WS on Reaction Cross Section, *Jan. 13, 2006*

“黒い”原子核描像に基づく核半径と反応断面積

- Contents:
  - Purpose
  - BS Approxi.
  - r_{BS} *vs.* r_m
  - σ_{BS} *vs.* σ_R, σ_I
  - Energy Depen.
  - React. CS Formula
  - Summary

The black-sphere picture
as a reference frame

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in collaboration with

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Ref. *Phys. Rev.* **C69,** 064316 (2004).
Phys. Rev. **C72**, 024602 (2005).

添付資料2（RIBF反応断面積実験での課題）

- ---実験サイドからのテーマ
  - ・・・・・
- ---グラウバー模型による解析（反応断面積から核半径へ）
- 1）300AMeV付近でのグラウバー模型
  - Optical limit or Few body、Zero-range or Finite range
  - どういうターゲットが良いか？
  - どういう測定が必要か？安定核での実験？
  - 変形をどう取り込むか？
- 2）グラウバー模型以外での解析の可能性は？

- ---どの領域を測定するか？
- 1）skin/haloの最新の予測
- 2）核半径によるほかの物理は？例えばEOS？
- 3）関連する実験の現状は？
  - (ア) 陽子弾性散乱実験の現状
  - (イ) SLOWRIにおける荷電核半径の測定
  - (ウ) SCRITの現状

研究目的

- 安定核の豊富なデータに基づき、中性子過剰不安定核の特徴を浮かび上がらせる。
  - 核半径、反応断面積の系統的解析。
- 目論見：弾性散乱データで得た尺度で、反応／相互作用断面積を眺める。ハロー核の密度が外側に広がっていれば両者に矛盾が生じる可能性がある。
→　ハロー核の特徴を引き出せるだろう。
- 現状：“くろたま”模型を構築し、陽子散乱データの系統的解析進行中。
  - 経過：次ページ（→）。

Present Status of Our Study

- We have analyzed p-A elastic scattering data in the black sphere approximation, which gives a scale "*a*". This "*a*" reproduces the first peak position and reaction cross section simultaneously.
- We have found that
  - the values of r_{BS} agree quite well with each other for A > 50 while they are systematically smaller than those of r_m deduced from elaborate scattering theory for A < 50. This suggests a significant deviation of the nucleon distribution from the rectangular one for A < 50.
  - the absorption cross section, σ_{BS} ($= \pi a^2$), is consistent with the empirical total reaction cross section for C, Sn, and Pb.
  - The energy dependence of σ_{BS} seems to be consistent with σ_R.

p-A Total React. Cross Sect.

Diffraction pattern is O.K., but …

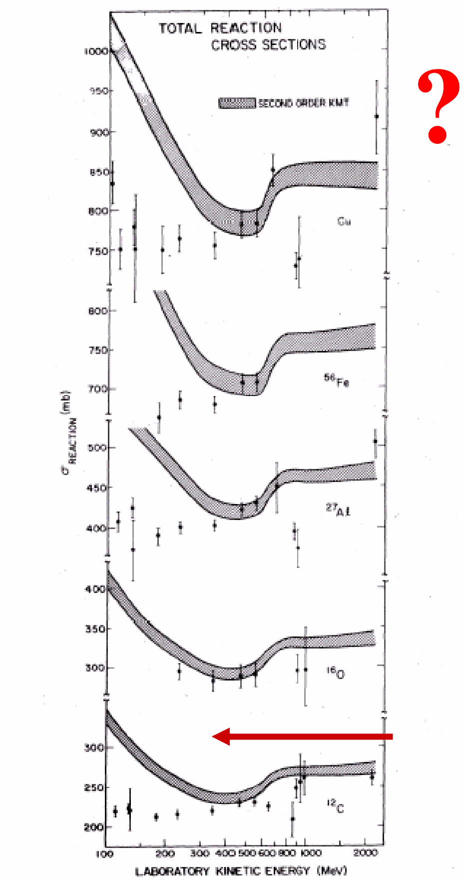


FIG. 4. Proton-nucleus total reaction cross sections for ^{12}C, ^{16}O, ^{27}Al, ^{56}Fe, and Cu predicted by second-

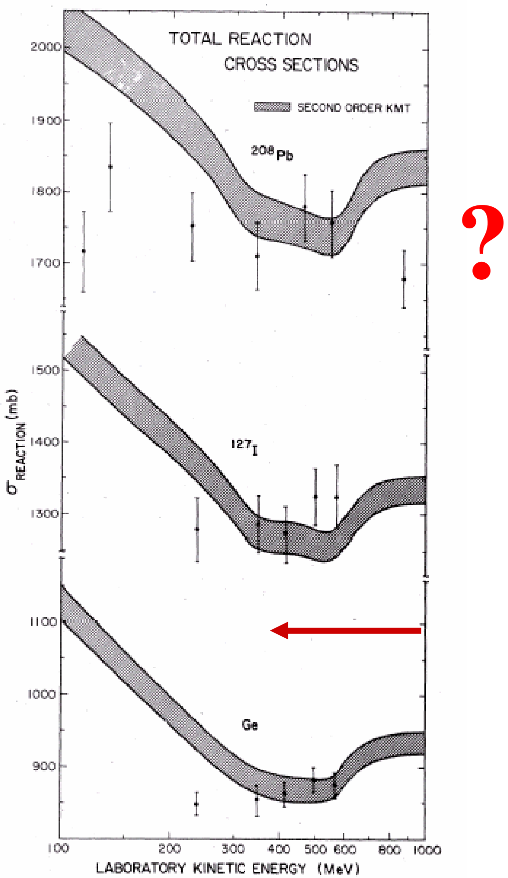
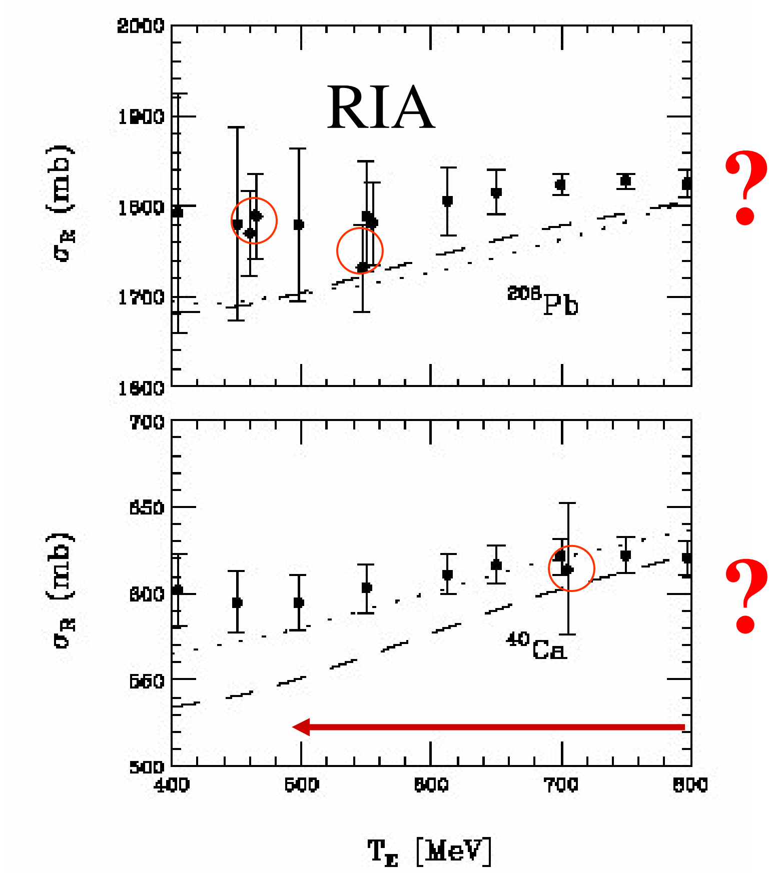


