Seeking for a novel fabrication technology to make a large-bore SRF-QWR cavity for 1-ampere class linac

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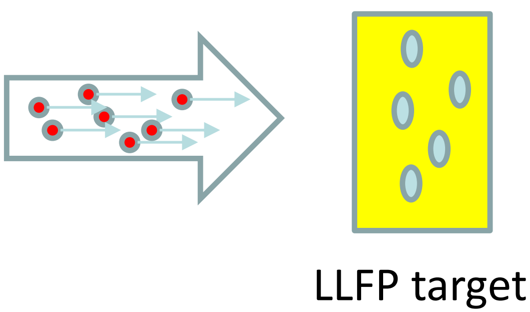
The Burden of Nuclear Waste

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**.

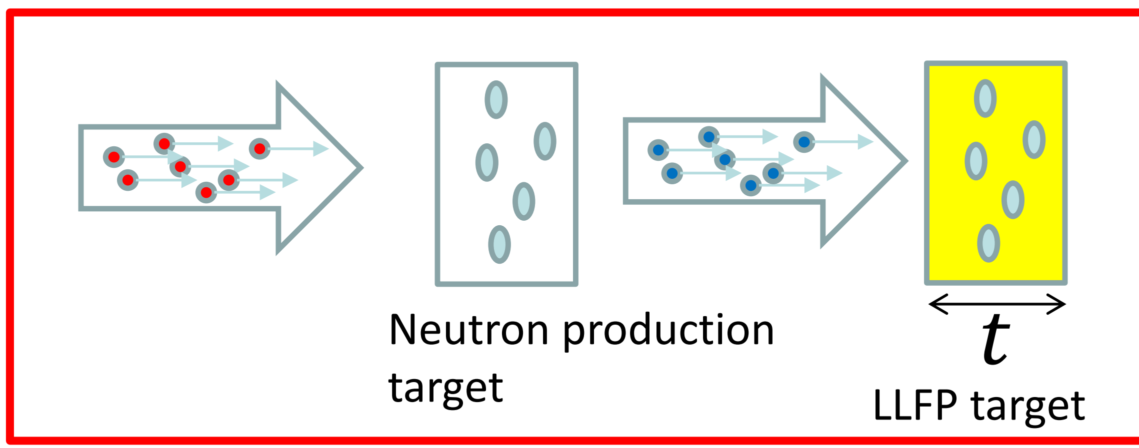
Nuclear transmutation by Deuteron

Direct irradiation



Neutron irradiation

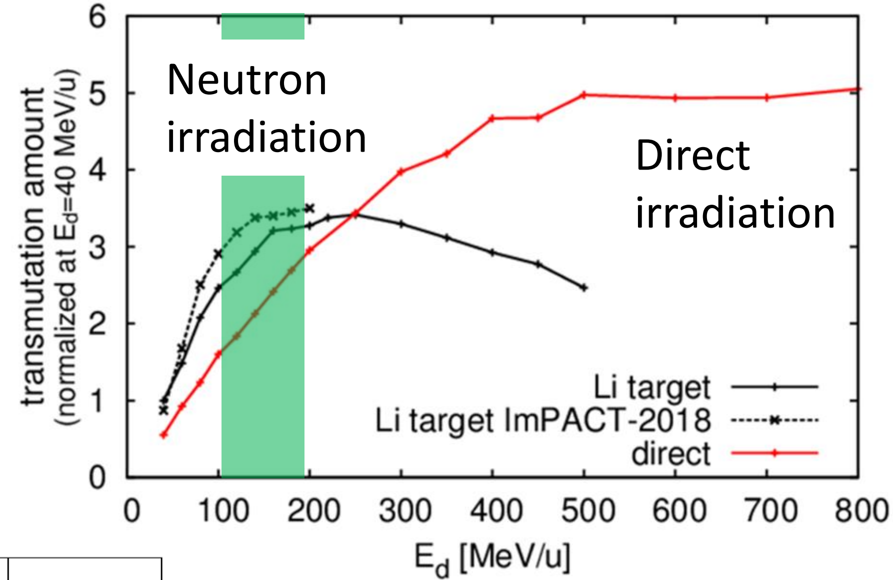
