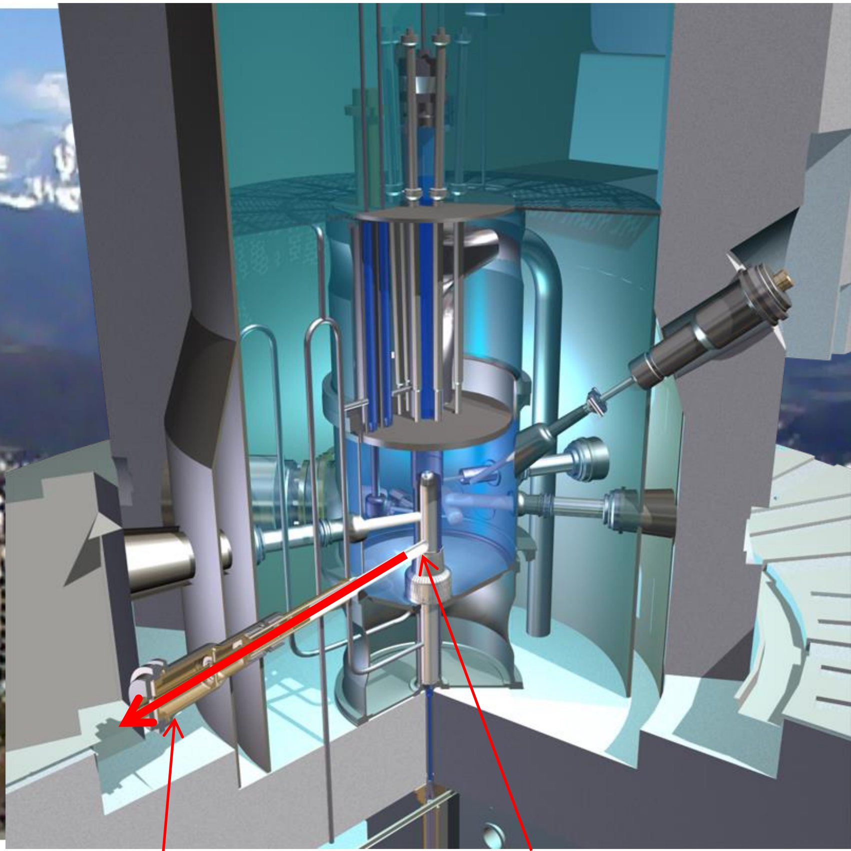
Nuclear physics study using fast and slow neutrons

중성자 및 하전 입자 생산, 활용 연구 동향과 전망

KIM Yung Hee (IBS CENS)

24/Nov/2022

Part 1: Thermal neutron experiments (at ILL)

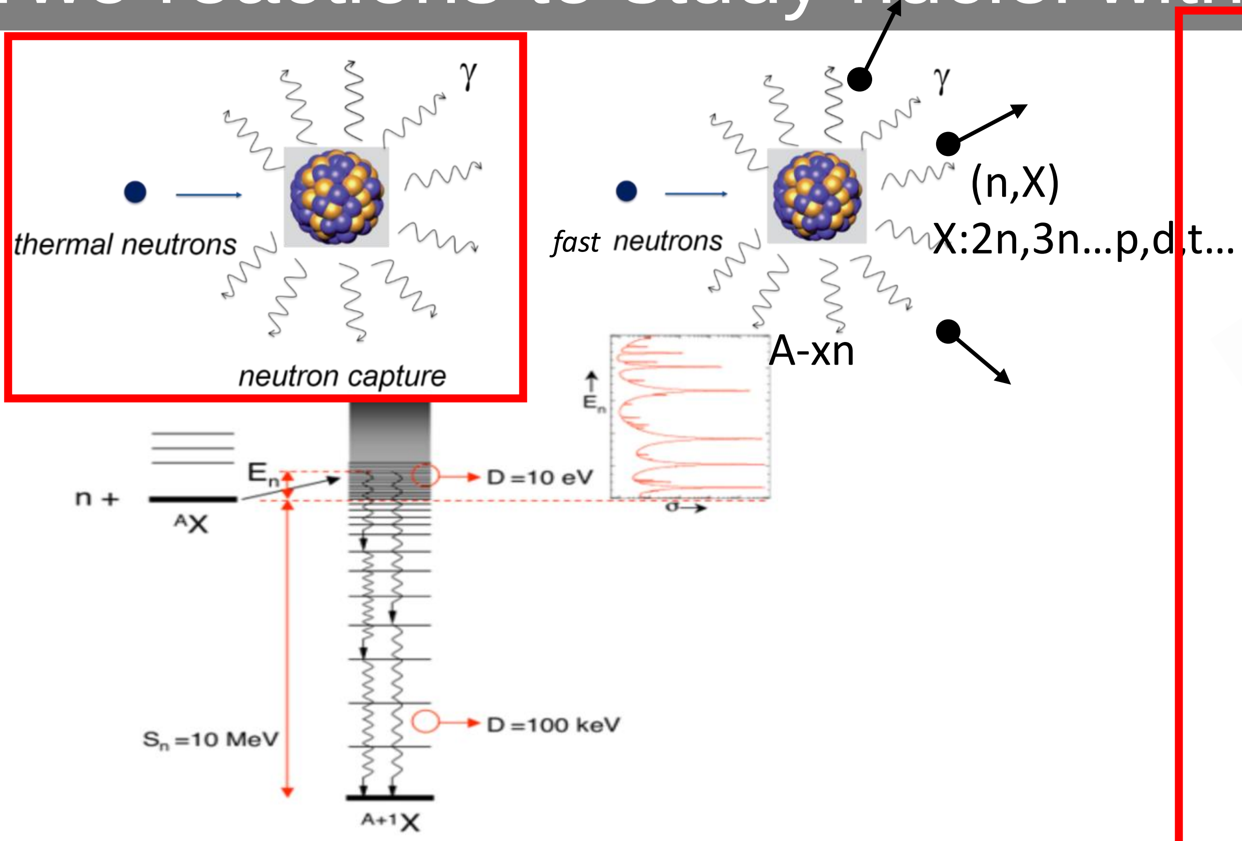


- Founded in 1967 to enhance Fr-Ge-UK collaboration
- 58 MW research heavy water reactor
- Strongest neutron source (moderated) in the world
- Operation time: ~100-200 days/ year

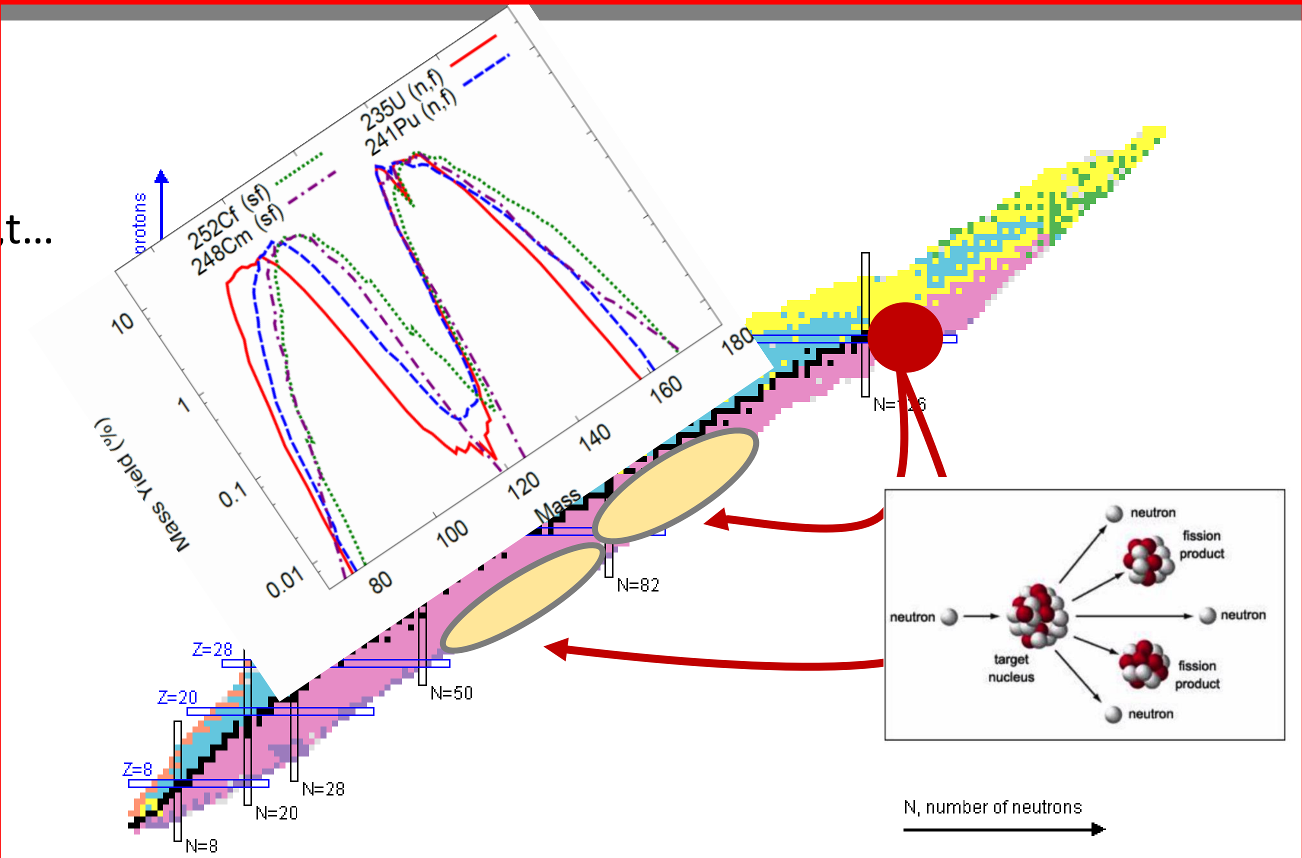
Neutron beam
$<2 \cdot 10^{10}$ n.cm^{-2}s^{-1}

Neutron irradiation
$<5 \cdot 10^{14}$ n.cm^{-2}s^{-1}

Two reactions to study nuclei with neutrons!



- Nuclei close to stability
- Nuclear excited states with low spin
- Cross-sections (applications medical science etc..)

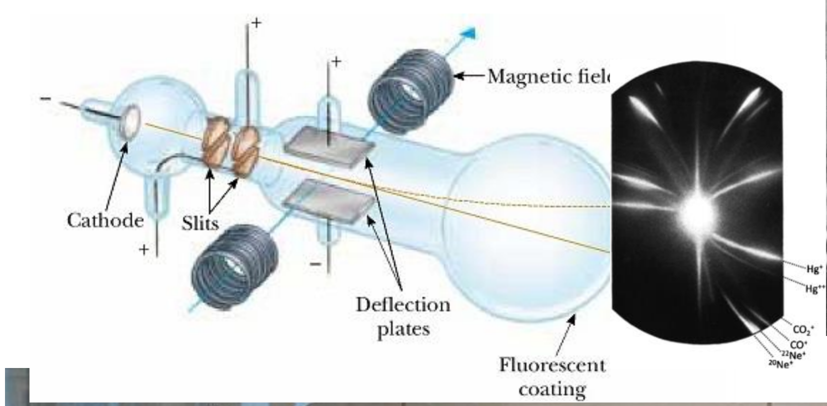


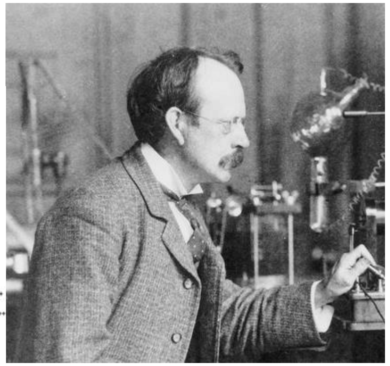
- Neutron rich nuclei far from stability using actinde targets
- Structure at relatively high spin states
- Fission yields and dynamics

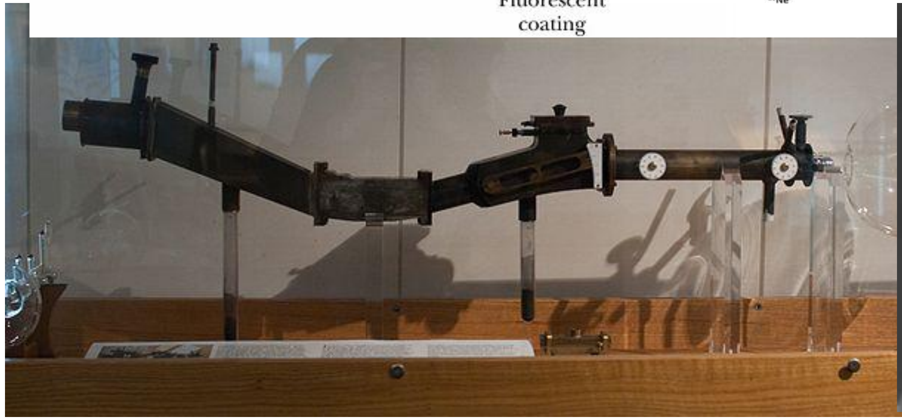
LOHENGRIN spectrometer

J.J. Thomson & F. Astons

The first isotope separation ($^{20/22}Ne$)







