Production and study of the most exotic neutron-rich nuclei via fast neutron induced fission

J.N. Wilson, IPN Orsay

Is it possible to use beams of fast neutrons to produce and study exotic nuclei?

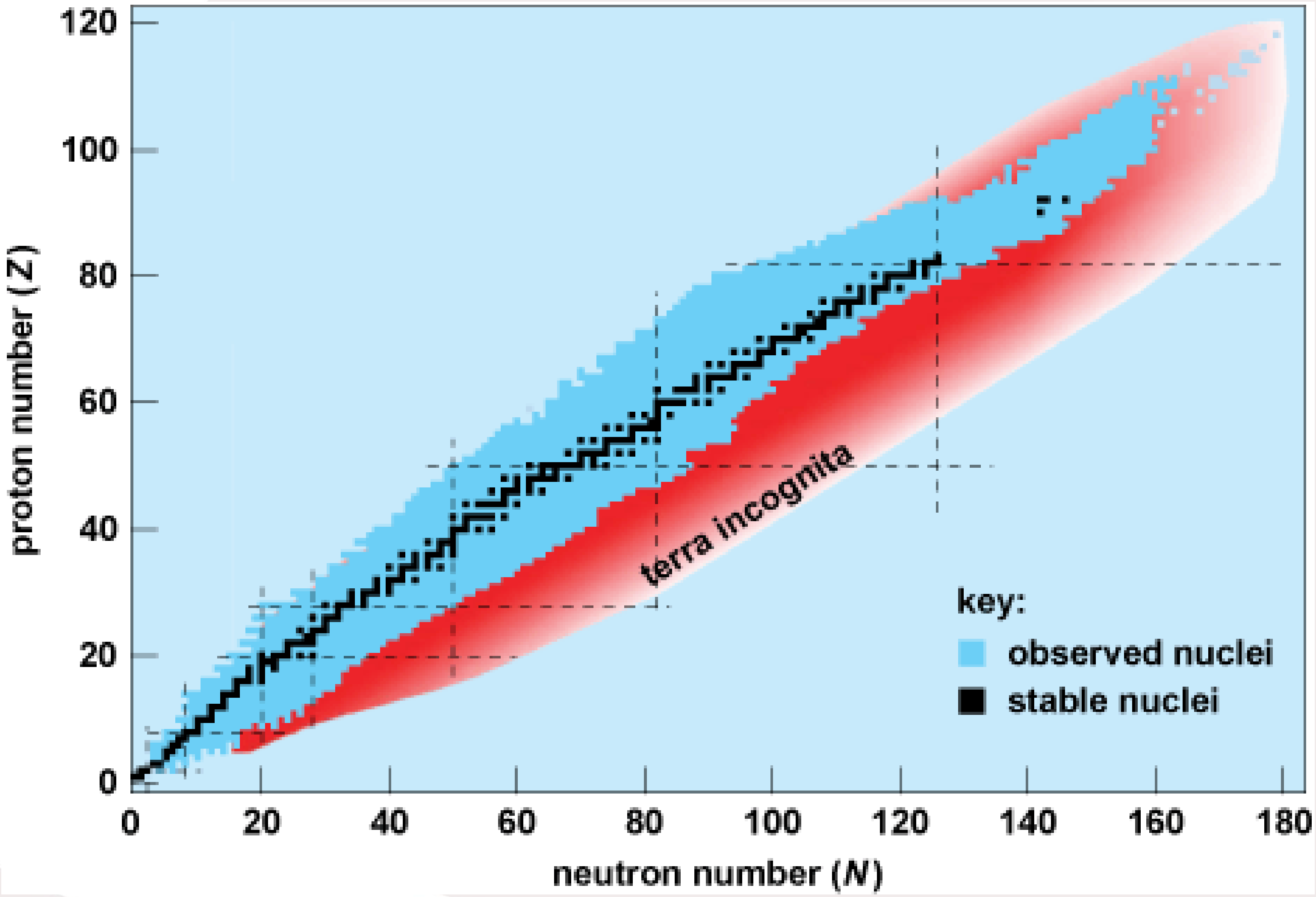
Part I

Fast neutron induced fission studies with LICORNE@IPNO (E_n ~ 2 MeV)

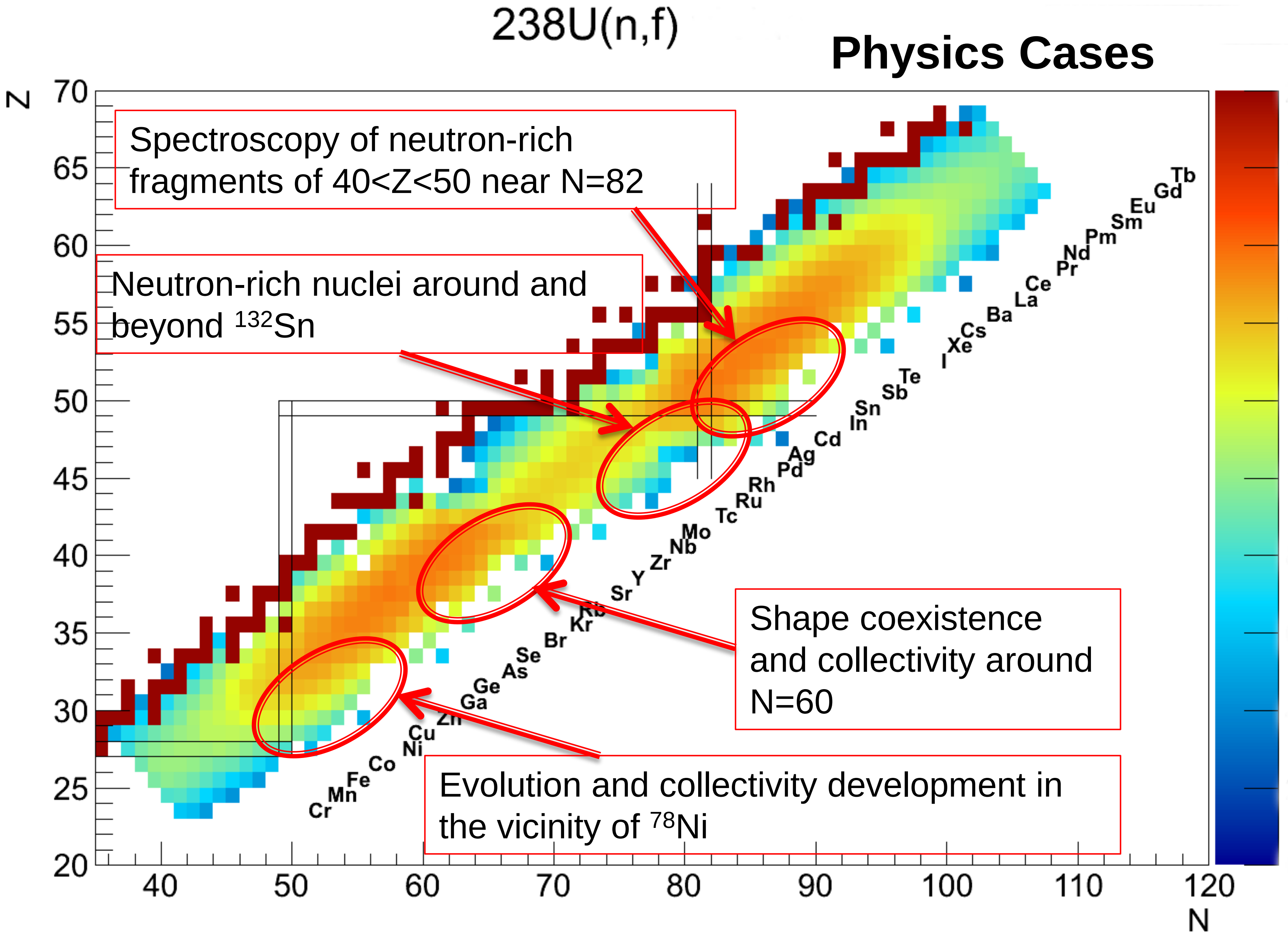
Part II

Potential fast neutron induced fission studies @IFMIF/DONES (E_n ~ 14 MeV)

THE NUCLEAR CHART



Physics Cases

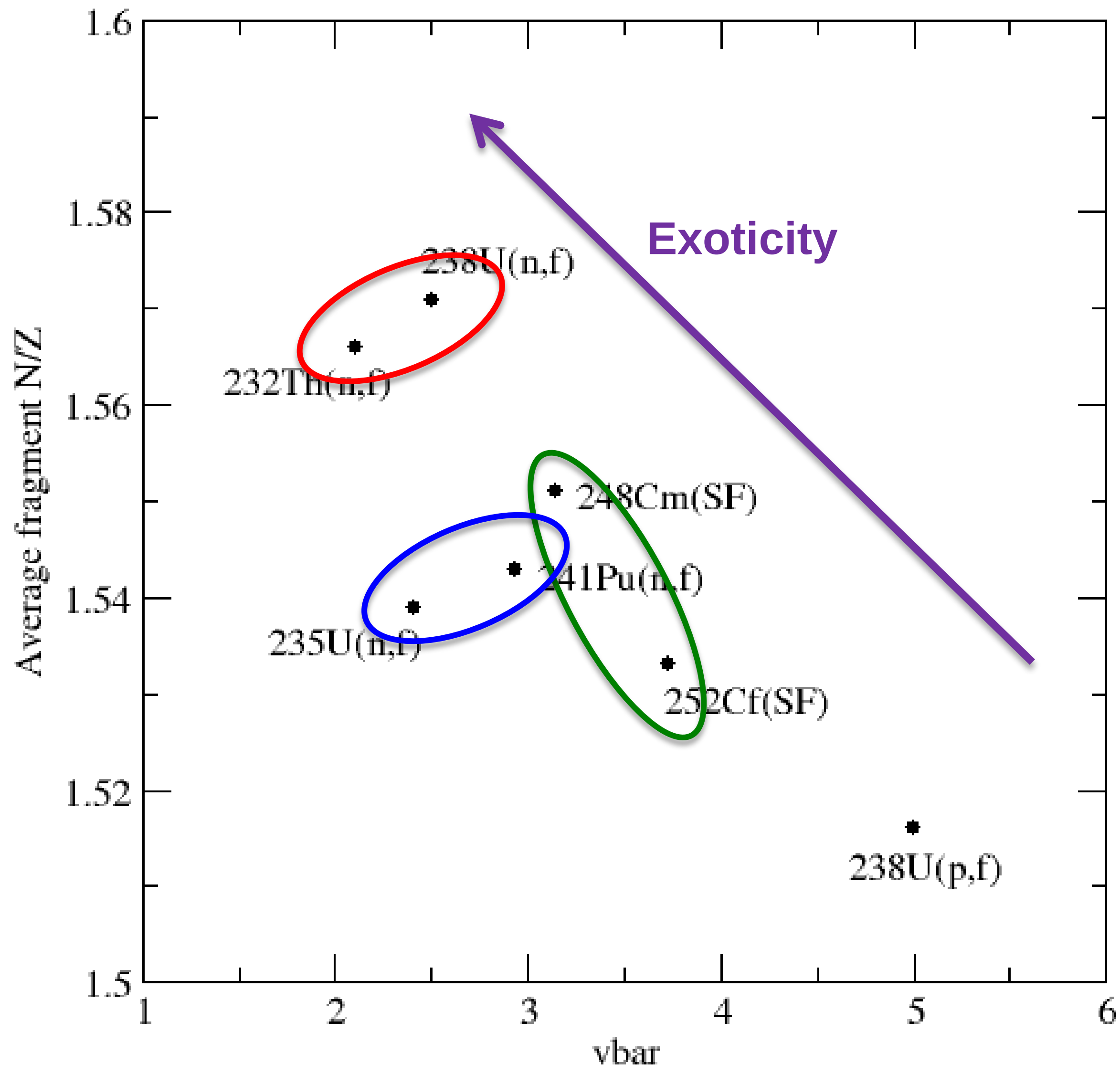


PRODUCTION OF EXOTIC NEUTRON RICH NUCLEI VIA FISSION

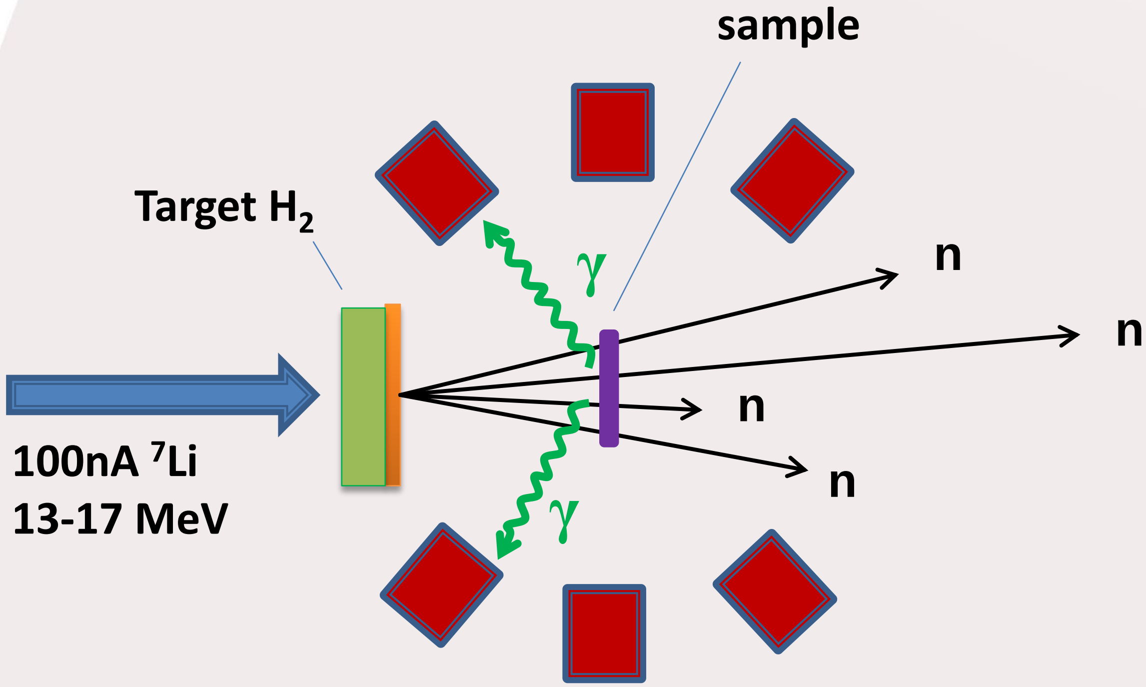
Spontaneous Fission
^{252}Cf(SF), ^{248}Cm(SF)
(Gammasphere, Euroball)

Fission induced by thermal neutrons
^{235}U(n_{th},f) ^{241}Pu(n_{th},f)
(EXILL Exogam@ILL)

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



NEUTRON PRODUCTION IN INVERSE KINEMATICS



Lithium Inverse Cinematiques ORsay NEutron source

- **reaction p(^{7}Li,^{7}Be)n using inverse kinematics**
- **Source of fast focused neutron (between 0.5 and 4 MeV)**

