Actinide fission induced by multi-nucleon transfer reaction in inverse kinematics at GANIL

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Abstract

In order to improve our understanding of the fission process and to obtain the data required for the design of new generation of reactors and the management of nuclear waste, new experimental methods have to be developed. We report on an experimental programme based on the surrogate method with multi-nucleon transfer reactions and the inverse kinematics technique to study the fission of minor actinides at low excitation energy.

Motivations

Fission, a tool for :

- testing shell models and nuclear dynamics
  - ⇒ low energy fission is asymmetric in actinide region
- data evaluation (IAEA/ENDF, OECD/JEFF, etc.)
  - ⇒ improving safety and allowing design studies for future facilities

In 2008 at GANIL, with a ^{238}U beam at 6.09A MeV on a ^{12}C target :

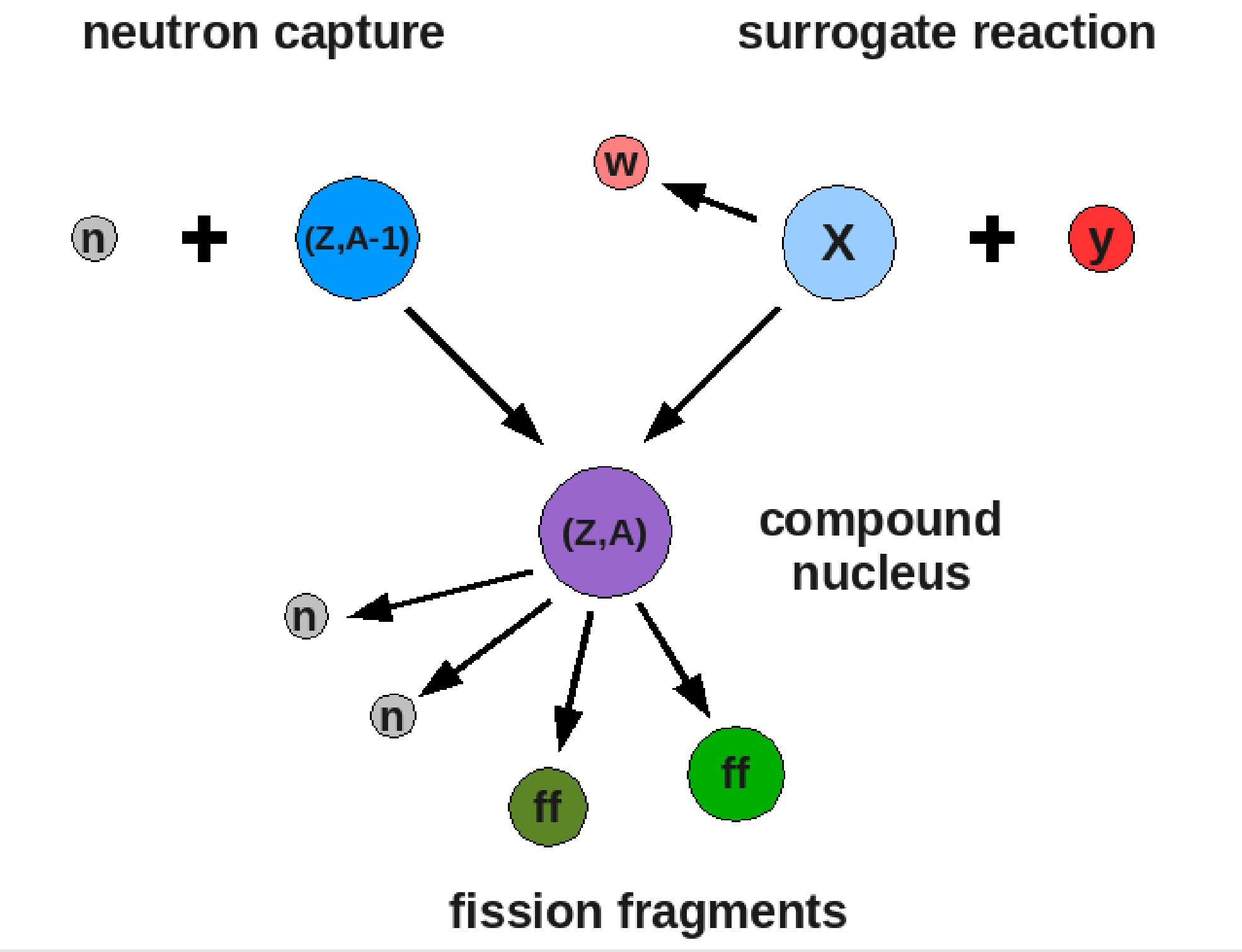
- producing exotic actinides with multi-transfer reactions
- measuring the fission probabilities of the actinides produced
- testing the limits of the surrogate method
- obtaining the fission fragment isotopic yields *via* the inverse kinematics

