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中國科學院
CHINESE ACADEMY OF SCIENCES

Beam Dynamics Design of CIADS linac

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On behalf of Linac Center

Institute of Modern Physics, CAS

Outline

- General introduction of CIADS
- Room temperature section
- Superconducting section
- High energy beam transport line
- Summary

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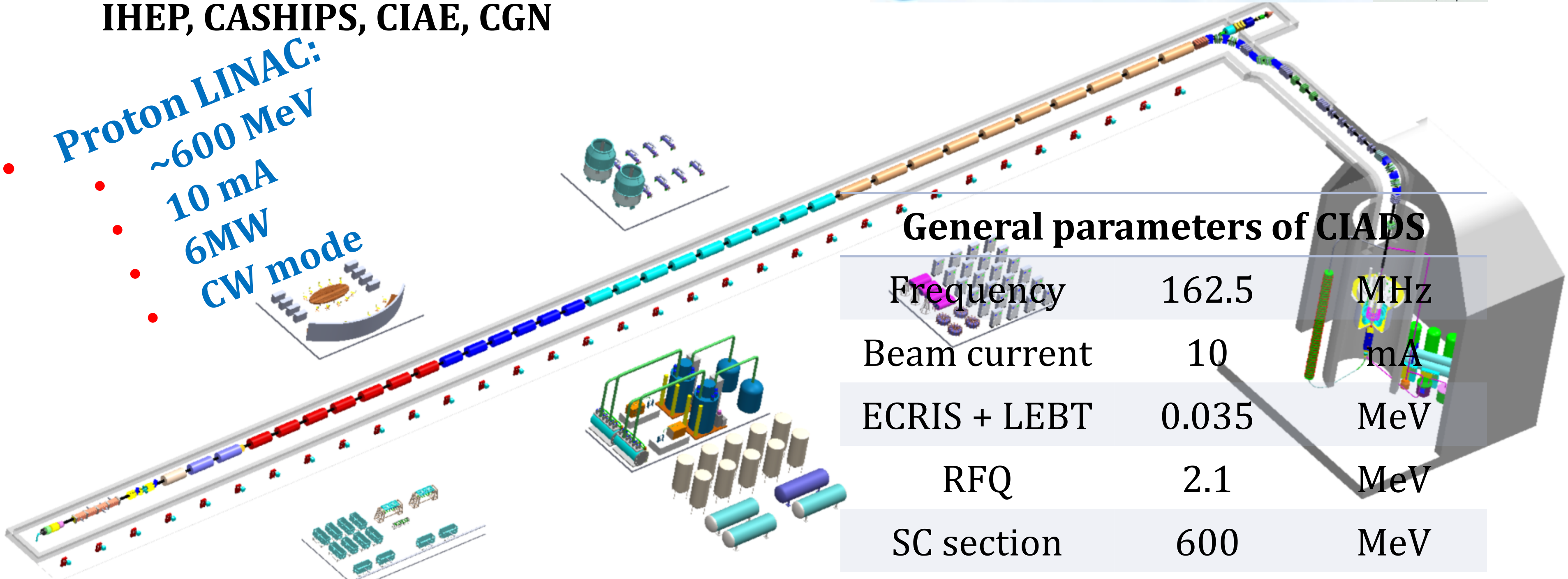
General introduction of CIADS

China Initiative Accelerator Driven System (CIADS)

- Approved in Dec. 2015, CD0
- Leading institute: IMP
- Budget: >1.8B CNY (Gov. and Corp.)
- Location: Huizhou, Guangdong Prov.
- Contribution Partners:
  IHEP, CASHIPS, CIAE, CGN



- Proton LINAC:
  - ~600 MeV
  - 10 mA
  - 6MW
  - CW mode

General parameters of CIADS

Frequency	162.5	MHz
Beam current	10	mA
ECRIS + LEBT	0.035	MeV
RFQ	2.1	MeV
SC section	600	MeV
Total length	~270	m

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Special functions of RT front end for CIADS

◆Low-Energy Beam Transport (LEBT)

① Scrape 20% or more particles to get a smaller transverse emittance

② Remove $^{2}H^{+}$ and $^{3}H^{+}$ particles to avoid them losing in RFQ cavities

③ Transport and match beam to RFQ

◆Radio-Frequency Quadrupole (RFQ)

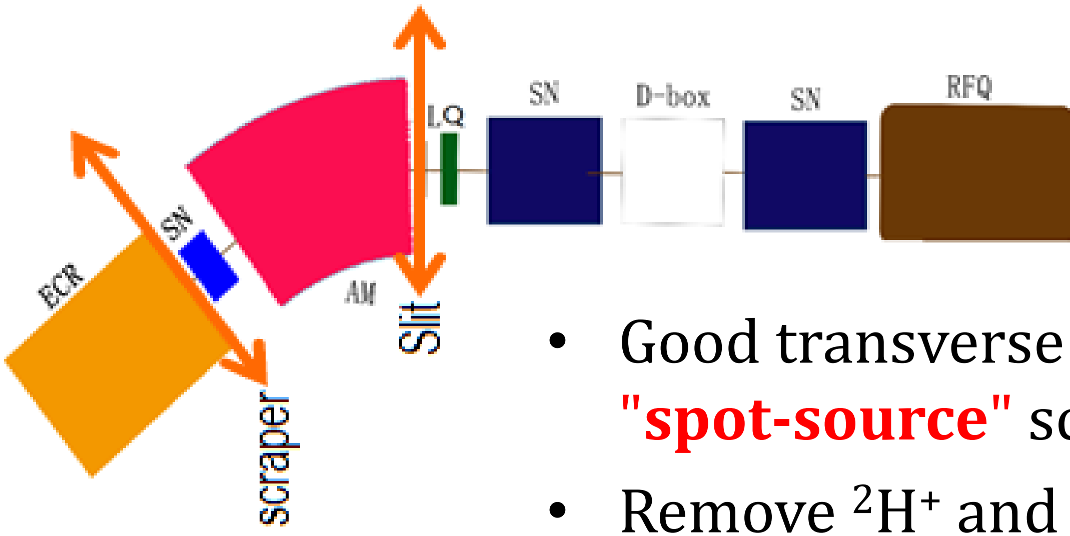
① Optimize RFQ design with a smaller longitudinal emittance (RMS & total longitudinal emittance)

◆Medium-Energy Beam Transport (MEBT)

① Measure beam parameters

② Transport and match beam to RFQ

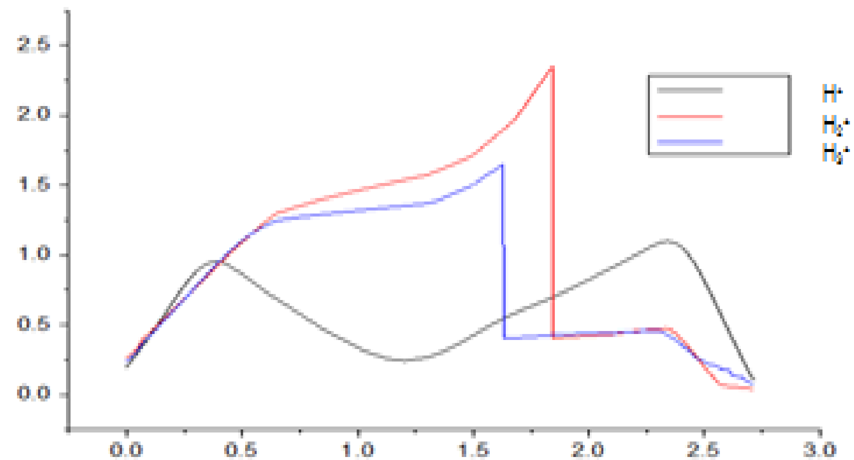
LEBT



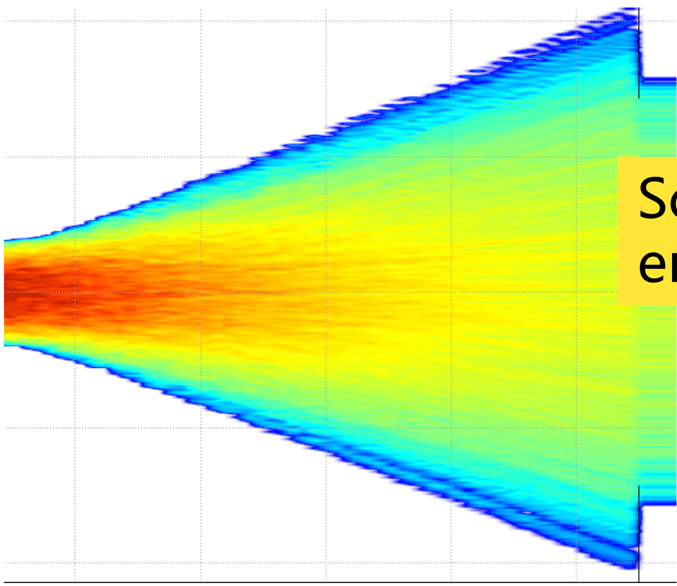
scrap the outer particles with large size and large divergence angle

