Spectroscopy of particle-phonon coupled states in ^{133}Sb by the cluster transfer reaction ^{132}Sn on ^{7}Li: an advanced test of nuclear interactions

Spokespersons: Silvia Leoni and Bogdan Fornal; Local contact: Magdalena Kowalska

S. Leoni[1,2], G. Benzoni[2], G. Bocchi[2], S. Bottoni[1], A. Bracco[1,2], F. Camera[1,2],F.C.L. Crespi[2], A. I. Morales[2]
B. Fornal[3], B. Szpak[3], P. Bednarczyk[3], N. Cieplicka[3], W. Królas[3], A. Maj[3] , K. Rusek[4], D. Bazzacco[5], S. Lunardi[5], D. Mengoni[5], F. Recchia[5], C.A.Ur[5], J. Valiente-Dobon[6], F. Gramegna[6], T. Marchi[6],
M. Huyse[7], R. Raabe[7], P. Van Duppen[7], M. Sferrazza[8], G. Georgiev[9], A. Blazhev[10], D. Rosiak[10], B. Siebeck[10], M. Seidlitz[10], P. Reiter[10], N. Warr[10], A.L. Hartig[11], C. Henrich[11], S. Ilieva[11], T. Kroell[11], M. Thürauf[11], R. Gernhaeuser[12], D. Mücher[12], R. Janssens[13], M.P. Carpenter[13], S. Zhu[13], M. Kowalska[14]

[1] Università degli Studi di Milano, Via Celoria 16, 20133, Italy, [2] INFN, sezione di Milano, Italy

