FIPPS
FIssion Product Prompt gamma-ray Spectrometer

ILL : *A. Blanc, A. Chebboubi, H, Faust, M. Jentschel, U. Kőster, P.Mutti, E. Ruiz-Martinez*
CEA-Saclay : *T. Materna*
LPSC-Grenoble : *G. Kessedjian, C. Sage, G. Simpson*
University of Warsaw : *W. Urban*

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

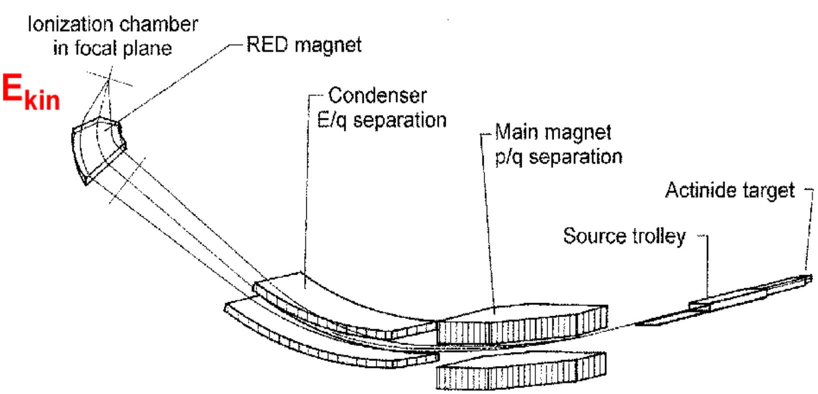
Nuclear Physics at ILL

- The LOHENGRIN fission fragment separator:

$\Delta A/A$ = 3E-4 – 3E-3
$\Delta E/E$ = 1E-3 – 1E-2

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

The LOHENGRIN recoil separator

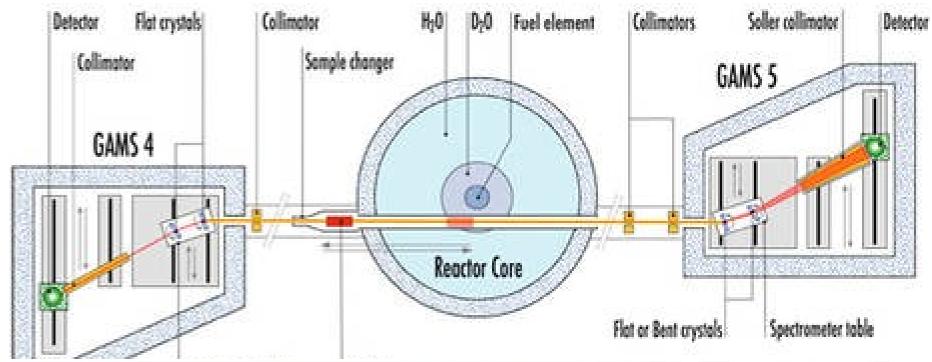


$$m v^2 / r_{el} = q E \qquad m v^2 / r_{magn} = q v B$$

$$E_{kin} / q = E / 2 r_{el} \qquad m v / q = B r_{magn}$$

P. Armbruster et al., Nucl. Instr. Meth. 139 (1976) 213.

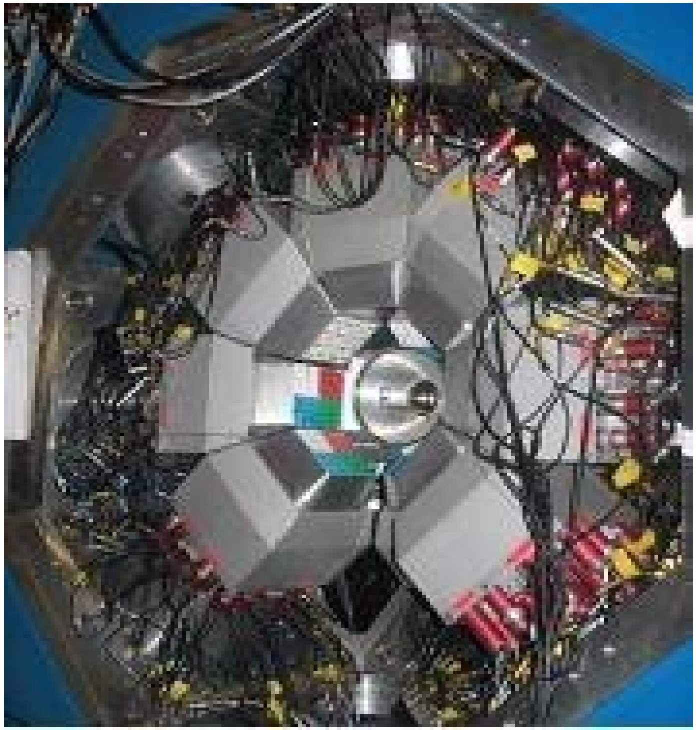
- Gamma-ray spectrometer (GAMS):



EXILL

- **Motivation**
- Setup
- Peformances

EXogam @ ILL



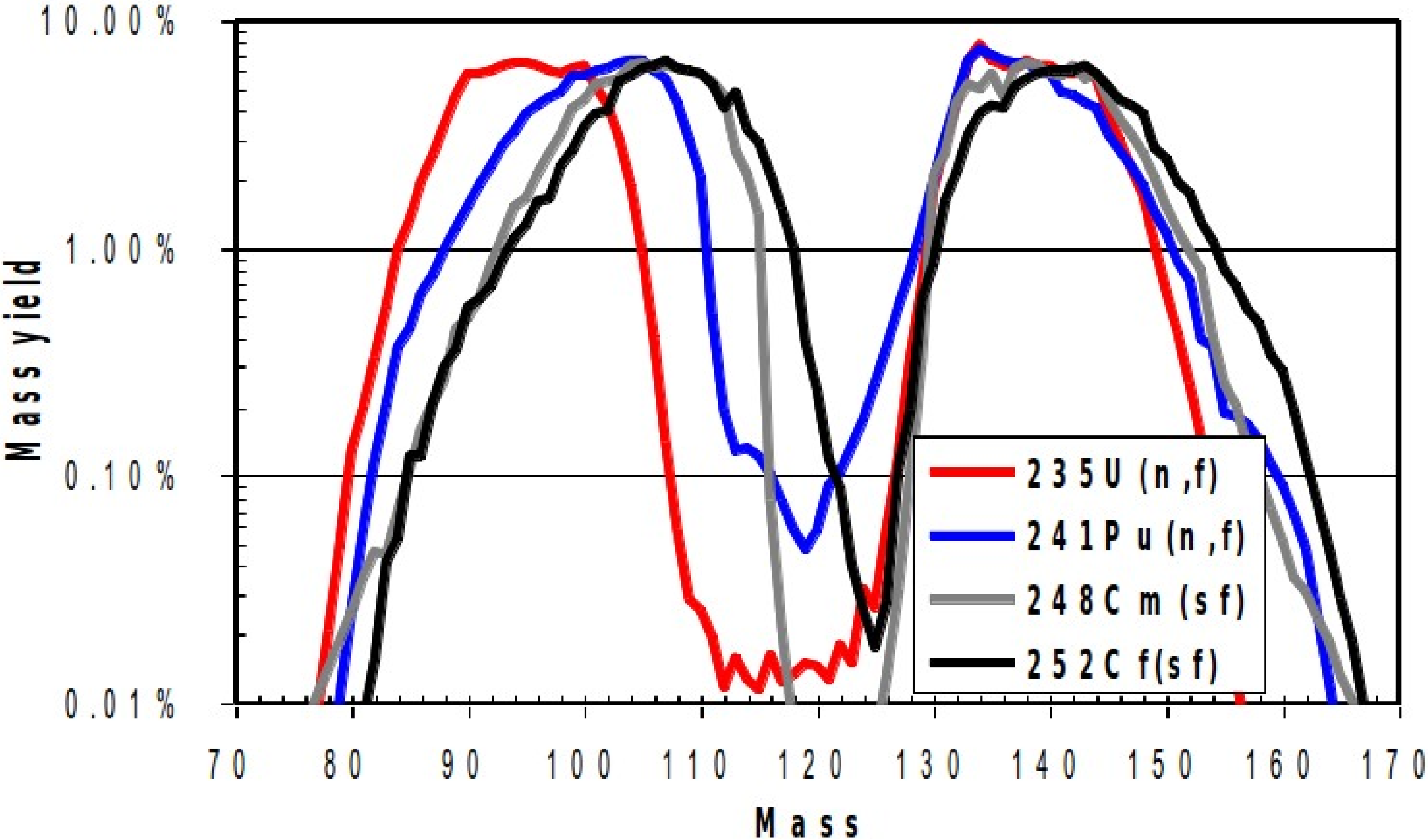
High efficiency germanium array

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}U(n,fission)

- ^{241}Pu(n,f) and ^{235}U(n,f) vs spontaneous fission sources



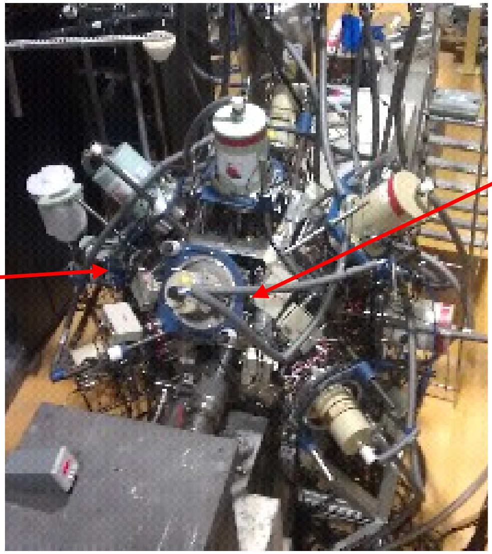
EXILL

- Motivation
- **Setup**
- Performances

The EXILL setup

▶ 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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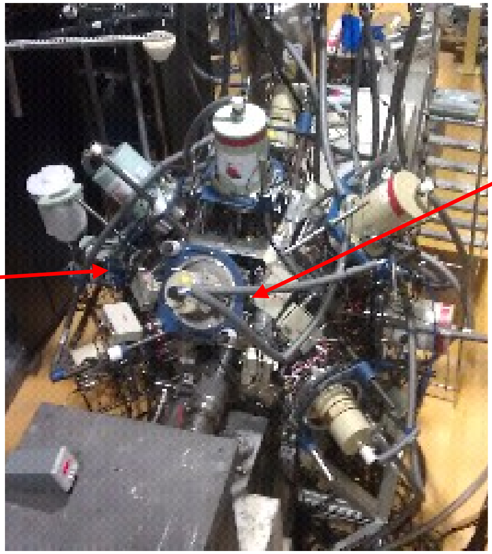
+ FATIMA LaBr array for ½ cycle



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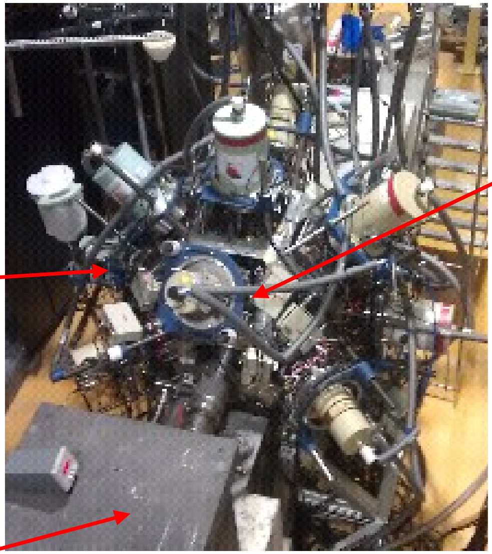
Collimation:
ϕ12 mm “pencil” neutron beam



