TCHoU Workshop

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University of Tsukuba

Reaction cross sections for proton-drip line nuclei

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Stable/ Unstable nuclei

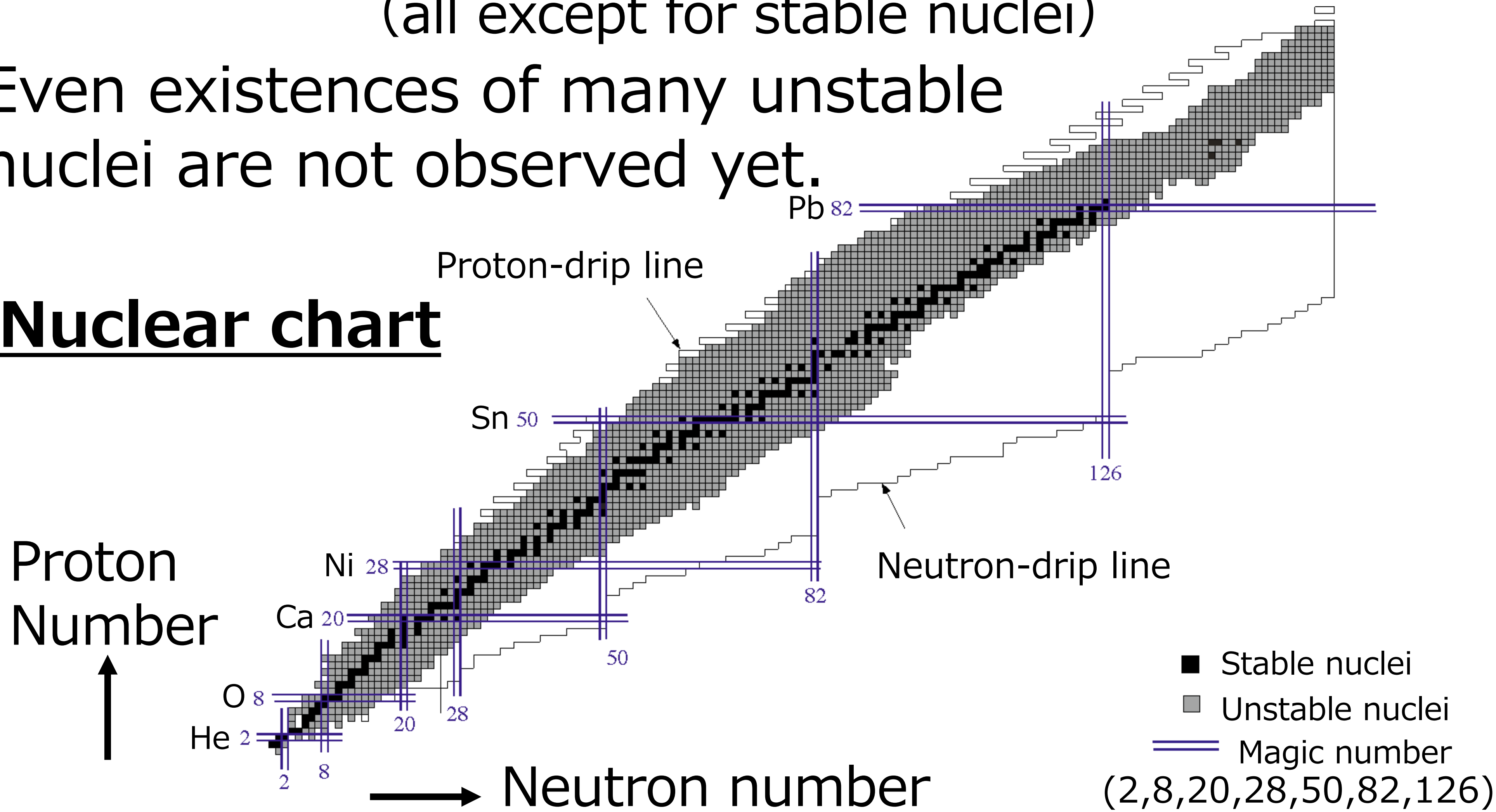
- Theoretical prediction : ~10000 nuclei

Stable nuclei : Exist in nature (~300)

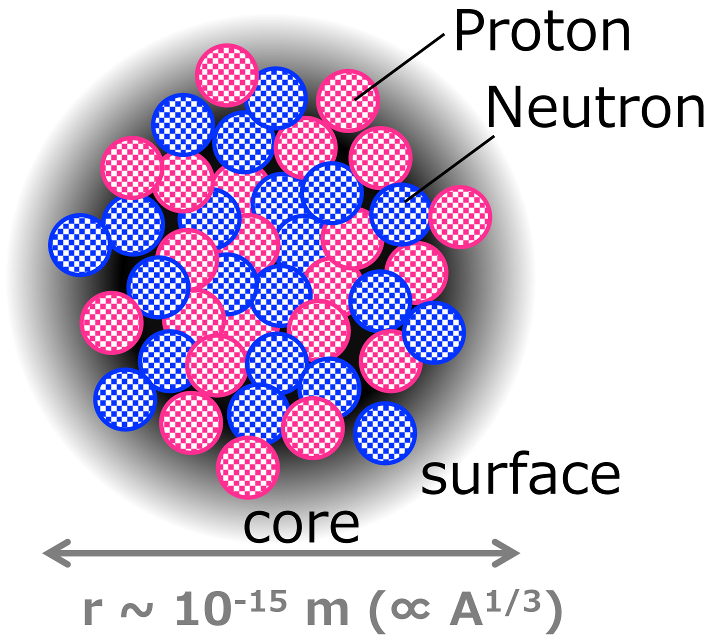
Unstable nuclei : Decay within their lifetime
(all except for stable nuclei)

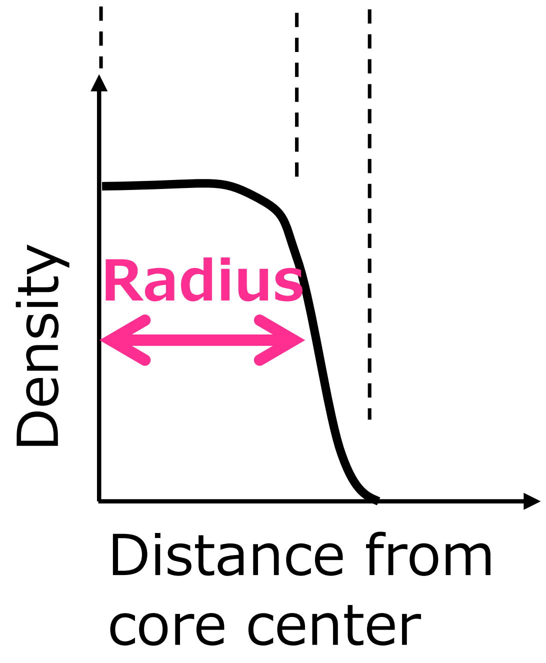
- Even existences of many unstable nuclei are not observed yet.

Nuclear chart



Nuclear density distribution



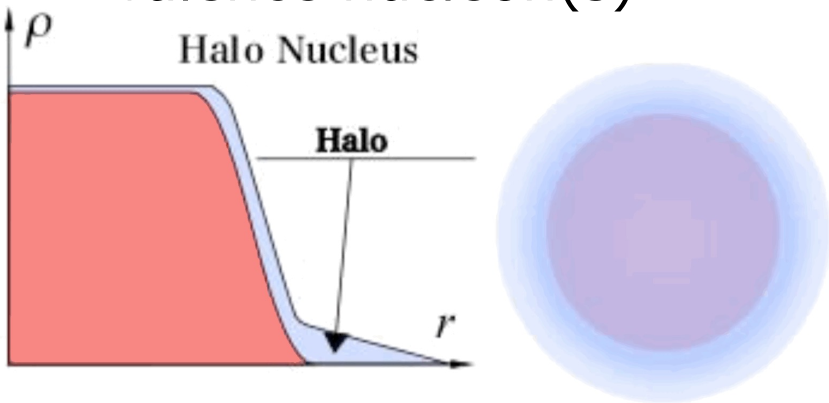


Stable nuclei

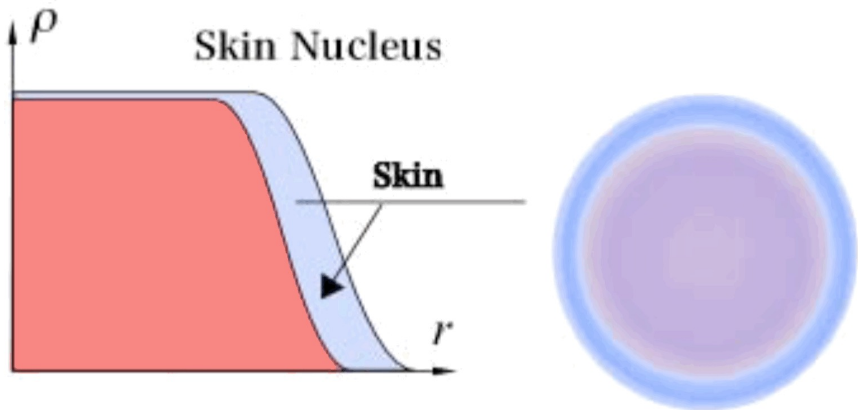
Proton and neutron are mixing uniformly.

