Determining neutron-induced reaction cross sections through surrogate reactions at storage rings

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Schools on **N**uclear **A**strophysics **Q**uestions

The NECTAR project - determine neutron-induced reaction cross sections

- Focus on short-lived nuclei, of interest to:

Nuclear astrophysics

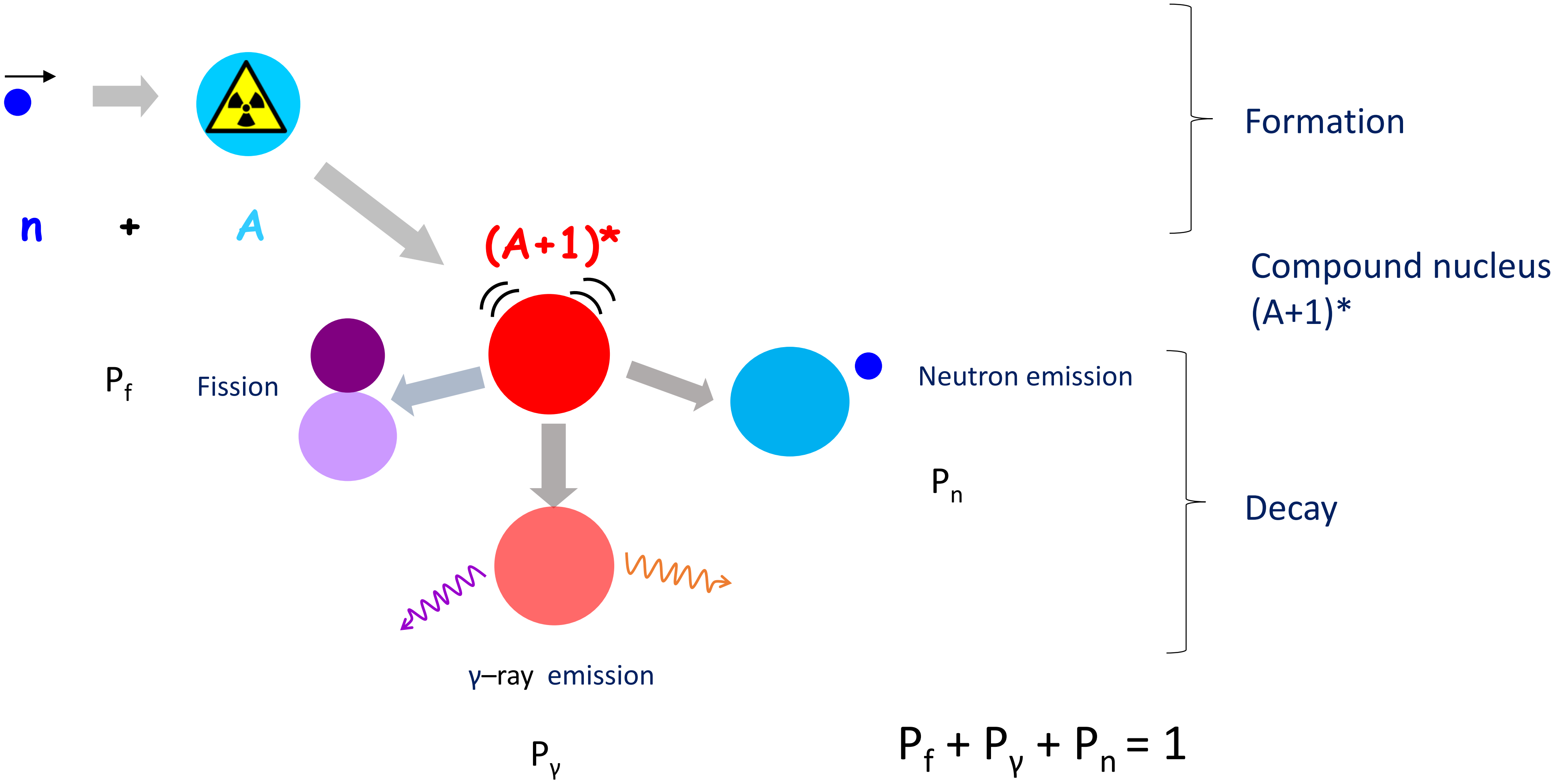
- Nuclear astrophysics
- Applications (e.g. nuclear energy, medicine)