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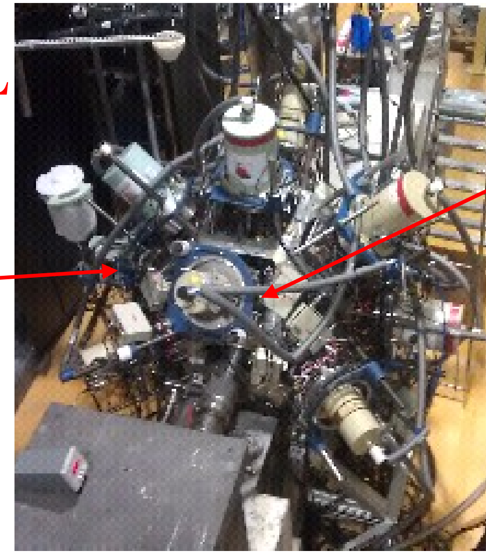
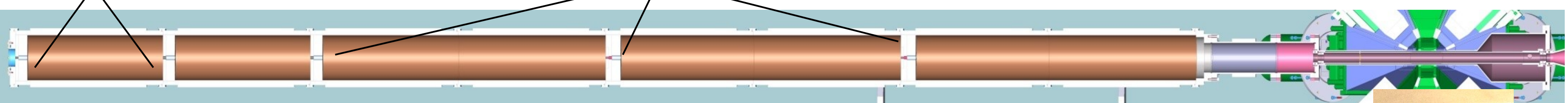


235U and 241Pu targets with thick backing

Borated plastics + ^{6}LiF
5 cm Pb

1cm B_4C ceramics
5 cm Pb



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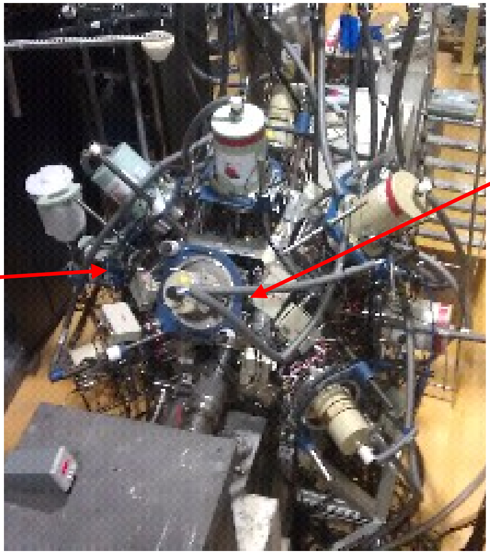

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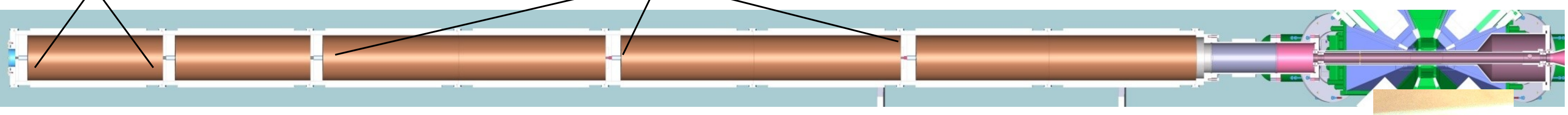

10^{10}

$20*6\ cm^2$

The EXILL setup

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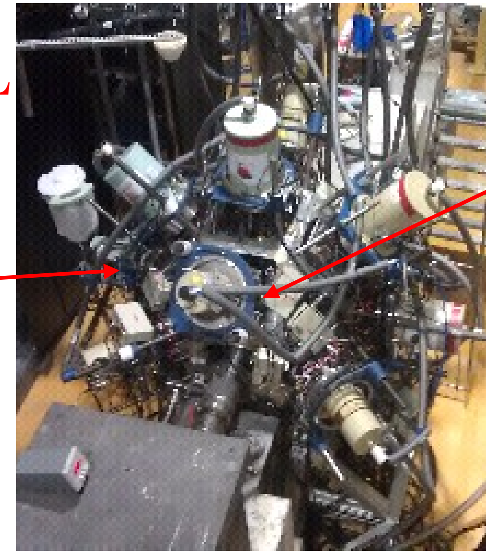

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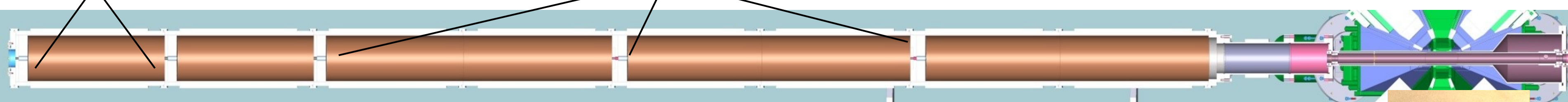


10^{10}

20*6 cm^2

→

10^{8}

1 cm^2

Fission targets

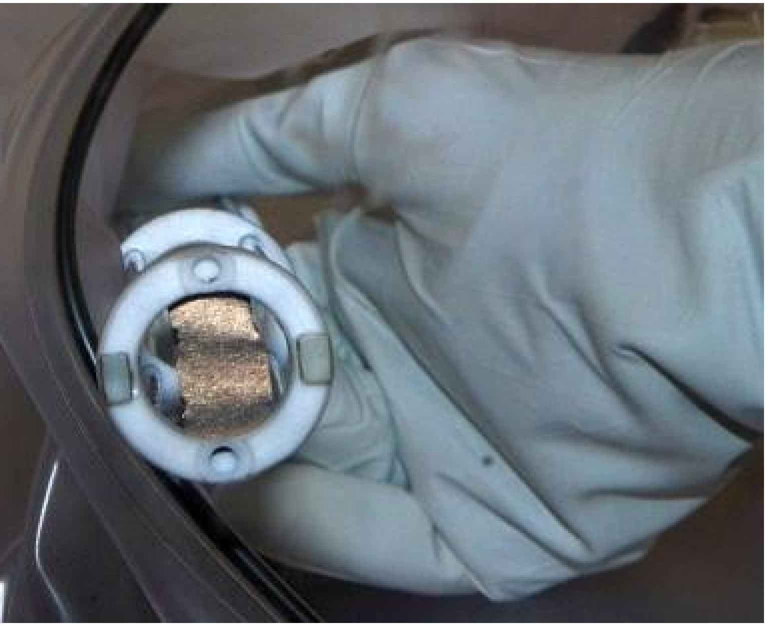
Targets **sandwiched between dense backings** for rapid stopping of fission fragments.

1. **^{235}U-Zr/Sn, nominal fission rate 70 kHz**
   3 layers UO_2 (total 575 μg/cm^2 of 99.7% enriched ^{235}U)
   laminated with Sn between 15 μm thick Zr foils (nuclear grade, <50 ppm Hf)

2. **^{235}U-Be, nominal fission rate 90 kHz**
   1 layer UO_2 (675 μg/cm^2 of 99.7% enriched ^{235}U)
   glued with thin layer of cyanoacrylate between 25 μm thick Be foils

3. **^{241}Pu-Be, nominal fission rate 70 kHz**
   1 layer PuO_2 (300 μg/cm^2 of 78.6% ^{241}Pu, plus non-fissile ^{240}Pu and ^{242}Pu)
   glued with thin layer of cyanoacrylate between 25 μm thick Be foils
   - ^{241}Am daughter freshly separated and target prepared at Kernchemie Mainz

^{241}Pu target and its inner vacuum chamber



^{241}Pu target and its inner vacuum chamber

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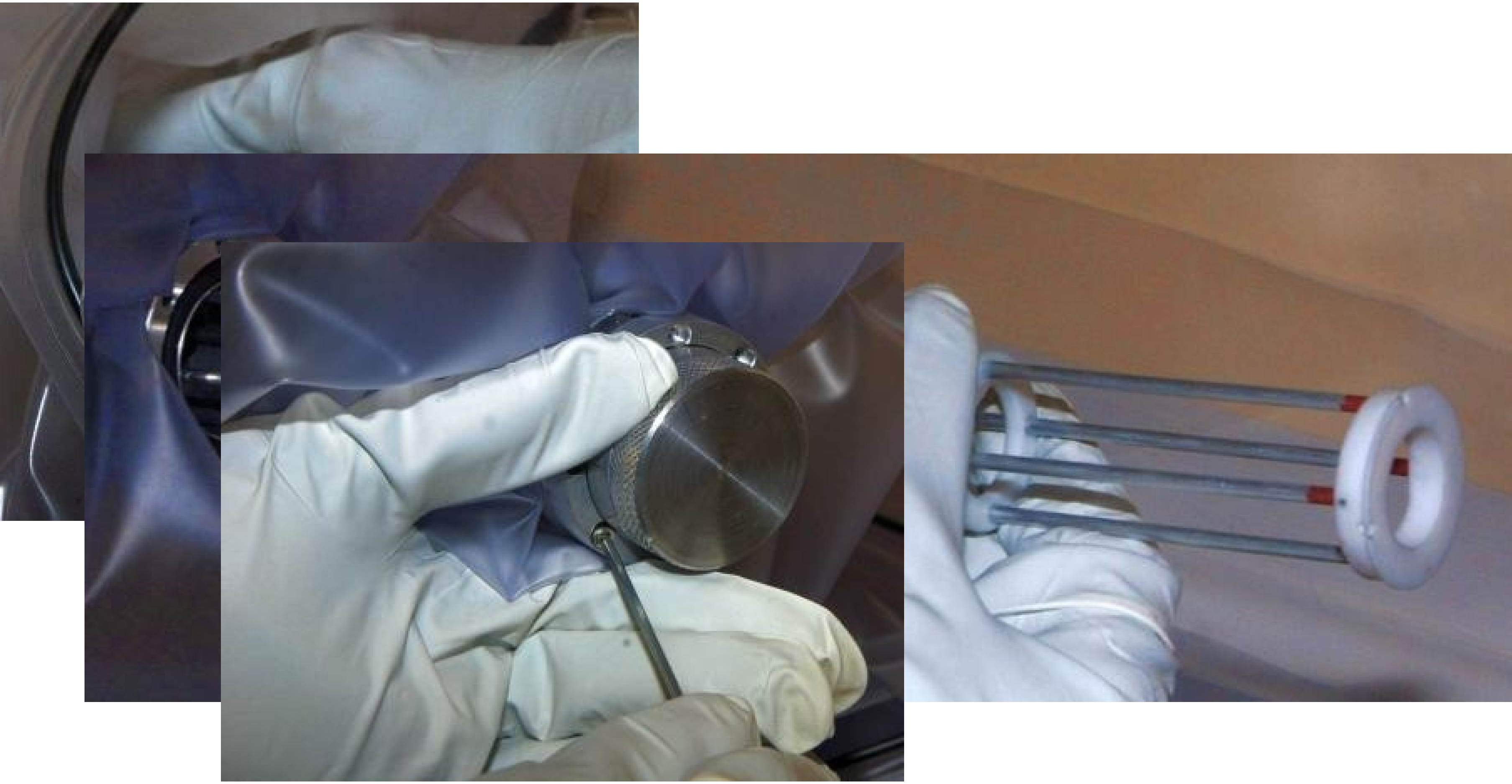

