Fission studies via the (p,n) reactions on unstable nuclei

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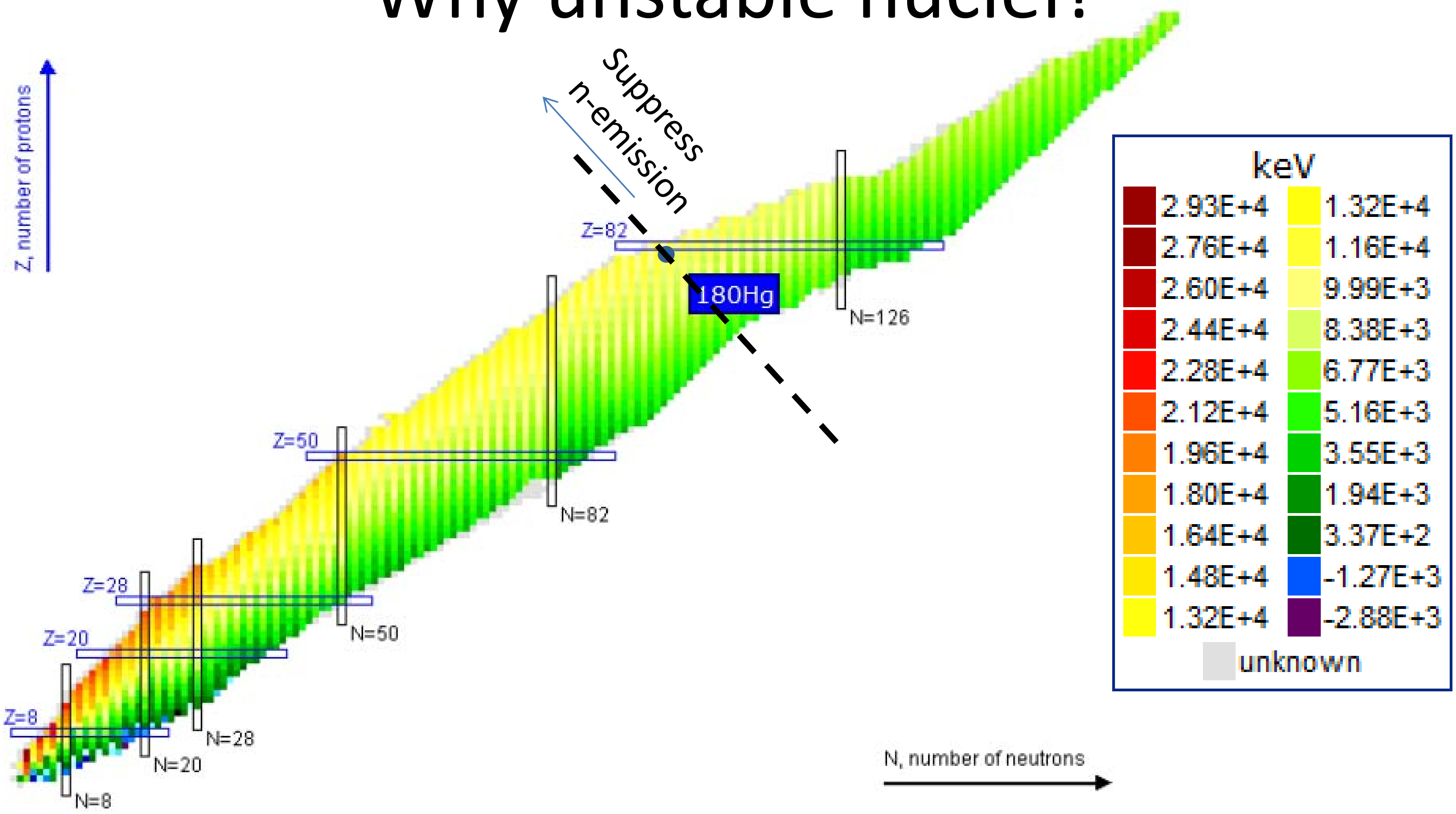
Outline

- General motivations to study unstable-nuclei fission
- Approach via (p,n)
- Advtages of RIKEN RIBF
- Show what kind of spectra CAN be seen

  (using example in stable nuclei)

Why unstable nuclei?

