Half-life measurement of neutron-rich nuclei at RIKEN-RIBF

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- ■Introduction
  - ✓ Motivation of Study on R-Process
- ■RIBF project at RIKEN
  - ✓ Performance of RIBF
  - ✓ Schedule of experiment at RIBF
- ■Half-life measurement
  - ✓Particle identification at RIKEN-RIPS
  - ✓Detector development
    - ✓Half-life measurement (>100ms)
    - ✓Half-life measurement (<100ms)
- ■Summary

Rapid Neutron-Capture Nucleosynthesis (R-process)

Motivations

1. **Heavy nuclei in the universe (A=60 ~ 250)**
    - They are synthesized through the r-process.
        - Where? When? How?

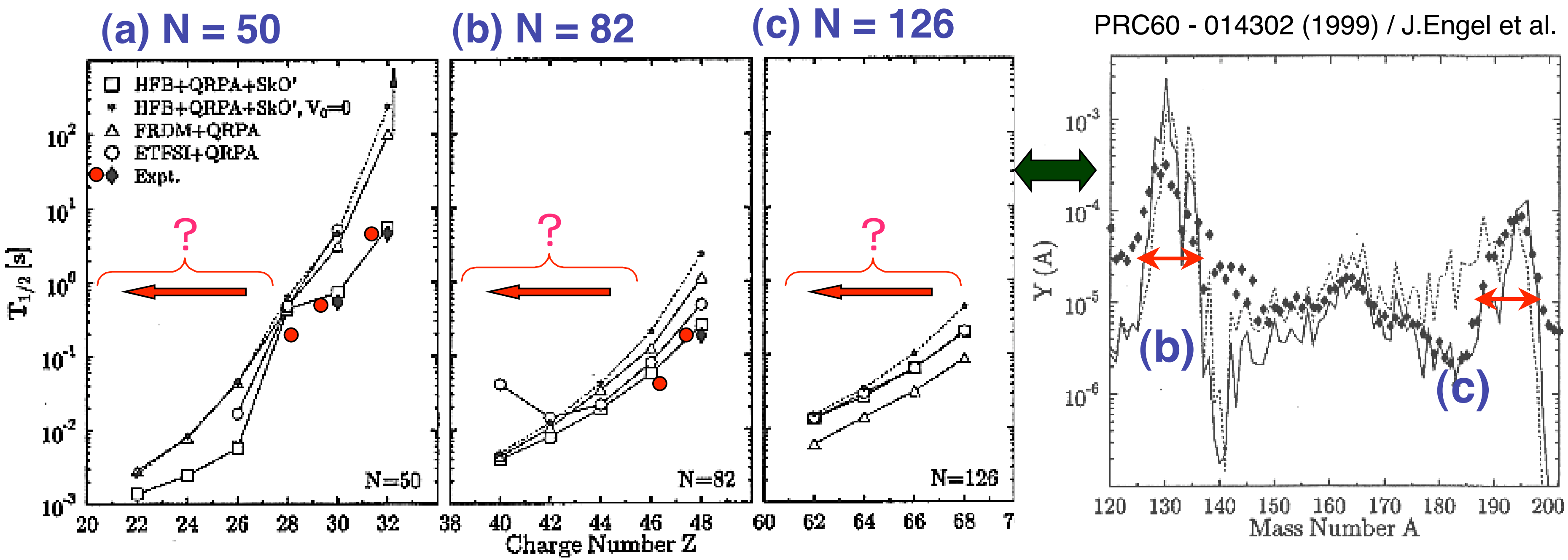
2. **Some r-process nuclei can be used as chronometers.**
    - Half-lives of ^{232}Th = 14.05 G yr
    - Half-lives of ^{238}U = 4.468 G yr
        - If we precisely predict the abundances distribution of the products of r-process nucleosynthesis,
          → ages of metal-poor objects can be estimated.

Nucleosynthesis with equilibrium approximation

- Nuclei tend to pile up at the waiting points.
- Abundance of nucleus is proportional to its half-life.

Measurement →
- β decay half-life ($T_{1/2}$)
- neutron separation energies (S_n)
- β delayed neutron emission probability (P_n)

