RIKEN NISHINA CENTER

Spin-aligned RI beams via two-step fragmentation reactions

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About this work

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nature physics

Production of spin-controlled rare isotope beams

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The degree of freedom of spin in quantum systems serves as an unparalleled laboratory where intriguing quantum physical properties can be observed, and the ability to control spin is a powerful tool in physics research. We propose a method for controlling spin in a system of rare isotopes which takes advantage of the mechanism of the projectile fragmentation reaction combined with the momentum-dispersion matching technique. The present method was verified in an experiment at the RIKEN RI Beam Factory, in which a degree of alignment of 8% was achieved for the spin of a rare isotope ^{32}Al. The figure of merit for the present method was found to be greater than that of the conventional method by a factor of more than 50.

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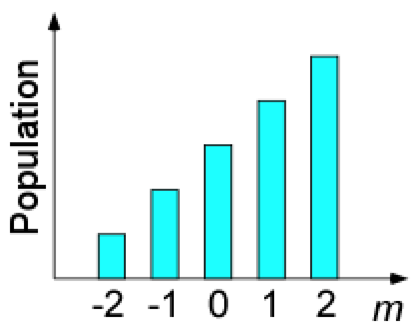
Principle for producing spin-aligned RI beam

What is spin alignment?

Spin Orientation

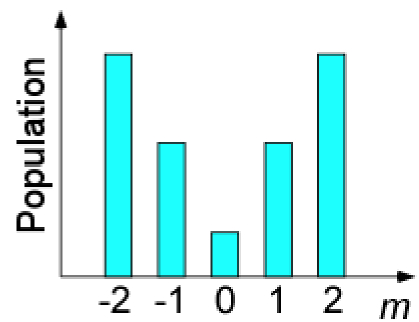
Spin Polarization

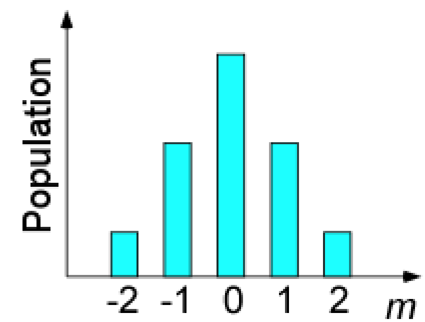
Orientation of rank=1
(average ≠ 0)



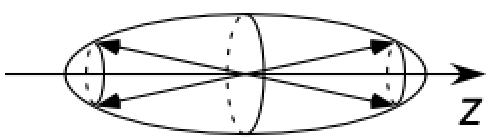
Spin Alignment

Orientation of rank=2
(average = 0)