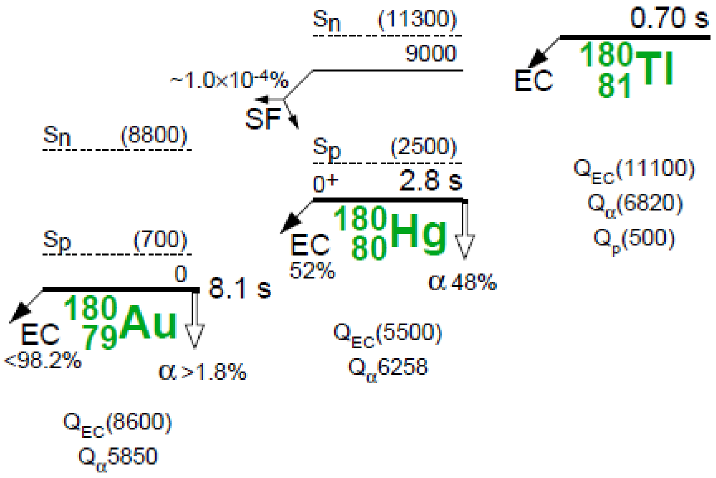


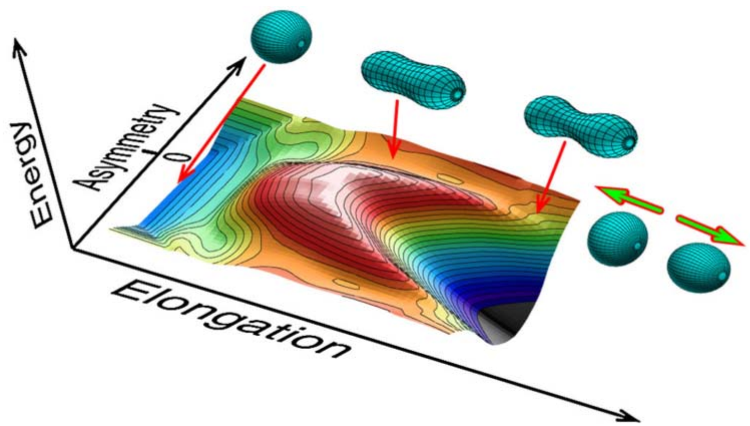
- Systematic studies

→ **Barrier shape** with change of isospin
Competition between fission and other processes
(larger Z → larger fissility, lower neutron emission)

An example: ^{180}Hg

Beta-delayed fission from ^{180}Tl
(A. Alexeyev et al., PRL105,252502 (2010))





^{180}Tl

→ EC/beta+ decays to ^{180}Hg
(Z=80, N=100)

→ Populates states around fission barrier

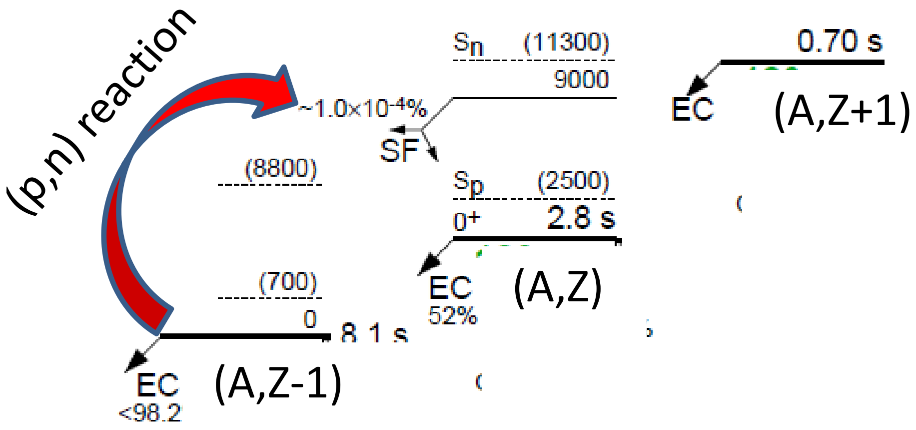
→ Asymmetric mass pattern
(not symmetric ^{90}Zr+^{90}Zr)

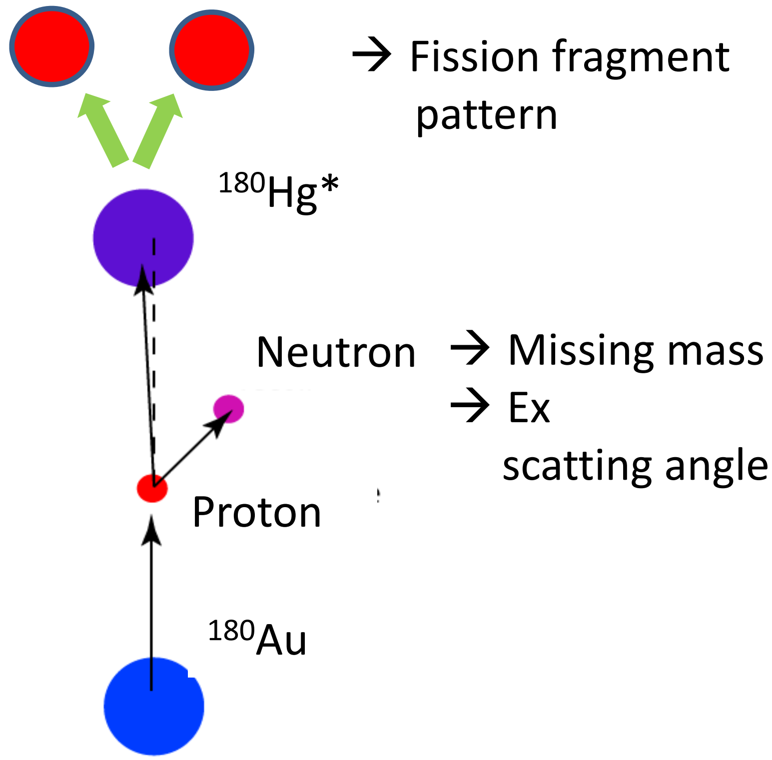
Limitations of EC studies…

- **No information on**
  - **total spin (J)**
  - **parity (π)**
  - **excitation energy (Ex)**
- **Ex < Q(beta) ~ 10 MeV**

My suggestion:
Populate states via the (p,n) reaction

Why (p,n) reaction?

