Reacciones con núcleos exóticos: desarrollos teóricos e interpretación de datos experimentales

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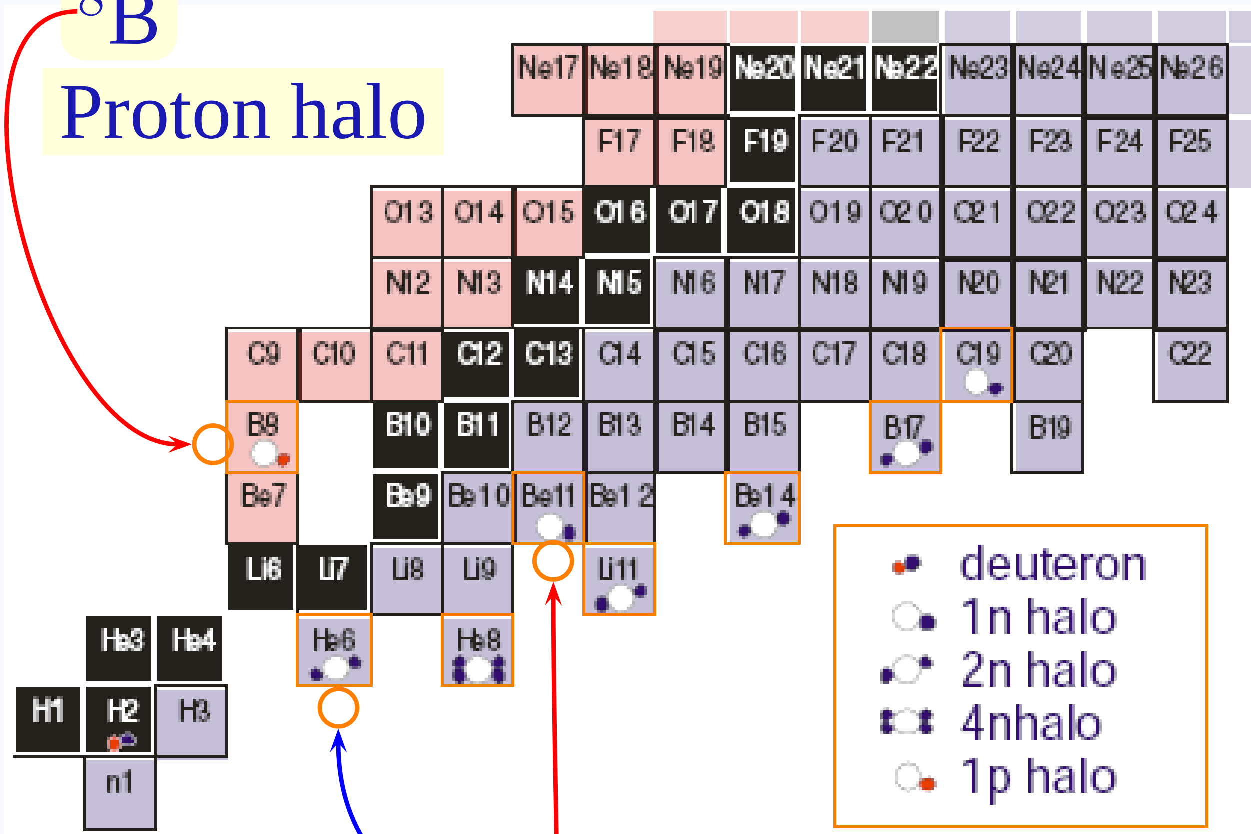
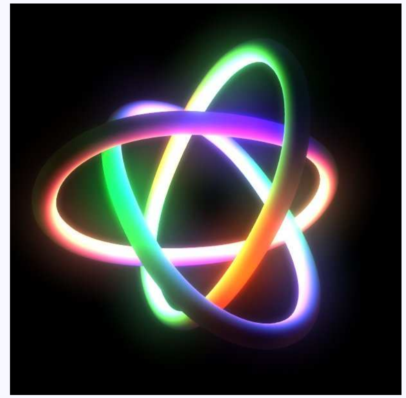
Esquema

- Motivación: núcleos halo
- Líneas de investigación desarrolladas:
  - Estructura de sistemas débilmente ligados
  - Reacciones nucleares de 3 y 4 cuerpos: continuum-discretized coupled-channels (CDCC)
    - Observables de ruptura de 4 cuerpos
    - ✓ Apoyo a grupos experimentales
  - Reacciones nucleares de interés astrofísico
  - Reacciones nucleares de 3 cuerpos: ecuaciones Faddeev/AGS
  - Reacciones de moléculas débilmente ligadas
- Nuevas líneas a investigar

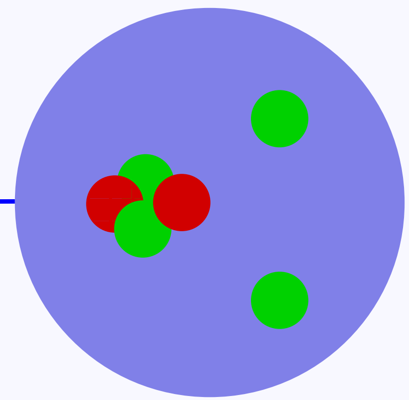
Motivación: Núcleos halo

^{8}B
Proton halo



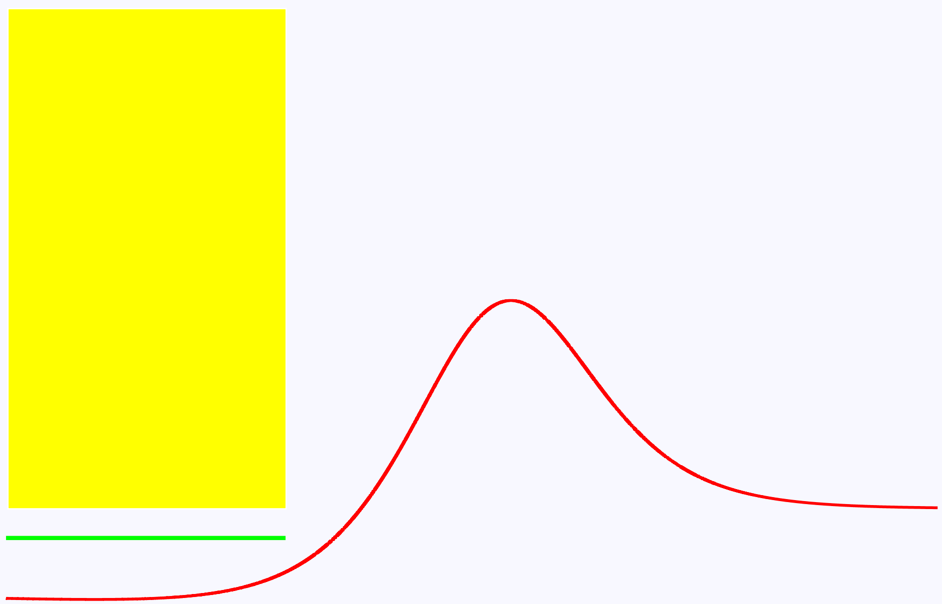


Borromean
2-neutron halo

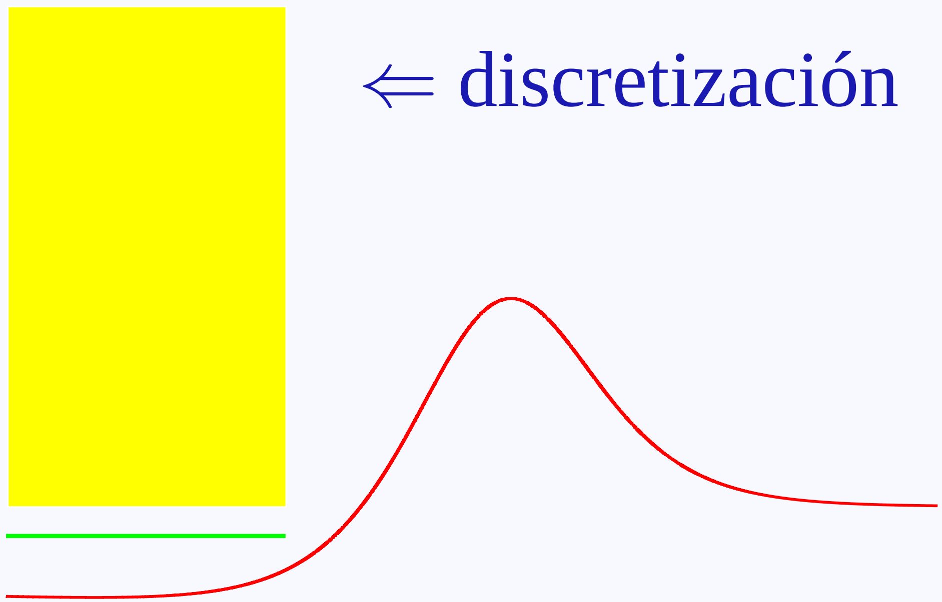


^{11}Be
1st neutron halo 1983

Estructura de sistemas débilmente ligados



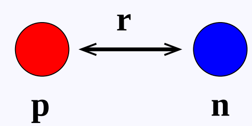
Estructura de sistemas débilmente ligados

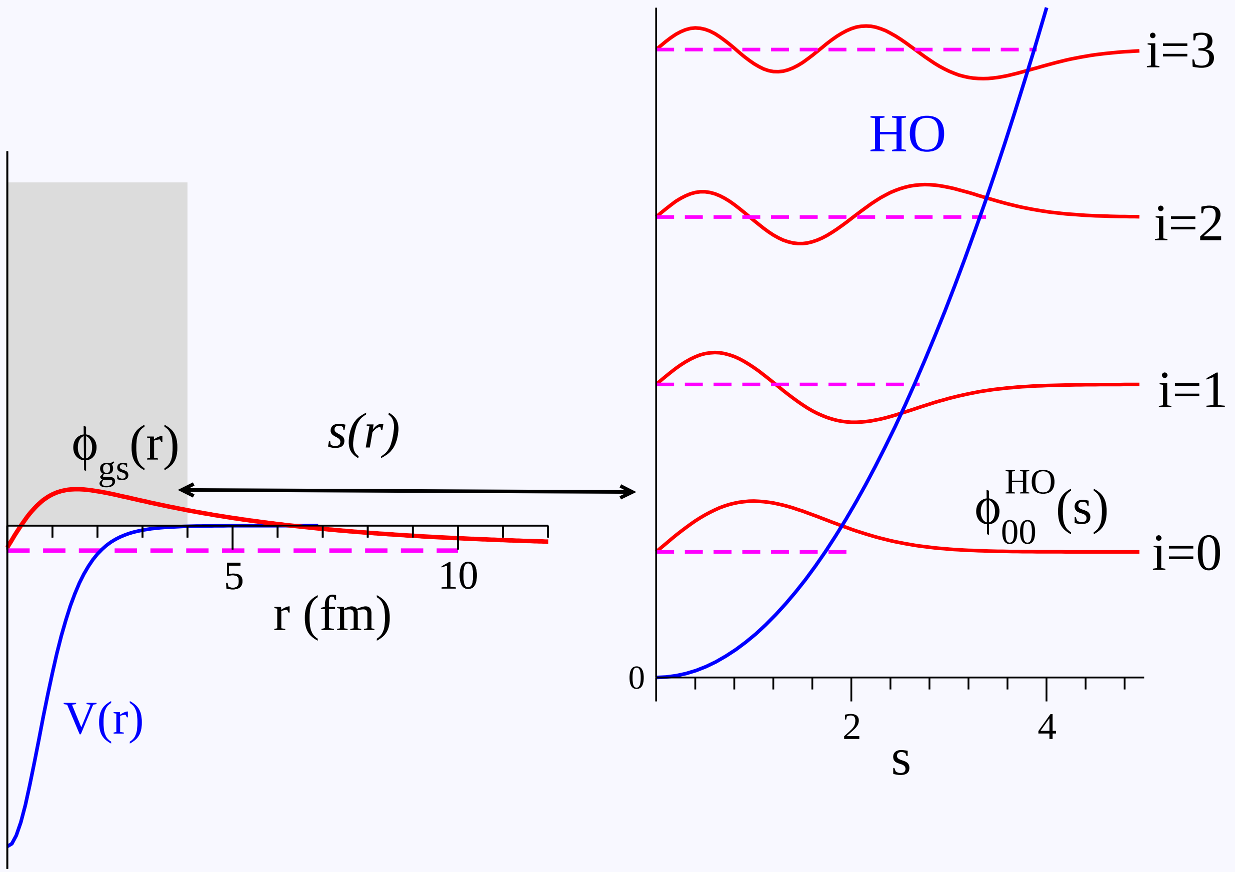


$\Leftarrow$ discretización

Método THO

- Ejemplo: deuterón en onda s



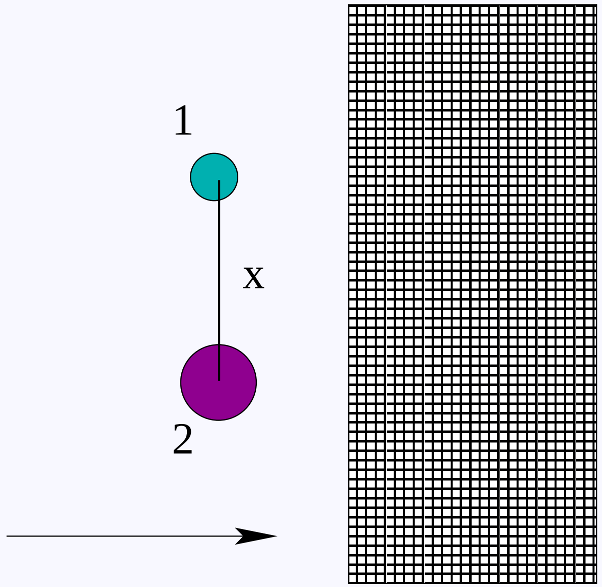


$$\int_0^r dr' r^2 |\phi_{gs}(r')|^2 = \int_0^s ds' s'^2 |\phi_{00}^{HO}(s')|^2$$

