Interaction cross section of two-neutron halo nucleus ^{22}C at 235 MeV/nucleon

Y. Togano et al., Phys. Lett. B **761**, 412 (2016).

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Contents

- Introduction: halo nucleus and matter radius
- Procedure: interaction cross section → radius
- Experiment: SAMURAI
- Results on ^{19}C, ^{20}C, and ^{22}C
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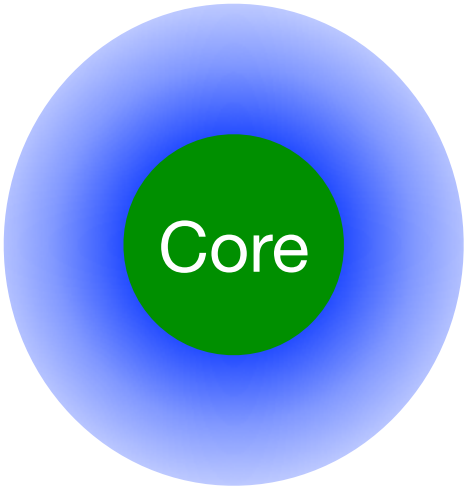
Halo nucleus



Extended matter distribution

Tunneling of neutron(s)

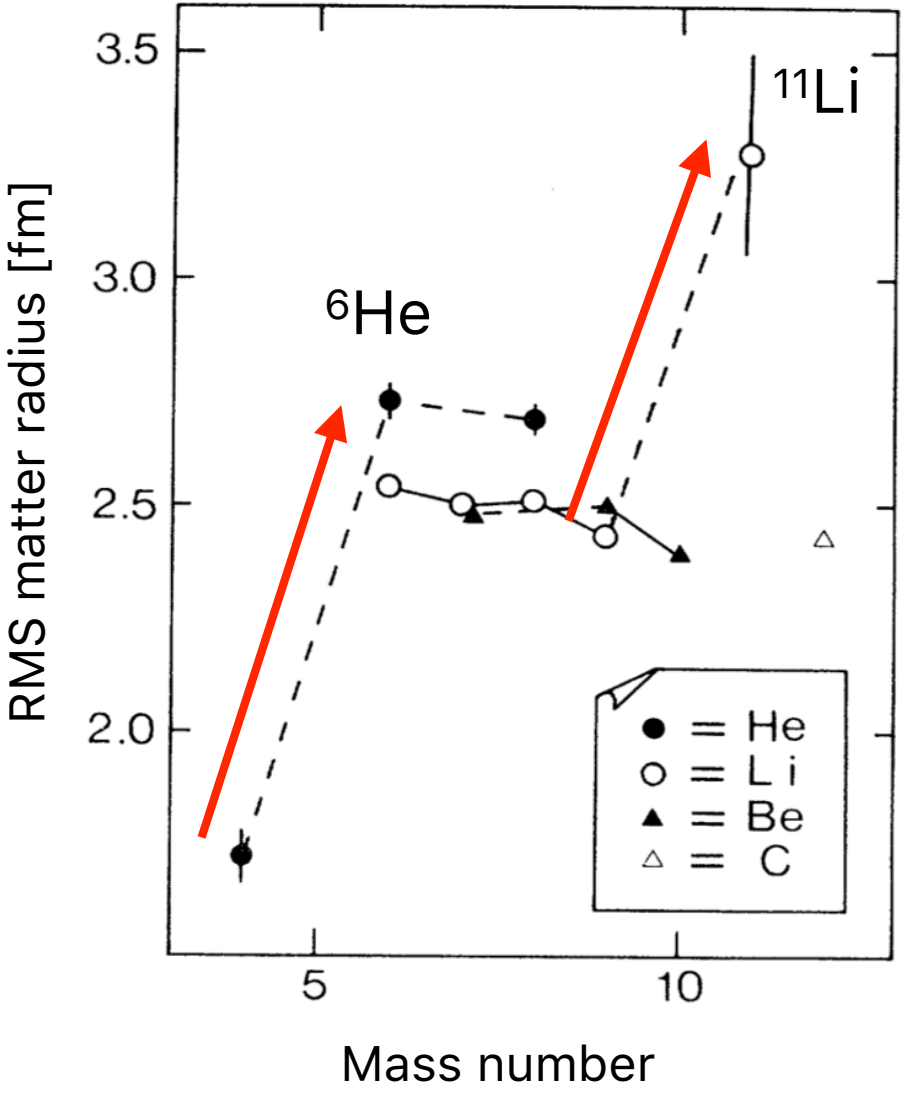
Low *L* of valence neutron(s)