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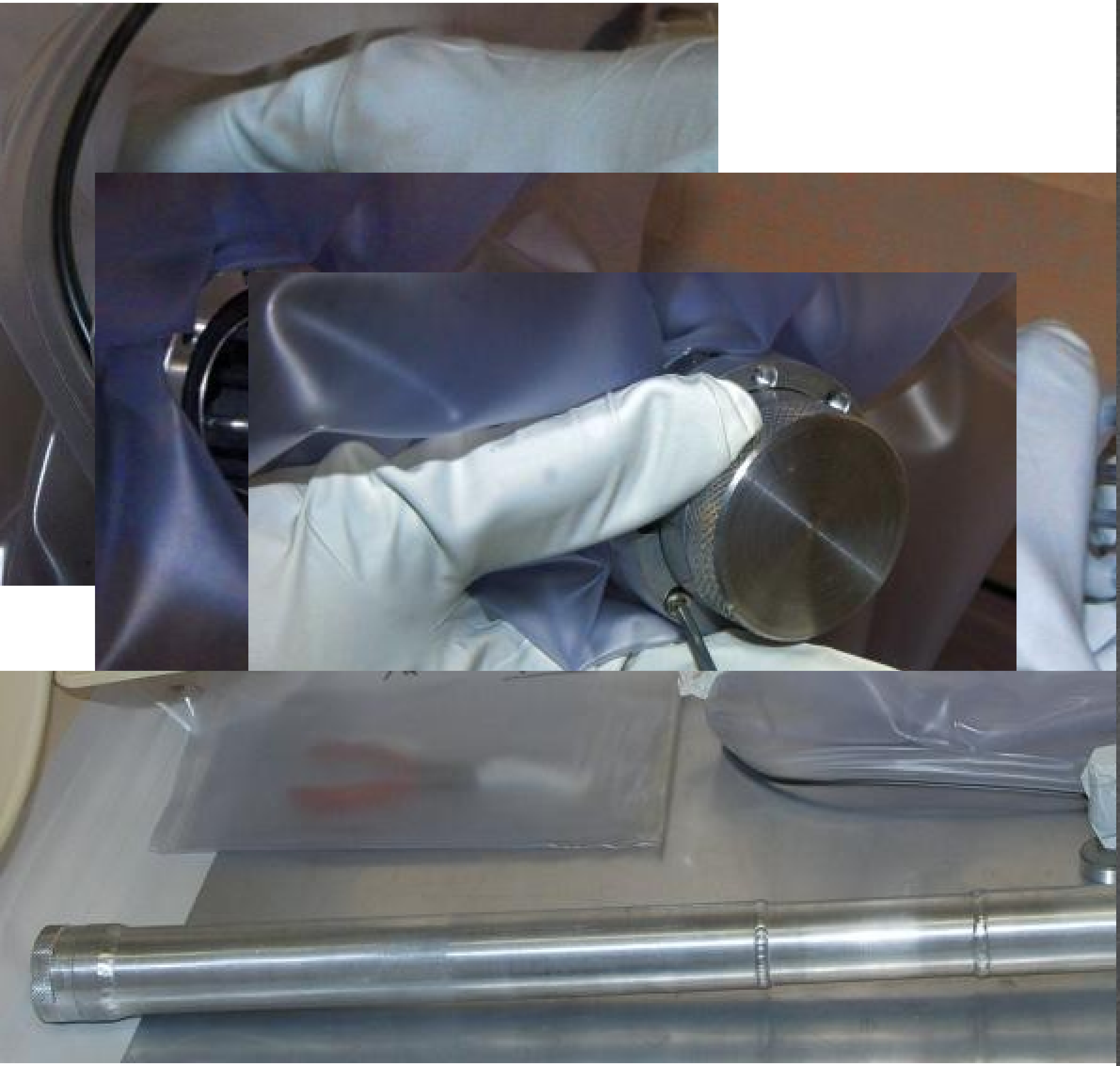
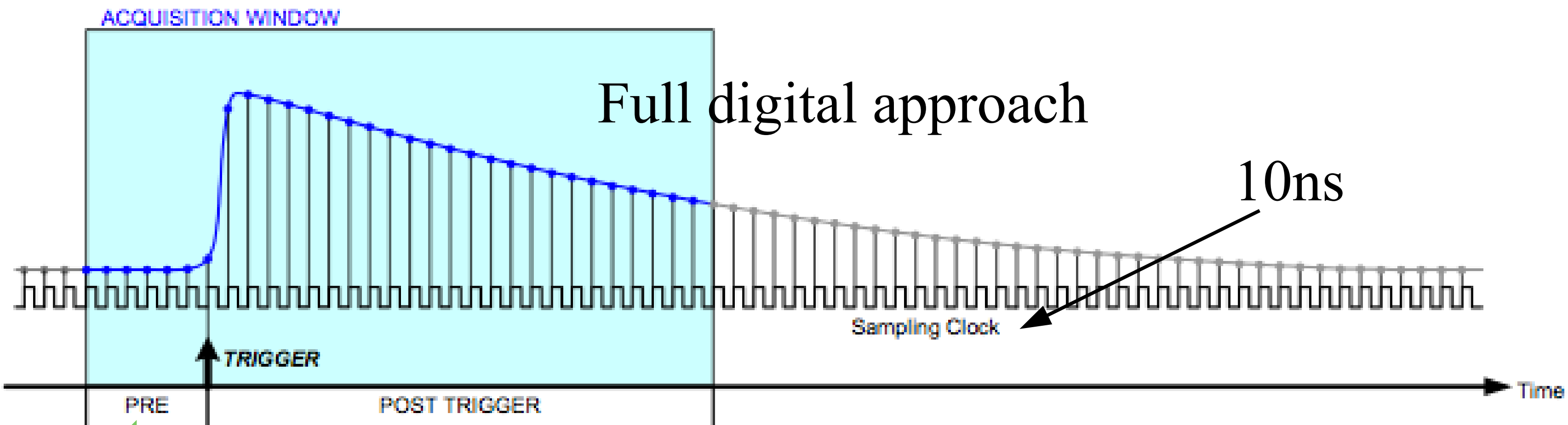
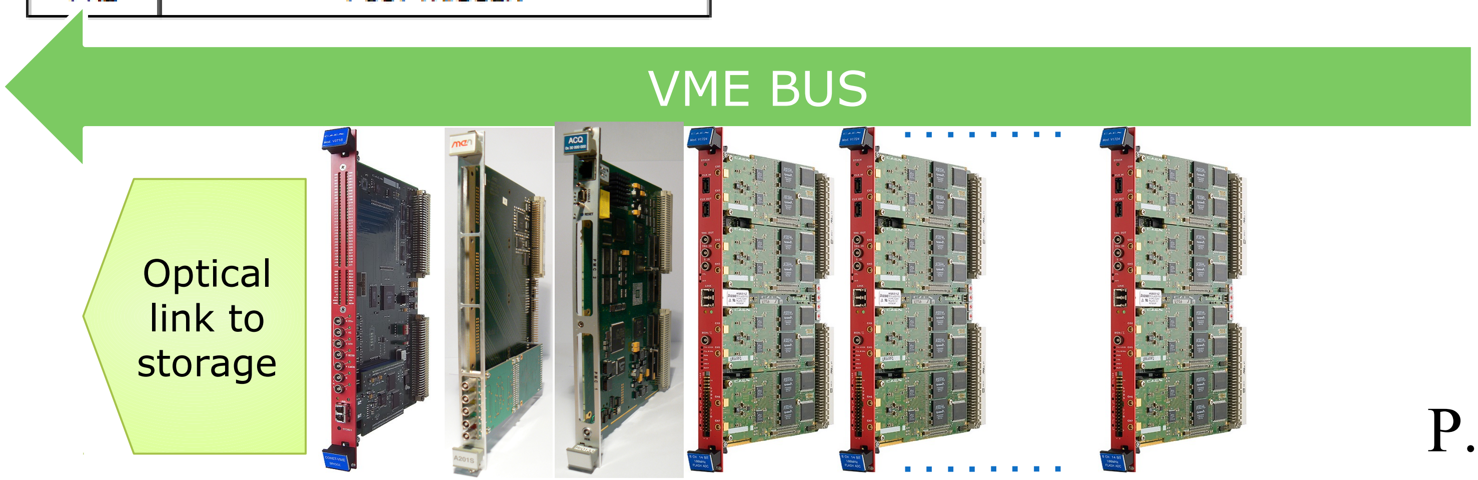


