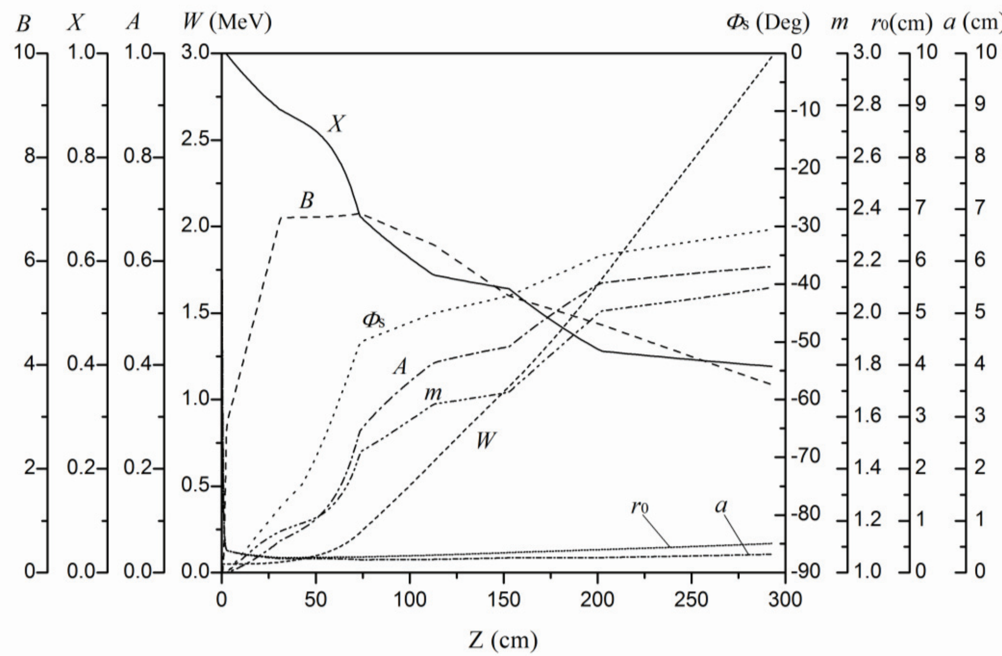
Design and simulation

PARMTEQM

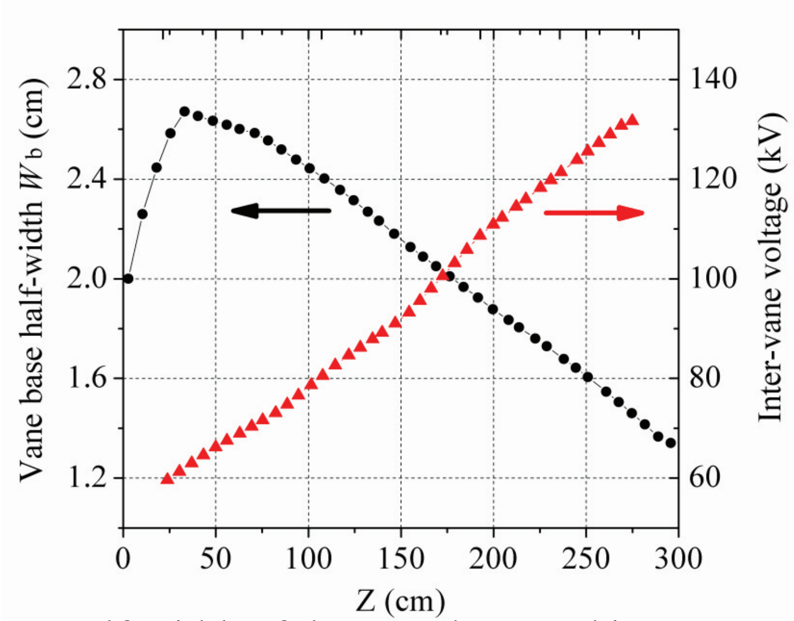
Simulation checked by TOUTATIS and TRACK





