A new method of production and study of the most exotic neutron rich nuclei

J.N. Wilson, IPN Orsay

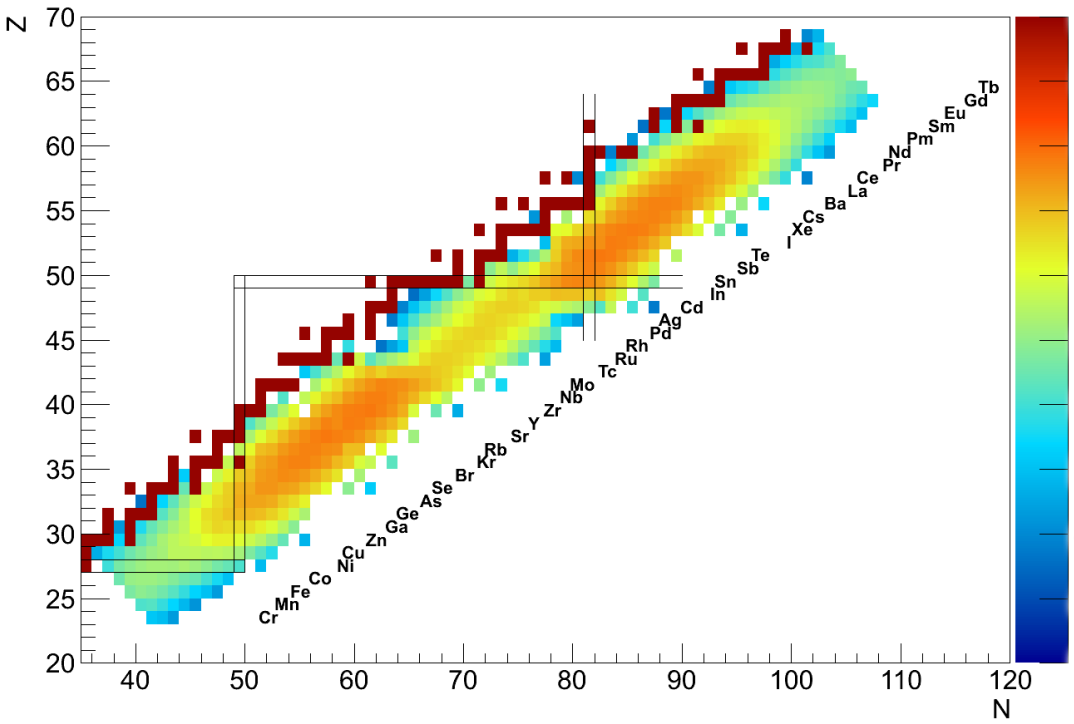
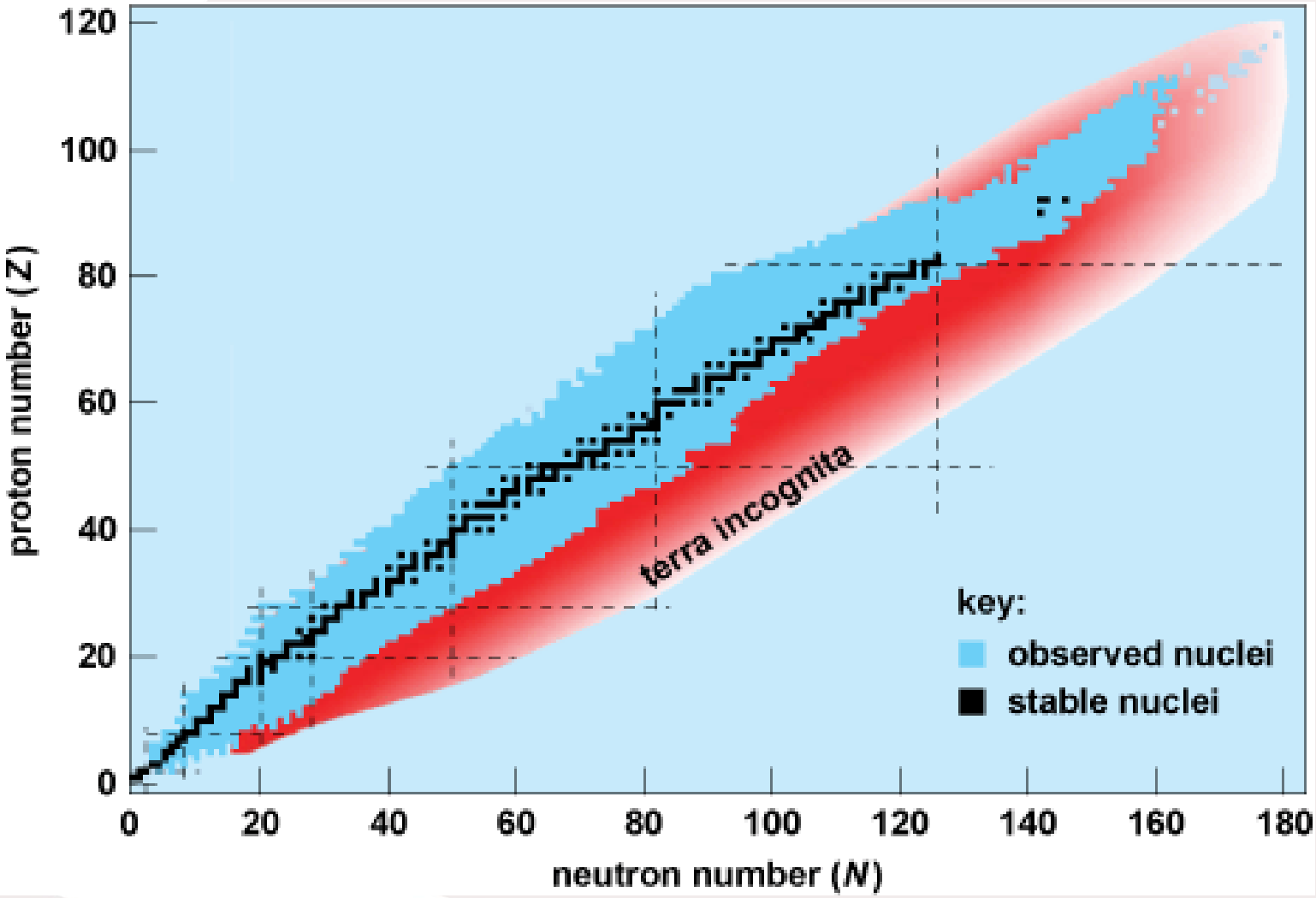
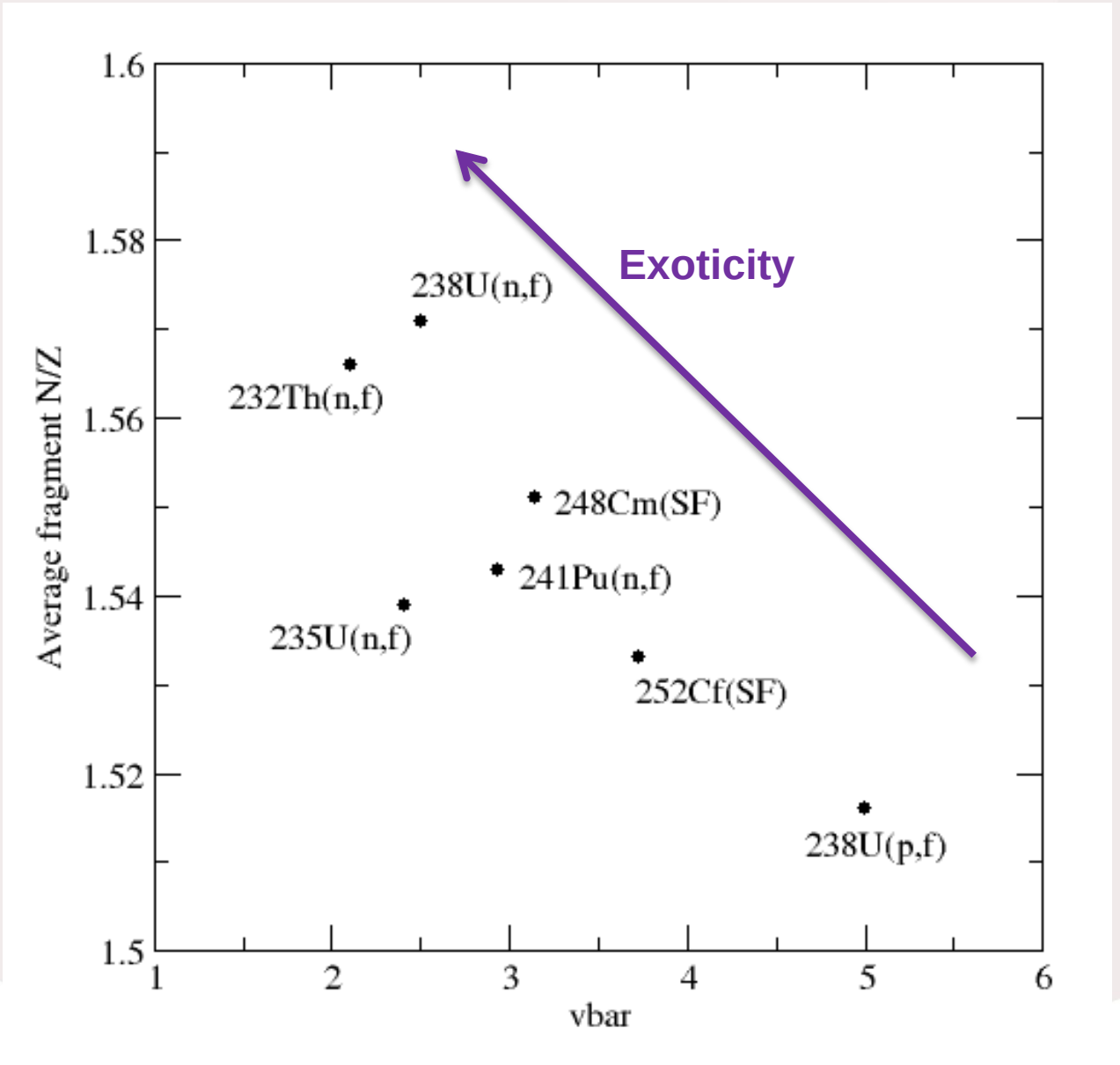


CHART OF NUCLIDES

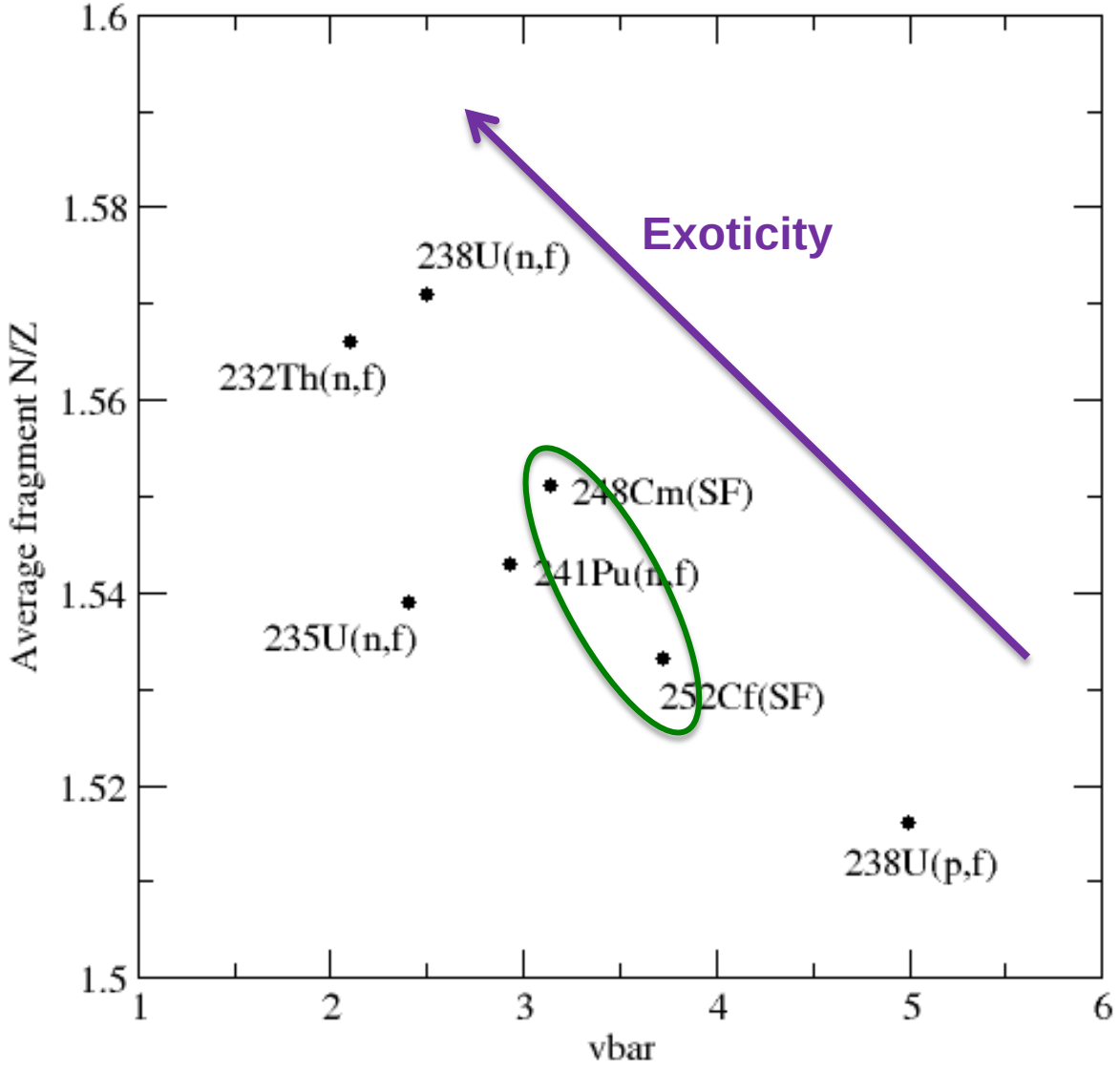


PRODUCTION OF EXOTIC NEUTRON RICH NUCLEI VIA FISSION



PRODUCTION OF EXOTIC NEUTRON RICH NUCLEI VIA FISSION

Spontaneous Fission
^{252}Cf(SF), ^{248}Cm(SF)
(Gammasphere, Euroball)



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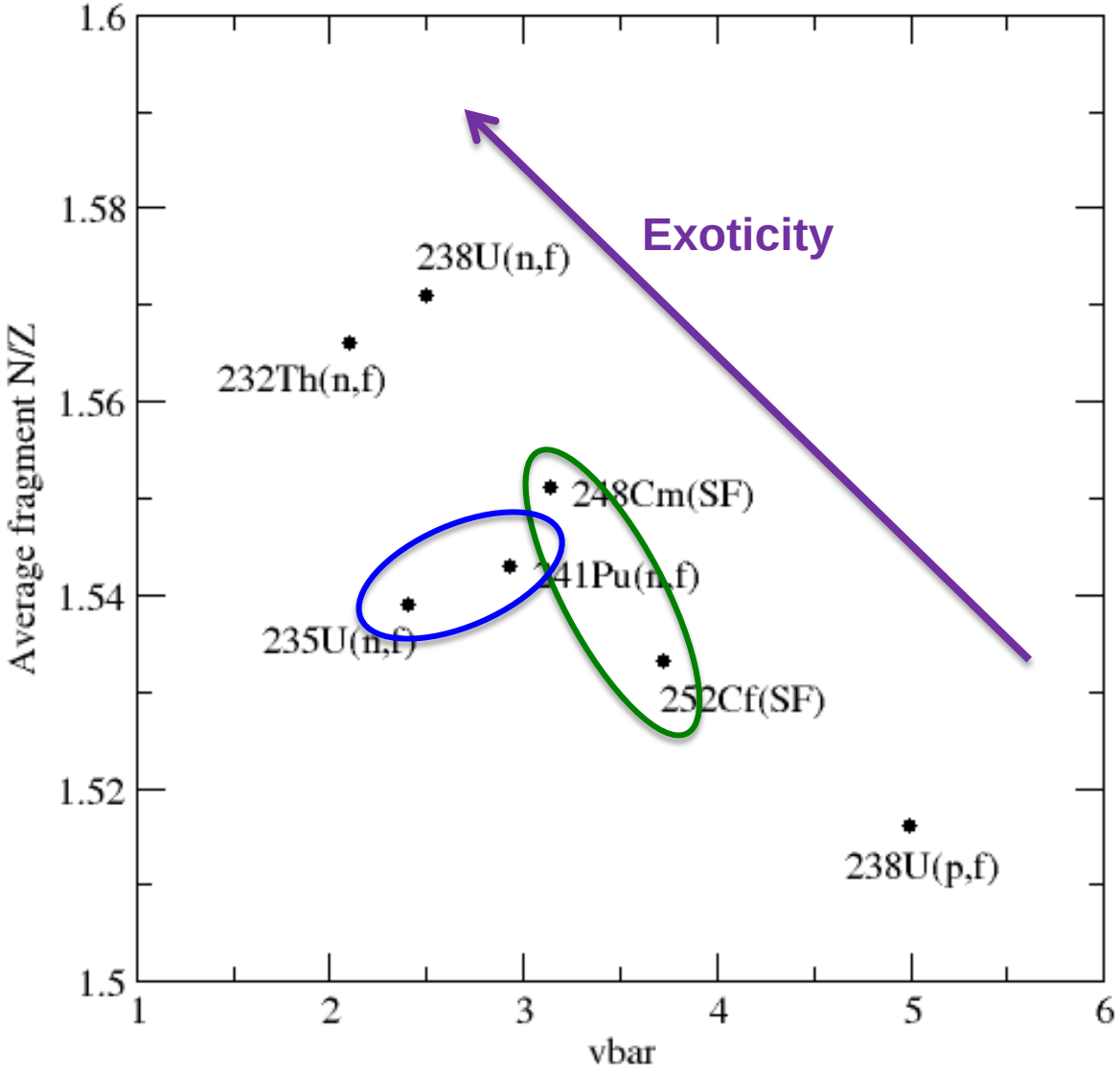
^{235}U(n_{th},f) ^{241}Pu(n_{th},f)
(EXILL Exogam@ILL)



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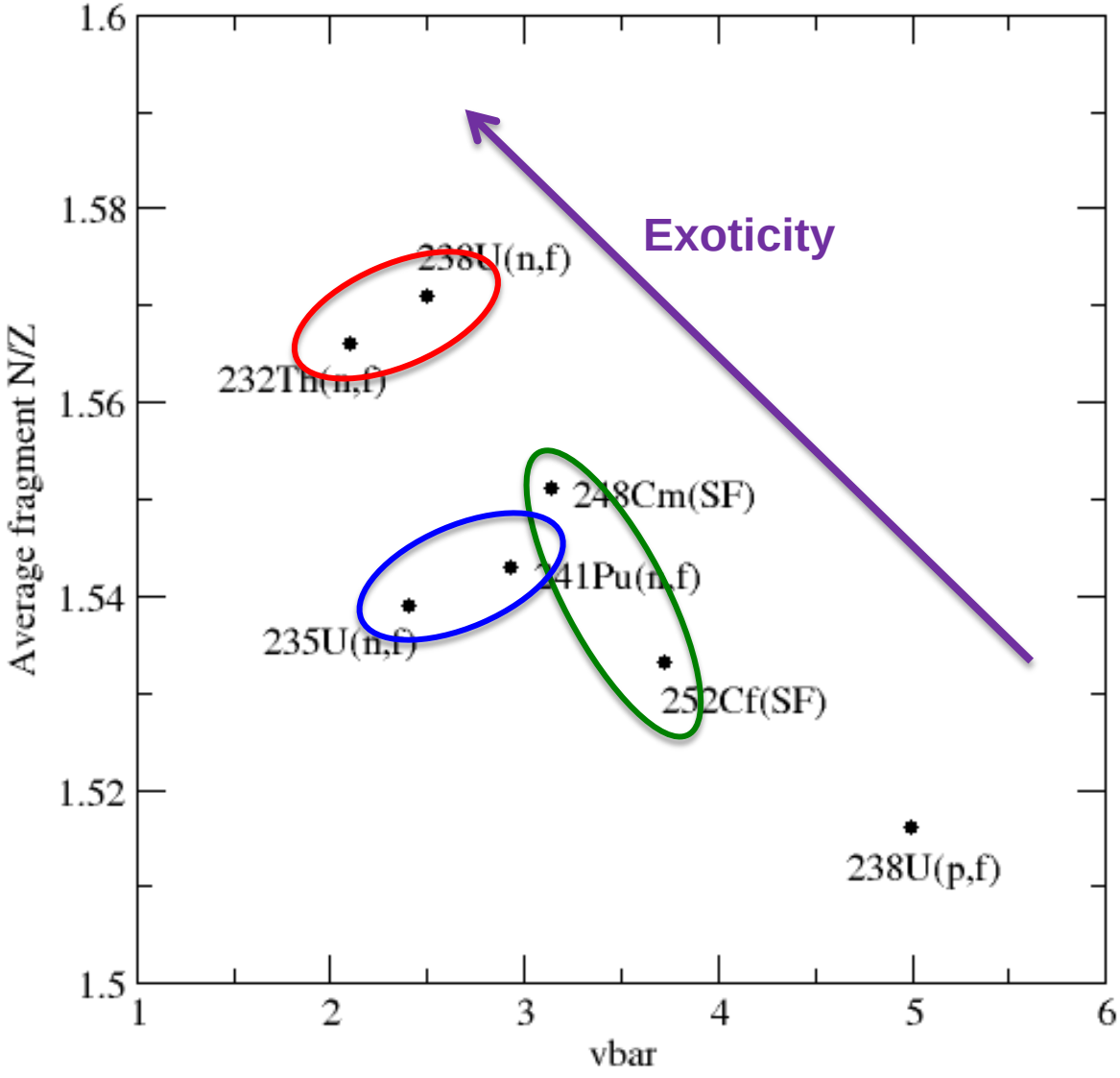
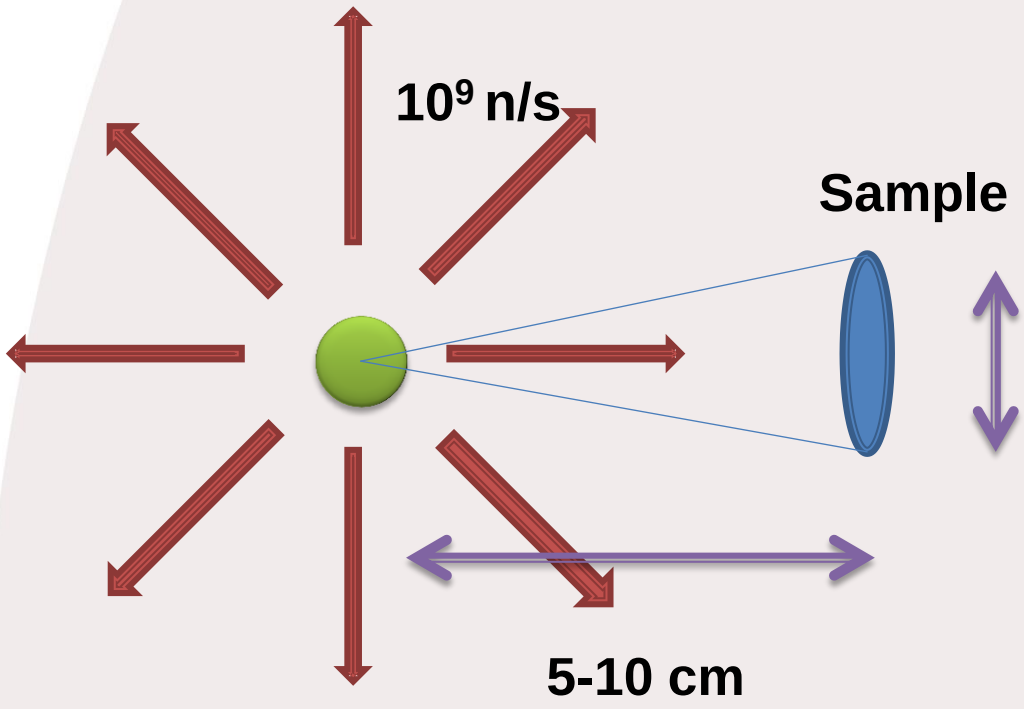
Fission induced by fast 1.5 MeV neutrons
^{238}U(n,f), ^{232}Th(n,f)
(LICORNE @ IPN Orsay)



STANDARD NEUTRON SOURCES

^{7}Li(p,n)
d(d,n)
d(^{9}Be,n)



Fluxes typically
10^{6} n/cm^{2}/s

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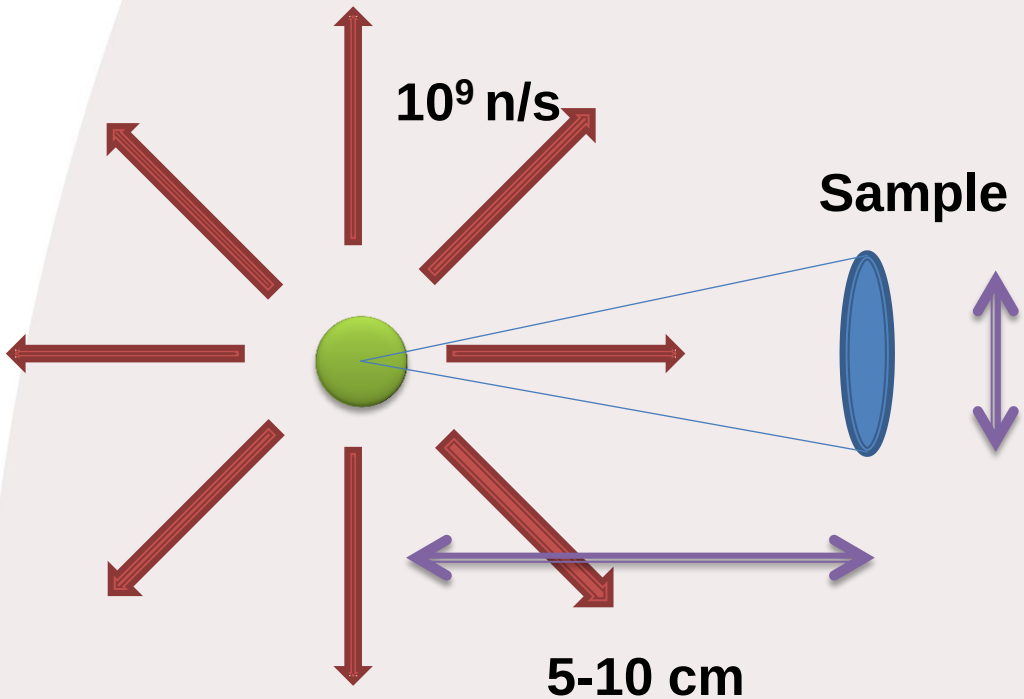

