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Measurements of Reaction Cross Sections with a Solid Hydrogen Target and Development of the Target System

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Outline

- Introduction & Solid hydrogen target (SHT)

- Reaction cross section measurements with the SHT
  - ^{11}Li (Neutron-rich)
  - ^{17}F, ^{17}Ne (Proton-rich)

- Developments of the target system
  - Improvements of the SHT
  - Solid Deuterium Target (SDT)

- Summary

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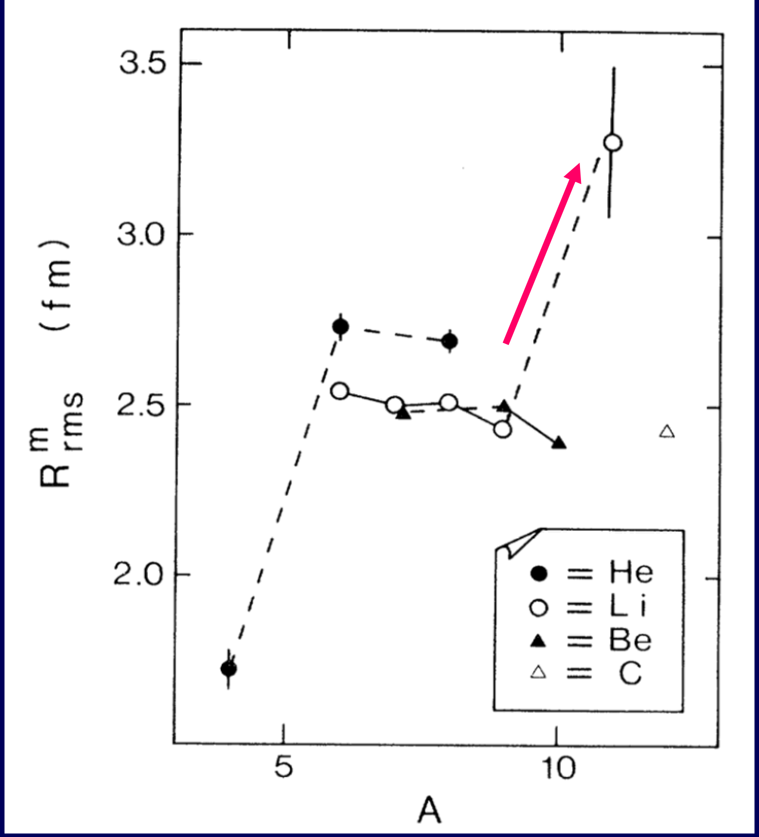
Introduction

- Reaction cross section (σ_R) and interaction cross section (σ_I) measurements contributed to extract root mean square (rms) nuclear radii of unstable nuclei, combined with the Glauber model calculation.
- So far, Be, C and Al were mainly used as reaction targets for σ_R measurements.



I. Tanihata et al., PRL55, 2676 (1985)

Beam	Target Be	Target C	Target Al
^{6}Li	651 ± 6	688 ± 10	1010 ± 11
^{7}Li	686 ± 4	736 ± 6	1071 ± 7
^{8}Li	727 ± 6	768 ± 9	1147 ± 14
^{9}Li	739 ± 5	796 ± 6	1135 ± 7
^{11}Li		1040 ± 60	
^{7}Be	682 ± 6	738 ± 9	1050 ± 17
^{9}Be	755 ± 6	806 ± 9	1174 ± 11
^{10}Be	755 ± 7	813 ± 10	1153 ± 16

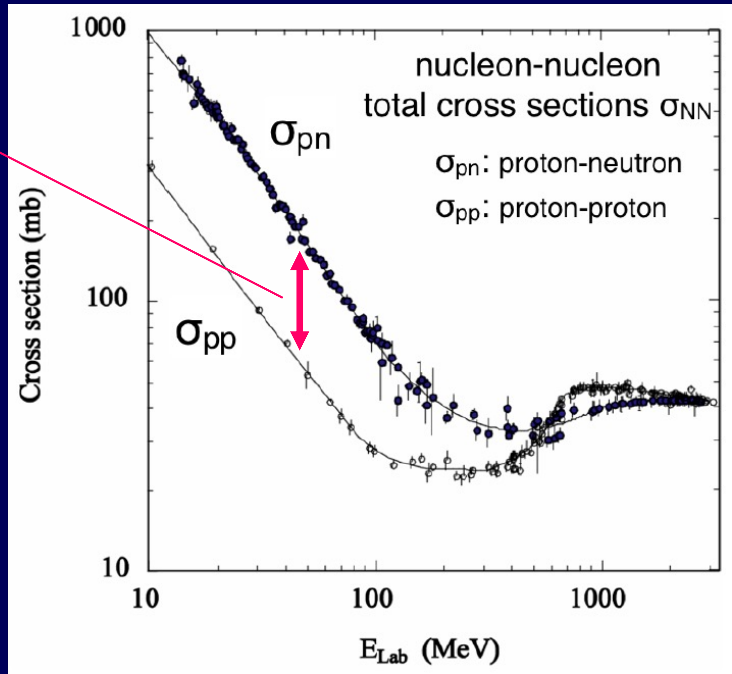
How about "Nucleon - nucleus" collision?

Isospin asymmetry of σ_{NN}

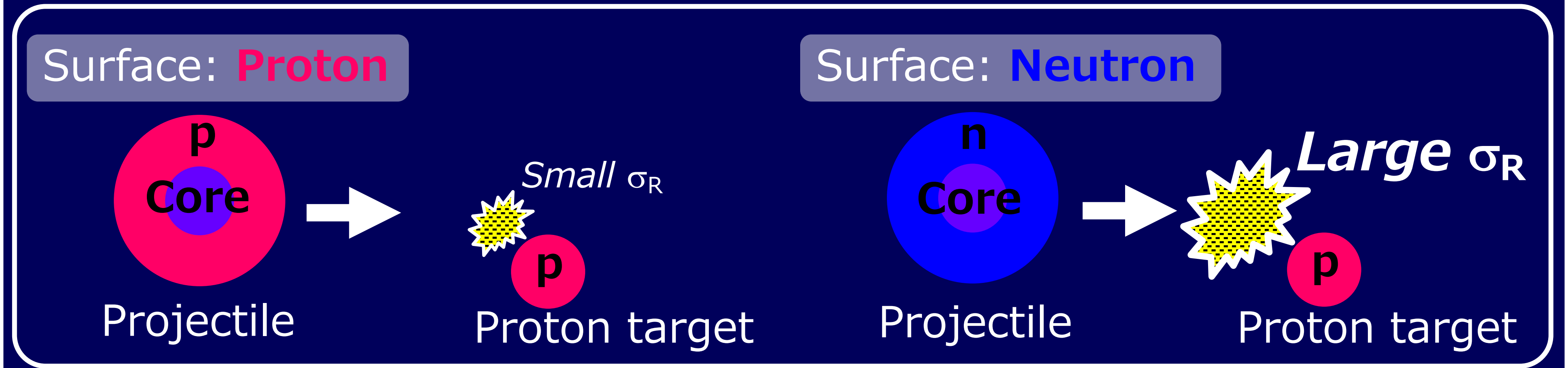
σ_{NN} : Nucleon-nucleon total cross section

σ_{pn} is about three times larger than σ_{pp} in the low energy.

⇨ <u>A proton target</u> is more sensitive to ρ_n of projectile than to ρ_p of it.



ρ_p : Proton density distribution
ρ_n : Neutron density distribution
ρ_m: Matter (nucleon) density distribution
* $\rho_m = \rho_p + \rho_n$



Hydrogen is a good material as a proton target.

CH_2

- Easy handling
- Statistical disadvantage due to the subtraction of reaction events with carbon in the CH_2

H_2

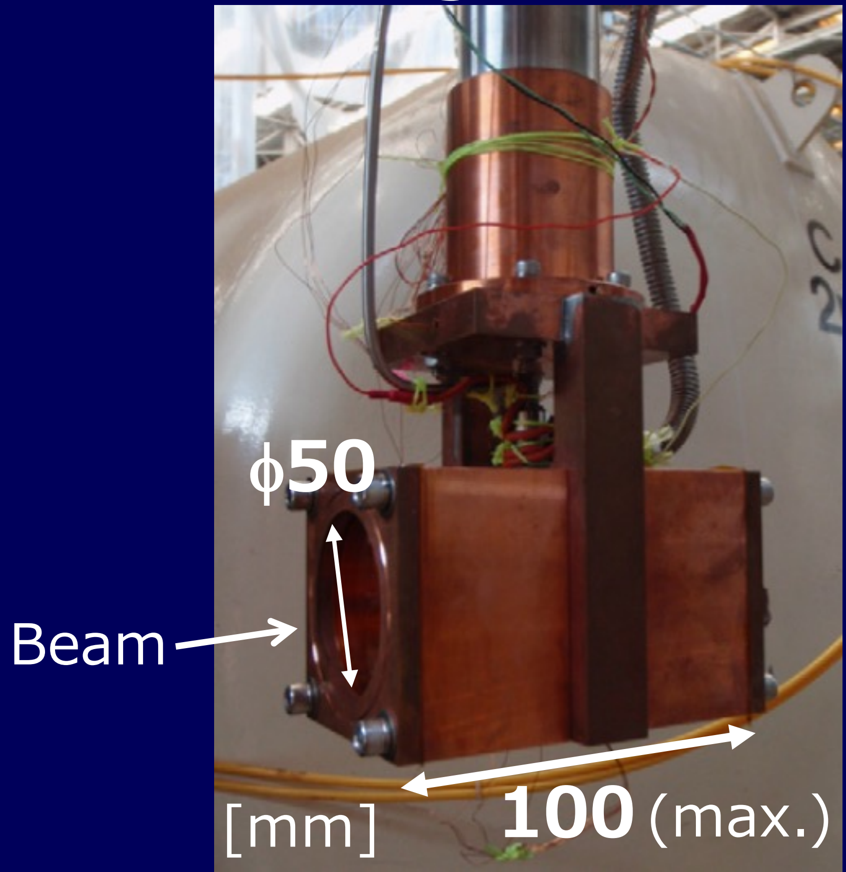
We proposed a solid hydrogen target.

