



Modeling
stopping with
in-medium
cross sections

B. Barker

Background

Cross section
Stopping

Motivation

Why is this
important?

Cross section
reduction
schemes

Screened

Rostock

Conclusions

Modeling nuclear stopping with in-medium nucleon-nucleon cross sections

B. Barker

National Superconducting Cyclotron Laboratory and Department of Physics
and Astronomy, Michigan State University

Research Experience for Undergraduates at MSU, 2006



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What is a cross section?

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Definition

“...the concept of a **cross section** is used to express the likelihood of interaction between particles.”

http://en.wikipedia.org/wiki/Cross_section_%28physics%29

- Visually, it is how much the nucleon sees of the other nucleon.



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What is stopping?

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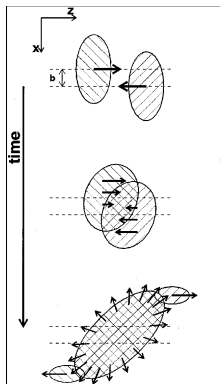
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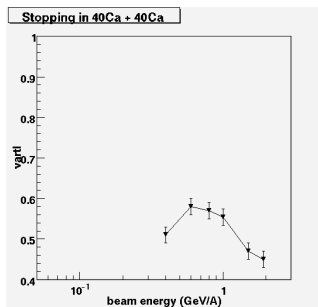
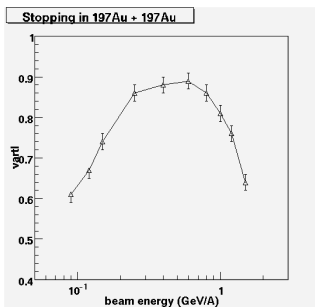


- Stages of reaction:
compression,
thermalization,
expansion, freeze-out.

Definition

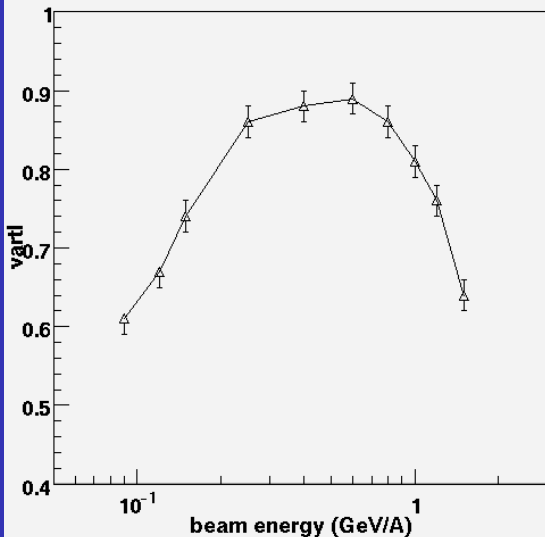
Stopping is “how much energy of the original longitudinal motion is transferred into internal degrees of freedom in the course of the reaction.” Annu. Rev. Nucl. Part. Sci. 1999. 49:581-632

- v_{artl} , “the ratio of the variances of the transverse to that of the longitudinal rapidity distributions.” W. Reisdorf *et al.*, *Phys. Rev. Lett.* **92**, 232301 (2004) [FOPI]