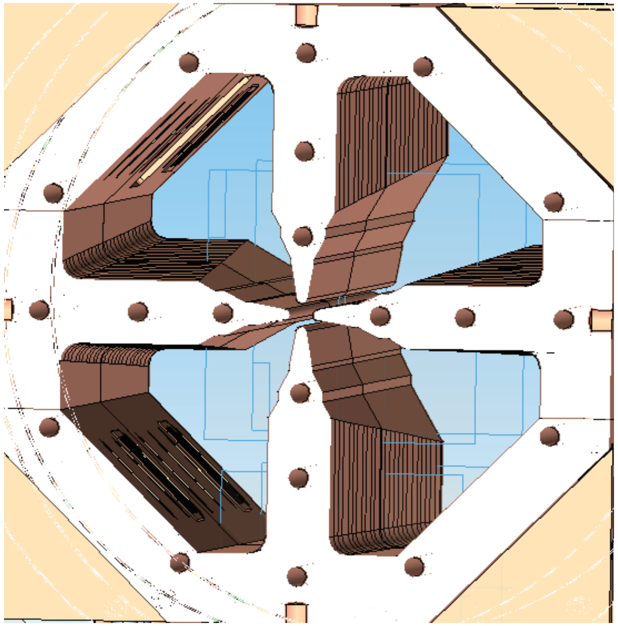


RFQ parameters



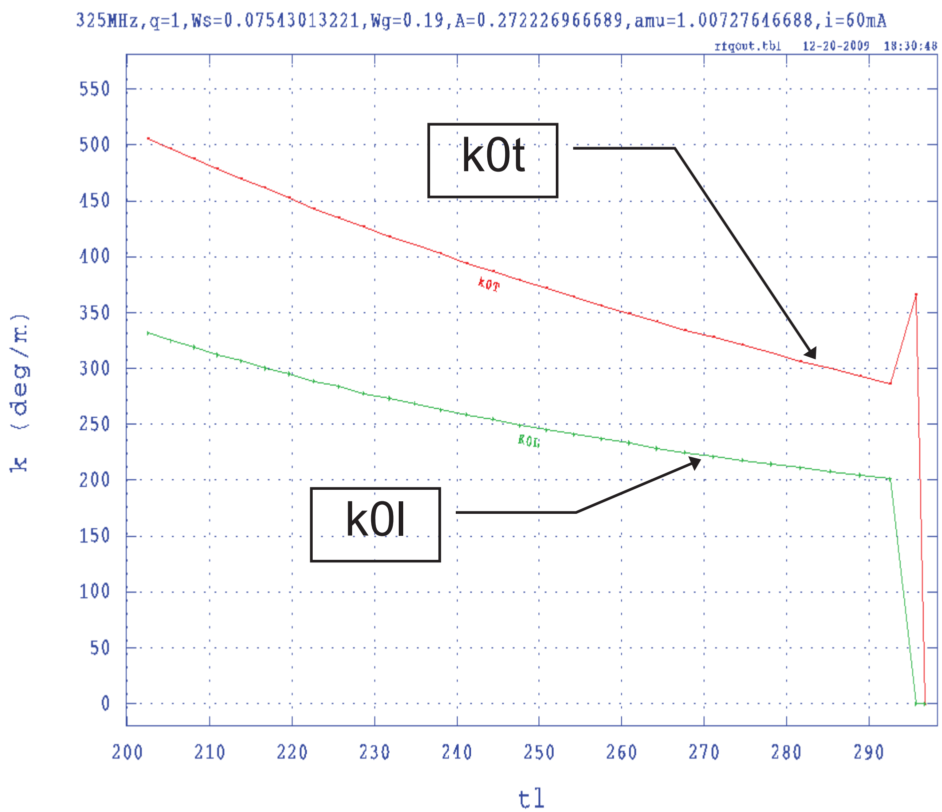
Half-width of the vane base and inter-vane voltage versus longitudinal position

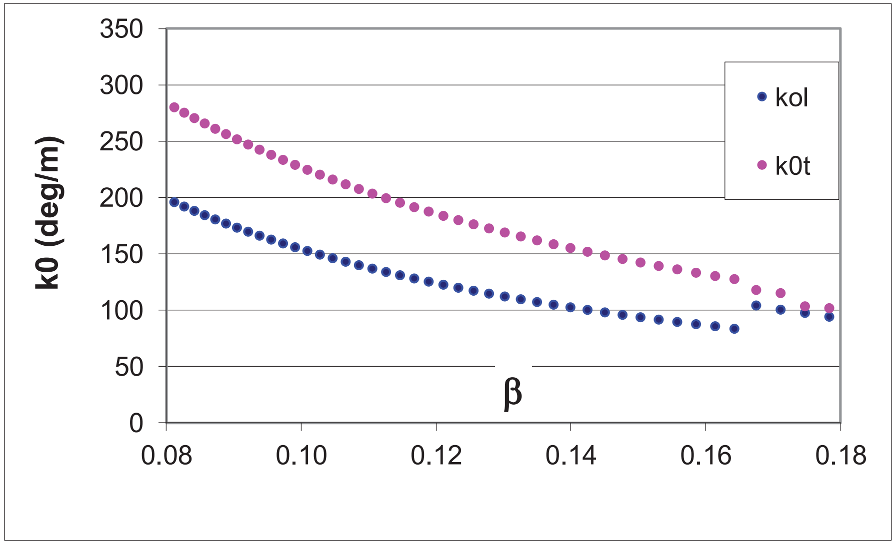
Parameters	Value	Unit
Type	Four-vane	
Frequency	325	MHz
Input beam energy	50	keV
Output beam energy	3.0	MeV
Peak beam current	50	mA
Emittance (norm. rms)	0.2	πmm· mrad
RF peak power	537	kW
Beam duty factor	2.5	%
Section number	3	