Thick *t* -> efficient transmutation

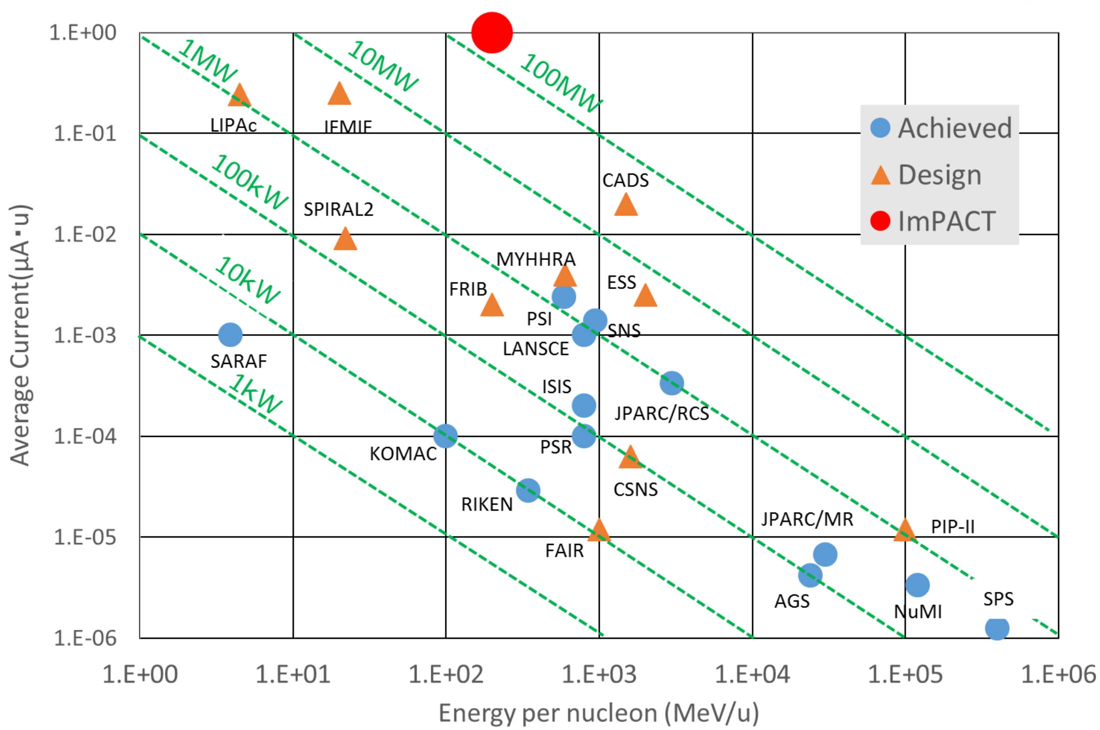


Accelerator for transmutation of LLFP

Requirements to the accelerator

- Particle : Deuteron
- Energy : 100-200 MeV/u
- Current : 1A
- Beam Power : 80MW-200MW x 2 (~100 MW class)

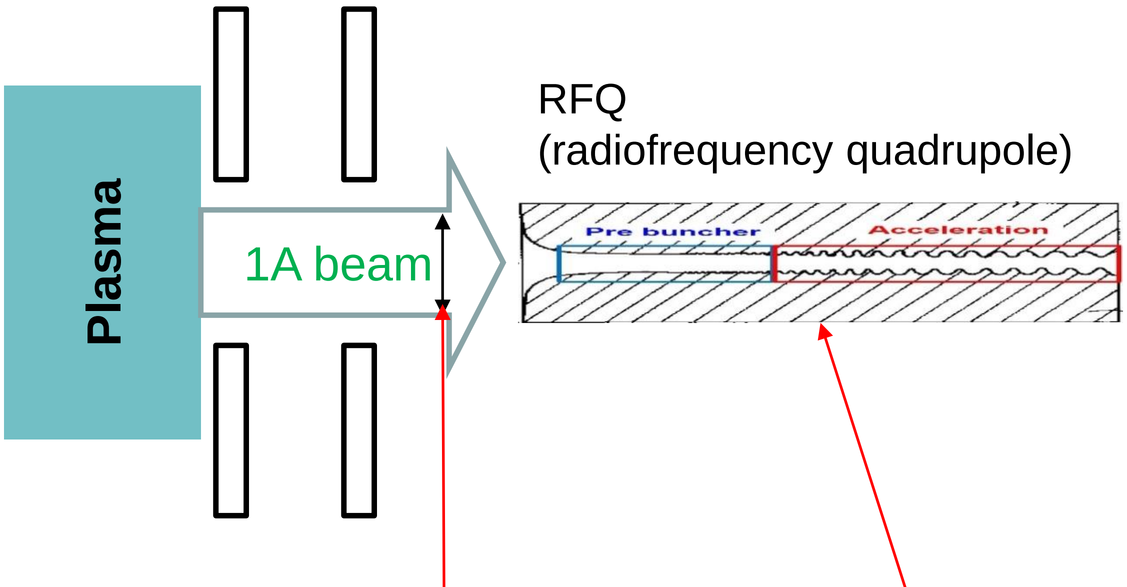


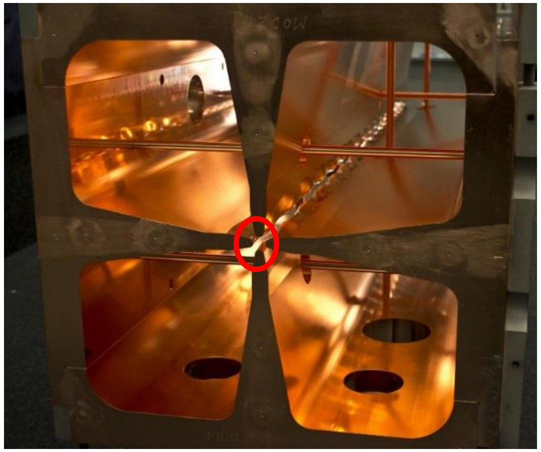


We need more than 100 times of the available maximum beam power in the world.

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.

