Using step-like nonlinear magnets for beam uniformization at target in high intensity accelerarors

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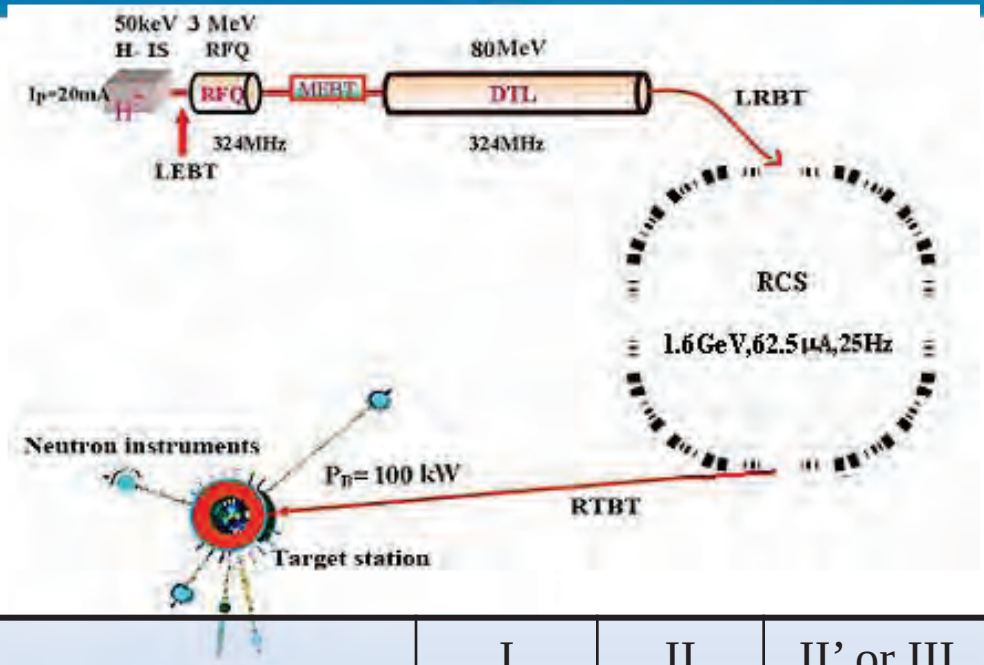
Topics

- Introduction to CSNS C-ADS IFMIF accelerators
- Beam spot uniformization
- Introduction of the step-like magnet
- Application on the CSNS C-ADS IFMIF

CSNS high power proton accelerator



CSNS (China Spallation Neutron Source) is a high-power proton accelerator based multi-disciplinary facility for research, mainly relying on neutron scattering techniques.

Construction: 2011-2017

Site: Dongguan, Guangdong

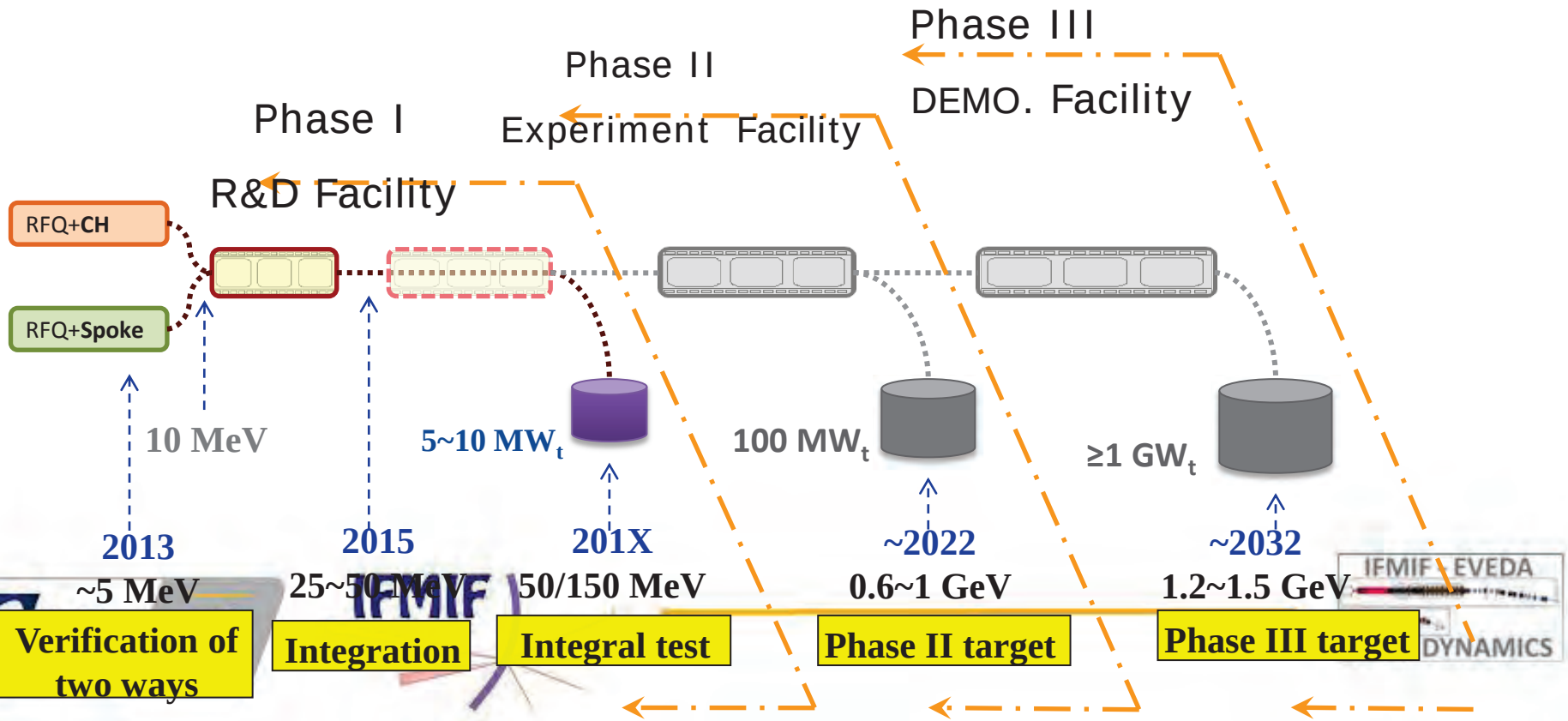
IHEP and IOP

Phase	I	II	II' or III
Beam power on target [kW]	100	200	500
Beam energy on target [GeV]	1.6	1.6	1.6
Ave. beam current [mA]	63	125	315
Pulse repetition rate [Hz]	25	25	25
Protons per pulse [10^{13}]	1.6	3.1	7.8
Linac energy [MeV]	80	132	250
Linac type	DTL	DTL	+SCL

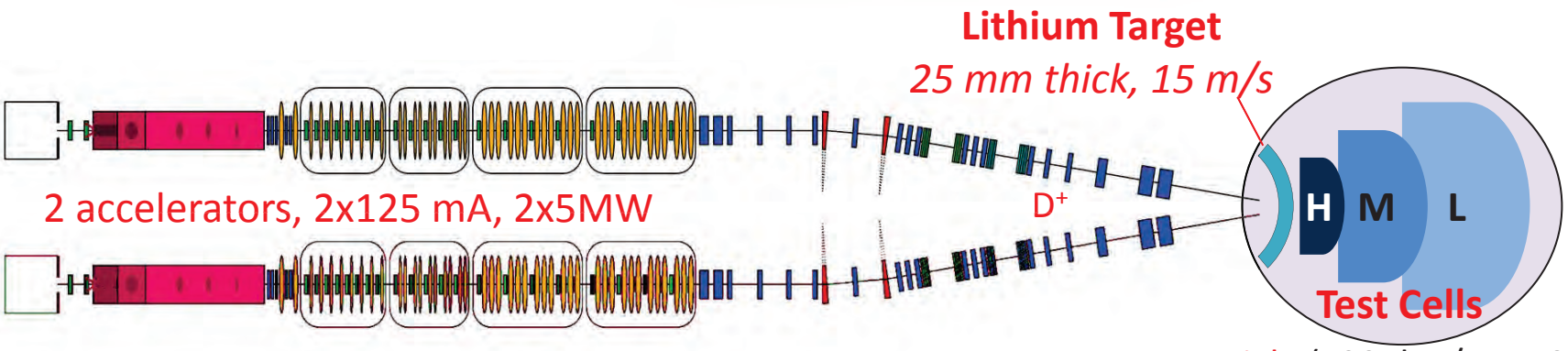
Irfu cea IFMIF

China ADS high power proton accelerator

- China is pursuing an ADS (Accelerator-Driven Subcritical System) program strongly, under CAS (IHEP, IMP, IPP and USTC)
- Accelerator: 10mA, CW proton beam

