Future Fission Studies in Inverse Kinematics at Storage Rings

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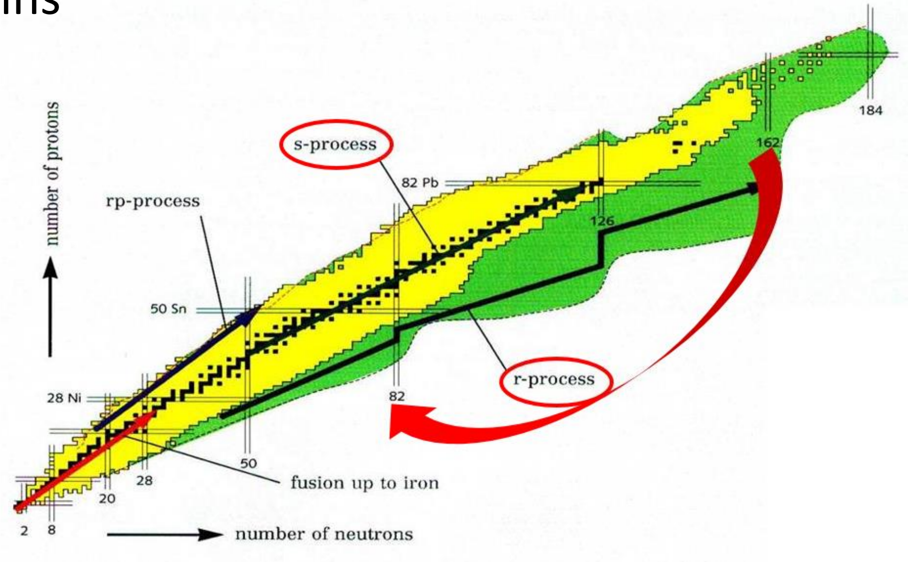
Outline

- **Motivation**
- **Surrogate-reaction Method**
    - **Validity**
- **Experiments in Direct Kinematics**
    - **Experimental setup**
    - **Technical limitations**
- **Moving to Inverse Kinematics at Storage Rings**
    - **Proposed experimental setup**
    - **Simulations**
- **Solar Cells as Heavy Ion Detectors**
    - **Advantages**
    - **Compability with SR environment**
    - **Response to heavy ions (E>1 MeV/u)**

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

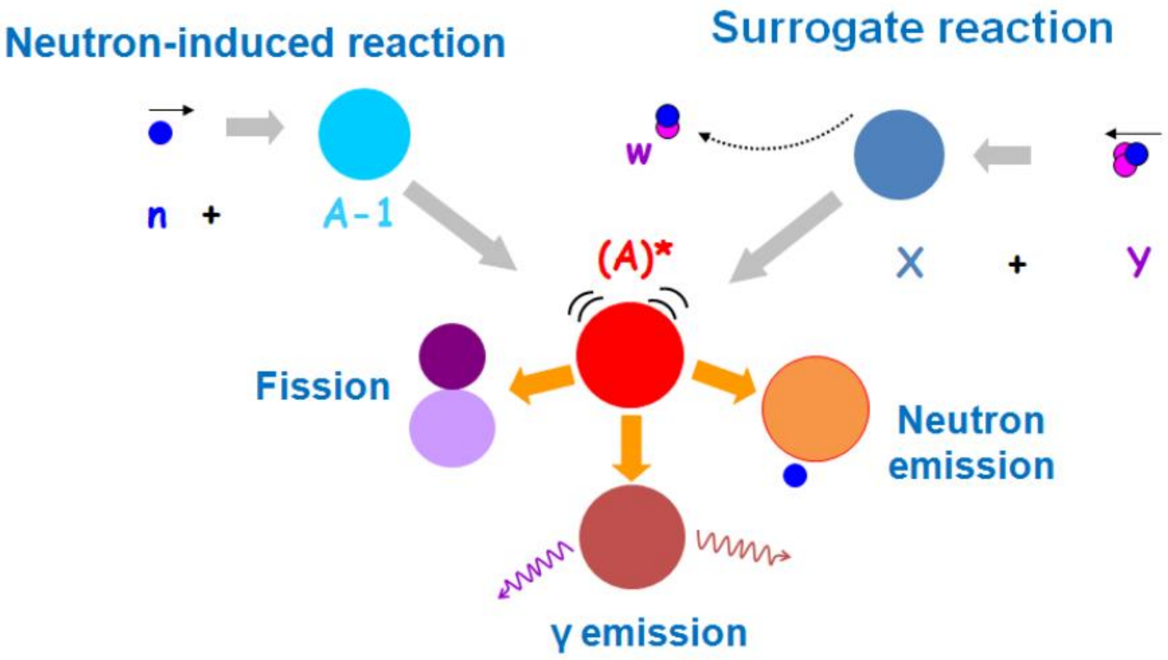
- **Medical applications**

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



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

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*)