Experimental Results and Theoretical Prediction

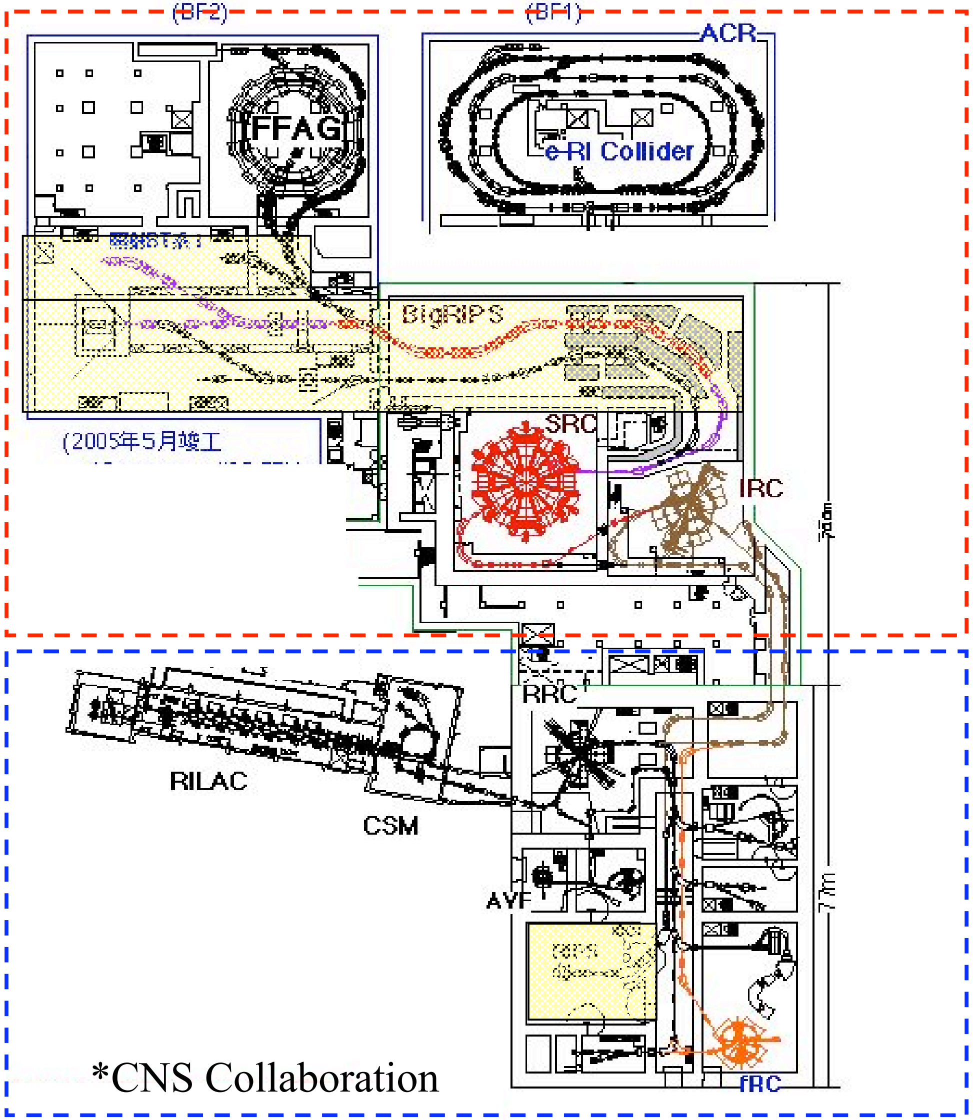


- Lacking the half-life information of neutron-rich nuclei.
- Expected half-life depends strongly on theoretical calculation.

① Important to measure half-life of nuclei for the network calculation of nucleosynthesis.

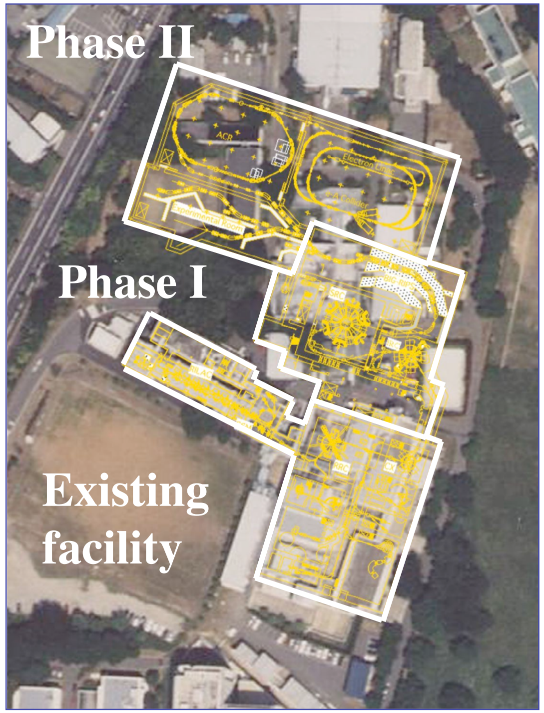
② Feedback from experimental results to theoretical calculation

RI Beam Factory (RIBF: 2006~)

