



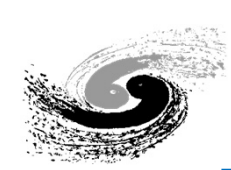
Beam diagnostics for CSNS-II linac commissioning and operation

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On behalf of the CSNS Accelerator Team & Collaboration

IHEP, CSNS campus

IBIC2024, Beijing, China, 10th September 2024-TUBC3



Outline

1

Overview of CSNS

2

Introduction of CSNS-II Linac

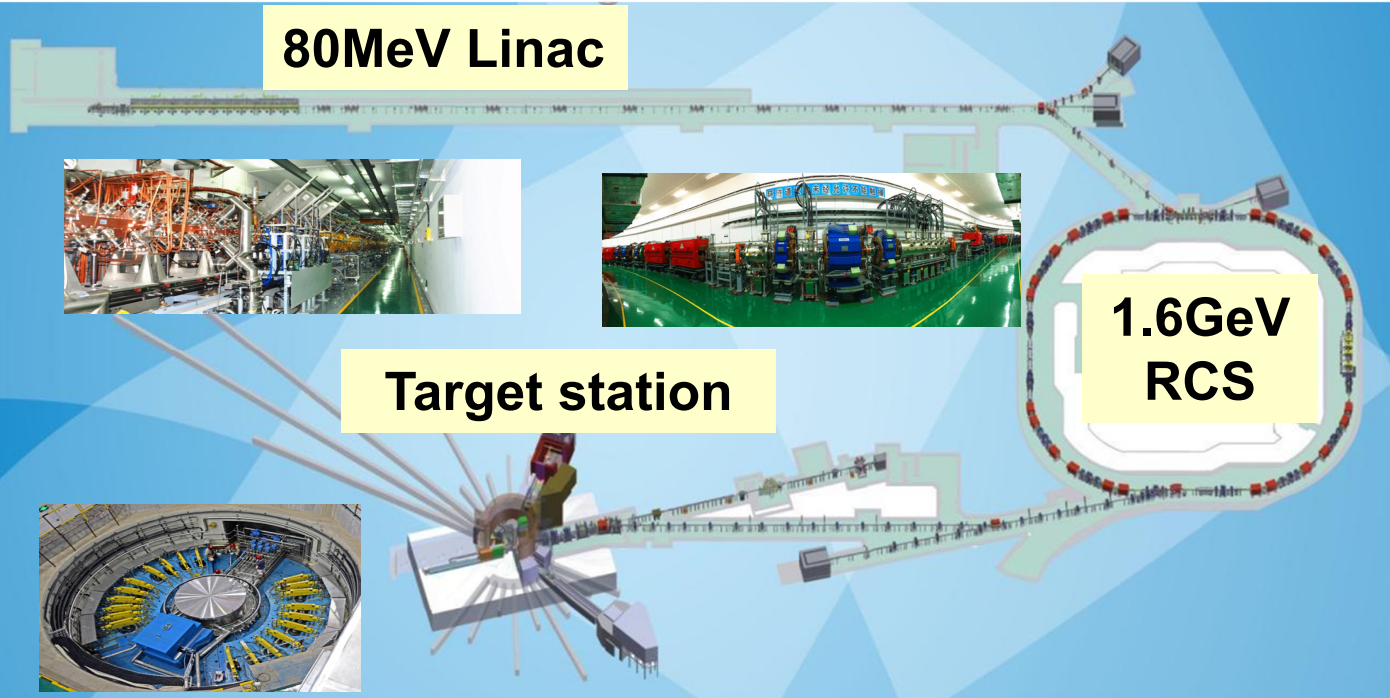
3

Beam diagnostics for commissioning and operation

4

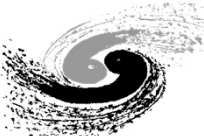
Summary

Overview of CSNS



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

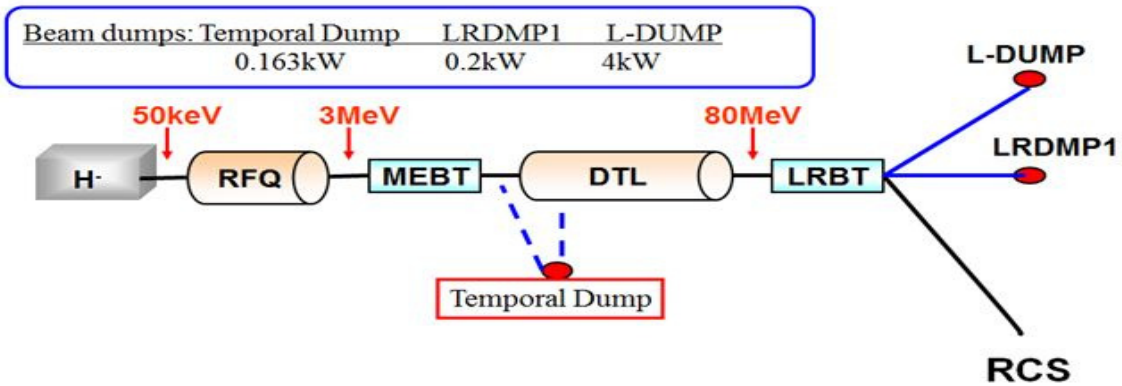


CSNS Linac status

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

FCT System

Phase	Amplit	Phase	Amplit	Phase	Amplit	Phase	Amplit	
MEBTFCT01	103.757	13.618145	DTLFC01	41.311600	0.053405	LRBTFCT01	175.313900	42.732746
MEBTFCT02	163.381000	11.542867	DTLFC02	115.767100	13.956392	LRBTFCT02	170.287900	19.616063
MEBTFCT03	71.174800	8.702266	DTLFC03	130.718900	15.321424	LRBTFCT03	72.507600	15.967305
MEBTFCT04	-7.807300	9.246198				LRBTFCT04	18.079900	0.675571
MEBTFCT05	-172.701000	20.999589				LRBTFCT05	-5.487800	16.073819

BPM System

Phase	Amplit
LRBTBPM02	-83.523559
LRBTBPM04	-4.086914
LRBTBPM06	-220.890688

能量计算: 计算能量值 **80.273770** MeV

BPM 计算能量

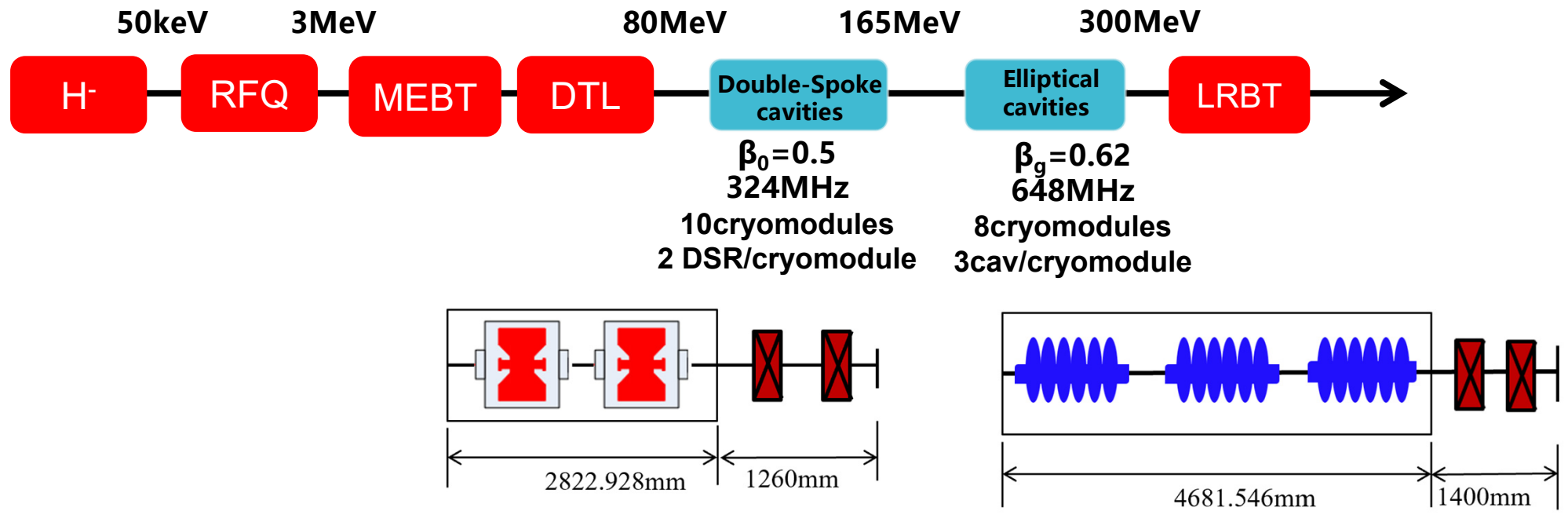
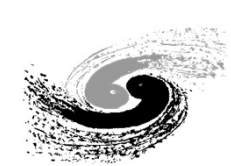
Measured energy: 80.3MeV
Design energy: 80.1MeV

EnergySelect的值为0-3, 依次代表 20MeV, 40MeV, 60MeV, 80MeV, 该选项仅对LRBT&DTL段起作用
再次, 根据需要可以设置调整周期数

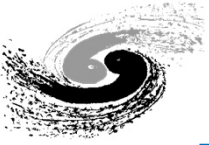
Activation level: <7mrem/hr@30cm

LINAC

Section	Counts
MEBLM01	106
MEBLM02	53
MEBLM03	98
T01BLM01	4
T01BLM02	1
T01BLM03	56
T01BLM04	2
T0101NBLM01	3
T0102NBLM02	99
T0103NBLM01	43
T02BLM01	40
T02BLM02	40
T03BLM01	87
T03BLM02	91
T04BLM01	41
T04BLM02	69
T0401BLM02	88
T0402BLM03	73
T0403BLM04	0
T0403NBLM01	1
LRBLM06	-2
LRBLM07	4
LRBLM08	4
LRBLM09	4
LRBLM10	5
LRBLM11	-6
LRBLM12	-6
LRBLM13	2
LRBLM14	-1
LRBLM15	-4
LRBLM16	1
LRBLM17	-6
LRBLM18	-2
LRBLM19	0
LRBLM20	352
INBLM02	25
INBLM03	25
INBLM04	4641
INBLM05	10307
INBLM06	0
LDBLM03	0
LDBLM04	-2
LDBLM05	0

