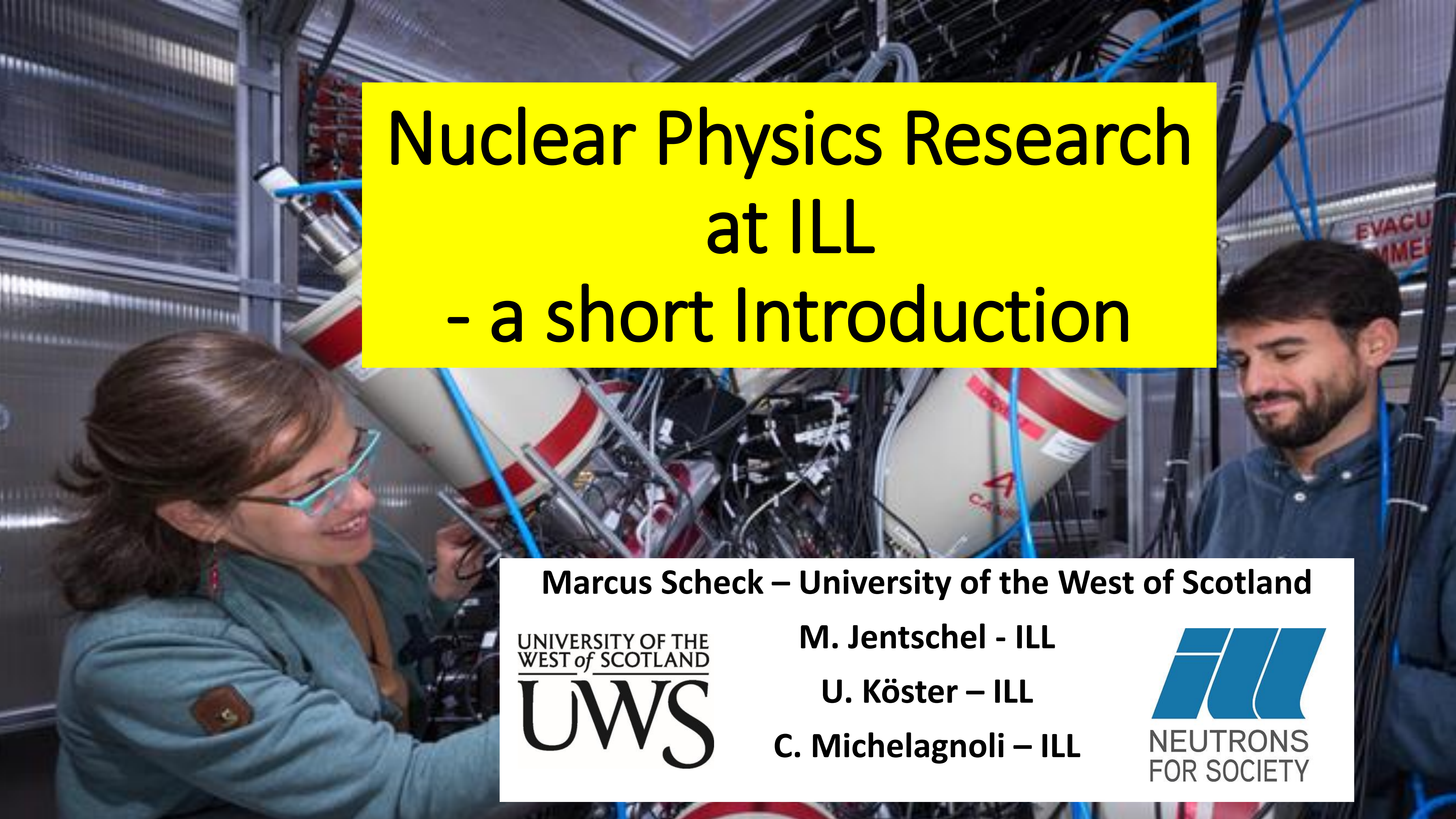

Nuclear Physics Research at ILL - a short Introduction

Marcus Scheck – University of the West of Scotland

UNIVERSITY OF THE WEST of SCOTLAND
UWS

M. Jentschel - ILL

U. Köster – ILL

C. Michelagnoli – ILL

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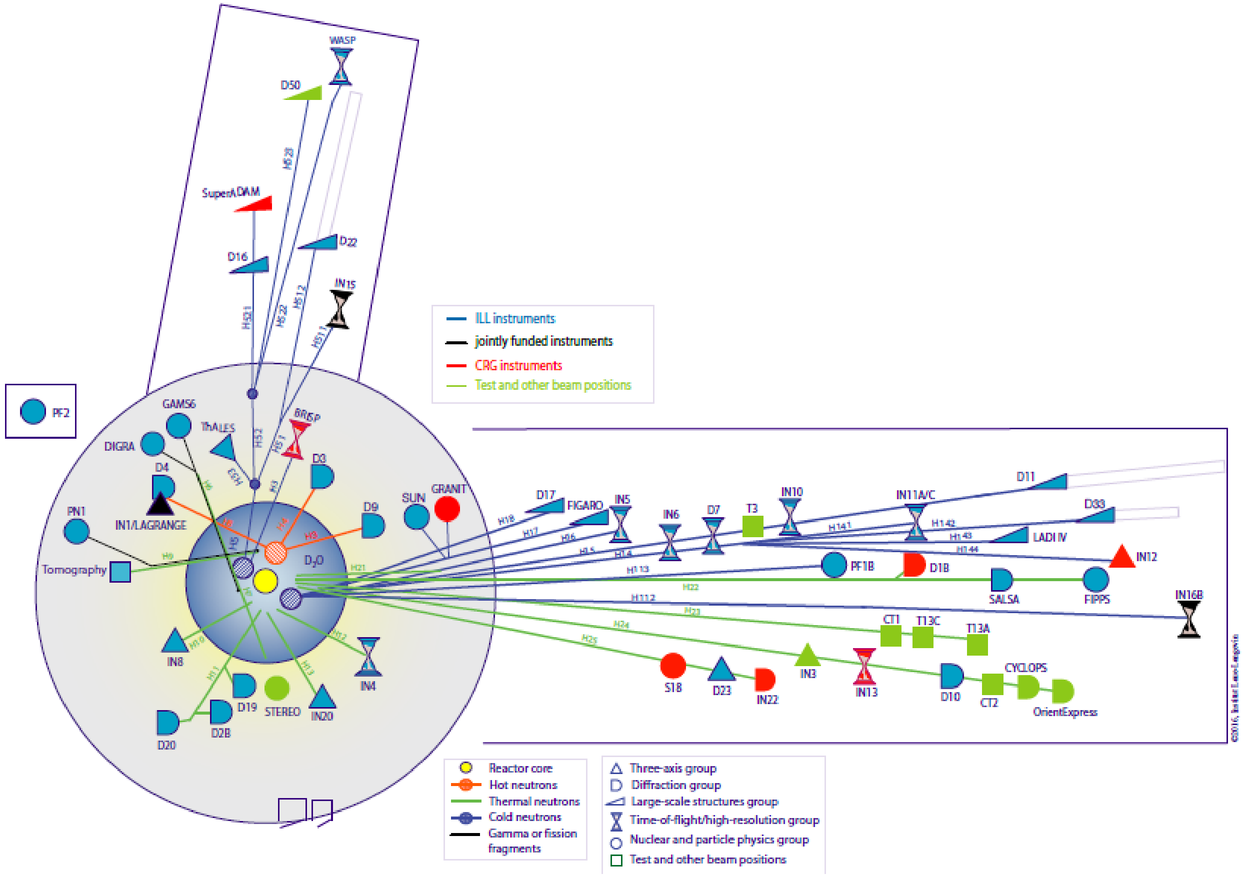
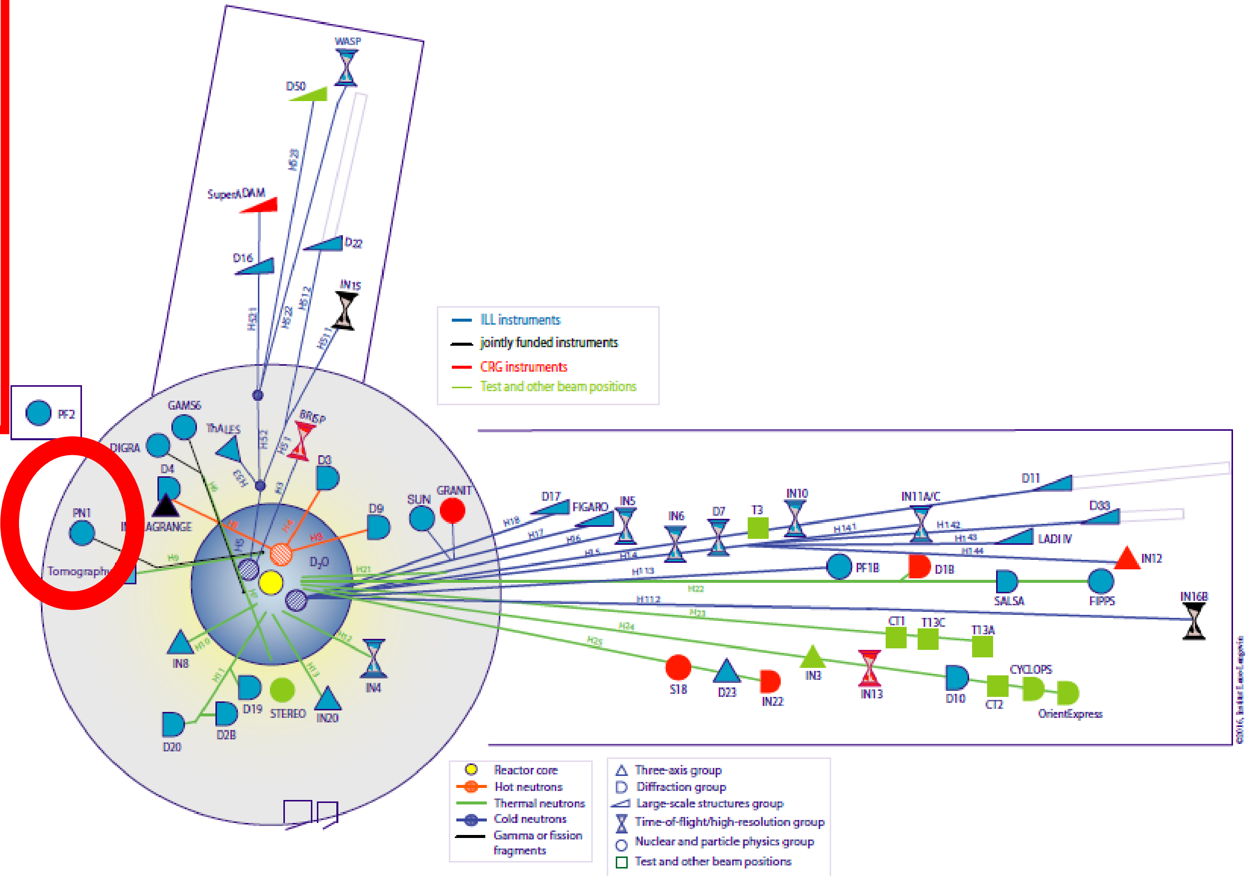
Infrastructure



