Fission Activities at the ILL Lohengrin spectrometer : Review and Perspectives

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Outline

Introduction : Motivations

1. **The ILL and the Lohengrin spectrometer**
2. **Past, present and near future activities :**
   - Mass Yields Measurements
   - Isotopic Yields measurements
   - Innovative measurements : symmetry + isomer ratios
3. **The FIPPS project**
4. **Conclusion** and perspectives

Motivations

Context of the fission yields studies :

- Post neutron fission yields needed in the current and innovative fuel cycles :
  - Inventory of spent fuel : isotopic composition
  - Residual power : minor actinides and fission products
  - Radiotoxicity of spent fuel
  - Fission yields variance-covariance matrices

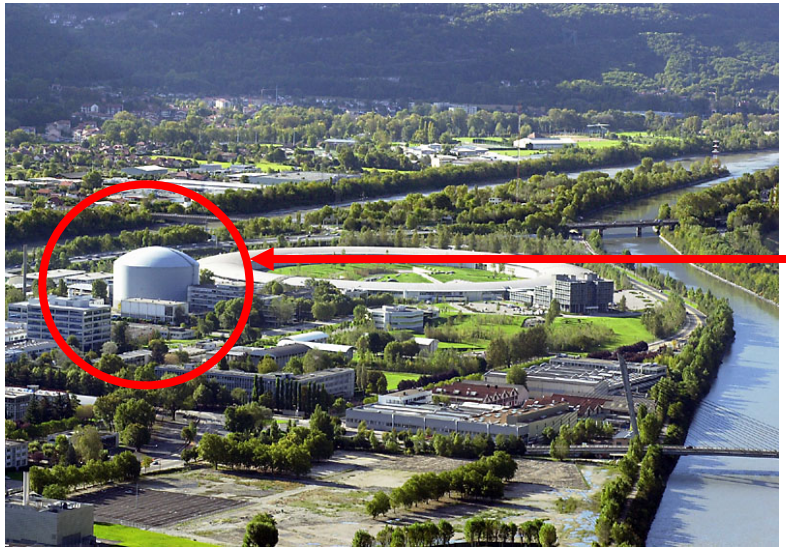
- Measurements for fission process study :
  - Supply experimental data to put constraints on fission models and improve their predictive power
  - Inconsistency between models or evaluations and experiments for heavy fragments and symmetric region
  - Isomer ratios can give information on spin distribution and on available excitation energy at scission

- In this context, since 2007, various experiments from our collaboration have been performed to investigate fission yields with a special focus on the heavy mass region

1. The Lohengrin facility

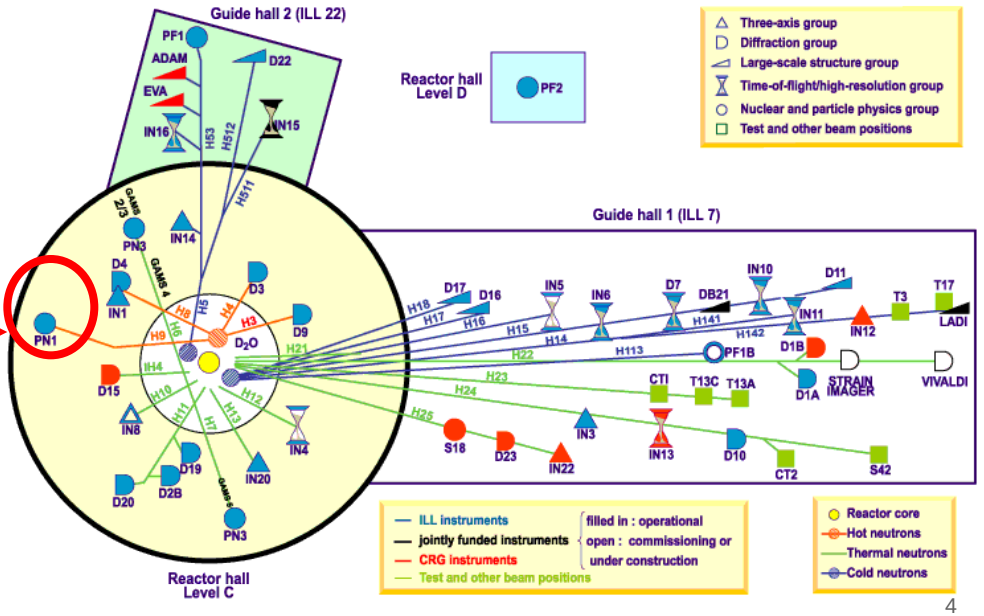
ILL research reactor features :

- Very high neutron flux. Target placed close to the reactor core : 5.3×10^{14} n/cm^2/s
- Study nuclei with low fission cross section (multiple capture technique)
- Possibility to use low mass samples (low energy loss, radiopratection issue)



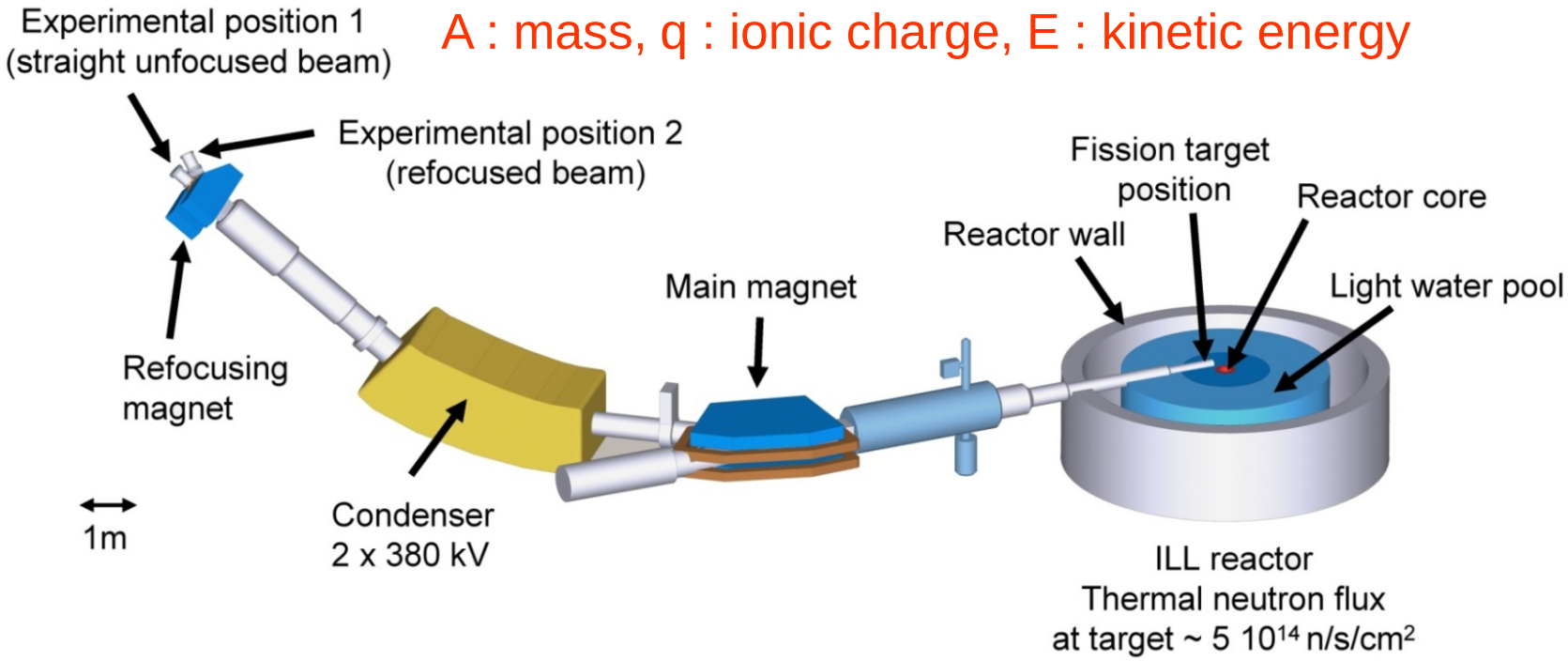
Reactor of the Institut Laue Langevin (Grenoble, France)

