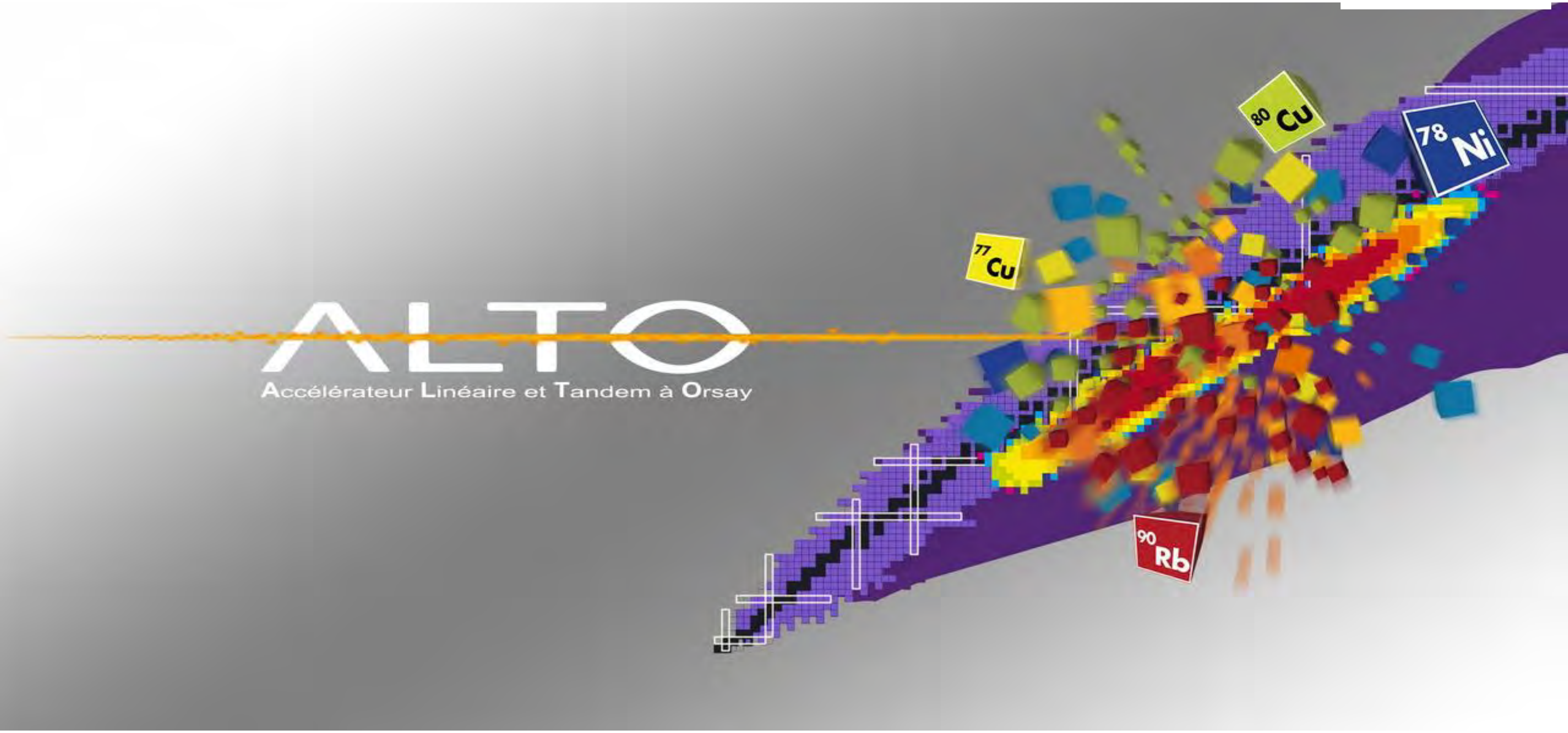
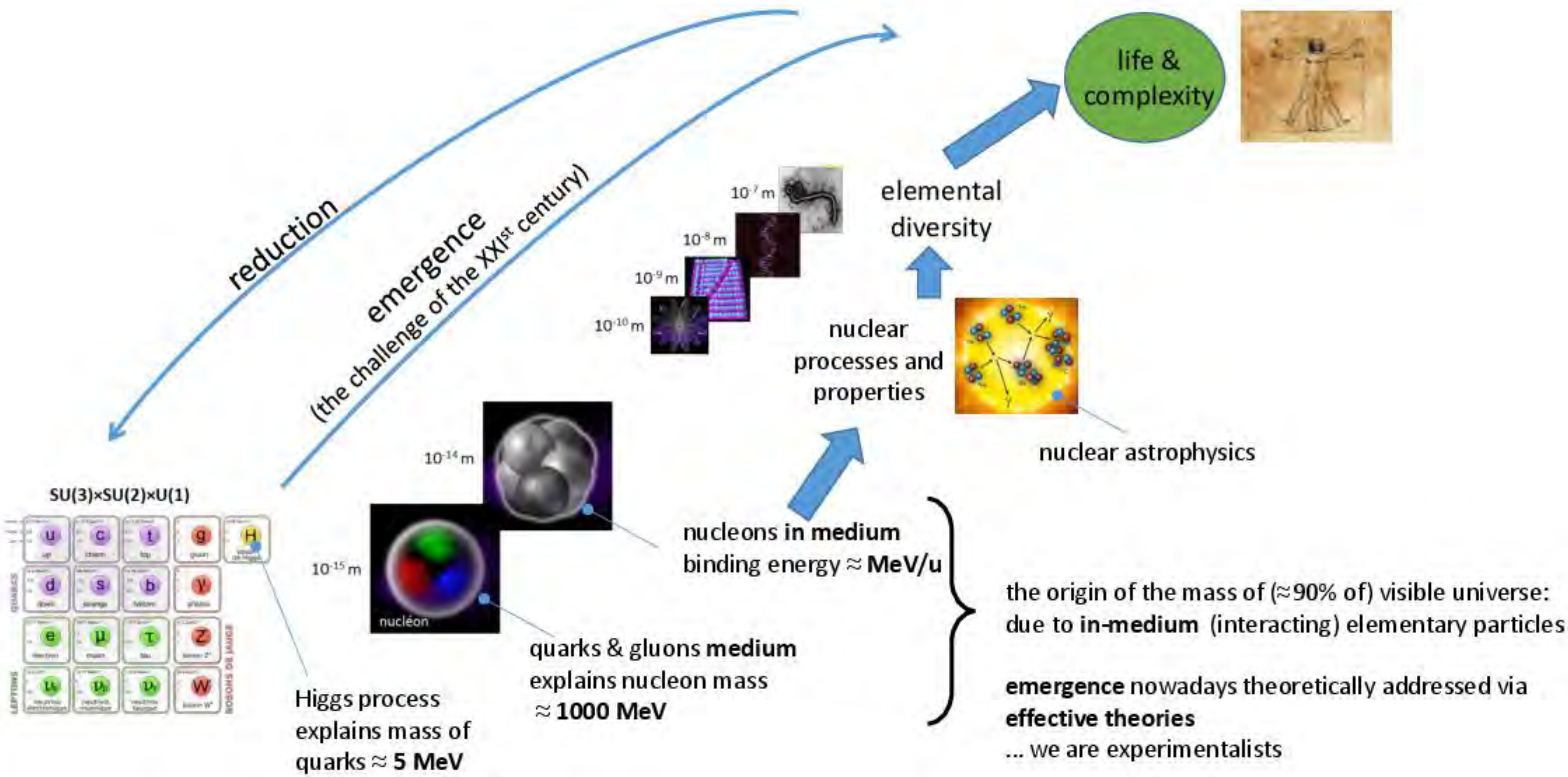
The ν-ball project at ALTO

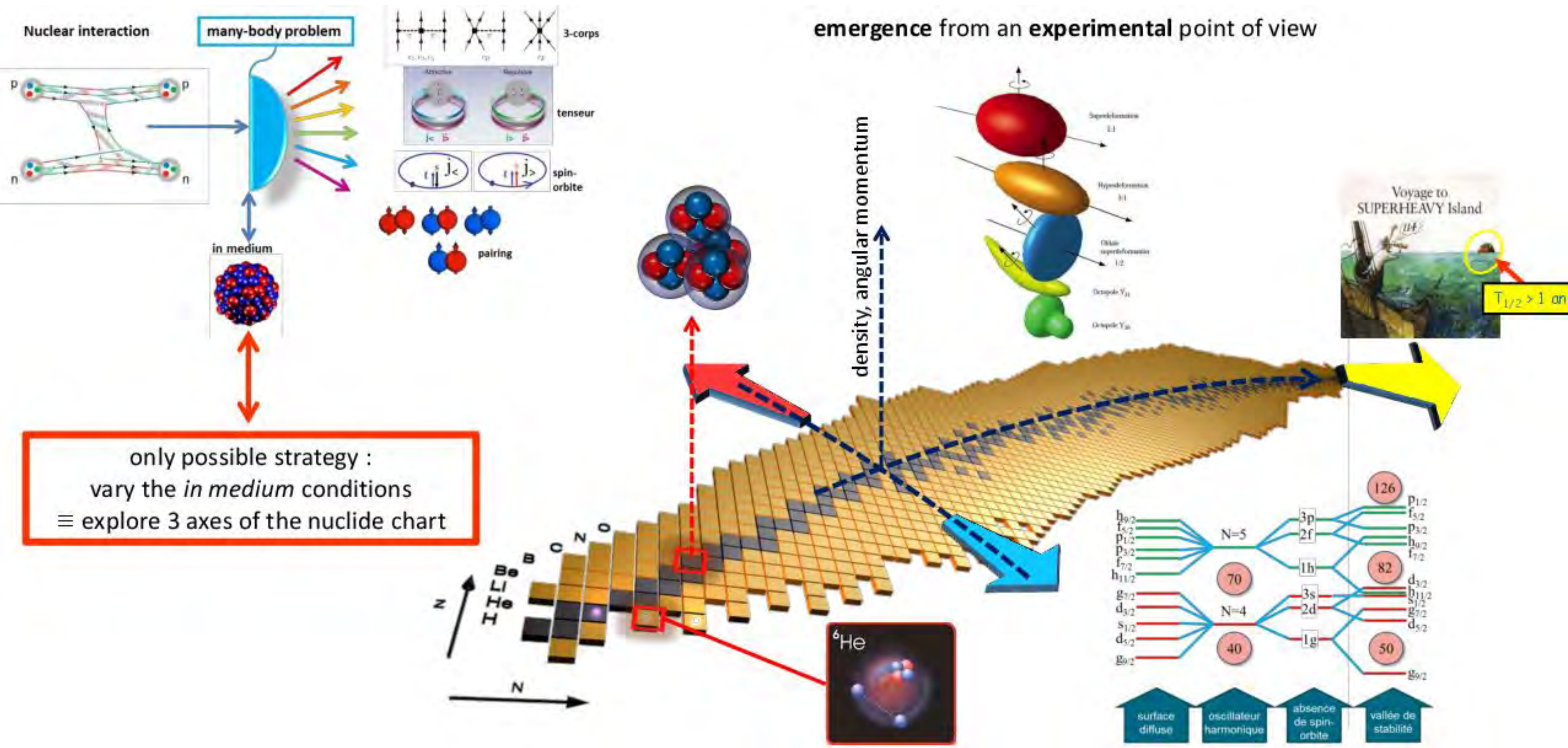
<u>Jonathan Wilson</u>, Matthieu Lebois,
Nikola Jovancevic, Liqiang Qi, Damien Thisse
IPN Orsay



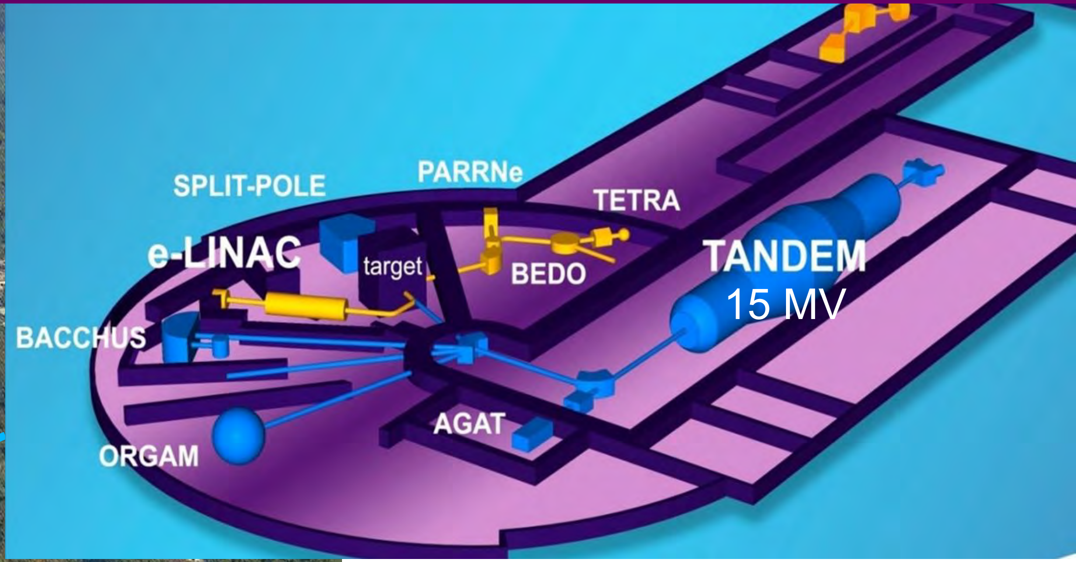
Why study atomic nuclei?



Experimental study of emergent phenomena at 10^{-14}m



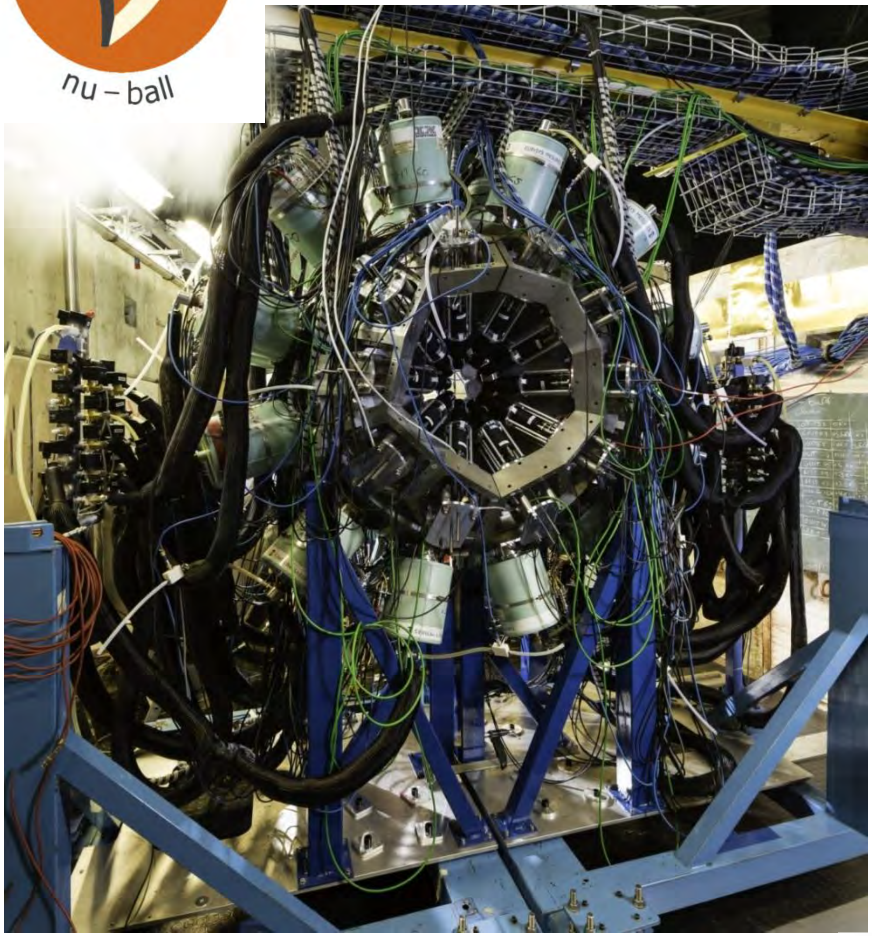
The ALTO facility



ALTO typically delivers ~3000 hours of beam time per year

- **Trans National Access Facility (ENSAR2, ARIEL)**
- **ALTO international PAC**

The ν-ball spectrometer @ ALTO



ν-ball international collaboration

153 researchers from 16 countries and 37 institutes, including 80 Ph.D students

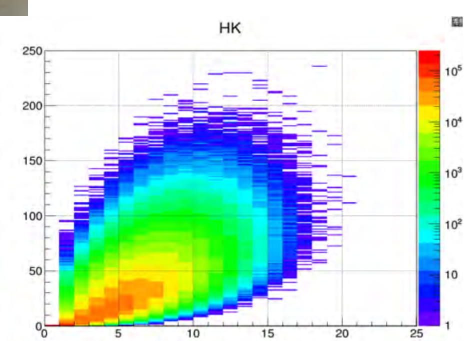
ν-ball experimental campaign

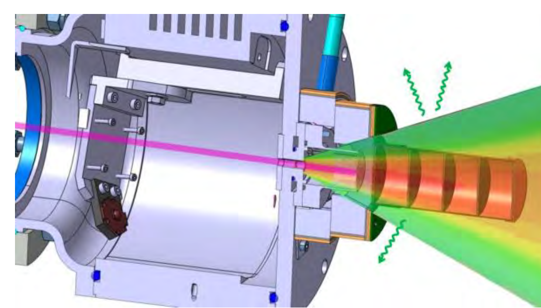
Nov. 2017-June 2018. 10 experiments
3000 hours of beam time

Innovations

- ✓ Hybrid Spectrometer (Ge/BGO/LaBr3) high resolution, high efficiency
- ✓ Coupling with the LICORNE directional neutron source
- ✓ Calorimetry for reaction studies/selection
- ✓ Fully digital, 200 channels, including BGO
- ✓ Modes Triggered or Triggerlesss

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





What physics questions does ν-ball address?

