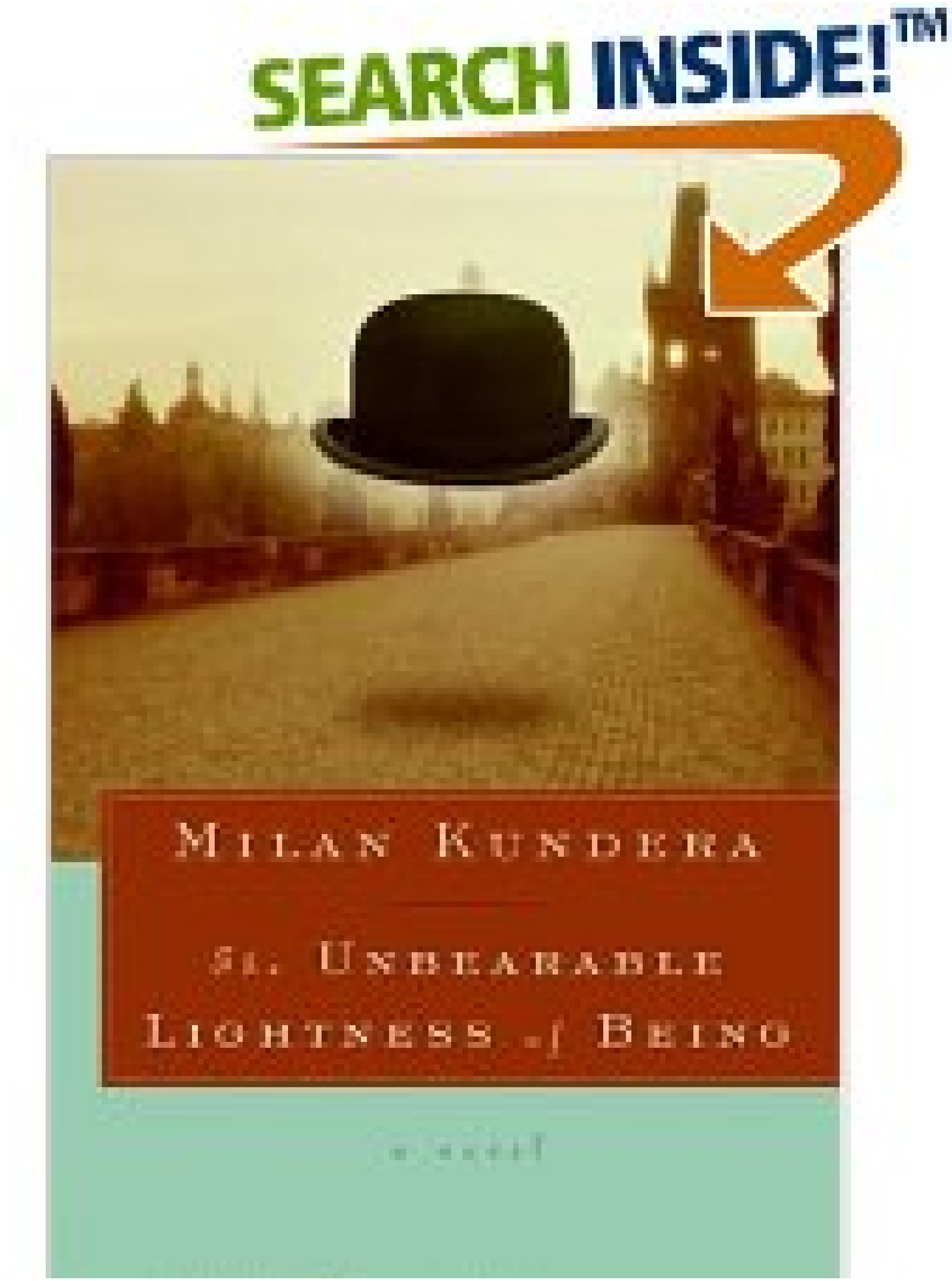
Angela Bonaccorso

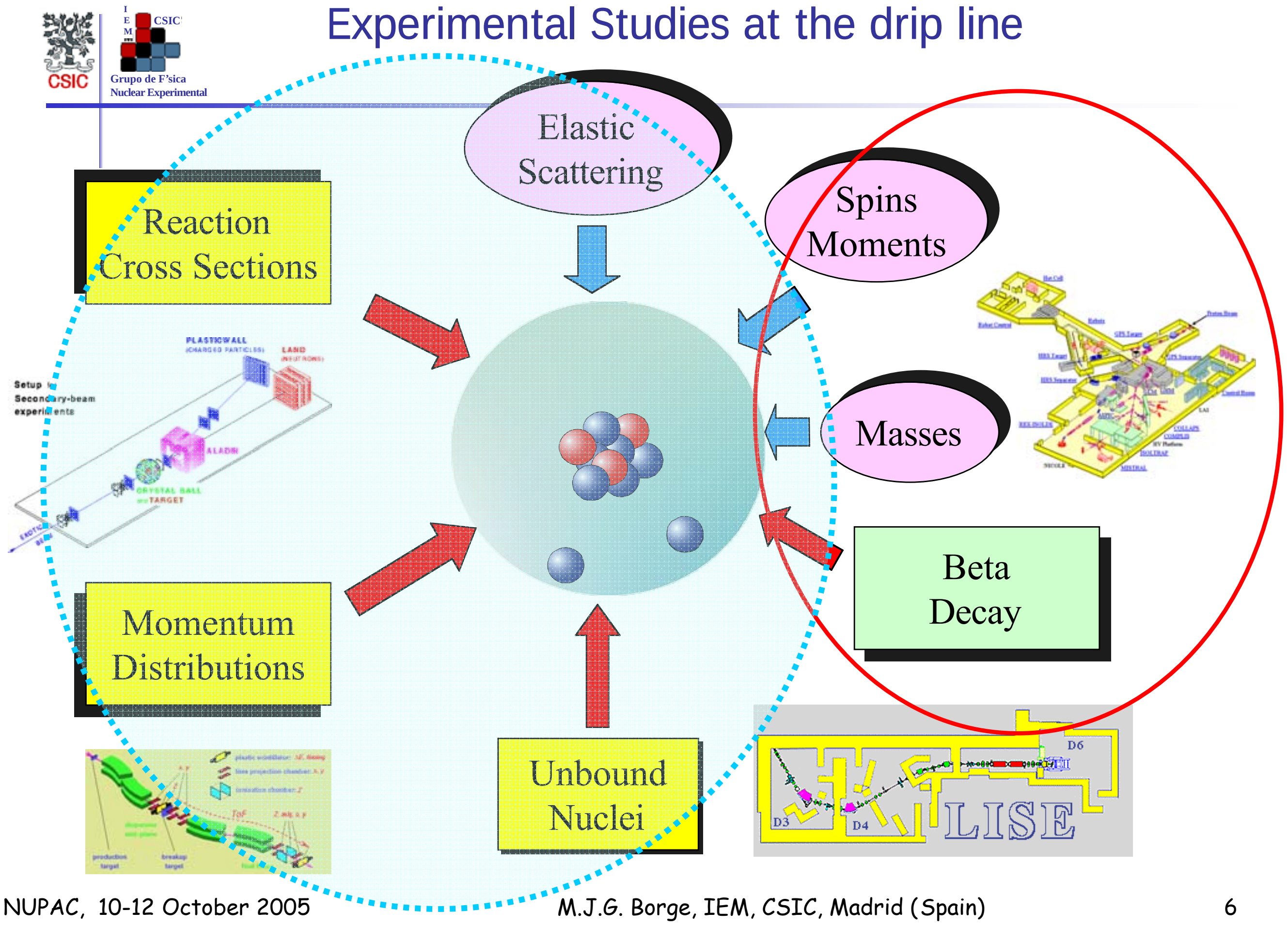
Istituto Nazionale
di Fisica Nucleare

SEZIONE DI PISA

Physics at the proton and neutron drip lines

Theoretical perspectives


SEARCH INSIDE!™
MILAN KUNDERA
THE UNBEARABLE
LIGHTNESS OF BEING
a novel



CSIC
IEM CSIC
Grupo de F'sica Nuclear Experimental

Experimental Studies at the drip line

Elastic Scattering

Reaction Cross Sections

Spins Moments

Masses

Beta Decay

Momentum Distributions

Unbound Nuclei

NUPAC, 10-12 October 2005 M.J.G. Borge, IEM, CSIC, Madrid (Spain) 6

Let us see how the “center-left” Physics needs ISOLDE and even an upgrade of it.

Unbound Nuclei

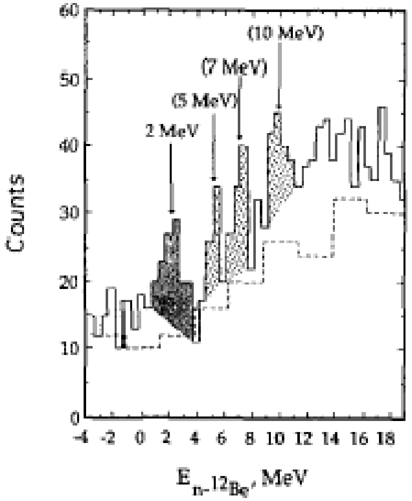
Nuclei *at* the driplines

They are what the reaction mechanism makes them to be…

*Interplay between structure and reaction aspects…**bound vs. continuum**…stronger than in any other part of the nuclear chart.*

A perfect balance between short and long range parts of the nuclear interaction.