[3] The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland

[4] Heavy Ion Laboratory, University of Warsaw, Poland

[5] University of Padova and INFN sez. Padova, Italy

[6] Legnaro National Laboratory, Italy

[7] Instituut voor Kern-en Stralingsfysisca, K.U.Leuven, Belgium

[8] Université libre de Bruxelles, Belgium

[9] CSNSM, Orsay, France

[10] Institut fur Kernphysik der Universitat zu Koln, Germany

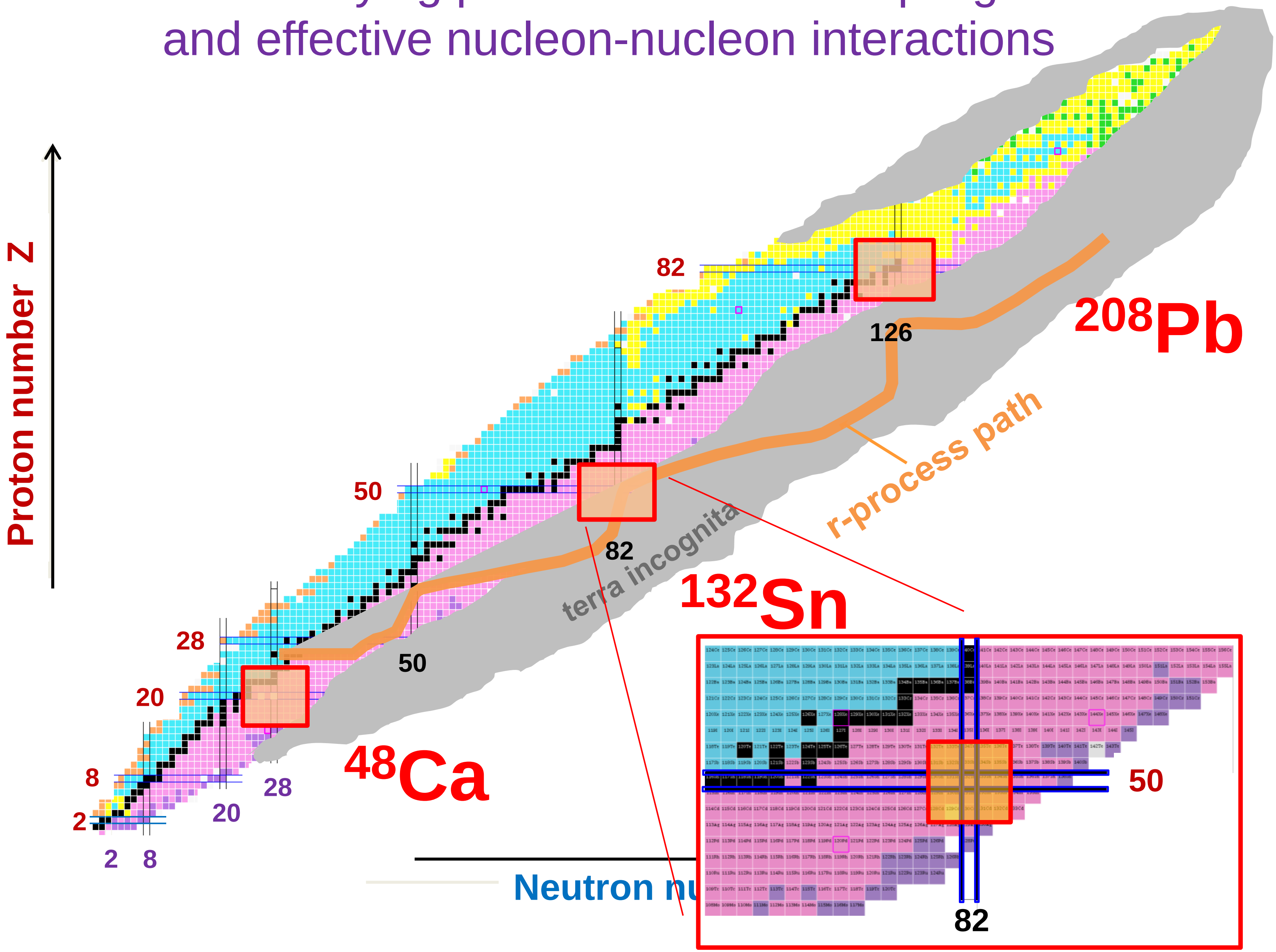
[11] TU Darmstadt, Germany

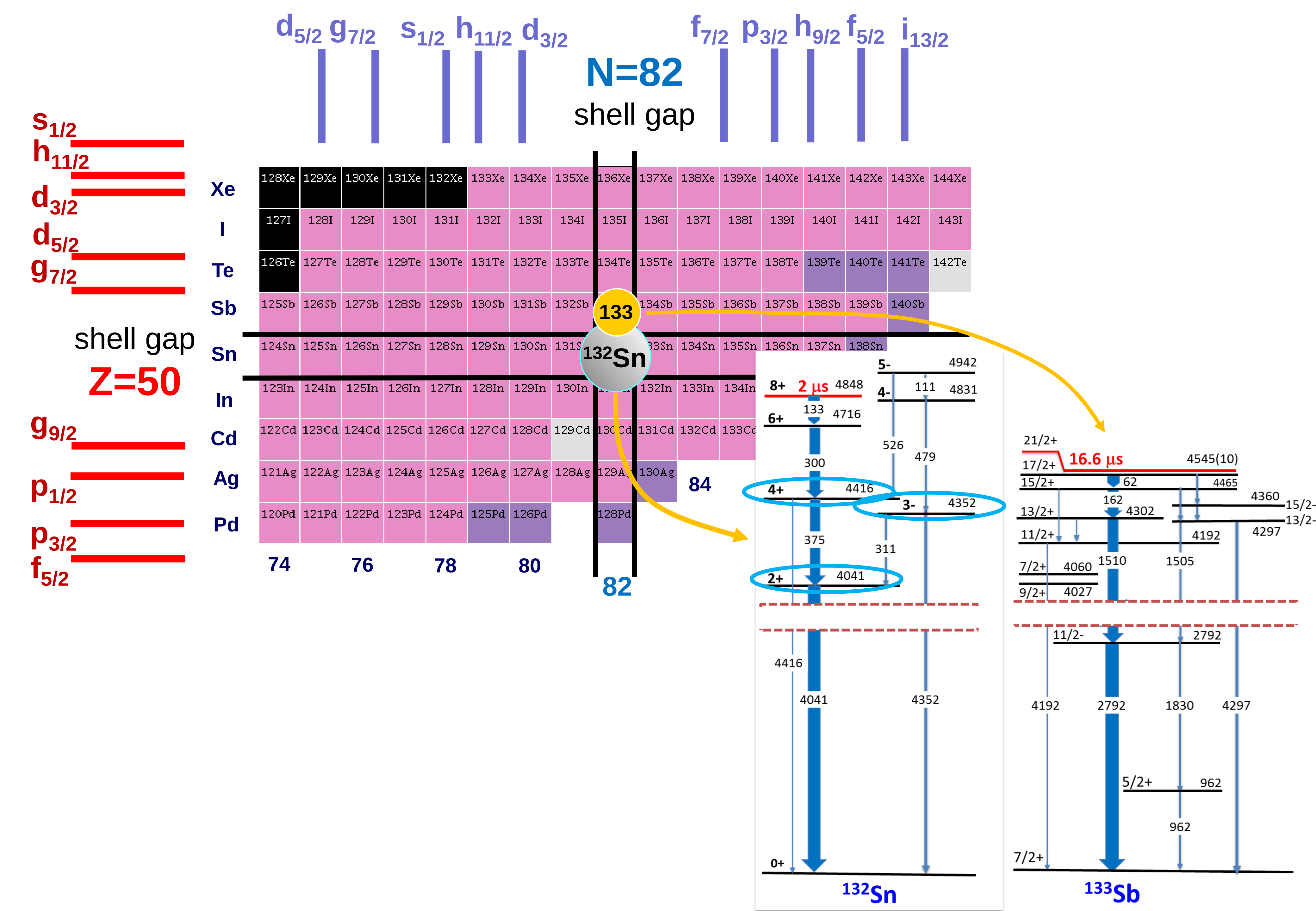
[12] TU Munchen, Germany

[13] Argonne National Laboratory, USA

[14] ISOLDE, CERN, Switzerland

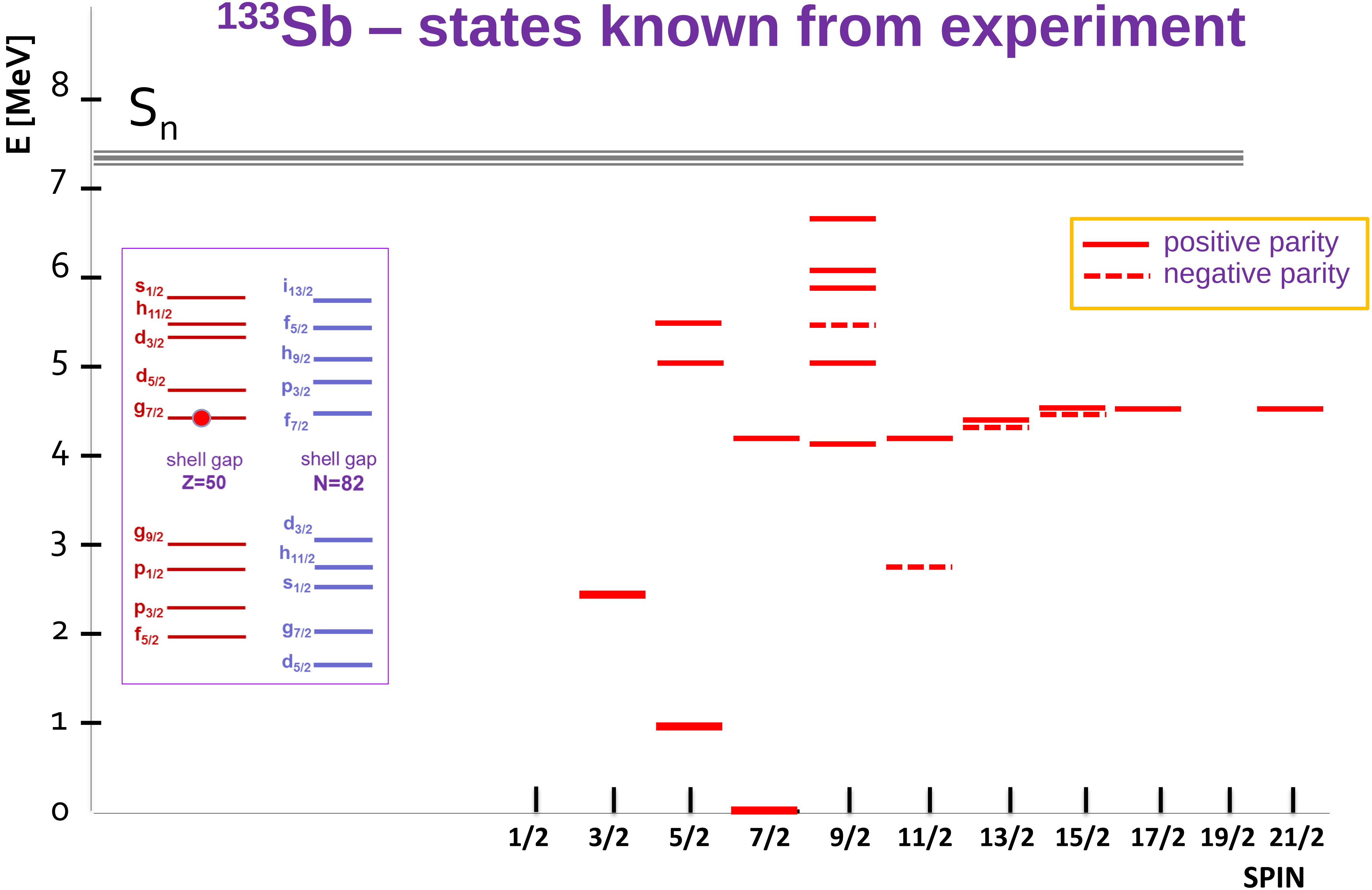
Neighborhoods of doubly-magic nuclei as a laboratory for studying particle-vibration couplings and effective nucleon-nucleon interactions





d5/2 g7/2 s1/2 h11/2 d3/2
N=82
shell gap
f7/2 p3/2 h9/2 f5/2 i13/2
s1/2
h11/2
d3/2
d5/2
g7/2
shell gap
Z=50
g9/2
p1/2
p3/2
f5/2
Xe
I
Te
Sb
Sn
In
Cd
Ag
Pd
128Xe 129Xe 130Xe 131Xe 132Xe 133Xe 134Xe 135Xe 136Xe 137Xe 138Xe 139Xe 140Xe 141Xe 142Xe 143Xe 144Xe
127I 128I 129I 130I 131I 132I 133I 134I 135I 136I 137I 138I 139I 140I 141I 142I 143I
126Te 127Te 128Te 129Te 130Te 131Te 132Te 133Te 134Te 135Te 136Te 137Te 138Te 139Te 140Te 141Te 142Te
125Sb 126Sb 127Sb 128Sb 129Sb 130Sb 131Sb 132Sb 134Sb 135Sb 136Sb 137Sb 138Sb 139Sb 140Sb
124Sn 125Sn 126Sn 127Sn 128Sn 129Sn 130Sn 134Sn 135Sn 136Sn 137Sn 138Sn
123In 124In 125In 126In 127In 128In 129In 130In 132In 133In 134In
122Cd 123Cd 124Cd 125Cd 126Cd 127Cd 128Cd 129Cd 131Cd 132Cd
121Ag 122Ag 123Ag 124Ag 125Ag 126Ag 127Ag 128Ag 130Ag
120Pd 121Pd 122Pd 123Pd 124Pd 125Pd 126Pd 128Pd
74 76 78 80 82 84
133
132Sn
8+ 2 μs 4848
133 4716
6+
300
4+ 4416
375
2+ 4041
5- 4942
4- 111 4831
526 479
3- 4352
311
4416
4041
4352
0+
132Sn
21/2+
17/2+ 16.6 μs 4545(10)
15/2+ 62 4465
162 4360 15/2-
13/2+ 4302 13/2-
11/2+ 4192 4297
7/2+ 4060 1510 1505
9/2+ 4027
11/2- 2792
4192 2792 1830 4297
5/2+ 962
962
7/2+
133Sb

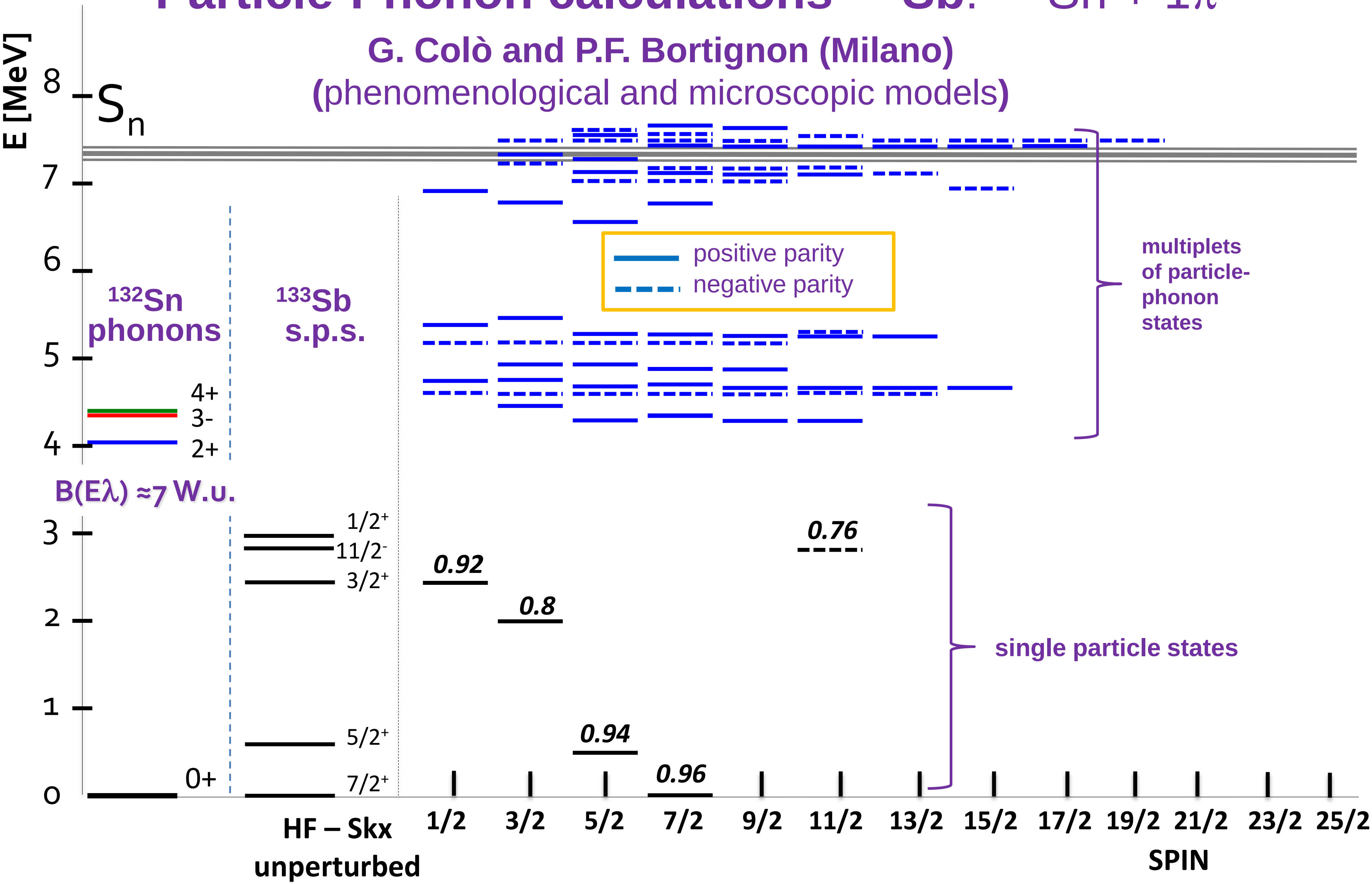
^{133}Sb – states known from experiment



Particle-Phonon calculations ^{133}Sb: ^{132}Sn + 1π

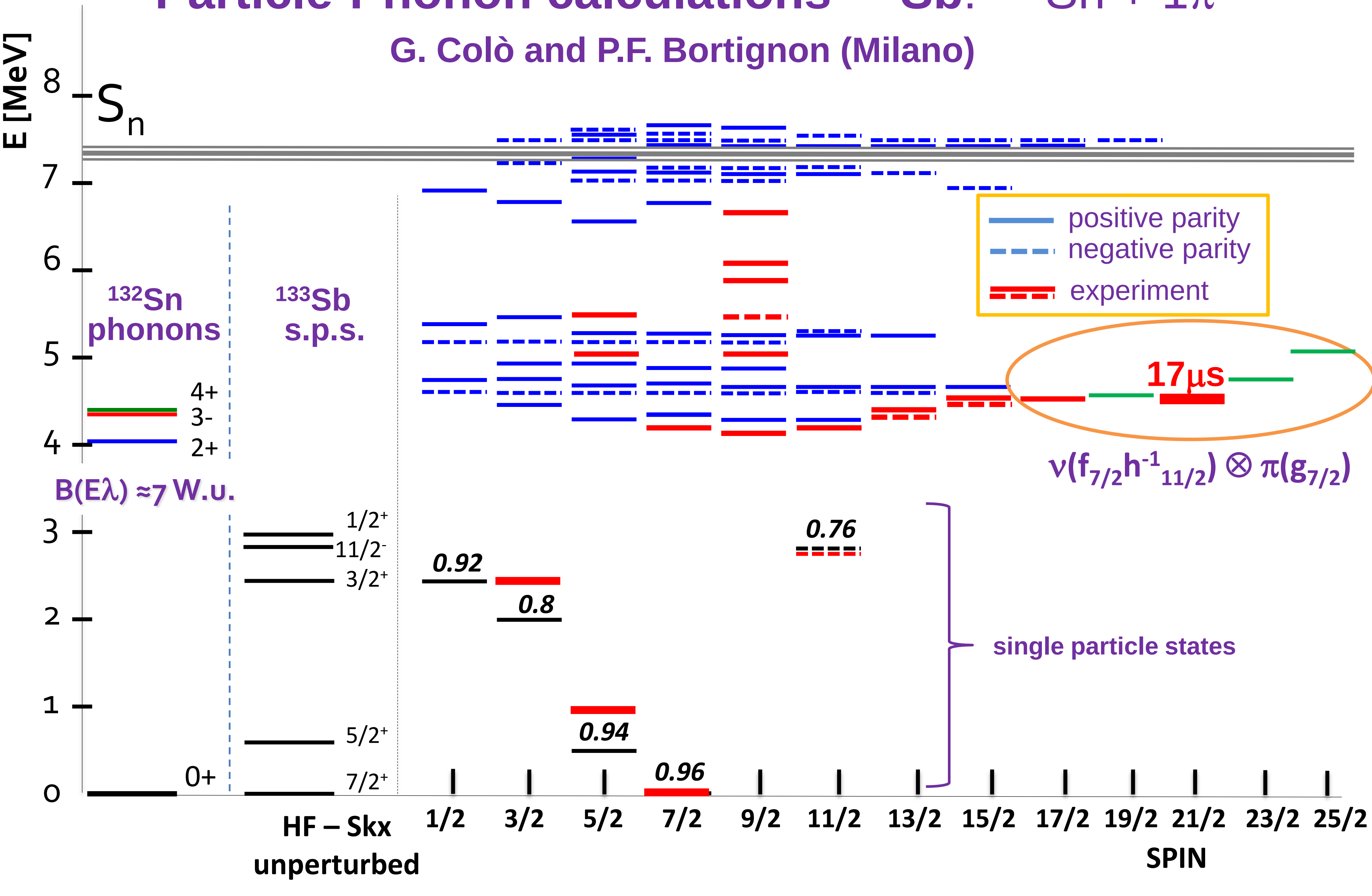
G. Colò and P.F. Bortignon (Milano)

