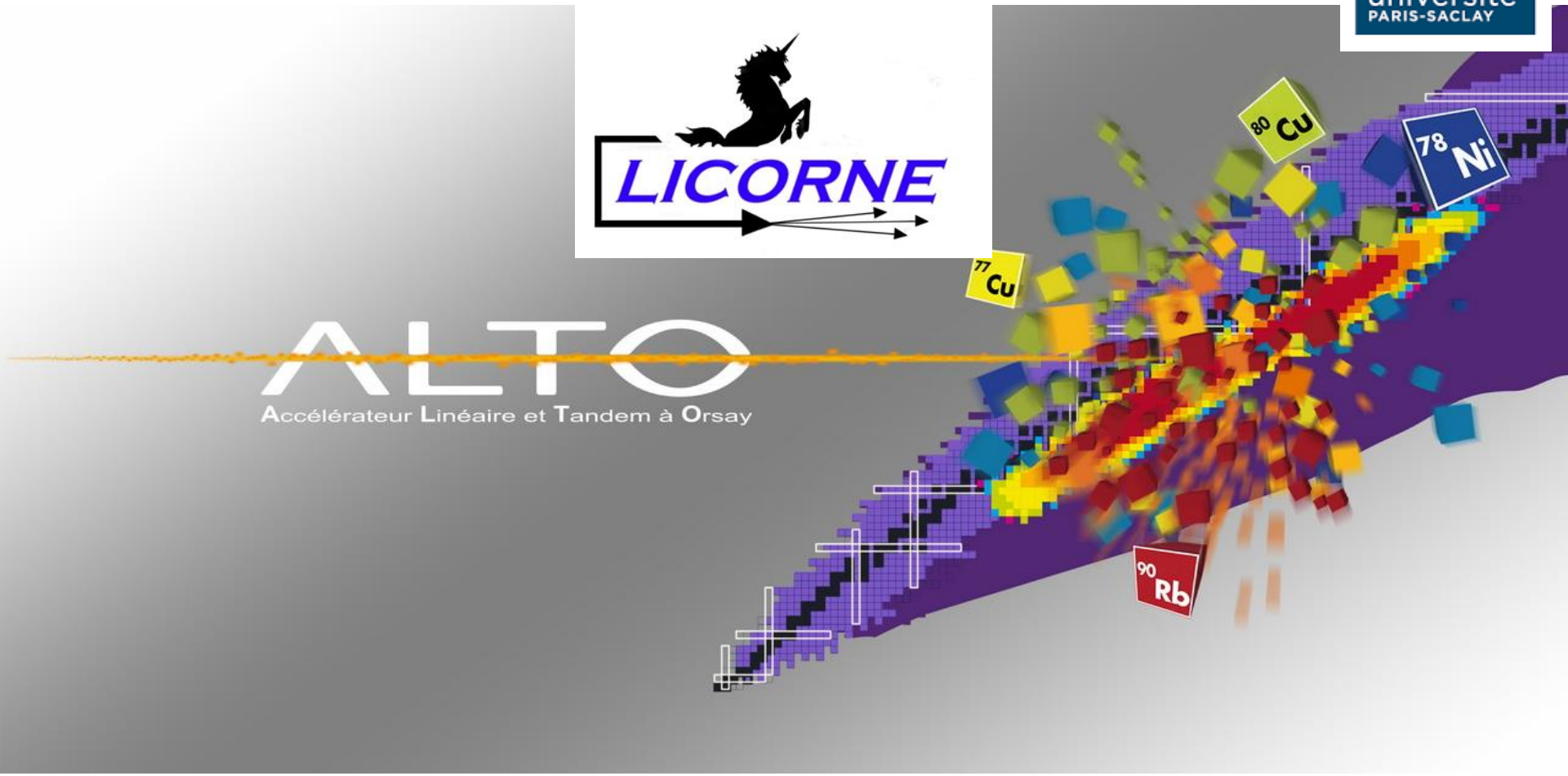
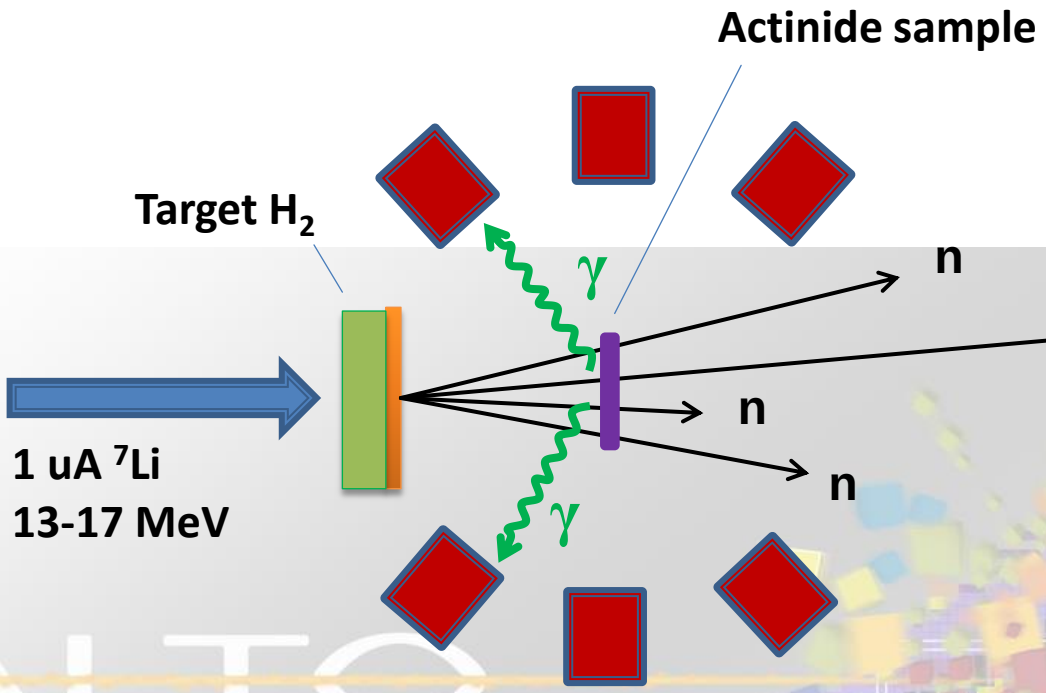
The LICORNE neutron source and its associated physics program

Jonathan Wilson, Matthieu Lebois, Liqiang Qi,
Nikola Jovancevic, Damien Thisse, IPN Orsay



LICORNE: Neutron production in inverse kinematics



Lithium Inverse Cinematiques ORsay NEutron source

- reaction p(^{7}Li,^{7}Be)n using inverse kinematics, or p(^{11}B,^{11}C)
- Source of fast focused neutrons (between 0.5 and 7 MeV)
- NATURAL DIRECTIONALITY AND HIGH FLUX: 10^8 n/cm^2/s on target

LICORNE II

H_2 pressure and flow control system
+ automatic shutdown

Hydrogen gas cells

Optimisation of:

1) Primary beam intesity
2) Transmission of the primary beam
3) Capacity of the target to withstand the beam

First fixed polypropylene target test experiment

Commissioning LICORNE II H_2 gas target

First Phys. Rev. C

ν-ball/LICORNE Experimental campaign

First expt. $^{235}U/^{238}U$ Fission γ's

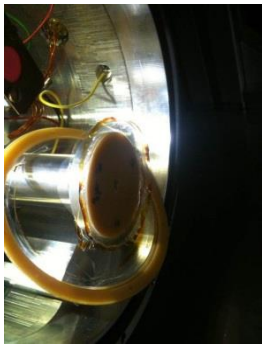
Max flux ~10^7 n/cm^2/s

Extension to 7 MeV with ^{11}B

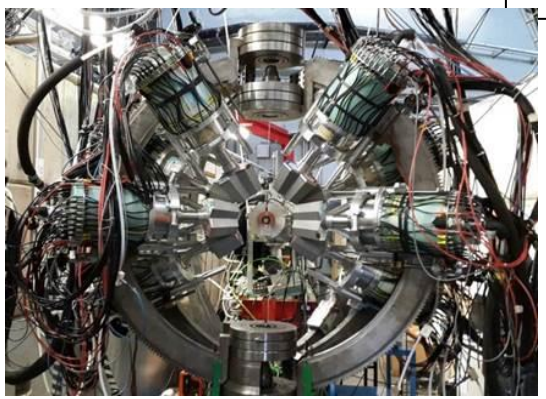
First in2p3 funding

First Phys. Rev. Lett.

2013 2014 2015 2016 2017 2018



Coupling LICORNE + MINIBALL



First use of ^{239}Pu targets

new ion source installation

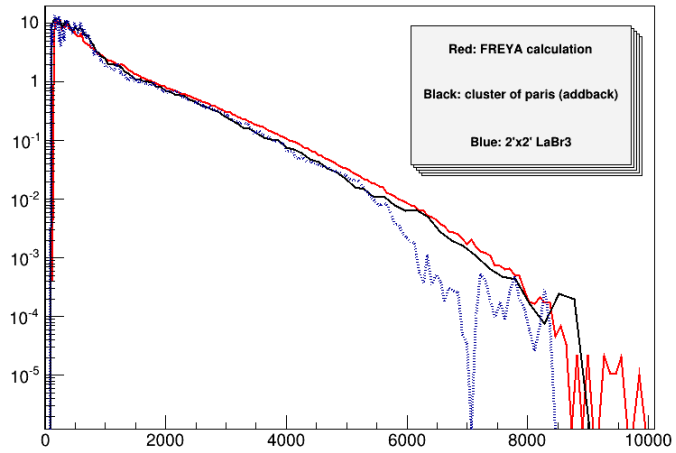
ν-ball installation

Max flux ~10^8 n/cm^2/s

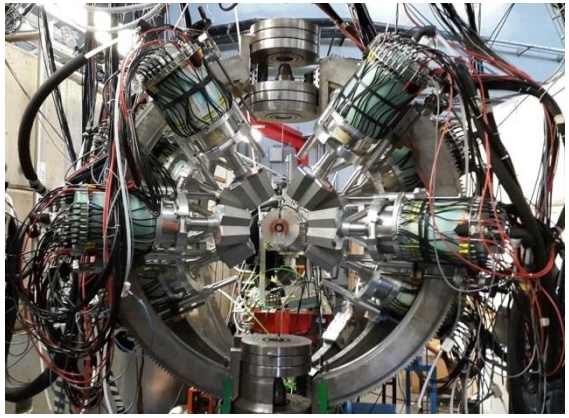
Commissioning of LICORNE I Rotating polypropylene target

The LICORNE Physics Program

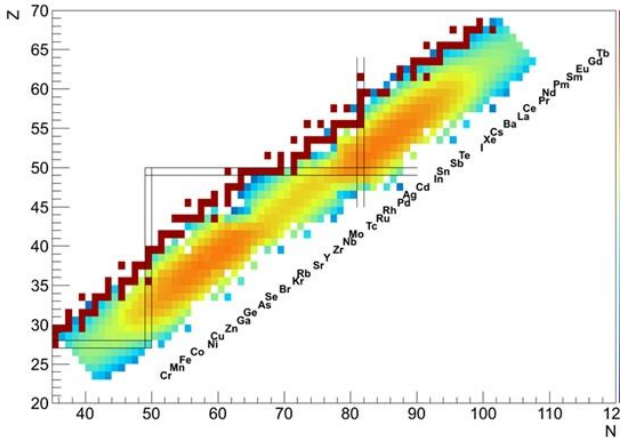
Prompt fission γ spectra characteristics



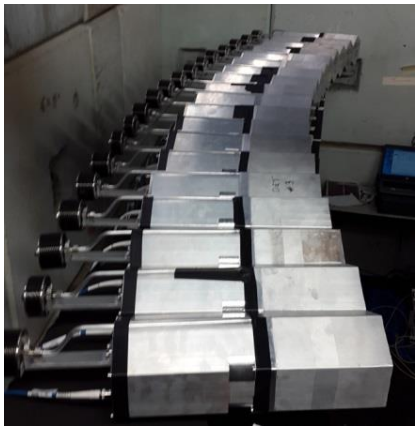
Procduction/Study of exotic nuclei



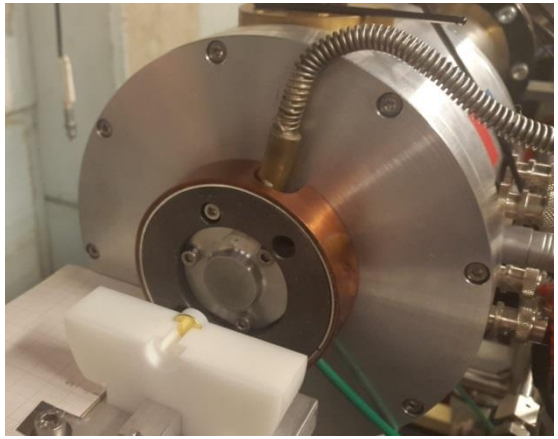
γ-ray spectroscopy of fission fragments: fission yields



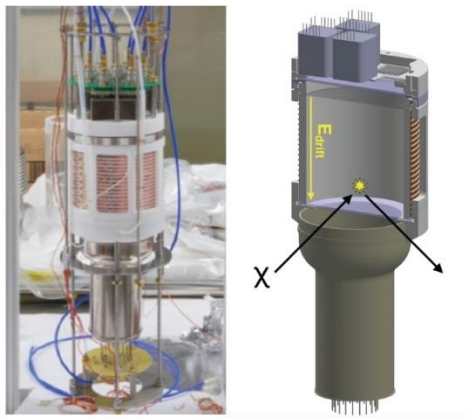
Fast Neutron Tomograpahy



Irradiations for Geochronology (x-section measurements)



