Prompt γ-rays as a probe of nuclear dynamics with PARIS@IPNO

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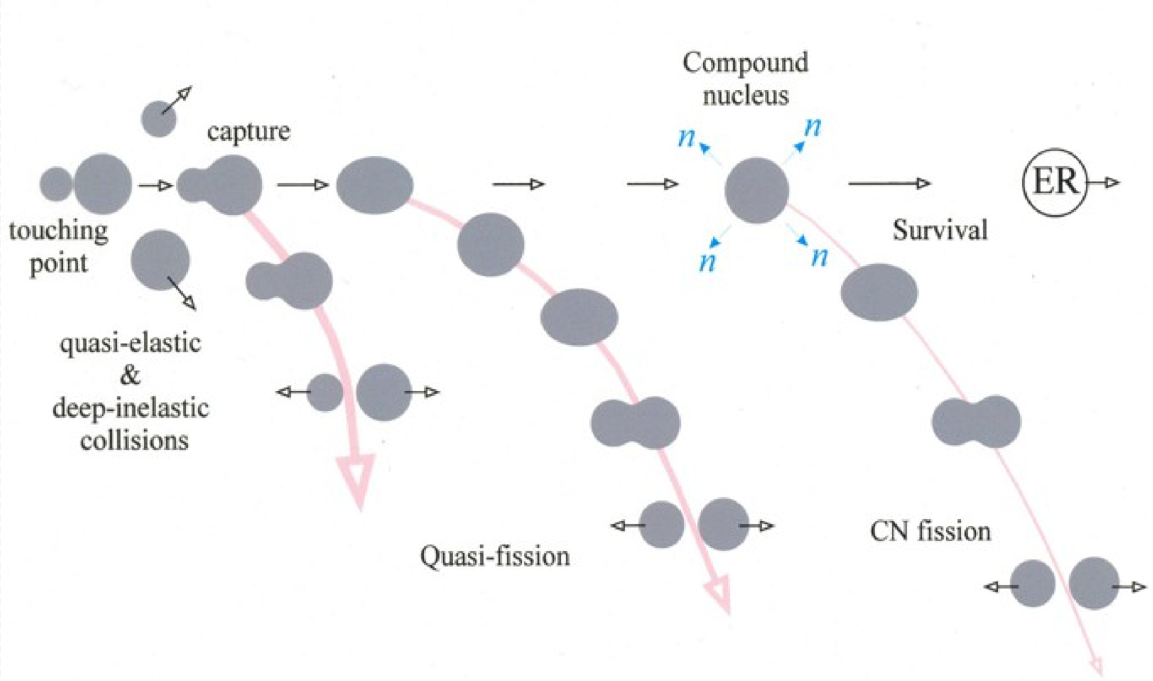
Motivation and Goal :
Challenging fission around the interaction barrier

$$^{32}\mathrm{S} + ^{197}\mathrm{Au} \rightarrow ^{229}\mathrm{Am}^*,\ E^* \approx 43\ \mathrm{MeV}$$

- Coupling of 3 detection systems: CORSET + ORGAM + PARIS;
- Extracting details on the shell effects characterizing two competing processes **fusion-fission (CNF)** and **quasi-fission (QF)** in (A,TKE) correlation;
- Measurement of prompt γ-rays in coincidence with binary reaction fragments obtained in the reactions: γ-rays for further insight.



- Are population and feedings of specific isotopes preferred in different mechanisms or CNF modes?
- How does the γ-ray multiplicity or the sum energy evolve with fragment mass A, TKE or their variances?

Experimental Setup: CORSET

$$^{32}\mathrm{S}+^{197}\mathrm{Au} \rightarrow ^{229}\mathrm{Am}^{*},\ E^{*} \approx 43\ \mathrm{MeV}$$

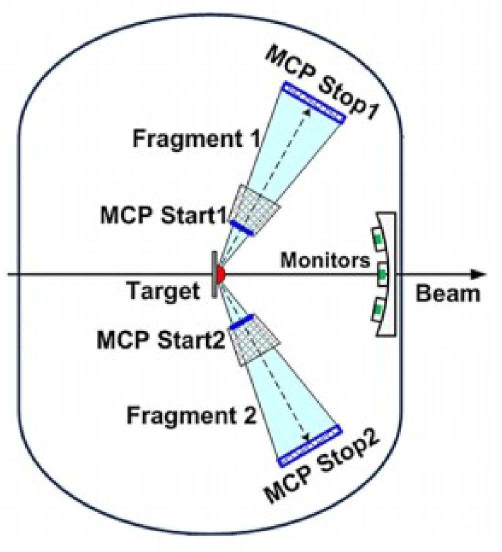
- CORSET:

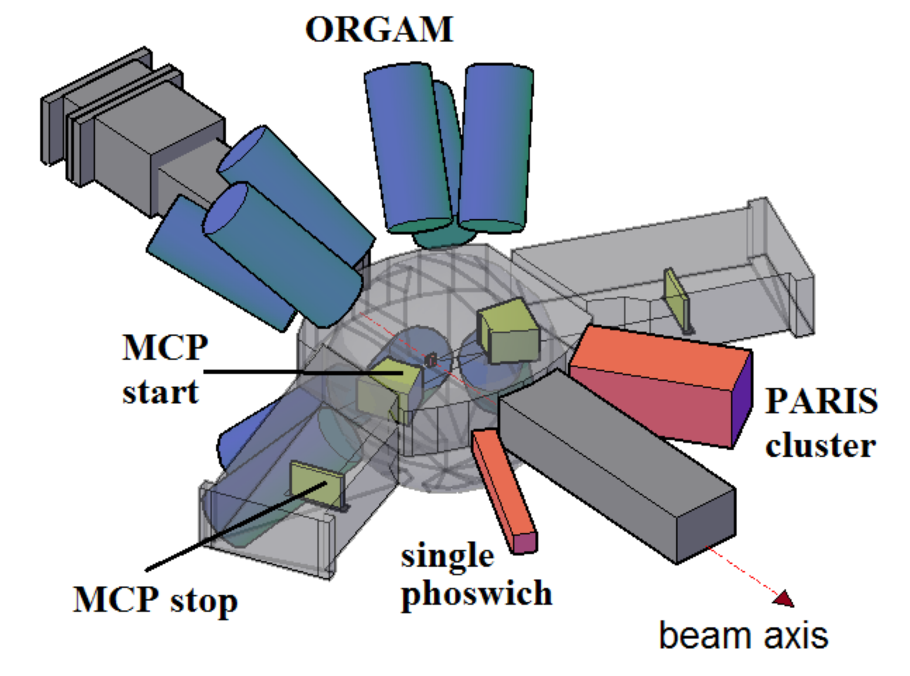
Measured parameters:

- ToF, X, Y

Extracted parameters :

- Velocity, energy, angles
- mass of fission fragments



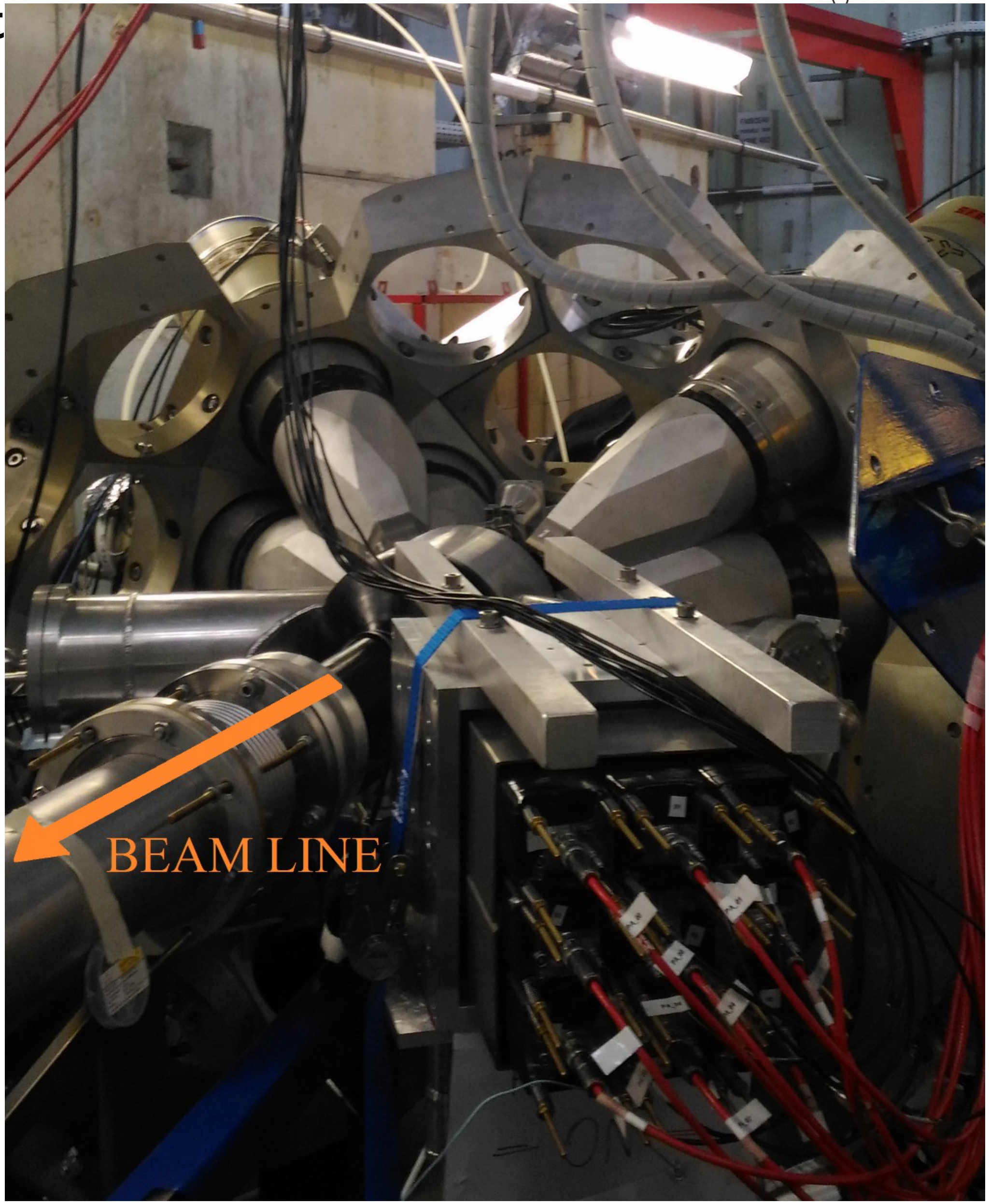


Parameter	Value
The Coulomb barrier (in lab. sys)	166 MeV
Irradiation time	~4 days
Beam current	~ 90 nA
Collected statistics for fission fragments	$\sim 2 \cdot 10^{6}$
Excitation energy of the CN	~43 MeV

Experimental Setup: Coincident γ-rays

- ORGAM: Prompt γ–rays coincident with fission fragment (FF).
- PARIS: Prompt –rays (including high-energy) coincident with FF.

