FIPPS
FIssion Product Prompt
gamma-ray Spectrometer

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Summary

- Nuclear physics at ILL
- EXILL
  - Motivation
  - Setup
  - Performances
- FIPPS
  - FIPPS layout
  - FIPPS Phase I and timeline
- Conclusion
Institut Laue-Langevin

- operates 58 MW high flux reactor with intense extracted neutron beams
- operating since 1971
- today 14 member states: F, D, UK, E, CH, A, I, CZ, S, HU, B, SK, DK, IN
- over 40 instruments, mainly for neutron scattering
- **user facility:** 2000 scientific visitors from 45 countries per year
Nuclear Physics at ILL

- The LOHENGREN fission fragment separator:
  \[ \Delta A/A = 3 \times 10^{-4} - 3 \times 10^{-3} \]
  \[ \Delta E/E = 1 \times 10^{-3} - 1 \times 10^{-2} \]

  up to \(10^5/s\) mass-separated fission fragments \((T_{1/2} \geq \mu s)\)

  The LOHENGREN recoil separator

  \[ p^2 / r_{el} = q E \]
  \[ E_{kin} / q = E / 2 r_{el} \]
  \[ m v^2 / r_{magn} = q v B \]
  \[ m v / q = B r_{magn} \]


Gamma-ray spectrometer (GAMS):
EXILL

- Motivation
- Setup
- Performances
EXogam @ ILL

High efficiency germanium array

58 MW high flux reactor with intense extracted neutron beams

=> γ-ray spectroscopy of cold neutron induced reactions on 14 stable and 3 actinide targets
\( ^{235}\text{U}(n,\text{fission}) \)

\( ^{241}\text{Pu}(n,f) \) and \( ^{235}\text{U}(n,f) \) vs spontaneous fission sources
EXILL campaign at PF1B: EXOGAM @ ILL
(October 2012 → April 2013)

EXOGAM+GASP array:
Provided by GANIL and LNL

235U and 241Pu targets with thick backing
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Collimation:
φ12 mm “pencil” neutron beam

235U and 241Pu targets with thick backing
The EXILL setup

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235U and 241Pu targets with thick backing

1cm B$_4$C ceramics
5 cm Pb
Borated plastics + $^6$LiF
5 cm Pb
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- 1cm B,C ceramics
- 5 cm Pb
- Borated plastics + 6LiF
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$10^{10}$
$20\times 6 \text{ cm}^2$
The EXILL setup

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5 cm Pb

Borated plastics + $^{6}$LiF
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$10^{10}$ 20*6 cm$^{2}$  $10^{8}$ 1 cm$^{2}$
Fission targets

Targets **sandwiched between dense backings** for rapid stopping of fission fragments.

1. **\(^{235}\text{U-Zr/Sn, nominal fission rate 70 kHz}\)**
   3 layers \(\text{UO}_2\) (total 575 \(\mu\text{g/cm}^2\) of 99.7\% enriched \(^{235}\text{U}\))
laminated with Sn between 15 \(\mu\text{m}\) thick Zr foils (nuclear grade, <50 ppm Hf)

2. **\(^{235}\text{U-Be, nominal fission rate 90 kHz}\)**
   1 layer \(\text{UO}_2\) (675 \(\mu\text{g/cm}^2\) of 99.7\% enriched \(^{235}\text{U}\))
glued with thin layer of cyanoacrylate between 25 \(\mu\text{m}\) thick Be foils

3. **\(^{241}\text{Pu-Be, nominal fission rate 70 kHz}\)**
   1 layer \(\text{PuO}_2\) (300 \(\mu\text{g/cm}^2\) of 78.6\% \(^{241}\text{Pu}\), plus non-fissile \(^{240}\text{Pu}\) and \(^{242}\text{Pu}\))
glued with thin layer of cyanoacrylate between 25 \(\mu\text{m}\) thick Be foils
   \(^{241}\text{Am daughter freshly separated and target prepared at Kernchemie Mainz}\)**
$^{241}\text{Pu}$ target and its inner vacuum chamber
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$^{241}\text{Pu}$ target and its inner vacuum chamber
$^{241}$Pu target and its inner vacuum chamber
New triggerless DAQ

Requirements:
- Handle high event rate (>600 kHz)
- Minimize dead time
- Accurate timing
- High data throughput