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➡ **Typically over 99% of neutrons ‘’wasted”**

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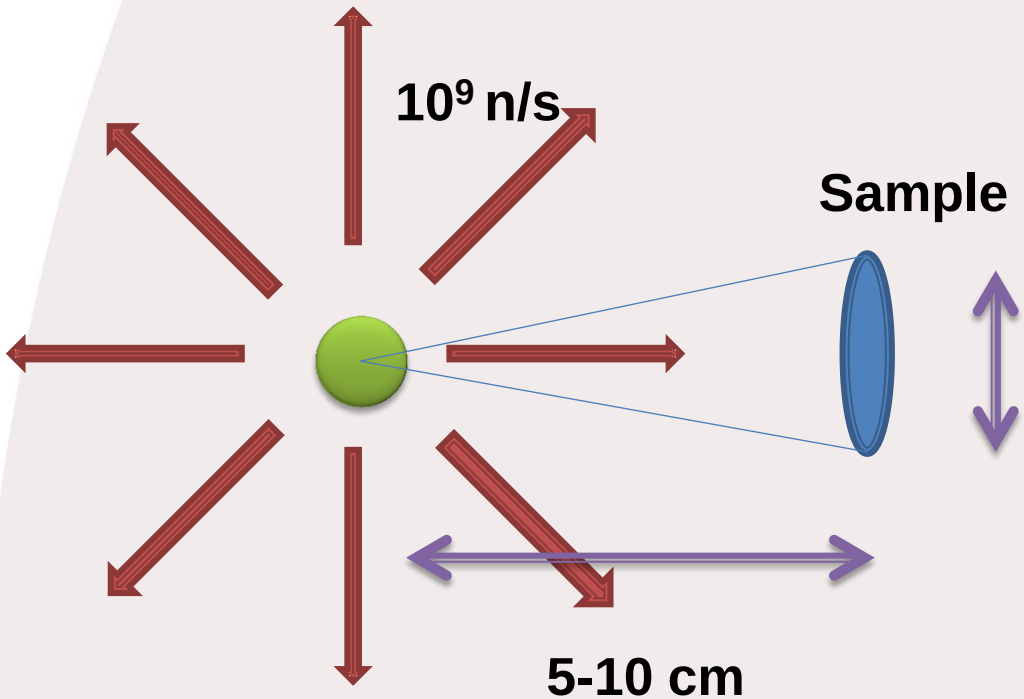

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- **Wasted neutrons contribute to the room background**

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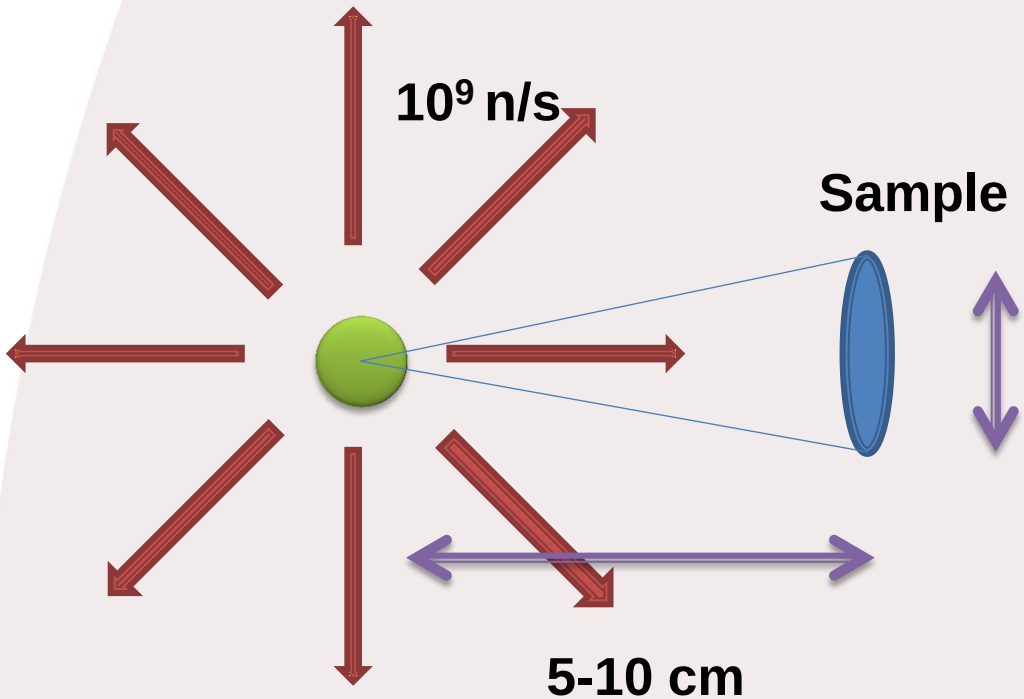
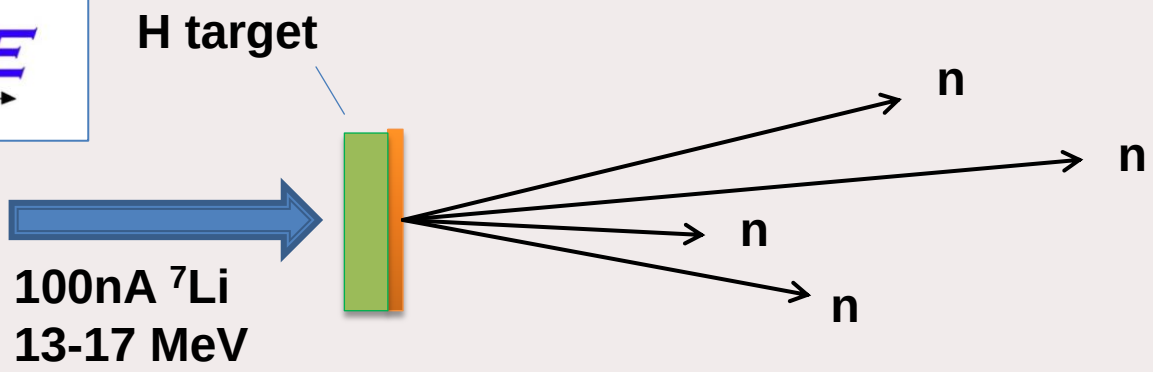


Fluxes typically 10^{6} n/cm^{2}/s

- **Typically over 99% of neutrons ‘’wasted”**
- **Wasted neutrons contribute to the room background**
- **Placement of gamma detectors impossible without heavy shielding**

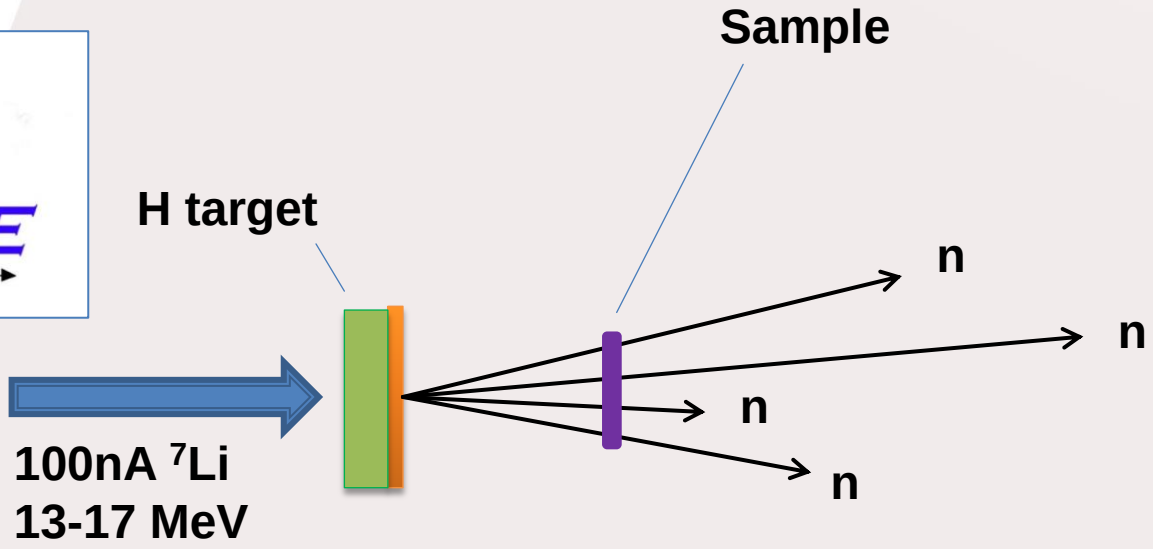
NEUTRON PRODUCTION IN INVERSE KINEMATICS



Lithium Inverse Cinematiques ORsay NEutron source

- p(^{7}Li,^{7}Be)n reaction in inverse kinematics
- Focused source of fast neutrons between 0.5 and 4 MeV

NEUTRON PRODUCTION IN INVERSE KINEMATICS



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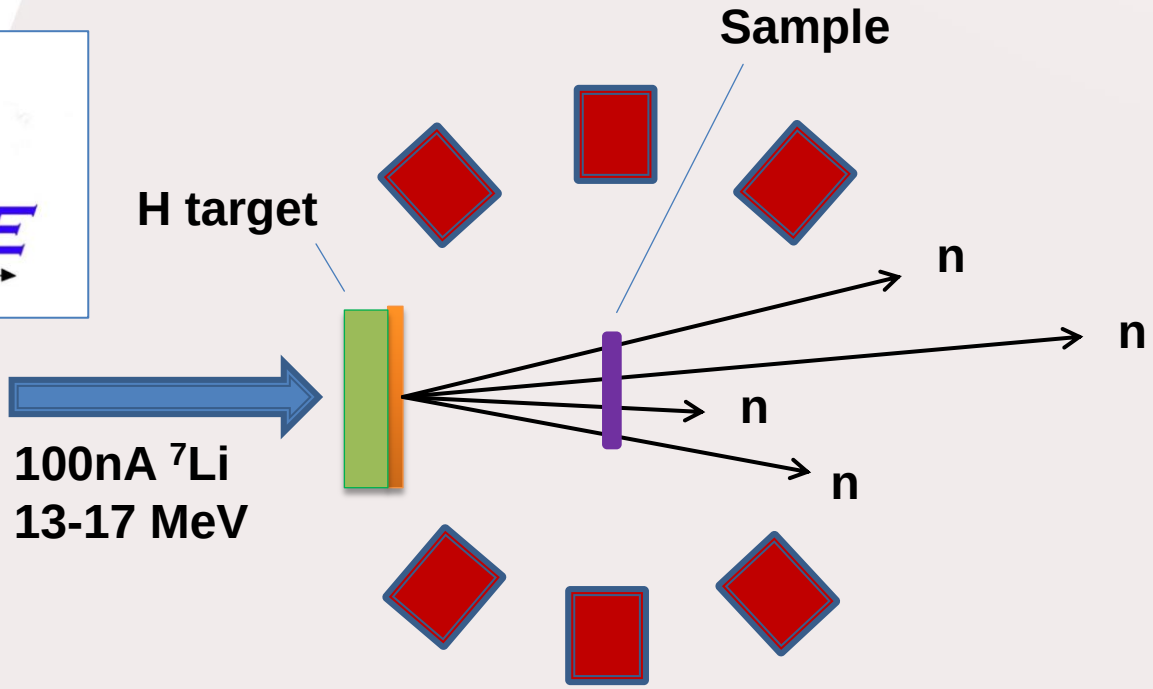

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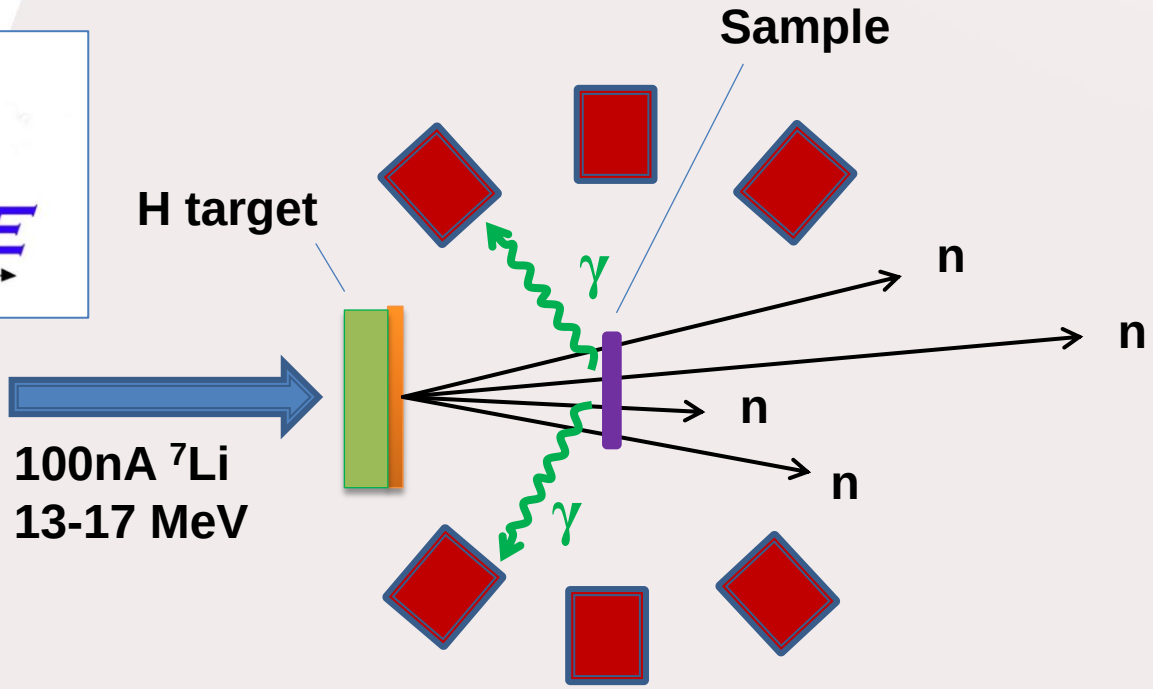

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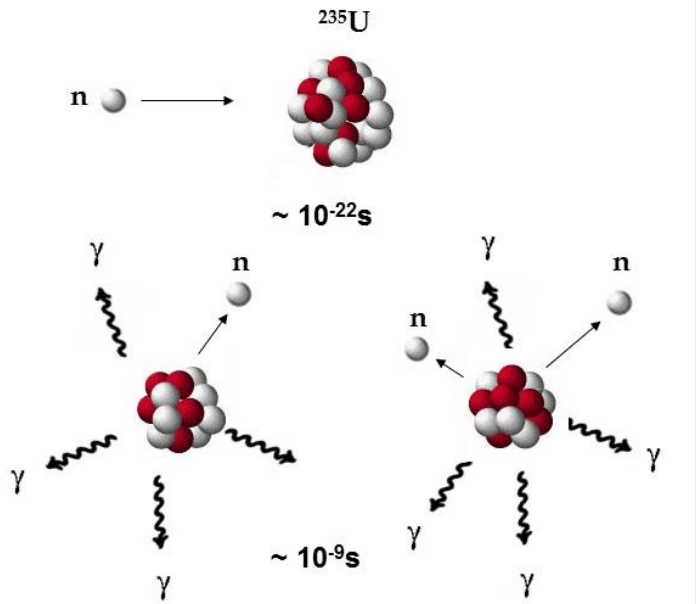
LICORNE II

H_2 pressure and flow control system

Hydrogen gas cells

PHYISCS PROGRAM: PROMPT EMISSION IN FISSION



“Development of a kinematically focused neutron source with the p(^{7}Li,n)^{7}Be inverse reaction”

M.Lebois, J.N. Wilson et al., Nucl. Instrum. Meth. A 735 145 (2014)

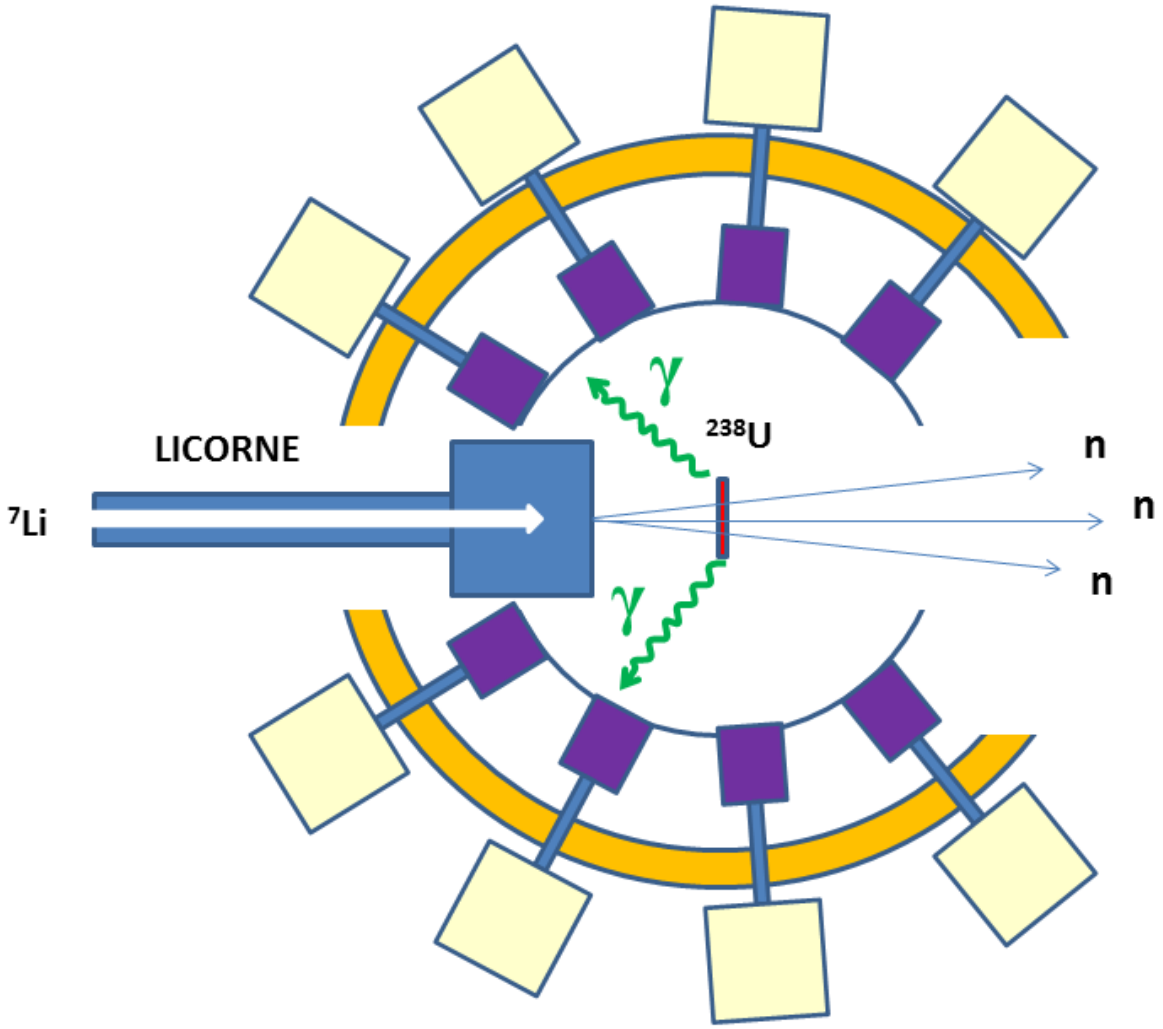
“Comparative measurement of prompt fission gamma-ray emission from fast neutron induced fission of ^{235}U and ^{238}U”

M. Lebois, J.N. Wilson, et al., Phys. Rev. C Rapid Communication In press (2015)

“Experimental studies of prompt fission neutron spectra”

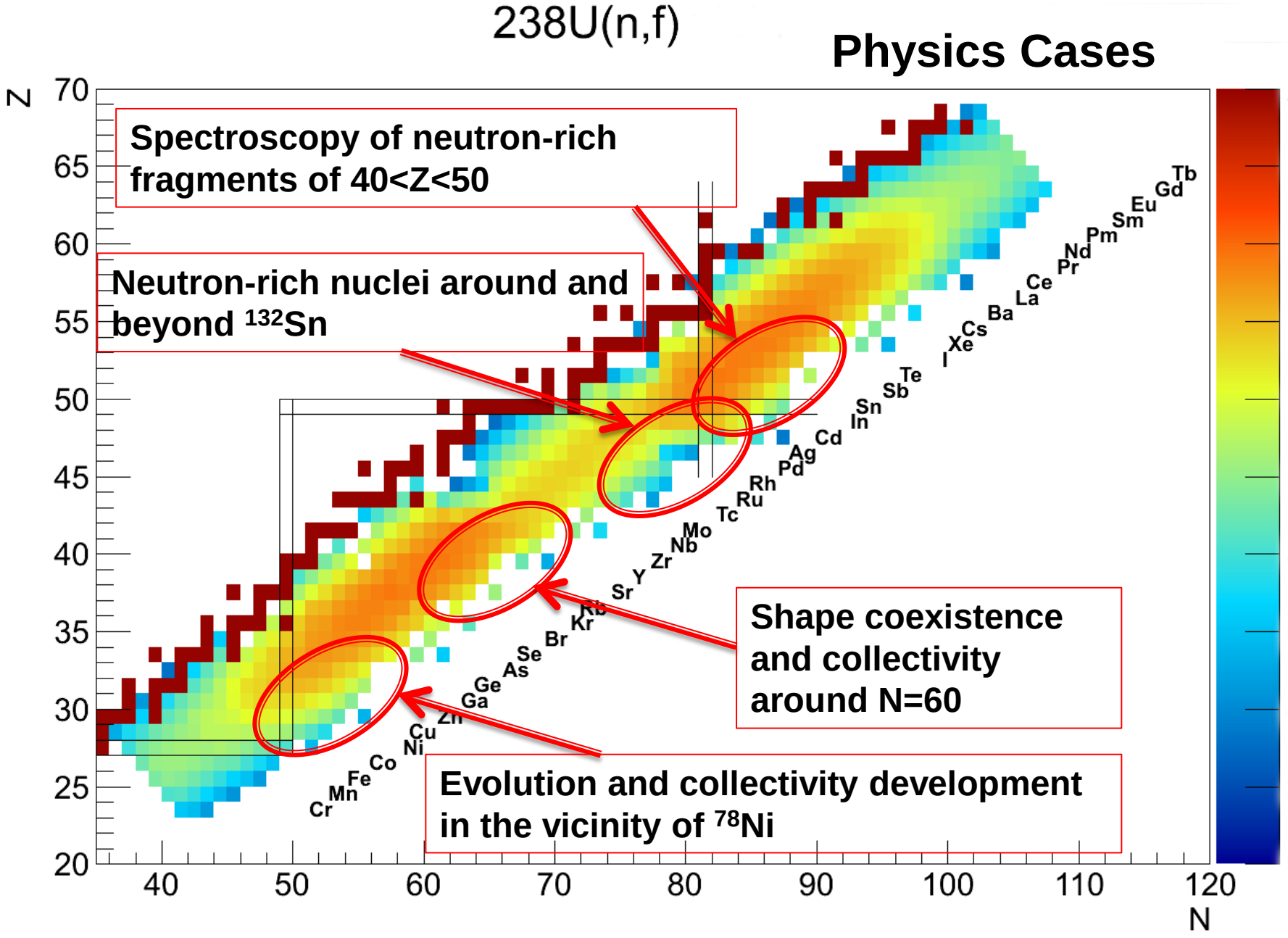
Alix Sardet, CEA/DAM/DIF Bruyeres-le-chatel, Ph.D thesis, 2 Oct. (2015)