^{13}Be: an example of *creation* by the reaction mechanism

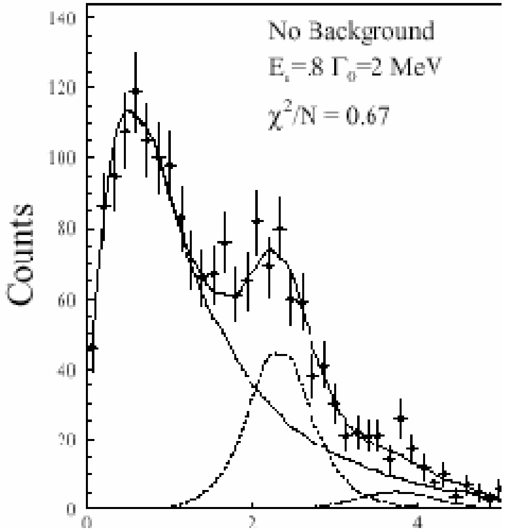


•transfer to the continuum: ^{12}Be (d,p) RIKEN (**Korsheninnikov**) (1995).

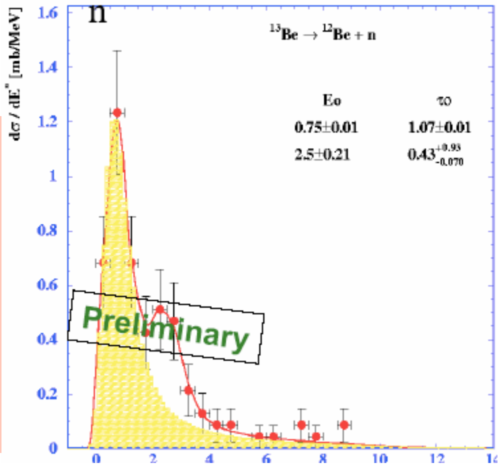
cf. ^{10}Li at REX-ISOLDE
H.B. Jeppesen, et al.,
NP A748, (2005)374

- ^{14}Be nuclear and Coulomb breakup: GANIL (K. Jones thesis, 2000).
- ^{14}C+ ^{11}B multinucleon transfer: (Berlin Group ,1998).
- ^{18}O fragmentation MSU (Thoennessen, 2001) n-core relative velocity spectra.

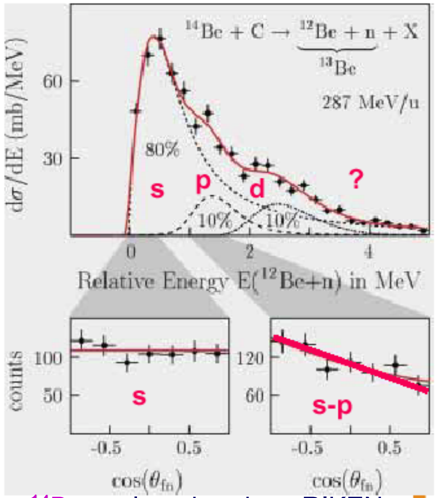
•^{14}B fragmentation: GANIL (**Lecouey**, Orr) (2002).



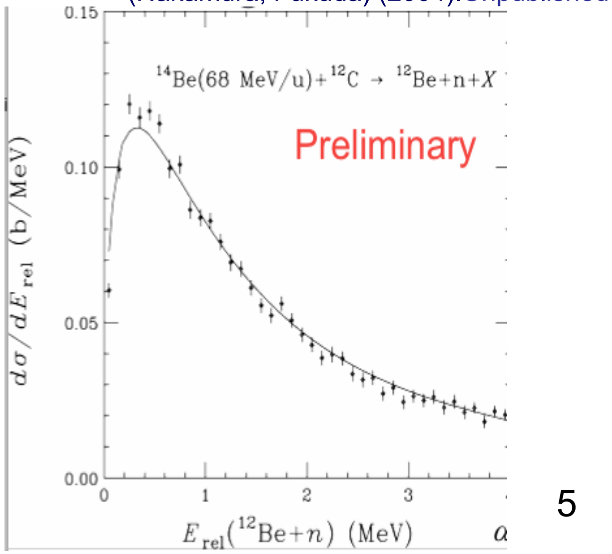
•GSI (U. Datta Pramanik)(2004).Unpublished

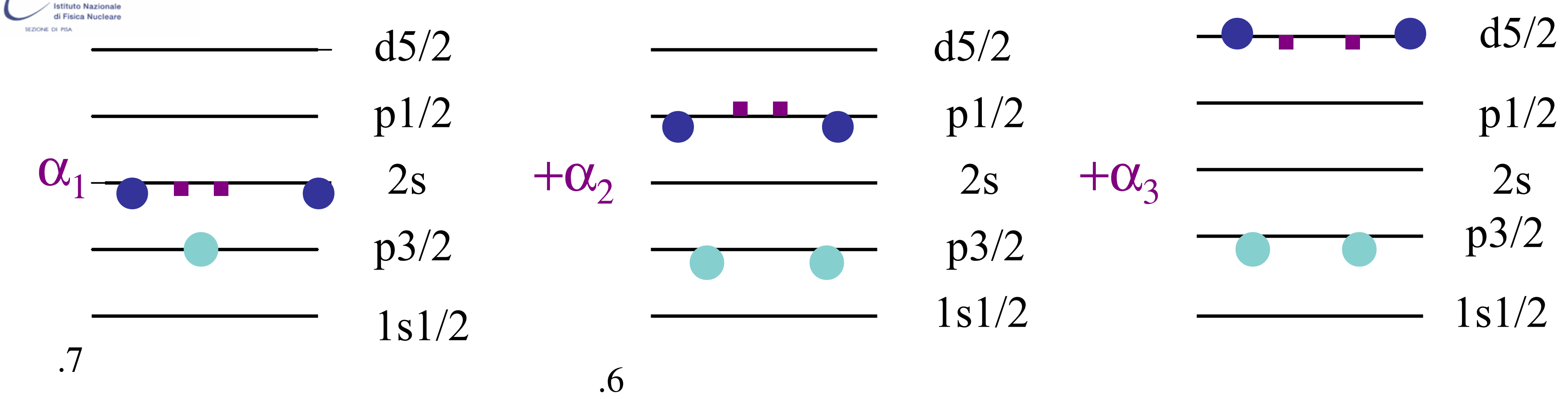


•^{14}Be nuclear breakup , GSI (**Simon**), 287AMeV, n-core angular correlation



•^{14}Be nuclear breakup: RIKEN (Nakamura, Fukuda) (2004).Unpublished





^{14}B $_{g.s.}$ = 2^- =π p3/2+ν 2s

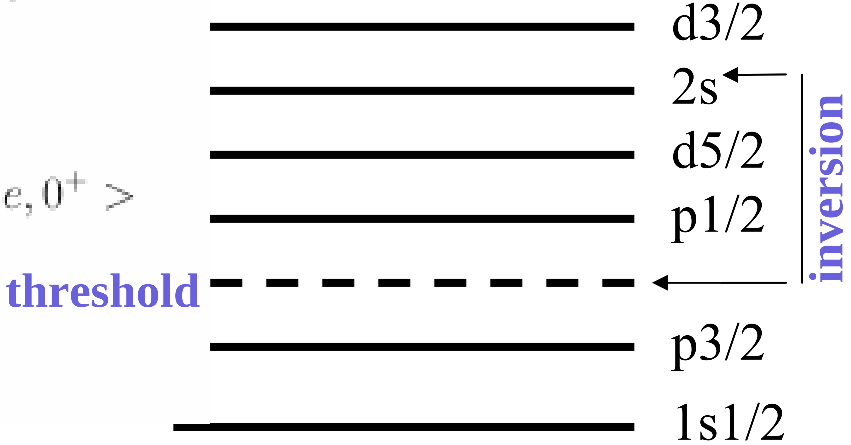
^{12}Be $_{g.s.}$ = 0^+

^{14}Be $_{g.s.}$ = 0^+ (?)

$$|^{14}B> = [a_1(p_{3/2}, 2s_{1/2}) + a_2(p_{3/2}, d_{5/2})] \otimes |^{12}Be, 0^+>$$

$$|^{14}Be> = [b_1(s_{1/2})^2 + b_2(1p_{1/2})^2 + b_3(1d_{5/2})^2] \otimes |^{12}Be, 0^+>$$

$$c_3(1d_{5/2})^2] \otimes |^{12}Be^*, 2^+>$$



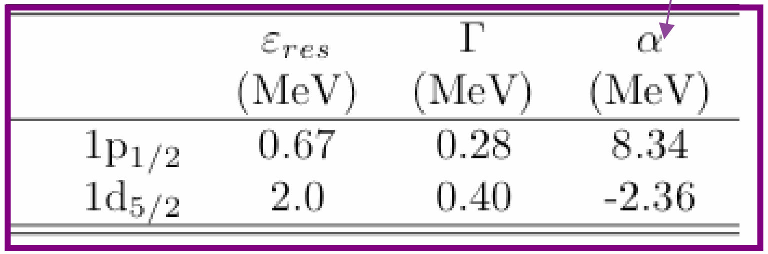
Potential corrections due to the particle-vibration coupling (N. Vinh Mau and J. C. Pacheco, NPA607 (1996) 163. also T. Tarutina, I.J. Thompson, J.A. Tostevin NPA733 (2004) 53)