CPHS RFQ mounted at Tsinghua University

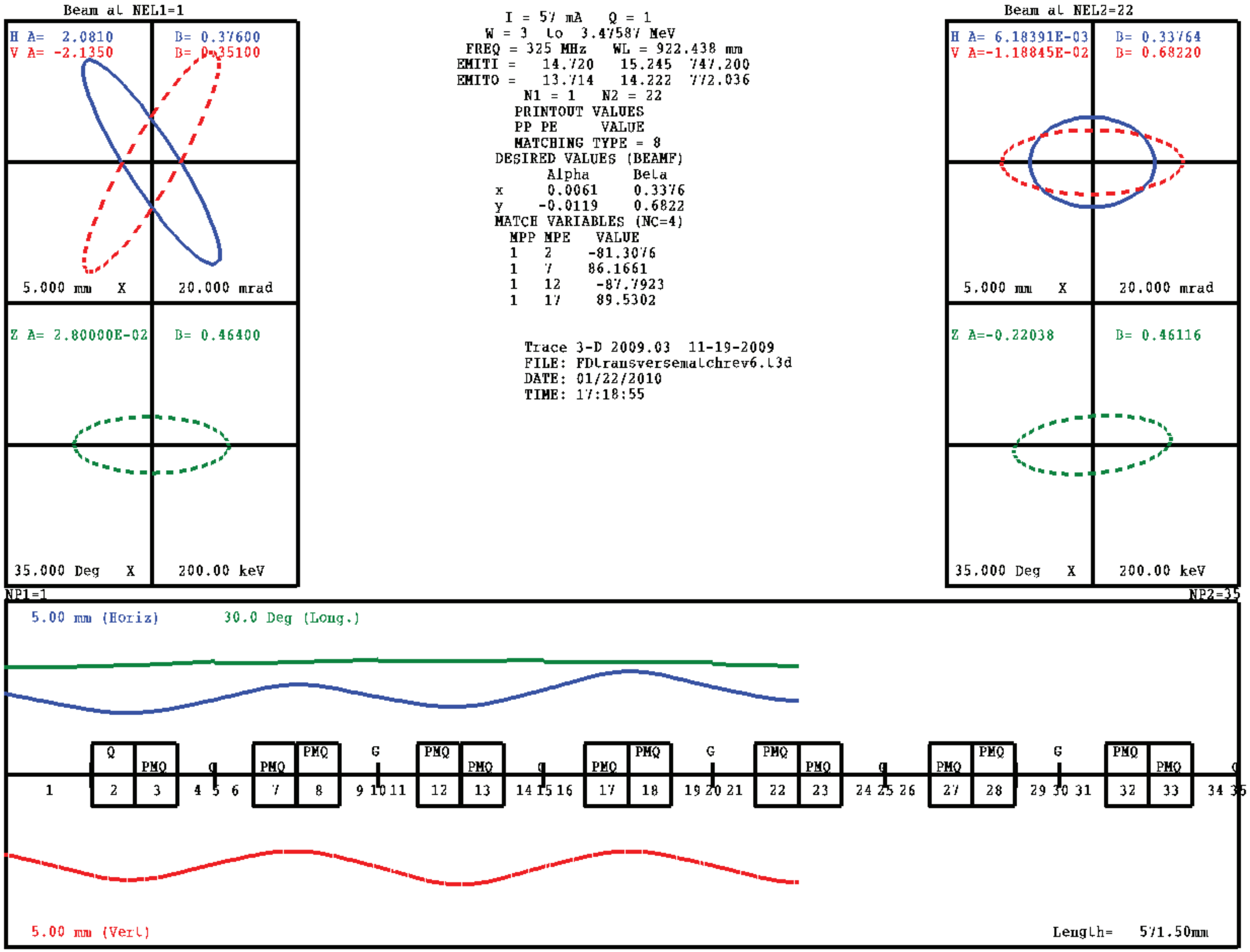
Matching between RFQ & DTL





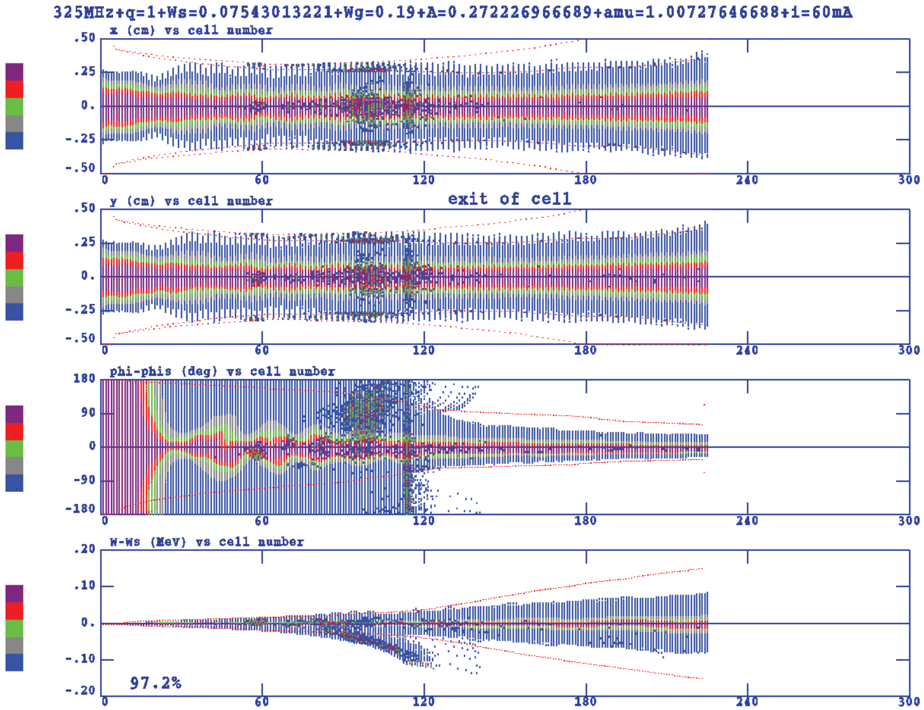
Focusing in RFQ (left) and DTL (right)

