Evaluation of inclusive breakup in reactions induced by weakly-bound nuclei within a three-body model

An old theory, but new stories

Jin Lei, A.M. Moro
Departamento de FAMN, Universidad de Sevilla,
Apartado 1065, 41080 Sevilla, Spain.

Outline

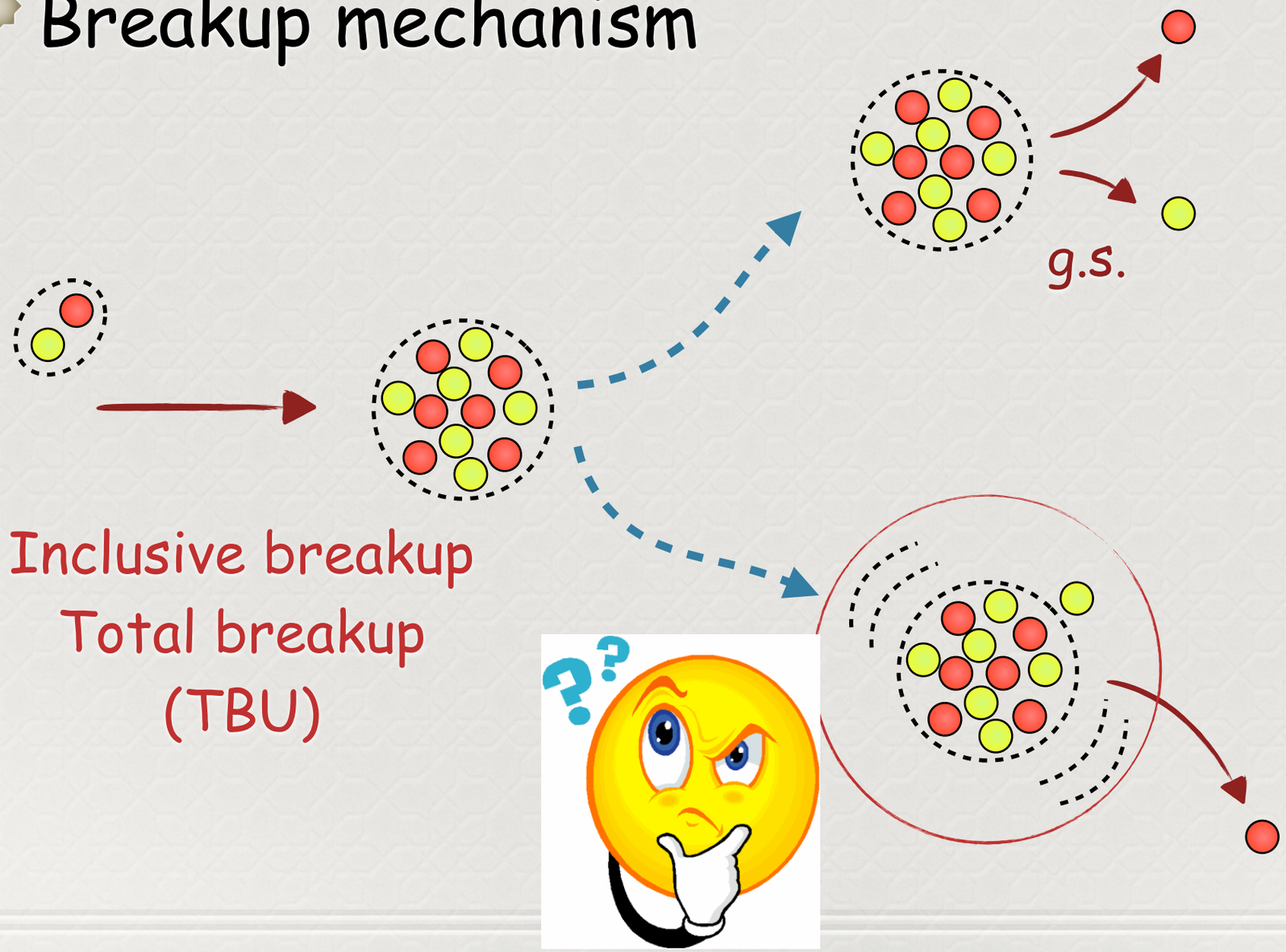
- An Old Theory
  - Introduction
  - Ichimura-Austern-Vincent Model
- New Stories
  - Related Topics
  - Applications

An Old Theory

Introduction

CDCC-FRESCO 😀

- Breakup mechanism



Elastic breakup
(EBU)
"Diffraction"

Inclusive breakup
Total breakup
(TBU)

Target excitation
Partial fusion
Any possible state

Non-elastic breakup
(NEB)
"Stripping"

