Reaction Cross Sections and Nucleon Density Distributions of Light Nuclei

Maya Takechi

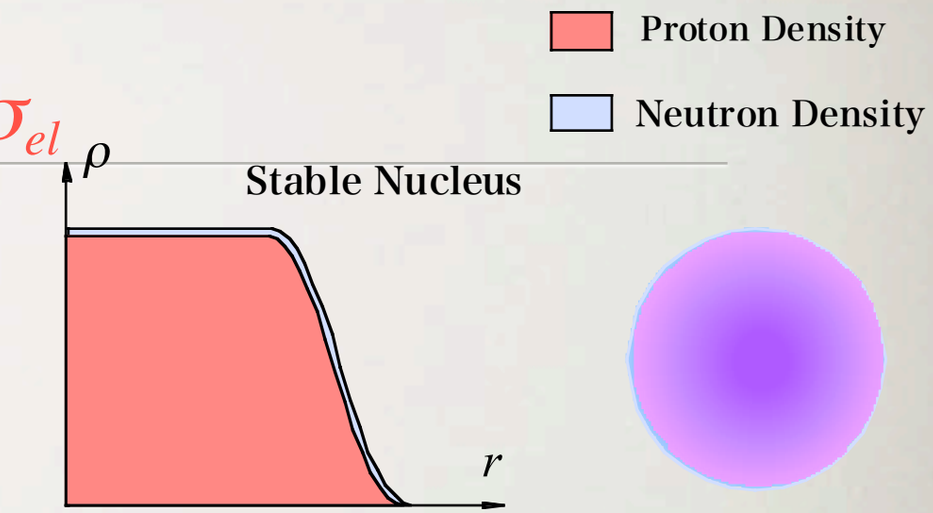
Collaborators

- Osaka Univ. M. Fukuda, M. Mihara, R.Matsumiya, J. Komurasaki, D. Nishimura, D. Ishikawa, K.Matsuta
- Fukui UT T. Minamisono
- Saitama Univ. S. Nakajima, K. Kobayashi, T. Kuboki, T. Yoshitake, T. Yamaguchi, T. Suzuki
- Niigata Univ. T. Izumikawa, T. Ohtsubo, T. Matsuyama
- Kochi UT S. Momota
- Tsukuba Univ. Y. Yasuda, Y. Hashidume, T. Hoya, T. Moriguchi, A. Ozawa
- NIRS M. Sasaki, S. Sato, M. Kanazawa, A. Kitagawa
- RIKEN K. Tanaka, T. Suda

Introduction

Sizes of Unstable Nuclei ?

~ Measurements of σ_R ~ $\sigma_R \equiv \sigma_{tot} - \sigma_{el}$



High Energy Region ~ 1GeV

σ_R ⟺ Nuclear Radii

Glauber Calculation (OLA)

At Intermediate Energies

↓

Nucleon Density Distribution !

Study of Density Distribution through Glauber Calculation

$\sigma_R \Longleftrightarrow \rho(r)$

Glauber Calculation

(Optical Limit and Zero-Range Approximations of Glauber Theory)

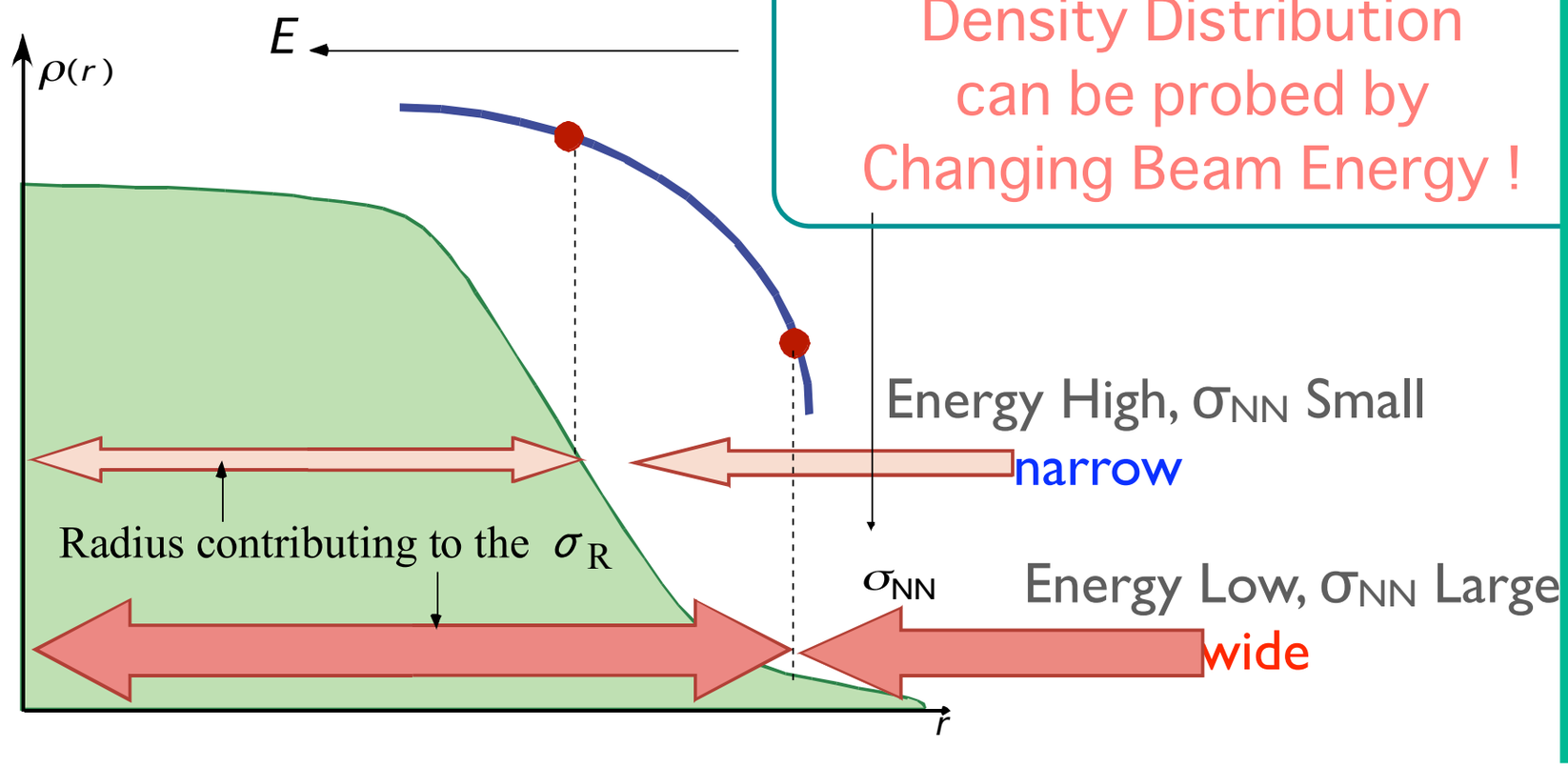
$$\sigma_R = \int \mathrm{d}\boldsymbol{b}\left[1-\exp\left(-\int d^2\boldsymbol{r}\sum_{i,j}\sigma_{NN}(E)\,\rho_z^{P_i}(\boldsymbol{r})\,\rho_z^{T_j}(\boldsymbol{r}-\boldsymbol{b})\right)\right]$$

ρ^P Projectile Density

ρ^T Target Density

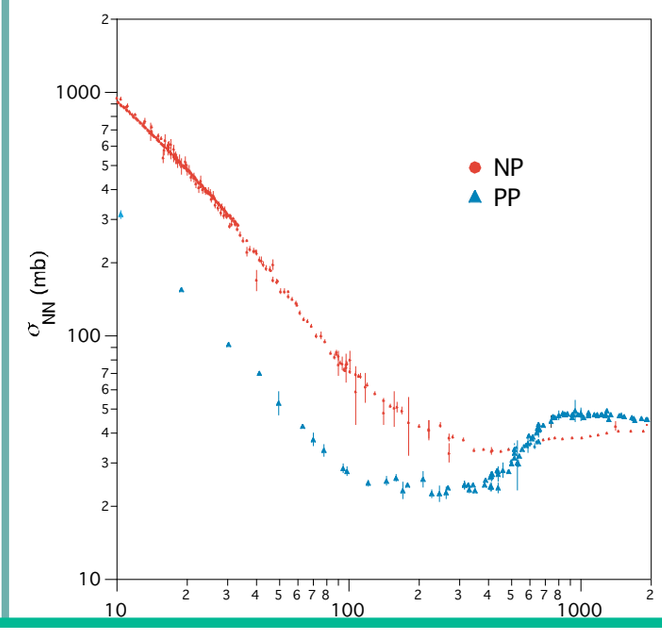
σ_{NN} NN total cross section

σ_R can be uniquely calculated by **3** quantities



Density Distribution can be probed by Changing Beam Energy !

