Analysis of exclusive inelastic breakup of halo nuclei within the CDCC framework

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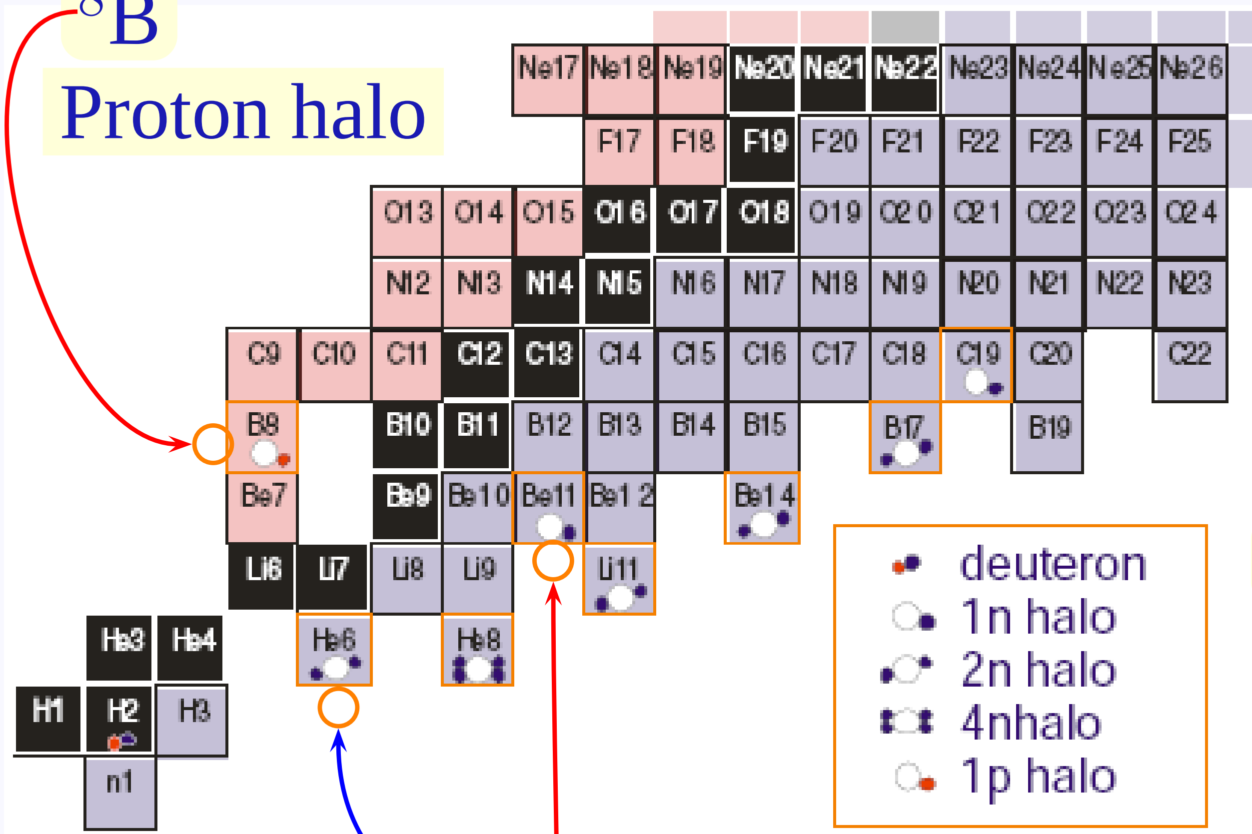
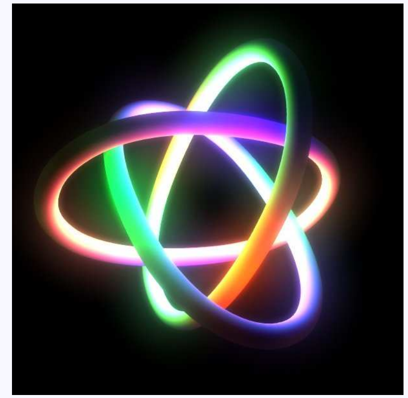
Outline

- Motivation: halo nuclei like ^{11}Be or ^{6}He
- Continuum-Discretized Coupled-Channels (CDCC)) framework:
  - How can we study the inelastic breakup of halo nuclei within CDCC formalism?
  - Application to reactions ^{11}Be+target: ^{11}Be+^{9}Be,^{48}Ti,^{197}Au at 41MeV/u
- Future work: ^{6}He+^{208}Pb at 41MeV/u
  - neutron correlation
- Summary and conclusions

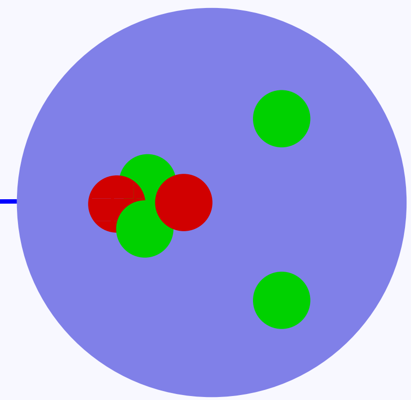
Motivation: Halo nuclei

^{8}B
Proton halo





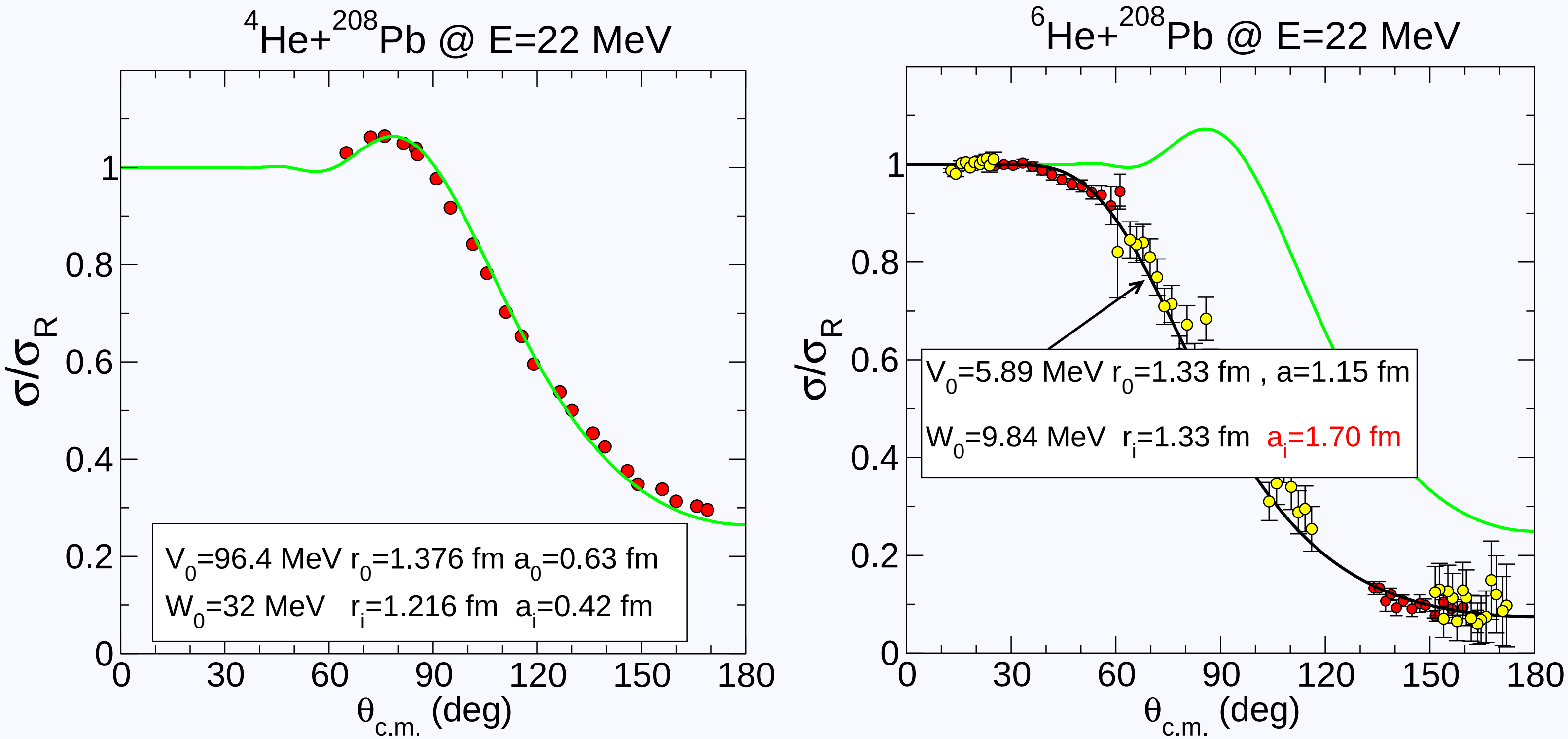
Borromean
2-neutron halo



^{11}Be
1st neutron halo 1983

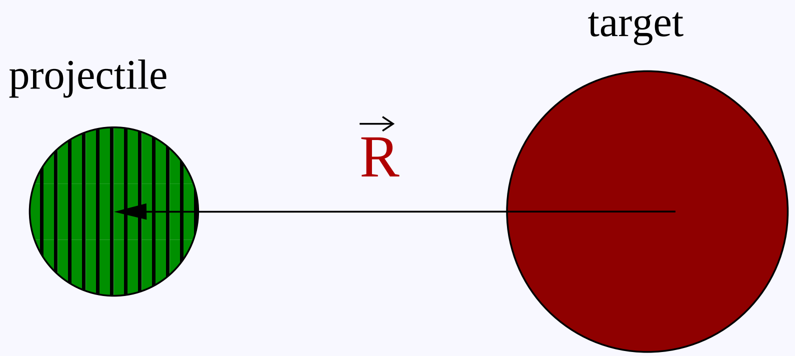
Motivation: Halo nuclei

Elastic cross section

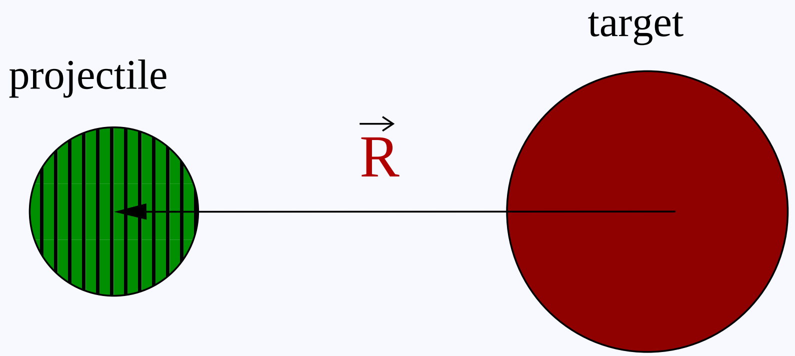


- ^{4}He+^{208}Pb: typical Fresnel pattern well reproduced by a "standard" optical potential: strong absorption
- ^{6}He+^{208}Pb: requires optical potentials with a very large diffuseness parameter ($a_i \approx 2$ fm): long-range absorption

