New control method of slowed-down RI beam and new PID method of secondary-reaction fragments at RIKEN RI beam factory

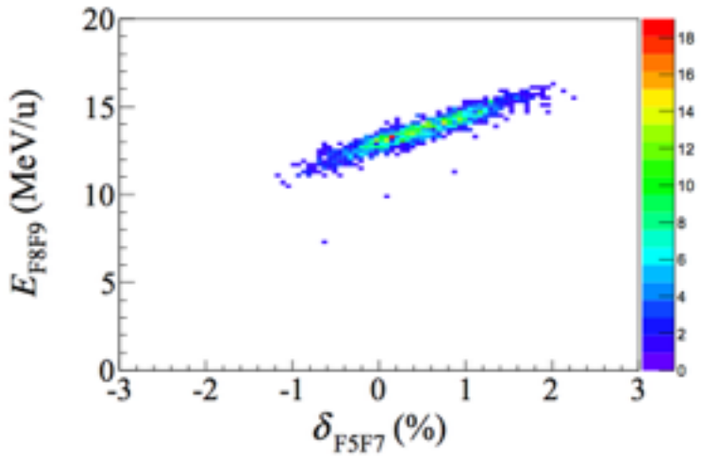
Toshiyuki Sumikama
RIKEN Nishina center

This work was funded by ImPACT Program of
Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

Slowed-down RI beam at RIBF

- Slowed-down RI beam from ~200 MeV/u to 10 or 20 MeV/u
  - transfer reaction, deep inelastic reaction, fusion reaction
- First test experiment at RIBF
  - ^{82}Ge ~15 MeV/u
  - (Width of E) > (Acc. of ZeroDegree spec.)

OEDO beam line by Michimasa Sep. 18th



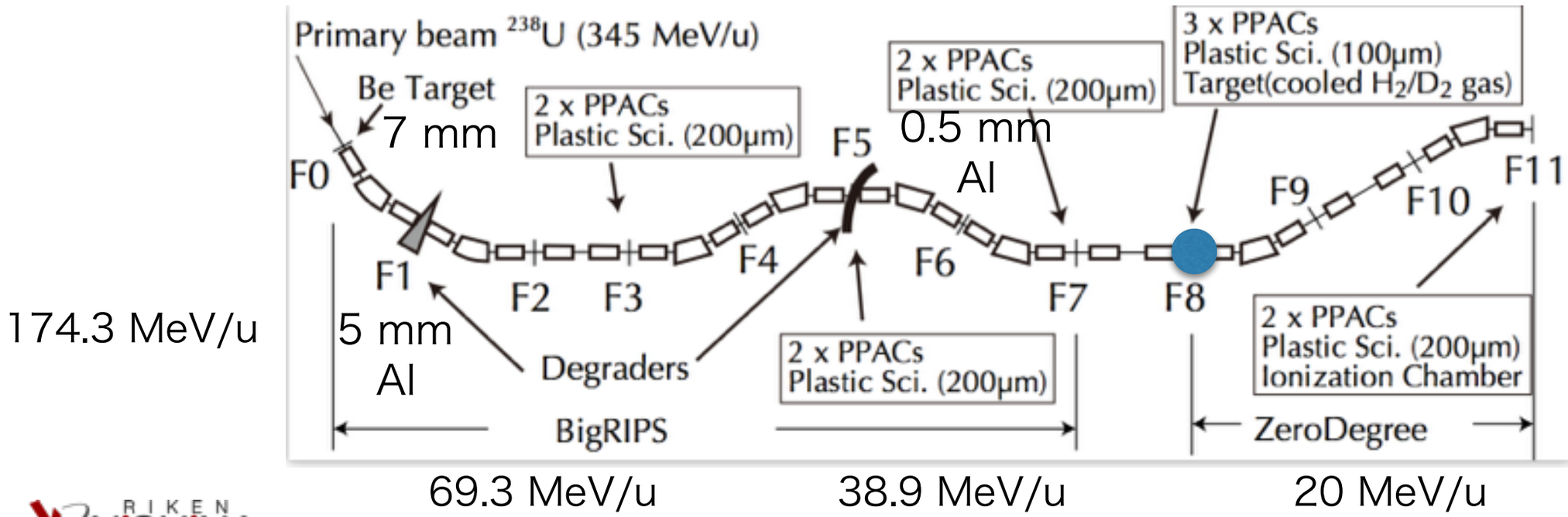
T.S. et al, NIMB 376 180(2016).

Present work

- Control method of slowed-down RI beam (^{93}Zr or ^{107}Pd)
  - Energy tuning after energy loss with thick degrader (^{93}Zr 20 MeV/u beam)
  - Narrow distribution (pos., ang., energy) if Yield(available) > Yield(required).
    Cross section of reaction products for ^{93}Zr + d or p. (a few 10^3 pps is required.)
- Particle Identification of reaction products after secondary-reaction target

Slowed-down RI beam Production
Energy control

- Energy control
  - Example, 174 —> 20 MeV/u (^{93}Zr)
    Thickness of degrader is close to range: d/R ~ 0.965. Prediction power is not enough.
    Need degrader to adjust energy (rotating degrader)
- Measurement of spallation-reaction cross section of LLFP(^{93}Zr or ^{107}Pd) + p or d reaction
  - Experiment: Particle IDs before and after secondary target
    - Any materials in the straight line behave like a target.
    - Requirement: minimize the materials in the straight line



Slowed-down RI beam Production
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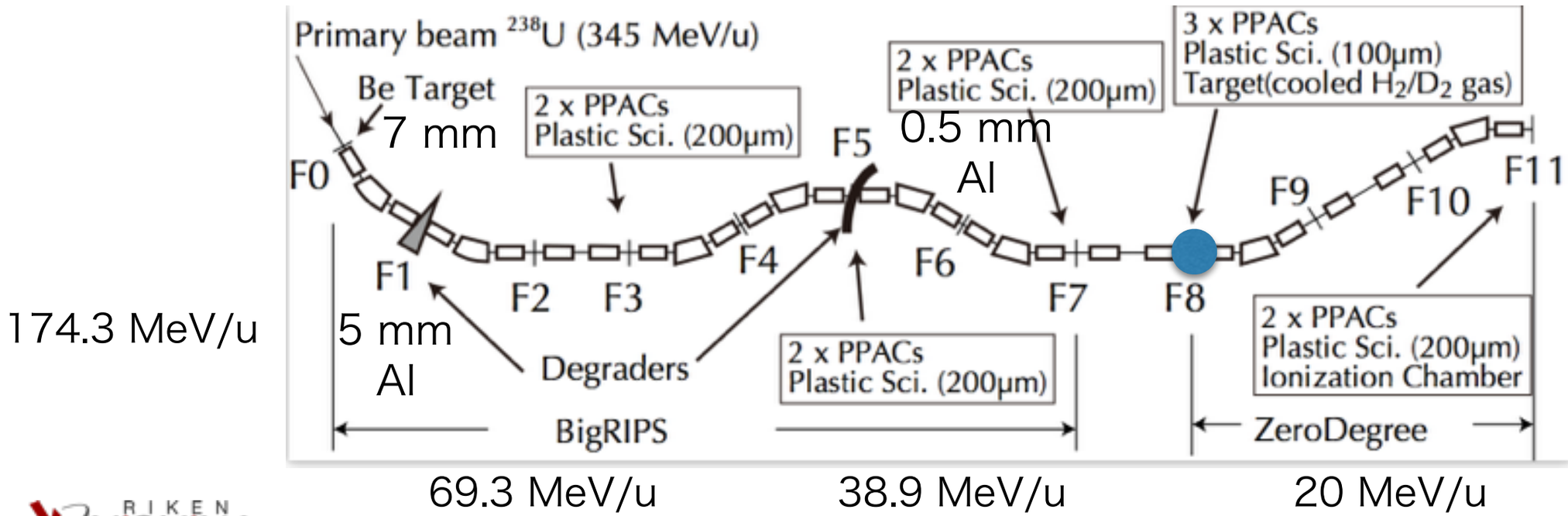
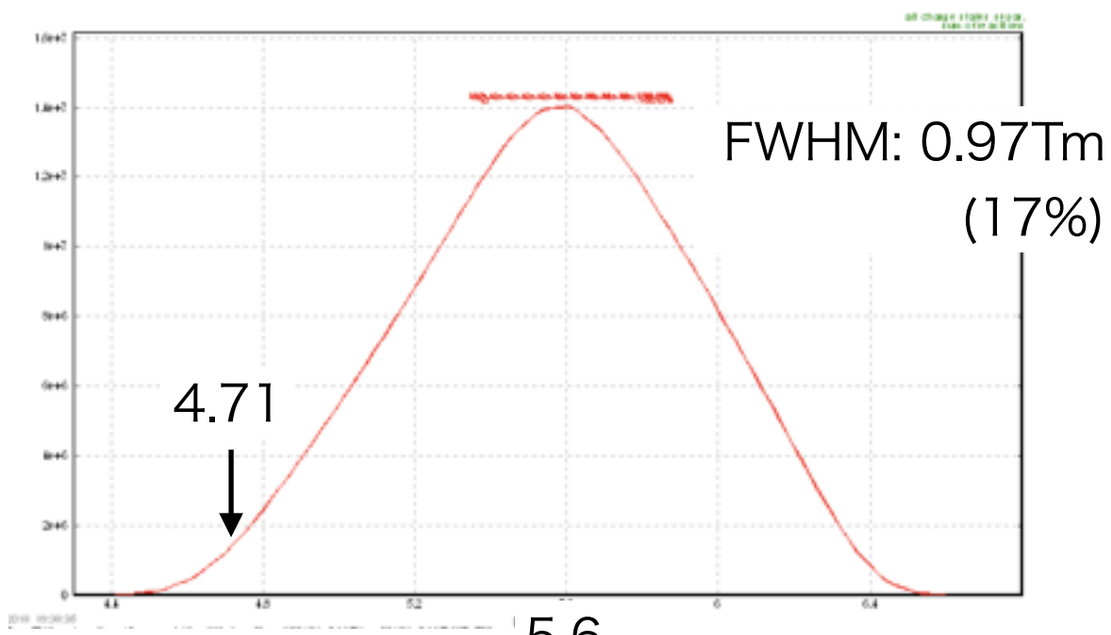
- Measurement of spallation-reaction cross section of LLFP(^{93}Zr or ^{107}Pd) + p or d reaction
  - Experiment: Particle IDs before and after secondary target
    - Any materials in the straight line behave like a target.
    - Requirement: minimize the materials in the straight line
    - Best method: never use the energy-adjusting degrader



Slowed-down RI beam Production
Energy control

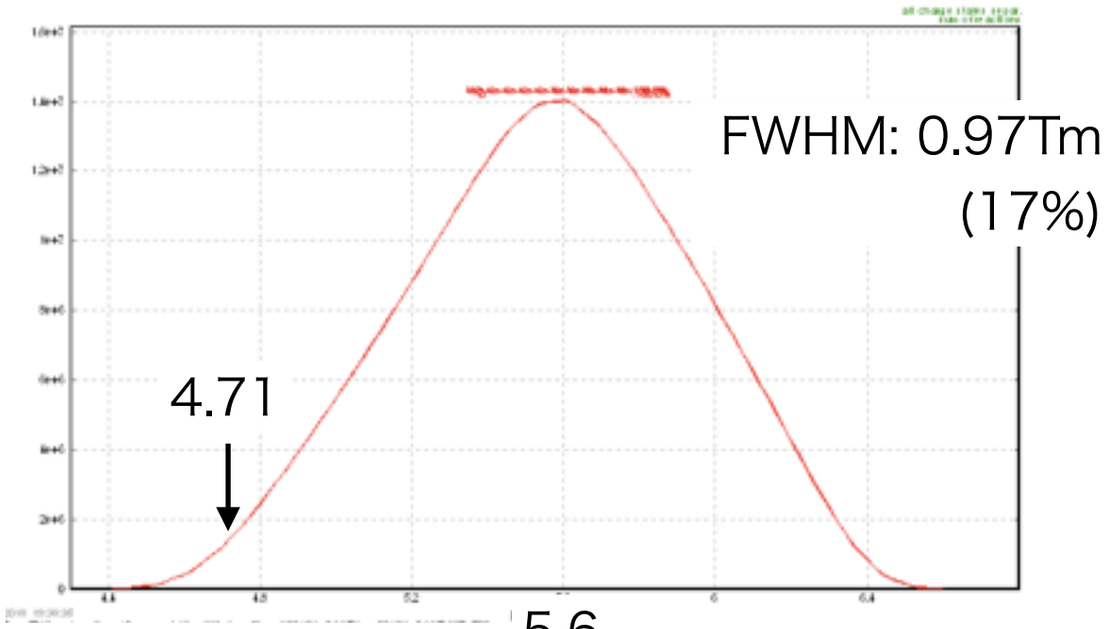
- Energy control
  - Example, 174 —> 20 MeV/u (^{93}Zr)
    Thickness of degrader is close to range: d/R ~ 0.965, d: thickness, R: range
  - Change momentum after production target slightly(~1%)



- Bρ distribution after 7-mm Be target

Slowed-down RI beam Production
Energy control

- Energy control
  - Example, 174 —> 20 MeV/u (^{93}Zr)
    Thickness of degrader is close to range: d/R ~ 0.965, d: thickness, R: range
  - Change momentum after production target slightly(~1%)
  - Prediction: Relative value is more reliable than absolute one.