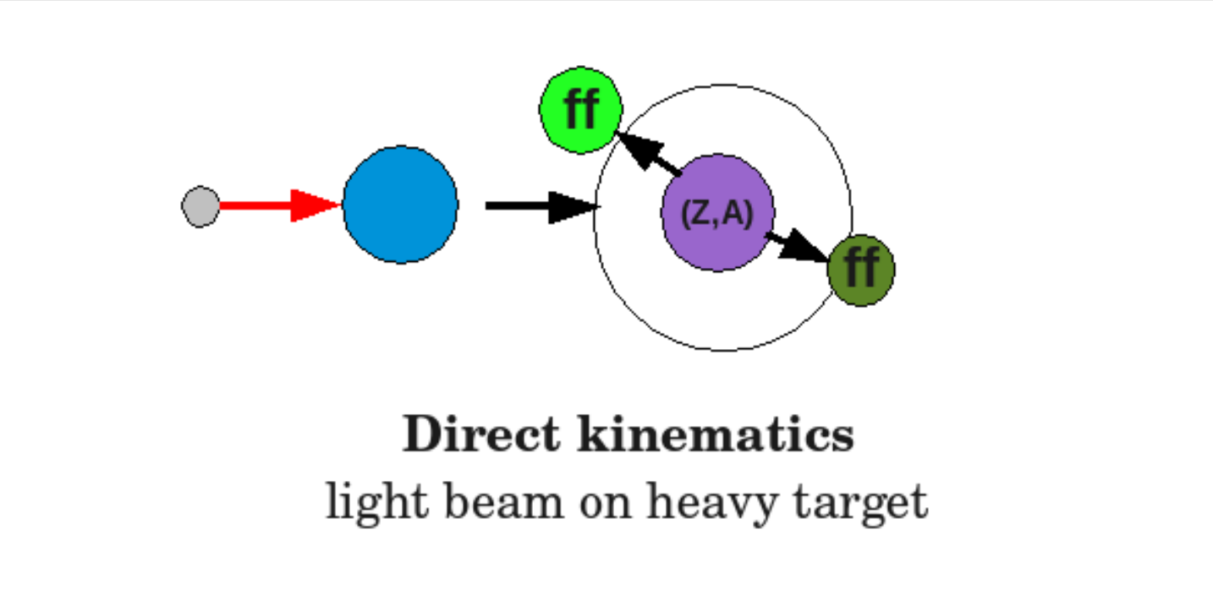
Methods

Surrogate method [1] to study actinides not accessible by (n,f)

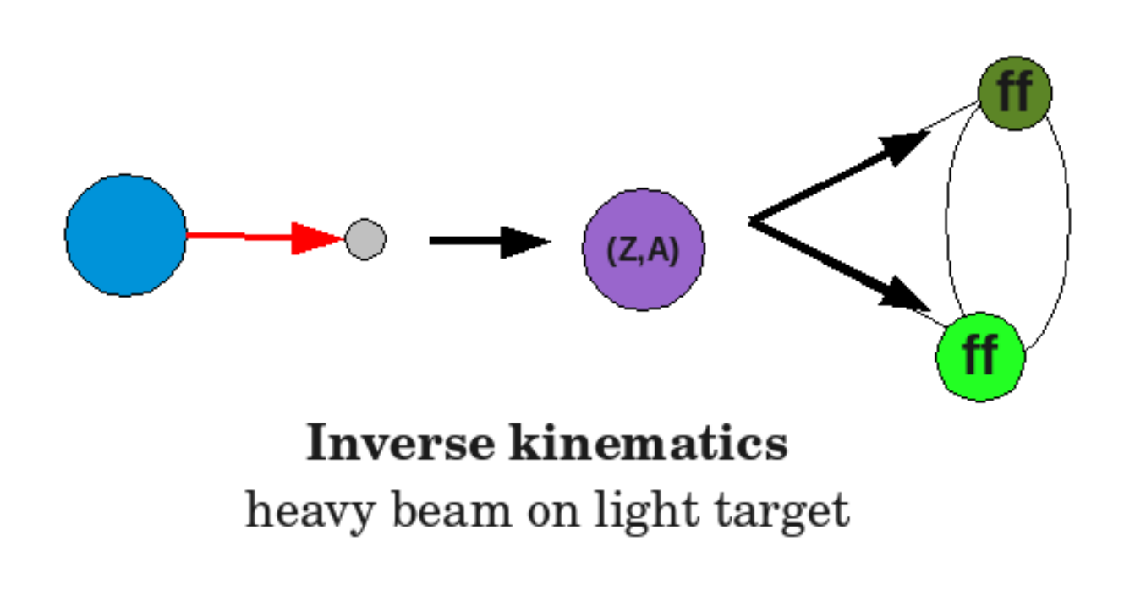
$$\sigma_{n\rightarrow fission}(E^*) = \sum_{J,\pi} \sigma_n^{CN}(E^*,J,\pi) \times P_{fission}(E^*,J,\pi)$$

Validity of $P_{\mathrm{fission}}(E^*,J,\pi) \simeq P_{\mathrm{fission}}(E^*)$ is still an open question





