KEK isotope separation system for β-decay spectroscopy of r-process nuclei

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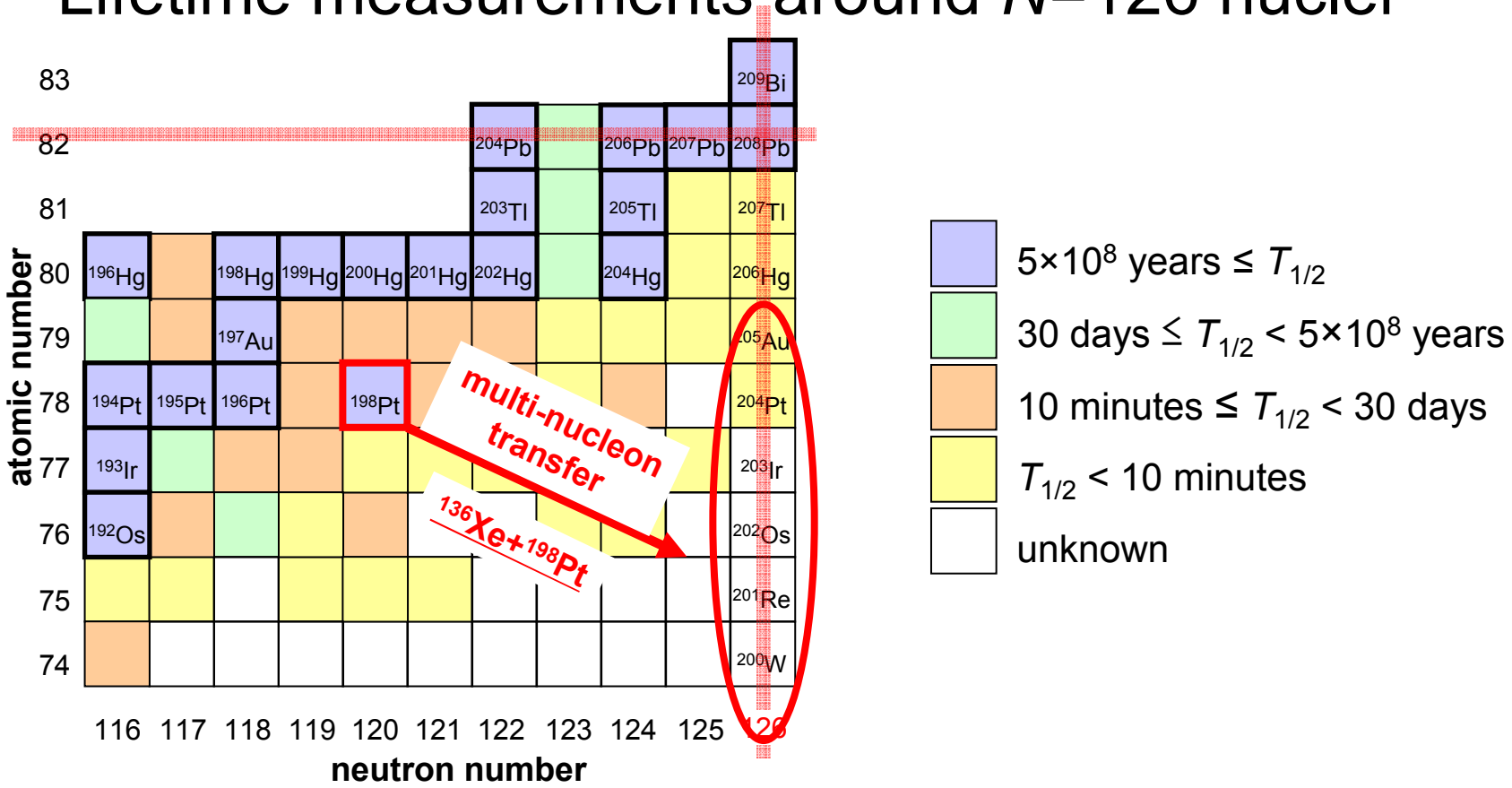
1. Outline
2. Multinucleon transfer reaction of ^{136}Xe+^{198}Pt
3. Gas catcher system for collection and separation
4. Detection system for lifetime measurements
5. Summary

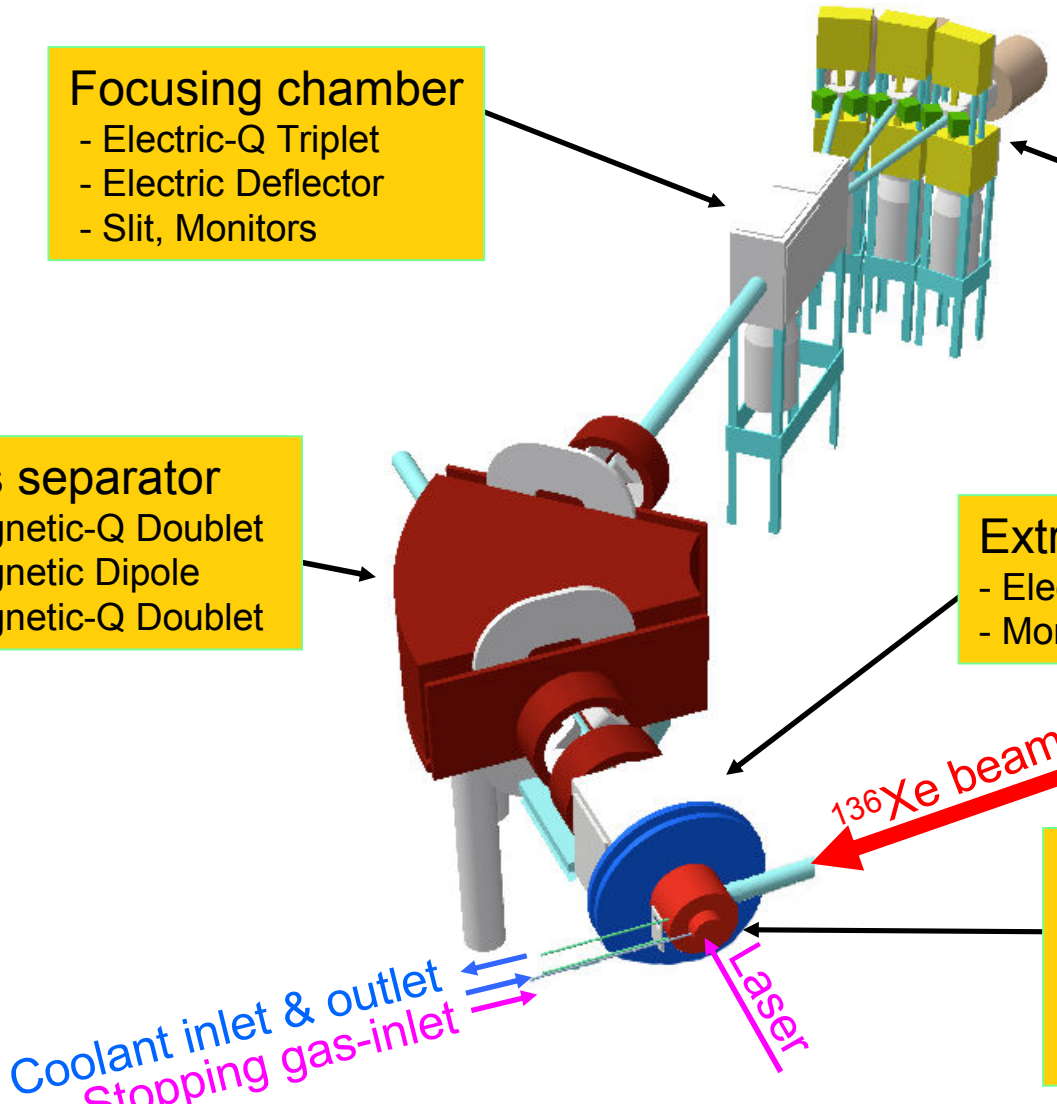
Lifetime measurements around *N*=126 nuclei