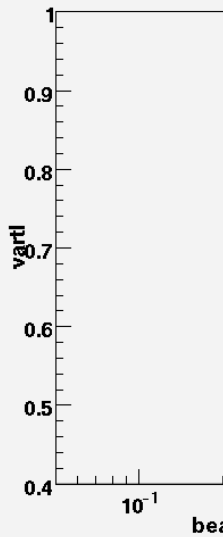


Stopping observable: v_{art}

Stopping in $^{197}\text{Au} + ^{197}\text{Au}$



Stopping in ^{40}Ca



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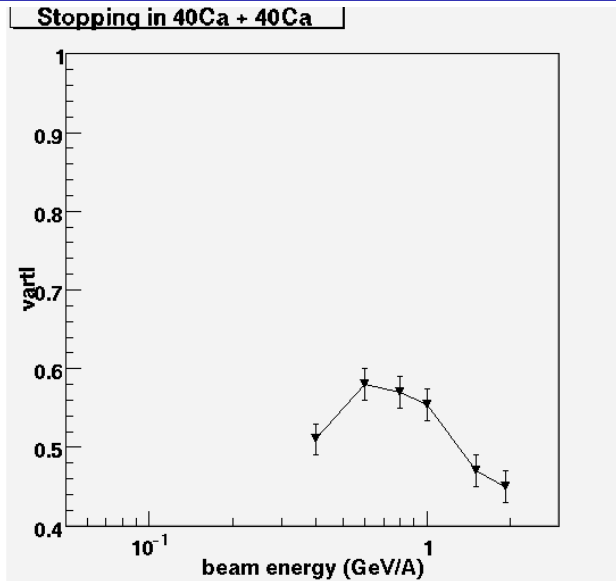
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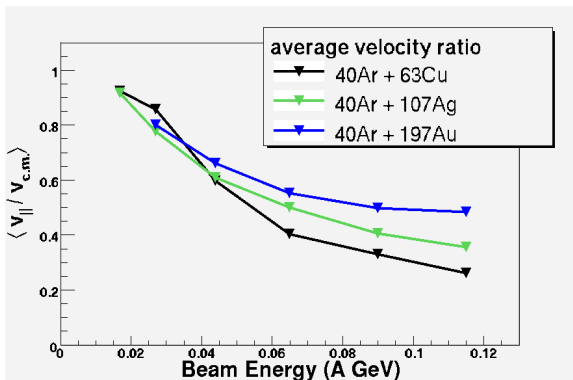
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- *average velocity ratio*, the ratio of the average velocity of the heaviest fragment group ($A > 50$) to the velocity of the center of mass. E. Colin *et al.*, *Phys. Rev.* **C57**, R1032 (1998) [Stony Brook]





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Cross section is tied to transport properties

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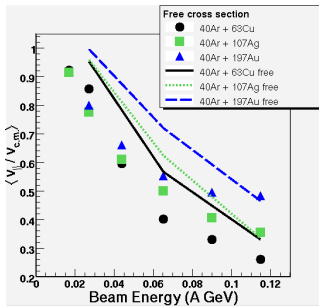
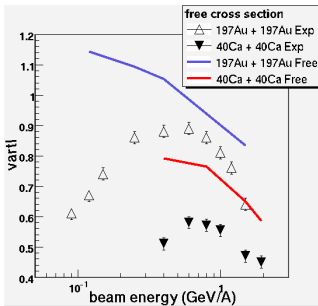
Conclusions

- Transport properties (viscosity, heat conduction) are fundamental and tied to in-medium interactions, like the cross section.
- important for understanding and modeling reactions

Theorem

There are no in-medium effects, and the interaction occurs as in free space.

- Calculating stopping with a BUU simulation yields:



Null hypothesis: free cross section

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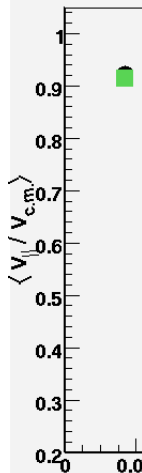
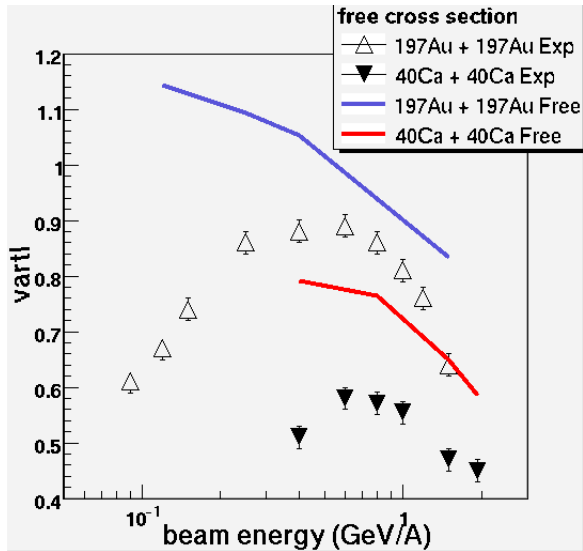
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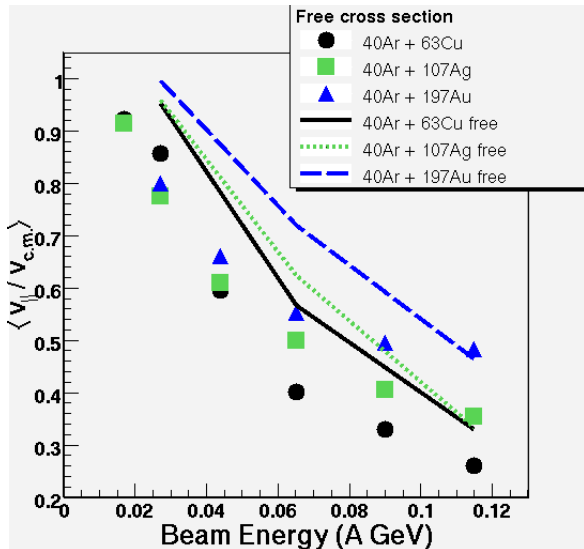
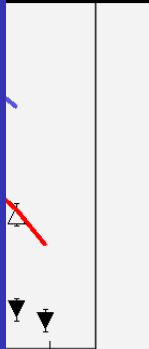
Free cross section

$^{40}\text{Ar} + ^{197}\text{Au}$ Exp

$^{40}\text{Ar} + ^{40}\text{Ca}$ Exp

$^{40}\text{Ar} + ^{197}\text{Au}$ Free

$^{40}\text{Ar} + ^{40}\text{Ca}$ Free





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Geometric cross section reduction

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Theorem

The geometric cross section should not exceed the interparticle distance,

$$\sigma_0 \lesssim y\rho^{-2/3}$$

where ρ is the nuclear density and y is some factor on the order of 1.