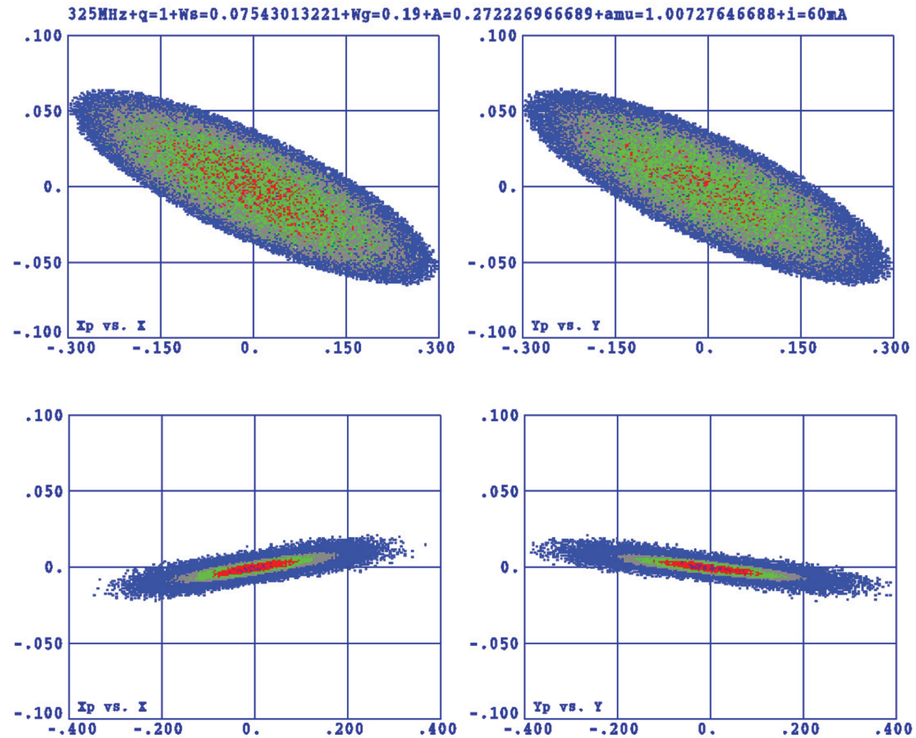
Matching between RFQ & DTL



Trace3d used first 4 quads in DTL to match beam from RFQ to DTL

RFQ simulation





courtesy L. Young

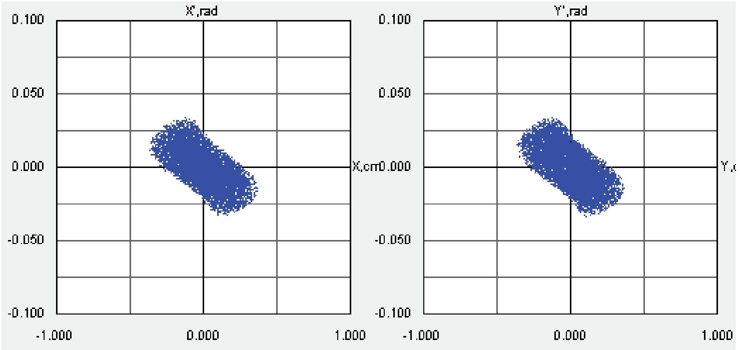
Beam transmission given by PARMTEQM

Particle distribution in the transverse plane x-y at the entrance (top) and exit (bottom) of the RFQ

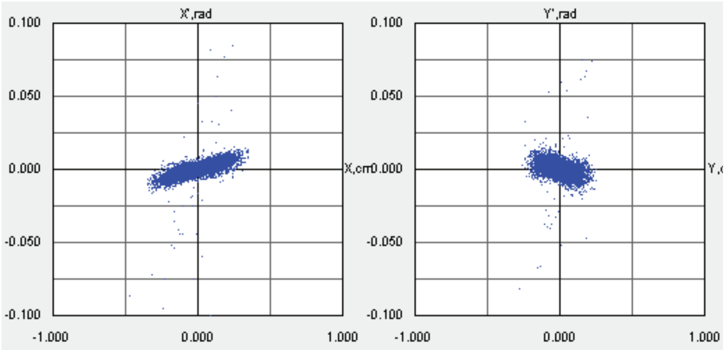
RFQ simulation

	PARMTEQM	TOUTATIS	TRACK	unit
Macroparticle number	10^5			
Input emittance	0.2			π mm*mrad
Input current	60			mA
Input Trans. α_i	1.35 (x) 1.35 (y)			
Input Trans. β_i	7.73 (x) 7.73 (y)			cm/rad
Output RMS emittance (Trans. Norm.)	0.246 (x) 0.248 (y)	0.258 (x) 0.263 (y)	0.259 (x) 0.262 (y)	π mm*mrad
Output Trans. α_o	-2.27 (x) 2.06(y)	-2.19 (x) 2.11(y)	-1.32 (x) 0.53(y)	
Output Trans. β_o	35.2 (x) 36.3 (y)	31.1 (x) 33.0 (y)	48.8 (x) 21.6 (y)	cm/rad
Output RMS emittance (Longi.)	0.144	0.133		MeV*deg
Output Longi. α_o	0.0931	-0.049	0.14	
Output Longi. β_o	474	472	40.5	deg/MeV
Transmission rate	97.2%	97.3%(Total) 96.3%(Acc.)	91.5%	

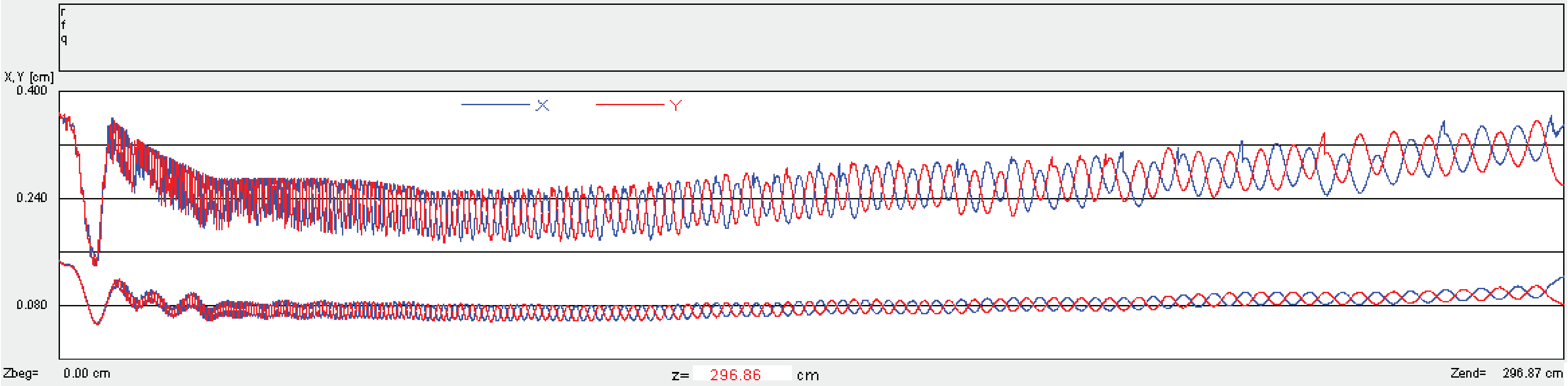
Simulation from LEBT to RFQ



Entrance



Exit



TRACK simulation result of the RFQ starting from the LEBT output (transmission rate is 84.0%)

