Beam halo control study on the ADS superconducting linac design at IHEP

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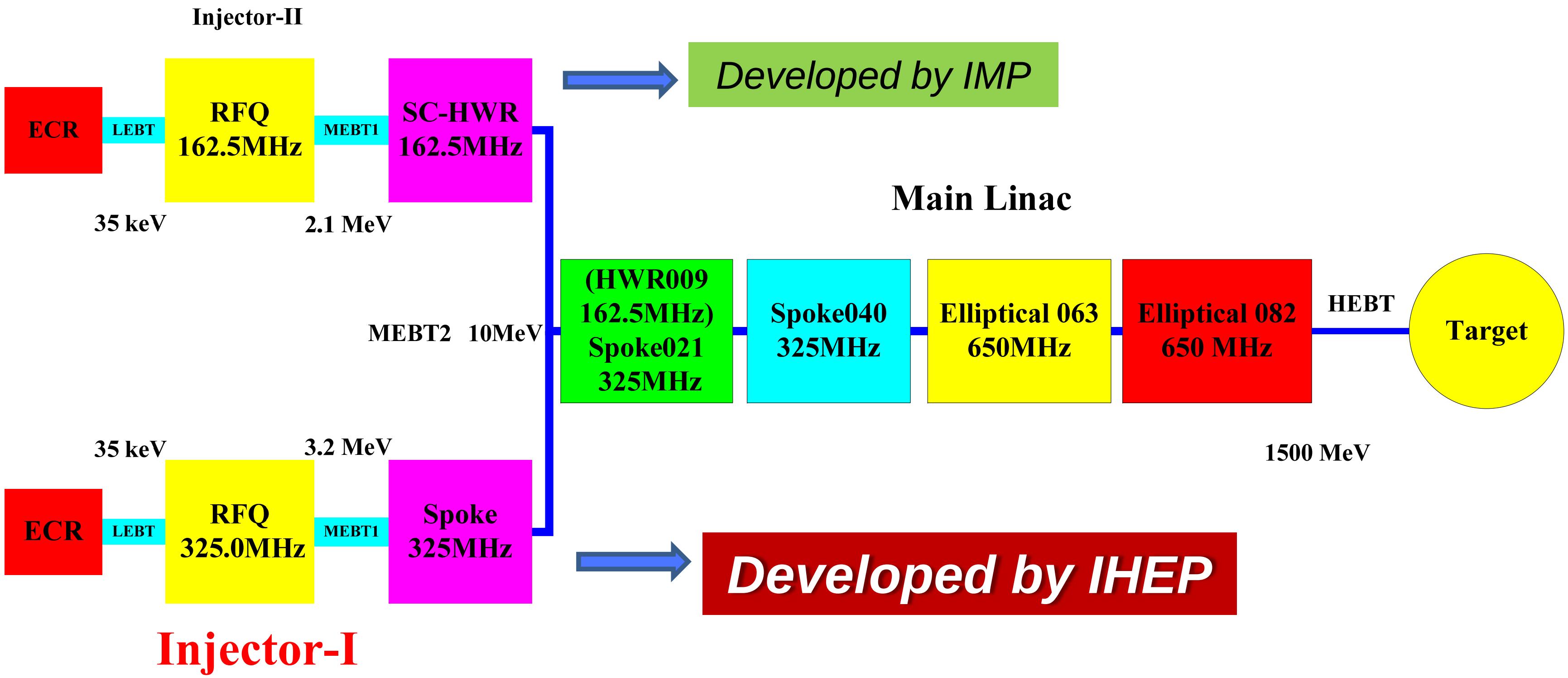
Outline

1. Introduction
2. Lattice design of the Injector-I test facility
3. Beam dynamics
4. Error analysis
5. New injector-I design with better acceptance
6. Summary

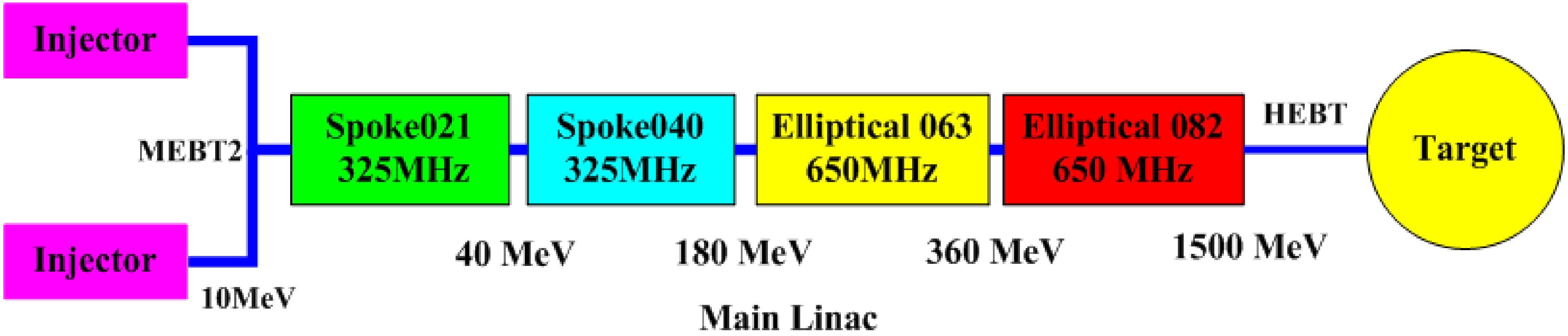
1. Introduction

Schematic of ADS driver linac:



1. Introduction

Schematic of ADS driver linac:

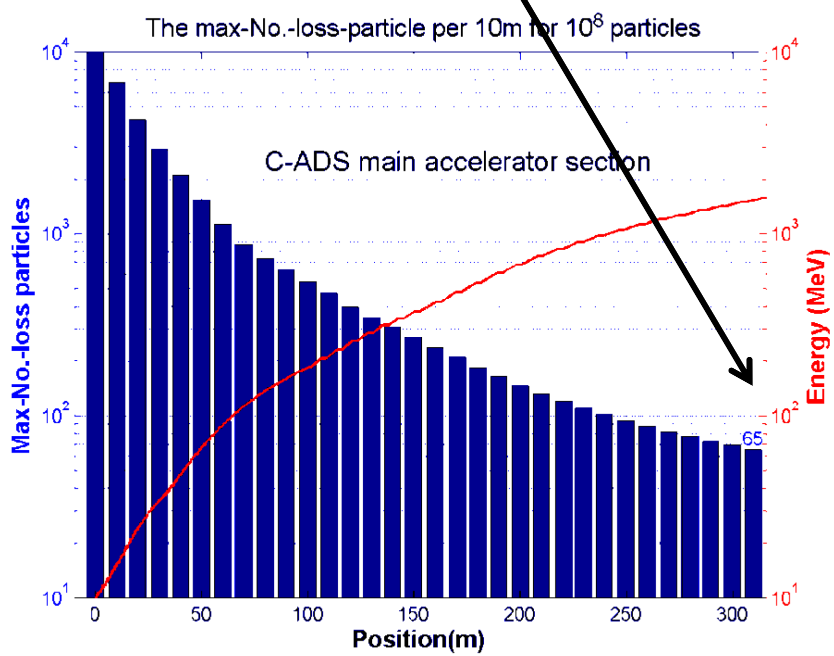


1. Introduction

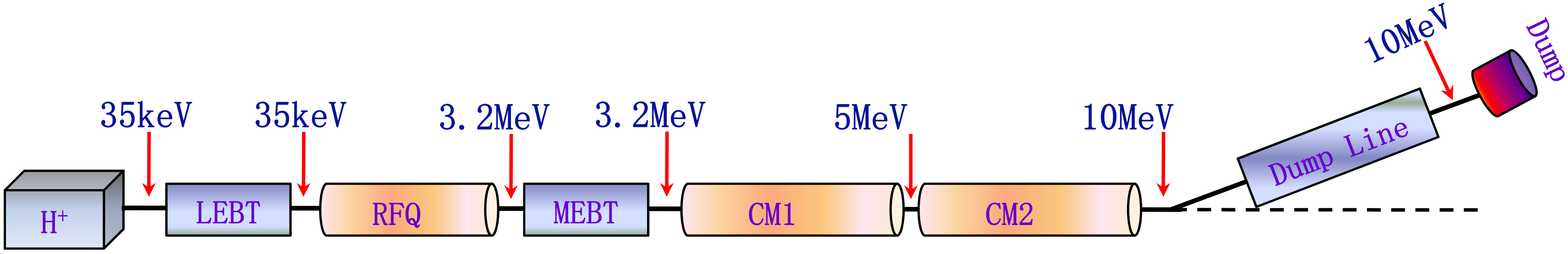
- *Beam loss limit of the China-ADS Driver linac:*

Max. beam power: 15MW，to fulfill the 1W/m requirement, the beam loss rate has to be controlled down to 7×10^{-8} /m.