Lohengrin: a giant decent

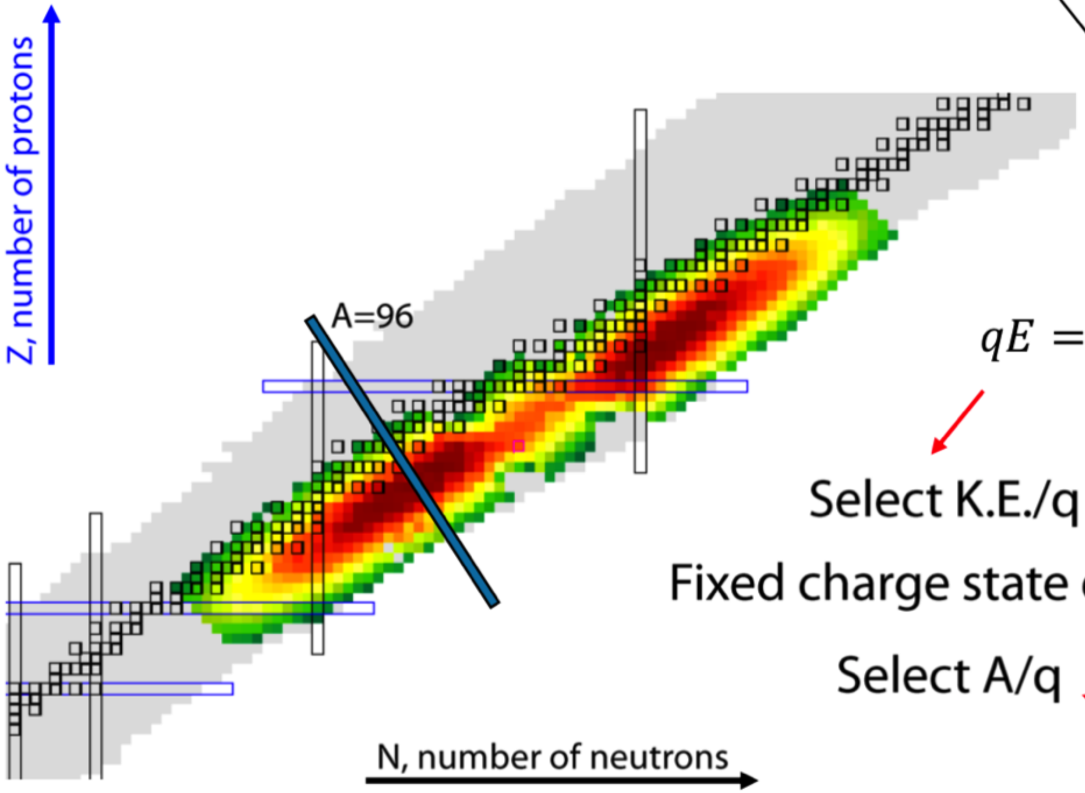
Lohengrin spectrometer

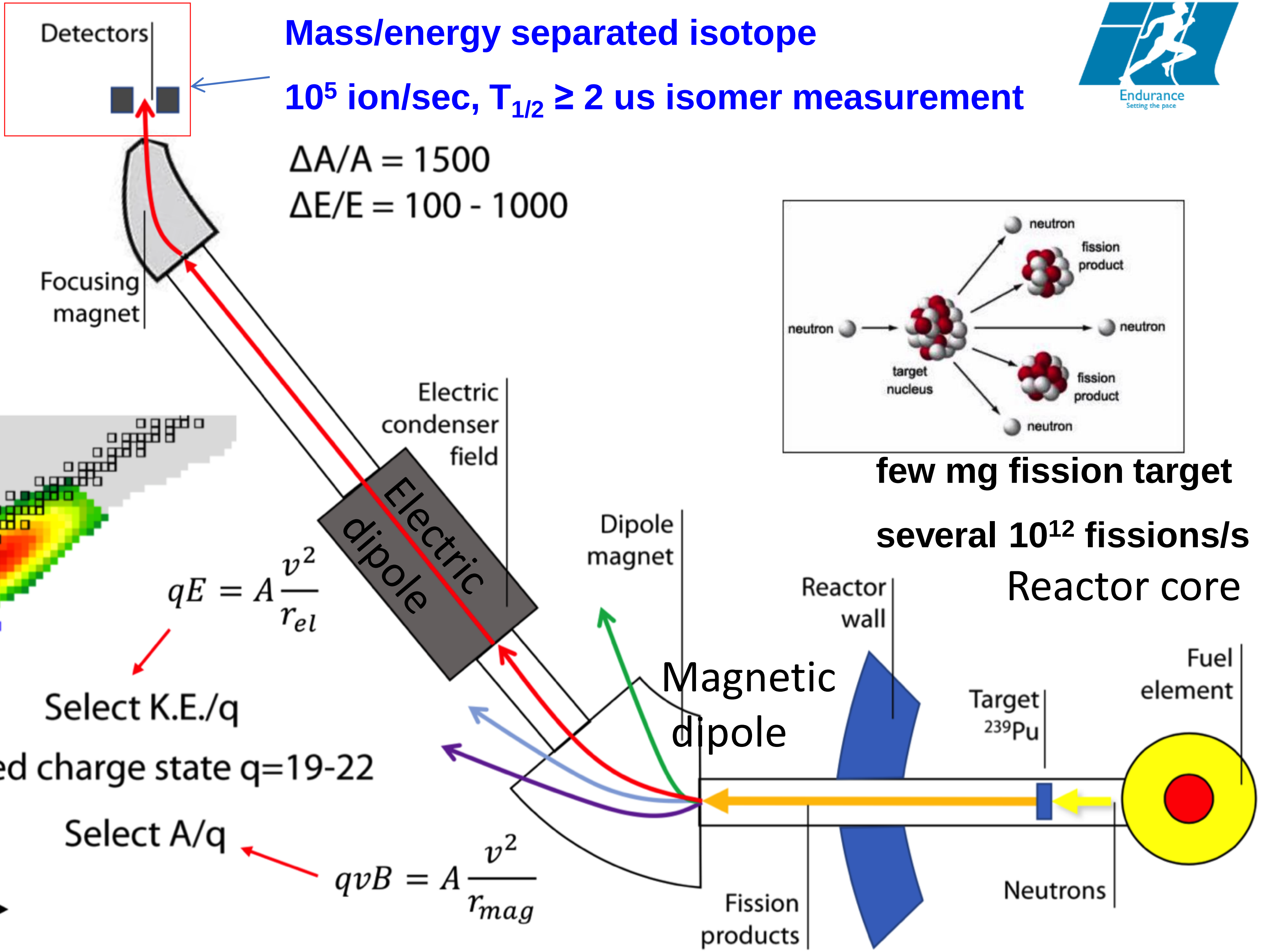
Mass/energy separated isotope

10^5 ion/sec, $T_{1/2} \geq 2$ us isomer measurement

$\Delta A/A = 1500$

$\Delta E/E = 100 - 1000$





few mg fission target

several 10^{12} fissions/s

$$qE = A\frac{v^2}{r_{el}}$$

Select K.E./q

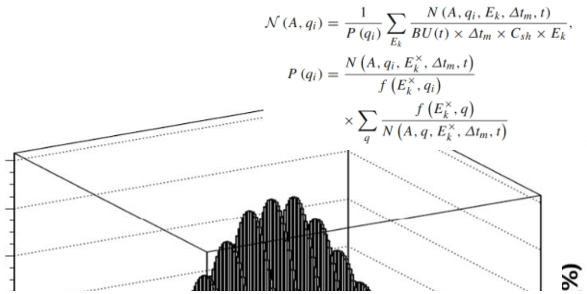
Fixed charge state q=19-22

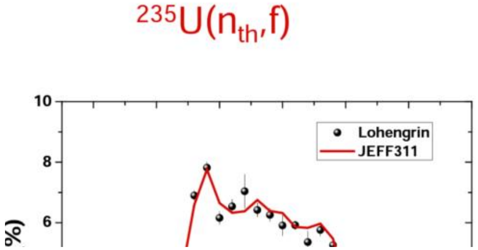
Select A/q

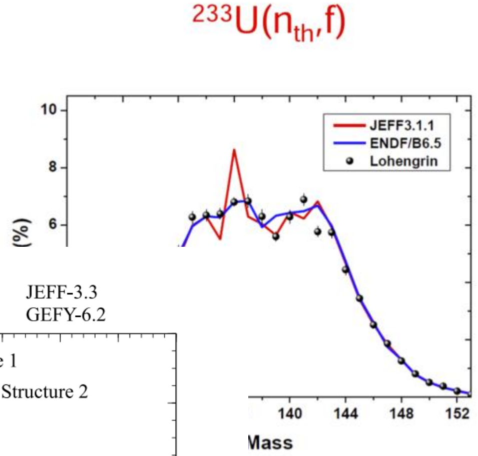
$$qvB = A\frac{v^2}{r_{mag}}$$

Mass distribution of fission fragments

Measurements with :
an ionization chamber
(mass yields)







ion

- Heav
recer
- High
meas

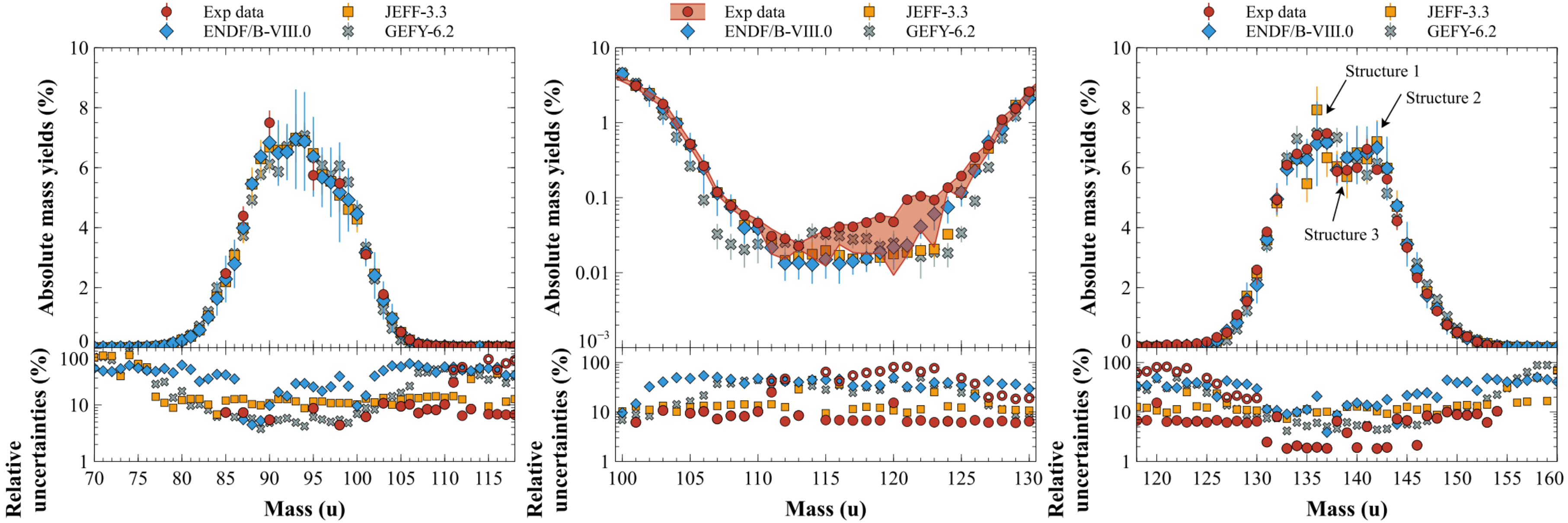
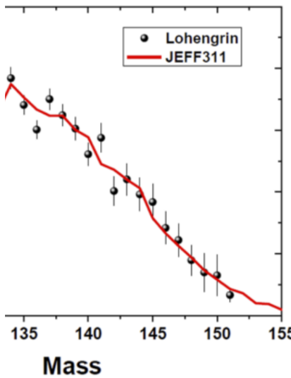


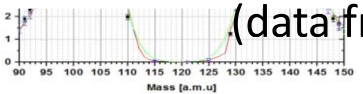
Fig. 13 Absolute fission product mass yields for $^{233}U(n_{th}, f)$ (red circle points) in comparison with ENDF/B-VIII.0 (blue diamond points), JEFF-3.3 (yellow square points) and GEFY-6.2 (grey cross points) libraries. ENDF/B-VIII.0 seems slightly in better agreement with our experimental data. Uncertainties of each data set are displayed in the lower part. The precision of LOHENGRIN data is of the order of 2% in the heavy mass peak and around 10% in the wings. In the symmetry region, the positive (red circle points) and negative (empty red circle) uncertainties are displayed. Lines are only to guide the eye

ıD Thesis (2013)
ɔnf. Proc. Of ANIMMA (2011)