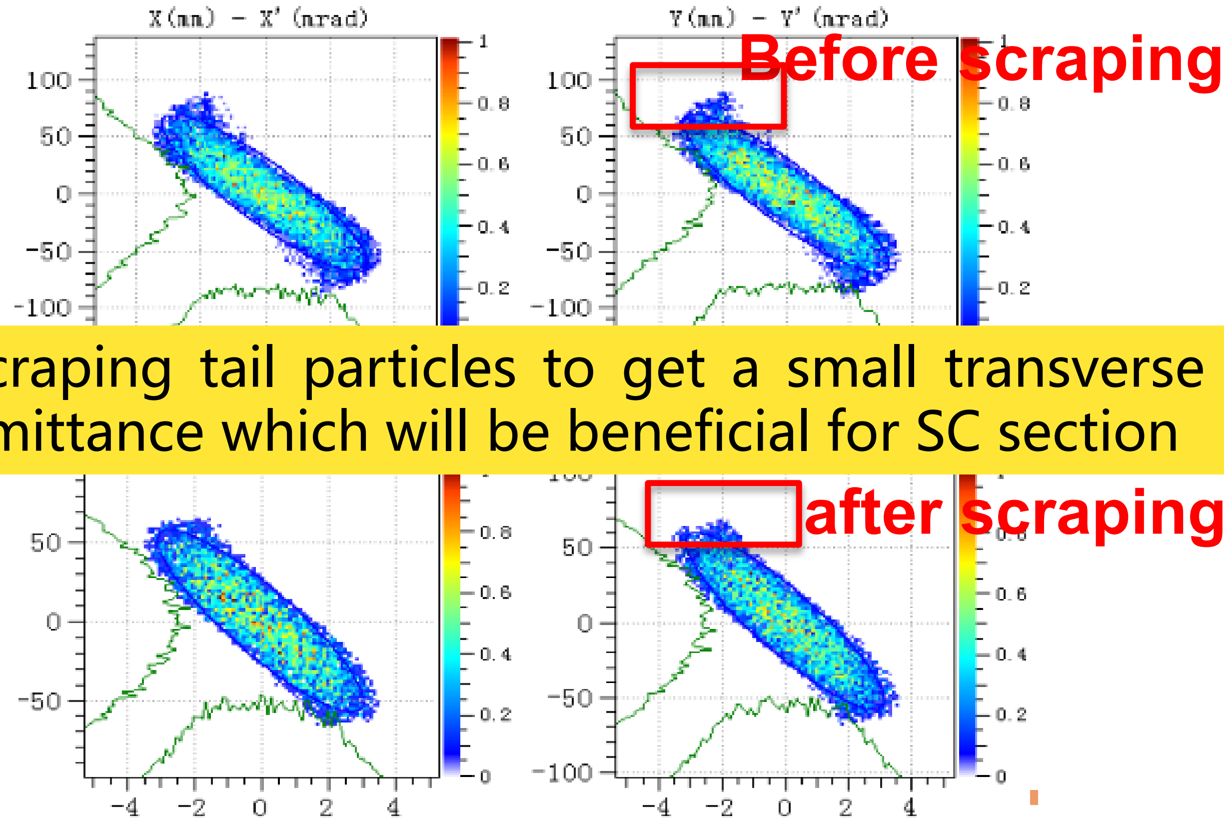
- Good transverse beam quality through **"spot-source"** scraping
- Remove $^{2}H^{+}$ and $^{3}H^{+}$ by bending magnet in case of losing in RFQ

Ions	H^{+}
Energy (keV)	35
Beam current (mA)	15
Emittance $^{rms\_norm.}$ (pi.mm.mrad)	0.186



Spot-source scraping

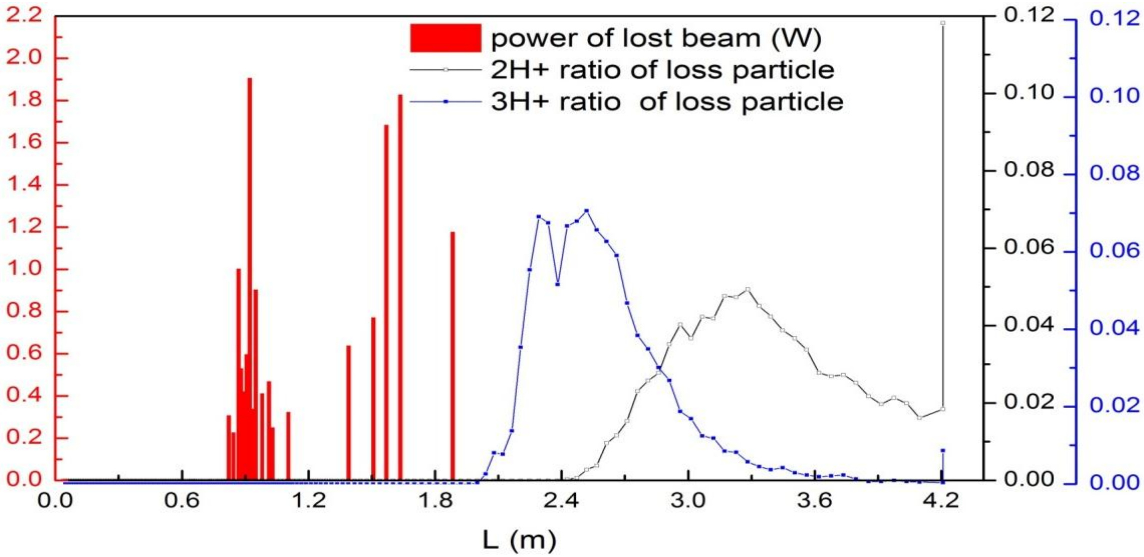


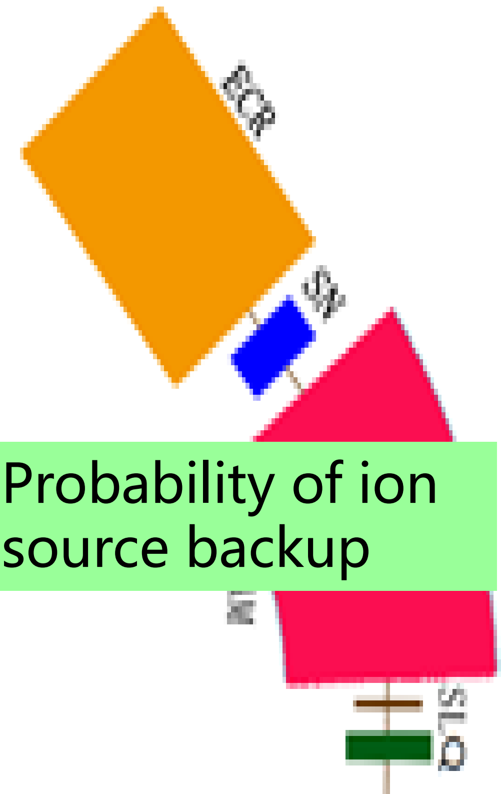


Scraping tail particles to get a small transverse emittance which will be beneficial for SC section

	Alaph x	Beta x	Alaph y	Betay	rms emit_x	rms emit_y	100% emit_x	100% emit_y
Before scraping	1.9282	0.1009	1.9895	0.1043	0.2176	0.2199	3.4215	3.0929
After scraping	1.9168	0.1146	1.9932	0.1186	0.1772	0.1787	1.6357	1.6978

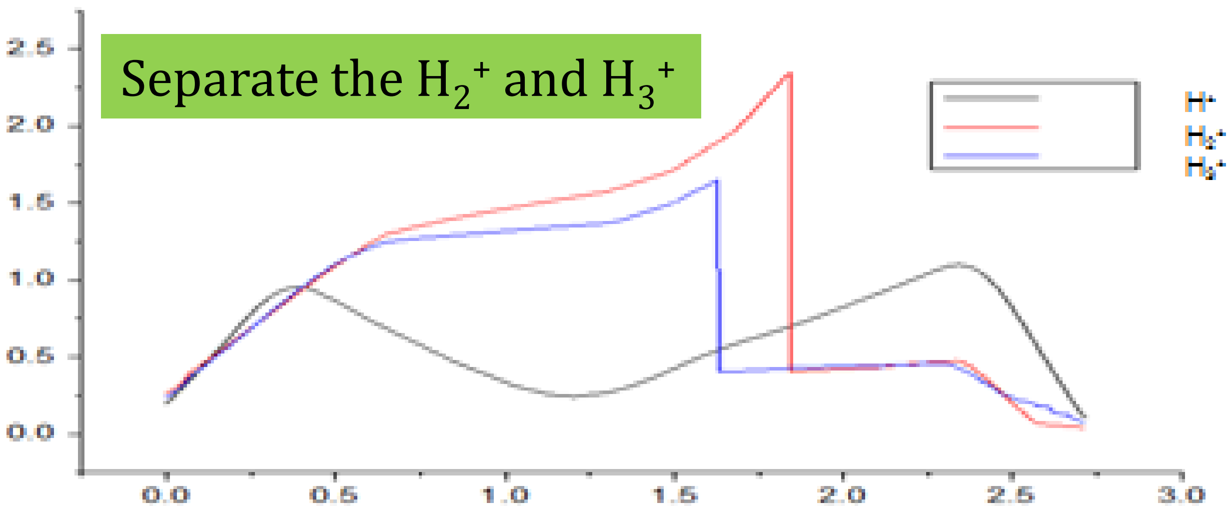
LEBT





Probability of ion source backup

Separate the H_2^+ and H_3^+



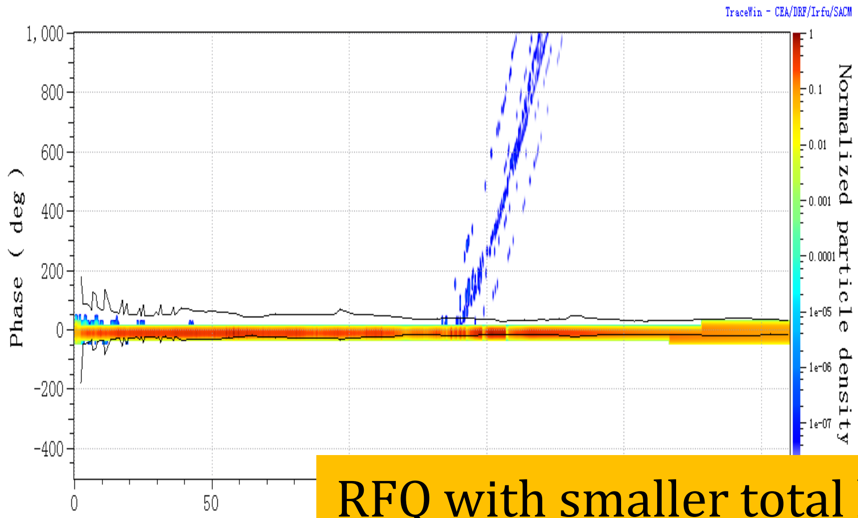
20°bend+6.3°edge angle to eliminate the asymmetric effect