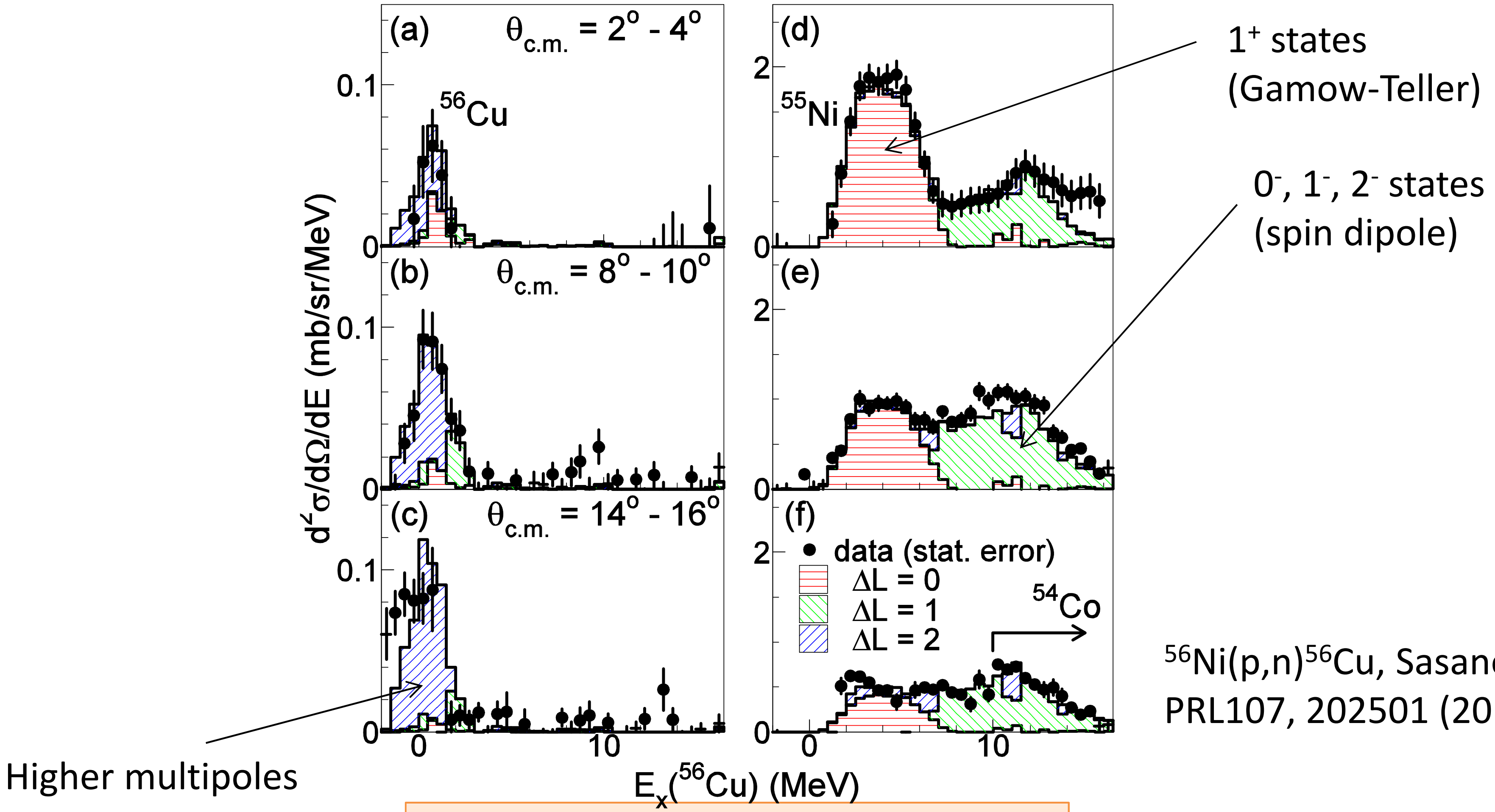




Populates states
- wide Ex window
- Uniformly (no phase space factor as in beta decays, 10^-5 → a few tens %)

Gives additional information such as
- Total spin J (or L), parity pi
- Energy

(p,n) w/ RI beam (An example in medium heavy region, ^{56}Ni)



^{56}Ni(p,n)^{56}Cu, Sasano et a
PRL107, 202501 (2011).

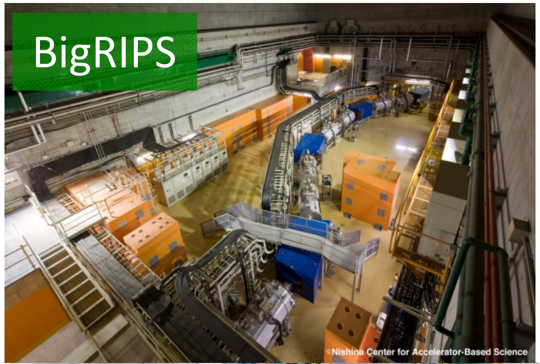
Experimental method
→ Recently established at NSCL, MSU
→ Can be performed at RIKEN RIBF
w/ the best efficiency in the world