- For calculations,

$$\sigma = \sigma_0 \tanh(\sigma_{\text{free}}/\sigma_0)$$

P. Danielewicz, *Acta Physica Polonica* **B33**, 45 (2002)

Screened: Results

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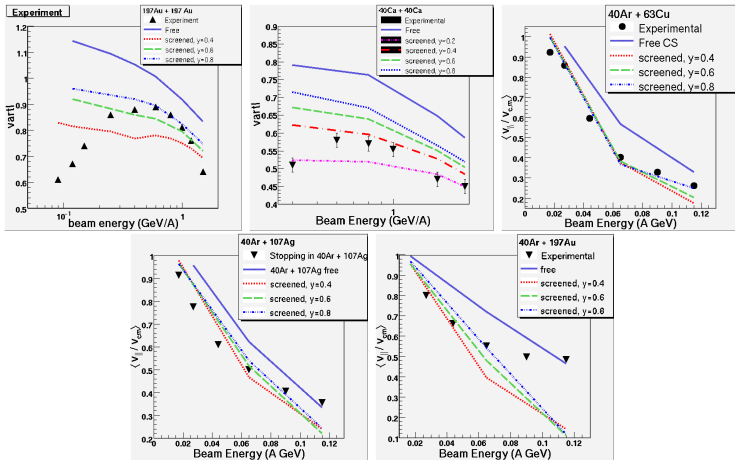
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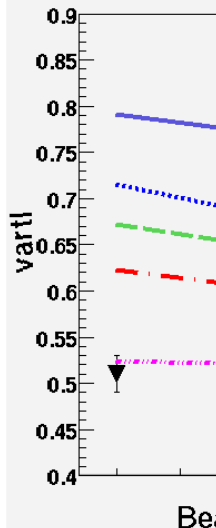
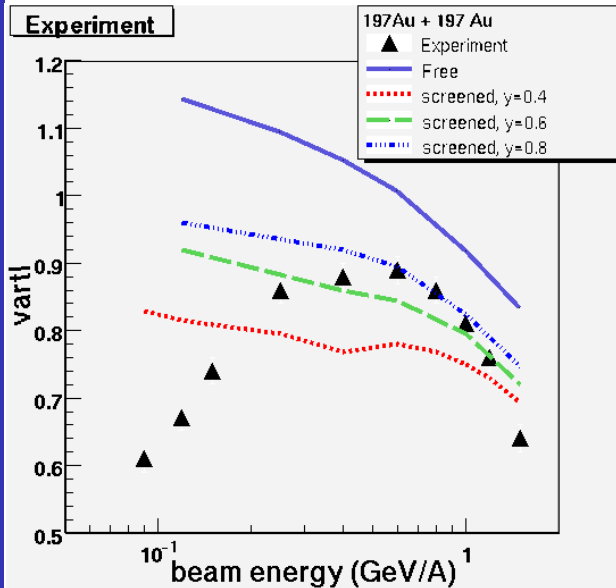
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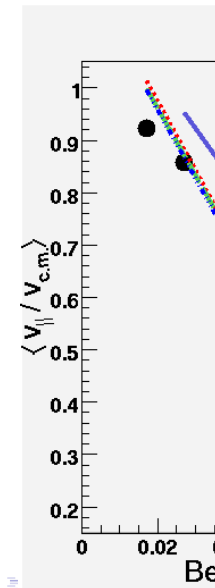