L= 0 or 1

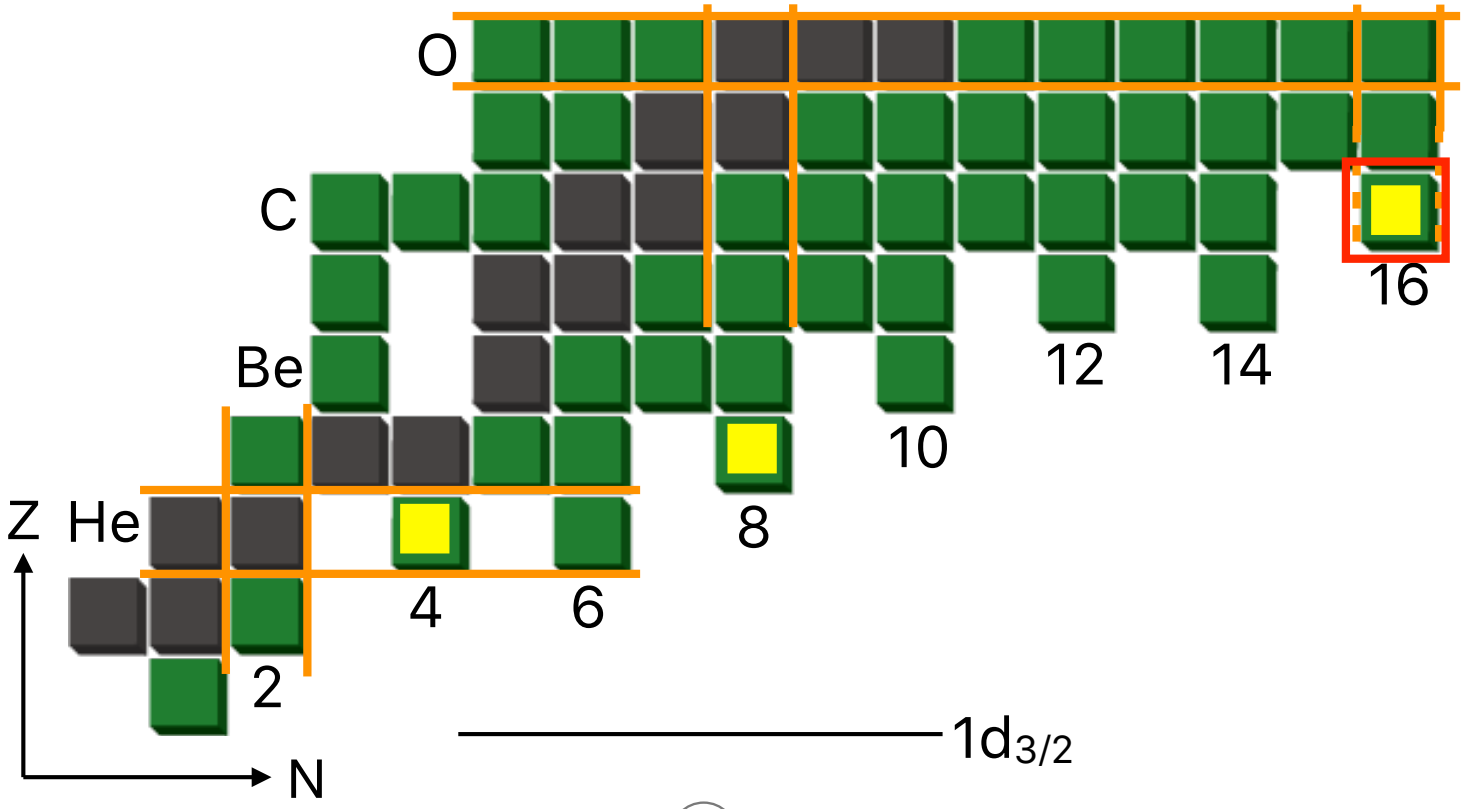
Low neutron separation energy

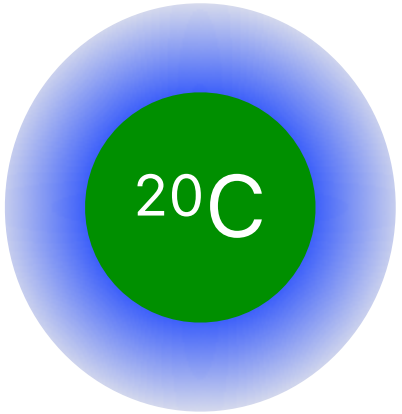
S_n < 1 MeV

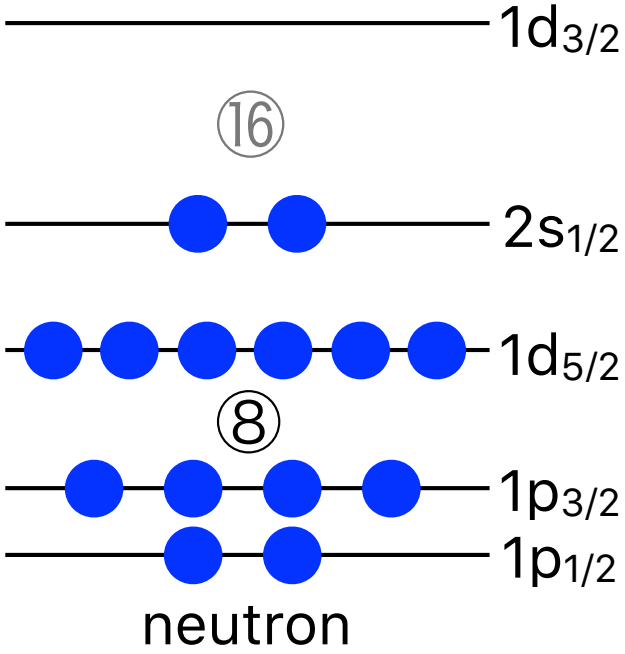
I. Tanihata et al., PRL 55, 2676 (1985).



Two-neutron halo nucleus ^{22}C







Valence neutrons: S wave

N. Kobayashi et al., PRC 86, 054604

S_{2n} = -0.14 ± 0.46 MeV

L. Gaudefroy et al., PRL 109, 202503

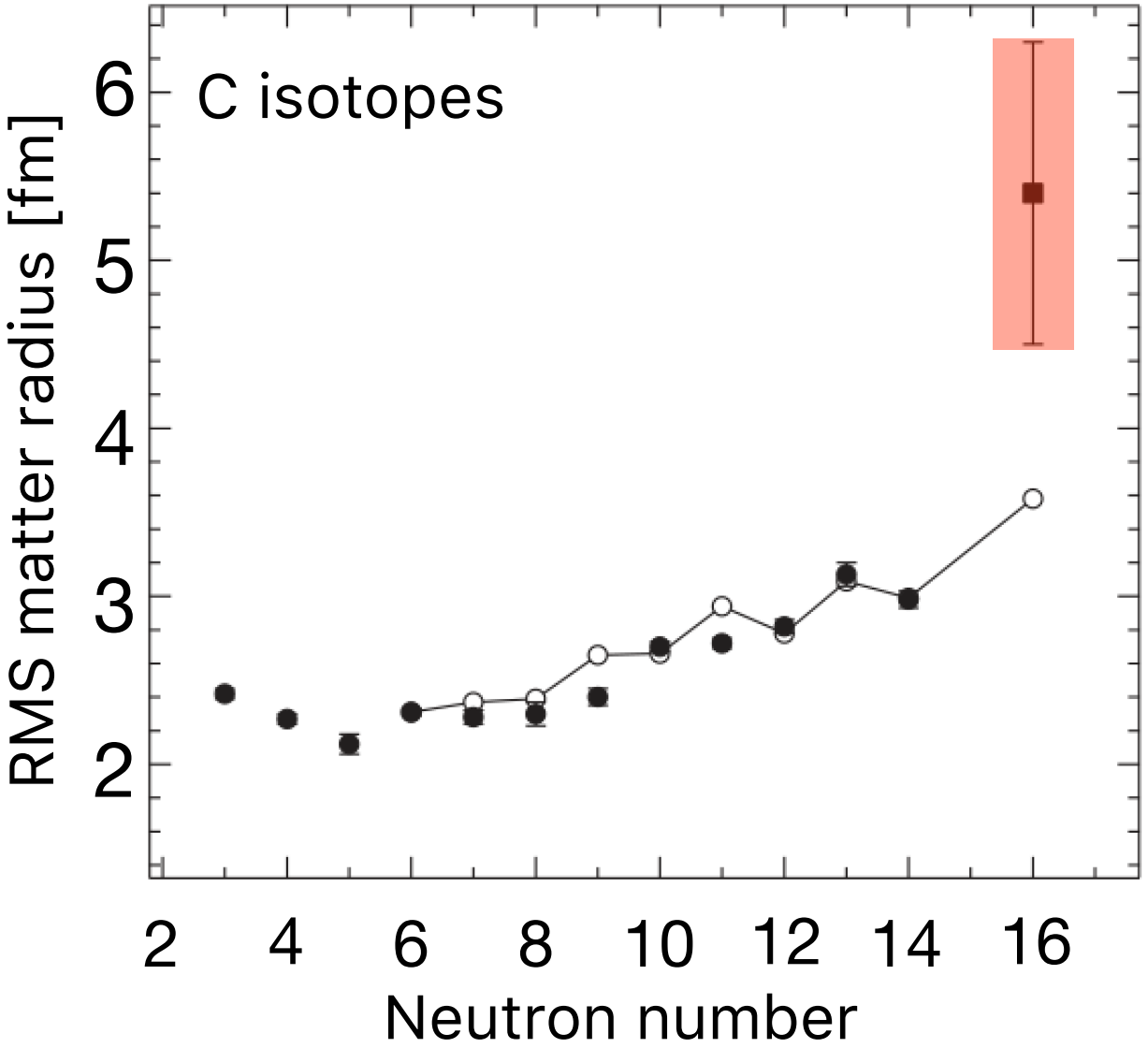
Matter radius studied by ^{22}C+*p*@40 *A*MeV