A. Chebboubi et al., Eur. Phys. J. A. (2021) 57:335
(data from 2009~2014)

D.A. Brown et al., Nucl



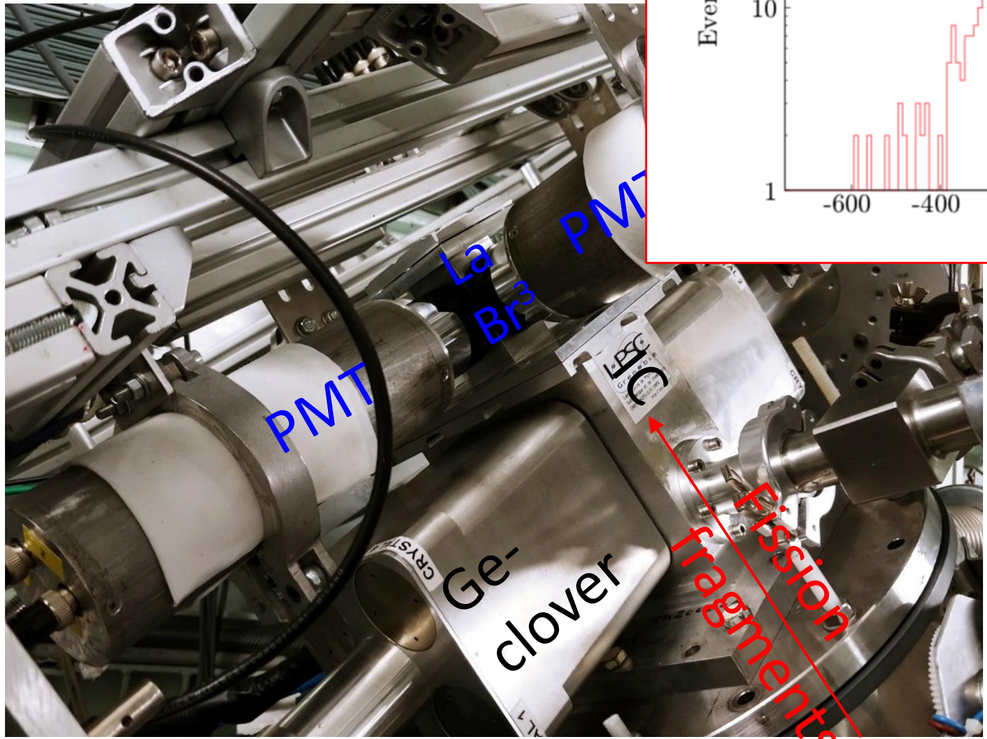
...n, PhD Thesis (2013)
F. Martin et al., IEEE Conf. Proc. Of ANIMMA (2011)

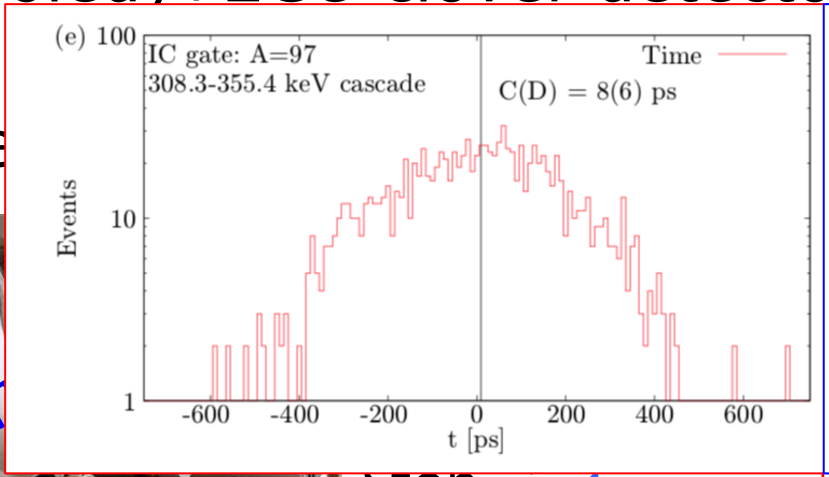
기초과학연구원 Institute for Basic Science

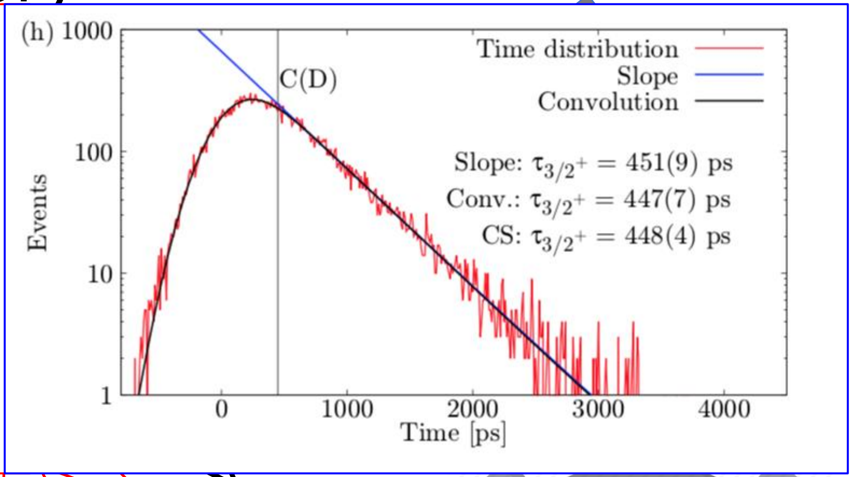
Recent nuclear structure study with LOHENGRIN

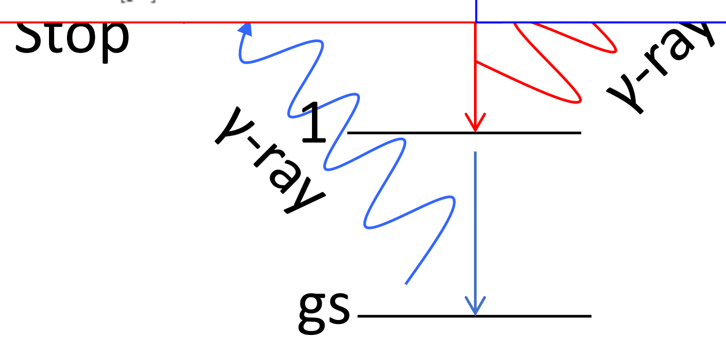
- γ/Conversion electron spectroscopy
  (Si-detector (LN2 cooled)+2Ge-clover detector)

- ps life-time measure







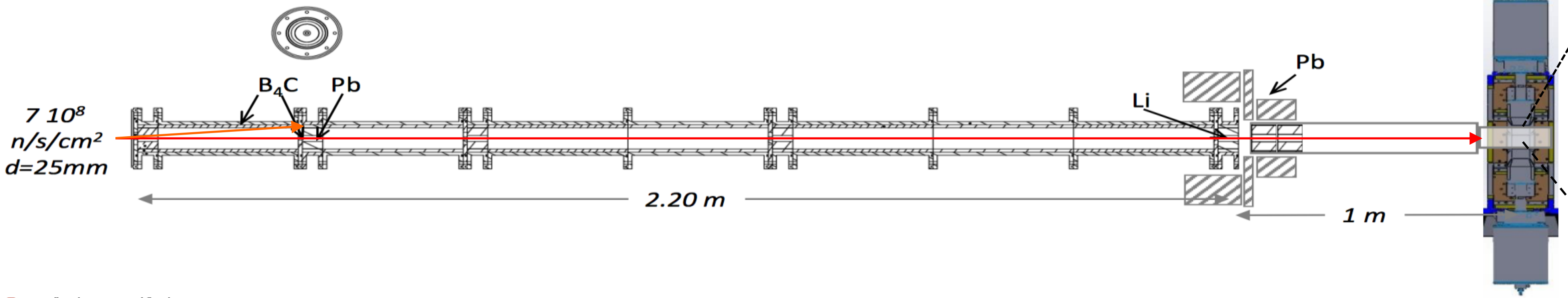


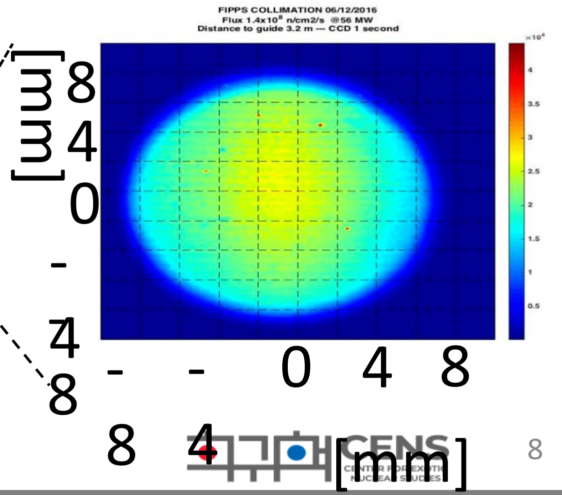
A. Esmaylzade et al., Phys. Rev. C (2019)

Nuclear state lifetime
-> Reduced transition probablity B(E2)
->Spin of state, shape of the nuclei (using theoretical support)
->Confirm hypothesis of the 5/2+ state is deformed

FIPPS HPGe spectrometer

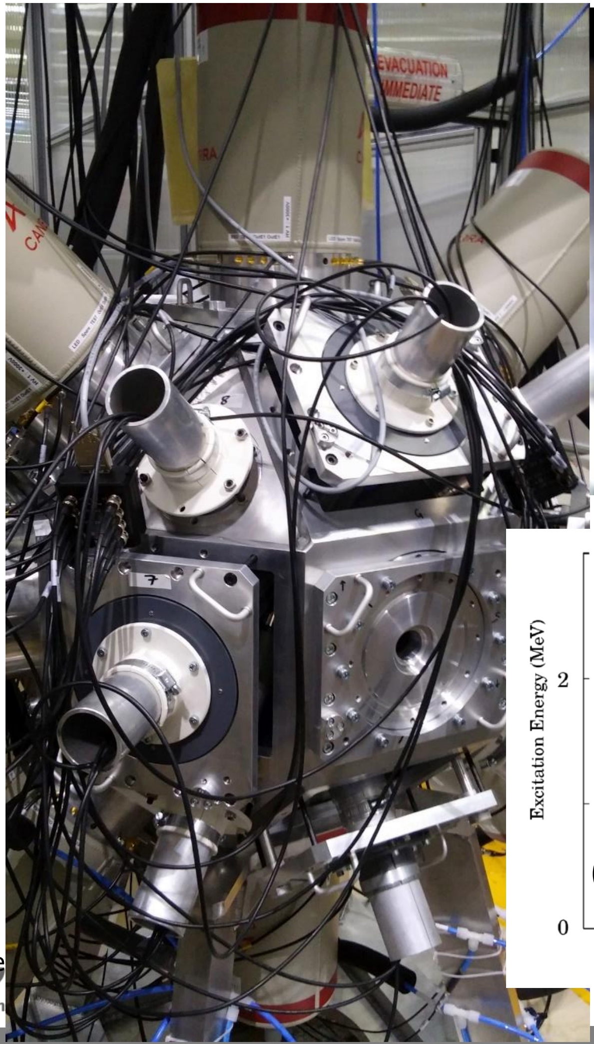
- High intensity pencil neutron beam using series of B, Li collimators (10^8 n/cm^2/s, d=1.5cm)
- 8 HPGe clover detectors+Anti-Compton Shields
  + Digital DAQ (<10 kHz/crystal)

