Measurement of ground-state and isomeric-state ratio in nuclei produced in multinucleon transfer reactions using JAEA Recoil Mass Separator

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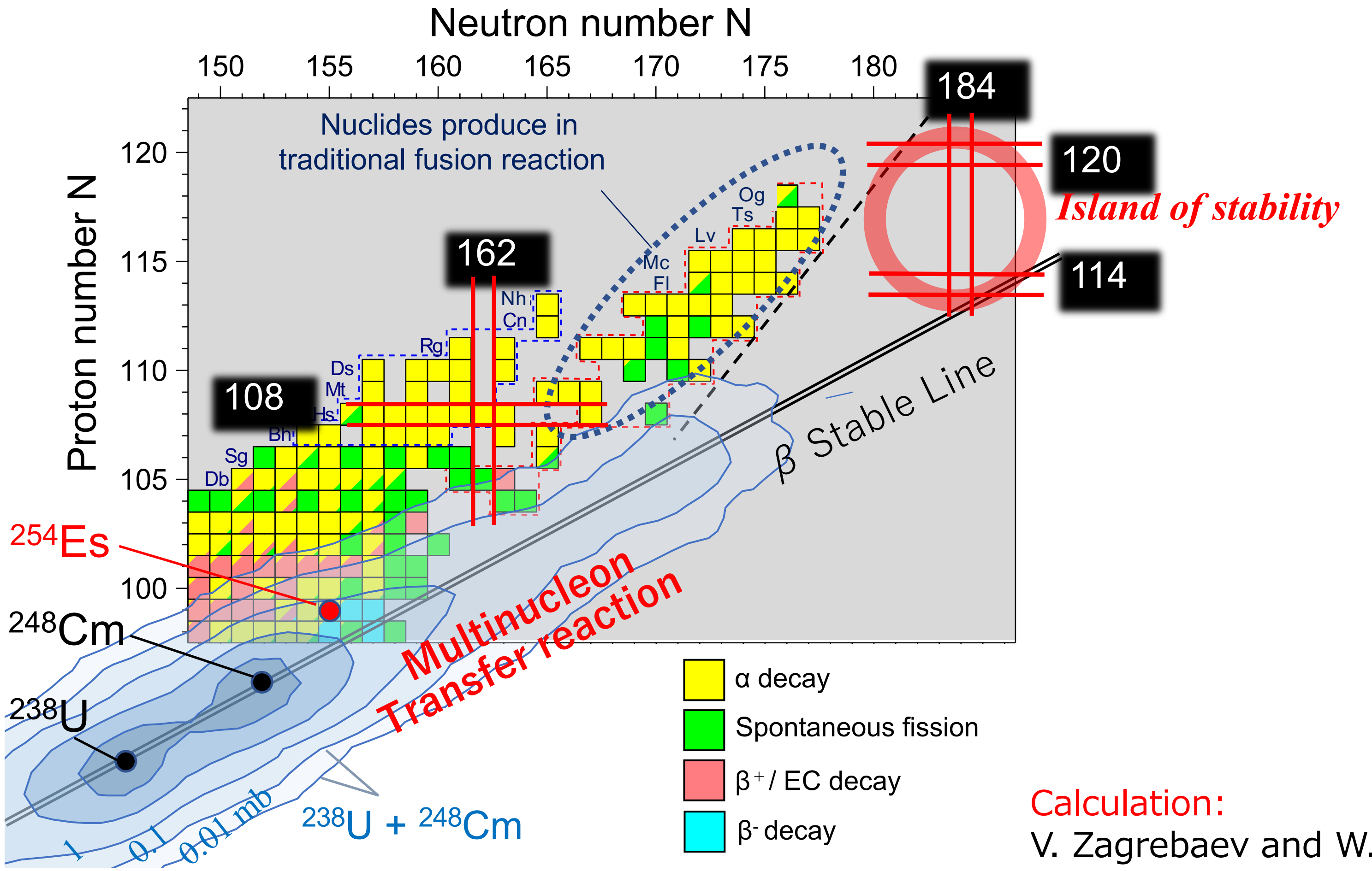
Fumi Suzaki (JAEA)

K. Nishio, K. Hirose, R. Orlandi, H. Makii, M. Asai, T.K. Sato, T. Ogawa (JAEA)
A.N. Andreyev (York Univ.)
Y.X. Watanabe, S.C. Jeong, Y. Hirayama, H. Miyatake, M. Mukai. Y. Ito (KEK WNSC)
T. Niwase (Kyushu Univ.), K. Nakajima(Kindai Univ.)
S. Kubono (RIKEN)
N. Iwasa, K. Tsukada (Tohoku Univ.)

