Proposal of a 1 A-class deuteron single-cell linac

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  - no RFQ
  - can accelerate large size beam
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- **1A class single cell linac**
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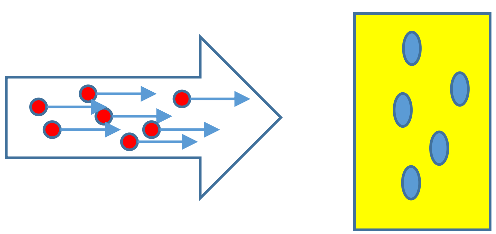
The Burden of Nuclear Waste

The current scenario for nuclear waste in Japan is that High level radioactive wastes (HLW) from Spent Nuclear Fuels are vitrified in glass and disposed in geological repository. **However, Japanese public are worried about the scenario.**

We would like to propose alternative solutions to HLW disposal in geological repository. **Transmutation of nuclear waste by beams from accelerators**.

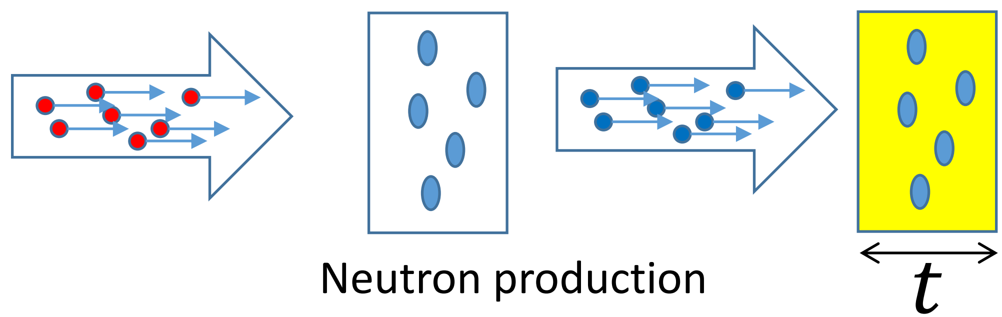
Nuclear transmutation using Deuteron

Direct irradiation



LLFP target

Neutron irradiation **Thick *t* -> efficient transmutation**



Neutron production target

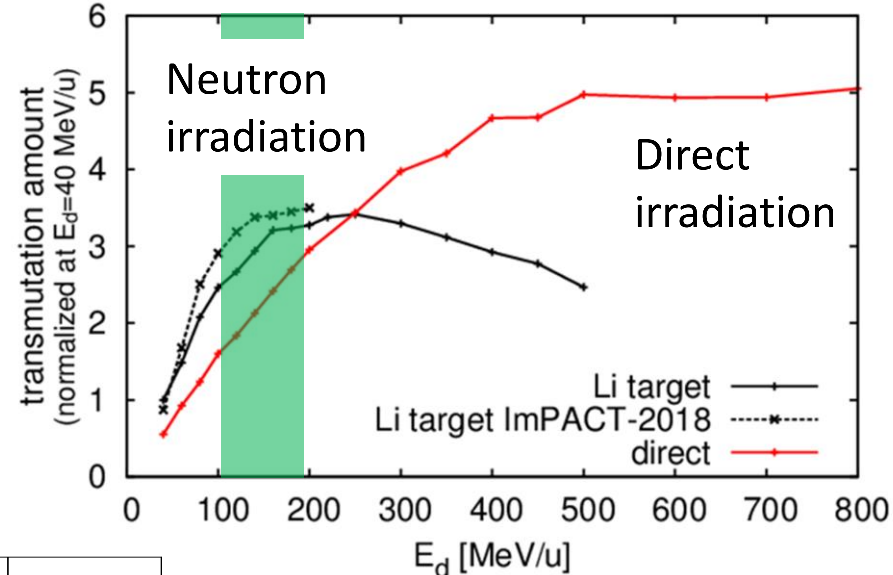
LLFP target

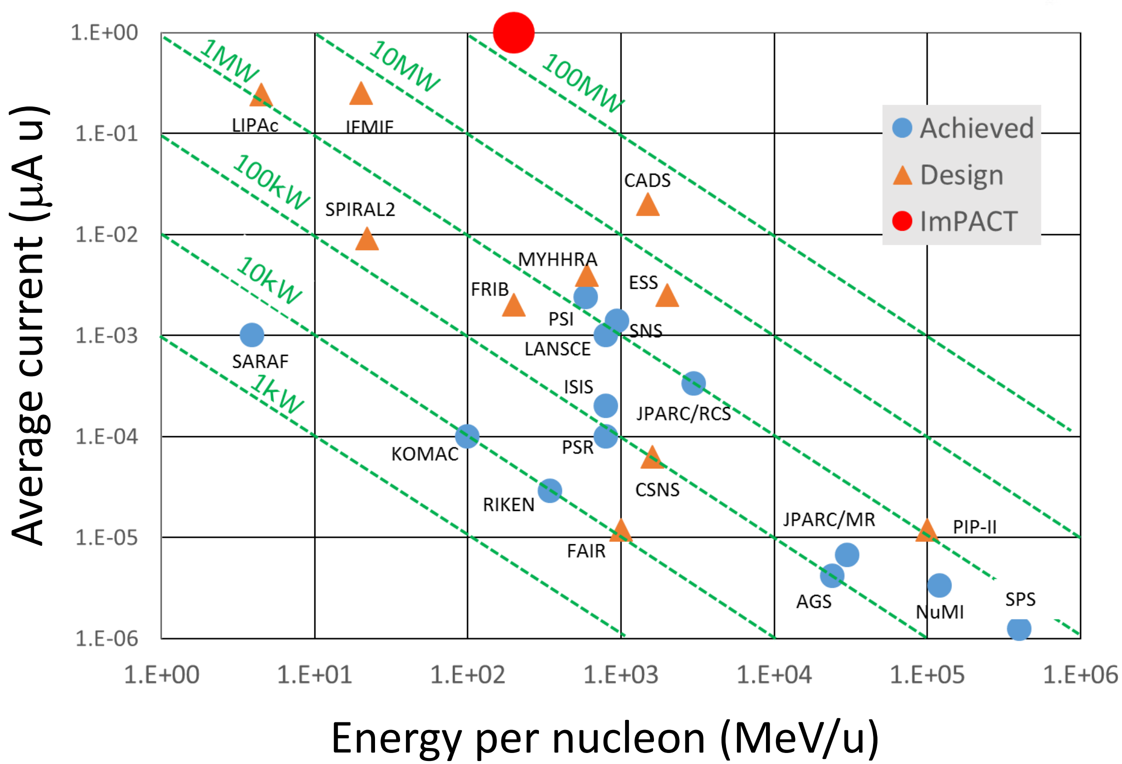
Accelerator for transmutation of HLW

Requirements to the accelerator

- Particle : Deuteron
- Output Energy : 100-200 MeV/u
- Current : 1A
- Beam Power : 80MW-200MW x 2

(~100 MW class)

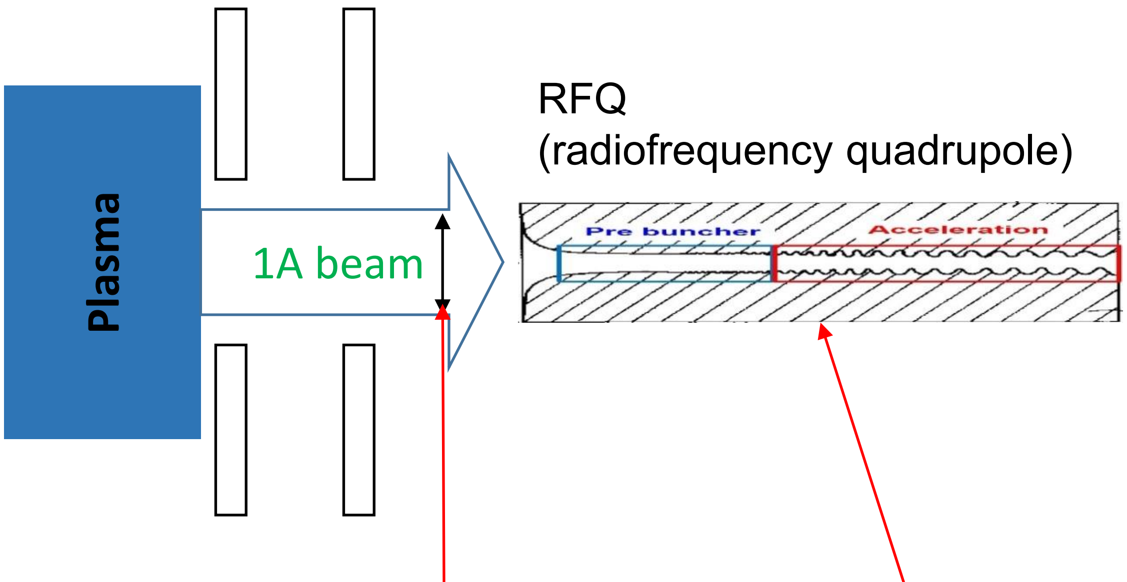


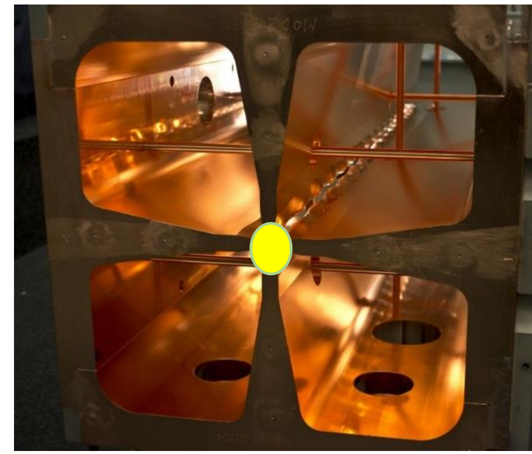


We need more than 100 times of the available beam power in the world.

