FIPPS

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

A. Blanc[1], A. Chebbοubi[1], H. Faust[1], M. Jentschel[1], U. Köster[1], C. Michelagnoli[1], P. Mutti[1], E. Ruiz-Martinez[1], G. Kessedjian[2], C. Sage[2], G. Simpson[2], D. Wilmsen[3], W. Urban[4]

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[2]LPSC-Grenoble
[3]GANIL
[4]University of Warsaw

SSNET workshop, Gif sur Yvette, France

9 November 2016

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)

- Introduction: Nuclear Physics at the Institut Laue-Langevin
- γ–ray spectroscopy after slow neutron-induced reactions
- EXogam at ILL (EXILL): setup and experimental campaign
- The FIPPS instrument: layout, physics possibilities, time–lines

(n,γ)

$\rightarrow$ close to stability

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

$\rightarrow$ cross-sections (applications)

(n,γ)

$\rightarrow$ close to stability

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

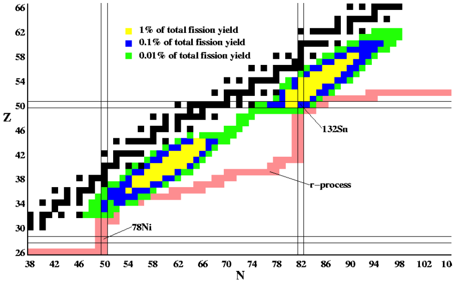
$\rightarrow$ cross-sections (applications)

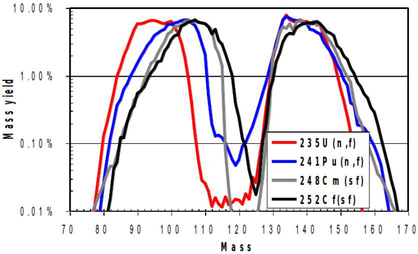
(n,fission)

$\rightarrow$ away from stability

$\rightarrow$ fission yields and dynamics

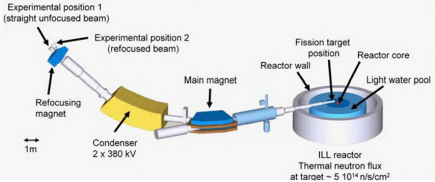
$\rightarrow$ structure of n-rich nuclei





LOHENGRIN
fission fragment separator

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



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

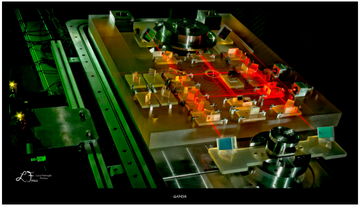
$\rightarrow \quad \Delta A/A = 3\,10^{-4} - 3\,10^{-3}$

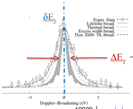
$\rightarrow \quad \Delta E/E = 10^{-3} - 10^{-2}$

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

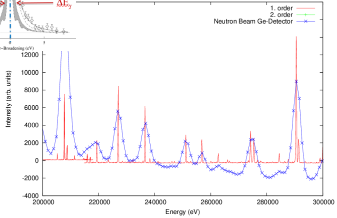
GAMma–ray Spectrometer (GAMS)

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



γ–ray spectroscopy of fission fragments: single-particle energies outside the ^{78}Ni core

β decay spectroscopy @ Lohengrin, ^{235}U(n$_{cold}$,fiss):

^{86}Se$\rightarrow$ ^{86}Br$\rightarrow$ ^{86}Kr

✓ level population in β decay

$\rightarrow \nu\, g_{7/2} \rightarrow \pi\, g_{9/2}$ component of the GT decays

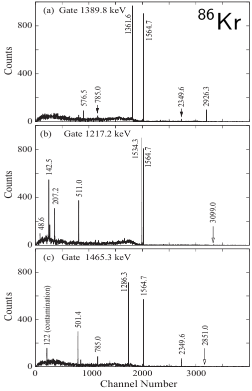


FIG. 8. γ spectrum gated on the (a) 1389.8-keV line, (b) 1217.2-keV line, and (c) 1465.3-keV line.