LICORNE II – COMMISSIONING NOV. 2014

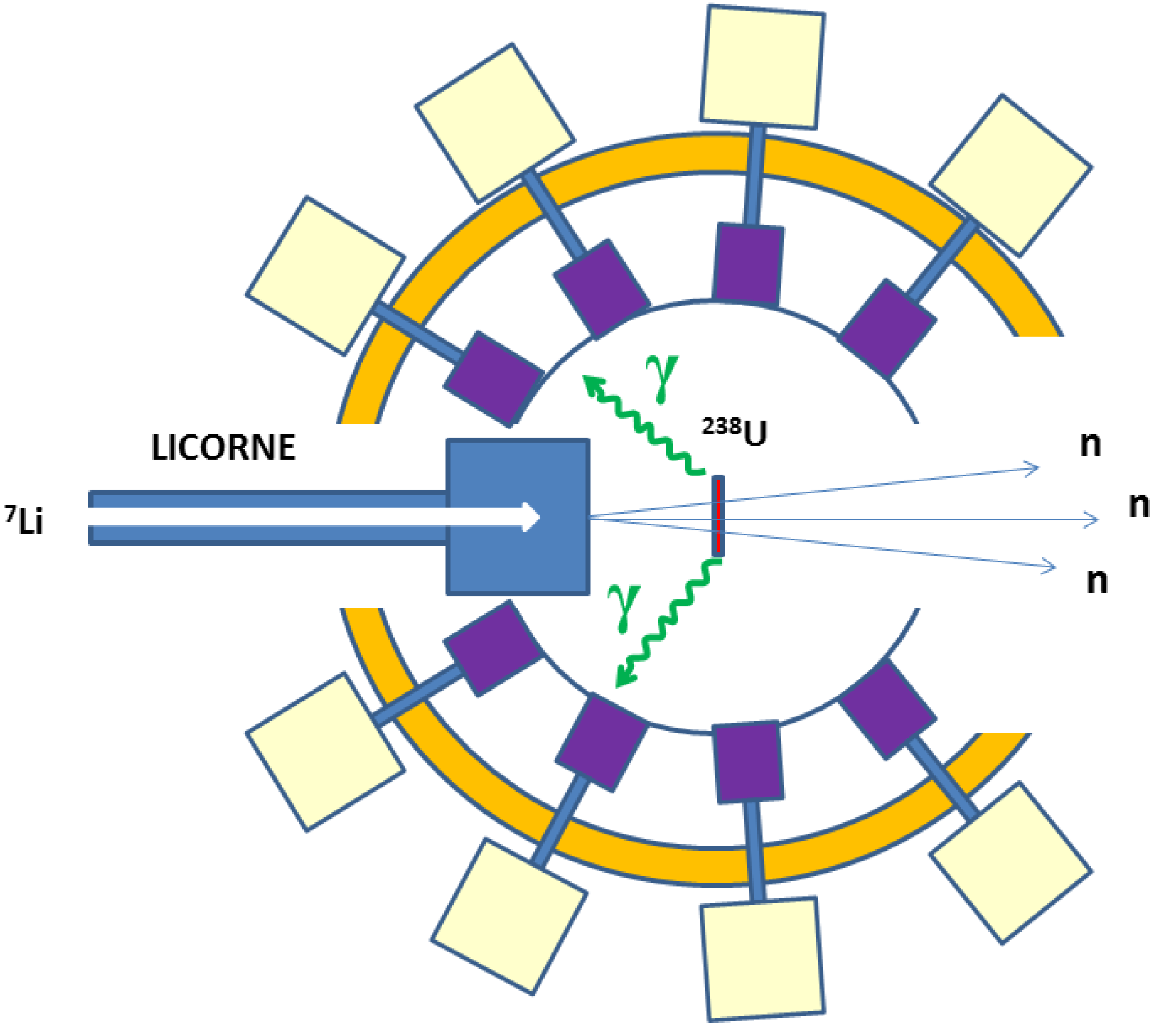
LICORNE

Hydrogen gas cells

H_2 pressure and flow control system

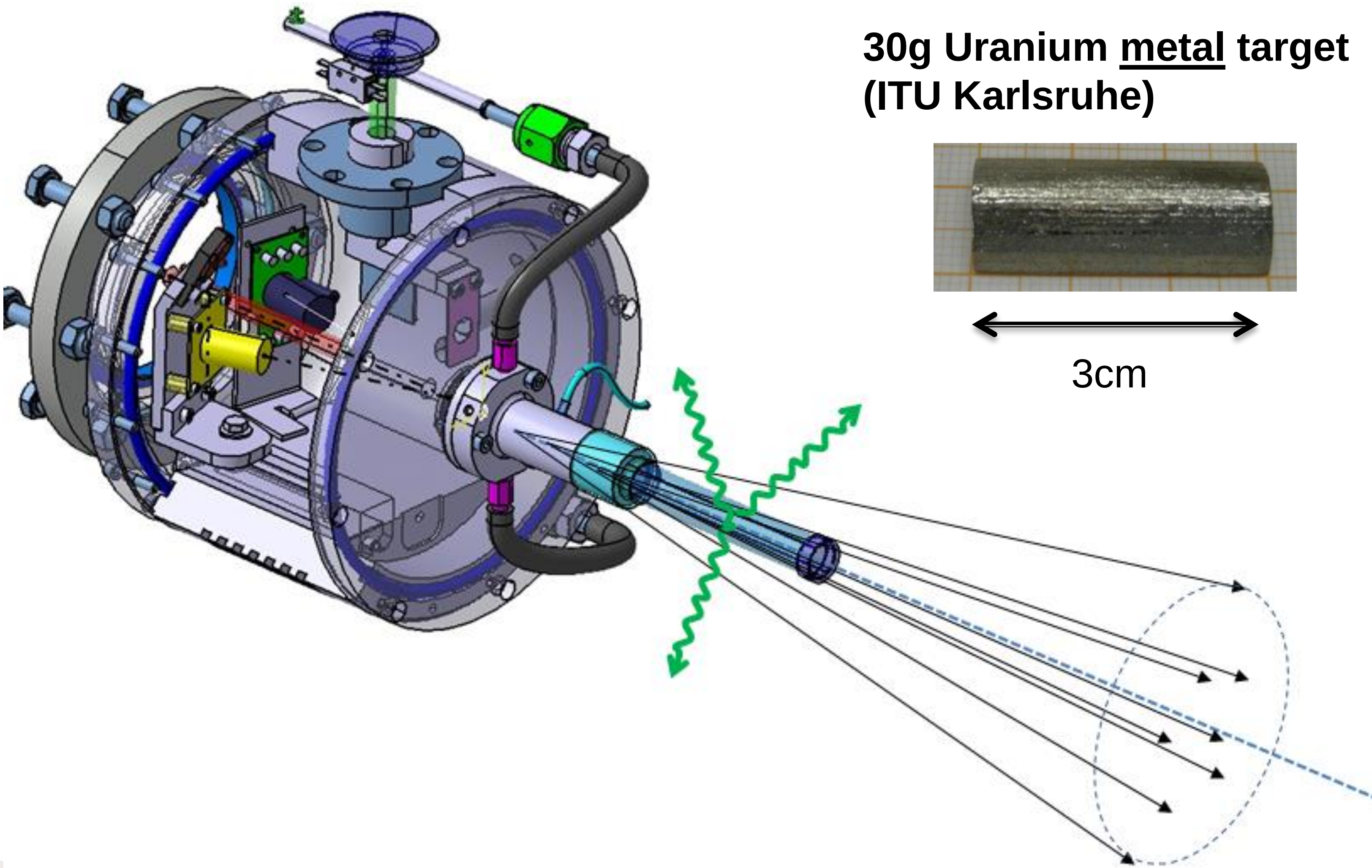
Development of a kinematically focused neutron source with the p(^{7}Li,n)^{7}Be inverse reaction
M.Lebois, J.N. Wilson et al., Nucl. Instrum. Meth. A 735 145 (2014)

COUPLING LICORNE + HPGE GAMMA SPECTROMETER



Precision spectroscopy of fast neutron induced reactions

EXPERIMENT IN MARCH 2015



30g Uranium <u>metal</u> target (ITU Karlsruhe)

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

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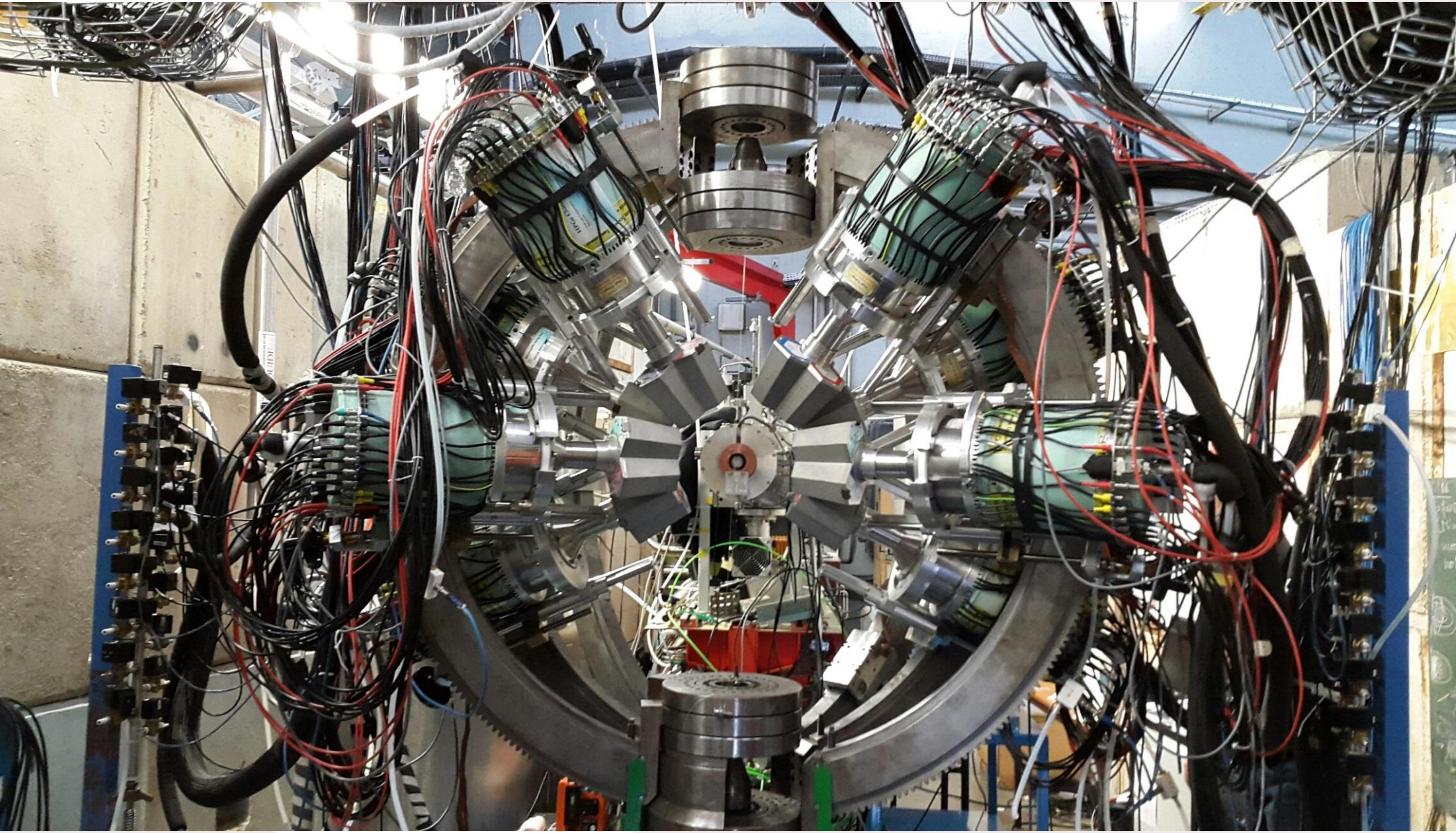
LICORNE + MINIBALL (MARCH 2015)

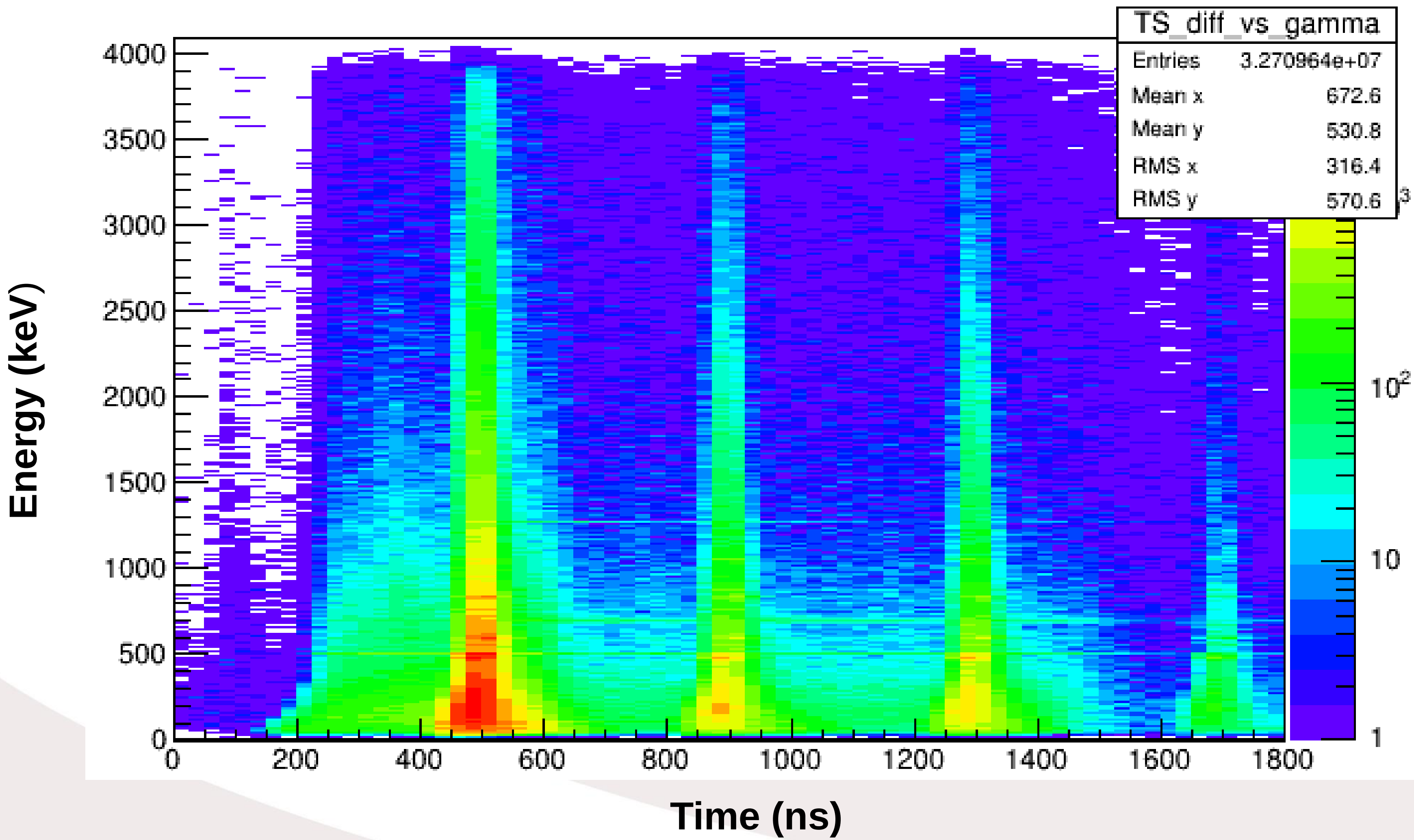


LICORNE + MINIBALL (MARCH 2015)

