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Recent progresses in nuclear many–body theories

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Lecce

Building a Many–Body Theory

Basic Elements

❶ Elementary components

❷ Interaction

Theoretical framework

❶ Quantum or classical

❷ Relativistic or non-relativistic

Atomic Nuclei

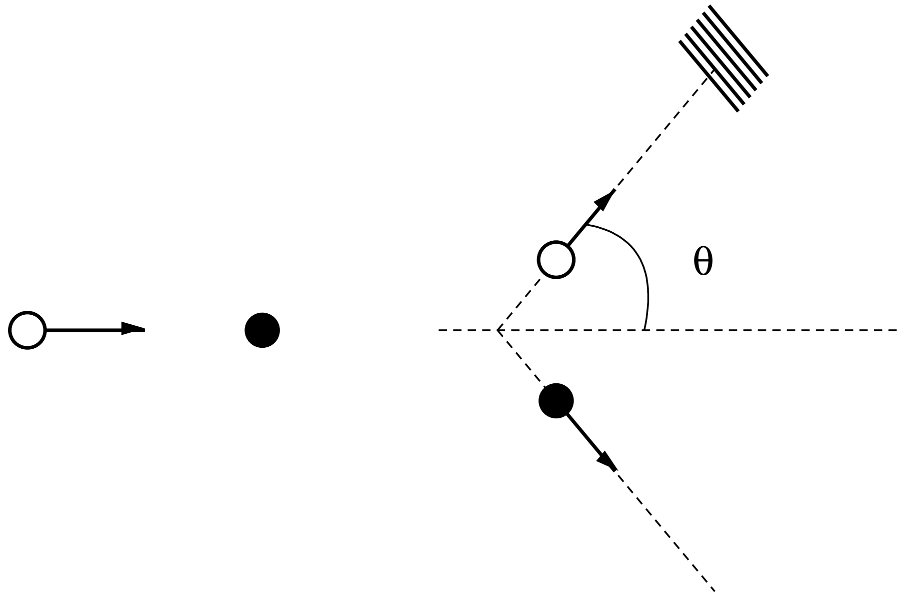
Elementary components: nucleons and mesons

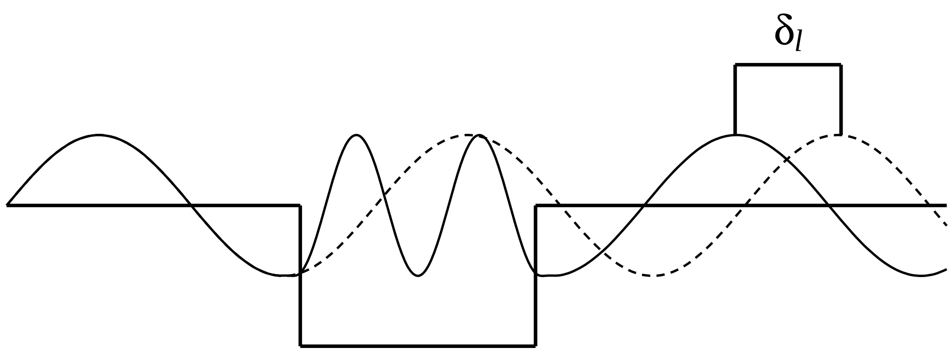
Interactions: strong, e-m and weak interactions