FIG. 5. Same as Fig. 4 except for Ge, ^{127}I, and ^{208}

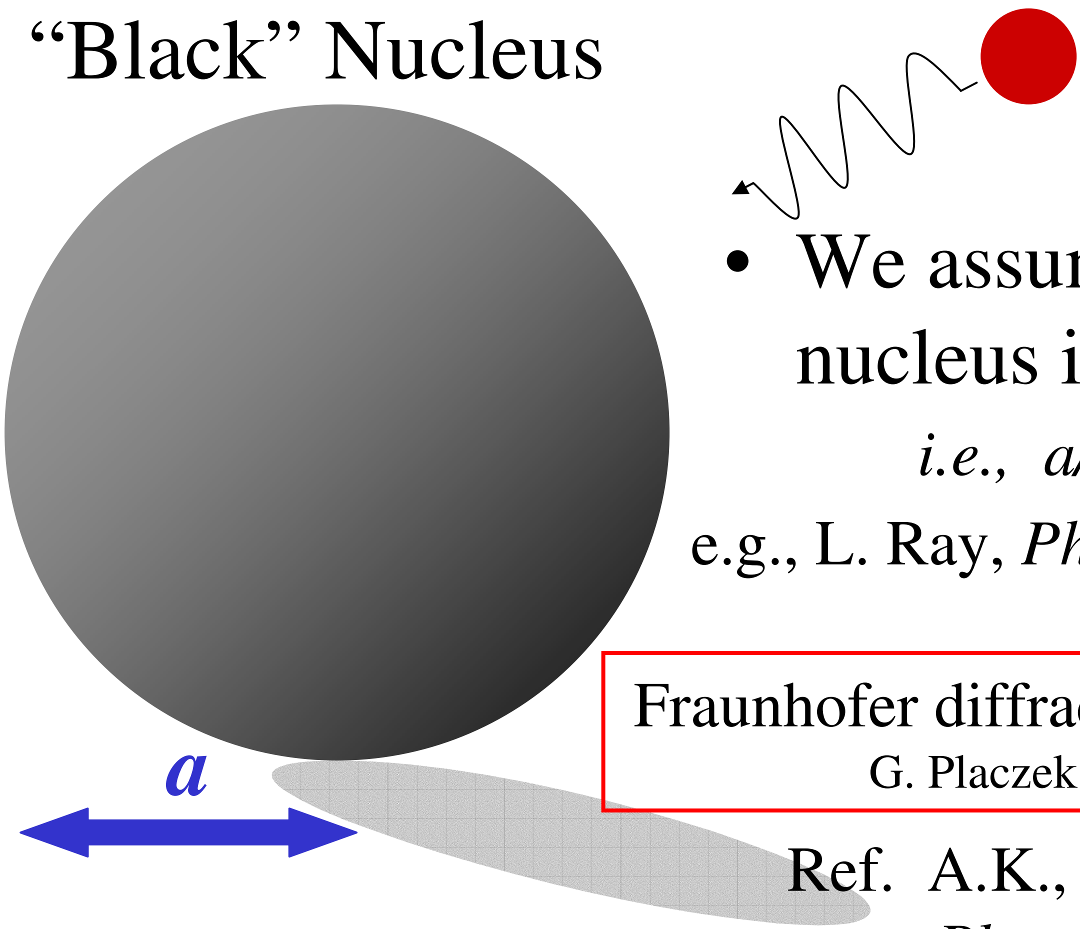


B.C. Clark, *Phys. Rev.*, **C67**, 054605 (2003).

up to the 2nd order of KMT.

L. Ray, *Phys. Rev.*, **C20**, 1857 (1979).

Black Sphere Approximation



$T_p \geqq 800$ [MeV].

$\lambda_p/a \ll 1.$

- We assume that the target nucleus is strongly absorptive.