Nuclear r
E
C
Tions
At storage
Rings

Nuclear medicine

Nuclear energy

→ One way: a neutron beam on a radioactive target:



$$P_f + P_\gamma + P_n = 1$$

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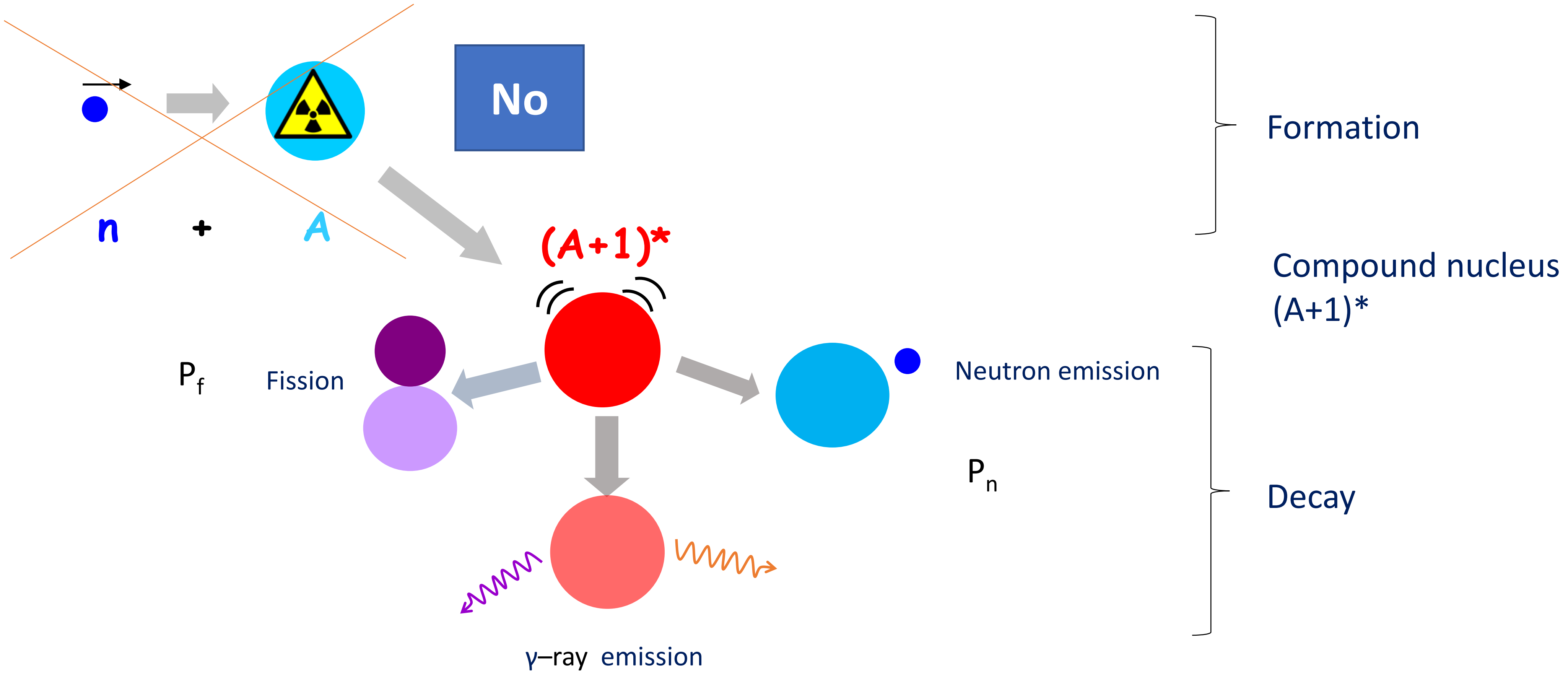
