HB2014
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Beam dynamics design and experiments of CPHS linac

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CPHS Compact Pulsed Hadron Source
TSINGHUA UNIVERSITY

OUTLINE

- Introduction
- Beam dynamics
  ---ECR source and LEBT
  ---RFQ
  ---DTL
  ---HEBT
  ---End to end simulation
- Experiments
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Introduction

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

TSINGHUA University 清华大学

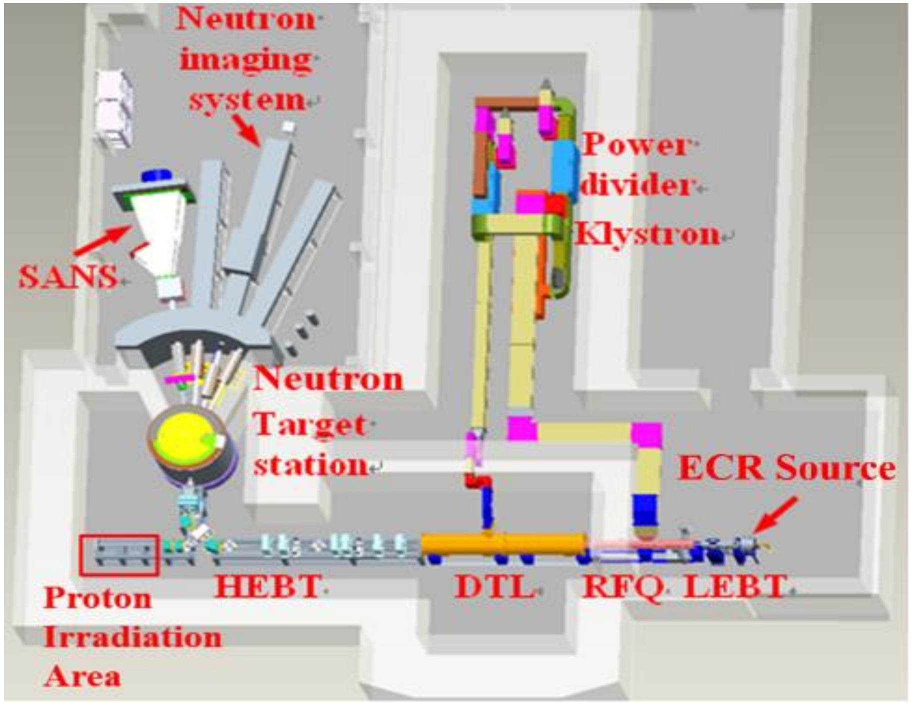
Thomson scattering X-ray source
汤姆逊散射实验平台

CPHS+TTX:

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

CPHS (Compact Pulsed Hadron Source) project

- Launched in June 2009
- Four neutron beam lines planned
- Target station: Beryllium
- Expected neutron flux: ~$5*10^{13}$ n/s
- Neutron beam test line and neutron imaging beam line constructed



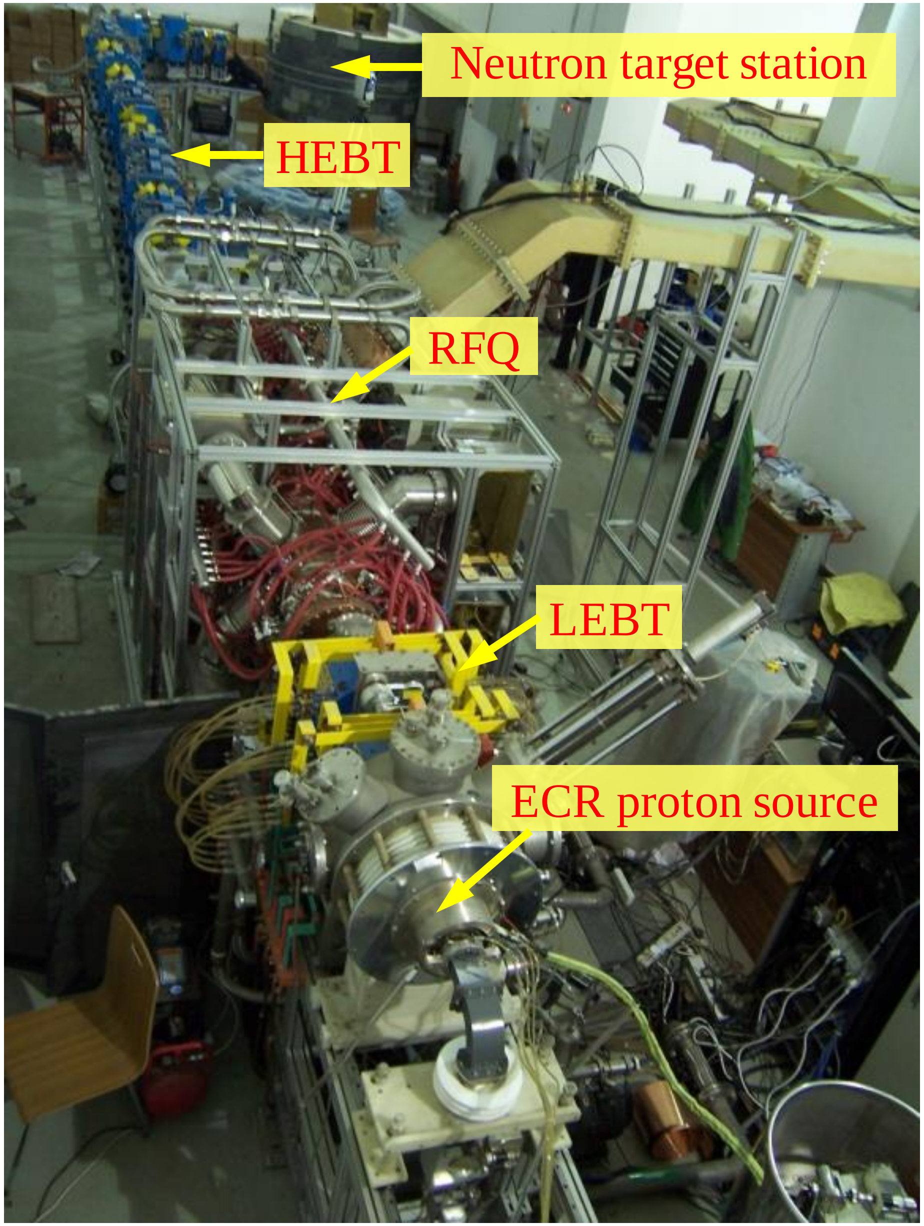
Proton linac requirement

Ion type	Proton	
Beam power	16	kW
Beam energy	13	MeV
Peak current	50	mA
Pulse repetition rate	50	Hz
Pulse Width	500	μs
RF frequency	325	MHz

Operation status – CPHS milestones

- RFQ conditioned to 550kW/50Hz/40μs on 2013/02
- First beam of RFQ on 2013/03/25
- Highest transmission of RFQ (88%, input 50mA, output 44mA) on 2013/03/27
- First neutron beam on 2013/07/18 (**mid-term objective achieved**)
- First neutron imaging on 2013/07/26
- Highest transmission of HEBT (> 90%) on 2013/08/13
- RFQ conditioned to 442kW/50Hz/500μs on 2014/04

CPHS linac –present status



Proton linac parameters

Ion type	**Proton**	
Beam energy	**3**	MeV
Peak current	**40**	mA
Pulse length	**100**	μs
Pulse repetition rate	**20**	Hz
RF frequency	**325**	MHz

Beam dynamics

- ECR source and LEBT

ECR source

Four-electrode extraction

LEBT

Two glaser lens each with two steering magnets inside

One cone structure before RFQ (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

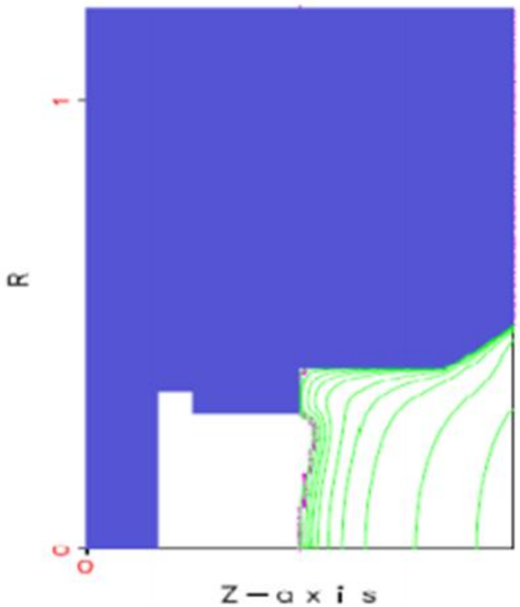
Output energy	50	keV
Output current	60	mA
Microwave frequency	2.45	GHz
Microwave average power	1.5~2.0	kW
Normalized RMS emittance	0.2	π mm·mrad
Reliability	120	hour