K. Tanaka et al., PRL104, 062701 (2010).

$$\sigma_R(^{22}\mathrm{C}) = 1.338(274)\ \mathrm{b}$$

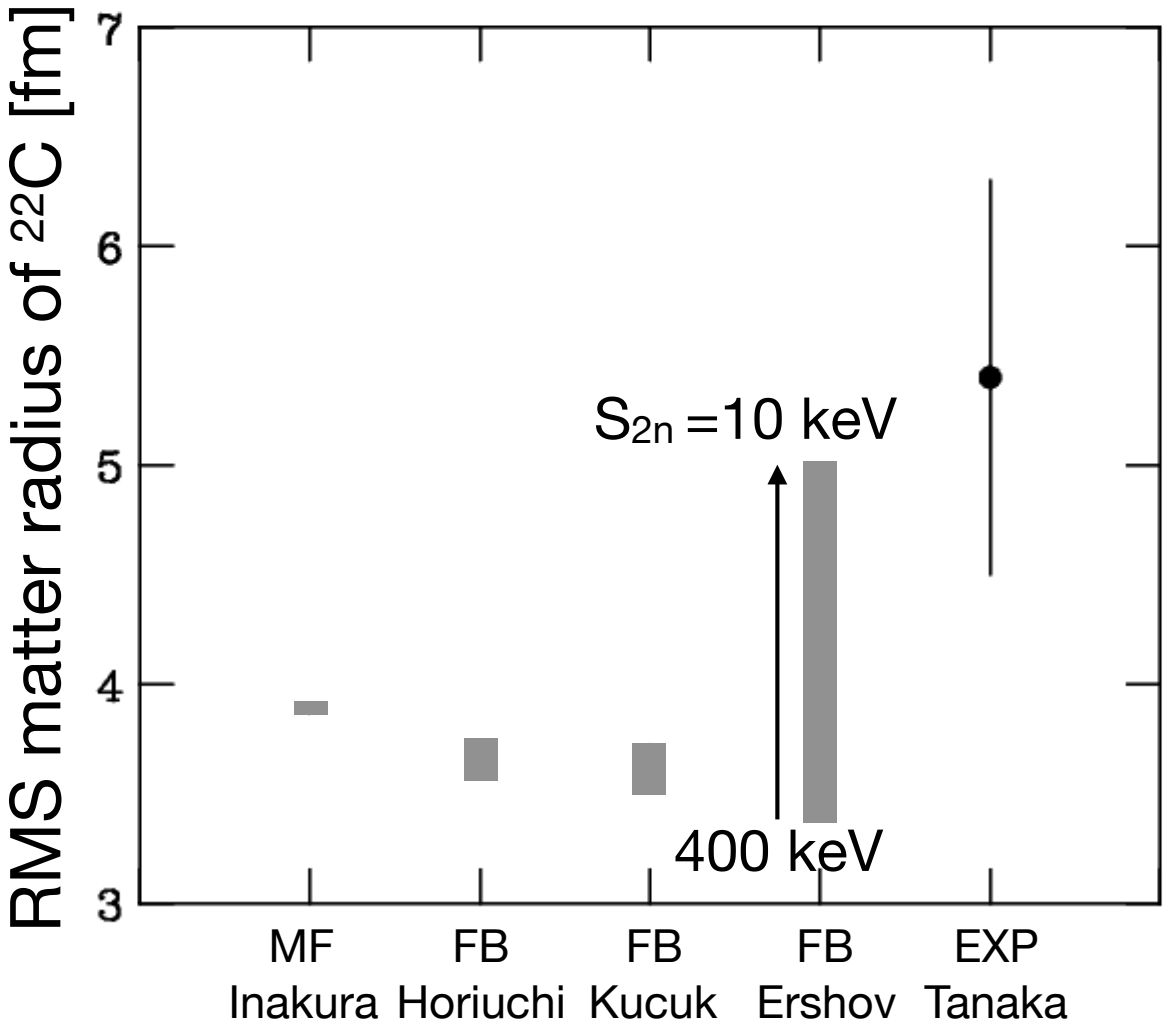
Glauber model

$$\sqrt{\langle r^2 \rangle} = 5.4(9)\ \mathrm{fm}$$



Comparison with theories

Large experimental error makes comparison difficult



T. Inakura et al., PRC 89, 064316 (2014).

W. Horiuchi et al., PRC 74, 034311 (2006).

Y. Kucuk et al., PRC 89, 034607 (2014).

S. N. Ershov et al., PRC 86, 034331 (2012).

Accurate ^{22}C radius data necessary

Precise interaction cross section of ^{22}C

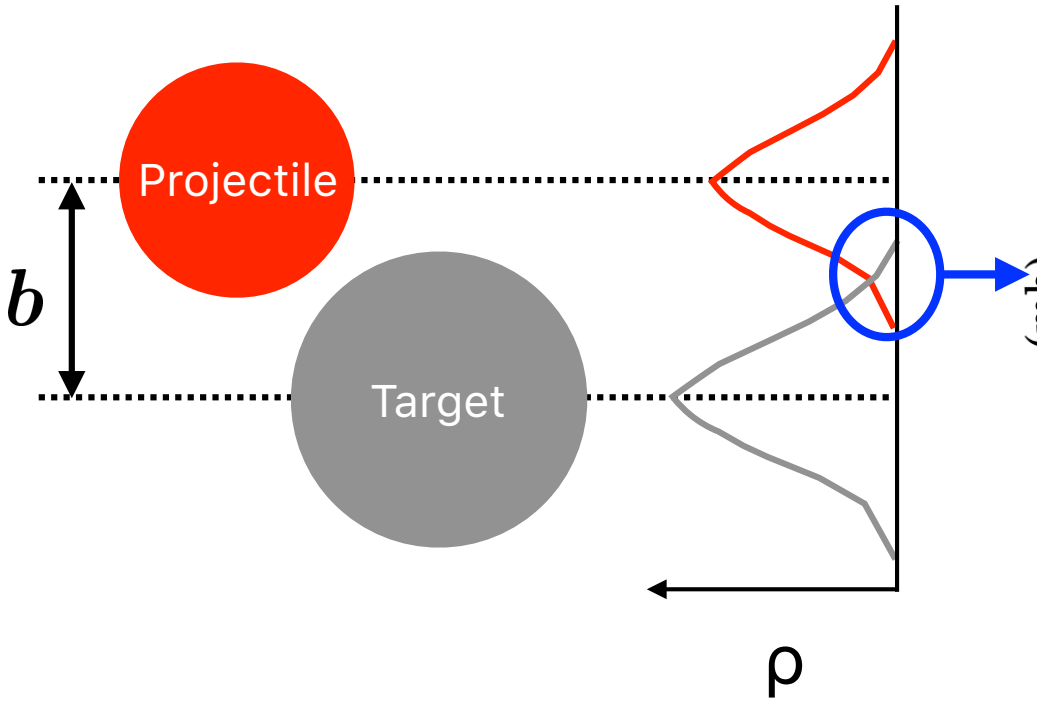
Matter radius and interaction cross section

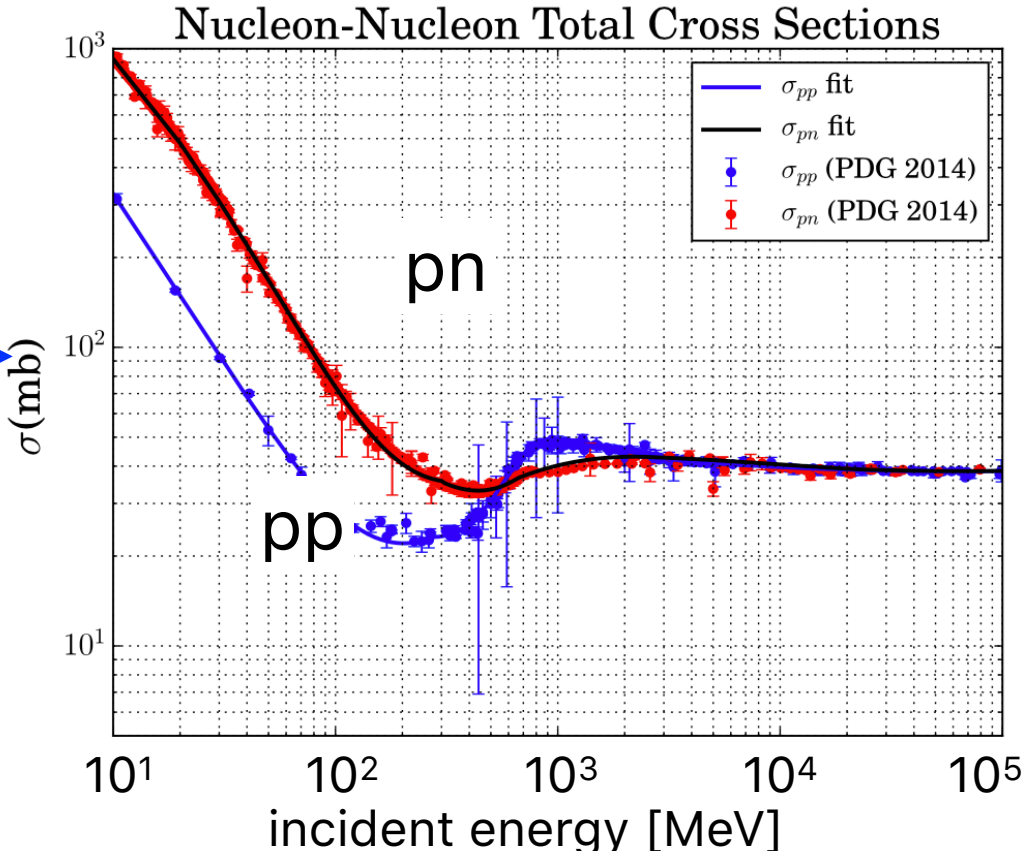
Reaction cross section: $\sigma_R = \sigma_{tot} - \sigma_{el}$

Interaction cross section: $\sigma_I = \sigma_R - \sigma_{inel} \quad \sigma_R \simeq \sigma_I$

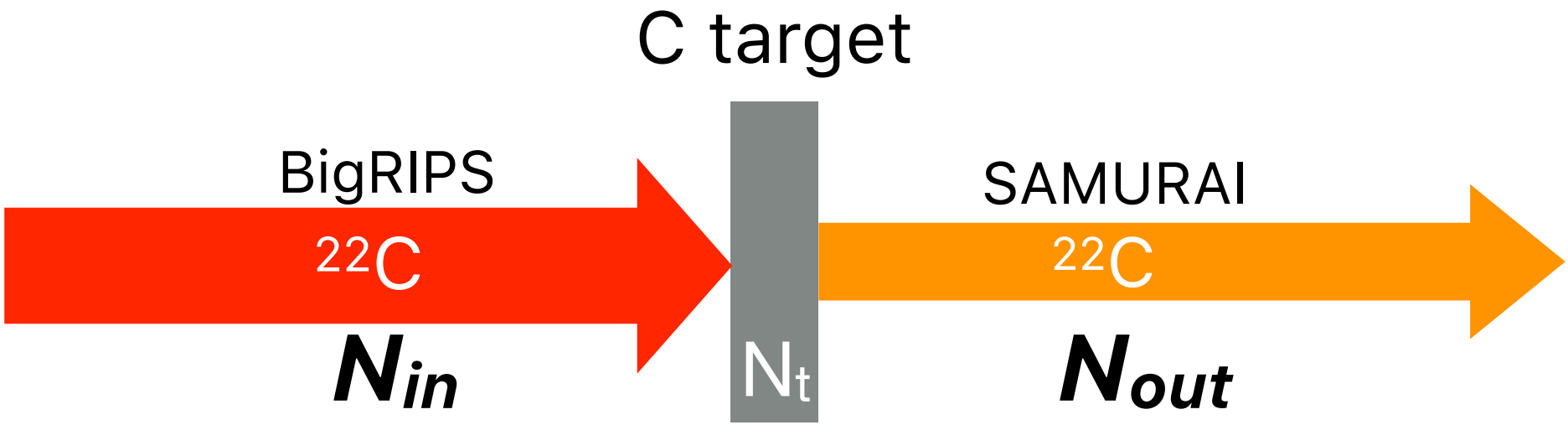
Glauber model

$$\sigma_R = \int d\boldsymbol{b} \left[1 - \exp\left(- \int d^2\boldsymbol{r} \sum_{i,j} \sigma_{NN} \rho_z^{Pi} \rho_z^{Tj} (\boldsymbol{r} - \boldsymbol{b}) \right) \right]$$





