FIPPS

FIssion **P**roduct **P**rompt γ–ray **S**pectrometer

a new instrument of ILL
for the spectroscopy of neutron-rich nuclei

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[2]LPSC-Grenoble

NUSPIN 2017

26-29 June 2017

The Institut Laue-Langevin (ILL) – *since 1971*

- 58 MW high flux reactor with intense extracted neutron beams
- 12 member states (F, D, UK, E, CH, A, I, CZ, S, B, SK, DK)
- $>$ 40 instruments (mainly for neutron scattering)
- user facility (2000 scientific visitors from 45 countries per year)

Outline

- Introduction:
  - spectroscopy after slow neutron-induced reactions
  - Nuclear Physics at the Institut Laue-Langevin
  - why FIPPS (EXogam at ILL (EXILL) campaign)

- The FIPPS instrument:
  - instrument layout
  - news from the first experimental campaign
  - future perspectives, physics possibilities

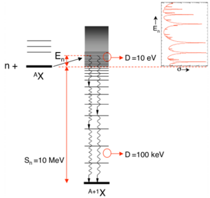
γ–ray spectroscopy after slow neutron-induced reactions

(n,γ)

$\rightarrow$ close to stability

$\rightarrow$ structure at low spin
(below n-separation energy)

$\rightarrow$ cross-sections (applicatio



γ–ray spectroscopy after slow neutron-induced reactions

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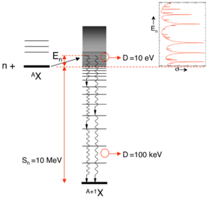
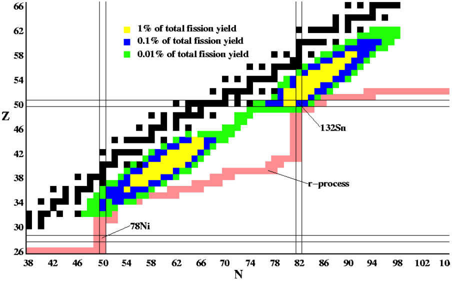


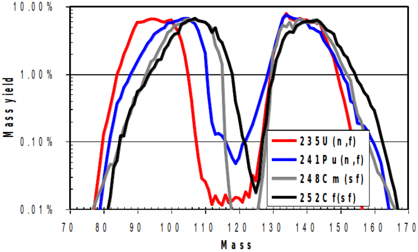
(n,fission)

→ away from stability

→ fission yields and dynamics

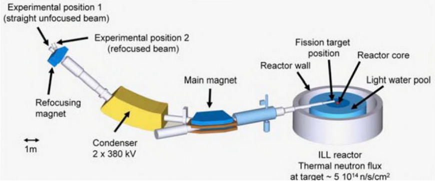
→ structure of n-rich nuclei





LOHENGRIN fission fragment separator

P. Armbruster et al., NIM **139**, 213–222 (1976)
G. Fioni et al., NIMA **332**, 175–180 (1993)



$E_{kin}/q = E/2r_{el} \qquad mv/q = Br_{magn}$

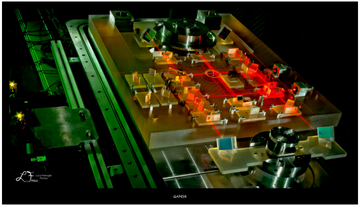
$\rightarrow \quad \Delta A/A = 3\,10^{-4} - 3\,10^{-3}$

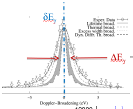
$\rightarrow \quad \Delta E/E = 10^{-3} - 10^{-2}$

up to $10^5\,\mathrm{s}^{-1}$ mass-separeted fission fragments, $T_{1/2} >= \mu s$

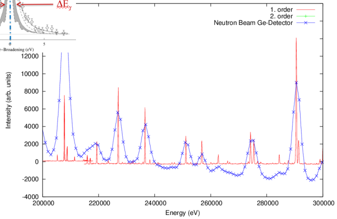
GAMma–ray Spectrometer (GAMS)

E. Kessler Jr et al., NIMA **457**, 187–202 (2001)
C. Doll et al., J. Res. Natl. Inst. Stand. Technol. **105**, 167 (2000)





High–resolution γ–ray facility



EXogam @ ILL (EXILL)