- The large number of atoms per unit mass
- No need of measurements using carbon target
- Complicated operation (flammable gas, gas handling, cryostat etc)

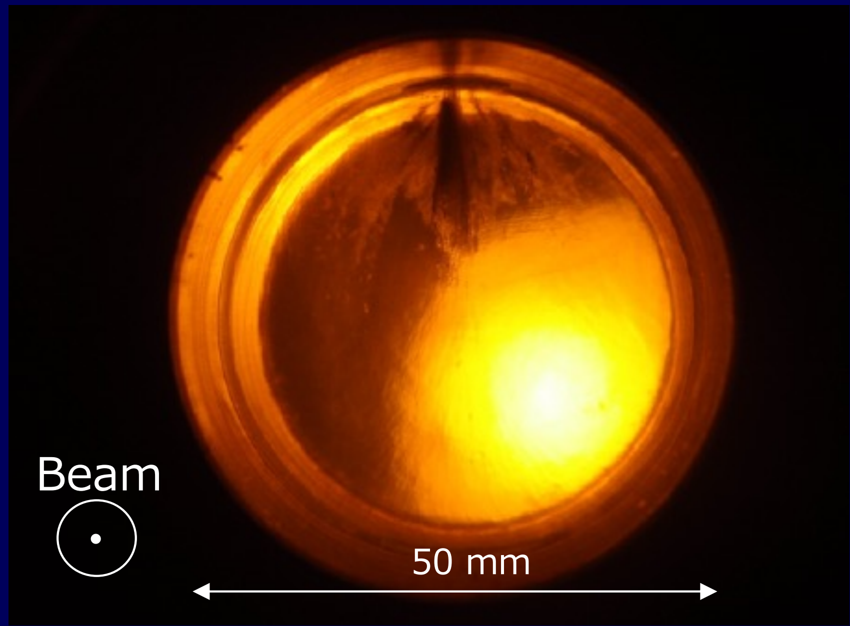
Solid hydrogen target (SHT)

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

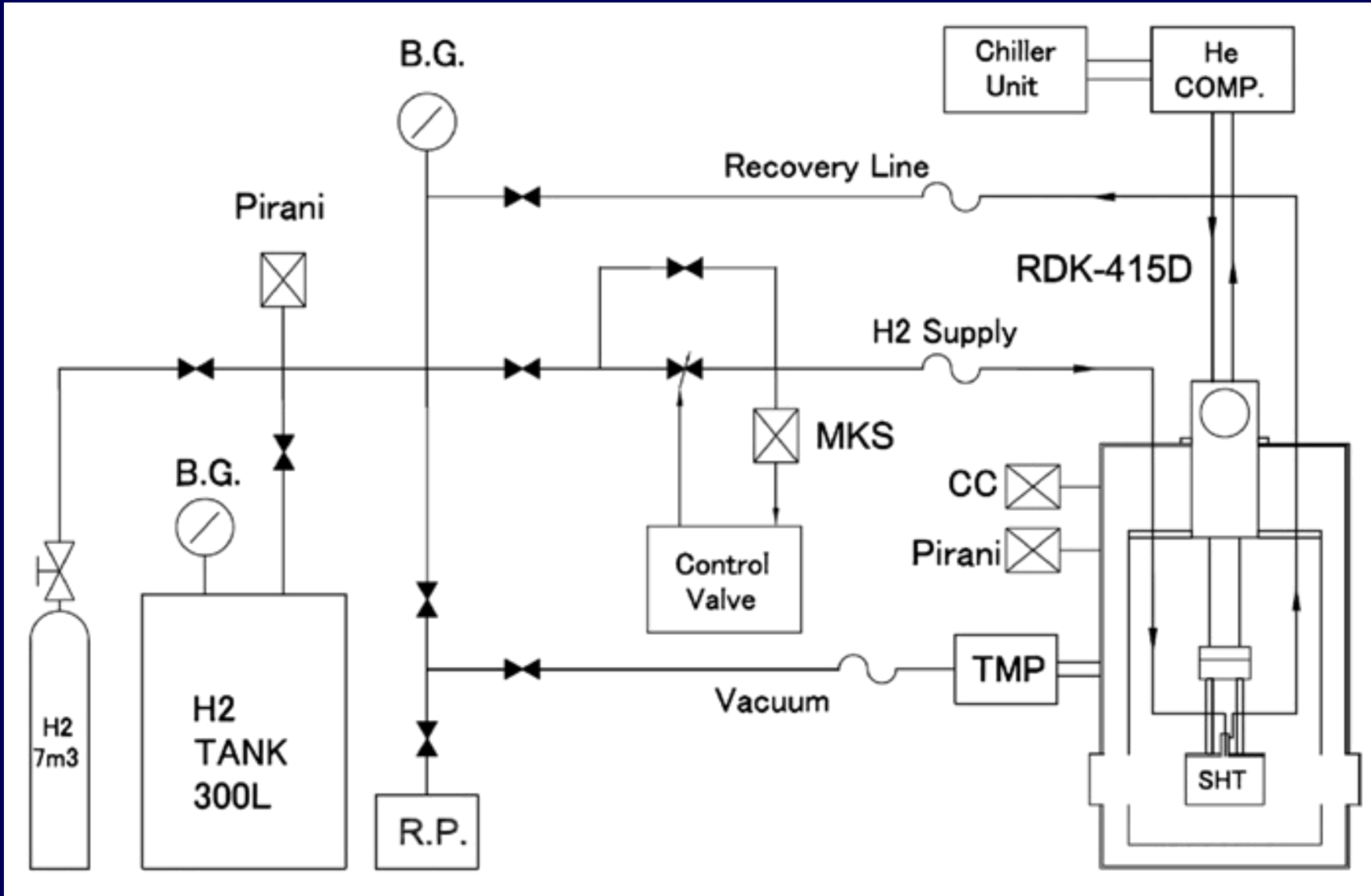


Appearance of a typical SHT



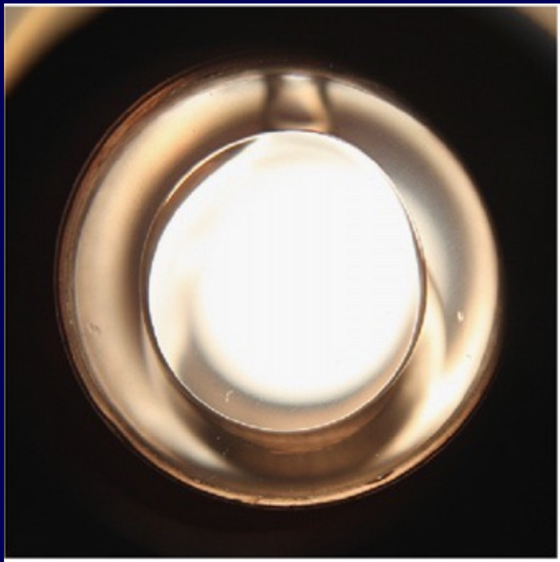
A thick and large SHT (Maximum volume : $\phi 50 \times 100\ \mathrm{mm}^3$) without any void or porous region was developed by optimization of the supply pressure.

Gas handling system for SHT

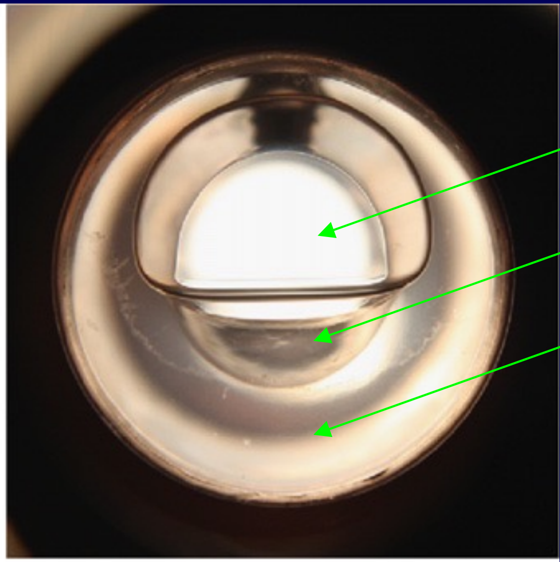


Growth of SHT (100 mm cell)

The supply pressure is 100 Torr, which is optimal value.



(1) 55 min.



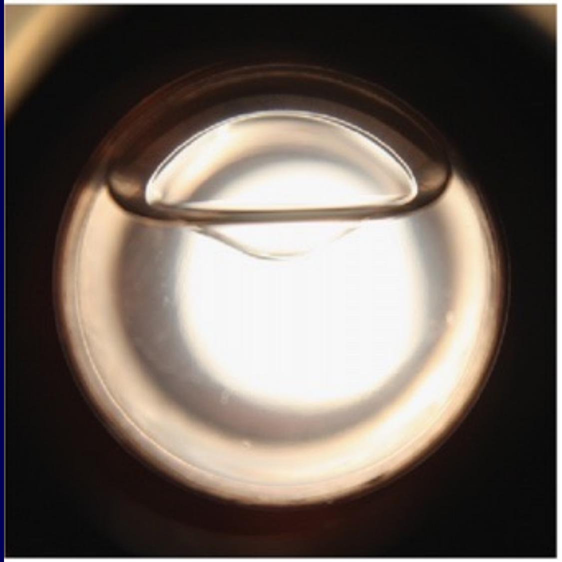
(2) 1 hr 30 min.