- Lifetime measurements of *N*=126 nuclei in our 5-year project since 2010
- Multinucleon transfer (MNT) reaction to access *N*=126 nuclei

  C.H. Dasso et al., Phys. Rev. Lett. 73 (1994) 1907.
  V. Zagrebaev and W. Greiner, Phys. Rev. Lett. 101 (2008) 122701.
  L. Corradi et al., J. Phys. G: Nucl. Part. Phys. 36 (2009) 113101.
- From ^{204}Pt down to ^{200}W by ^{136}Xe+^{198}Pt MNT reaction

KEK isotope separation system



Focusing chamber
- Electric-Q Triplet
- Electric Deflector
- Slit, Monitors

Detection system
- 3 detector stations
  : tape-transport system
  : Multi-layered plastic scintillators
  : Ge detectors
- β-decay spectroscopy

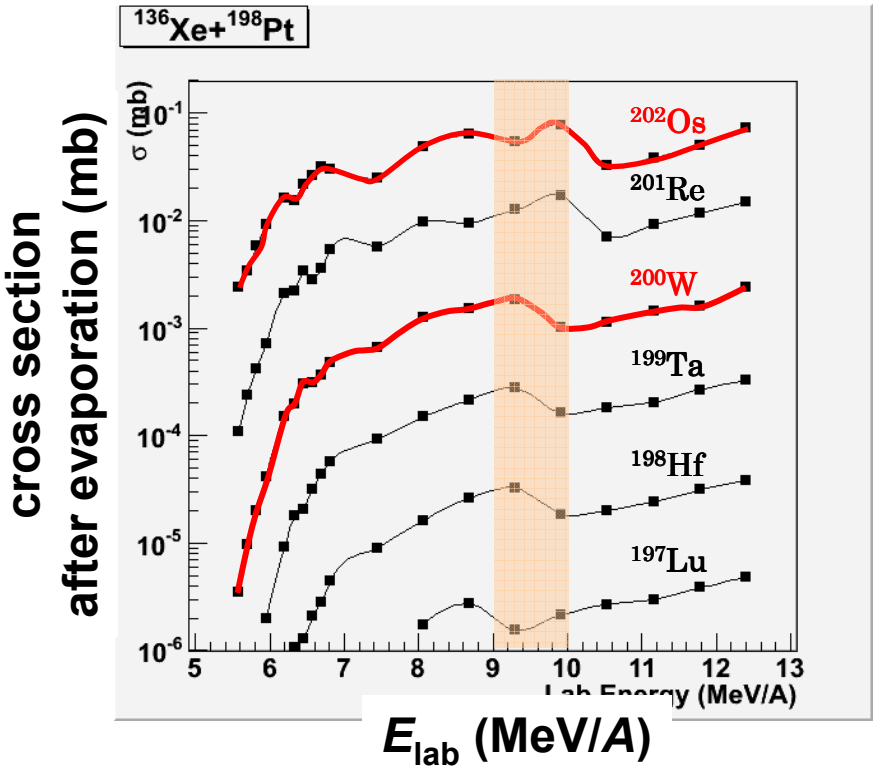
Mass separator
- Magnetic-Q Doublet
- Magnetic Dipole
- Magnetic-Q Doublet

Extraction chamber
- Electric lens
- Monitors

Gas catcher system
- Target (^{198}Pt)
- Gas cell
- Laser resonance ionization
- SextuPole Ion-Guide

MNT reactions of ^{136}Xe+^{198}Pt

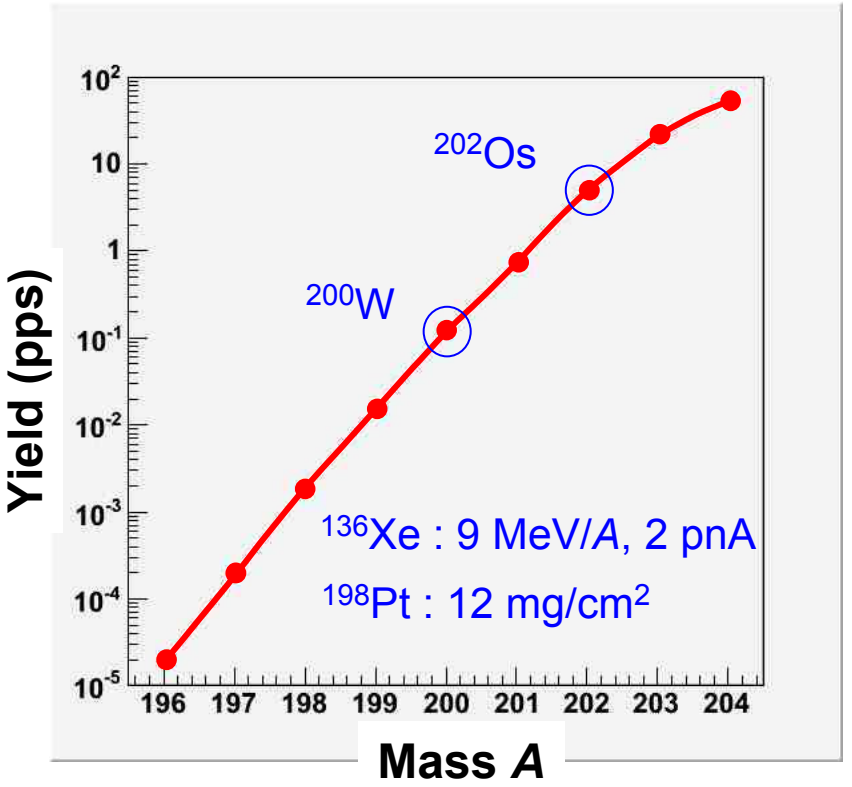
Excitation functions
for the production of *N* = 126 isotones