Parameter	ORGAM	PARIS
Number and type of Detectors	10 x Ge + BGO shielding	10 x LaBr3(Ce)-NaI(Tl) *(phoswich)*
Photo-peak Efficiency	~1%	~1%
Energy resolution	2.6(3.4)keV @121(1408)keV	62keV @1332keV
Dynamical range	$E_\gamma < 2.5$MeV	$E_\gamma < 15$MeV

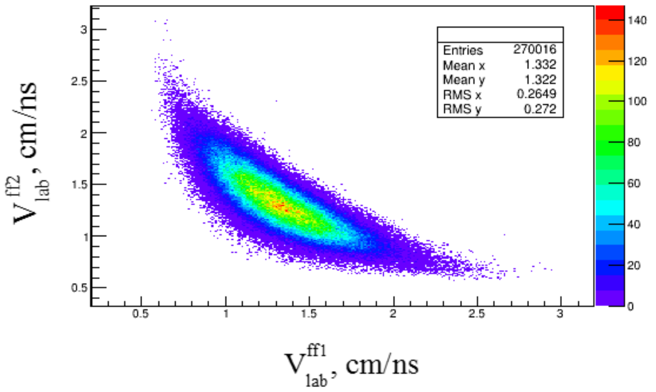


CORSET Data

$$^{32}S + ^{197}Au \rightarrow ^{229}Am^*, \; E^* \approx 43 \text{ MeV}$$

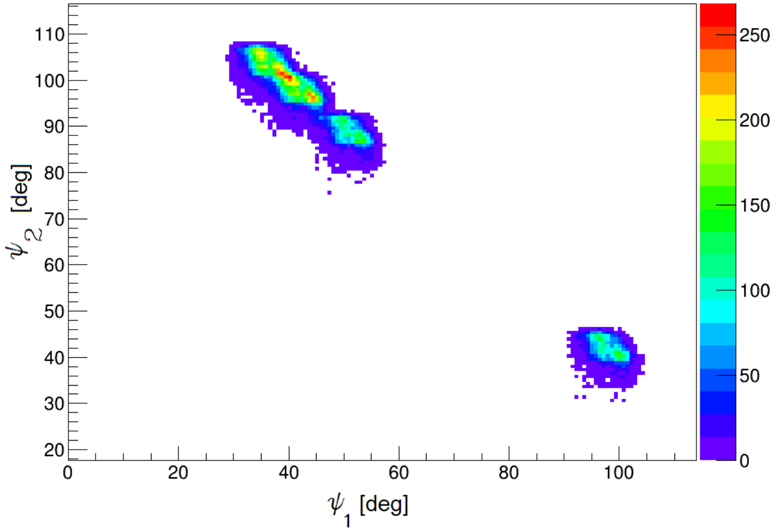
E_{lab} (MeV)	$\theta_{lab}^{grazing}$ (deg)	η_0	$Z_p Z_t$	B_{lab}^{Bass} (MeV)
166	141.5	0.72	1264	164.8

- Access to velocity vectors of FF and angles between FF and γ-ray detectors granted