Gas

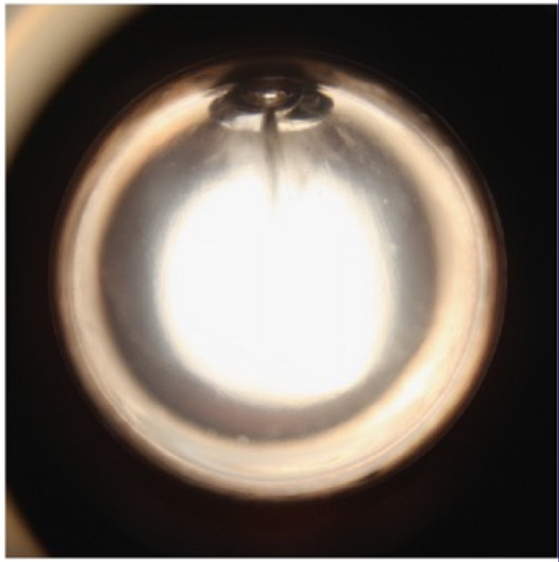
Liquid

Solid

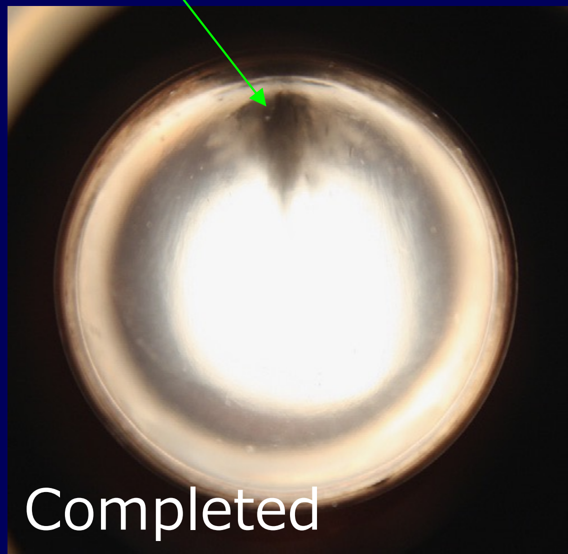
Crack {made by the change of density due to a large temperature gradient}



(3) 1 hr 35 min.



(4) 2 hr 10 min.



(5) 2.5 hr

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Principle of measurement of σ_R

<Transmission method>

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

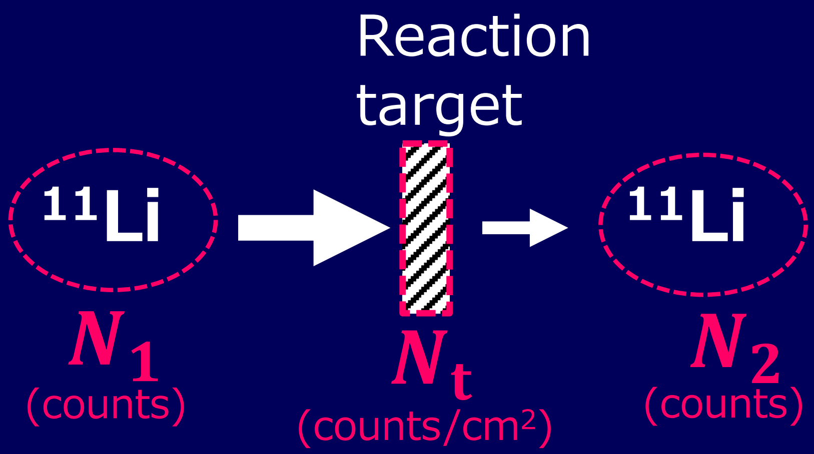
N_1: The number of incident nuclei

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

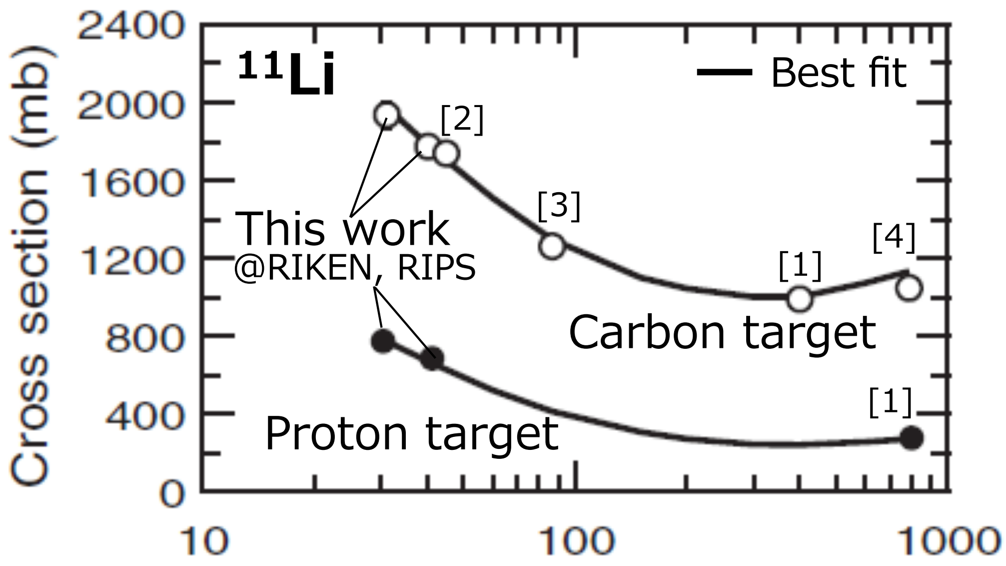
Γ_{out}: Γ for a target-out measurement



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

σ_R of ^{11}Li

T. Moriguchi et al., PRC88, 024610 (2013).

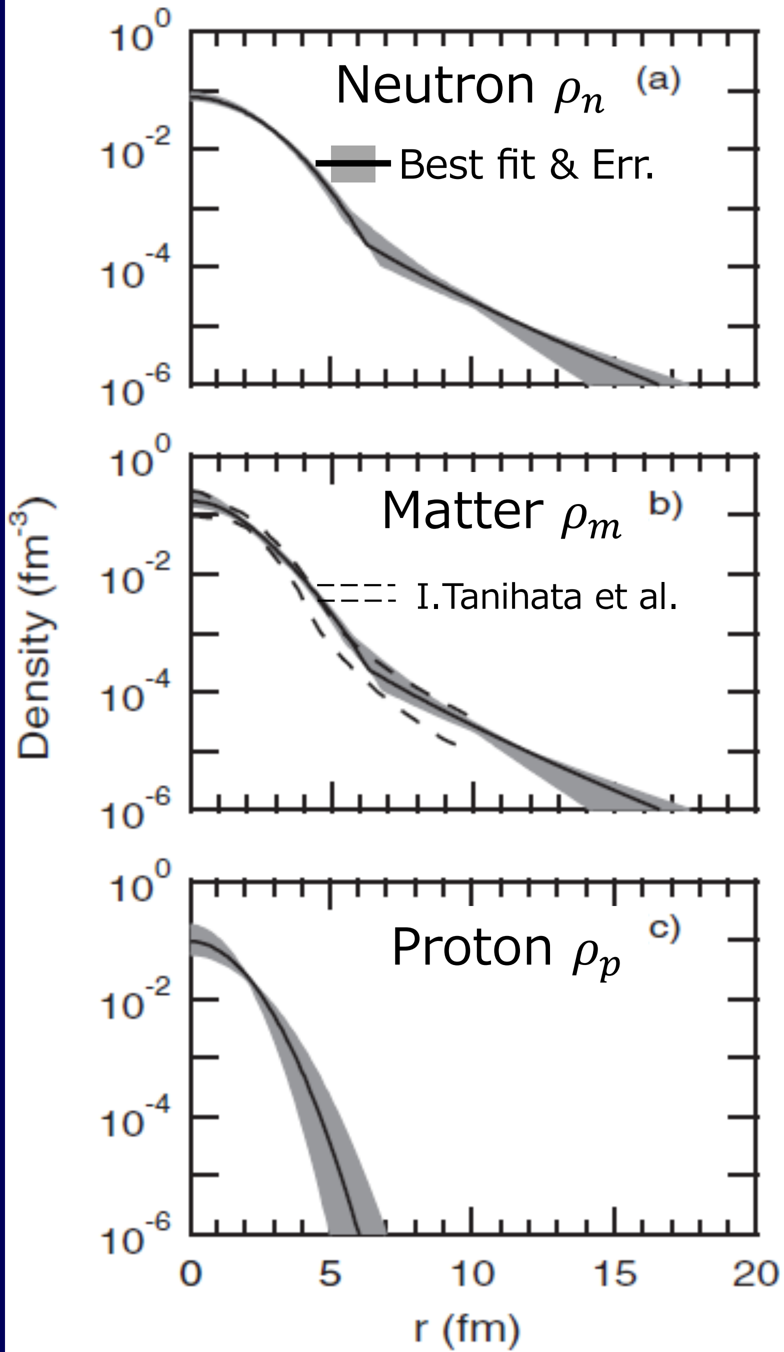


[1] I.Tanihata et al., PLB, 287, 307 (1992).
[2] N.Inabe et al., RIKEN APR, 24, 9 (1991).
[3] B.Blank et al., NPA, 555, 408 (1993).
[4] I.Tanihata et al., PLB, 206, 592 (1988).

- Assumed density functions
  - ρ_p : Gaussian
  - ρ_n : Gaussian + tail

  Free parameters
  - Gaussian width of ρ_p : a_p
  - Gaussian width of ρ_n : a_n
  - Slope of the tail : λ
  - Tail amplitude : (X_n/Y_n)

- Solid lines are the best-fit curves obtained from the Glauber model calculation.