- Bρ distribution after 7-mm Be target

- Method
  Use of relative values of prediction.
  $(E-E_0)/E_0$ vs $(B\rho-B\rho_0)/B\rho_0$ @D1

Slowed-down RI beam Production
Energy control

- Energy control
  - Example, 174 —> 20 MeV/u (^{93}Zr)
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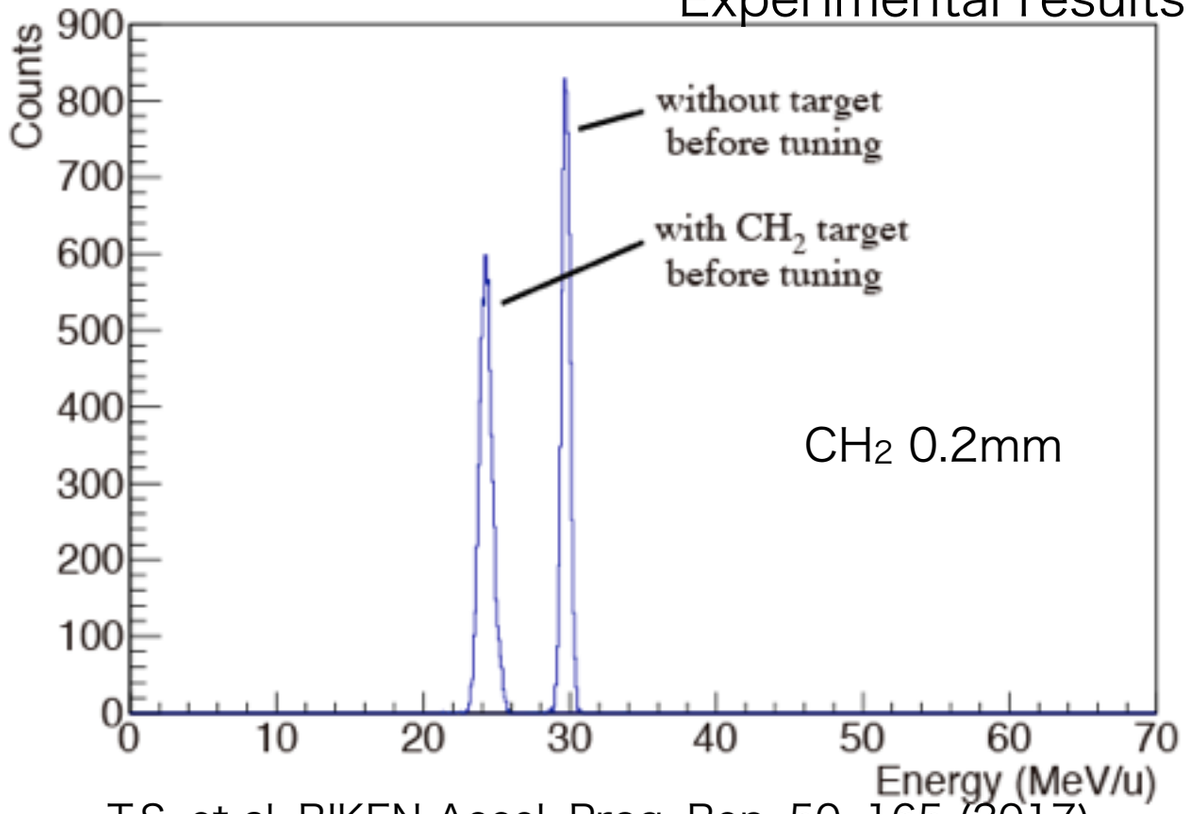
Experimental results



T.S. et al, RIKEN Accel. Prog. Rep. 50, 165 (2017).

- Method
  Use of relative values of prediction.
  $(E-E_0)/E_0$ vs $(B\rho-B\rho_0)/B\rho_0$ @D1

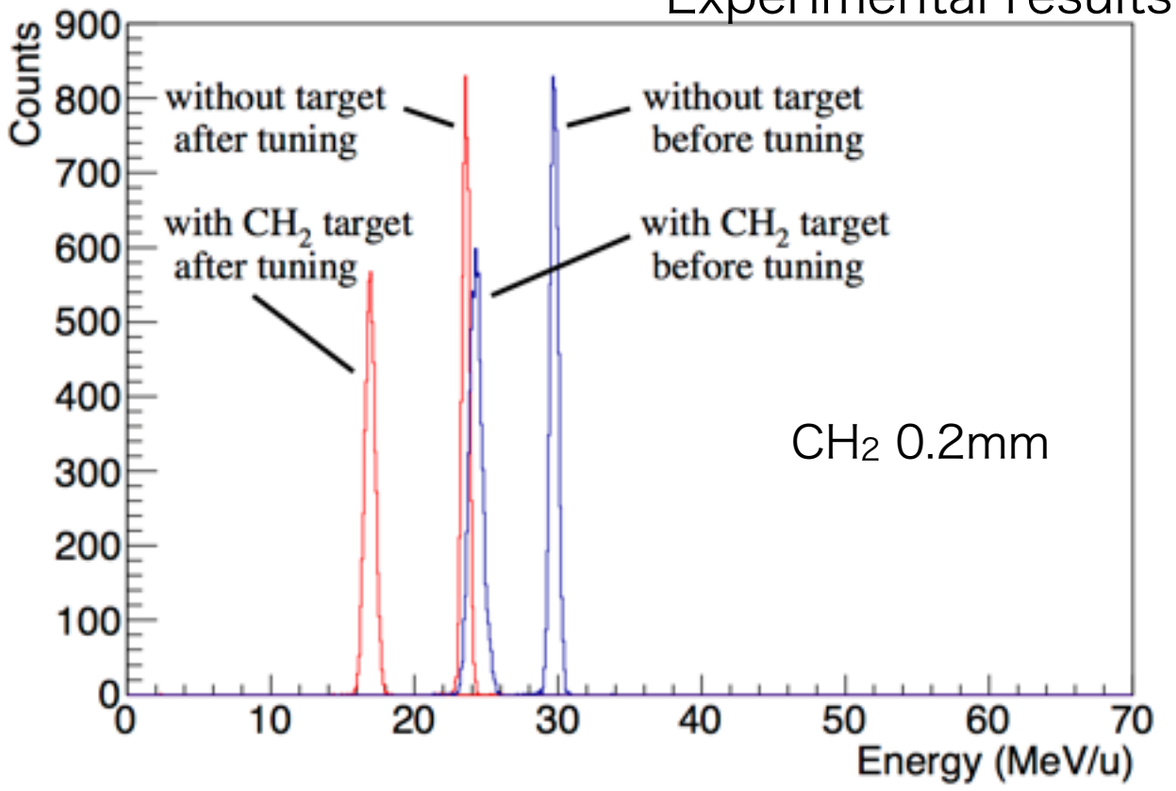
- Energy @ target center
  27.0 MeV/u

  D1 $B\rho$: 0.56% down

Slowed-down RI beam Production
Energy control

- Energy control
  - Example, 174 —> 20 MeV/u (^{93}Zr)
    Thickness of degrader is close to range: d/R ~ 0.965, d: thickness, R: range
  - Prediction: Relative value is more reliable than absolute one.
  - Change slightly momentum(~1%) after production target

Experimental results



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- Method
  Use of relative values of prediction.
  $(E-E_0)/E_0$ vs $(B\rho-B\rho_0)/B\rho_0$ @D1

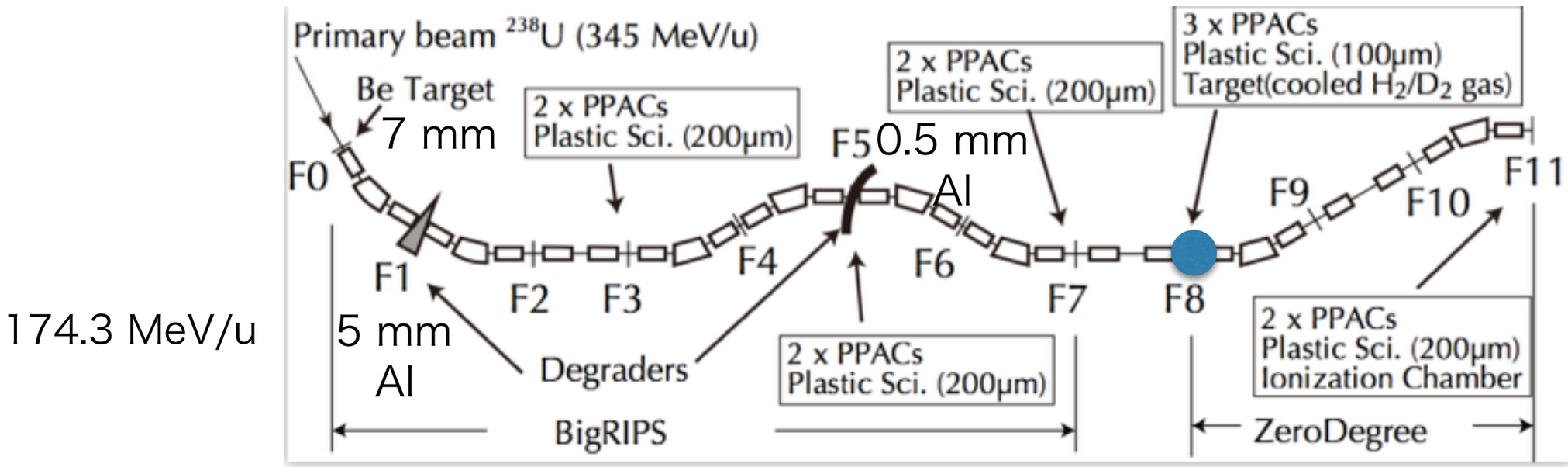
- Energy @ target center
  27.0 —> 20.2 MeV/u