…can be modeled as:

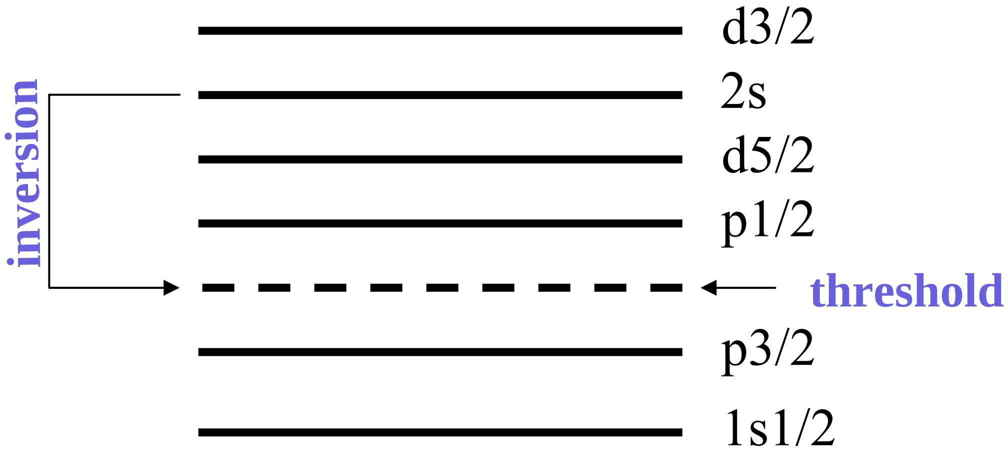
$$U(r) = V_{WS} + V_{so} + \delta V$$

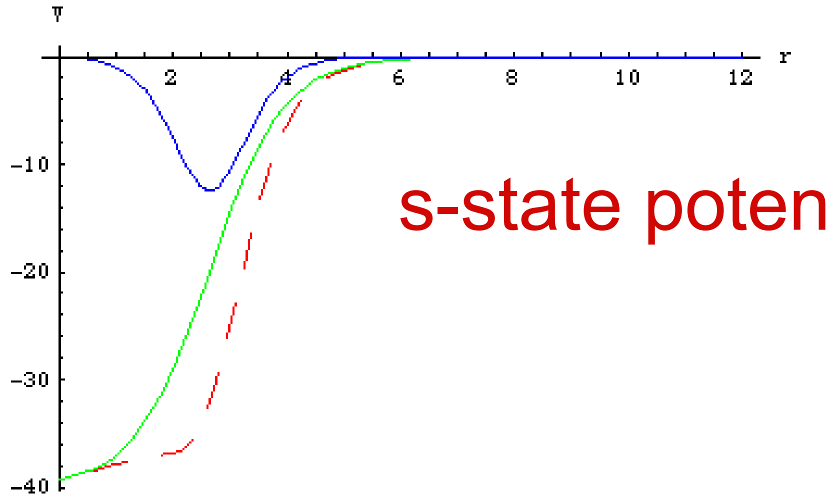
$$\delta V(r) = 16\,\alpha\, e^{(r-R)/a} / (1+e^{(r-R)/a})^4$$

n+^{12}Be:

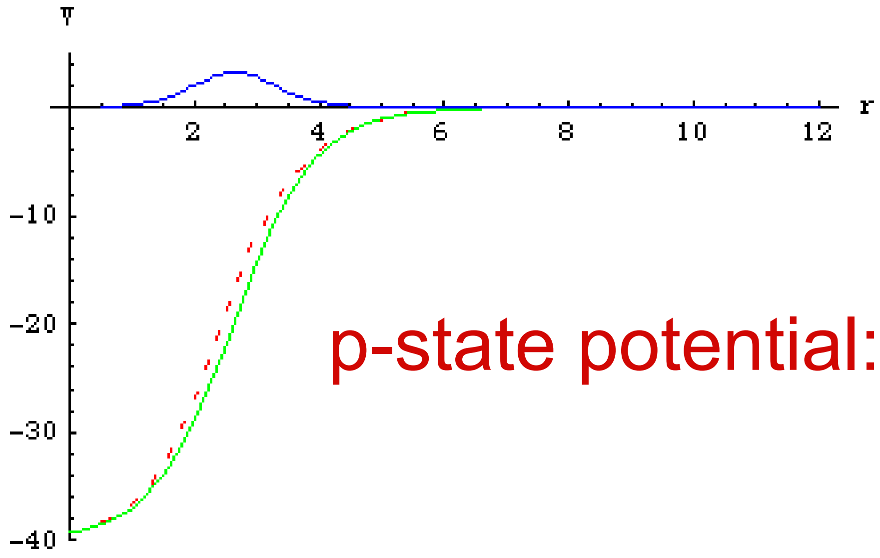


	ε_{res} (MeV)	Γ (MeV)	α (MeV)
$1p_{1/2}$	0.67	0.28	8.34
$1d_{5/2}$	2.0	0.40	-2.36





s-state potential:long range added

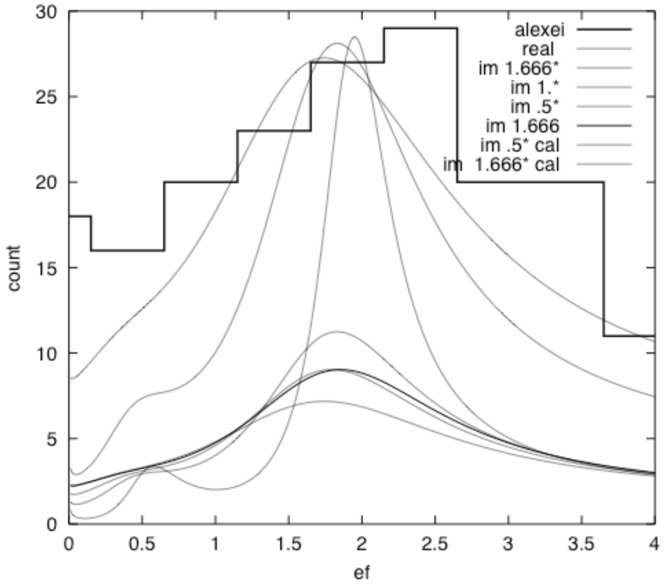


p-state potential:long range subtracted

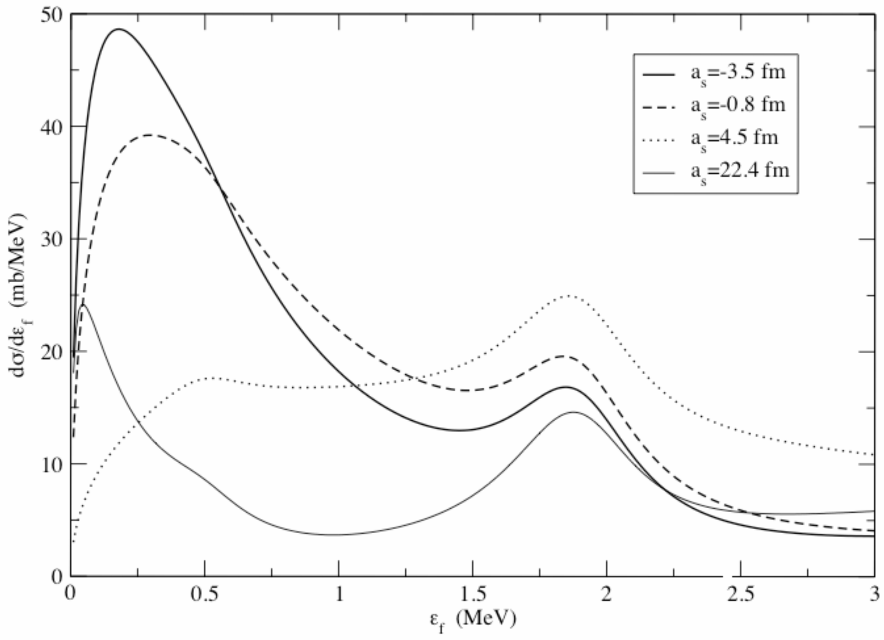
G. Blanchon, A. B. and N. Vinh Mau
Unbound exotic nuclei studied by transfer to the continuum reactions
Nucl. Phys. A739 (2004) 259.

