Beam diagnostics for CSNS-Ⅱ linac commissioning and operation

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Outline

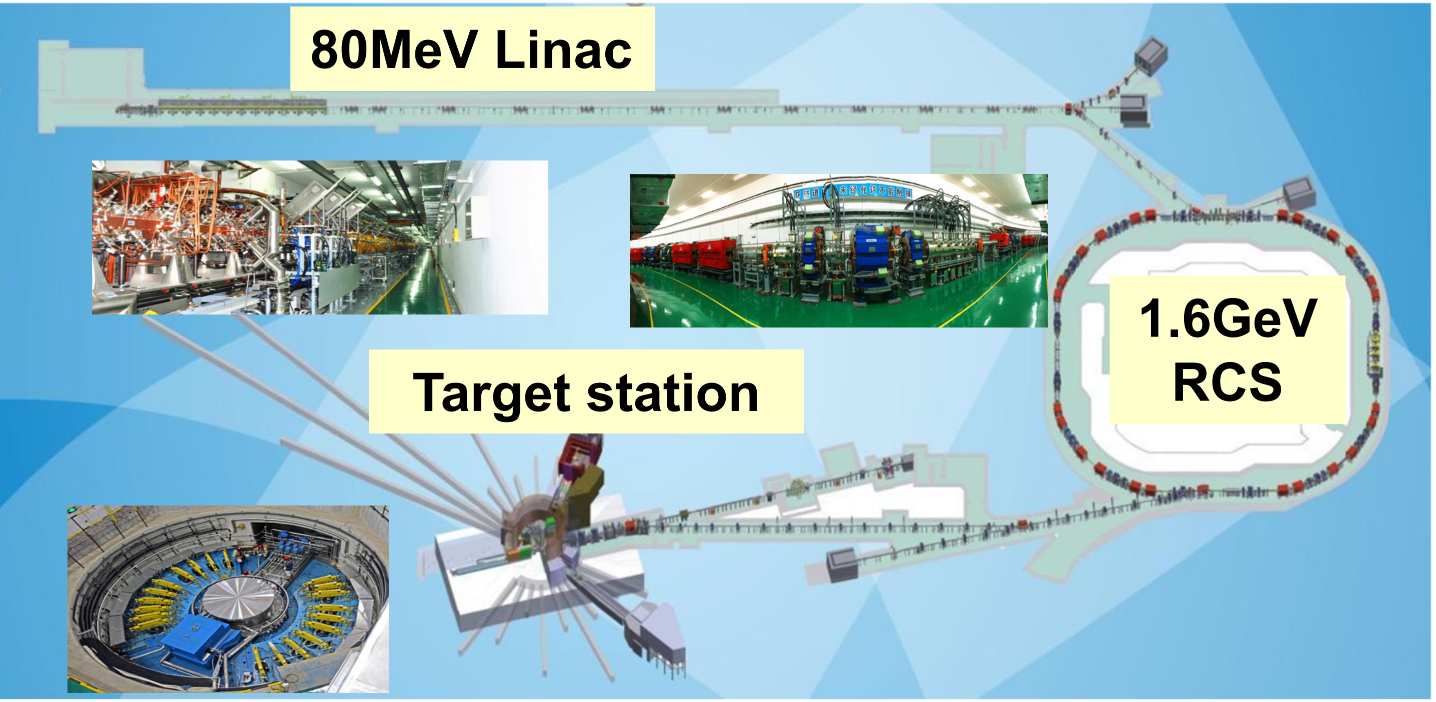
1 Overview of CSNS

2 Introduction of CSNS-Ⅱ Linac

3 Beam diagnostics for commissioning and operation

4 Summary

Overview of CSNS

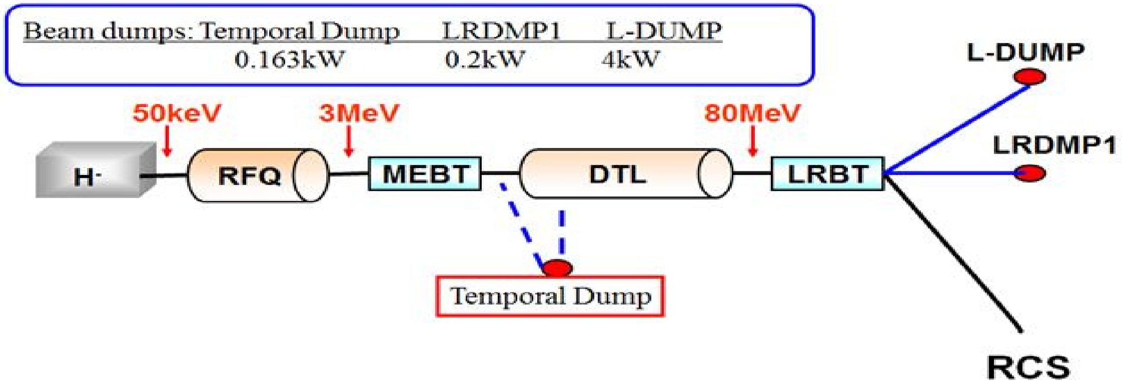


	CSNS	CSNS-II
Average power (kW)	100	500
Pulse repitition frequency(Hz)	25	25+25
Energy (GeV)	1.6	1.6
Average current(μA)	62.5	312.5
Linac beam energy (MeV)	80	300
Linac beam peak current (mA)	15	40
Pulse width(μs)	500	650

- 2011 start construction
- 2015 start beam commissioning
- 2018 start operation for user program(20kW)
- 2020 Reach the design power (100kW)
- 2024 60% more than the design power （160kW）
  lauch the CSNS power upgrade project (**CSNS-II**)

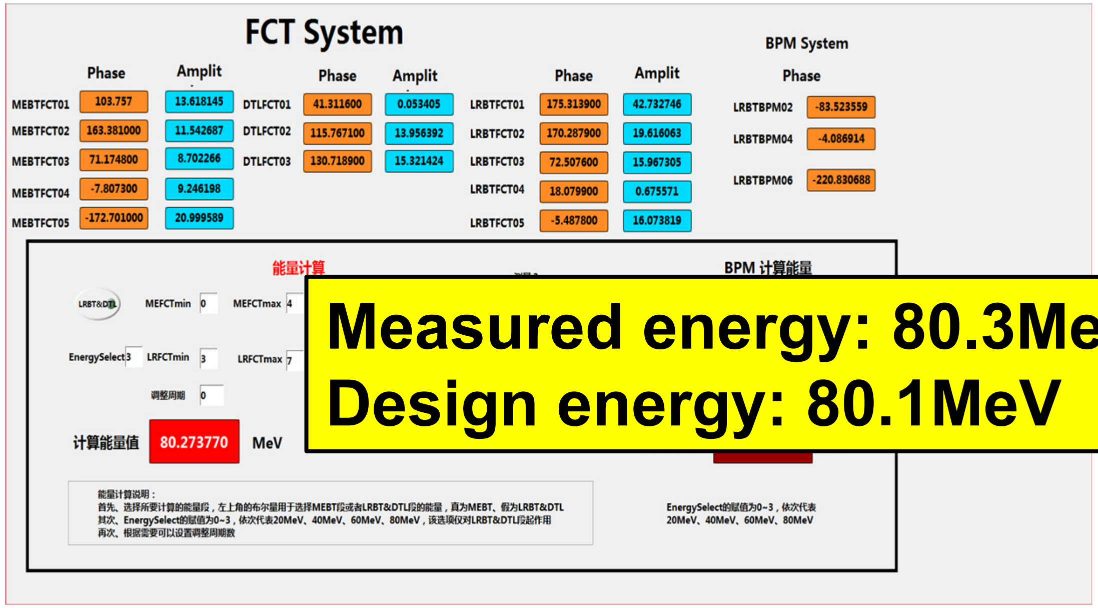
CSNS Linac status

With 42% chopping

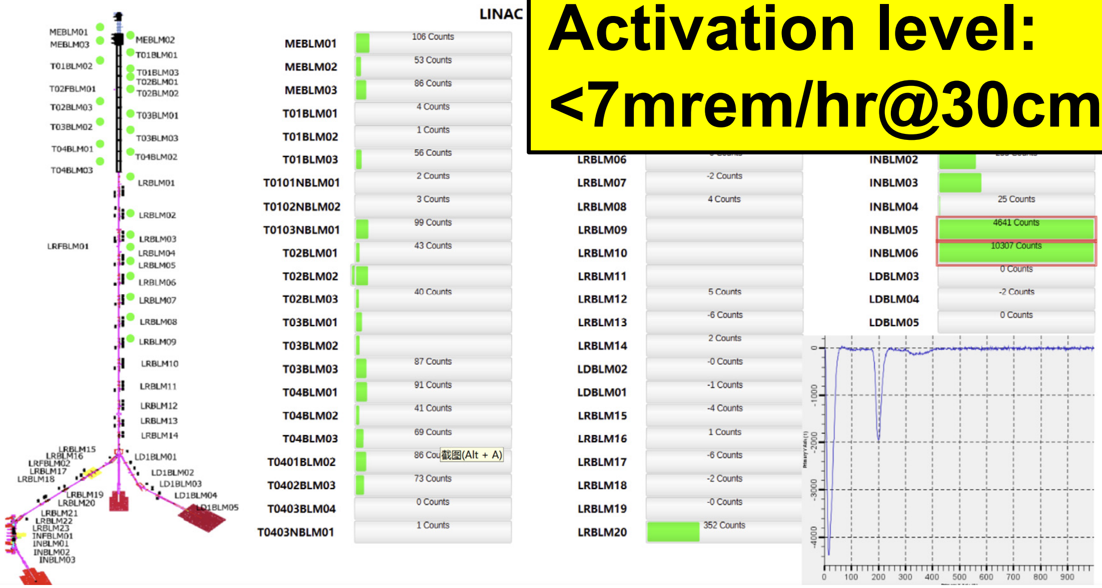


束流状态 2024-07-30 18:33:06

LEBT CT01	36.57	mA	RTBT CT02	2.486	E13
LEBT CT02	4.46	mA	RTBT CT03	2.464	E13
MEBT CT01	7.72	mA	MEBT Trans	100.1	%
MEBT CT02	7.72	mA	DTL Trans	99.6	%
LRBT CT01	7.69	mA	LRBT Trans	100.4	%
LRBT CT02	7.70	mA	EXT Trans	101.1	%
LRBT CT03	7.72	mA	RCS Trans	97.3	%
DCCT-INJ	2.522	E13	RTBT Trans	99.4	%
DCCT-EXT	2.453	E13	Linac Energy	80.294	MeV
RTBT CT01	2.480	E13	Beam Power	160.45	kW