Dark Matter TPC characterisation



LICORNE Publications (2013-2019)

16) Statistical study of the prompt-fission γ-ray spectrum for 238U(n, f) in the fast-neutron region , Phys. Rev. C 98, 014612 (2018)
15) Measurement of the liquid argon energy response to nuclear and electronic recoils, Phys. Rev. D 97, 112005 (2018)
14) Studies of fission fragment yields via high-resolution γ-ray spectroscopy
J.N. Wilson, M. Lebois, L. Qi, et al., Proceedings of the Theory-4 international workshop, Varna, Bulgaria (2017)
13) Neutron-rich isotopes from 238U(n,f) and 232Th(n,f) studied with the nu-ball spectrometer coupled to the LICORNE neutron source
J.N. Wilson, M. Lebois , and L. Qi, Proceedings of the FISSION-2017 international conference, Chamrousse (2017)
12) Anomalies in the charge yields of fission fragments from the 238U(n,f) reaction, Phys. Rev. Lett. 118, 222501 (2017)
11) Production and study of neutron-rich nuclei using the LICORNE directional neutron source
J.N. Wilson, M. Lebois, L. Qi et al., Proceedings of the Zakopane international conference, Acta Physica Polonica B Vol.48 395 (2017)
10) Studies of γ-ray emission in the fission process with LICORNE
M. Lebois, J.N. Wilson, et. al , Proceedings of the CNR*15 international conference , EPJ Web of Conferences 122, 01010 (2016)
9) Comparative measurement of prompt fission gamma-ray emission from fast neutron induced fission of 235U and 238U
M. Lebois, J.N. Wilson, et al, Phys. Rev. C 92 034 618 (2015)
8) Prompt Emission in Fission Induced with Fast Neutrons
J.N. Wilson, M. Lebois, P. Halipré, S. Oberstedt, A. Oberstedt, Physics Procedia, Volume 64, Pages 107–113 (2015)
7) Future research program on prompt gamma-ray emission in nuclear fission
S. Oberstedt, R. Billnert, F. -J. Hambsch, M. Lebois, A. Oberstedt and J. N. Wilson , Eur. Phys. J. A, 51 12 (2015) 178
6) Development of a kinematically focused neutron source with the p(7Li,n)7Be inverse reaction
M. Lebois, J.N. Wilson, P. Halipre, B. Leniau, I. Matea, A. Oberstedt, S. Oberstedt, D. Verney, Nucl. Instrum. Meth. A 735 46 (2014)
5) The LICORNE neutron source and measurements of prompt gamma rays emitted in fission
J.N. Wilson, M. Lebois, et al., Proceedings GAMMA-2 International Workshop, Sremski Karlovci, Serbia (2013)
4) Prompt fission gamma-rays from fast neutron-induced fission of 238U, 232Th and 235U with LICORNE
M. Lebois, J.N. Wilson et al., Proceedings GAMMA-2 International Workshop, Sremski Karlovci, Serbia (2013)
3) Measurements of prompt gamma-rays from fast-neutron induced fission with the LICORNE directional neutron source
J.N. Wilson, M. Lebois, P. Halipre, A. Oberstedt, S. Oberstedt, Proceedings of the final ERINDA meeting, CERN, Geneva (2013)
2) The LICORNE neutron source
J.N. Wilson, M. Lebois et al., Proceedings of the International Conference, FISSION2013, Caen, France (2013)
1) Nuclear Research with Quasi Mono-Energetic Neutrons at the IPNO LICORNE Facility
S. Oberstedt, J.N. Wilson, R. Billnert, G. Georgiev, P. Halipre, M. Lebois, B. Leniau, J. Ljungvall, I. Matea, A. Oberstedt, D. Verney, International Atomic Energy Agency (IAEA), Proceedings technical meeting IAEA-F1-TM-42752 (2013)

153 users from 37 different institutions in 16 different countries

LICORNE Highlights

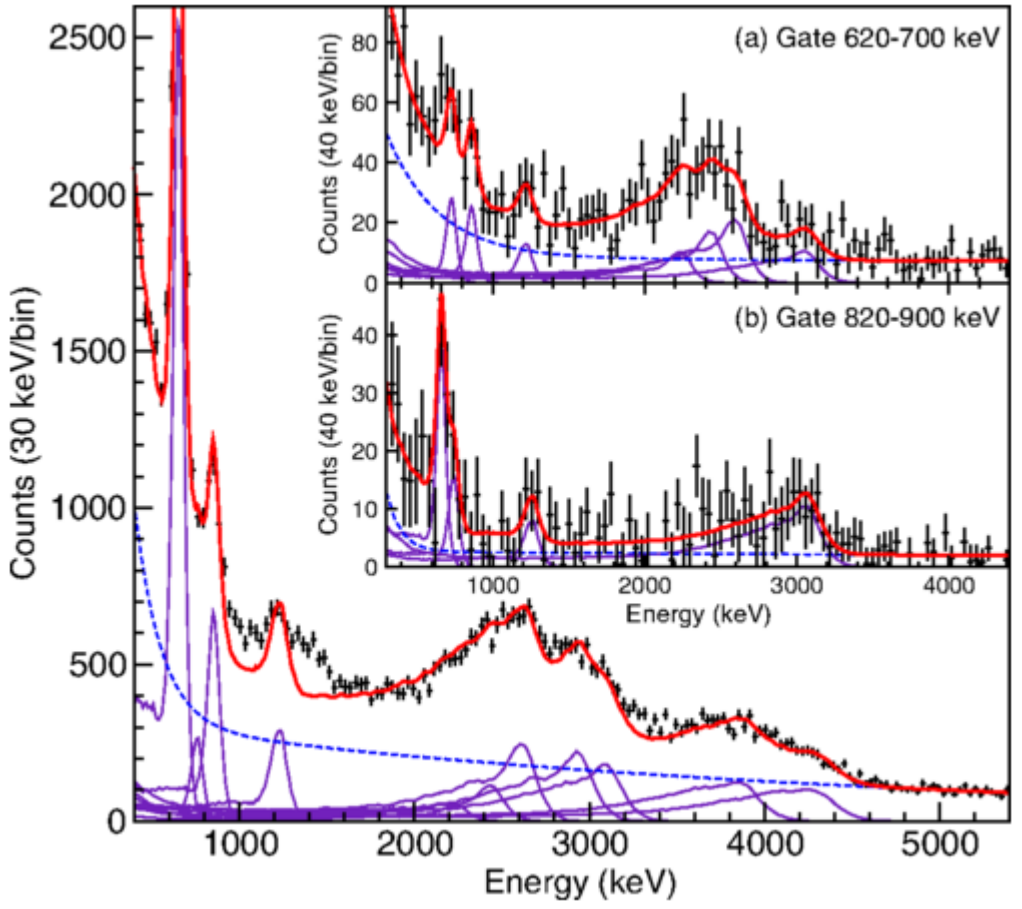
γ-ray spectroscopy of the most neutron rich nuclei

Higher spin states of very neutron-rich nuclei?

In-flight

e.g. RIKEN - Big Rips separator + DALI2 spectrometer
Reaction: $^{9}Be(^{238}U,f)$ @ 345 MeV/a
Complete A,Z selectivity
Very high v/c: Extreme Doppler broadening of in-beam fragment γ-decay

- Decays from high spin states are thus very difficult to measure



ISOL

e.g. Isolde – Miniball spectrometer
Reaction: $^{238}U(p,f)$ @ 600 MeV
Complete A,Z selectivity

- γ-spectroscopy after beta-decay : High spin states not populated

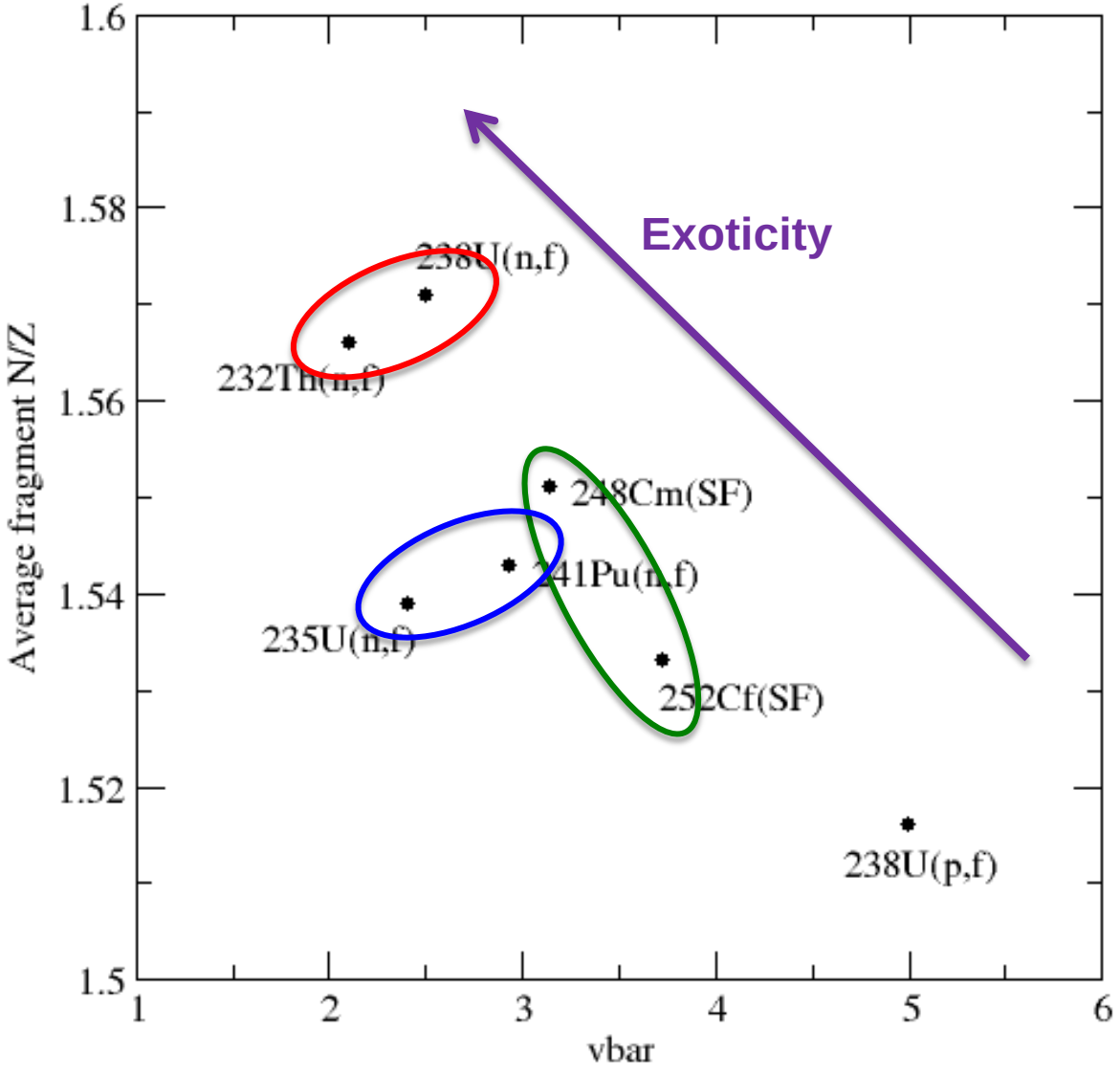
Limited possibilities for access to information on higher spin states of very neutron-rich nuclei

Exotic Nuclei Production/Study from Fission Reactions

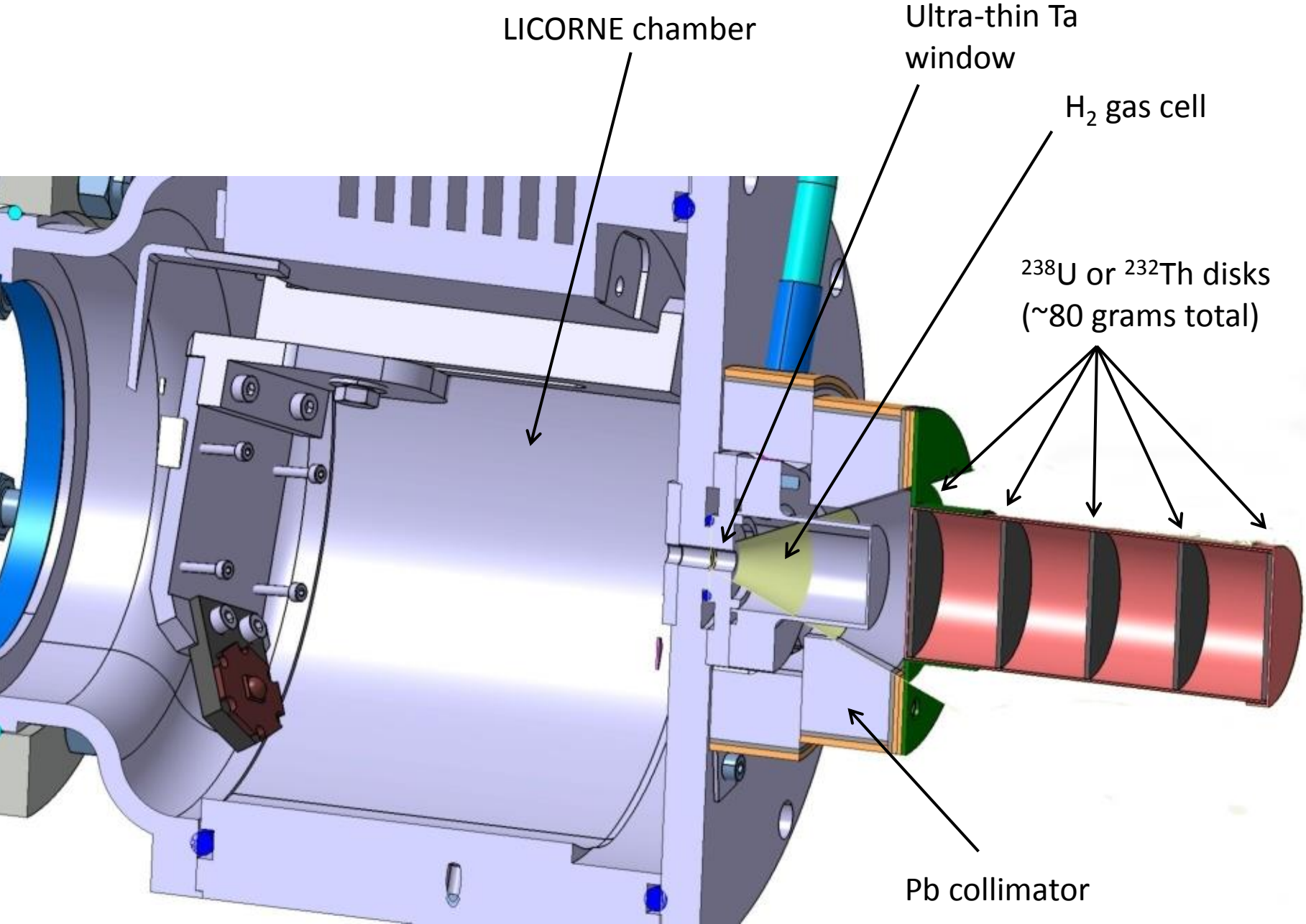
Spontaneous Fission
^{252}Cf(SF), ^{248}Cm(SF)
(Gammasphere, Euroball)

