The Study of Gamma Emission in the Fission Process

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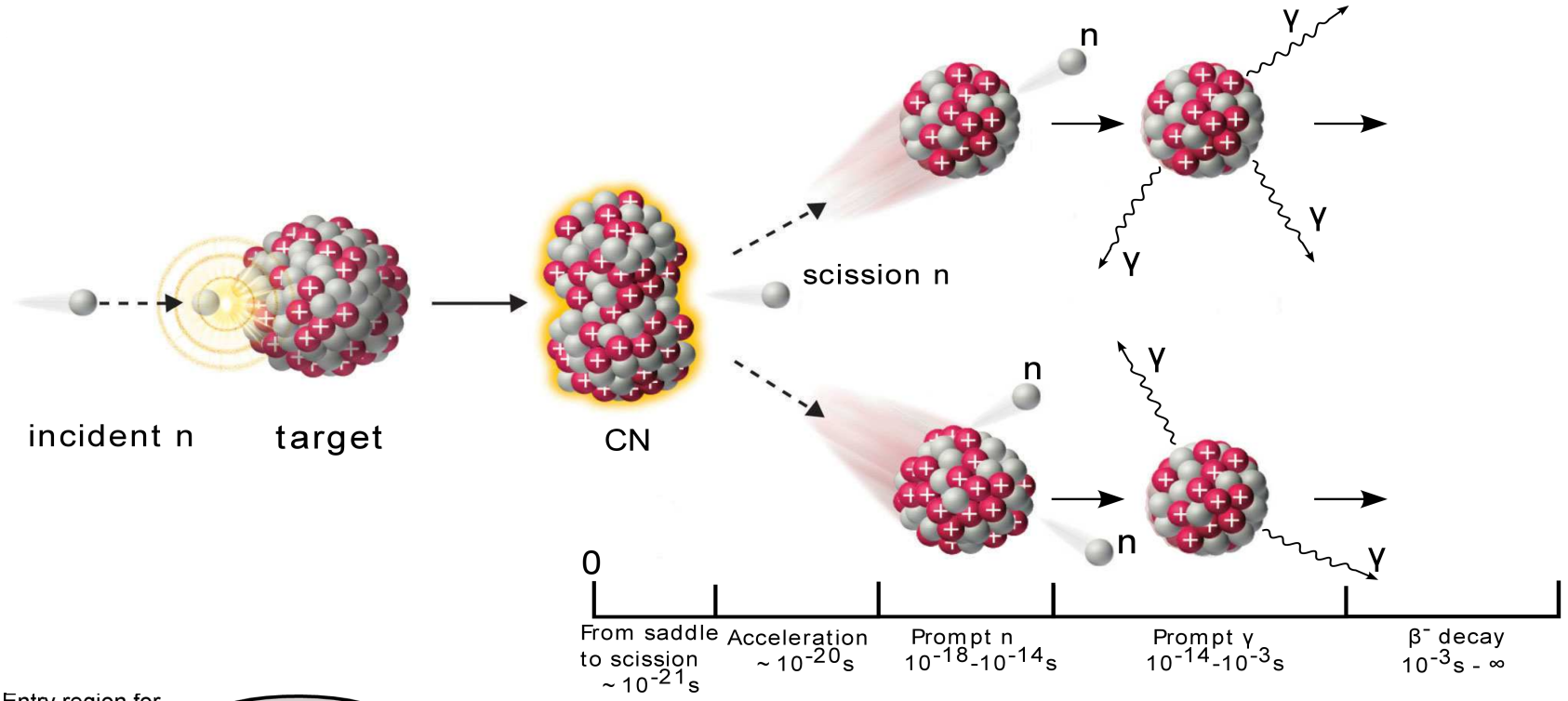
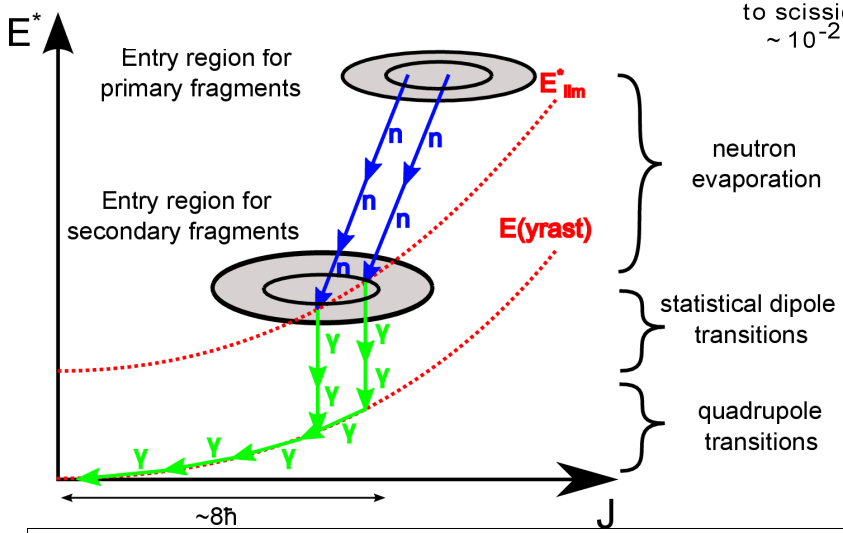
Fundamental Physics

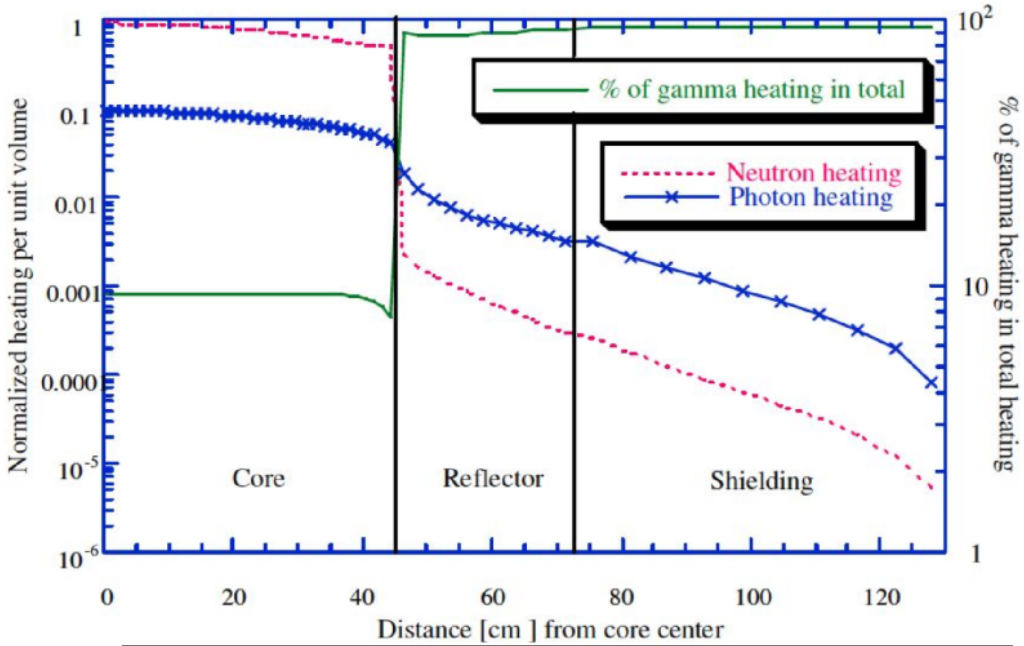




- 1. Energy partition in fission;
- 2. Angular momentum generation;
- 3. Competition between neutron and gamma ray emission;
- 4. Nuclear structure information.

O. Litaize and O. Serot, Phys. Rev. C 82, 054616.

Reactor Physics



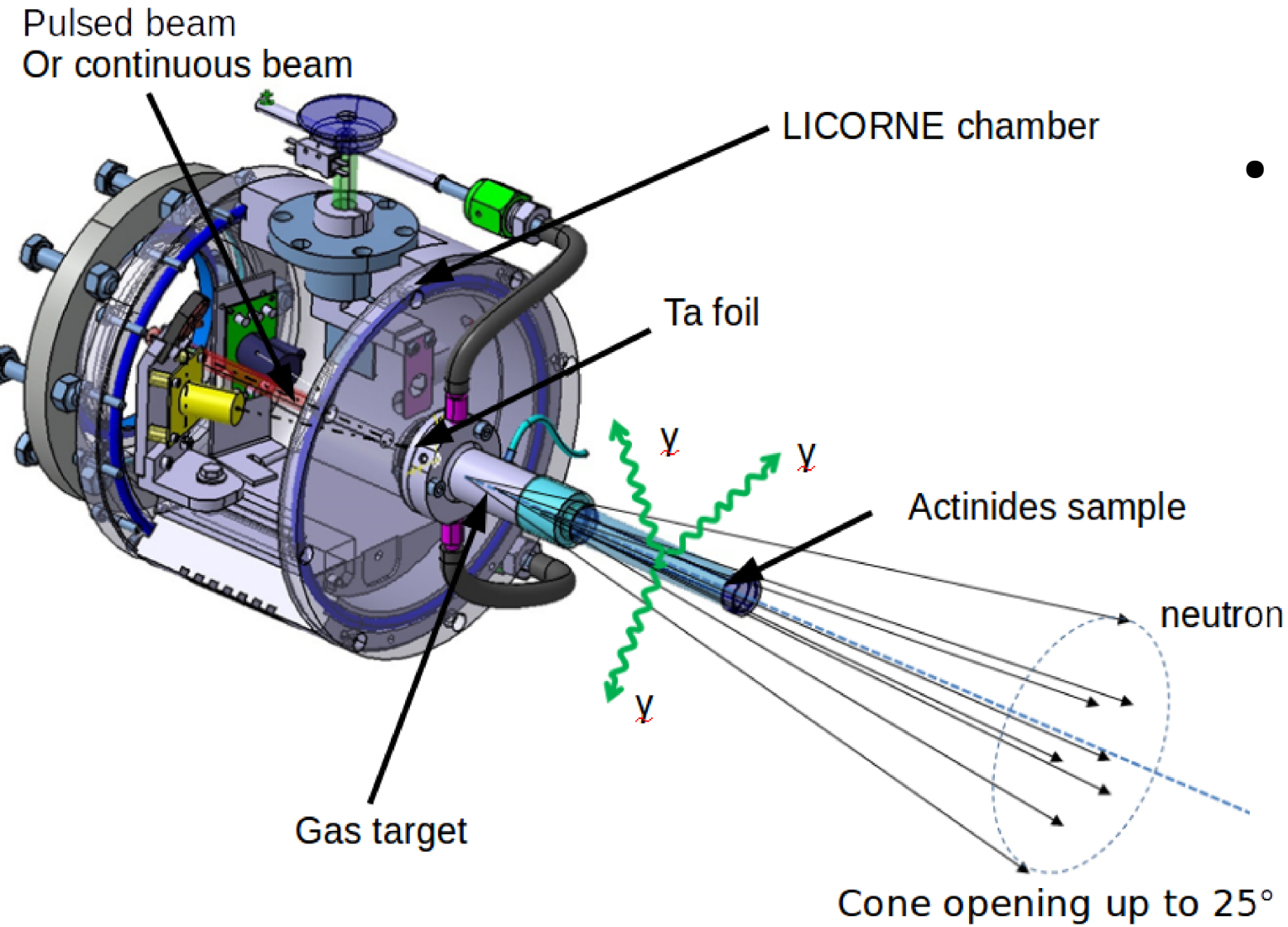
A-C. Colombier et al., EPJ Web of Conferences 42, 04001 (2013)

- Electricity production: 5% from prompt fission γ rays (PFG);
- Major heat source in other components of reactor;
- Generation IV reactors;
- 10% to 28% underestimation of PFG;
- High Priority Request List of OECD/NEA.