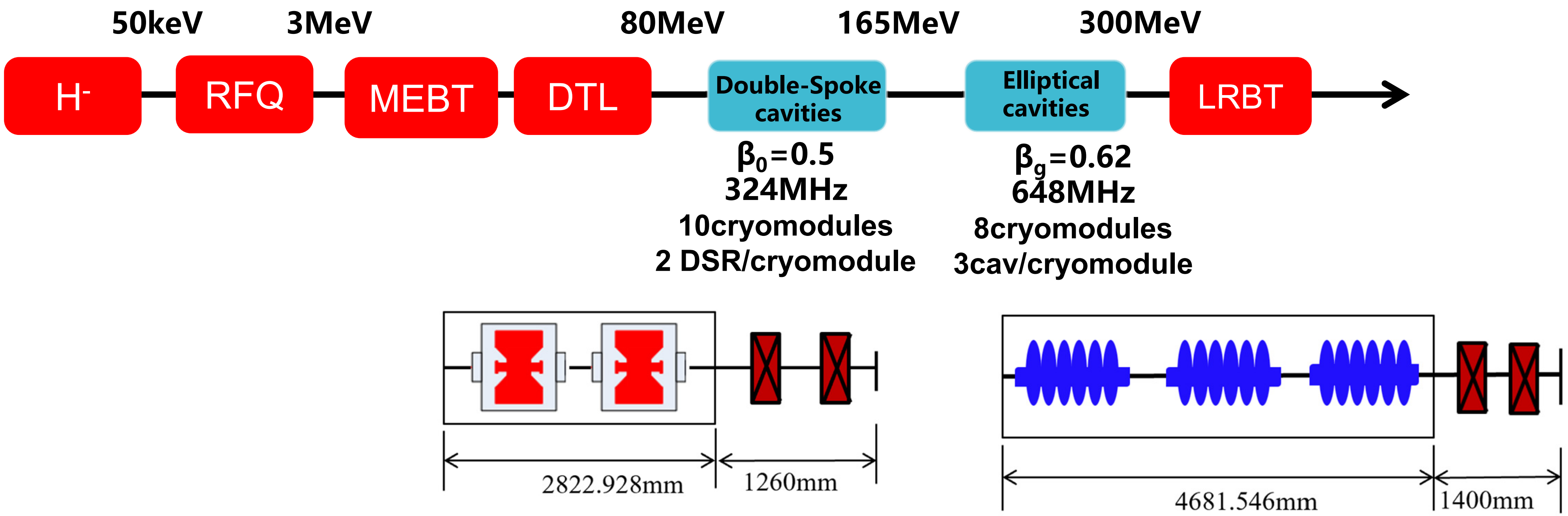


Measured energy: 80.3MeV
Design energy: 80.1MeV



Activation level: <7mrem/hr@30cm

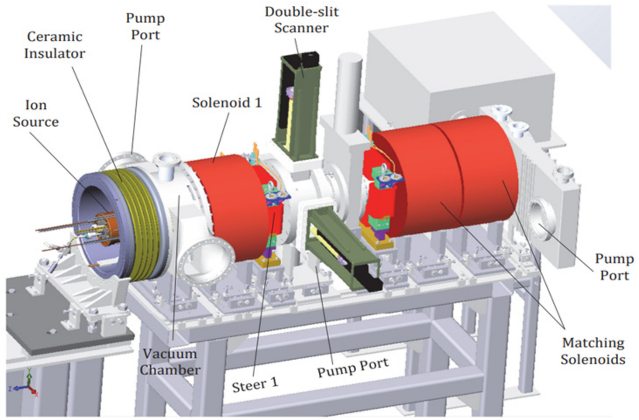
CSNS-II Linac



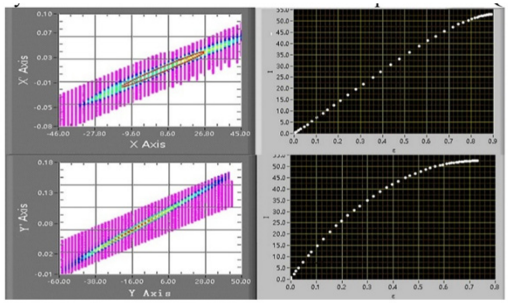
- The ion source has been changed from a Penning surface plasma source to an RF-driven H^- source
- The RFQ has been redesigned to reduce the surface electric field.
- The focusing lattice of the DTL will change from FFDD to FD to reduce the beam envelope.
- A new superconducting linac will be installed after the DTL to increase energy to 300MeV.
- The LEBT、 MEBT and LRBT have all been adjusted for higher beam intensity.

LEBT adjustment

LEBT for CSNS linac (15mA, 80MeV)

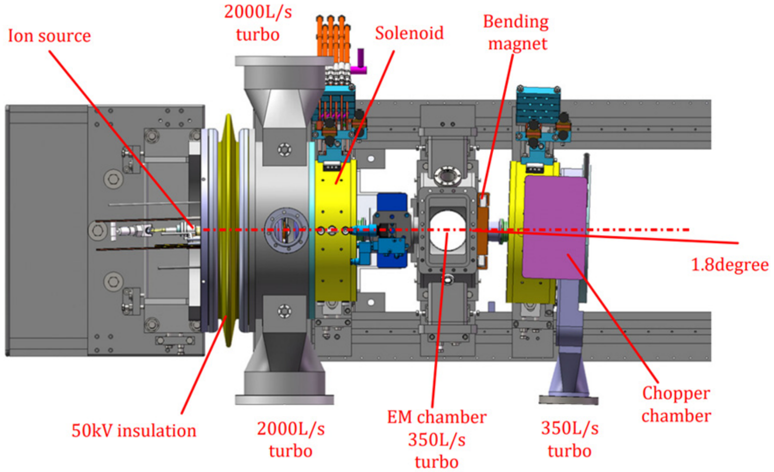


3 solenoid magnets
1 pre-chopper and a beam collimator
2 CTs
1 EM

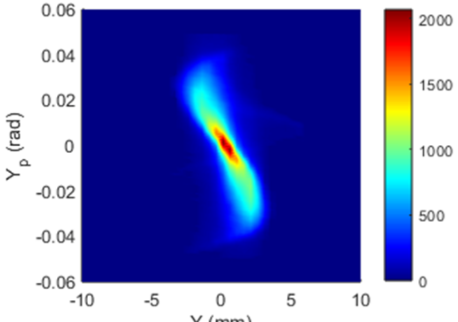


I=53mA, ex=0.892Pi. mm.mrad
ey=0.742Pi.mm.mrad

LEBT for CSNS-Ⅱ linac (40mA, 300MeV)



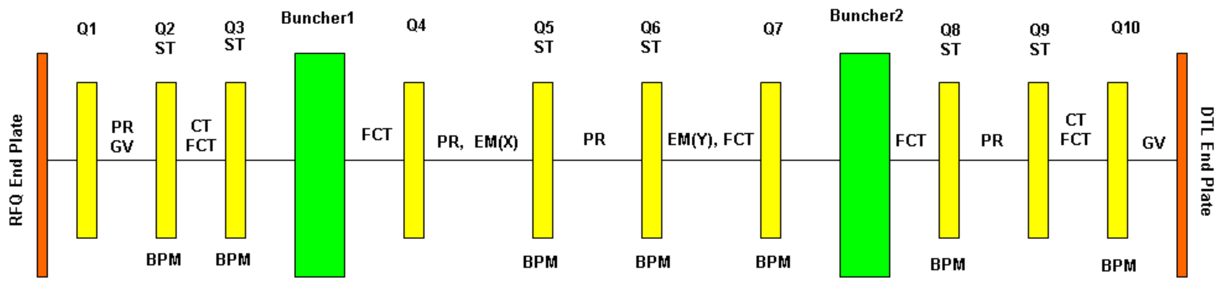
2 solenoid magnets
1 pre-chopper
2 CTs
1 EM



I=52mA, ex=0.236Pi. mm.mrad
ey=0.230Pi.mm.mrad

MEBT adjustment

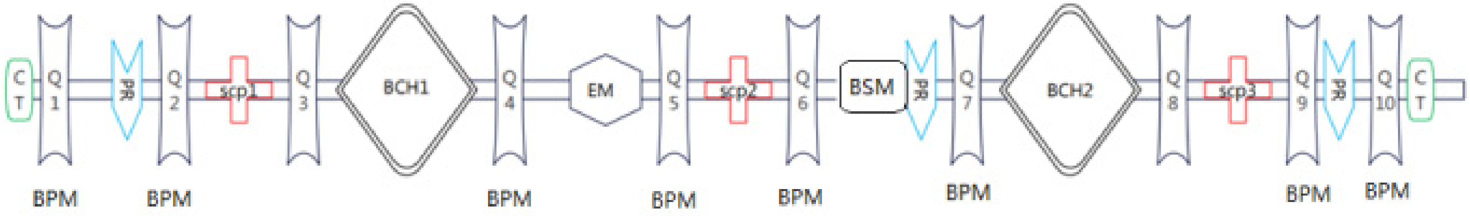
MEBT for CSNS linac (15mA, 80MeV)



BPM=beam position monitor
PR=profile monitor
FCT=fast current monitor
CT=current monitor
Q=quadrupole magnet
EM=emittance monitor
GV=gate vale
ST=steering magnet
DR=drift space

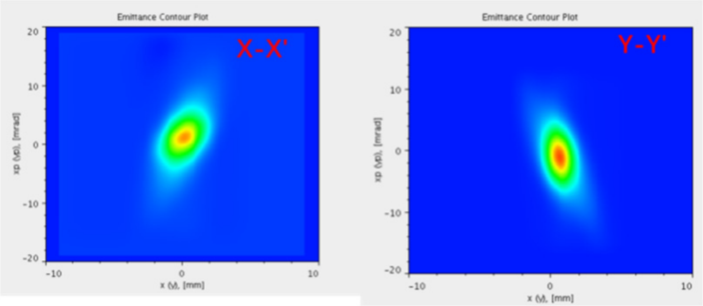
10quads, 2 bunchers, 3.04 meters long
7 BPM+6 steers
2 CTs
5 FCTs
1 EM
4 WSs
3 BLMs

MEBT for CSNS-Ⅱ linac (40mA, 300MeV)

