Single-Particle absolute Spectroscopic Factors

I- Single-particle motion in nuclei

Spectroscopic factors ,Sum-rules

II Experimental quest : One nucleon Transfer and e,e' p Knock out .

Advantages and limitations :Experiments and reaction processes

III Beyond bound states :transfer to resonances in the continuum

IV Single particle states far of Stability

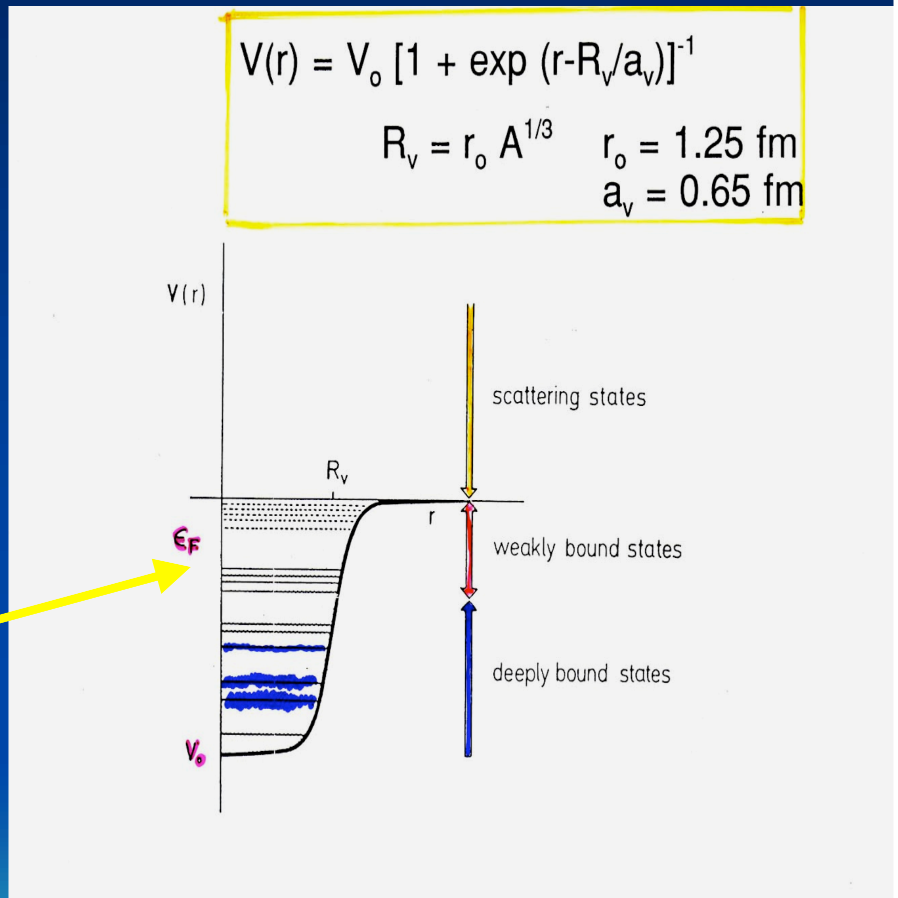
Nucleon-Nucleus mean field

°Mean field concept similar for bound (shell model) and scattering (optical model) states.

°°In nuclei the mean field is non-local. V(r,r') velocity dependence

Fluctuations of V give rise to collective modes . Coupling of s-p motion to Collective modes leads to V(r,r',E).

°°°Local equivalent

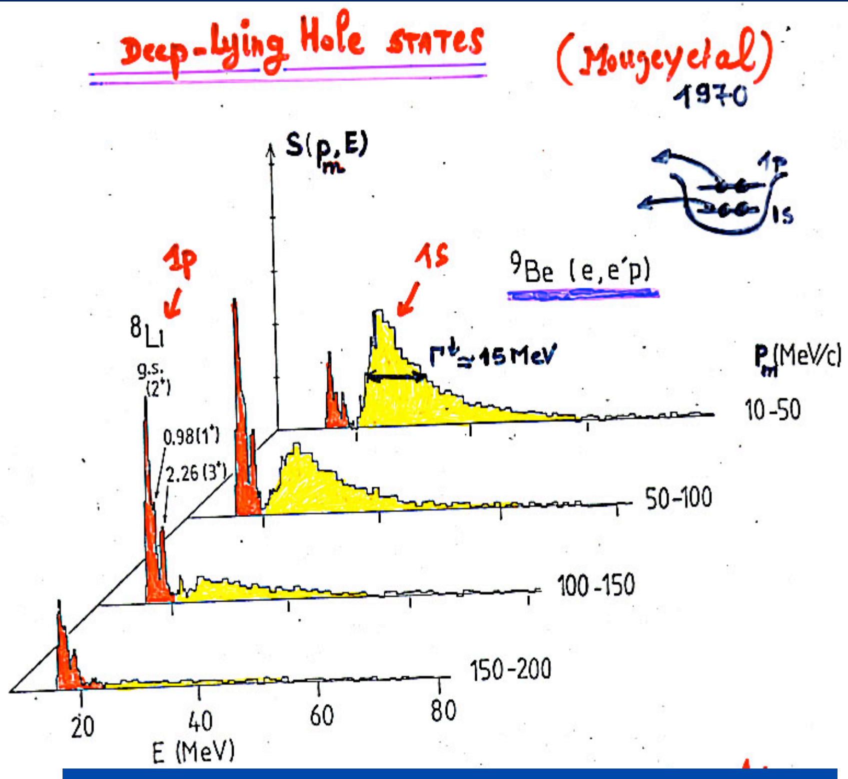


$V(r,E)=V_{HF}(r,E)+\Delta V(r,E)$

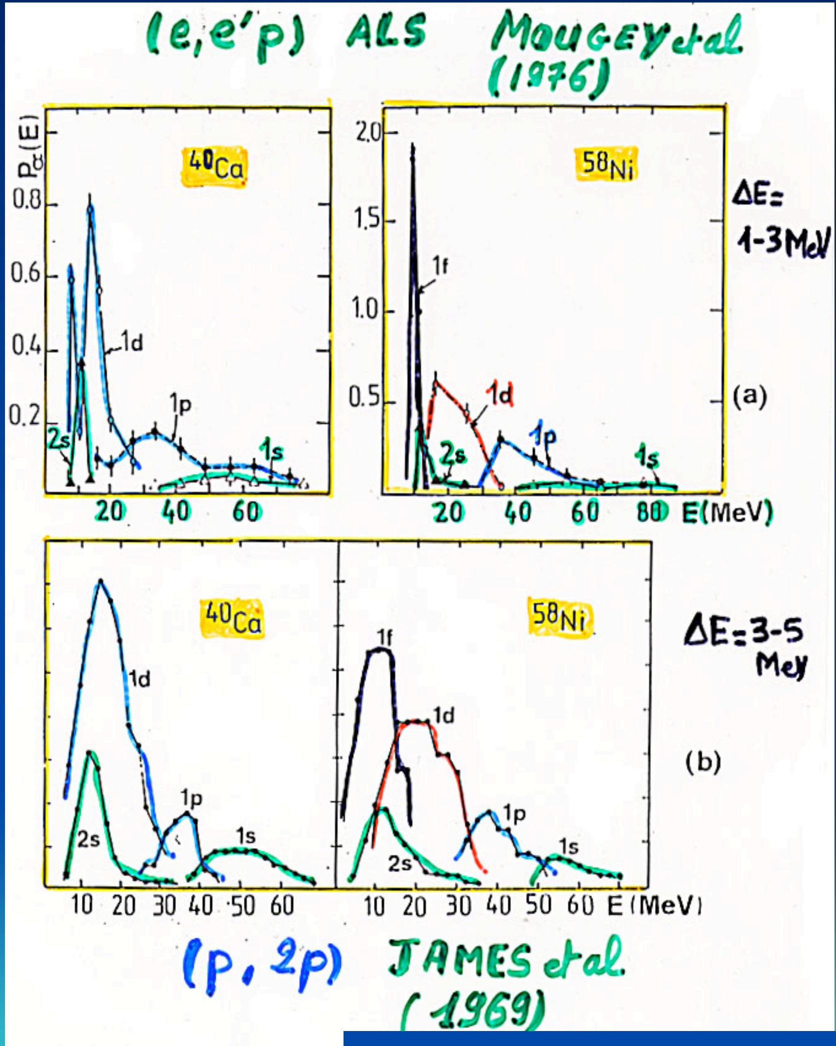
Dynamical content of IPM

Potential depth A independent

Single Particle states
Early experimental evidences

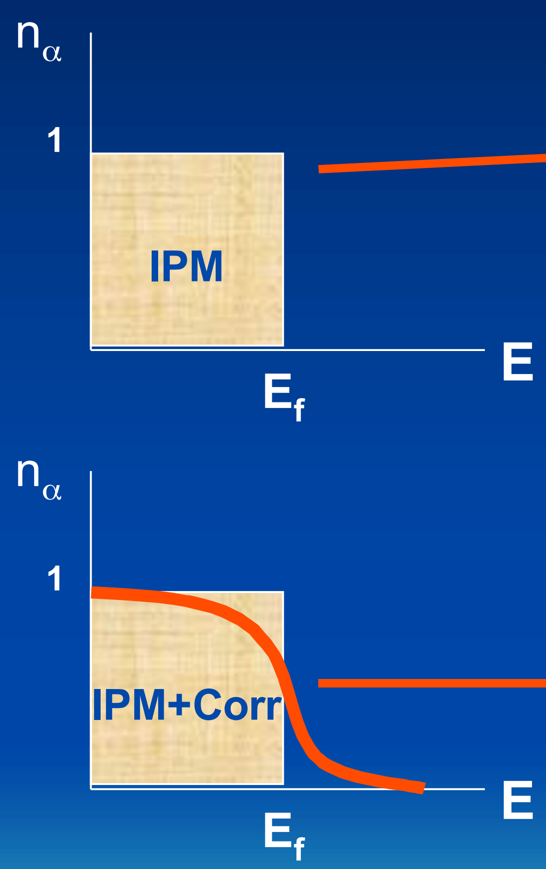


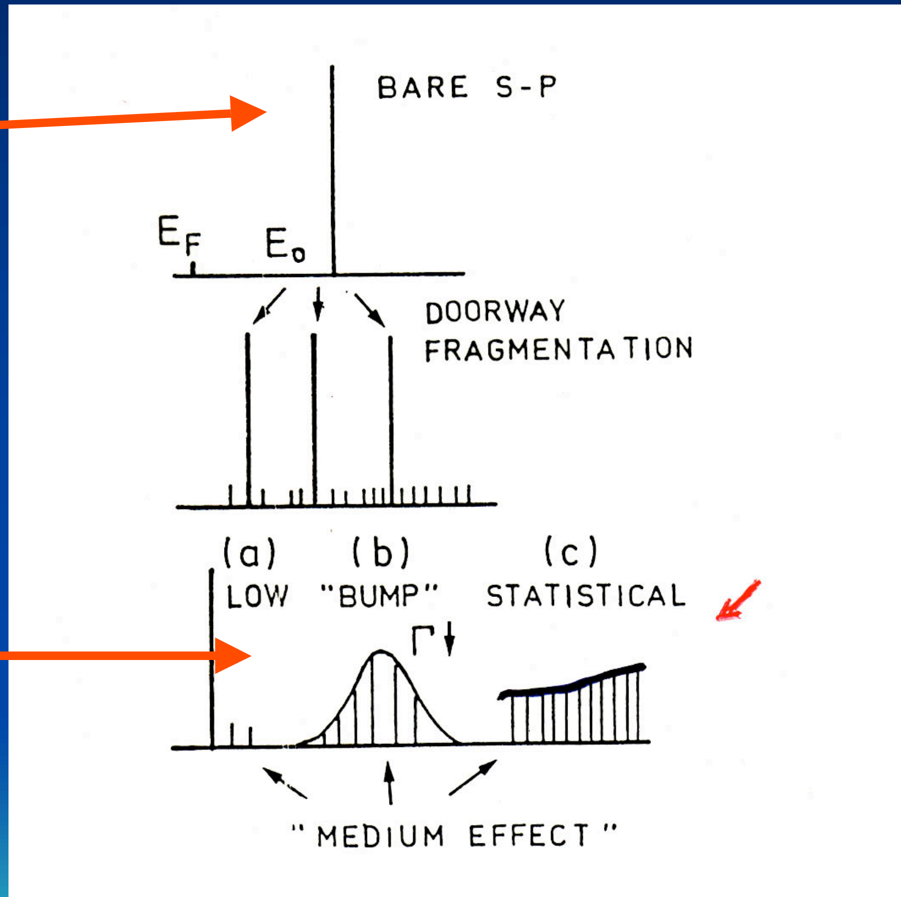
Light-Nuclei :Well separated shells
Broad inner 1s shell



Medium and heavy nuclei
Rapidly overlapping shells

Coupling to (1p-1h) ,…, (np-nh)