Theories for inclusive breakup

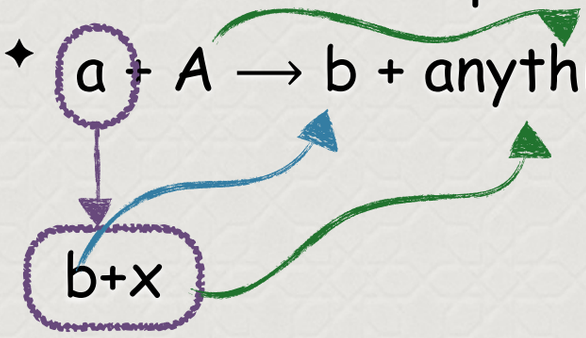
- **Prior Form**
  - Kerman, McVoy(KM)
    - Ann. Phys. (N.Y.) 122, 197 (1979)
  - Udagawa, Tamura(UT)
    - Phys. Rev. C 24, 1348 (1981)
    - Phys. Rev. C 30, 1895 (1984)
- **Post Form**
  - Baur & co: surface approximation
    - Nucl. Phys. A311, 141 (1978)
  - Ichimura, Austern, Vincent(IAV):sum rule
    - Phys.Rev. C 32, 431 (1985)
    - Phys. Rep. 154, 125 (1987)
- **Spectator Model**
  - Hussein, McVoy
    - Nucl. Phys. A 445, 124 (1985)

30 years old!!!😂

The old theory

IAV Model

- Inclusive breakup :
  - a + A ⟶ b + anything → (x+A)*



unbound/bound states

x,A ground states
Elastic Breakup

x,A excited states
Inelastic Breakup

particle transfer
between x and A

x absorbed by A
incomplete fusion

- Inclusive differential cross sections :

$$\sigma_b^{TBU} = \sigma_b^{EBU} + \sigma_b^{NEB}$$

CDCC

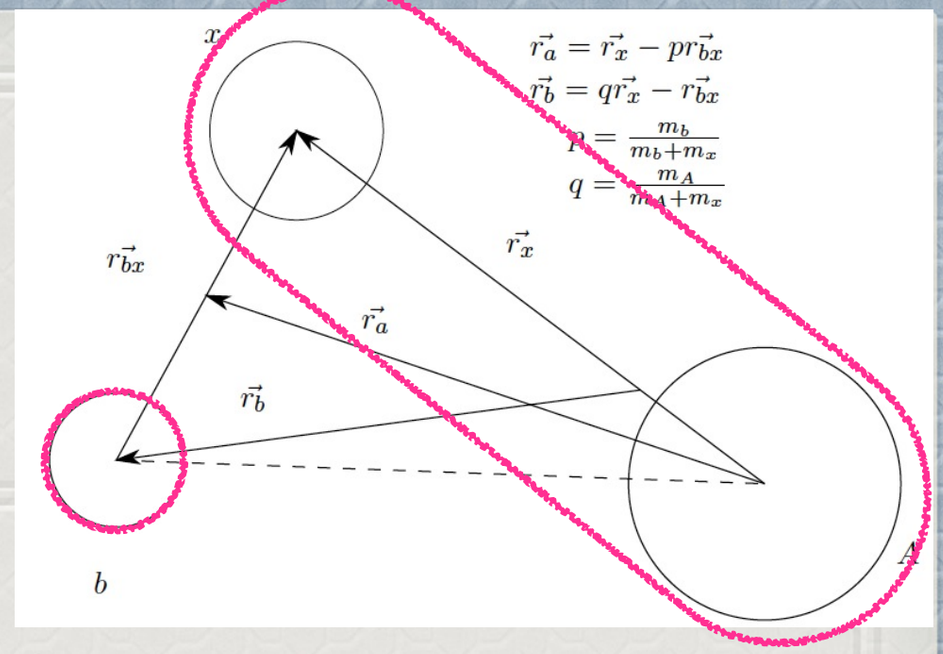
- Post form expression for inclusive breakup

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega_b \mathrm{d}E_b} = \frac{2\pi}{\hbar \upsilon_a} \rho(E_b) \sum_c \left| \left\langle \chi_b^{(-)} \Psi_{xA}^{c,(-)} \middle| V_{bx} \middle| \Psi^{(+)} \right\rangle \right|^2 \delta(E - E_b - E^c)$$

Nonelastic breakup

exact many body wave function

IAV Model



- Distinction between two cluster constituents:
  - b particle is a spectator described by OMP;
  - the interaction between x and A retains target degrees of freedom
- Using the Feshbach optical reduction, x-A wave function following breakup and projected on the A_{gs}

$$\left(E_x - K_x - U_x\right)\varphi_x^0(\vec{r}_x) = \left(\chi_b^{(-)}\middle|V_{bx}\middle|\Psi^{3b}\right\rangle$$