- To understand the detailed nuclear structure of very neutron-rich isotopes far from nuclear stability

- To study precisely fast-neutron-induced nuclear fission using new techniques to extract new observables and new correlations

- To further develop state-of-the art fast timing techniques to measure sub nanosecond lifetimes, study nuclear isomerism, extract nuclear moments

- To facilitate diverse spectroscopy experiments proposed by the national and international users of the ALTO facility

The ν-ball Letter of Intent (2015)

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

J.N. Wilson[1], P.H.Regan[2,3] ,G. Georgiev[4], I. Matea[1], D. Verney[1], M. Lebois[1], P. Halipre[1], L. Qi[1], A. Gottardo[1], J. Ljungvall[4], Zs.Podolyak[2], S.M.Judge[2,3], R. Shearman[2,3], R. Carroll[2], M. Rudigier[2], A.Pearce[3], G.Lorusso[2,3], A.M. Bruce[5], N. Marginean[6], T. Kroell[7], S. Ilieva[7], A. Ignatov[7], G. Fernandez[7], V. Werner[7], L.M. Fraile[8], V. Vedia[8], J. Jolie[9], J.M. Regis[9], W. Korten[10], J.F. Smith[11], P.M. McKee[11], E. Parr[11], M. Smolen[11], S.Lalkovski[2,12], S. Kisyov[12], A. Görgen[13], S.Siem[13], K. Hadynska-Klek [13], E. Sahin[13]A. Oberstedt[1,14], S. Oberstedt[15]

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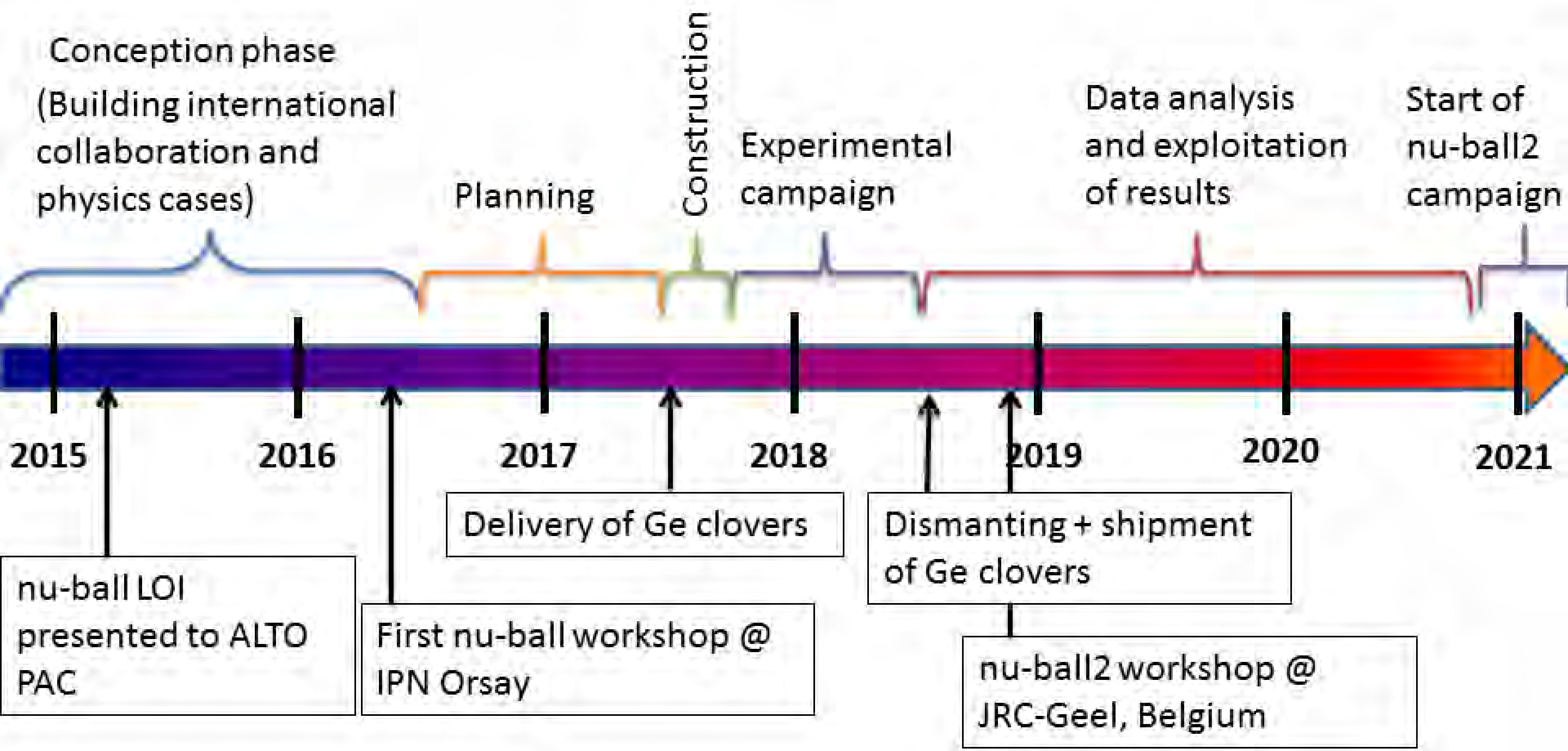
[2]*Department of Physics, University of Surrey, UK*
[3]*AIR Division, National Physical Laboratory,Teddington, UK*
[4]*CSNSM Orsay, France*
[5]*University of Brighton, UK*
[6]*IFIN-HH. Maguerele, Bucharest, Romania*
[7]*TU Darmstadt, Germany*
[8]*U. Complutense, Madrid, Spain*
[9]*IFK- Köln, Germany*
[10]*CEA Saclay, France*
[11]*Universiyt of West of Scotland, Paisley, UK*
[12] *University of Sofia, Bulgaria*
[13] *University of Oslo, Norway*
[14] *Chalmers University, Sweden*
[15]*European Commission JRC-IRM, Geel, Belgium*

The first nu ν-ball workshop, May 2016

- building the ν-ball international collaboration

ν-ball time line



The ν-ball International Collaboration

153 researchers from 16 different countries, 37 instutitues, including ~80 thesis students

France(44)
IPN Orsay (16)
CSNSM Orsay (6)
CEA DAM/CEA Saclay (5)
Subatech, Nantes (3)
CENBG Bordeaux (6)
IPHC Strasbourg (3)
GANIL (2)
LPC Caen (2)
ILL (1)

UK(29)
University of Surrey (13)
National Physical Laboratory (5)
University of Brighton (2)
University of West Scotland (4)
University of Manchester (3)
University of York (2)

Germany(16)
TU Darmstadt (7)
IFK- Koln (9)

Poland(14)
IFJ-PAN Krakow (8)
University of Warsaw (6)

Italy(8)
University of Milano(6)
University of Padova(1)
Legnaro(1)

Finland(2)
Jyvaskyla(2)

Spain(6)
Madrid (4)
IFIC Valencia (2)

Belgium(4)
JRC-Geel (3)
Leuven (1)

Bulgaria(8)
University of Sofia (8)

Romania(7)
IFIN-HH, Bucharest (1)
ELI-NP, Bucharest (6)

Norway(6)
University of Oslo (6)

India(1)
Tata Institute (1)

Canada(4)
University of Guelph (4)

Serbia(2)
University of Novi Sad (1)
University of Belgrade (1)

South Africa(1)
iThemba (1)

Japan(1)
Riken(1)

ν-ball management and human resources

Scientific

- **Jonathan Wilson – DR2 (Responsable)**
- **Matthieu Lebois – MdC (Responsable)**
- **Nikola Jovancevic – Postdoc CNRS**
- **Liqiang Qi - Thesard**
- **Damien Thisse – Thesard**
- **Guillaume Mavilla - Technican NESTER**

- **Rhiann Canavan (Surrey) - Thesard**
- **Rosa-belle Gerst (Köln) - Thesard**
- **Joseph Nemer – Stagiaire**
- **Yannick Popovitch - Stagiaire**

ALTO technical staff

- Abdelhakim Said (Responsable ALTO)
- Robert Leplat
- Alain Semsoum

Technical staff

- Bernard Genolini – IR1 (Responsable)

Mechanics

- Christine Legalliard – IR1 (Responsable)

Ge Detector Maintenance

- Gabriel Charles – IR2 (Responsable)
- Nourredine Hammoudi - AI

DAQ and Informatics

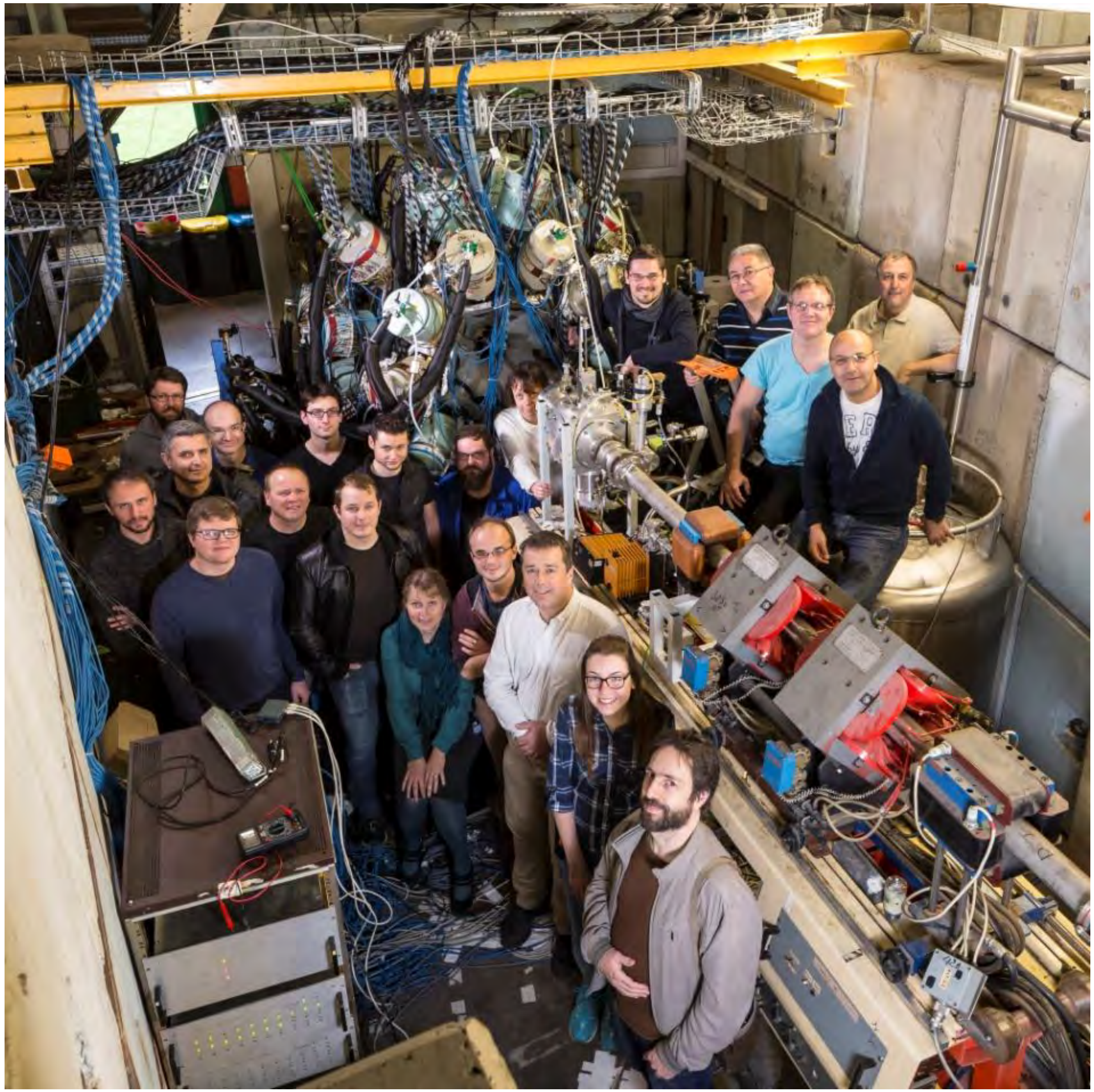
- David Etasse (LPC Caen)
- Patrick LeJeannic (IPNO)
- Eric Legay (CSNSM)

Administration

- Pascale Pichot
- Celine Gaubert

Estimated FTE = 6 person.years

The ν-ball core team



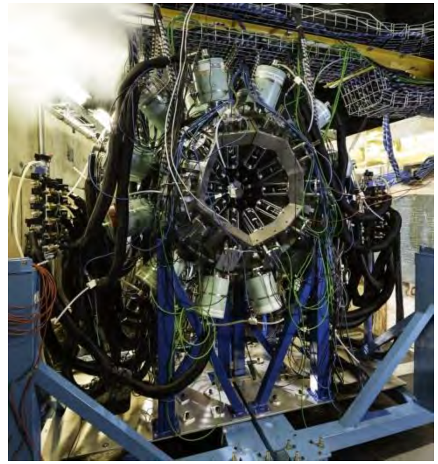
ν-ball financing + equipment resources

Financing
2017 – AP in2p3 80 k euro
2018 – AP in2p3 72 k euro
2019 – AP in2p3 42 k euro
Total: 194 k euro

Renewal of ALTO DAQ with ~180 channel state-of-the-art digital system

Essential equipment borrowed from:
24 Ge Clover detectors + holding frame + some cables (Gammapool, MOU 2017)
10 Ge Phase I detectors (Loan pool)
26 LaBr3 – Surrey + Madrid + Manchester Universities, UK
4 PARIS clusters – The PARIS collaboration (MOU 2018)
BGO HV supplies – Jyvaskyla University, Finland
^{252}Cf fission chamber – CEA DAM
Extra DAQ cards (coupling with PARIS) – LPC CAEN
100Tb data acquisiton and buffer disk– CSNSM/P2IO Big data
Clover HV supplies – GANIL
Extra cables – Madrid University, Spain, Manchester University, UK

ν-ball project positive side effects



Nu-ball

Renewal of the obsolete ALTO DAQ system

Renewal of the IPN Ge detector laboratory

Increase in the international visibility/attractivity of the ALTO facility

ν-ball experimental campaign (Nov. 2017-June 2018) 3200 hours of beam time delivered

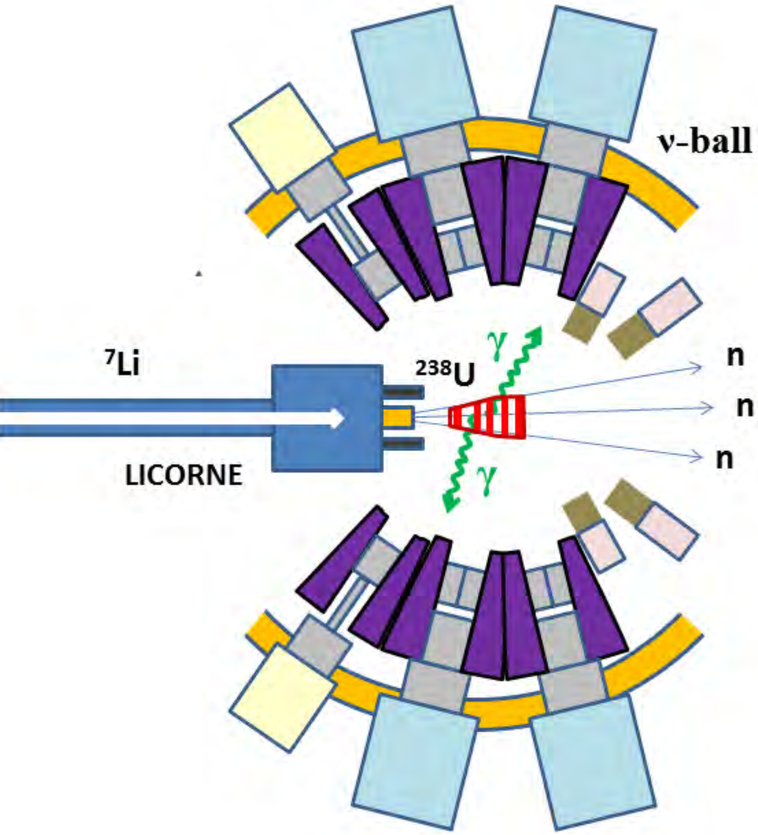
Heavy Ion Reaction γ spectroscopy:

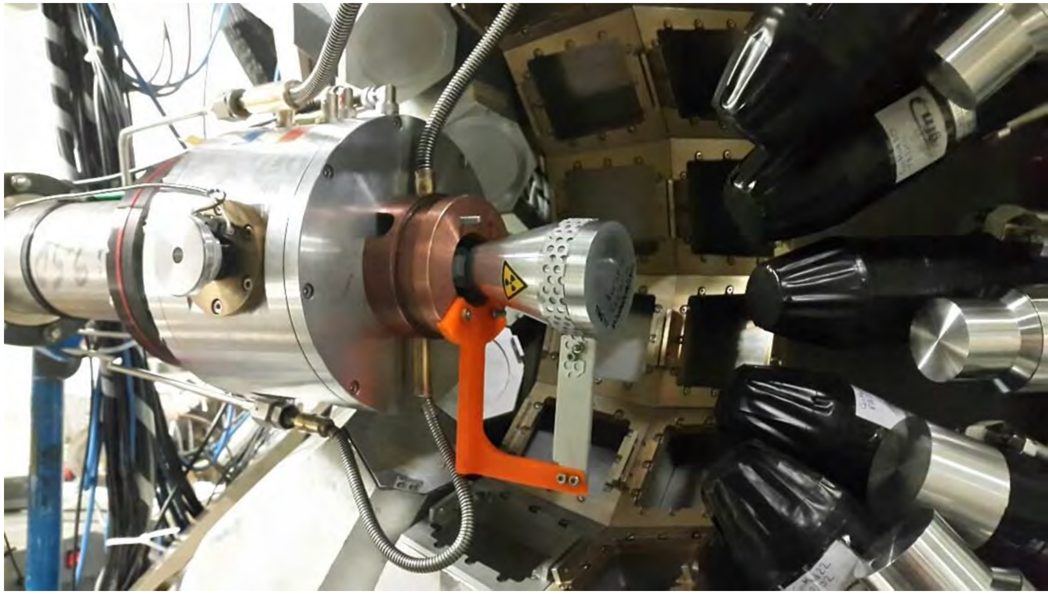
- Half-life measurement and isomer spectroscopy in the neutron-rich deformed nucleus ^{166}Dy (1 week)
- Electromagnetic transition rates in the nucleus ^{136}Ce (1 week)
- Pinning down the structure of ^{66}Ni by 2n- and 2p-Heavy-Ion transfer reactions and g-factor measurement (2 weeks)
- A study on the transition between seniority-type and collectivity excitations in the YRAST 4^{+} state of ^{206}Po (1 week)
- Measurement of the super-allowed branching ratio of ^{10}C (2 weeks)
- Feeding of low-energy structures of different deformations by the GDR decay: the nuBall array coupled to PARIS (1 week)

Neutron induced reaction γ spectroscopy:

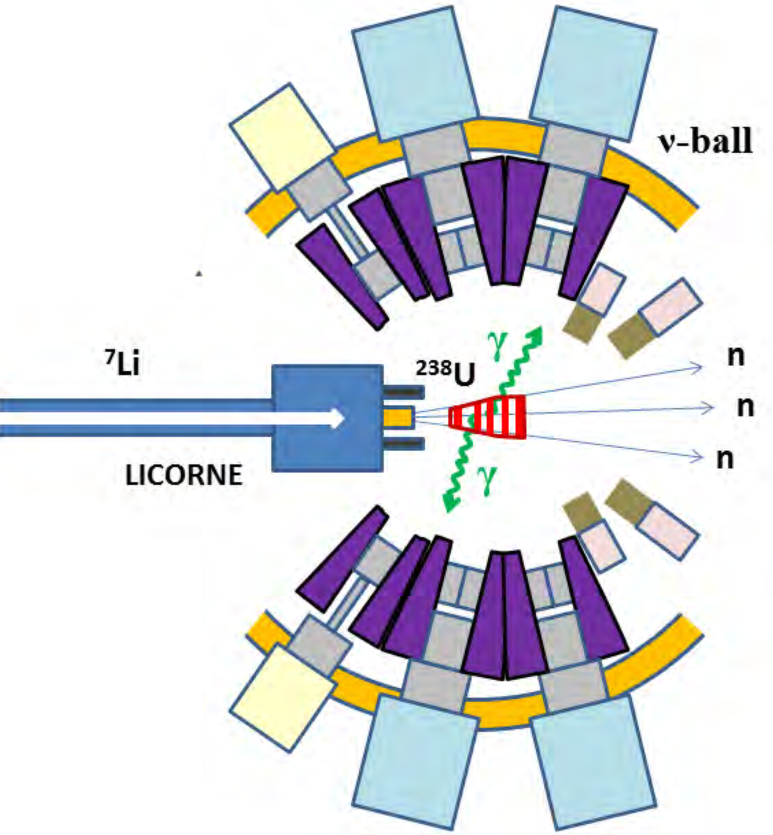
- Spectroscopy of the neutron-rich fission fragments produced in the ^{238}U(n,f) and ^{232}Th(n,f) reactions (5 weeks)
- Spectroscopy above the shape isomer in ^{238}U (2 weeks)

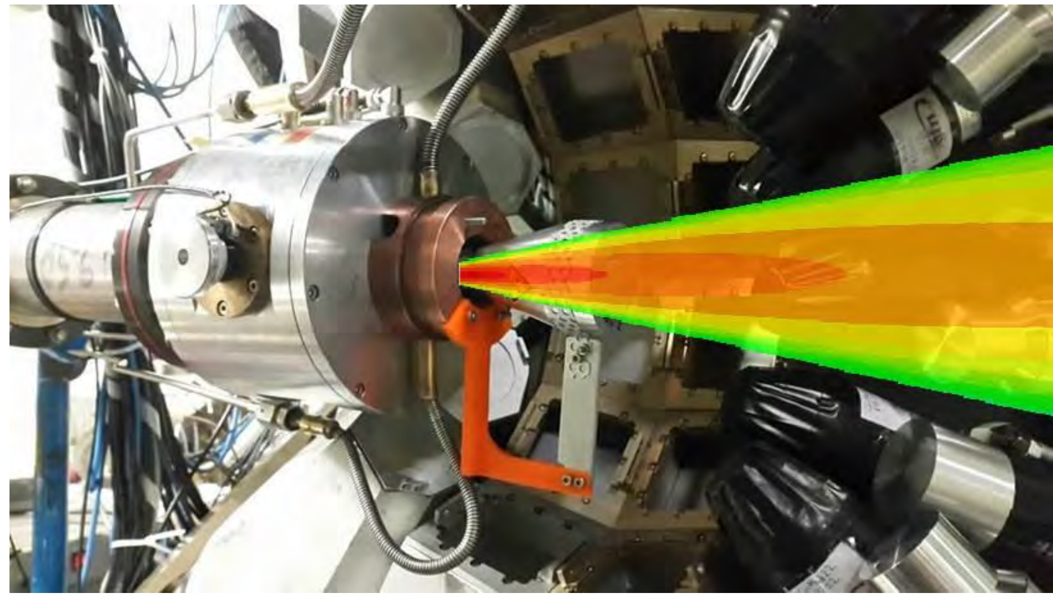
LICORNE/ν-ball coupling principle





LICORNE/ν-ball coupling principle





Primary beam
2 x 10^{11} /s

^{7}Li (16 MeV)

Target

H_2

3 x 10^{20} atoms/cm^2

Secondary beam
2 x 10^{7} /s

1.5 MeV neutrons

Sample

10^{5} fissions/s

^{238}U

^{232}Th ~100 g

MENU

nature

International journal of science

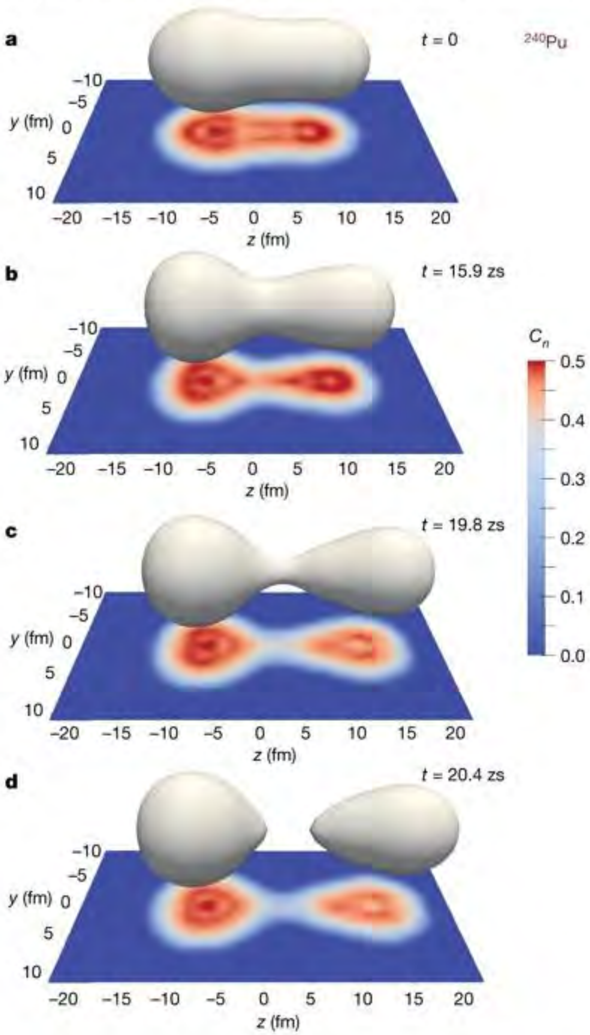
Letter | Published: 19 December 2018

Impact of pear-shaped fission fragments on mass-asymmetric fission in actinides

Guillaume Scamps & Cédric Simenel

Nature **564**, 382–385 (2018) | Download Citation

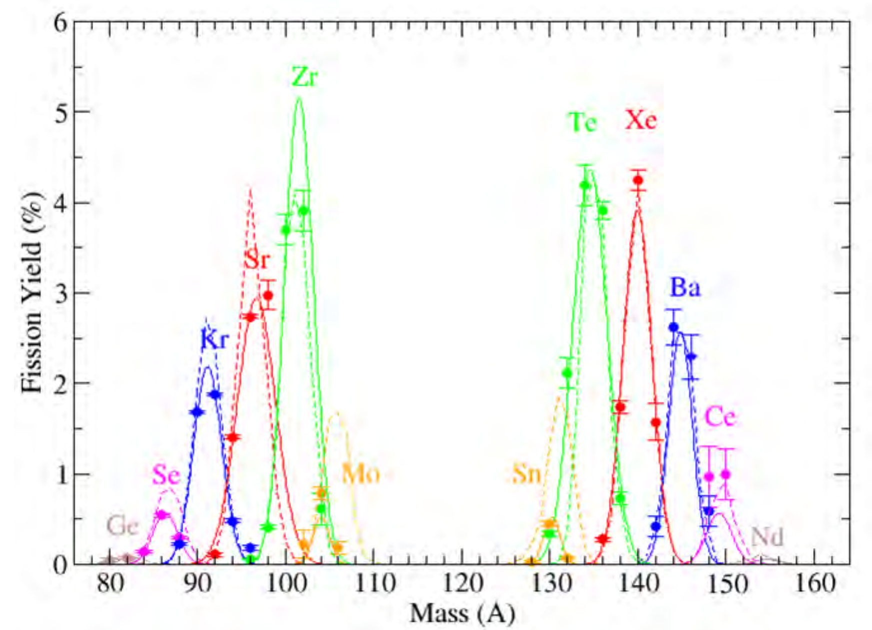
Fig. 1: Microscopic calculations of asymmetric fission of ^{240}Pu.



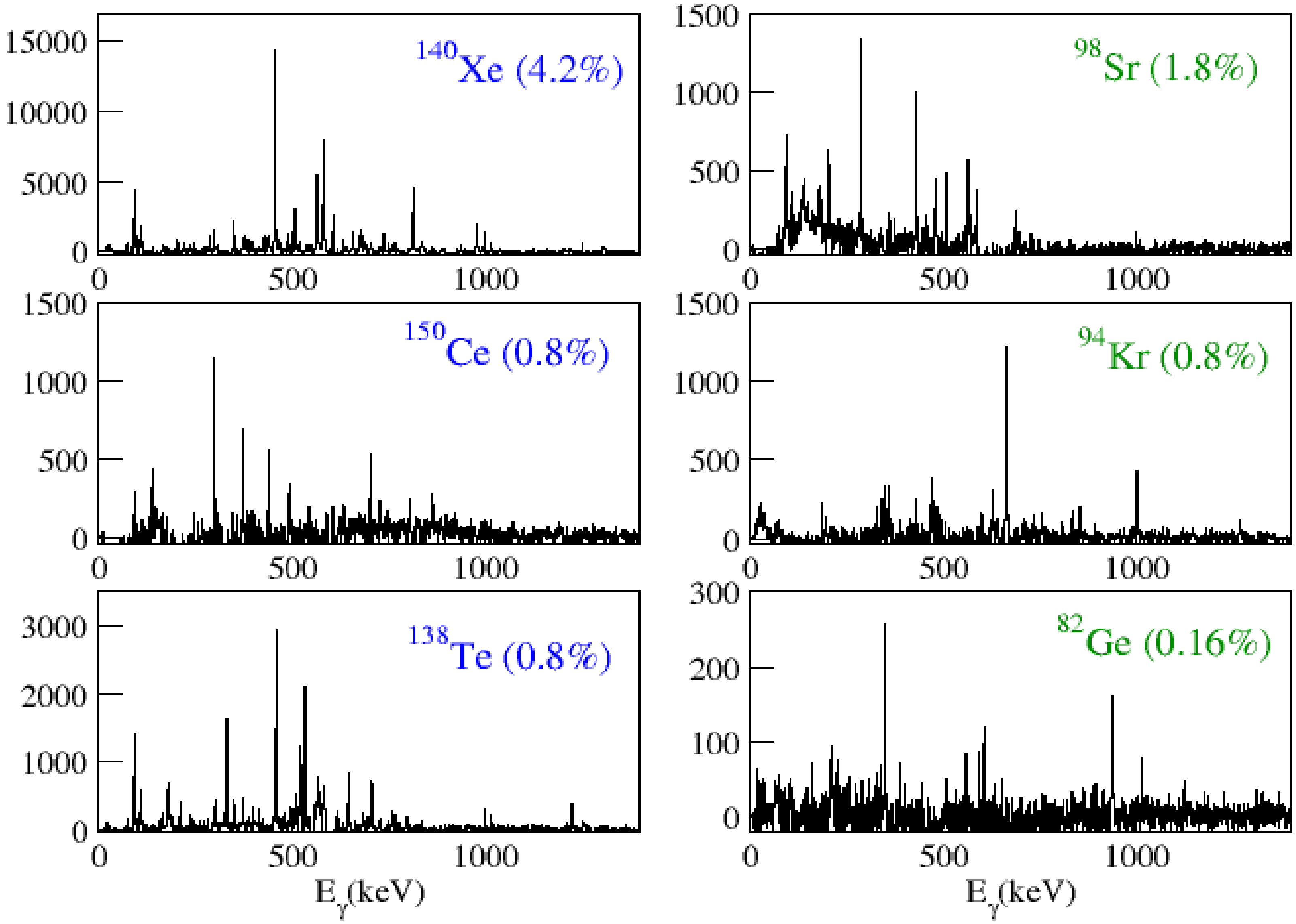
Anomalies in the charge yields of fission fragments from the ^{238}U(n,f) reaction

J.N. Wilson, M. Lebois, L. Qi et al.,

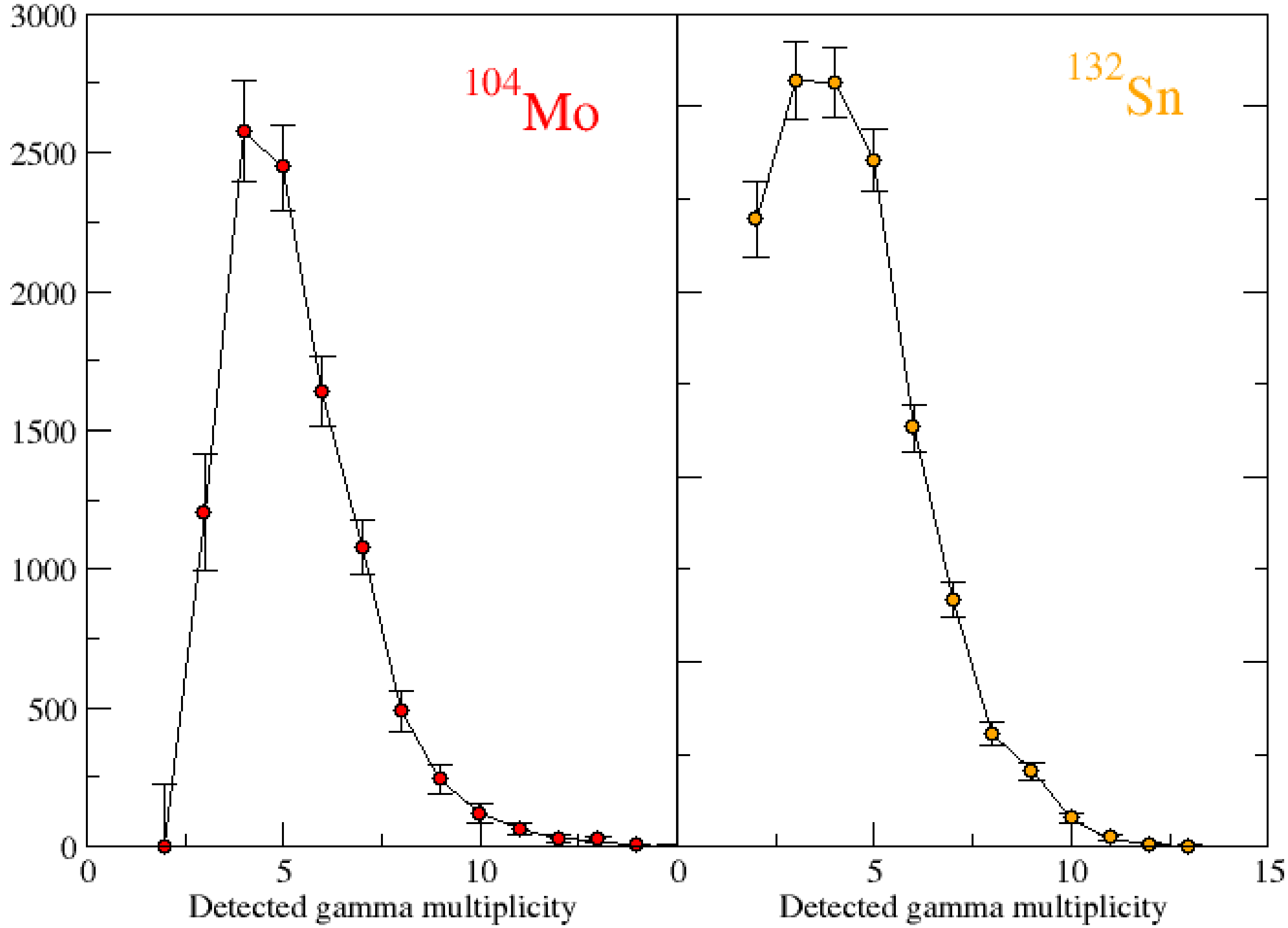
Phys. Rev. Lett. 118, 222501 (2017)



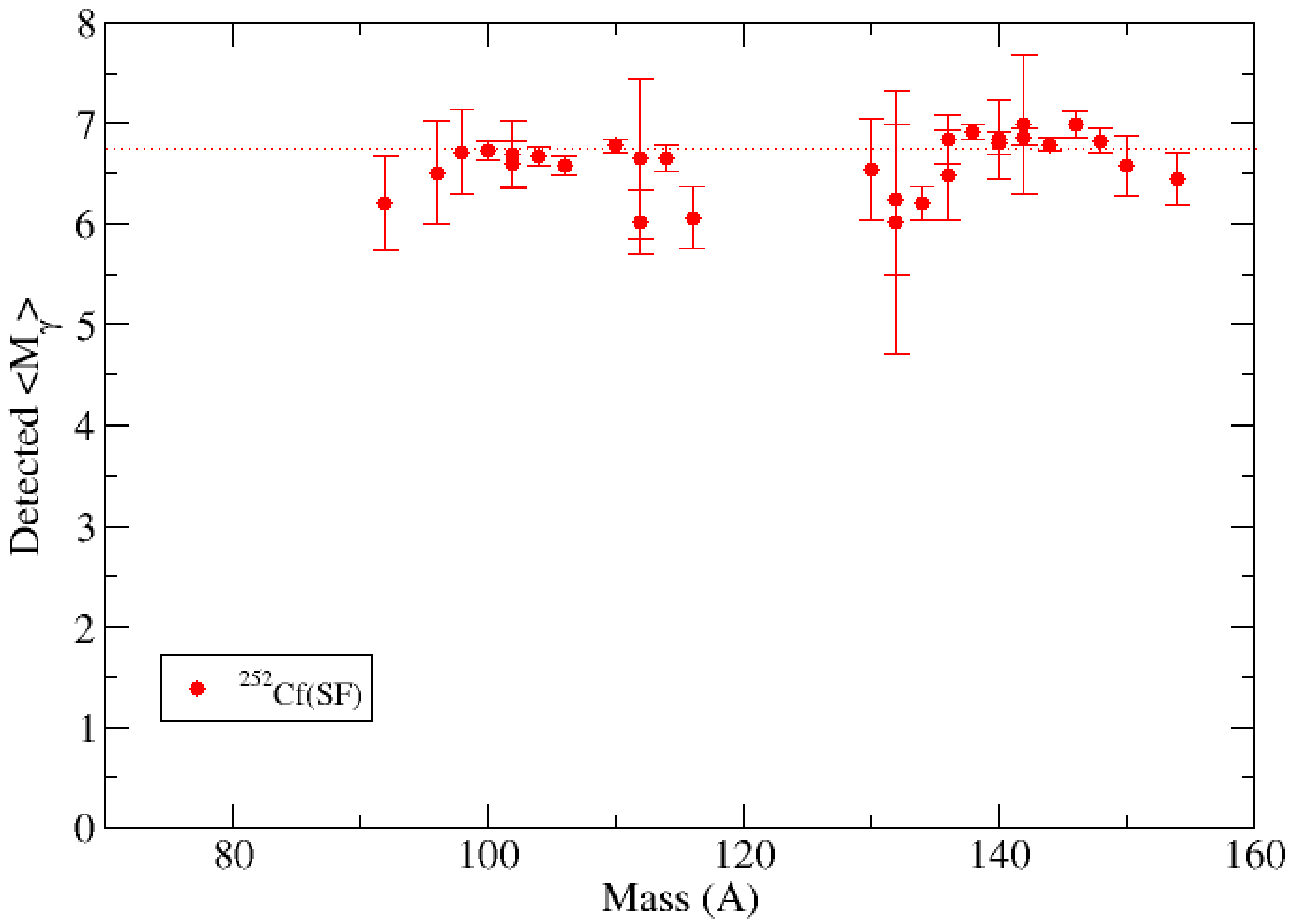
$^{238}U(n,f)$ Fission Fragment Selection