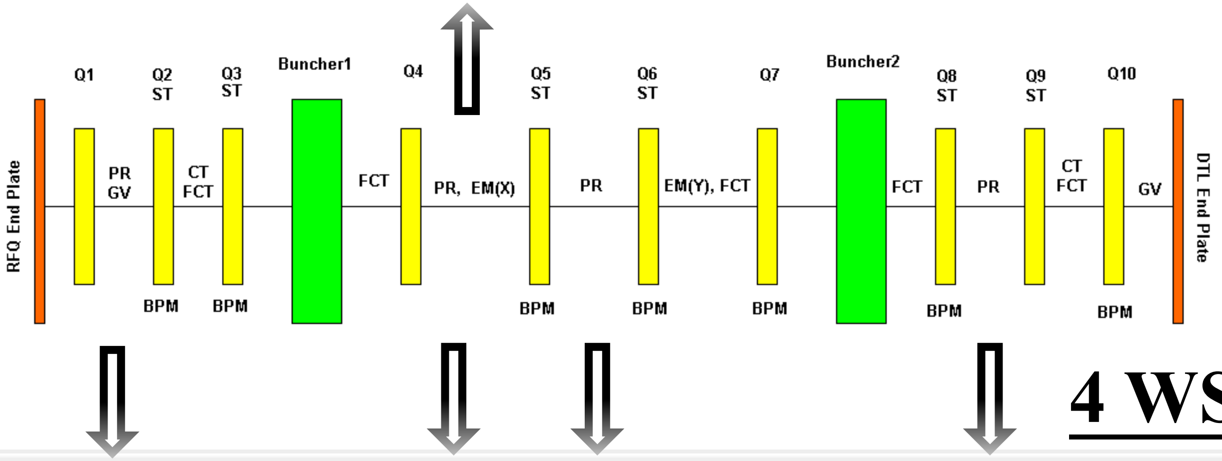


10quads, 2 bunchers, 2.93 meters long
8BPM+9 steers
2 CTs
1 EM
3 WSs
3 BLMs
1 BSM
1 FC
3 Transverse collimators

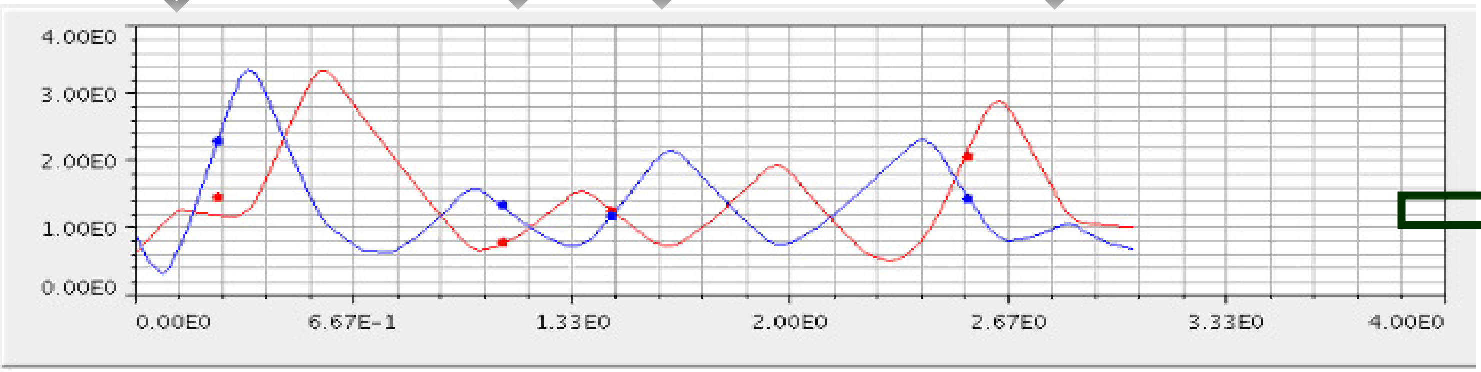
MEBT transverse emittance measurement



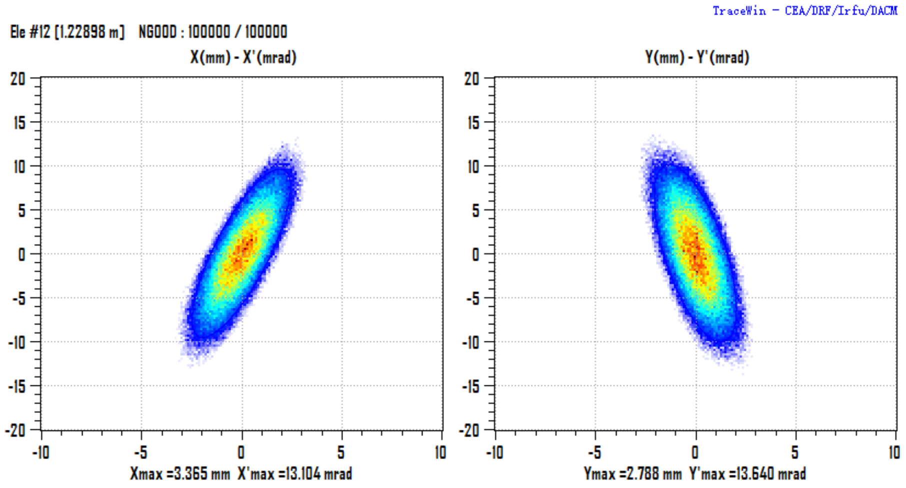
1 EM



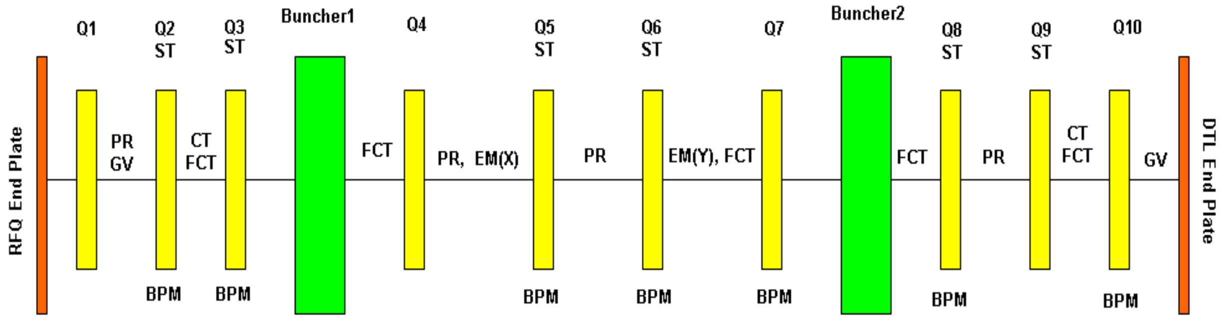
4 WSs



	Δα(%)	Δβ(%)	$\Delta\varepsilon_{RMS}$(%)
X-X'	12.15	11.37	-2.07
Y-Y'	4.57	5.7	11.42