Polarizabilidad sistema 2 cuerpos

$$\boxed{\alpha(THO) = \sum_n \left(\langle B|P_2(x)|n\rangle\langle n|P_2(x)|B\rangle\right)/(\varepsilon_n - \varepsilon_B)}$$

i_{max}	α (e^2fm^2/MeV)
1	0.52155
2	0.70895
3	0.71720
4	0.71721
5	0.71721
exacto	0.71721

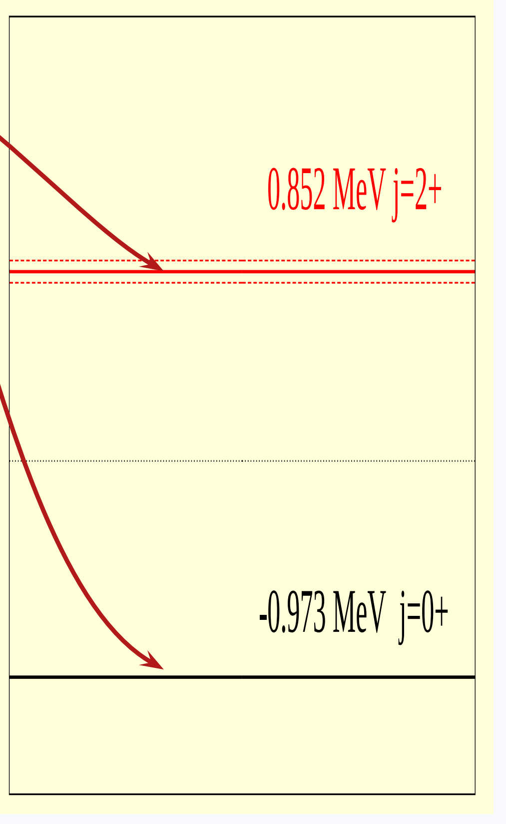


☞ I. Martel, et al., **PRA** 65 (2002) 052708

Propiedades de estructura: ^{6}He

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

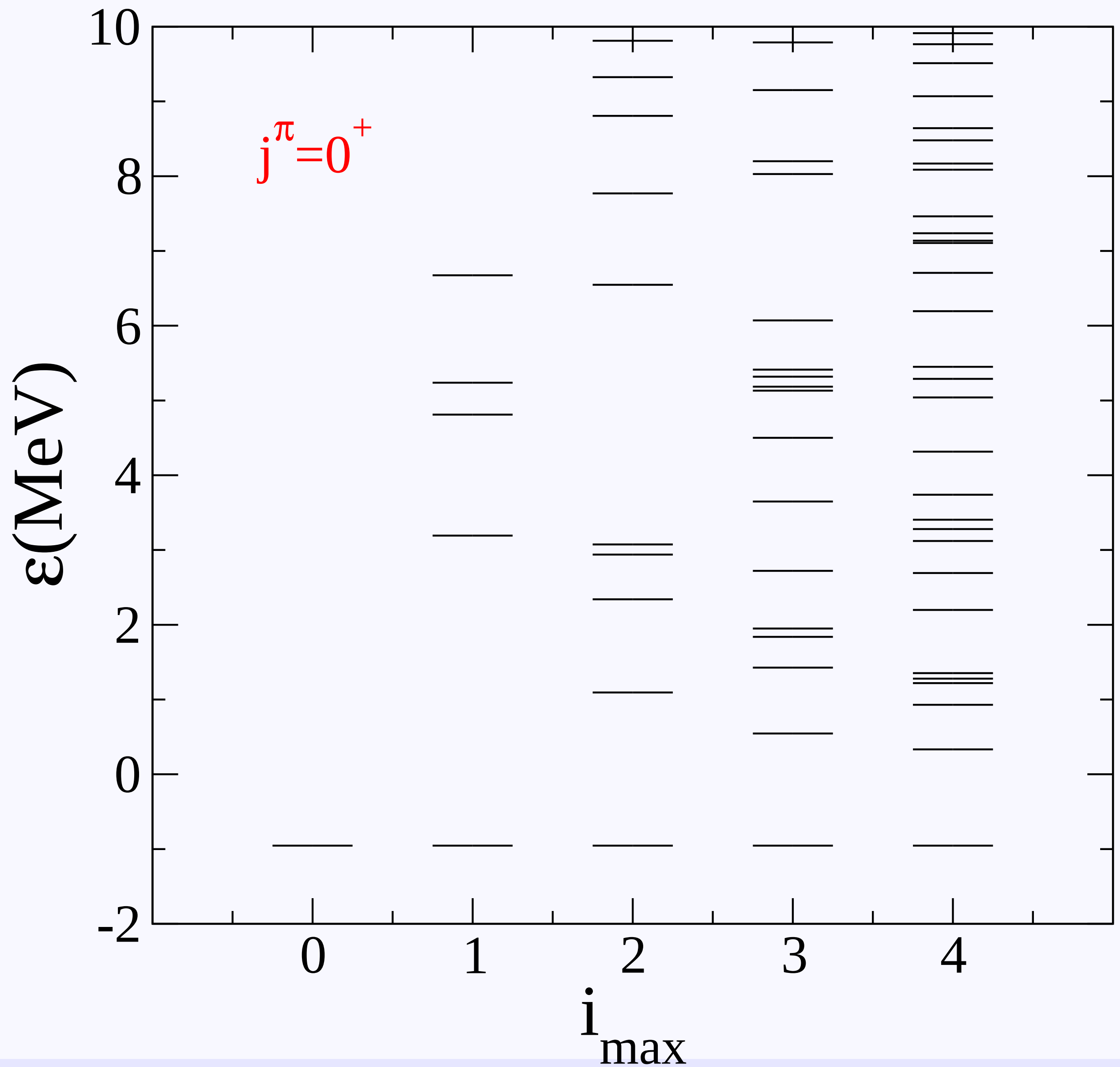
$$V = V_{n\alpha} + V_{n\alpha} + V_{nn} + V_{nn\alpha}$$



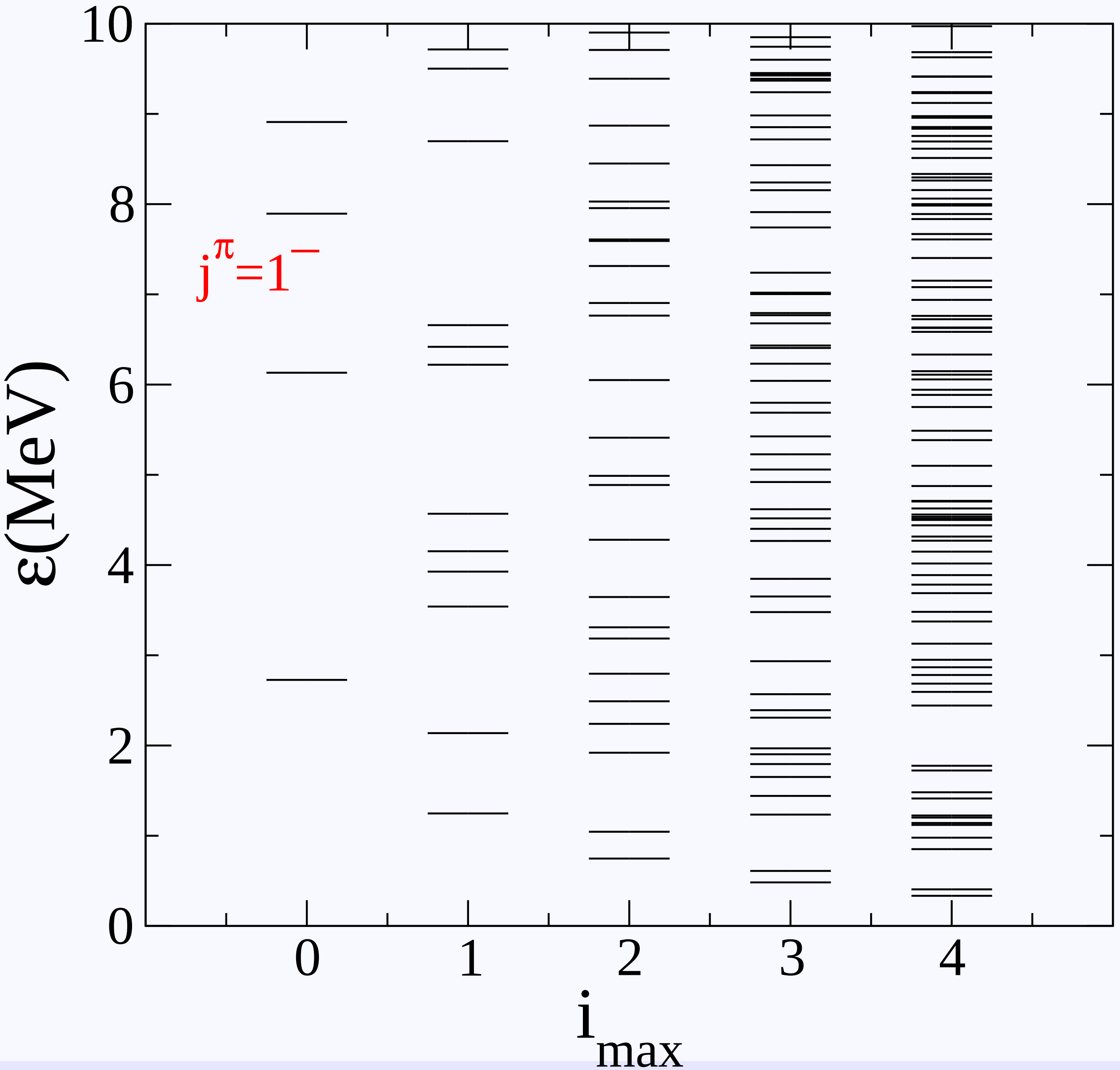
☛ Estados prohibidos de Pauli: V_c repulsivo en onda s

