Present and future investigations using the surrogate-reaction method

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Sakura-2019 Workshop

Motivation

The study of neutron-induced fission and capture cross sections of **short-lived nuclei** is very important to many domains

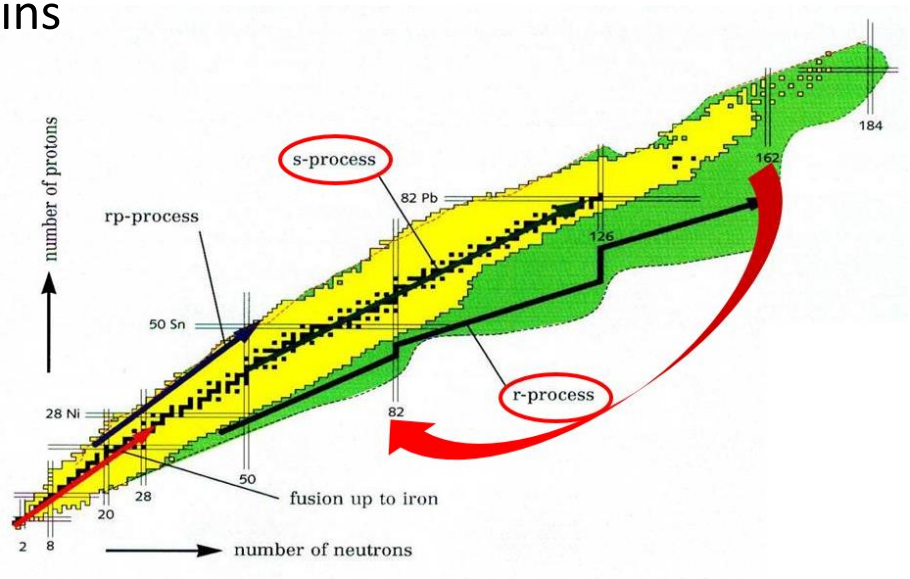
- **Nuclear astrophysics**

understanding the origin of the elements

- **Reactor physics**

development of more efficient reactors

- **Medical applications**

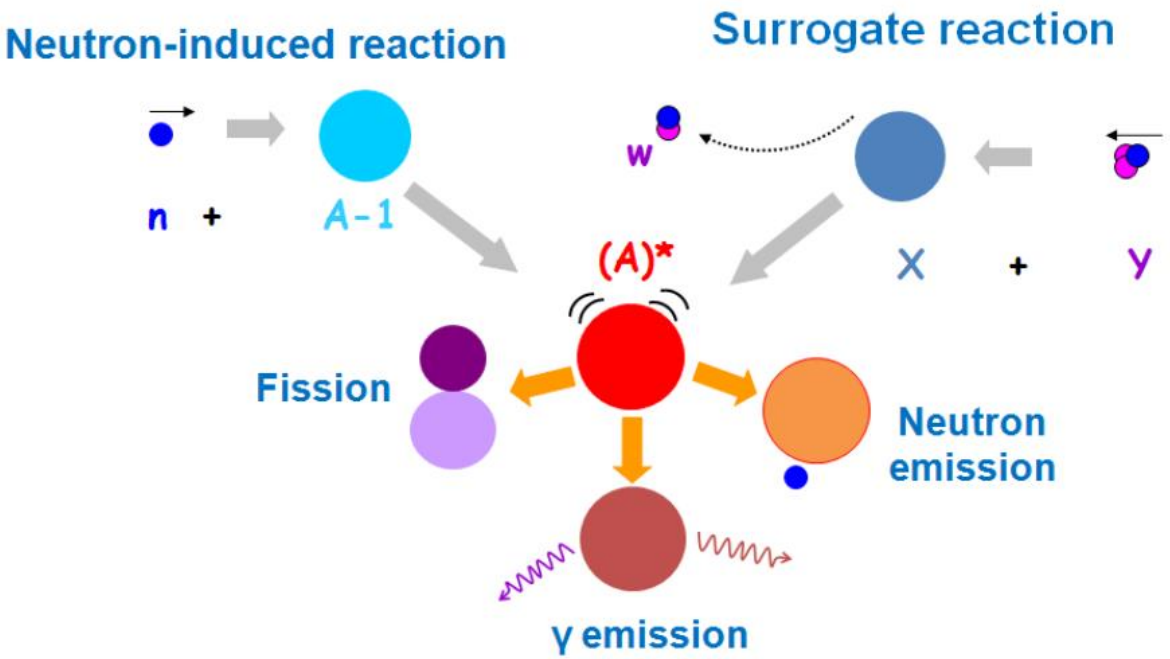


Often cross sections are very difficult or even impossible to measure due to the high radioactivity of the targets involved!

