“Effective yet elusive : exploring single-particles” – feedback of ESNT workshop

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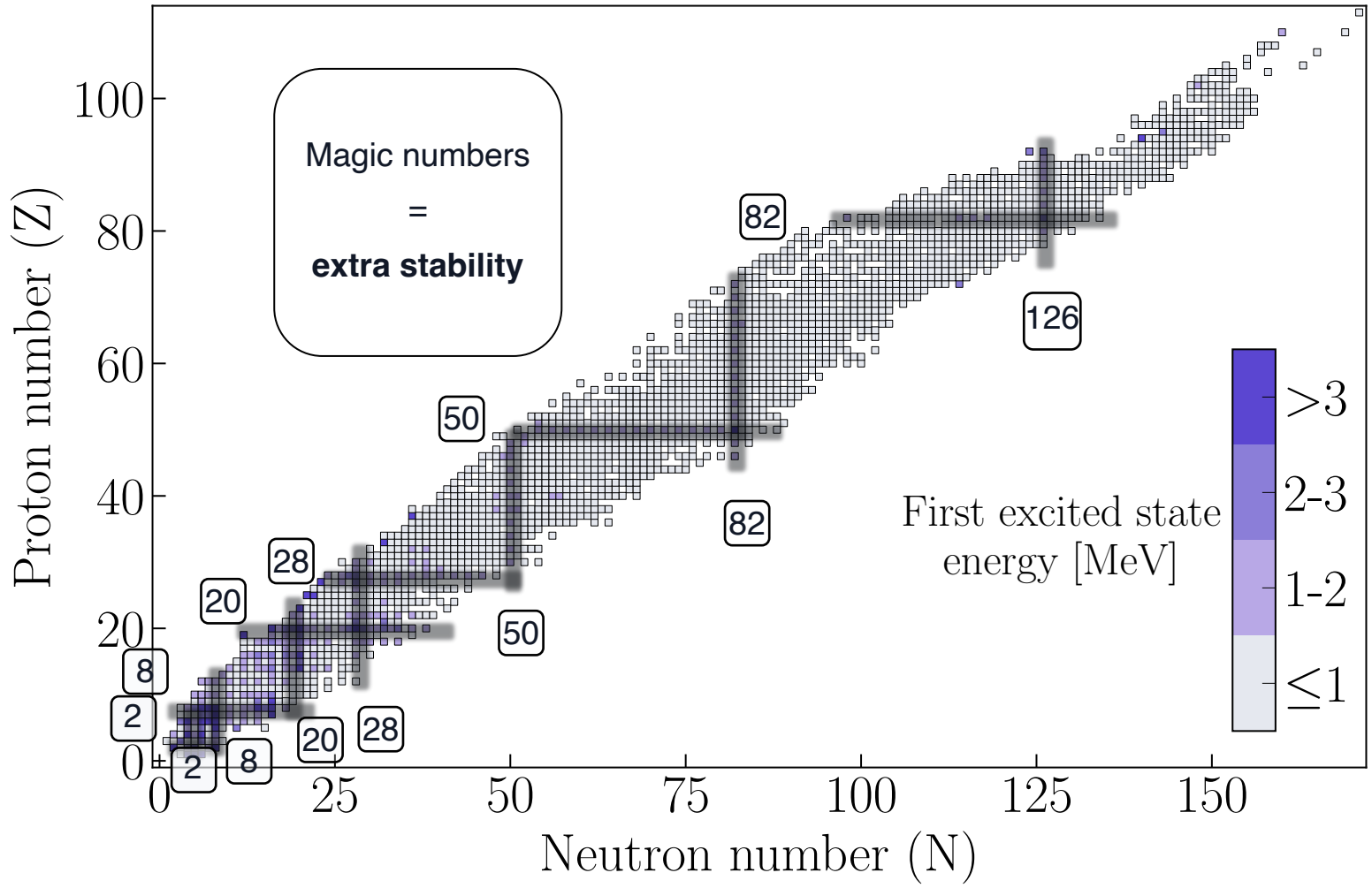
Journée P2I