Particles	proton
Energy (GeV)	1.5
Beam current(mA)	10
Beam power(MW)	15
Duty factor(%)	100
Beam loss (W/m)	<1



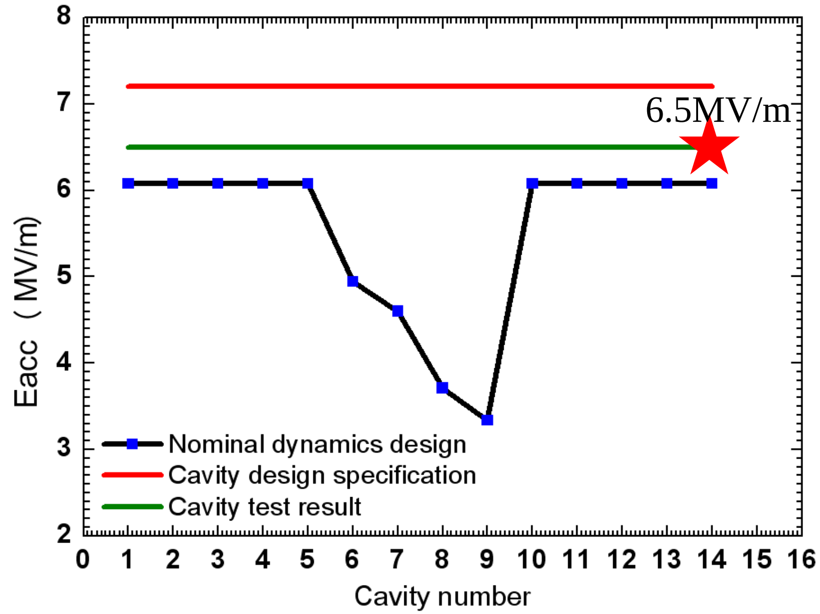
1. Introduction



- The Injector-I testing facility is being built in IHEP.
- It is composed of: ECR ion source, LEBT, RT RFQ, MEBT line and a superconducting section.
- The beam dump line is used for transporting the proton beam out of the SC segment to the beam dump.
- The front end from source to RFQ has been installed in the IHEP campus, and 90% beam duty factor has been achieved with 90% transmission out of RFQ.

2. Lattice design: SC section

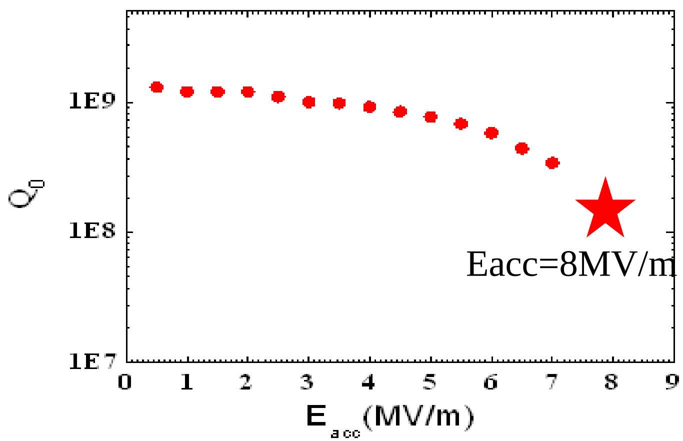
Spoke012 cavity gradients



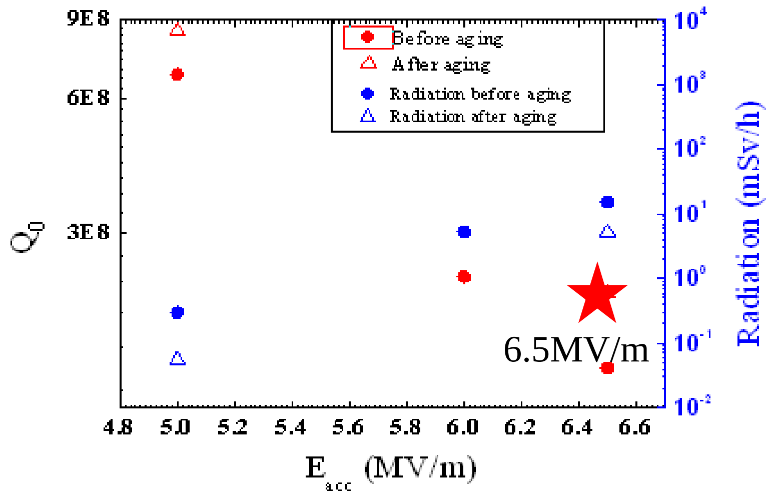
- Vcav0=0.8MV, TTF=0.76, Eacc0=5.53 MV/m.
- The maximum Spoke012 cavity voltage and gradient used in the nominal dynamics simulation are Vcav=1.1×Vcav0=1.1×0.8MV=0.88MV/m and Eacc=1.1×Eacc0=1.1×5.53MV/m=6.08 MV/m, respectively.
- The achieved gradient 6.5MV/m by the Spoke012 cavity prototype test can satisfy dynamics requirement.