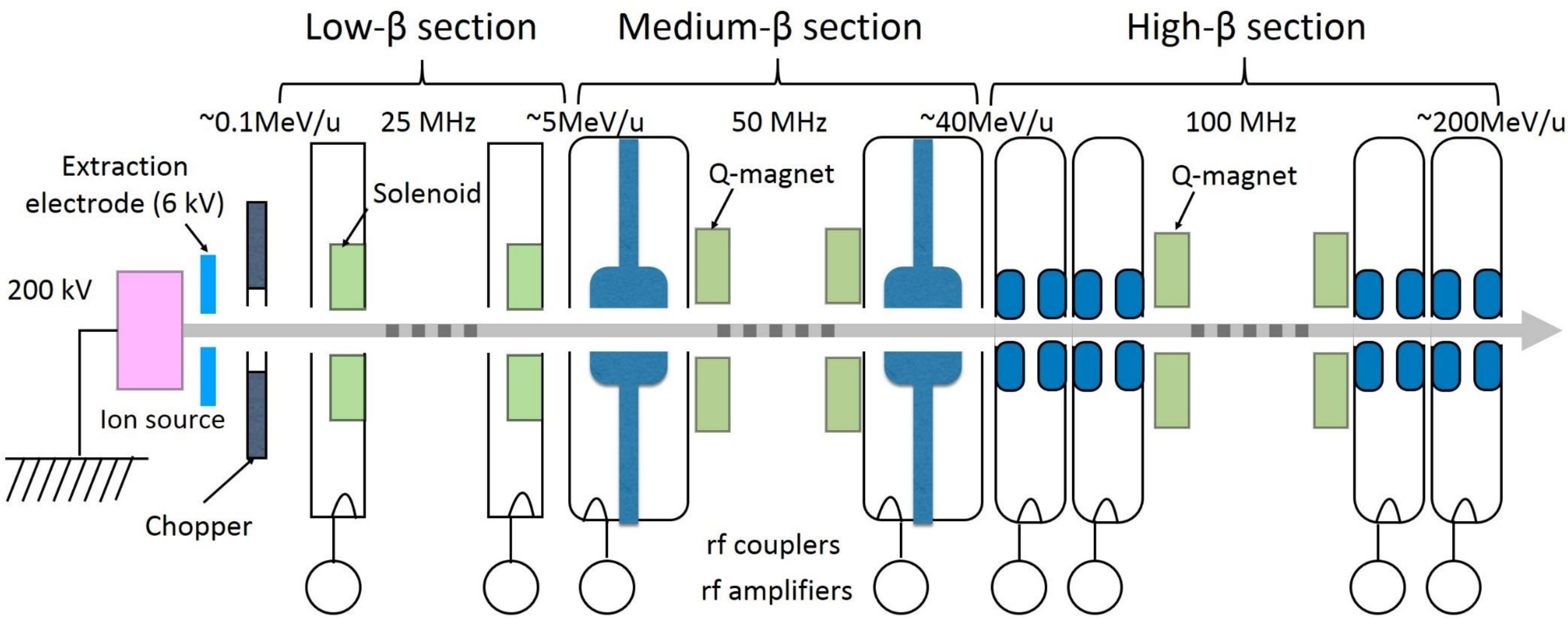
Size of 1A beam >10cmϕ >> 1cm: acceptance of RFQ

We can’t use RFQ ! !

Proposal of 1-ampere class single cell linac

Single-cell cavities + magnetic focusing elements

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.

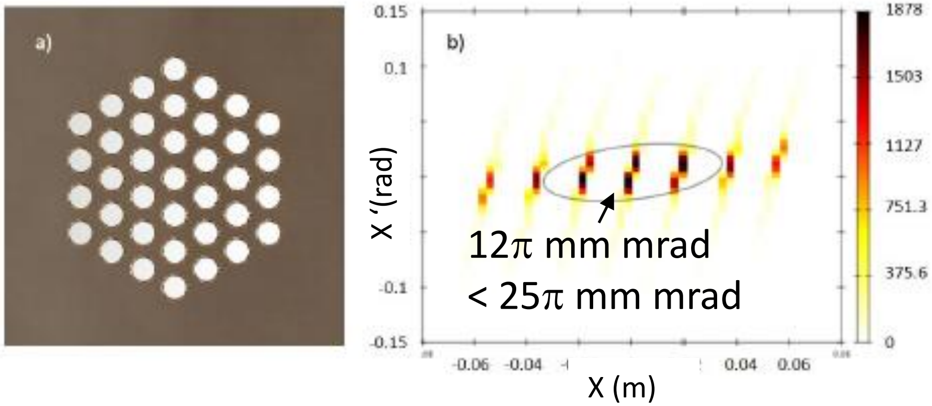


Ion source + cavities forLow β section

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.

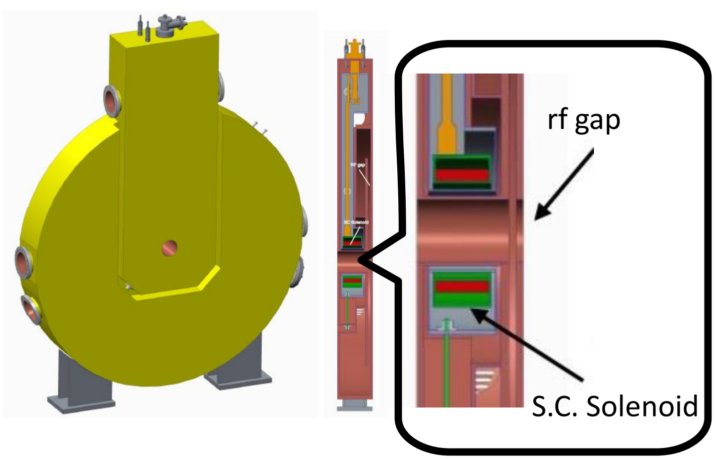
Multi-holes for beam extraction (14mmϕ x 37)