G. Blanchon, A. B., D. M. Brink and N. Vinh Mau,
Unbound exotic nuclei studied by projectile fragmentation reactions.
IFUP-TH 29/2004: submitted to NPA

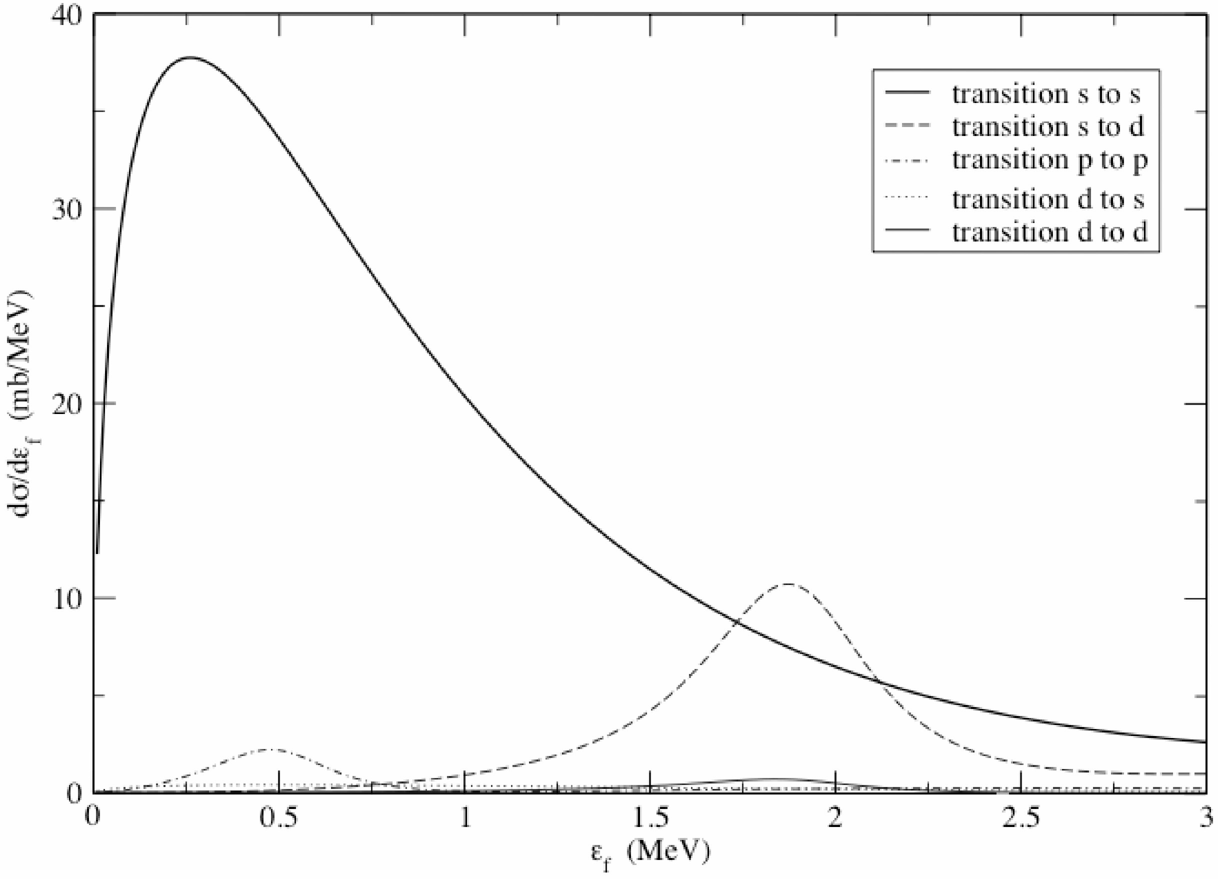
^{12}Be (d,p)



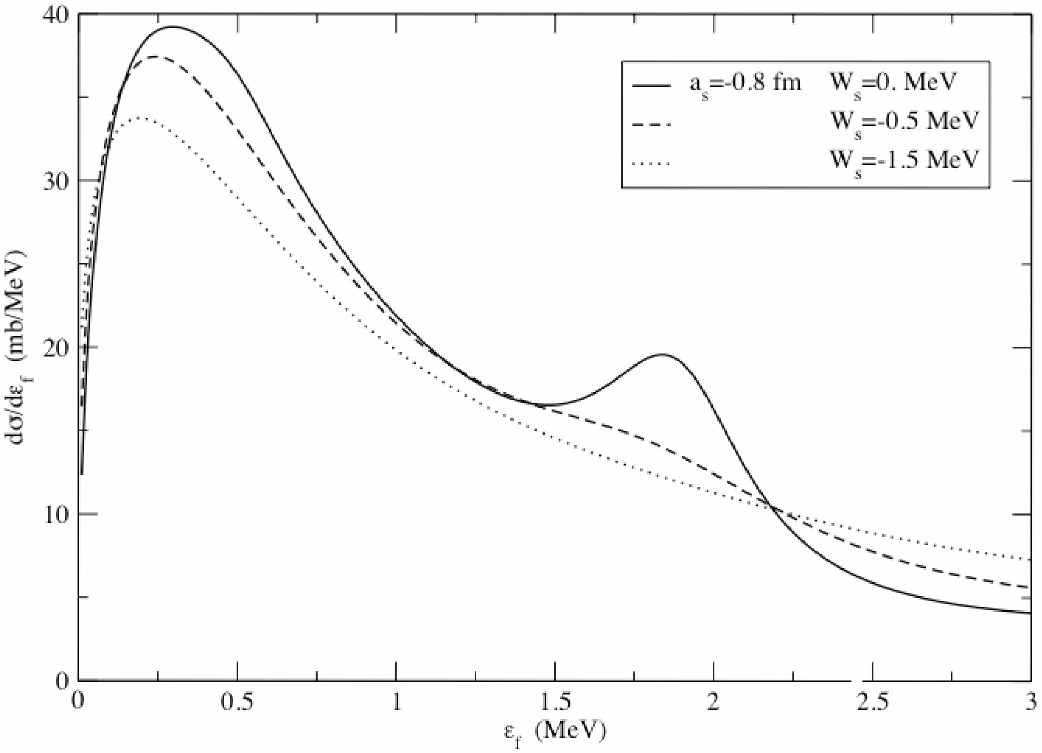
Final s-state **bound** vs **continuum**



Bound to unbound transitions

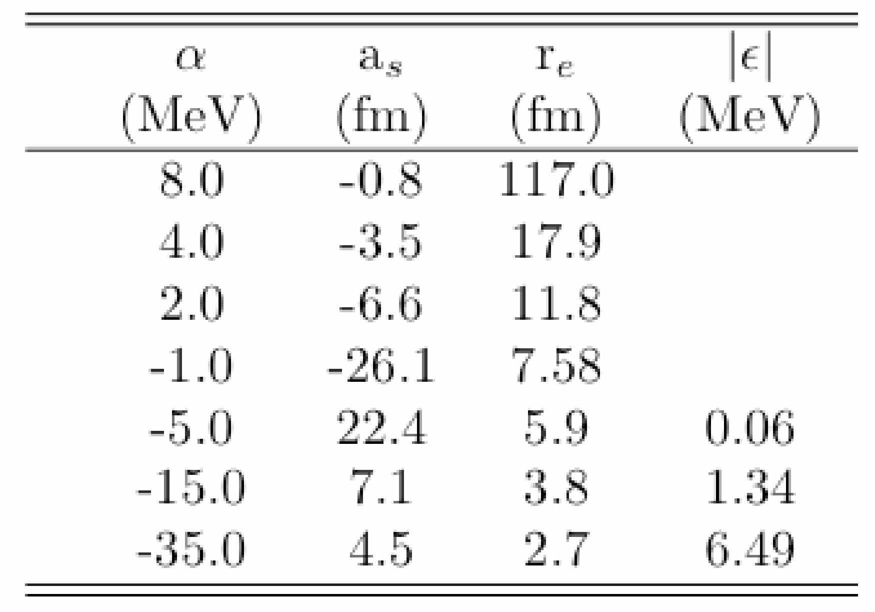


Core excitation simulated by imaginary part of n-core optical potential



effective range theory (1^0 order)

$$k \cot\text{an}\, \delta = -\frac{1}{a_s} + \frac{1}{2} r_o k^2$$



α (MeV)	a_s (fm)	r_e (fm)	$\lvert\epsilon\rvert$ (MeV)
8.0	-0.8	117.0	
4.0	-3.5	17.9	
2.0	-6.6	11.8	
-1.0	-26.1	7.58	
-5.0	22.4	5.9	0.06
-15.0	7.1	3.8	1.34
-35.0	4.5	2.7	6.49

All aspects of the nuclear interaction discussed in structure models: short range vs. long range, real vs. imaginary…volume vs. surface…

