Intense-Beam Issues in CSNS and C-ADS Accelerators

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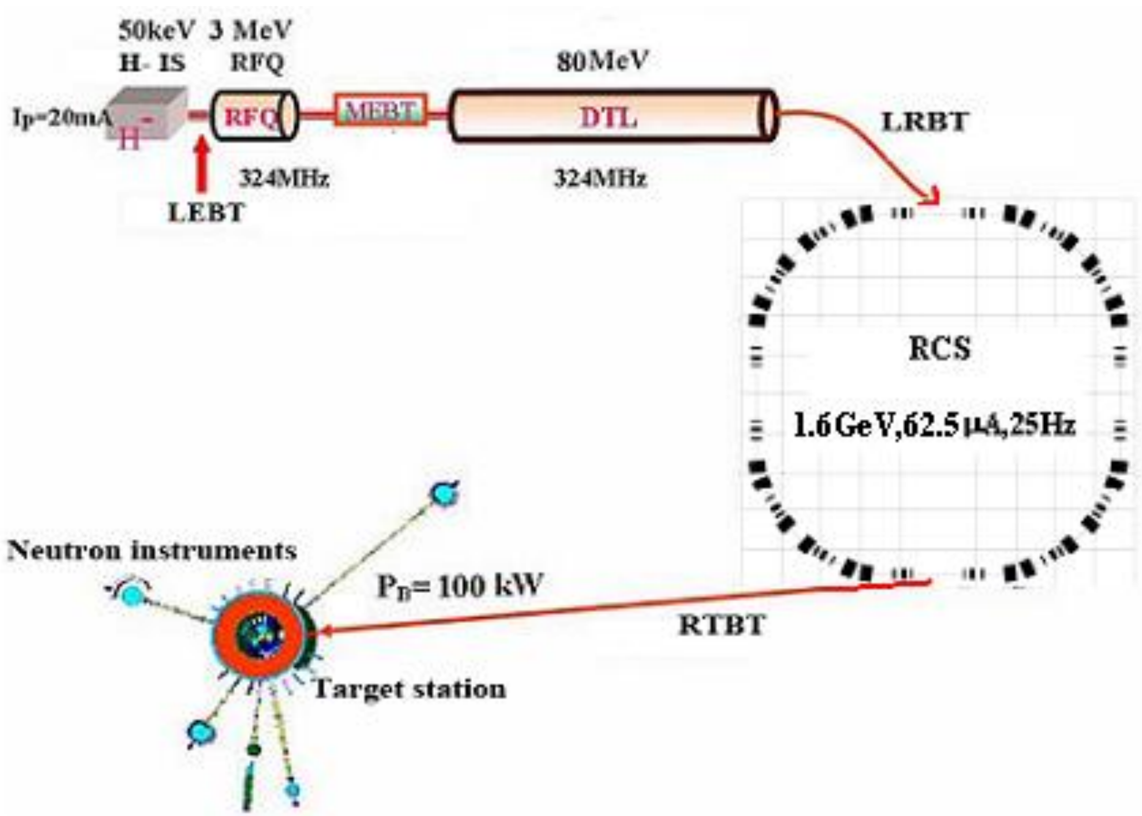
Contents

- Introduction to CSNS and C-ADS
- Beam loss study on CSNS Accelerator
- Beam loss control study in C-ADS linac
- Experimental beam halo study
- Other aspects
- Summary

1, Introduction to CSNS and C-ADS

CSNS Overview

- The phase-I CSNS facility consists of an 80-MeV H^- linac, a 1.6-GeV RCS, 2 beam transport lines, a target station, and 3 instruments.
- Upgradable to 500kW at 25Hz and 20 instruments



	CSNS-I	CSNS-II
Beam power (kW)	100	500
Repetition rate (Hz)	25	25
Target number	1	1
Average current (μA)	62.5	312
Proton energy (GeV)	1.6	1.6
Linac energy (MeV)	80	250

Budget

- **Baseline--- the largest big-science project in China**
  - **1.7B CNY(~US$250M) from central government for project construction**
  - **0.5B CNY and land from Guangdong/Dongguan local government for additional supports**
- **R&D**
  - **35M CNY (received) from CAS for R&D 1**
  - **40M CNY (received) from Dongguan government for R&D 2 (included in 0.5B CNY additional supports)**
- **Operation**
  - **0.14B CYN per year from central government**

IHEP set up a new branch at Dongguan for CSNS construction. And operation. Civil construction started on 5 May, 2012.

May 2009: before land breaking

Aug 2011: land was prepared

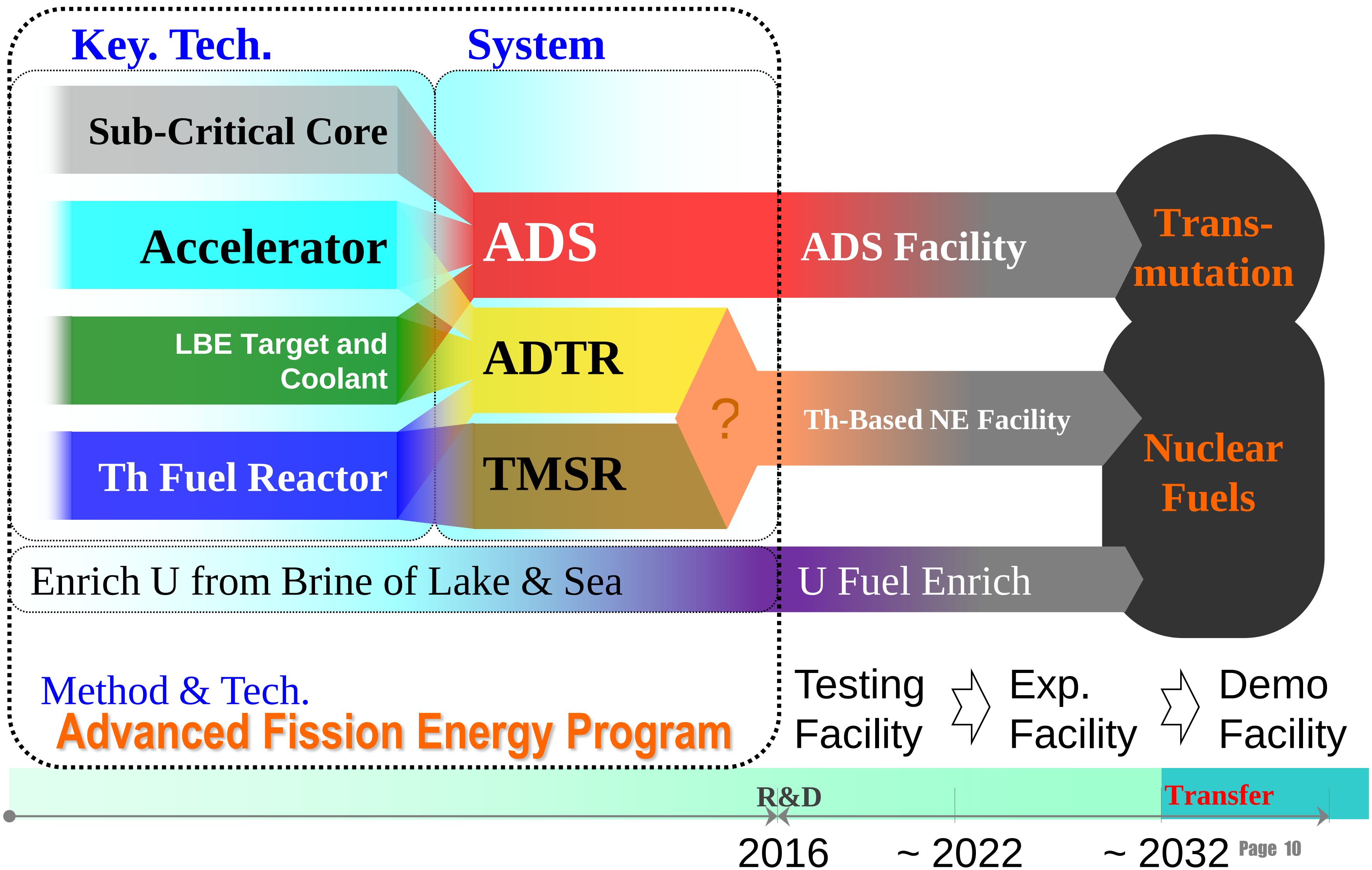
Construction of China Spallation Neutron Source (CSNS) has been launched in September 2011. And it is scheduled to complete the project in March 2018.