Theoretical framework: non-relativistic quantum mechanics

Many-Body Schrödinger Equation

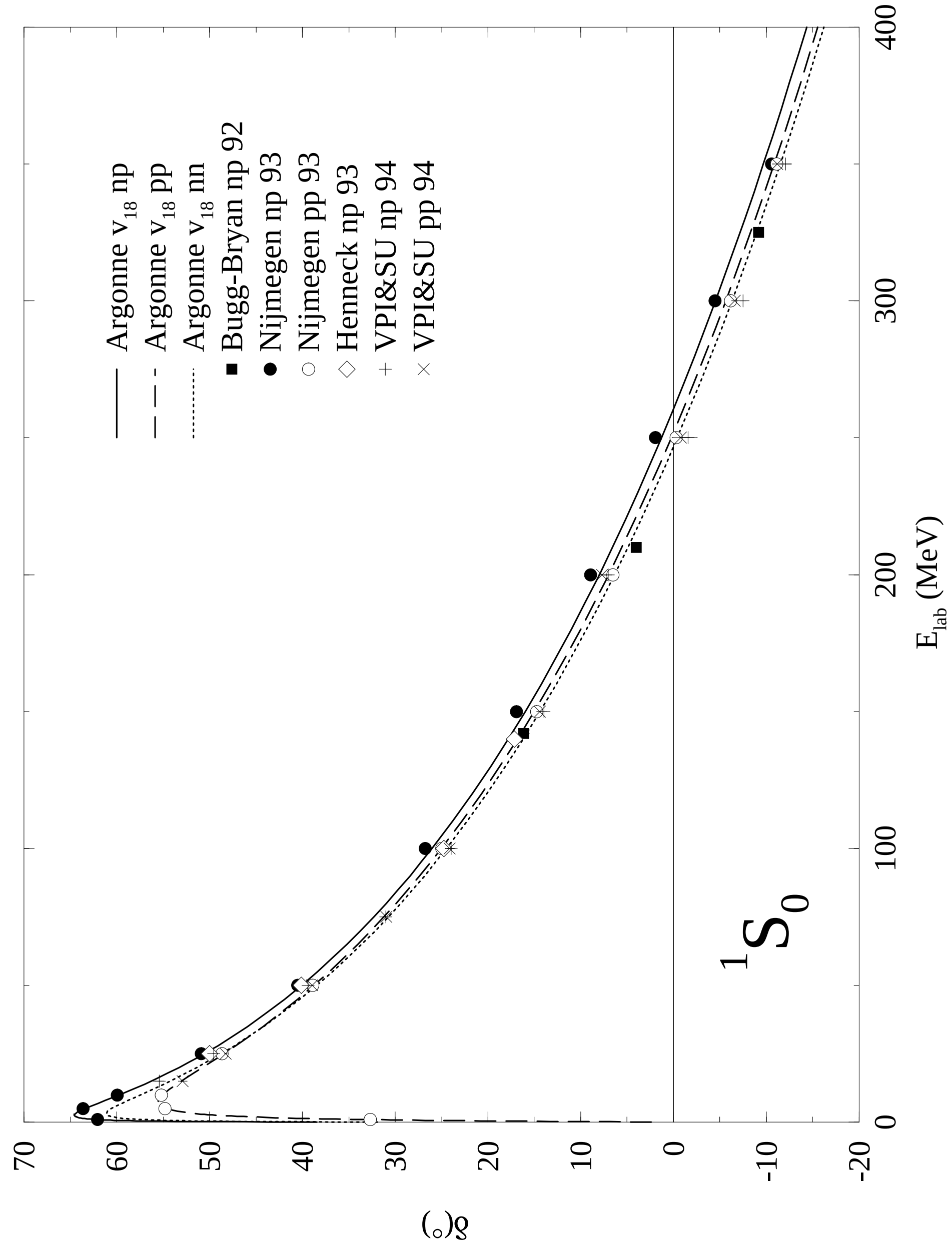
$$H|\Psi >= (T + V)|\Psi >= E|\Psi >$$



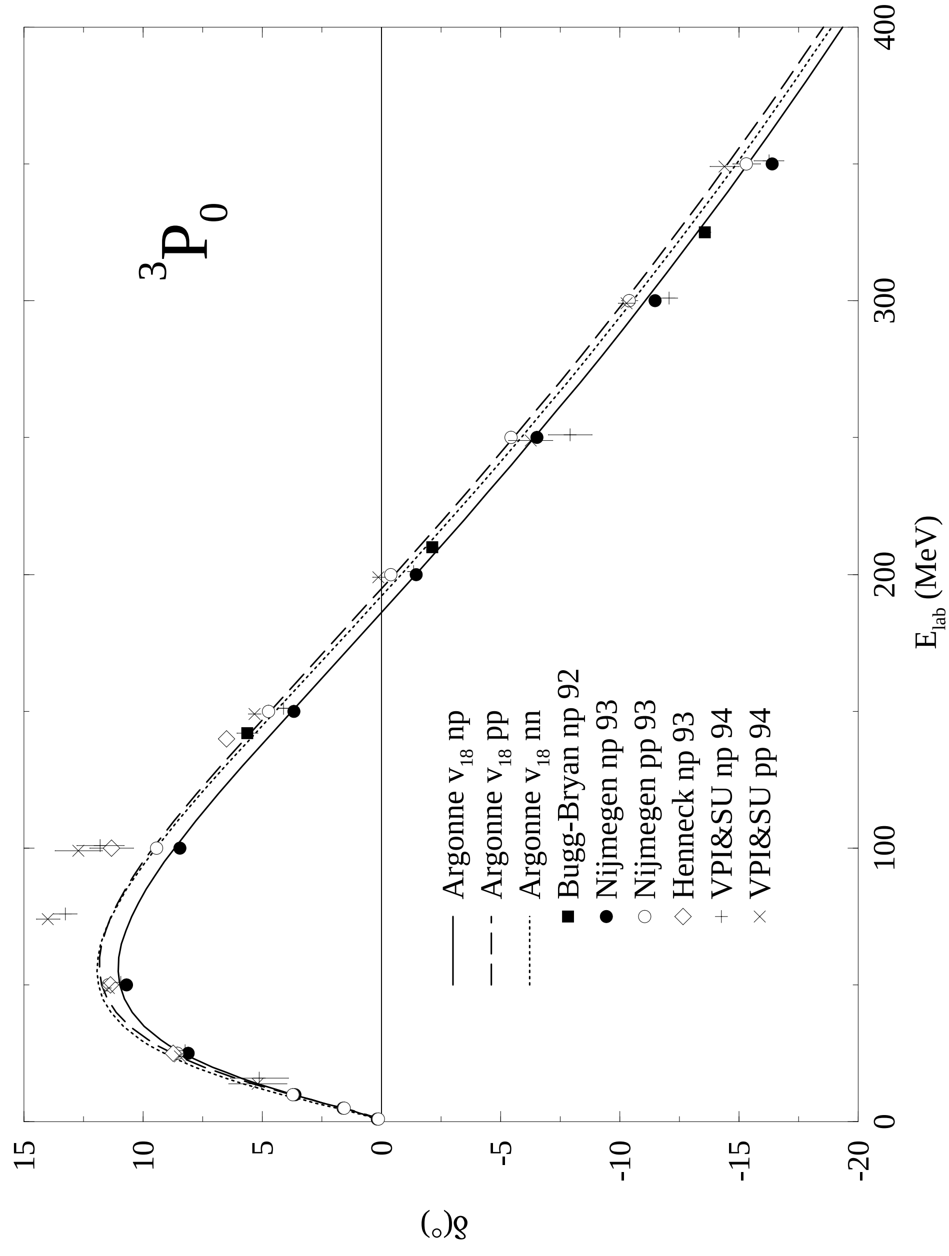


$$\frac{d\sigma}{d\theta} = |\sum_{L=0}^{\infty}(2L+1)e^{i\delta_L}\sin\delta_L P_L(cos\theta)|^2$$