New triggerless DAQ

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

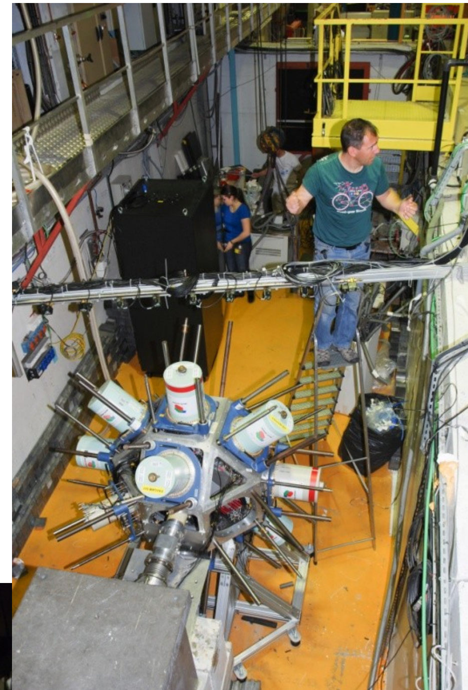
Full digital approach

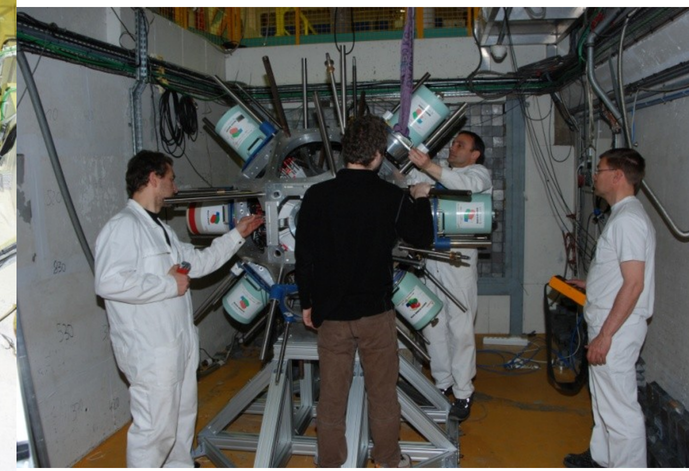


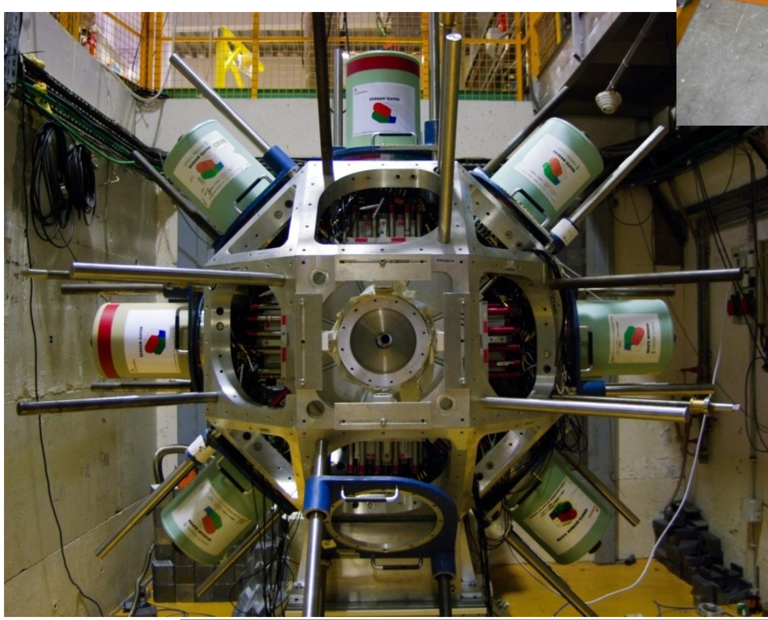


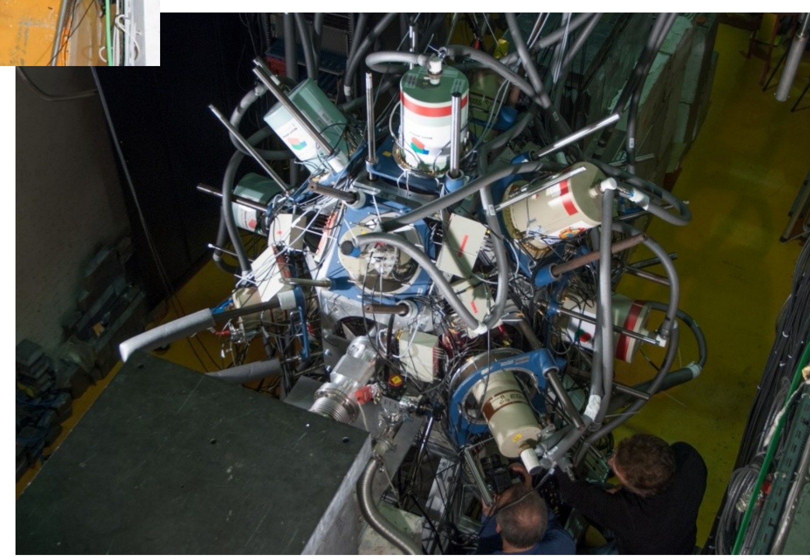
P. Mutti, ILL

EXILL installation within 10 days









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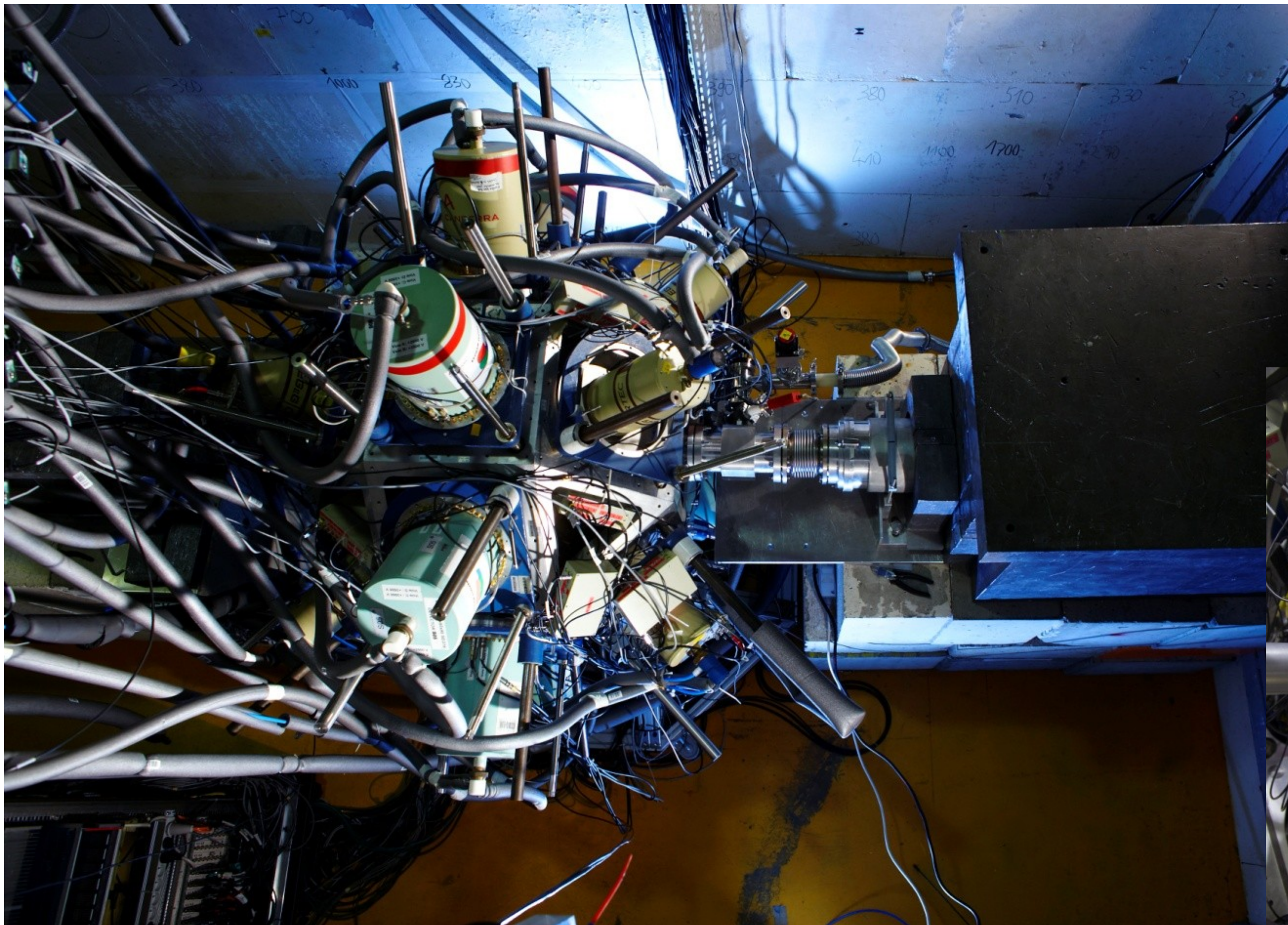
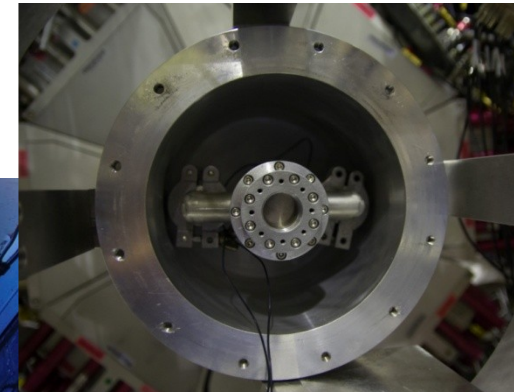
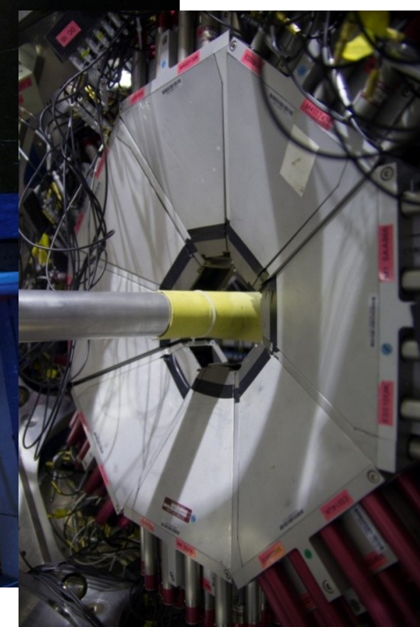






