# Construction of a Cryogenic Gas Cell for Multinucleon Transfer Reactions at HIAF

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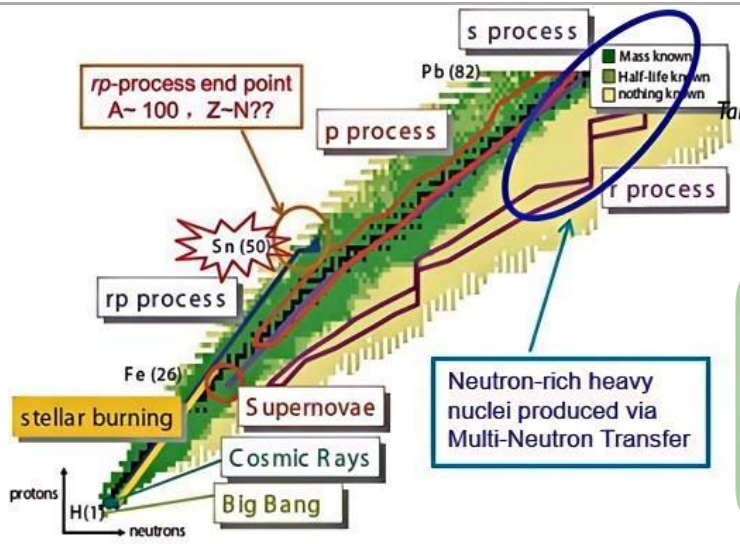
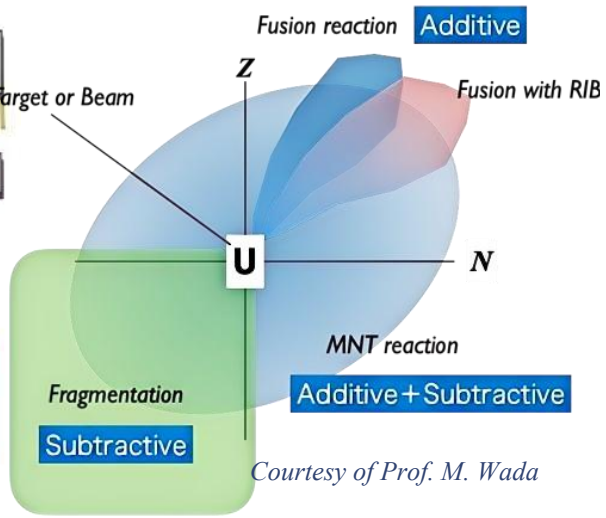
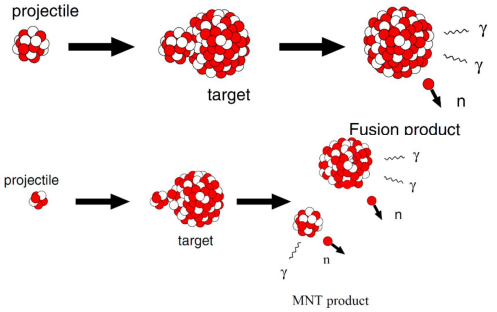
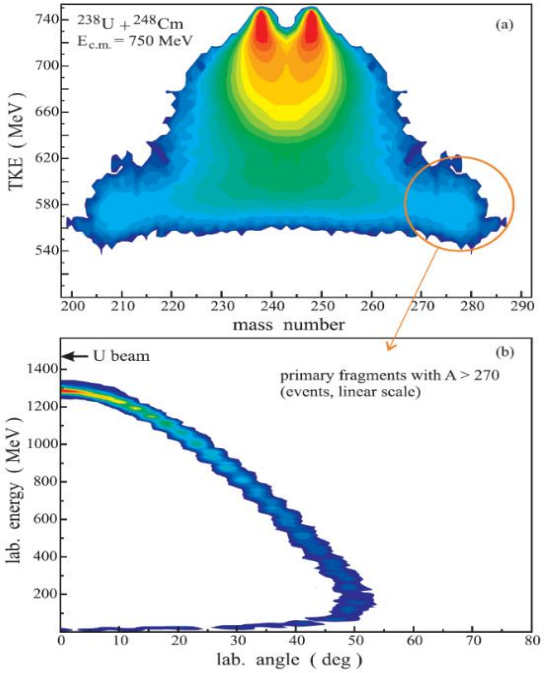