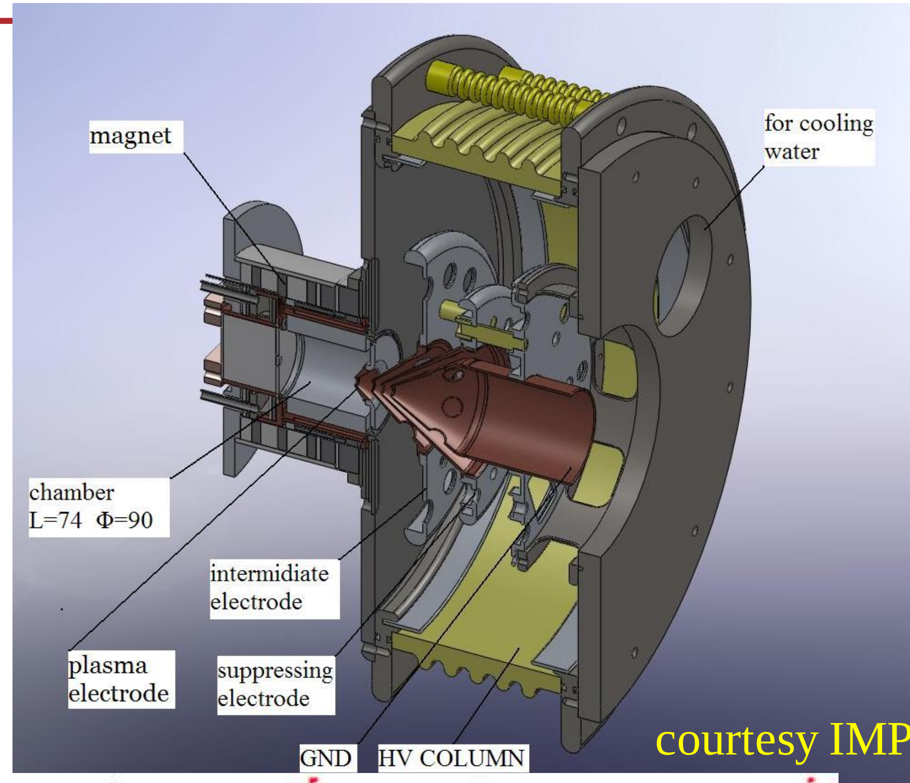
Required Twiss parameters at the entrance of RFQ