✉ Rodríguez-Gallardo et al. PRC 72 (2005) 024007

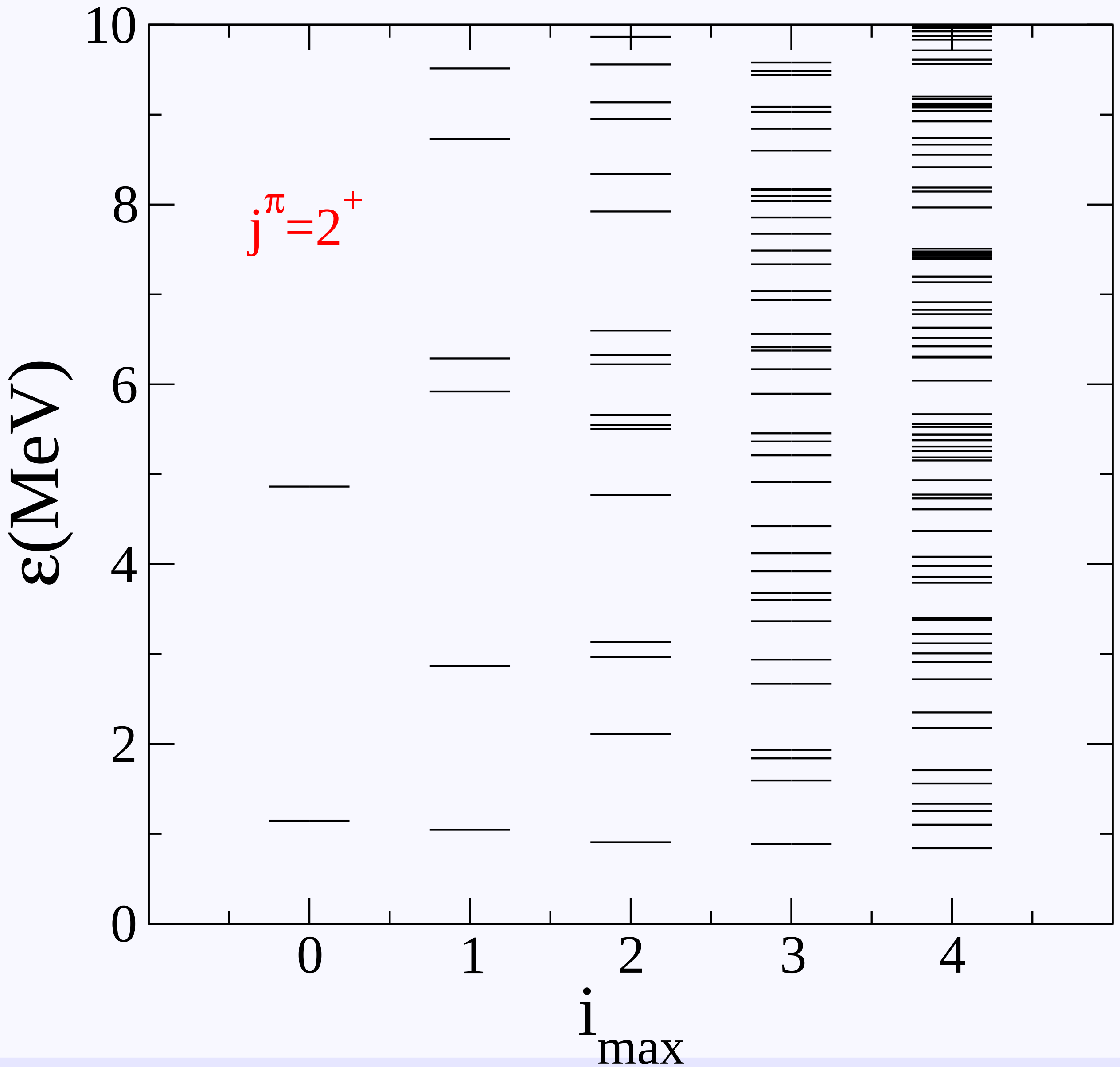
THO: espectros de energía



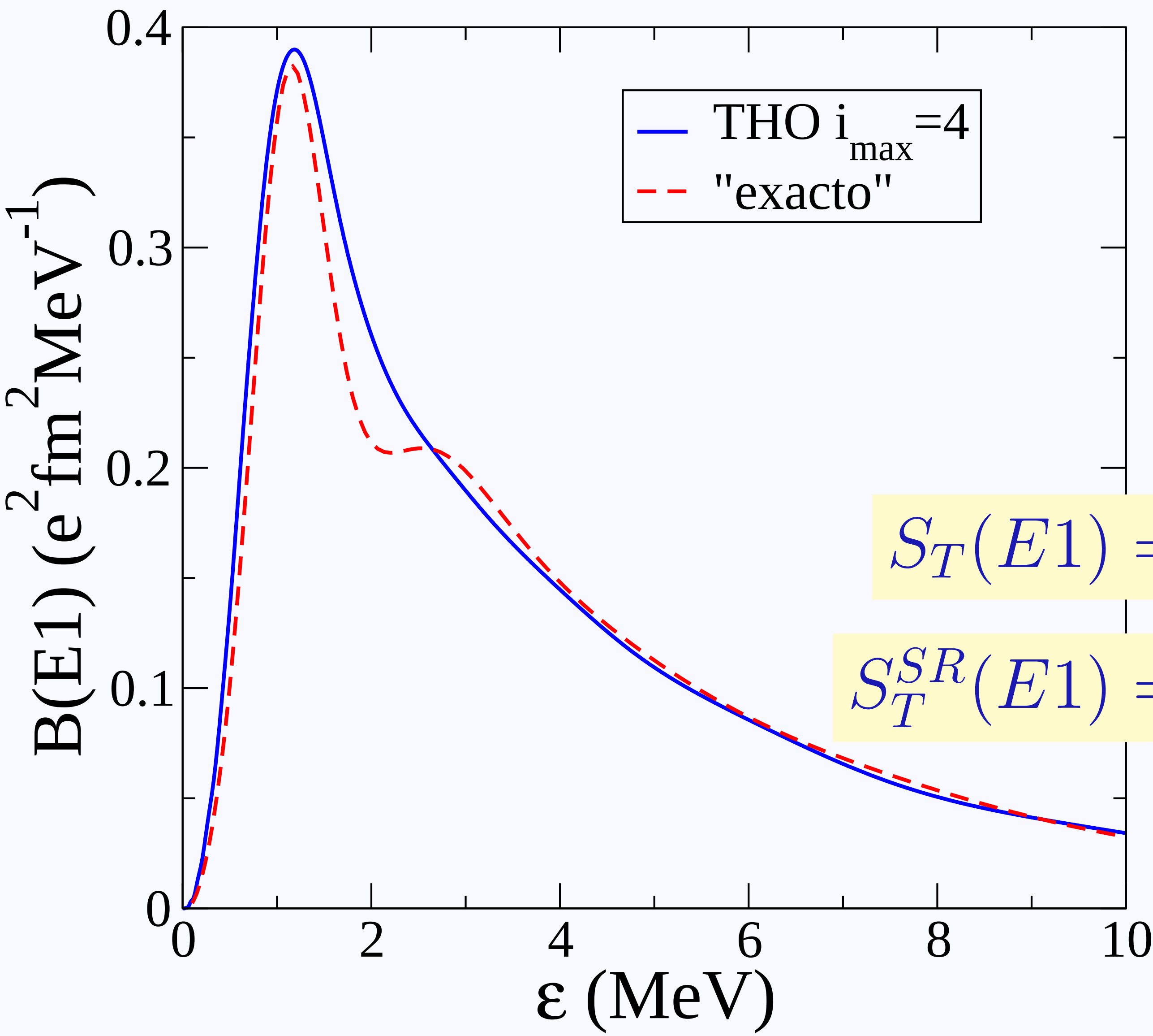
THO: espectros de energía



THO: espectros de energía



Distribución de $B(E1)$



$S_T(E1) = 1.498$ e^{2}fm^2

$S_T^{SR}(E1) = 1.500$ e^{2}fm^2

Rodríguez-Gallardo et al. PRC 72 (2005) 024007

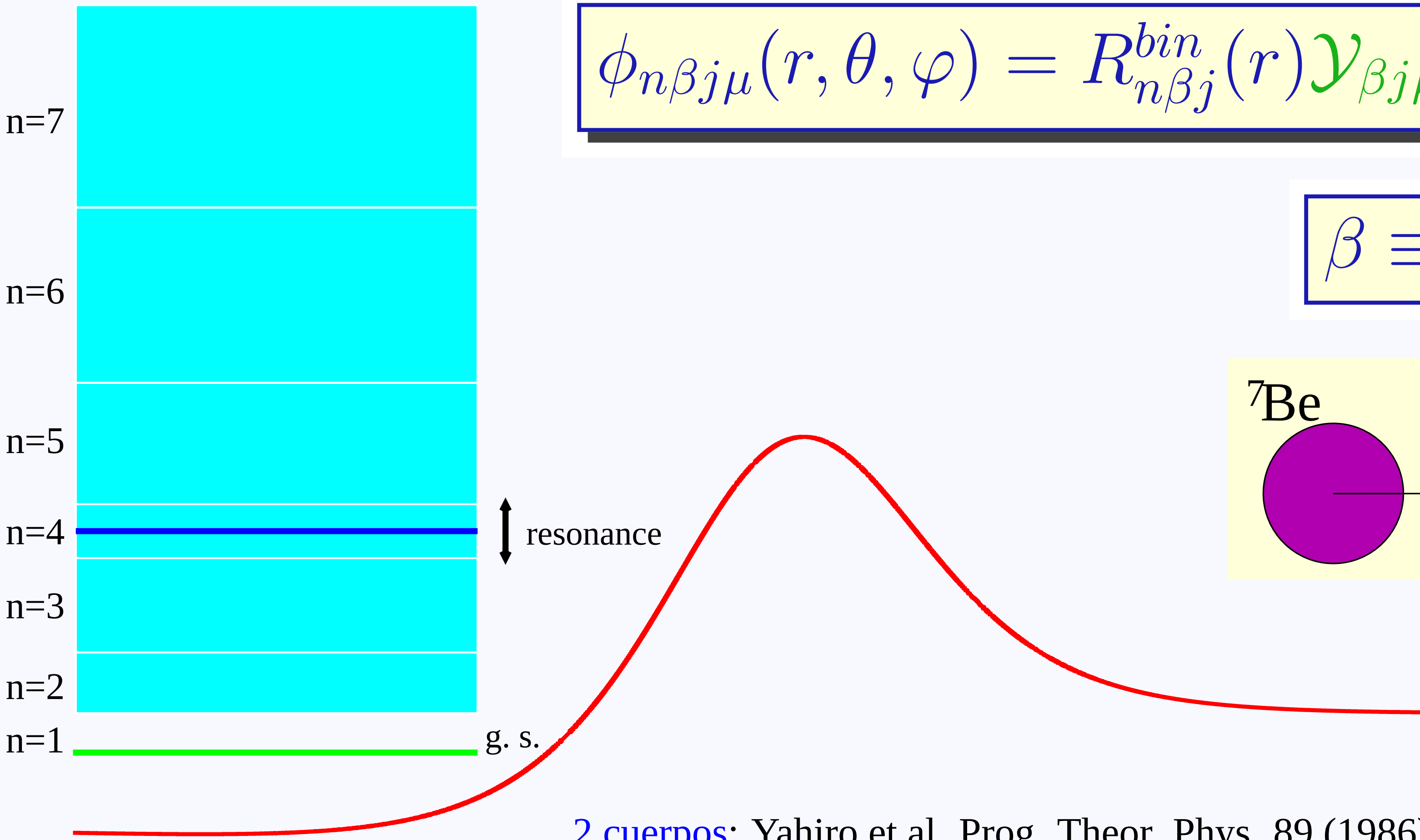
Otro método: *binning*

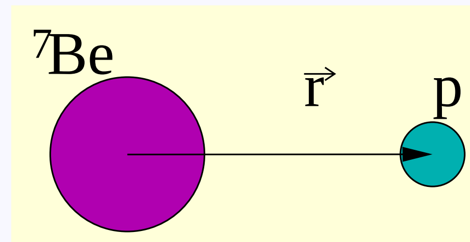
$\boxed{\times\beta}$

sistema de 2 cuerpos

$$\phi_{n\beta j\mu}(r,\theta,\varphi) = R^{bin}_{n\beta j}(r)\mathcal{Y}_{\beta j\mu}(\theta,\varphi)$$

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

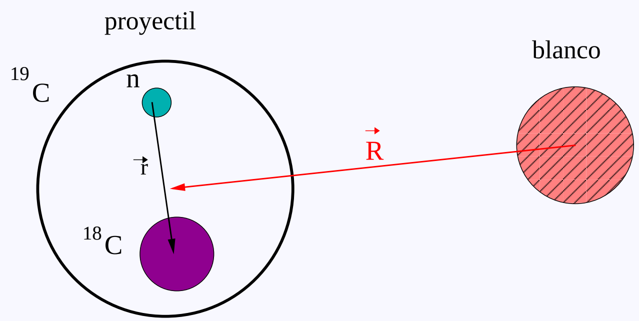


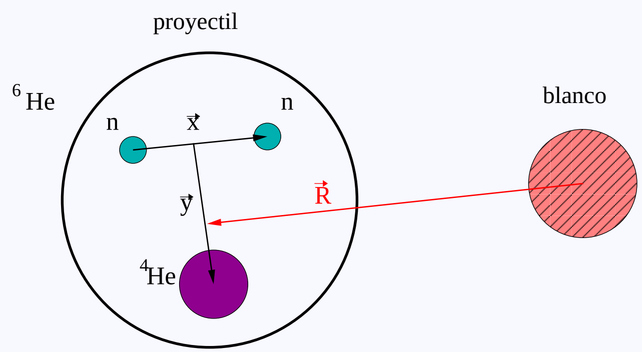


2 cuerpos: Yahiro et al. Prog. Theor. Phys. 89 (1986) 32

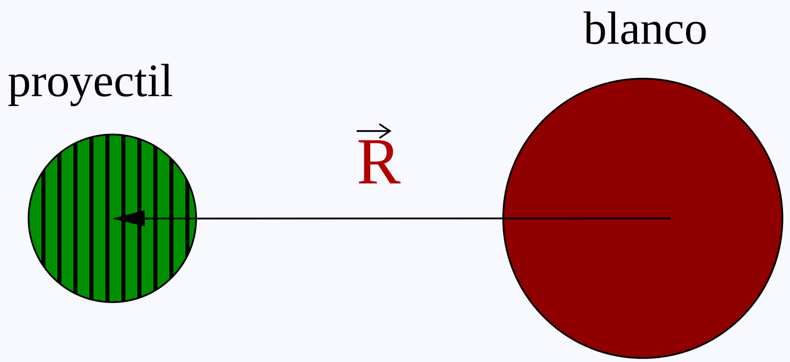
3 cuerpos: Rodríguez-Gallardo et al. PRC 80 (2009) 051601(R)

Reacciones nucleares de 3 y 4 cuerpos: formalismo CDCC

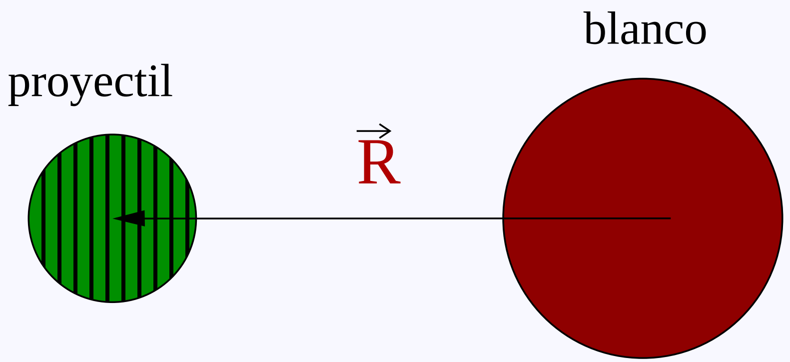




Formalismo CDCC

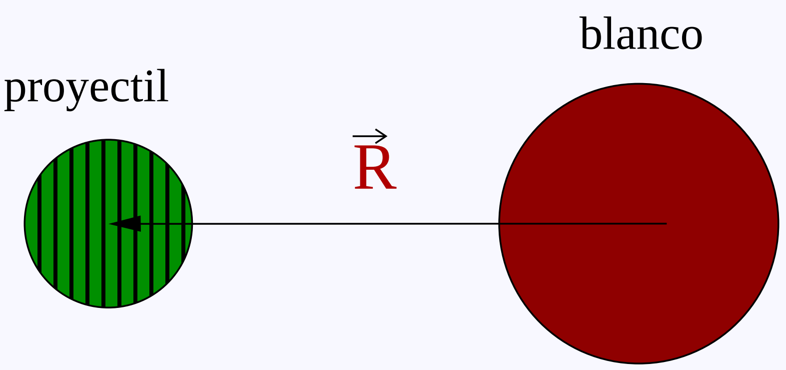


Formalismo CDCC



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

Formalismo CDCC

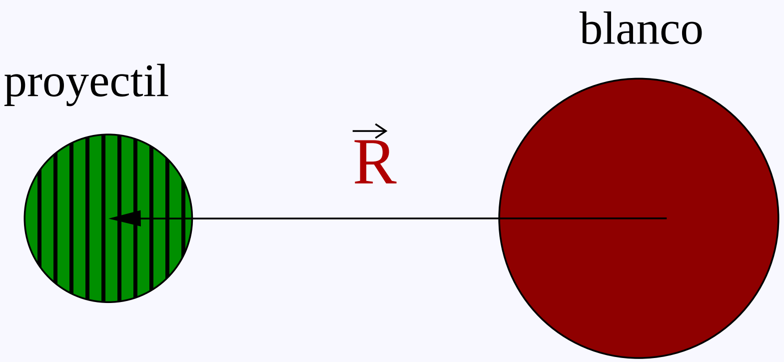


$$\boxed{\Psi_J^M(\vec{R},\xi) = \sum \phi_{jn}^{\mu}(\xi)\langle L M_L j \mu | J M\rangle \frac{i^L}{R} Y_L^{M_L}(\widehat{R}) f_{Lnj}^J(R)}$$

sistema de canales acoplados

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

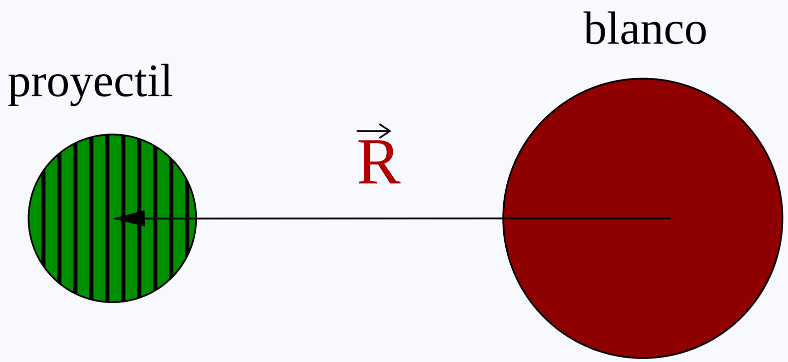
Formalismo CDCC



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

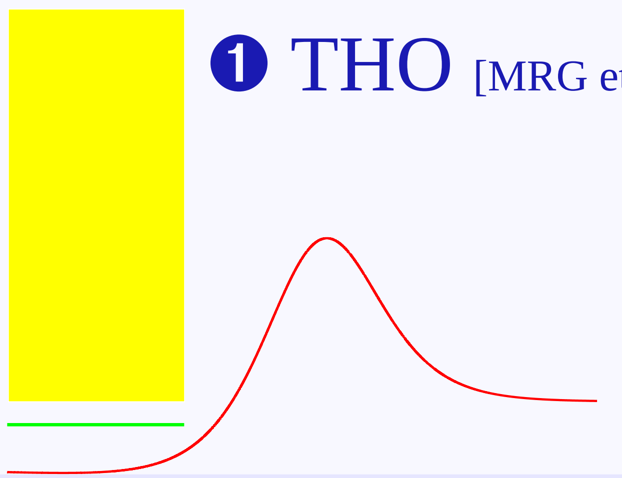
$\phi_n^{j\mu}(\xi)$?