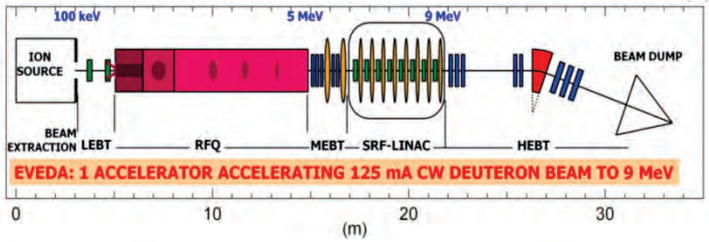


IFMIF: International Fusion Materials Irradiation Facility



Typical reactions $^{7}Li(D,2n)^{7}Be$ $^{6}Li(D,n)^{7}Be$ $^{6}Li(n,T)^{4}He$

High (>20 dpa/year, 0.5 L)
Medium (>1 dpa/year, 6 L)
Low (<1 dpa/year, > 8 L)



The highest average current linac under developing in the world, pose many challenges

Beam spot uniformization

One of the critical issues concerning the interface between a high-power beam and its irradiation target is the spot uniformity to reduce the peak current density at the target and reduce the beam halo

CSNS

Beam footprint in rectangular shape: 12 cm (H) x 5cm (V)

Ratio of the peak current density to the average: <3

C-ADS

Beam footprint in rectangular shape: 4.4cm (H) x 4.4cm (V)

Ratio of the peak current density to the average: <2.5

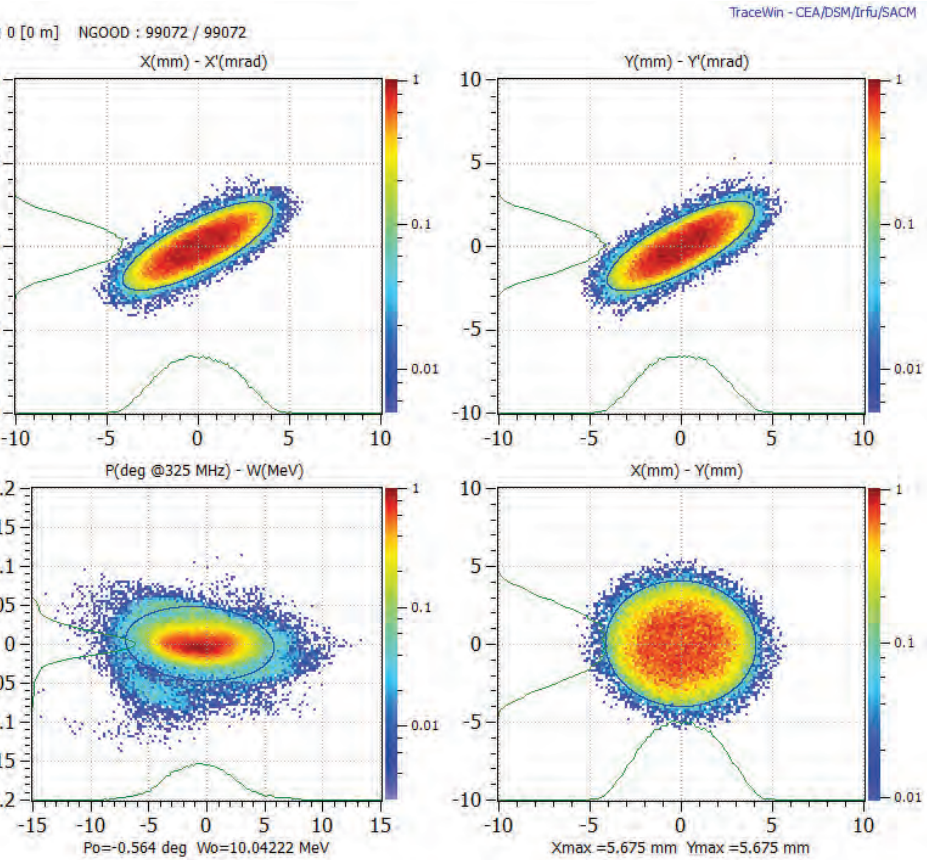
IFMIF (to be revised)

Beam footprint in rectangular shape: 20 cm (H) x 5 cm (V)

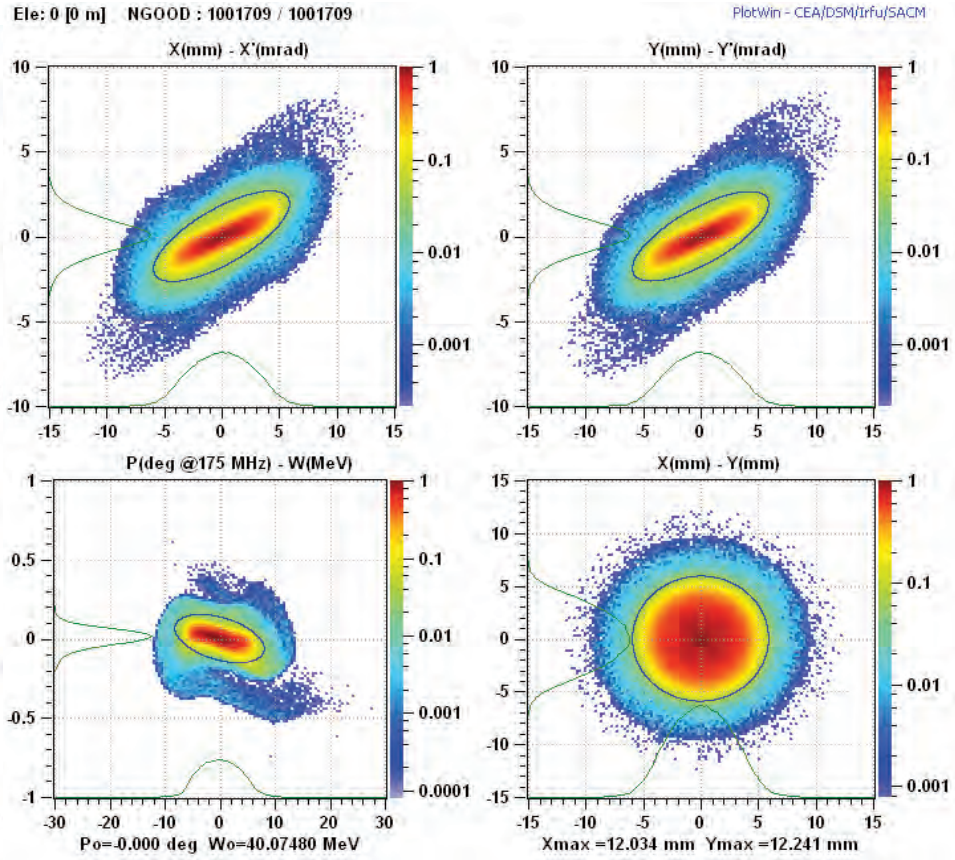
Current density across the flat top is uniform (±5%)

Current density: < 0.5 μA/cm^2 (for |x|>11 cm)

Input beam of C-ADS beam transfer line

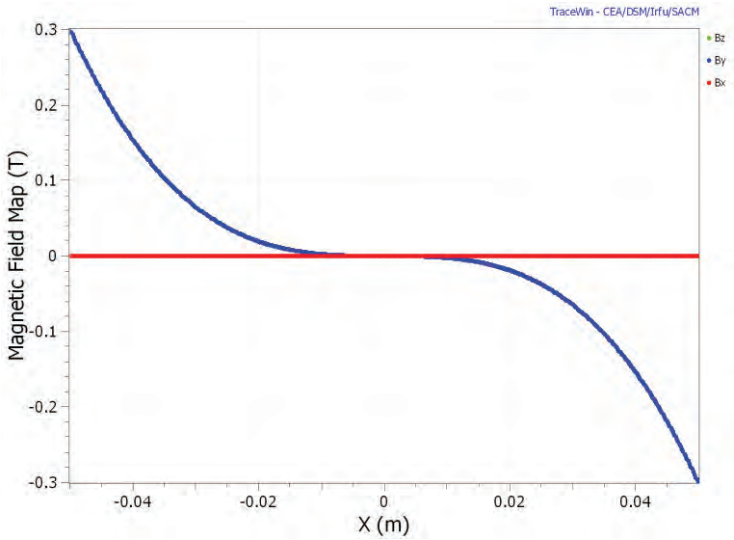


Input beam of IFMIF-HEBT

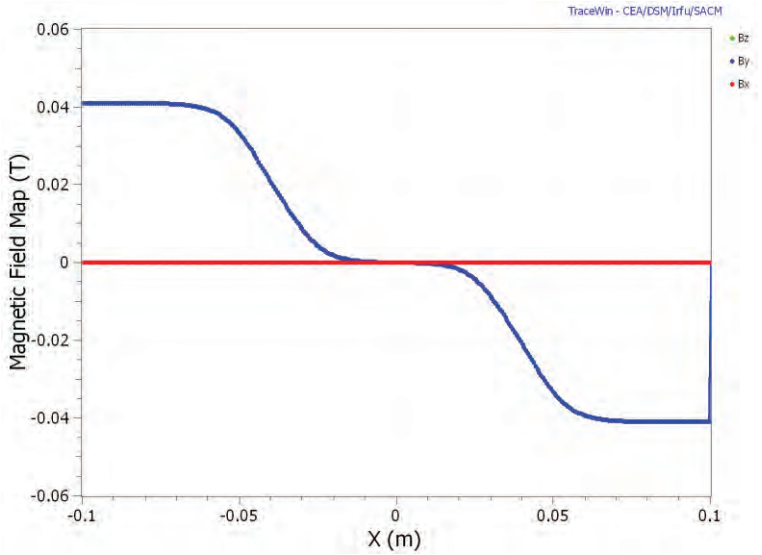


- Nonlinear magnets are needed for the beam spot uniformization at target
  - More conventional: single octupole or pair of octupole and dodecapole for each plane (horizontal or vertical)
  - New concept-1: step-like field magnets, initially proposed for ESS and CSNS
  - New concept-2: simplified multipole magnets including different combinations of anti-symmetric second-order, third-order, fourth-order and fifth-order field magnets, recently proposed at IHEP