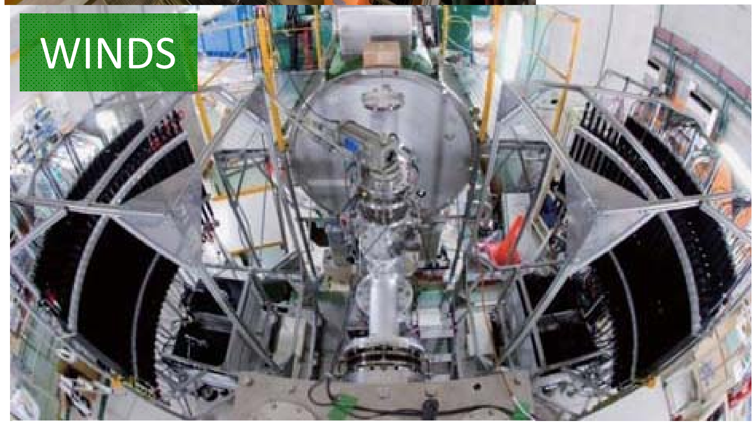
RIKEN RIBF

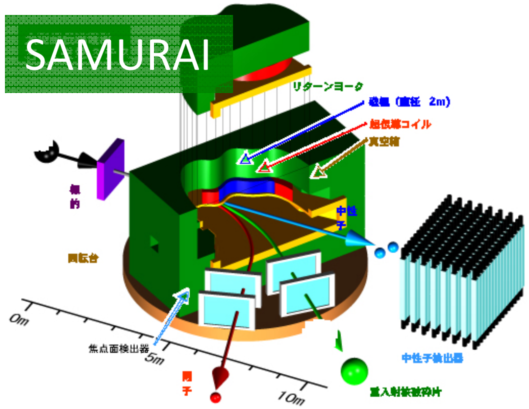
RIKEN RIBF
Beam (BigRIPS):
high intensity (> 10^4 pps necessary)
with a good beam energy (200--300 MeV)

Neutron detection (WINDS):
60 scintillator bars

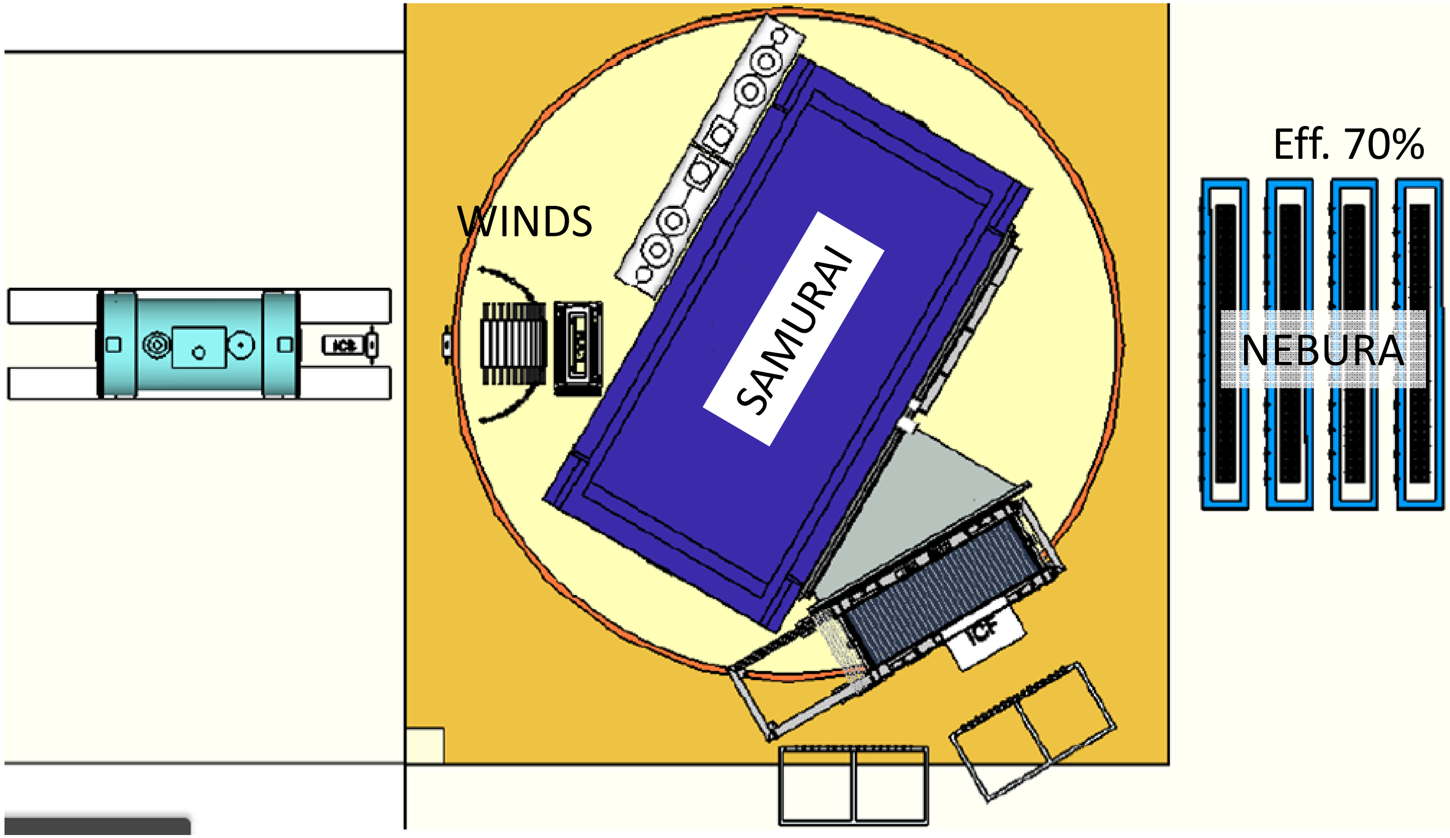
Residue tag (SAMURAI):
→ Acceptance covers all the fission fragments