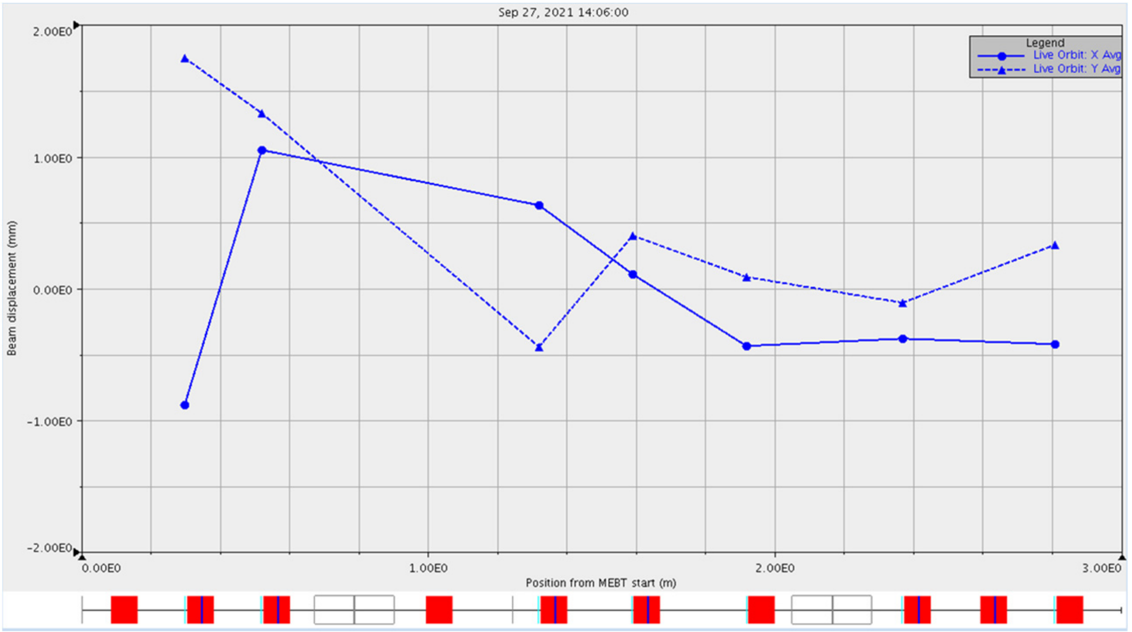


MEBT orbit correction

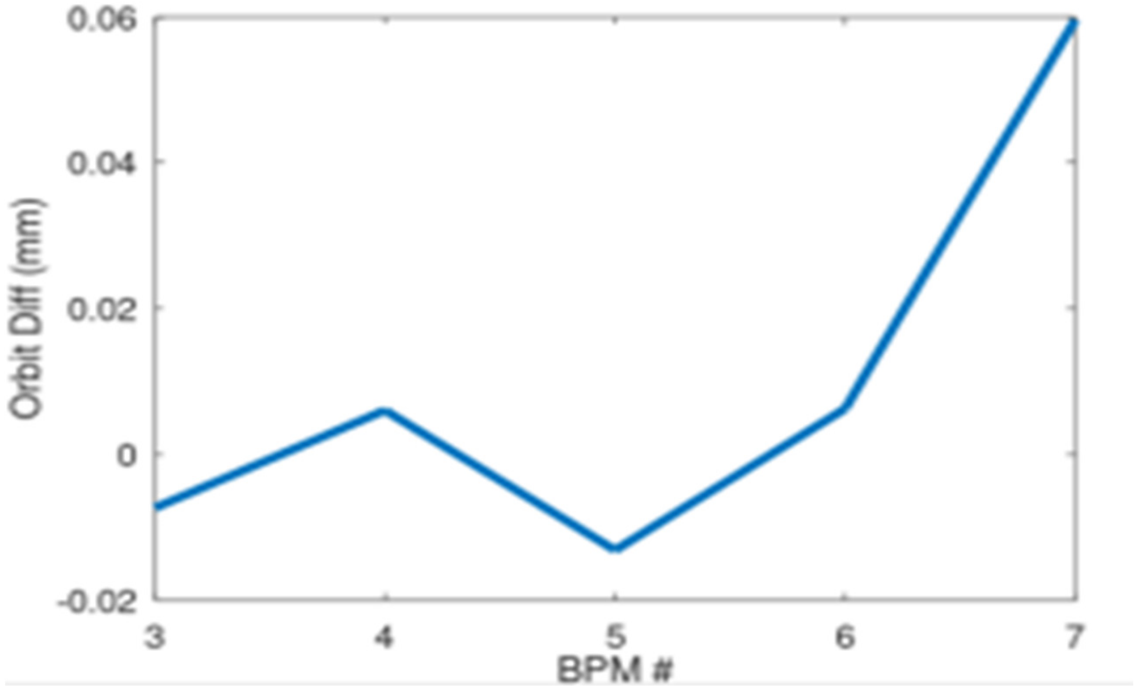


7 BPMs + 6 Steers

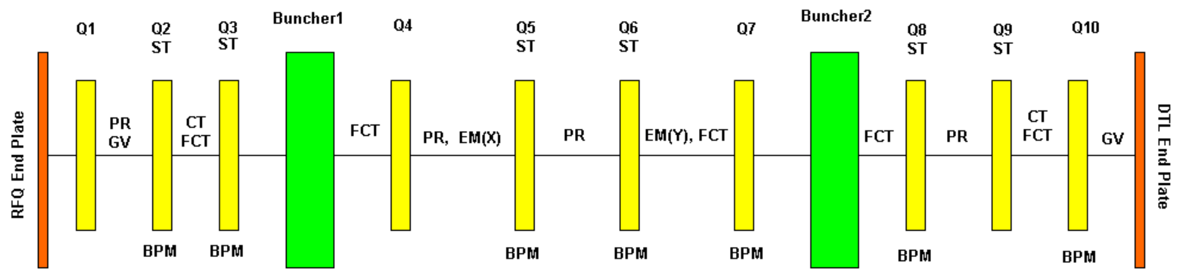
Beam orbit<$\pm 1mm$



Difference between simulation and measurement



MEBT energy measurement and phase scan



5 FCTs, stability within ±0.5°

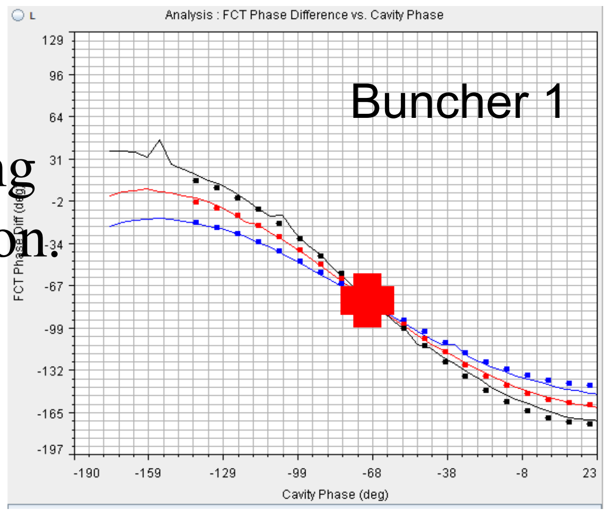
□ Energy measurement

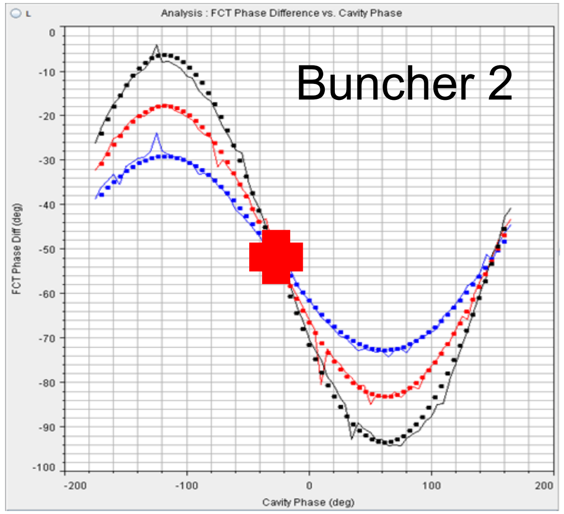
- The 1st FCT and 5th FCT are used for energy measurement, the distance is >19 βλ
- The design energy of the RFQ is 3.0258MeV
- Measuring the beam energy with TOF (Time Of Flight) method： 3.027MeV

□ Phase scan

- The intersection point is the bunchering phase -90°
- The cavity amplitude can be dertermined by comparing the measured beam phase difference with model prediction.

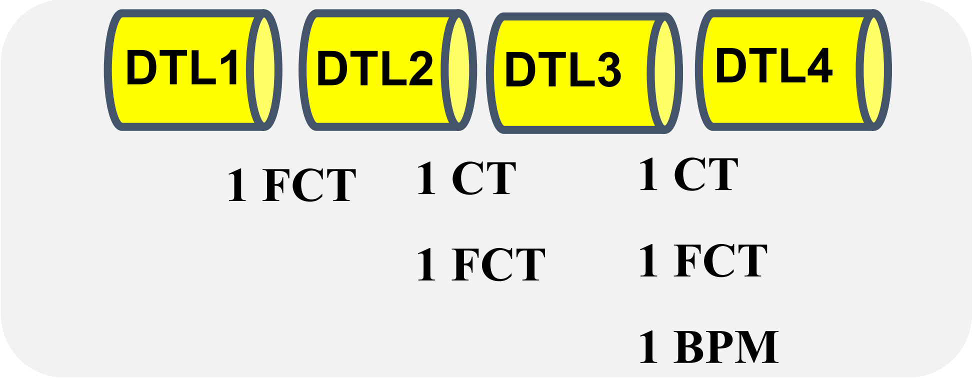
$$W_{out} = E_0 TL\cos(\varphi_s + \Delta\varphi) + W_{in}$$



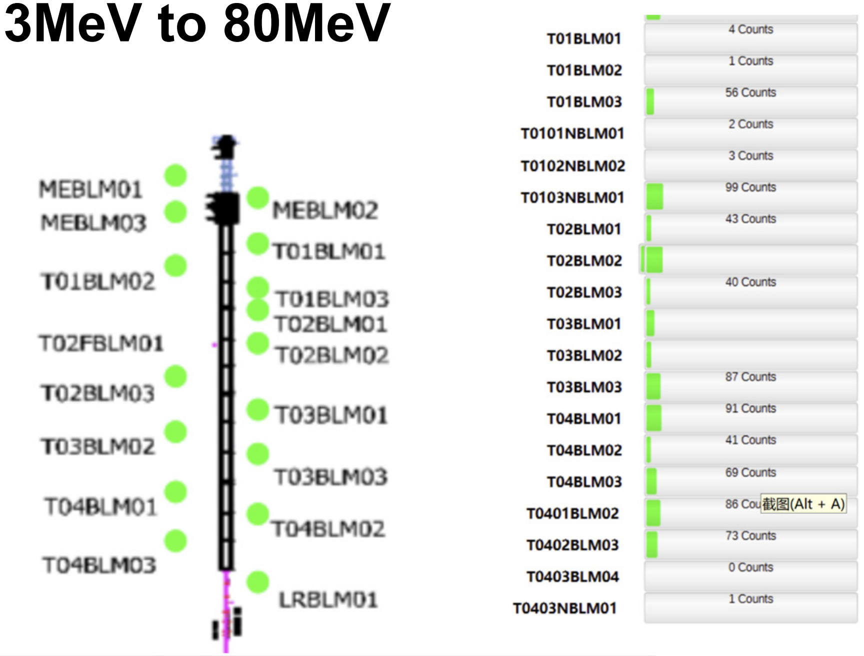


DTL beam orbit and beam transmission

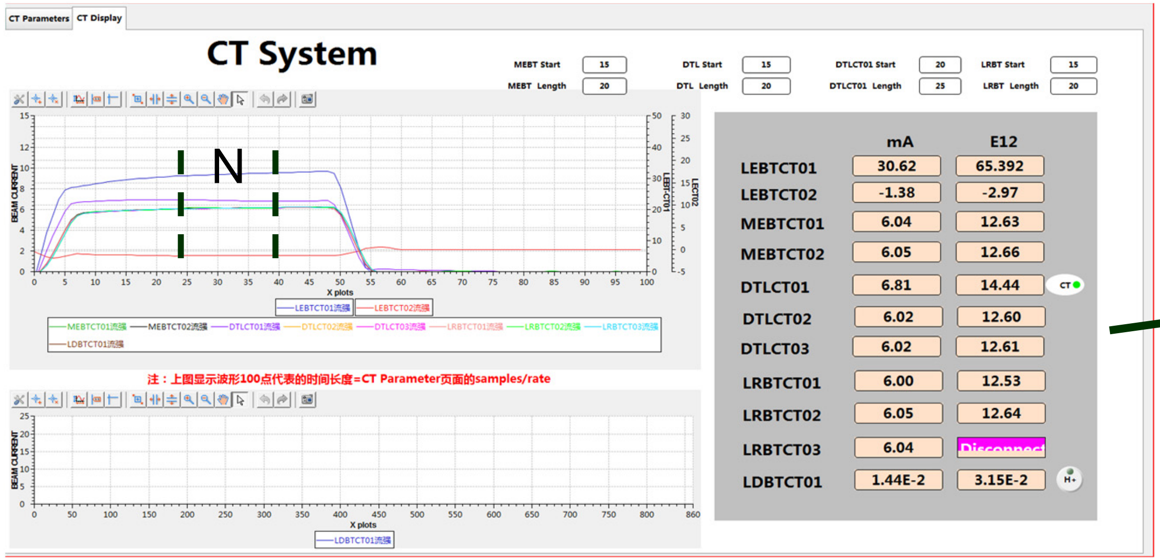
The CSNS DTL contains 4 tanks, accelerating beam from 3MeV to 80MeV