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

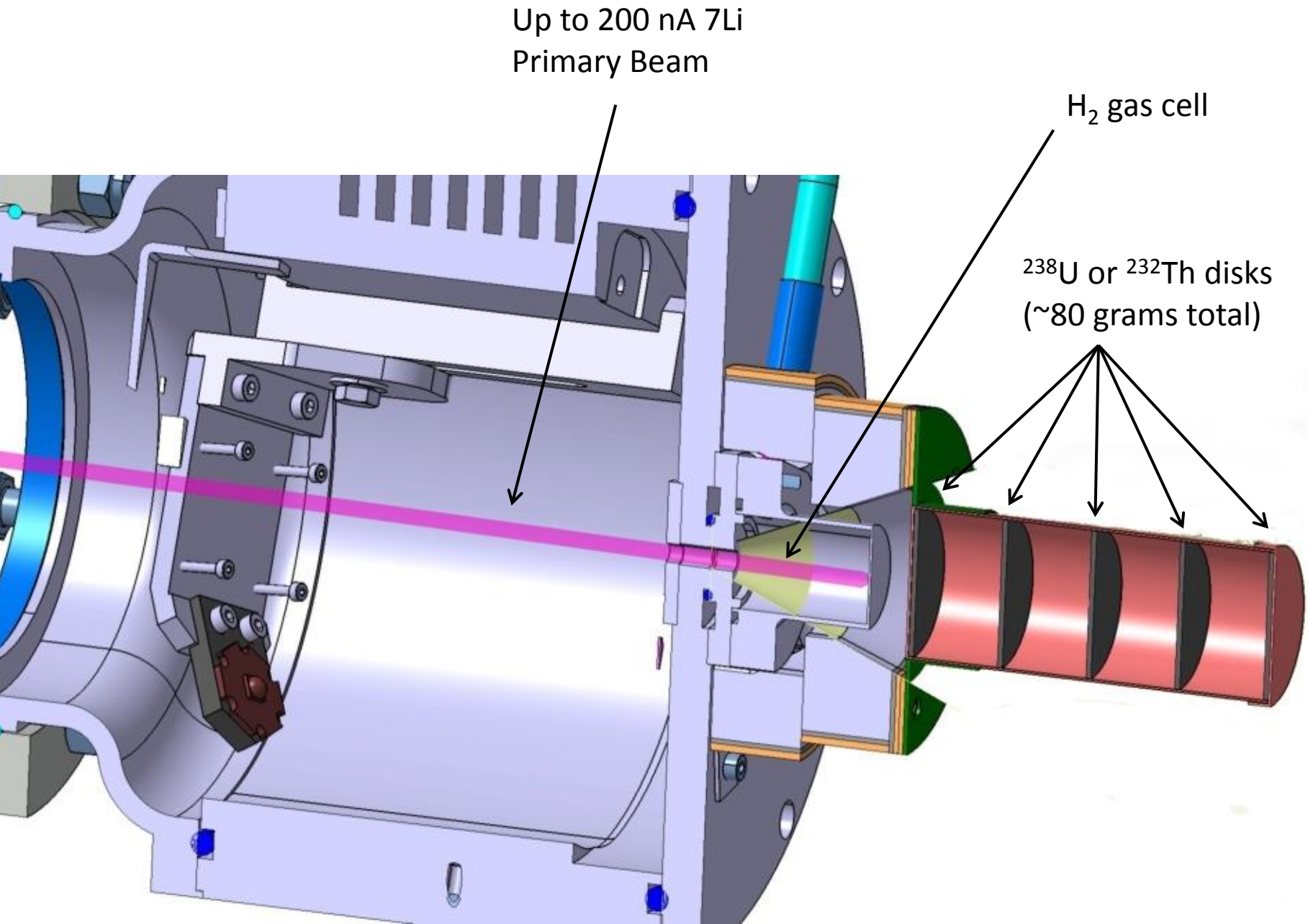
Fission induced by fast ~2 MeV neutrons
^{238}U(n,f), ^{232}Th(n,f)
(LICORNE @ IPN Orsay)