$\sigma_{NN}(E)$



Problem

$\sigma_{R(Exp)} > \sigma_{R(Glauber\ Calc.)}$

Glauber Calculation underestimates σ_R at Intermediate Energies

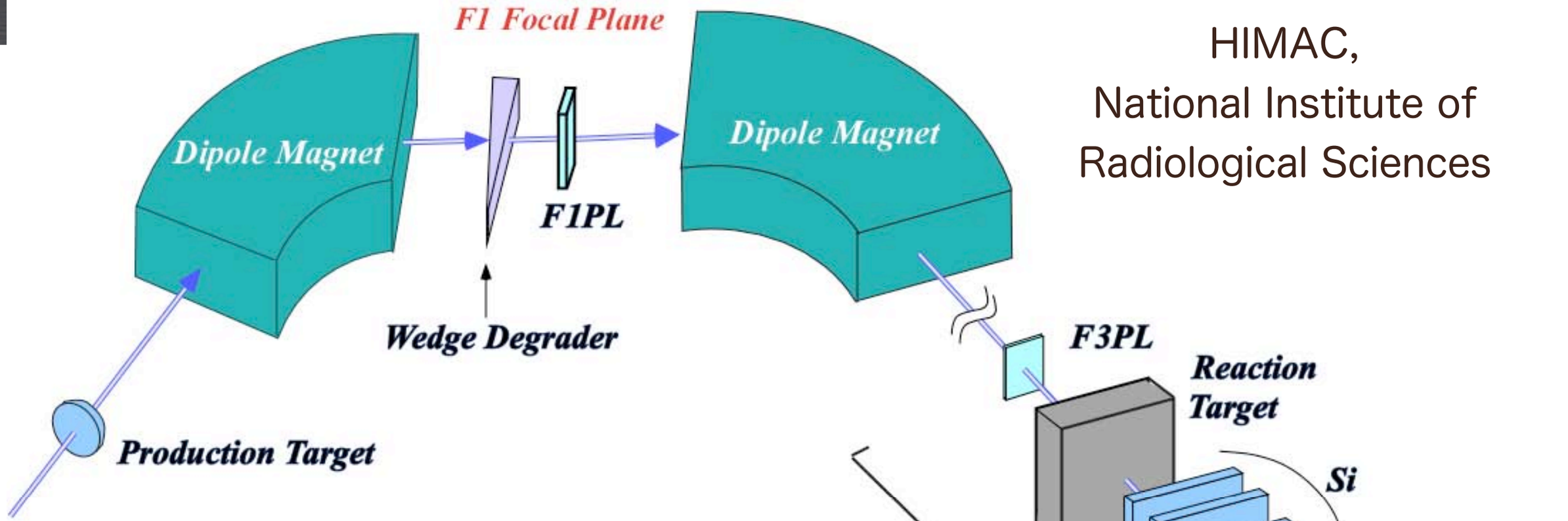
Investigation

Measurements of σ_R for ^{12}C, ^{11}Be

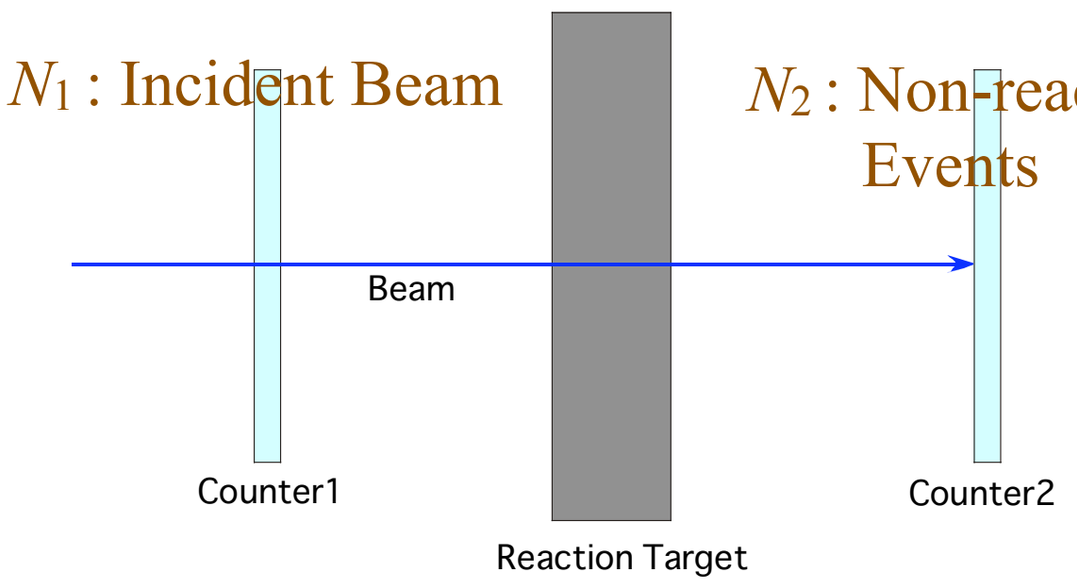
Experiment

^{12}C on Be, C, Al and ^{11}Be on Be

HIMAC,
National Institute of
Radiological Sciences



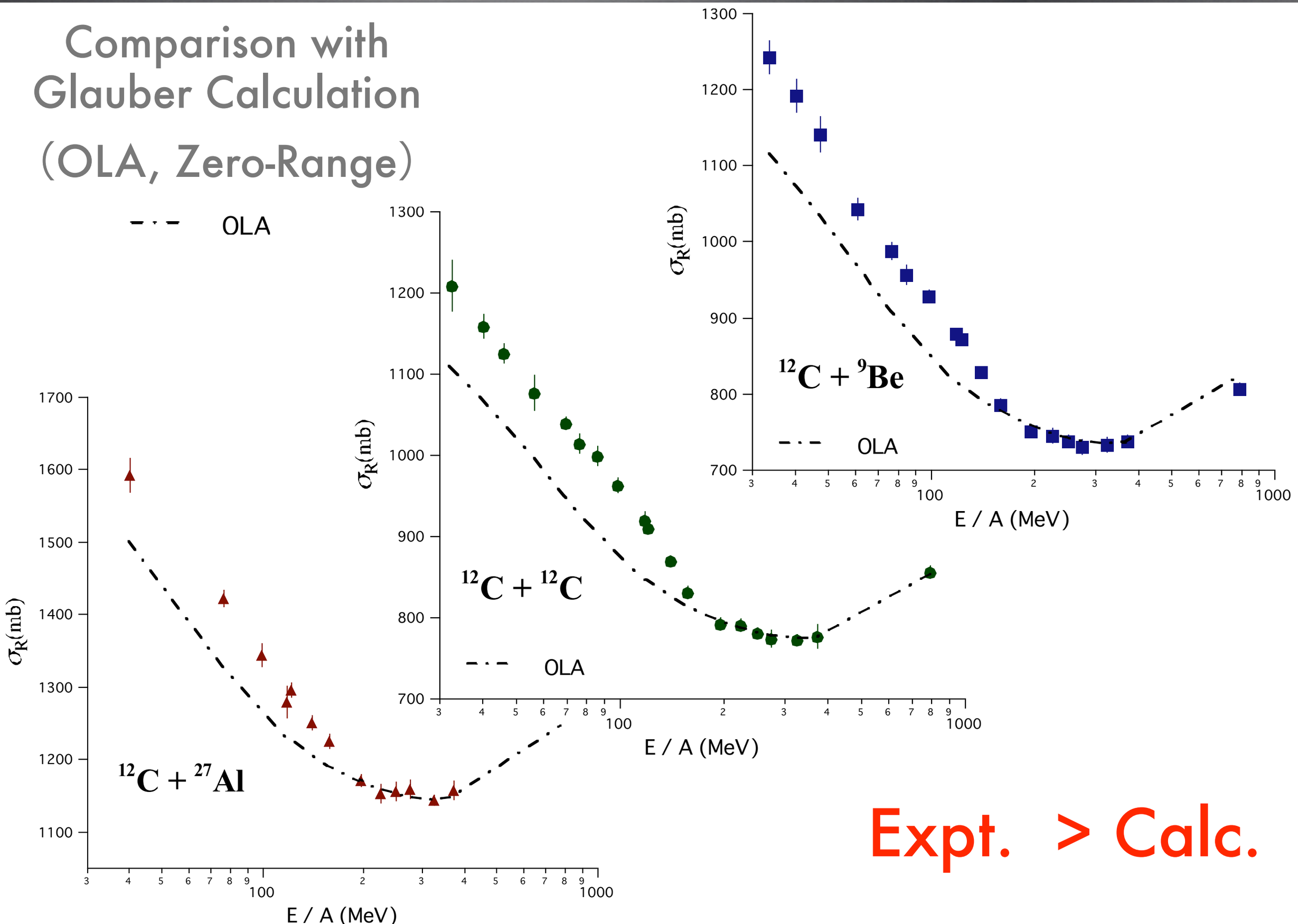
Transmission Method



$$\sigma_R = -\frac{1}{t}\ln\left(\frac{N_2}{N_1}\right)$$

Result of σ_R for ^{12}C

Comparison with Glauber Calculation (OLA, Zero-Range)



Expt. > Calc.

Improvement of Galuber Calculation ~ 3 Points ~

- *Neglect of Internal Motion of Nucleons*

  $E_{nucleon} = E_{proj}$

  → Take into Account Fermi Motion Effect

- *Optical Limit Approximation*

  Not Appropriate for Halo Nucleus

  → Take into Account Multiple Scattering Effect

  (Important for Halo Nucleus.)