Emittance of extracted beam



Low β section: repetition of single gap cavity with S.C. solenoid which works like RFQ

Single gap cavity with capacitive plate (25 MHz)

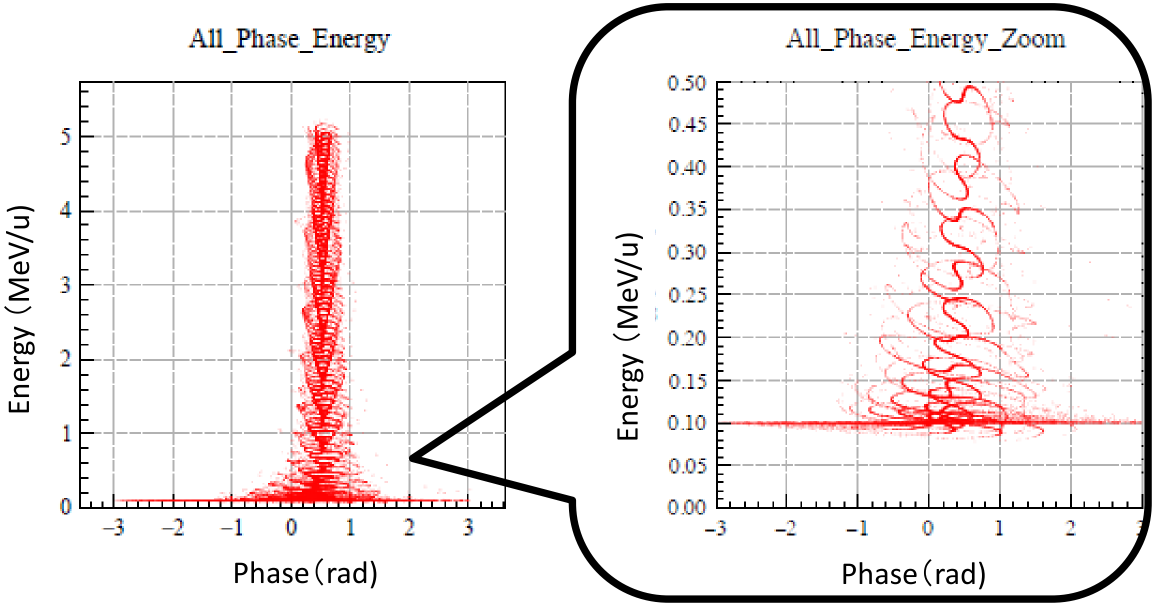


Basic parameters

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

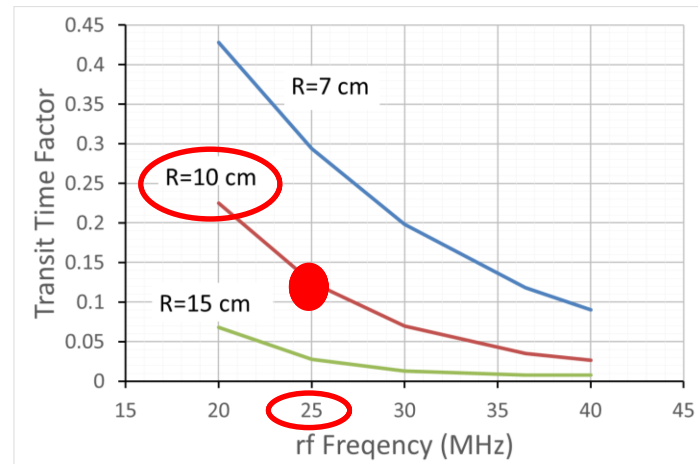
Low β section (adiabatic rf capture and TTF)

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

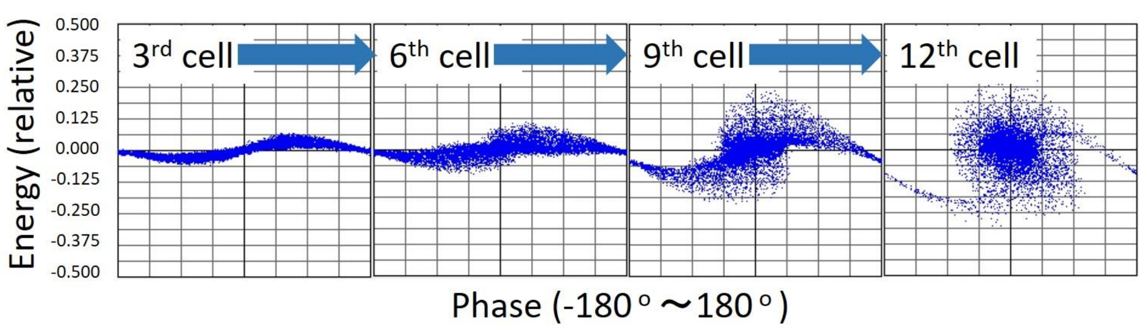


Large bore → broad E distribution
→ Low rf frequency is required
→ keep TTF larger