R.B. Wiringa, V.G.J. Stocks and R. Schiavilla, Phys. Rev. C 51 (1995), 38



R.B. Wiringa, V.G.J. Stocks and R. Schiavilla, Phys. Rev. C 51 (1995), 38

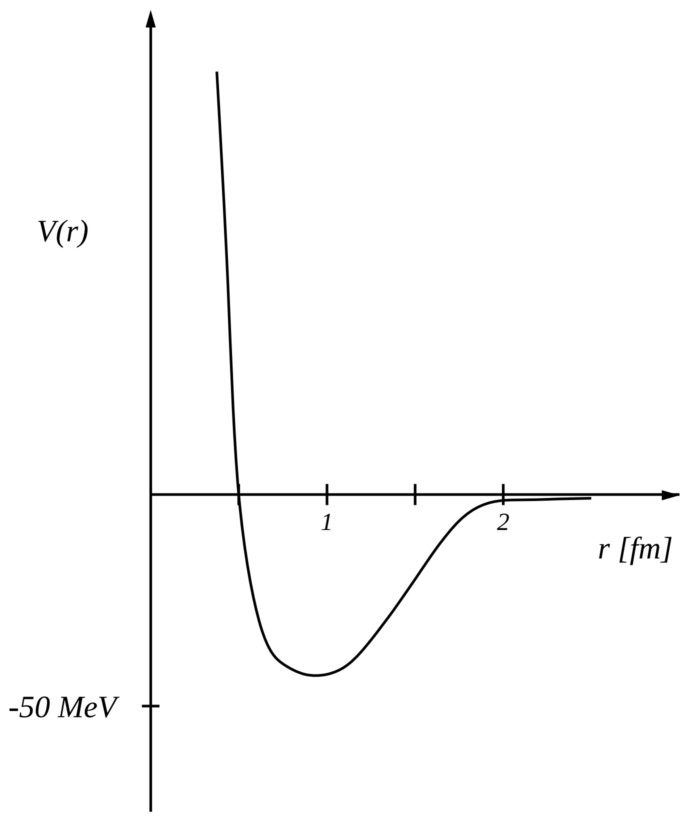


The nucleon - nucleon interaction

$$V(i,j) = \sum_{p=1,18} v_p(r_{ij}) O^p_{ij}$$

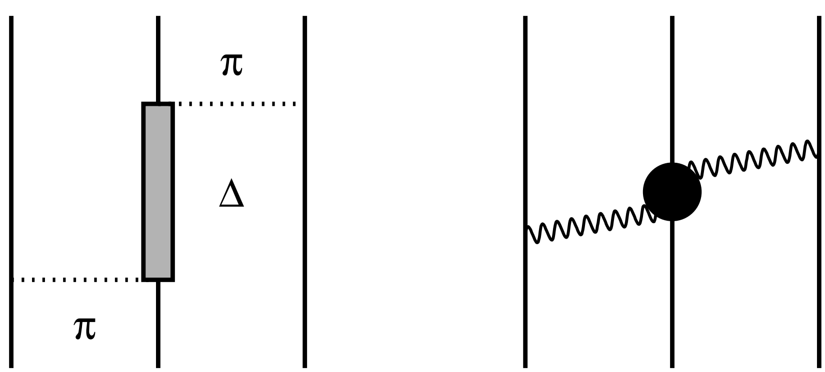
$$\begin{aligned} O_{ij}^{p=1,14} &= \left[1, \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j, S_{ij}, (\mathbf{L}\cdot\mathbf{S}), \mathbf{L}^2, \mathbf{L}^2(\boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j), (\mathbf{L}\cdot\mathbf{S})^2\right] \\ &\otimes \quad [1, \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j] \end{aligned}$$

$$O_{ij}^{p=15,18} = [1, \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j, S_{ij},] \otimes [T_{ij}, \tau_{zi} + \tau_{zj}]$$

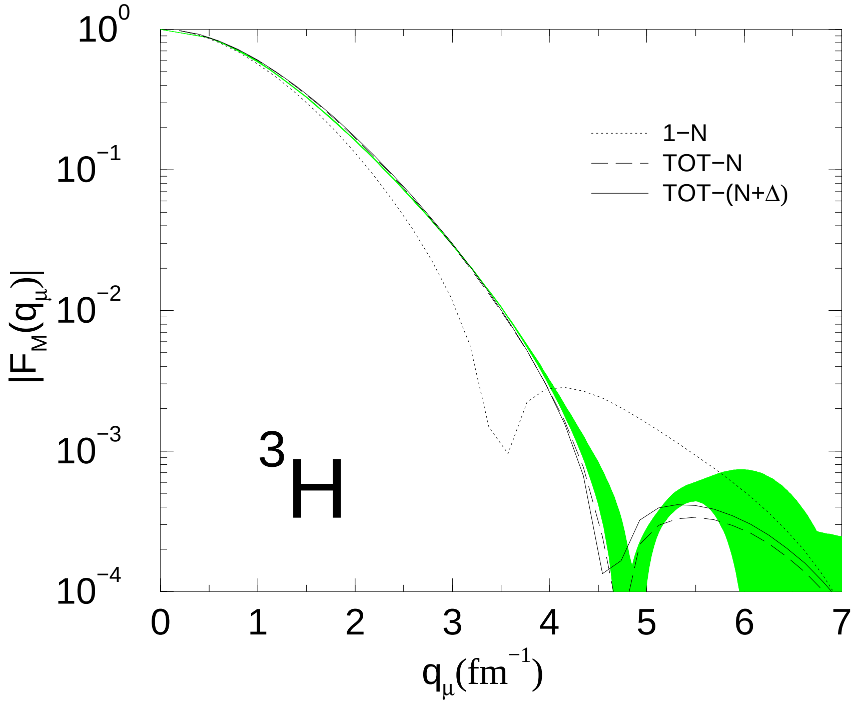


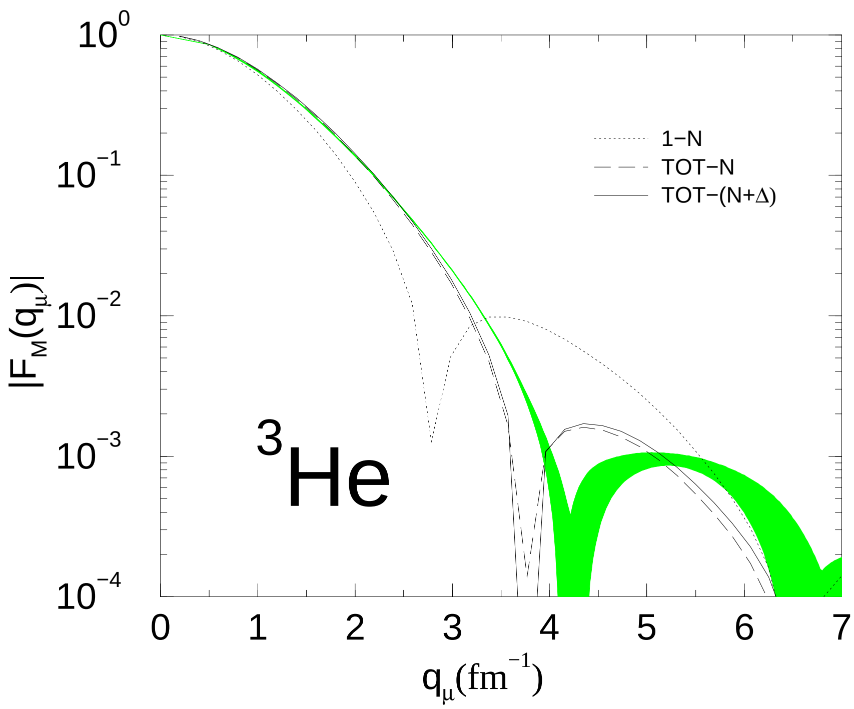
^{3}H Binding energy Exp 8.48 MeV

2 N potential	2N	2N + 3N
CD Bonn	7.953	8.483
Nijm II	7.709	8.477
Nijm I	7.731	8.480
Nijm 93	7.664	8.480
Reid 93	7.648	8.480
AV14	7.683	8.480
AV18	7.576	8.479