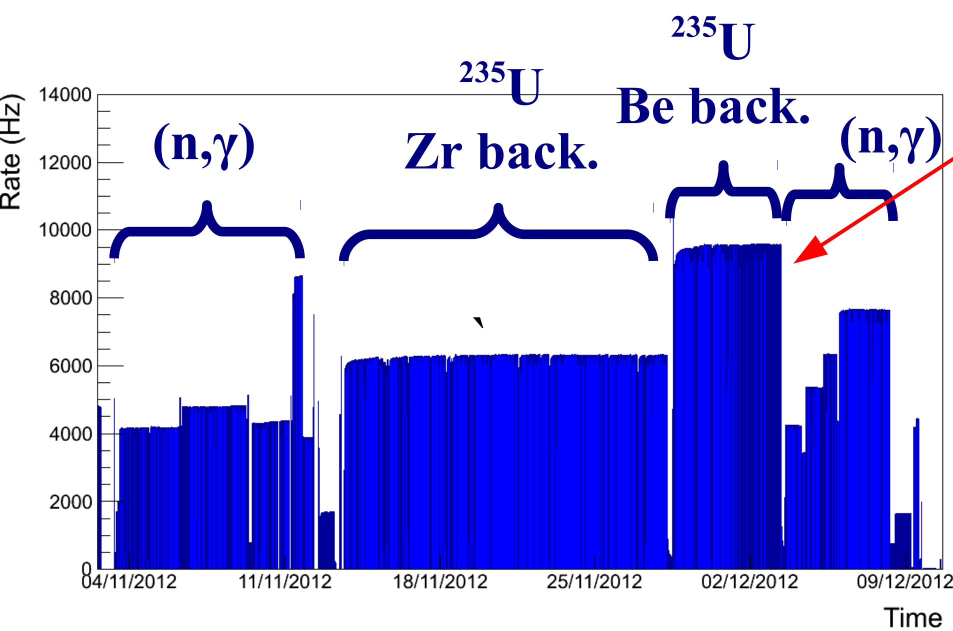
EXILL

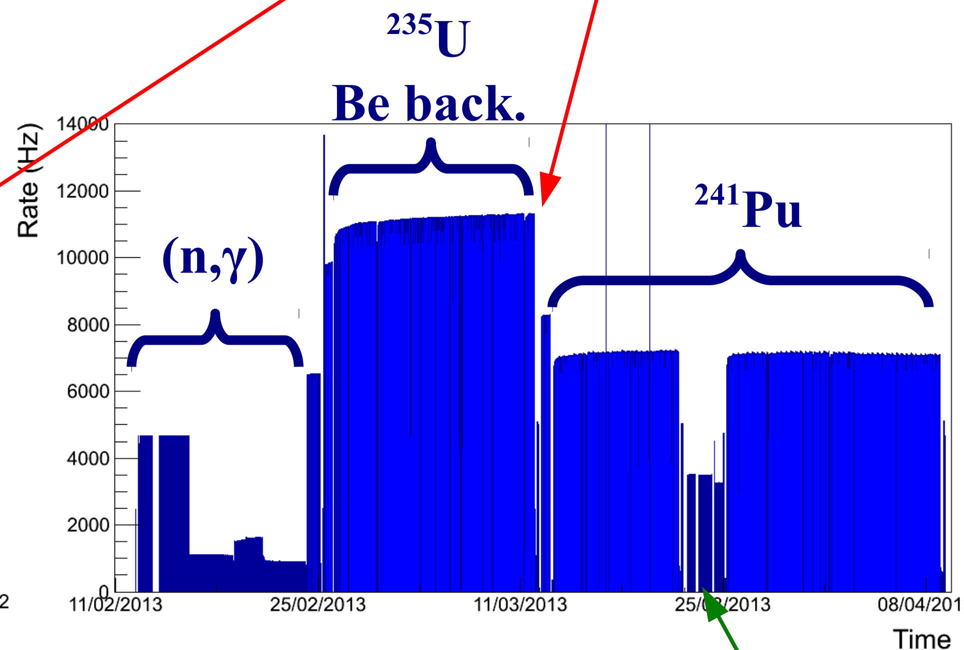
- Motivation
- Setup
- **Performances**

Data taking

10 kHz per crystal trigerless data taking achieved, 60 crystals

- Clover 0, Crystal 0 rate as a function of time

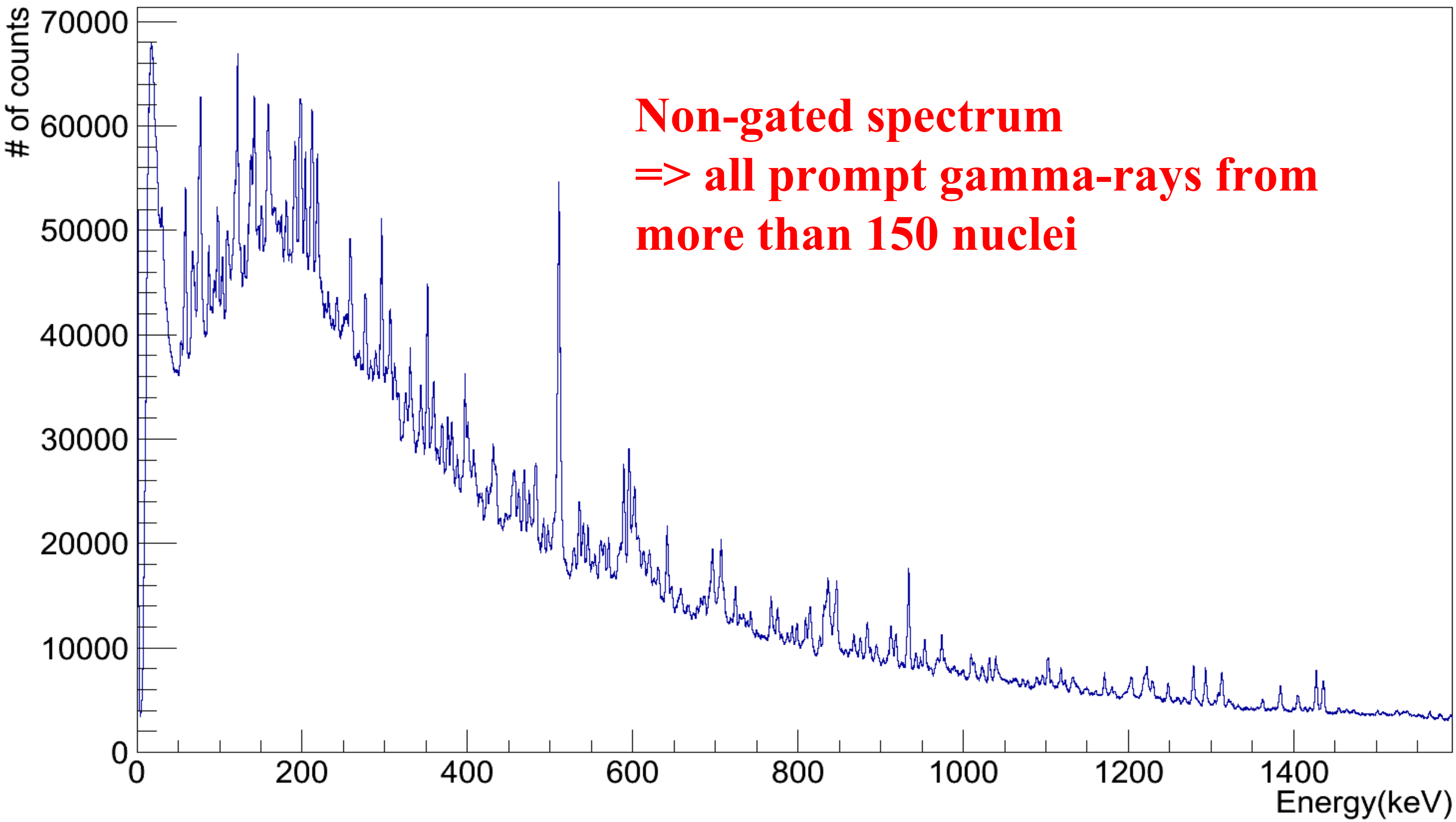




Setup changing, (n,γ) during nights

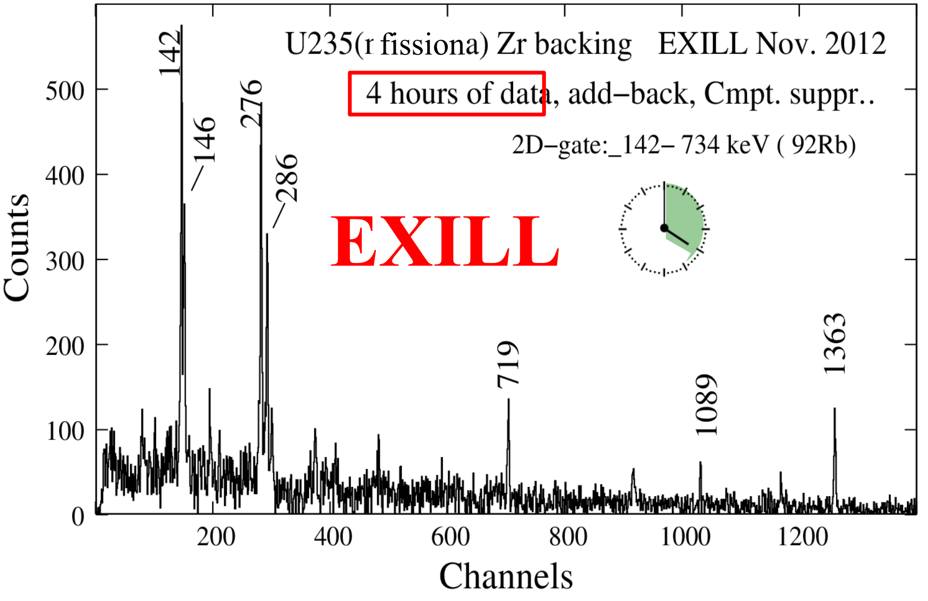
=> >95% of beam time dedicated to measurement

“Online” spectroscopy: ^{92}Rb



“Online” spectroscopy: ^{92}Rb

- ^{92}**Rb**: gamma-gamma spectrum **gated on 142-734 keV** γ-rays



W. Urban, ILL

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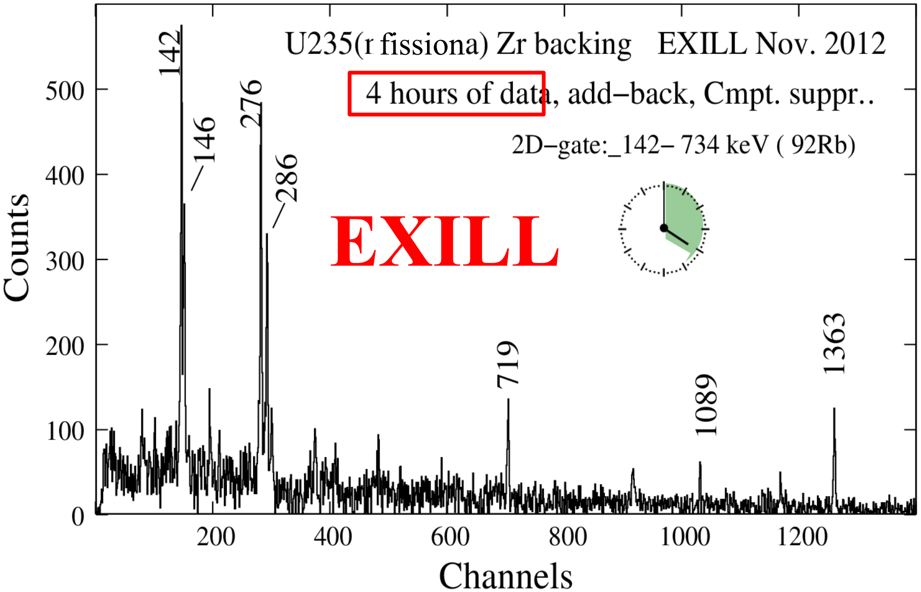
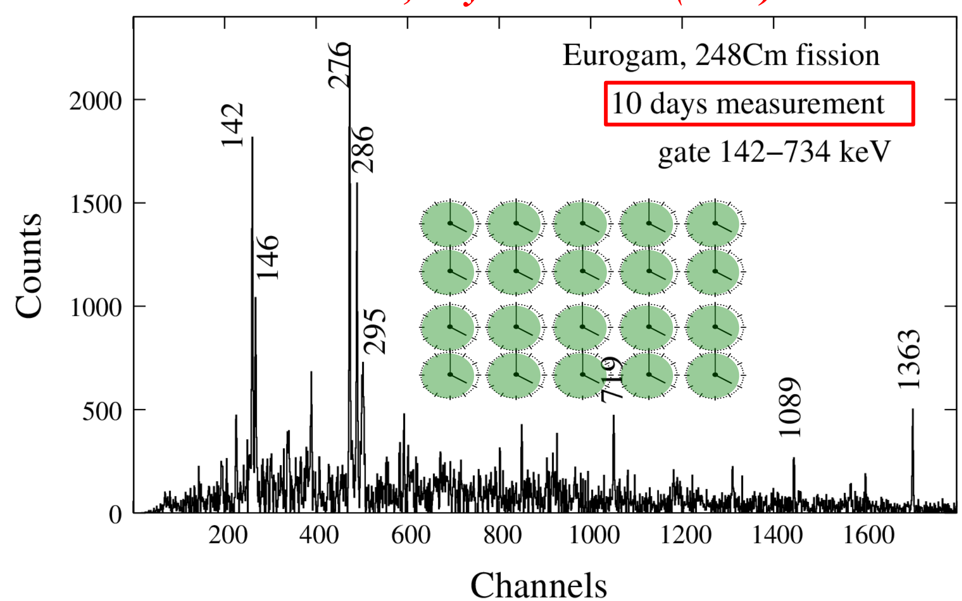


EUROGAM

W. Urban et al., Phys. Rev. C 85 (2012) 014329



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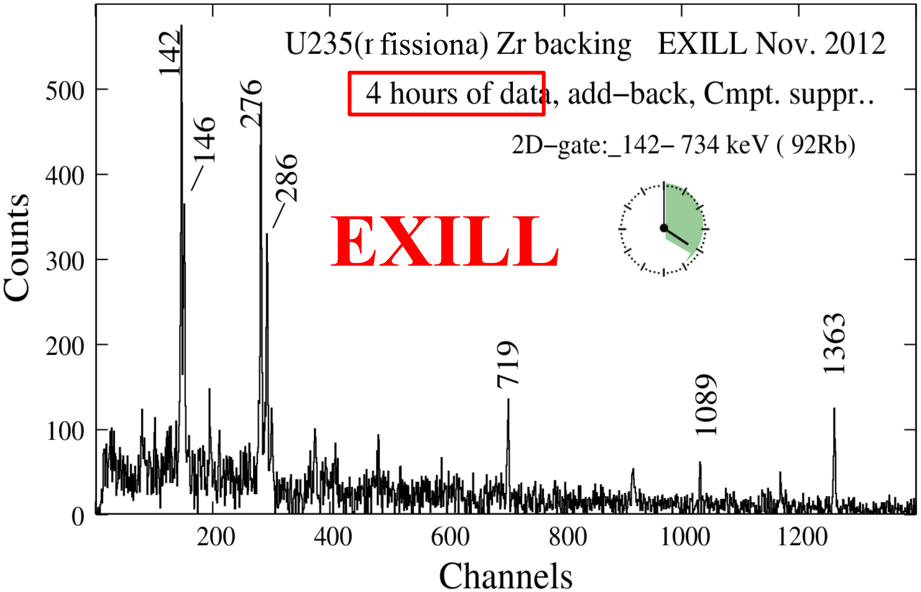