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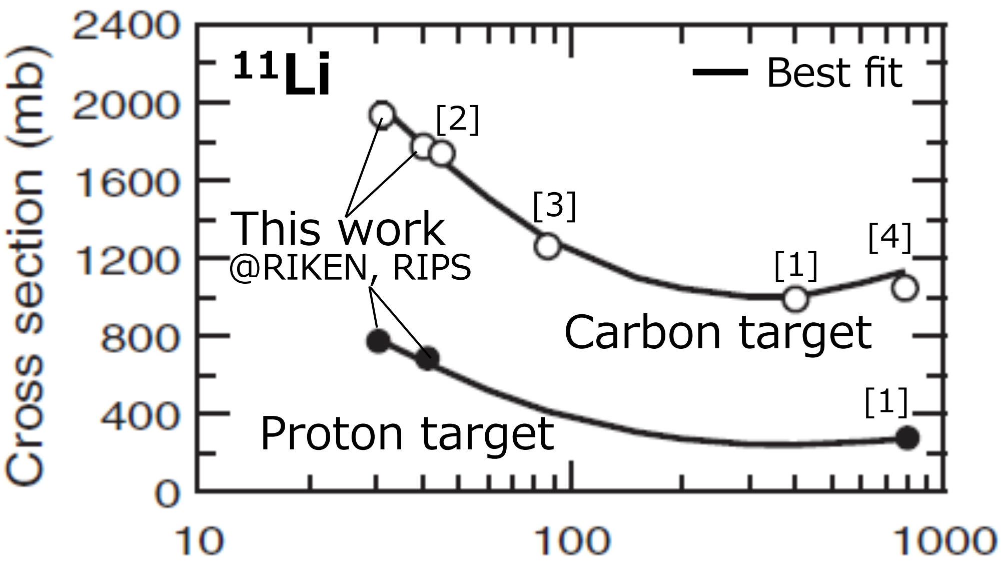

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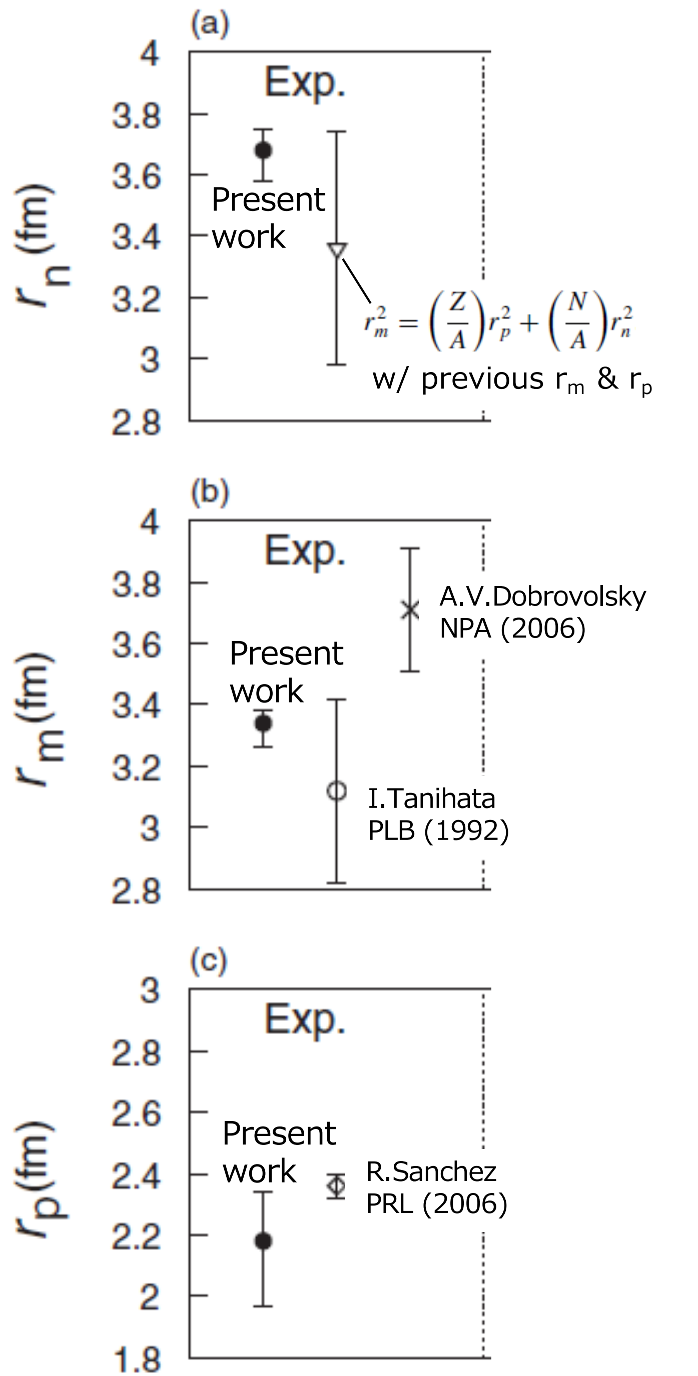
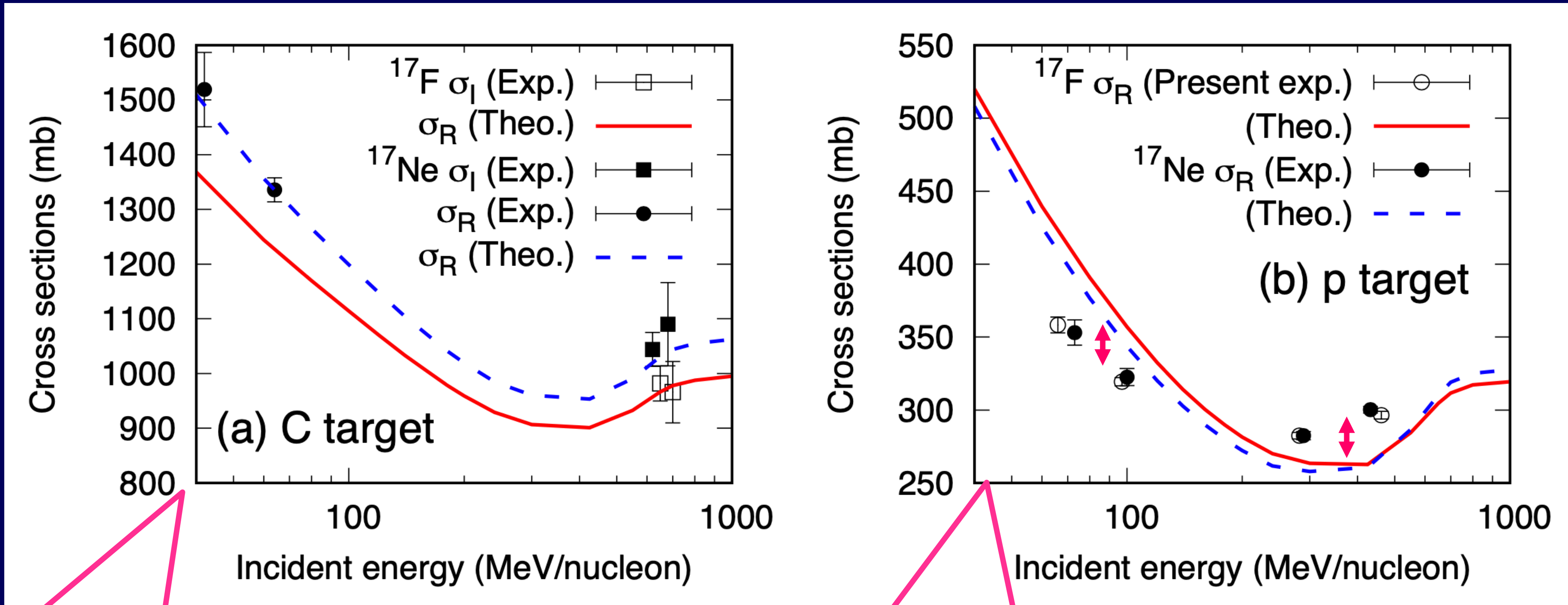


σ_R for ^{17}F and ^{17}Ne

Two-proton halo

Target dependence

T. Moriguchi et al., PCR110(2024)014607.



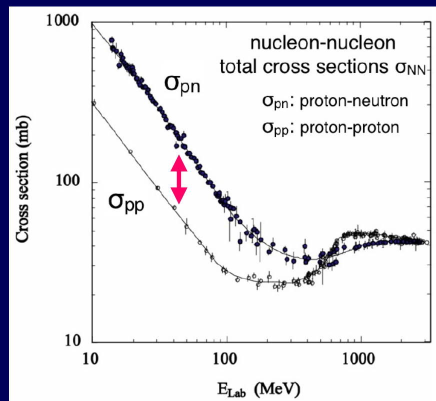
$\sigma_R(^{17}\mathrm{F}) < \sigma_R(^{17}\mathrm{Ne})$

⇨ The spatial spread of a density distribution of nucleus.

$\sigma_R(^{17}\mathrm{F}) \geq \sigma_R(^{17}\mathrm{Ne})$

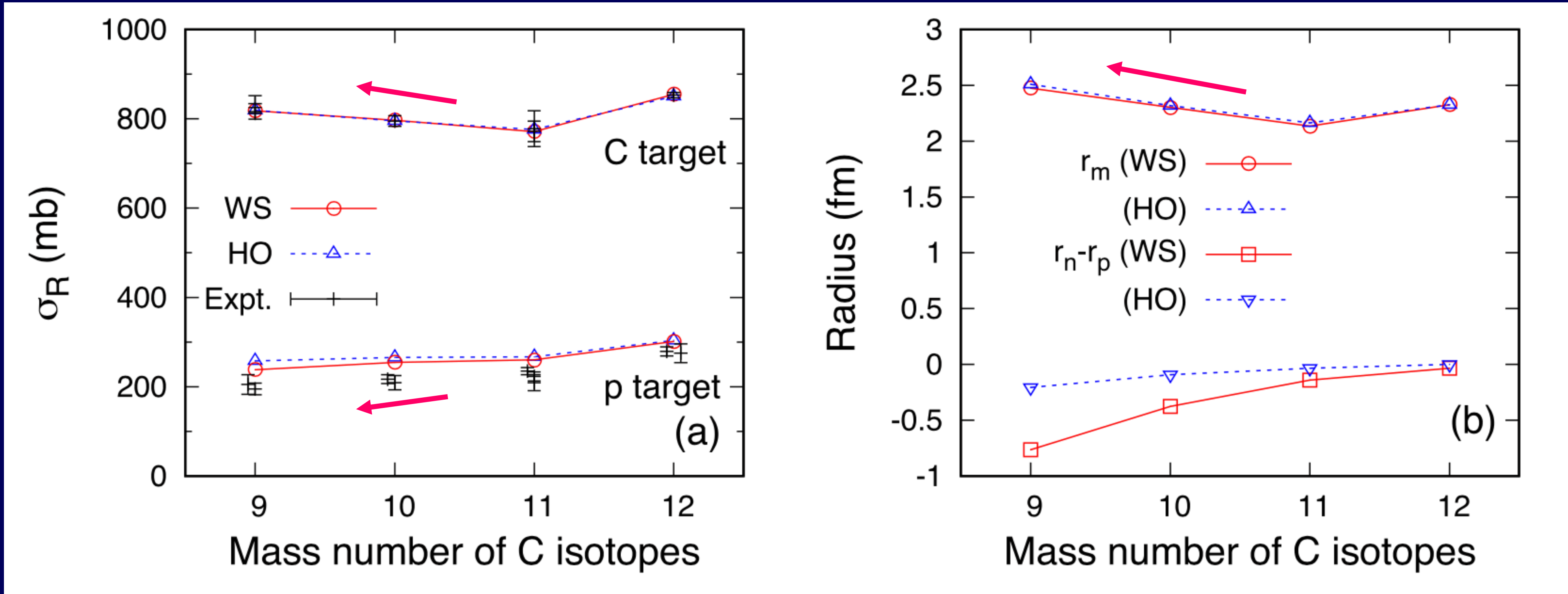
⇨ Isospin asymmetry of σ_{NN}

	^{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 & radii toward proton dripline

[K. Makiguchi, W. Horiuchi, PTEP2022, 073D01.]