(phenomenological and microscopic models)



Particle-Phonon calculations ^{133}Sb: ^{132}Sn + 1π

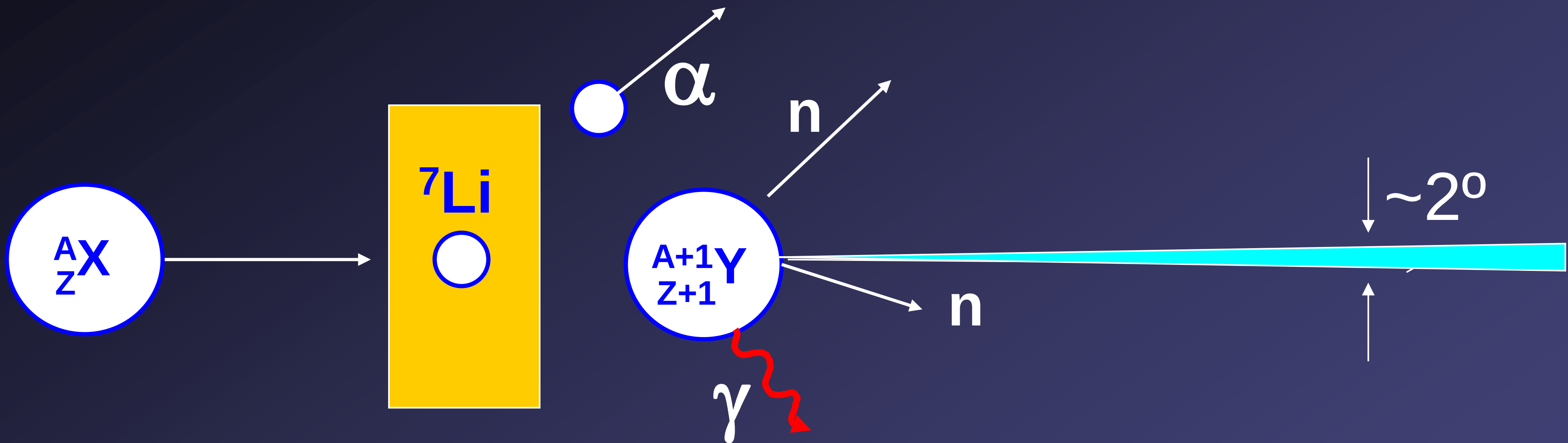
G. Colò and P.F. Bortignon (Milano)



EXPERIMENTAL TOOLS for gamma-ray spectroscopy of excited states in neutron-rich nuclei

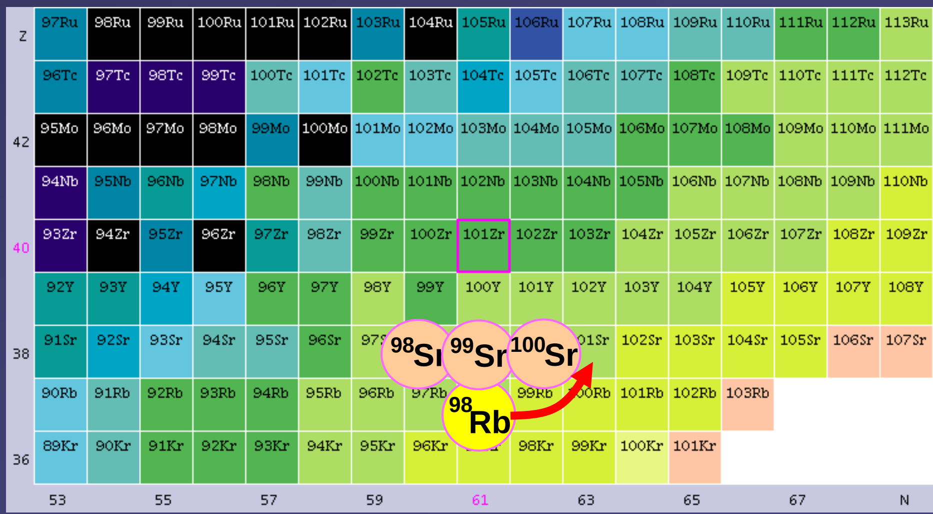
β-decay	Fission, Deep-Inelastic	Fragmentation
low-lying selected states	YRAST Spectroscopy	ISOMER spectroscopy

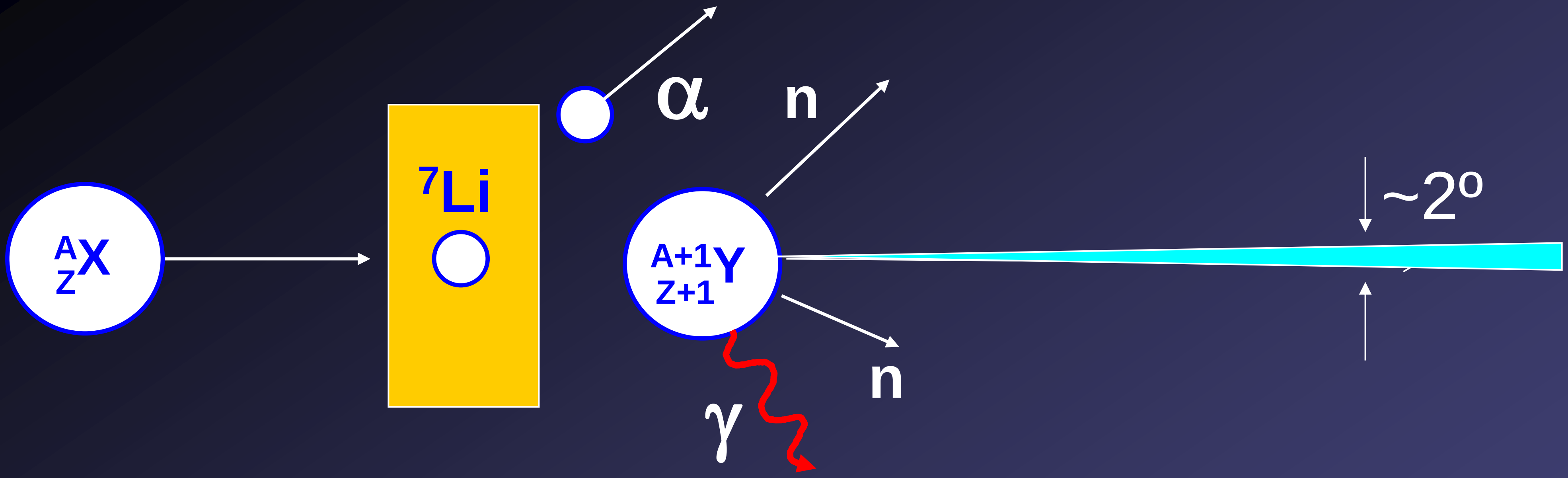
To perform gamma-ray spectroscopic studies of yrast and non-yrast structures in neutron-rich nuclei, we proposed to use the triton transfer process induced by radioactive beams on a ^{7}Li target



EXAMPLE:

$$^{98}Rb + ^{7}Li \longrightarrow ^{101-x}Sr + \alpha + xn$$





Advantages of the proposed method:

The very inverse kinematics guarantees that the product nuclei travel downstream in a very small recoil cone, thus Doppler correction does not require recoil detection.

Reaction channel of interest will be uniquely associated with the emission of an α particle: emitted alpha particles may be used as event tags.

REX-ISOLDE experiment – test of the method

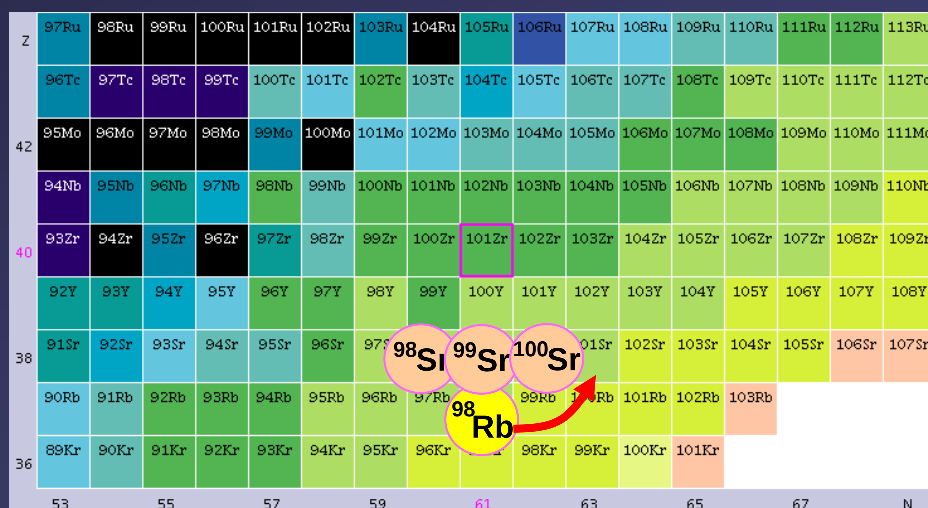
„Spectroscopy of n-rich $^{98-100}$Sr nuclei with triton transfer reaction induced by ^{98}Rb on ^{7}Li: Introduction to HIE-ISOLDE studies of n-rich Sb and Tl isotopes with Sn and Hg radioactive beams"