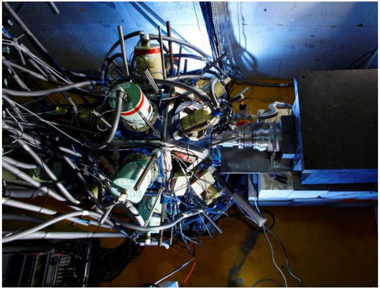
→ Highly collimated neutron beam from ILL reactor (PF1B guide)

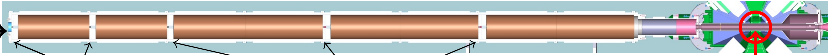
→ High efficiency and resolution Ge array (up to 52 Ge crystals, 6% @ 1.3MeV) + $LaBr_3$ detectors for fast timing

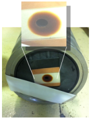
→ Fully digital electronics, trigger-less (>10 kHz/crystal)

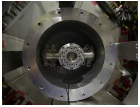
→ 2 reactor cycles ($\approx$ 100 days)

→ 14 stable (rare) and 3 actinide targets







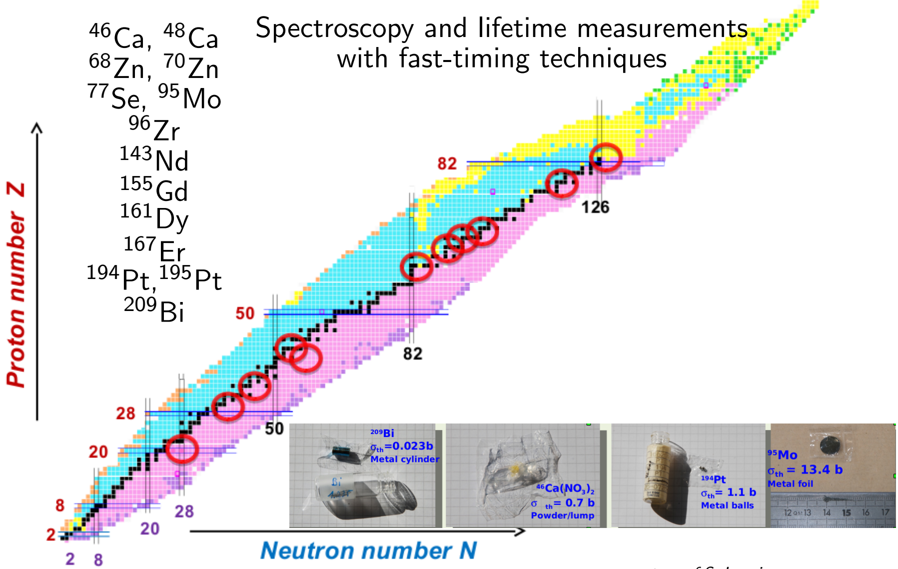


A. Blanc et al., EPJ Conf. **93**, 01015 (2015)
P. Mutti et al., EPJ Conf. **62** (2013)
J. Regis et al., NIMA **763** (2014)

The EXILL campaign: (n,γ) reactions on (rare) stable targets

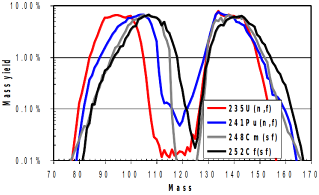
^{46}Ca, ^{48}Ca
^{68}Zn, ^{70}Zn
^{77}Se, ^{95}Mo
^{96}Zr
^{143}Nd
^{155}Gd
^{161}Dy
^{167}Er
^{194}Pt, ^{195}Pt
^{209}Bi

Spectroscopy and lifetime measurements with fast-timing techniques

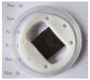


courtesy of S. Leoni

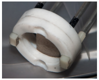
The EXILL campaign: (n,fission) reactions on actinides



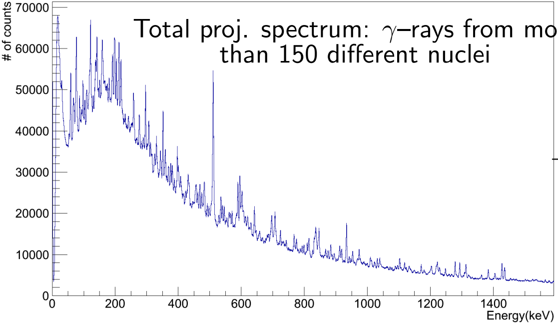
$^{235}UO_2$, σ_f =586 b
Layer sandwiched between Zr or Be backings