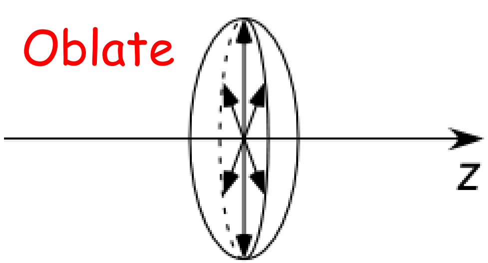




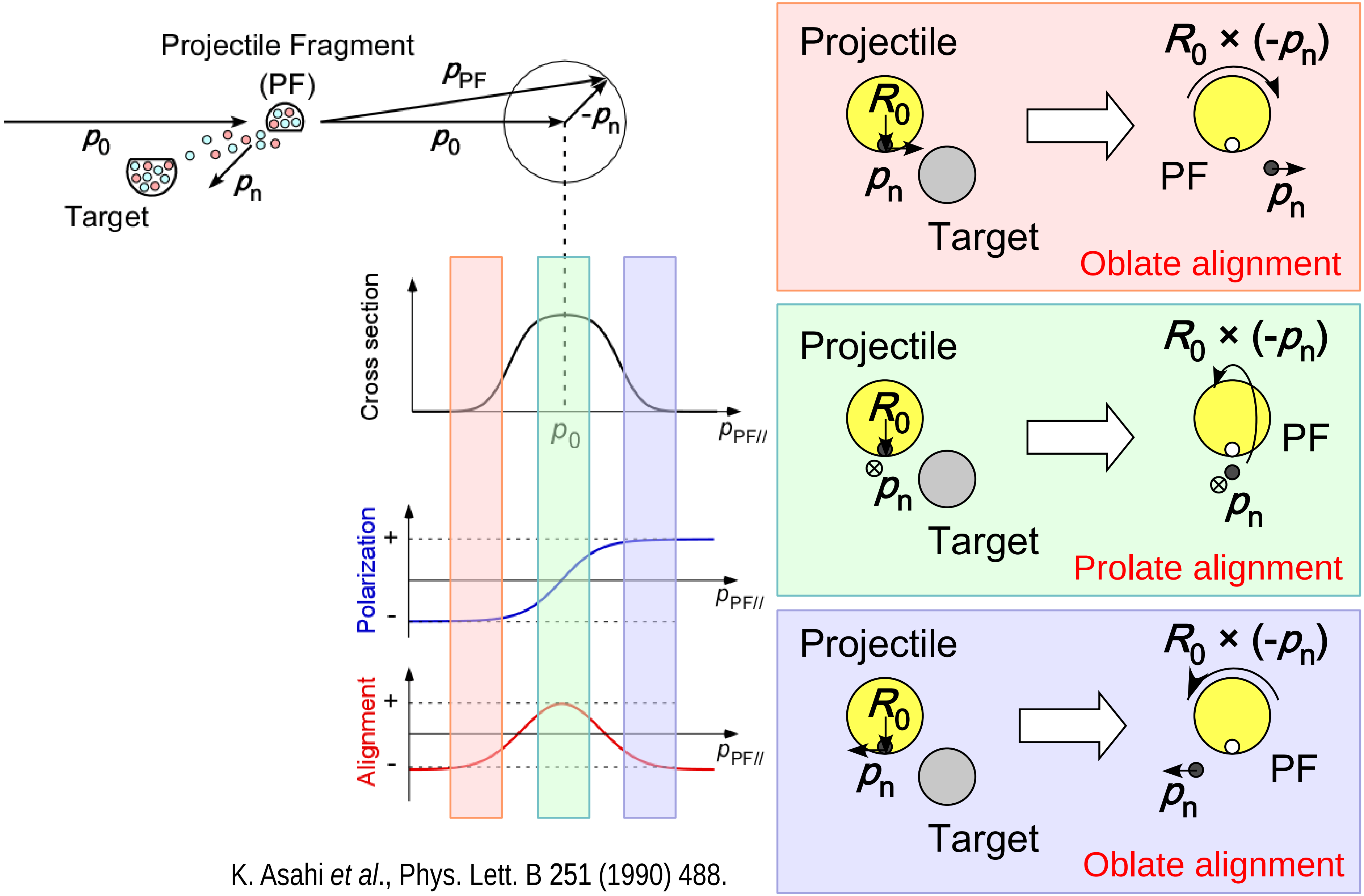
Prolate



Oblate

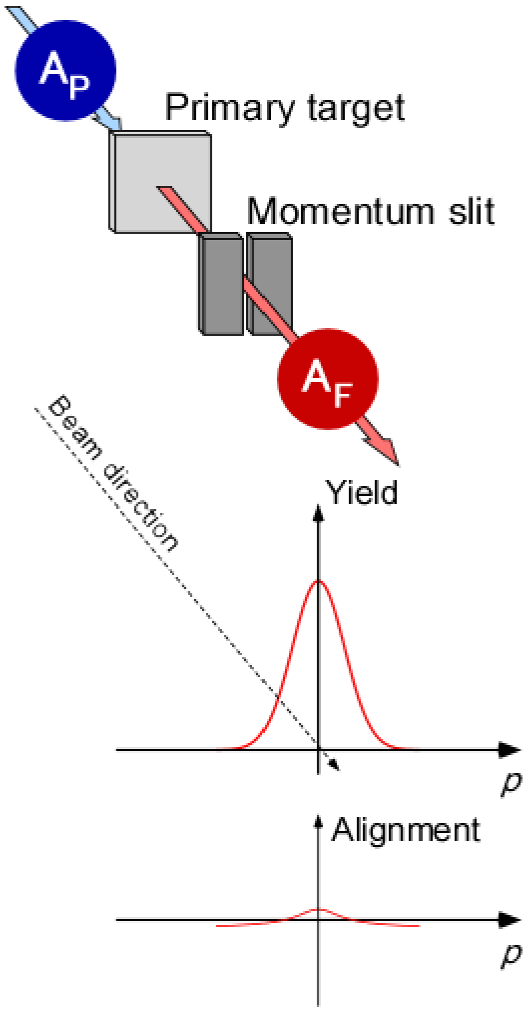


Production of spin-aligned RI beam

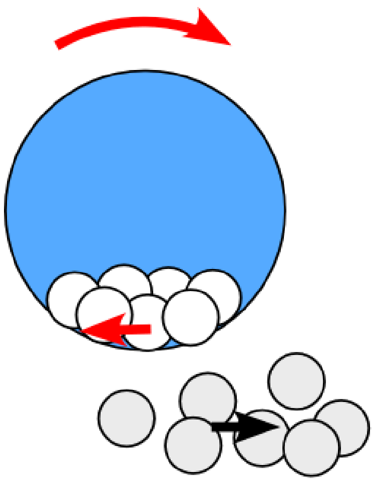


K. Asahi *et al.*, Phys. Lett. B 251 (1990) 488.

Conventional one-step method

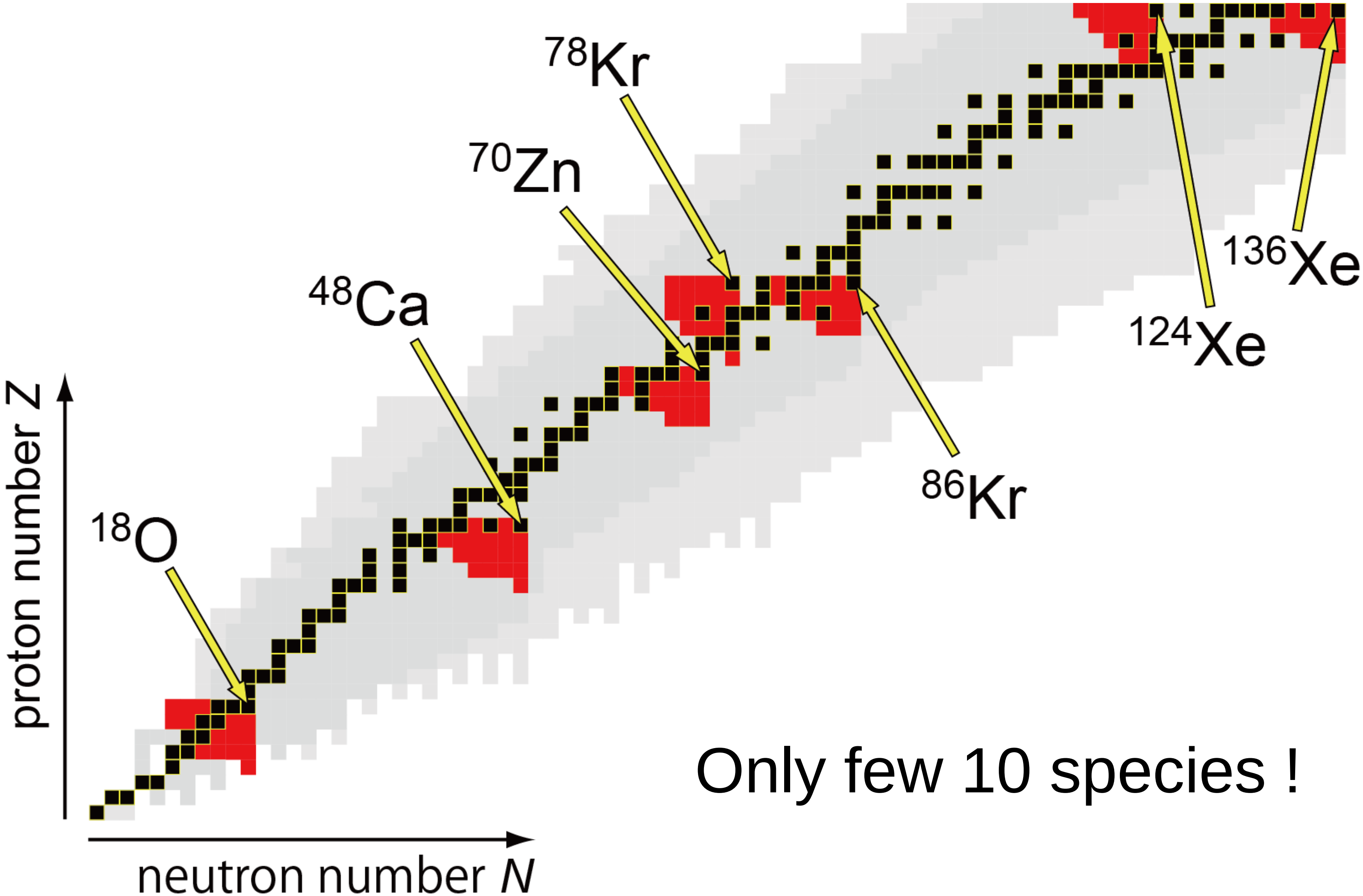