Direct kinematics
light beam on heavy target

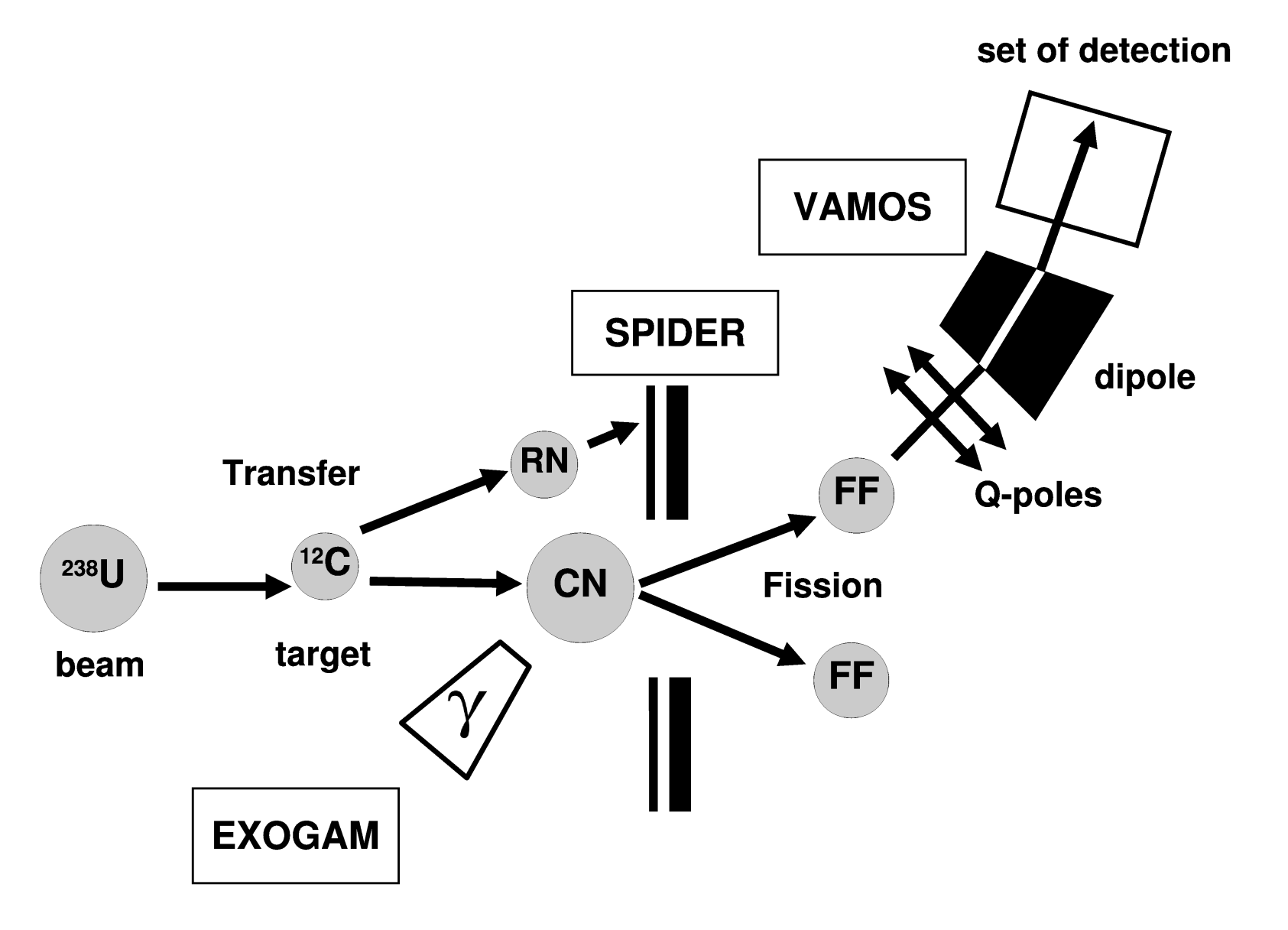


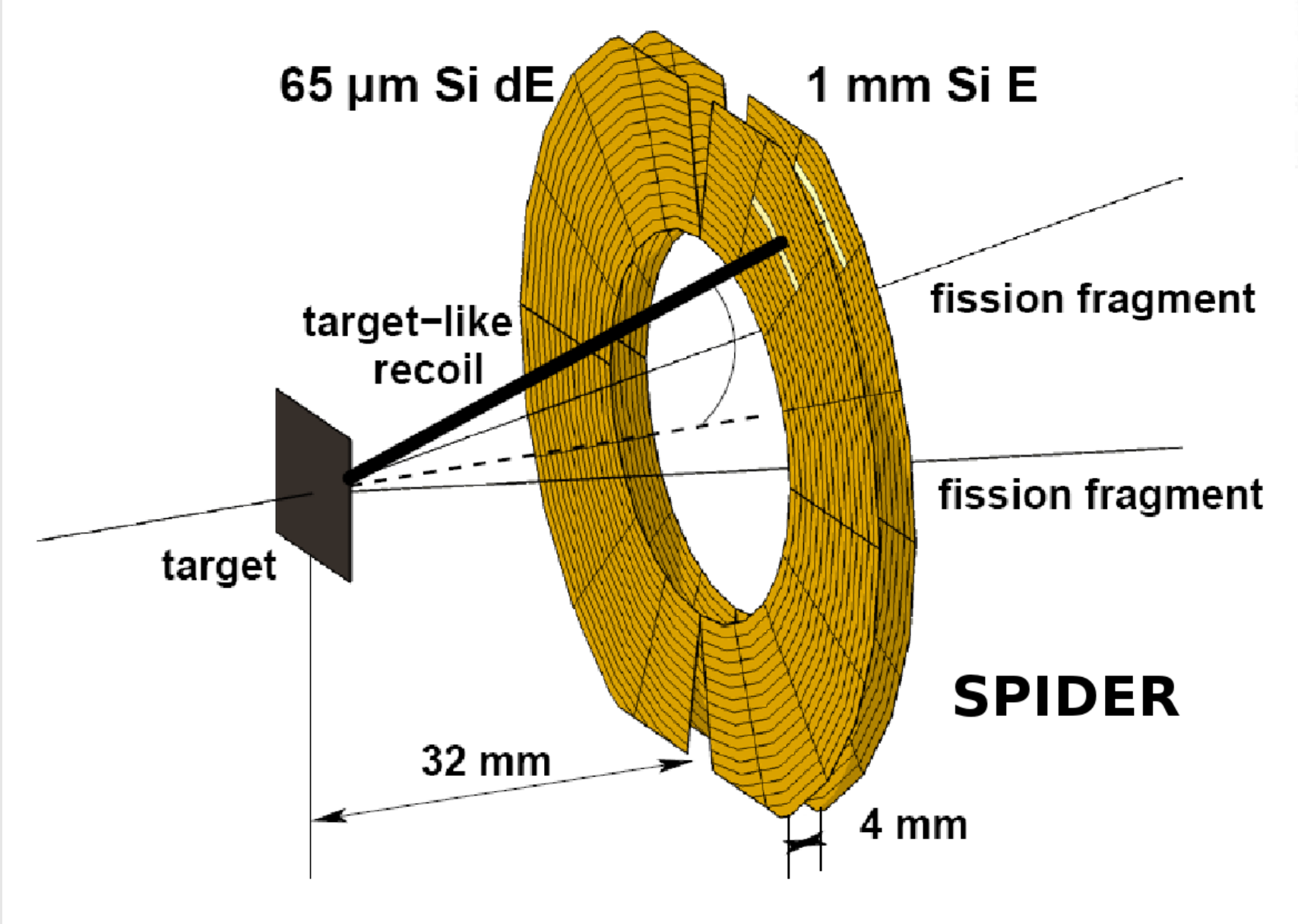
Inverse kinematics
heavy beam on light target

Advantages of inverse kinematics :

- forward focus of fission fragments
- higher resolution for identification, even for the heaviest fragments
- light targets less contaminated than actinides ones

Experimental set-up





- **SPIDER** : highly-stripped **ΔE**-E annular silicon telescope
  - ⇒ Identification of the target-recoil nuclei (RN) [2]
- **VAMOS** : large acceptance spectrometer
  - ⇒ Identification of the fission fragments [3]
- **EXOGAM** : Germanium array
  - ⇒ Identification and spectroscopy of the fission fragments [4]

Bibliography

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Actinide identification with SPIDER