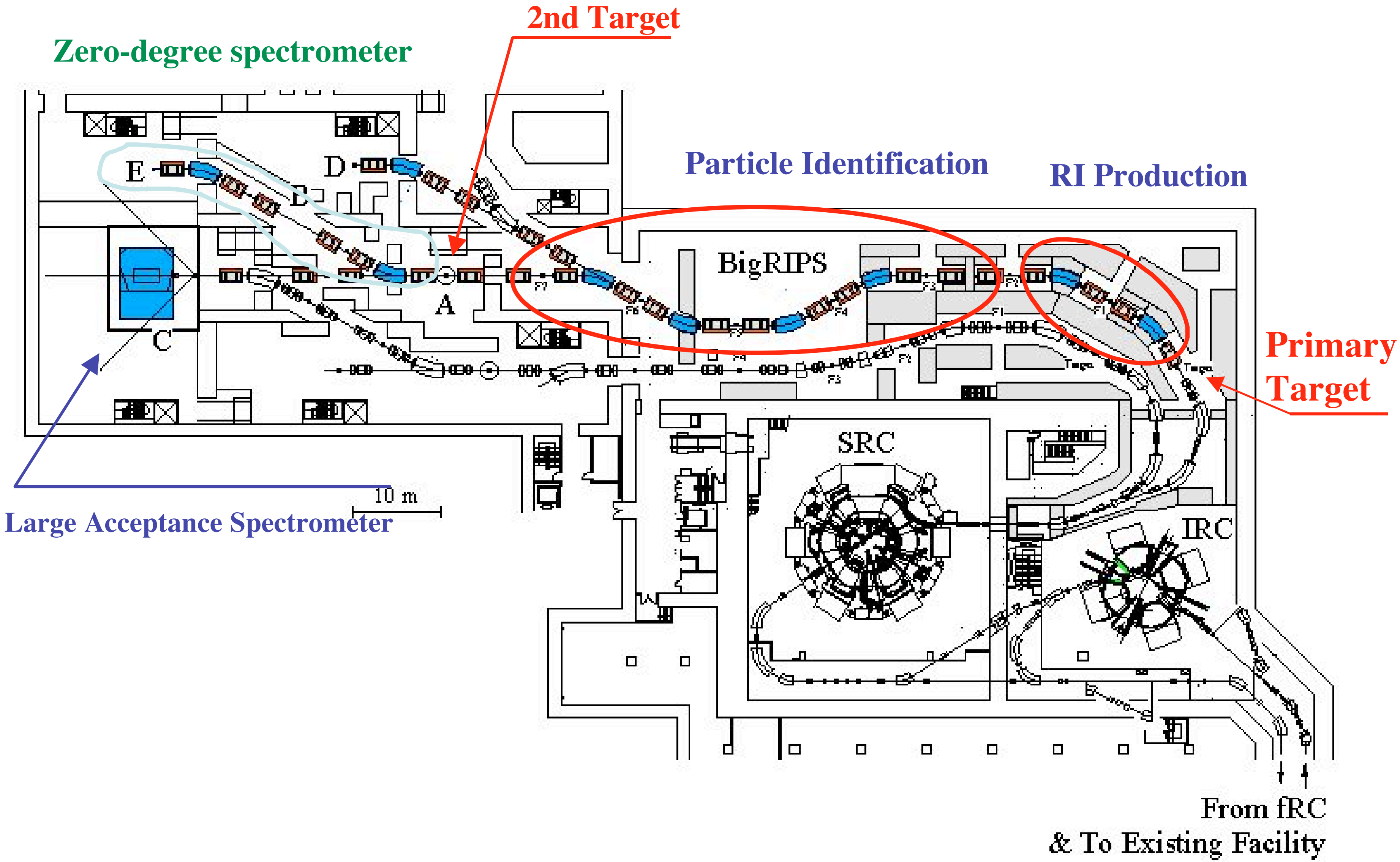


Future Facility (RIBF)

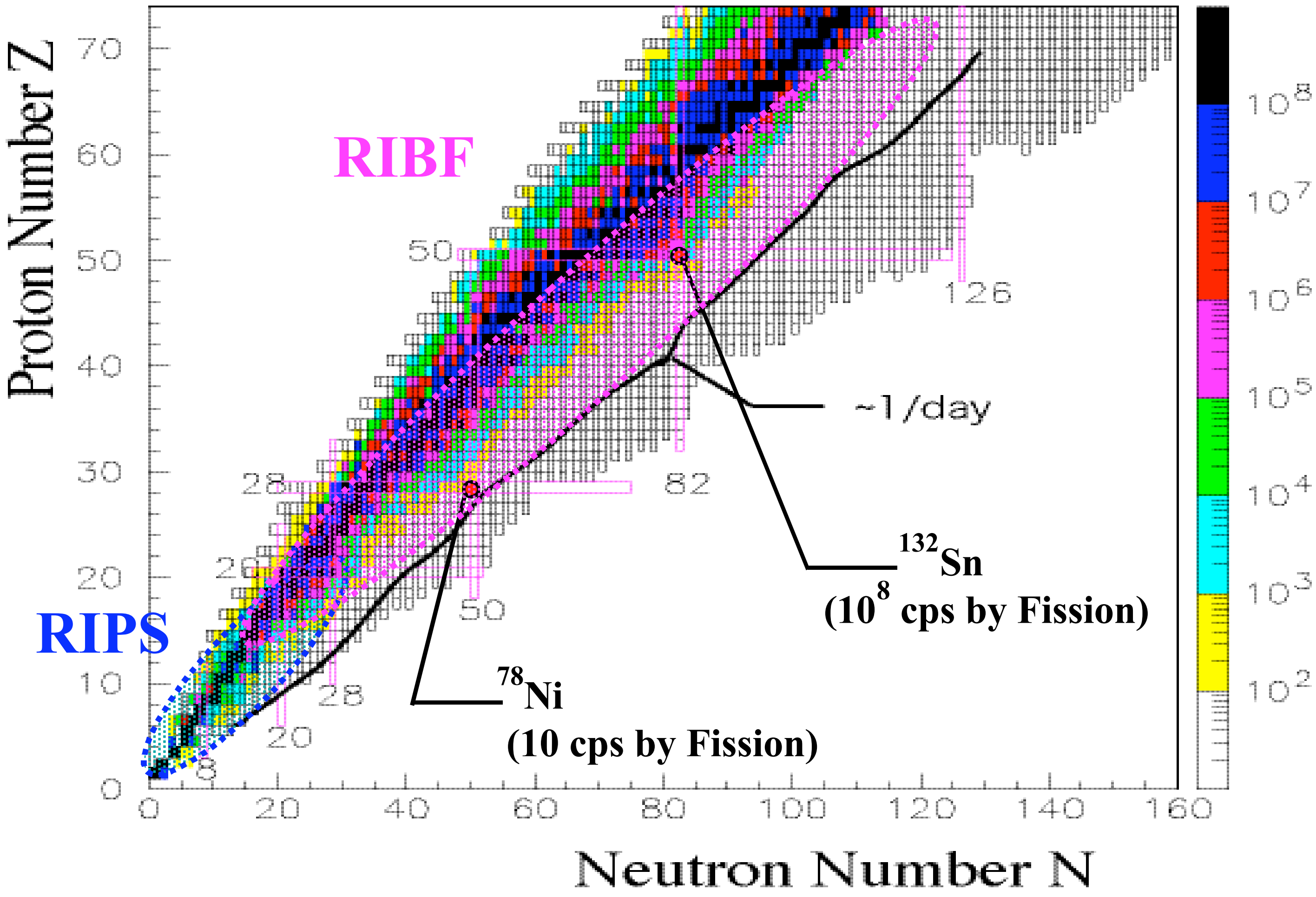
Existing Facility



Experimental Area



Half-life of nuclei and production rate at RIKEN



Schedule of Experiment for RIKEN-RIBF

■ Phase I : Lighter mass region (N=28~50) @ RIPS (2002~)