- Primary beam :
  rare gas + some metals
- Large number of nucleon-removal



Small spin orientation

Previous accessible nuclei



Only few 10 species !

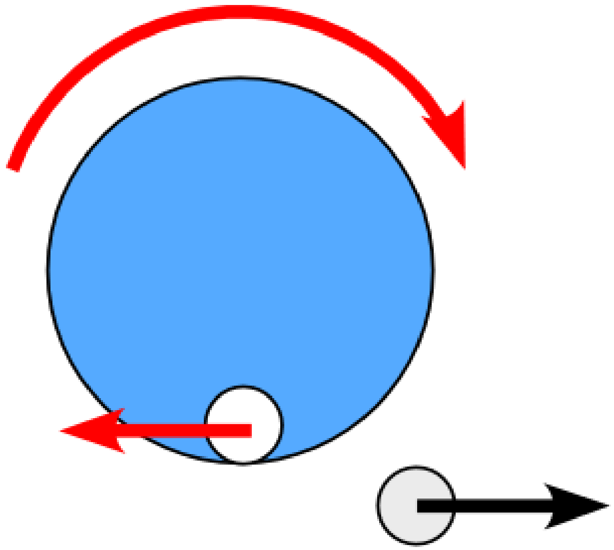
Motivation

Global way to

produce spin-aligned RI beams

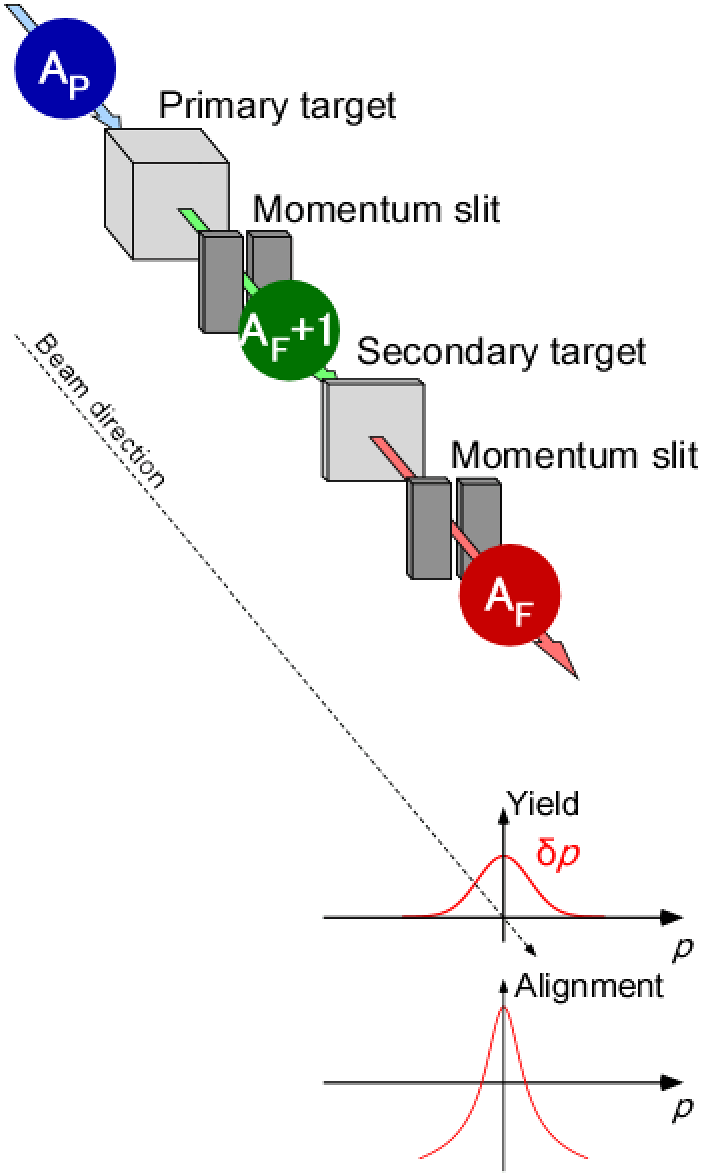
Maximize the magnitude of spin alignment