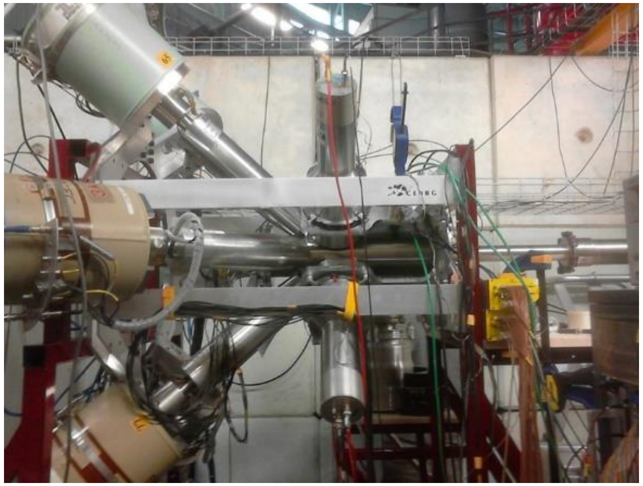
Validity determined a posteriori

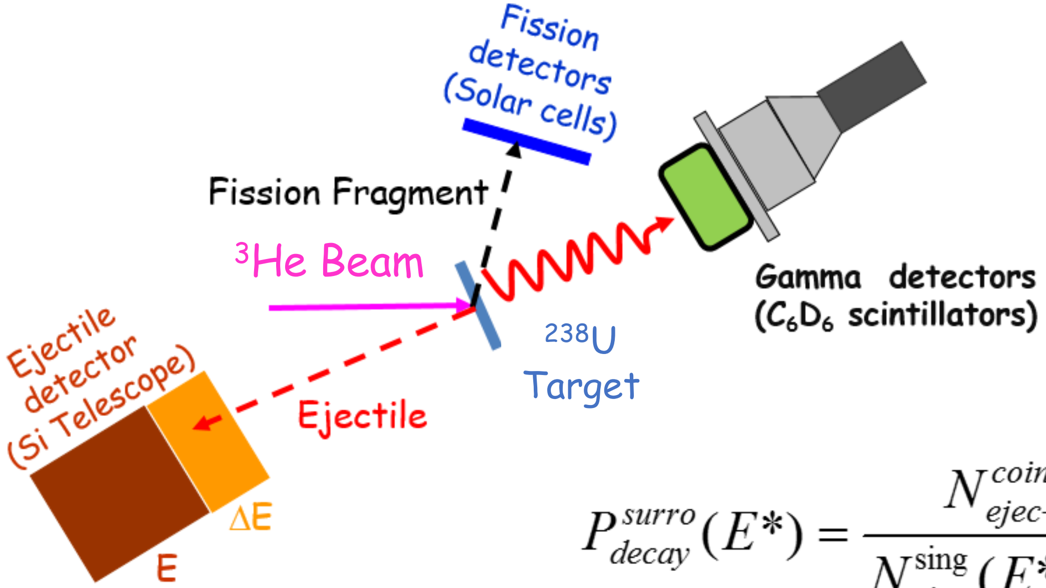
Data obtained with the surrogate method need to be compared to neutron-induced data

Surrogate Reaction Method - Experiment

Simultaneous measurement of fission and γ-decay probabilities

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





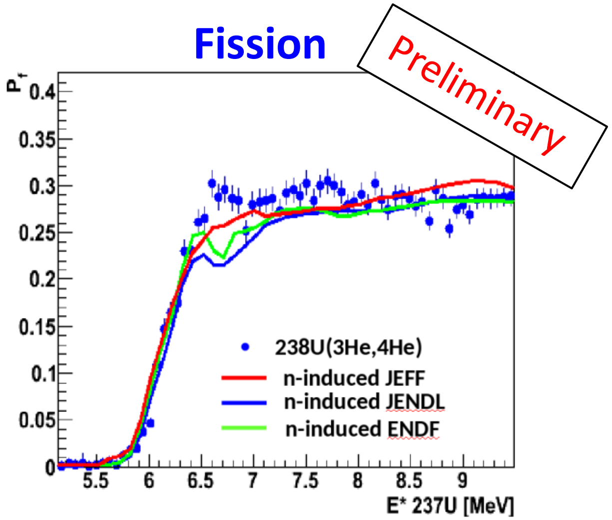
$$ P_{decay}^{surro}(E^{*}) = \frac{N_{ejec-decay}^{coin}(E^{*})}{N_{ejec}^{\mathrm{sing}}(E^{*}) \cdot \varepsilon_{decay}(E^{*})} $$

Surrogate Reaction Method - Results

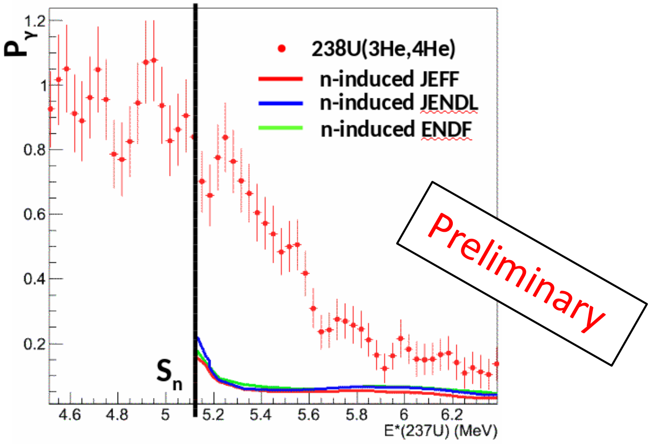
Comparison to neutron-induced calculations