Surrogate Reaction Method

J. Cramer and H. Britt, Nucl.Sci.Eng. 41 (1970)

Production of the ion of interest through an alternative reaction
to overcome the difficulties to **produce and manipulate** radioactive isotopes



$$\sigma^{A}_{n,decay}(E^*) = \underbrace{\sigma^{A+1}_{CN}(E^*)}_{\text{Theory}} \cdot \underbrace{P^{surro}_{decay}(E^*)}_{\text{Experiment}}$$

Optical model

Surrogate Reaction Method - Validity

Neutron-induced and surrogate reaction must lead to the formation of a compound

$$\sigma^{A}_{n,decay}(E^*) = \sigma^{A+1}_{CN}(E^*) \cdot P^{surro}_{decay}(E^*)$$

The decay only depends on E*, *J* and π!

In addition, $P^{surro}_{decay}(E^*) = P^{n}_{decay}(E^*)$

At a limit:

- The populated *J* and π distributions are equal
- The decay is independent of *J* and π (Weisskopf-Ewing limit valid at high E*)

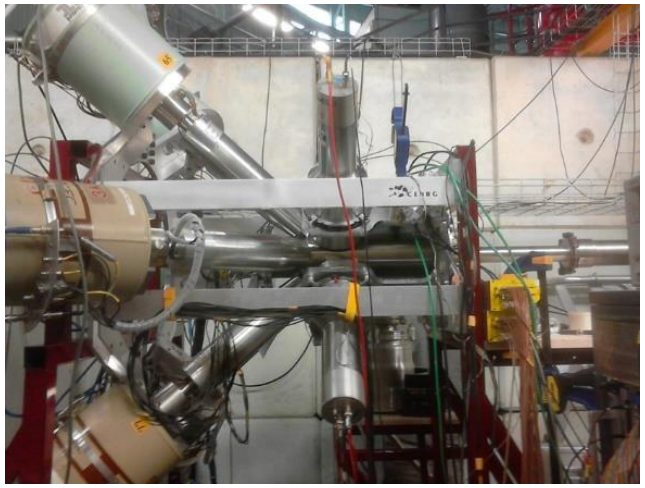
Validity determined a posteriori

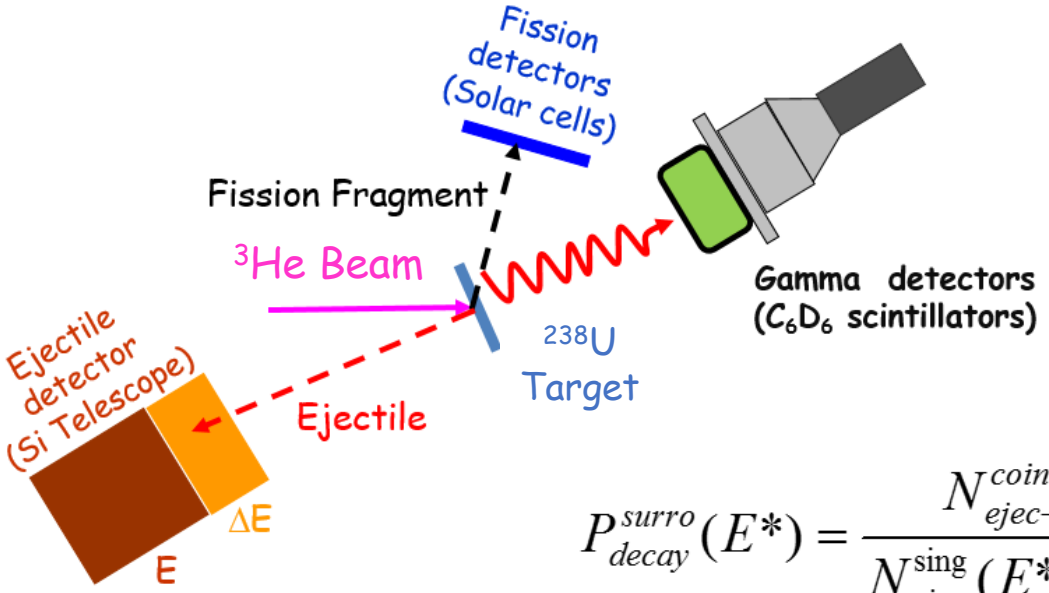
Data obtained with the surrogate method need to be compared to neutron-induced data