The simplest & promising way



One-nucleon removal reaction

(Simple) Two-step fragmentation



- High spin alignment
  by one-nucleon removal
- No projectile dependence
- Low yields due to
  double momentum selections

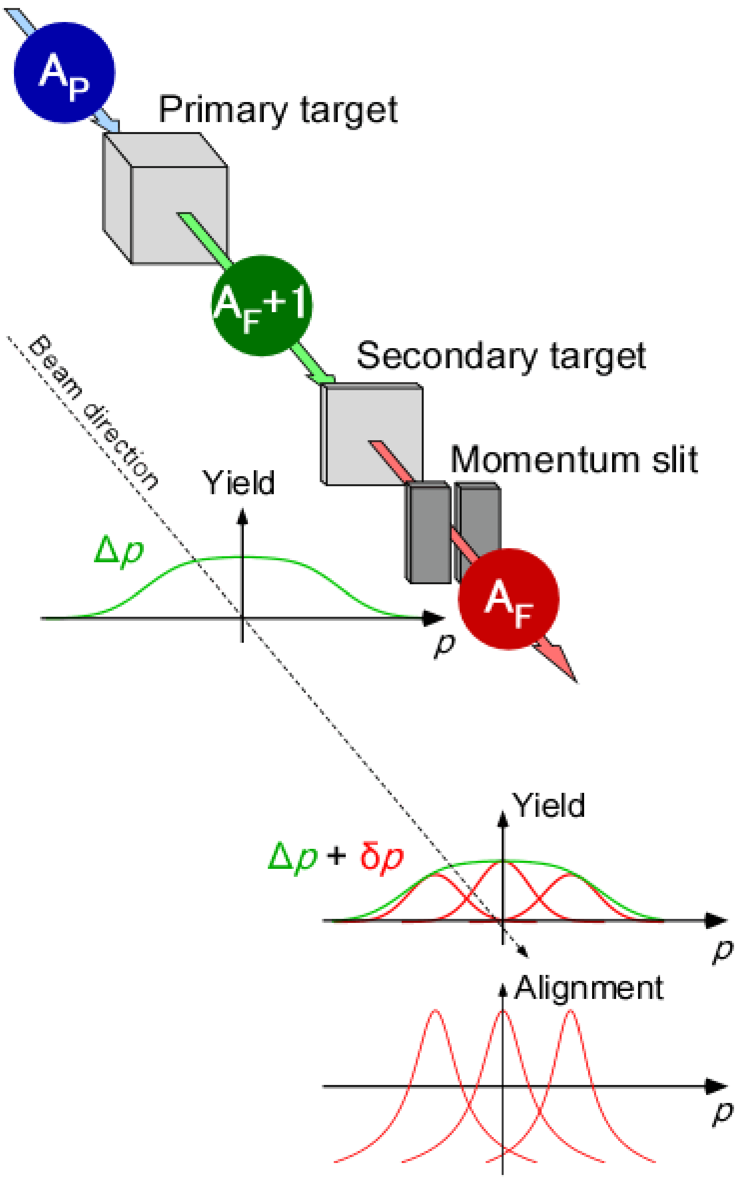
An idea

Production of alignment is related to the momentum change in 2nd reaction

↓

Direct extraction of "relative" momentum change

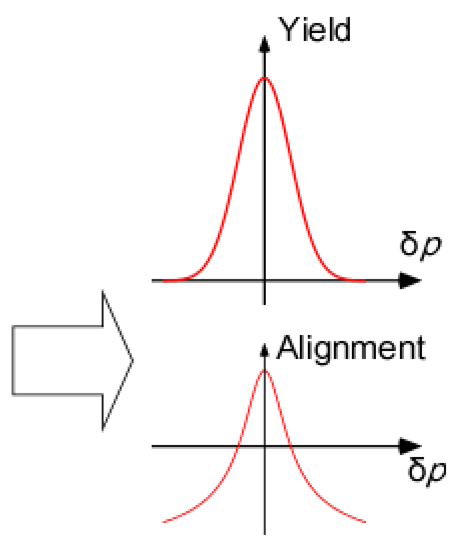
Combination with dispersion-matching technique



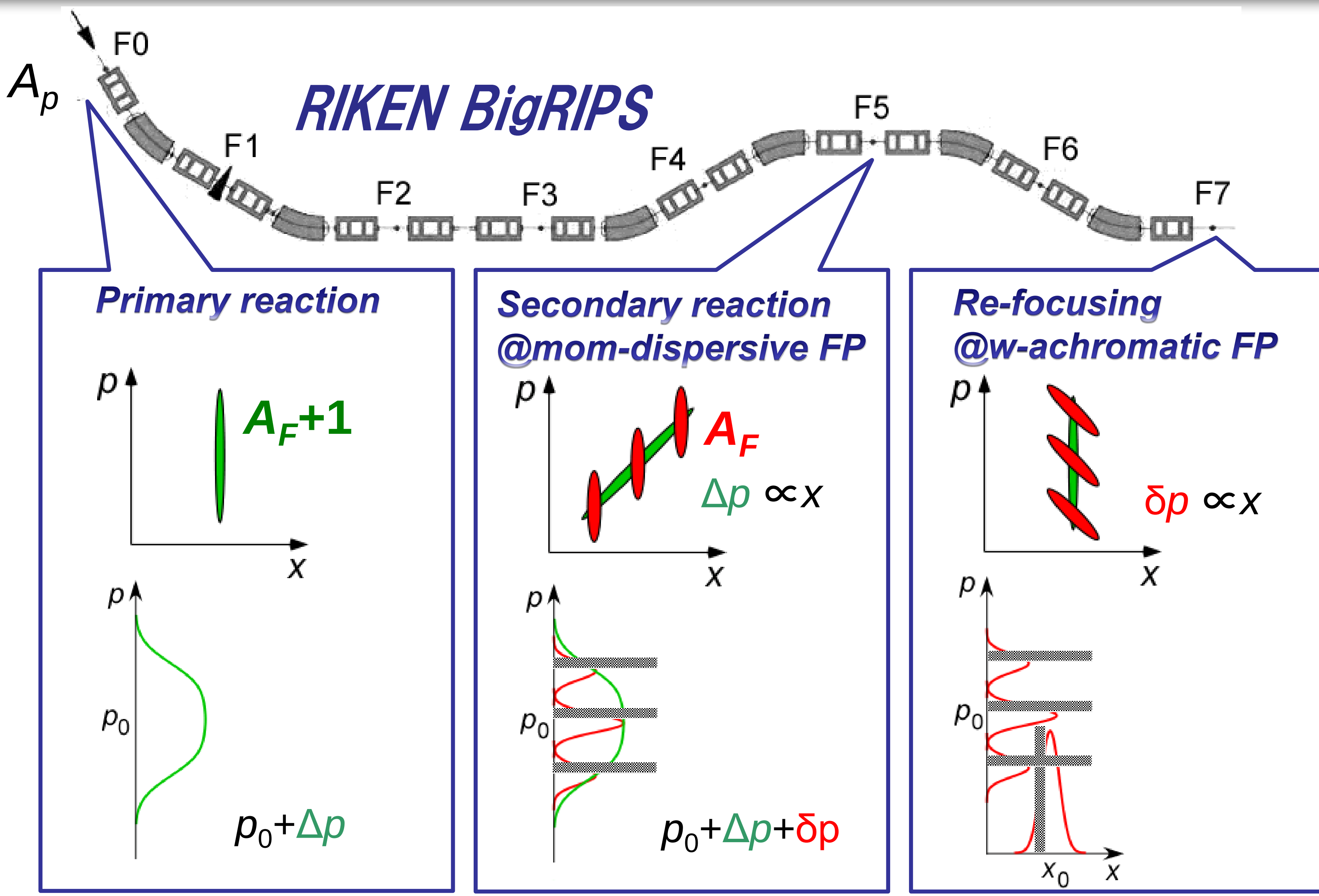
2nd PF @ Momentum Dispersive FP
Slit @ Double Achromatic FP