*M. Arnould, S. Goriely, Prog. Part. Nucl. Phys. 112, 103766 (2020).*




*Courtesy of Prof. M. Wada*



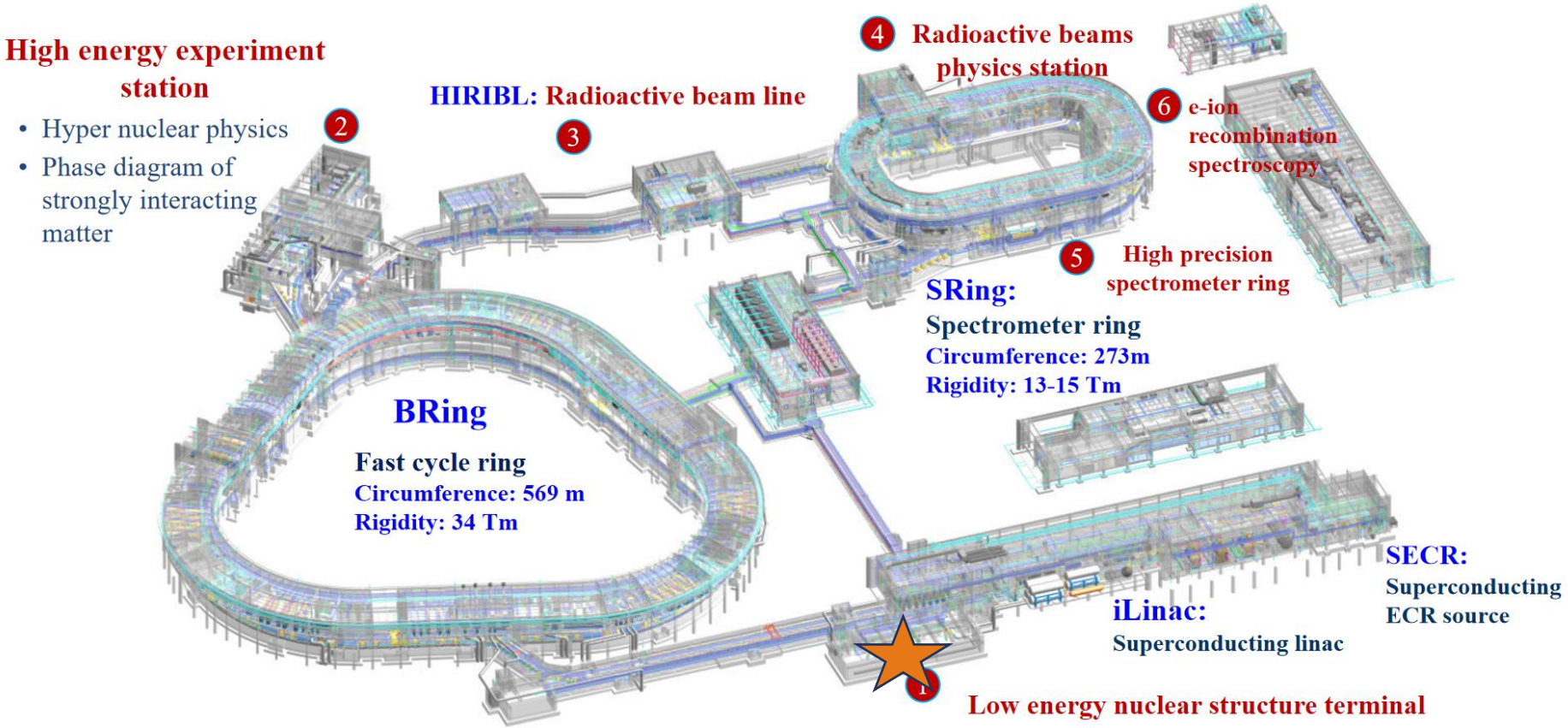

*Zagrebaev & Greiner, PRC 83, 044618 (2011)*

- **r-process produces neutron-rich nuclei**

**Goal:**
**Produce and study neutron-rich nuclei multinucleon transfer(MNT) reactions**

**Broad distributions**

**Efficient stopping and ion extraction are required !**


High energy experiment station
• Hyper nuclear physics
• Phase diagram of strongly interacting matter
2
HIRIBL: Radioactive beam line
3
4 Radioactive beams physics station
6 e-ion recombination spectroscopy
5 High precision spectrometer ring
SRing:
Spectrometer ring
Circumference: 273m
Rigidity: 13-15 Tm
BRing
Fast cycle ring
Circumference: 569 m
Rigidity: 34 Tm
SECR:
Superconducting ECR source
iLinac:
Superconducting linac
1
Low energy nuclear structure terminal

# Why helium ?

*Charge exchange in helium* $M^{q+} + He \rightarrow M^{(q-1)+} + He^{+}$

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H | | | | | | | | | | | | | | | | | He |
| Li | Be | | 1+ | | 2+ | | 3+ | | | | | B | C | N | O | F | Ne |
| Na | Mg | | | | | | | | | | | Al | Si | P | Se | Cl | Ar |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| Cs | Ba | | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| Fr | Ra | | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| Ac | Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |

Highest ionization energy

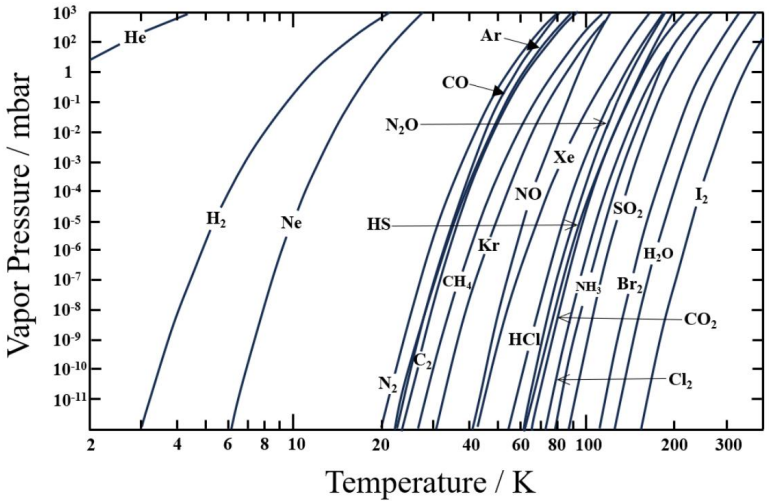
↓

Low charge states (1+, 2+, 3+)