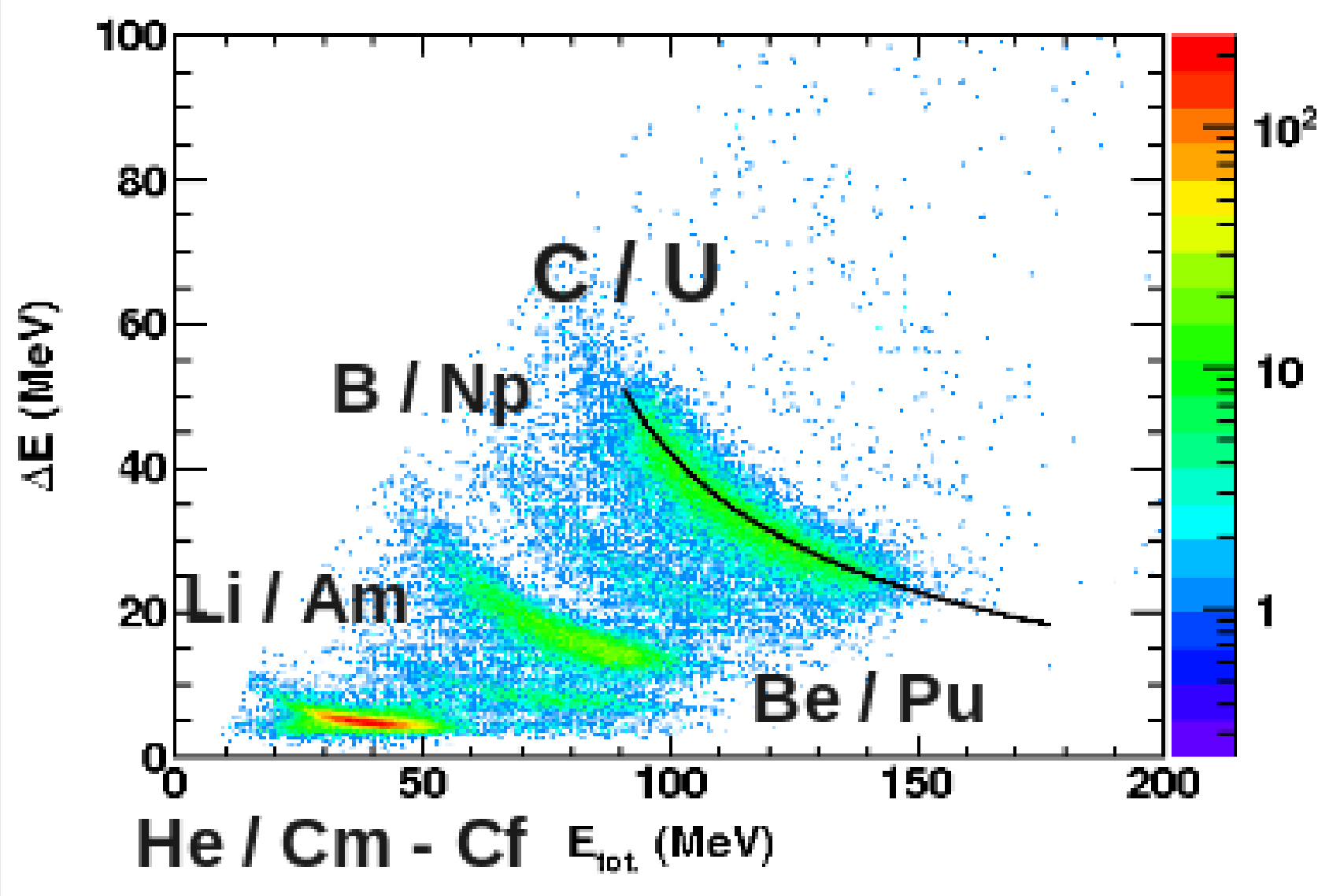
$$(\Delta E, E_{\mathrm{res.}}, \theta)_{\mathrm{recoil}} \rightarrow (Z, A, E^*)_{\mathrm{actinide}} \ (\text{assuming } E^*_{\mathrm{actinide}} \simeq E^*_{\mathrm{system}})$$

⇒ 4 transfer channels open
but no isotopic identification

Numerous technical issues [2] :

- high current (>1 μA)
- high temperature
- high flux of δ electrons
- spatial instability of the beam

⇒ Important loss of resolution !



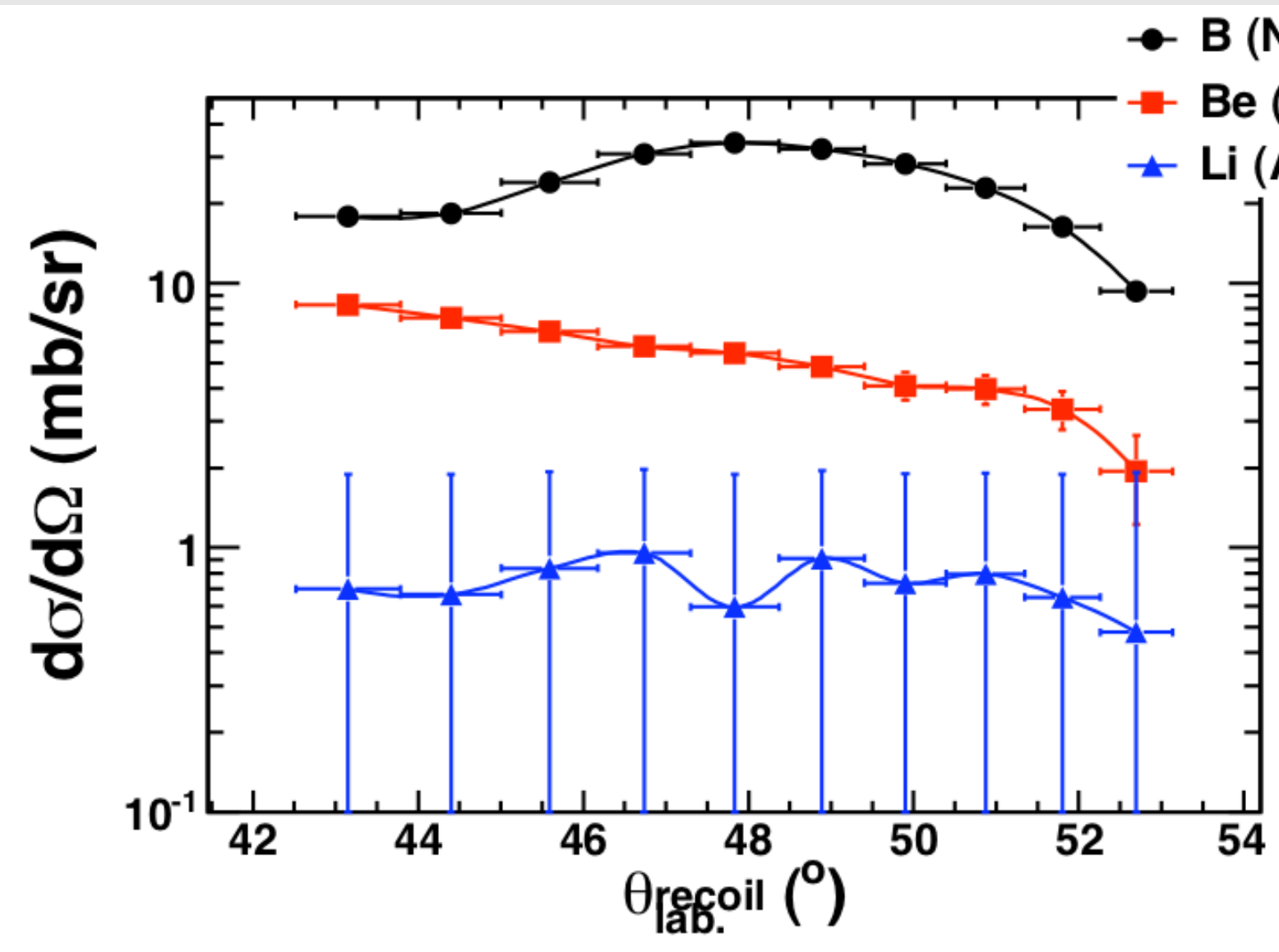
Choosing the most probable isotope per Z channel