PHYSICAL REVIEW C **94**, 044328 (2016)

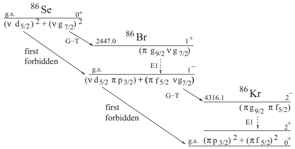


FIG. 12. Schematic drawing of the proposed decay scenario in $A = 86$ isobars, involving the $\nu g_{7/2} \rightarrow \pi g_{9/2}$, G-T decay.

W. Urban et al., PRC **94**, 044328 (2016)

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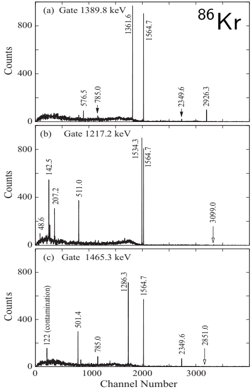

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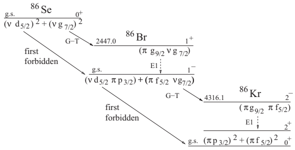

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prompt γ–ray spectroscopy @ EXILL:

✓ high–spin states

✓ transitions multipolarity

✓ SM calculations

$\rightarrow 1^+$, 2^+_2, 3^+_1 mixed simmetry states from p excitation only

W. Urban et al., PRC **94**, 044328 (2016)

EXogam @ ILL (EXILL)

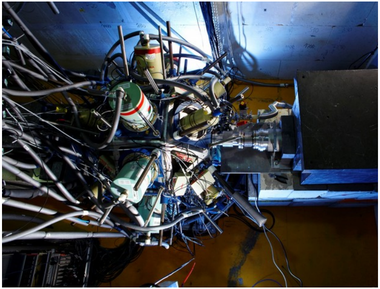
→ Highly collimated neutron beam from ILL reactor (PF1B guide)

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

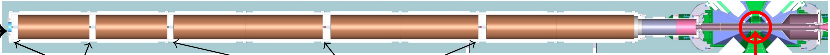
→ Fully digital electronics, trigger-less (>10 kHz/crystal)

→ 2 reactor cycles (≈ 100 days)

→ 14 stable (rare) and 3 actinide targets



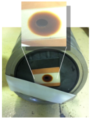
10^{10} n/s/cm^2
20×6 cm^2

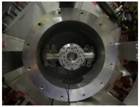


1 cm B_4C ceramics
5 cm Pb

Borated plastics + ^{6}LiF
5 cm Pb

10^8 n/s/cm^2
1×1 cm^2



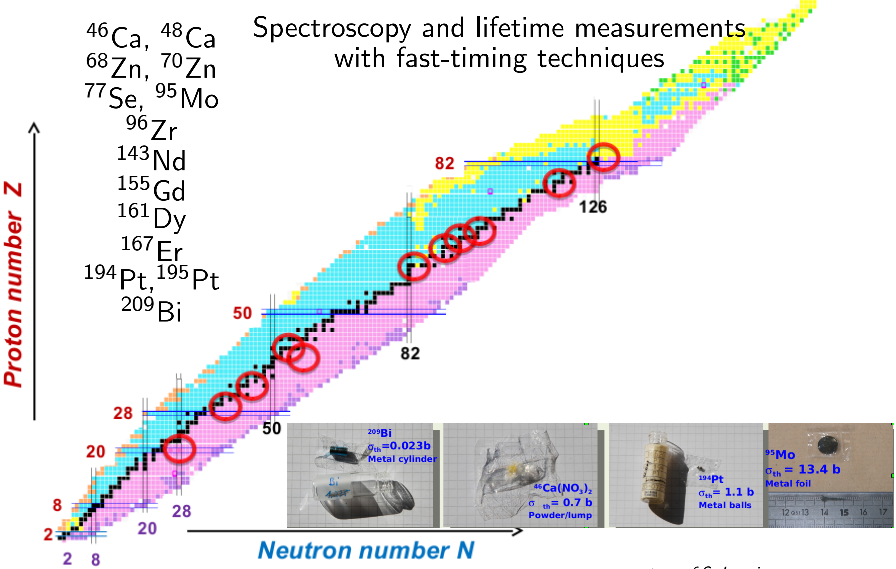


A. Blanc et al., EPJ Conf. **93**, 01015 (2015)
P. Mutti et al., EPJ Conf. **62** (2013)
J. Regis et al., NIMA **763** (2014)