COUPLING LICORNE + HPGE GAMMA SPECTROMETER

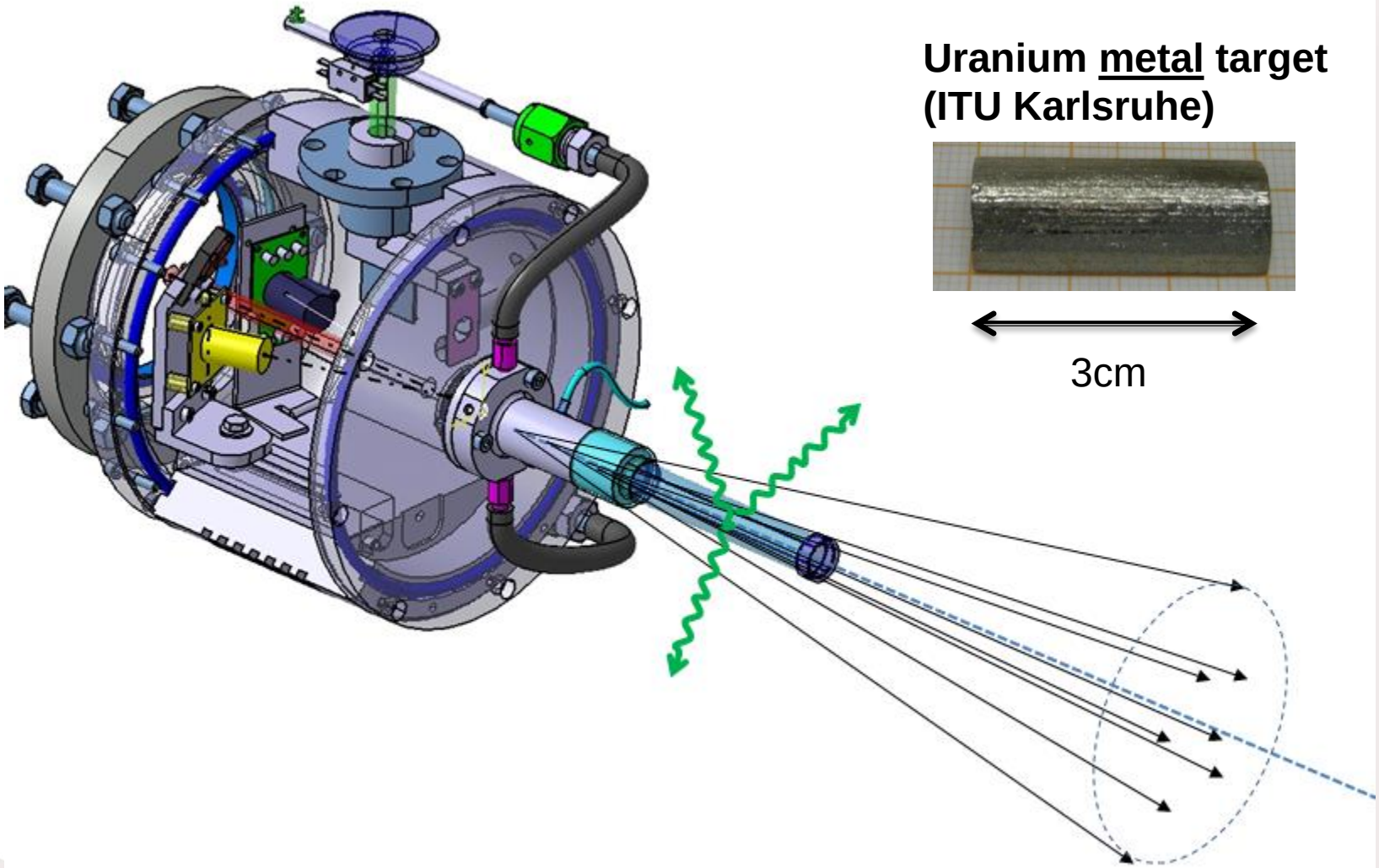


Precision spectroscopy of fast neutron induced reactions

Physics Cases



EXPERIMENT IN MARCH 2015



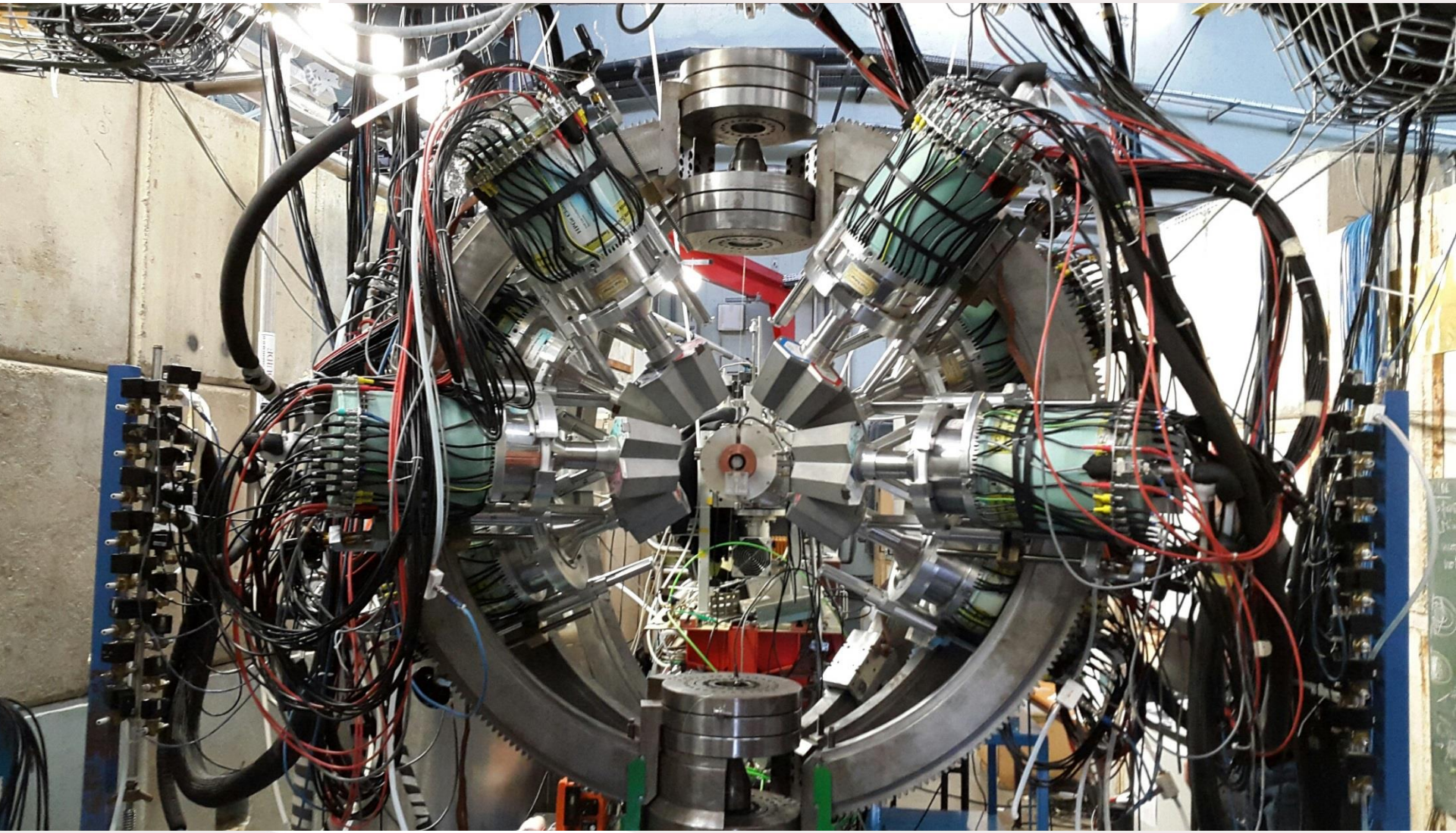
Uranium <u>metal</u> target (ITU Karlsruhe)

3cm

Total Fission Rate > 150 kHz at 100nA ^{7}Li

IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

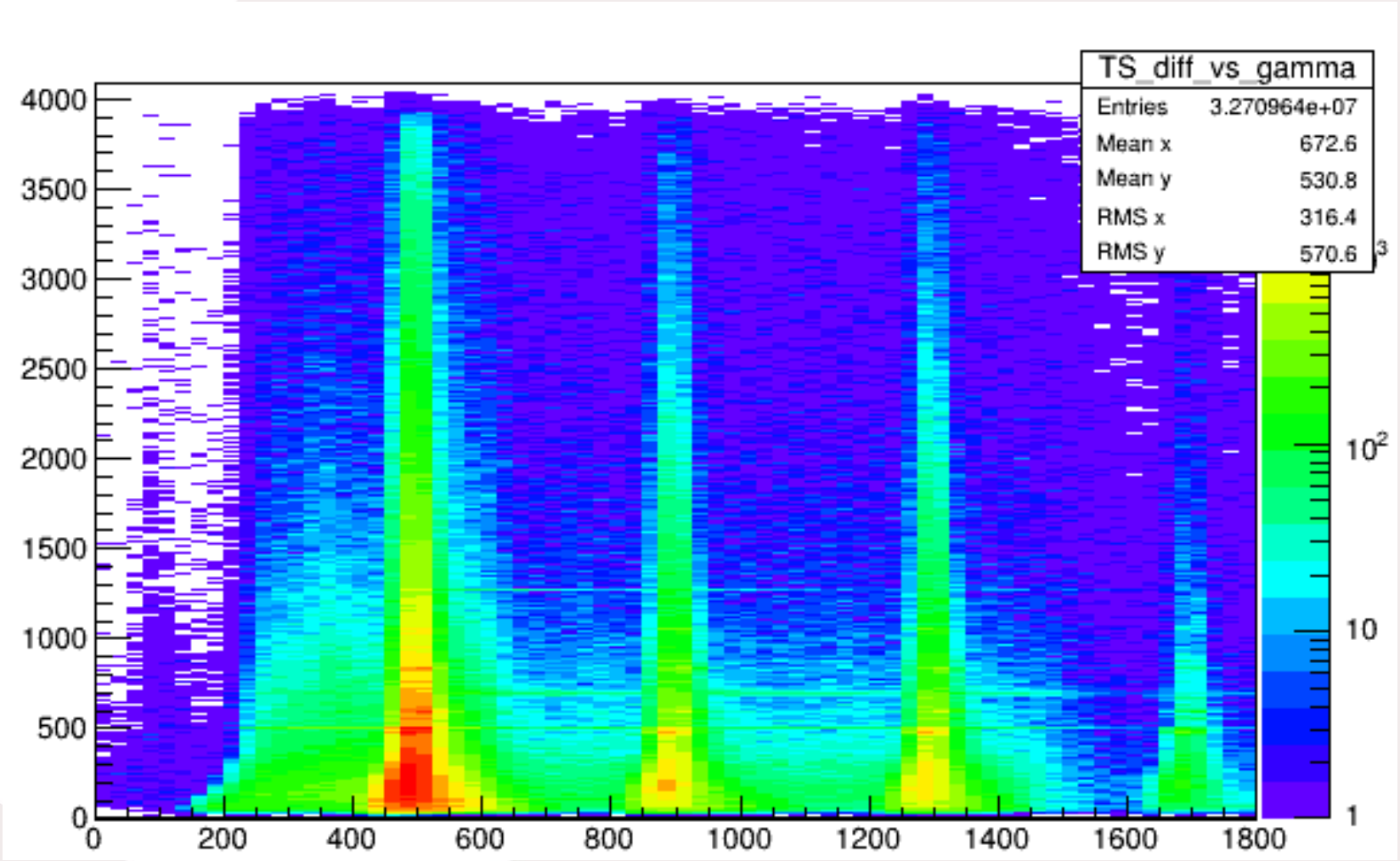
LICORNE + MINIBALL (MARCH 2015)



LICORNE + MINIBALL (MARCH 2015)

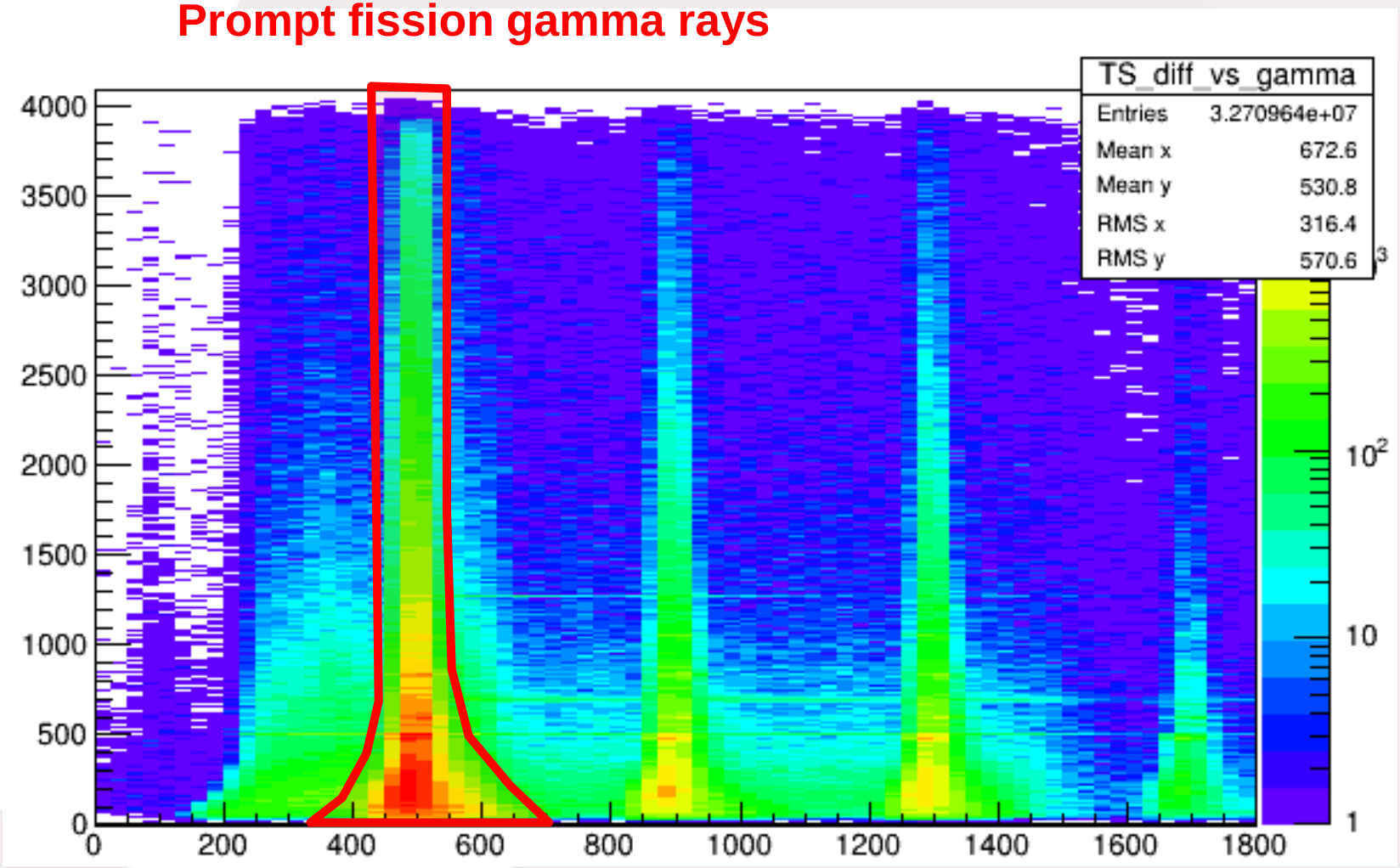
3 weeks of beam time: ~ 3 × 10^9 events with M_γ >= 3

SELECTION OF PROMPT GAMMA RAYS

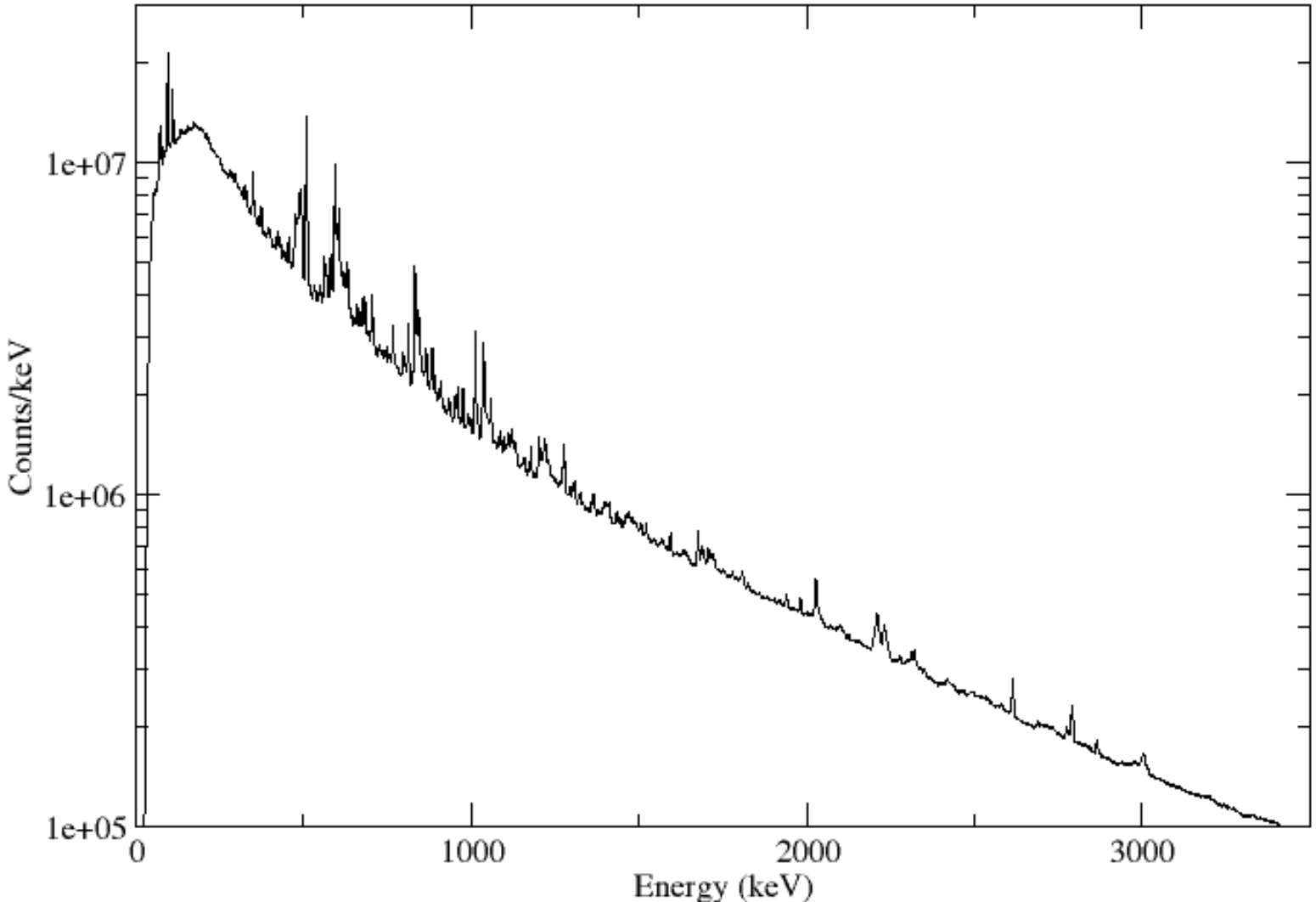


SELECTION OF PROMPT GAMMA RAYS

Prompt fission gamma rays



ALL PROMPT GAMMA RAYS



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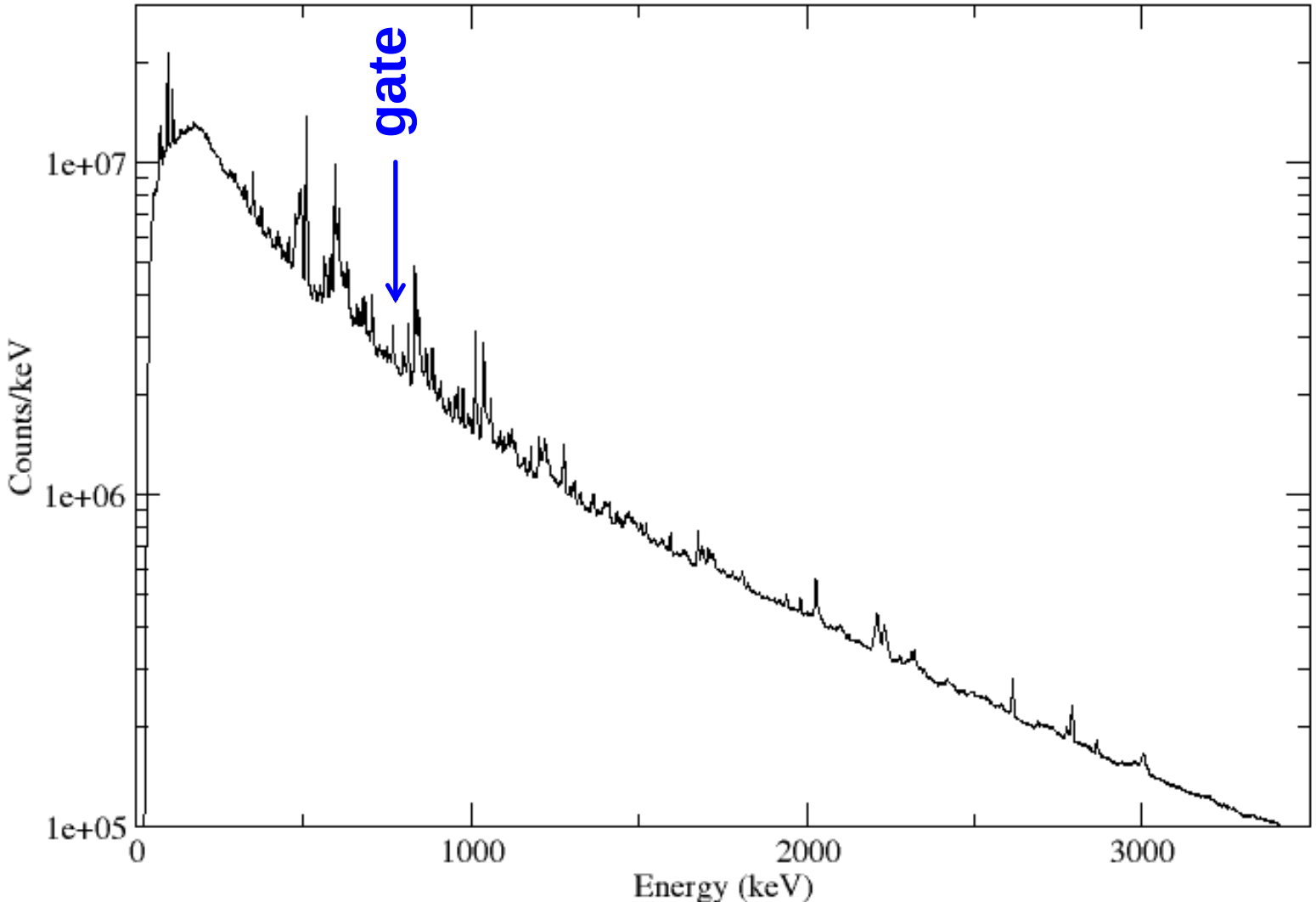
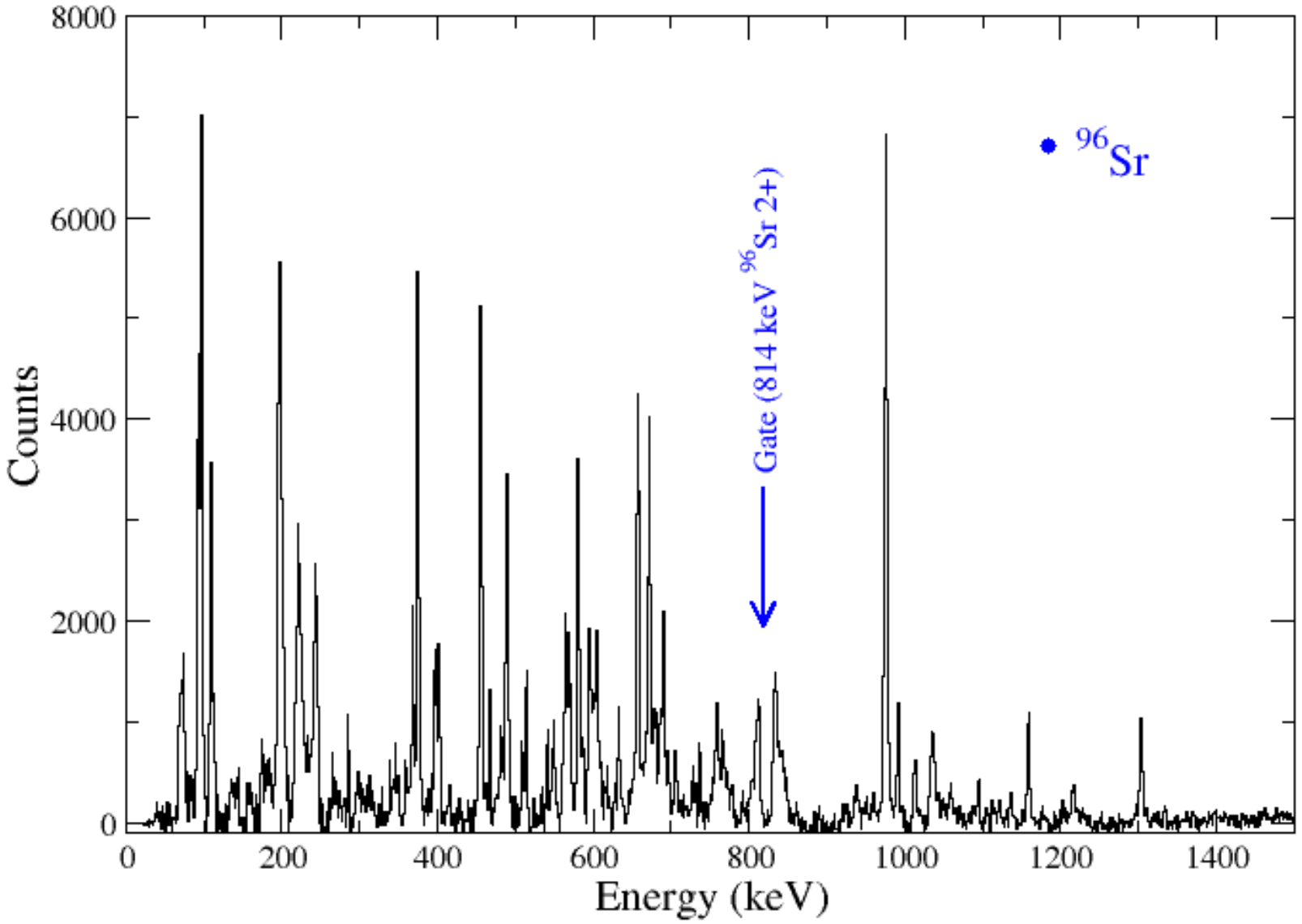