☐ Beam loss



☐ Beam transmission



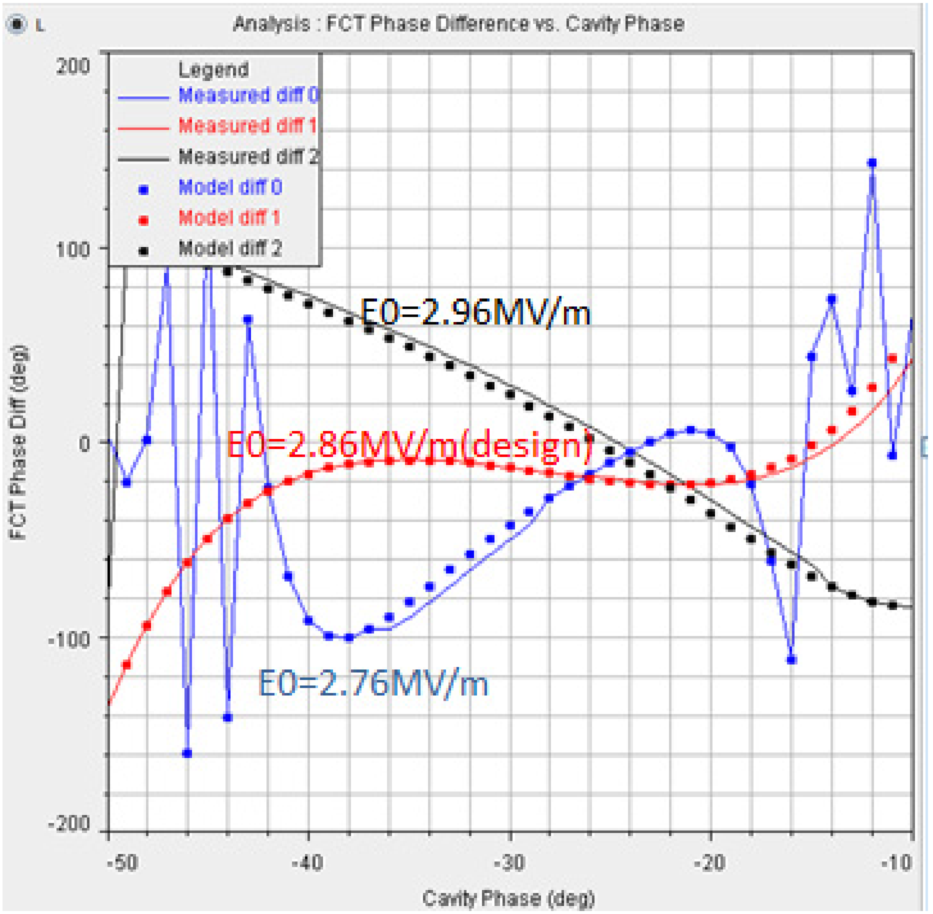
CT Display 2019-11-01 08:36:02

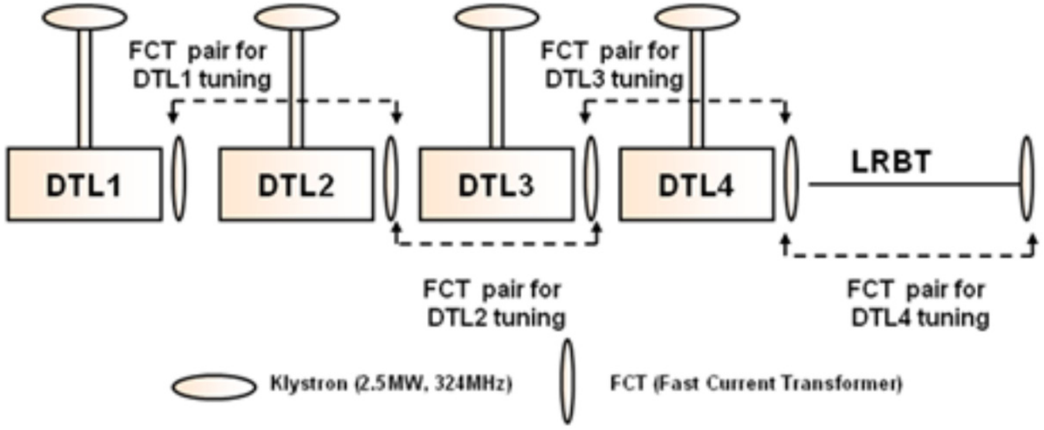
LEBT CT01	30.90	mA	RTBT CT02	1.246	E13
LEBT CT02	-1.38	mA	RTBT CT03	1.253	E13
MEBT CT01	6.06	mA	MEBT Trans	100.2	%
MEBT CT02	6.07	mA	DTL Trans	99.4	%
LRBT CT01	6.04	mA	LRBT Trans	100.4	%
LRBT CT02	6.06	mA	EXT Trans	101.1	%
LRBT CT03	6.06	mA	RCS Trans	98.0	%
DCCT-INJ	1.256	E13	RTBT Trans	100.6	%
DCCT-EXT	1.232	E13	Linac Energy	80.27	MeV
RTBT CT01	1.245	E13	Beam Power	80.12	kW

MEBT CT02
LRBT CT01

DTL phase scan

- **Phase Scan Signature Matching Method**
  XAL, Pasta (an RF phase scan and tuning application)

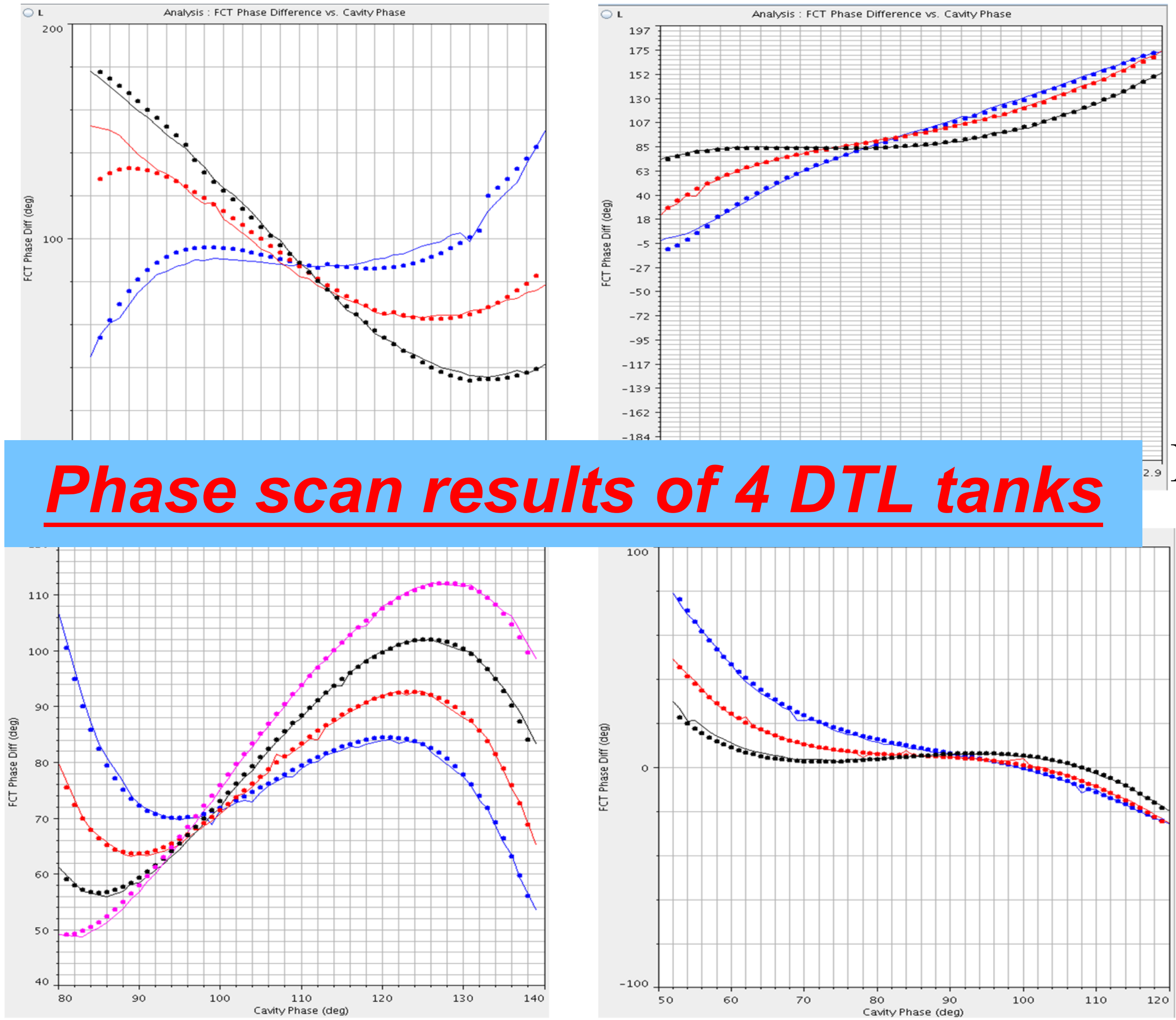




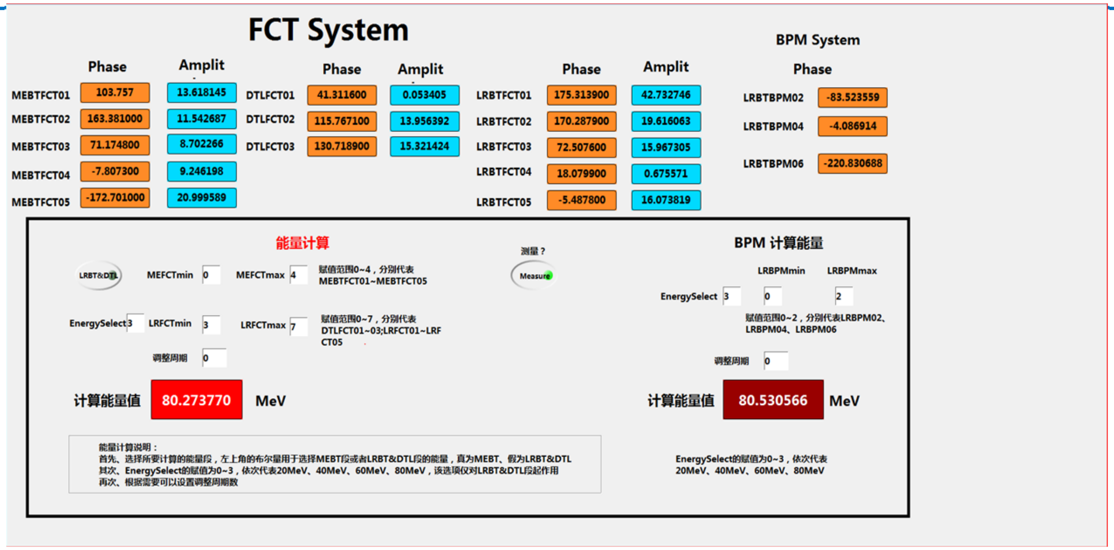
Variables:

- **Input energy**
- **RF amplitude**
- **Phase offset**

DTL energy measurement



Phase scan results of 4 DTL tanks

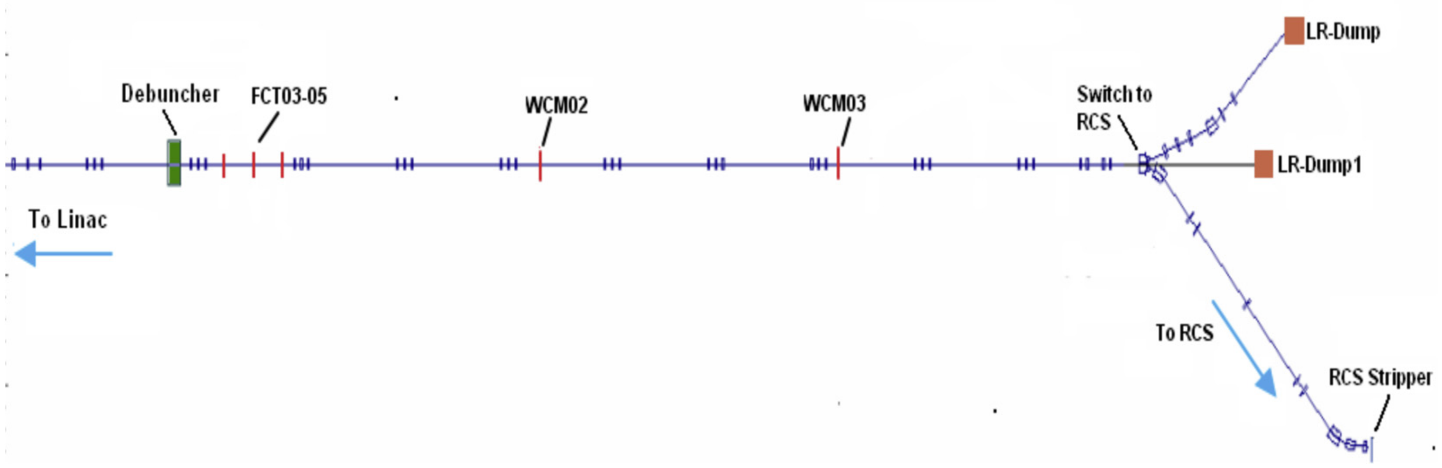


Beam energy measured with two methods

	Design [MeV]	Phase scan [MeV]	TOF [MeV]
RFQ	3.026	3.029	3.027
DTL1	21.669	21.802	21.685
DTL2	41.415	41.52	41.566
DTL3	61.072	60.917	61.09
DTL4	80.01	79.87	80.28

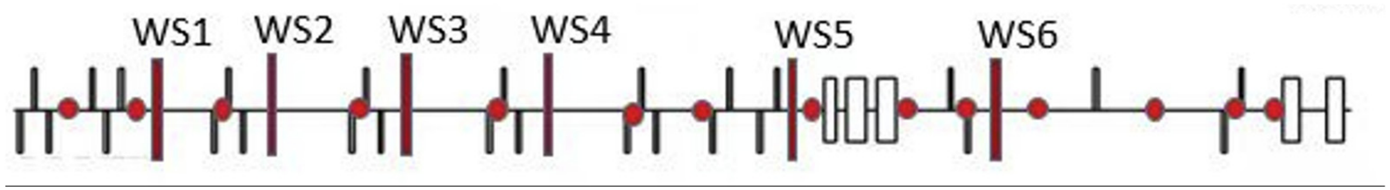
LRBT adjustment

LRBT for CSNS linac （15mA, 80MeV)



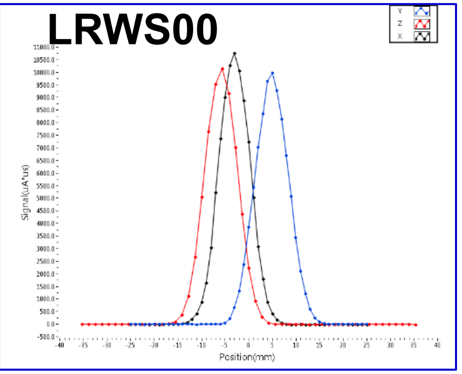
1 Debuncher,
3matching sections, 9 triplets, 1 anti-sysmetric achromatic setcion
18 BPM
3 CTs
5 FCTs
3 WCMs
6 WSs
23 BLMs

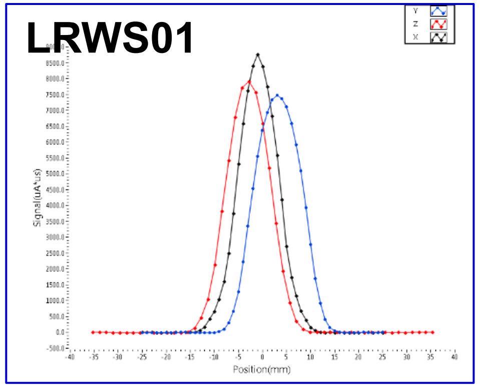
LRBT for CSNS-Ⅱ linac （40mA, 300MeV)

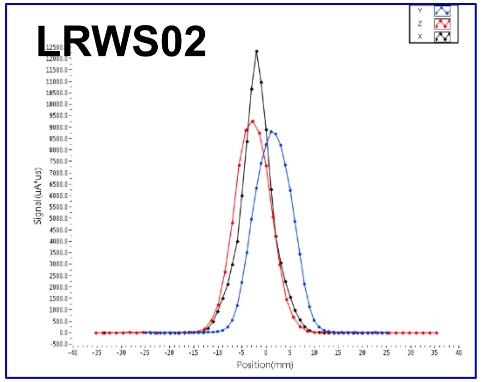


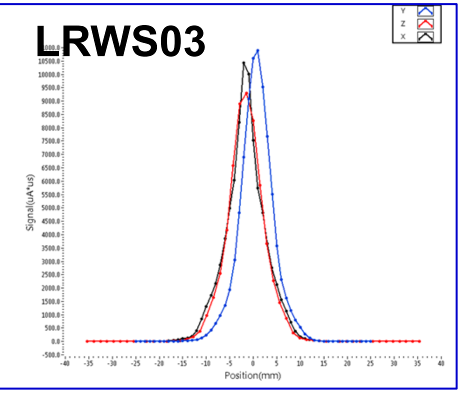
2 Debuncher,
3matching sections, 5 triplets, 1 anti-sysmetric achromatic setcion
14 BPMs
3 CTs
3 WCMs
6 WSs
1 BSM
1 foil collimator