- DTL

Configuration

Constant gradient PMQ

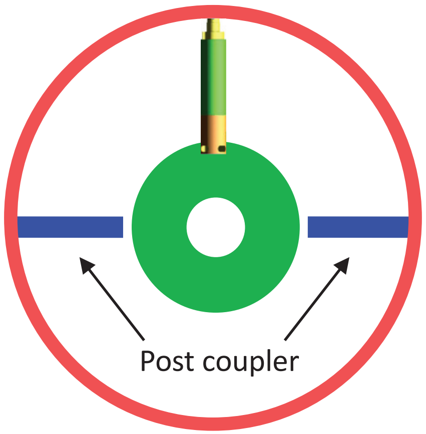
FDFD lattice

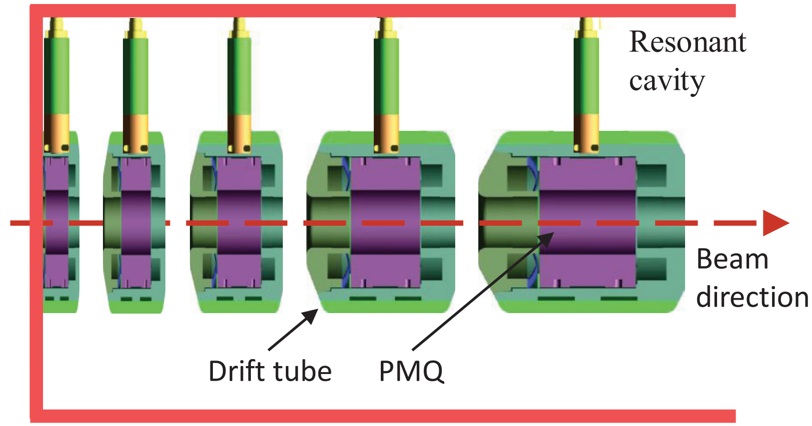
No MEBT

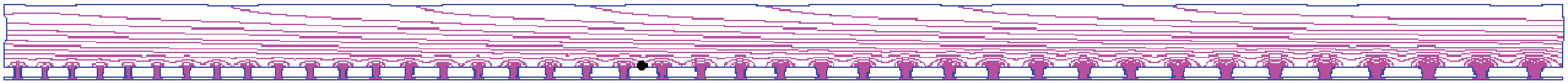
Design and simulation

Parmila

Input/output energy	3.0/13	MeV
Peak current	50	mA
Synchronous phase	-30→-24	Degree
Accelerating field	2.2→3.8	MV/m
Peak power	1.2	MW
Lens gradient	84.6	T/m
Lens effective length	4	cm
Cell number	40	
Total length	4.37	m