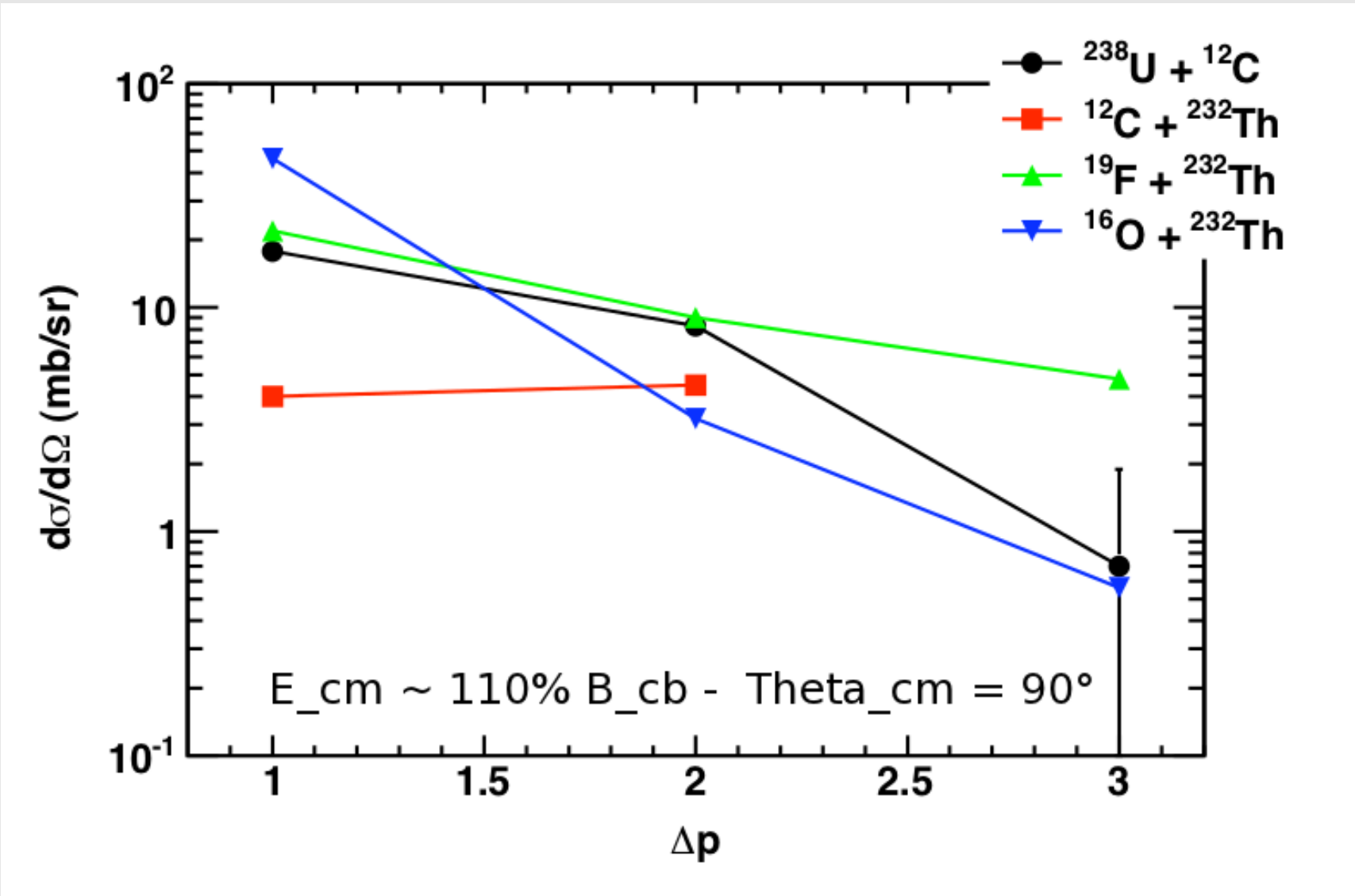
For the different isotopes, $\sigma_{transfer}$ exponentially decreases with the corresponding Q-value [5]

