GAMMA RAY SPECTROSCOPY AT EXTERNAL NEUTRON BEAMS OF THE ILL

Michael Jentschel

Institut Laue-Langevin, Grenoble, France

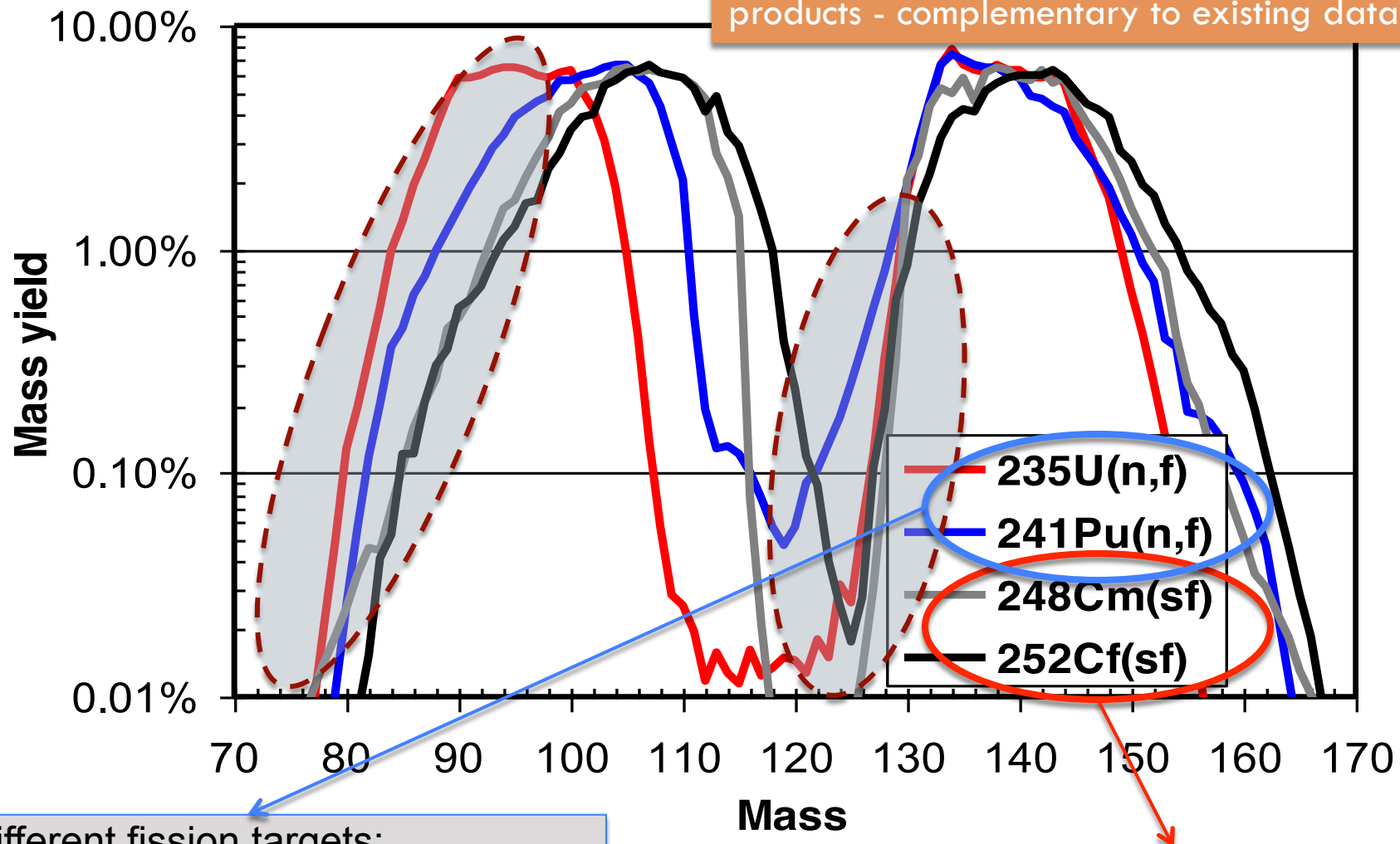
The exill core team

- ***ILL:*** *A. Blanc, M. Jentschel, U. Köster, P.Mutti, T. Soldner, W. Urban*
- ***LPSC:*** *G. Simpson*
- ***GANIL:*** *G. De France*
- ***LNL:*** *C.A. Ur*
- ***IKP Cologne:*** *J.M. Regis for FATIMA/ EXILL*

Motivation

Yields in (n,f) of ^{235}U and ^{241}Pu

Prompt spectroscopy of neutron induced fission products - complementary to existing data sets



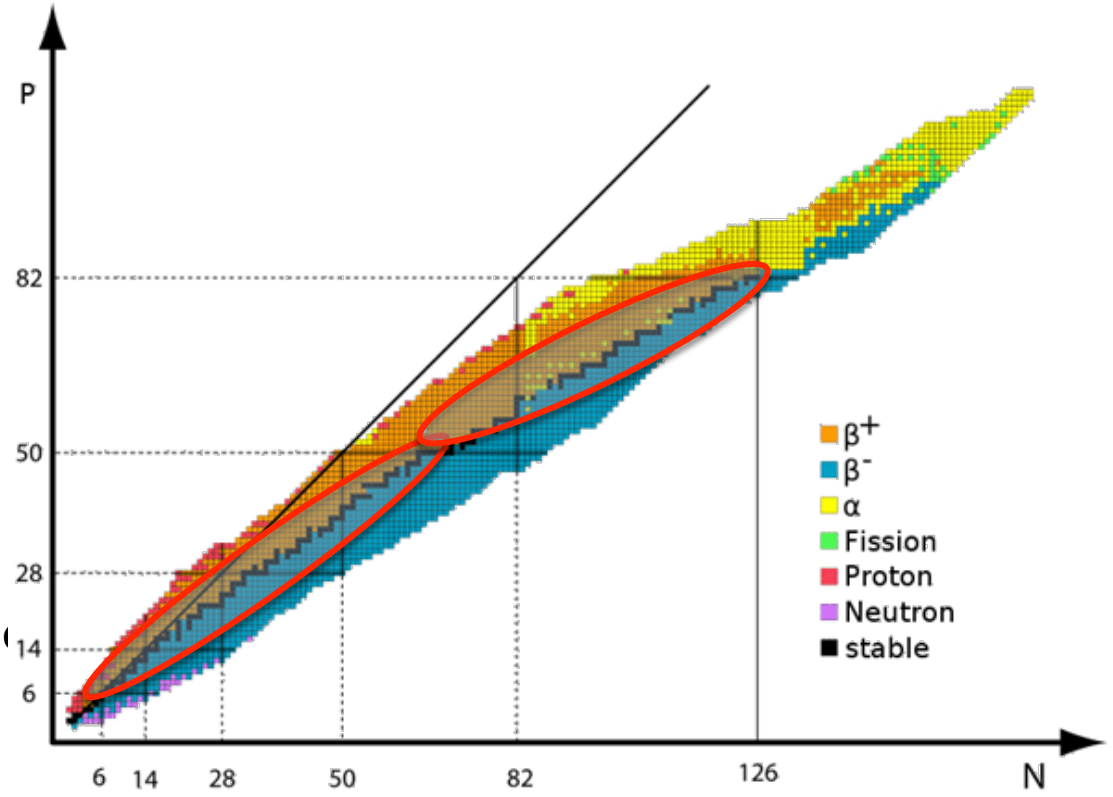
Two different fission targets:
^{241}Pu (σ_{th}=1010 b) and ^{235}U (σ_{th}=586 b)

Activities limited by safety issues

Motivation II: nuclear structure close to stability

(n,γ) – non selective process for population of low spin states

- **study of collective models, symmetries**
  - multi-phonon excitations
  - shape phase transition
  - symmetries
  - particle – phonon coupling
  - …
- **study of statistical properties of nuclei**
  - level density
  - pygmy dipole
- **applications**
  - radioisotope fabrication

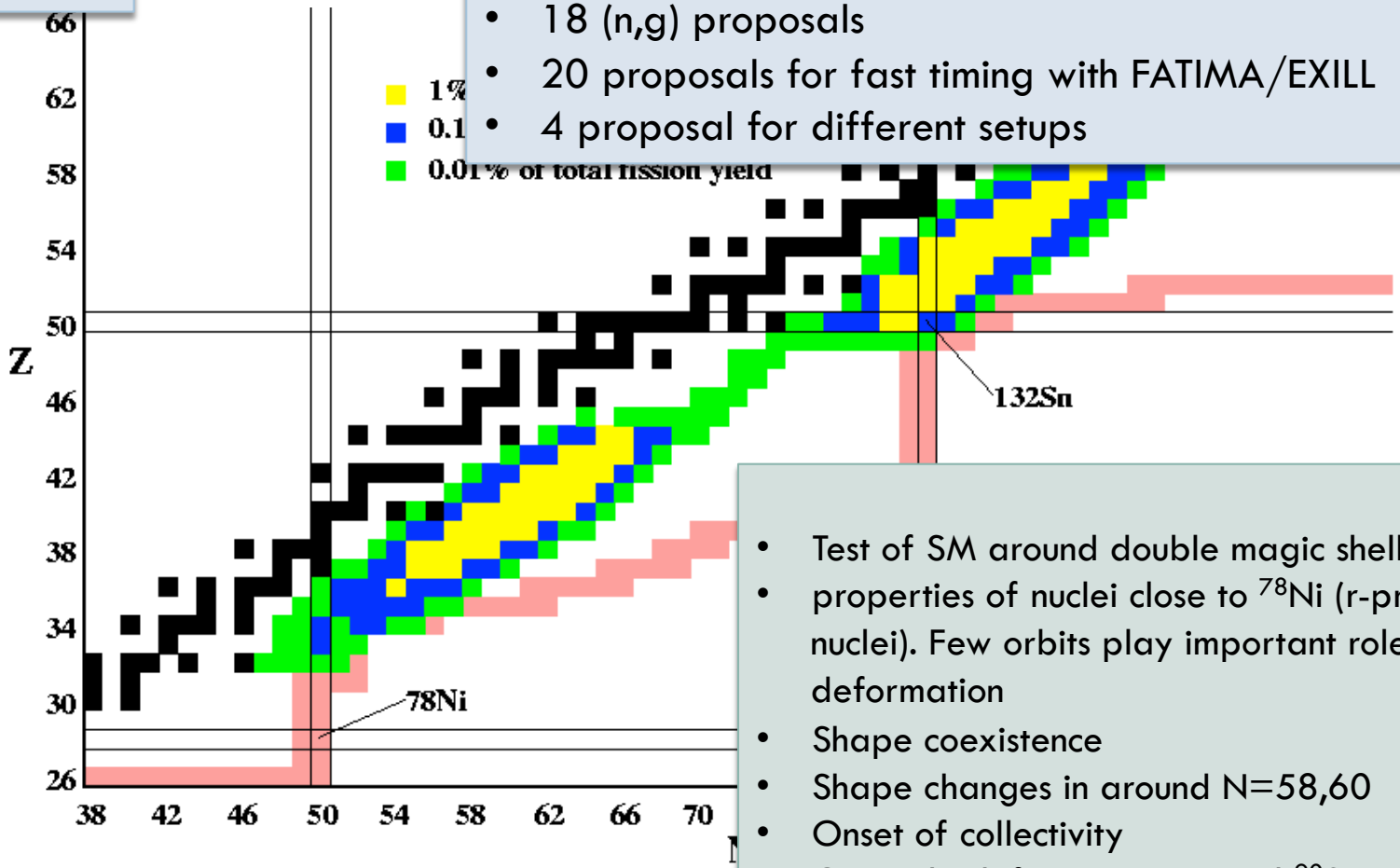


Prompt spectroscopy of fission products

For 100 days of beam time:

- 35 Proposals for promp fission product spectroscopy
- 18 (n,g) proposals
- 20 proposals for fast timing with FATIMA/EXILL
- 4 proposal for different setups

Fission of ^{241}Pu



- Test of SM around double magic shell ^{132}Sn
- properties of nuclei close to ^{78}Ni (r-process nuclei). Few orbits play important roles in deformation
- Shape coexistence
- Shape changes in around N=58,60
- Onset of collectivity
- Octupole deformation around ^{90}Se
- …

Concept: EXogam @ ILL

What was needed:

- EXOGAM clover detectors + HPGe detectors
  - High efficiency for γγγ
- Trigger less acquisition system
  - All events are written, all channels ~ 10 kHz event rate
  - Identification of fission products via coincidences
- Well collimated neutron beam
- Target environment allowing (n,f) of ^{235}U and ^{241}Pu
- Combination with $LaBr_3$:Ce for ultrafast timing
- User community

6 GASP Detectors from LNL

2 Clovers from Lohengrin

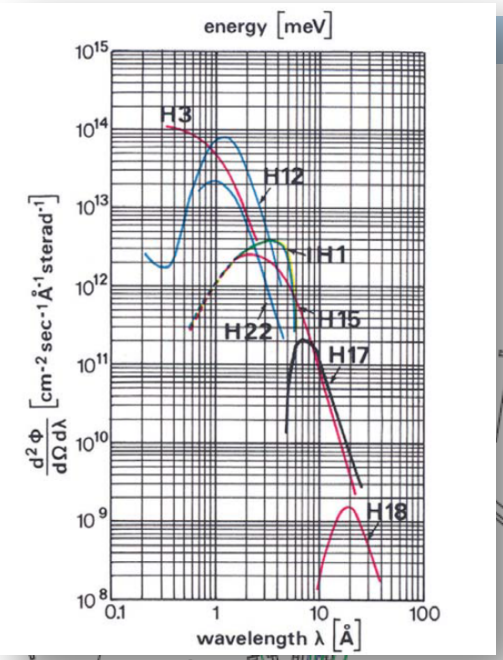
The EXILL collaboration

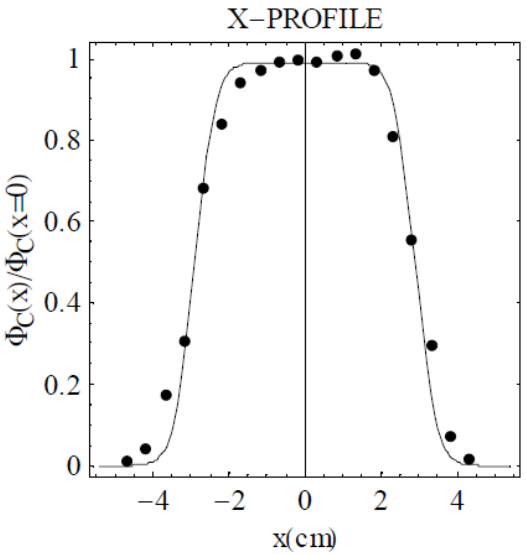
ILL NEUTRONS FOR SCIENCE
CSNSM
CEA DE LA RECHERCHE À L'INDUSTRIE
Yale University
LUX ET VERITAS
BARC ATOMS IN THE SERVICE OF THE NATION
TECHNISCHE UNIVERSITÄT DARMSTADT
MTA atomki DEBRECEN
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG
IPN
UNIVERSITAS COMPLVTENSIS MATRITENSIS
UNIVERSITAS VARSOVIENSIS
UNIVERSITE JOSEPH FOURIER SCIENCES, TECHNOLOGIE, SANTÉ
University of Brighton
LPSC Grenoble Laboratoire de Physique Subatomique et de Cosmologie
GANIL laboratoire commun CEA/DSM spiral2 CNRS/IN2P3
UNIVERSITY OF SURREY
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

