Transfer ^{3}He(X,n)Y reactions for nuclear structure studies: development of a new sputtered ^{3}He target.

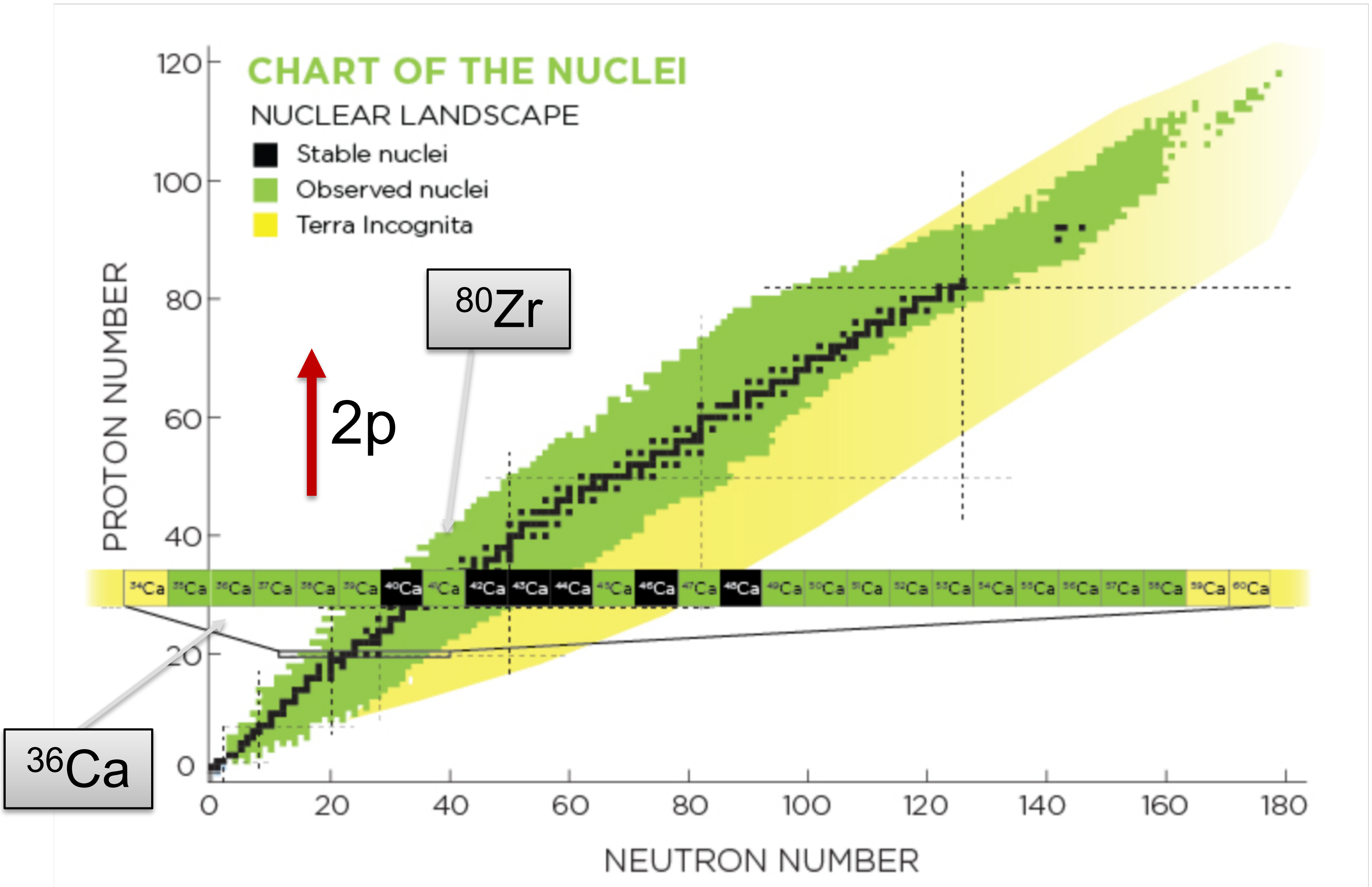
Jose Javier Valiente Dobón

Laboratori Nazionali di Legnaro (INFN), Italy.

Overview

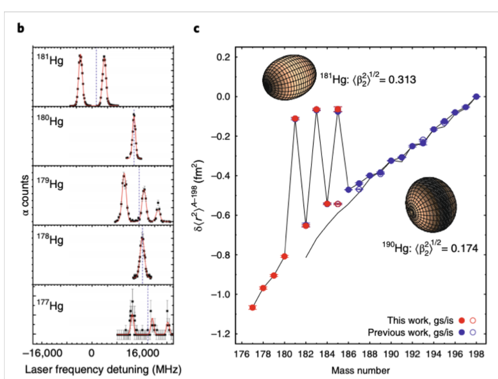
- Motivation for the developmentof a solid ^{3}He target
  - Population of 0^{+} states inverse kinematics RIB
  - ps lifetime measurements
- Physics examples for a solid ^{3}He target
  - The N=Z ^{80}Zr case
  - The CMED in ^{36}Ca-^{36}S
- The challenge of producing a solid ^{3}He target
- Some preliminary results
- Summary

What can we reach with (^{3}He,n)?

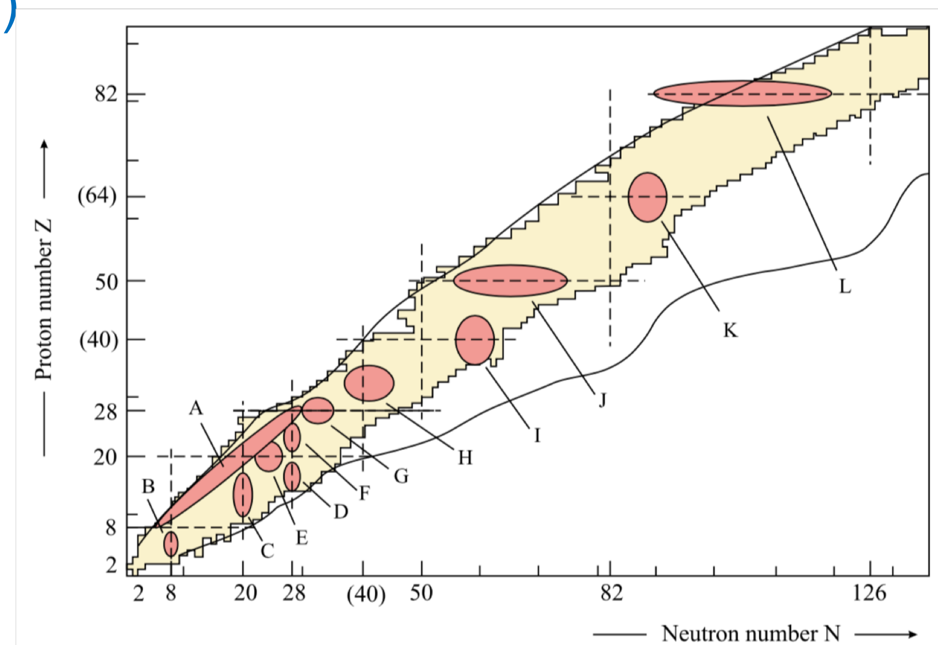


Study of the low-lying states

- Intruder 0+ configurations competing in energy with the 0p-0h 0+ one. Interplay between pairing (driving nuclei to spherical shapes) and residual interactions.
- How to measure shape coexistence? Transfer reaction in inverse kinematics with RIBs
  - Conversion electrons p(E0)
  - Lifetime measurements
  - Coulomb excitation
  - Isotope shifts (radii)
  - …