CDCC framework

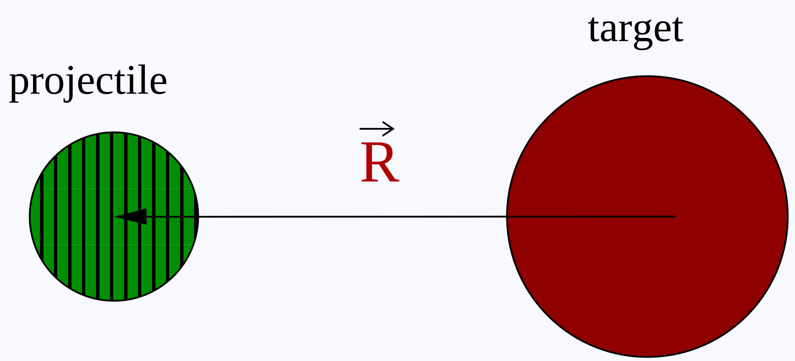


CDCC framework



$$\Psi_J^M(\vec{R},\xi) = \sum \phi_{jn}^{\mu}(\xi)\langle L M_L j \mu | J M\rangle \frac{i^L}{R} Y_L^{M_L}(\widehat{R}) f_{Lnj}^{J}(R)$$

CDCC framework

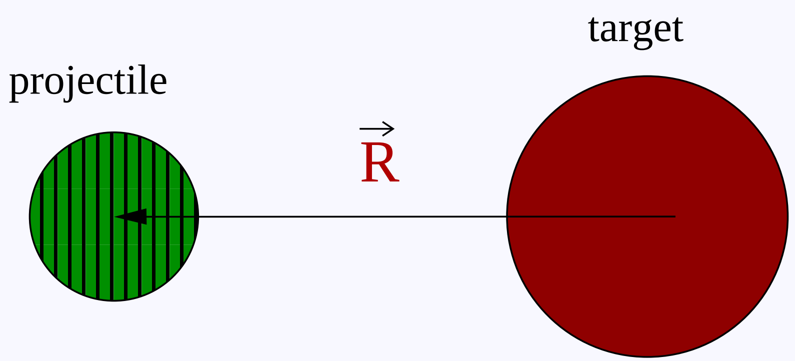


$$\Psi_J^M(\vec{R},\xi) = \sum \phi_{jn}^{\mu}(\xi)\langle L M_L j \mu | J M\rangle \frac{i^L}{R} Y_L^{M_L}(\widehat{R}) f_{Lnj}^J(R)$$

Coupled channels system

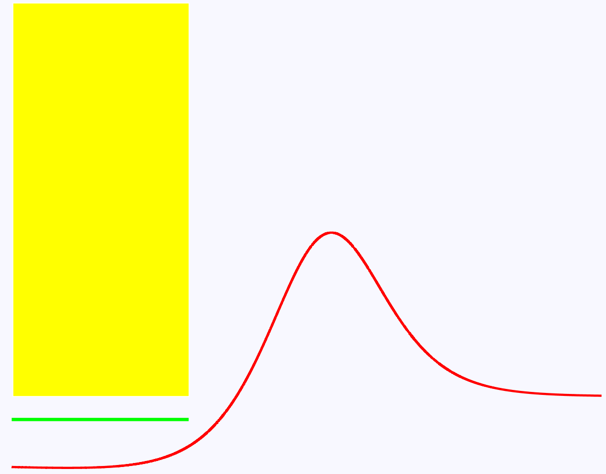
$$\left[-\frac{\hbar^2}{2m_r}\left(\frac{d^2}{dR^2} - \frac{L(L+1)}{R^2}\right) + \varepsilon_{nj} - E\right] f_{Lnj}^J(R)$$
$$+ \sum_{L'n'j'} i^{L'-L} V_{Lnj,L'n'j'}^J(R) f_{L'n'j'}^J(R) = 0$$

CDCC framework

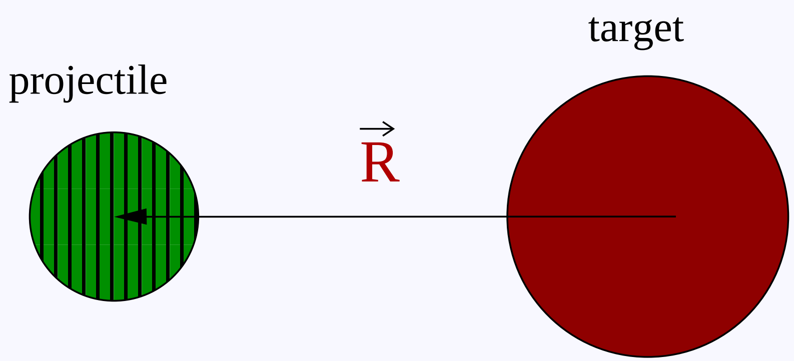


$$\Psi_J^M(\vec{R},\xi) = \sum \phi_{jn}^{\mu}(\xi)\langle L M_L j\mu | J M\rangle \frac{i^L}{R} Y_L^{M_L}(\widehat{R}) f_{Lnj}^J(R)$$

$\phi_n^{j\mu}(\xi)$?

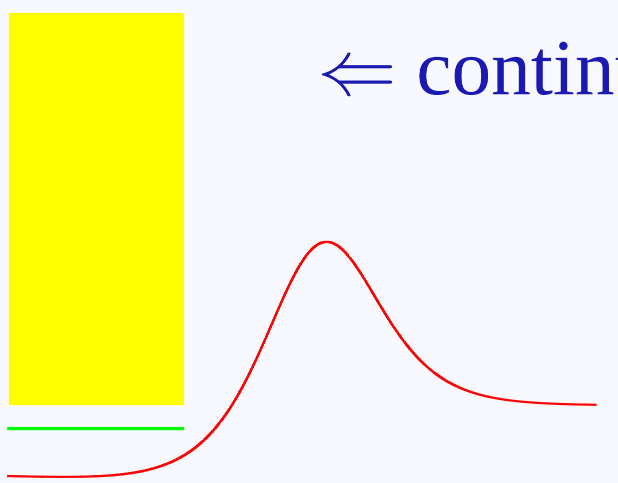


CDCC framework



$$\Psi_J^M(\vec{R},\xi) = \sum \phi_{jn}^{\mu}(\xi)\langle L M_L j \mu | J M \rangle \frac{i^L}{R} Y_L^{M_L}(\widehat{R}) f_{Lnj}^J(R)$$

$\phi_n^{j\mu}(\xi)$?