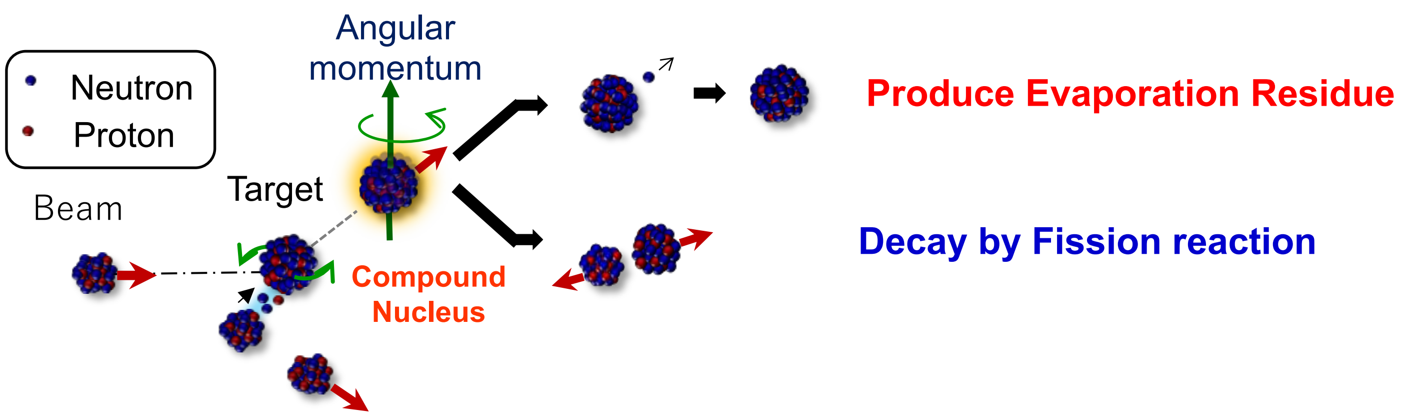
Multinucleon Transfer reaction

Multinucleon transfer (MNT) reaction has attracted interest in the field of superheavy-elements and astrophysical nucleosynthesis because they can produce neutron-rich nuclei.
For example, the $^{238}U+^{248}Cm$ reaction can produce neutron-rich isotopes of superheavy elements close to the beta stability line.

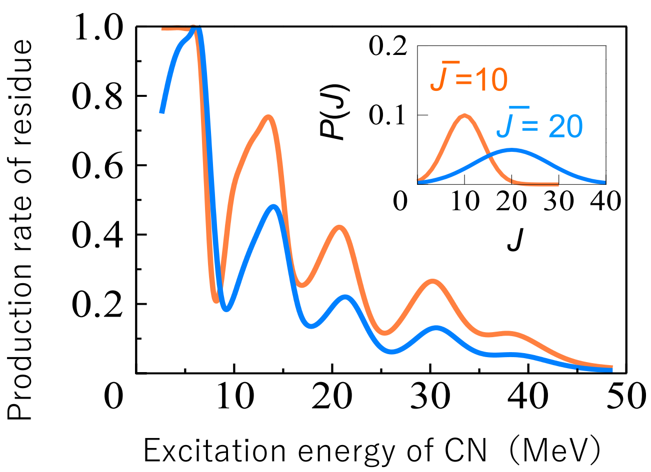


Calculation:
V. Zagrebaev and W. Greiner, J. Phys. G 31, 825 (2005)

Goal : Understanding the mechanism of MNT reaction



Calculated by HIVAP



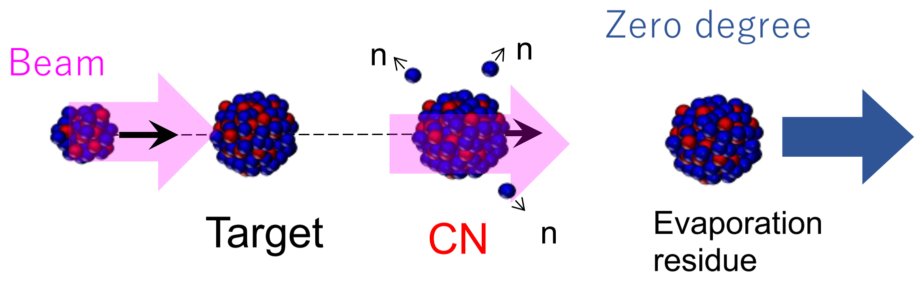
Process of forming superheavy elements in MNT reactions consists of two parts
(1) Produce compound nucleus (CN) with excited states
(2) The CN must survive in competition with fission, to form evaporation residues(ERs)

Production rate of ERs depends on Excitation energy of CN, Spin distribution of CN
→
We aim to derive Excitation energy distribution and Spin distribution from the measurement of evaporation residue.

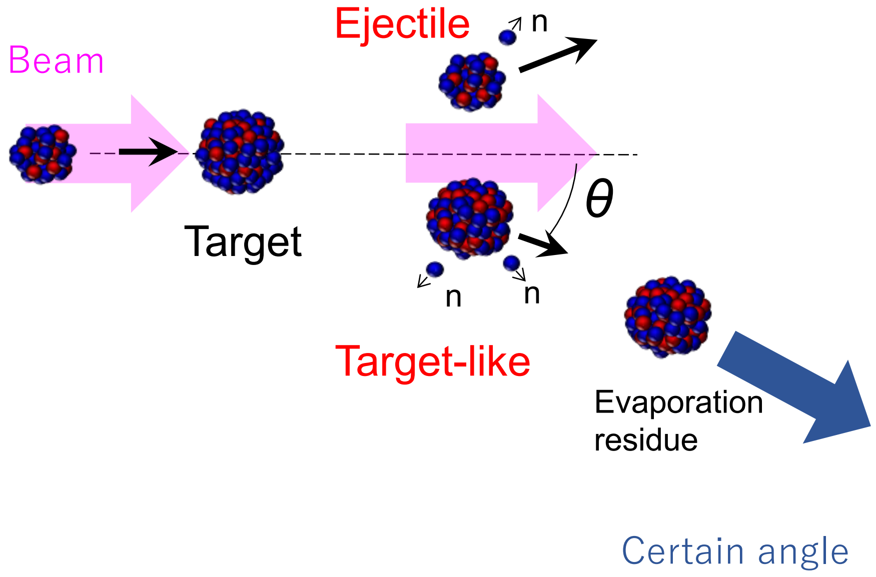
As a first step, we choose the reaction $^{30}Si + ^{209}Bi$ as the CN around ^{209}Bi do not fission in the deexcitation process, we can focus on the process (1).