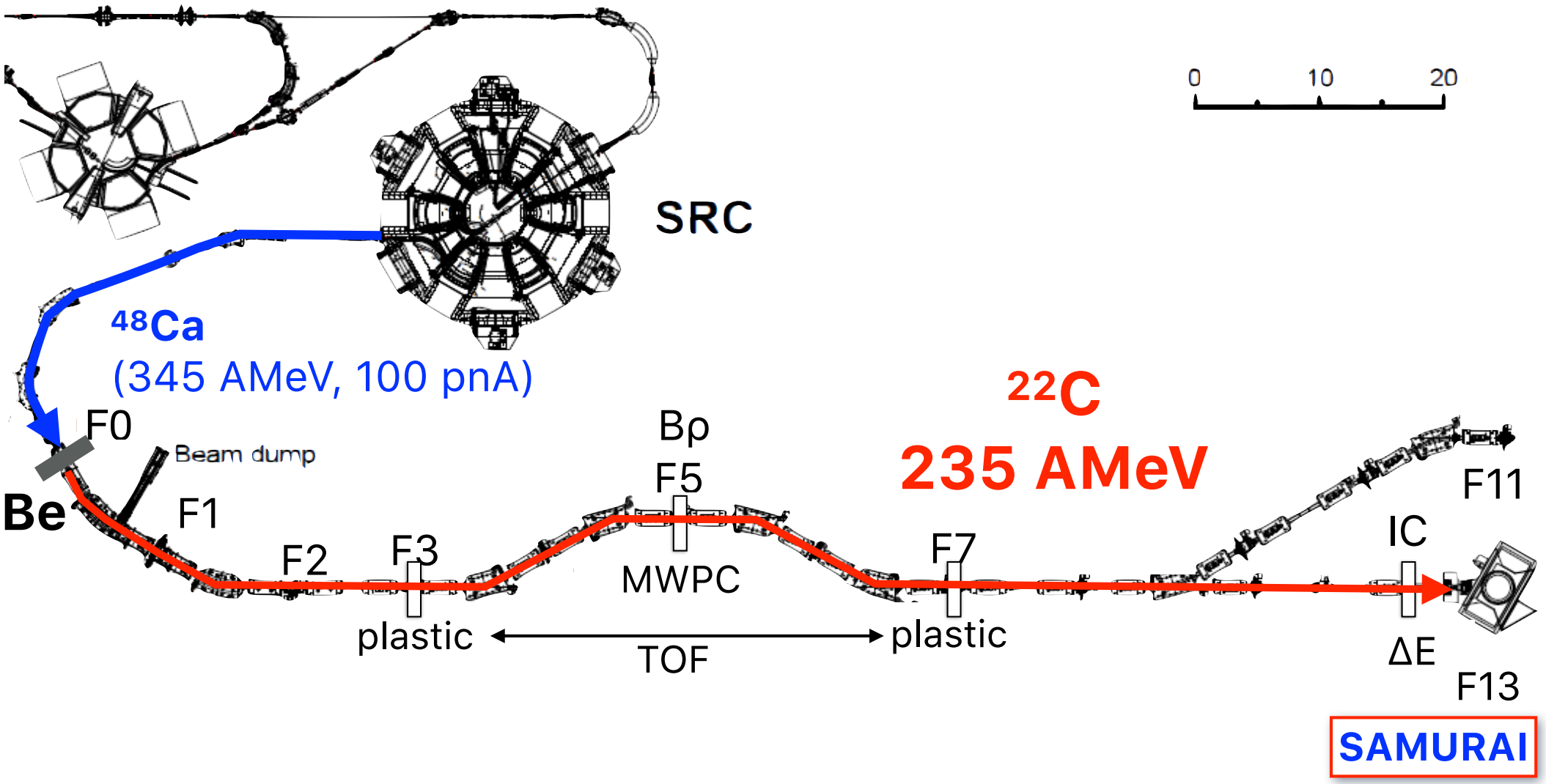
Procedure: Transmission method



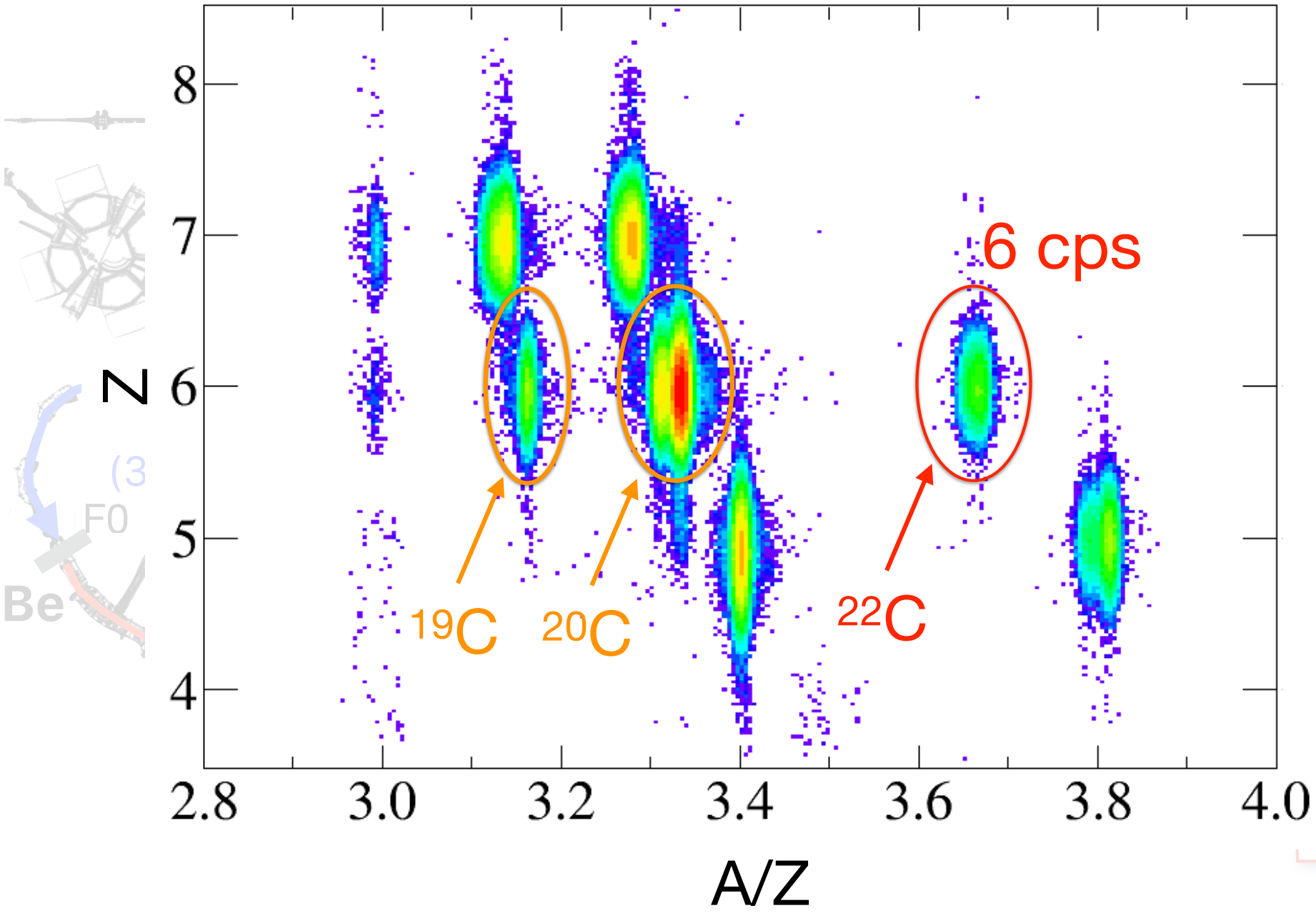
$$\sigma_I = -\frac{1}{N_t}\log\left(\frac{\Gamma}{\Gamma_0}\right) \qquad \Gamma = \frac{N_{out}}{N_{in}}$$