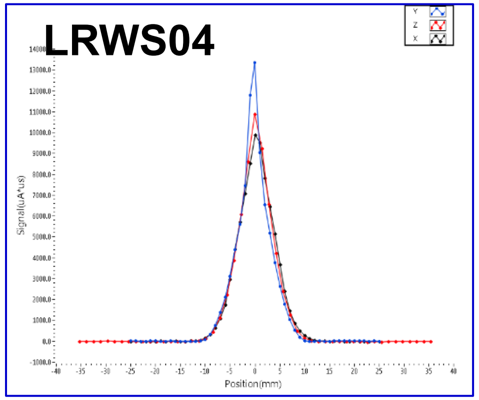
LRBT emittance measurement

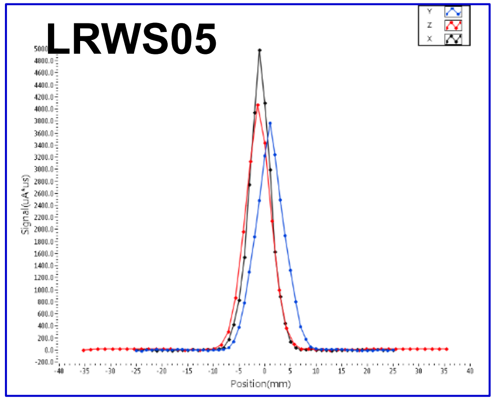


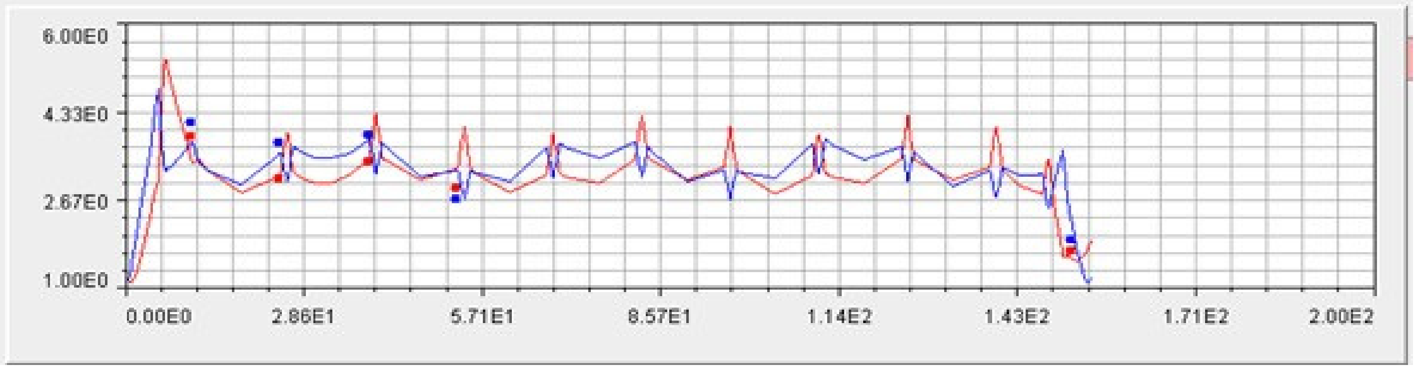






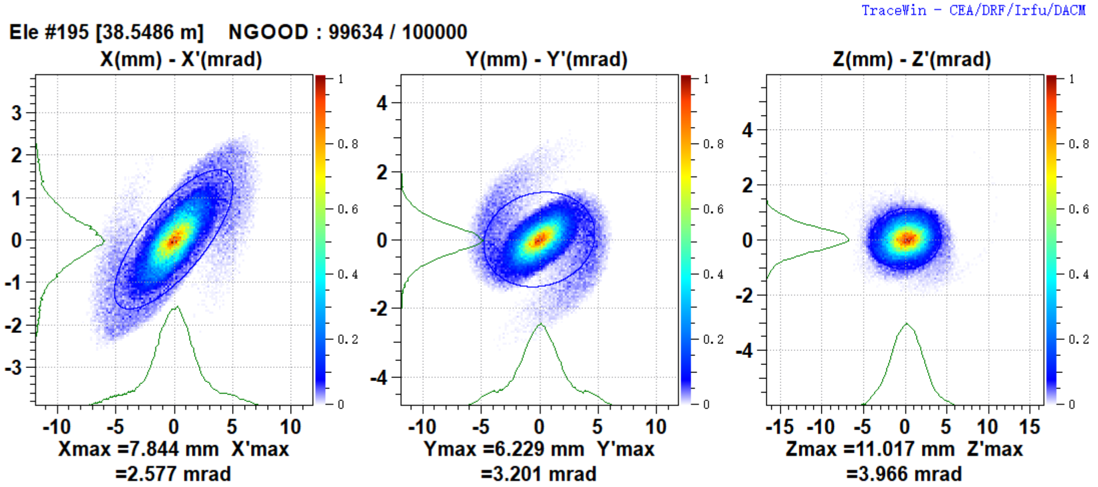






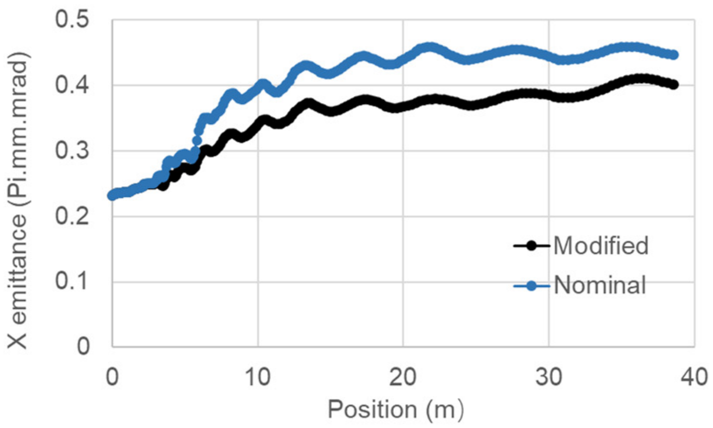
□ Emittanc at the exit of the DTL

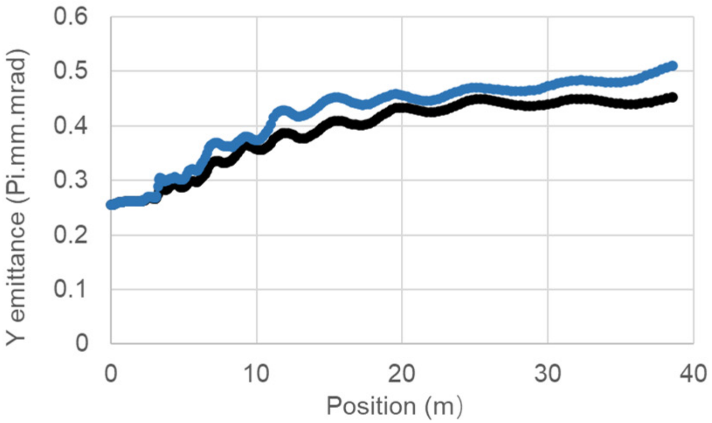
	α	β (mm/pi mrad)	ε Norm.rms (pi mm mrad)
Horizontal			
Simulation	-0.796	2.725	0.359
Measurement	-0.316	3.064	0.449
Vertical			
Simulation	-0.302	3.363	0.418
Measurement	-0.832	3.349	0.406



Transverse emittance mitigation

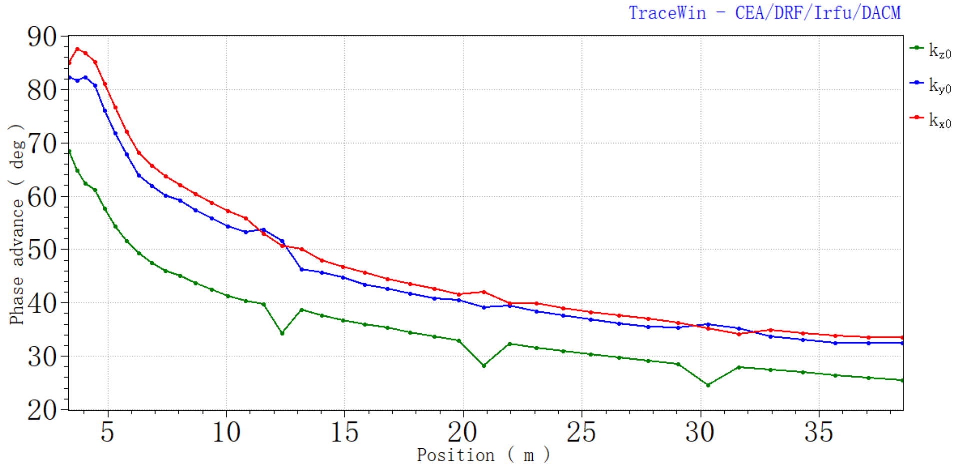
☐ Modifying the buncher settings

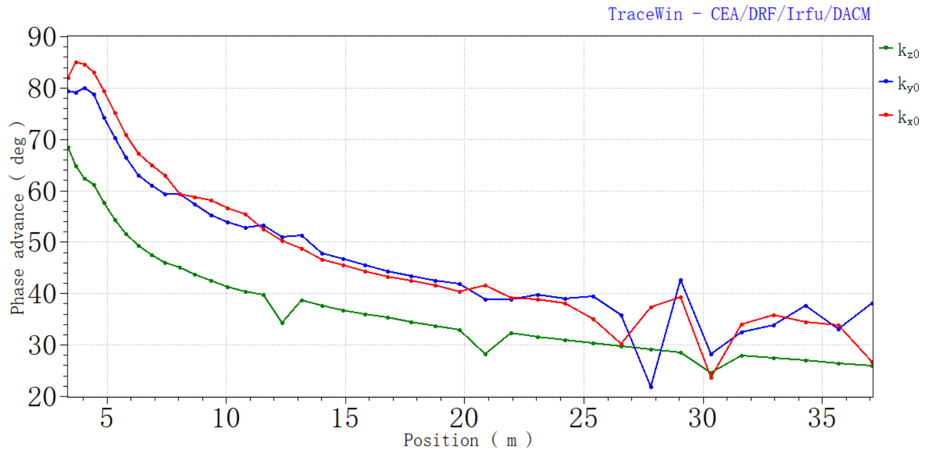




	α	β (mm/pi mrad)	ε Norm.rms (pi mm mrad)
Horizontal			
Nominal	-0.294	2.925	0.468
Modified	-0.316	3.064	0.449
Vertical			
Nominal	-0.929	3.373	0.443
Modified	-0.832	3.349	0.406