  D1 $B\rho$: 0.56% down

One step tuning

Slowed-down RI beam Production
Distribution of position, angle, and energy

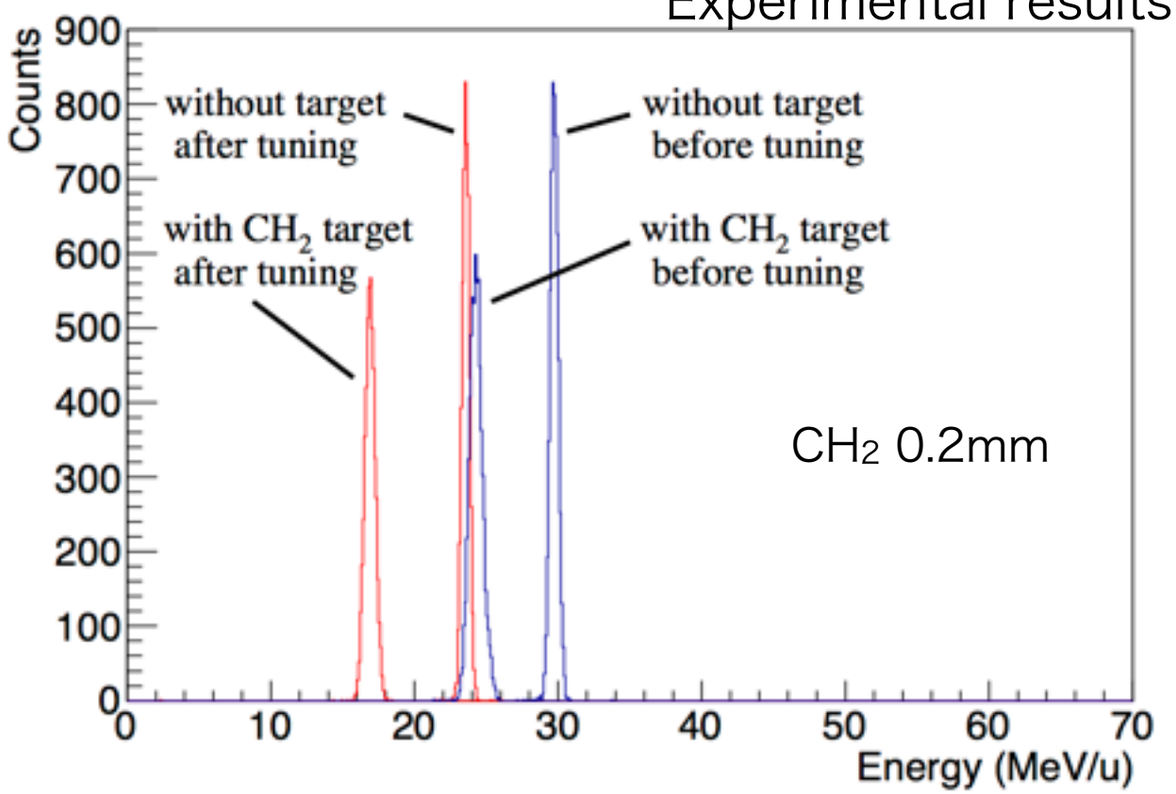
- Distribution
  - Effective emittance given by position, angle, and momentum(energy) distribution
    - Increase by x1/(1 – d/R) = 28.6 with d/R ~ 0.965
- Measurement of spallation-reaction cross section of LLFP(^{93}Zr or ^{107}Pd) + p or d reaction
  - Required Yield: a few x 10^3 pps (limited by the trigger condition)
  - Available Yield: ~ 10^6 pps
  - Is it possible to make a narrow distribution if a required yield is less than the available one?



Slowed-down RI beam Production
Energy control

- Narrow Energy Distribution
  - Narrow slit setting was combined with:
    - Good momentum resolution (1/3200) on the curved degrader made from the polished 0.5-mm Al plate (@ F5)
    - Mono energetic degrader + small spot size
    - Position @ F7 depends on δ p/p

Experimental results



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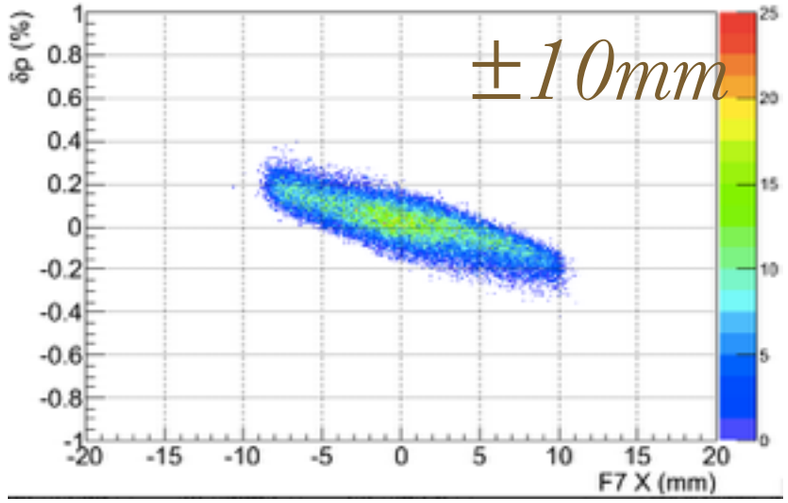
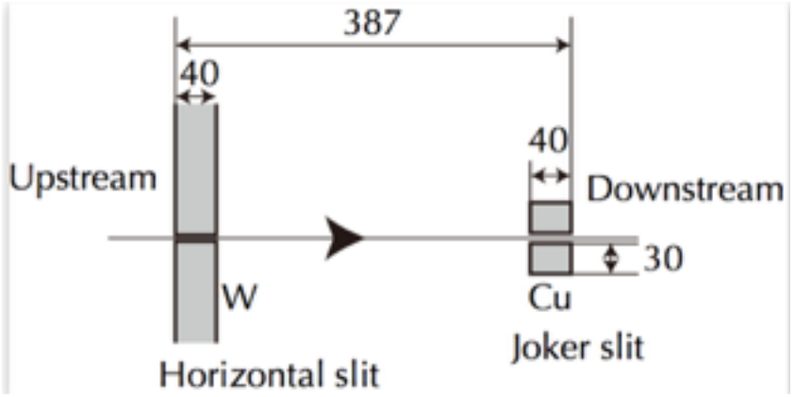


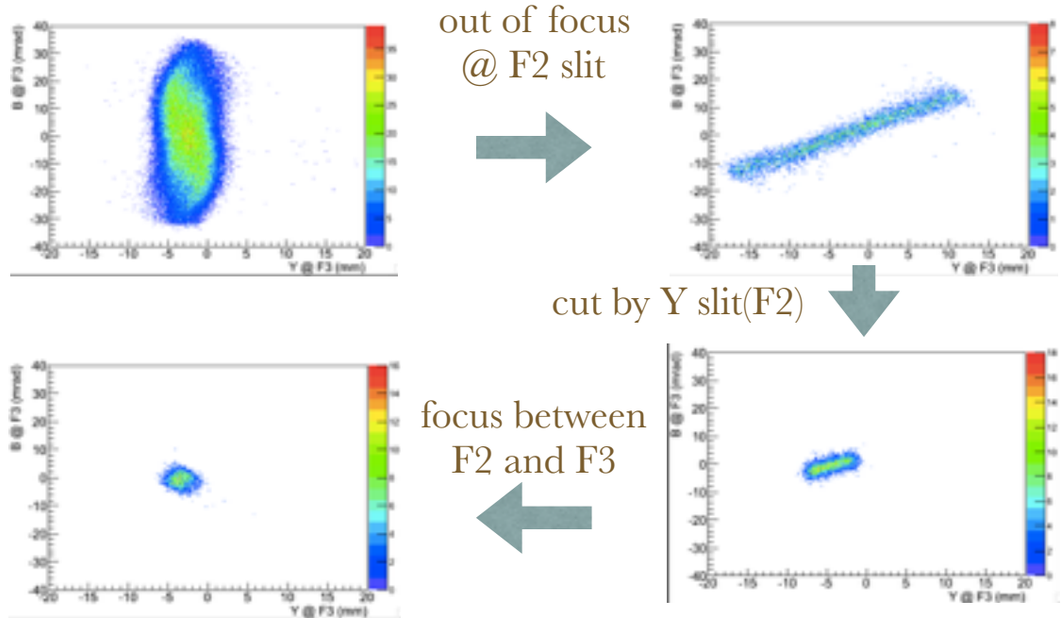
For ^{93}Zr 17 MeV/u after CH2 target,
Width(FWHM) E: 0.82 MeV/u, δ p/p: 2.4%
within acc. (6%) of ZeroDegree Spec.

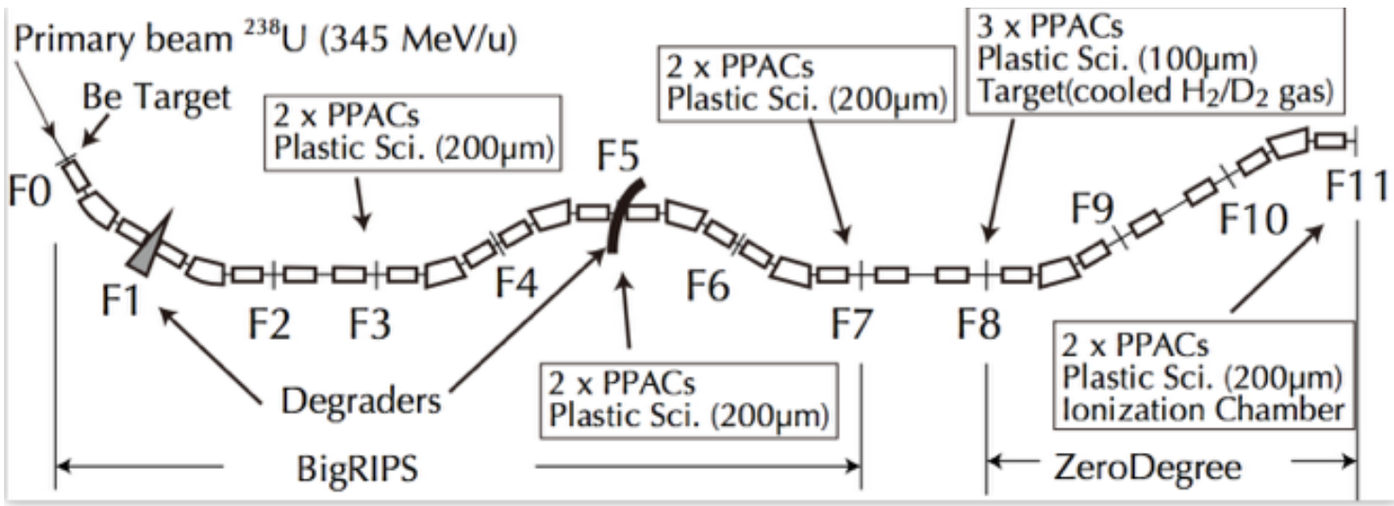
Slowed-down RI beam Production
Position & angle control

- X direction
  Use 2 slits @ F1



- Y direction
  Use defocus beam on F2 slit
  refocus at F3

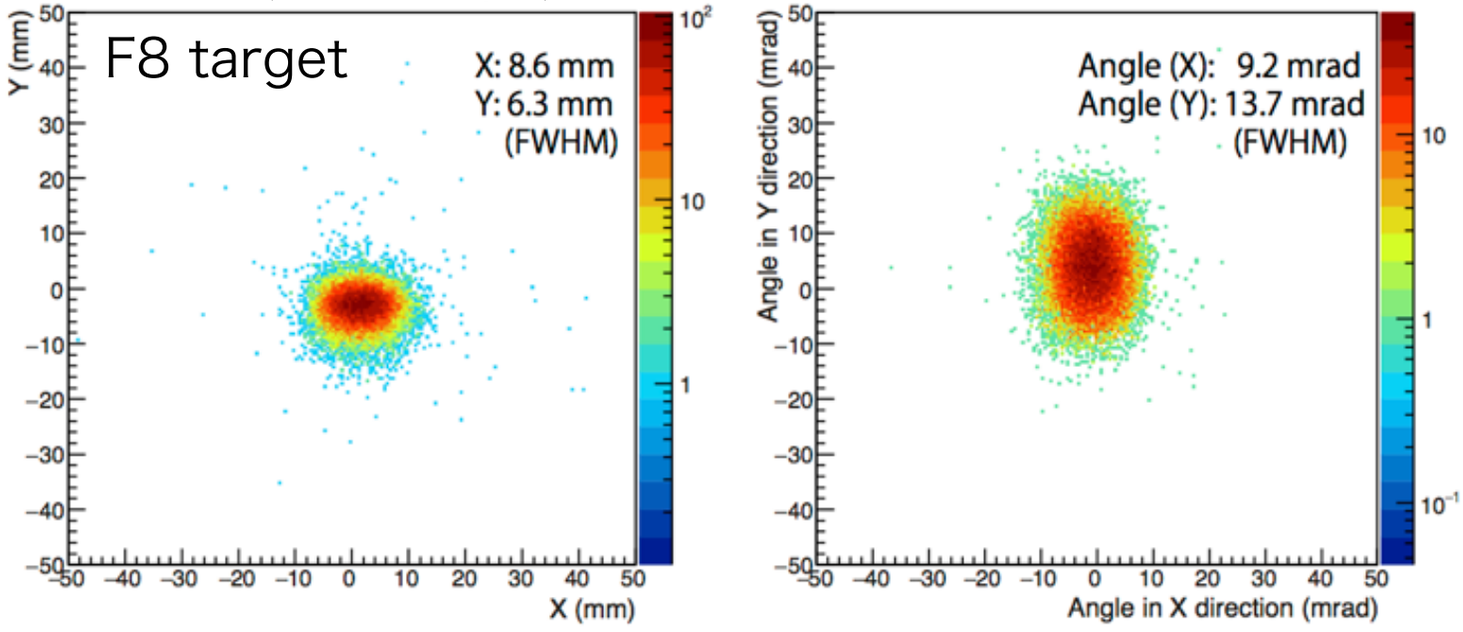




Slowed-down RI beam Production
Position & angle control

- Distribution on secondary target

^{107}Pd (50 MeV/u)