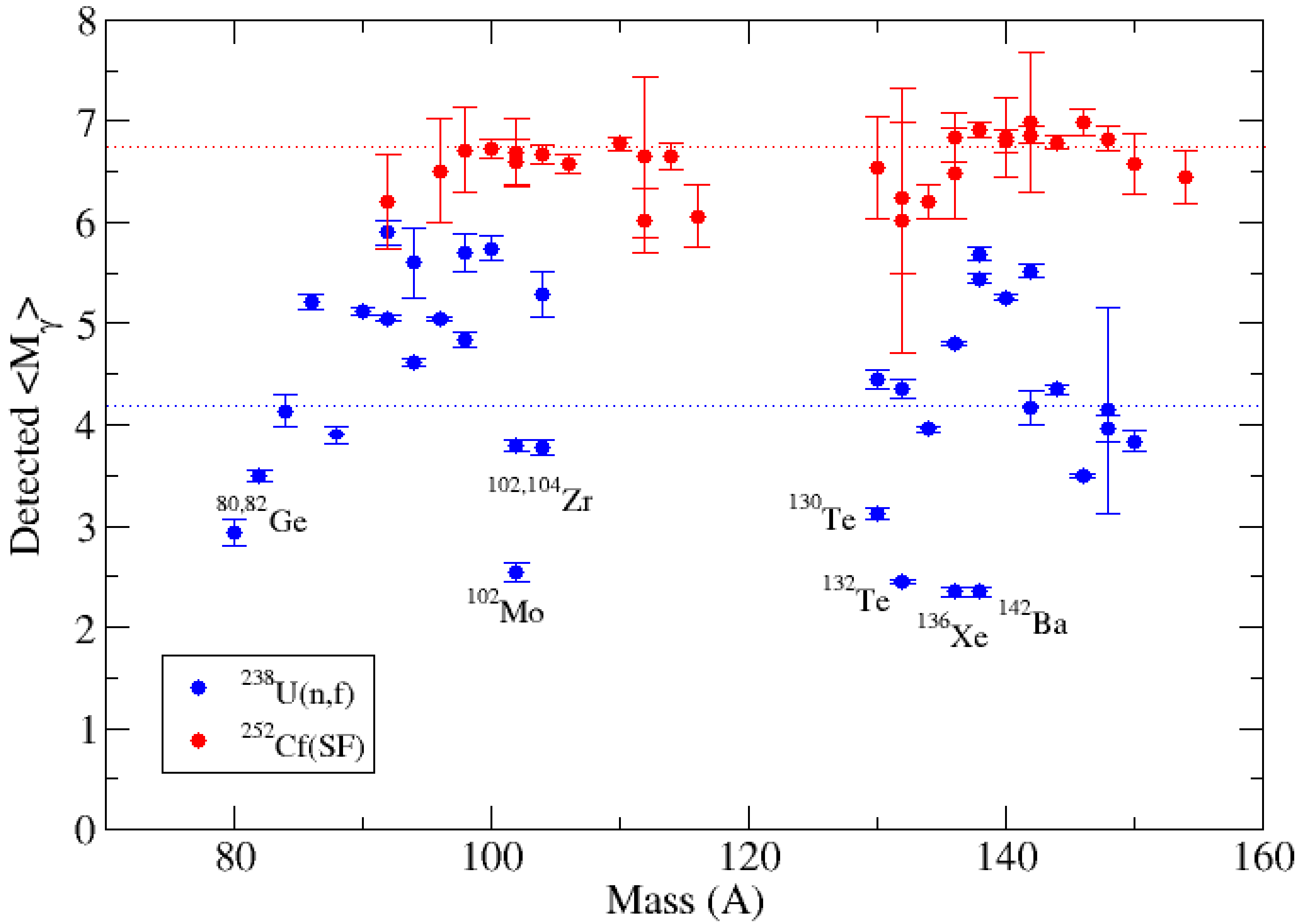
^{238}U(n,f) Gamma Multiplicity Distributions correlated with A/Z



Average gamma multiplicities



Average gamma multiplicities

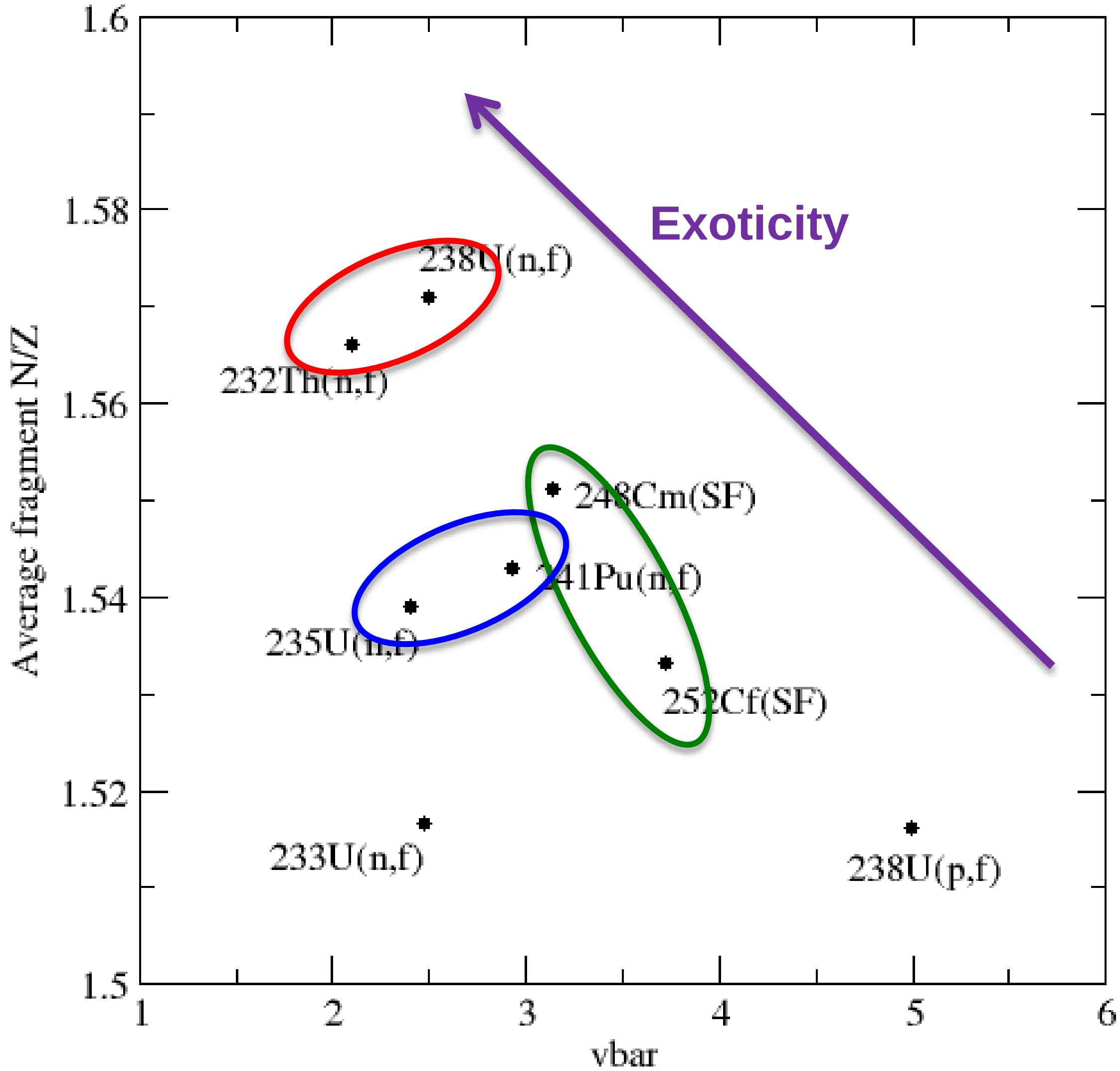


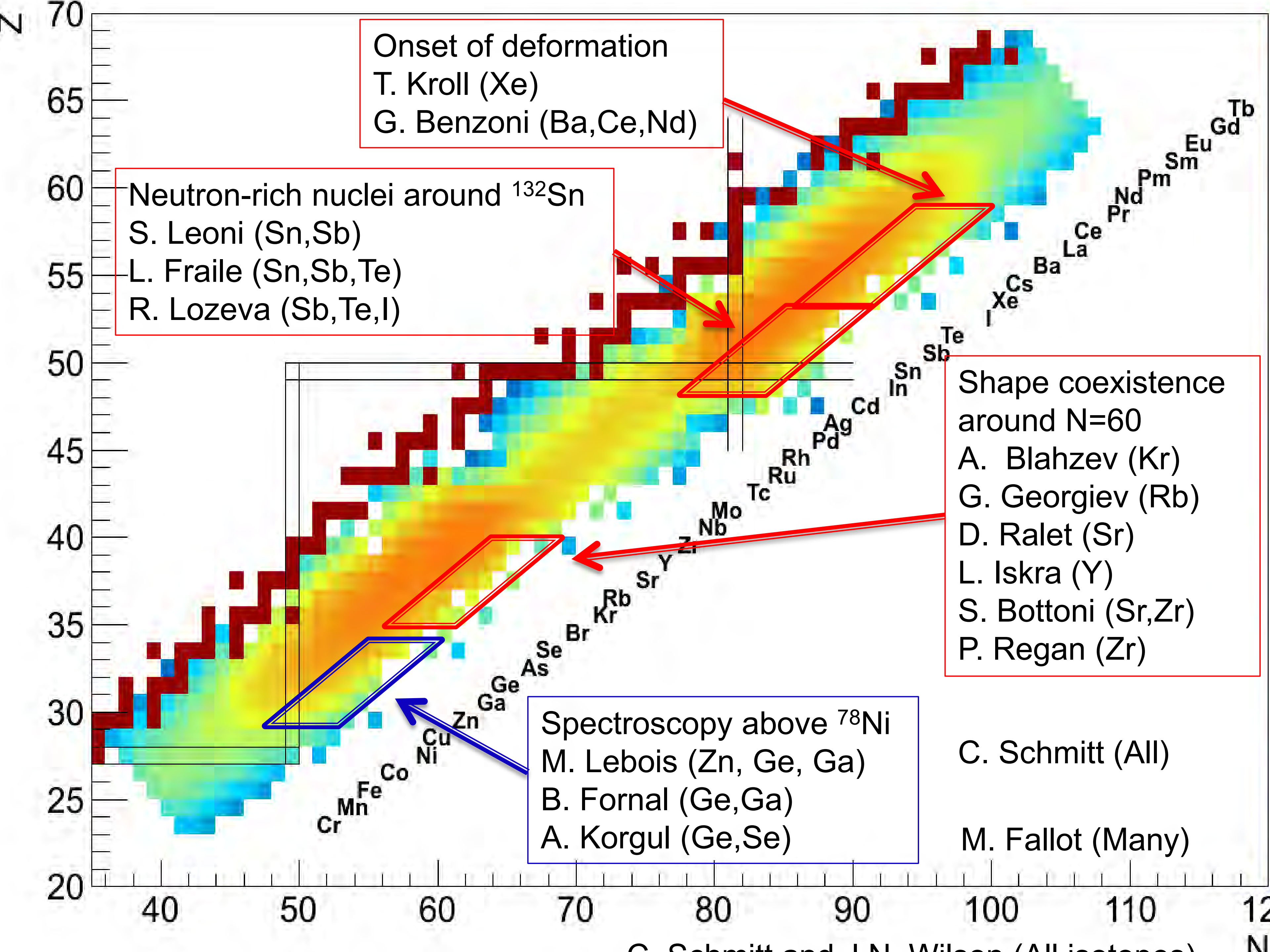
Exotic Nuclei Production/Study from Fission Reactions

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)

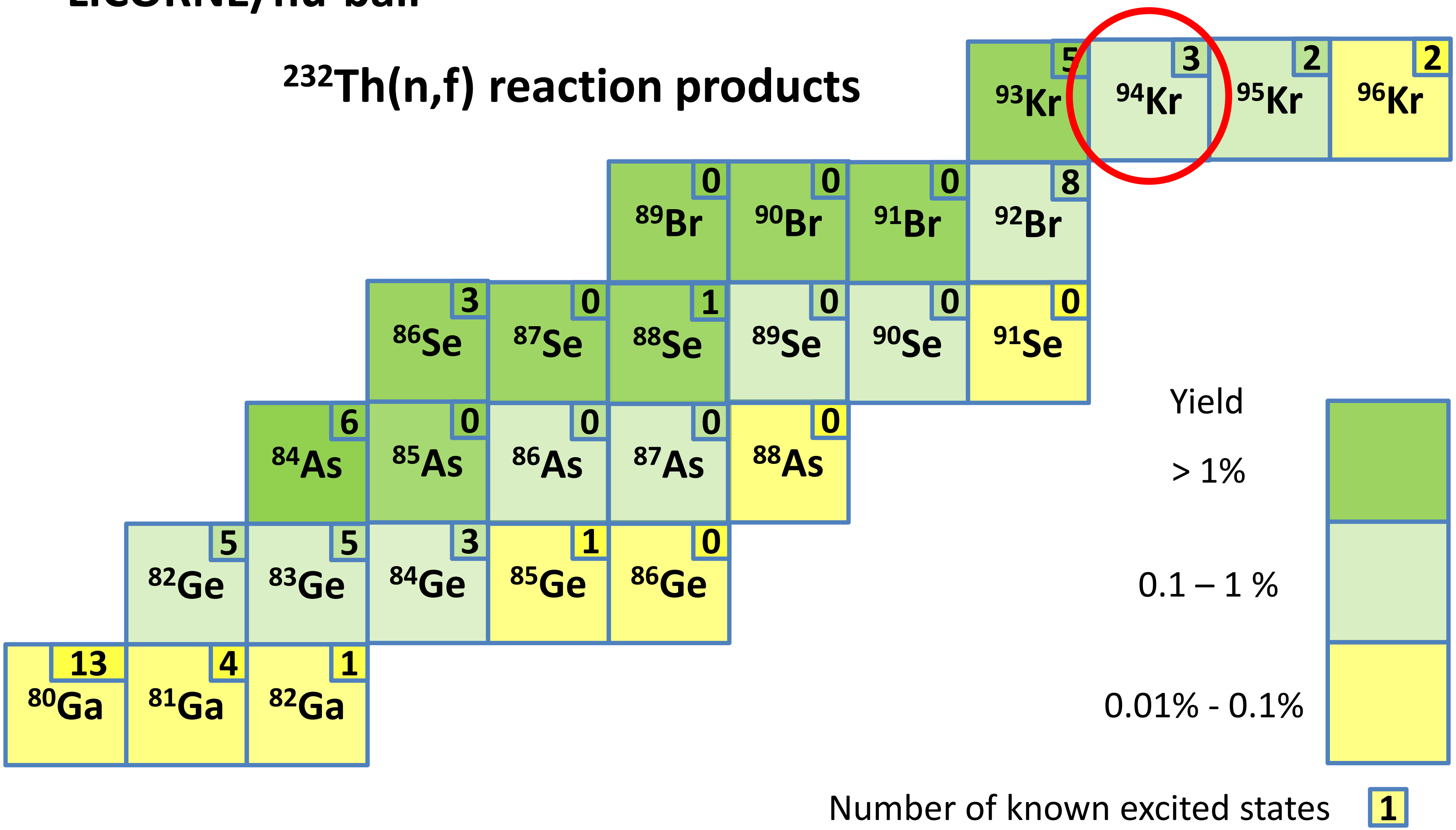
Fission induced by fast ~2 MeV neutrons
^{238}U(n,f), ^{232}Th(n,f)
(LICORNE @ IPN Orsay)

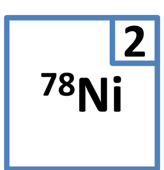



Z
Onset of deformation
T. Kroll (Xe)
G. Benzoni (Ba,Ce,Nd)
Neutron-rich nuclei around ^{132}Sn
S. Leoni (Sn,Sb)
L. Fraile (Sn,Sb,Te)
R. Lozeva (Sb,Te,I)
Shape coexistence
around N=60
A. Blahzev (Kr)
G. Georgiev (Rb)
D. Ralet (Sr)
L. Iskra (Y)
S. Bottoni (Sr,Zr)
P. Regan (Zr)
Spectroscopy above ^{78}Ni
M. Lebois (Zn, Ge, Ga)
B. Fornal (Ge,Ga)
A. Korgul (Ge,Se)
C. Schmitt (All)
M. Fallot (Many)
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
20 25 30 35 40 45 50 55 60 65 70
40 50 60 70 80 90 100 110
N