Fission product spectrometer PN1 "LOHENGRIN" : recoil mass spectrometer



1. The Lohengrin facility

Lohengrin spectrometer : A/q & E/q selection
A : mass, q : ionic charge, E : kinetic energy



Lohengrin spectrometer features :

- Combination of magnetic and electric field : FP selection according to A/q and E/q
- 23 m length, travel time ~ 2 µs : FP detected before β decay.
- Excellent mass resolution ΔA/A = 0.3 %
- Energy resolution : 1 %

1. The Lohengrin facility

Lohengrin spectrometer : A/q & E/q selection
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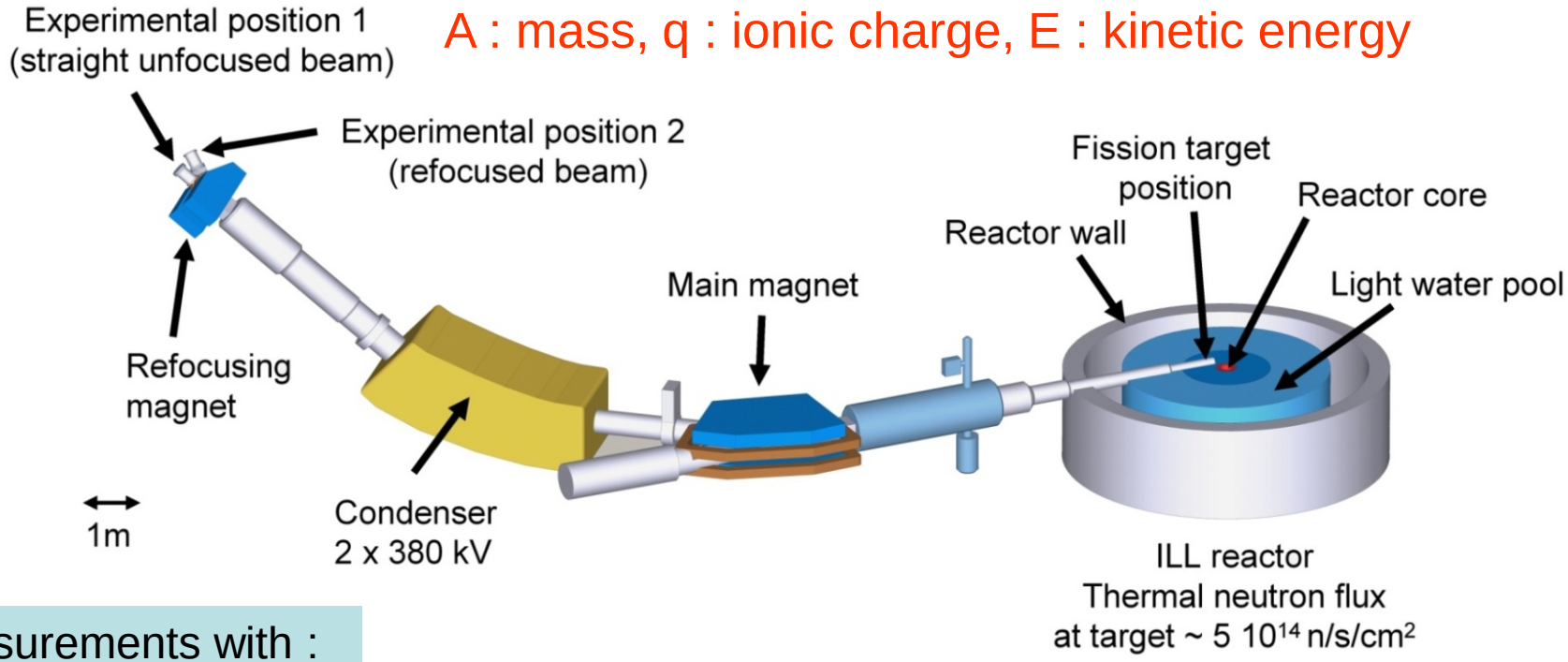
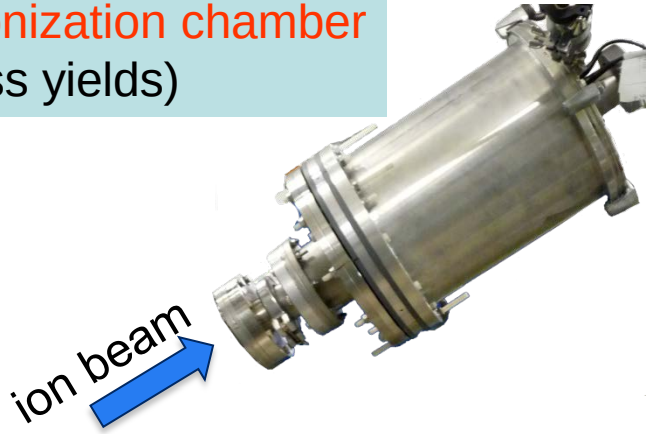
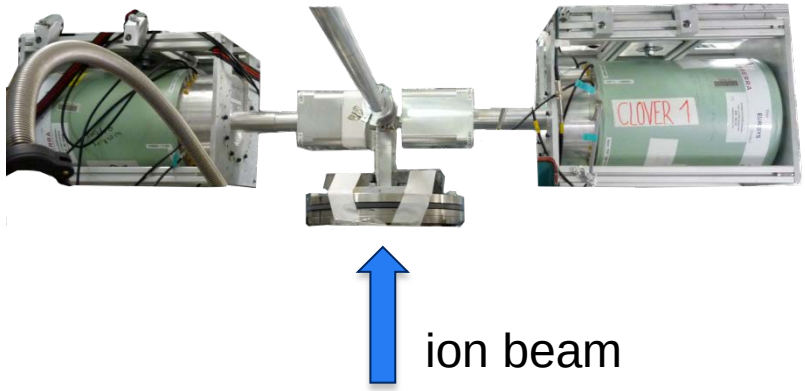


Measurements with :
an ionization chamber
(mass yields)