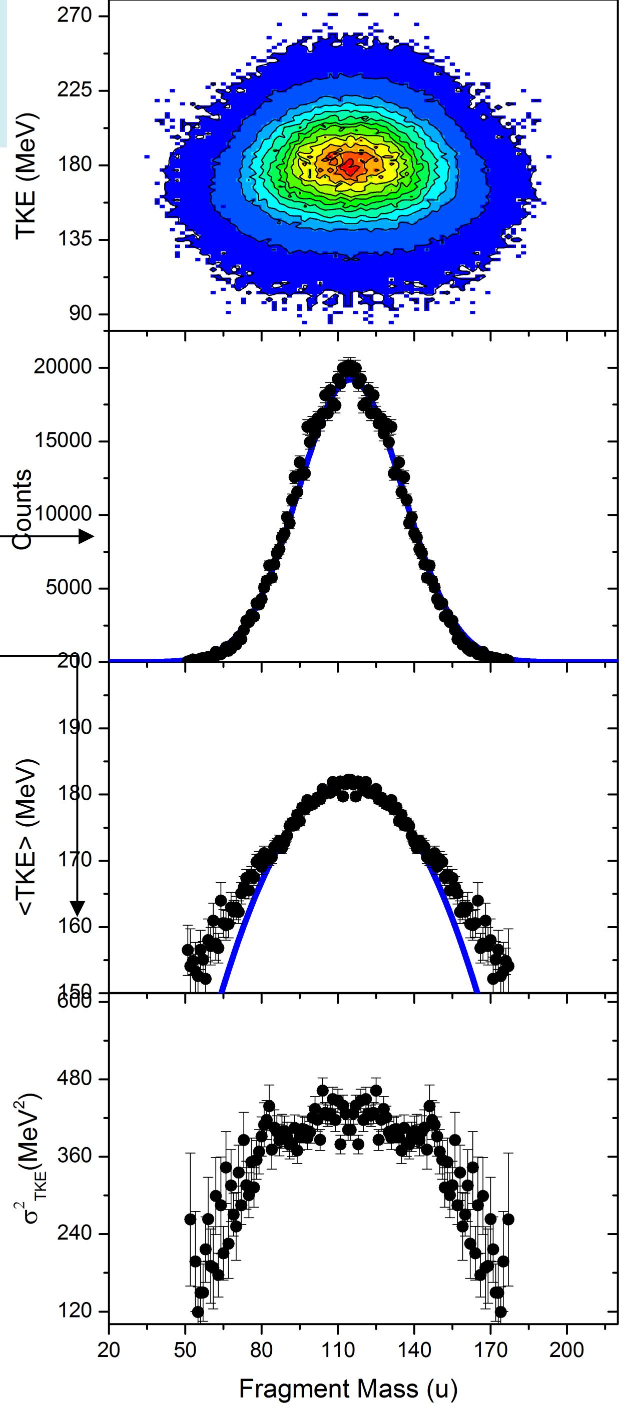


to be used for precise Doppler

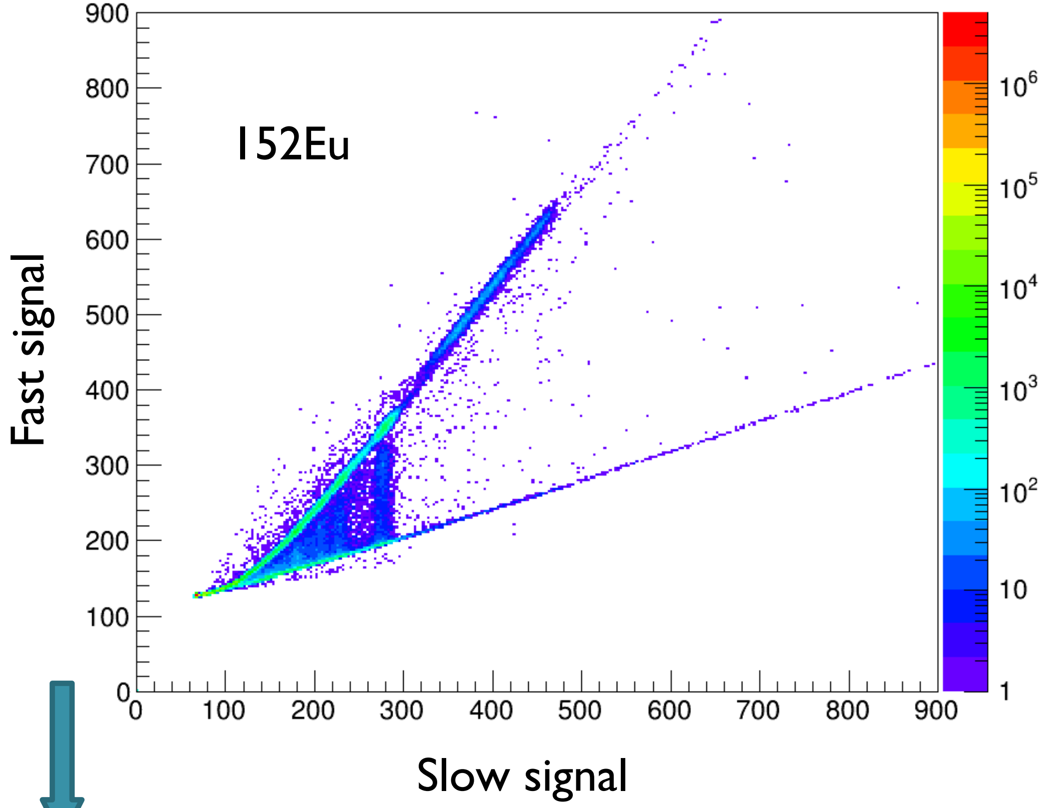
corrections on γ-ray energies

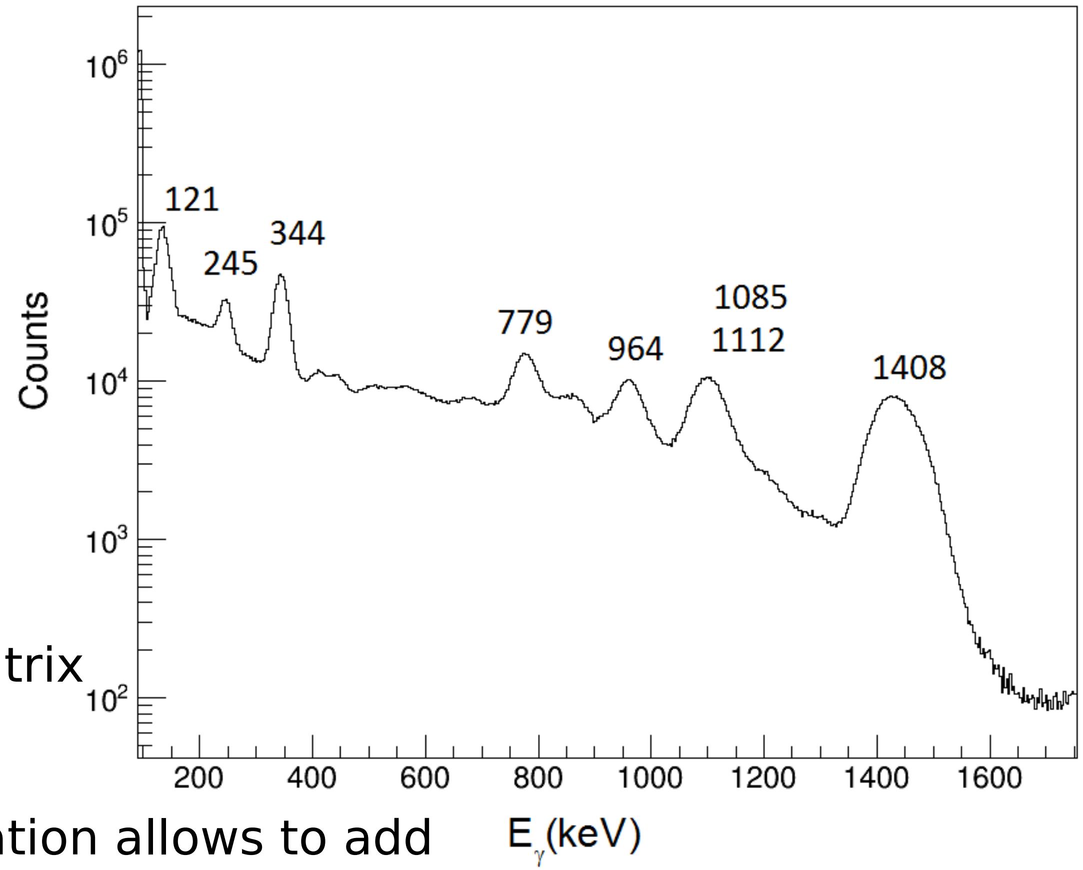


LDM prediction



calibration sources

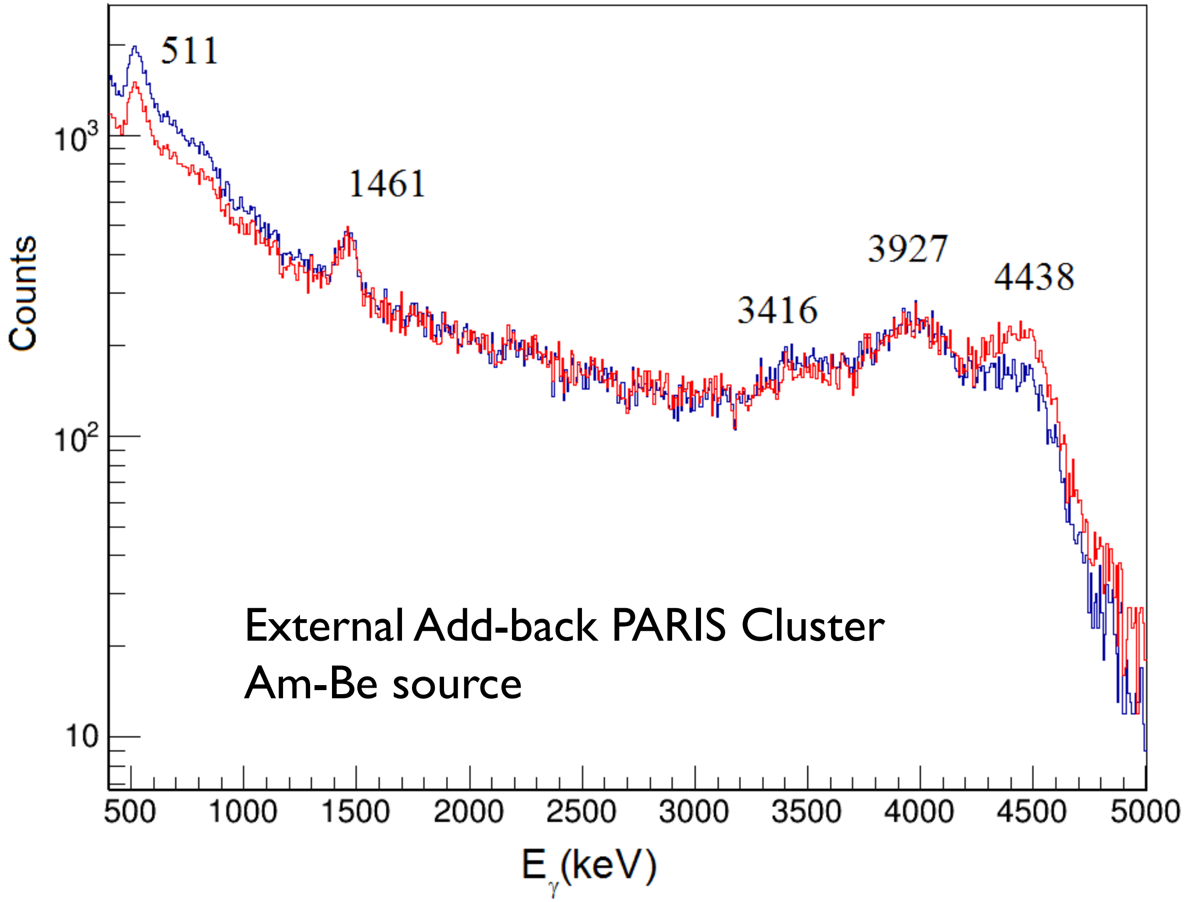




1. "Internal" add-back: by rotating the matrix to form parallel lines with the Y axis → Reconstruction of the total energy

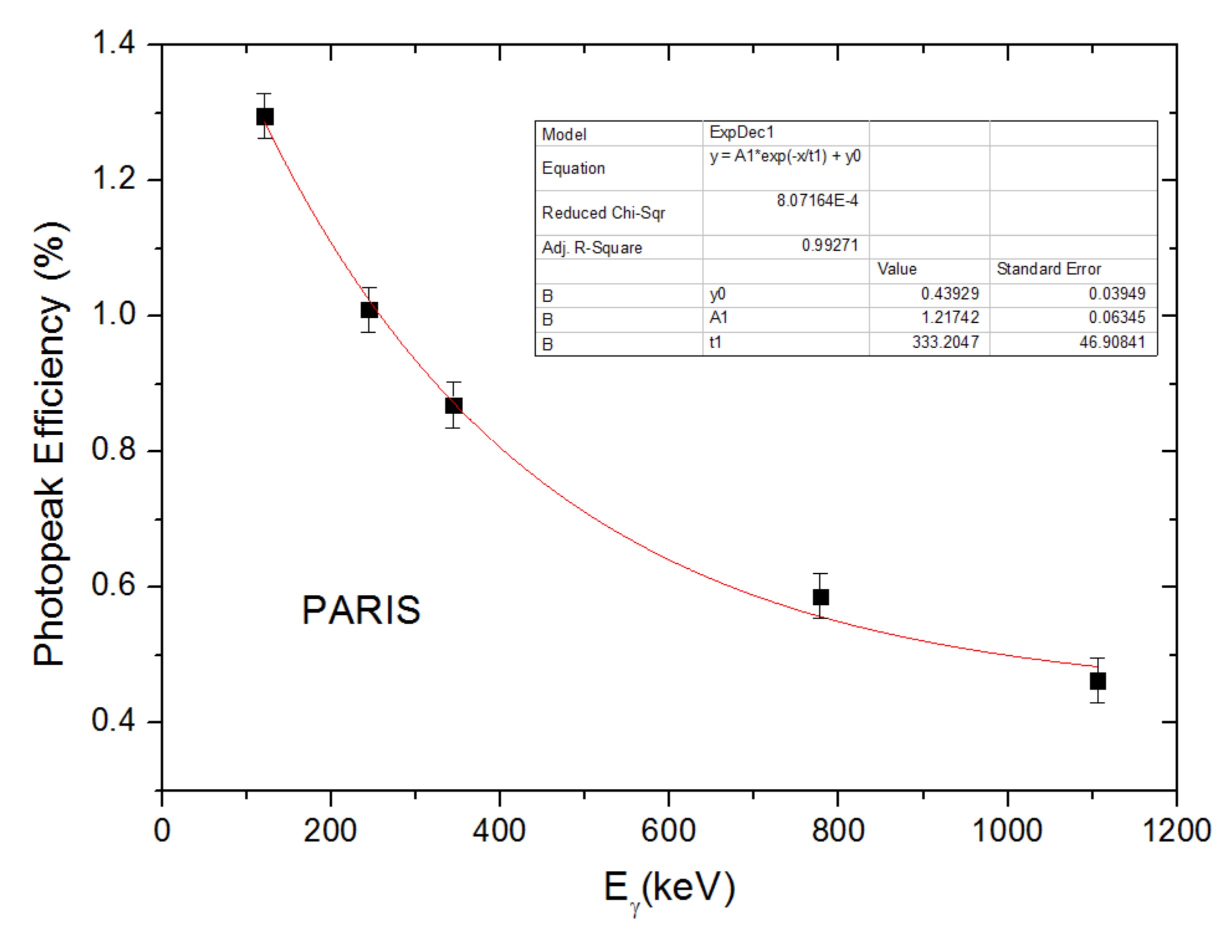
2. External add-back: the cluster configuration allows to add the escaped scattered γ-rays together and fill the original spectrum with the whole detected energy of the photon.