$\Leftarrow$ continuum discretization

Binning procedure

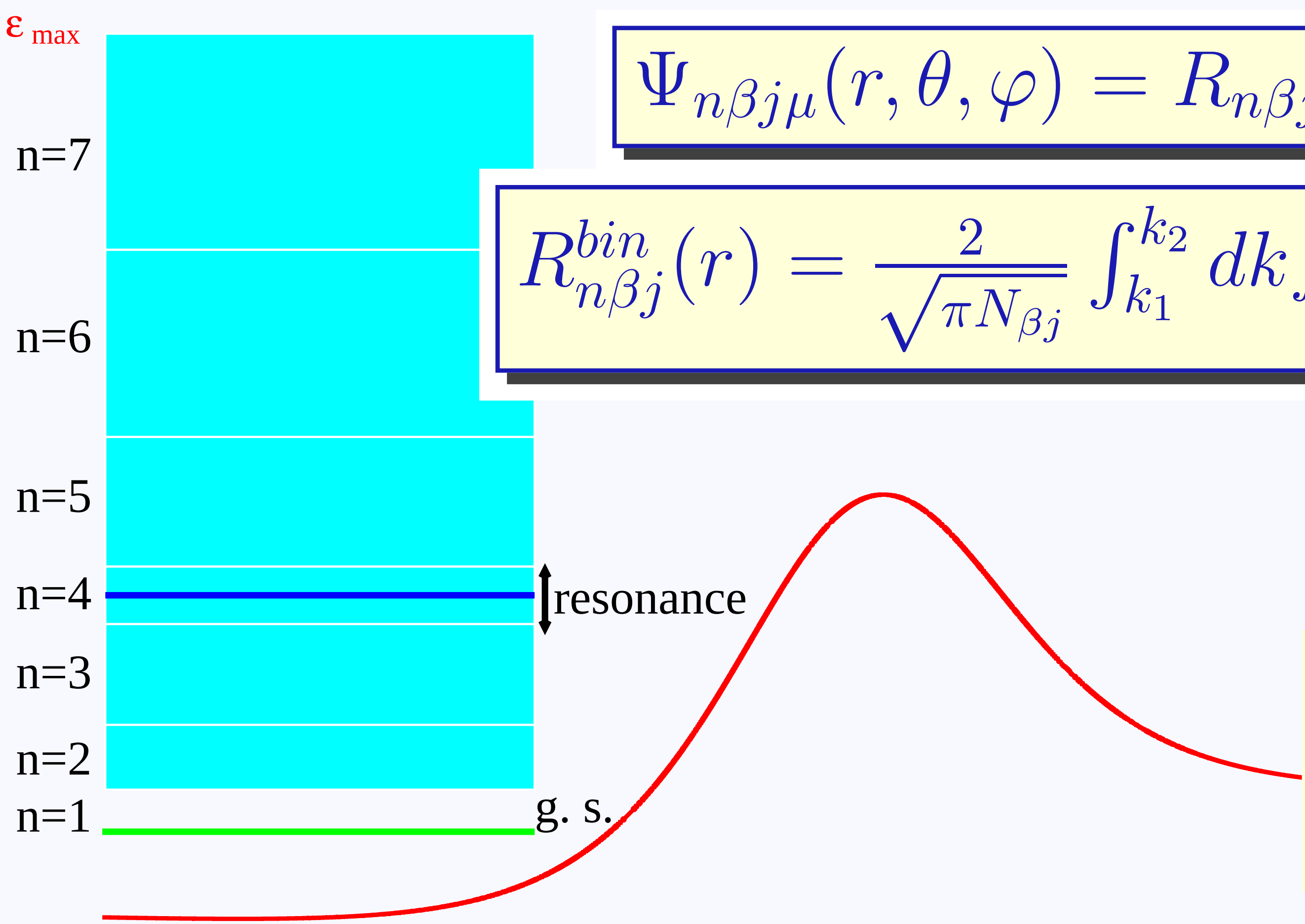
$\times \beta$

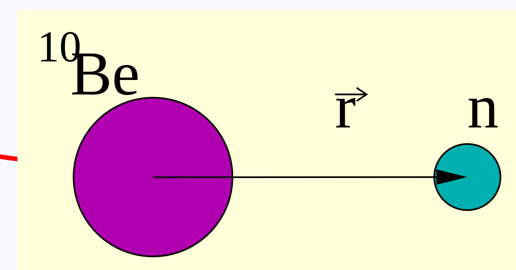
2-body projectile

$$\Psi_{n\beta j\mu}(r,\theta,\varphi) = R_{n\beta j}(r)\mathcal{Y}_{\beta j\mu}(\theta,\varphi)$$

$$R^{bin}_{n\beta j}(r) = \frac{2}{\sqrt{\pi N_{\beta j}}} \int_{k_1}^{k_2} dk\, f_{\beta j}(k) R_{\beta j}(kr)$$

$$\beta \equiv \{l, s\}$$





✧ M. Yahiro et al., Prog. Theor. Phys. Suppl. 89 32 (1986)

Projectile-target interactions

Standard CDCC

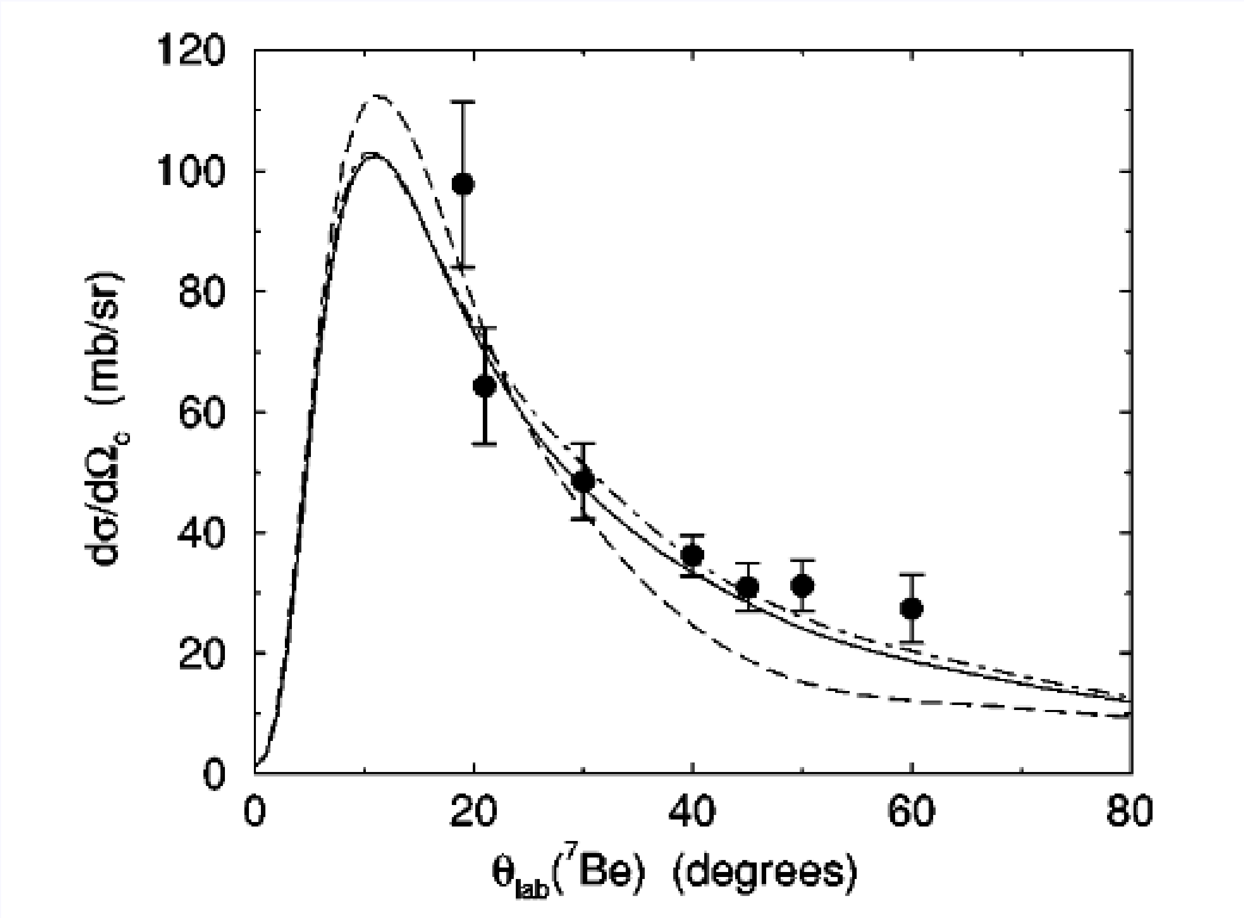
$U_{ct}(r_c)$

$U_{vt}(r_v)$ $\Longrightarrow$ Optical potential $U = V + iW$

- W absorbs the flux corresponding to processes not included explicitly in the formalism like:
  - target or core excitation
  - transfer of the valence particle to the target
- We get only the "elastic breakup":
  - the projectile breaks up into their constituents
  - all the fragments (core, valence particle and target) preserve their identity and their g.s.