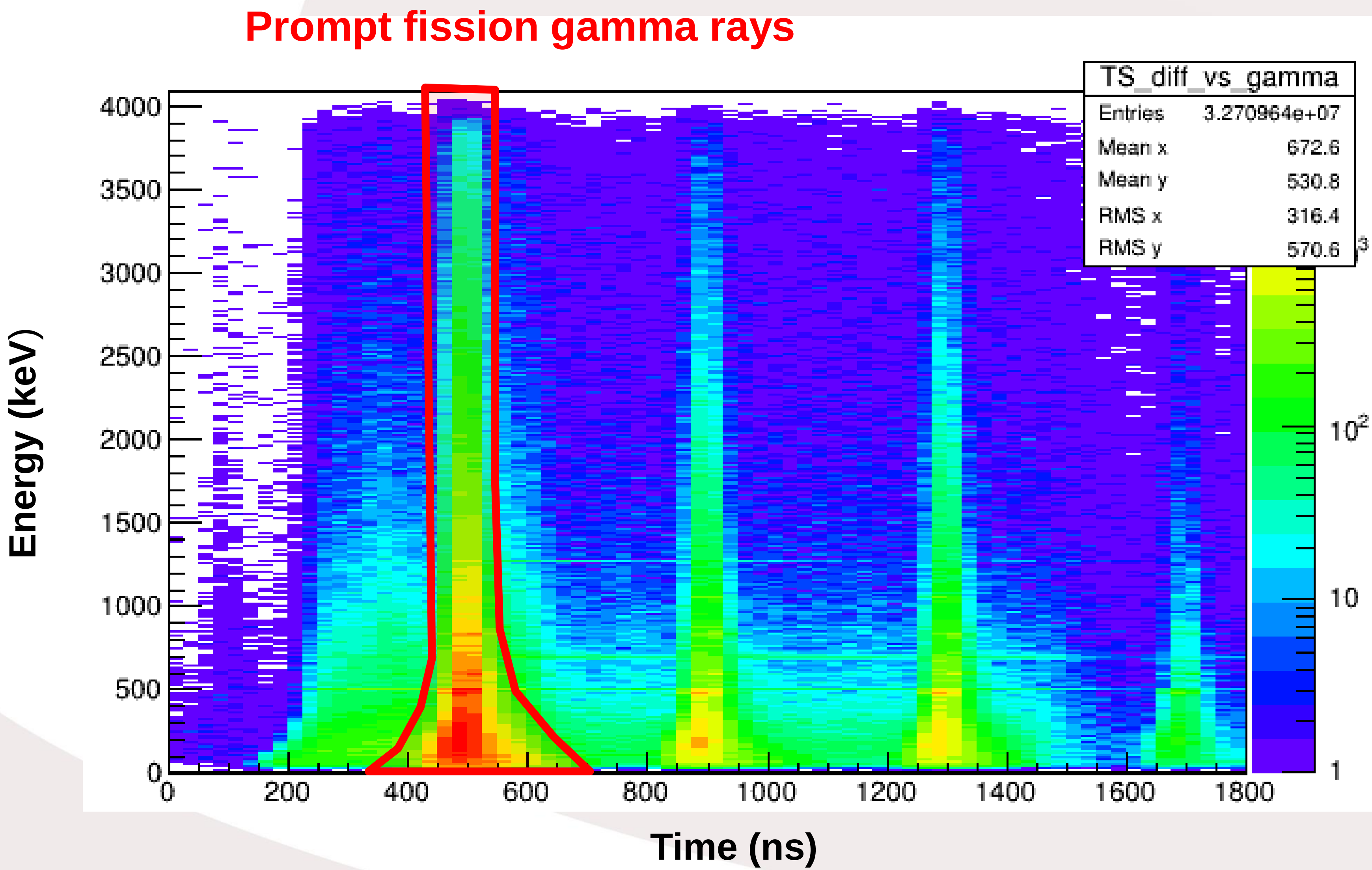
Ge singles rates
~ 8kHz

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

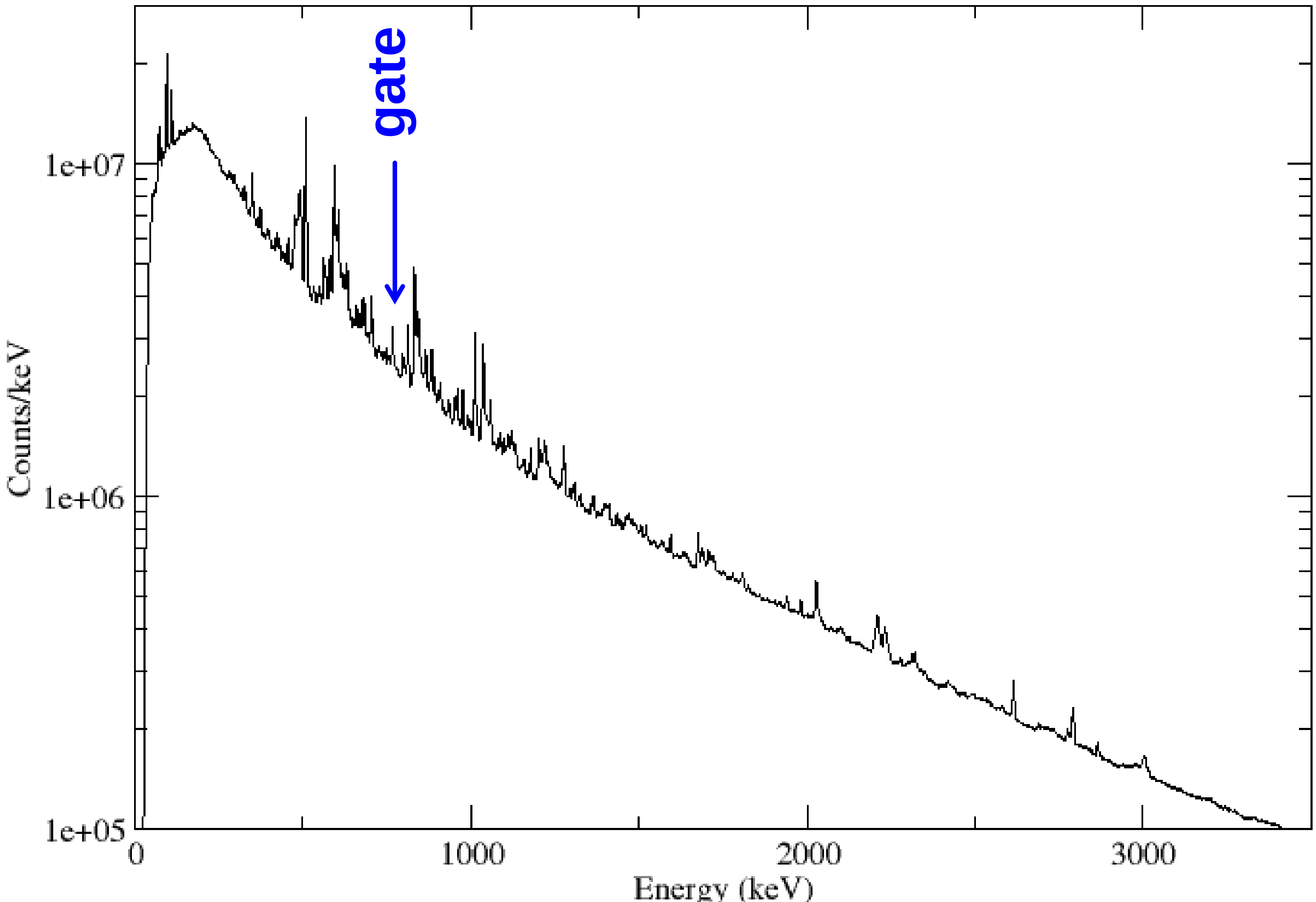
SELECTION OF PROMPT GAMMA RAYS



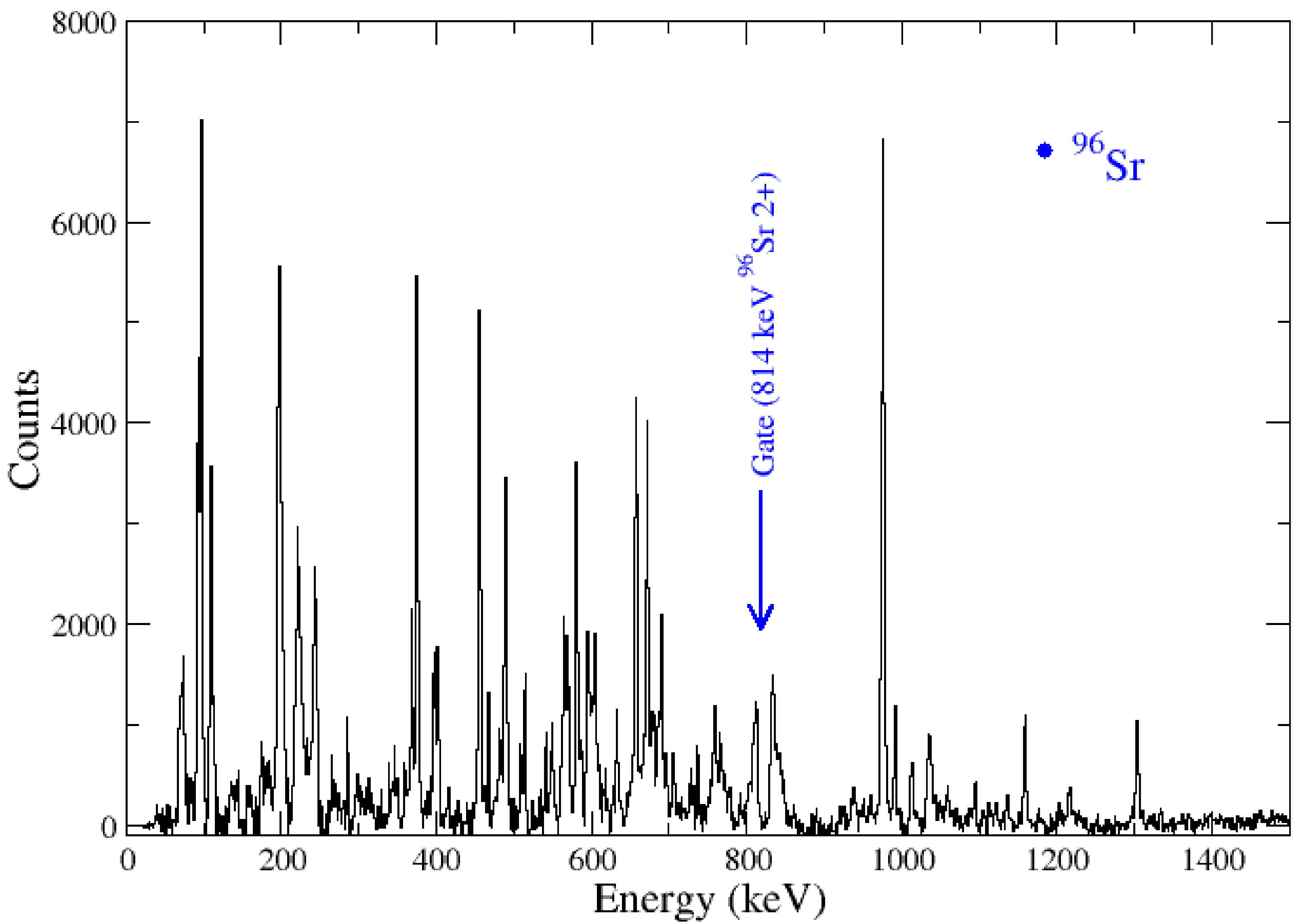
SELECTION OF PROMPT GAMMA RAYS