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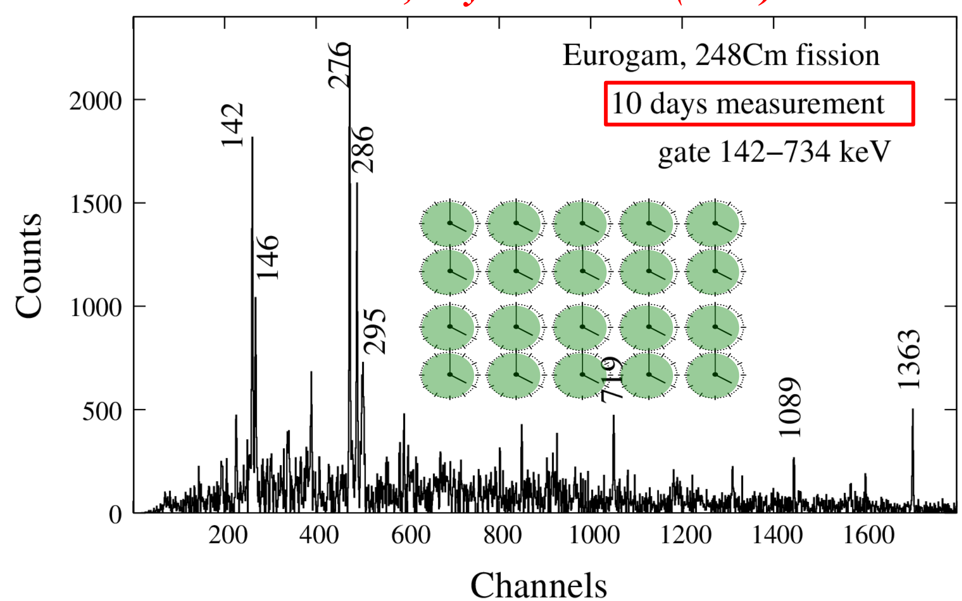

Much higher statistics
=> allow studying much weaker populated nuclei

W. Urban, ILL

Selection of results

- *"Germanium-gated γ–γ 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 196Pt using cold-neutron capture"*, J. Jolie et al., NuclearPhysics A 11/2014

- *"B(E2;2+1→0+1) value in Kr90"* , J.M. Regis & al., Phys. Rev. C 90, 067301

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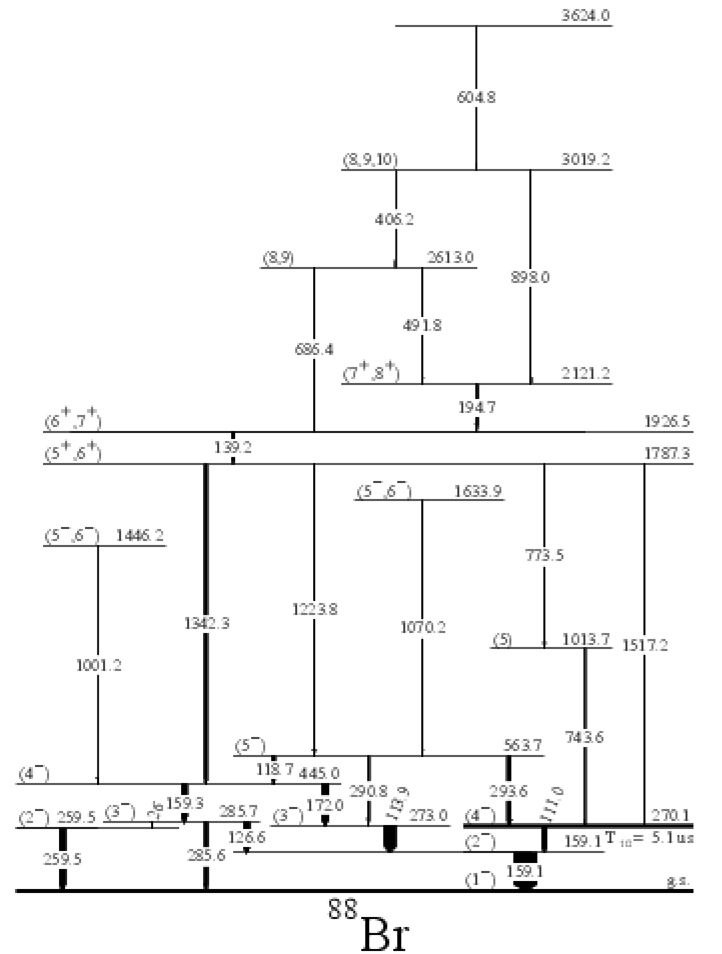
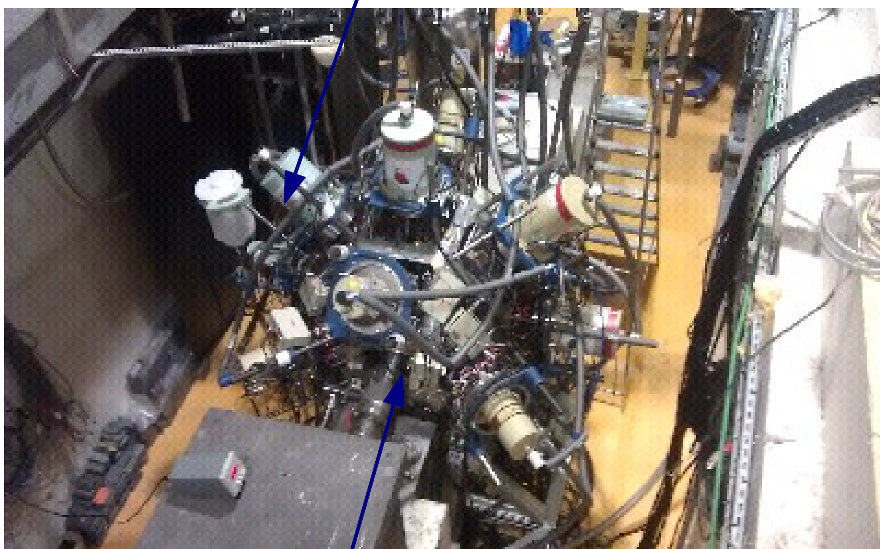


FIssion Product Prompt γ-ray Spectrometer

- **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

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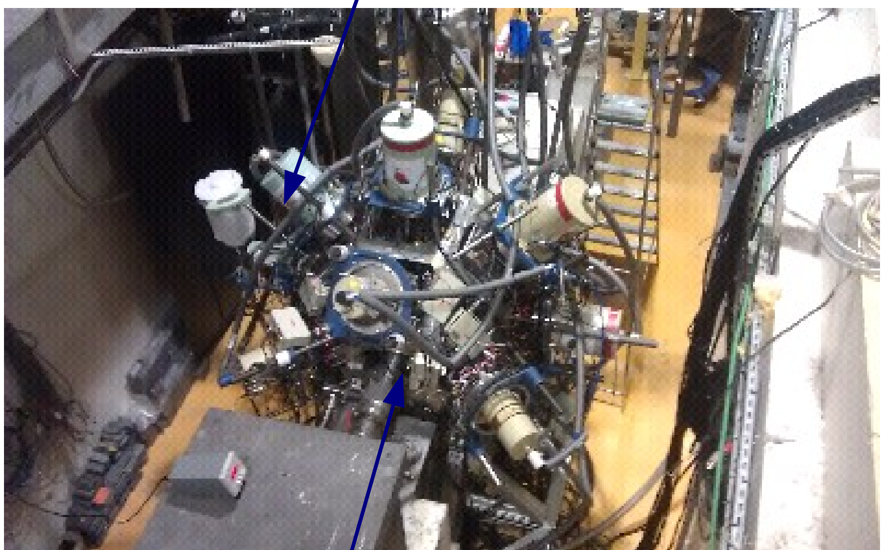

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+

Spectrometer

FIPPS layout

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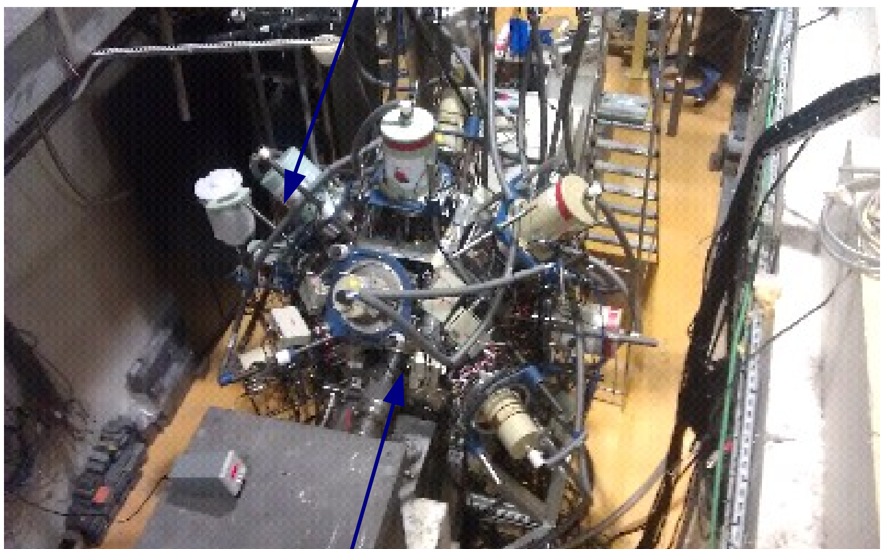

Fission target with a thick backing

+

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

FIPPS layout

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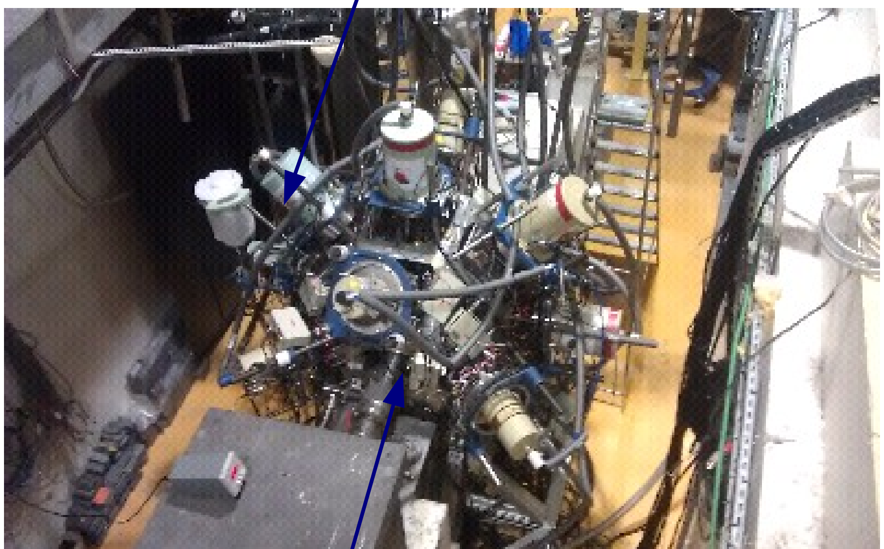