$^{241}PuO_2$, σ_f =1010 b
Layer sandwiched between Be backings



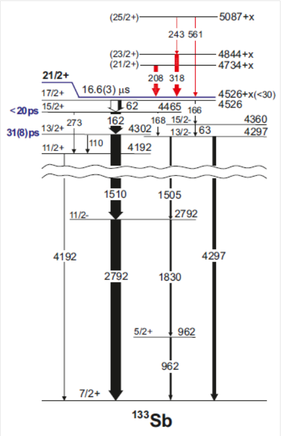
Total proj. spectrum: γ–rays from more than 150 different nuclei



$\rightarrow$ multiple γ–ray coincidences, also with fission partners

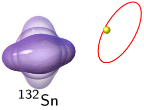
Single-particle vs. collective phenomena around ^{132}Sn: delayed γ-ray spectroscopy of n-induced fission fragments

Selected highlight from the EXILL fission campaign:

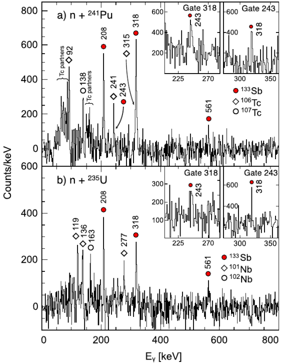


G. Bocchi et al., PLB **760**, 273–278 (2016)

$\rightarrow$ New event-builder for cross-isomer coincidences



Milan-Cracow collaboration

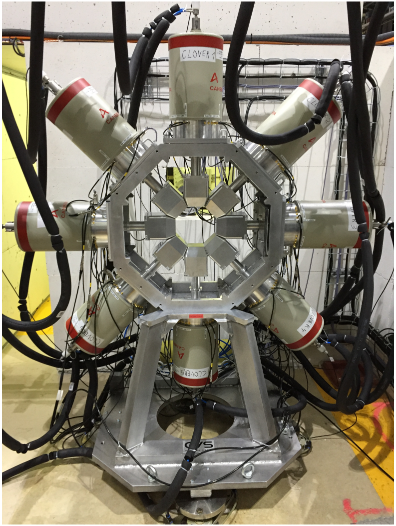


✓ Prompt-delayed γ coincidences across the isomer

✓ Lifetimes from $LaBr_3$ data (FATIMA campaign)

✓ New microscopic approach to particle-core couplings

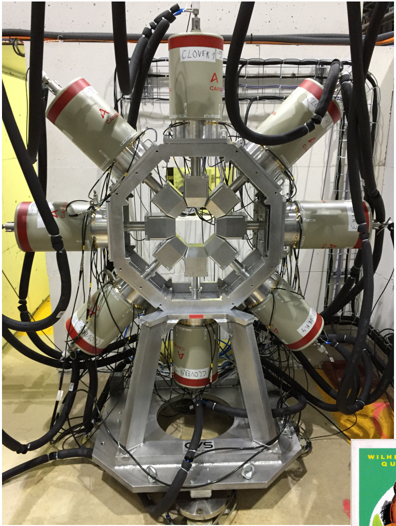
The new ILL instrument FIPPS (phase I)



- ✓ intense thermal neutron pencil beam
- ✓ stable, radioactive and actinide targets
- ✓ γ–ray detection:
  - → high-resolution HPGe clovers
  - → symmetry around target position
  - → digital electronics, list-mode data
- ✓ ancillary detectors

Endurance
Setting the pace

The new ILL instrument FIPPS (phase I)



✓ intense thermal neutron pencil beam

✓ stable, radioactive and actinide targets

✓ γ–ray detection:

- → high-resolution HPGe clovers
- → symmetry around target position
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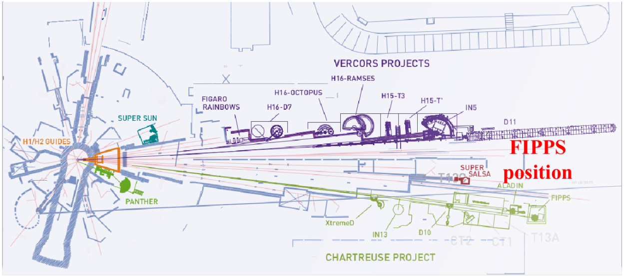
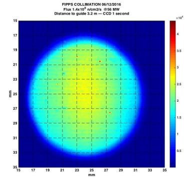
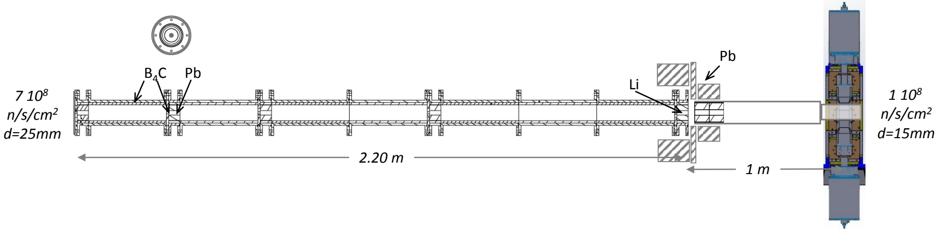
✓ ancillary detectors

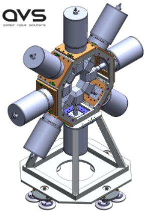


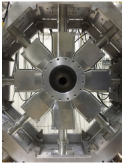


- ✓ thermal neutron guide (H22)
- ✓ n flux [n/cm^2/s]: 7×10^8 prior collimation $\rightarrow$ 1×10^8 at target pos.
- ✓ external γ-ray background 5 to 10 times better than at PF1b (EXILL)



The HPGe detector system. FIPPS efficiency





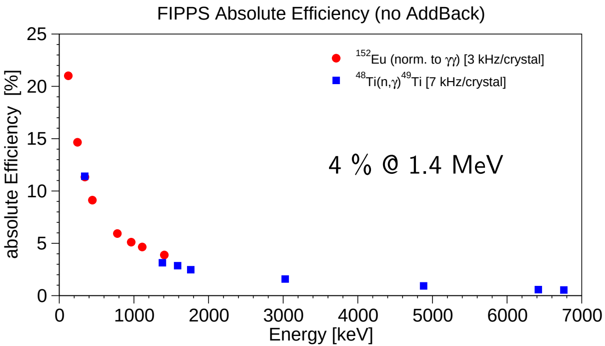
- ✓ 8 HPGe clovers (4x50x80)
- ✓ target-to-clover distance = 9 cm
- ✓ FWHM @ 1.3 MeV (^{60}Co) ≈ 2 keV
- ✓ digital electronics (100 MHz, CAEN V1724)
  → high count-rate

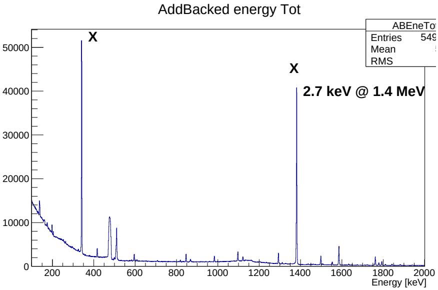
Add-Back factor:

1.11 (2) @ 340 keV

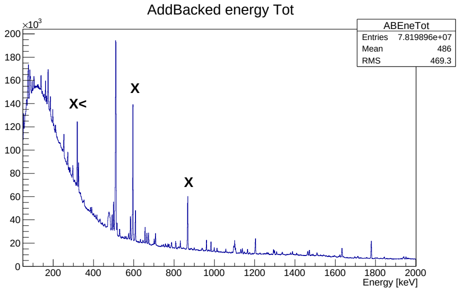
1.27 (3) @ 1.4 MeV

1.55 (6) @ 6.8 MeV





^{48}Ti(n,γ)^{49}Ti, 17 mg, $\sigma = 6$ b



^{209}Bi(n,γ)^{210}Bi, 3 g, $\sigma = 11$ mb

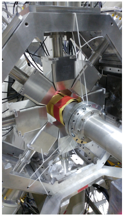
Main background sources:

n capture on B (will be improved in next campaign)

Compton (no shields)