<u>Toward proton dripline</u>

σ_R on C target : Reflects the matter radius

σ_R on p target : Low contribution of σ_{pn} due to small neutron number

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

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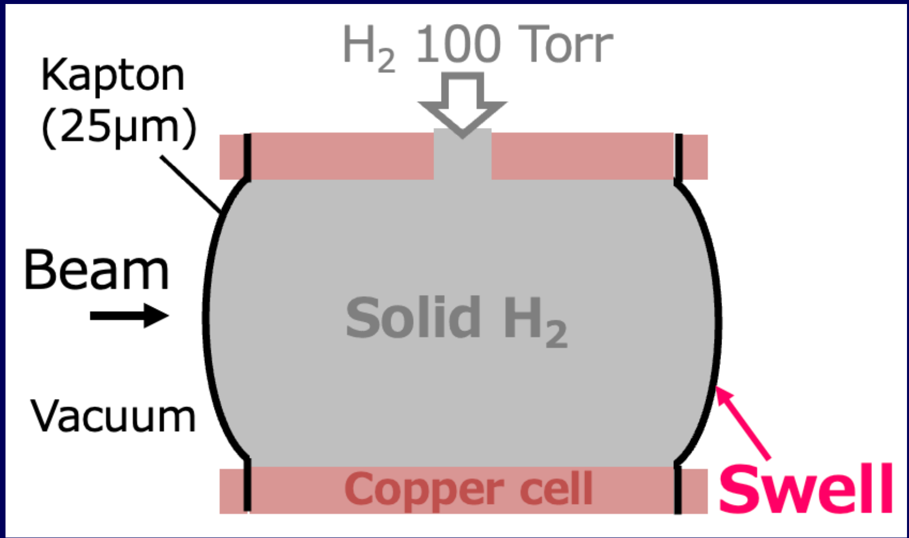
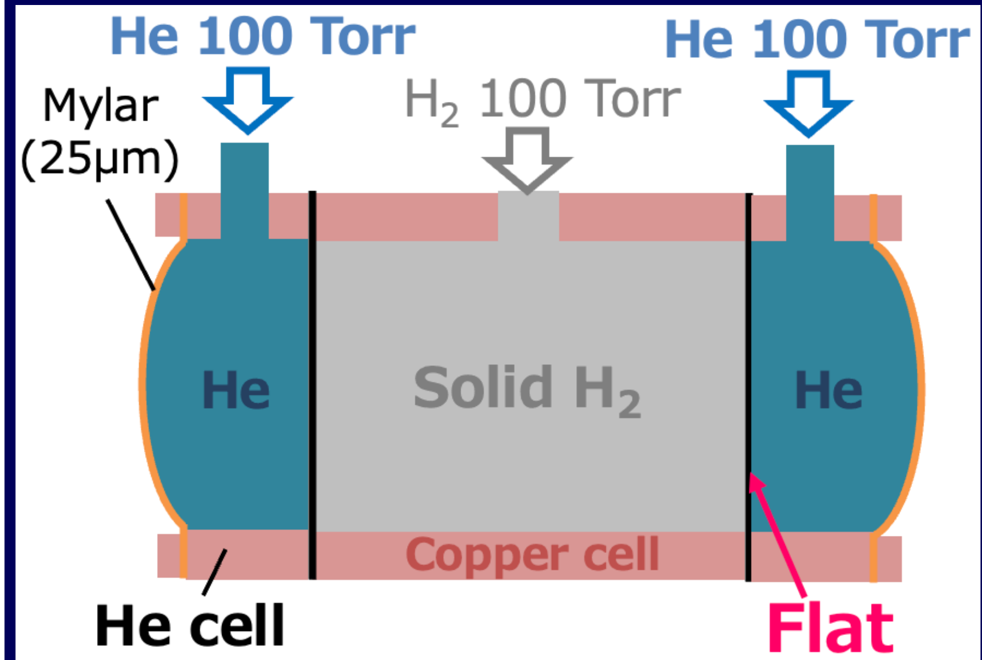
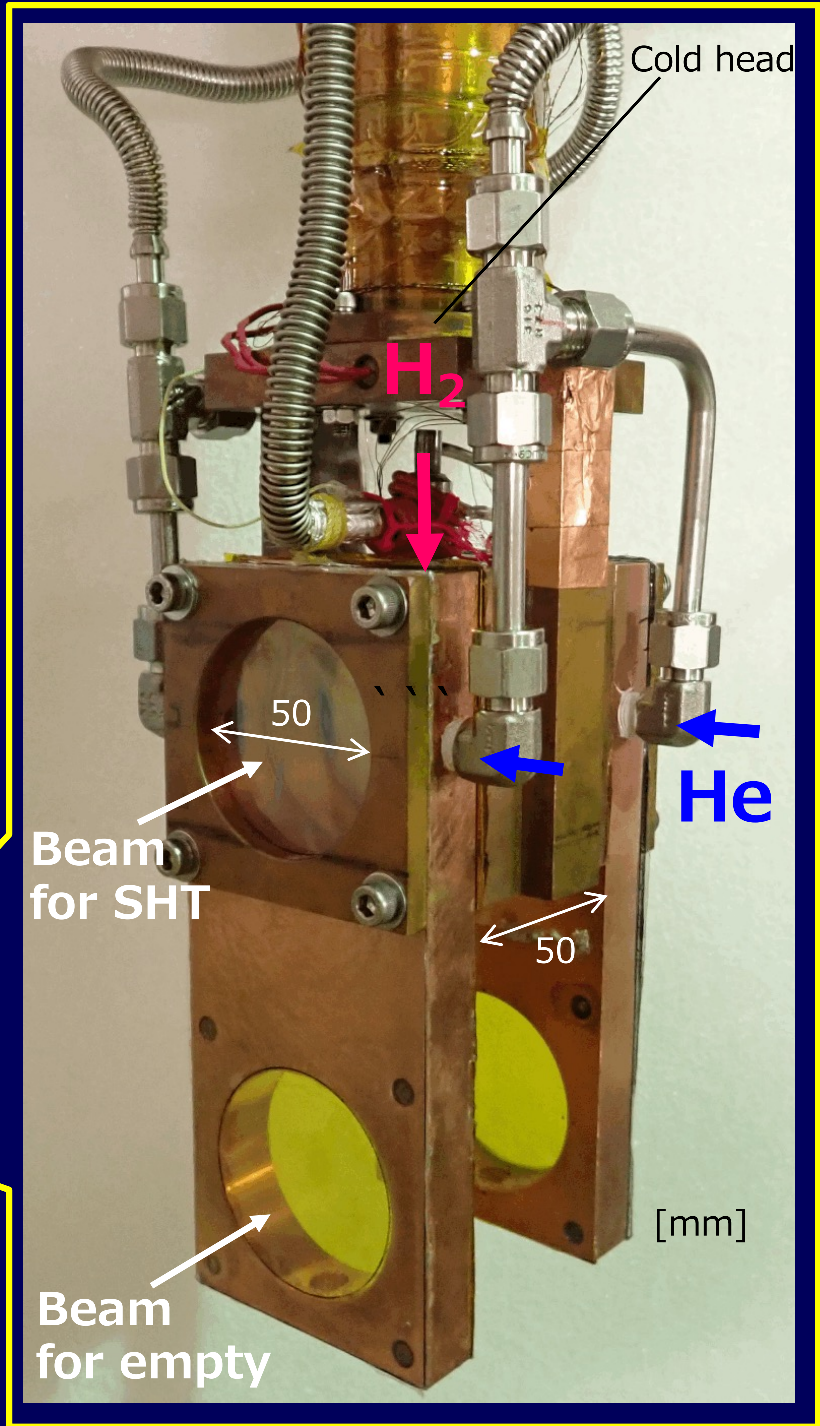
Previous cell

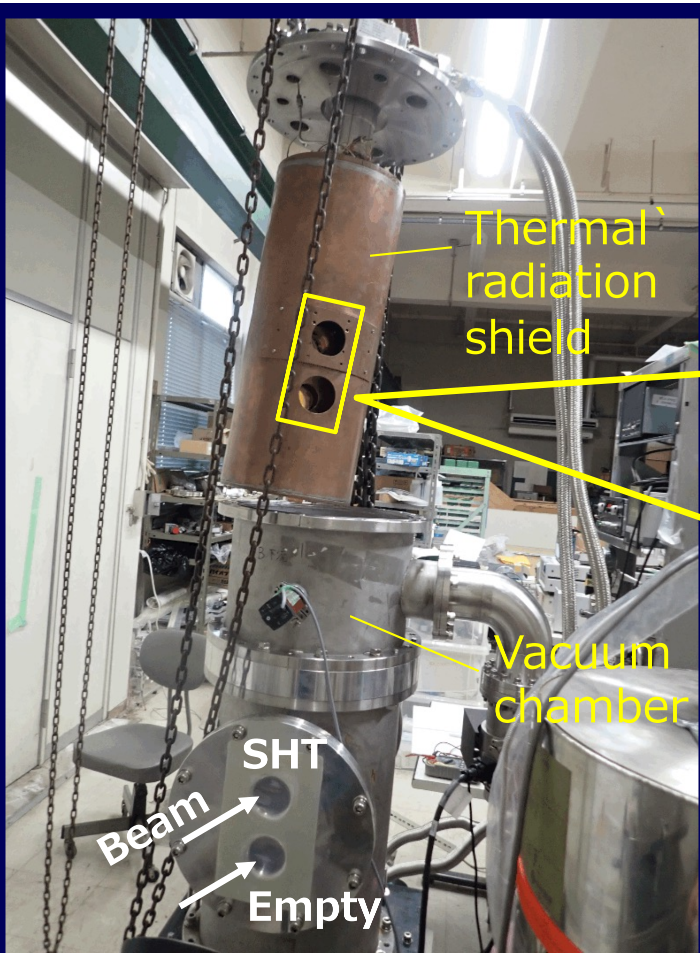
Thickness of SHT depends on the position.