Formalismo CDCC



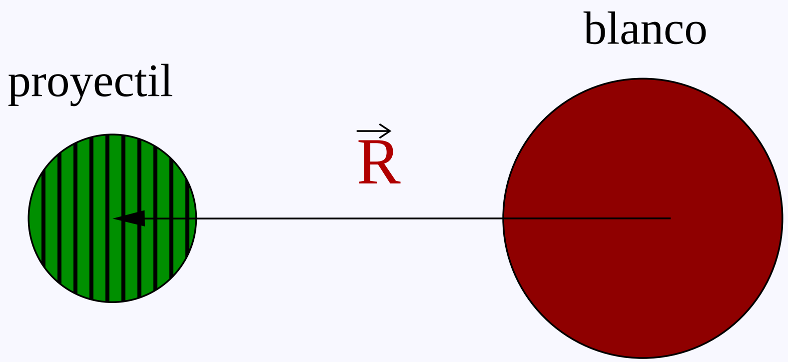
$$\boxed{\Psi_J^M(\vec{R},\xi) = \sum \phi_{jn}^{\mu}(\xi)\langle L M_L j\mu | J M\rangle \frac{i^L}{R} Y_L^{M_L}(\widehat{R}) f_{Lnj}^J(R)}$$

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



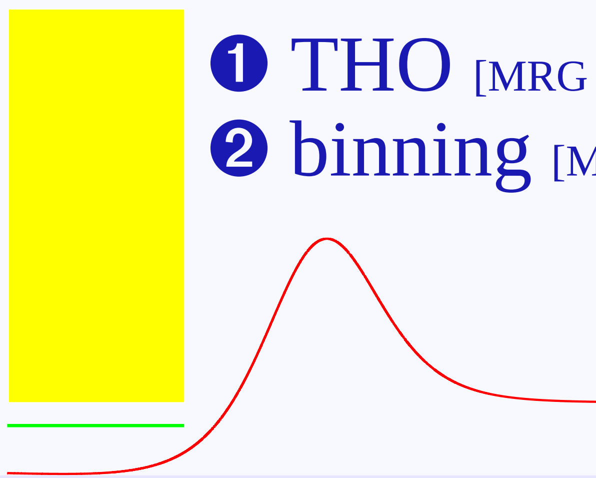
❶ THO [MRG et al. PRC 77 (2008) 064609]

Formalismo CDCC



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

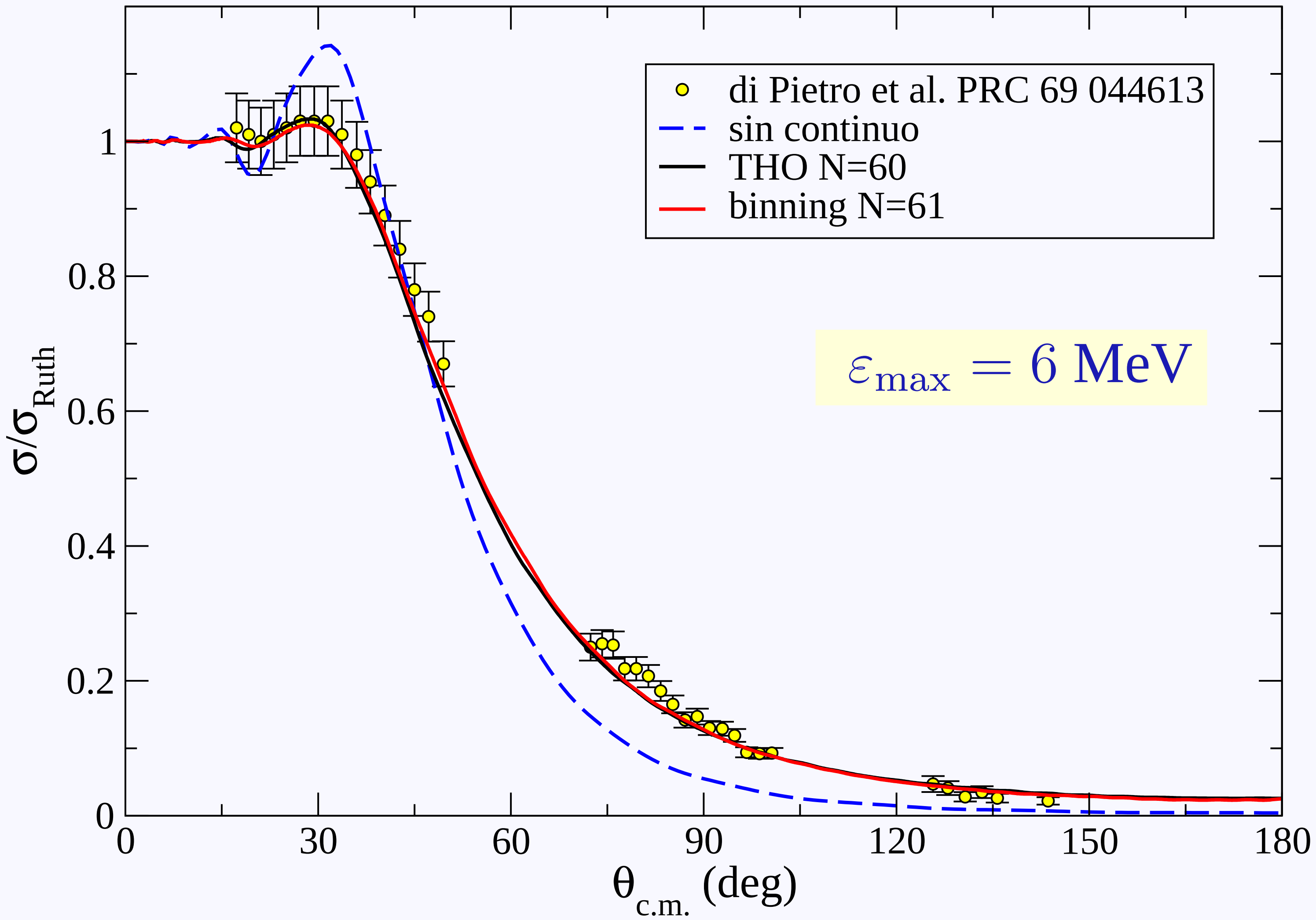
$\phi_n^{j\mu}(\xi)$?



❶ THO [MRG et al. PRC 77 (2008) 064609]

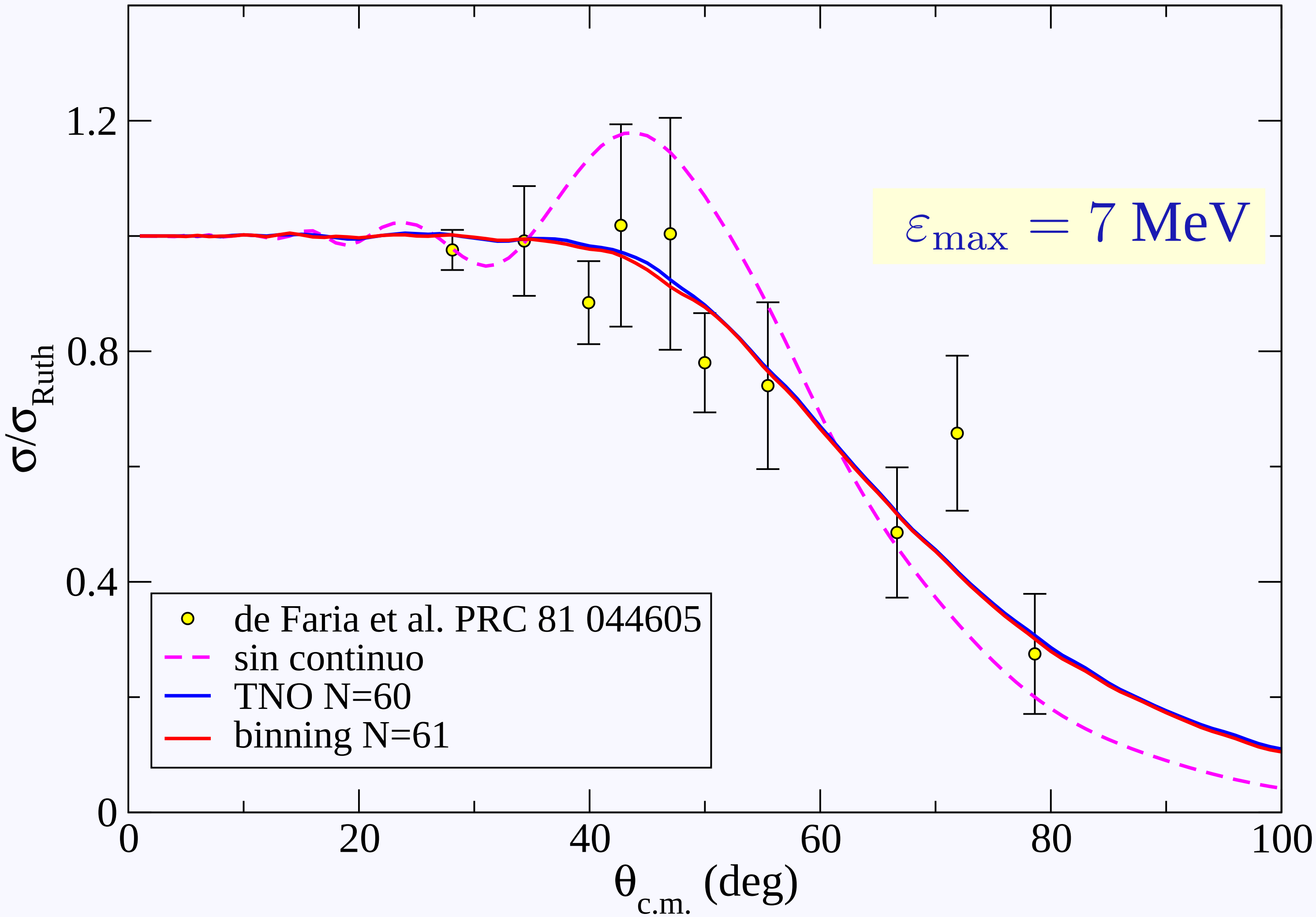
❷ binning [MRG et al. PRC 80 (2009) 051601(R)]

^{6}He+^{64}Zn@13.6MeV: elástico



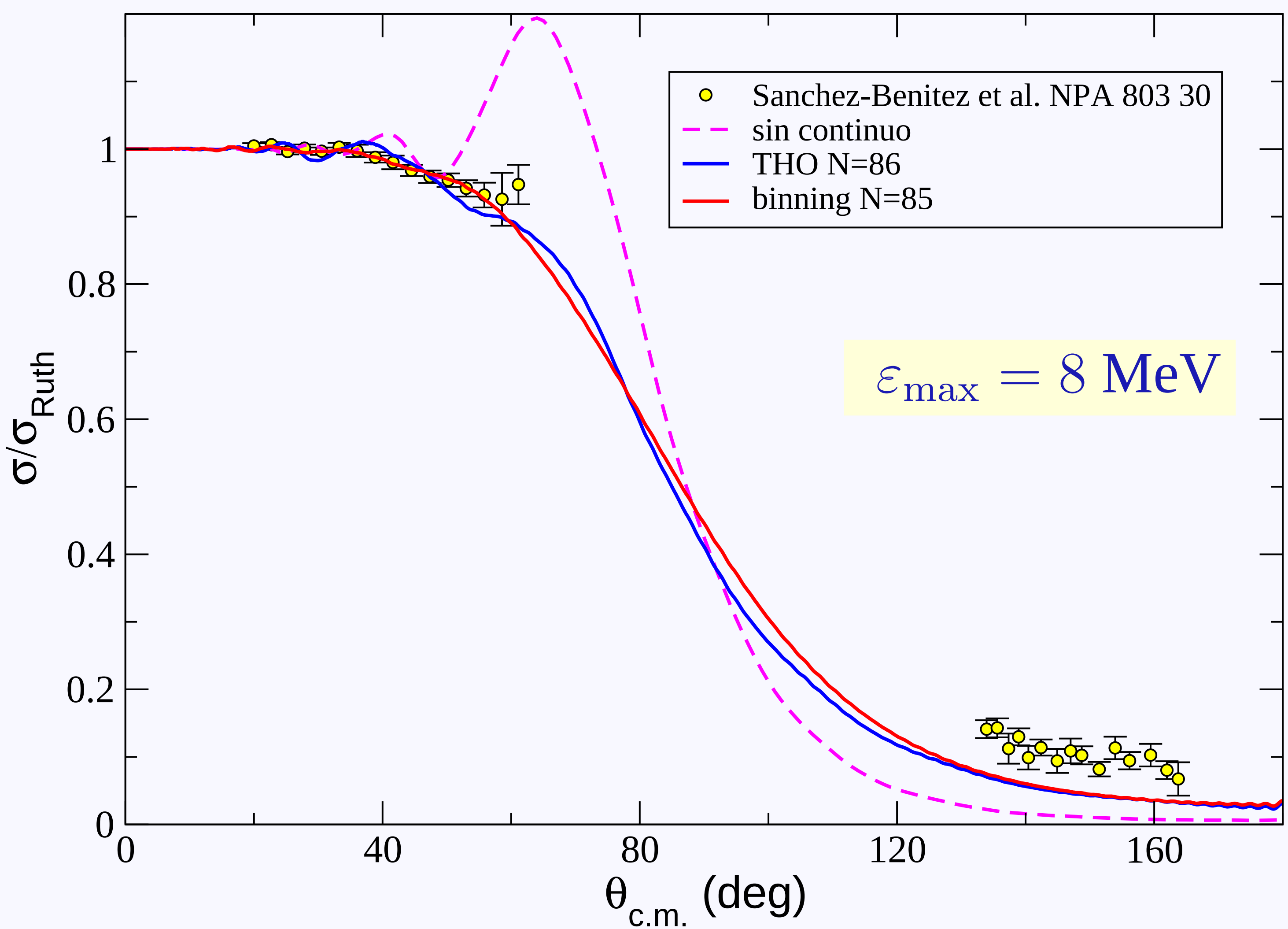
- THO: Rodríguez-Gallardo et al., PRC 77 (2008) 064609
- bin: Rodríguez-Gallardo et al., AIPCP 1231 (2010) 235-236