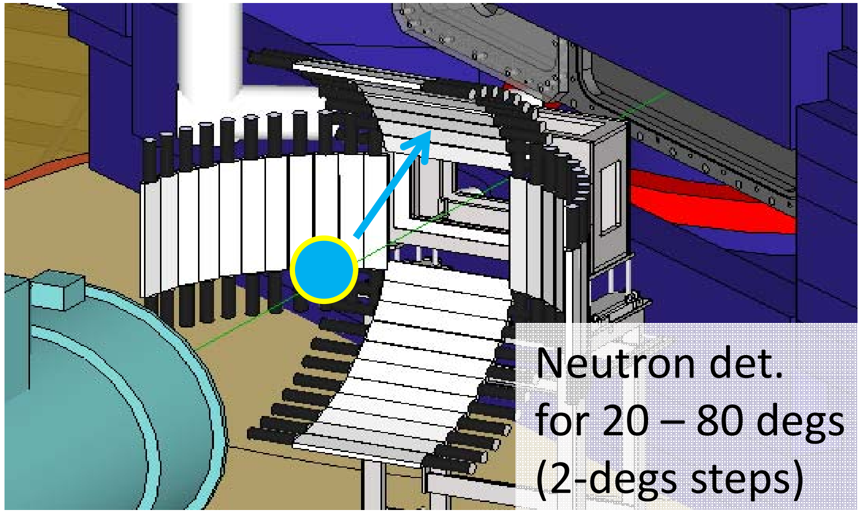


A top view of setup



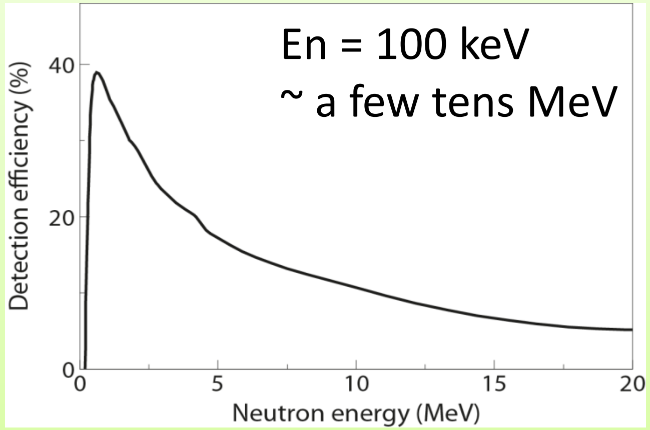
A/Q
IC → ΔE
MWDC → Trajectory radius
Plastic hodoscope → TOF

Low energy neutron detector (WINDS)



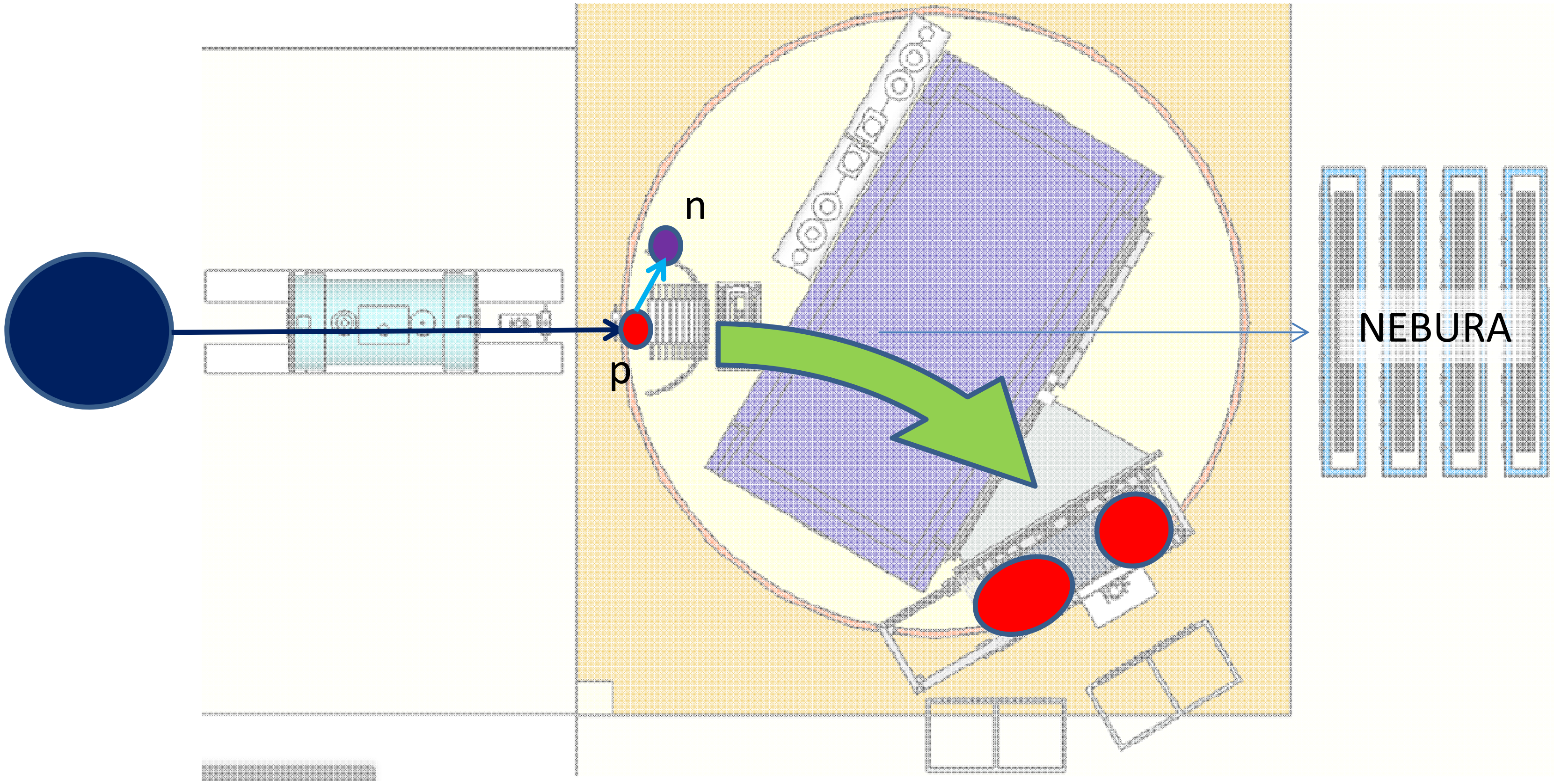
(assuming proton rich side)