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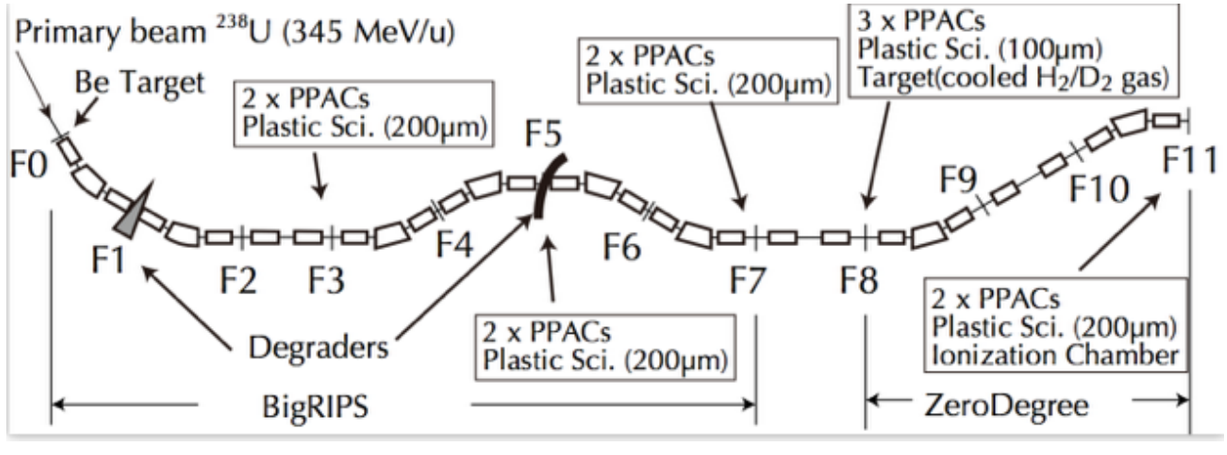
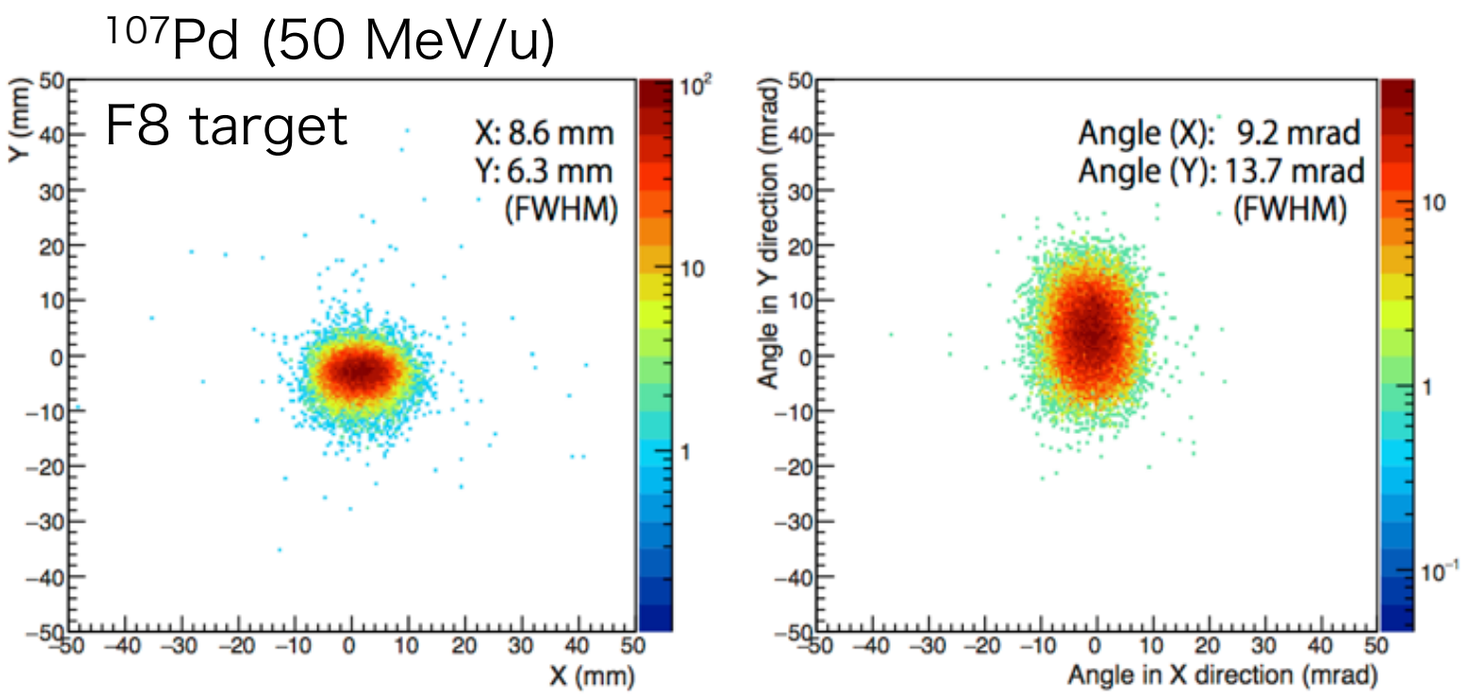


Slowed-down RI beam Production
Position & angle control

- Distribution on secondary target



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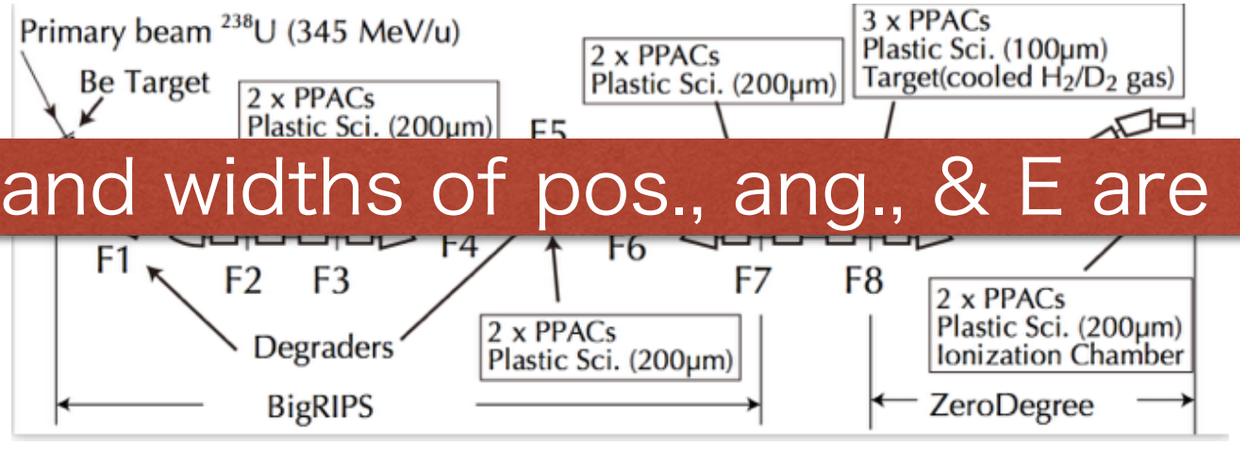
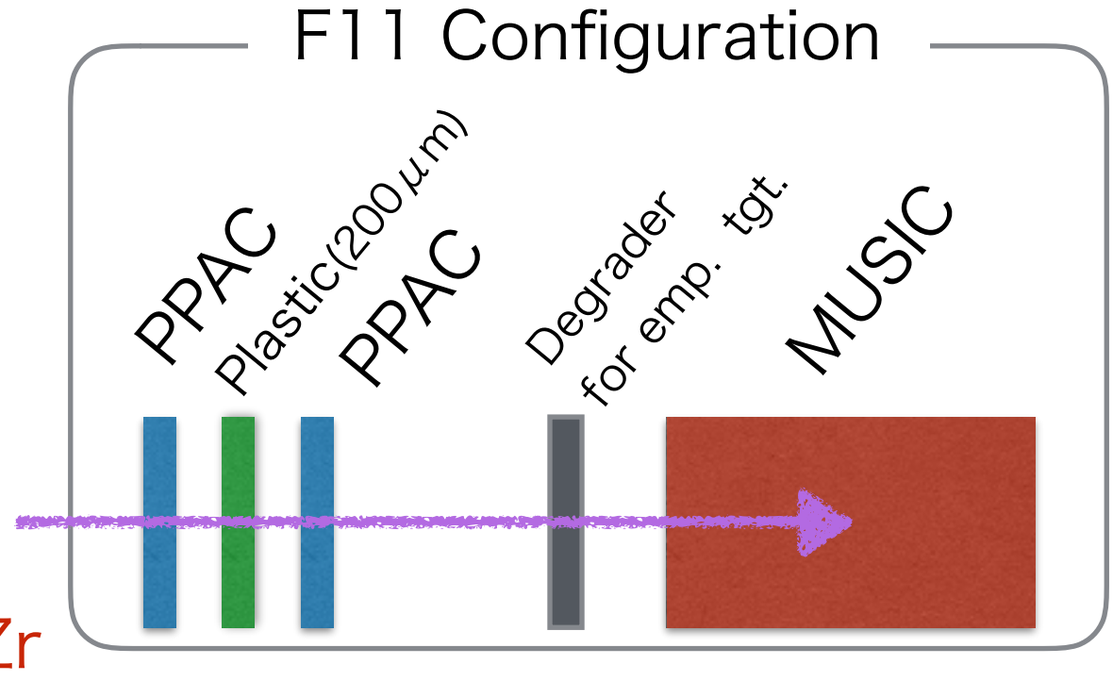
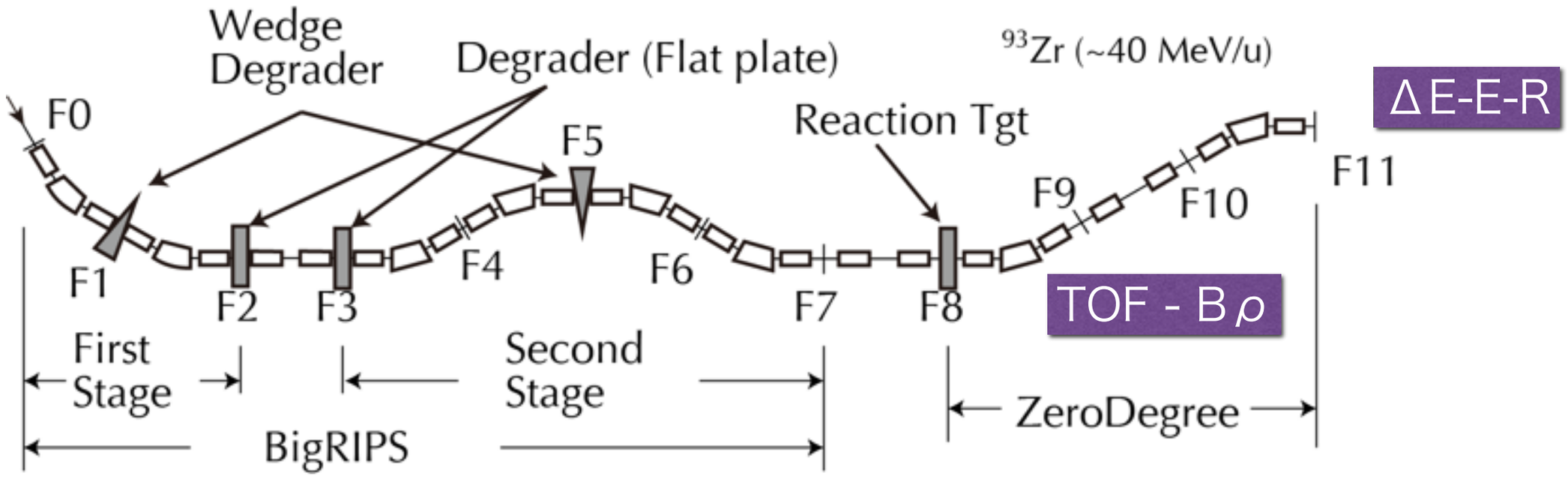


Energy and widths of pos., ang., & E are under control.