↓

Easy ion extraction

# Why Cryogenic Helium ?



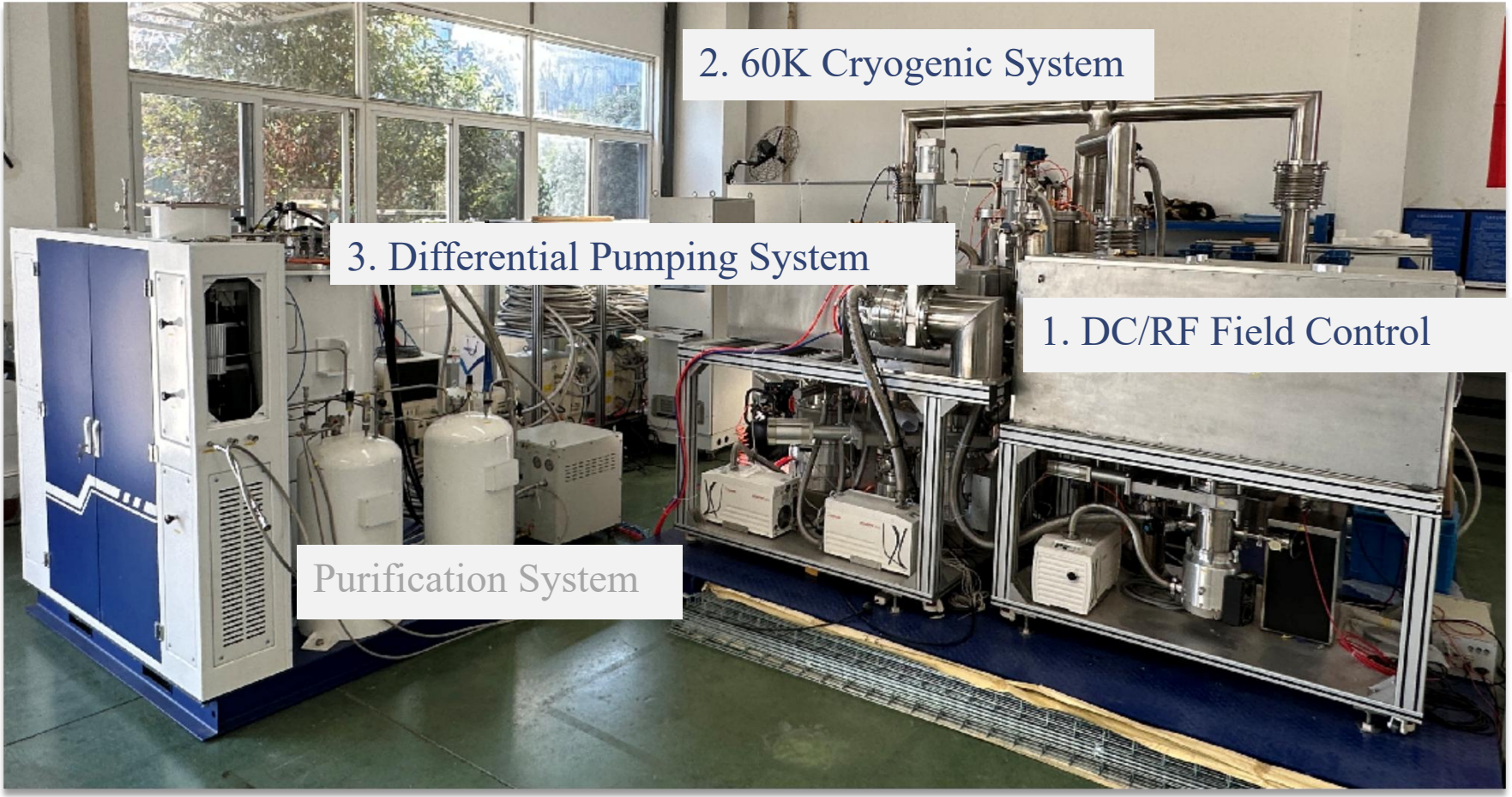

$O_2$ / $H_2O$ freeze out

↓

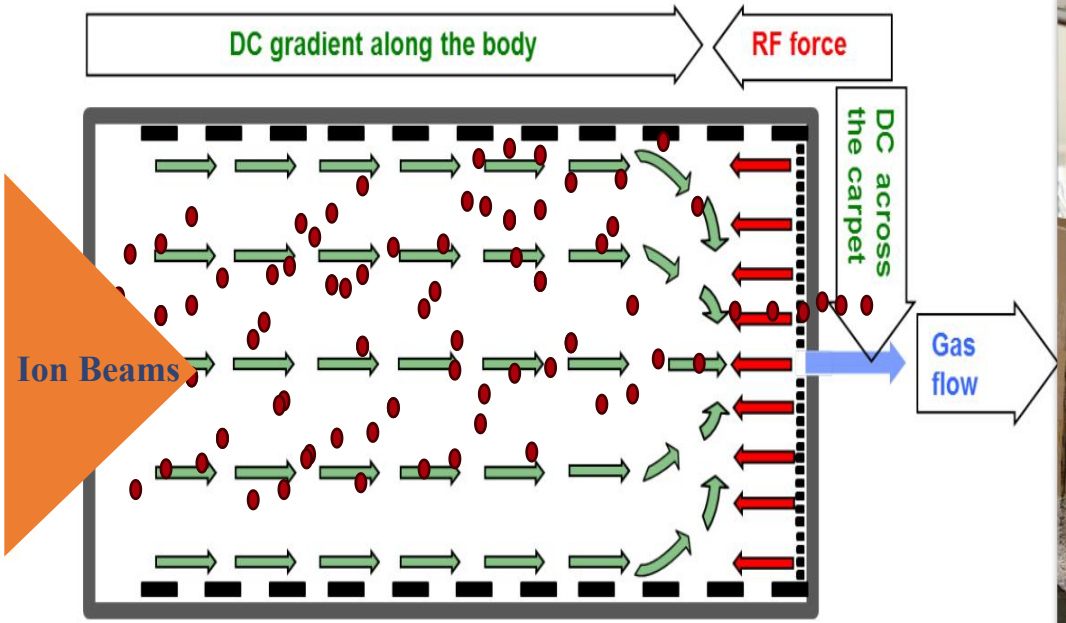
Cleaner helium environment

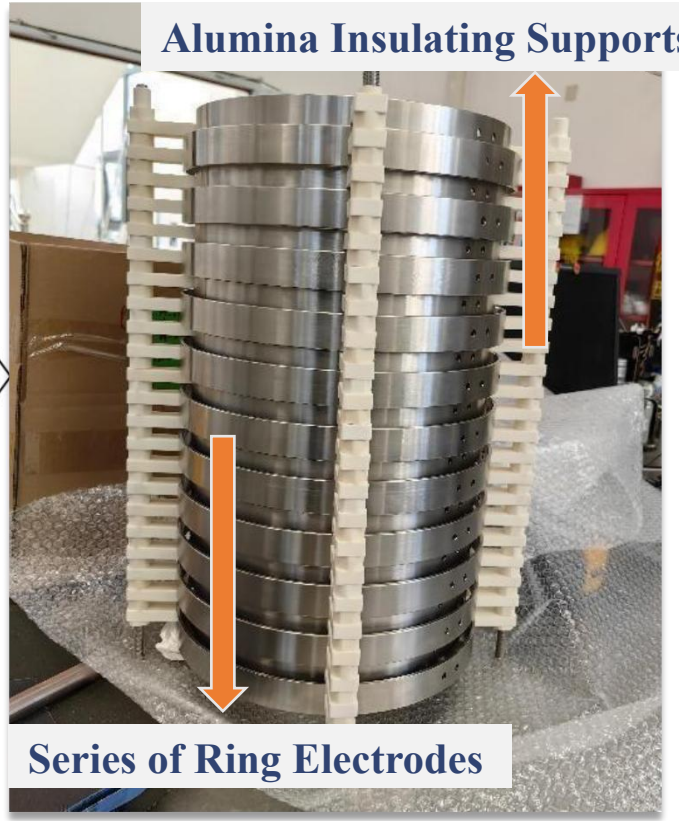
↓

Less ion neutralization


2. 60K Cryogenic System
3. Differential Pumping System
1. DC/RF Field Control
Purification System