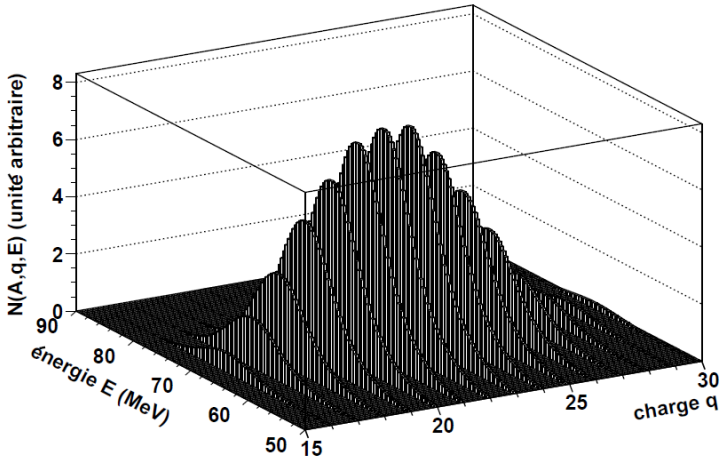


or with : Ge detectors (isotopic yields)



2. Mass yields measurements

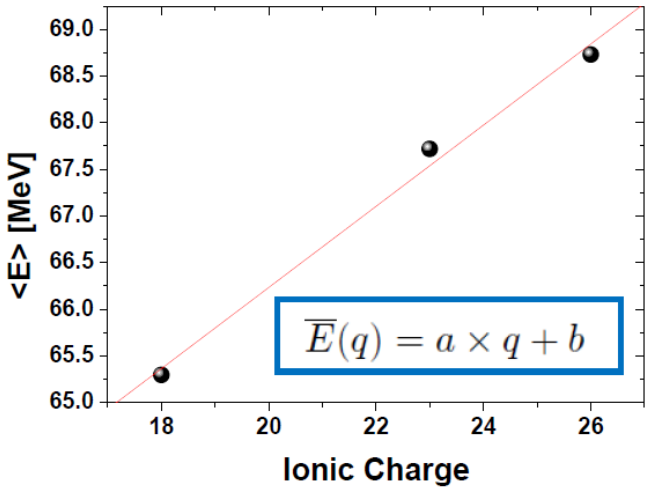
Mass yield measurements and analysis :
(more details in the ND2013 conf. Proceedings)



- Determination of the counting rate for a given mass A, ionic charge q and kinetic energy E.

- Integrate over kinetic energy E and ionic charge q : E distribution at the mean q
  q distribution at the mean E

- Determination of the correlation between E and q : scan on E for three different ionic charges



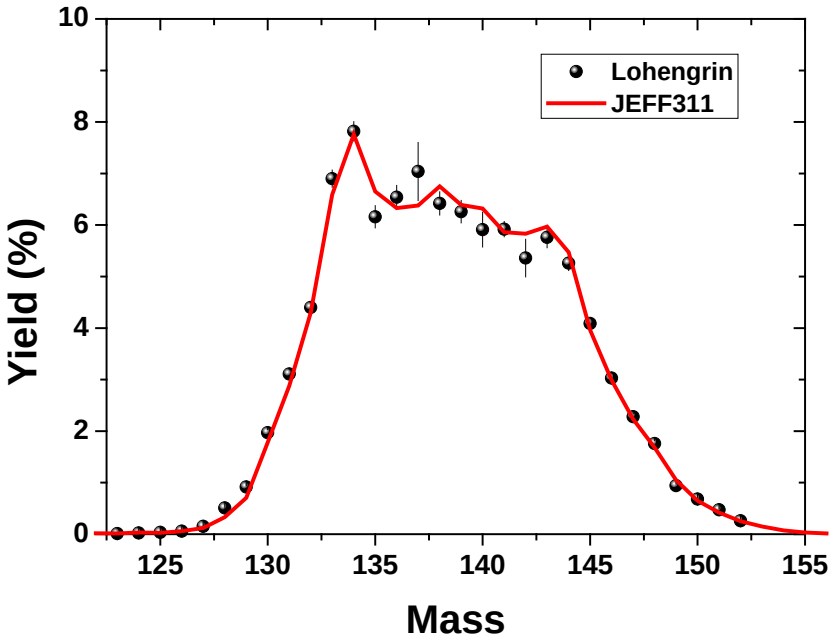
- Correction for the burn-up of the sample : Main source of uncertainties, inducing correlation