IJCLab - November 26th, 2025

Outline

1. Scientific context
2. ESNT workshop : highlights
3. Outputs of the workshop

Scientific context



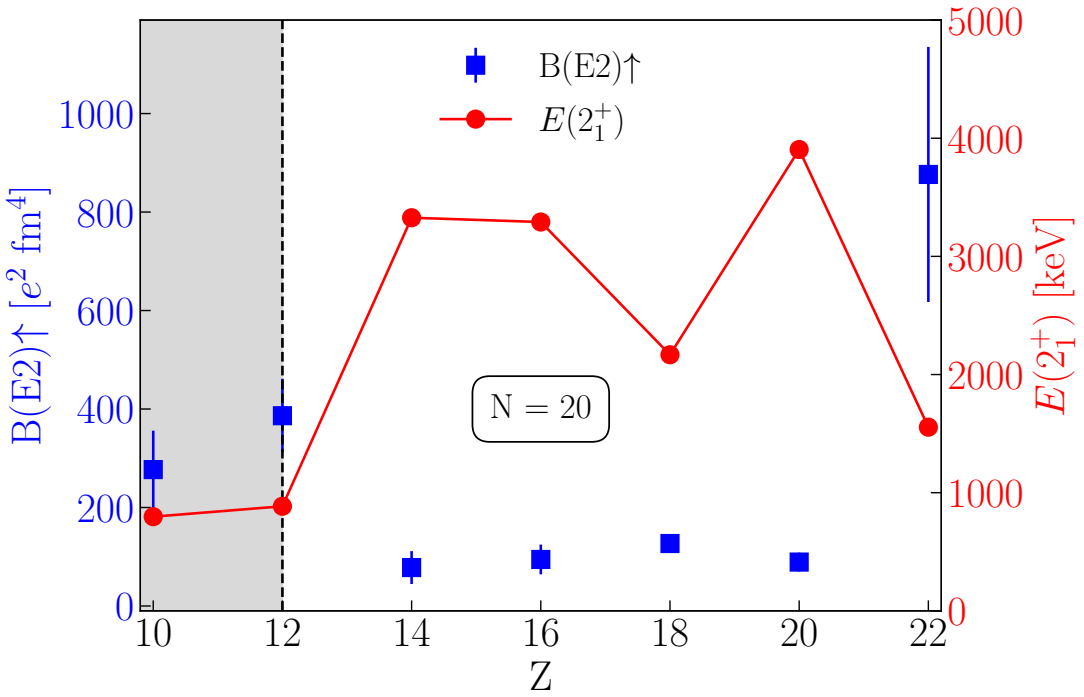
Nudat Database, 2025

Two questions

How do magic numbers emerge ?

How to they evolve as nucleons are added/ removed?

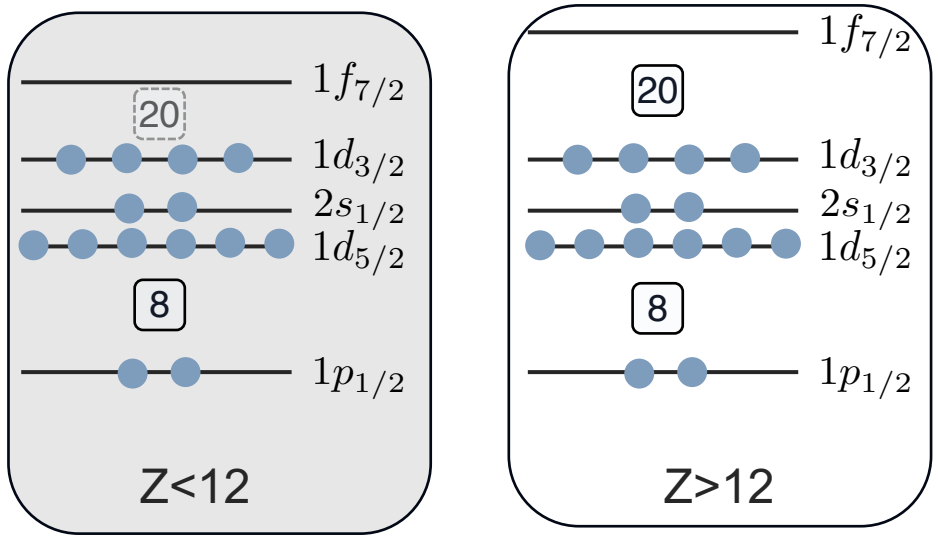
Signatures of « single-particle » behaviours



B(E2) = transition probability from the 1st excited state to the ground state

Large first excited state

Expect a « large single particle gap »



Qualitative pictures

Discovery : as moving away from stable nuclei (extreme N/Z) : may lose their magic nature (~80's)

→Scientific program: study evolution of observables associted to magicity w/ this single-particle picture

Magic numbers : where do we stand ?