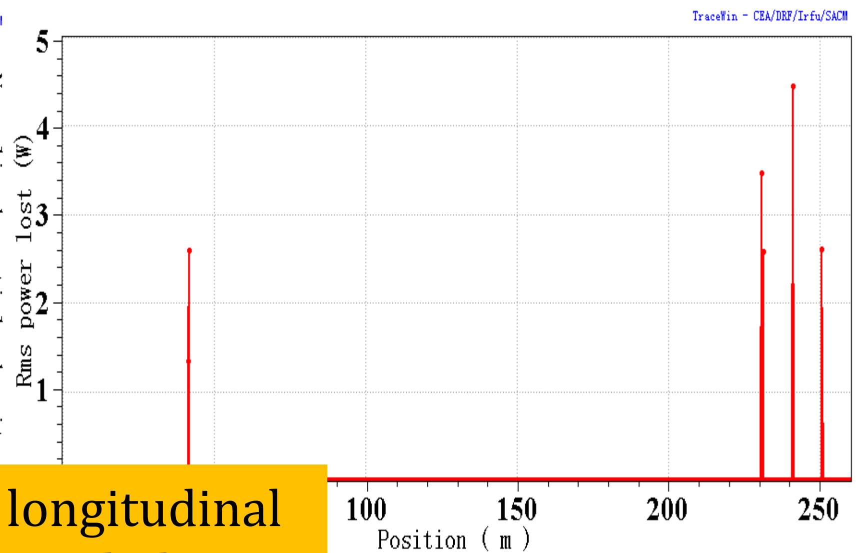
RFQ

Parameters	RFQ for injectorII	RFQ2
Inter-vane voltage(kV)	65	70
KP factor	1.2	1.32
Min.aperture(mm)	3.2	3.33
Modulation	1-2.38	1-2.19
Syn.Phase(deg)	-90 ~ -22.7	-90 ~ -25
Long.Emittance_rms(keV ns)	**0.0534**	**0.0506**
Long.Emittance_max(keV ns)	**2.4267**	**1.9156**
Lcavity/Lelectrode(cm)	420.8/419.2	450
Transmission(%)	99.6	99.4
Cell number	192	247

RFQ

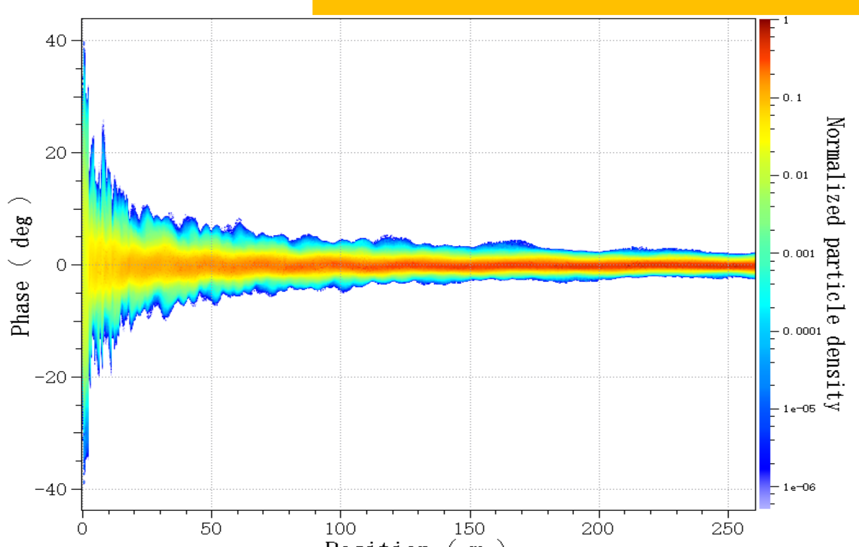
RFQ for injcetorII

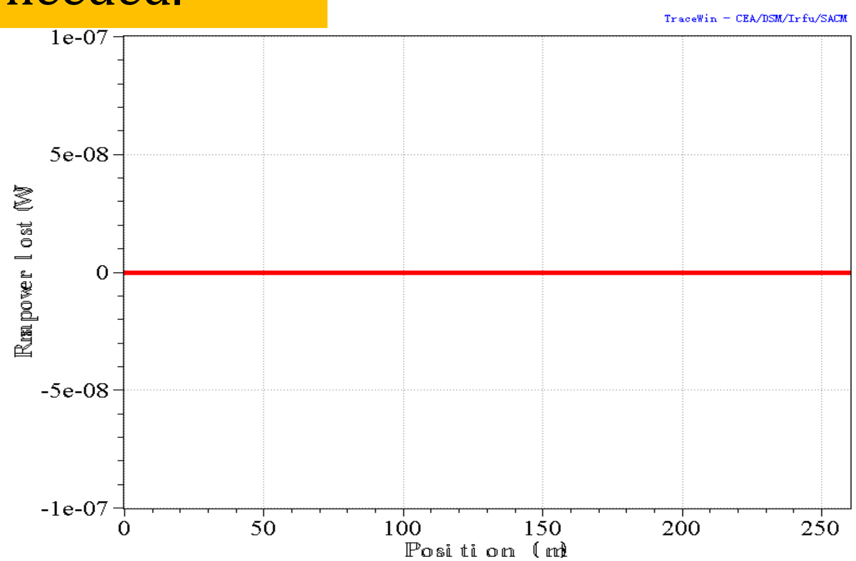




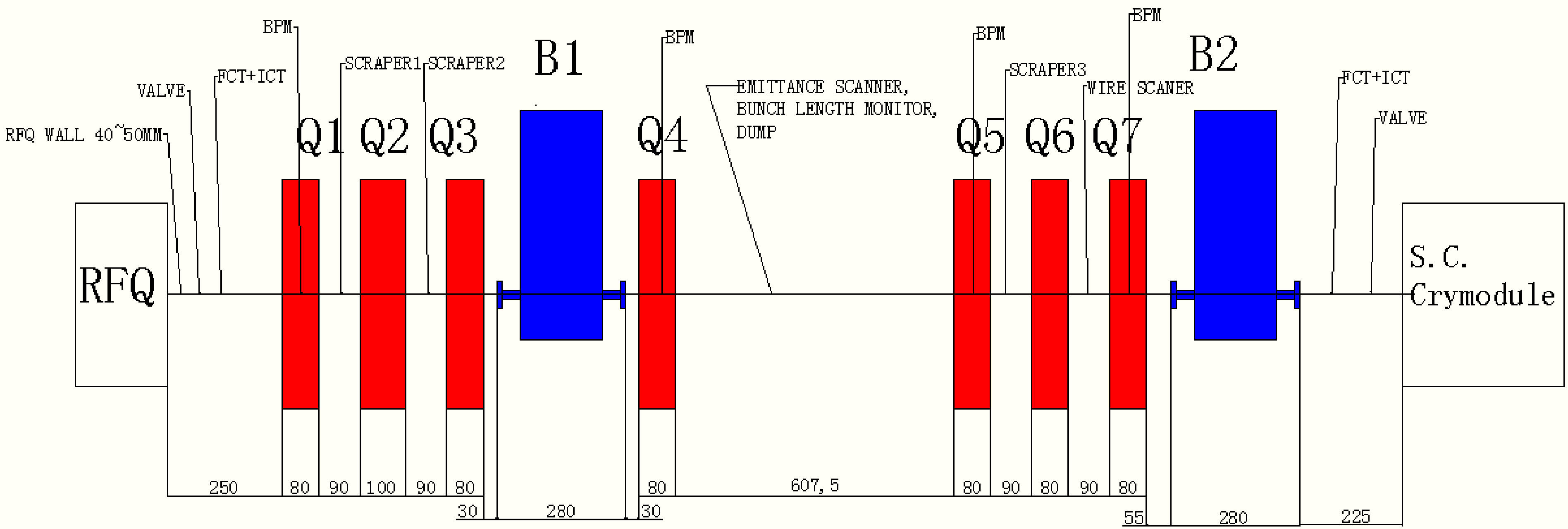
RFQ with smaller total longitudinal emittance for CIADS is needed.