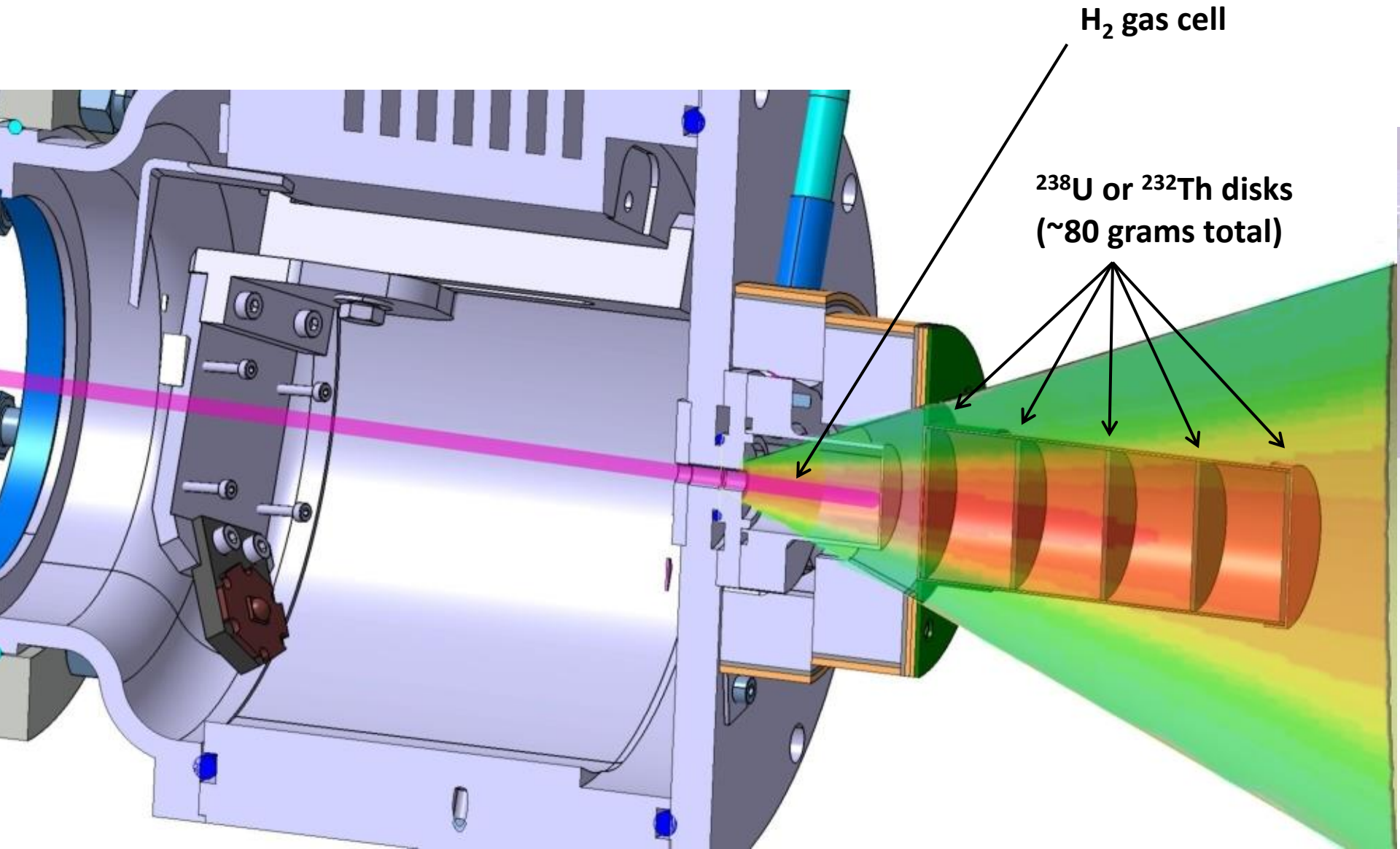
LICORNE/ν-ball concept



LICORNE/ν-ball concept

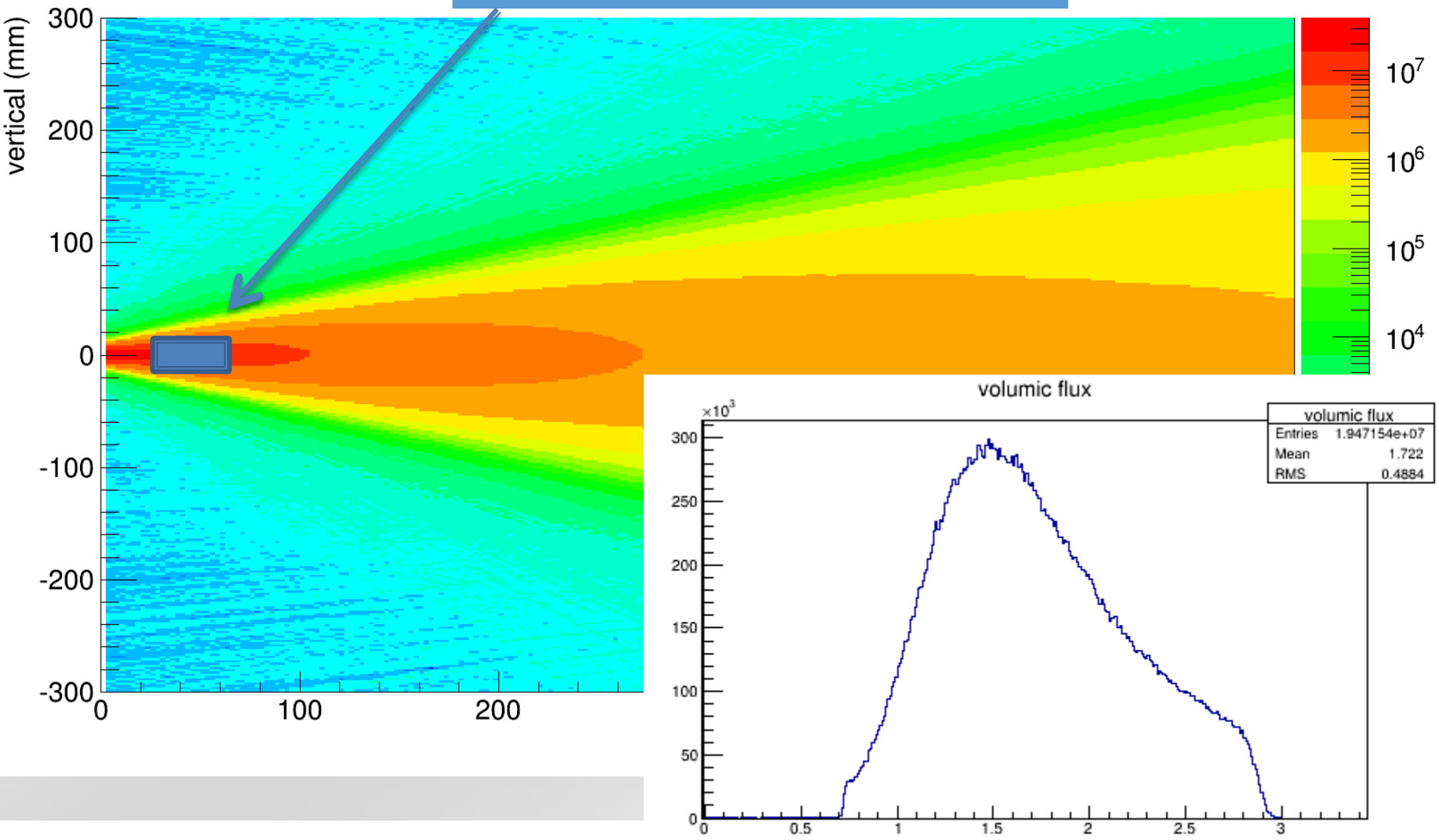


LICORNE/ν-ball concept

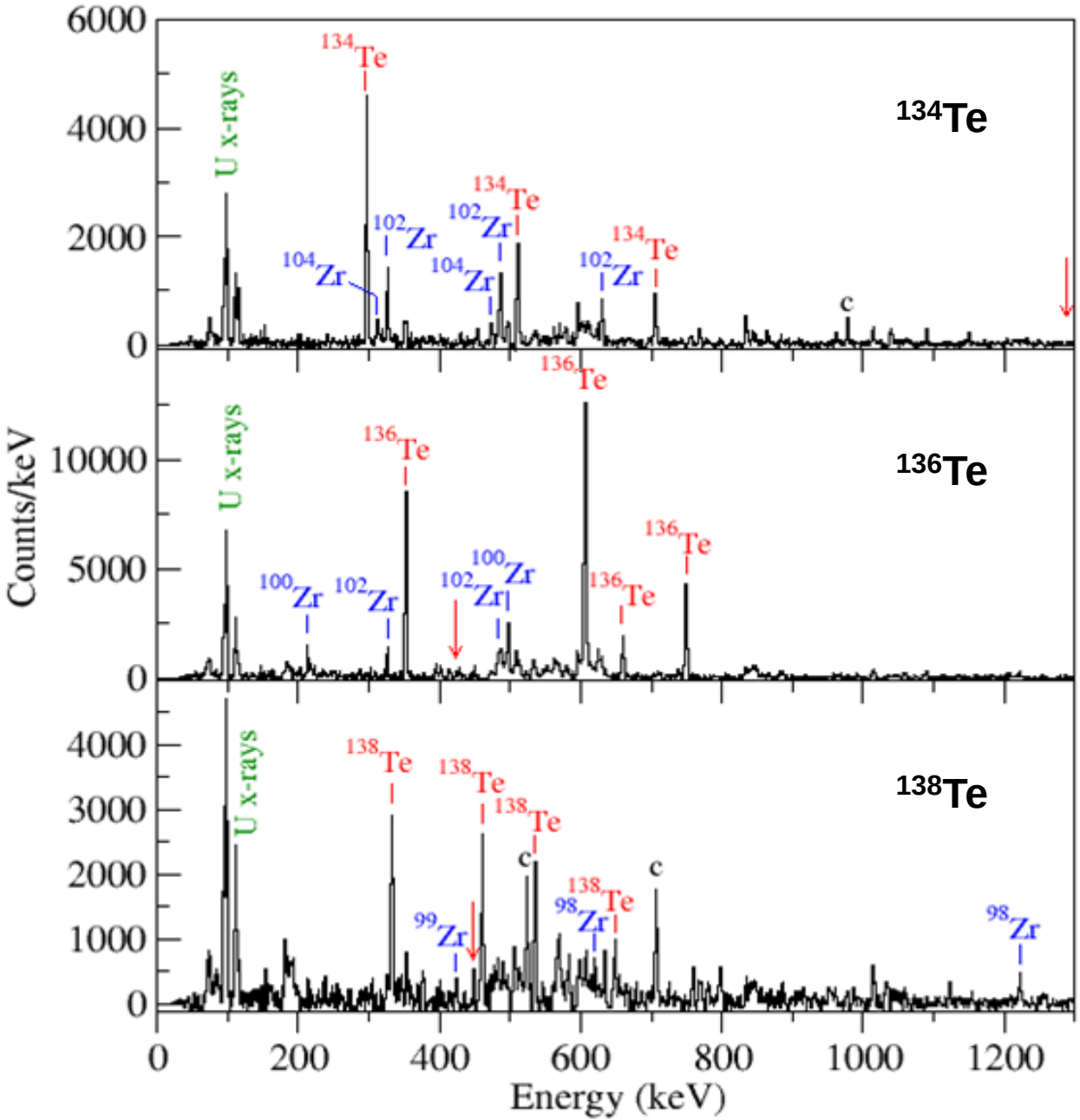


Achievable Fission Rates

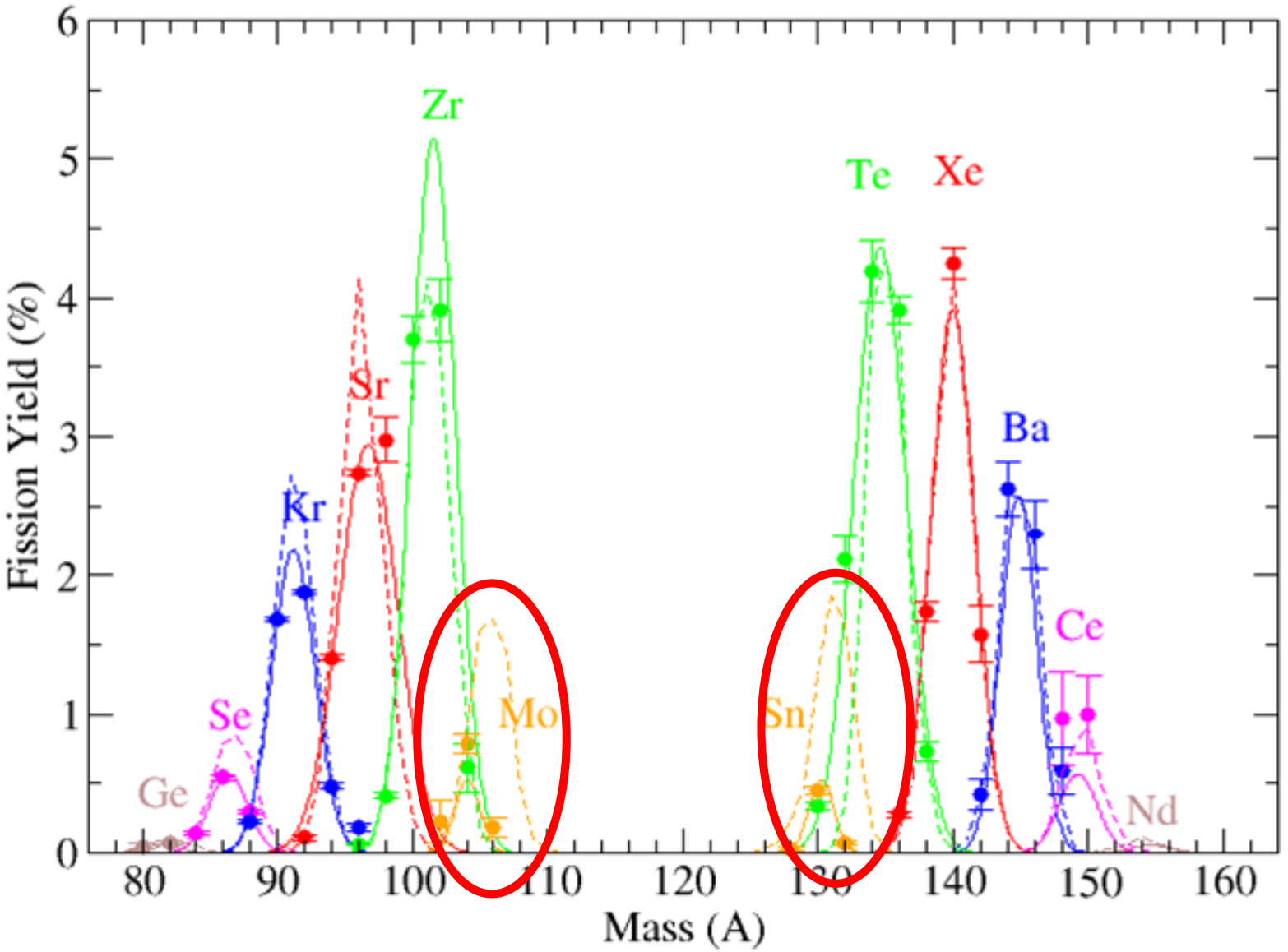
~100 kHz fission rate for ^{238}U(n,f)
~20 kHz fission rate for ^{232}Th(n,f)



Spectroscopy of Te isotopes with Minball (2015)

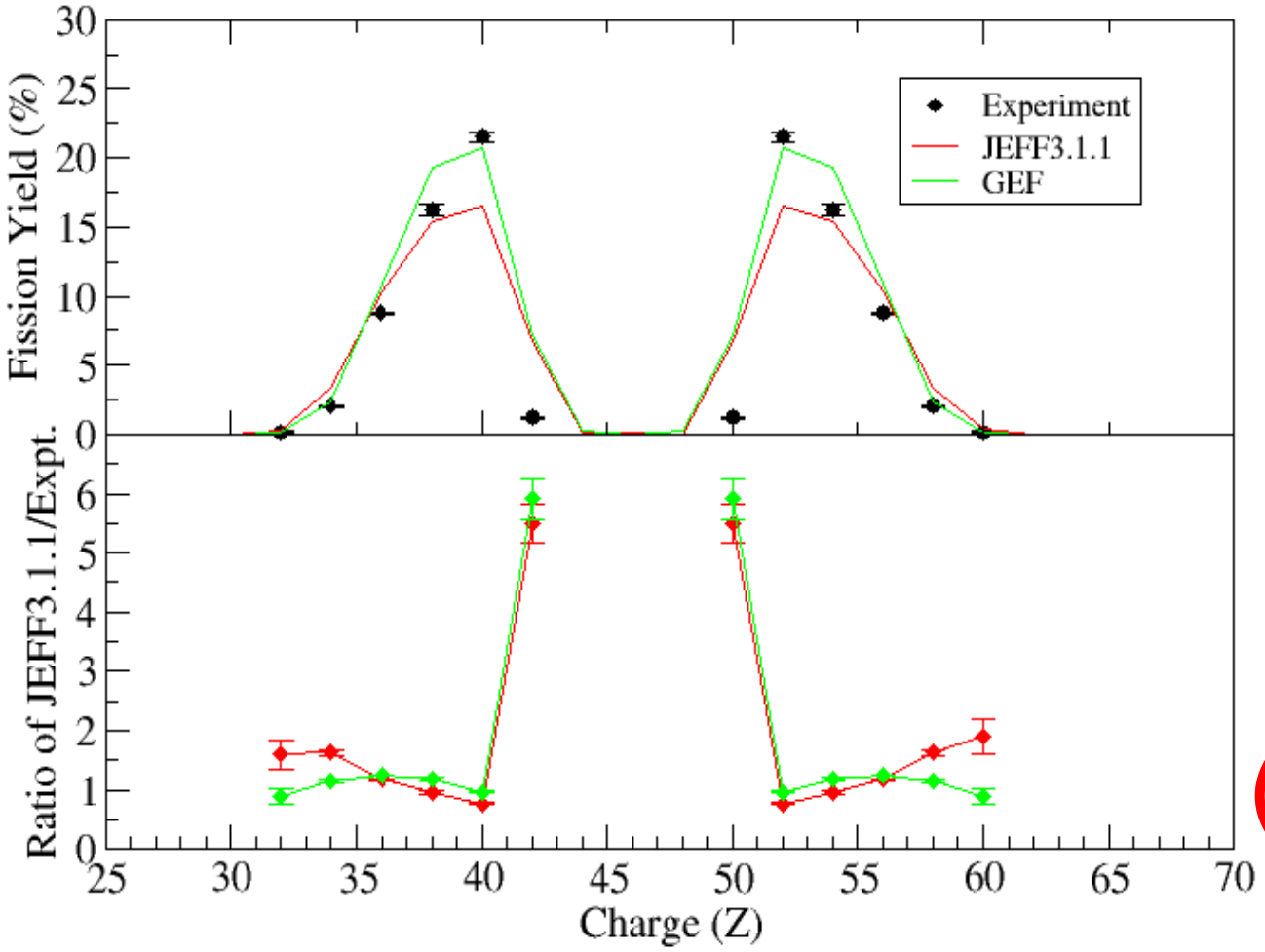


^{238}U(n,f) Fission Yield Measurements



Anomalies in the Charge Yields of Fission Fragments from 238U(n,f)

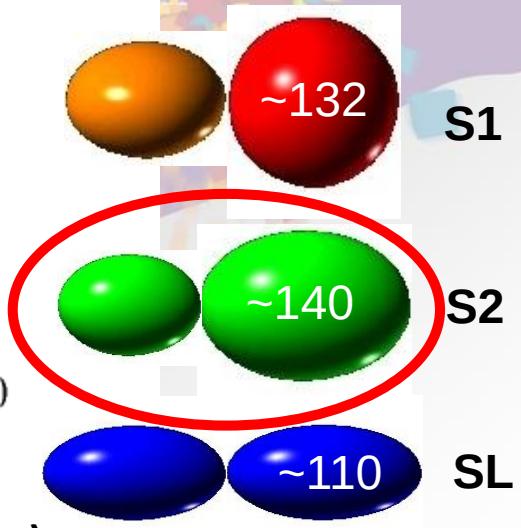
- **Measured charge yields for ^{238}U(n,f)show up to <u>600%</u> discrepencies between models and experiment!**