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

Fission

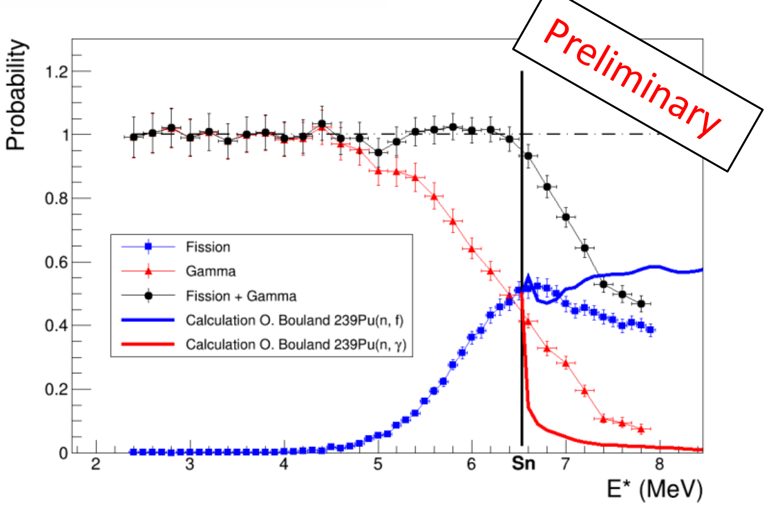


Gamma emission



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

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 probability by tuning the parameters of the statistical model

Step 3: Predict the desired neutron cross-sections

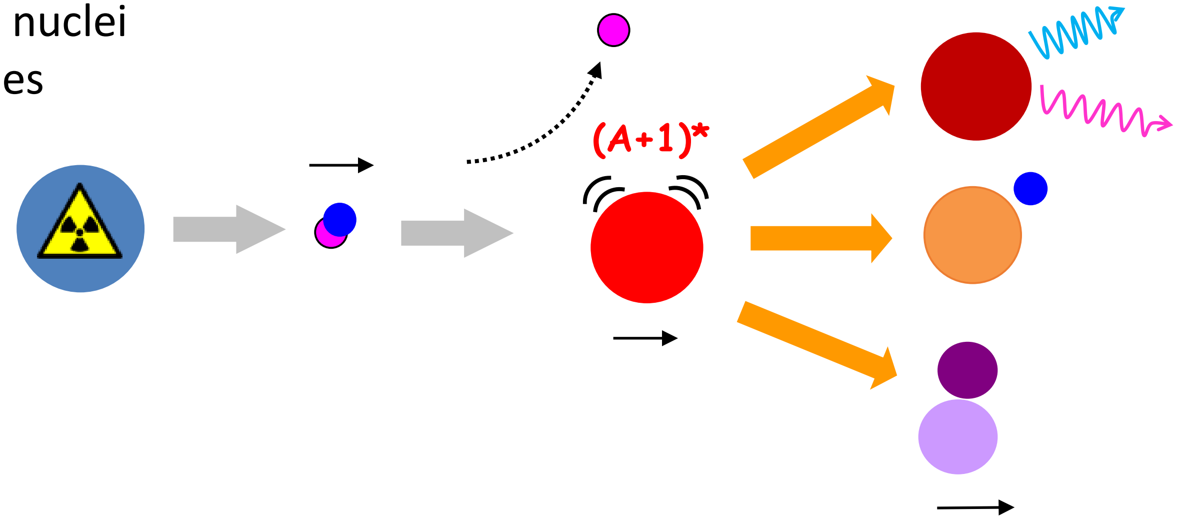
$$P_{surro,decay}(E^*) = \sum_{J^\pi} P_{surro}^{form}(E^*, J^\pi) \cdot P_{decay}(E^*, J^\pi)$$