PROMPT GAMMA-RAY SPECTRA



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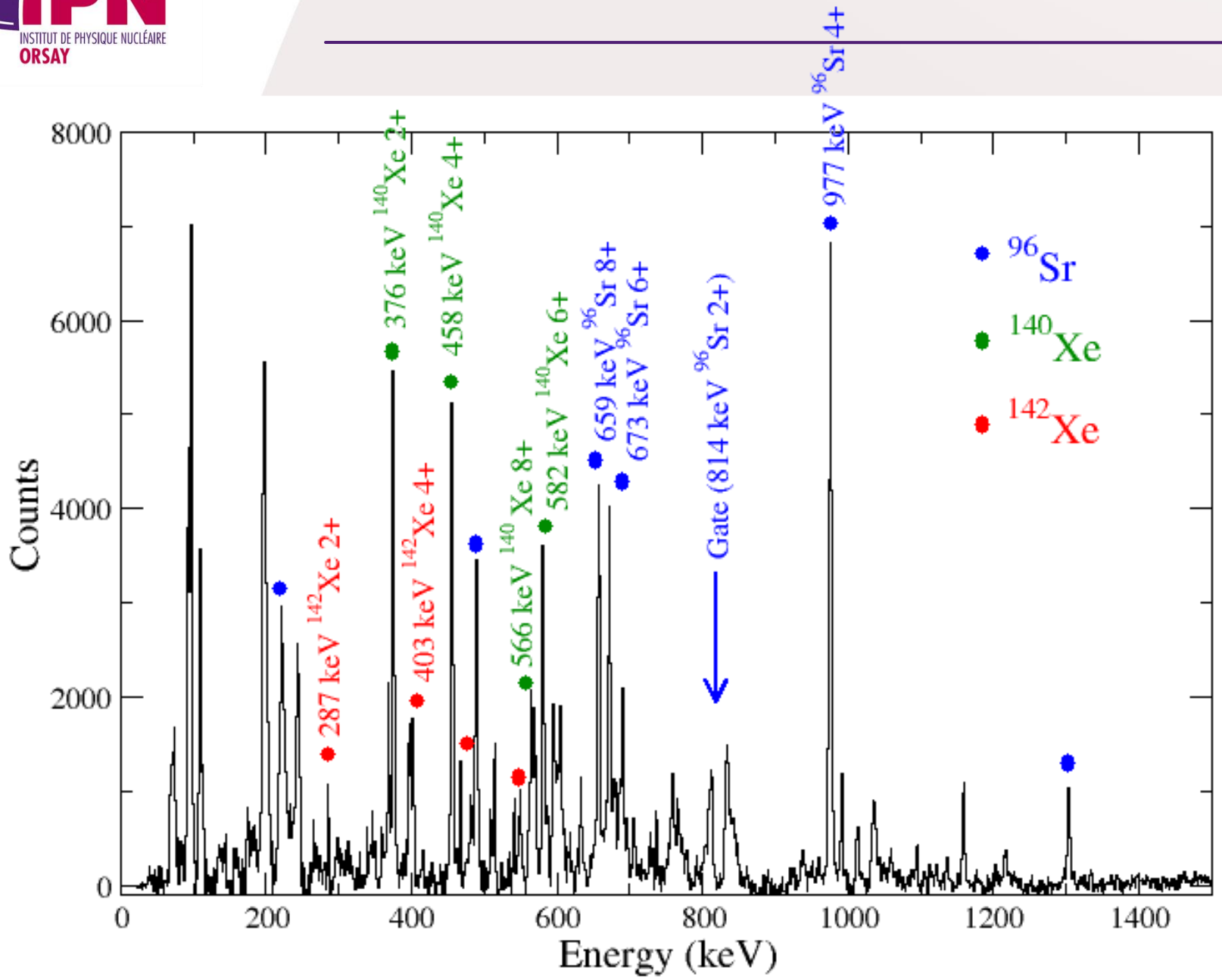
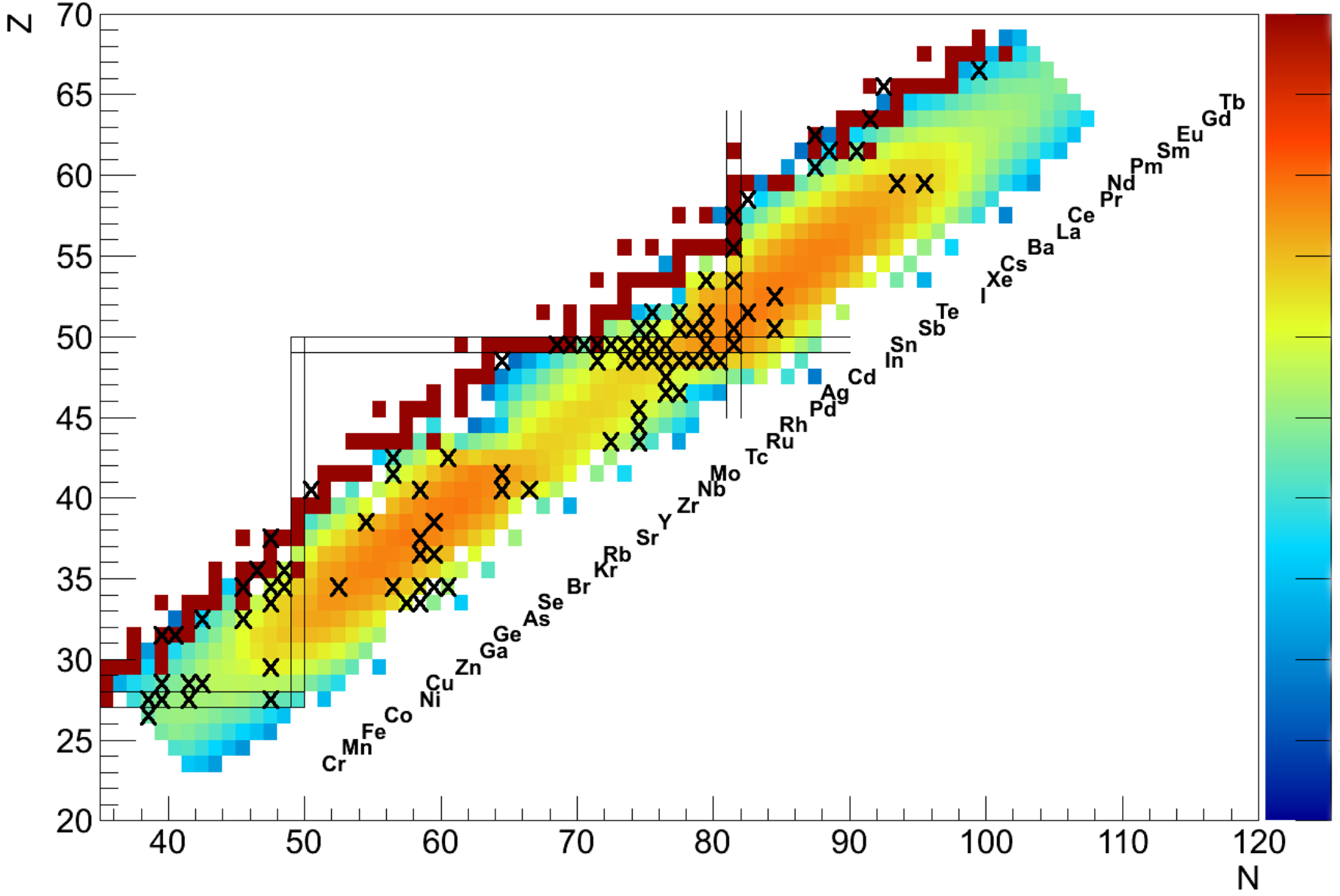
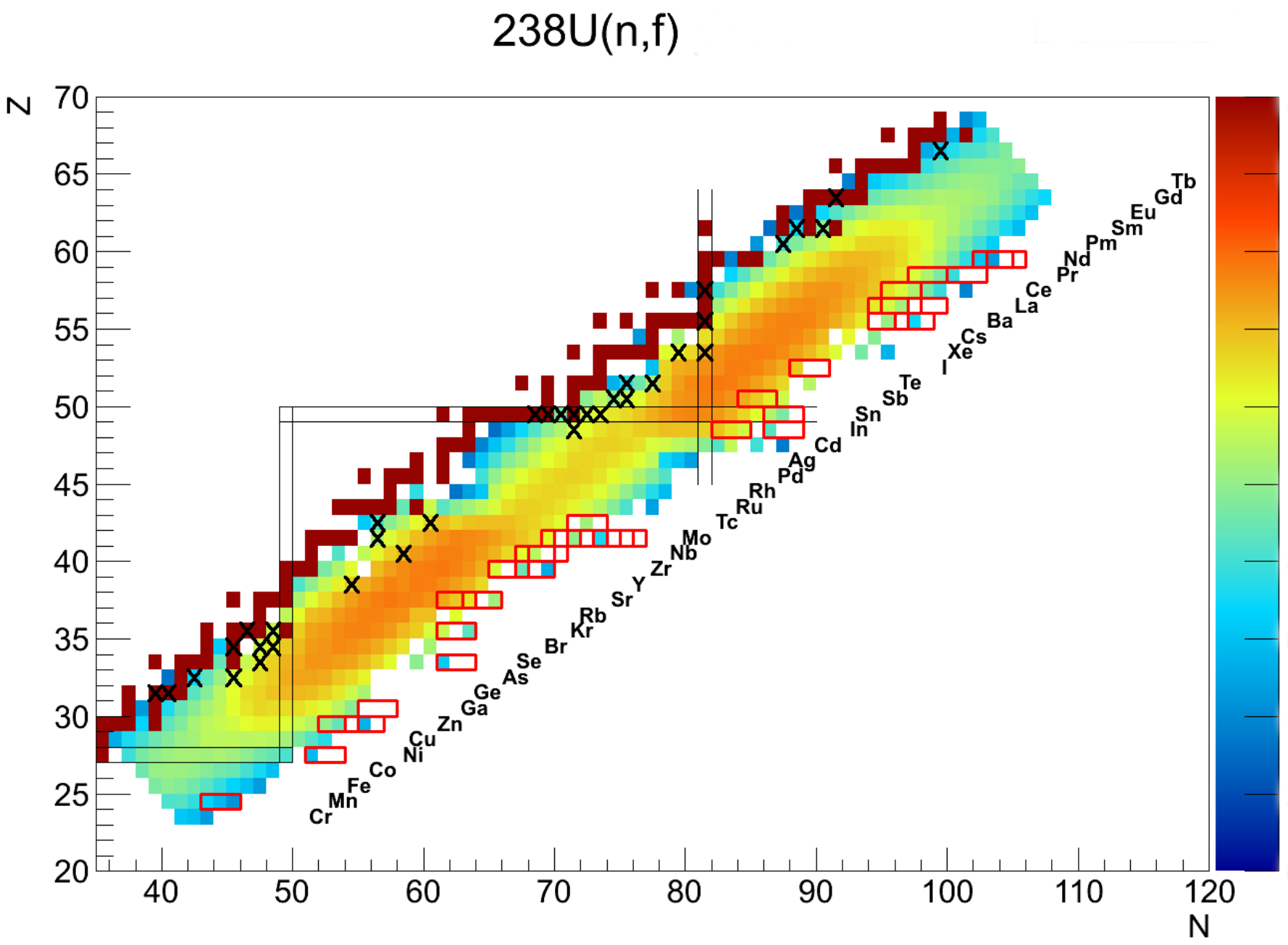
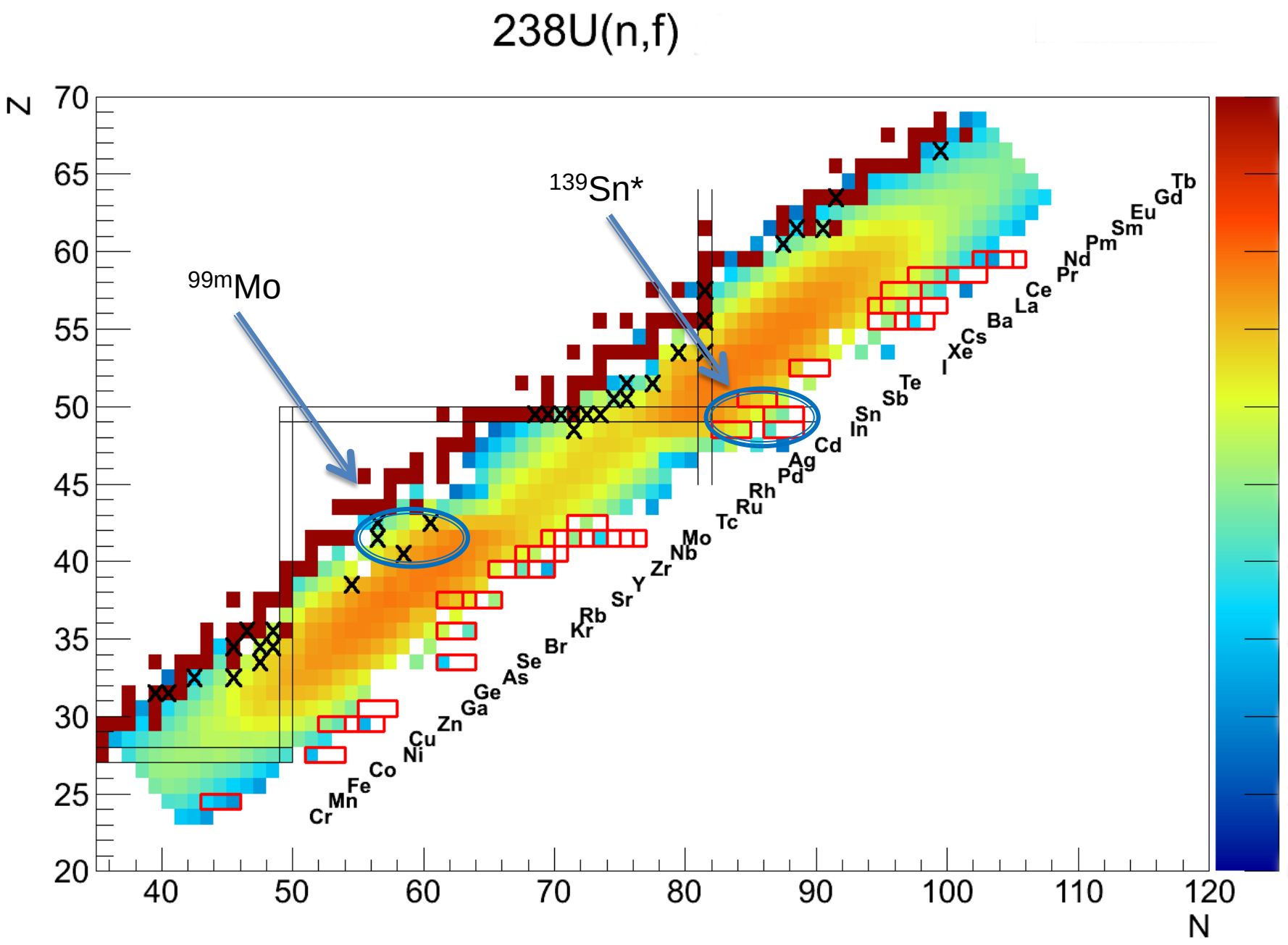


Fission Fragment Isomers (10ns - 10μs)





TIPS – Tagging Isomer PartnerS



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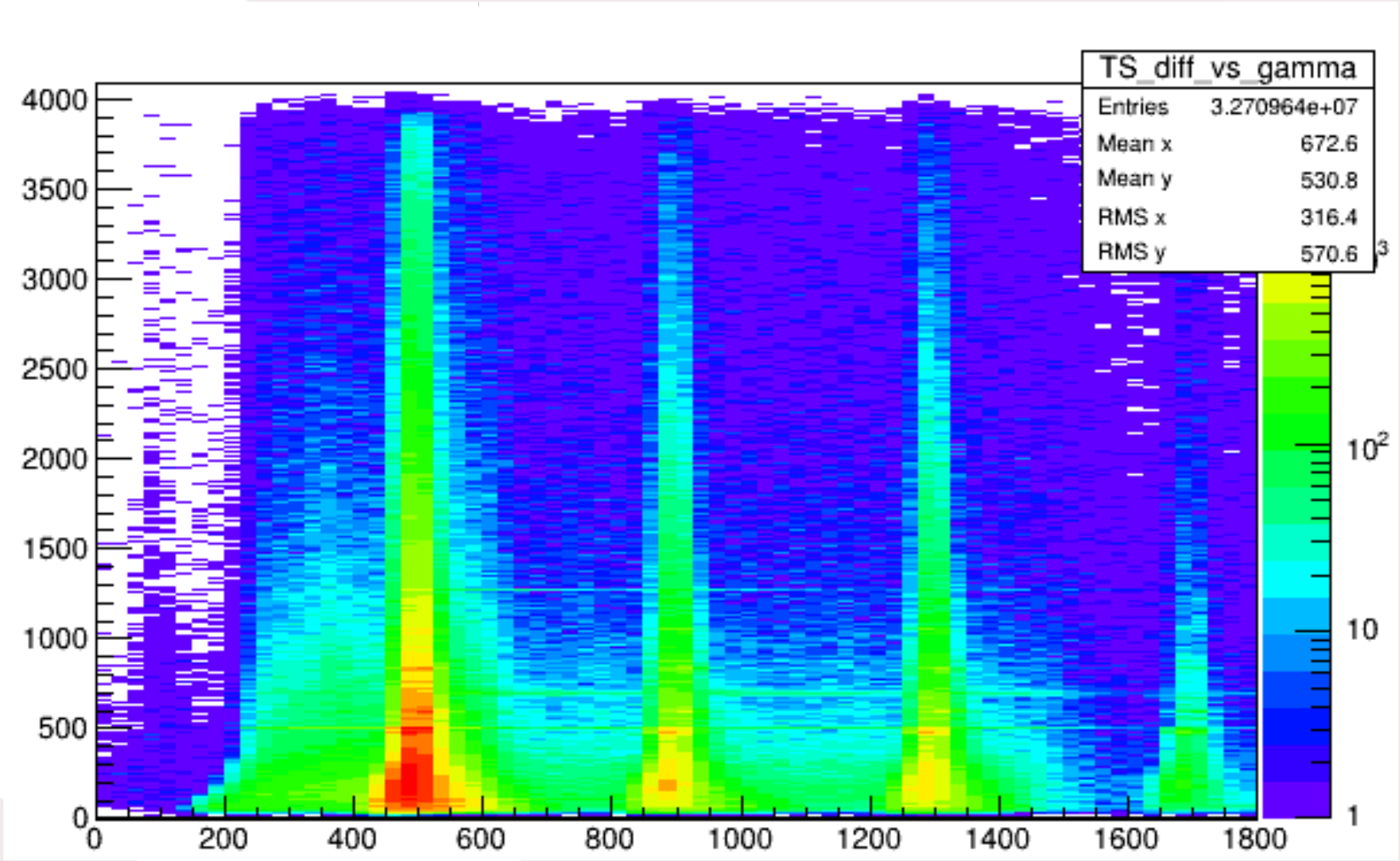
SELECTION OF DELAYED GAMMA RAYS



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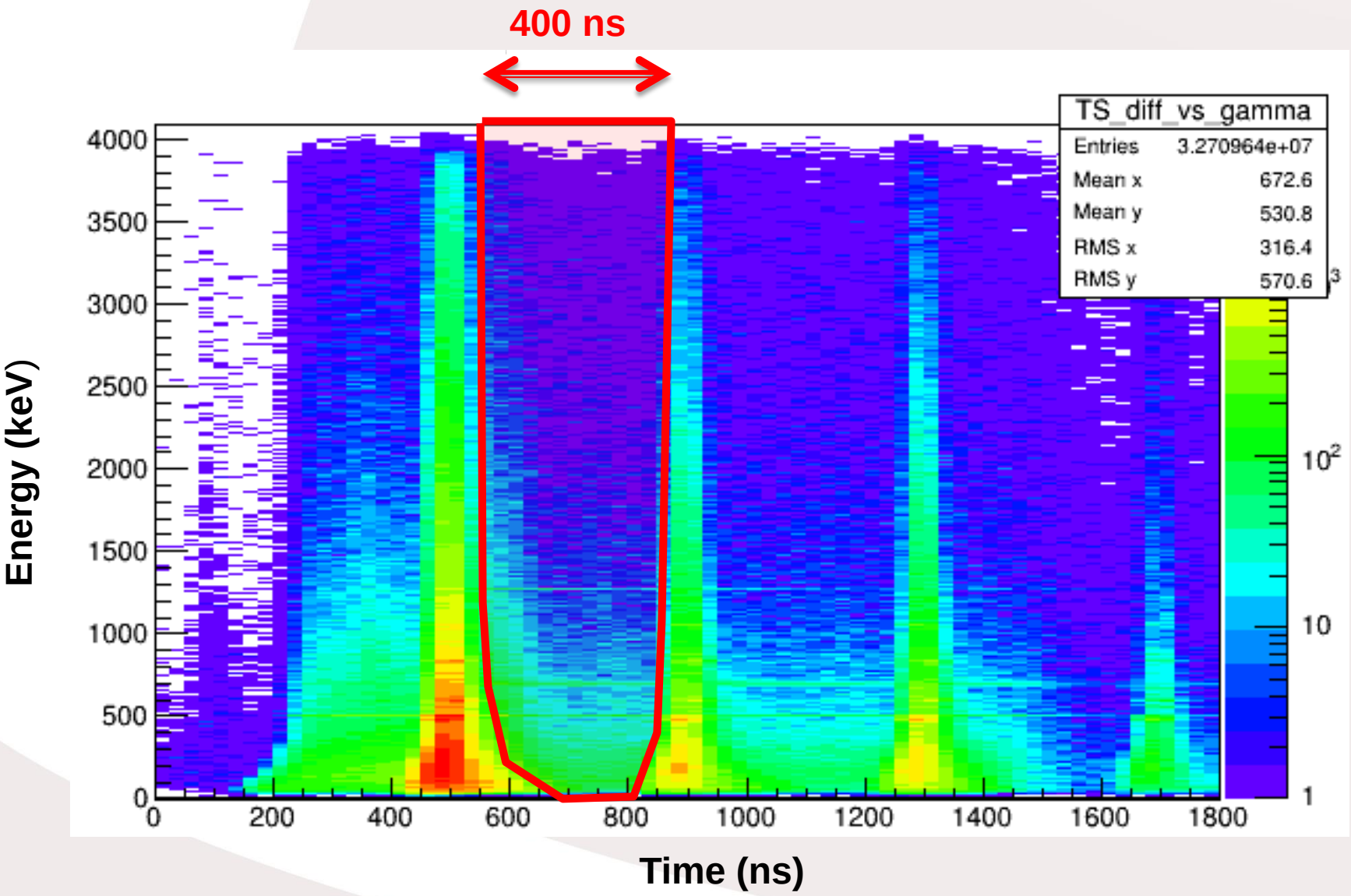
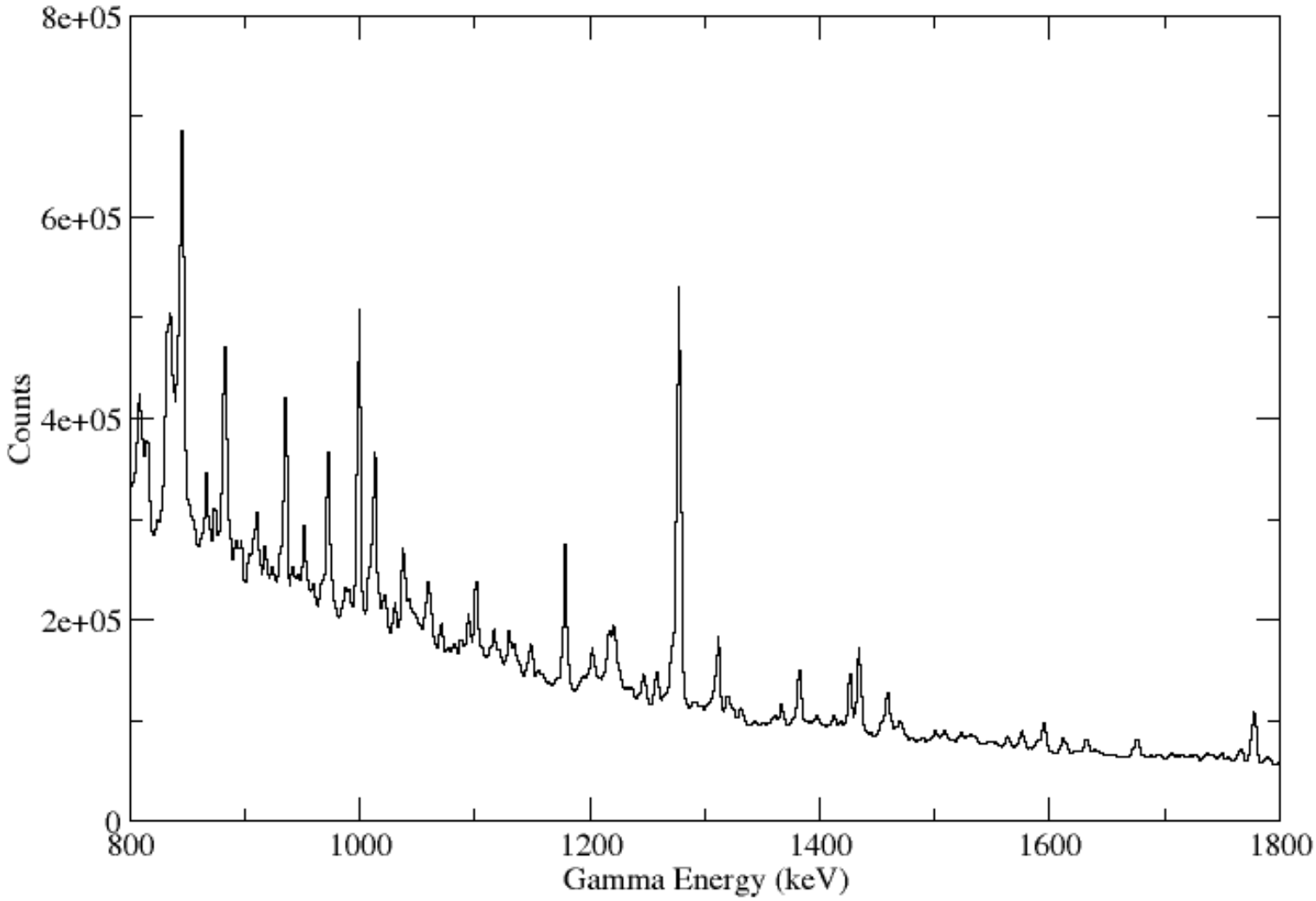