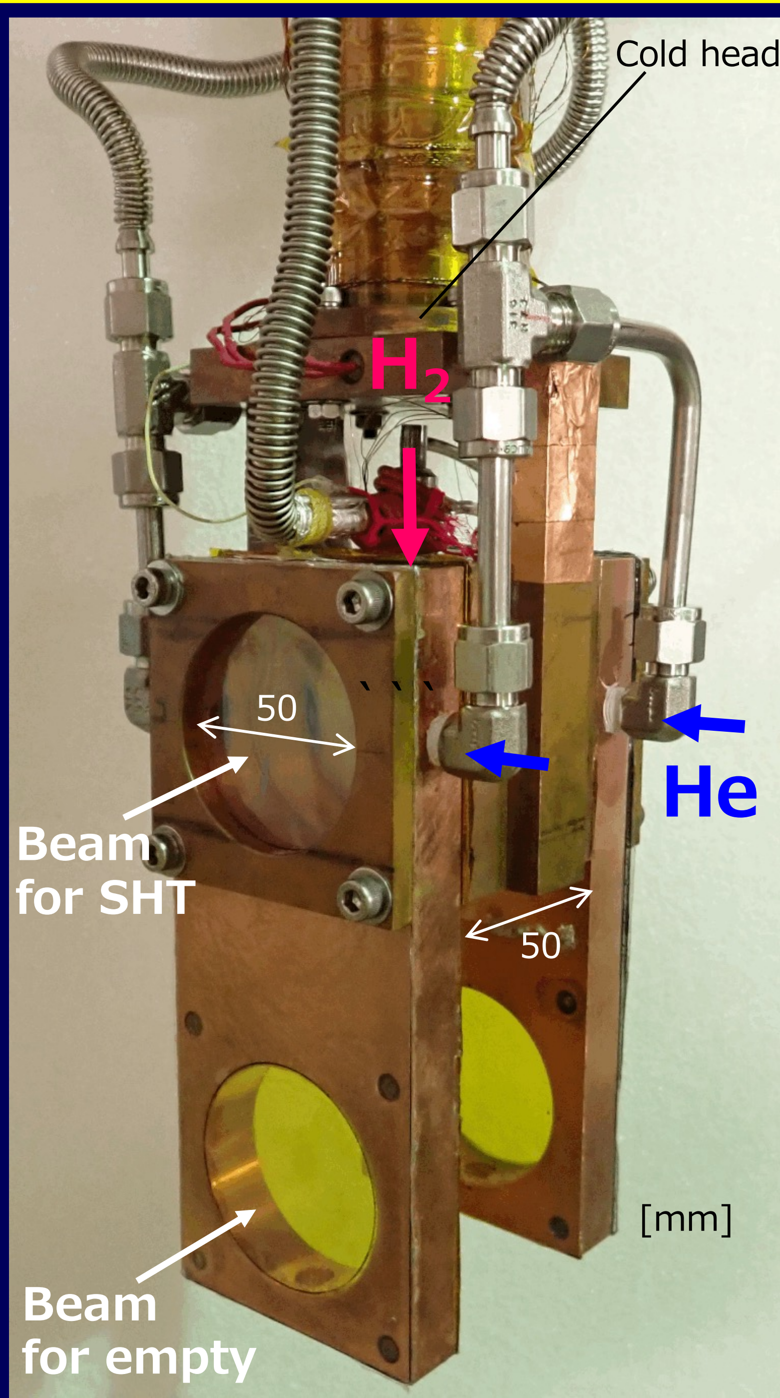


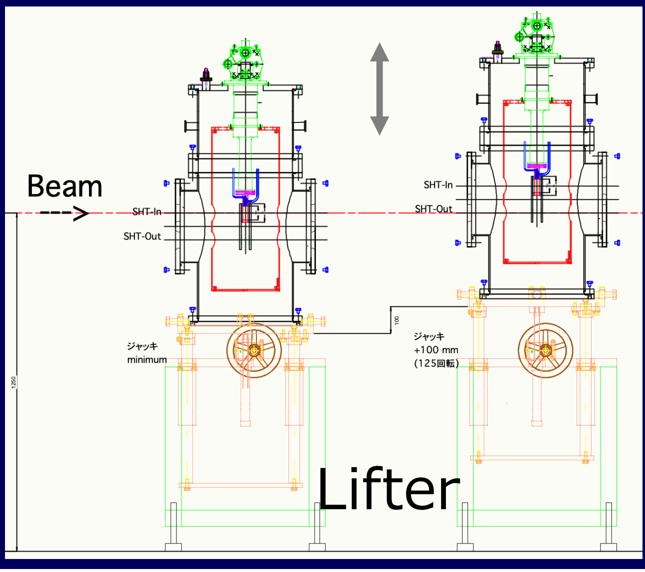
Present cell







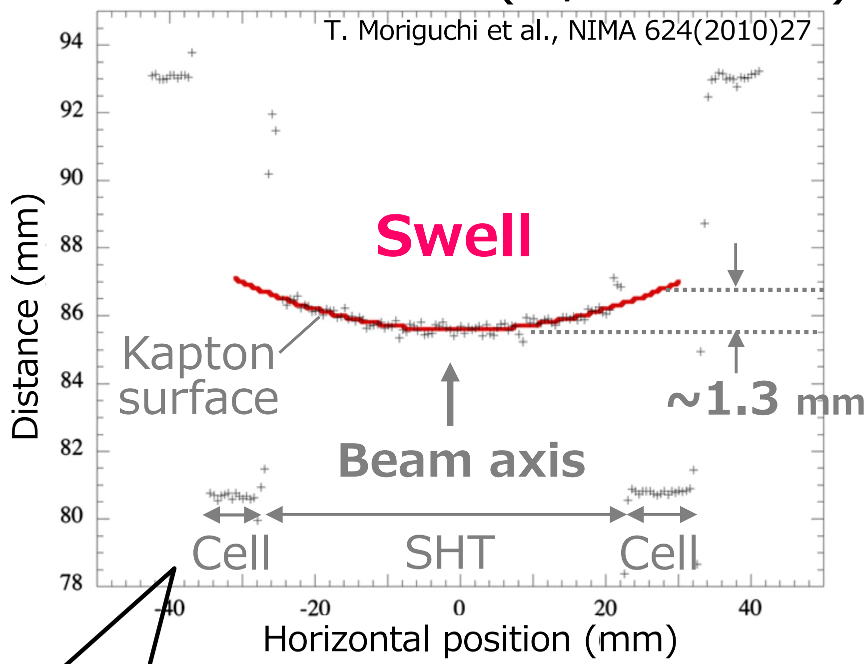


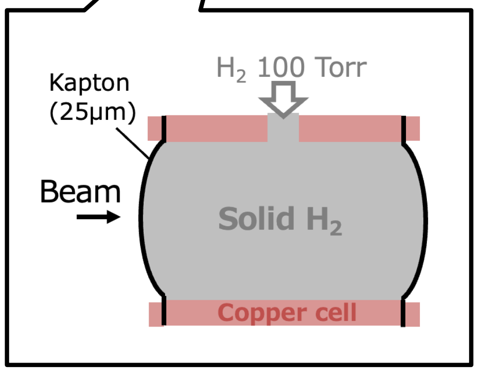


SHT and empty runs can be switched by lifting (lowering) of the chamber.

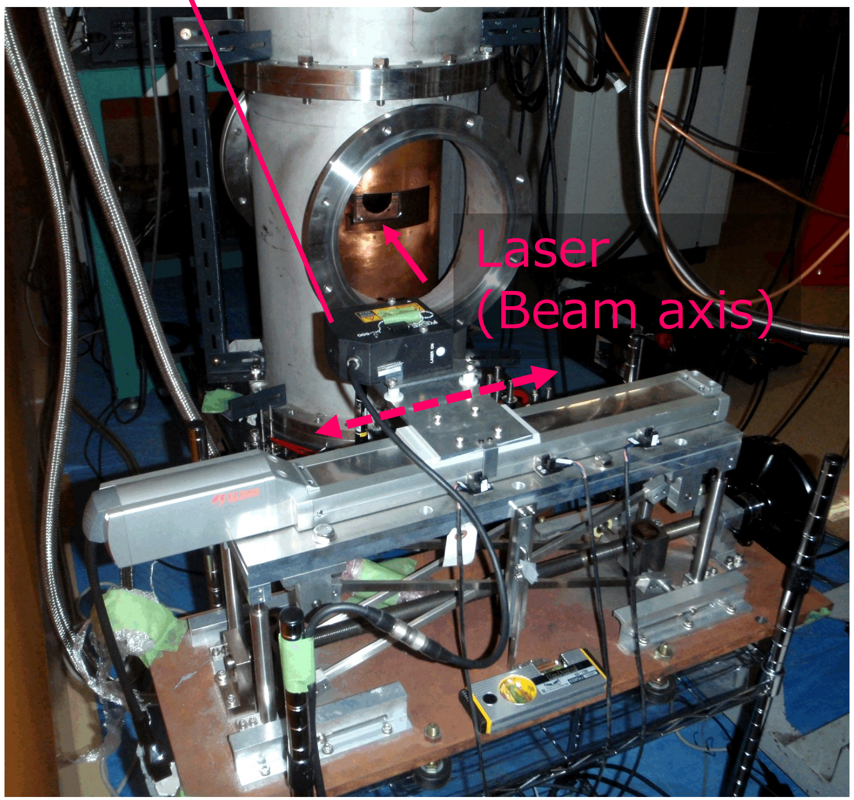
Shape of Kapton surface measured by a laser distance meter

Previous SHT (w/o He cell)