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

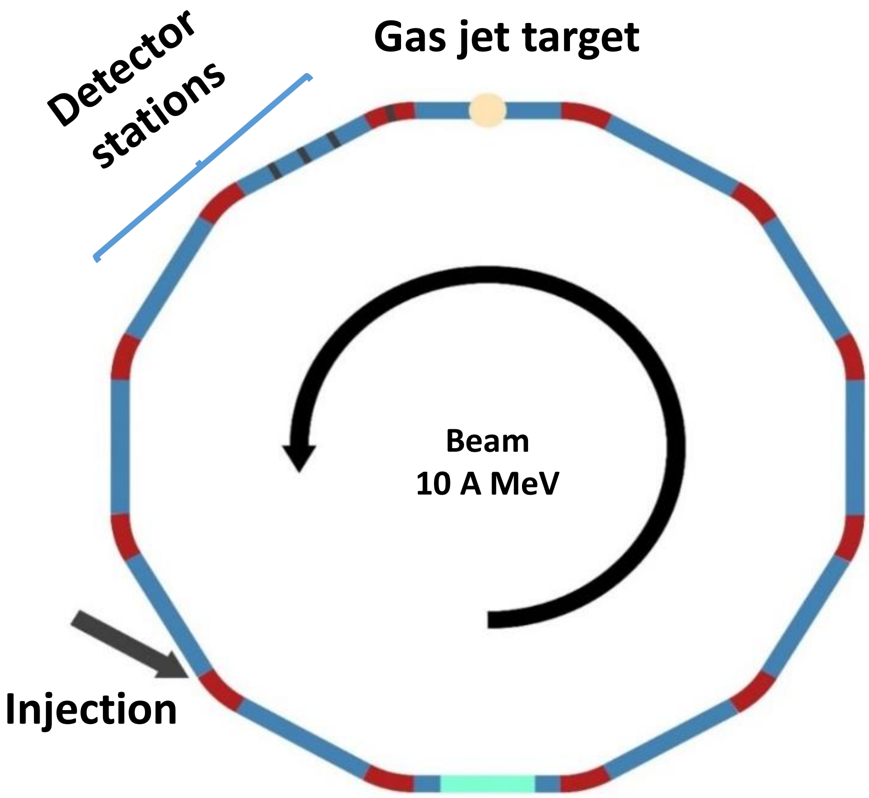
Access to very short-lived nuclei
Detection of heavy residues