Each neutron detector:
Plastic scintillator (Bicron BC403)
60 x 10 x 3 (depth) cm^3



Covers : 0 – 20 MeV & 1 – 20 degrees in c.m.s.
The excitation energy resolution :
1 MeV
Overall (intrinsic + coverage) efficiency :
10—30% at forward angles (GEANT3 simulation)

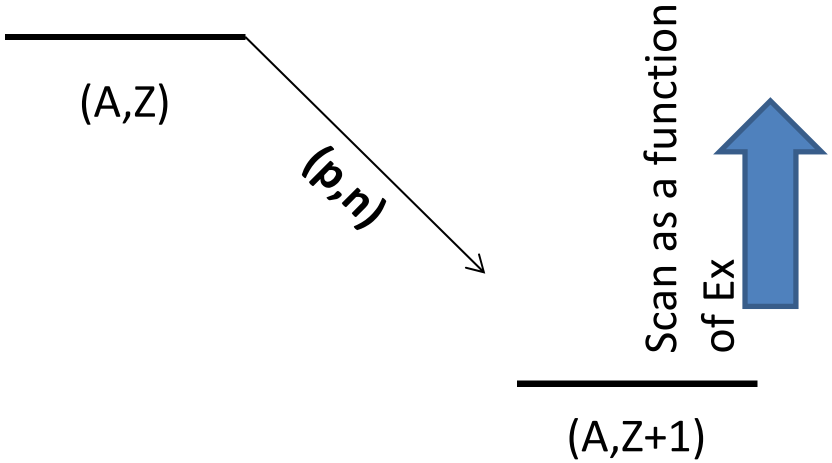
A top view of setup

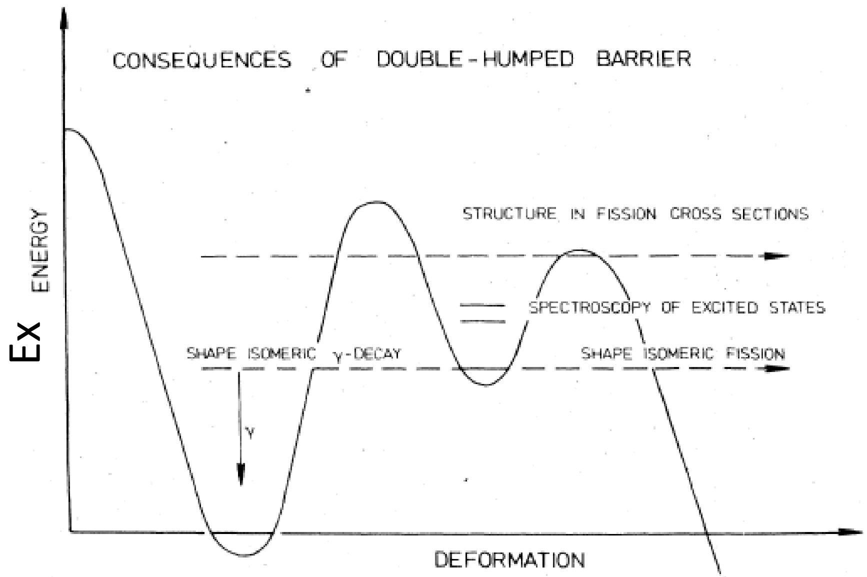


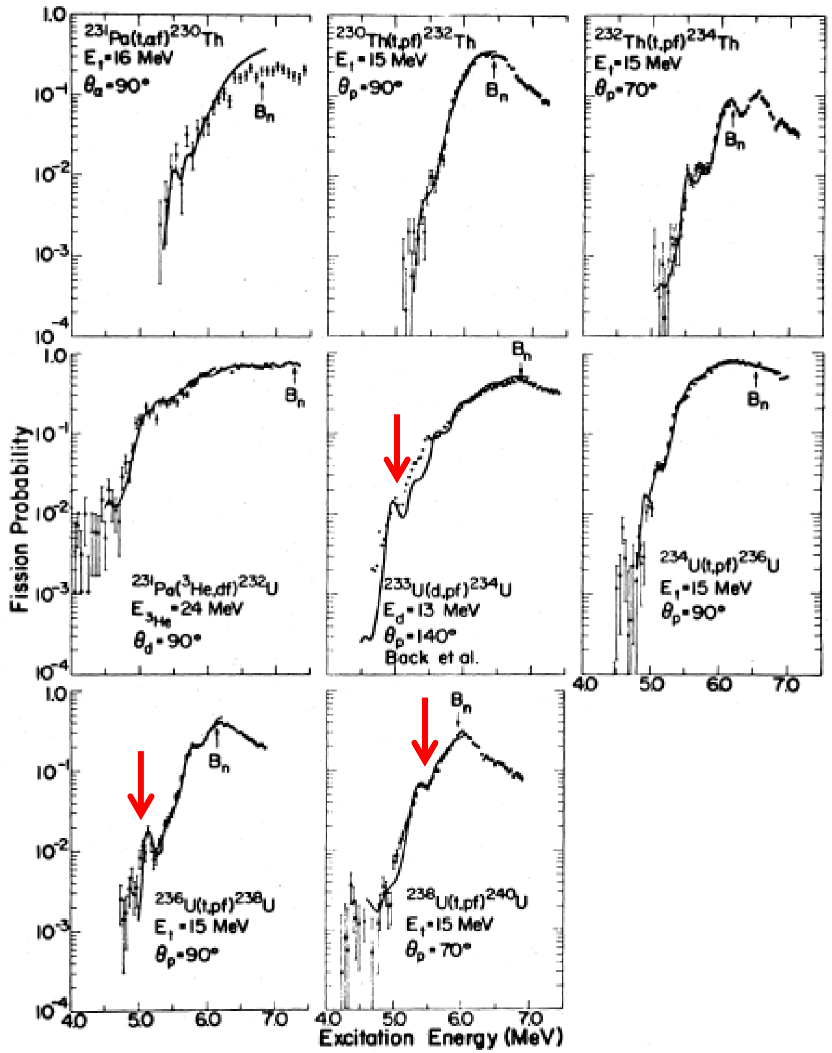