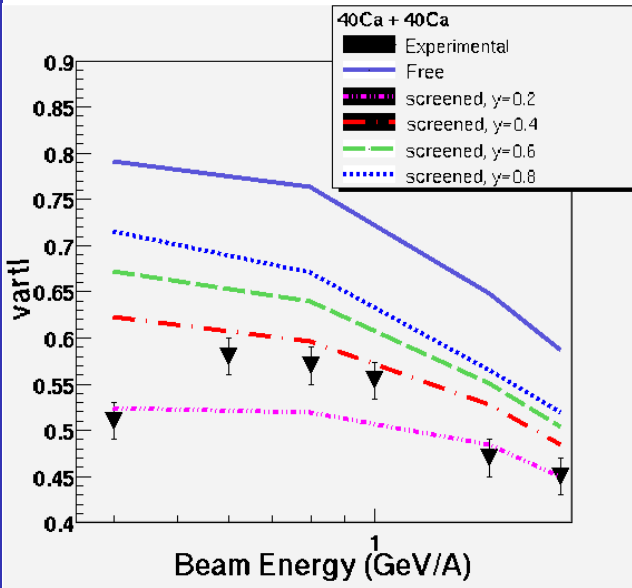
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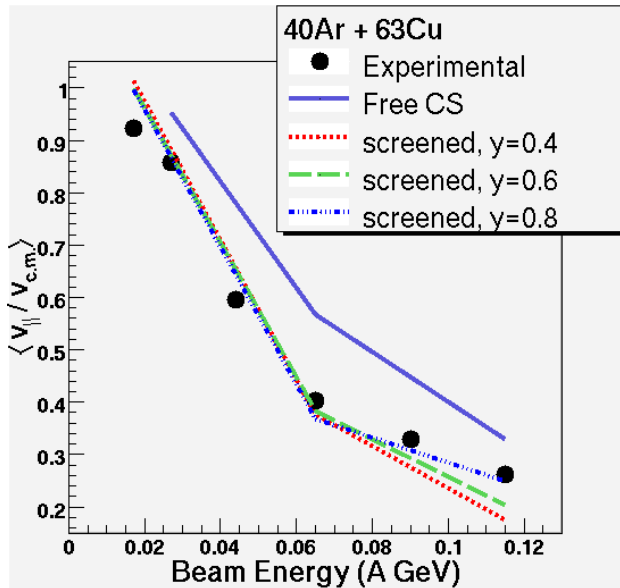
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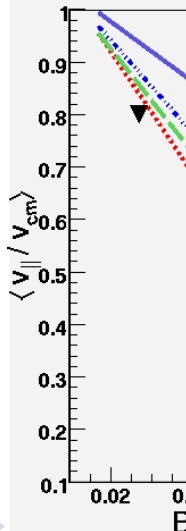
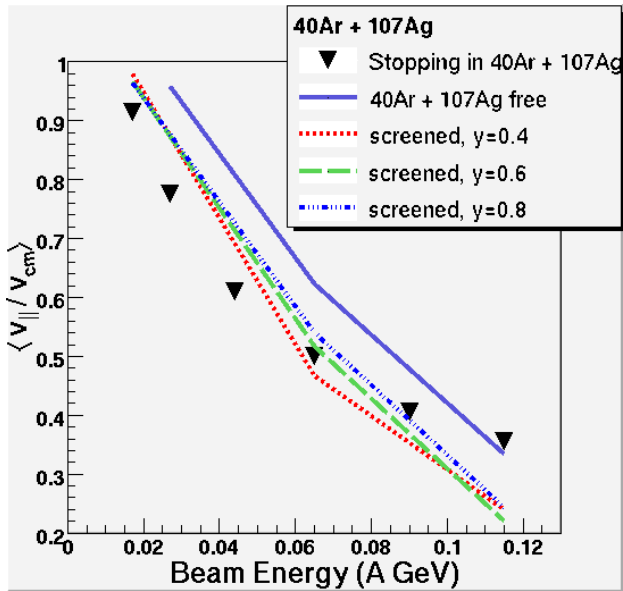
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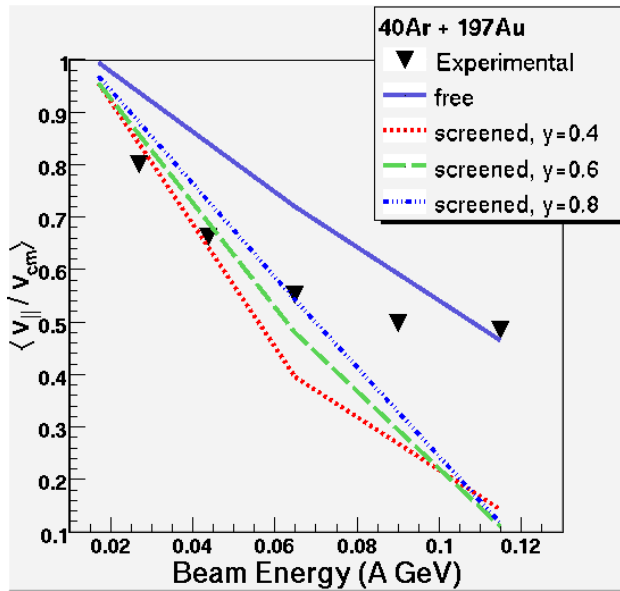
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Including the Pauli principle