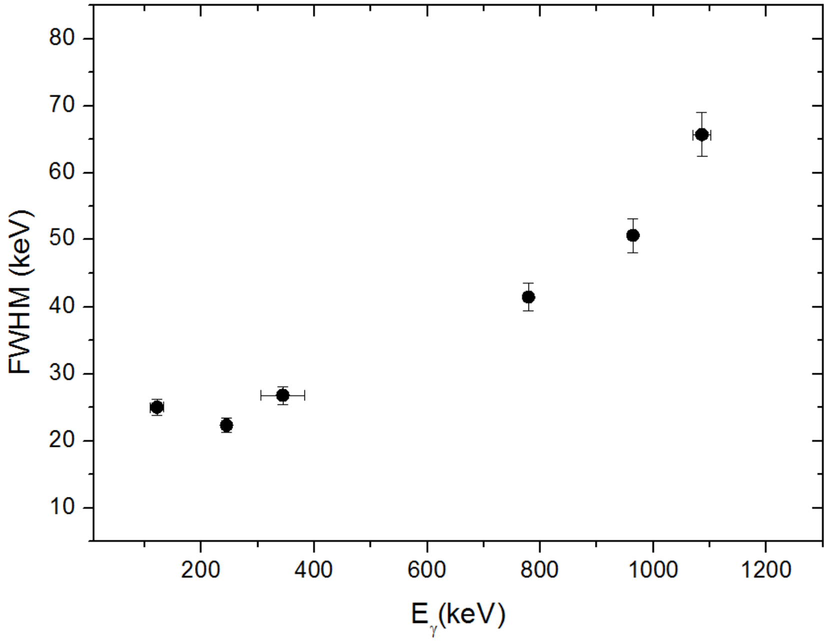
PARIS Add-back *calibration source Am-Be*