Spectroscopic Factors & sum-rule

Pick-up $S^{-}_{lj}(A,A-1) = |\langle \Phi_f(A-1) | a_{lj} | \Phi_0(A) \rangle|^2$

Stripping $S^{+}_{lj}(A,A+1) = |\langle \Phi_f(A+1) | a^{+}_{lj} | \Phi_0(A) \rangle|^2$

Sum-Rule

Sum of S^{lj} on all final sates f with lj quantum numbers give

$$\Sigma_f S_{lj} = \langle \Phi_0(A) | a^{+}a | \Phi_0(A) \rangle = n_{lj}$$

number of nucleons lj in the ground state

Two obvious problems in deducing absolute values for this sum-rule

Sum of all final fragments limited in Energy short range correlations (up to high Ex)

Accuracy of reaction models
Cross-sections dependence on form factors ,
Optical parameters

Reaction model for one-nucleon transfer

- DWBA A+a → B+b b=a+/-1n one-step
- $T_{BA} = \iint dr_{aA}\, dr_{bB}\, X_b^{-*}(k_b, r_{bB})\, F(r_{aA}, r_{bB})\, X_a^{+}(k_a, r_{aA})$

OM elas channels

- EFR-DWBA

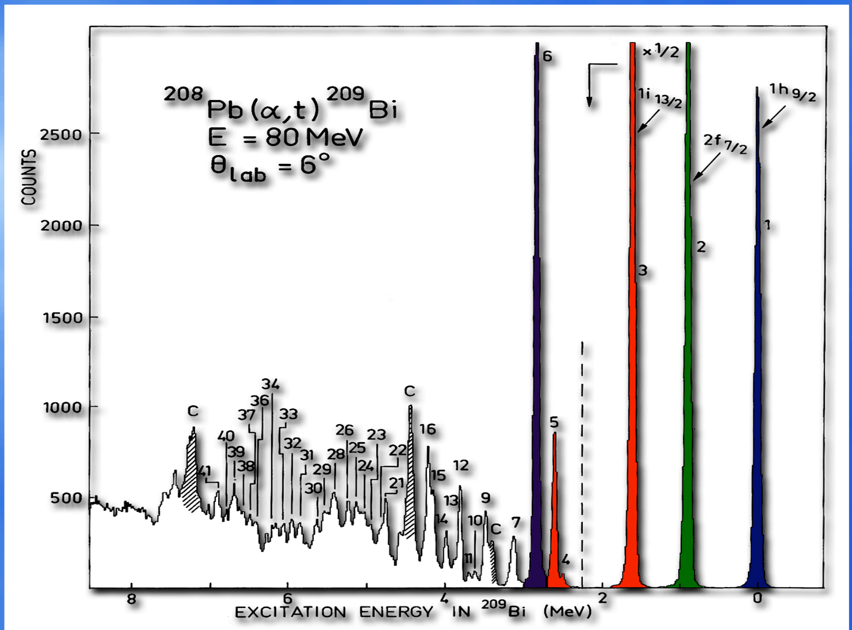
$$d\sigma/d\omega_{EXP}(\theta) = C^2 S^{lj}.\ K.\ [\ T_{BA}]^2 = C^2 S\ d\sigma/d\omega_{EFR\text{-}DW}(\theta)$$

. F contains

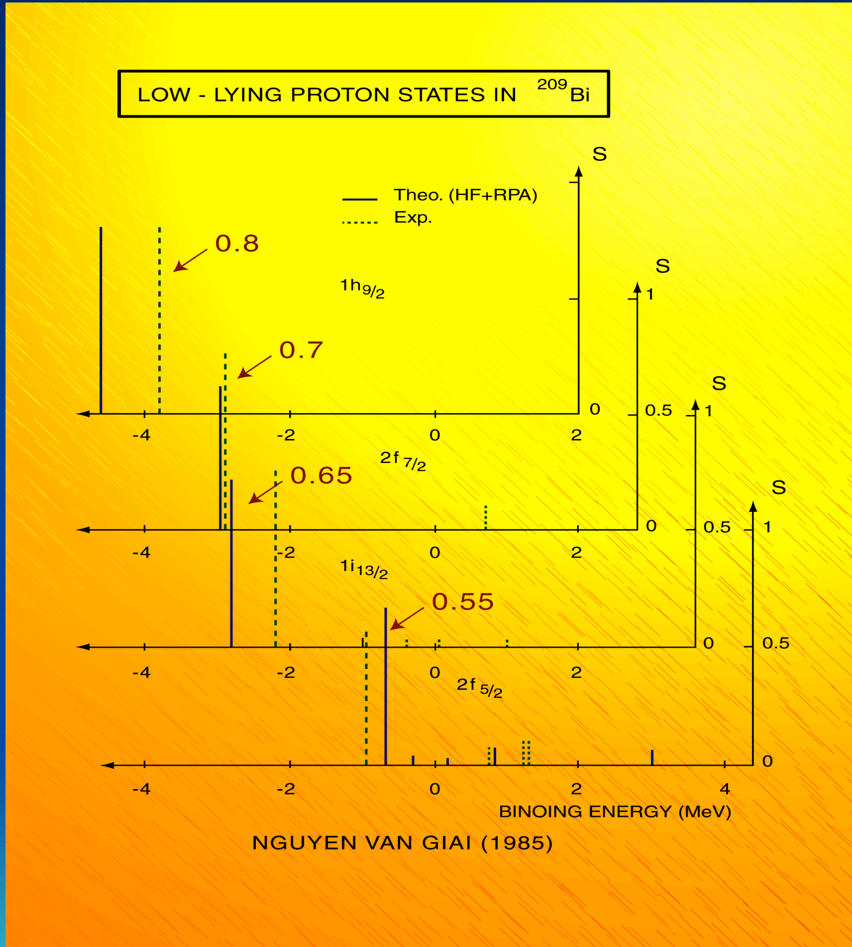
1) the V_{nb} interaction between the ejectile b and the transferred nucleon n (from n-n or n-b phase shifts at low energies)
Zero Range $V_{nb} = Do\ \delta(r_{bn})\delta_{l0}$

2) the form factor $f_{lj}(r)$. Calculated in WS potential ,to reproduce correct binding (SE, energy dependence) . $d\sigma/d\omega_{DW}(\theta)$ displays strong dependence on the radius

Proton Stripping reaction
Single-particle states ^{208}Pb+1p



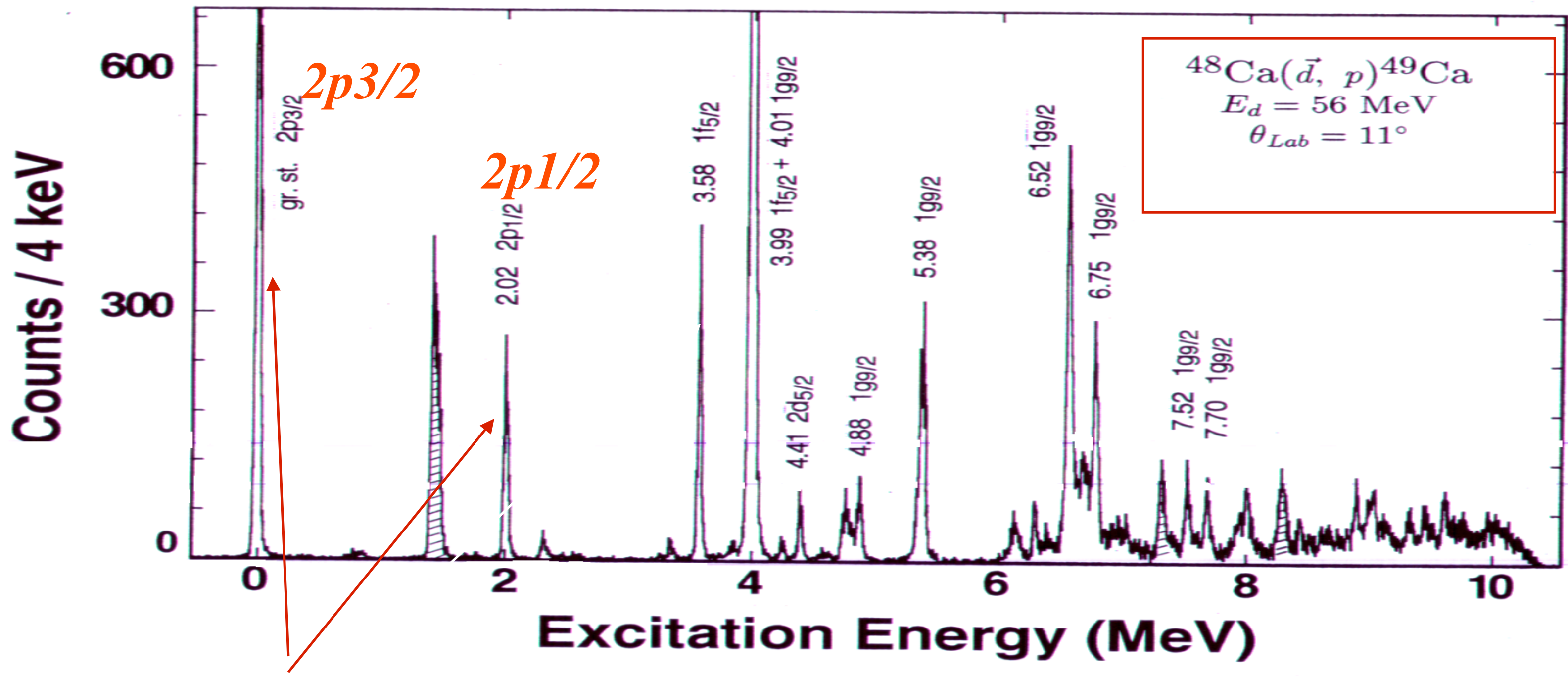
Proton S-P STATES ^{208}Pb+p



Above 2.5 MeV strong fragmentation of Single –particle strengths !!!

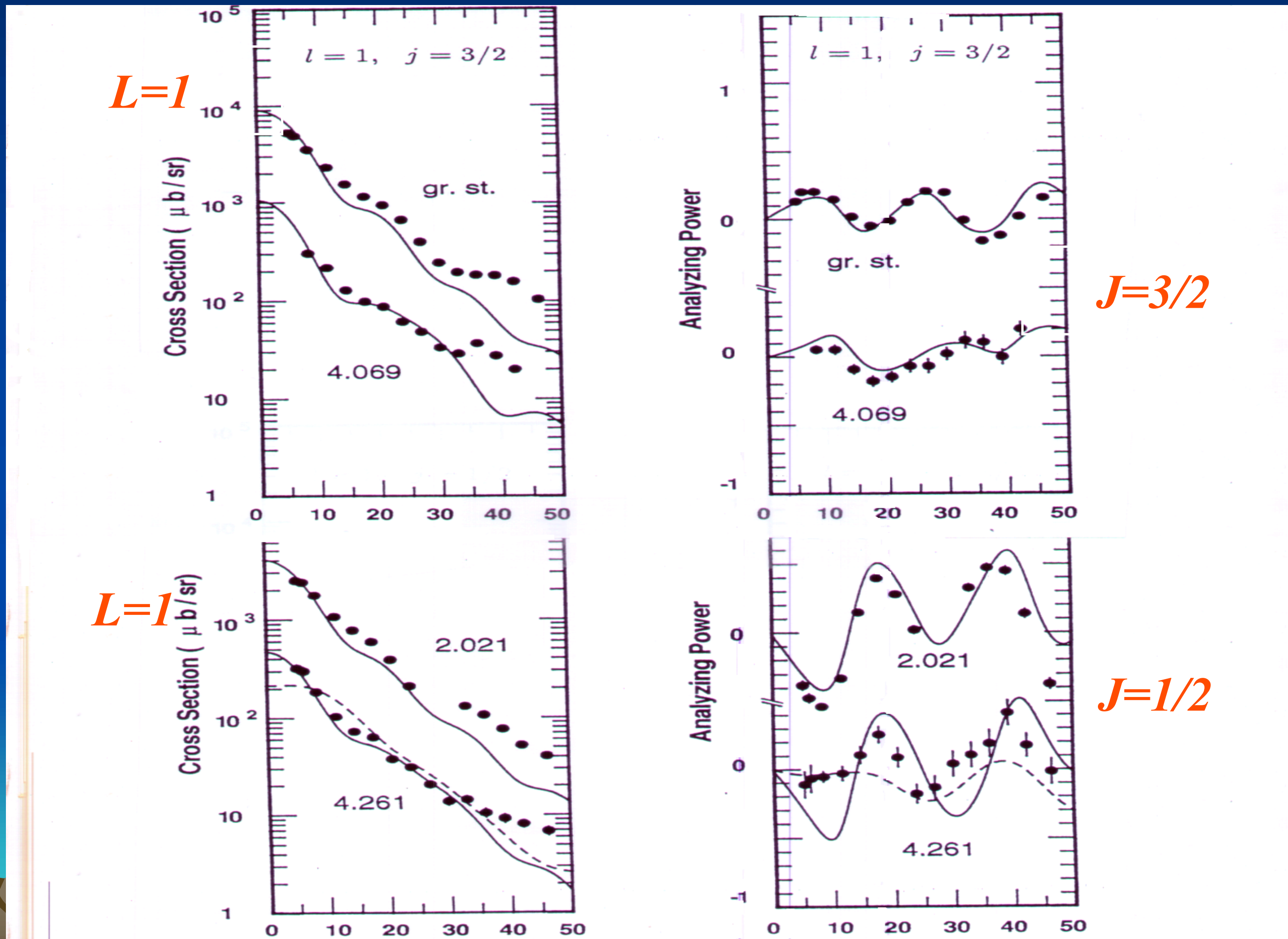
Bound states and polarized beams in transfer