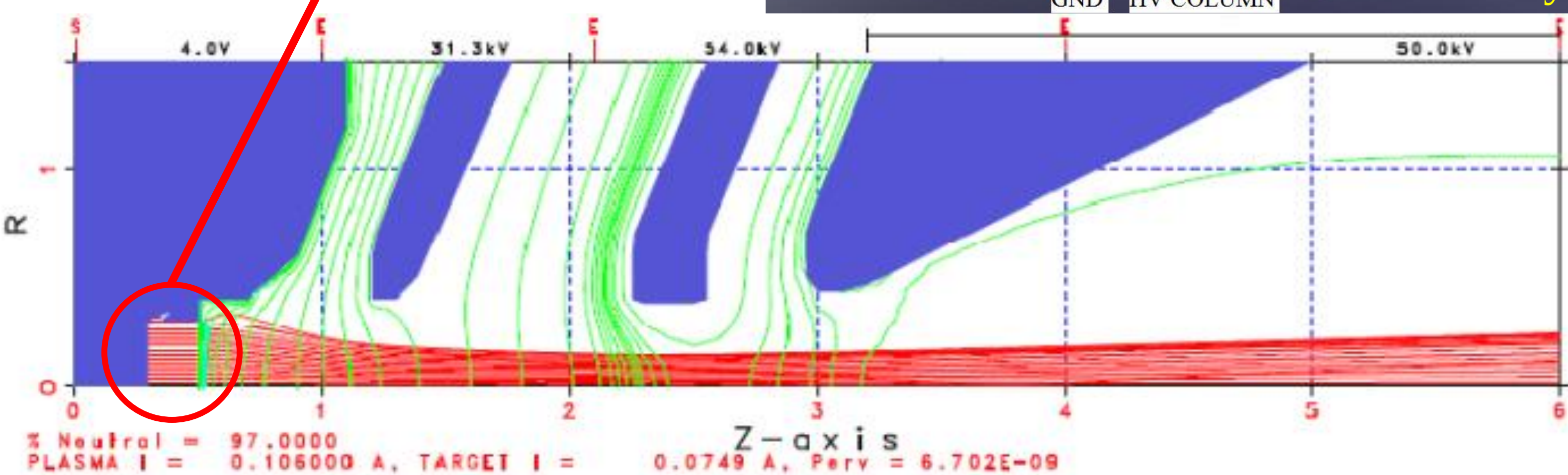
α	1.35	
β	7.73	cm/rad

ECR source

ECR extraction region

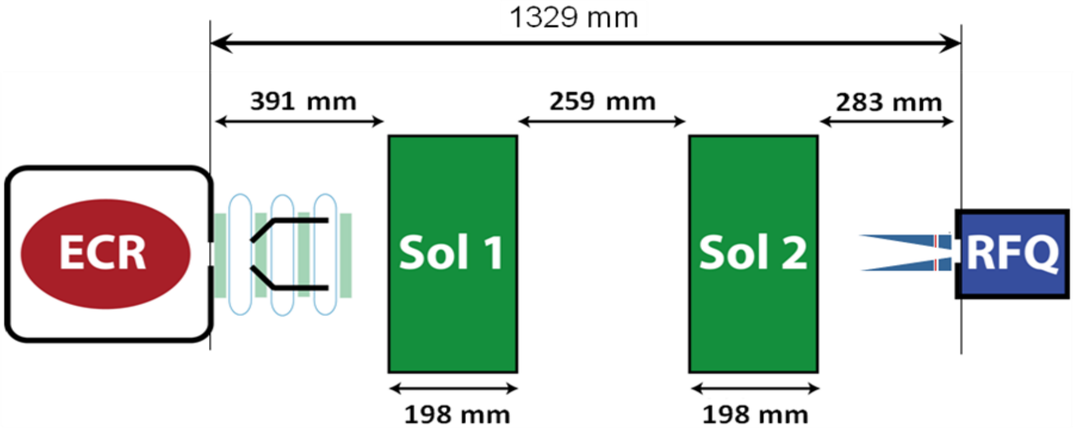


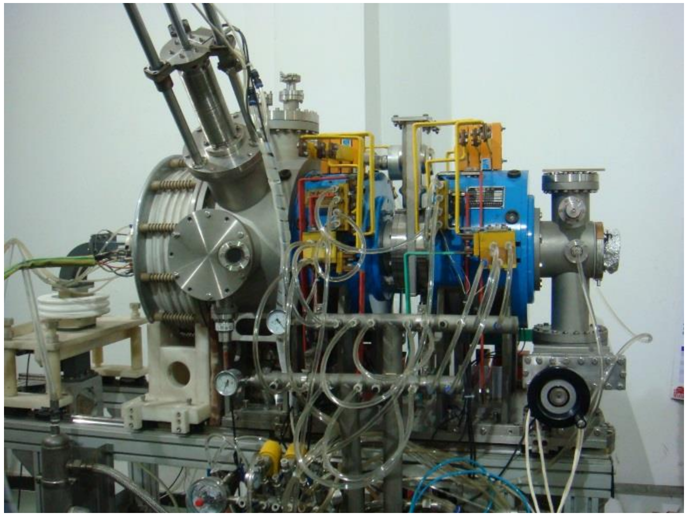


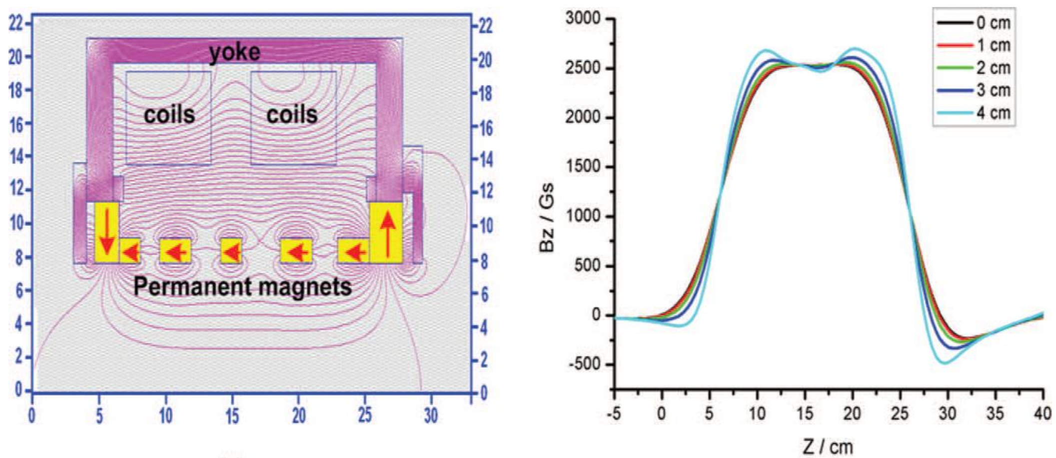


ECR extraction simulation by PBGUNS

LEBT

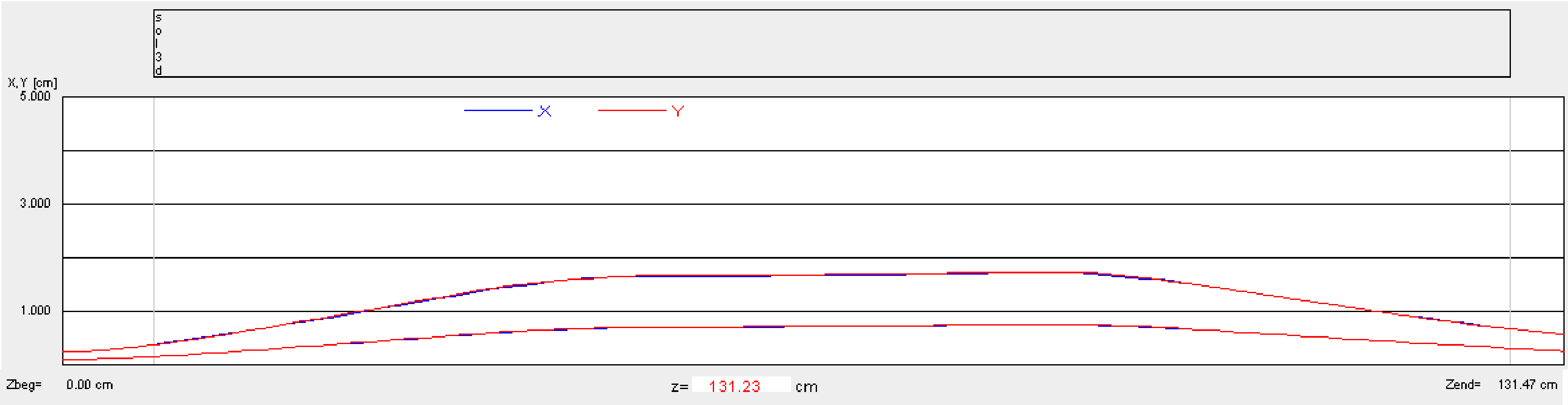

1329 mm
391 mm
259 mm
283 mm
ECR
Sol 1
Sol 2
RFQ
198 mm
198 mm

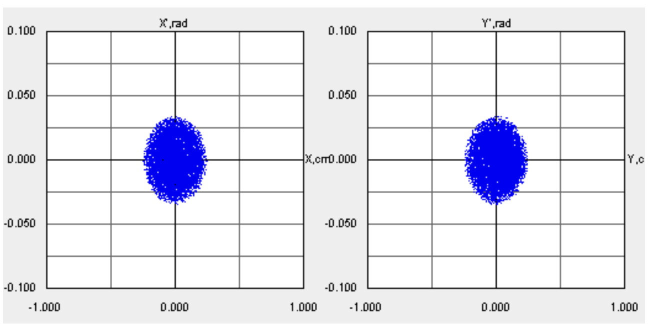



yoke
coils
coils
Permanent magnets
Bz / Gs
Z / cm
0 cm
1 cm
2 cm
3 cm
4 cm

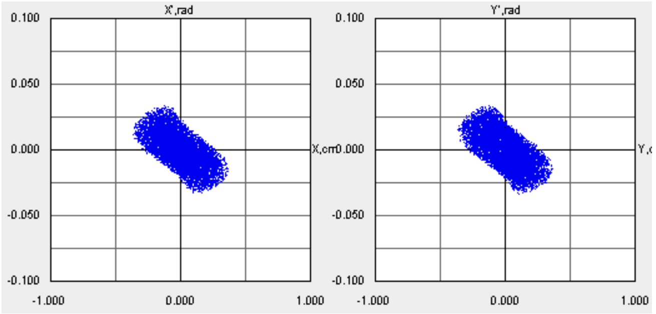
(a) (b)

LEBT





LEBT simulation by Track code



Beam dynamics

- RFQ

Configuration

Shorter length: coupling plates are not necessary

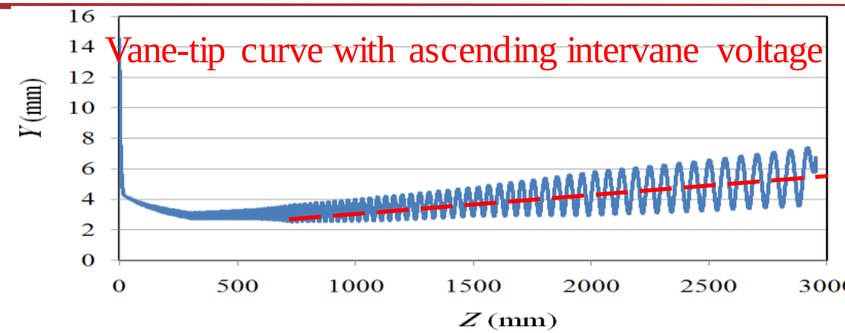
Optimization design of the peak field and the multipole field: vane-tip geometry are tailored as a function of longitudinal position

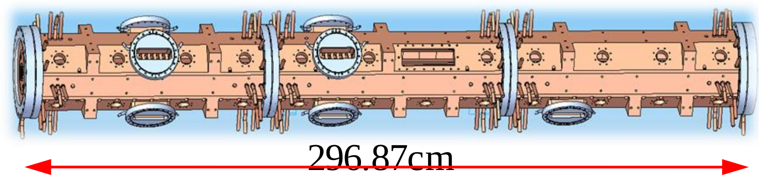
No MEBT

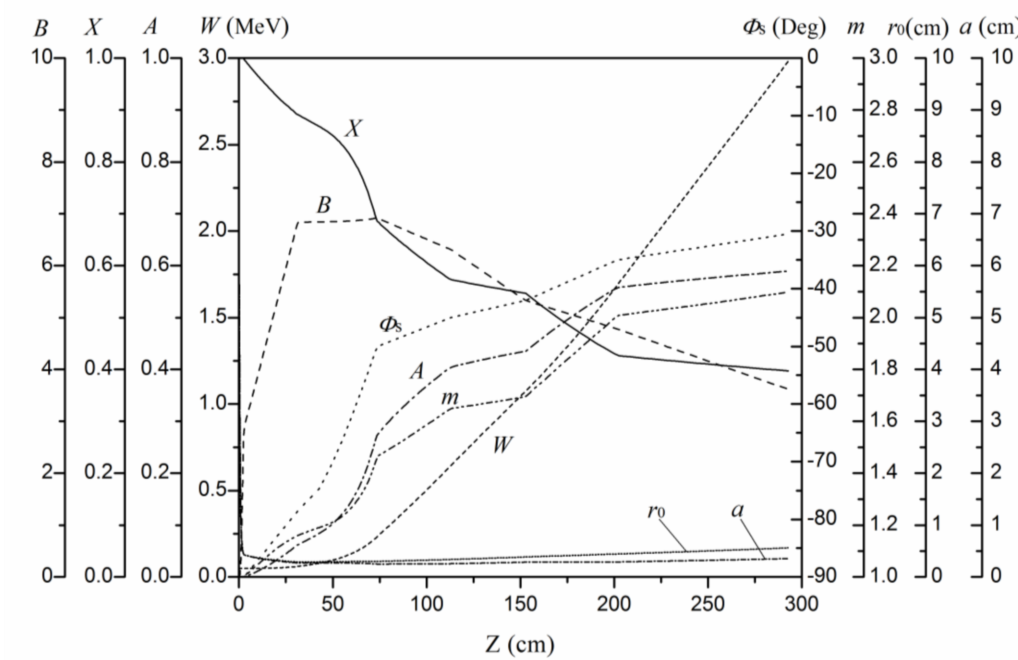
Design and simulation

PARMTEQM

Simulation checked by TOUTATIS and TRACK





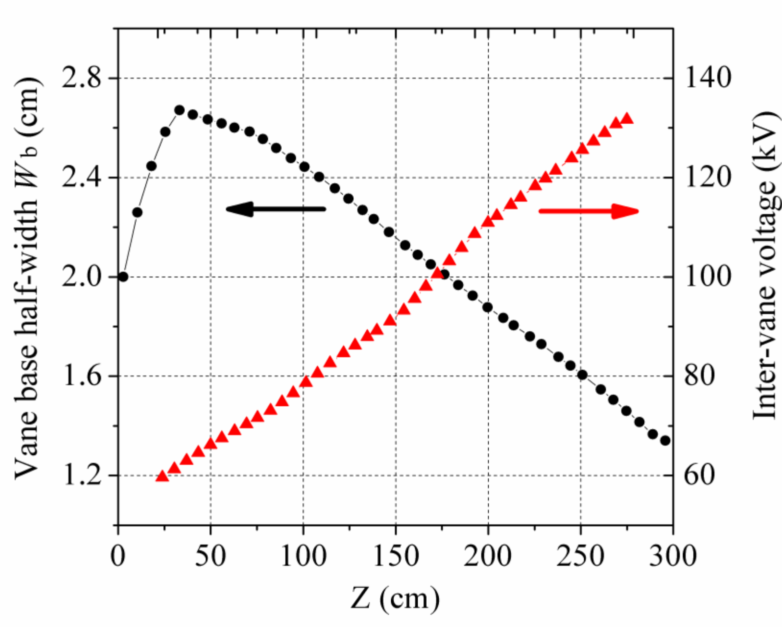


RFQ

RFQ parameters

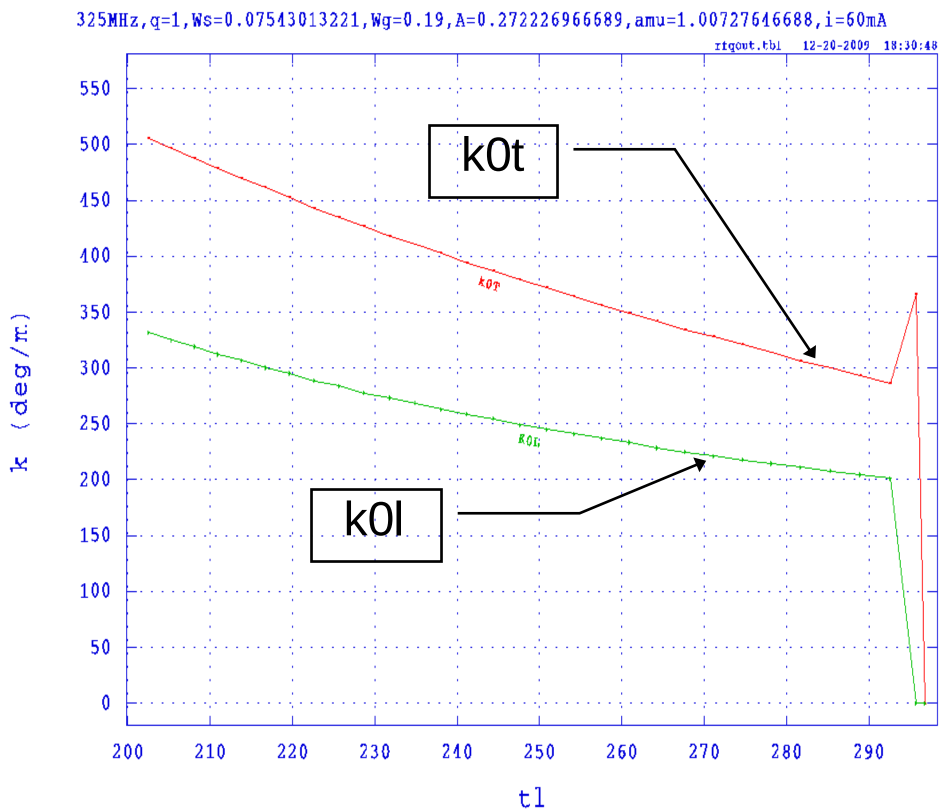
Parameters	Value	Unit
Type	Four-vane	
Frequency	325	MHz
Input beam energy	50	keV
Output beam energy	3.0	MeV
Peak beam current	50	mA
Emittance (norm. rms)	0.2	πmm· mrad
RF peak power	537	kW
Beam duty factor	2.5	%
Section number	3	