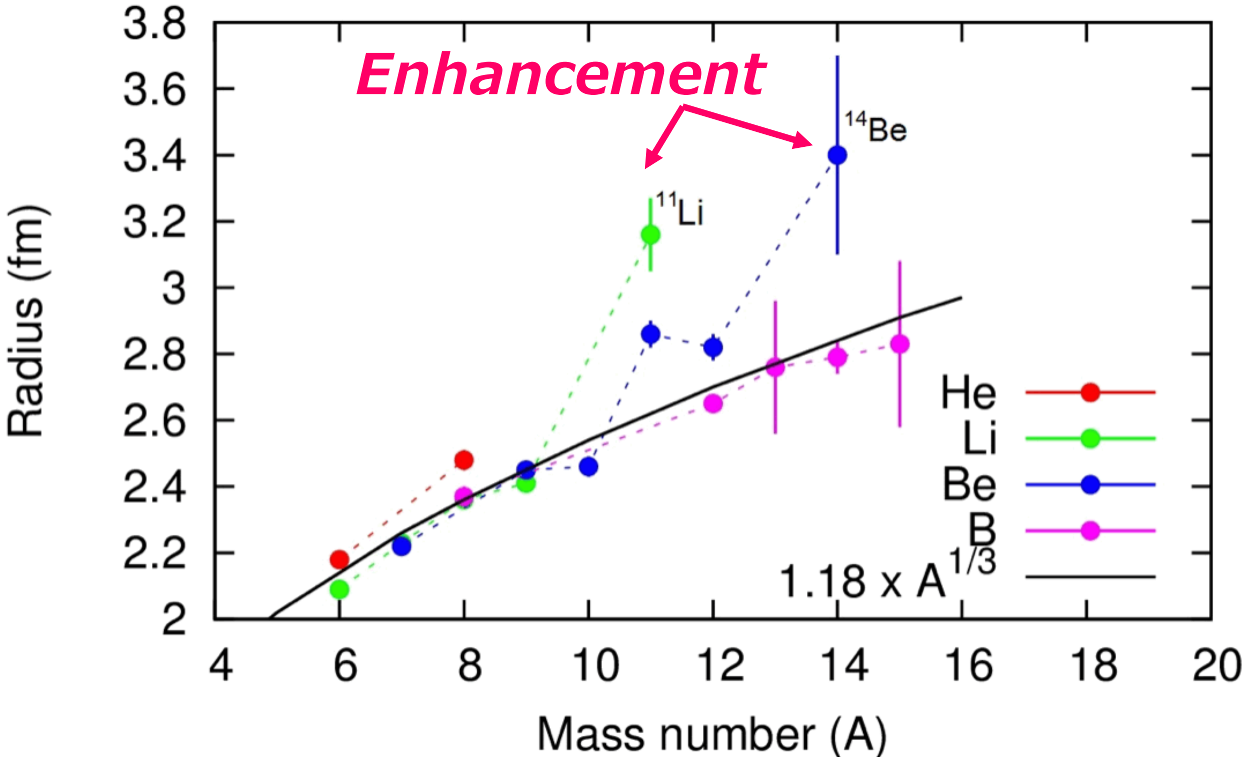
Untable nuclei

Halo: Expansion of weakly bound of valence nucleon(s)



Skin: Layer of proton or neutron around nuclear surface

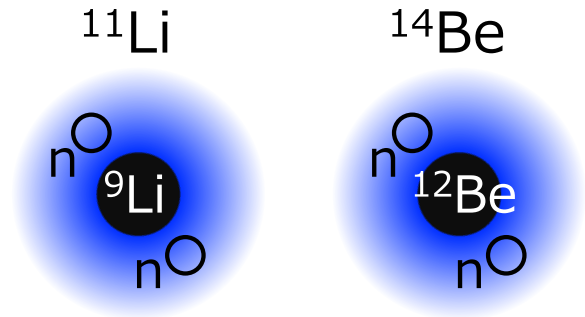




I. Tanihata et al., PRL55, 2676 (1985). I. Tanihata et al., PLB 88, 592 (1988)

First observation of the enhancement of radii of neutron-rich nuclei

Neutron halo



– σ_R measurements are effective methods to extract the nuclear size properties.

- So far, Be, C and Al were mainly used as reaction targets for σ_R measurements.

⇨ **How about "Nucleon - nucleus" collision?**

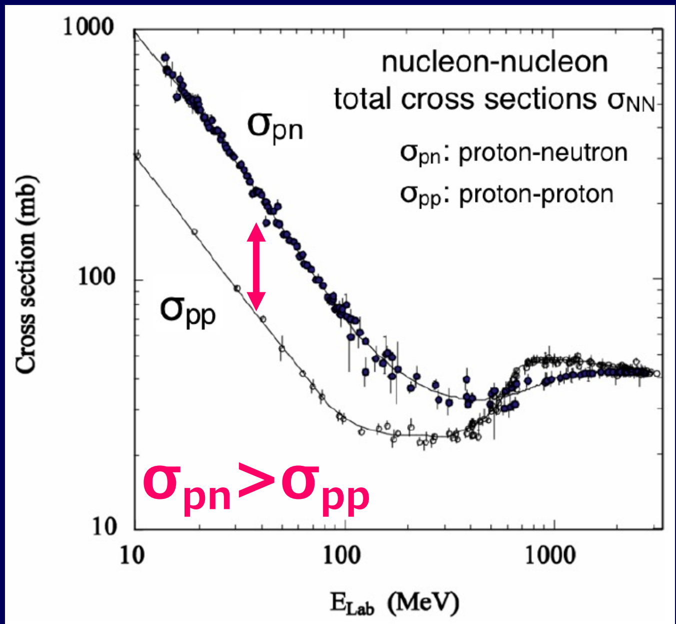
- Only a few experimental σ_R for proton-unstable nucleus collisions.

Proton target for σ_R measurement

- Measurement of total reaction cross section (σ_R) is an effective method to investigate nuclear size properties.
- A proton target has several advantages.

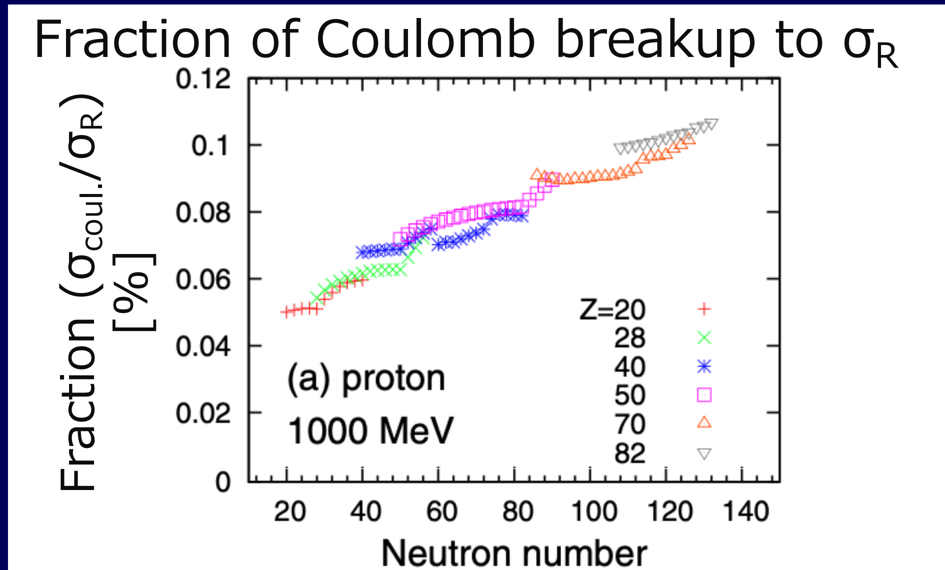
Separation of proton and neutron density distributions (ρ_p and ρ_n)

Extraction of the nuclear size of medium and heavy nuclei properly



Isospin asymmetry of σ_{NN}

⇨ Proton target is more sensitive to ρ_n of projectile.



W. Horiuchi et al., PRC93,044611(2016)

For proton target, the contribution of the Coulomb breakup is very small. (e.g. Carbon ~4% for Z=50)

Only a few experimental σ_R for unstable nuclei on a proton target are reported at this time.

⇨ It is important to understand the collisions between unstable nuclei and a proton.

(For proton-rich nuclei, investigations are not performed well yet in both experimental and theoretical sides.)

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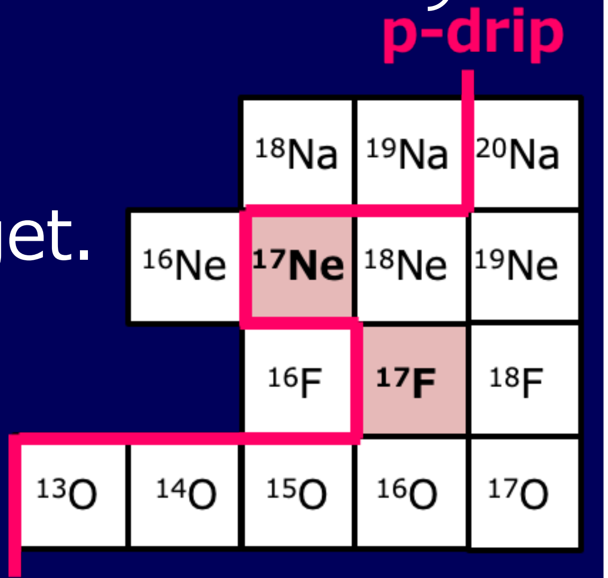
⇨ It is important to understand the collisions between unstable nuclei and a proton.

(For proton-rich nuclei, investigations are not performed well yet in both experimental and theoretical sides.)

Present study

We measured σ_R for ^{17}F & ^{17}Ne on a p target.

Proton dripline nuclei



^{17}F

- Candidate of a proton skin for ^{17}F (g.s., $5/2^+$)

^{17}Ne

- Known as the two-proton halo nucleus

⇨ Nuclear size : ^{17}F $\leq$ ^{17}Ne
(r_m=2.54(8) fm) (r_m=2.68(6) fm)

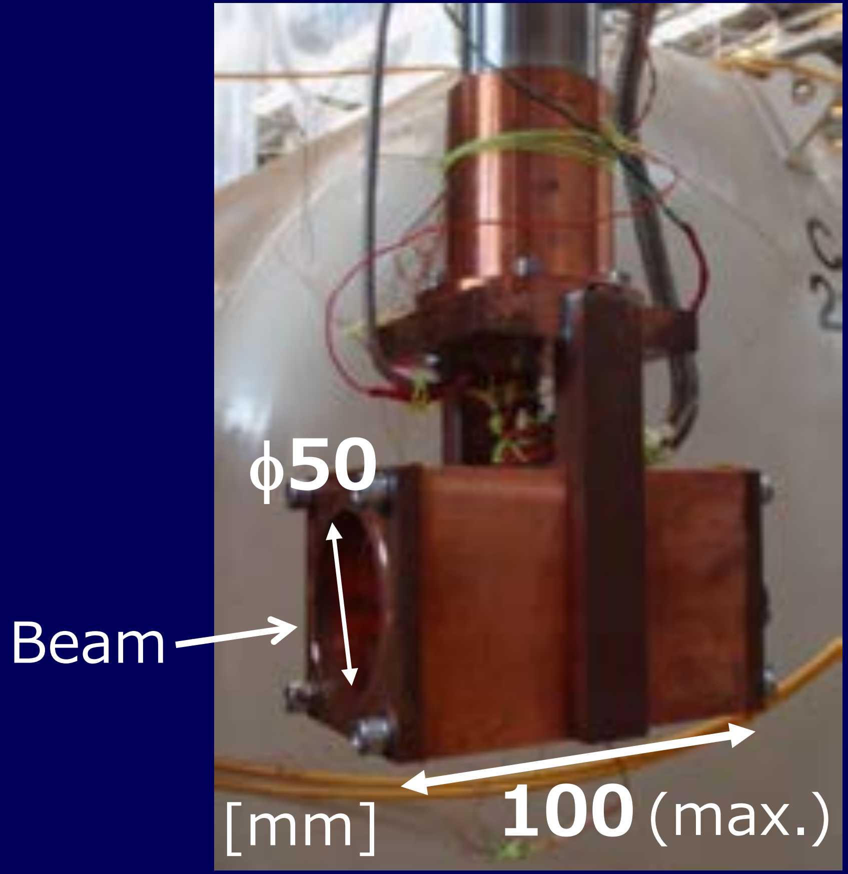
⇨ Neutron number: ^{17}F > ^{17}Ne
(N=8) (N=7)