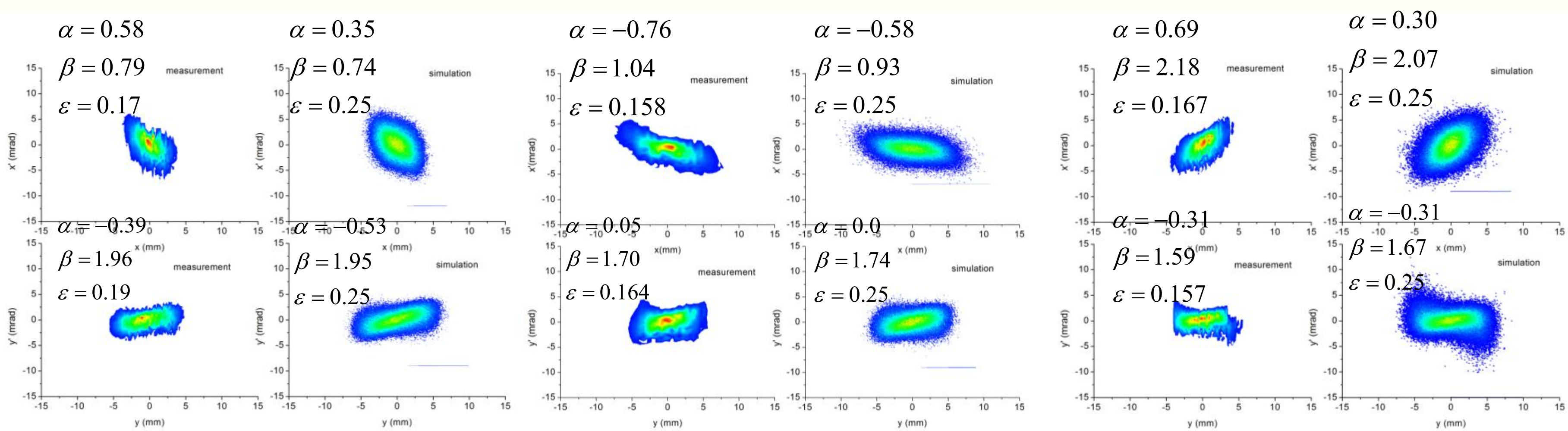
RFQ 2





MEBT


RFQ WALL 40~50MM
VALVE
FCT+ICT
BPM
SCRAPER1
SCRAPER2
B1
BPM
EMITTANCE SCANNER,
BUNCH LENGTH MONITOR,
DUMP
BPM
SCRAPER3
WIRE SCANER
BPM
B2
FCT+ICT
VALVE
RFQ
Q1 Q2 Q3
Q4
Q5 Q6 Q7
S.C. Crymodule
250
80
90
100
90
80
30
280
80
30
607,5
80
90
80
90
80
55
280
225


$\alpha = 0.58$
$\beta = 0.79$
$\varepsilon = 0.17$
measurement
$\alpha = 0.35$
$\beta = 0.74$
$\varepsilon = 0.25$
simulation
$\alpha = -0.76$
$\beta = 1.04$
$\varepsilon = 0.158$
measurement
$\alpha = -0.58$
$\beta = 0.93$
$\varepsilon = 0.25$
simulation
$\alpha = 0.69$
$\beta = 2.18$
$\varepsilon = 0.167$
measurement
$\alpha = 0.30$
$\beta = 2.07$
$\varepsilon = 0.25$
simulation
$\alpha = -0.39$
$\beta = 1.96$
$\varepsilon = 0.19$
measurement
$\alpha = -0.53$
$\beta = 1.95$
$\varepsilon = 0.25$
simulation
$\alpha = 0.05$
$\beta = 1.70$
$\varepsilon = 0.164$
measurement
$\alpha = 0.0$
$\beta = 1.74$
$\varepsilon = 0.25$
simulation
$\alpha = -0.31$
$\beta = 1.59$
$\varepsilon = 0.157$
measurement
$\alpha = -0.31$
$\beta = 1.67$
$\varepsilon = 0.25$
simulation
x (mm)
x' (mrad)
y (mm)
y' (mrad)

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Superconducting section

General parameters

1、 Less SC cavity family
2、 High acceleration efficiency
3、 High power utilization

Lattice design

1、 Phase advance per meter continuous and smooth
2、 Keep envelope smooth
3、 Less than 90° of zero-current period phase advance to avoid envelope instability and resonance crossing with space charge
4、 Period phase advance of every segment begin with value near 90° to improve accelerating efficiency
5、 Optimize frequency transitions and cavity types for smooth beam matching along the linac

Multiparticle simulation

Minimize the emittance growth

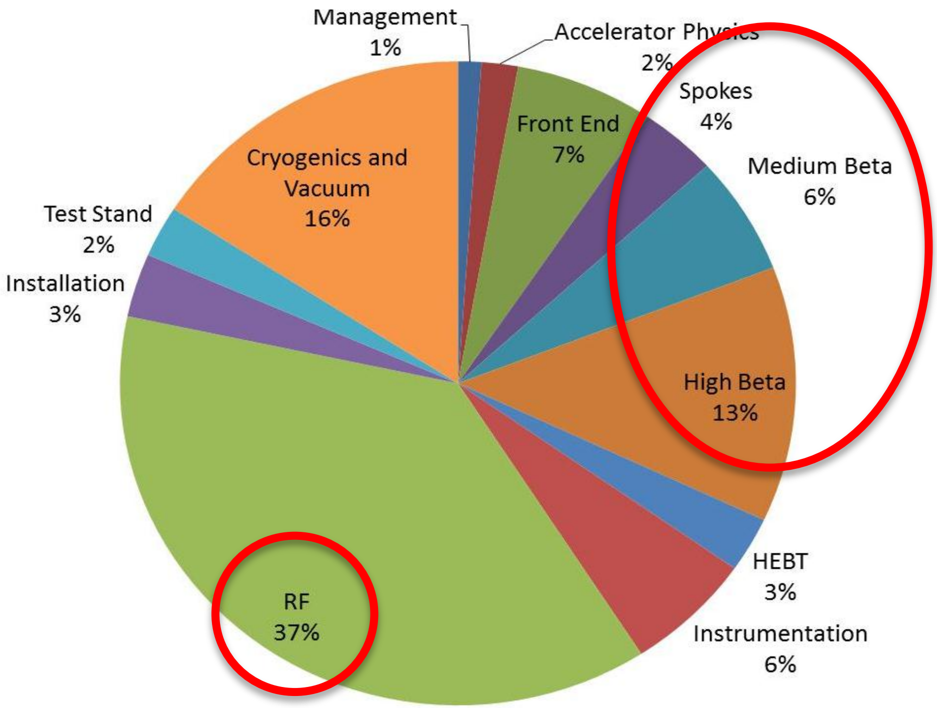
Avoiding beam lost

Error analysis

Test lattice structure robustness

General parameters

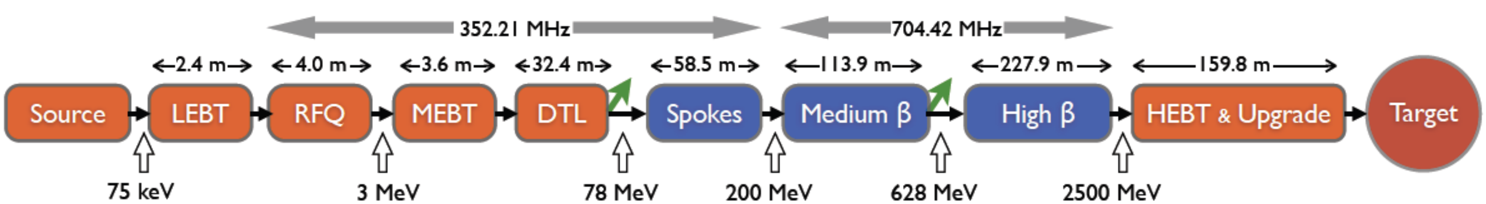
ESS Costing Report 2012



- Design Features
  - 2.5 GeV, 50mA, 2.86 mS, 14 Hz (pulse 4%)
  - 98% superconducting
  - Superconducting linac at 352 & 704 MHz

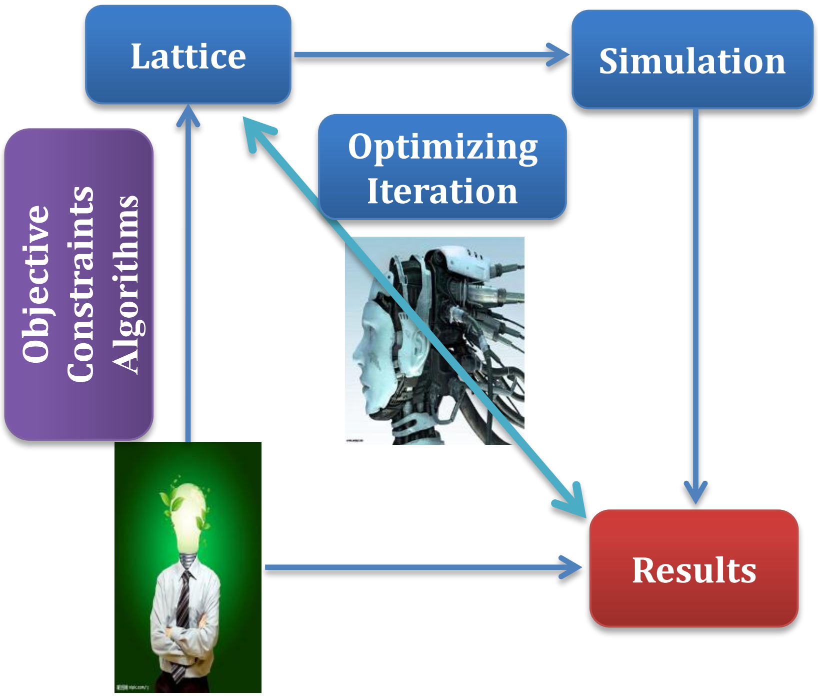
Cavity + Power = 60%

FDSL_2012_10_02



David McGinnis, ESS Design Options, 4 March 2013

General parameters



Cavity Family			
Cavity Type	HWR	Spoke	Ellip
Frequency(MHz)	162.5	325	650
Gap Number	2	3	5
Epeak(MV/m)	25/32	32	35

Variable:

Geometric beta

Algorithm:

Particle Swarm Optimization

Constraints：

Input energy: 2.1 MeV

Output energy: 1.5 GeV

TTF continuous

Energy gain continuous

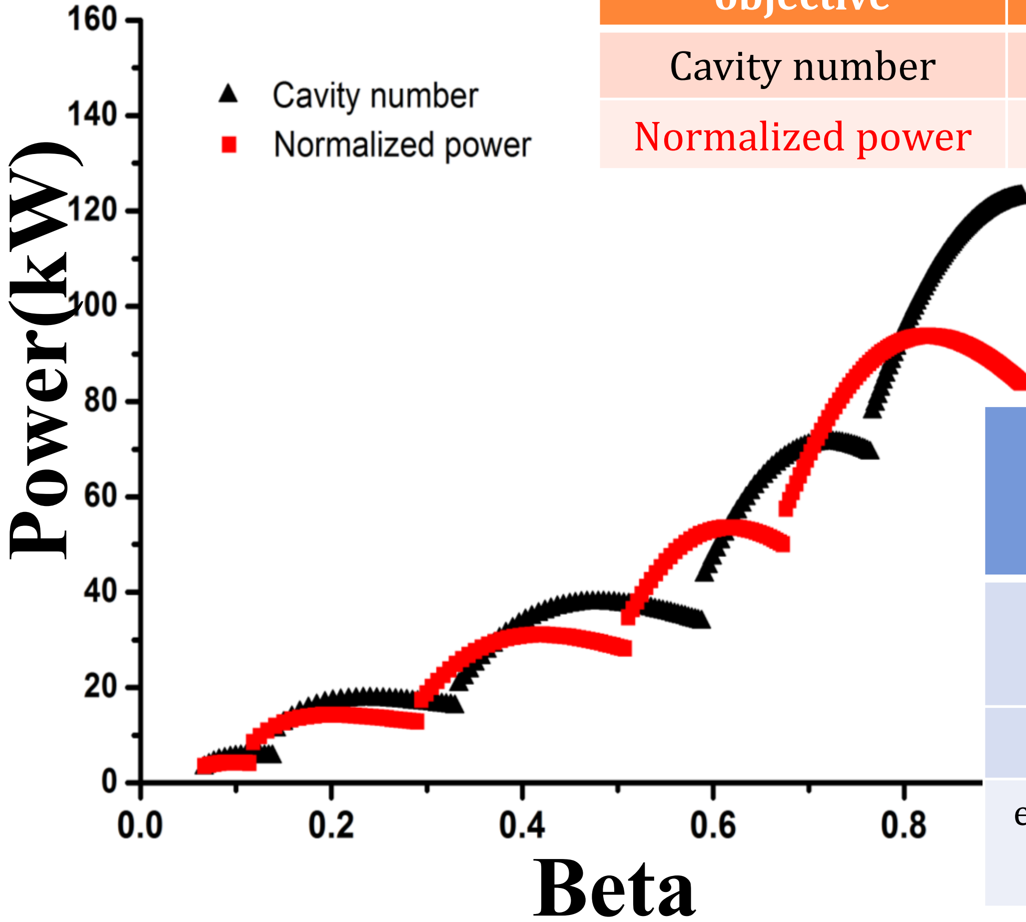
Objective：

Cavity number

Normalized power

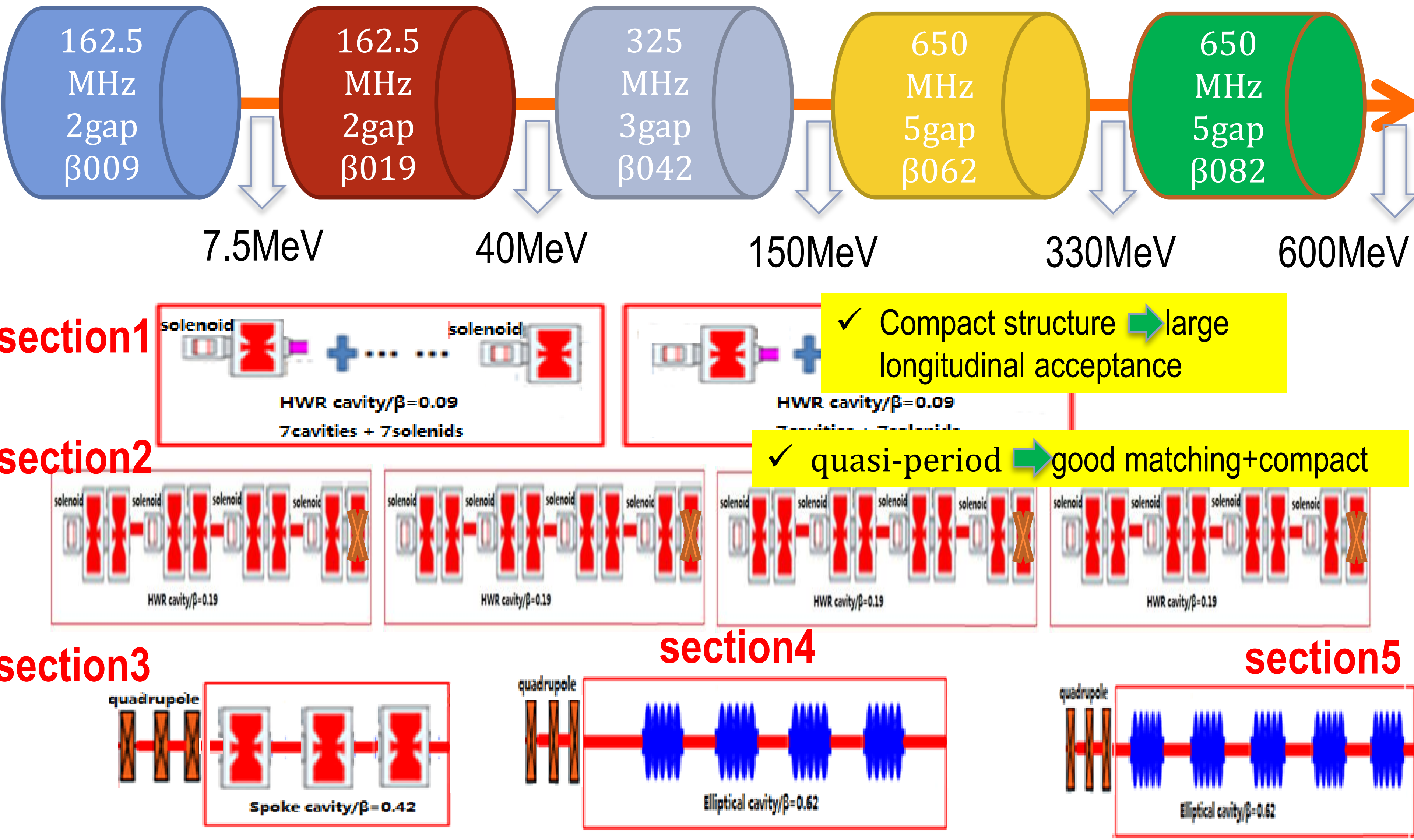
General parameters

Optimization objective	Cavity number	Max power_single cavity (kW)
Cavity number	227	134
Normalized power	249	94



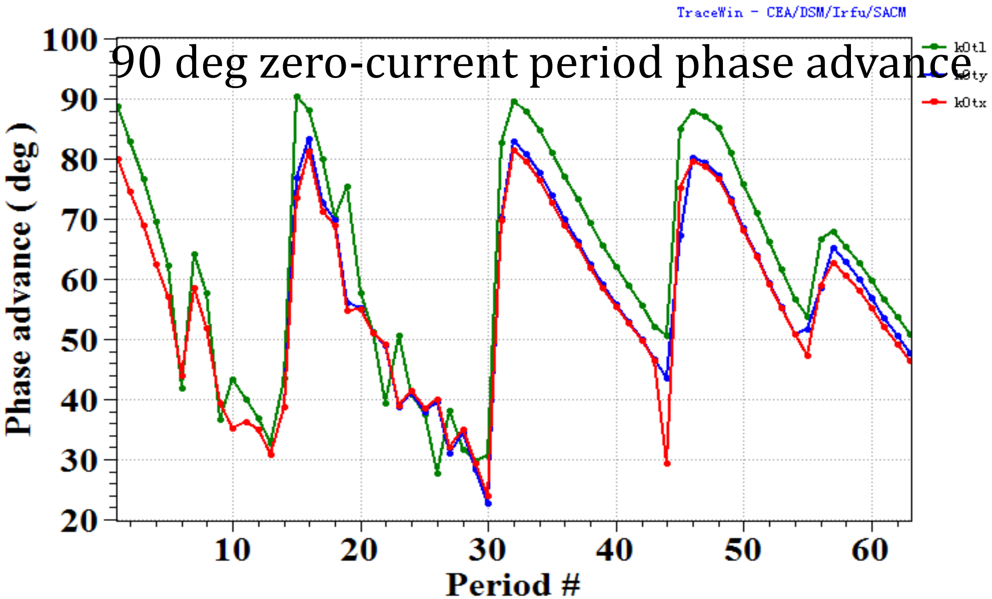
Cavity type	β	Freq (MHz)	Epeak (MV/m)	Epeak_Operation (MV/m)	NO. cavity
HWR	0.09	162.5	25	**18.75**	14
	0.19	162.5	32	**24**	28
Spoke	0.42	325	32	**24**	42
elliptical	0.62	650	35	**26.25**	44
	0.82	650	35	**26.25**	40