Recoil angle measurement

Fusion reaction



Multi Nucleon Transfer reaction

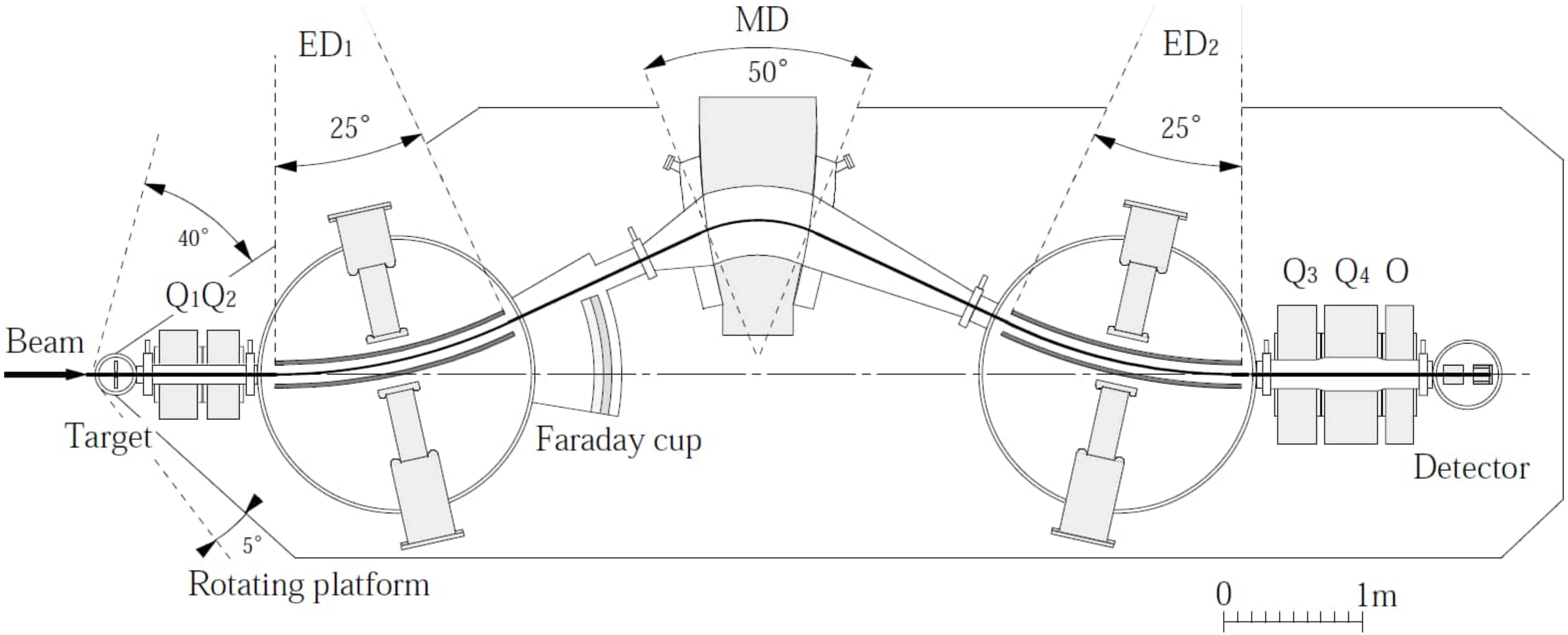


Fusion reactions recoils out the ERs to the beam direction, whereas in the MNT reaction, nuclei are ejected at a certain angle θ.

→In order to study MNT reactions, it is important to measure anglar distribution of ERs.

We measure the cross sections of ERs produced in the MNT reaction and their angular dependence using JAEA Recoil Mass Separator at the JAEA tandem facility.

Recoil Mass Separator at JAEA Tandem

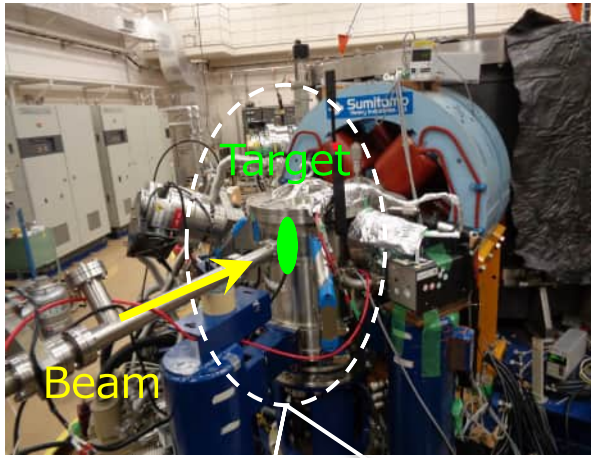


Mass Acceptance: ±4%
Energy Acceptance: ±12%
Solid angle: 20msr
Rotating angle: 0° ~ +40°