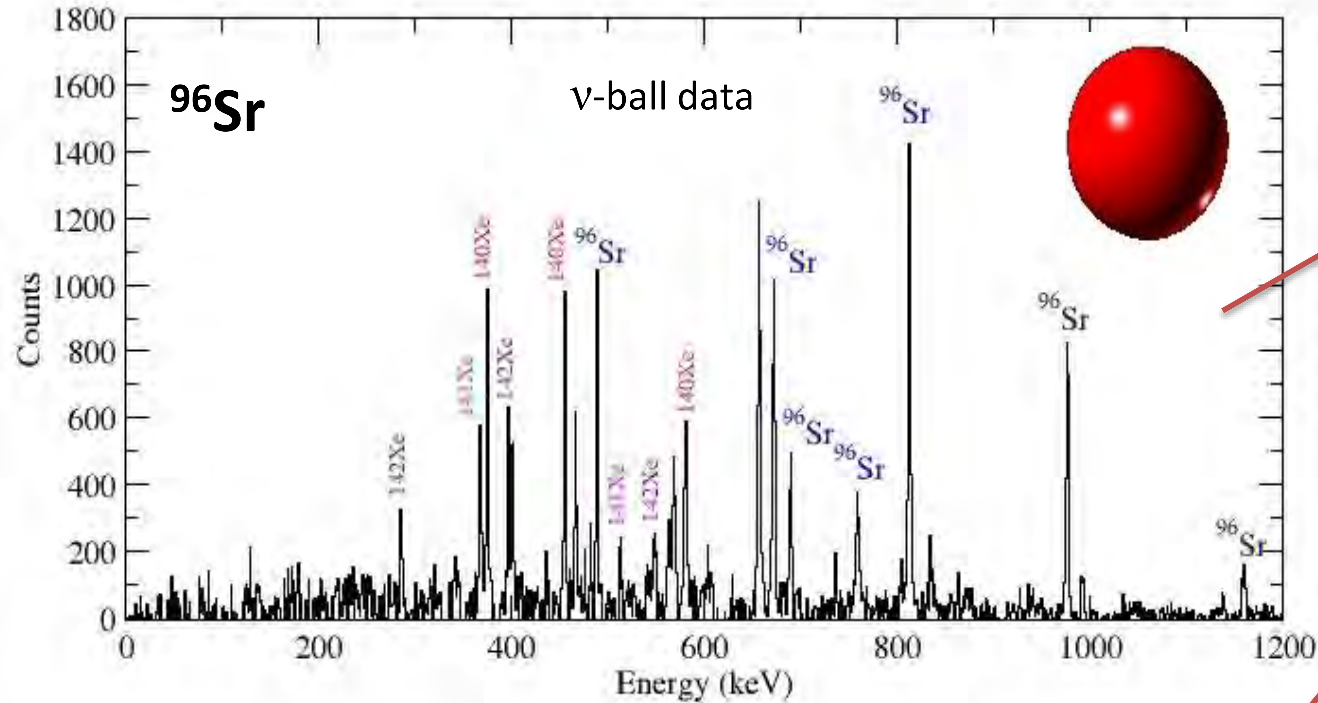
Production and study of neutron-rich nuclei above ^{78}Ni with LICORNE/nu-ball

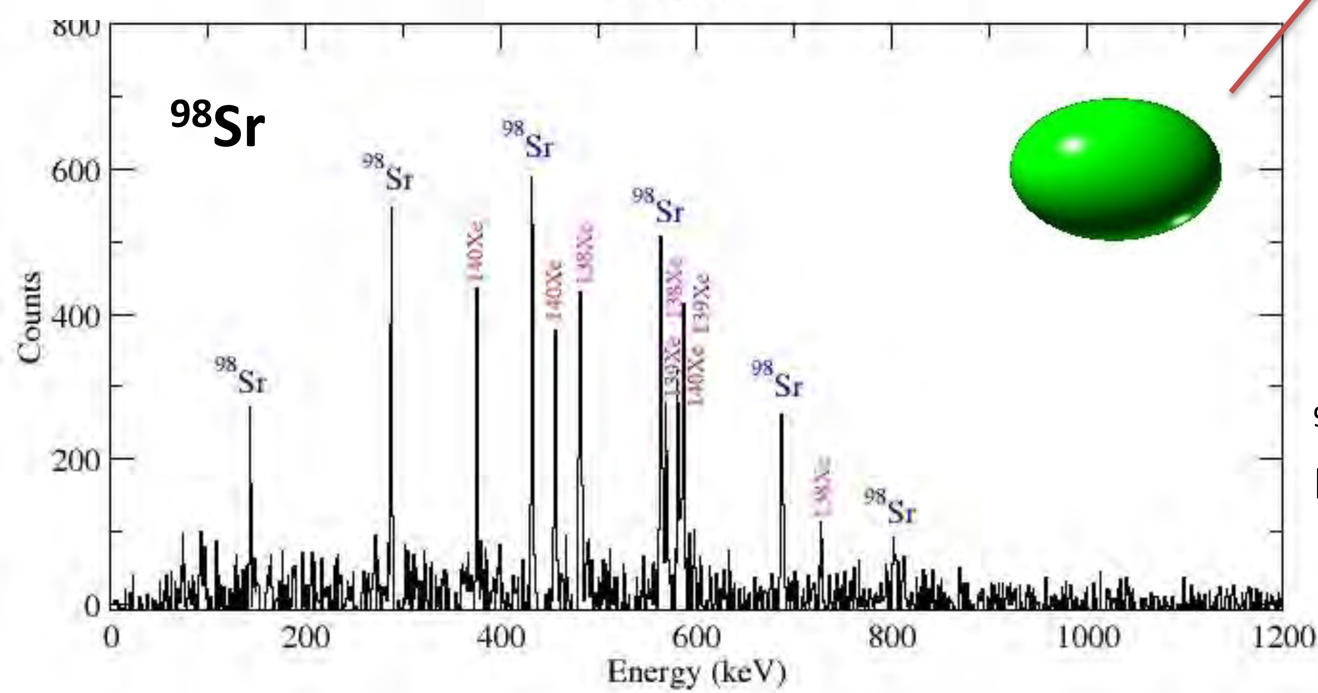
^{232}Th(n,f) reaction products





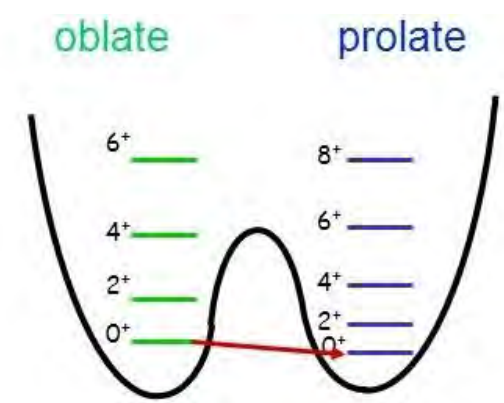
"^{78}Ni revealed as a doubly magic stronghold against nuclear deformation"
R. Taniuchi, et al. Nature, volume 569, pages 53–58 (2019)





N= 60

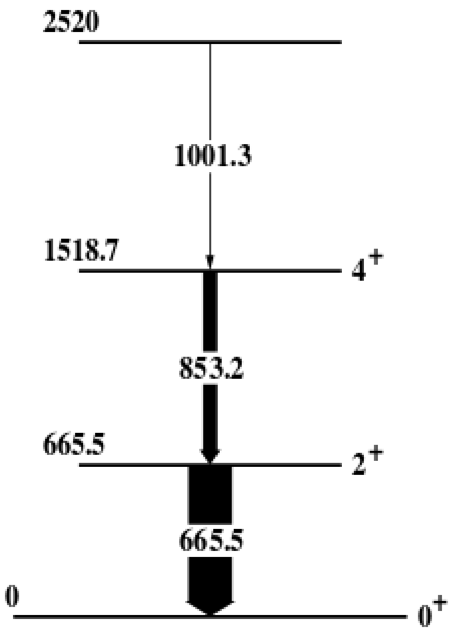
^{96}Sr	^{97}Sr	^{98}Sr
^{95}Rb	^{96}Rb	^{97}Rr
^{94}Kr	^{95}Kr	^{96}Kr

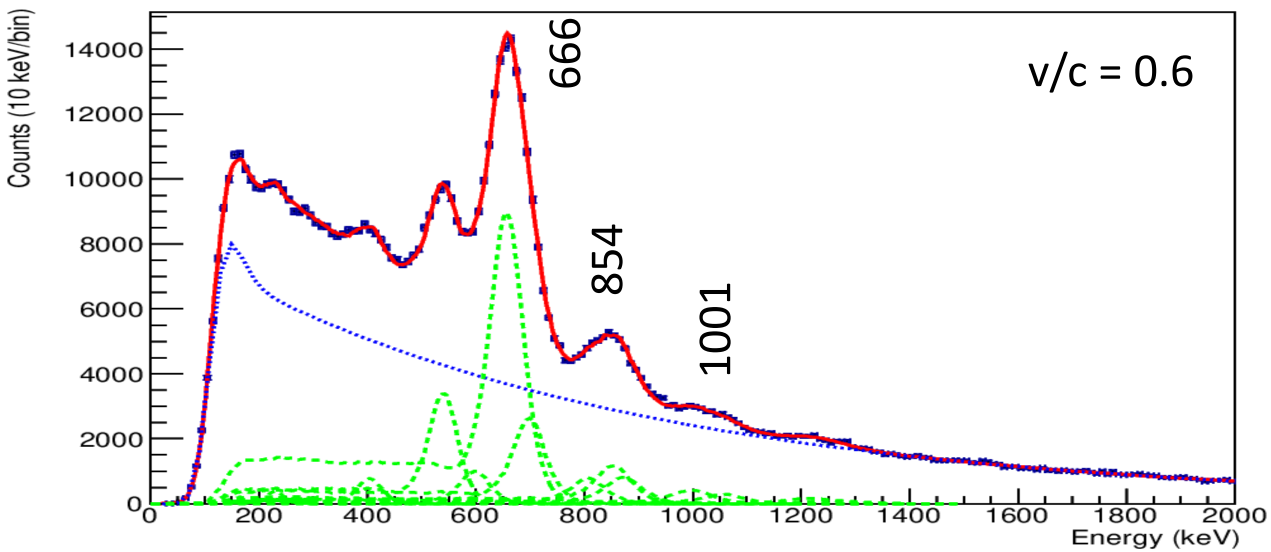


^{96}Kr Low-Z boundary of the Island of Deformation at N=60

J. Dudouet et al.
PRL 118, 162501 (2017)

^{94}Kr recent RIKEN Big RIPS data





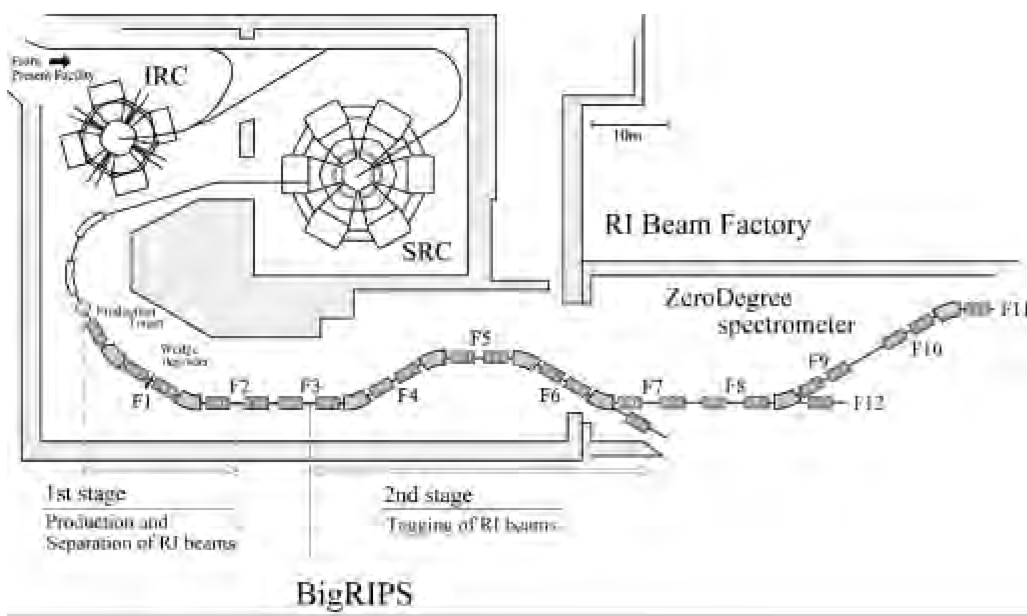
(courtesy of R-B. Gerst)

Previous results confirmed

$^{94}_{36}\mathrm{Kr}_{58}$

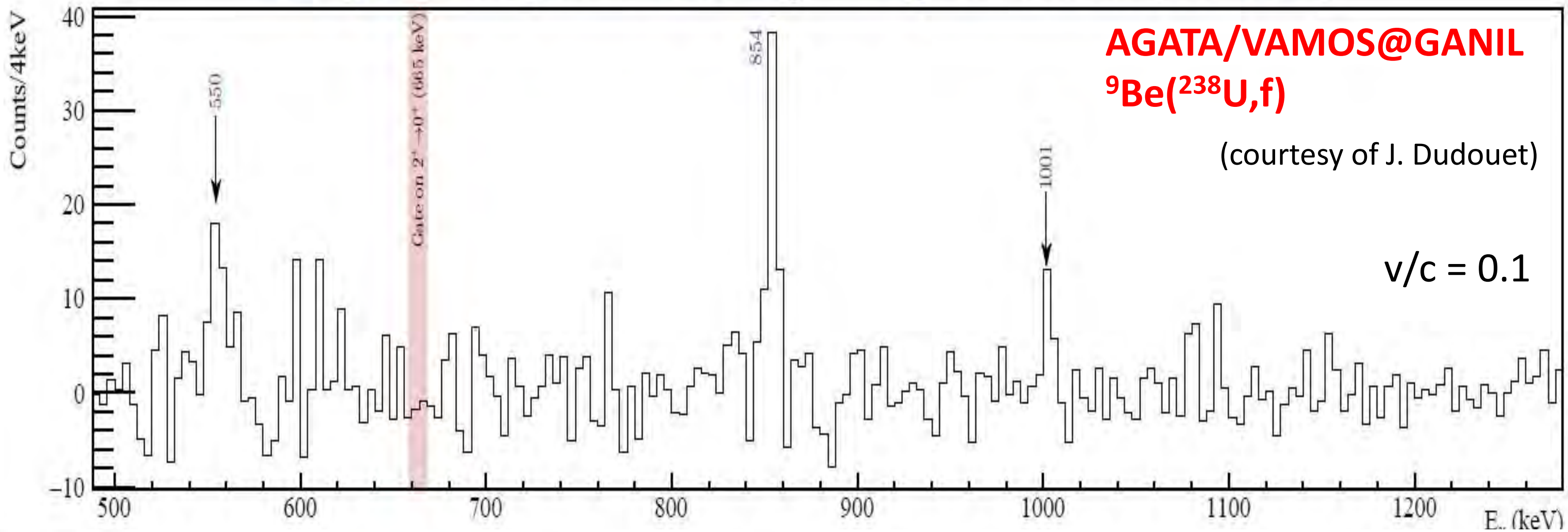
T. Rzaca-Urban et al.
Eur. Phys. J. A9, 165–169 (2000)

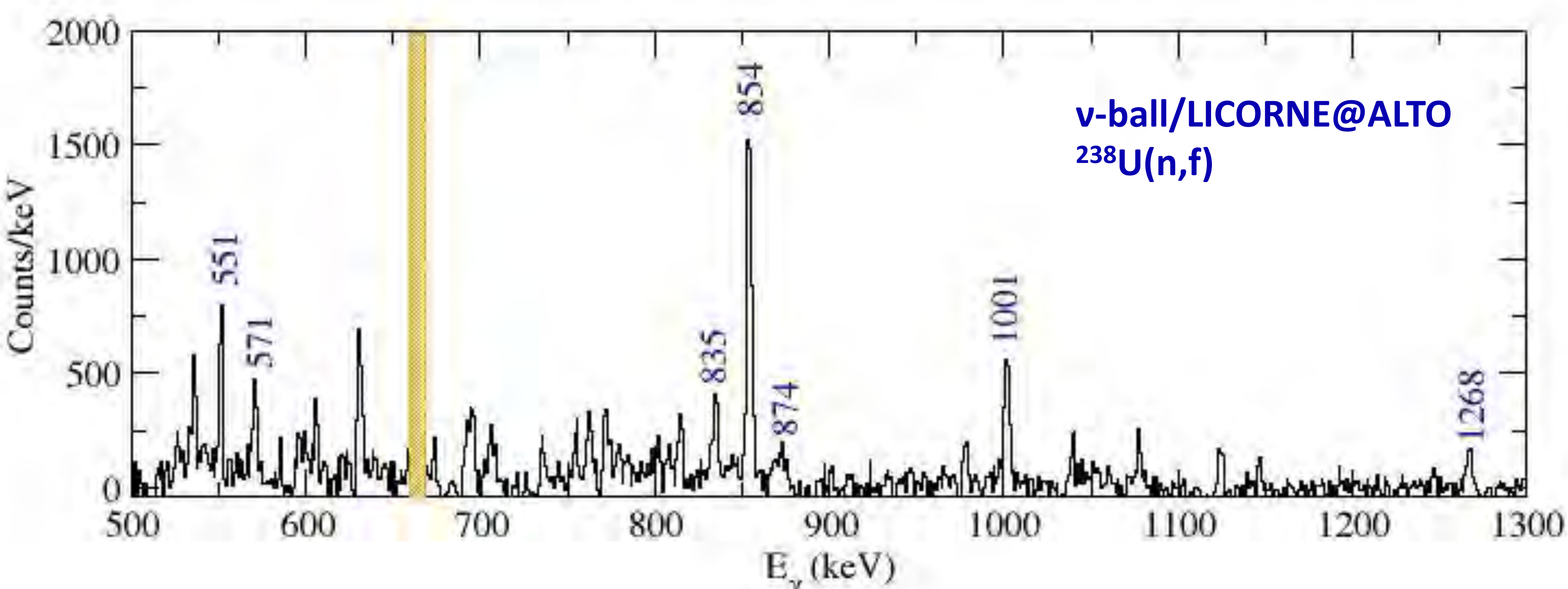
^{248}Cm(SF)