<u>Interpretation:</u>

Spherical shell effects in the nascent fragments (S1) become much less important

Fission modes

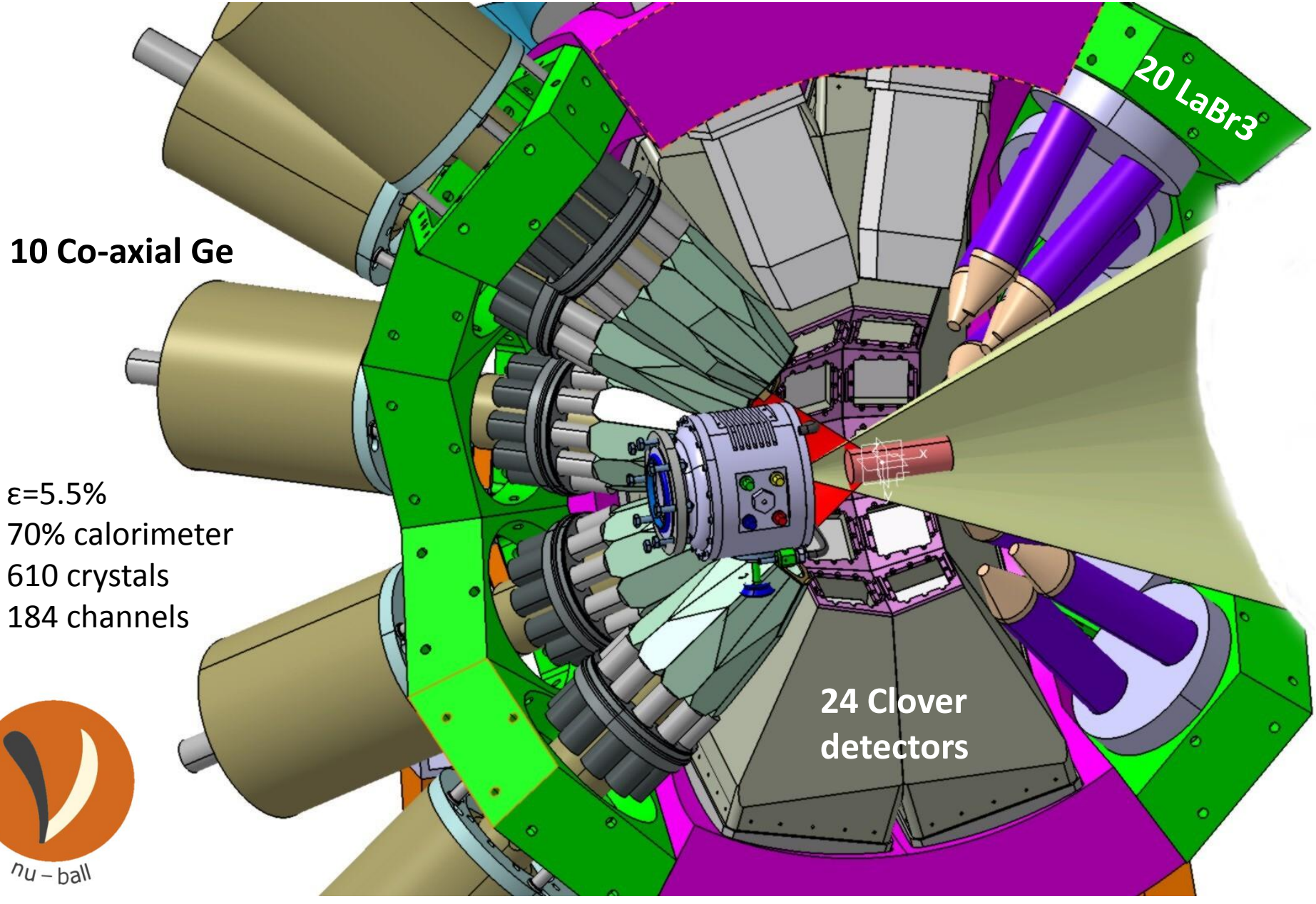


J.N. Wilson, M. Lebois, L. Qi et al., Phys. Rev. Lett. 118, 222501 (2017)

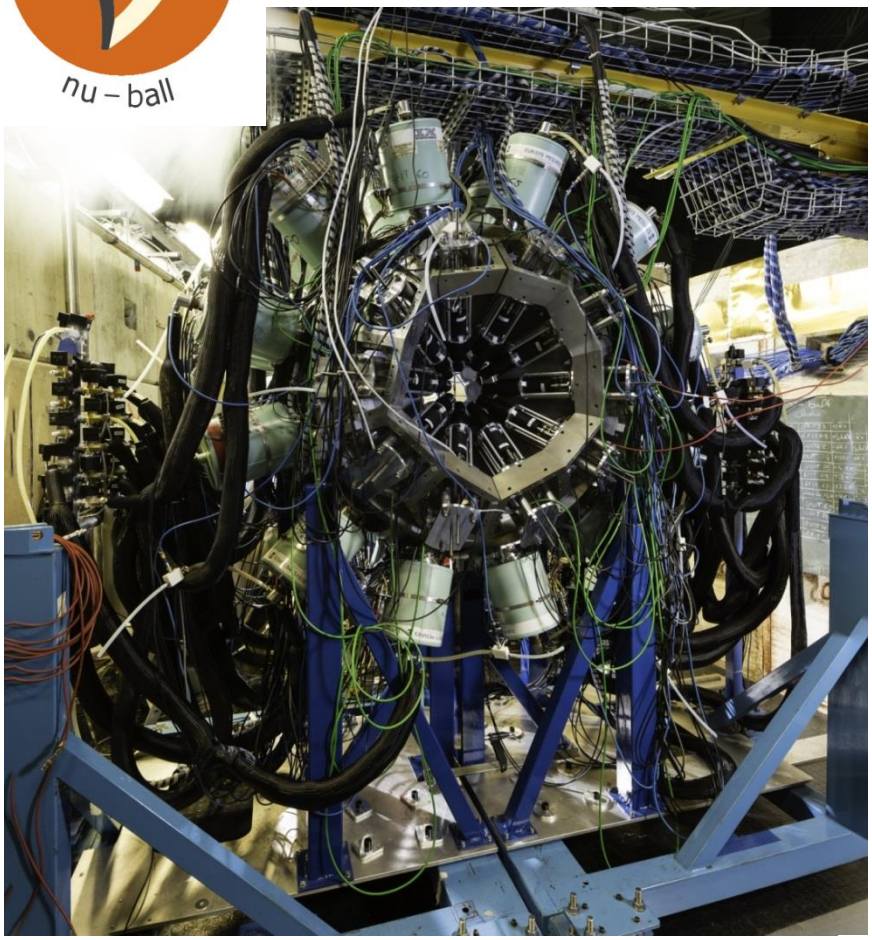
The ν-ball project

Nuclear Physics News Vol. 28, No.4 (2018)

Nu-ball experimental campaign 2017/2018



ν-ball @ ALTO



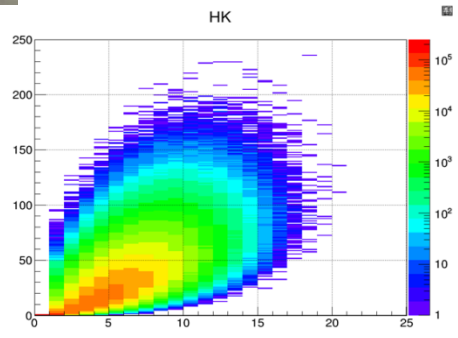
ν-ball experimental campaign

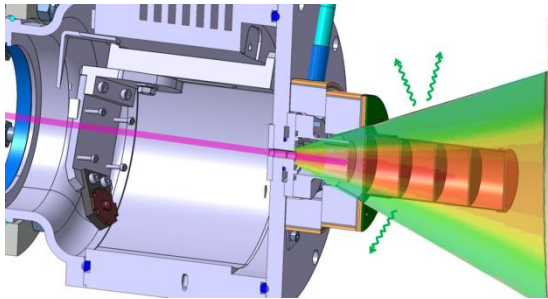
Nov. 2017-June 2018. 10 experiments,
~ 3200 hours of beam time

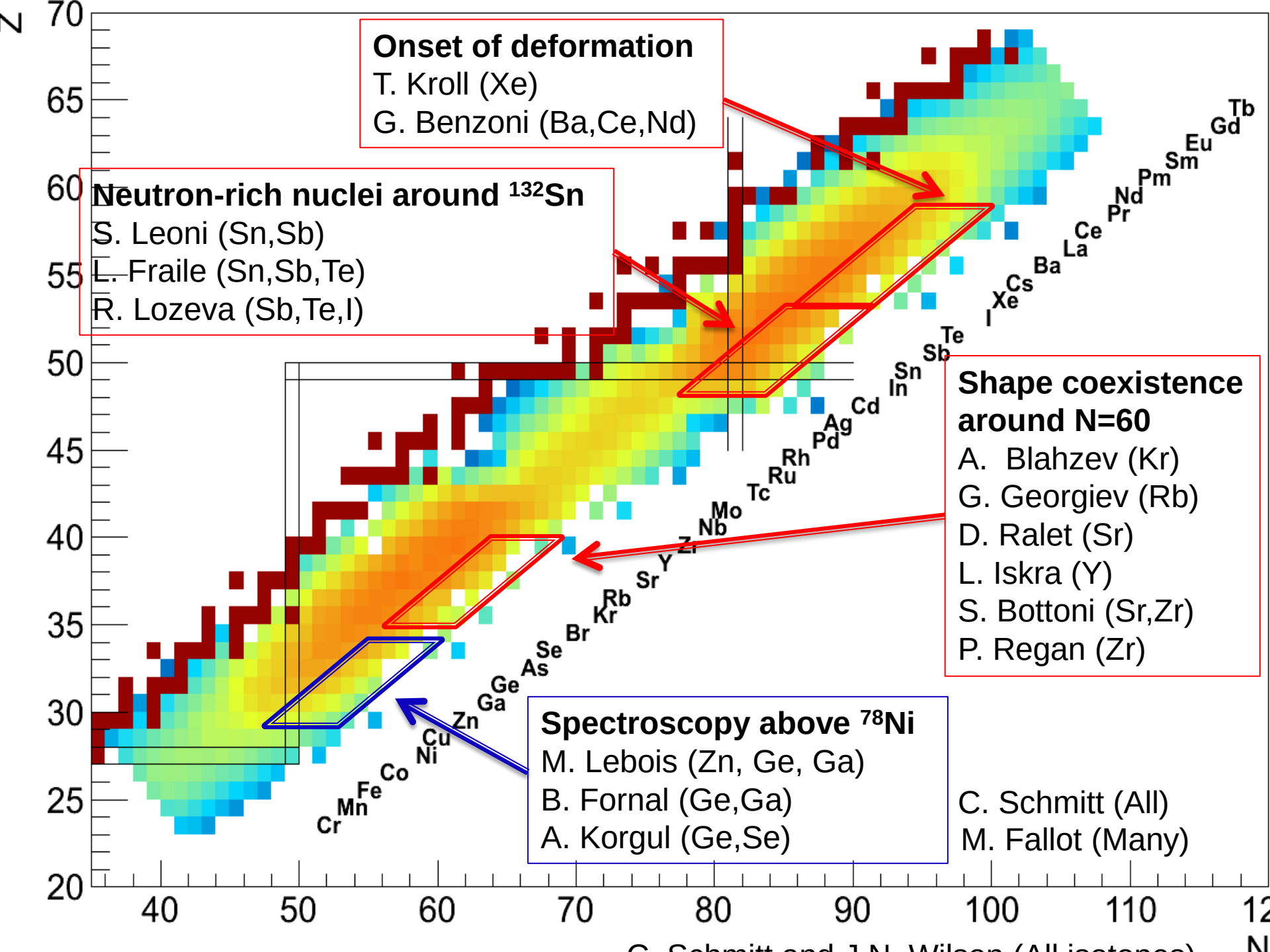
Innovations

- ✓ Hybrid spectrometer (Ge/LaBr3) high resolution, high efficiency
- ✓ Coupling with the LICORNE directional neutron
- ✓ Calorimetry for reaction selection
- ✓ Fully digital DAQ including BGO (200 chans)
- ✓ Triggered or Triggerlesss modes