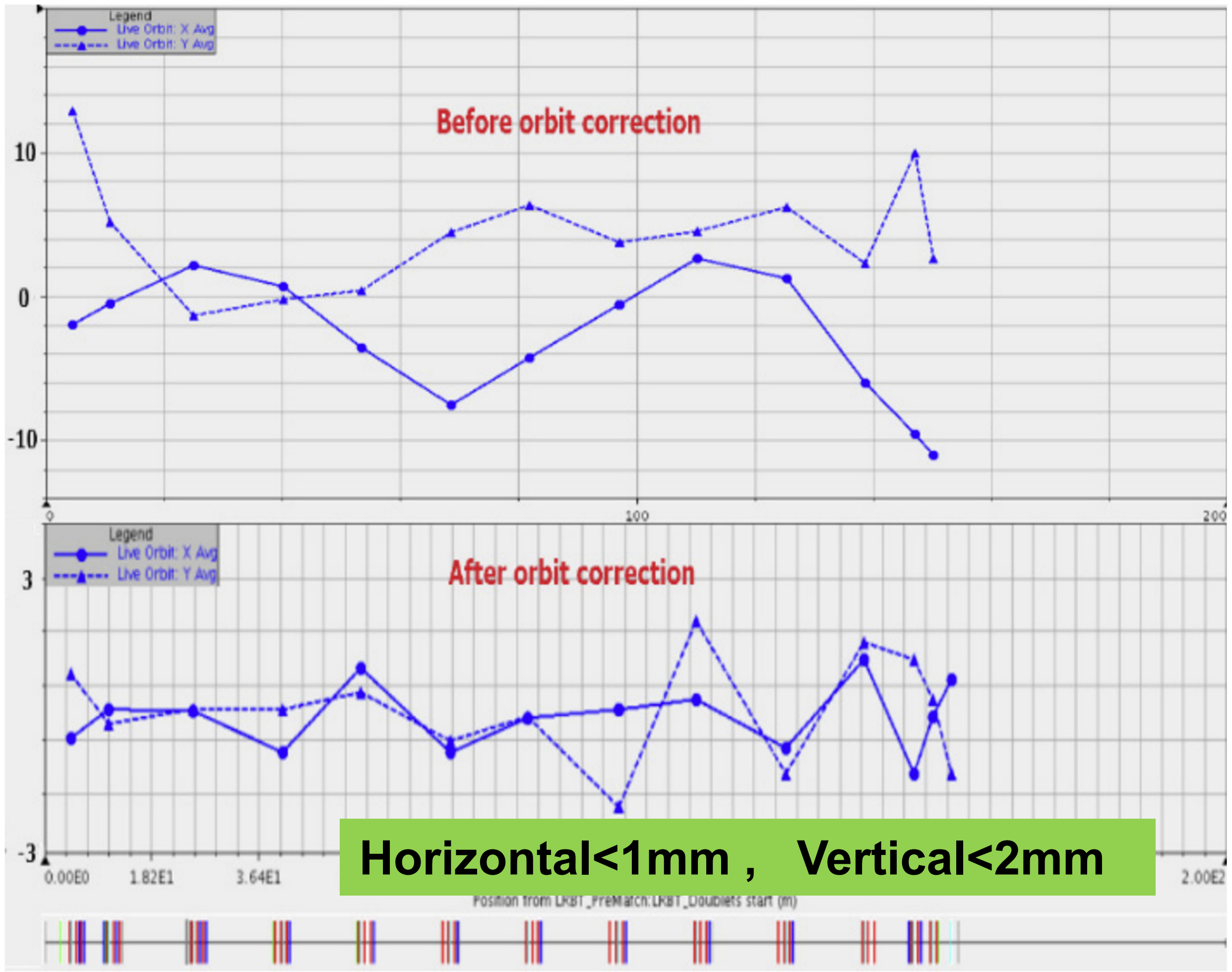
☐ Adjusting the DTL lattice





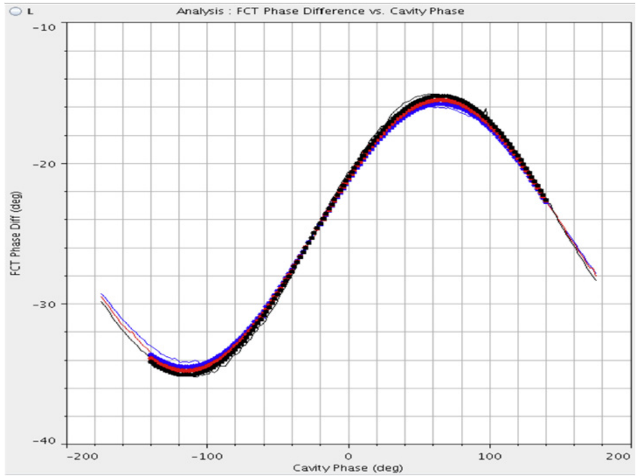
LRBT obrit orrection and phase scan

☐ Orbit correction

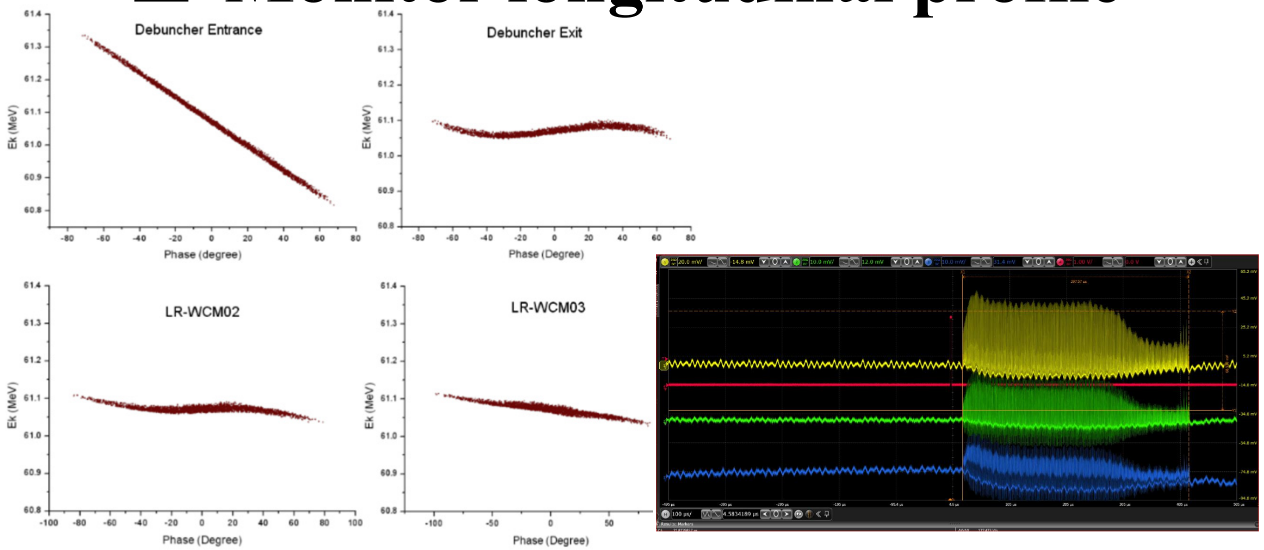


Horizontal<1mm， Vertical<2mm

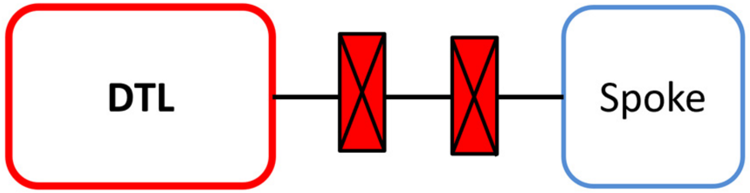
☐ Phase scan by FCTs

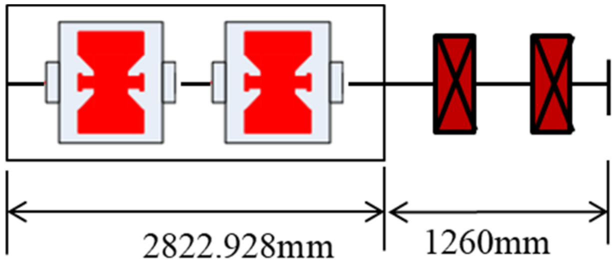


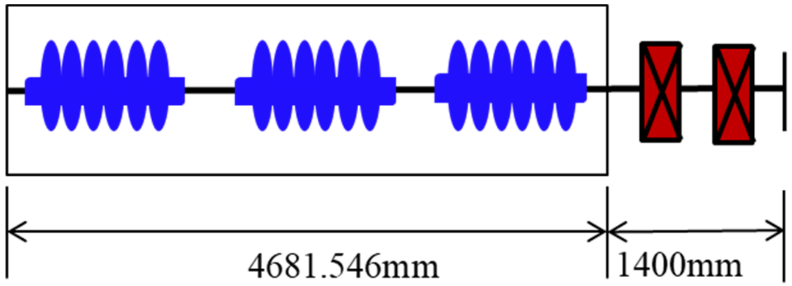
☐ Monitor longitudinal profile



Superconducting linac diagnostics







LEDP:

1 WS
1 BCM
2 BPM
1 BLM
1 BSM
1 FC

Spoke section:

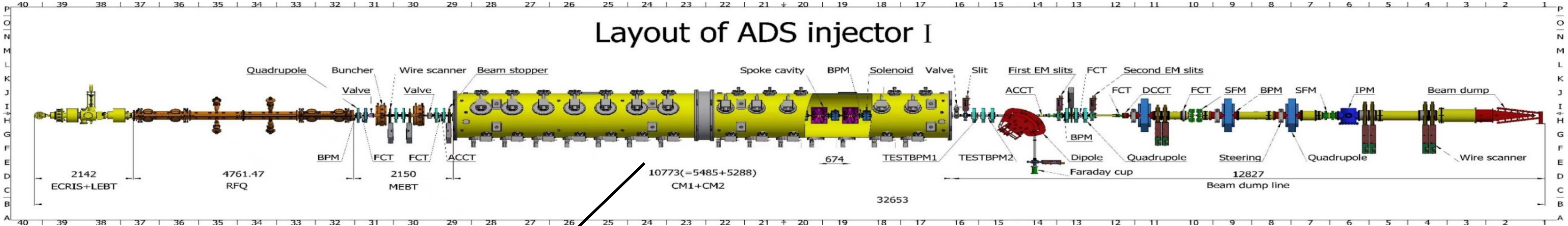
2 ×10 BLM
1 ×10 BPM
4 WS
1 BCM

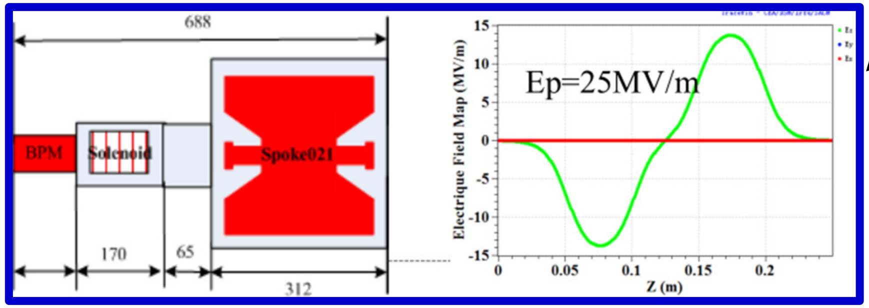
Elliptical section:

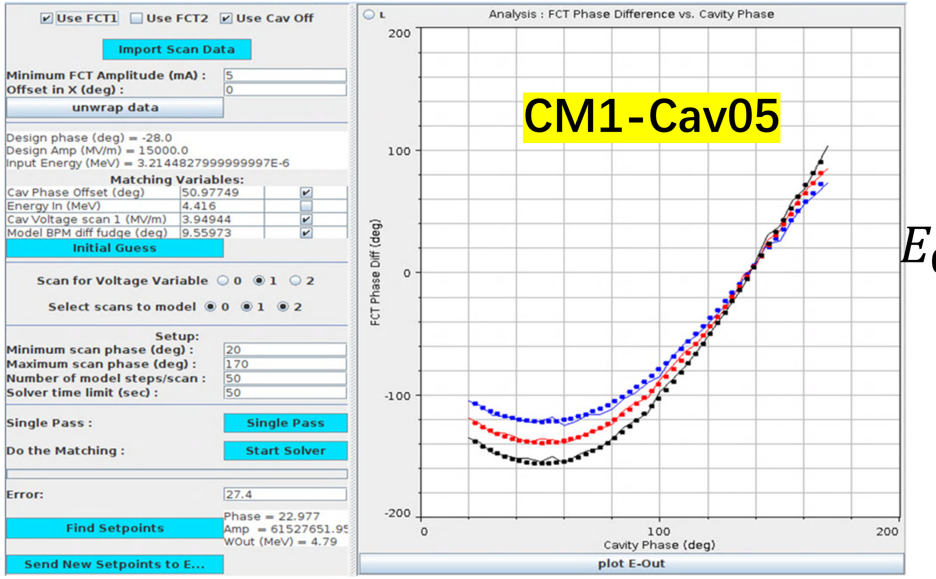
3 ×8 BLM
1 ×8 BPM
4 WS
1 BSM
1 BCM

- BSM locations： LEDP, ELL8
- WS locationS： LEDP, Spoke2,Spoke3,Spoke4,Spoke5
  ELL2,ELL3,ELL4,ELL5

Commissioning of superconducting linac







Phase scan

$$\Delta W = E_0 T L \cos(\varphi_s + \Delta\varphi)$$

Cavity number	Beam energy(MeV) Measurement	Beam energy(MeV) Design	Difference (%)
RFQ	3.18	3.22	-1.09
Bnch01	3.18	3.22	-1.09
Bnch02	3.18	3.22	-1.09
CM101	3.34	3.39	-1.47
CM102	3.76	3.72	1.08
CM103	4.10	4.06	0.87
CM104	4.43	4.42	0.32
CM105	4.87	4.97	-2.07
CM106	5.48	5.42	1.11
CM107	5.85	5.81	0.69
CM201	6.27	6.20	1.13
CM202	6.69	6.60	1.36
CM203	7.12	7.04	1.14

Summary

- The CSNS Linac has been tuned to the design energy and design beam intensity. The diagnostics installed in the linac are functioning well for commissioning and operation

- In order to increase the beam intensity of the CSNS-Ⅱ Linac, the diagnostics for longitudinal measurement are essential for performing beam matching.

- After the existing lianc, a new superconducting linac will be installed, and new non-intercepting diagnostics need to be developed.

Thanks For Your Attention!