Spokespersons: Bogdan Fornal and Silvia Leoni

(November 2012)

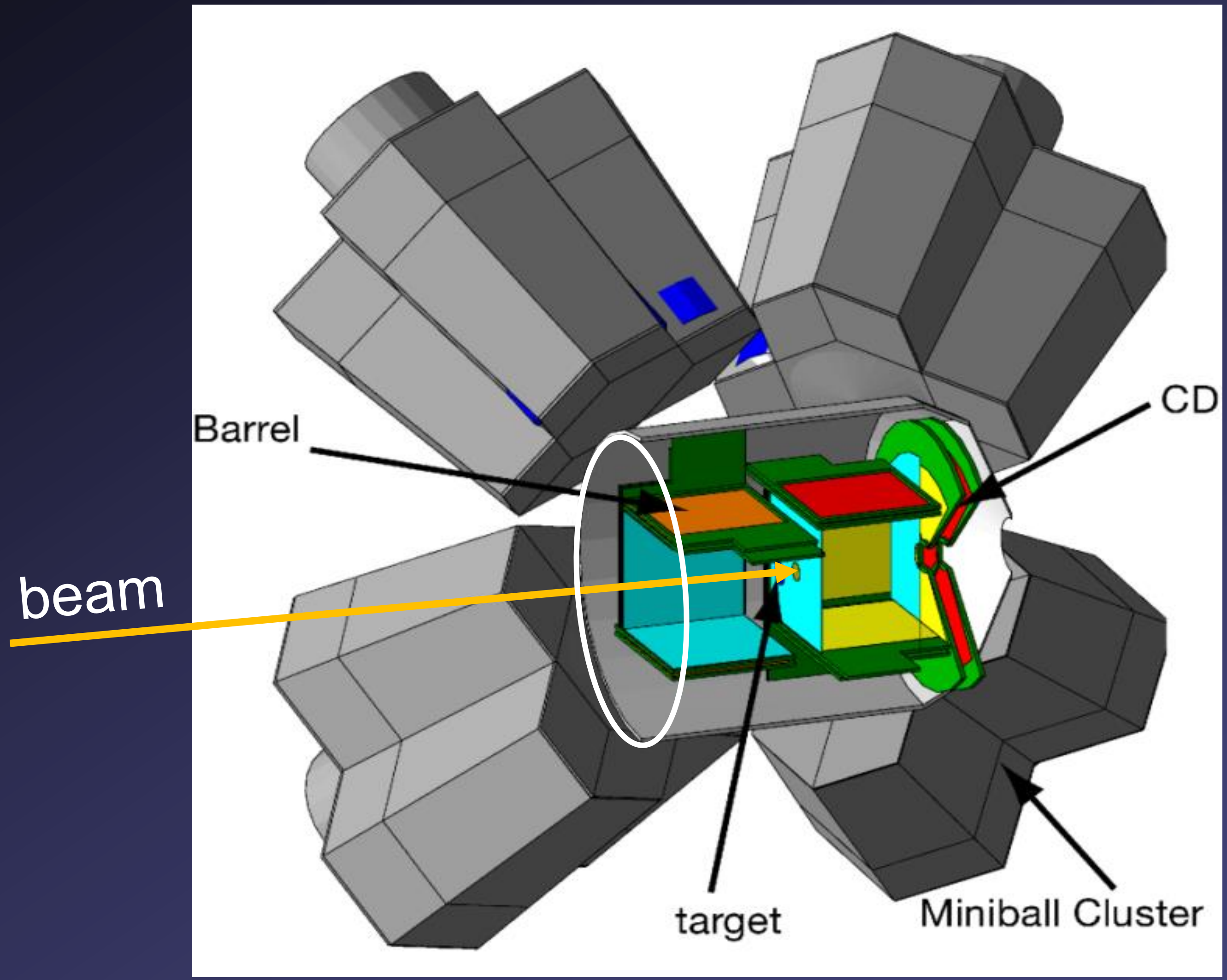
Collaboration: IFJ PAN Kraków, Univ. of Milan, SLCJ Warsaw, GANIL, LNL Legnaro, Univ. of Padova, K.U.Leuven, Université Libre de Bruxelles, CSNSM Orsay, Univ. of Köln, TU Darmstadt, TU Munchen, LPSC Grenoble, Argonne Nat. Lab., IFIN-HH Bucharest, IRNE-BAS Sofia, ISOLDE CERN.

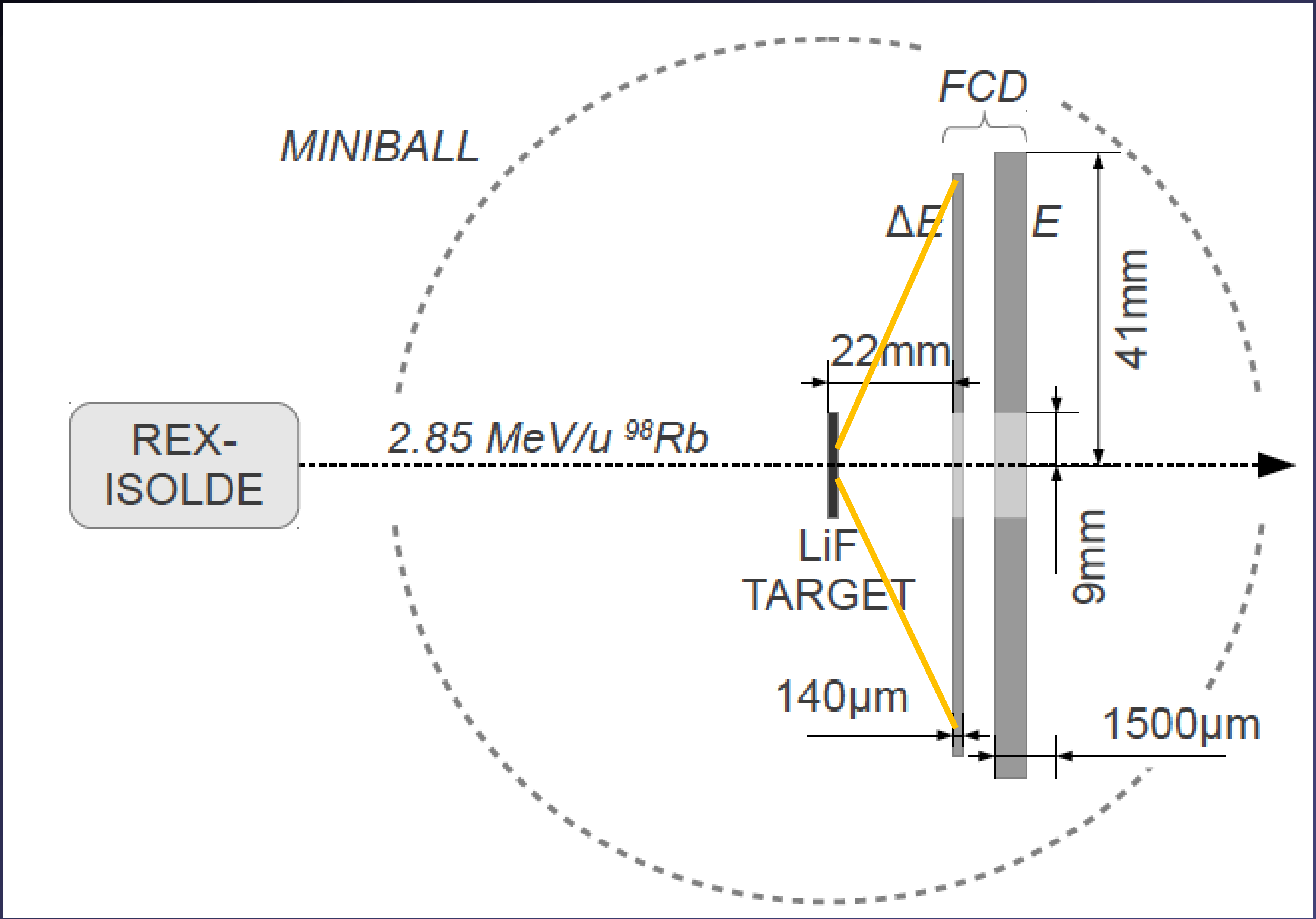
$$^{98}\mathrm{Rb} + {}^{7}\mathrm{Li} \longrightarrow {}^{101-x}\mathrm{Sr} + \alpha + xn$$



REX-ISOLDE + MINIBALL + T-REX

^{98}Rb(60%)+^{98}Sr(40%) (2.84 MeV/u) + ^{7}LiF (1.5 mg/cm^{2})



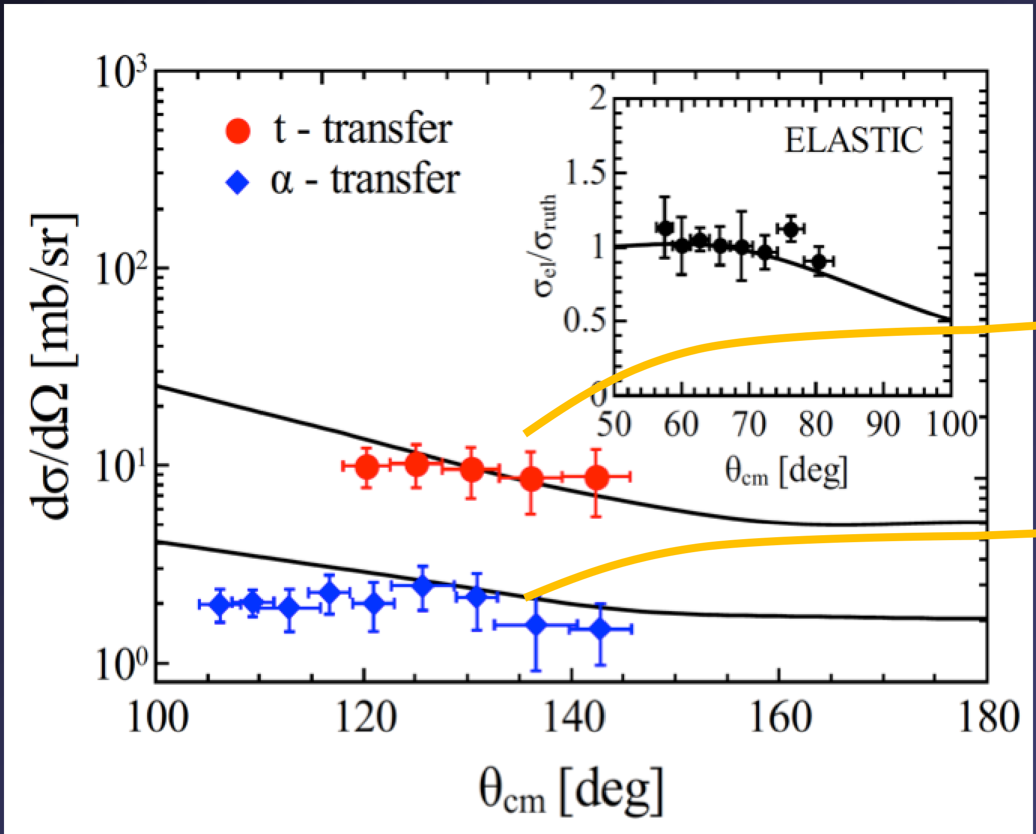

MINIBALL
FCD
ΔE
E
22mm
41mm
REX-
ISOLDE
2.85 MeV/u ^{98}Rb
LiF
TARGET
9mm
140µm
1500µm