Introduction of the step-like magnet



8 poles -r50 mm
Field on pole 0.30 T
Octupole



2 dipoles-r100 mm
Field on pole 0.040 T
Step-like magnet

Advantage

- **Flexibility**

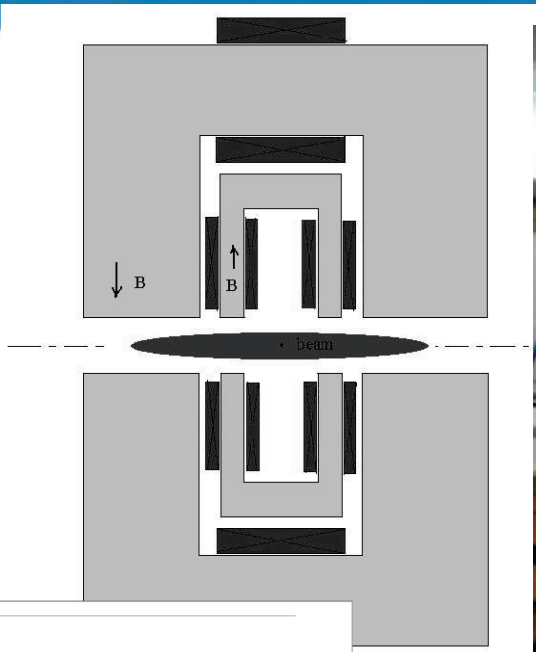
  uniformization of beam core and beam halo can be done separately by two steps

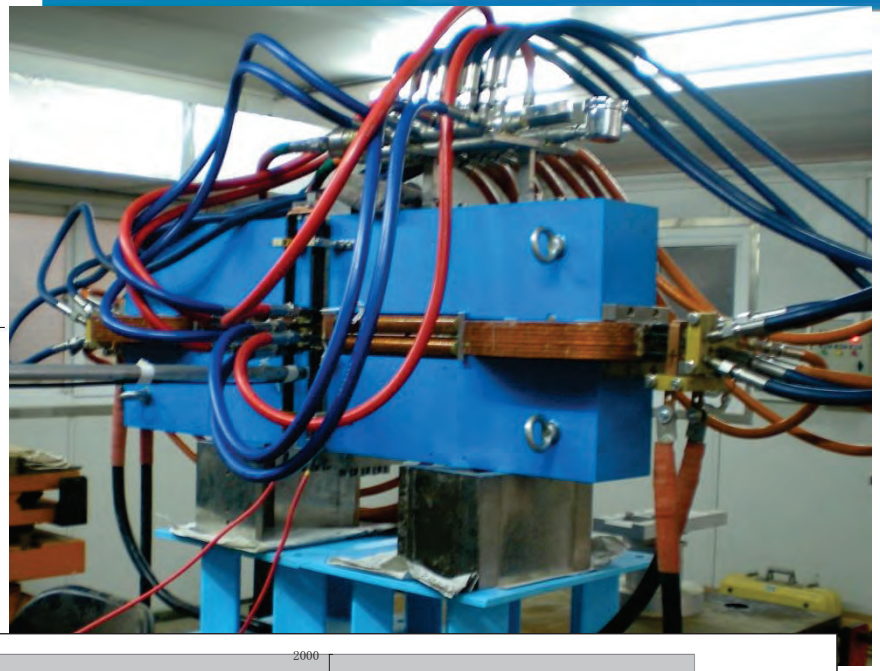
- **Cheaper**

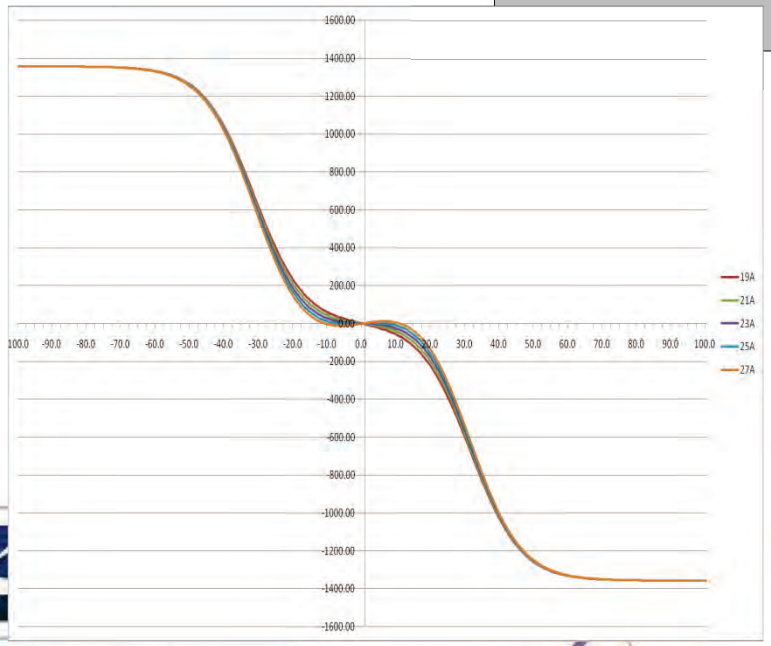
  standard multipoles: 100 thousand dollars

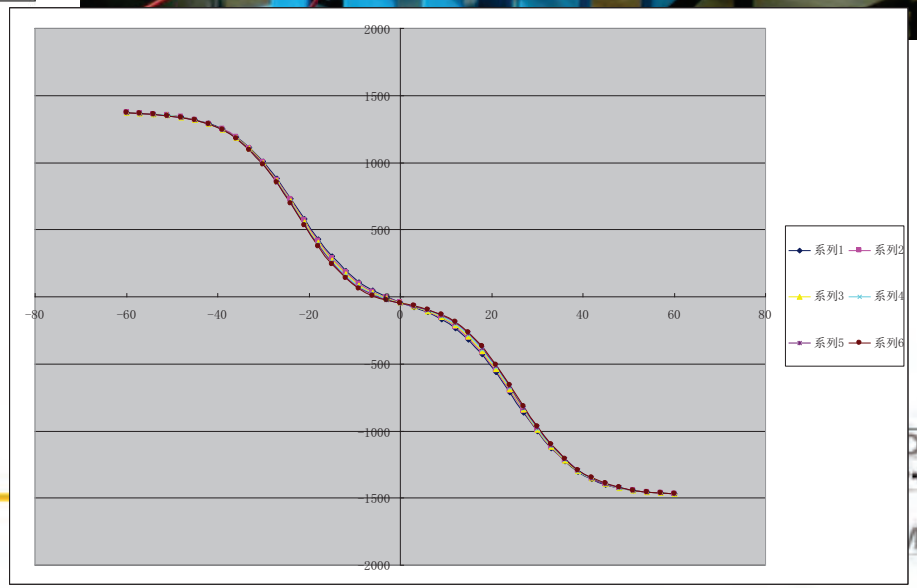
  step-like magnets : 20-40 thousand dollars