DWBA

$$\Psi^{3b} \simeq \chi_a \varphi_a \Phi_A$$

- Nonelastic breakup (NEB): loss of flux leaving the x-A_{gs} channel

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E_b \mathrm{d}\Omega_b} = -\frac{2}{\hbar v_a}\rho_b(E_b)\left\langle \varphi_x^0 \middle| W_x \middle| \varphi_x^0 \right\rangle$$

imaginary part

New Stories

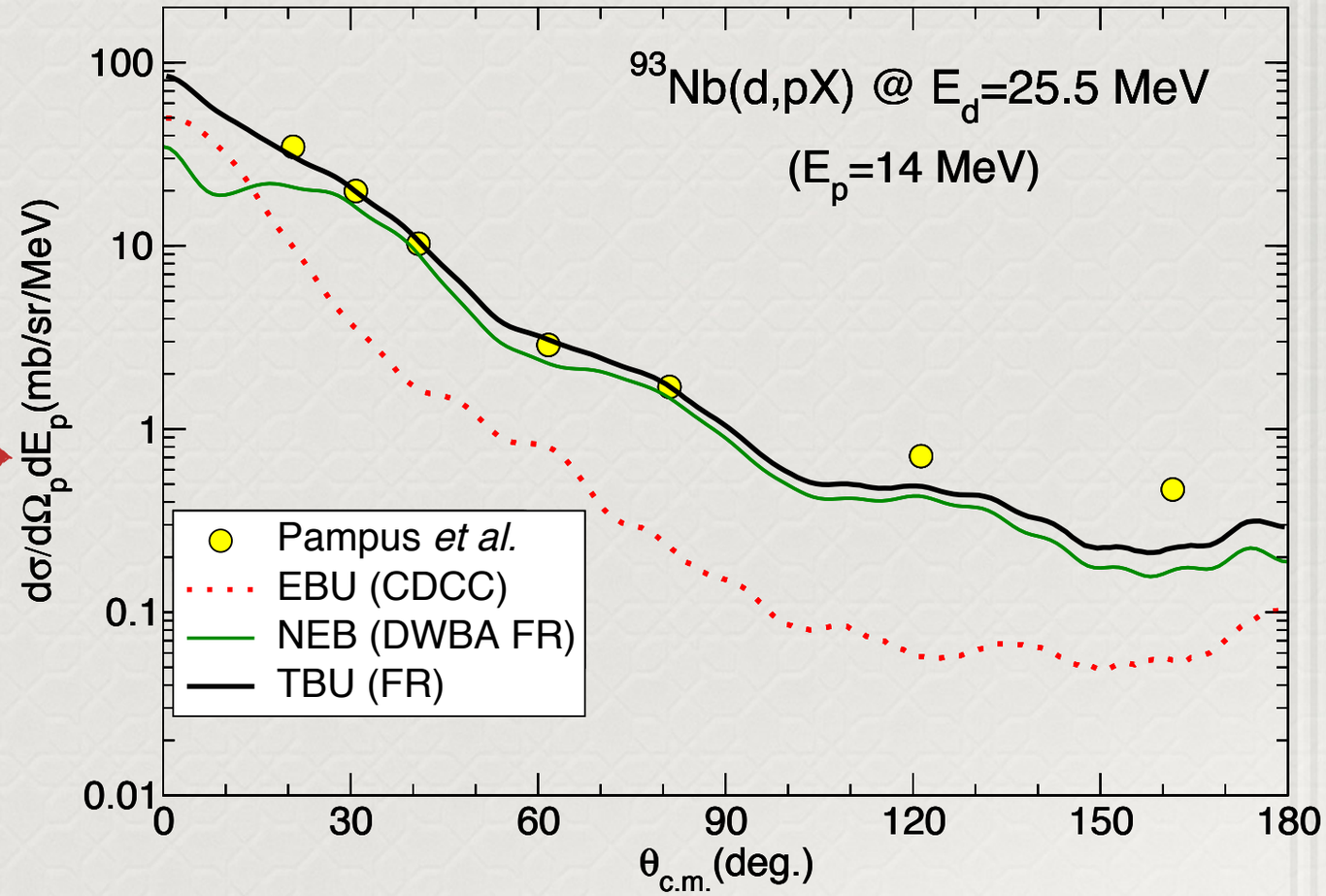
New Stories

- Low energy
  - Reaction mechanisms of breakup around Coulomb barrier
    - d + A⟶ p + X
    - ^{6,7}Li + A ⟶ α + X
  - Incomplete fusion: part of Nonelastic breakup
    - ^{6}Li + A ⟶ α + B
    - Surrogate reaction
      - A(n,f) ⇒ A(d,pf) : f is a fission fragment
- Intermediate energy
  - Knockout reaction (stripping)
    - ^{8}B+^{9}Be ⟶ ^{7}Be + X