Solid hydrogen target (SHT)

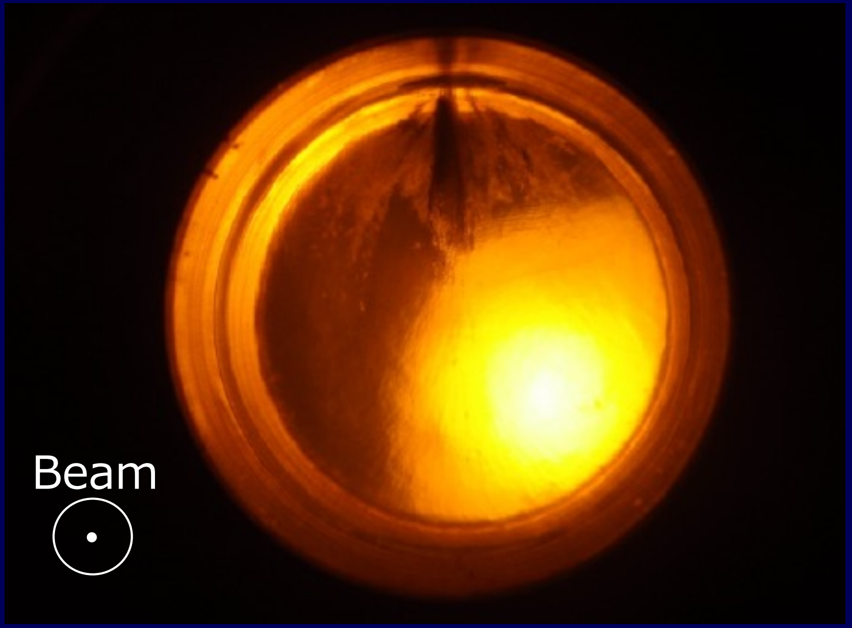
We have developed a thick and large solid hydrogen target (SHT) for σ_R measurements with RI beams.

[T. Moriguchi et al., NIMA 624(2010)27]

Target cell



Appearance of a typical SHT



A thick and large SHT (Maximum volume : ϕ50 x 100 mm^3) without any void or porous region was developed by optimization of the supply pressure.

Principle of measurement of σ_R

<Transmission method>

$$\sigma_R = -\frac{1}{N_t}\ln\left(\frac{\Gamma_{in}}{\Gamma_{out}}\right), \qquad \Gamma = \frac{N_2}{N_1}$$

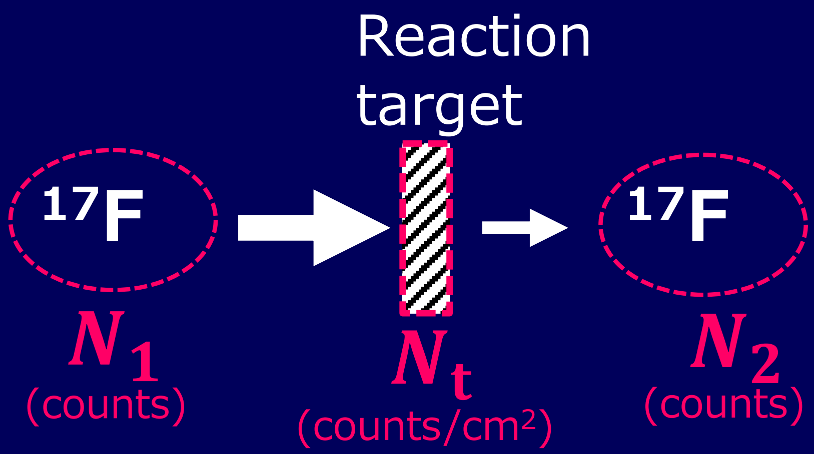
N_1: The number of incident nuclei

N_2: The number of non-interacting nuclei

N_t: The number of target nuclei per unit area

Γ_{in}: Γ for a target-in measurement

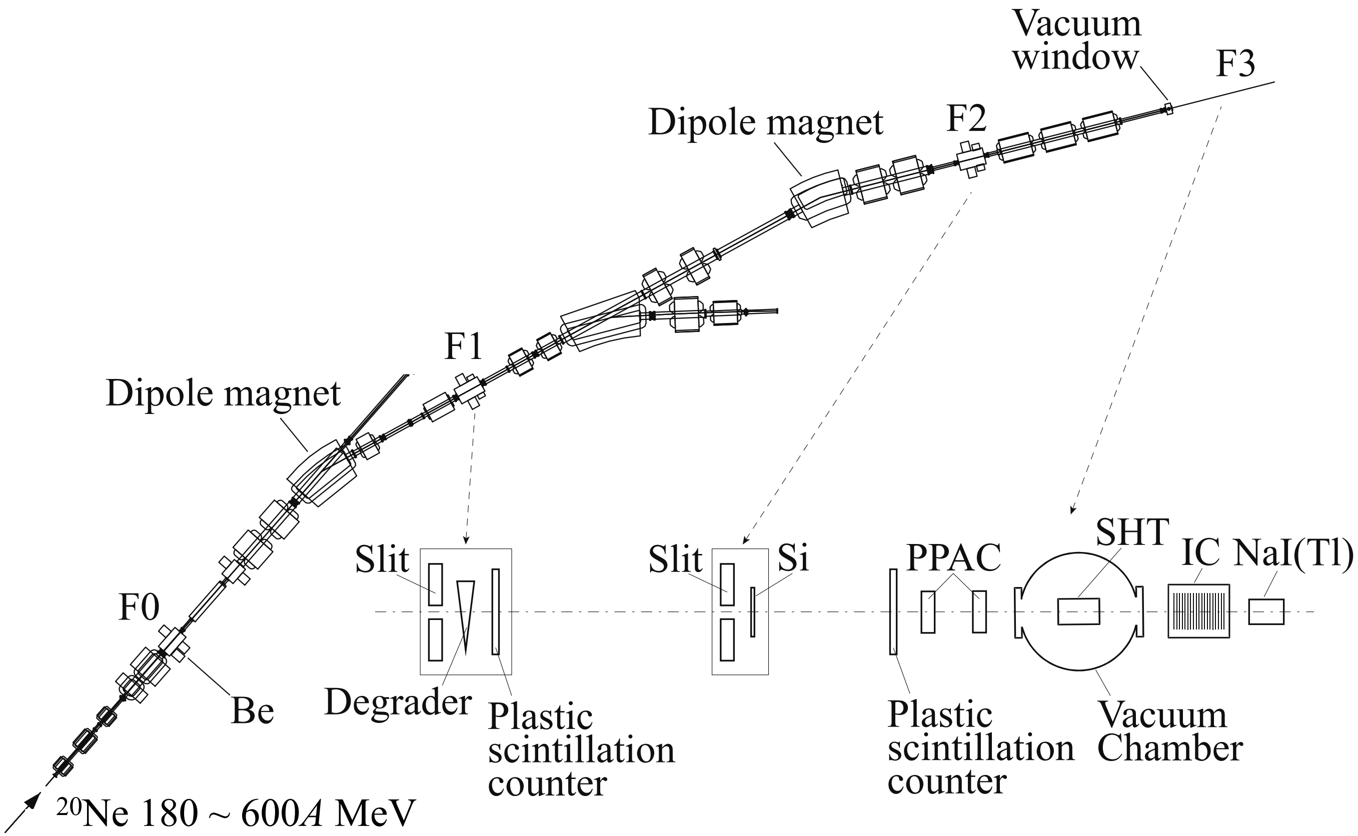
Γ_{out}: Γ for a target-out measurement



For counting N_1 and N_2, particle identifications both upstream and downstream of the reaction target are needed in the experiment.

Experiment @ HIMAC (Japan)

Fragment separator (SB2 course) [M. Kanazawa et al., NPA 746(2004) 393c]



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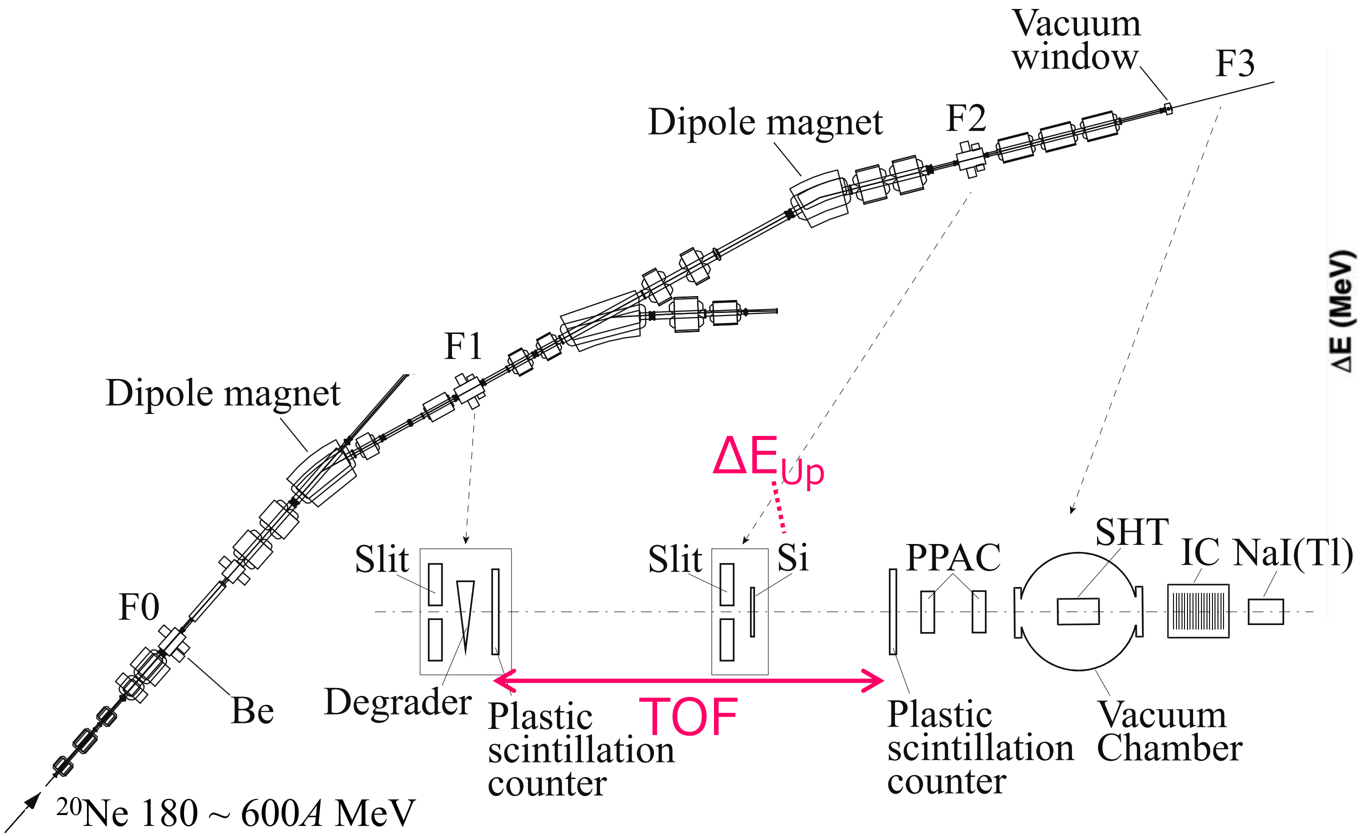
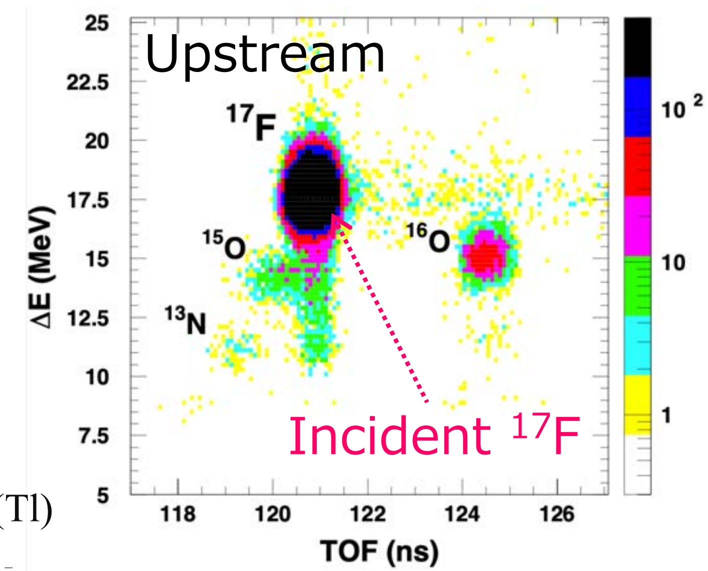