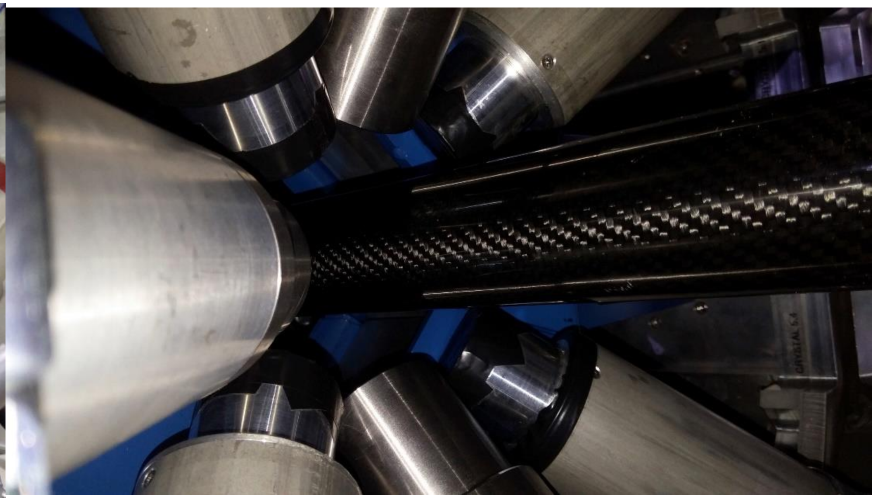


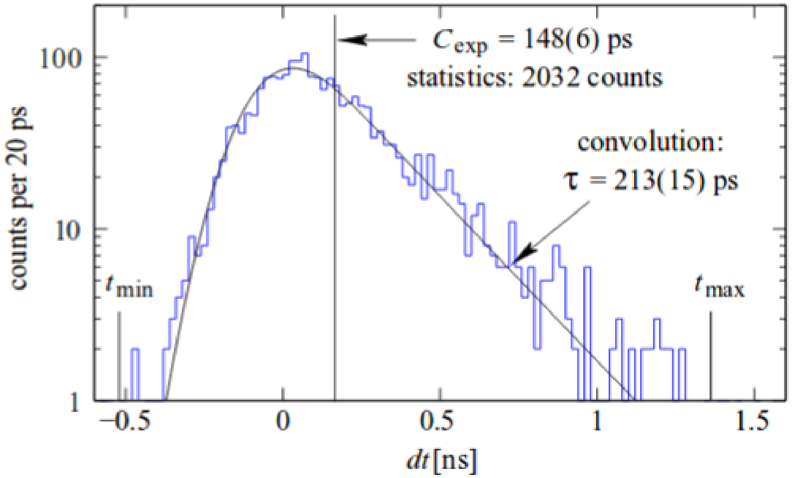


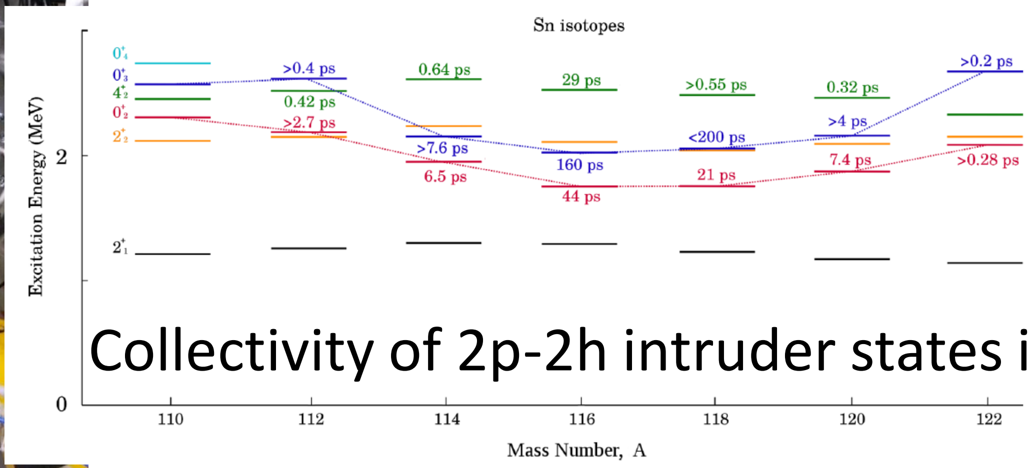
Recent neutron capture γ-ray spectroscopy experiment

- (n,γ) reaction 16 LaBr3 fast timing experimental campaign

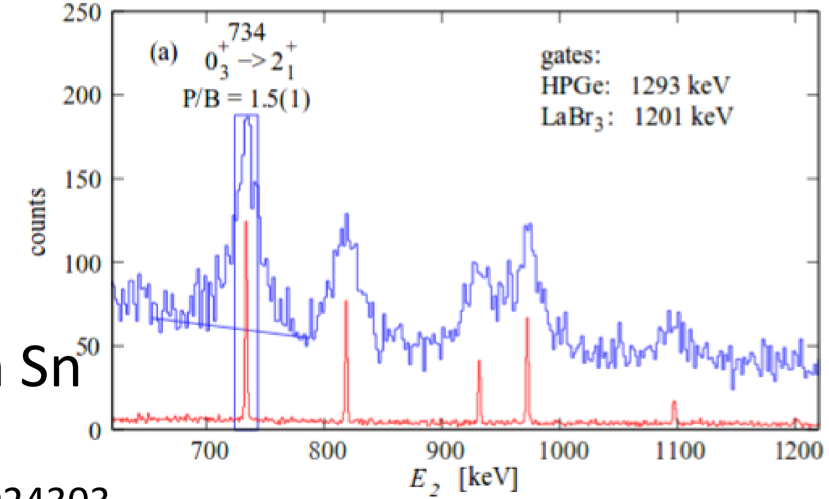








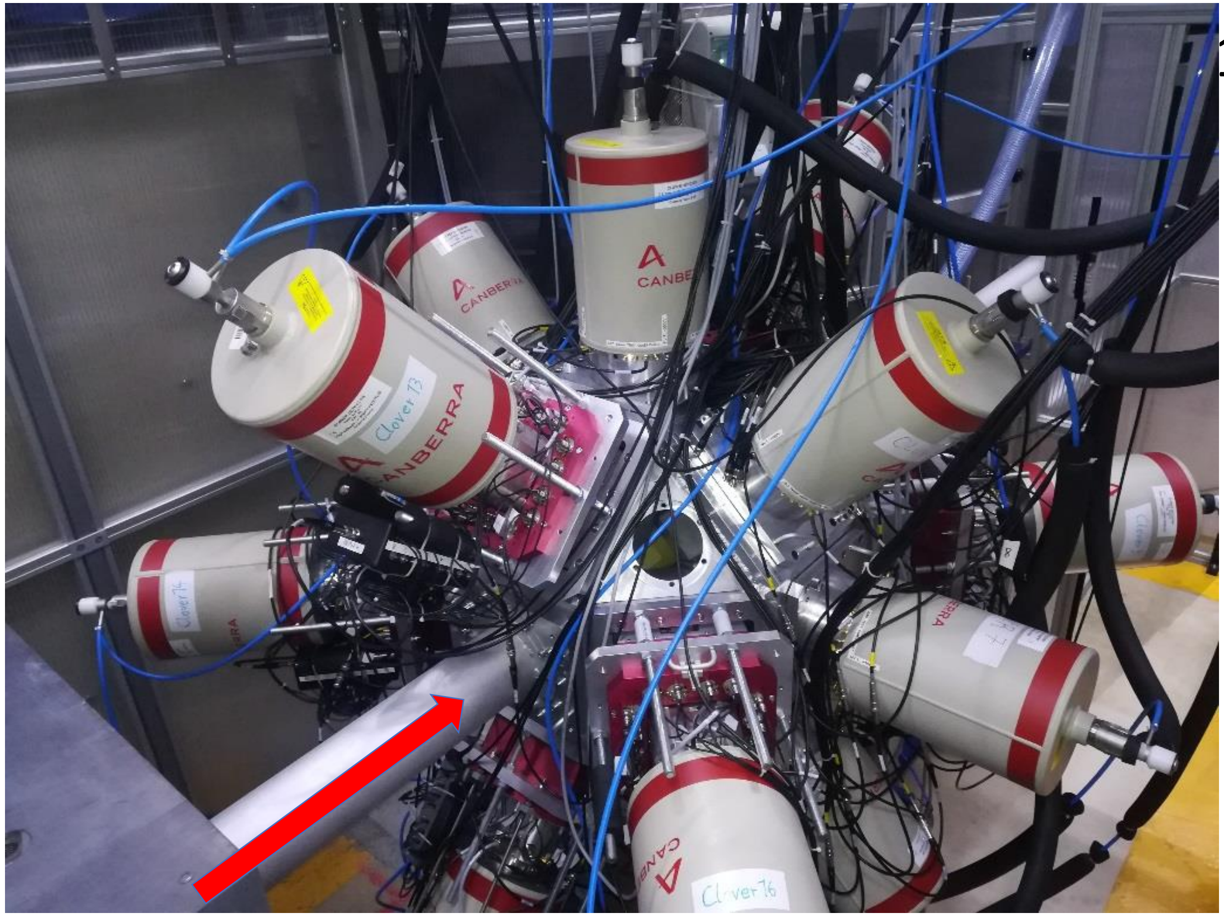
Collectivity of 2p-2h intruder states in Sn



C. M. Petrache..Y. H. Kim et al., Phys. Rev. C. 99 (2019) 024303

Recent neutron capture γ-ray spectroscopy experiment

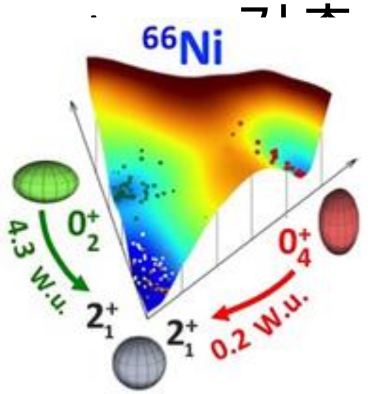
- (n,γ) 실험 캠페인 + 8 Ge clover (IFIN-HH)

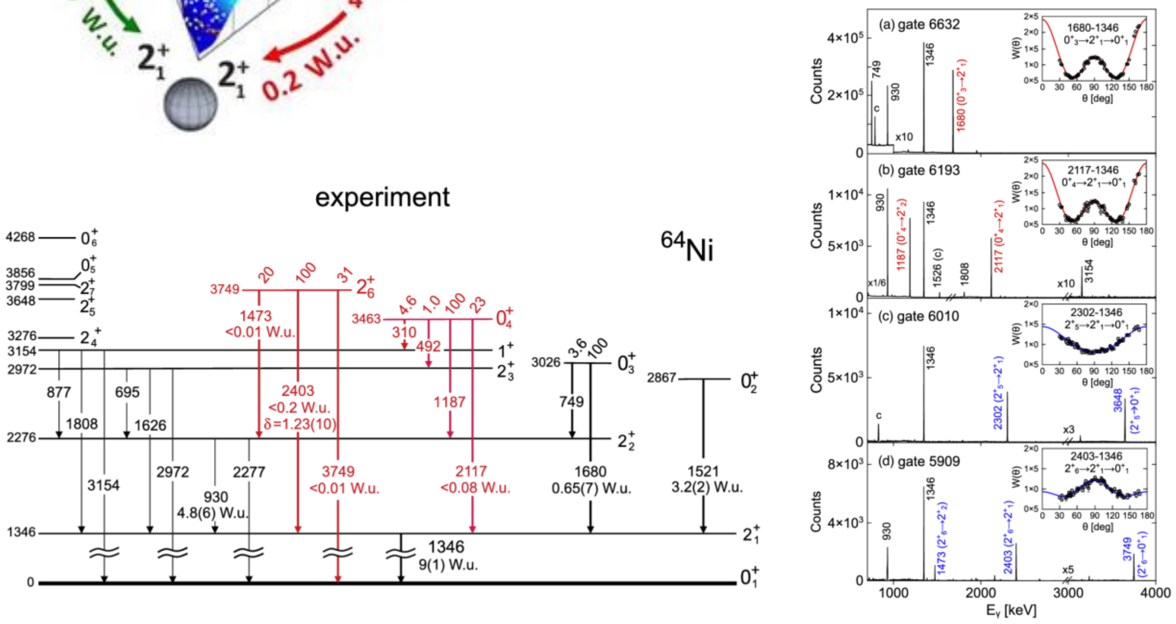


16 G 기 array와 열 중성자 빔 사용;

% at 1.4 MeV

incidence 검출 효율





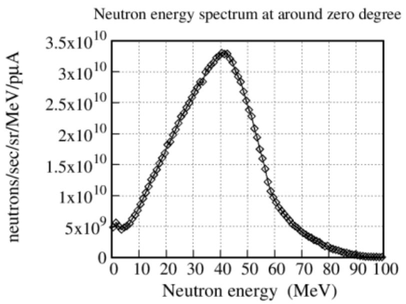
N. Mărginean... Y. H. Kim... *et al.* Phys. Rev. Lett. **125, 102502 (2020)**

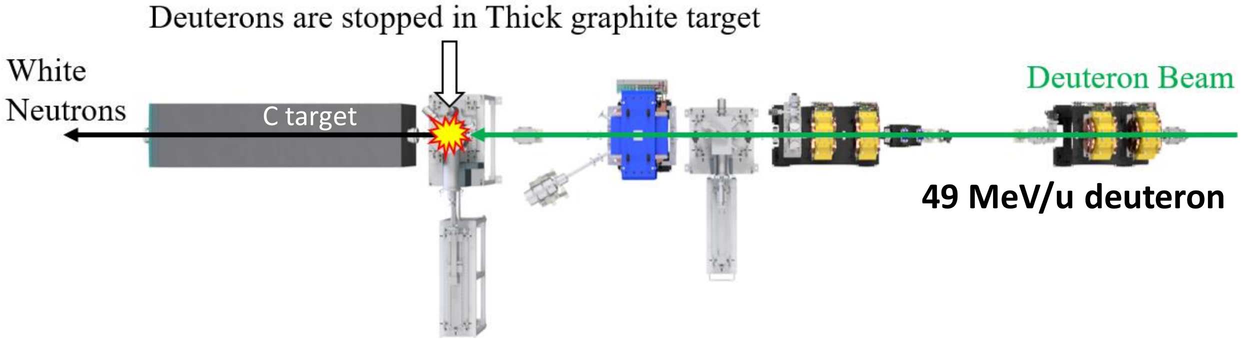
^{66}Ni: *S. Leoni et al., PRL118 (2017) 162502*
MCSM: T. Otsuka et al., JPG43 (2016) 024009