Technical issue: beam size

RFQ (radio-frequency quadrupole) linacs are widely used as front-end accelerators in the high-intensity, high-energy proton (deuteron) linacs. It works as a buncher of DC beam from ion source, electrical transverse focusing elements, accelerator.





Cross sectional view of RFQ

The area which beam can go through.

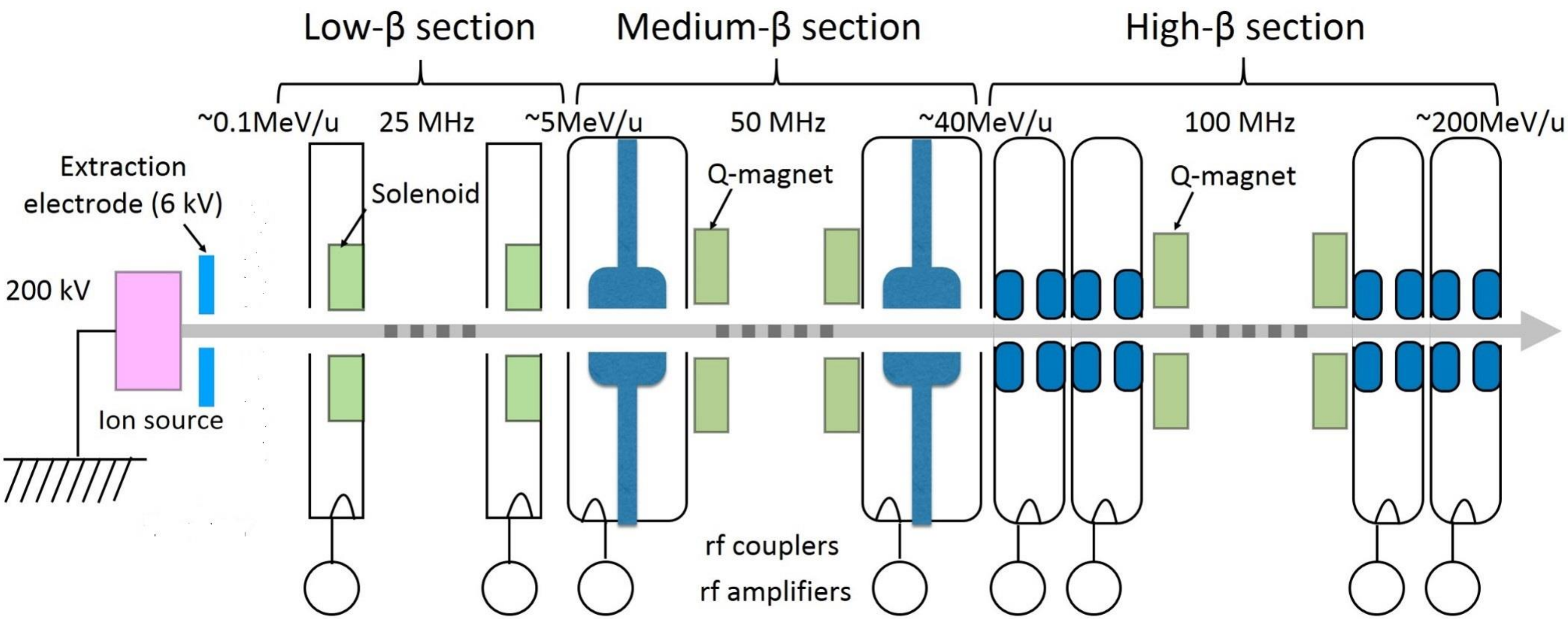
Size of 1A beam >10cmϕ >> 1cm: typical acceptance of RFQ

We can't use RFQ ! !

Proposal of 1-ampere class single cell linac

Single-cell cavities + magnetic focusing elements (without RFQ)

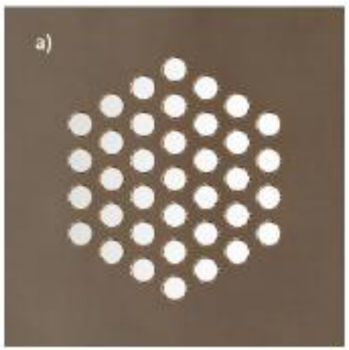
Merits :
1: It can accept large beams because it uses magnet focusing elements free from discharge.
2: Low current density owing to the large beam size mitigates space charge force.
3: Voltage and phase of each cell can be independently selected to compensate for the longitudinal space charge effects, and also to implement an efficient bunching function for a DC beam like an RFQ entrance section.