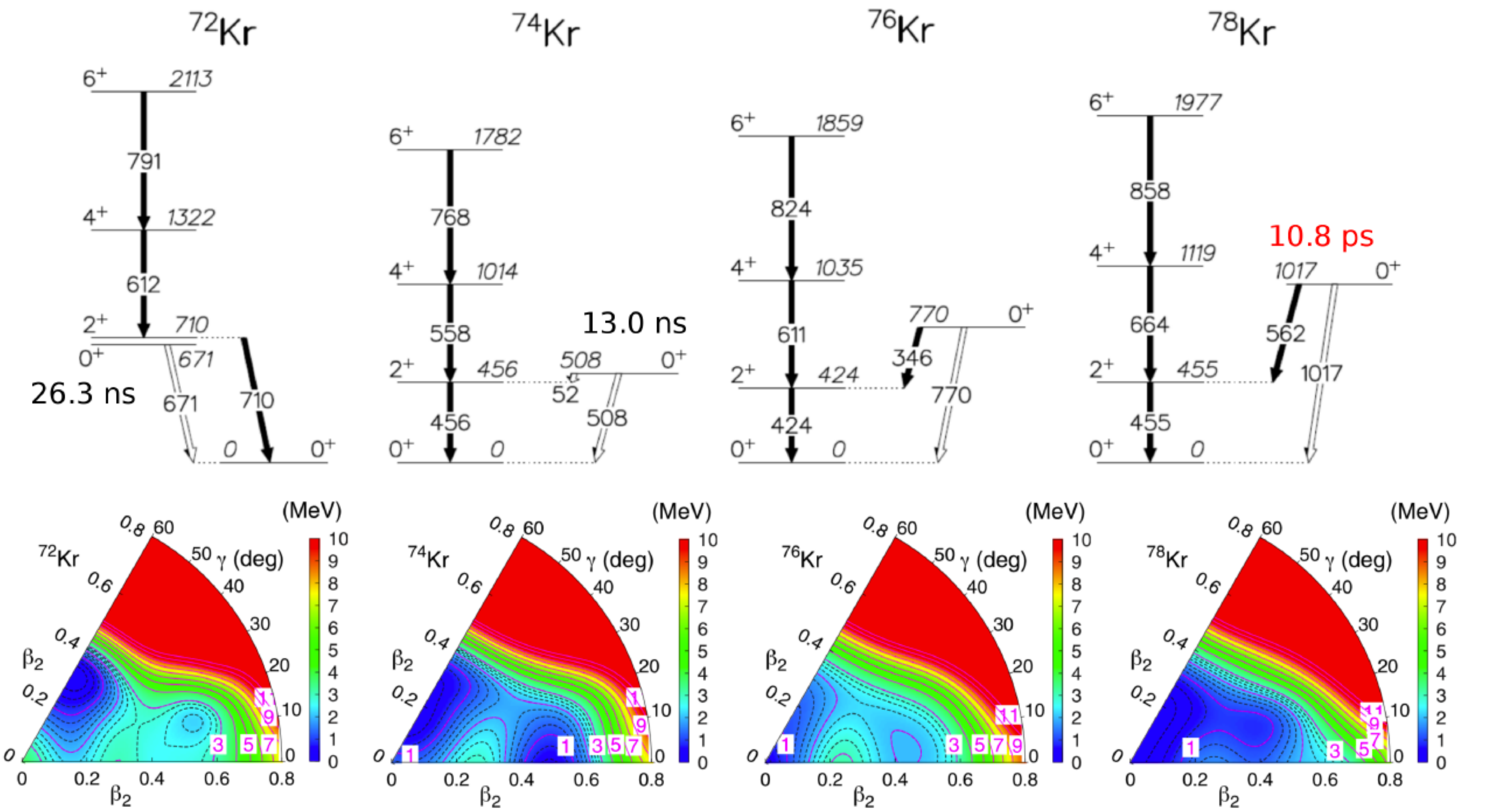
Nature Physics 14 2018, 1163



K. Heyde J.L. Wood REVIEWS OF MODERN PHYSICS 83, 2011.

Shape coexistance in Kr isotpes

delayed conversion
electron spectroscopy



Transfer reactions $^{3}He,n$

Let's look at one example: ^{60}Zn

PHYSICAL REVIEW C VOLUME 10, NUMBER 2 AUGUST 1974

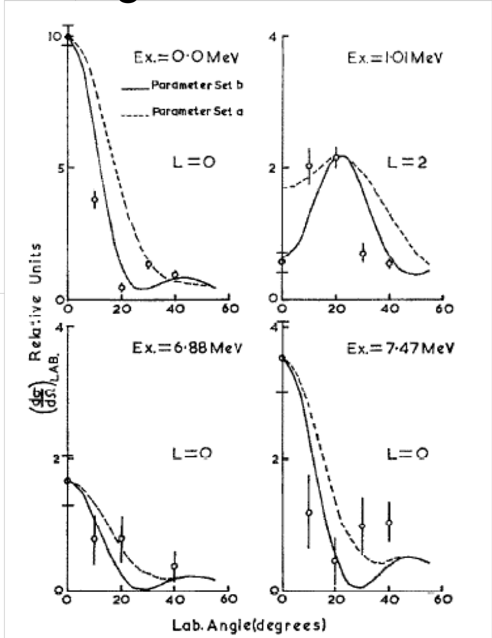
γ-ray transitions in ^{48}Cr and ^{60}Zn

R. Kamermans, H. W. Jongsma, J. van der Spek, and H. Verheul
Natuurkundig Laboratorium der Vrije Universiteit, Amsterdam, The Netherlands

(Received 28 January 1974)

The level structure of the $N = Z =$ even nuclei ^{48}Cr and ^{60}Zn was investigated. The levels were excited in the (^{3}He, n) reaction. By measuring direct γ radiation in coincidence with the outgoing neutrons information about the γ decay of the levels was obtained.

Angular distribution



distributions from the $^{58}Ni(^{3}He,n)^{60}Zn$ reaction. Curves predictions.