L. Marcucci, D. O. Riska and R. Schiavilla, Phys. Rev. C 58 (1998) 3069.





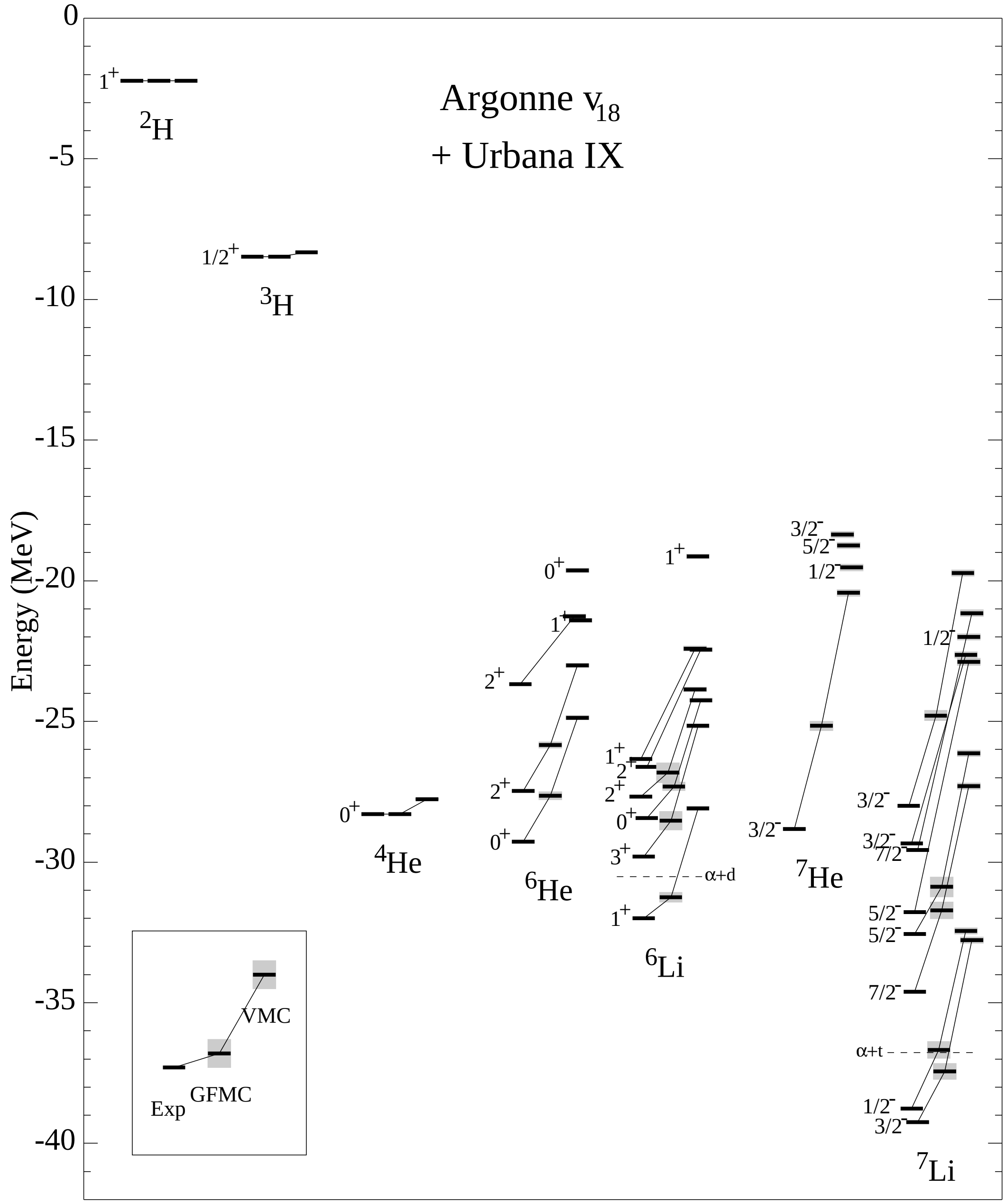
B.S. Pudliner, V.R. Pandharipande, J. Carlson, S.C. Pieper, R.B. Wiringa
Phys. Rev. C 56 (1997) 1720.

Argonne V18 plus Urbana IX interactions

	Exp	GFMC	VMC
^{3}H	8.48	8.47(1)	8.32(1)
^{4}He	28.30	28.30(2)	27.76(3)
^{6}He	29.27	27.64(14)	24.87(7)
^{6}Li	31.99	31.25(11)	28.09(7)
^{6}Be	26.92	25.52(11)	22.79(7)
^{7}He	28.82	25.16(16)	20.43(12)
^{7}Li	39.24	37.44(28)	32.78(11)

B.S. Pudliner, V.R. Pandharipande, J. Carlson, S.C. Pieper, R.B. Wiringa

Phys. Rev. C 56 (1997) 1720.



Number of spin–isospin configurations

$$N_{conf} = 2^A \frac{A!}{Z!(A-Z)!}$$

Nucleus	Z	N=A-Z	N_{conf}
^3H	1	2	24
^3He	2	1	24
^4He	2	2	96
^6He	2	4	960
^6Li	3	3	1280
^8He	2	6	7168
^{12}C	6	6	3784704
^{16}O	8	8	$\sim 8.4 \cdot 10^8$
^{40}Ca	20	20	$\sim 1.5 \cdot 10^{23}$
^{48}Ca	20	28	$\sim 4.7 \cdot 10^{27}$