PID @ ZeroDegree spectrometer

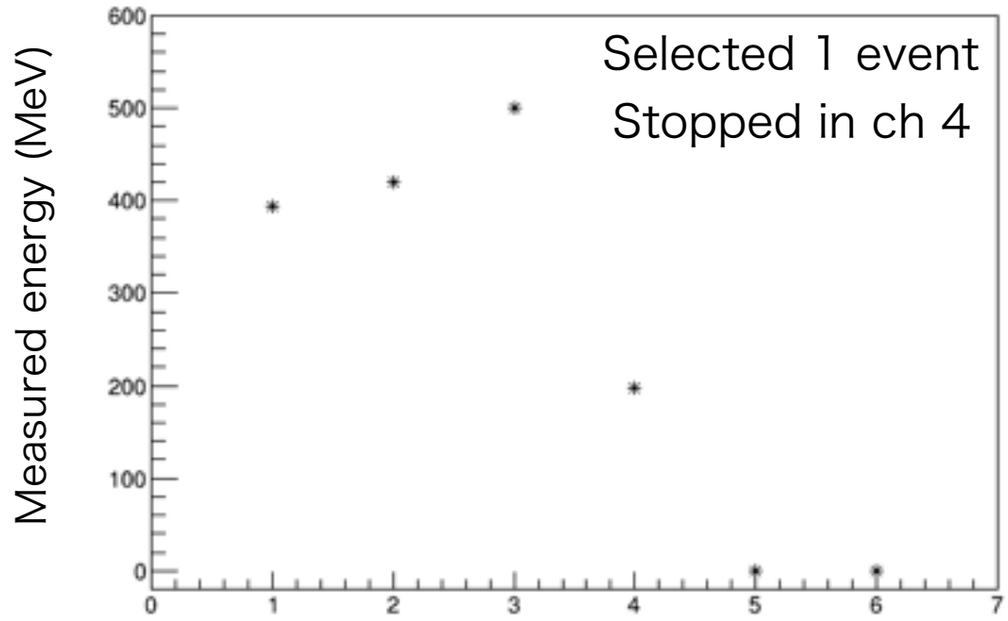
- Charge-state change in material
  - No detectors @ F9, F10
  - Dispersive mode (A/Q from TOF – Bρ)
    – wide beam (240 mm) for mom. meas.
  - Stopped in MUSIC (Multi-sampling IC)
    - Wide coverage
    - Range instead of kinetic E(TKE)
  - ΔE - E - Range

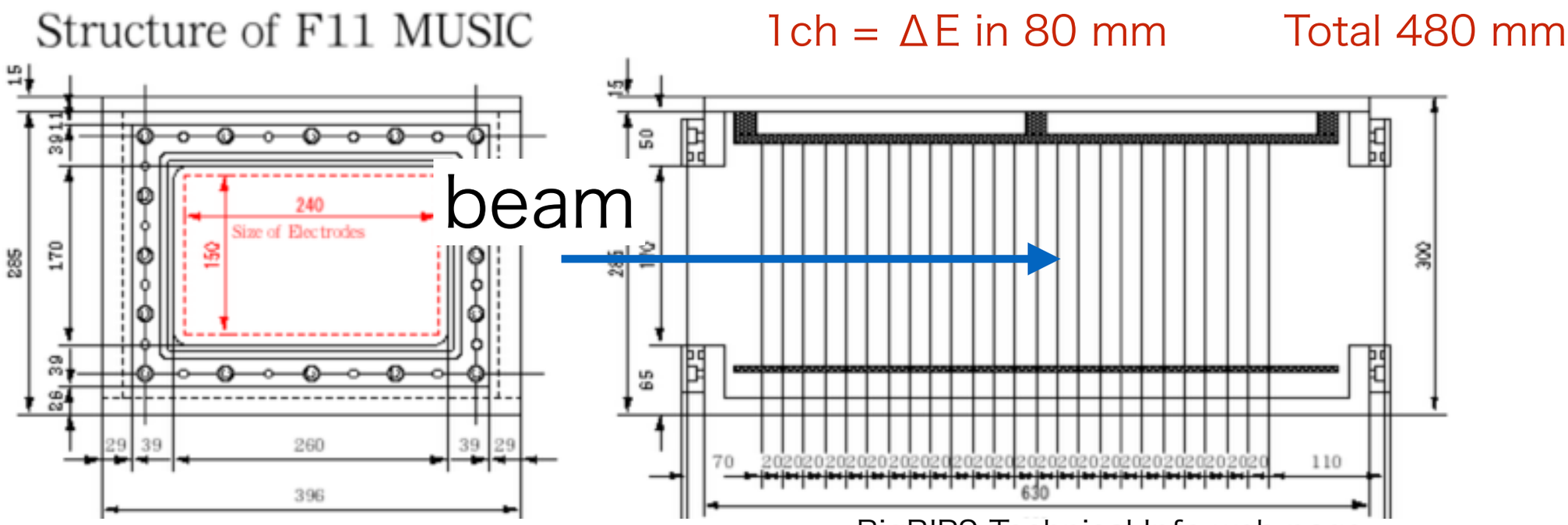




New PID with range
Range Determination

- MUSIC
  - P10 gas (1atm)
  - 80 mm per channel
  - electrodes: 4-μm aluminized Mylar



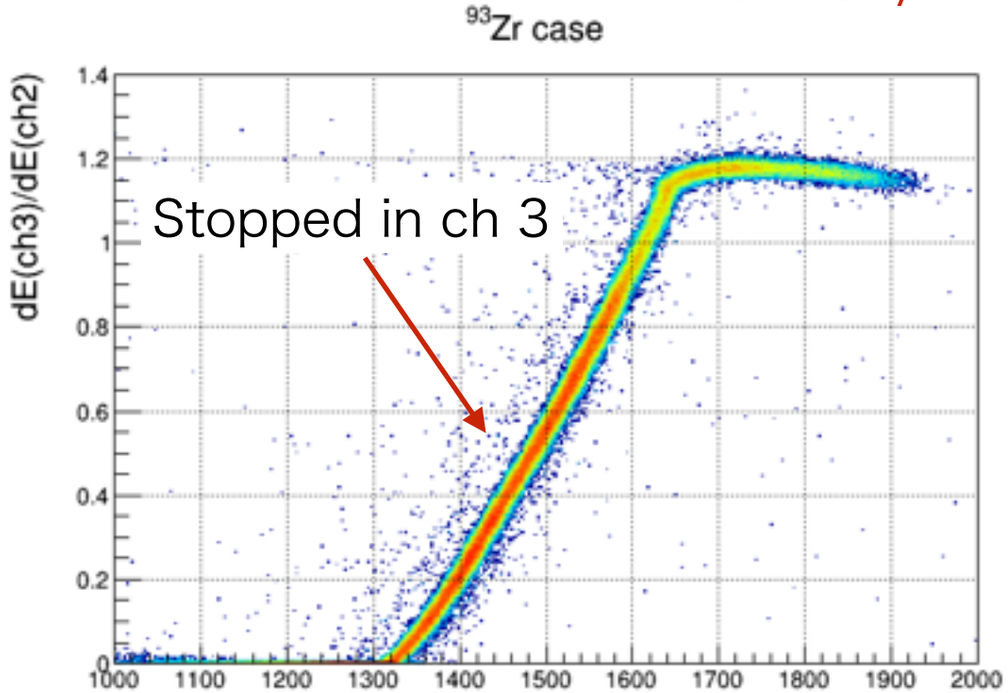


New PID with range
Range Determination

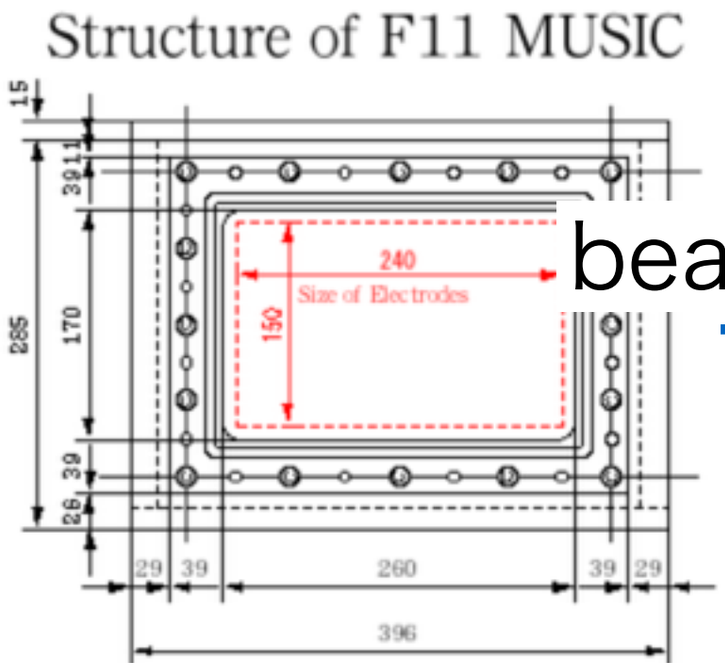
^{93}Zr

40 MeV/u

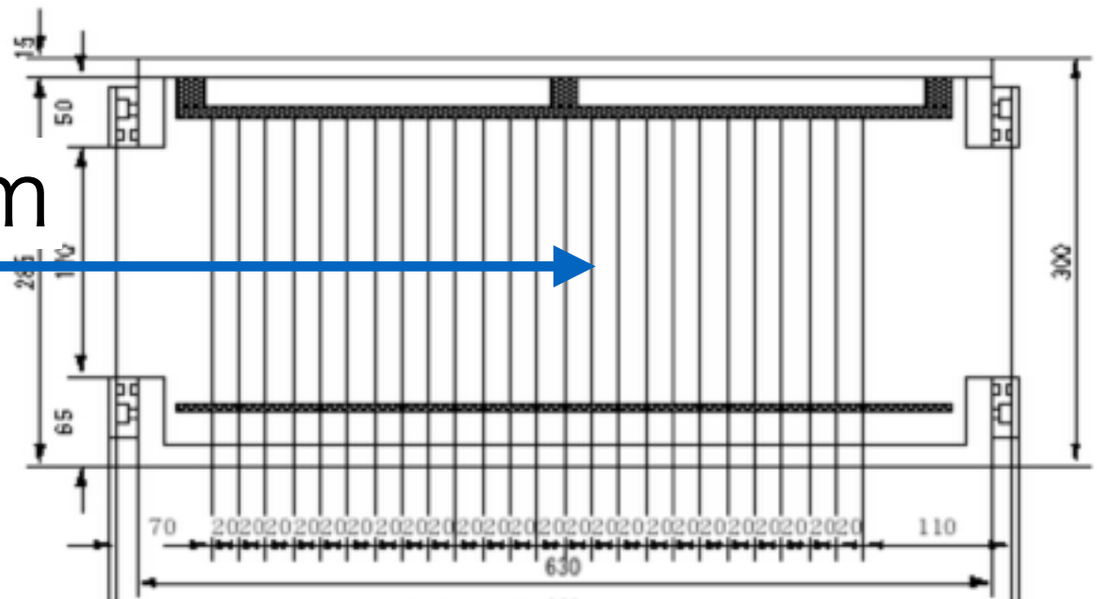
- Simple ΔE ratio of MUSIC
  - Very good correlation with E (MUSIC)
  - Range can be determined much more precisely than the sampling length (8cm/ch).