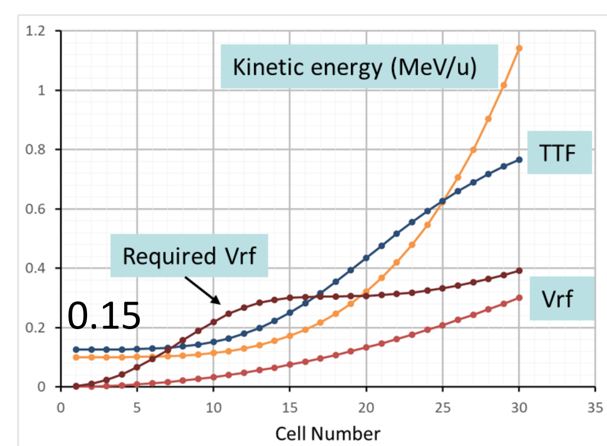
Transit Time Factor at injection



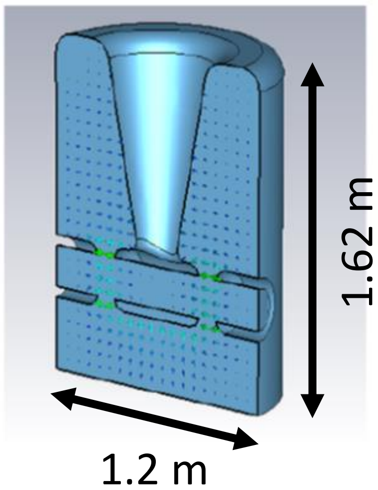
Longitudinal Beam behavior using PIC
with nonlinear space-charge forces



TTF and rf voltage



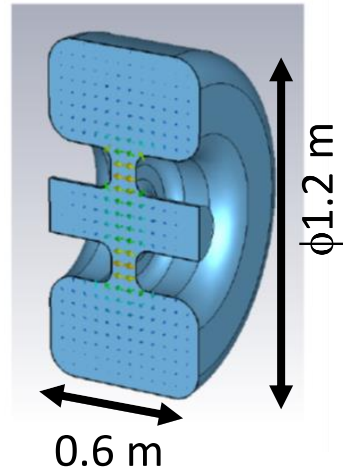
The cavities in the medium- and high- β sections



QWR at 50 MHz

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 voltager per cell (MV)	1.24
Shunt impedance (MΩ)	1.0×10^{12}
Q0	2.0×10^{9}
Geometrical b	0.193
TTF at 40 MeV/u	0.74

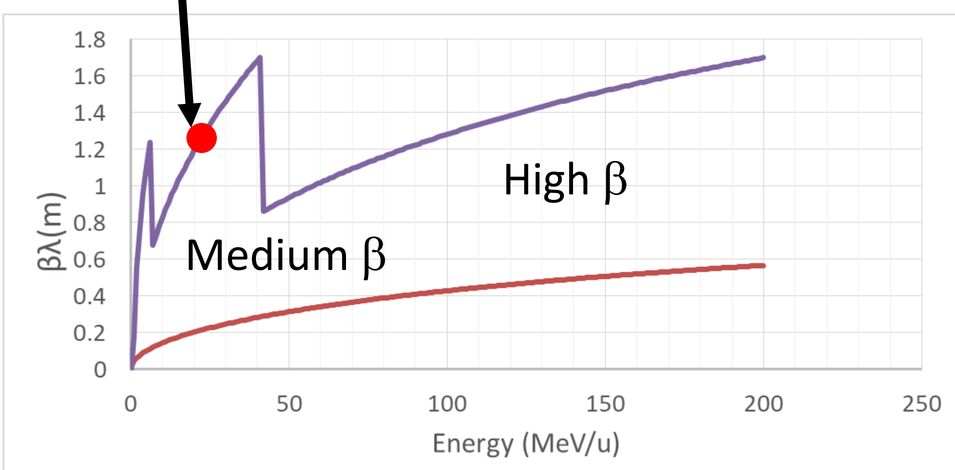
Inner surface area
=10 m^2
TESLA cavity 0.7 m^2
RIKEN SRILAC 2.3m^2



Reentrant at 100 MHz

Structure	Reentrant
Frequency (MHz)	100
Cavity diameter (m)	1.25
Cavity length (m)	0.6
Aperture radius (cm)	10–15
Maximum rf voltager per cell (MV)	2.3
Shunt impedance (MΩ)	1.72×10^{11}
Q0	1.2×10^{9}
Geometrical b	0.193
TTF at 40 MeV/u	0.96

Inner surface area
=5.3 m^2



Reduction in size of the cavities
1: increase rf frequency
2: number of frequency jumps
→(Sacrify)
1: TTF in the low energy (Large bore)
2: longitudinal acceptance

→Therefore, we like to seek for fabrication method for these size of cavities.

Comparison between Thin Nb film and Bulk Nb

Item	Thin Nb film	Bulk Nb
Thickness of Nb	1~10 μm	~mm [2.8 mm (Tesla)]
Magnetic shield	Not required	Required (in high frequency)
Thermal stability	Good (Cu thermal cond.)	Not so good
Q value at 4 K	Good	Good
Q value at 2 K	Developing (HiPIMS)	Good

Type (Inner surface area)	Thin Nb film(weight/thickness)	Bulk Nb (weight/thickness)
Medium beta		
QWR (10 m^2)	OK(0.857 kg/10 μm)[1)]	OK(429 kg/5 mm) [2)]
High beta		
Reentrant (5.3 m^2)	NG	OK(227 kg/5 mm) [2)]
HWR (7.4 m^2)	NG **-> OK??**	OK(317 kg/5 mm) [2)]
Elliptical (11 m^2)	OK [3)]	OK(472 kg/5 mm) [2)3)]

We select it.