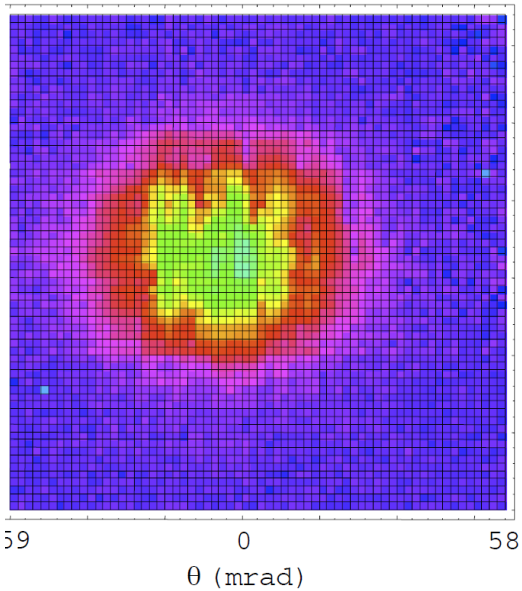
The EXILL Campaign 2012/13

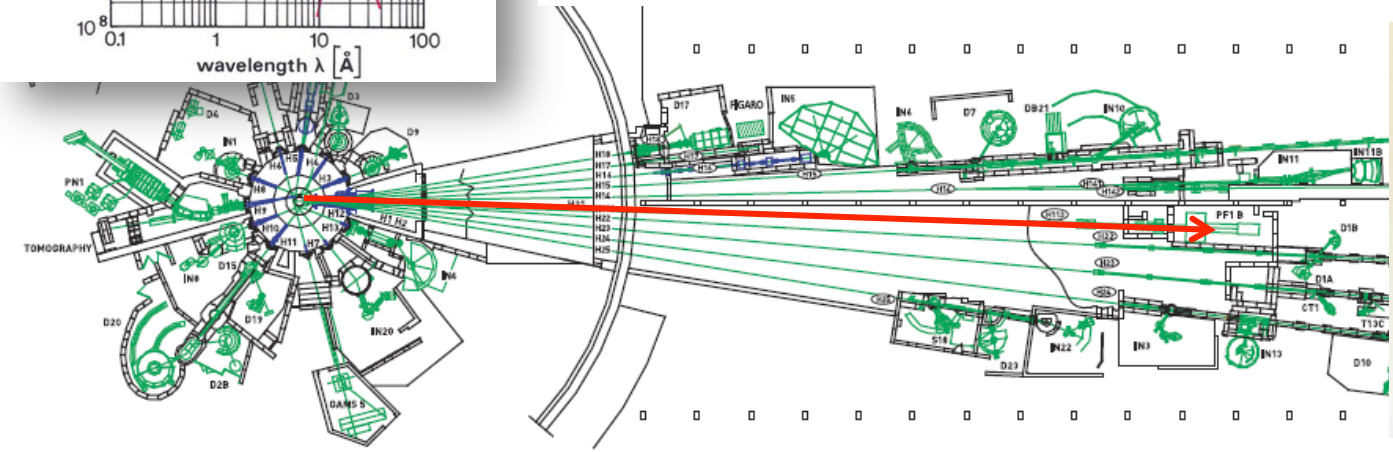
SETUP

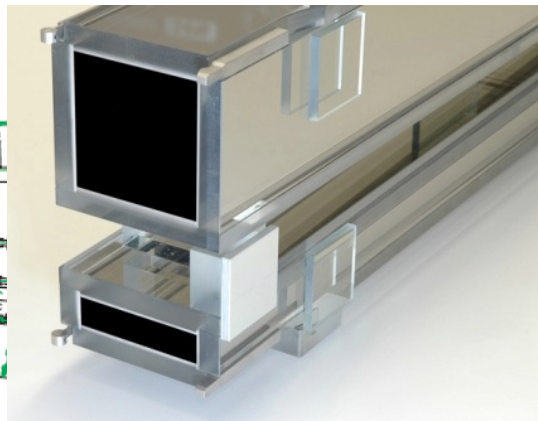
From the reactor to PF1b









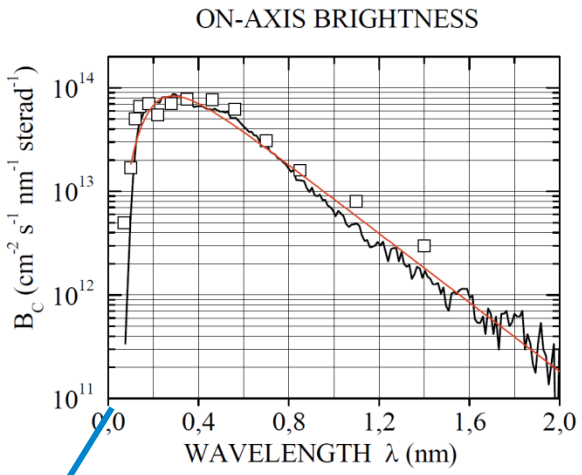


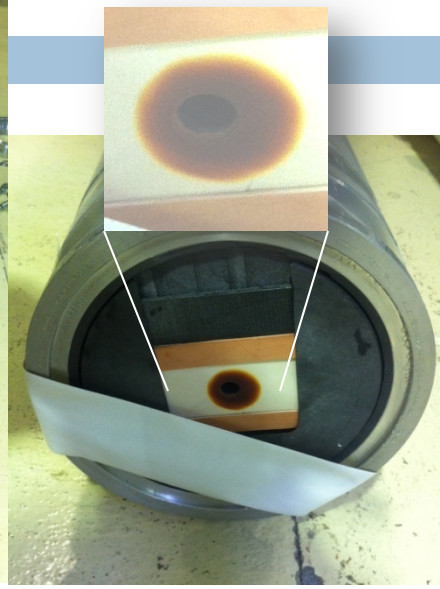
Reactor hall ILL 5
Experimental level (C)

Neutron guide hall - ILL 7
Chartreuse side (EAST)

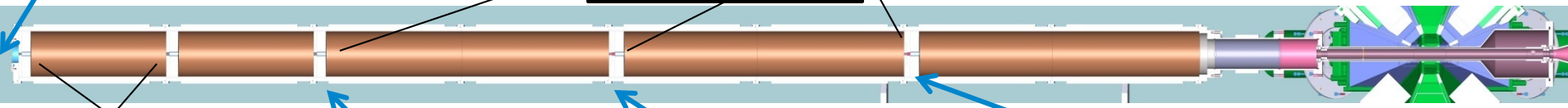
reactor (5×10^{14} n cm^{-2} s^{-1}) → ballistic neutron guide → PF1b zone (2×10^{10} n cm^{-2} s^{-1})