σ ~ **10^{-1}** mb for **^{202}Os**
σ ~ **10^{-3}** mb for **^{200}W**

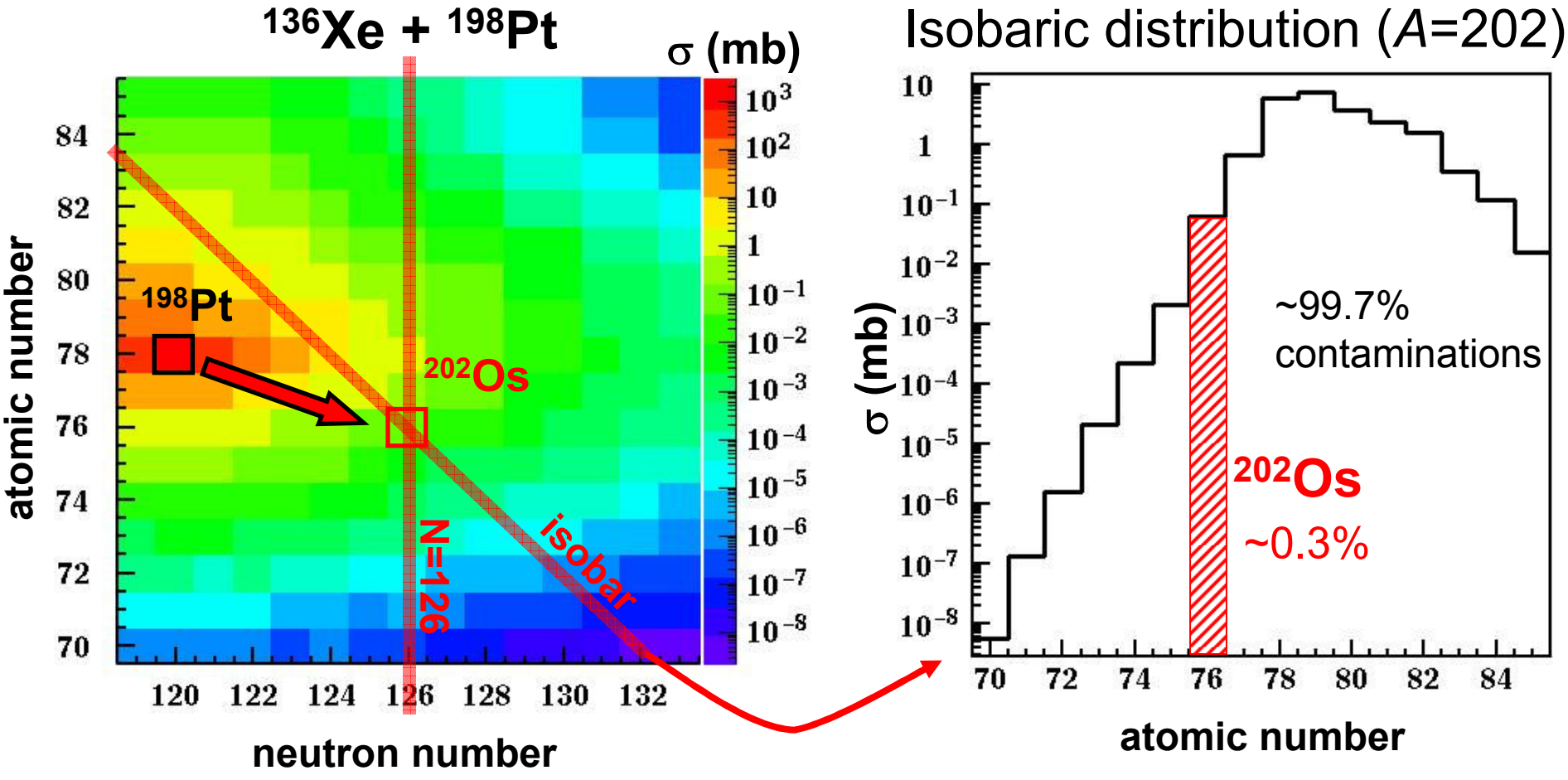
calculated by GRAZING code
(http://personalpages.to.infn.it/~nanni/grazing)

Expected yields for *N* = 126 isotones



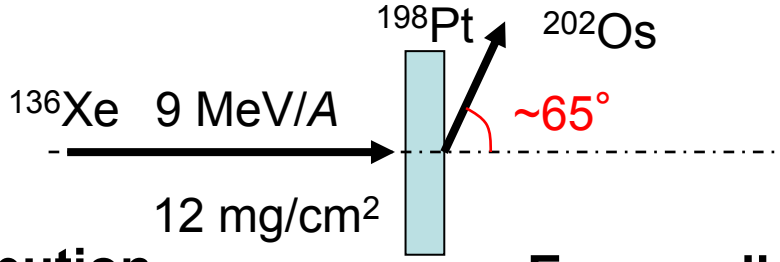
5.0 pps for **^{202}Os**
0.1 pps for **^{200}W**