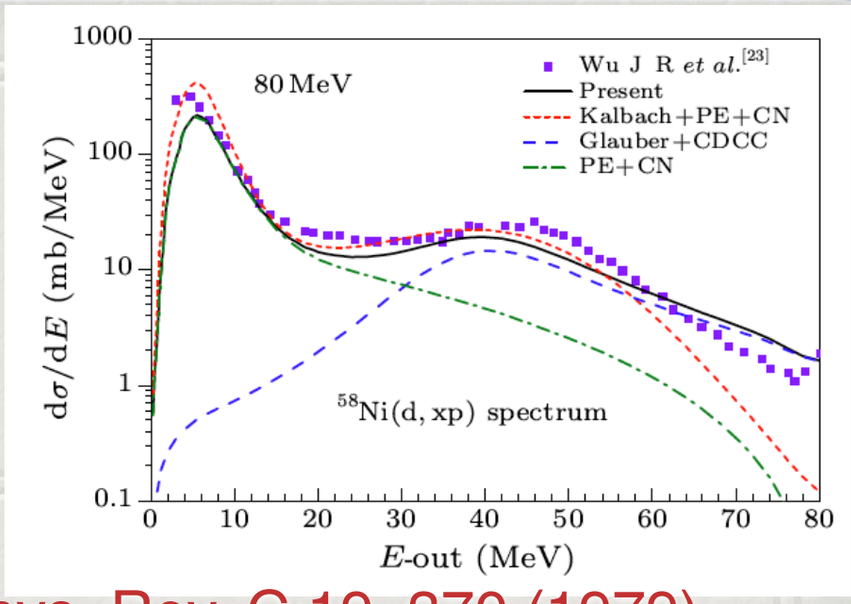
Deuteron Breakup

- d ⇒ (n + p), S_p=2.224 MeV
- only proton is detected
- EBU : CDCC
- NEB : IAV model
  - DWBA $\Psi^{3b} \simeq \chi_a \varphi_a \Phi_A$
  - Exact Finite Range
- TBU=EBU+NEB 😀