^{58}Ni (^{3}He,n) ^{60}Zn

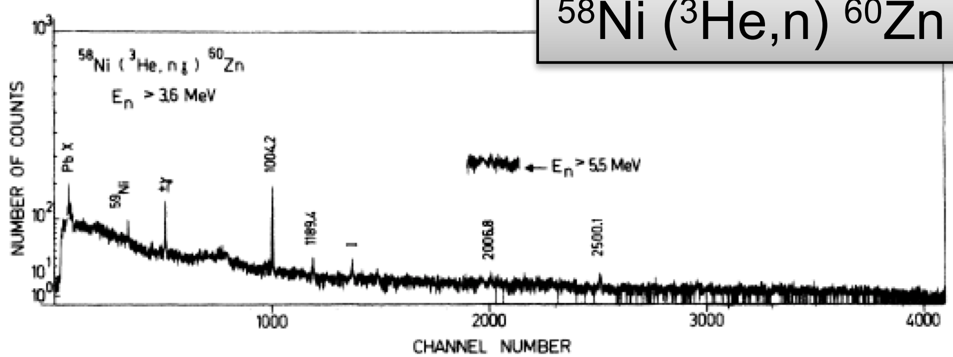
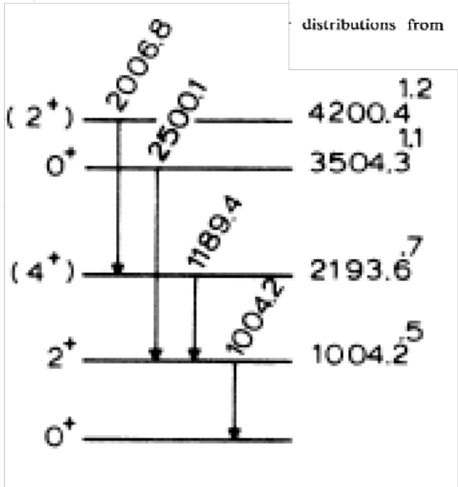
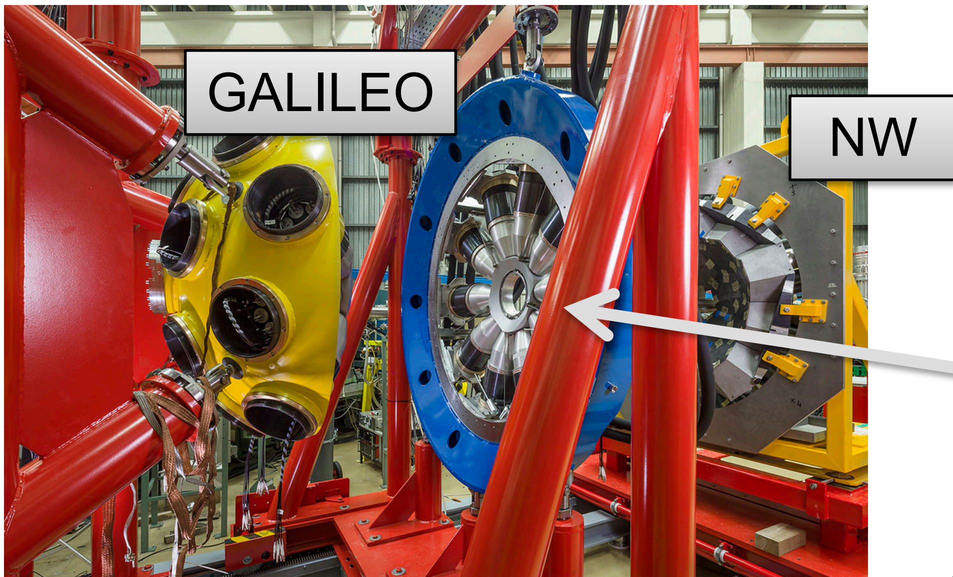


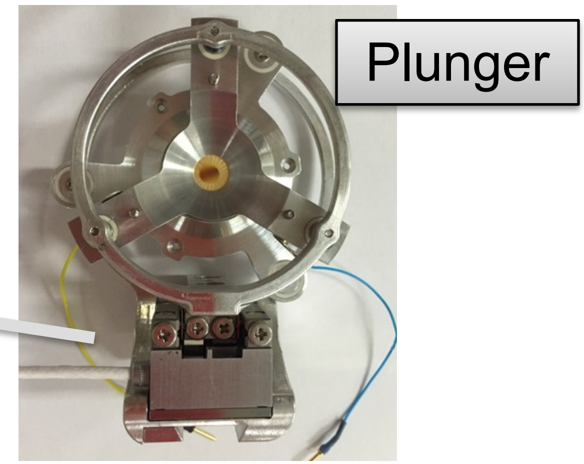
FIG. 5. γ spectrum coincident with neutrons with an energy above 3.6 MeV.

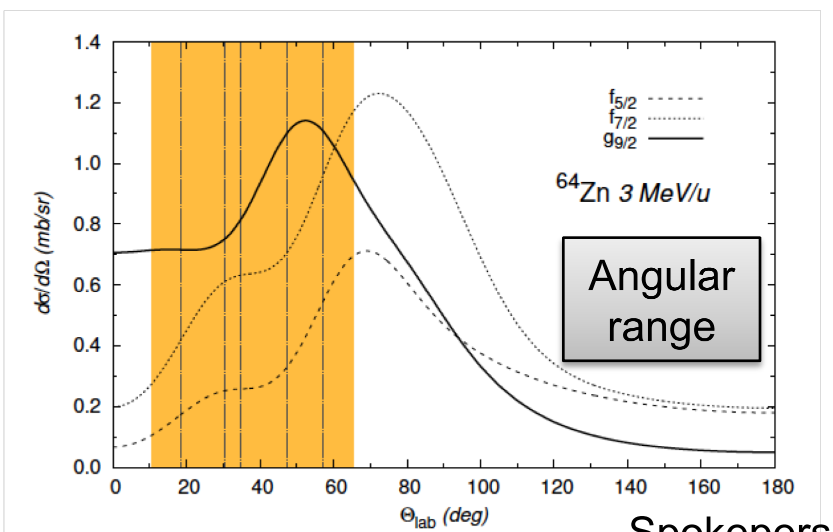


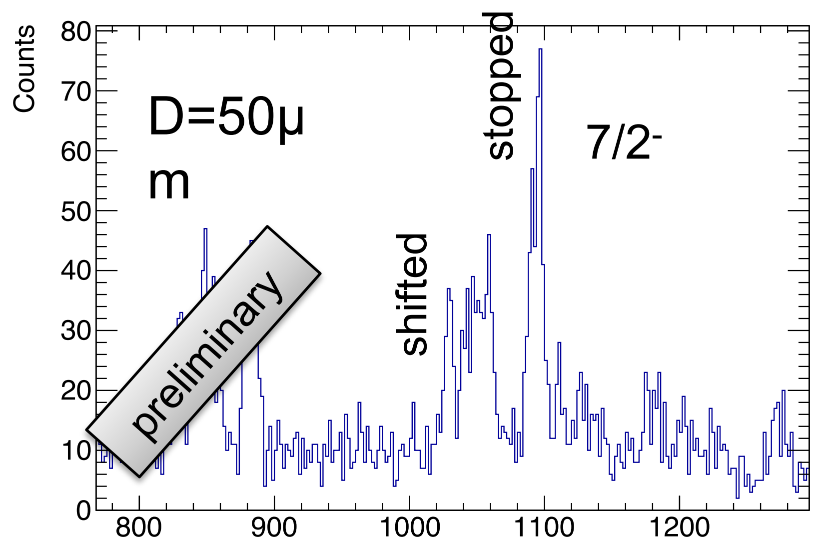
Neutron detectors NE213 n/γ discrimination and a HPGe detector