24 Clover Ge + BGO
10 Coaxial Ge + BGO
20 LaBr3
or 36 PARIS phoswich





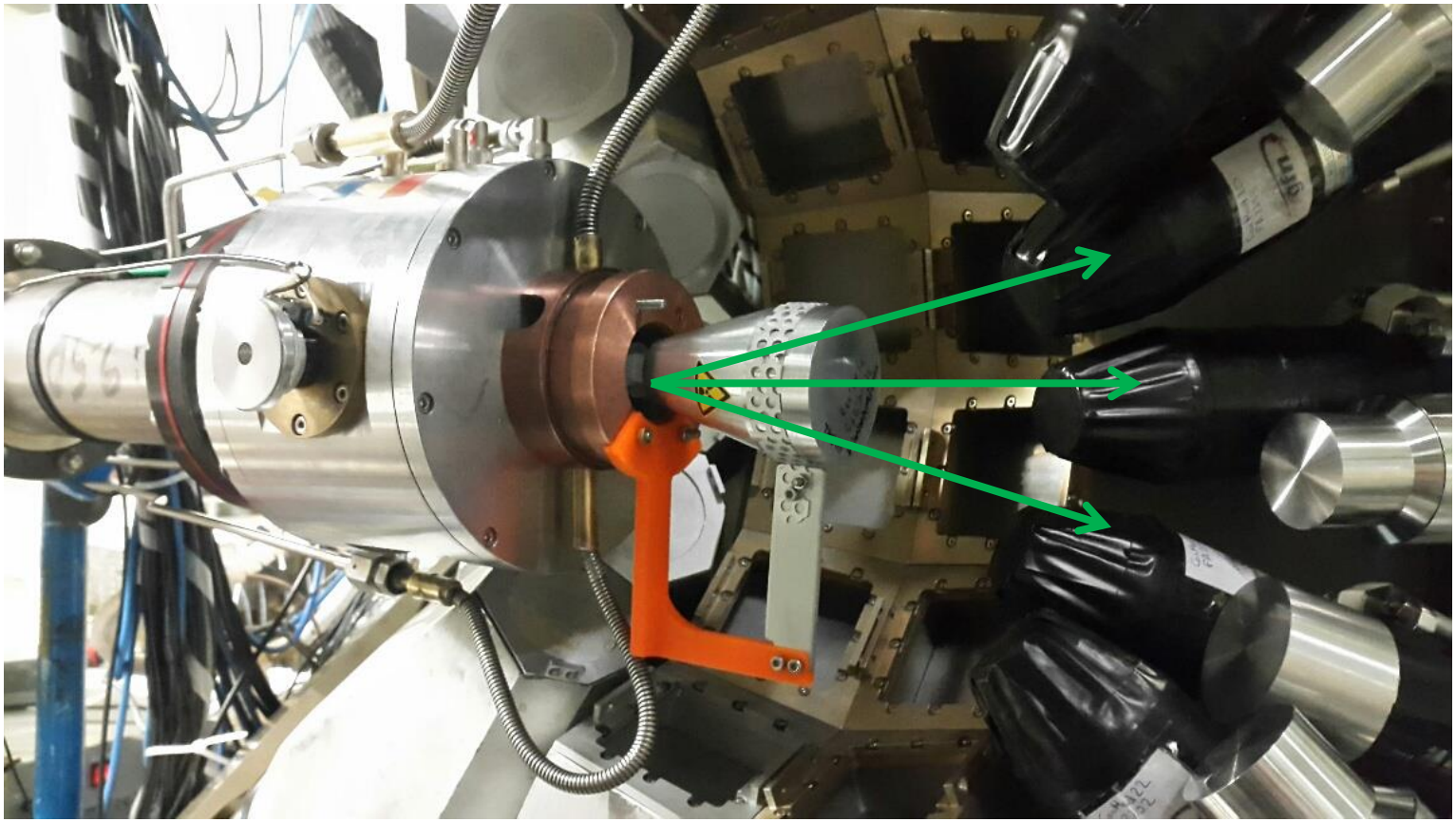

Onset of deformation
T. Kroll (Xe)
G. Benzoni (Ba,Ce,Nd)
Neutron-rich nuclei around 132Sn
S. Leoni (Sn,Sb)
L. Fraile (Sn,Sb,Te)
R. Lozeva (Sb,Te,I)
Shape coexistence around N=60
A. Blahzev (Kr)
G. Georgiev (Rb)
D. Ralet (Sr)
L. Iskra (Y)
S. Bottoni (Sr,Zr)
P. Regan (Zr)
Spectroscopy above 78Ni
M. Lebois (Zn, Ge, Ga)
B. Fornal (Ge,Ga)
A. Korgul (Ge,Se)
C. Schmitt (All)
M. Fallot (Many)
C. Schmitt and J.N. Wilson (All isotopes)
N
Z
70
65
60
55
50
45
40
35
30
25
20
40
50
60
70
80
90
100
110
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Tc
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb

Nu-ball/LICORNE coupling 2018

^{238}U(n,f) @ 1.7 MeV – 2 weeks

^{232}Th(n,f) @ 1.7 MeV – 3 weeks

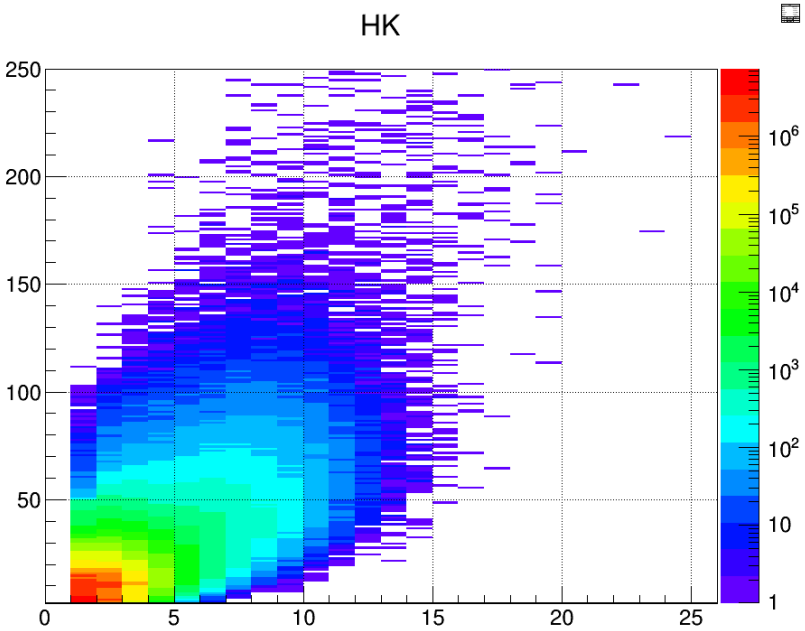
^{238}U(n,f) @ 3.4 MeV – 2 weeks



First preliminary results: ^{252}Cf ionisation chamber + ν-ball

ν-ball calorimetry

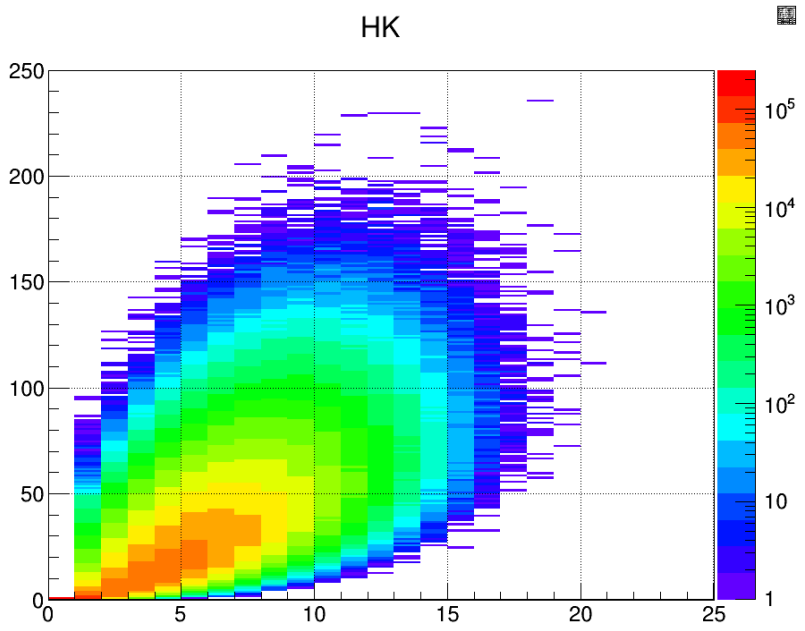
^{152}Eu beta decay events



γ multiplicity

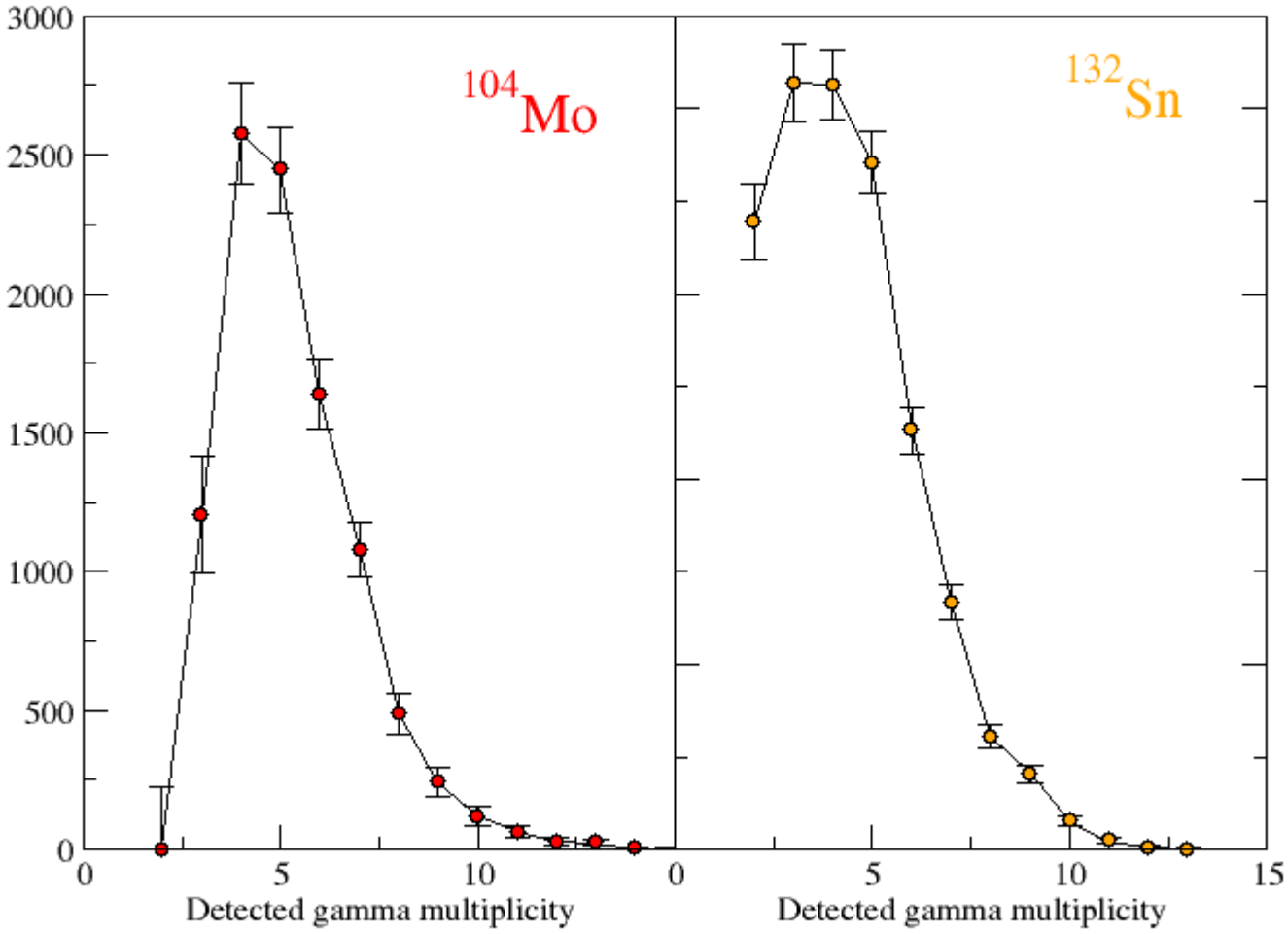
Sum Energy

^{252}Cf fission events



γ multiplicity

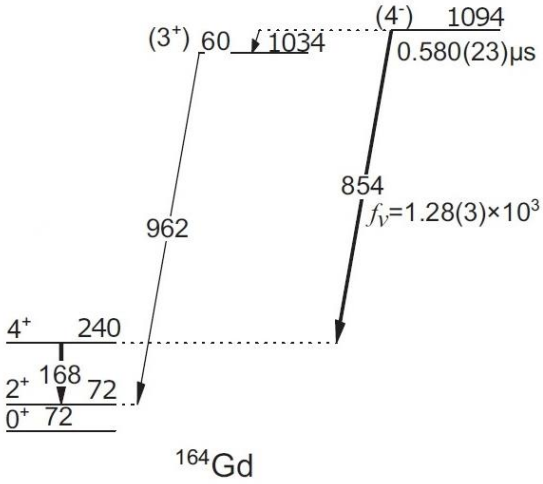
^{238}U(n,f) Gamma Multiplicity Distributions correlated with A/Z



Preliminary results: ^{252}Cf ionisation chamber + ν-ball

RIKEN

Isomer in ^{164}Gd discovered at BIGRIPS focal plane in 2017



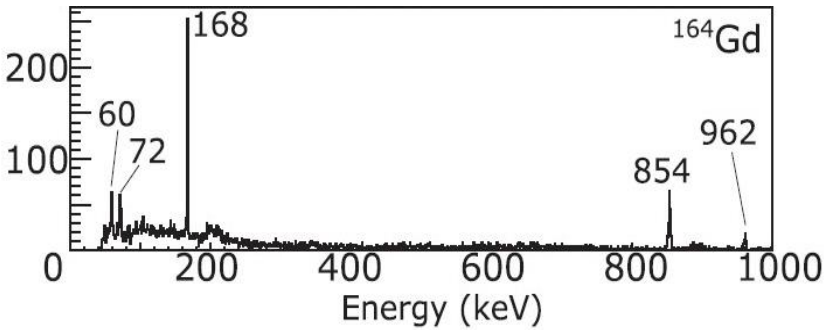
ν-ball

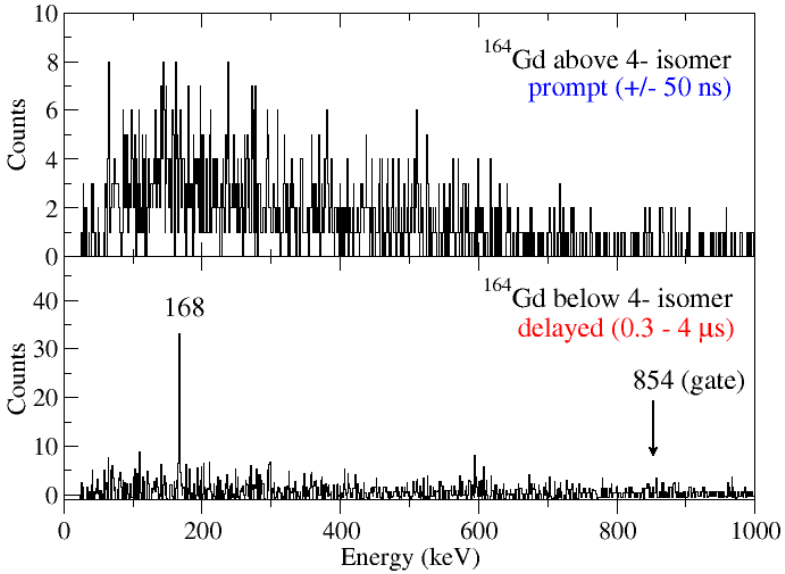
^{164}Gd isomer identified after only 48 hours of data