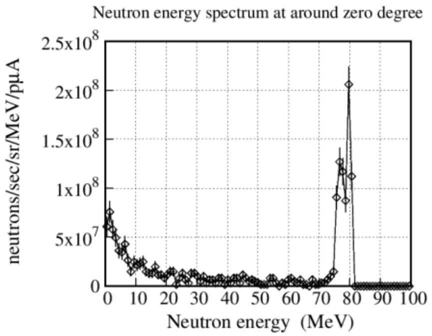
^{65}Ni

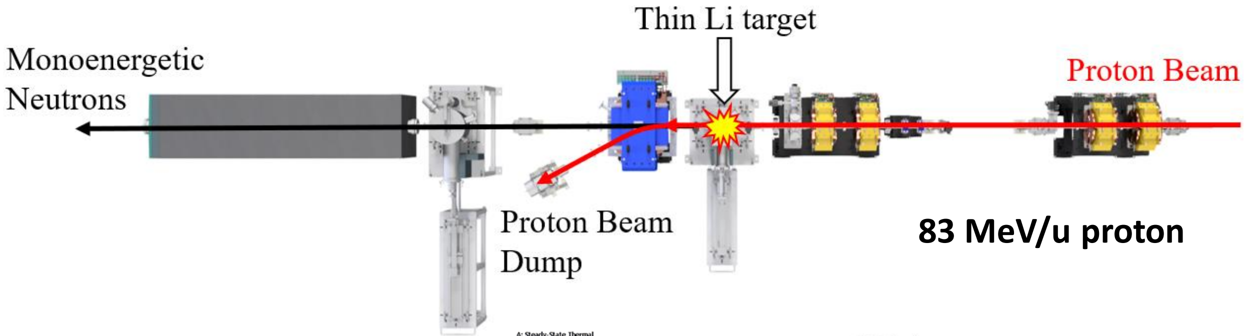
Preliminary, courtesy of S. Leoni

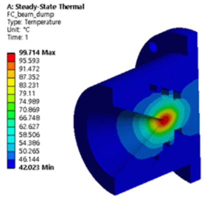
Part2
Fast neutron study at future NDPS

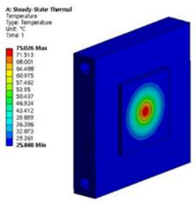






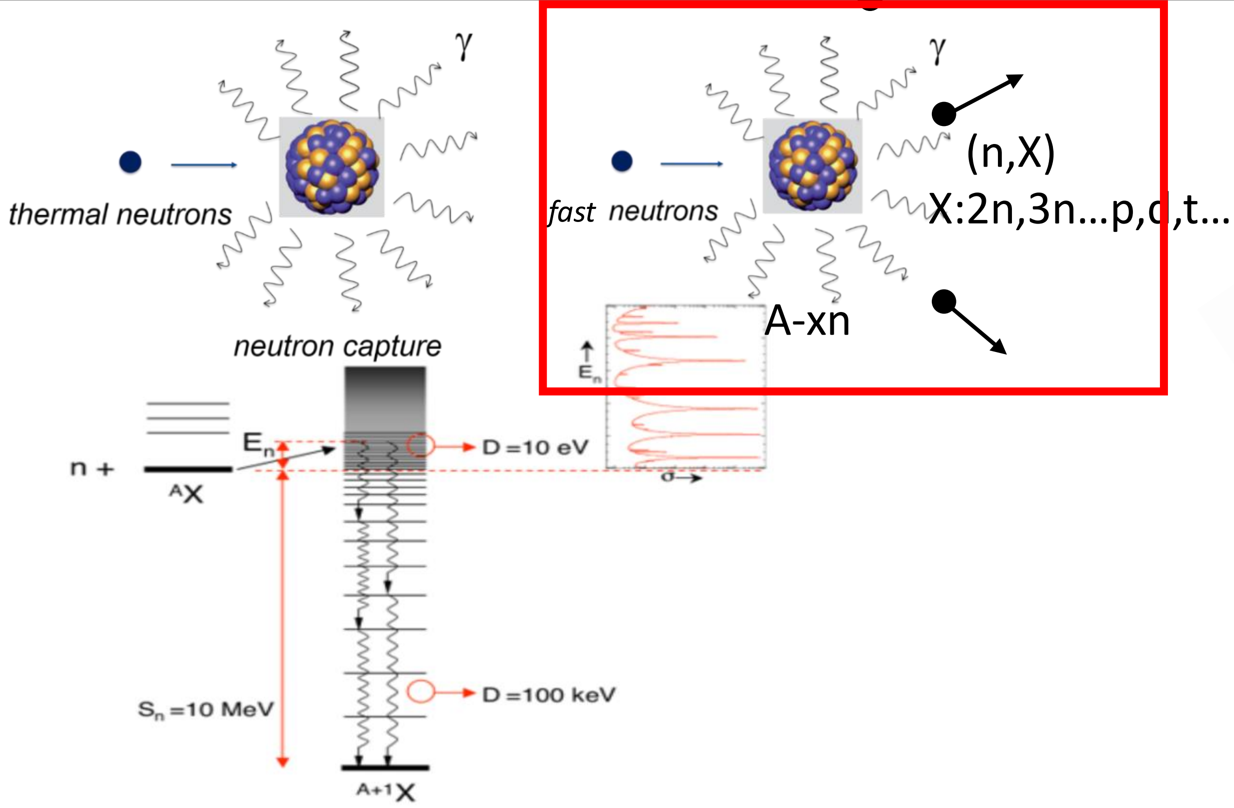


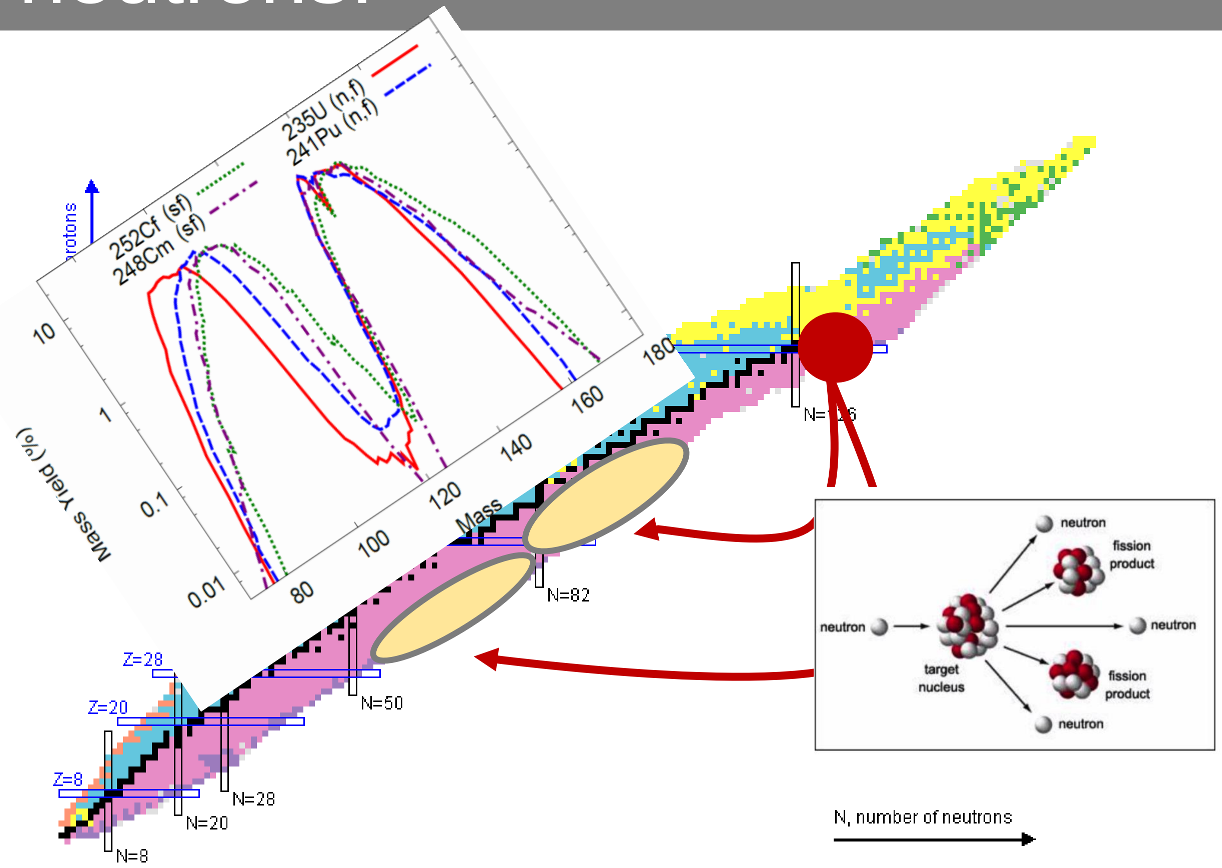




11

Two reactions to study nuclei with neutrons!



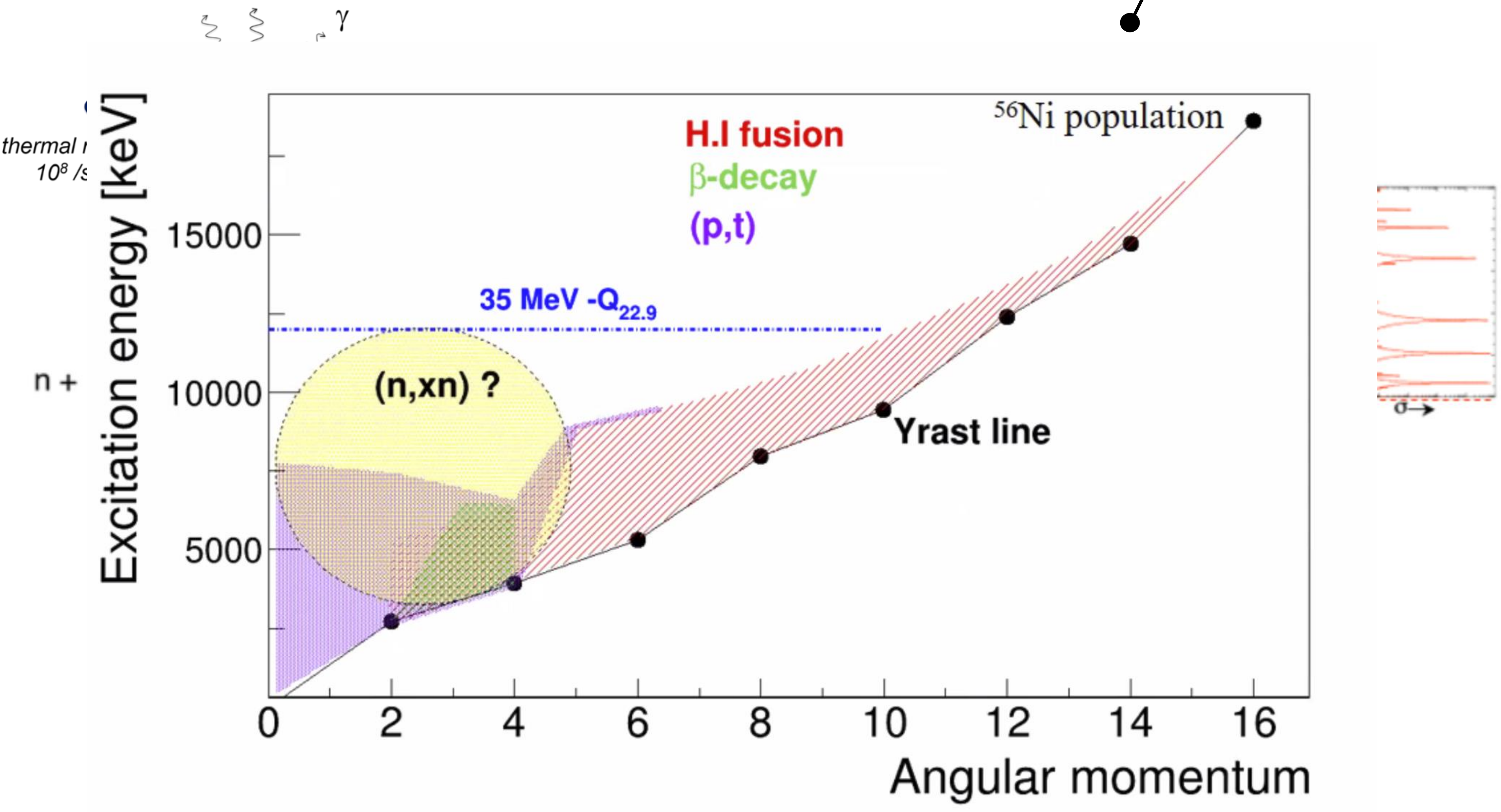


- Nuclei close to stability
- Nuclear excited states with low spin
- Cross-sections (applications medical science etc..)