Independent Particle Model

$$
\begin{aligned}
H &= \sum_i t_i + \sum_{i<j} v_{ij} + \sum_{i<j<k} v_{ijk} + \sum_i (u_i - u_i) \\
&= \sum_i (t_i + u_i) + \sum_{i<j} v_{ij} + \sum_{i<j<k} v_{ijk} - \sum_i u_i \\
&= H_0 + V_{res}
\end{aligned}
$$

$$E_0|\Phi >= H_0|\Phi >= \sum_i h_i|\Phi >$$

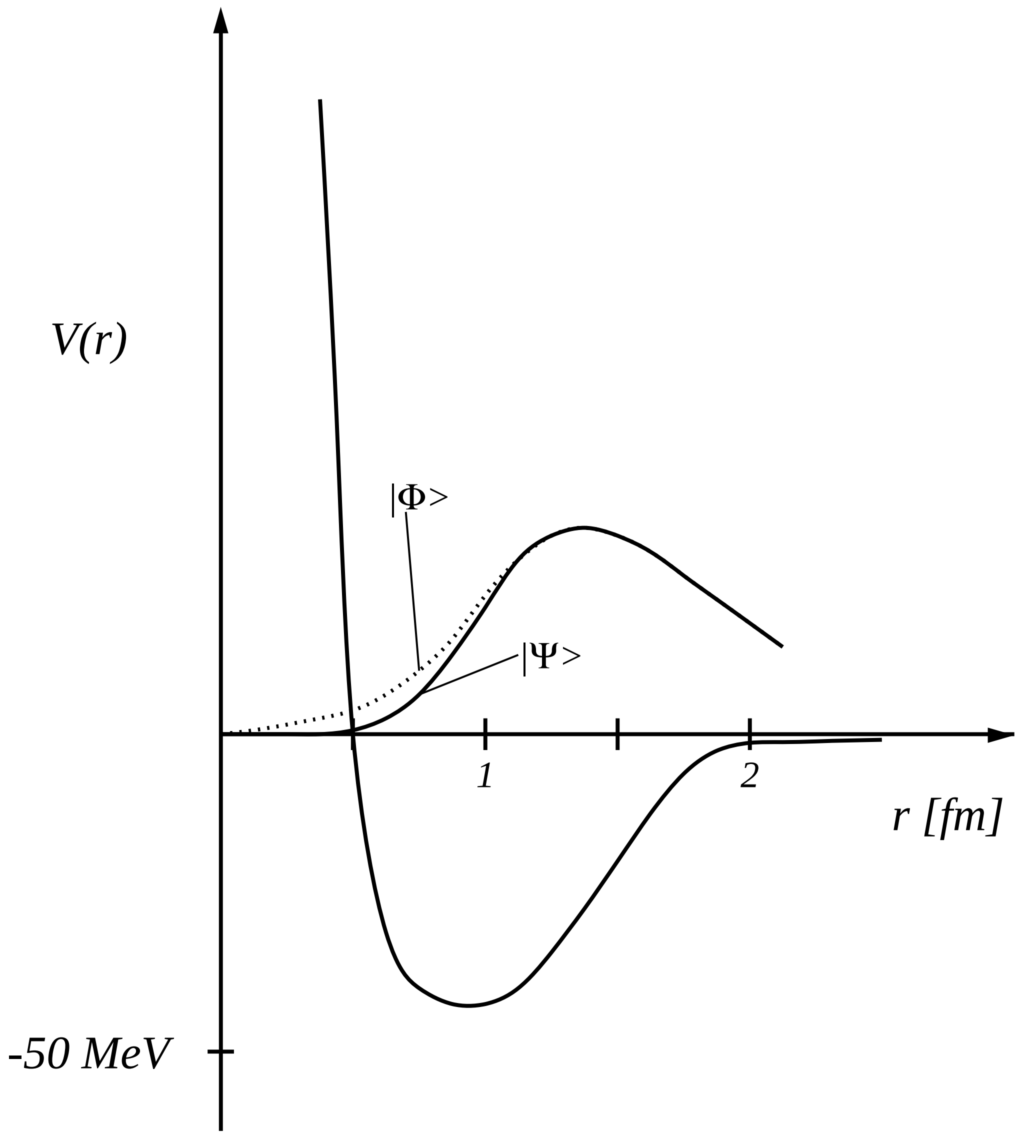
$$|\Phi >= det\Big[|\phi_i >\Big]$$

$$h_i|\phi_i >= \epsilon_i|\phi_i >$$

Many–body problem $\longrightarrow$ many one-body problems

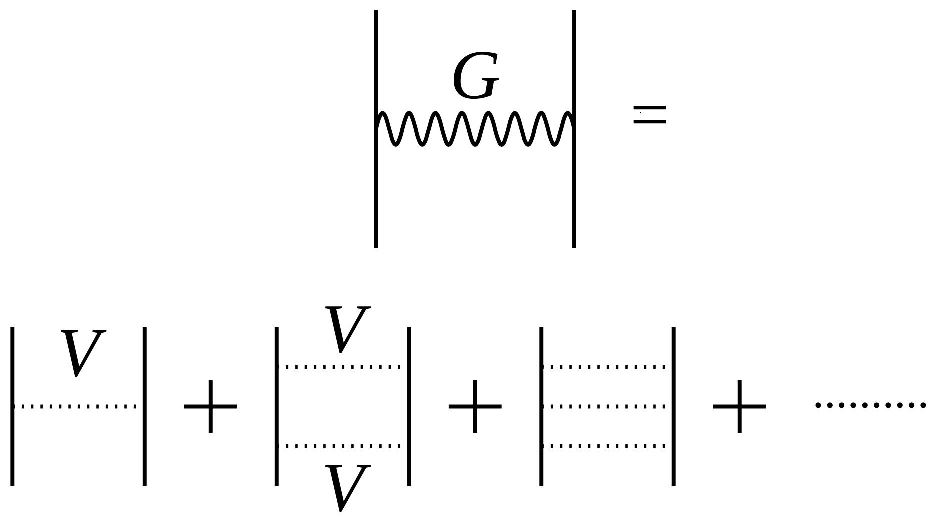
Perturbation Theory

$$E = E_0 + \langle \Phi | V_{res} \sum_{n=0}^{\infty} \left(\frac{1}{E_0 - H_0} V_{res} \right)^n | \Phi \rangle_c$$



G - Matrix

$$
\begin{aligned}
G &= V + V\frac{Q}{e}G \\
&= V + V\frac{Q}{e}\left(V + V\frac{Q}{e}\left(V + ...\right)\right)
\end{aligned}
$$