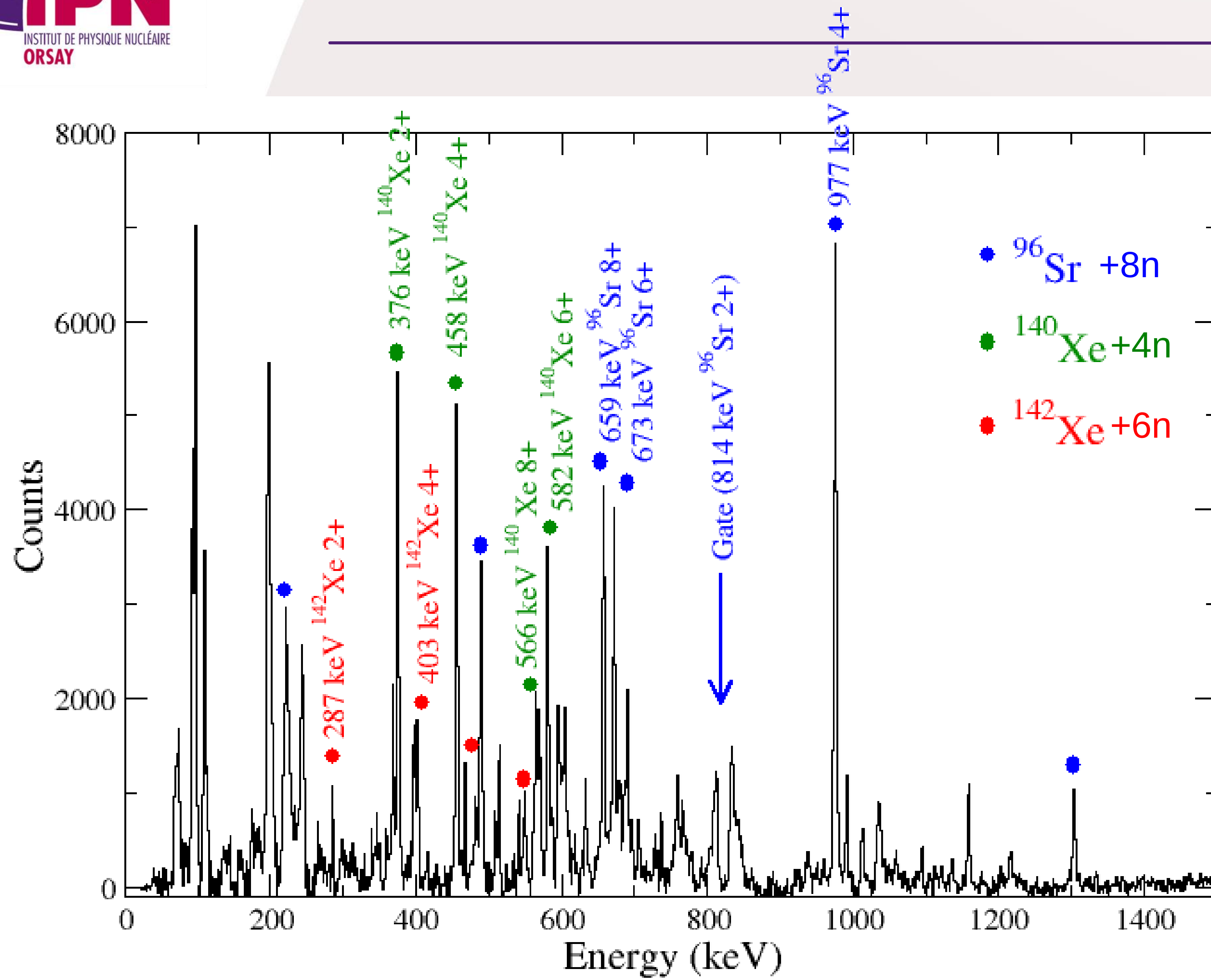
ALL PROMPT GAMMA RAYS



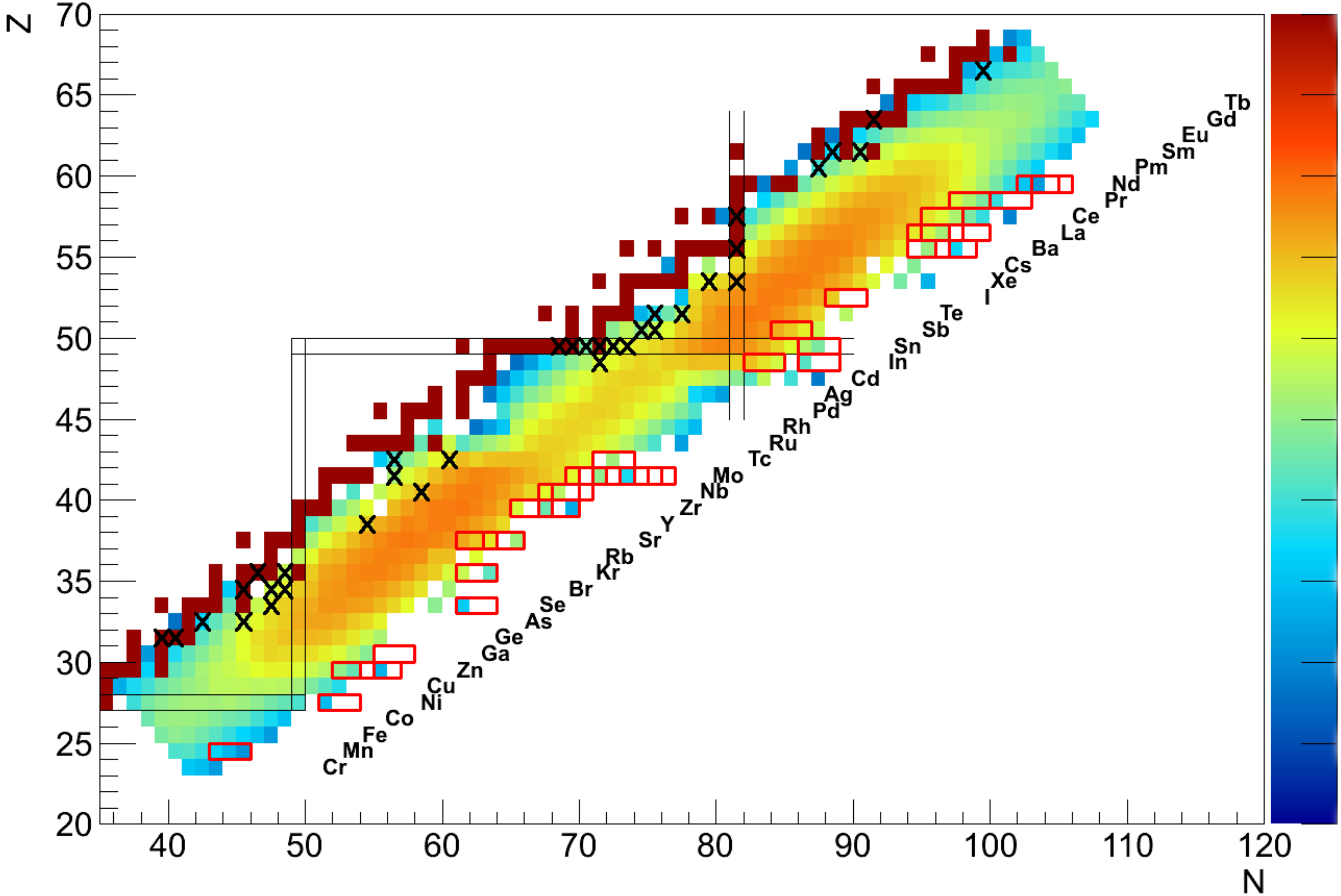
PROMPT GAMMA-RAY SPECTRA



PROMPT GAMMA-RAY SPECTRA

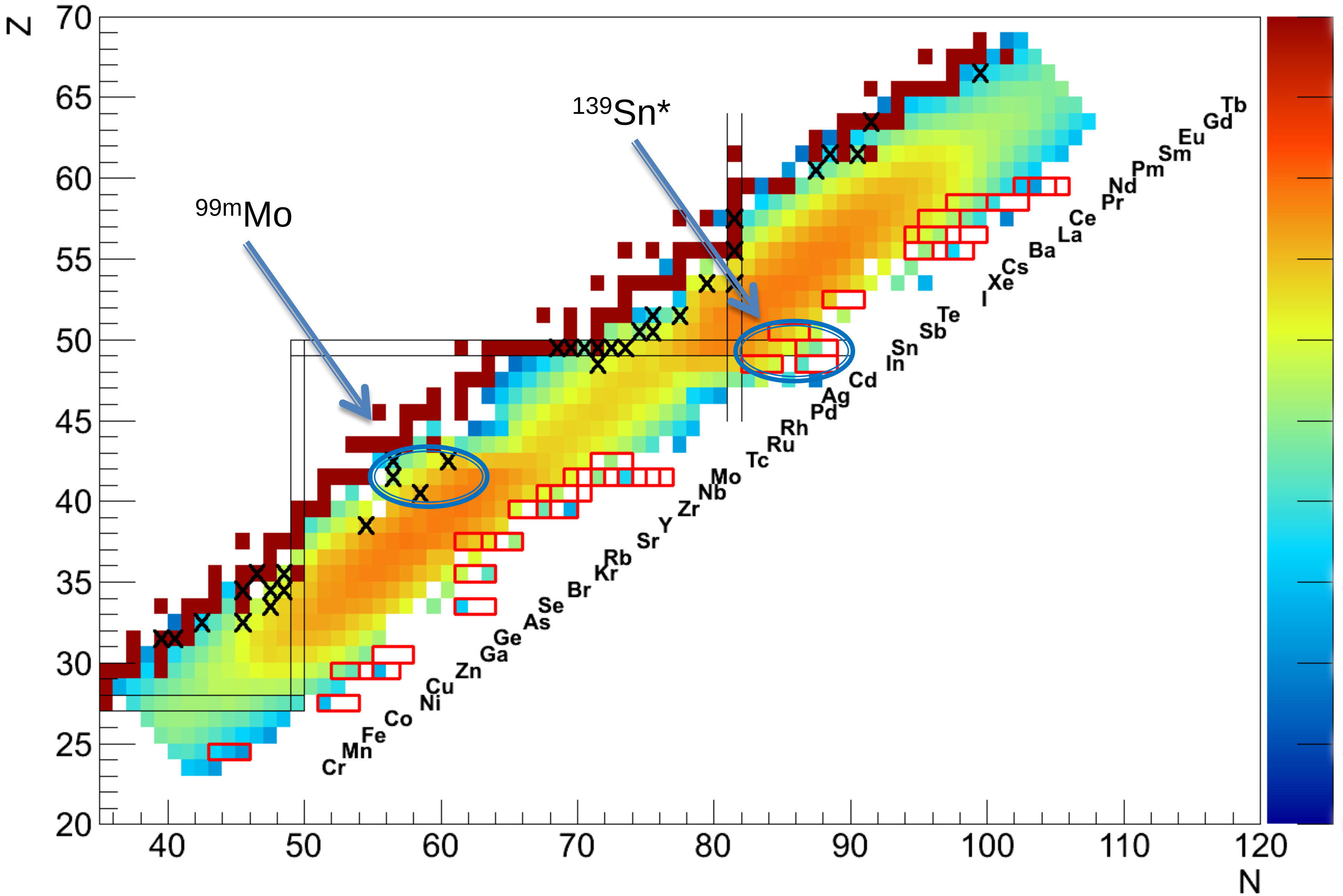


238U(n,f)



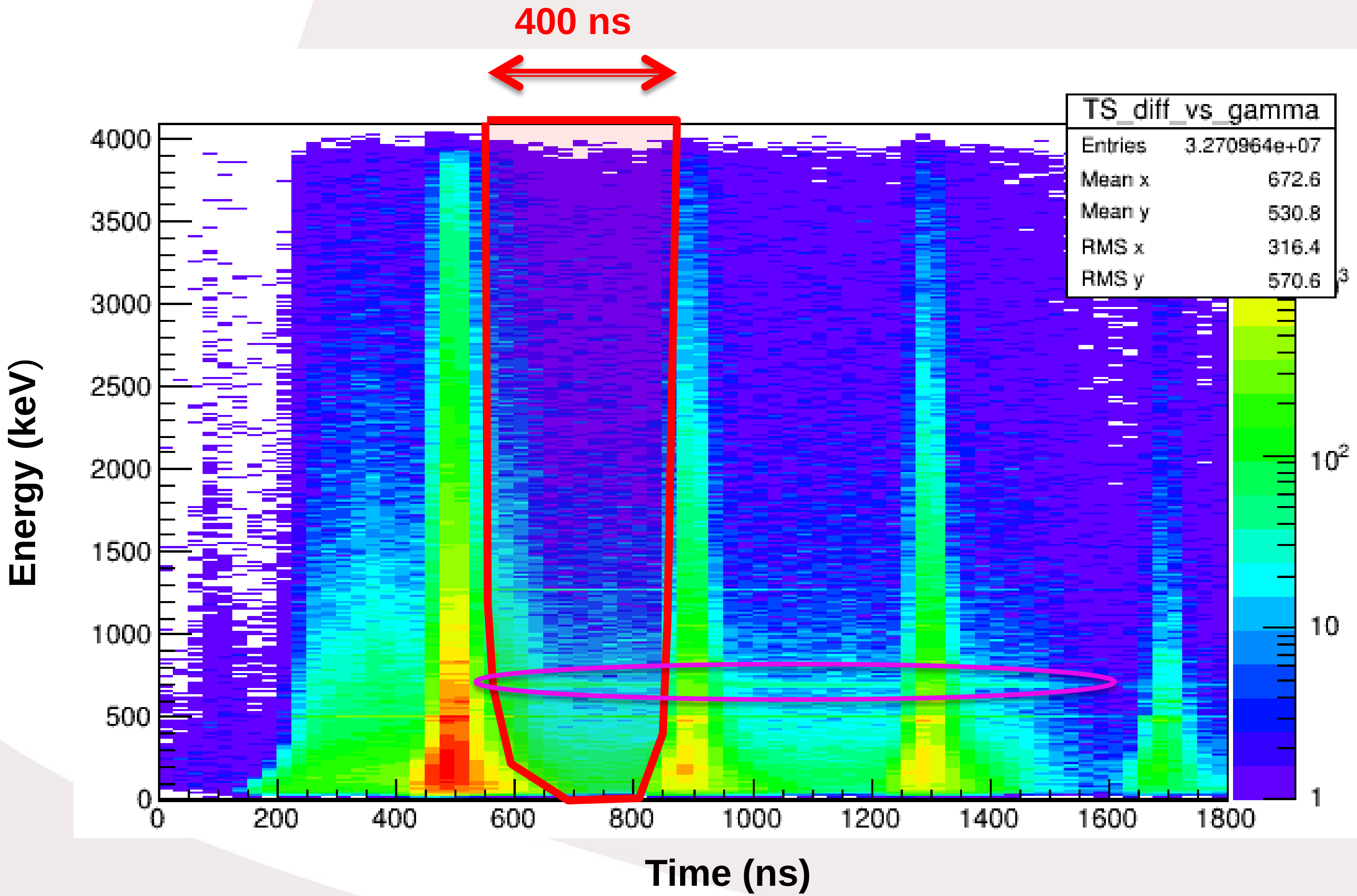
TIPS – Tagging Isomer PartnerS

238U(n,f)