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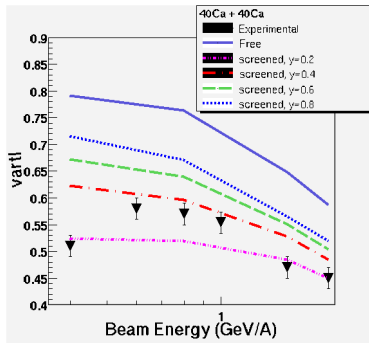
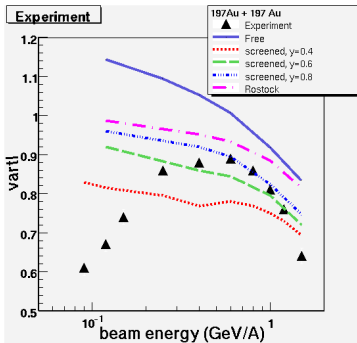
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Conclusions

- Maybe better to include Pauli principle and single-particle energy modifications for intermediate states
- Use parameterization of the Rostock group's calculations,

$$\sigma = \sigma_{\text{free}} \exp \left(-0.6 \frac{\rho}{\rho_0} \frac{1}{1 + (T_{\text{c.m.}}/150 \text{ MeV})^2} \right)$$





Results: vartl

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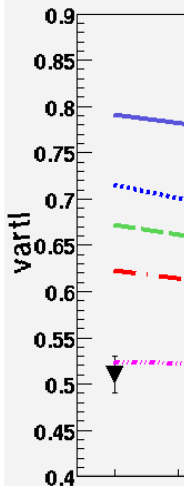
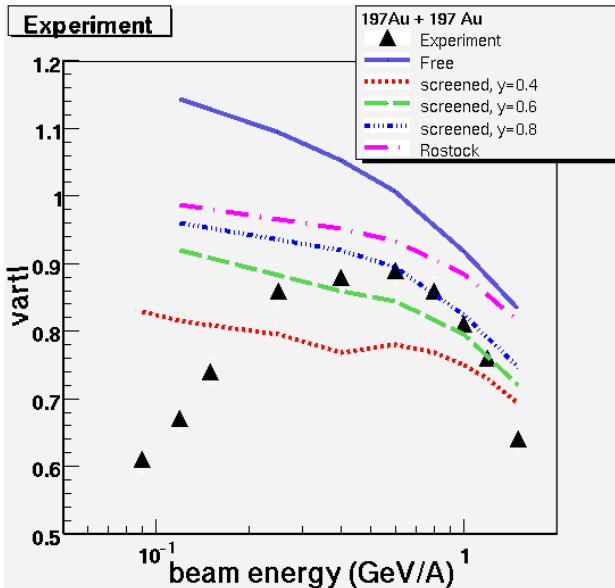
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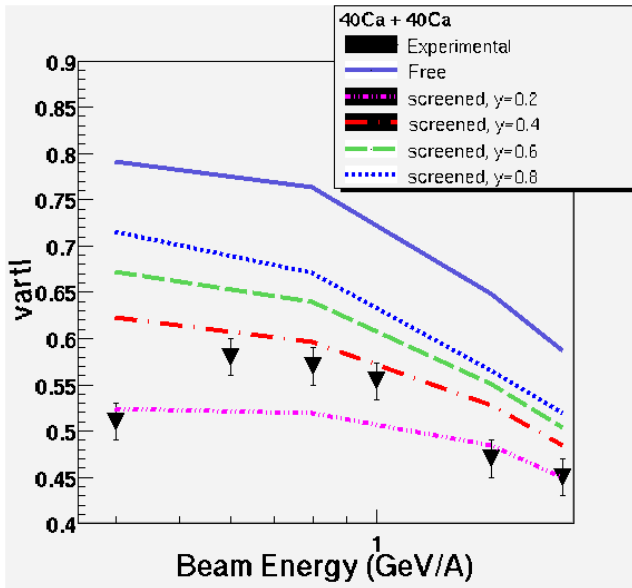
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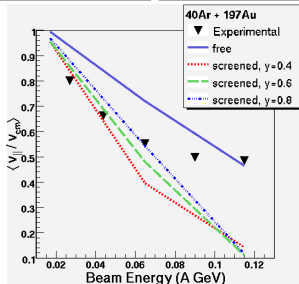