electrodes: 4-μm Mylar



1ch = ΔE in 80 mm Total 480 mm



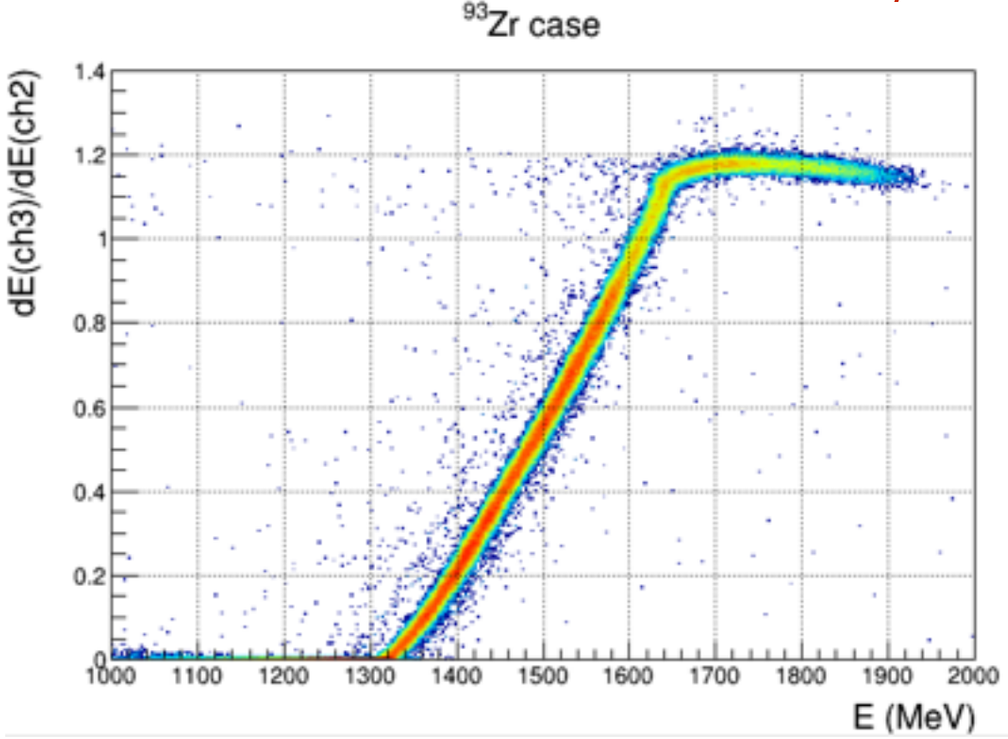
BigRIPS Technical Info web page

New PID with range
Range Determination

^{93}Zr

40 MeV/u

- Conversion To Range
  - Conversion Table using ATIMA calc.
    - $\Delta E_{i+1} / \Delta E_i$ —> Range
  - σ_R = 1.5 mm
  - Several lines –> Z dependence



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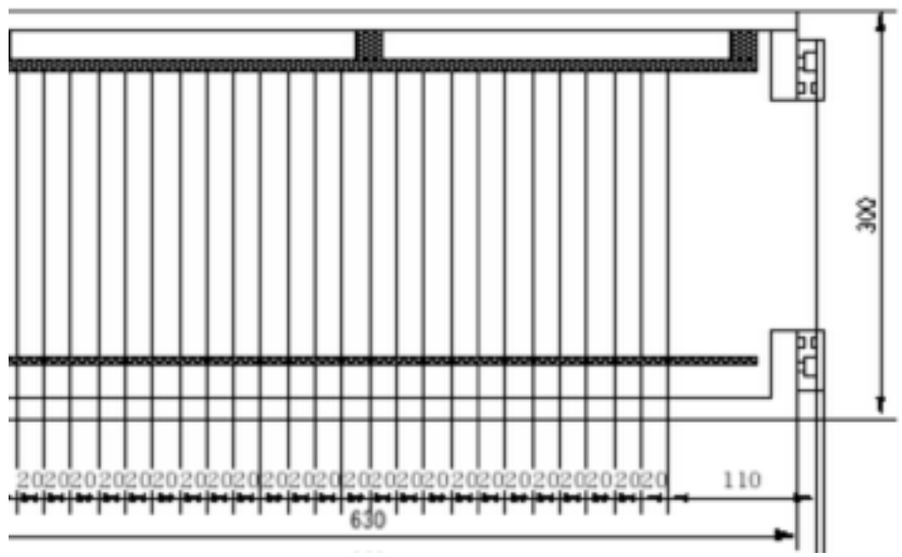
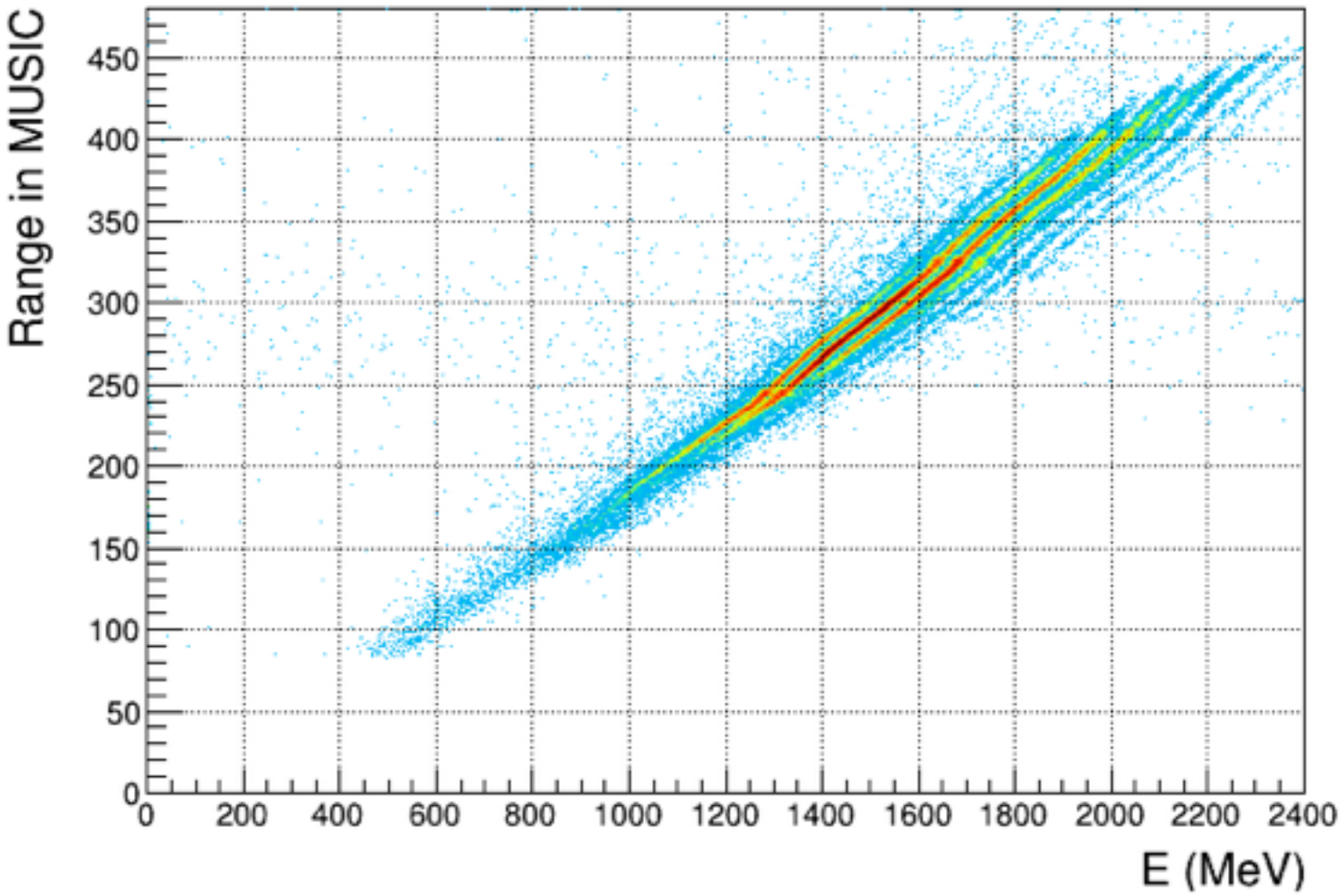
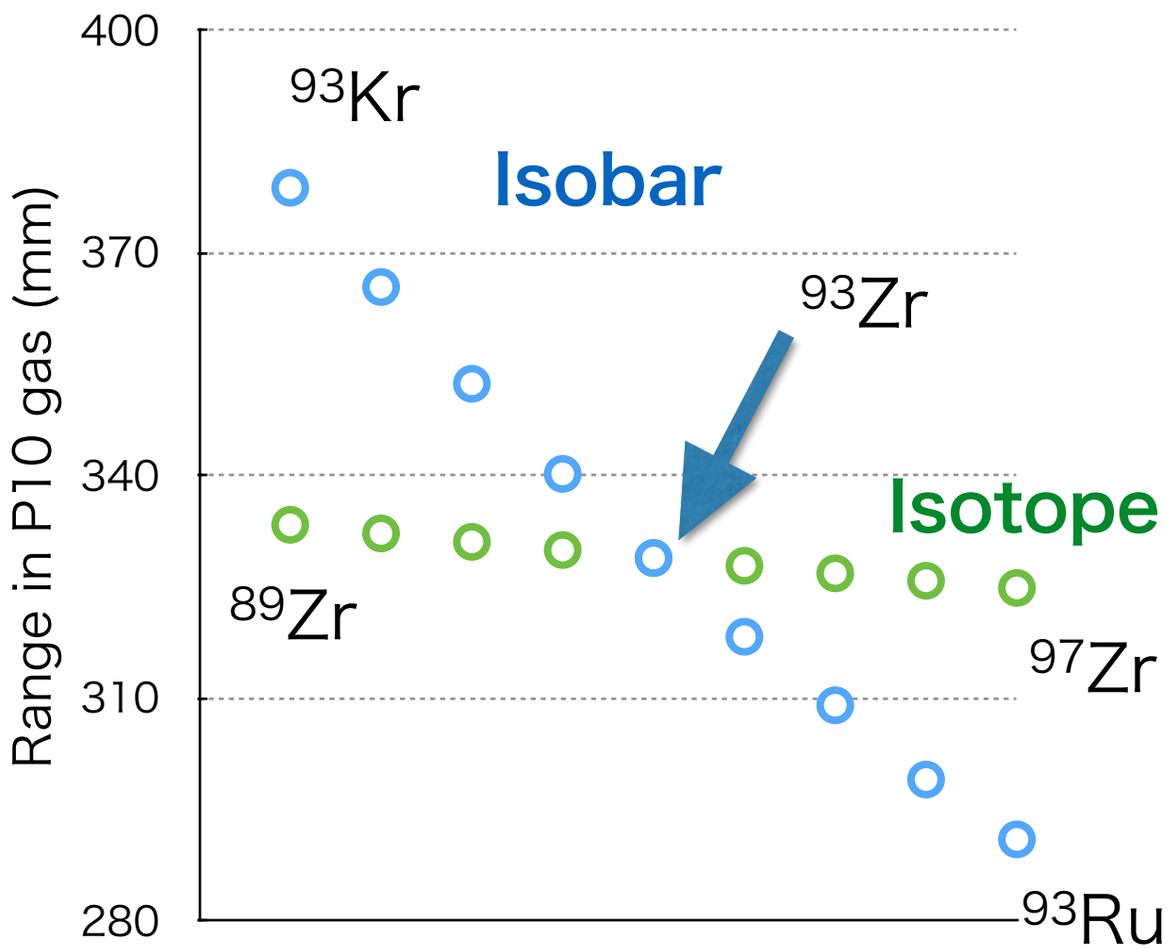