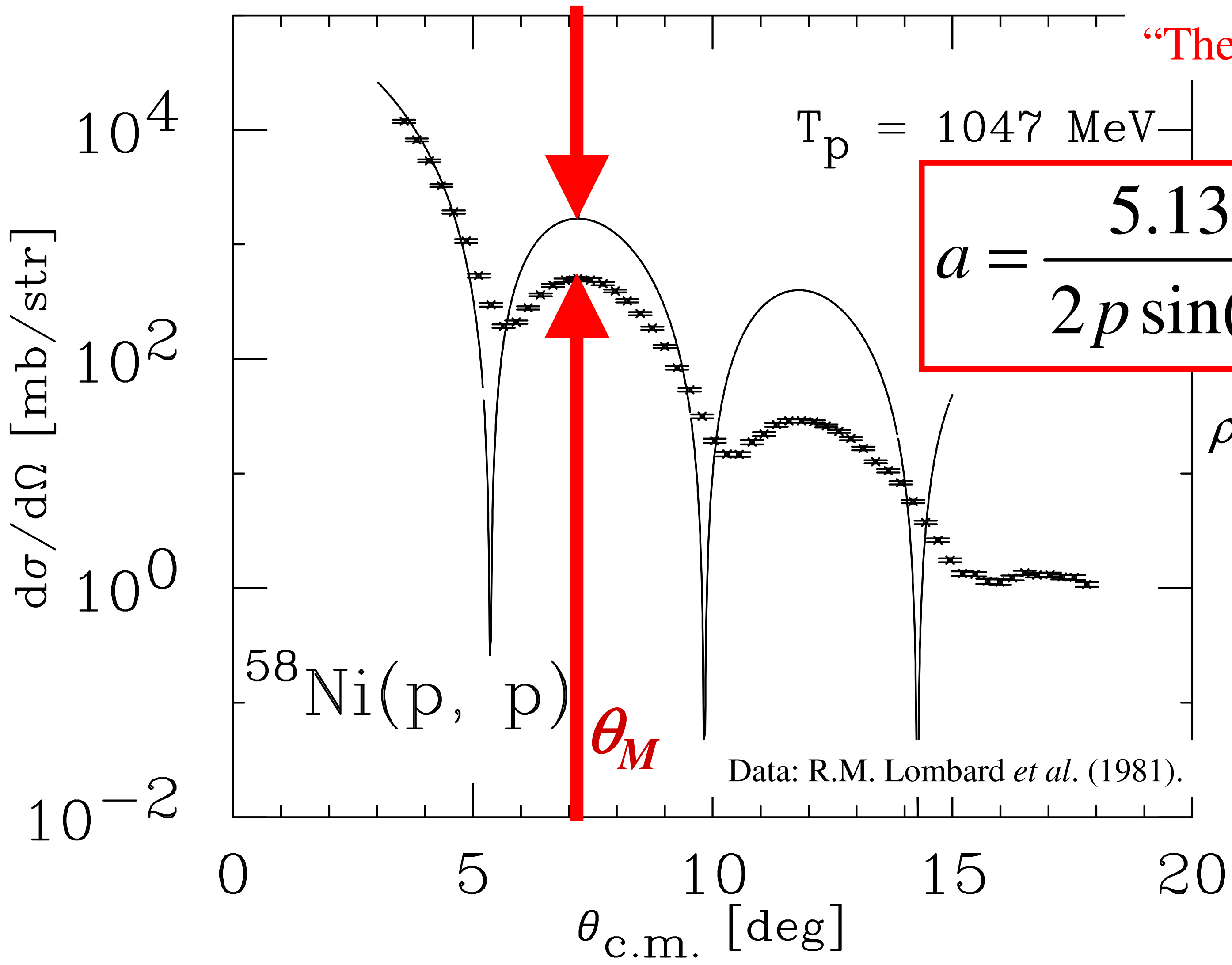
i.e., $a/(1/\rho_0\sigma_{pN}) \gg 1.$

e.g., L. Ray, *Phys. Rev.* **C20**, 1857 (1979).

Fraunhofer diffraction formula is applicable.
G. Placzek and H.A. Bethe (1940).

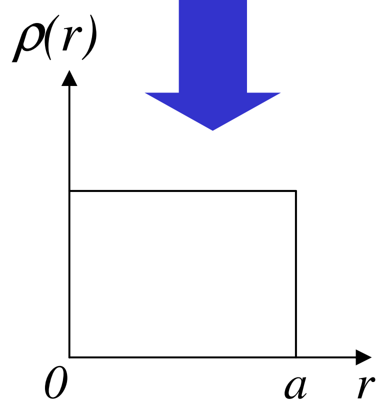
Ref. A.K., K. Iida, and K. Oyamatsu, *Phys. Rev.* **C69**, 064316 (2004).

How to determine “*a*” ?



“The radius formula”

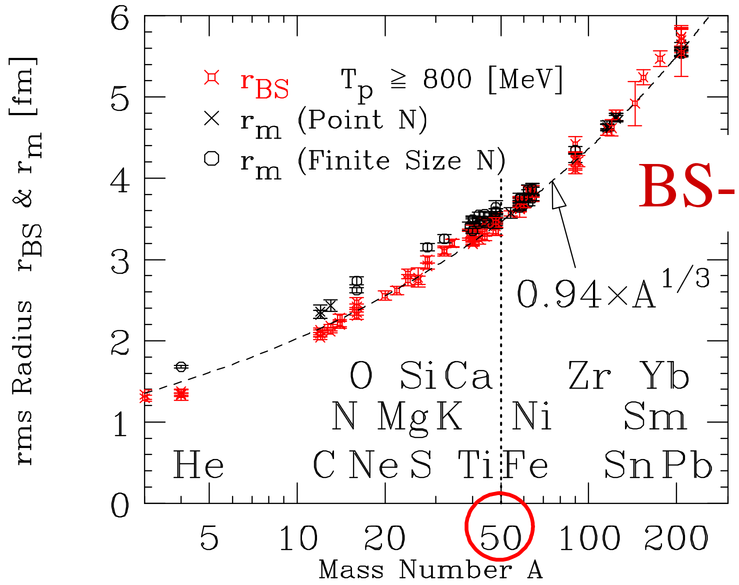
$$a = \frac{5.1356\cdots}{2p\sin(\theta_M/2)}.$$



$$r_{BS} = \sqrt{3/5}\,a.$$

Recent Results: for *stable* nuclei

r_{BS} as a function of A (≧ 3)