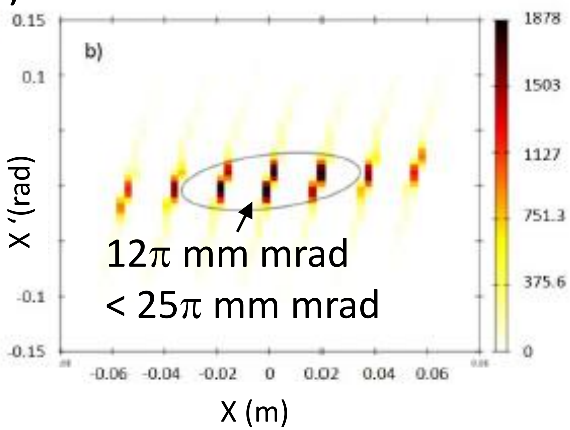
Ion source + LEBT(low energy beam transport)

Ion source: A cusp-field confinement type Ion source used for NBI (Neutral beam injector) in Tokamak fusion reactors. Extraction from the multi hole is inevitable.

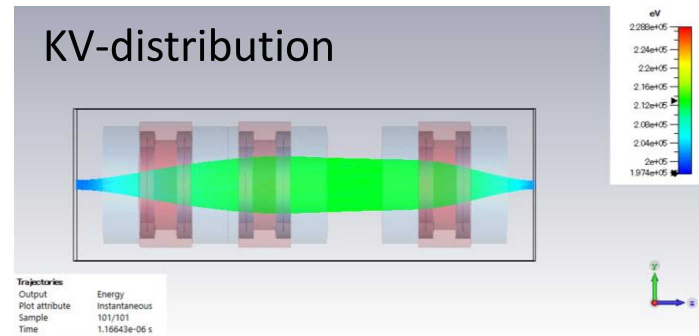
Multi-holes for beam extraction (14mmϕ x 37)

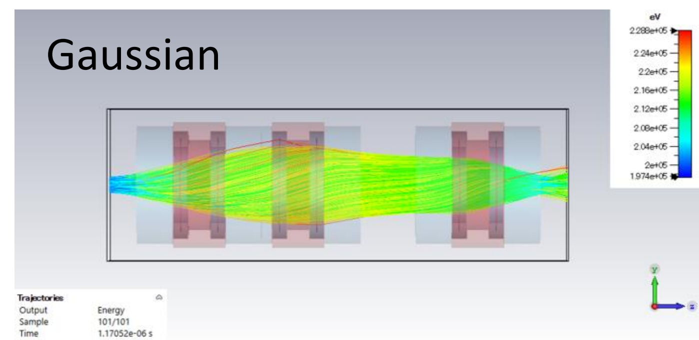


Emittance of extracted beam

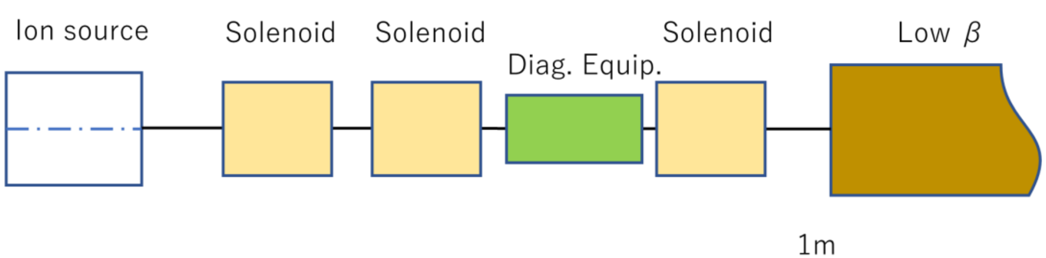


Beam envelope in the LEBT
(no neutralization is assumed.)





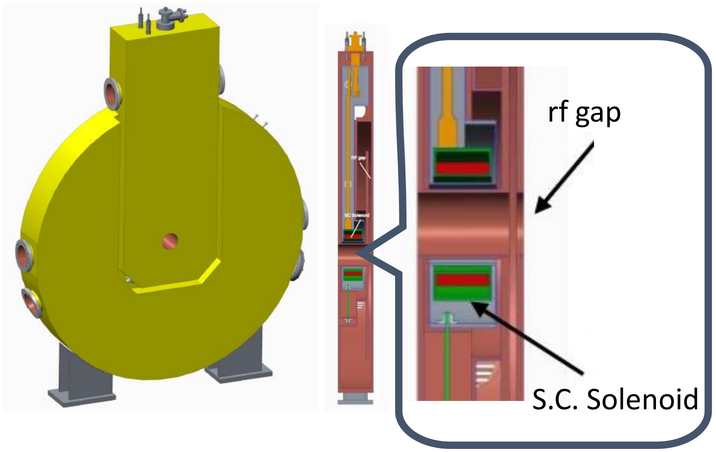
Plan view of LEBT



studying on beam halo with various initial conditions

Low β section (adiabatic rf capture)

90 cells
(Single gap with S.C. solenoid)