Particle identification



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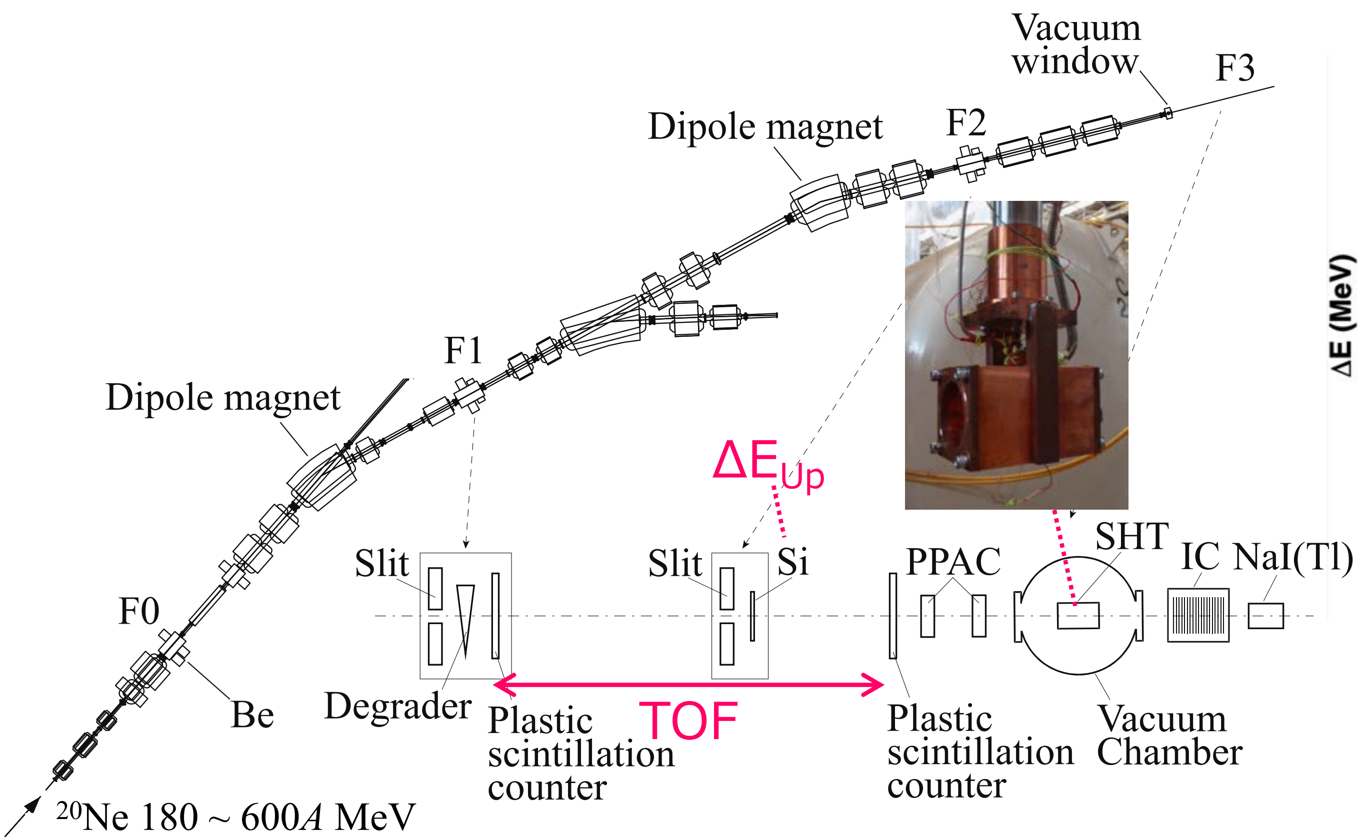
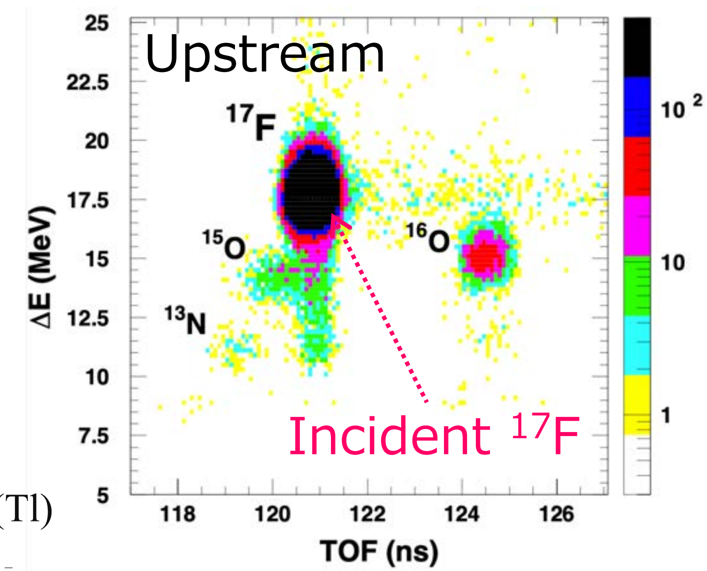


Particle identification



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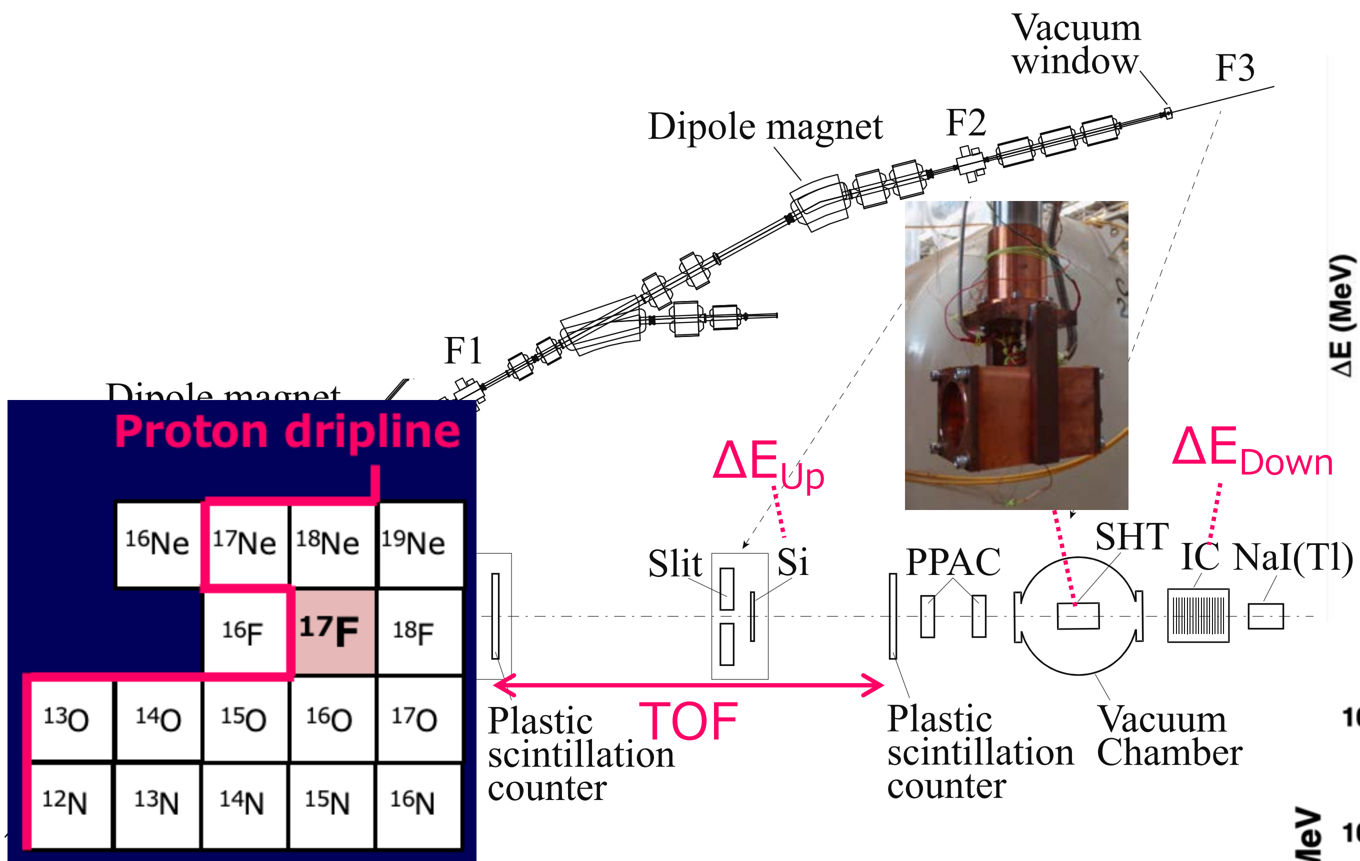
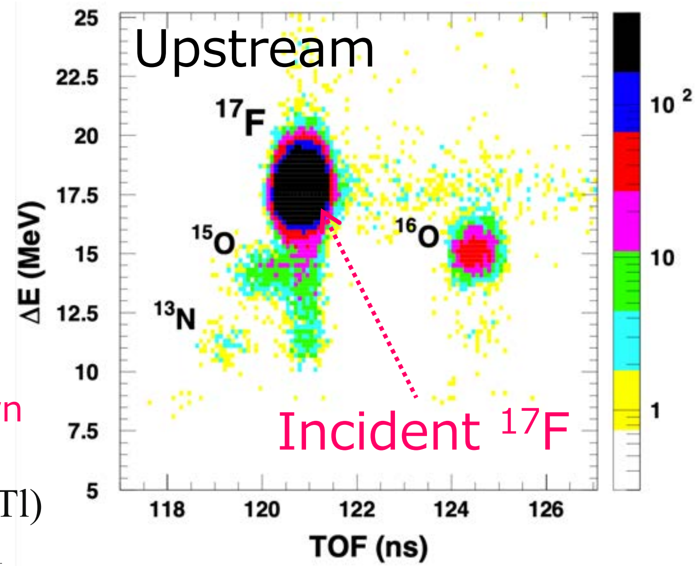
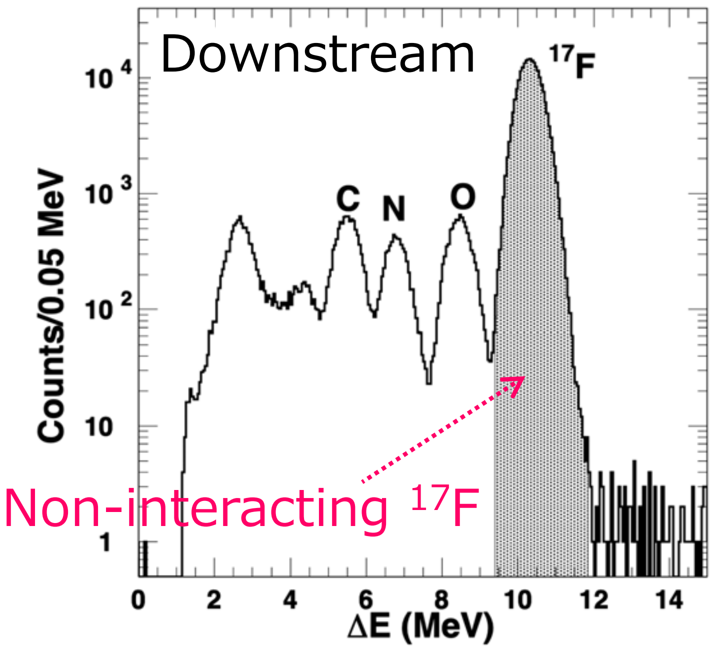