# Working Principle of the DC Filed



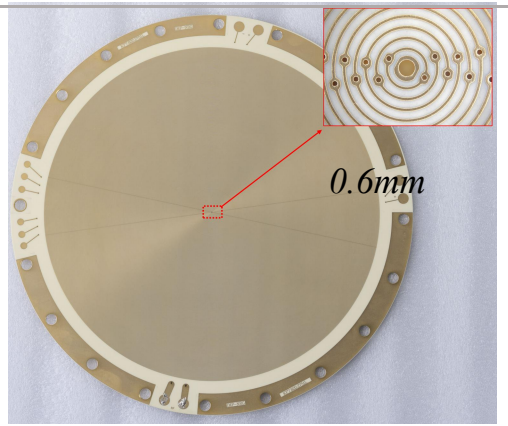



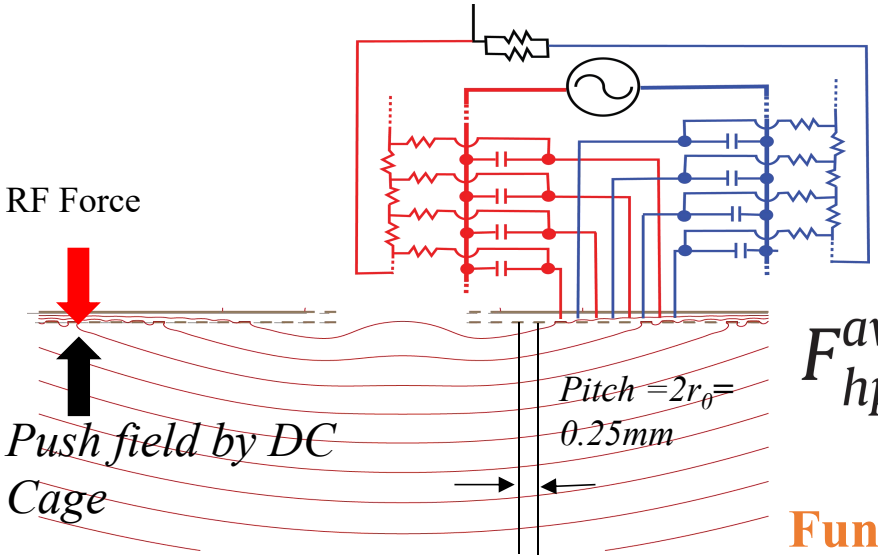

**Function:**

**Axial transport of ions**

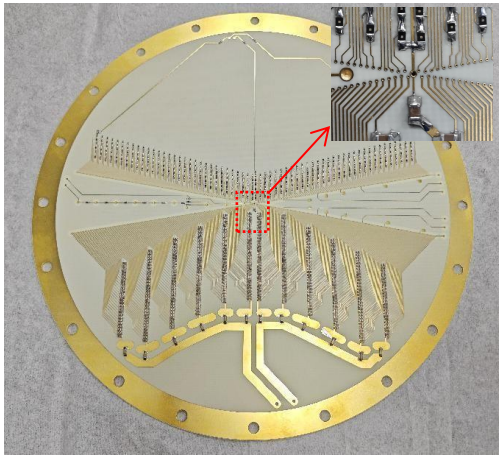
# Principle of RF Carpet Ion Transport

- RF electrodes generate equipotential field distribution
- RF pseudo-potential repels ions
- DC gradient transports ions