Spoke012 cavity prototype test

Vertical test 2012.12.24

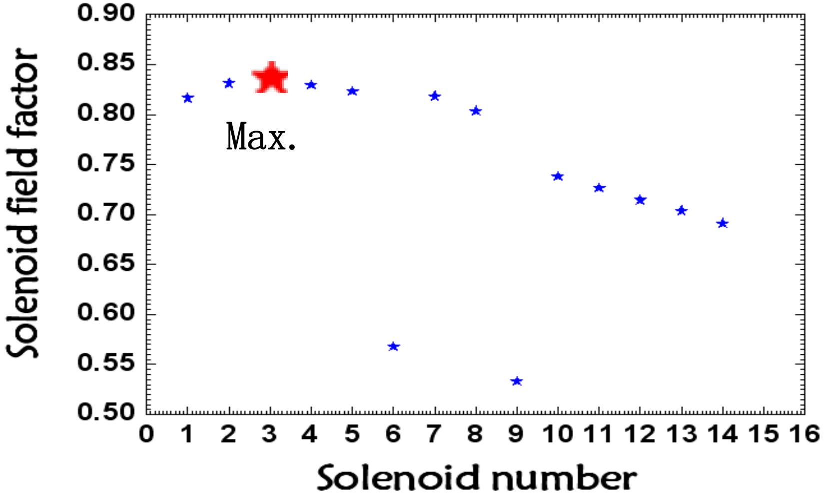


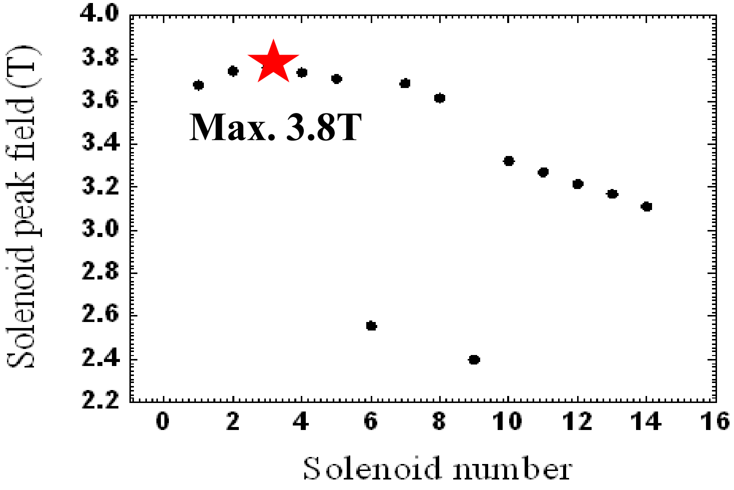
Horizontal test @2013.09.16



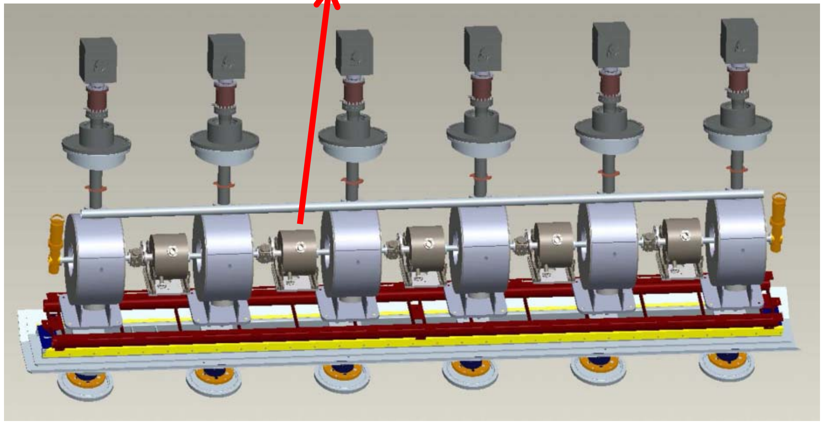
2. Lattice design: SC section

- *Solenoid strength*

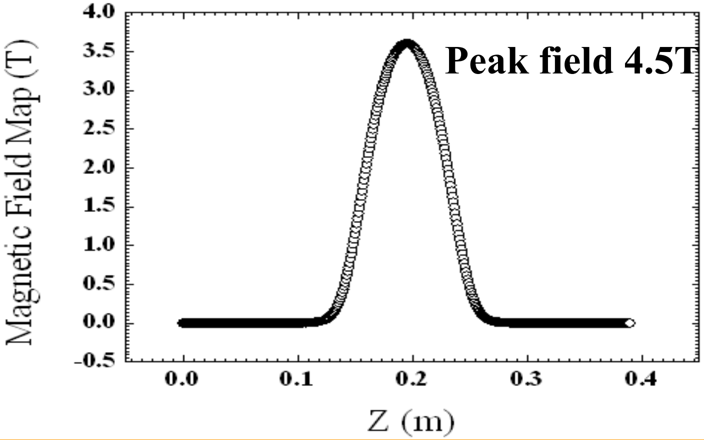




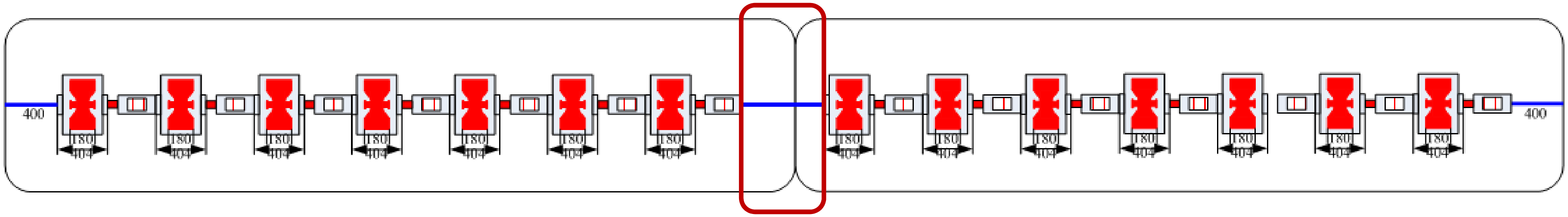
Solenoid in the CM1



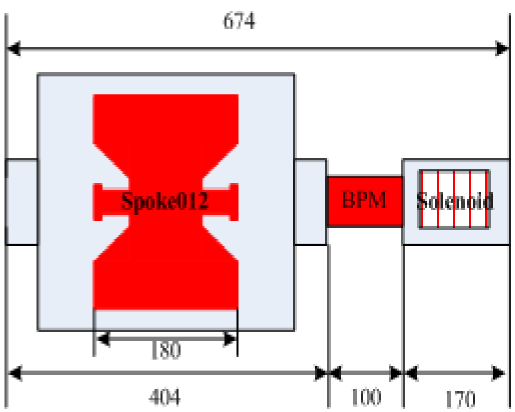
On-axis solenoid field map

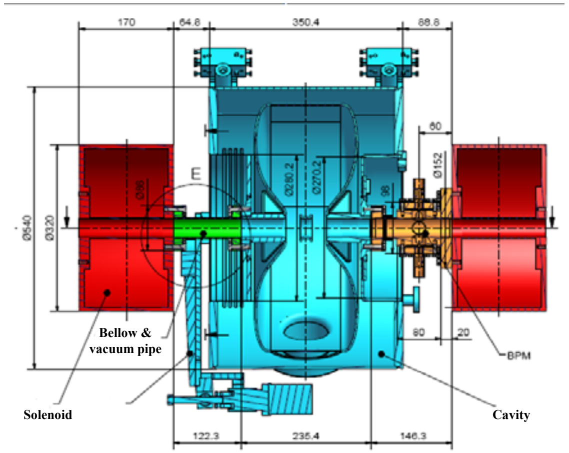


2. Lattice design: SC section



608 mm





2. Lattice design: SC section

- ***Avoiding the longitudinal parametric resonances***

$$k_{mm} L = \pi$$

⇓

$$k_{\ell 0} = k_{mm} \Big/ \sqrt{1+3\eta_l^{\,2}} = \pi / L \Big/ \sqrt{1+3\eta_l^{\,2}}$$

⇓ $\eta_l = 0.67$

$$\sigma_{l0} = 118^\circ$$

When filling factor is considered

⇓

$$\varepsilon = \frac{\sigma_{l0}}{2} \frac{\sin(\pi l_{eff} / L)}{\pi l_{eff} / L}$$

⇓ $l_{eff} / L = 0.163$

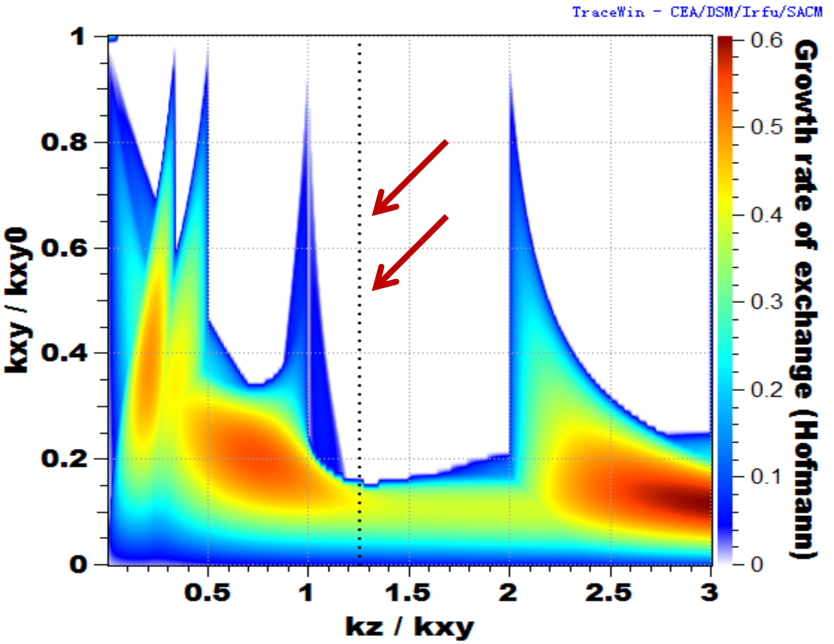
$$\sigma_{l0} = 92.9^\circ \,!!$$

2. Lattice design: SC section

- ***Avoiding the transverse and longitudinal coupling***

1. The linac is designed with fixed phase advance ratio to fulfill the equipartioning condition and give a current free design:

$$\frac{k_{t0}}{k_{l0}} = \left(\frac{3\varepsilon_{nl}}{2\varepsilon_{nx}} - \frac{1}{2}\right)^{1/2}$$



2. The longitudinal emittance out of RFQ is designed to be smaller than transverse to give maximum longitudinal acceleration;

3. The working points are distributed around the equipatition line and between the $k_l / k_t = 1$ and $k_l / k_t = 2$ stop bands.

2. Lattice design: SC section

- ***Avoiding the transverse structure resonances***

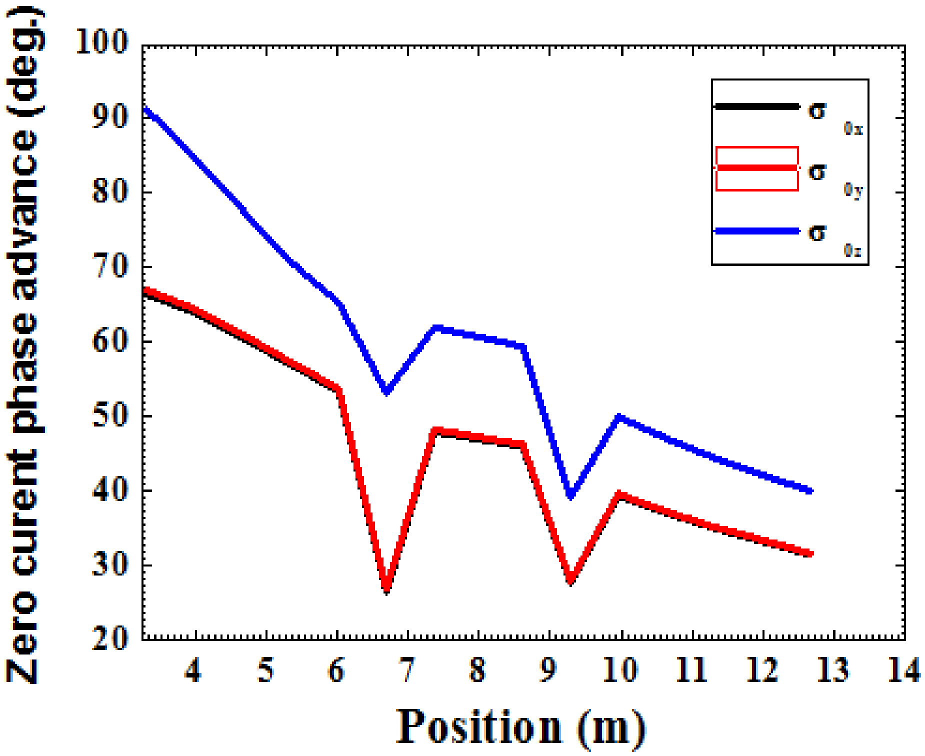
$\sigma_l < 60°$

✓ To avoid the 2nd / 4th resonances:

$2\sigma_t \ or \ 4\sigma_t < 180 \ or \ 360$

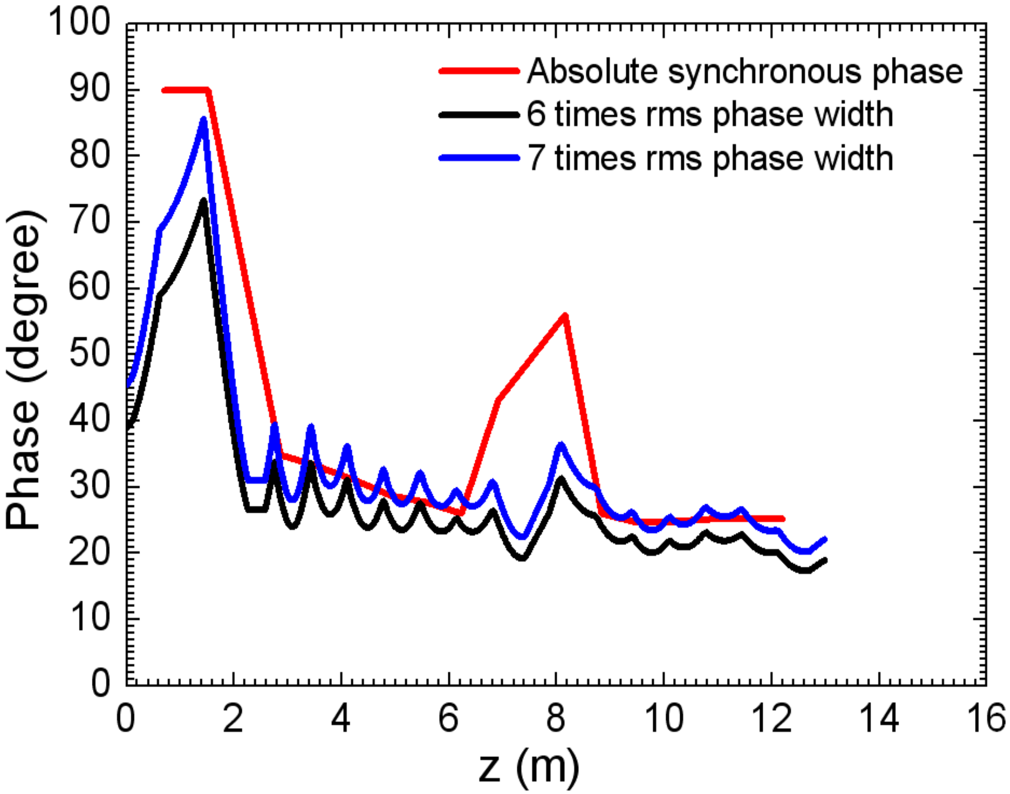
✓ 3rd order of structure resonances:

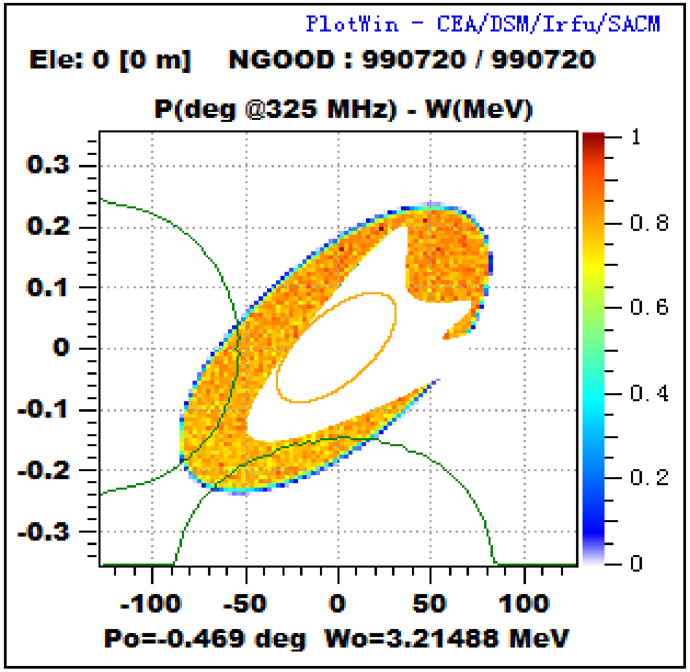
$3\sigma_t < 180$



2. Lattice design: SC section

- *Acceptance*
  - Transverse acceptance: 7.8 times (aperture/ rms beam size)
  - The absolute value of synchronous phase is bigger than 6 times of the rms phase width. The longitudinal acceptance is 6.3 times*.





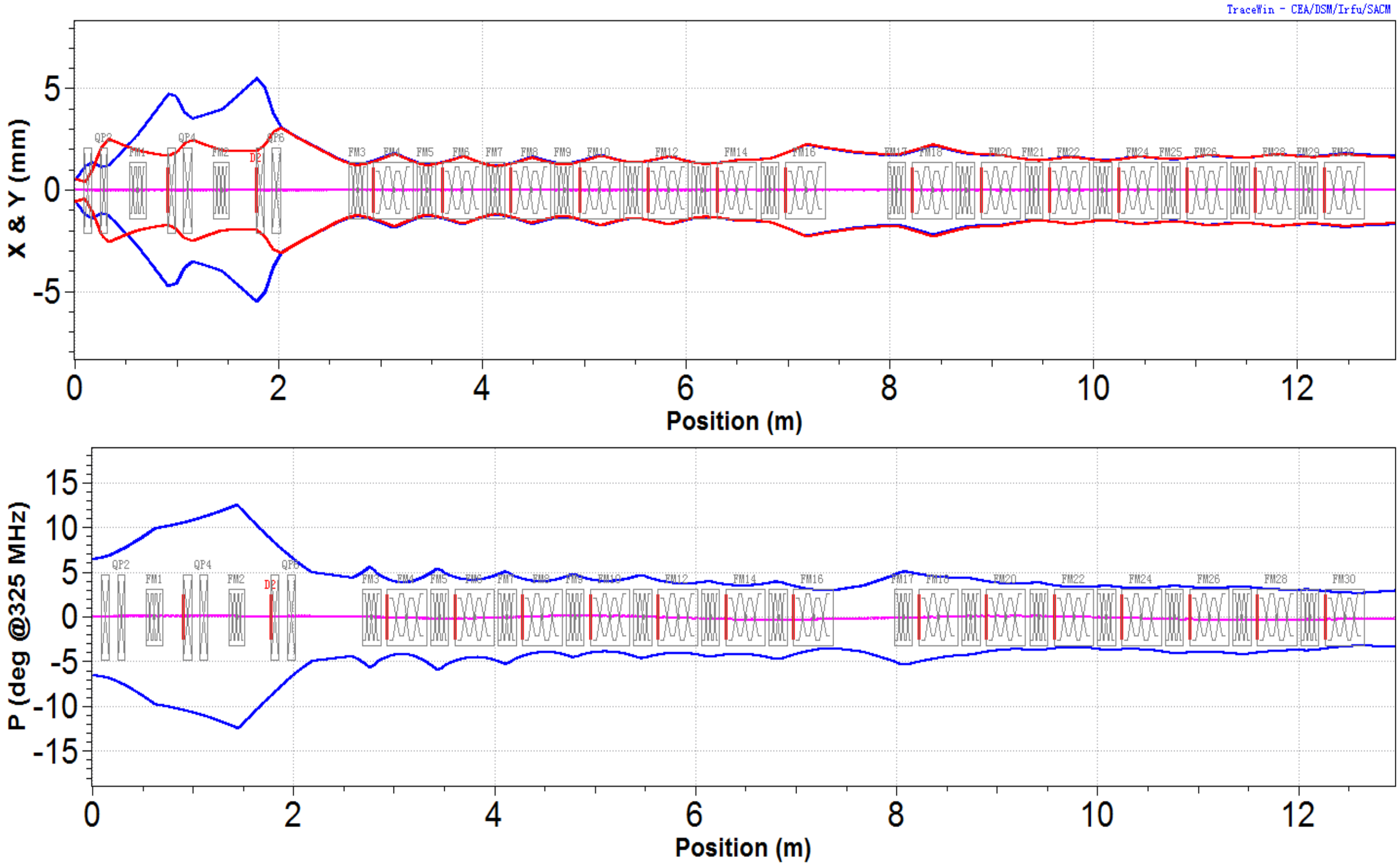
* The acceptance is calculated over the entrance emittance including 95.4% particles (Gaussian distribution)

3. Beam dynamics: conditions

- TraceWin program is used for beam dynamics and error analysis;
- Using RFQ simulated output:
  - Simulated with Parmteq.
  - 6d waterbag input with 100000 macro particles for the RFQ entrance.
  - Normalized rms emittance in x and y: 0.198 π.mm.mrad /0.199 π.mm.mrad.
  - Normalized rms emittance in z: 0.159 π.mm.mrad (i.e. ,0.058 π .deg.MeV).
- Integrated with MEBT;
- 3d cavity and solenoid fields are used in the multi-particle simulations;
- 1000 seeds are generated randomly for the error analysis of each scenario.