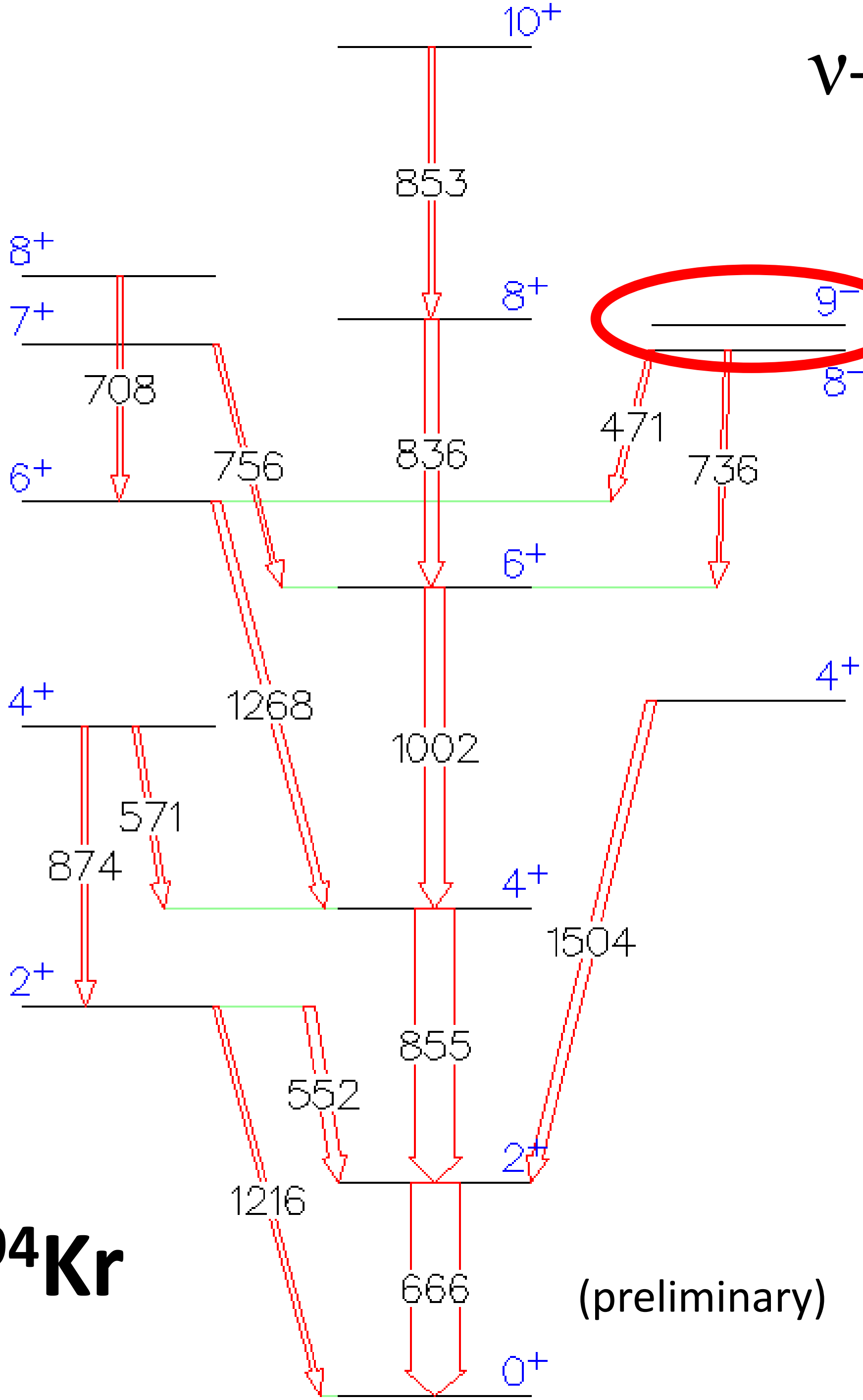
^{238}U + Pb @ 350 MeV/A

^{94}Kr spectrum gated on the $2_1^+ \rightarrow 0_1^+$ transition (665 keV)



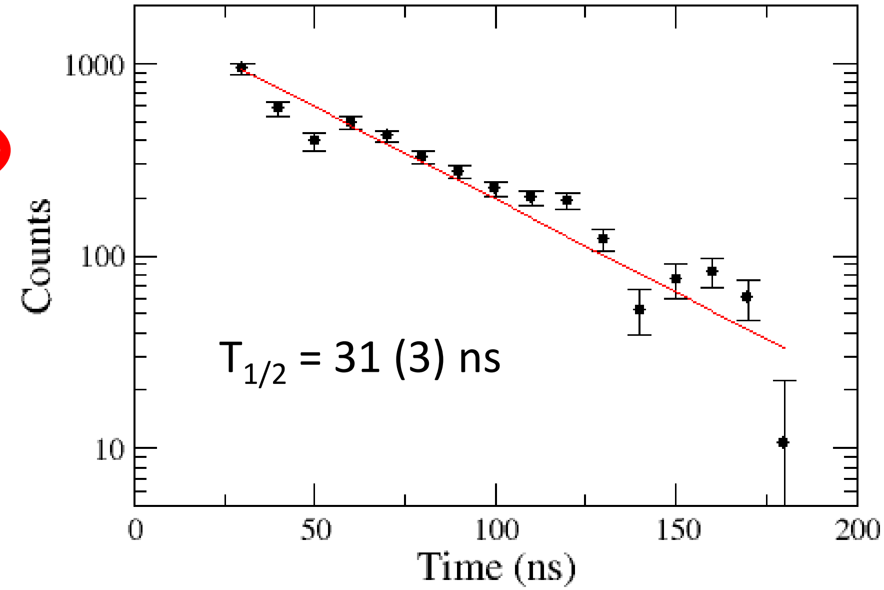


ν-ball/LICORNE $^{238}U(n,f)$ data



^{94}Kr

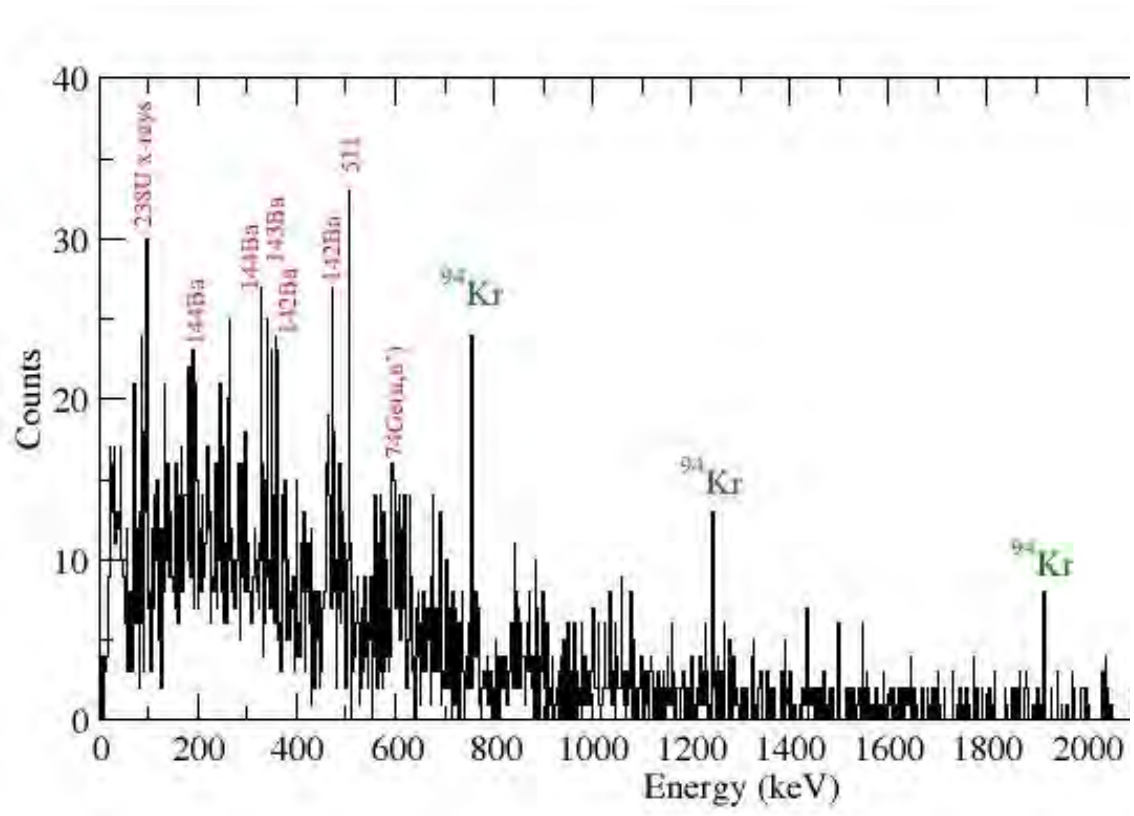
(preliminary)

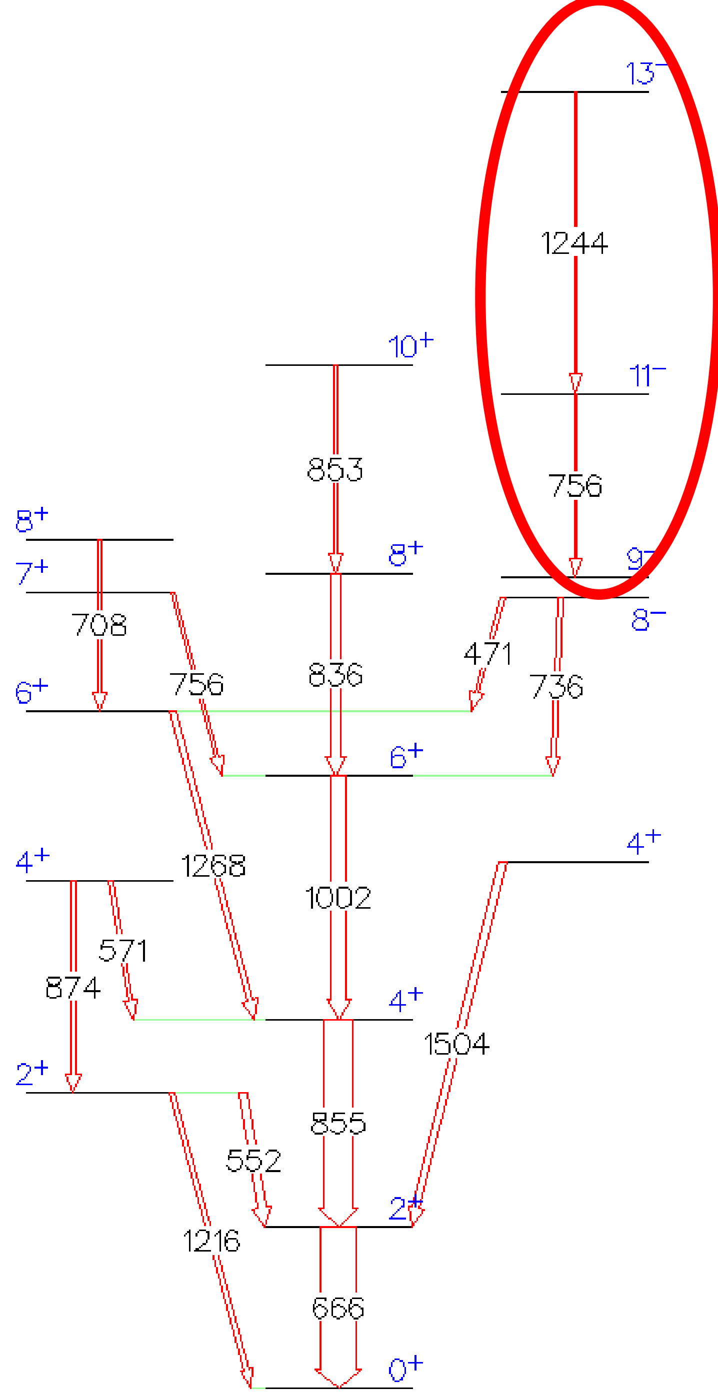


$K_\pi = 9_- = n_{11/2-}[505] \otimes {}_{7/2+}[404]$

$K_\pi = 7_- = n_{11/2-}[505] \otimes {}_{3/2+}[411]$

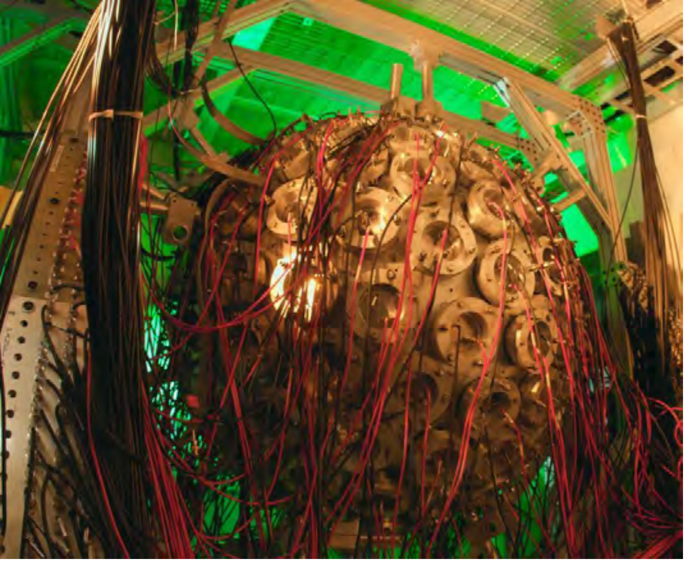
Above the isomer in ^{94}Kr





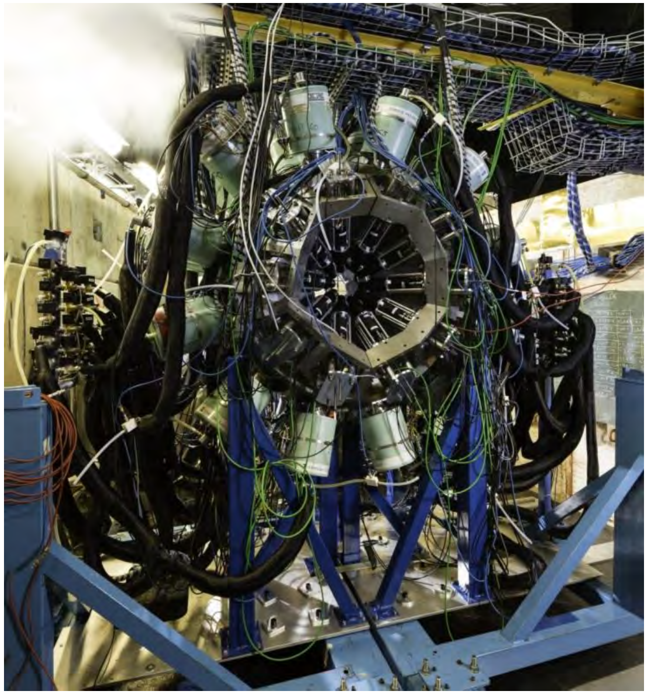
ν-ball in context

Fission studies



DANCE @ Los Alamos
(neutron-induced fission calorimetry)

Big RIPS @ RIKEN (Pb(238U,f))



nu-ball @ ALTO
232Th(n,f), 238U(n,f)

The structure of neutron-rich nuclei

FIPPS @ ILL
235U(n,f) 241Pu(n,f)

AGATA/VAMOS@GANIL
9Be(238U,f)

Strengths

- **Excellent new scientific opportunities, unique (worldwide) to the ALTO facility**
- **High impact scientific production potential, but with low cost**
- **Correctly dimensioned for ALTO facility. Internationally attractive. Lots of available beam time**
- **Excellent technical support from IPN Orsay and LPC Caen (DAQ)**

Weaknesses

- **Poor local informatics infrastructure (data transfer bandwidth, local data storage, etc.) lags behind current needs. Informatics support for longer-term data storage at CC-Lyon is practically inexistent**

- **The nu-ball project has far too much dependence on mutualized resources (e.g. Gamma Pool detectors) that maximizes the amount of work (for IPNO) and minimizes the availability of the device**

Opportunities

nu-ball coupled to the LICORNE directional neutron source presents clear and unique opportunities to perform precision in-beam spectroscopy of fast neutron-induced reactions.

When nu-ball/LICORNE is fully optimized, it can (or has already) become a world-beating device in three separate domains:

- Research into new fission process observables and their correlations
- The detailed study of the nuclear structure of very neutron-rich nuclei (high spin)
- Sub nanosecond fast timing to study nuclear isomerism and nuclear moments

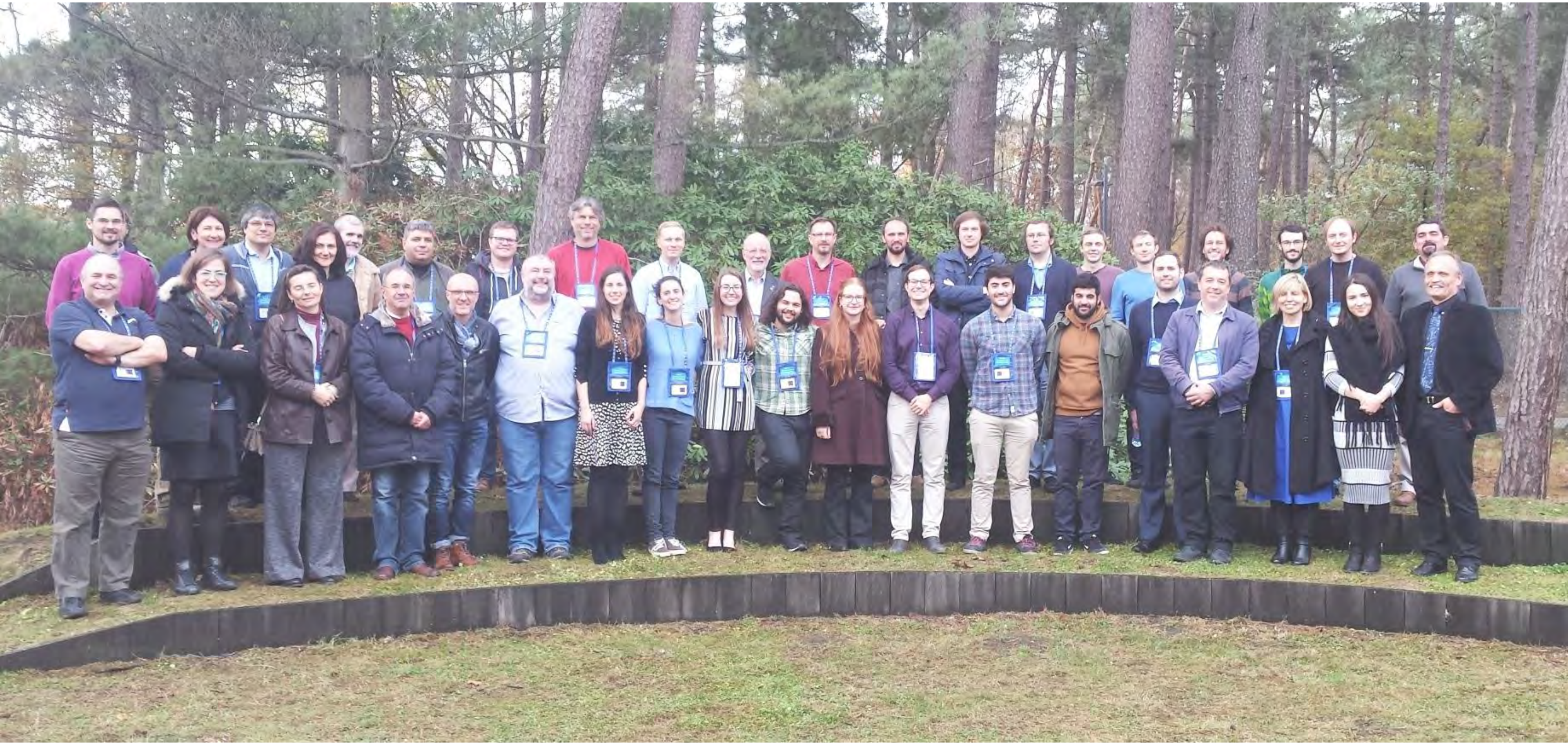
Threats

<u>ν-ball is vital instrumentation for the ALTO facility</u>

The heavy dependence of the project on mutualized, internationally-used, resources gives an inherent lack of predictability about the future development of the project, and introduces extra unnecessary and preventable risks to the project timeline and future campaign(s)