Neutron Collimation System

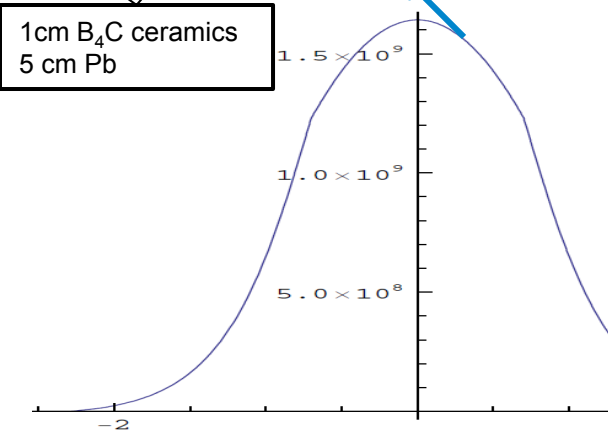


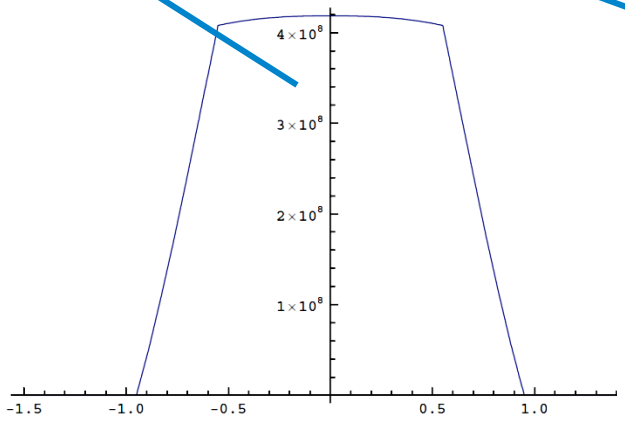


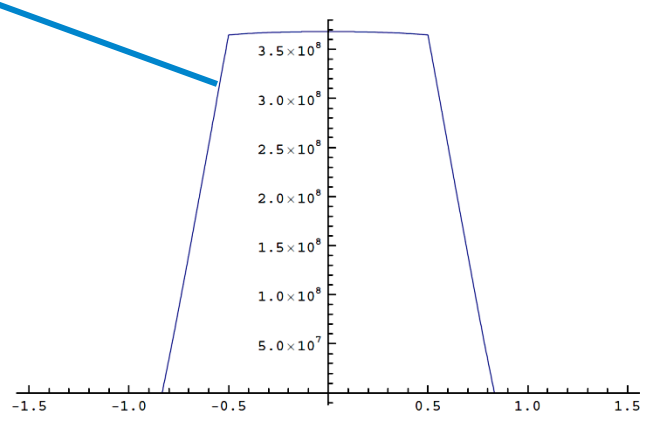
Borated plastics + ^{6}LiF
5 cm Pb



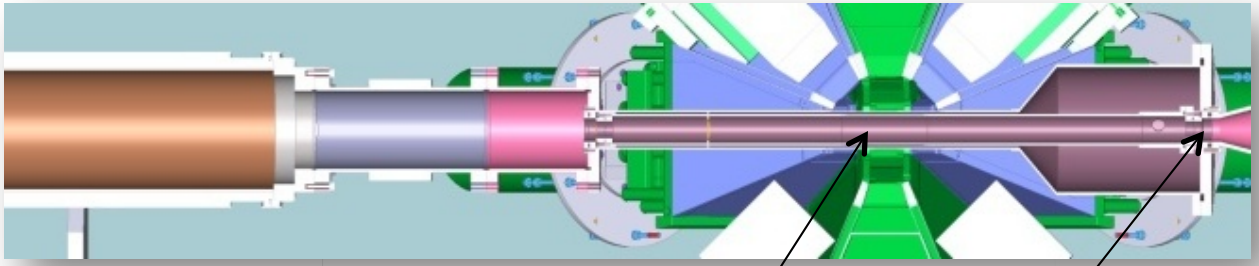
1cm B_4C ceramics
5 cm Pb

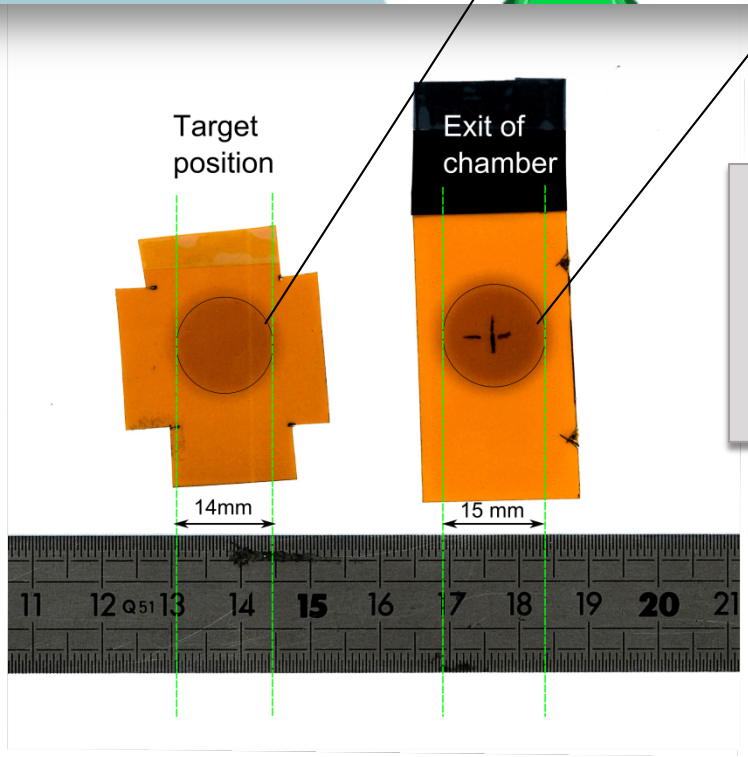






Measurement of collimation performance



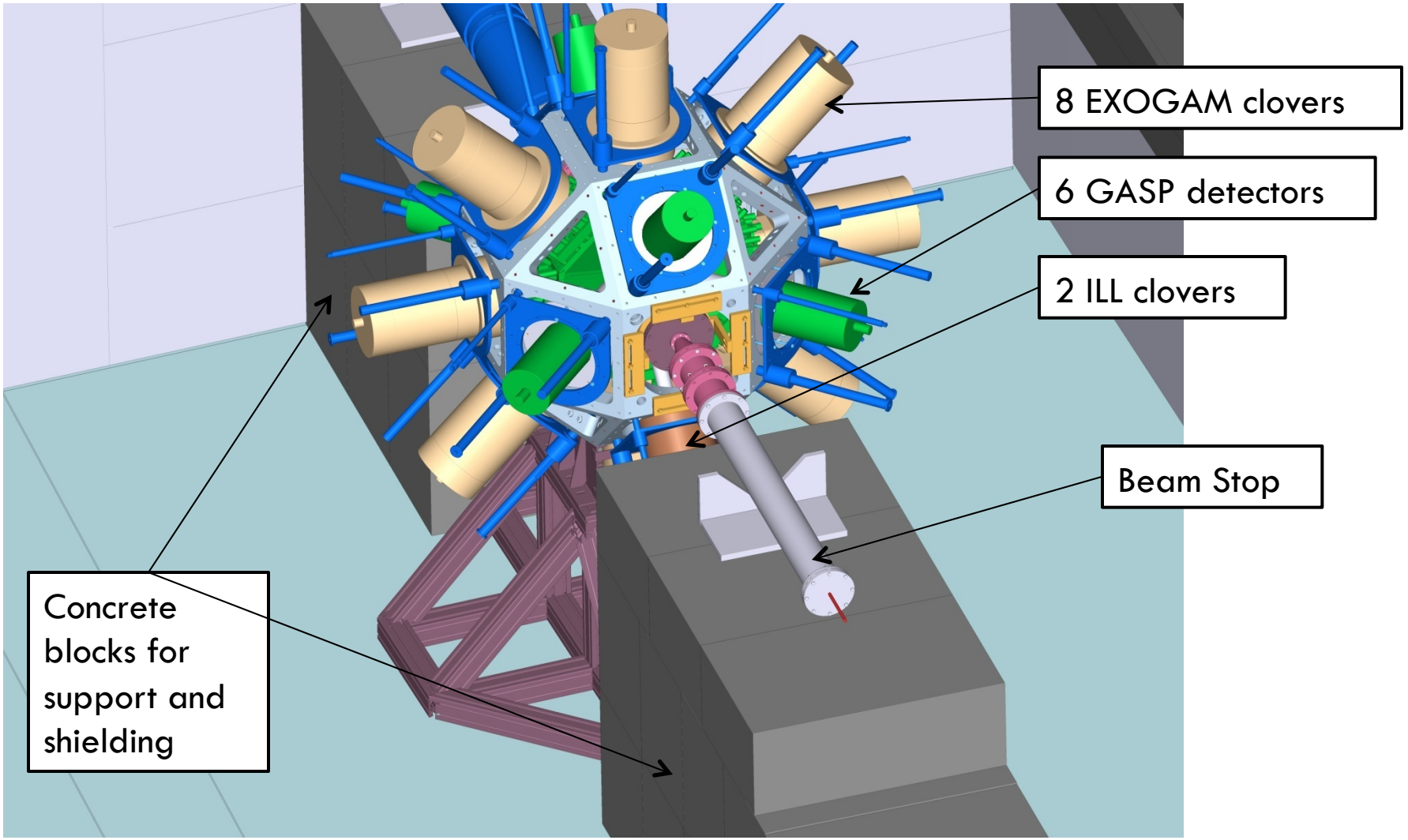


Beam profile measured with dosimetry film containing ^{6}Li

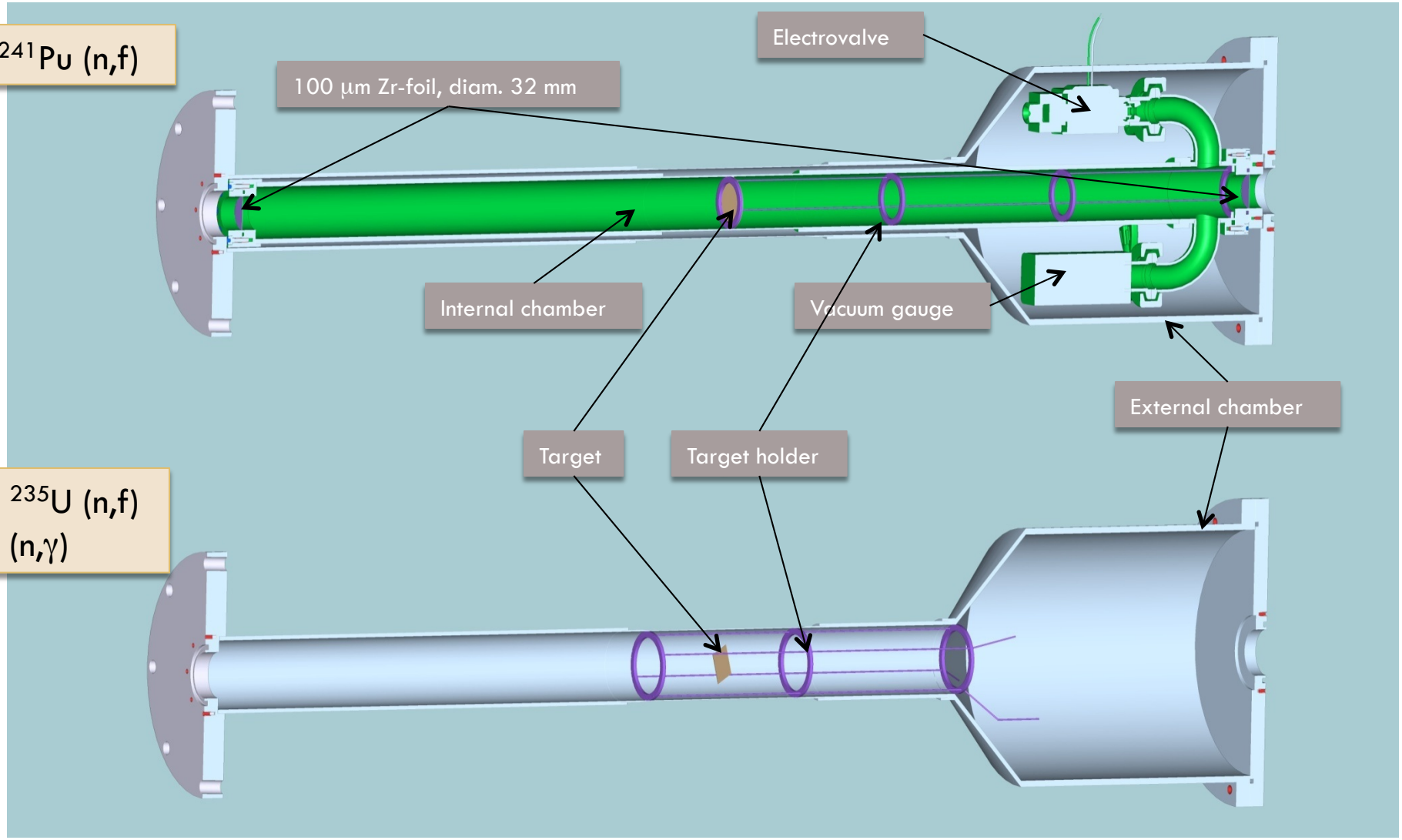
Flux measured with 1 cm diameter Gold foil activation:

$\Phi = 9 \times 10^{7}$ neutr. cm^{-2} s^{-1}

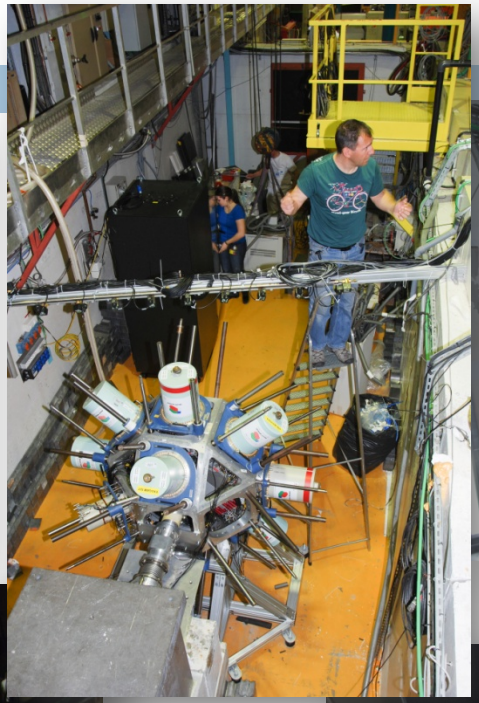
EXILL in PF1b experimental zone

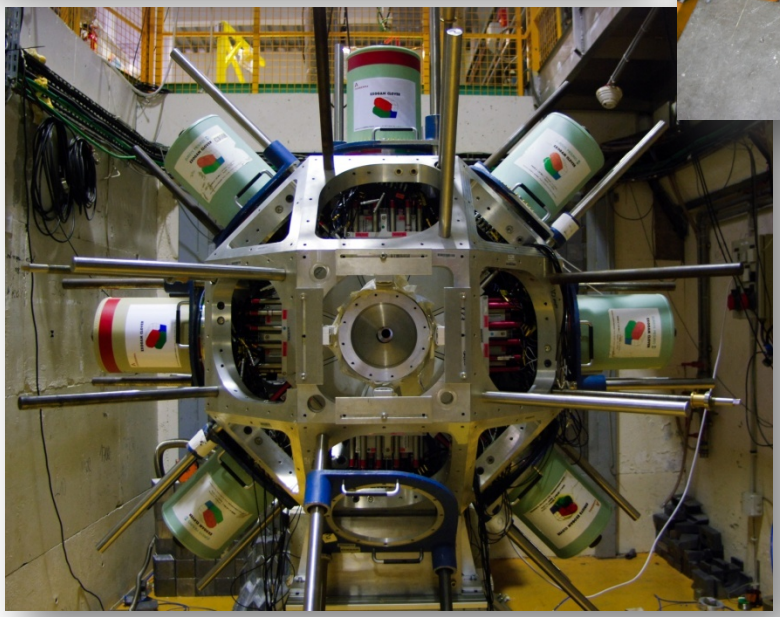


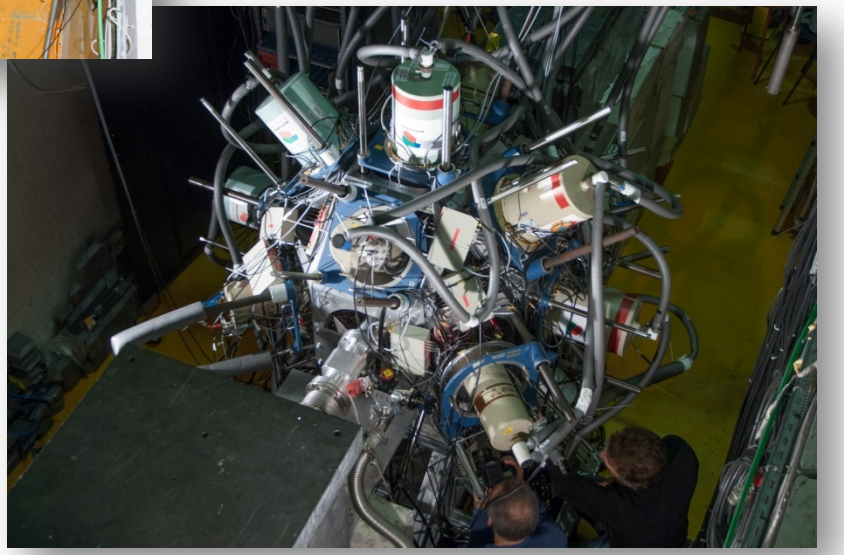
EXILL chamber: two configurations



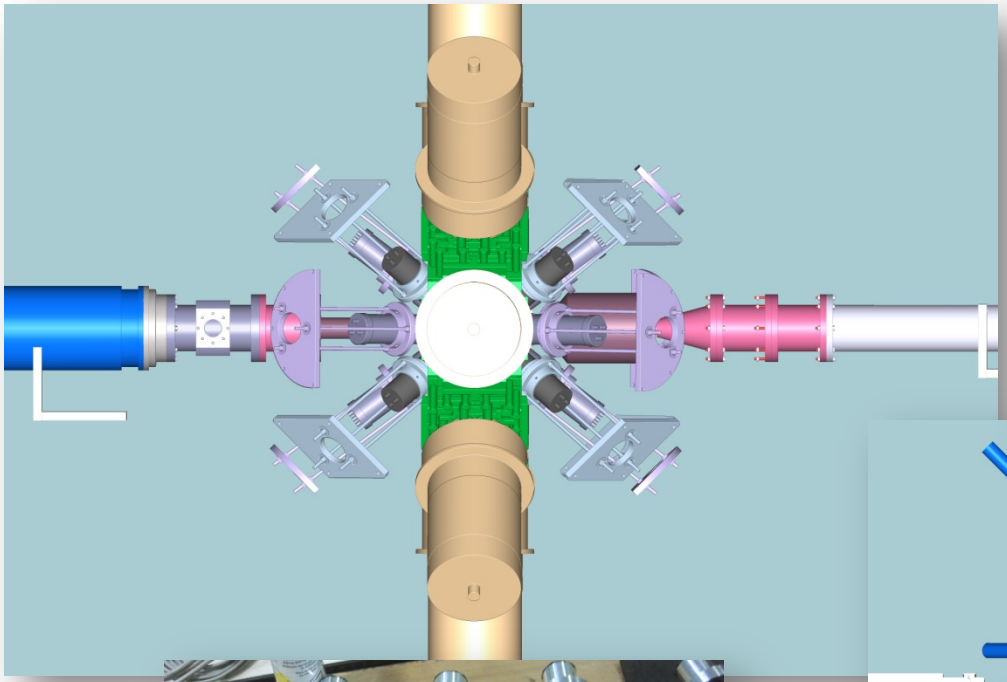
EXILL-installation within 10 days

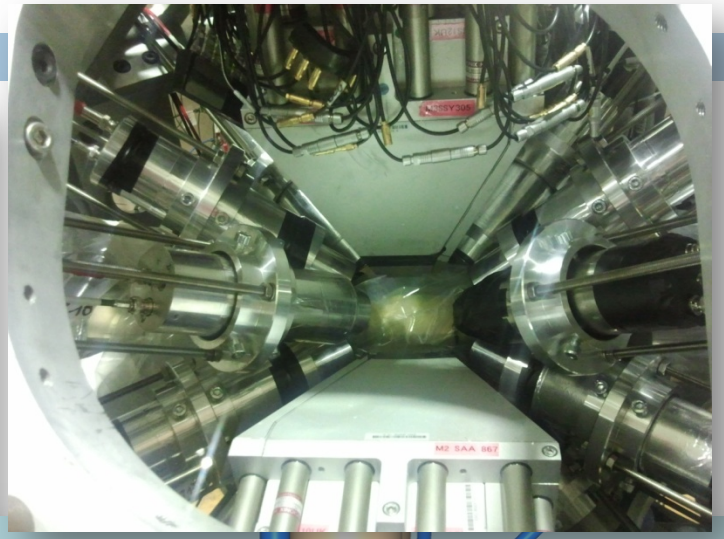


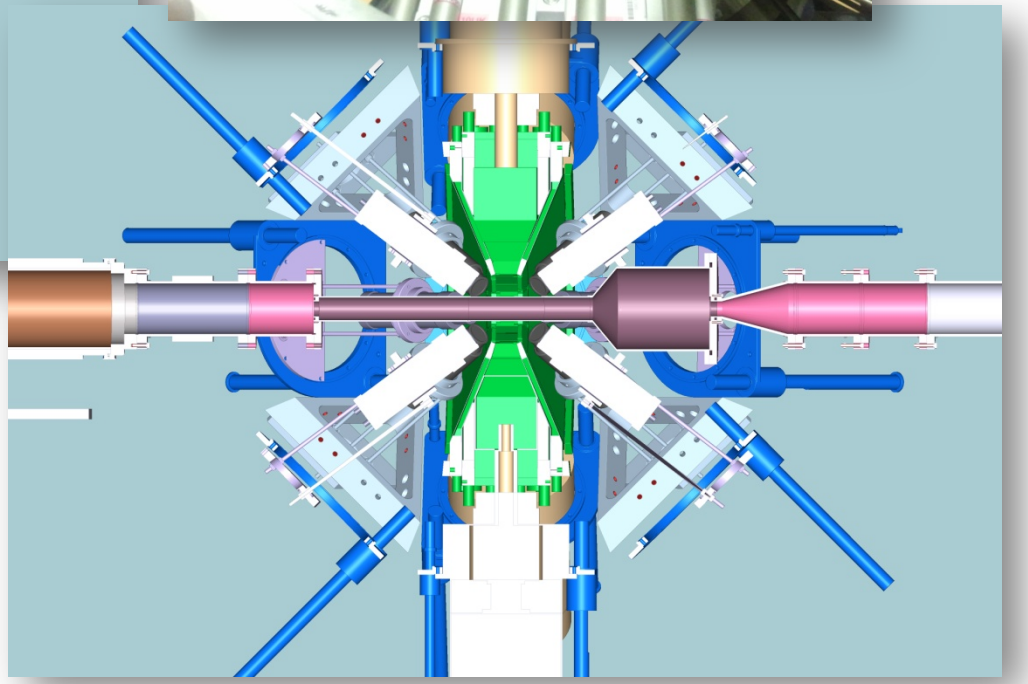




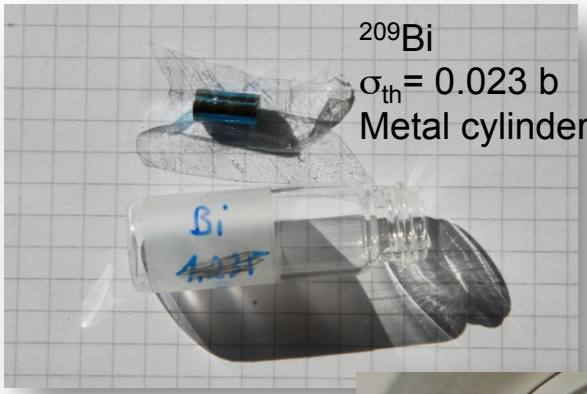
Arrangement of Fatima and EXOGAM detectors