$$\frac{\sigma_{(Z,Ai)}}{\sigma_{(Z,Aj)}} = \frac{\exp Q_{(Z,Ai)}}{\exp Q_{(Z,Aj)}}$$

$$\sigma_{(Z,total)} = \sigma_{(Z,A1)} + \sigma_{(Z,A2)}$$

Recoil	Actinide	Q_0 (MeV)	$d\sigma/d\Omega$ (mb.sr^{-1})		Q_{opt} (MeV)
^{12}C	^{238}U	0.00	X		0
^{13}C	^{237}U	-1.21	X		
^{11}B	^{239}Np	-10.67	235.0 ± 2 {	234.6	-10.98
^{10}B	^{240}Np	-17.06		0.4	
^{10}Be	^{240}Pu	-15.42	51 ± 4.3 {	42.3	-22.22
^{9}Be	^{241}Pu	-17.00		8.7	
^{7}Li	^{243}Am	-24.78	7 ± 10 {	6.1	-33.70
^{6}Li	^{244}Am	-26.66		0.9	

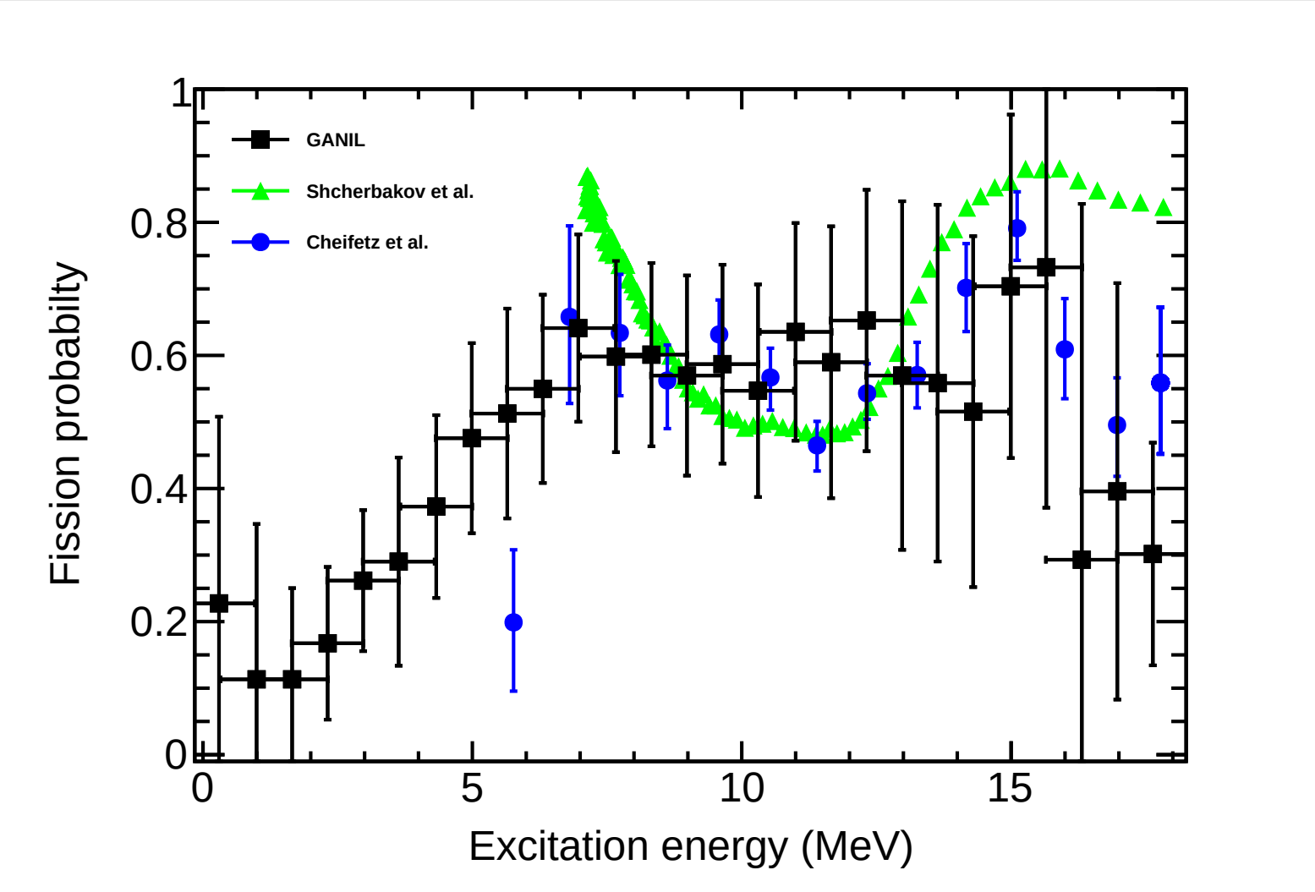




⇒ Good agreement with previous measurements from similar systems !