$^{64}Zn(d,n)^{65}Ga$ lifetimes 3 MeV.A



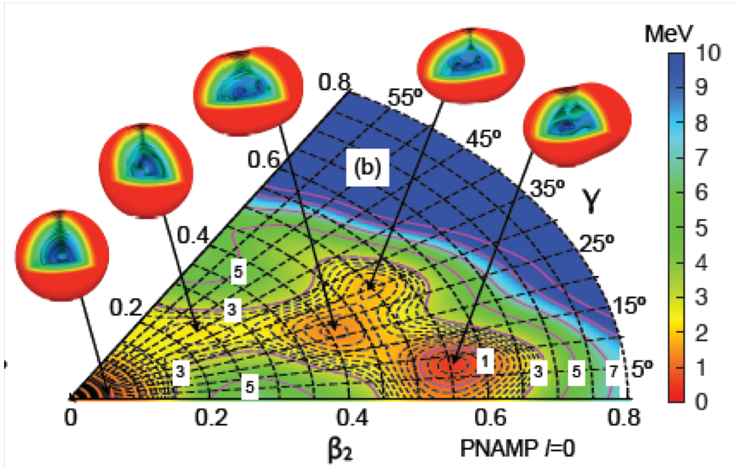






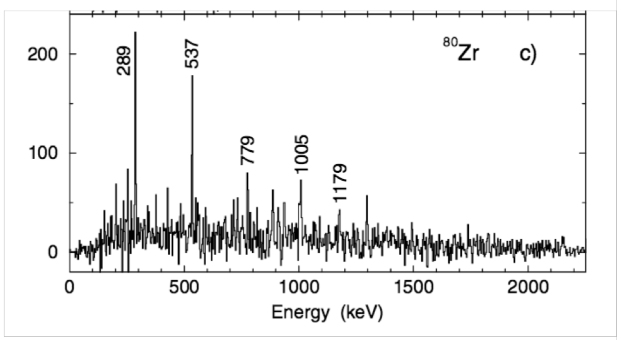
Spokeperson: V. Modamio

Shape coexistence in ^{80}Zr

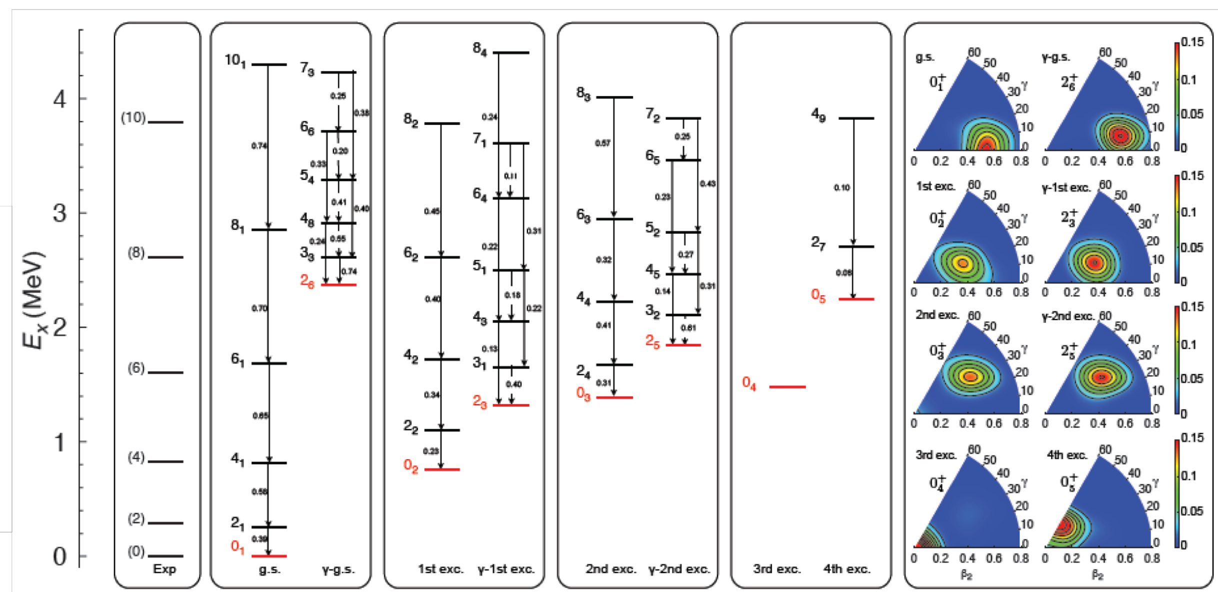


Five 0+ states below 2.25 MeV that correspond to different minima in the triaxial potential energy landscape which constitutes a unique example of multiple shape coexistence in the nuclear chart.

Fusion-evaporation reaction ^{24}Mg (^{58}Ni,2n)



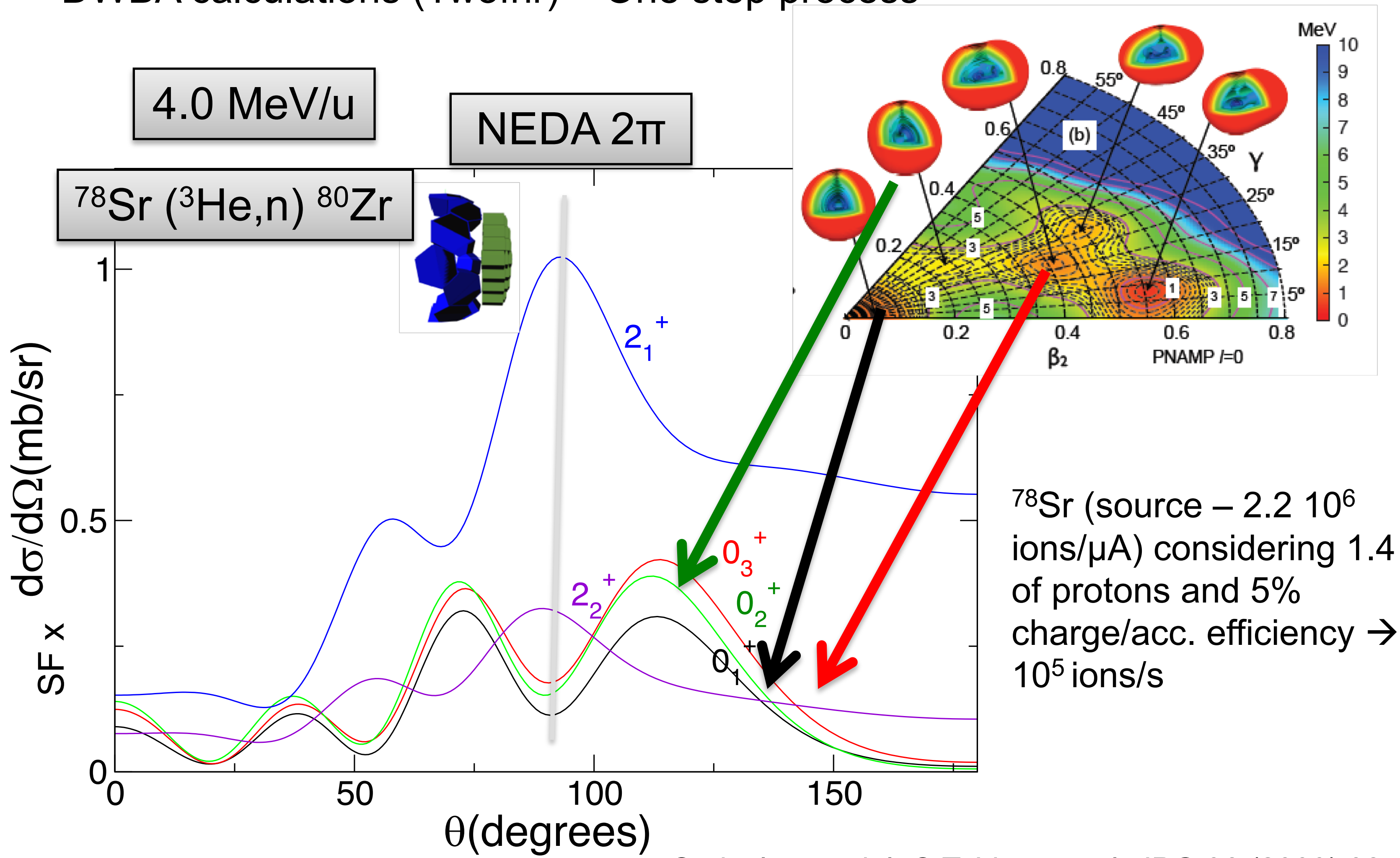
S.M. Fisher et al., PRL87, 132501 (2001)