Particle identification

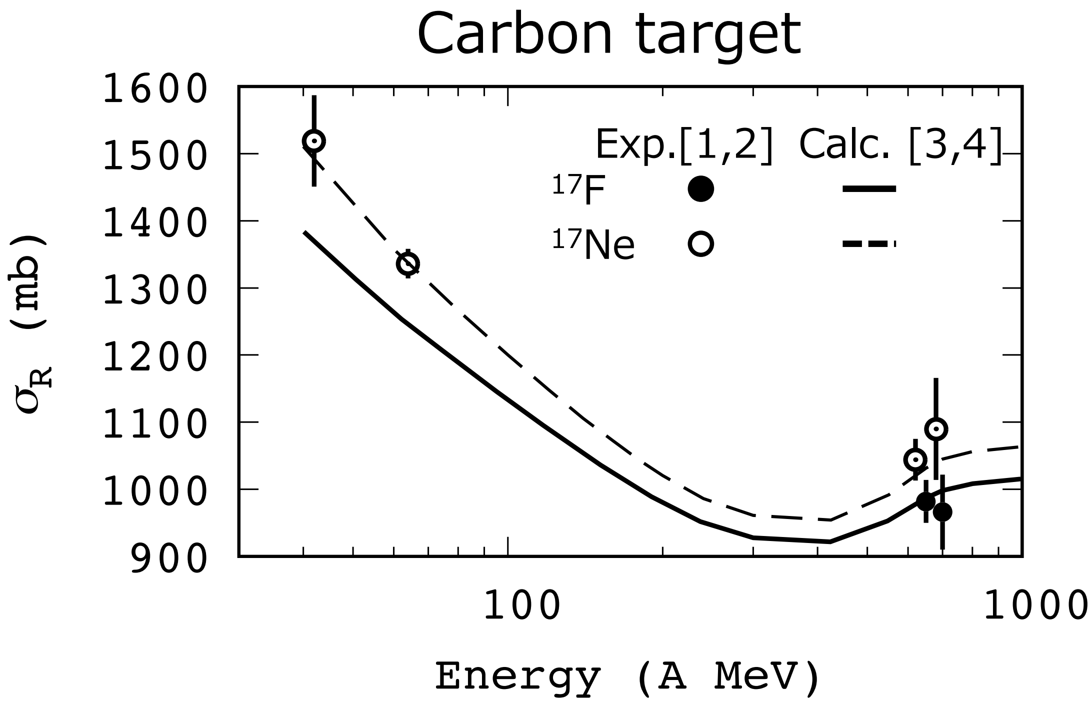




- ^{16}F is unbound. ⇨ No "^{17}F $\xrightarrow[-1n]{}$ ^{16}F"
- SHT is used. ⇨ No "^{17}F $\xrightarrow[+1n]{}$ ^{18}F"
  (No neutron in the target)

Non-interacting ^{17}F can be identified by only ΔE downstream of SHT.

σ_R on a carbon target



Exp.

[1] A. Ozawa et al., NPA693(2001)32.

[2] K. Tanaka et al., PRC82(2010)044309.

Calc. (Glauber model)

[3] B. Abu-Ibrahim and Y. Suzuki, PRC61(2000)051601.

[4] W. Horiuchi et al., PRC75(2007)044607.

σ_R on a carbon target

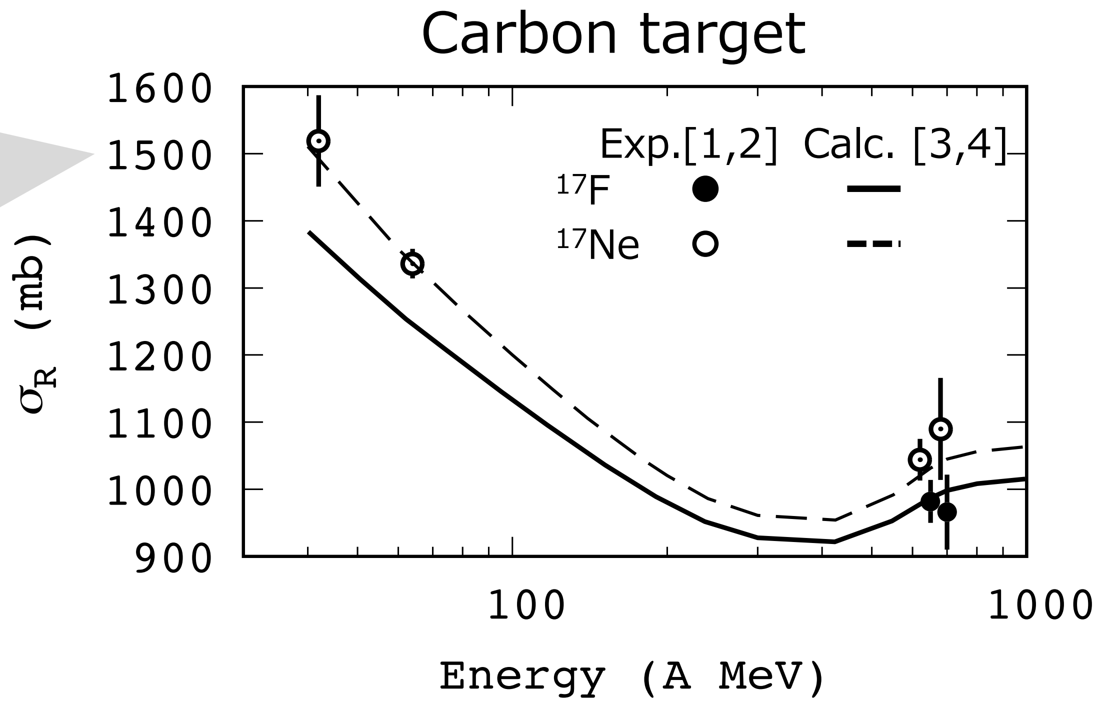
$\sigma_R(^{17}F) < \sigma_R(^{17}Ne)$

Glauber model calculation supports the experimental data for ^{17}F and ^{17}Ne.

^{17}Ne is known to be a two-proton-halo nucleus, but ^{17}F in the ground state is not.

⇨ Nuclear size : $^{17}F < ^{17}Ne$

σ$_R$ on a carbon target reflects the spatial spread of a density distribution of nucleus.