CBF FHNC–SOC

$$\delta E[\Psi] = \delta \frac{\langle \Psi | H | \Psi \rangle}{\langle \Psi | \Psi \rangle} = 0$$

$$\Psi(1, 2...A) = G(1, 2...A)\Phi(1, 2...A)$$

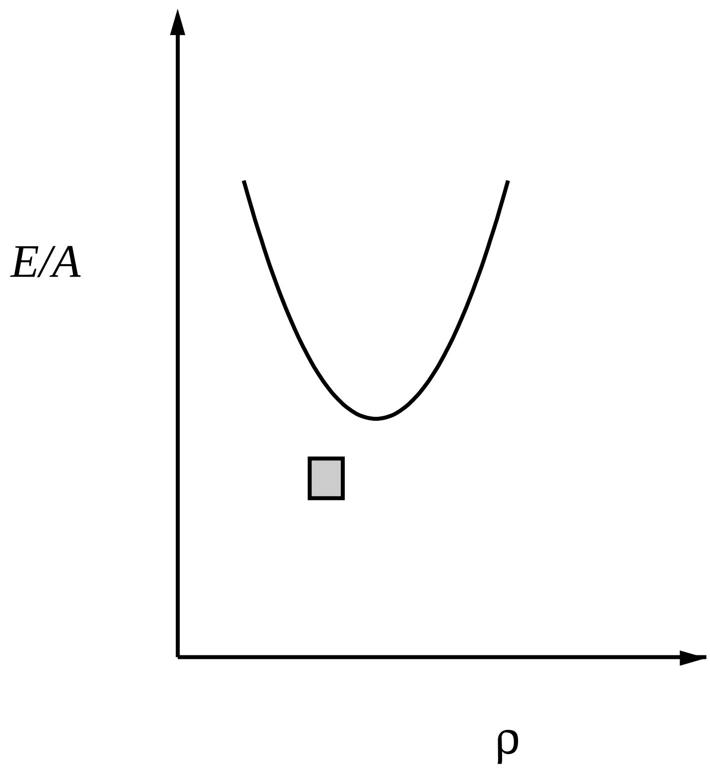
$$G(1, 2...A) = \prod_{i<j} F_{ij}$$

$$F_{ij} = \sum_{p=1,8} f^p(r_{ij}) O_{ij}^p$$

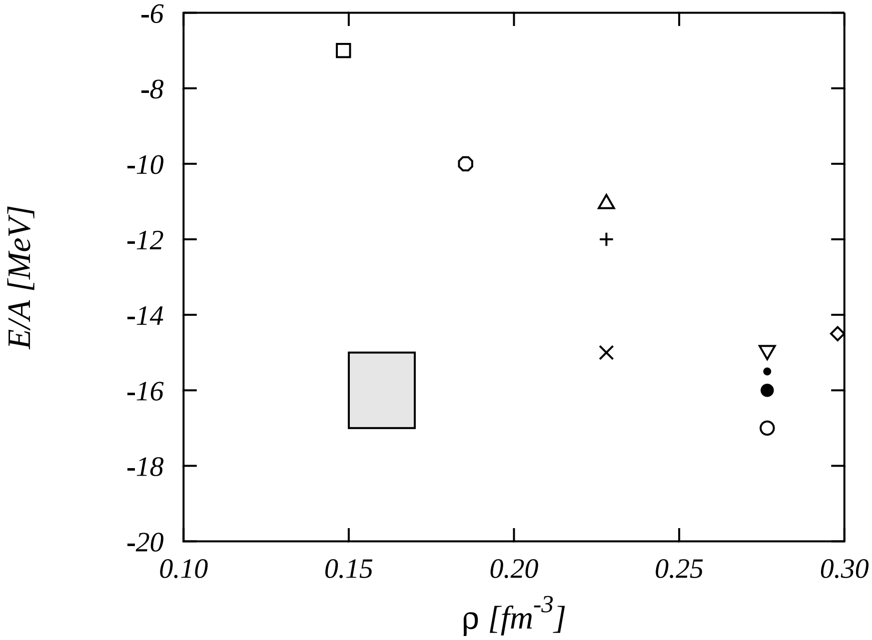
$$O_{ij}^{p=1,8} = [1, \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j, S_{ij}, (\mathbf{L} \cdot \mathbf{S})_{ij}] \otimes [1, \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j]$$

Nuclear matter

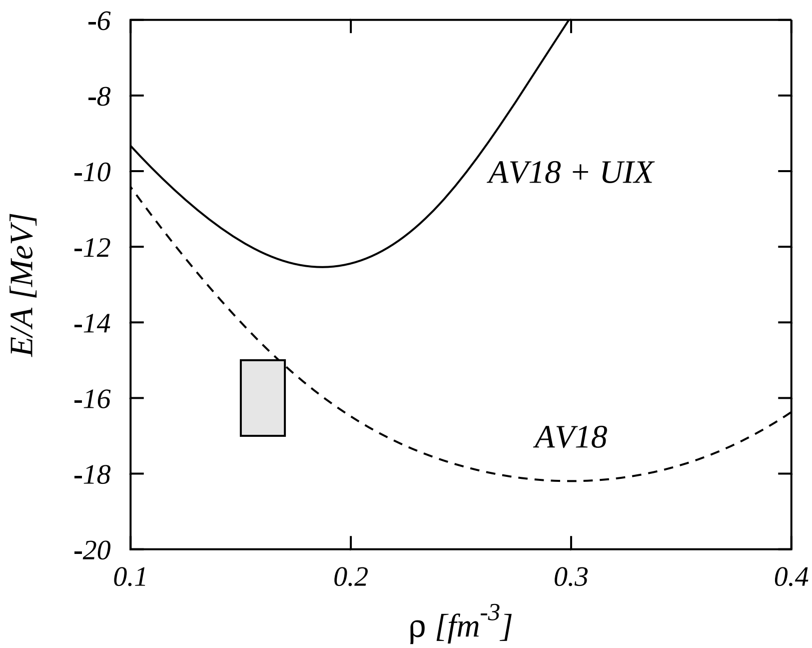
- Infinite system of nucleons
- N=Z
- No Coulomb interaction



$$\frac{E}{A} = -16.0 \pm 1.0 \ MeV \qquad \rho = 0.16 \pm 0.01 \ fm^{-3}$$



-6
-8
-10
-12
-14
-16
-18
-20
E/A [MeV]
0.10
0.15
0.20
0.25
0.30
ρ [fm-3]