REX-ISOLDE + MINIBALL + T-REX

^{98}Rb(60%)+^{98}Sr(40%) (2.84 MeV/u) + ^{7}LiF (1.5 mg/cm^2)

Data were analyzed by Simone Bottoni,
Ph.D. Thesis Univ. of Milano and KU Leuven

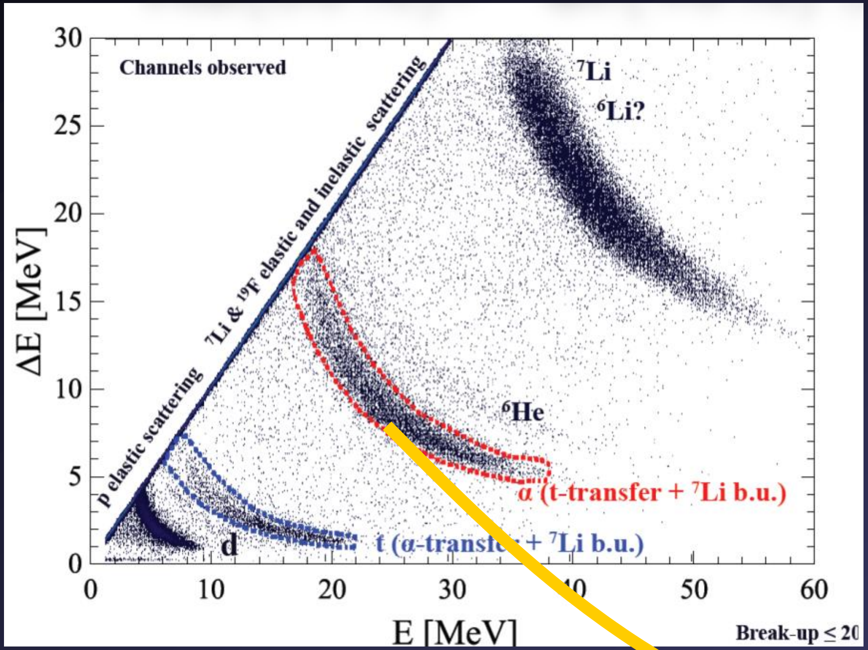
Experimental data on cross-section for t- and α-transfer

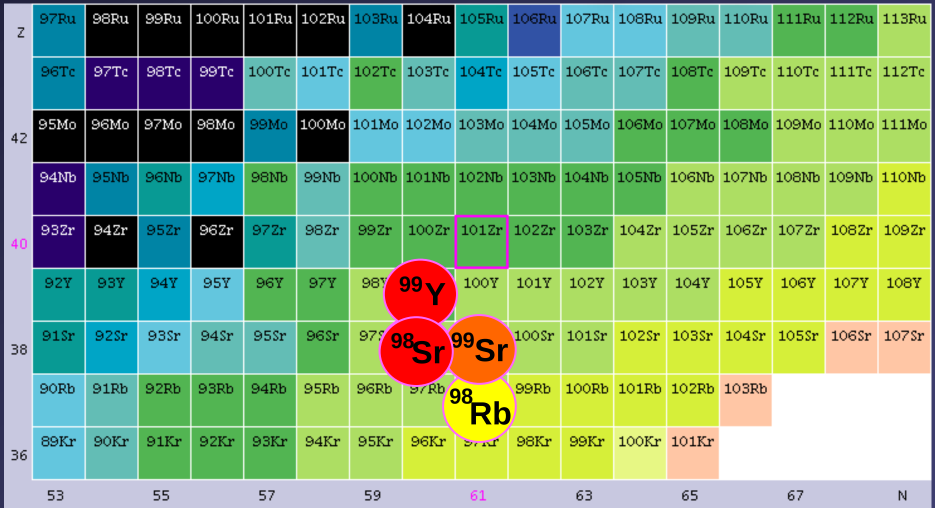


Process	MEASURED cross section [mb]	ESTIMATED TOTAL cross section [mb]
triton transfer	**27**	**~90**
alpha transfer	**5**	**~15**

REX-ISOLDE + MINIBALL + T-REX

^{98}Rb(60%)+^{98}Sr(40%) (2.84 MeV/u) + ^{7}LiF (1.5 mg/cm^{2})



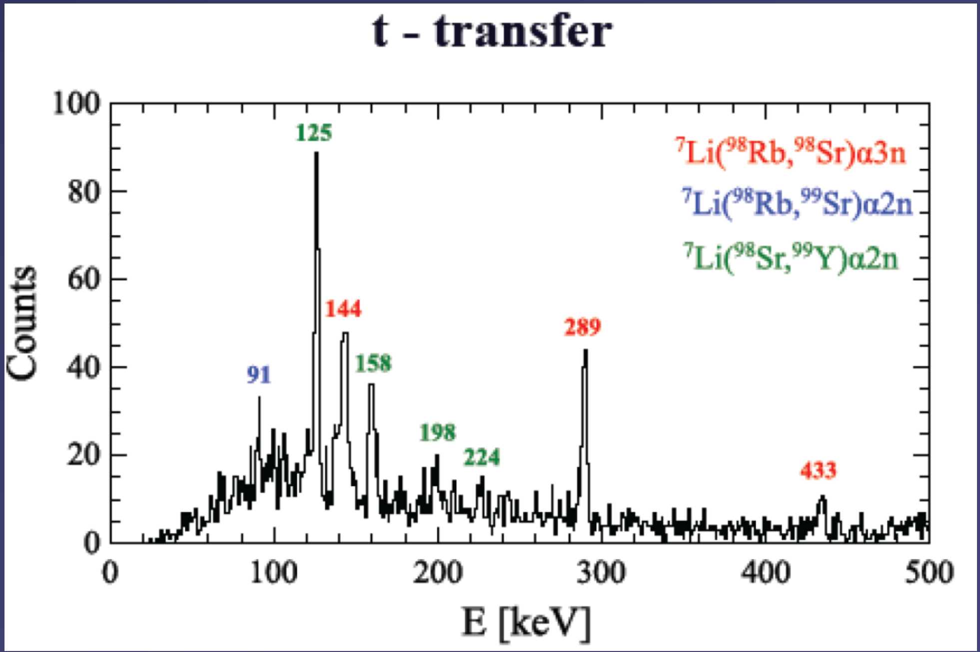


I_{BEAM} (^{98}Ru/^{98}Sr) ≈ 2.5 x 10^{4} pps

Counting rate:

~0.03 <u>ev/s</u> **for** α-γ

(10 k in 4 days)



Data were analyzed by Simone Bottoni, Ph.D. Thesis Univ. of Milano and KU Leuven

REX-ISOLDE + MINIBALL + T-REX

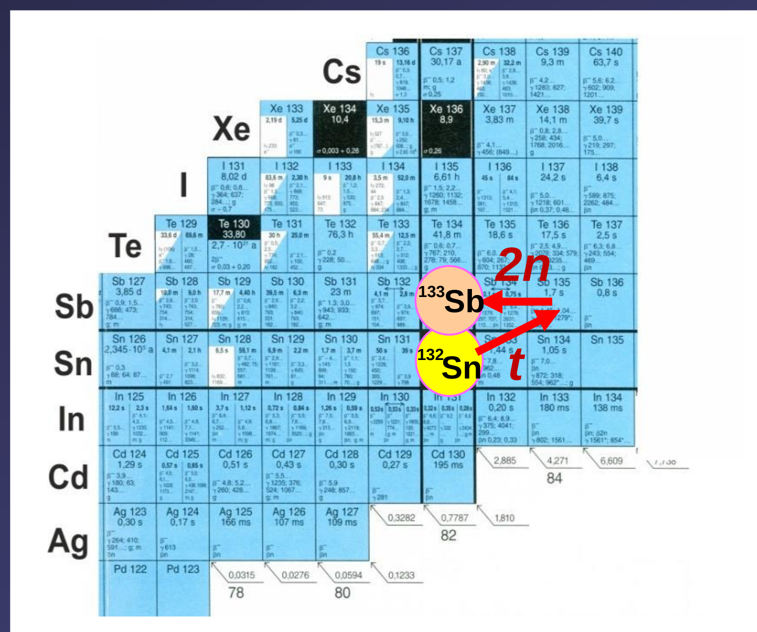
^{98}Rb(60%)+^{98}Sr(40%) (2.84 MeV/u) + ^{7}LiF (1.5 mg/cm^2)

Results:

- **Transfer of tritons into ^{98}Rb, with emission of alpha particles, has a sizeable cross-section as predicted by DWBA calculations.**
- **By tagging on α particles one obtains clean γ-ray spectra from triton transfer products.**
- **Yrast, near-yrast and non-yrast states are populated.**

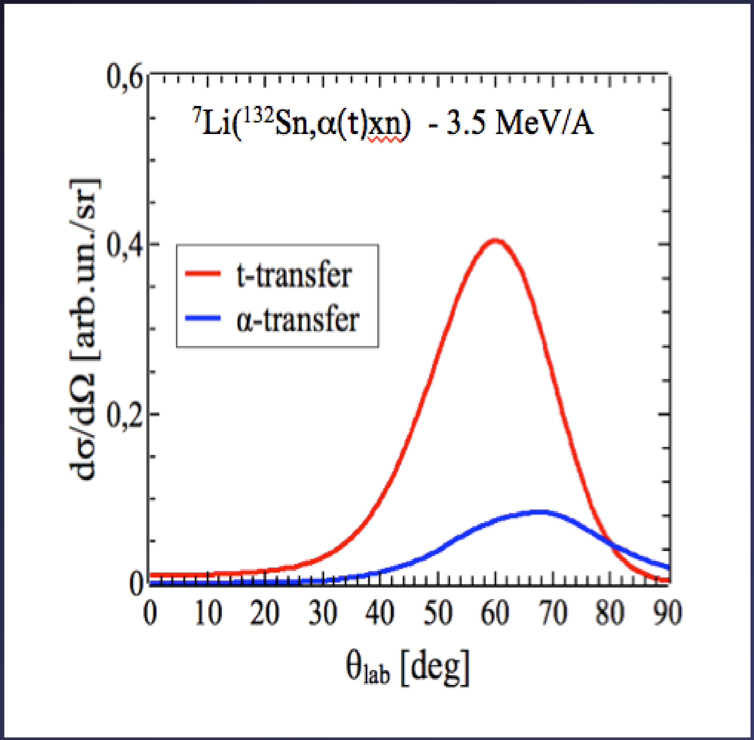
We would like to study the structure of ^{133}Sb by using the method that was introduced and tested in our previous REX-ISOLDE IS-534 experiment, now, by using a ^{132}Sn beam from HIE-ISOLDE:

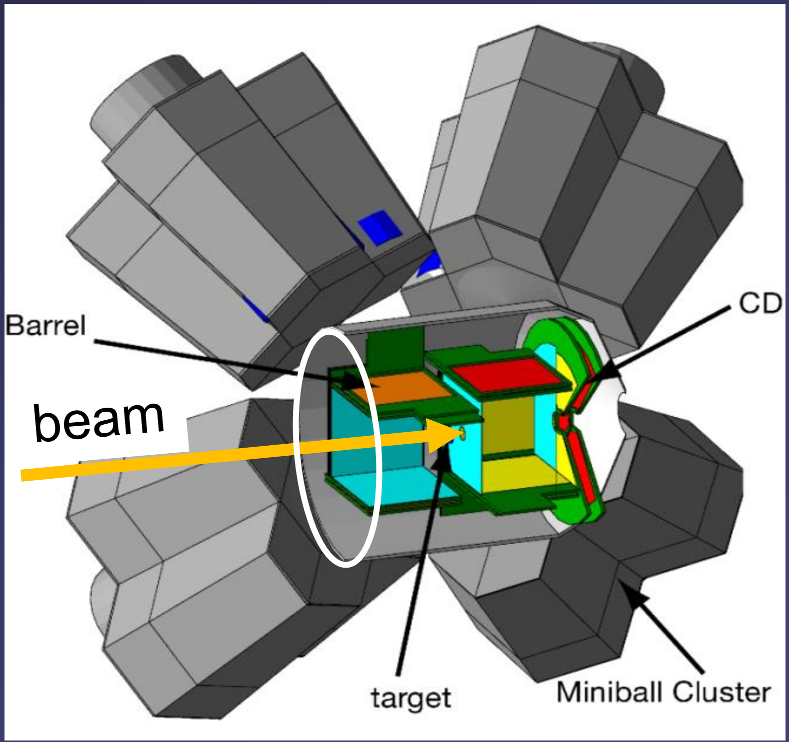
$$^{132}\text{Sn}\ (510\ \text{MeV}) + {}^{7}\text{Li} \longrightarrow {}^{133}\text{Sb} + \alpha + 2n$$



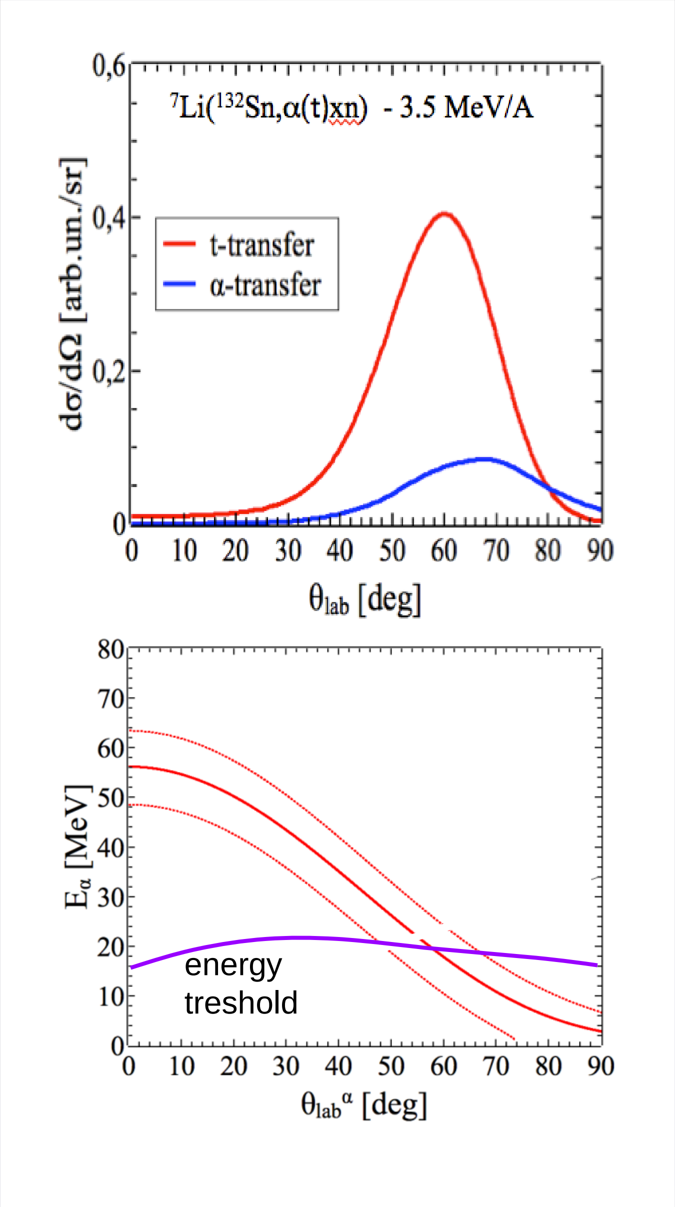
^{132}Sn (510 MeV) + ^{7}Li ⟶ $^{135-x}Sb+\alpha+xn$

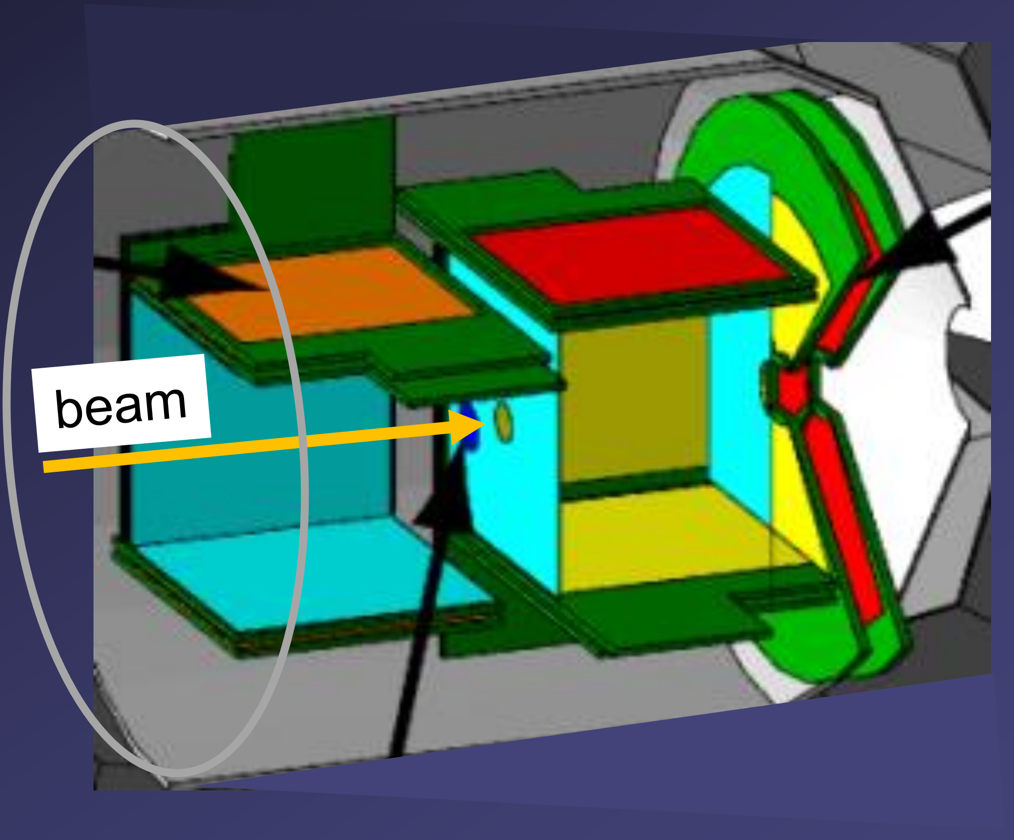
DWBA calculations of alpha particles emitted following t-transfer reaction



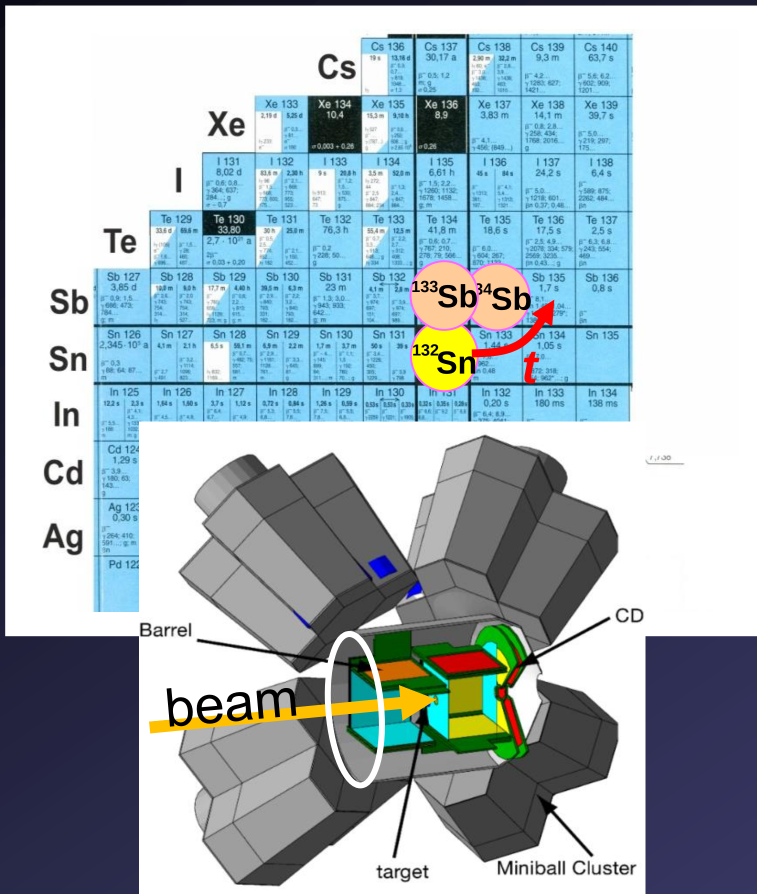


^{132}Sn (510 MeV) + ^{7}Li ⟶ $^{135-x}Sb+\alpha+xn$





^{132}Sn (510 MeV) + ^{7}Li ⟶ $^{135-x}Sb+\alpha+xn$



Reaction data and counting rates:

Beam: ^{132}Sn, E_{beam}=510 MeV (3.9 MeV/A)
$8*10^5$ pps (on target)