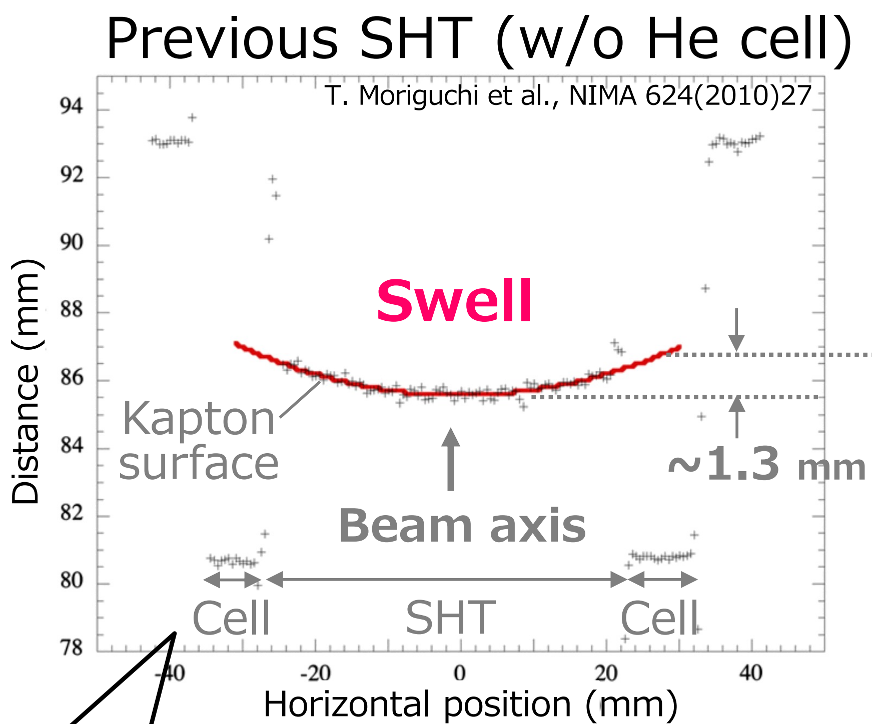


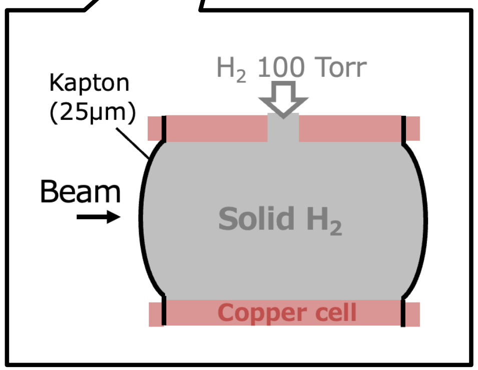


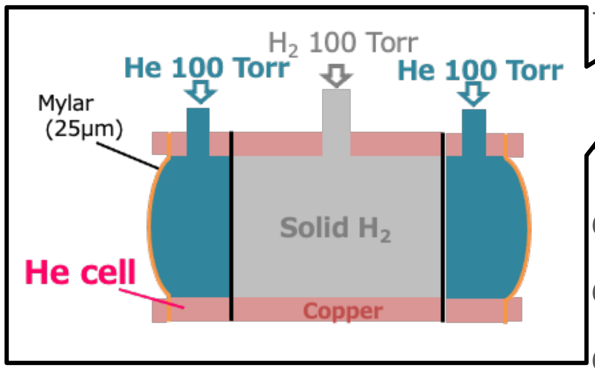
Laser distance meter (Keyence, LK500)

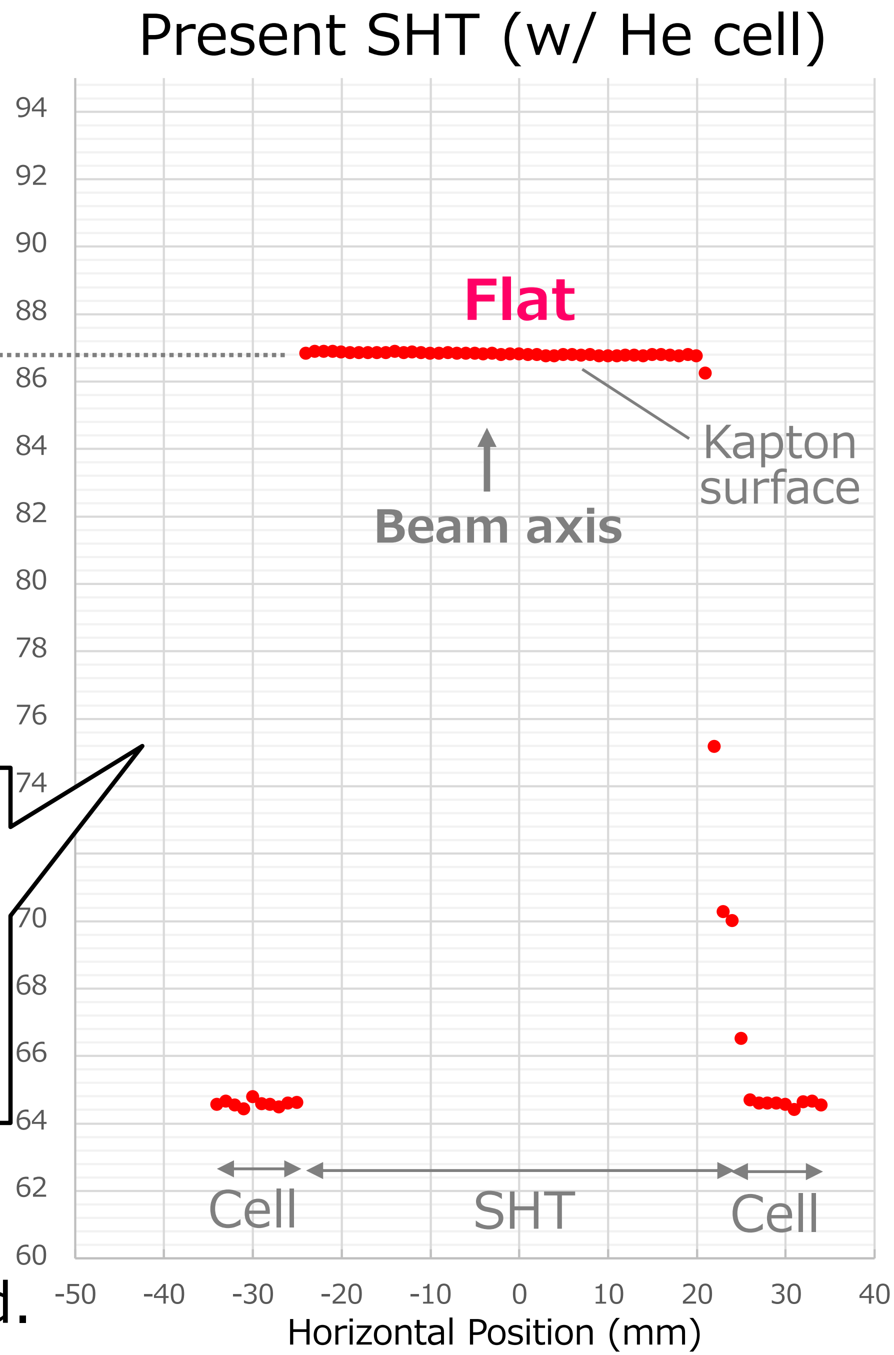


Shape of Kapton surface measured by a laser distance meter





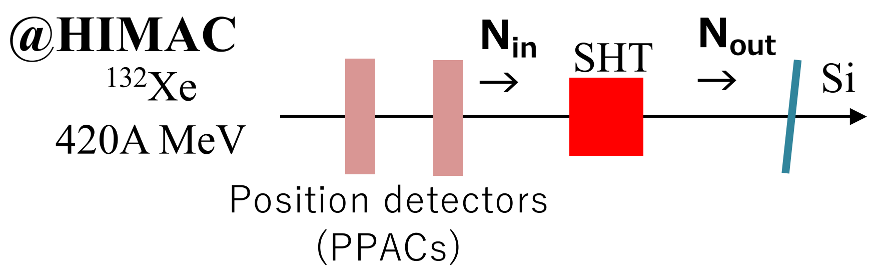




Swell of Kapton is successfully suppressed.