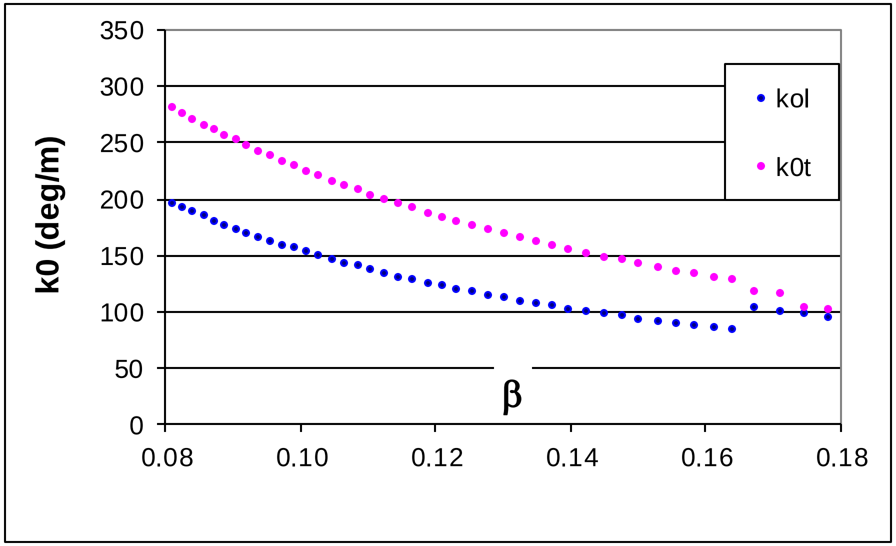
Half-width of the vane base and inter-vane voltage versus longitudinal position



RFQ

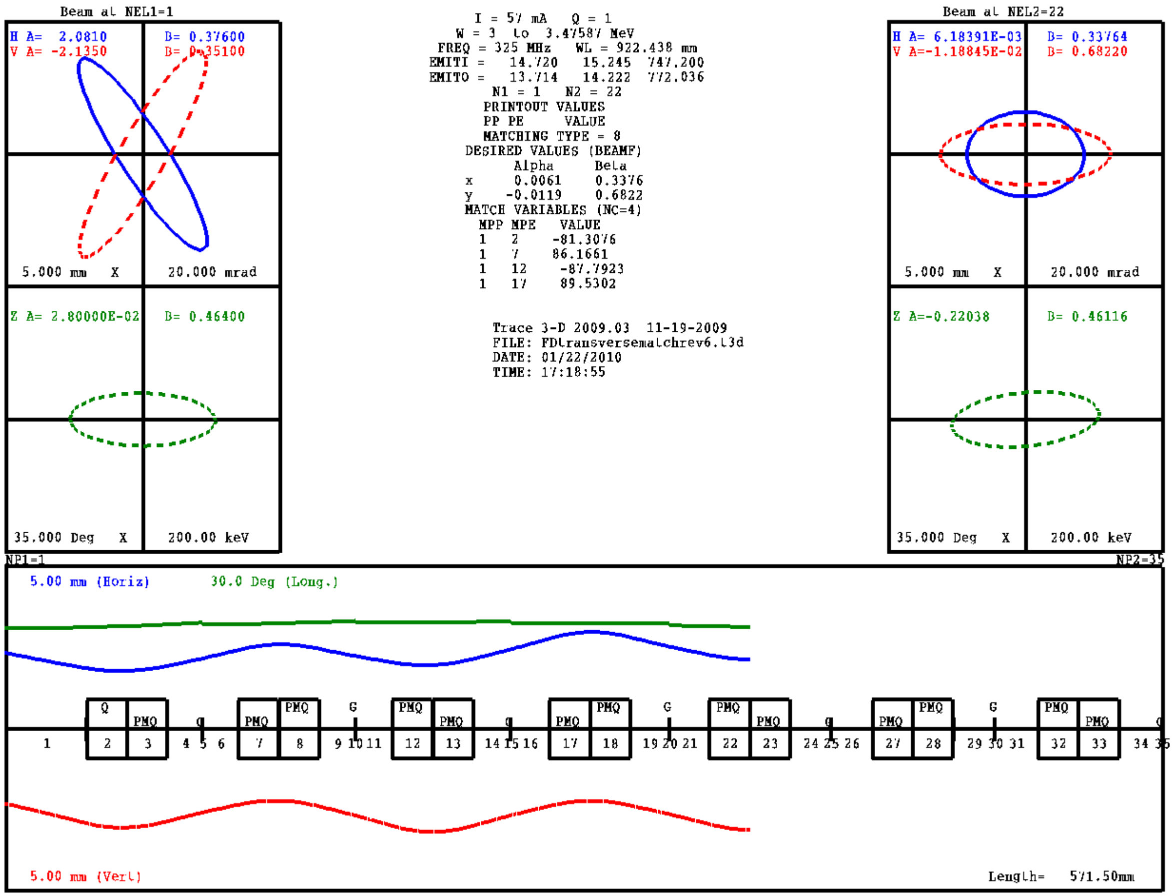
Matching between RFQ & DTL





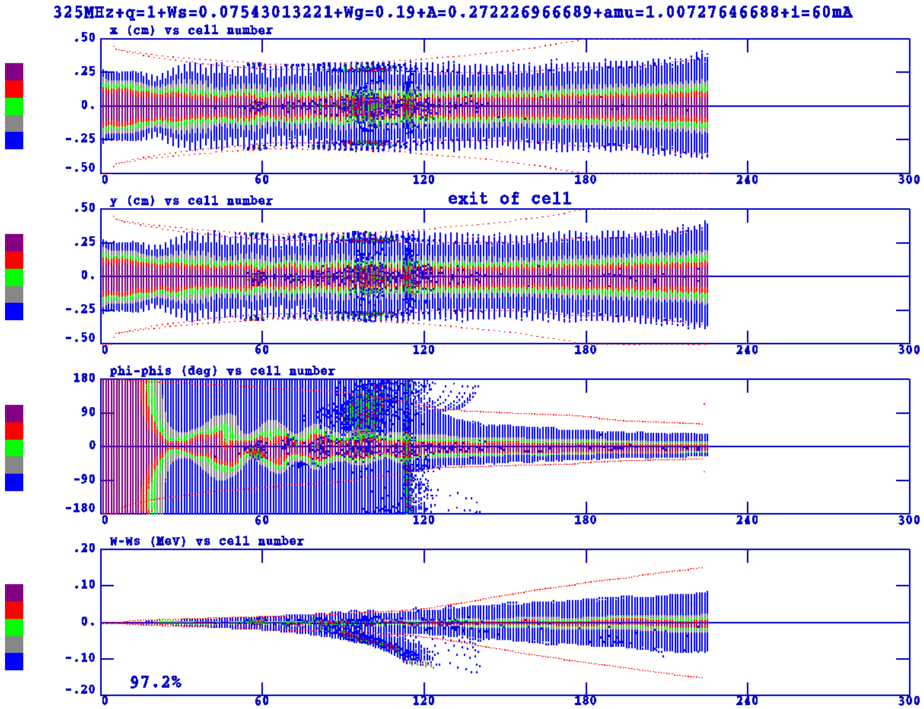
Focusing in RFQ (left) and DTL (right)
zero-current phase shift