T. Rodriguez and J.L. Egido, Physics Letters B 705 (2011) 255–259

Shape coexistence in ^{80}Zr

DWBA calculations (Twofnr) – One step process



^{78}Sr (source – 2.2 10^6 ions/μA) considering 1.4 μA of protons and 5% charge/acc. efficiency → 1.5 10^5 ions/s

Optical potential: C.T. Liang et al. JPG 36 (2009) 085104

Broken mirrors: the ^{36}Ca-^{36}S case

PHYSICAL REVIEW C **98**, 011302(R) (2018)

Rapid Communications

Broken mirror symmetry in ^{36}S and ^{36}Ca

J. J. Valiente-Dobón,[1] A. Poves,[2] A. Gadea,[3] and B. Fernández-Domínguez[4]

[1]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Legnaro, Italy*

[2]*Departamento de Física Teórica and IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-2804 Madrid, Spain*

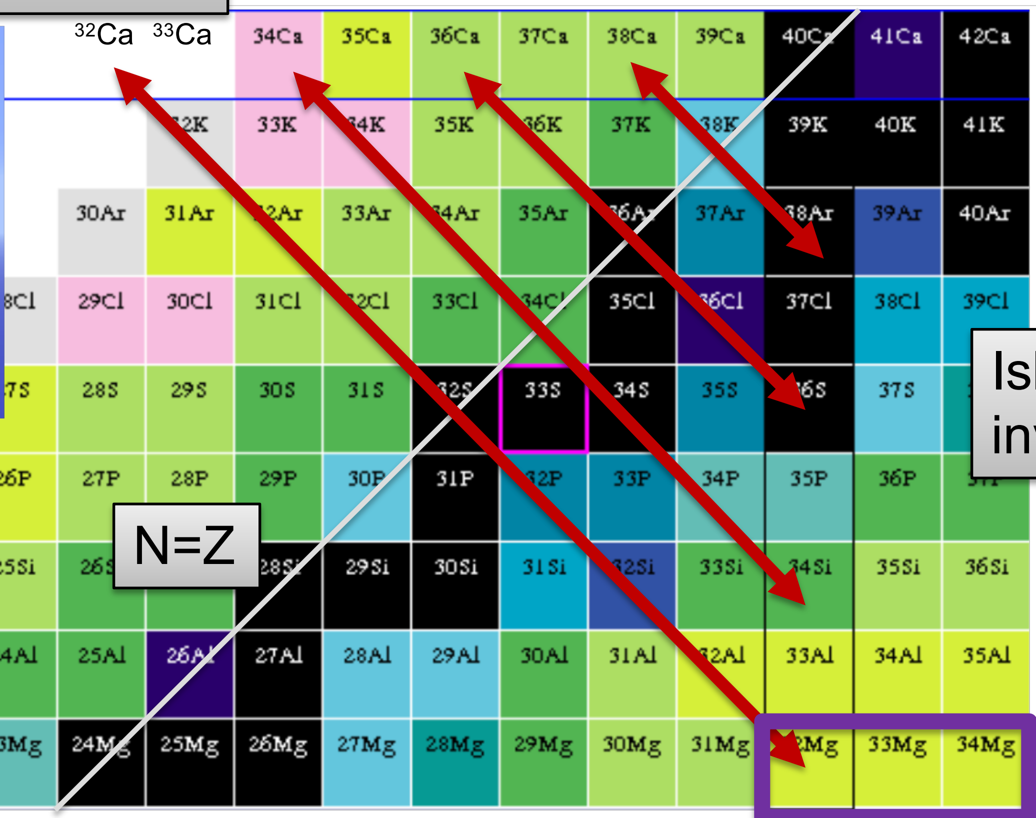
[3]*Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain*

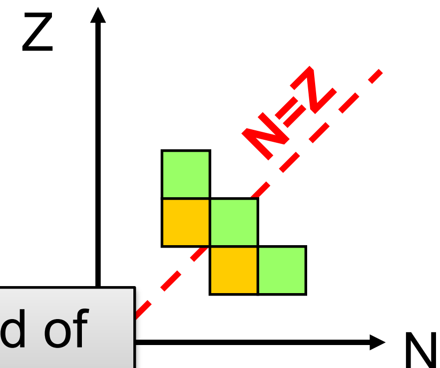
...mento de Física de Partículas and IGFAE, Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain

Isospin symmetry Island of inversion

Mirror Energy Differences

$$MED_J = E_{J,Z>} - E_{J,Z<}$$





Island of inversion

LSSM calculations for ^{36}Ca-^{36}S

PHYSICAL REVIEW C 86, 064609 (2012)

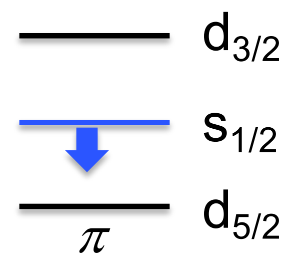
Cross sections for one-neutron knock-out from ^{37}Ca at intermediate energy