Step-like field magnet prototyping



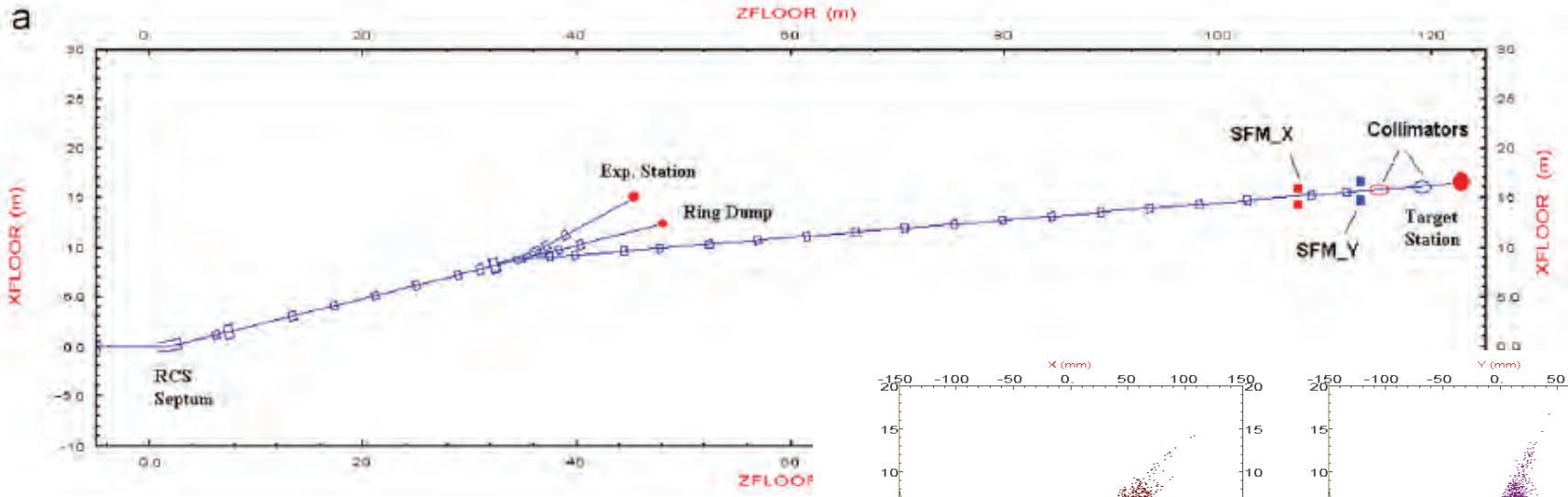






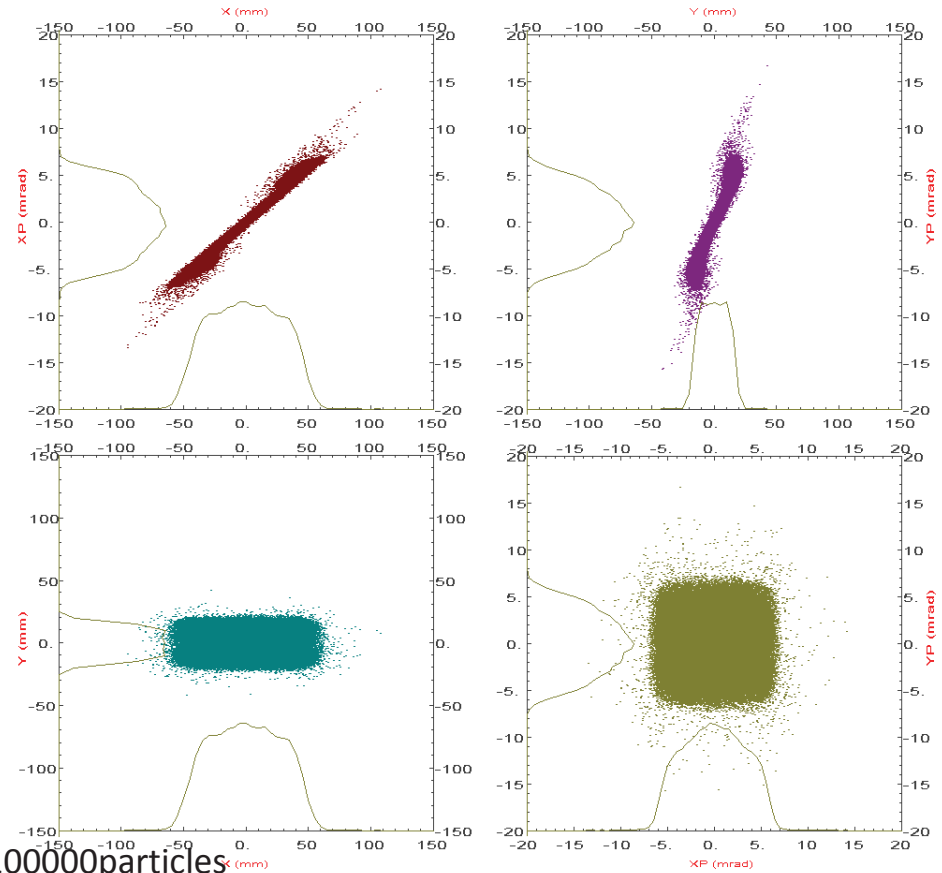
- Optimization principle

1. Change the last four or six quadrupoles and the length of drift to get a larger beam spot on the target and fulfill the request of the flat beams and phase advances (linear optics)
2. Adjust the parameters of the step-like magnets to obtain a good beam spot on the target (nonlinear optics)
3. Repeat 1. and 2. several times to find the best result



Studies at IHEP:

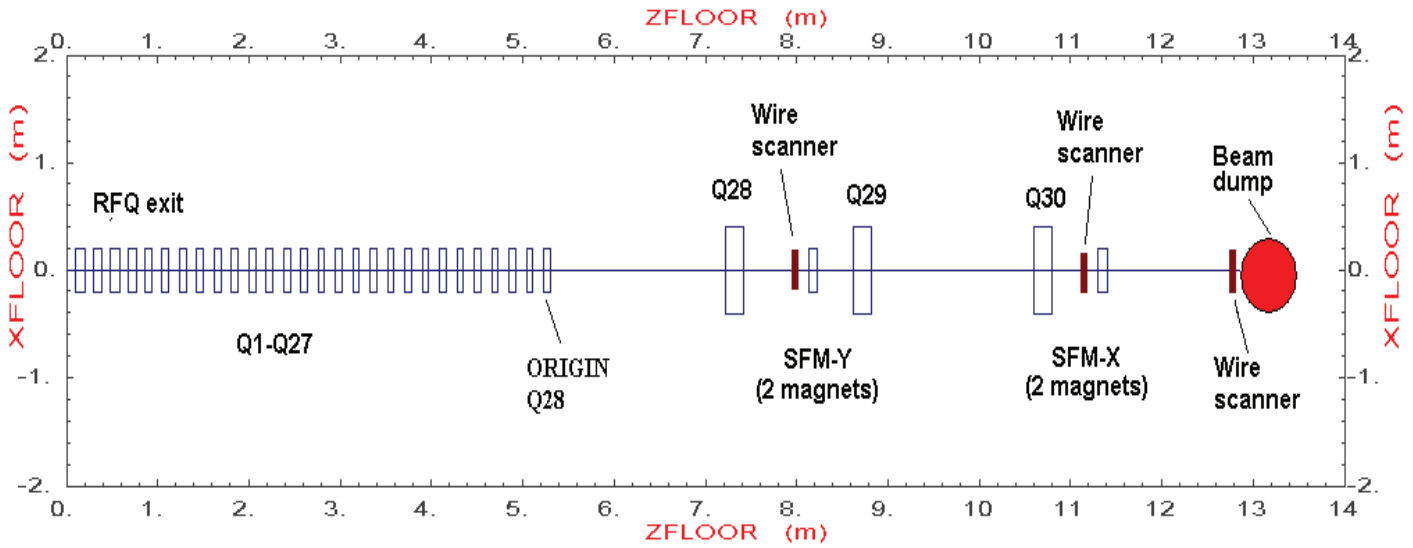
Using step-like field magnets (SFM) for spot uniformization at CSNS