BS-Scaling

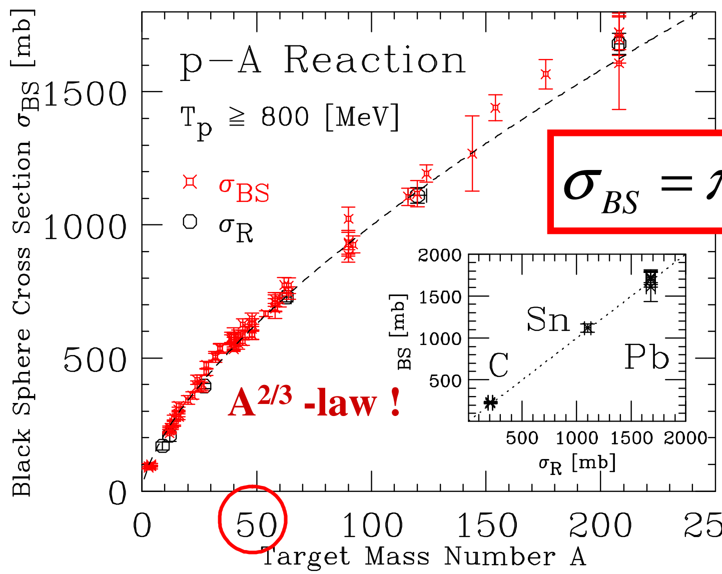
$$r_{BS} = \sqrt{3/5}\,a.$$

r_m is obtained from the conventional multiple-scattering theory.

T_p ≧ 800 MeV:

- $r_m = r_{BS}$ for A > 50.
- $\sigma_R = \sigma_{BS}$ for A ≧ 3.

p-A Reaction Cross Sections

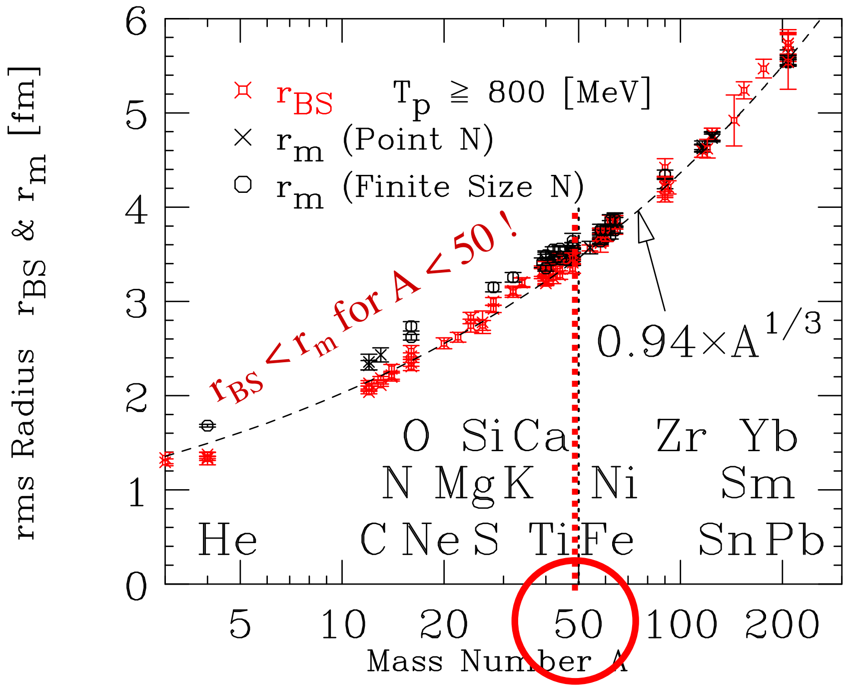


$$\sigma_{BS} = \pi a^2.$$

Data: ^{9}Be, ^{12}C, ^{27}Al, Cu, Sn, Pb.

A.K, K. Iida, and K. Oyamatsu, *Phys. Rev.* **C72**, 024602 (2005).

r_{BS} as a function of A (≧ 3)



r_{BS} follows $A^{1/3}$-law.

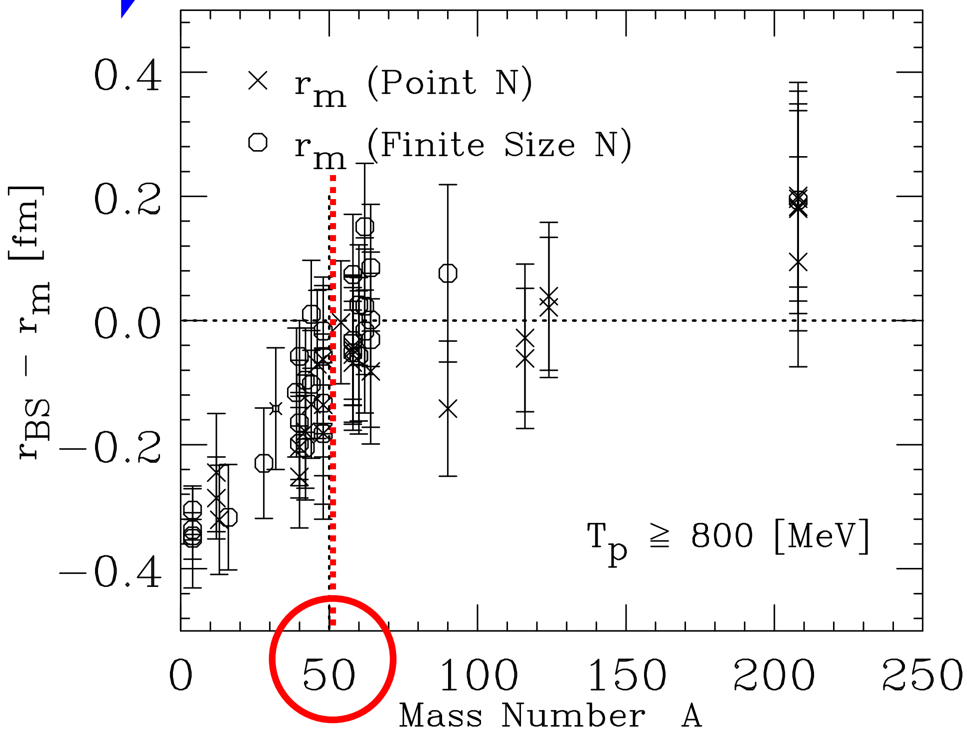
# of Nuclide: 18.