  B. Abu-Ibrahim and Y. Suzuki PRC **62** (2000) 034608.

- *Zero - Range Approximation*

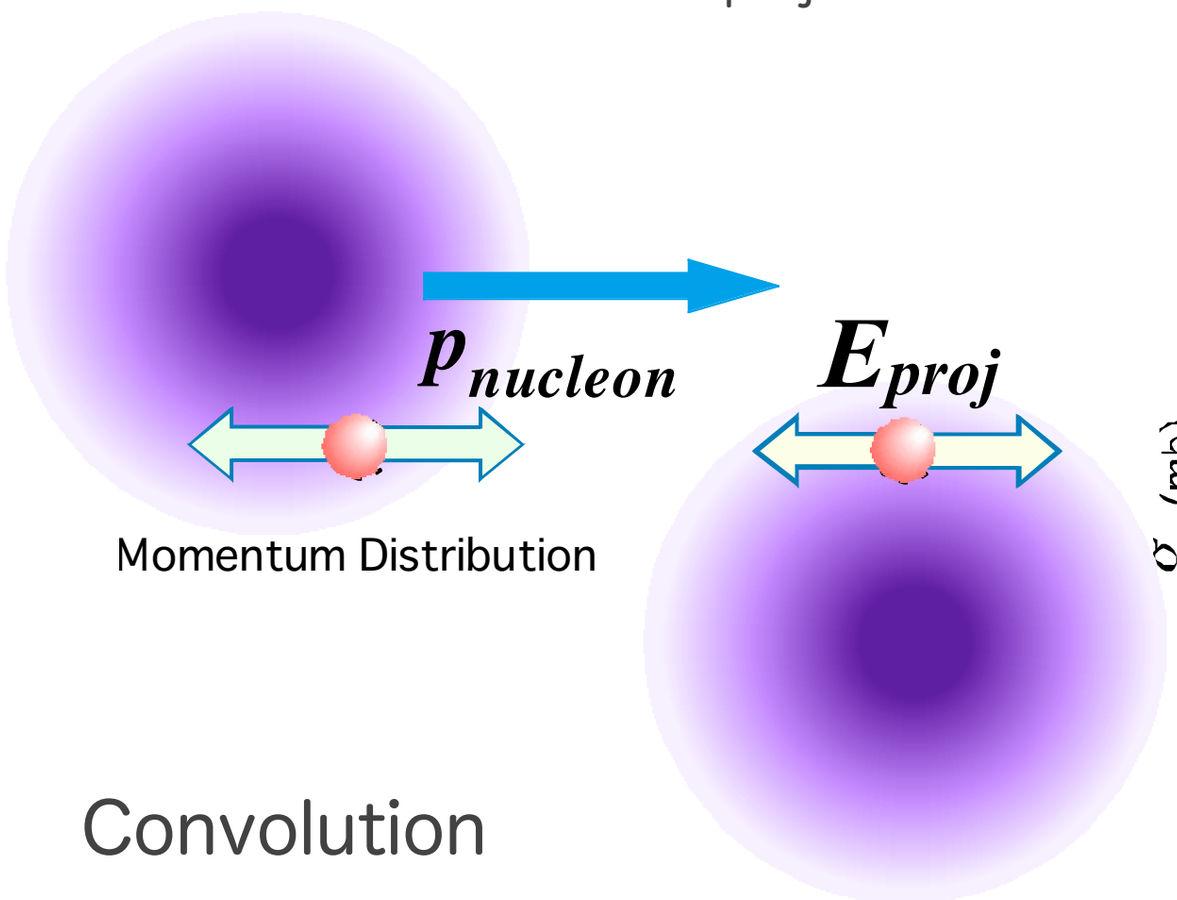
  Zero Nucleon - Nucleon Range

  → Finite Range Calculation

Modifications for Galuber Calculation ~ 3 Points ~

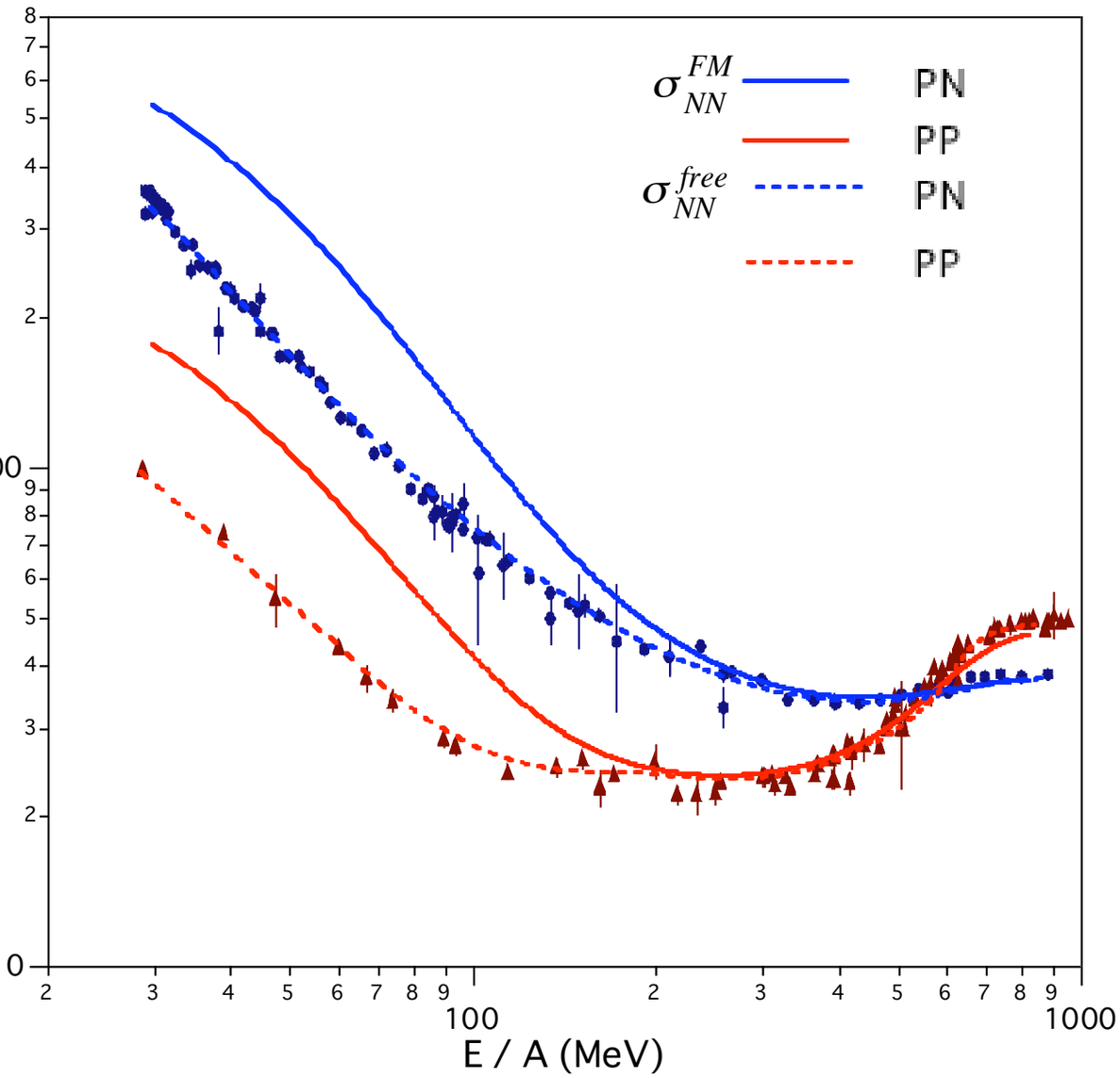
~~*Neglect of Internal Motion of Nucleons*~~

$E_{nucleon} = E_{proj}$



Momentum Distribution

Take into Account Fermi Motion Effect

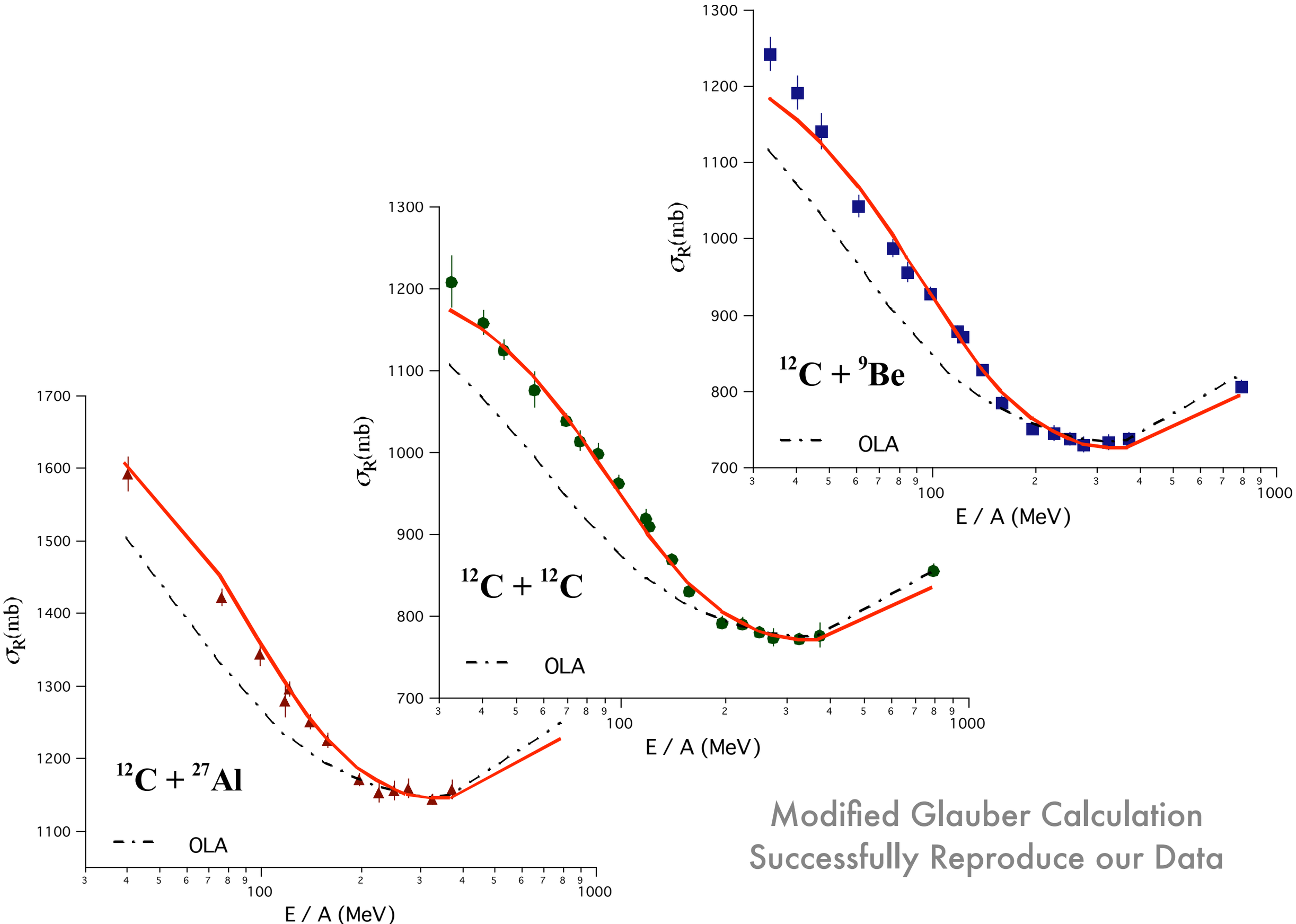


Convolution

$$\sigma_{NN}^{FM}(E_{nucleon}) = \int_{-\infty}^{+\infty} dp_{nucleon}\, \sigma_{NN}^{free}(p_{nucleon}) P(p_{nucleon})$$