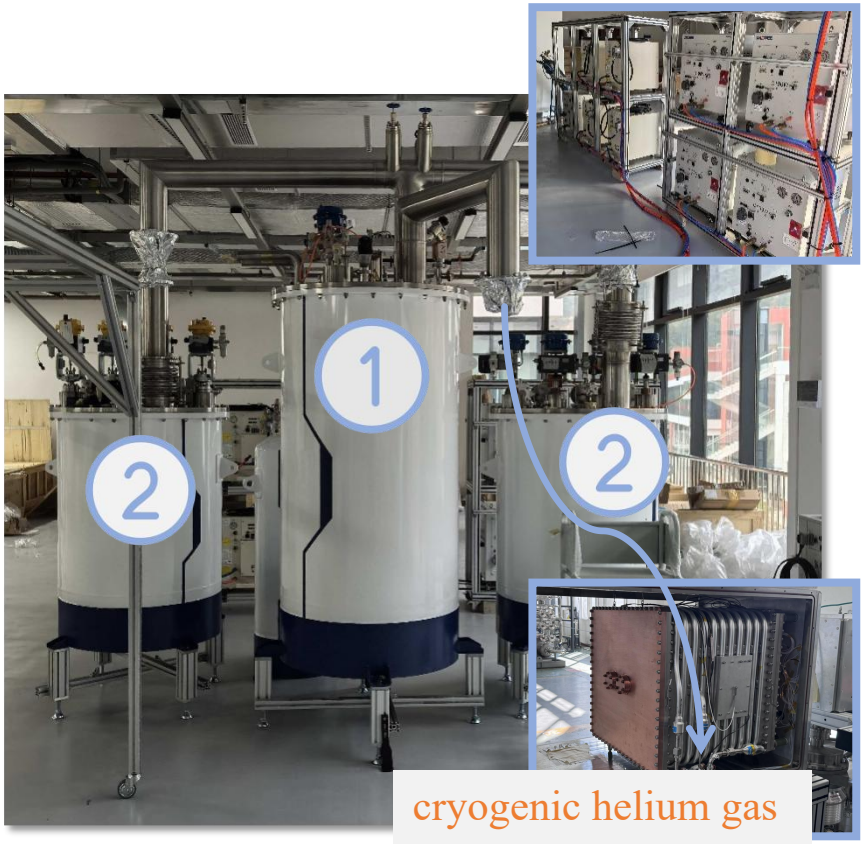




$$F_{hp}^{avg} = m\mu^2 \frac{V_{RF}^2}{r_0^3}$$



**Function:**
**Confine and extract ions**

*RF Carpet Ion Transport Simulation Based on SIMION*

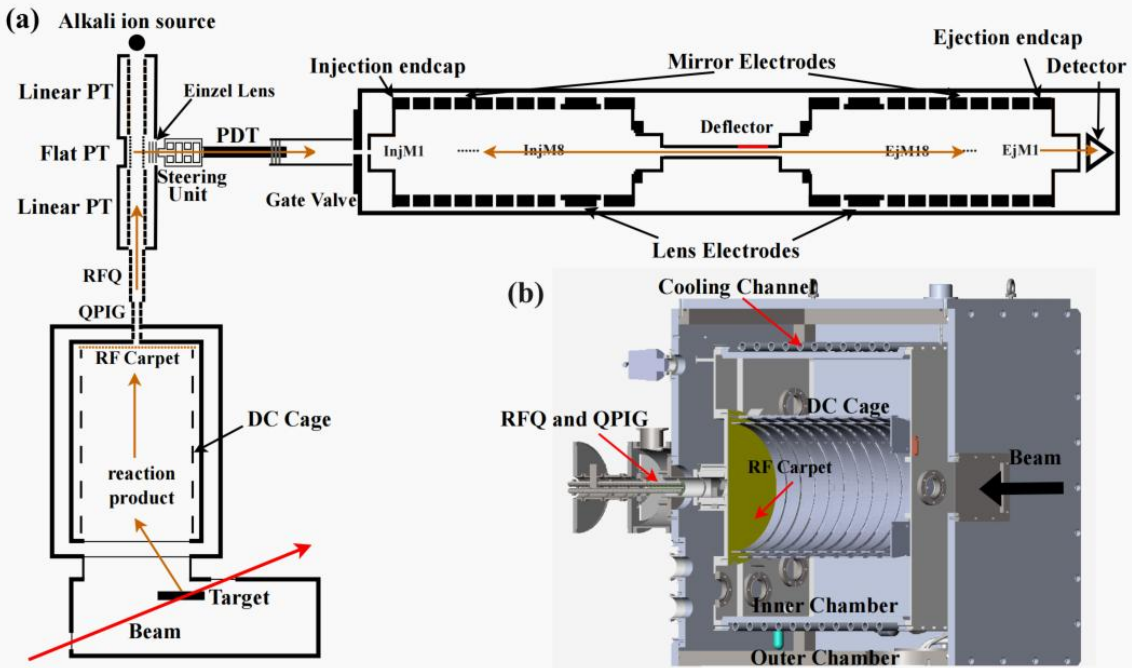



Laboratory setup

1. Liquid nitrogen pre-cooling
↓
2. Cryocoolers
↓
3. Helium gas circulation

**Function:**
**Maintain a stable and clean 60 K helium environment**

**Facilitate a smooth transition from the high-pressure environment of the gas cell to the high-vacuum environment required for the MRTOF.