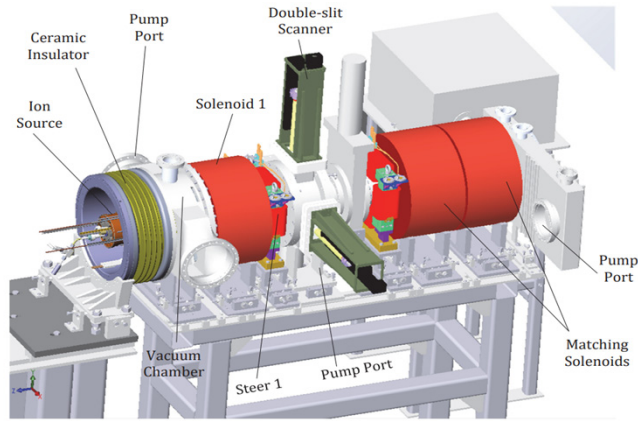


- The ion source has been changed from a Penning surface plasma source to an RF-driven H⁻ source
- The RFQ has been redesigned to reduce the surface electric field.
- The focusing lattice of the DTL will change from FFDD to FD to reduce the beam envelope.
- A new superconducting linac will be installed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

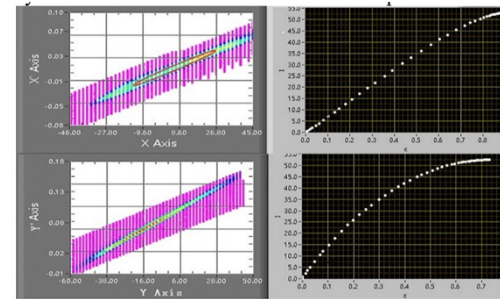


LEBT adjustment

LEBT for CSNS linac (15mA, 80MeV)

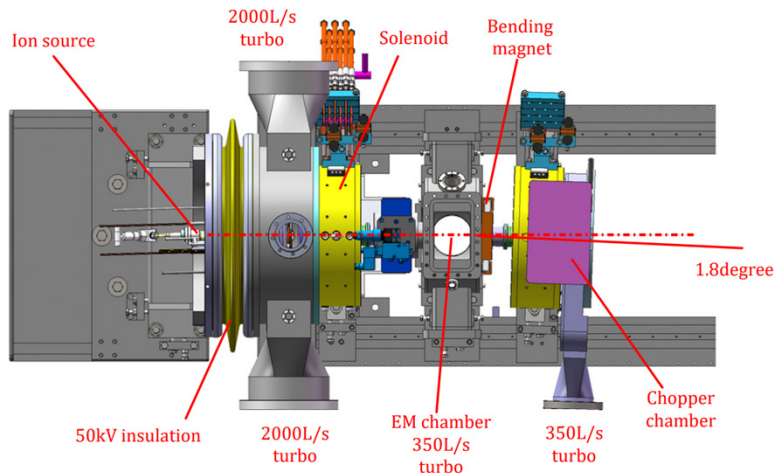


- 3 solenoid magnets
- 1 pre-chopper and a beam collimator
- 2 CTs
- 1 EM

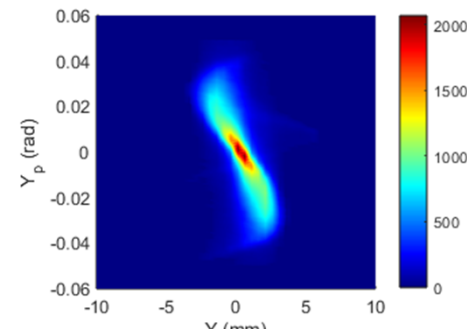


$I=53\text{mA}$, $e_x=0.892\text{Pi. mm.mrad}$
 $e_y=0.742\text{Pi.mm.mrad}$

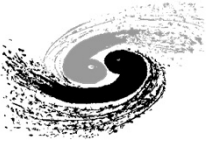
LEBT for CSNS- II linac (40mA, 300MeV)



- 2 solenoid magnets
- 1 pre-chopper
- 2 CTs
- 1 EM

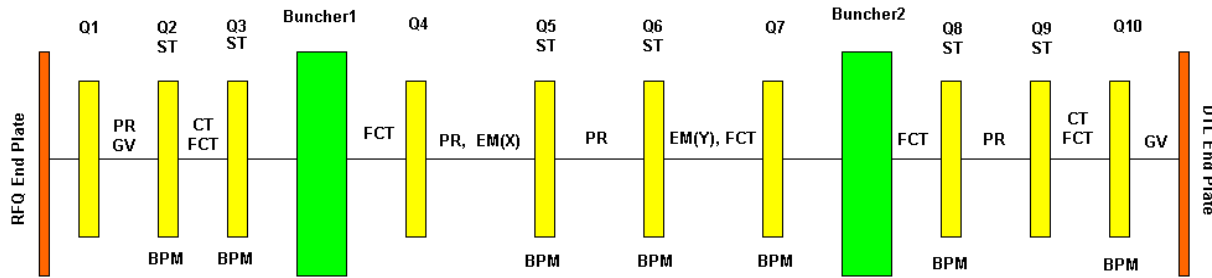


$I=52\text{mA}$, $e_x=0.236\text{Pi. mm.mrad}$
 $e_y=0.230\text{Pi.mm.mrad}$



MEBT adjustment

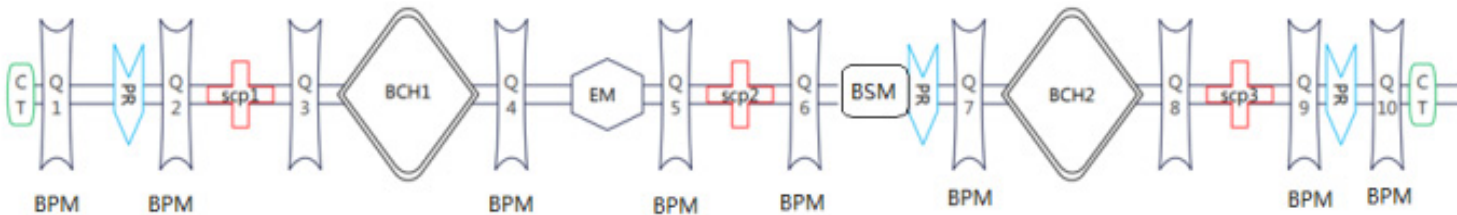
MEBT for CSNS linac (15mA, 80MeV)



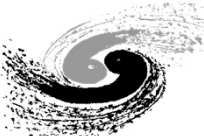
- 10quads, 2 bunchers, 3.04 meters long
- 7 BPM+6 steers
- 2 CTs
- 5 FCTs
- 1 EM
- 4 WSs
- 3 BLMs

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

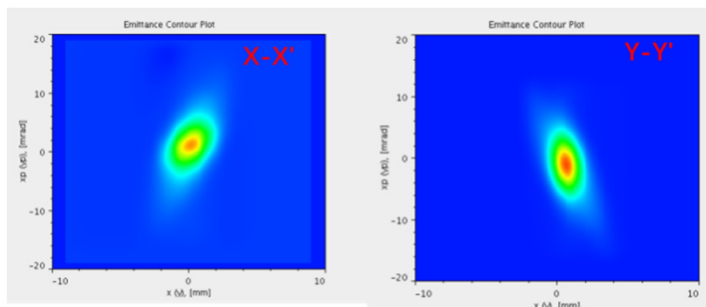
MEBT for CSNS- II linac (40mA, 300MeV)



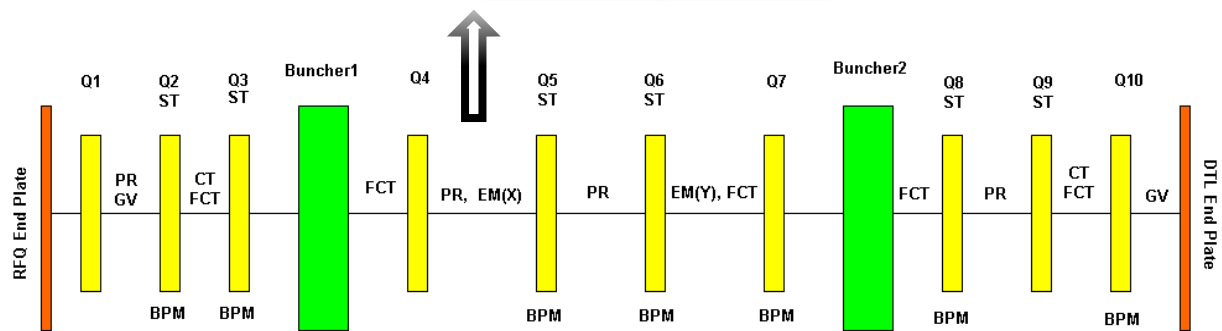
- 10quads, 2 bunchers, 2.93 meters long
- 8BPM+9 steers
- 2 CTs
- 1 EM
- 3 WSs
- 3 BLMs
- 1 BSM**
- 1 FC**
- 3 Transverse collimators**