# of Data : 81 (r_{BS}), 63 (r_m).

(used EXFOR)

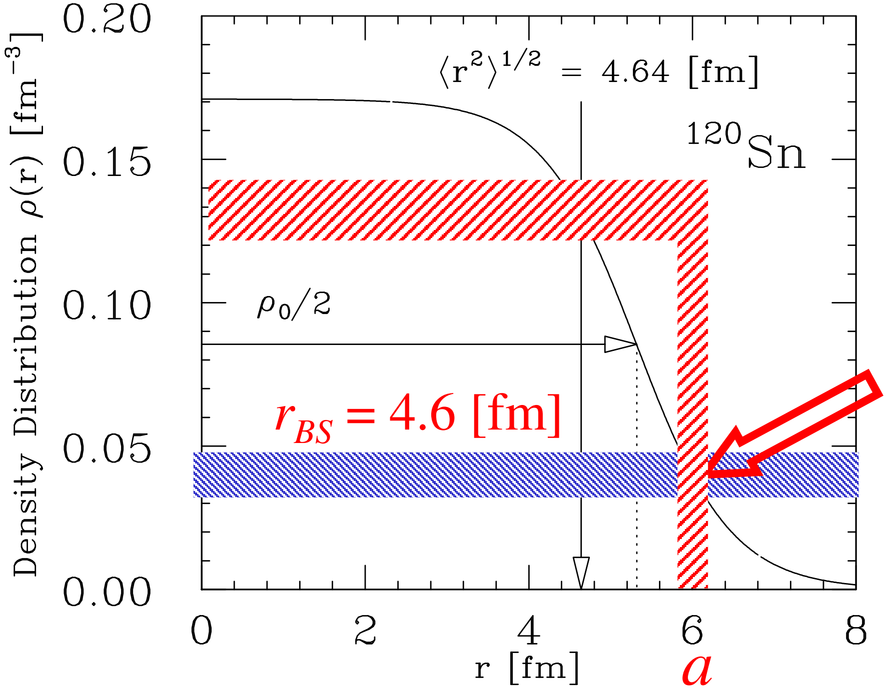
This feature is consistent with the charge density distribution.

r_{BS} - r_m

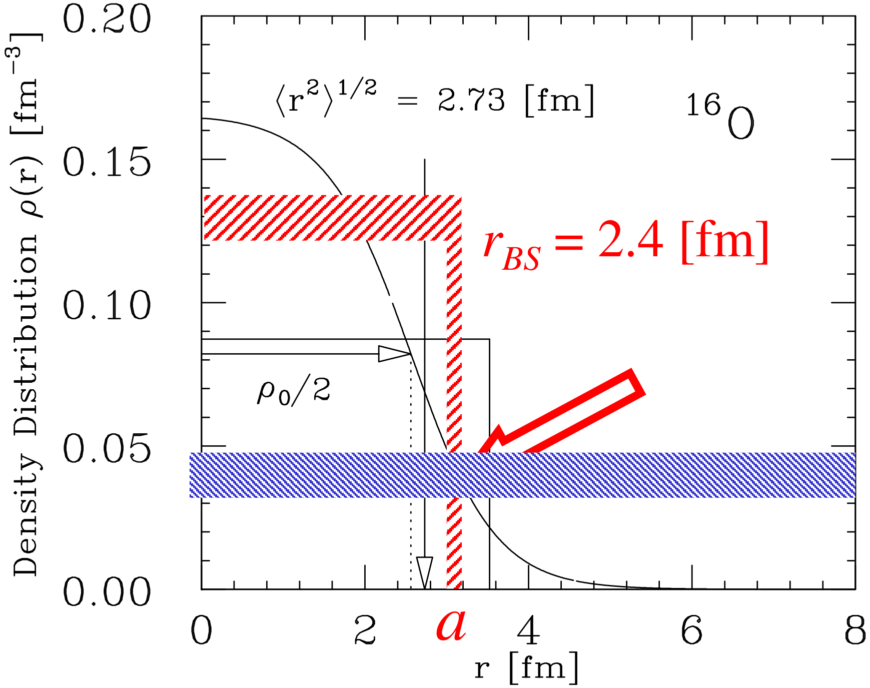


Which part is probed?

Case of A > 50



Case of A < 50



A possible interpretation is: the incident proton “sees” a certain definite density region. Similar discussion was done by P.J. Karol (PRC11) and S. Kox (PRC35).

σ_I *vs.* σ_{BS} : for *stable* nuclei

$$\sigma_{BS} = (5/3)\pi\{r_{BS}(^{12}C) + 0.94A^{1/3}\}^2.$$

$$\sigma_R \cong \sigma_{BS} \geqq \sigma_I.$$

A.K., K.Iida, K.Oyamatsu, Phys. Rev. C 72, 024602 (2005).