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

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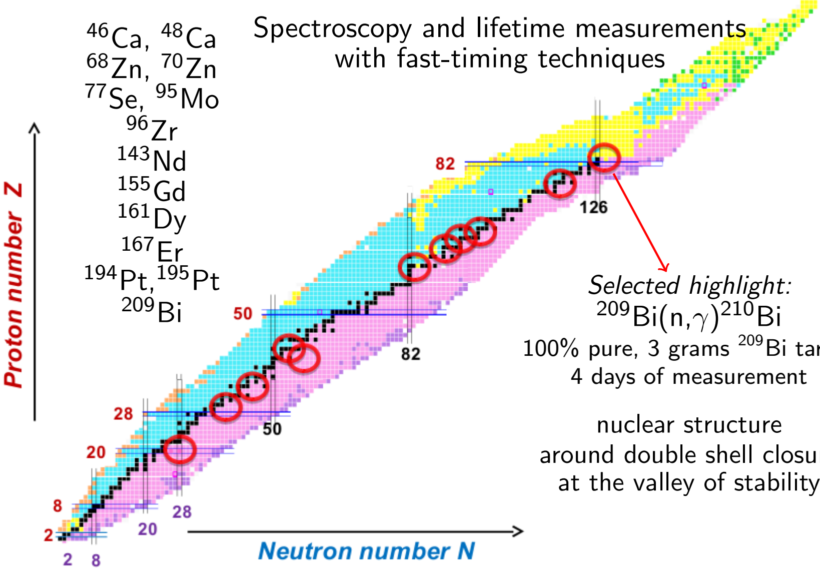
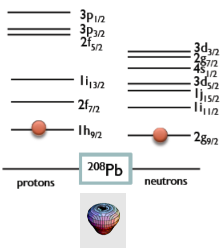


Selected highlight:
$^{209}\text{Bi}(n,\gamma)^{210}\text{Bi}$
100% pure, 3 grams ^{209}Bi target
4 days of measurement

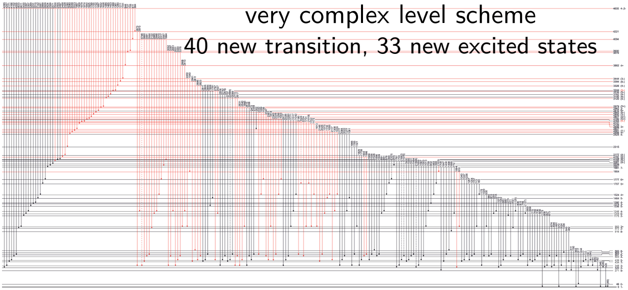
nuclear structure
around double shell closure
at the valley of stability

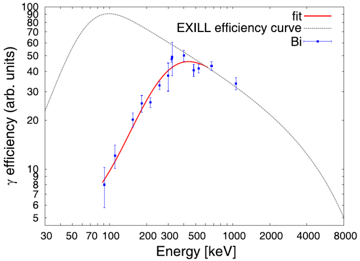
^{210}Bi



very complex level scheme

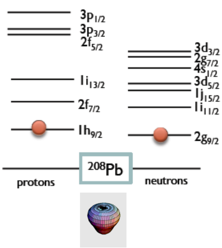
40 new transition, 33 new excited states