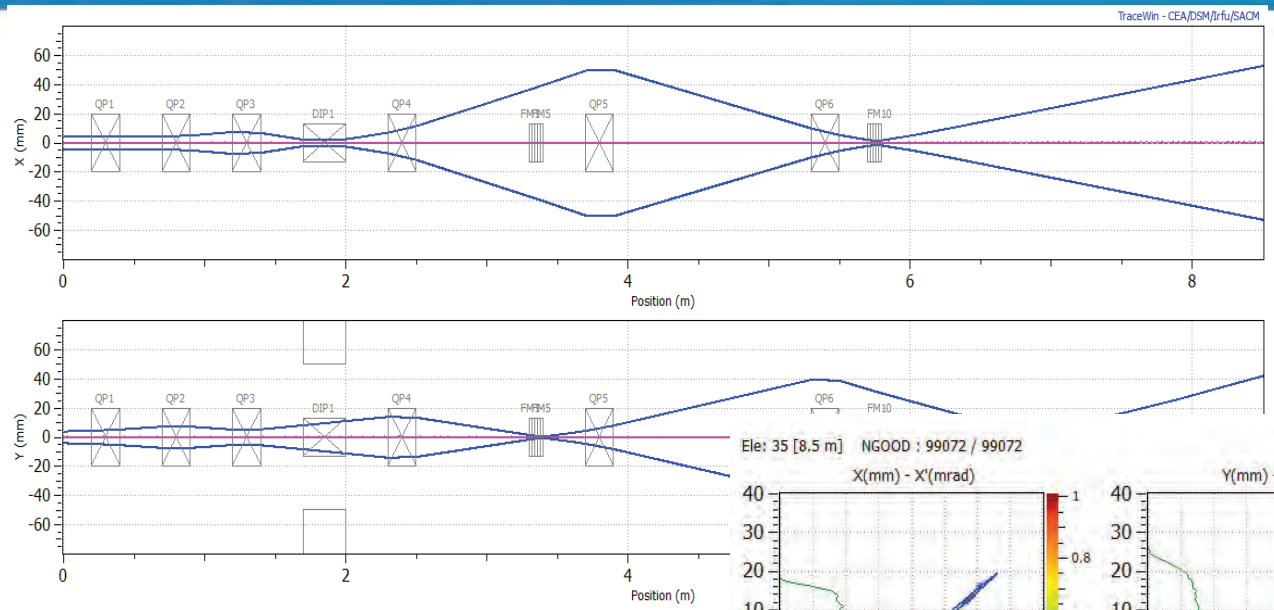
100000particles

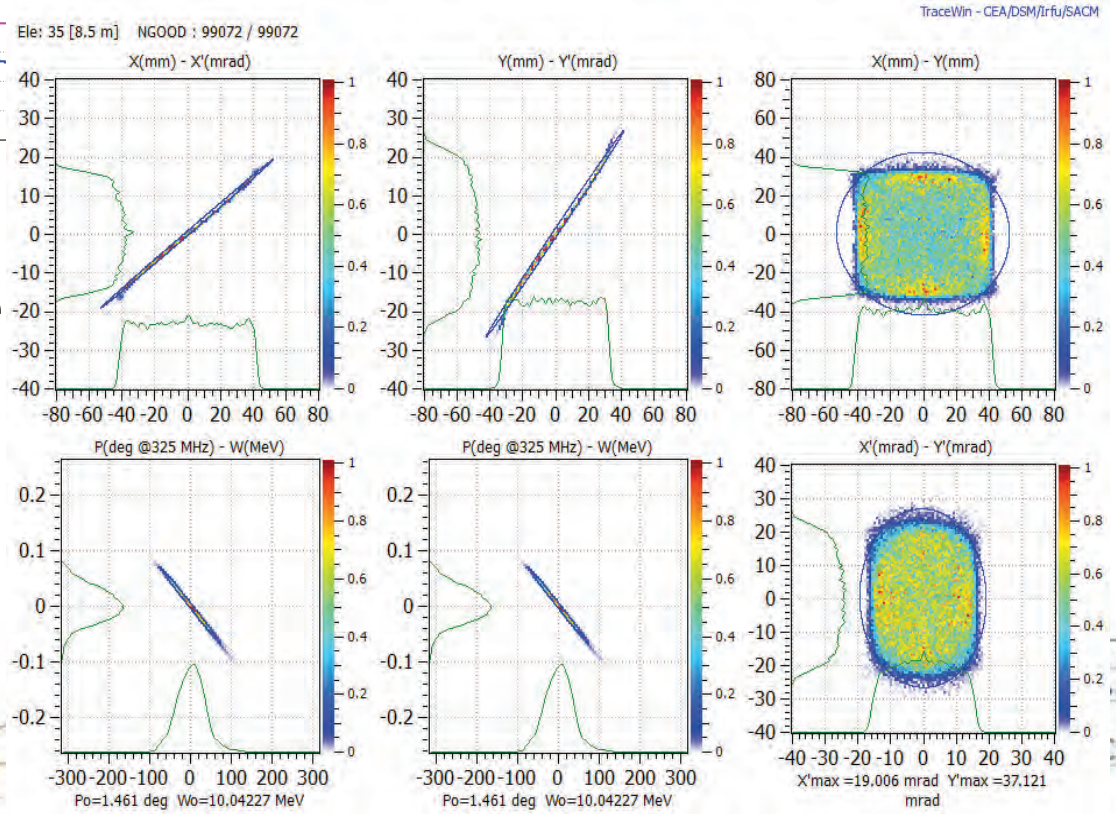
Tests with beam for spot uniformization

- A test beam line using the ADS-RFQ is being set up for studies on both halo development and spot uniformization (plan under modification)



SFM can be step-like field magnets or simplified high-order magnets



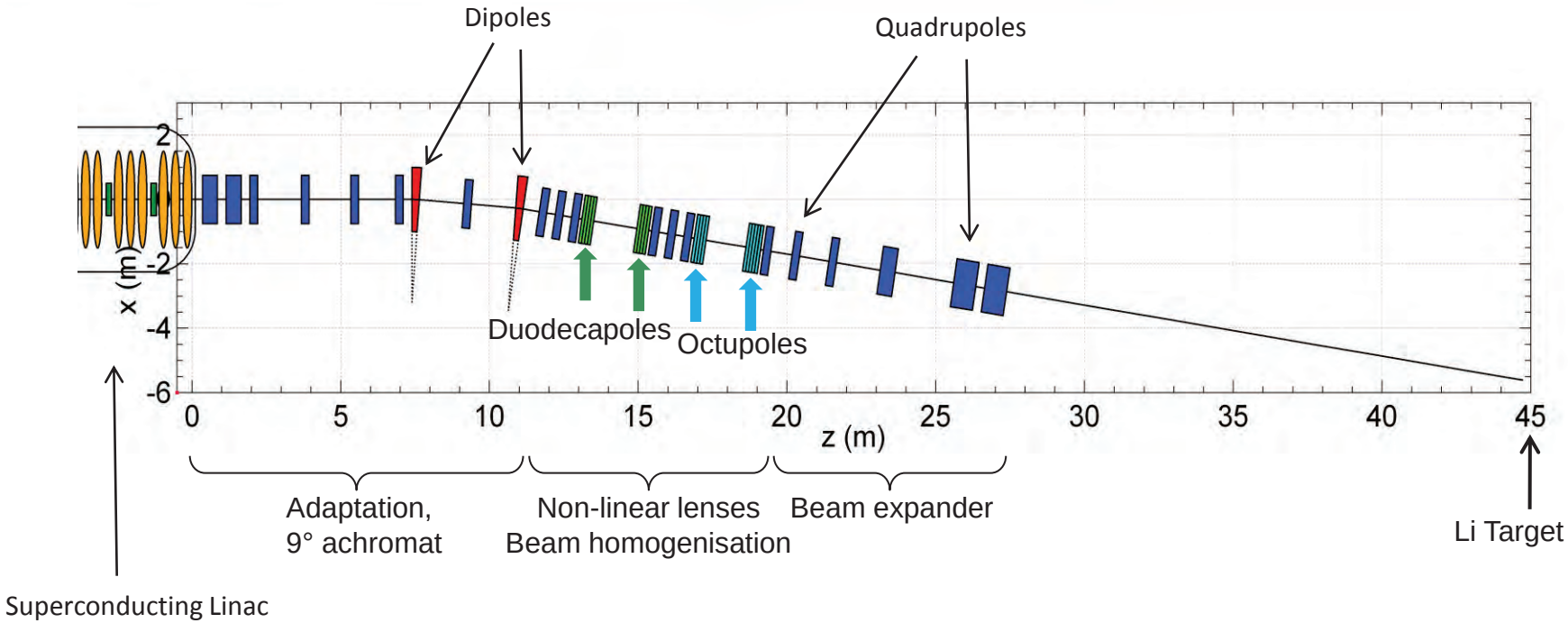


Studies at ADS beam line (dump):