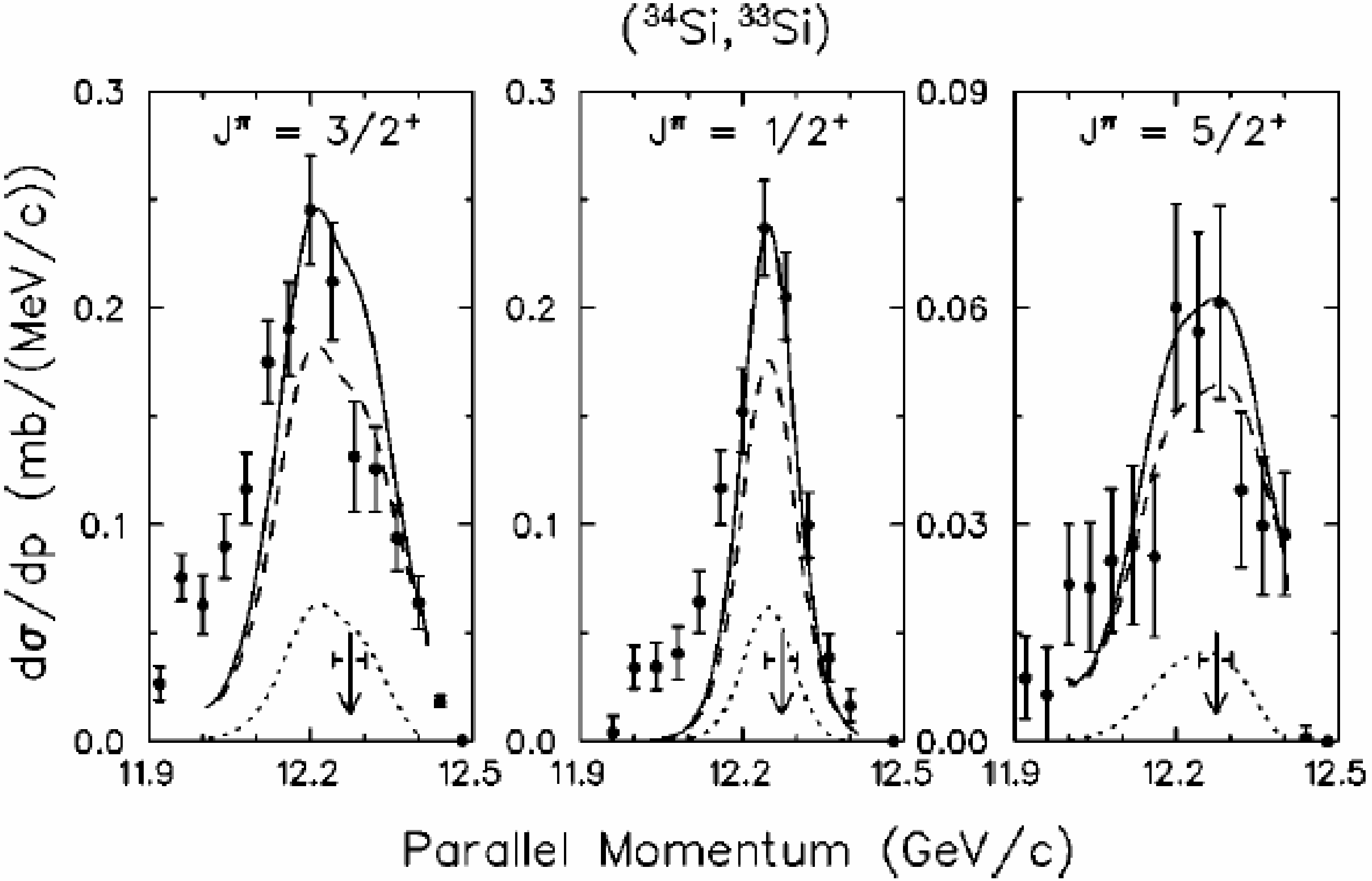
amplified at the driplines

Spin-orbit coupling effects

J.Enders et al., PHYSICAL REVIEW C **65** 034318

Mo
Dis

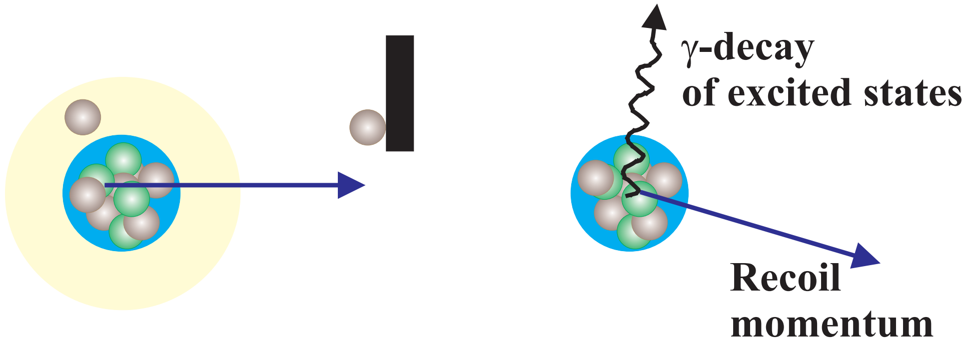
ons



Spectroscopic factors from knockout reactions

(P.G.Hansen et al.)

- Spectroscopic factors from excited states of fragment.



$$\sigma(nI^{\pi}) = \sum_j C^2 S(j, nI^{\pi})\, \sigma_{sp}(j, B_n)$$

$$\sigma_{sp}(j,B_n) = \sigma_{sp}^{strip}(j,B_n) + \sigma_{sp}^{diffr}(j,B_n)$$

- ℓ of nucleon from momentum distribution of fragment.

Ela alo Nu

Proposal to the ISOLDE &NTOF Committee

Elastic scattering and fusion studies in the reactions ^{10,11}Be+^{64}Zn.

A. Amorini[1], C. Angulo[2], M.J.G. Borge[3], A. Di Pietro[1], P. Figuera[1], L.M. Fraile[4], M. Lattuada[1], M. Milin[5], F. Pansini[1], M.G. Pellegriti[6], R.Raabe[7], F. Rizzo[1], M. Sawicka[7],V. Scuderi[1], O. Tengblad[3], M. Zadro[5]

1)INFN- Laboratori Nazionali del Sud and Università di Catania, Catania, Italy
2)CRC- Louvain la Neuve,Belgium
3)Insto. de Estructura de la Materia, CSIC, Madrid, Spain
4)CERN, Geneva, Switzerland
5)Ru_er Bo_kovi_ Institute, Zagreb, Croatia
6)GANIL, Caen, France
7)Instituut voor Kern-en Stralingsfysica, University of Leuven, Leuven,Belgium

Spokeperson : A. Di Pietro
Contactperson: L.M. Fraile

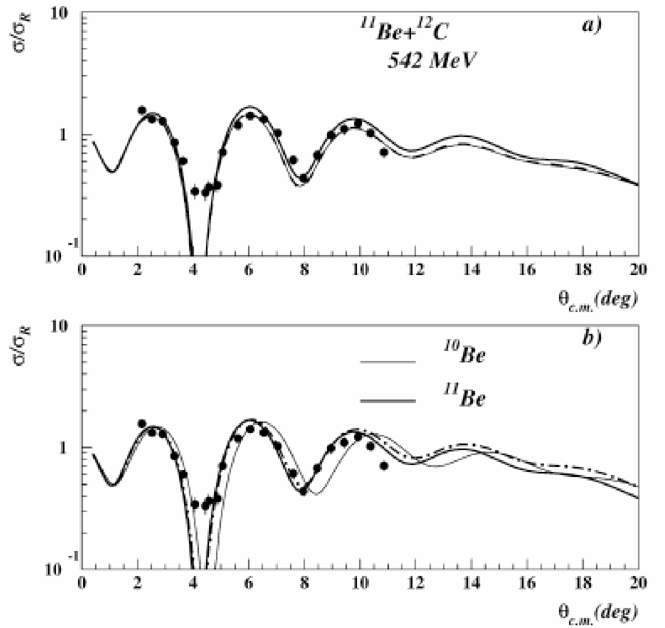
Abstract

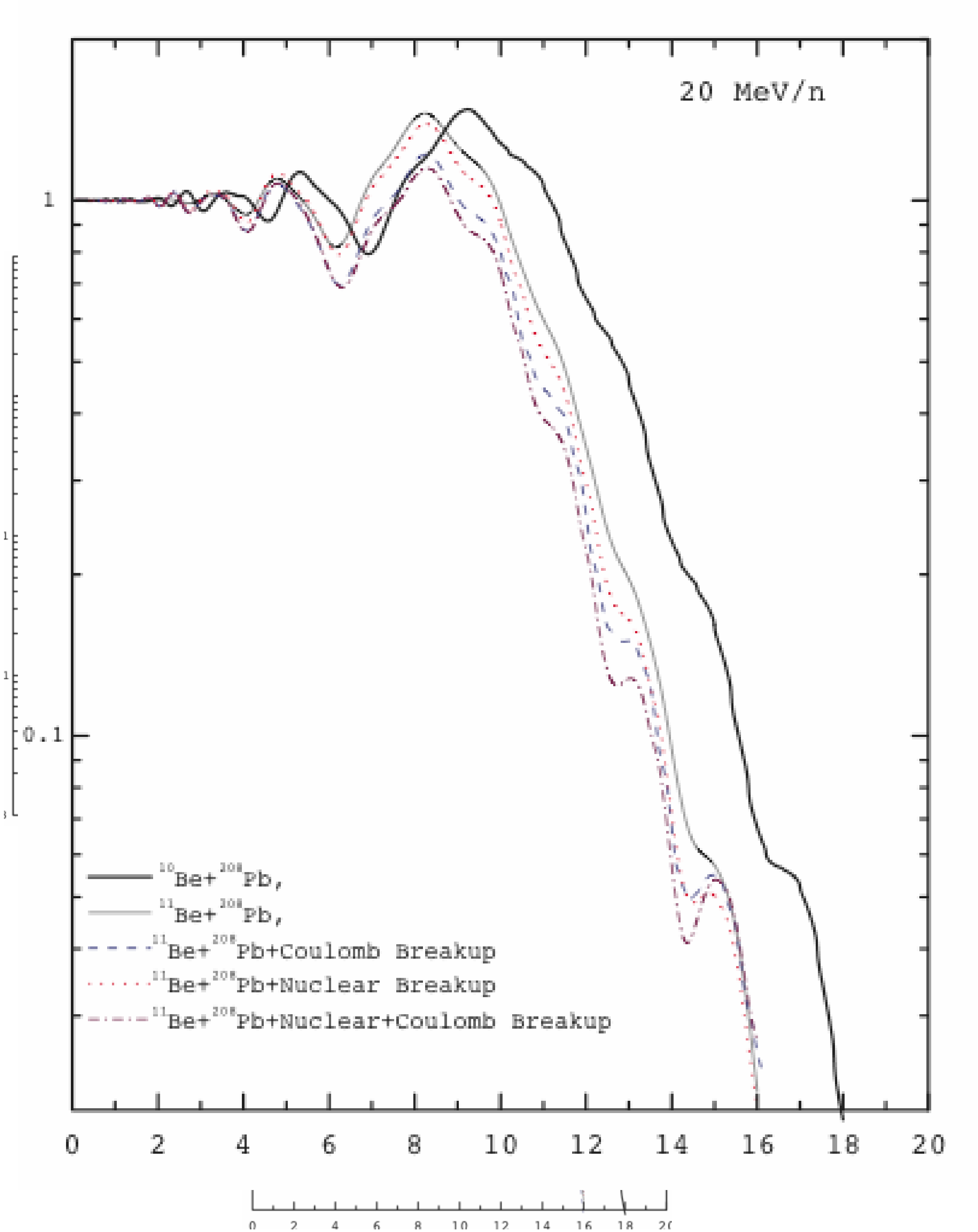
We propose to measure elastic scattering and fusion excitation functions for the reactions ^{10,11}Be+^{64}Zn at 3.1 MeV/u . The aim of the experiment is to investigate possible effects of the halo structure of the ^{11}Be nucleus on the reaction mechanisms at energy around the Coulomb barrier. For this purpose a comparison with the reaction induced by the ^{10}Be nucleus is required.