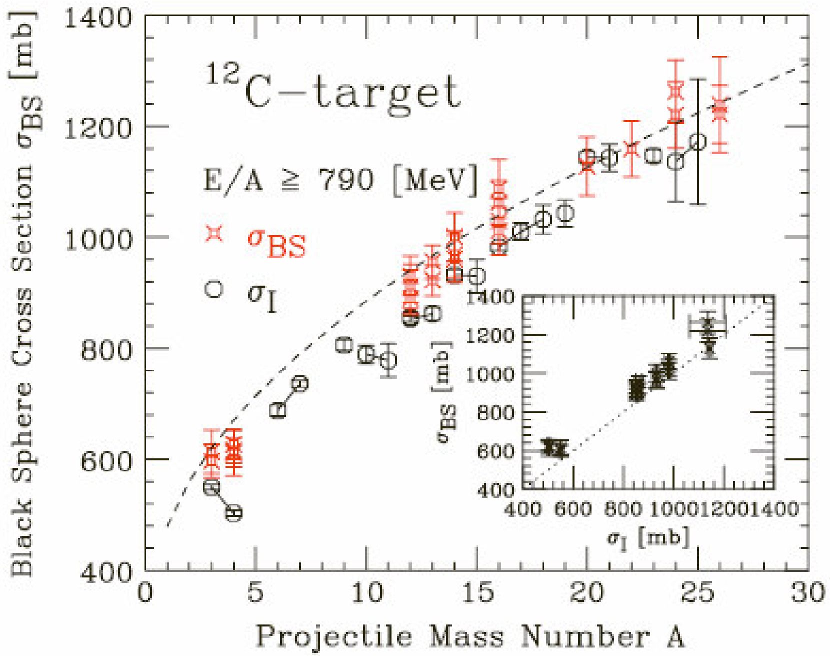
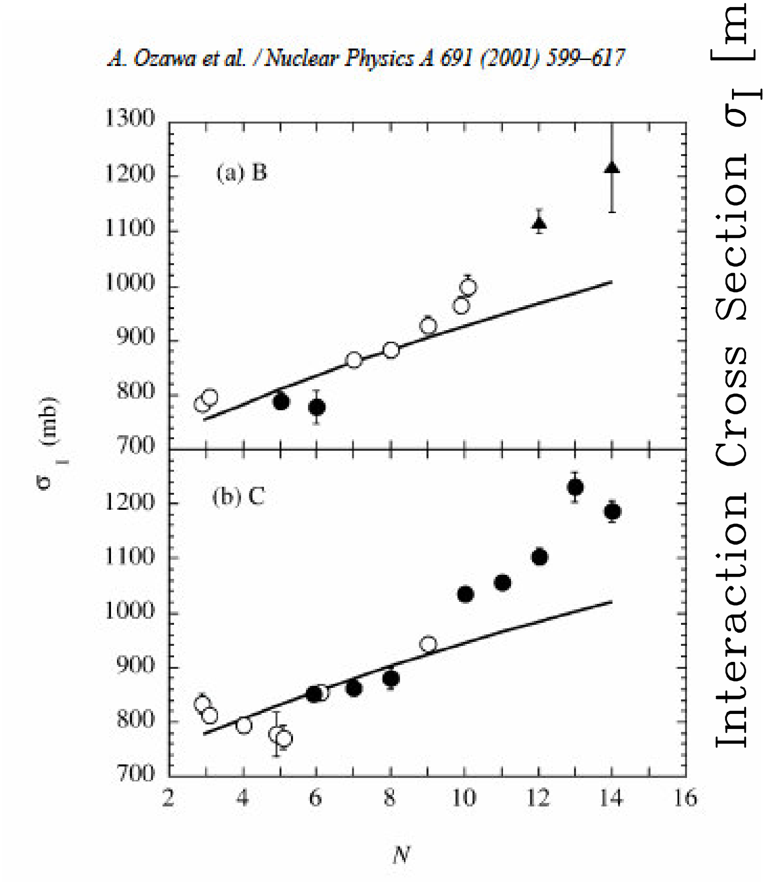
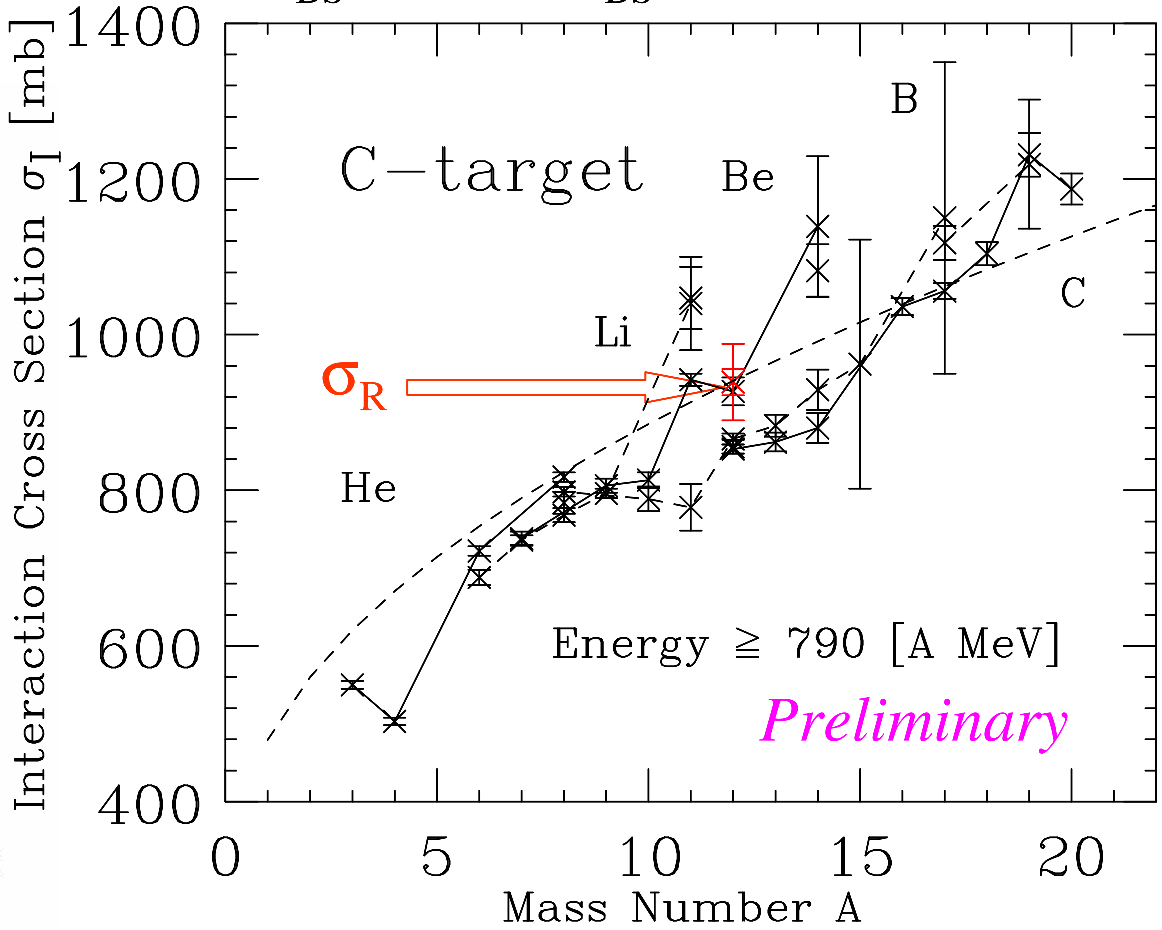