- Neutron rich nuclei far from stability using actinde targets
- Structure at relatively high spin states
- Fission yields and dynamics

Gamma-ray spectroscopy with neutrons

1. neutron induced capture/xn reaction



- High E neutron still can induce n-capture reaction
- N-induced capture, xn reaction can excite low spin (J=0~4) state at high energy

Courtesy of E. Clement's presentation

Gamma-ray spectroscopy with neutrons

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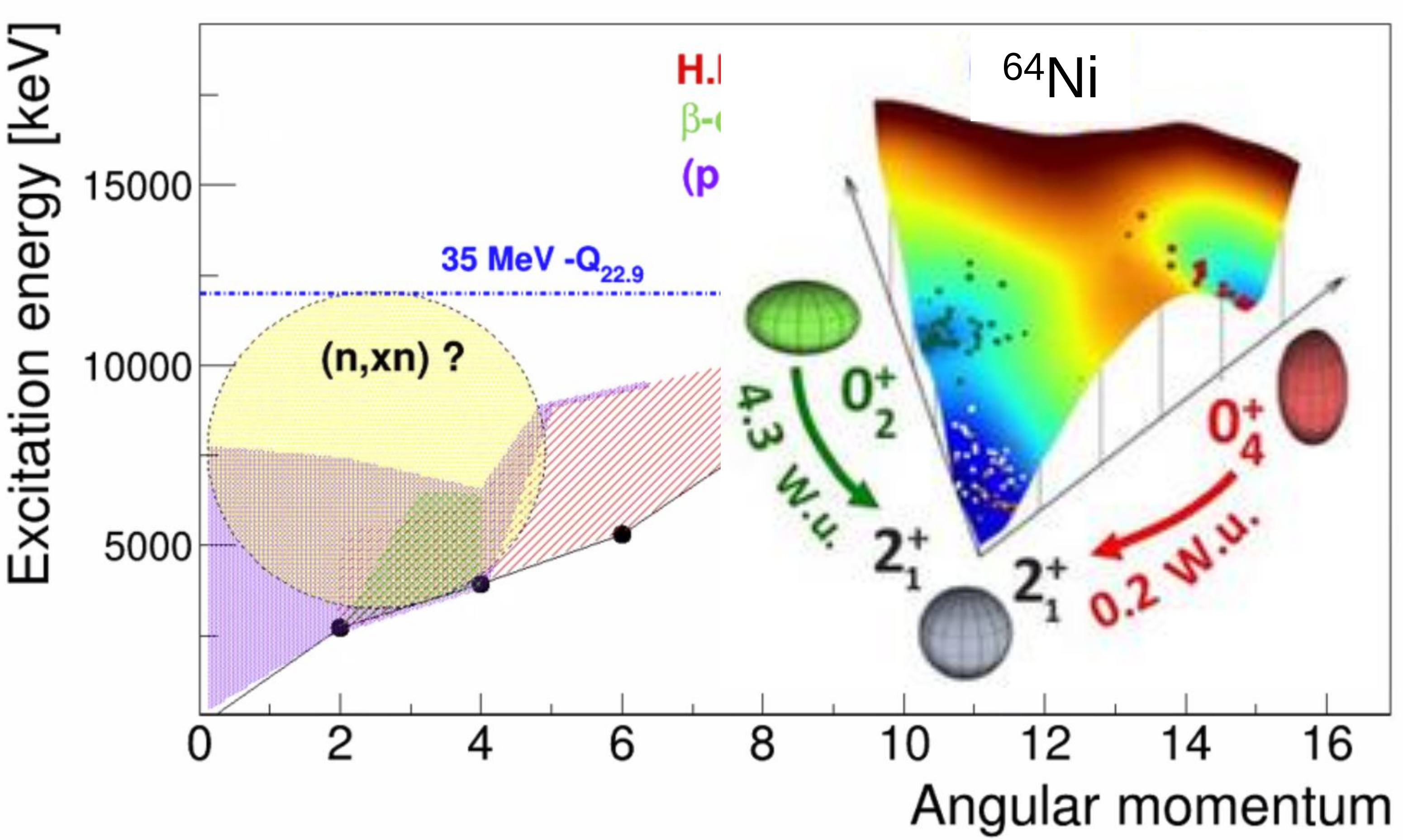

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N. Mărginean… Y. H. Kim… *et al.* Phys. Rev. Lett. **125, 102502 (2020)**

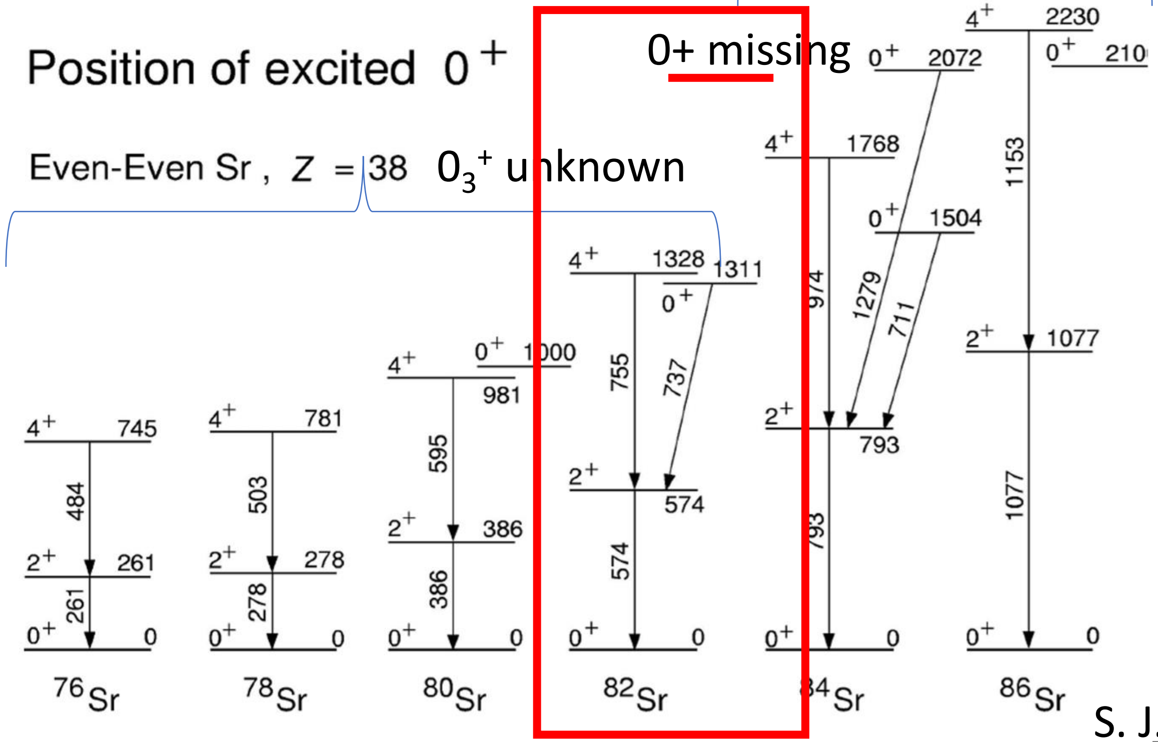
Gamma-ray spectroscopy with neutrons

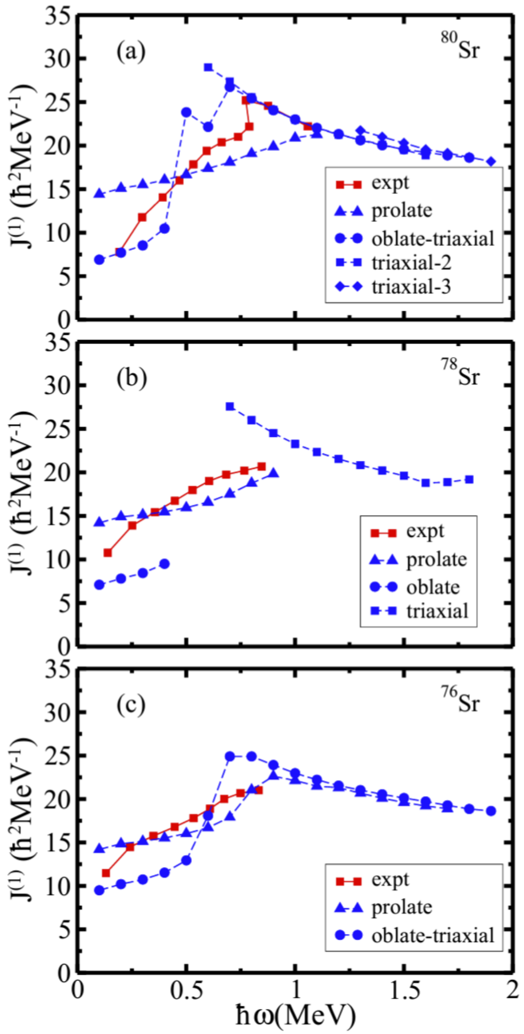
- n-deficient Sr predicted
  to have complex shape co-exsistence
- ^{82}Sr-^{82}Rb medical isotope parent, production cross section r

Stable 0_3^+ known

0+ missing

0_3^+ unknown





S. J. Zeng et al., PRC 90,064309 (2014)

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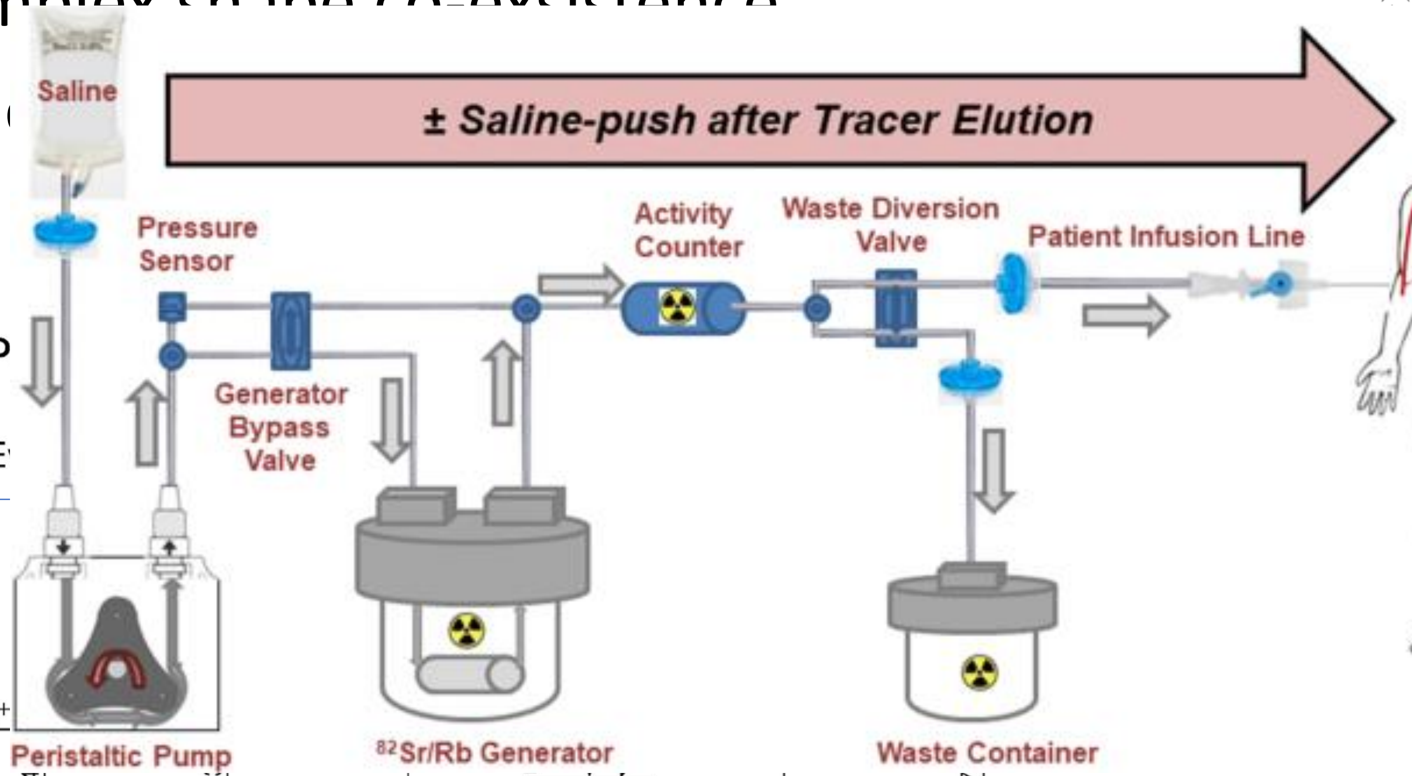