-6
-8
-10
-12
-14
-16
-18
-20
E/A [MeV]
0.1
0.2
0.3
0.4
ρ [fm-3]
AV18 + UIX
AV18

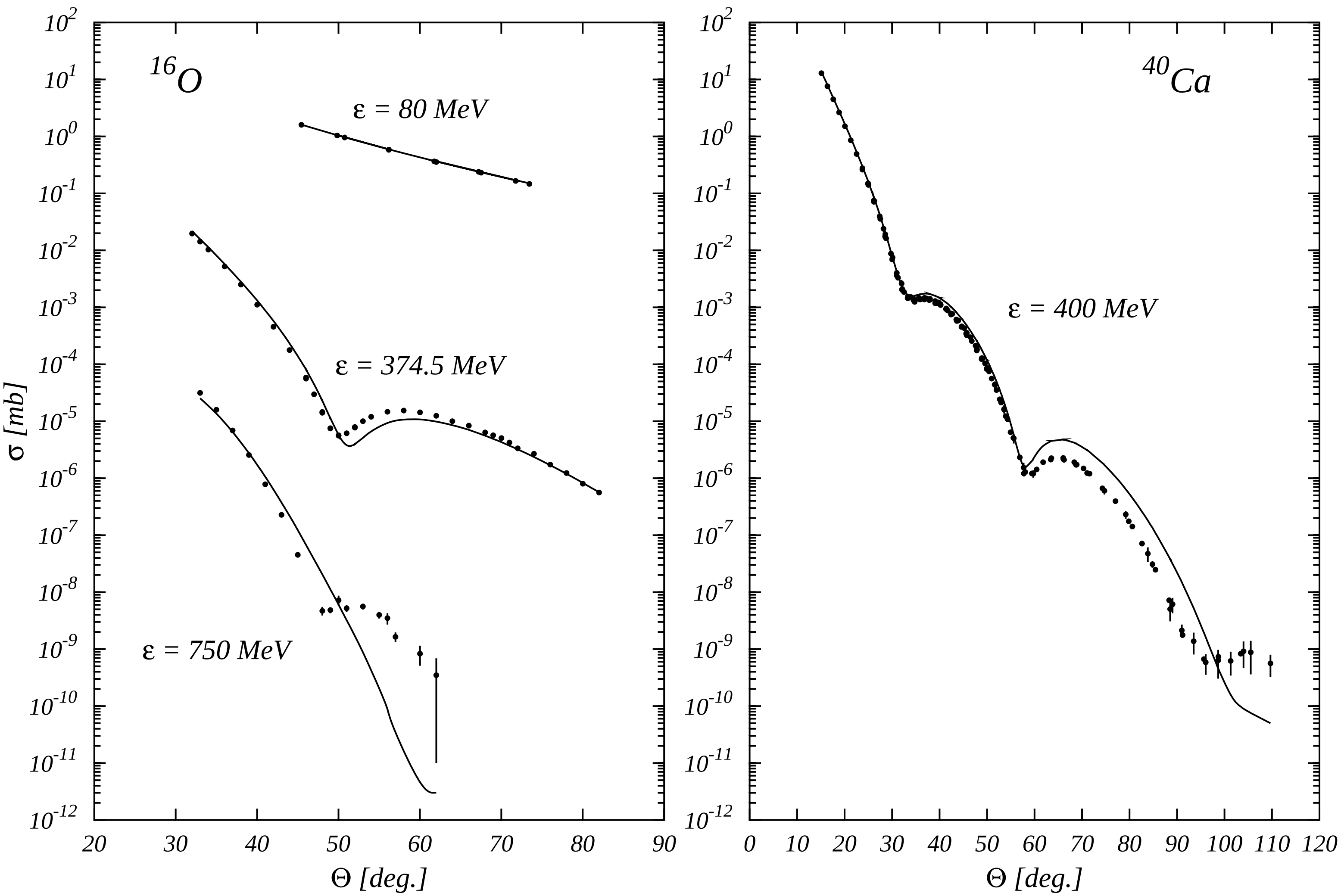
Finite nuclei

Energies per nucleons in MeV

	^{16}O	^{40}Ca
$\langle T \rangle$	32.64	38.15
$\langle v_{8,ij} \rangle$	-37.79	-46.34
$\langle v_{ijk}^{2\pi} \rangle$	-2.36	-2.98
$\langle v_{ijk}^{R} \rangle$	3.00	3.94
E_{cm}	0.64	0.23
$\langle v_{Coul} \rangle$	0.94	2.10
ΔE	-1.21	-1.28
E	-5.41	-6.64
$\langle R \rangle$ [fm]	2.67	3.39
E_{exp}	-7.97	-8.55
$\langle R \rangle$ [fm]	2.73	3.48