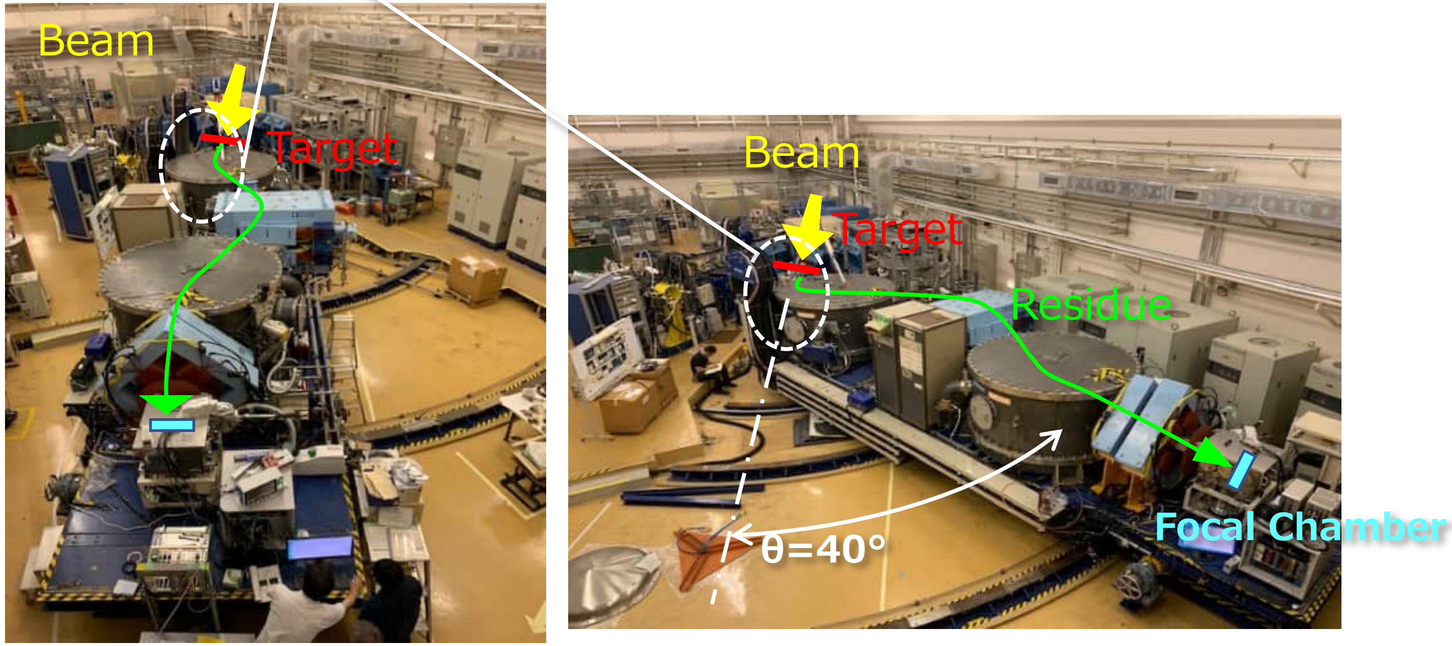
H. Ikezoe et al., NIMA 376(1996) 420

- rotate itself

Rotate RMS for investigation of MNT reaction



We can rotate RMS freely (0°~ +40°)
without breaking the vacuum of the target chamber.