Measurement of PFG for different fissioning system: $^{252}Cf(sf)$, $^{238}U(n_{fast},f)$ and $^{239}Pu(n_{fast},f)$

LICORNE Project

Wilson, J. N., et al. In EPJ Web of Conferences (Vol. 62, p. 05006).

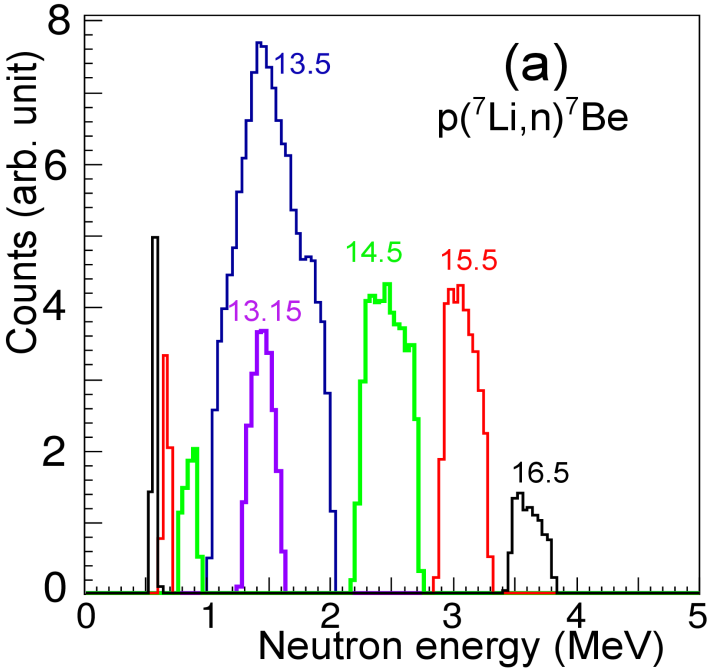


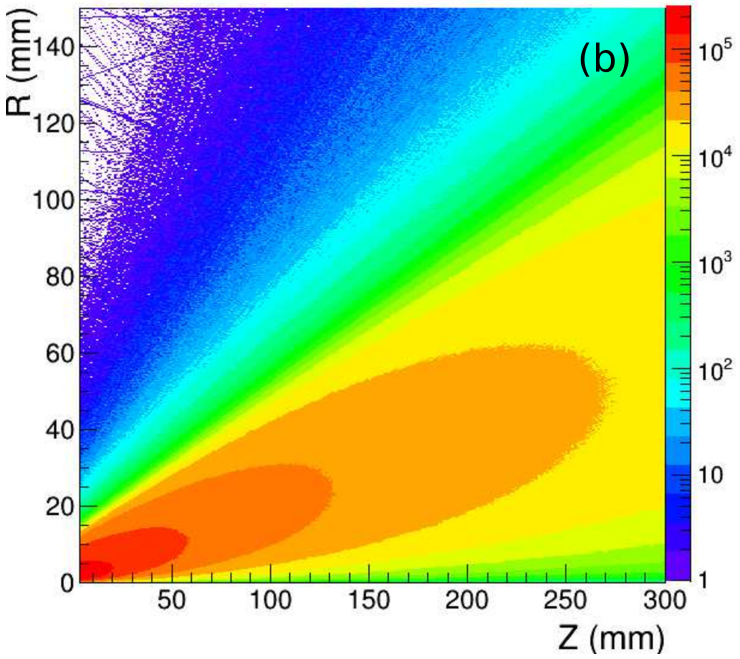
- Lithium Inverse Cinematiques ORsay NEutron source

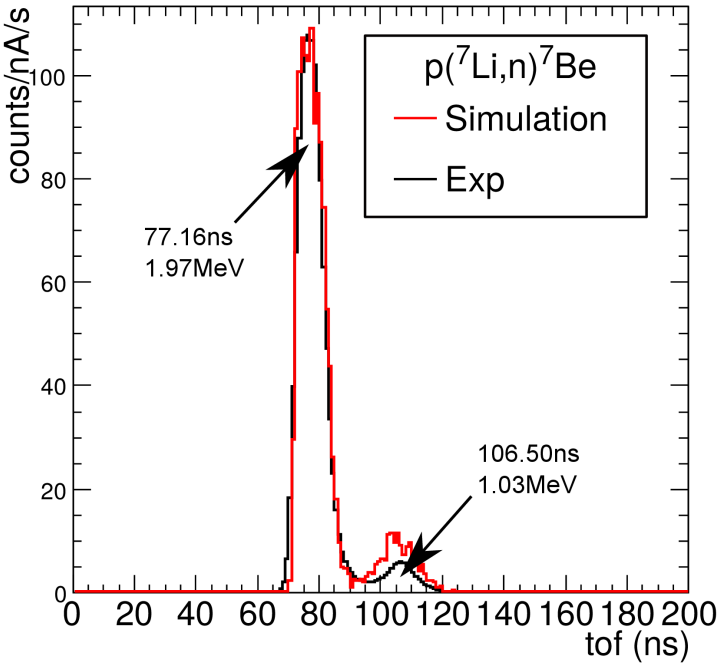
  $p(^{7}Li,n)^{7}Be$

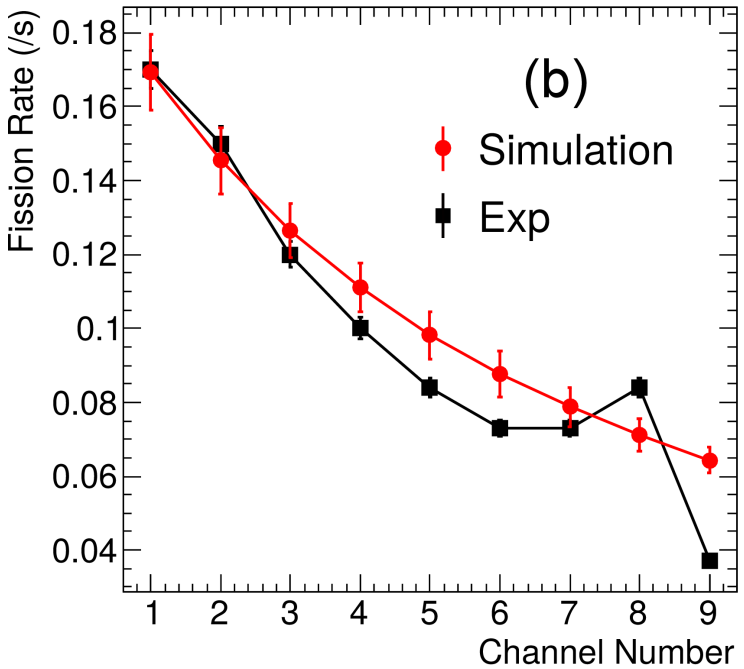
  $p(^{11}B,n)^{11}C$

Quasi Mono-Energetic Neutron Source









^{252}Cf(sf), ^{238}U(n,f) - March, 2016

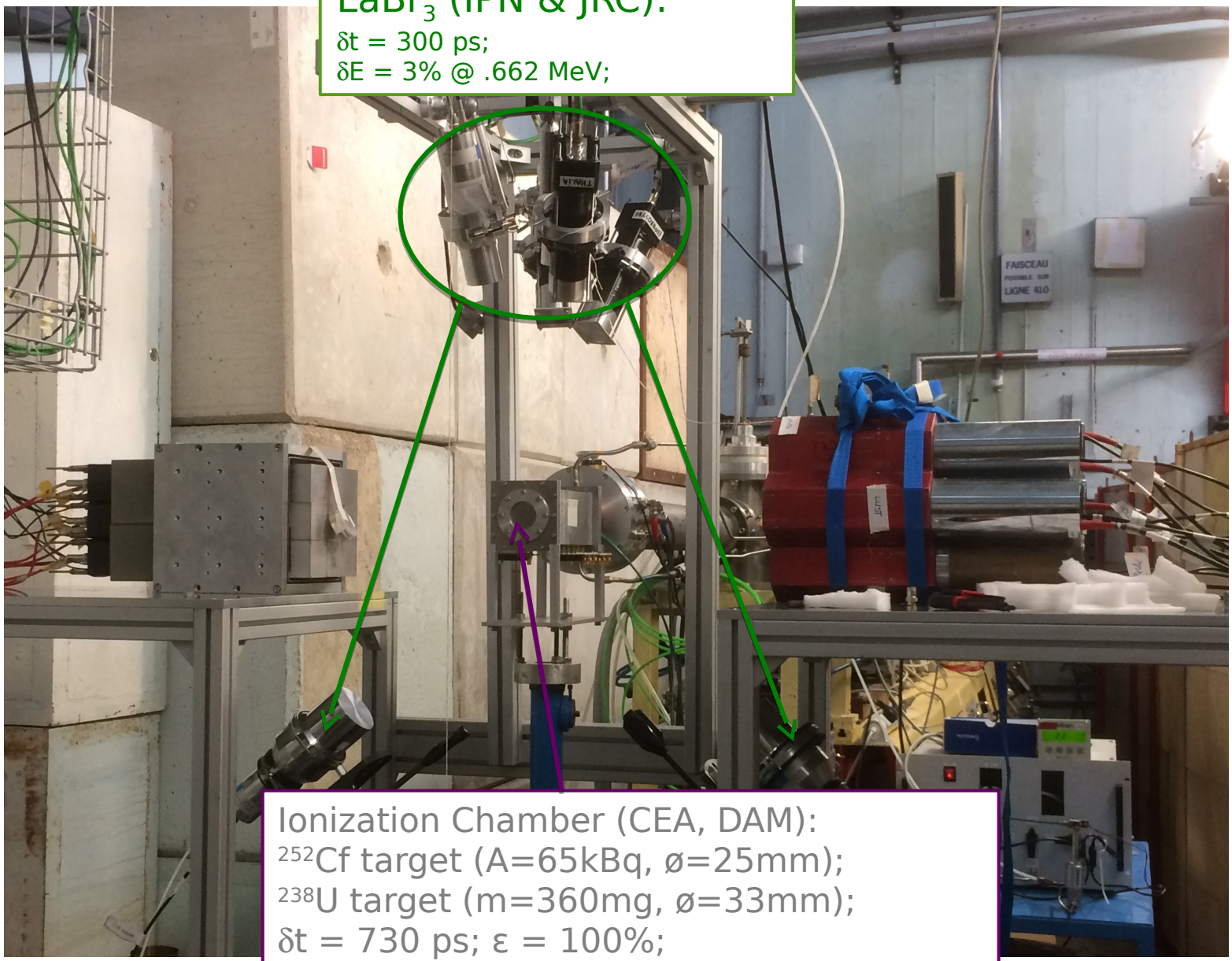
^{252}Cf(sf), ^{238}U(n,f) - March, 2016

Ionization Chamber (CEA, DAM):
^{252}Cf target (A=65kBq, ø=25mm);
^{238}U target (m=360mg, ø=33mm);
δt = 730 ps; ε = 100%;
<0.5% overlapping in α/FF discrimination;

Taieb, J., et al. Nuclear Instruments and Methods in Physics Research Section A, 833 (2016): 1-7.