Ex resolution : ~ 1 MeV
Scattering angle : decompose different L (1+, 0-, 1-, 2-, …)
Fission fragments : Charge res. 0.2, Mass res. 0.4
(10^4 pps RI beam)

What can be seen?
(Examples in stable nuclei)

Fission probability as a function of Ex

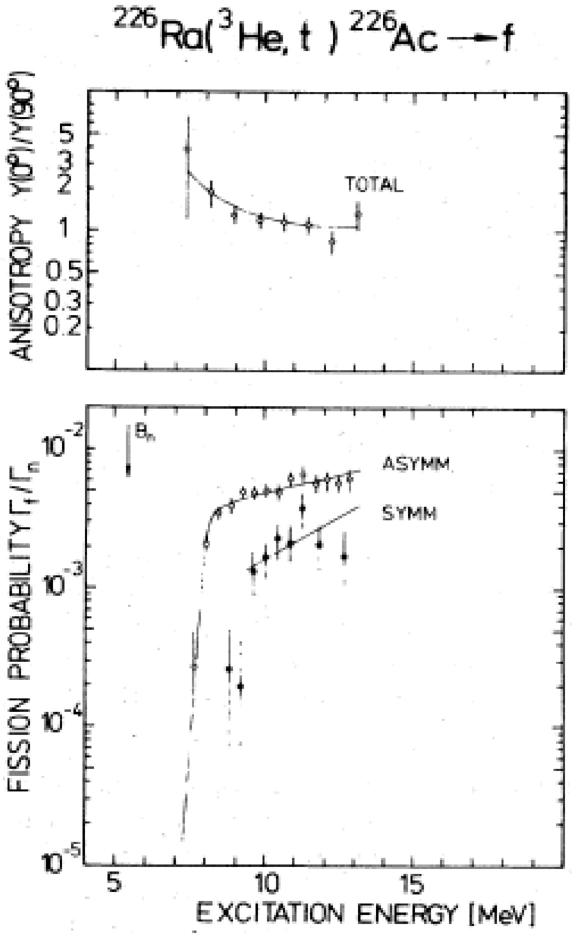


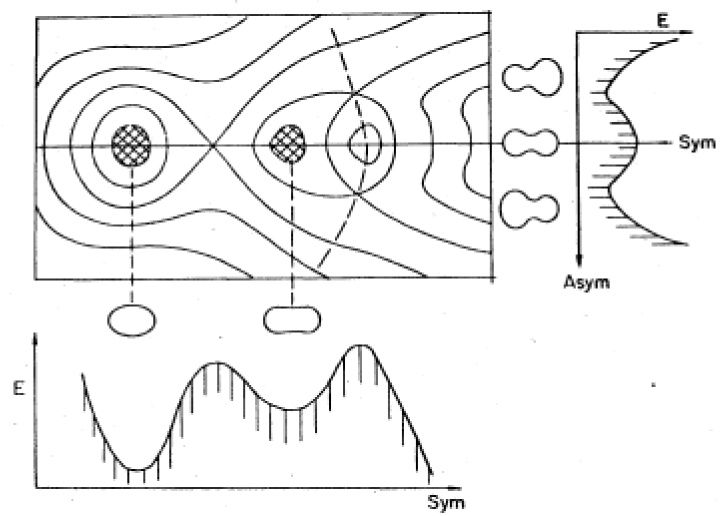




Hans J. Specht, Rev. Mod. Phys. 46, 773-787 (1974).