Full digital approach

10ns

Optical link to storage

VME BUS

P. Mutti, ILL
EXILL installation within 10 days
EXILL installation within 10 days
EXILL

- Motivation
- Setup
- Performances
Data taking

Clover 0, Crystal 0 rate as a function of time

- $^{235}\text{U}$ Zr back.
- $^{235}\text{U}$ Be back.
- $^{235}\text{U}$ Be back.
- $^{241}\text{Pu}$

10 kHz per crystal triggerless data taking achieved, 60 crystals

$\Rightarrow >95\%$ of beam time dedicated to measurement

Setup changing, $(n,\gamma)$ during nights
“Online” spectroscopy: $^{92}$Rb

Non-gated spectrum
=> all prompt gamma-rays from more than 150 nuclei
"Online" spectroscopy: $^{92}\text{Rb}$

$^{92}\text{Rb}$: gamma-gamma spectrum gated on 142-734 keV $\gamma$-rays

W. Urban, ILL
“Online” spectroscopy: $^{92}\text{Rb}$

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EXILL

EUROGAM


W. Urban, ILL
“Online” spectroscopy: $^{92}\text{Rb}$

$^{92}\text{Rb}$: gamma-gamma spectrum gated on 142-734 keV $\gamma$-rays

Much higher statistics
=> allow studying much weaker populated nuclei

W. Urban, ILL
Selection of results

"Germanium-gated $\gamma$–$\gamma$ fast timing of excited states in fission fragments using the EXILL&FATIMA spectrometer", J.M. Regis & al., NIM A, 763, Pages 210–220

"Test of the SO(6) selection rule in $^{196}$Pt using cold-neutron capture", J. Jolie et al., NuclearPhysics A 11/2014

"$B(E2;2+\rightarrow0+1)$ value in $^{90}$Kr", J.M. Regis & al., Phys. Rev. C 90, 067301

"Near-yrast excitations in nucleus $^{83}$As: Tracing the $\pi g_{9/2}$ orbital in the Ni 78 region", P. Bączyk & al., Physical Review C 91(4) · April 2015

"Neutron-proton multiplets in the nucleus $^{88}$Br", M. Czerwinski & al., Physical Review C 92(1) · July 2015

"The mutable nature of particle-core excitations with spin in the one-valence-proton nucleus $^{133}$Sb", G.Bocchi & al., Physics Letter B, accepted this week
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"Near-yrast excitations in nucleus As 83 : Tracing the $\pi g_9/2$ orbital in the Ni 78 region", P. Bączyk & al., Physical Review C 91(4) · April 2015

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"The mutable nature of particle-core excitations with spin in the one-valence-proton nucleus 133Sb", G.Bocchi & al., Physics Letter B, accepted this week
FIssion Product Prompt
γ-ray Spectrometer

- FIPPS layout
- FIPPS Phase I and timeline
FIPPS layout

γ-ray detection with Ge array (EXILL-like)

Fission target with a thick backing
FIPPS layout

γ-ray detection with Ge array (EXILL-like)

Spectrometer

Fission target with a thick backing
FIPPS layout

- γ-ray detection with Ge array (EXILL-like)
- Spectrometer
  - Moveable (for fast neutrons studies)
  - Large acceptance ~10% (close to Ge array efficiency)
  - Not necessarily good mass resolution (~3-4 is acceptable)
  - Focal plan (for fission and 0.1 us isomers studies)
  - Allows Ekin measurement
  - Allows dE/dx measurement

Fission target with a thick backing
FIPPS layout

\( \gamma \)-ray detection with Ge array (EXILL-like)

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- Allows dE/dx \) measurement
EXILL-like

“Left” fission fragment: stopped in backing → Doppler free $\gamma$ detection

“Right” fission fragment:

→ mass identification with a Gas-Filled magnet for filtering
→ $E_{kin}$ & $dE/dx$ measurement with Ionization chamber using intrinsic energy loss in the gas
FIPPS layout

EXILL-like
“Left” fission fragment: stopped in backing
→ Doppler free $\gamma$ detection

Ancillary detectors:
→ neutron detectors
→ $\text{LaBr}_3(\text{Ce})$ for fast timing
→ low energy Ge detectors
→ ...