Aug 2012: Base construction of the linac tunnel (left) and RCS building (right)

ADS Overview-Nuclear Power in China

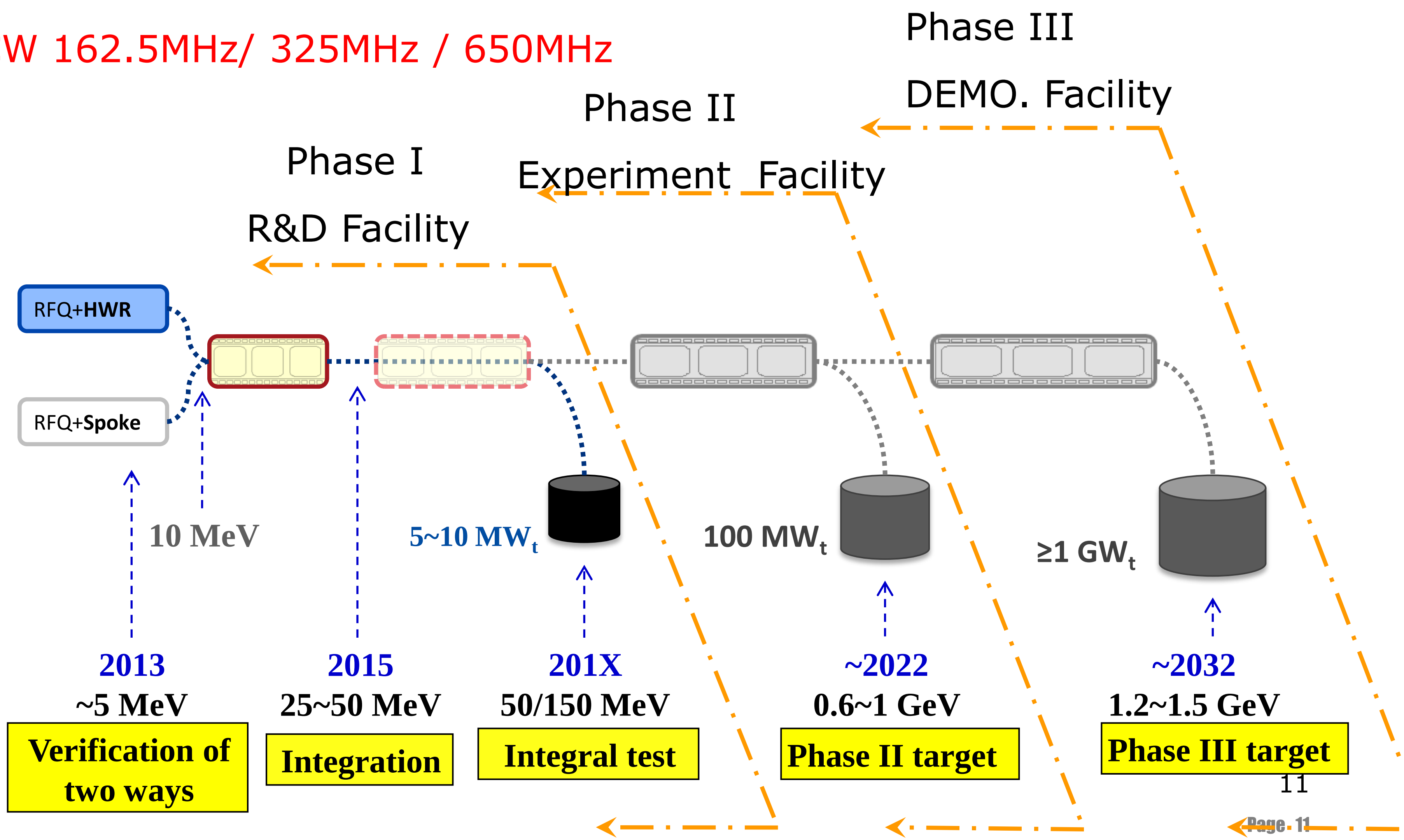
- **To 2010.10**
  - **Operation reactor 13 sets, 10.23GW$_e$**
  - **Constructing reactor 23 sets, 25.90GW$_e$, is the largest in construction scale over the world**
- **According to some information:**
  - **2020: >70 GW$_e$ NPP in operation and 30GW$_e$ NPP under construction; >5% of NP to total installed capacity**
  - **2030: ~10% of NP to total installed capacity**
  - **2050: >400 GW$_e$ NPP → almost same as the scale of the total in the world today!**

Special Program of NE in CAS

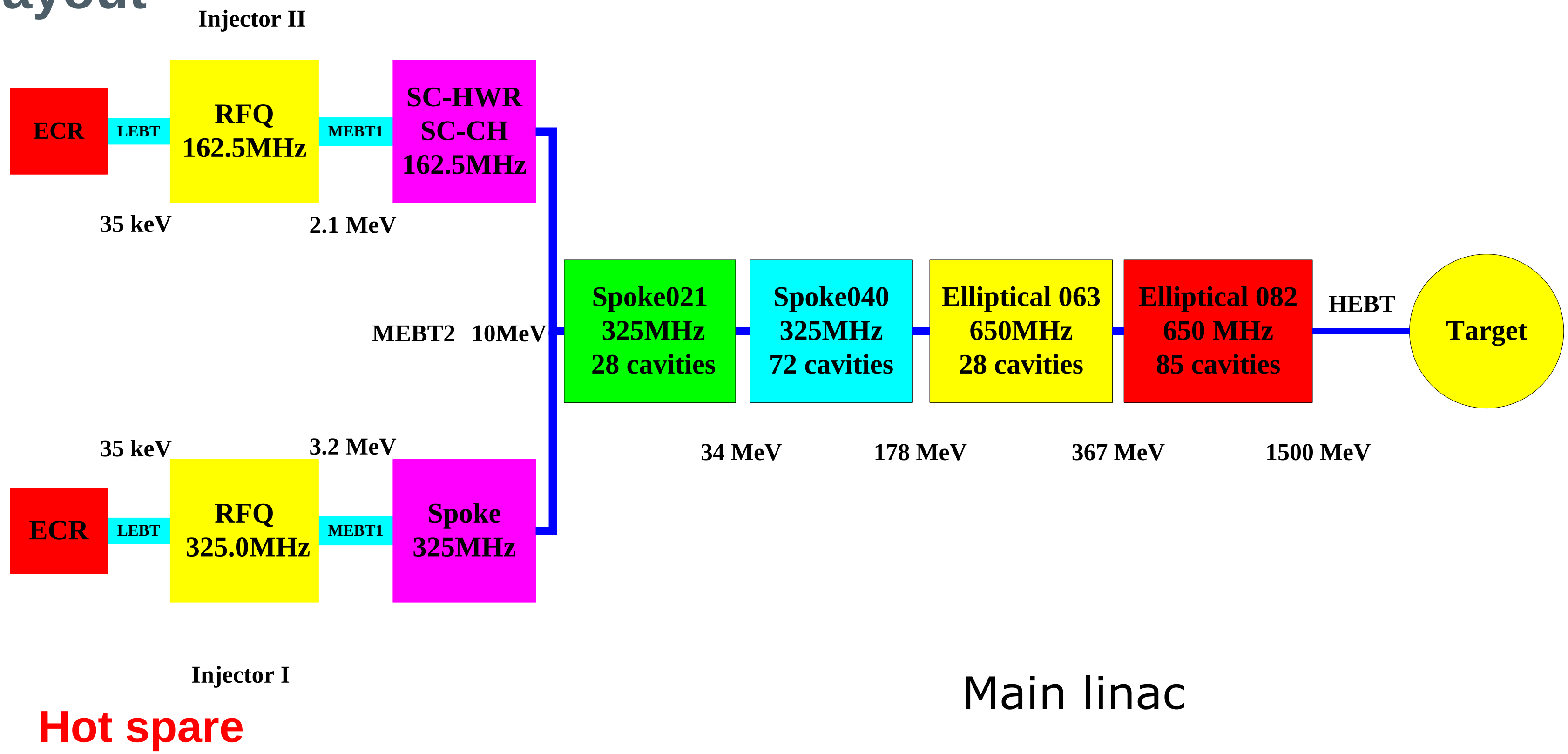


ADS Roadmap in China

CW 162.5MHz/ 325MHz / 650MHz



Layout

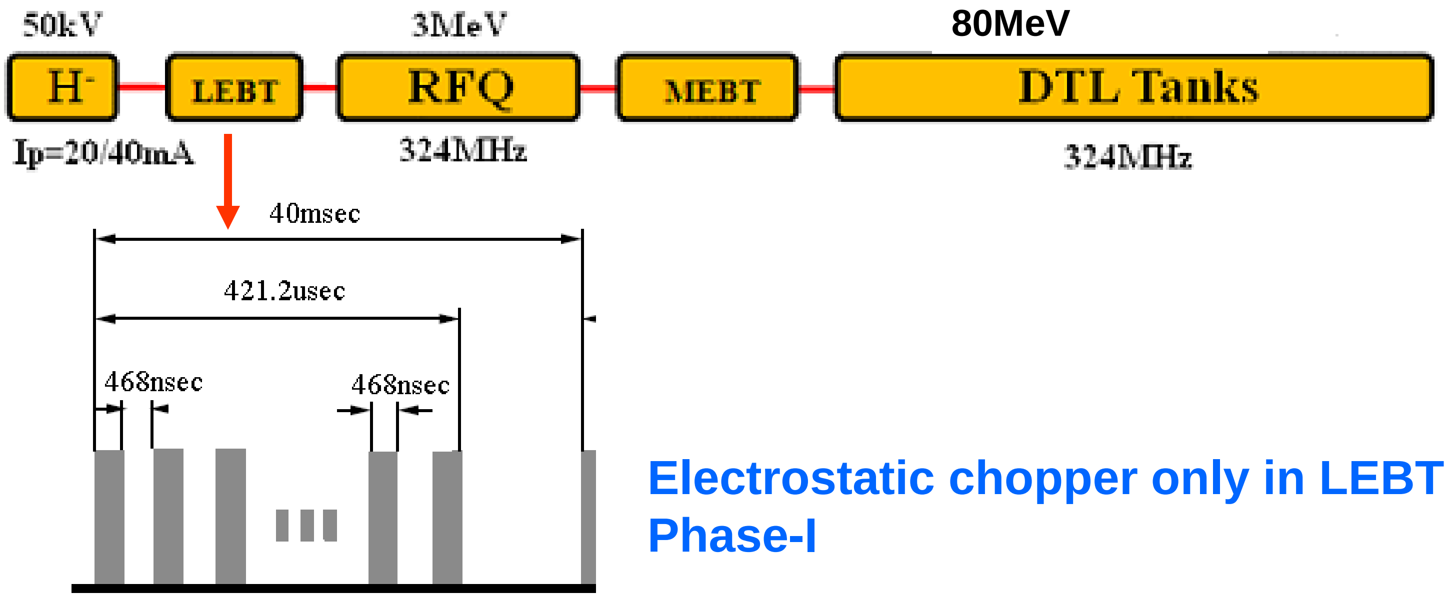


Finished in three phases:

- **2013: 5MeV accelerator;**
- **2015: 50MeV accelerator and 10MW reactor, target;**
- **2020: 600MeV accelerator and 100MW reactor, target;**
- **2030: 1.5GeV and 1000MW reactor, target;**

2, Beam loss study on CSNS Accelerator

- **CSNS Linac Design**



Electrostatic chopper only in LEBT in Phase-I

	Ion Source	RFQ	DTL
Input Energy（MeV)		0.05	3.0
Output Energy(MeV)	0.05	3.0	80
Pulse Current (mA)	20/40	20/40	15/30
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

- **CSNS Linac Design**

J.Peng:TUO3B04

Tank parameters of CSNS DTL

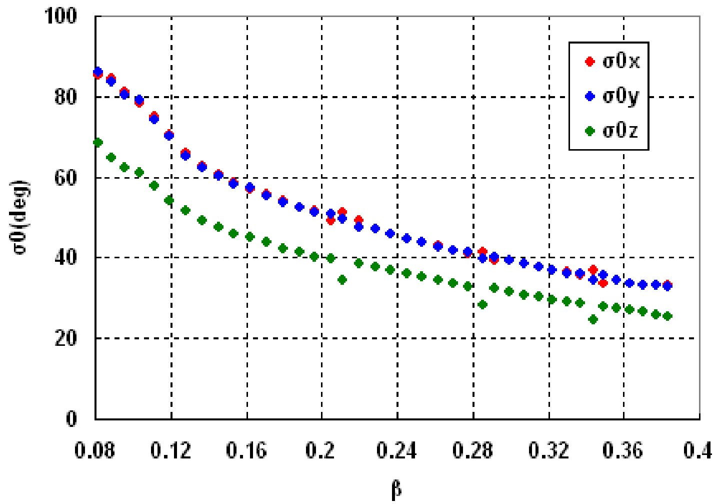
Tank number	1	2	3	4
Output energy (MeV)	21.67	41.41	61.07	80.1
Length (m)	8.51	8.56	8.78	8.8
Number of cell	64	37	30	26
RF driving power (MW)	1.35	1.32	1.32	1.34
Total RF power (MW)	1.91	1.92	1.92	1.93
Accelerating field (MV/m)	2.86	2.96	2.96	3.0
Synchronous phase (degree)	-35 to -25	-25	-25	-25

- The total RF power with a 30mA beam in a tank is about 2MW. Each tank is fed by a 2.5MW klystron.
- FFDD lattice is used.

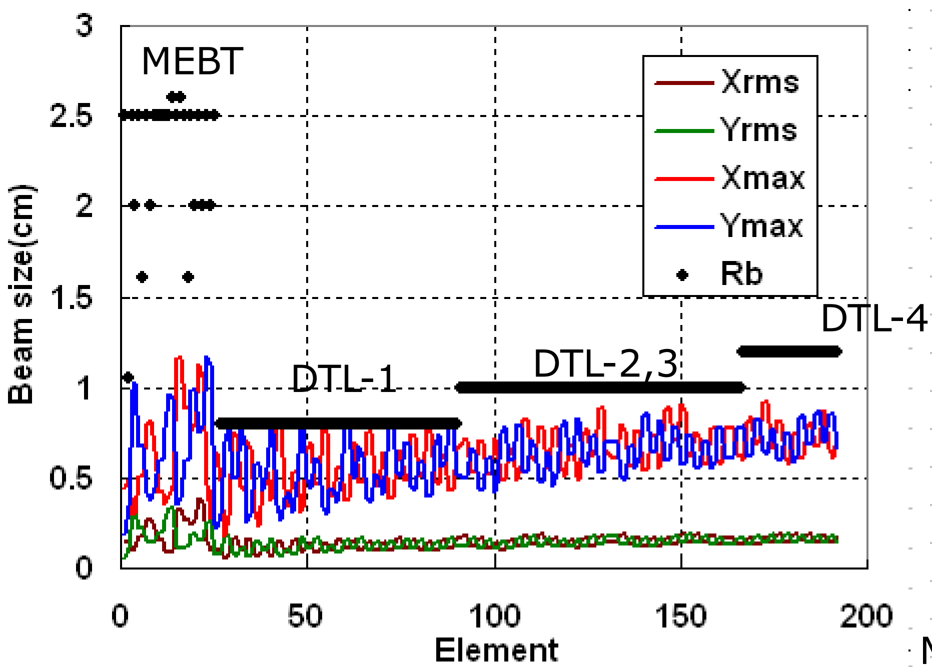
Equipartitioning Design of CSNS Linac

- σ_{t0}, σ_{z0}<90^o to avoid space-charge induced structural resonance of beam envelope.
- $$\frac{T_\perp}{T_\parallel} = \frac{k_x \varepsilon_{nx}}{k_z \varepsilon_{nz}} = \gamma_0^2 \frac{\varepsilon_{nx}^2}{\varepsilon_{nz}^2} \cdot \frac{z_m^2}{a^2} = 1$$ to prevent space charge induced coupling between trans. and longit.

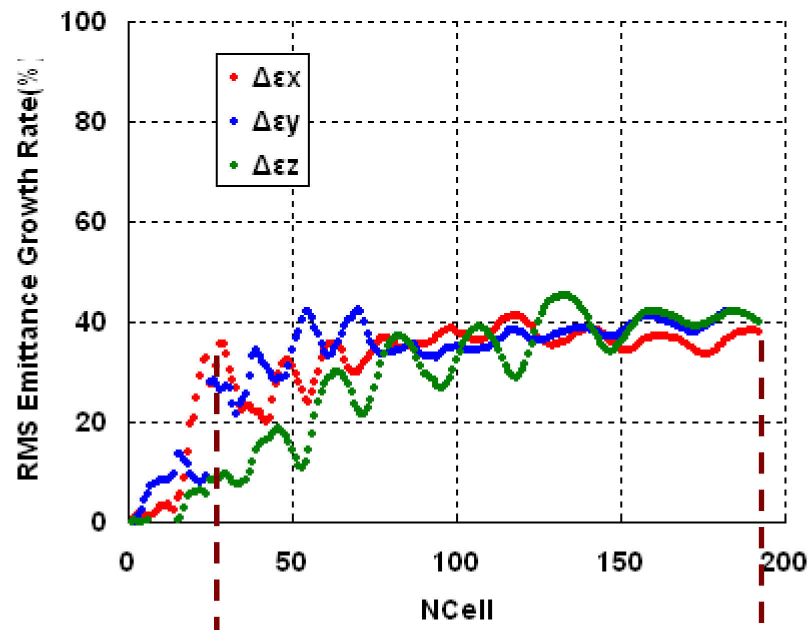
$$\frac{k_{t0}}{k_{z0}} = \sqrt{\frac{3}{2}\frac{\varepsilon_{nz}}{\varepsilon_{nt}} - \frac{1}{2}}$$



Equipartitioning Design of CSNS Linac



Beam size along the linac

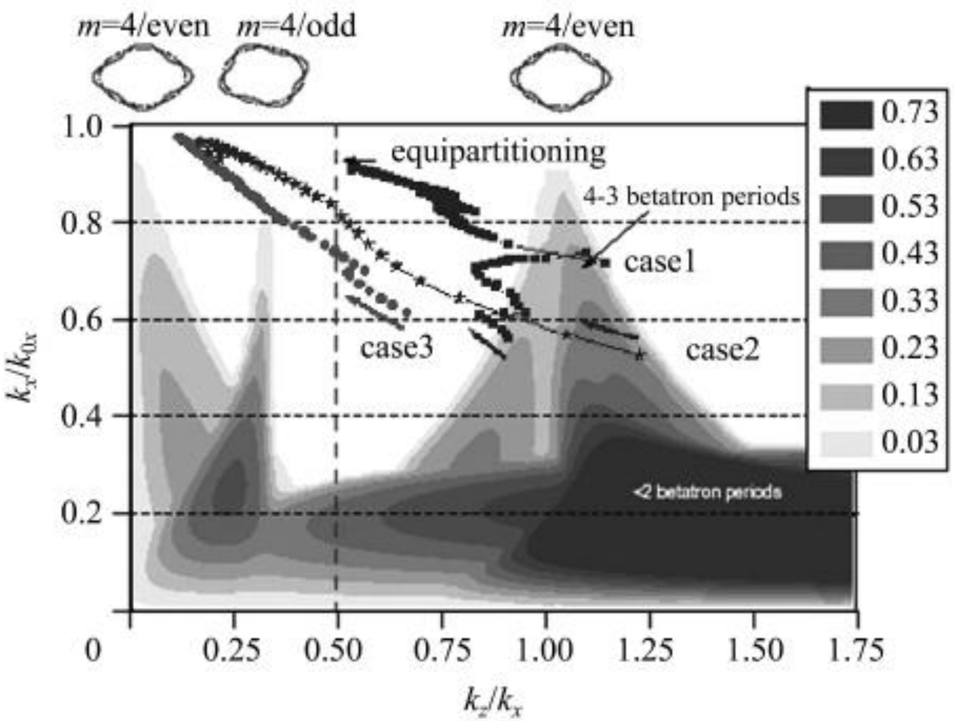


MEBT out:
$\Delta\varepsilon_x$=+28%
$\Delta\varepsilon y$=+28%
$\Delta\varepsilon z$=+9%