$\Gamma_0 : \Gamma$ without target: reaction in detectors

Experiment: BigRIPS

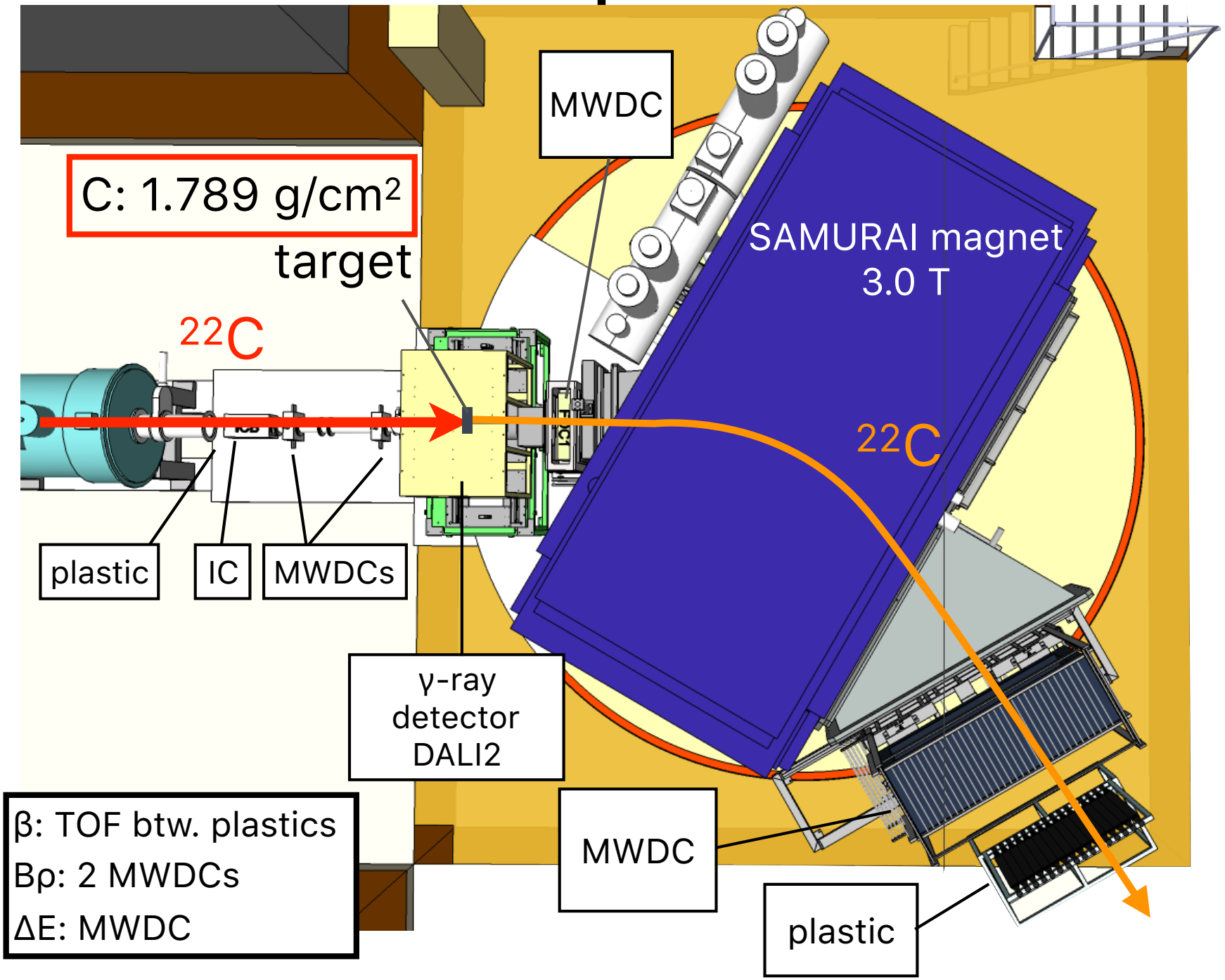


Experiment: BigRIPS

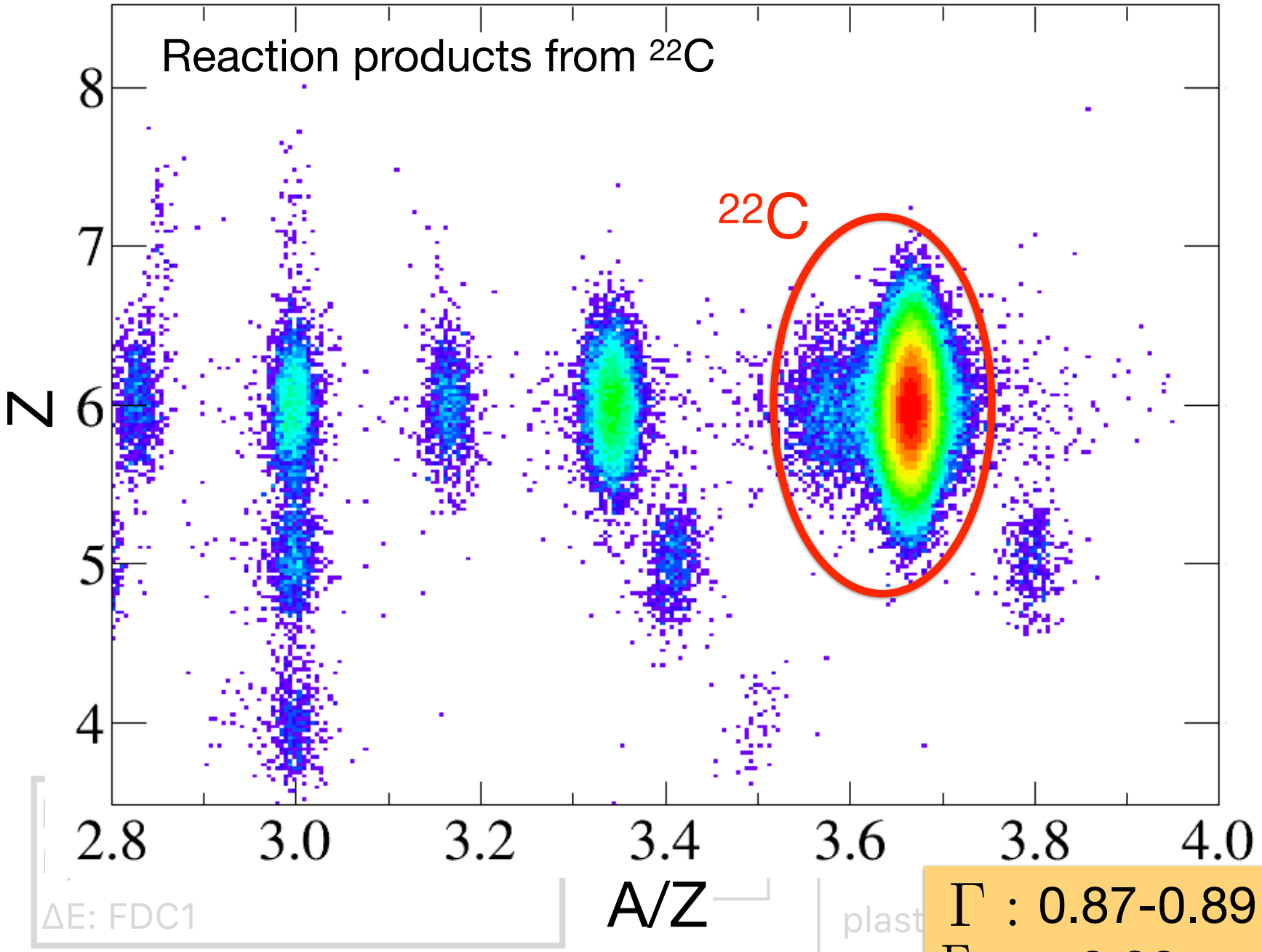


10 cph K. Tanaka et al. (2010)