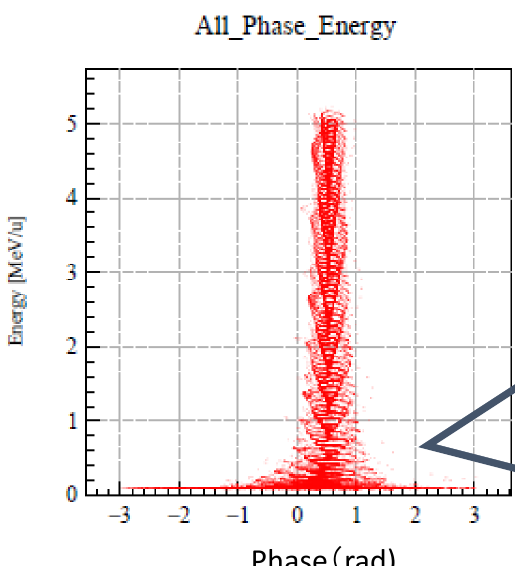
Energy (MeV/u)

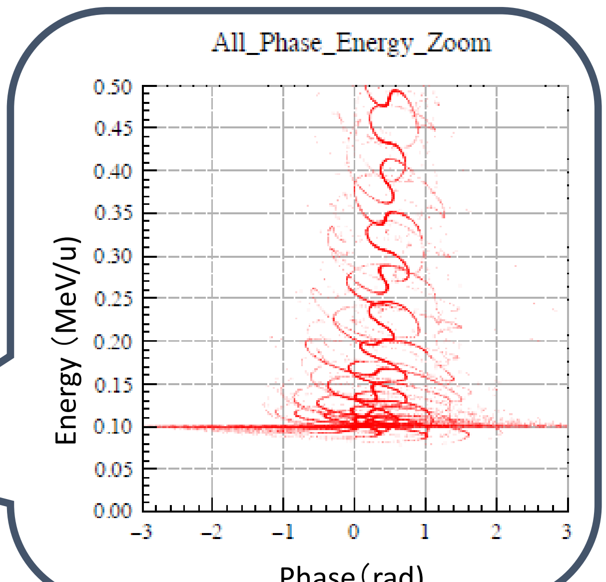
Basic parameters

Structure	Reentrant with cappacitive plate
Frequency (MHz)	25
Cavity diameter (m)	2
Aperture radium (cm)	15
Cell Length (m)	0.25–0.4
Maximum rf voltage (kV)	300
Shunt impedance (MΩ)	0.775
Q0	20006
Transit Time Factor	0.966 at 5 MeV/u

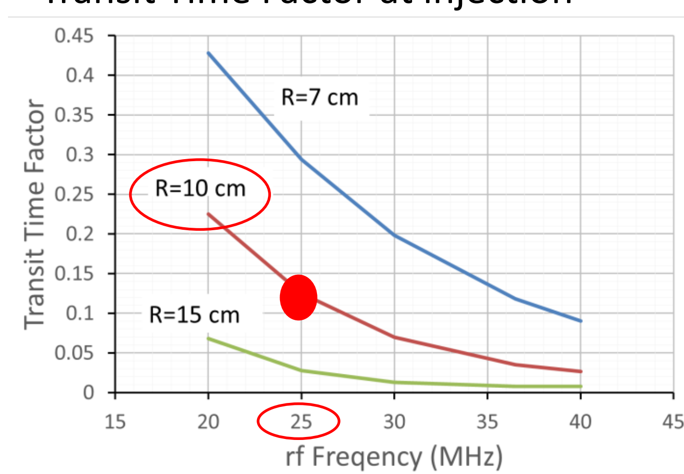
Longitudinal Beam behavior:
Adiabatic rf capture (DC→bunched beam)

Large bore → broad E distribution
→ Low rf frequency is required to keep TTF larger