**

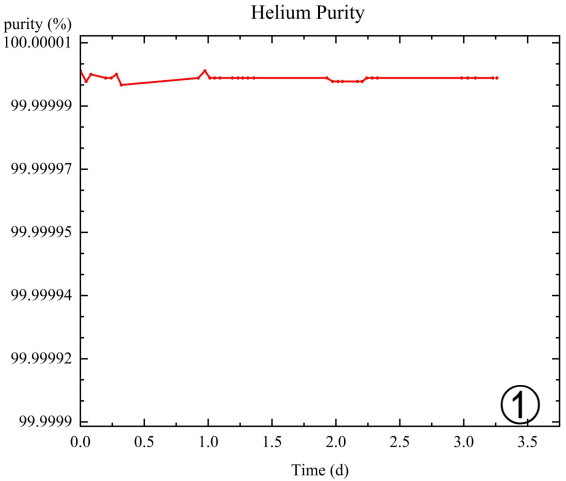


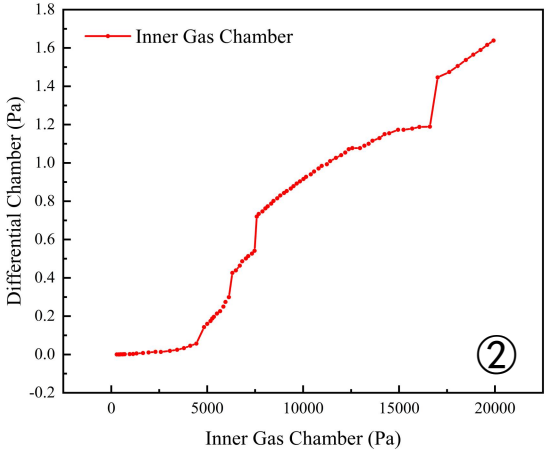

## Two Stages of Differential Pumping:

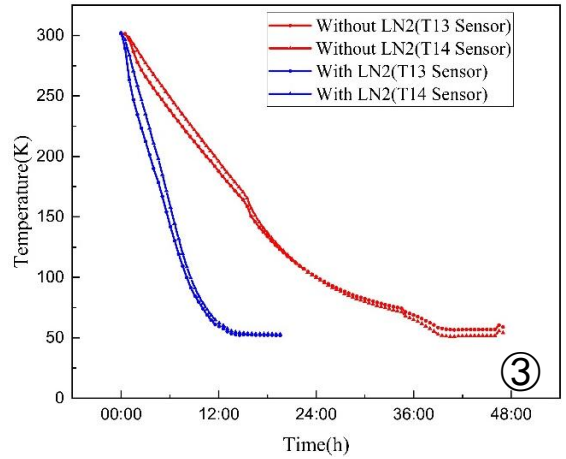
① 0.6 mm orifice

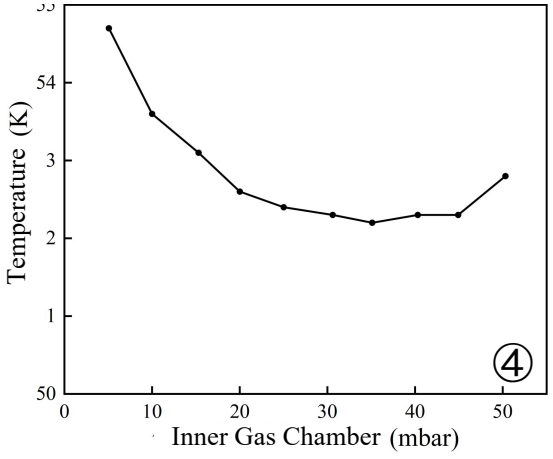
② turbo-molecular pumps

- Leybold TVi850 (850 L/s) × 2
- Leybold MAG W1300 iP (1100 L/s) × 2
- Leybold MAG W2200 iP (2050 L/s) × 2
- Leybold ECODRY 25/35 plus (25/35 $m^3/h$) × 6