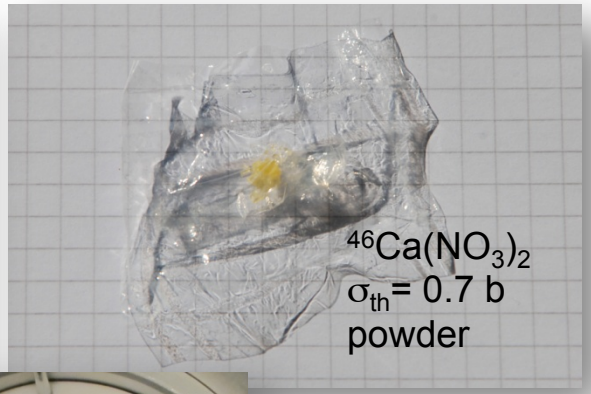


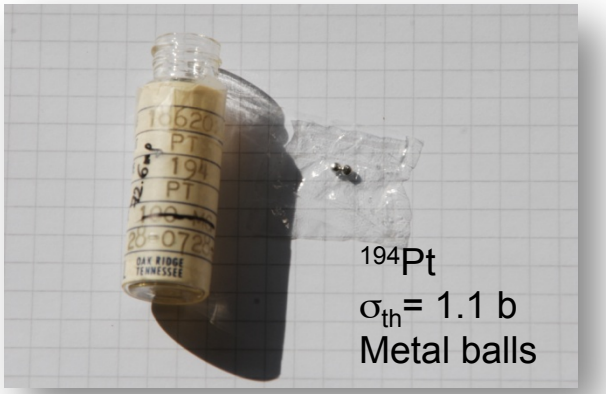


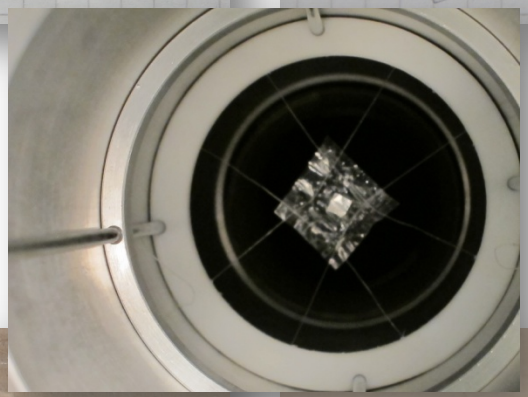


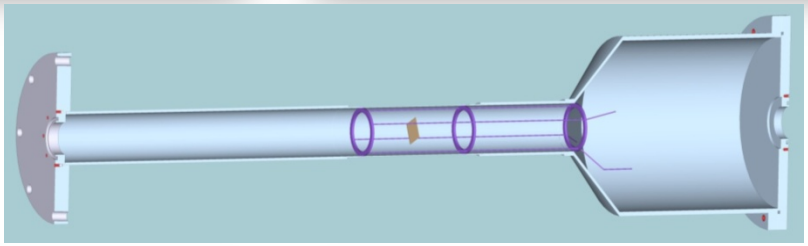
(n,γ) targets

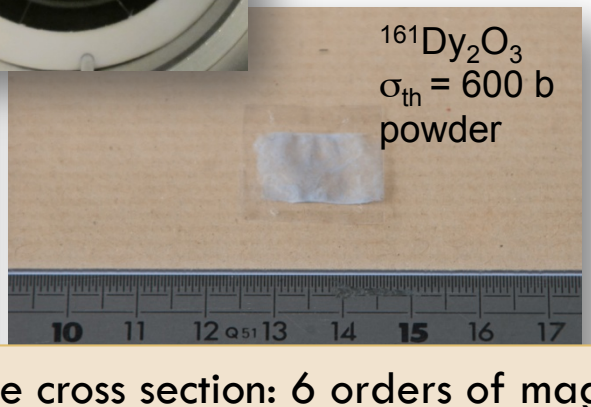


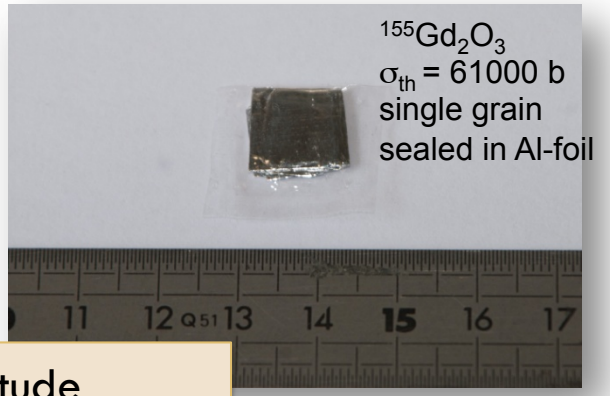










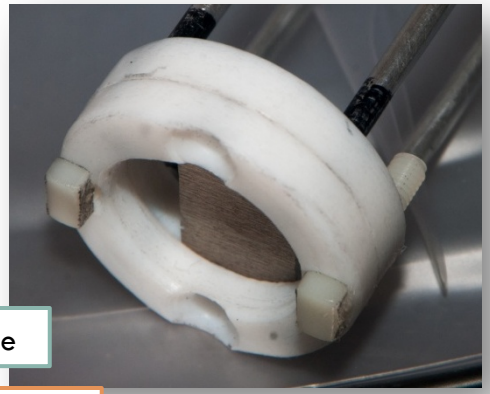


Variation capture cross section: 6 orders of magnitude

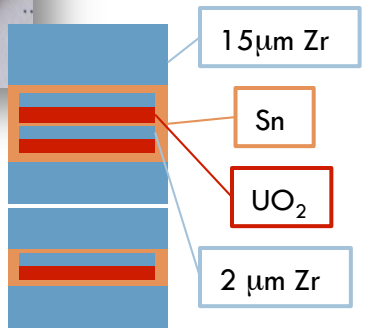
Fission targets

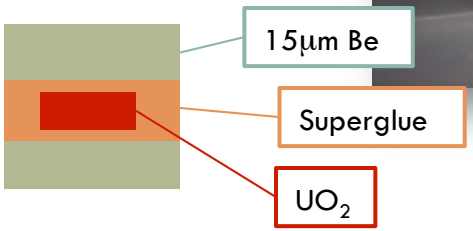
$^{235}UO_2$
σ_f = 586 b
Layer sandwiched between Zr or Be backing

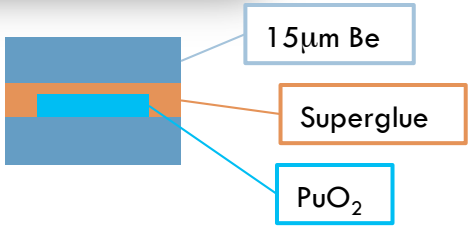
Starting material:
Actinide layers on metal backing

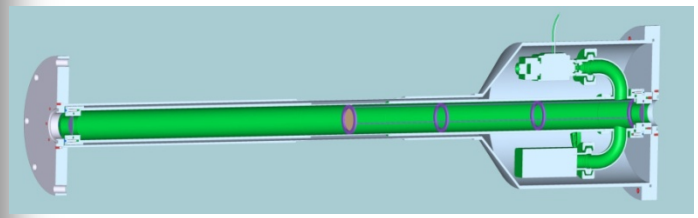


$^{241}PuO_2$
σ_f = 1010 b
Layer sandwiched between Zr backing

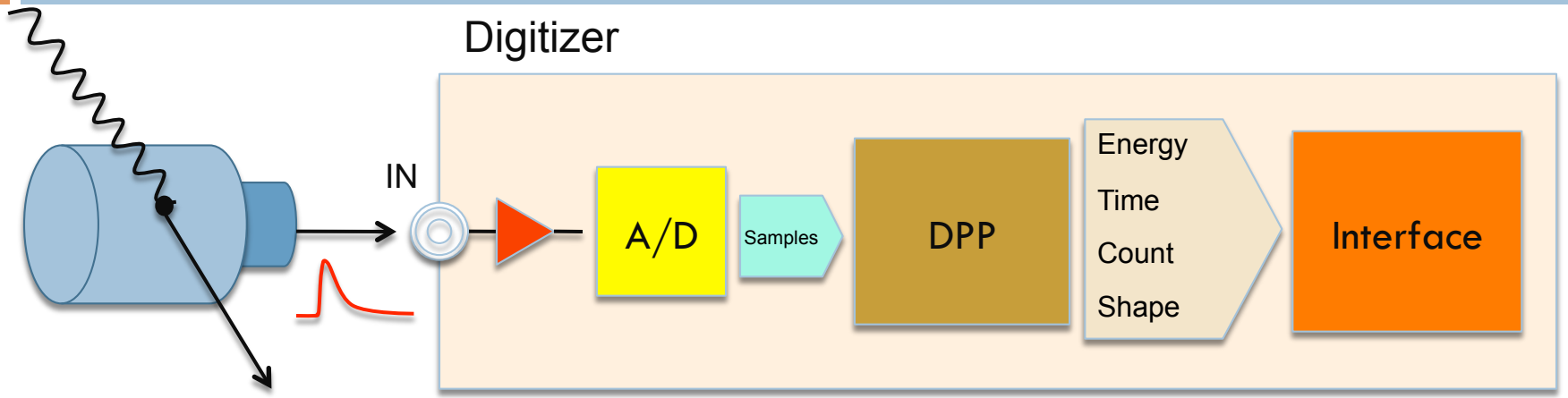






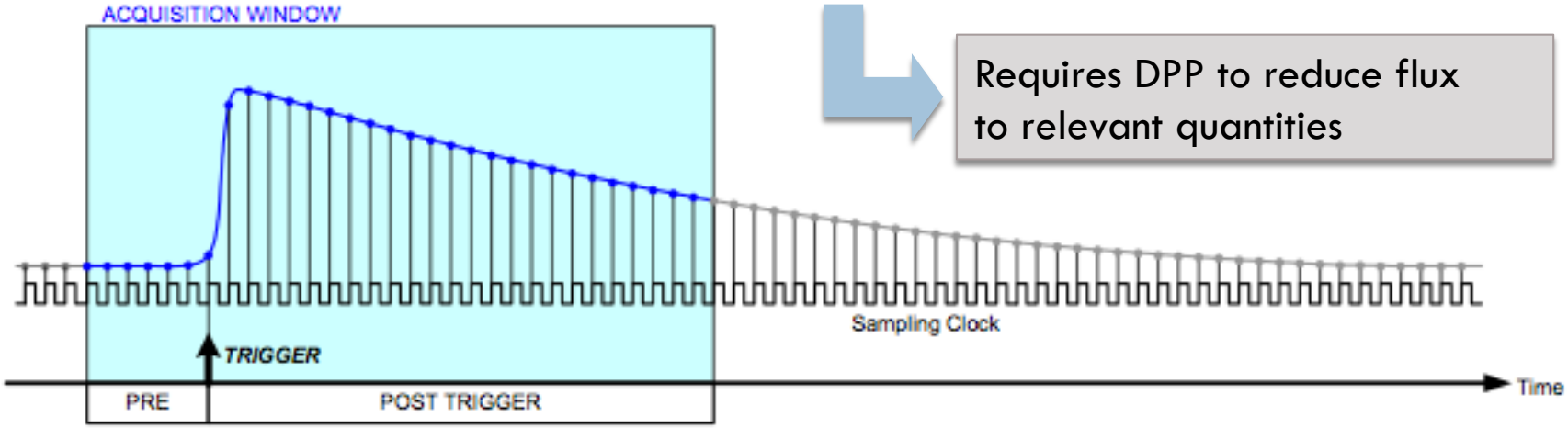


A Full Digital Approach



Very high throughput of data

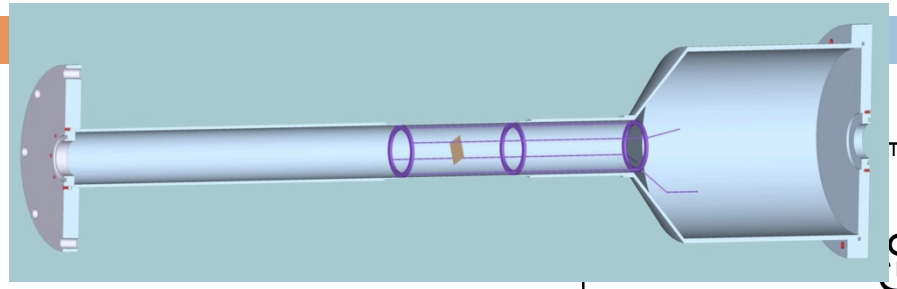
Requires DPP to reduce flux to relevant quantities