Online test for thickness of SHT

Thickness $\propto$ Reaction rate

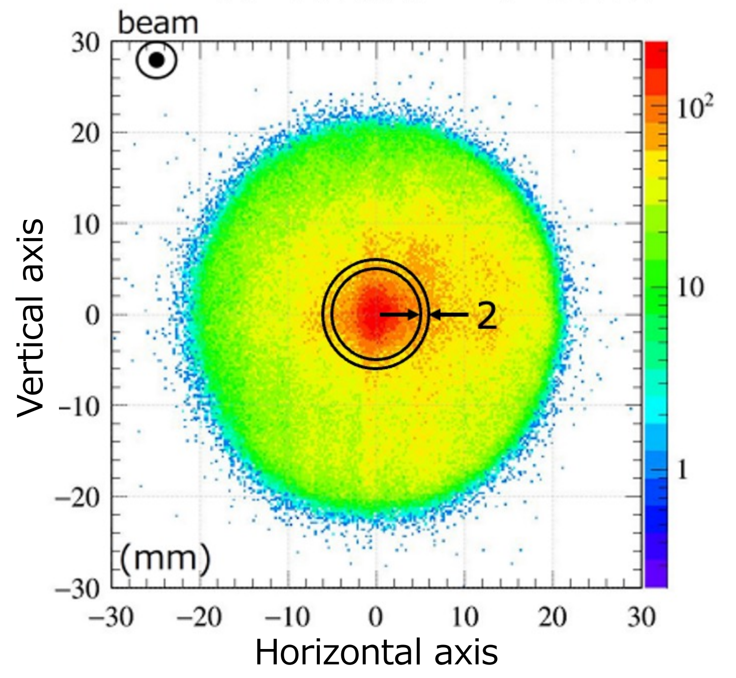


Reaction rate $= N_{out}/N_{in}$

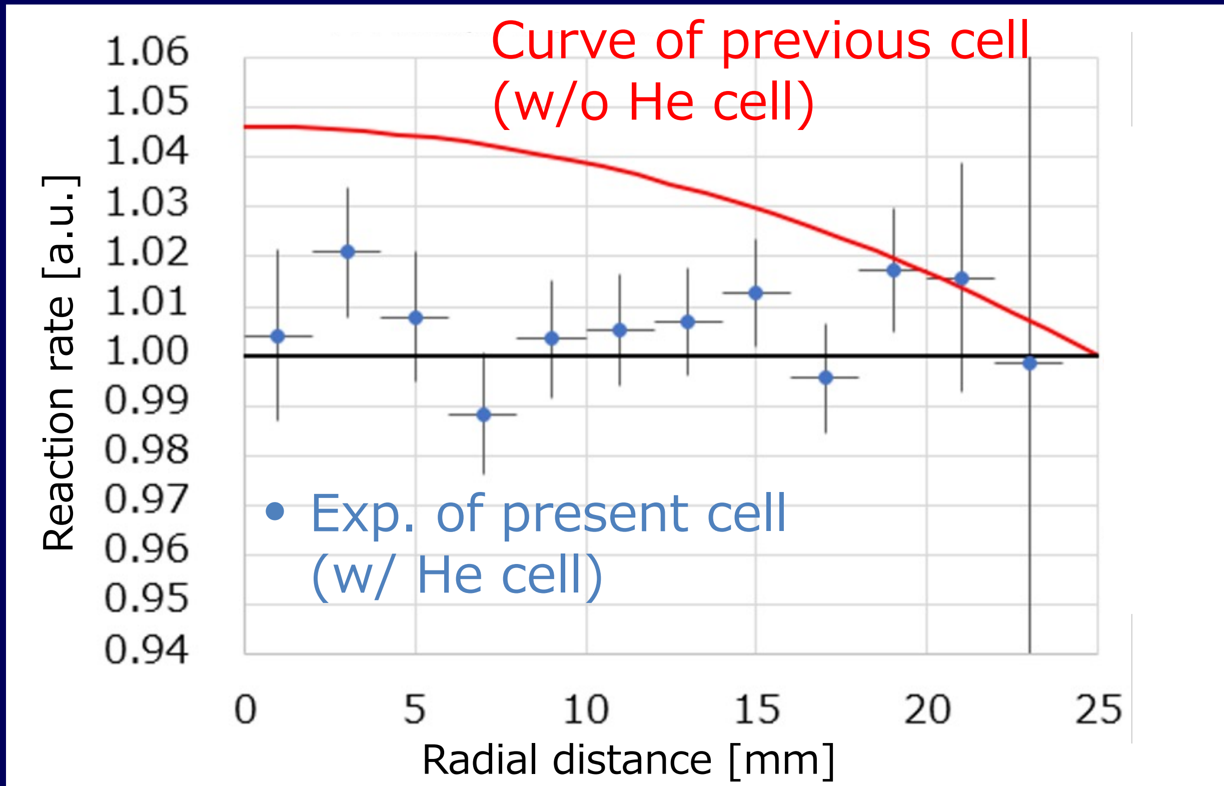
N_{in} : Number of ^{132}Xe before SHT

N_{out} : Number of Xe isotopes after SHT

Beam profile @ SHT



Reaction rate



Confirmed no swell on the surface of the SHT

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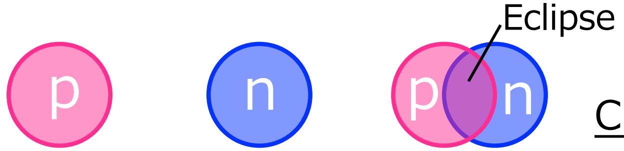
Deuteron target for σ_R

"Nucleus - proton" &
"Nucleus - neutron"

Eclipse effect of proton & neutron in deuteron



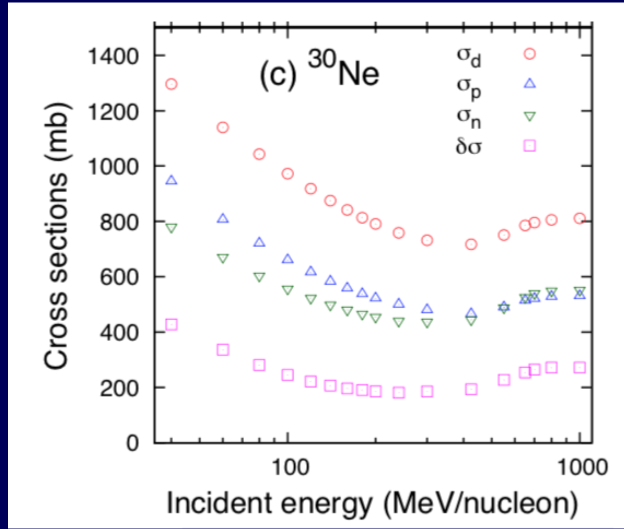
$$\delta\sigma = \sigma_p + \sigma_n - \sigma_d$$

Theory, Exp., **Ext.**, Exp.

Cross section σ

- σ_p Nucleus - proton
- σ_n Nucleus - neutron
- σ_d Nucleus - deuteron
- $\delta\sigma$ Defect

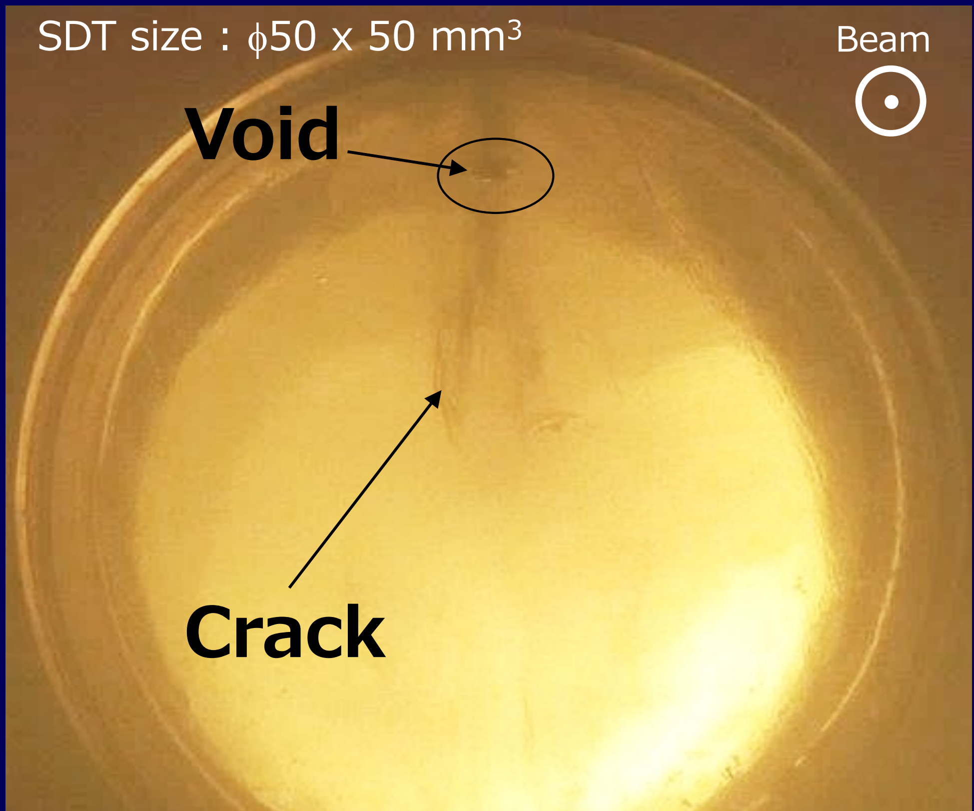
W. Horiuchi et al., PRC102, 054601 (2020).



- σ_R measurements on proton and deuteron targets
  - ⇨ Extracting σ_R on a neutron target
  - ⇨ Unambiguous way to determine the neutron and proton radii of unstable nuclei
- Difficulty of preparation for a deuteron target
  - CD_2 : Expensive
  - D_2 gas : Complicated operation ⇨ Application of SHT for Solid Deuterium Target (SDT)

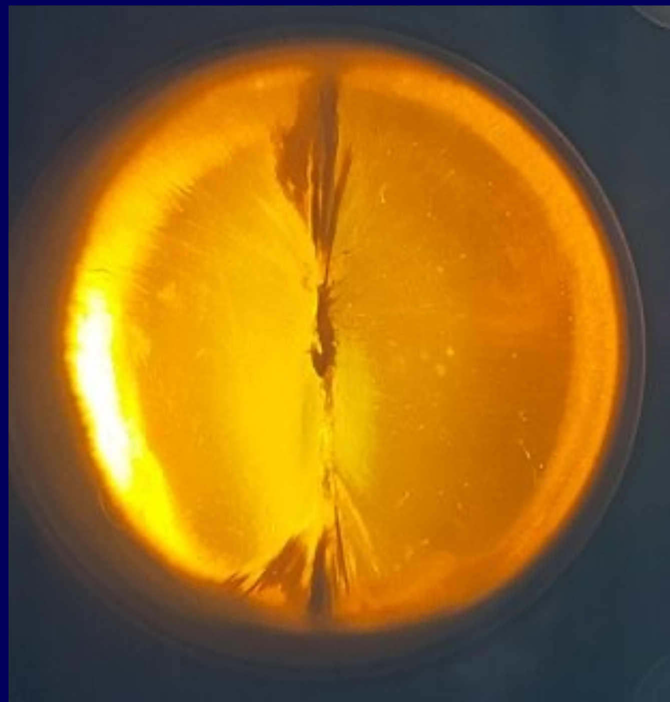
Development of solid deuterium target (SDT)

- Our SHT system can be used for the SDT.
- For the SDT without cracks and voids, we should control below.
  - ☐ Temperature of the cell
  - ☐ Supply pressure of D_2 gas



Typical SDT
(15 K, 170 Torr)

SDT made under the same condition of SHT(4 K, 100 Torr)



Optimization for the best SDT is currently in progress.

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Summary

- We have developed and operated a large-volume solid hydrogen target (SHT) for σ_R measurements.

  For ^{11}Li :

  Separation of proton and neutron density distributions

  For ^{17}F, ^{17}Ne :

  Contribution of isospin asymmetry of nucleon-nucleon total cross section

- We are developing the target system.

  ✓ Suppressing the swell of the surface of the SHT

  ✓ Optimizing the making condition for a solid deuterium target

- We will measure σ_R for unstable nuclei using proton and deuteron targets to investigate nuclear size properties (radii, density distribution, halo, skin..).