- Self-normalization to 1 if all the masses of the heavy peak are measured

- Experimental variance-covariance matrix

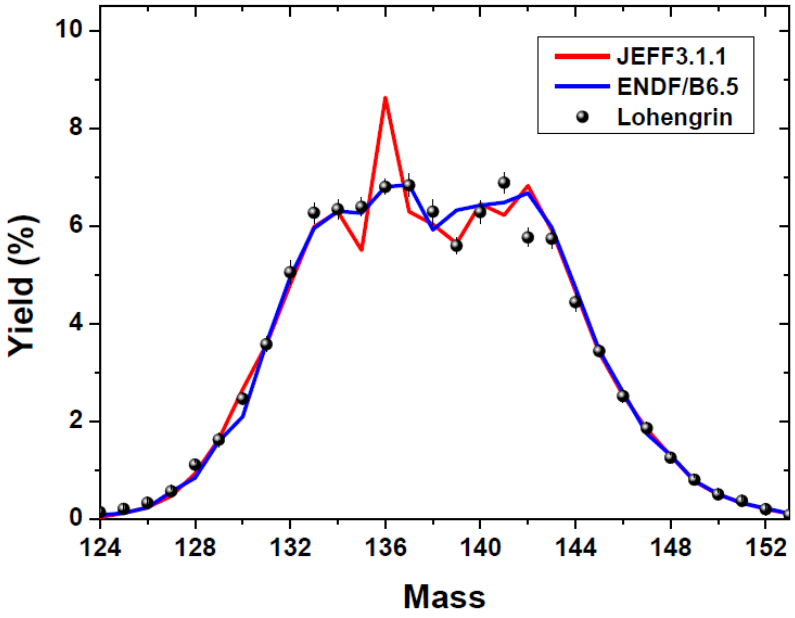
2. Mass yields measurements

$^{235}U(n_{th},f)$



A. Bail, PhD Thesis (2009)

$^{233}U(n_{th},f)$

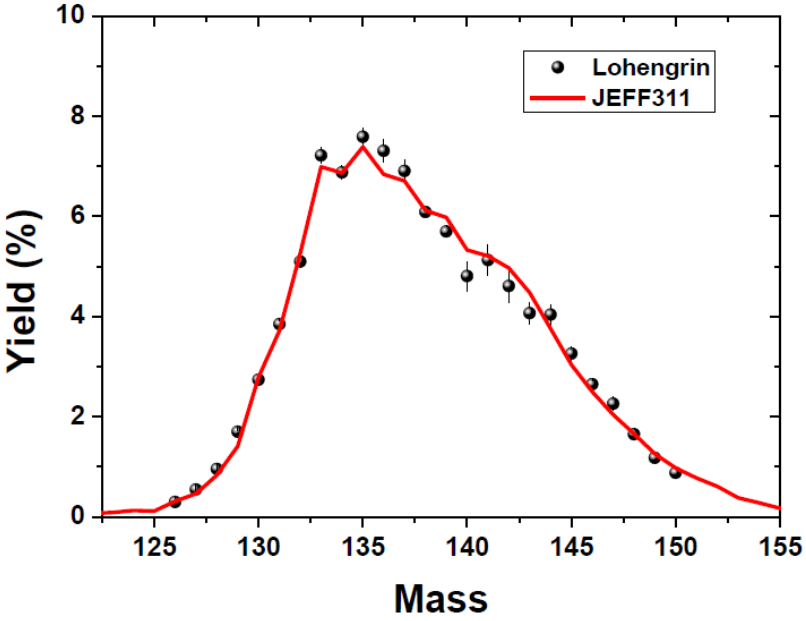


F. Martin, PhD Thesis (2013)

F. Martin et al., IEEE Conf. Proc. Of ANIMMA (2011)

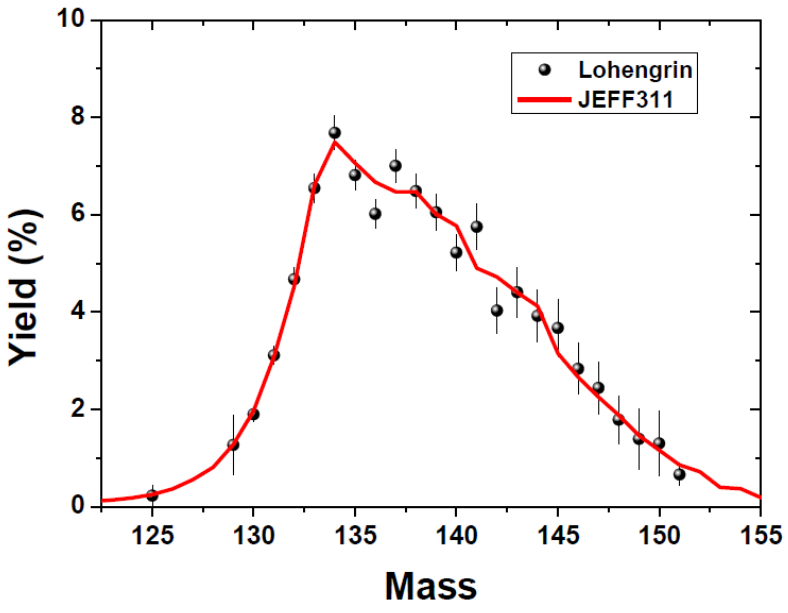
2. Mass yields measurements

$^{239}Pu(n_{th},f)$



A. Bail, PhD Thesis (2009)

$^{241}Pu(n_{th},f)$

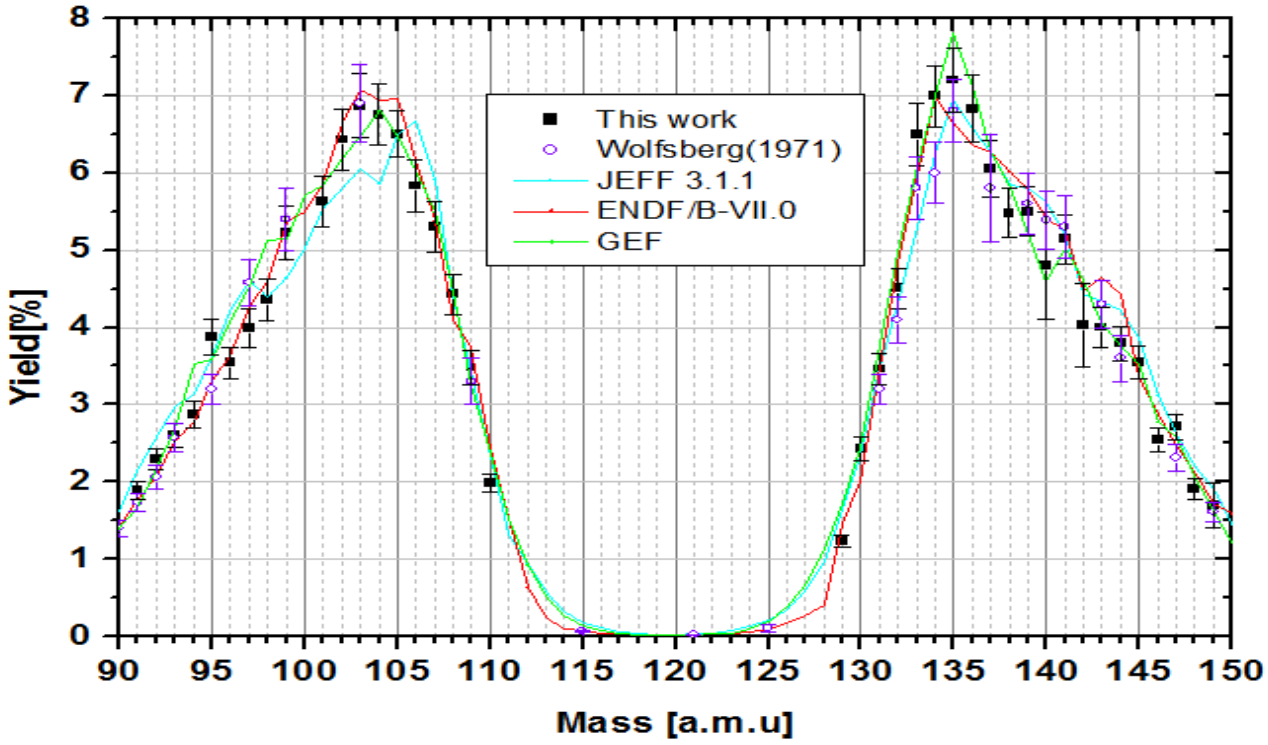


F. Martin, PhD Thesis (2013)

F. Martin et al., IEEE Conf. Proc. Of ANIMMA (2011)

2. Mass yields measurements

$^{241}Am(2n_{th},f)$



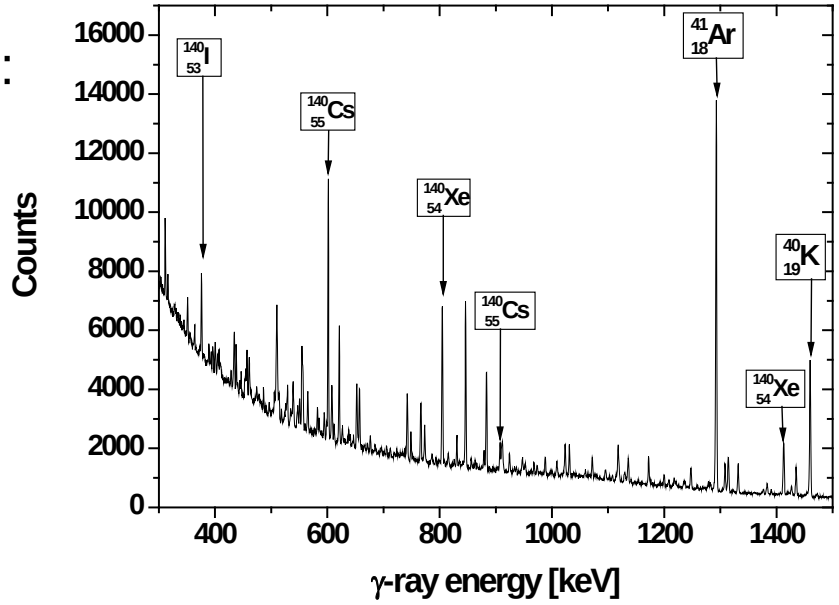
C. Amouroux, PhD Thesis (ongoing)