FIG. 4. (Color online) Absorption cross section, σ_{BS}, for a projectile stable nucleus of $A < 30$ and a ^{12}C target. We fix $r_{BS} = 2.086 \pm 0.05$ fm for ^{12}C. For comparison, we plot the interaction cross section, σ_I (○), measured at $E/A \gtrsim 800$ MeV for a projectile of $^{3,4}He$, $^{6,7}Li$, ^{9}Be, $^{10,11}B$, $^{12,13}C$, $^{14,15}N$, $^{16,17,18}O$, ^{19}F, $^{20,21}Ne$, ^{23}Na, and $^{24,25}Mg$ incident on a ^{12}C target [51]. The dashed curve represents $(5/3)\pi(2.086 + 0.94A^{1/3})^2$ fm^2. Inset: σ_{BS} versus σ_I for ^{4}He, $^{12,13}C$, ^{14}N, ^{16}O, ^{20}Ne, and ^{24}Mg. The dotted line represents $\sigma_{BS} = \sigma_I$.

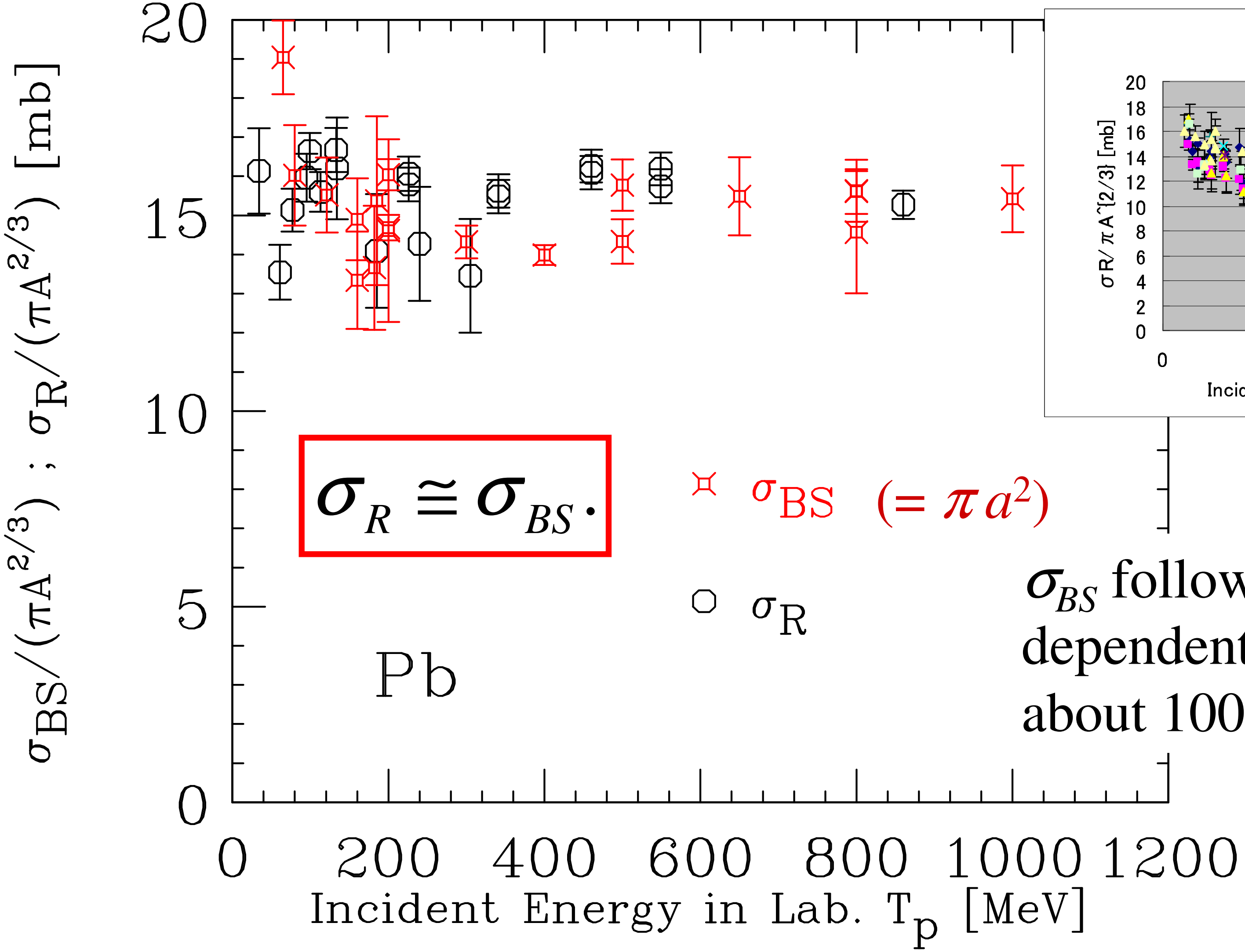
σ_I *vs*. BS-scaling: for neutron-rich *unstable* nuclei

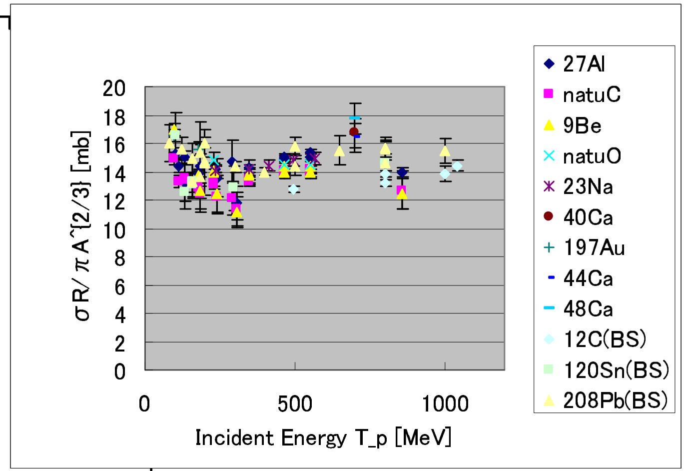
$$\sigma_{BS} = (5/3)\pi\{r_{BS}(^{12}C) + 0.94A^{1/3}\}^2.$$