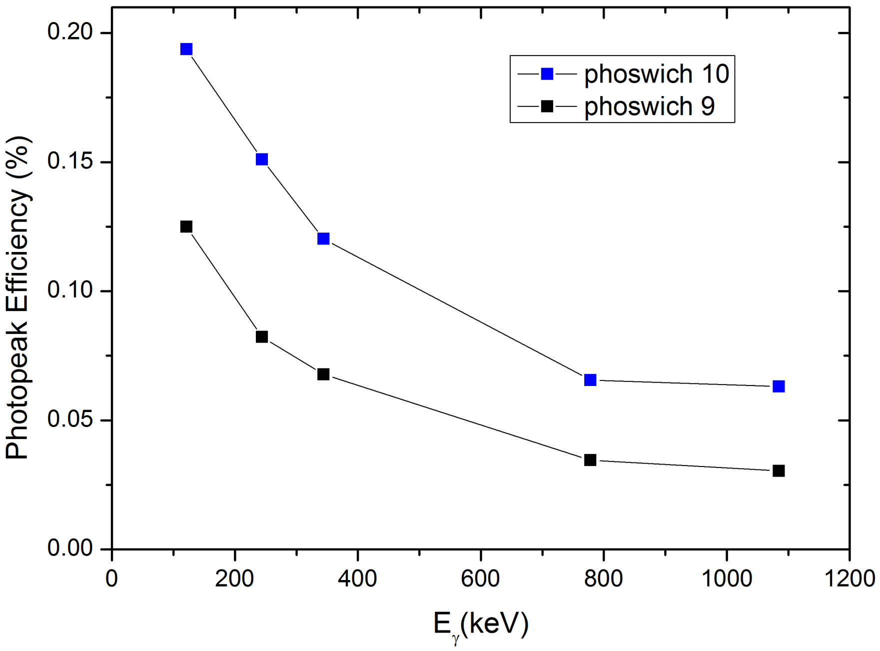


Efficiency before addback	0.2% @ 4.4MeV
Efficiency after addback	0.4% @ 4.4MeV

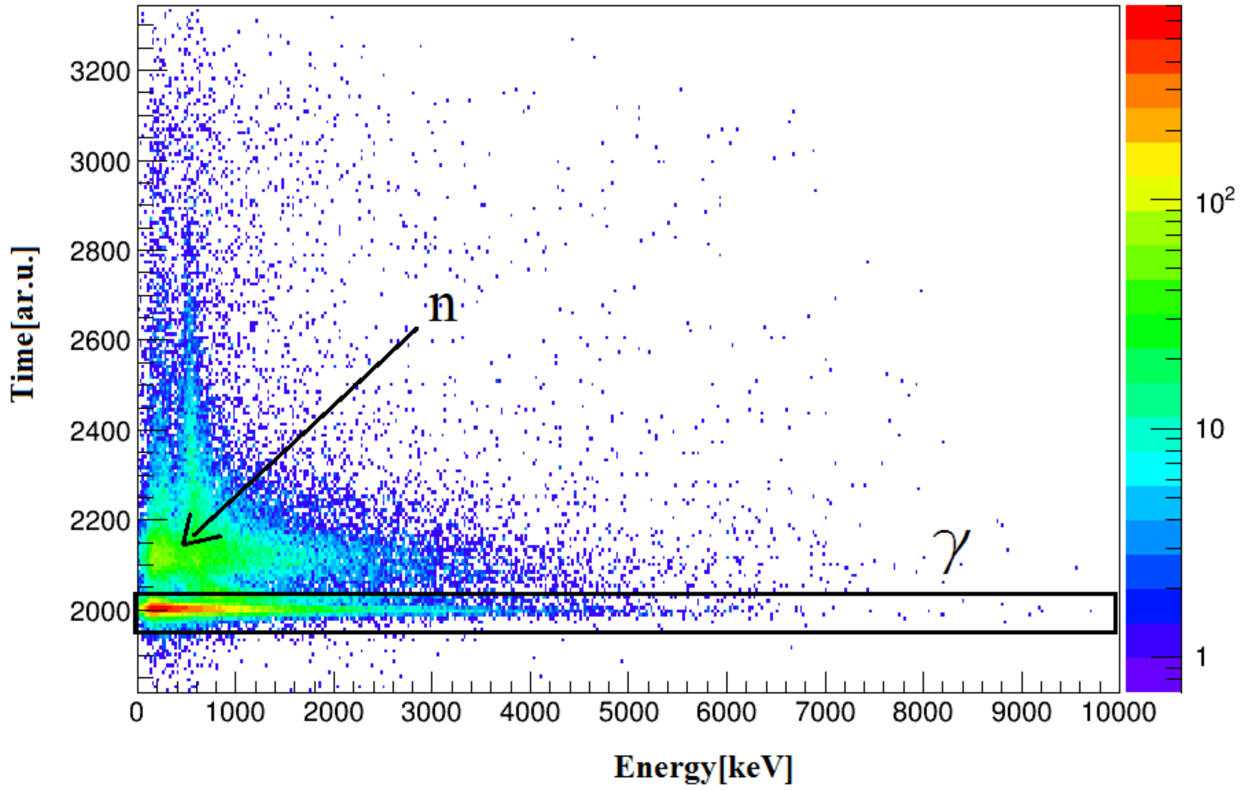
Efficiency and Resolution





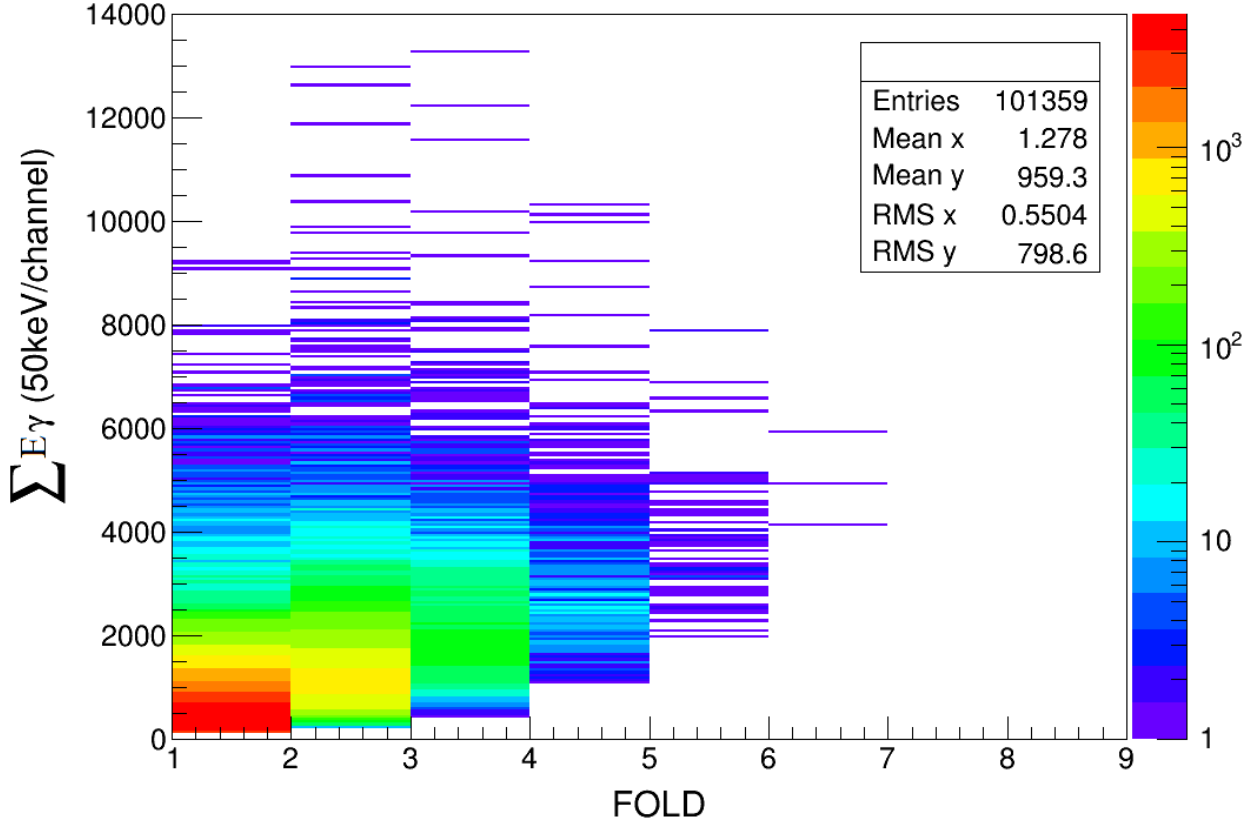


γ– Coincident with FF

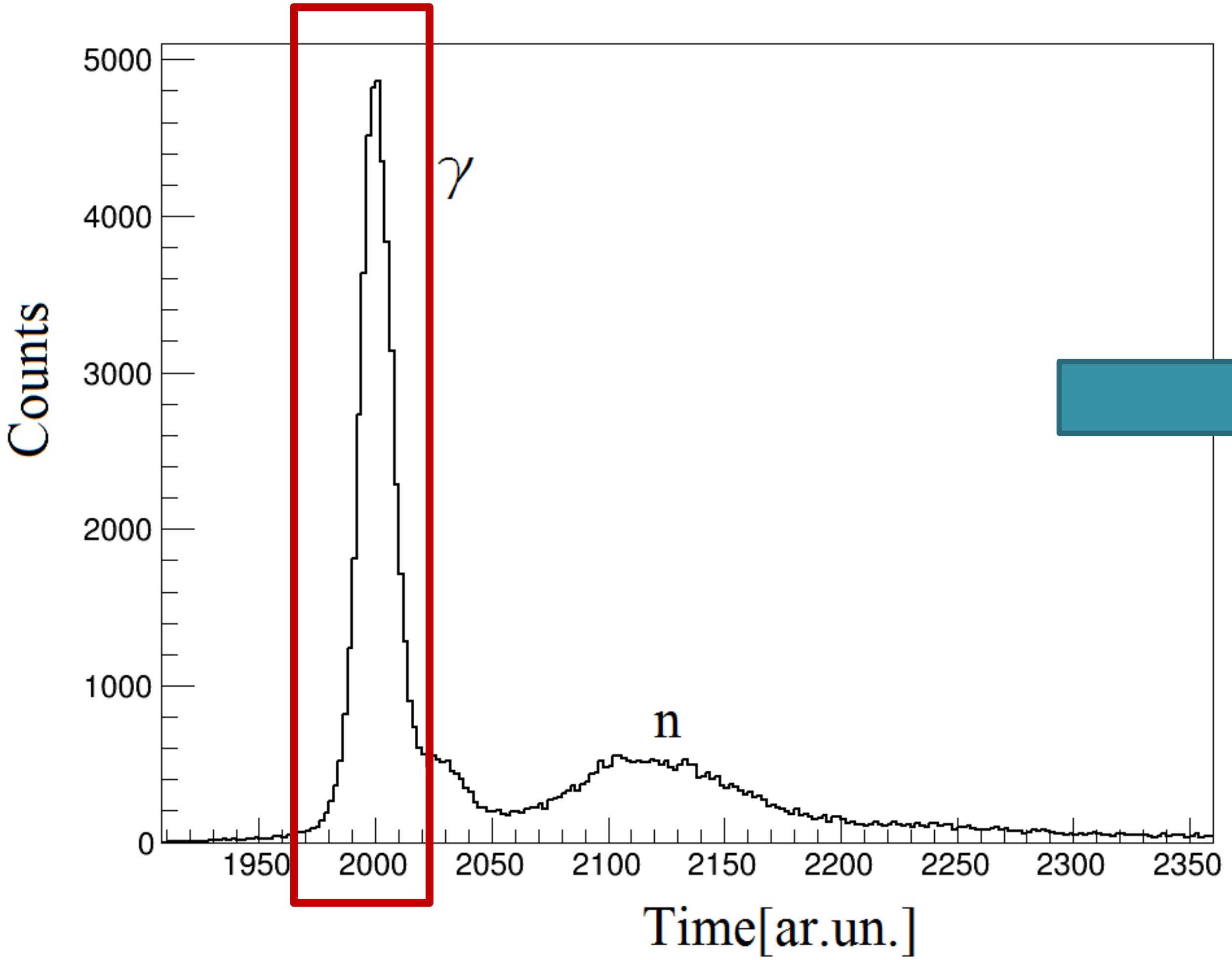


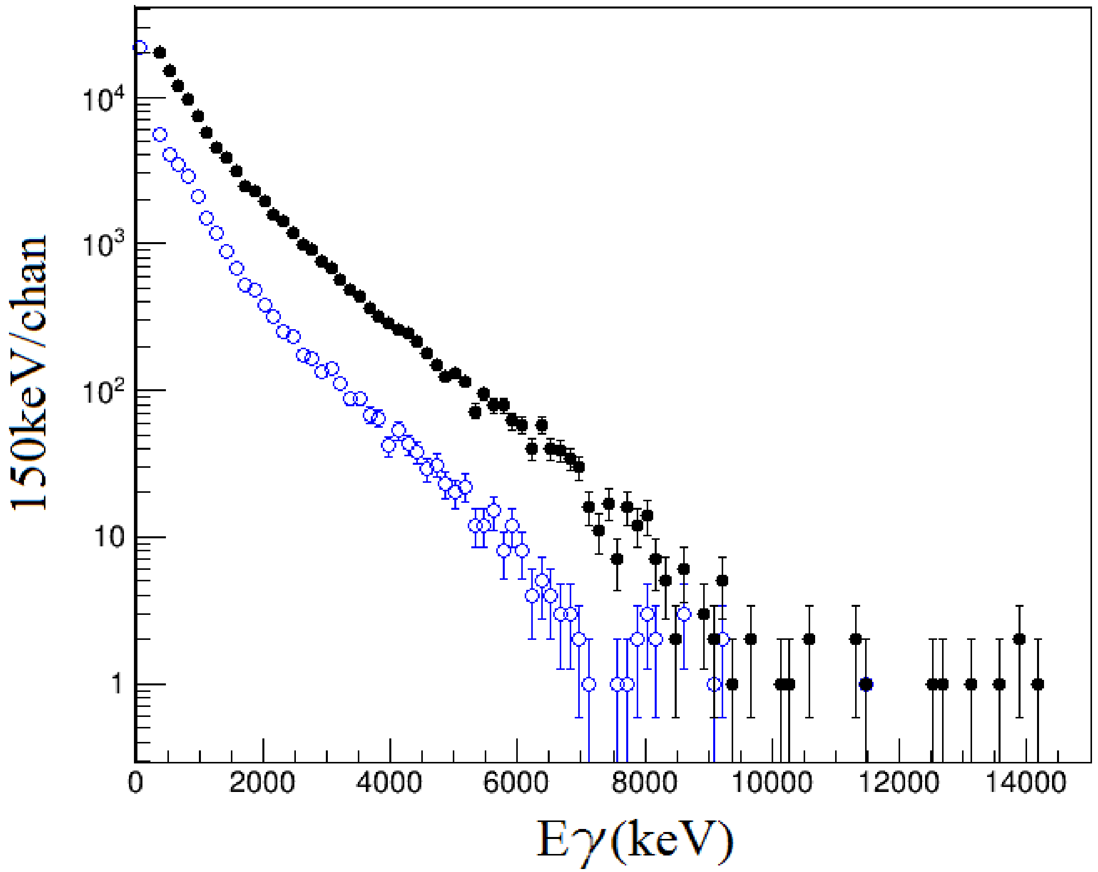
- Good time resolution allowing discrimination of γ–rays against neutrons.
- Wide energy range.
- Able to accept a high counting rate.