Using step-like field magnets (SFM) for spot uniformization

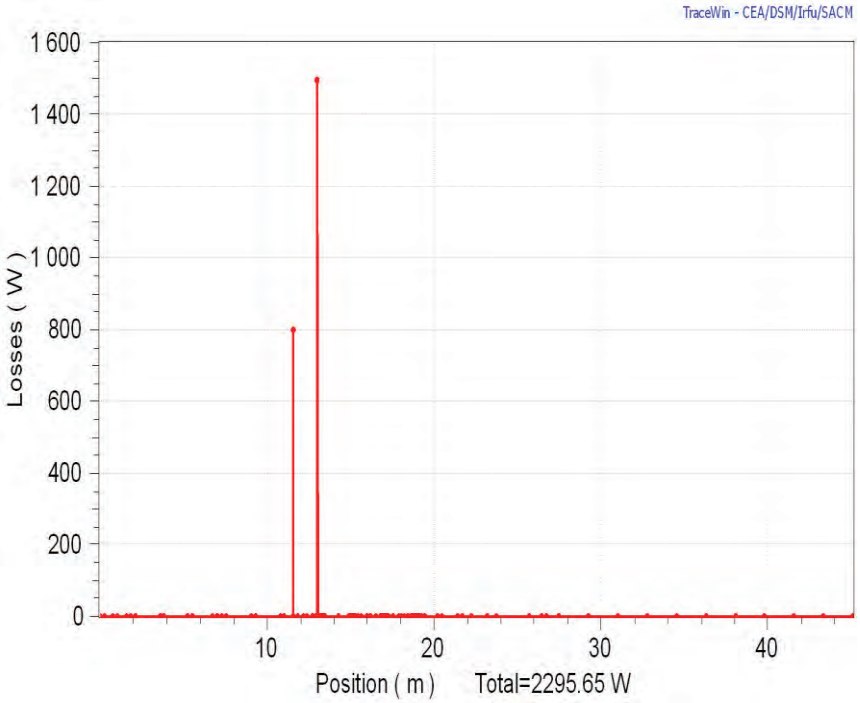
Irfu cea IFMIF

"Classical" HEBT structure



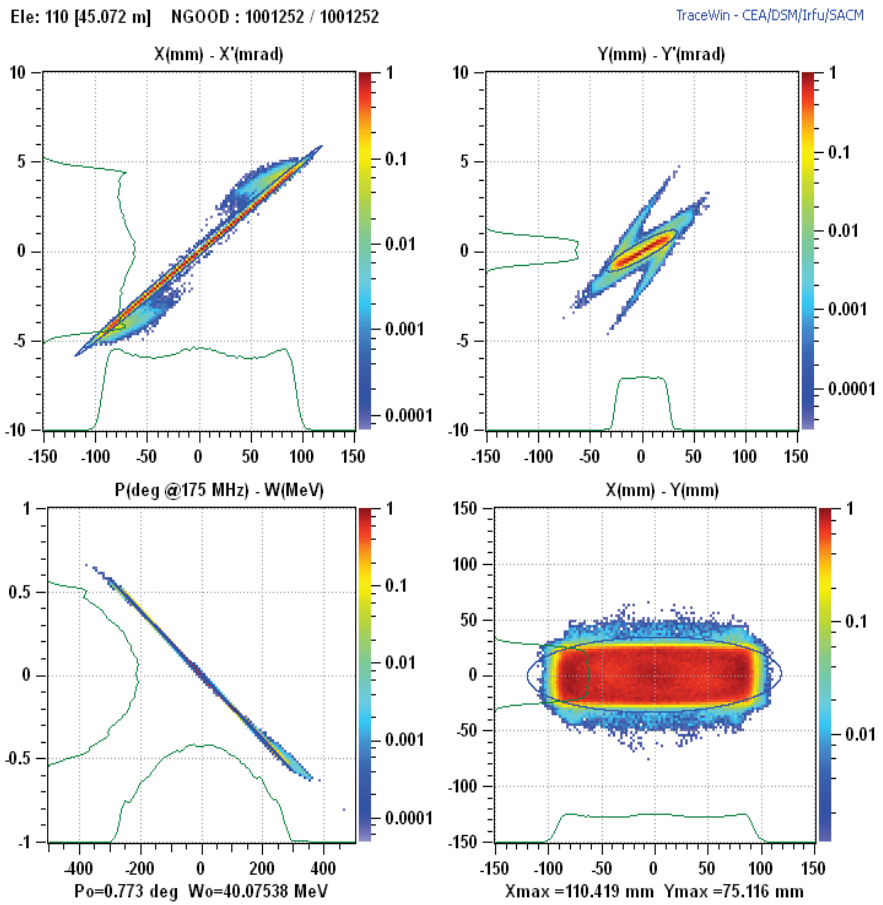
R. Duperrier, J. Payet, D. Uriot, Proc. of EPAC 2004

Beam losses



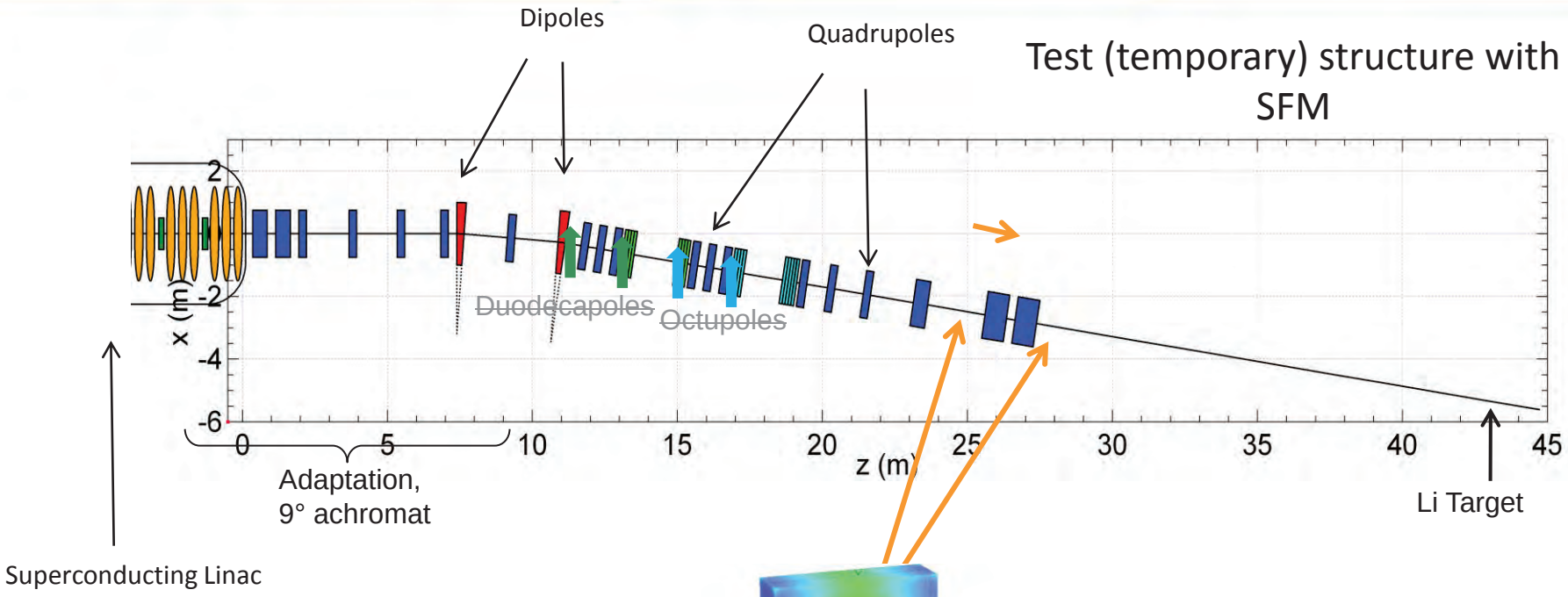
scrapers 2.3 kW
(to be optimised)

Beam distribution at Li Target



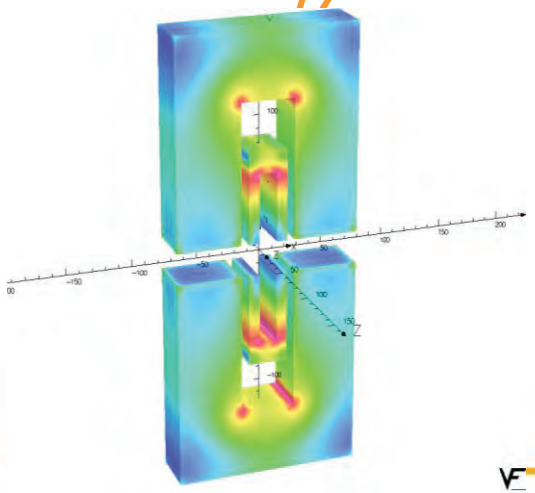
To be improved
Tuning strategy to be defined