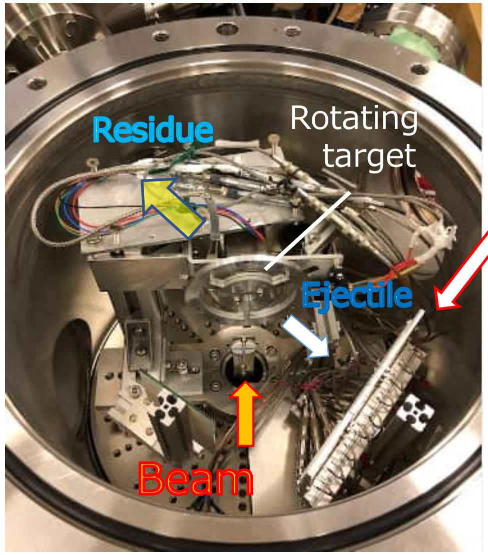


0°   40° rotation

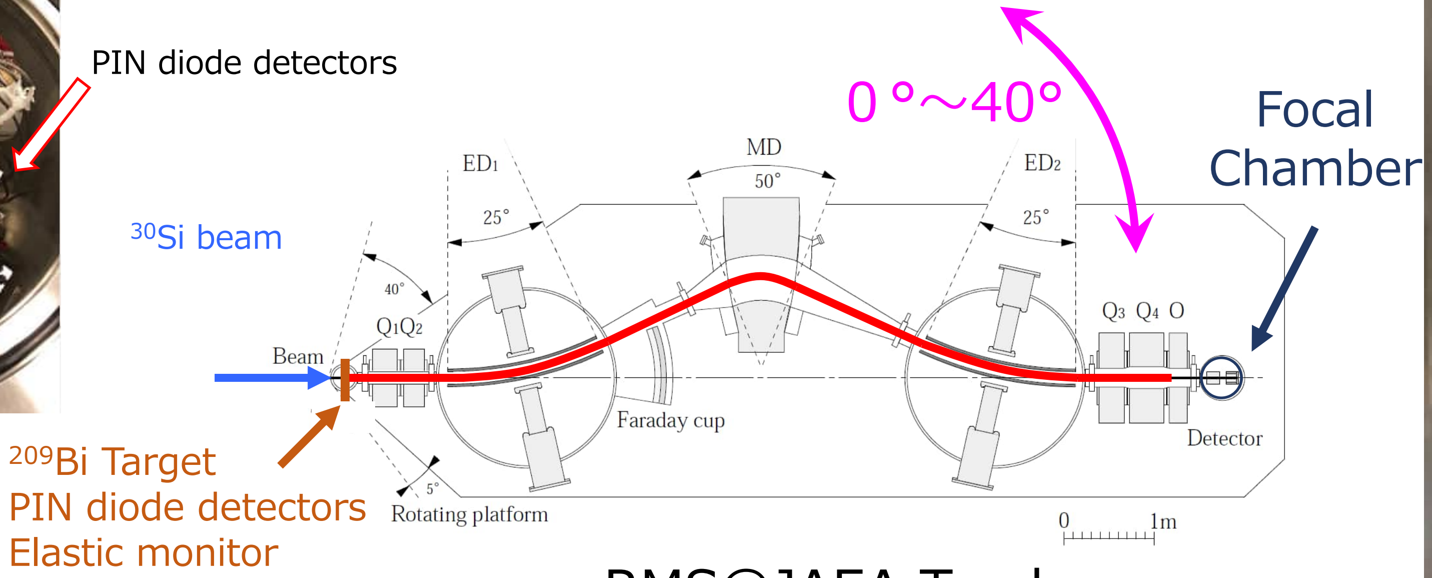
Experiment

【Setting parameter】Recoil Angle θ_{recoil} and Recoil Energy E_{recoil}

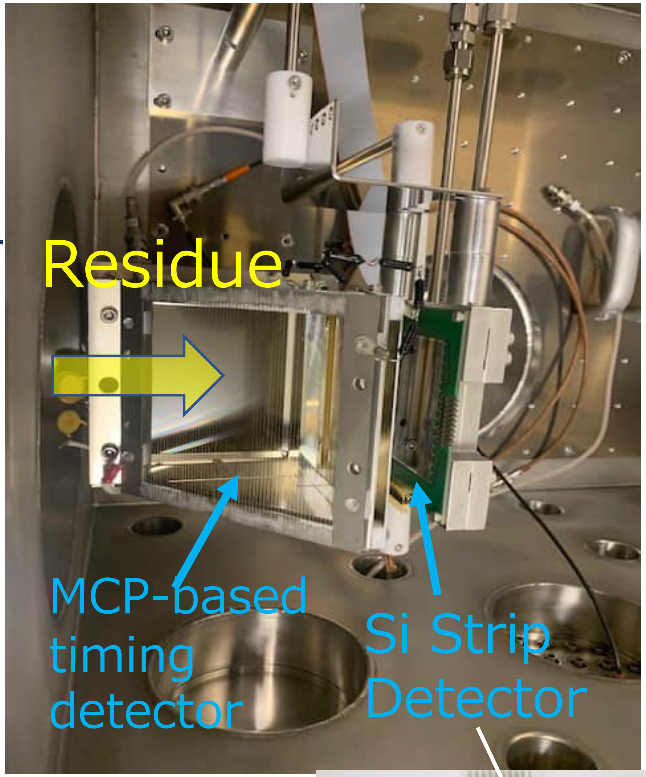
【Separation time】 ~ 1 μs, useful to study isomeric state of neutron-rich nuclei

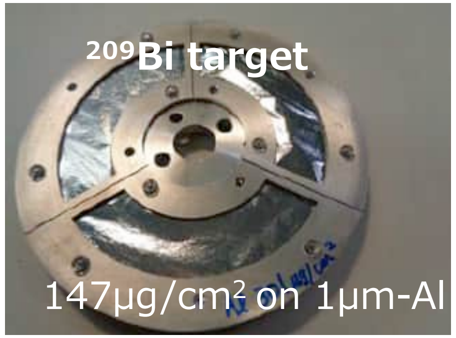


(e.g.) $^{209}\mathrm{Bi}(^{30}\mathrm{Si},^{26}\mathrm{Mg})^{213}\mathrm{At}^{*} \rightarrow {}^{213\text{-}xn}\mathrm{At} \rightarrow \alpha$ decay