^{6}He+^{120}Sn@17.4MeV: elástico



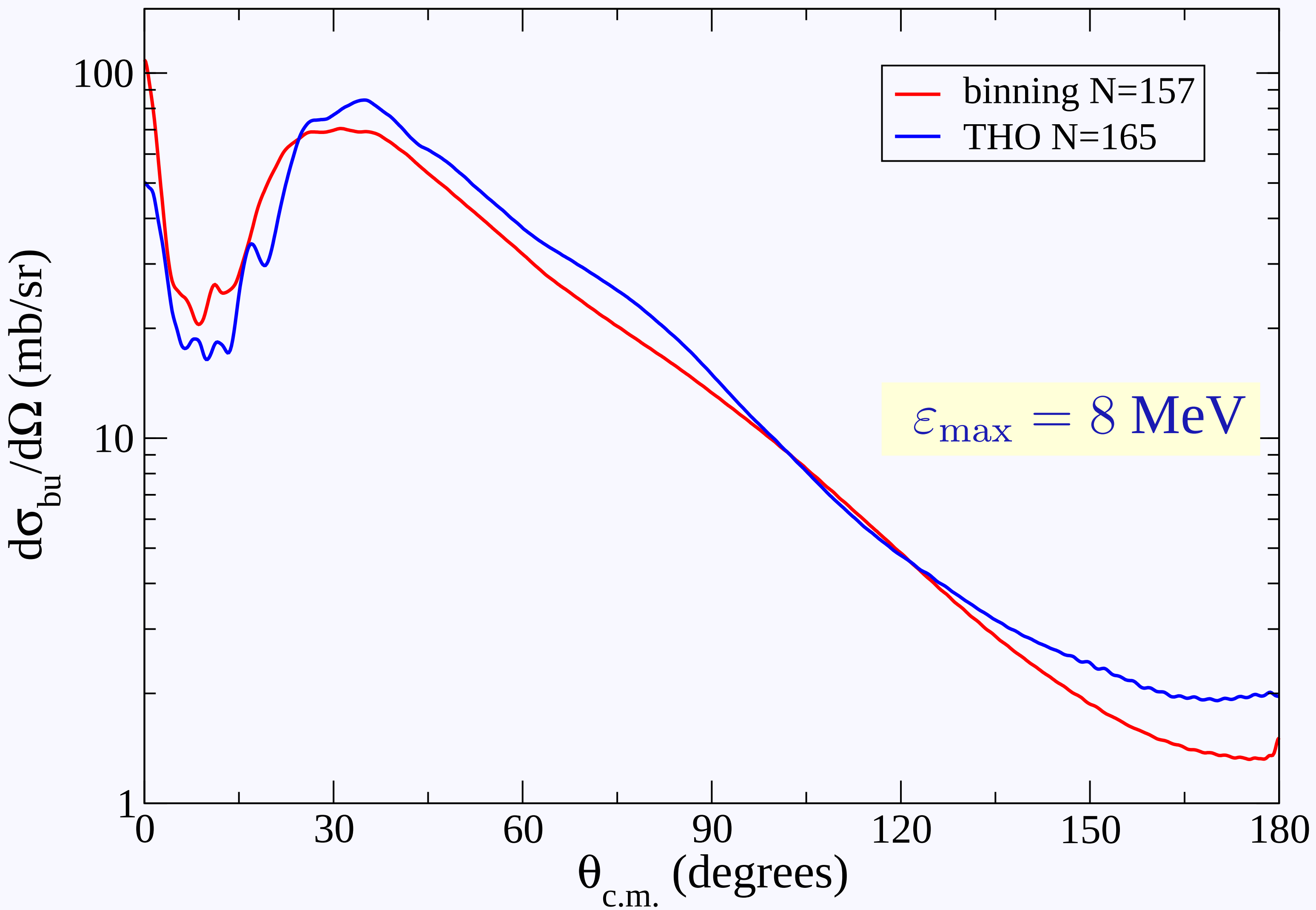
- THO: de Faria et al. PRC 81 (2010) 044605
- bin: Rodríguez-Gallardo and Moro. AIP Conf. Proc. 1351 (2011) 29-38

^{6}He+^{208}Pb@22MeV: elástico



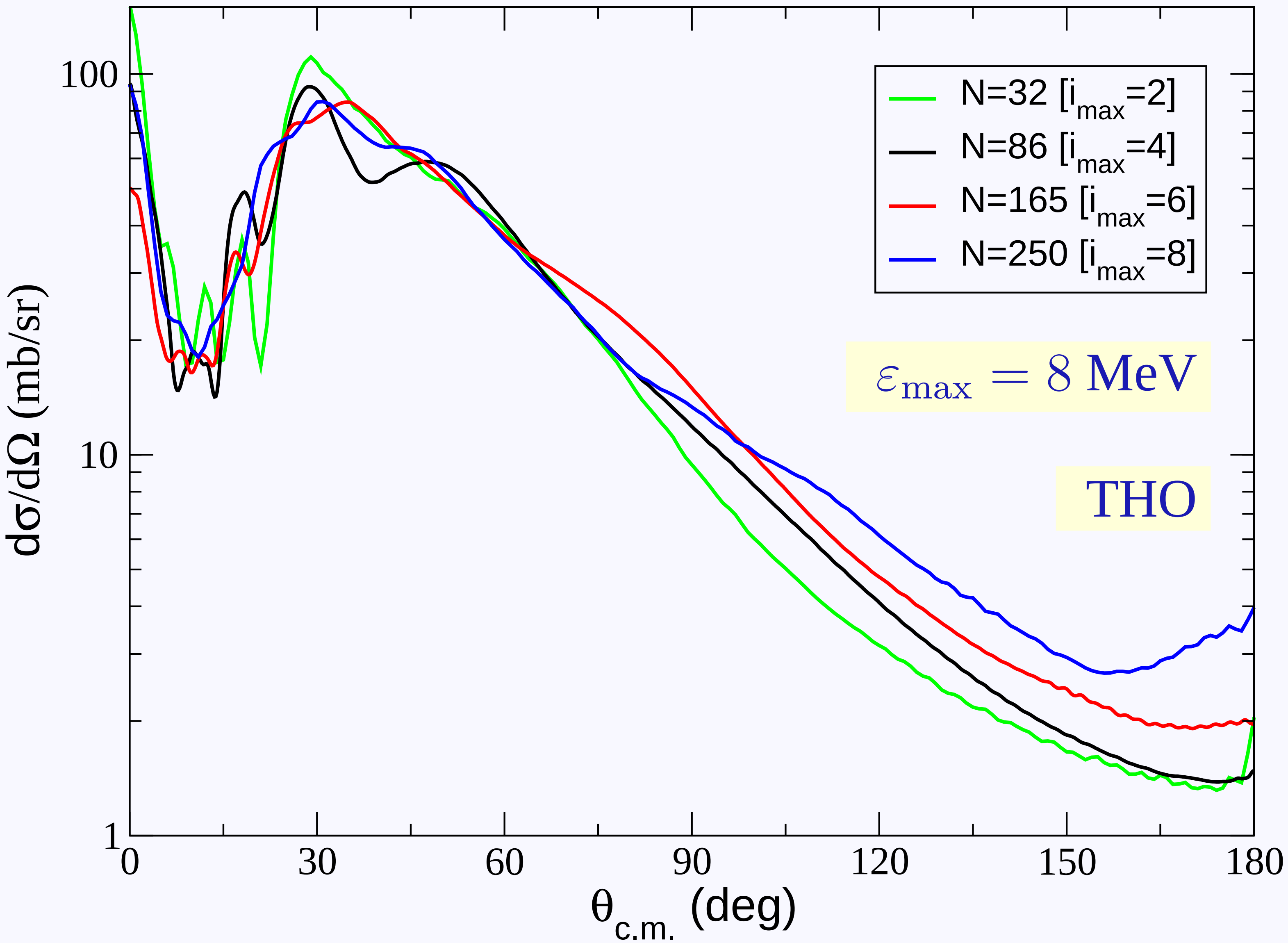
- THO: Rodríguez-Gallardo et al., PRC 77 064609 (2008)
- bin: Rodríguez-Gallardo et al. PRC 80 (2009) 051601(R)

^{6}He+^{208}Pb@22MeV: breakup

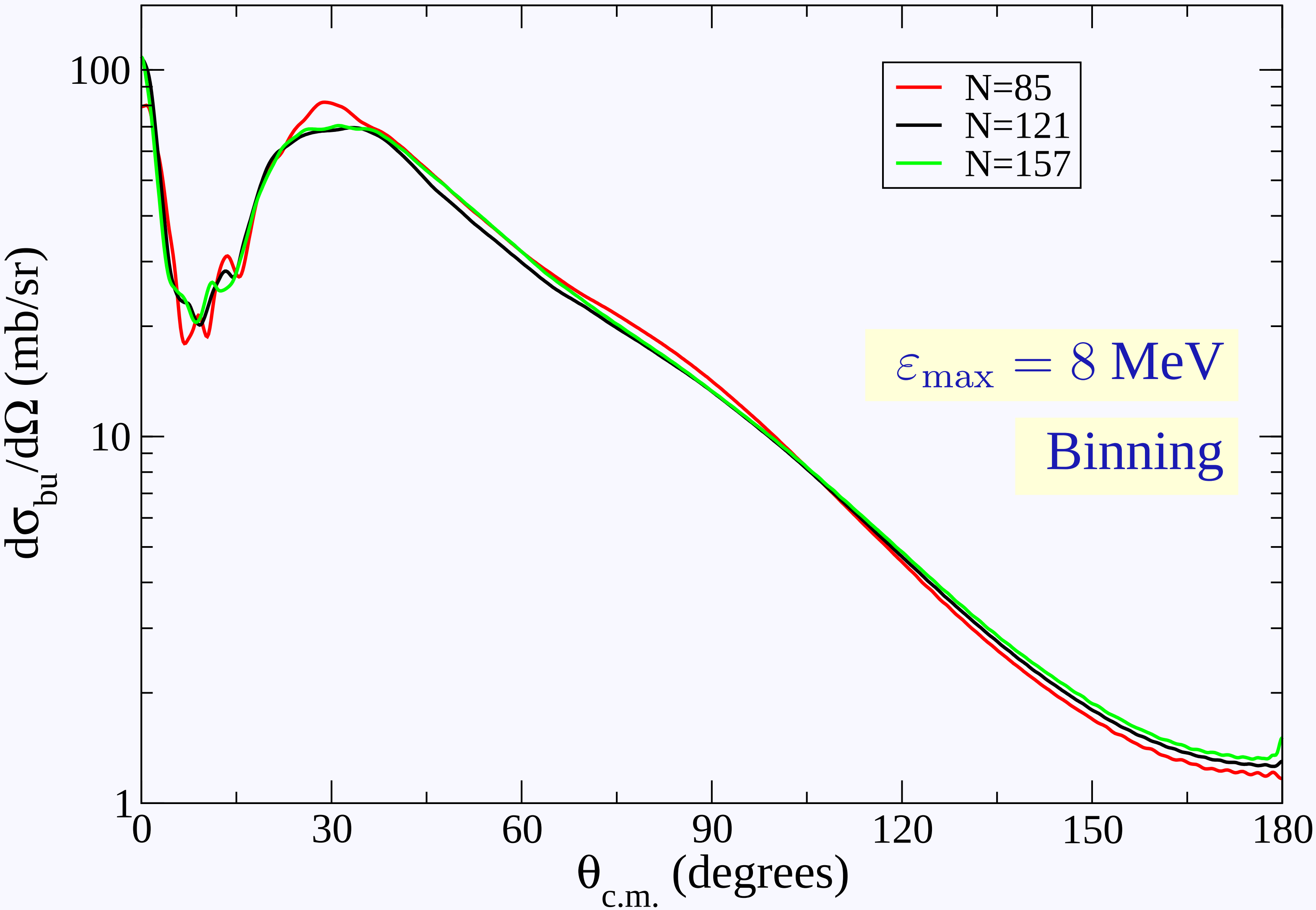


- bin: Rodríguez-Gallardo and Moro. AIP Conf. Proc. 1351 (2011) 29-38
- THO: sin publicar