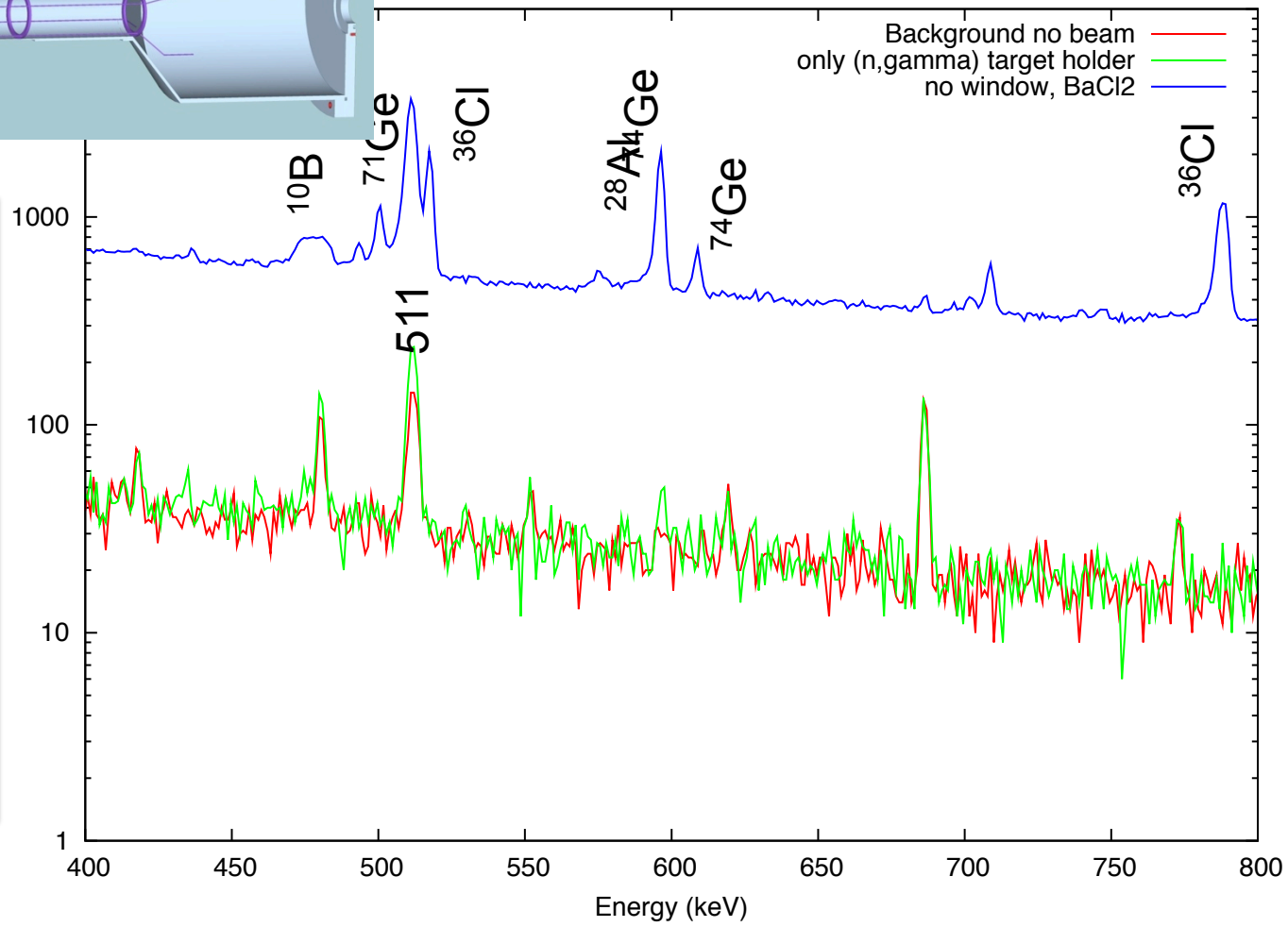
The EXILL Campaign 2012/13

PERFORMANCES

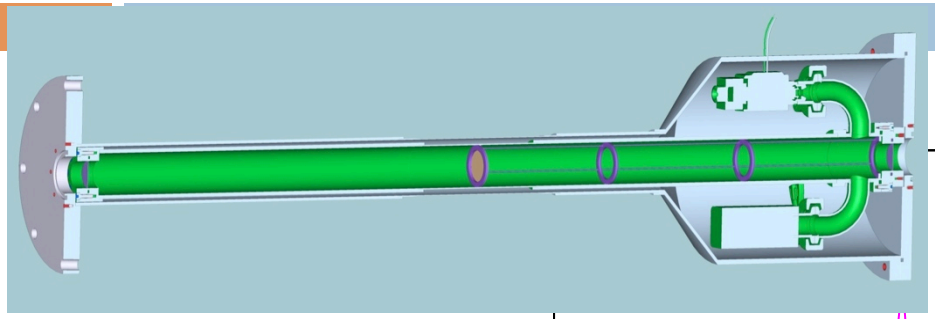
Tuning EXILL: (n,γ) mode



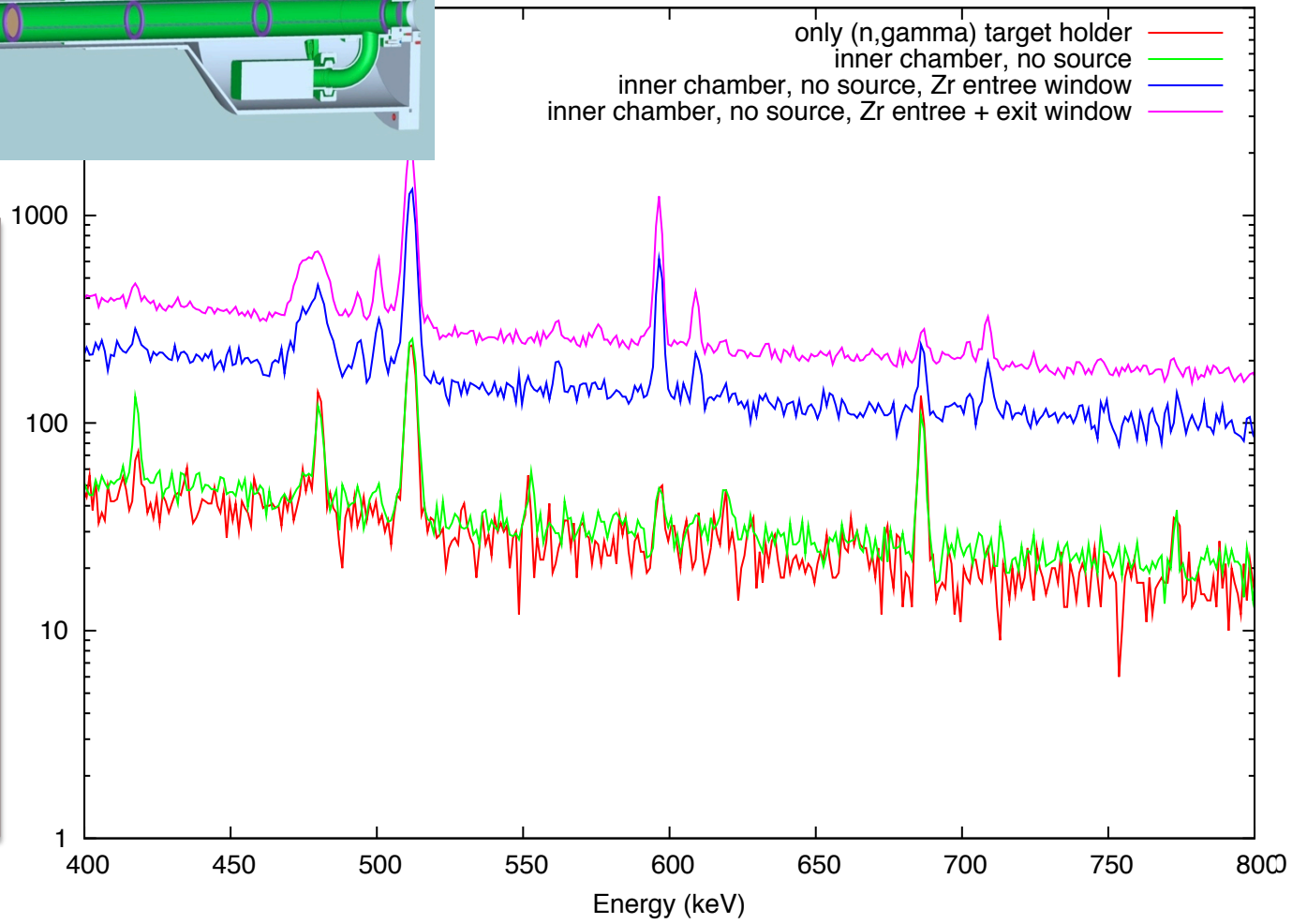
- Background dominated by ambient
- Source scatters neutrons
  - Ge lines appear
  - Confirmed by Al lines



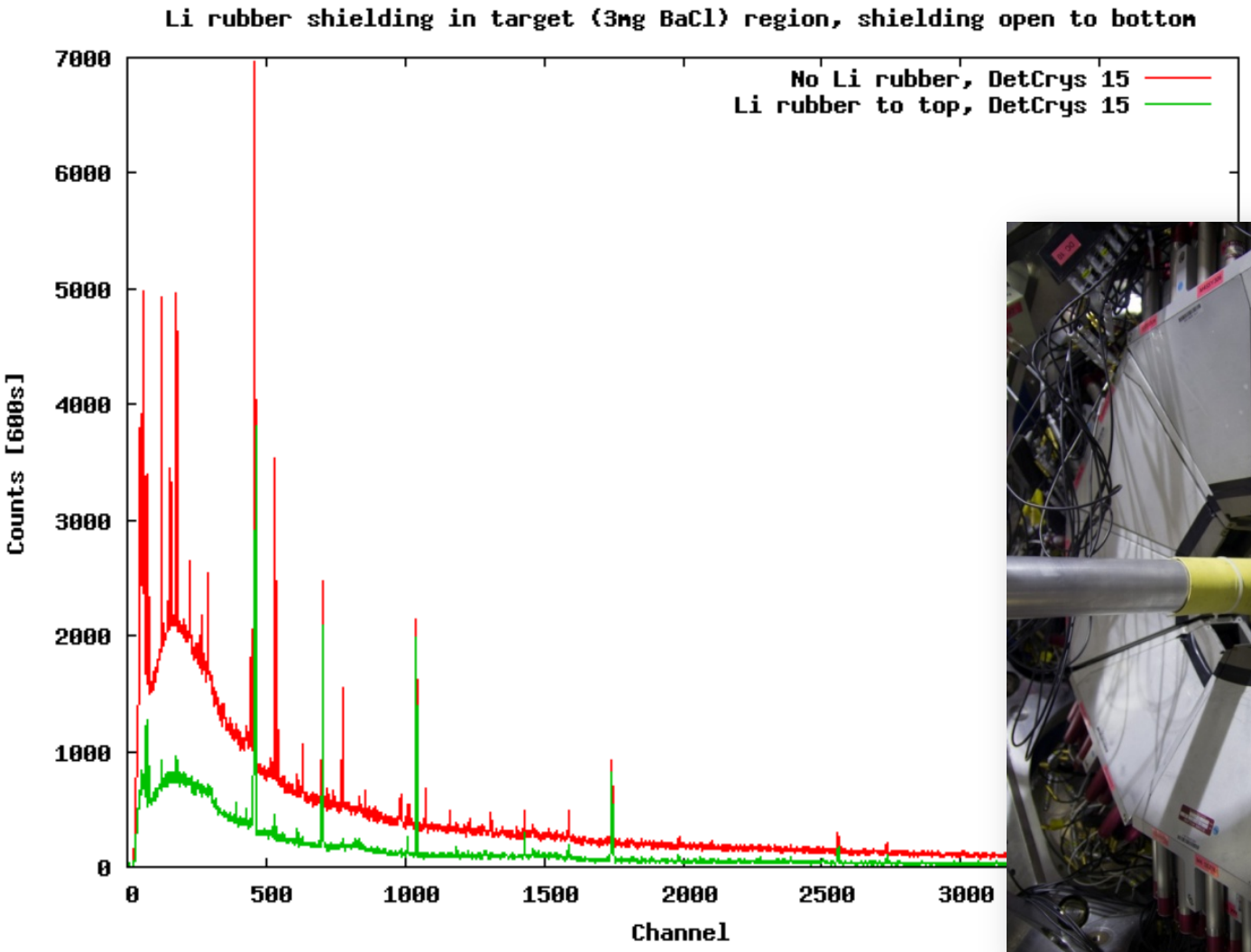
Tuning EXILL: fission mode

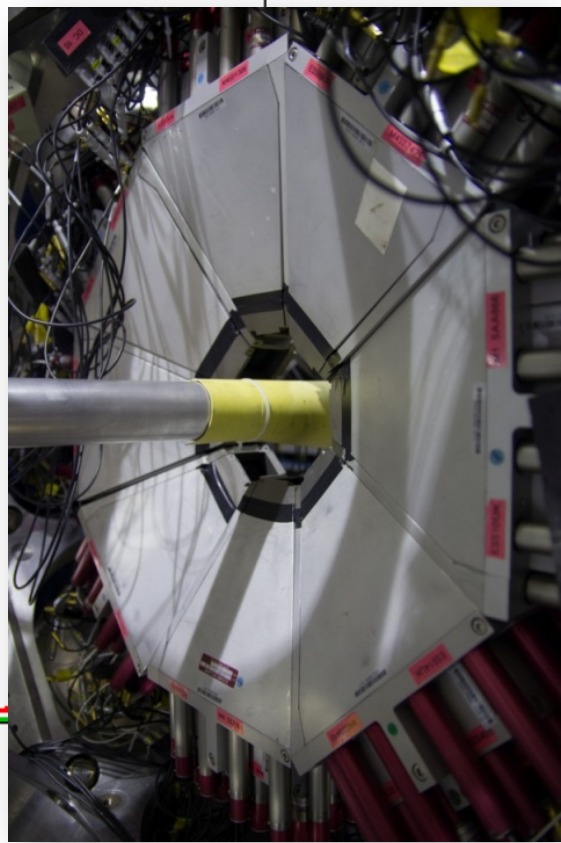


- No background due to inner chamber
- Zr-windows scatter substantially
- No Al-line, stronger B-line