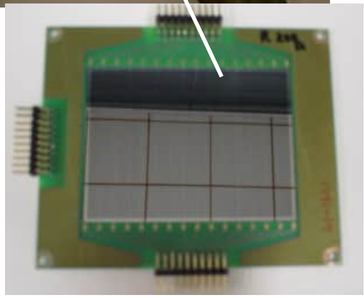


RMS@JAEA Tandem

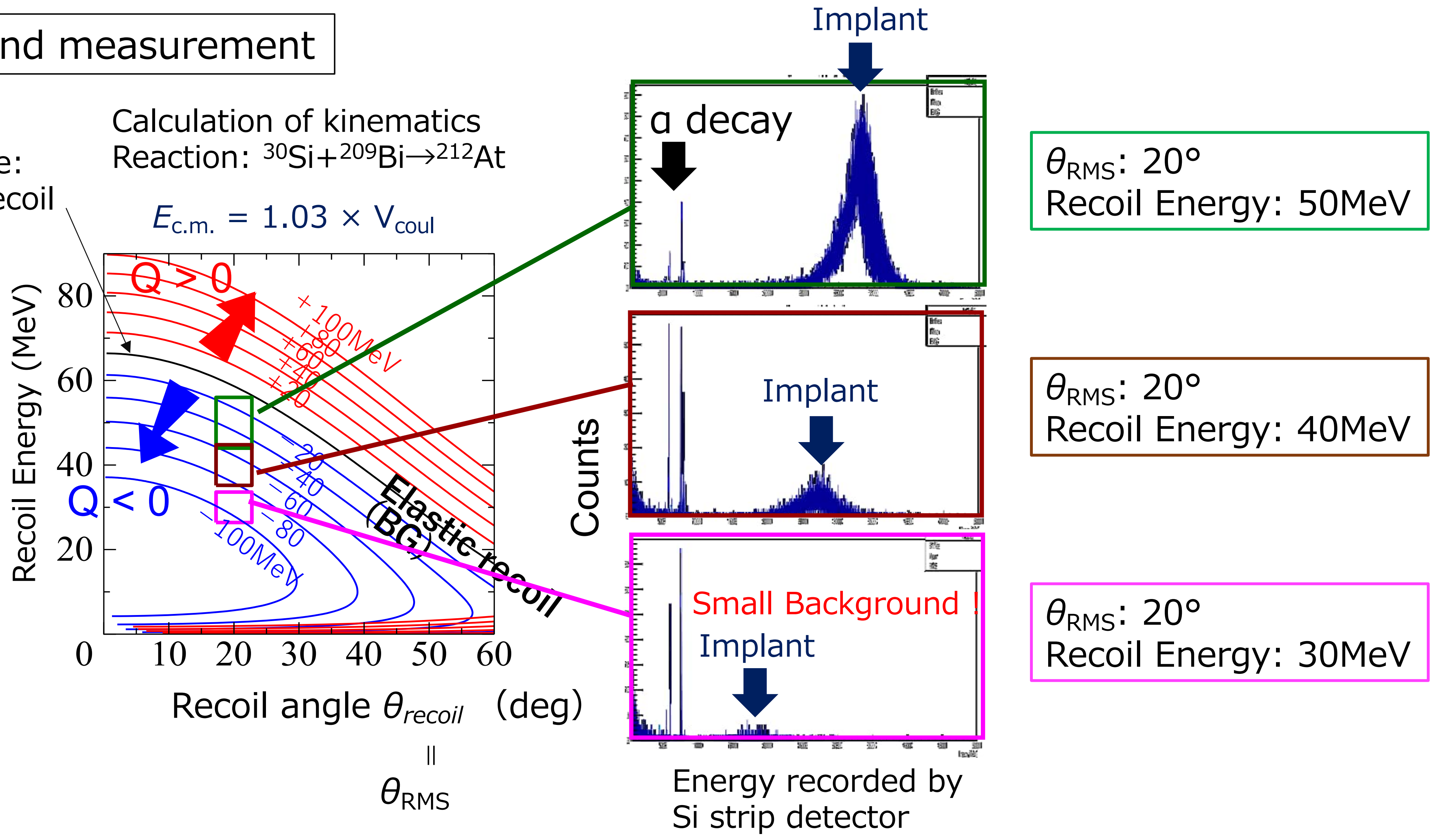




Place an MCP-based timing detector to distinguish implant residual nuclei from alpha decay