< 0.01% of the total yield

Decays from states *above* the isomer observed for the first time

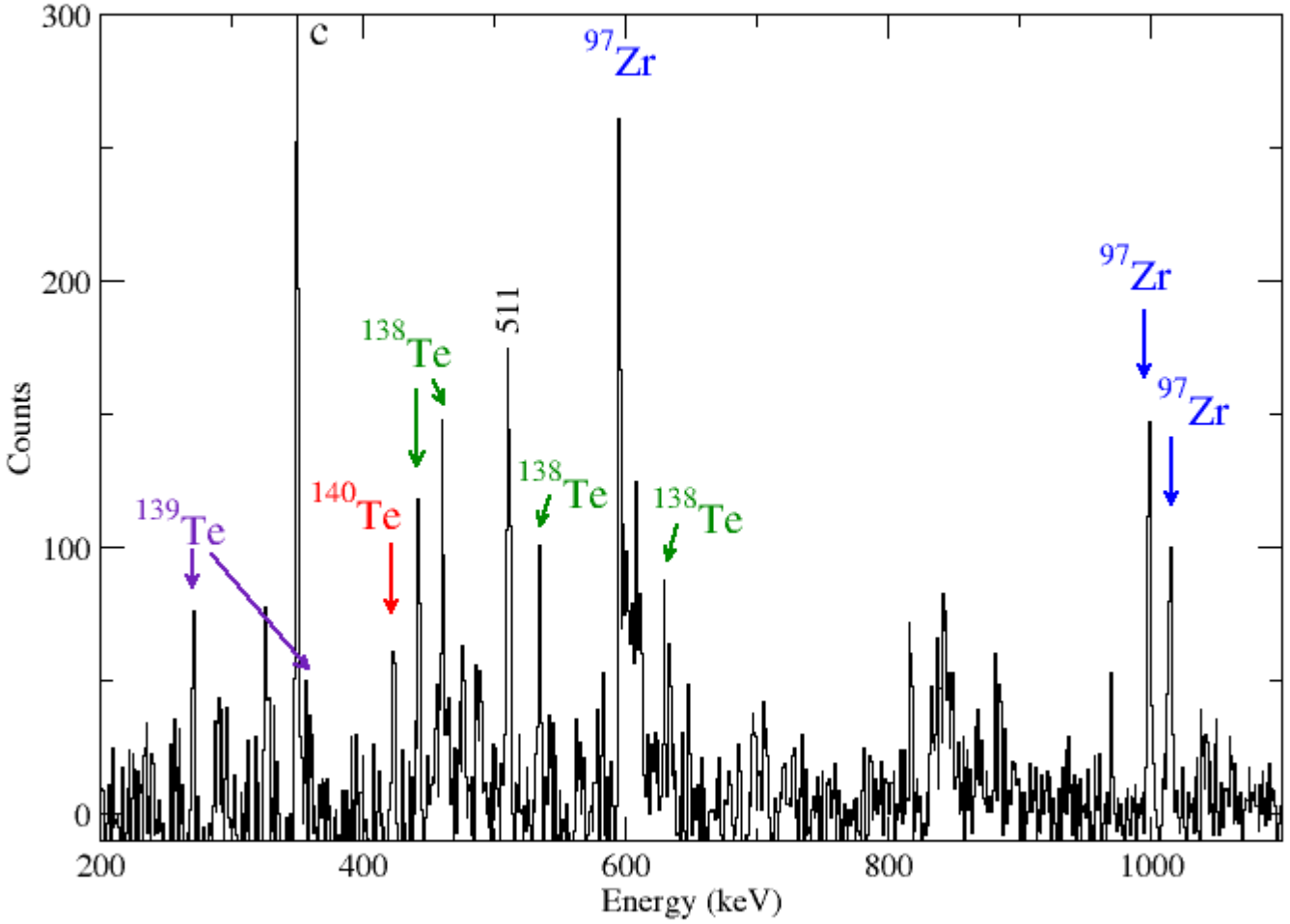
Prompt decays impossible to observe





Preliminary results: LICORNE ^{238}U(n,f) + ν-ball

Gate on 1103 keV transition – 100 ns isomer in ^{97}Zr



^{140}Te discovered at RIKEN in 2017 [B. Moon et al. Phys. Rev. C 95, 044322 (2017)]

Fast Neutron Tomography with LICORNE and NEDA

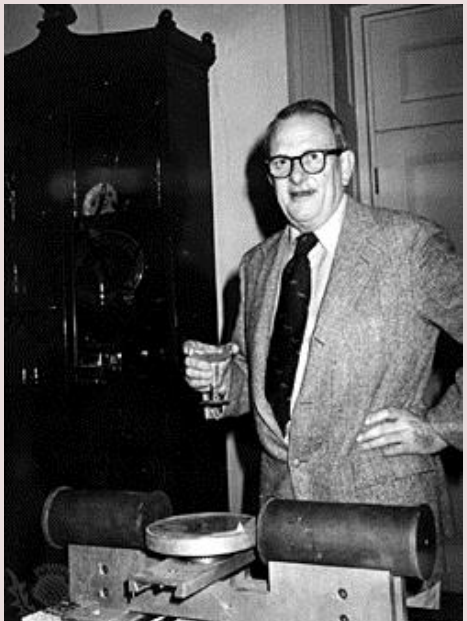
IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

First x-ray Images

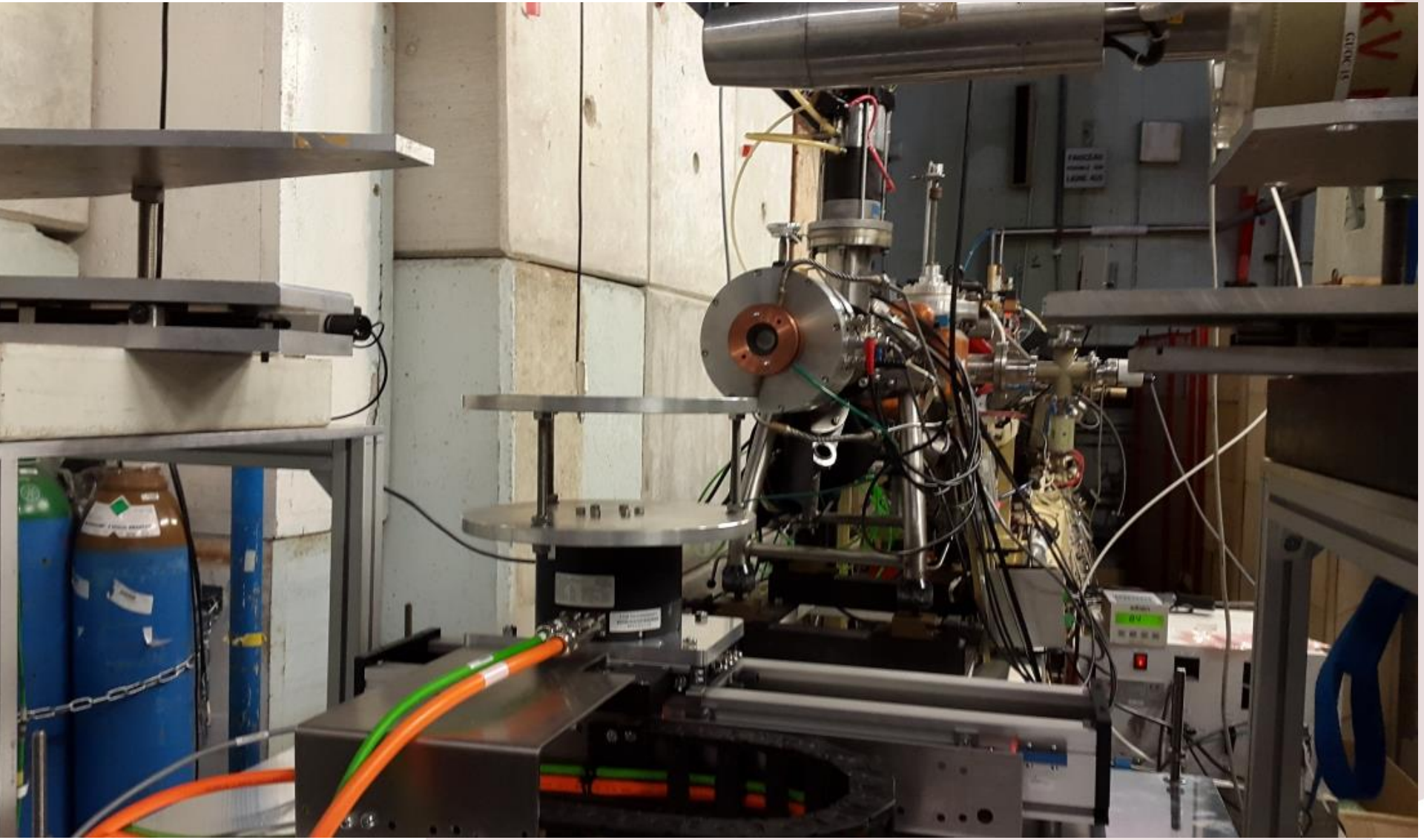
Willhelm Röntgen (1895)
1st ever Nobel Prize (1901)

First x-ray Computed Tomographic Images

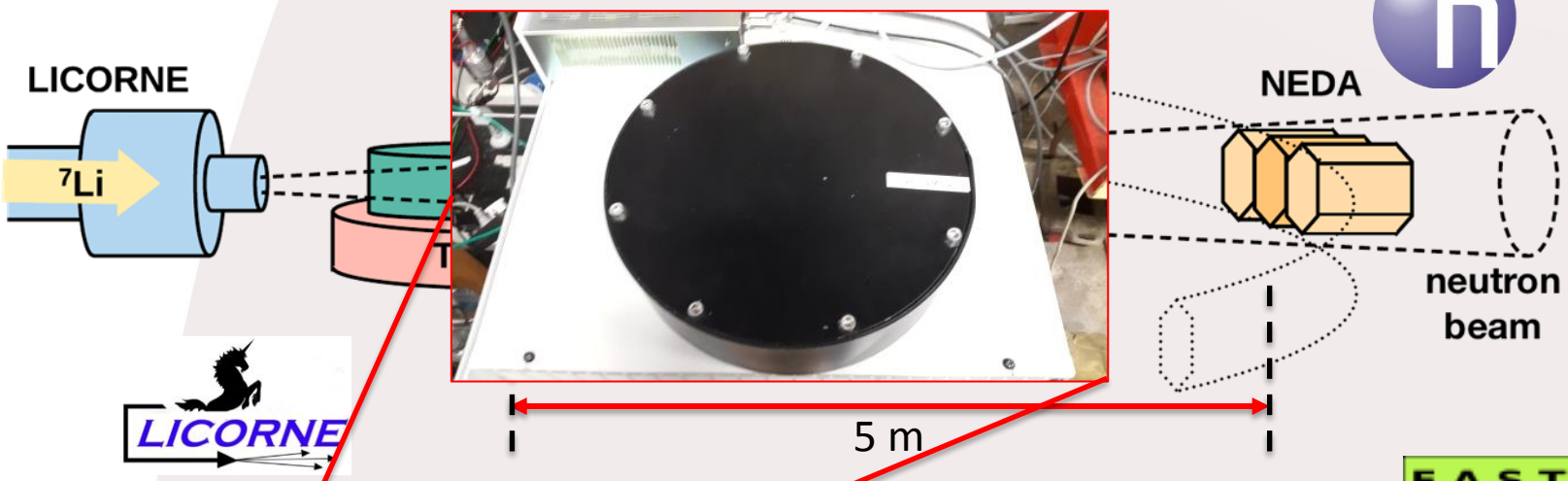
Allan M. Cormack &
Godfrey N. Hounsfield
Nobel Prize in Medicine (1979)

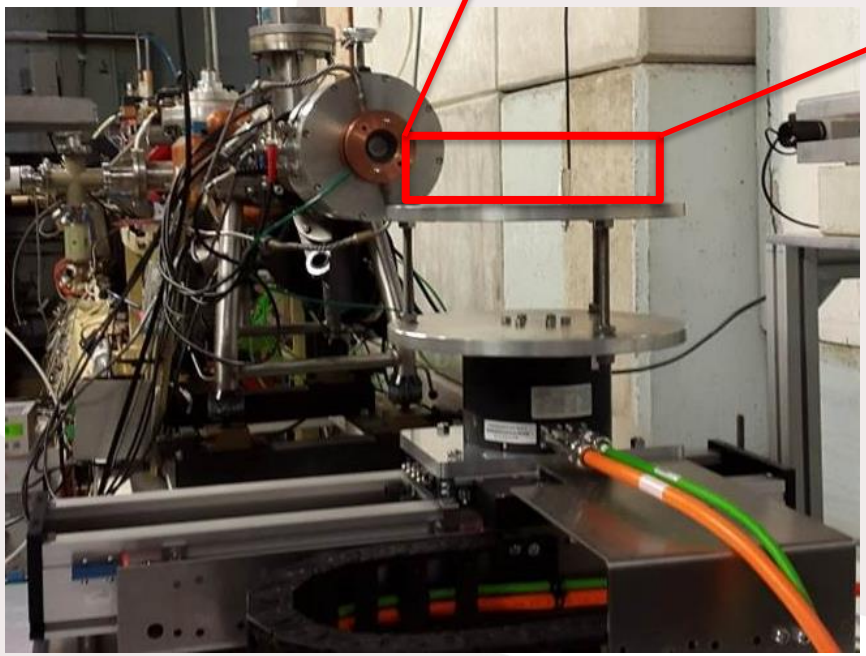


IPN Orsay scanning table + LICORNE

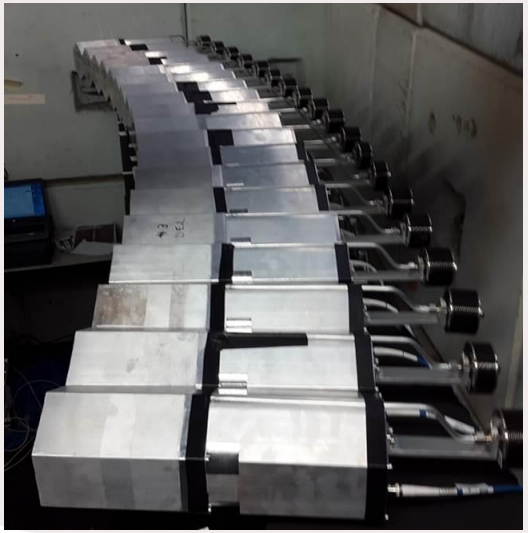


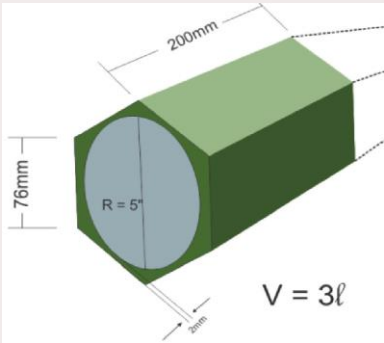
Fast Neutron Tomography with LICORNE and NEDA (december 2016)