State of the art :OSAKA 1993

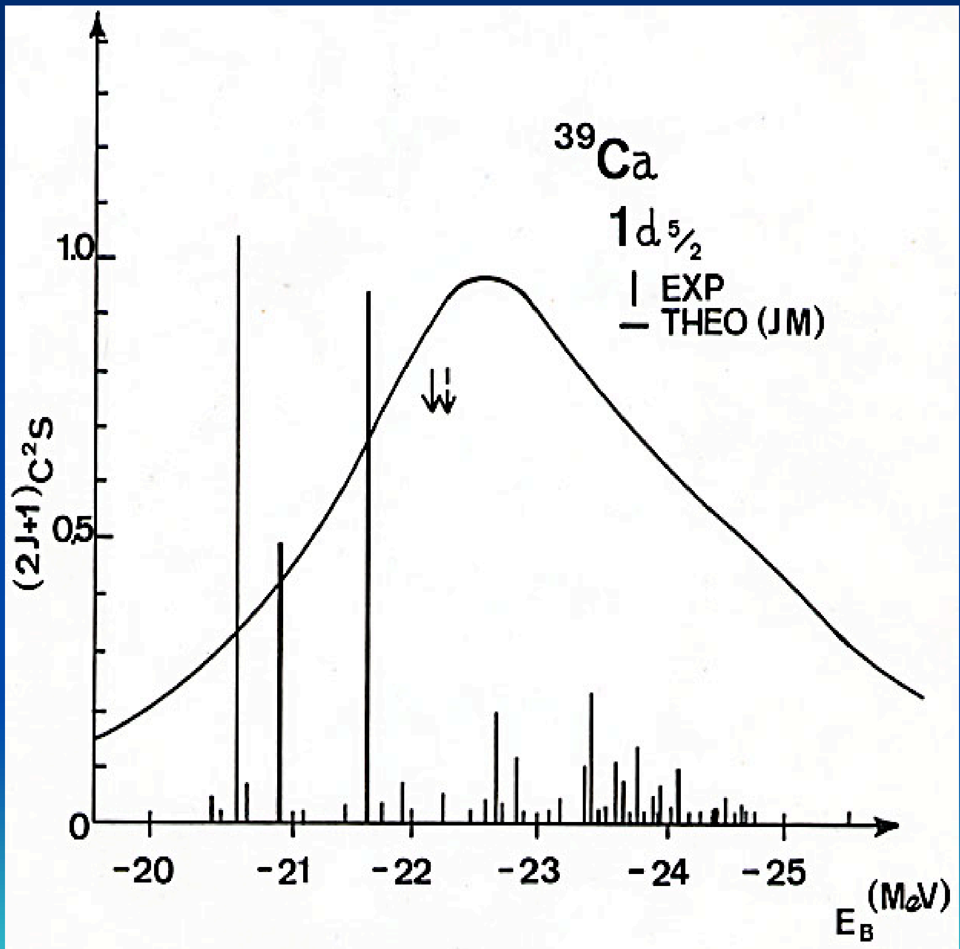


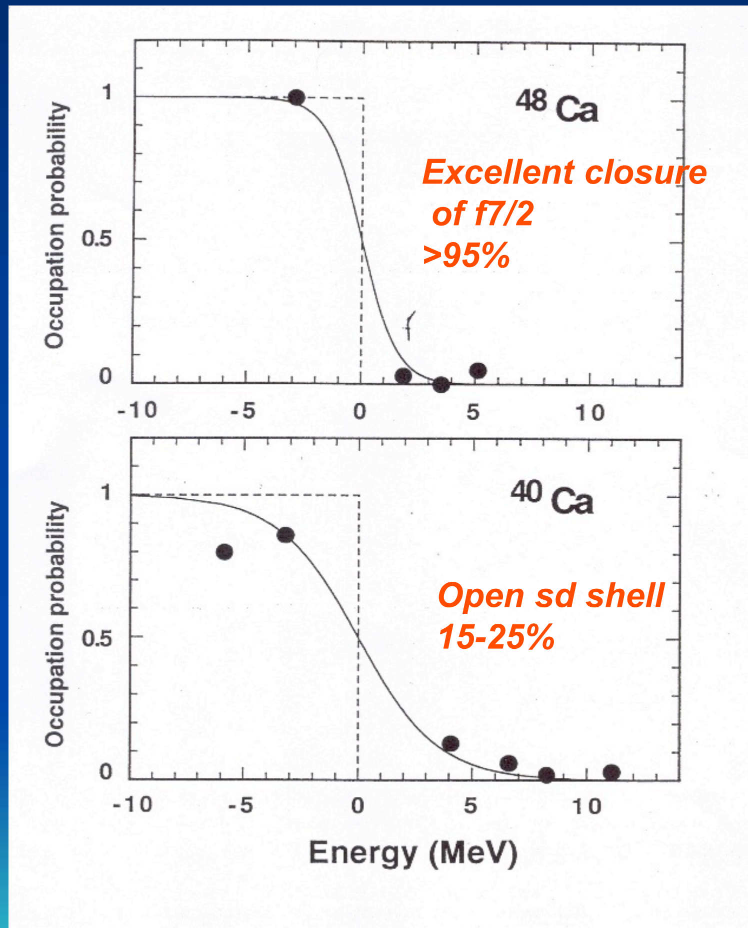
P=80%
30KeV

Examples :
Angular distributions and asymmetries
2p3/2 ,2p1/2 in ^{49}Ca



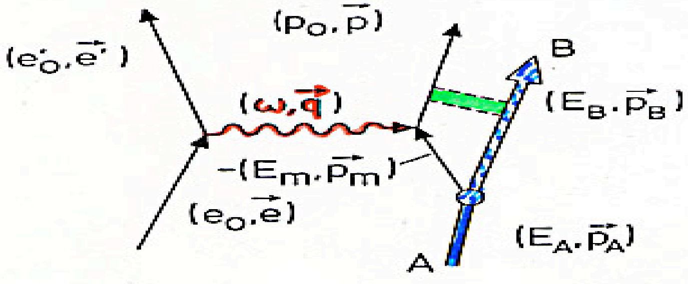
From stripping and pick-up :occupation numbers and shell closure





Proton knock-out process: (e, e ‘,p)

A(e,e'p)B



$$\begin{cases} E_m = E_{SEP} + E_x \\ \vec{P}_m = \vec{q} - \vec{p} \end{cases}$$

PWIA

$$S(E_m, P_m) = (K\,\sigma^{*}_{ep})^{-1} \times \frac{d^6\sigma}{de'_0 \; d\Omega_{e'} \; dT_p \; d\Omega_p} = \Sigma\, S_{n\ell j}(E_m)\; \rho_{n\ell j}(P_m)$$

WHERE $\rho_{n\ell j}(pm) = \left| \int \Phi_{n\ell j}(r)\, e^{iP_m r}\, dr \right|^2$

CORRECTIONS

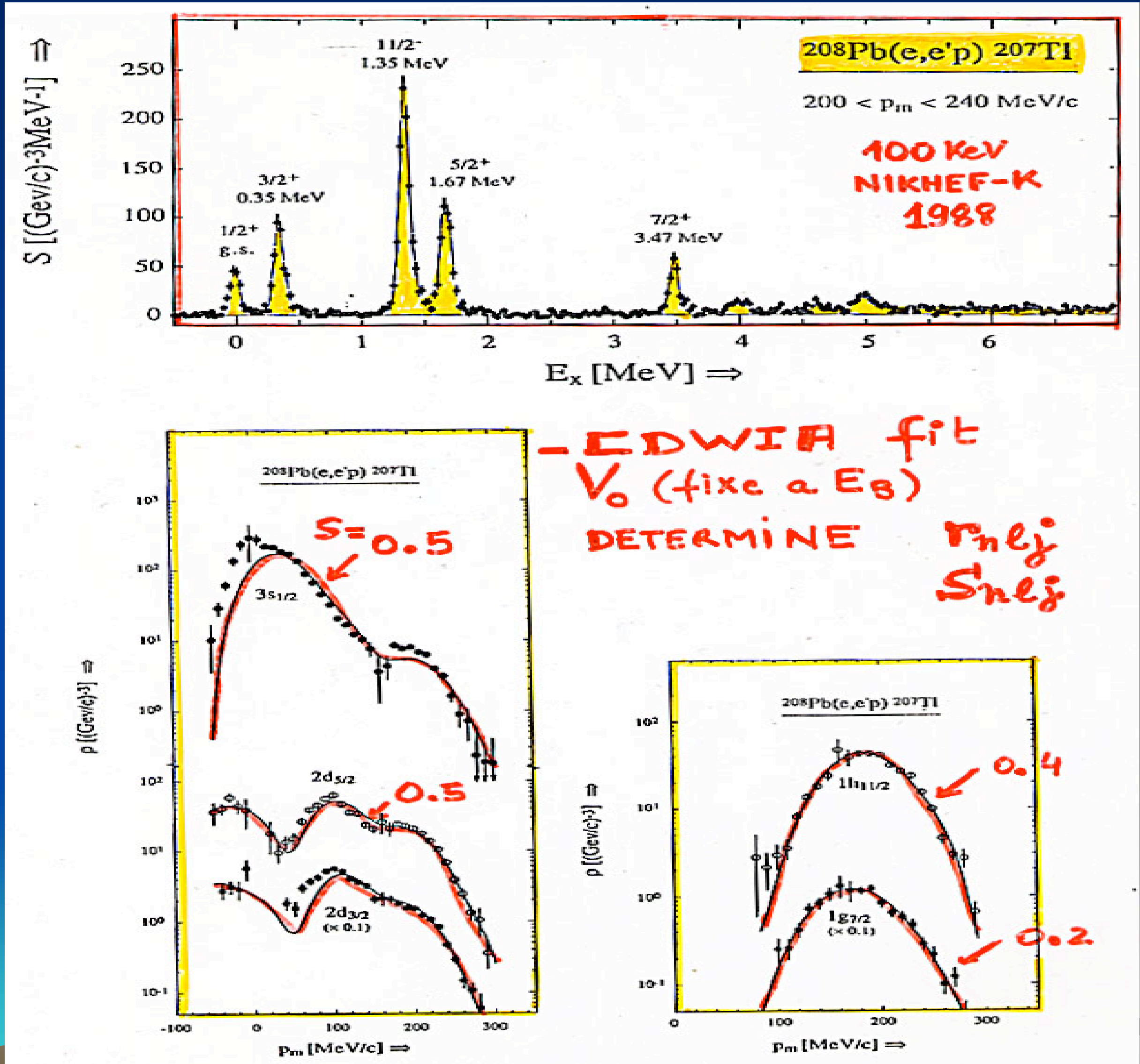
FSI $(p,B) \rightarrow W \rightarrow \rho^D_{n\ell j}(e_m)$ DWIA

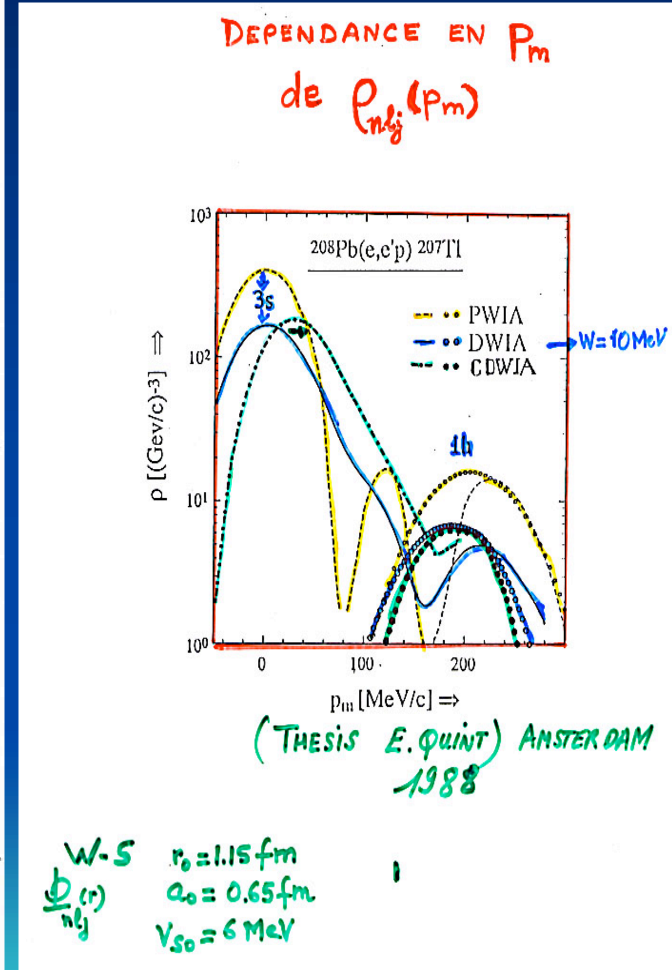
COULOMB DISTORSIONS → CDWIA

$$\left(\frac{d\sigma}{d\Omega}\right)_{EXP} = K\,\sigma^{*}_{ep}\; S^D(E_m, P_m) \qquad (\vec{q} \parallel \vec{p})$$