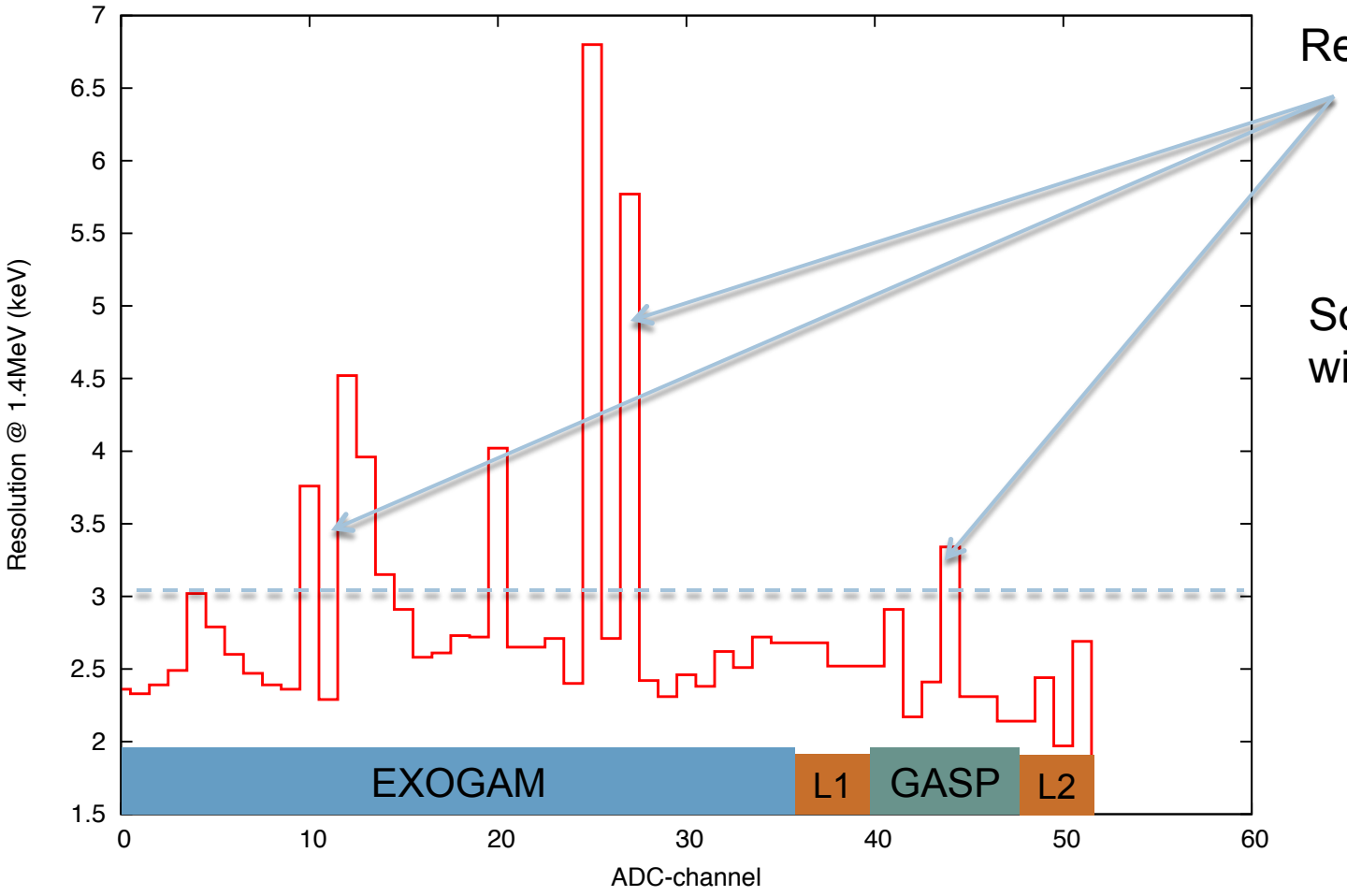


Impact of ^{6}Li-rubber shielding for $^{35}Cl(n,\gamma)^{36}Cl$





Detector resolution (global) @ 2kHz



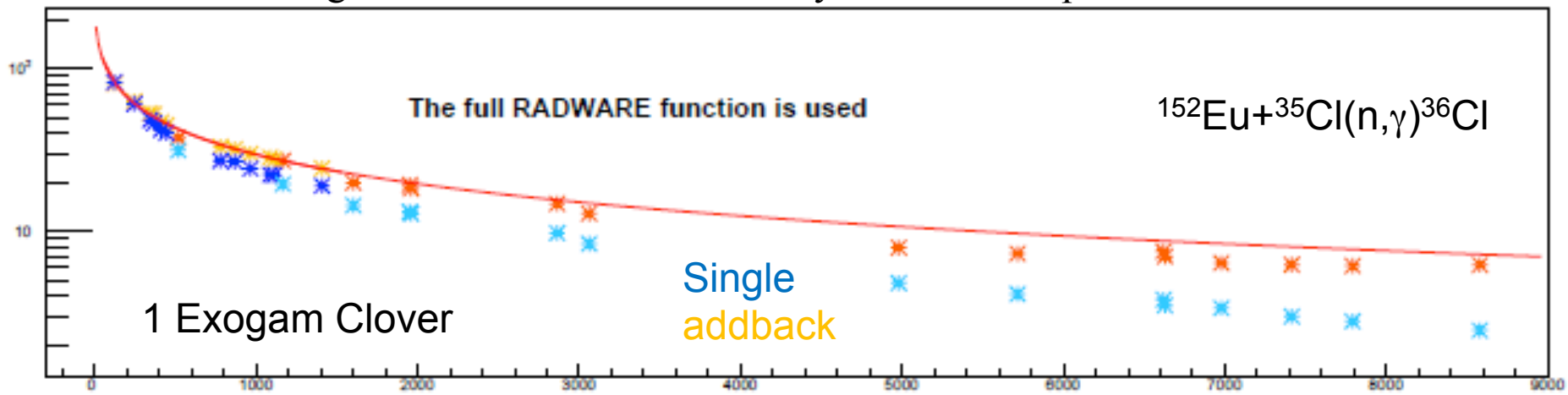
Resolution > 3 keV!

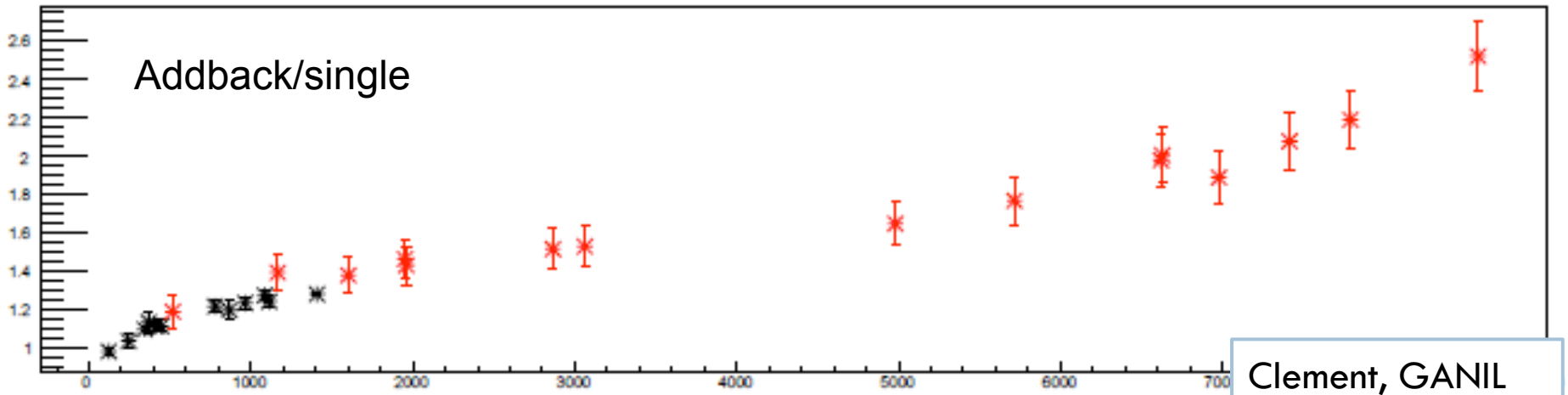
Some detectors with noisy baseline

P. Mutti

Efficiency of EXOGAM with Add-back

Exogam Clover Relative efficiency : measured up to 9 MeV !!!!!!!!

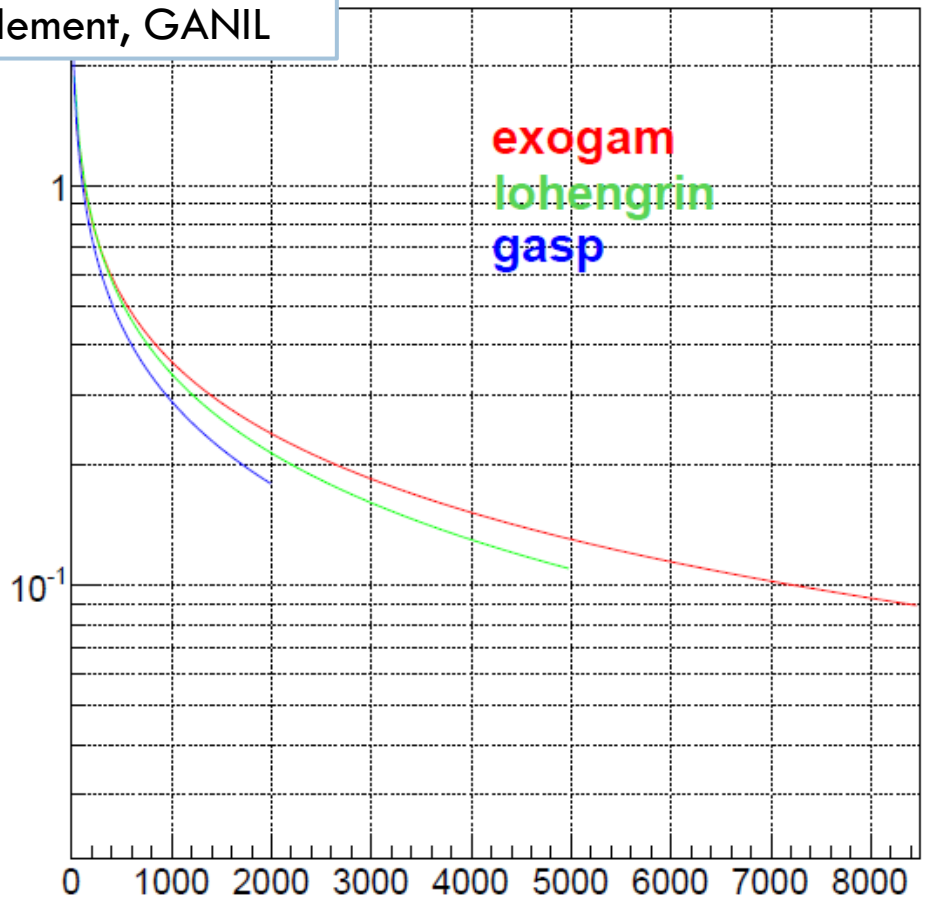




Clement, GANIL

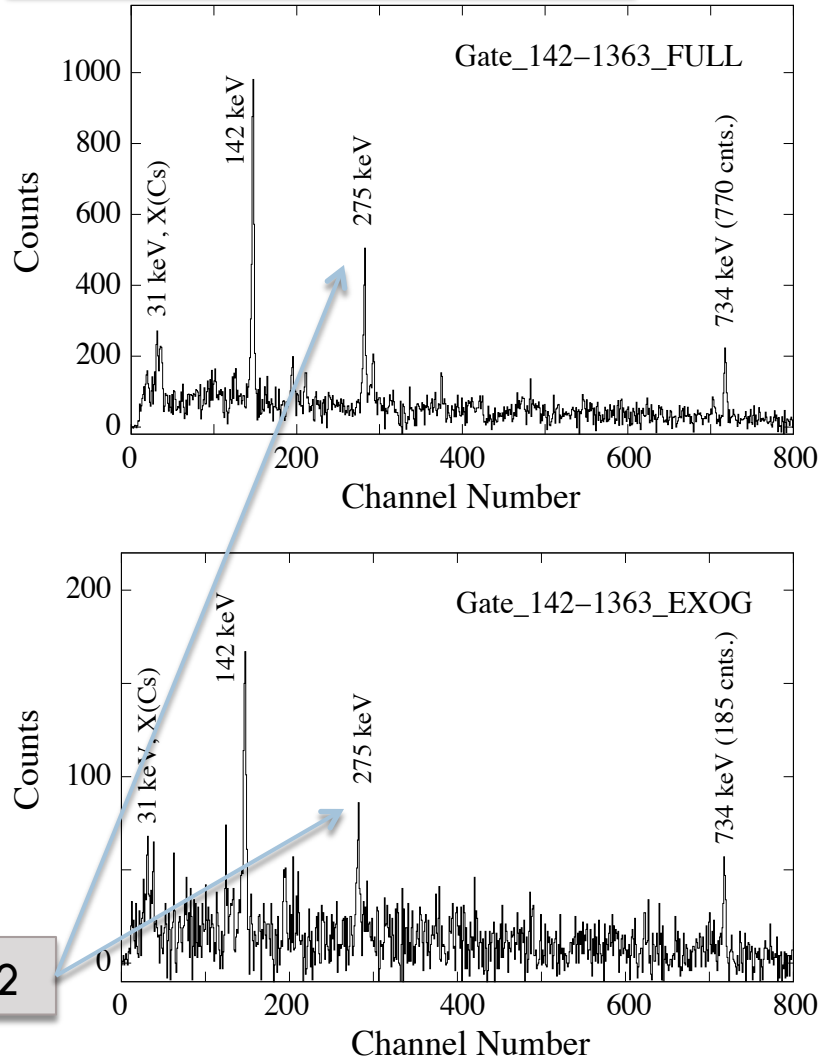
Efficiency of detectors, 8 x EXOGAM vrs. complete EXILL

Clement, GANIL



Gate: ^{92}Rb, 142, 1363 keV

Urban, ILL



Adding 6 GASP+2ILL boosts triple rate by factor 4.2

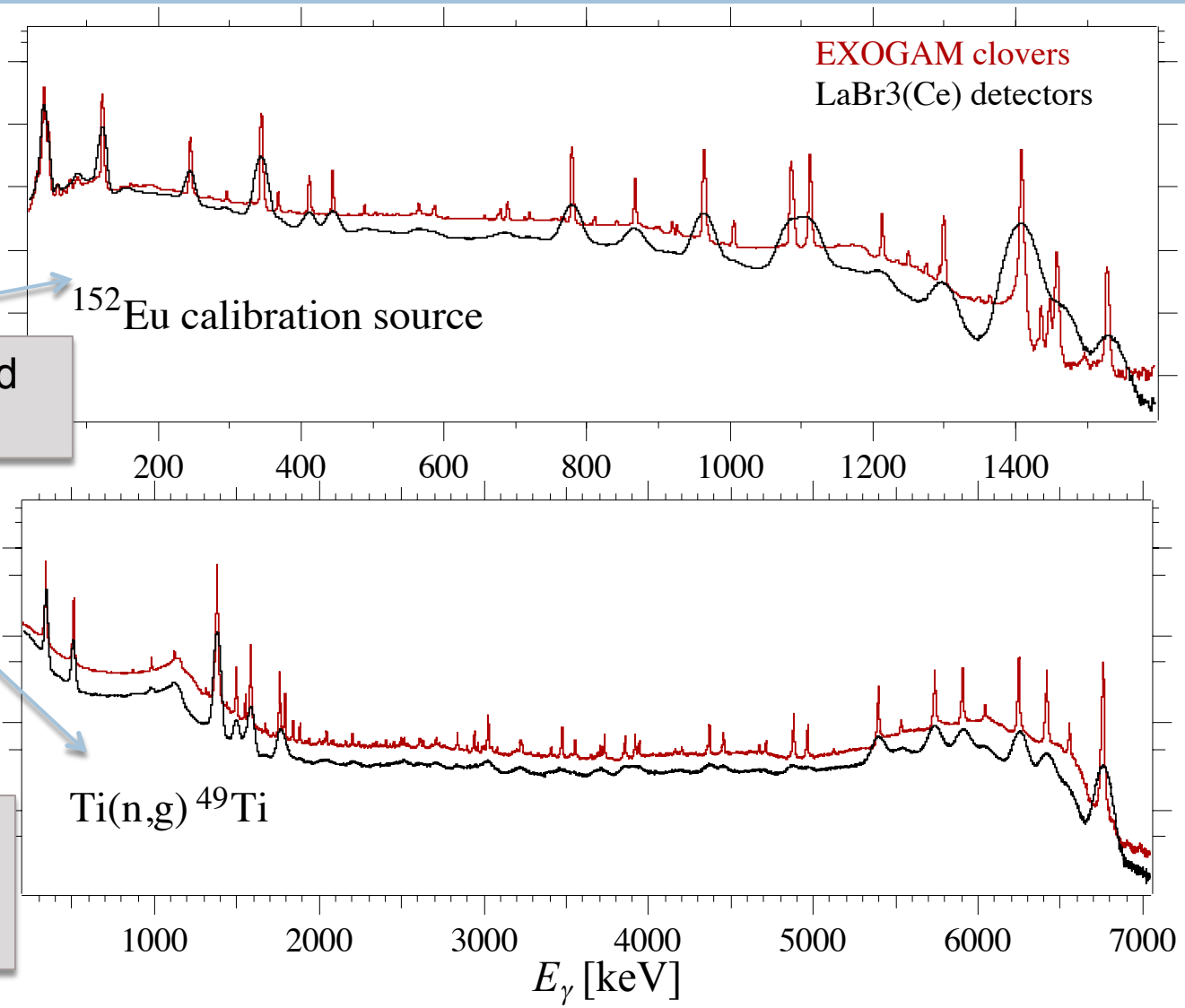
Energy resolution of Fatima/EXILL

Singles spectra:

Summation after gain matching

Two sources for energy and timing performance tests

Full energy peak efficiency of EXOGAM and FATIMA are the same!