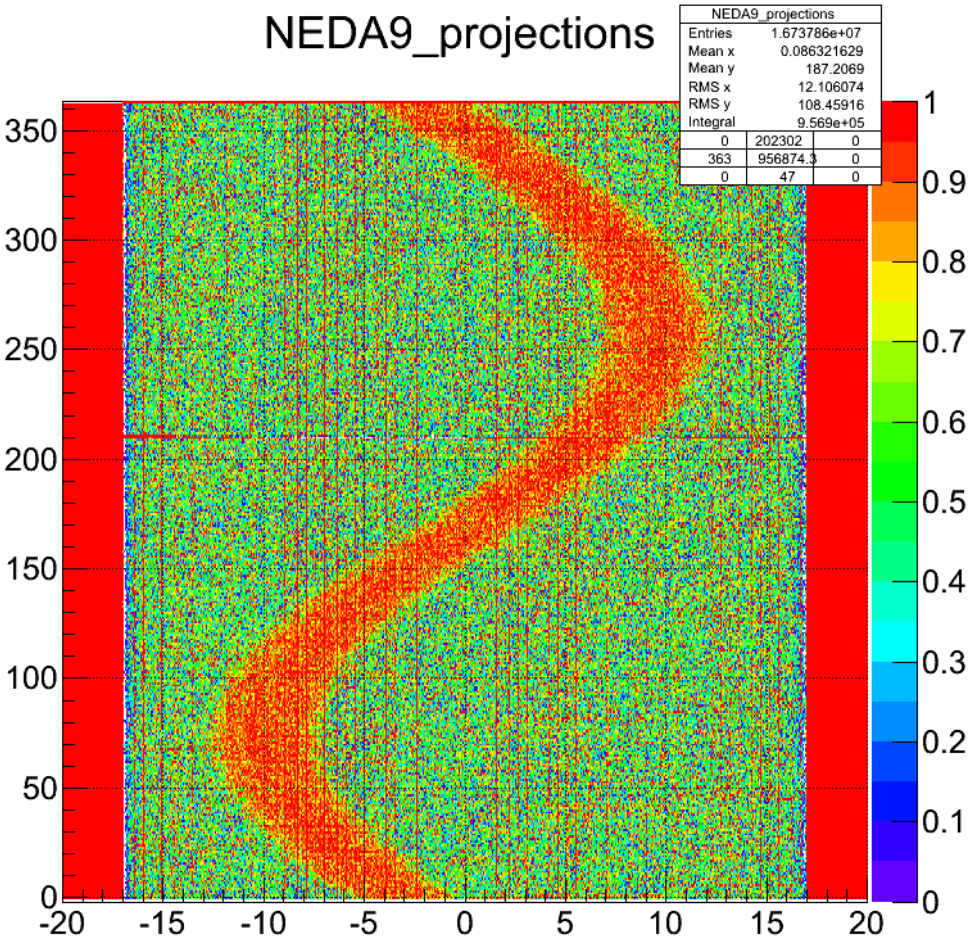
First Use of **NEDA** with FASTER



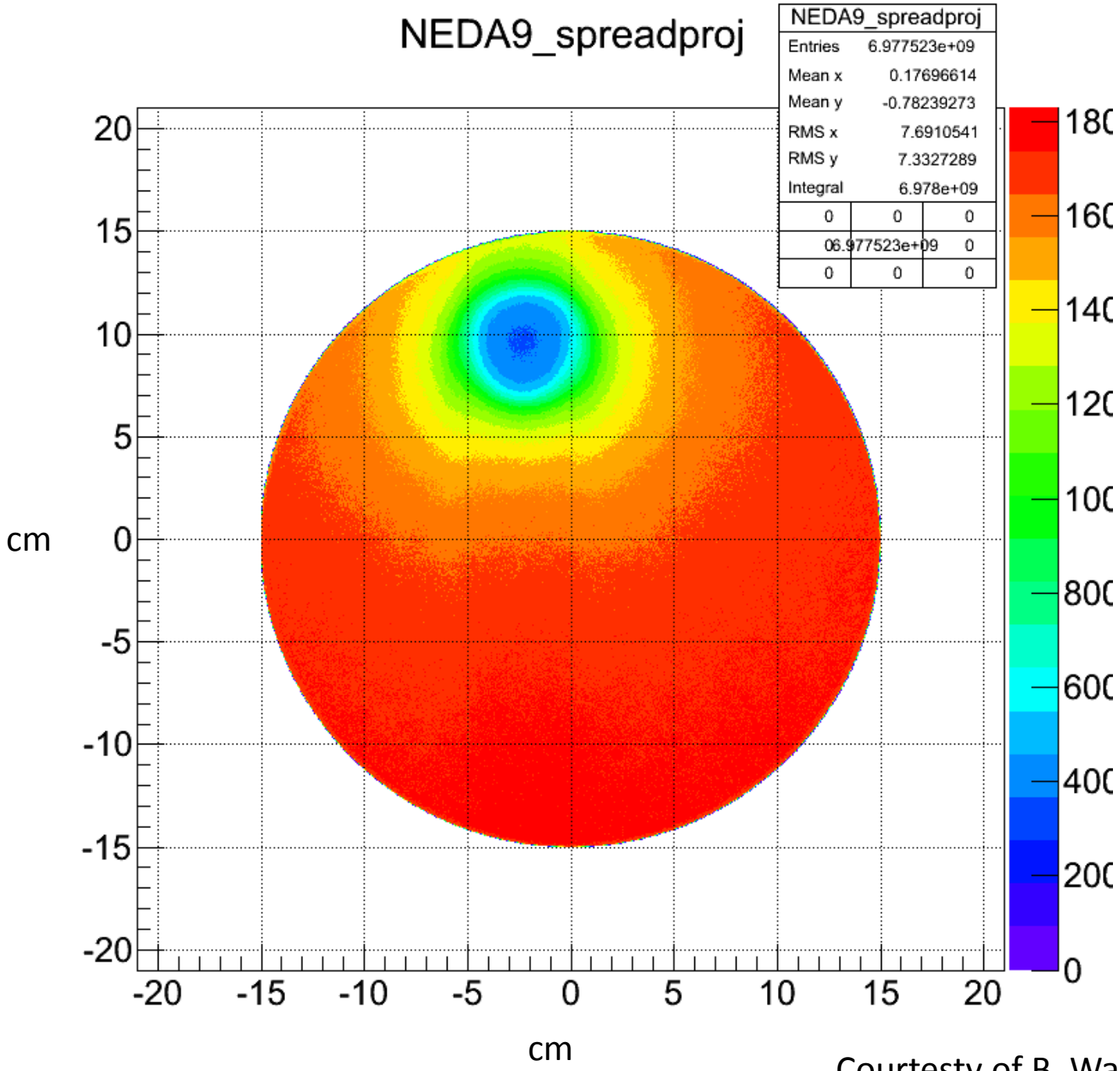


BC501A

First Results

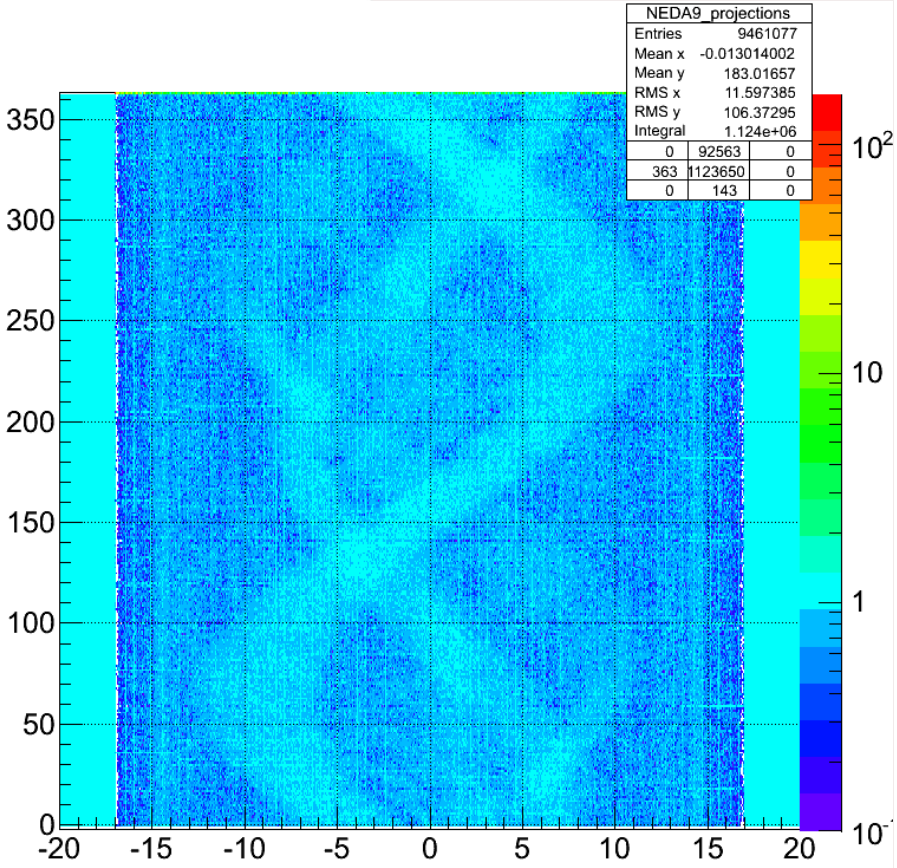


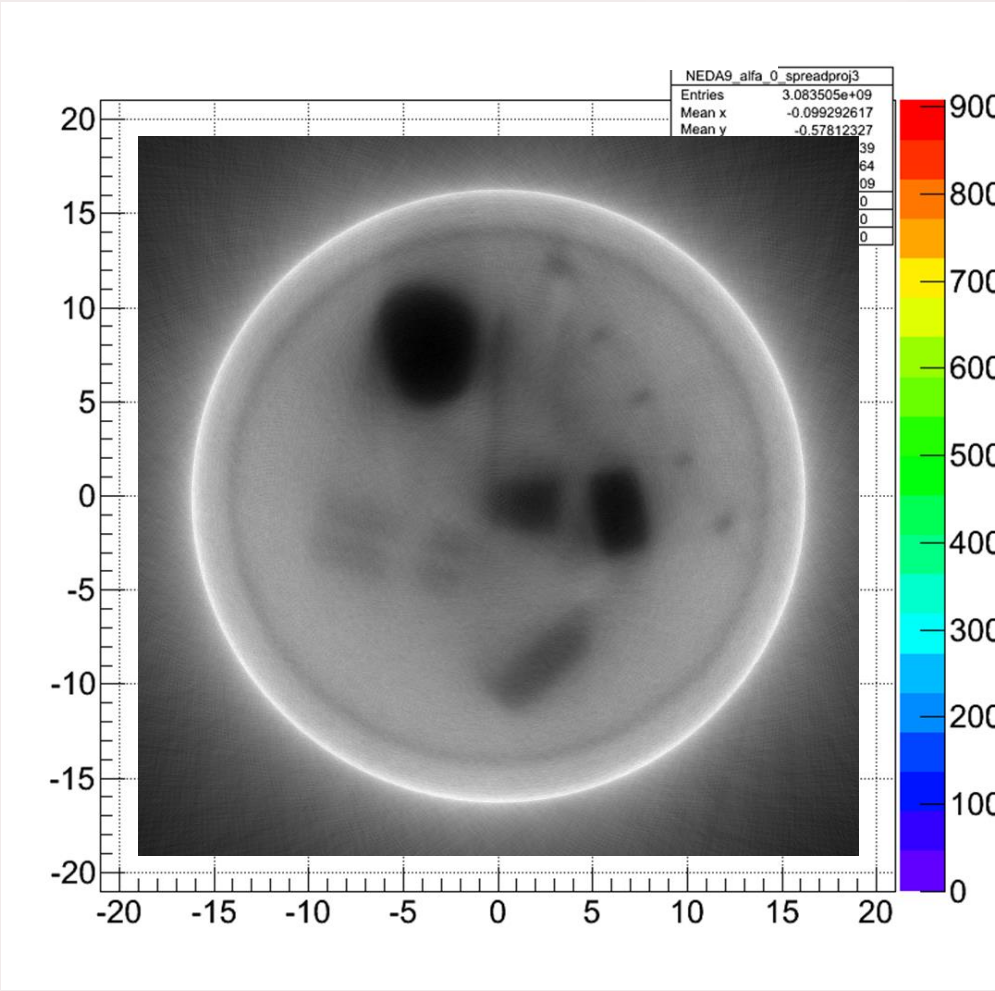
Courtesty of B. Wasilewska



Courtesty of B. Wasilewska

Fast Neutron Tomography with LICORNE and NEDA





Courtesty of B. Wasilewska

ν-ball2 experimental campaign

Starting 2021 at the IPN Orsay