Surrogate Reaction Method - Experiment

Simultaneous measurement of fission and γ-decay probabilities

$^{3}He + {}^{238}U \rightarrow {}^{4}He + \underline{{}^{237}U^{*}} \Leftrightarrow n + {}^{236}U$





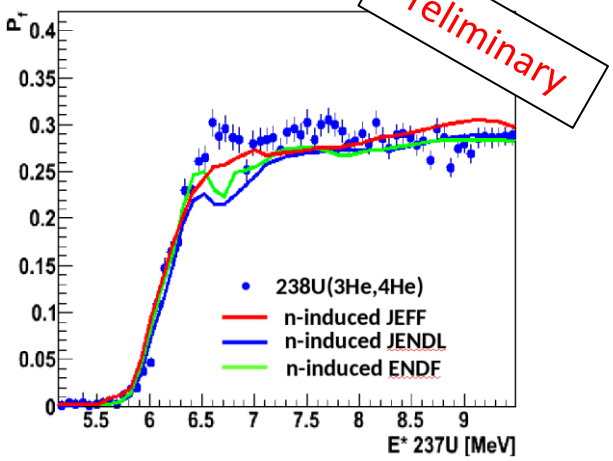
$$P_{decay}^{surro}(E^*) = \frac{N_{ejec-decay}^{coin}(E^*)}{N_{ejec}^{sing}(E^*) \cdot \varepsilon_{decay}(E^*)}$$

Surrogate Reaction Method - Results

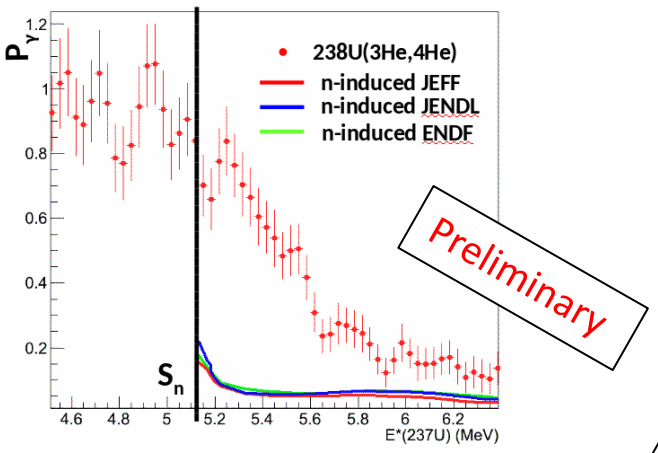
Comparison to neutron-induced calculations

$^{3}He + {}^{238}U \rightarrow {}^{4}He + \underline{{}^{237}U^{*}} \Leftrightarrow n + {}^{236}U$ P. Marini et al., to be published

Fission

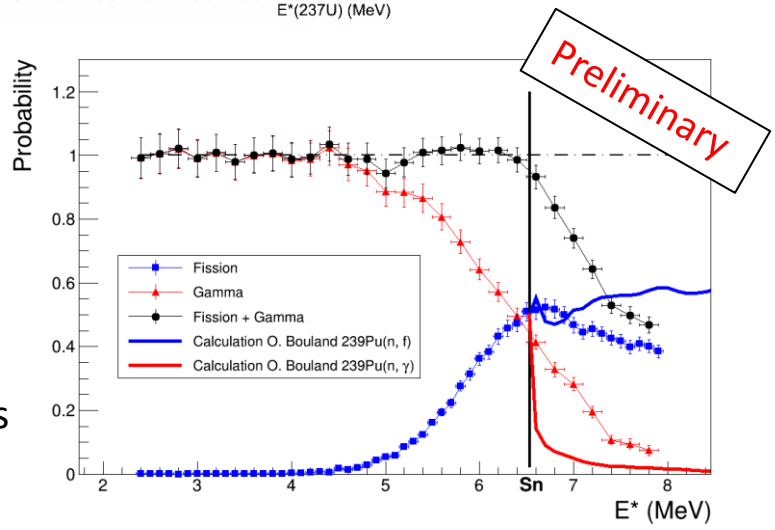


Gamma emission



$^{4}He + {}^{240}Pu \rightarrow {}^{4}He' + \underline{{}^{240}Pu^{*}} \Leftrightarrow n + {}^{239}Pu$