2000's

Combined effort in theory [pheno. interacting shell model] and experiments to understand evolution of magic numbers.

Highlight : 2008 review

Progress in Particle and Nuclear Physics 61 (2008) 602–673

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

Nuclear magic numbers: New features far from stability

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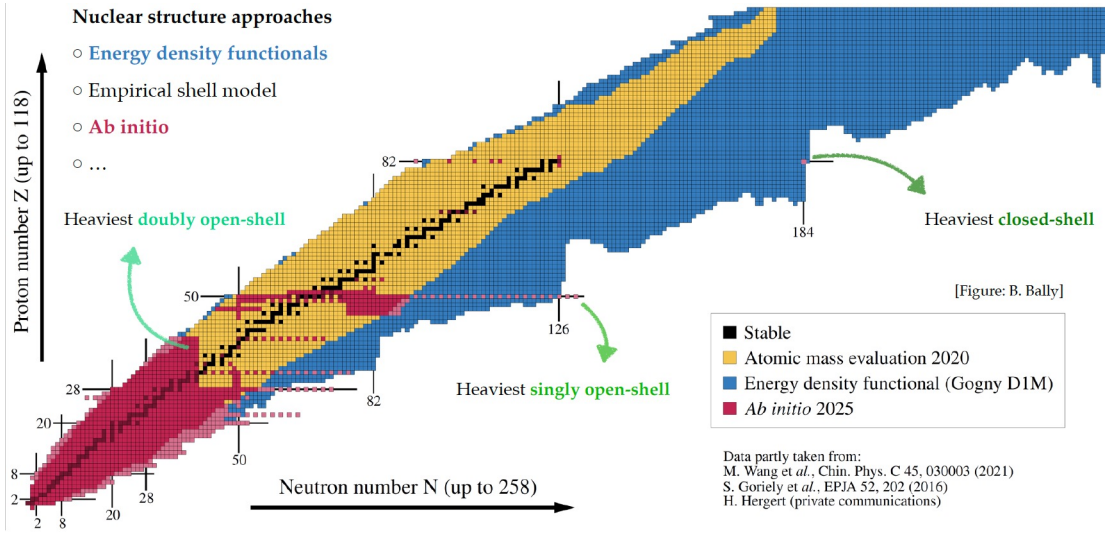
2010's

⇒ Rise of « Ab Initio » methods, based on χ EFT-like potentials

⇒ Made explicit the non-observable nature of « single-particle. By applying a unitary transformation can shift single-particle content without chaning observables.

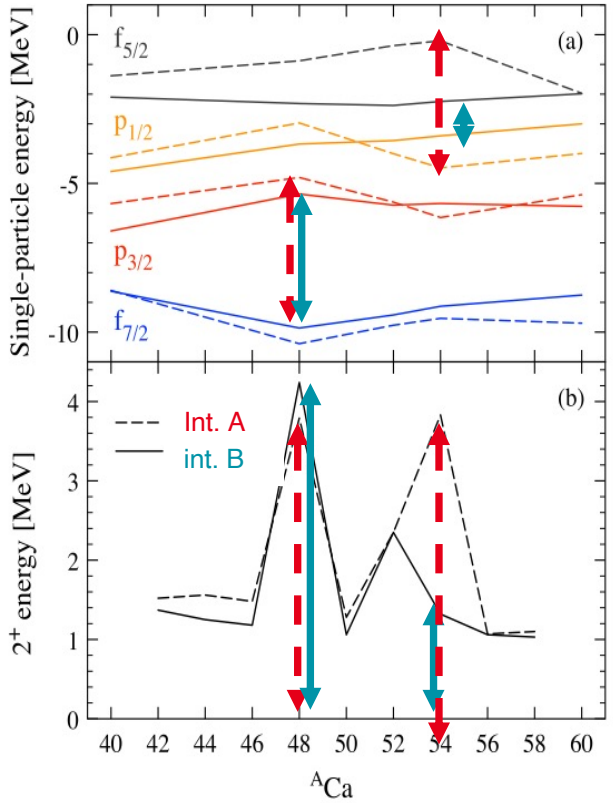
⇒ Tension : useful & intuitive picture, motivated scientific program. But : « contaminated » interpretation of experimental data.