“Right” fission fragment:
→ mass identification with a Gas-Filled magnet for filtering
→ $E_{\text{kin}}$ & $dE/dx$ measurement with Ionization chamber using intrinsic energy loss in the gas
FIPPS layout

Gas-Filled Magnet: **design on going**

Ionization chambers → **LPSC know-how** (in used at Lohengrin since 20 years)
FIission Product Prompt \(\gamma\)-ray Spectrometer

- FIPPS layout
- FIPPS Phase I and timeline
FIPPS Position:
- Thermal neutron guide
- Flux: $7 \times 10^8$ n.cm$^{-2}$.s$^{-1}$ prior collimation
- $\gamma$-ray background 5 to 10 times better than at PF1b
FIPPS phase I: Ge array

- 8 clovers (CANBERRA 50mm x 80mm) in a central ring
  - Not segmented
  - Permanently at ILL
  - Large space around the ring for additional detectors
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=> other Ge, LaBr, neutron detectors, ...
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First 2 clovers delivery in september
All the clovers by the end of the year
FIPPS phase I: some ideas

Ideas from: _EXILL meetings
_informal discussion with users (O. Litaize, G. Kessedjian, O. Serot, G. Simpson, ...)

Nuclear structure:
- DPM measurements
  → we learnt a lot from the EXILL-DPM measurement
- plunger measurements
- g factor measurements
- new spectroscopy campaign

Fission:
- prompt $\gamma$-ray (NEA High Priority Request List for 235U and 239Pu)
  A. Oberstedt et al., PRC 87, 051602 (2013)
  → possible observables: total $\gamma$-ray spectra, $E_\gamma$ distribution and multiplicity, per fission or per fragment pair
  → EXILL data analysis difficult: need complex $\gamma$-$\gamma$-$\gamma$ analysis with background from long-life isomers
- neutron emission
  → neutron-$\gamma$ correlations ??
- actinides (n,$\gamma$) measurements
FIPPS phase I: targets

(n, γ) on stable targets

(n, fission) on actinide targets

(n, γ) on radioactive exotic targets
(n, γ) on stable targets

(n, fission) on actinide targets

Typical program foreseen in the coming 3-4 years (2-3 cycles/year):
FIPPS phase I: targets

(n, γ) on stable targets

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2016: cycle 3 (Nov.-Dec.): (n,γ) on stable targets (commissioning)

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Typical program foreseen in the coming 3-4 years (2-3 cycles/year):

- **2016:** cycle 3 (Nov.-Dec.): (n,γ) on stable targets (commissioning)
- **2017:** cycle 1 (Jan.-March) : (n,γ) on stable targets, proposal deadline 15 Sept. 2016
  cycle 2 (Aug.-Oct.): (n,γ) on radioactive targets, proposal deadline 14 Feb. 2017
  cycle 3 (Nov.-Dec.): (n,fission) on closed 235U target
FIPPS phase I: targets

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  - cycle 3 (Nov.-Dec.): (n,fission) on closed 235U target

- 2018:
  - cycle 1: (n,fission) on closed 233U target
  - cycle 2: (n,fission) on 235U target (plunger / magnetic moment commissioning)

- 2019:
  - cycle 1: (n,fission) on 235U (GFM commissioning)
  - cycle 2: (n,fission) on closed 241Pu target
  - cycle 3: (n,fission) on closed 239Pu target

(n, γ) on radioactive exotic targets

(n, fission) on actinide targets
Conclusion
Conclusion (1)

All EXILL requirements achieved:

- Halo-free pencil neutron beam (1 cm²), ~10⁸ n.cm⁻².s⁻¹
- Safe target environment allowing (n,f) of actinides targets (²³⁵U, ²⁴¹Pu)
- Up to 50 Ge crystals and 16 LaBr scintillators operating simultaneously
- Triggerless DAQ, >10 kHz/crystal, >600kHz total

~100 days of data taking

>60 Tb of data stored, storage shared between:
   CC IN2P3 Lyon
   ILL
   LPSC-Grenoble
Conclusion (2)

**FIPPS:**

Phase I: Ge array

- safe-handling of various actinide targets → **ILL know-how**
- halo-free pencil beam of neutron → **experimentally validated**
- safe operation of Germanium array close to neutron beam → **experimentally validated**
- triggerless DAQ with high-rate capability (~6kHz/crystal) → **experimentally validated**
- fission veto/tagging using scintillating active target → **being tested**

Phase II: Ge array + Spectrometer

- Designing phase

→ **possible use of** 233U, 235U, 239Pu, 241Pu, 245Cm, 247Cm, 249Cf, 251Cf, ...
Conclusion (3)

All FIPPS clovers at the ILL by the end of 2016

=> commissioning with \((n,\gamma)\) measurements during the last cycle of 2016

=> FIPPS available for proposals for beamtime in 2017 (see www.ill.fr/users for more details)

Send an email to blanc@ill.fr, koester@ill.fr or jentschel@ill.fr before submitting
The EXILL collaboration

Yale University

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