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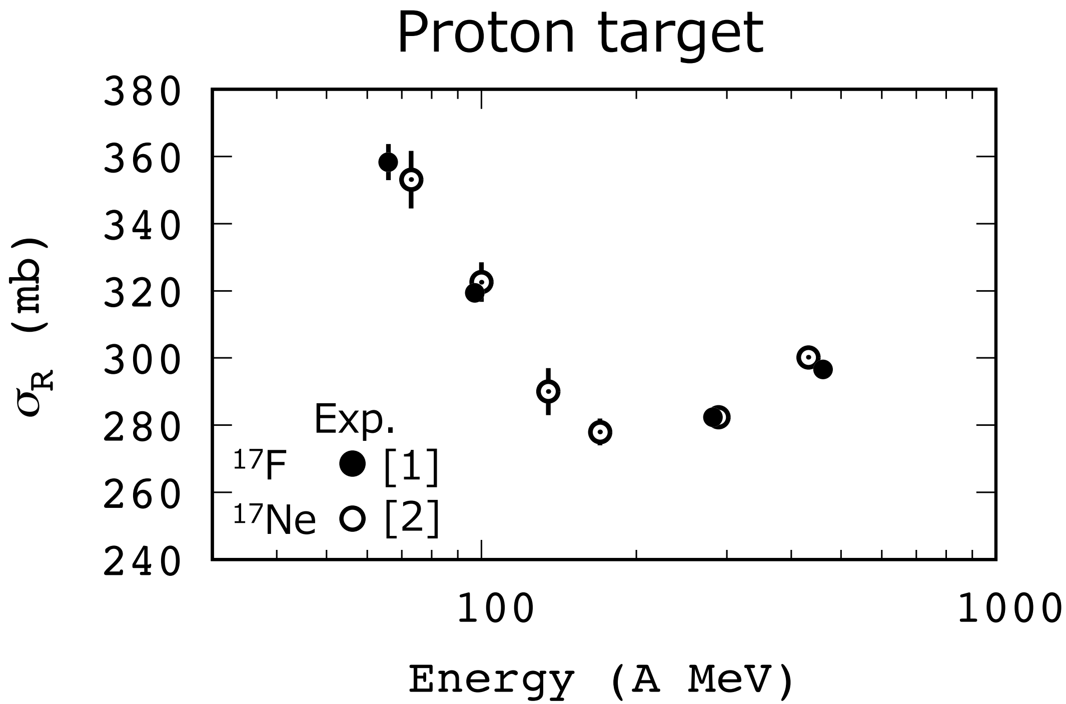
σ_R on a proton target

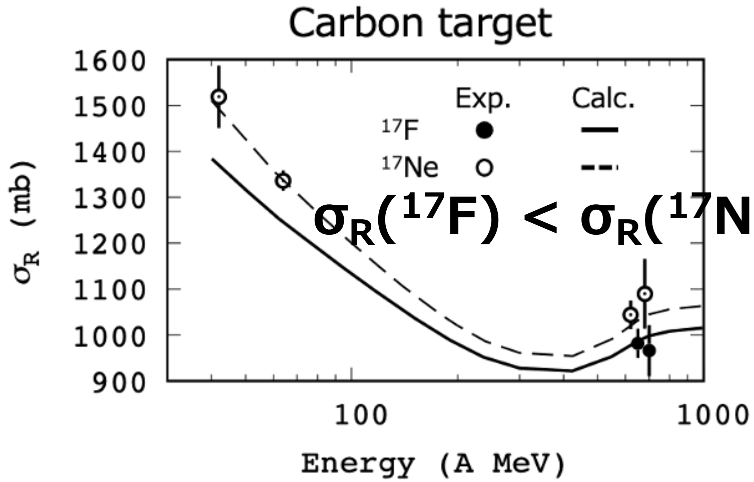


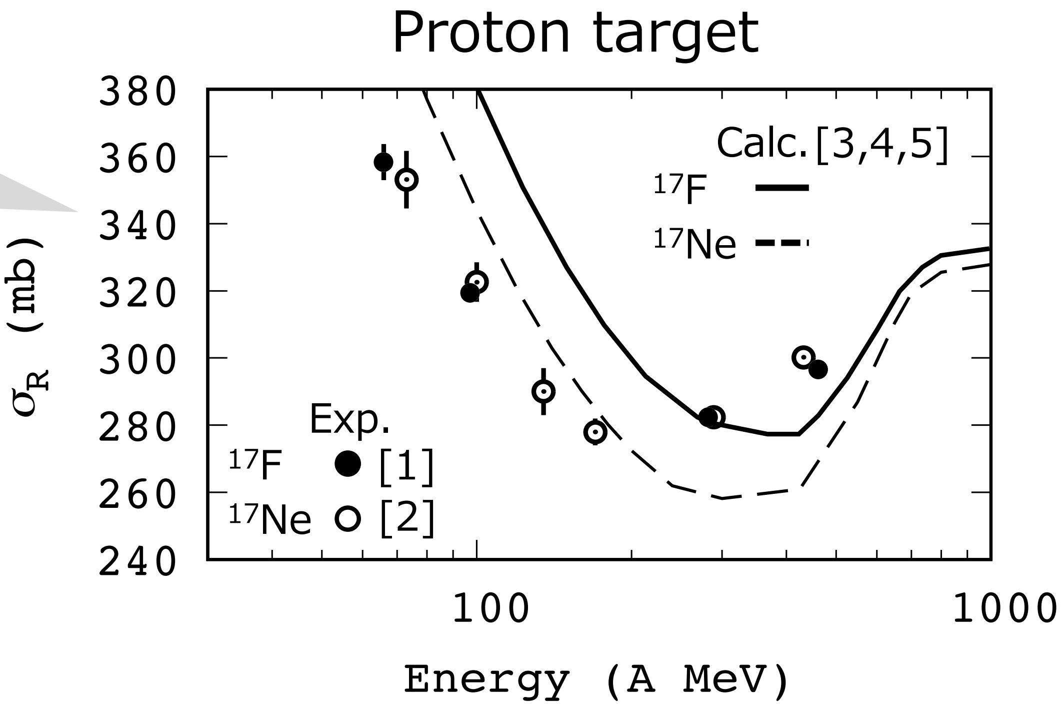
[1] T. Moriguchi et al., submitted to PRC.
[2] T. Moriguchi et al., NPA994(2020)121663.

σ_R on a proton target

$\sigma_R(^{17}F) \geqq \sigma_R(^{17}Ne)$

In contrast to a carbon target





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[2] T. Moriguchi et al., NPA994(2020)121663.
[3] Y. Suzuki et al., Structure and reactions of light exotic nuclei, Taylor&Francis, London, 2003.
[4] R. J. Glauber, Lectures in Theoretical Physics, Interscience, New York, Vol. 1 (1959).
[5] B. Abu-Ibrahim et al., PRC77(2008)034607.

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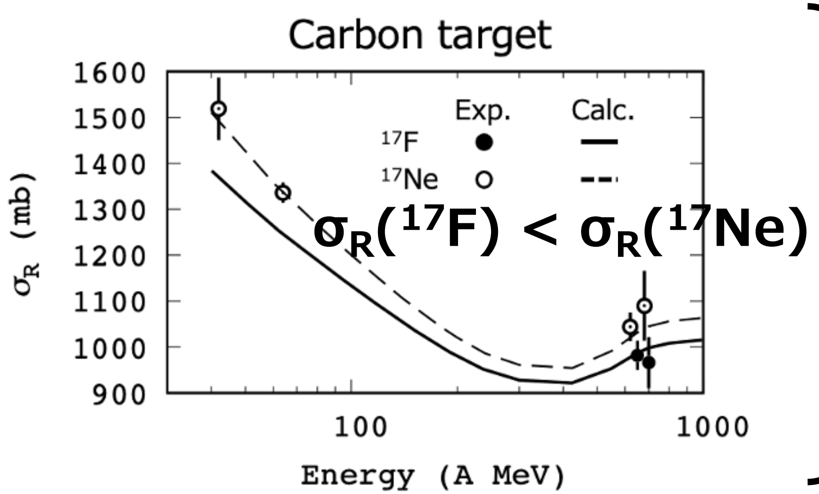

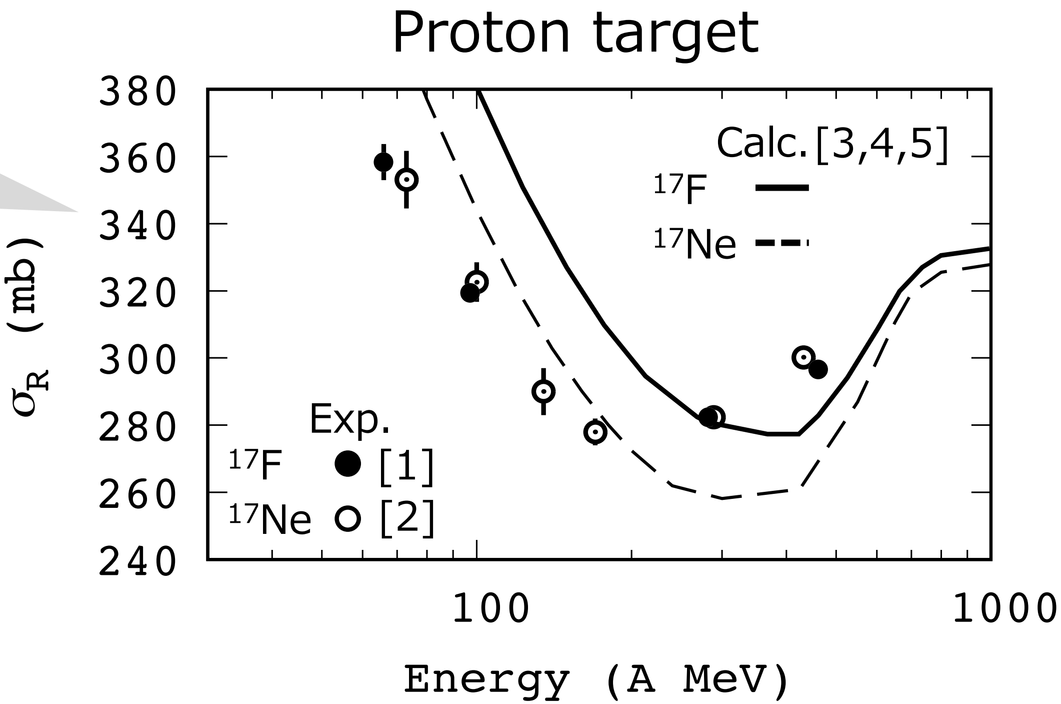

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[5] B. Abu-Ibrahim et al., PRC77(2008)034607.

Isospin asymmetry of σ_{NN} ($\sigma_{pn} > \sigma_{pp}$)

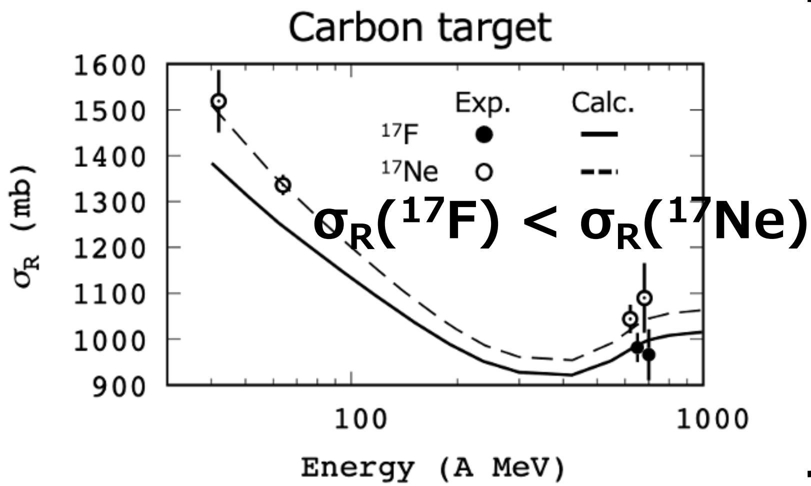
- Proton target is sensitive to neutrons in a projectile.