Energy Dependence of σ_{BS}



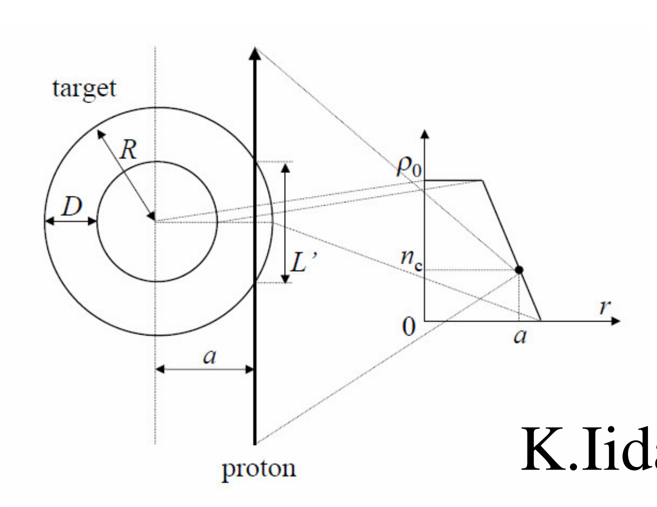


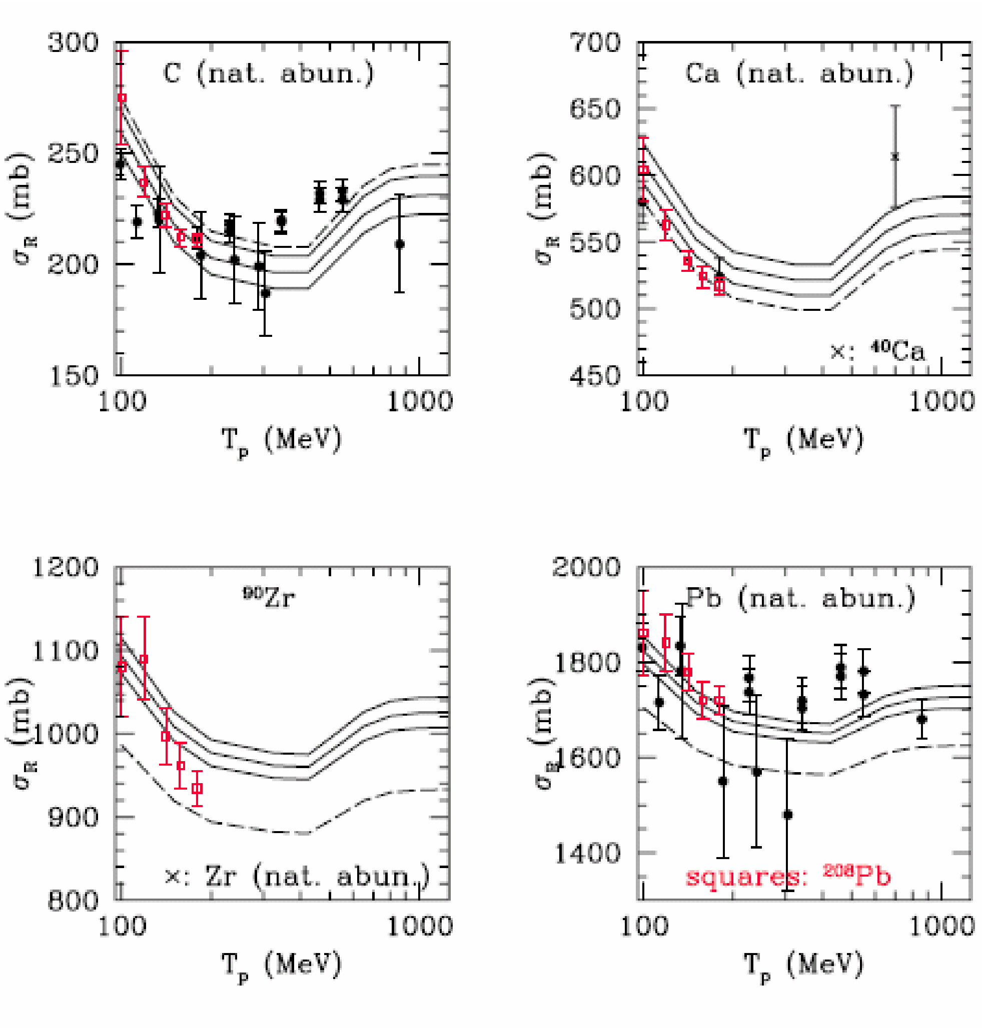
σ_{BS} follows σ_R energy-dependently down to about 100 MeV.

React. Cross Sect. Formula

$$\sigma_R = \pi\, a_0^2\, (1 + \Delta a/a_0)^2.$$

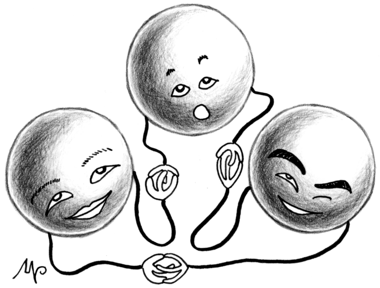
- Based on the “optical” dept $\tau = \sigma_{pN}\, n_c\, L' \cong 0.9$, the energy-dependence of Δa is translated into that of σ_{pN} .
- Isospin-dependence can be included.





K.Iida, A.K., K.Oyamatsu, *nucl-th/0601039*.

まとめ



- 陽子散乱から物質半径推定可。（ただし質量数50あたり以上）
  – 軽い核についても“反応半径”を与える。
- 反応断面積公式“出荷”。（ただし核子あたり100MeV以上）
  – アイソスピン依存性も取り込める。
    - K.Oyamatsu and K.Iida, *Prog. Theo. Phys.*, **109**, (2003) 631.
- 反応断面積の基準値として使ってもらえると嬉しい。