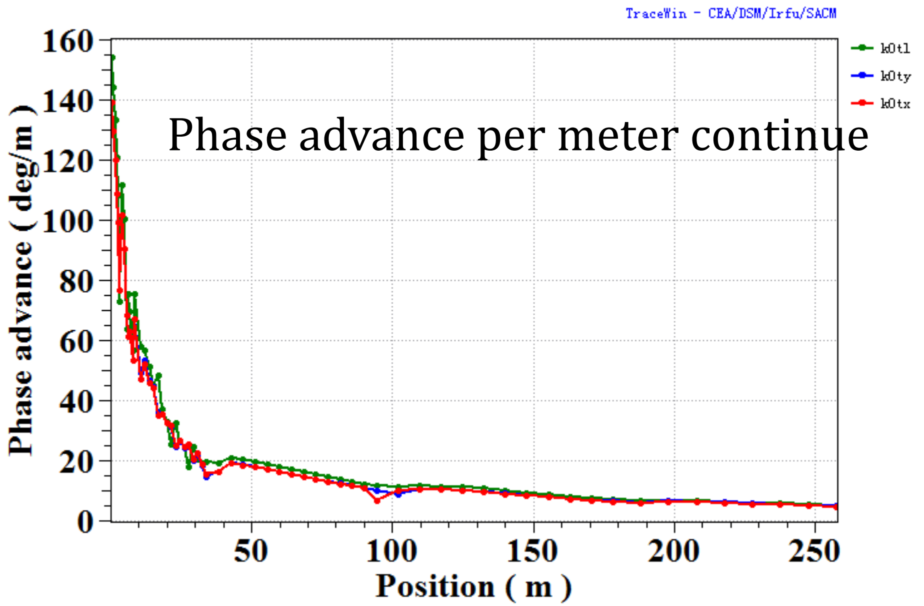
Lattice design

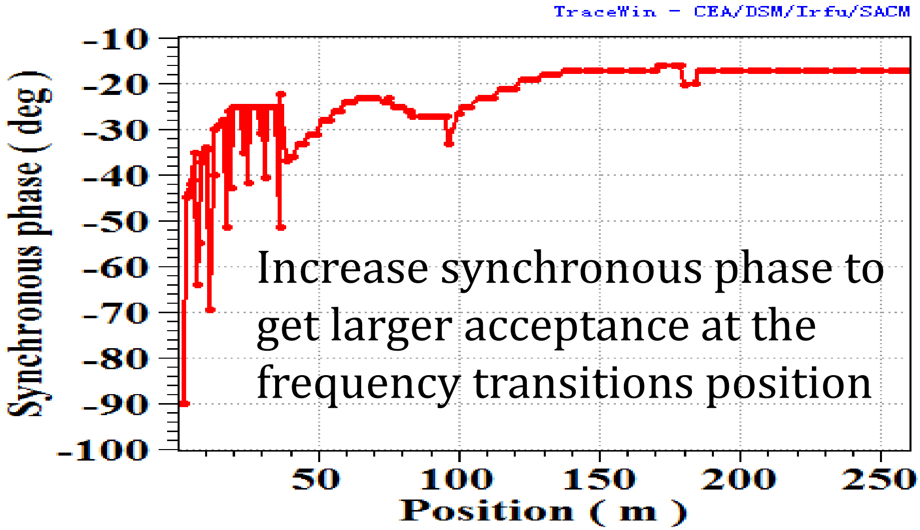


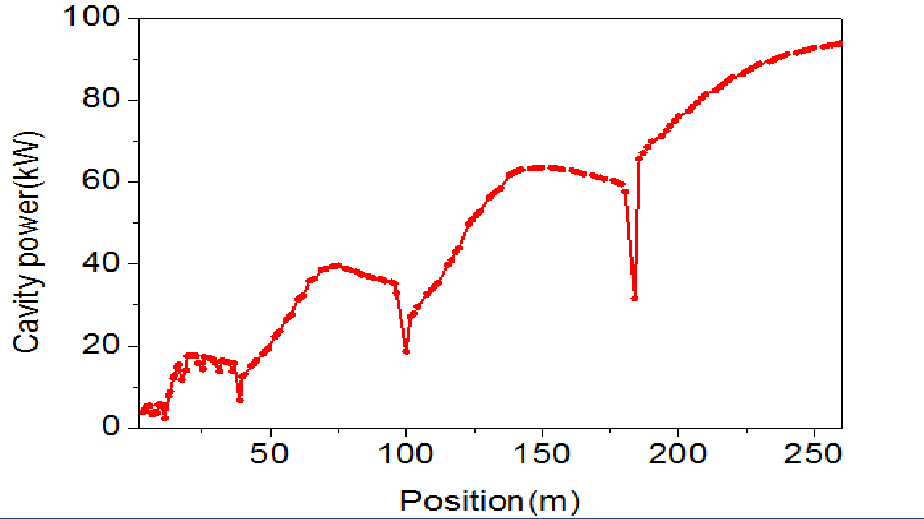
- ✓ Compact structure → large longitudinal acceptance
- ✓ quasi-period → good matching+compact