Momentum Distribution

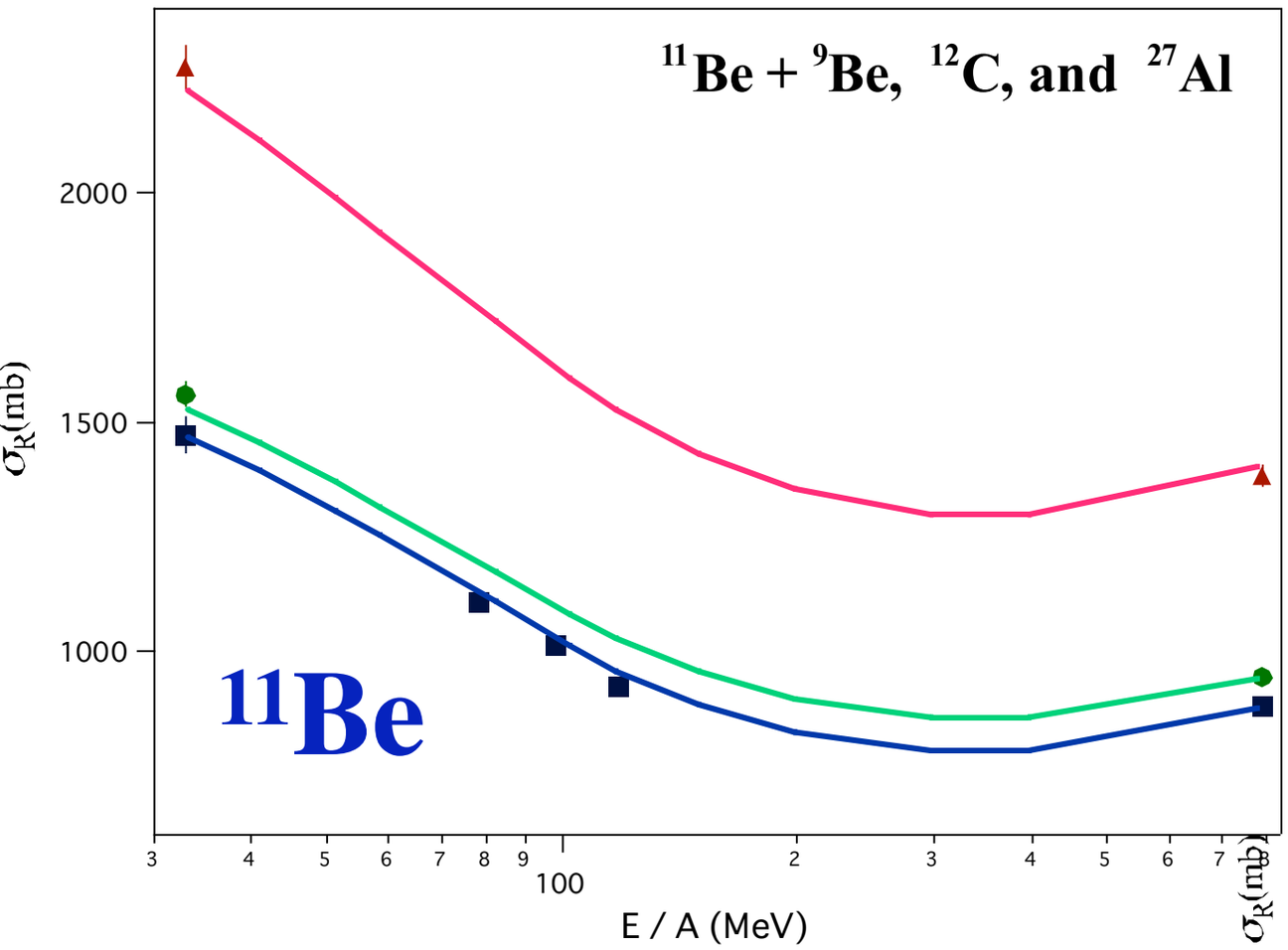
Modified Glauber Calculation and Data of ^{12}C

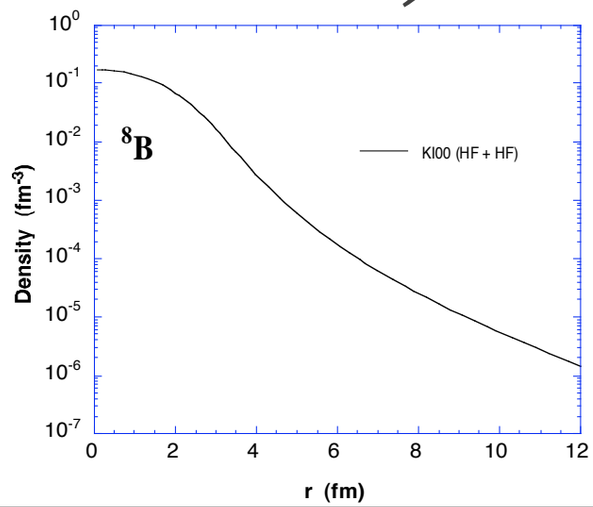


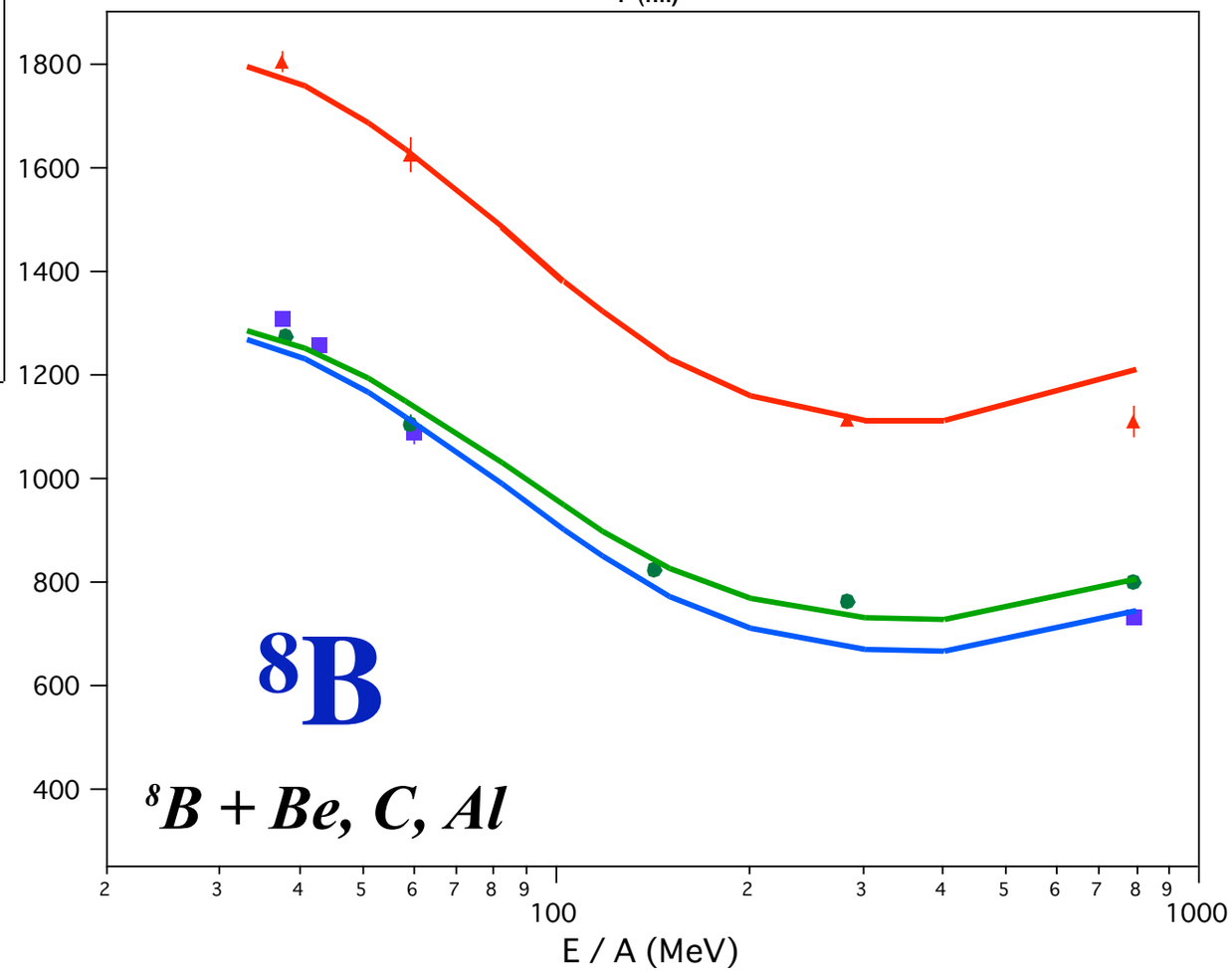
Modified Glauber Calculation
Successfully Reproduce our Data

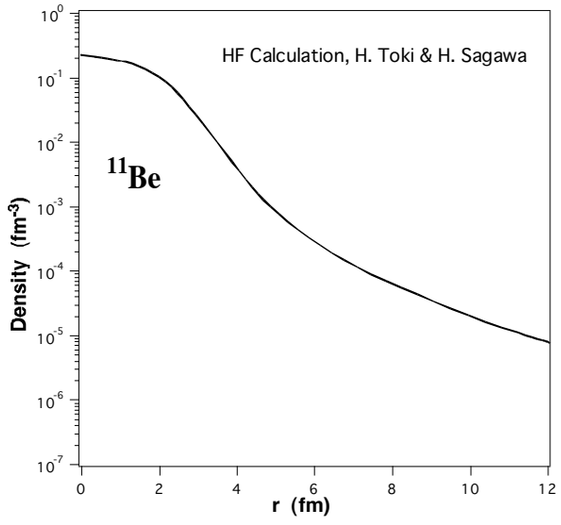
Comparison with the Data for Unstable Nuclei

Well-Known Halo Nuclei ^{11}Be, ^{8}B









HF Densities ・・・H. Sagawa and H. Toki, J. Phys. G **13**, 453 (1987). and Private Communications

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I. Tanihata et al., Phys. Lett. **206B** (1988) 592
B. Blank et al., Nucl. Phys. **A 624** (1997) 242.
M. Obuti et al., Nucl. Phys. **A609** (1996) 74.

- Modified Glauber Calculation successfully reproduces σ_R for various nuclei including halo nuclei.
  The Problem ($\sigma_{R(calc.)} < \sigma_{(RExpt.)}$) has been solved.