PhD thesis of R. Perez-Sanchez



Even-even nucleus, low density of states near the fission barrier
Significant **discrepancies** for gamma and fission probabilities

Surrogate Reaction Method

Surrogate Reactions can be use to tune parameters in theoretical models

Step 1: Calculate spin-parity distributions

Step 2: Match the experimental surrogate decay probabiity by tuning the parameters of the statistical model

Step 3: Predict the desired neutron cross-sections

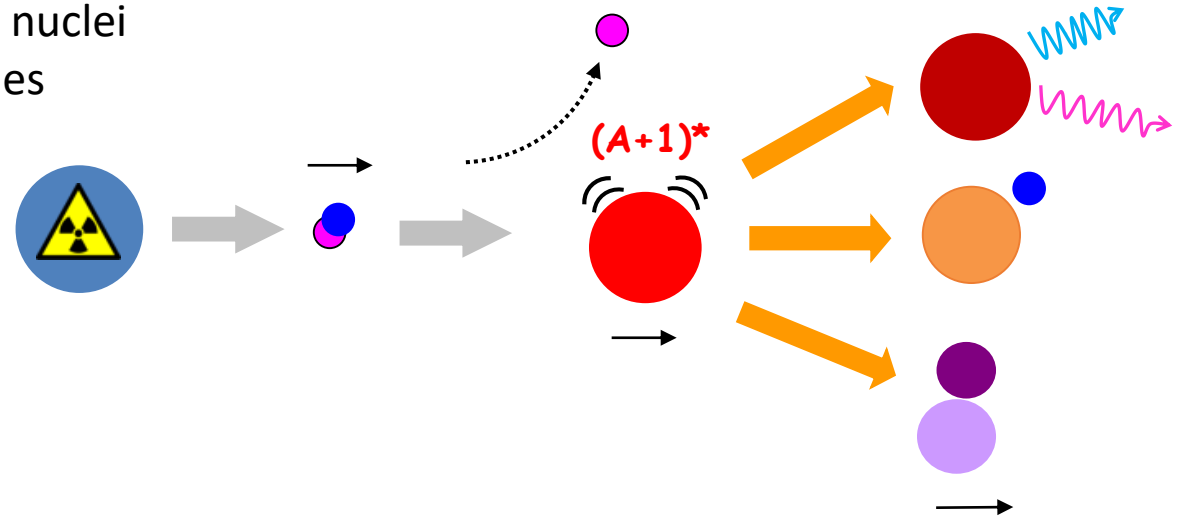
$$P_{surro,decay}(E^*) = \sum_{J^\pi} P_{surro}^{form}(E^*, J^\pi) \cdot P_{decay}(E^*, J^\pi)$$

Technical limitations of Direct Kinematics

- Unavailability of targets from short-lived nuclei
- High background from target contaminants
- P_γ: low detection efficiency; discrimination of gammas from fission fragments
- P_n: measurement of low-energy neutrons and neutron efficiency