DELAYED GAMMA RAY SPECTRUM



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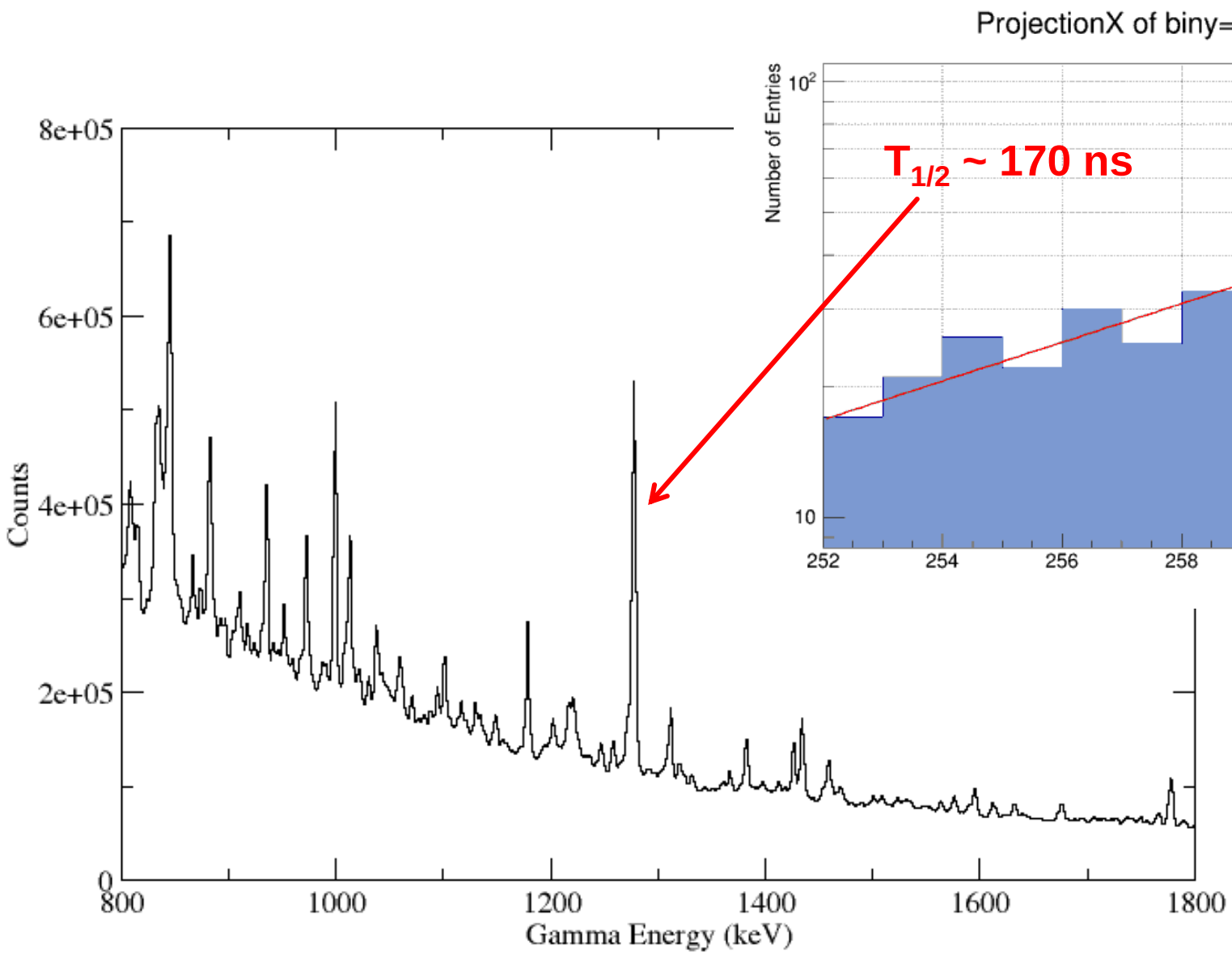
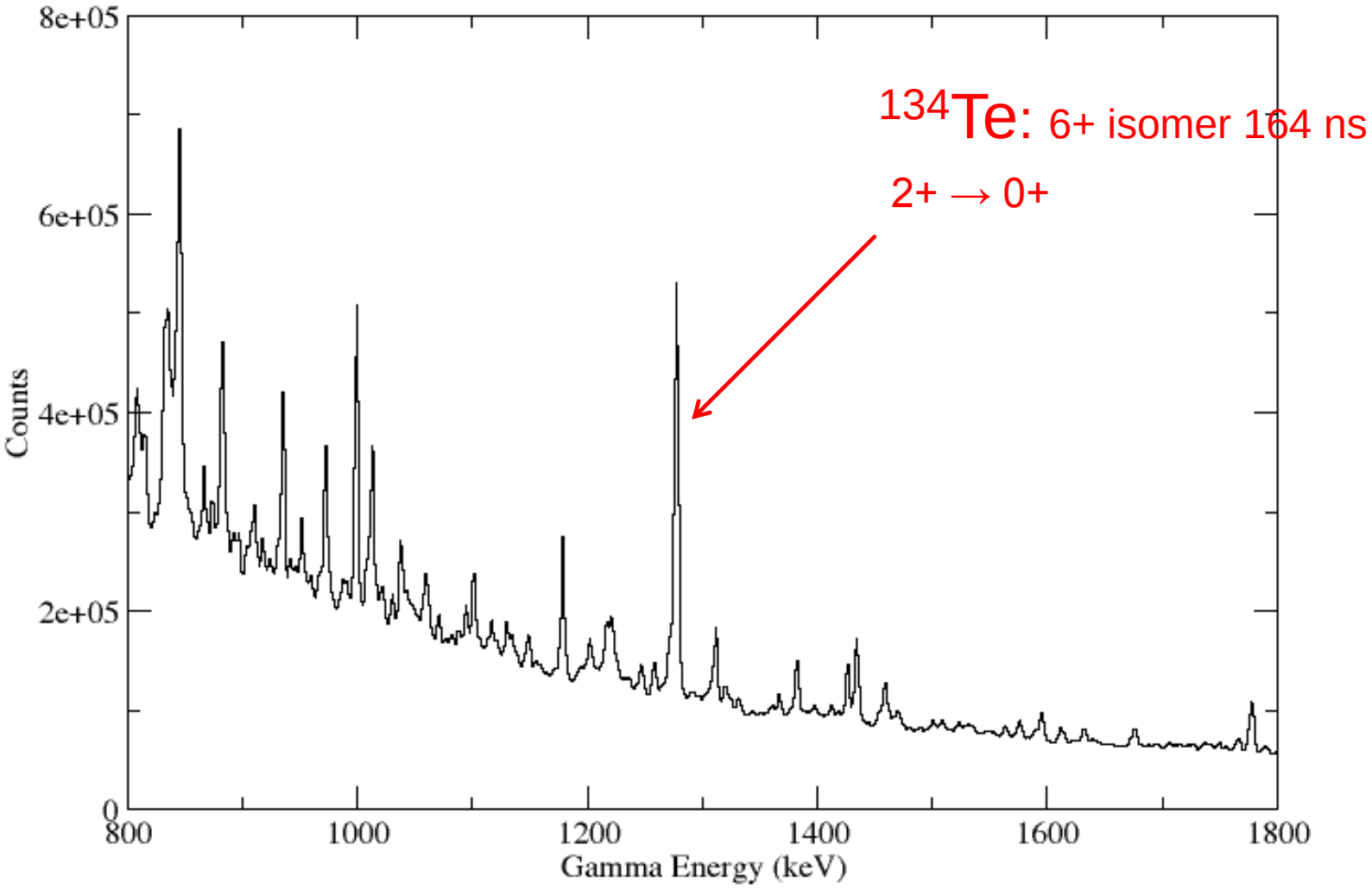


$T_{1/2}$ ~ 170 ns

DELAYED GAMMA RAY SPECTRUM



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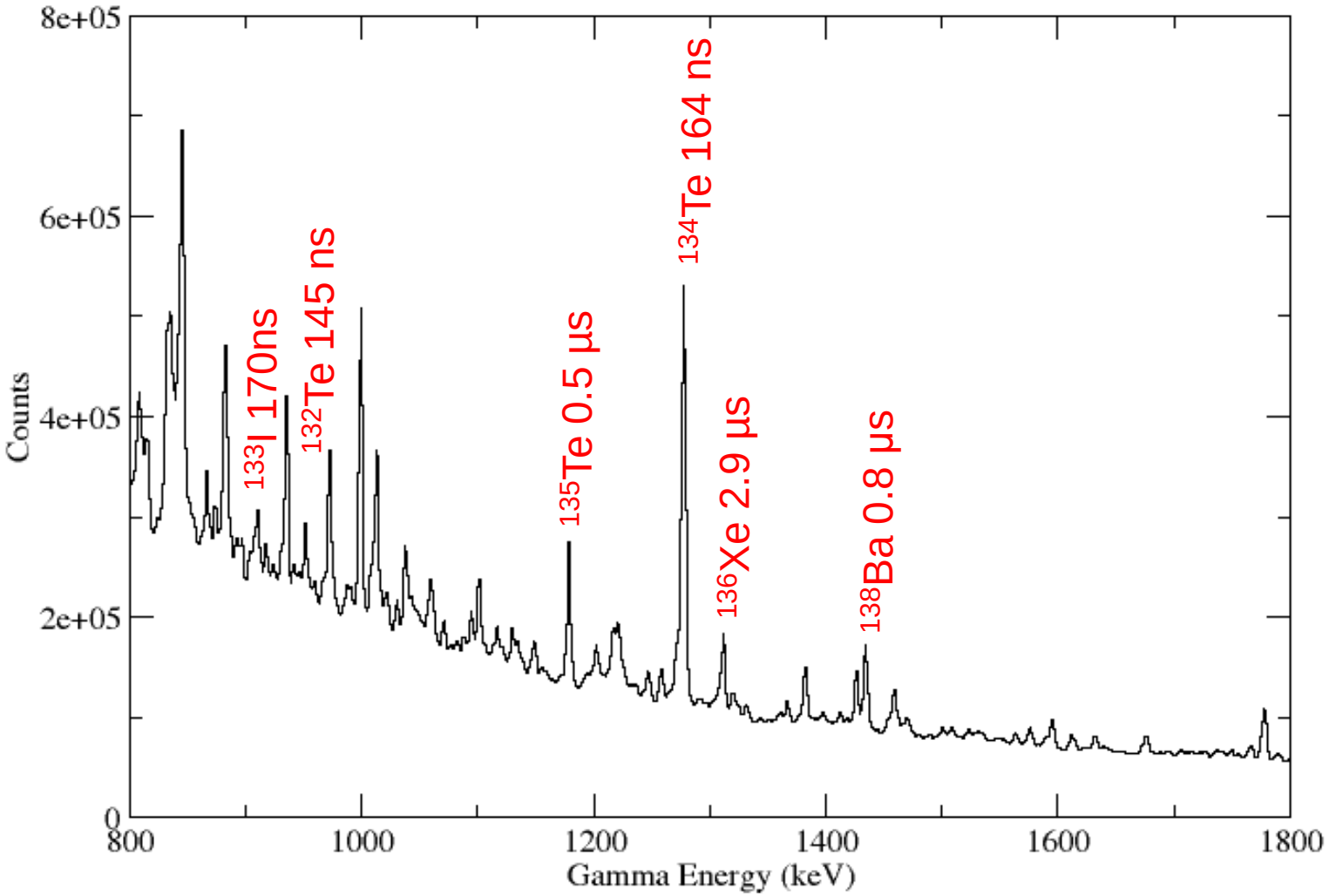

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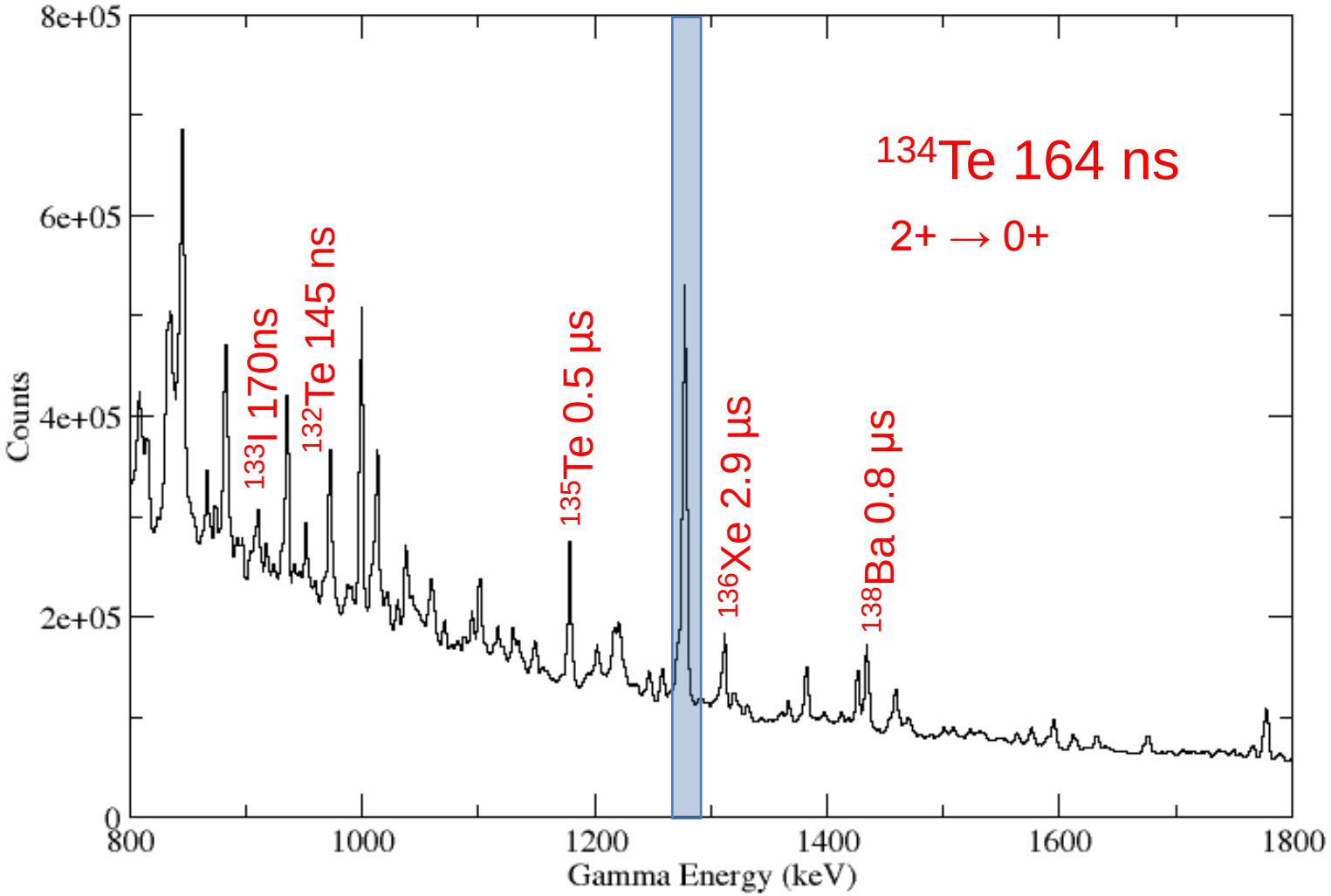
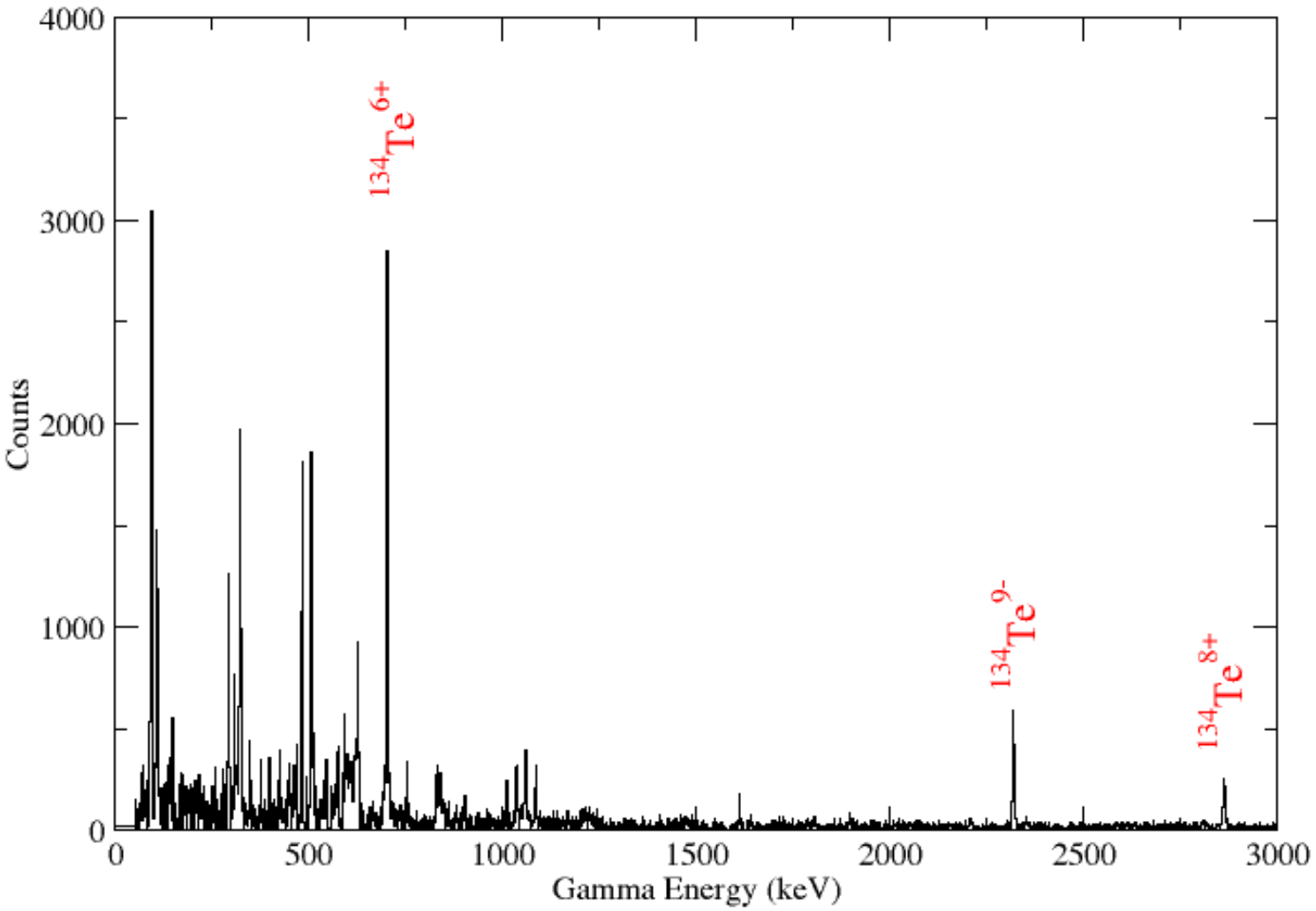


PROMPT GAMMA RAYS IN COINCIDENCE



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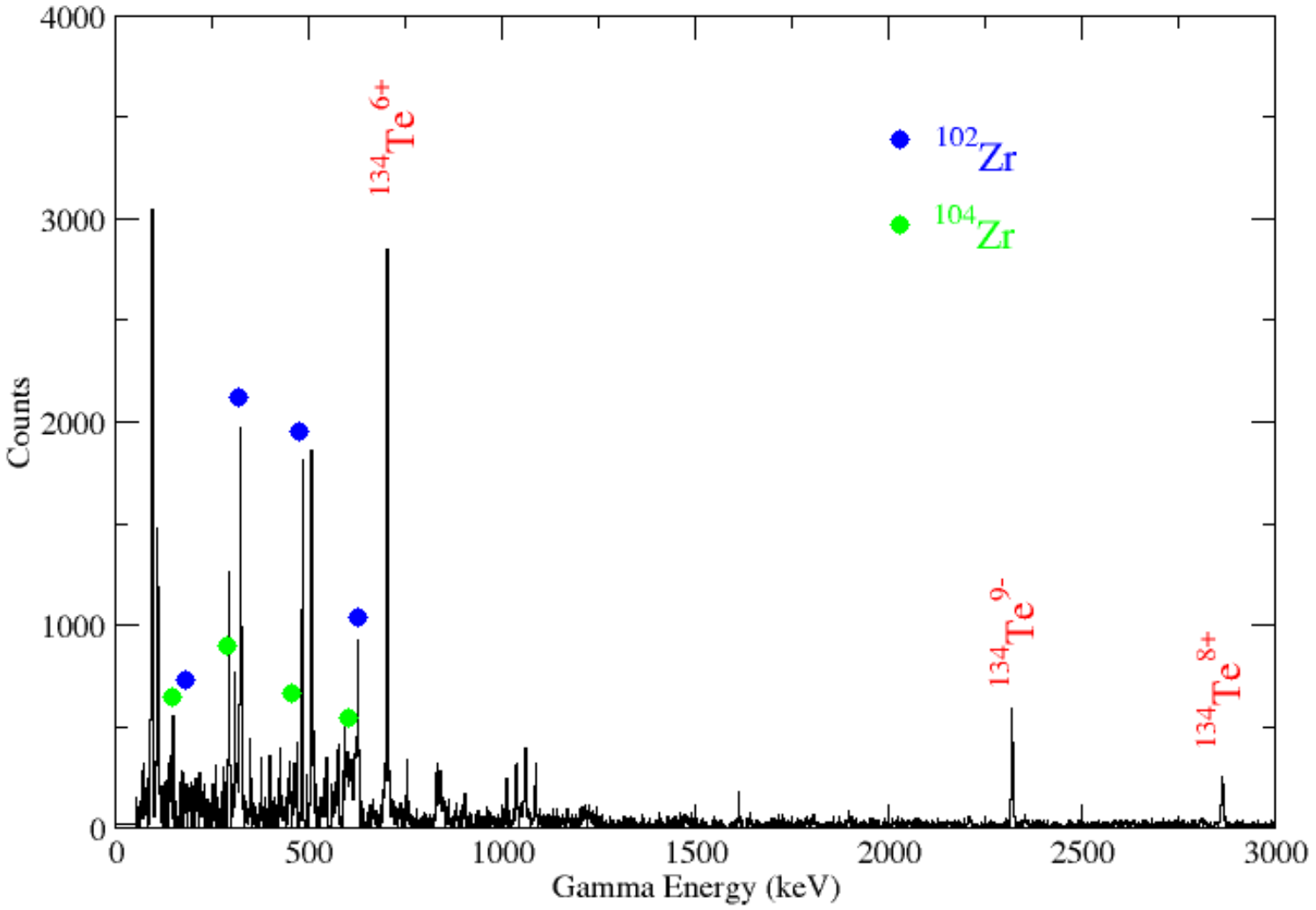
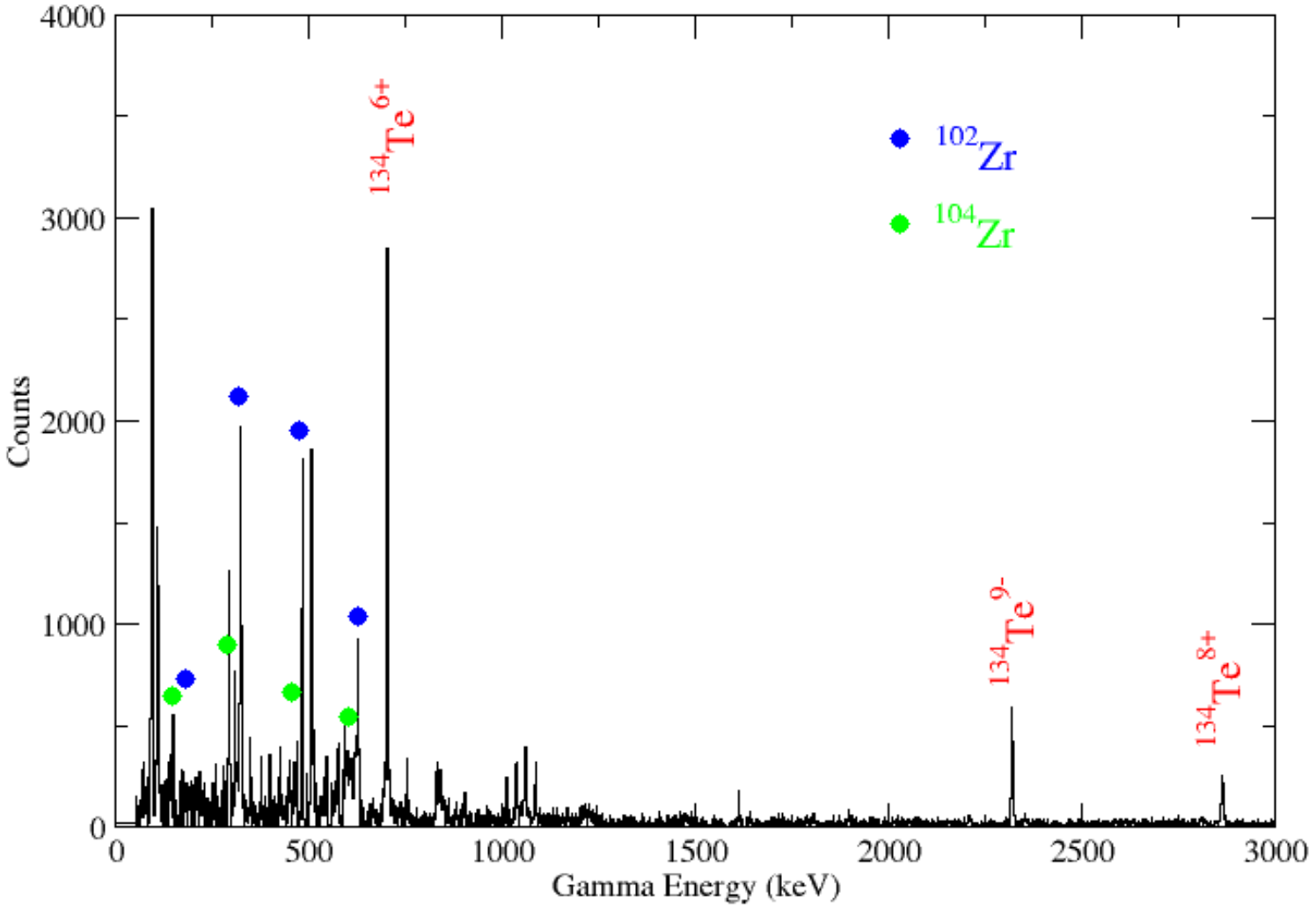