Elastic breakup analysis

$^8B+^{58}Ni$ at 25.8 MeV

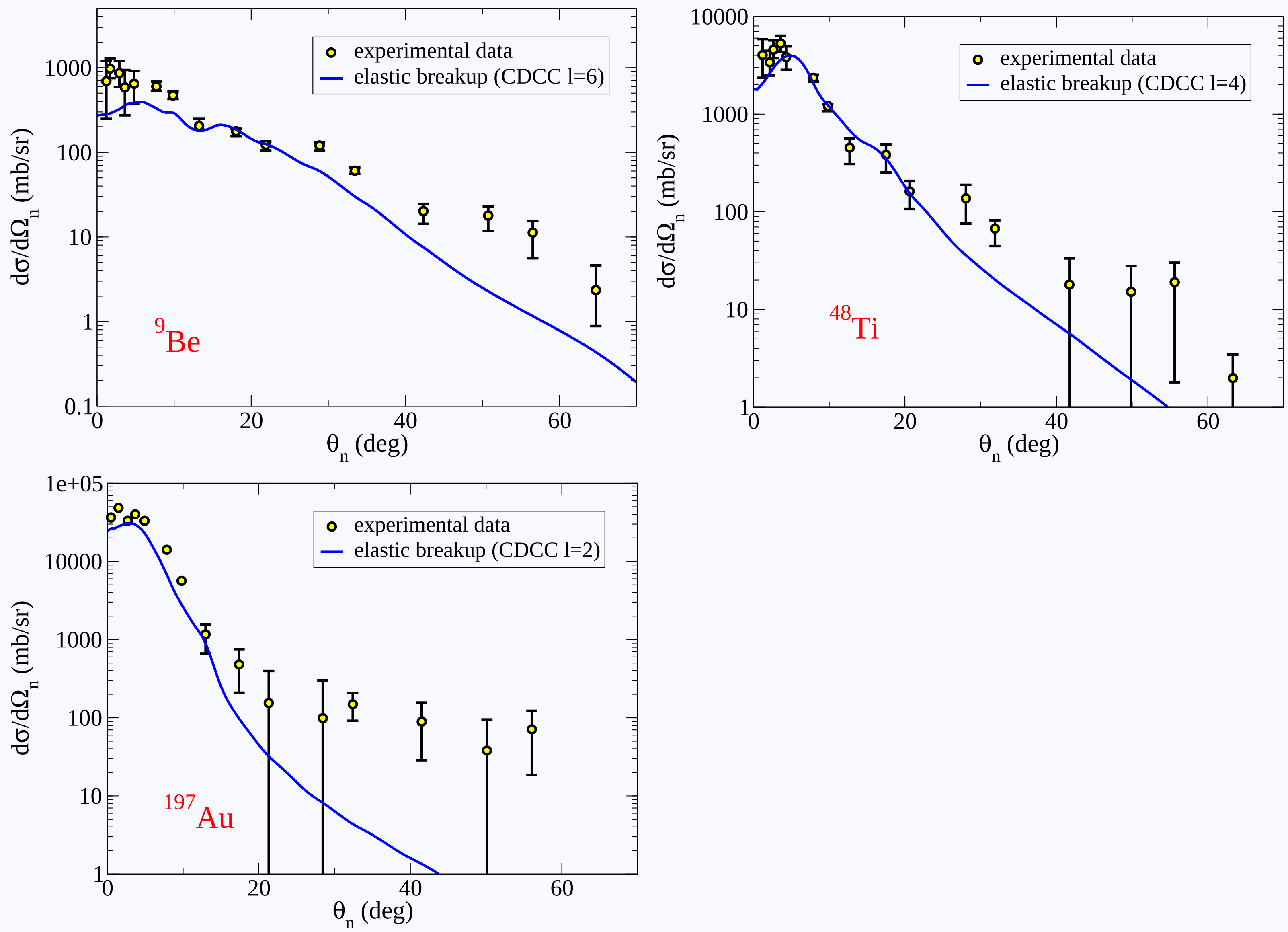


- J. A. Tostevin et al., Phys. Rev. C 63 (2001) 024617

Experiment at GANIL: inelastic bu

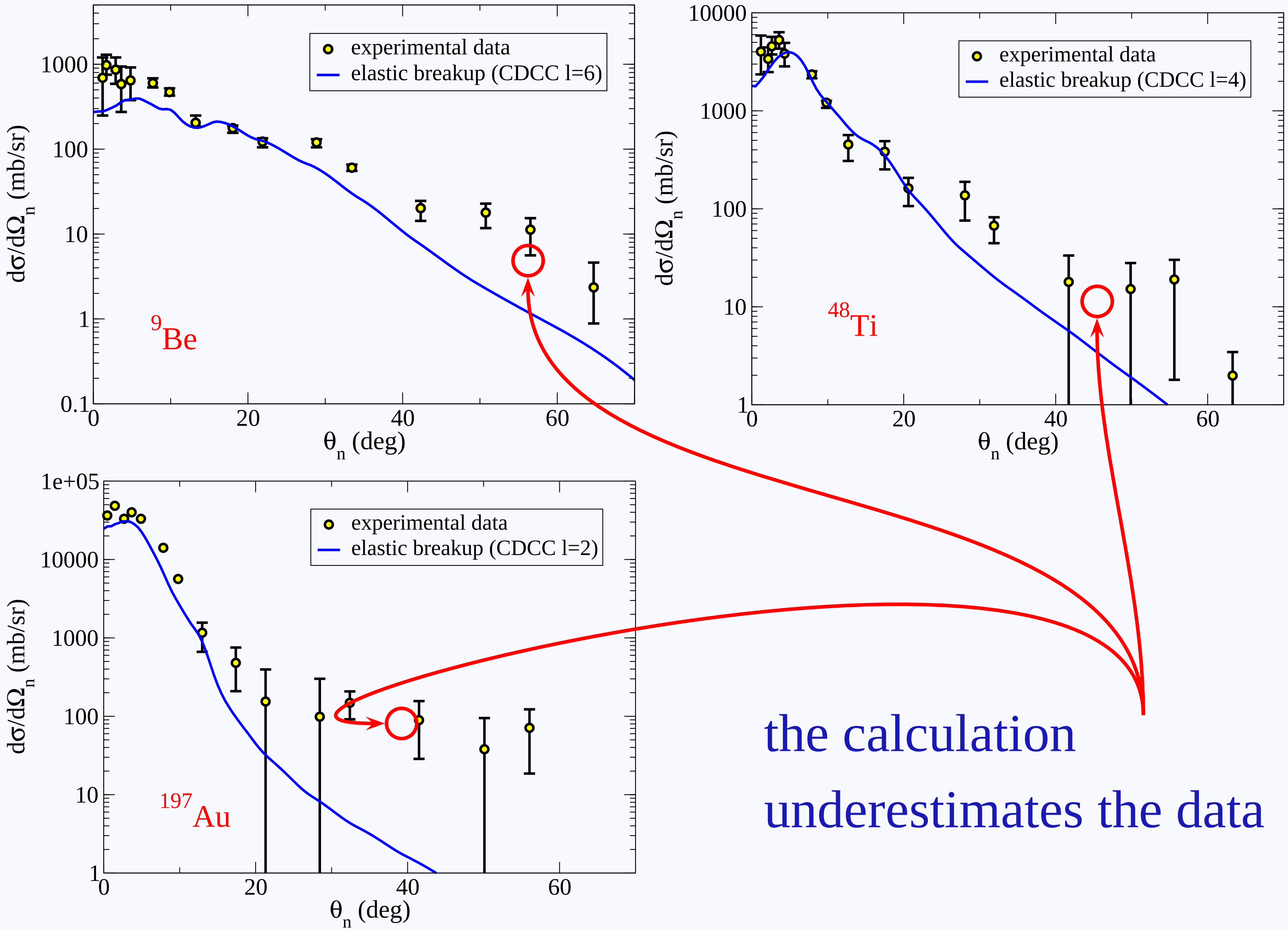
- Details:
  - Projectile: ^{11}Be
  - Targets: ^{9}Be, ^{48}Ti, and ^{197}Au
  - Lab incident energy: 41 MeV/u
  - Particles detected: ^{10}Be and n
  - States of the fragments after the collision: unknown
- The experiment measures the “exclusive inelastic breakup” where:
  - the fragments preserve their identity
  - but not necessarily their g.s.

What happens with standard CDCC?



Exp. data: Anne et al., NPA 575 (1994) 125

What happens with standard CDCC?



Exp. data: Anne et al., NPA 575 (1994) 125

How do we obtain this inelastic bu?

New prescription

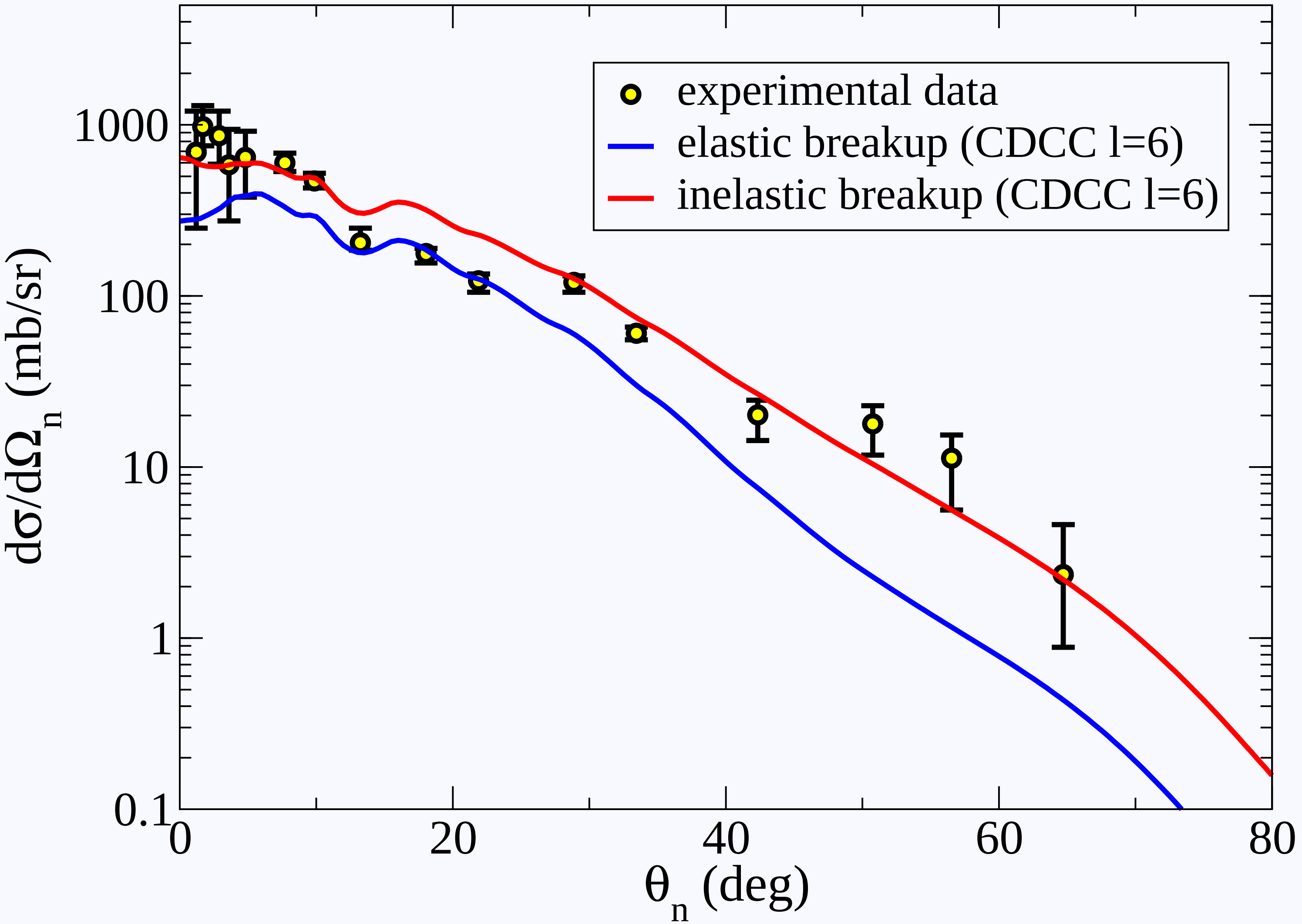
❶ We switch off the imaginary part of the optical potentials to include the flux corresponding to core and target excitation processes

$$W_{ct} = W_{vt} = 0$$

❷ We include an imaginary fusion potential to eliminate the flux corresponding to this process