J. Pampus et al, Nucl. Phys. A311, 141 (1978).



Deuteron Breakup

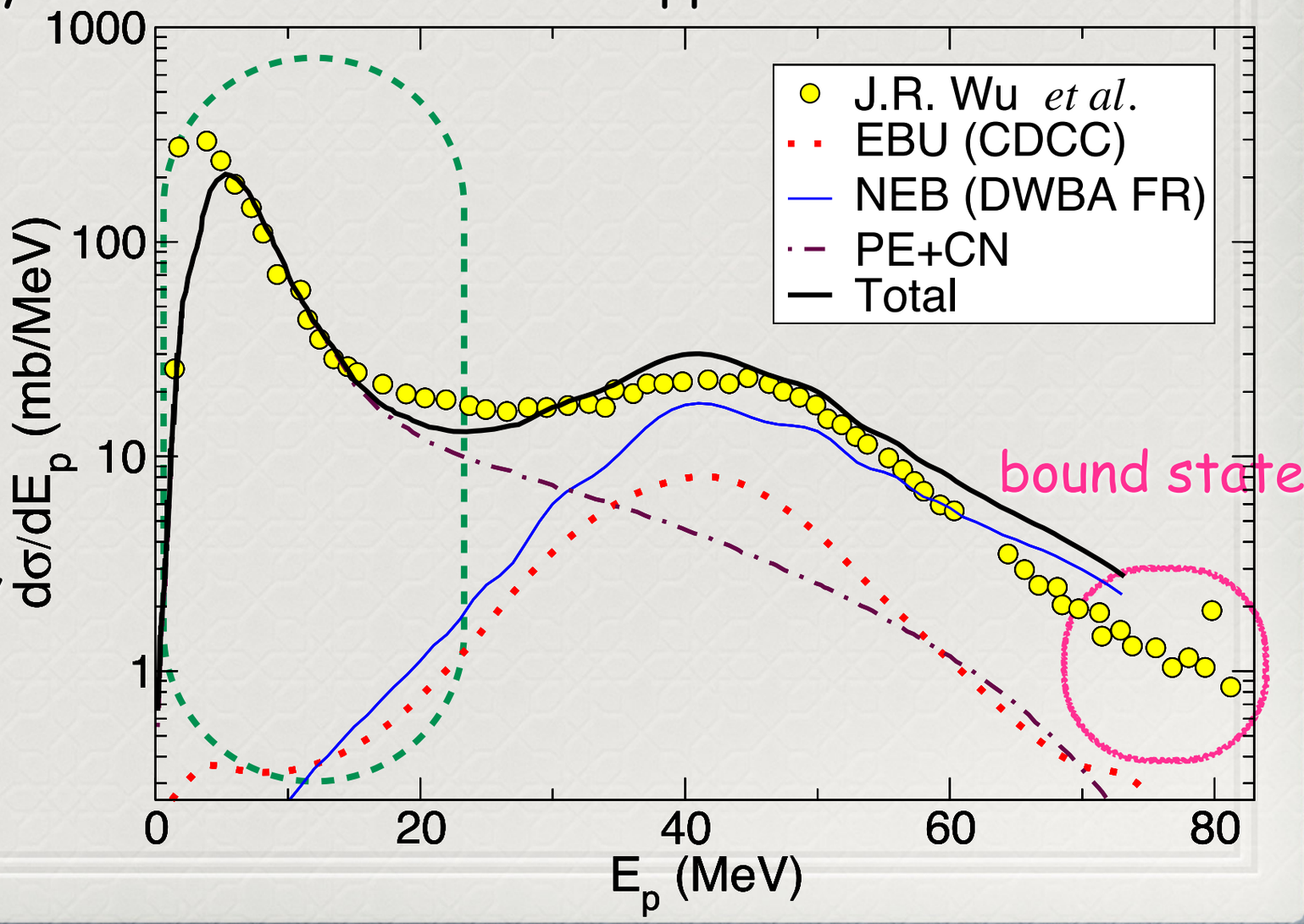


J. R. Wu, Phys. Rev. C 19, 370 (1979).

J. Wang et al, Chinese Phys. Lett. 28, 112401 (2011).

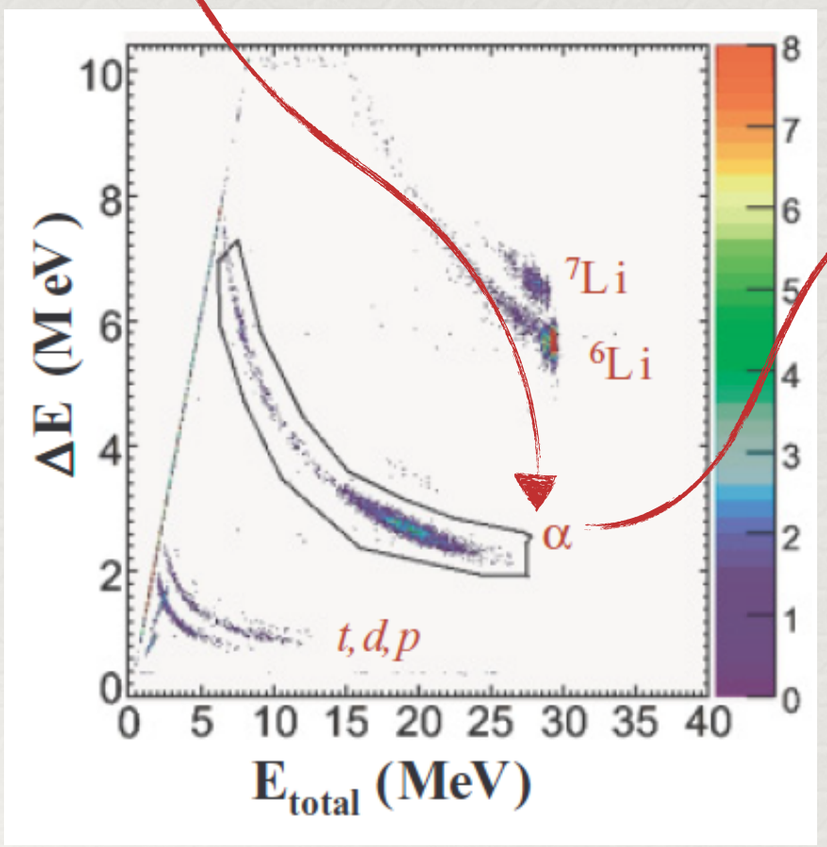
- In the intermediate energy
- NEB part was studied by semi-classical Glauber approach

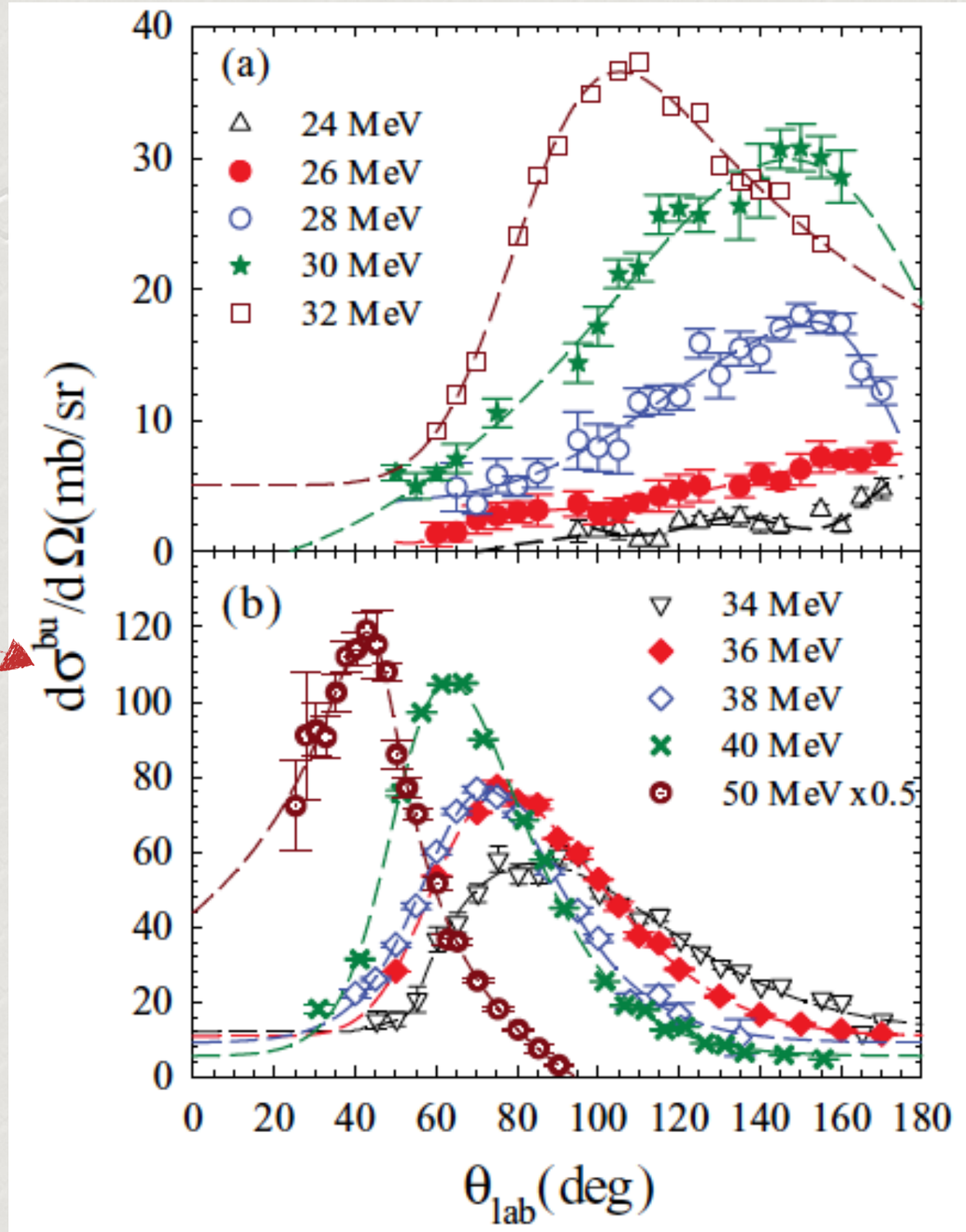
- ^{58}Ni(d,pX) @ 80 MeV
- EBU : Elastic Breakup
- NEB : Nonelastic Breakup
- PE+CN : Pre-equilibrium and compound nucleus followed by evaporation
- Total=EBU+NEB+PE+CN