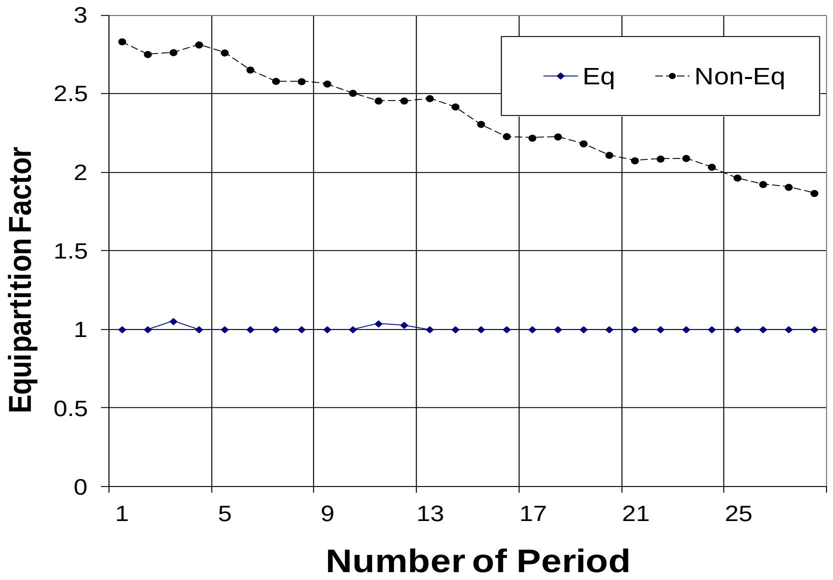
DTL out:
$\Delta\varepsilon_x$=+38%
$\Delta\varepsilon y$=+40%
$\Delta\varepsilon z$=+40%

Emittance growth along the linac

Equipartitioning Design of CSNS Linac



$$f = \frac{k_x \varepsilon_{nx}}{k_z \varepsilon_{nz}}$$

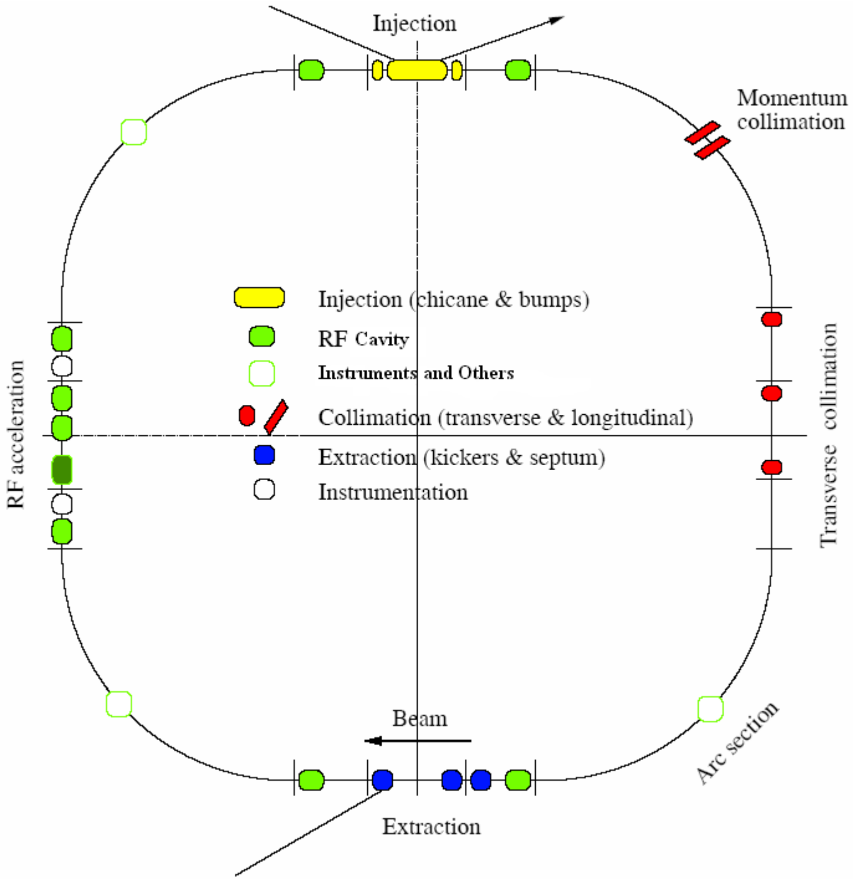


Hofmann stability chart for equipartitioning design of three lattice cases.

TRACE3-D code was modified to generate a full equipartitioning design

Beam Loss Control in CSNS RCS

Lattice design—4-fold Structure



Parameters	Unit	Value
Inj./Ext. energy	GeV	0.08/1.6
Circumference	m	228
Beam population	$\times 10^{13}$	1.56
Harmonic number	*h*	2
RF frequency	*MHz*	1.02-2.44
Repetition frequency	Hz	25
Betatron tune	ν_x/ν_y	4.86/4.78
Chromaticity	*h/v*	-4.3/-8.2
Trans. acceptance	πmm·mrad	540

Beam Loss Control in CSNS RCS

- **Minimize sources of beam loss**
  - **Optimization of the lattice design**
  - **Adequate physical aperture**
  - **Chopping in linac**
  - **Painting injection ⇒ to minimize space charge effects**
  - **RF Voltage and phase ⇒ for efficient longitudinal trapping**
  - **Minimization of errors and instabilities**
- **Beam collimation system**
  - **Scrapping of transverse and longitudinal beam halo**
  - **Special shading for the collimator section**

Beam Loss Control in CSNS RCS

L.S. Huang:WEO1A03

Transversal resistive wall impedance is most likely to appear.

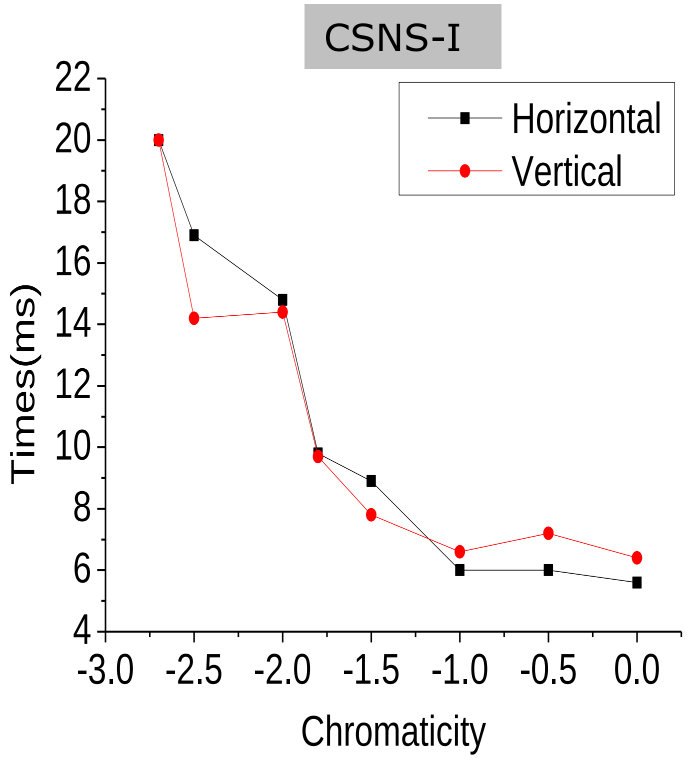
$$(\Delta\omega_\beta)_{coh} = -\frac{ir_p k_b N_p v Z_\mathrm{T}}{2\omega_\beta \gamma T_0^2},$$

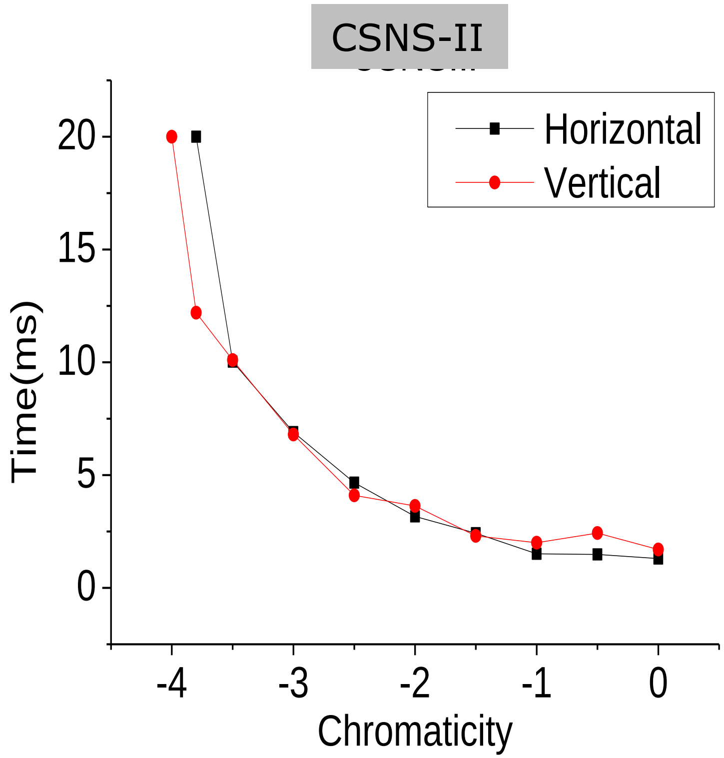
$$\frac{1}{\tau} = \frac{N_p k_b r_p \omega_0^2}{2\pi\beta\gamma c Z_0}\beta_{av}\,\mathrm{Re}(Z_\mathrm{T}).$$

Item	Inj. Hor. (ms)	Inj.Vert. (ms)	Ext. Hor. (ms)	Ext.Vert. (ms)
CSNS-I	5.2	6.4	8.3	10.1
CSNS-II	1.4	1.7	1.8	2.1

Beam Loss Control in CSNS RCS

Tune spread induced by natural chromaticity can increase the growth time.