PARIS



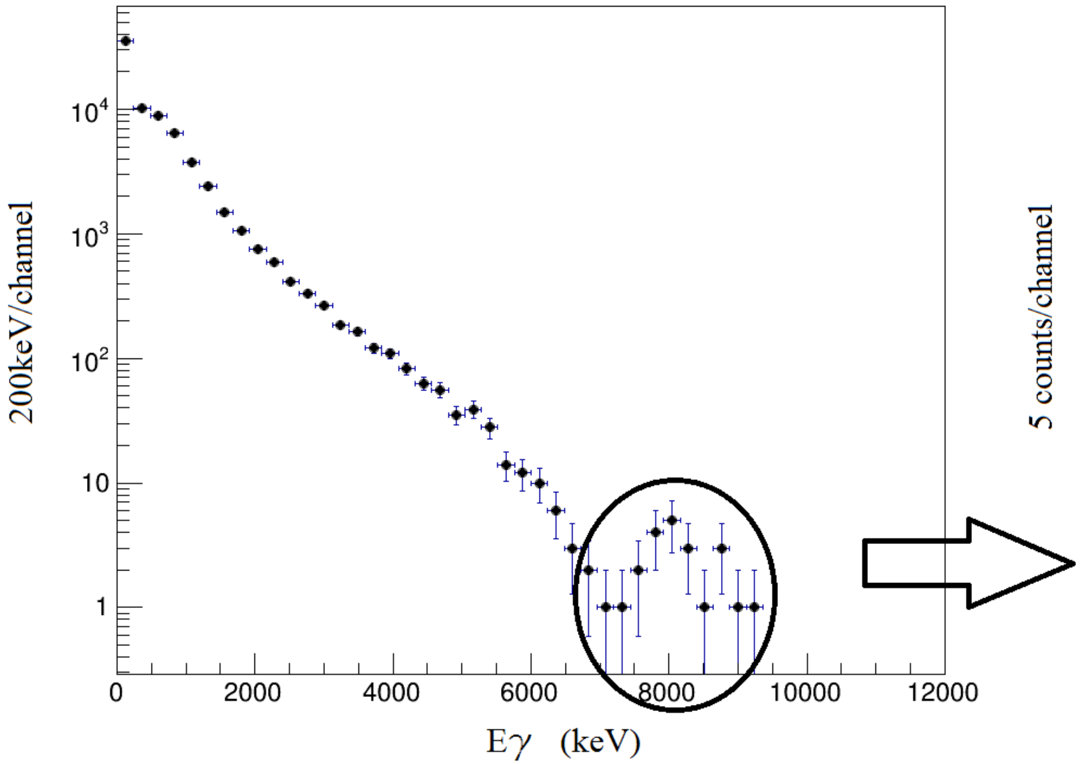
γ– Coincident with FF PARIS

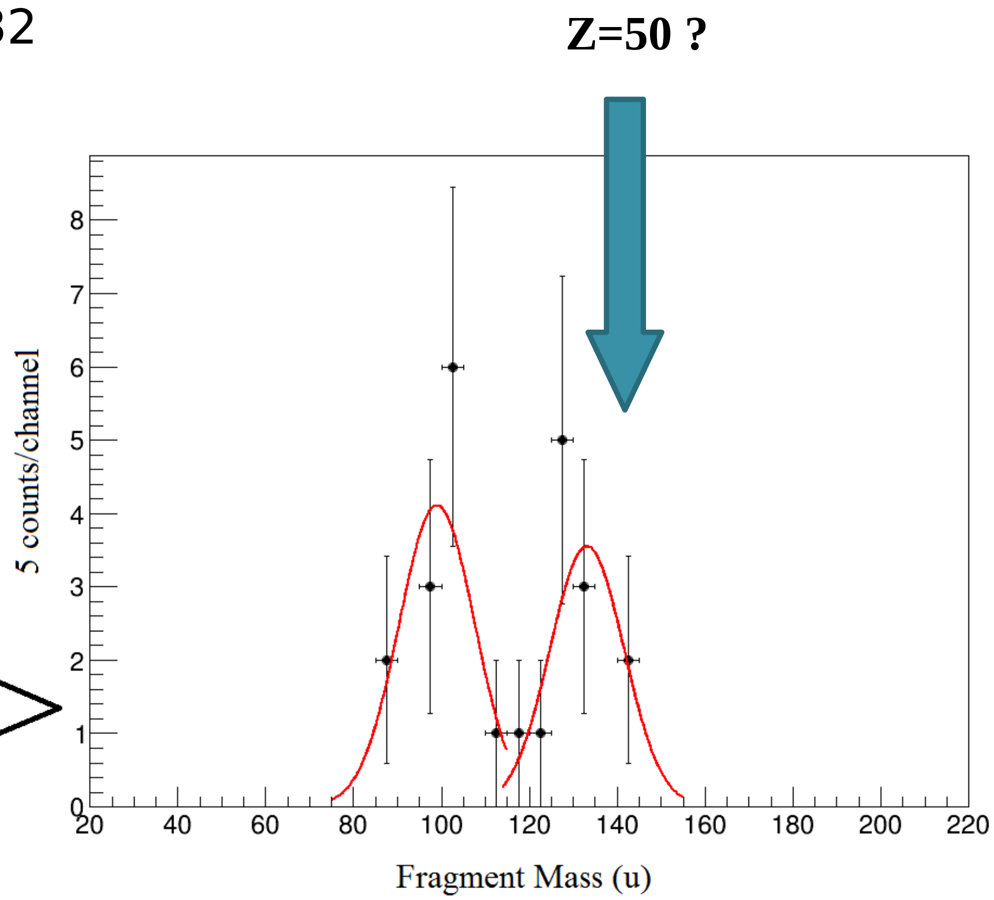




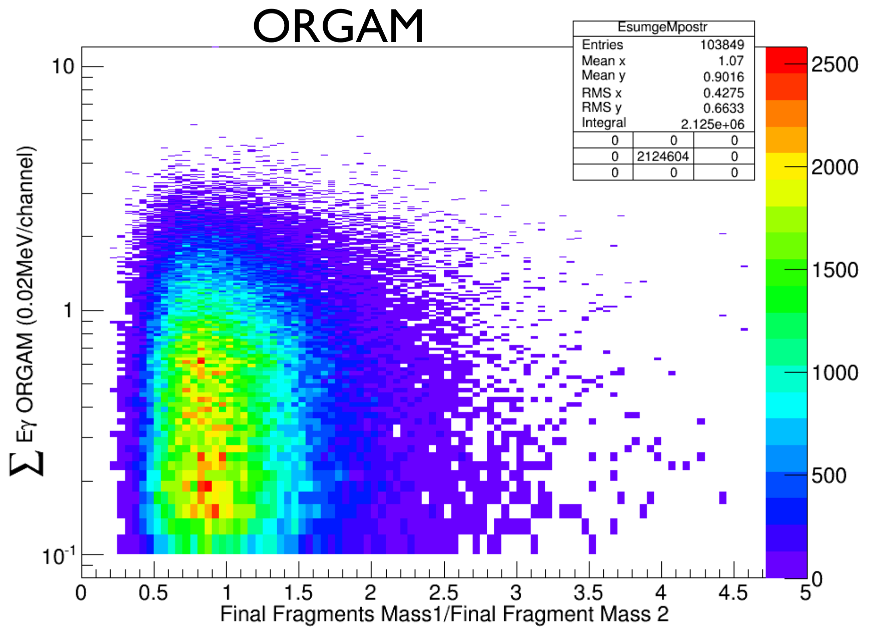
γ-rays– Coincident with FF

The high energy component of the γ -ray spectrum shows a dependency on the fragment mass split, particularly in the region of masses 120::132