$^{209}Bi(^{6}Li,\alpha X)$

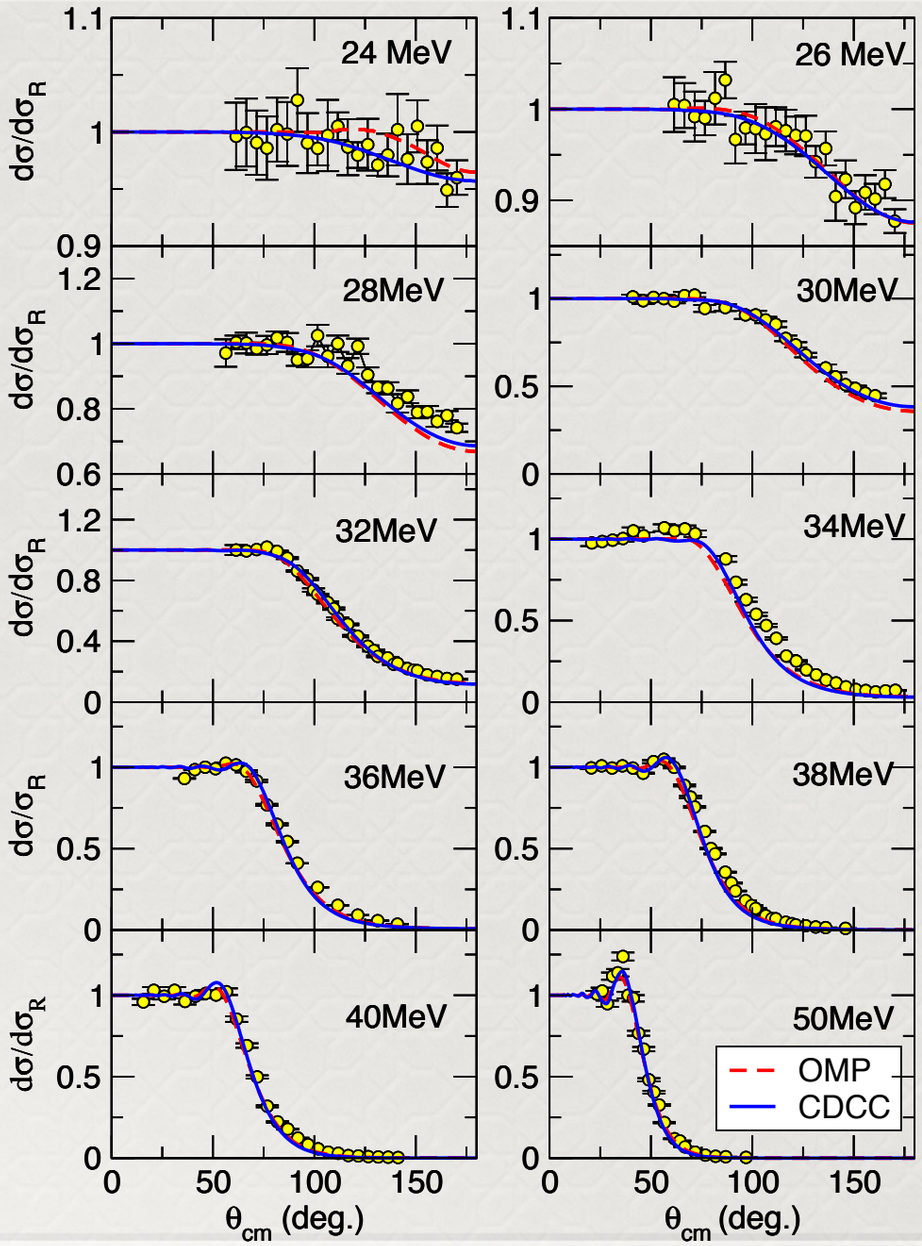
- 6Li ⇒ (α+d), Q_α = -1.474 MeV
- α is detected