The ν-ball2 International Workshop

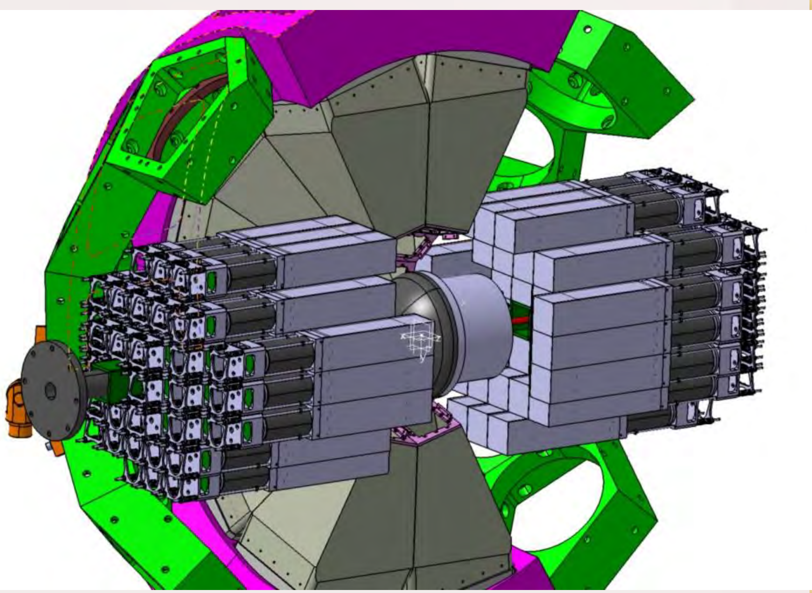
JRC-Geel, European Commission, Belgium, November 2018



We envisage asking for in2p3 support for a ν-ball2 campaign in 2021 and 2022

Backup Slides

ν-ball2 campaign forseen 2021 - 2022

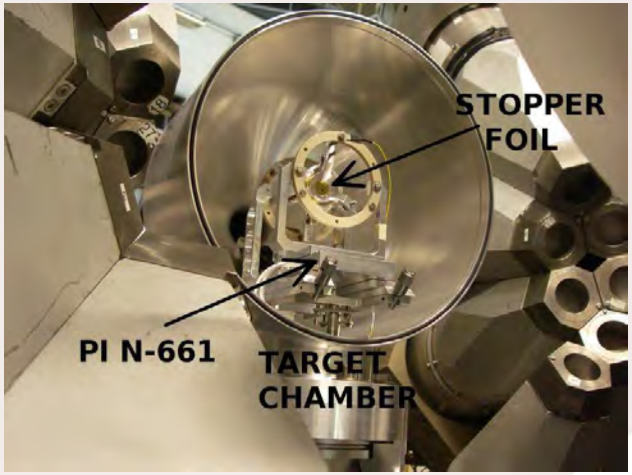


New Configurations

ν-ball/PARIS
GDR studies. High energy gamma detection for light nuclei (ALTO high intensity ^{6,7}Li, ^{14}C beams)

ν-ball/OUPS plunger and/or charged particle detector
RDM lifetimes

ν-ball/Fast Timing
24 clovers coupled with 40 FATIMA for best hybrid array performance. Lifetime measurements 10-ps 10ns range for weakly populated states



ν-ball/LICORNE
Improve fission technique: Reduce gamma backgrounds from the source and intrinsic target activity. More primary beam. Low density targets for DPM lifetime measurements. ^{252}Cf IC

ν-ball Ge detector maintenance

Operations

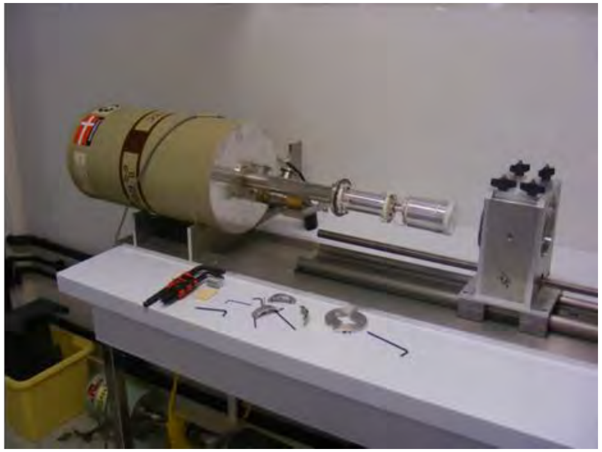
- Failure diagnostic
- Pumping
- Annealing (80°C)
- FET replacement (<u>Clean room required</u>)
- HV Filter replacement
- Charge preamplifier test and replacement
- Replace ORTEC's obsolete preamplifier by Canberra material

11 detectors were repaired during the campaign. 25 FET's replaced.

Components are <u>expensive</u>
HV Filter - 860 euros
FET - 180 euros
Preamplifier - 1600 euros

<u>Timeline was very tight</u>

New technique developed in 2018 to replace Preamplifier components rather than whole board



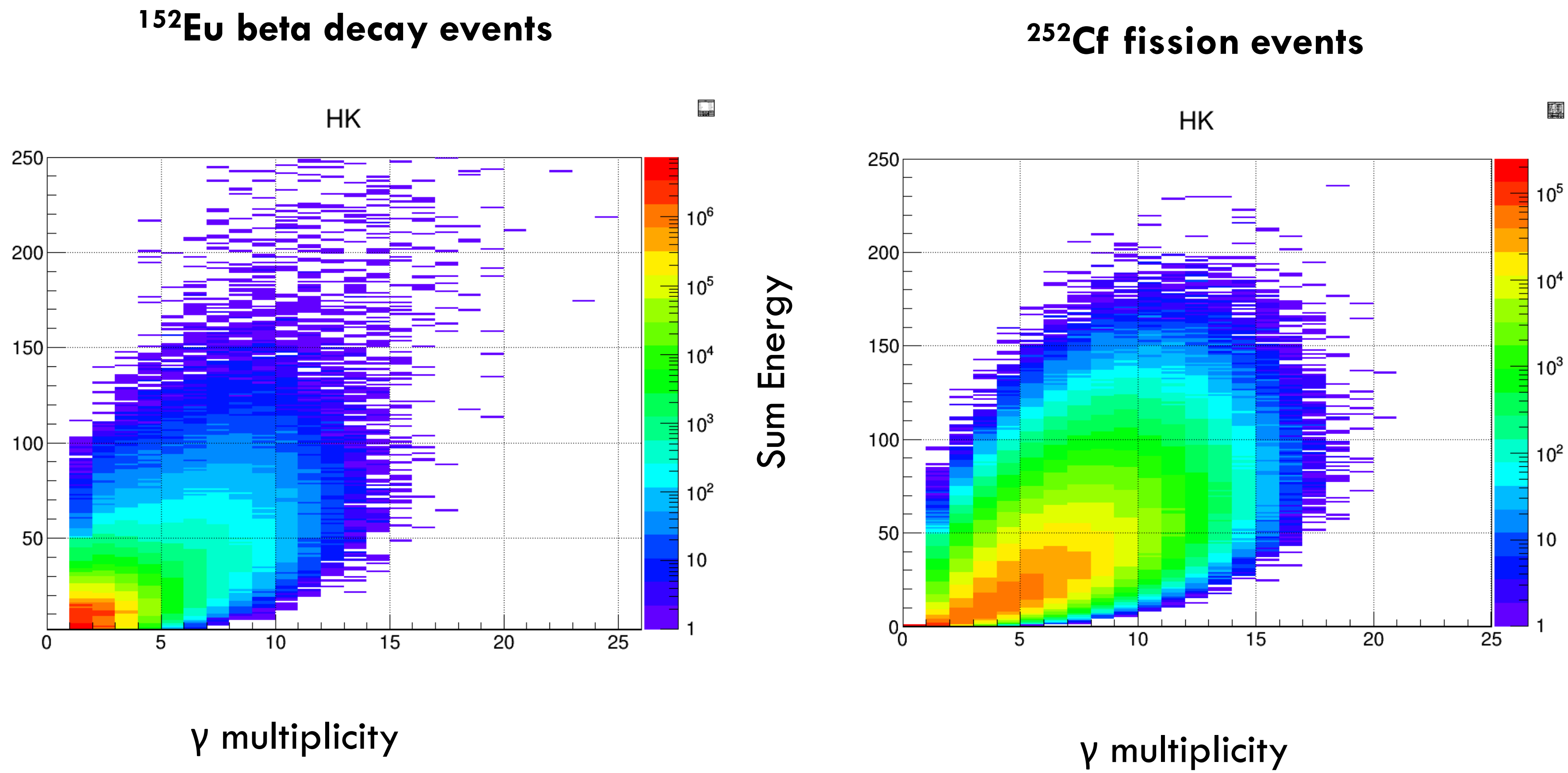
Gammapool Problems

Gammapool: International committee of 12 members existing since 2002
Deployment of ~20M euros of ex-Euroball detector resources

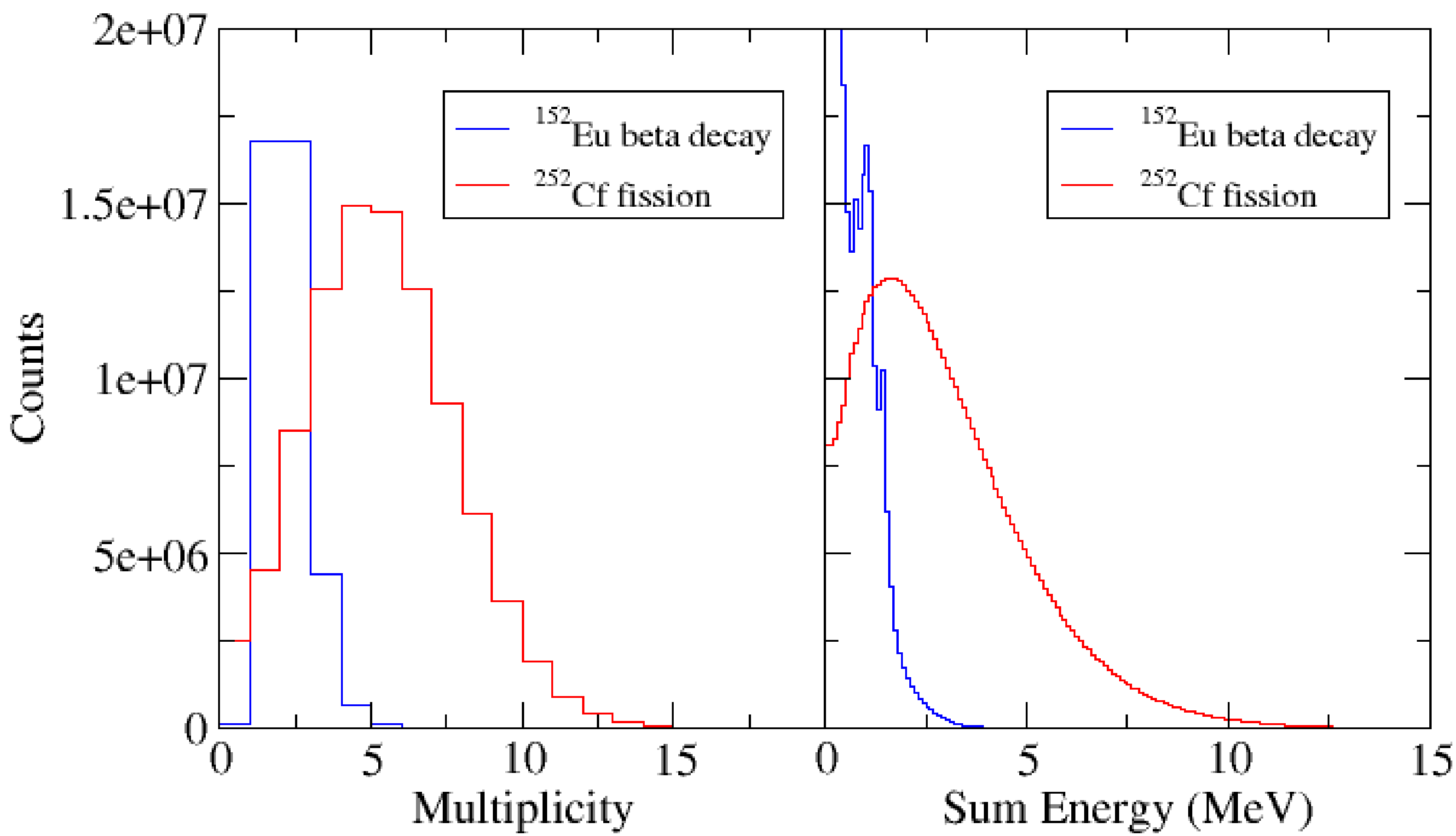
- Conflicts of Interest (e.g. Members voting themselves equipment for their own research)
- Committee members from non-French countries unnacountable to their funding agencies
  (e.g. Seats can be transfered between friends or colleagues -no appointment procedure)
- Seats for life. No obligation to sit for fixed term mandates.
- Lack of French representation (only 8% or 16% of committee)
  (Over 50% of nu-ball equipment was originally financed by France)
- Poorly written MOU with no end-of-life clause. Resources and MOU are considered eternal
- Unlike Loanpool, countries who contributed nothing to Gammapool and borrow equipment are not required to pay any rental costs
- The scientific context in which the 2002 MOU was written has changed dramatically

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

ν-ball calorimetry



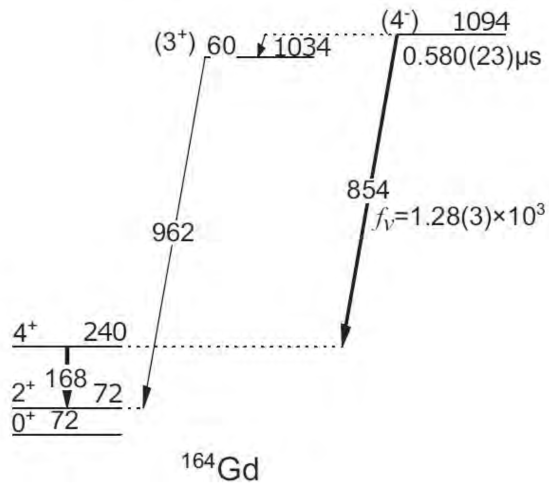
First preliminary results: ν-ball calorimetry



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

RIKEN

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



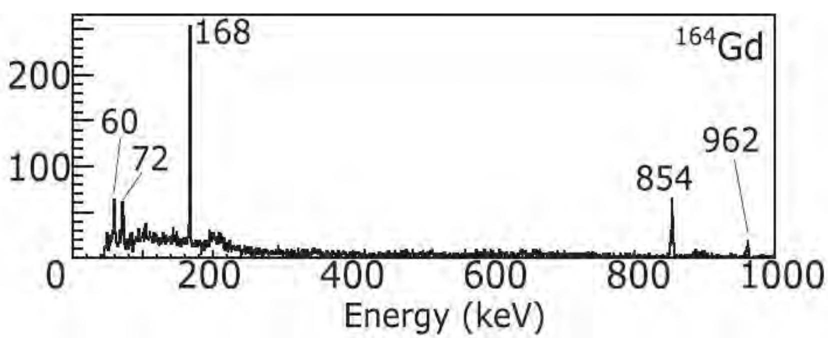
ν-ball

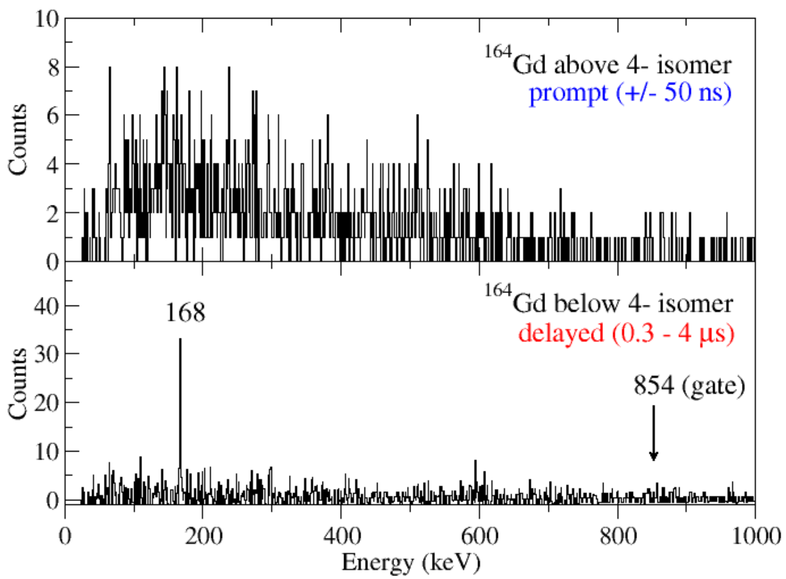
^{164}Gd isomer identified after only 48 hours of data