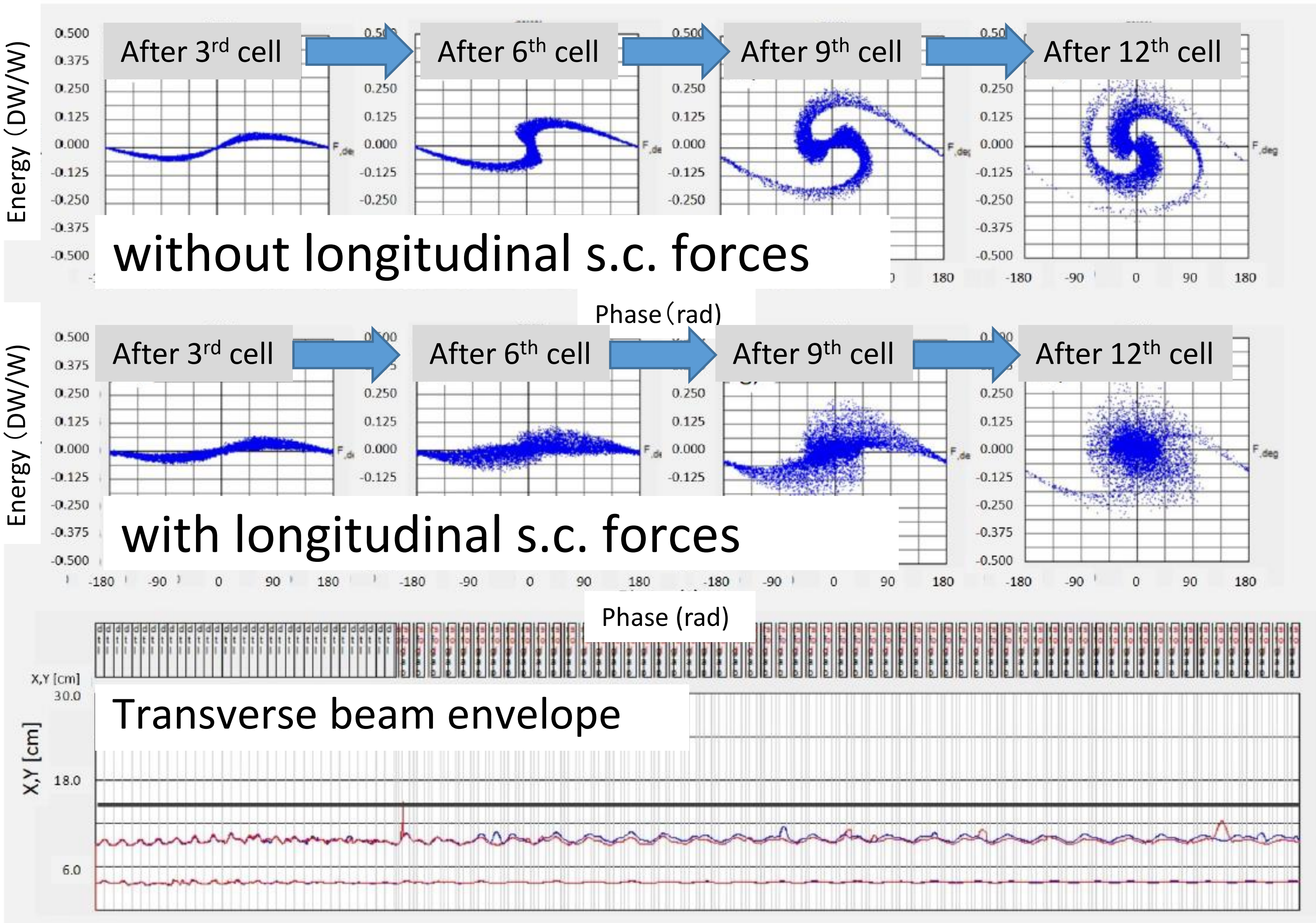


Transit Time Factor at injection



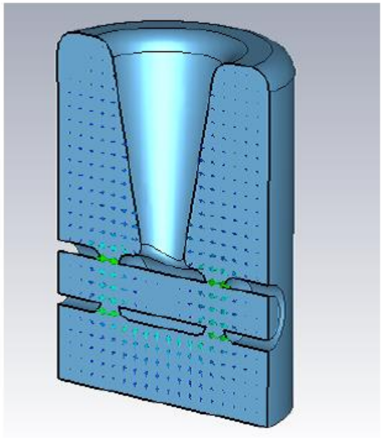
3D beam envelope simulation in the low β section

TRACK code (developed by P. Ostroumov, et al.,):
that includes the space charge effect and non-linear phenomena owing to this effect



Medium β section (5-40 MeV/u)

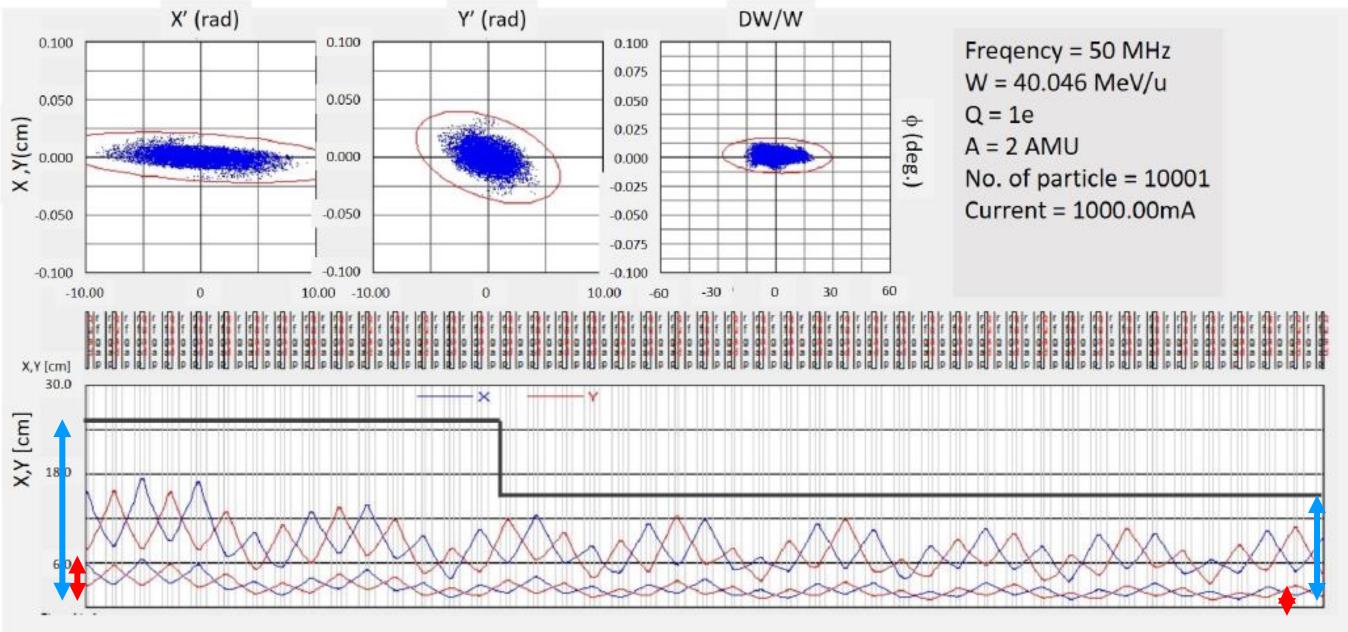
Structure of the cavity (44 quarter-wave resonator)