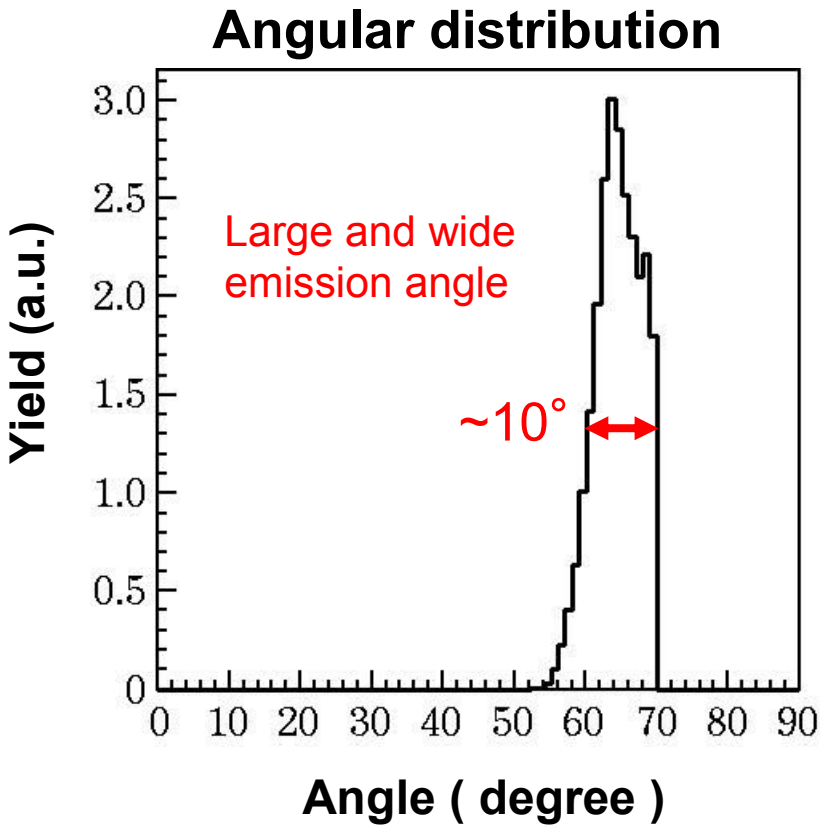
Contaminations

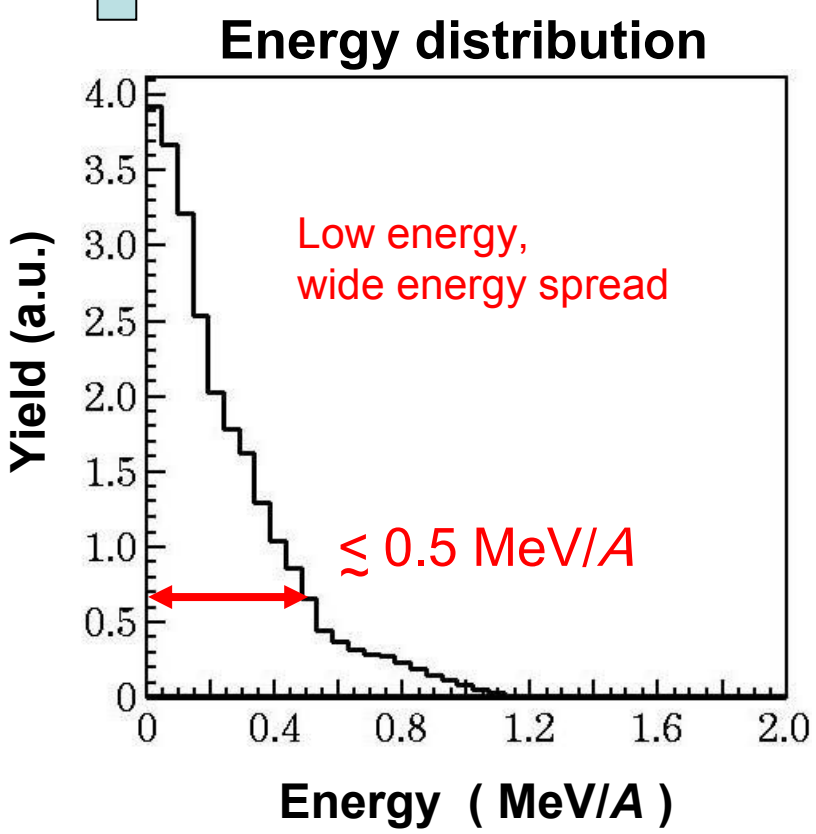


Z and *A* separations are essential
for the lifetime measurements of rare channel products.