MEBT transverse emittance measurement

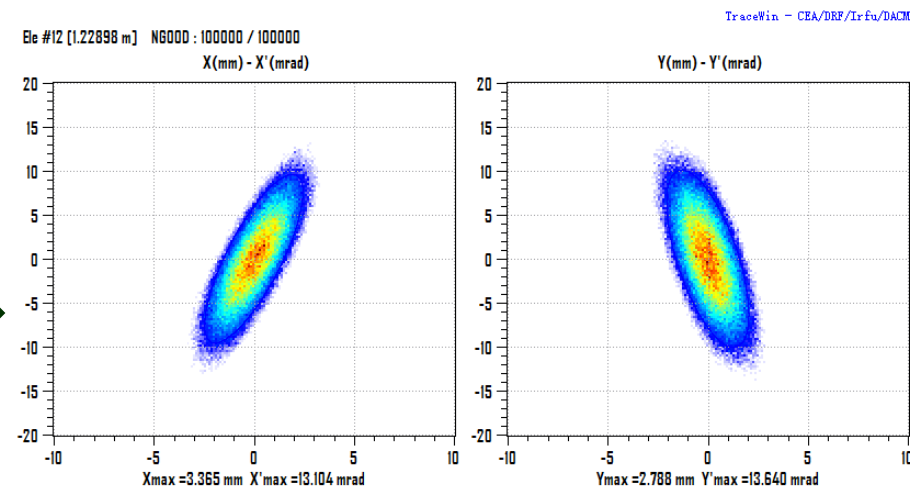
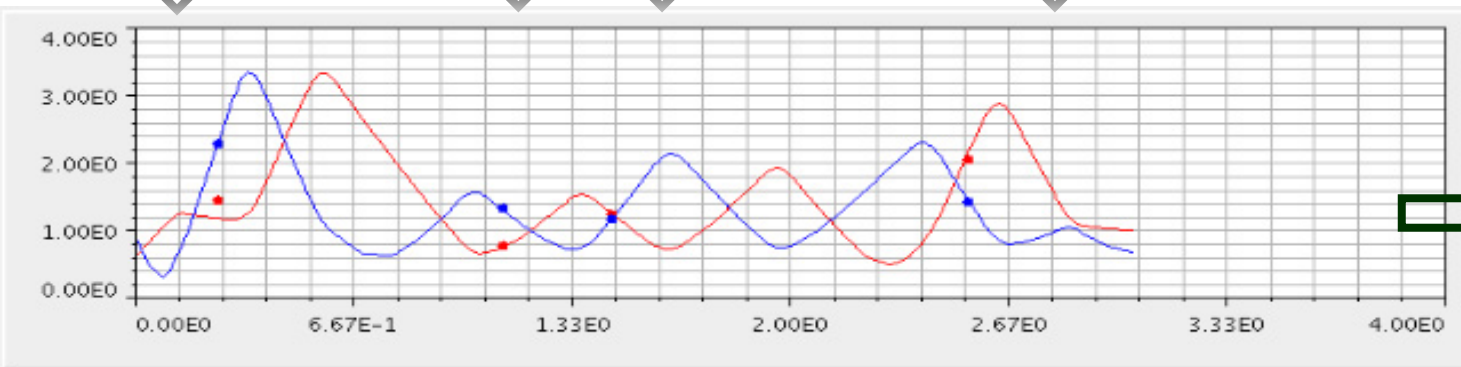


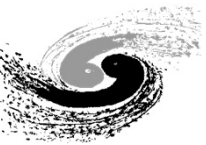
1 EM



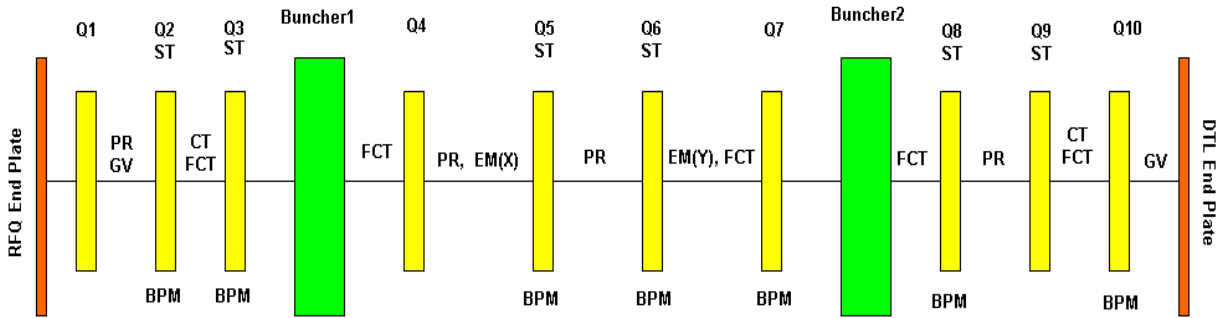
	$\Delta\alpha(\%)$	$\Delta\beta(\%)$	$\Delta\epsilon_{RMS}(\%)$
X-X'	12.15	11.37	-2.07
Y-Y'	4.57	5.7	11.42

4 WSs



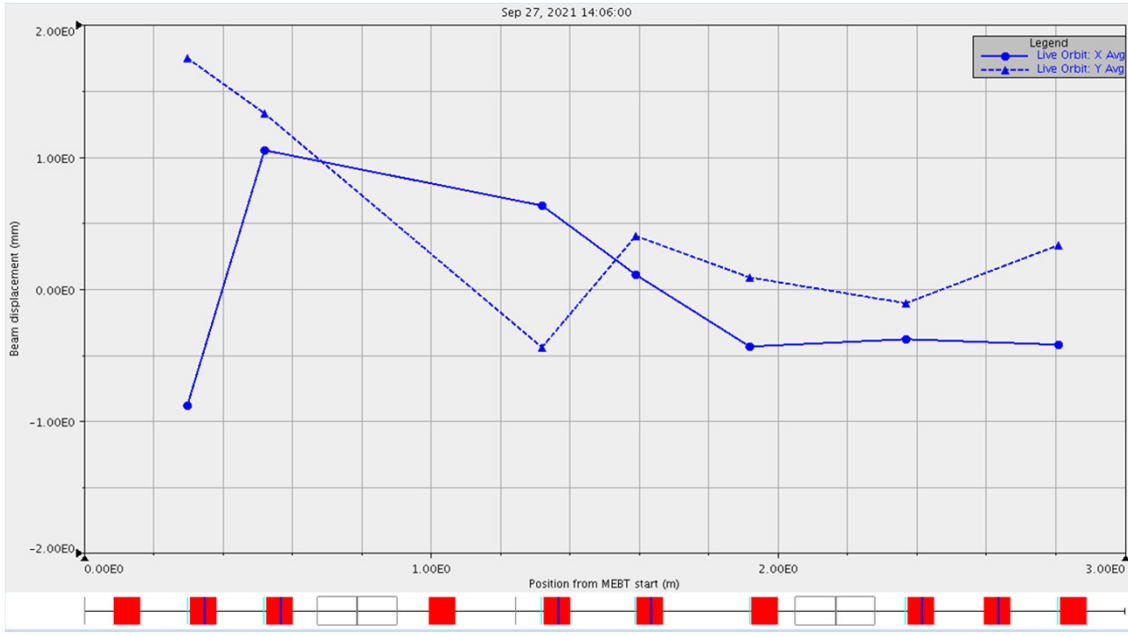


MEBT orbit correction

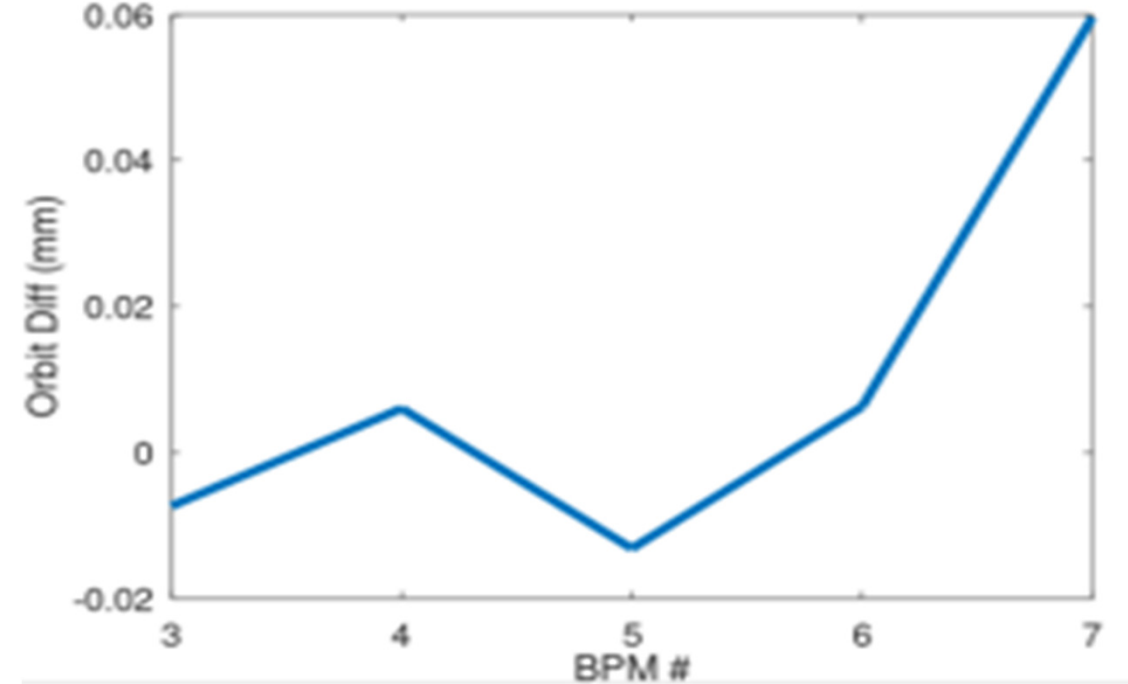


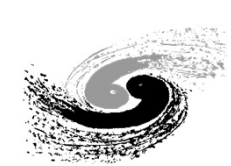
7 BPMs + 6 Steers

Beam orbit $< \pm 1\text{mm}$



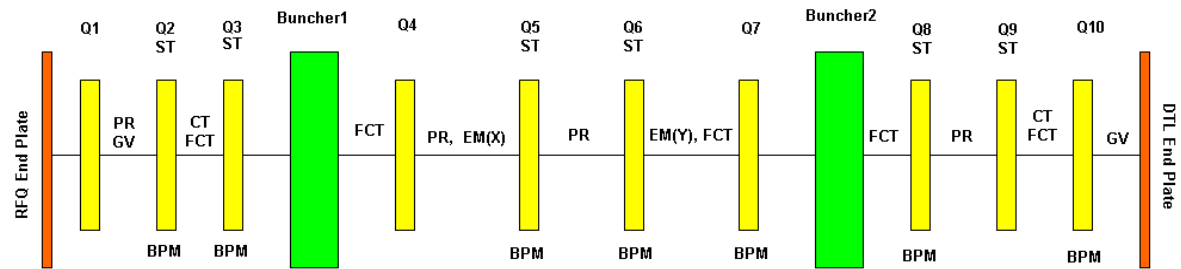
Difference between simulation and measurement