N. Cieplicka-Oryńczak et al., PRC **93**, 054302 (2016)

^{210}Bi



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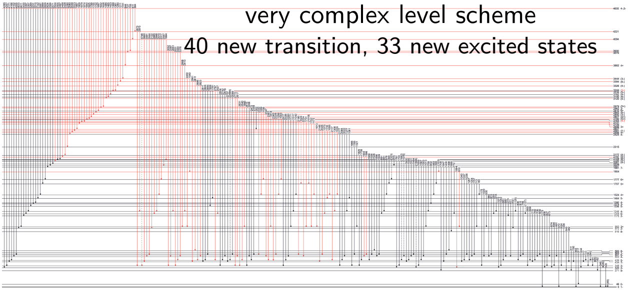
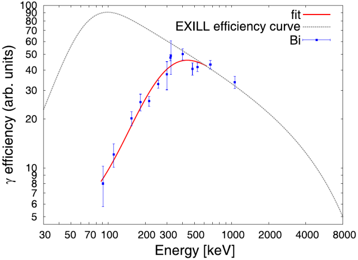


→ comparison with large scale shell model calculations

E_{ex} <2 MeV: valence particle couplings;
E_{ex} >2 MeV: single part-phonon excitations



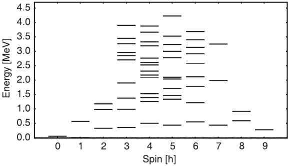


FIG. 10. The energy-spin distribution of states observed in the decay following cold-neutron capture on ^{209}Bi and having their calculated counterparts.

N. Cieplicka-Oryńczak et al., PRC **93**, 054302 (2016)

Transitions multipolarity from angular correlations:

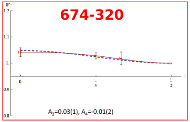
almost pure M1 character

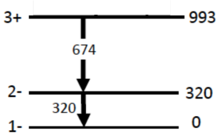
for the 320 keV transition

$\rightarrow$ reduction of the uncertainty

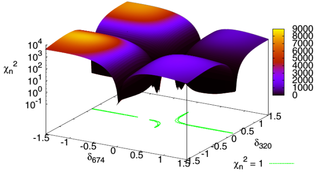
on the ^{209}Bi(n,γ)^{210m}Bi, ^{209}Bi(n,γ)^{210g}Bi

cross sections

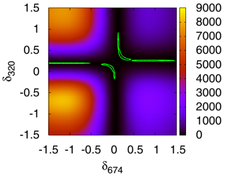




Multivariable analysis of angular correlations:



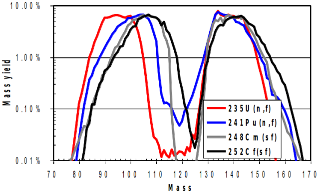
(a) 674-320



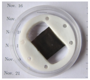
(b) 674-320

N. Cieplicka-Oryńczak et al., PRC **94**, 014311 (2016)

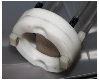
The EXILL campaign: (n,fission) reactions on actinides



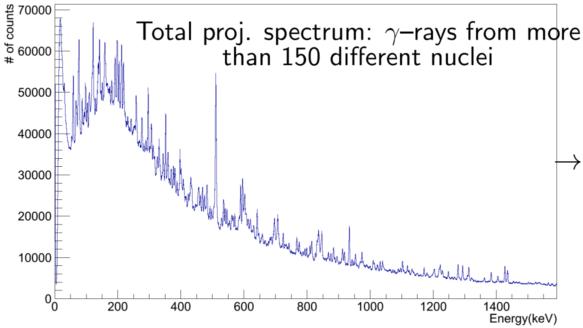
$^{235}UO_2$, σ_f =586 b
Layer sandwiched
between Zr or Be backings



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



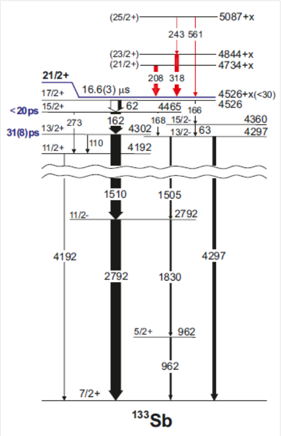
see L. Iskra (^{96}Y) and L. Fraile (^{136}Te) talks