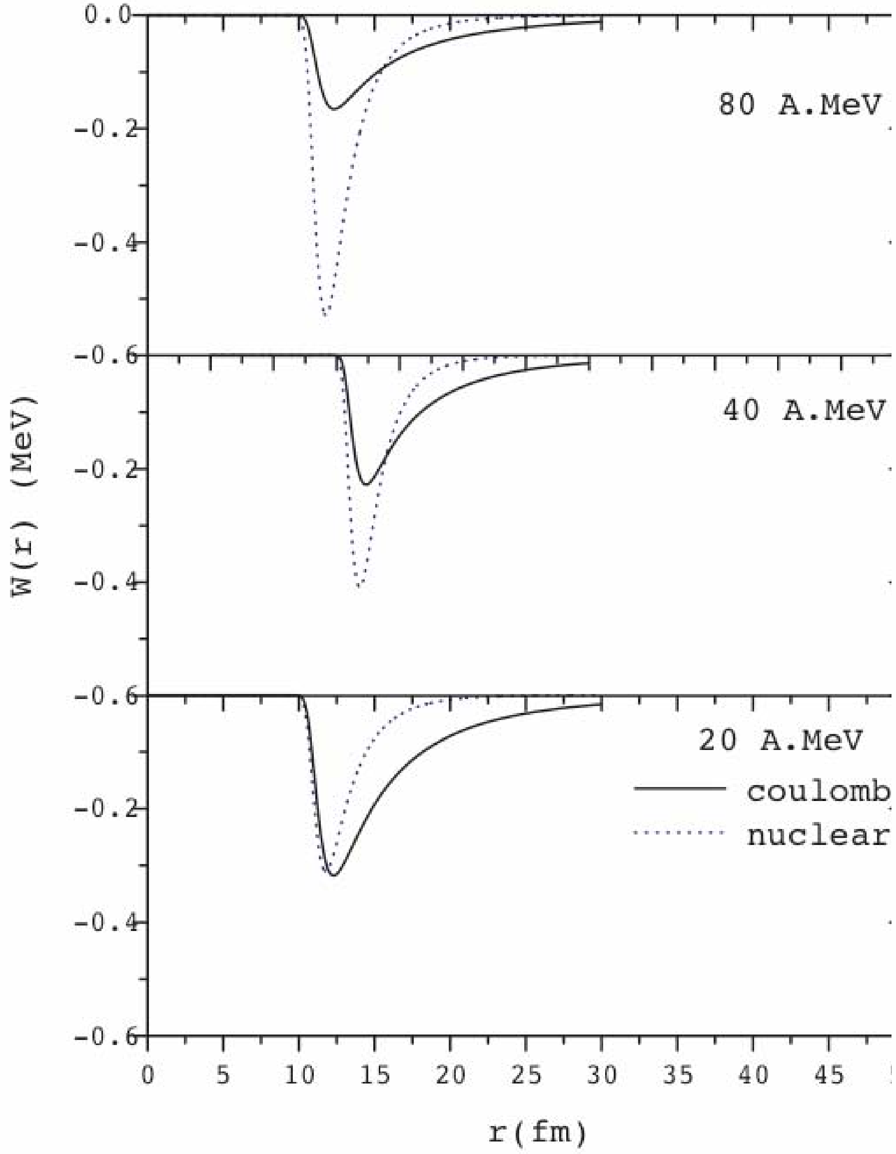
A. B. and F. Carstoiu

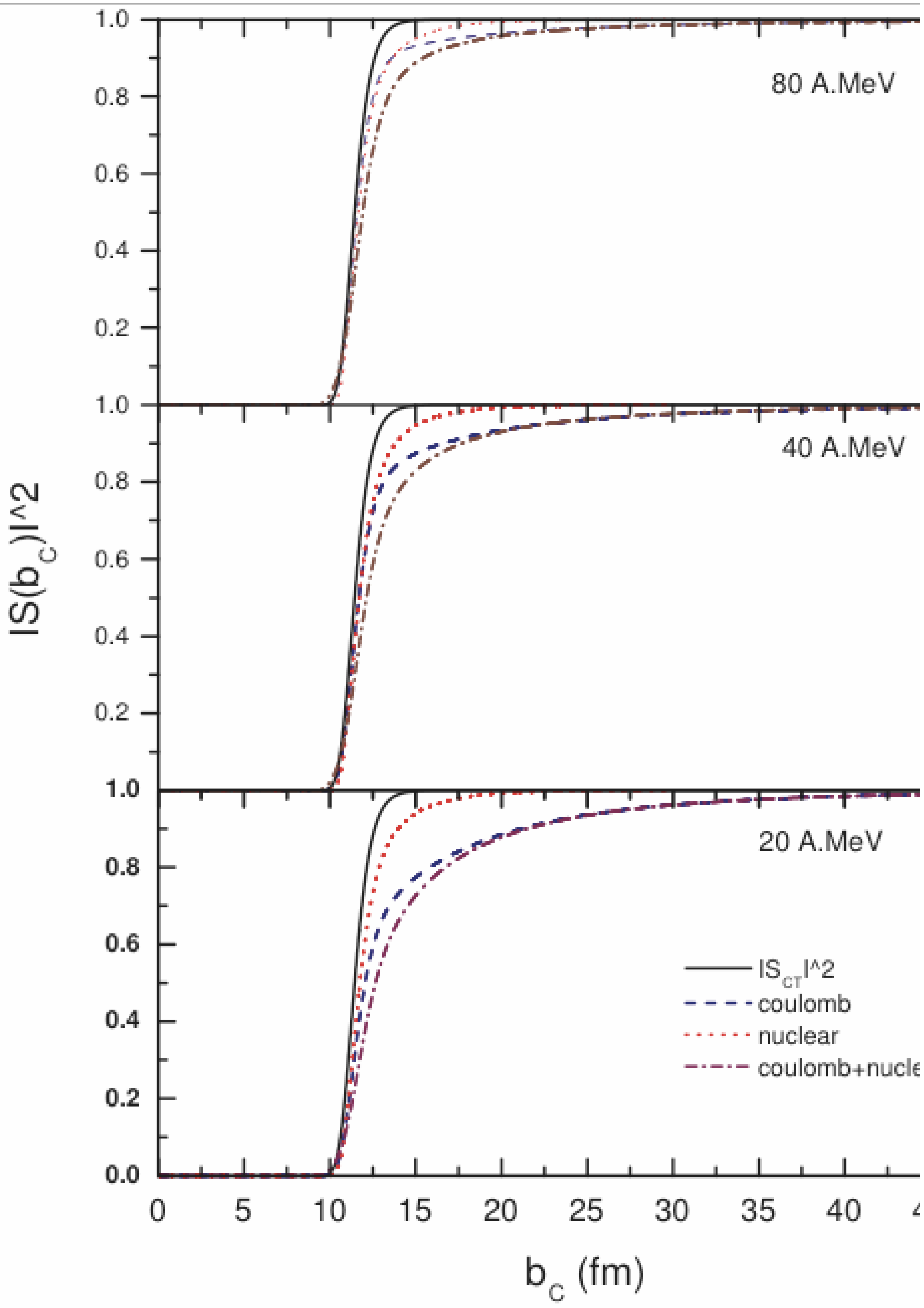
Optical potentials of halo and weakly bound nuclei