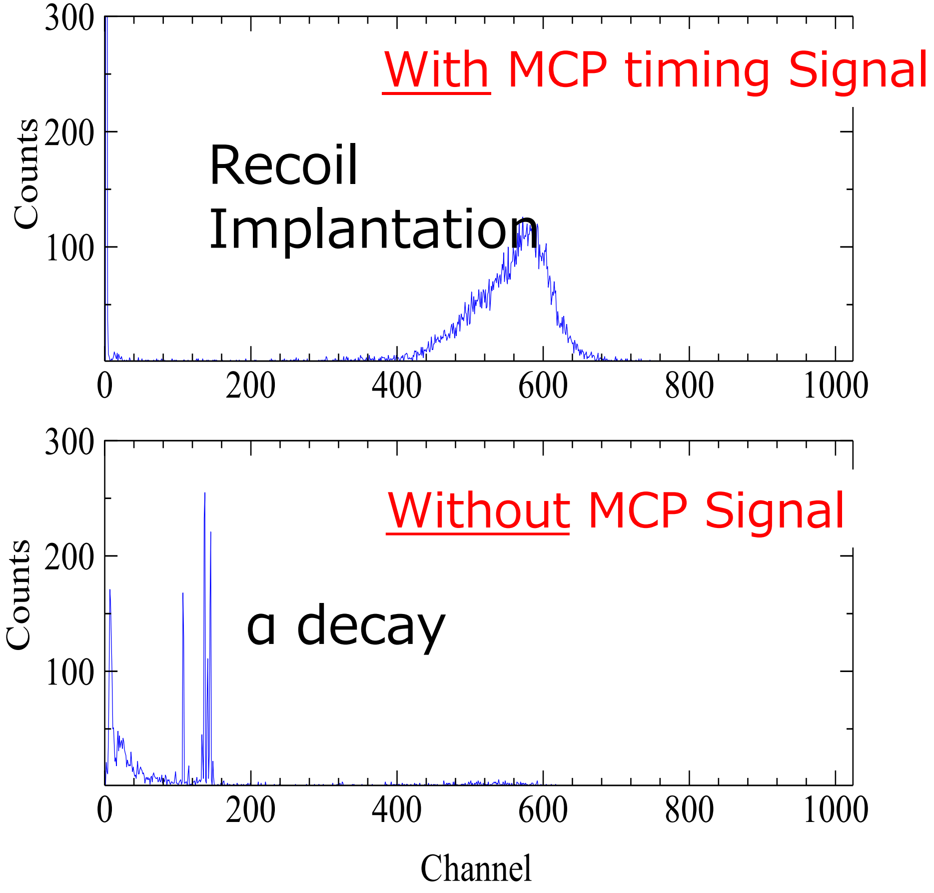
Low background measurement



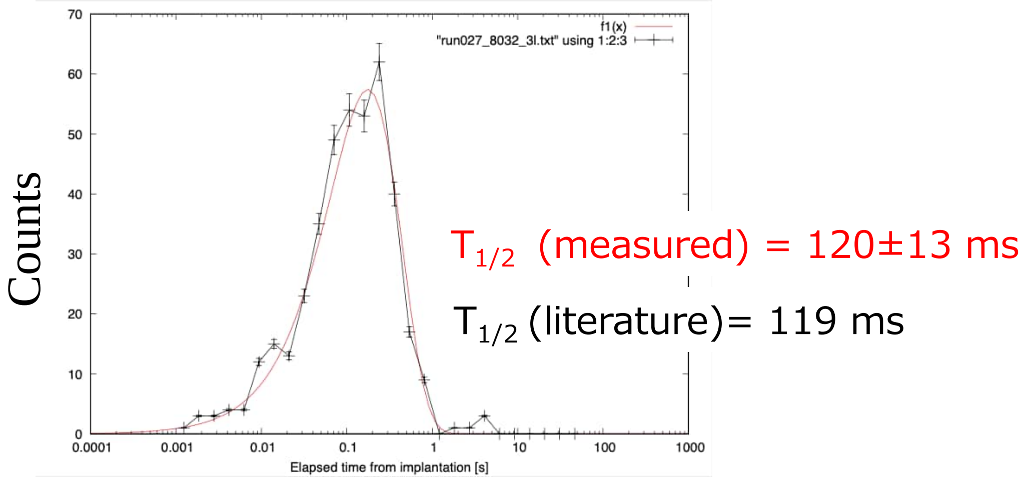
It was observed in the experiment that the background became smaller when recoil energy is smaller than elastic recoils.

Particle Identification using alpha decay

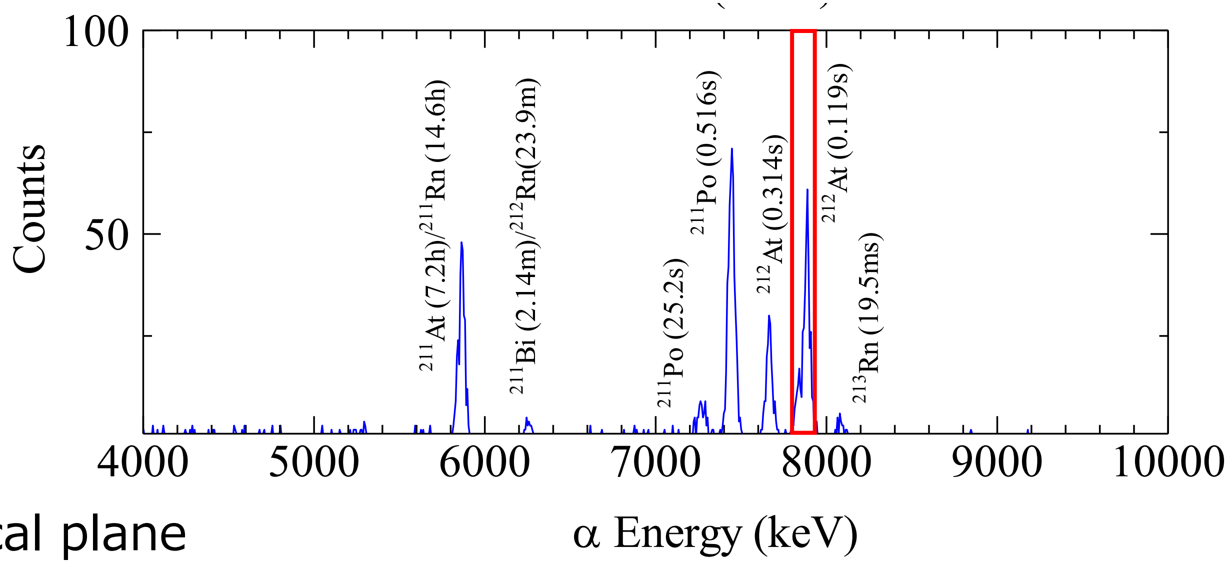
【RMS Setting】 E_{recoil} = 45.5 MeV, θ_{RMS}= 20^{o}



Pulse height spectrum from Si-strip detector at focal plane



Time difference between Implantation and α-decay (s)