^{6}He+^{208}Pb@22MeV: breakup



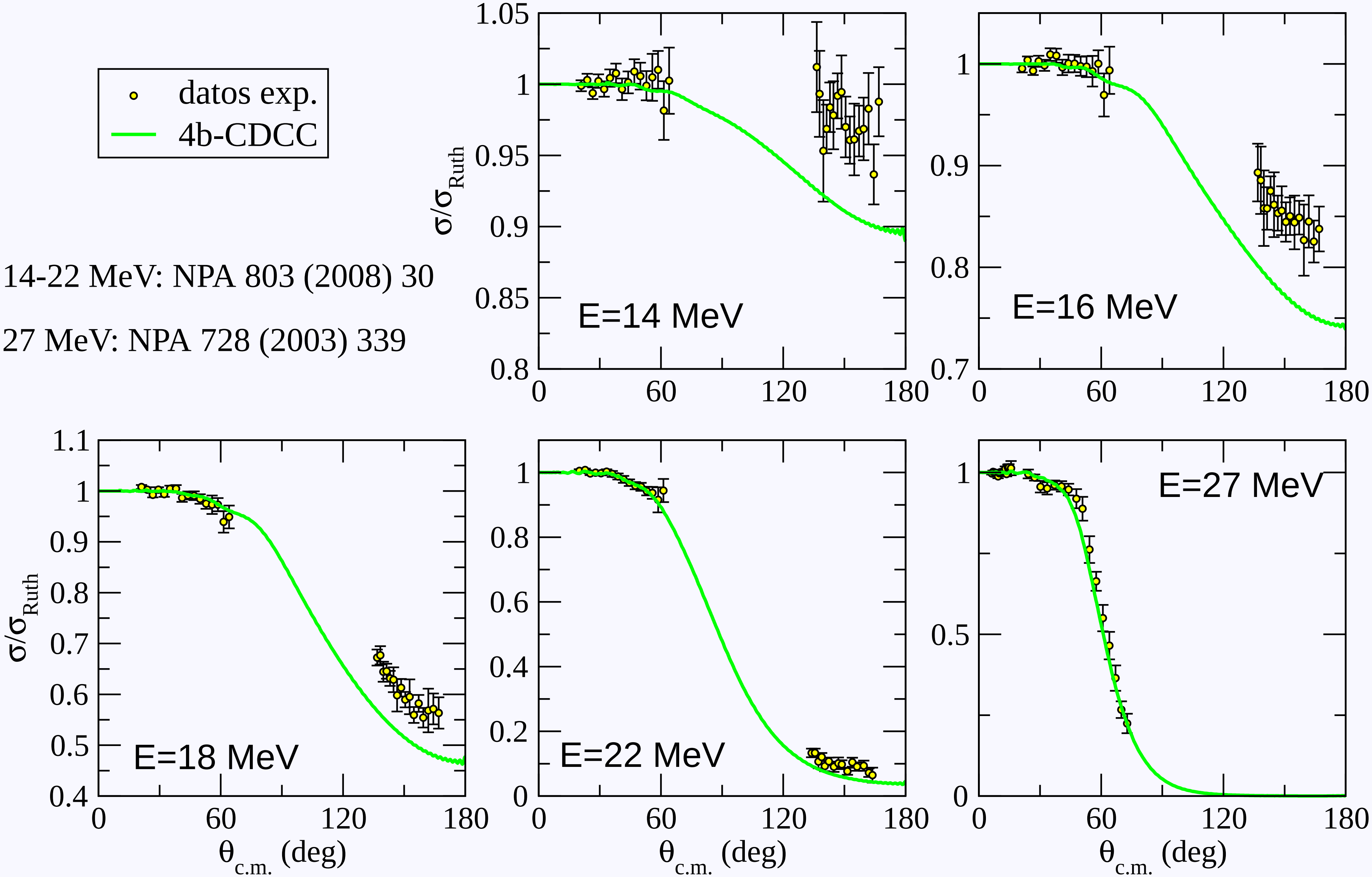
^{6}He+^{208}Pb@22MeV: breakup



$\varepsilon_{\max} = 8$ MeV

Binning

$^{6}He+^{208}Pb$@14,16,18,22,27MeV



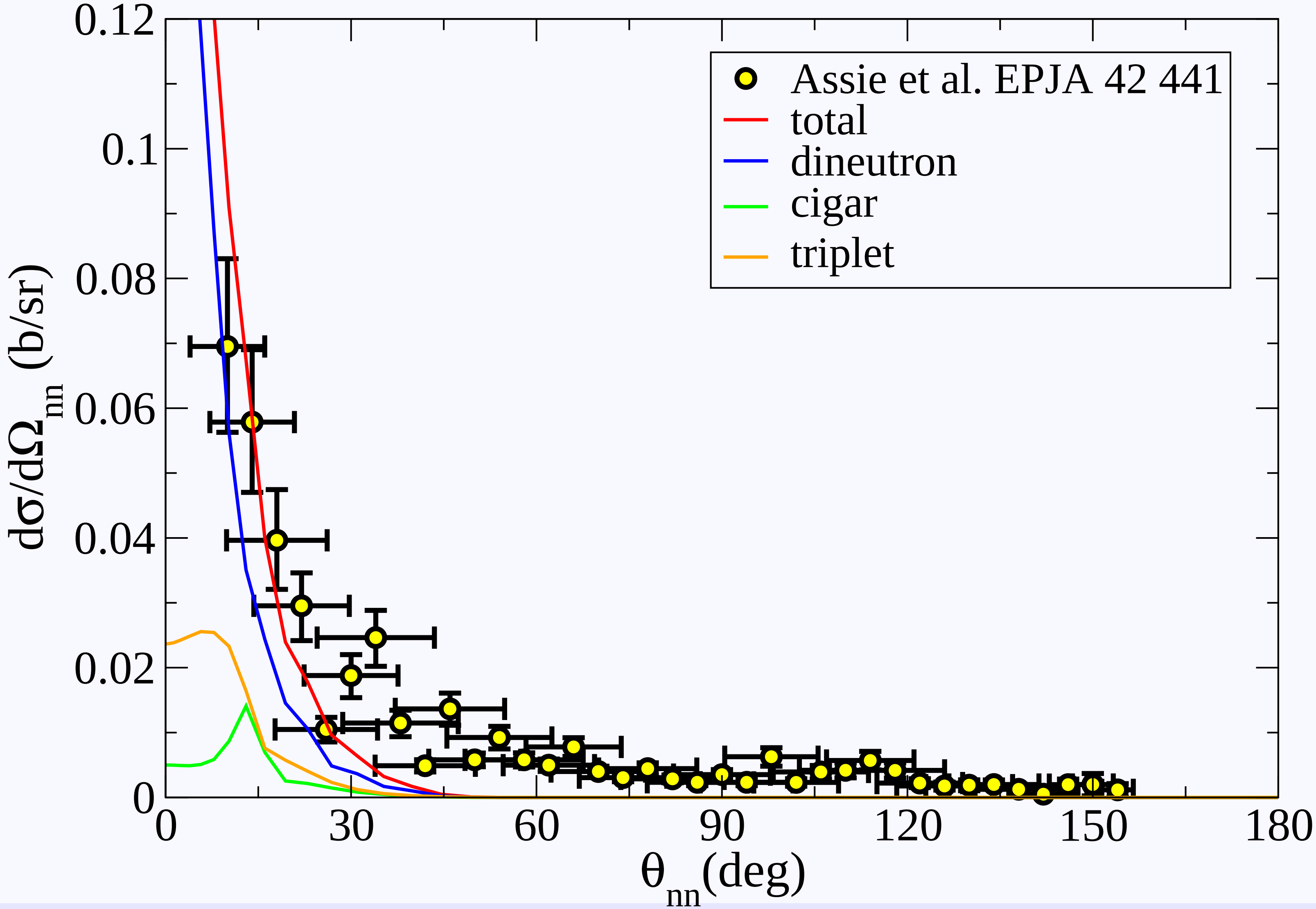
14-22 MeV: NPA 803 (2008) 30

27 MeV: NPA 728 (2003) 339

Fernández-García et al. NPA 840 (2010) 19-38; PLB 693 (2010) 310-315

Observables de ruptura de 4 cuerpos

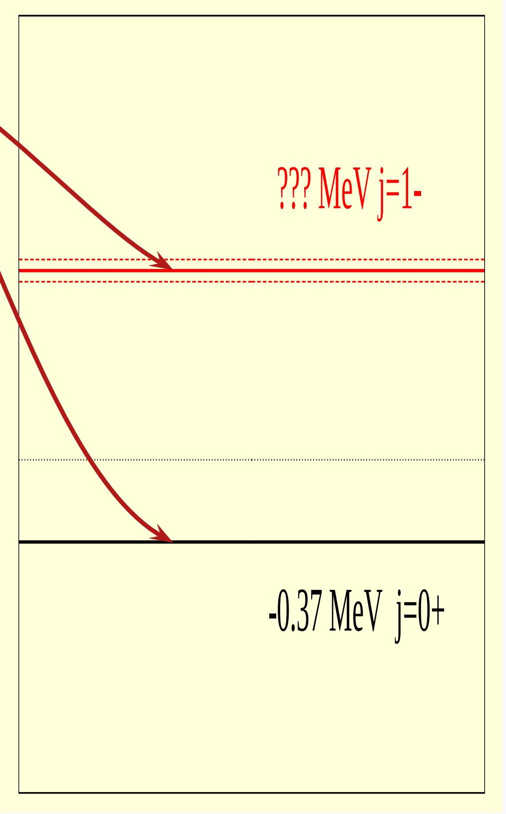
$^{6}He+^{208}Pb@120MeV$



^{11}Li: ¿qué sabemos?