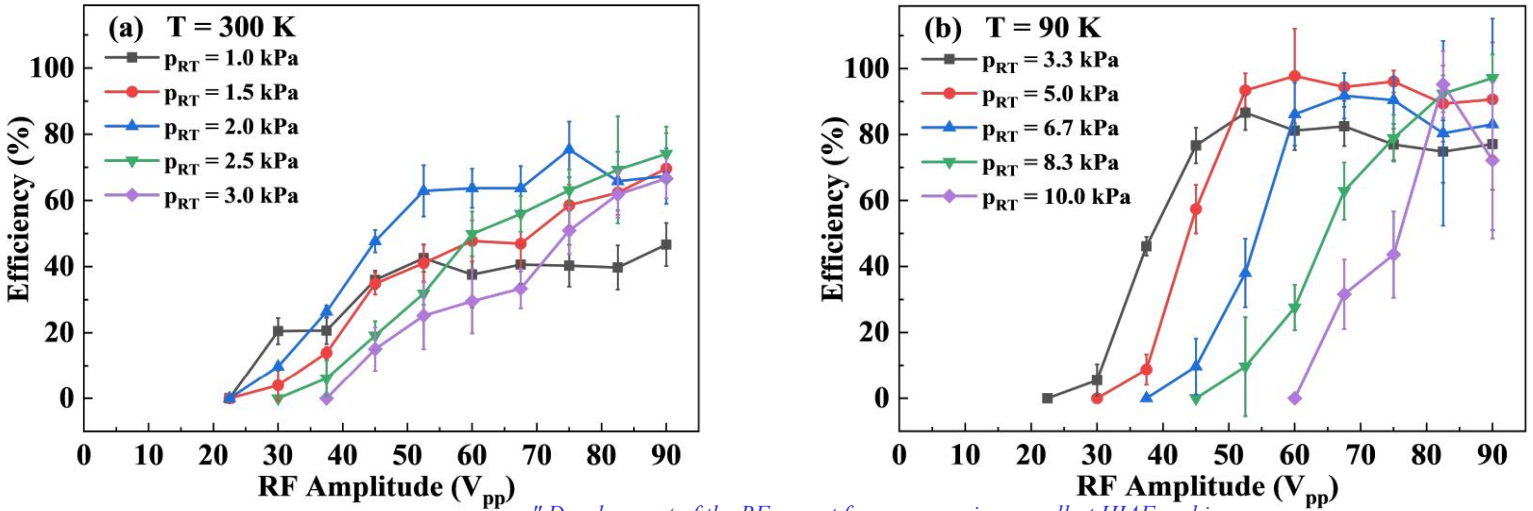

① High-purity helium

② 4-order pressure reduction

③ Fast cool-down

④ Stable 60K operation

**All subsystems meet the design requirements and are ready for ion-extraction experiments.**

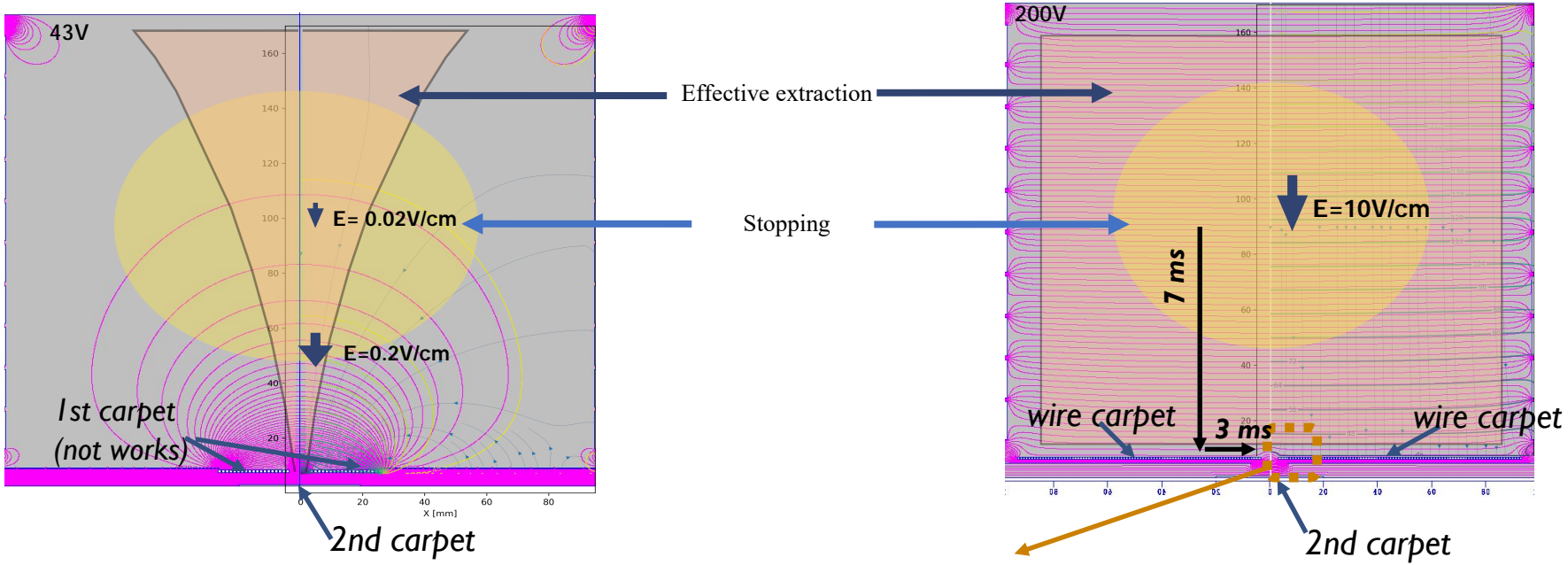



*" Development of the RF carpet for a cryogenic gas cell at HIAF and ion transport simulations" —— accepted by Nuclear Science and Techniques.*

- Ion-extraction efficiency of the RF carpet with $^{133}Cs+$ ion source.