$\Phi_{n\ell j}(r)$ from W-S POTENTIAL (E_B, r, a)

(e,e',p) State of the art





Advantages and limitations
(e,e'p) versus Transfer

STRENGTH DISTRIBUTIONS
"ABSOLUTE VALUES" OF SPEC. FACTORS

e,e'p	TRANSFER

A) REACTION MECHANISM

e,e'p	TRANSFER
• FSI → DWIA → W_{OPT}	• DWBA → OPT POT W_{IN}, W_{OUT}
COULOMB DIS → CDWIA	
CHARGE EXCHANGE CORR (WEAK) (TWO STEP)	TWO-STEP AT "30-200 MEV)n (WEAK)
• e - p COUPLING IN MEDIUM	• EXACT FINITE RANGE CALCULATION
	$V_{EJECT-NUCLEON}$ (L.E. PHASE SHIFTS)

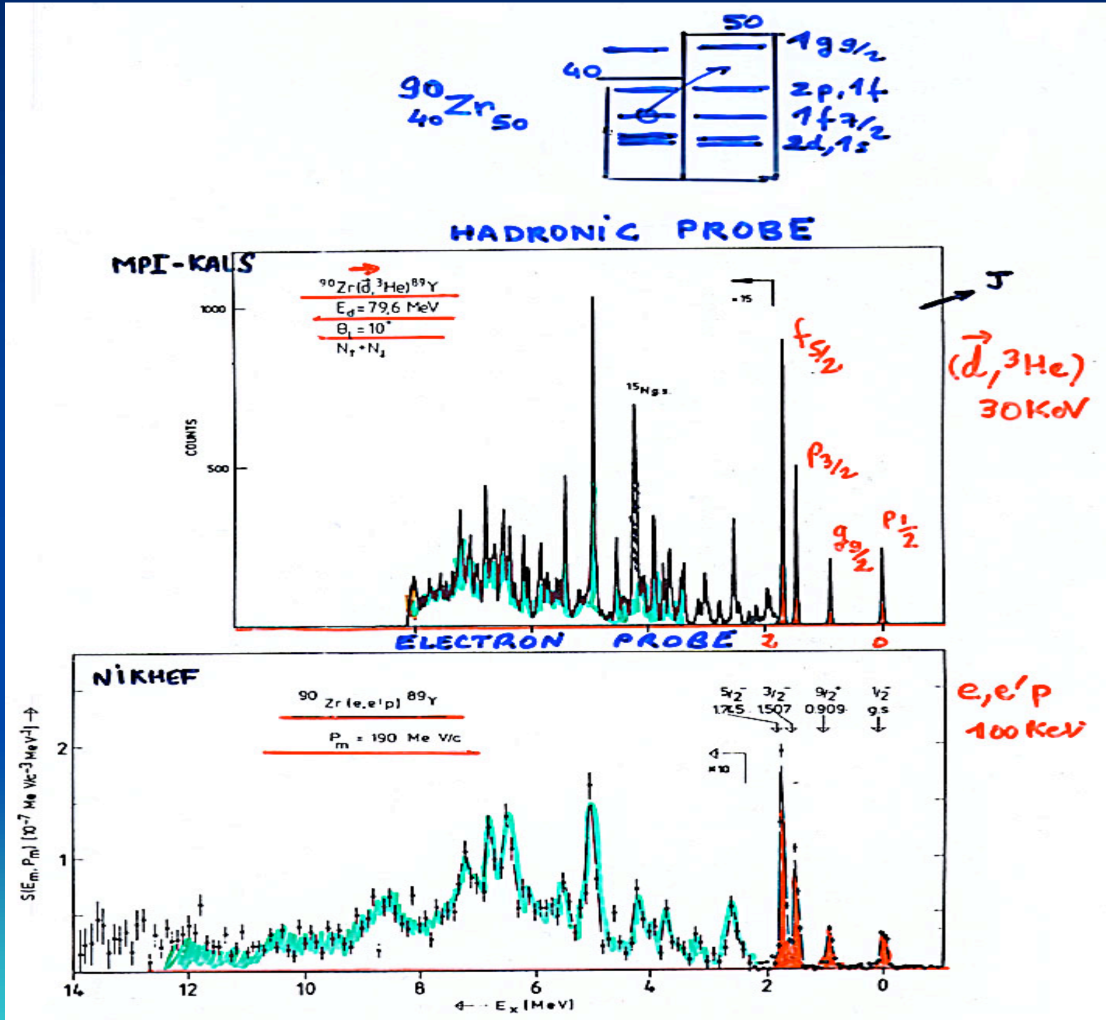
B) NUCLEON FORM FACTOR

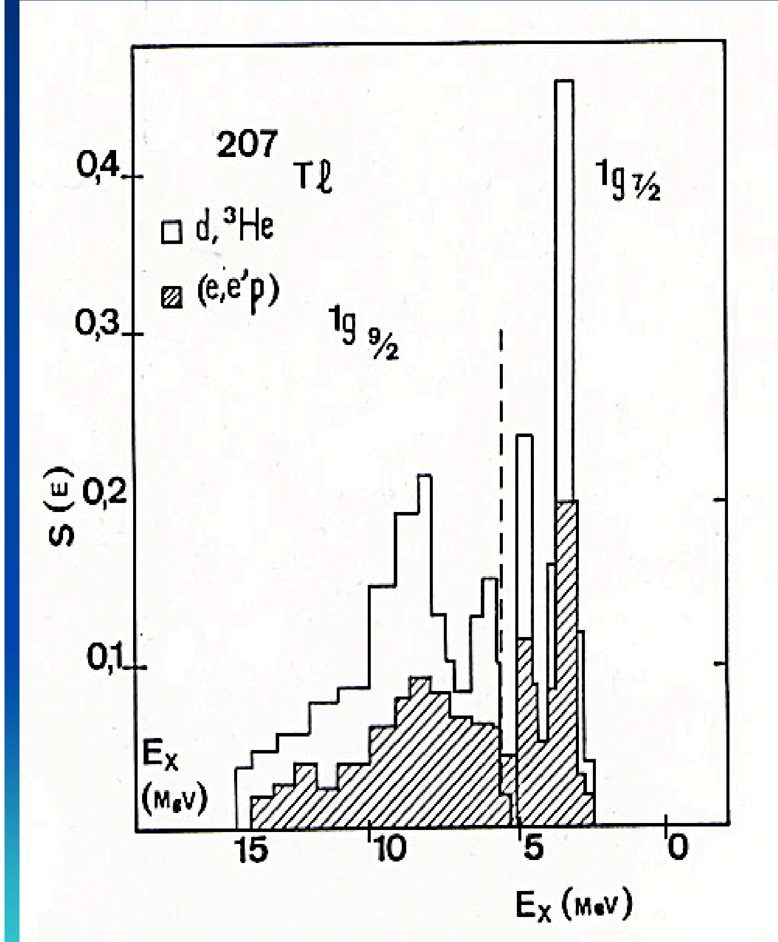
e,e'p	TRANSFER
E_B FROM EXP	E_B FROM EXP
$\langle r^2\rangle^{1/2}$ FROM ρ (P_m)	STRONG $\langle r^2\rangle^{1/2}$ DEPENDENCE OF σ_{DW}
$\langle r^2\rangle^{1/2}$ FROM (E,E'P) DIFF.	* $\frac{\Delta r}{r} \simeq 1\ \%$ $\frac{\Delta S}{S} \simeq 5\ \%$
≠ $\langle r^2\rangle^{1/2}$ FROM MAGN. SCATT.	USE $\langle r^2\rangle^{1/2}$ FROM (e,e'p)

C) ANALYSIS

e,e'p	TRANSFER
• L DEDUCED FOR ISOLATED PEAKS	SAME
• MULTI L ANALYSIS FOR BROAD STRUCTURES	SAME
• NOT J	• J → POLARIZED BEAMS
	* INCERTAINTIES IN THE SUBTRACTION OF THE CONTINUUM.

Comparison of Hadronic and electromagnetic processes





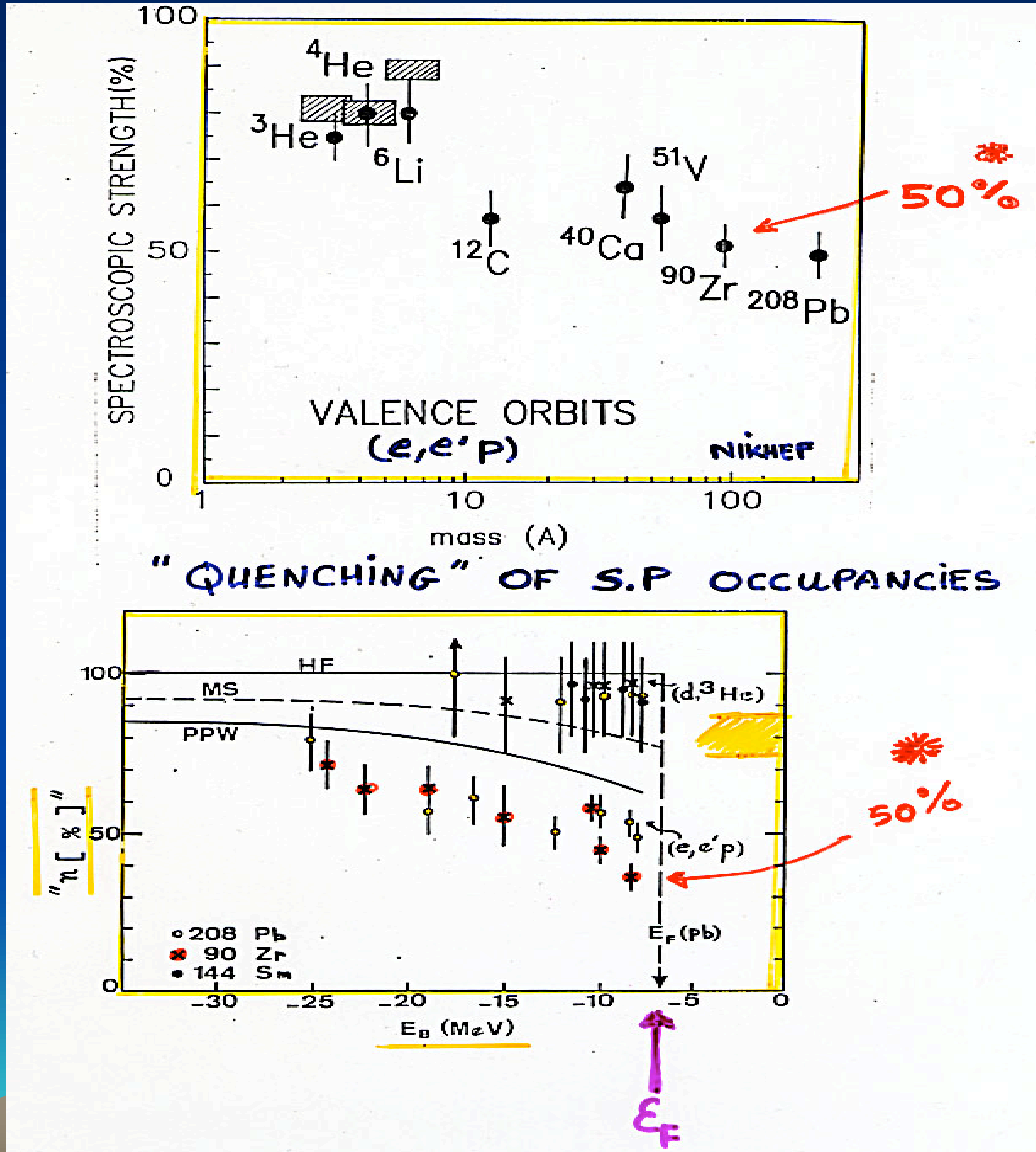
Quenching of S-P strengths

Summary 1

A) For bound states close the Fermi sea e,e'p observed a severe quenching (50+/-10%) not observed in transfer reactions (90+-15%)