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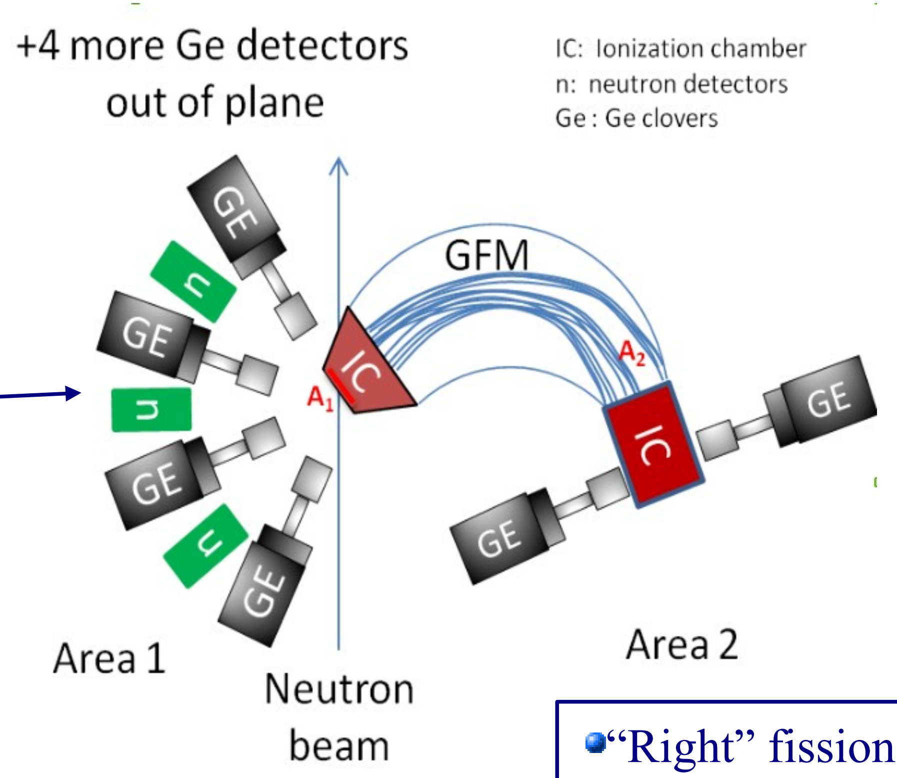
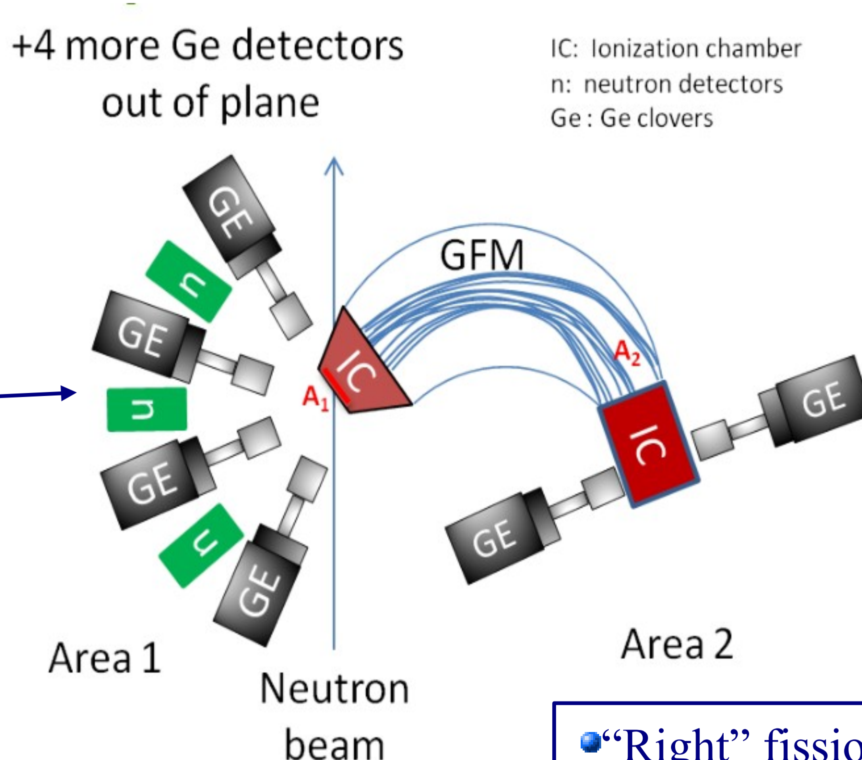


EXILL-like

- "Left" fission fragment: stopped in backing
→ Doppler free **γ detection**

- "Right" fission fragment:
→ mass identification with a Gas-Filled magnet for **filtering**
→ **Ekin & dE/dx** measurement with Ionization chamber **using intrinsic energy loss in the gas**

FIPPS layout

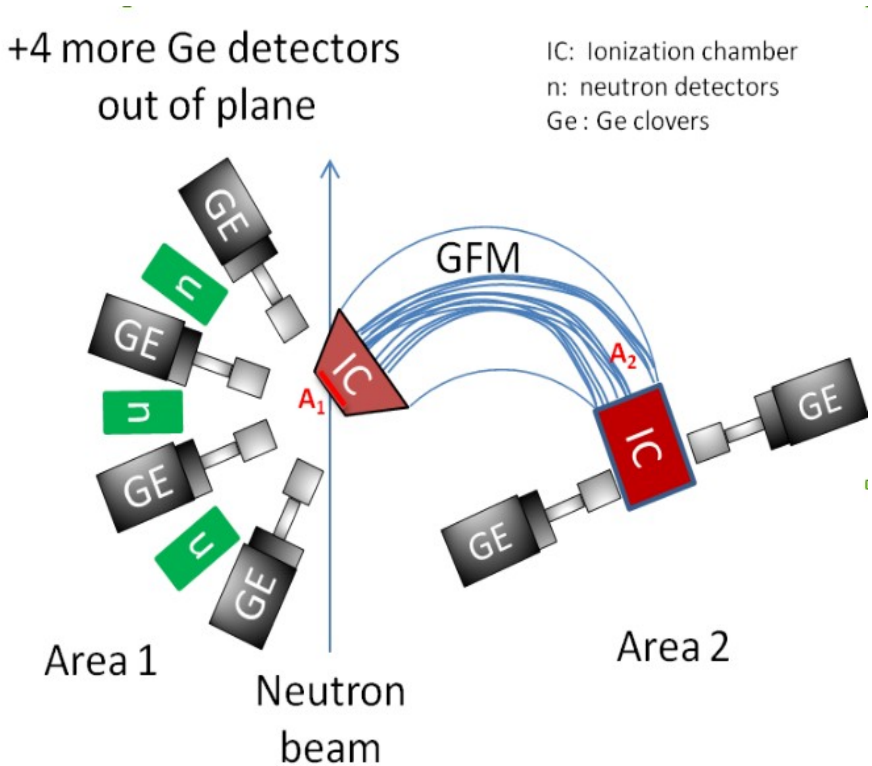


EXILL-like
- "Left" fission fragment: stopped in backing → Doppler free **γ detection**

\+ Ancillary detectors:
→ neutron detectors
→ LaBr3(Ce) for fast timing
→ low energy Ge detectors
→ ...

- "Right" fission fragment:
→ mass identification with a Gas-Filled magnet for **filtering**
→ **Ekin & dE/dx** measurement with Ionization chamber **using intrinsic energy loss in the gas**

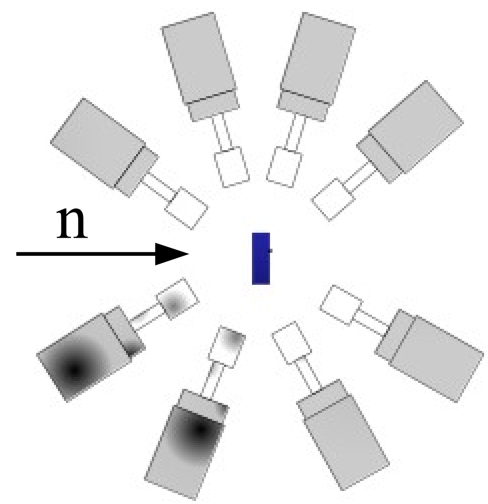
FIPPS layout



- Gas-Filled Magnet: **design on going**
- Ionization chambers → **LPSC know-how** (in used at Lohengrin since 20 years)

FIssion Product Prompt γ-ray Spectrometer

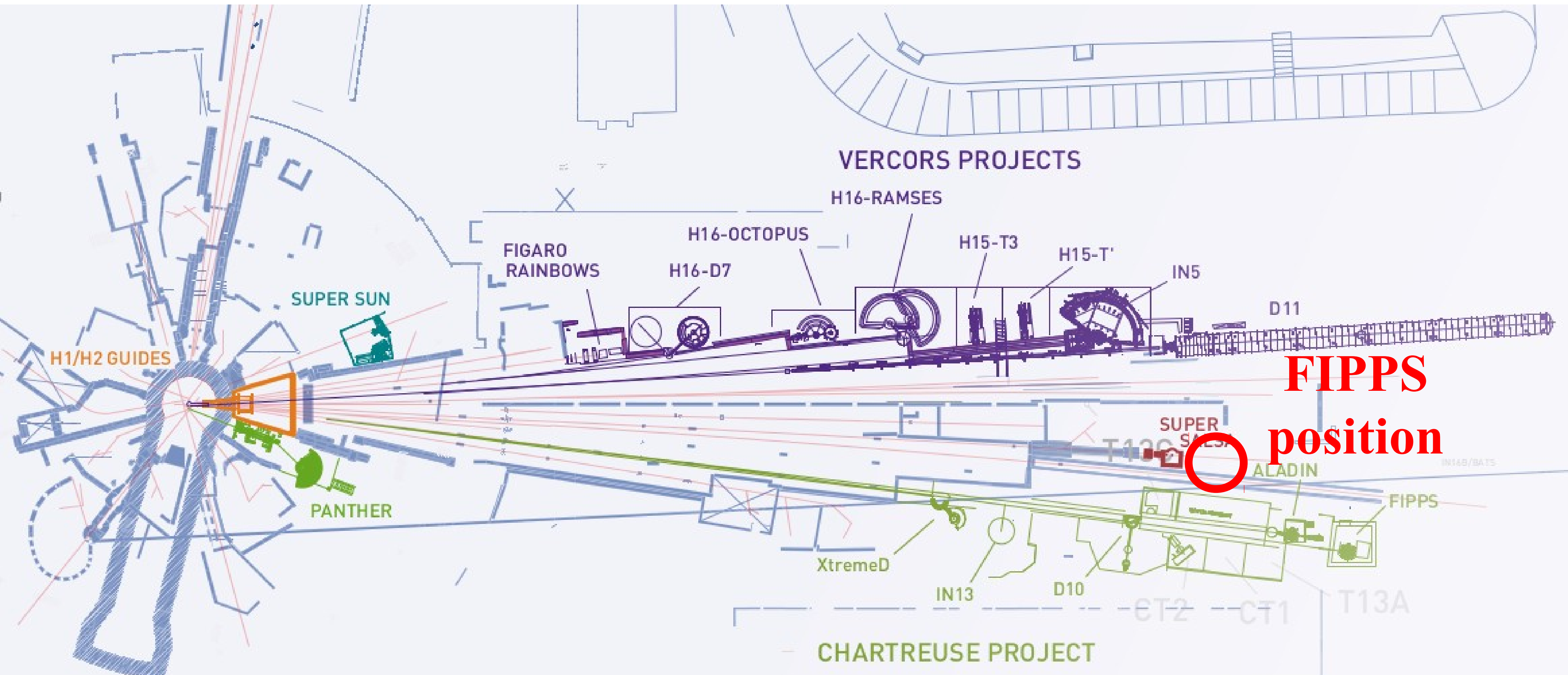
- FIPPS layout
- FIPPS Phase I and timeline



FIPPS location

FIPPS Position:

- Thermal neutron guide
- Flux: 7.10^8 n.cm^{-2}.s^{-1} prior collimation
- γ-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

CANBERRA

TECHNICAL DATA SHEET

CANBERRA CLOVER
CLOV 4 X 50 X 80 BCT for FIPPS
Clover : crystal diameter 50mm – length 80mm
Each Clover detector will be an assembly
of 4 individual crystals with front tapering.