- Observed clear RF amplitude threshold for efficient extraction; efficiency saturates post-threshold.
- Experiments at T=300 K and T=90 K, under varying He pressures
- Max. efficiency: **43-75% at 300 K** vs. **87-98% at 90 K.**

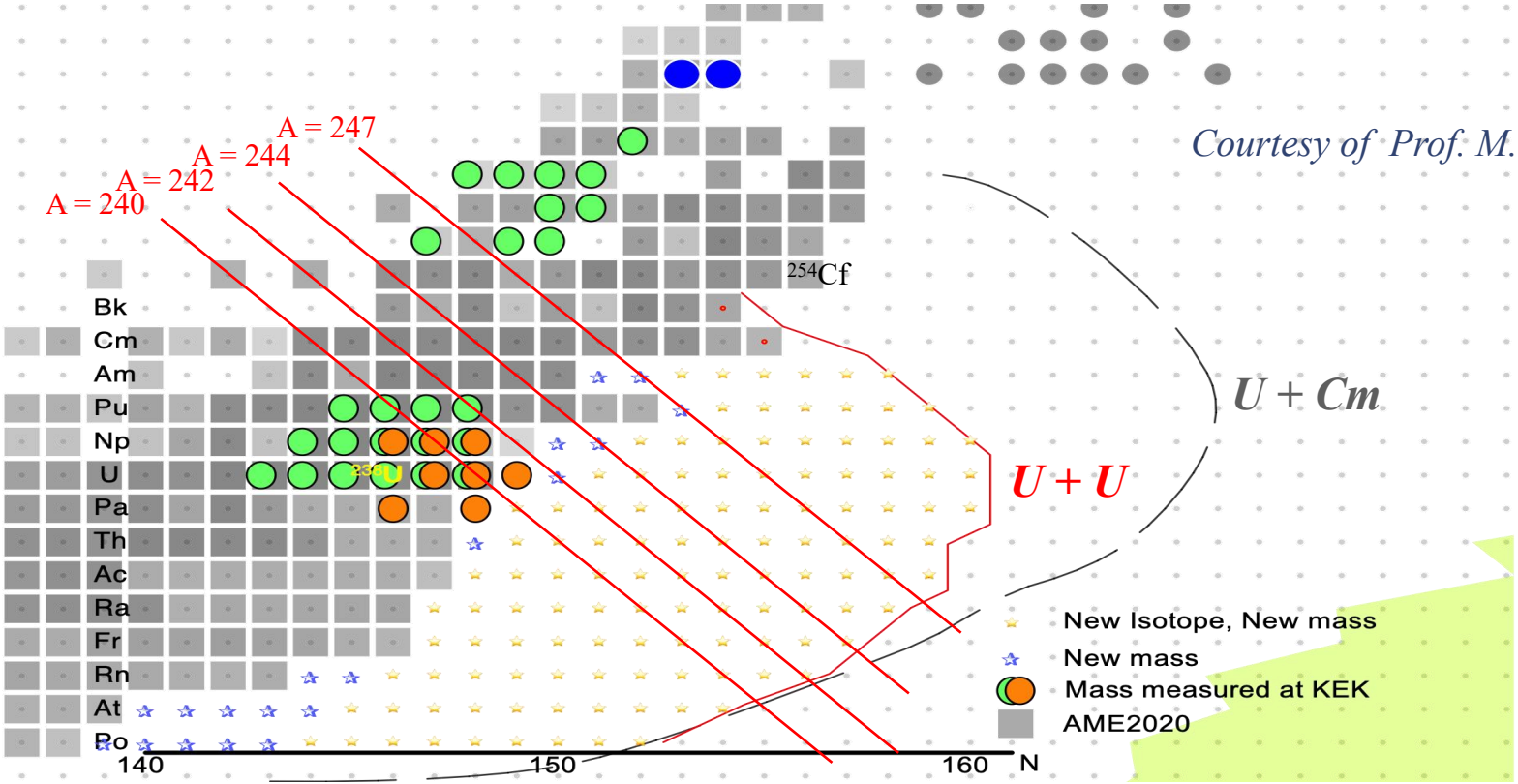
# Update of the gas cell ----wire RF carpet

Wada Michiharu




- ✓ Faster ion transport
- ✓ Space-charge suppression
- ✓ >10^7 pps

# With 150 pnA U beam on U target, 1% total efficiency, ~100 new isotopes

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