S. Santra et al, Phys. Rev. C 85, 014612 (2012).

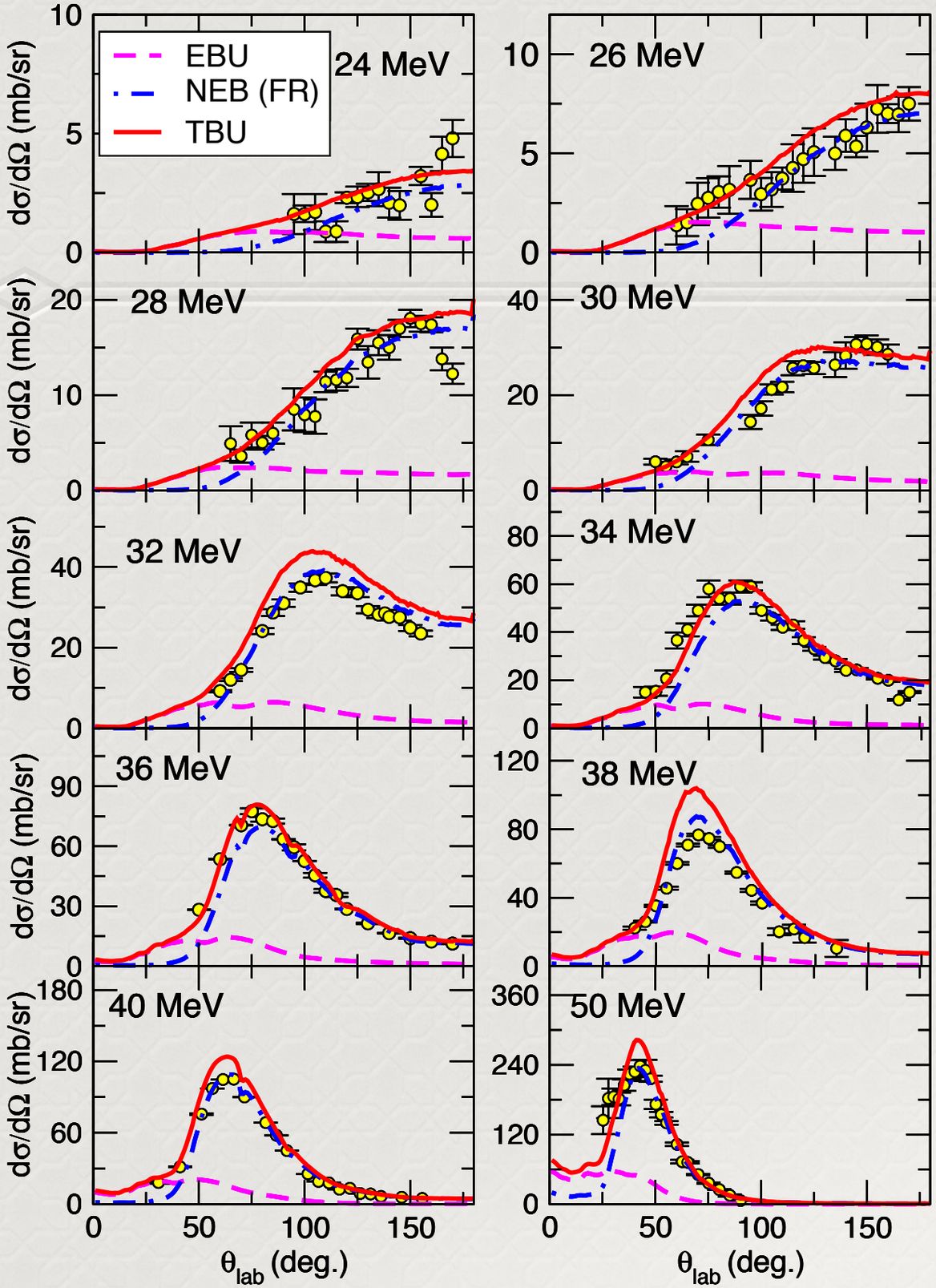
$^{209}Bi(^{6}Li,aX)$



- Elastic scattering
  - data : S. Santra et al, Phys. Rev. C 83, 034616 (2011).
- J. Cook potential, used for NEB
  - J. Cook, Nucl Phys A 388, 153 (1982).
- CDCC calculation
  - d+^{209}Bi : Y. Han, Phys. Rev. C 74, 044615 (2006). Removed surface term of imaginary part
  - α+^{209}Bi : A. R. Barnett, Phys. Rev. C 9, 2010 (1974).