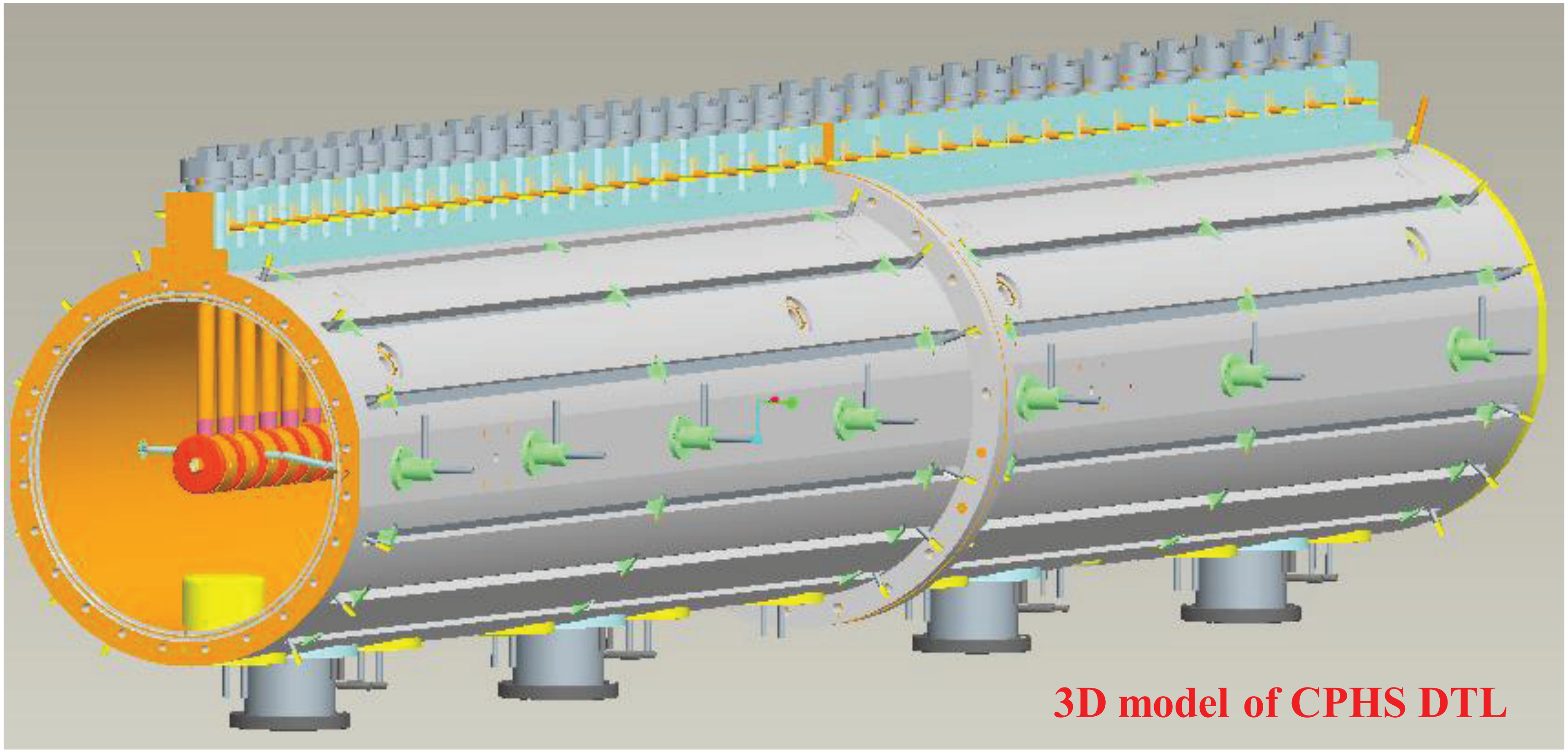




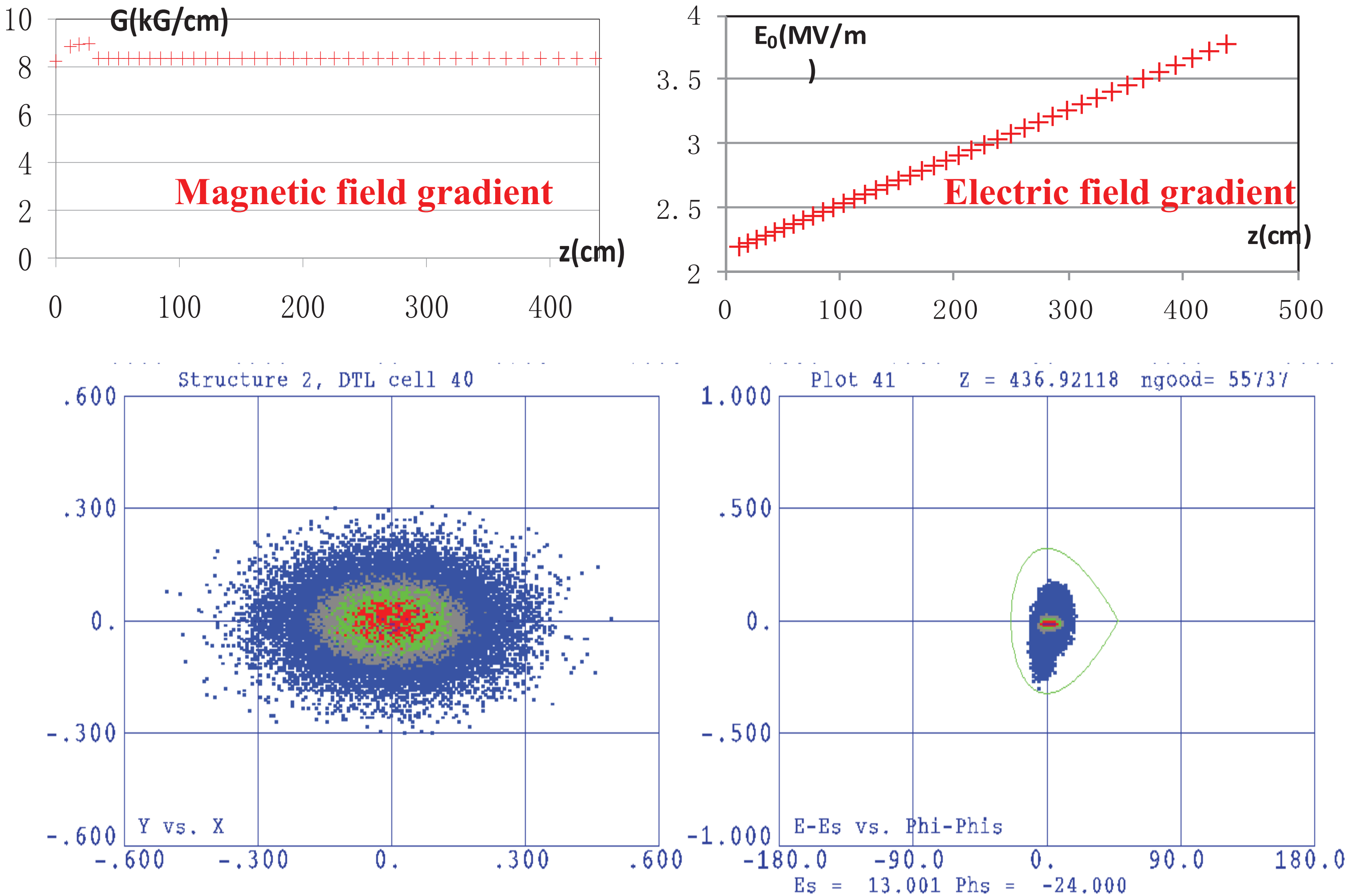


Field calculation by Superfish code

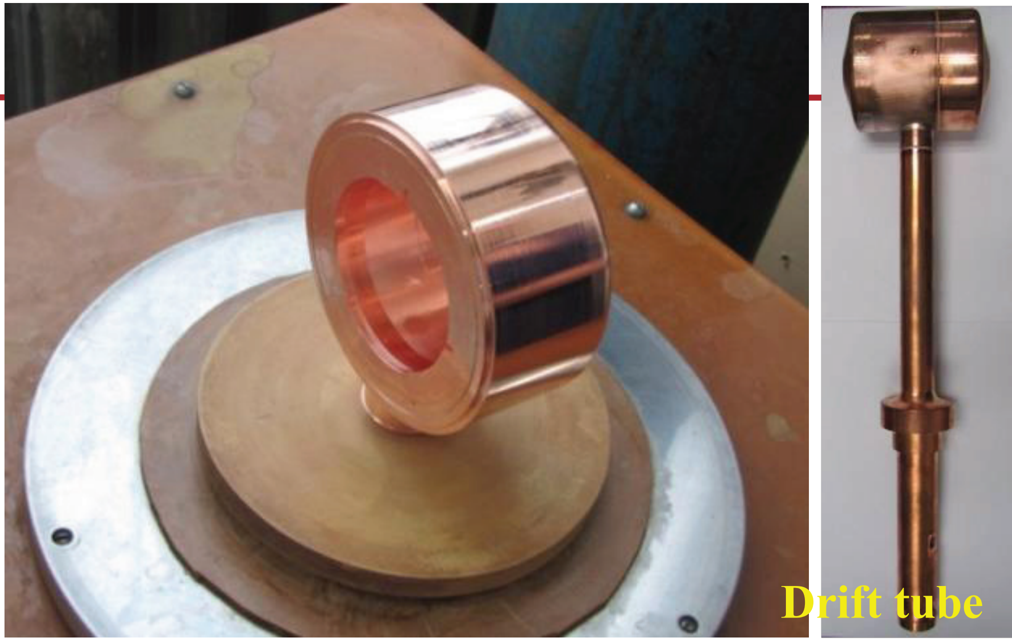
DTL design



DTL design and simulation



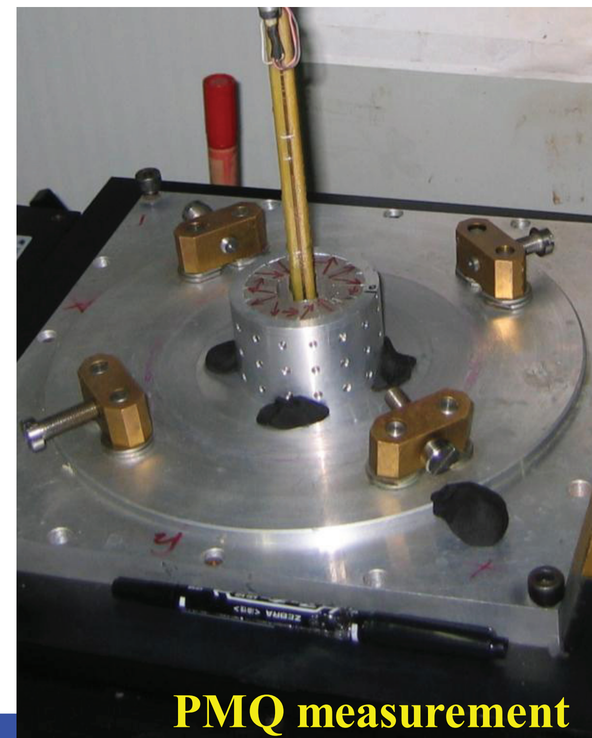
Particle distribution in the real space (left) and phase space (right) at the end of the DTL by Parmila code



Drift tube

Helmholtz coil

DTL cavity model



PMQ measurement

Simulation from LEBT to DTL

LEBT--->RFQ--->DTL: TSTEP --> TOUTATIS --> PARMILA

	Output particle number	Transmission rate
TSTEP (LEBT)	65099	
TOUTATIS (RFQ)	55529 (Accelerated)	85.3%
PARMILA (DTL)	55467 (Accelerated)	99.9%

TSTEP: first solenoid set at 90% of its maximum design strength and second solenoid set at 95% of its maximum design strength

Beam loss: most of the lost particles locate in the drift and the first four DTL cells

To be cross-checked: TRACK

- HEBT

Role

Deliver low emittance proton beam from DTL to target station

Uniform round beam spot (diameter of 5 cm) on Be-target

Design and simulation procedures

TRANSPORT (1st order) =>

Basic parameters of each elements (Quad, Dipole)