Fission-fragment mass pattern as a function of Ex





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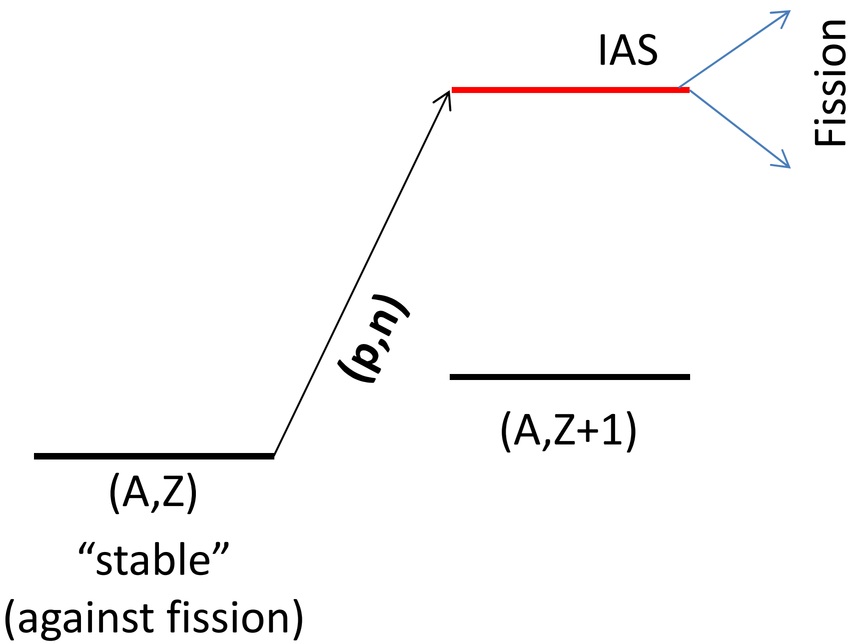
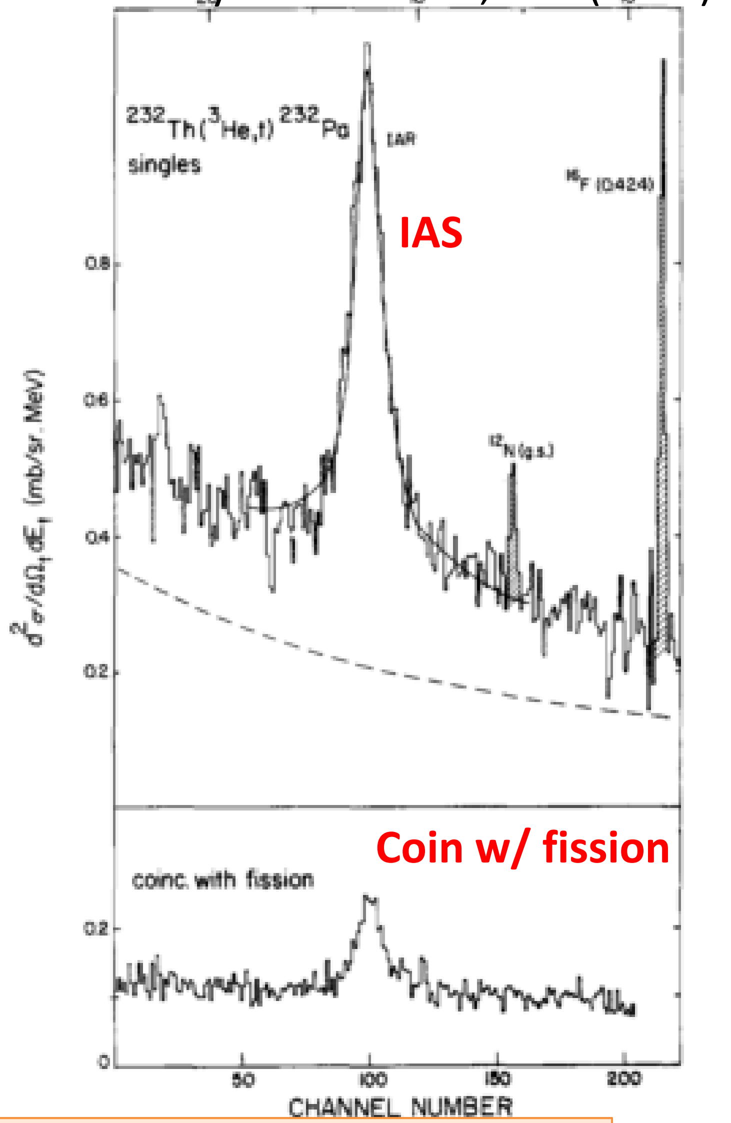
Fission from IAS

S. Y. van der Werf et al.,
Phys. Lett. B 105, 133 (1981).

(p,n)
→ high-lying collective states
(+ low-lying states)

Isobaric analog state (IAS)
→ Discrete peak even at a **high** energy (Ex ~ 15-20 MeV)
→ Well defined state
having the same structure as the initial ground state





Such highly-lying well-defined (discrete) state cannot be populated by transfer/knockout
Structure just before fission ← studying the initial ground state

Summary

- Suggested the use of (p,n) reaction to induce fission in ur… …i
  - Total spin, isospin, excitation energy
- Advantages at RIKEN RIBF
  - A high intensity beam
  - A large neutron detector array, W…
  - A large acceptance spectro… …KAI
- Can determine
  - Fission probabilit… …n of Ex
    → humped… …r fission barrier
  - Symme… …etric mass pattern
  - Fis… …e IAS (highly lying, well defined)

Hope comments, suggestions, …