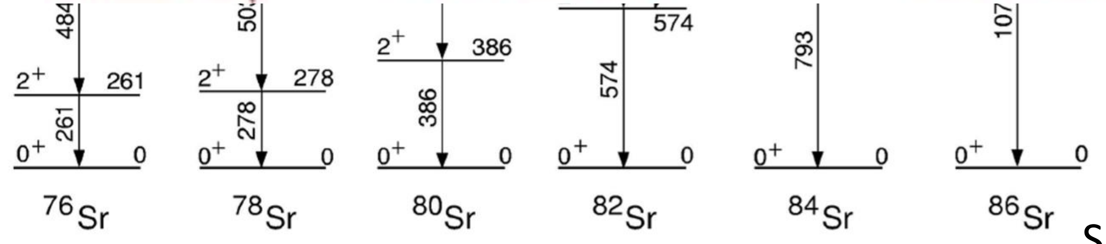

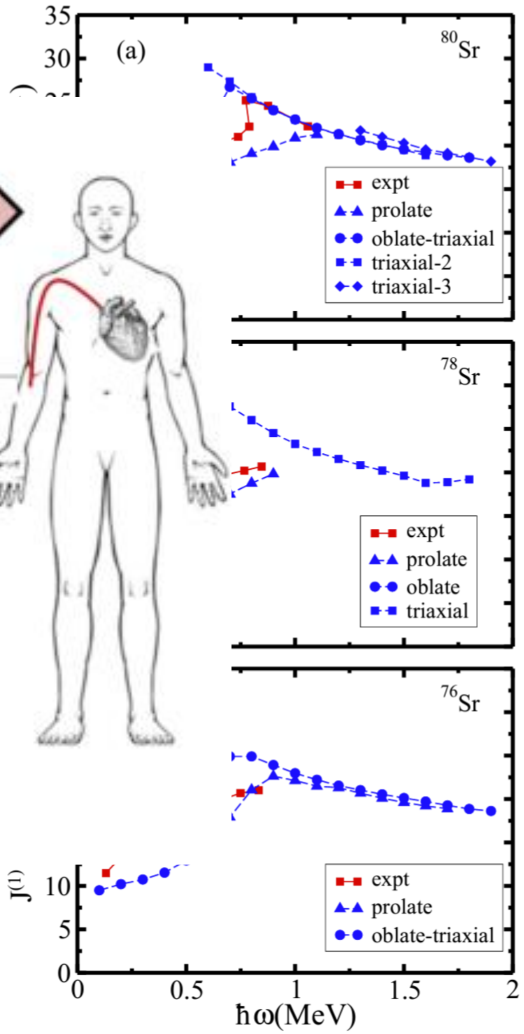

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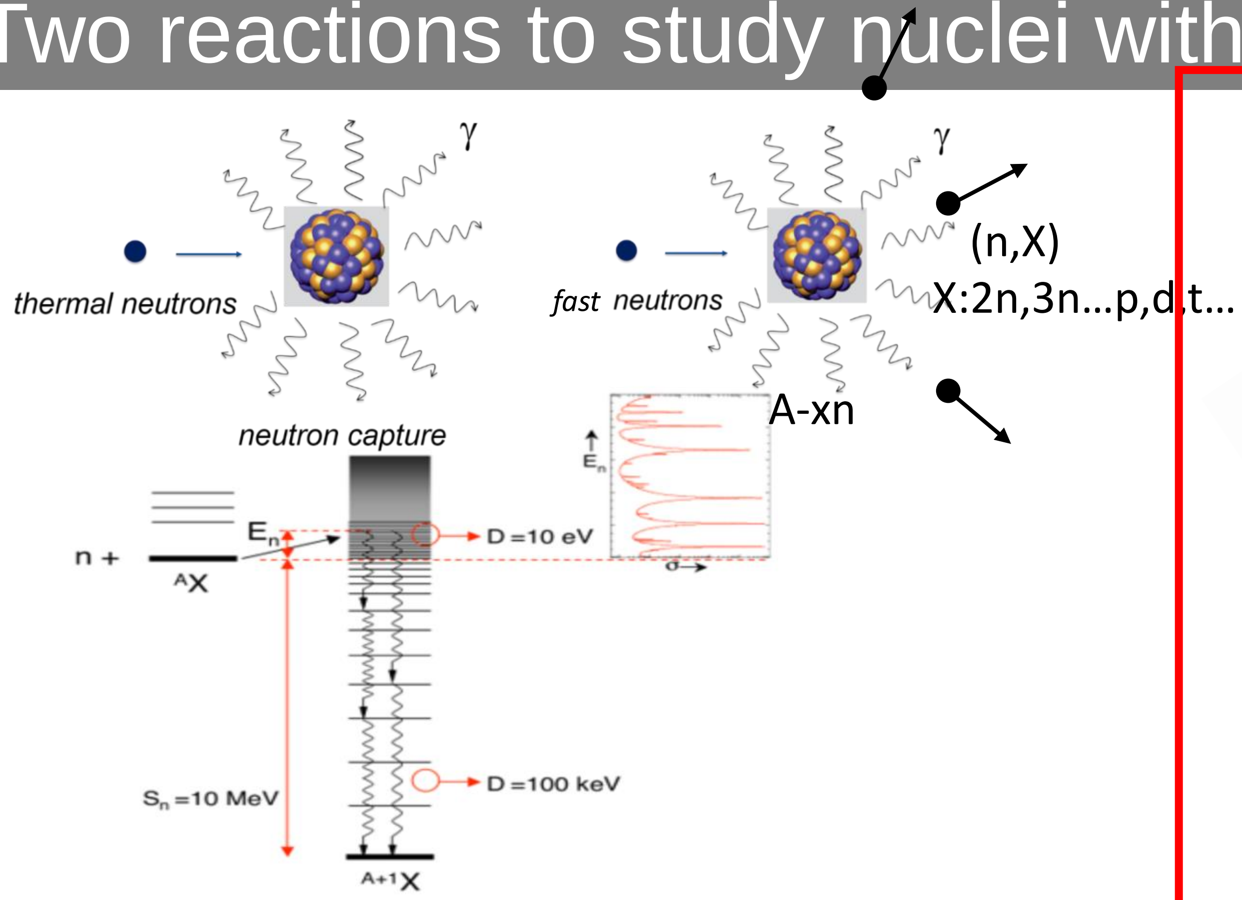

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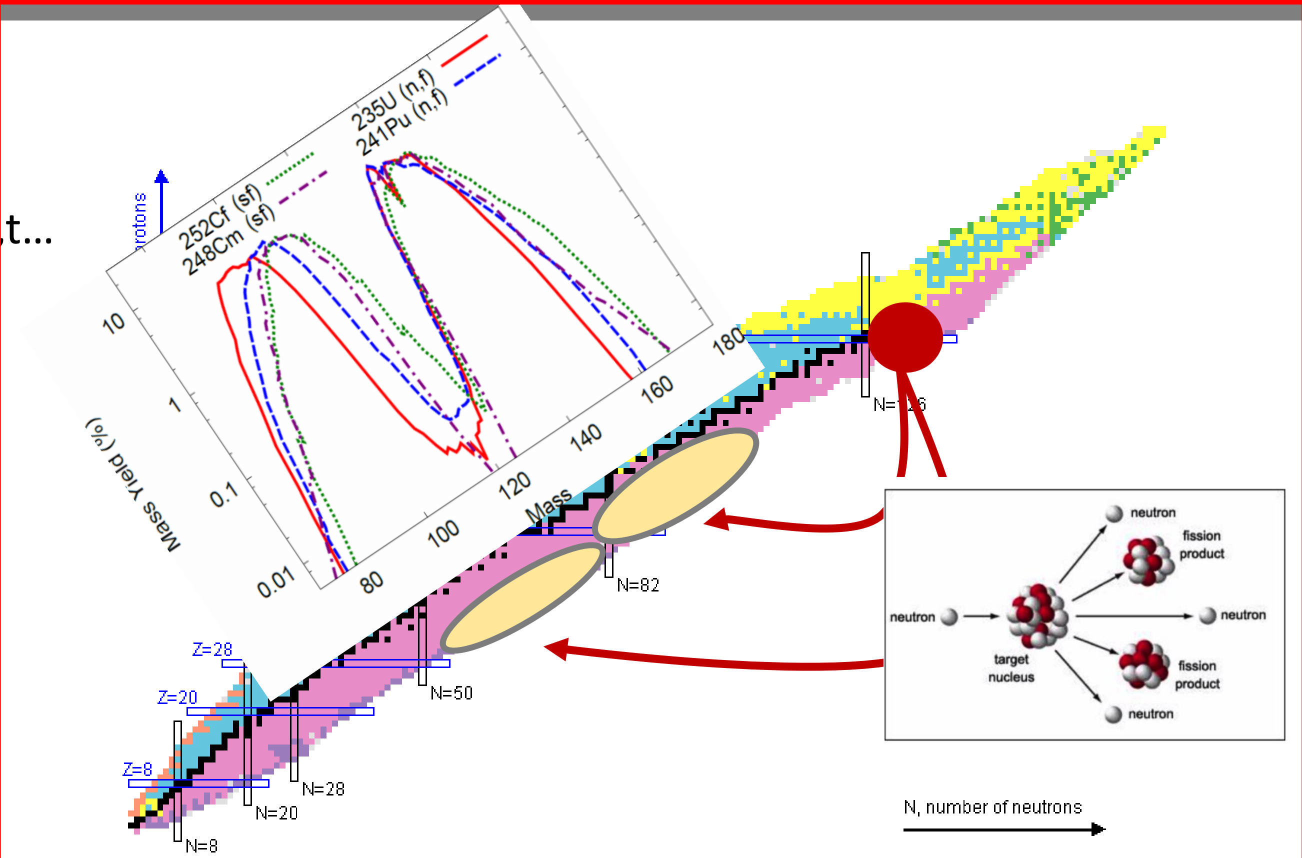

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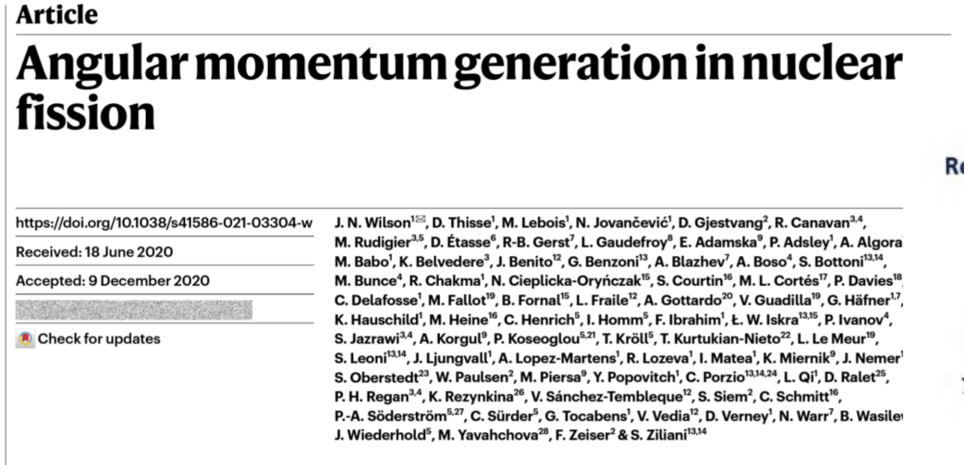
Gamma-ray spectroscopy with neutrons



Article

Angular momentum generation in nuclear fission

https://doi.org/10.1038/s41586-021-03304-w

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Check for updates

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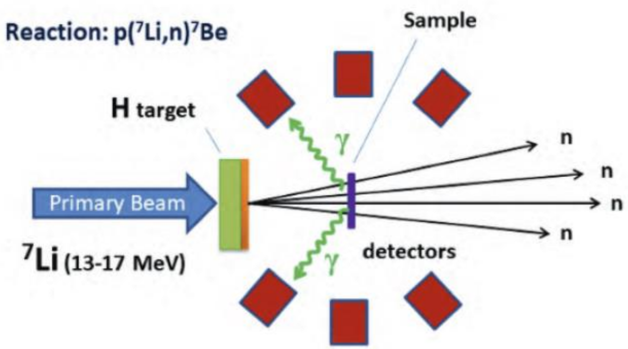


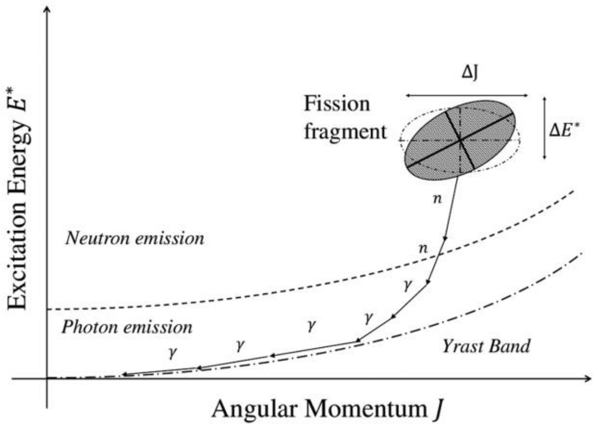
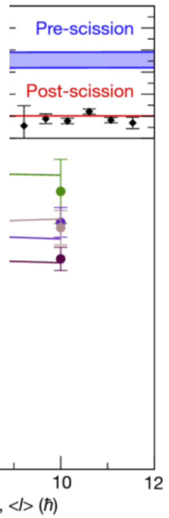


FIG. 1. Schematic representation of neutron and γ-ray emission from fission fragments. The neutron separation energy is indicated by a dashed line, and the yrast rotational band is indicated as a dot-dashed line [12].



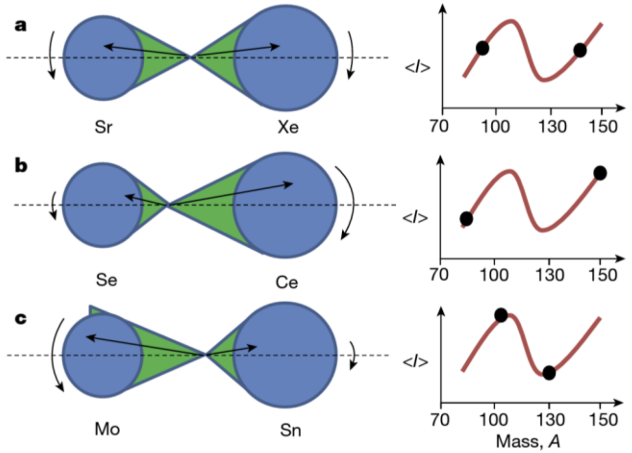


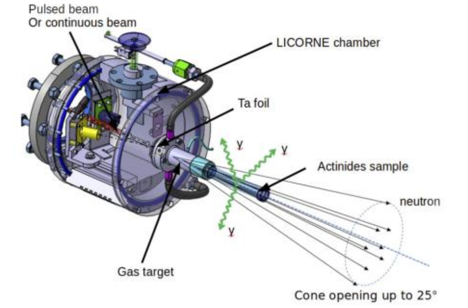
Fig. 3 | Schematic diagram of post-scission angular momentum generation.