SAMURAI spectrometer



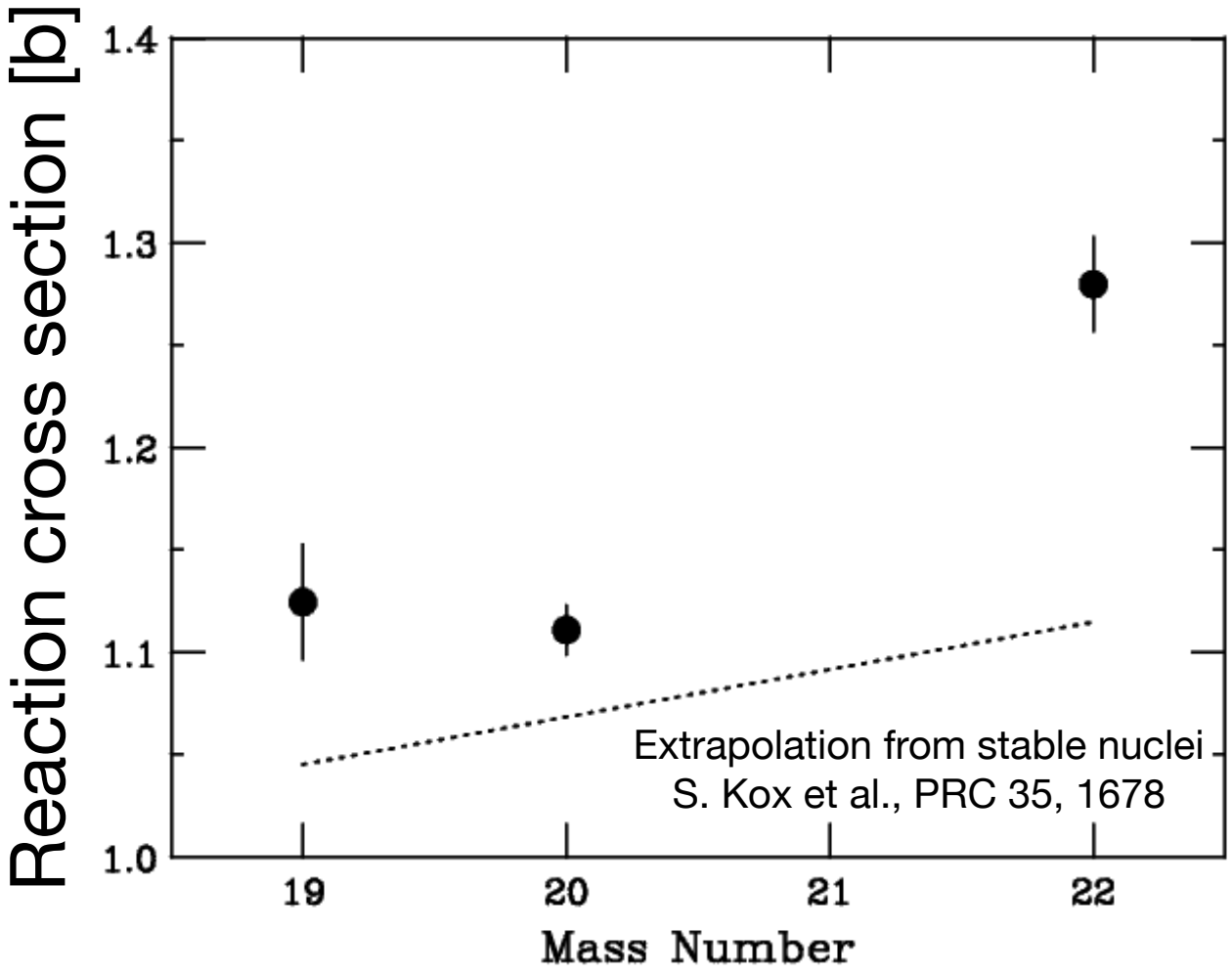
SAMURAI spectrometer



Γ : 0.87-0.89

Γ_0 : ~0.98

Result: σ_R of ^{19,20,22}C



A	E_{beam} [AMeV]	σ_R [b]
19	307	1.125(28)
20	280	1.111(12)
22	235	1.280(23)

^{22}C+*p* @ 40 AMeV

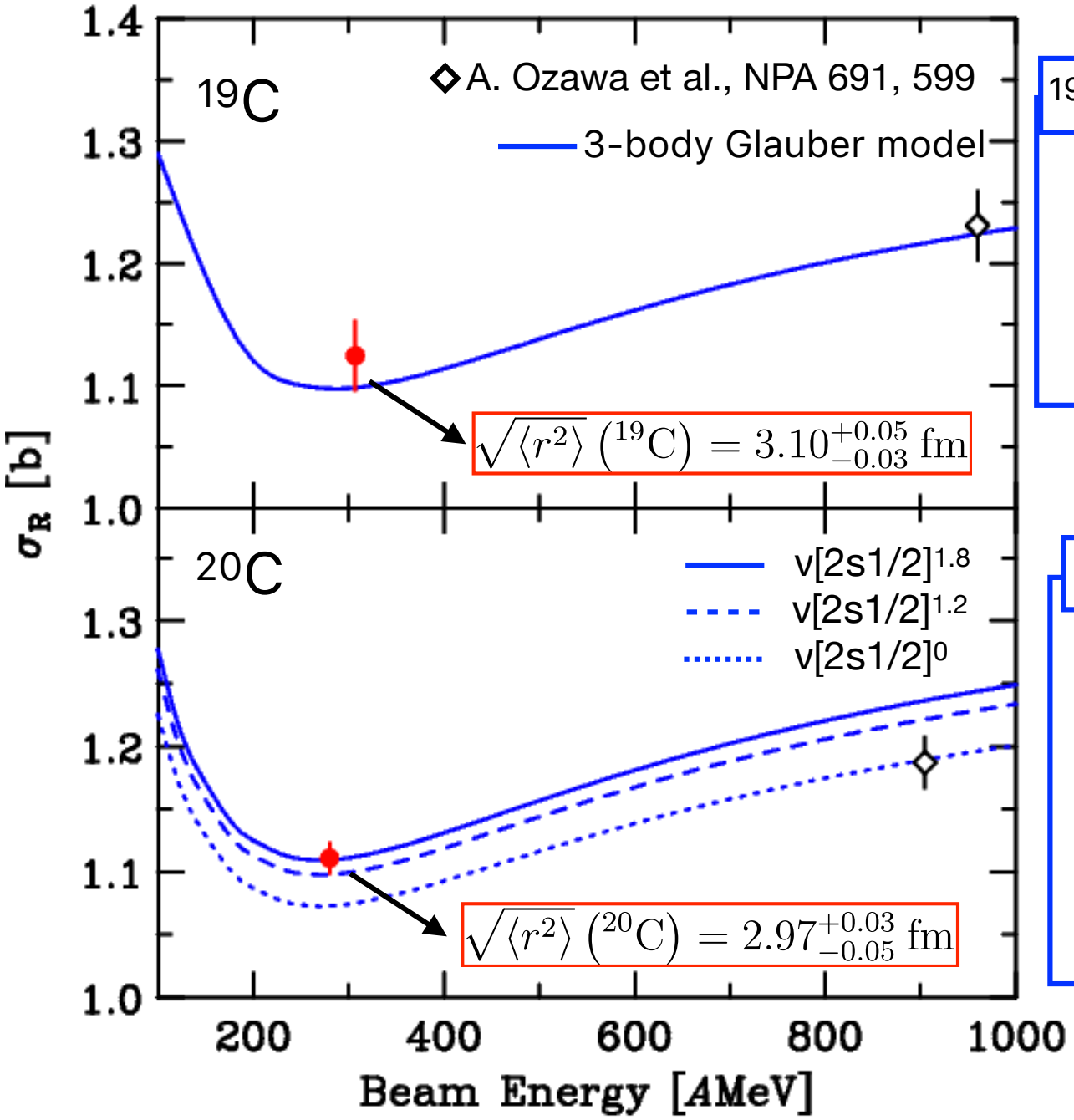
$\sigma_R = 1.338(274)$ b

Big jump from ^{20}C to ^{22}C

^{22}C is halo nucleus

100 times smaller uncertainty

Energy dependence of σ_R: ^{19,20}C



J.S. Al-Khalili et al., PRL 76, 3903.

^{19}C: ^{18}C+n→C: 3-body Glauber

^{18}C dist.: HF calc. (SkX)

$\sqrt{\langle r^2\rangle}\,(^{18}\mathrm{C}) = 2.75$ fm

S_n=0.58 MeV

^{20}C: ^{20}C→C: 2-body Glauber

S_n=2.93(26) MeV

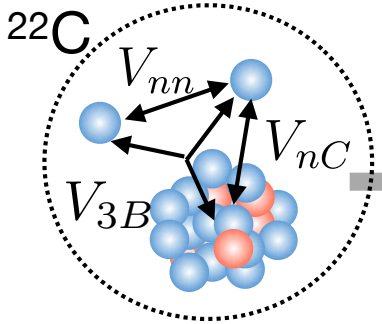
dist.: HF calc. (SkX)