Target: ^{7}LiF, 1.5 mg/cm^2

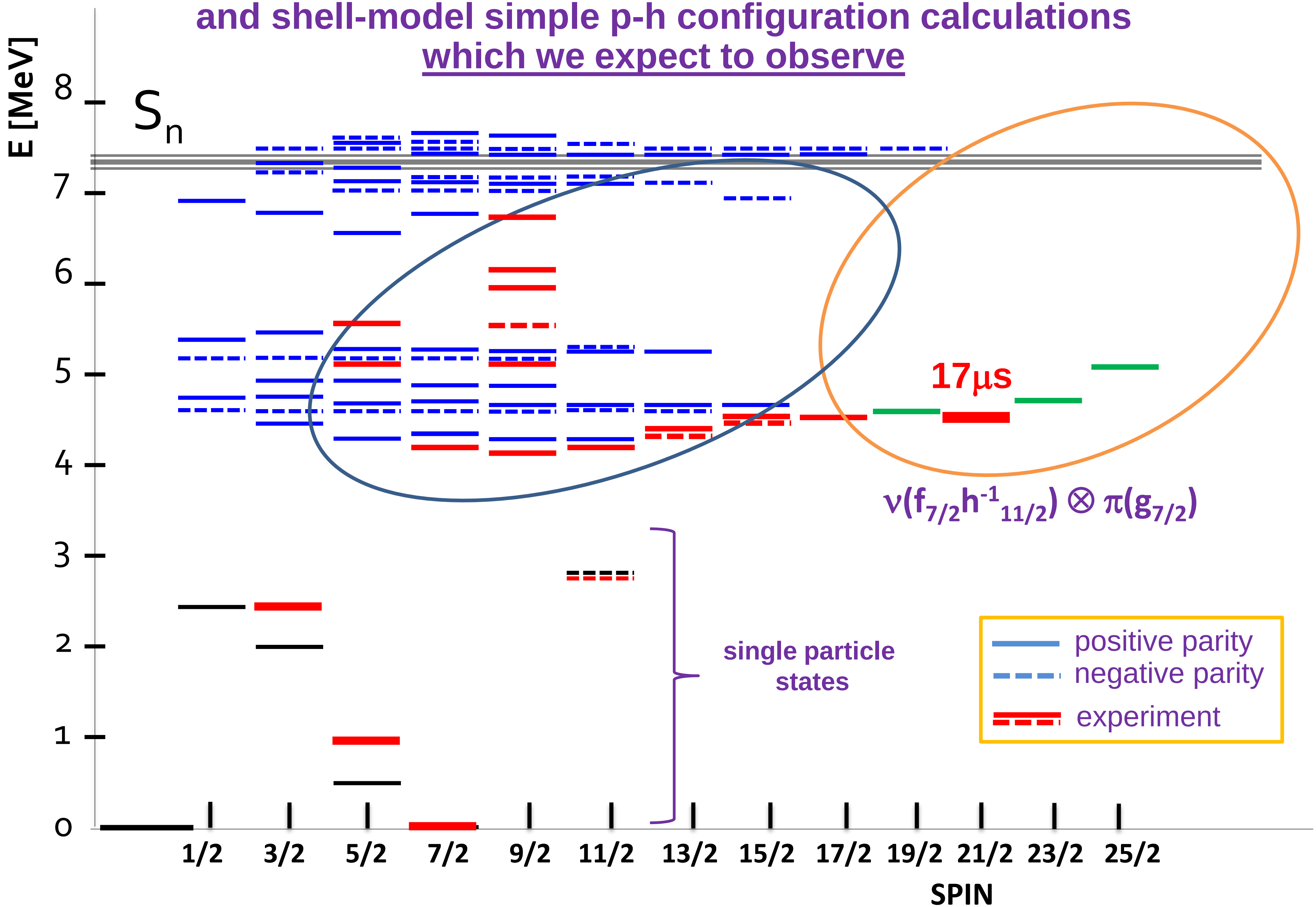
Cross section: 100 mb for *t*-transfer
(^{135}Sb production)

Final products: 80% 2n-evap. ^{133}Sb
20% 1n-evap. ^{134}Sb

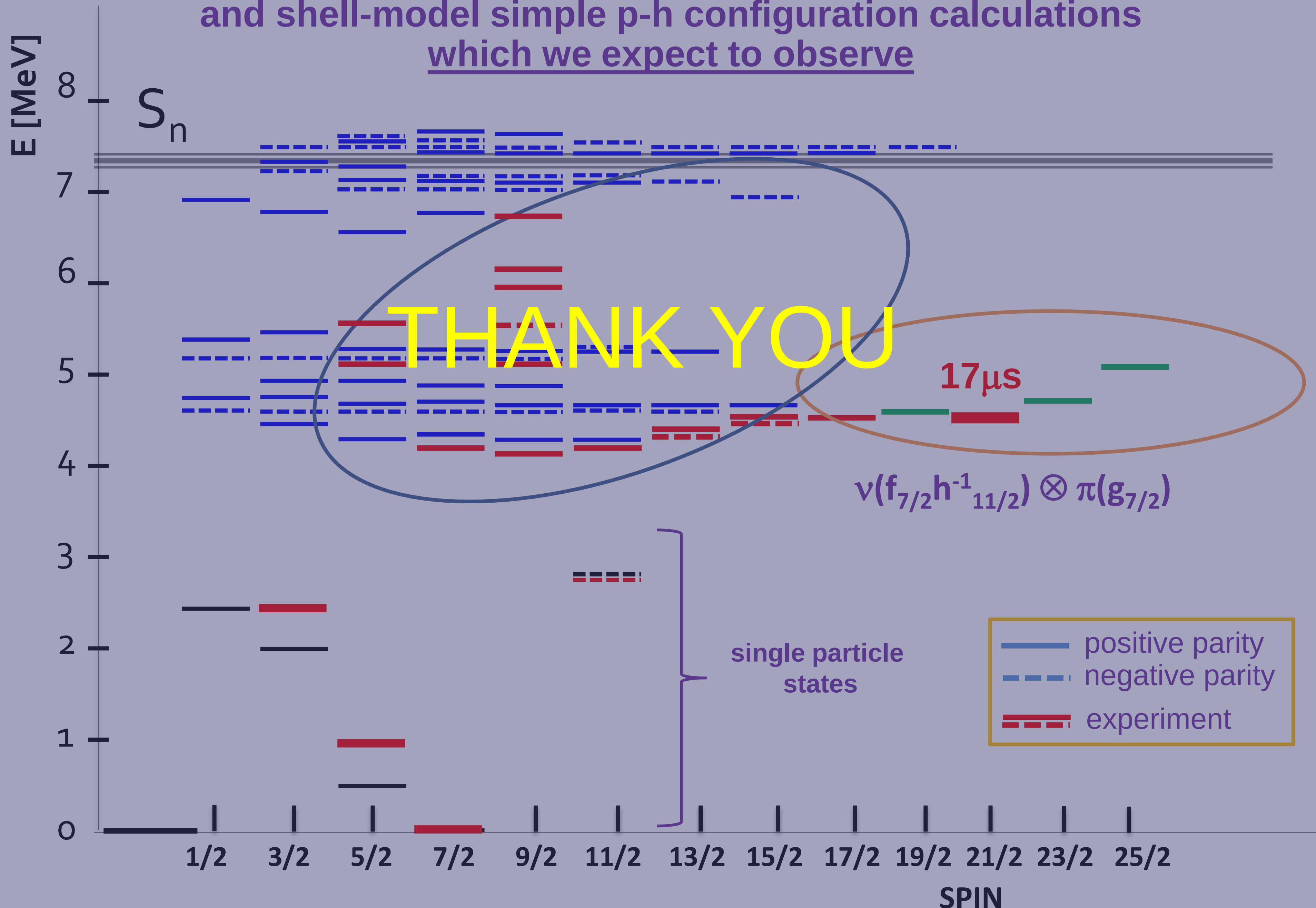
Counting rates: ≈1 α-particle/s in T-REX
for a γ line with 1% intensity: 300 counts in 7days

We ask for 21 shifts

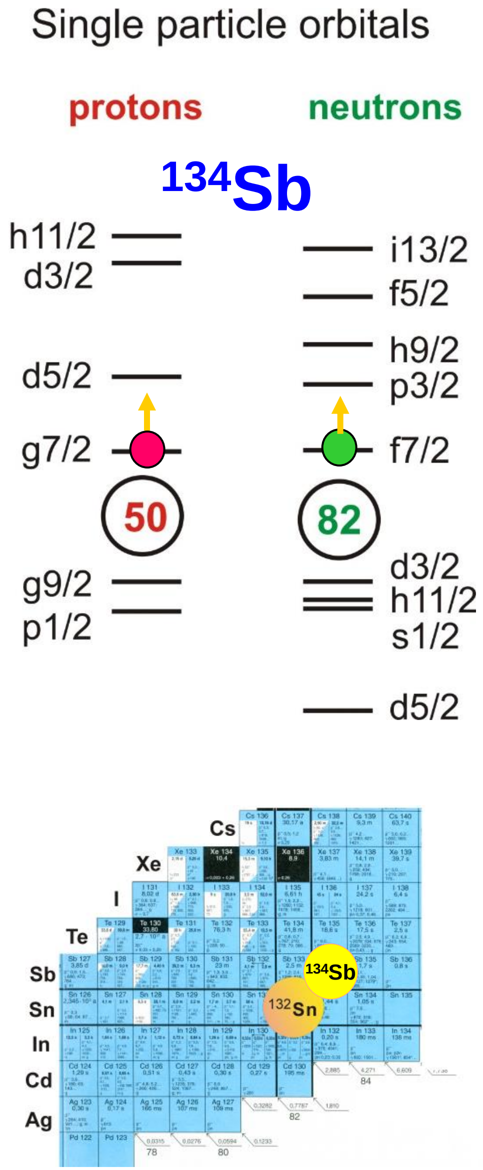
States in ^{133}Sn predicted by the particle-phonon and shell-model simple p-h configuration calculations which we expect to observe