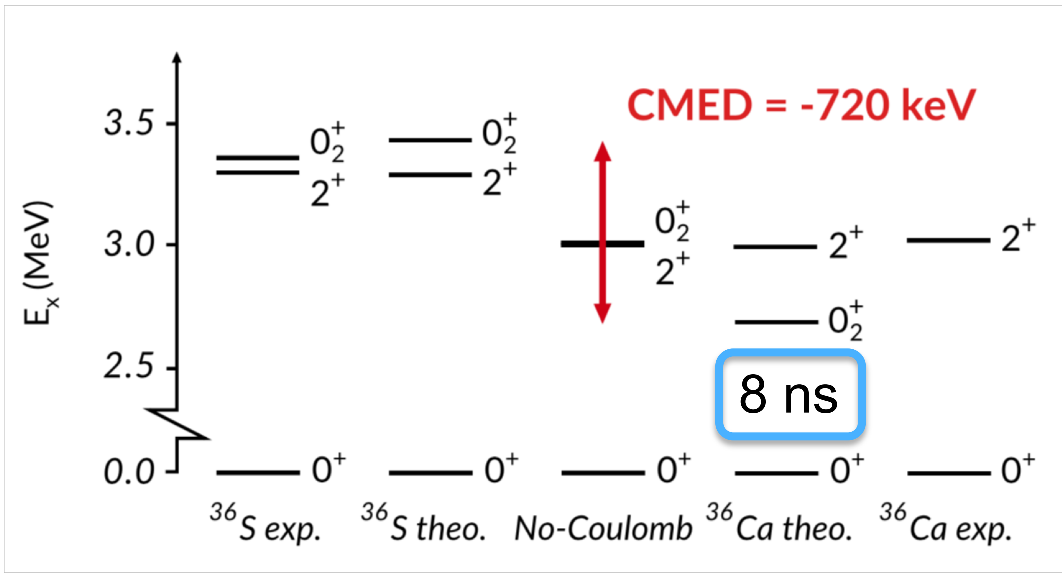
A. Bürger,[1,2,*] F. Azaiez,[3] A. Algora,[4] A. Al-Khatib,[1] B. Bastin,[5] G. Benzoni,[6] R. Borcea,[7] C. Bourgeois,[3] P. Bringel,[1] E. Clément,[2] J.-C. Dalouzy,[8] Z. Dlouhý,[9] Z. Dombrádi,[4] A. Drouart,[2] C. Engelhardt,[1] S. Franchoo,[3] Z. Fülöp,[4] A. Görgen,[2] S. Grévy,[8] H. Hübel,[1] F. Ibrahim,[3] W. Korten,[2] J. Mrázek,[9] A. Navin,[8] F. Rotaru,[7] P. Roussel Chomaz,[8] M.-G. Saint-Laurent,[8] G. Sletten,[10] D. Sohler,[4] O. Sorlin,[8] M. Stanoiu,[7] I. Stefan,[8] C. Theisen,[2] C. Timis,[11] D. Verney,[3] and S. Williams[11]

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Physics Letters B 647 (2007) 237–242
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

The $T = 2$ mirrors ^{36}Ca and ^{36}S: A test for isospin symmetry of shell gaps at the driplines

P. Doornenbal[a,b], P. Reiter[a,*], H. Grawe[b], T. Otsuka[c,d], A. Al-Khatib[e], A. Banu[b], T. Beck[b], F. Becker[b], P. Bednarczyk[b,f], G. Benzoni[g], A. Bracco[g], A. Bürger[e], L. Caceres[b,h], F. Camera[g], S. Chmel[e], F.C.L. Crespi[g], H. Geissel[b], J. Gerl[b], M. Górska[b], J. Grębosz[b,f], H. Hübel[e], M. Kavatsyuk[b,i], O. Kavatsyuk[b,i], M. Kmiecik[f], I. Kojouharov[b], N. Kurz[b], R. Lozeva[b,j], A. Maj[f], S. Mandal[k], W. Meczynski[f], B. Million[g], Zs. Podolyák[l], A. Richard[a], N. Saito[b], T. Saito[b], H. Schaffner[b], M. Seidlitz[a], T. Striepling[a], Y. Utsuno[c,d], J. Walker[b], N. Warr[a], H. Weick[b], O. Wieland[g], M. Winkler[b], H.J. Wollersheim[b]



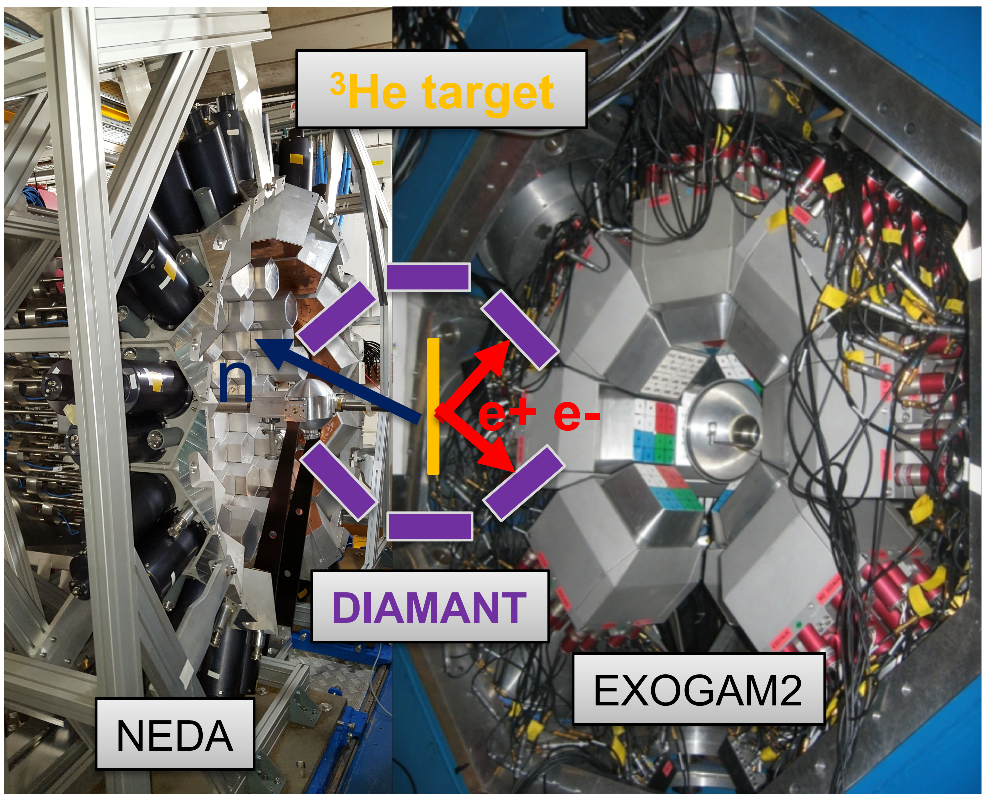


π	^{36}Ca	υ
$(sd)^{12}$		$d_{5/2}^6 s_{1/2}^1 d_{3/2}^1$
$d_{5/2}^6 s_{1/2}^2 d_{3/2}^2\ (pf)^2$		$d_{5/2}^6 s_{1/2}^1 d_{3/2}^1$
$(sd)^{12}$		$d_{5/2}^6 s_{1/2}^2$

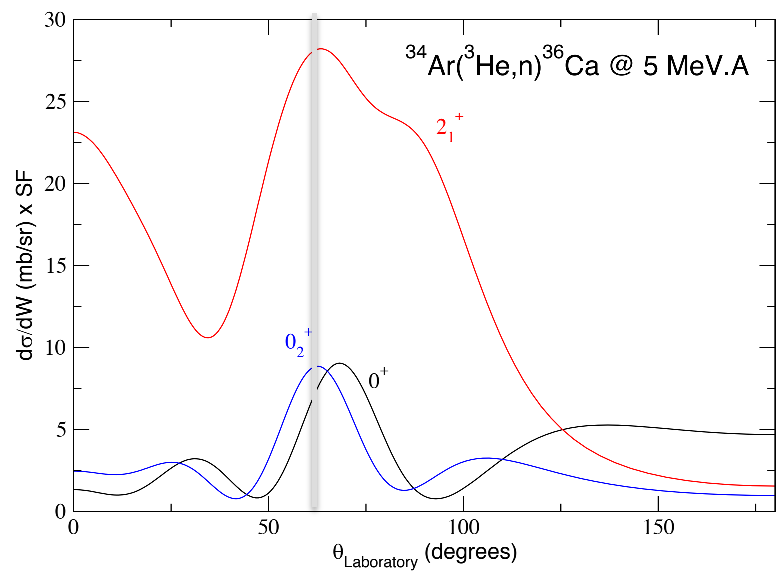
- Sdpfu-mix interaction: model space (sdpf)$\pi\nu$ and (sd) $\pi\nu$
- two-body matrix elements of the Coulomb potential

How to measure the CMED in ^{36}Ca?