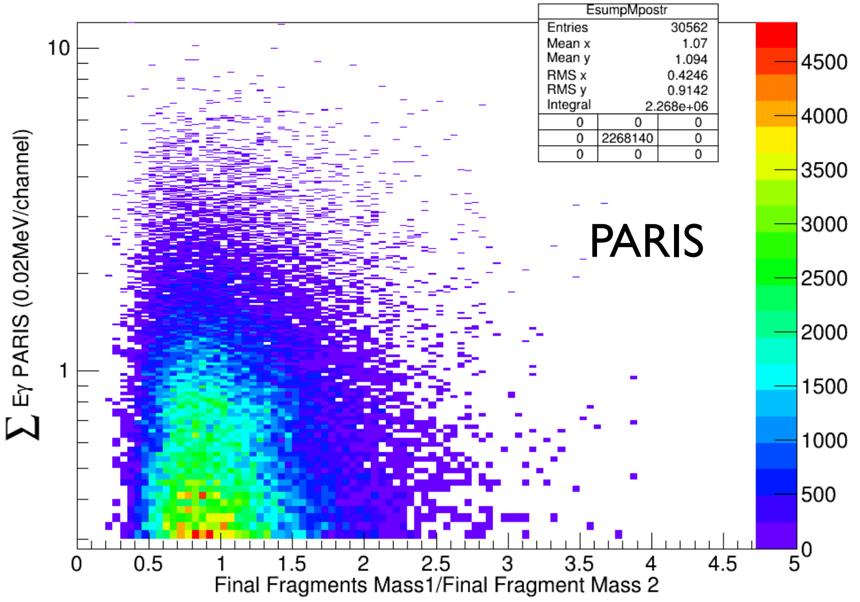


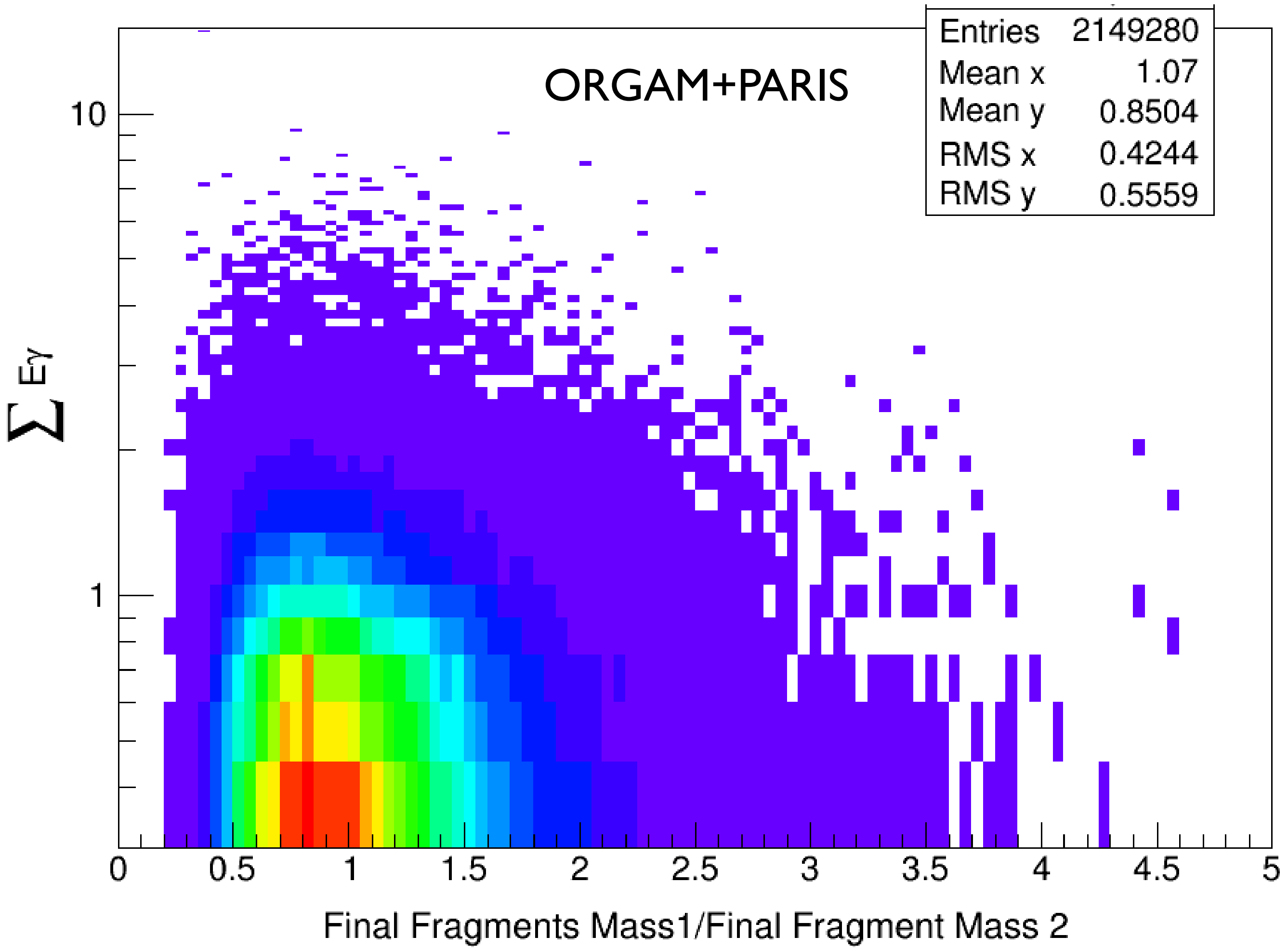
EFFICIENCY CORRECTED Eγ



The total number of γs in ORGAM+PARIS after efficiency correction

$$N_\gamma^{ORGAM+PARIS} = 2149280 \rightarrow < M_\gamma > = \frac{N_\gamma^{ORGAM+PARIS}}{N_{FF}} = 7.8.$$





Fold to Multiplicity conversion

If we have a number of N detectors, each of efficiency $\Omega_1, \Omega_2 ... \Omega_N$, the $P(M, F, k)$ will be:

$$P(M,F,k) = \binom{M}{k} \left(\sum_{i=1}^{N} \Omega_i \right)^k \left(1 - \sum_{i=1}^{N} \Omega_i \right)^{M-k},$$

and the $P(F, k)$ will be:

$$P(F,k) = \sum_{l=0}^{F} (-1)^{F-l} \binom{N-l}{N-F} \sum_{Pa(l)} \left[\frac{\Omega_{a1} + ... + \Omega_{al}}{\sum_{i=1}^{N} \Omega_i} \right]^k,$$

where $\sum_{Pa(l)}$ is the sum over all permutations which take l out of N detectors.

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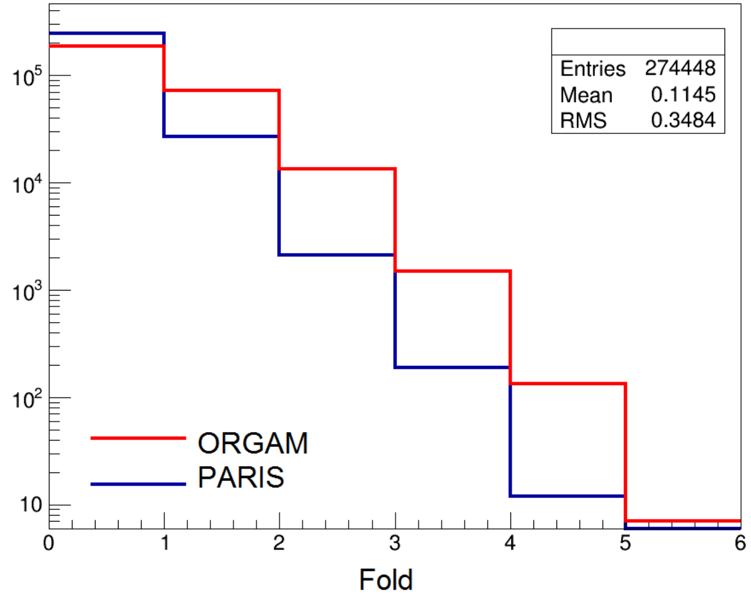
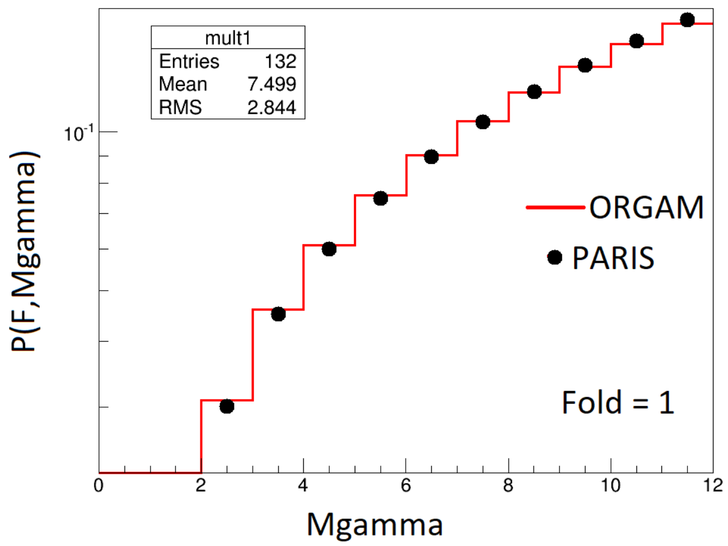
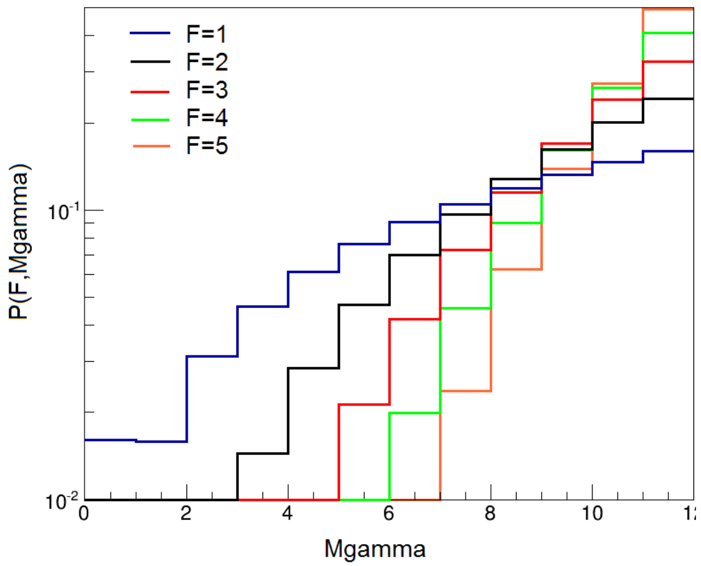
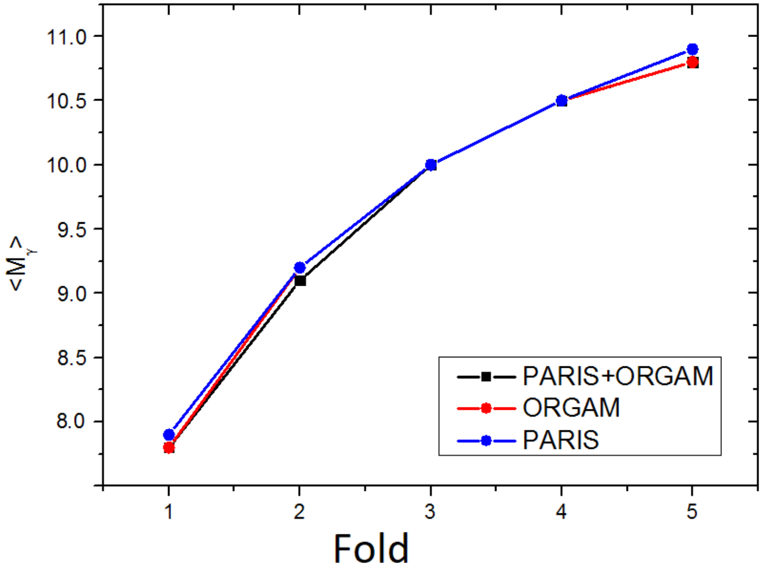