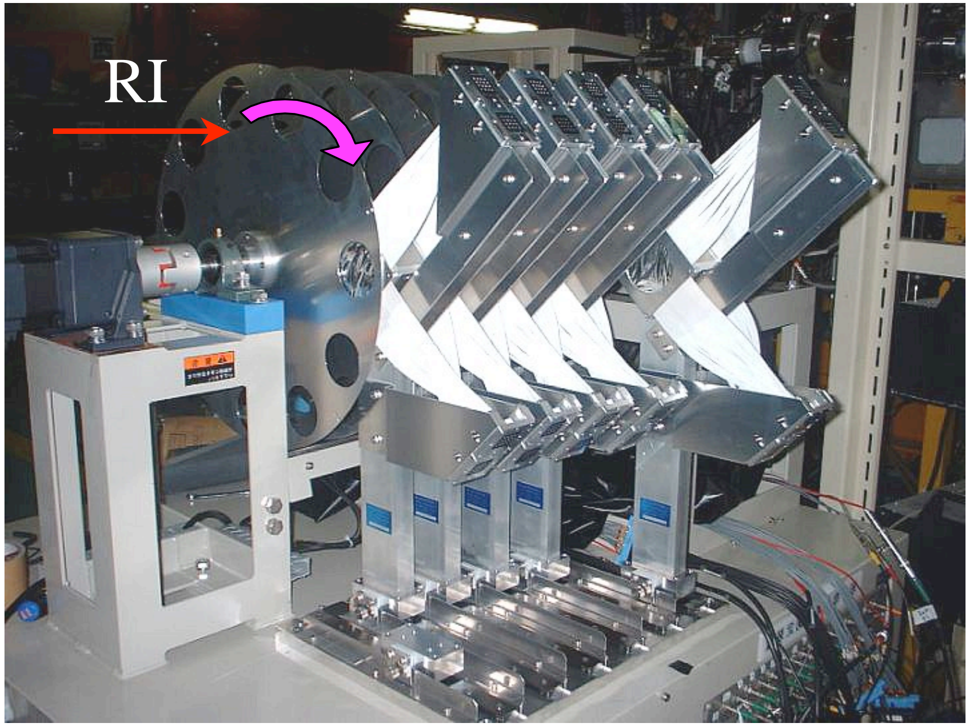
- Preparation of Experiment for RIBF Phase II

■ Phase II : Heavier mass region: N=~50, ~82 (~126) @RIBF (2006〜)

■ Issues

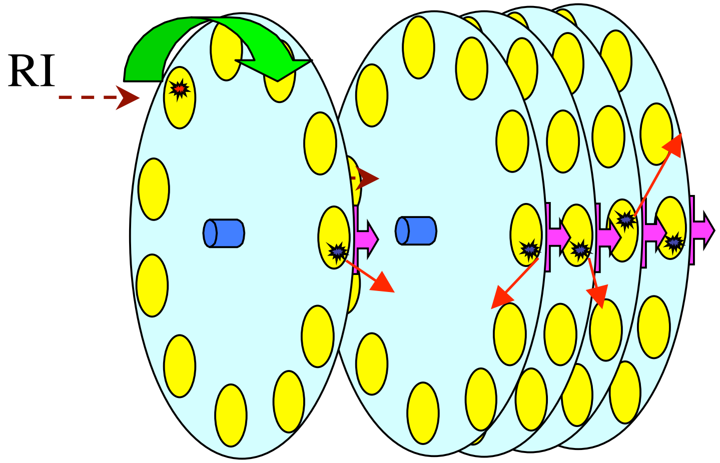
- Low production rate for neutron rich nuclei far from stable region.
  - ✓ **Mixed-beam** with **high detection efficiency**.
  - ✓ Use **continuous beam** instead of pulsed beam.
  - ✓ Perform long run experiment without radiation damage.
- Heavy RI
  - ✓ Radiation hardness of detectors
  - ✓ Identification of neutron rich particles, mass measurement.
    - Development of **high resolution TOF, dE/dX, E**

Half-life Measurement (I) : Rotation Stopper Foils



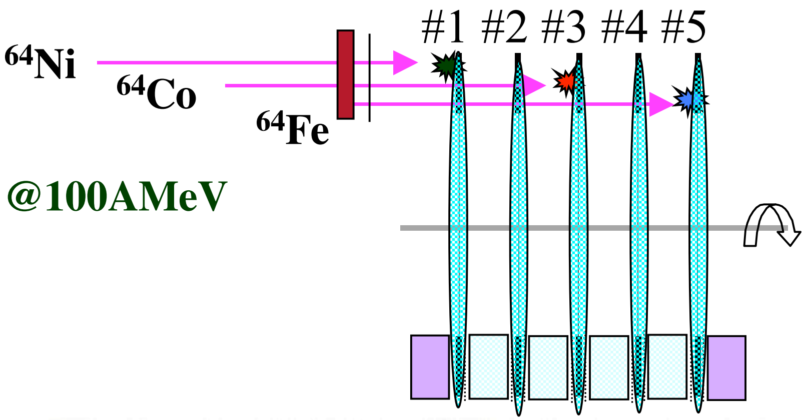
Multi-layer Stopper Foils

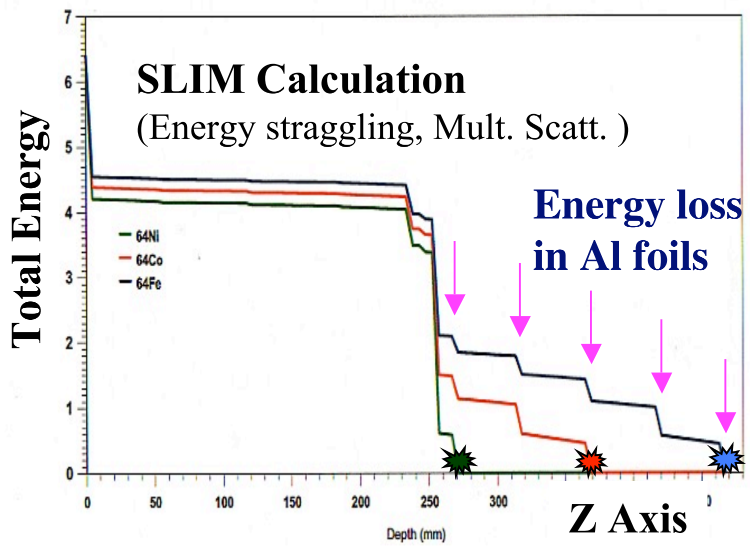
- Number of Foils : 5 layers x 11 holes = 55
- Position Control: 0.2mm
- Controller System : Programmable.