To be continued …

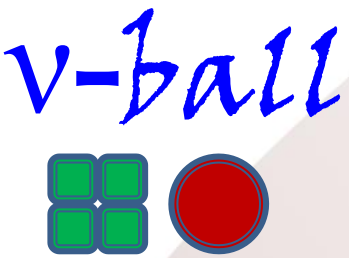


Conclusions

- ^{238}U(n,f) or ^{232}Th(n,f) reactions can be used to study neutron rich fission fragments for the first time (LICORNE@IPNO)
- Cold fission (E_n ~ 1.5 MeV produced with ^{7}Li beam)
- Simultaneous production & study of hundreds of exotic nuclei
- Excellent selectivity of fission fragments and their partners via isomer tagging from ~50 ns – few µs (TIPS)

Perspectives

- Hybrid Ge/LaBr3 array to get lifetime information (v-ball)
- Fission tagging with gamma calorimeter or ionisation chamber



A hybrid $LaBr_3$-Ge array for fast timing spectroscopic studies at the IPN Orsay

- Construction of a hybrid Ge + $LaBr_3$ array @ IPN Orsay
- Goal: to approach 10% total gamma photopeak efficiency
- LOI (2015) signed by 43 scientists from 17 different institutions
- Run for > 2 months using the $^{238}U(n,f)$ and $^{232}Th(n,f)$ reactions

- Workshop planned for early 2016 to physics cases

Collaborators

J. N. Wilson[1], M. Lebois[1] ,Q. Liqiang[1], R. Shearman[2,3], I. Matea[1], S. Oberstedt[4] , A. Oberstedt[5, 6]
R. J. Carroll[2], P. H. Regan[1,2], P. Amador-Celdran[7], D. L. Bleuel[8], J. A. Briz[9], W. N. Catford[1]
D. Doherty[10], R. Eloirdi[7], G. Georgiev[11] , A. Gottardo[3], K. Hadynske-Klek[12] , K. Hauschild[11]
V. Ingeberg[12] , J. Ljungvall[11] , A. Lopez-Martens [3] , G. Lorusso[2], R. Lozeva[13] , P. Marini[14]
Th. Materna[15,] L. Mathieu[14] ,S. Panebianco[10] , Zs. Podolyák[1] , A. Porta[9] , K. Resynkina[11] ,
S. J. Rose[12] , E.Sahin[12] ,S. Siem[12] , A. G. Smith[16] , G. Tveten[12,] D. Verney[3] , N. Warr[17] , F. Zesier[12]
and M. Zielinska[10]

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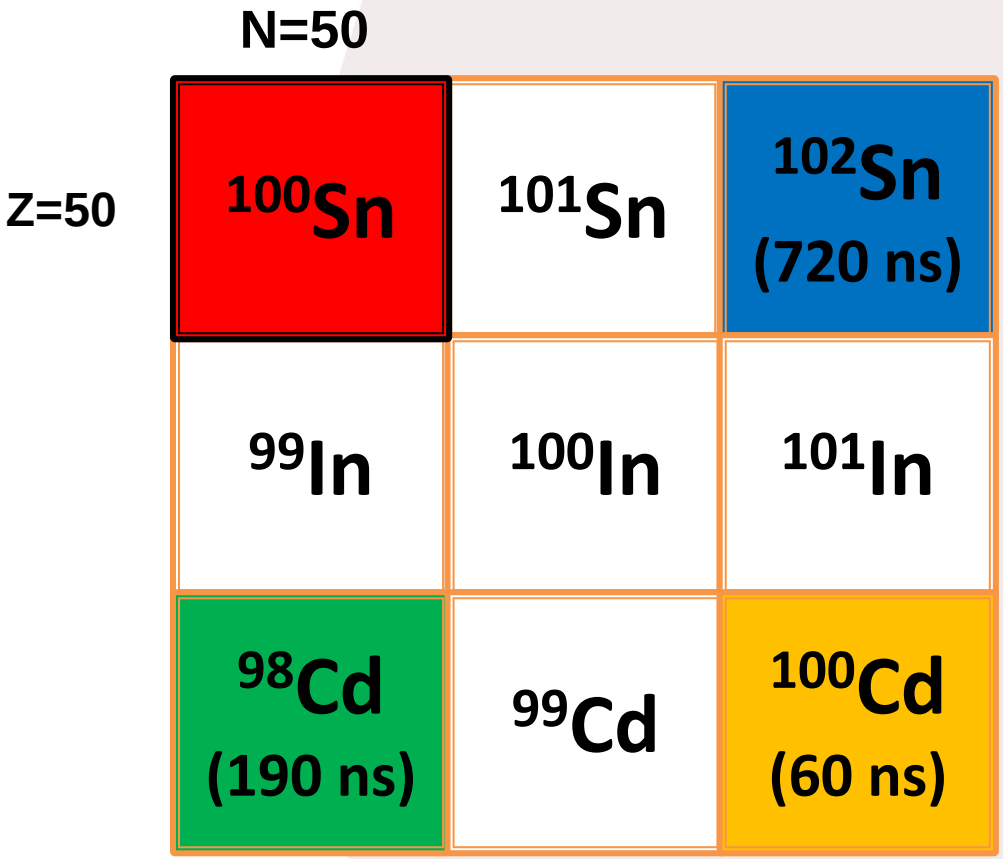
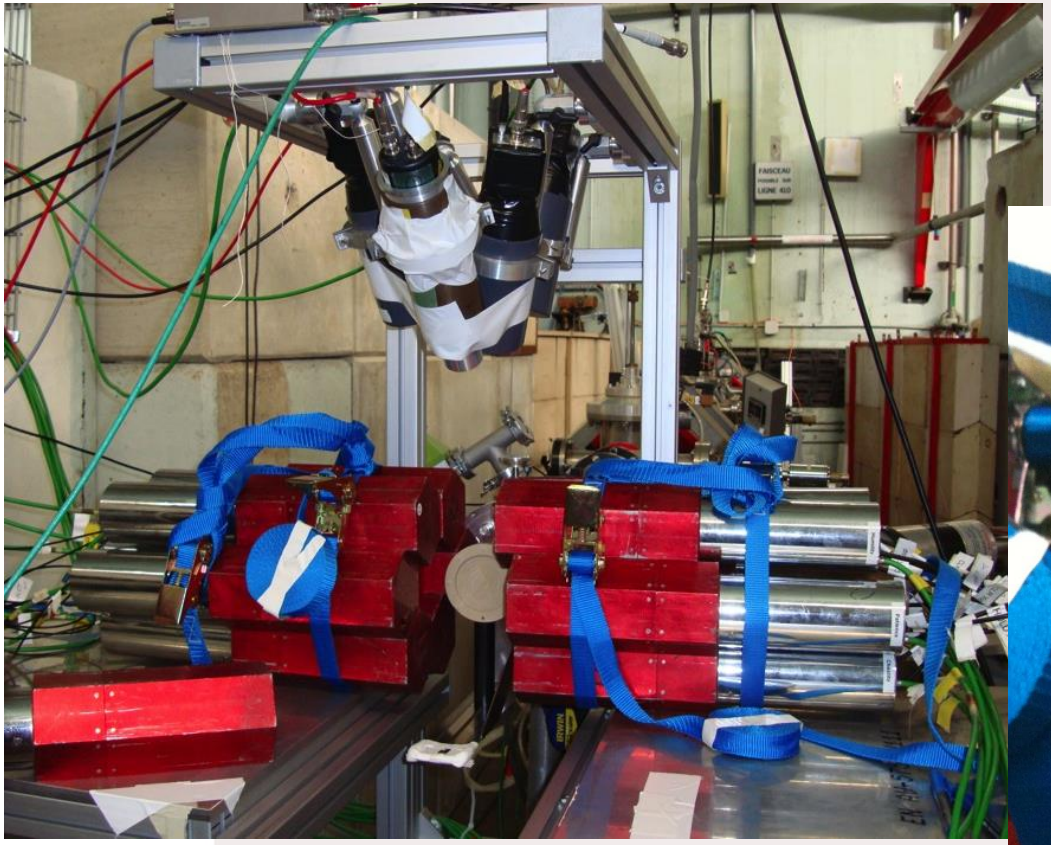


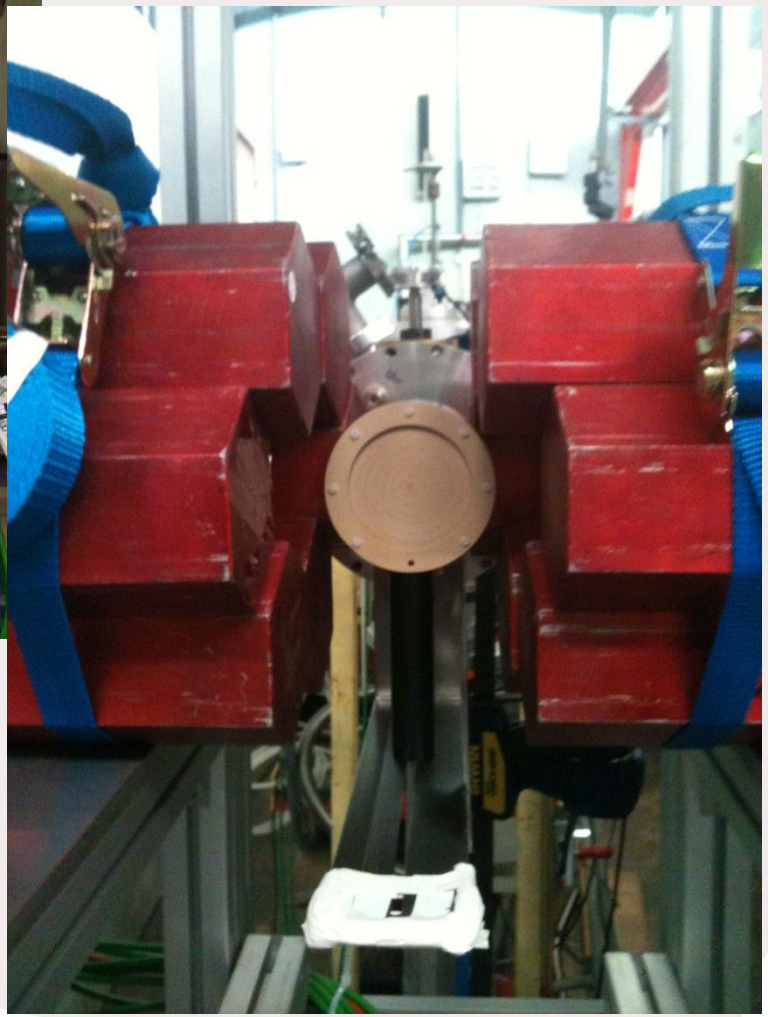
M. Lipoglavsek et al., "Polarization charge in ^{102}Sn". Phys. Lett B 440, 246 (1998)

R.M. Clark and J.N. Wilson et al. "Yrast and near yrast excitations up to high spin in ^{100}Cd", Phys. Rev. C61 044311 (2000)

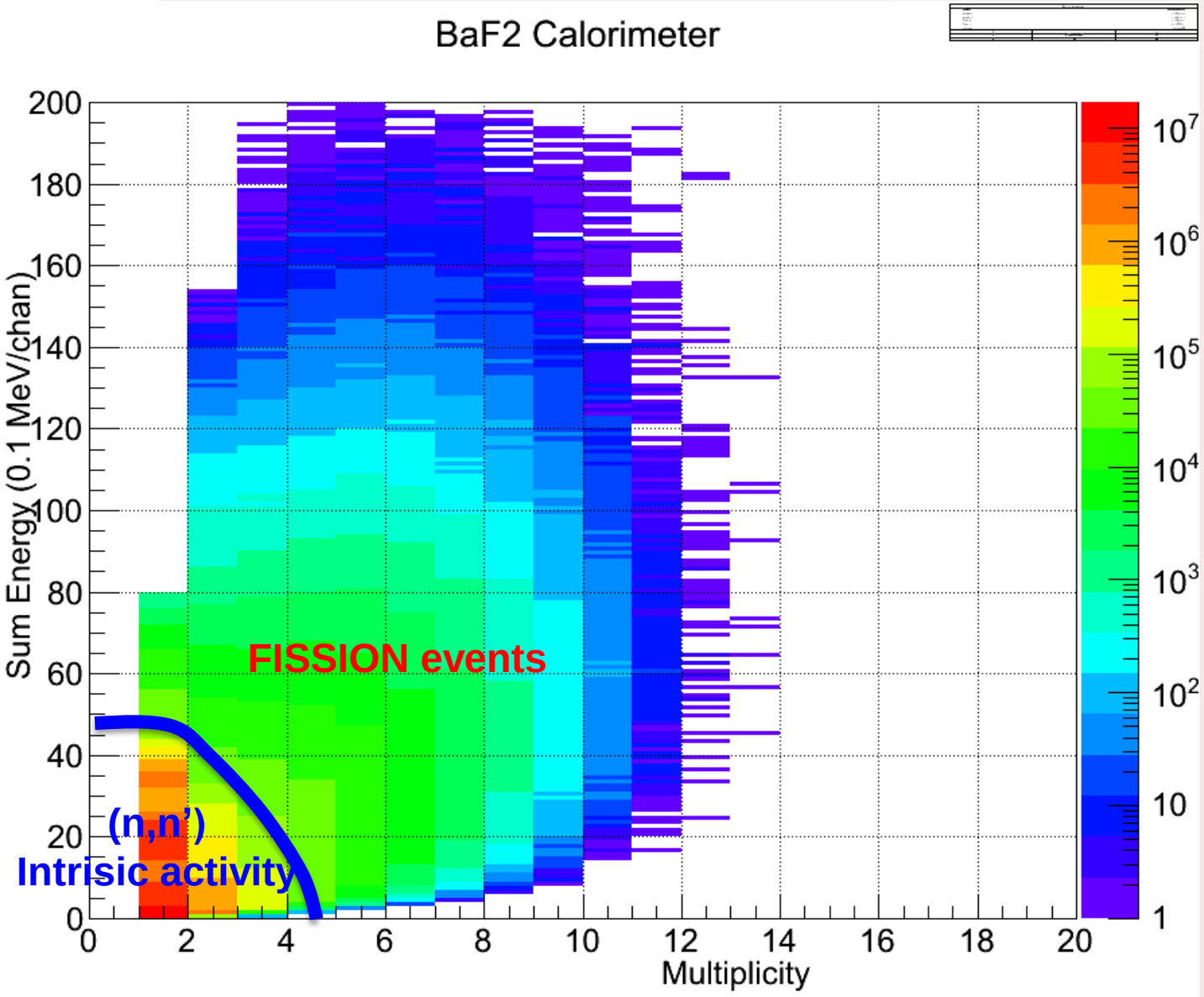
M. Gorska et al., "^{98}Cd – The two proton hole spectrum in ^{100}Sn", Phys. Rev. Lett. 79 2415 (1997)

EXPERIMENTAL SETUP: ENERGY DEPENDENCE OF PROMPT-γ EMISSION. JULY 2013

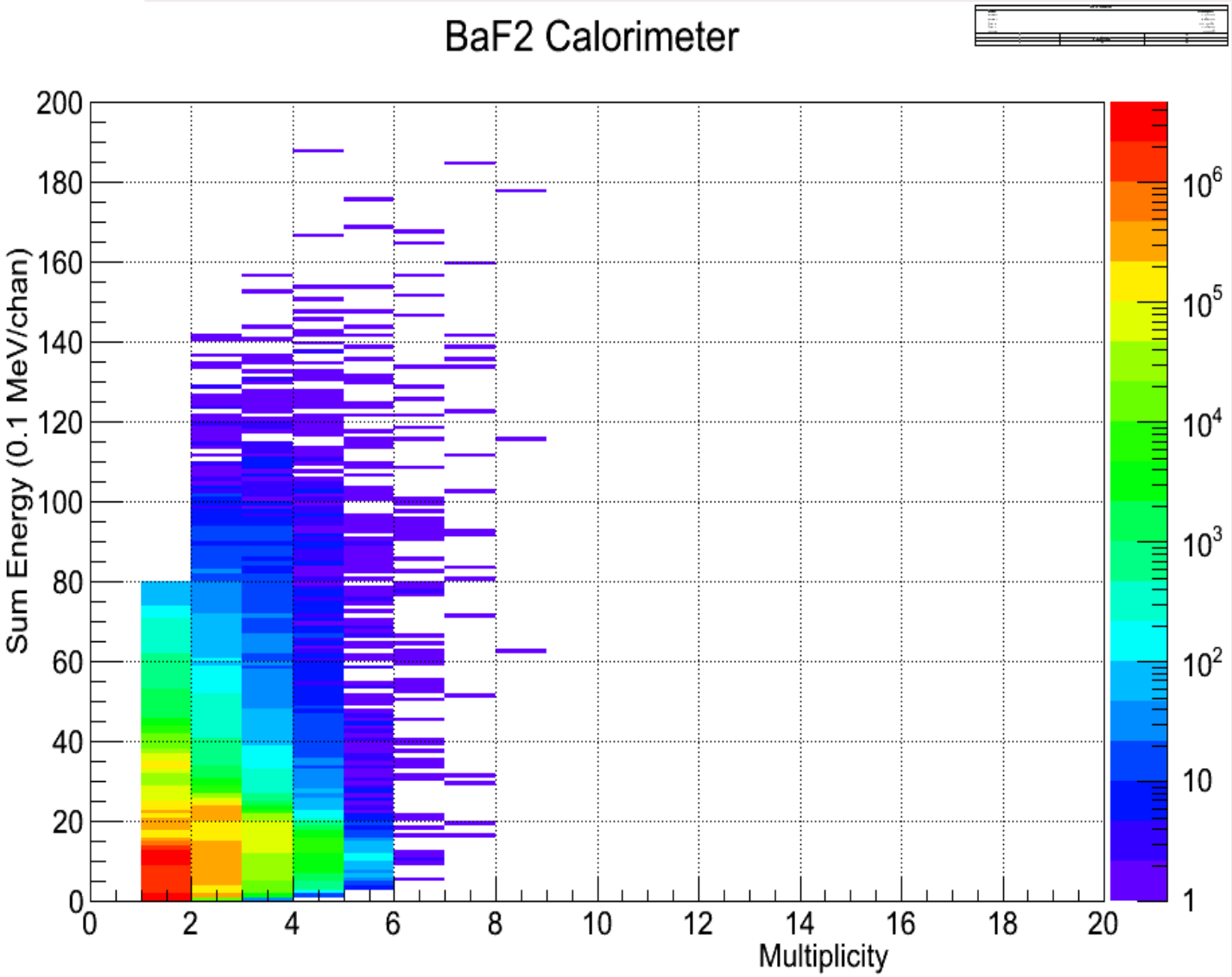




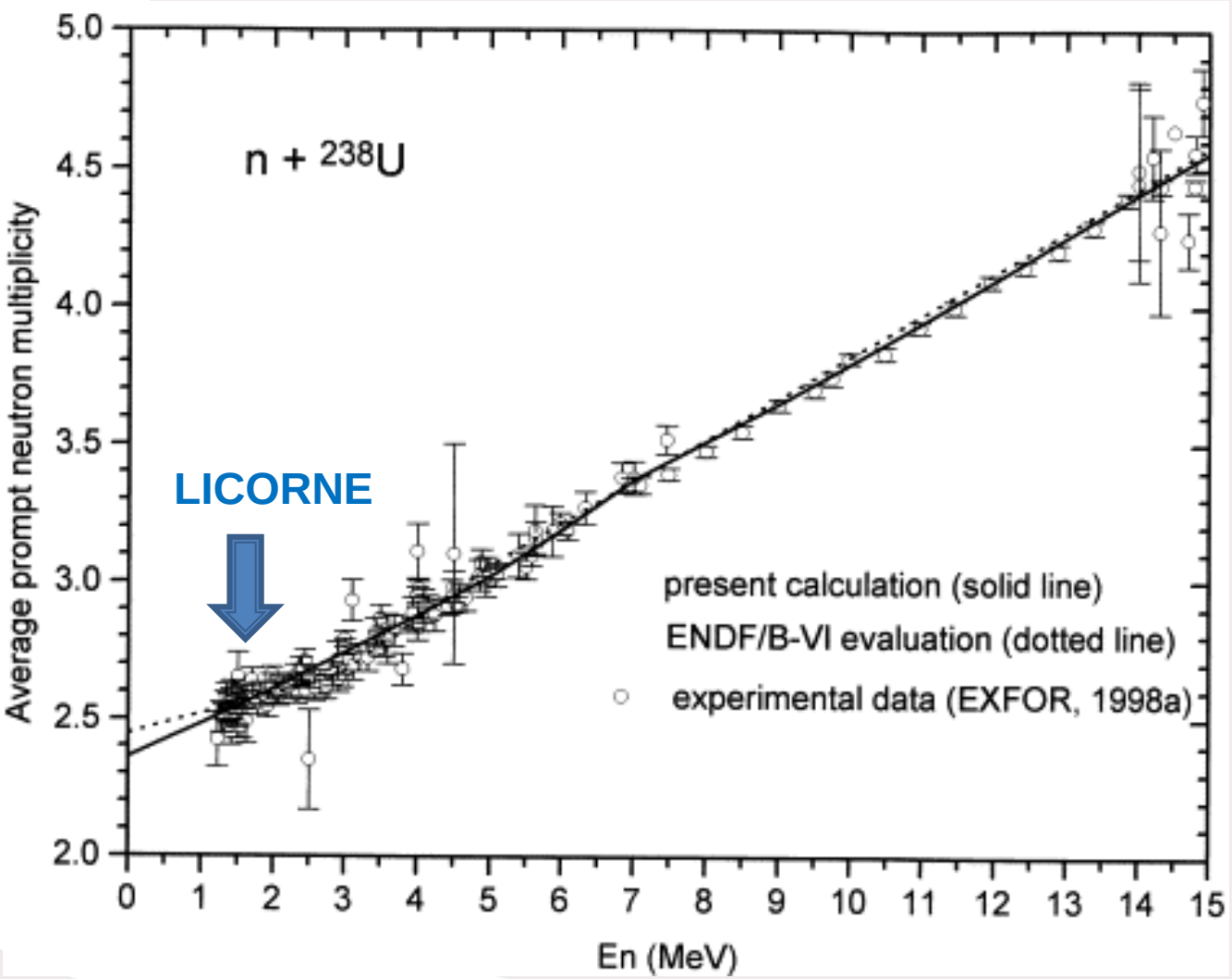
MULTIPLICITY VERSUS ENERGY DISCRIMINATION: ^{252}Cf



MULTIPLICITY VERSUS ENERGY DISCRIMINATION: ^{60}CO



NEUTRON MULTIPLICITIES



Fission becomes more symmetric with increasing E_n

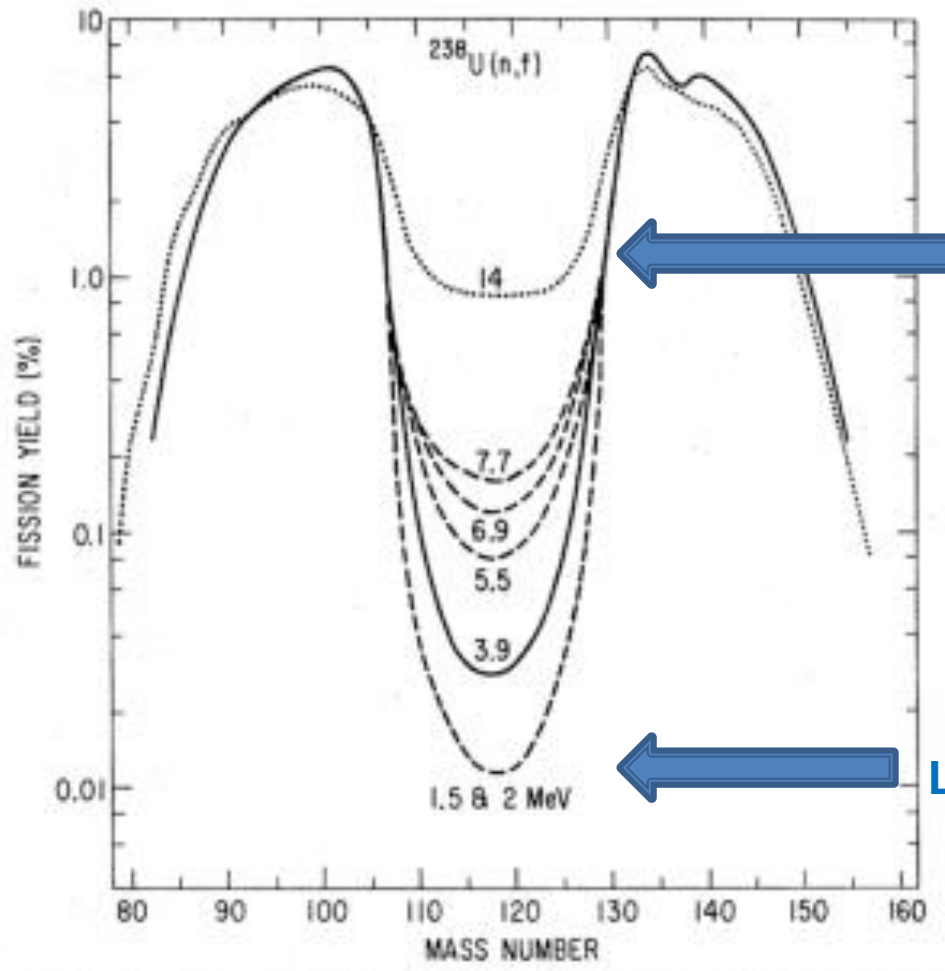
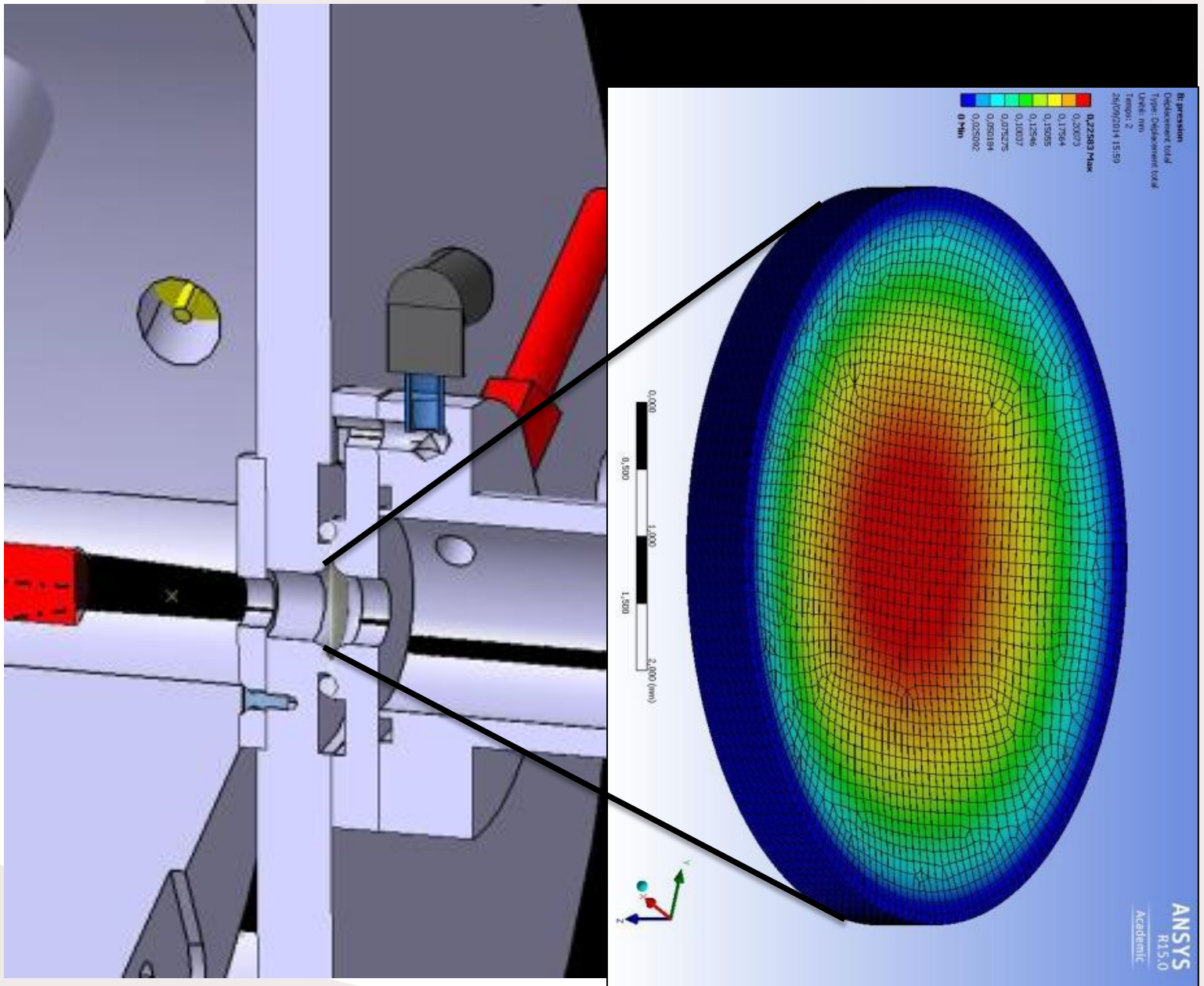