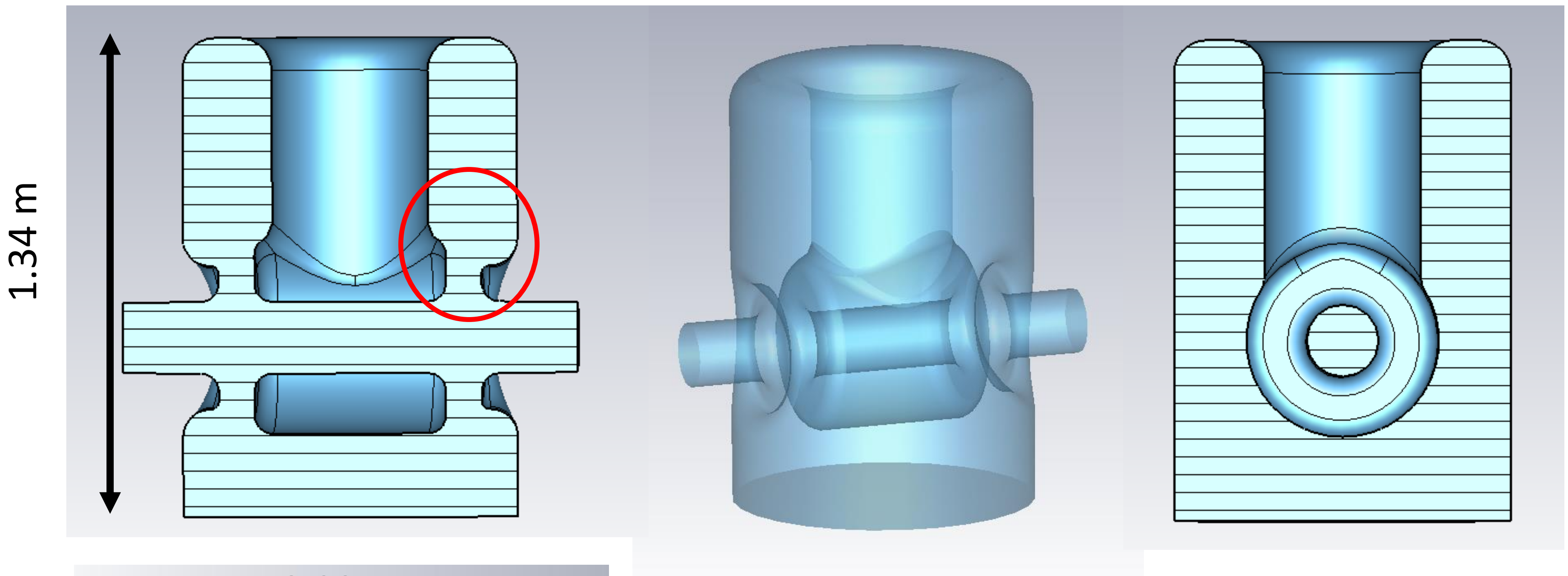
1) Twice of HIE-ISOLDE QWR.

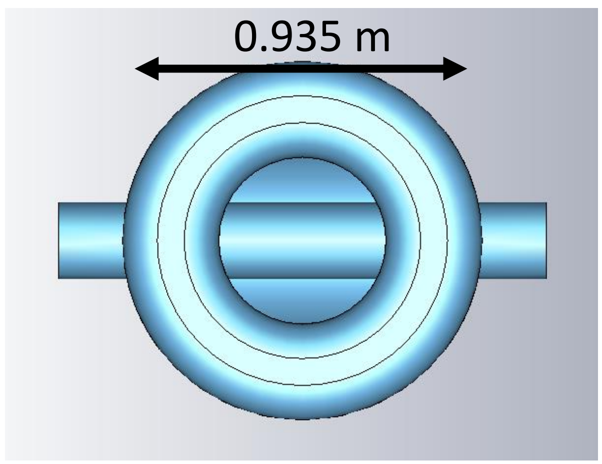
2) Hugh amount of Nb is required.

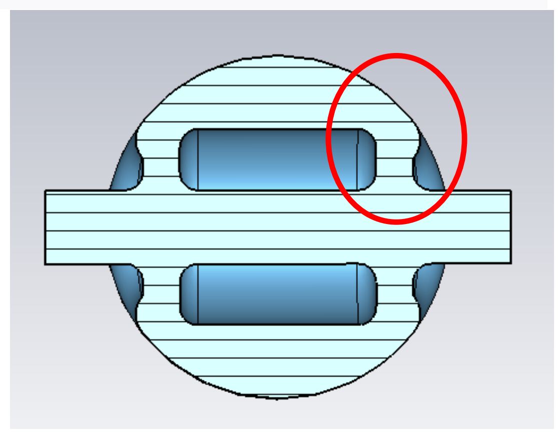
3) Too large cavity

QWR for thin Nb film method (medium β)