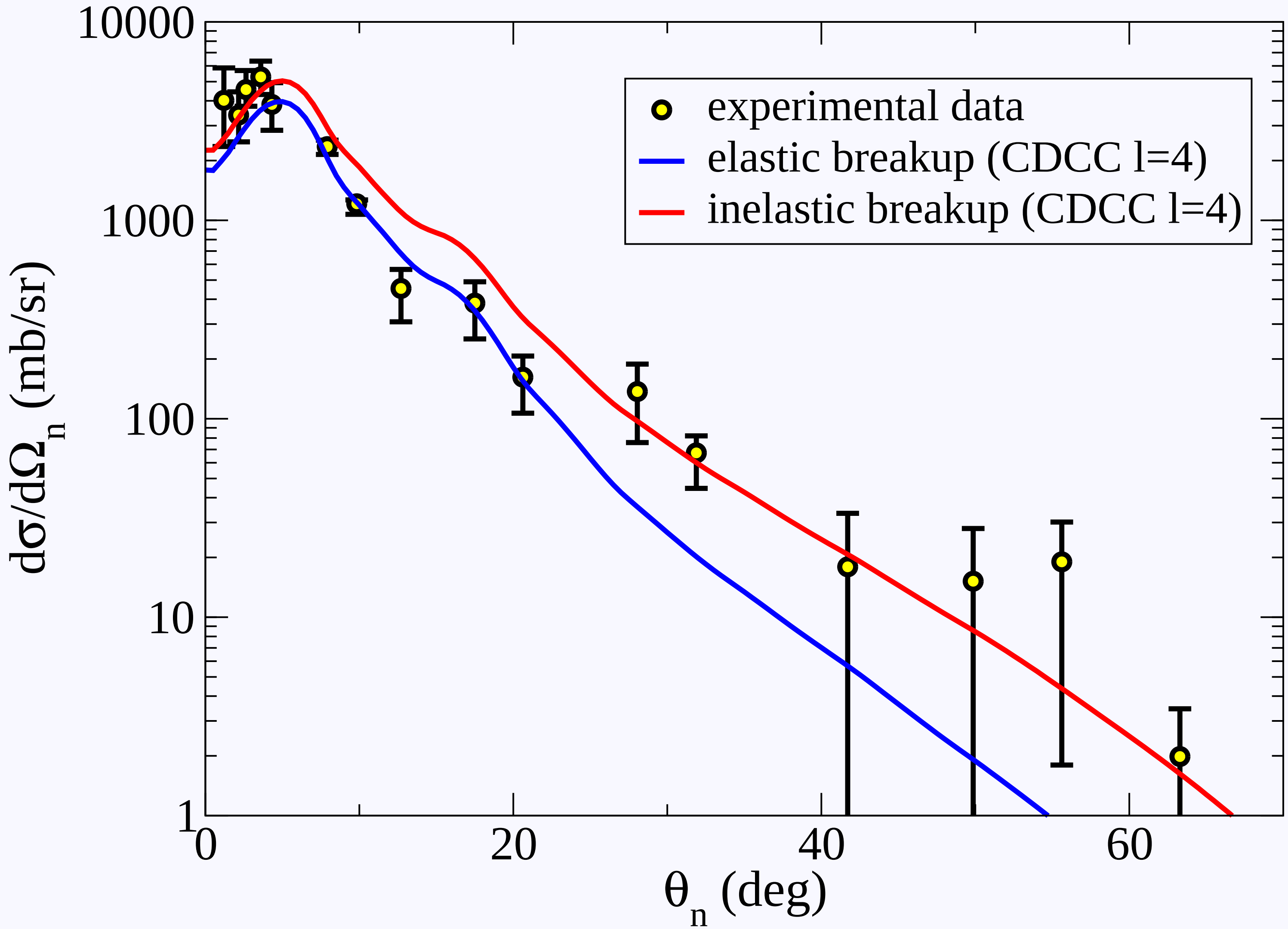
$$W_{\text{fusion}}(r) = -\frac{w}{1+\exp\left(\frac{r-R_O}{a}\right)}$$