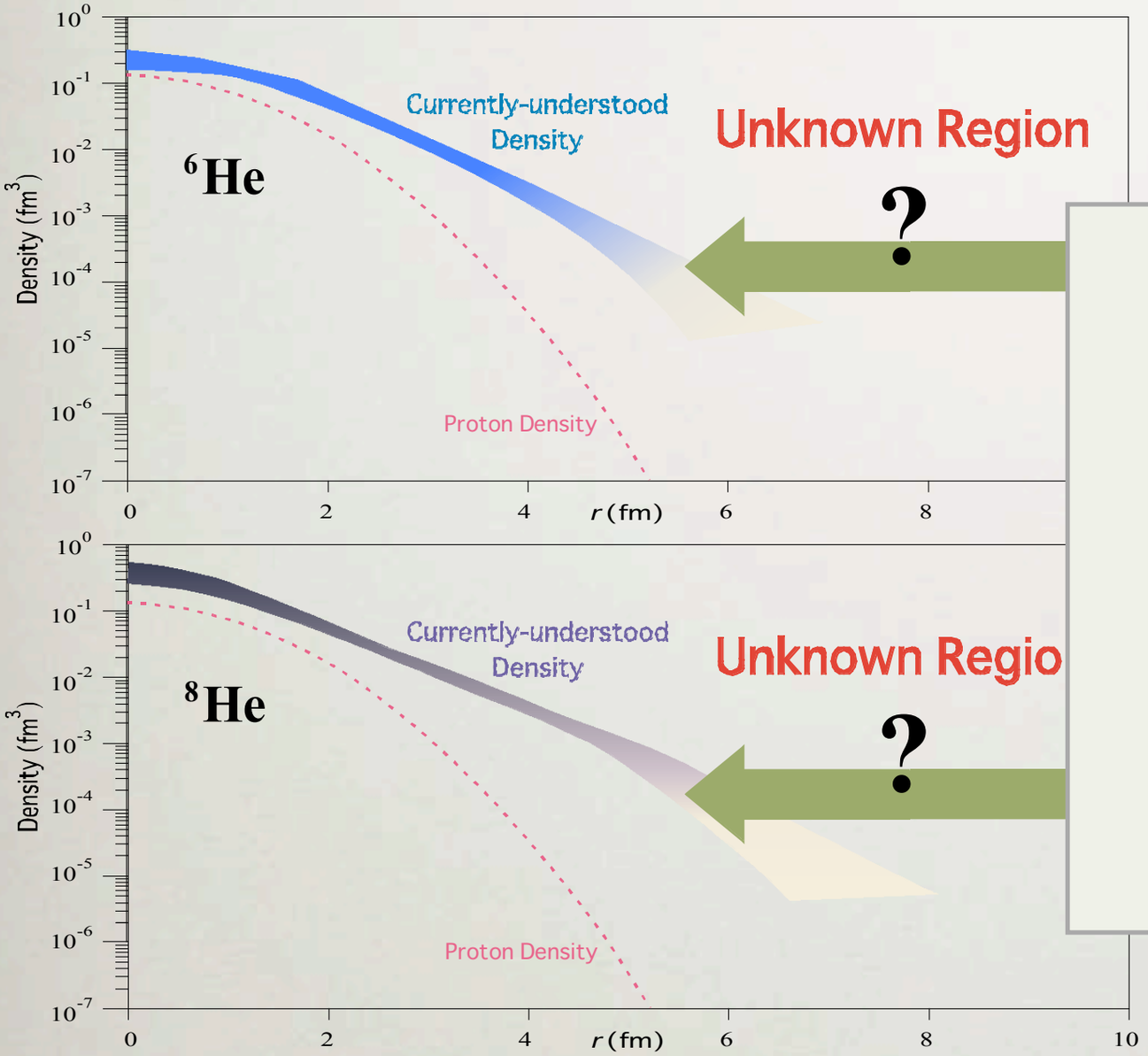
- Now we can deduce nucleon density distributions of unstable nuclei

We have already investigated several nuclei.

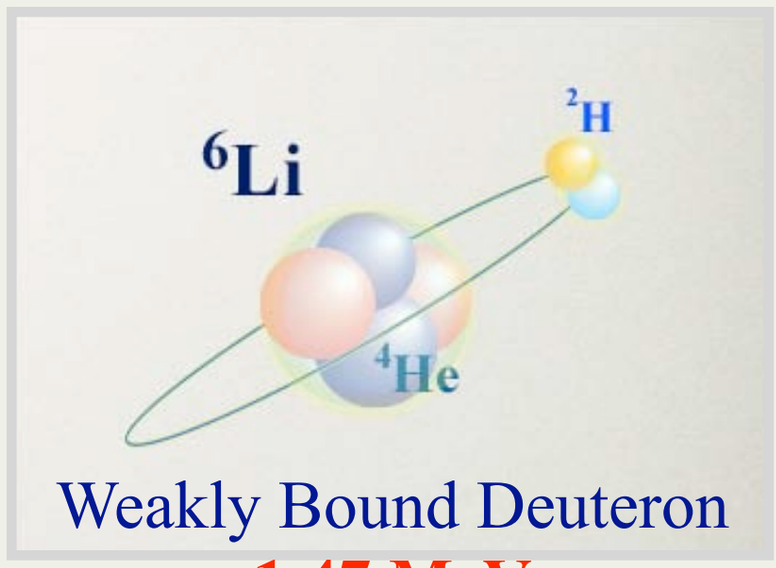
^{6}He, ^{8}He, and ^{6}Li

Skin and Halo Nuclei

^{6}He, ^{8}He so-called **Neutron-Skin Nuclei**



and ^{6}Li *Cluster Structure*



Weakly Bound Deuteron

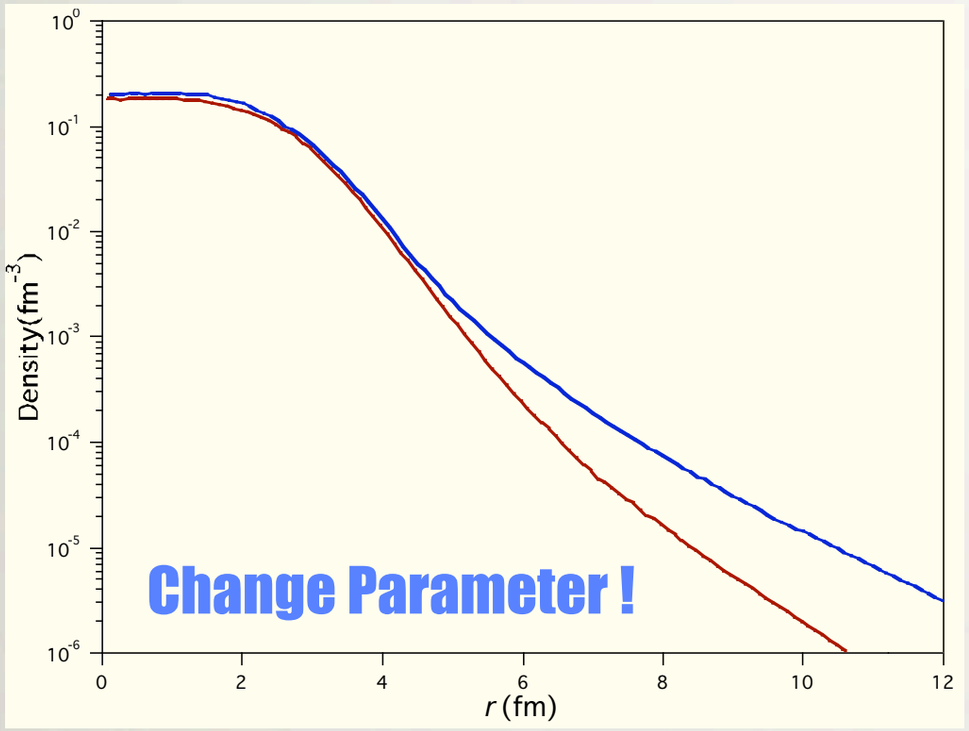
1.47 MeV

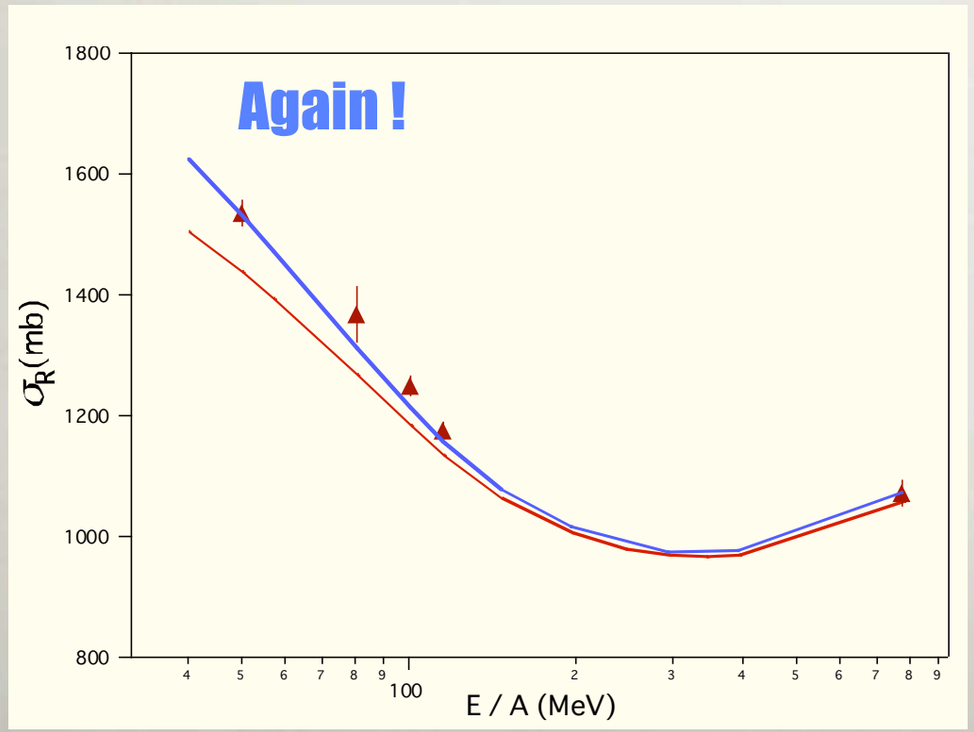
It is not Clear whether there is Halo Tail

Halo or Skin ?