MEBT energy measurement and phase scan

5 FCTs, stability within $\pm 0.5^\circ$



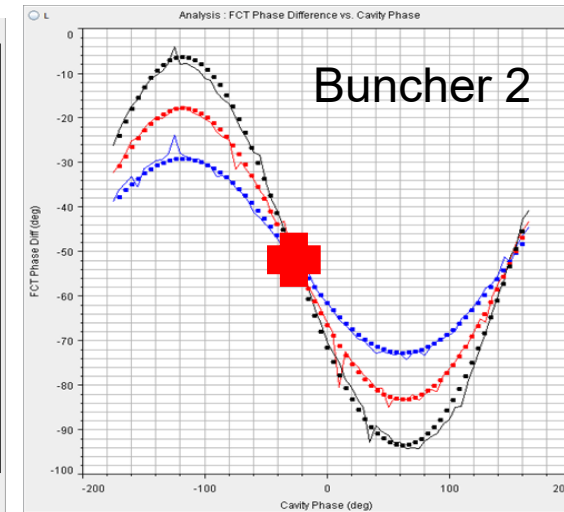
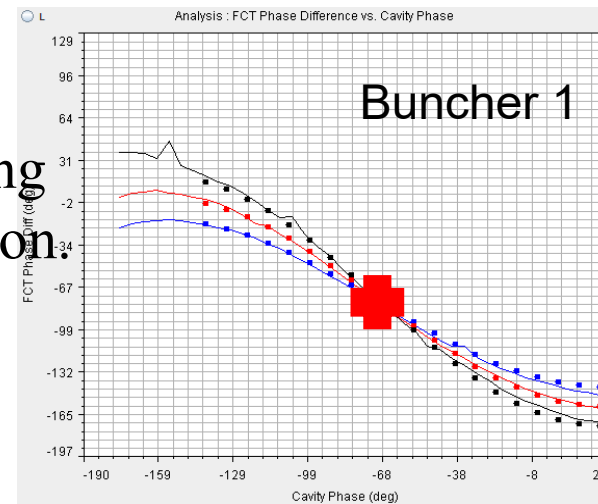
□ Energy measurement

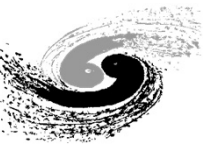
- The 1st FCT and 5th FCT are used for energy measurement, the distance is $>19 \beta\lambda$
- The design energy of the RFQ is 3.0258MeV
- Measuring the beam energy with TOF (Time Of Flight) method : **3.027MeV**

□ Phase scan

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

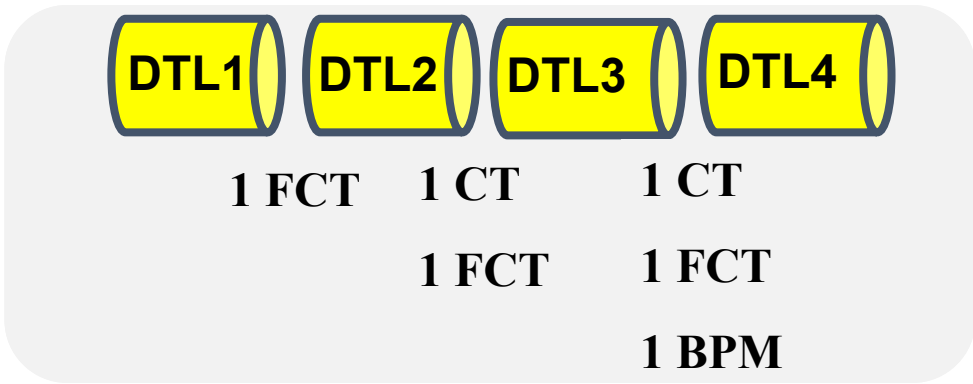
$$W_{out} = E_0 T L \cos(\varphi_s + \Delta\varphi) + W_{in}$$



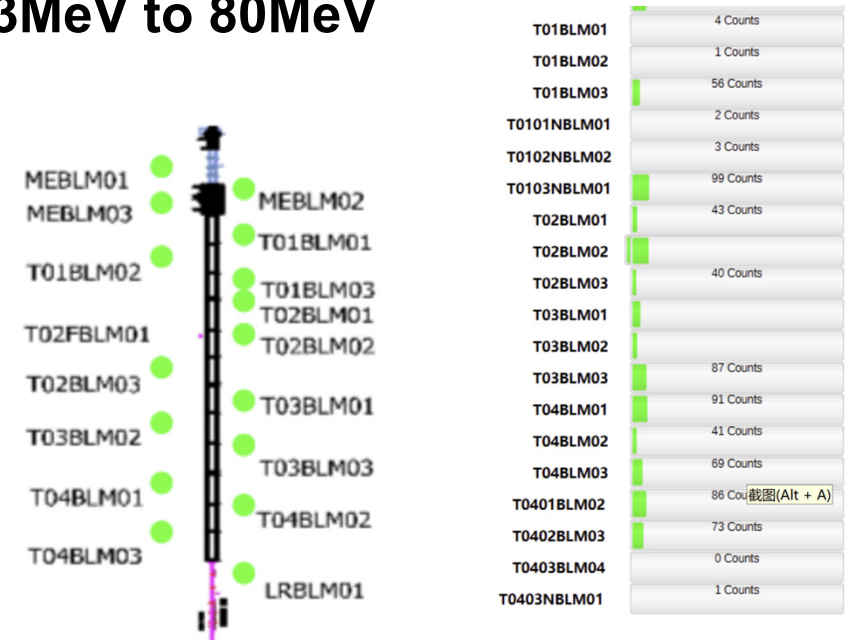


DTL beam orbit and beam transmission

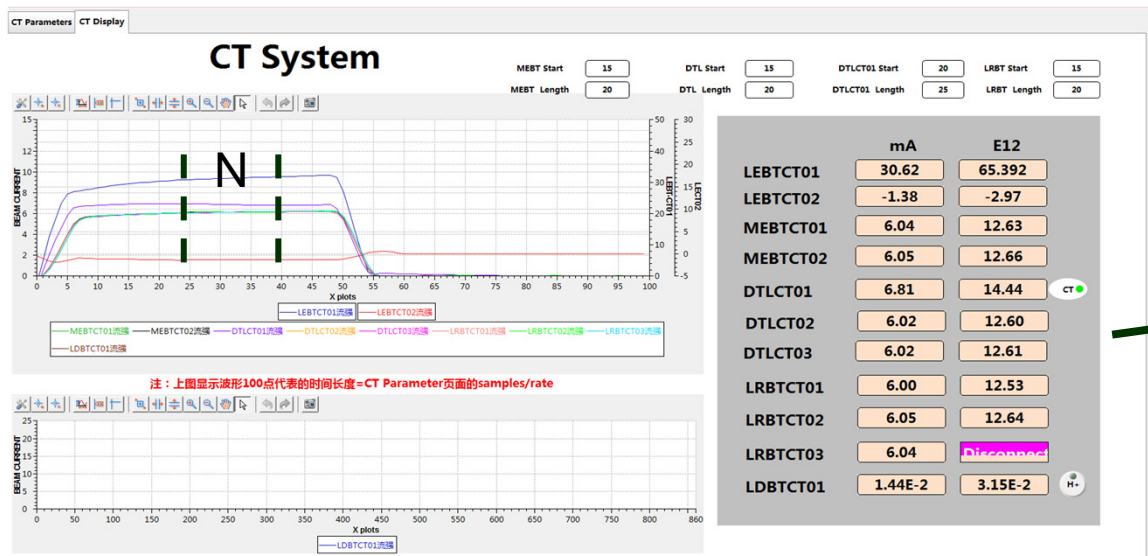
The CSNS DTL contains 4 tanks, accelerating beam from 3MeV to 80MeV