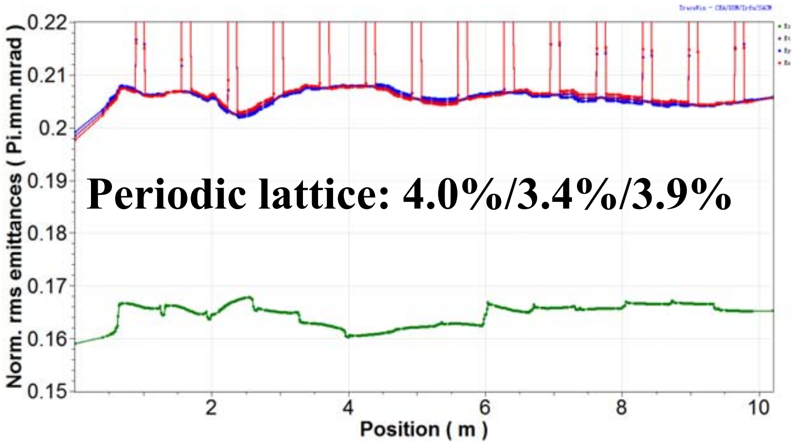
3. Beam dynamics:

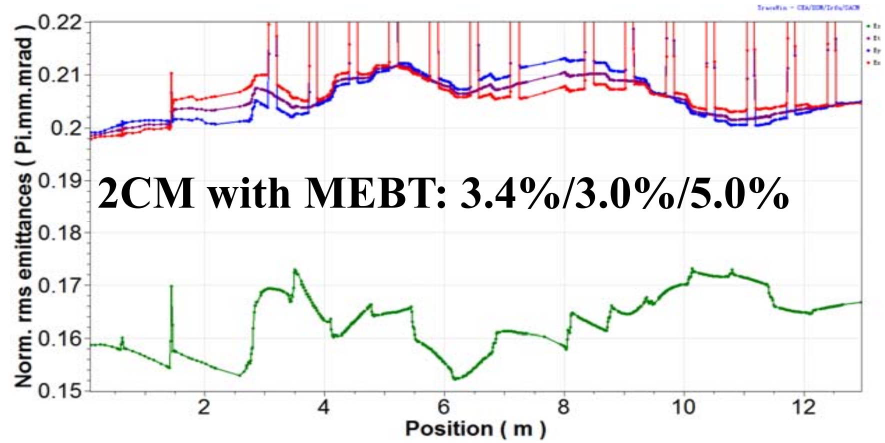
- *RMS envelope evolution*
  - **Output beam energy: 10MeV**
  - **Integrated with MEBT:**



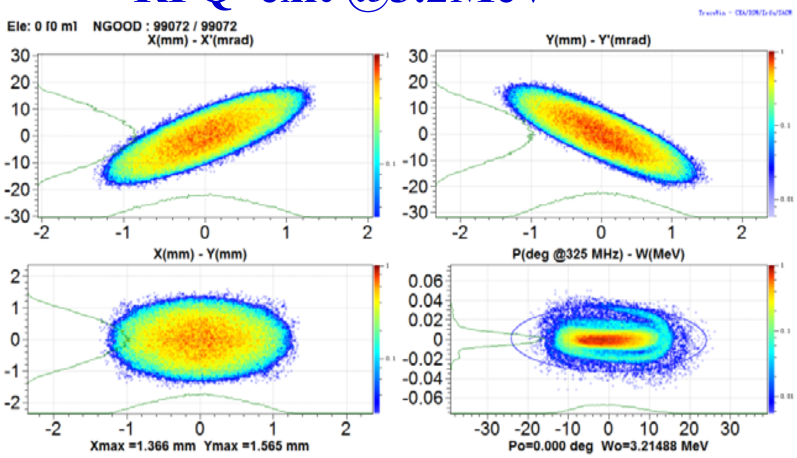
3. Beam dynamics:

- *Normalized RMS emittance evolution*

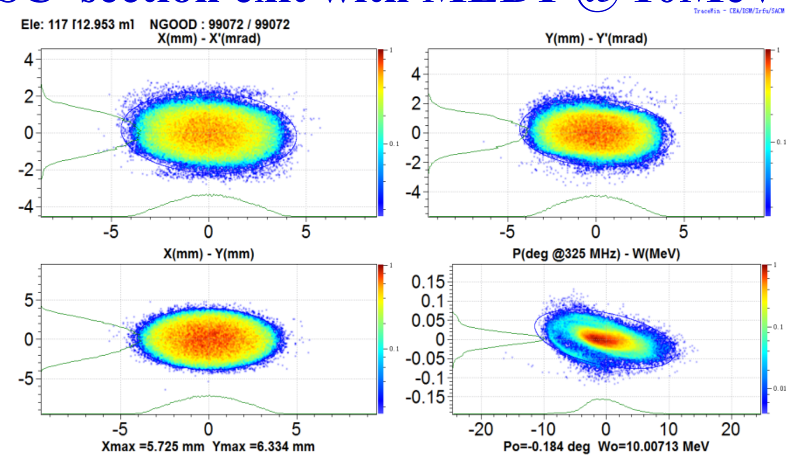




RFQ exit @3.2MeV



SC section exit with MEBT @ 10MeV



4. Error analysis

- ***Misalignment & RF error settings in beam dynamics***

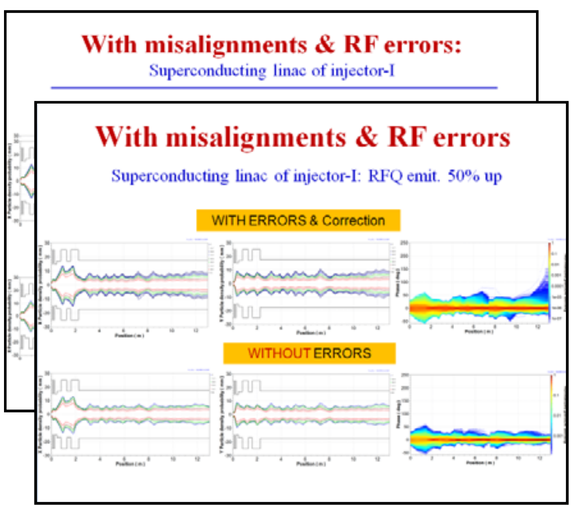
Error type		Error amplitude					
		Buncher / Cavity		Q / Solenoid		B magnet	
		Static	Dynamic	Static	Dynamic	Static	Dynamic
Displacement	δx (mm)	0.1 /1	0.002/0.01	0.1 /1	0.002/0.01	0.5	0.005
	δy (mm)	0.1 /1	0.002/0.01	0.1 /1	0.002/0.01	0.5	0.005
Rotation	Rx (mrad)	2	0.02	2	0.02	2	0.02
	Ry (mrad)	2	0.02	2	0.02	2	0.02
	Rz (mrad)			2	0.02	2	0.02
Gradient	δg (%)	0.5	0.25	0.5	0.05	0.1	0.05
RF phase	δφ (°)	0.5	0.25				
Longitudinal displacement	δg (mm)	0	0	0	0	0	0

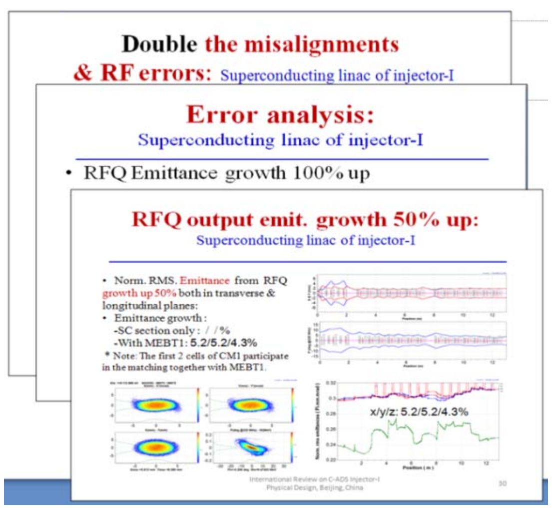
The BPM uncertainty is assumed to be 0.4mm.
All errors are uniformly distributed between the +/- maximum values.