Experimental results

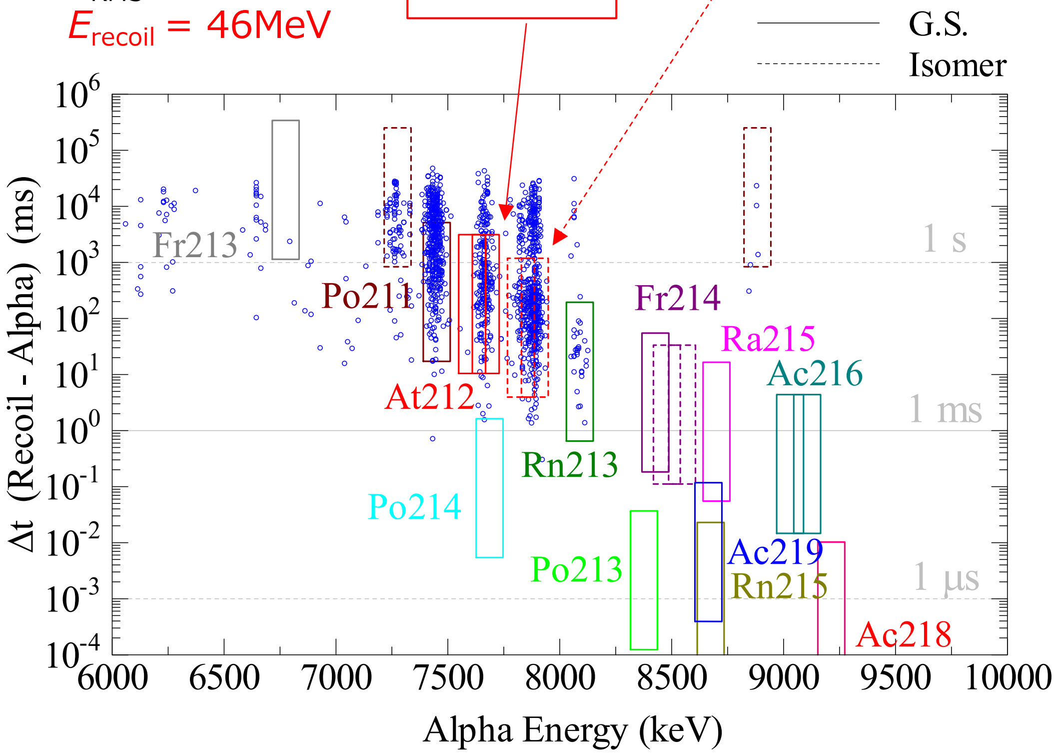
※Squares represents Literature value
Solid line(E_α from ground state)
Dashed line(E_α from isomer state)

^{212}At g.s.	^{212}At isomer
$J^\pi = 1^-$, $T_{1/2}$=0.314s	$J^\pi = 9^-$, $T_{1/2}$=0.119s

$E_{c.m.}$ = 1.03*V_{coul}

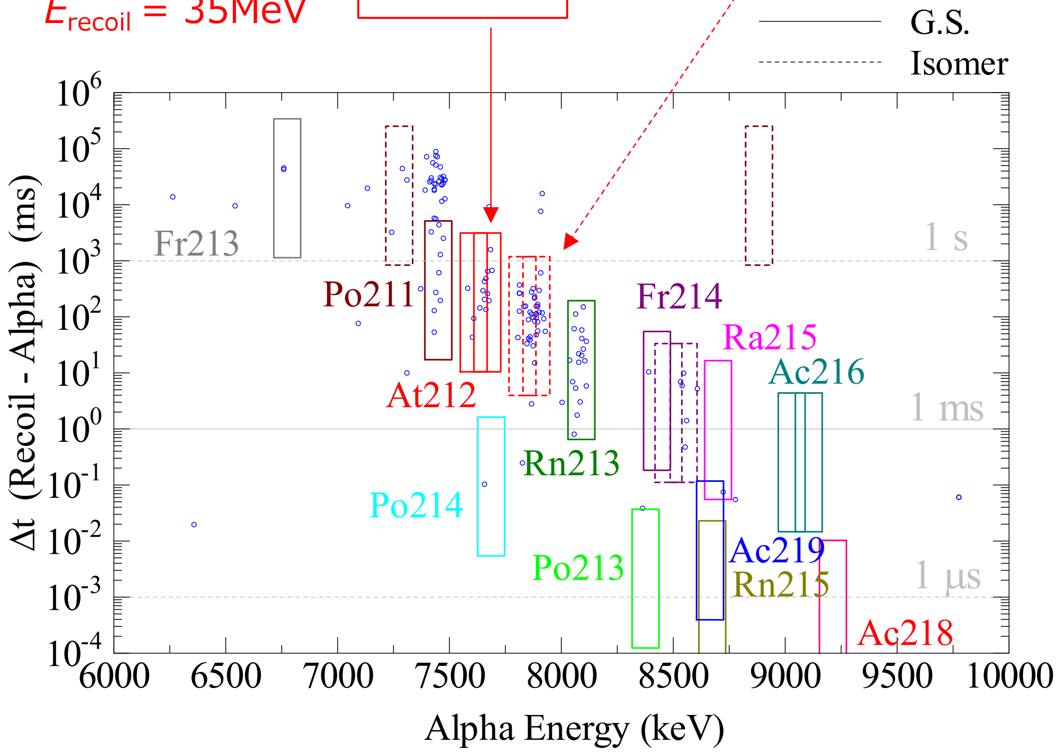
θ_{RMS} = 20°
E_{recoil} = 46MeV

^{212}At$^{g.s.}$ < events ^{212}At^{isomer}



θ_{RMS} = 20°
E_{recoil} = 35MeV

^{212}At$^{g.s.}$ < ^{212}At^{isomer}



We performed measurements by varying the following conditions

1) Beam Energy: $E_{c.m.}$=0.95*V_{coul}, 1.03*V_{coul}, 1.10*V_{coul}
2) RMS setting angle: $\theta_{RMS}(\theta_{recoil})$= 0, 10, 20, 34deg
3) Recoil Energy setting: E_{recoil}= 0~80 MeV