Dispersion matching

Single momentum selection
by relative momentum change



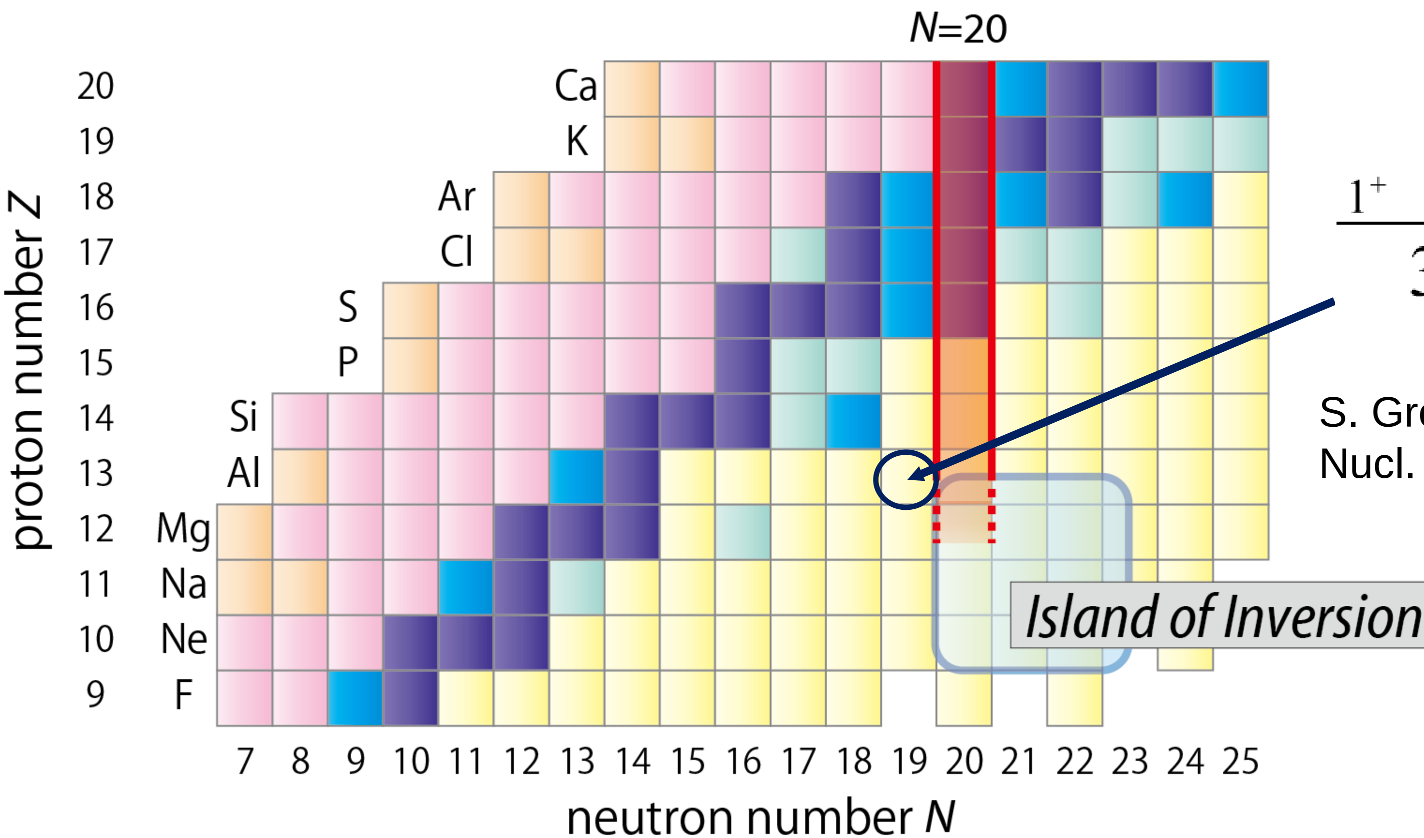
Separate roles of focal planes

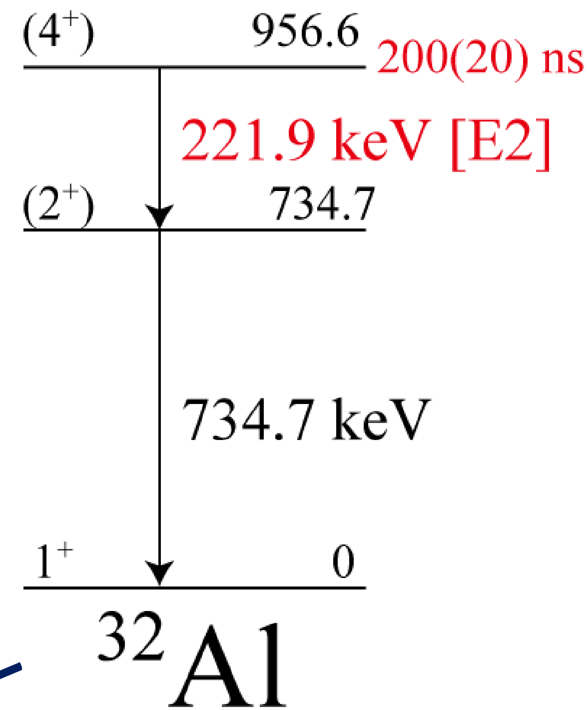


Enhancement of yield with keeping spin-alignment

Experiment at RIKEN RIBF using ^{32m}Al

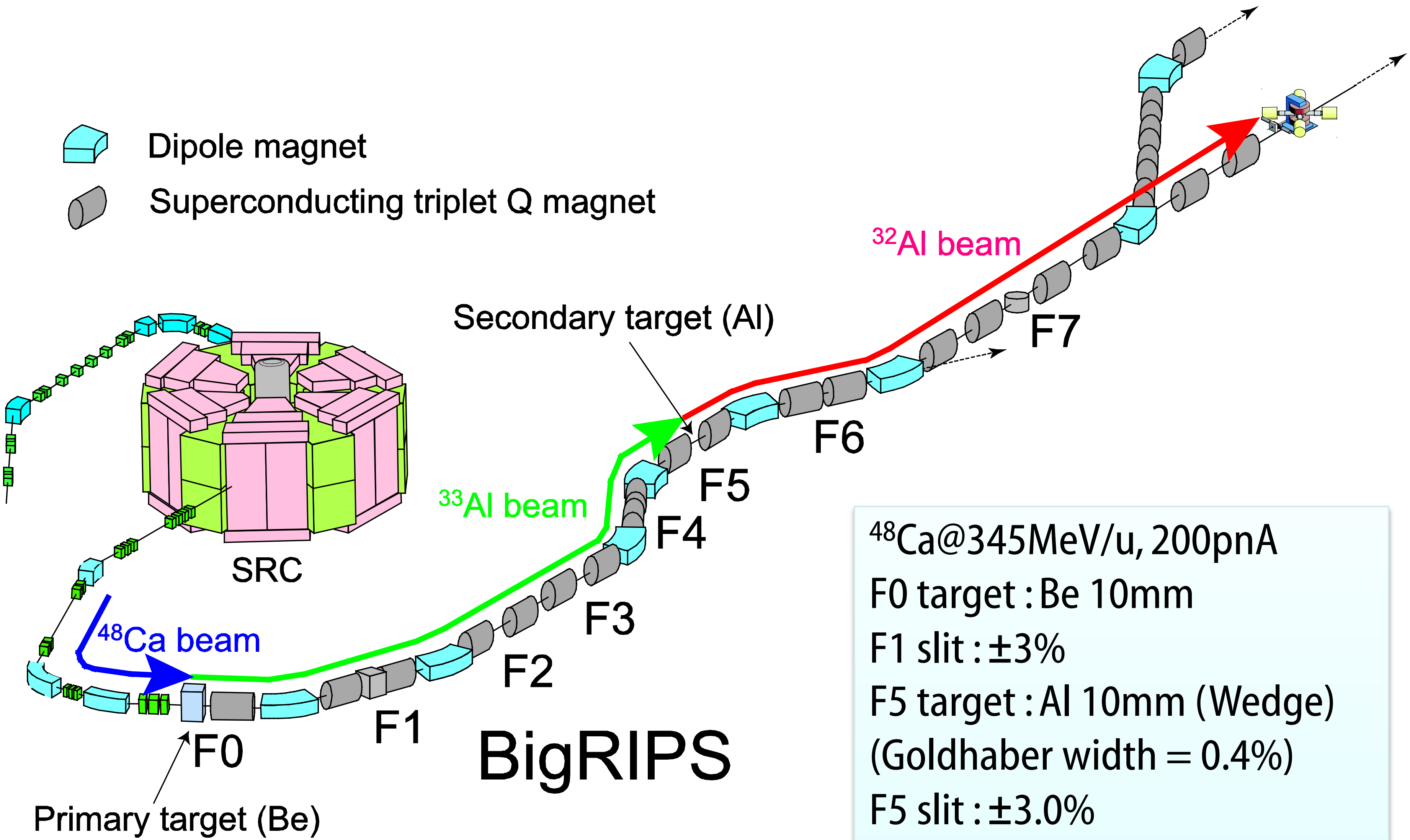