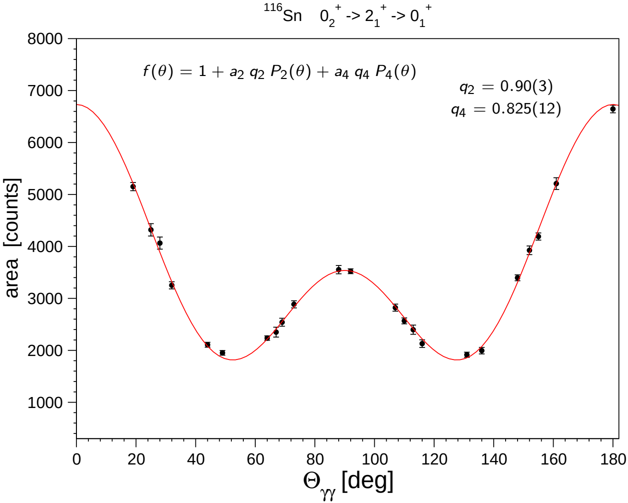
FIPPS performance: angular correlations

use individual crystals in order to increase the number of angular combinations



$^{115}Sn(n,\gamma)^{116}Sn$

gate on 1293 keV $\rightarrow$ 463 keV



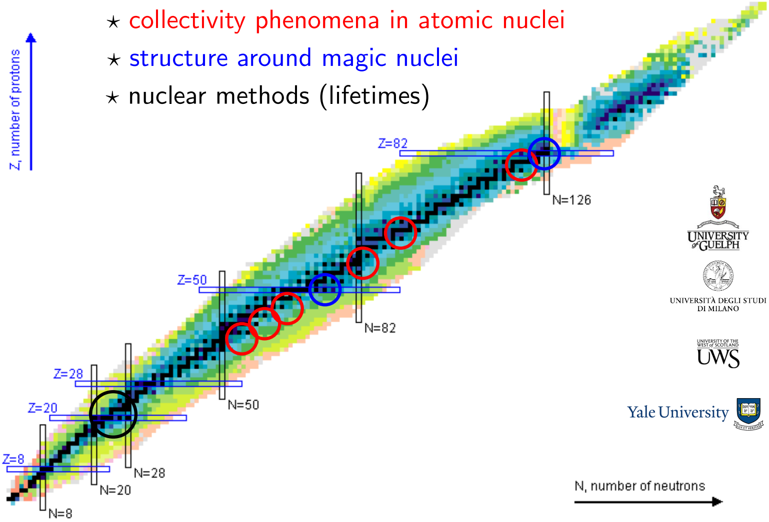
J. Jolie & ILL

FIPPS first experimental campaign (Dec. 2016, Jan.-March 2017)

6 experiments, ≈ 30 users, 11 universities and labs (EU, US, CAN)

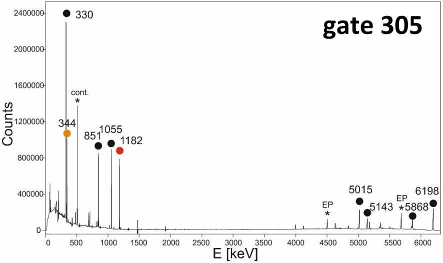
γ-ray spectroscopy after (n,γ) reactions on stable isotopes (15 targets):

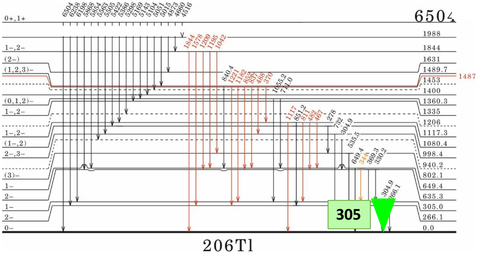
- ⋆ collectivity phenomena in atomic nuclei
- ⋆ structure around magic nuclei
- ⋆ nuclear methods (lifetimes)

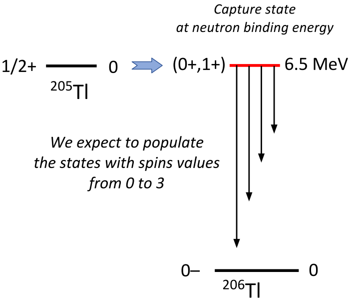


NEUTRONS FOR SOCIETY · LPSC Grenoble · PAN · Universitas Varsoviensis · University of Guelph · INFN Istituto Nazionale di Fisica Nucleare · Università degli Studi di Milano · GANIL · UWS University of the West of Scotland · CSNSM · Yale University · IKP · Technische Universität Darmstadt · Manchester 1824 The University of Manchester