- Populate the 0_2^+ via ^{34}Ar (^{3}He,n) ^{36}Ca 5MeV.A
- Measure the $0^+ \rightarrow 0^+$ transition internal pair production e^+e^- The e+e- pair production branch in the 0+ → 0+ transition is 50 more intense than the EC branch.
- E_{e+e-} = 2700 – 1022 ~ 1700 keV (DIAMANT to measure)
- Solid ^{3}He target (patent)
- Exp. apparata: EXOGAM2, DIAMANT, NEDA



DWBA calculations (Twofnr) – One step process – Abs value for evaluation normalized to ^{36}Ar (^{3}He,n) ^{38}Ca

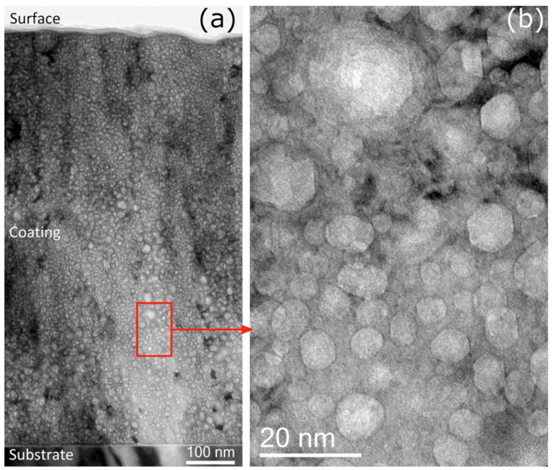


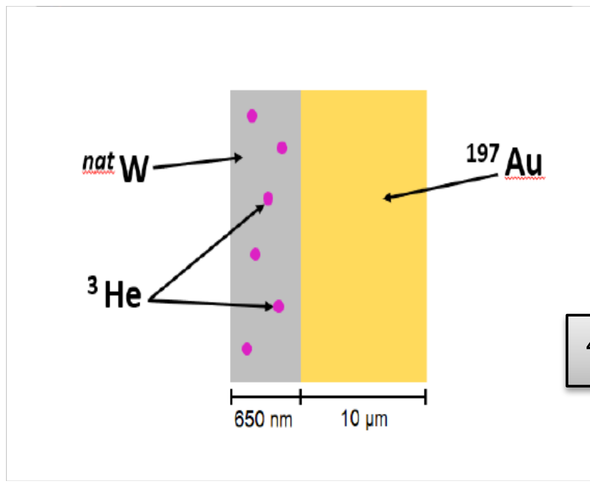
NEDA angular coverage

^{3}He targets for transfer

Sevilla: J. Gómez (CNA), F.J. Ferrer Fernández (CNA), B. Fernández (CNA), Mª A. Fernández (ICMSE), Vanda Godinho (ICMSE)

Research line: Development of nanoporous films fabricated by magnetron sputtering (MS) to stabilize gas nanobubbles at ultra-high density and pressure.





Incorporation of the process gas (i.e. ^{4}He) during MS growth of nanoporous cobalt films
B. Lacroix, V. Godinho, A. Fernández*. Micron 108 (2018) 49-54*

^{4}He - implantation – 10^{17} at/cm^2

Letter to the Editor
An implanted ^{4}He target for experiments with radioactive beams
L. Weissman [a,*], R. Raabe [a], M. Huyse [a], G. Koops [a], H. Pattyn [a], G. Terwagne [b], P. Van Duppen [a]
[a] *Instituut voor Kern-en Stralingsfysica, University of Leuven, B-3001 Leuven, Belgium*
[b] *Laboratoire interfacultaire d'Analyses par ractions nuclaires (LARN), Facultes Universitaires N-D de la Paix, 22 Rue Muzet, B-5000 Namur, Belgium*
Received 1 November 1999; received in revised form 7 March 2000

Main challenges for the study of the (^{3}He,n) reactions:

- To fabricate ^{3}He solid targets. Constituted by ^{3}He trapped in a matrix of a high atomic weight element. First option W:^{3}He targets. Second option Au:^{3}He targets.
- To minimize the ^{3}He consumption during fabrication of the targets.
- To reduce main contaminants C, O, N or H. The production of pure targets (^{3}He and the matrix element). Impurities lower than 5%.

Low ^{3}He consumption

To minimize the ^{3}He consumption during fabrication of the targets.
Application of the magnetron sputtering methodology under static or quasi-static conditions. Spanish Patent application nr. P201831107. Submitted 15-Nov-2018.
"Prodedimiento de obtención de un material sólido con agregados gaseosos mediante pulverización catódica por magnetrón en condiciones estáticas o cuasiestáticas para reducir el consumo de gas". A. Fernández, D. Hufschmidt, V. Godinho, M.C. Jiménez.

The first set of W:^{3}He solid targets. Sample Lote 4

The density of ^{3}He is 3×10^{17} atoms/cm^2 (equivalent to 1.4 μg/cm^2) for a total thickness of 650 nm. The ^{3}He makes up to 7.5 at% of the whole target composition.
Contaminants such as ^{12}C, ^{16}O and H are also present, 3%, 11% and 11% respectively.
Nitrogen not detectable. Total trace elements (Ti,Cr, Ni,Fe,Cu,Ta) below 2 at%. Main contamination O and H.

The second set of W:^{3}He solid targets. Sample E33

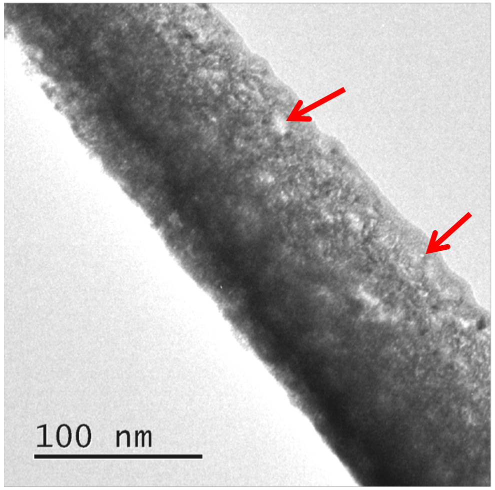
The density of ^{3}He is 1.1×10^{18} atoms/cm^2 (equivalent to 5.5 μg/cm^2) for a total thickness of 2.4 μm. The ^{3}He makes up to 8.5 at% of the whole target composition.
Contaminants such as ^{12}C, ^{16}O and H are also present, 14%, 2% and 10% respectively.
Nitrogen not detectable. Total trace elements (Ti,Cr, Ni,Fe,Cu,Ta) not significant. Main contamination C and H.