□ Beam loss



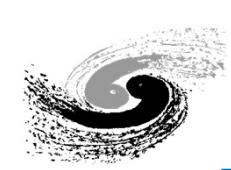
□ Beam transmission



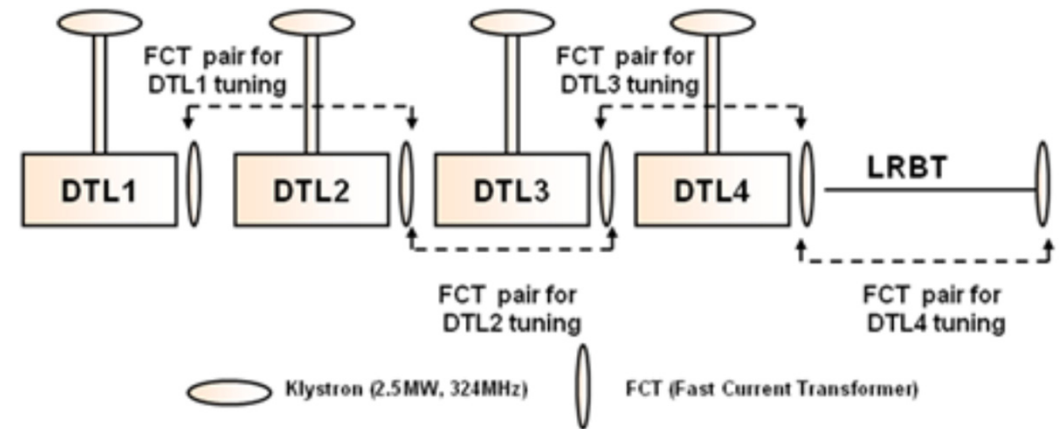
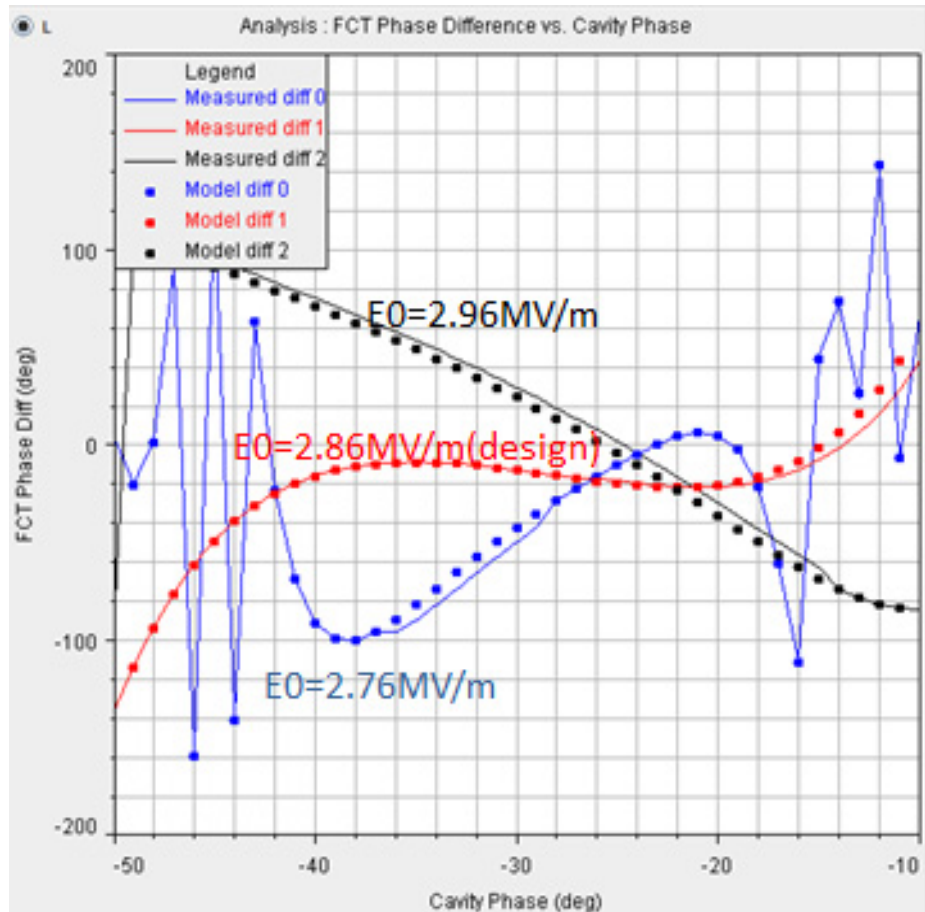
CT Display 2019-11-01 08:36:02

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

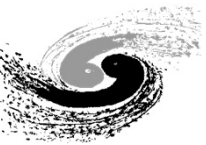


Phase Scan Signature Matching Method XAL, Pasta (an RF phase scan and tuning application)

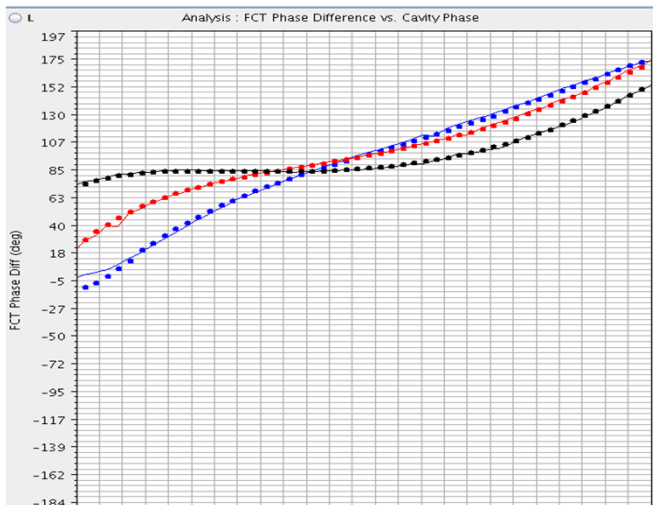
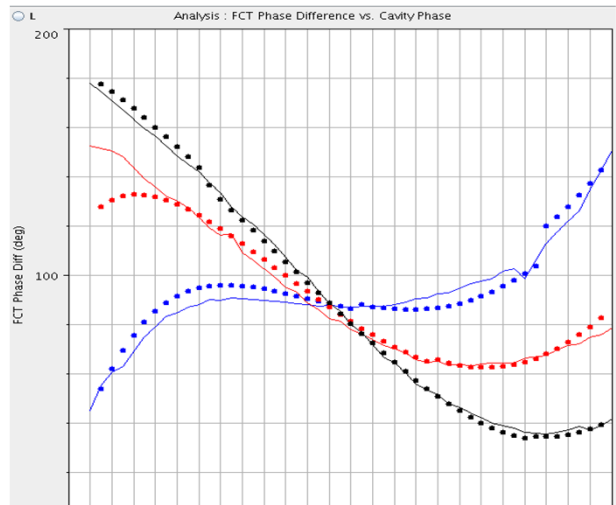


Variables:

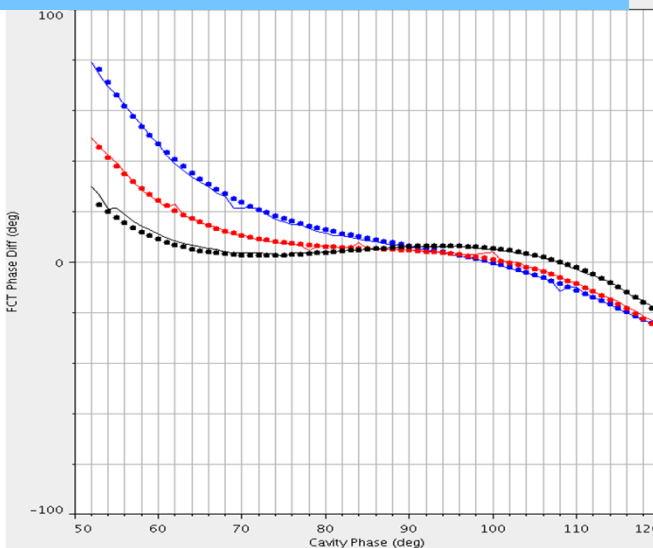
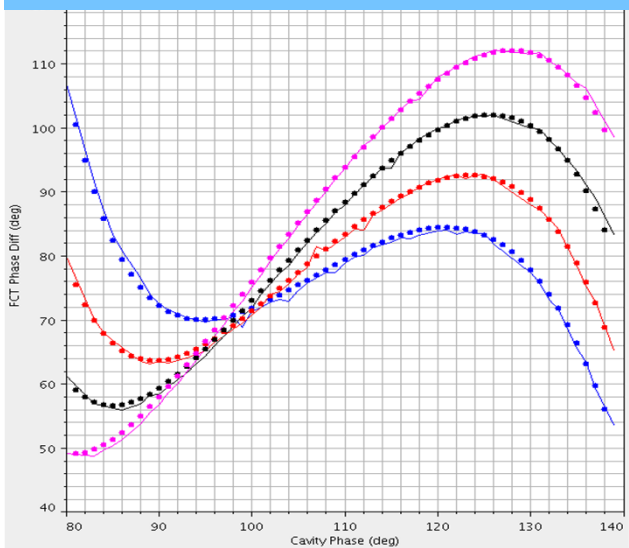
- Input energy
- RF amplitude
- Phase offset



DTL energy measurement



Phase scan results of 4 DTL tanks



FCT System

Phase		Amplit		Phase		Amplit		Phase		Amplit	
MEBTFCT01	103.757	13.618145		DTLFC01	41.311600	0.033405		LRBTFCT01	175.313900	42.732746	
MEBTFCT02	163.381000	11.542687		DTLFC02	115.767100	13.956392		LRBTFCT02	170.287900	19.616063	
MEBTFCT03	71.174800	8.702266		DTLFC03	130.718900	15.321424		LRBTFCT03	72.507600	15.967305	
MEBTFCT04	-7.807300	9.246198						LRBTFCT04	18.079900	0.675571	
MEBTFCT05	-172.701000	20.999589						LRBTFCT05	-5.487800	16.073819	

BPM System	
Phase	
LRBTPM02	-83.523559
LRBTPM04	-4.086914
LRBTPM06	-220.830688

能量计算

LRBtoDtl: MEFTmin: MEFTmax: 数值范围-4, 分别代表 MEBTFCT01-MEBTFCT05

EnergySelect3: LRFCTmin: LRFCTmax: 数值范围-7, 分别代表 DTLFC01-03, LRFCT01-LRFCT05

调整周期:

计算能量值: **80.273770** MeV

能量计算说明:
首先, 选择所要计算的能量段, 左上角的布尔量用于选择MEBT信号或LRBT&DTL段的能量, 真为MEBT, 假为LRBT&DTL
其次, EnergySelect的数值为0-3, 依次代表20MeV, 40MeV, 60MeV, 80MeV, 该选项仅对LRBT&DTL段起作用
再次, 根据需要进行调整周期数