^{205}Tl(n,γ)^{206}Tl: nuclear structure around ^{208}Pb







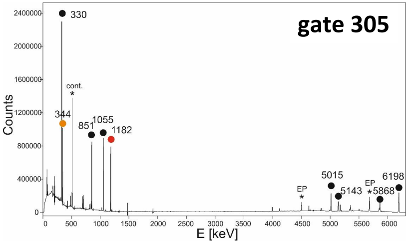
We expect to populate the states with spins values from 0 to 3

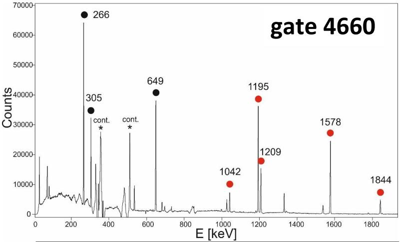
C.C.Weitkamp, J.A.Harvey, G.G.Slaughter, E.C.Campbell, Bull.Am.Phys.Soc. 12, No.6, 922, Y10 (1967)

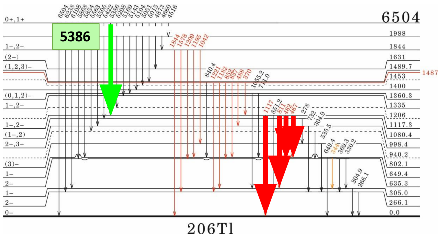
G.A.Bartholomew, E.D.Earle, M.A.Lone, Bull.Am.Phys.Soc. 15, No.4, 550, EG11 (1970),

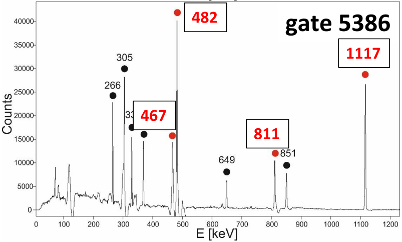
exp. 17-3-8, N. Cieplicka et al.

^{205}Tl(n,γ)^{206}Tl: nuclear structure around ^{208}Pb









exp. 17-3-8, N. Cieplicka et al.

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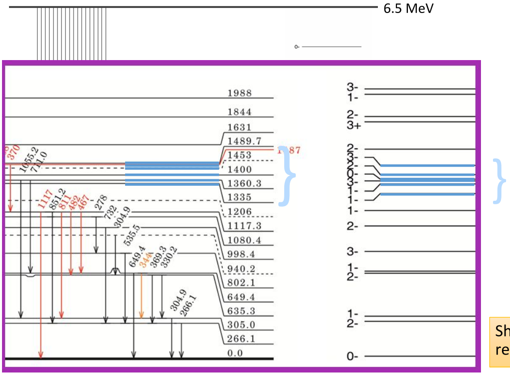


A preliminary comparison – good agreement with theoretical calculations.

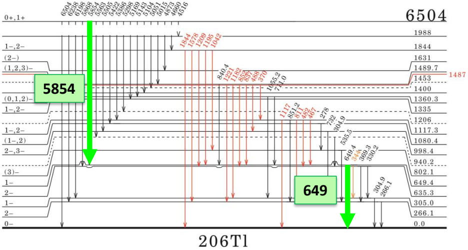
Clear correspondence between theory and expriment including the group of 6 states around 1.4 MeV.

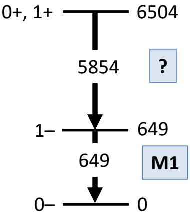
Shell-Model calculations with realistic Kuo-Herling interactions

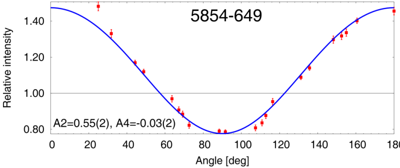
exp. 17-3-8, N. Cieplicka et al.