C. Amouroux et al., WONDER-2012, EPJ Web of Conf. 42 (2013)

C. Amouroux et al. Proc. Fission-2013, Caen (2013)

2. Isotopic yields measurements

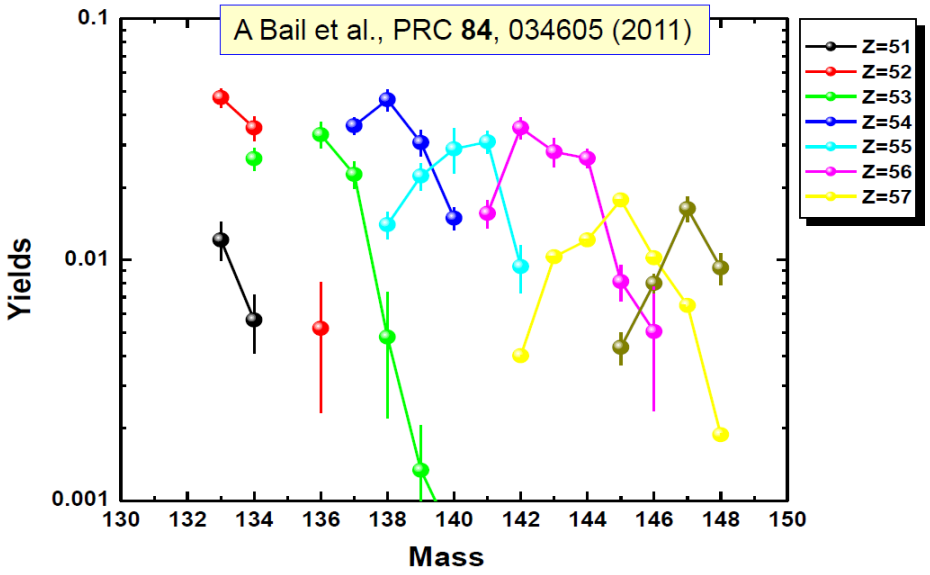
Isotopic yields measurement and analysis :
(more details in the ND2013 conf. Proceedings)



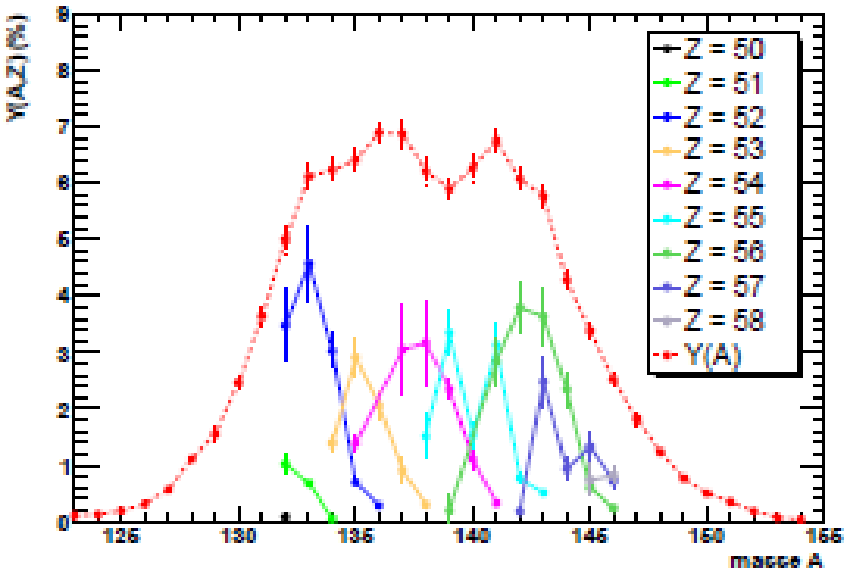
- Isotopic identification by γ spectrometry
- Background measurement and corrections :
  - Efficiency
  - Gamma-ray intensity
  - Summing correction
  - Burn-up of the sample
- Integrate over kinetic energy E and ionic charge q
- Correction for the production and disappearance of nuclei by solving Bateman equations
- Normalization
- Experimental variance-covariance matrix

2. Isotopic yields measurements

$^{239}Pu(n_{th},f)$



$^{233}U(n_{th},f)$



F. Martin, PhD Thesis (2013)

2. Mass and isotopic yields measurements

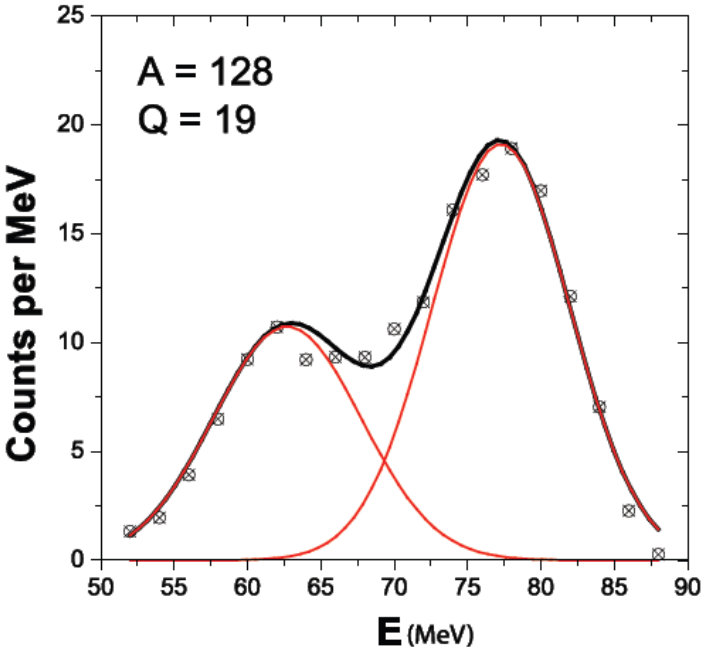
- Mass yields measurements performed with an ionization chamber in the heavy mass region for $^{233,235}U(n_{th},f)$, $^{239,241}Pu(n_{th},f)$, $^{241}Am(2n_{th},f)$. Measurements foreseen for $^{243,245}Cm(n_{th},f)$.

- Isotopic yield measurements by gamma spectrometry (mainly in the heavy mass region) for ^{233}U (finished) and ^{241}Pu, ^{241}Am (in progress)

- Development of a new analysis procedure : correlation (E,q), self-normalization and experimental variance-covariance matrix calculation.