^{11}Be+^{9}Be@41MeV/u



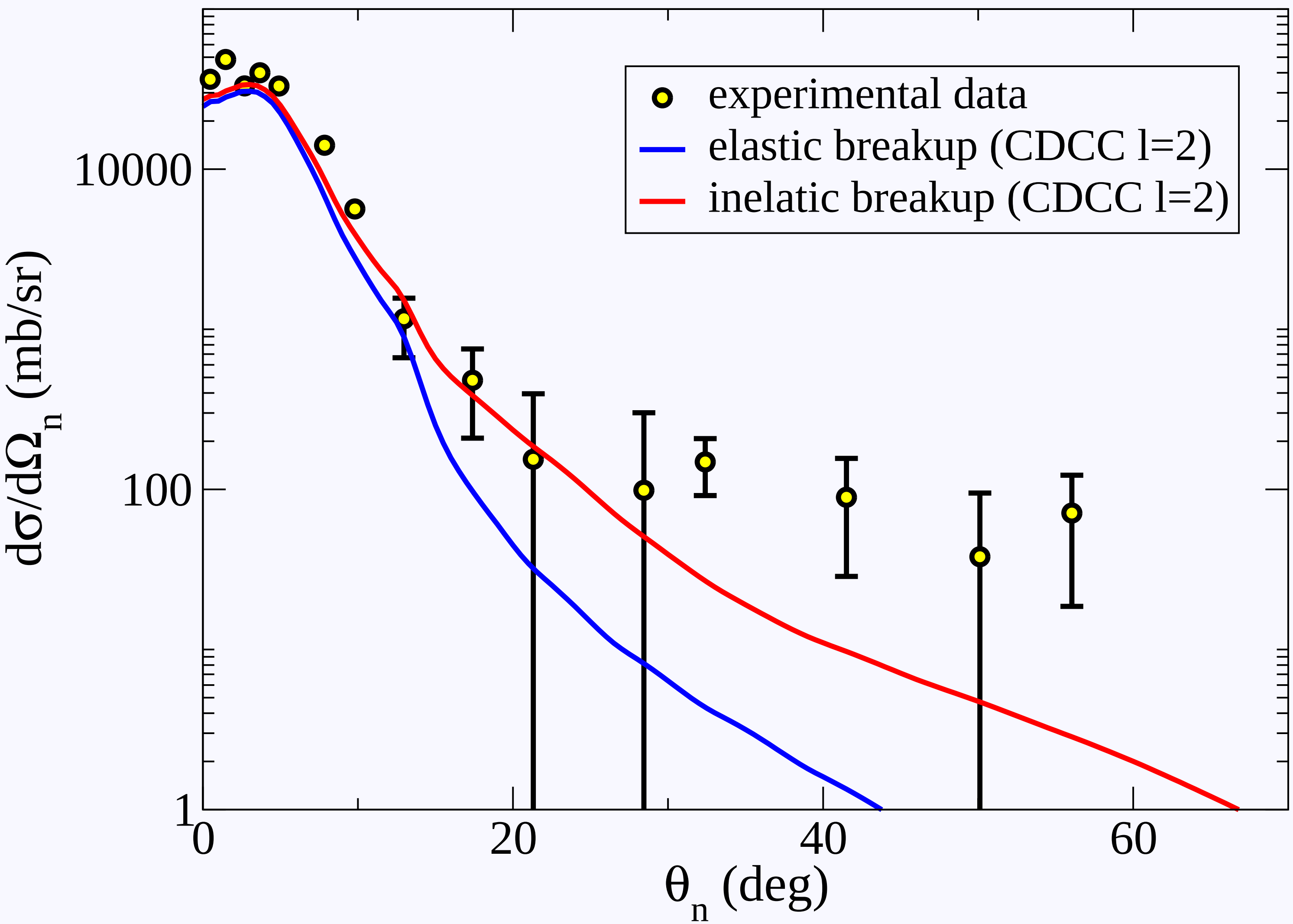
✍ Preliminary

^{11}Be+^{48}Ti@41MeV/u



✍ Preliminary

^{11}Be+^{197}Au@41MeV/u

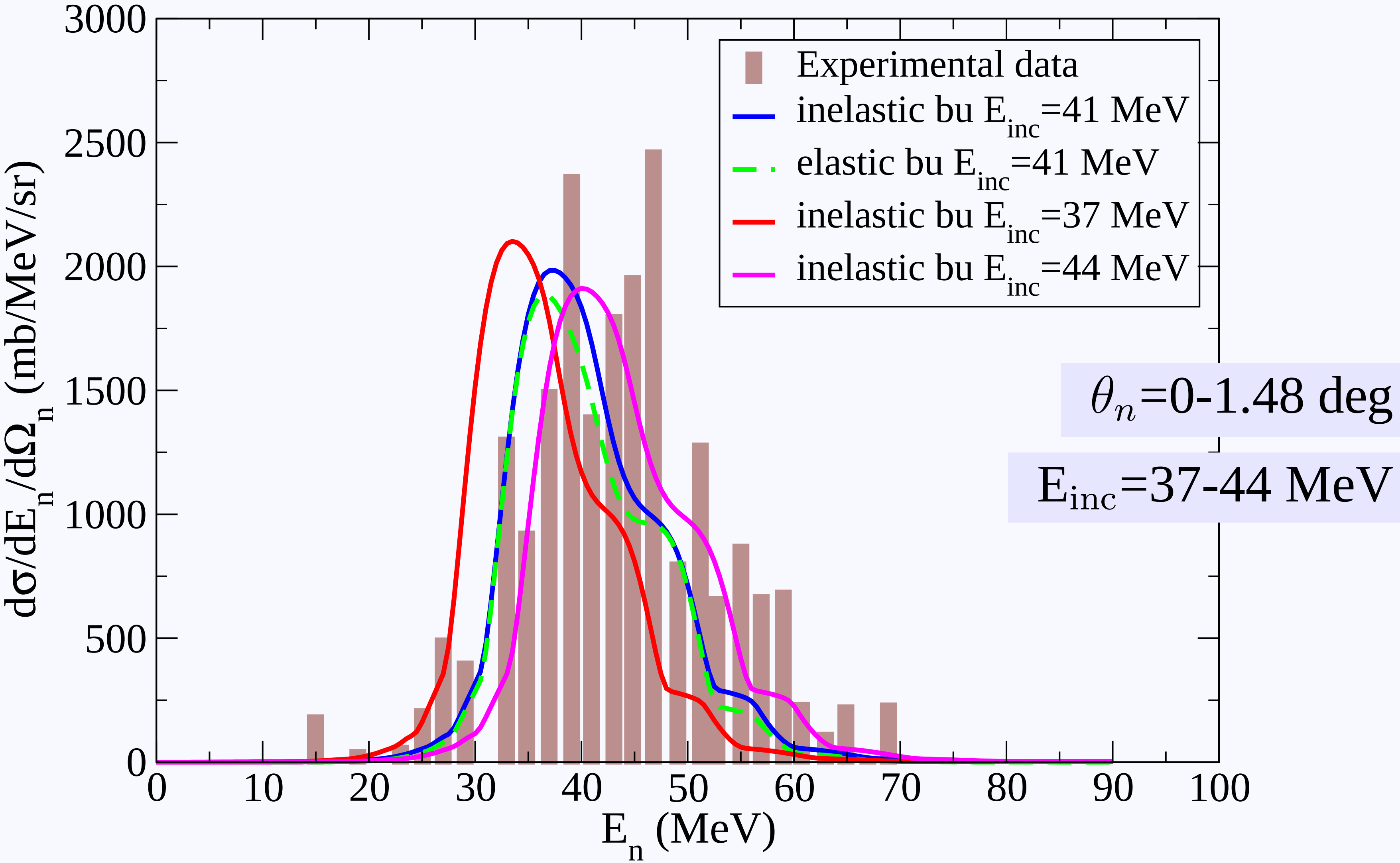


✍ Preliminary

Total inelastic breakup cross section

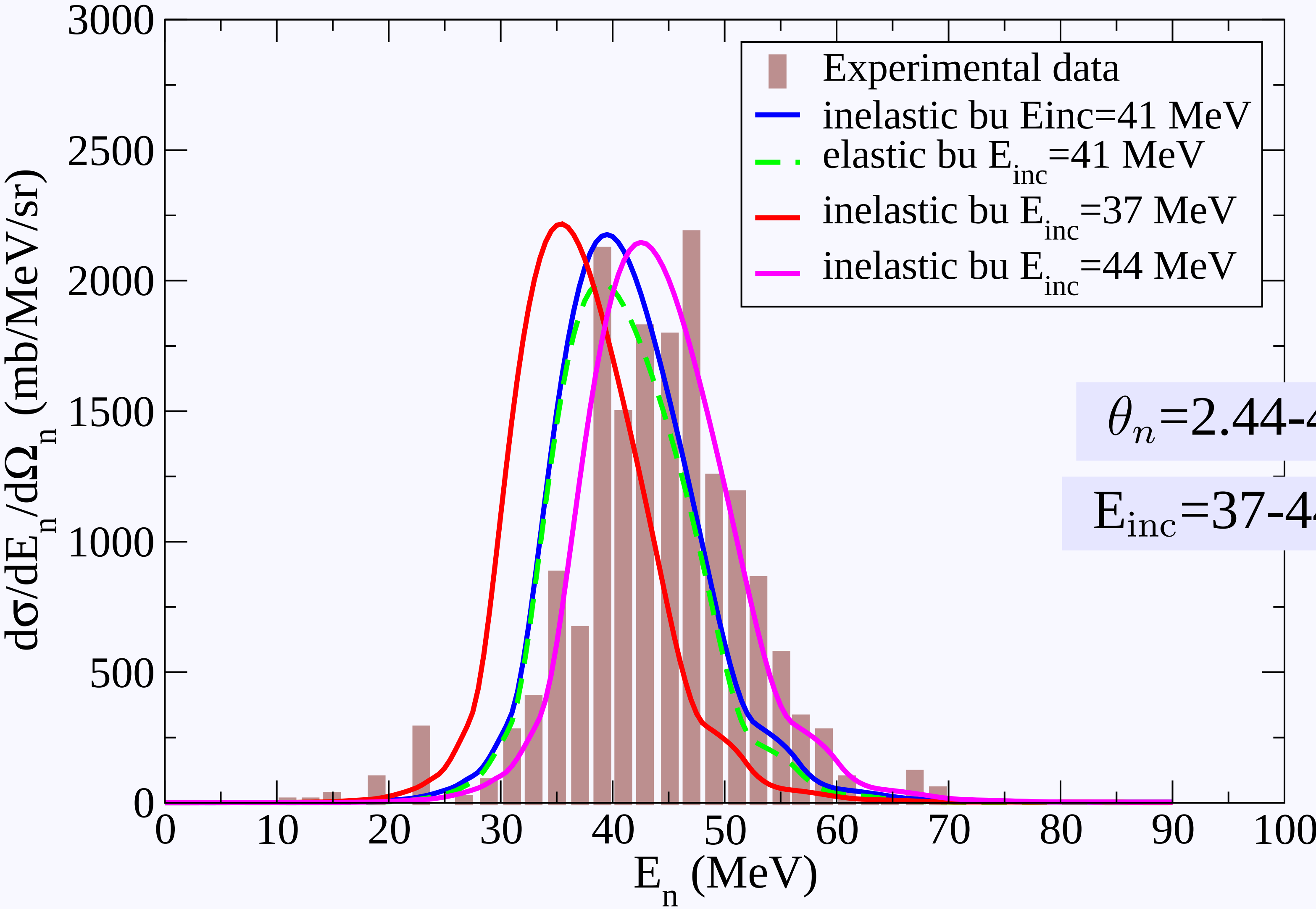
target	inelastic bu exp	elastic bu CDCC	inelastic bu CDCC
^{9}Be	0.24	0.14	0.28
^{48}Ti	0.55	0.42	0.69
^{197}Au	2.5	1.07	1.88

^{11}Be+^{197}Au: energy distribution (1)



✍ Preliminary

^{11}Be+^{197}Au: energy distribution (2)



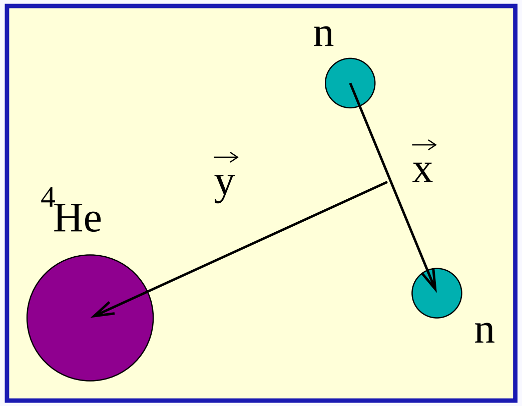
θ_n=2.44-4.4 deg

E_{inc}=37-44 MeV

✍ Preliminary

Future work: ^{6}He+^{208}Pb@41MeV/u

- ^{6}He: 3-b projectile $\longrightarrow$ 4-b reaction formalism



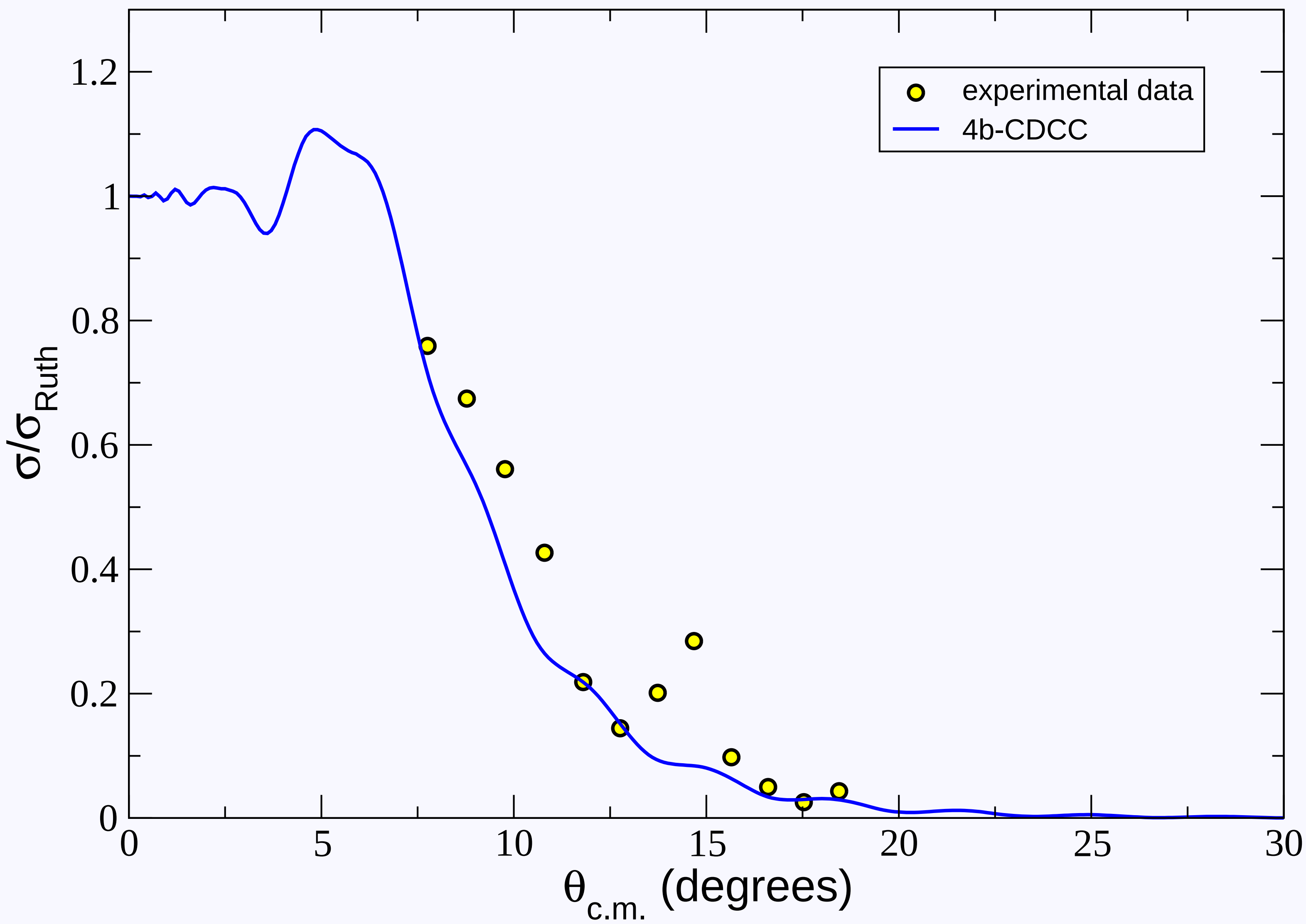
$$\rho^2 \equiv x^2 + y^2$$
$$\tan\alpha = x/y$$

$$\Omega \equiv \{\alpha, \widehat{x}, \widehat{y}\}$$
$$\beta \equiv \{\mathrm{K}, l_x, l_y, l, S_x, j_{ab}\}$$

- 4-b CDCC: recently developed with the extension of the binning procedure to 3-b projectiles