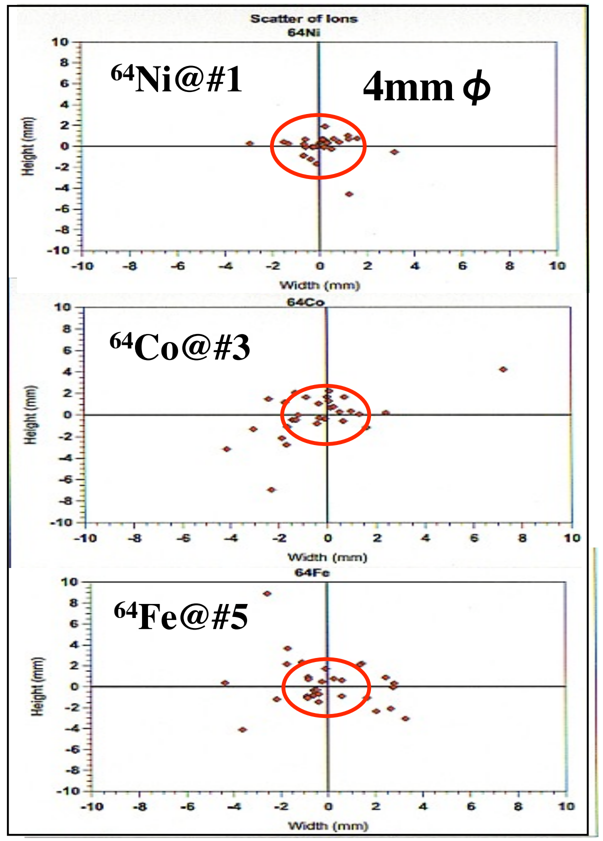
Step 1. : Catch RI by stopper foils.
Step 2. : Move stopper foils to β detector in ~ 100ms.
Step 3. : Detect β-ray and γ-ray.
Step 4. : Measure decay time of RI after event matching.
- Event matching by position information.
- RI Stopped Position (X,Y) = Decay Position (X,Y)

Separation of RI using Multi-Layer Foils





(X-Y Plane)

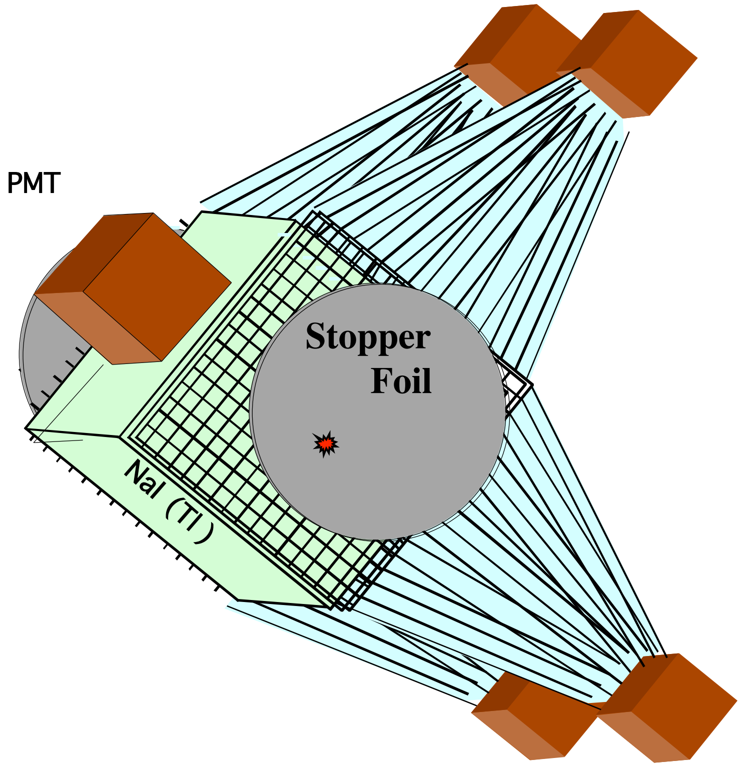


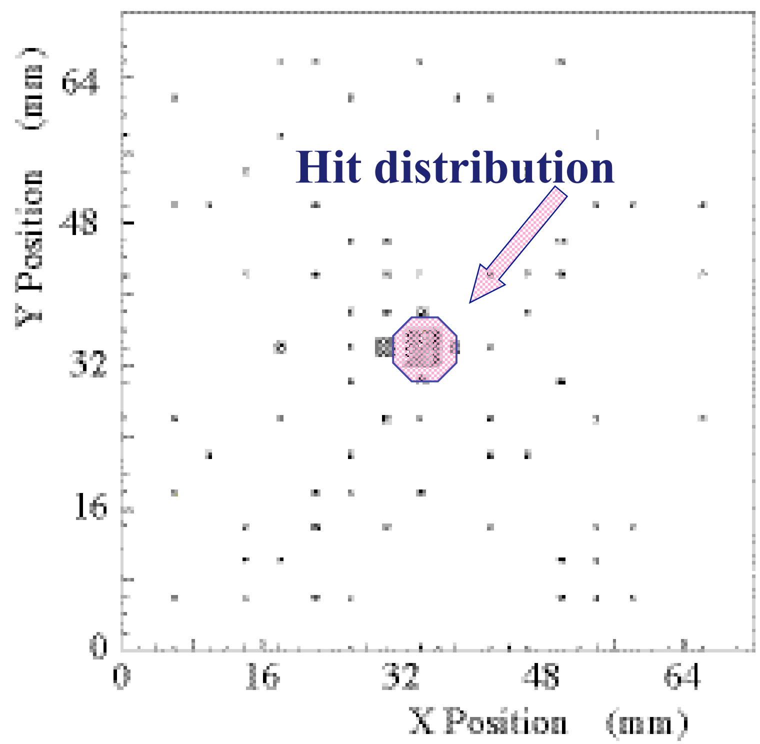
- Separate mixed isotopes by multi-layer foils.
- Measure half-life of different nuclei simultaneously.

→ Known RI for the consistency check.