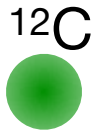
valence neutron($2s_{1/2}$): 0~1.8

Shell model (WBP): 1.2

^{22}C: 4-body Glauber model

Y. Kucuk and J. A. Tostevin, PRC89, 034607





$\sqrt{\langle r^2 \rangle}\,(^{12}\mathrm{C}) = 2.32\ \mathrm{fm}$

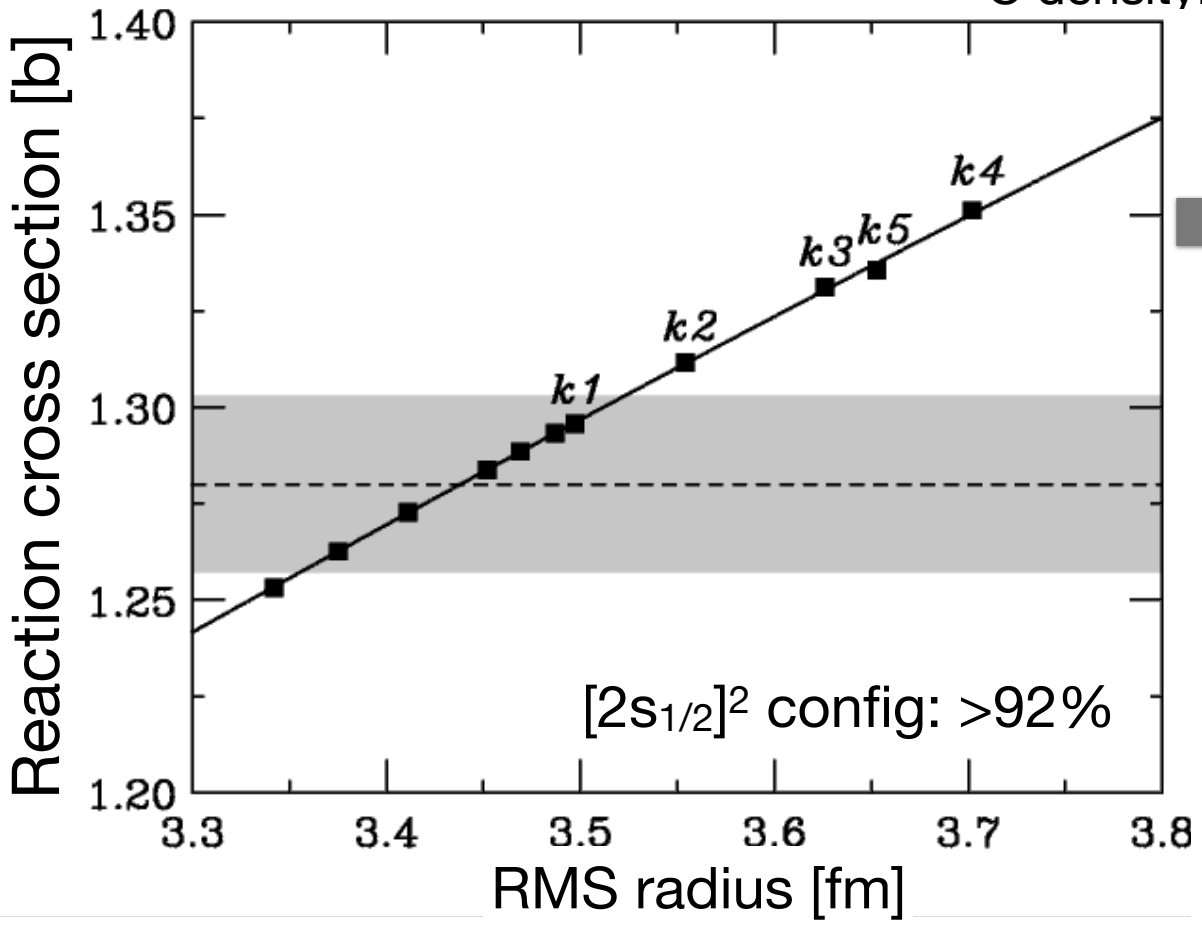
V_{nn} : GPT interaction (D. Gogny et al., PLB 32, 591)

V_{nC}^{l} : $\dfrac{V_0^l}{1+\exp\left(\frac{r-R}{a}\right)}$ + LS $\quad V_0^{l=0}$: Parameter, $V_0^{l=2} = 42.0\ \mathrm{MeV}$

V_{3B} : Attractive hyperradial 3-body force (parameter)

^{20}C density: HF calculation with SkX interaction

filled 1d$_{5/2}$ shell $\sqrt{\langle r^2 \rangle}\,(^{20}\mathrm{C}) = 2.89\ \mathrm{fm}$



$\sqrt{\langle r^2 \rangle}\,(^{22}\mathrm{C}) = 3.44 \pm 0.08\ \mathrm{fm}$

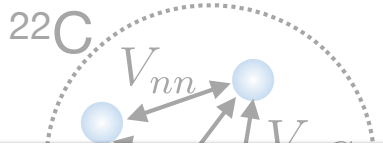
Smaller
but consistent in ~2σ

$\sqrt{\langle r^2 \rangle}\,(^{22}\mathrm{C}) = 5.4 \pm 0.9\ \mathrm{fm}$

^{22}C+p @40 AMeV (K. Tanaka et al.)

^{22}C: 4-body Glauber model

Y. Kucuk and J. A. Tostevin,
PRC89, 034607



V_{nn} : GPT interaction (D. Gogny et al., PLB 32, 591)

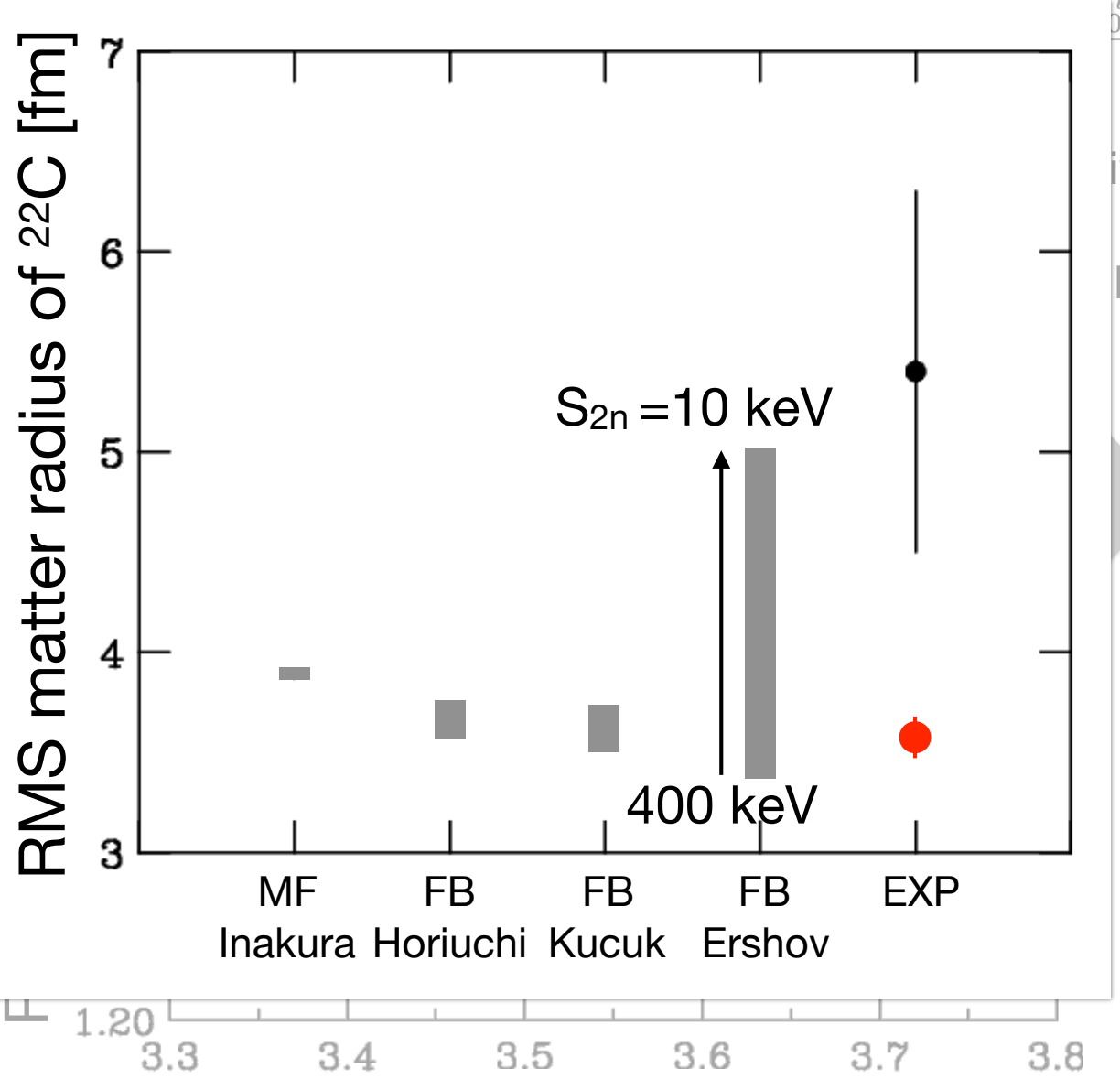
$\left(\frac{r-R}{a}\right)$ + LS $V_0^{l=0}$: Parameter

$V_0^{l=2} = 42.0$ MeV

ive hyperradial 3-body force (parameter)

HF calculation with SkX interaction

filled 0d$_{5/2}$ shell $\sqrt{\langle r^2 \rangle}\,(^{20}\mathrm{C}) = 2.89$ fm