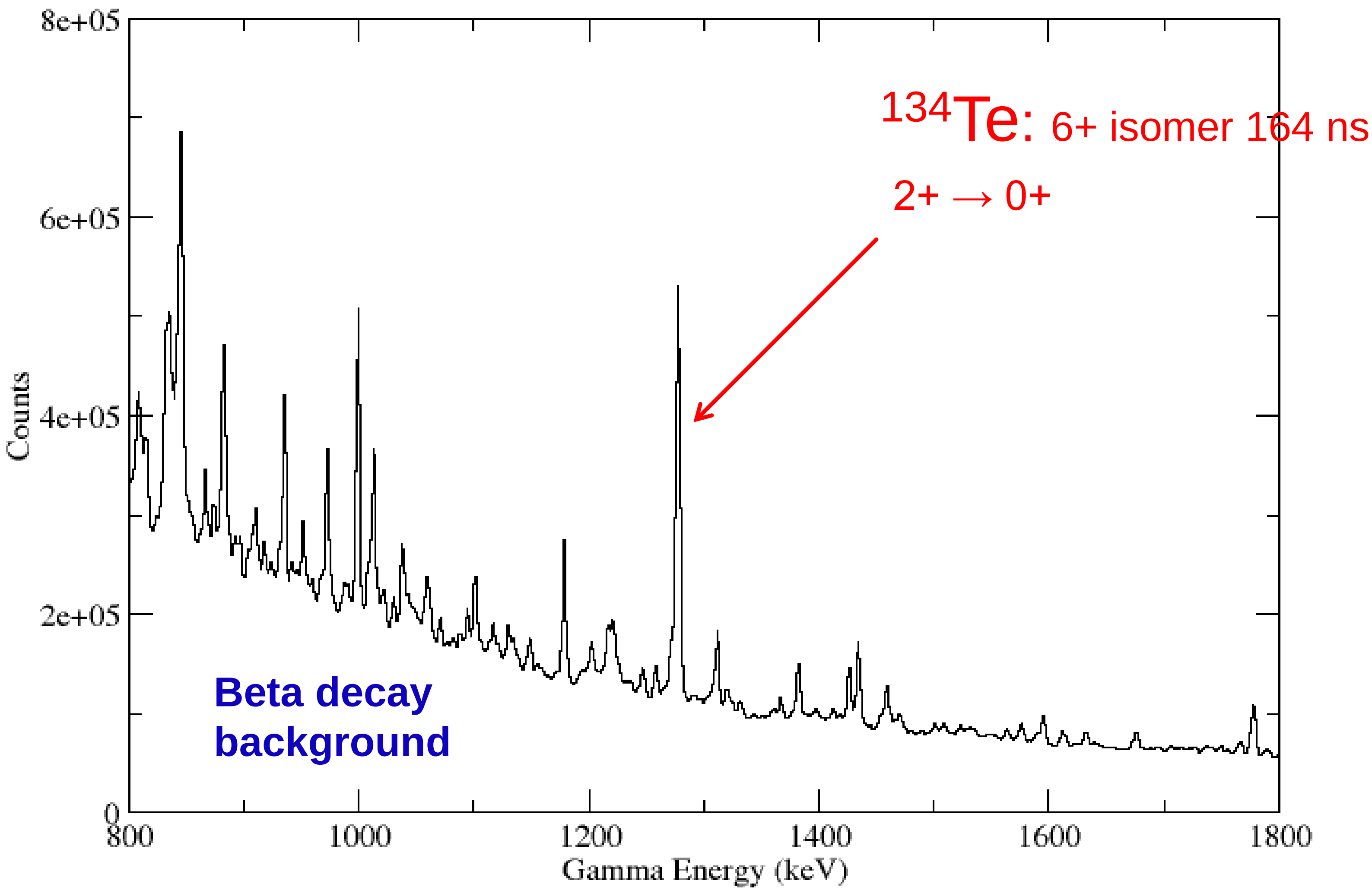


TIPS – Tagging Isomer PartnerS

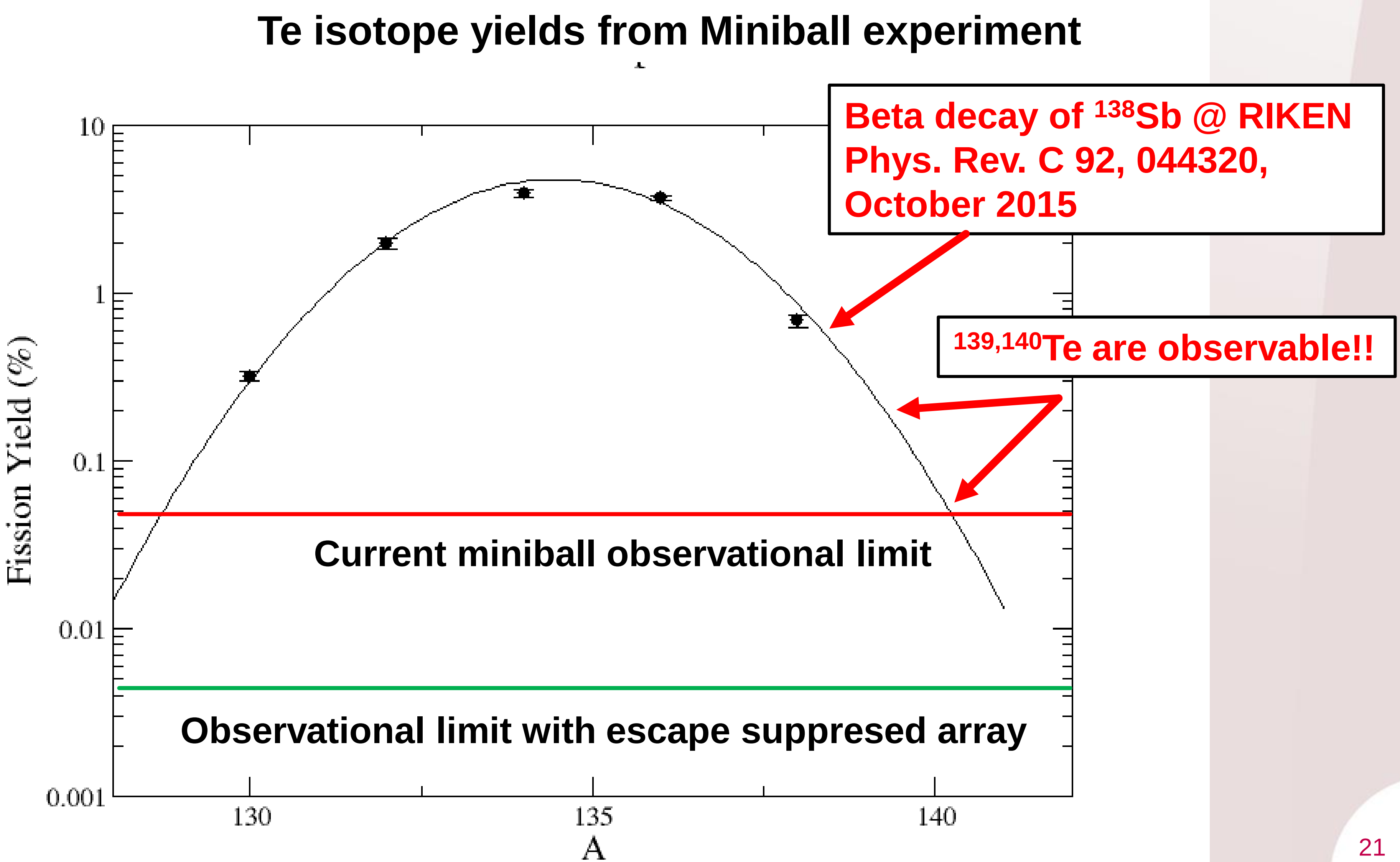
SELECTION OF DELAYED GAMMA RAYS



DELAYED GAMMA RAY SPECTRUM

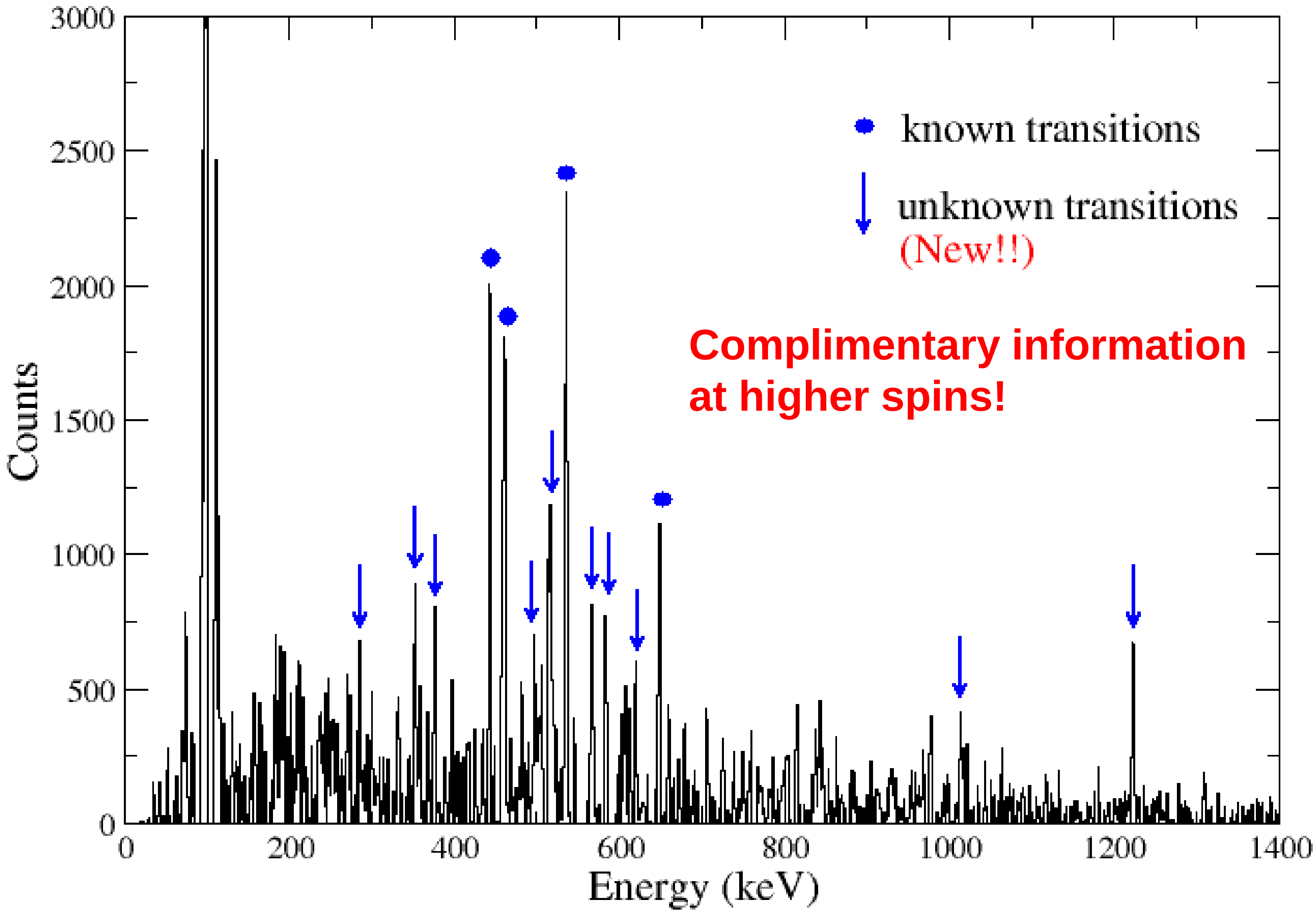


What about new physics?

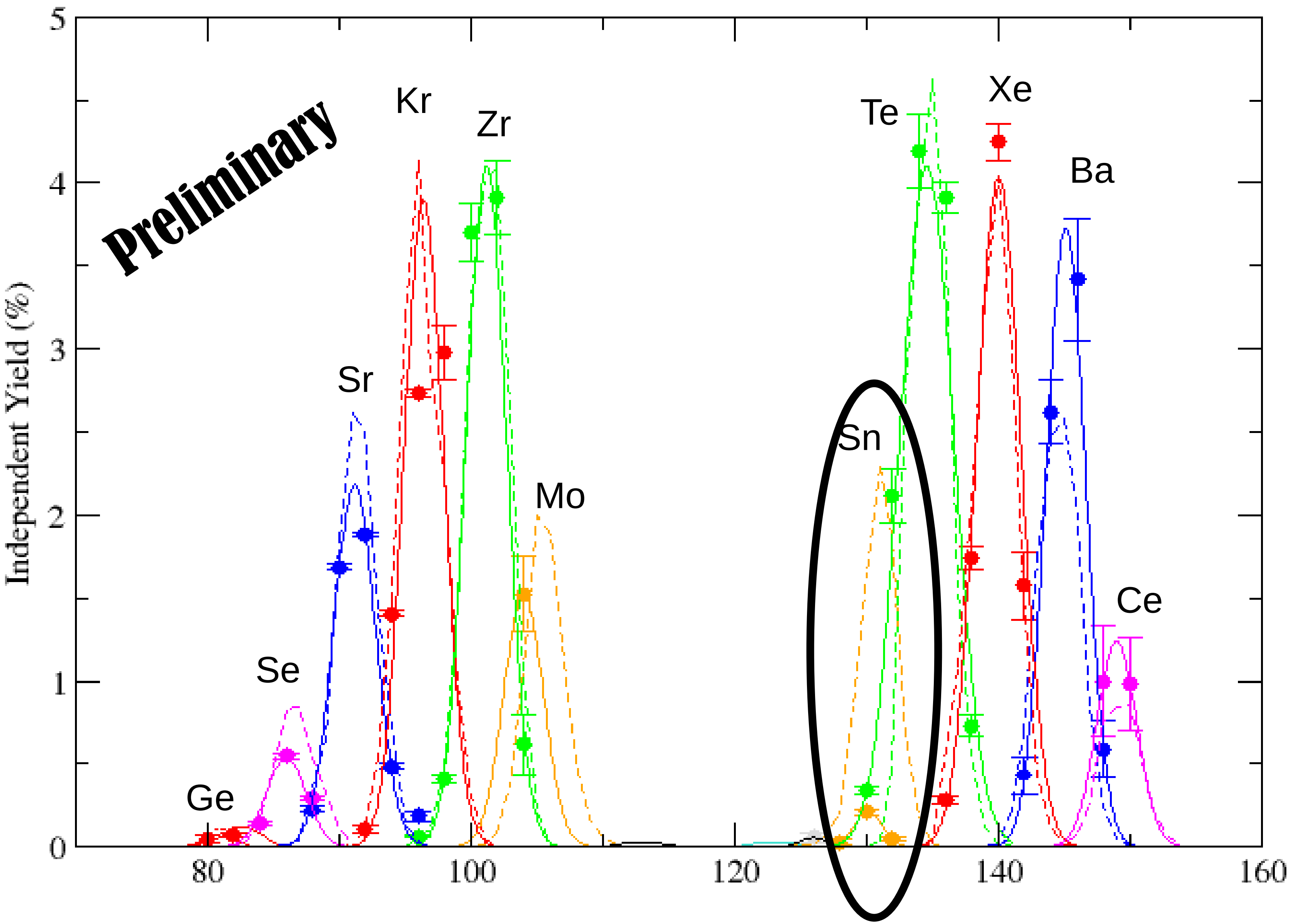


^{138}Te

LICORNE + Miniball data



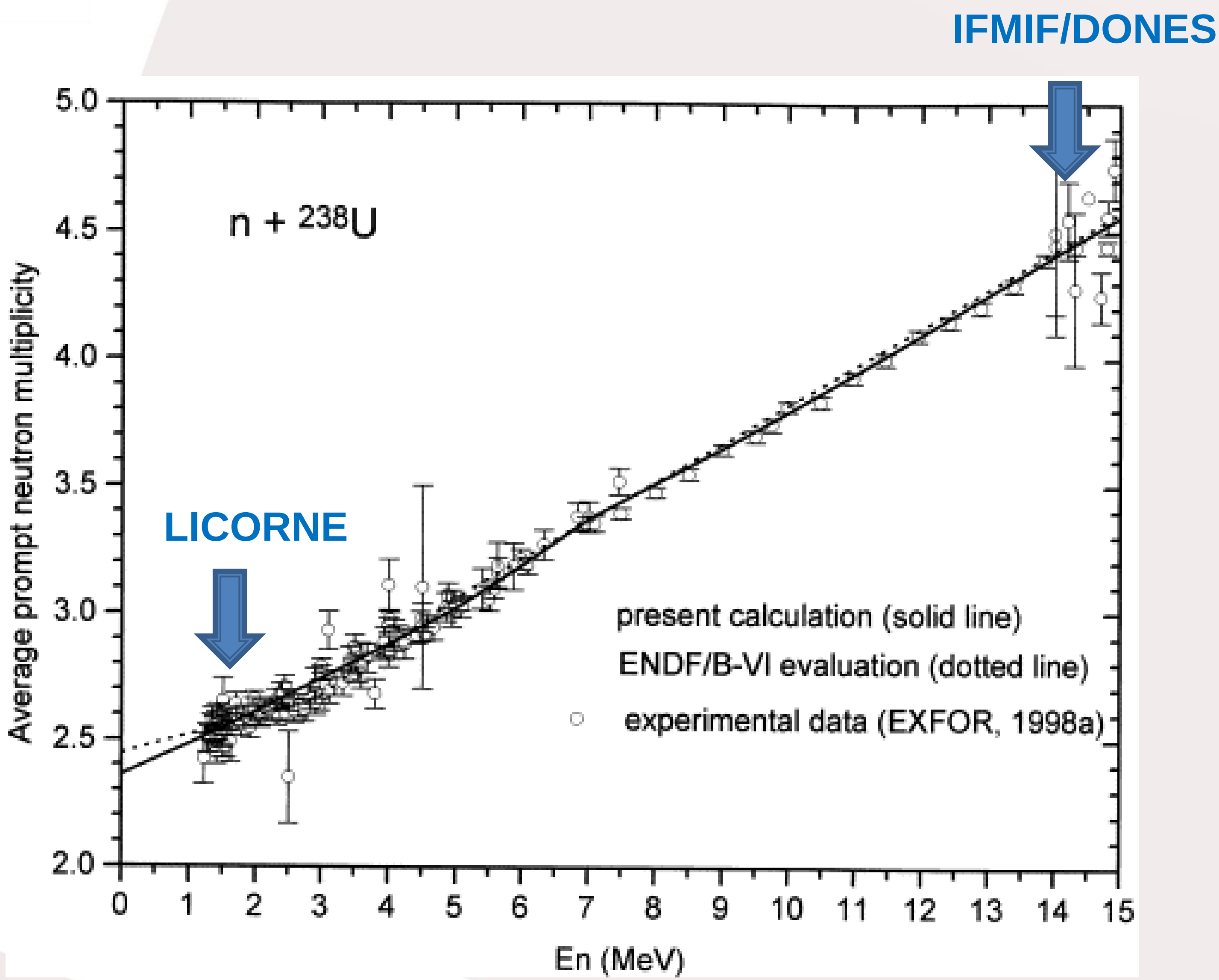
Measured fission yields for 238U(n,f) @ 2MeV with LICORNE/Miniball