Area of inner surface=7.5 m^2







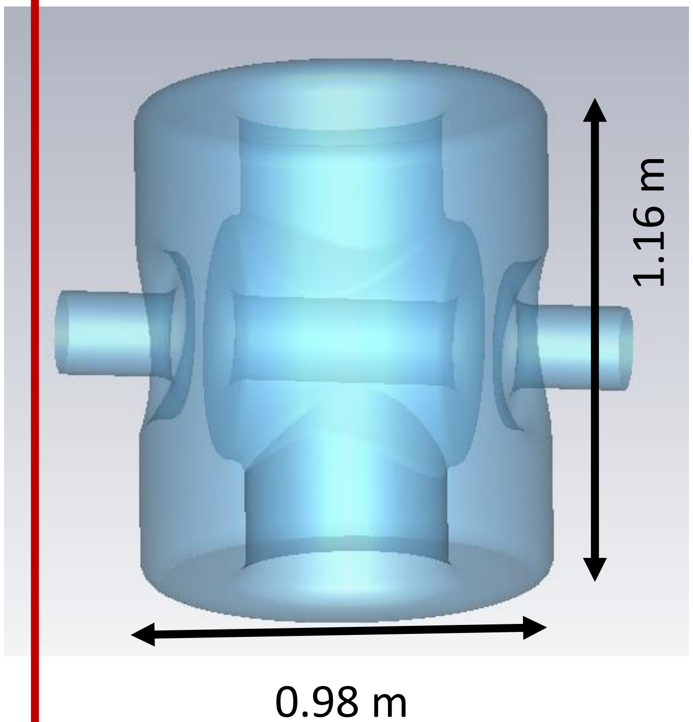
Simple and smooth shape is required for uniform coating.

◯ should be improved!

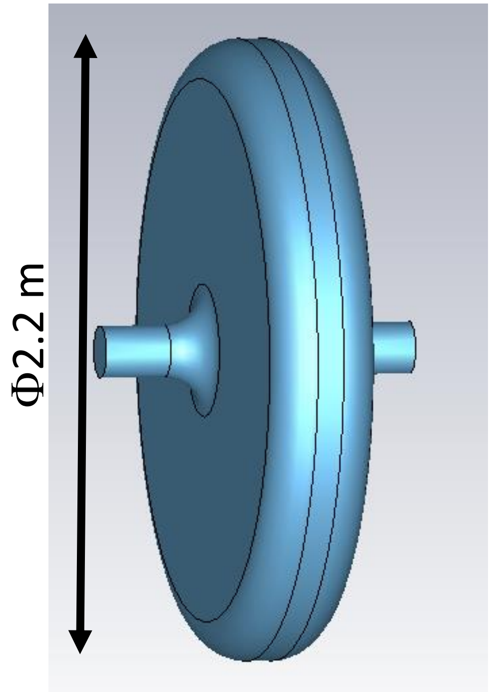
Size of the cavity is twice of that for HIE-ISOLDE. This extrapolation would be a big step for the coating technology!

Cavities for the high β section

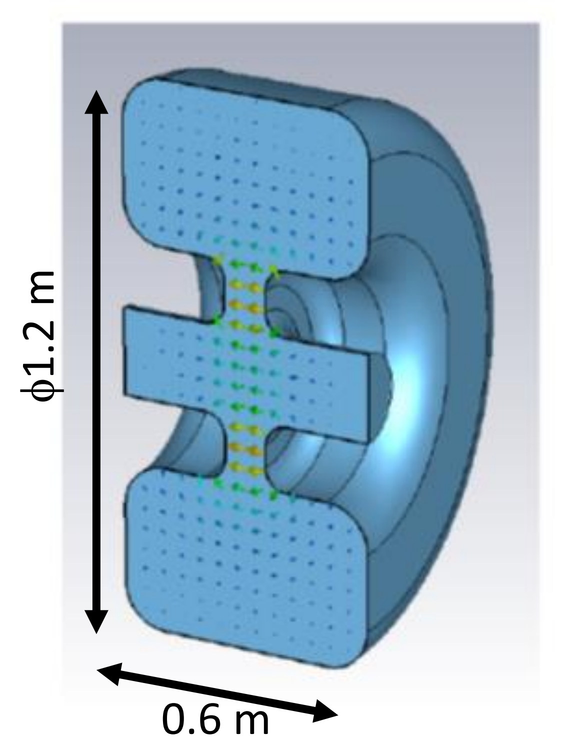
HWR (7.4 m^2)



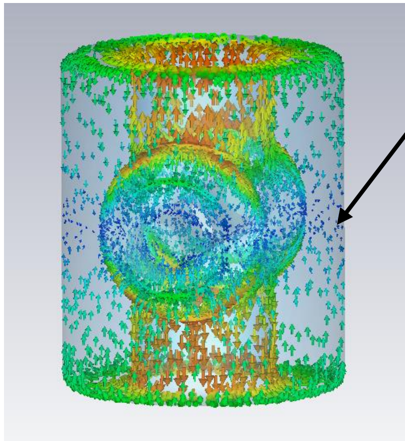
Elliptical (11 m^2)



Reentrant (5.3 m^2)



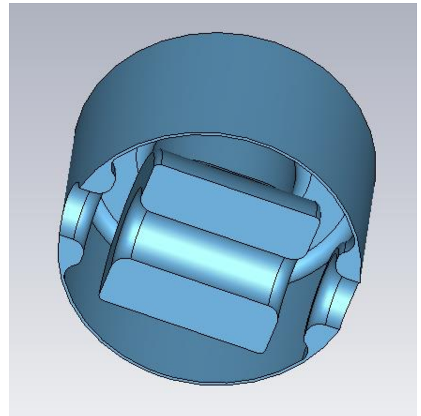
Possible to make HWR by connecting two QWRs?