→ multiple γ–ray coincidences,
also with fission partners

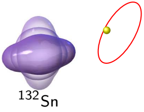
Single-particle vs. collective phenomena around ^{132}Sn: delayed γ-ray spectroscopy of n-induced fission fragments

Selected highlight from the EXILL fission campaign:

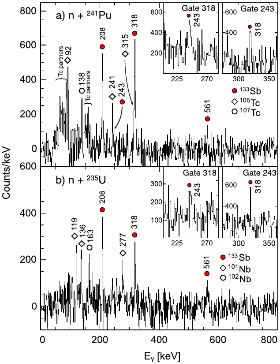


G. Bocchi et al., PLB **760**, 273–278 (2016)

→ New event-builder for cross-isomer coincidences



Milan-Cracow collaboration

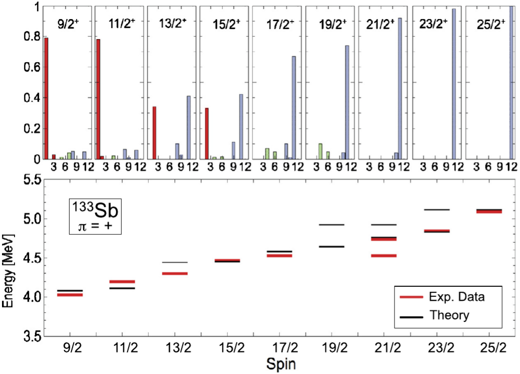


✓ Prompt-delayed γ coincidences across the isomer

✓ Lifetimes from $LaBr_3$ data (FATIMA campaign)

✓ New microscopic approach to particle-core couplings

New microscopic approach to particle–core excitations around ^{132}Sn



1: $\pi g_{7/2} \otimes 2^+_1$
2: $\pi g_{7/2} \otimes 4^+_1$
3: $\pi d_{5/2} \otimes 2^+_1$
4: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}, \pi g^{-1}_{9/2} g_{7/2}]_{6^+_1}$
5: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}, \pi g^{-1}_{9/2} g_{7/2}]_{2^+_2}$
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8: $\pi g_{7/2} \otimes [\pi g^{-1}_{9/2} g_{7/2}]_{3^+_2}$
9: $\pi g_{7/2} \otimes [\pi g^{-1}_{9/2} g_{7/2}]_{5^+_2}$
10: $\pi g_{7/2} \otimes [\pi g^{-1}_{9/2} g_{7/2}]_{7^+_2}$
11: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}]_{8^+_1}$
12: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}]_{9^+_1}$

$\rightarrow$ more and more fragmented wave functions with increasing angular momentum

Theoretical calculations: Hybrid Configuration Mixing (HCM) model

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

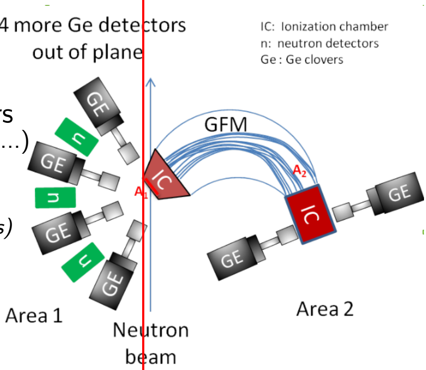
From EXILL to FIPPS (**FI**ssion **P**roduct **P**rompt γ–ray **S**pectrometer[1])

Phase I

→ 8 Ge clovers

→ ancillary detectors
(fast timing, n dets, ...)

→ active targets
for fission trigger
(D. Wilmsen PhD Thesis)



[1] A. Blanc et al., EPJ Conf. **93**, 01015 (2015).