PART II

Potential fast neutron induced fission studies @IFMIF/DONES (En ~ 14 MeV)

AVERAGE NEUTRON MULTIPLICITIES



Fission becomes more symmetric with increasing E_n

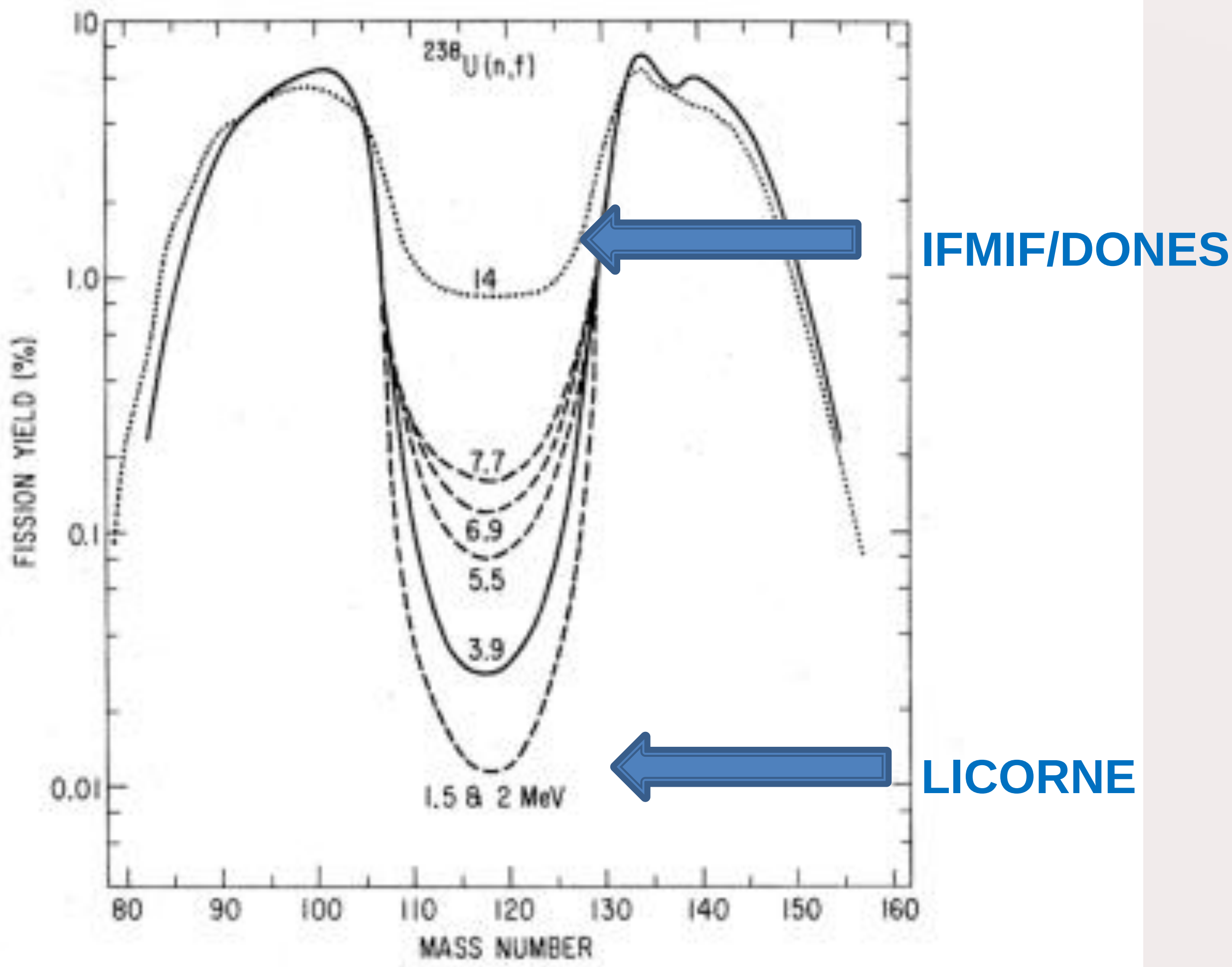


FIG. 1. Mass-yield curves for monoenergetic-neutron-induced fission of ^{238}U.

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MOVING TO HIGHER FLUX REGIME

Current fluxes
$\sim 10^6$ n/s/cm^2

Very high fluxes
$\sim 10^9$ n/s/cm^2

Thick targets essential (~10^1 grams)

Stopped fragments (~ps)

Thin targets possible (~10^{-2} grams)

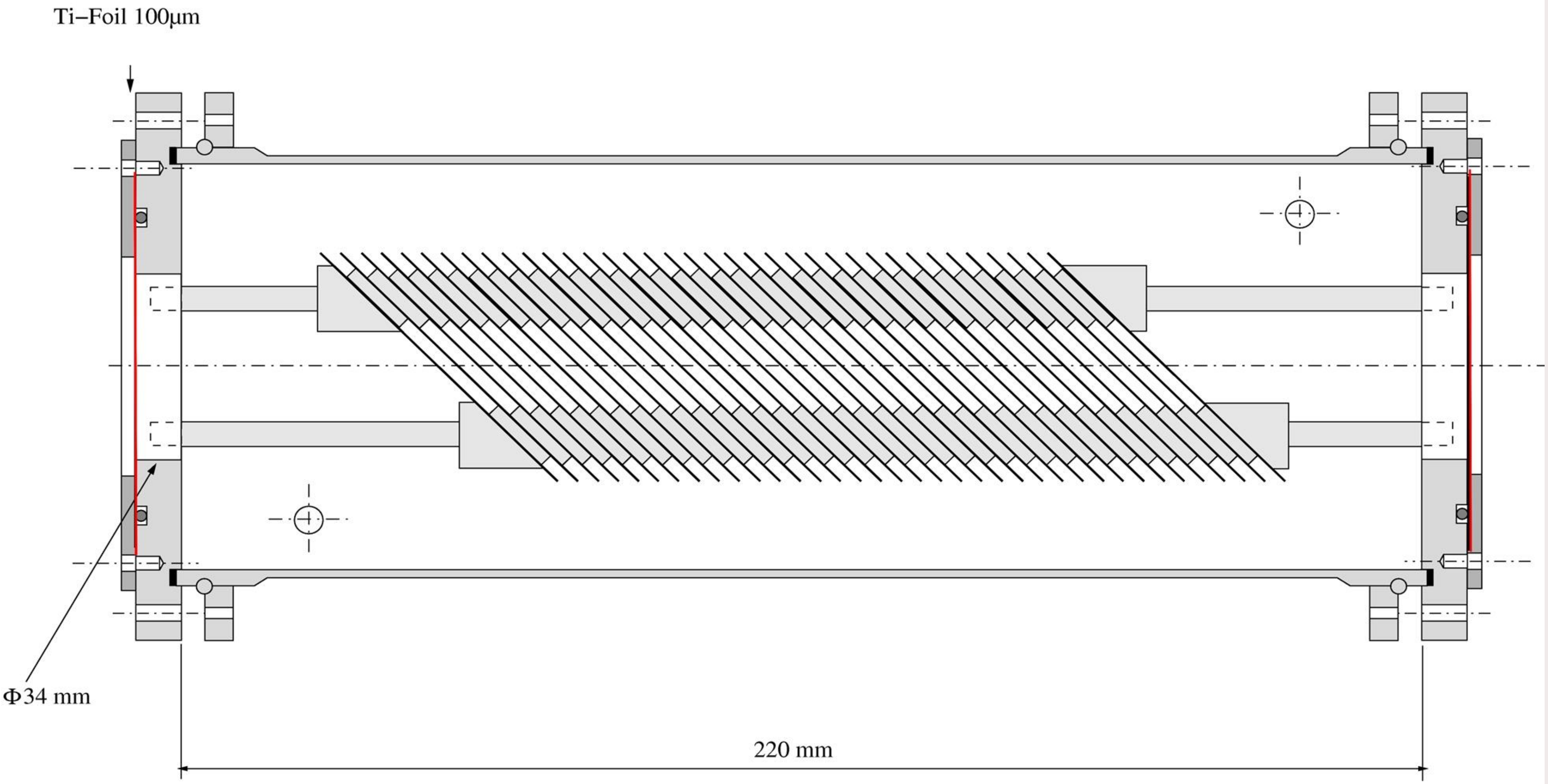
Moving fragments (v ~ 1cm/ns)

Doppler correction essential

Fission tag possible

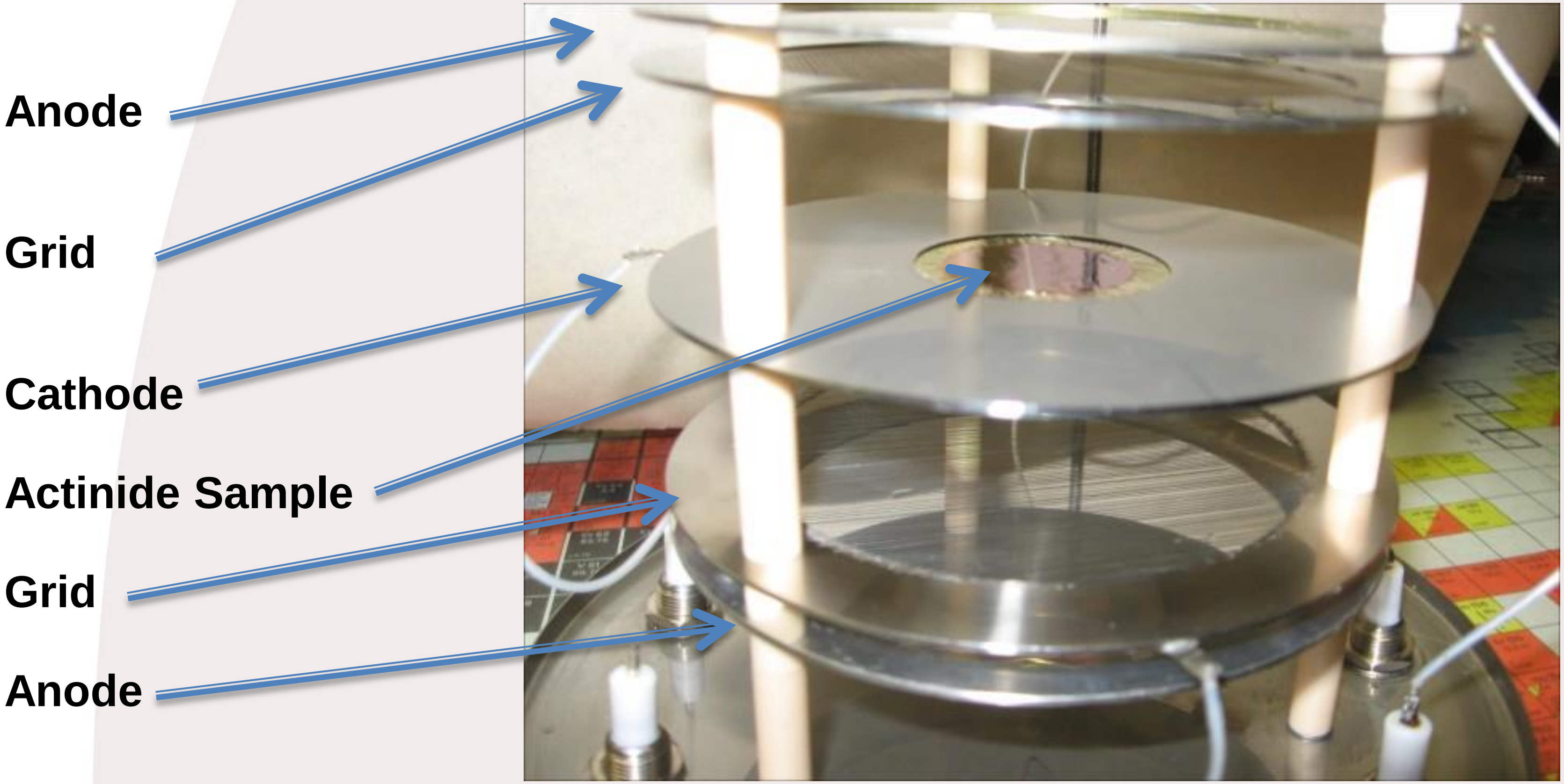
A/Z characterization possible

IONISATION CHMABER AS A FISSION TAG



- **High mass of actinide material (up to ~1g of fissile material). High event rates.**
- **Excellent fission tag**
- **No fragment directionality information**
- **No information on A/Z**

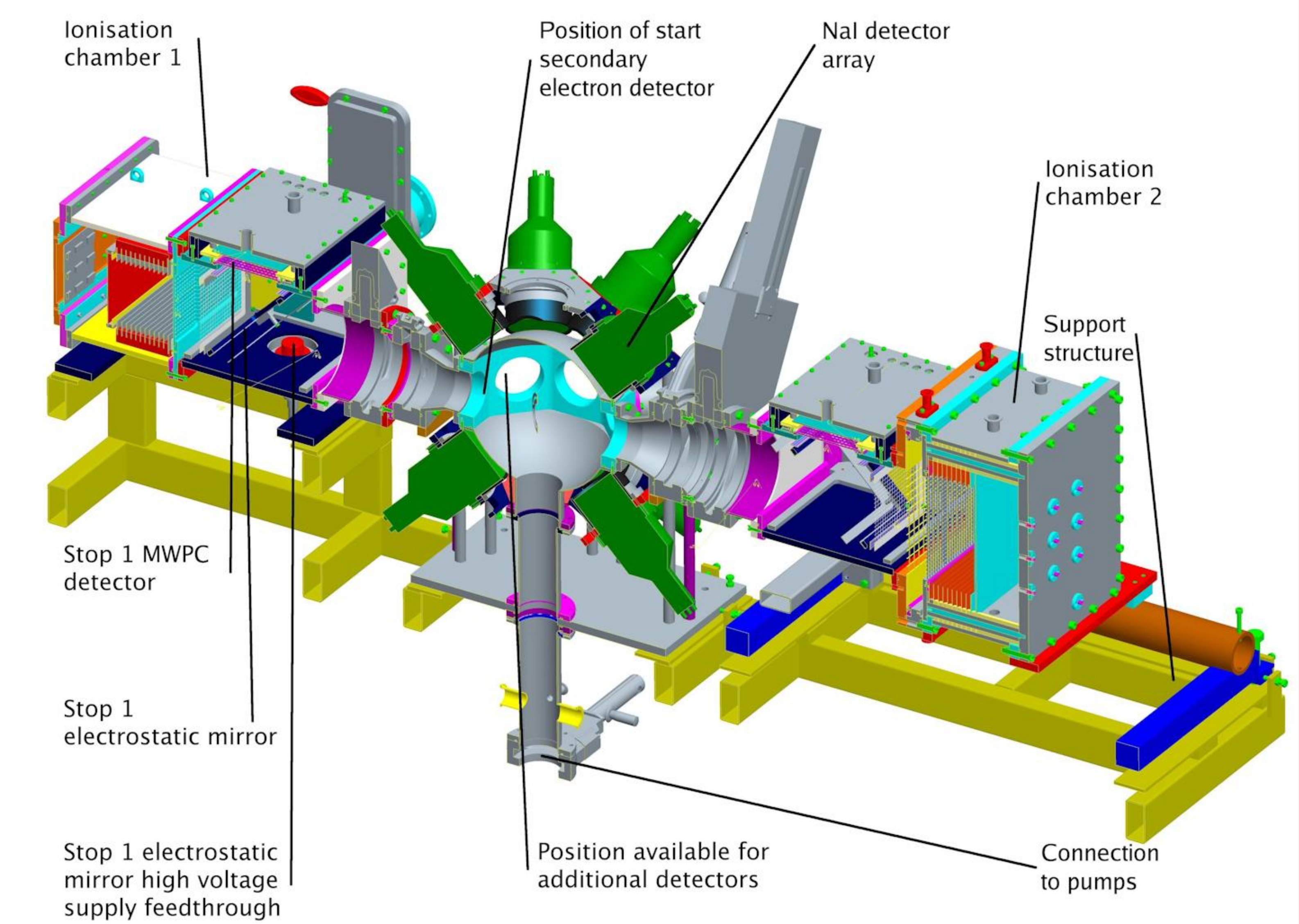
IRMM IONISATION CHAMBERS



- ~10mg of actinide sample
- Excellent fission tag
- Mass resolution of ~4 mass units
- Fragment directionality information