Inverse kinematics

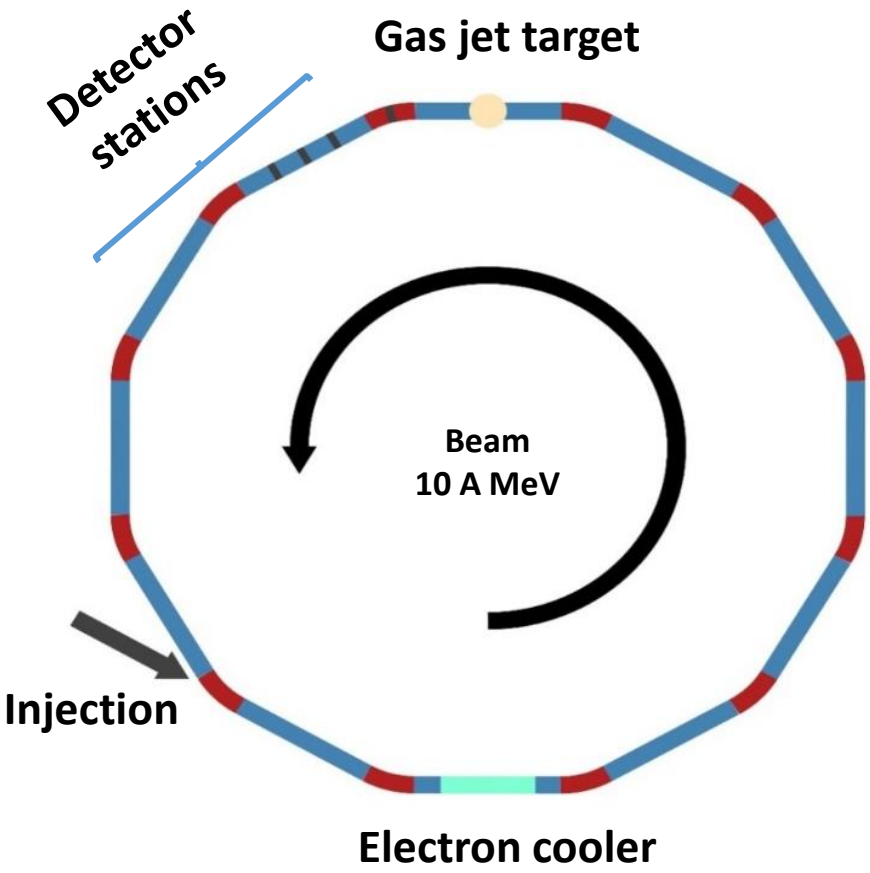
Access to very short-lived nuclei
Detection of heavy residues