How to Deduce Nucleon Density Distribution

~ χ^2 fitting procedure ~





$\rho(r)$

$\rho(r)$: Model Density

Glauber Calculation

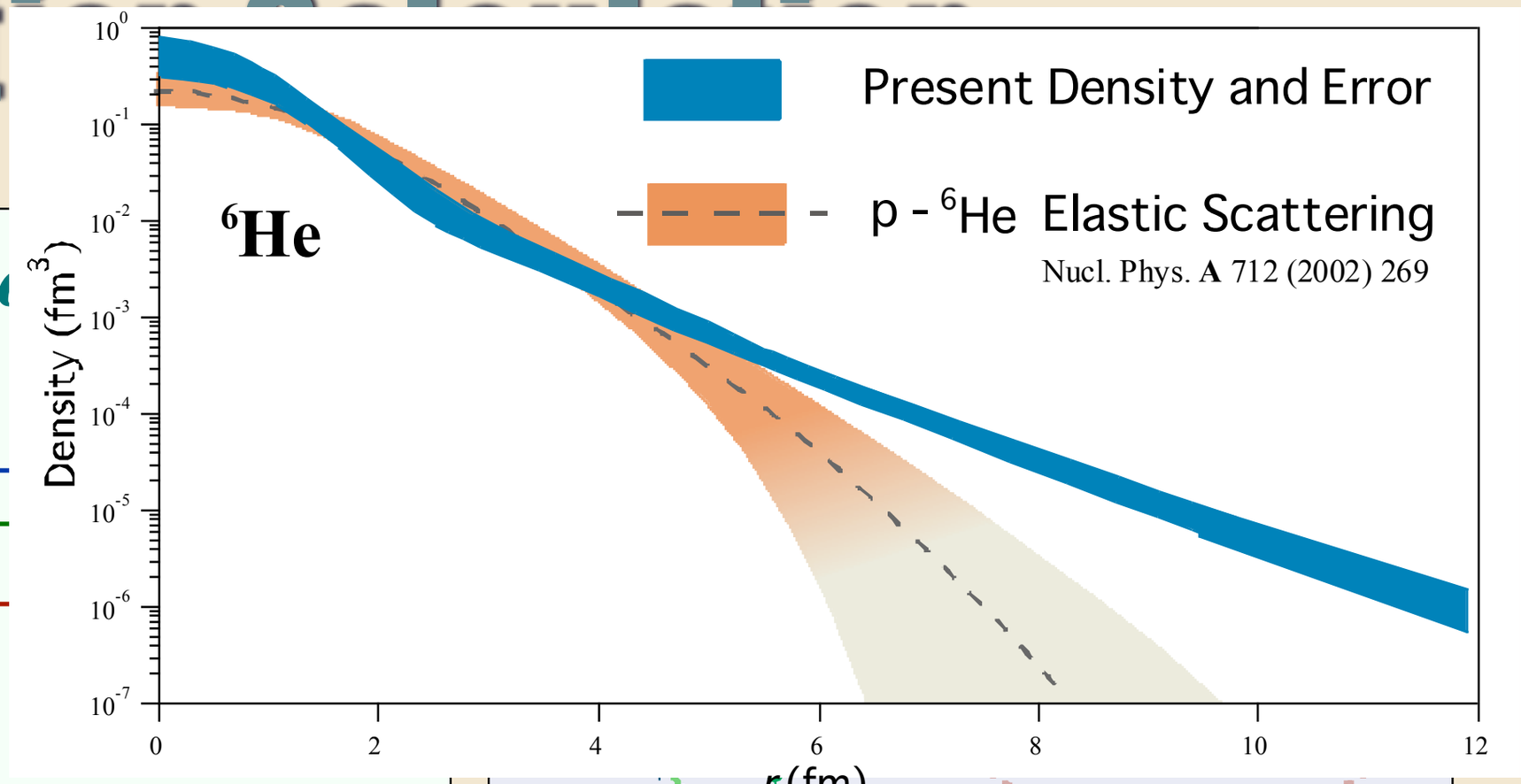
σ_R(Calc.)

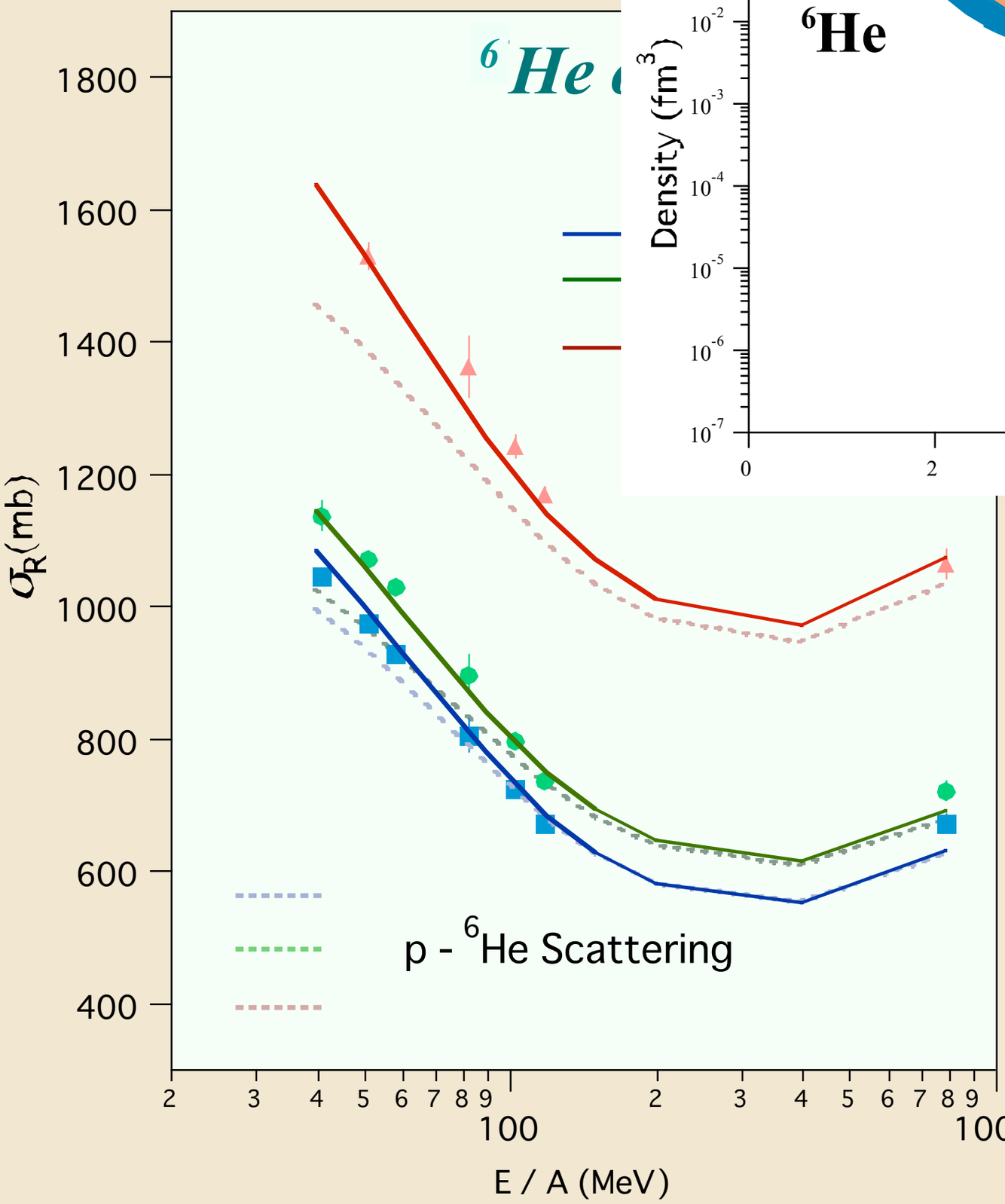
Compare

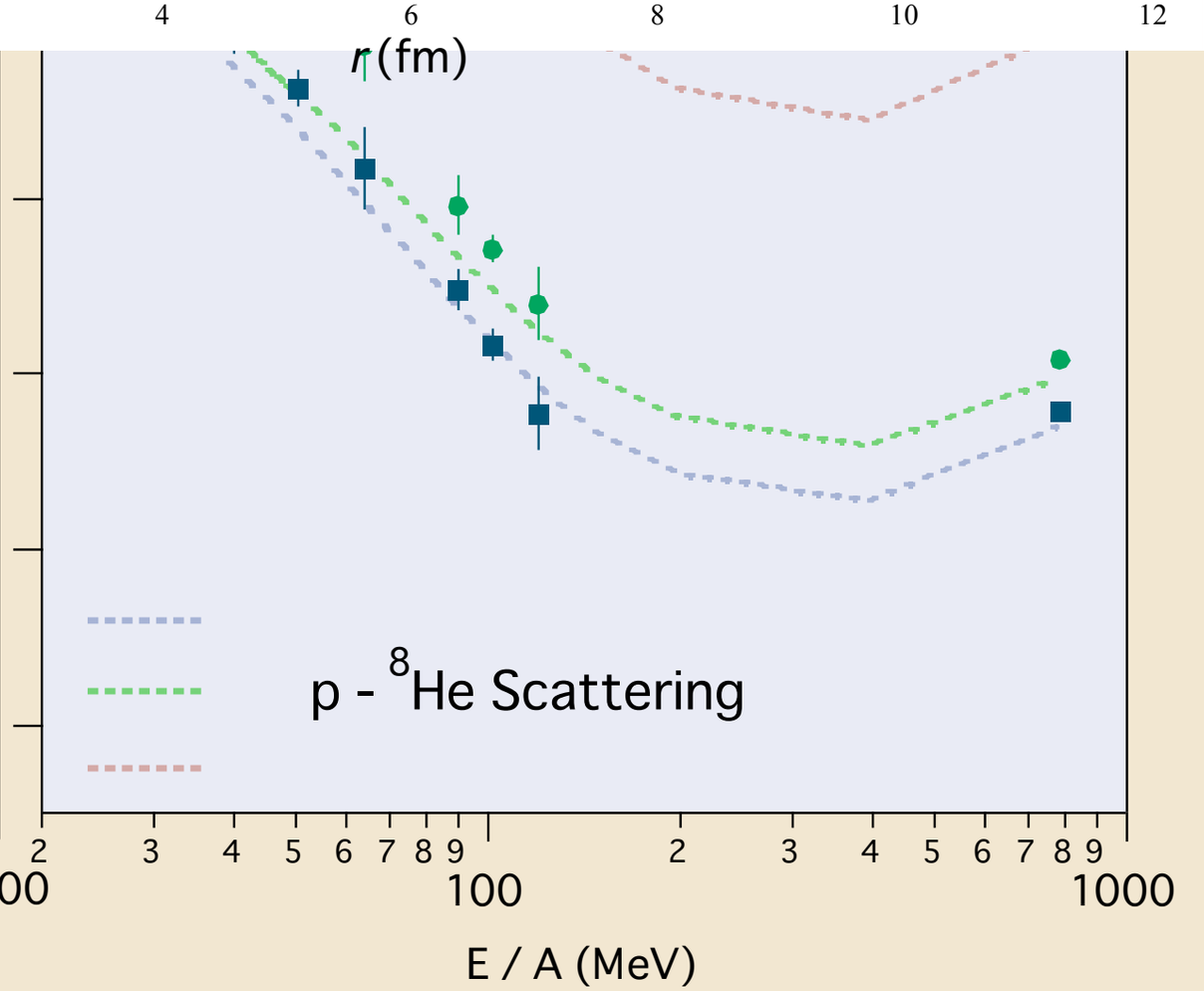
σ_R(Expt.)