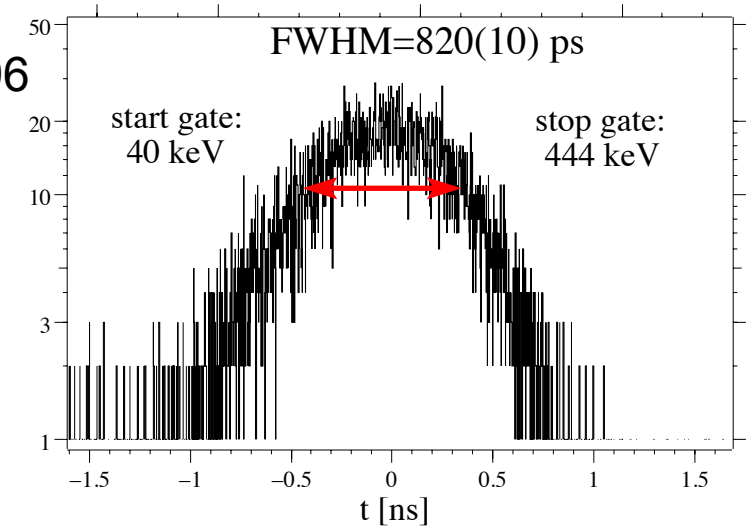


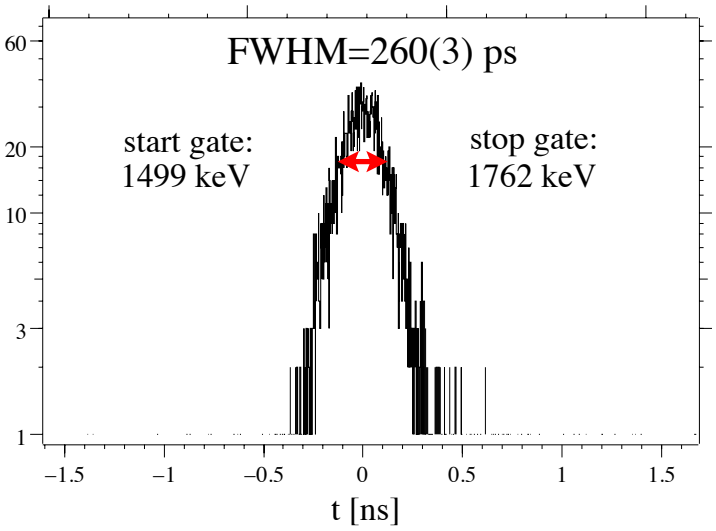
Timing Performance of FATIMA

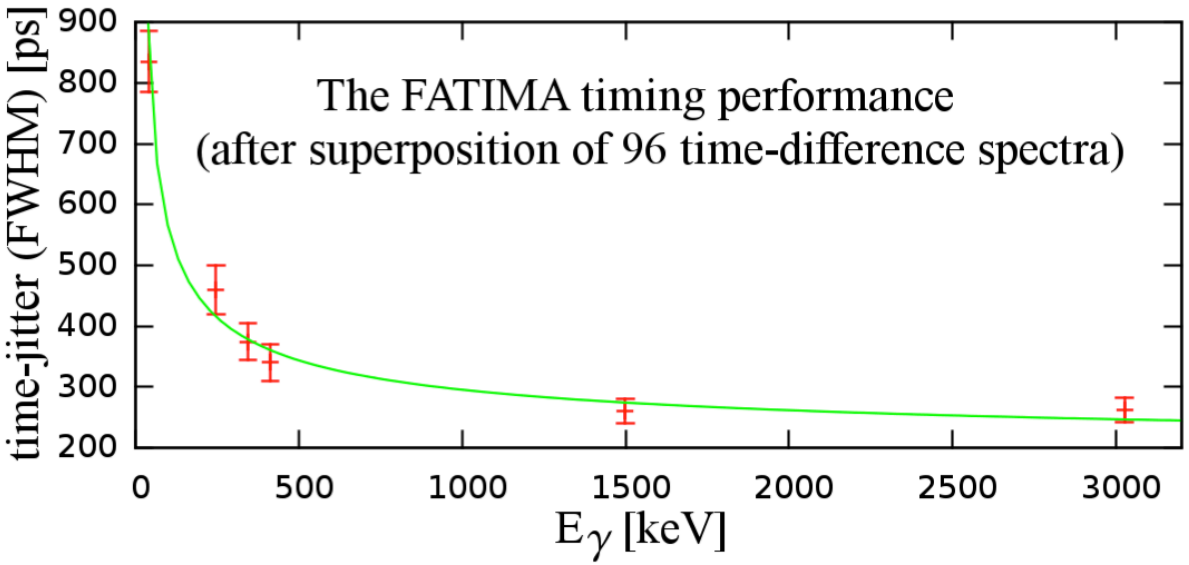
Experimental FATIMA prompt response function (PRF):

Superposition of 96 "TAC" matched time-difference spectra using constant shift values ij

Shift values are instr. constant of Fatima



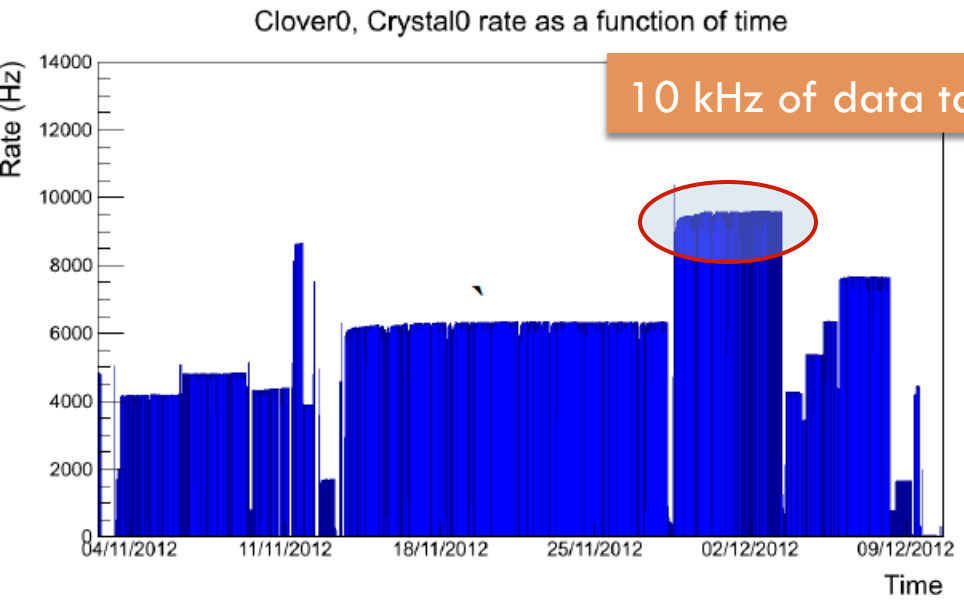




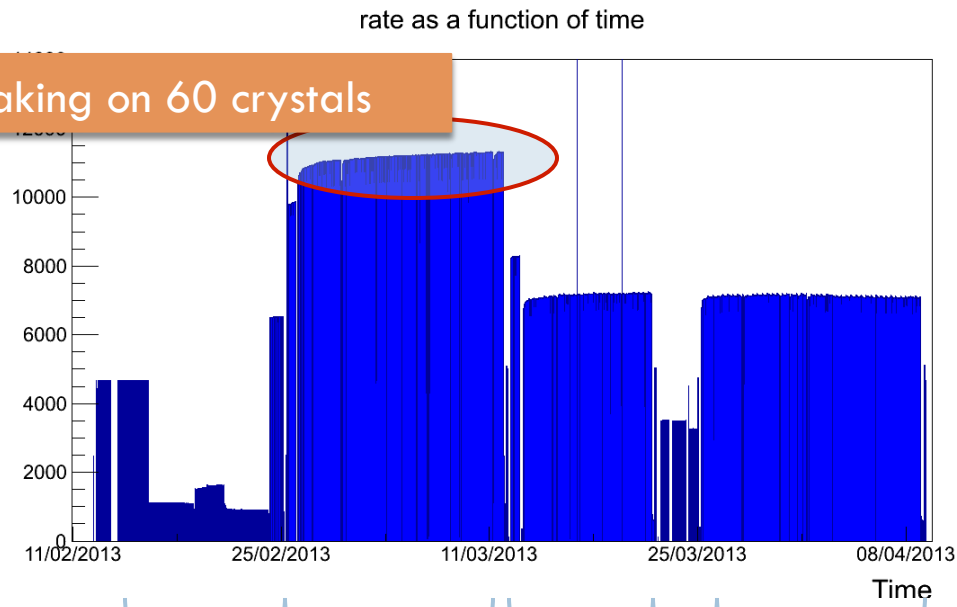
For Eg> 300 keV and 1000 events:

PRF < 5 ps!

Data taking



10 kHz of data taking on 60 crystals



(n,γ) campaigns

$^{68\text{-}70}$Zn, ^{48}Zn, ^{143}Nd, ^{167}Er, ^{77}Se, ^{194}Pt

prompt spectroscopy
^{235}U on Zr-backing

DPM
^{235}U on Be-backing

(n,g):
^{209}Bi, ^{46}Ca, ^{96}Zr

FATIMA (n,γ)