BPM 计算能量

LRBPMmin: LRBPMmax:

EnergySelect: 数值范围0-2, 分别代表LRBPM02, LRBPM04, LRBPM06

调整周期:

计算能量值: **80.530566** MeV

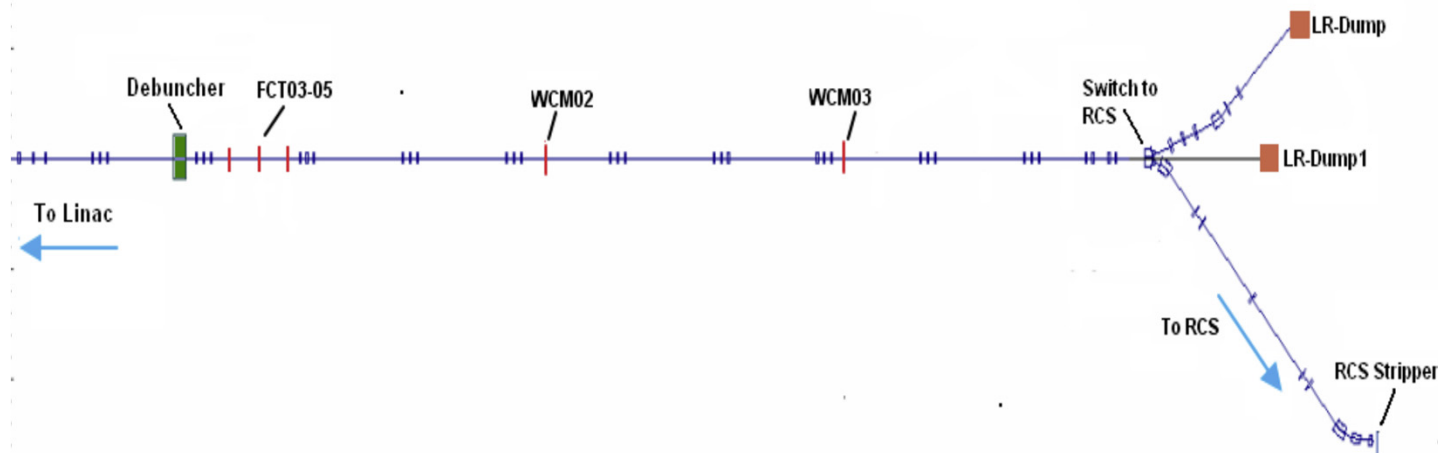
EnergySelect的数值为0-3, 依次代表 20MeV, 40MeV, 60MeV, 80MeV

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)

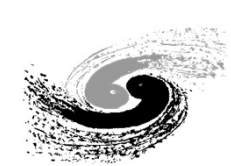


1 Debuncher,
3 matching sections, 9 triplets, 1 anti-symmetric achromatic section
18 BPM
3 CTs
5 FCTs
3 WCMs
6 WSs
23 BLMs

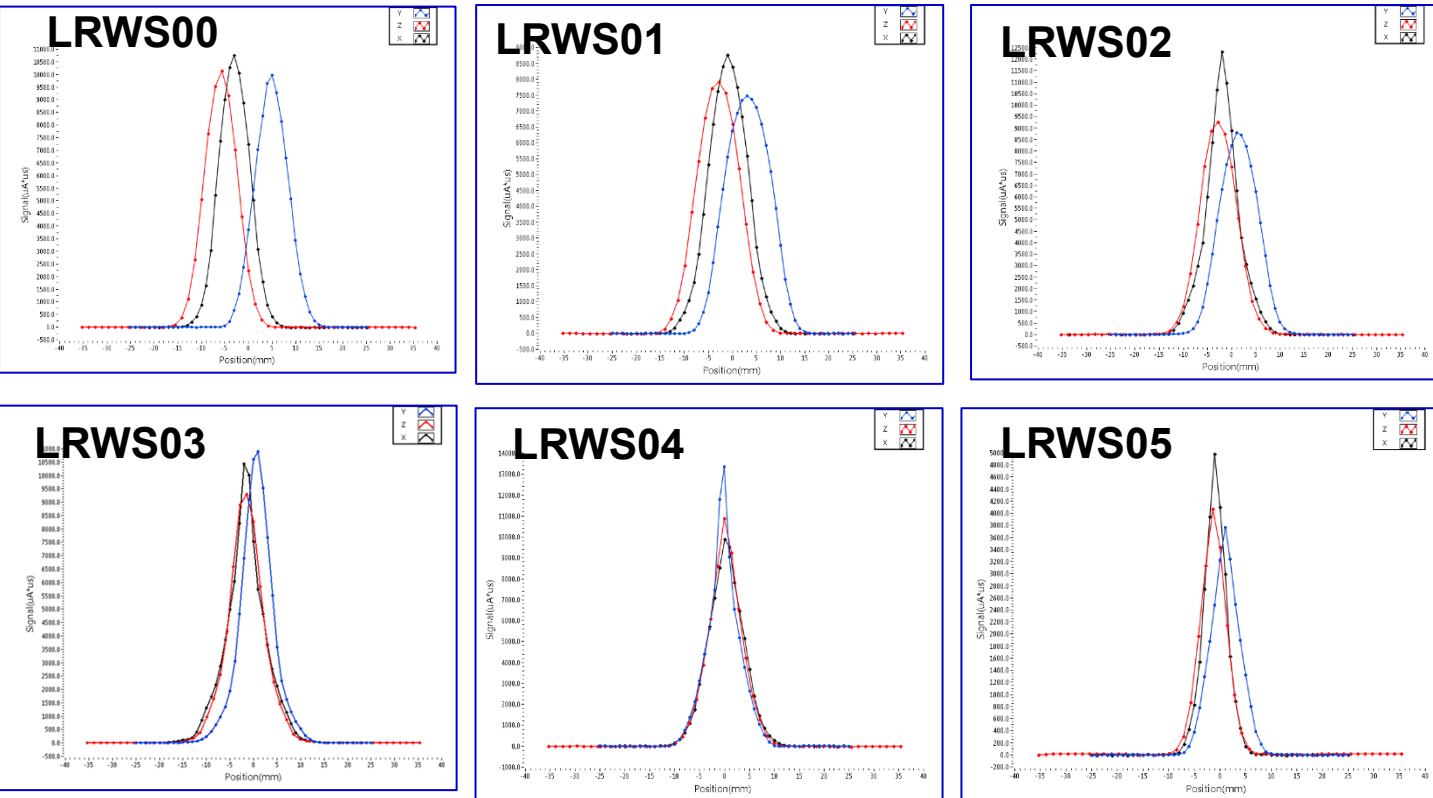
LRBT for CSNS- II linac (40mA, 300MeV)



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



LRBT emittance measurement

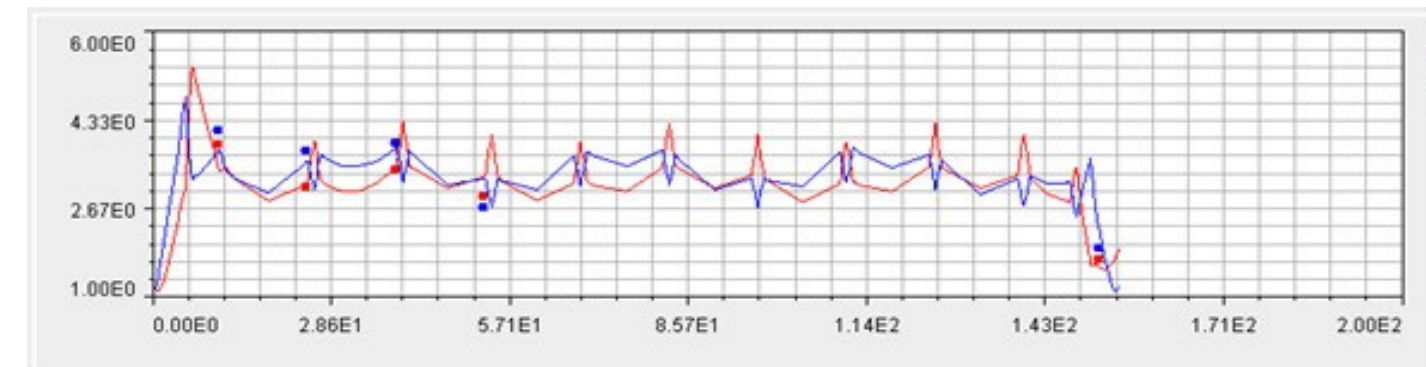
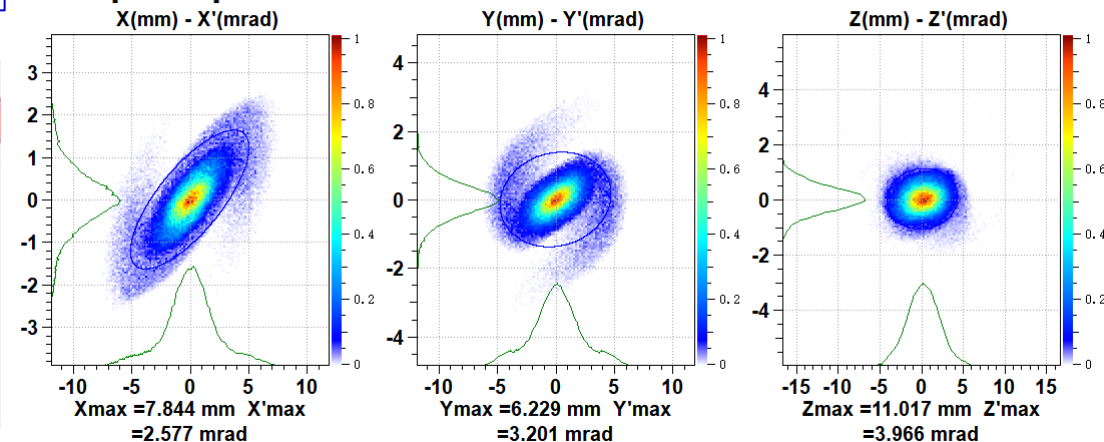