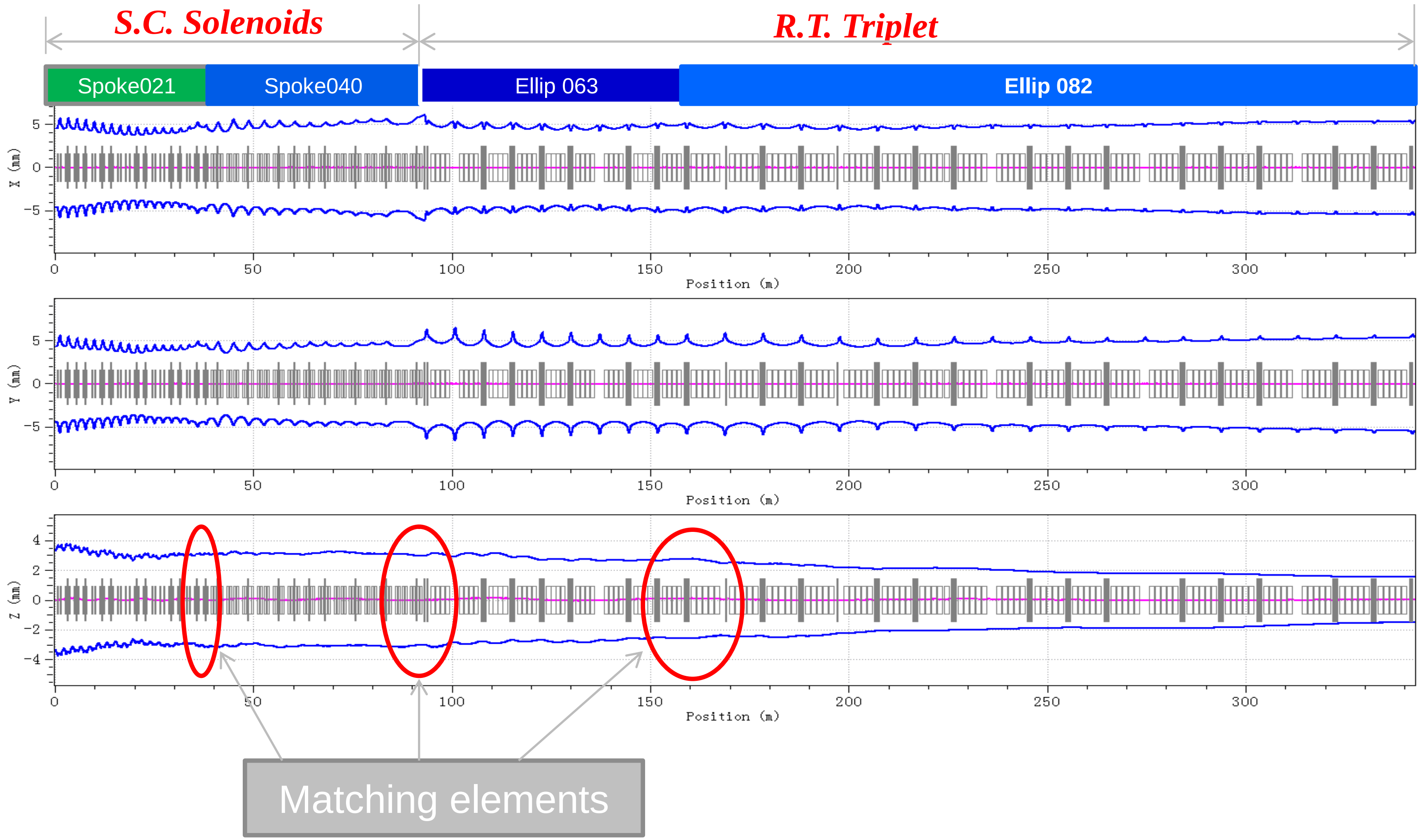
3. Beam loss control study in C-ADS linac

The design philosophy

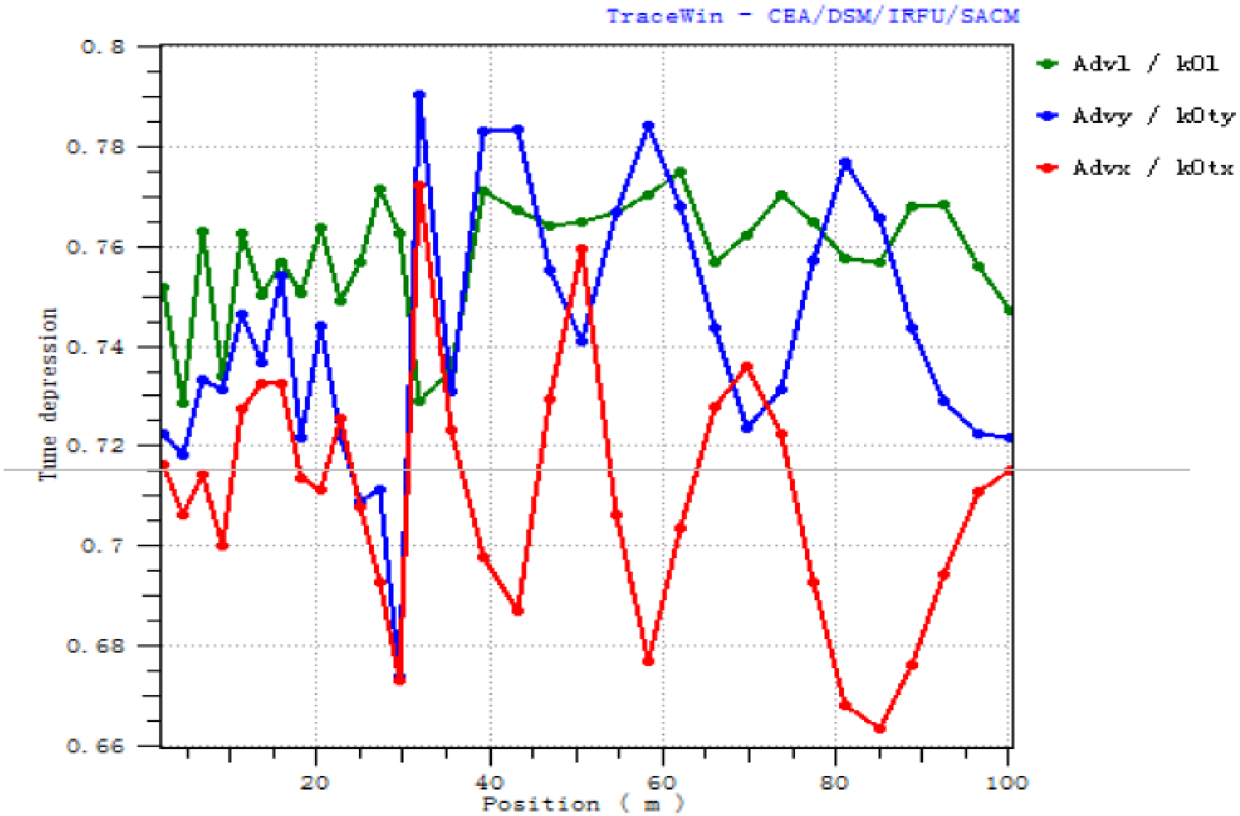
Z.H. Li:THO3A02

- Equipartitioning design;
- The zero current phase advance in all three planes remains below 90 degree to avoid envelope resonance ;
- Smaller longitudinal emittance than transverse emittance to get more accelerating efficiency of the cavity;
- Long drift at both end of the period to avoid cryomodule separation causing emittance growth;
- Derated cavity nominal gradient for compensation in case any one cavity is lost;
- Using triplets instead of doublets in the elliptical section;
- The field setting bigger than 50% of the nominal design to avoid multipacting effect.

Main linac design



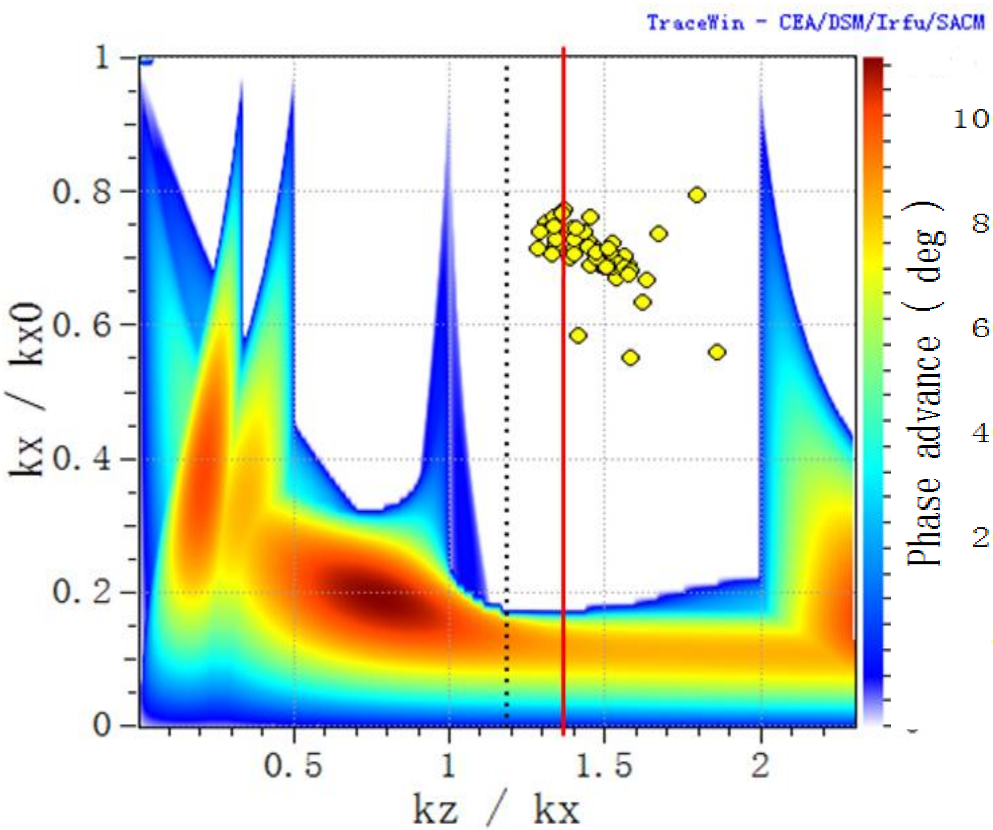
Space charge tune depression in the low energy section of the main linac