FATIMA
^{235}U on Be

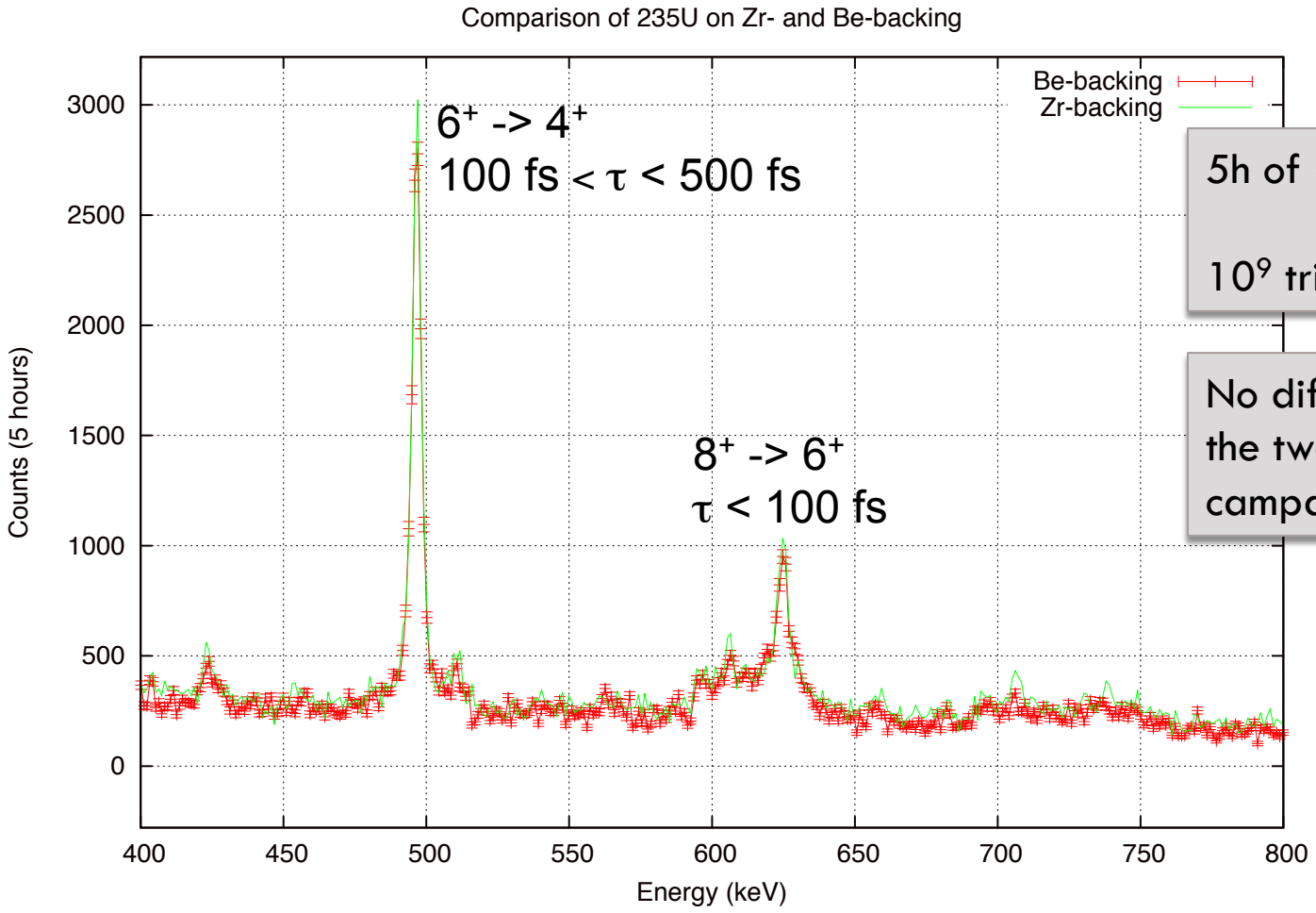
FATIMA
^{241}Pu on Zr

promp spectr.
^{241}Pu on Zr

(n,g):
^{95}Mo, ^{195}Pt

> 95% of beam time dedicated to measurements! ➔ 60 Tbyte of data

DPM: Be- vrs Zr-backing



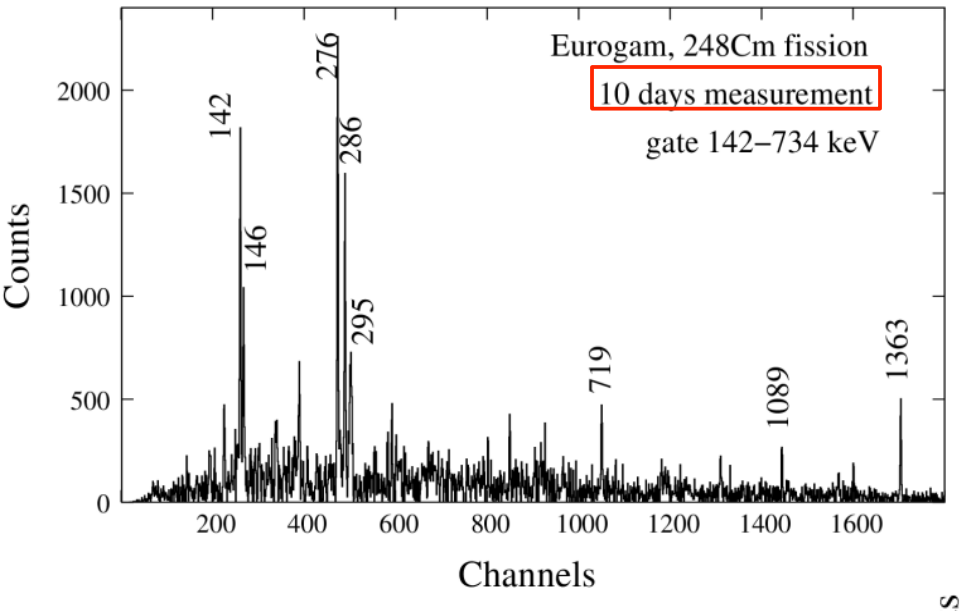
5h of ^{235}U on Be

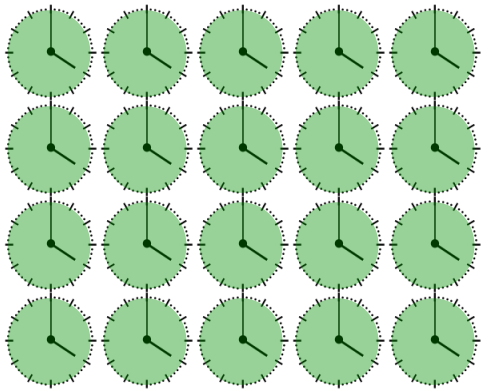
10^9 triple coincidences

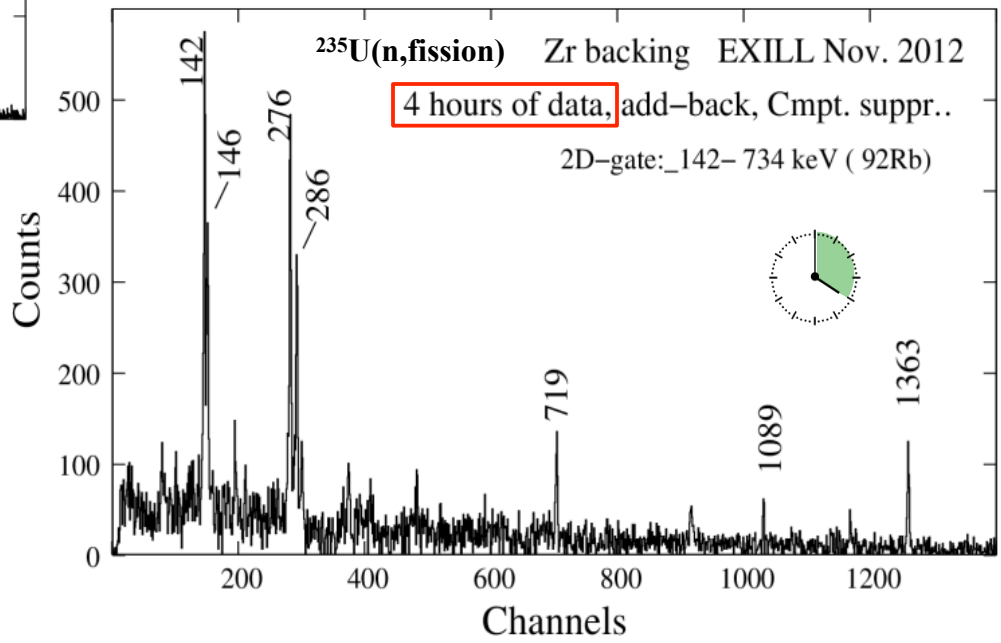
No difference between the two backing, DPM campaign stopped

Comparison with ^{248}Cm – Spectroscopy of ^{92}Rb

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





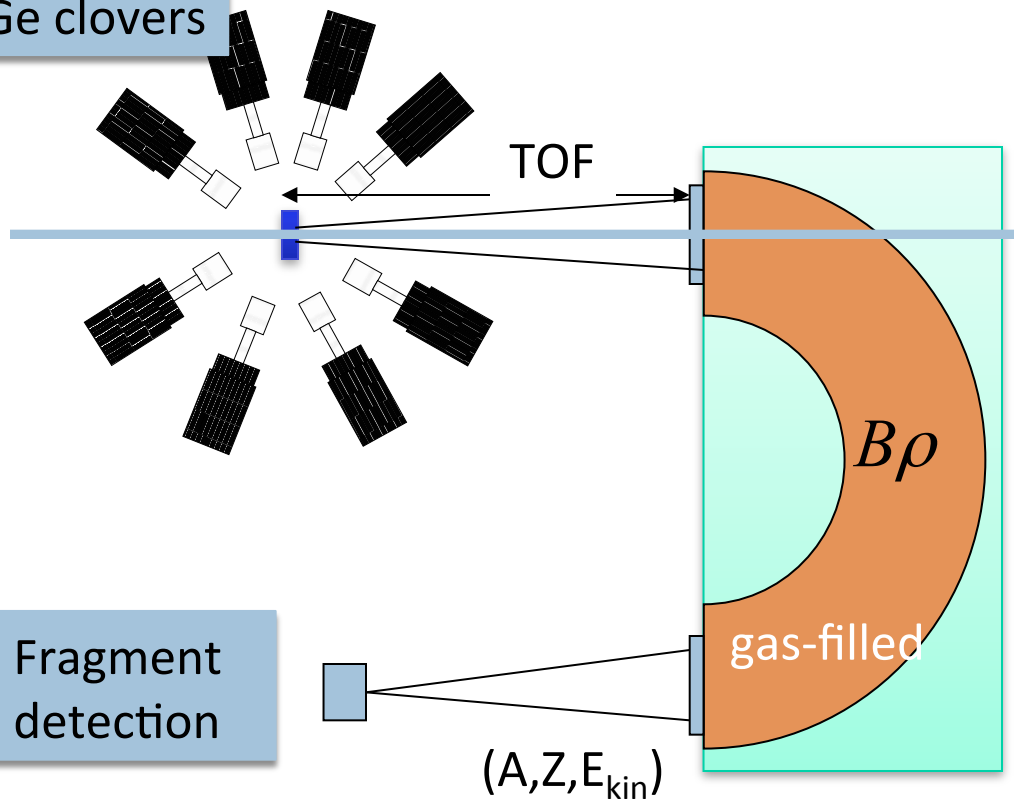


W. Urban, ILL

What's next?

- Problems of EXILL
  - At the limit of man power capabilities (ILL has only 5 nuclear physicists)
  - In beam time competition with low energy particle physics
  - Limitations with respect to fission material (only 0.7mg of ^{241}Pu,…)
  - Limitations with respect to target chamber (volume, shape, …)
  - Limitation with respect to additional detectors (tracking of fission products,particle detectors,…)
- Any new campaign similar to EXILL could solve only part of problem
- Alternative approach: a dedicated instrument: FIPPS

FIPPS – schematic layout (version I)



left fragment: stopped in backing

→ determination of: A,Z,E*,J,yield

right fragment:

TOF: velocity

GFM: A,Z

from conservation laws:

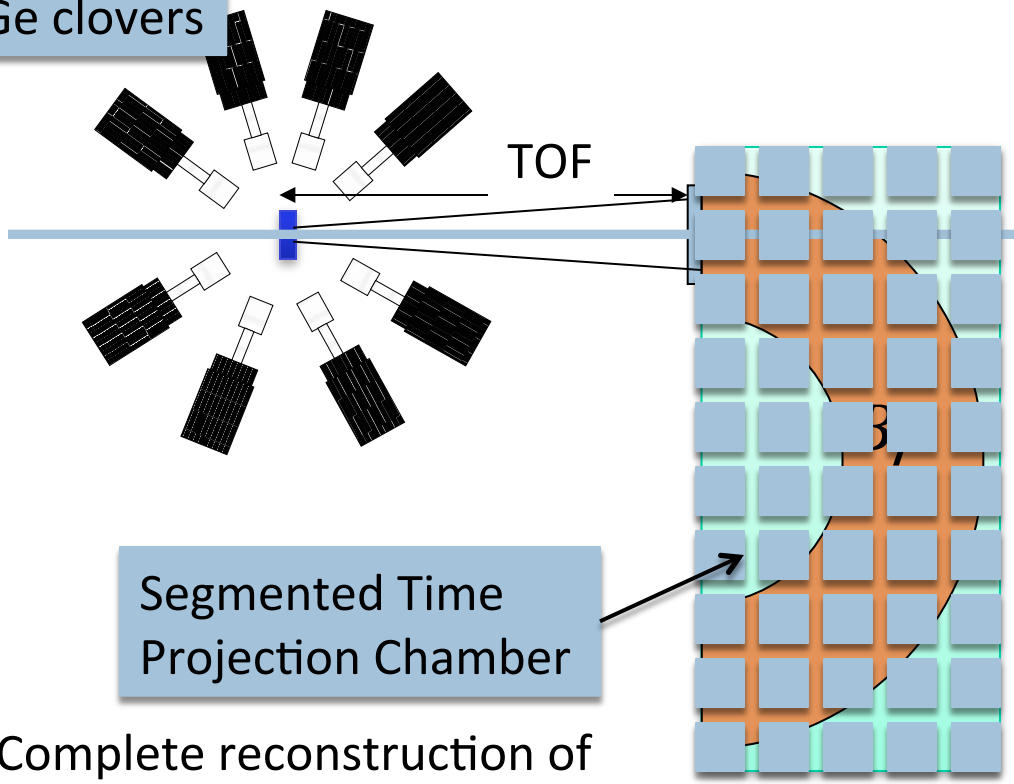
E$_{kin}$1,E$_{kin}$2,TKE,TXE, n-evaporation

Gas-filled magnet properties:
- Ionic charge focusing
- determination of A, (Z)

Rate < 10^6 fission/s

Possible targets : ^{229}Th, ^{232,233,235}U, ^{238,239,241}Pu, ^{242m}Am, ^{243,245,247}Cm,^{249,251}Cf

FIPPS – schematic layout (version II)



left fragment: stopped in backing

→ determination of: A,Z,E*,J,yield

right fragment:

TOF: velocity

GFM: A,Z

from conservation laws:

$E_{kin}1$,$E_{kin}2$,TKE,TXE, n-evaporation

Gas-filled magnet properties:
- Ionic charge focusing
- determination of A, (Z)

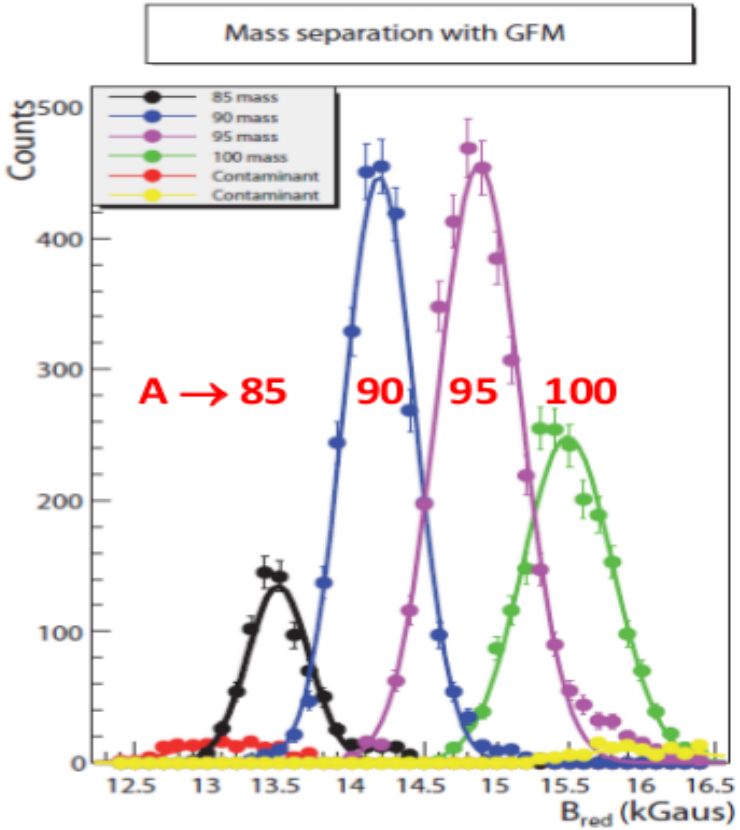
Complete reconstruction of right fragment trajectory

Rate < 10^6 fission/s

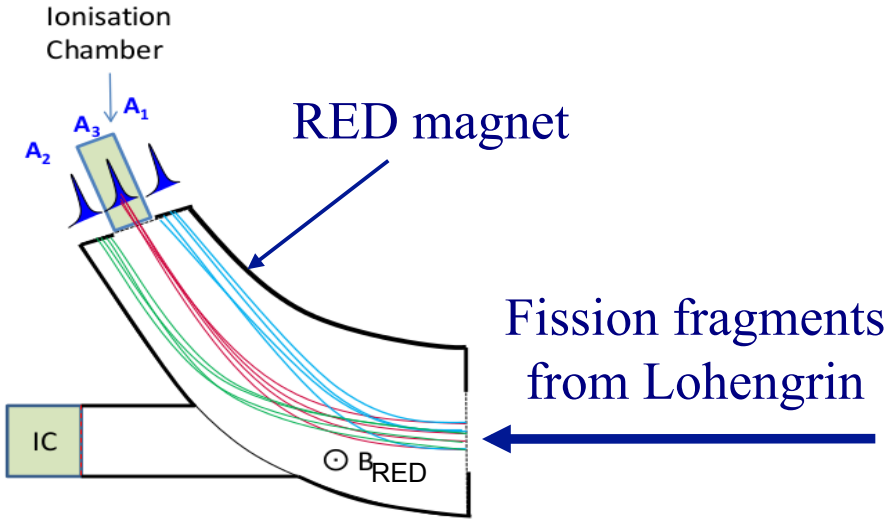
Possible targets : ^{229}Th, ^{232,233,235}U, ^{238,239,241}Pu, ^{242m}Am, ^{243,245,247}Cm,^{249,251}Cf

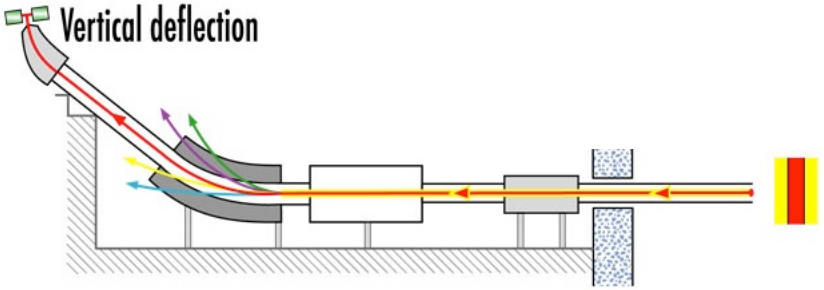
R&D for FIPPS

Primary Goal: Improve Lohengrin
FIPPS-RD: tdata as input for simulations



Investigation of different gases, pressures,fields…





G. Kessedjian, LPSC-Grenoble

Conclusion

- Spectroscopy @ neutron beams yield efficient tool for study of neutron rich isomers or close to stability
- Handling of neutron beam feasible
- Most planned experiments done
- Problems:
  - DPM targets
  - AC-shields
  - Background
- Next step FIPPS: permanent instrument allowing to carry out spectroscopy and fission studies