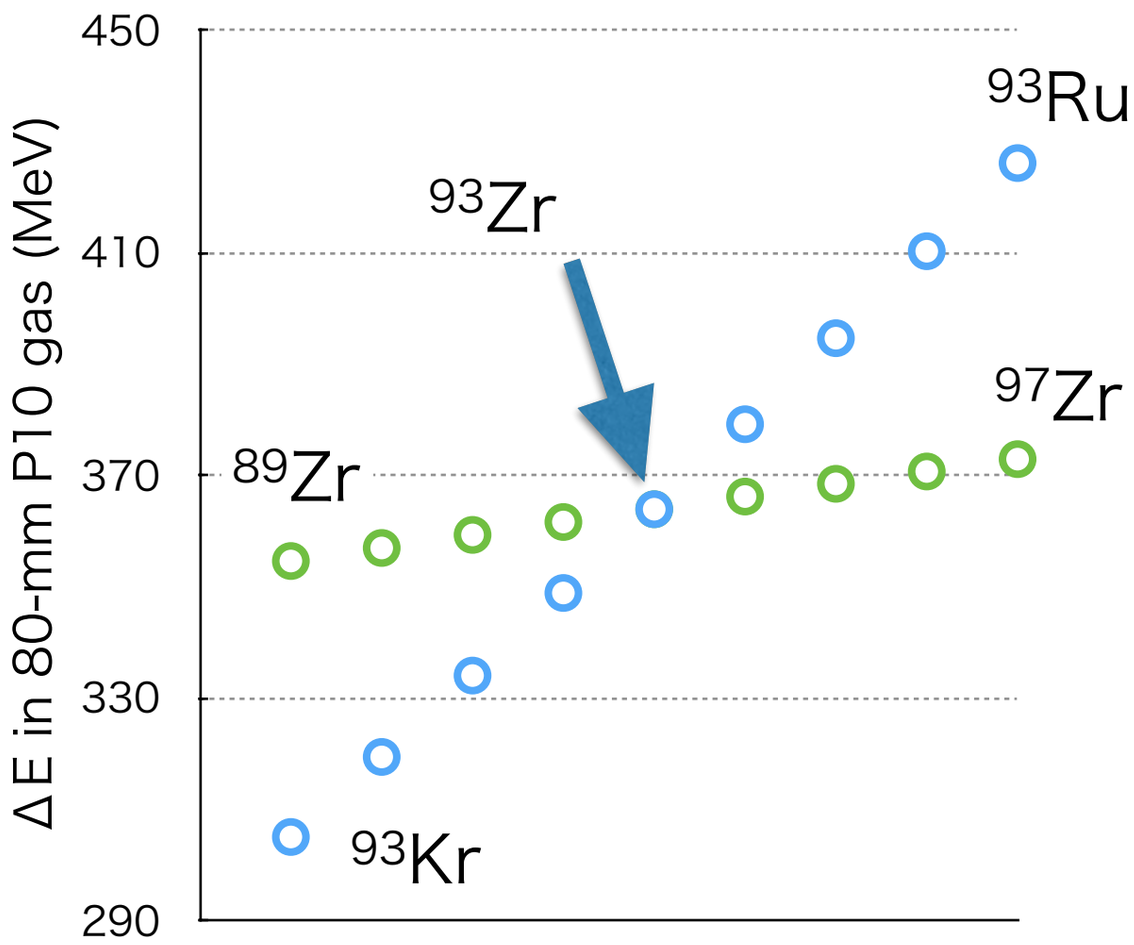
Z, A dependence of *R*-*E*, and Δ*E*-*E*

- d E /dx is same for isotopes at same velocity.
- If E is same, the range of isotopes becomes almost same.

Range for E=1.6 GeV

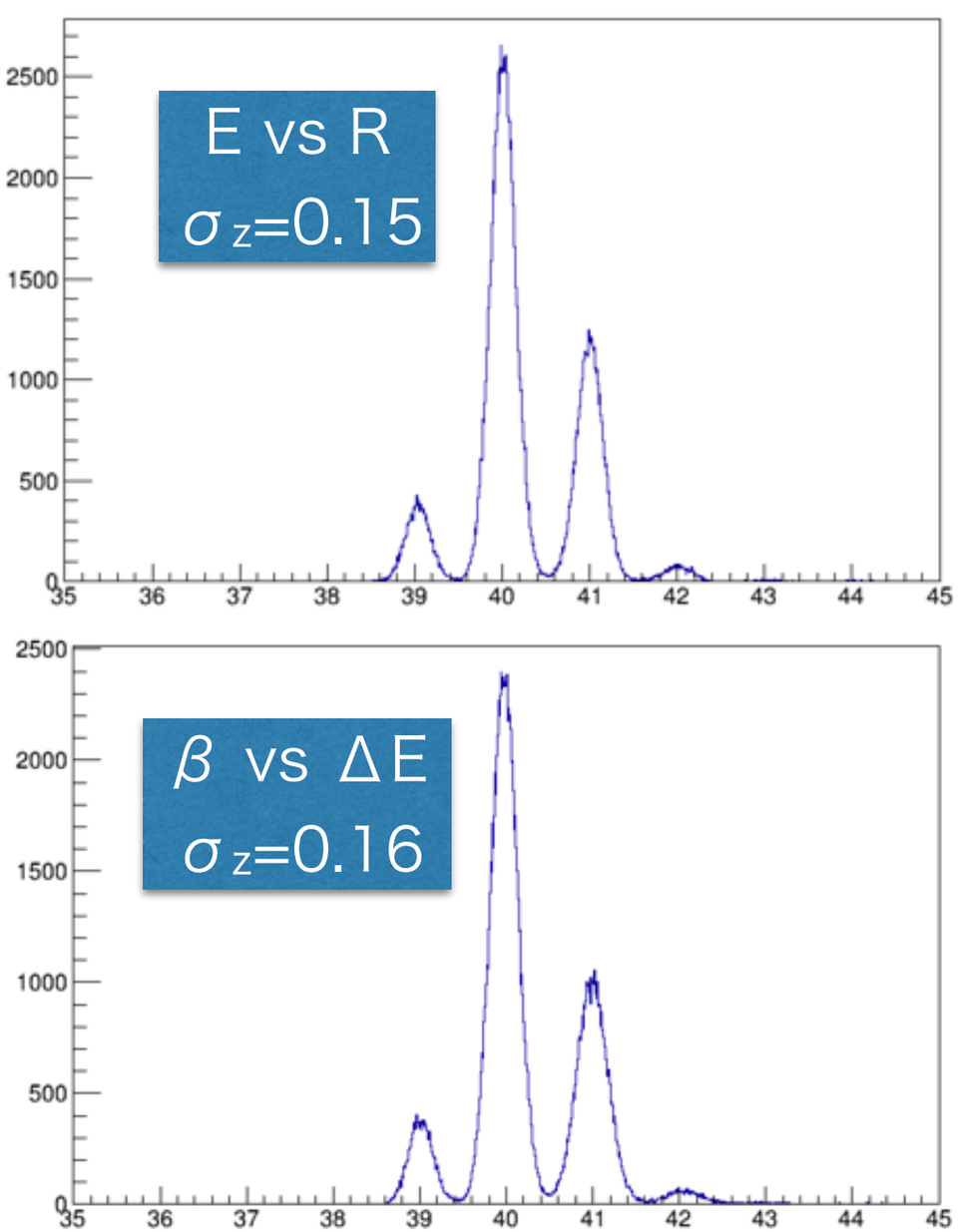


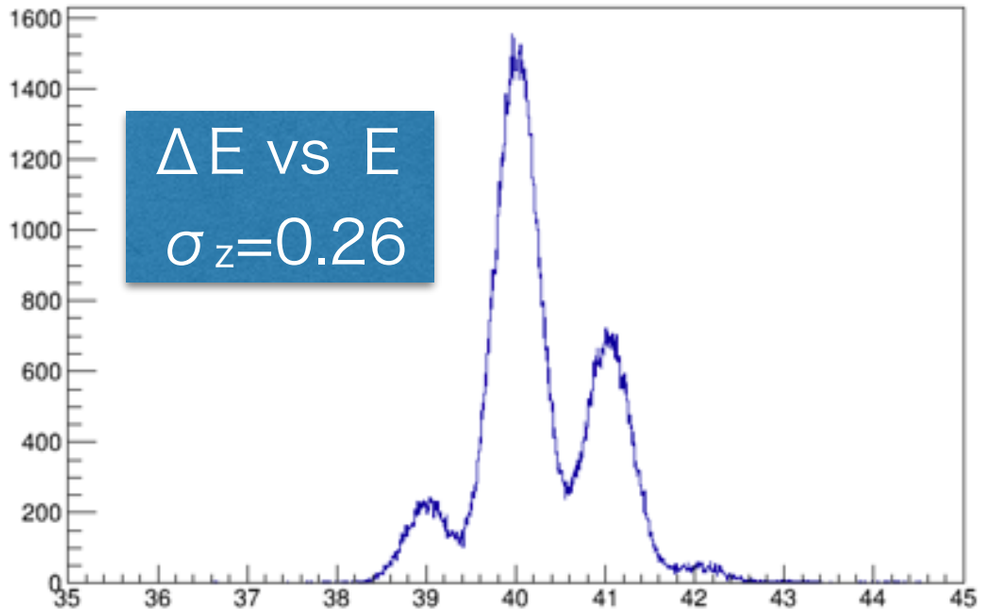
ΔE for E=1.6 GeV



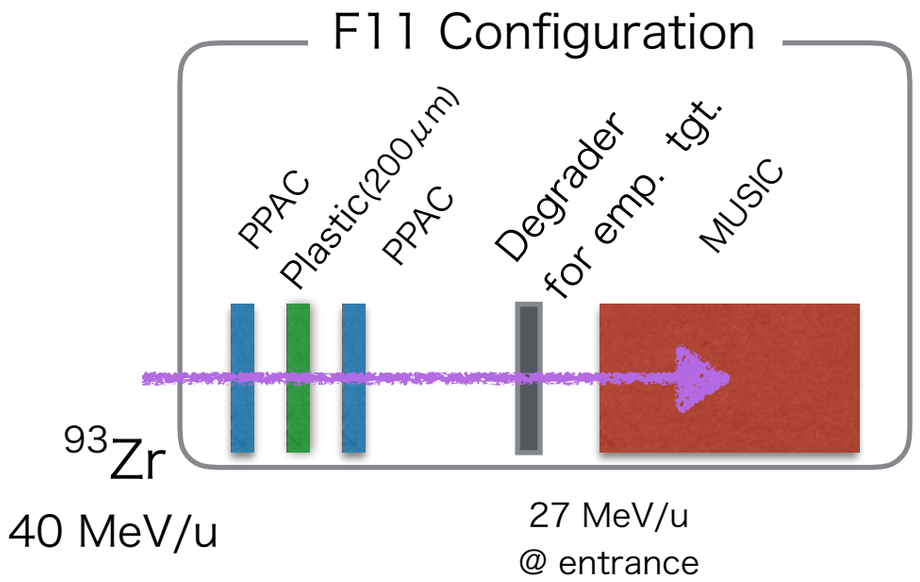
New PID with range
Comparison of Z determination

- E vs R provides Z with a good resolution.





- β vs ΔE
  E loss before MUSIC
  Coupling w/ A

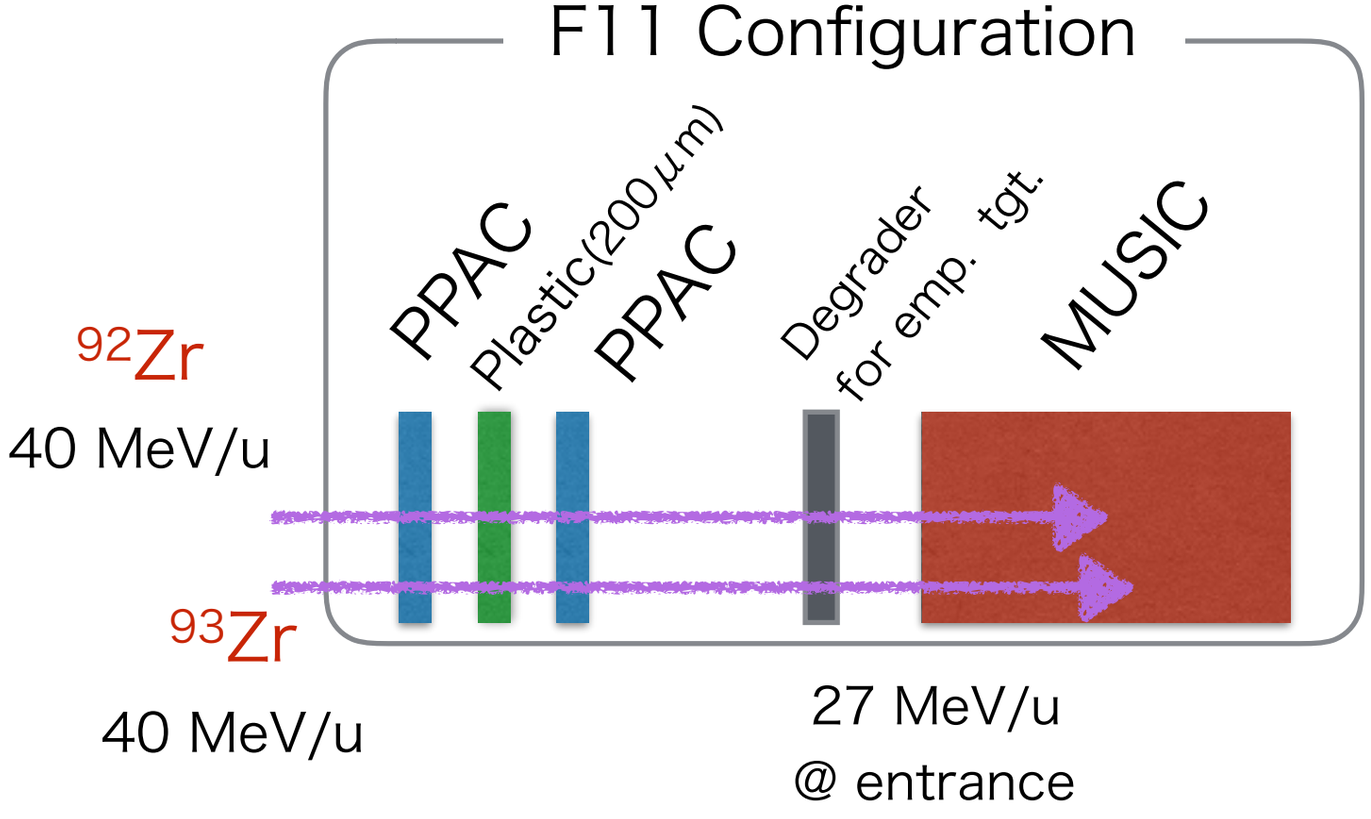


New PID with Range

^{93}Zr

40 MeV/u

- Standard method: β - TKE —> A,
- Range was measured instead of TKE



R(^{93}Zr)-R(^{92}Zr) = 11 mm

Range —> 10.9*(A - 4.6Z) = const.