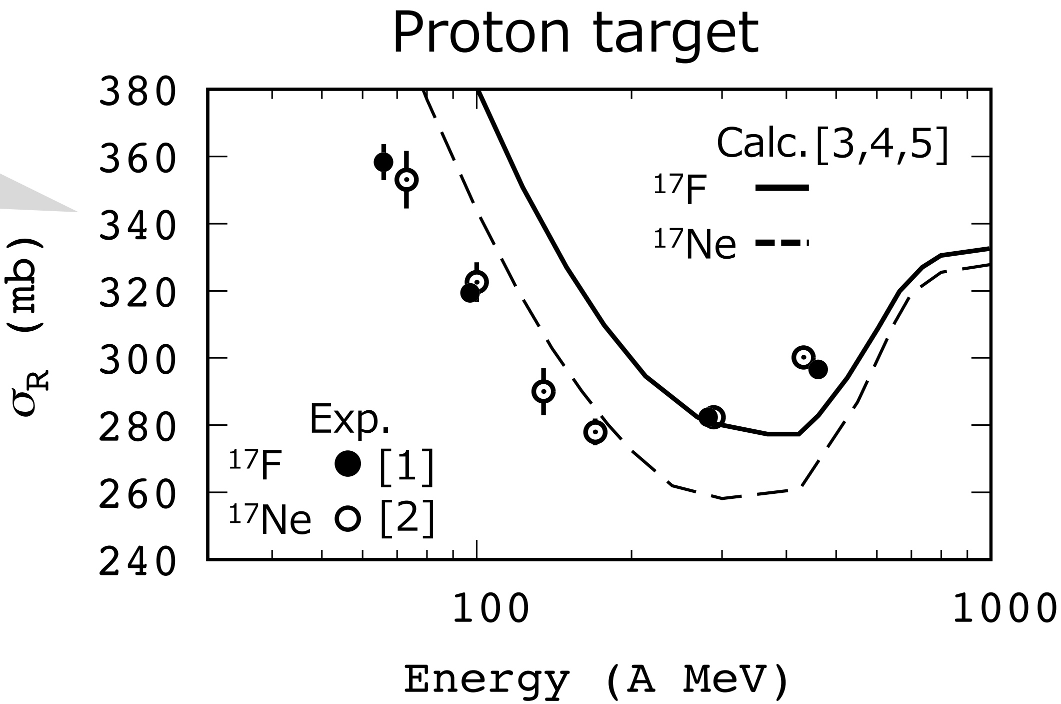
	^{17}F	^{17}Ne
Density spread	Small (w/o halo)	Large (w/ halo)
Contribution of σ_{pn} to σ_R on proton target	Large (*N*=8)	Small (*N*=7)

σ_R on a proton target

$\sigma_R(^{17}F) \geqq \sigma_R(^{17}Ne)$

In contrast to a carbon target





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Isospin asymmetry of σ_{NN} ($\sigma_{pn} > \sigma_{pp}$)

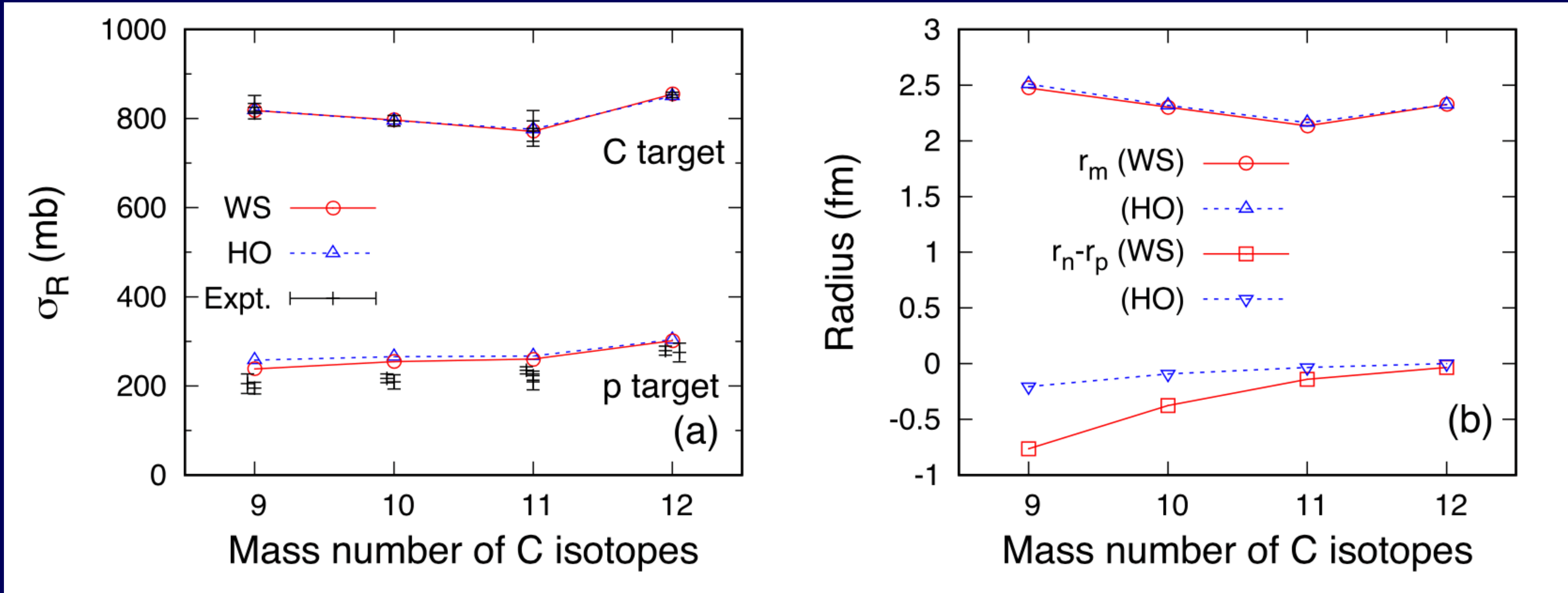
- Proton target is sensitive to neutrons in a projectile.

	^{17}F	^{17}Ne
Density spread	Small (w/o halo)	Large (w/ halo)
Contribution of σ_{pn} to σ_R on proton target	Large (*N*=8)	Small (*N*=7)

For proton-rich nuclei, the isospin asymmetry of σ_{NN} is dominant for σ_R on a proton target, not the density spread.

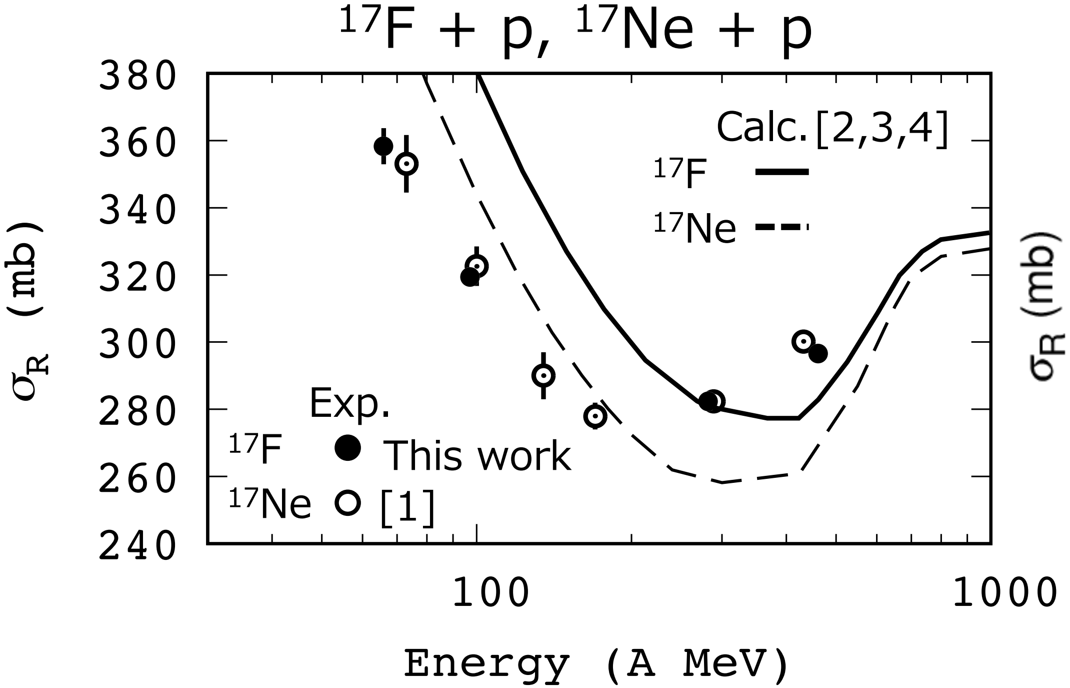
The decrease of σ_R on a proton target despite the increase of matter radii towards the proton dripline

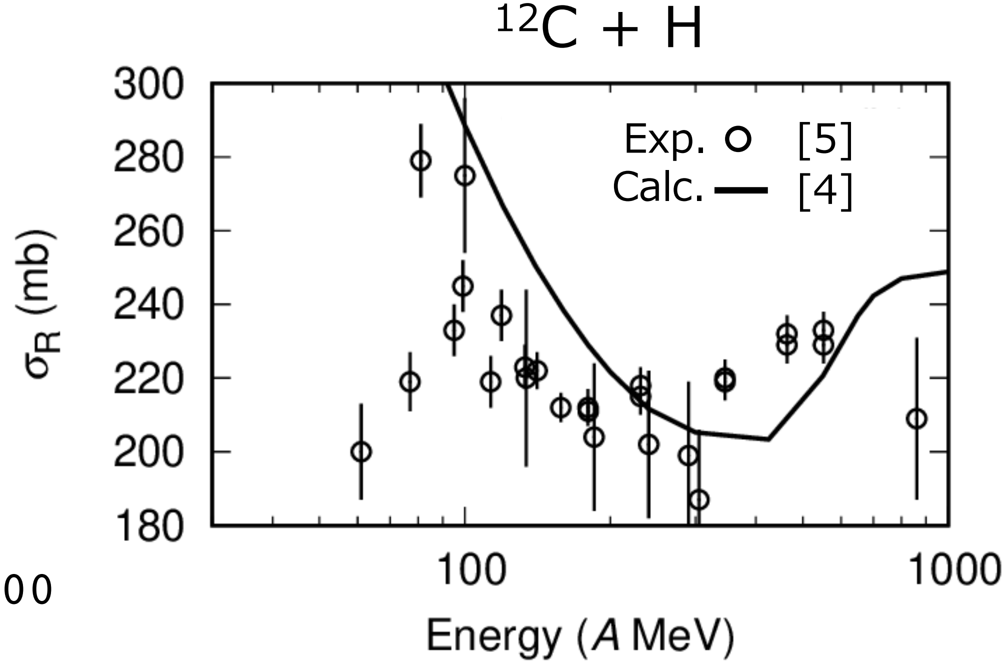
Glauber model calculation [K. Makiguchi, W. Horiuchi, PTEP2022, 073D01.]