- Investigation of the symmetry region for $^{233,235}U$ and ^{241}Pu mass yields :

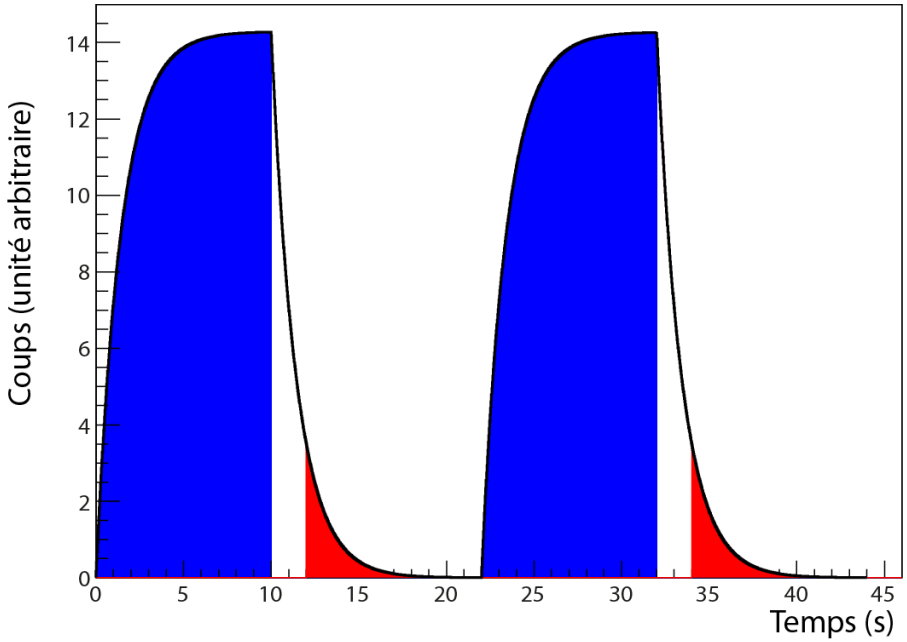
Two components are observed in the kinetic energy distribution : presence of a heavy mass contaminant.
Dedicated experiments were performed to clarify this point and extract the yields in the symmetry region.



2. Isomer ratios measurements

➢ 1. Beam cut method : for isomers living a few seconds

Allows to separate isomer state and GS feeding from a same gamma line



Masse	Isotope	Period	γ
136	^{m}I I Xe	46,9 s 83,4 s 2,95 µs	**197/381/1313**/369 **1313**/1321/2289/ **197/381/1313**
130	^{m}Sb Sb	6,3 m 39,5 m	**839/793/182**/1017 **793/839/**330/**182**
132	^{m}Sb Sb Te	4,10 m 2,79 m 28,1 µs	**974/697/103/150** **974/697/103/**989 **974/697/103/150**