2E 2V SPECTROMETERS

(e.g. STEFF, FALSTAFF, VERDI, SPIDER)



CONCLUSIONS

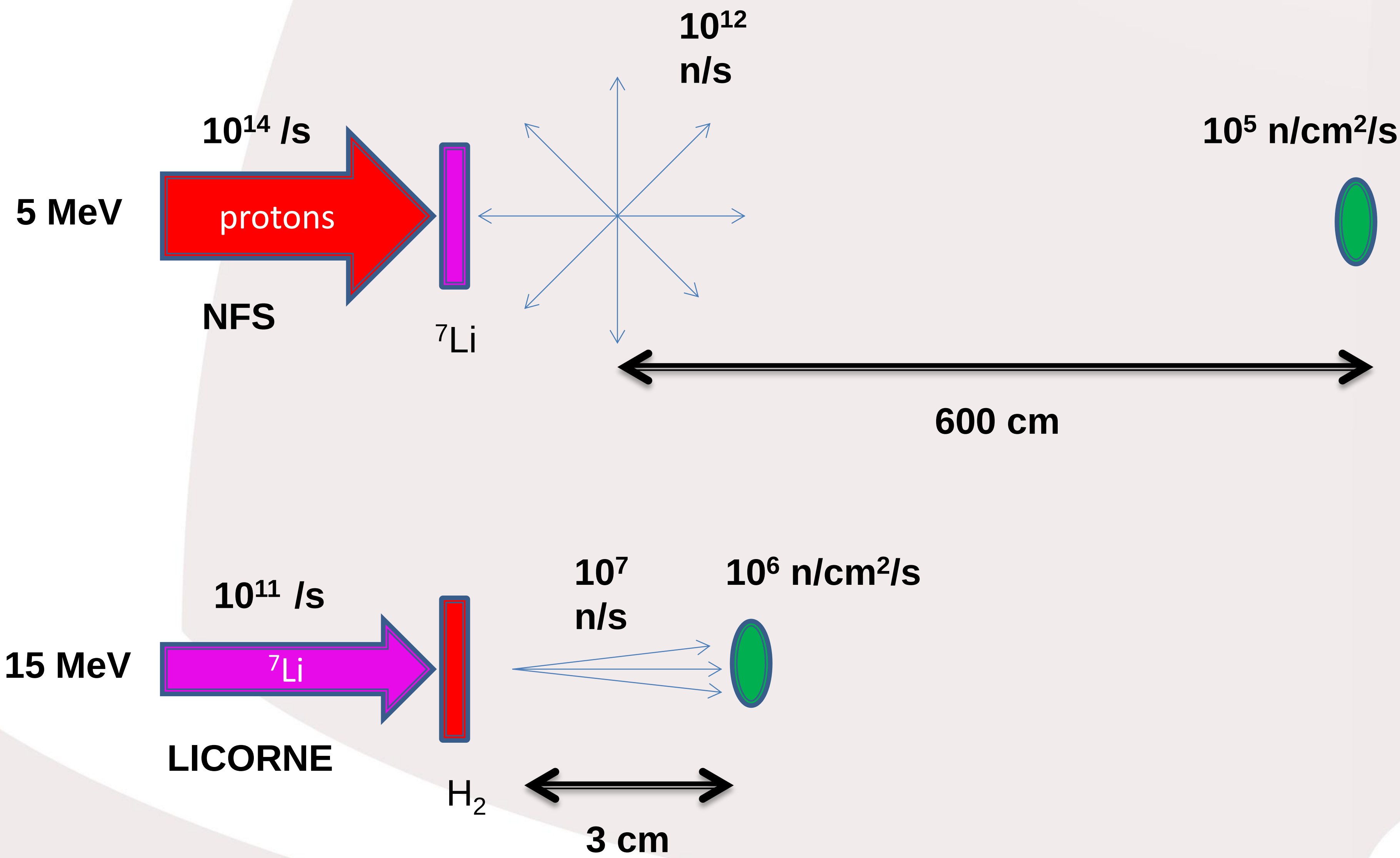
- Spectroscopy of exotic fission fragments is a posssible physics case for IFMIF/DONES
- Equipment required is at least a high resolving power Ge spectrometer
- High neutron fluxes means that thin actinide targets could be considered
- Doppler correction needed (i.e. fragment directional information essential)
- But varying degrees of mass/charge selectivity are possible
- Selectivity from:

- Isomeric states (good fission tag require to separate isomers/beta decay)
- Ionisation chambers (the greater the selectivity the lower the detected event rate)
- Gass filled magnet (see next talk)

ALTO/ ν-ball hybrid spectrometer workshop 2016

19th – 20th May, at the IPN Orsay

https://indico.in2p3.fr/event/12783/

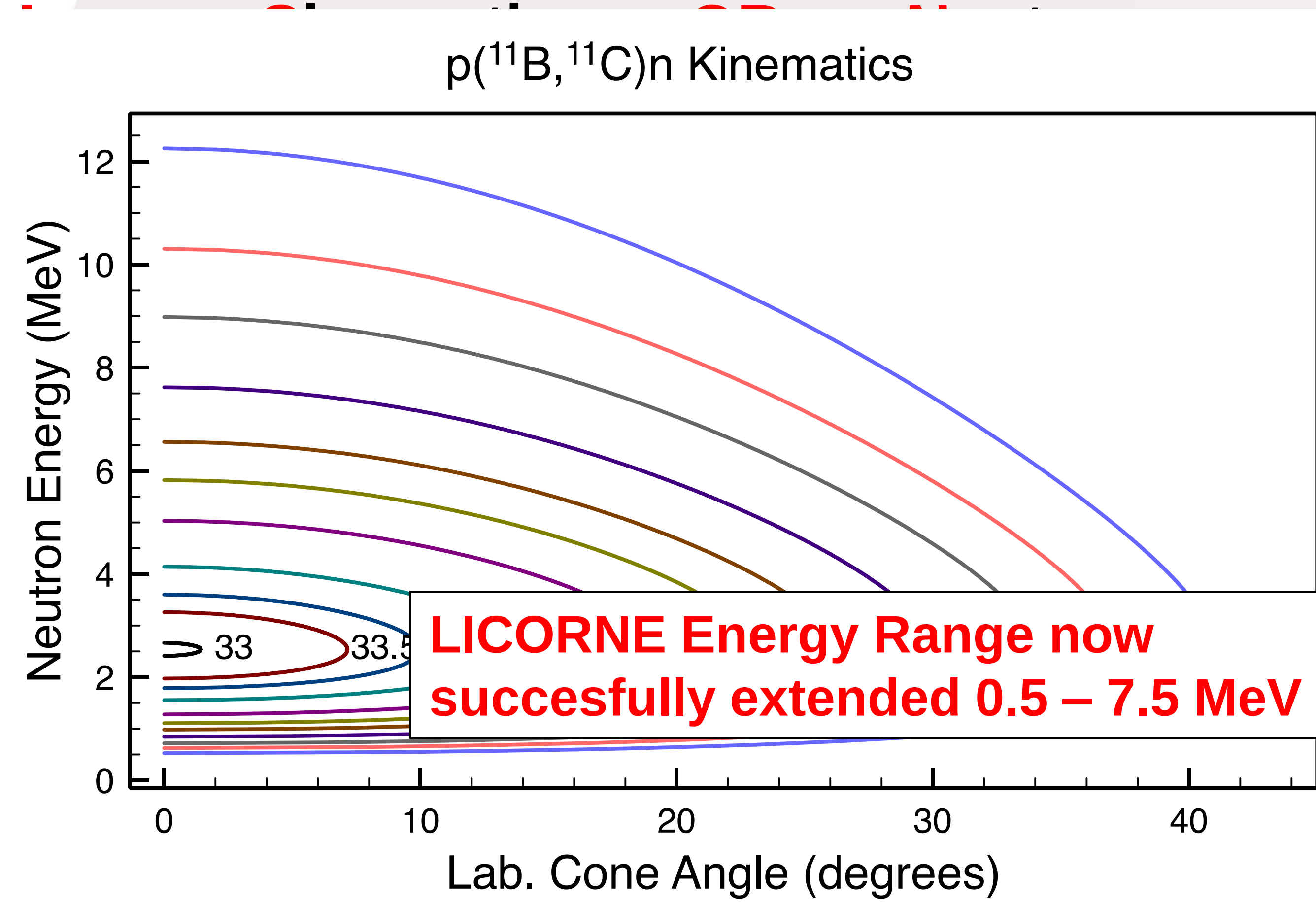

10^{12} n/s
10^{14} /s
10^{5} n/cm^2/s
5 MeV
protons
NFS
^{7}Li
600 cm
10^{7} n/s
10^{6} n/cm^2/s
10^{11} /s
15 MeV
^{7}Li
LICORNE
H_2
3 cm

THE NEUTRON BEAM CHARACTERISTICS: ENERGY RANGE, FLUX, ...

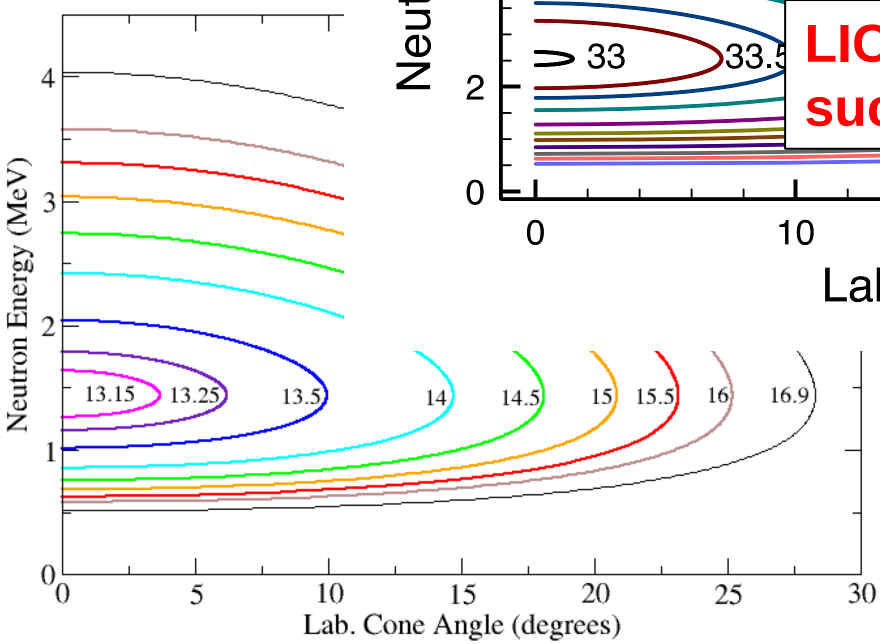
Lithium ... e

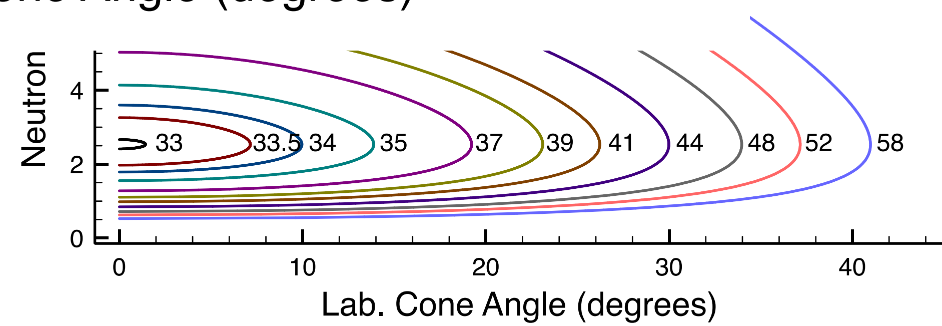
H target

100 nA ^{7}Li 13-17 MeV



LICORNE Energy Range now succesfully extended 0.5 – 7.5 MeV





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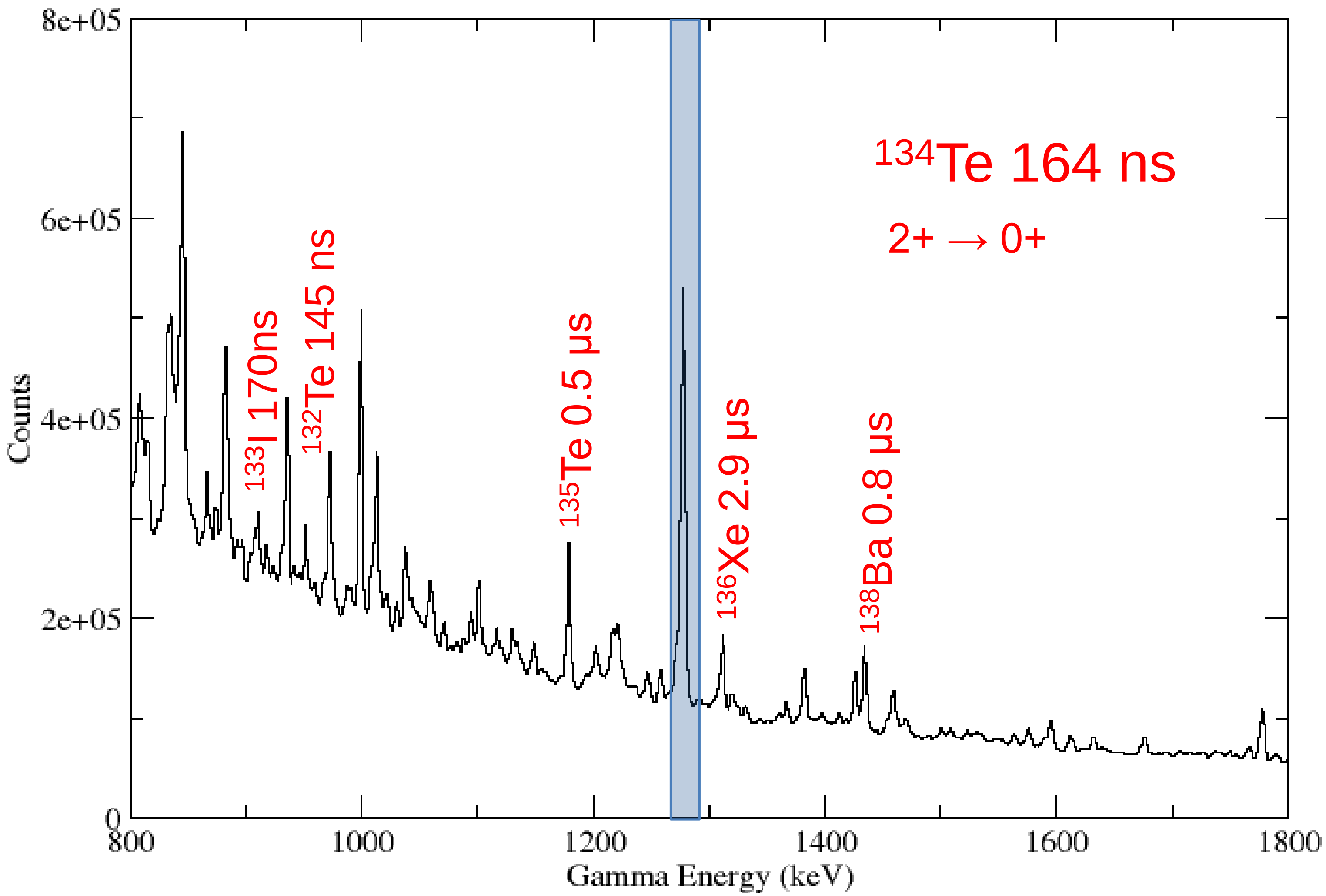
DELAYED GAMMA RAY SPECTRUM