Basic parameters

Table III. Typical specifications of the rf cavity of the medium-β section .

Structure	QWR
Frequency (MHz)	50
Diameter of the outer cylinder (m)	1.16
Height of the outer cylinder (m)	1.62
Aperture radius (cm)	15-25
Maximum rf voltage per cell(MV)	1.24
Shunt impedance(Ω)	1.0×10^{12}
Q_0	2.0×10^{9}
Geometrical β	0.193
Transit time factor (@40 MeV/u)	0.74



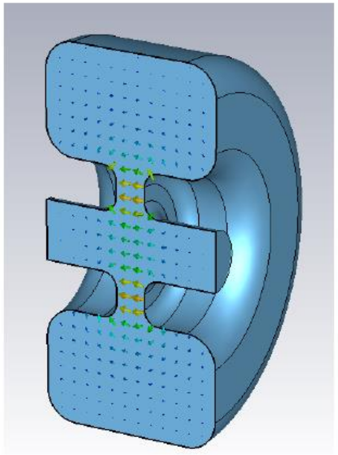
Results from 3D simulation

R(beam pies)/RMS
4(at entrance), 6 (at exit)
→ <1kW beamloss

Beam scrapers are placed between the sections, and further study will be made to suppress the beam halo.

High β section (40 – 200 MeV/u)

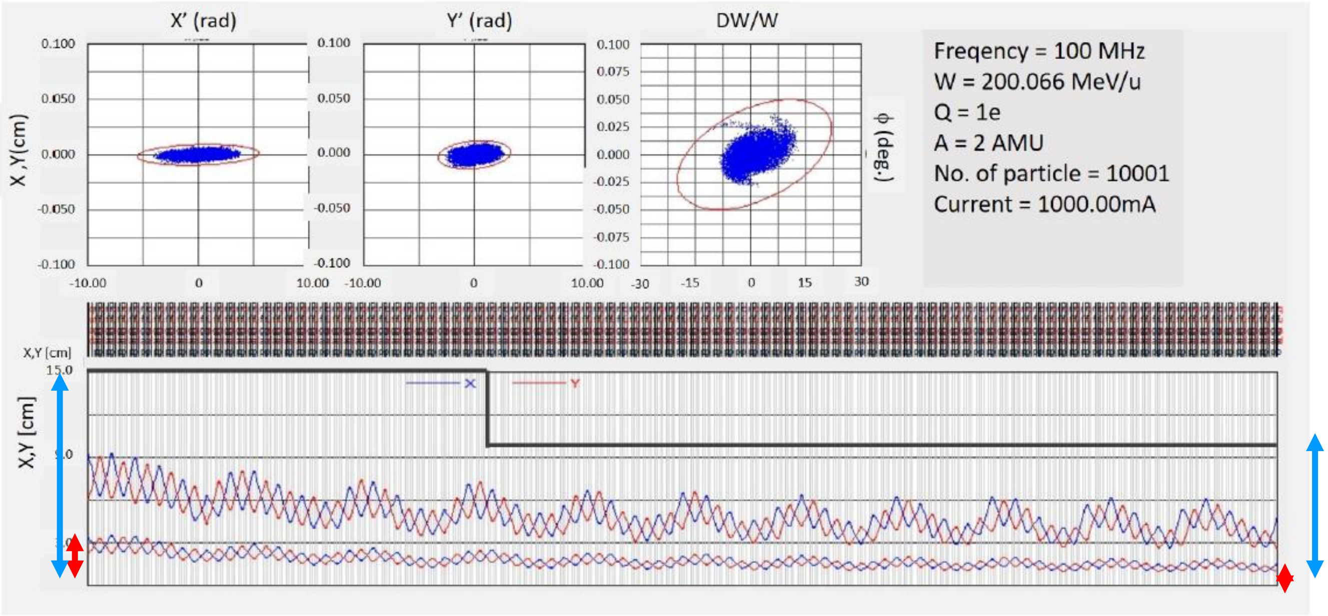
Structure of the cavity
(200 Reentrant cavity)



Basic parameters

Table IV. Typical specifications of the rf cavity for the high-β section.