2. Isomer ratios measurements

➢ 2. Coincidence method : for isomers living a few µs

Coincidence between ionization chamber and γ detectors

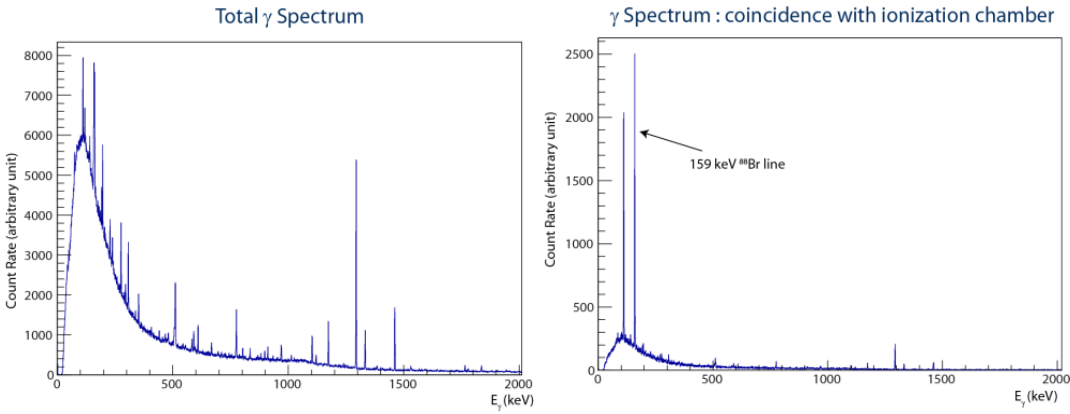
$$\Delta T_{Gate} = 10 T_{1/2}$$

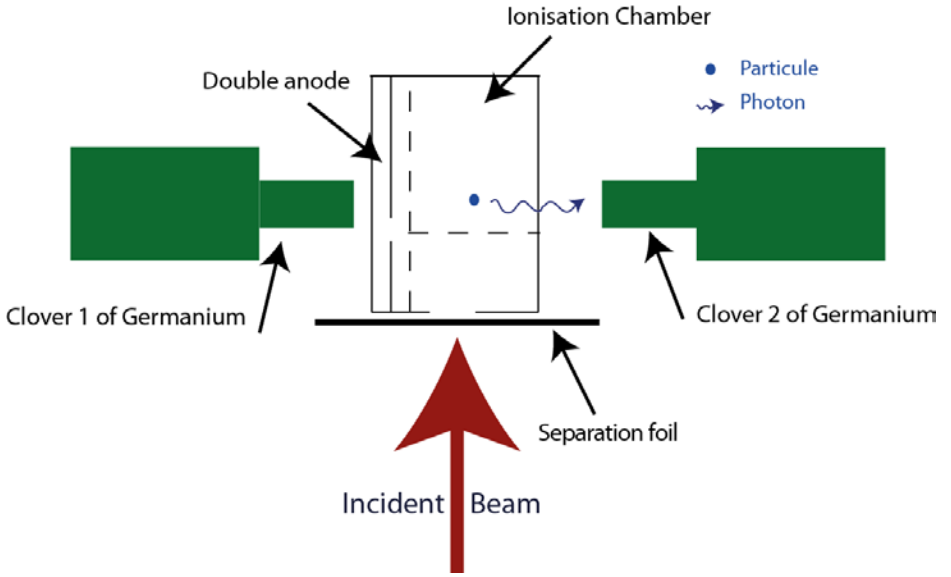
→ Isomeric state measurement

Total γ spectrum → GS measurement. More difficult

For long live GS, loss by gas pumping → correction needed

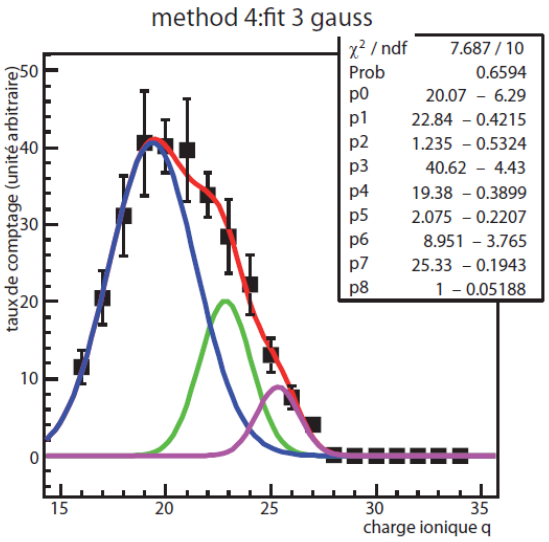
$$\lambda_{Gas} \ll \lambda_{\beta}$$

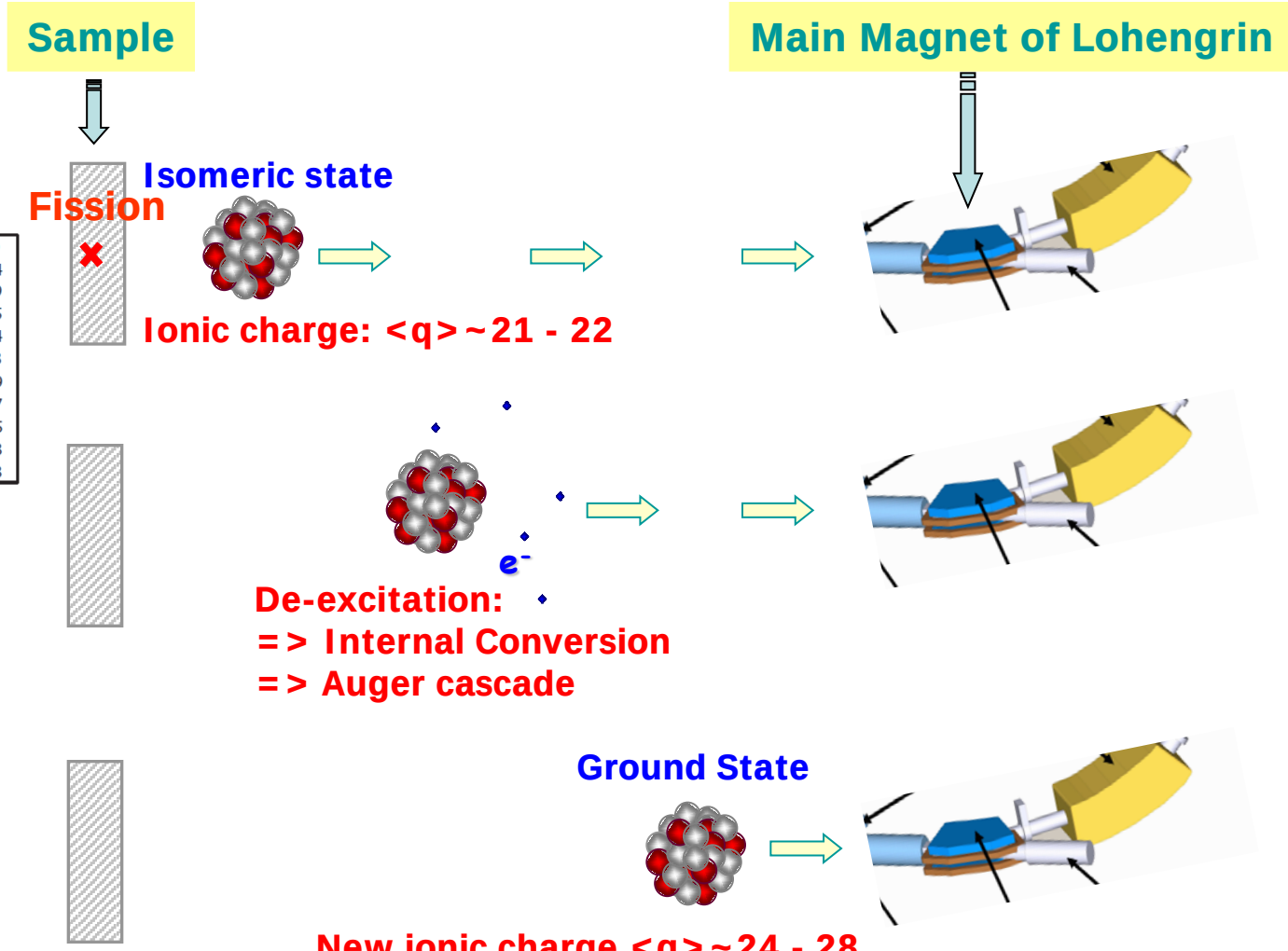




2. Isomer ratios measurements

➢ 3. nanosecond isomers : Structure effect will deform the ionic charge distribution





2. Isomer ratios measurements

- **Isomer ratios** : Recent measurement on Lohengrin

Min/s Isomers :
$^{136}I,\ ^{132}Sb,\ ^{130}Sb,\ ^{129}Sb,\ ^{129}Sn,\ ^{99}Nb,\ ^{98}Y$

µs Isomers :
$^{136}Xe,\ ^{132}Te,\ ^{129}Sb,\ ^{99}Y,\ ^{98}Y,\ ^{94}Y,\ ^{88}Br$

ns Isomers :
Almost all isotopes in heavy mass region

- Goal : comparison with fission simulating codes : Fifrelin (CEA Cadarache)

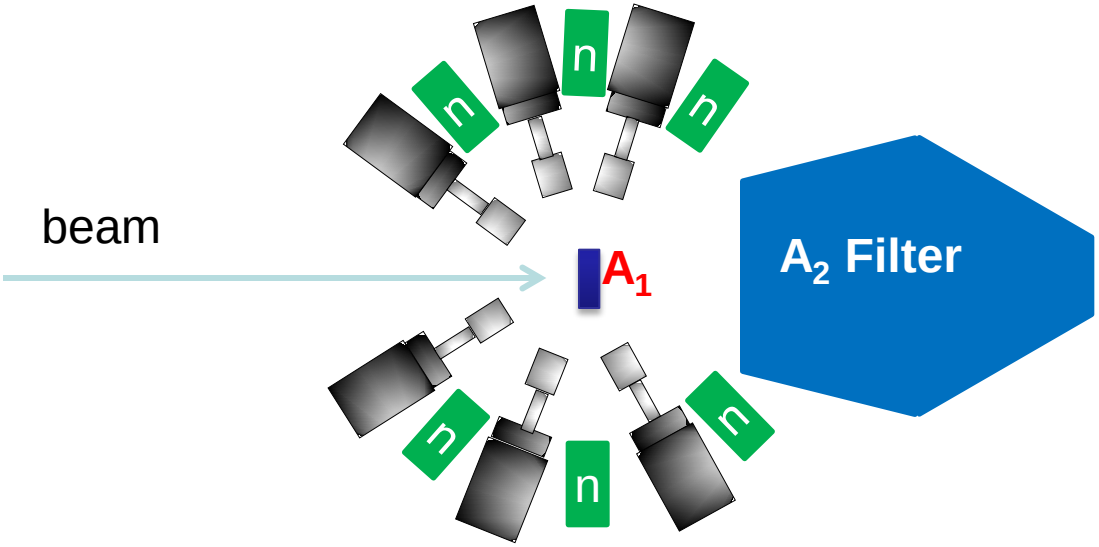
- Lohengrin limits : 2 µs TOF → no prompt particle study

- **FIPPS Goals :**
  - Direct measurement of prompt particles
  - Fission product spectroscopy
  - Neutron emission
  - Short lifetime isomers