Optimal position of octupole magnets

TURTLE (3rd order) =>

Parameters of three octupole magnets

Beam line

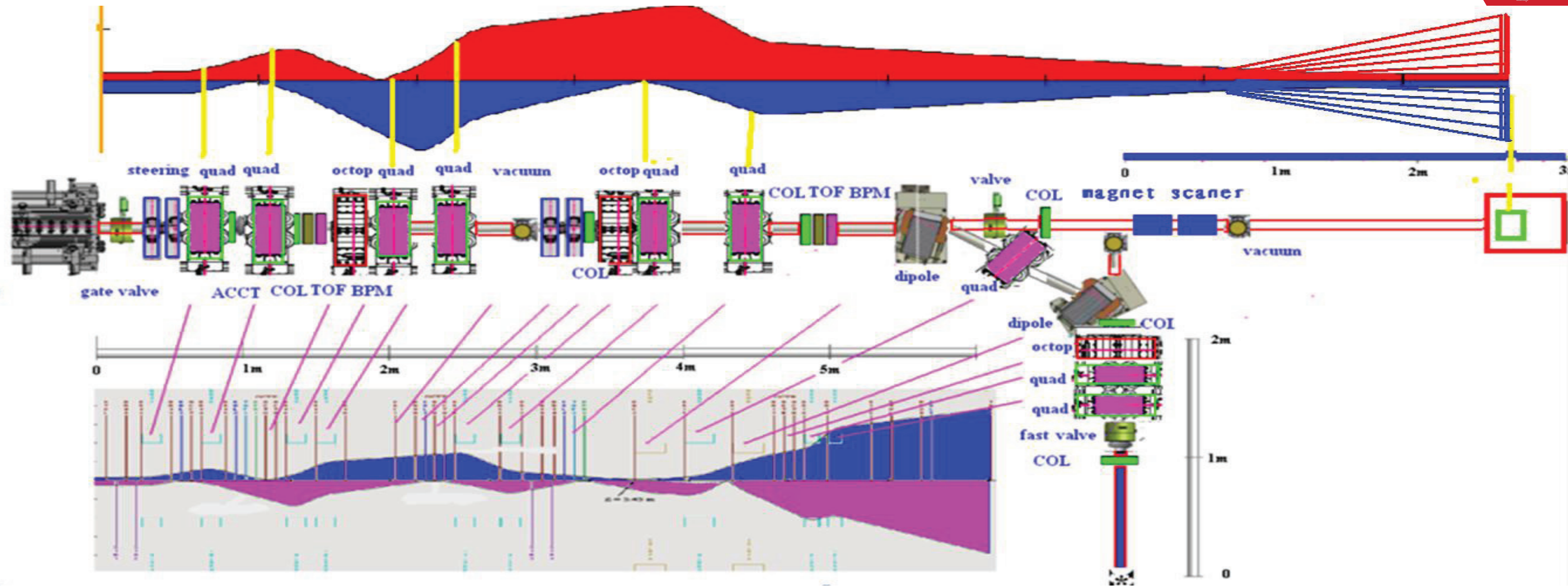
2 dipoles

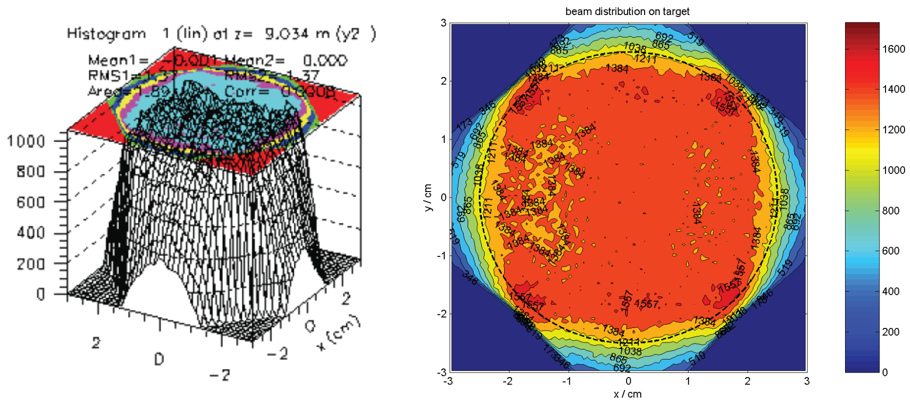
9 quadrupoles

3 octupoles

2 set of steering magnets

HEBT simulation

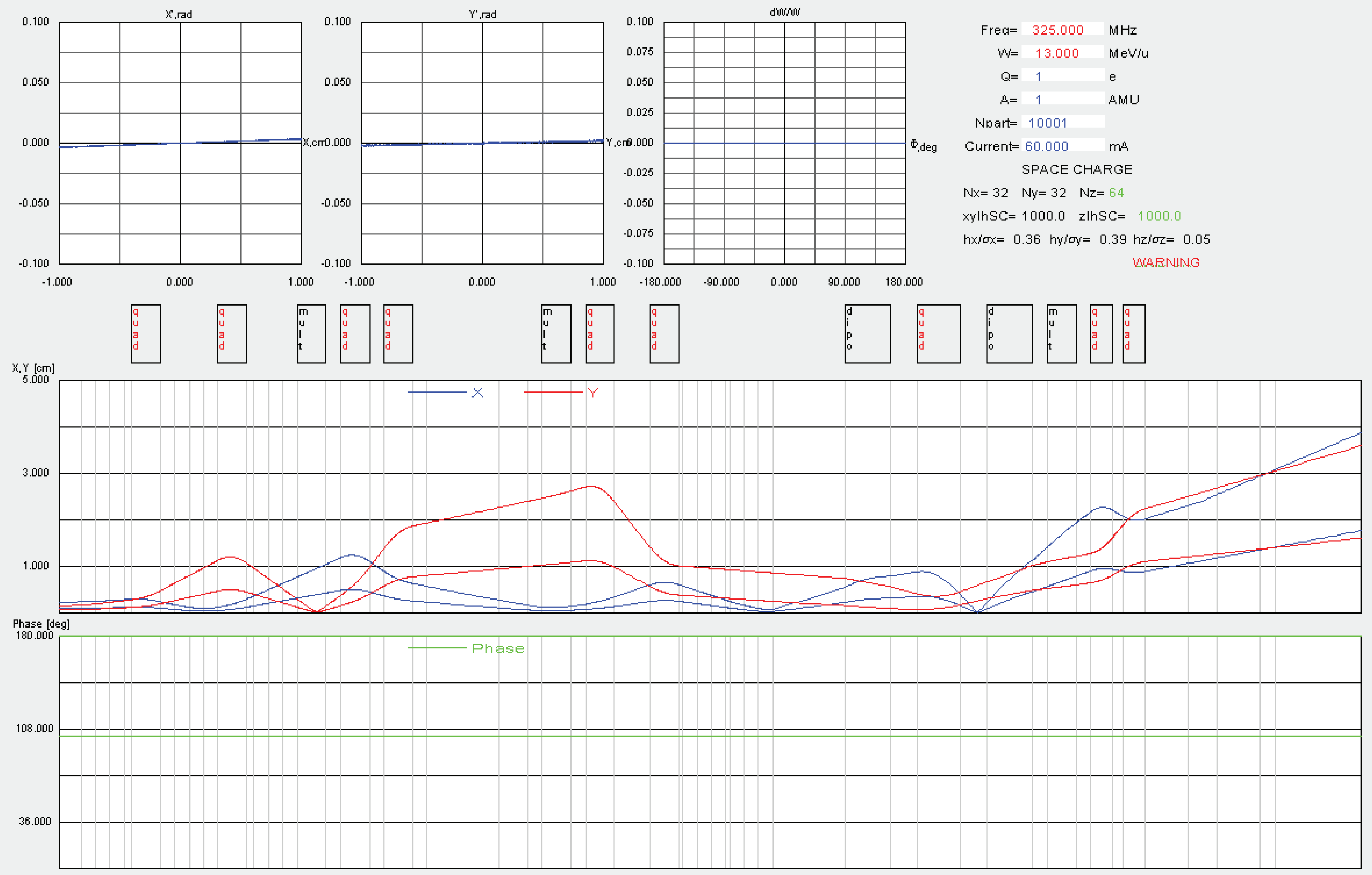




courtesy G.H. Li

Beam distribution on the target by TURTLE code

HEBT simulation



Summary

- Beam dynamics simulation has been carried out by various codes for the CPHS Linac
- Field aberration of the solenoids is one main reason for the mismatching between the LEBT and RFQ
- With the particle distribution from the LEBT as input, the transmission rate in the RFQ decreases to about 85%
- Transmission in the DTL is almost 100% for the accelerated particles
- Simulation is being cross-checked by TRACK

谢 谢！

Thank you for your attention!