B) One can reconcile partly e,e'p and transfer reactions values using the radius determined in knock out experiments
, $^{12}C, ^{16}O, ^{40}Ca, ^{90}Zr, ^{208}Pb$ (70+/-15%)

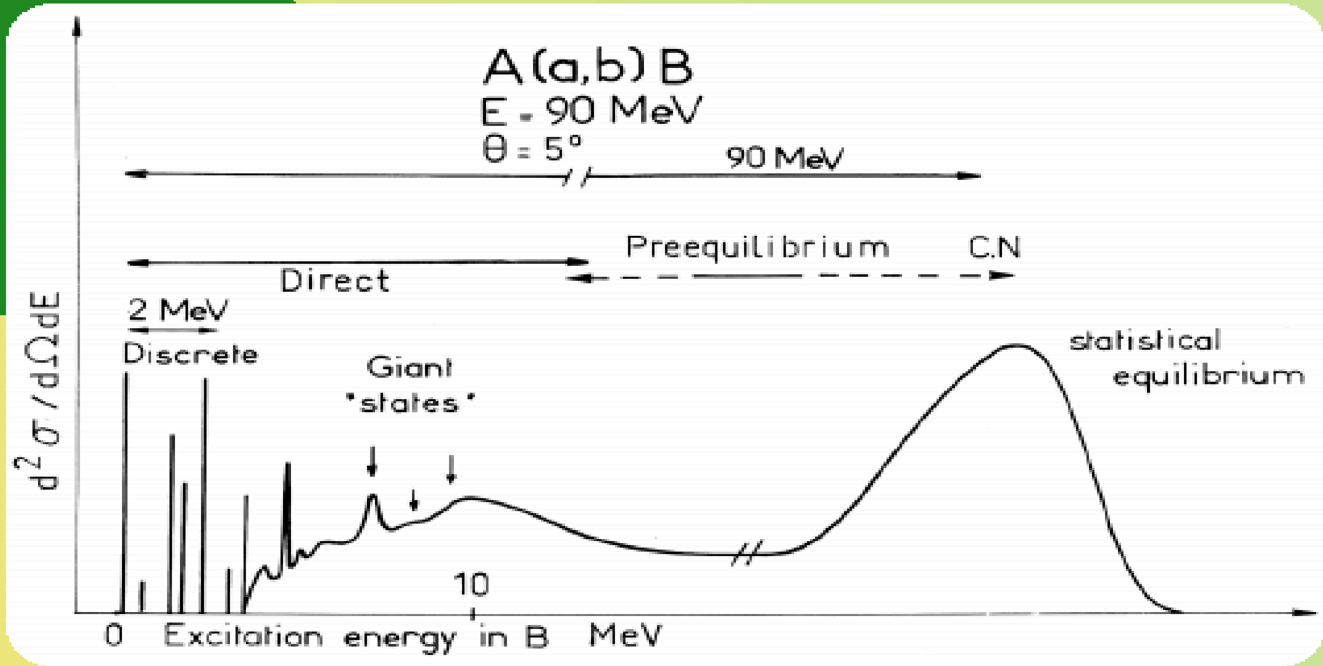
Two questions remains :
How realistic is the use of this radius ? (p_m shift in ang. dist)
Is there hidden inconsistencies in the analysis of e,e'p
Renormalization of quasi-elastic
Coulomb coupling σ_{ep}*
If σ_{ep} up by 10%
n increases from 50 to 70%



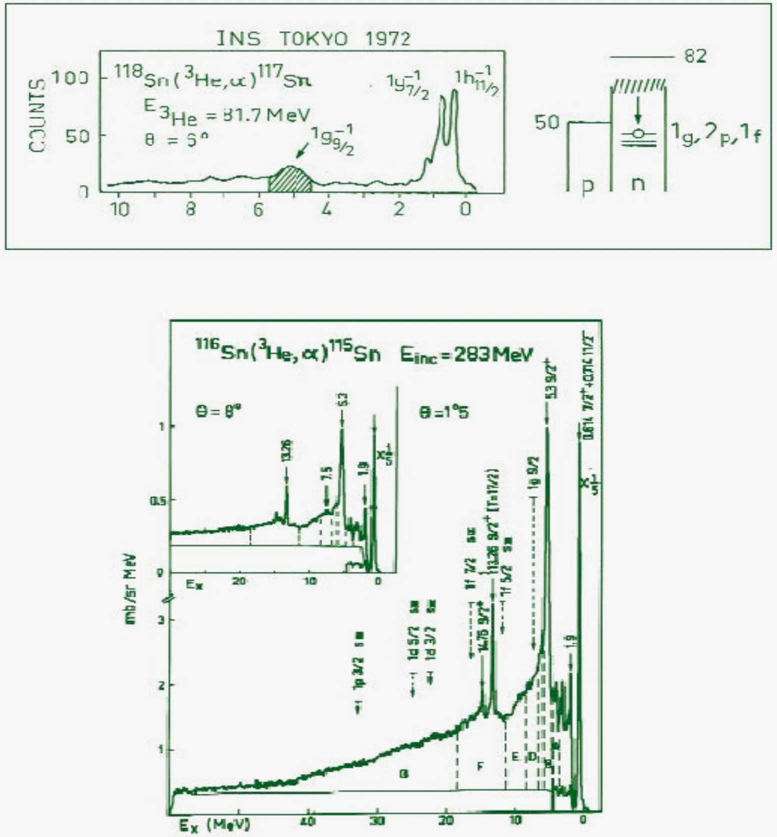
Persistence of s-p motion at high excitation energy ?

Transfer to the continuum

Inclusive single -particle spectra
Strength functions for resonance in the continuum
Exclusive experiments and decay properties.



First evidence of deeply-bound hole states in heavy nuclei



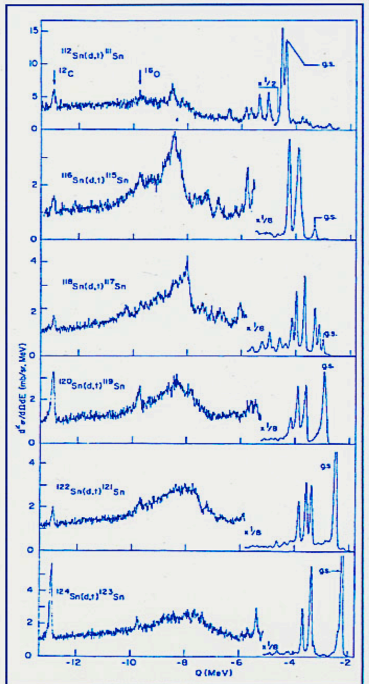
Physical Review Leterrs 712-715 (1974)

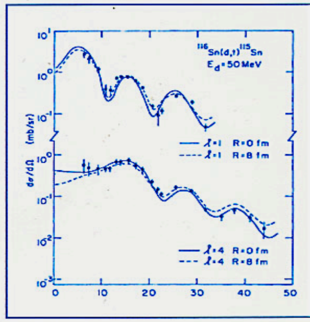
DEEPLY BOUND HOLE STATES AS A GIANT-RESONANCE-LIKE PHENOMENON

S. Y. VAN DER WERF, B. R. KOOISTRA, W. H. A. HESSELINK, F. IACHELLO+, L. W. PUT, and R. H. SIEMSSEN

Kernfysisch Versneller Instituut, Groningen, The Netherlands

Received 10 June 1974





Selectivity for large L transfer (5-8)

TRANSFER CHANNELS

HIGH-LYING S-P NEUTRON STATES

outer subshells

$1j_{13/2}$

$1k_{17/2}$

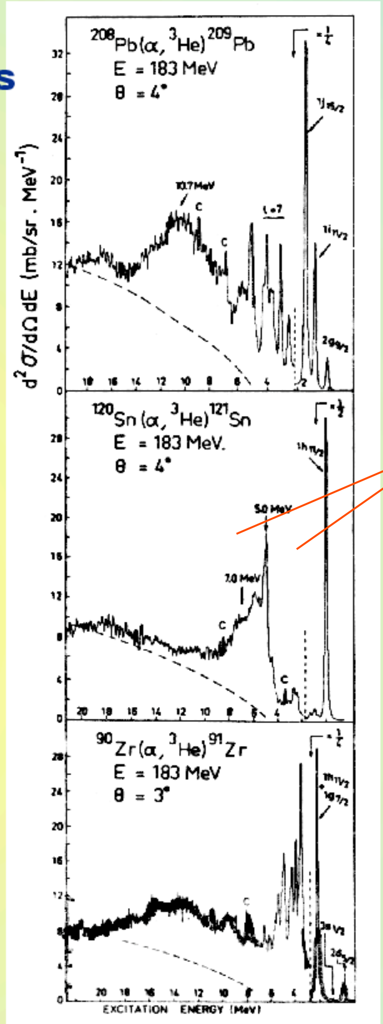
$1l_{19/2}$

$1i_{13/2}$

$1h_{9/2}$

$1i_{13/2}$

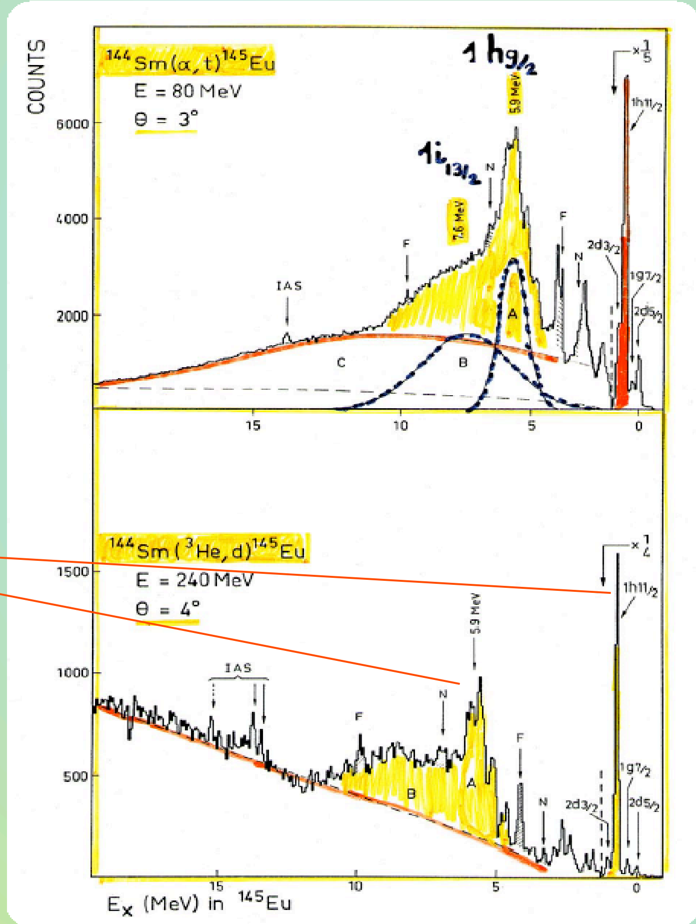
$1h_{9/2}$



(α, ^{3}He) at 183 MeV ORSAYK220 SC (1984)

Direct observation of Spin-orbit partners

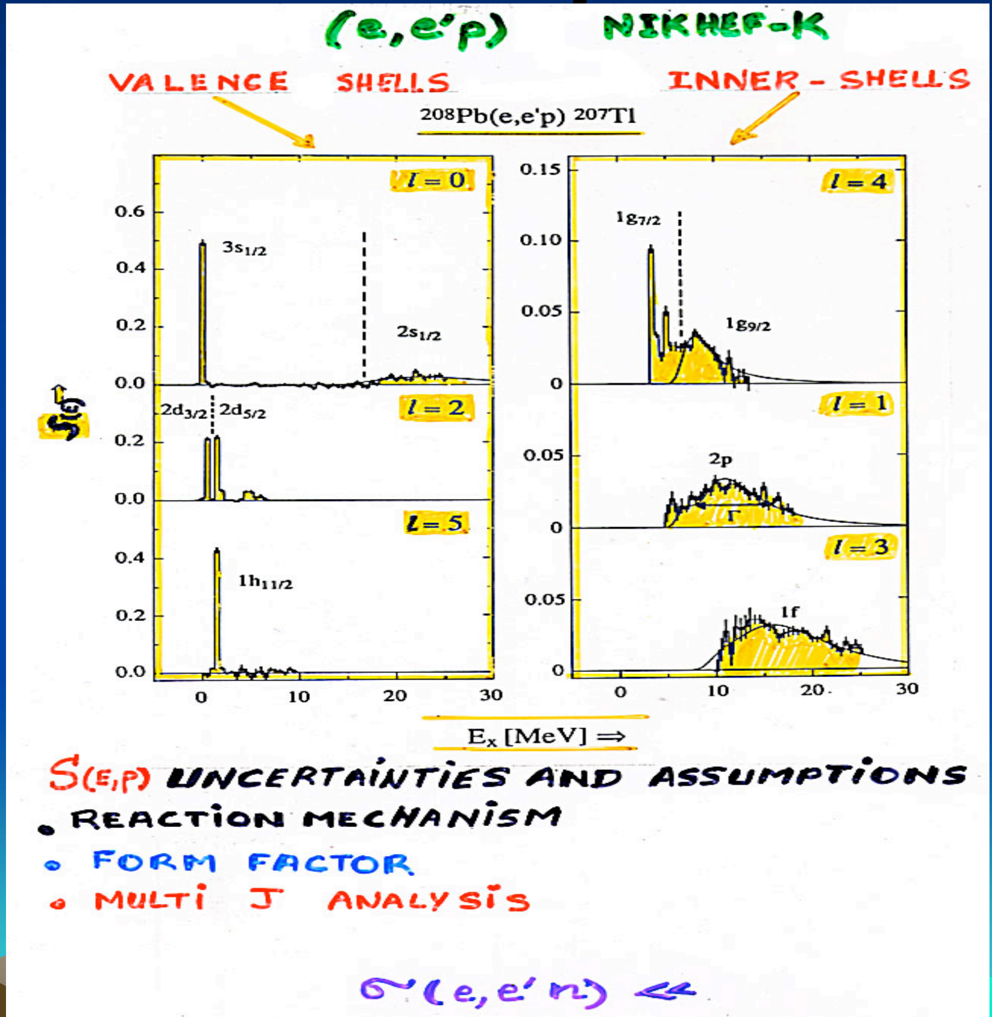
EXPERIMENTAL EVIDENCE OF S-P PROTON RESONANCES



The shape of fhe continuum is strongly dependant on the projectile

Break-up phase space (α, tp) or (^{3}He, dp)