Storage Rings

Energy resolution – 100 keV
No target contaminants

Surrogate Reactions at Heavy-ion Storage Rings



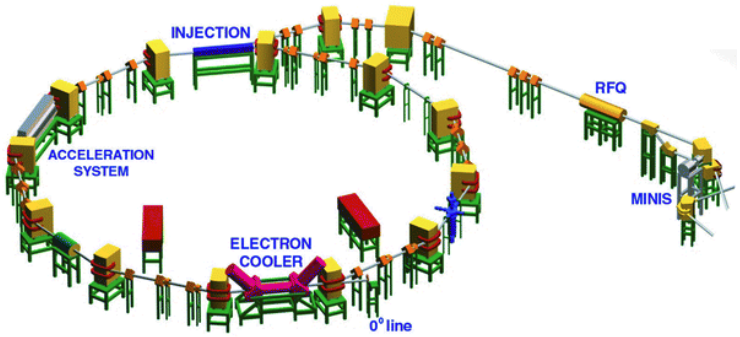
-Pure, ultrathin gas target

without contaninants

-Excelent beam energy resolution due to e^- cooling

-Excelent spacial resolution

ε_{beam} up to 0.05 mm·mrad

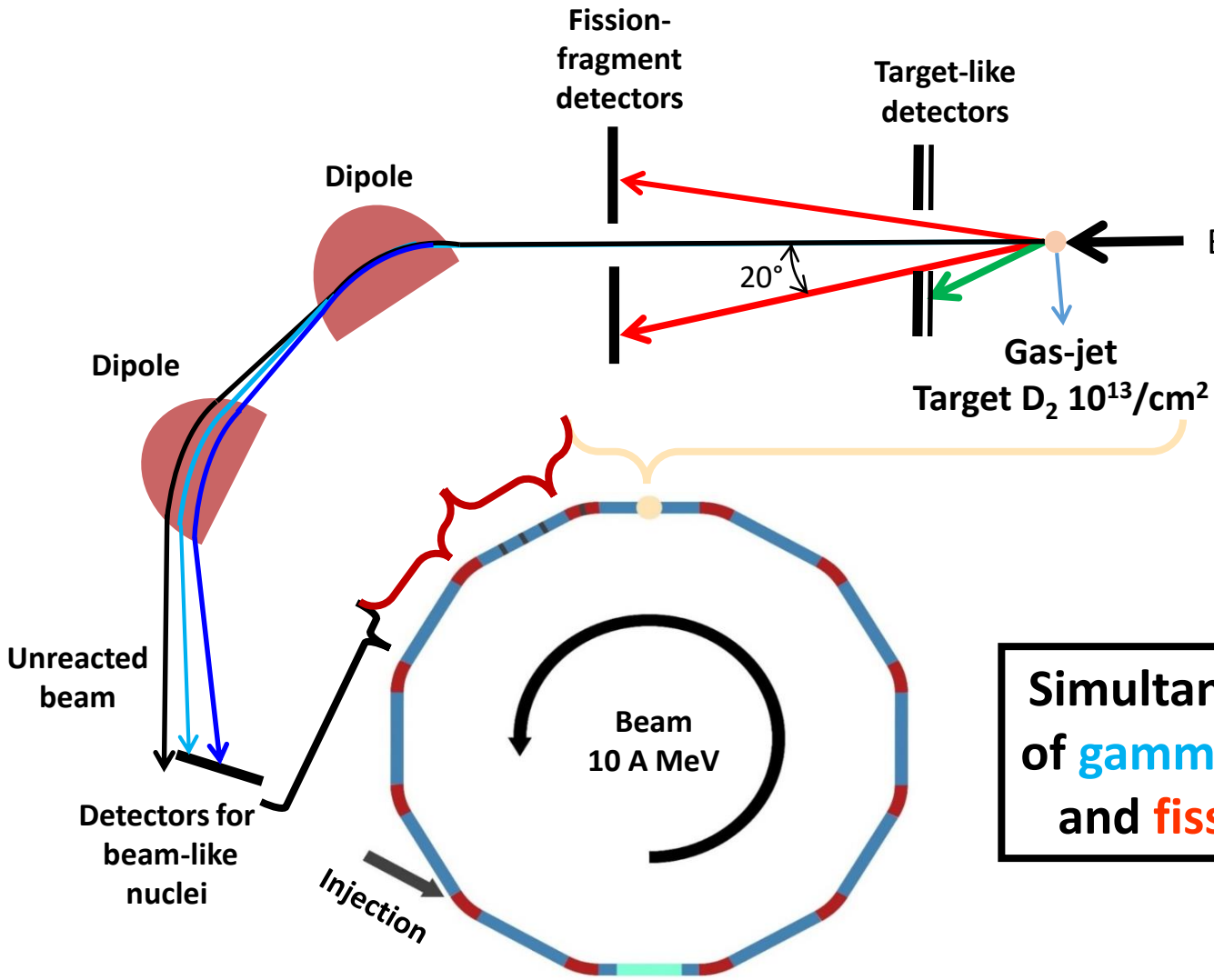


CRYRING @ GSI

Extreme High Vacuum