^{205}Tl(n,γ)^{206}Tl: nuclear structure around ^{208}Pb

^{205}Tl(n, γ)^{206}Tl – angular correlations of γ rays







Multiplicity of the 5854-keV γ ray

(theoretical values for different spin hipothesis):

E1 0+ → 1– ⇨ A2 = 0.5, A4 = 0.0

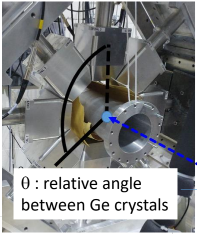
E1 1+ → 1– ⇨ ~~A2 = -0.25, A4 = 0.0~~

exp. 17-3-8, N. Cieplicka et al.

Gamma-ray Induced Doppler Shift Attenuation Method: Test Experiment

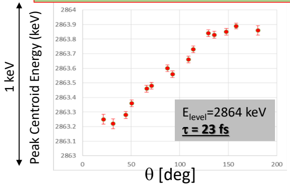
- from 29/01/2017 to 06/02/2017 on FIPPS
- **PRINCIPLE:**
  In a two-step cascade, the emission of a primary gamma-ray is Inducing a recoil of several hundreds of eV on the emitting nucleus. The energy of a sufficiently fast emitted second gamma ray will be Doppler shifted.
- Comparison measured Doppler shifts to those calculated from simulations of the atomic slow down process yields ***information on the lifetimes of the nuclear levels.***

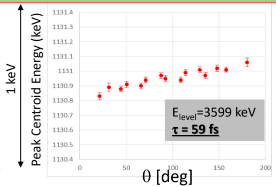
TARGETS used:
NaCl (^{36}Cl), Ti_2O_3 (^{49}Ti), Ti metallic (^{49}Ti),
NiF_2 (^{59}Ni), Ni metallic (^{59}Ni)

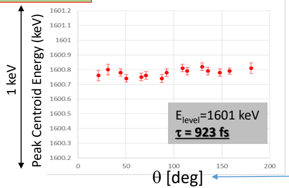


Data from ^{36}Cl associated to states with different lifetimes

Short lifetime → →→→→→→→→→→→→→→→→→→ Long Lifetime



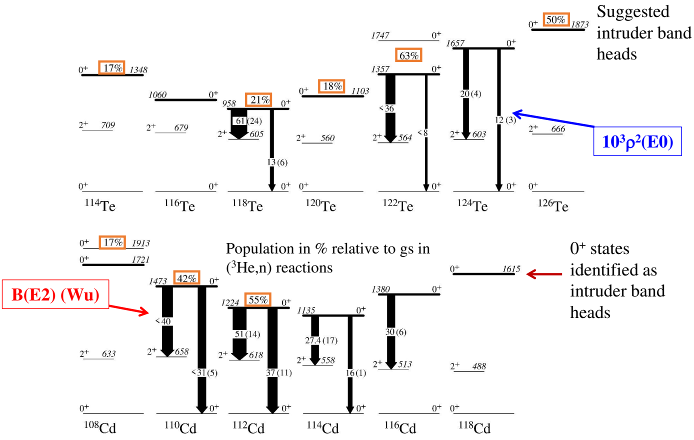




exp. 17-3-7, F.C.L. Crespi, M. Jentschel et al.

Shape coexistence and nature of low-lying states in mid-shell Cd-Te isotopes

Strong similarity in structure of Cd and Te nuclei – properties of 0_2^+ states in Te match intruder 0^+ states in Cd

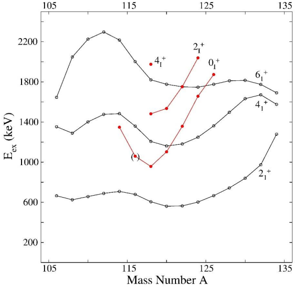


exp. 17-3-3, P. Garret et al.

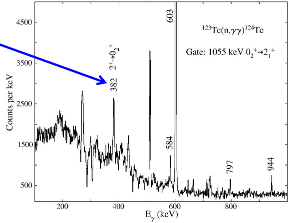
Shape coexistence and nature of low-ying states in mid-shell Cd-Te isotopes

Requirement: seek missing low-energy transitions amongst states to aid in identifying intruder band – use the ^{123}Te(n,γ) reaction