Kinematic condition for ^{202}Os

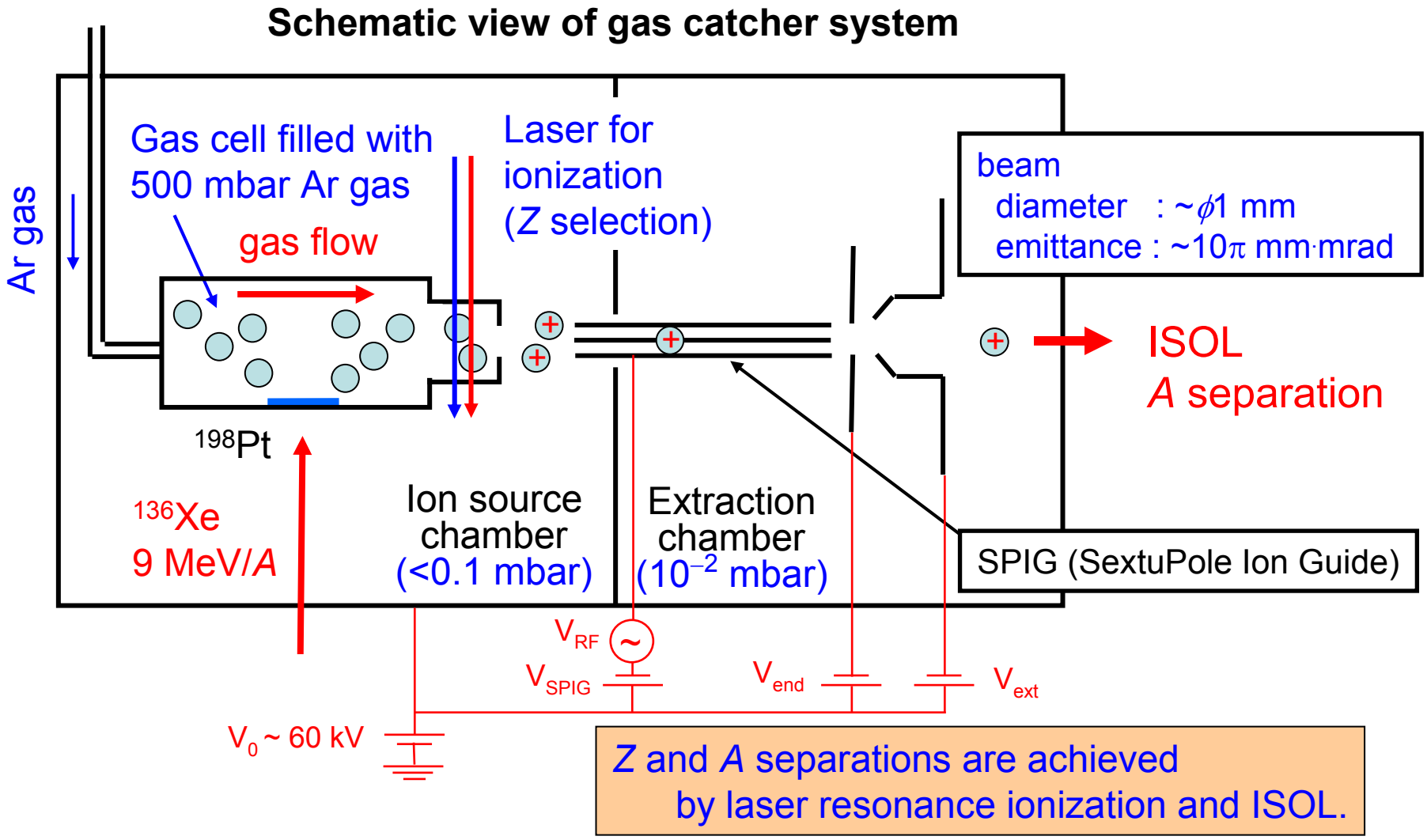






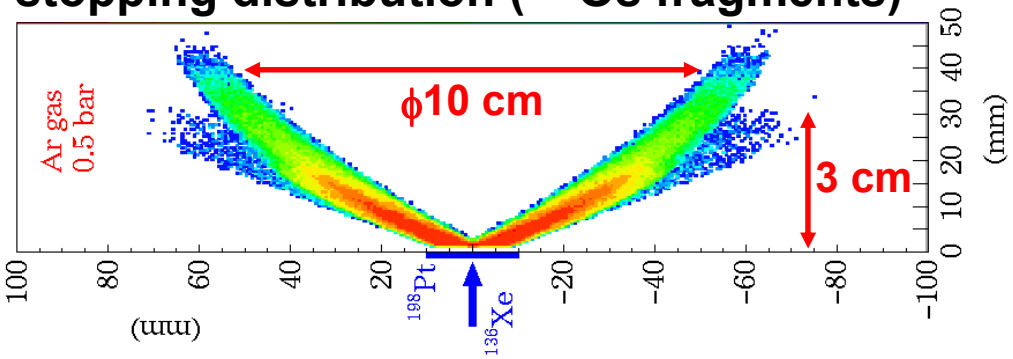
Efficient collection and separation ⇨ Gas catcher system

Gas catcher system
- Laser resonance ionization + ISOL -

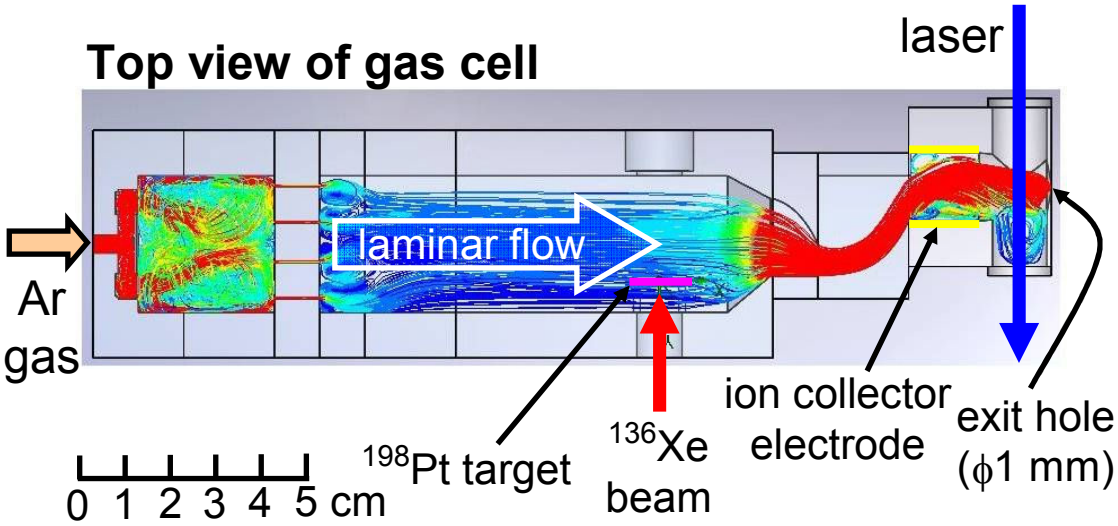


Gas cell design

Cross-sectional view of stopping distribution (^{202}Os fragments)



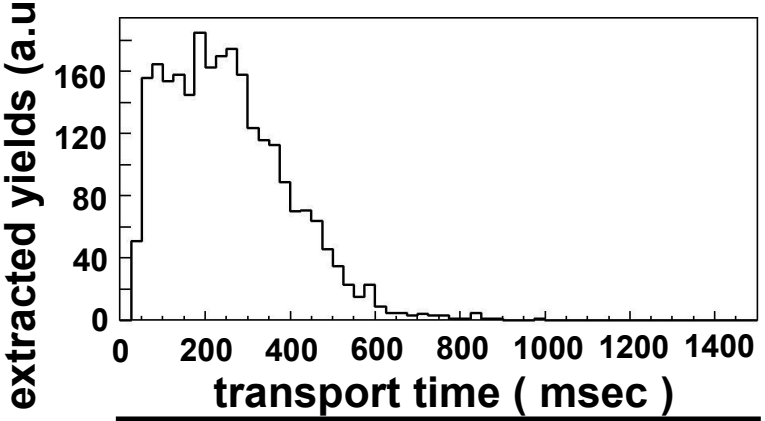
Top view of gas cell



Simulation by hydrodynamic calculations

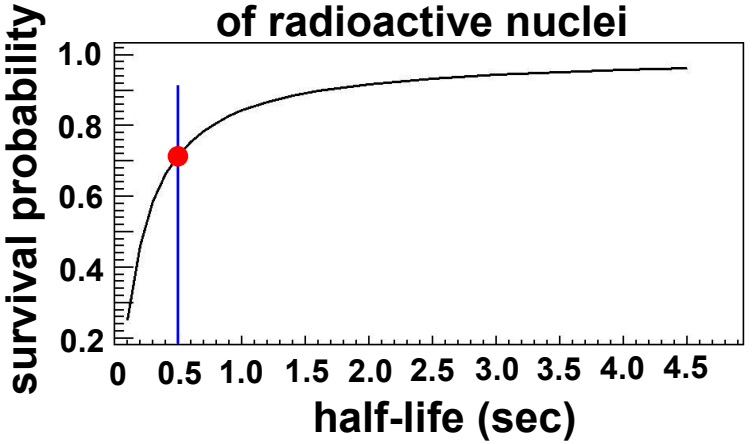
Stopping efficiency : ε_{stop} = 87 %

Transport time profile



Mean-time = 253 ms
Transport efficiency : ε_{tra} = 56%

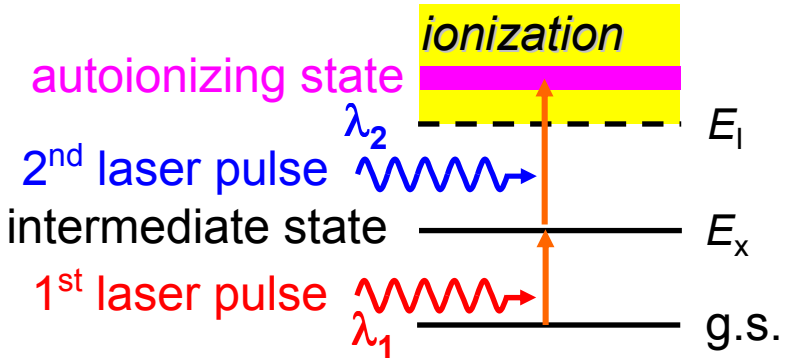
Survival probability of radioactive nuclei



Survival probability : ε_{sur} = 72%
($T_{1/2}$ = 500 msec)