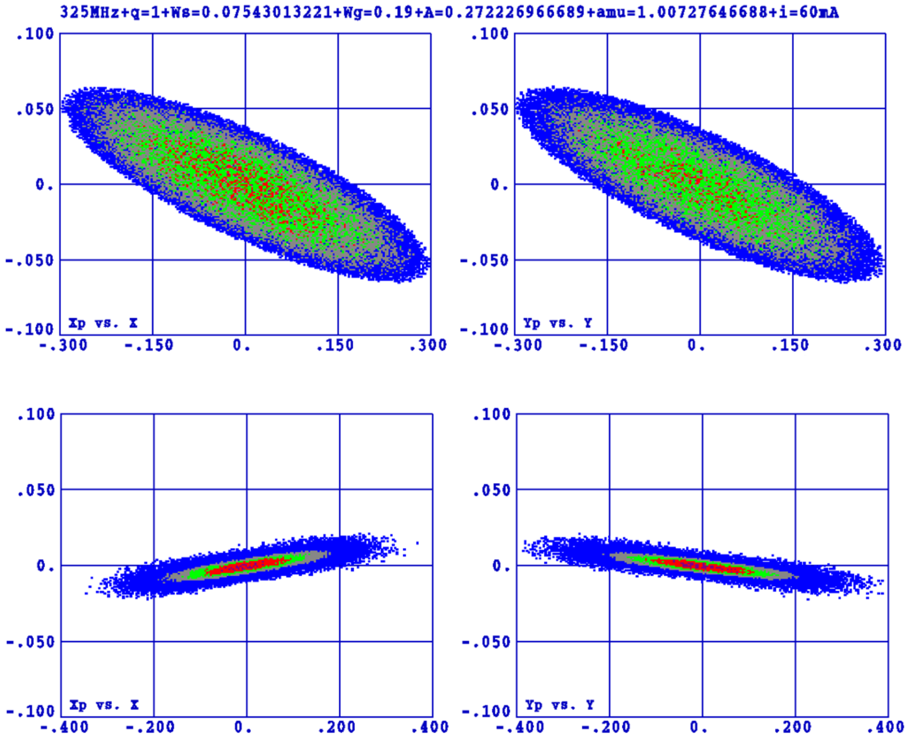
Matching between RFQ & DTL



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	0.014	
Output Longi. β_o	474	472	405	deg/MeV
Transmission rate	97.2%	97.3%(Total) 96.3%(Acc.)	91.5%	