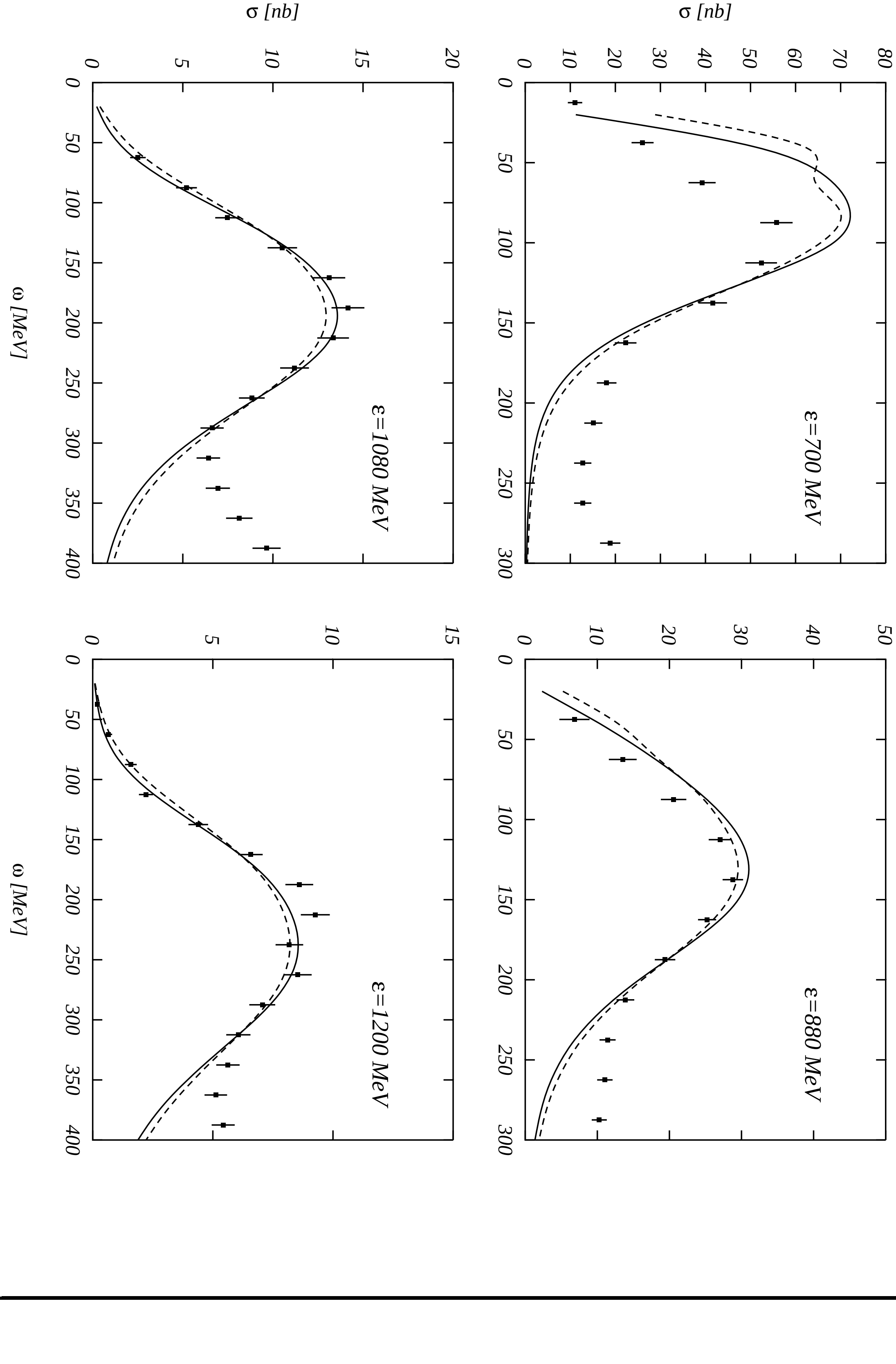
A. Fabrocini, F. Arias de Saavedra, and G. C.

Phys. Rev. C 61 (2000) 044302



σ [mb]
Θ [deg.]
^{16}O
ε = 80 MeV
ε = 374.5 MeV
ε = 750 MeV
^{40}Ca
ε = 400 MeV

G. C. and A.M. Lallena, to be published on Ann. Phys.



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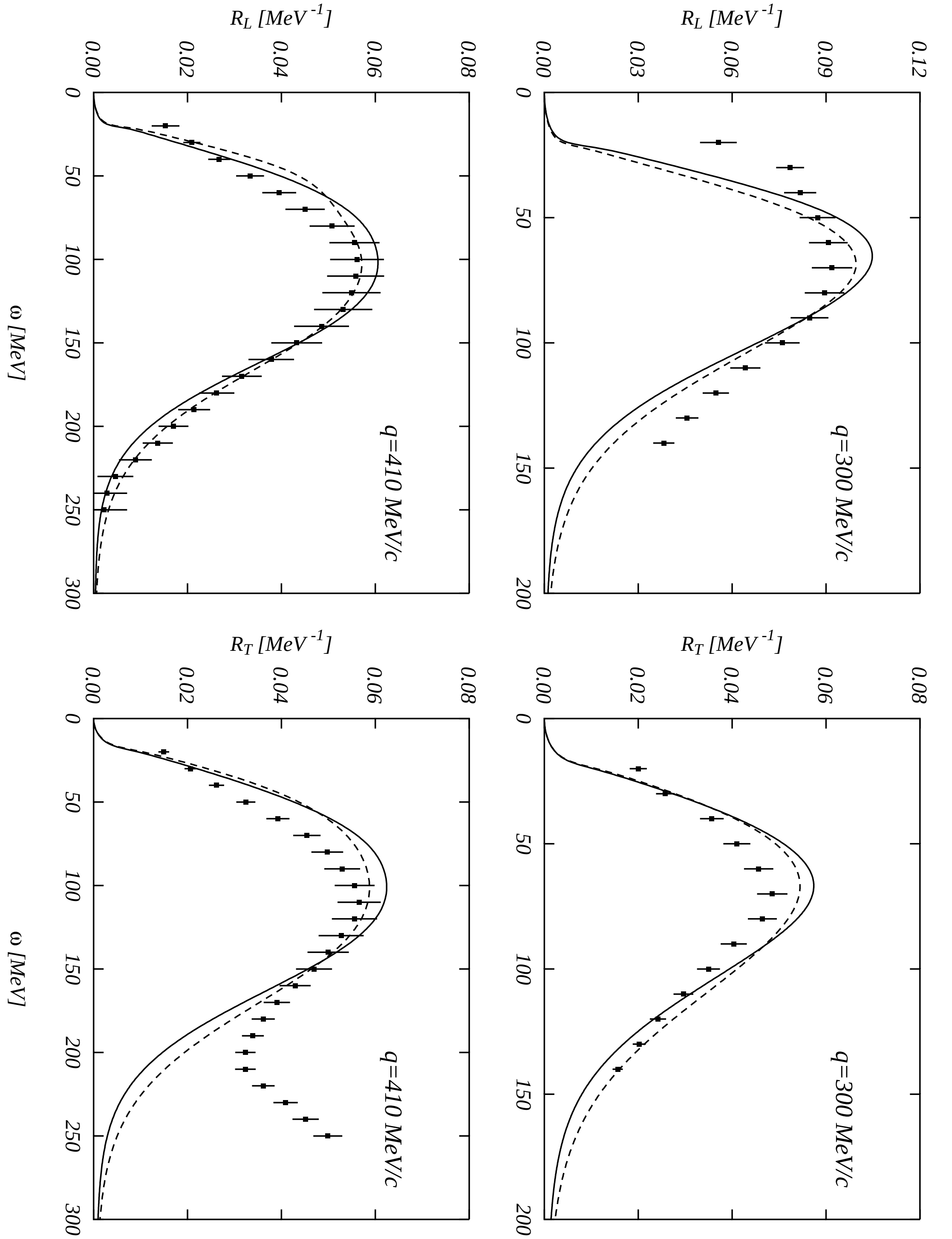

S.R. Mokhtar, G. C. and A.M. Lallena, to be published on Phys. Rev. C