^{252}Cf(sf), ^{238}U(n,f) - March, 2016

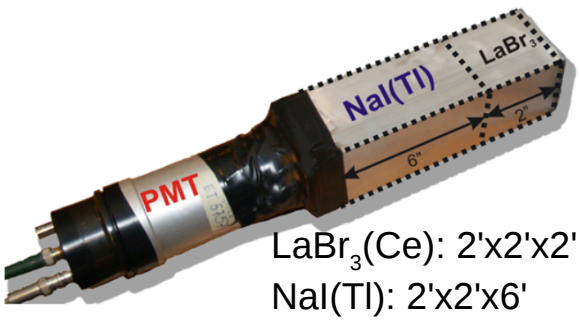
$LaBr_3$ (IPN & JRC):
δt = 300 ps;
δE = 3% @ .662 MeV;



Ionization Chamber (CEA, DAM):
^{252}Cf target (A=65kBq, ø=25mm);
^{238}U target (m=360mg, ø=33mm);
δt = 730 ps; ε = 100%;
<0.5% overlapping in α/FF discrimination;

Taieb, J., et al. Nuclear Instruments and Methods in Physics Research Section A, 833 (2016): 1-7.

^{252}Cf(sf), ^{238}U(n,f) - March, 2016



$LaBr_3$(Ce): 2'x2'x2'
NaI(Tl): 2'x2'x6'

PARIS Cluster:
δt = 300 ps;
δE = 4-5% @ .662 MeV;

Maj, A., et al. PARIS project. In Presented at the Zakopane Conference on Nuclear Physics.

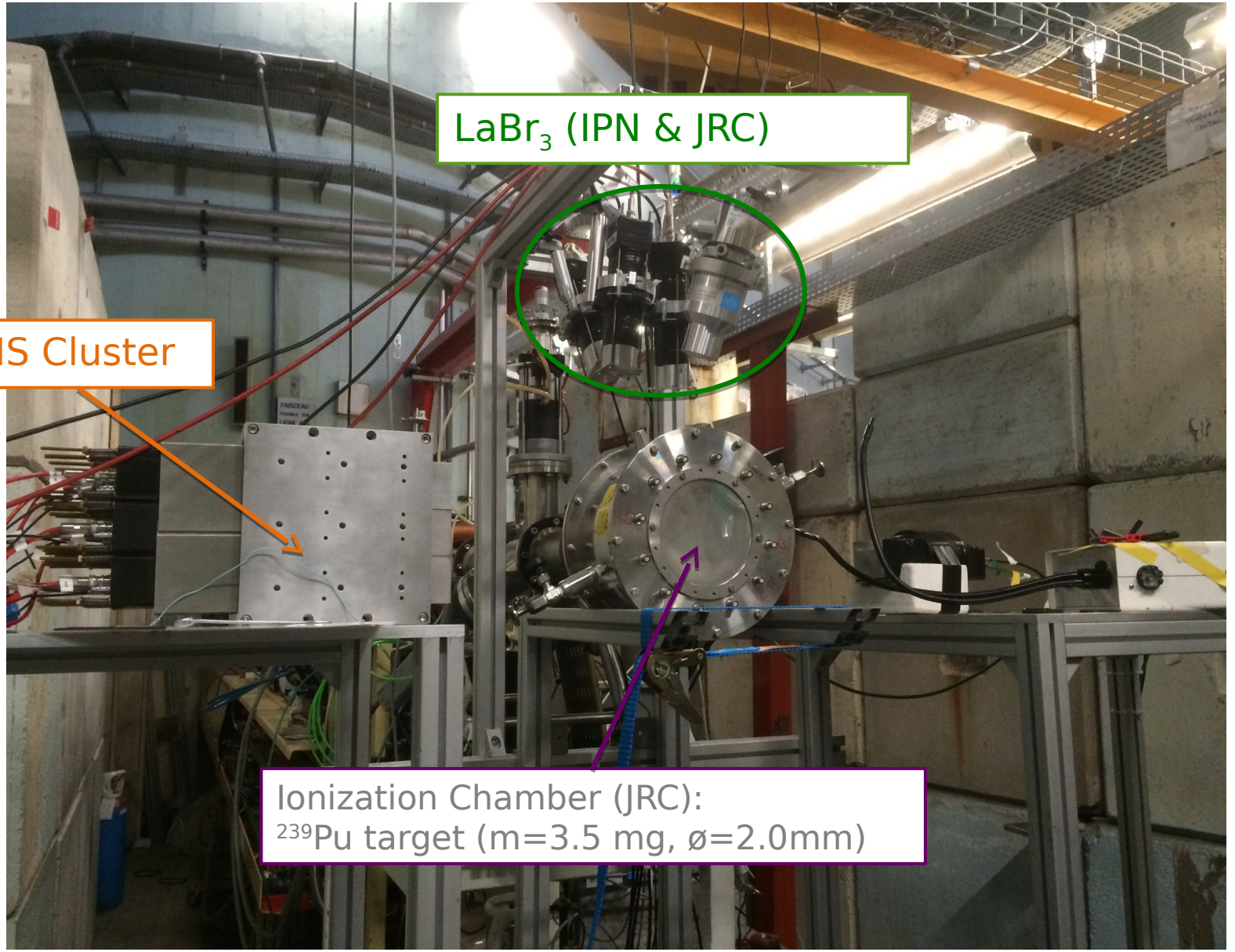
$LaBr_3$(Ce) (IPN & JRC):
δt = 300 ps;
δE = 3% @ .662 MeV;

BaF_2 (Château de Cristal)
δt = 600 ps;
δE = 10% @ 1.3 MeV;

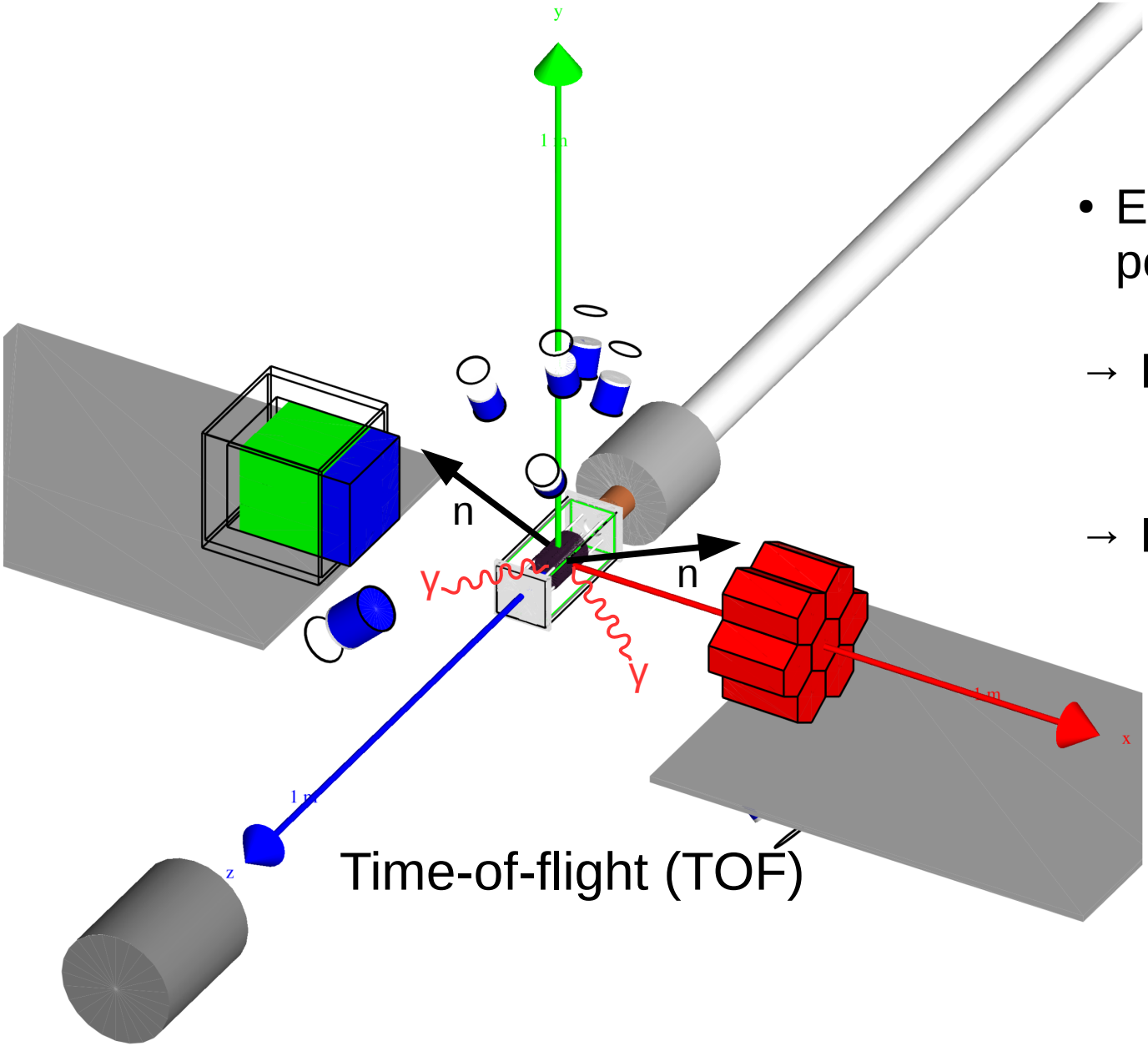
Ionization Chamber (CEA, DAM):
^{252}Cf target (A=65kBq, ø=25mm);
^{238}U target (m=360mg, ø=33mm);
δt = 730 ps; ε = 100%;
<0.5% overlapping in α/FF discrimination;

Taieb, J., et al. Nuclear Instruments and Methods in Physics Research Section A, 833 (2016): 1-7.

^{239}Pu(n,f) - December, 2016



n/γ discrimination



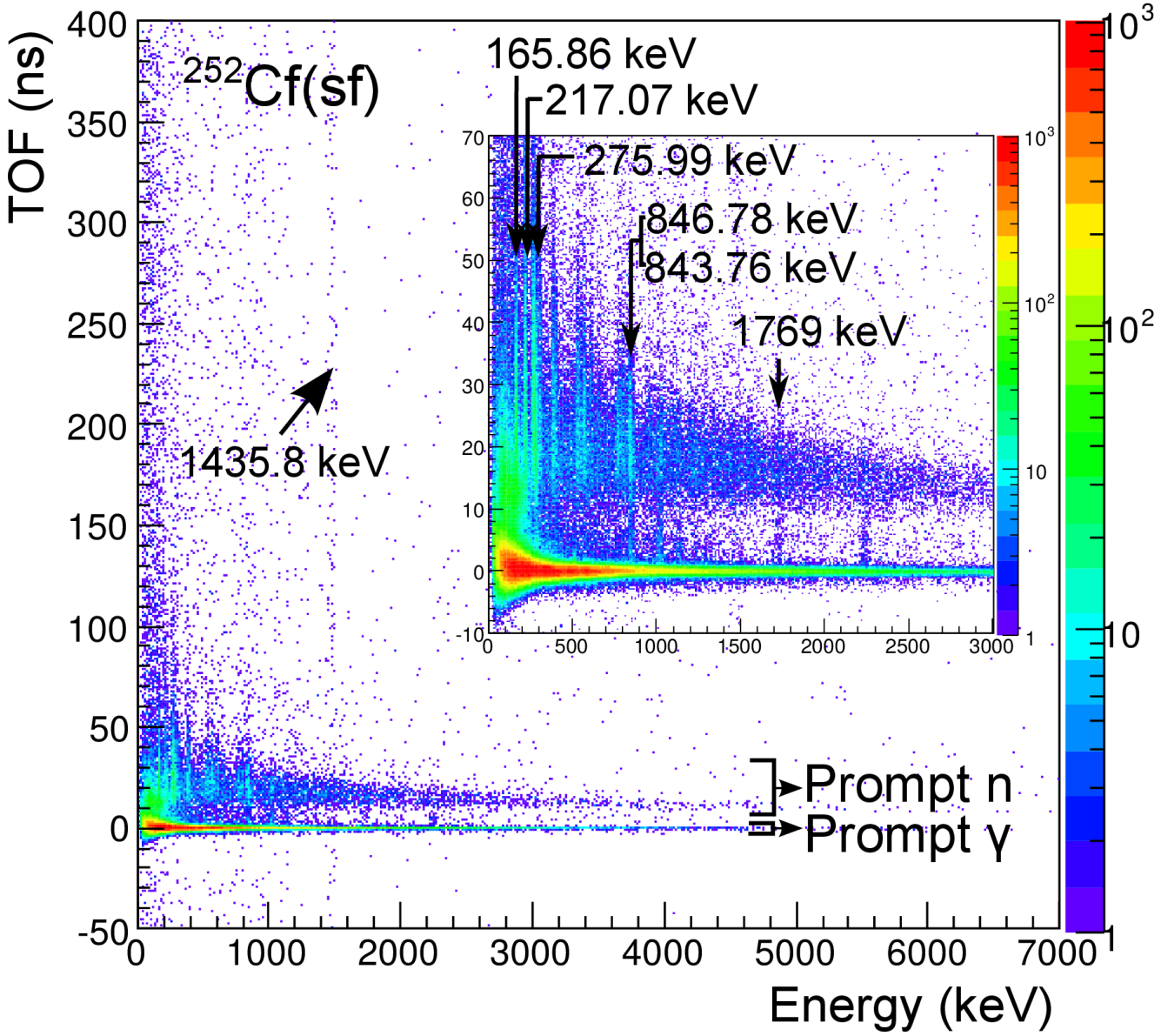
Time-of-flight (TOF)