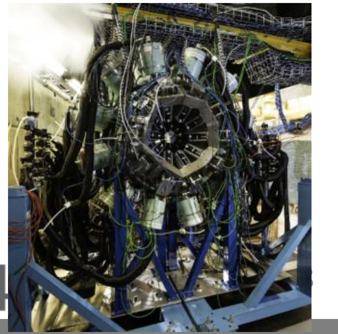
- After 70 years of discovery of fission n-induced fission dynamics from 238U/232Th gives high impact journal papers!

  Related to the next gen reactor development.

- Fission fragment angular momentum measured by gamma-ray using Ge-detector array nu-ball.

- Demonstrated angular momentum generation is independent of partner nuclei's angular momentum.

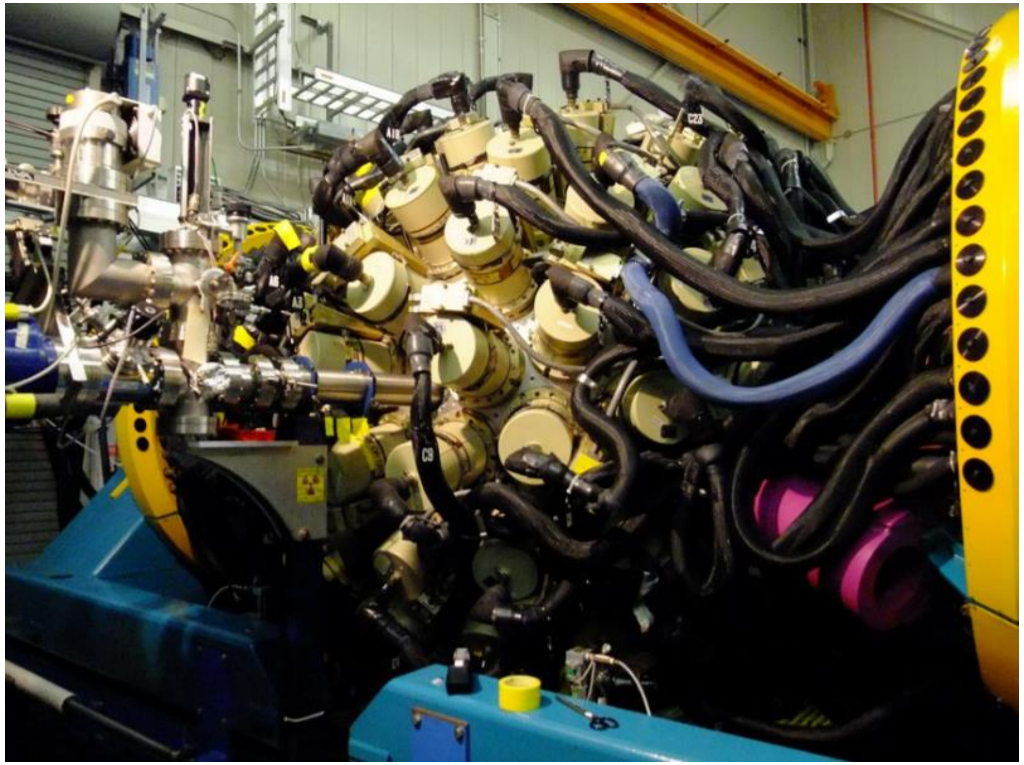




J. N. Wilson et al., Nature 590 (2021) 566

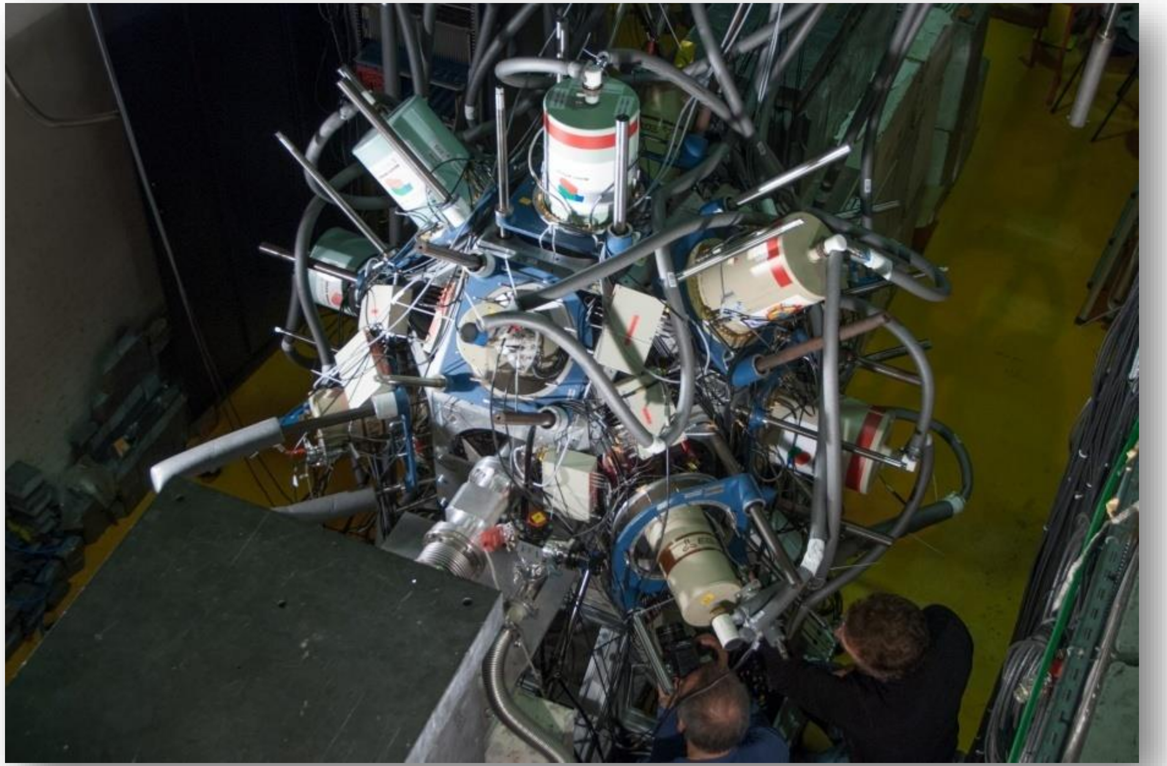
e.g. Gamma sphere / EXILL-campaign

Started late 90's



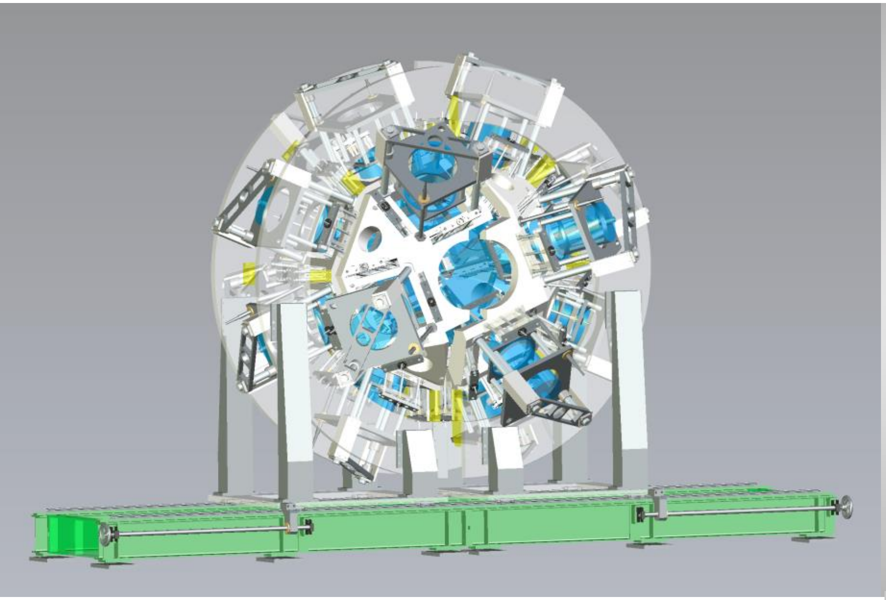
252Cf fission > 140 publications!

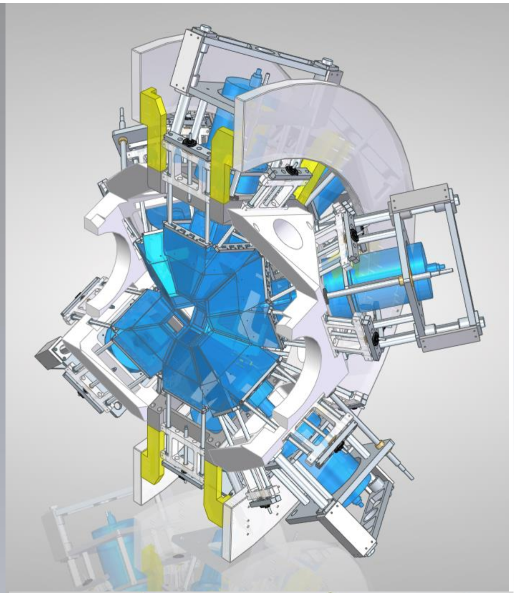
Started 2012

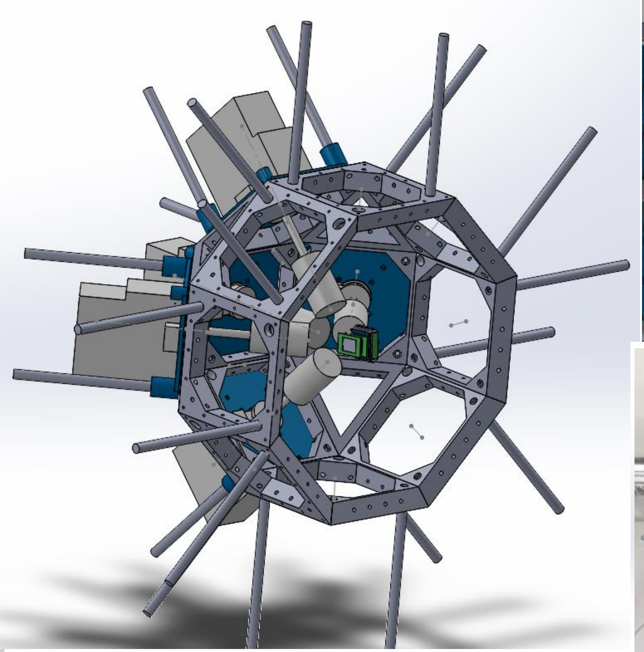


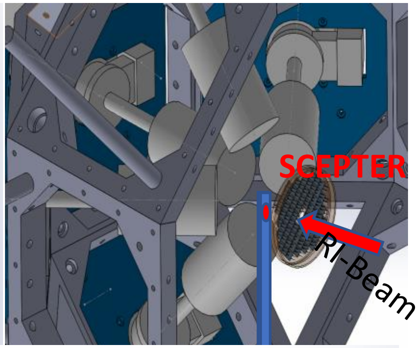
$^{235}U/^{241}Pu$+nth,
More than total 40 publications

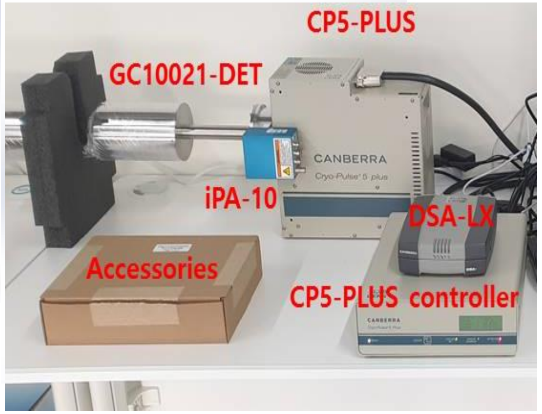
Possible γ-ray spectroscopy setup at NDPS











- ASGARD (Array of Super clover GAmma-Ray Detectors) is a large high-resolution in-beam γ-ray spectrometer.
- 5 clover detectors are available (total 8 units will be procured by 2023).
- The supporting frame will be constructed in 2023.

- Decay spectroscopy for nuclear structure & weak interaction study
- Multi-purpose beamline for Low energy beamline & ISOL beamline
- Versatile detection system with different ancillary detectors under development (e.g. active stopper, conversion electron detector, neutron detectors, Si charged particle detectors)

Summary

- Thermal neutron induced reaction is actively used to study nuclear structure and reaction
- γ-ray spectroscopy using neutron induced reaction can offer unique chance to study nuclear structure and fission dynamics.
- N-induced reaction (n,3n) can be used to populate low spin states near stable nuclei.
- n-induced fission 238U/232Th/etc… can be used to populate RI nuclei and study fission process, nuclear structure.
- Need study to minimize radiation damage from scattered neutrons