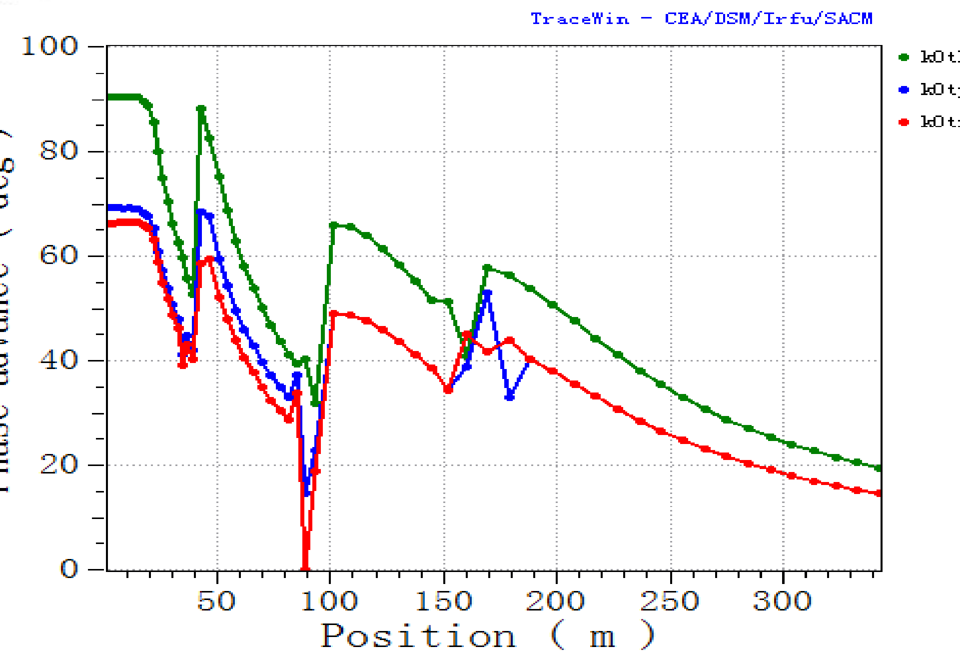


Spoke section with10 mA beam current for injector-I

Equipartitioning Design

F. Yan: MOP221

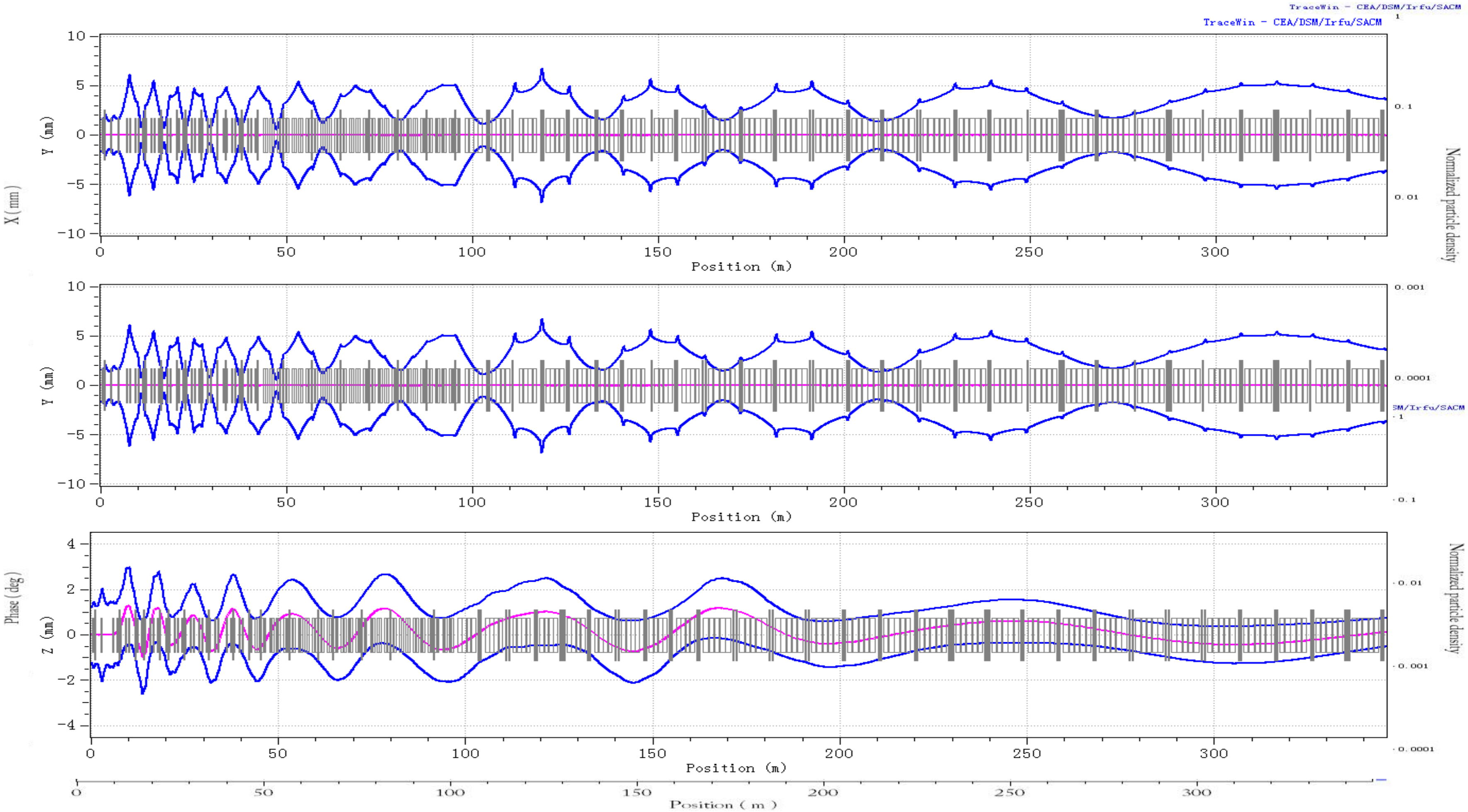




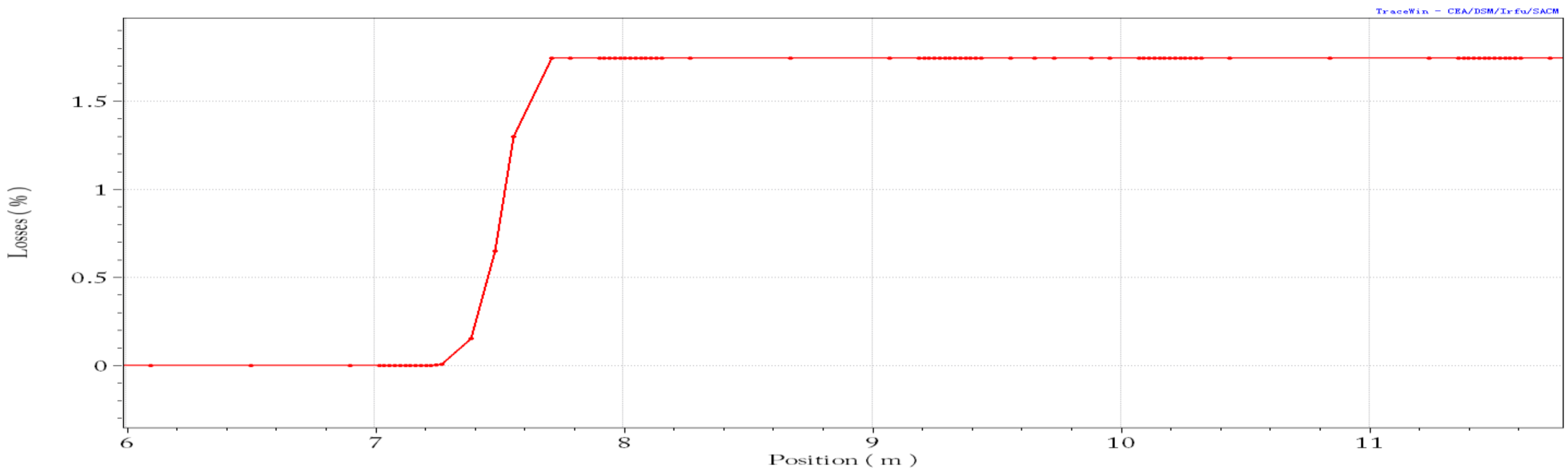
Avoiding any kind of resonance;
Keeping focusing changing smoothly;

中国散裂中子源

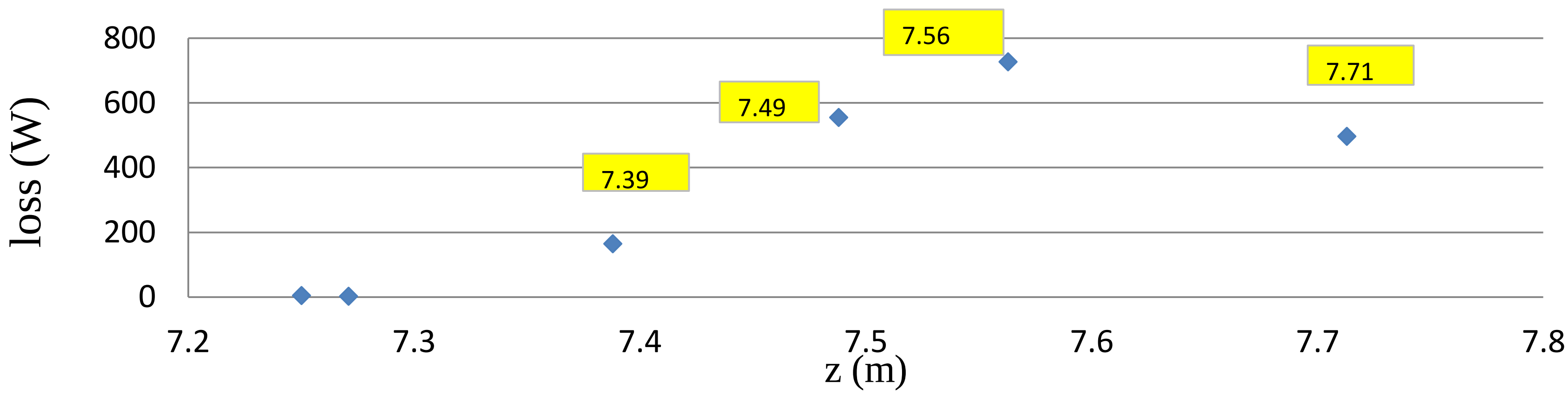
S.C. Solenoid quench effect and compensation



One solenoid quench: Mismatching induced beam envelope oscillation not only in transversal but also in longitudinal directions.