- Emission time from saddle point in seconds

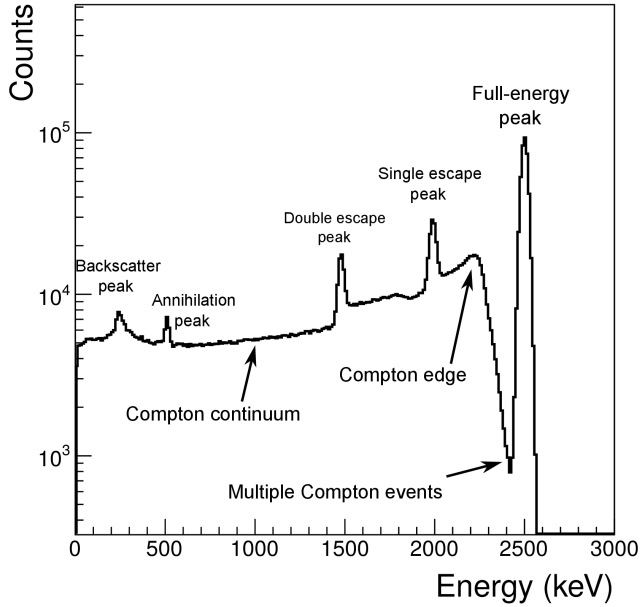
→ Prompt Neutron:
10^{-18} – 10^{-14}

→ Prompt Gamma rays:
10^{-14} – 10^{-3}

Measured Spectrum: g(x)



Deconvolution (Unfold)



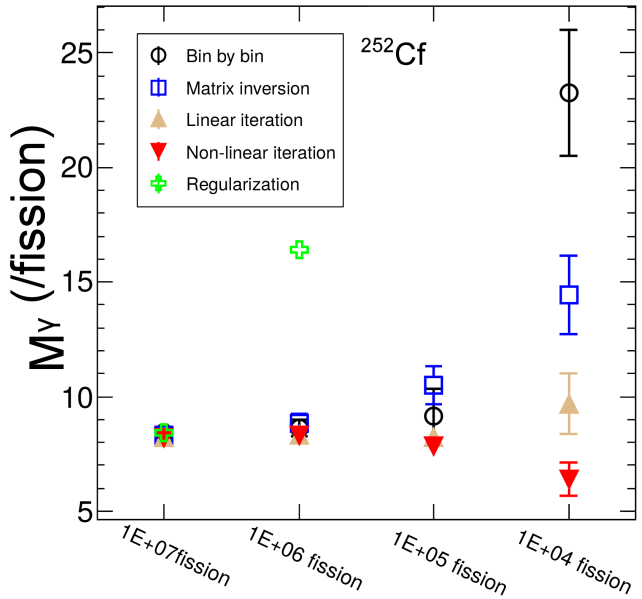
Inverse problem:

$$g(x) = \int_0^\infty R(x,y) f(y)\,\mathrm{d}y$$

g(x): measured spectrum (observation)

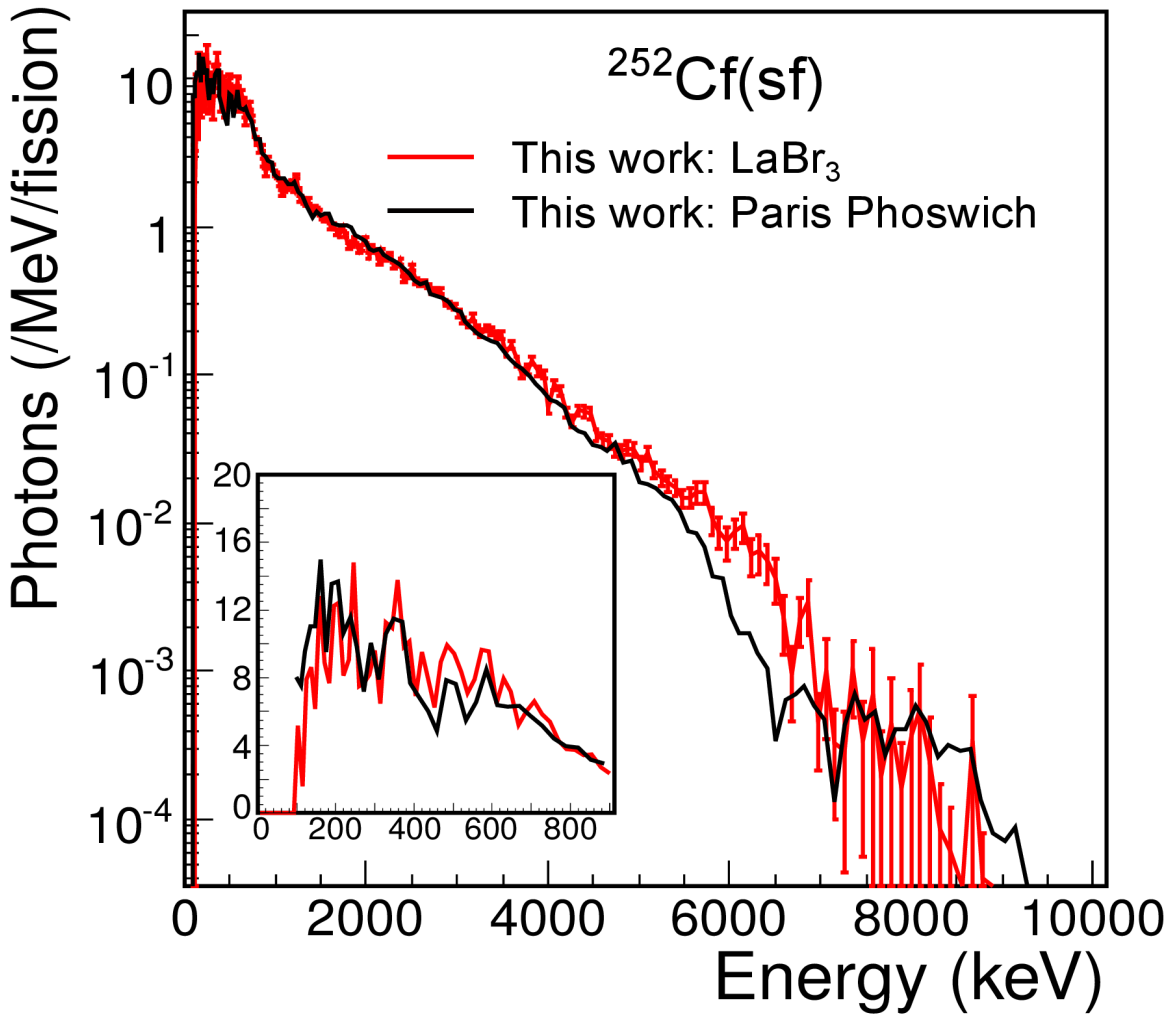
R(x,y): response function (simulated)

f(y): emission spectrum (unknown)



Unfolding techniques tested:
[1] Billnert, R., et al. Physical Review C, 87(2), 024601.
[2] László, A. In Journal of Physics: Conference Series (Vol. 368, No. 1, p. 012043).
[3] Zech, G. Nuclear Instruments and Methods in Physics Research Section A, 716, 1-9.
[4] P. C. Hansen, http://www.imm.dtu.dk/~pch/TR/Lcurve.ps

Results and Discussions - ^{252}Cf(sf)