⇒ **What should be done ?**



Non-observable nature of single-particles

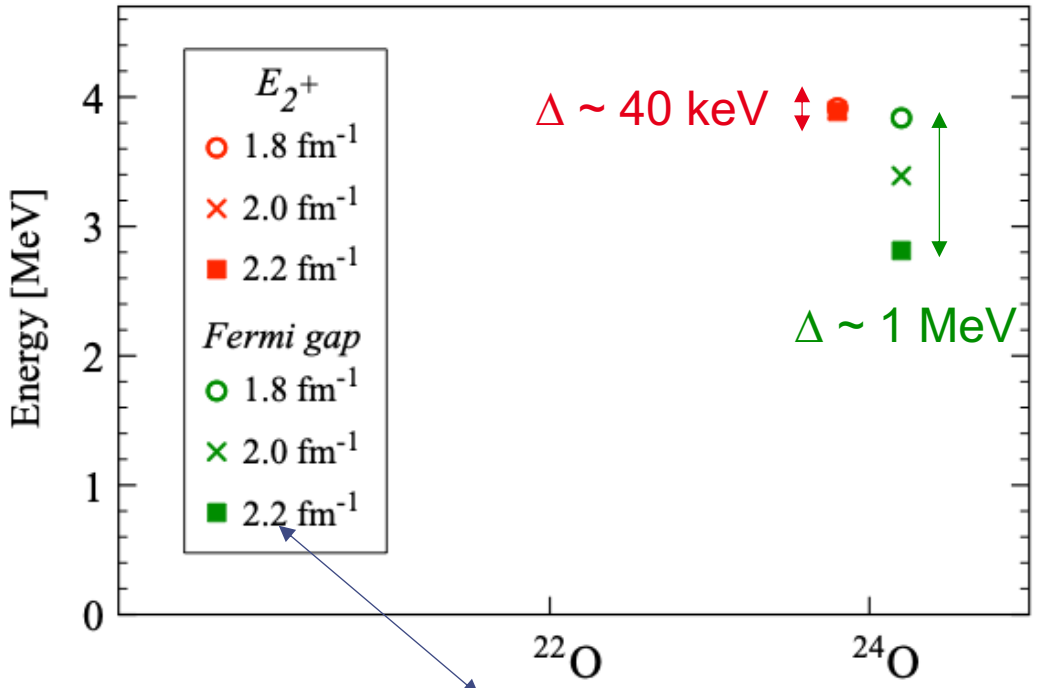
Phenomenological shell model :
few neutrons active in a « valence space »
With a two-body pheno. interaction



Duguet *et al.*, Phys. Rev. C **92** (2015)

Correlation
Fermi gap ↔ 2+ energy

Microscopic shell model :
few neutrons active in a « valence space »
+ interactions derived « consistently » from bare ones



Freedom : SRG scale λ, of a unitary transformation

Unitary transformation
Does not alter observable (up to truncation error)
Shifts single particle content
→**Correlation altered**

ESNT Workshop

« **ESNT** » **: Espace de structure nucléaire théorique,** hosts ~4-5 workshops / year. Supported by CEA

« Effective Yet Elusive : exploring single-particles. »

17th-20th November 2025

Organisers : L. Heitz (IJCLab, CEA), D. Verney (IJCLab), J.-P. Ebran (CEA), E. Khan (IJCLab)

« Effective » : helps in understanding, building intuition & much phenomenological sucess

« Elusive »: no theoretical counterpart, « scheme & scale » dependant

⇒ **Generic question :** How to properly talk about a quantum many-body system ?

⇒ **Goal** : bridge the gap between experimentalists & theoreticians via the concept of single particle widely used to interpret observables.