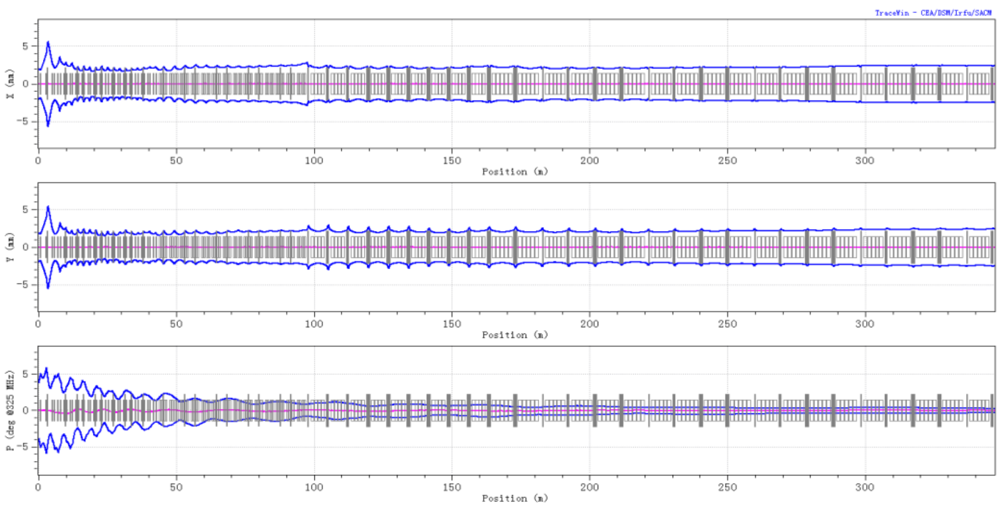


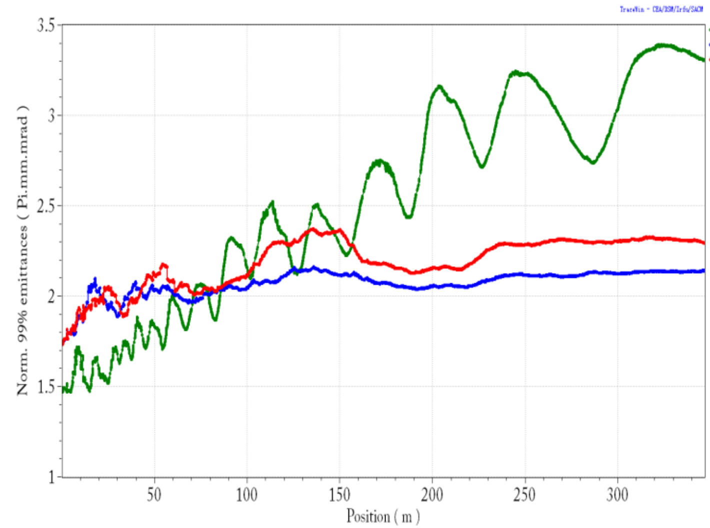
losses of the first solenoid failure

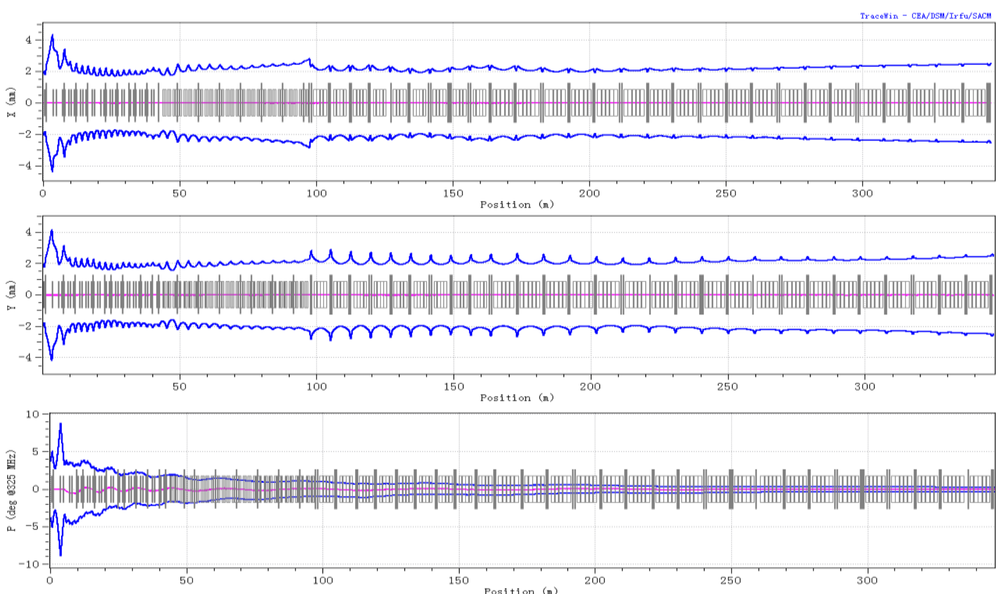


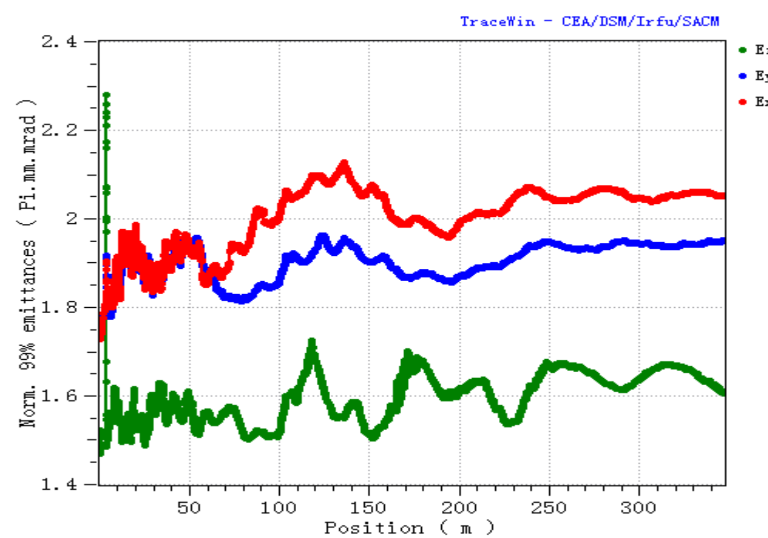
Beam loss rate and power is rather large: 2kW beam power in about 0.5m.

Compensation must be set up:not only transversally (upper), but also longitudinally (lower)