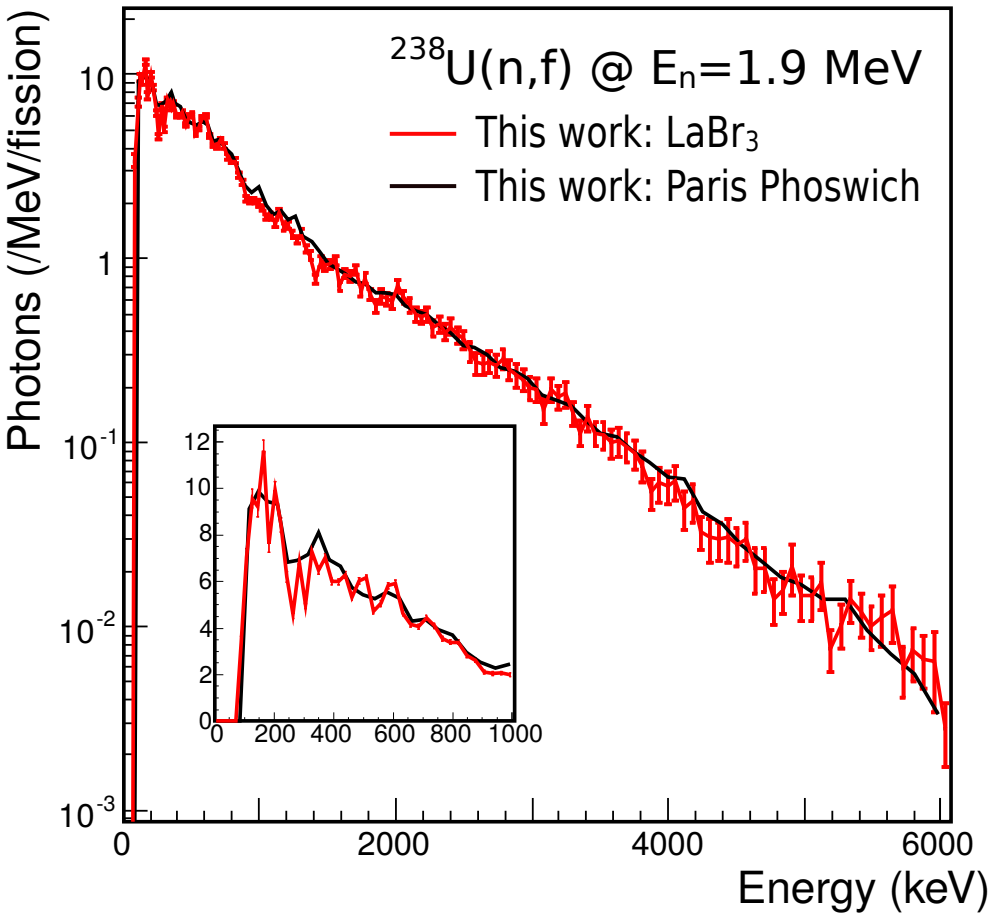


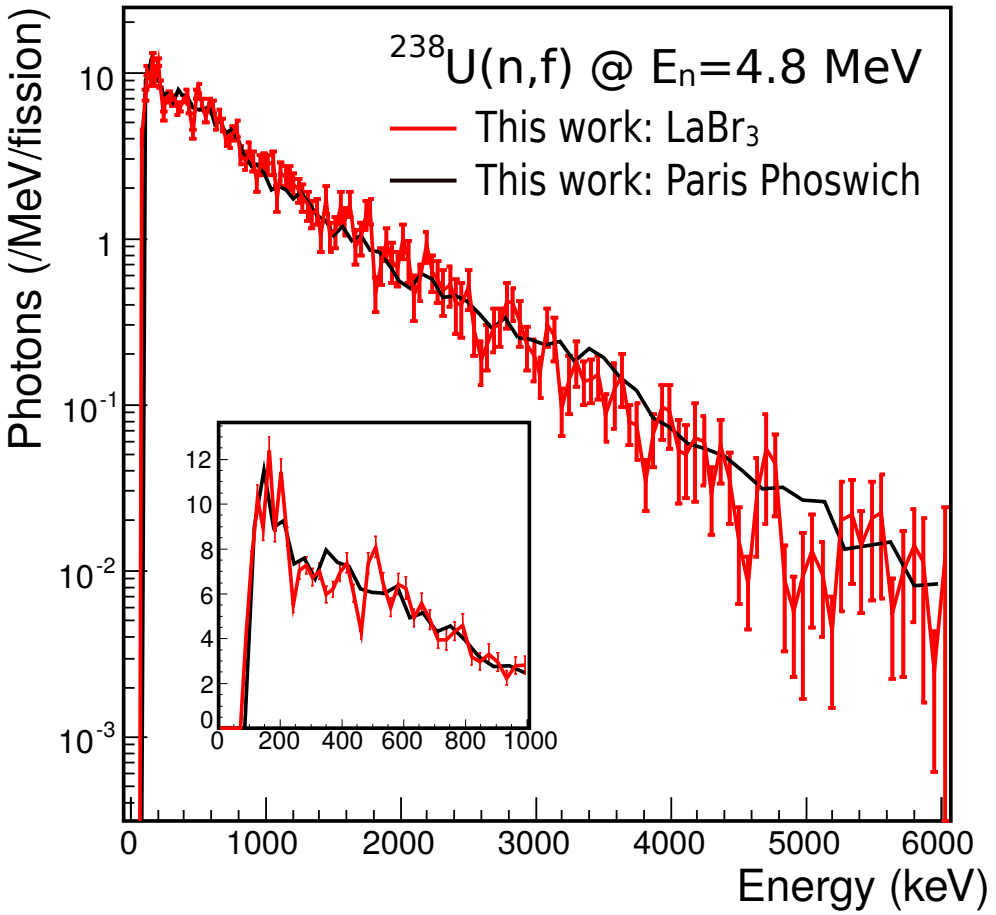
	$\bar{M}_\gamma(/fission)$	$E_{\gamma,tot}(MeV)$	$\epsilon_\gamma(MeV)$
This work: $LaBr_3$	8.30±0.15	6.60±0.05	0.80±0.02
This work: PARIS	8.40±0.19	6.70±0.08	0.80±0.02
R. Billnert *et al.*[22]	8.30±0.09	6.64±0.10	0.80±0.01
A. Chyzh *et al.*[27]	8.14±0.40	7.65±0.55	0.94±0.05
ENDF/B-VII.1*[28]	7.79	6.70	0.86

* Energy range: 0.1-6.0 MeV.

[1] Billnert, R., et al. Physical Review C, 87(2), 024601.
[2] Chyzh, A., et al. Physical Review C, 85(2), 021601.

Results and Discussions – $^{238}U(n_{fast},f)$

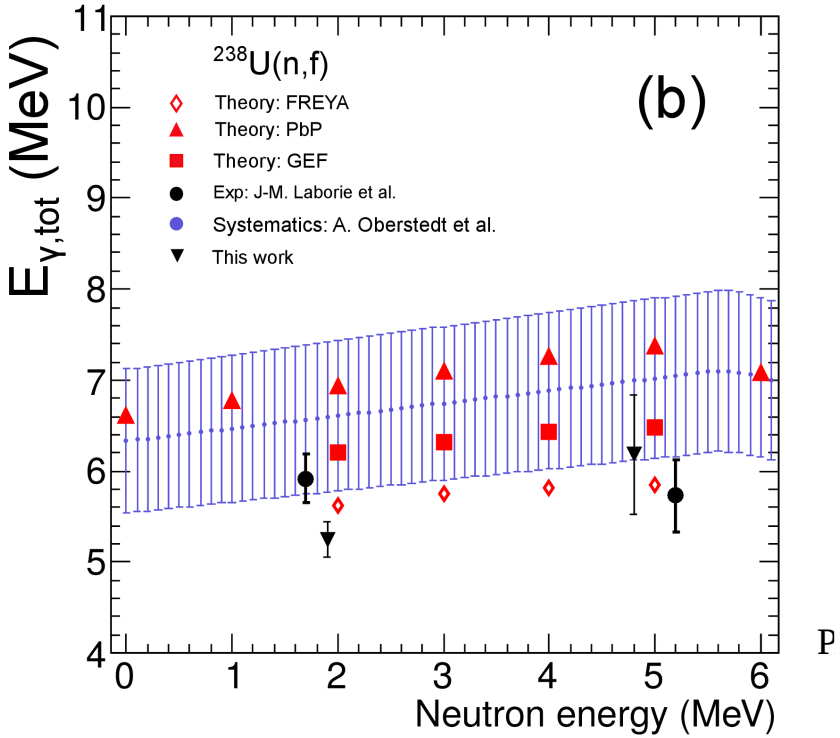




Results and Discussions – $^{238}U(n_{fast},f)$

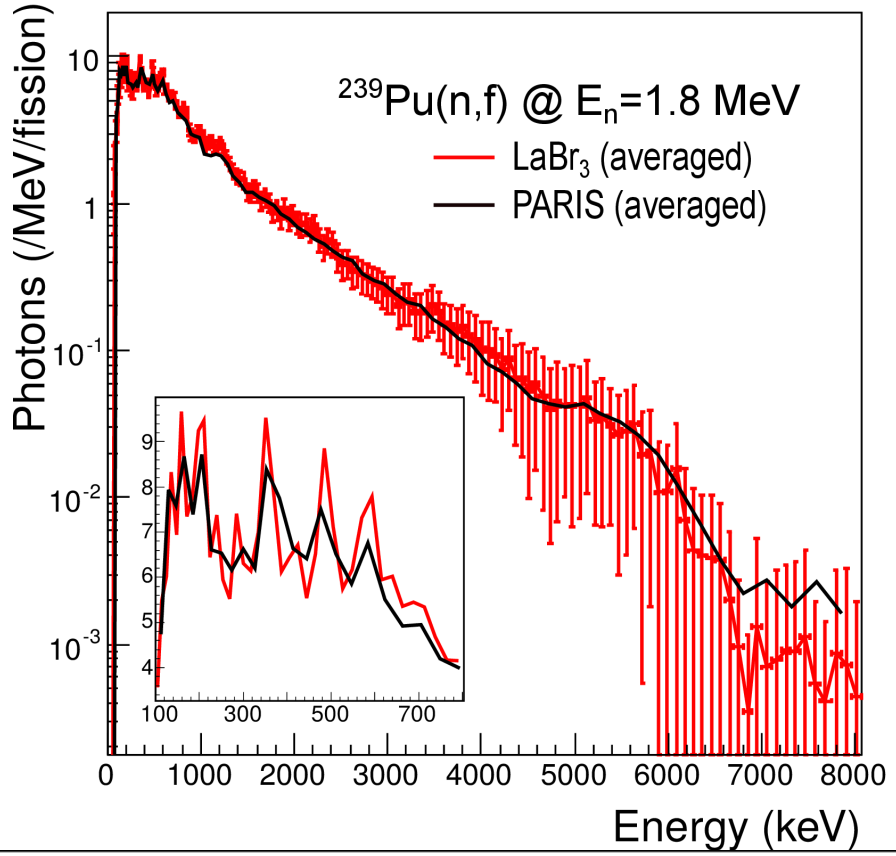
	E_n(MeV)	$M_\gamma(/fission)$	$E_{\gamma,tot}(MeV)$	$\epsilon_\gamma(MeV)$
$LaBr_3$	1.9	6.38±0.19	5.15±0.21	0.81±0.04
	4.8	7.37±0.49	6.29±0.69	0.85±0.11
PARIS	1.9	6.69±0.19	5.35±0.19	0.80±0.04
	4.8	7.25±0.42	6.06±0.60	0.84±0.10
total	1.9	6.54±0.19	5.25±0.20	0.80±0.04
	4.8	7.31±0.46	6.18±0.65	0.84±0.11
J-M.Laborie	1.7	7.05±0.20	5.92±0.24	0.84±0.03
et al. [7]	5.2	7.25±0.35	5.73±0.40	0.79±0.04

J-M. Laborie, G. Belier and J. Taieb, Phys. Procedia 31, 13 (2012).



- The average PFGS characteristics do not change significantly with increased excitation energy;
- The extra excitation energy is mainly evacuated by prompt neutron emission;
- The gamma emission sets in the vicinity of the neutron separation energy;

Results and Discussions – $^{239}Pu(n_{fast},f)$

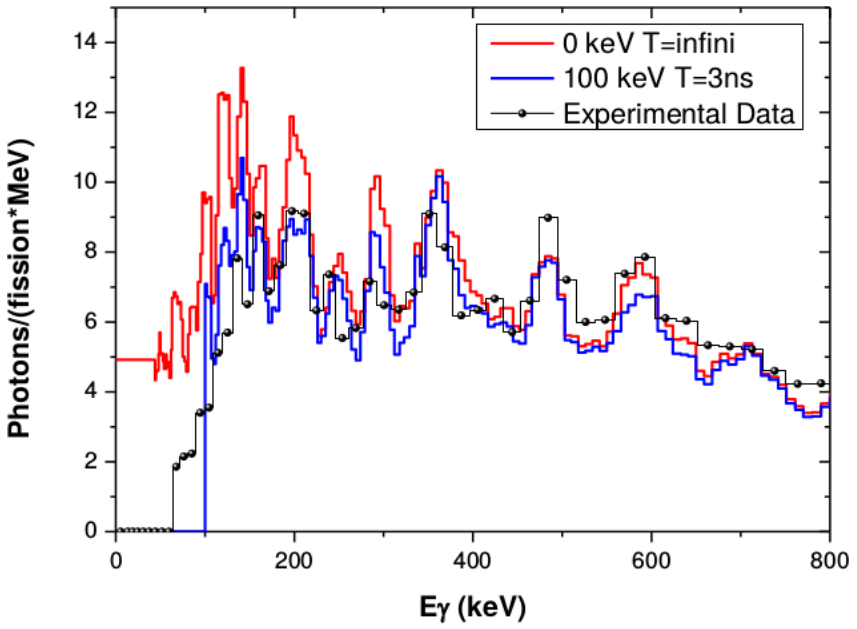


Detector	$\bar{M}_\gamma$(/fission)	$E_{\gamma,tot}$(MeV)	ϵ_γ(MeV)
This work ($LaBr_3$)	7.41±0.27	6.77±0.22	0.91±0.04
This work (PARIS)	7.15±0.26	6.69±0.22	0.94±0.04
$^{239}Pu(n_{thermal},f)$	7.35±0.12	6.27±0.11	0.85±0.02