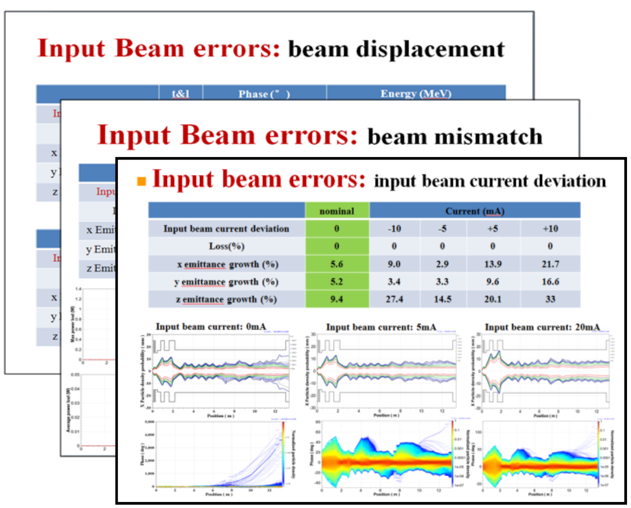
4. Error analysis

Injector-I SC section

- **Error analysis with nominal RF errors and misalignments**
- **With doubled nominal RF errors and misalignments.**
- **Error analysis with input beam 50% emittance deviation.**
- **Error analysis with input beam 100% emittance deviation.**





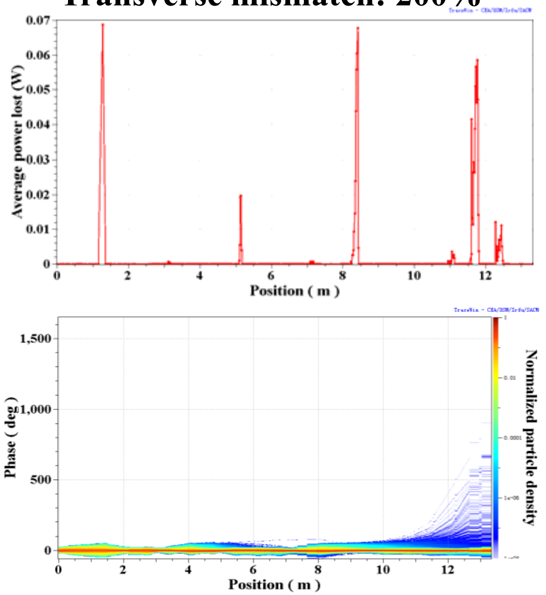


4. Error analysis

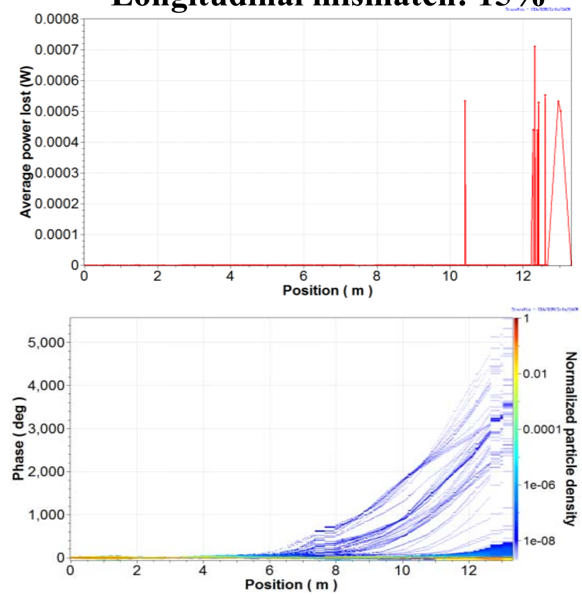
Input beam mismatches

	Nominal	Transverse (%)		Longitudinal (%)		
Input beam mismatch	0	150	200	5	10	15
Loss(%)	0	0	0.0014	0	0	8e-6
x emittance growth (%)	5.6	95.9	137	5.9	6.1	6.4
y emittamce growth (%)	5.2	144.8	219.8	5.0	5.1	5.1
z emittance growth (%)	9.4	45.5	44.3	11.1	14.1	27.2