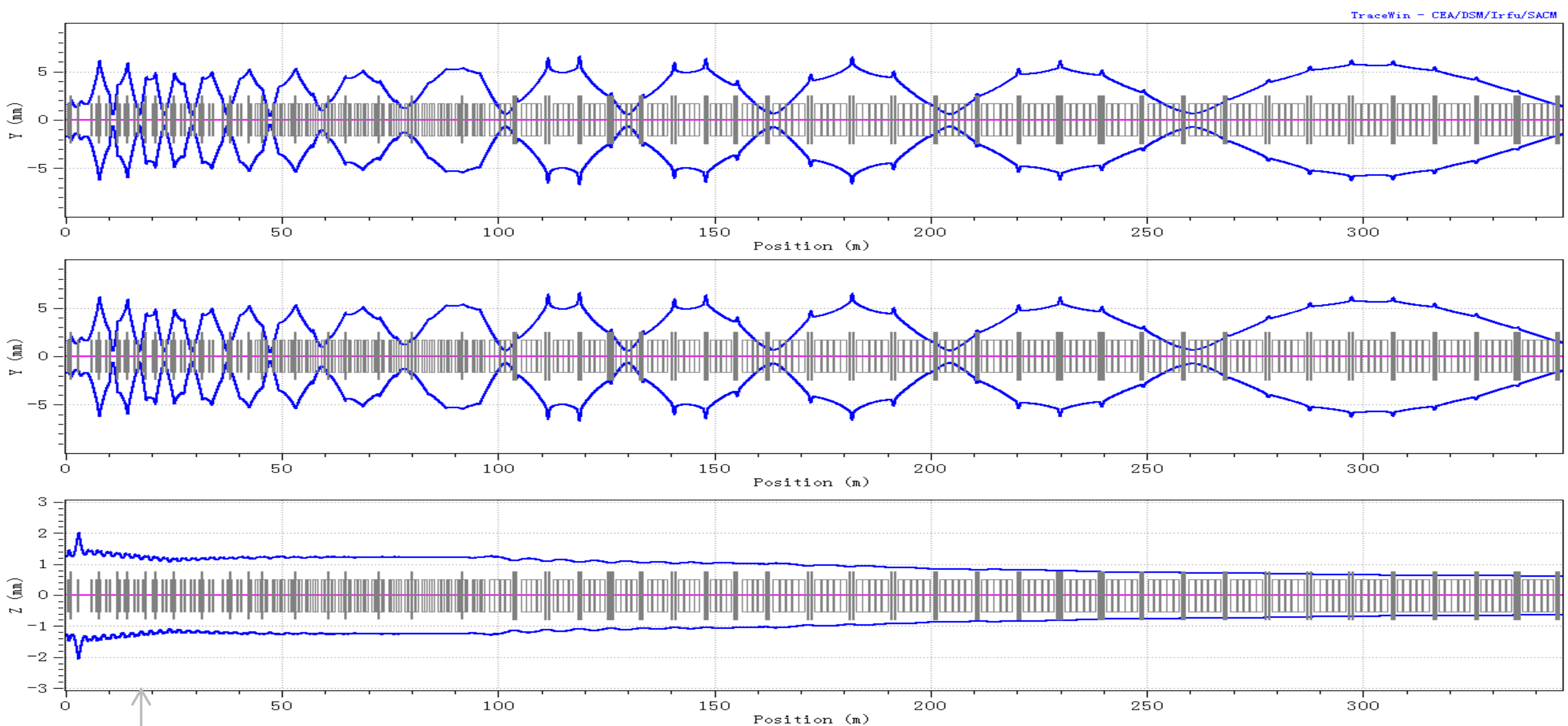






Envelope(linear)

Strong transversal non-linear coupling to longitudinal direction due to large beam radius and strong accelerating field in S. C. linac.

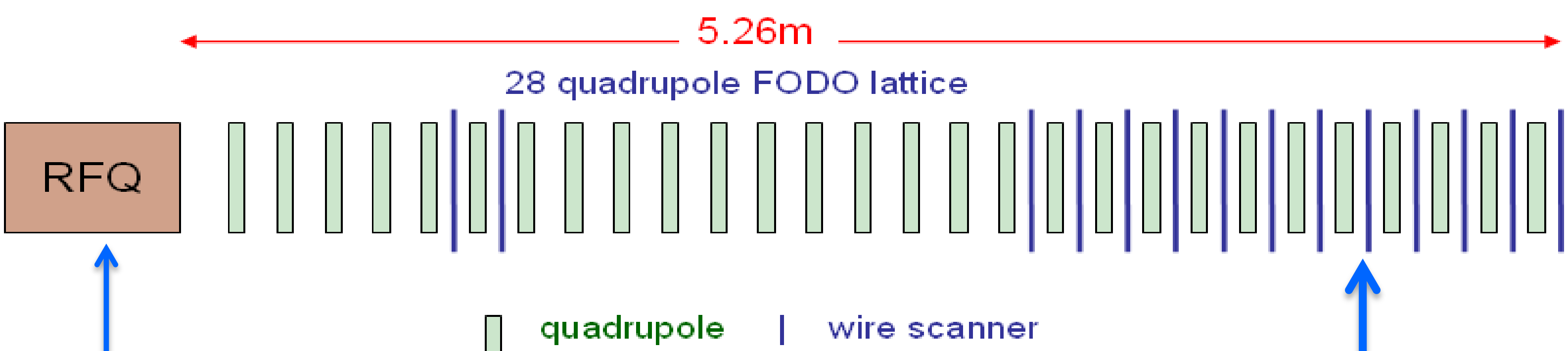


Linear optics: no coupling with longitudinal direction!

4, Experimental beam halo study

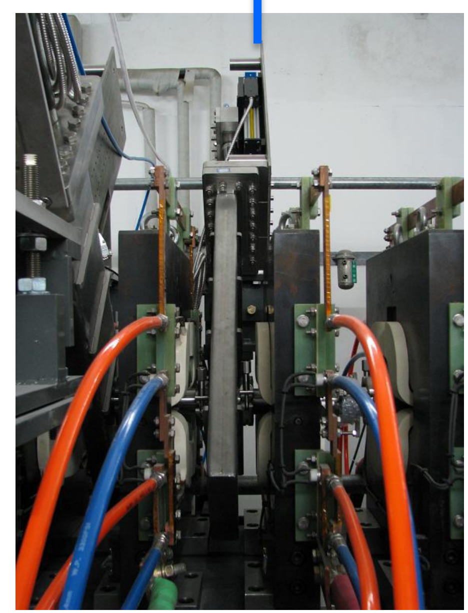
O.Y. Huafu:MOP243

Experimental study on beam halo is undergoing with the output beam from an intense beam RFQ. A periodical channel has been set up with 28 quadrupoles, 14 wire scanners, 6 BPM， 2 ACCT， 2 FCT.

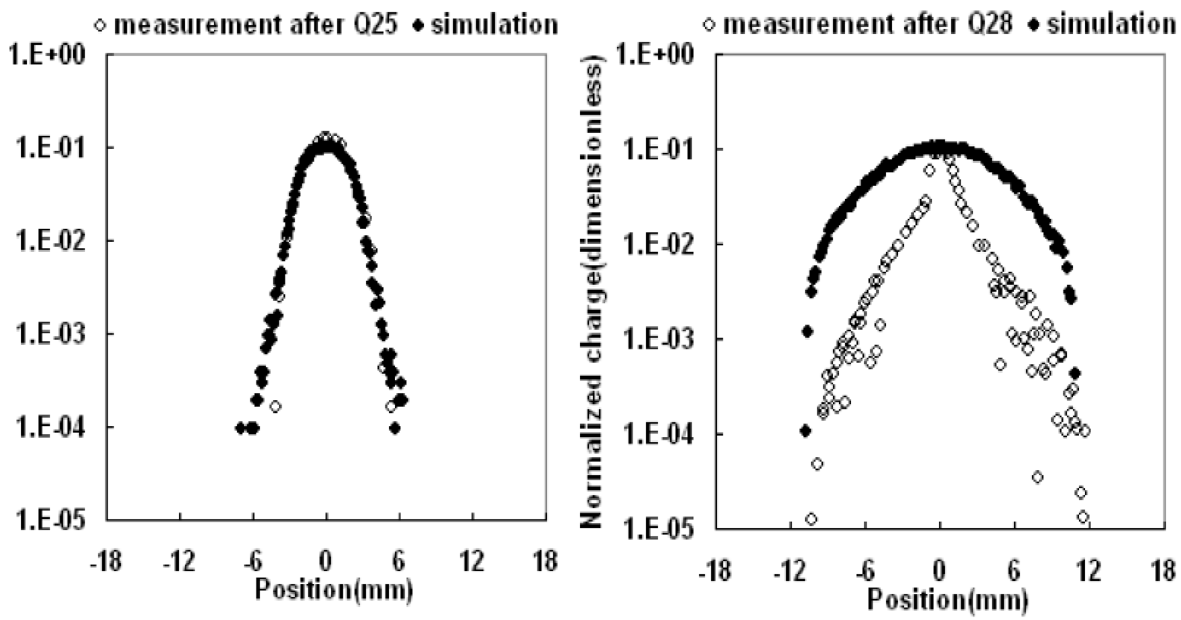


3.5MeV
20-40mA
0.005-15% duty

Wire and scraper: Dynamic range 10^5



Comparison between measure beam profile with the multi-particle simulations at I=20mA.



Measured and simulated beam profiles for matched beam(left) and mismatched beam(right) (mismatch factor=2)

5, Other aspects

1, Sheng Wang, et al., Beam Commissioning Plan for CSNS Accelerators,TUO3C05

2, Ming-Yang Huang, et al., Study on the beam losses in the injection region for CSNS/RCS, MOP213

3, Yuwen An, et al., The Study on Measuring Beta Functions and Phase Advances in the CSNS/RCS, MOP215

4, Na Wang , et al.,The Design Study on the Longitudinal Beam Dynamics for CSNS/RCS, MOP216

5, Shou Yan Xu, et al., Effects of Magnetic Field Tracking Errors and Space Charge on Beam Dynamics at CSNS/RCS, THO1A02

6, Jin-Fang Chen, et al., Dual-Harmonic Acceleration Studies at CSNS RCS, THO1A03

7, Hua Shi, et al., Test of ferrite rings for CSNS/RCS RF cavities, MOP214

8, Taoguang Xu, et al., The beam diagnostics of CSNS, TUO1C03

9, C. Meng et al., "Error Analysis and Correction Scheme in C-ADS Injector-I", MOP219

10, Zhen Guo et al., "The MEBT2 Design for the C-ADS", MOP217

11, Peng Cheng et al., Preliminary Study of HOMs and the Associated Instabilities for C-ADS Linac, MOP212

12, Hongping Jiang , et al., Dynamics of Particles in a Tilted Solenoidal Focusing Channel, MOP218

13, Biao Sun, et al., Compensation-rematch for major element failures in the C-ADS accelerator, MOP220

14, Zheng Yang, et al., Using step-like nonlinear magnets for beam uniformization at IFMIF target, WEO3B05

15, Yaliang Zhao, et al., Development of the Linac Design and Tracking Code PADSC,MOP222

SUMMARY

1, CSNS, ADS projects in China need deep understanding on high intensity beam physics.
2, Beam loss is a key issue for the intense beam accelerator design.
3, Space charge effect play an essential role in the beam loss and emittance growth in these accelerators.
4, A series of intense beam physics studies has been conducted for beam loss control, in theoretically and experimentally.

Thank you very much for your attention