XHV-10^{-11}->10^{-12} mbar

Surrogate Reactions at Heavy-ion Storage Rings

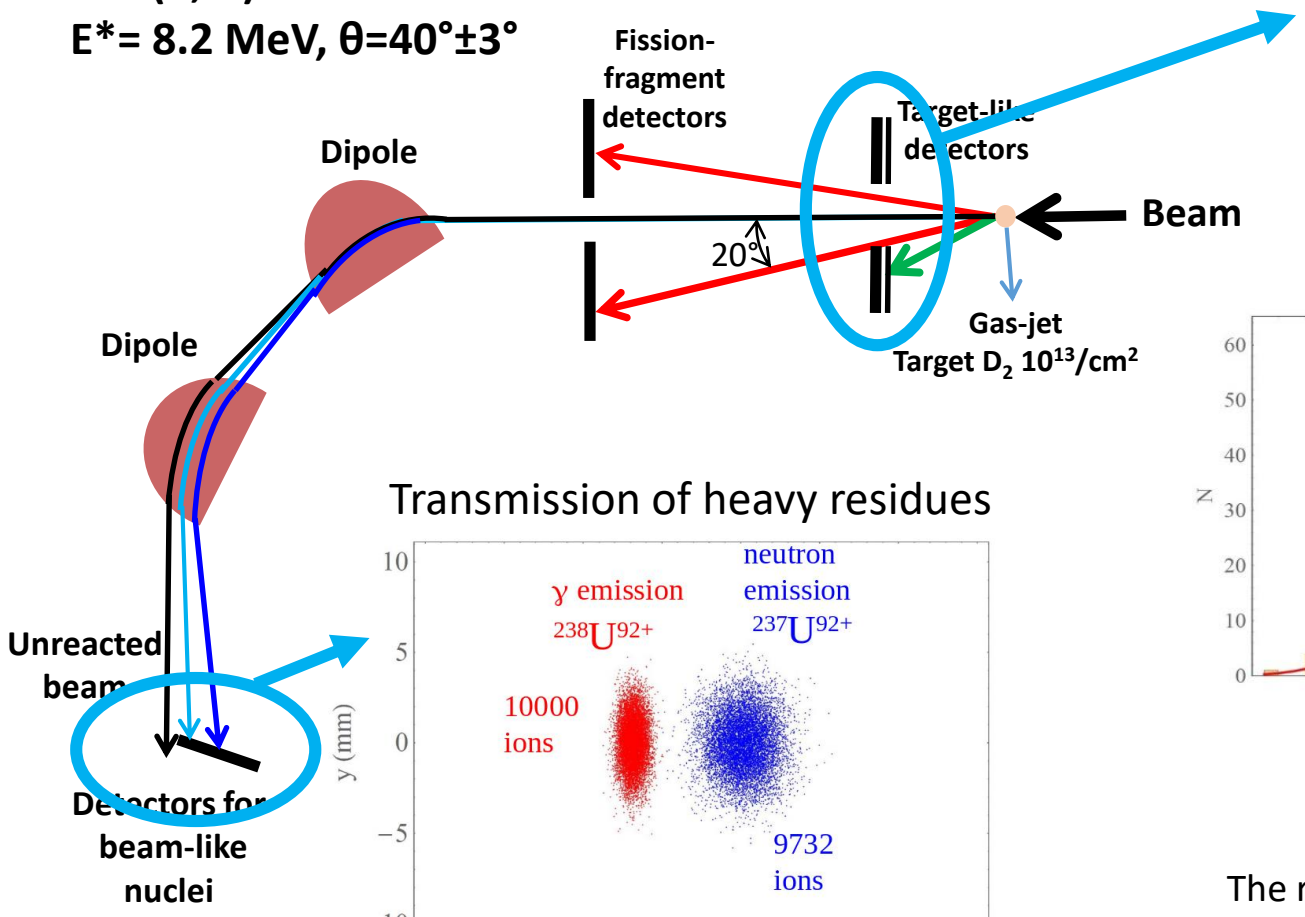


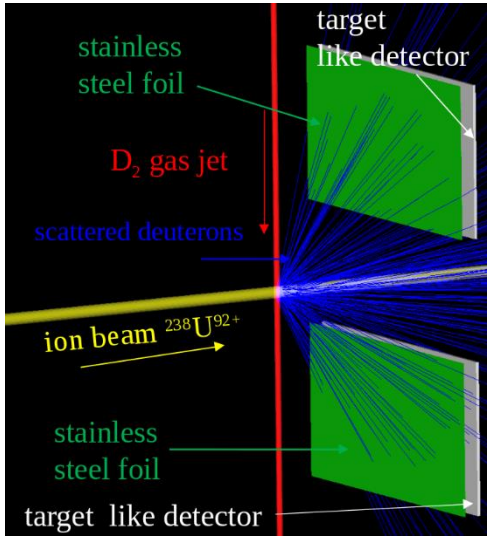
Simultaneous measurement of gamma, neutron-emission and fission probabilities!!

Surrogate Reactions at Storage Rings

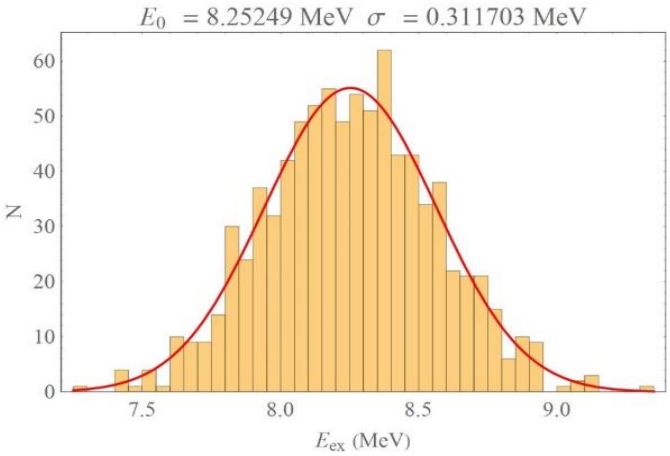
Very realistic **simulations** Manfred Grieser – MPIK, Germany