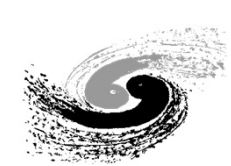
Emittance at the exit of the DTL

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

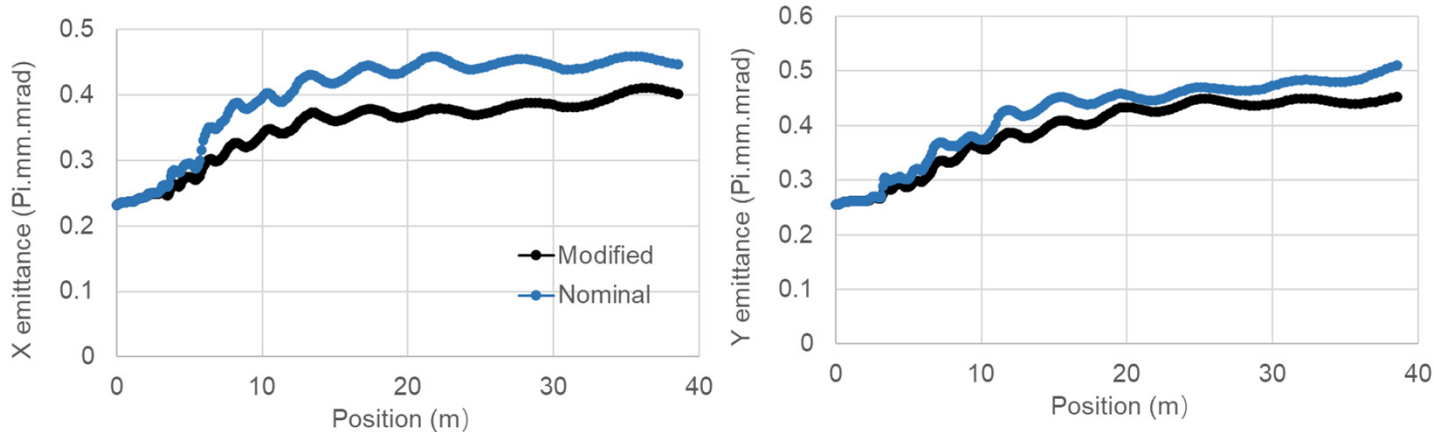
TraceWin - CEA/DRF/Irfu/DACM

Ele #195 [38.5486 m] NGOOD : 99634 / 100000



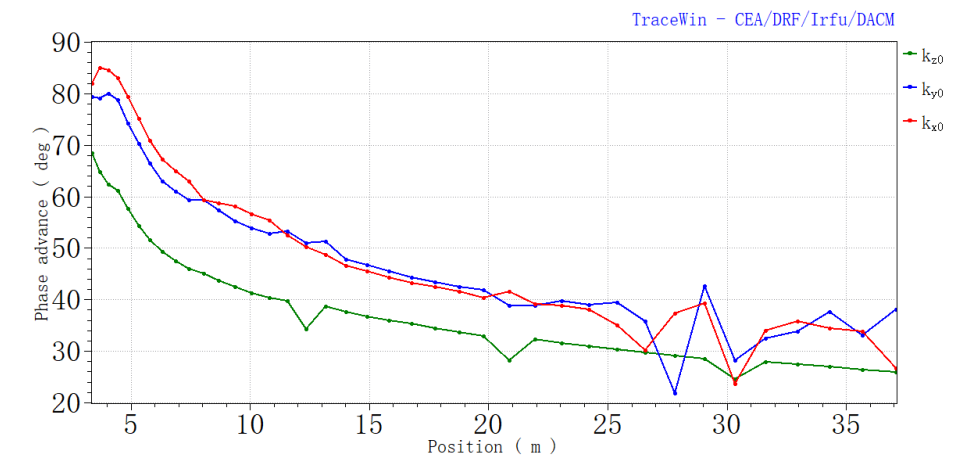
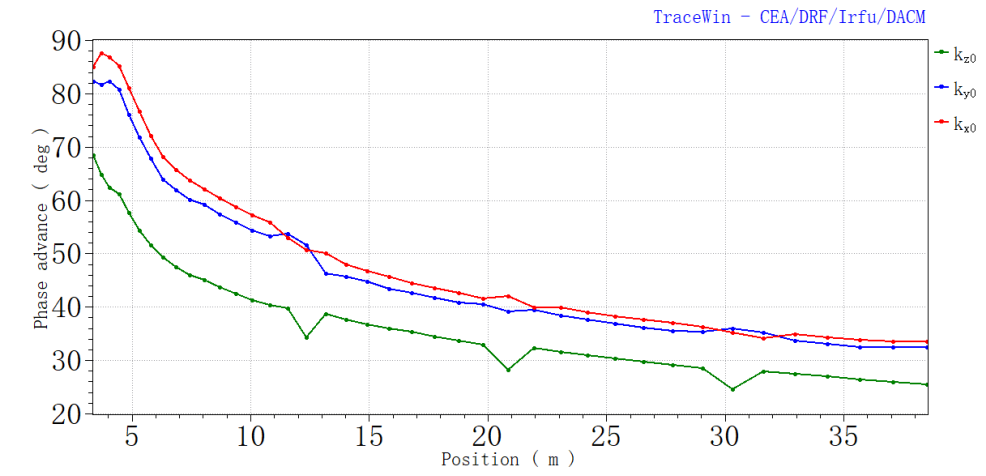