Measurement of β -decay by fiber scintillator

Scintillation Fiber Array (Bicron BCF-12: 1x1mm^2)
PMT: Hamamatsu R5900-M16

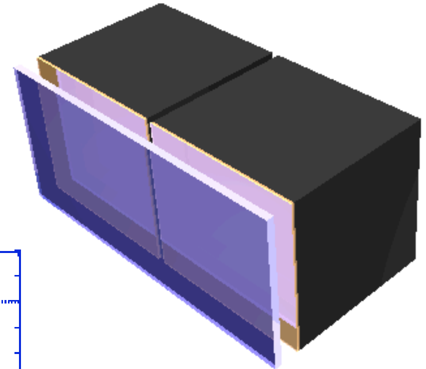


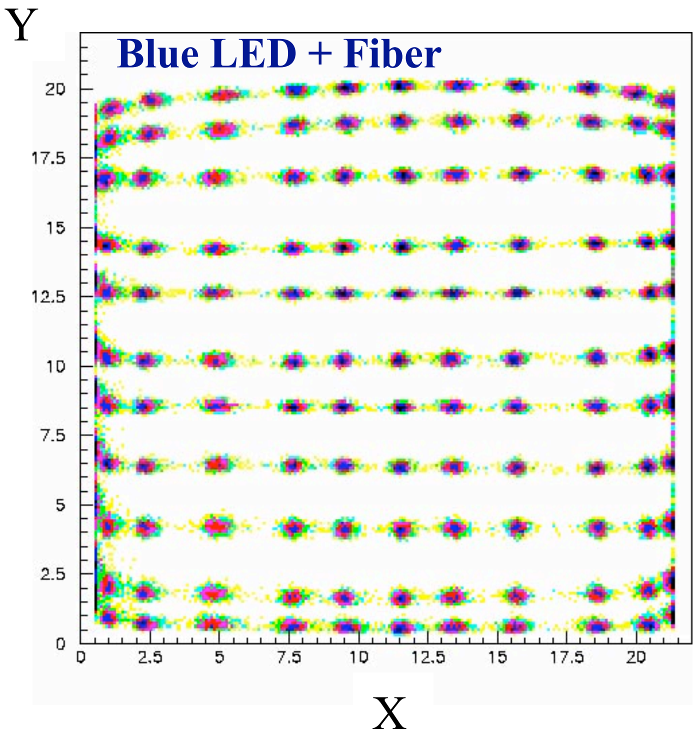


1. **Area : 64mm x 64mm.**
2. **Position resolution : < ~ 3mm (Adjustable)**
3. **Efficiency : 50% per layer**

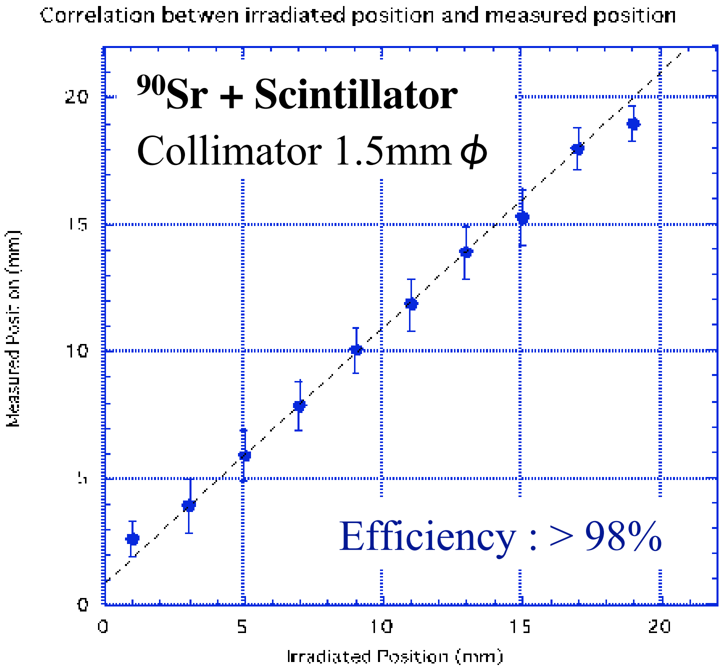
New Position Sensitive β -ray Detector

- Hamamatsu R8520 (22x22mm^2) + Charge division readout (4 ch)
- Plastic Scintillator (0.5mm^t)