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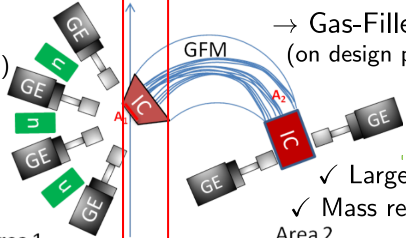

Phase II

→ Gas-Filled-Magnet (GFM)
(on design phase, LPSC-Grenoble)

✓ Large acceptance (≈10%)

✓ Mass resolution of some units

→ Measurement of kin en

→ Measurement of dE/dx

Full reconstruction of the ion trajectories
using a low–pressure TPC
(ILL-GANIL collaboration, PhD project)

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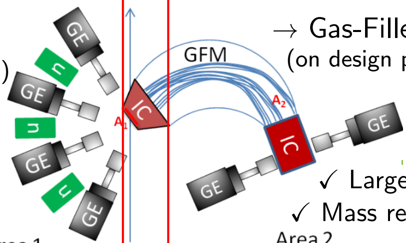
Installation
on going !!



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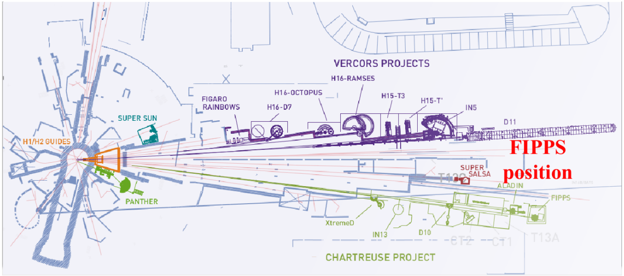
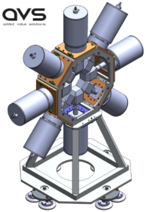
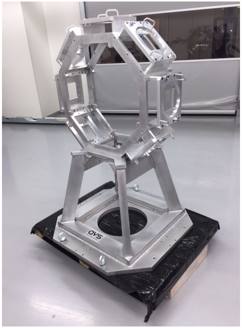
FIPPS work in progress



FIPPS position:

- ✓ thermal neutron guide
- ✓ 7.10^8 n/cm^2/s prior collimation
- ✓ γ-ray background 5 to 10 times better than at PF1b





Ge clovers in ring structure
d=9 or 13 cm

4 clovers already delevered and tested in lab

FWHM @ 1.3 MeV
$\approx$ 2.1 keV

FIPPS possibilities/timelines

(n,γ) on stable and radioactive targets, (n,fission) on actinides

1 cycle = 50 days

- Nov 2016: Ge detectors installation and source tests;
- Nov-Dec 2016 (cycle 3): (n,γ) on stable targets, instrument commissioning;
- Jan-March 2017 (cycle 1): (n,γ) on stable targets, proposals submitted Sept. 2016 ($\approx$100 days asked for FIPPS!)

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Possibilities:

- (n,γ) on rare stable targets
- (n,γ) on radioactive targets
- (n,fission) with ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu etc. targets
- progressive installation of ancillary methods: $LaBr_3$, magnetic moment measurements, plunger, GFM...

The future program is science-driven and depends on your input!

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- Jan-March 2017 (cycle 1): (n,γ) on stable targets, proposals submitted Sept. 2016 ($\approx$100 days asked for FIPPS!)

Possibilities:

- (n,γ) on rare stable targets
- (n,γ) on radioactive targets
- (n,fission) with ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu etc. targets
- progressive installation of ancillary methods: $LaBr_3$, magnetic moment measurements, plunger, GFM...

Next proposal submission deadline on February 14th

Aug-Oct 2017 (cycle 2), Nov-Dec 2017 (cycle 3)

The future program is science-driven and depends on your input!

Outline and conclusions

- γ–ray spectroscopy after slow neutron-induced reactions at ILL: Lohengrin, EXILL, **FIPPS**
- nuclear structure around double shell closure (selected highlights) studied at EXILL
- FIPPS phase I is under installation at ILL and will provide a permanent station at ILL for prompt and delayed γ–ray spectroscopy after (n,γ) and (n,fission) reactions
- your are all very welcome in the collaboration and to propose experiments at ILL !!!

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