Lattice design

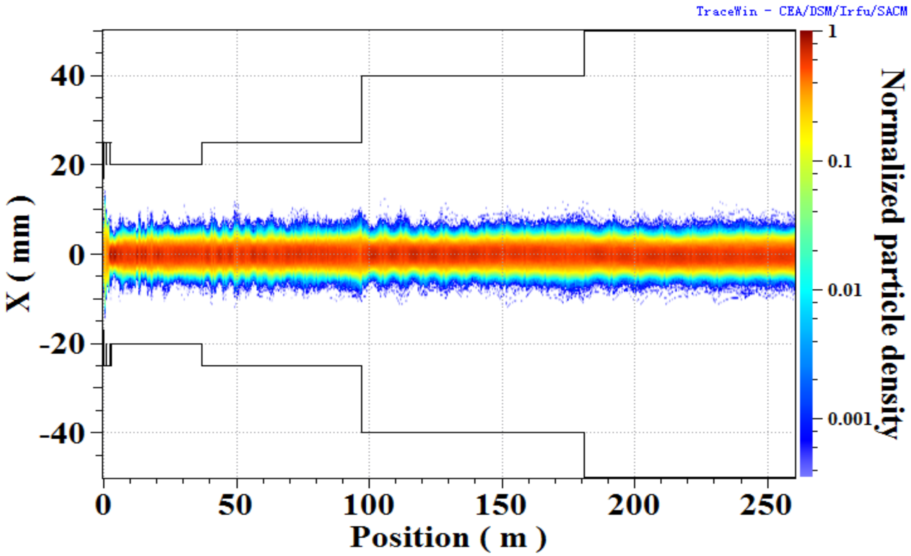


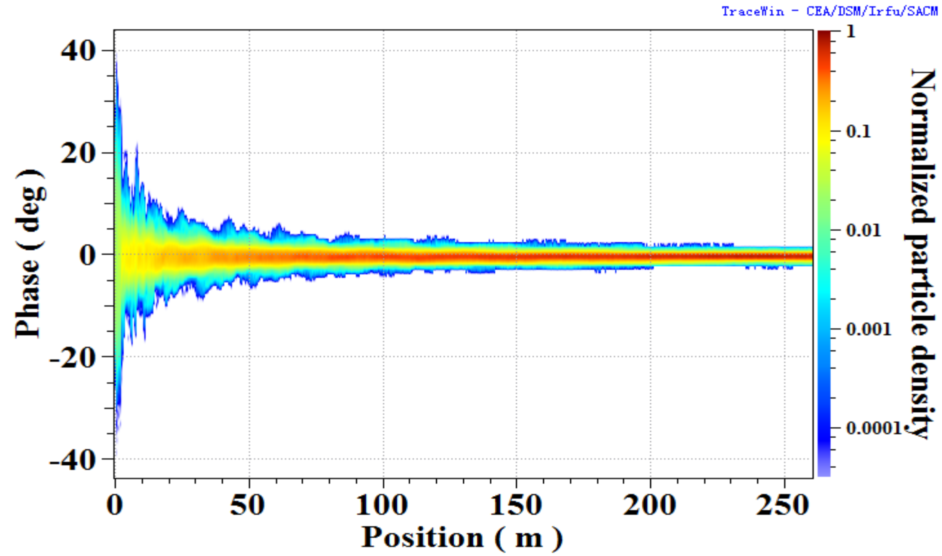


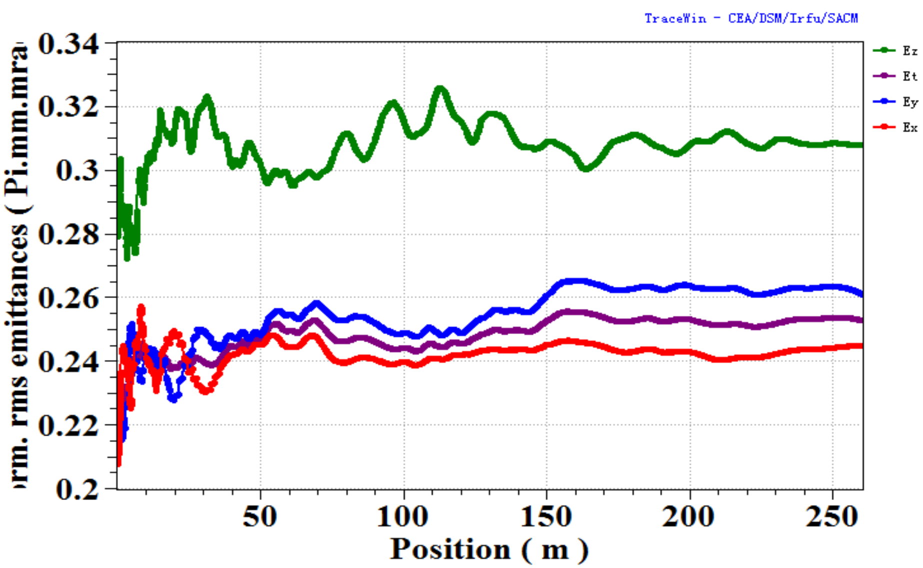


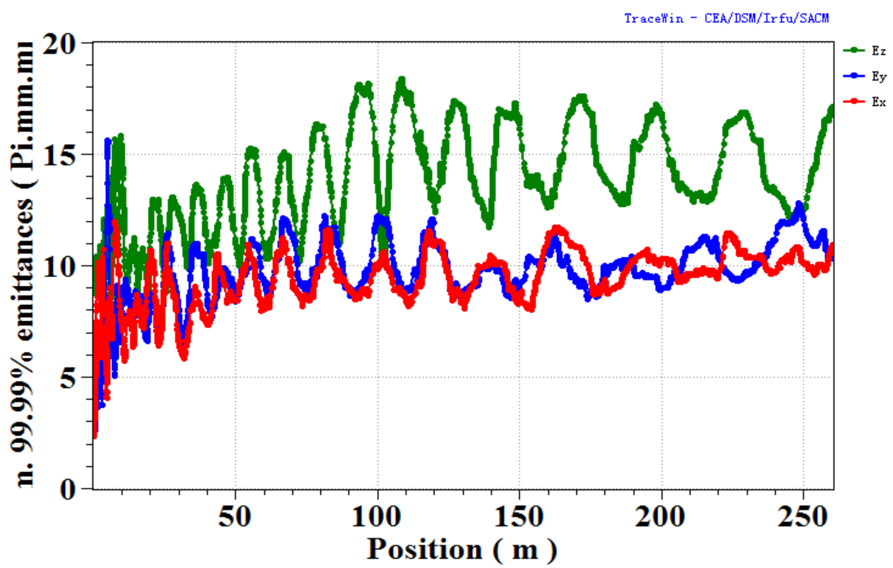


Multiparticle simulation







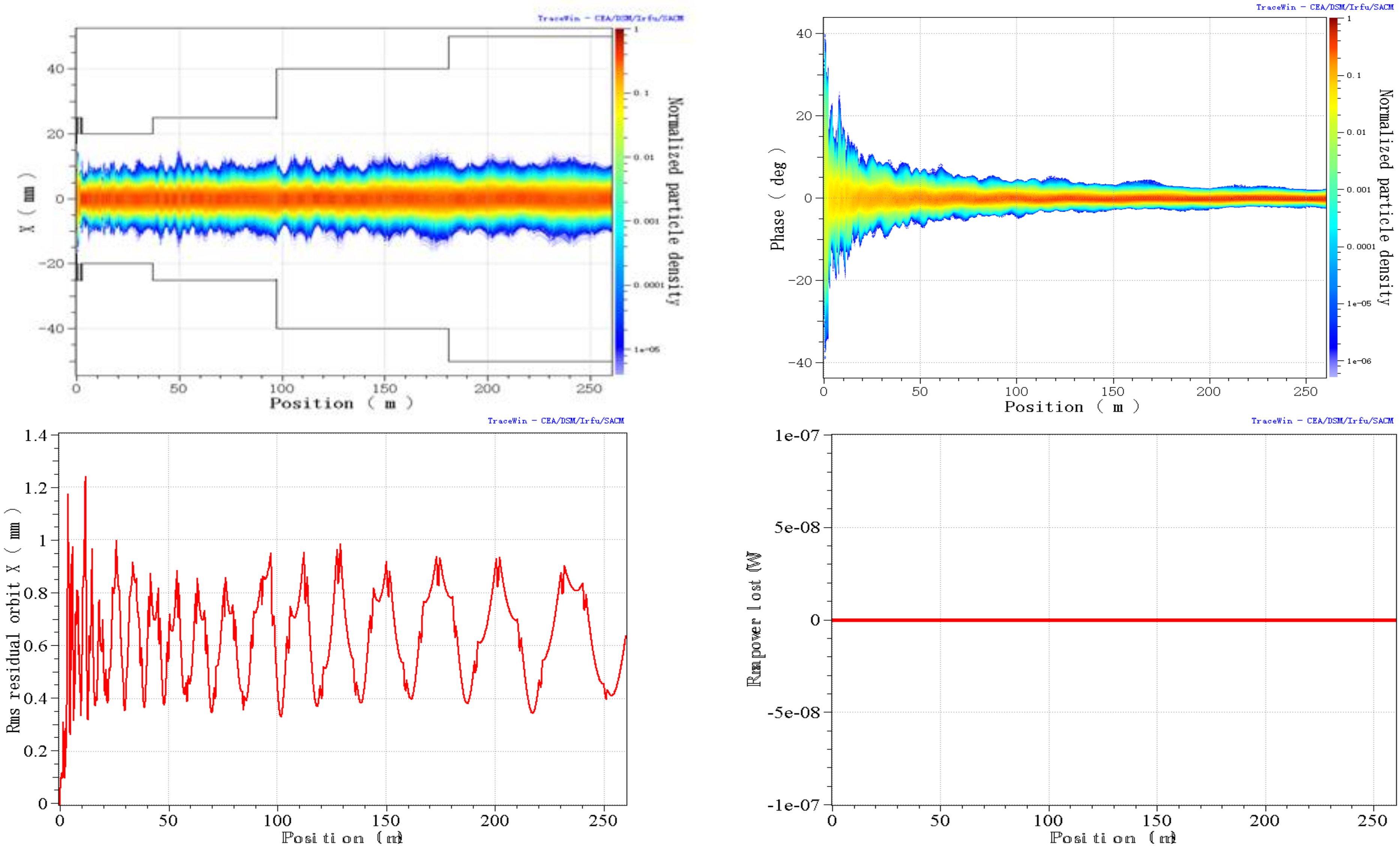


Error analysis

- TraceWin code is used for error analysis;
- End to end simulation including MEBT and SC section using RFQ simulated output distribution;
- 3d cavity fields are used in the multi-particle simulations;
- 100seeds are generated randomly for the error analysis

Error type	Static (buncher/cavity)	Dynamic (buncher/cavity)	Static (Q/solenoid)	Dynamic (Q/solenoid)
δx (mm)	0.1/1	0.002/0.01	0.1/1	0.002/0.01
δy (mm)	0.1/1	0.002/0.01	0.1/1	0.002/0.01
Rx (mrad)	2	0.02	2	0.02
Ry (mrad)	2	0.02	2	0.02
Rz (mrad)	×	×	2	0.02
δg (%)	0.5	0.25	0.5	0.05
δφ (°)	0.5	0.05	×	×
δz (mm)	0	0	0	0

Error analysis



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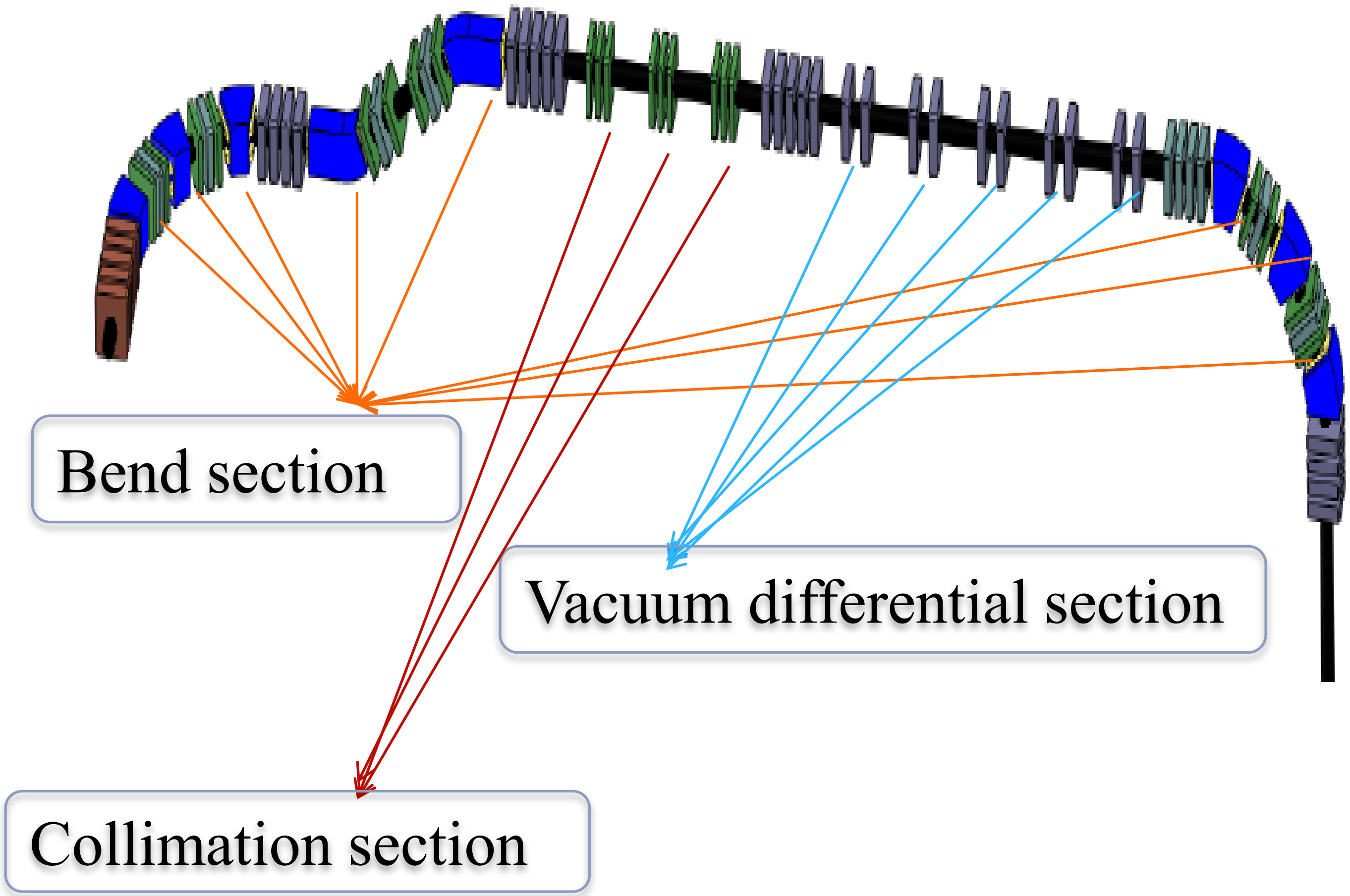
High energy beam transport line