Test (temporary) structure with SFM



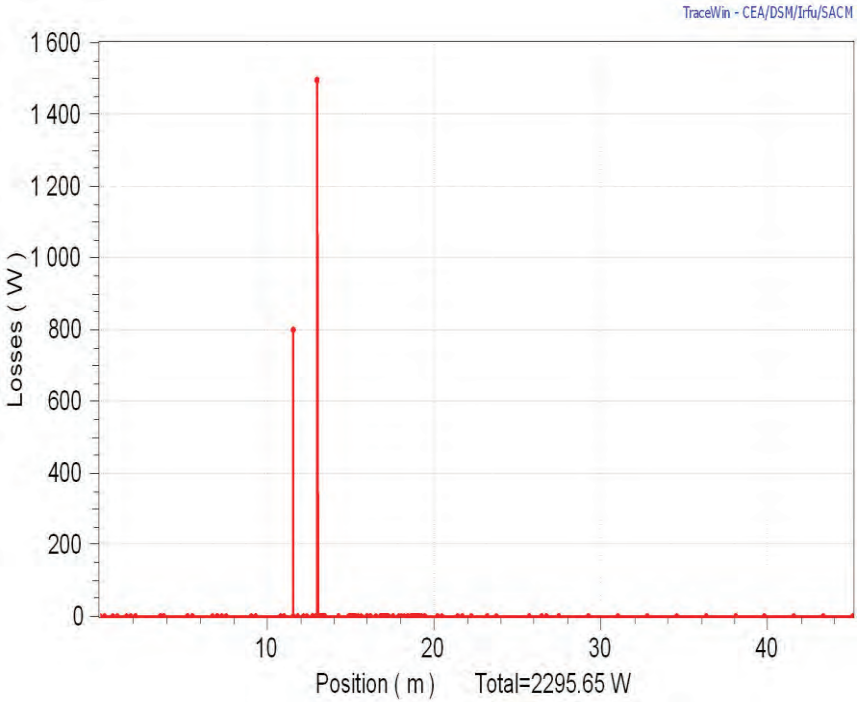
Step-like Field Magnet

J.Y.Tang, H.H. Li, S.Z. An, R. Maier
NIMA, 2004



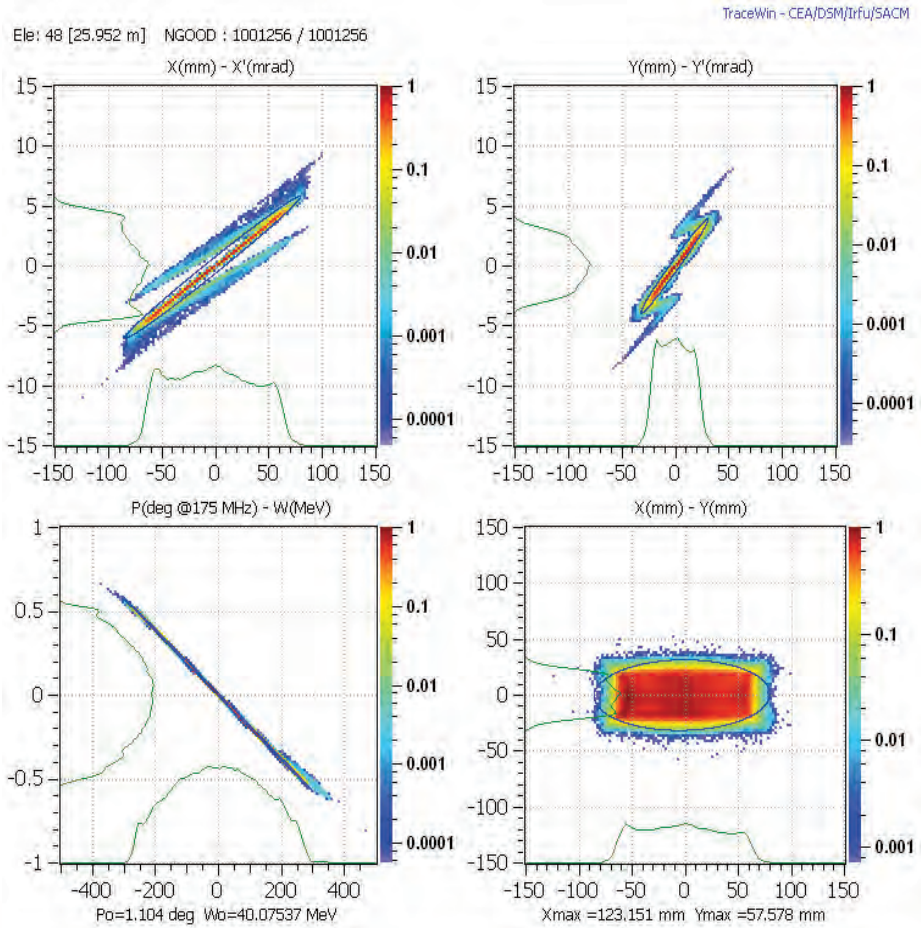
IFMIF - EVEDA
BEAM DYNAMICS

Beam losses



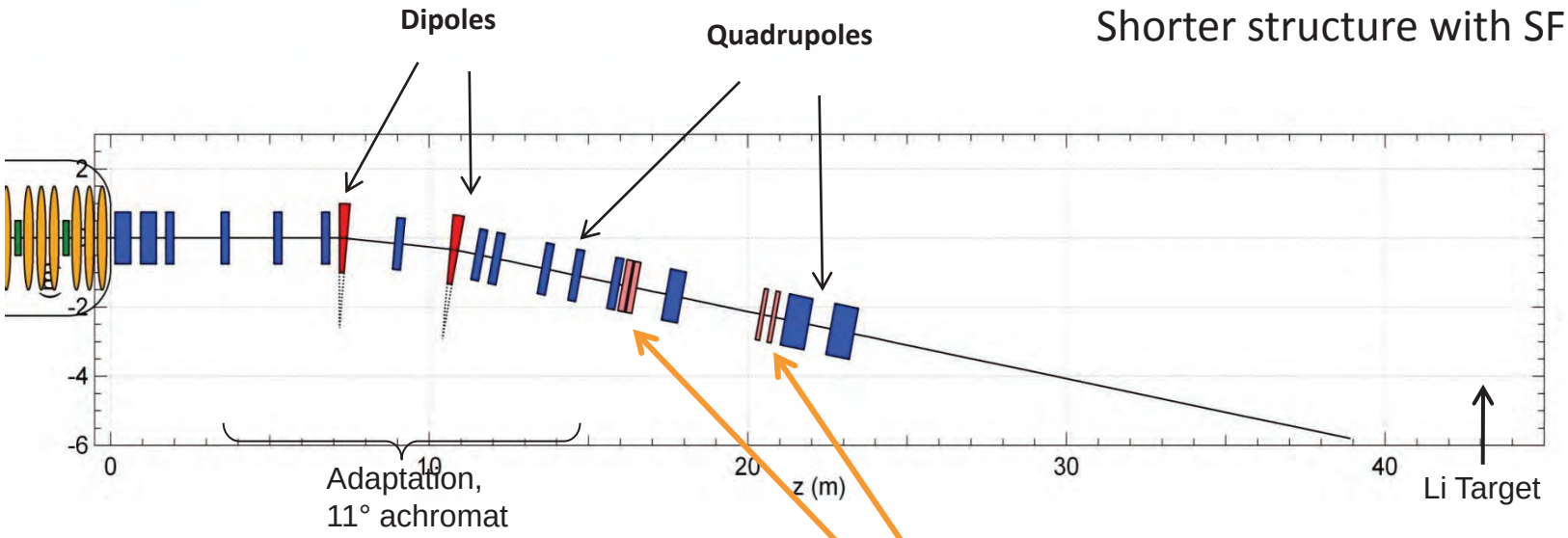
scrapers 2.3 kW
(to be optimised)