Laser resonance ionization

Schematic diagram of atomic level



λ_1 and λ_2 are intrinsic to each element

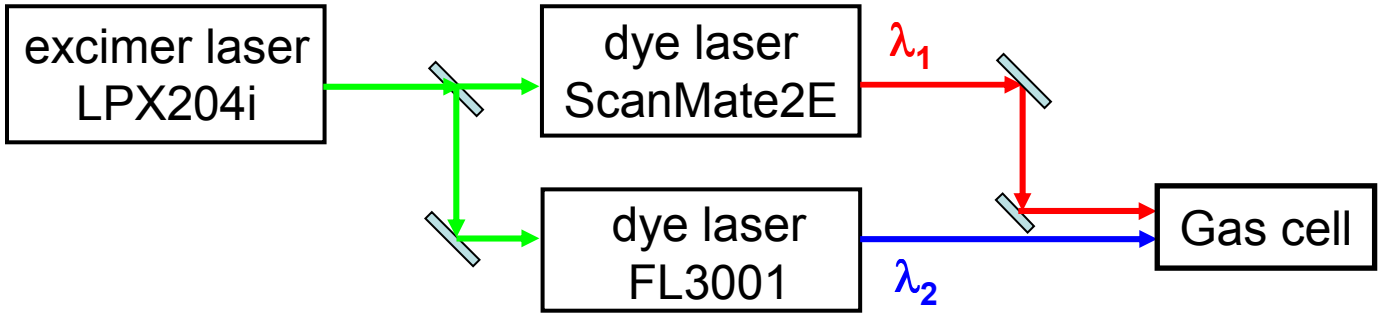
⇨ Z selection

Laser wavelength
for ionization of stable isotopes (Z=69~78)

λ_1 : 250 – 590 nm

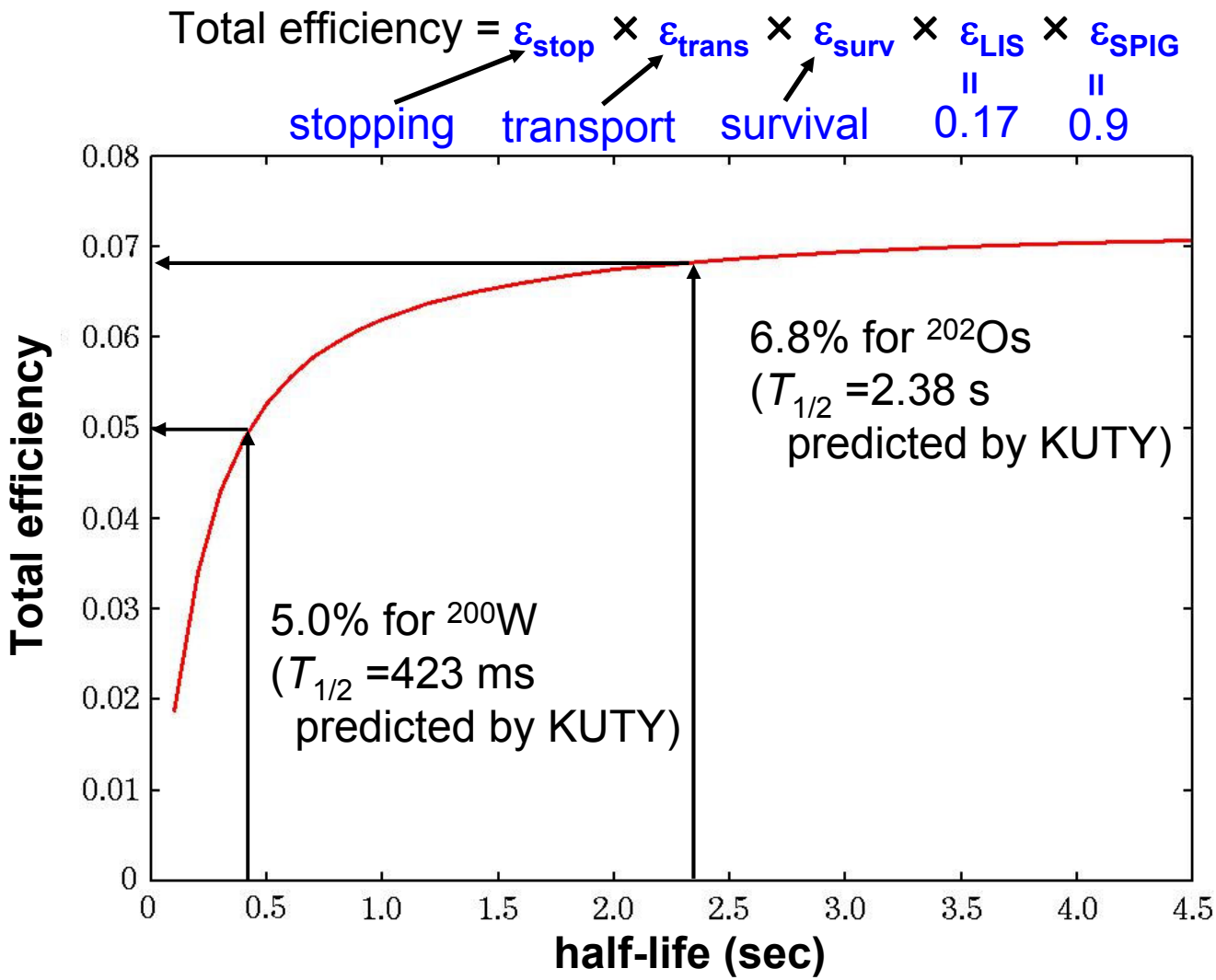
λ_2 : 220 – 460 nm

λ_1 and λ_2 are known,
but we need to confirm and search
the most efficient ionization schemes