Feed Back

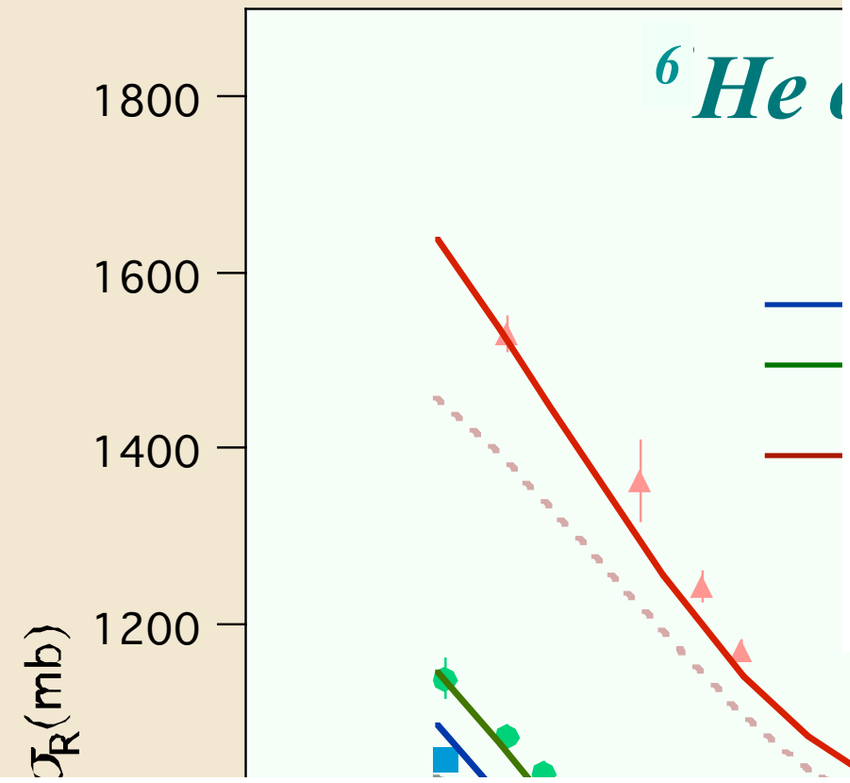
Cross Section Calculation

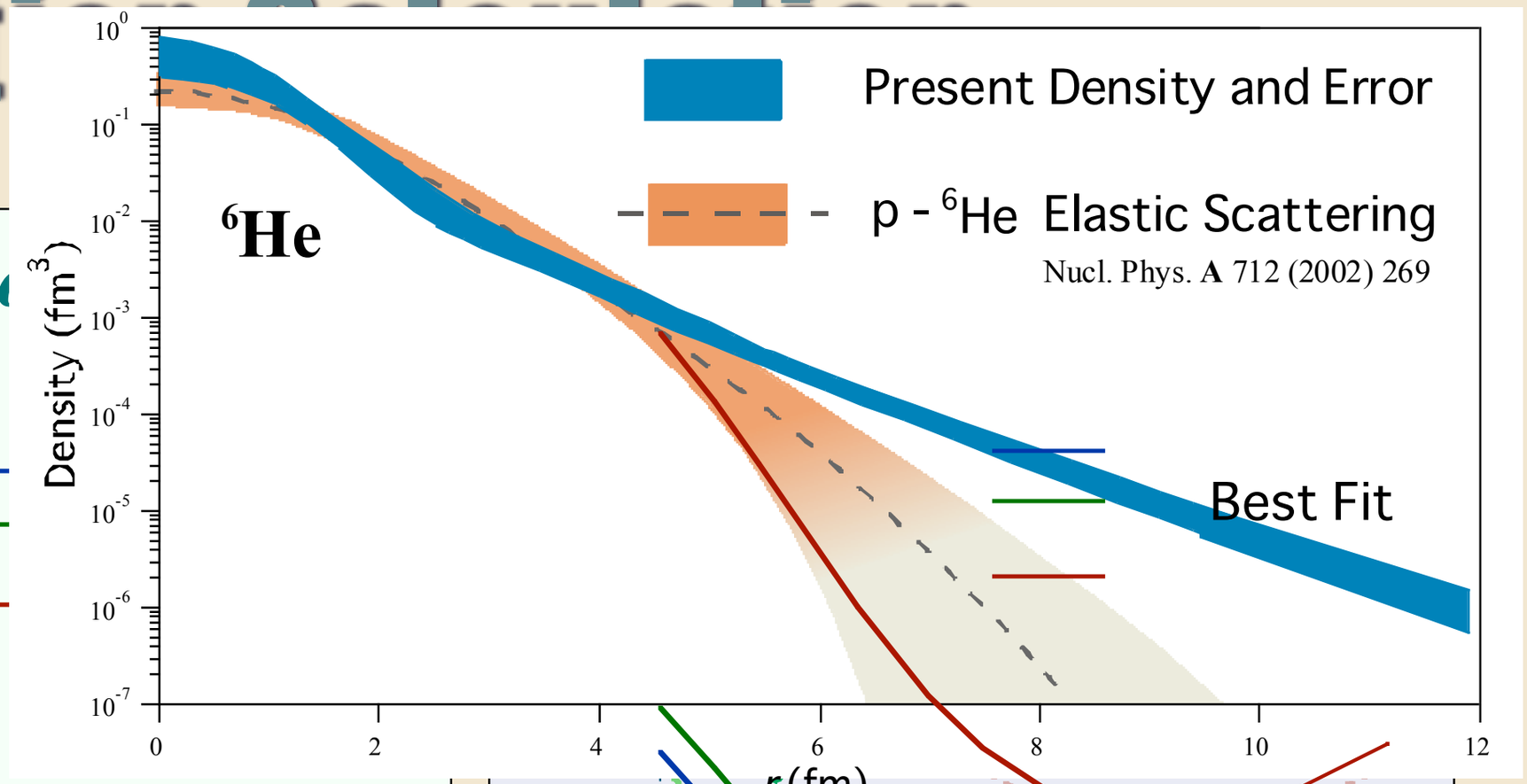


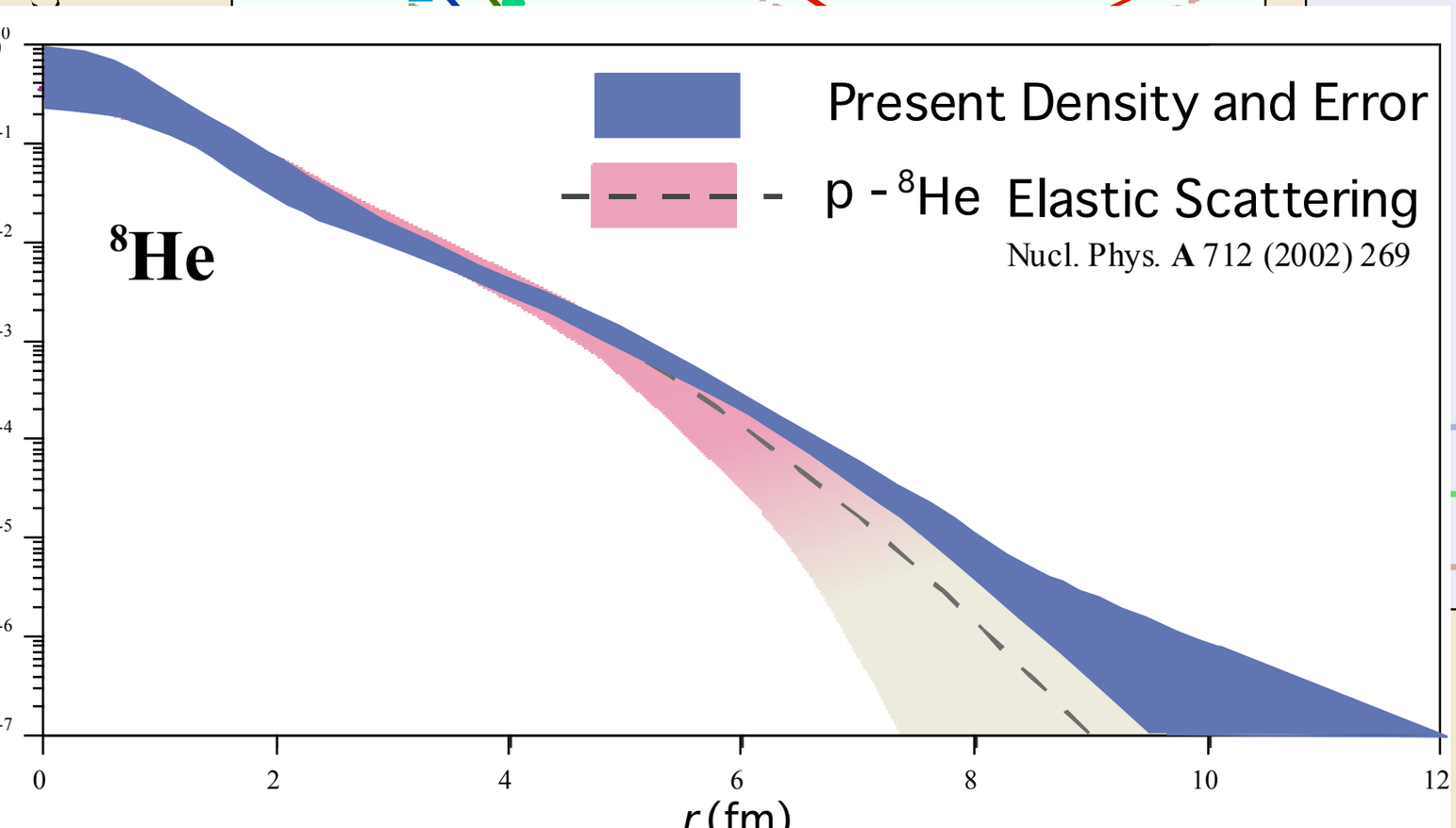


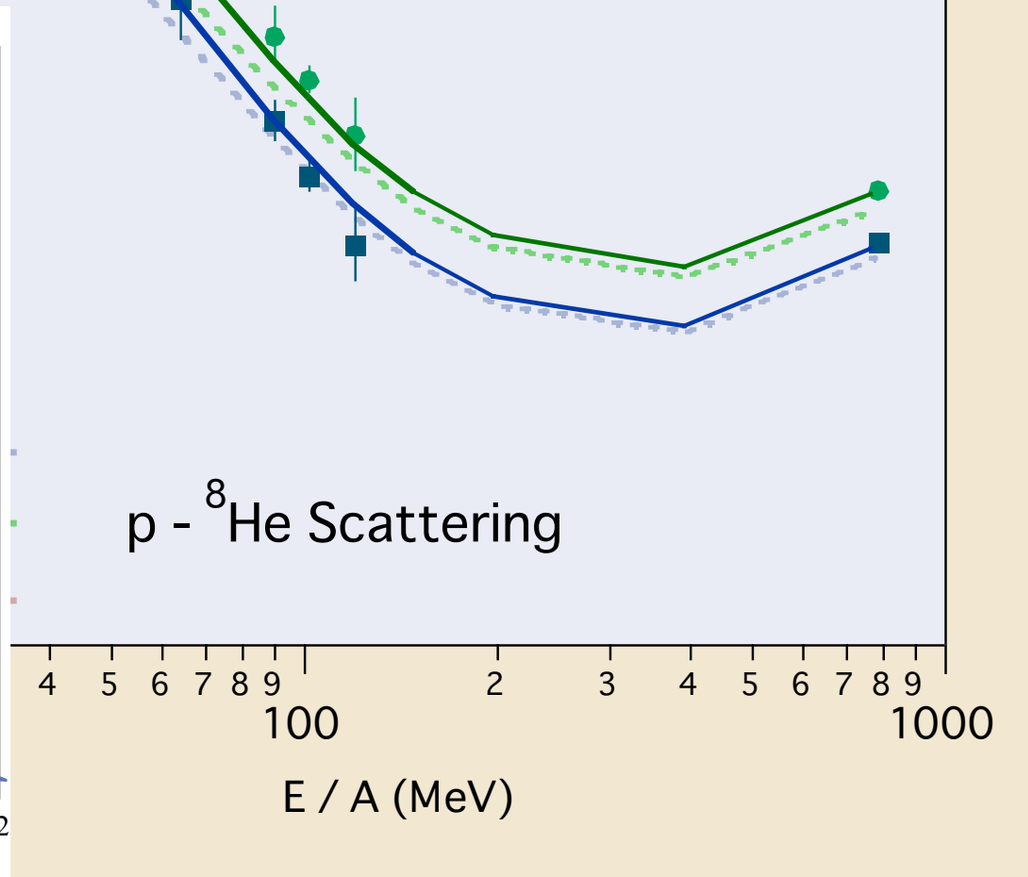


Cross Section Calculation

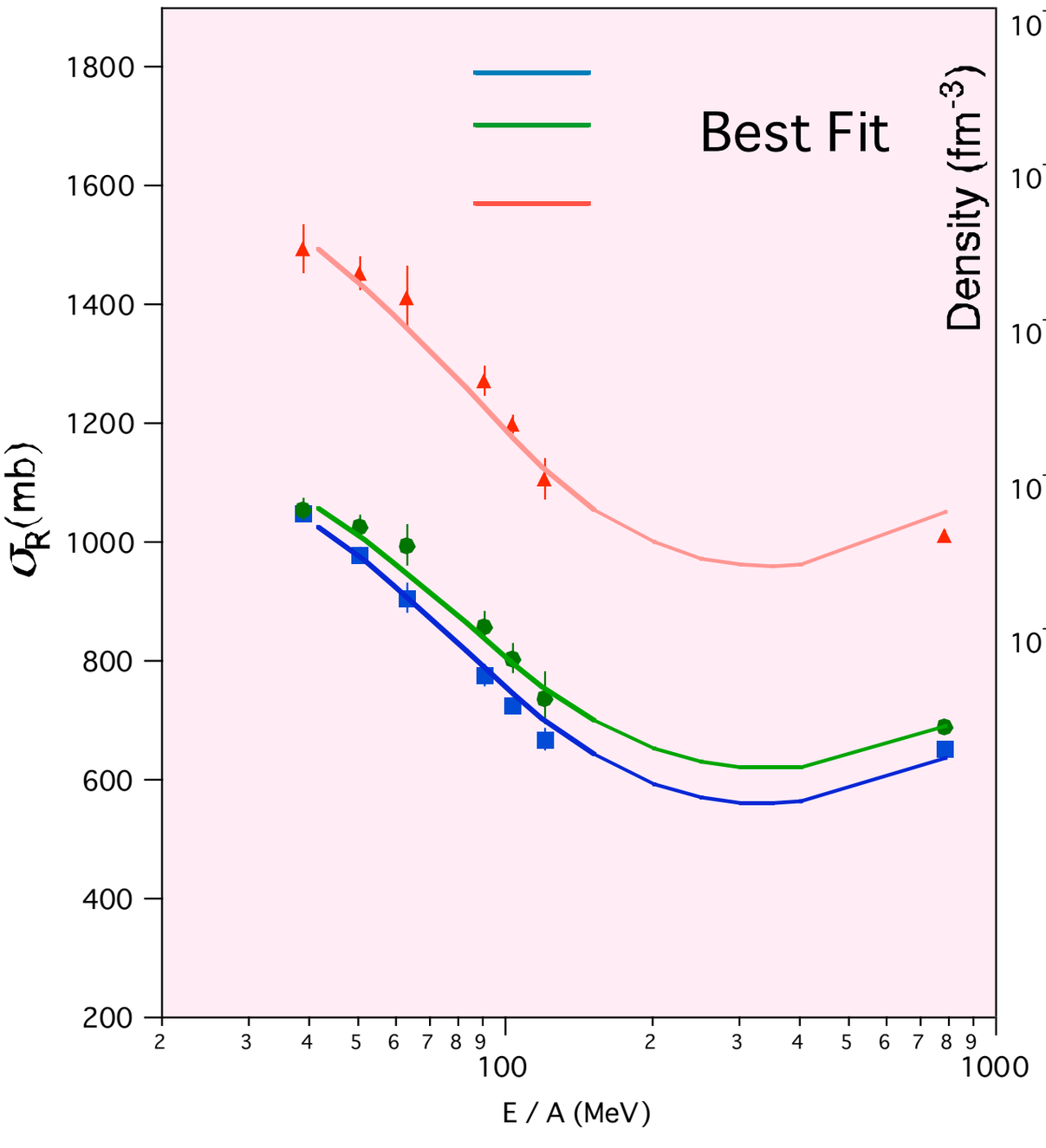


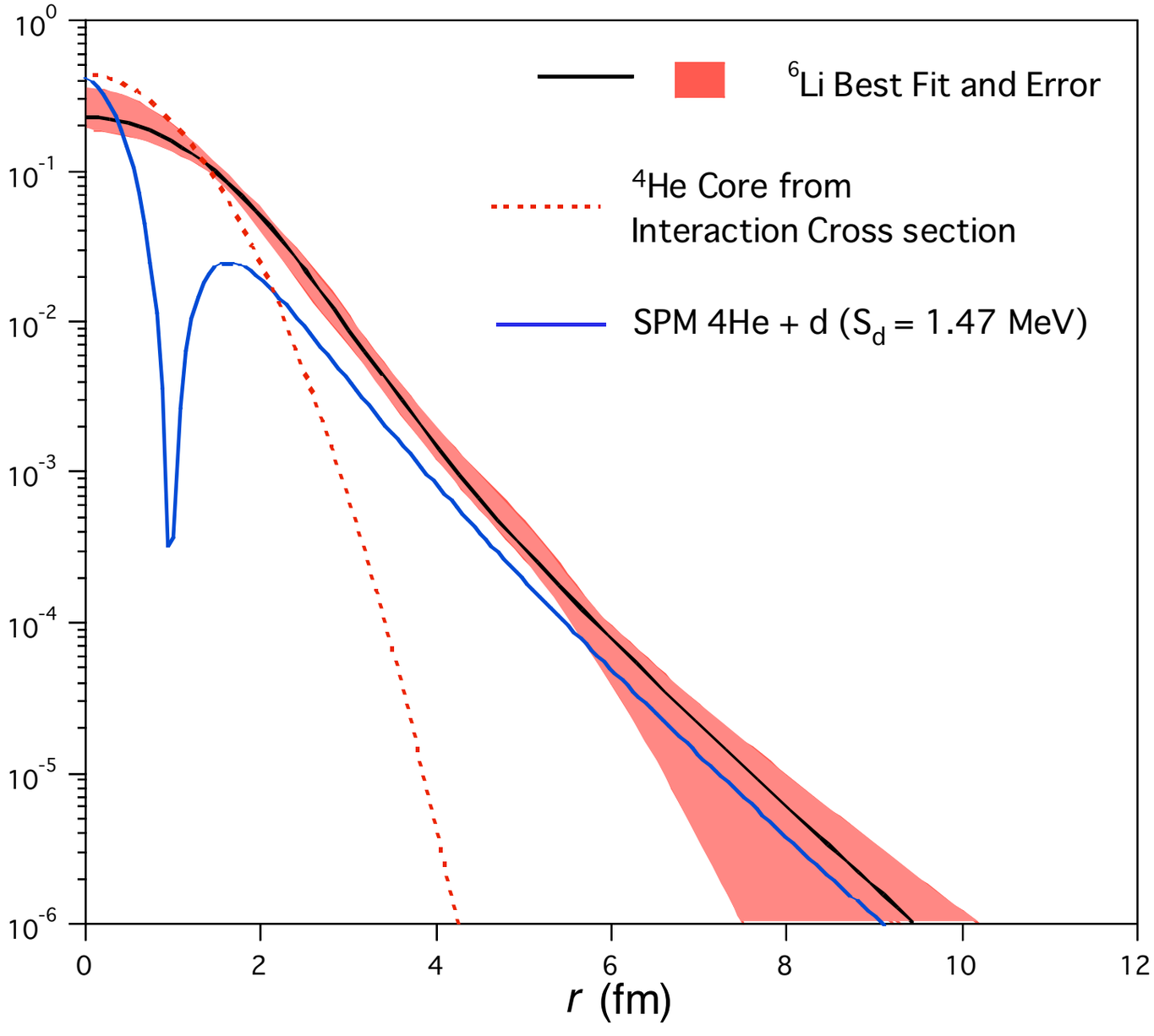






Result for ^{6}Li





Summary

- We precisely measured reaction cross sections for ^{12}C and ^{11}Be at intermediate energies to investigate the applicability of Glauber Calculation to the intermediate energy region.

- By taking into account Fermi-Motion Effect, Multiple Scattering Effect, and Finite Range Effect, Glauber Calculation successfully reproduce the data.

- Using Modified Glauber Calculation, investigations of nucleon density distributions for various nuclei will be carried out.