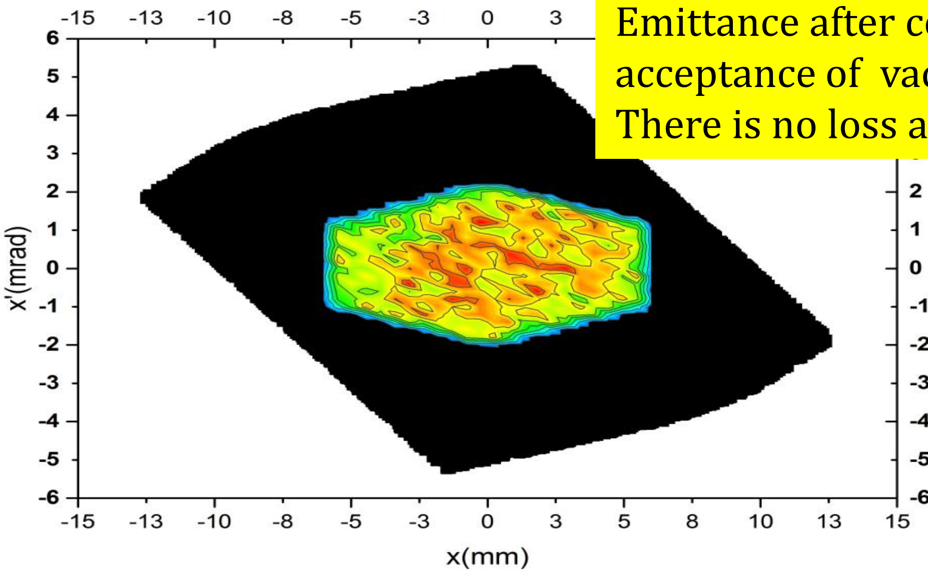


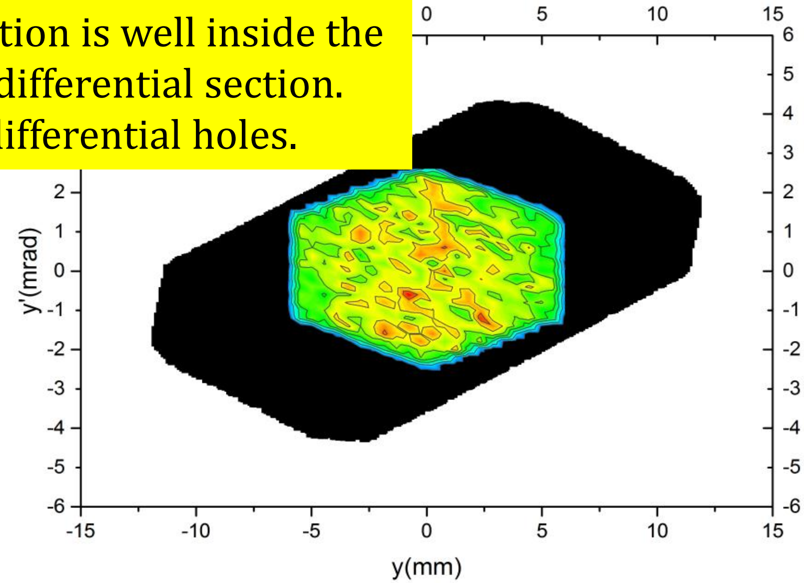
Design strategy:

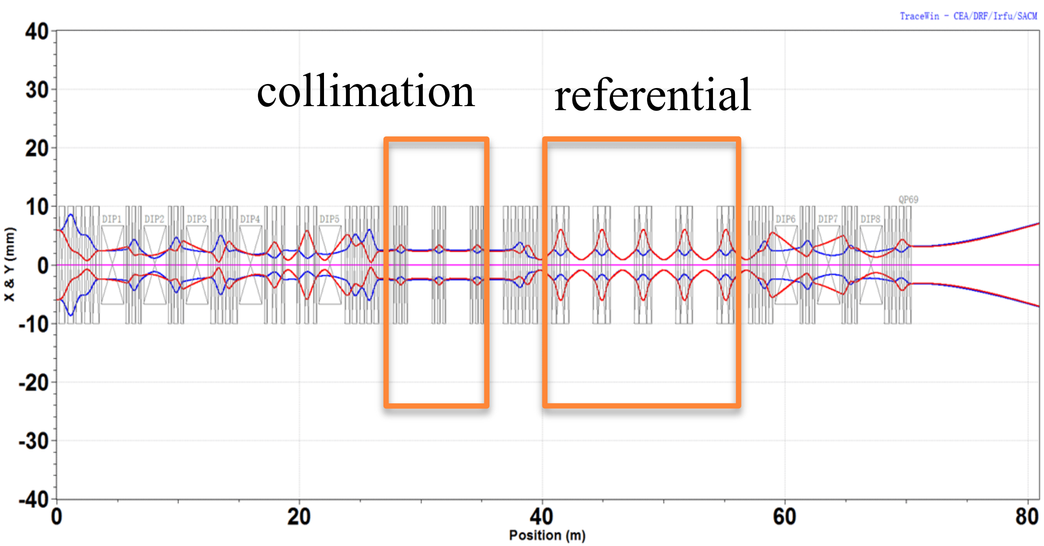
- Bend section is used to bend beam and meet the requirements for target.
- Collimate beam to avoid beam losses at the differential hole and other parts of the HEBT.
- Vacuum differential sectioin is used to complete vacuum transition
- Uniformity is done by the redundancy scanning magnets. Wobbler scanning is considered.

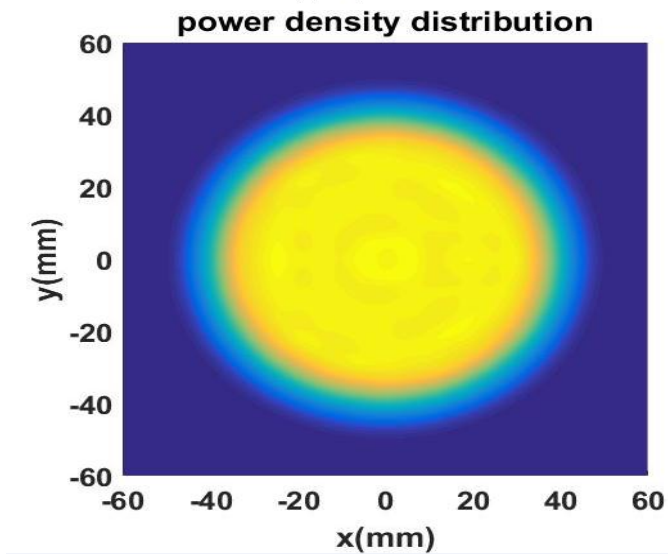
High energy beam transport line

Emittance after collimation is well inside the acceptance of vacuum differential section. There is no loss at the differential holes.









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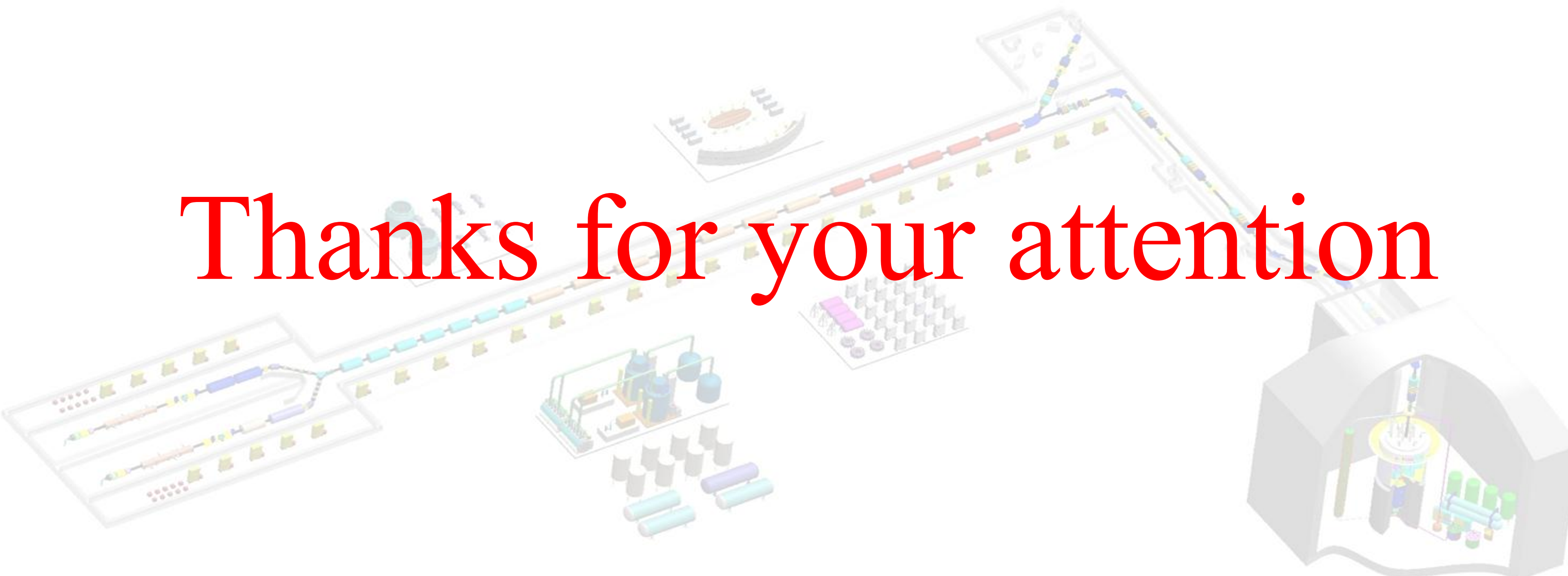
Summary

- The beam dynamics design of CIADS linac are presented, and the most concern is beam loss control
- The error analysis integrated with MEBT and SC section are presented
- The preliminary design for HEBT are presented, and the beam power uniformity is 97.3% on target
- More detail works need to be done



Thanks for your attention