Storage Rings

Energy resolution – 100 keV
No target contaminants

Surrogate Reactions at Heavy-ion Storage Rings



Detector stations

Gas jet target

Beam
10 A MeV

Injection

Electron cooler

Extreme High Vacuum

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

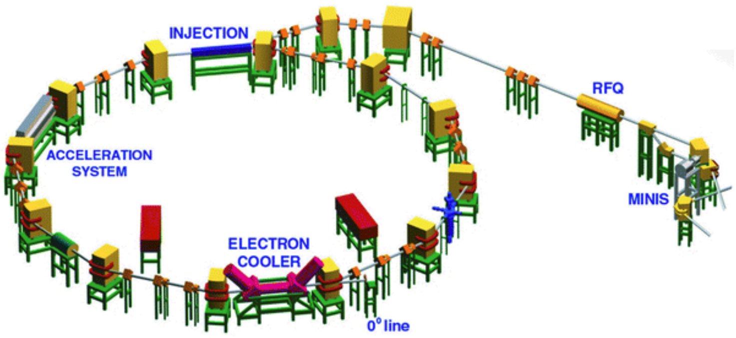
-Pure, ultrathin gas target

without contaninants

-Excelent beam energy resolution due to e^- cooling

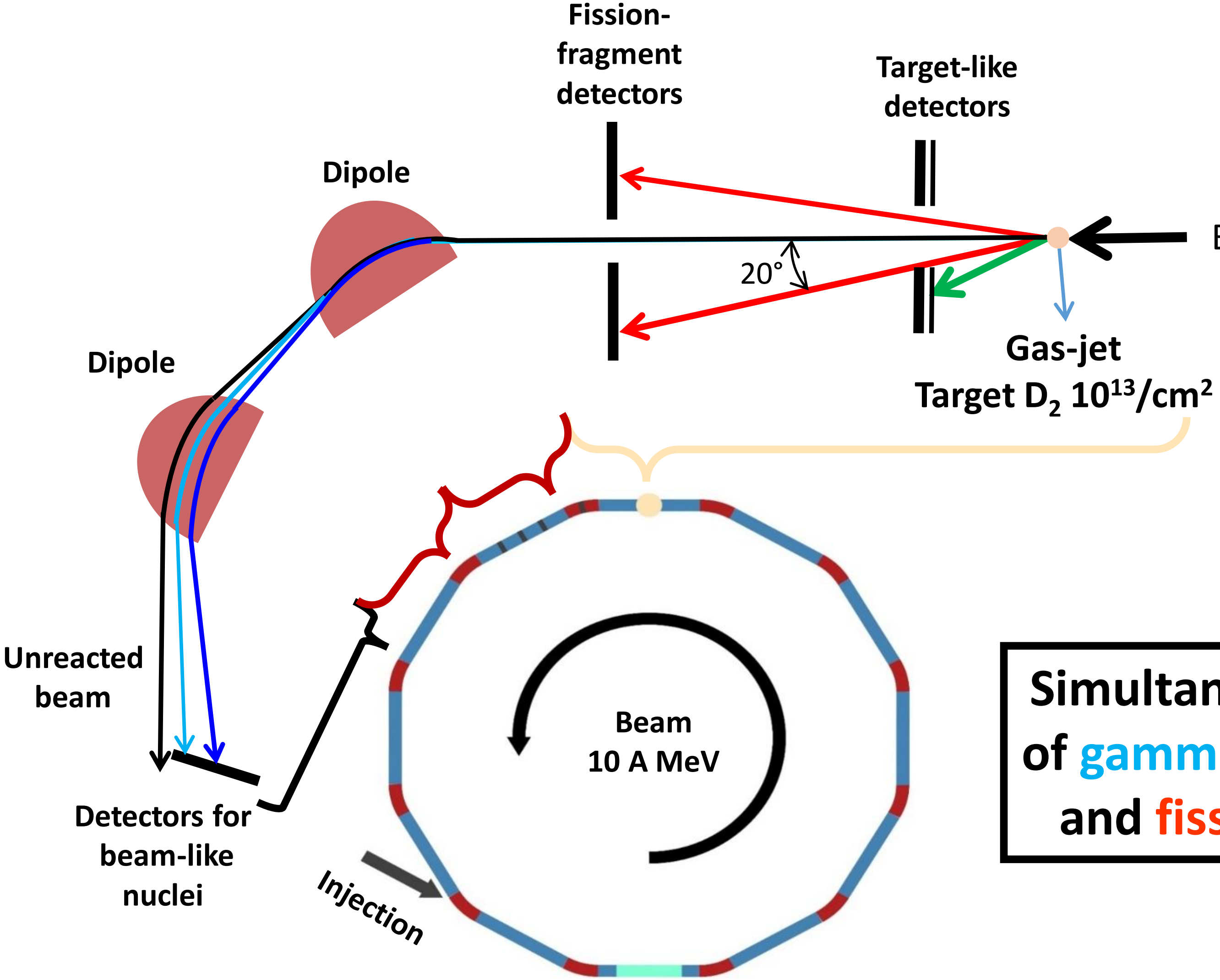
-Excelent spacial resolution

ε_{beam} up to 0.05 mm·mrad



CRYRING @ GSI

Surrogate Reactions at Heavy-ion Storage Rings



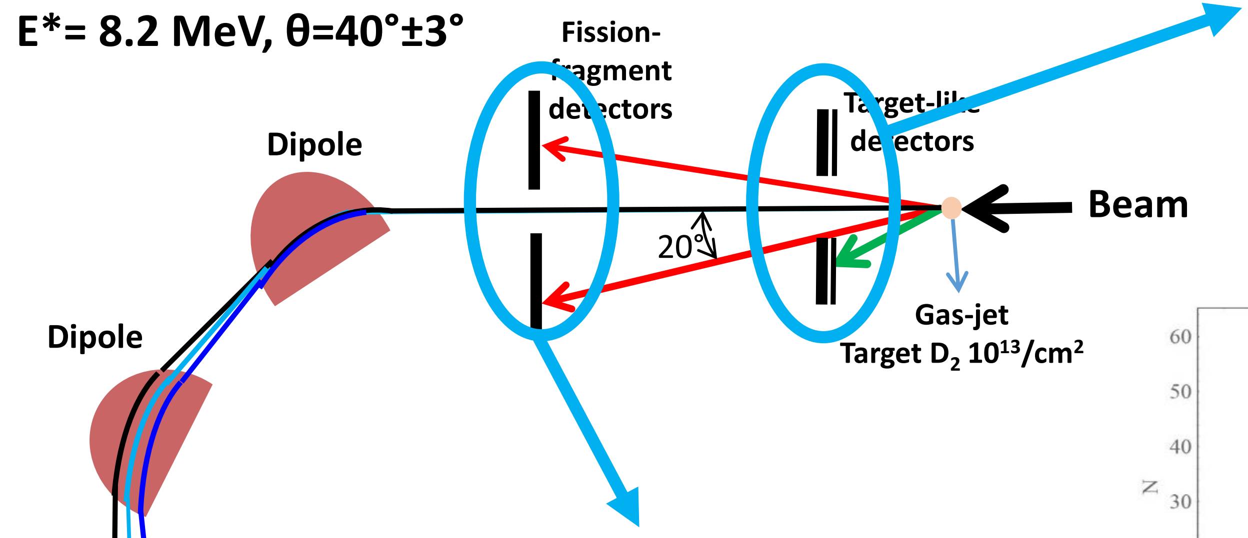
Simultaneous measurement of gamma, neutron-emission and fission probabilities!!

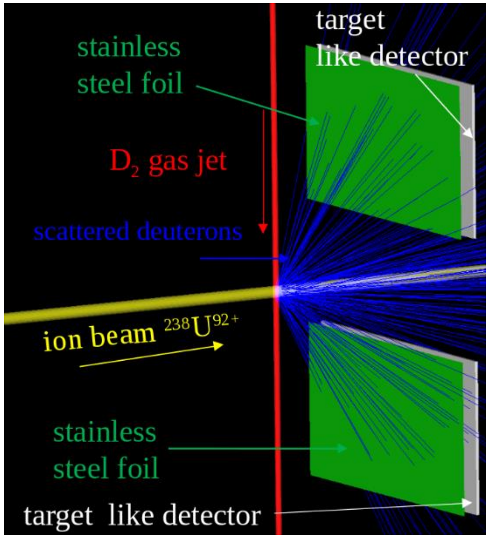
Surrogate Reactions at Storage Rings

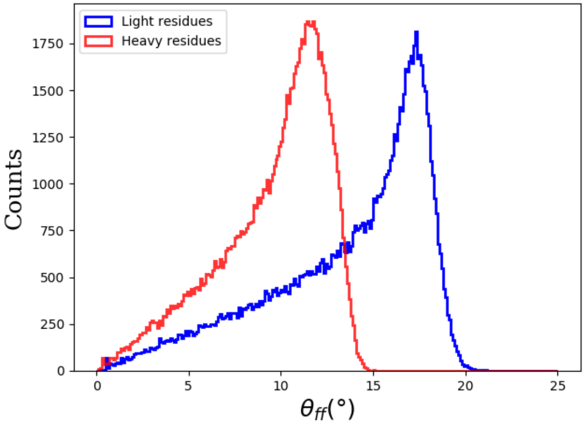
Very realistic **simulations** Manfred Grieser – MPIK, Germany