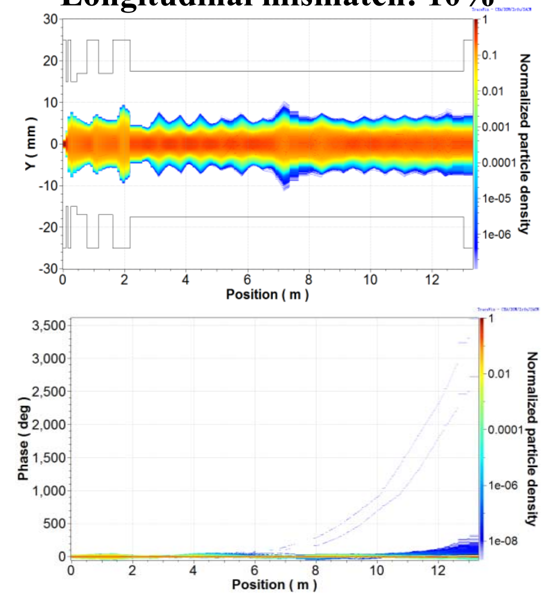
Transverse mismatch: 200%



Longitudinal mismatch: 15%



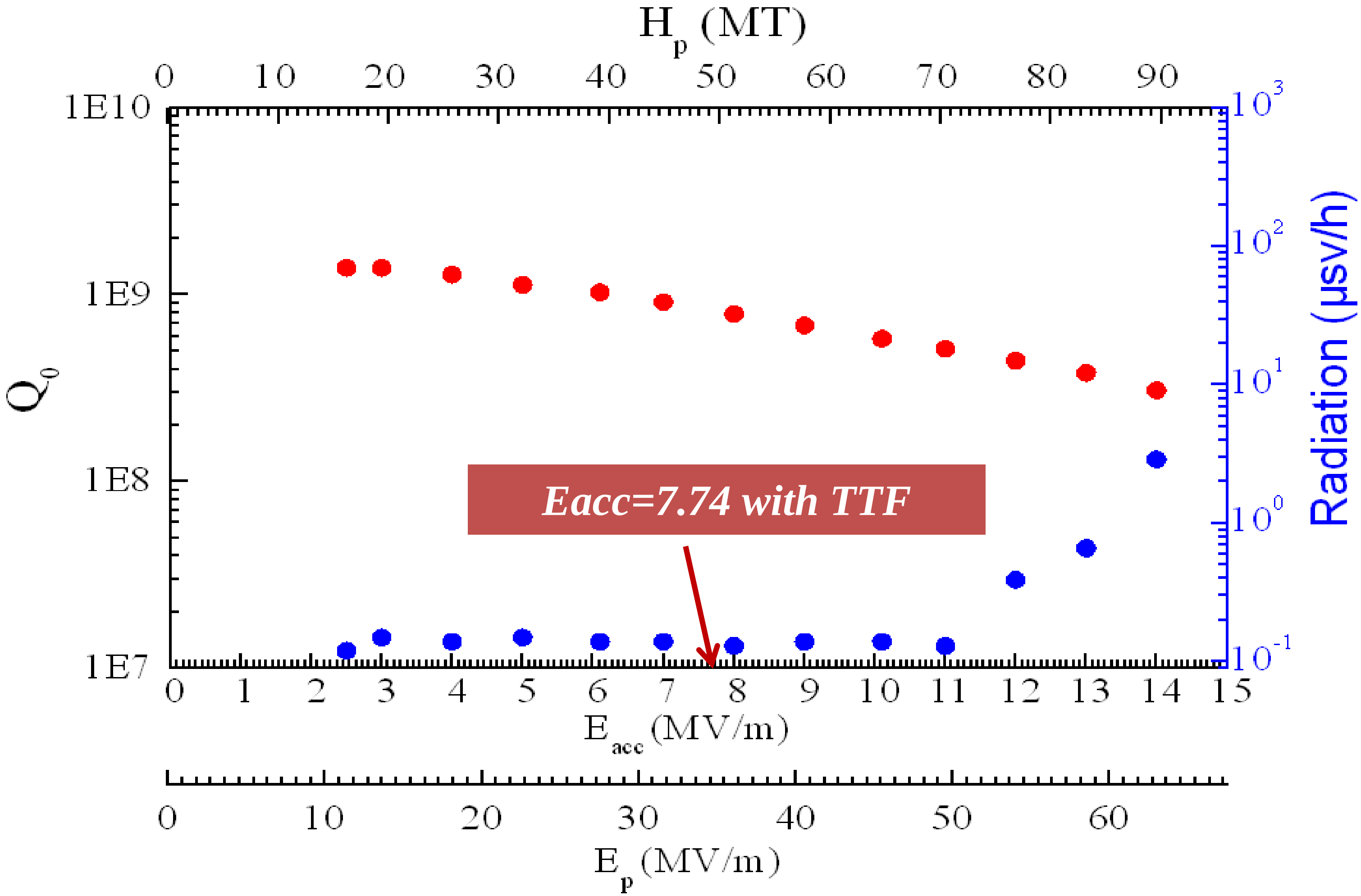
Longitudinal mismatch: 10%



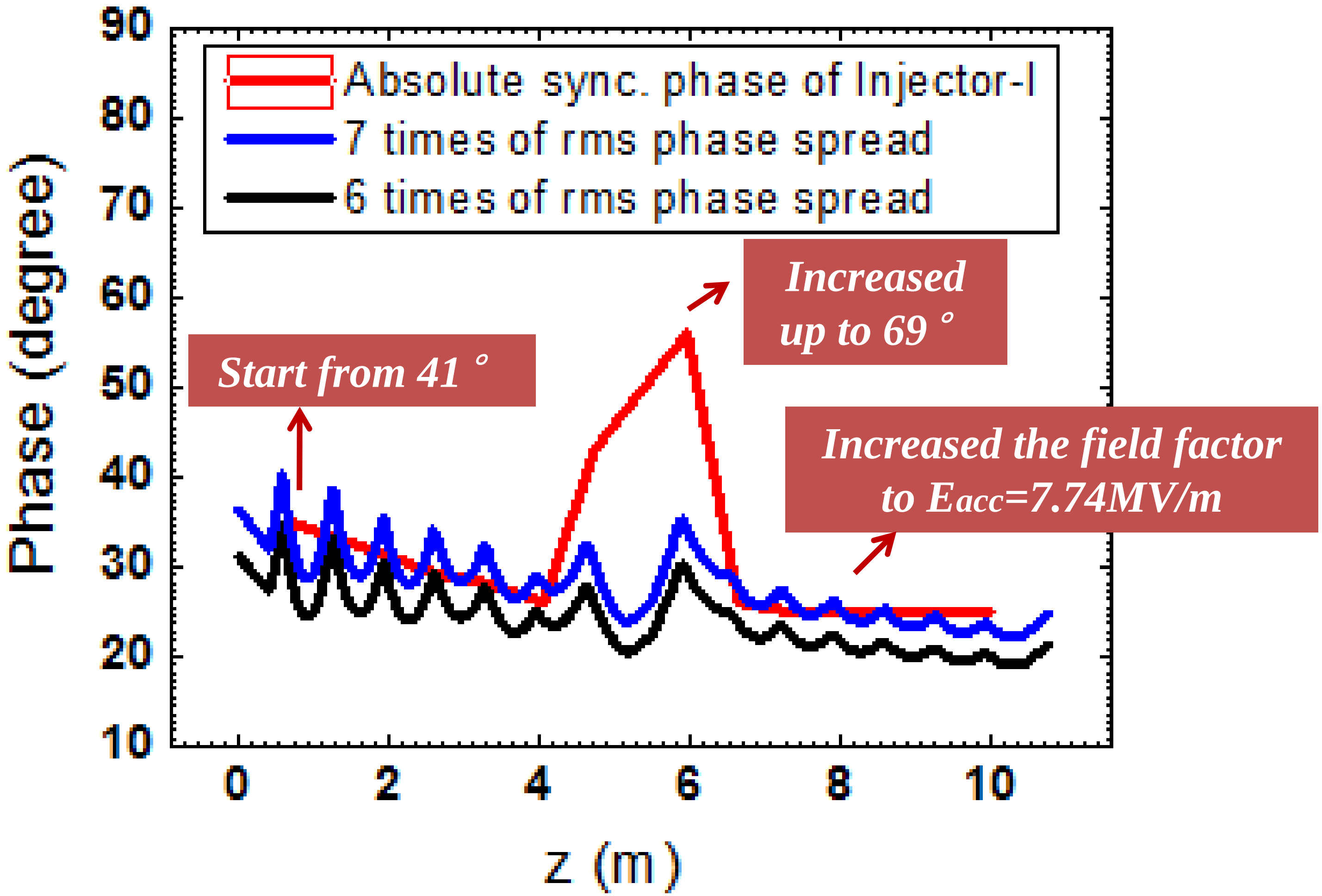
5. New injector-I design with better acceptance

Spoke012 vertical test results@20141023

Max. Eacc of 14.1MV/m（Bpeak=90.2mT、Epeak=63.5MV/m）@Q0=3.0e8

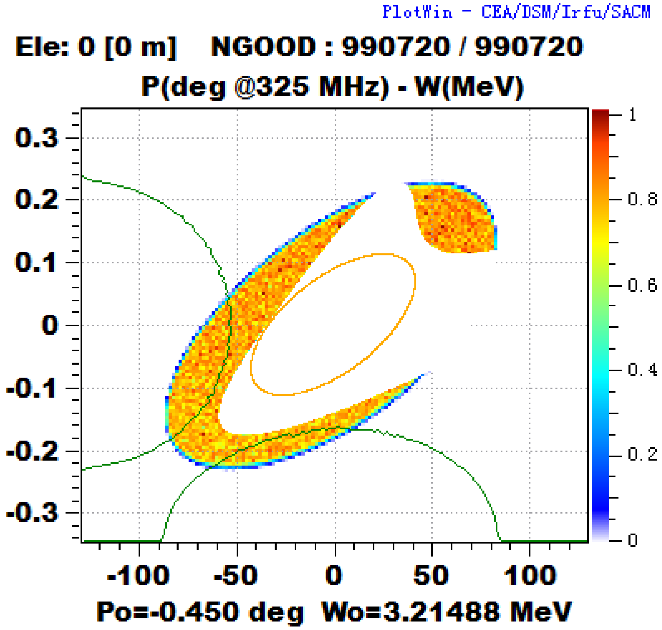


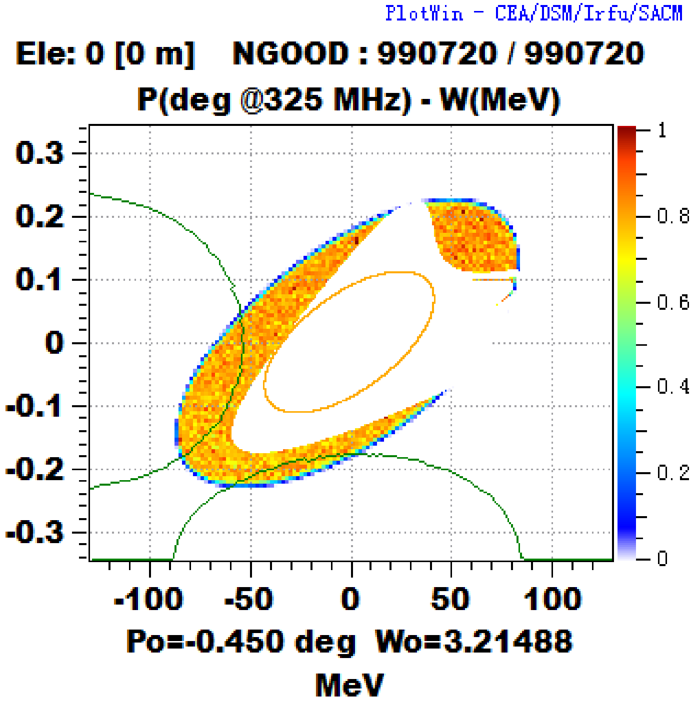
5. New injector-I design with better acceptance



➢ ***The acceptance mainly decided by the acceptance of the first CM and the first cavity sync. phase of the second CM!!***

5. New injector-I design with better acceptance





325MHz injector-I:
1st CM: 10.5 times

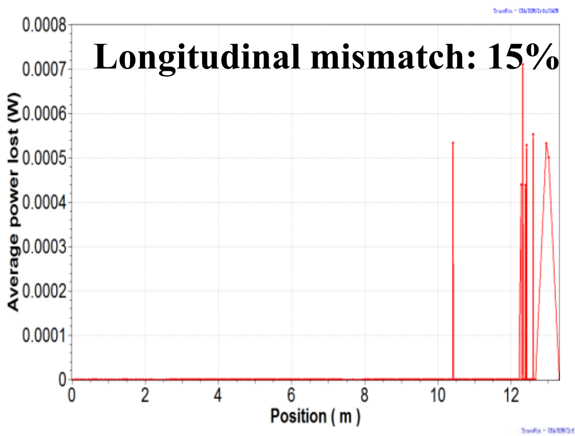
325MHz injector-I:
Two CM: 10. times

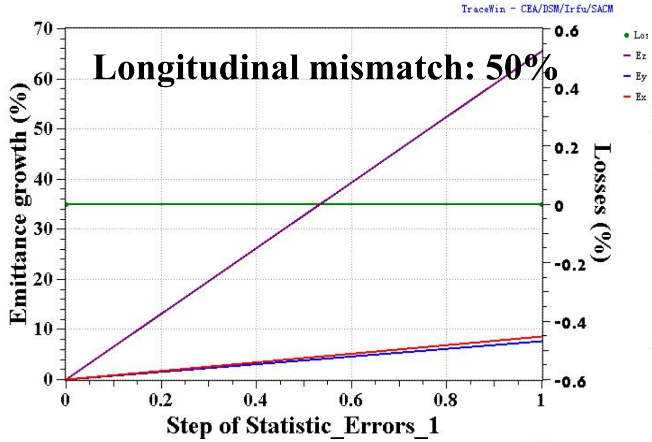
* The acceptance is calculated over the entrance emittance included 95.4% particles (Gaussian distribution)