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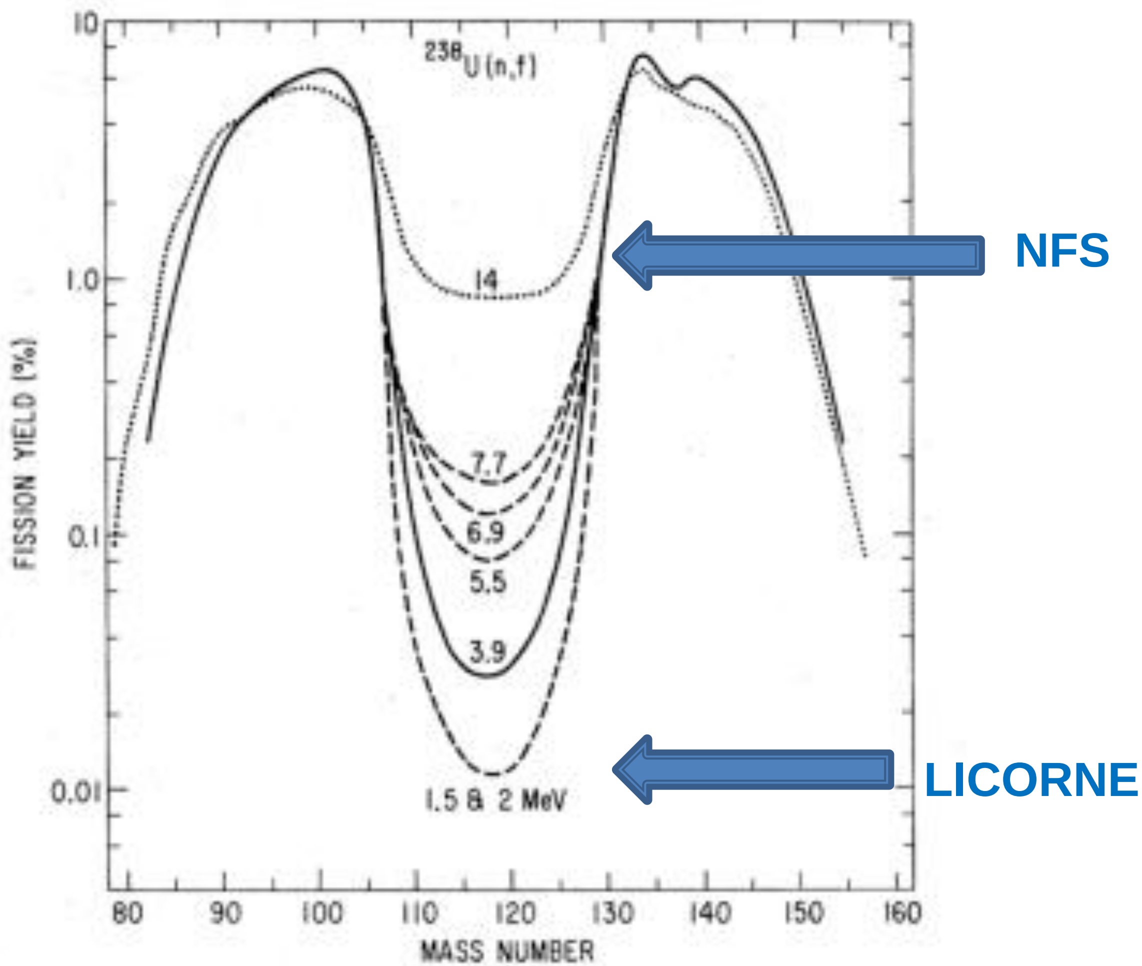
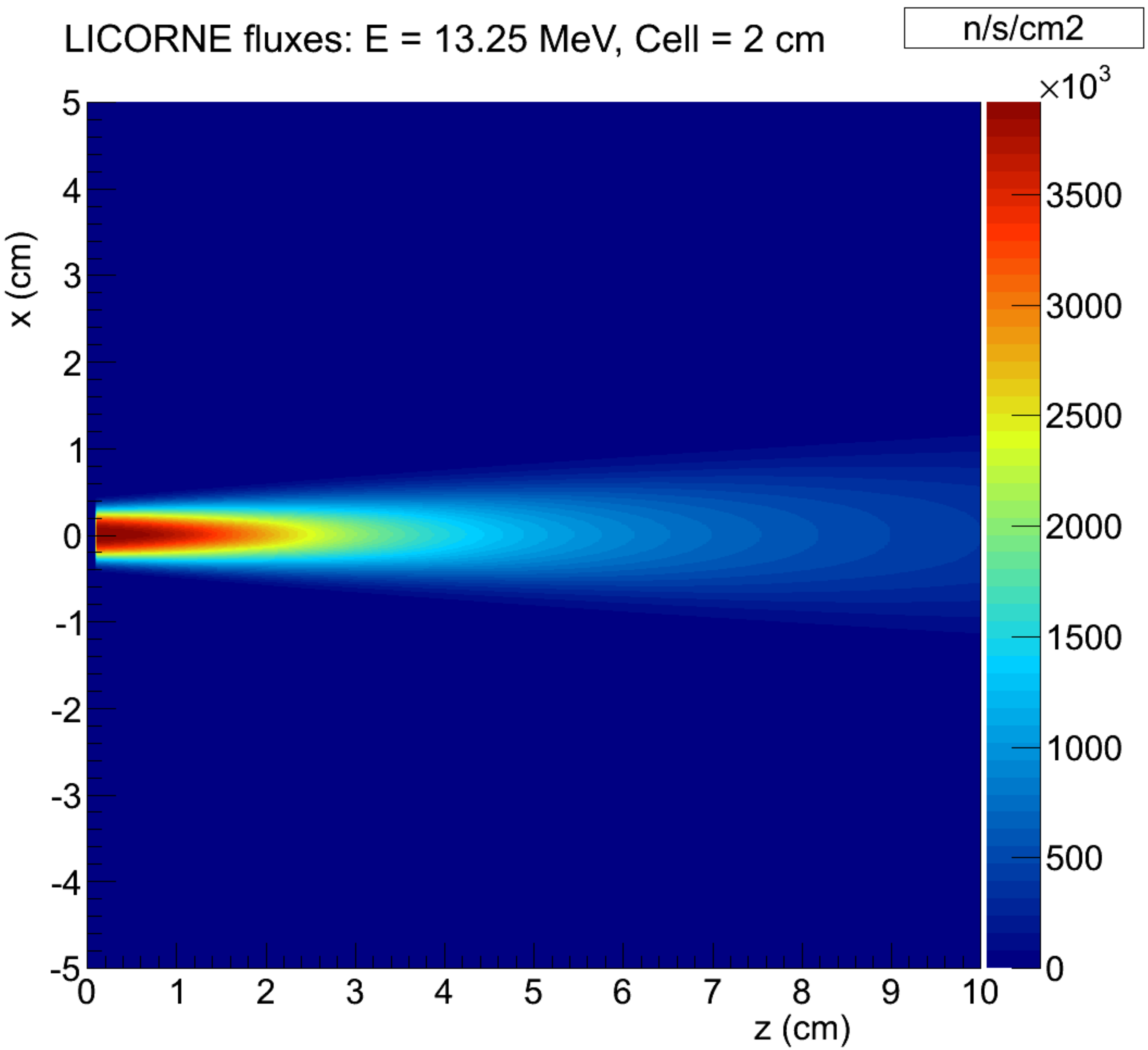


FIG. 1. Mass-yield curves for monoenergetic-neutron-induced fission of ^{238}U.

AVAILABLE FLUXES



Studies for γ-ray emission in the fission process with LICORNE

<u>M. Lebois</u>, J.N. Wilson, Q. Liqiang, P. Halipré,
G. Belier, R. Carroll, M. Fallot, G. Georgiev, A. Gottardo, J-M. Laborie, B. Laurent, R. Lozeva, I. Matea, P. Marini, L. Mathieu, A. Oberstedt, S. Oberstedt, A. Sardet, J. Taieb, A. Porta, P. Regan, S. Rose, C. Schmitt, R. Shearman, S. Siem, P. Regan, C.Varignon, D. Verney, N. Warr

Thank you

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Perspectives

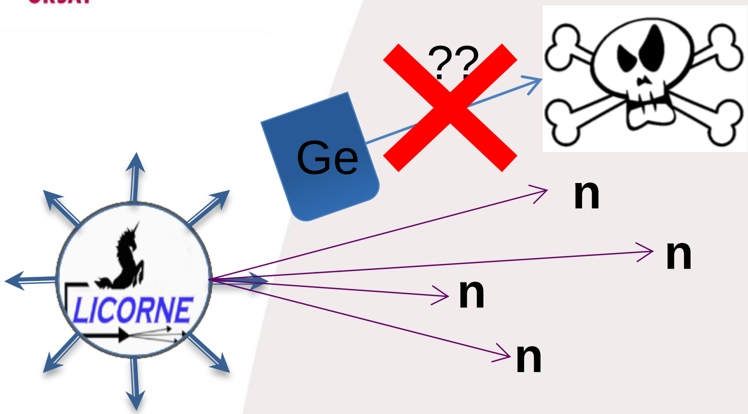
A hybrid $LaBr_3$-Ge array for fast timing spectroscopic studies at the IPN Orsay

- **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 May 2016 to fully develop physics cases**

DEVELOPMENT OF A GAS TARGET FOR LICORNE

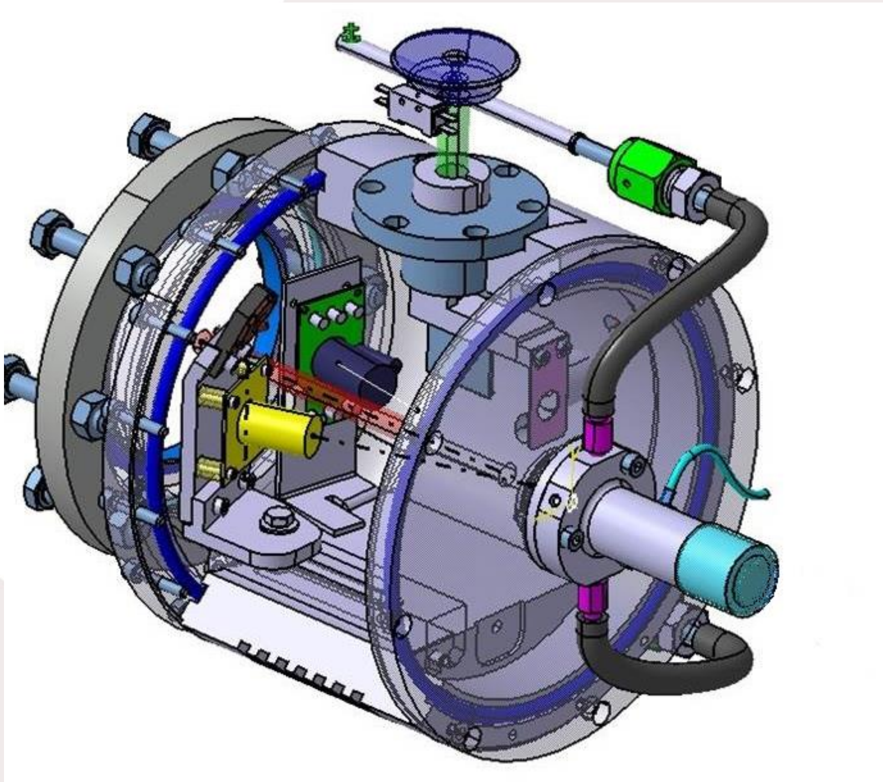
(commissionning performed nov. 2014)

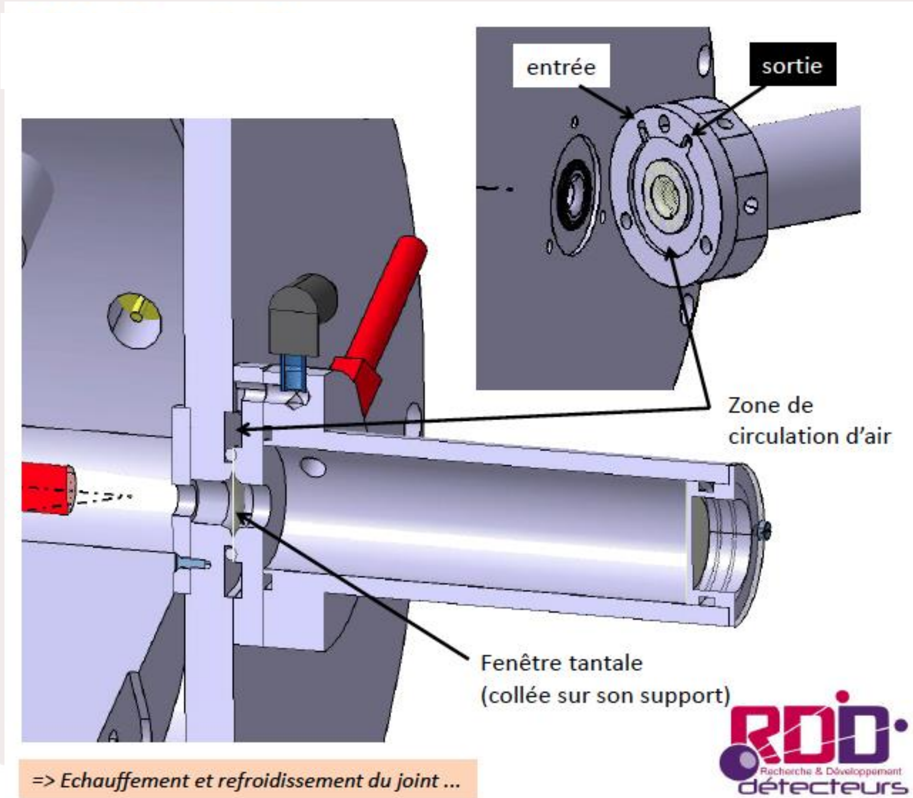


Parasitic fusion evaporation reaction of ^{7}Li on ^{12}C

Need to change the PP target ➔Gas target

Elements with Z > 73 required in the beam path





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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

Design based around the Eurogam II spectrometer frame

- **24 Clover detectors in two rings, providing 4.5% photopeak efficiency**
- **20 holes available in two rings, for either Ge or LaBr3 detectors**
- **Frame built in Strasbourg, France**
- **17 Clovers paid for by France, 17 UK**

[Currently all in Jyvaskyla, where French equipment has been based for 8 years]

Campaign to start in early 2017