Beam dynamics

- DTL

Configuration

Constant gradient PMQ

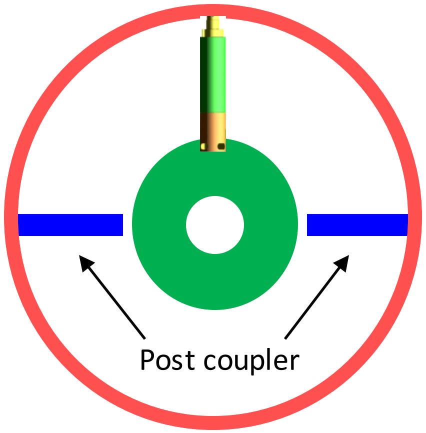
FDFD lattice

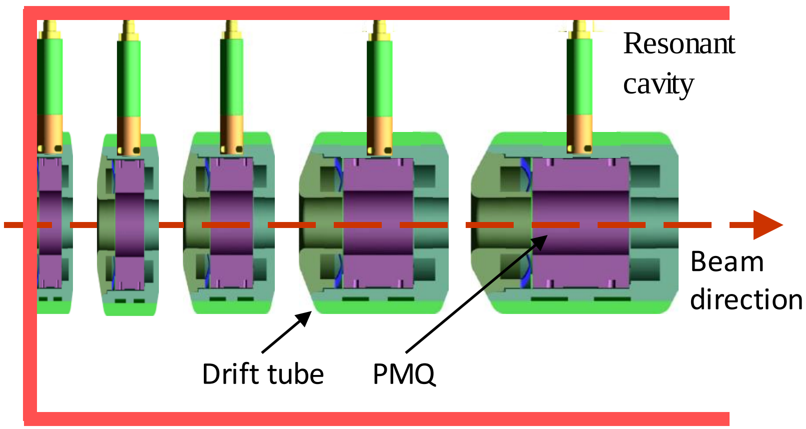
No MEBT

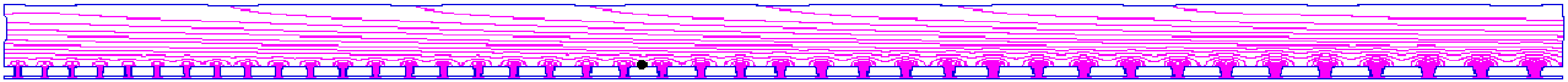
Design and simulation

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

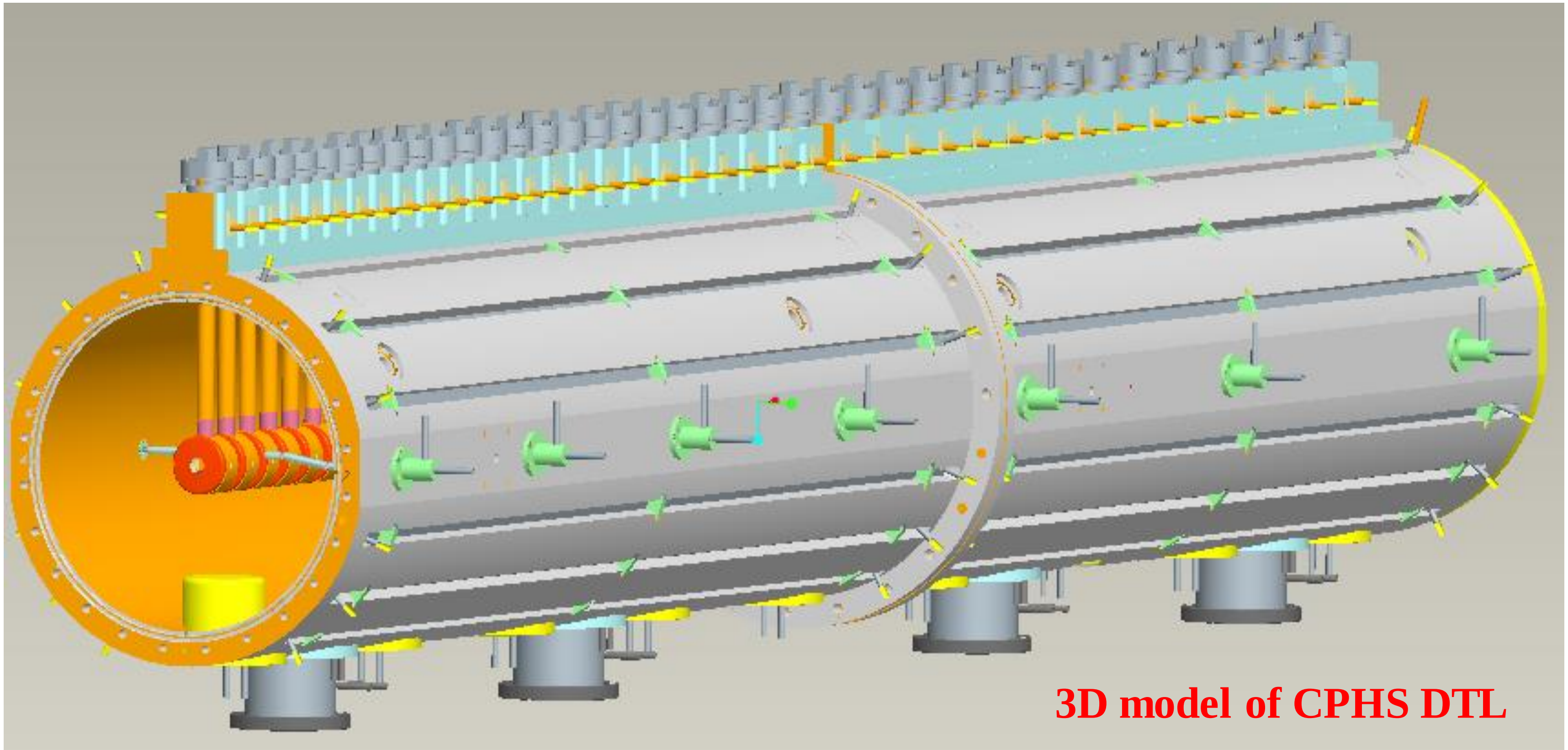






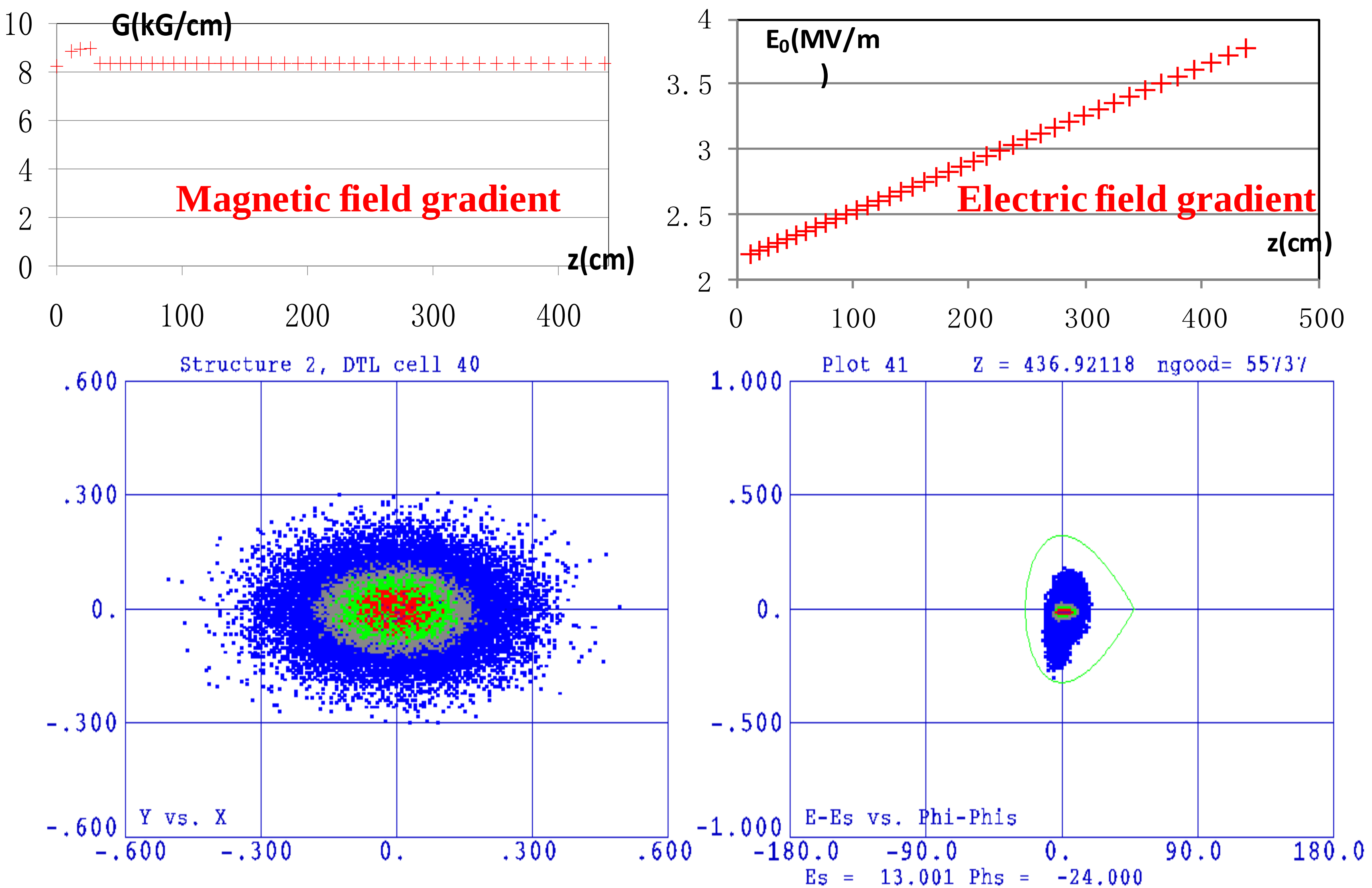
Field calculation by Superfish code

DTL design



3D model of CPHS DTL

DTL design and simulation



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

Beam dynamics

- 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

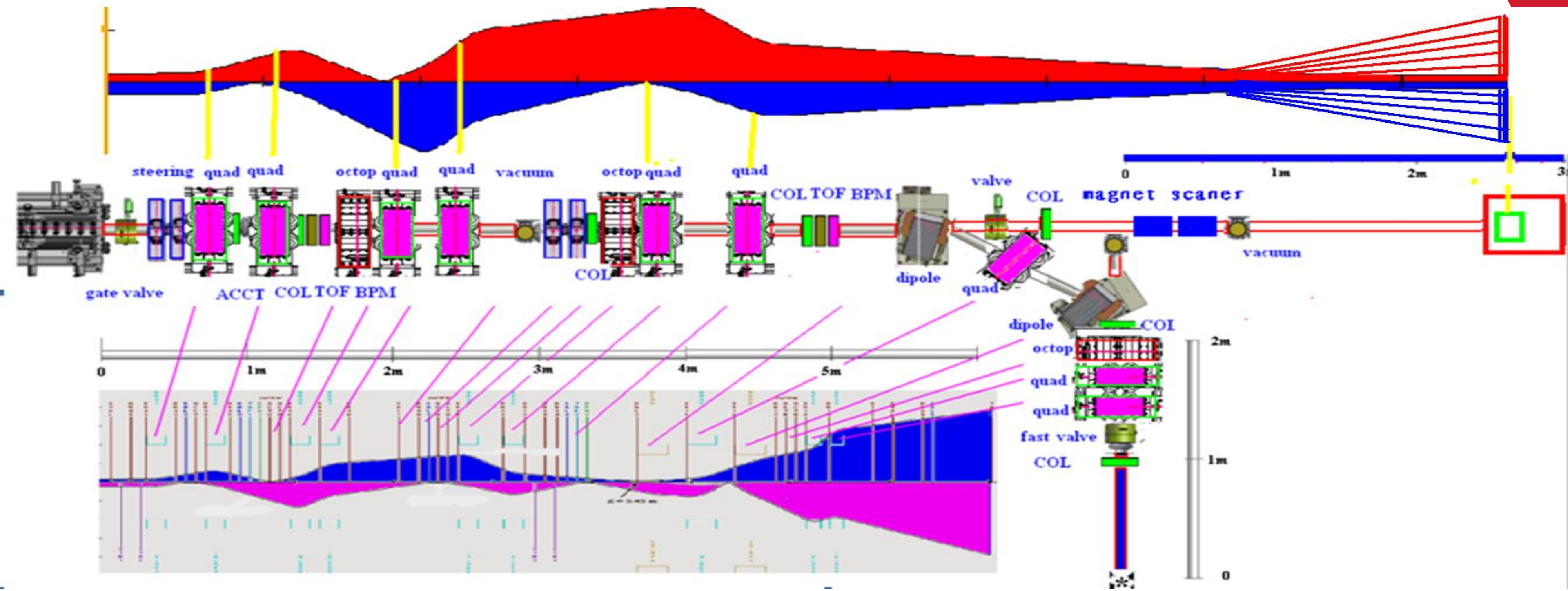
TURTLE (3rd order) =>

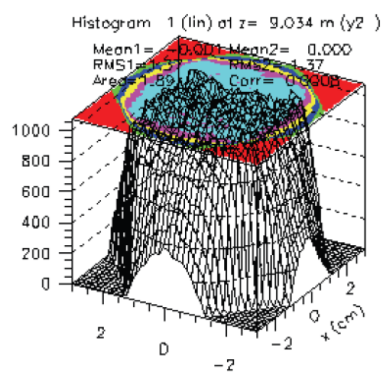
Parameters of three octupole magnets

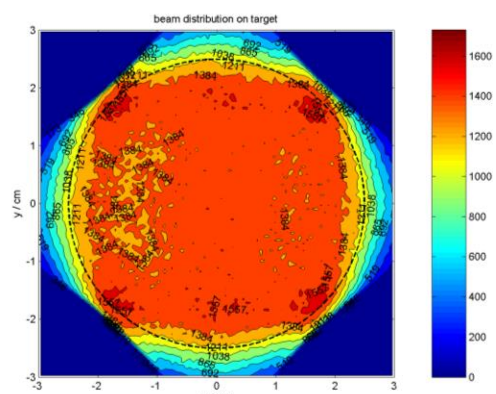
Beam line

2 dipoles
9 quadrupoles
3 octupoles
2 set of steering magnets

HEBT simulation







Beam distribution on the target by TURTLE code

courtesy G.H. Li

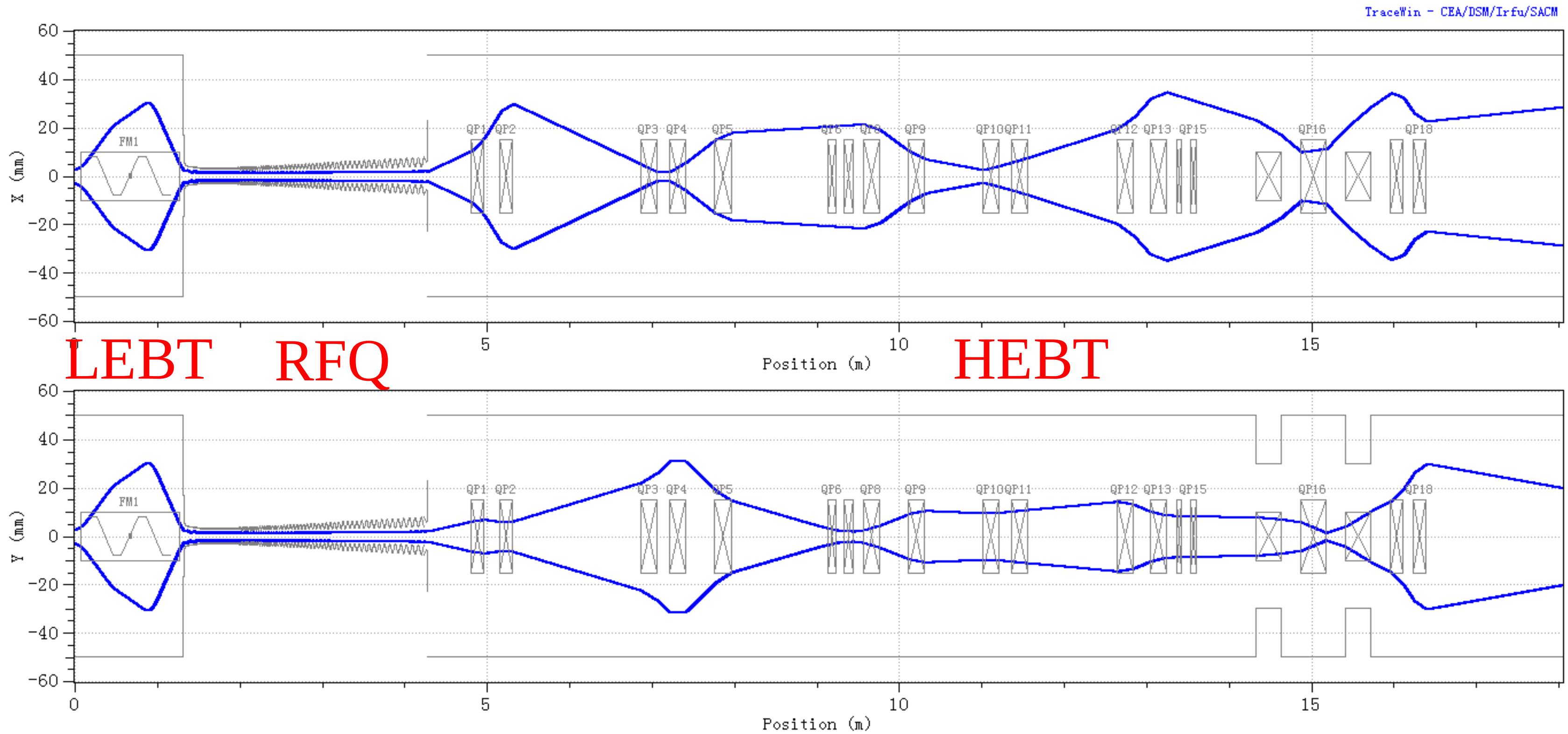
Beam dynamics

- End to end simulation

Simulate the present status of the linac.