This theoretical study supports the present σ_R for ^{17}F and ^{17}Ne on a proton target.

Energy dependence of σ_R on a proton target





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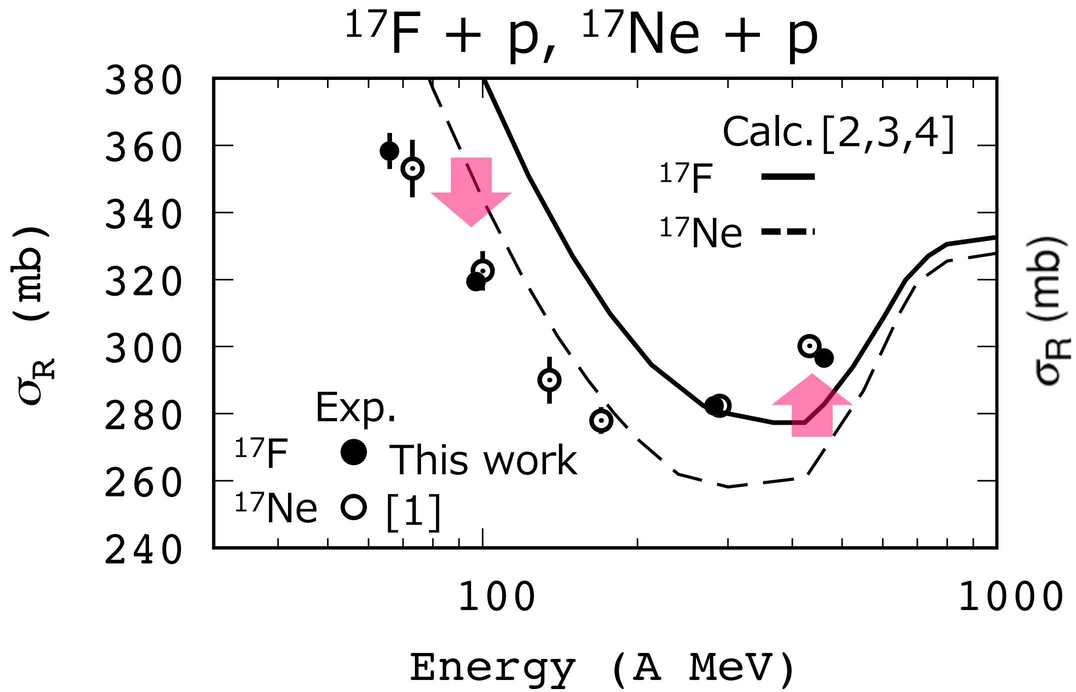
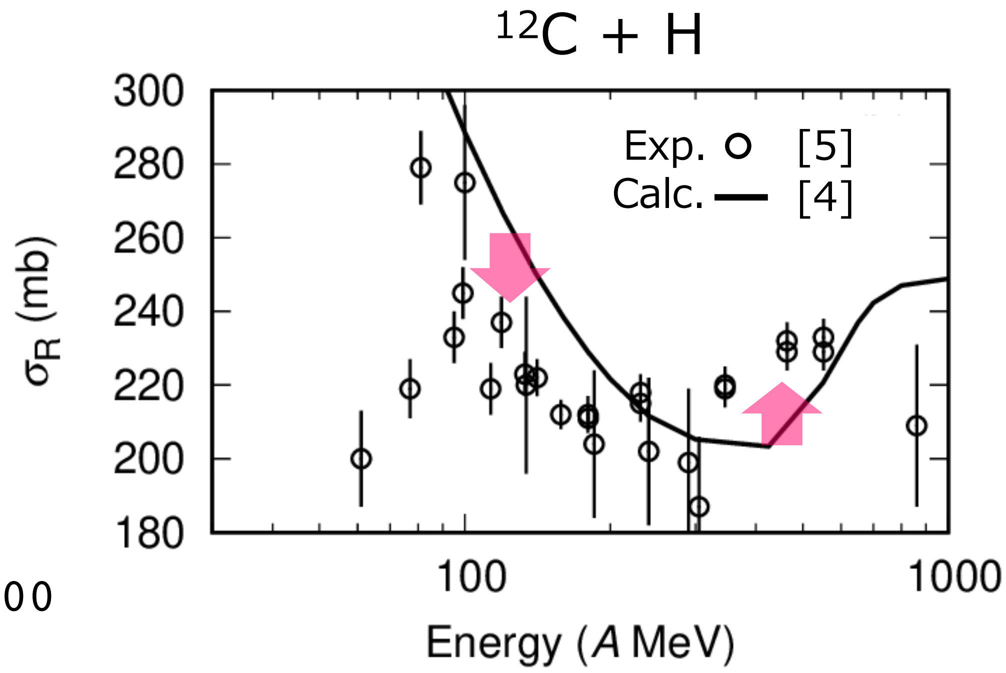
Energy dependence of σ_R on a proton target





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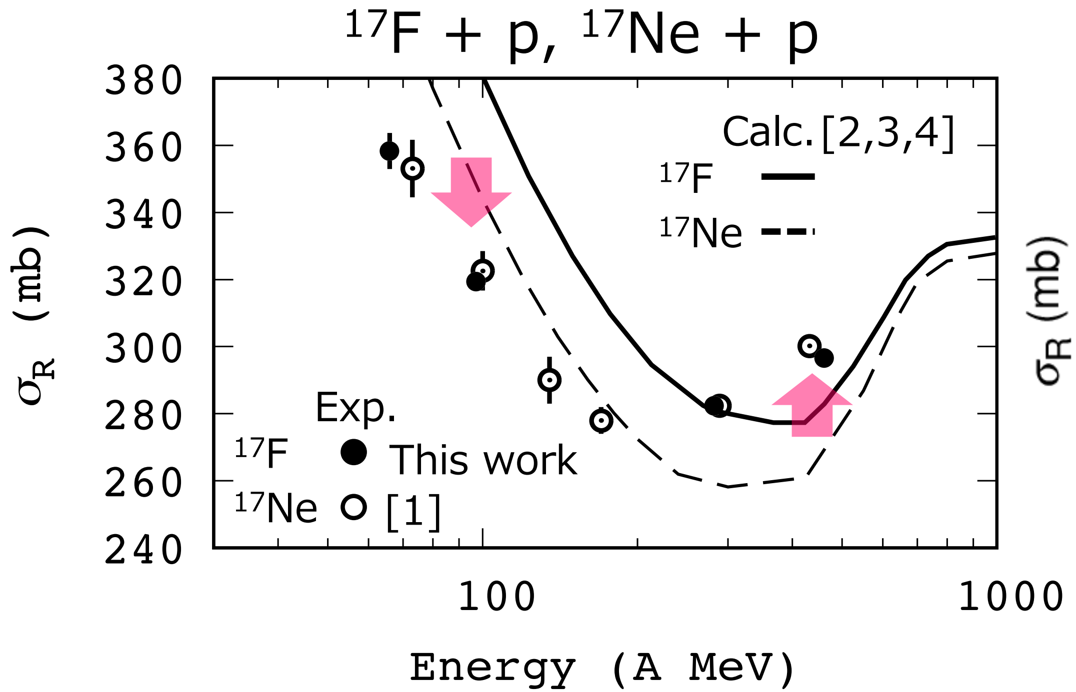
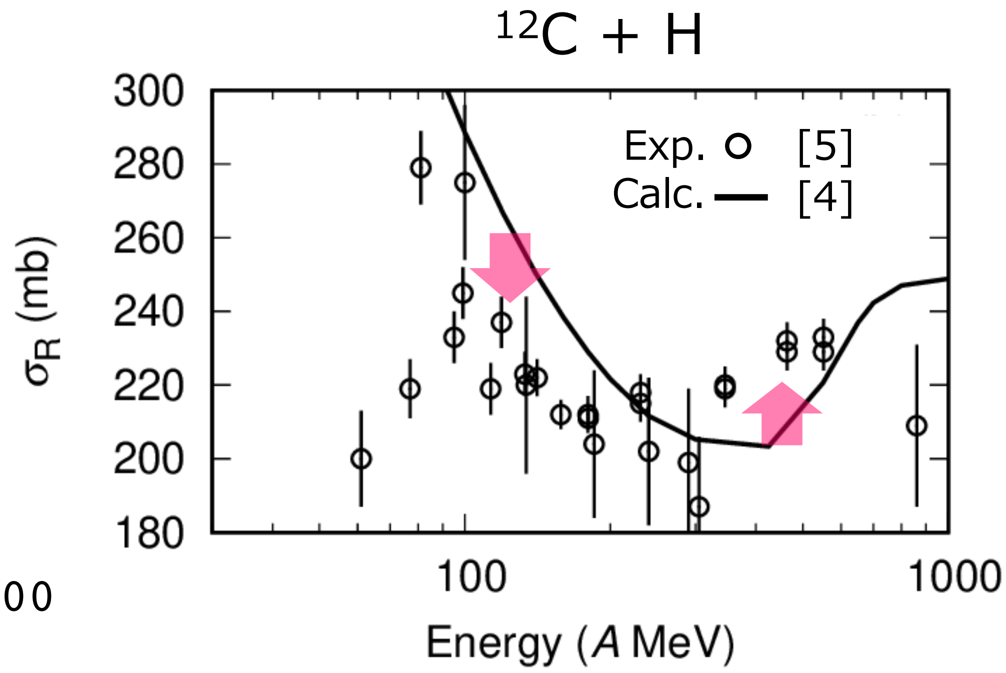
Low energies : Exp. < Calc. (Glauber model)
Intermediate energies: Exp. > Calc. (Glauber model)

Energy dependence of σ_R on a proton target





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[5] R. Carlson, At. Data Nucl. Data Tab. 63 (1996) 93.

Low energies : Exp. < Calc. (Glauber model)
Intermediate energies: Exp. > Calc. (Glauber model)

- Nuclear medium effects (Fermi motion, Pauli blocking)
  Low energies : Sensitive
  Intermediate energies : Not so sensitive

It seems to be difficult to explain the experimental σ_R at low and intermediate energies simultaneously with nuclear medium effects.

Summary

- We measured σ_R for ^{17}F & ^{17}Ne on a proton target.
- Solid hydrogen target (SHT) was used as a proton target.
- For proton dripline nuclei ^{17}F and ^{17}Ne,

  <u>σ_R on a carbon target</u>

  ⇨ Contributed by the spread of the density distribution

  <u>σ_R on a proton target</u>

  ⇨ Contributed by an isospin asymmetry of the nucleon-nucleon total cross section ($\sigma_{pn} > \sigma_{pp}$)

  <u>Energy dependence of σ_R on a proton target</u>

  ⇨ Discrepancy between exp. and calc.

Future plan

- Measurement of σ_R with the SHT and C for Sn isotopes
- Measurement of σ_R with a solid deuterium target