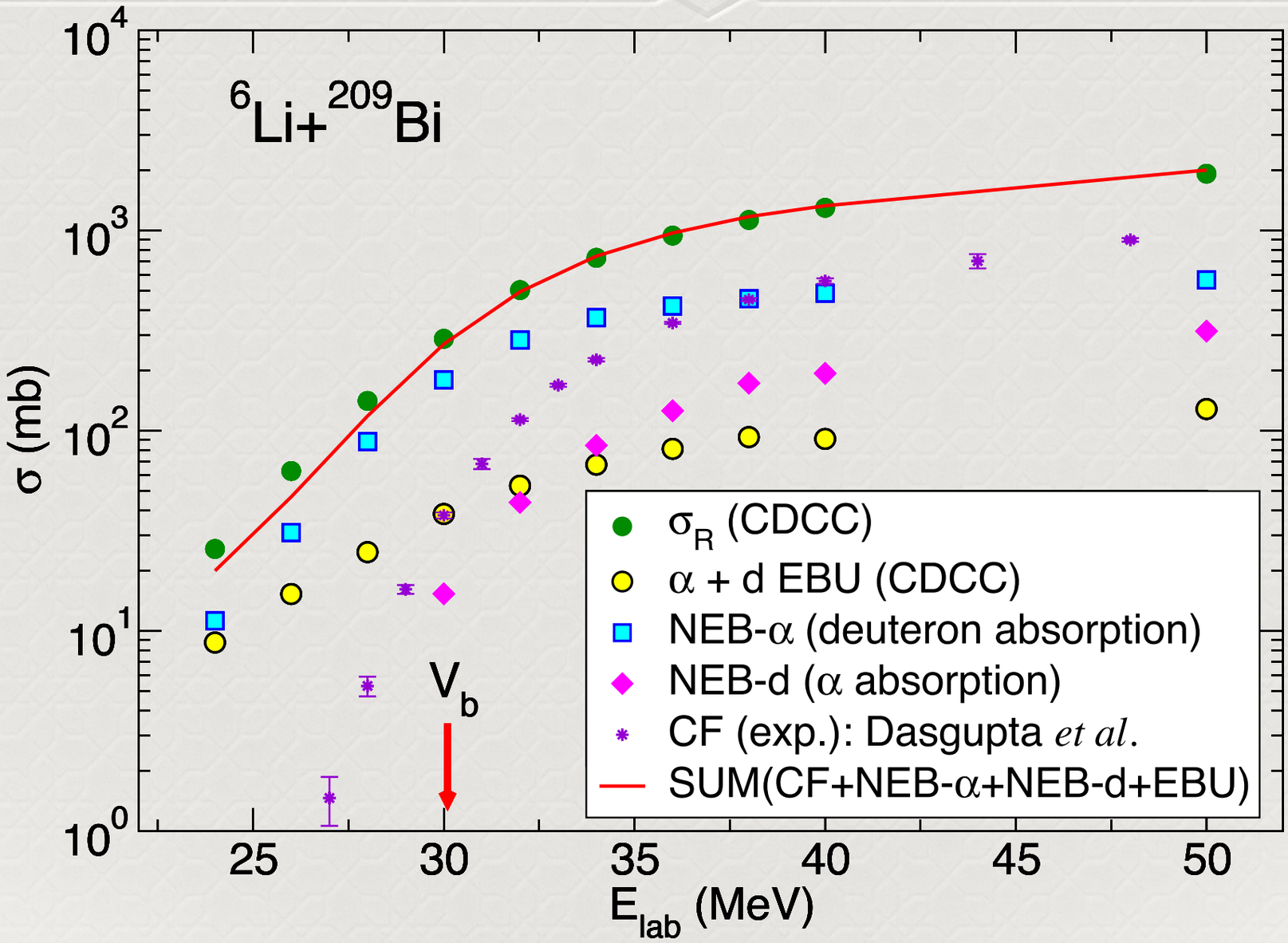
$^{209}Bi(^{6}Li,aX)$

- Inclusive a
  - data: S. Santra et al, Phys. Rev. C 85, 014612 (2012).
- EBU : CDCC calculation
  - forward angles: weak absorption ("distant trajectories")
- NEB : IAV model DWBA
  - dominate inclusive a
- TBU=EBU+NEB
  - overall agreement with data



$^{6}Li+^{209}Bi$:energy dependence of cross sections

M. Dasgupta et al, Phys. Rev. C 70, 024606 (2004).



$$\sigma_R \approx \sigma_{\alpha+d}(\mathrm{EBU}) + \sigma_{\alpha}(\mathrm{NEB}) + \sigma_{d}(\mathrm{NEB}) + \sigma(\mathrm{CF})$$

Summary

- We have addressed the problem of the calculation of inclusive breakup:

  revisited the model proposed by Ichimura, Austern and Vincent

  - Using DWBA version of this formula for Nonelastic Breakup (NEB)
  - CDCC framework for Elastic Breakup (EBU)

- Calculation for deuteron and 6Li on several targets and at different energies showing a satisfactory agreement with the available data.
- This good agreement suggests that this approach could be useful to estimate the amount of incomplete fusion (ICF) from Nonelastic breakup

To be continued…

Thank you for your attention!!!