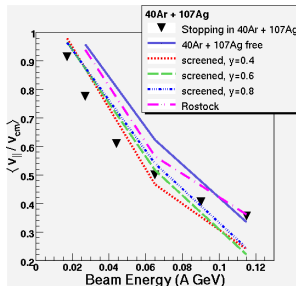
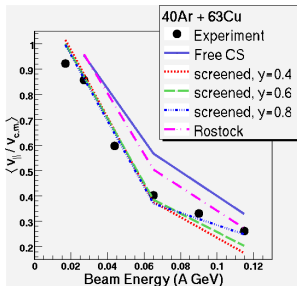
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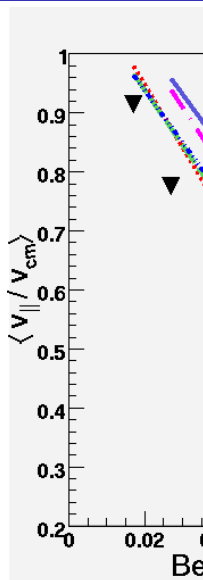
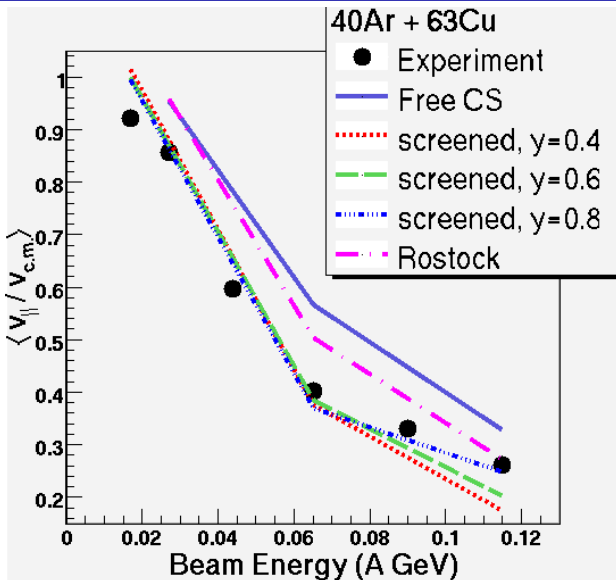
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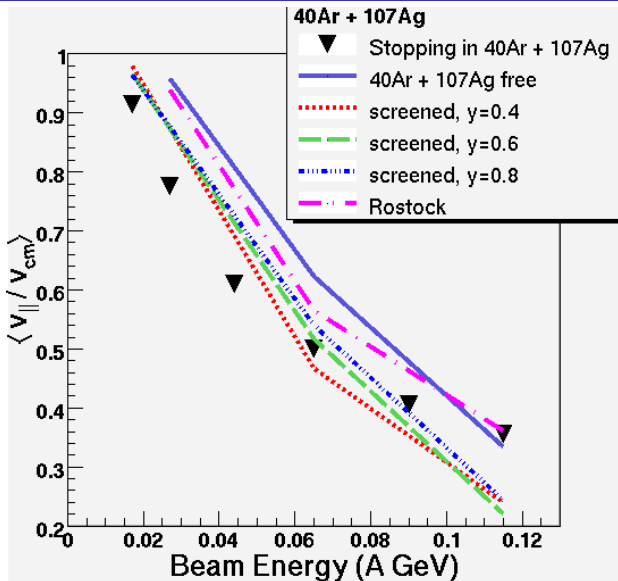
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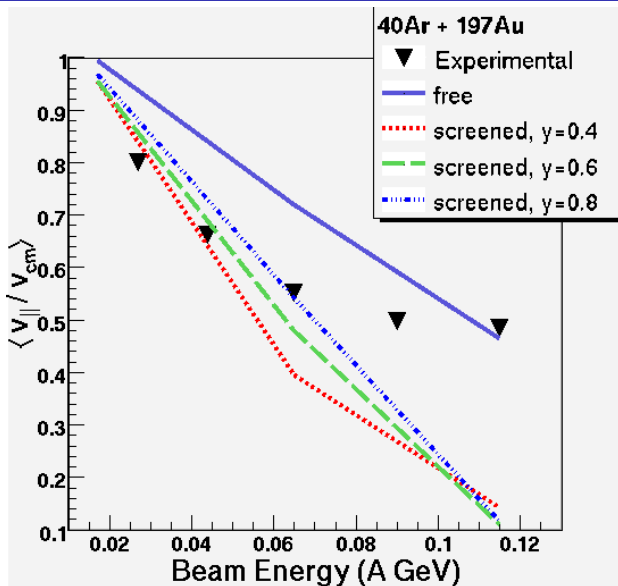
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Conclusions

- Free cross sections are insufficient to describe the data. A reduced cross section model describes the data better.

Therefore

Therefore, stopping is affected by in-medium effects.

- Gross features of the reduced cross section are determined, but more details need to be probed.