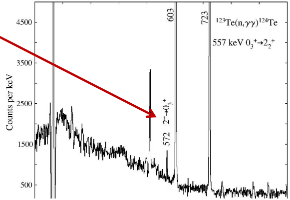
Energy systematics in the Te isotopes



γ decay from suggested 2^+ member of intruder band



Newly observed γ decay from higher lying 2^+ state to 0_3^+ state



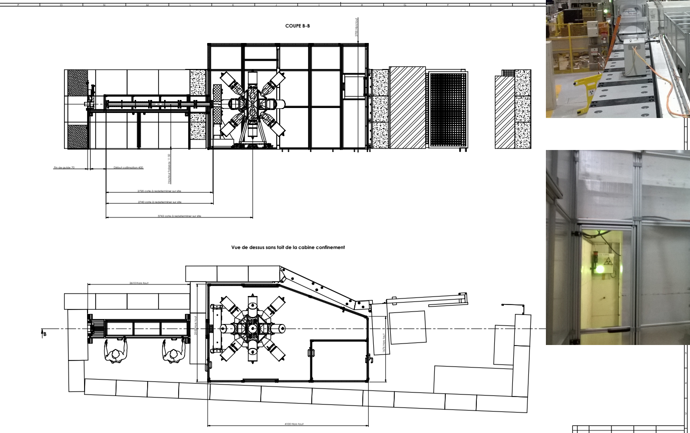
exp. 17-3-3, P. Garret et al.

- Last proposal round: 14 proposals, 300 days
  (cf. 90 days to be scheduled Oct-Dec 2017/beginning 2018)
- Oct. 2017-Dec. 2017:
  (n,γ) on (rare) stable targets,
  test of (n,fission) on ^{233,235}U with active targets

Possibilities:

- installation of additional Ge detectors (up to 16 clovers)
  + anti-Compton shields
- progressive installation of ancillary methods
  ($LaBr_3$, magnetic moment measurements, X-ray detectors...)
- (n,fission) with ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu etc. targets
- test and use of fission tags (active targets, diamond detectors, ...)
- gaseous targets, radioactive targets and actinides (with fission veto)

✓ tight polycarbonate casemate
(handling of radioactive targets)



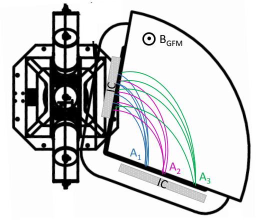
✓ new C-fiber reaction chamber
(future installation of low-energy X-ray dets)

✓ holding structure for $LaBr_3$ dets
and additional HPGe clovers (up to 16)

Study the structure of n-rich nuclei and fission mechanism

HPGe clovers + Gas-Filled-Magnet (GFM) for fission fragment selection

FIPPS phase II project submitted for *Endurance II*



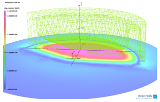
$$\Delta A/A = 2.2\,\%$$

acceptance:

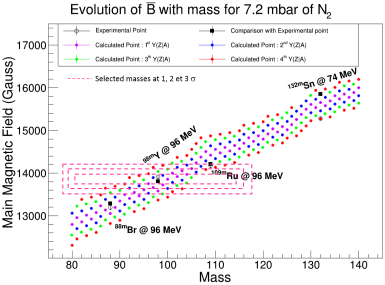
0.4 % extracted beam;

full reconstruction of ion tracks using a low-pressure TPC

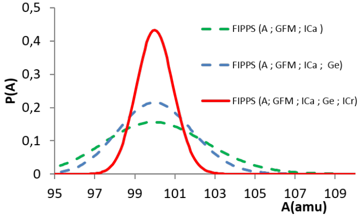
$\rightarrow$ 3.5 %



superconducting magnet designed by E. Froidefond (LPSC Grenoble)



A. Chebboubi PhD Thesis



G. Kessedjian et al.

Concluding remarks

- Nuclear studies after slow-neutron induced reactions @ ILL: Lohengrin, GAMS, EXILL campaign $\rightarrow$ structure of nuclei close to stability and n-rich nuclei produced in fission (^{133}Sb)
- FIPPS is the new Nuclear Physics instrument of ILL for prompt gamma-ray spectroscopy after slow-neutron induced reactions
- promising results are coming from the first experimental campaign ((n,γ) on stable targets -^{206}Tl,^{124}Te)
- rich experimental program for coming years ((n,γ) on radioactive targets, fission, ancillary devices, GFM...
  it depends strongly on your input!)

NEUTRONS FOR SOCIETY

Endurance
Setting the pace