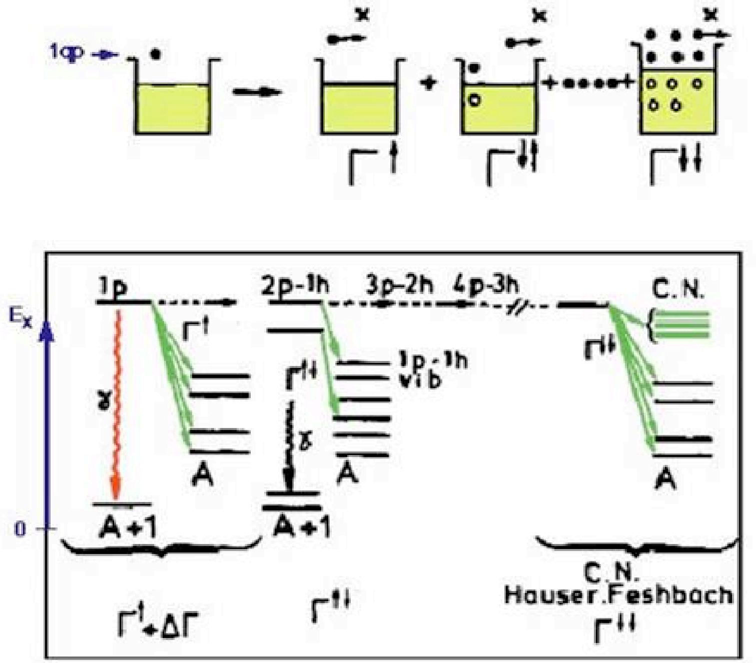
Fragmentation and damping of S-P strengths for valence and deeply-bound states in e,e'p



Damping Mechanism

$\Gamma^{\downarrow} = 2\pi \langle V \rangle^2 \rho = 2\langle W \rangle$

DAMPING OF S - P MODE



Transfer to Unbound states

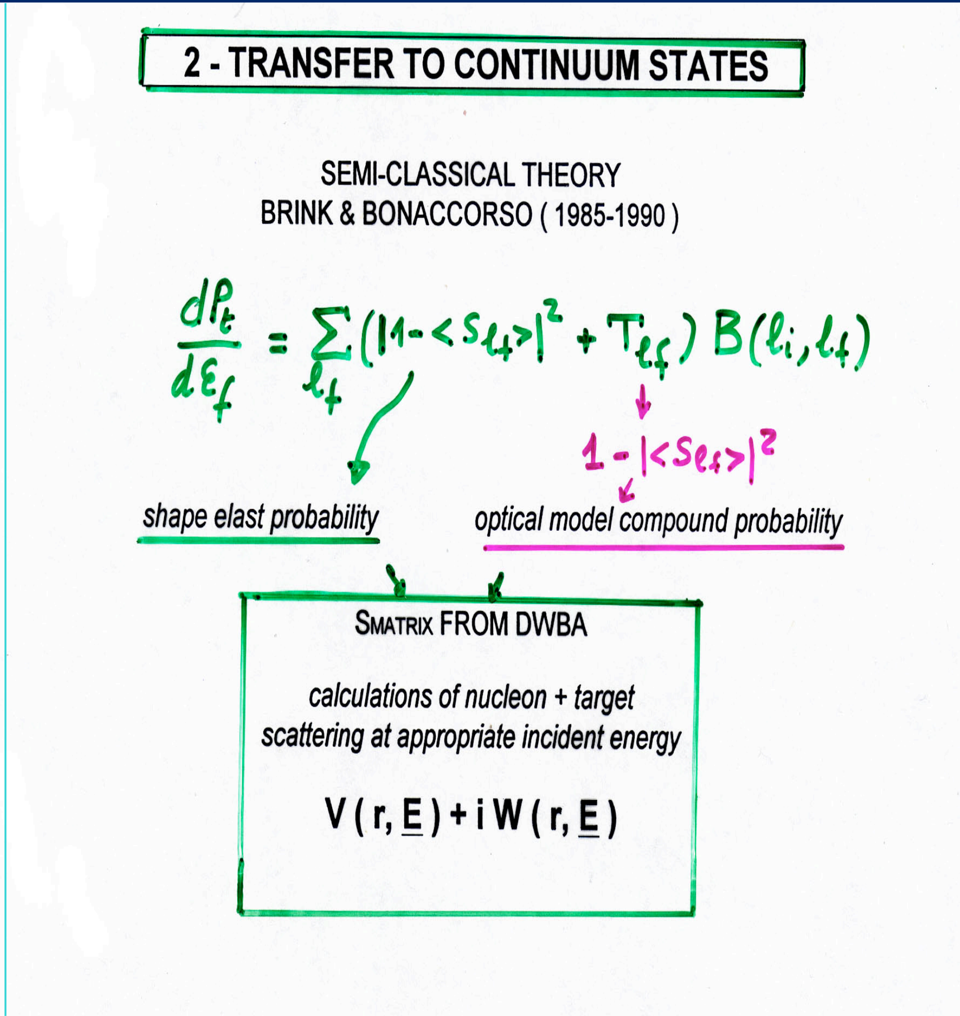
Standard DWBA

- Unbound state Form Factor
- Gamov function pole of the Green s-p wave function

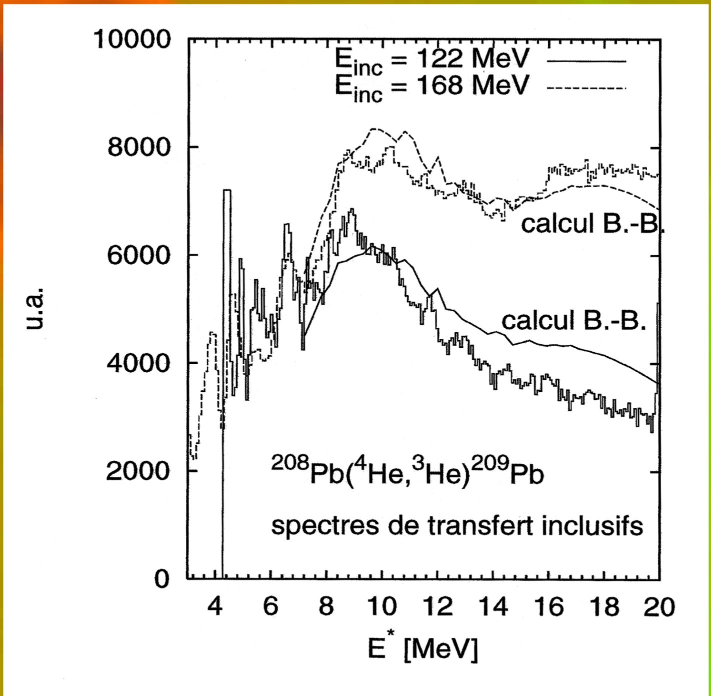
- $g^{R}_{lj}(r,k_r) = (\mu\Gamma^{lj} /h2kr)\ e^{i\xi_{lj}}\ O_{lj}$

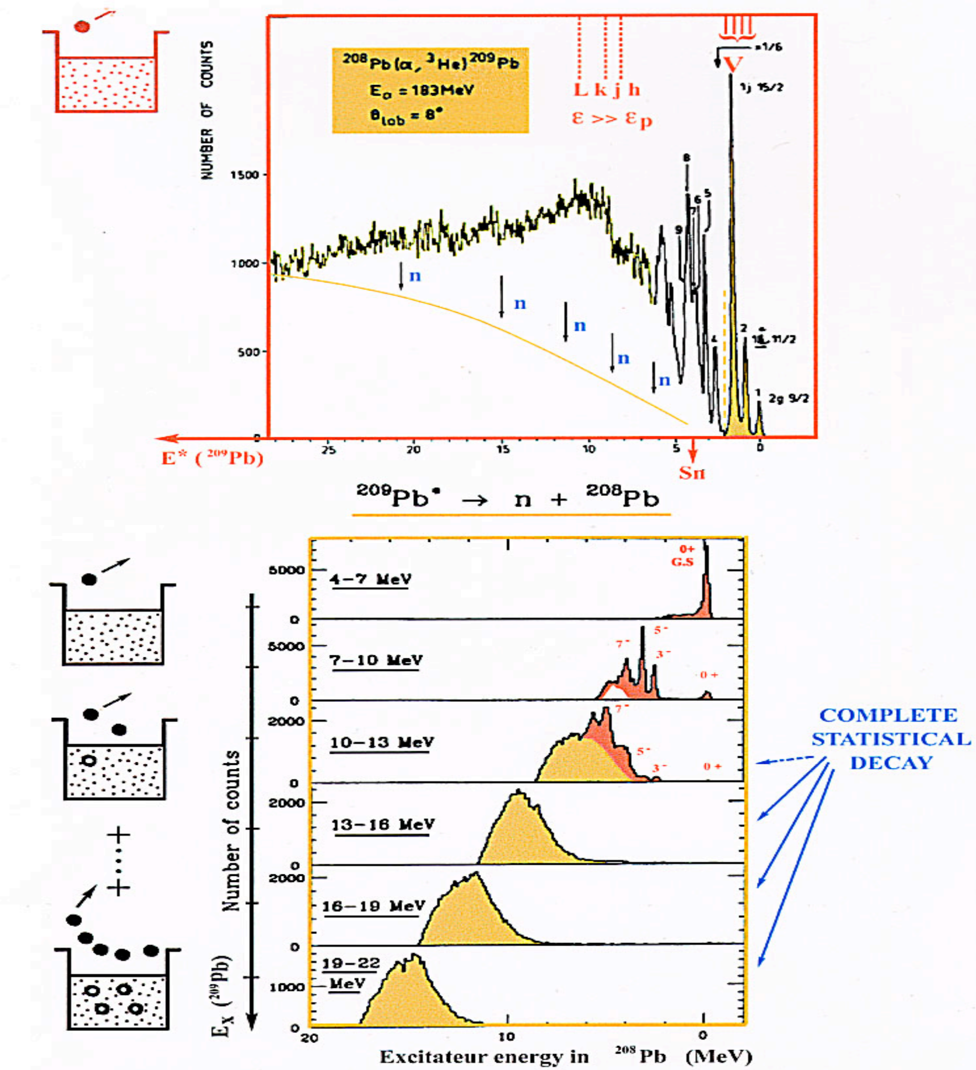
Solution of Schrodinger equation for the complex energy

$$E_{Res=}\ E_R - i\ \Gamma/2$$



Experimental observation of the damping steps (1p-1h) to (np-nh)