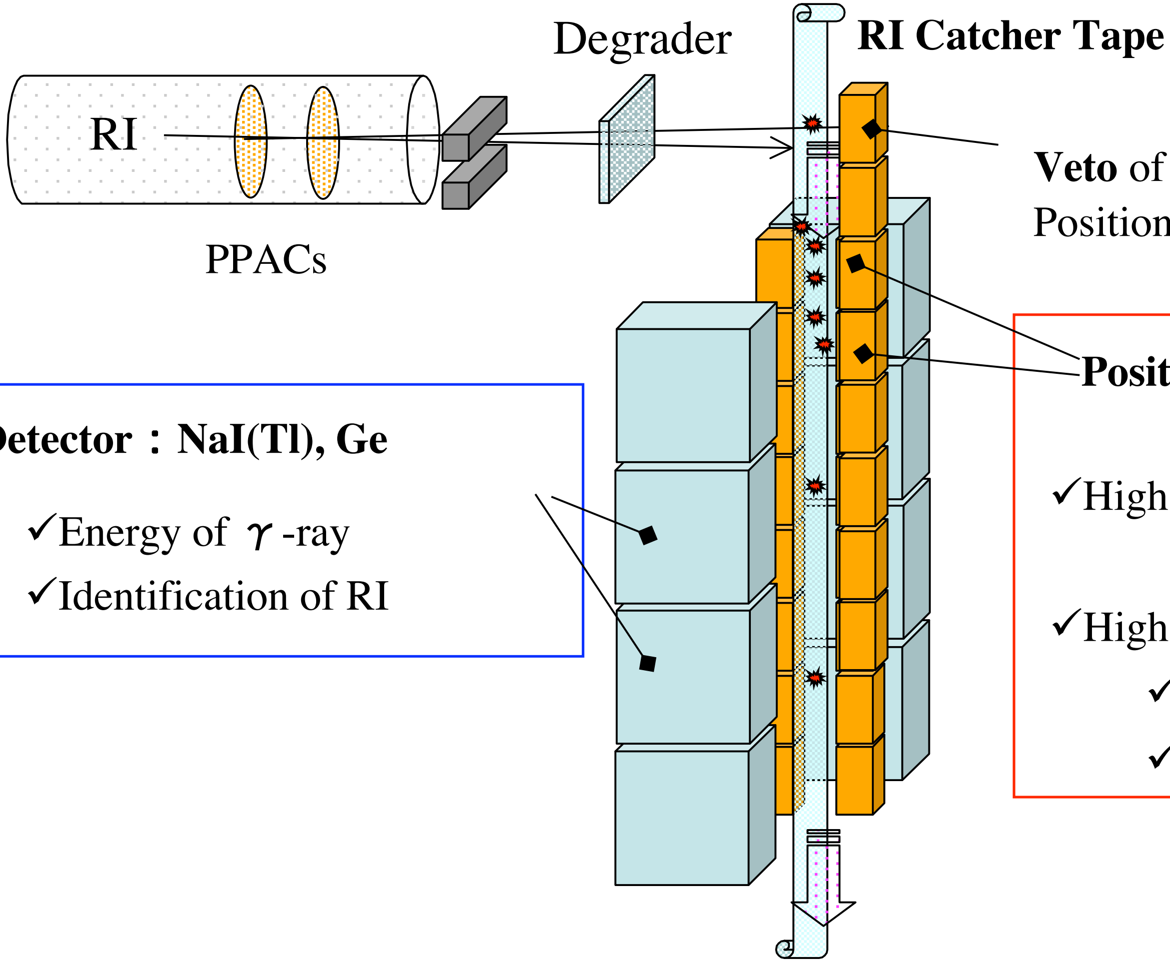


$\sigma_{x,y}$ < ~ **0.2 mm**



1 . Simple Structure
2 . Less Number of Channels (**4ch/PMT**).
3 . Good Position Resolution. ($\sigma_{x,y}$ $\leq$ **0.7mm**)
4 . High Detection Efficiency. ($\geq$ **98%**)
5 . Dead space : **5% or less**

New System for Shorter Half-Life (<100ms~)



Veto of Implanted RI after Tape
Position Sensitive ***β*** **-ray Detector**

γ -Detector : NaI(Tl), Ge

✓Energy of γ -ray
✓Identification of RI

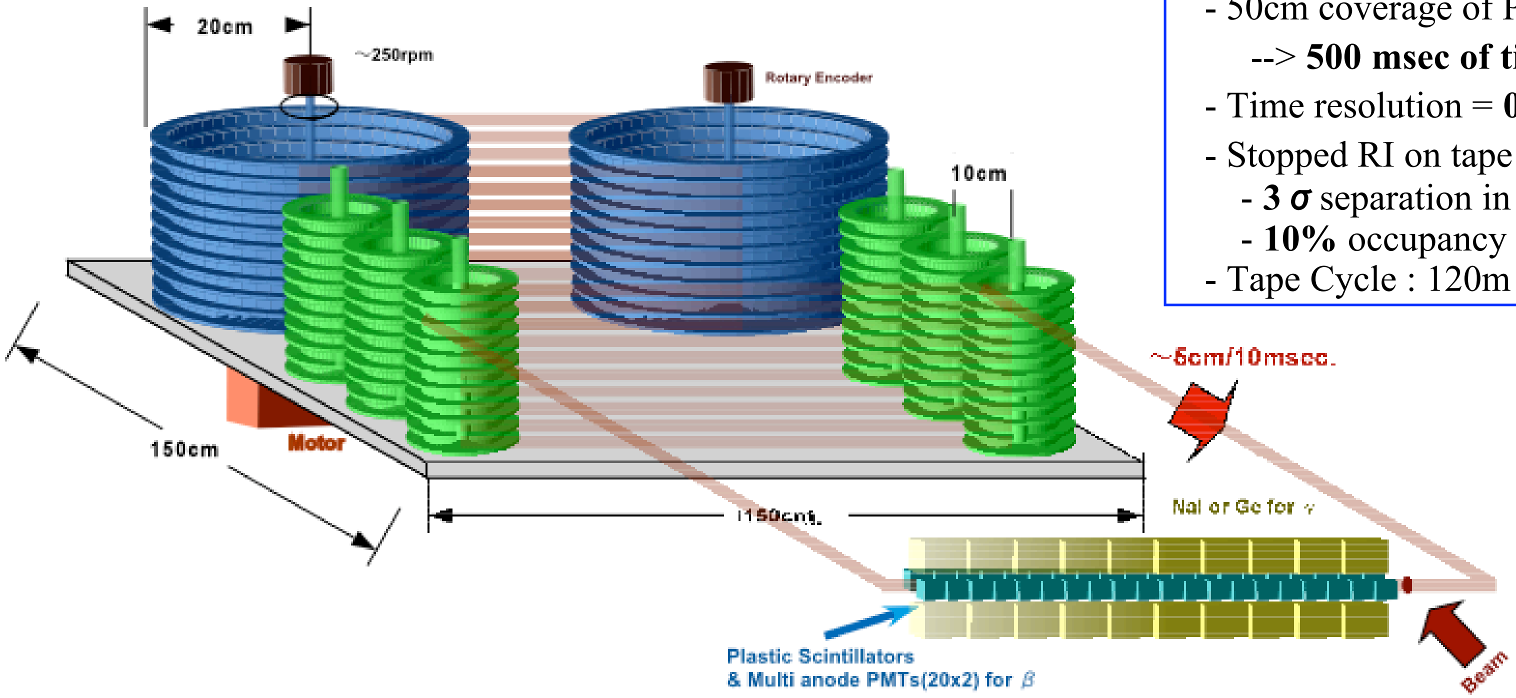
Position Sensitive *β* -ray Detector

✓High Resolution (σ x, σ y) =**~0.7mm**
➡ Event Matching
✓High Efficiency
✓: Detection Efficiency ≥ ~ **98%**
✓Full Coverage