A. Gatera, et al. Phys. Rev. C 95, 064609.

Comparison to FIFRELIN calculation code

Fifrelin calculation performed with:
- Time width=+10^{10} s and Energy threshold=0 (red curve) → <M_γ>=8.40; <ε_γ>=0.84; <E_γ>=7.08
- Time width=+3x10^{-9} s and Energy threshold=100 keV (blue curve) → <M_γ>=7.24; <ε_γ>=0.94; <E_γ>=6.81



Fifrelin calculation performed with:
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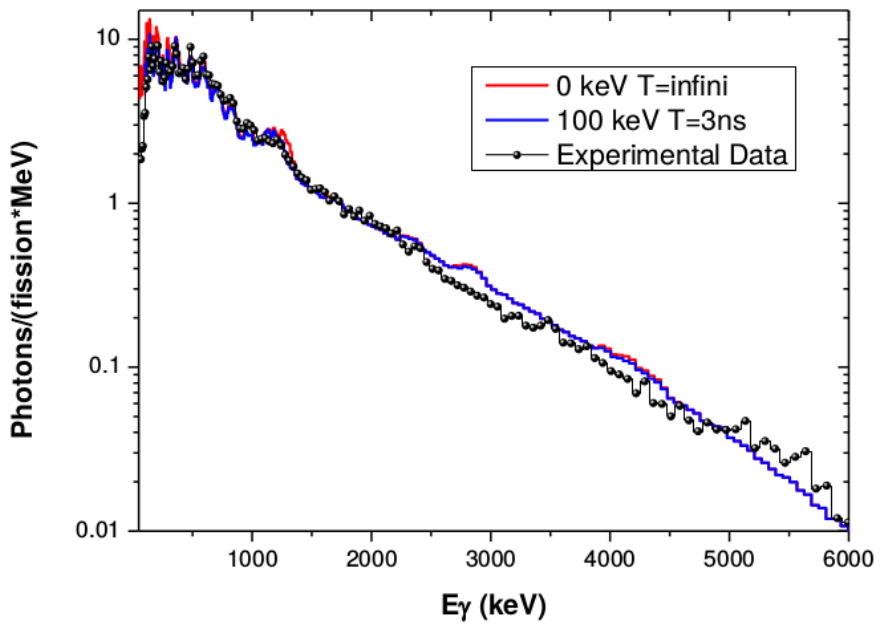
- Time width=+3x10^{-9} s and Energy threshold=100 keV (blue curve) → <M_γ>=7.24; <ε_γ>=0.94; <E_γ>=6.81



Conclusions

- PFGS measurement in different fissioning systems, including ^{252}Cf(sf), ^{238}U(n_{fast},f) and ^{239}Pu(n_{fast},f), by using $LaBr_3$(Ce) and PARIS phoswich;

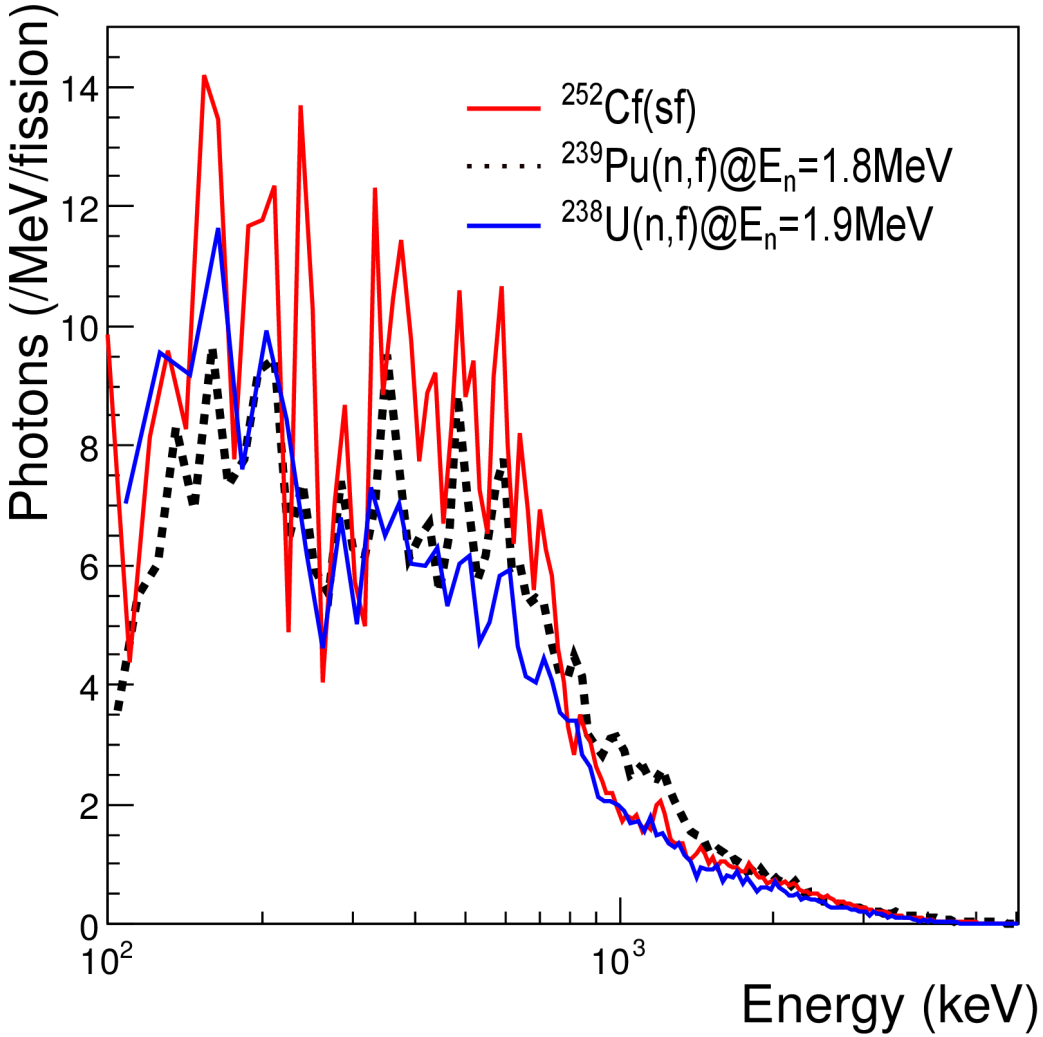
- PFGS and characteristics are Important Nuclear data:

→ Design Gen IV reactors;

→ Refine and validate the fission models;

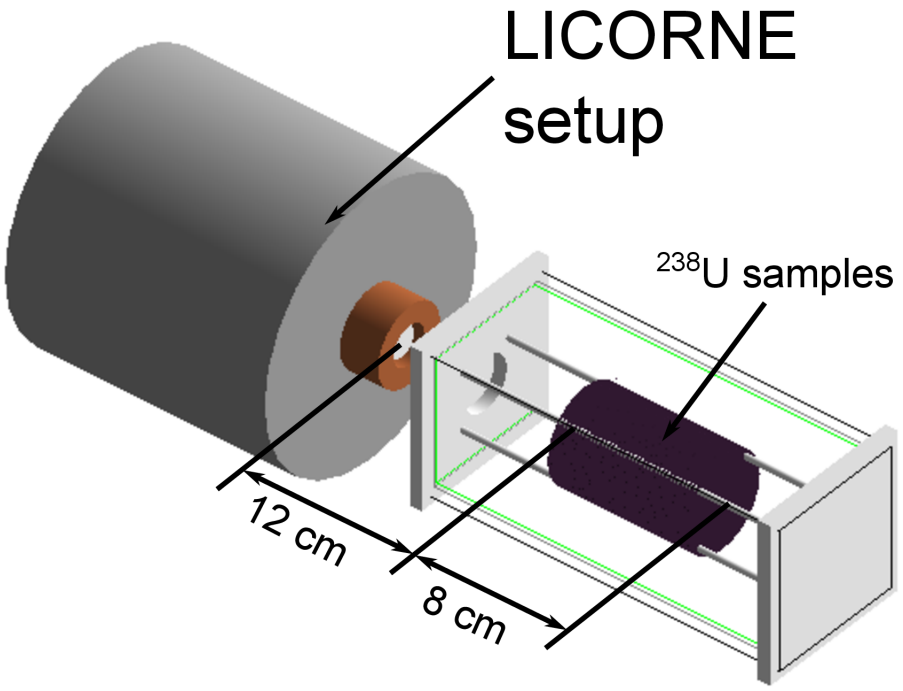
Thank you for your attention

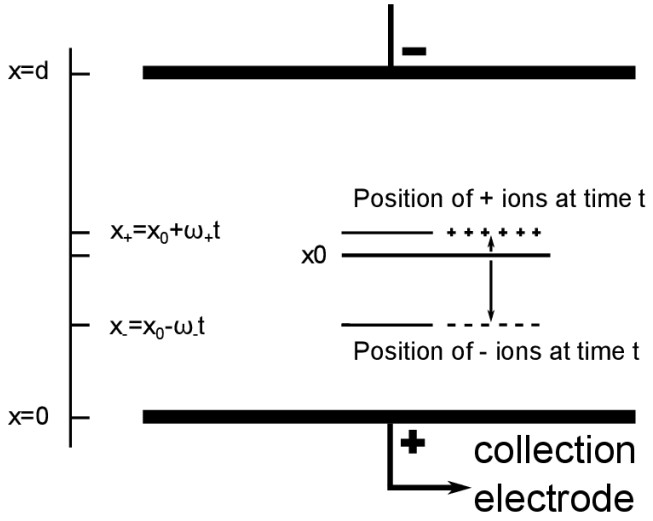
Backup

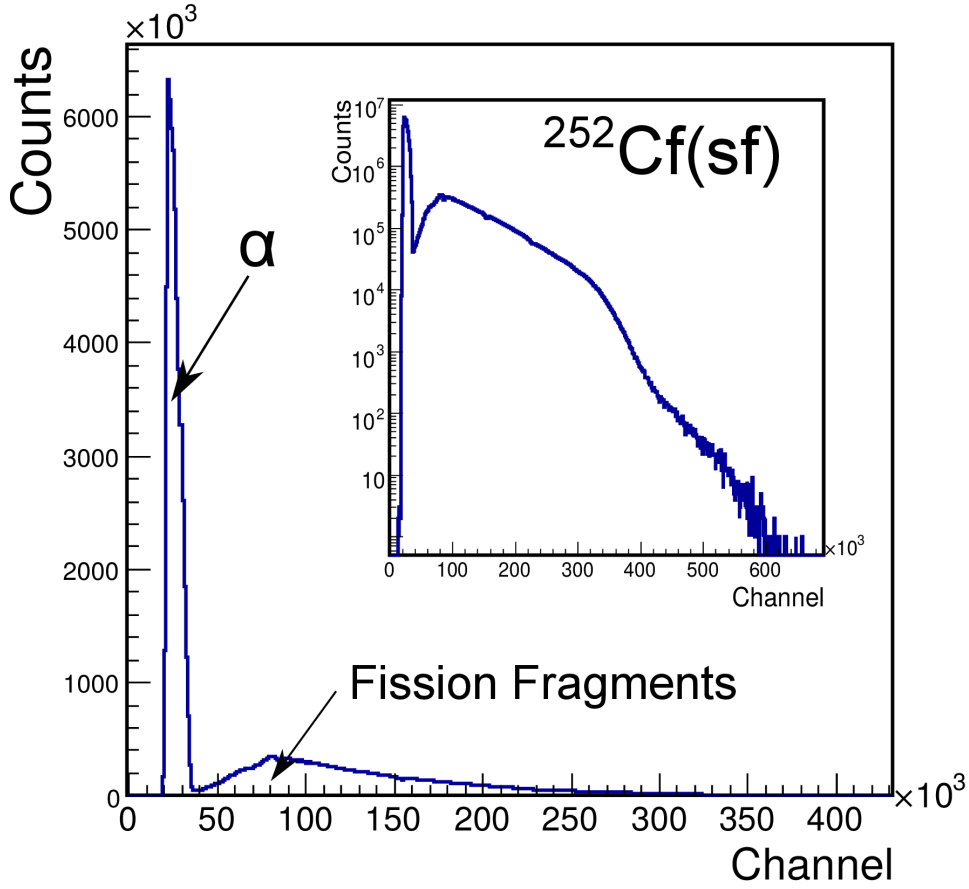


- In all the fissioning systems the low energy range shows lots of structure due to the contribution of individual fission fragments.