Infrastructure

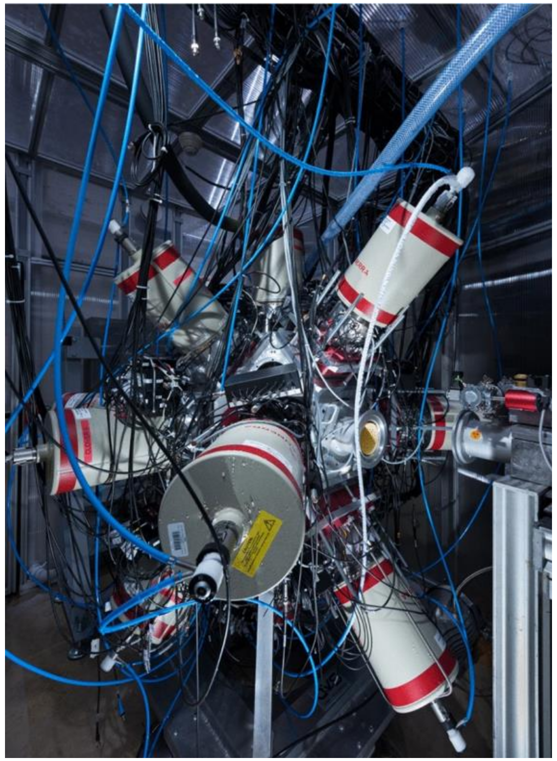
Lohengrin

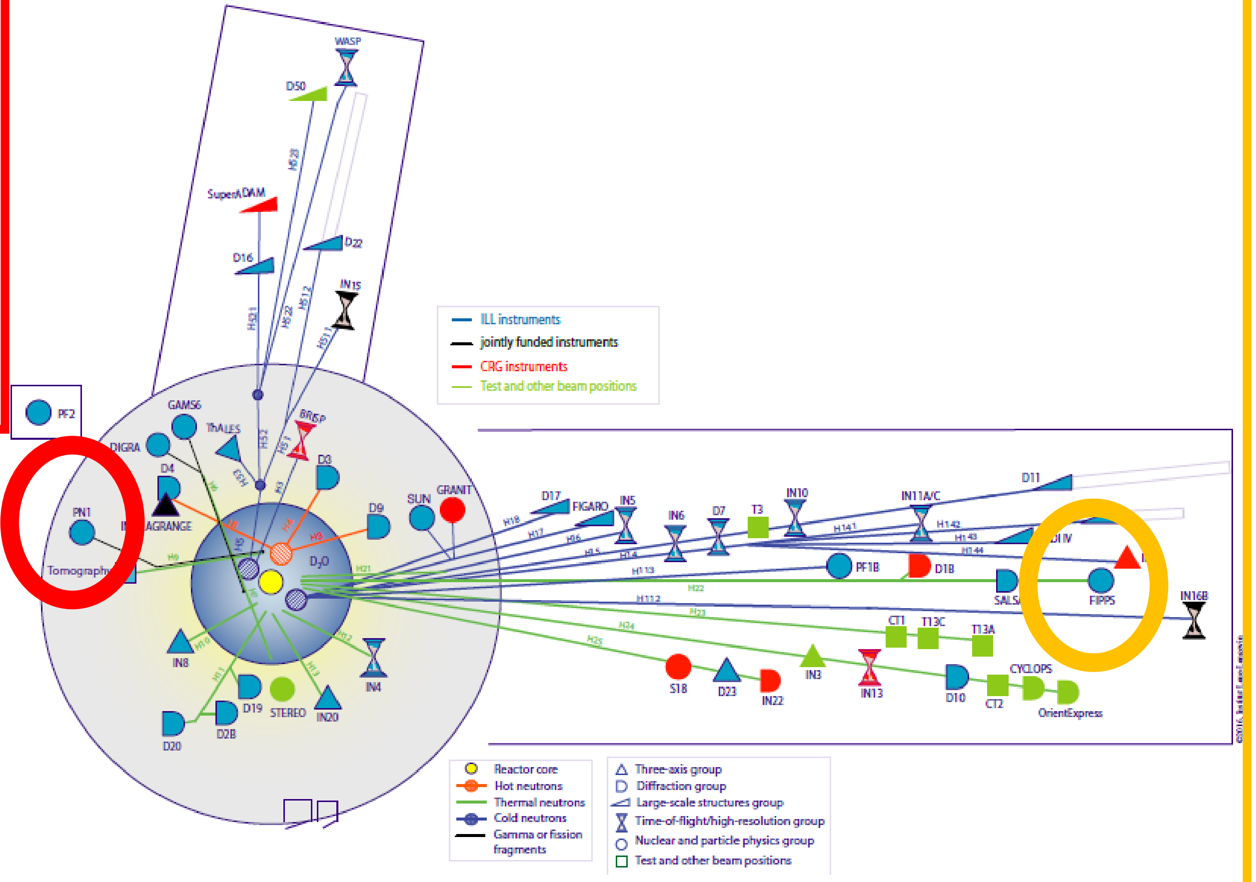


Infrastructure

Lohengrin

FIPPS
Fission-Product Prompt γ-ray Spectrometer





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Lohengrin

recoil mass spectrometer for fission fragments

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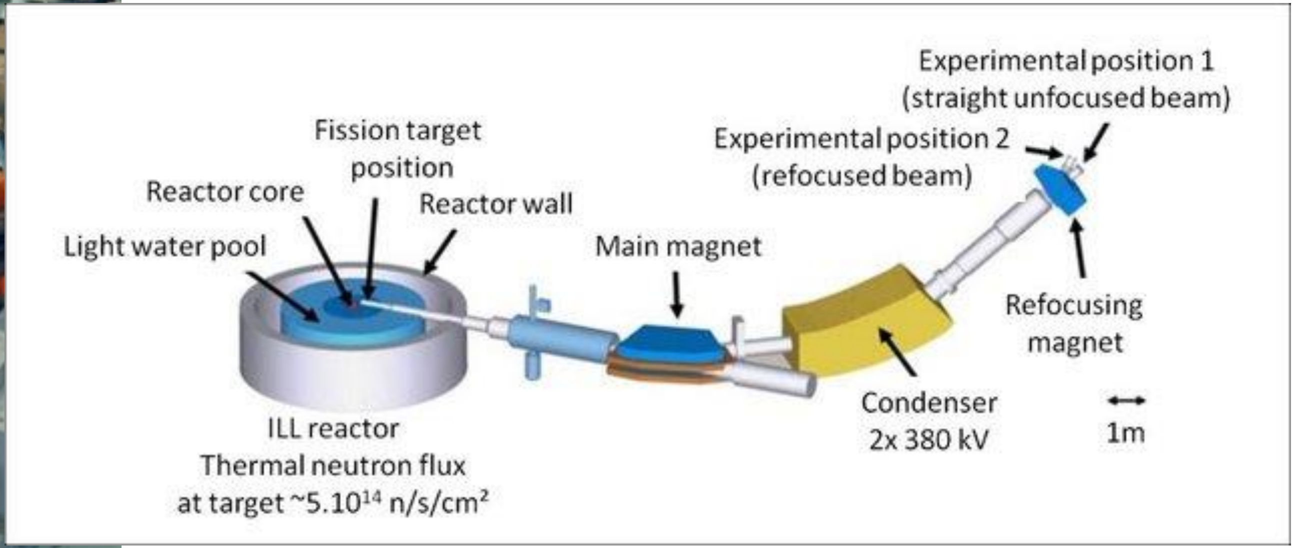
Lohengrin

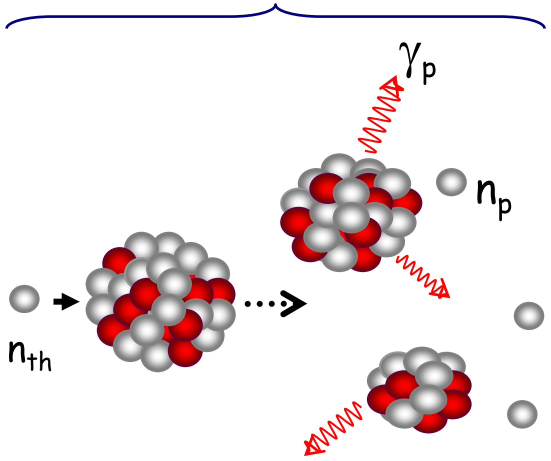
recoil mass spectrometer for fission fragments



Lohengrin

recoil mass spectrometer for fission fragments

Nuclear fission in the Lohengrin target

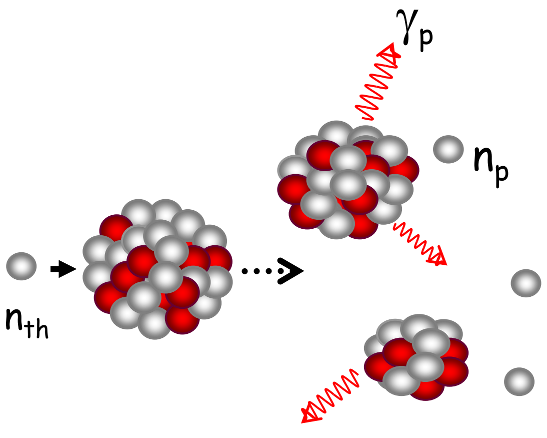


10^{-18} - 10^{-16}s

Lohengrin

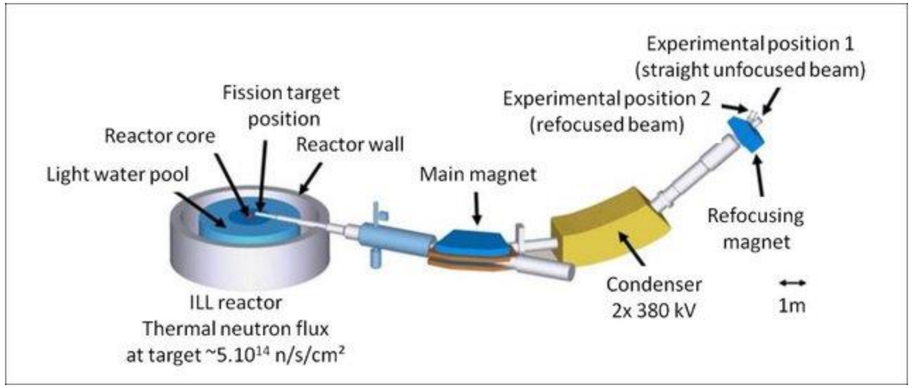
recoil mass spectrometer for fission fragments

Nuclear fission in the Lohengrin target



10^{-18} - 10^{-16}s

Transfer through spectrometer

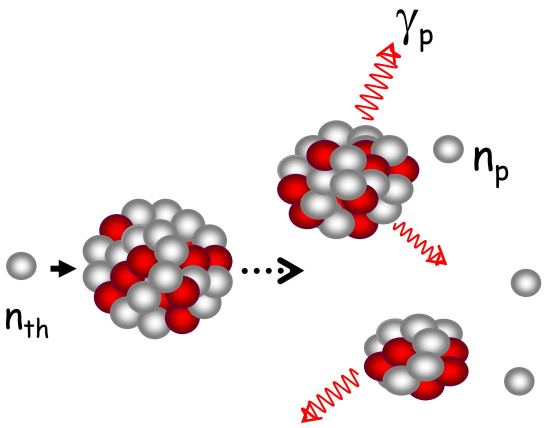


1-2 μs

Lohengrin

recoil mass spectrometer for fission fragments

Nuclear fission in the Lohengrin target



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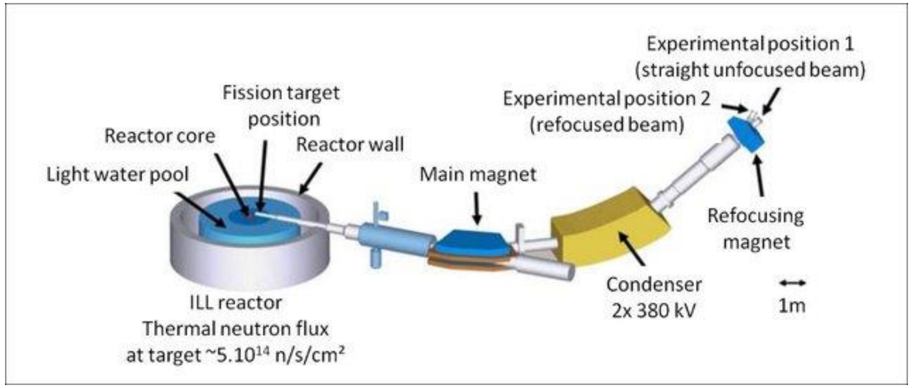
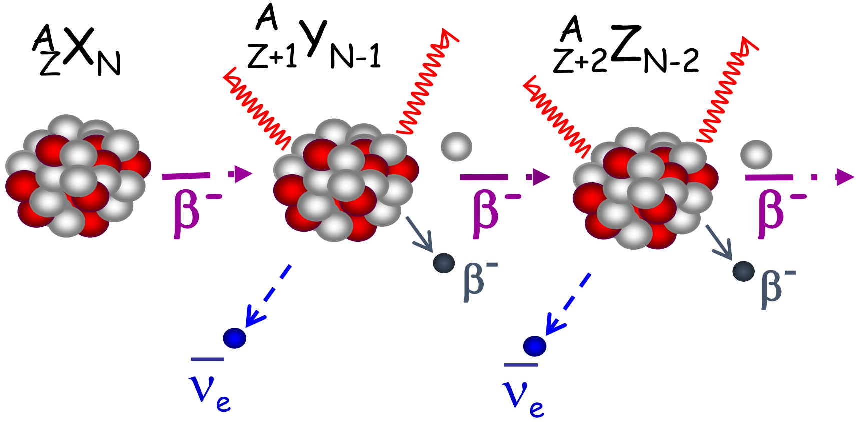


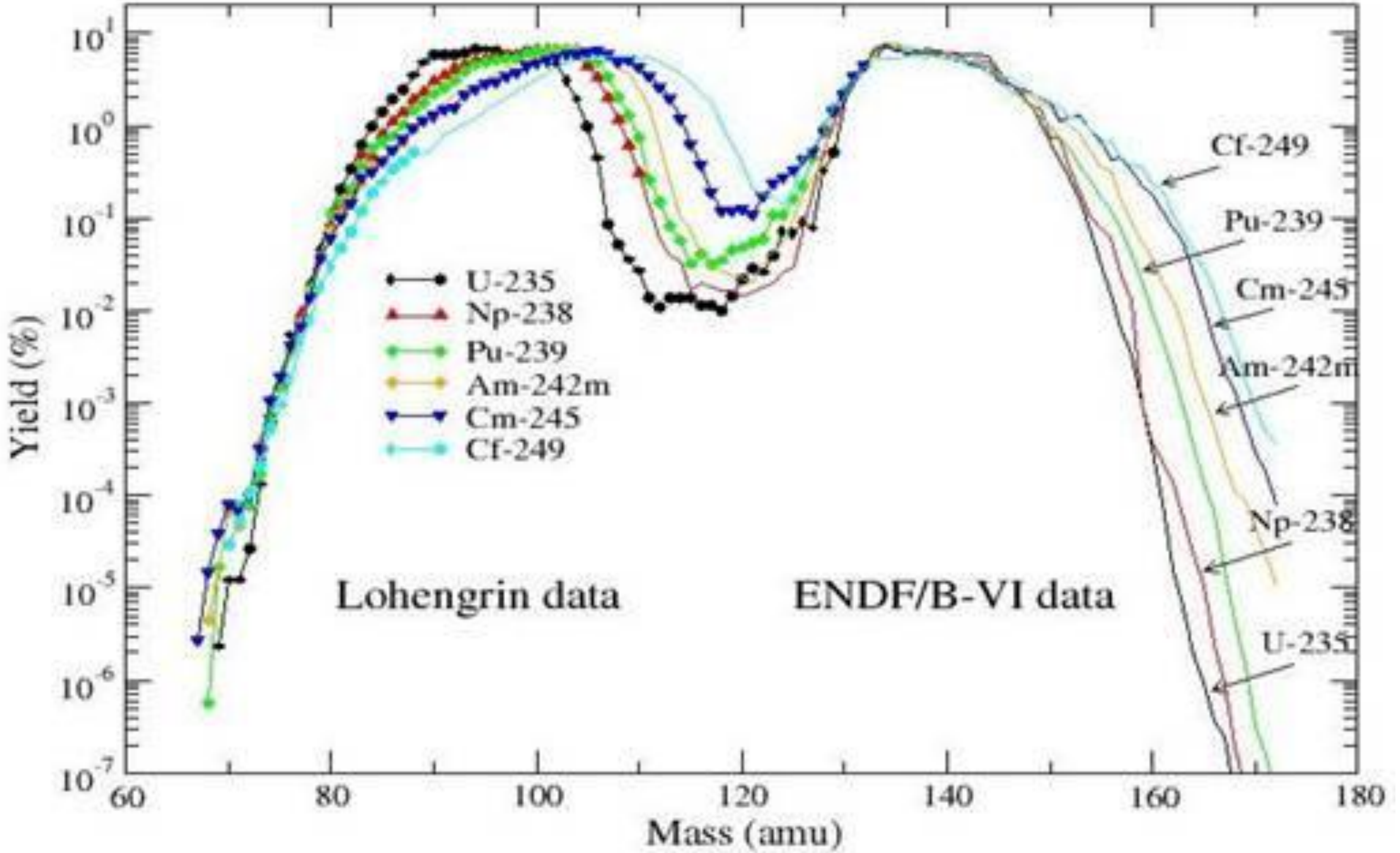
1-2 μs

Isomeric decays and β decays in the detection system



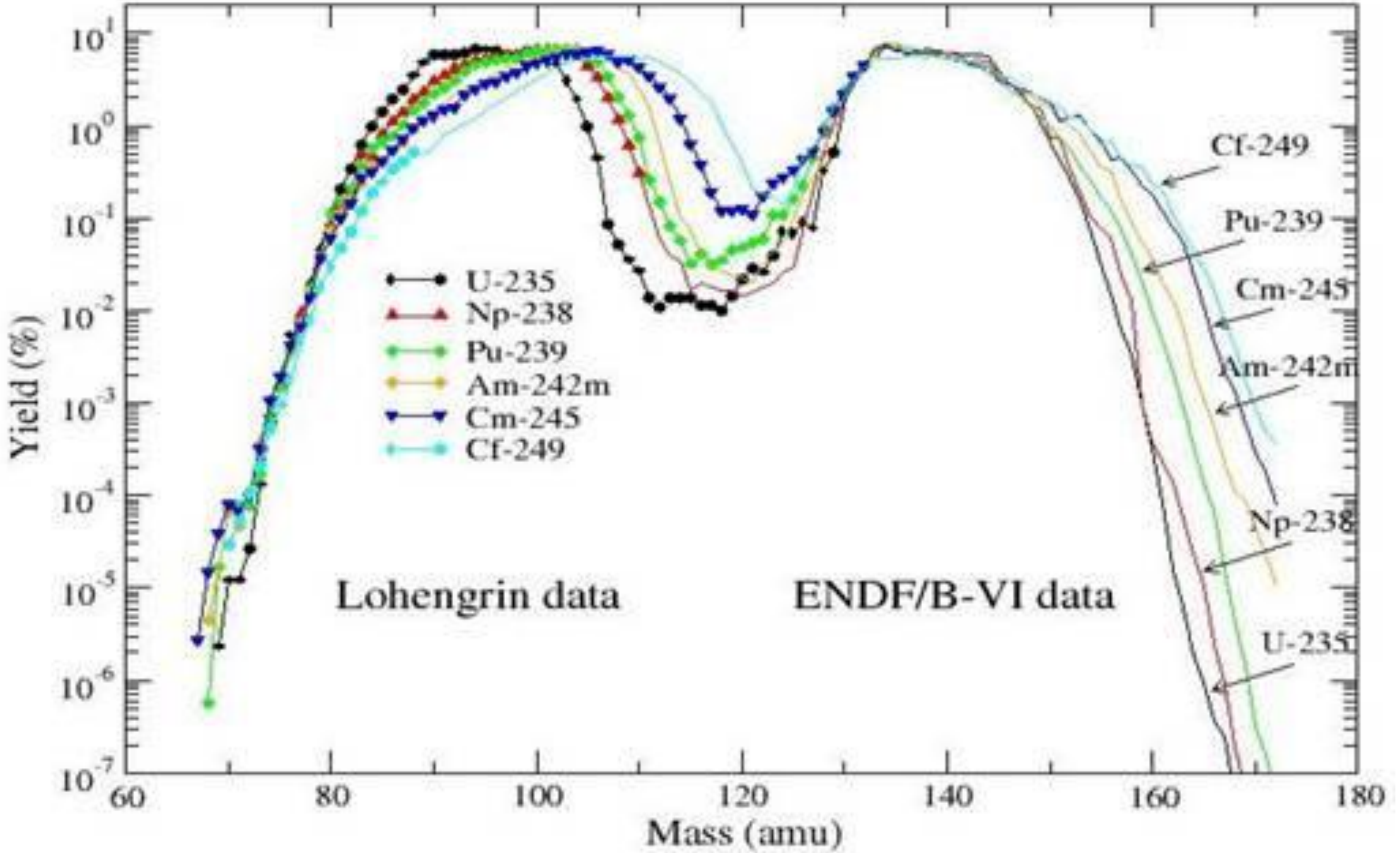
μs to s

Lohengrin
recoil mass spectrometer for fission fragments



Fission fragment yields of actinides, including short-lived targets produced in situ by (n,γ), e.g. ^{238}Np ($T_{1/2}$=2.1d).