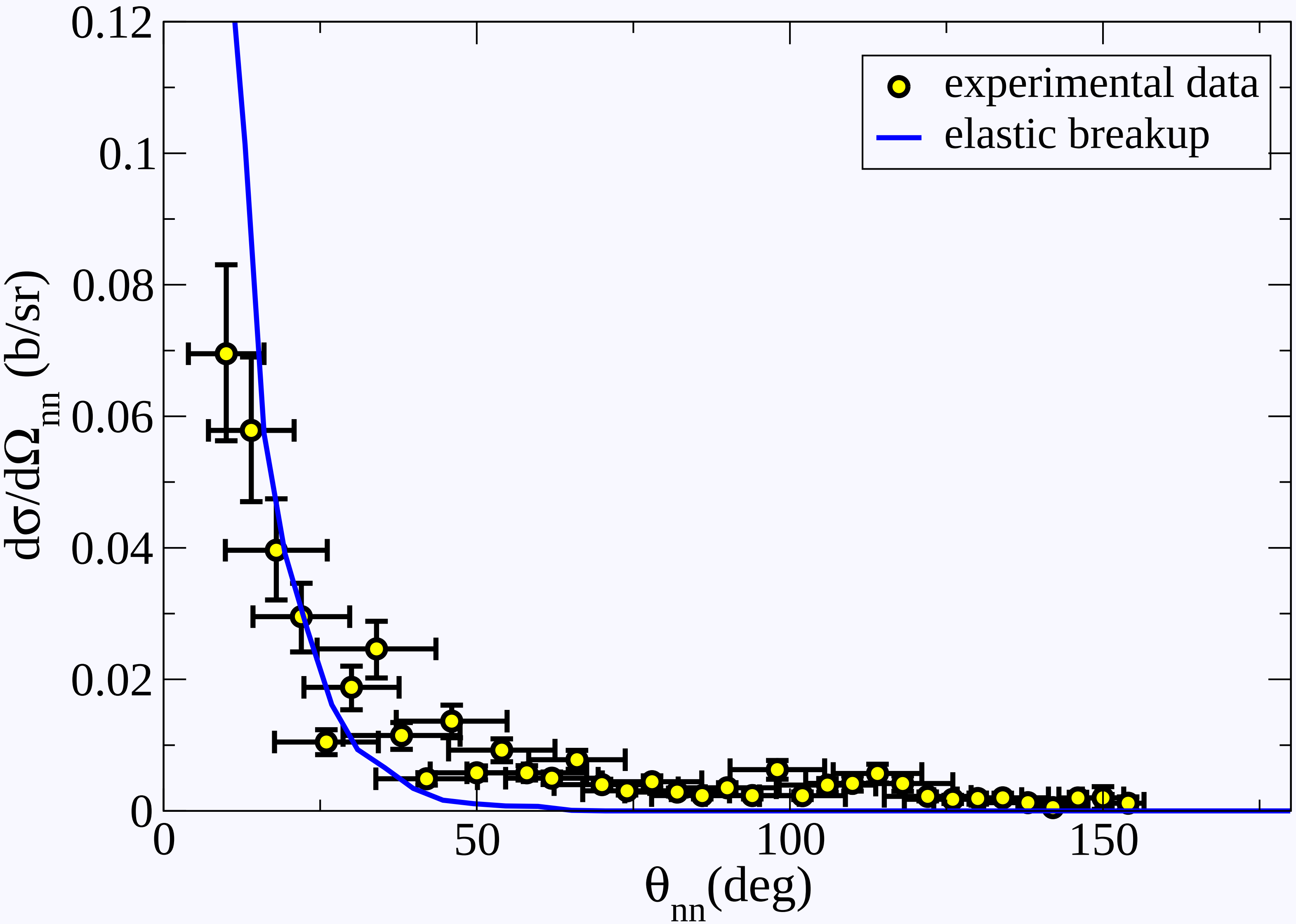
✉ *Rodríguez-Gallardo et al. PRC 80 (2009) 051601(R)*

^{6}He+^{208}Pb@41MeV/u: elastic



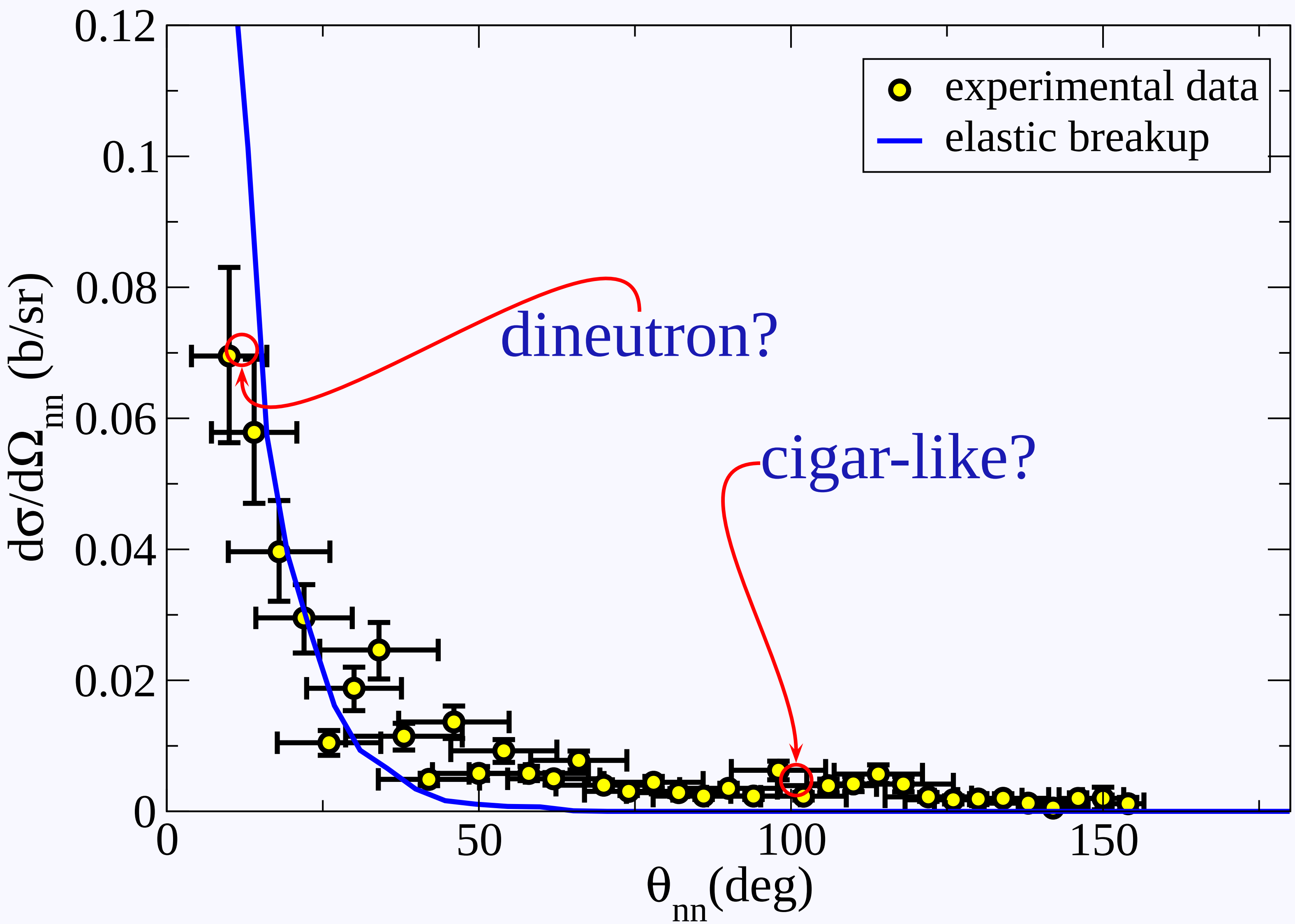
- Exp. data: Assiè et al., Private Communication

$^{6}He+^{208}Pb$@41MeV/u: n-n correlation



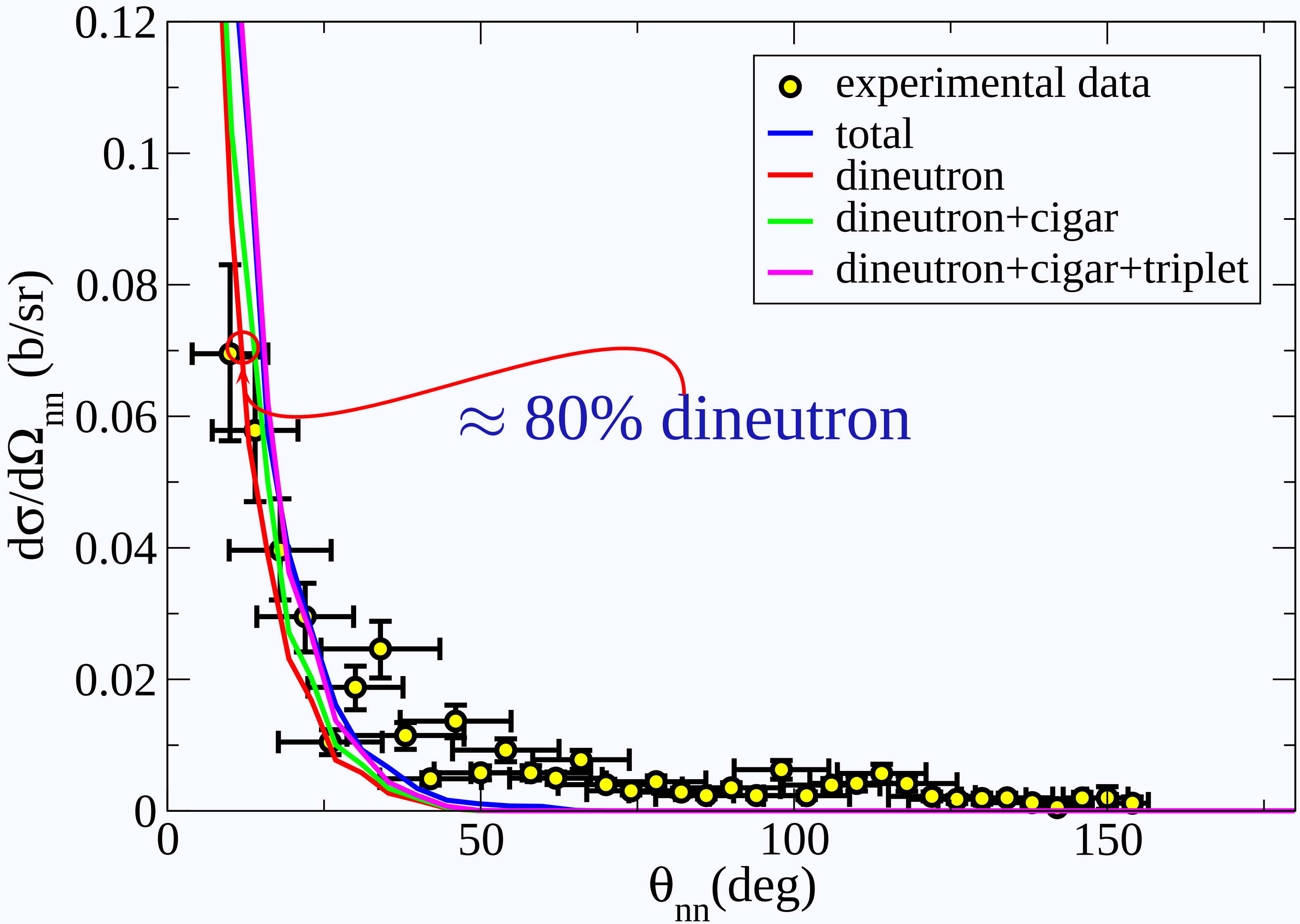
Exp. data: Assiè et al. EPJA 42 (2009) 441