3. The FIPPS Project

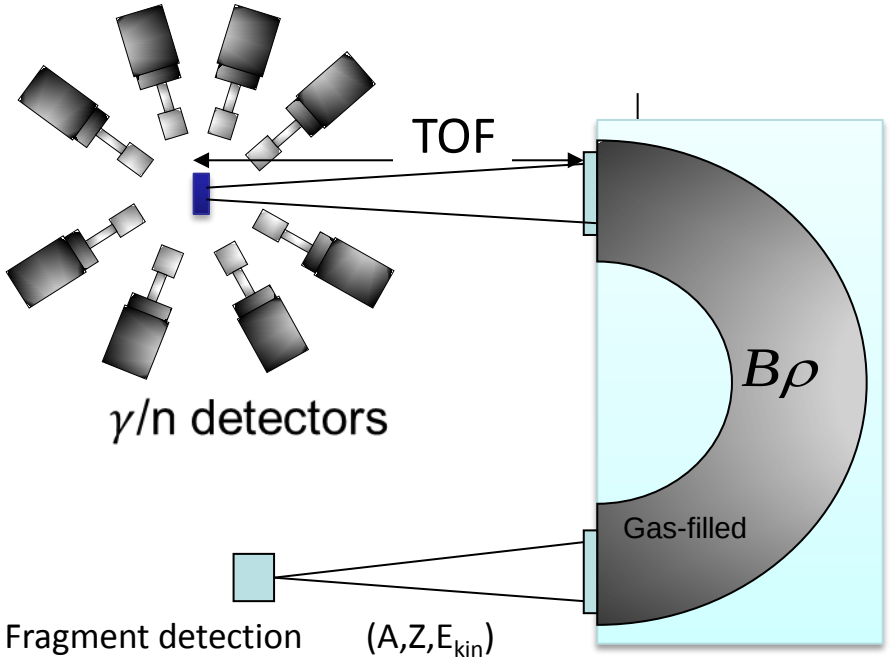
FIPPS : FIssion Product Prompt gamma-ray Spectrometer

- Project of new instrument, complementary to the Lohengrin facility
- n/gamma detectors coupled to a fission fragment filter
- Goal of the filter :
  - Characterize the complementary mass (A_2, E_k)
  - Clean the gamma spectrum to identify the discrete gamma rays of (A_2, Z_2)



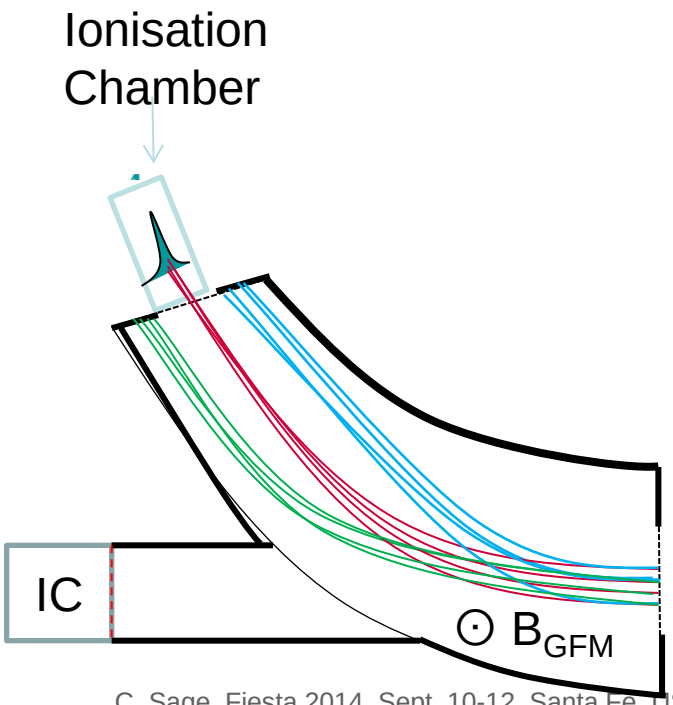
3. The FIPPS Project

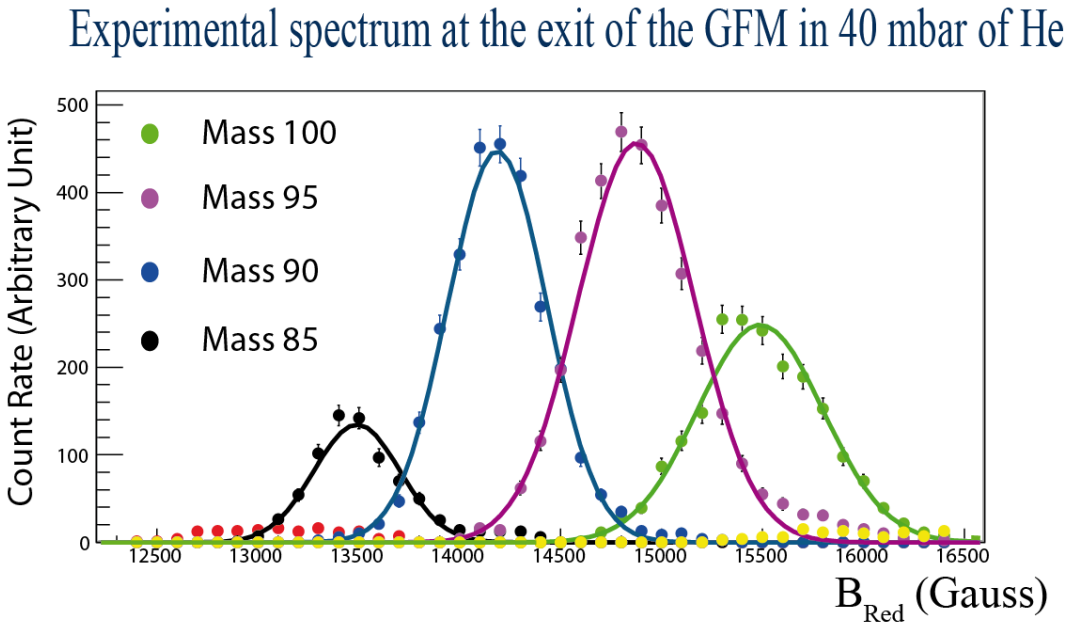
- Which filter to use : Gas Filled Magnetic device (GFM)
- Existing results of Jülich GFM spectrometer to foresee the design
- Reconversion of the RED magnet @Lohengrin for GFM tests



3. The FIPPS Project

- Reconversion of the RED magnet @Lohengrin for GFM tests





- Experimental tests allow to characterize the dispersion/resolution of the GFM in mass and isotope
- Comparison with a dedicated Monte Carlo simulation code

(PhD A. Chebboubi)

Conclusion et perspectives

- Mass and isotopic yields measurements on-going at the Lohengrin spectrometer for various isotopes : ^{233,235}U, ^{239,241}Pu, ^{241}Am and ^{243,245}Cm.

- Development of a new analysis procedure : correlation (E,q), self-normalization and experimental variance-covariance matrix calculation.

- Investigation of the symmetry region for ^{233,235}U and ^{241}Pu mass yields.

- Isomer ratios measurements on-going with three different techniques for isomers with lifetimes from ns to second. Goal : comparision with fission codes (Fifrelin)

- FIPPS project : new instrument @ILL. Accepted at the ILL Endurance program (7 upgrades and 7 new instruments for 2020) in 3 phases :
  - Phase I : Ge array only at H22 end position
  - Phase II : H22 end position with spectro (GFM)
  - Phase III : dedicated casemate

- Potential interests : detailed spectroscopy of neutron rich nuclei, nuclear fission study, fast neutron beam (moveable instrument)

Conclusion et perspectives

Collaboration for the measurement campaign @Lohengrin :

C. Sage, G. Kessedjian, A. Chebboubi, A. Bidaud, A. Billebaud, N. Capellan, S. Chabod, O. Méplan
LPSC, UJF, INP, Grenoble

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CEA/Saclay

L. Mathieu, ***CENBG, Bordeaux***

C. O. Bacri, X. Doligez, ***IPN, Orsay***