Lohengrin
recoil mass spectrometer for fission fragments



Fission fragment yields of actinides, including short-lived targets produced in situ by (n,γ), e.g. ^{238}Np ($T_{1/2}$=2.1d).

Fission still not well understood!
See J.N. Wilson et al., Nature **590** (2021) 566

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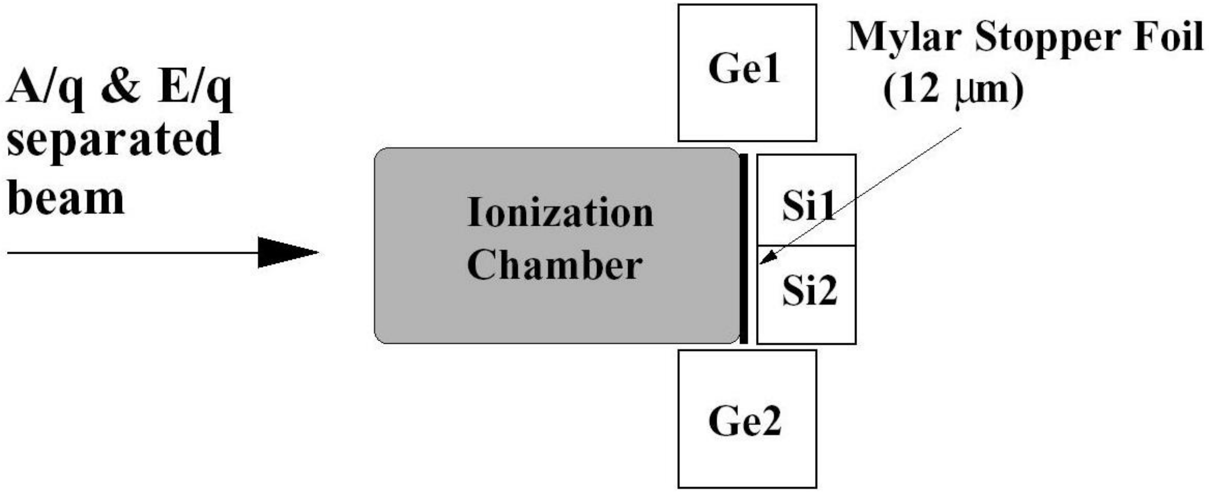
an example for an experimental setup



Ionization chamber:

Specific energy loss $-\frac{dE}{dx}$

$\Rightarrow$ ion identification

Lohengrin

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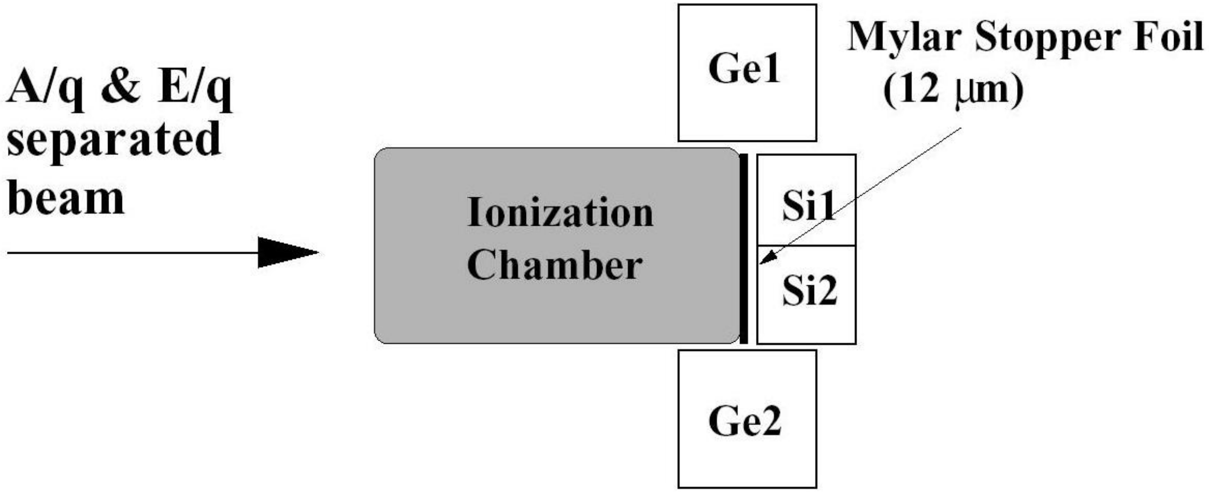

Ge:
Clover high-purity germanium detector for high-resolution ($\Delta E/E \approx 1/1000$) γ-ray spectroscopy with 160% relative detection efficiency

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Lohengrin

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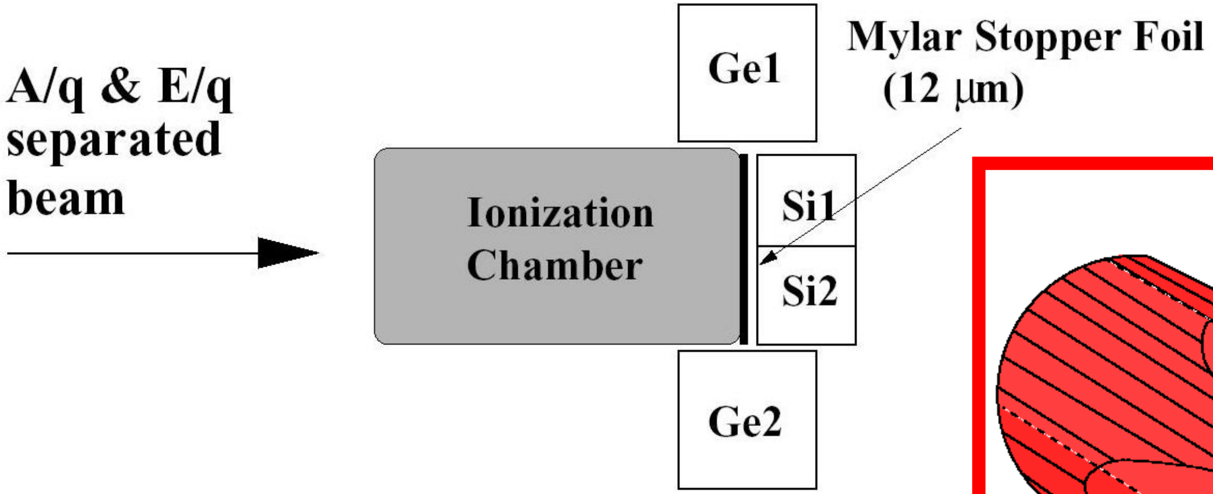

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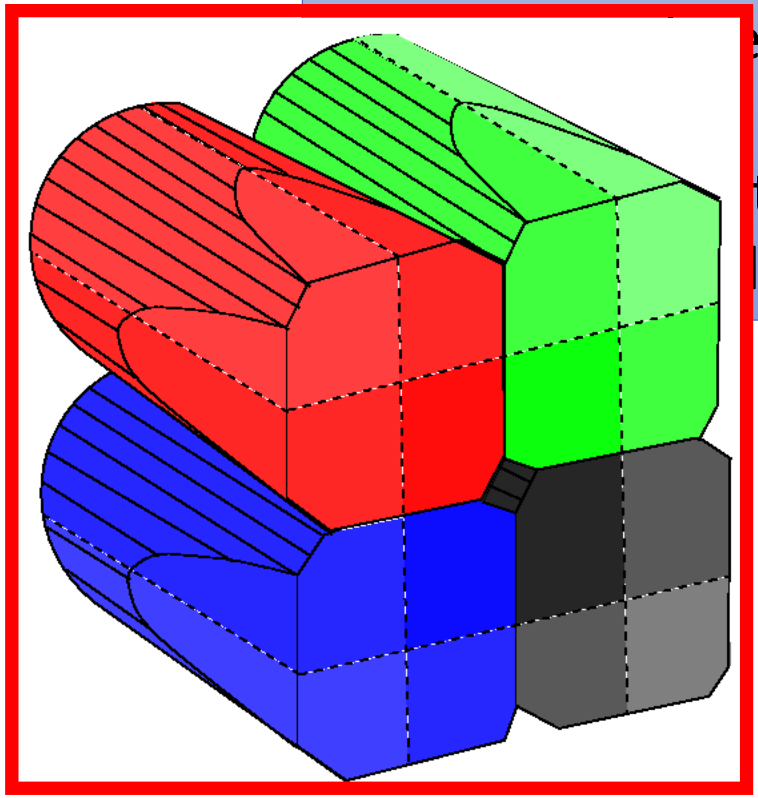

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Lohengrin

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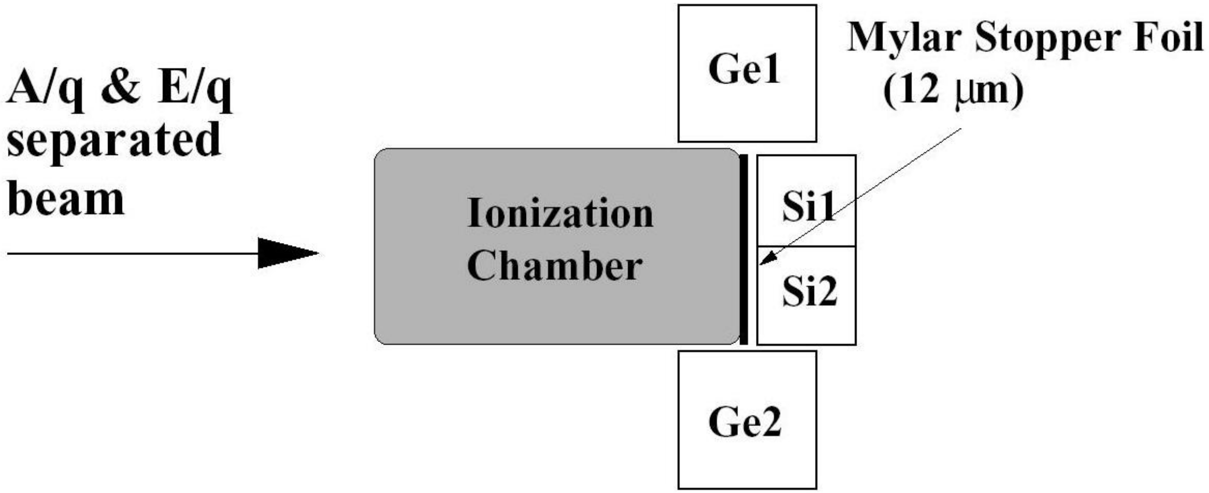

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Si:
Silicon detectors for electron (β particles, conversion electrons) detection

Lohengrin

an example for an experimental setup

Ge:
Clover high-purity germanium
...000)
...ency

However, **flexible**!
For example,

- $LaBr_3$ detectors for fast-timing measurements
- Beta-delayed neutron detectors, etc.

Ionization chamber:
Specific energy loss $-\frac{dE}{dx}$
$\Rightarrow$ ion identification

Si:
Silicon detectors for electron
(β particles, conversion electrons)
detection

Lohengrin

an example for an experimental setup

A/q & E/q
separated
beam

Ge:

r high-purity germanium

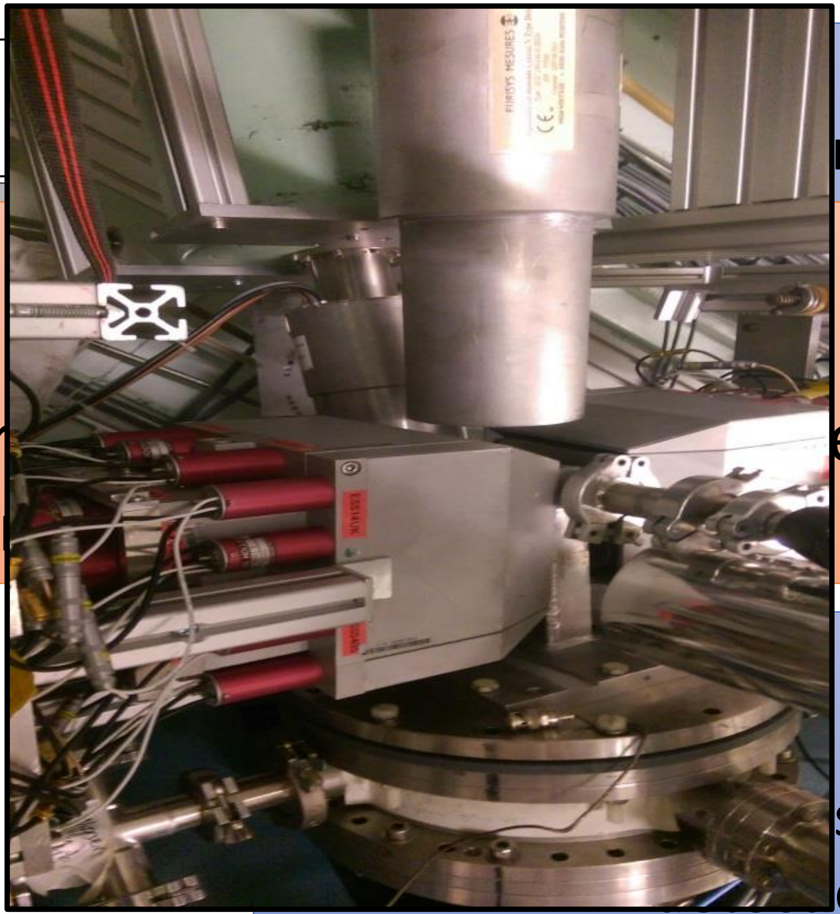
000)

ency

- $LaBr_3$ detector

ents

- Beta-delayed



Ionization chamber:

Specific energy loss $-\frac{dE}{dx}$

$\Rightarrow$ ion identification

for electron

sion electrons)

on

Lohengrin

a recent physics example: β decay of ^{96}Y to ^{96}Zr

Daya Bay Reactor Neutrino Experiment:
Reactors emit only 94.6(22) % of the expected high-energy (>1.8 MeV) antineutrinos.
F.P. An et al., PRL **116**, 061801 (2016)
& Erratum: PRL **118**, 099902 (2018)

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Antineutrinos from
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Likely source: Pandemonium effect
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Lohengrin

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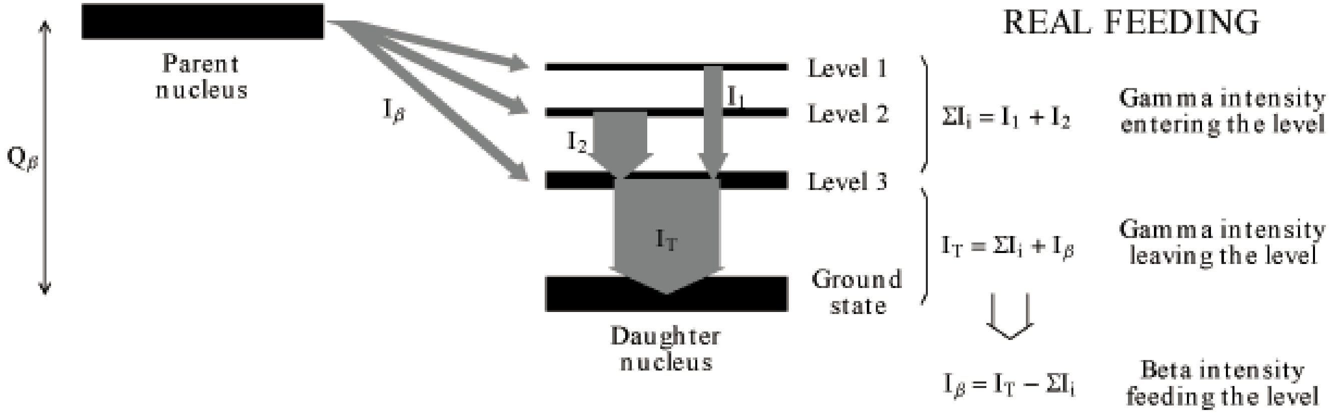