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

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

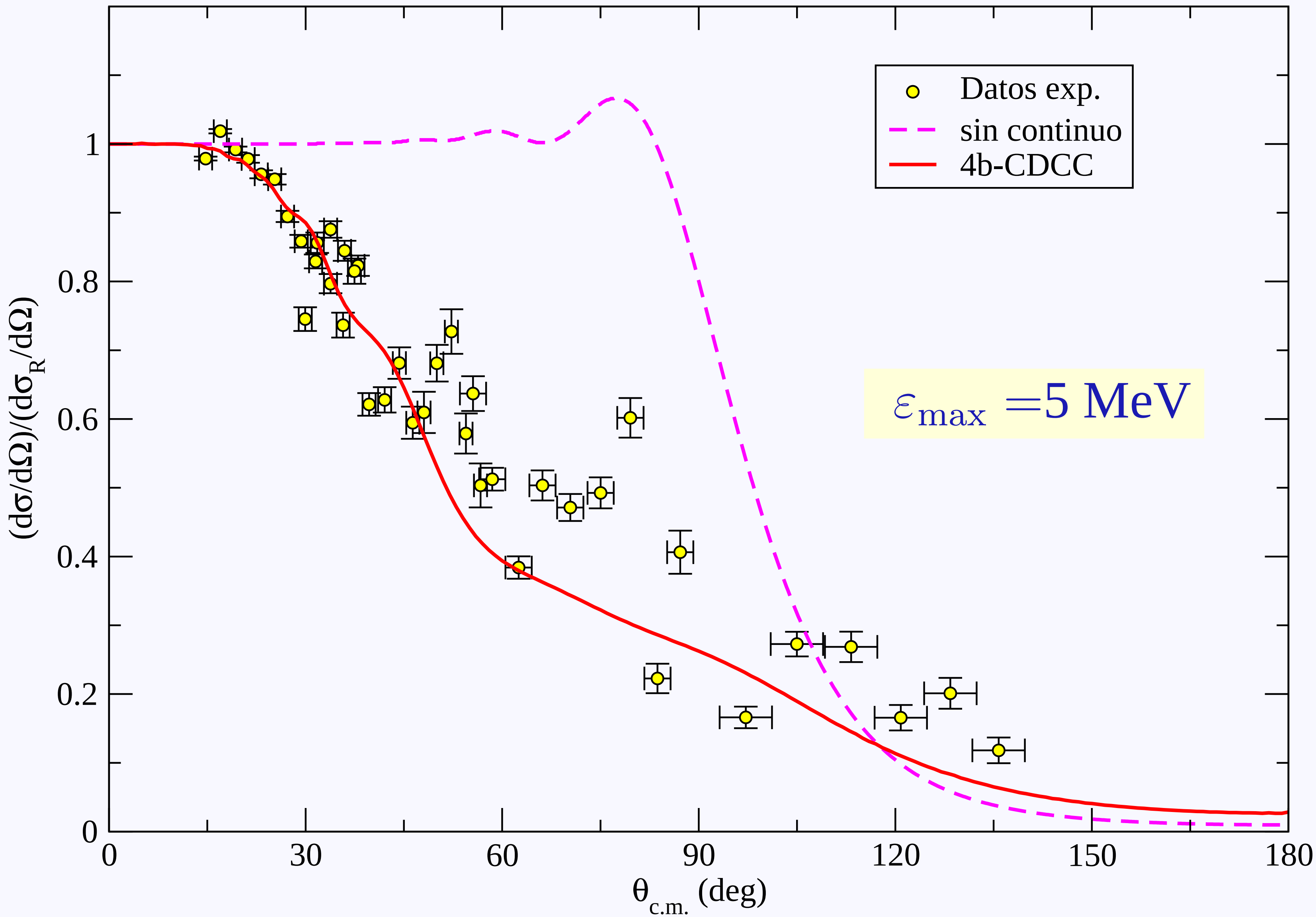


sin espín del core

☛ estados prohibidos de Pauli: método PA

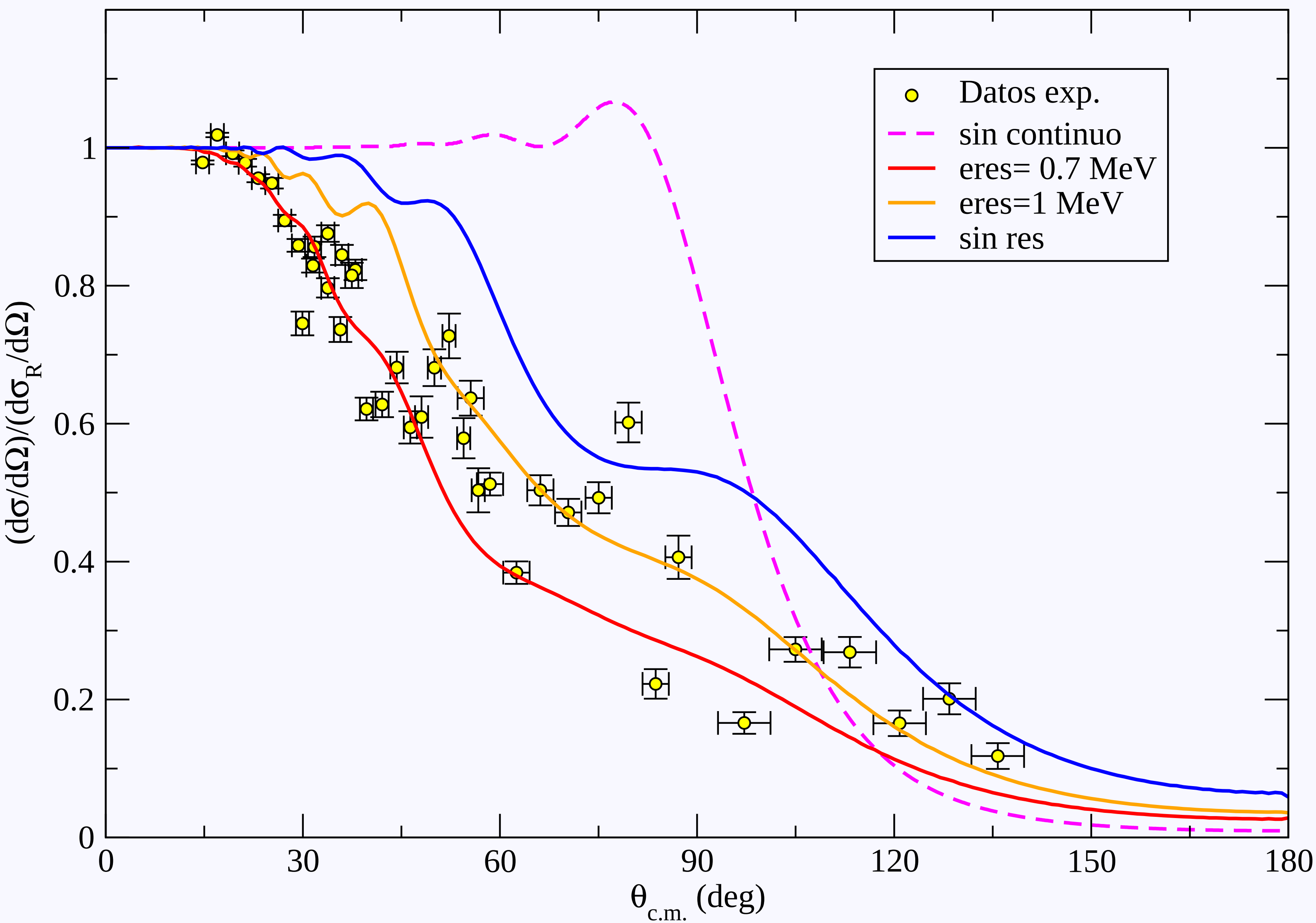
✉ Cubero et al. PRL 2012; Fernández-García et al. eviado a PRL 2012

^{11}Li+^{208}Pb@29.8MeV: elástico

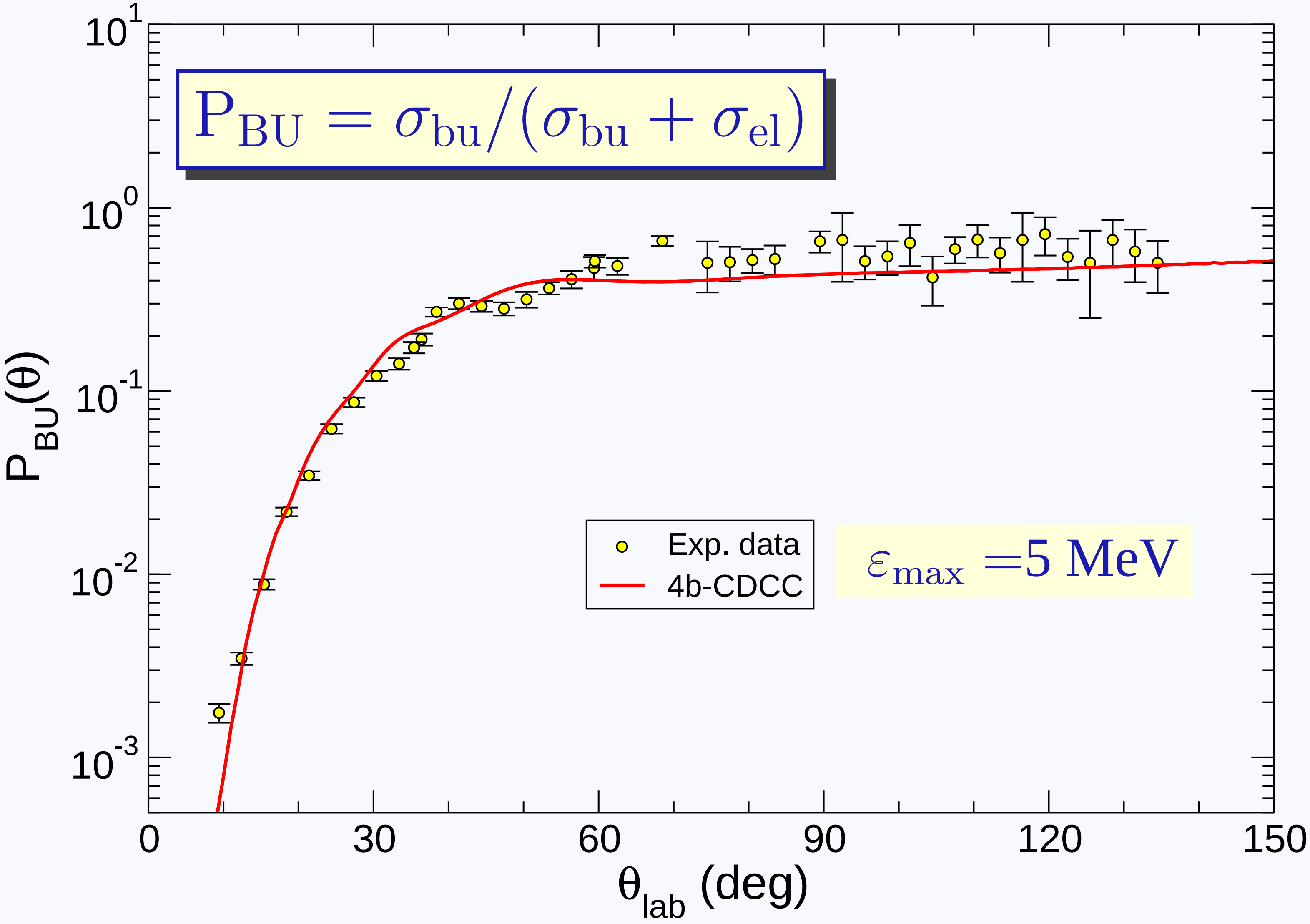


✉ Cubero et al., PRL 2012

^{11}Li+^{208}Pb@29.8MeV: elástico

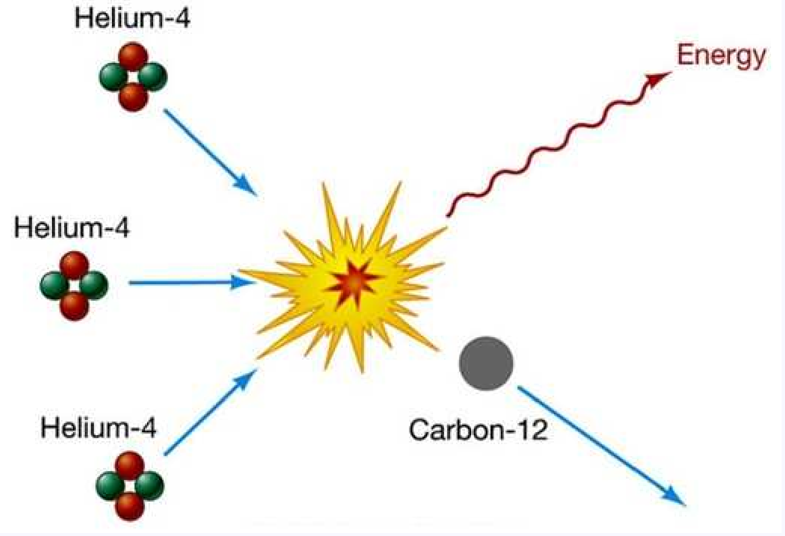


^{11}Li+^{208}Pb@29.8MeV: prob. breakup



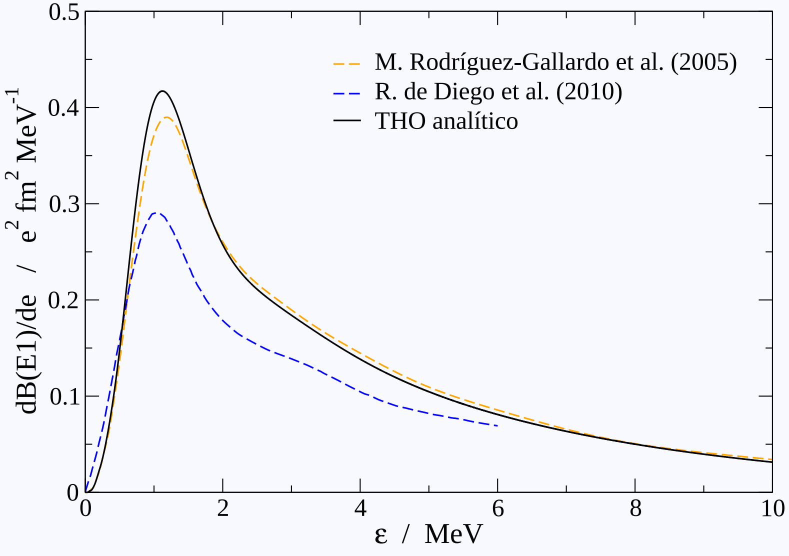
Fernández-García et al., enviado a PRL 2012

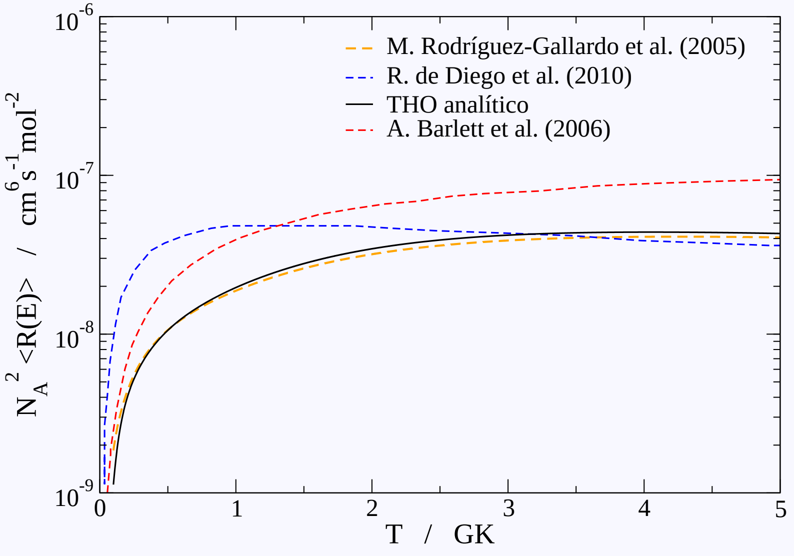
Reacciones nucleares de interés astrofísico:



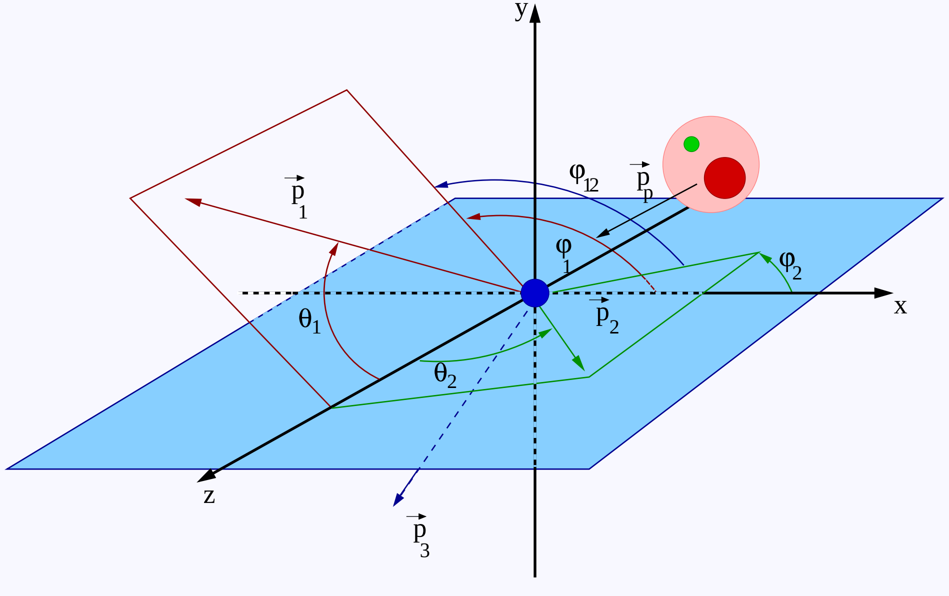
Reac. nucleares de interés astrofísico

- Trabajo Fin de Máster de Jesús Casal Berbel
  - Método THO analítico para calcular las propiedades de estructura
  - Cálculo de las tasa de reacción a partir de las transiciones eléctricas y magnéticas
  - Aplicación a ^{6}He(α+n+n):