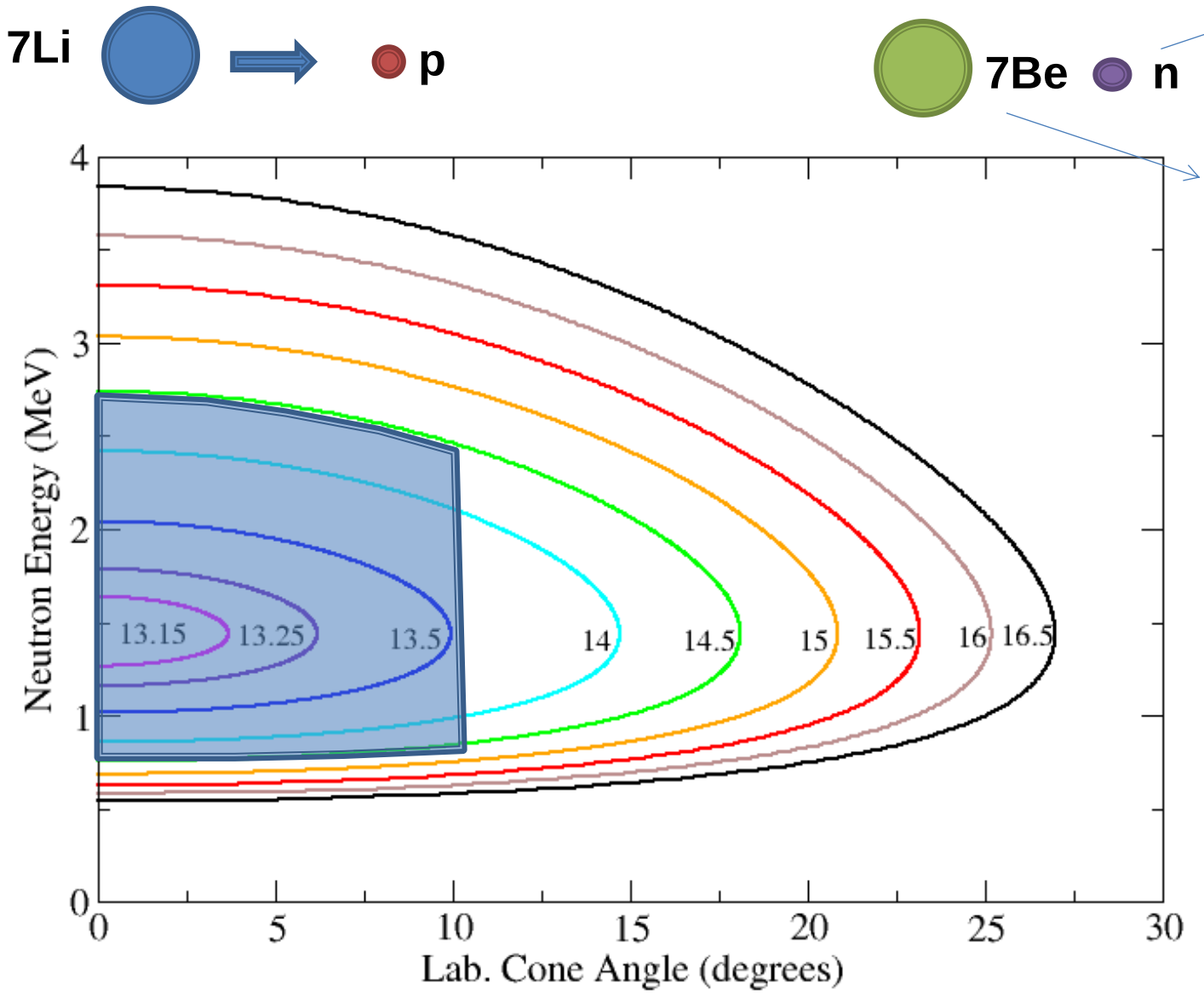
FIG. 1. Mass-yield curves for monoenergetic-neutron-induced fission of ^{238}U.

NFS

LICORNE

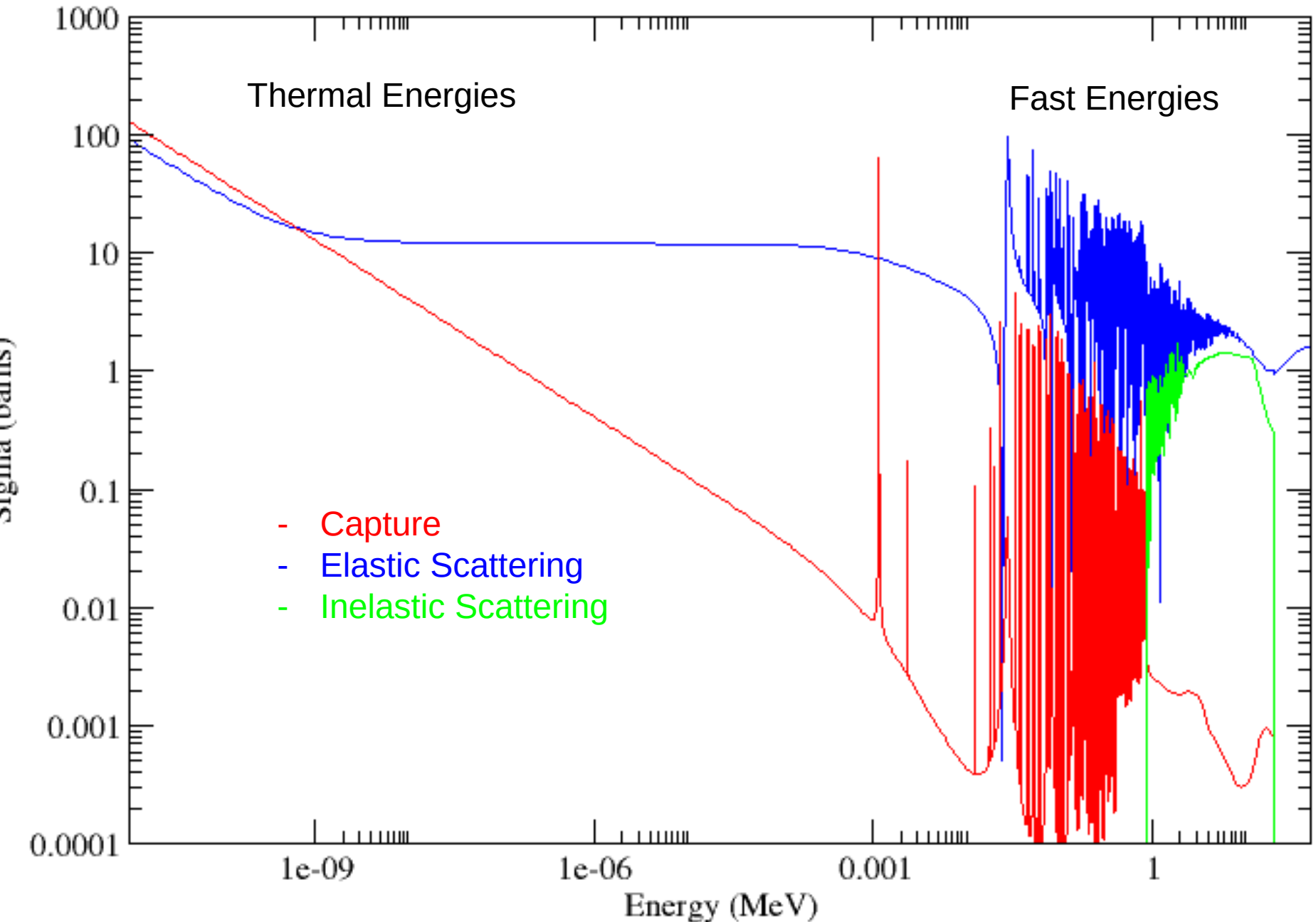
GAS TARGET WINDOW



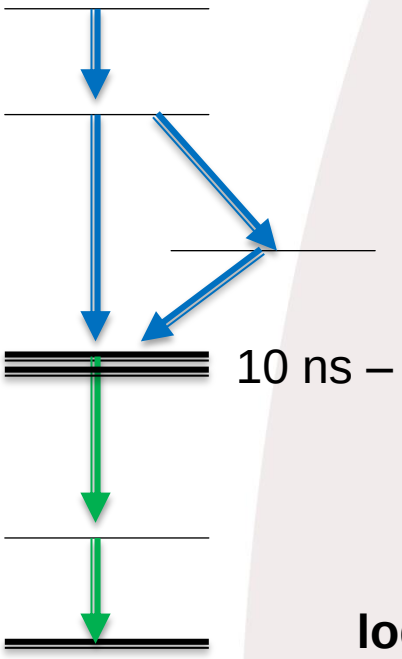


Maximum fluxes ~10^8 n/s/steradian

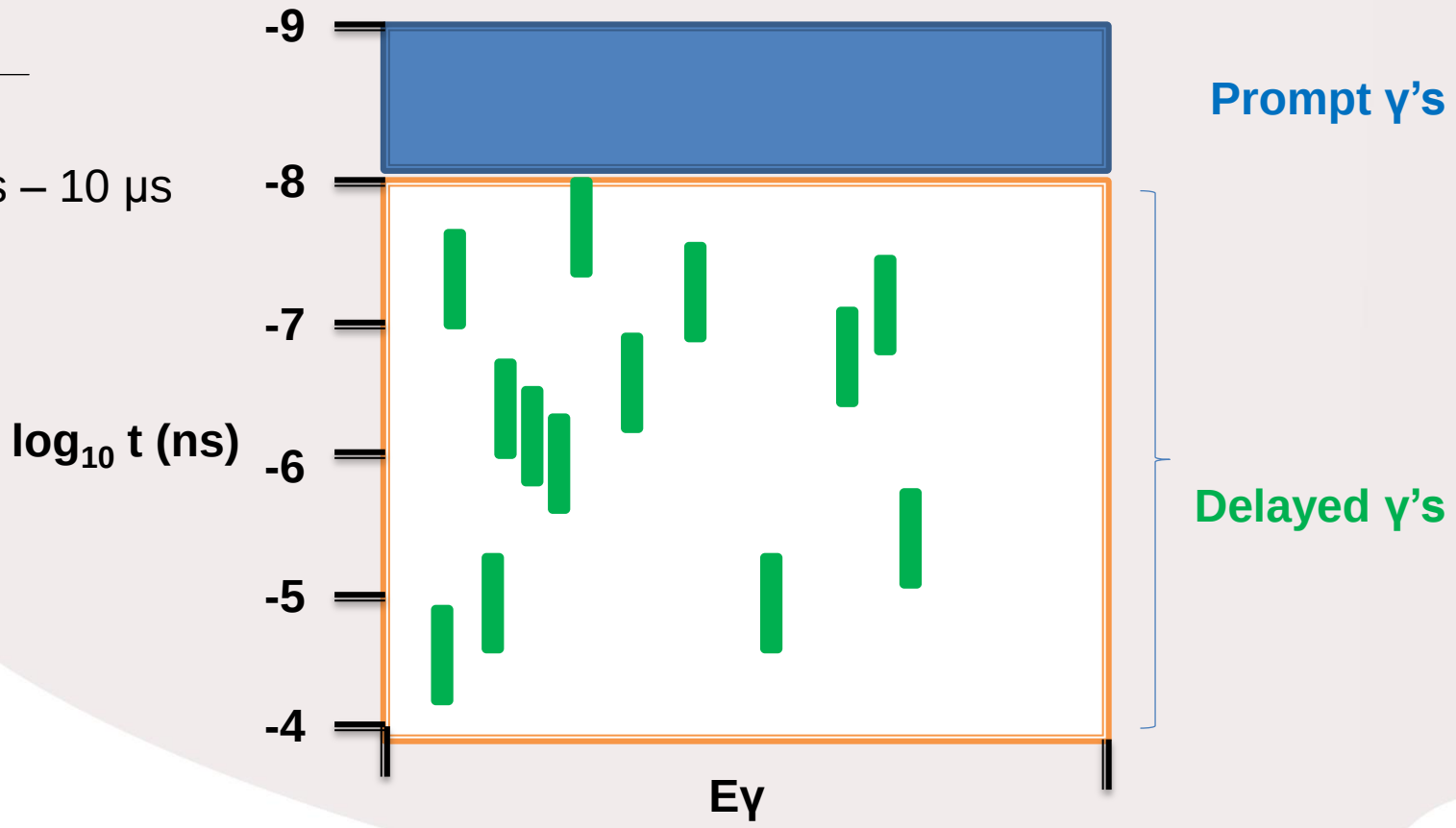
^{56}Fe Neutron Capture and Scattering Cross Sections



ISOMER TAGGING

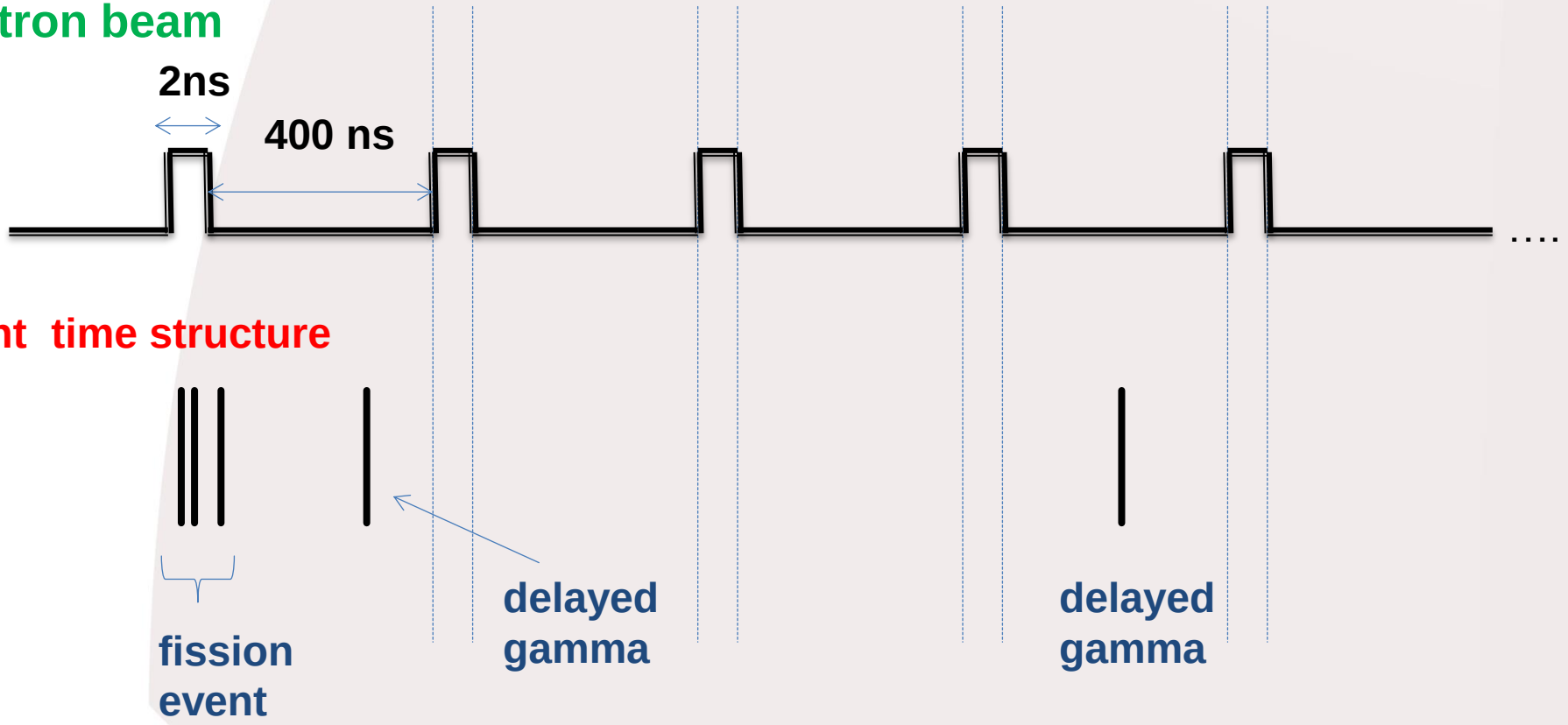


10 ns – 10 µs



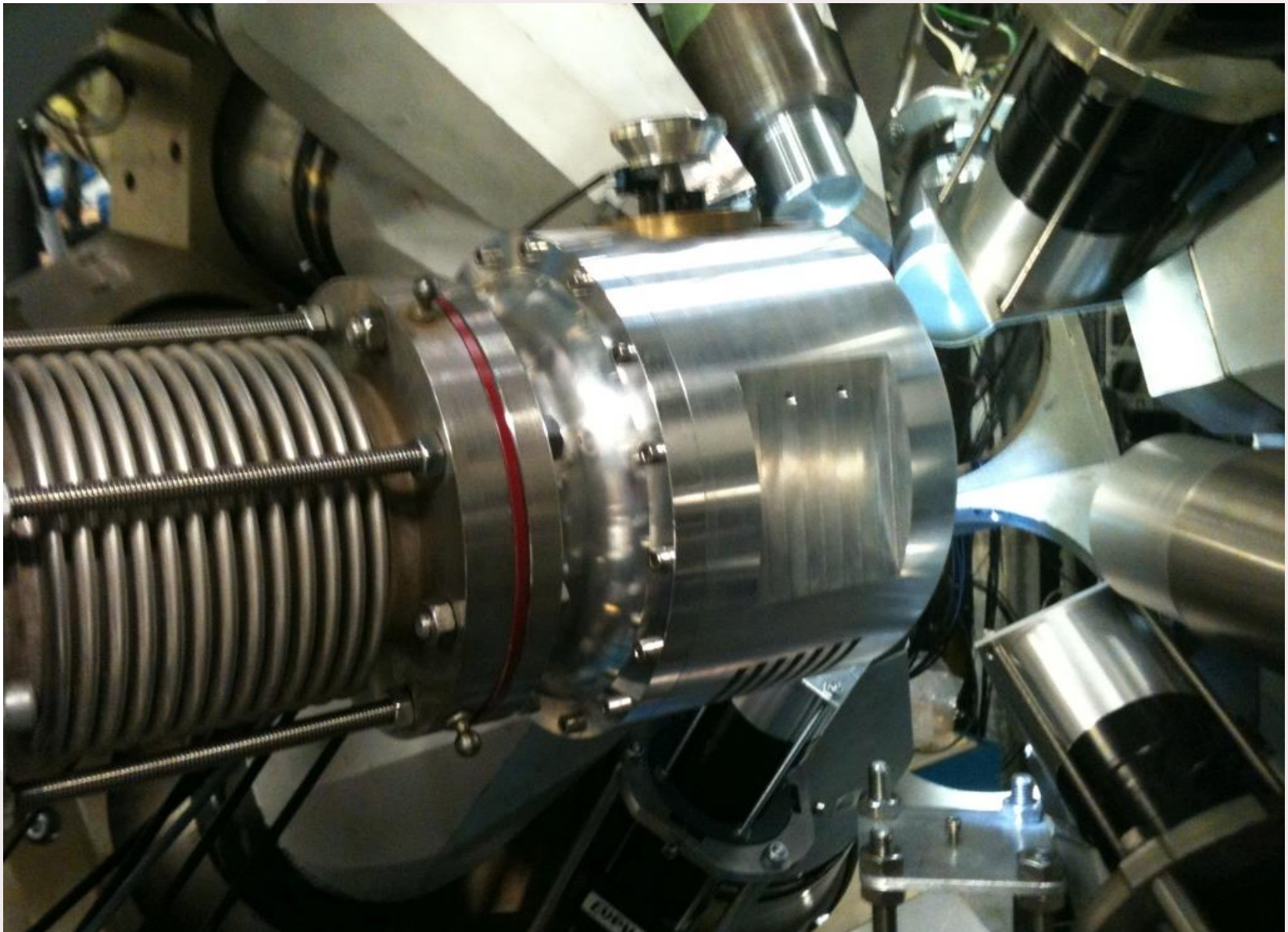
PULSED NEUTRON BEAM

LICORNE pulsed neutron beam

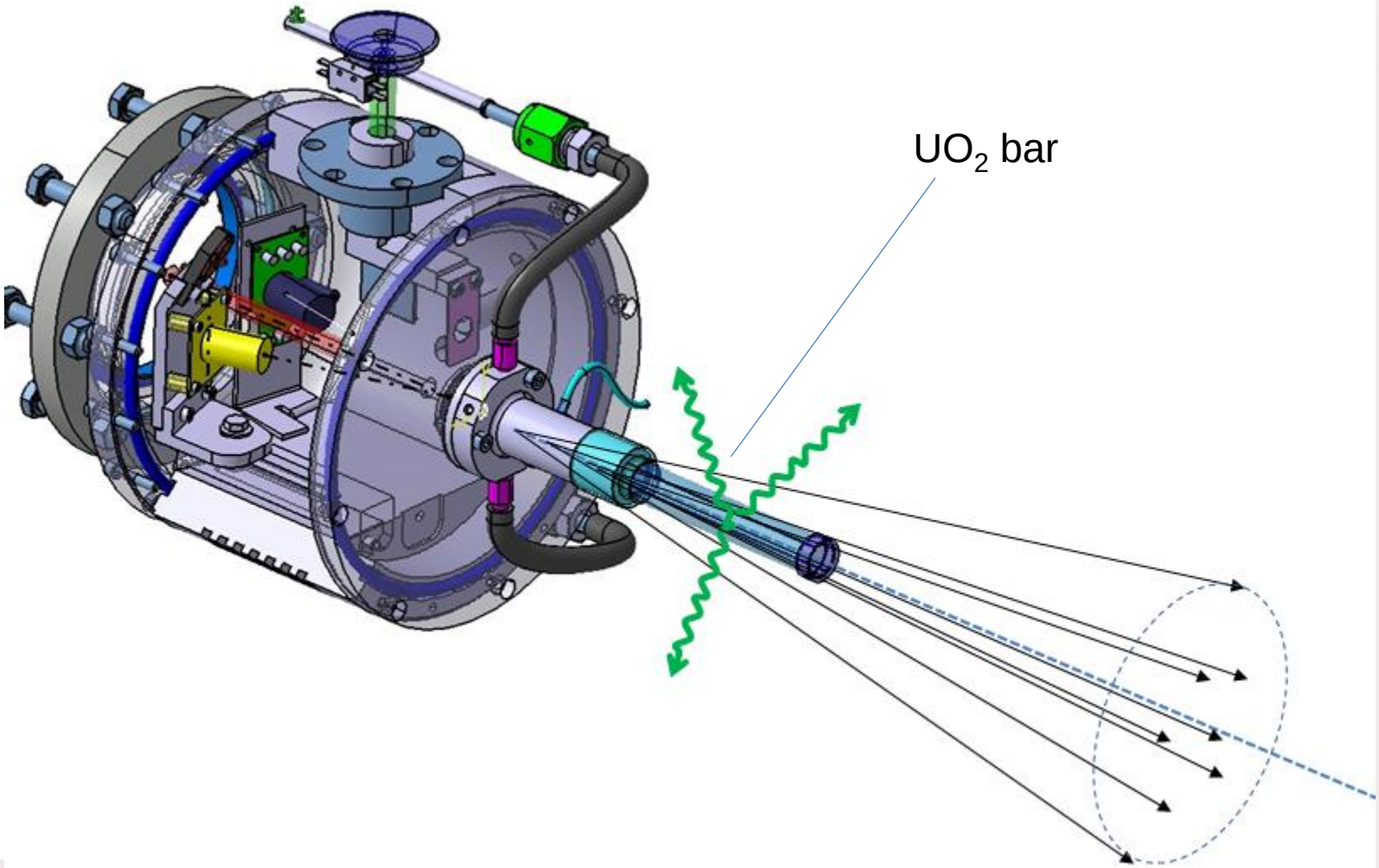


- **Average time between fission events is ~100 us**
- **Effective time window 10 ns – 10 µs? Or longer?**