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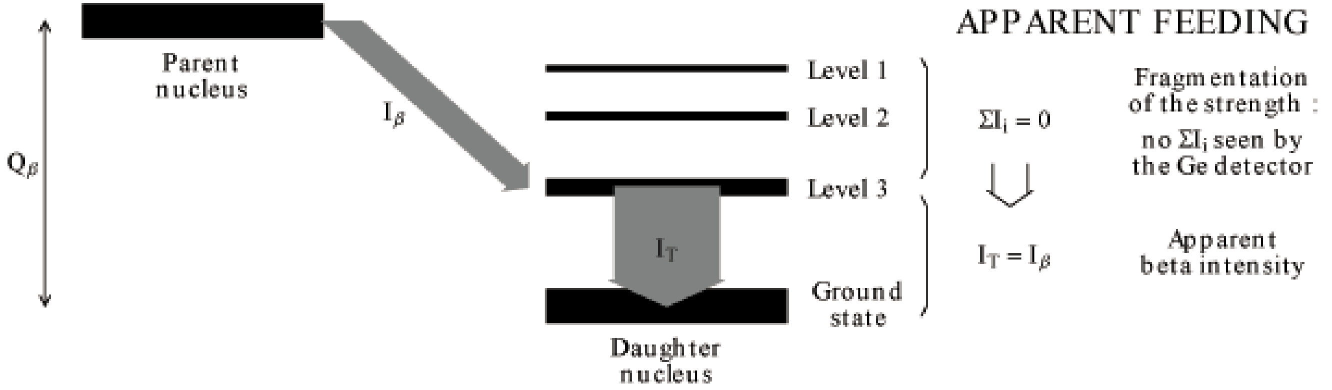

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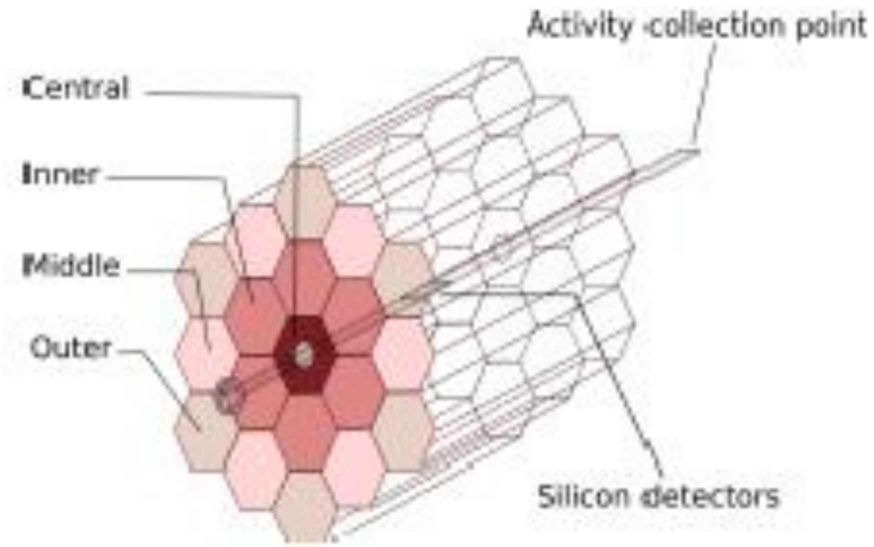
a recent physics example: β decay of ^{96}Y to ^{96}Zr

Standard Answer:
Total Absorption γ-ray Spectroscopy
using massive NaI detectors



A.Fijalkowska et al.,
Acta. Phys. Pol. B45, 545 (2014)

Lohengrin

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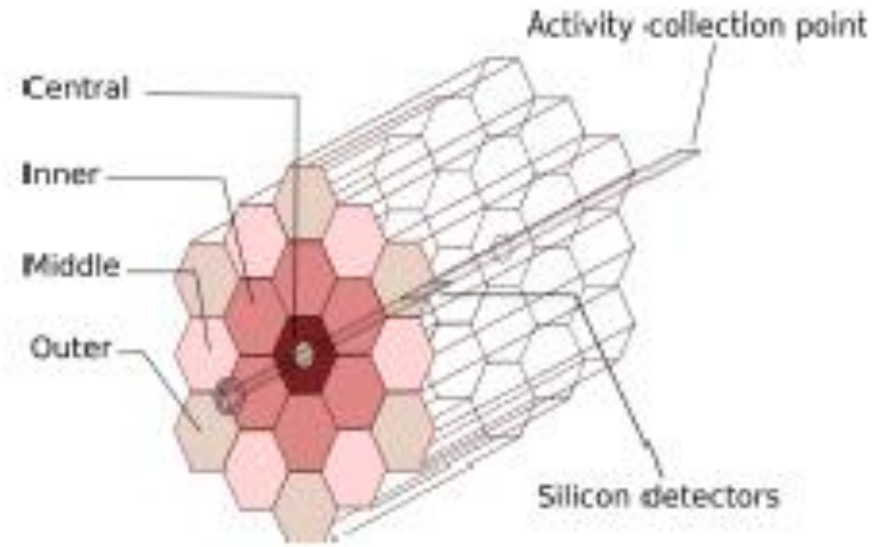

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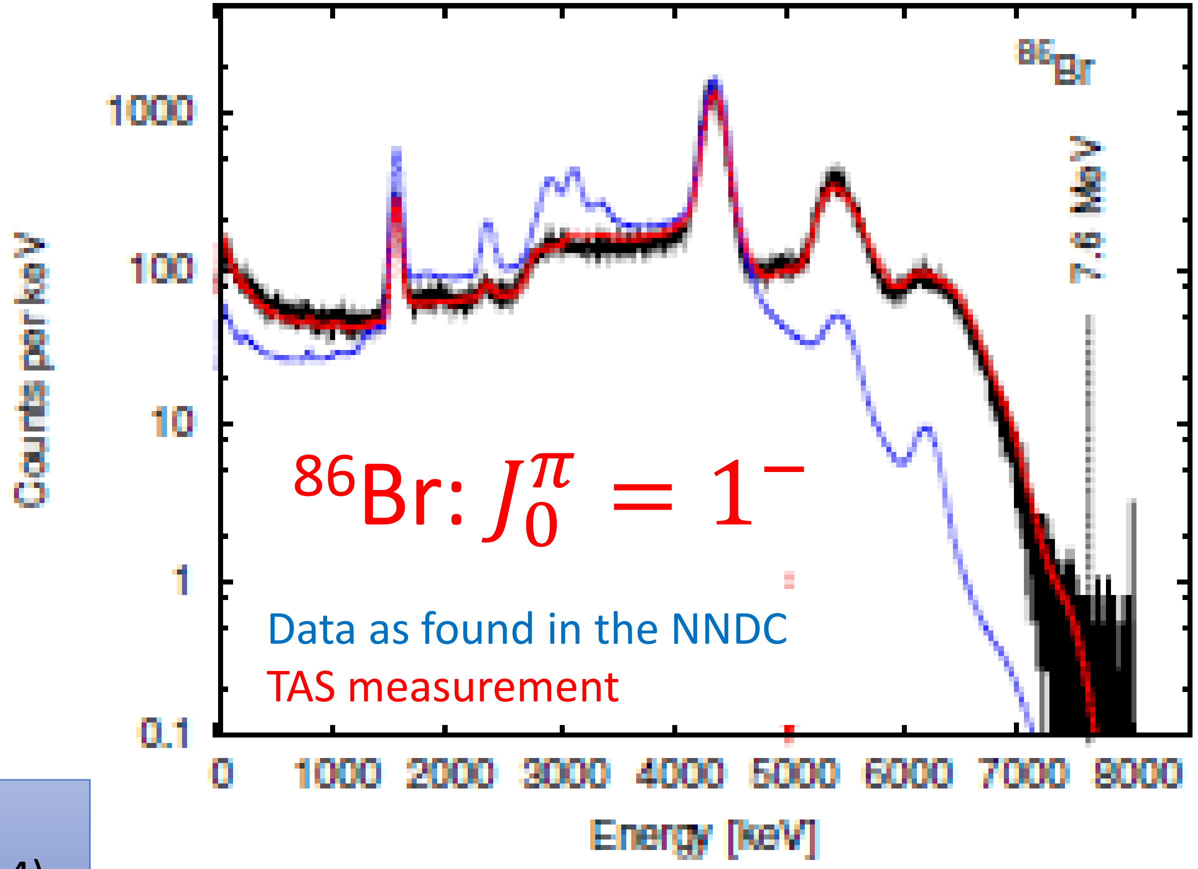

$^{86}\mathrm{Br}: J_0^\pi = 1^-$

Data as found in the NNDC
TAS measurement

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a recent physics example: β decay of ^{96}Y to ^{96}Zr

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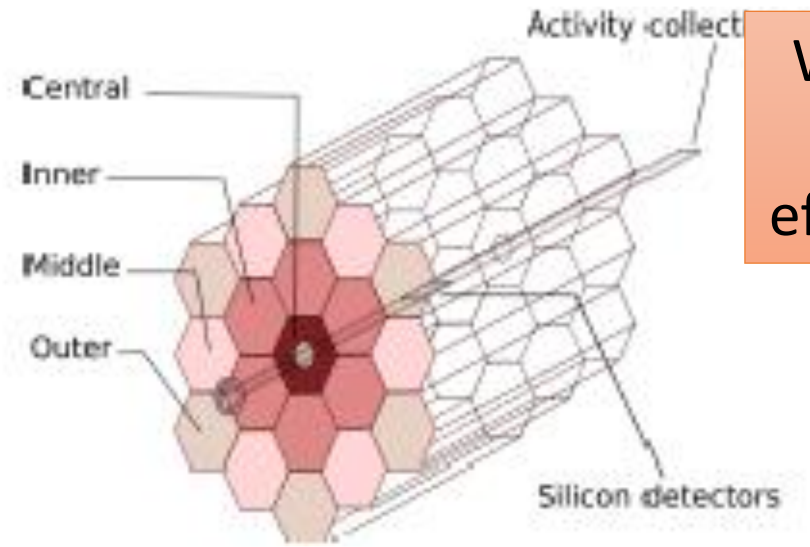
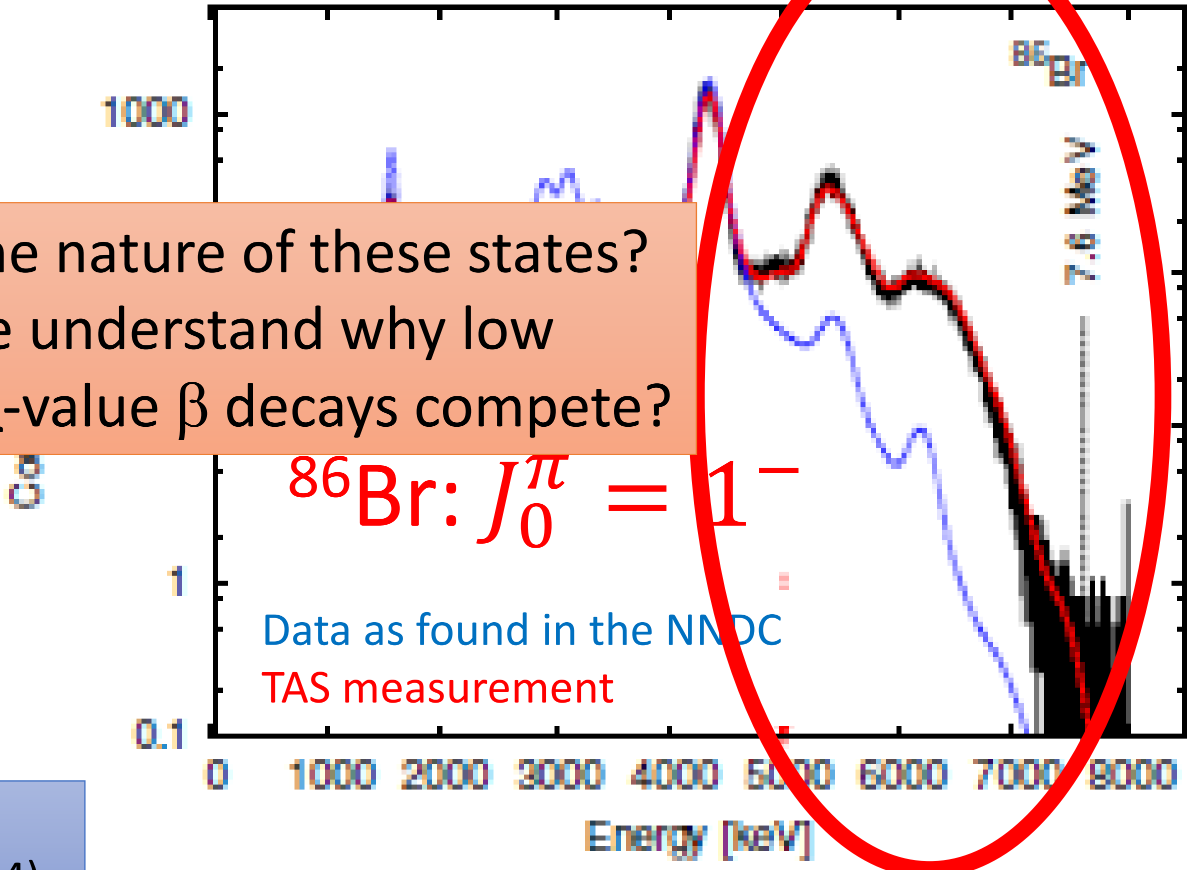


What is the nature of these states?
Can we understand why low effective Q-value β decays compete?