Nuclear Models: Damping Mechanisms Mass ,Energy Dependence of S(E),Γ

- A) HF+RPA N. Van Giai et al Pb

  Bertsch, Broglia, Bortignon Sn, Pb self-consistent or effective coupling

  B) Mean field + Dispersion Relation C. Mahaux et al

  ^{40}Ca to ^{208}Pb Empirical –Optical potential W-S .All coupling included

  C) Semi-classical description Brink & Bonnacorso, n-N optical model

  D) Quasiparticle-Phonon Model

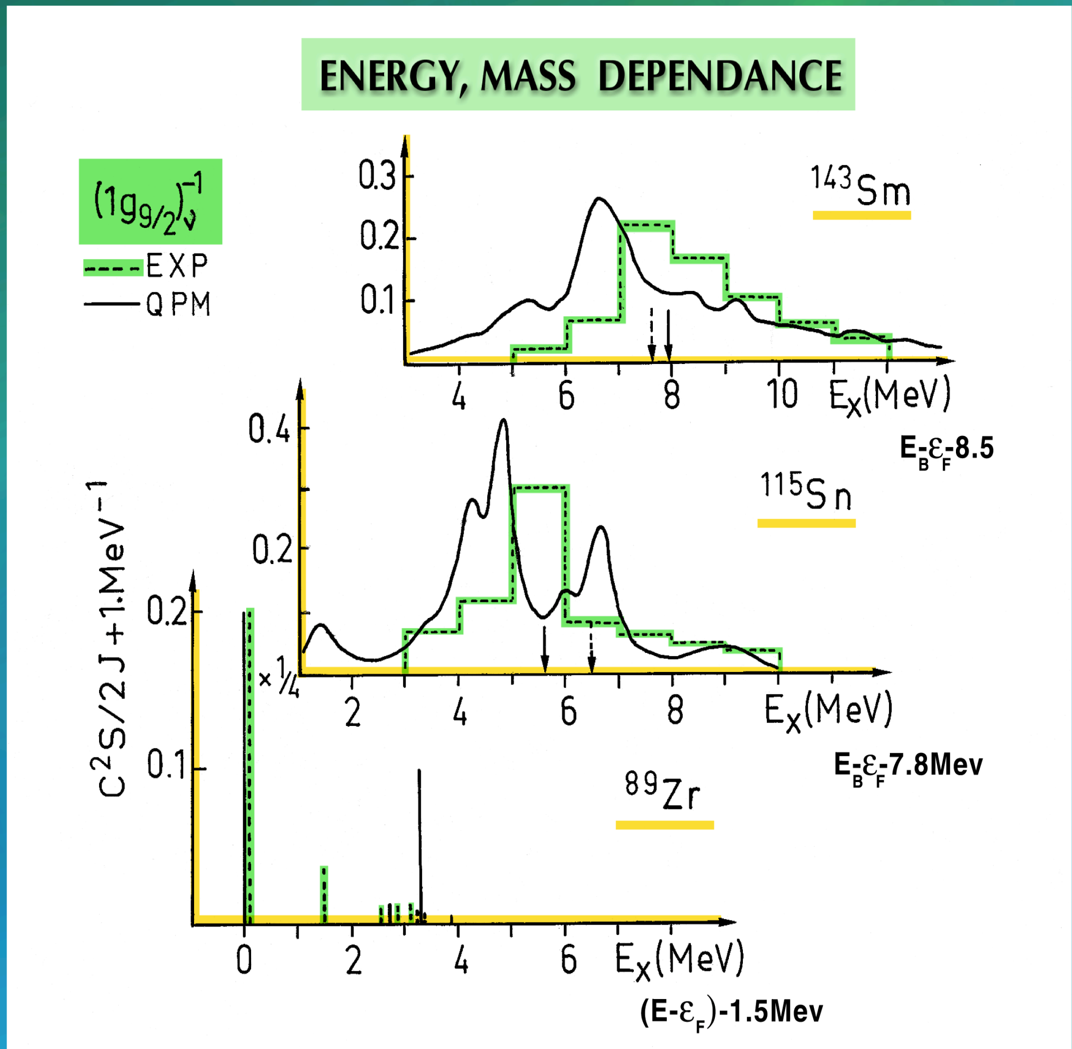
  V.G.Soloviev,Ch.Stoyanov,A.I.Vdovin,V.Voronov et al From Zr to Pb

$H = H_{sp} + H_{pair} + H_{multipole} + H_{spin\text{-}multipole}$

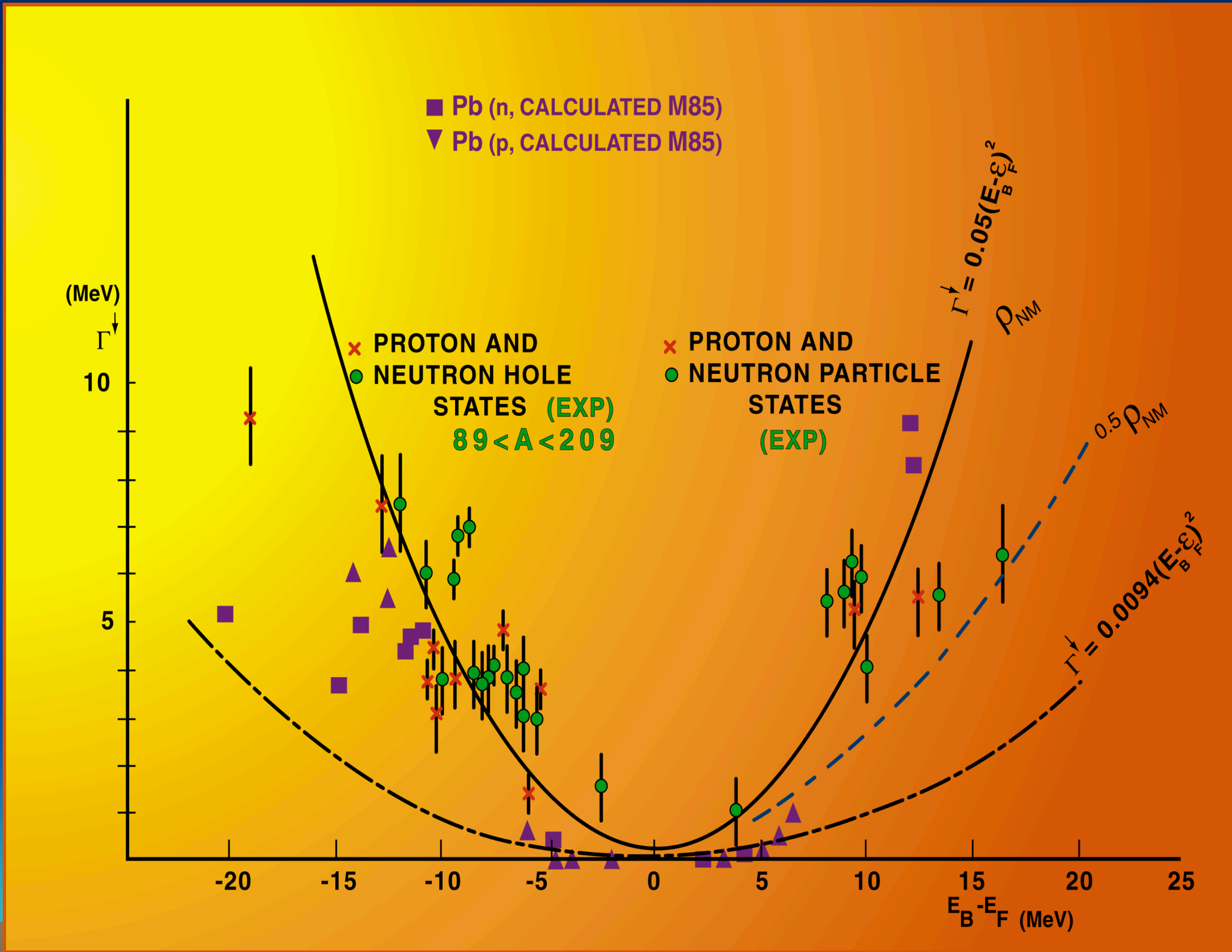
WS	**Monopole**	**Multipole**	**spin-multipole**
	part-part	**part-hole**	**part-hole**

Large basis s-p ,phonons (up to 25 MeV,l>5)

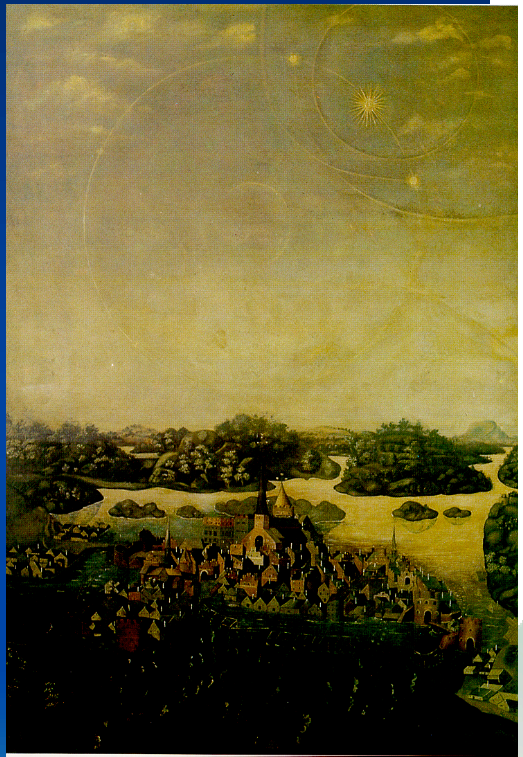
S-P response function: Exp versus QPM



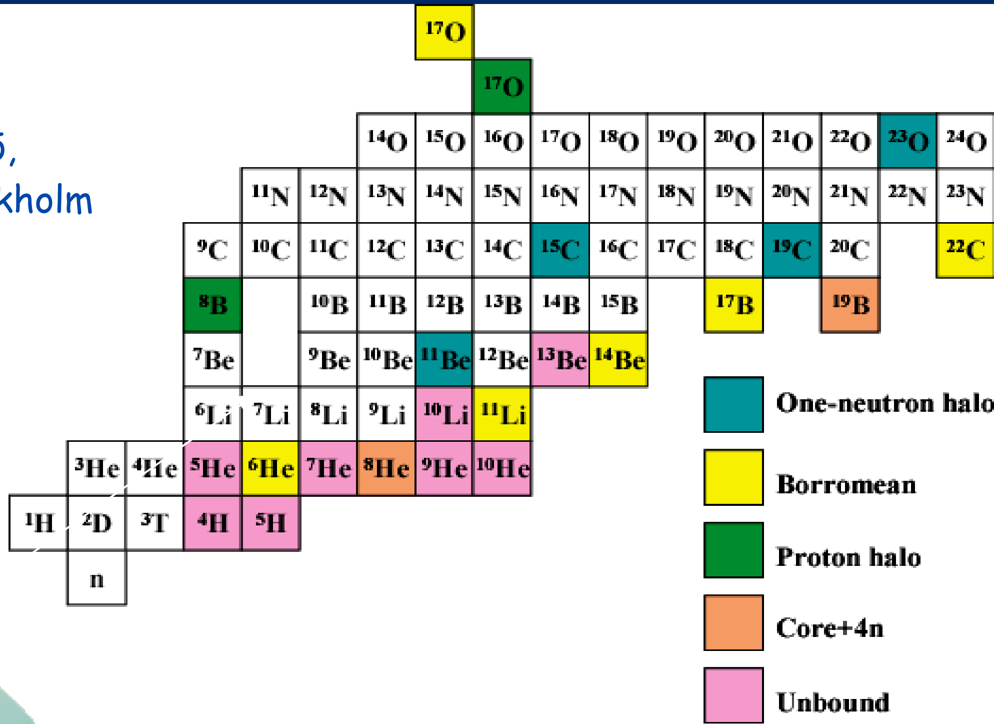
Energy dependence of the damping width for s-p response function

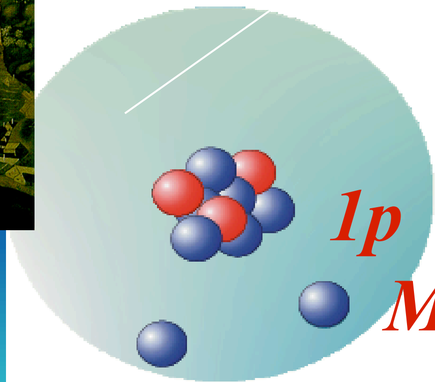


Single-particle motion far of stability



John Elbfas, 1535,
Storkyrkan, Stockholm





1p splitting , ^{8}He,$^{12\text{-}14}$Be,^{20}C,^{22}O
Mainly Pol (p,d) and (d,p)