Schedule

Exp. | Th. structure | Th. reaction

Introductory lectures | **DPhN Seminar**

	Monday	Tuesday	Wednesday	Thursday
09h15	Verney	Gottardo	Bender	Heitz
10h30	Break	Break	Break	Break
10h4	Duguet	Dickhoff	Lalanne	Manea (Seminar @ 11h00)
12h15	Lunch	Lunch	Lunch	Lunch
14h00	Sorlin	Péru	Somà	Round Table III
15h00	Break	Break	Break	Break
15h15	Hebborn	Round Table I	Round Table II	Round Table III

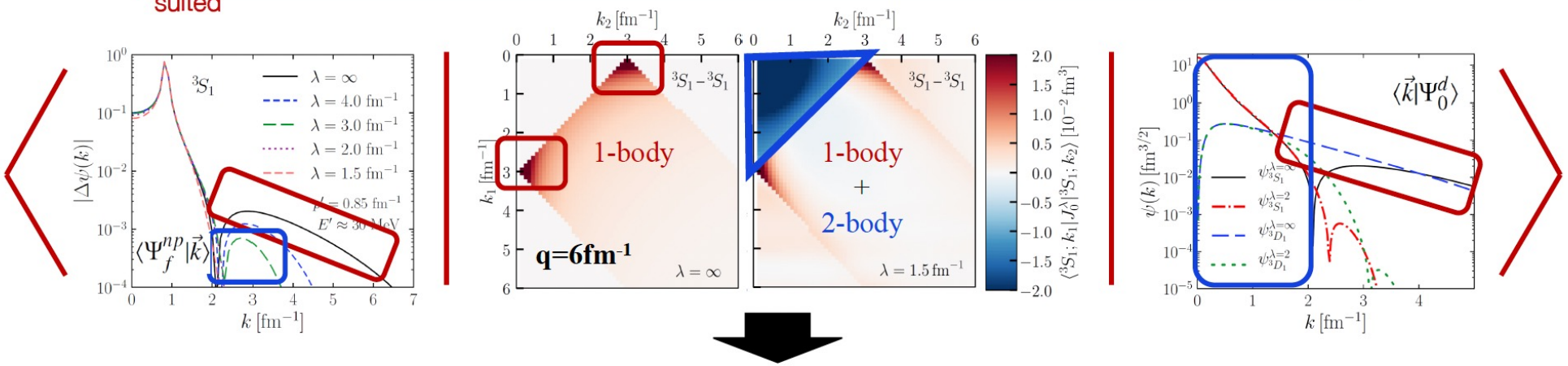
Round tables

I/ What do we mean by a « Single-Particle »?
II/ What cares should be taken when talking about experimental observables ?
III/ How to illustrate model dependance of single-particles ?

Selected highlights : alternative, equally as good explanations

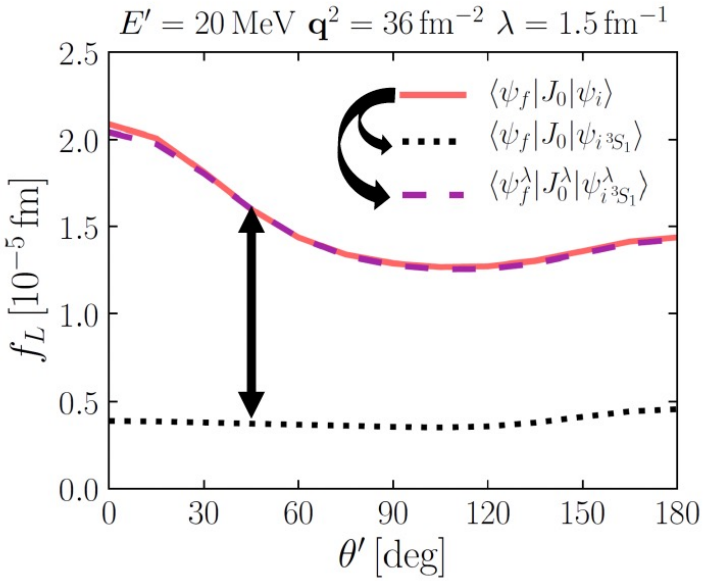
SRC and D-state probability at low momentum $p'=0.67\,fm^{-1}$ and large momentum transfer $q=6\,fm^{-1}$

Kinematics conditions typical of SRC studies ⇔ Common wisdom says low-resolution potentials are ill suited



Interpretation at *high* resolution scale

→Direct high-k process from J_μ^{1B}
→Highly sensitive to D-wave
→High momentum of Ψ^d
"=" SRC
"=" Tensor force probe
→FSI constitute a critical element