Isomeric state of ^{32}Al





S. Grevy *et al.*,
Nucl. Phys. A 734, 369 (2004).

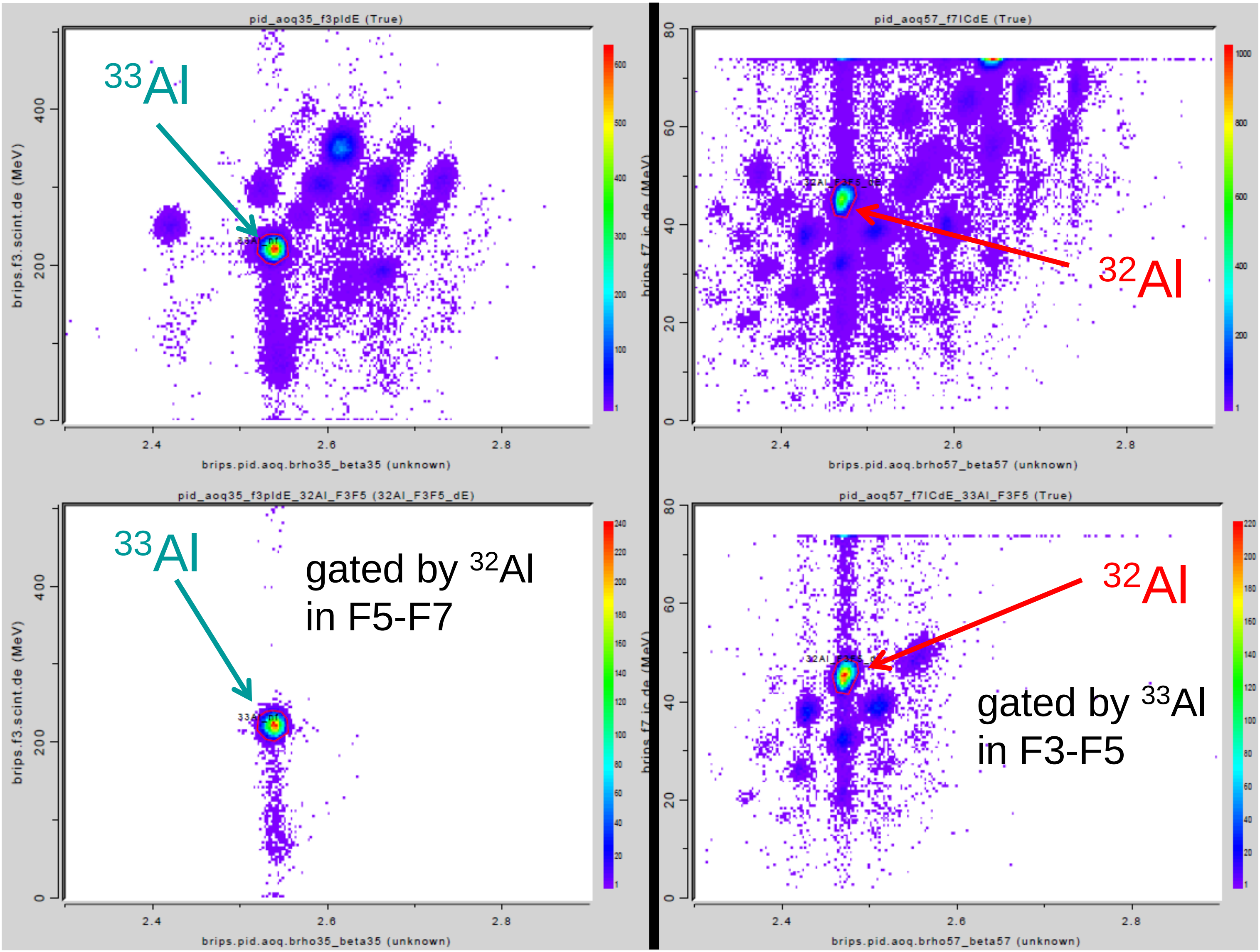
Experimental condition



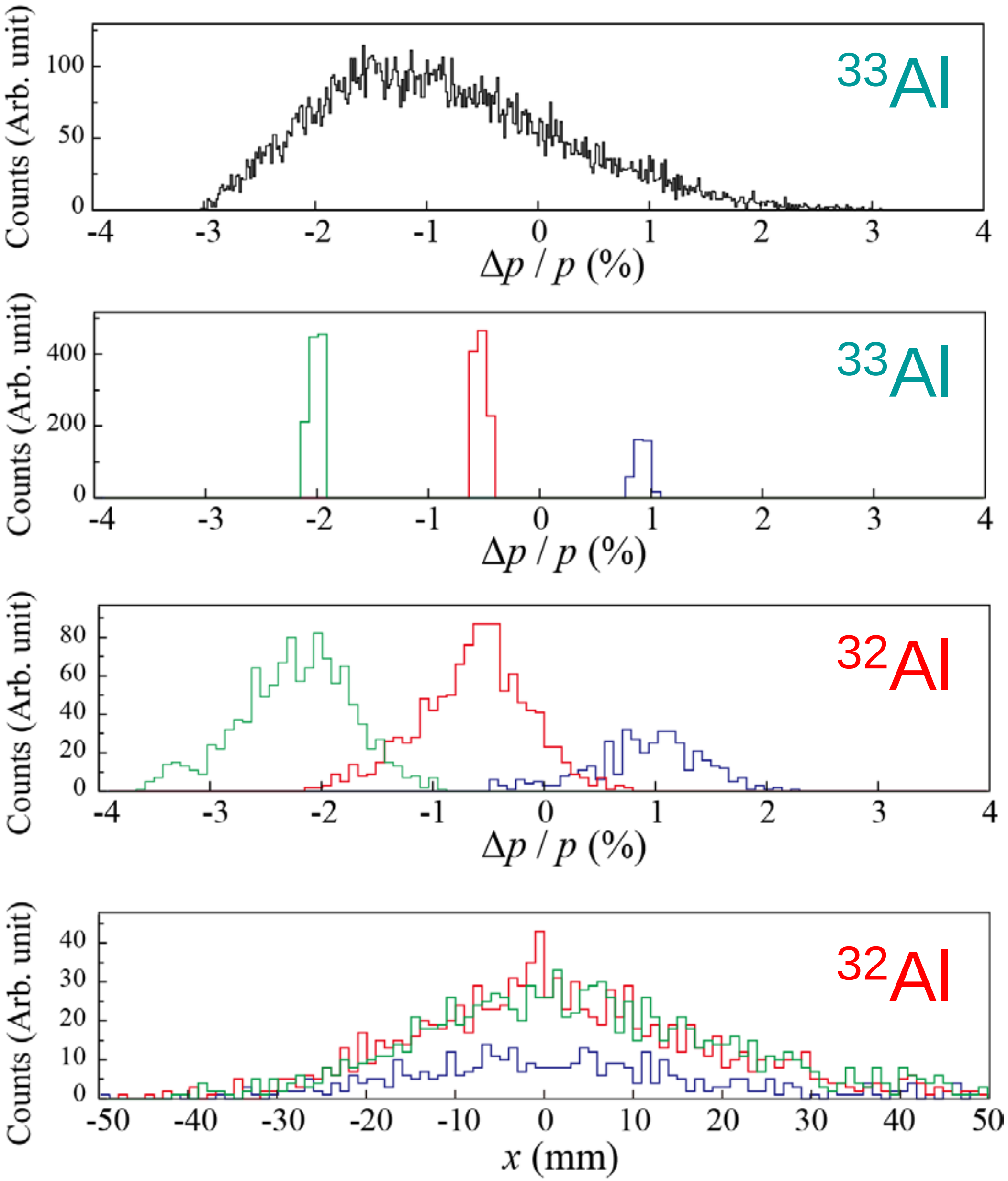
^{48}Ca@345MeV/u, 200pnA
F0 target : Be 10mm
F1 slit : ±3%
F5 target : Al 10mm (Wedge)
(Goldhaber width = 0.4%)
F5 slit : ±3.0%
F7 slit : center±0.15%