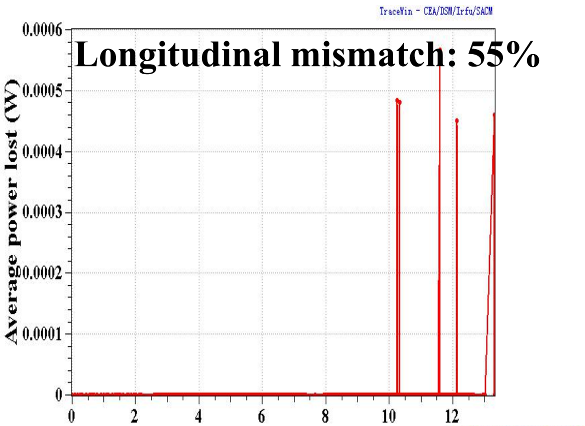
5. New injector-I design with better acceptance

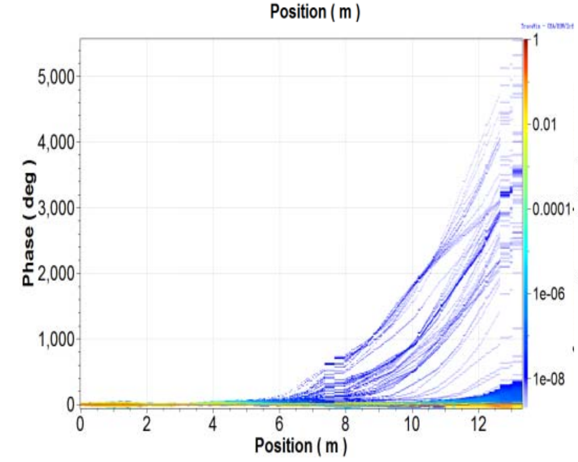
Longitudinal mismatch of the new design

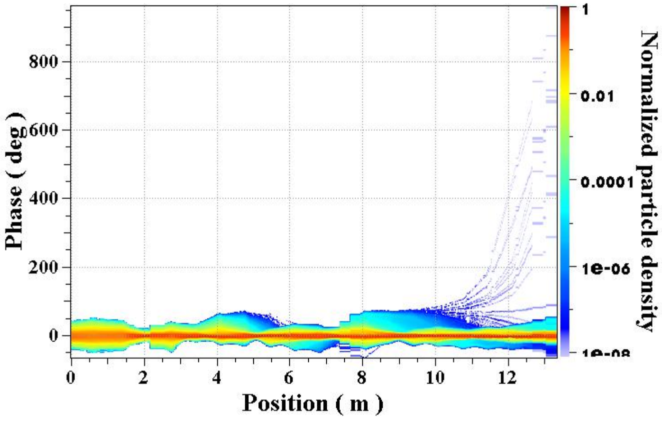
Old design	*New design*

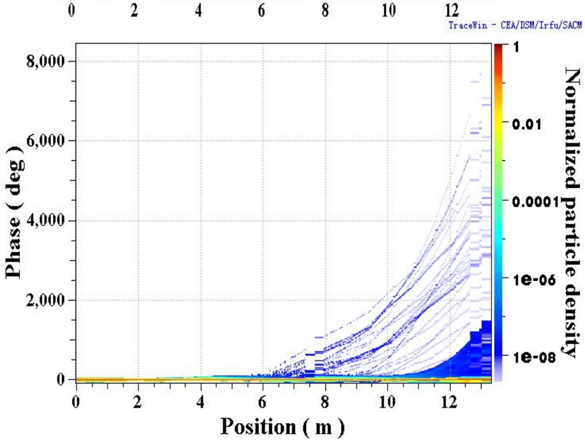






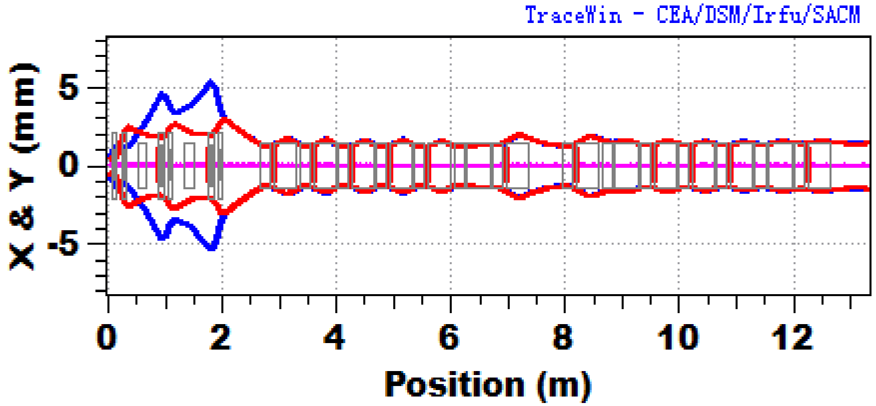


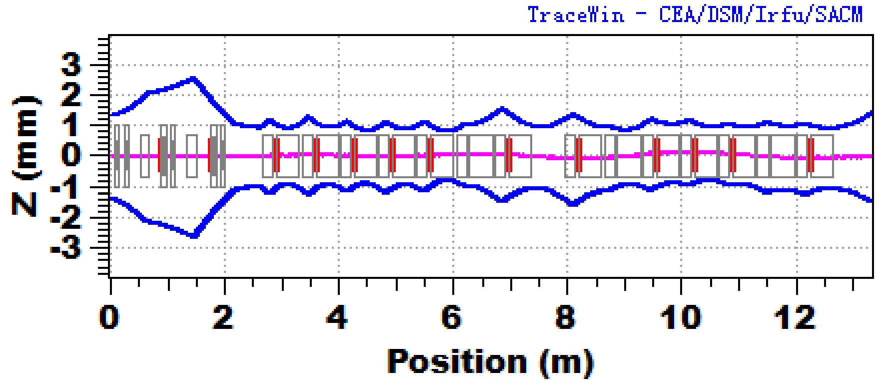




5. New injector-I design with better acceptance

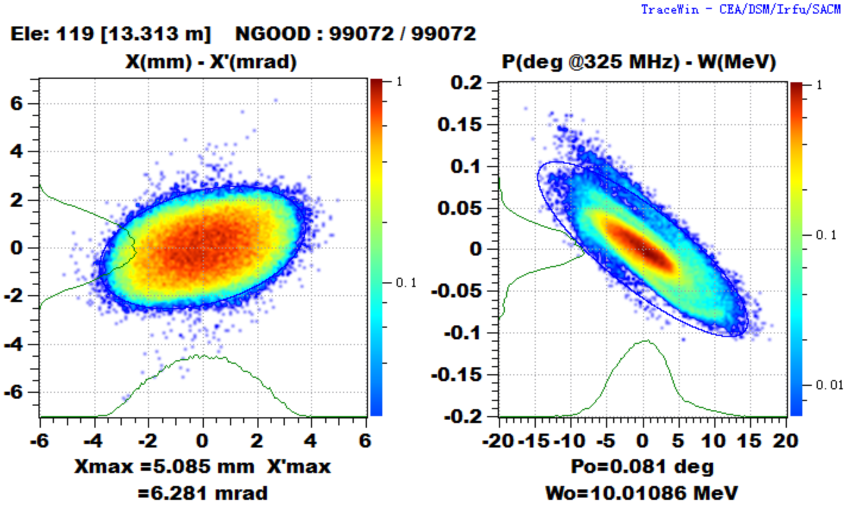
Transverse & longitudinal envelope evolution

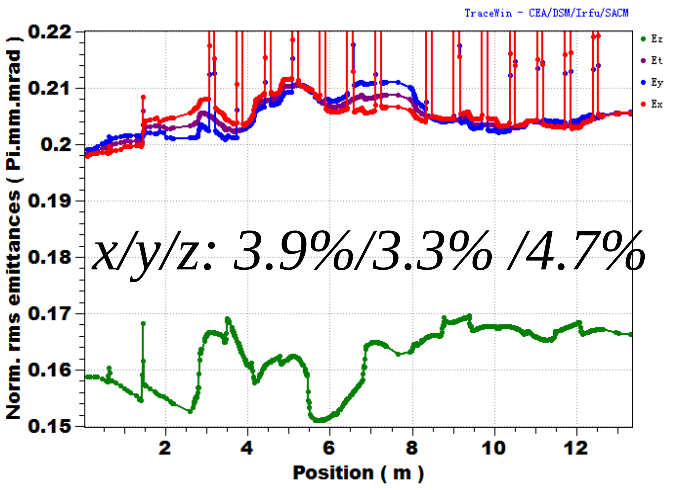




SC section exit @10 MeV

Normalized rms emittance





6. Summary

- To control the possible beam halo growth in the Injector-I SC section, several aspects are considered to get a stable design:

- ✓ Avoiding the longitudinal parametric resonances
- ✓ Avoiding the transverse structure resonances
- ✓ Avoiding the transverse and longitudinal coupling
- ✓ And design with bigger longitudinal acceptance can improve the sensitivity of the basic design.

Thanks！