^{238}U(d,d') at 11 A MeV

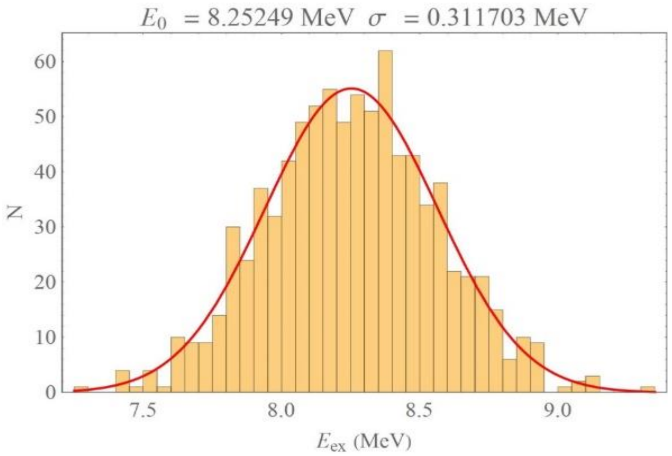
E*= 8.2 MeV, θ=40°±3°







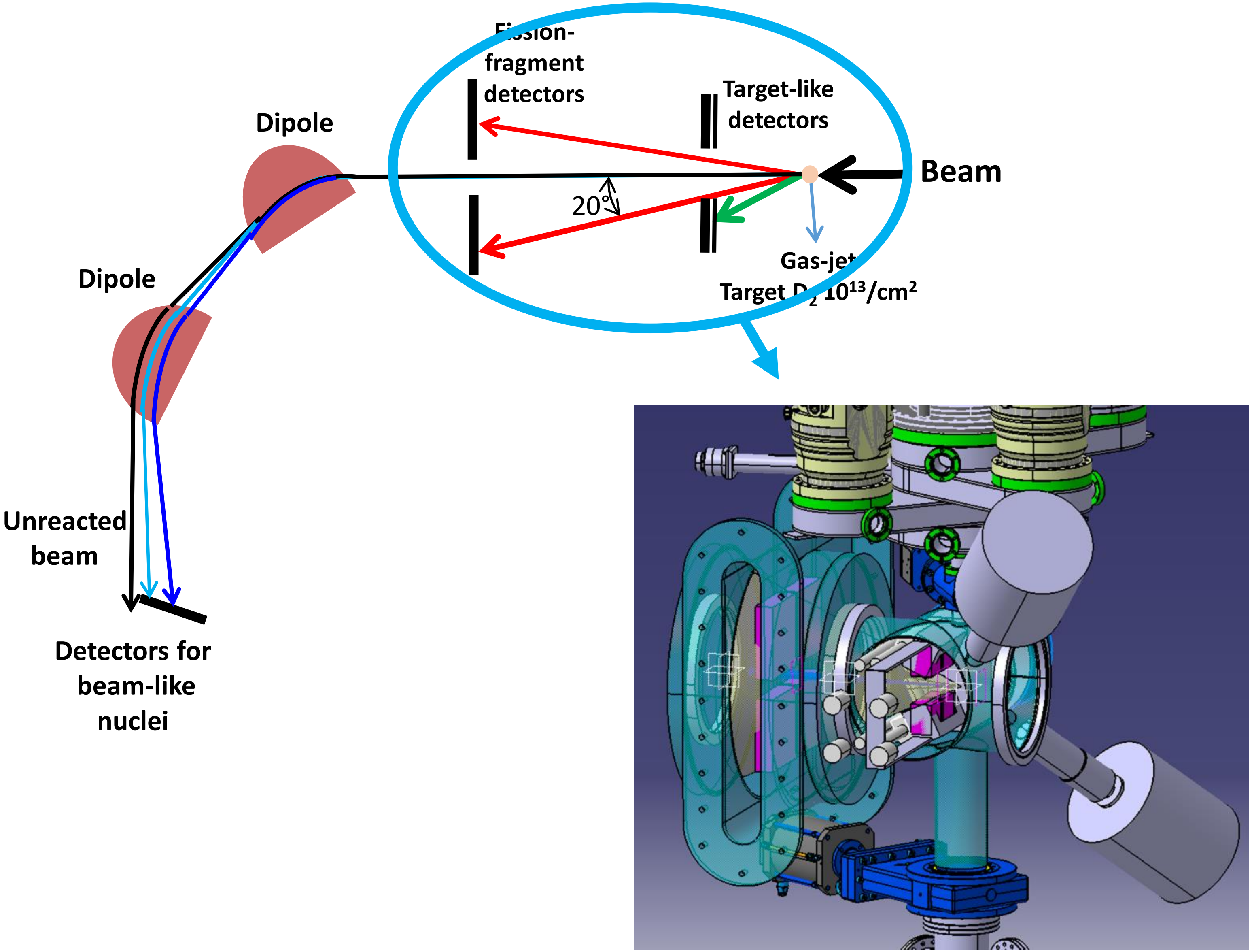
Fission fragments emitted in a 20° cone



E* resolution of 200-400 keV