SPECIFICATIONS FOR EACH INDIVIDUAL CRYSTAL

ENERGY RESOLUTION:

- For 1.33MeV gamma rays from a ^{60}Co source, the energy resolution of each crystal will be ≤ 2.15keV full width half maximum (FWHM).
- For 122keV gamma rays from a ^{57}Co source, the energy resolution of each crystal will be ≤ 1.20keV FWHM.
- These resolutions will be measured with a main spectroscopy amplifier time constants of ≥ 6µs. For each measurement, the total count rate will be ≤ 1000 counts/s and the total number of counts in the photopeaks will be ≥ 10^5.

SIZE OF EACH INDIVIDUAL CRYSTAL:

- The diameter of the crystal will be 50mm before shaping.
- The length of the crystal will be a nominal of 80mm.
- The relative efficiency at 1.33MeV will be ≥ 23% after shaping, source at 25cm from the front face of each crystal, mean value on the 4 crystals.

PEAK TO COMPTON:

- The measured Peak to Compton for 1.33MeV gamma rays (measured after IEC 973 international norm) should have a minimum value of 45.

Phone contact information

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Japan 81-3-3500-5808 - **Russia** (7-495)429-6577 - **Sweden** +46 18 14 83 00 - **United Kingdom** (44)1235 838333 - **United States** (1) 203-238-2351
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or contact the CANBERRA Lingolsheim office or CANBERRA U.S.A. office
Printed in France 1/10 Clover 4x50x80BCT for FIPPS dated 04/04/2016

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

=> other Ge, LaBr, neutron detectors, ...

CANBERRA

TECHNICAL DATA SHEET

CANBERRA CLOVER
CLOV 4 X 50 X 80 BCT for FIPPS
Clover : crystal diameter 50mm – length 80mm
Each Clover detector will be an assembly of 4 individual crystals with front tapering.

SPECIFICATIONS FOR EACH INDIVIDUAL CRYSTAL

ENERGY RESOLUTION:

- For 1.33MeV gamma rays from a ^{60}Co source, the energy resolution of each crystal will be ≤ 2.15keV full width half maximum (FWHM).
- For 122keV gamma rays from a ^{57}Co source, the energy resolution of each crystal will be ≤ 1.20keV FWHM.
- These resolutions will be measured with a main spectroscopy amplifier time constants of ≥ 6µs. For each measurement, the total count rate will be ≤ 1000 counts/s and the total number of counts in the photopeaks will be ≥ 10^5.

SIZE OF EACH INDIVIDUAL CRYSTAL:

- The diameter of the crystal will be 50mm before shaping.
- The length of the crystal will be a nominal of 80mm.
- The relative efficiency at 1.33MeV will be ≥ 23% after shaping, source at 25cm from the front face of each crystal, mean value on the 4 crystals.

PEAK TO COMPTON:

- The measured Peak to Compton for 1.33MeV gamma rays (measured after IEC 973 international norm) should have a minimum value of 45.

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First 2 clovers delivery in september
All the clovers by the end of the year

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Phone contact information

Benelux/Denmark (32)2 481 85 30 - Canada 905-660-5373 - Central Europe +43(0)2230 37000 - France (33)1 39 48 52 00 - Germany (49) 6142 73820
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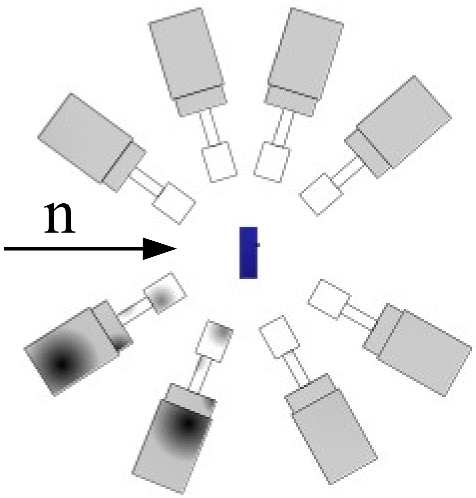
FIPPS phase I: some ideas

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



Nuclear structure:

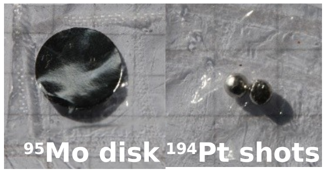
- **DPM** measurements
  → we learnt a lot from the EXILL-DPM measurement
- **plunger** measurements
- **g factor** measurements
- new **spectroscopy** campaign

Fission:

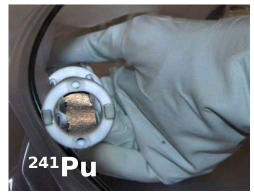
- **prompt γ-ray** *(NEA High Priority Request List for 235U and 239Pu)*
  A. Oberstedt et al., PRC 87, 051602 (2013)
  → possible observables: total γ-ray spectra, Eγ distribution and multiplicity, per fission or per fragment pair
  → **EXILL data** analysis difficult: need complex **γ-γ-γ analysis**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

FIPPS phase I: targets

(n, γ) on stable targets

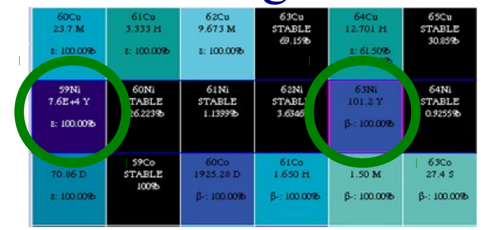


(n, fission) on actinide targets



(n, γ) on radioactive

exotic targets



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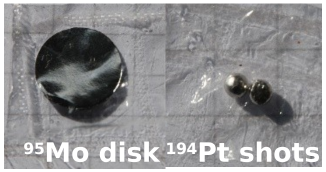

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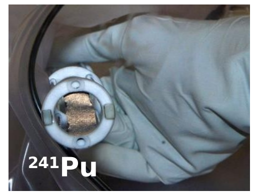

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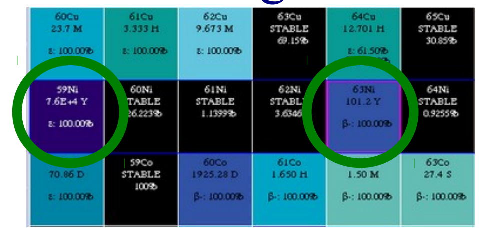

<u>Typical program foreseen in the coming 3-4 years (2-3 cycles/year):</u>

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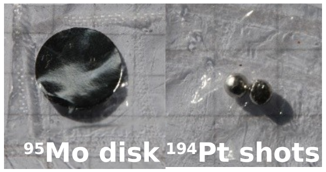

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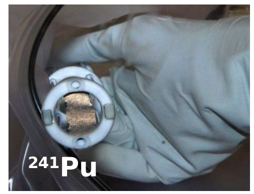

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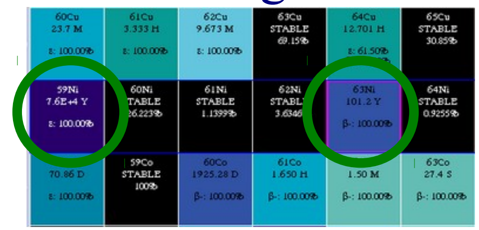

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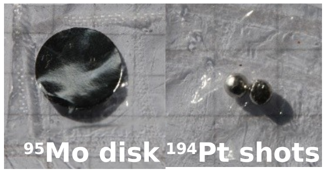

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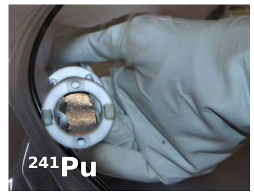

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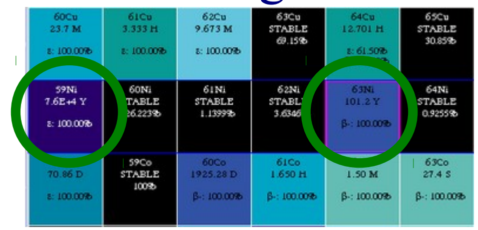

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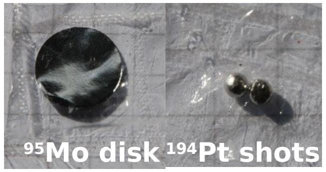

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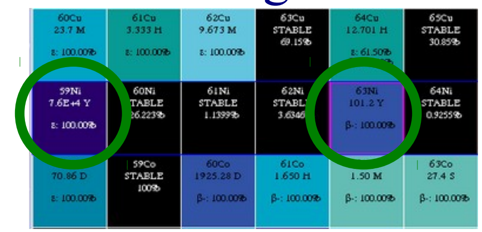

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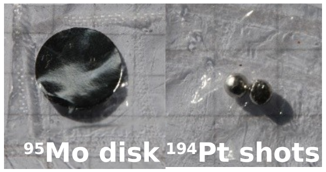

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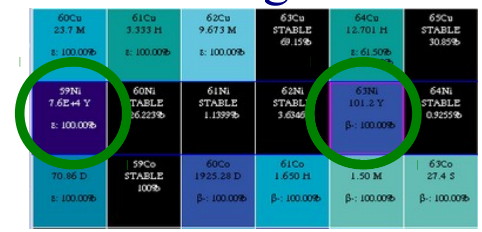

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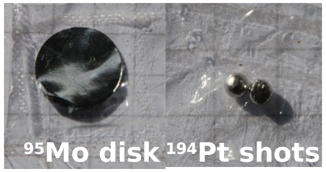

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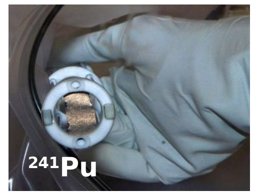

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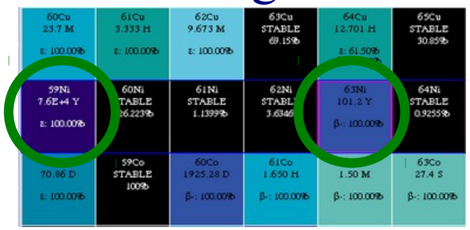

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  cycle 3 (Nov.-Dec.): (n,fission) on closed 235U target
- **2018:** **cycle 1: (n,fission) on closed 233U target**
  cycle 2: (n,fission) on 235U target (plunger / magnetic moment commissioning)
- **2019:** **cycle 1: (n,fission) on 235U (GFM commissioning)**
  cycle 2: (n,fission) on closed 241Pu target
  cycle 3: (n,fission) on closed 239Pu target

Conclusion

Conclusion (1)

- All **EXILL** requirements achieved:
  - Halo-free **pencil neutron beam** (1 cm^2), ~10^8 n.cm^{-2}.s^{-1}
  - **Safe target environment** allowing (n,f) of actinides targets (^{235}U, ^{241}Pu)
  - Up to **50 Ge crytals and 16 LaBr scintillators** operating simultaneously
  - **Trigerless 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,γ) measurements during the last cycle of 2016

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

Autumn 2016 council

Proposal dead line: 15 September 2016 (midnight European time); web opens for submission on 1 July

Subcommittee meetings: 22-23 November 2016

Scientific Council: 24-25 November 2016

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

The EXILL collaboration

NEUTRONS FOR SCIENCE

CSNSM

cea

Yale University

BARC

TECHNISCHE UNIVERSITÄT DARMSTADT

MTA atomki DEBRECEN

IPHC Institut Pluridisciplinaire Hubert Curien Strasbourg

University of Brighton

Université Joseph Fourier

LPSC Grenoble Laboratoire de Physique Subatomique et de Cosmologie

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3

UNIVERSITY OF SURREY

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