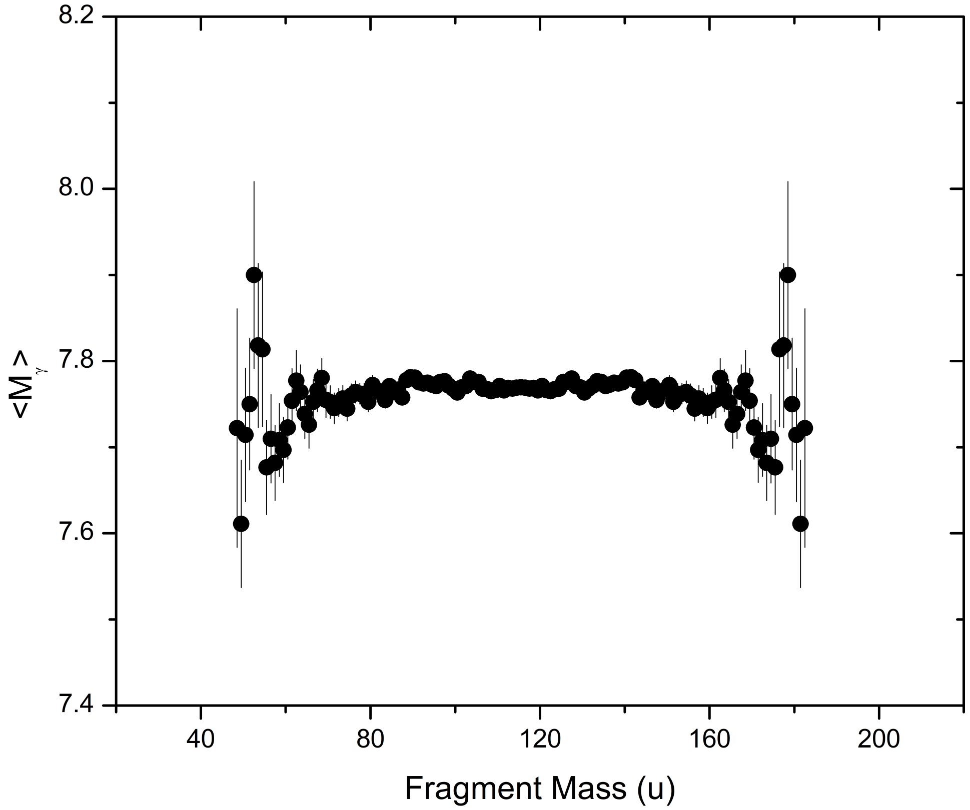


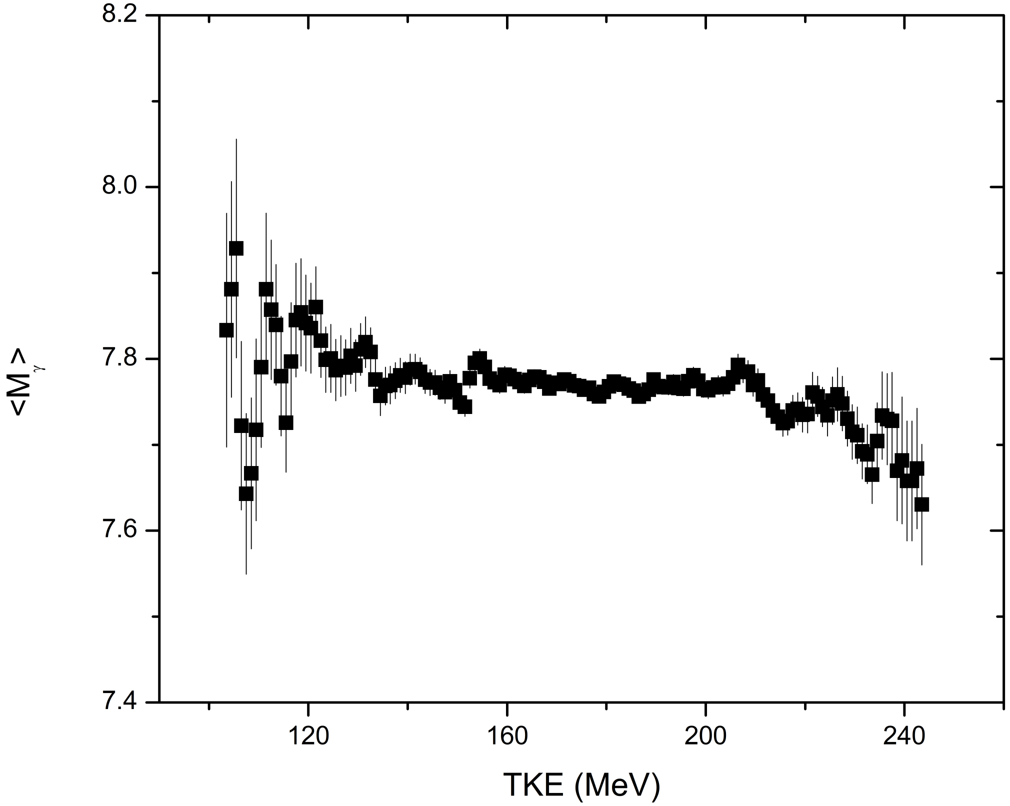




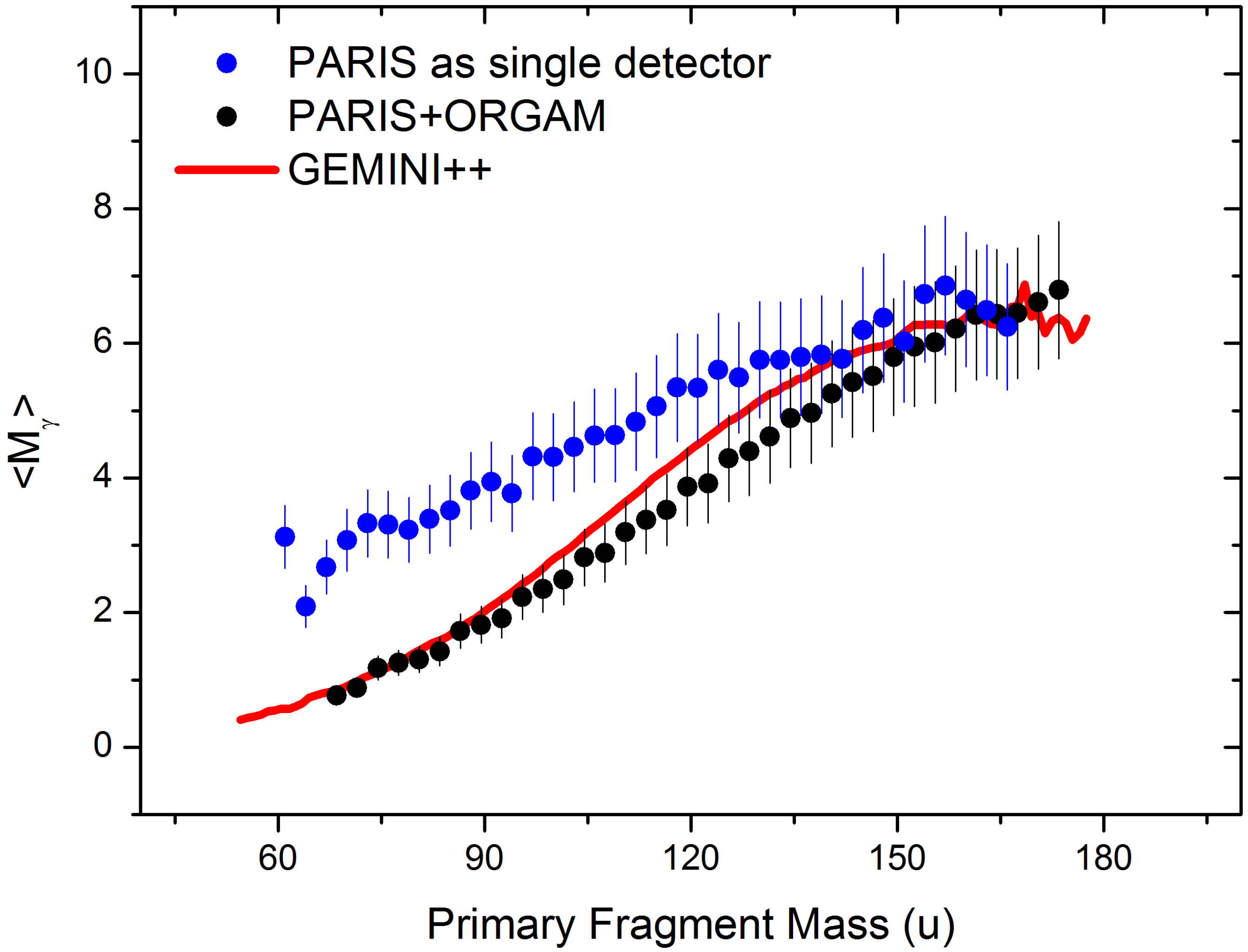
Fold to Multiplicity conversion

$$M_\gamma(A) \,\&\, M_\gamma(TKE)$$





Dividing the Multiplicity for each fragment



$$I_i = \frac{\mathcal{I}_i I_T}{\sum_i \mathcal{I}_i + \mu R^2}, \quad \mathcal{I}_i = \frac{2}{5} r_0^2 A_i^{5/3}$$

L.G. Moretto et al. Nuclear Physics A 502 (1989) 453c-472c

$$M_{\gamma A_1} = \frac{A_1}{2 n_{A_1} A_{CN}} \frac{n_\gamma}{p_\gamma}.$$

Frances Pleasonton, Robert L. Ferguson, and H.W. Schmitt, PRC volume 6, number 3

Thank you for your attention !

- The 3 detection systems CORSET + ORGAM + PARIS were successfully coupled at IPNO;
- THE Mass-TKE correlation was obtained within a very good resolution (2 amu, 5 MeV);
- Obtained the total γ-multiplicities, event by event -> which should give us access to the description of the pre-scission shapes of the quasi-fission process or fissioning nucleus at the saddle points && more…

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