Structure	Reentrant
Frequency (MHz)	100
Cavity diameter(m)	1.25
Aperture radius(cm)	10-15
Cavity length(m)	0.6
Maximum rf voltage per cell(MV)	2.3
Shunt impedance(Ω)	1.72×10^{11}
Q_0	1.2×10^9
Transit time factor (@200 MeV/u)	0.96



Results from 3D simulation

R(beam pies)/RMS
4(at entrance), 6 (at exit)
→ <1kW beamloss

Beam scrapers are placed between the sections, and further study will be made to suppress the beam halo.

Summary

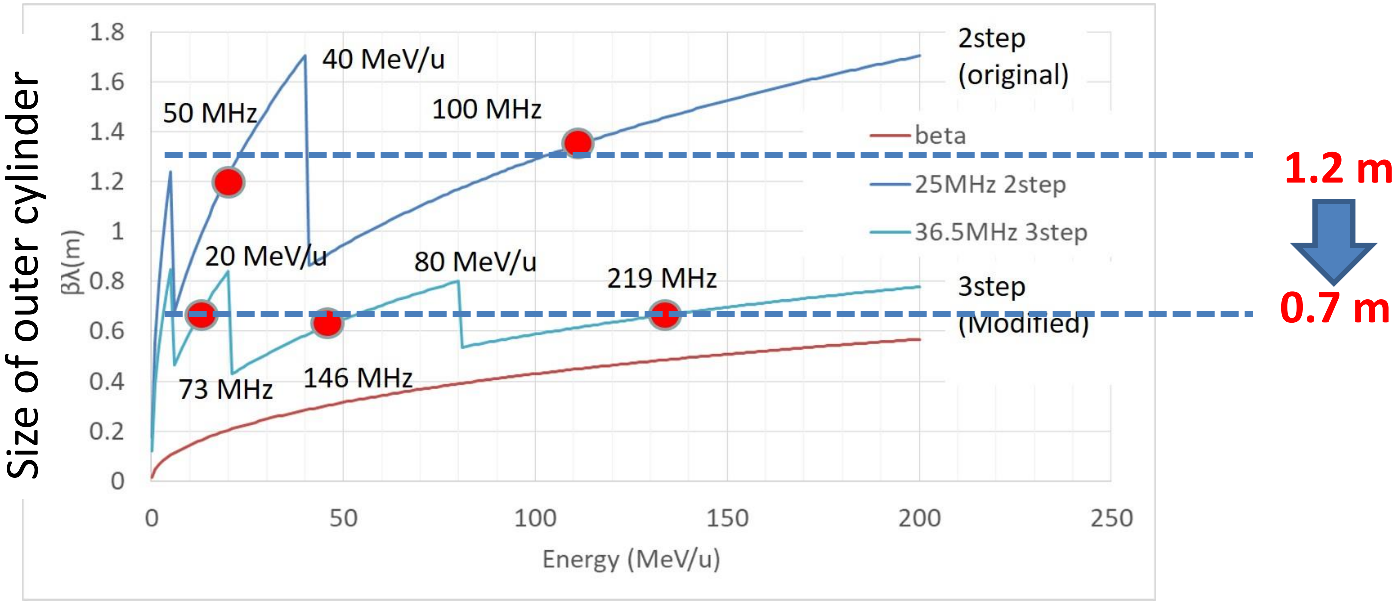
- Required specifications for nuclear transmutation of HLW
  - Deuteron ＞１A、 >100MW, 100MeV/u~200MeV/u
  - Large bore for high current from I.S. but limit of bore of RFQ
- 1 A class single cell linac was proposed
  - No RFQ, Single cell cavity with magnetic focusing.
  - Low-beta section: Single gap cavity with a superconducting solenoid.
    - Study on beam dynamics including space charge forces
    - Successful bunching of 1 A DC beam from the ion source
  - Medium-beta and High-beta section (beam dynamics, design study of the cavity)
- Future issues

Future issues

- **Issues for Accelerator physics**
  - Ion sources
    - Beam current limitation due to space charge force (Langmuir-Child limit)
    - Deuteron beam（Imax ~30 mA/1hole）
  - Beam dynamics
    - Dynamics in the longitudinal direction（at the entrance of low-β and medium-β）
    - Resonance
    - Beam halo
    - Rf acceleration
    - Beam loading
    - instability
- **Issues for Engineering**
  - RF source
    - Low frequency rf sources　～several 10MHz
    - high power　(beam power：～100MW)
    - Multi coupler：digital control
  - Energy saving（Improvement of efficiency of rf amp、permanent magnet.)
  - Radiation damage

What we are doing now.

- **Study on suppression of beam halo**
  - There are many sources of beam halo.
  - How to suppress space charge induced beam halo
  - Ion source will be set up for experimental study.
- **Practical solution for the SC cavities.**
  - More compact cavities
    - Frequencies. (25 MHz →36.5 MHz)
    - Frequency jump (2step → 3step)



Thank you for your attention.