LICORNE + ORGAM

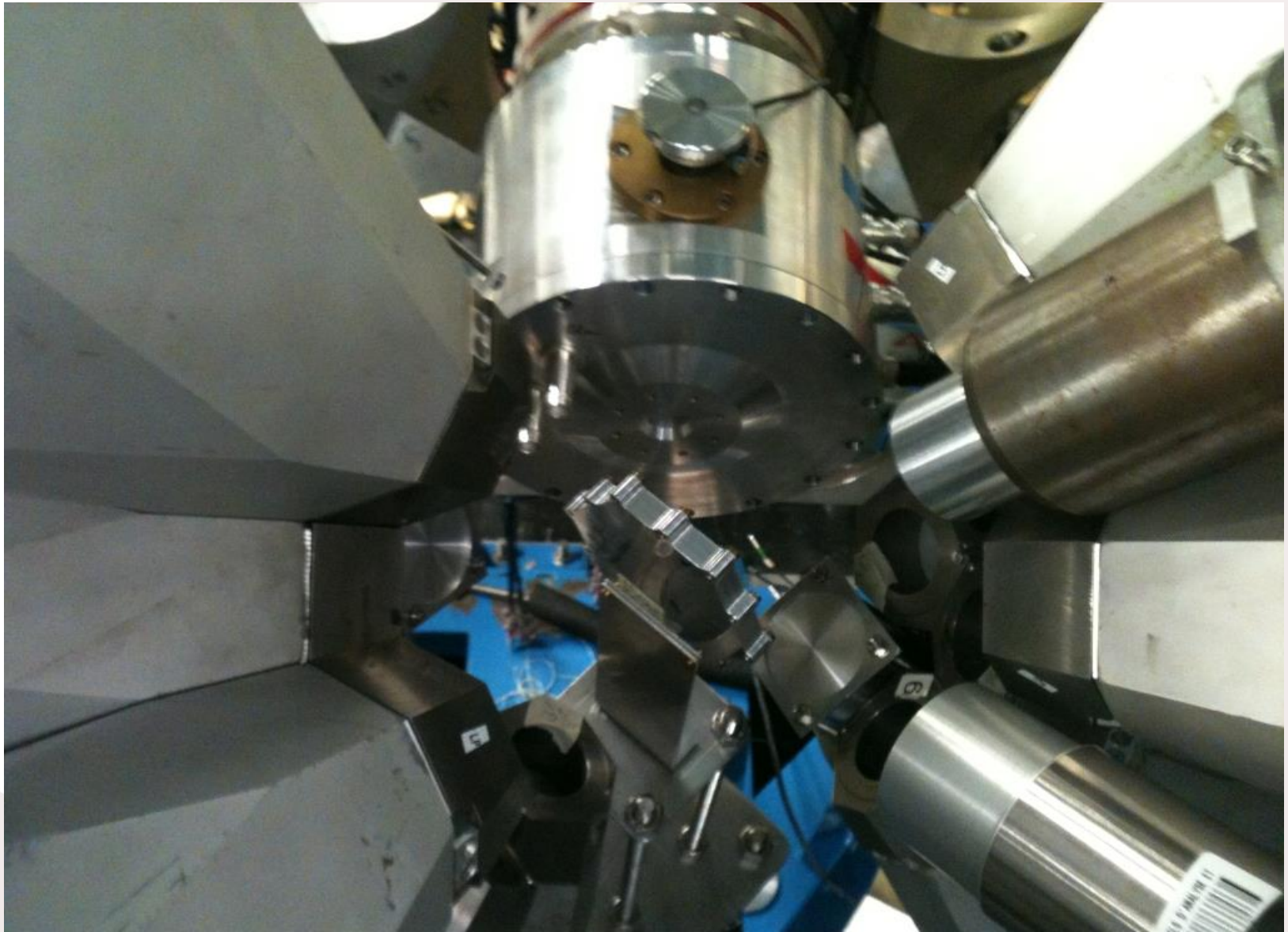


PROSPECTIVES FOR FUTURE MEASUREMENTS



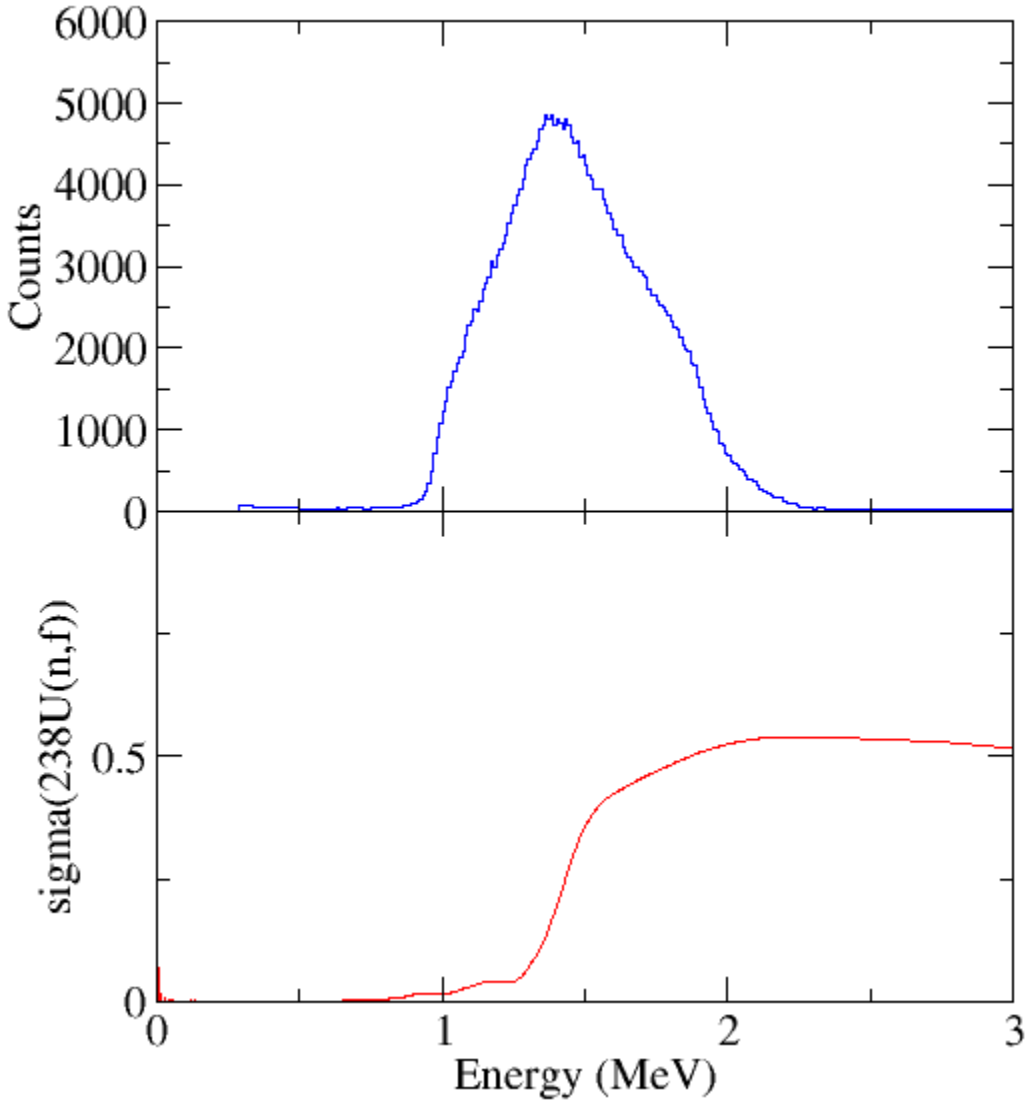
Total Fission Rate > 150 kHz at 100nA ^{7}Li

LICORNE + ORGAM

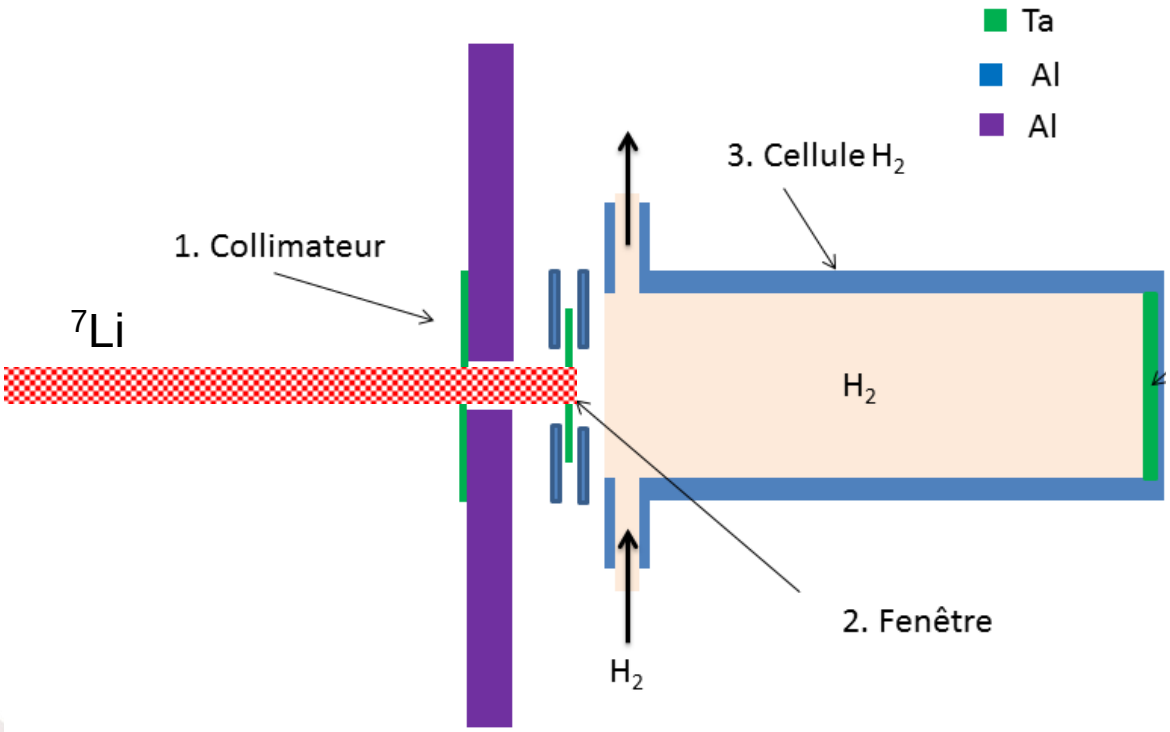


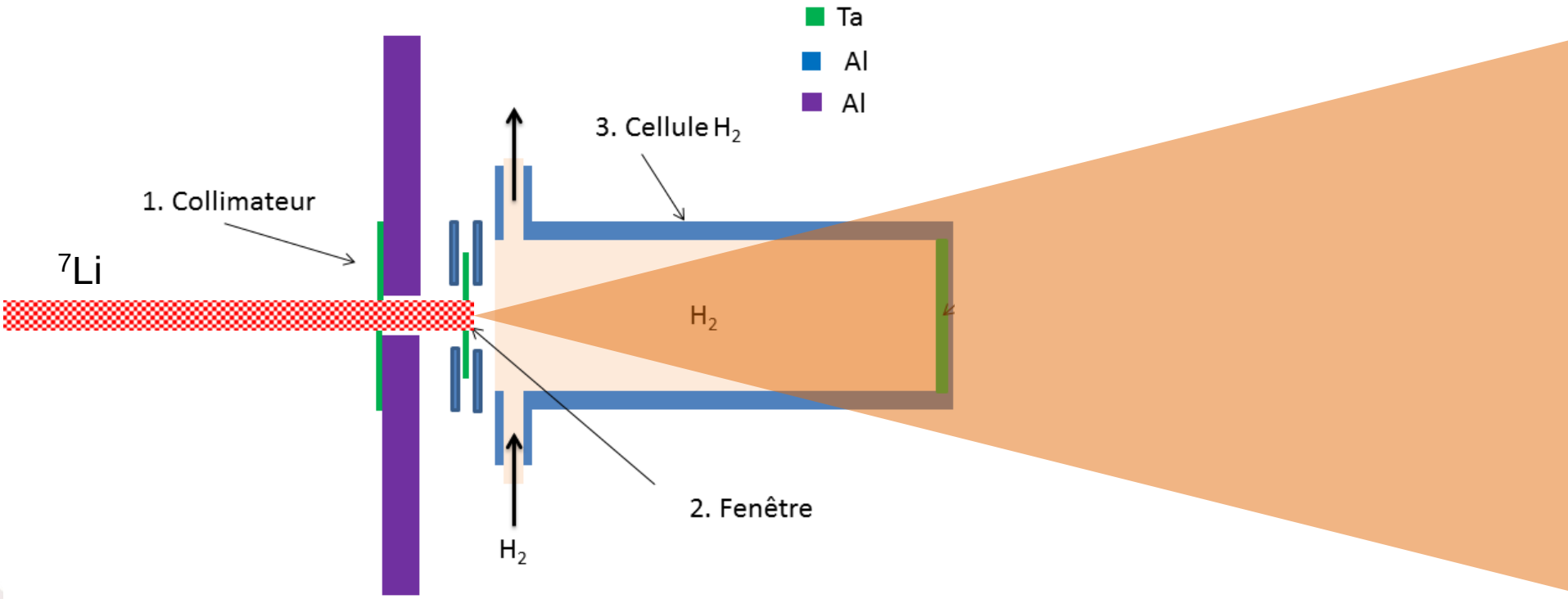
LICORNE NEUTRON SPECTRUM

E_{beam}=13.5 MeV

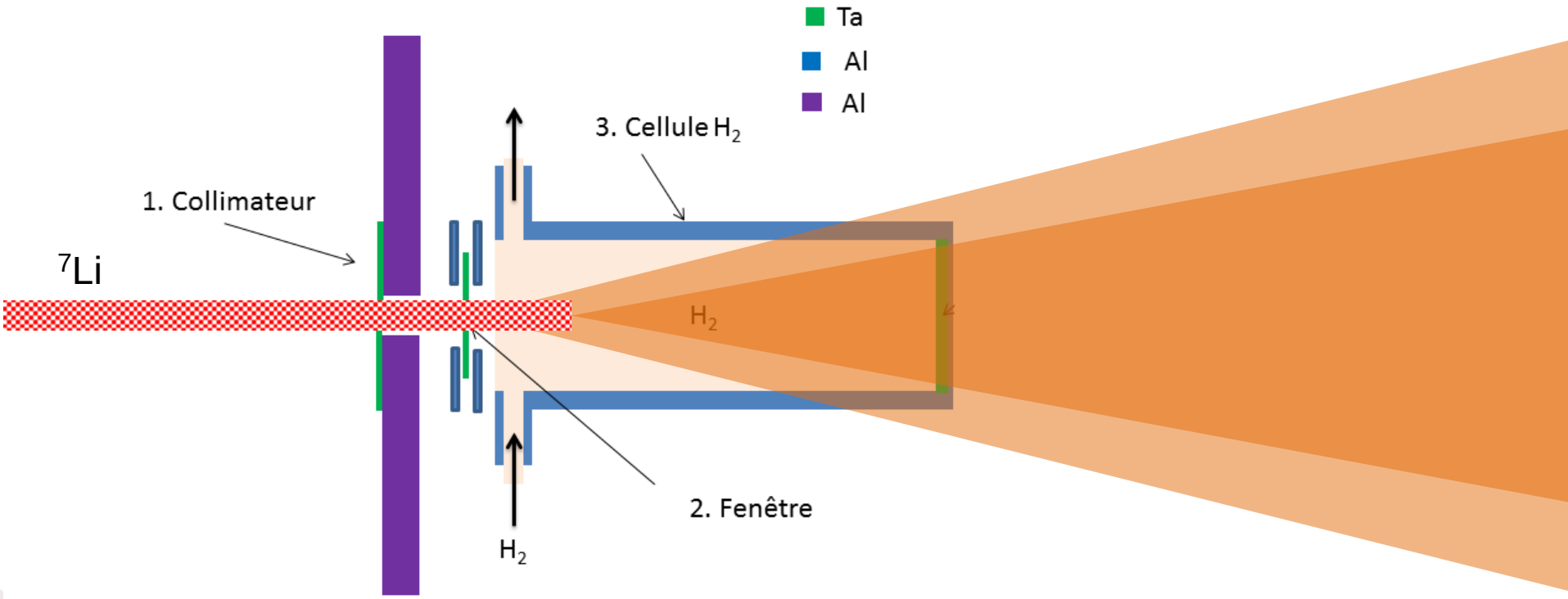


LICORNE GAS TARGET

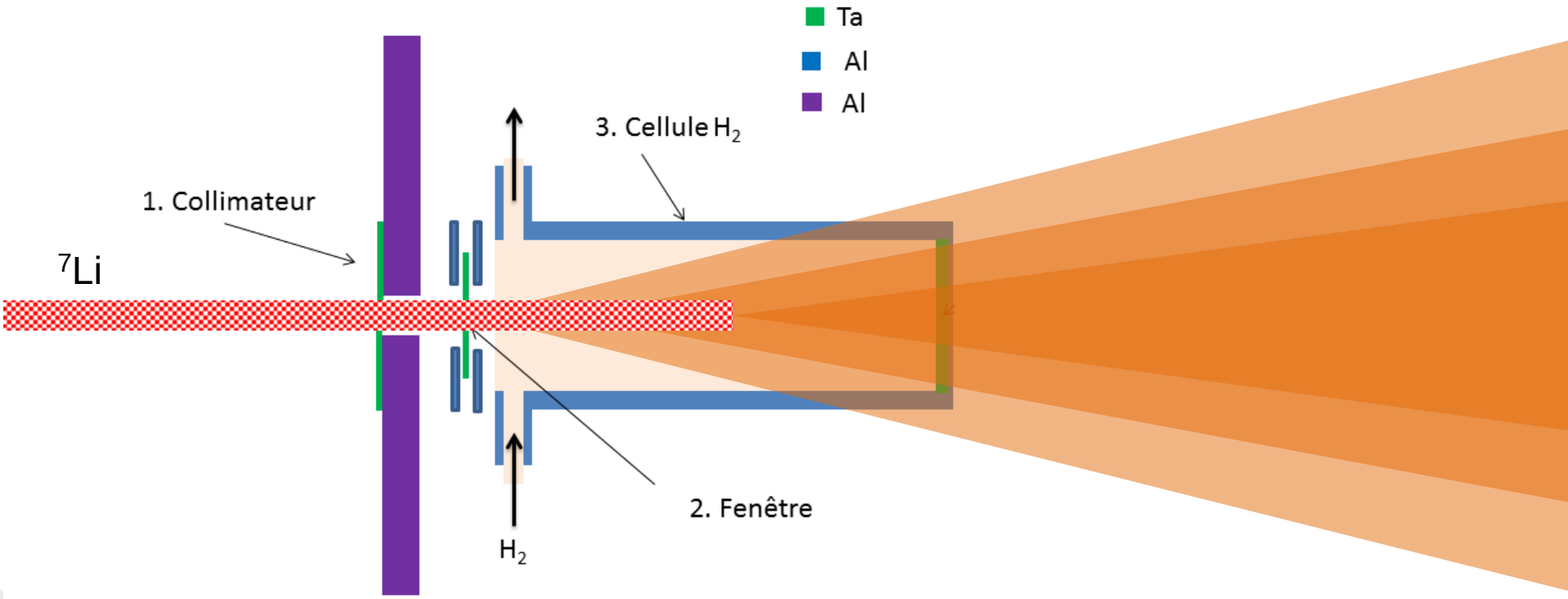




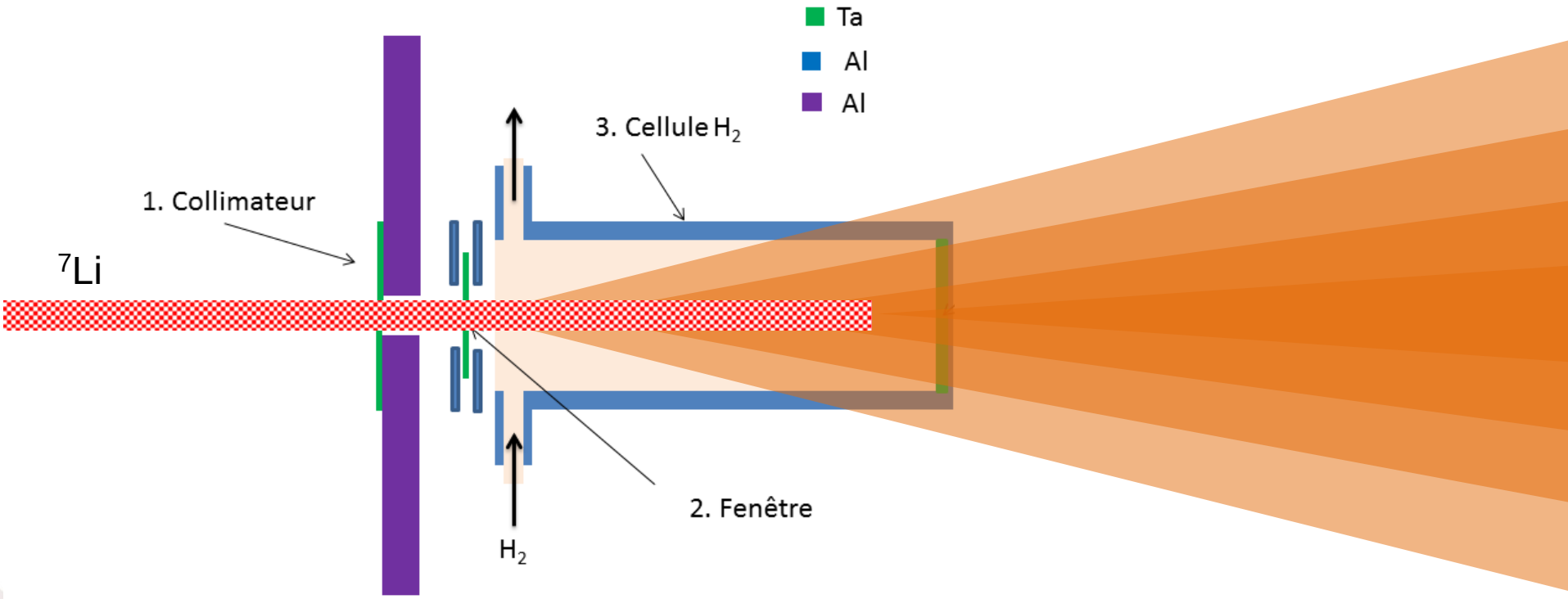
E=15 MeV



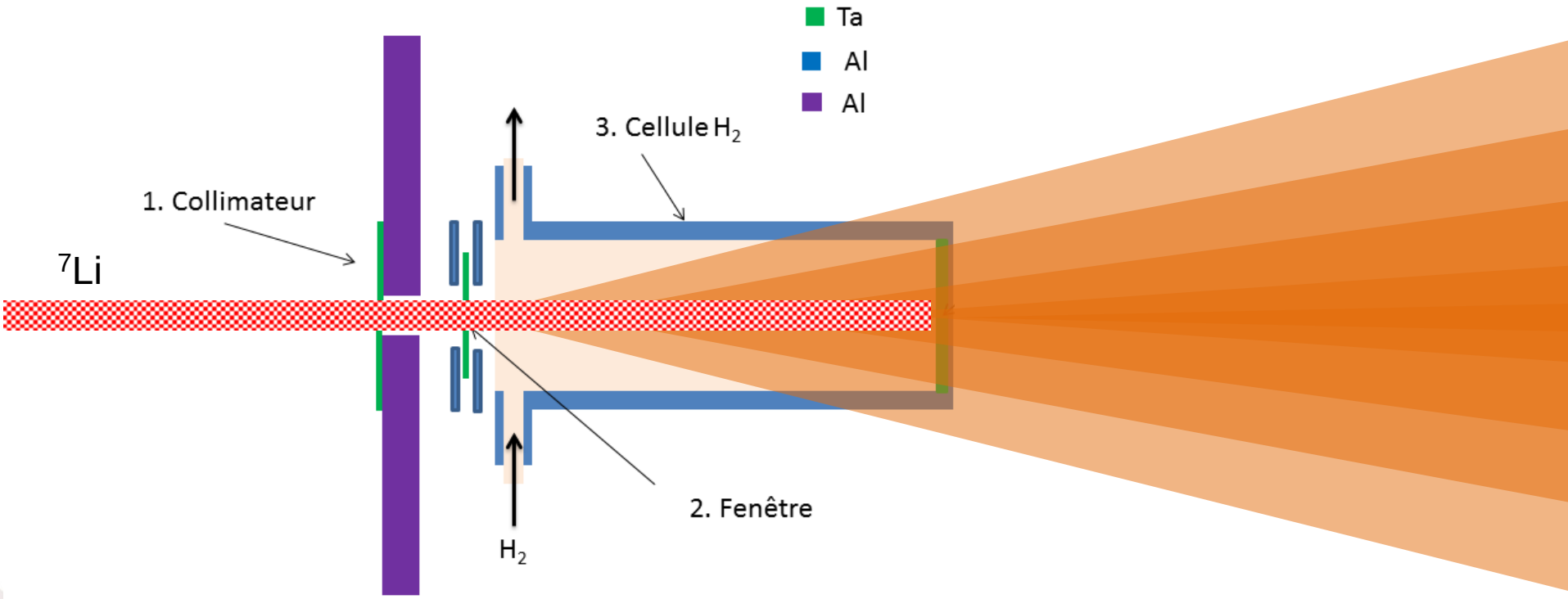
E=14.5 MeV



E=14 MeV



E=13.5 MeV



E=13 MeV