^{238}U(d,d') at 11 A MeV
E*= 8.2 MeV, θ=40°±3°





Transmission of heavy residues

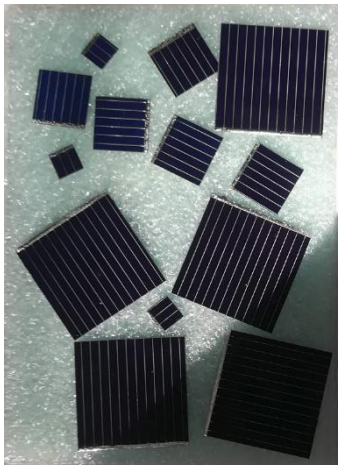


E* resolution of 200-400 keV

The reconstructed E* resolution is most limited by the detector resolution.

Surrogate Reactions at Storage Rings

Solar Cells -> Heavy ion detectors @ Storage Rings



- Low cost
- Very robust
- Flexible geometry
- Operates without bias voltage
- High radiation damage resistance
- High capacitance ≈ 38 nF/cm^2

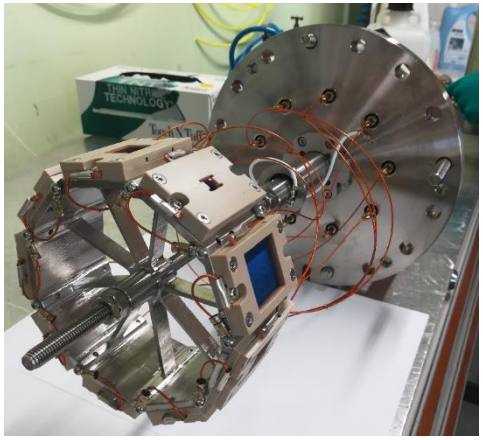
NUCLEAR INSTRUMENTS AND METHODS 164 (1979) 437-438, © NORTH-HOLLAND PUBLISHING CO

PHOTOVOLTAIC CELLS AS FISSION PRODUCT DETECTORS

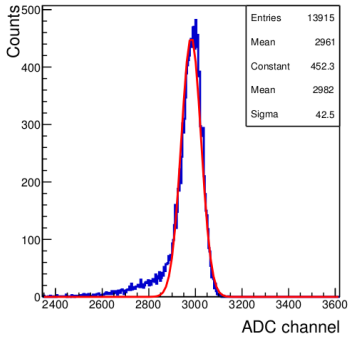
GÜNTER SIEGERT*
Institut Laue Langevin, Grenoble, France

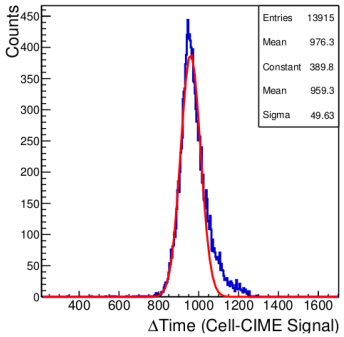
- **Study XHV compability**
  - -Outgasing rate < 5.10^{-11}mbar.l/(s.cm^2)
- **Develop specific pre-amplifiers**
- **Irratiation of cells**
  - -Heavy ions above 1 A MeV

Experiment @ GANIL, France
^{84}Kr, ^{129}Xe beams @ 2 to 15 A MeV



5x5 mm^2 cell at ^{129}Xe at 10 MeV/u





Energy resolution:
2-3 %
Time resolution:
4 ns

So far, suitable for SR experiments

Conclusions and Outlook

- **Surrogate method** as a promising method to infer neutron-induced cross sections
- An experimental setup was developed at CENBG to **measure simultaneously the gamma emission and fission probabilities**
  - Studies in direct kinematics have opened many questions regarding its direct comparison to neutron induced reactions
  - Surrogate reactions can be very useful to constrain model parameters

- Moving to inverse kinematics at **storage rings** will enable to **measure simultaneously the gamma, neutron-emission and fission probabilities** with high quality data
  - We are developing a setup to be used at the **CRYRING@GSI**
  - Some preliminary studies of the ^{238}U(d,d') reaction have indicated efficiencies close to 100%, E* resolution of 300 keV

- **Solar cells** are foreseen to work as **heavy ion detectors** and we have conducted a series of sucessful exploratory tests to evalue their compability with the future measurements and the storage ring environment.

Thank you!