Particle tracking by TraceWin with 10^6 particles.

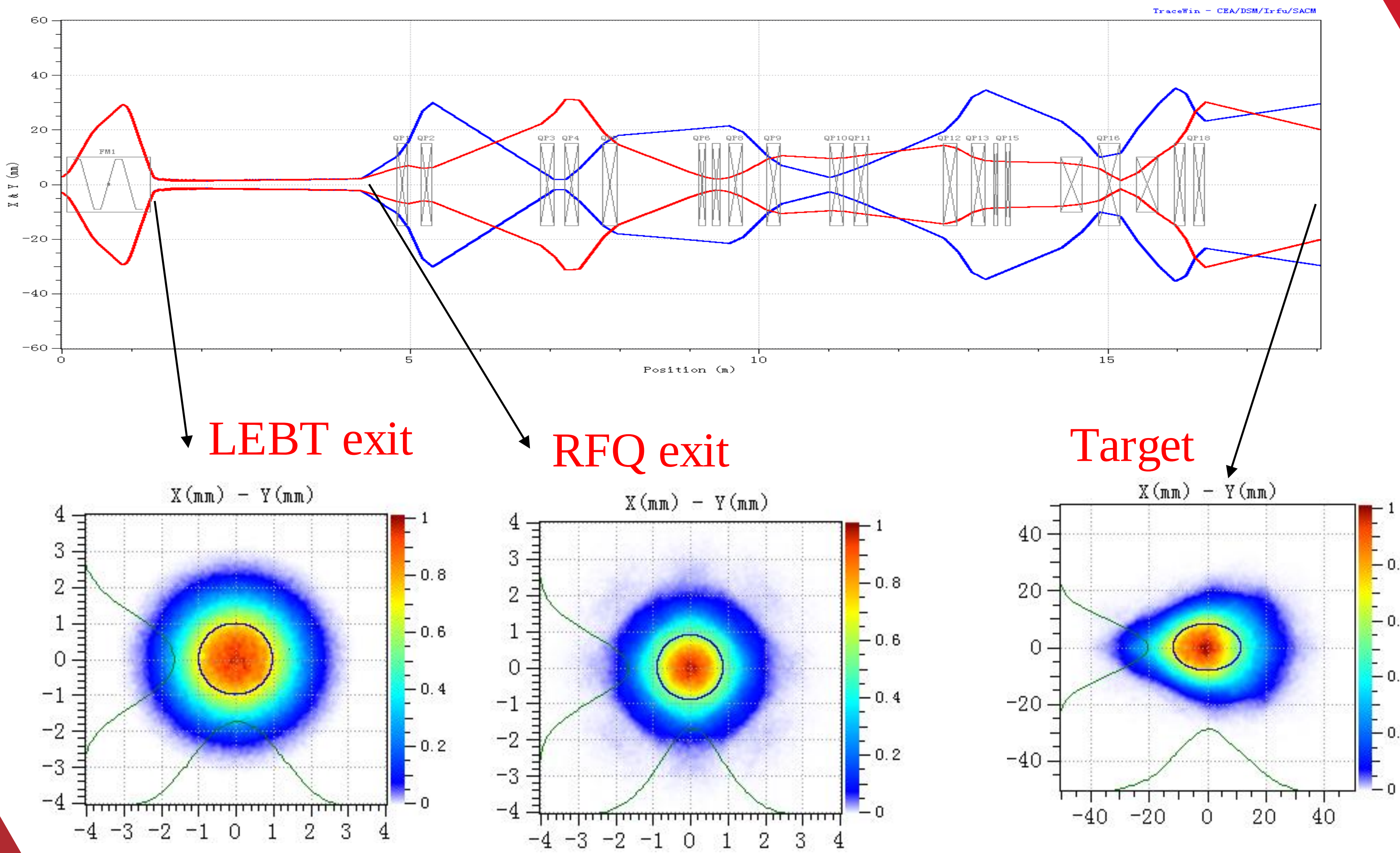
From IS to the neutron target station.



Transmission rate: LEBT, 100%; RFQ, 96.2%; HEBT, 99.7%

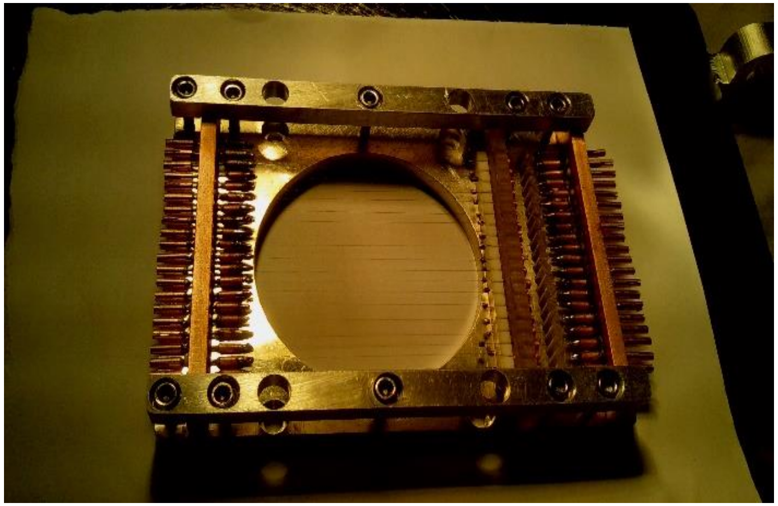
Beam dynamics

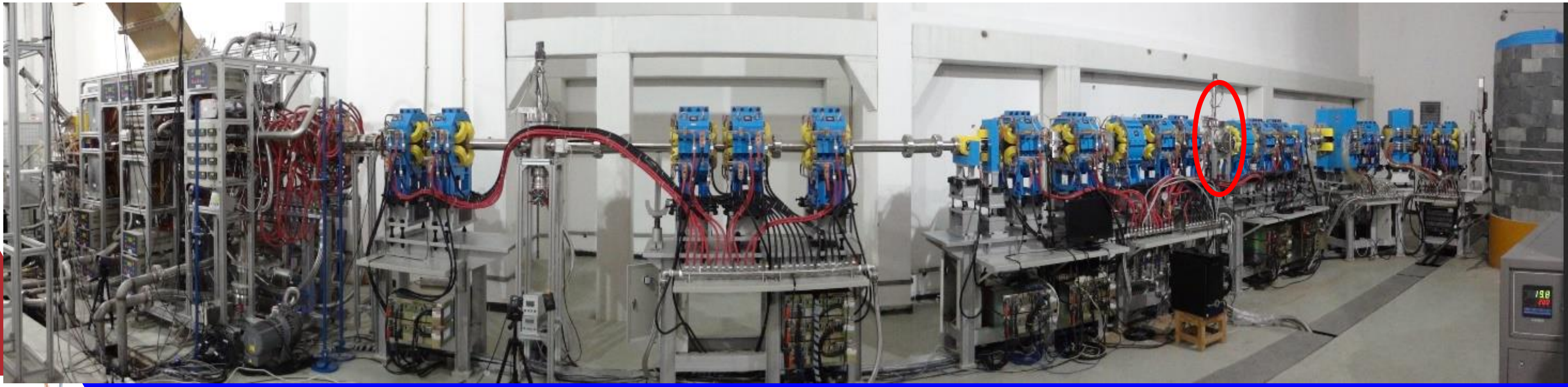
- End to end simulation



Beam profile measurement

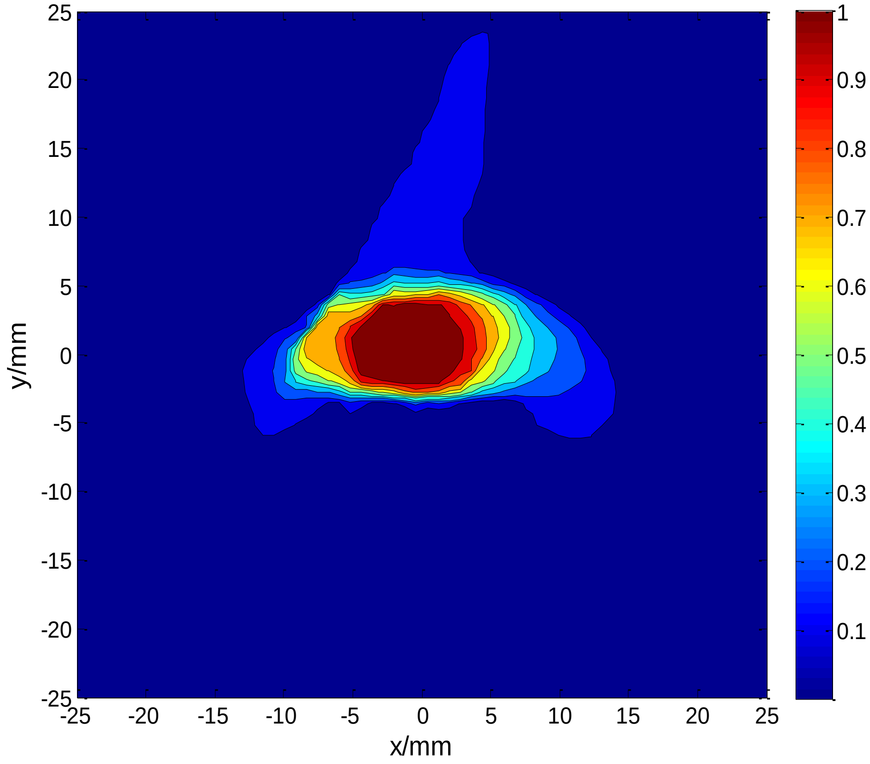
- 2D profile
- Twenty carbon wires rotatable with the diameter of 30 μm.
- The current signal is obtained from the Secondary Electron Emission and then amplified by a set of electronics system.