Particle identification

PID in F3-F5 → PID in F5-F7



Confirmation of dispersion matching



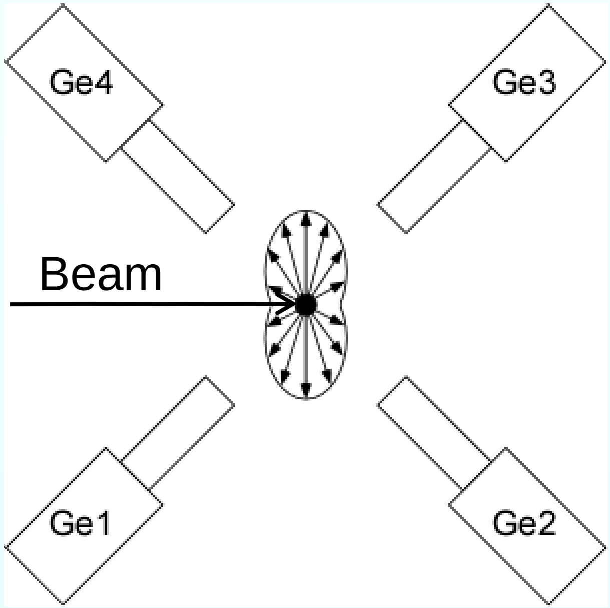
Momentum Distribution@F3

Gate for Momentum

Gated Momentum Distribution @F5-F7

x position@F7

Time Differential Perturbed Angular Distribution (TDPAD) method



- Spin-aligned beam
- Larmor precession

$$\omega_L = -\frac{g\,\mu_N B_0}{\hbar}$$

B_0 : Magnetic field
μ_N : Nuclear magneton
$\hbar$: Dirac constant
g : g-factor

- γ counting rate for each Ge

$$W(\theta + \omega_L \cdot t)$$

Experimental setup

Beam Stopper

- Annealed Cu
- 3mm thickness

Magnet

- B_0=2.59 kGauss
- 0.1% unceryainty

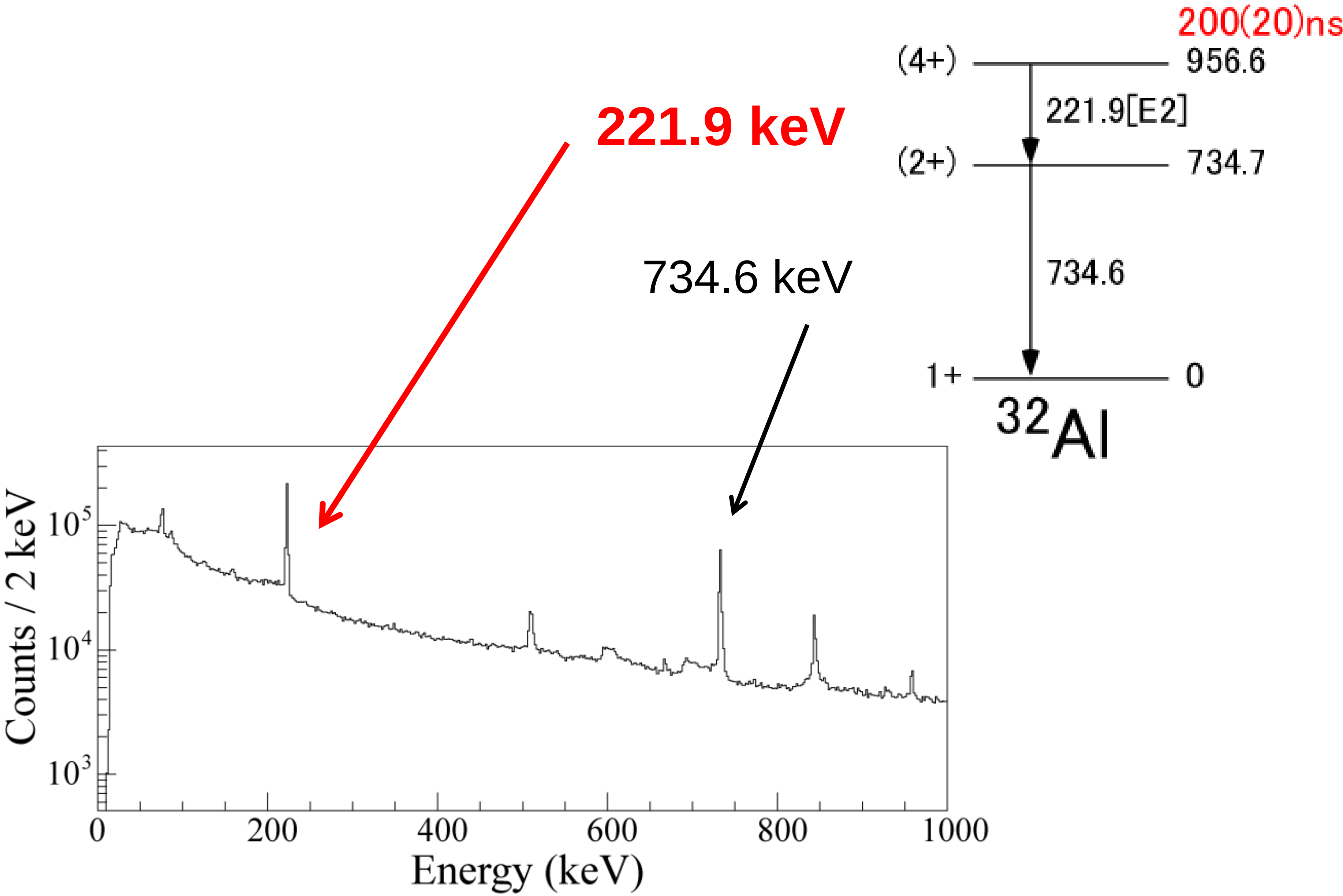
Ge detector

- Relative Efficiency
  35%×1,15-20%×3
- Distance
  7cm from center

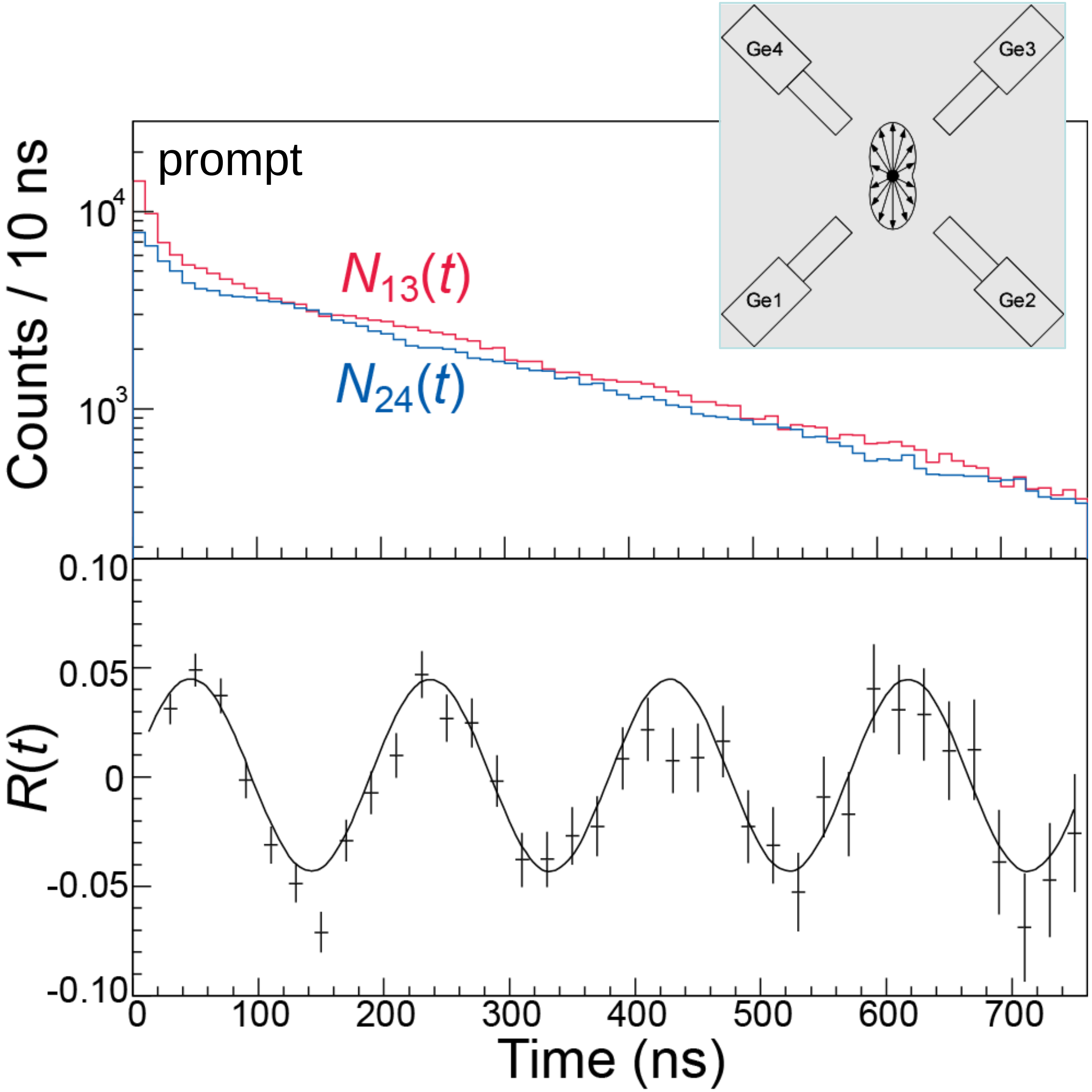
Plastic scintillator

- 0.1mm thickness
- Start timing for PAD

Energy spectrum



Time spectrum & R (t) ratio



R(t) ratio

$$R(t) = \frac{N_{13}(t) - \varepsilon \cdot N_{24}(t)}{N_{13}(t) + \varepsilon \cdot N_{24}(t)}$$

$$= \frac{3AB_2F_2}{4 + AB_2F_2} \cos(2\omega_L t + \alpha)$$

$$\omega_L = -\frac{g\mu_N B_0}{\hbar}$$

F_2 : Anisotropy parameter

B_2 : Statistical tensor for complete alignment (B_2F_2 = 0.7143 for E2 transition of $4^+ \rightarrow 2^+$)

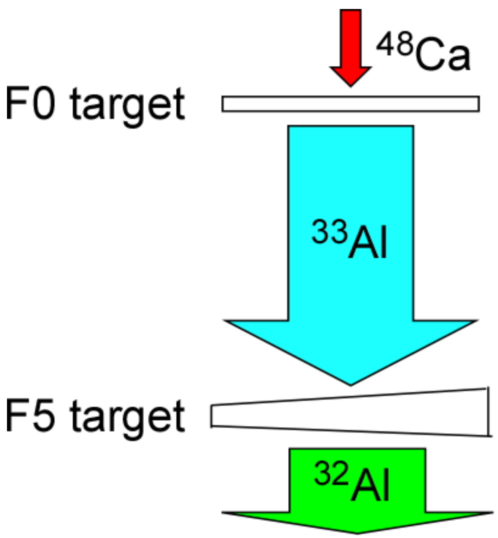
A: Spin alignment

A=8(1)%

Evaluation of new method

Validity of dispersion matching

Two-step fragmentation w/ Dispersion matching



^{48}Ca@345MeV/u, 200pnA
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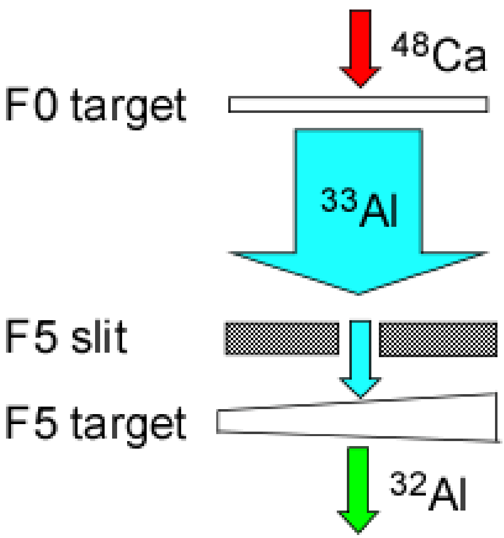
F1 slit : ±3%
F5 target : Al 10mm (Wedge)
(Goldhaber width = 0.4%)
F5 slit : ±3.0%
F7 slit : center±0.15%

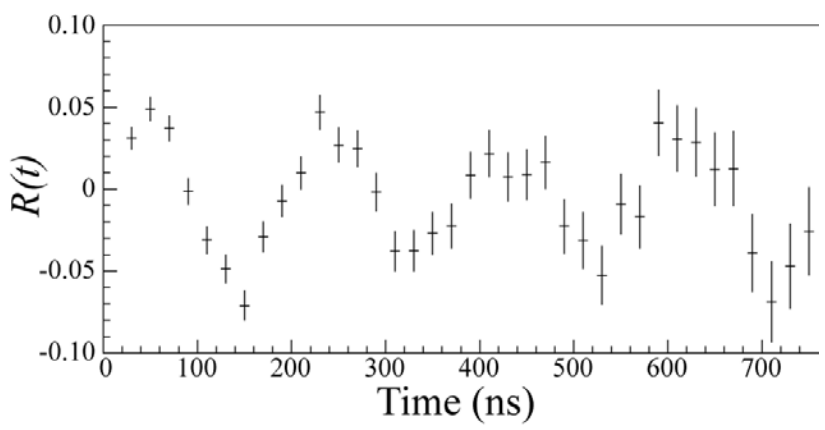
Two-step fragmentation w/o Dispersion matching



^{48}Ca@345MeV/u, 200pnA
F0 target : Be 10mm
F1slit : ±3%
F5 target : Al 10mm (Wedge)
(Goldhaber width = 0.4%)
F5 slit : ±0.5%
F7 slit : center±0.15%