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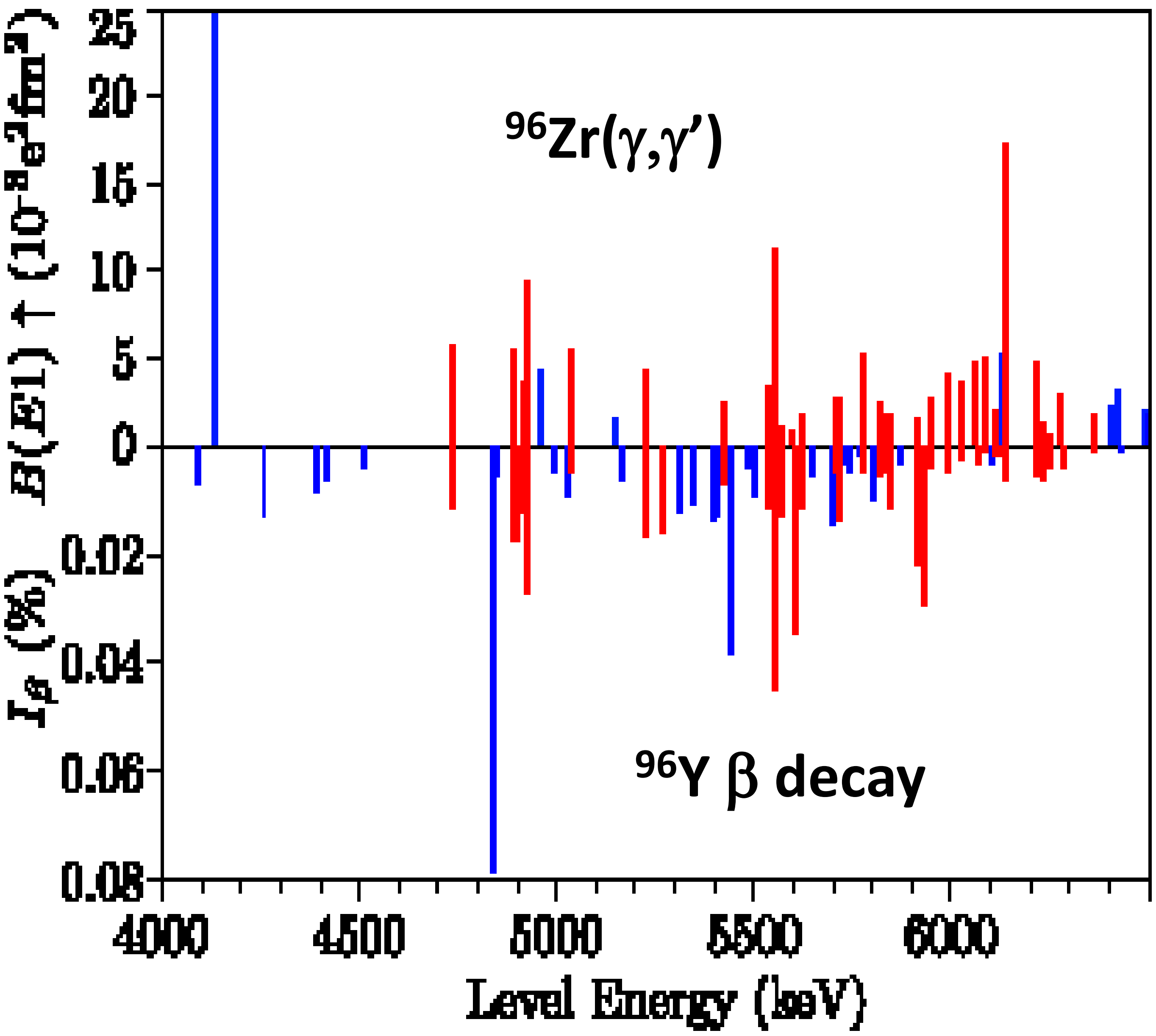
Multi-messenger approach: β decay & $^{96}Zr(\gamma,\gamma')$



(γ,γ′) data:
M. Zweidinger, PhD thesis, TU Darmstadt
Courtesy of N. Pietralla & W.Tornow

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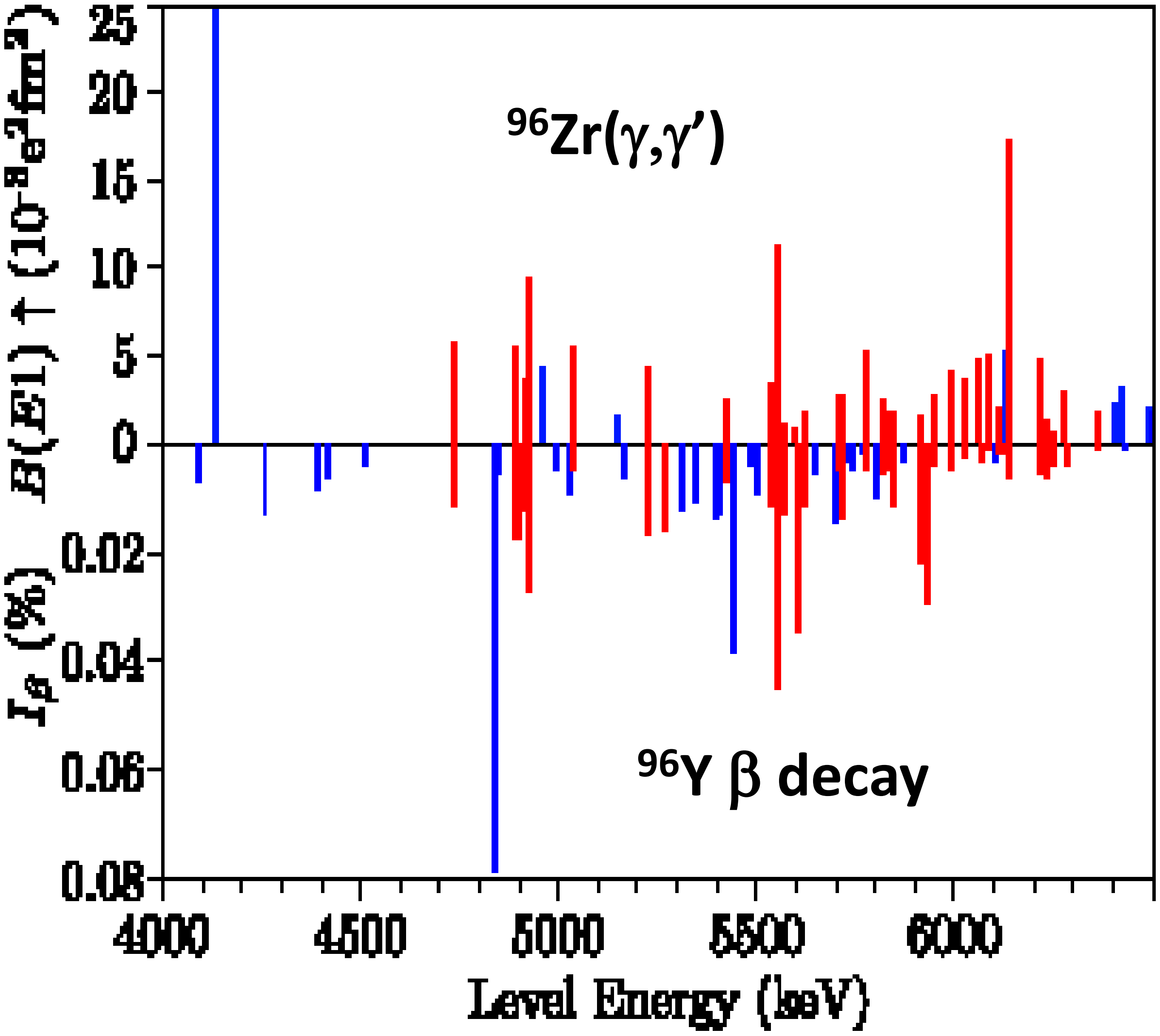
Multi-messenger approach: β decay & $^{96}Zr(\gamma,\gamma')$



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^{96}Y ground state $J^\pi = 0^-$
⇒ Gamow-Teller β decays to 1^- levels in ^{96}Zr

(γ,γ') data:
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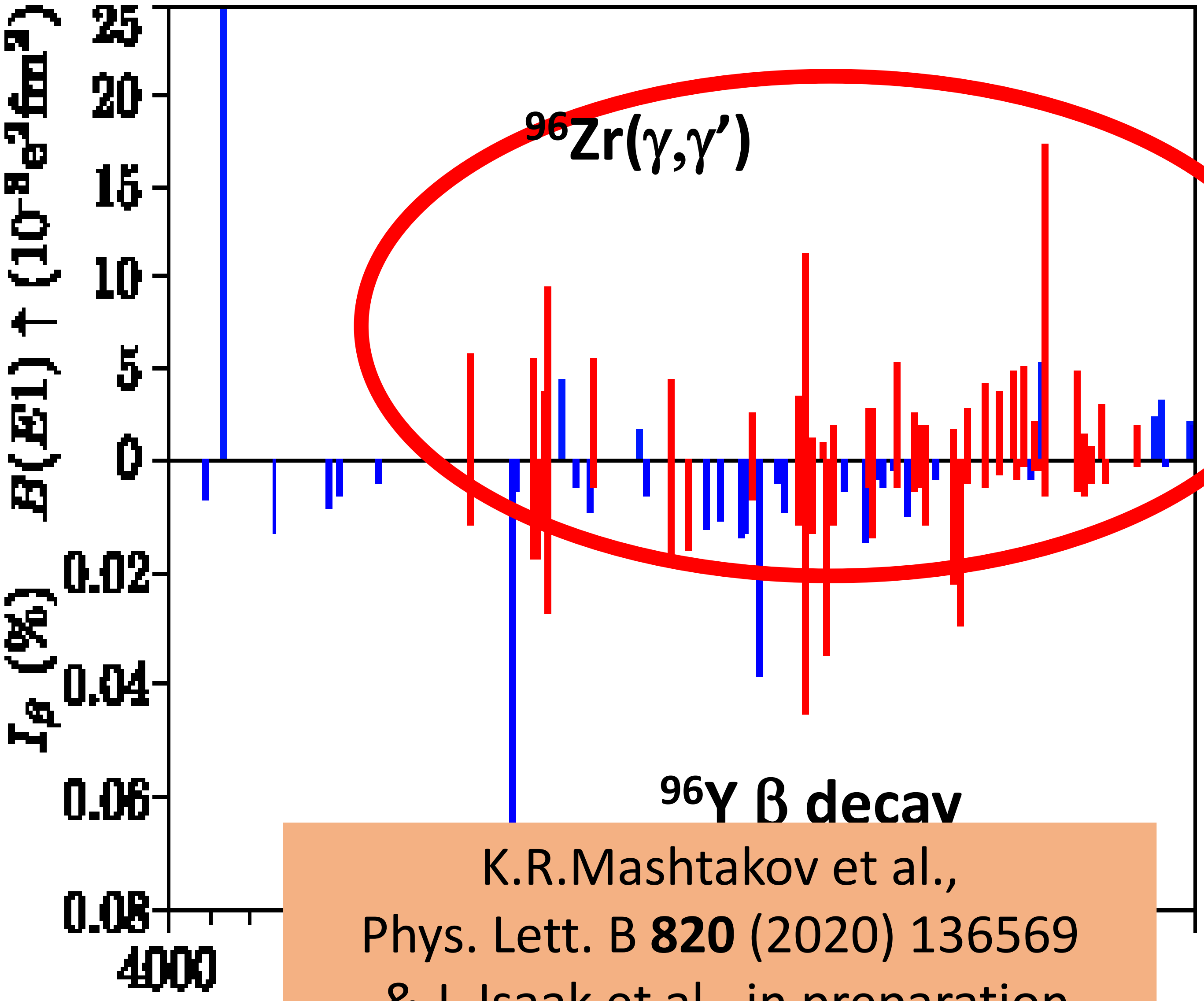
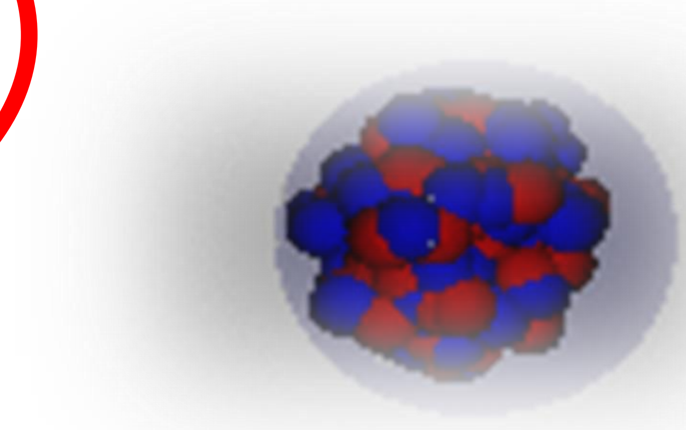
Multi-messenger approach: β decay & ^{96}Zr(γ,γ')



K.R.Mashtakov et al.,
Phys. Lett. B **820** (2020) 136569
& J. Isaak et al., in preparation



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1$^-$ levels associated with the Pygmy Dipole Resonance

(γ,γ') data:
M. Zweidinger, PhD thesis, TU Darmstadt
Courtesy of N. Pietralla & W.Tornow

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FIPPS

Fission-Product Prompt γ-ray Spectrometer

Core: 16 Clover high-purity germanium detectors
for high-resolution $(\Delta E/E \approx 1/1000)$
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Auxiliary: LaBr detectors for lifetime measurements fast-timing technique

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Fission-Product Prompt γ-ray Spectrometer

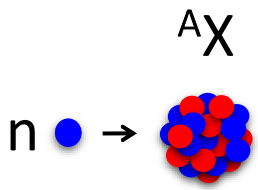
Core: 16 Clover high-purity germanium detectors for high-resolution ($\Delta E/E \approx 1/1000$) with active shielding

Auxiliary: LaBr detectors for lifetime measurements fast-timing technique

Future: A multitude of detectors for fragment identification

FIPPS
employable reactions (n_{th},γ) or (n_{th},f)

(n_{th},γ) thermal neutron capture



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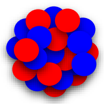
$^{A+1}X^*$



B_n (≈4-10 MeV)

Ground state

FIPPS
employable reactions (n_{th},γ) or (n_{th},f)

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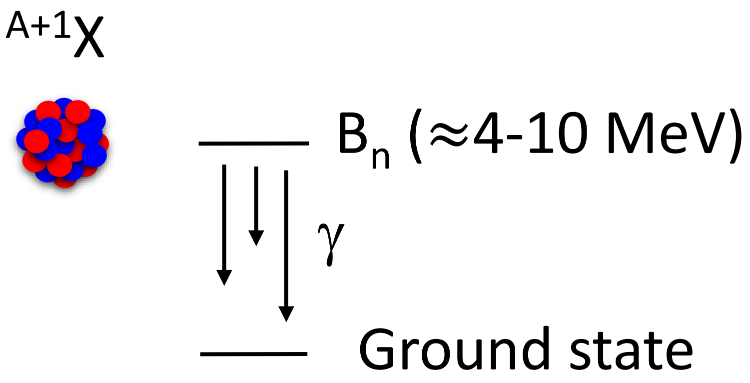

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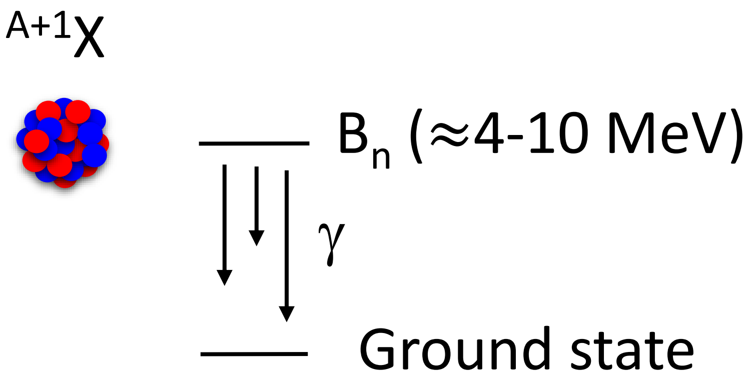

Targets are stable or long-lived radio-isotopes
➔ close to stability
➔ structure at low spin
(below n-separation energy)
➔ cross-sections (applications)

FIPPS

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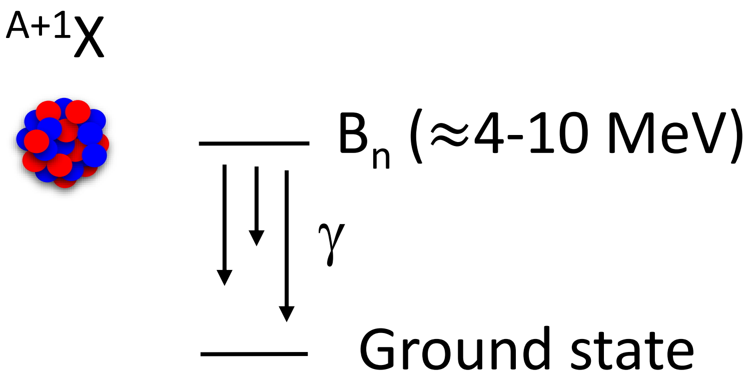

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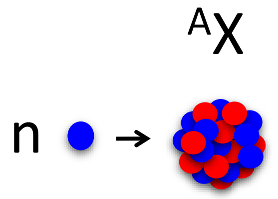
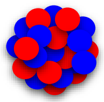
(n_{th},f) neutron-induced fission

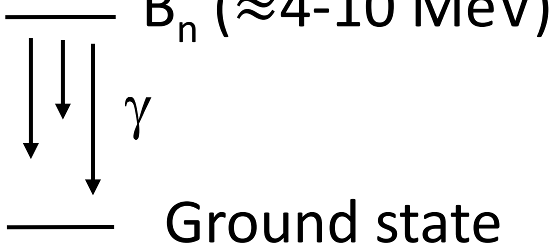


FIPPS
employable reactions (n_{th},γ) or (n_{th},f)