No current in the symmetric plane

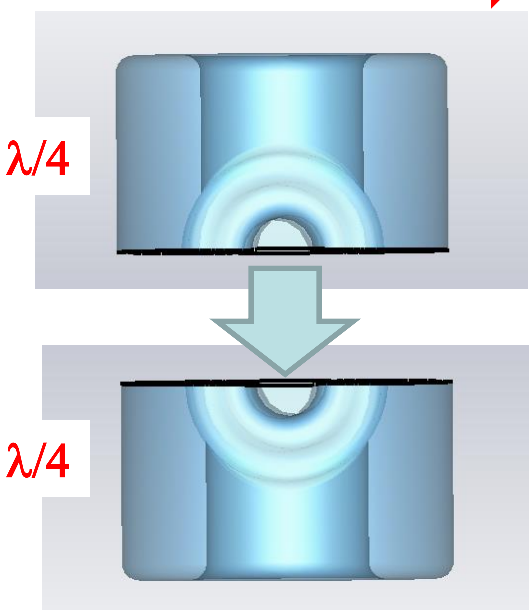
It can be divided to two parts which work as QWRs.

1: Two sets of the λ/4 cavity are made using thin Nb film method.

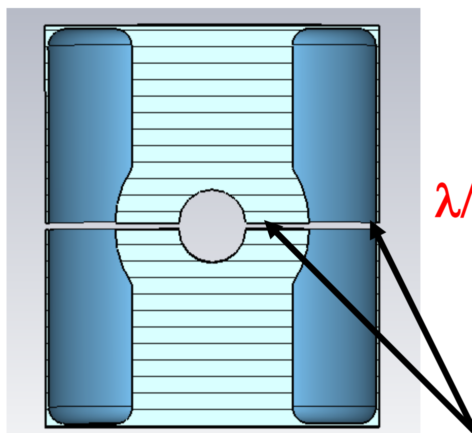


Coating: Feasible
RF and Beam dynamics: should be assessed

2: Assembled



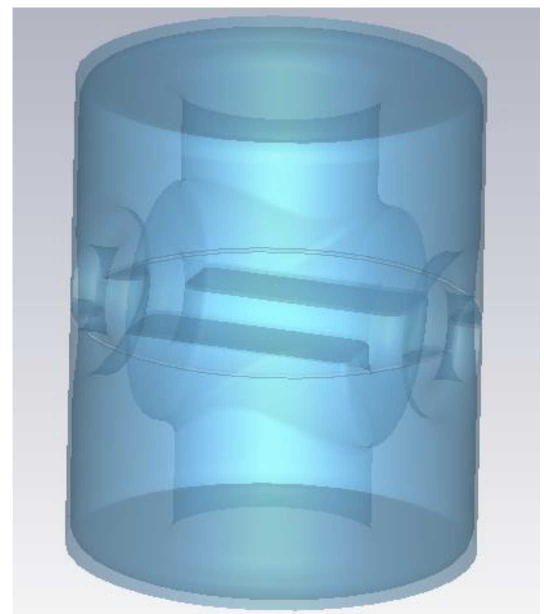
3: Connecting



λ/2

Something superconducting?

4: HWR is made.

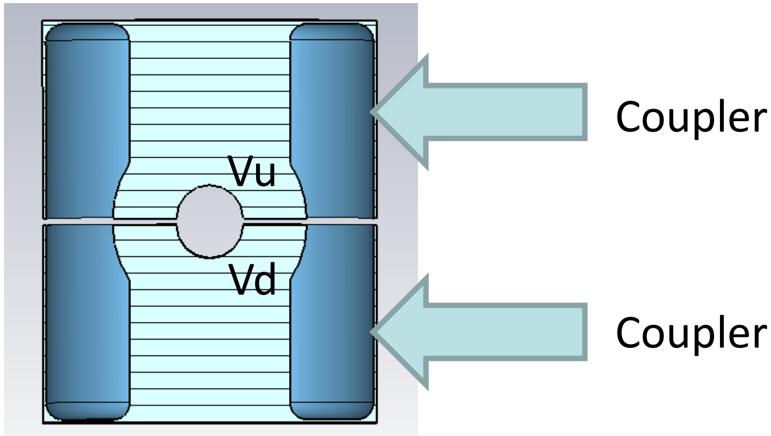


Summary

- We proposed **1 ampere class single cell linac to realize nuclear transmutation of High level nuclear waste using accelerator.**
- 1-ampere class single cell linac (Deutron, 1A, 200 MeV/u)
  - **no RFQ**
  - **Can accept large size beam**
  - **Low frequency rf system**
- **Large bore rf cavity**
  - Two types of the cavities should be fabricated.
- **Thin Nb film on Cupper vs. Bulk Nb**
  - General comparison
  - **Simple and smooth shape of QWR for thin Nb film method (x2 HIE-ISOLDE)**
  - **Proposal of a new fabrication method of HWR using thin NB film method**

Thank you for your attention!

Coupler position



- **Vu = Vd . If not, beam is bent vertical.**
- **To keep symmetry, positions of two couplers should be symmetric.**

No welding after coating