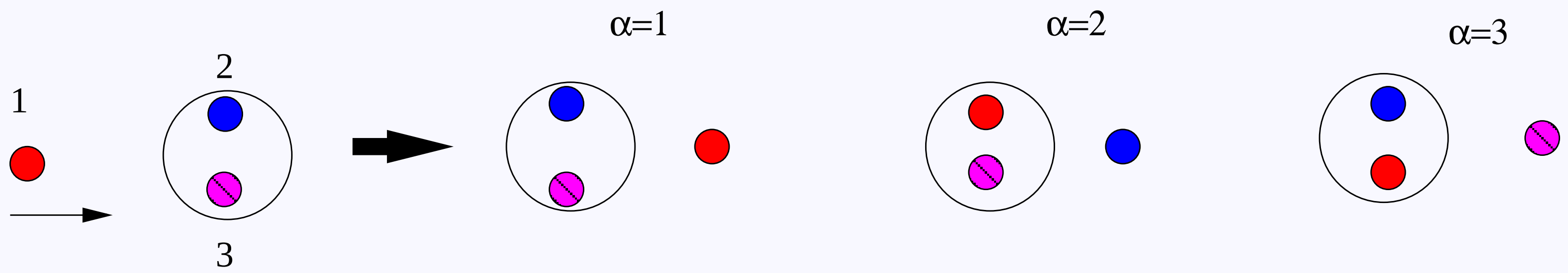
Reacciones nucleares de 3 cuerpos: ecuaciones de Faddeev



Ecuaciones de Faddeev/AGS

$$\boxed{U^{\beta\alpha} = \bar{\delta}_{\beta\alpha} G_0^{-1} + \sum_{\gamma} U^{\beta\gamma} G_0 t_{\gamma} \bar{\delta}_{\gamma\alpha}}$$

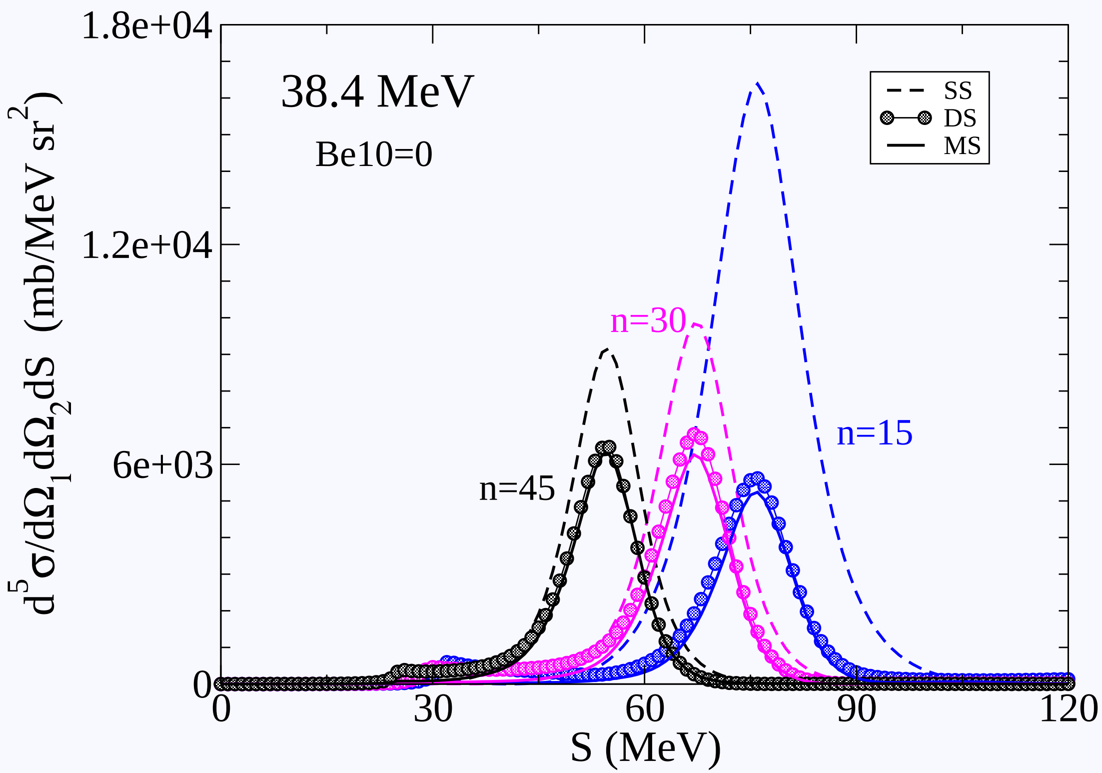
- Trata las 3 partículas de igual manera



- Resolución en el espacio de momentos:
  - Se elimina el problema del continuo
  - Surge el problema de Coulomb -> solución: potencial apantallado suavizado

$$\boxed{V(r) = V_R(r) e^{-(r/R)^n}}$$

Algunas aplicaciones: $p+^{11}$Be



- Crespo et al.,

PRC 77 (2008) 024601

$$\boxed{S = \int \sqrt{dE_1^2 + dE_2^2}}$$

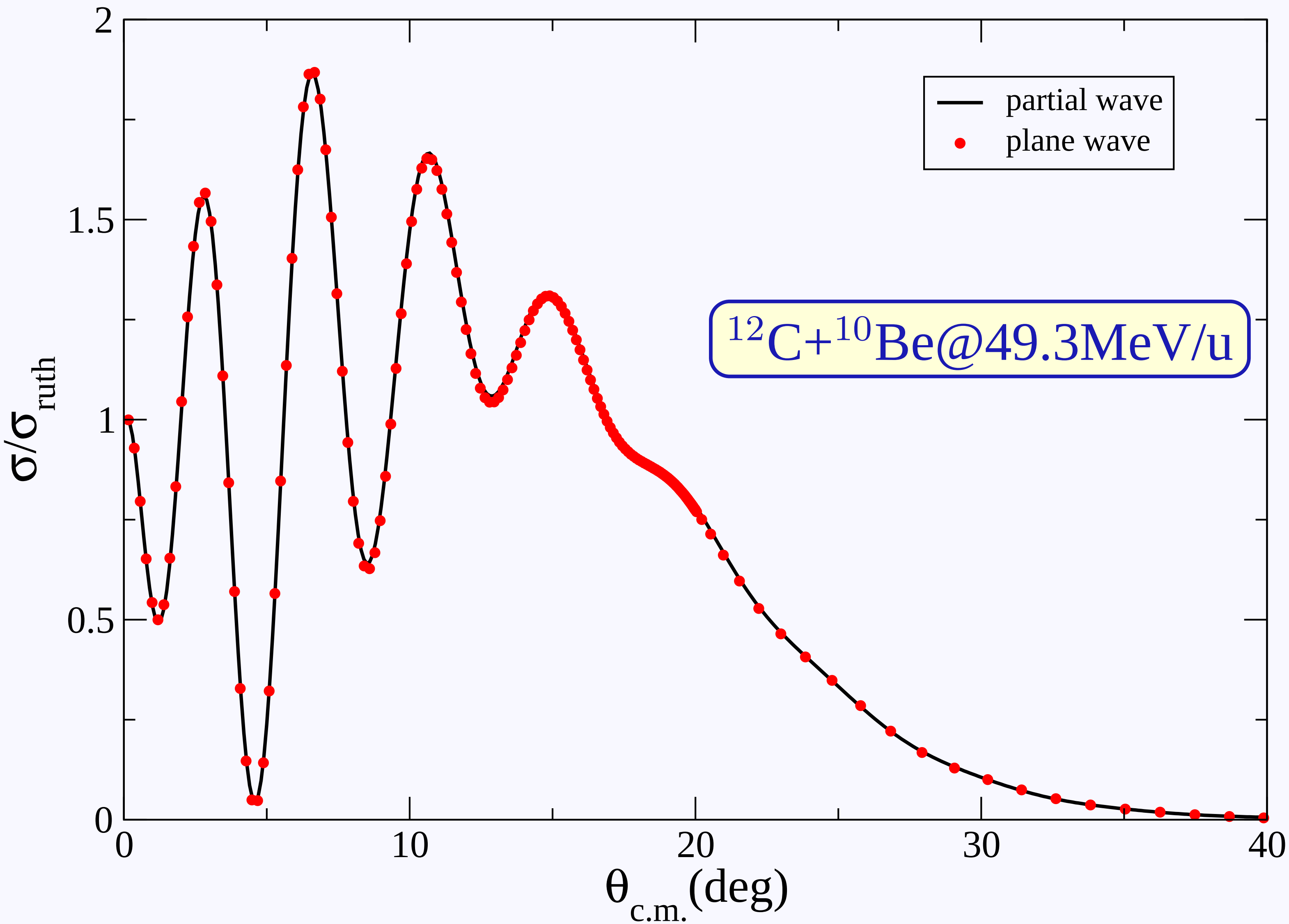
partícula 1: ^{10}Be

partícula 2: n

Otras aplicaciones:

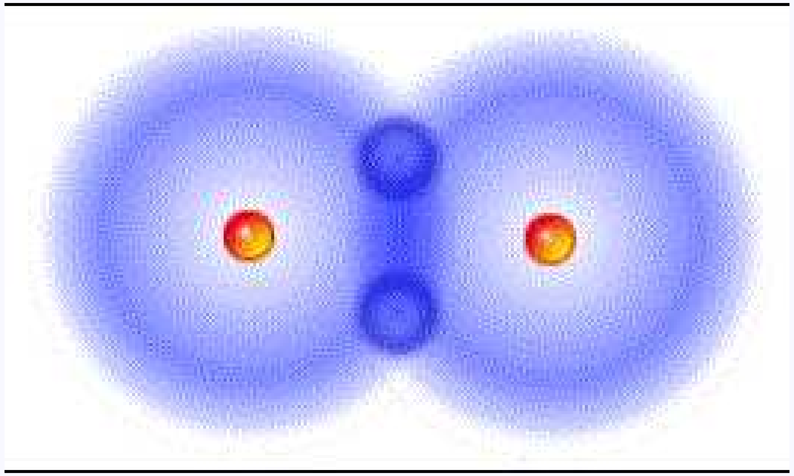
- Crespo et al., PRC 76 (2007) 014620: $p+^{11}$Be a 100, 150 y 200 MeV (test de la aproximación de Glauber)
- Crespo et al., PRC 79 (2009) 014609: $p+^{14}$Be a 69 MeV (1n-knockout)
- Crespo et al., EPJA 42 (2009) 609-611: $p+^{11}$Be a 38.4 y 200 MeV (comparación con PWIA)
- Crespo et al., PRC 83 (2011) 054613: $p+^{19}$C a 70 MeV (comparación con 3b-CDCC)

Onda plana vs onda parcial



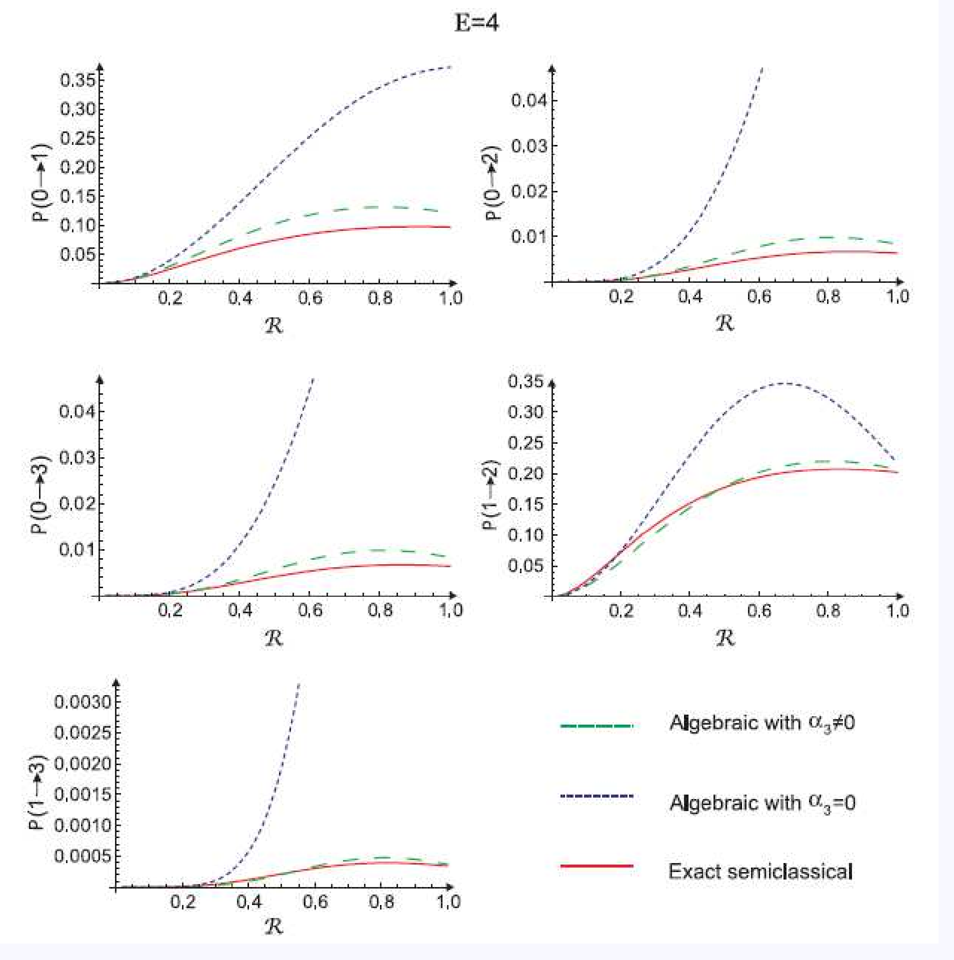
Rodríguez-Gallardo et al, PRC 78 (2008) 034602; EPJA 42 (2009) 609-611

Reacciones moleculares



Reacciones moleculares

$\boxed{H_2 + He}$



- H_2: pot. Morse
- $E = 4\hbar\omega$ (unidades características)
- $P(i \to j)$: probabilidad de pasar del estado i al j
- *R*: parámetro que controla la intensidad de la interacción

Álvarez-Bajo et al, JPB 40 (2007) 4513-4527

Nuevas líneas a investigar

- Cálculos de transferencia y knockout
- Cálculos preliminares para grandes instalaciones
- Aplicación a Física Atómica de los modelos desarrollados

- Reacciones nucleares de interés astrofísico: ^{9}Be(α+α+n), ^{17}Ne(^{15}O+p+p), ^{12}C(α+α+α)
- 4b-CDCC para reacciones ^{17}Ne+target (GSI)
- Códigos para observables de ruptura de 4 cuerpos
- Completar el programa de Faddeev en onda plana