(n_{th},γ) thermal neutron capture

^{A+1}X





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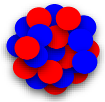

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employable reactions (n_{th},γ) or (n_{th},f)

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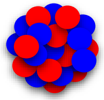
^{A+1}X



B_n ($\approx$4-10 MeV)

γ

Ground state

Targets are stable or long-lived radio-isotopes
➔ close to stability
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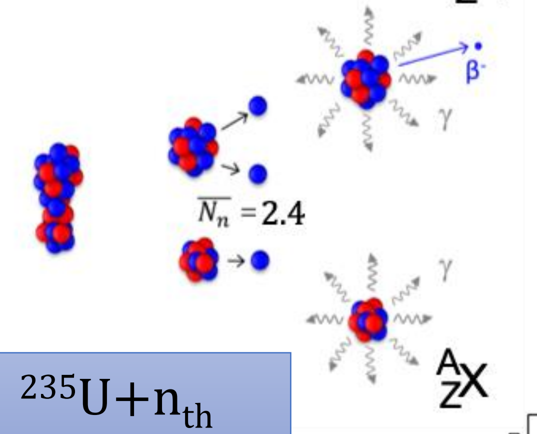
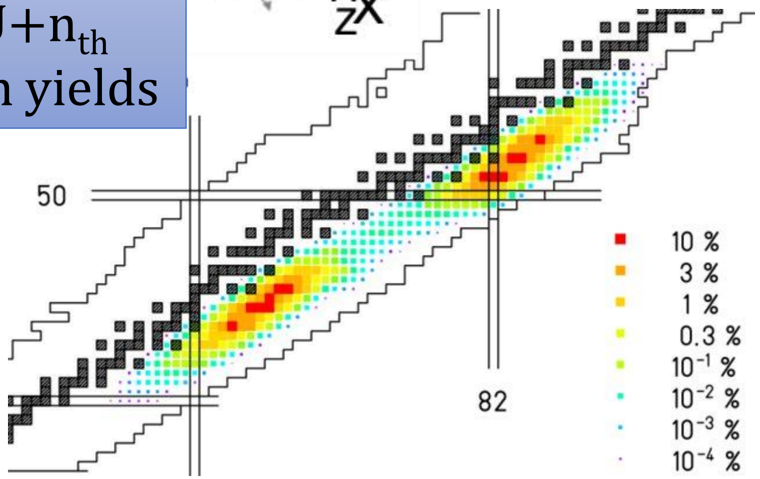


$^{235}U + n_{th}$
fission yields

Many 'exotic' isotopes



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FIPPS
employable reactions (n_{th},γ) or (n_{th},f)

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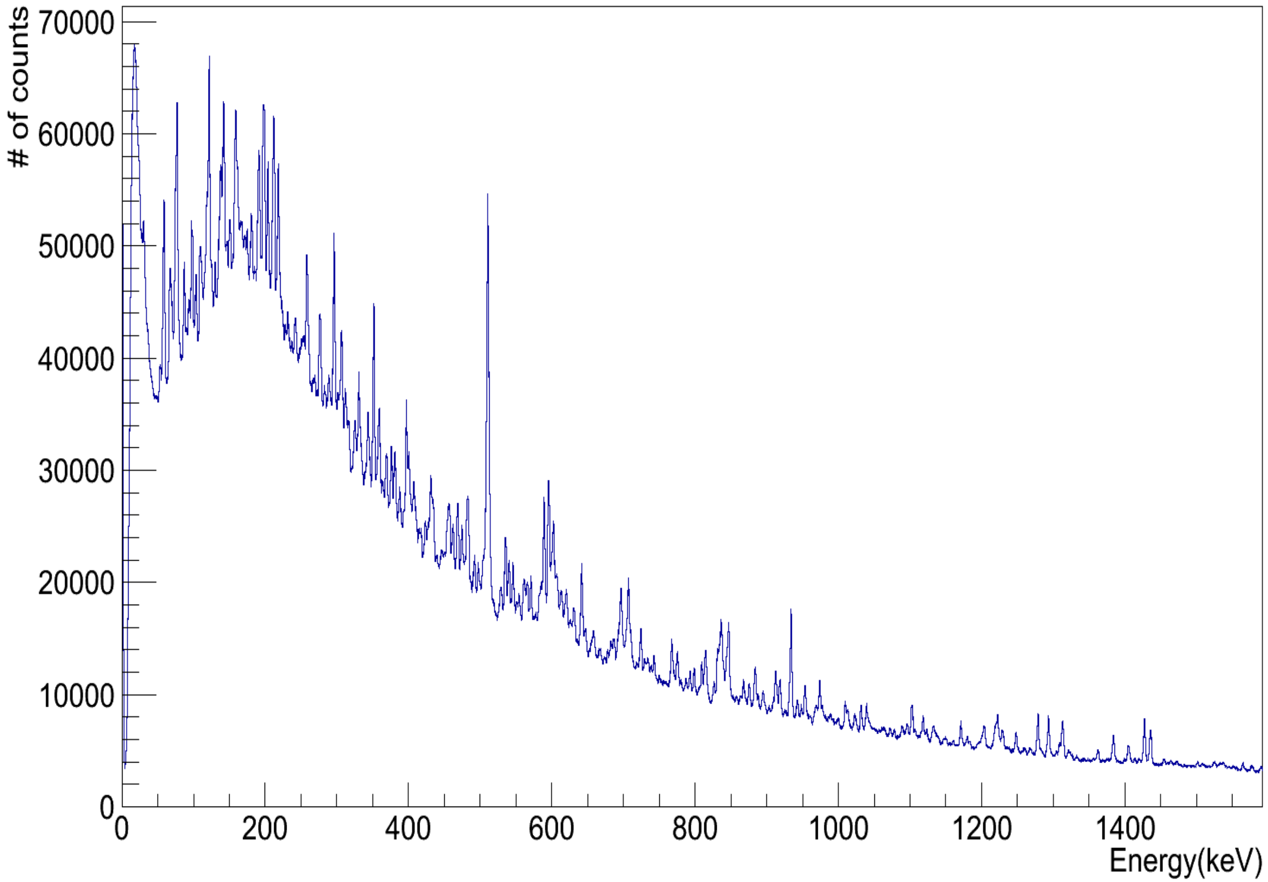
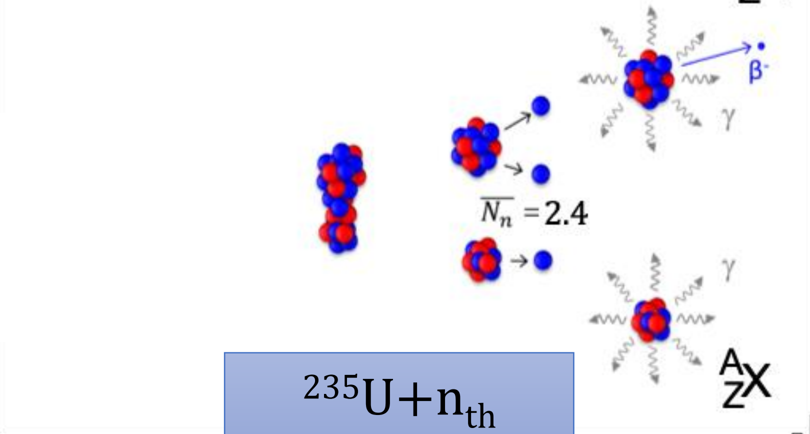
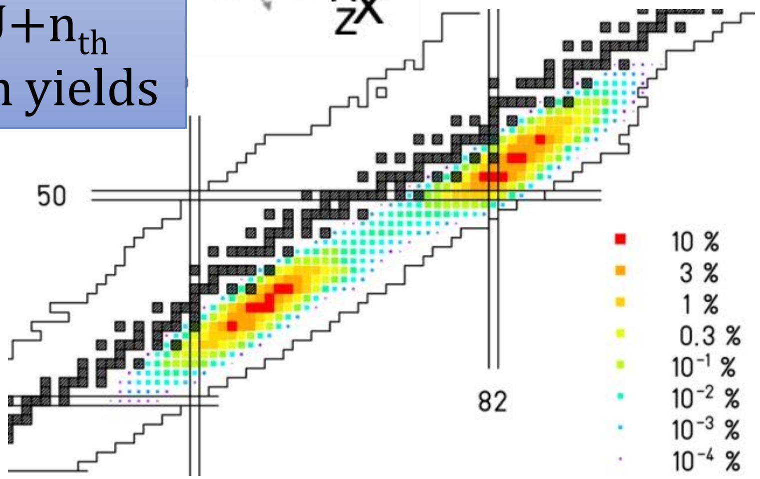
$^{235}U+n_{th}$ total (unfiltered) γ-ray spectrum



(n_{th},f) neutron-induced fission



$^{235}U+n_{th}$
fission yields



Many 'exotic' isotopes

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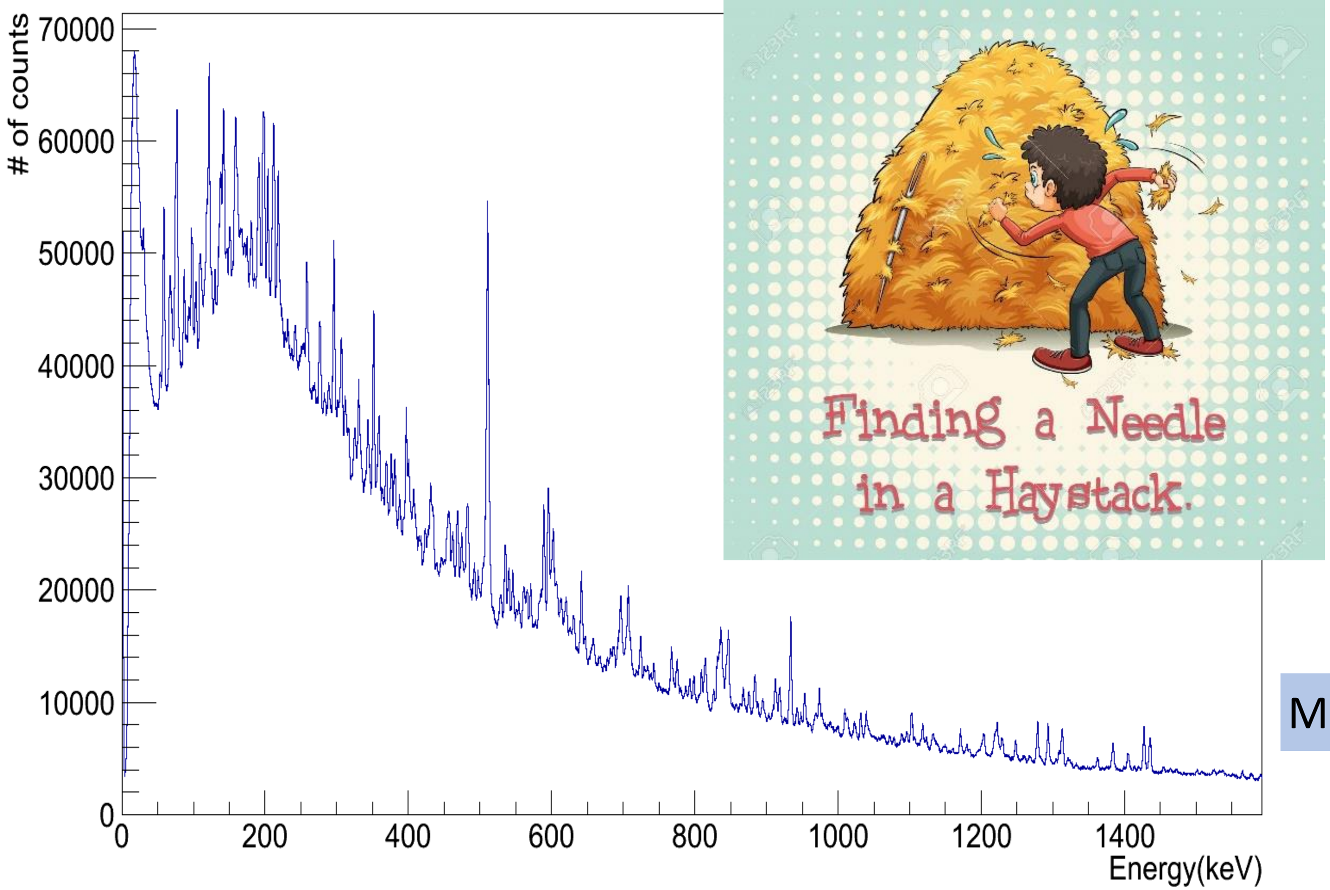
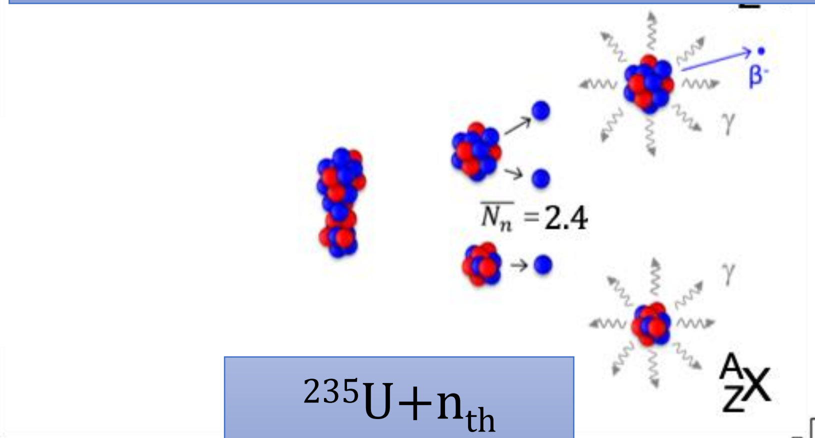
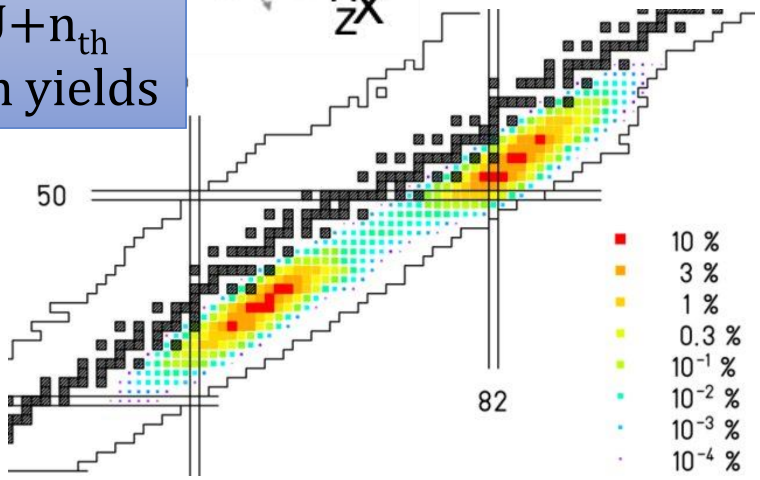