Interpretation at *low* resolution scale

→Low-k 2-body process J_μ^{2B}
Modeled by simple 2B contact
→D-wave completely irrelevant
→Simple low-k $\Psi_0^d(^3S_1)$
"=" No SRC
"=" Short-range 2-body current
→FSI reduced

Courtesy : T. Duguet

Selected highlights : History of the single particle concept

Electron scattering

Sensitive to charge distribution $\rho_c(r)$

First approximation

$$\frac{d\sigma}{d\Omega} \propto |F_c(q)|^2 \sim \left| \int d\vec{r} \rho_c(\vec{r}) e^{i\vec{q}\cdot\vec{r}} \right|^2$$

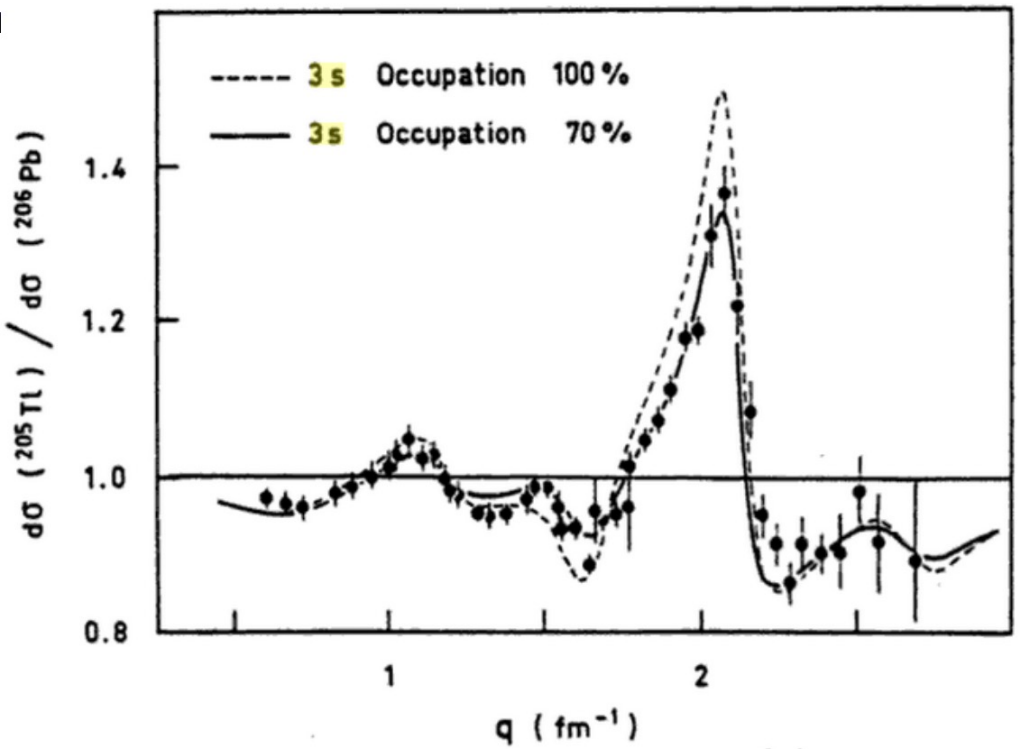
^{206}Pb = ^{205}Tl + **1p**

Naive picture : **1p** = 1proton in 3s1/2

Idea : take a ratio (or difference)

$d\sigma(^{205}\mathrm{Tl})/d\sigma(^{206}\mathrm{Pb})$

→ **Should ressemble 3s1/2…**



B. Frois *et al.*, Modern Topics in Electron Scattering (World Scientific 1991)

=>Same shape as 3s1/2 (!)