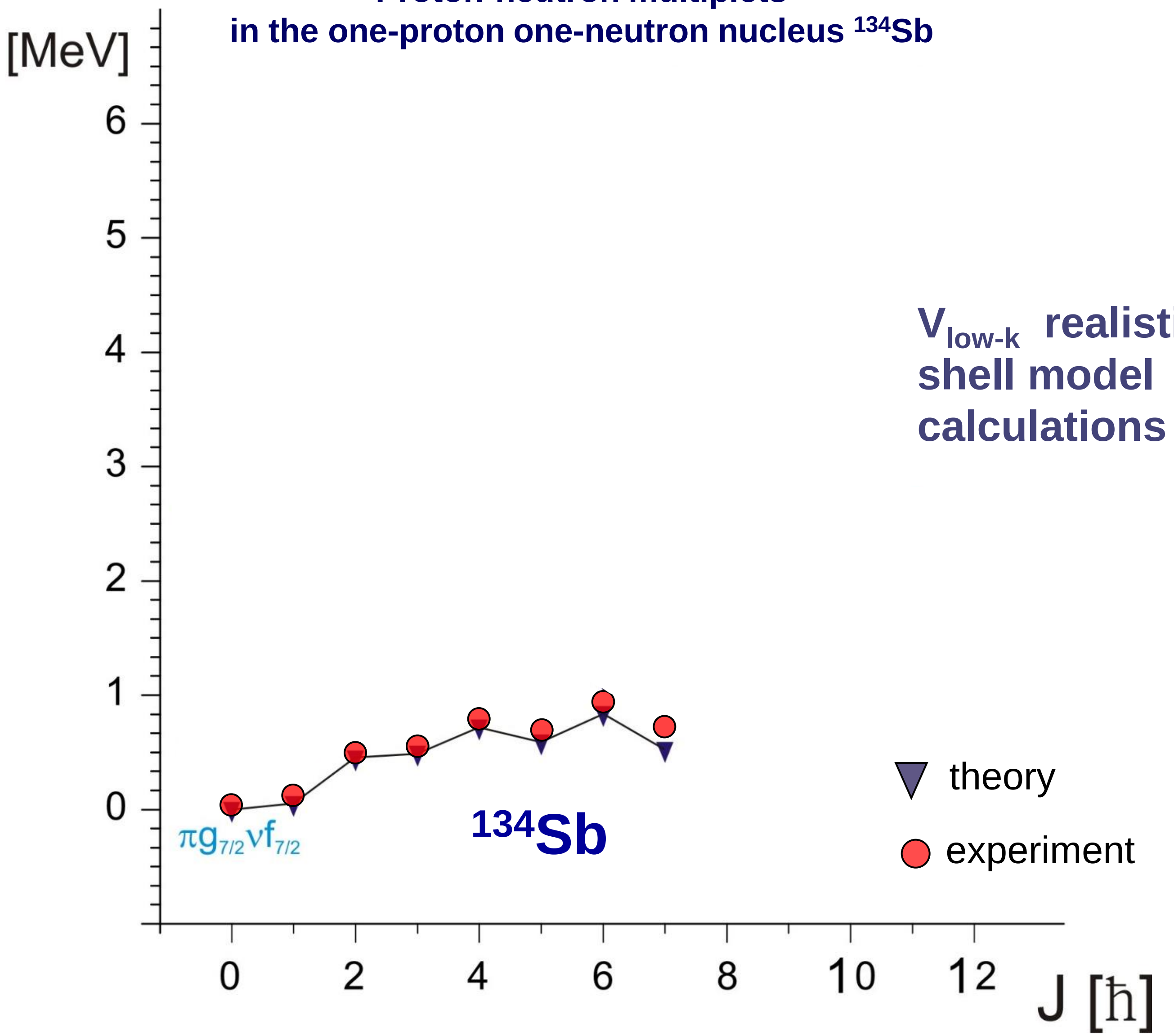


States in ^{133}Sn predicted by the particle-phonon and shell-model simple p-h configuration calculations <u>which we expect to observe</u>



Proton-neutron multiplets in the one-proton one-neutron nucleus ^{134}Sb

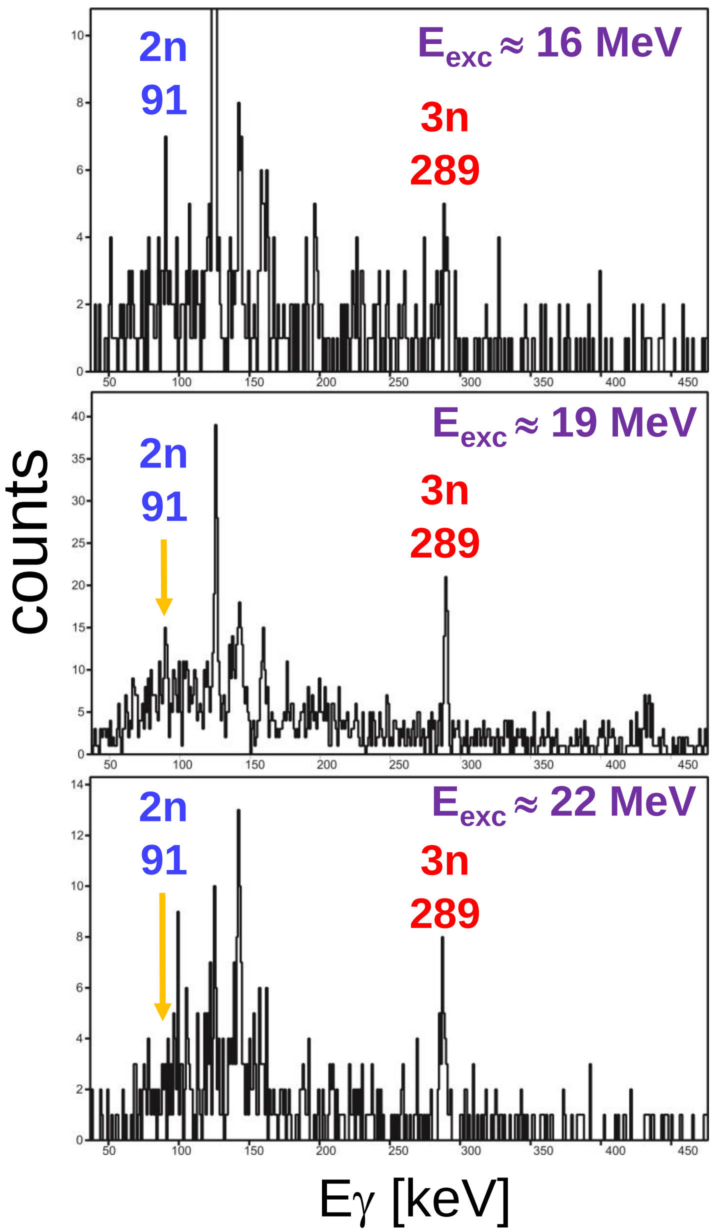


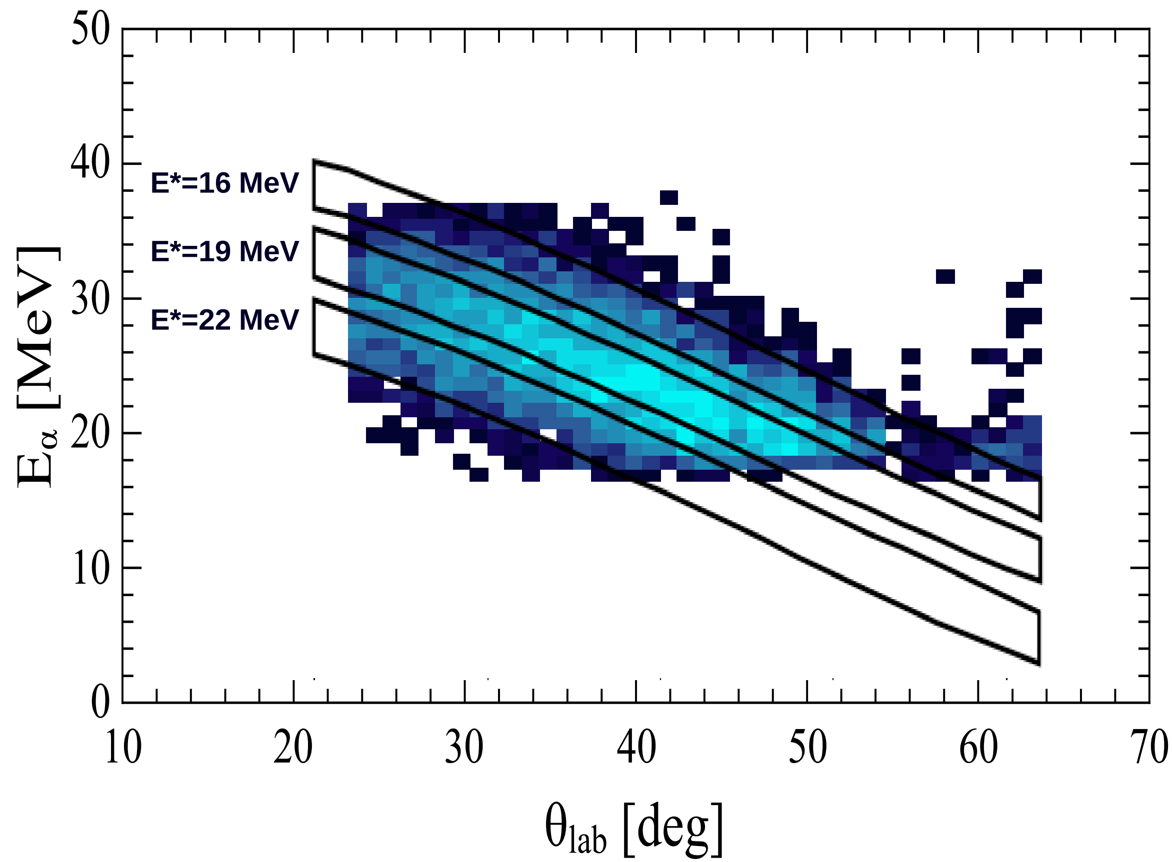


$V_{low\text{-}k}$ realistic shell model calculations

What little is known comes mainly from beta-decay studies or spectroscopic investigations of fission products.

Identification method





Theoretical Description

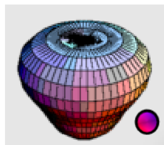
PHENOMENOLOGICAL

Particle-phonon
WEAK coupling calculations
(Bohr & Mottelson)

^{49}Ca

$3^{-} \otimes p_{3/2}$

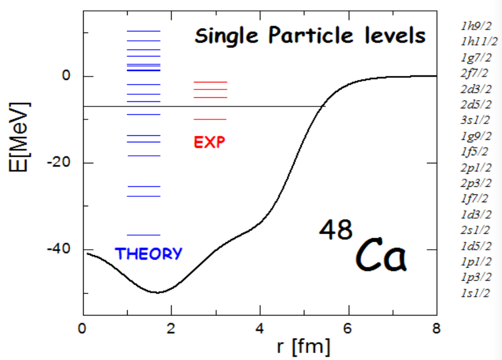
$[\lambda \otimes j_1]_I$



Multiplet of States $9/2^+, 7/2^+, 5/2^+, 3/2^+$

Energy Shift
$$\delta E(I)_{a,b,c,d} = \pm \sum_{j_2} \frac{h^2(j_2, j_1, \lambda)}{\varepsilon(j_1) - \varepsilon(j_2) \pm \hbar\omega_\lambda} \times C_{recoupling}$$

- $\hbar\omega_\lambda$, B(Eλ)
  → Exp. Values/Theory
- s.p. Energies
  $\varepsilon(j_1)$, $\varepsilon(j_2)$
  → HF – SkX
- matrix element
  $h(j_2, j_1, \lambda)$
  → Bohr & Mott.

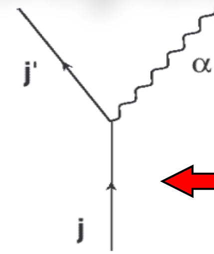


MICROSCOPIC

Calculations based on

SELF-CONSISTENT Scheme

(Colò, Bortignon, Sagawa, ...)



- **Hartee-Fock with V_{eff}**
  → short-range correlations included
- **Particle-Vibration coupling on top**
  → same Hamiltonian or EDF
- **NO approximation in the vertex**

EXACT treatment of COUPLING
use of WHOLE phonon wave function

Need for More Experimental Input

G. Colò, H. Sagawa, P.F. Bortignon, PRC 82, 064307 (2010).