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

Surrogate Reactions at Storage Rings



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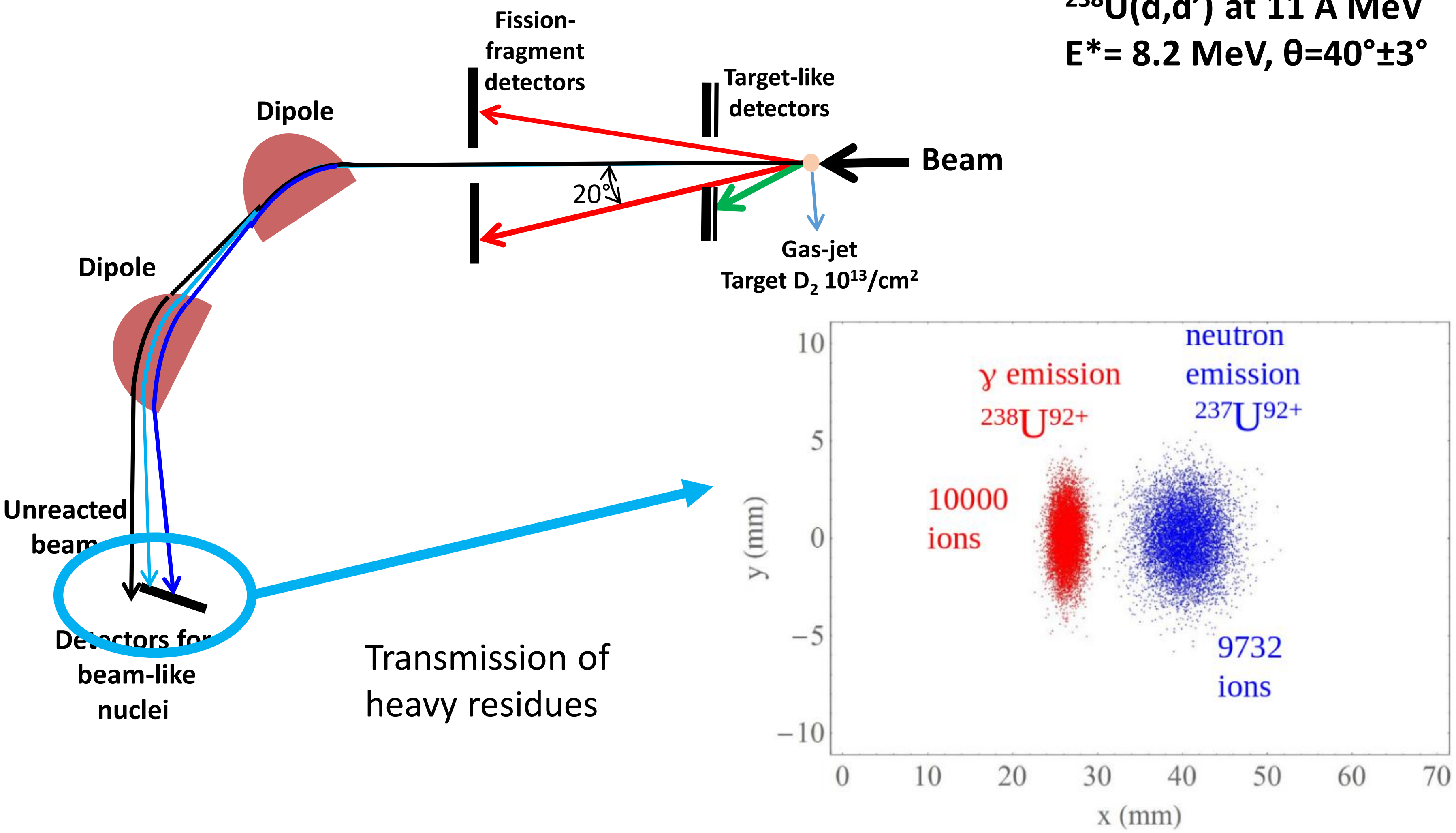
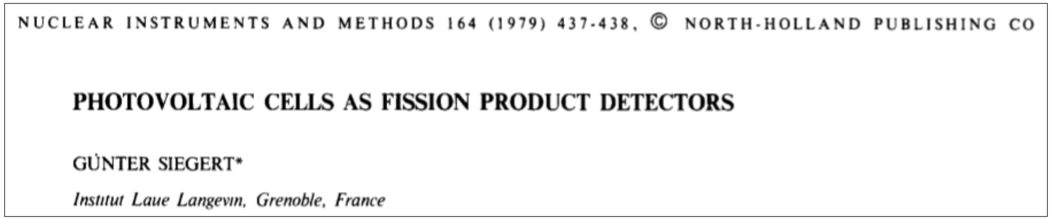