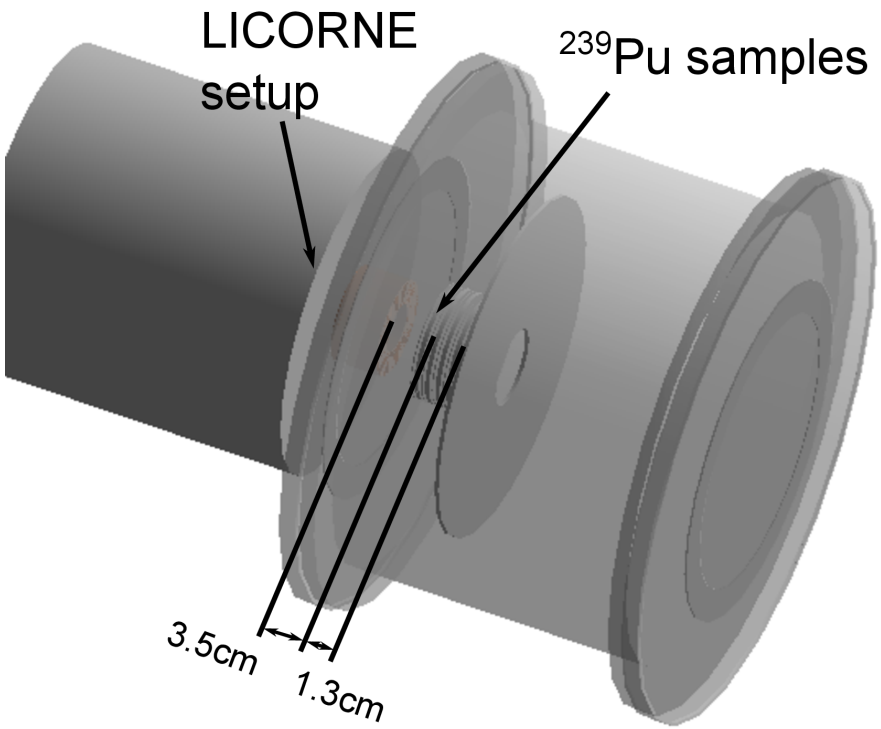
Backup

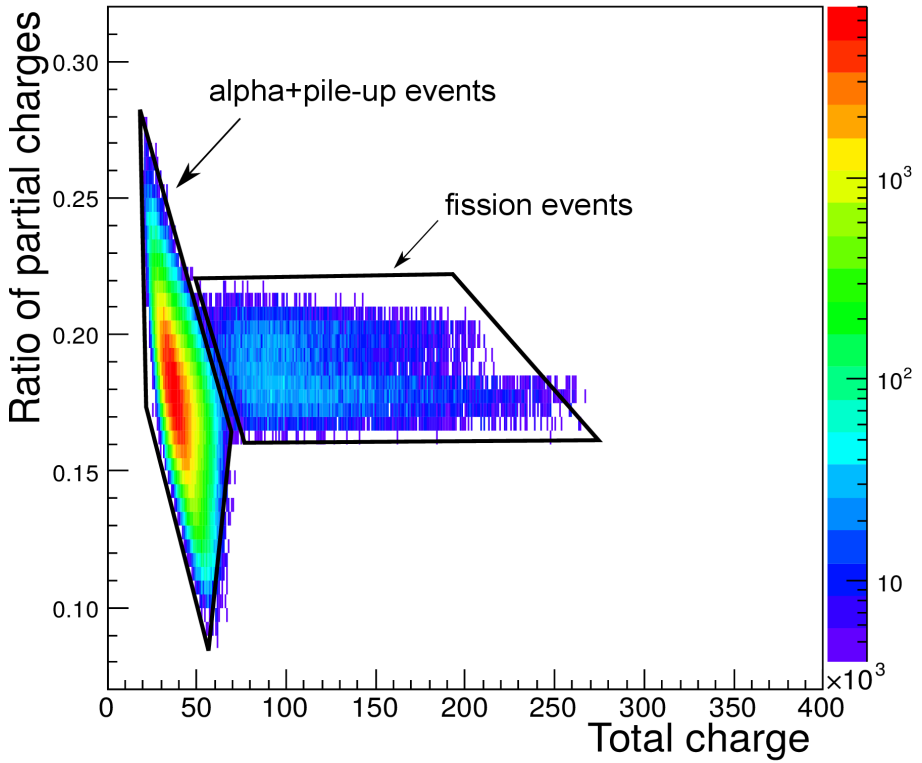

LICORNE
setup
^{238}U samples
12 cm
8 cm


x=d
x=0
Position of + ions at time t
x0
Position of - ions at time t
collection
electrode

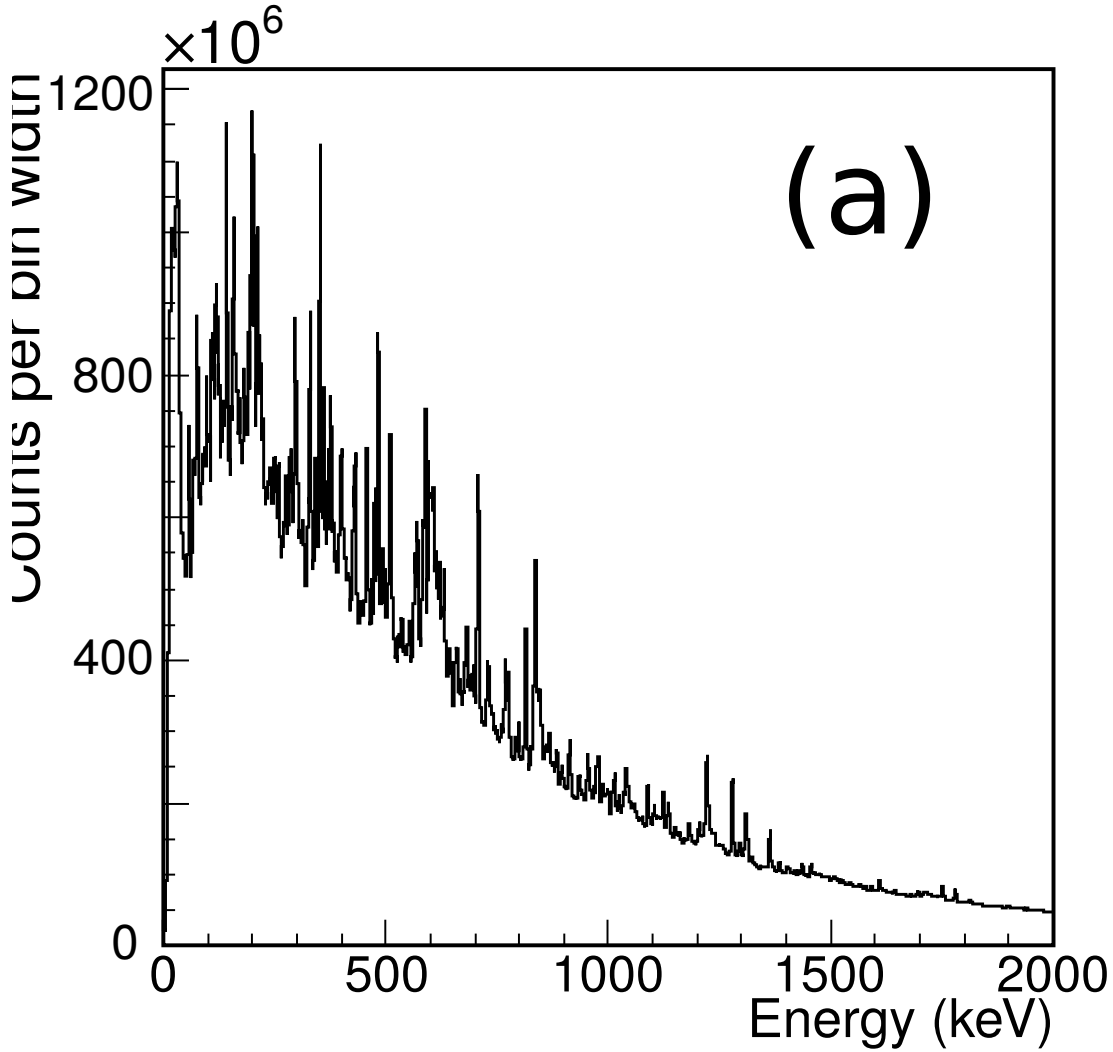

Counts
α
Fission Fragments
Channel
^{252}Cf(sf)

Backup


LICORNE
setup
239Pu samples
3.5cm
1.3cm

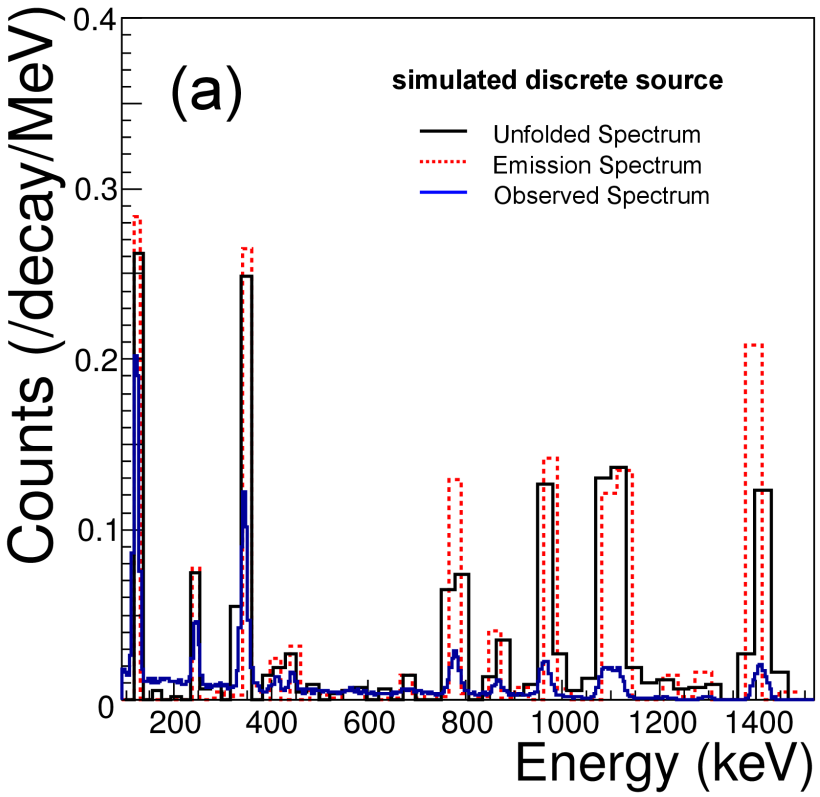

Ratio of partial charges
0.30
0.25
0.20
0.15
0.10
alpha+pile-up events
fission events
0
50
100
150
200
250
300
350
400
Total charge
×10^3
10^3
10^2
10