(n_{th},f) neutron-induced fission



$^{235}U+n_{th}$ fission yields



Many ‘exotic’ isotopes

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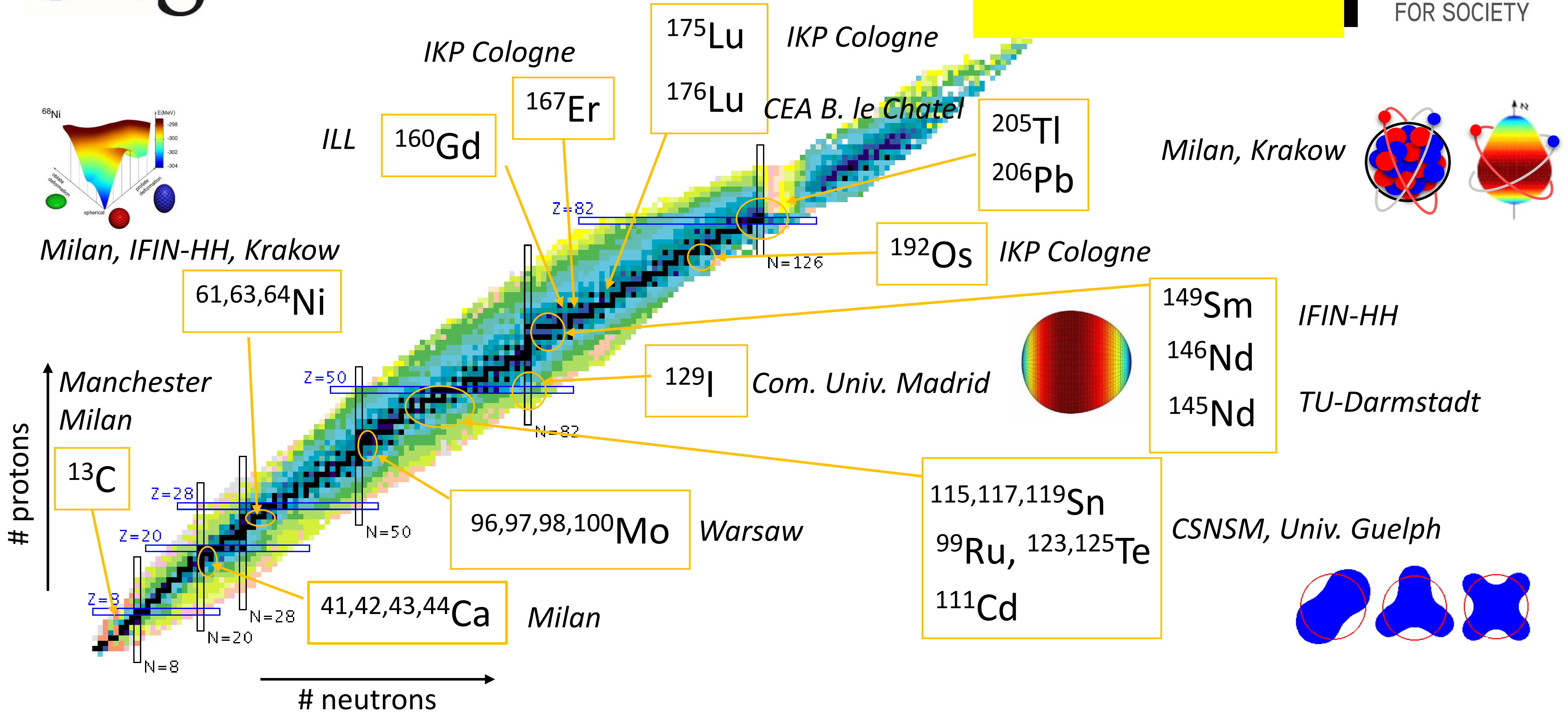
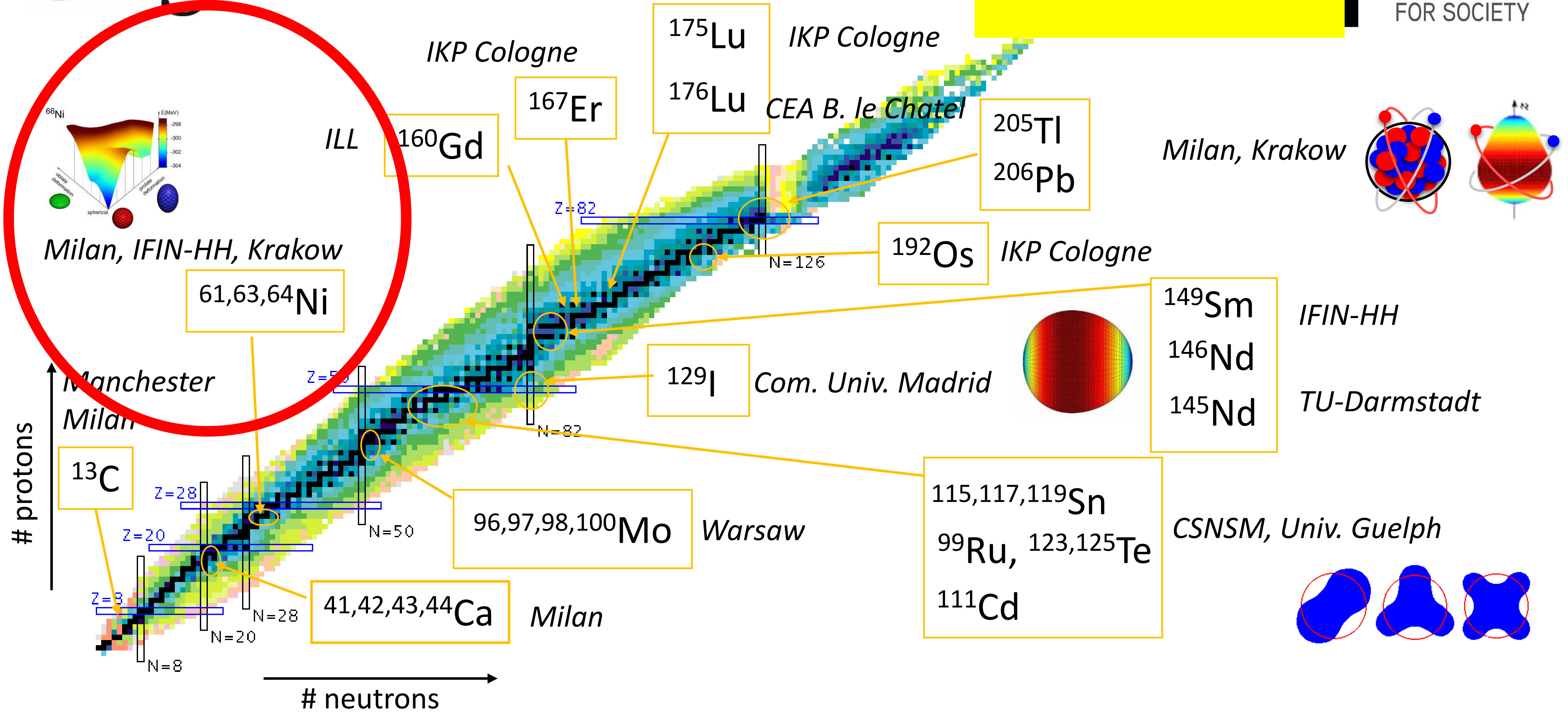
FIPPS
A workhorse...

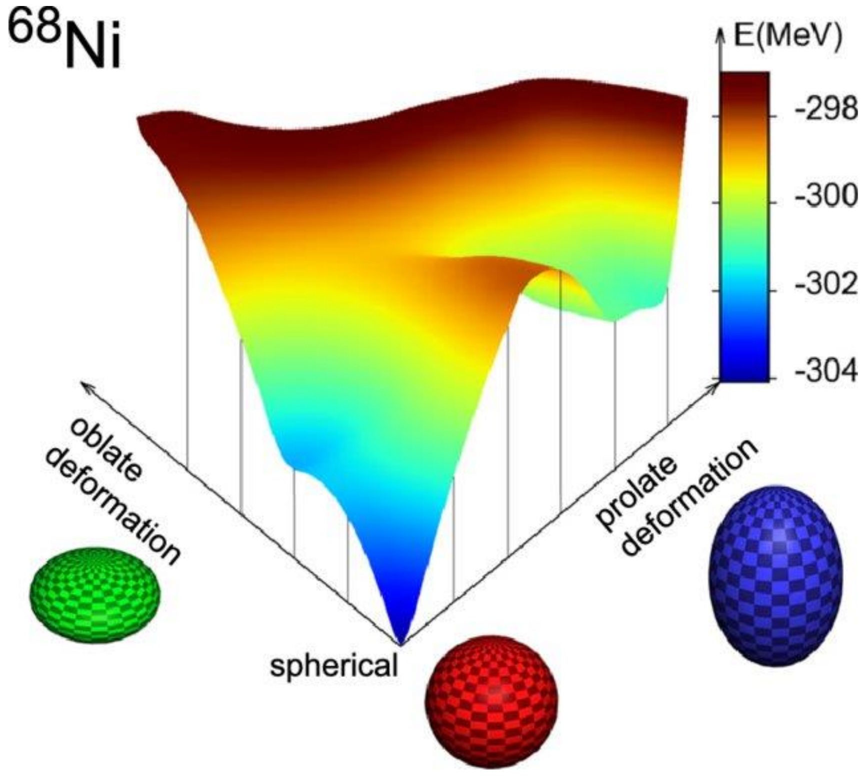
NEUTRONS FOR SOCIETY



FIPPS
A workhorse...



FIPPS
Type-II shell evolution driven shape co-existence



Large Scale Shell Model Calculations Including Tensor Force for excited states

Y. Tsunoda et al.,
Phys. Rev. C (2014) 031301(R)

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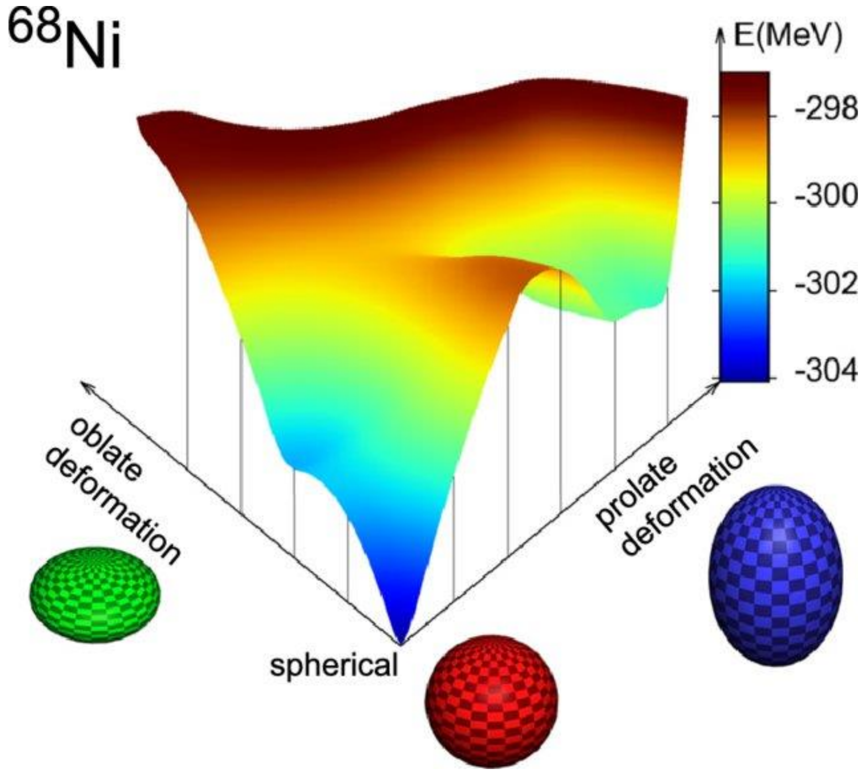
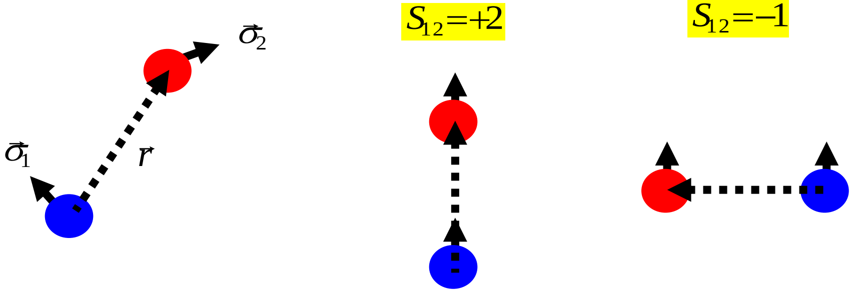
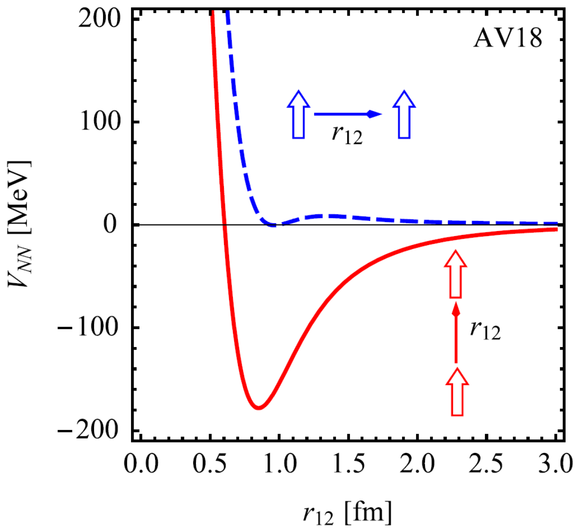
Type-II shell evolution driven shape co-existence



Large Scale Shell Model Calculations Including Tensor Force for excited states

$$S_{12}=3\frac{(\vec{\sigma}_1\cdot\vec{r})(\vec{\sigma}_2\cdot\vec{r})}{r^2}-(\vec{\sigma}_1\cdot\vec{\sigma}_2)$$





R. Roth et al., Prog. Nucl. Part. Phys. 65, 50 (2010)

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Type-II shell evolution driven shape co-existence

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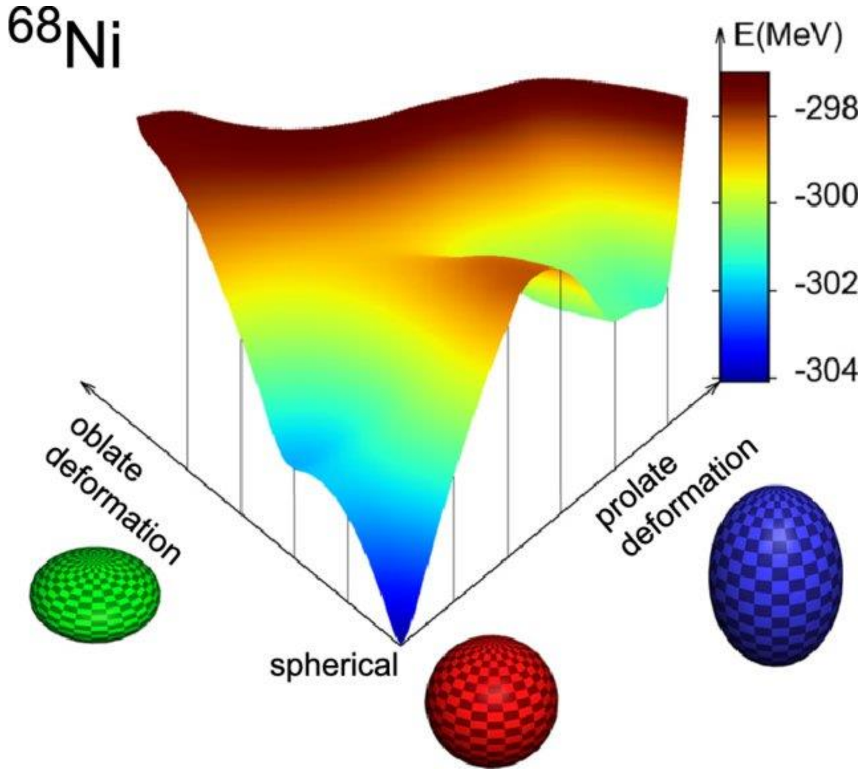
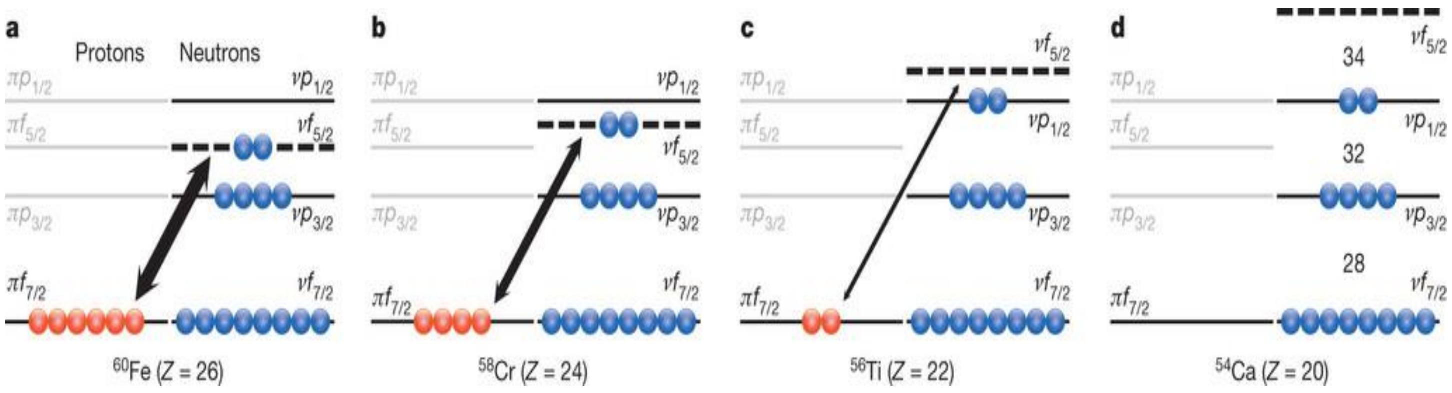