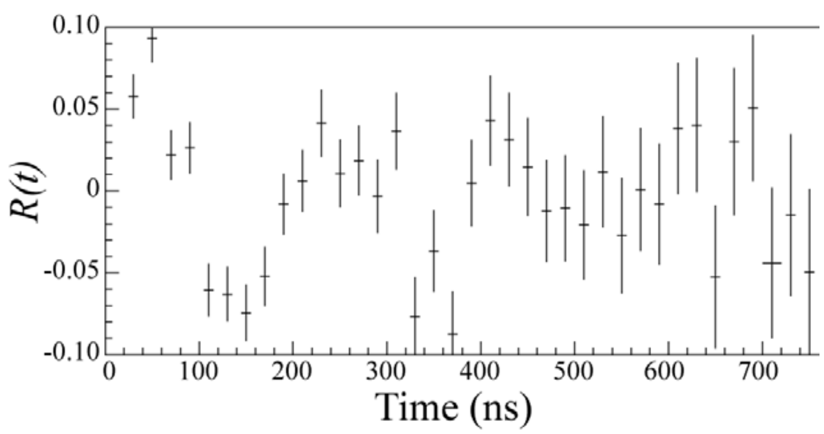
Validity of dispersion matching

Two-step fragmentation w/ Dispersion matching



$A = 8(1)\%$

Two-step fragmentation w/o Dispersion matching

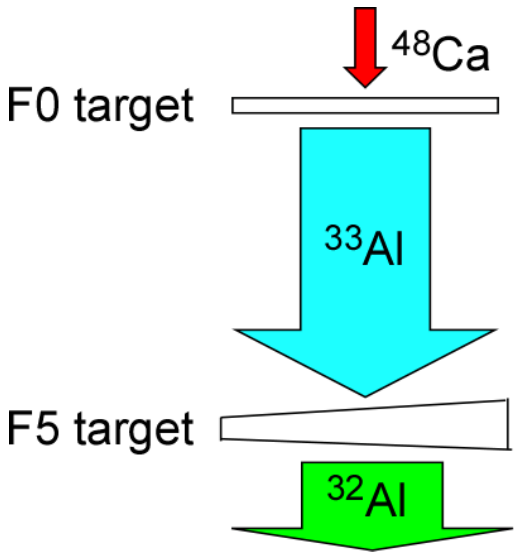


$A = 9(2)\%$

Validity of dispersion matching has been confirmed

Comparison with conventional method

Two-step fragmentation w/ Dispersion matching



^{48}Ca@345MeV/u, 200pnA

F0 target : Be 10mm

F1 slit : ±3%

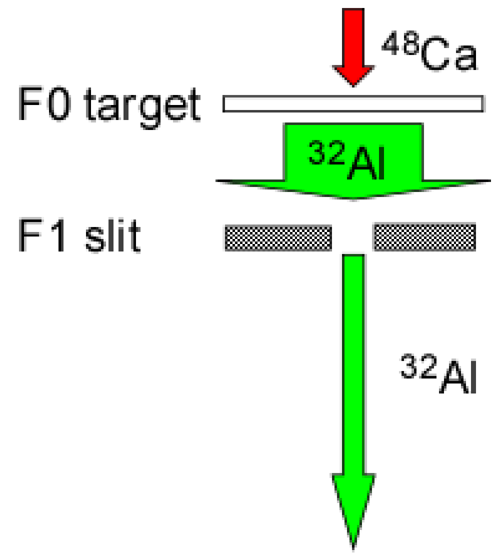
F5 target : Al 10mm (Wedge)

(Goldhaber width = 0.4%)

F5 slit : ±3.0%

F7 slit : center±0.15%

One-step fragmentation



^{48}Ca@345MeV/u, 200pnA

F0 target : Be 4mm

(Energy loss = 3%

Goldhaber width = 4%)

F1 slit : ±0.5%

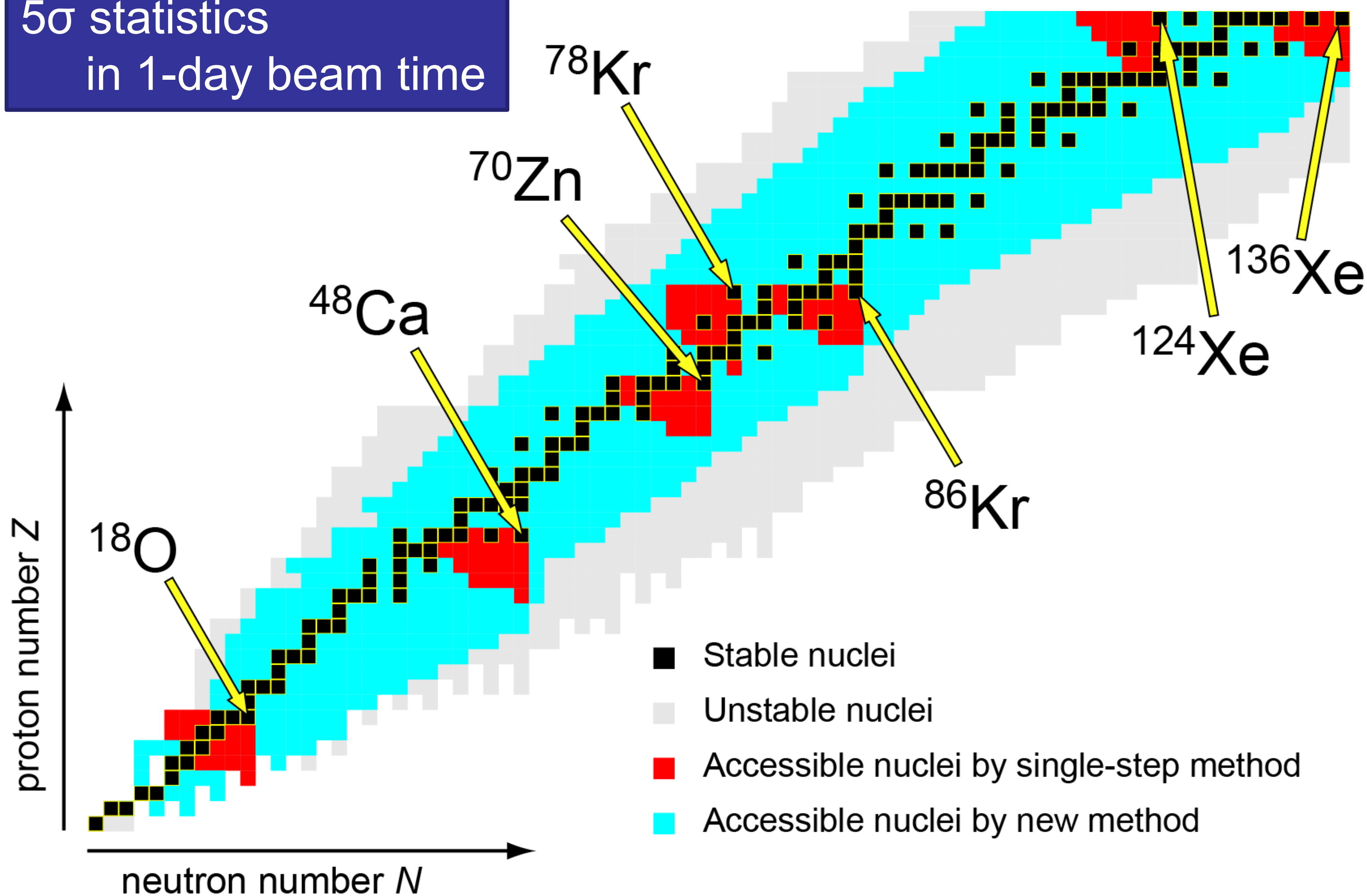
Figure of merit

	Two-step	One-step
Reaction	$^{48}Ca \rightarrow {}^{33}Al \rightarrow {}^{32}Al$	$^{48}Ca \rightarrow {}^{32}Al$
Energy	200 MeV/u	345 MeV/u
Target	10mm Be	4mm Be
Goldhaber Width	0.4%	4%
Mom. Acceptance	±0.15%	±0.5%
^{32m}Al Yield@F12	0.54(5) kcps	0.87(6) kcps (Att.1/100)
^{32}Al Yield@F12	2.3(2) kcps	8.6(3) kcps (Att.1/100)
Isomer Ratio	50(6)%	59(5)%
Alignment	8(1)%	<0.8% (2σ confidence)
Meas. Duration	11.9 h	9.3 h

Figure of merit ($Y \cdot A^2$) is better by 50 times or more

Broadening of accessible nuclei

5σ statistics
in 1-day beam time



Summary

- **New method to produce high spin alignment**
  - ✓Two-step frag. by one-nucleon removal
  - ✓Dispersion matching technique
- **Experiment using ^{32m}Al**
  - ✓BigRIPS at RIKEN RIBF
  - ✓8(1)% spin alignment
- **Evaluation of new method**
  - ✓Figure of merit was improved by >50 times
  - ✓2-dimensional broadening of accessible nuclei

Collaborators

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