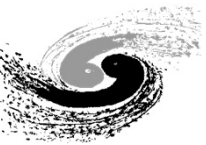
□ Modifying the buncher settings



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

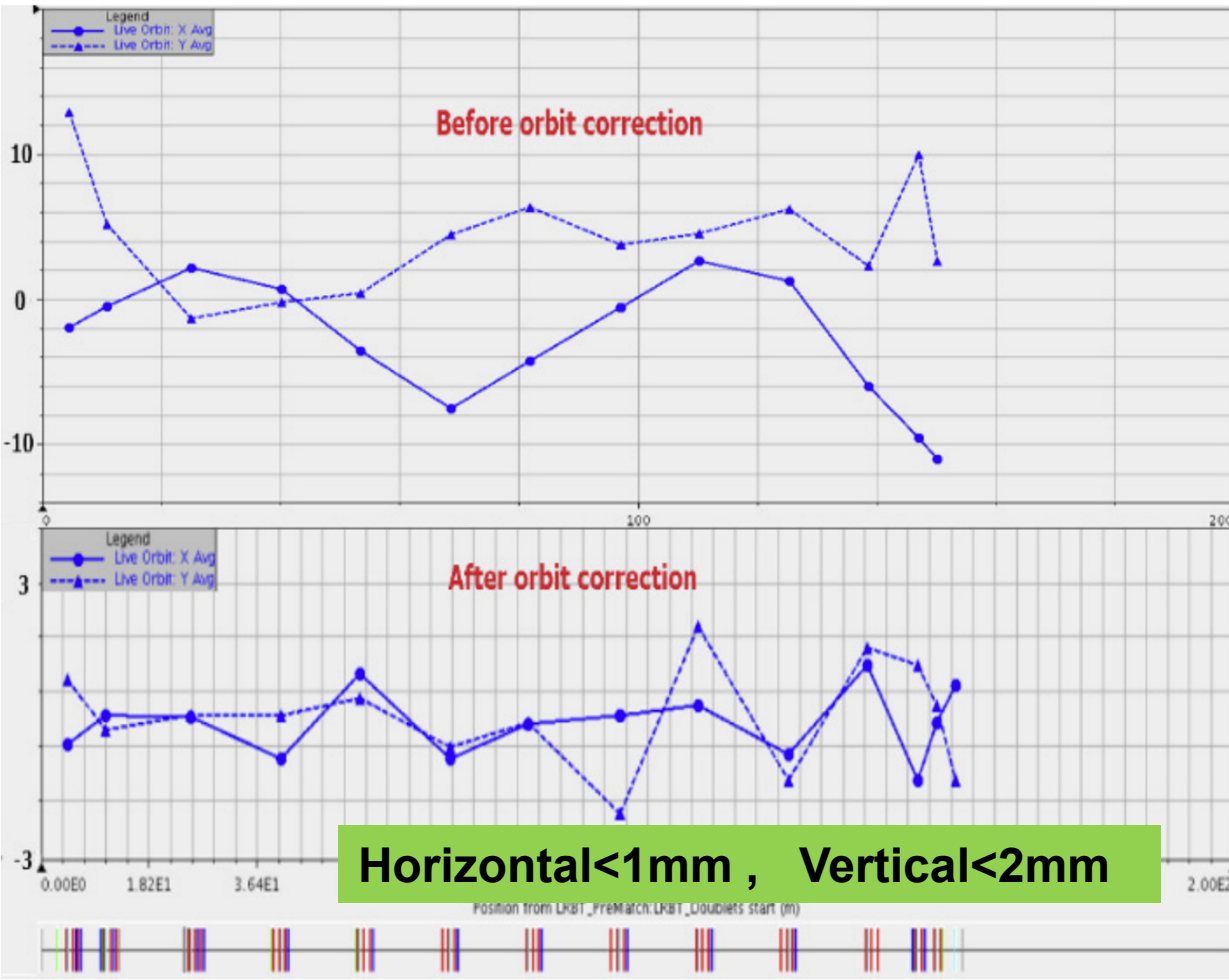
□ Adjusting the DTL lattice



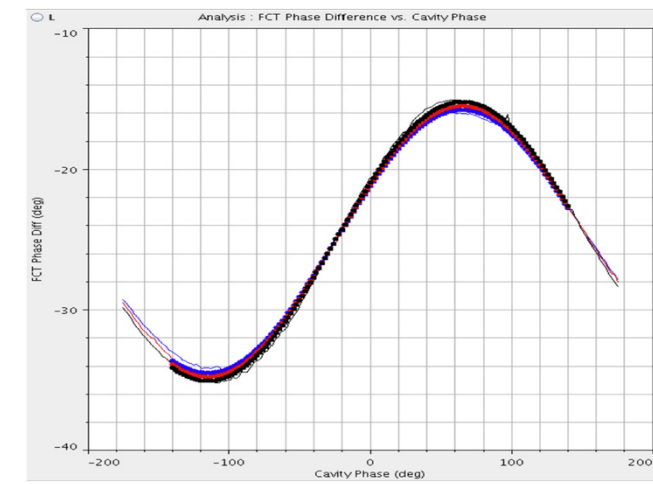


LRBT orbit correction and phase scan

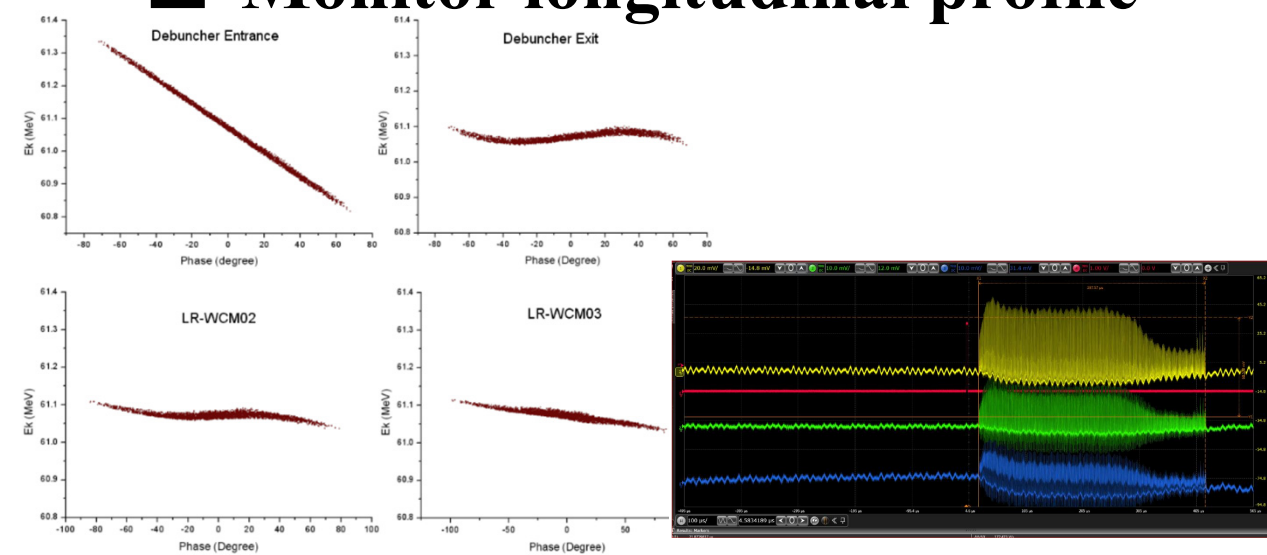
□ Orbit correction

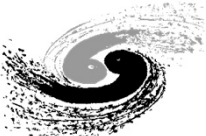


□ Phase scan by FCTs

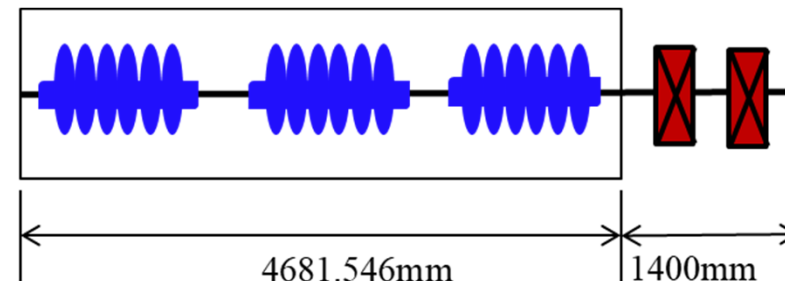
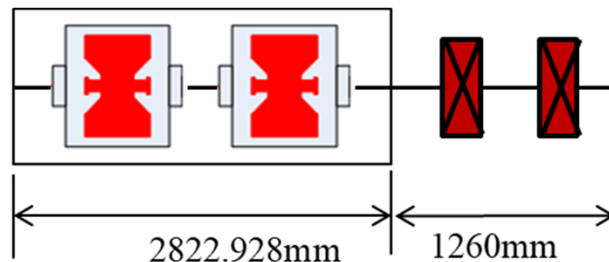
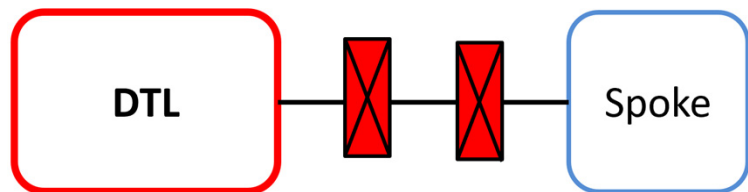


□ Monitor longitudinal profile





Superconducting linac diagnostics



LEDP:

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

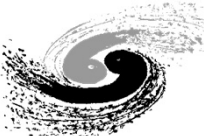
Spoke section:

- 2 × 10 BLM
- 1 × 10 BPM
- 4 WS
- 1 BCM

Elliptical section:

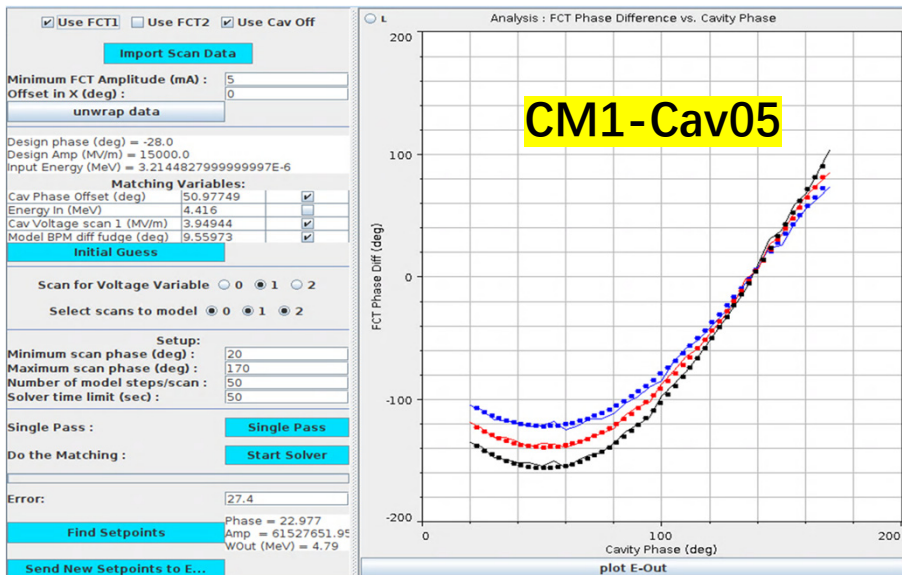
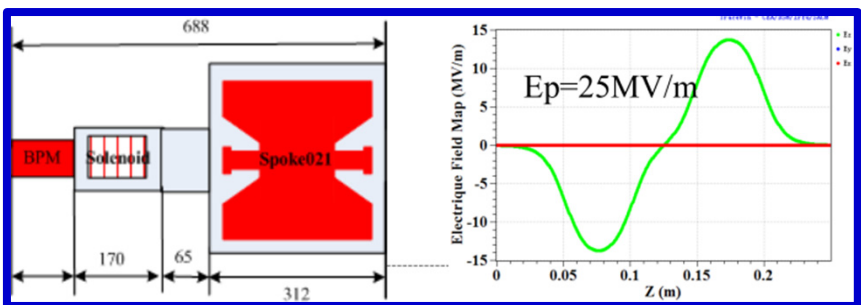
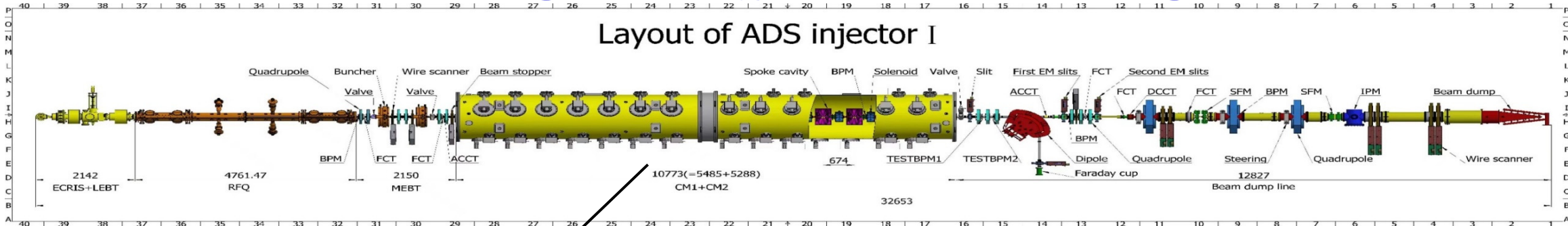
- 3 × 8 BLM
- 1 × 8 BPM
- 4 WS
- 1 BSM
- 1 BCM

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



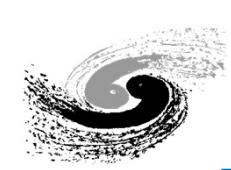
Commissioning of superconducting linac

Layout of ADS injector I



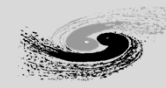
Phase scan
 $\Delta W = E_0 T L \cos(\varphi_s + \Delta\varphi)$

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!