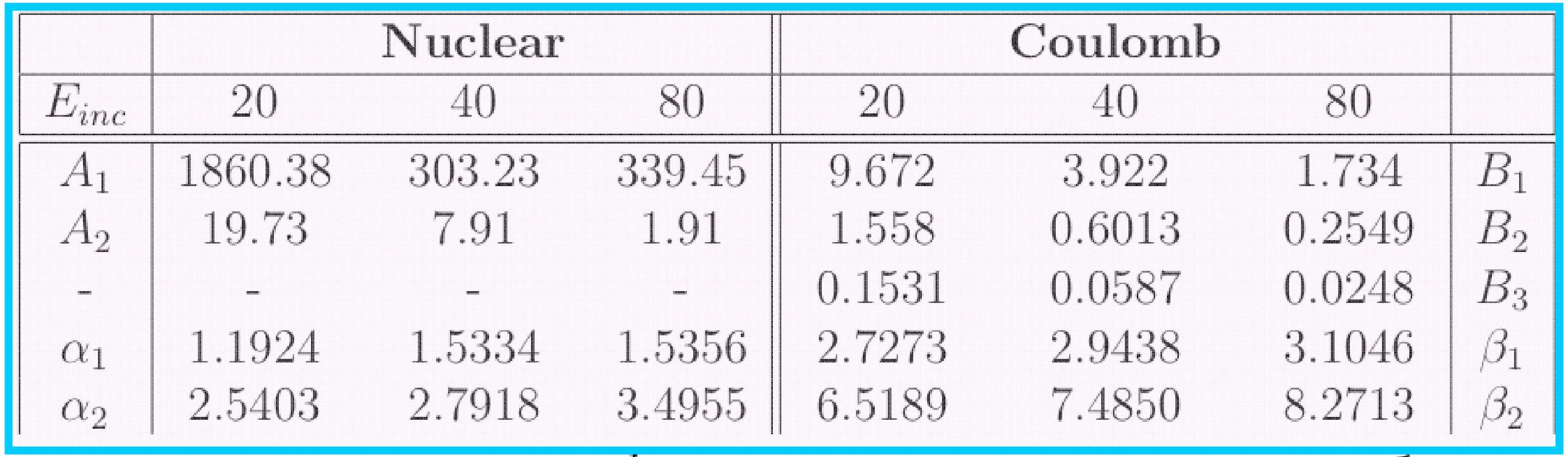
Nucl. Phys. A706 (2002) 322.






0.0
-0.2
-0.4
-0.6
-0.2
-0.4
-0.6
-0.2
-0.4
-0.6
W(r) (MeV)
80 A.MeV
40 A.MeV
20 A.MeV
coulomb
nuclear
0
5
10
15
20
25
30
35
40
45
r(fm)


1.0
0.8
0.6
0.4
0.2
1.0
0.8
0.6
0.4
0.2
1.0
0.8
0.6
0.4
0.2
0.0
|S(b_C)|^2
80 A.MeV
40 A.MeV
20 A.MeV
|S_CT|^2
coulomb
nuclear
coulomb+nucle
0
5
10
15
20
25
30
35
40
b_C (fm)



	Nuclear			Coulomb			
E_{inc}	20	40	80	20	40	80	
A_1	1860.38	303.23	339.45	9.672	3.922	1.734	B_1
A_2	19.73	7.91	1.91	1.558	0.6013	0.2549	B_2
-	-	-	-	0.1531	0.0587	0.0248	B_3
α_1	1.1924	1.5334	1.5356	2.7273	2.9438	3.1046	β_1
α_2	2.5403	2.7918	3.4955	6.5189	7.4850	8.2713	β_2

$$W_S^N(r) = -\frac{\hbar v}{2} P_0 \sum_n A_n \ \exp(-r/\alpha_n) \frac{1}{\sqrt{2\pi\alpha_n r}}.$$

$$W_S^C(r) = -\frac{\hbar v}{2} P_0 \sum_n B_n \ \exp(-r/\beta_n) \frac{1}{\sqrt{2\pi\beta_n r}}.$$

$\alpha_2 \approx 1/2\gamma$, $\gamma = \sqrt{2\mu\varepsilon_i}/\hbar$

decay length of initial wave function

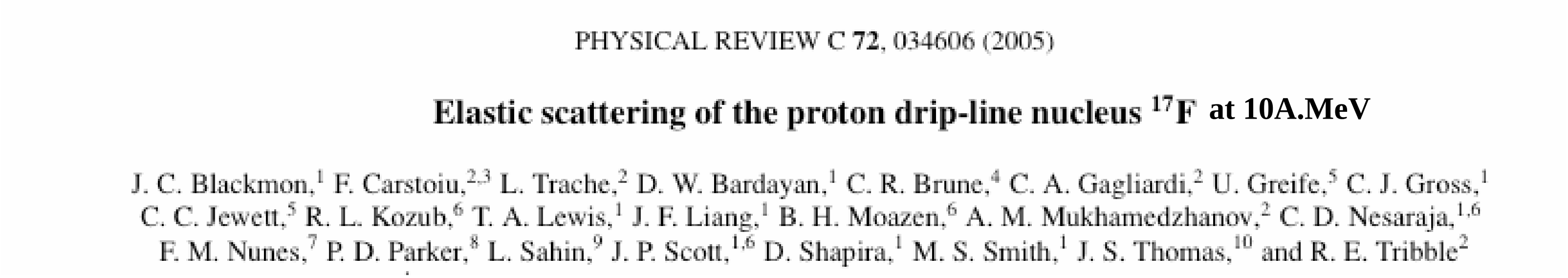
$\beta_3 \approx (\varepsilon_f - \varepsilon_i)/\hbar v$

adiabaticity parameter of Coulomb excitation theory

…see also a classical reference

Effect of the breakup channel on 11Li elastic scattering,
J.S. Al-Khalili, Nucl. Phys. A 581 (1995) 315-330

…and one of the most recent



PHYSICAL REVIEW C **72**, 034606 (2005)

Elastic scattering of the proton drip-line nucleus ^{17}F at 10A.MeV

J. C. Blackmon,[1] F. Carstoiu,[2,3] L. Trache,[2] D. W. Bardayan,[1] C. R. Brune,[4] C. A. Gagliardi,[2] U. Greife,[5] C. J. Gross,[1]
C. C. Jewett,[5] R. L. Kozub,[6] T. A. Lewis,[1] J. F. Liang,[1] B. H. Moazen,[6] A. M. Mukhamedzhanov,[2] C. D. Nesaraja,[1,6]
F. M. Nunes,[7] P. D. Parker,[8] L. Sahin,[9] J. P. Scott,[1,6] D. Shapira,[1] M. S. Smith,[1] J. S. Thomas,[10] and R. E. Tribble[2]

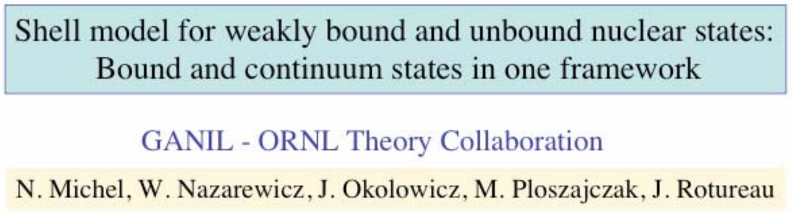
…and references therein.

For the *structure* aspect…see also

“Evolution of nuclear structure, shapes, and fission”

Evolution Of Shell Structure, Shapes & Collective Modes

Dario Vretenar
vretenar@phy.hr

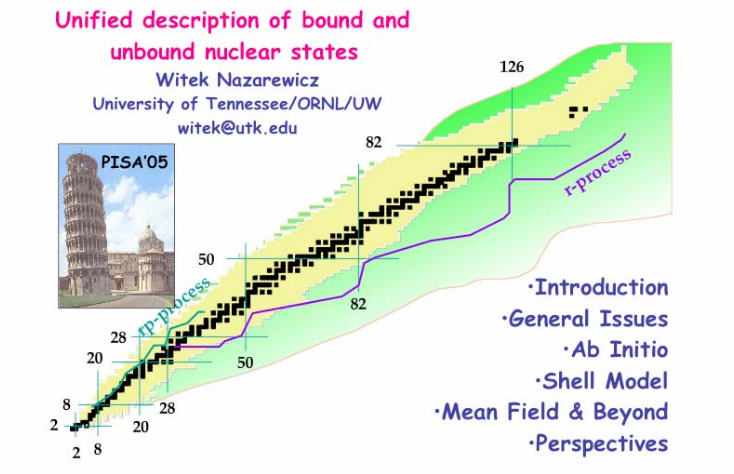


Shell model for weakly bound and unbound nuclear states:
Bound and continuum states in one framework

GANIL - ORNL Theory Collaboration

N. Michel, W. Nazarewicz, J. Okolowicz, M. Ploszajczak, J. Rotureau

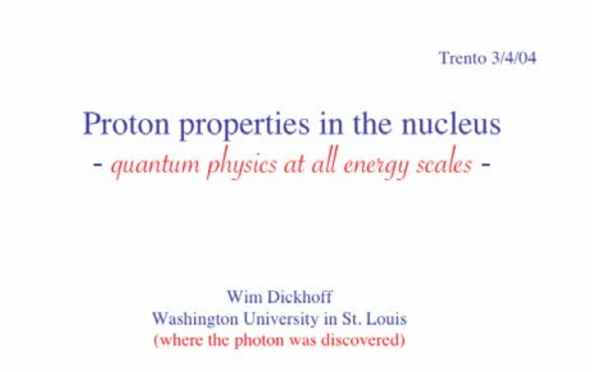
http://www.df.unipi.it/~angela/finalprogram.html