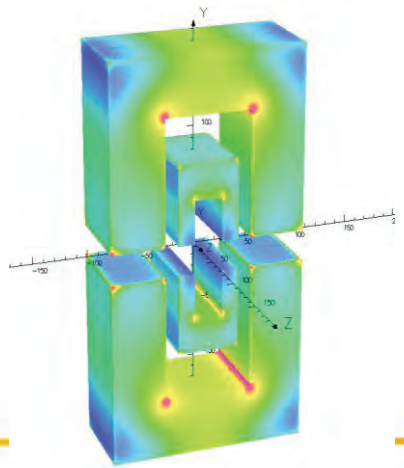
Beam distribution at Li Target

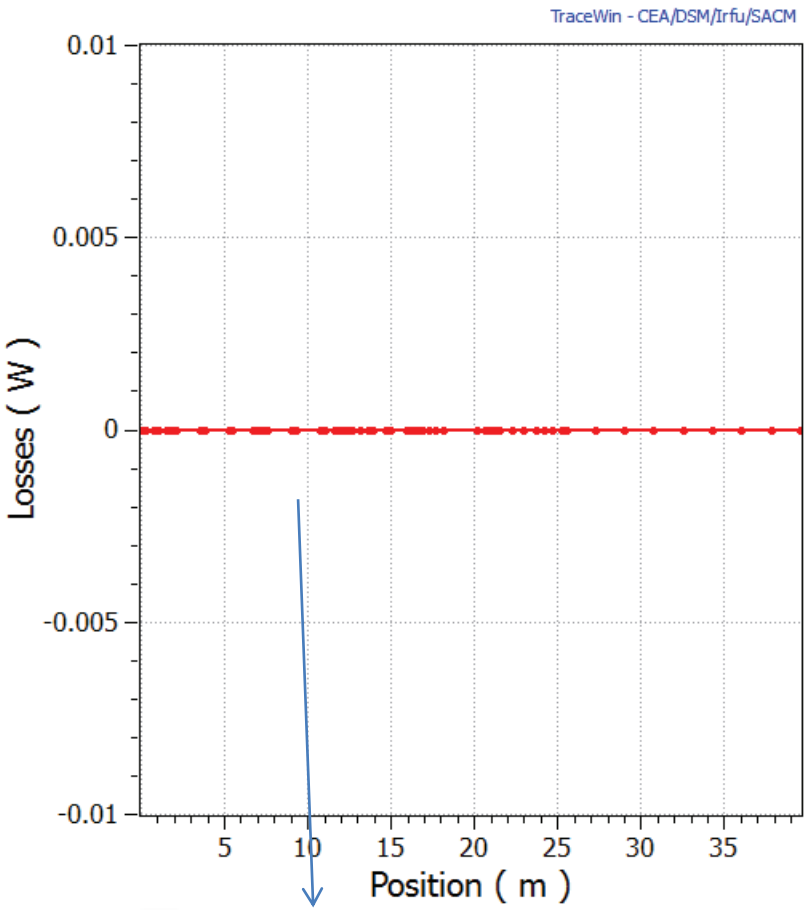


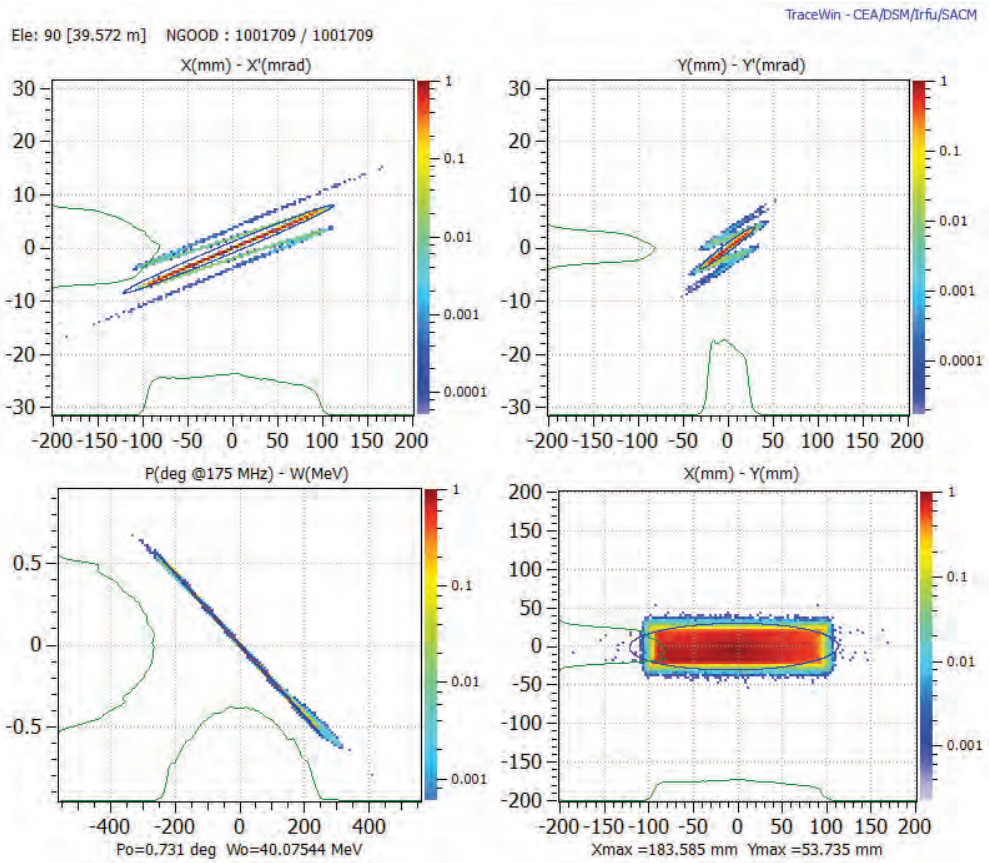
To be improved
Larger Footprint
Tuning strategy to be defined

Shorter structure with SFM

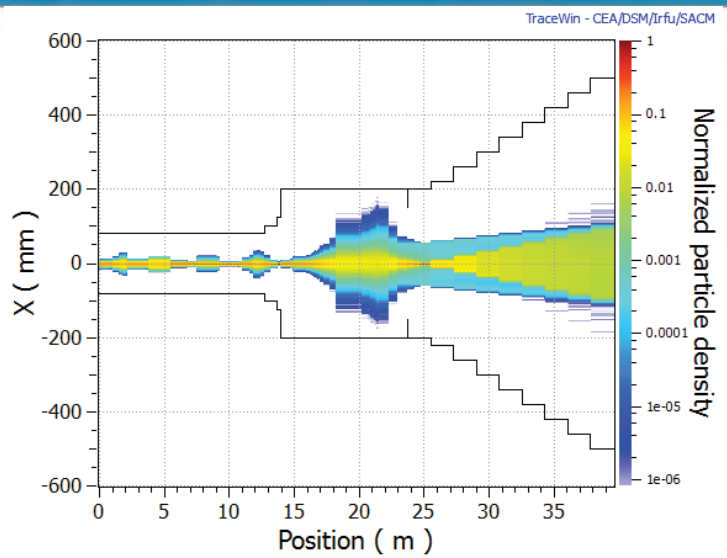


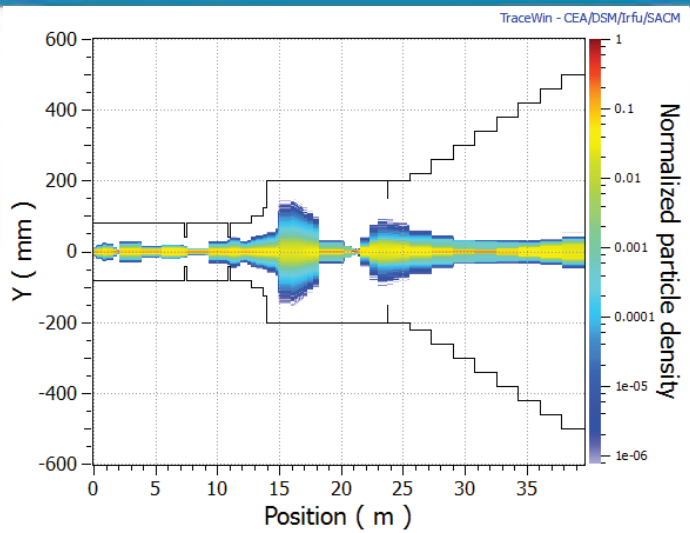



TraceWin - CEA/DSM/Irfu/SACM
Losses (W)
Position (m)
0.01
0.005
0
-0.005
-0.01
5
10
15
20
25
30
35

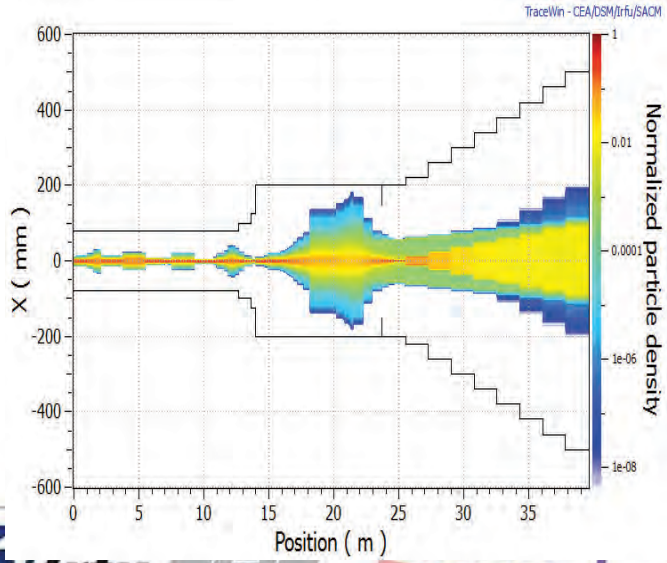

TraceWin - CEA/DSM/Irfu/SACM
Ele: 90 [39.572 m] NGOOD : 1001709 / 1001709
X(mm) - X'(mrad)
Y(mm) - Y'(mrad)
P(deg @175 MHz) - W(MeV)
X(mm) - Y(mm)
Po=0.731 deg Wo=40.07544 MeV
Xmax =183.585 mm Ymax =53.735 mm

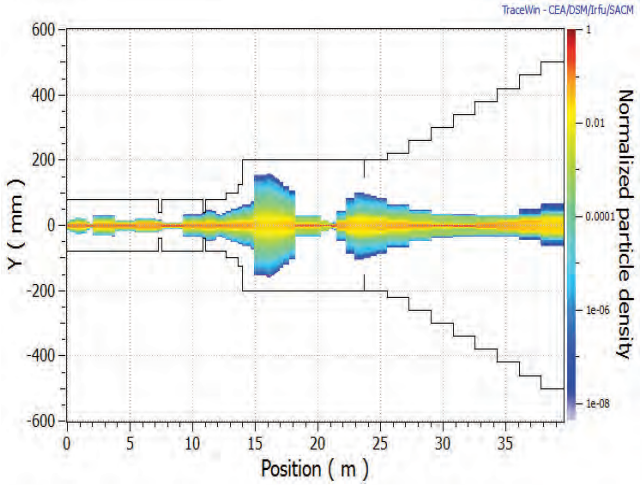
No beam loss





Density
Start-to-end
without errors





Density
Start-to-end with
errors

Thank you