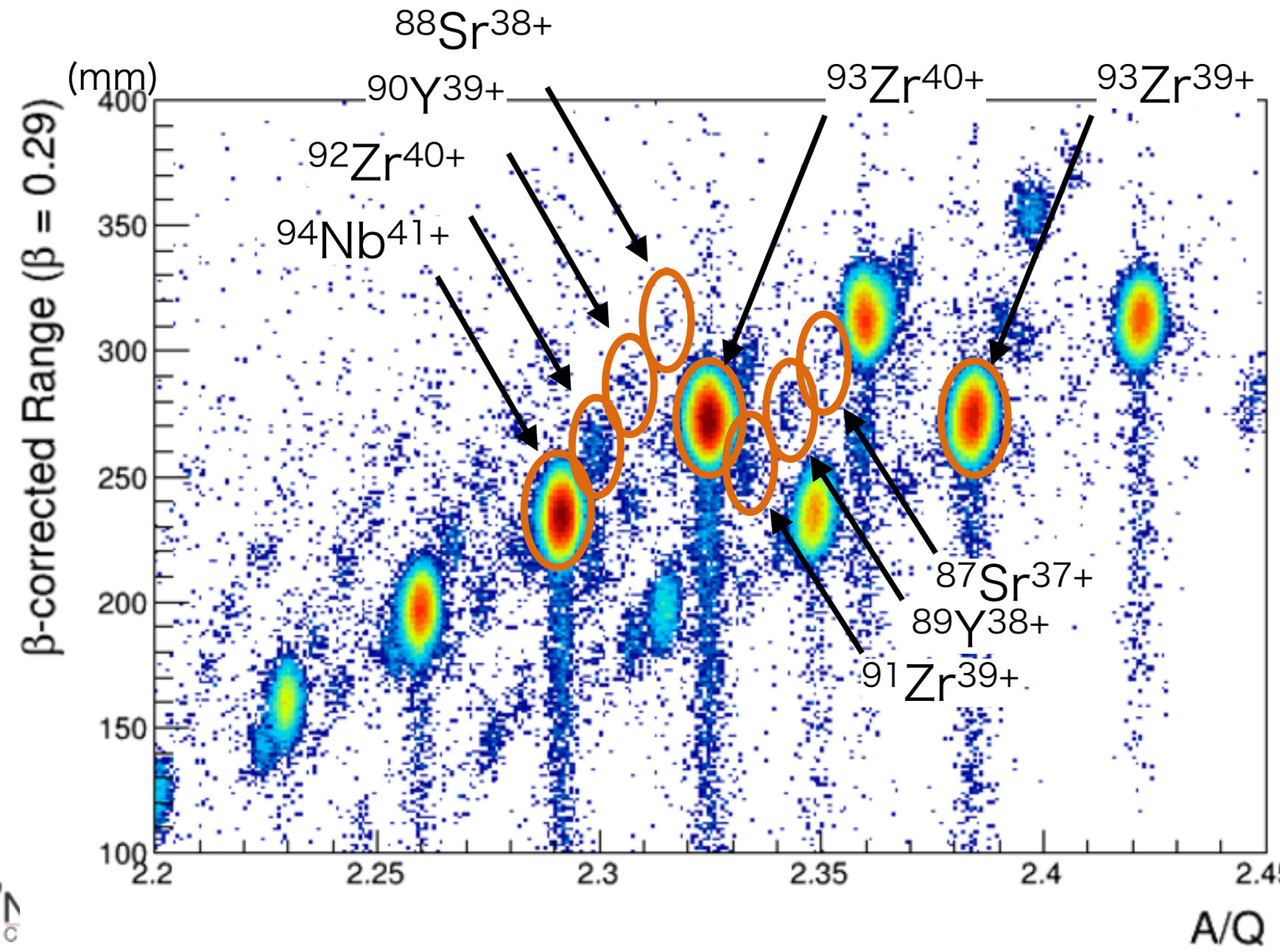
New PID with Range

^{93}Zr

40 MeV/u

- Standard method: β - TKE —> A,
- Range @ β = 0.29 was obtained from Range vs β correlation
- Range —> 10.9*(A - 4.6Z) = const.

C target (90 mg/cm^2)



R(^{93}Zr)-R(^{92}Zr) = 11 mm

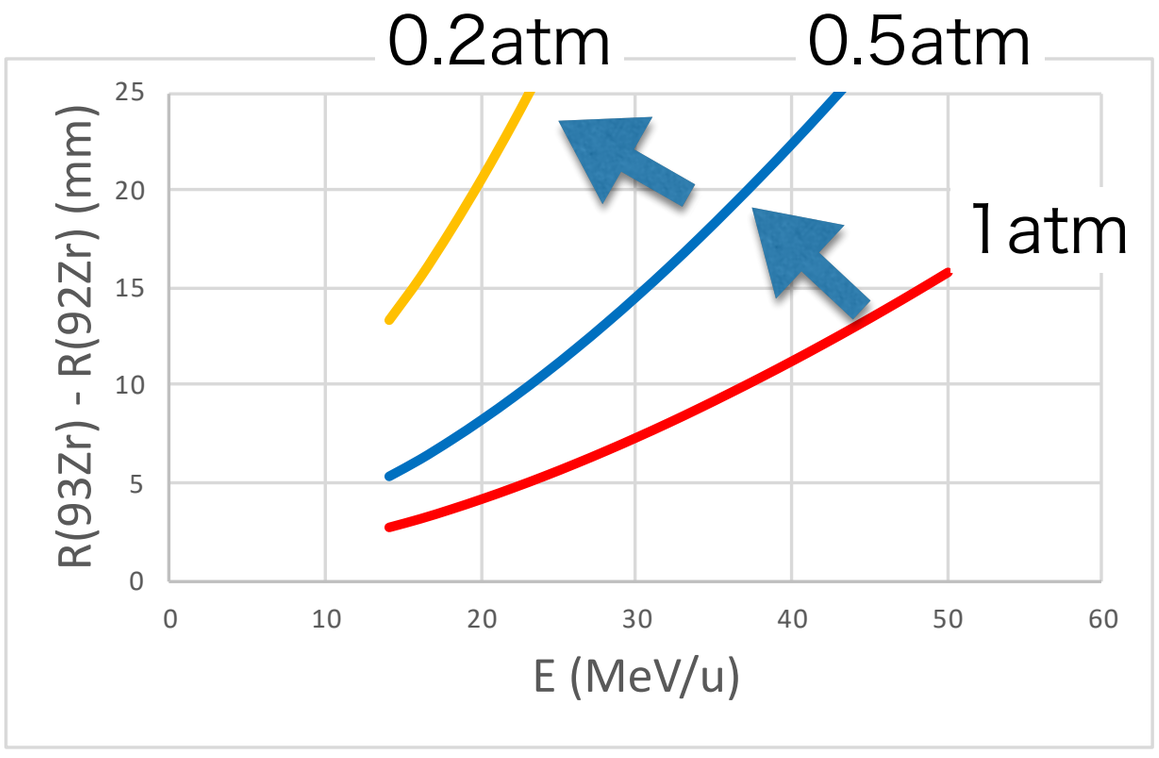
σ_R = 6 mm

Range strag.

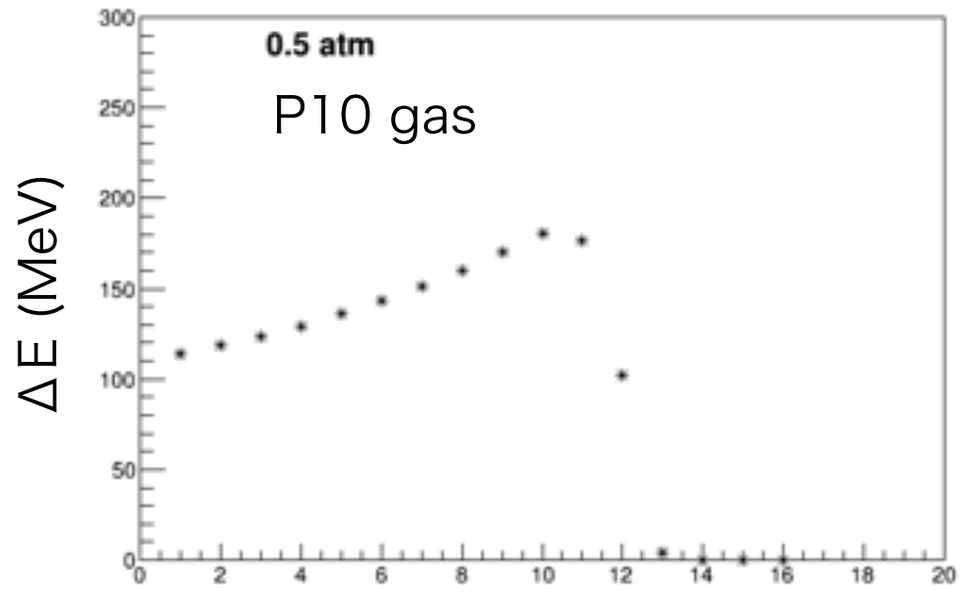
σ_A = 0.55

Lower energy capability

- Lower pressure to distinguish $R(^{93}Zr)$ and $R(^{92}Zr)$
- Bragg curve can be easily obtained. —> Good resolution of Range



Simulation



50.5mm/ch

→ Applied to OEDO/SHARAQ beam line
by Michimasa Sep. 18th

Collaborators

- T. Sumikama, D.S. Ahn, N. Fukuda, Y. Shimizu, H. Suzuki, H. Takeda,
  K. Yoshida, N. Inabe, H. Wang, N. Chiga, H. Otsu, S. Kubono, (RIKEN)
- S. Kawase, K. Nakano, J. Suwa, Y. Watanabe, (Kyushu Univ.)
- Y. Togano, A. Saito, S. Takeuchi, T. Tomai, A. Hirayama, (Tokyo Tech.)
- M. Matsushita, S. Michimasa, S. Shimoura, (CNS, Univ. Tokyo)
- M. Takechi, K. Chikaato (Niigata Univ.)
- J. Amano (Rikkyo Univ.)

Summary

- The control method of the slowed-down RI beam was developed.
  - The beam energy was successfully tuned with relative value of calculations.
  - The narrow distribution is technically available if the required yield is lower than the available one.

    e.g. FWHM width

    8.6 mm (X), 9.2 mrad (A), 6.3 mm (Y), 14 mrad (B) for ^{107}Pd 50 MeV/u

    0.82 MeV/u (E) for ^{93}Zr 20 MeV/u
- Particle identification of reaction product
  - Range in MUSIC works well for Z and A determination.

Thank you for your attention

This work was funded by ImPACT Program of
Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).