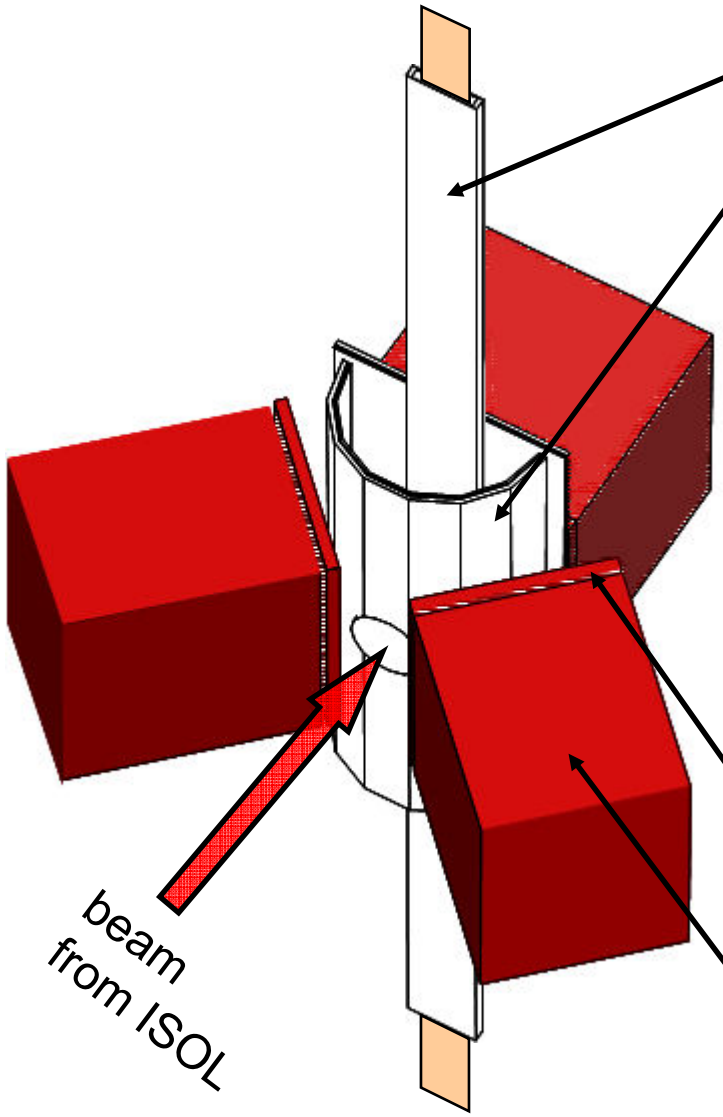
Frequency tunable dye lasers

Total efficiency of gas catcher system



KUTY : T.Tachibana, M. Yamad, Proc. Inc. Conf. on exotic nuclei and atomic masses, Arles, 1995, p763.

Detection system



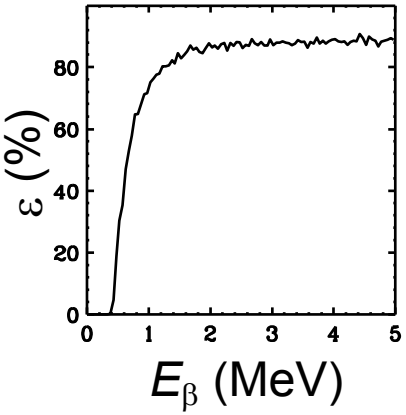
Tape transport system

Plastic scintillators for β rays

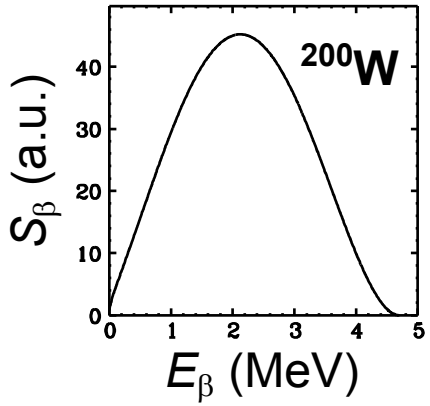
two–layer 1 mm^t and 2 mm^t
back: 10 cm wide 20 cm height
front: 4 cm radius 20 cm height

ε_β = 80% (for Q_β = 4.5 MeV)

Detection efficiency



β-ray energy spectrum



Ge detectors for X rays

10cm x 10 cm x 5 mm thick

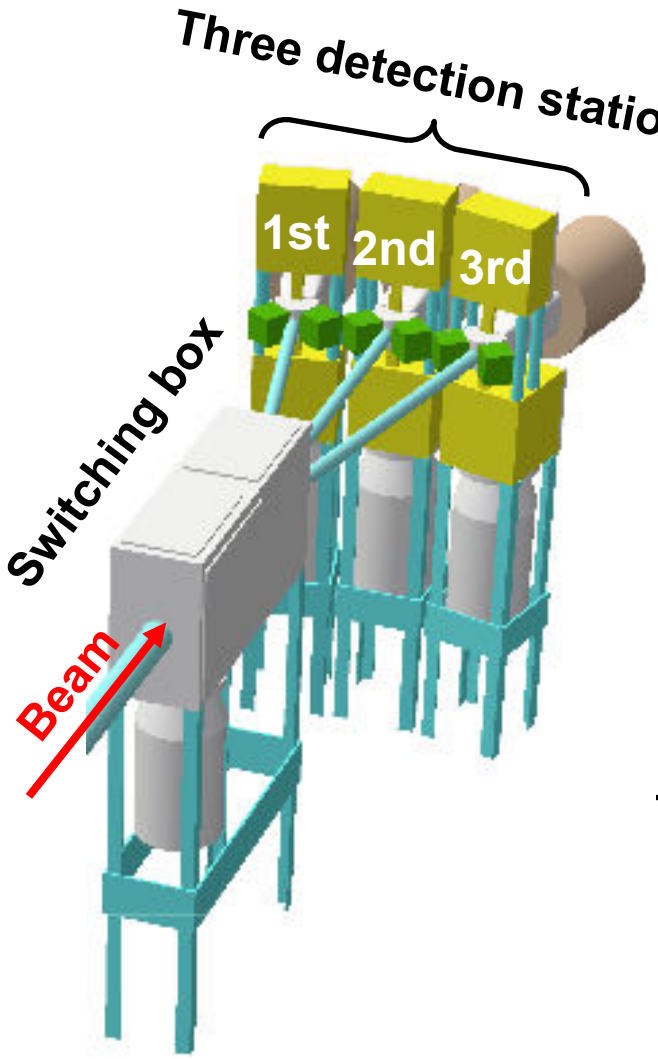
ε_X = 60% (for 70 keV X-ray)