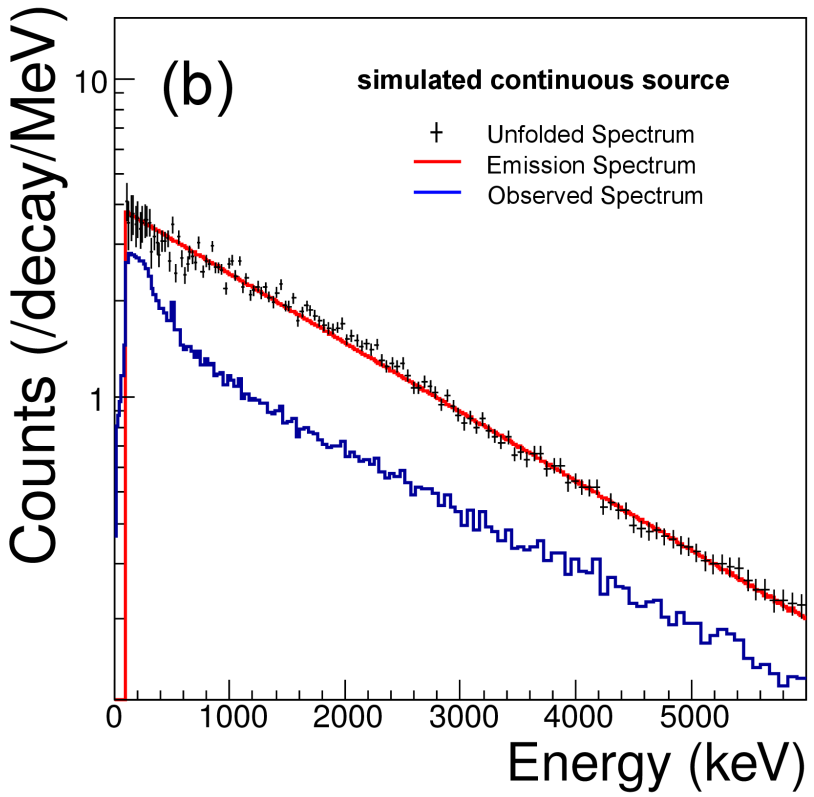
Backup



HPGE

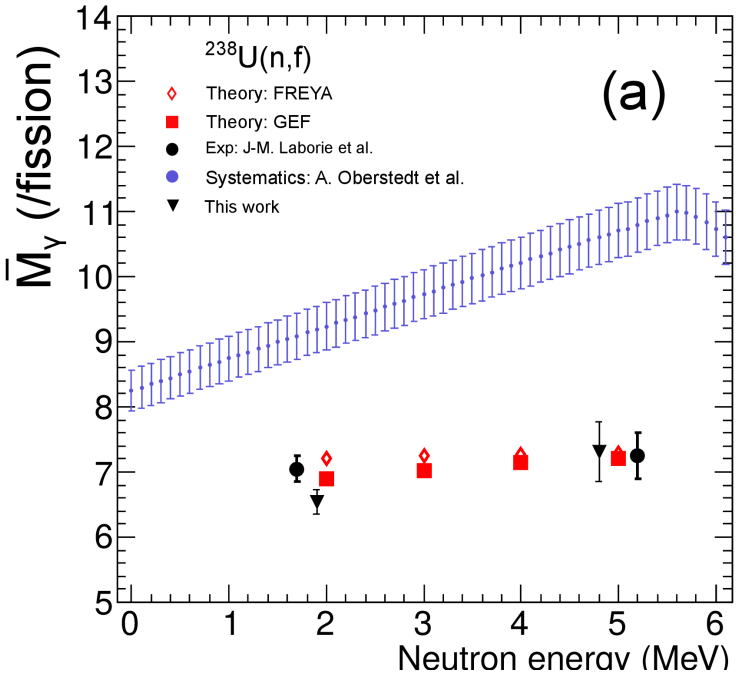
Backup

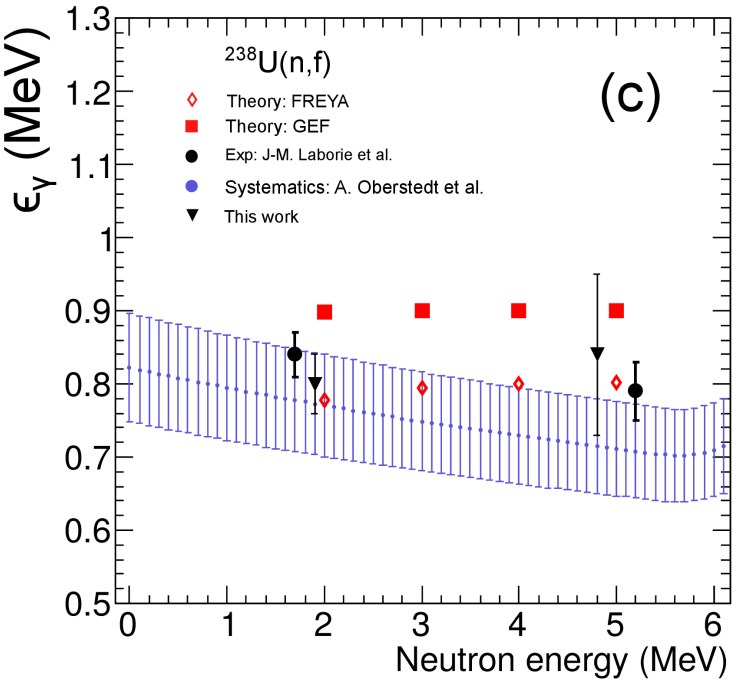


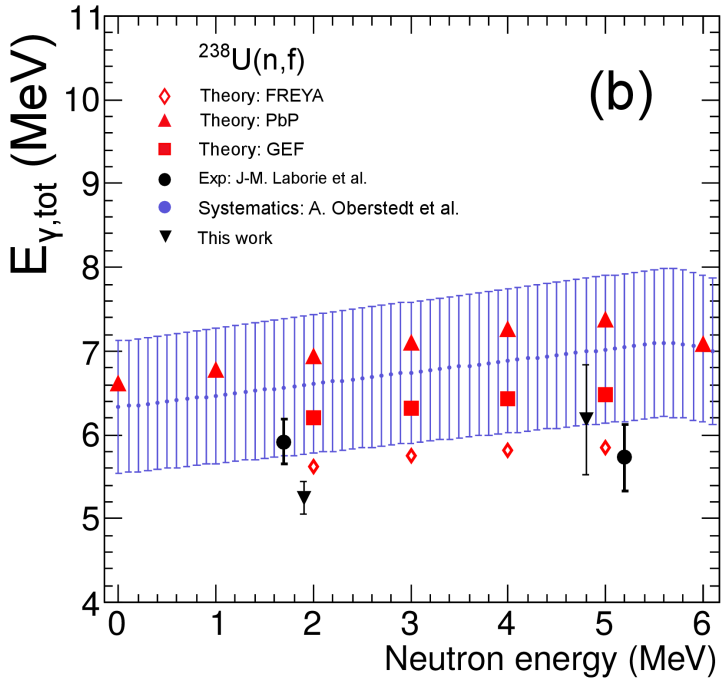


		$M_\gamma(/fisison)$	$E_{\gamma,tot}(MeV)$	$\epsilon_\gamma(MeV)$
^{152}Eu	unfolded	1.65±0.06	1.16±0.02	0.70±0.03
source	emission	1.58±0.01	1.11±0.00	0.71±0.01
exponen-	unfolded	7.28±0.08	12.93±0.07	1.77±0.02
tial	emission	7.25±0.02	12.86±0.00	1.77±0.00

Backup


^{238}U(n,f)
(a)
Theory: FREYA
Theory: GEF
Exp: J-M. Laborie et al.
Systematics: A. Oberstedt et al.
This work
$\bar{M}_\gamma$ (/fission)
Neutron energy (MeV)

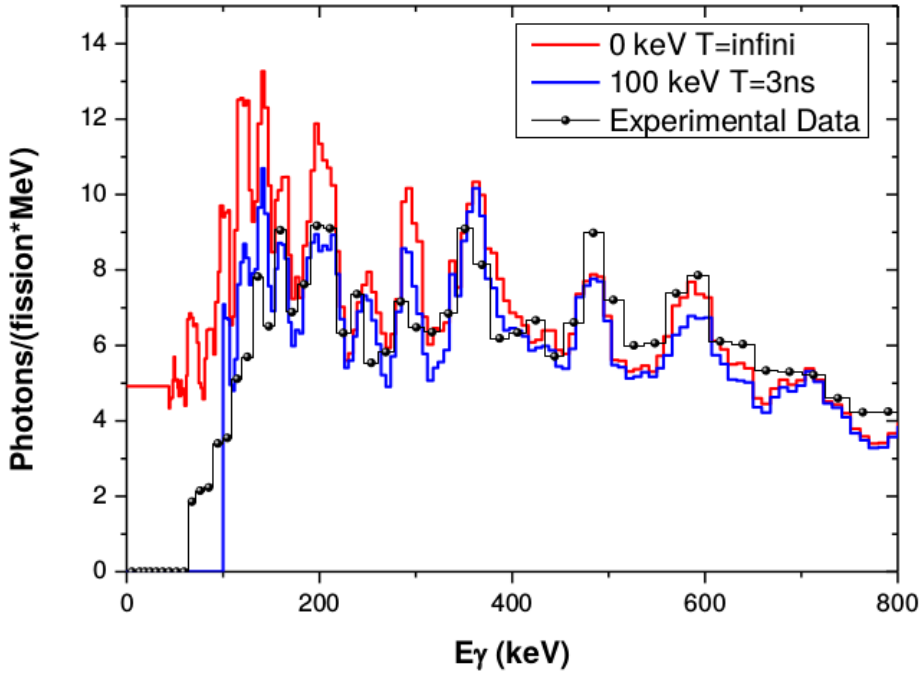

^{238}U(n,f)
(c)
Theory: FREYA
Theory: GEF
Exp: J-M. Laborie et al.
Systematics: A. Oberstedt et al.
This work
ϵ_γ (MeV)
Neutron energy (MeV)


^{238}U(n,f)
(b)
Theory: FREYA
Theory: PbP
Theory: GEF
Exp: J-M. Laborie et al.
Systematics: A. Oberstedt et al.
This work
$E_{\gamma,tot}$ (MeV)
Neutron energy (MeV)

Backup

Fifrelin calculation performed with:

- Time width=+10^{10} s and Energy threshold=0 (red curve) → <M_γ>=8.40; <ε_γ>=0.84; <E_γ>=7.08
- Time width=+3x10^{-9} s and Energy threshold=100 keV (blue curve) → <M_γ>=7.24; <ε_γ>=0.94; <E_γ>=6.81



Fifrelin calculation performed with:

- Time width=+10^{10} s and Energy threshold=0 (red curve) → <M_γ>=8.40; <ε_γ>=0.84; <E_γ>=7.08
- Time width=+3x10^{-9} s and Energy threshold=100 keV (blue curve) → <M_γ>=7.24; <ε_γ>=0.94; <E_γ>=6.81