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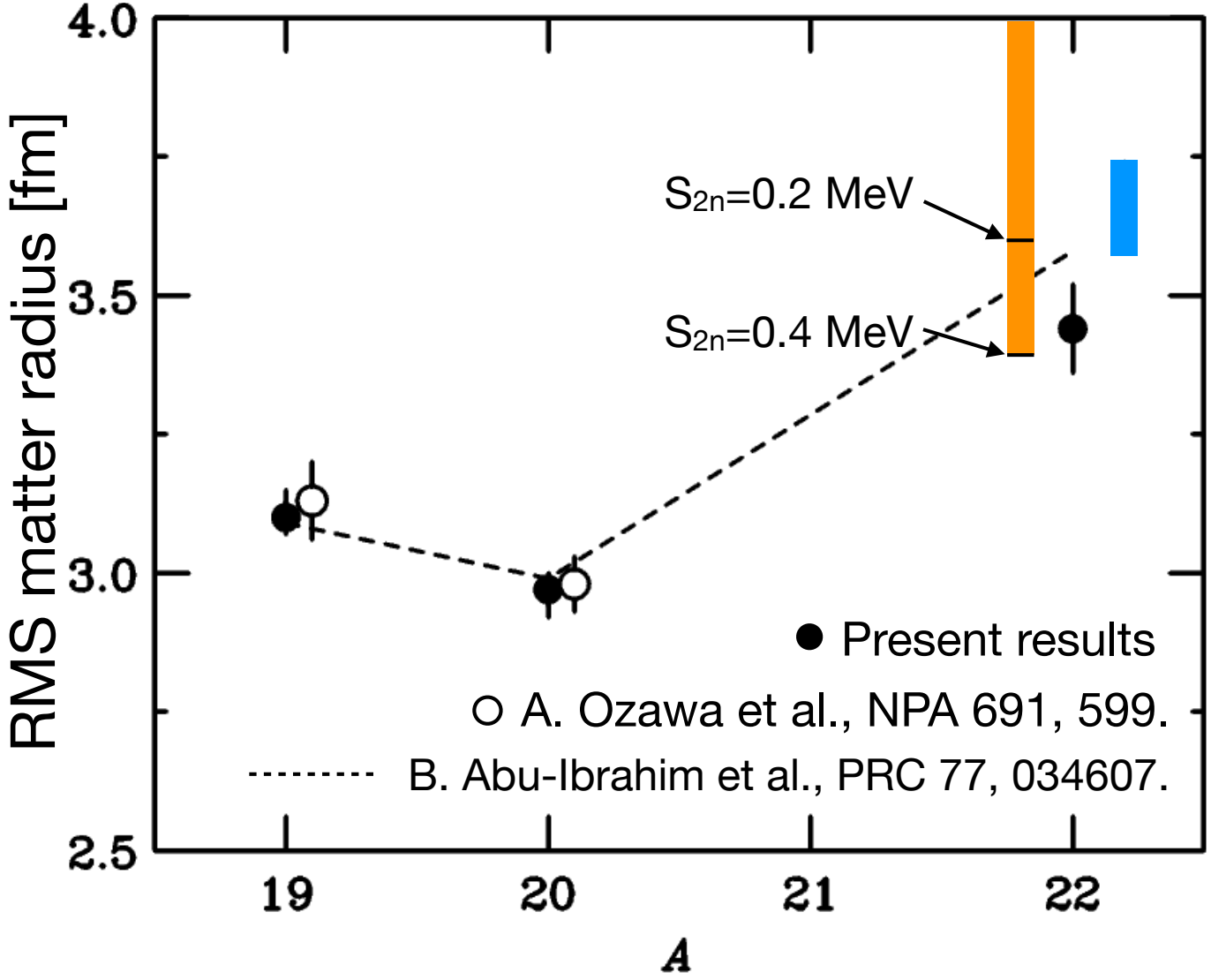
^{22}C+p @40 AMeV (K. Tanaka et al.)

Matter radius of ^{19,20,22}C



W. Horiuchi et al., PRC 74, 034311.

S_{2n} range: 0.39 ~0.57 MeV

S. N. Ershov et al., PRC 86, 034331.

S_{2n} range: 0.4~0.01 MeV

+ present model for ^{22}C

Halo neutrons: $[2s_{1/2}]^2 \geqq 90\%$

$0.2\ \text{MeV} \leqq S_{2n} \leqq 0.6\ \text{MeV}$

3-body model incorporate core polarization

T. Suzuki et al., Phys. Lett. B 753, 199 (2016).

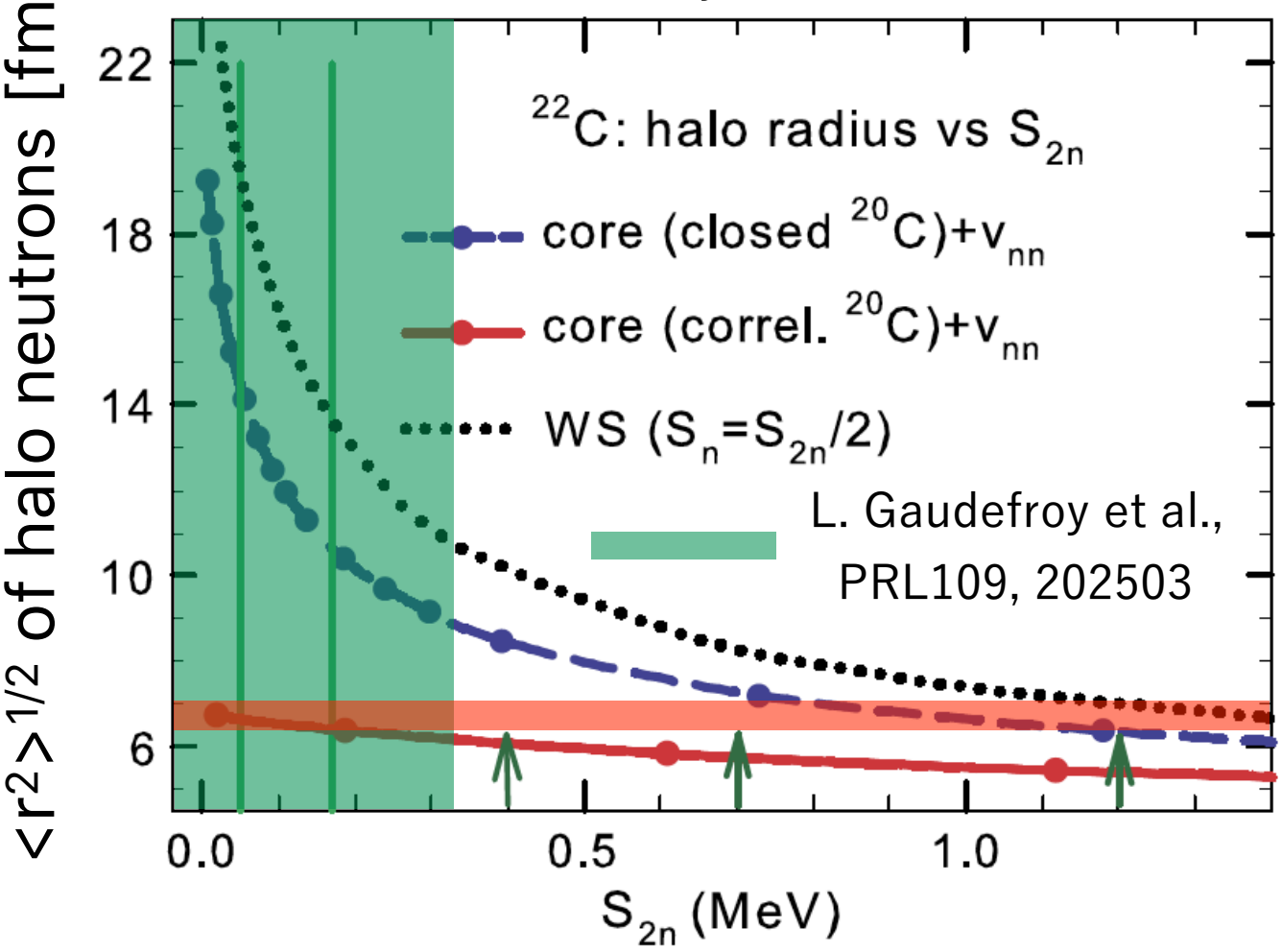
^{20}C ground state: valence neutrons in $2s_{1/2}$ (SM & n removal from ^{20}C)

N. Kobayashi et al., PRC 86, 054604

→ ^{20}C in ^{22}C: Halo neutrons in $2s_{1/2}$

→ neutron in ^{20}C cannot occupy $2s_{1/2}$

→ Core excitation by ~1 MeV



$$\sqrt{\langle r^2_{^{22}C}\rangle} = 3.44 \pm 0.08 \text{ fm}$$

$$\sqrt{\langle r^2_n\rangle} \simeq \sqrt{\frac{22}{2}\left[\langle r^2_{^{22}C}\rangle^2 - \frac{20}{22}\langle r^2_{^{20}C}\rangle^2\right]}$$

$$\sqrt{\langle r^2_n\rangle} \simeq 6.8 \text{ fm}$$

Consistent at

$S_{2n} < 0.25$ MeV

Summary

- Interaction cross sections of ^{19,20,22}C+C @ ~250 MeV/nucleon
- $\sigma_R(^{22}\mathrm{C})$: larger than neighboring isotopes
- Analysis with 4-body Glauber → $\sqrt{\langle r^2 \rangle}\left(^{22}\mathrm{C}\right) = 3.44 \pm 0.08\ \mathrm{fm}$
  - Smaller than the previous result, but consistent at 2σ level.
- Comparison with models
  - WITHOUT core polarization: 0.2 MeV ≦S_{2n}≦ 0.6 MeV.
  - WITH core polarization: S_{2n}< 0.25 MeV

Determination of S_{2n}

Y. Togano et al., Phys. Lett. B **761**, 412 (2016).

Y. Togano et al., Phys. Lett. B **761**, 412 (2016).

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