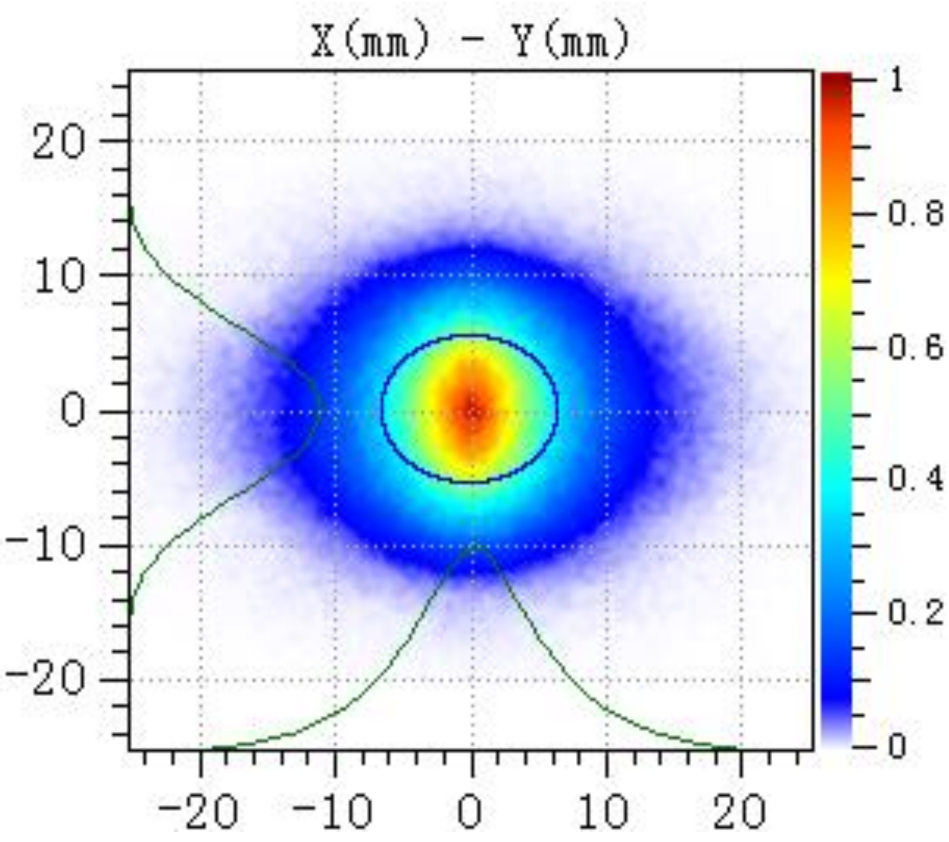
Beam profile measurement

- Total Variation Algebraic Reconstruction Techniques (TV-ART) CT Algorithm is used to rebuild the image of the beam profile.
- The electronics system for the measurement of the twenty wires will be ready at the end of this year.
- The dynamic range is expected to be 10^5
- One profile measurement is expected to be finished in ten minutes.

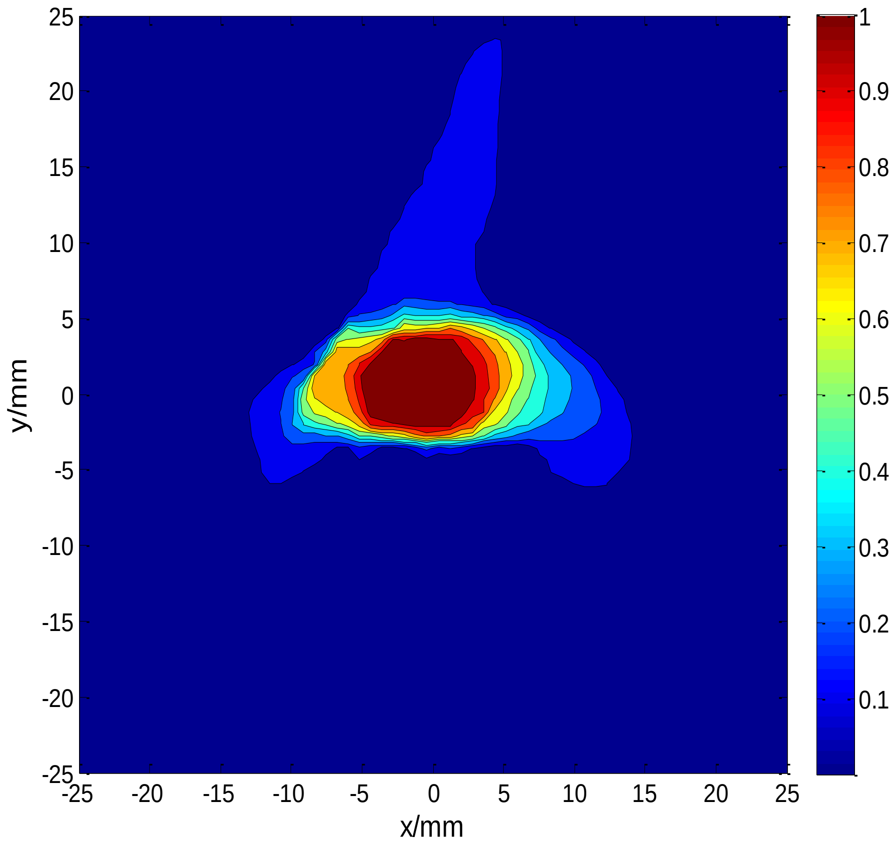


Beam profile measurement

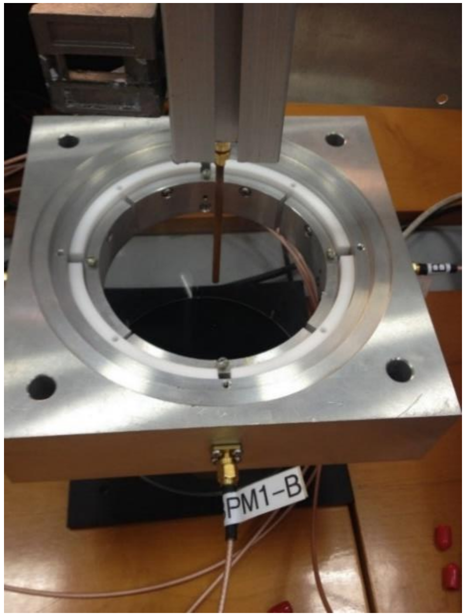
Simulation



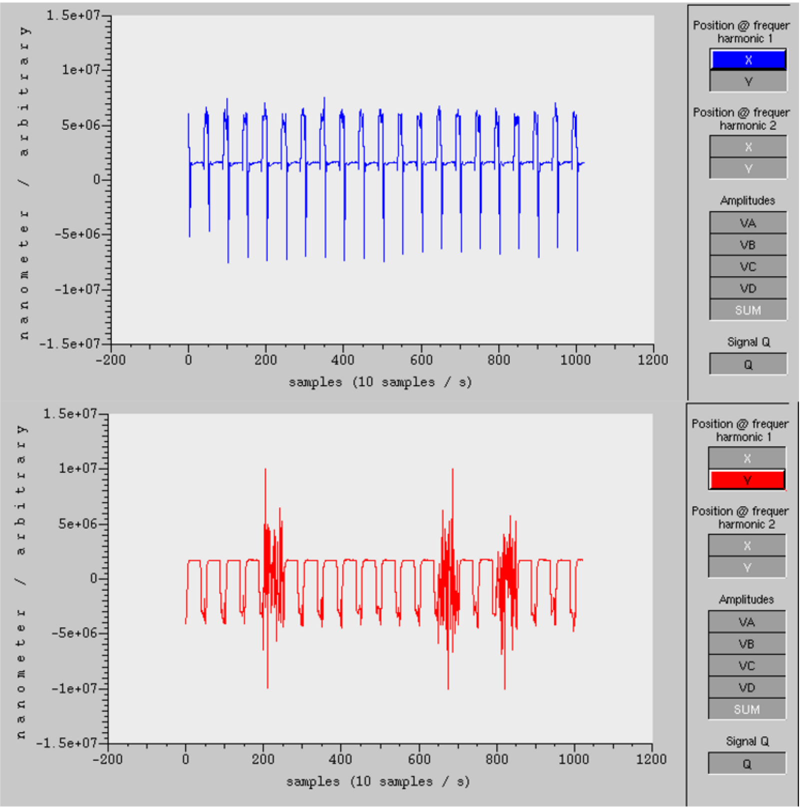
Measurement



Beam position measurement



- Button-type BPM.
- 20 dB amplifier.
- hadron phase & position processor- Libera Single Pass H.
- IQ sample signals can be obtained by using the method of undersampling and digital orthorhombic demodulation. These signals are used to calculate the amplitude and phase.



Summary

- Beam dynamics simulation has been carried out by various codes for the CPHS Linac.
- End to end simulation has been accomplished by TraceWin, as a cross-check to the design and a reference to the operation.
- Beam profile measurement system and Beam position measurement system are under development. The primary measurements have been finished.

Thank you for attention!