Fission probability of ^{240}Pu

$$P_{fission}(Z,A,E^*) = \frac{\text{Number of (Z,A, E*) fissioning actinides}}{\text{Number of (Z,A,E*) produced actinides}}$$



- ^{238}U + ^{12}C ⟶ ^{240}Pu* + ^{10}Be
  two proton transfer (present work at GANIL)
- ^{12}C + ^{236}U ⟶ ^{8}Be + ^{240}Pu*
  α transfer by Cheifetz *et al.*, PRC 24, 519 (1981)
- ^{239}Pu + n ⟶ ^{240}Pu*
  (n,f) by Shcherbakov *et al.*, EXFOR (2001)

⇒ Experimental method validated !

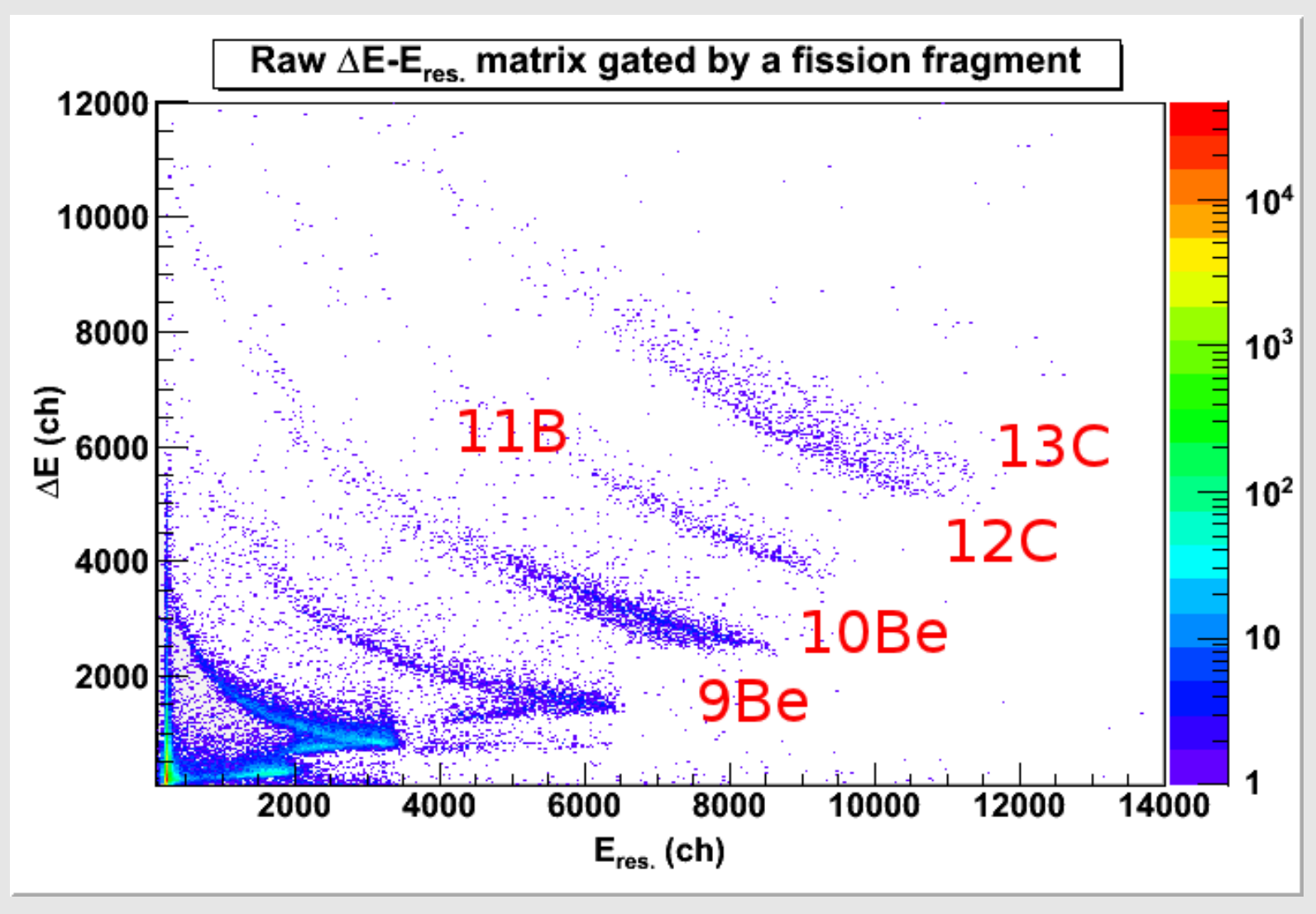
SPIDER 2.0

New experiment in July 2011

Modifications :

- new detectors
- cooling system (liquid silicone)
- radiation shielding

⇒ Isotopic identification achievable !



Conclusion

Multi-nucleon transfer reactions are a valuable a tool to study actinides

→ the original experiment was a "proof of concept"
→ the technical feasability has been demonstrated
→ the lastest experiment will provide excellent results !

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