Structure of ^{11}Be g.s. through (p,d) reaction

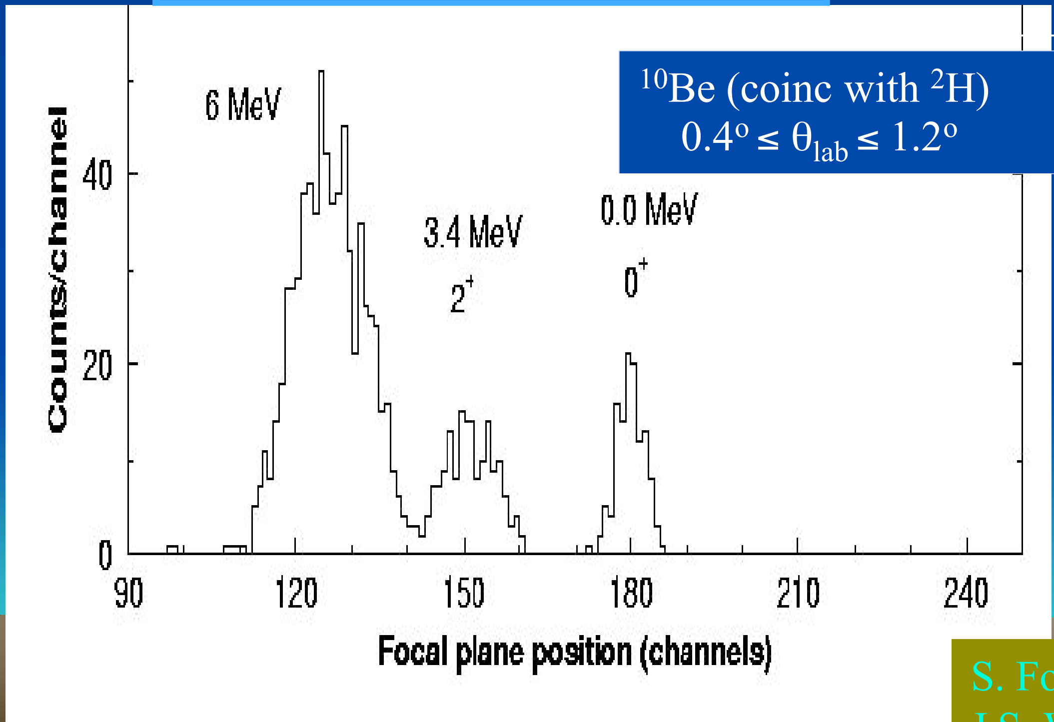
H(^{11}Be,^{10}Be)^{2}H

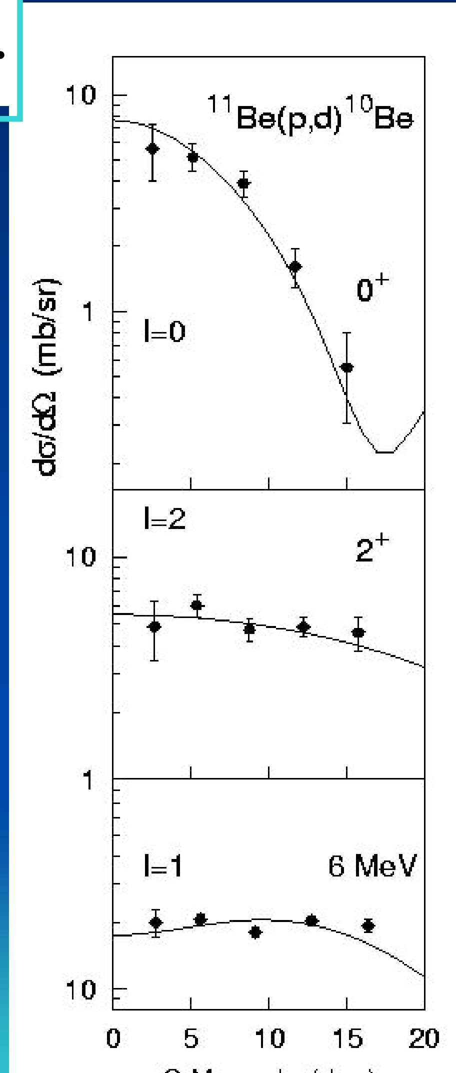
E = 35 A.MeV

$$|{}^{11}_{4}Be_{g.s.}\rangle = S^{1/2}(0^+)\,|{}^{10}Be_{0^+}\otimes 2s\rangle + S^{1/2}(2^+)\,|{}^{10}Be_{2^+}\otimes 1d\rangle + \ldots..$$

$$(d\sigma/d\Omega)_{exp} = S(d\sigma/d\Omega)_{calc}$$

$$\frac{S(2+)}{S(2+) + S(0+)} = 0.2$$

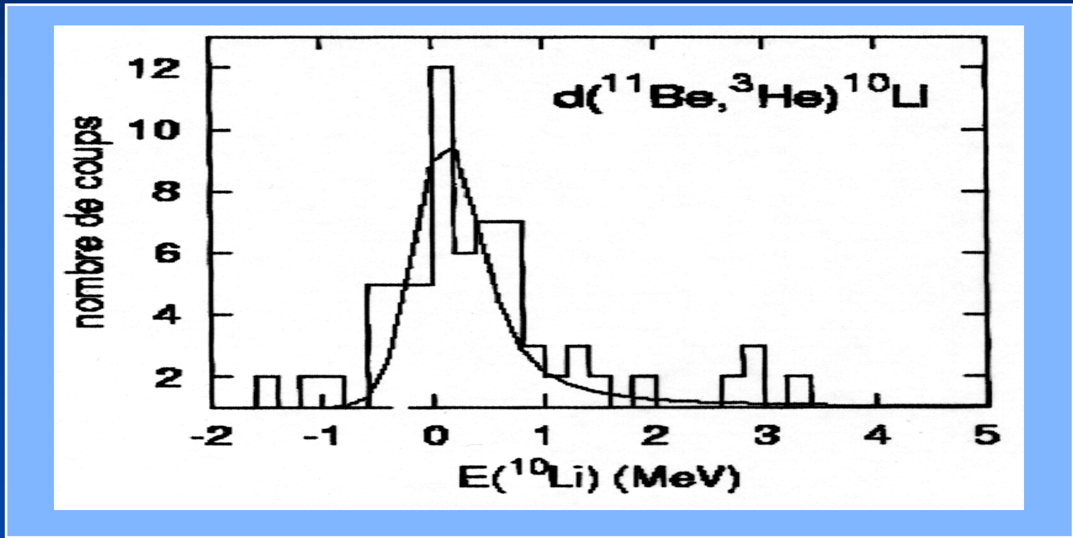


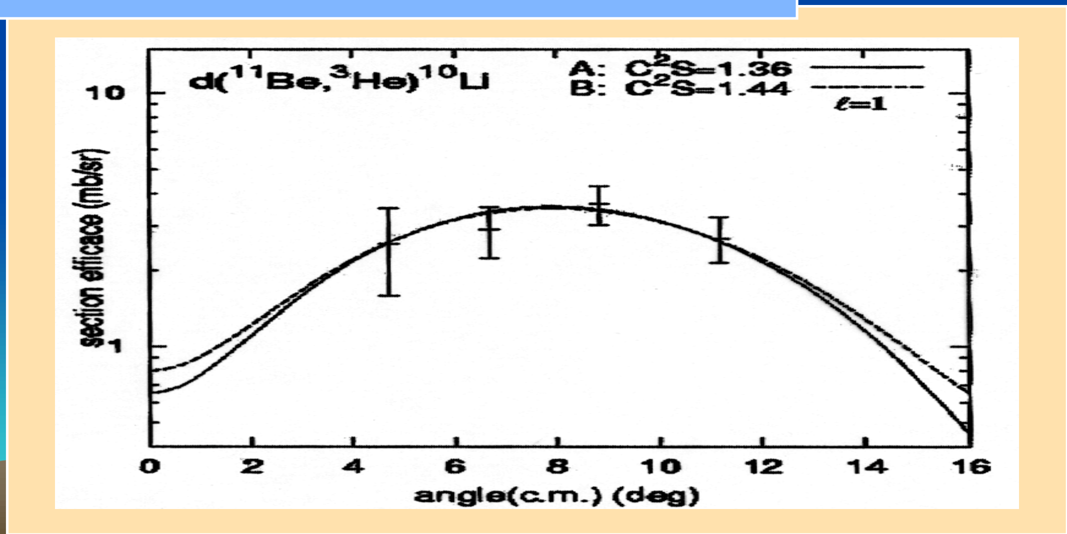


S. Fortier et al. PLB 461 (1999) 22
J.S. Winfield et al. NPA 683 (2001) 48

Structure of ^{10}Li G. S via transfer reactions

10^5 ^{11}Be /s





S.Pita
PhD thesis
Orsay,2000

Structural changes with neutron excess

Diffuse Nuclear Surface
Leads to vanishing
Spin-orbit splitting

New « magic numbers »
Test cases
N=20, 1d splitting
^{28,30}Ne,^{32}Mg,^{34}Si
Z=20 N=28-40
^{46}Ar
Z=28 N=28-40,1f
^{56}Ni,^{68}Ni

N=50-82 1g 2d

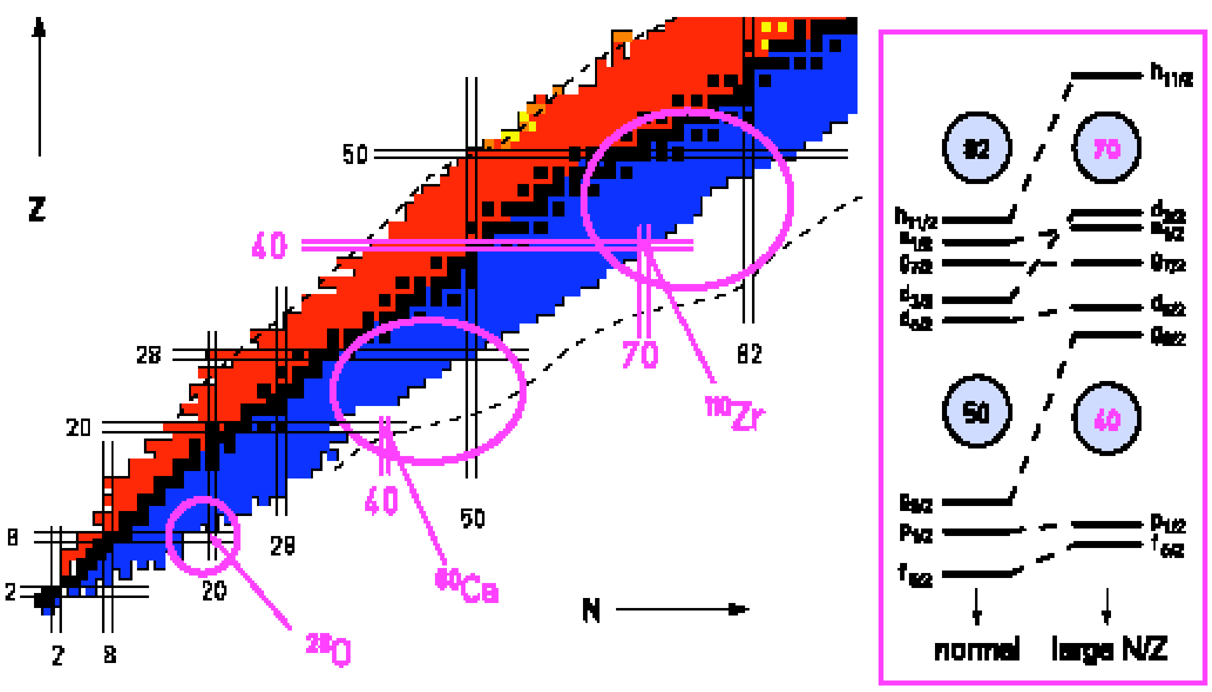


Fig. 16: Nuclear chart in the light- and medium-mass region. The circles indicate areas with possibly new magic numbers. The right-hand side shows the single-particle energies for nuclei close to stability and for nuclei with a large N/Z ratio.

Absolute Spectroscopic factors from Nuclear knock-out reactions Brown,Hansen,Sherill,Tostevin

- One nucleon removal partial cross-sections to final identified (nlj) bound states have been measured for about 25 nuclei in sd shell and on ^{12}C and ^{16}O
- Theoretical s-p removal cross-sections σ_{th}**(nlj)** has been calculated using shell model predictions for the s-f and eikonal reaction theory

- $\sigma_{th}(nlj) = \Sigma_j S_{nlj}\, \sigma_{sp}(B_n, lj)$ $R = \sigma_{exp}/\sigma_{th}$

∀ **$\sigma_{sp}(B_n, lj)$ calculated from a define set of parameters**

S-Matrix from free nn np cross-sections, δ interaction or Gaussian range functions

n-core w-f calculated with empirical W-S (r,a) standard set

Outcome

R=1 for l=0 and 2 transitions for $^{25-27}Si$, ^{10,11} Be, $^{14-18}C$

R=0.5-0.6 for n and p hole in ^{12}C and ^{16}O g.s .Strong quenching like in e,e' p !!

How we understand that ? How it compares to p,2p knock out ?

**Conclusions

- **Absolute spectroscopic factors for strong s-p bound valence states with are within reach ,combining careful analysis from nucleon transfer and electron knock-out with an accuracy of (10% at best)**

- Highly fragmented sp **strengths, in** particular for unbound resonances embedded in the continuum suffer greatly from the use of inadequate « standard » parameters (E dependence of form factors , continuum) .
- Form factors from HF-RPA or QPM models may improve the accuracy.

However these nuclear models explains and reproduce quite well the main features of s-p response all over the mass range (E_{qp},Γ, S(E). The level of accuracy is poorer (25-50%).

Nuclear Knock-out seems promising, in particular for “exotic” nuclei,careful evaluation of the reaction model parameters and various kinematics ,and target conditions are certainly needed to assess the potential of this approach.

END