< 0.01% of the total yield

<u>Decays from states *above* the isomer observed for the first time</u>

Prompt decays impossible to observe

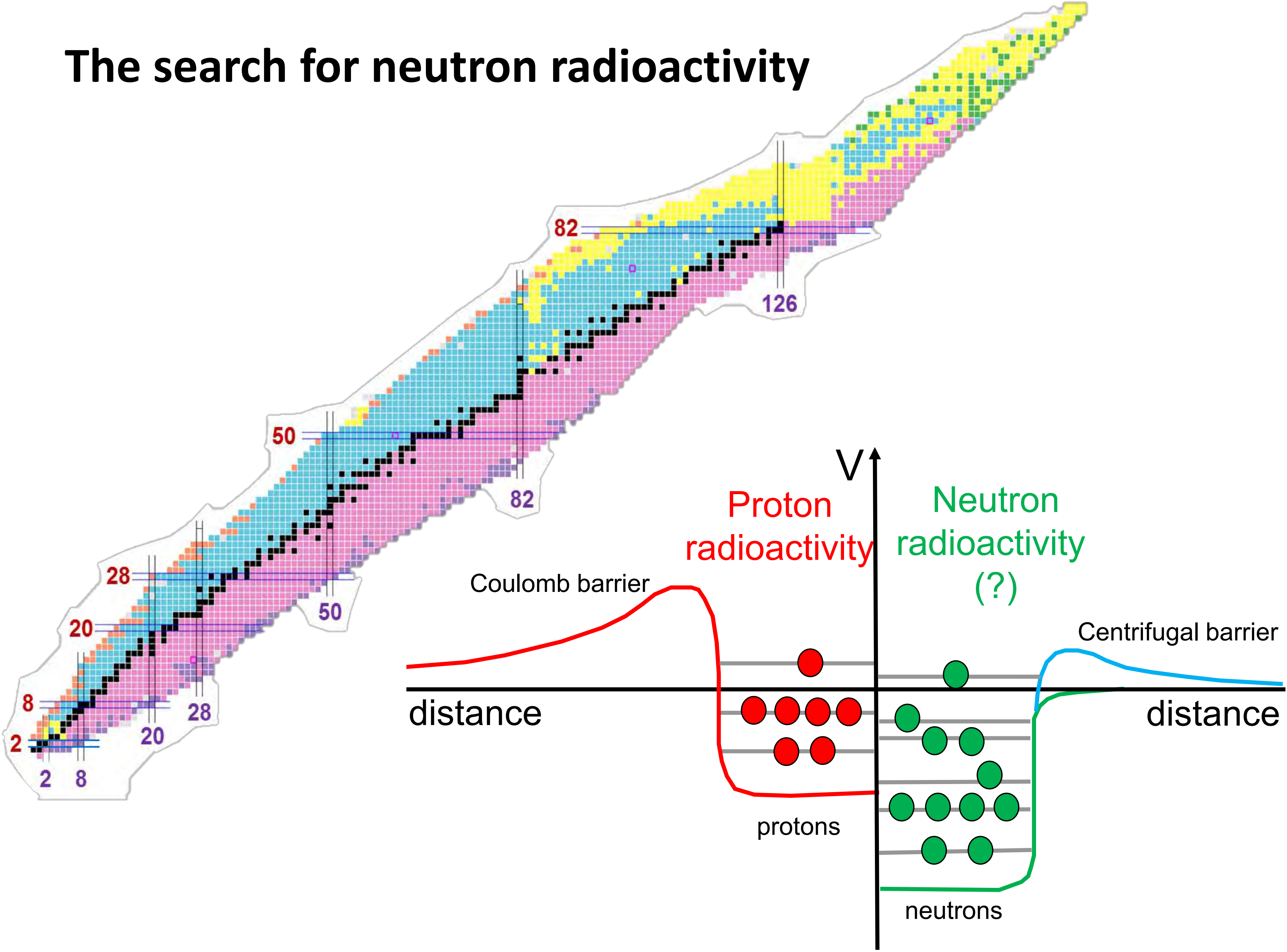




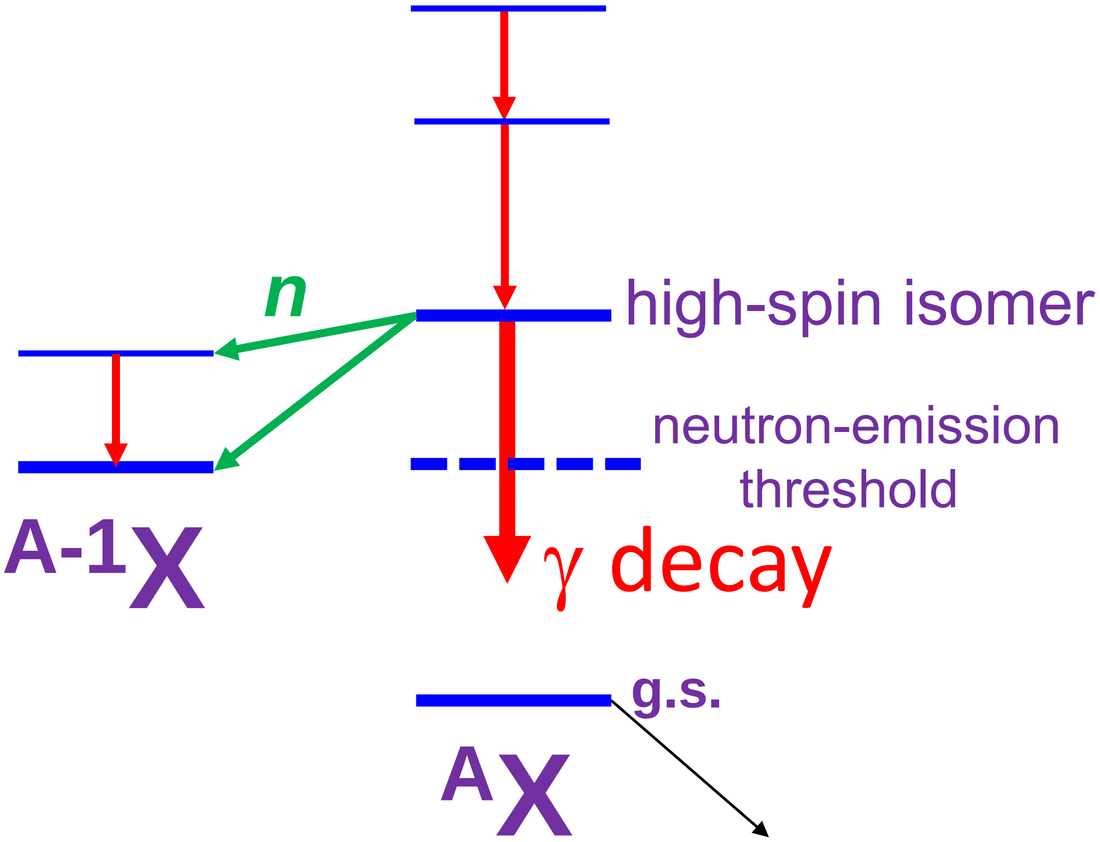
Summary of nu-ball/LICORNE fission experiments:

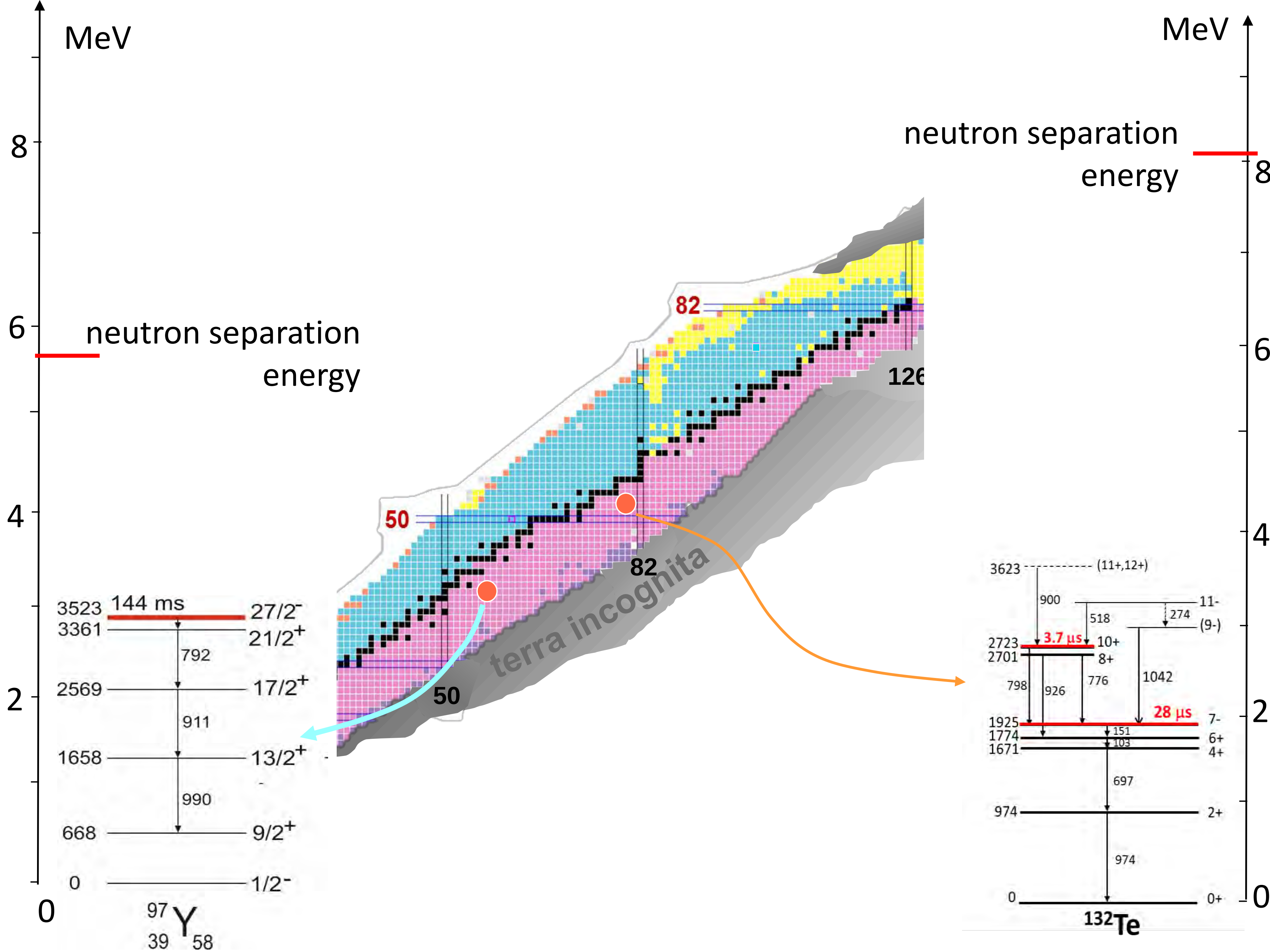
Expt.	Target mass	^{7}Li Current	E_n	Fission Rate	Time	Data	Total Fissions
^{252}Cf(SF)	-	-	-	3 kHz	2 days	50Gb	5.2×10^{8}
^{238}U(n,f)	81 g	10 nA	1.7 MeV	8 kHz	9 days	11Tb	6.0×10^{9}
^{232}Th(n,f)	129 g	80 nA	1.7 MeV	26 kHz	19 days	80Tb	4.0×10^{10}
^{238}U(n,f)	81 g	100 nA	3.4 MeV	28 kHz	7 days	25Tb	1.7×10^{10}

The search for neutron radioactivity



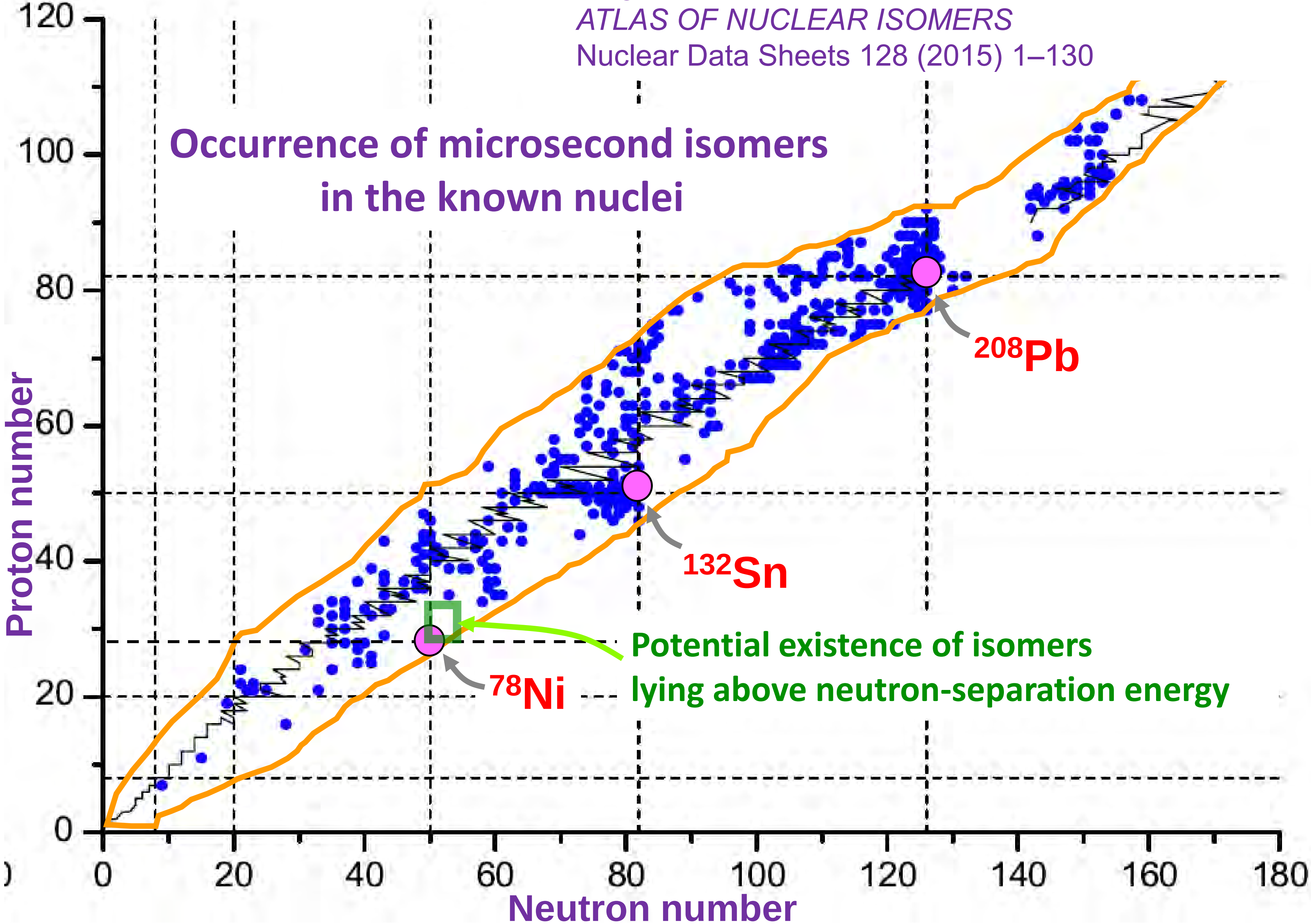
Neutron radioactivity

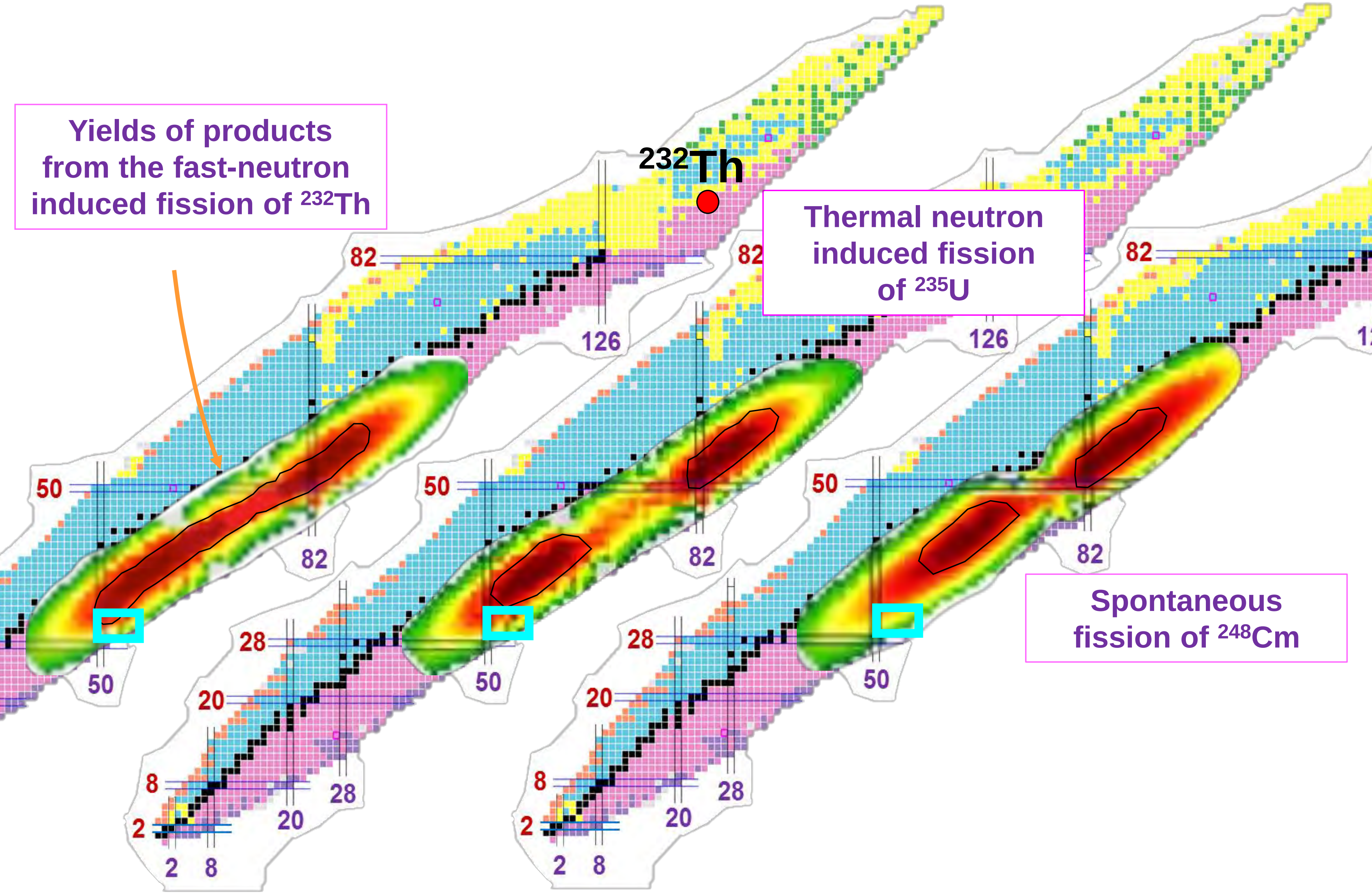




MeV
8
6
4
2
0
neutron separation energy
3523
144 ms
27/2-
3361
21/2+
792
2569
17/2+
911
1658
13/2+
990
668
9/2+
0
1/2-
$^{97}_{39}Y_{58}$
50
82
126
50
82
terra incognita
MeV
neutron separation energy
8
6
4
2
0
3623
(11+,12+)
900
518
274
11-
(9-)
2723
3.7 μs
10+
2701
8+
798
926
776
1042
1925
28 μs
7-
1774
151
6+
1671
103
4+
697
974
2+
974
0
0+
^{132}Te

A.K. Jain, B. Maheshwari, S. Garg, M. Patial, and B. Singh
ATLAS OF NUCLEAR ISOMERS
Nuclear Data Sheets 128 (2015) 1–130





Yields of products from the fast-neutron induced fission of 232Th
232Th
Thermal neutron induced fission of 235U
Spontaneous fission of 248Cm
82
126
50
82
50
28
20
8
2
2
8
20
28