Large Scale Shell Model Calculations Including Tensor Force for excited states



D. Steppenbeck et al., *Nature 502 (2013) 207*

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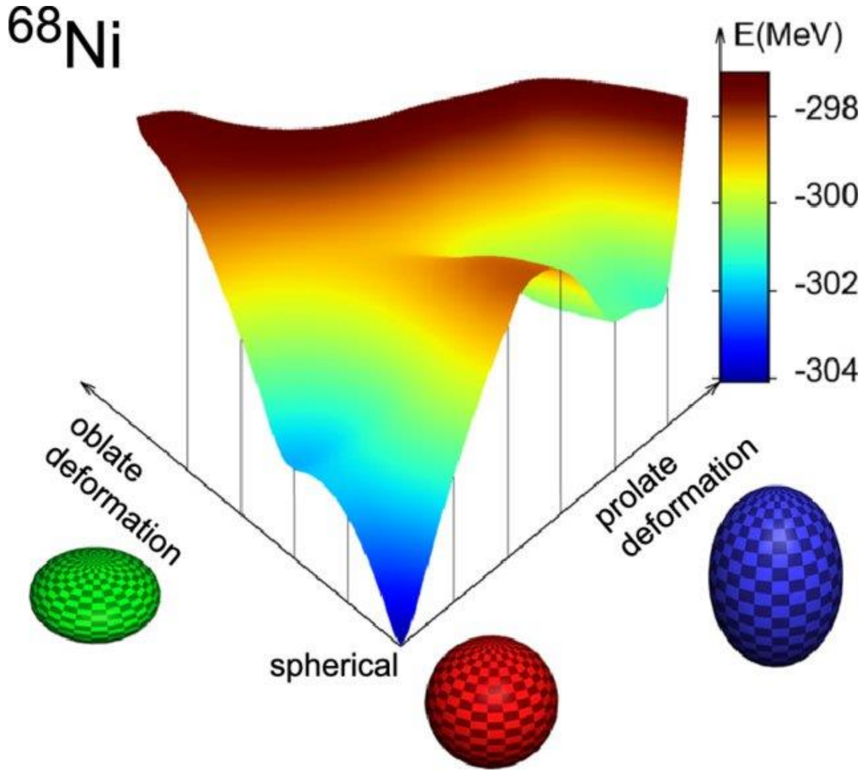
Type-II shell evolution driven shape co-existence



Large Scale Shell Model Calculations
Including Tensor Force for excited states

⇒ Occupation number dependent shell structure

⇒ Eventually high degeneracy near new Fermi level

⇒Jahn-Teller effect causes spontaneous symmetry breaking

Y. Tsunoda et al.,
Phys. Rev. C (2014) 031301(R)

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Type-II shell evolution driven shape co-existence

^{63}Ni(n_{th},γ) thermal neutron capture
as part of a
campaign of multiple experiments

^{63}Ni is radioactive:
$T_{1/2}$ = 102.2 years
2 GBq sample
20 days beam time

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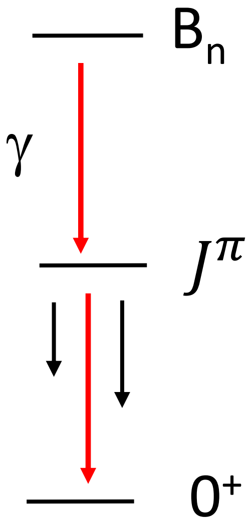
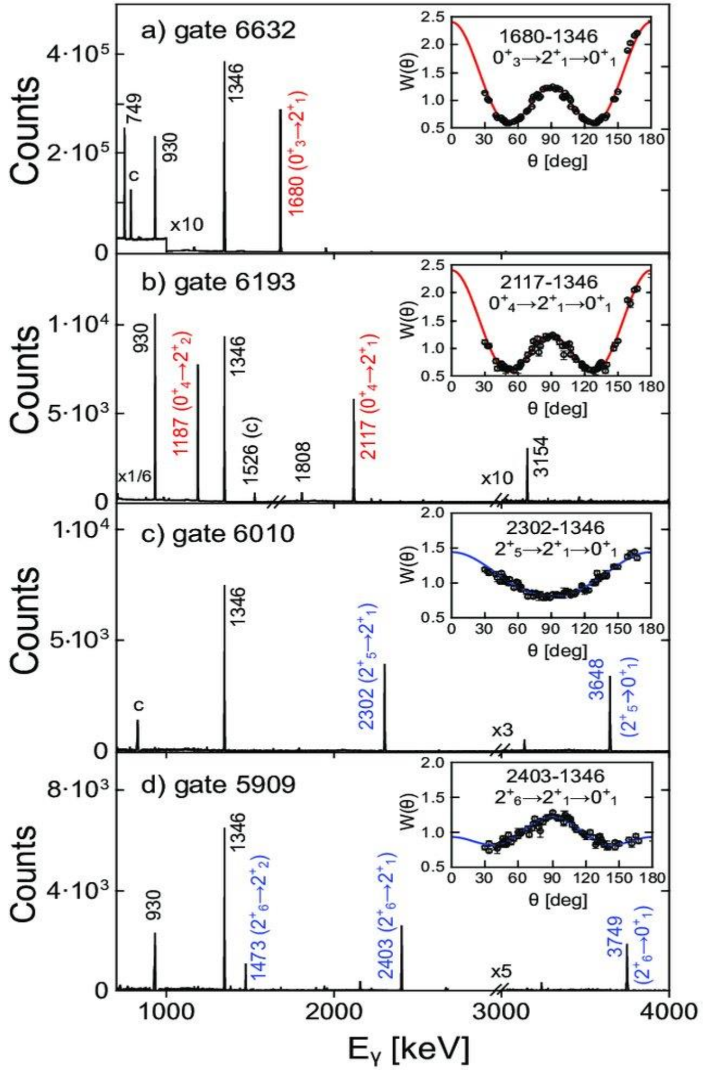
Type-II shell evolution driven shape co-existence

^{63}Ni(n_{th},γ) thermal neutron capture as part of a campaign of multiple experiments





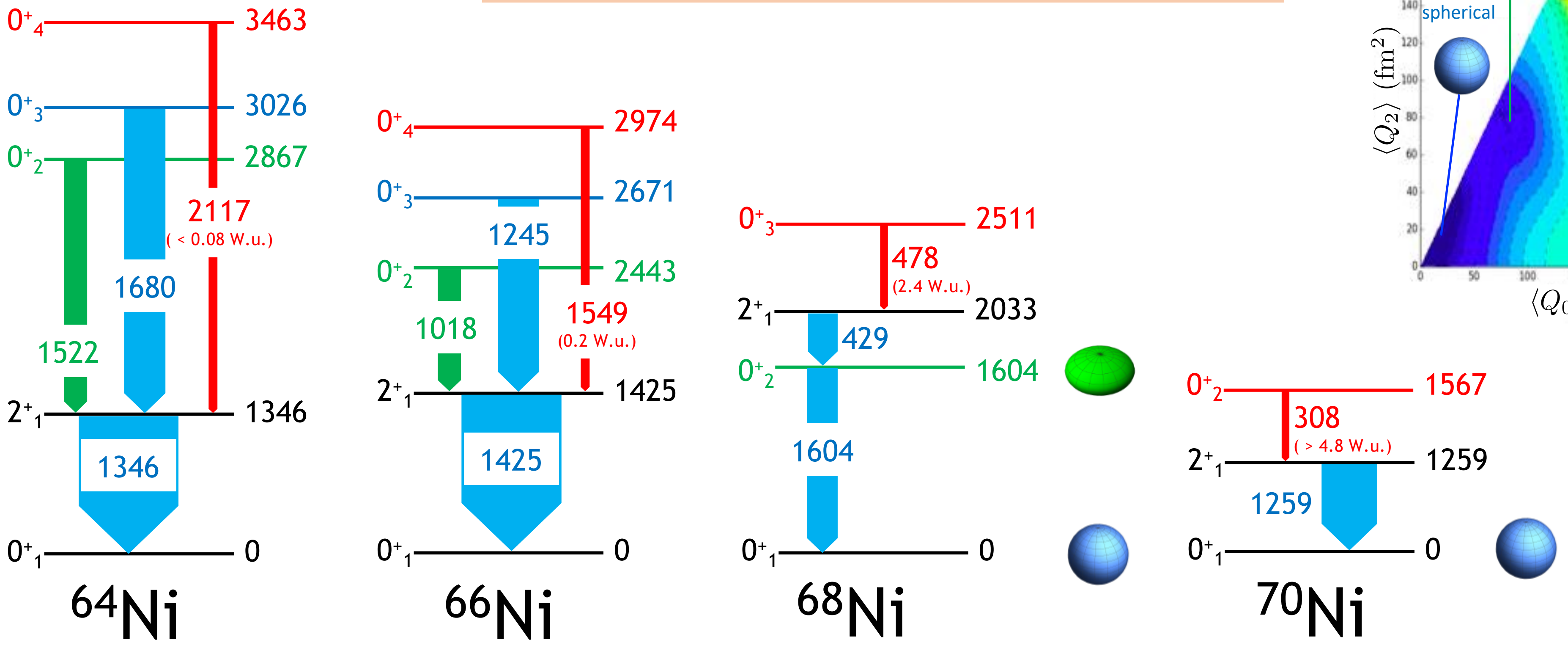
^{63}Ni is radioactive:
$T_{1/2}$ = 102.2 years
2 GBq sample
20 days beam time

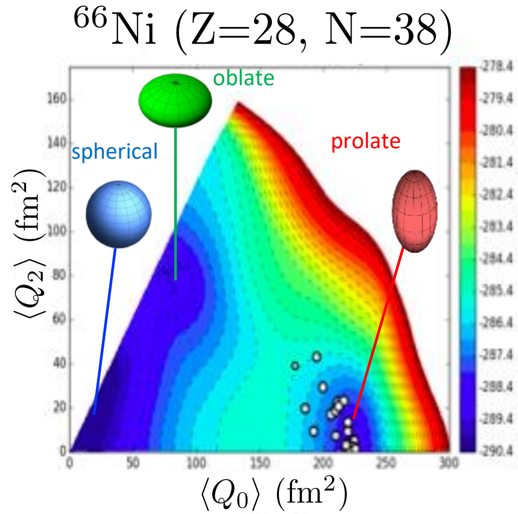
High granularity of FIPPS
⇒Angular correlations
⇒ Firm assignment of spins, relative intensities, & fast-timing

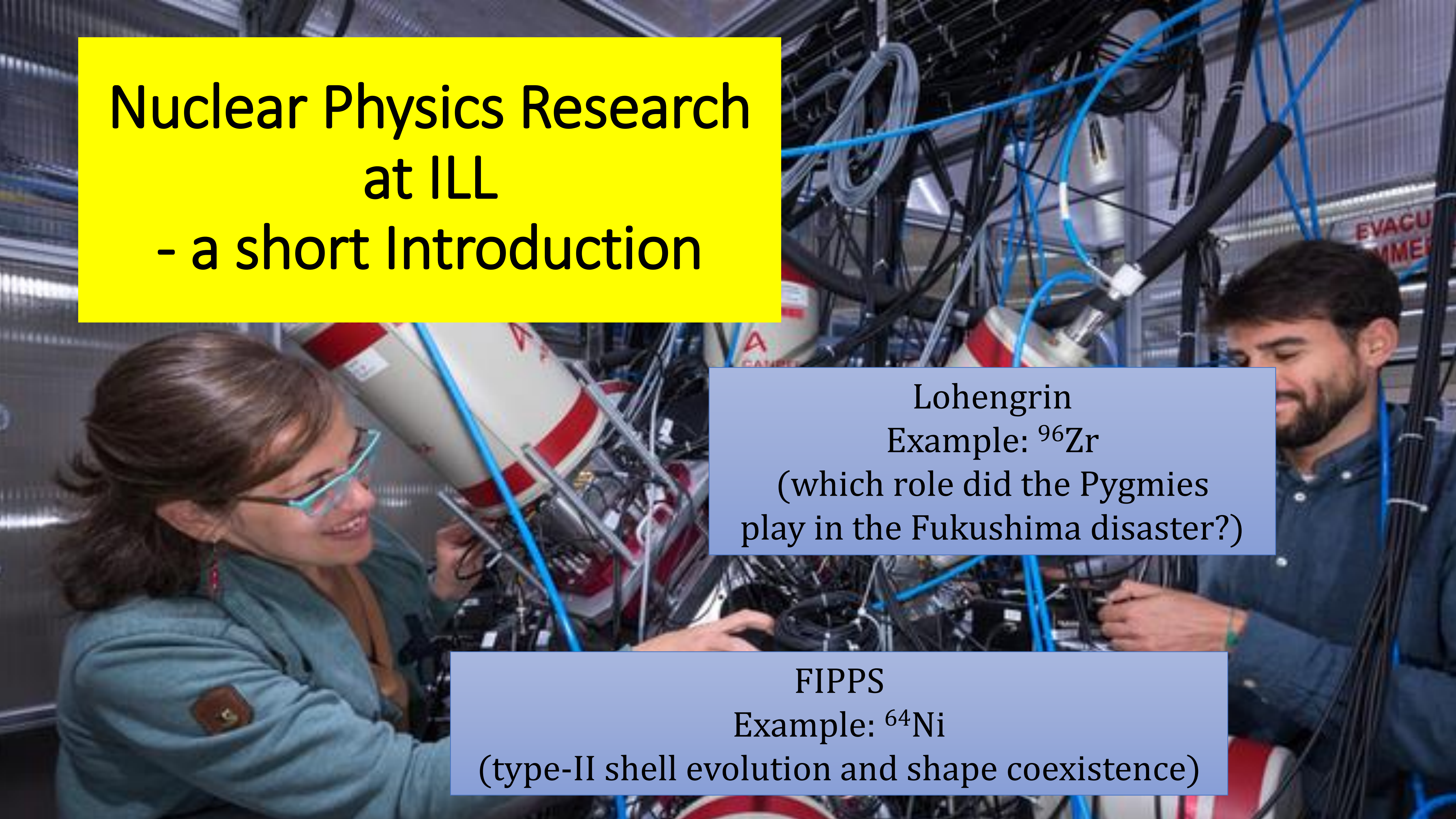
FIPPS

Type-II shell evolution driven shape co-existence

- N. Mărginean *et al.*, PRL **125** (2020) 102502
- S. Leoni *et al.*, PRL **118** (2017) 162502
- B. Crider *et al.*, PLB **763** (2016) 108







Nuclear Physics Research at ILL - a short Introduction

Lohengrin
Example: ^{96}Zr
(which role did the Pygmies play in the Fukushima disaster?)

FIPPS
Example: ^{64}Ni
(type-II shell evolution and shape coexistence)