^{6}He+^{208}Pb@41MeV/u: n-n correlation



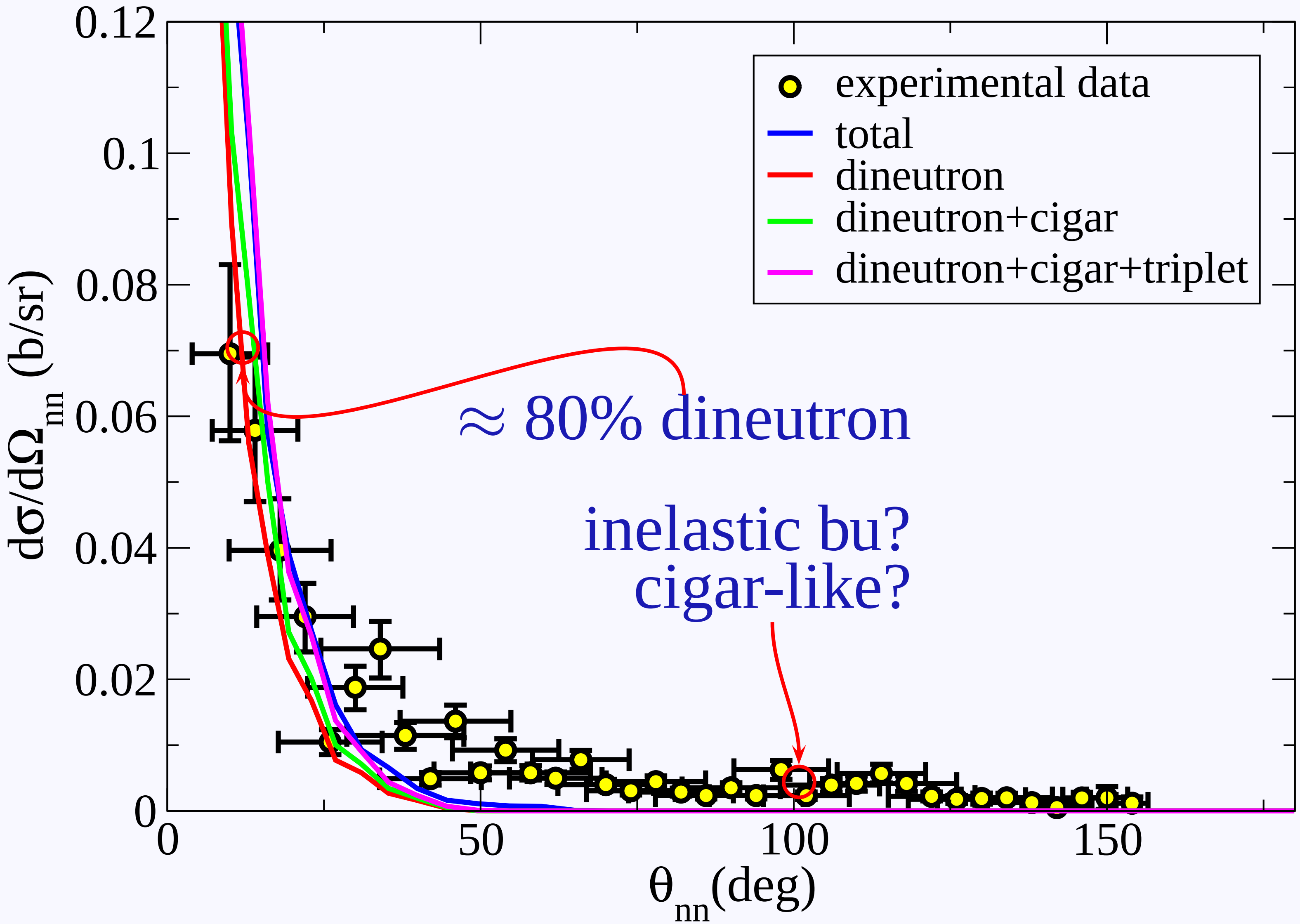
Exp. data: Assiè et al. EPJA 42 (2009) 441

$^{6}He+^{208}Pb$: n-n configurations



- Exp. data: Assiè et al. EPJA 42 (2009) 441

$^{6}He+^{208}Pb$: n-n configurations



Exp. data: Assiè et al. EPJA 42 (2009) 441

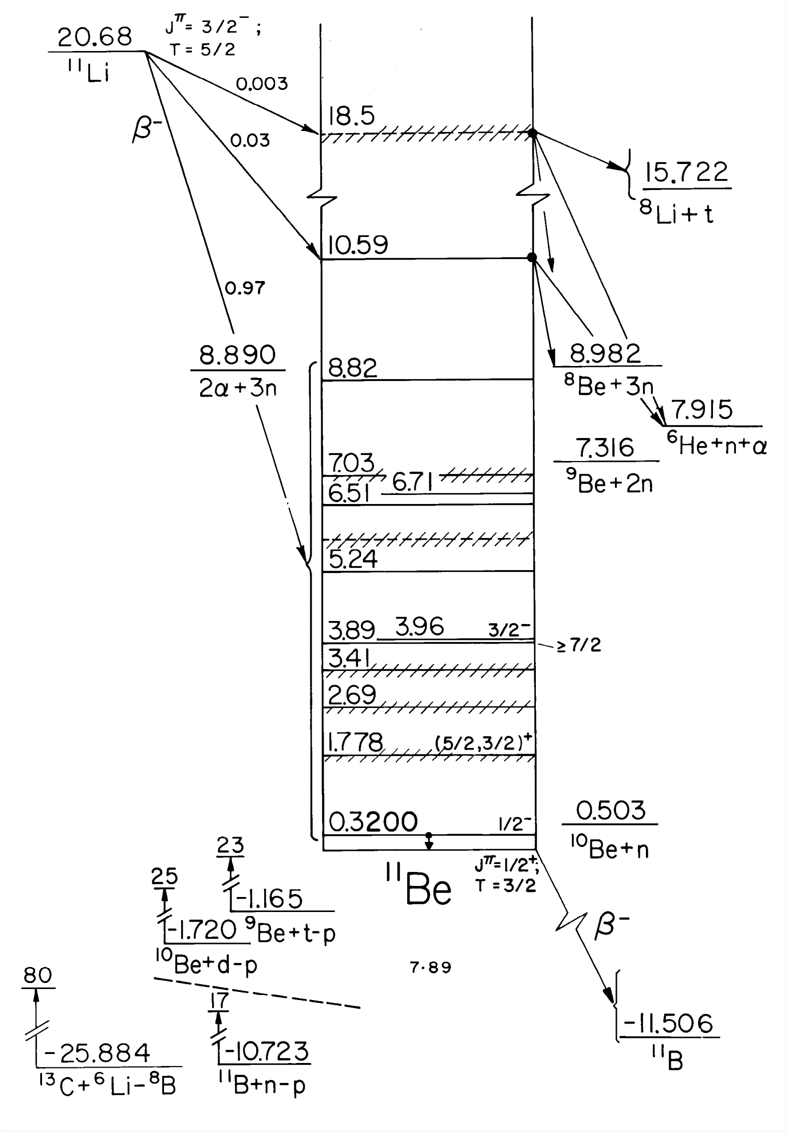
Summary and Conclusions

- We have presented a new prescription in order to calculate the inelastic breakup observables within the 3b-CDCC framework
- The formalism has been applied to reactions induced by the halo nucleus ^{11}Be
- We have been able to reproduce the experimental neutron distributions
- We will apply this new prescription within the 4b-CDCC framework to study the neutron-neutron correlation in reactions of the halo Borromean nucleus ^{6}He

Collaborators

- Depto. de FAMN, Universidad de Sevilla
  J. Gómez-Camacho and A. M. Moro
- IPN, Université Paris-Sud 11
  M. Assiè and J. A. Scarpaci
- GANIL
  D. Lacroix

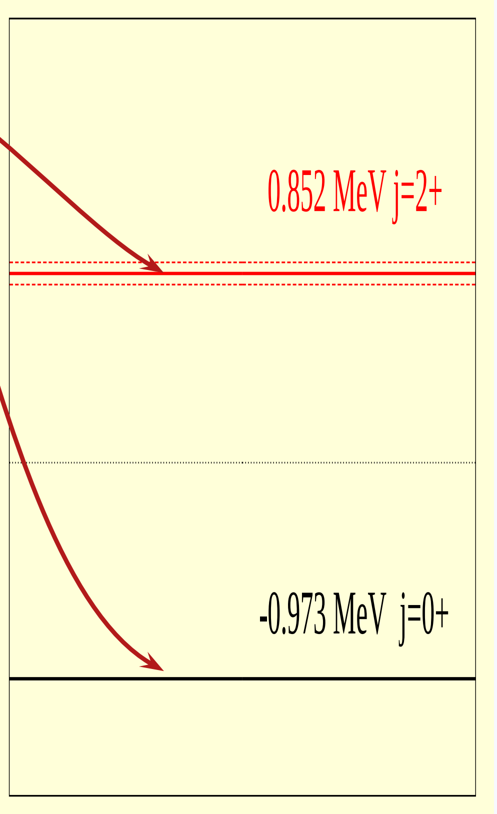
^{11}Be sprectrum



^{6}He Hamiltonian

$$\widehat{H}(\rho,\Omega) = \widehat{T}(\rho,\Omega) + \widehat{V}(\rho,\Omega)$$

$$V = V_{n\alpha} + V_{n\alpha} + V_{nn} + V_{nn\alpha}$$



$$K_{max} = 8$$

$$\Downarrow$$

$$n^{0+} = 15 \quad n^{1-} = 26 \quad n^{2+} = 46$$

$$N = (i_{max} + 1) \times n$$

☛ Pauli forbidden states: repulsive V_c for s-waves