Work in progress to reduce main contaminants C, O and H

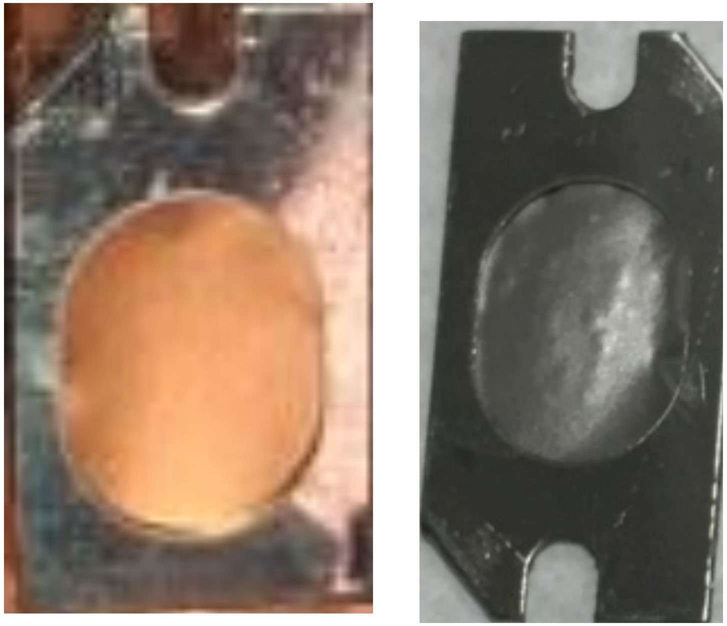
Microstruture of the W:^{3}He solid targets

The compositional IBA analysis and the microestructural study by TEM was done on W:^{3}He films grown on Si substrates. Films were grown simultaneously on a a gold foil with thickness 10 mg/cm^2 for the required target fabrication.

The microstructure of the W:^{3}He solid targets



TEM image of a film slice showing pores marked with arrows



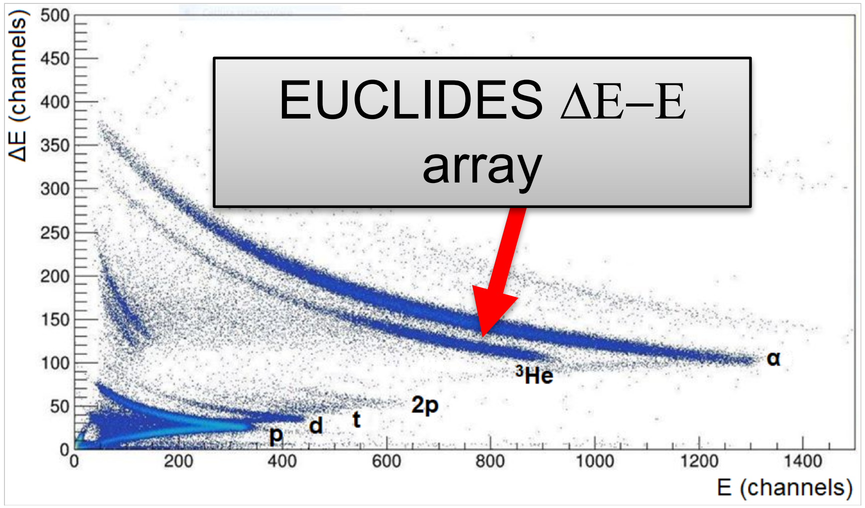
Target fabrication onto a gold foil. Photographs before and after target growth.

Sevilla: J. Gómez (CNA), F.J. Ferrer Fernández (CNA),
B. Fernández (CNA), Mª A. Fernández (ICMSE), Vanda Godinho (ICMSE)

^{3}He target test at LNL

$^{64}Zn(^{3}He,n)^{66}Ge$

G. Carozzi Tesi Magistrale, U. di Padova 2018



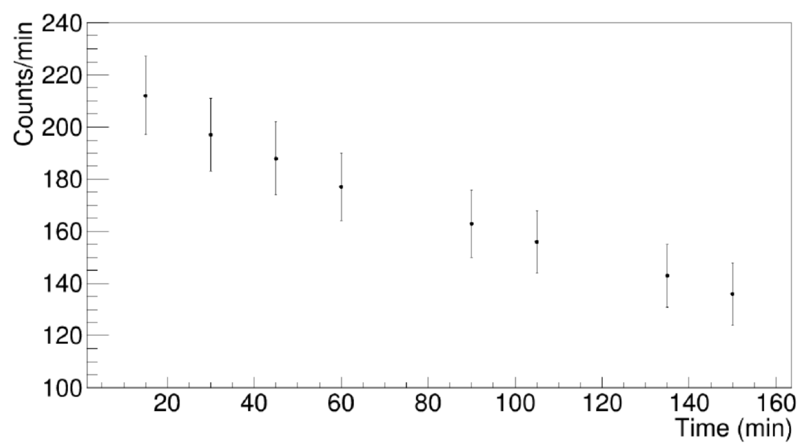


Figure 5.3: Change over time of the counting rate of ^{3}He in one of the front facing detectors of EUCLIDES. For all of the data points in this chart, the intensity of the beam is constant at 5 pnA.

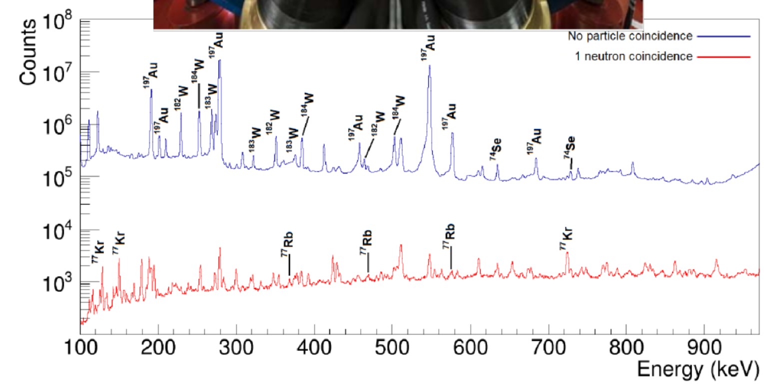


Figure 5.4: Comparison of the γ-ray energy spectrum measured by GALILEO, with (in red) and without (in blue) the condition of coincidence between each γ ray and one neutron. To produce this spectrum, the small neutron cut in the TOF-ZCO matrix shown in Figure 4.7 was used. For some of the peaks, the corresponding nucleus is reported.

Diminish the contaminants, Au substrate?

Summary

- Study of shape coexistance, population of intruder 0^+ states/low-lying states with transfer reactions in inverse kinematics (RIB)
- Development of solid ^{3}He targets
  - for plunger measurements/DSAM
  - need of efficient detectors for e+e-
- Many challenges in the development of solid(sputtered) ^{3}He targets
  - High-Z substrates to reduce background
  - Low ^{3}He consuption
  - Low contaminations
- Continuus developments ongoing to reach the final goal Sevilla/LNL

END