Unified description of bound and unbound nuclear states
Witek Nazarewicz
University of Tennessee/ORNL/UW
witek@utk.edu

- Introduction
- General Issues
- Ab Initio
- Shell Model
- Mean Field & Beyond
- Perspectives

Structure of proton-radioactive nuclei
Lídia S Ferreira and Enrico Maglione 2005 J. Phys. G: Nucl. Part. Phys. 31 S1569-S1572

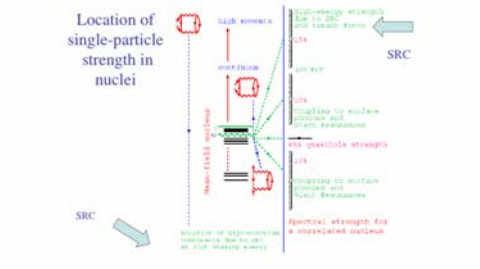


Trento 3/4/04

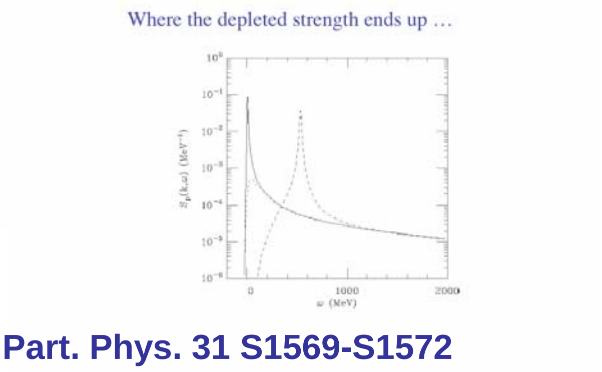
Proton properties in the nucleus
- *quantum physics at all energy scales* -

Wim Dickhoff
Washington University in St. Louis
(where the photon was discovered)

http://www.df.unipi.it/~angela/talks.html



Location of single-particle strength in nuclei



Where the depleted strength ends up …

Location of single-particle strength in nuclei

488 *W.H. Dickhoff, C. Barbieri / Progress in Particle and Nuclear Physics 52 (2004) 377–496*

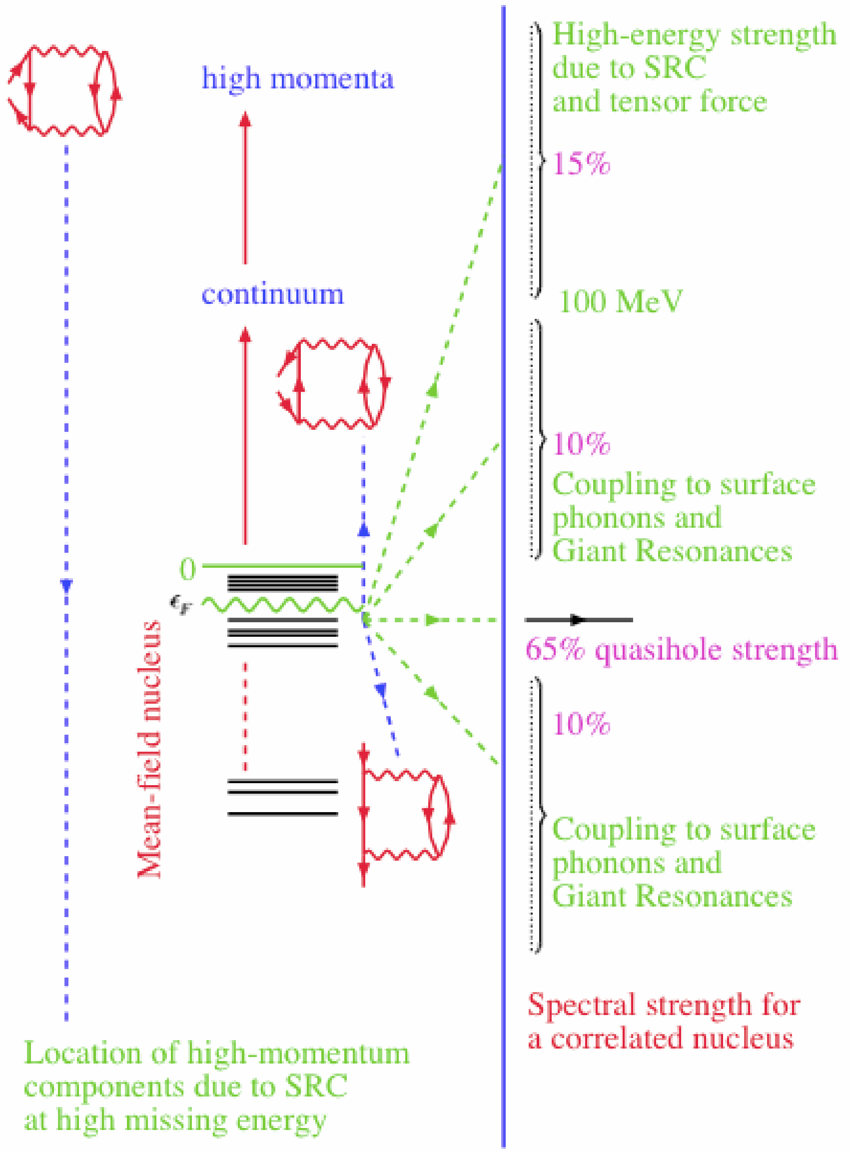


Fig. 55. The distribution of single-particle strength in a nucleus like ^{208}Pb. The present summary is a synthesis of experimental and theoretical work discussed in this review. A slight reduction (from 15% to 10%) of the depletion effect due to SRC must be considered for light nuclei like ^{16}O.

Conclusions and Outlook

."Exotic" threshold characteristics of dripline nuclei enhanced by low energy experiments at $E_{inc} \leq 20A.MeV$.

. Study of dripline nuclei will lead us to the *best possible* *phenomenological* *energy dependent* *nuclear potential* for *bound* and *scattering* states.

My guess for the future:

- We will have to redefine the $n-n$ interaction in terms of a "n-body" interaction (3-body terms are already necessary !!).
- Paring ($n-p$) will be understood (I hope!!) on a microscopic basis…(*effective field theories ??*).

Spectroscopic Factors, Trento 04

Hi Gregers, would you agree…?

Appendix I: transfer vs. inelastic

transfer to the continuum

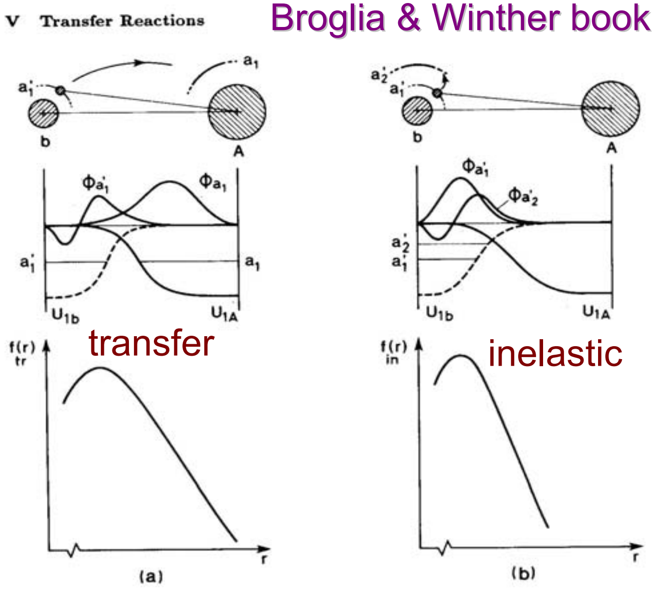
$$\frac{dP_t}{d\varepsilon_f} \approx \Sigma_{l_f}(2l_f+1)|1-S_{l_f}|^2 B_{l_f,l_i}, \qquad B_{l_f,l_i} \approx \frac{e^{-2\eta b_c}}{b_c}$$

projectile fragmentation:inelastic excitation

$$\frac{dP_{in}}{d\varepsilon_f} \approx \Sigma_{l_f}(2l_f+1)|1-\bar{S}_{l_f}|^2 I_{l_f,l_i}, \qquad I_{l_f,l_i} \approx \frac{e^{-2\gamma b_c}}{b_c^3}$$

$$\bar{S}_{l_f} = S_{l_f} e^{2i\alpha} = e^{2i(\delta+\alpha)}$$

S and $\bar{S}$ correspond to different phase shifts



Broglia & Winther book

check of sudden approximation
- E_{inc}: independent
- ε_{if} : important

Appendix II: potential from phase shift.

$$|S_{NN}(b)|^2 = e^{-4\delta_I(b)}$$

$$\delta_I(b) = -\frac{1}{2\hbar}\int_{-\infty}^{+\infty}(W_V(\mathbf{r}(t)) + W_S(\mathbf{r}(t)))\,dt$$

$$\int_{-\infty}^{+\infty} W_S(\mathbf{r}(t))dt = -\frac{\hbar}{2}P_{b_{up}}$$

$$\mathbf{r}(t) = \mathbf{b_c} + vt$$

$$|S_{NN}|^2 = |S_{CT}|^2 e^{-P_{b_{up}}}$$

$$W_S^N(r) = -\frac{\hbar v}{2}p^N_{b_{up}}(r)\frac{1}{\sqrt{2\pi a r}}$$