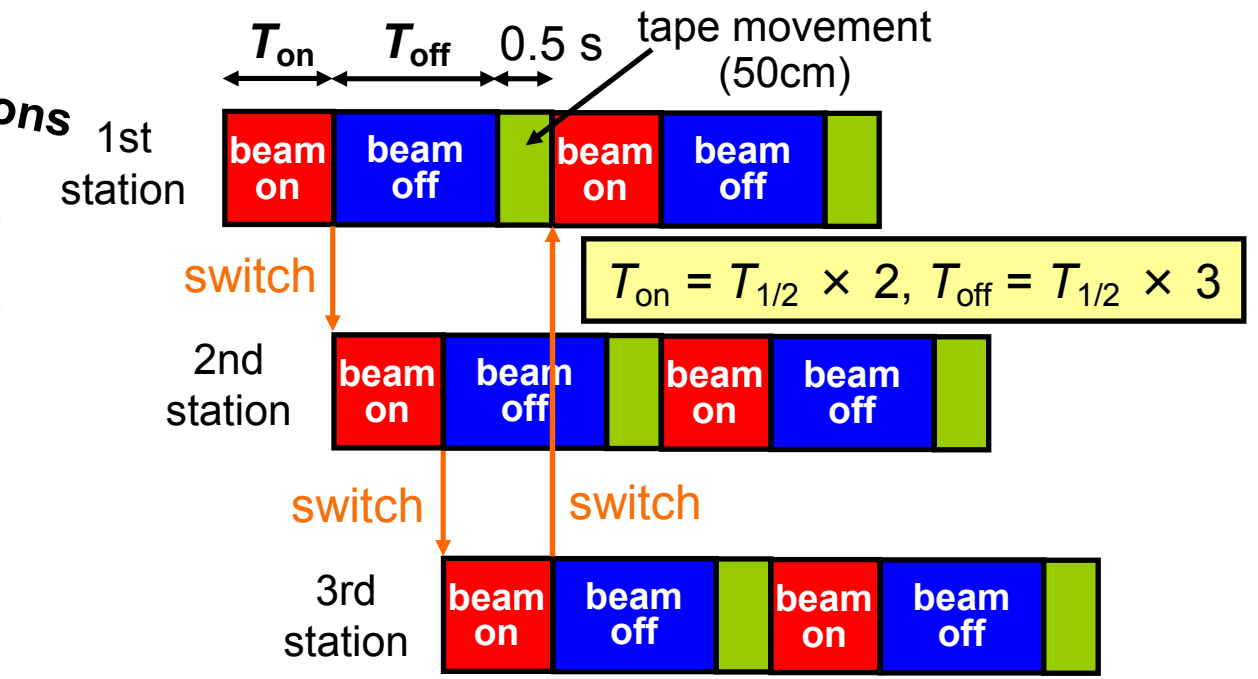
Ge detectors for γ rays (option)

10cmx10cmx10cm long

ε_γ = 20% (for 500 keV γ-ray)

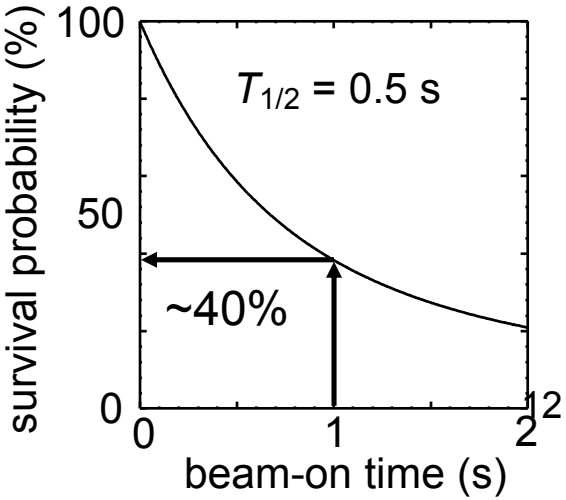
Beam-on/off time-sequence





^{200}W ($T_{1/2}$ ~ 0.5 s)

T_{on} = 1.0 s
T_{off} = 1.5 s



Statistical estimation

^{200}W : production rate = 0.11 pps ⟶ ~1 × 10^4 particles/day

Good *Z* separation by laser resonance ionization
(isobaric contaminations ~ 0.1%)

Collection efficiency	Survival probability during beam-on	Detection efficiency of β ray
5.0%	~40%	80%

β-decay detection : **~160 counts/day**

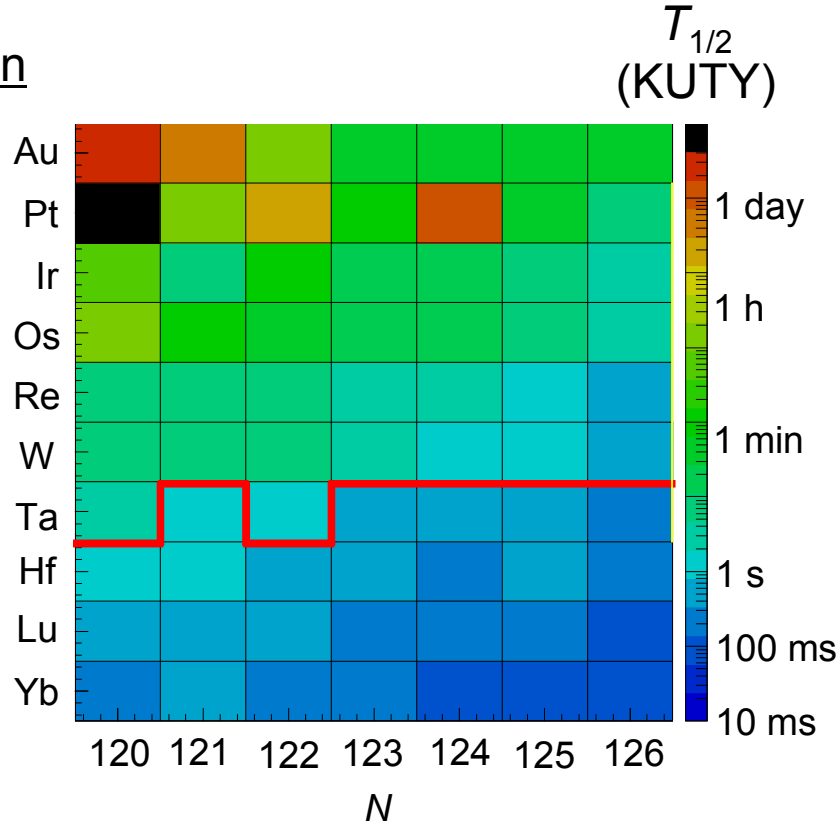
⇨ **lifetime with 10% error**

Additional X-ray detection

Emission probability of $K\alpha_2$ X ray	Detection efficiency of X ray
16 %	60 %

Detection : **~16 counts/day**

⇨ **lifetime with 30% error**



Region down to the red line could be accessed

Summary

- **Lifetime measurements for unstable nuclei produced by MNT reactions of ^{136}Xe+^{198}Pt in 5 years: ^{204}Pt~^{200}W (N=126)**
- **Gas cell + laser resonance ionization + ISOL**
  rapid & efficient collection with laminar flow
  Z & A separation with laser resonance ionization & ISOL
  efficiency = 5.0% for ^{200}W ($T_{1/2}$~423 ms)
- **Tape transport + β-decay measurements**
  Three detection stations → suppression of decay loss
  160 counts/day for ^{200}W → lifetime is determined with 10% error
- **Research & Development in 2 years**
  Multi-nucleon transfer reaction: feasibility
  Gas cell design: transport efficiency, transport time profile
  Laser resonance ionization: wavelength tuning
  for most efficient ionization-scheme
- **Studies toward waiting nuclei**

  Low-energy intense neutron-rich RIBs such as ^{140}Xe

Collaboration

- KEK

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- TITech

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