<u>Characteristics</u>

- High detection efficiency of *β* -ray(≥ 98%)
- Wide range of half-life measurement (**< 100ms~**)
- **Reduction of B.G.** using long tape.
- **Selection of RI** with thin tape
- Operation under **high beam intensity**
- **Continuous beam** instead of pulsed beam
- Reduction of B.G. from **daughter RI**
- Easy to **upgrade** the system

Tape System with Programmable Control



◎Example (constant speed)

- Tape speed = **1 m / sec**
- 50cm coverage of PMTs (**20x2 PMTs**)
  --> **500 msec of time coverage**
- Time resolution = **0.7 ms**
- Stopped RI on tape **: 400 RIs / sec**
  - **3 σ** separation in x and y
  - **10%** occupancy
- Tape Cycle : 120m / (1m/sec) = **2 min.**

■Tape Control

✓Discrete Mode

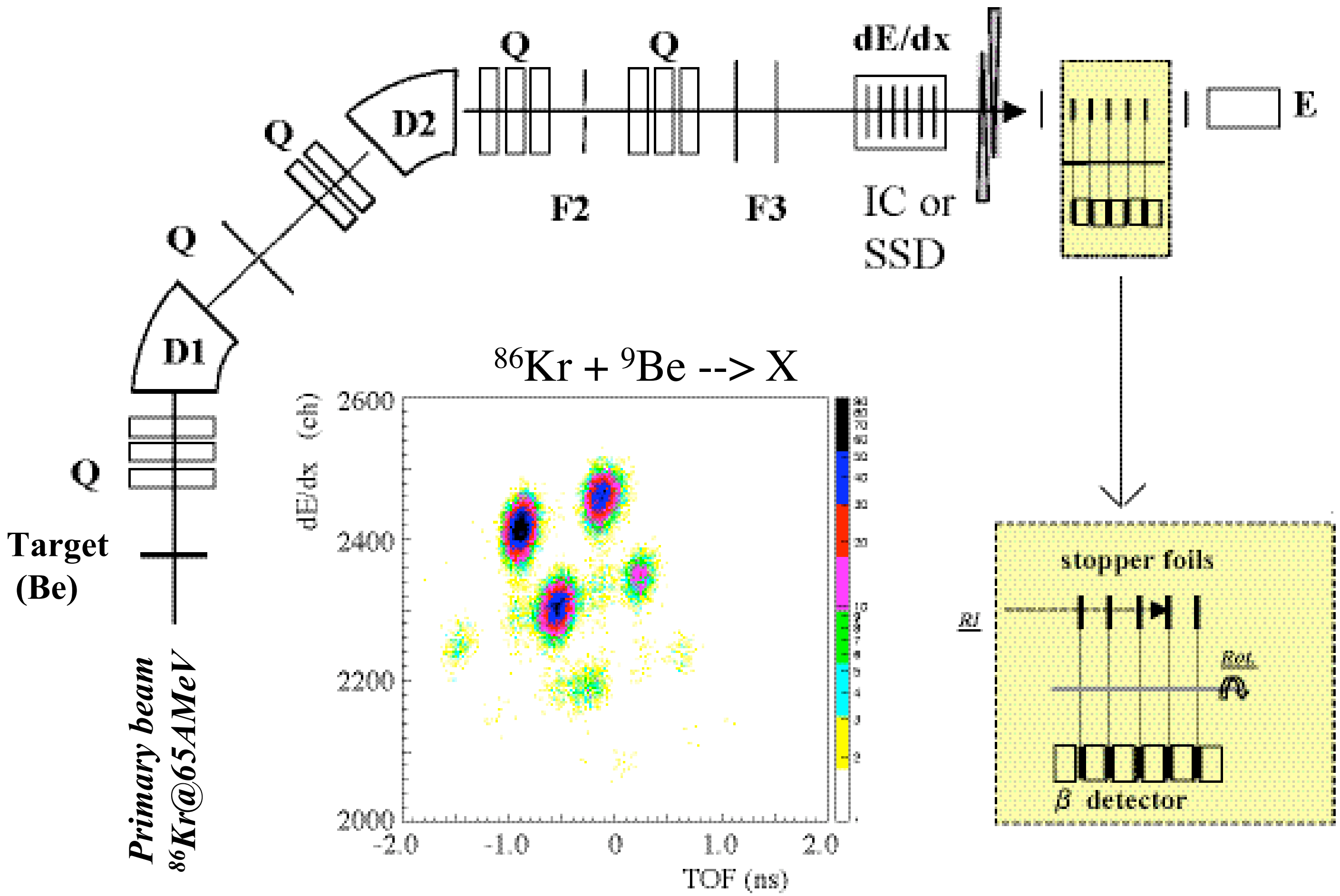
✓Constant Speed Mode (Max speed of 5m/sec with radius of 20cm)

■Possibility of Extending the Length of Tape (N x 60 m)

Experimental Setup at RIKEN RIPS (Stage I)

1. Produce radioactive isotopes (RI).
2. Identify RI by TOF, dE/dx, and rigidity.
3. Measure the half-life by $T_{1/2}$ detector system.

Experiment in Dec. 2002 using ^{86}Kr as a primary beam.



Summary

- **RIBF is in Progress.**
  - ✓**Experiment will be started from 2005.**
- **System for Half-life Measurement (> 100ms)**
  - ✓**Multi-layer stopper foils**
  - ✓**Scintillation fiber detector for β-ray detection**
    - **Position resolution 3mm (adjustable)**
    - **Efficiency : 50% / layer**
    - **Half-life > 100 ms**
- **New System for Shorter Half-life (< 100ms ~)**
  - ✓**Long Tape as a RI Catcher**
  - ✓**High Performance of β-ray Detector**
    - **Position resolution : ~ 0.7 mm**
    - **β-ray detection efficiency : 95%**
    - **γ detectors (NaI(Tl), Ge)**
- **Development of Particle Identification Detectors for Heavy RI.**
  - **Development of TOF detector ($\sigma_{TOF} \sim < 9$ ps).**
  - **Multi-Layered Ion Chamber of dE/dx instead of SSD.**