Transmission of heavy residues

Surrogate Reactions at Storage Rings

Solar Cells -> Heavy ion detectors @ Storage Rings



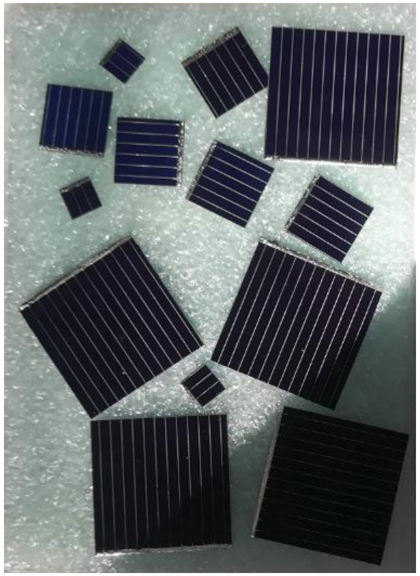
NUCLEAR INSTRUMENTS AND METHODS 164 (1979) 437-438, © NORTH-HOLLAND PUBLISHING CO

PHOTOVOLTAIC CELLS AS FISSION PRODUCT DETECTORS

GÜNTER SIEGERT*

Institut Laue Langevin, Grenoble, France

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



- Specific pre-amplifiers

- Study XHV compability

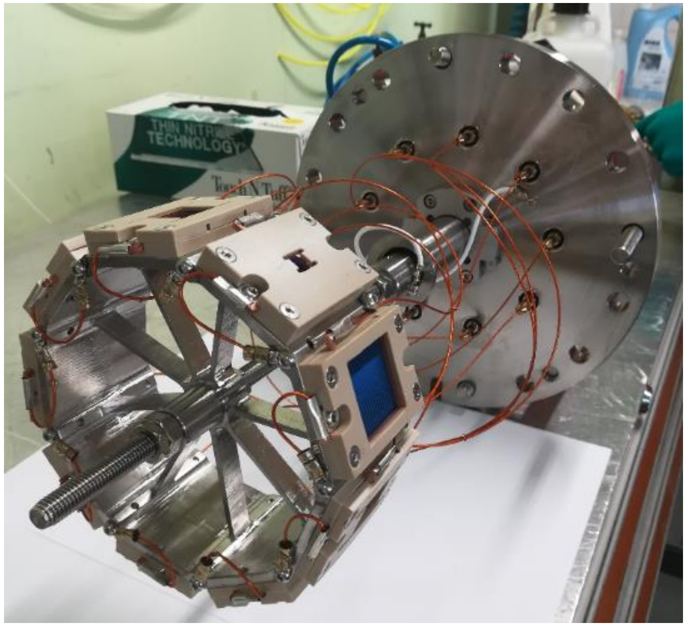
  -Outgasing rate < 5.10^{-11}mbar.l/(s.cm^2)

- Irratiation of cells

  -Heavy ions above 1 A MeV

Surrogate Reactions at Storage Rings

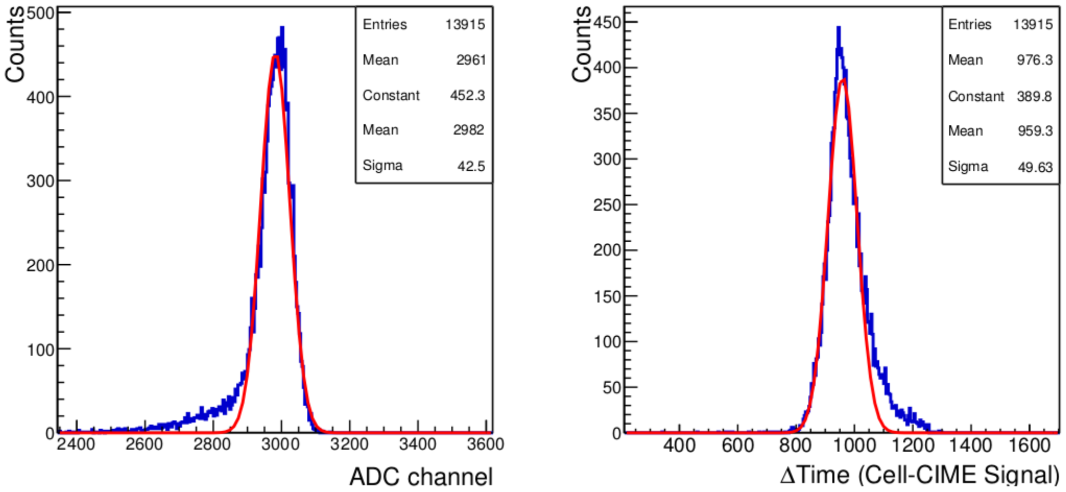
Solar Cells -> Heavy ion detectors @ Storage Rings



Experiment @ GANIL, France

^{84}Kr, ^{129}Xe, ^{238}U 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

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 tune 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 evaluate their compability with the future measurements and the storage ring environment.

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Thank you!

GSI/FAIR Facility