=> scaling factor = « spectroscopic factor »

« The closest thing we have from a 'picture' of a 'single particle' evolving inside the nucleus »

Courtesy : D. Verney

Selected highlights : « spectroscopic factor »

Example : « spectroscopic factor » computed in ≠ ways, should not be confused

→Three possible **theoretical** schemes to **compute spectroscopic probability matrices**

	Valence-space shell model scheme	**Full space ab initio scheme**	**Direct reaction scheme**
***Built in* empirical range for E_k^{+-}**	10s of MeVs	**100s of MeVs**	**Few MeVs**
Computation of $s_{n_p n_q}^{\pm l_p j_p}(k)$	$s_{n_p n_p}^{\pm l_p j_p}(k) \equiv \mathrm{SF}_k^{\pm}$	$s_{n_p n_q}^{\pm l_p j_p}(k)$	$s^{\pm l_p j_p}(k) \equiv \sigma_{\exp}(l_p j_p)/\sigma_{th}^{\pm}(k)$
Access to E_k^{+-}	Consistently from theory	Consistently from theory	From experiment

=> Care should be taken when comparing spectroscopic factors, highly model-dependant

Courtesy : T. Duguet

Selected highlights : cares taken during the workshop

^{61}Cr as a Doorway to the N=40 Island Of Inversion

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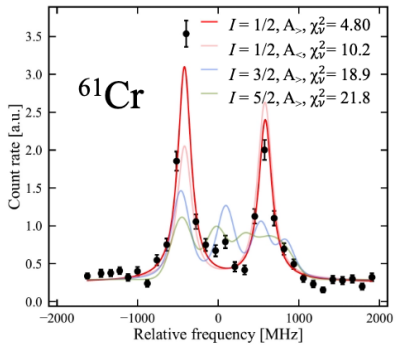
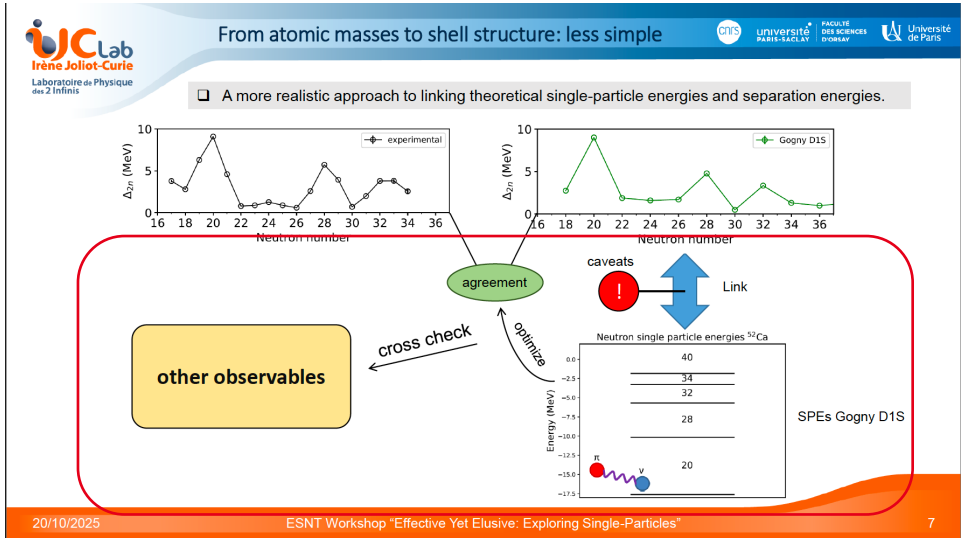
- Spin ^{61}Cr found to be 1/2 , disagrees with 5/2 assignment from literature :
  - Spin-parity assignment of first two ^{61}Cr excited state from multipol.(1)
  - Over estimation beta feeding in ^{61}Mn (2)
- Moment shows a neutron $p_{1/2}$ config
- Large Scale Shell Model and Discrete Non-Orthogonal SM calculations:

Theoretical scheme :

Shell-Model
Protons : *pf*-shell
Neutrons : $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$, $0g_{9/2}$ and $1d_{5/2}$ orbitals
On top of an inert ^{48}Ca core
Interaction : LNPS Hamiltonian
Basis : spherical HO (LSSM) and deformed HF (DNO)
Bare operator for mag moment



Courtesy : L. Lalanne



Courtesy : V. Manéa

Outputs of the workshop

1. Agreed on cares to be taken when talking about A-body system. Need to specifify as much as possible scheme (~dofs) and scale (~momentum resolution scale) at play. => Help at clarifying the debate and the questions at play.

2. News collaborations theory / experiment between among participants

3. Project : illustrate how single particle content is different from one theory to another; while all of them reproduce a given observable. Pedagogical paper to highlight cares to be taken when talking about sp

Thank you for your attention !