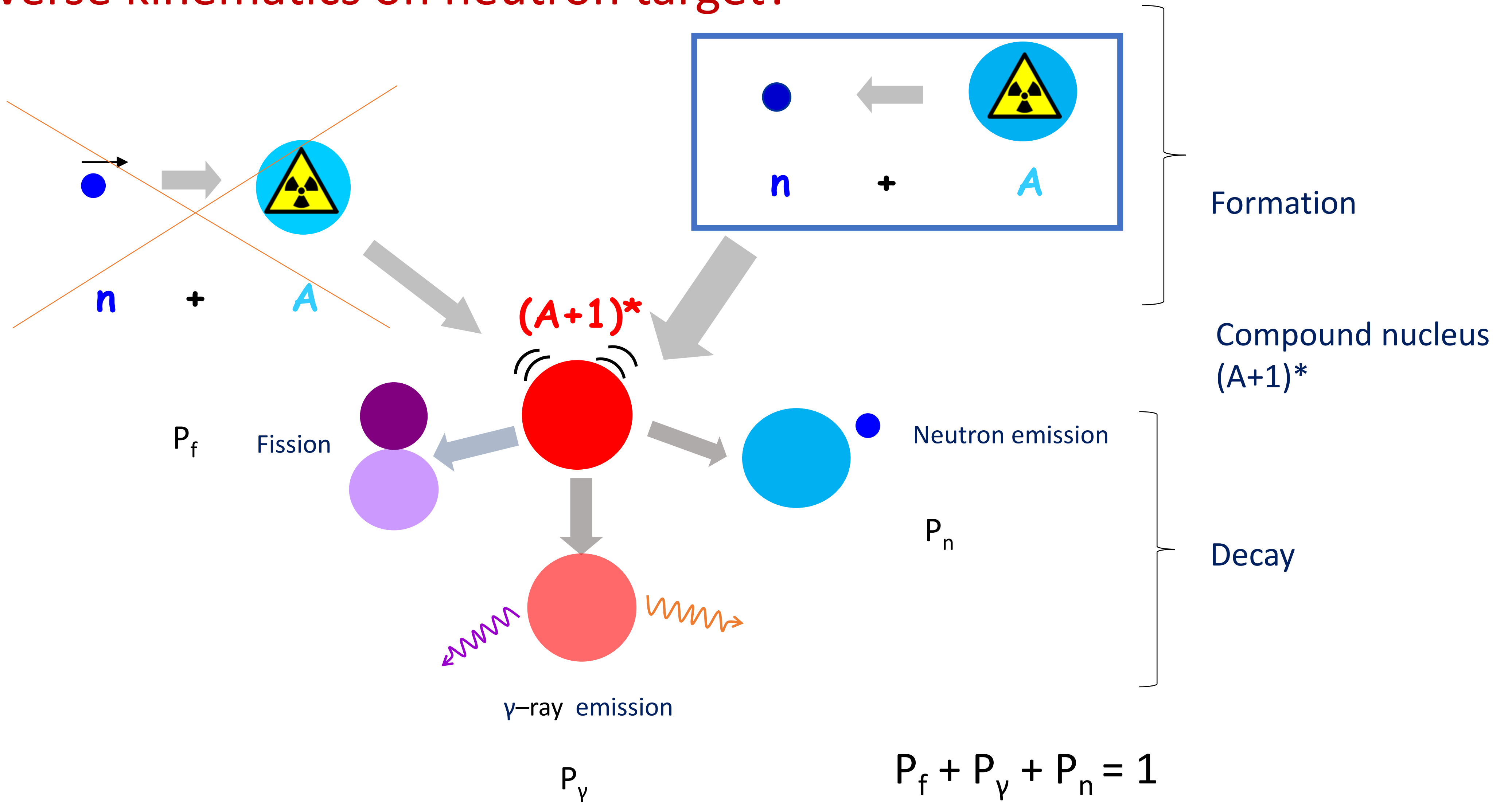


P_f P_n P_γ

$$P_f + P_\gamma + P_n = 1$$

→ Then, in inverse kinematics on neutron target?



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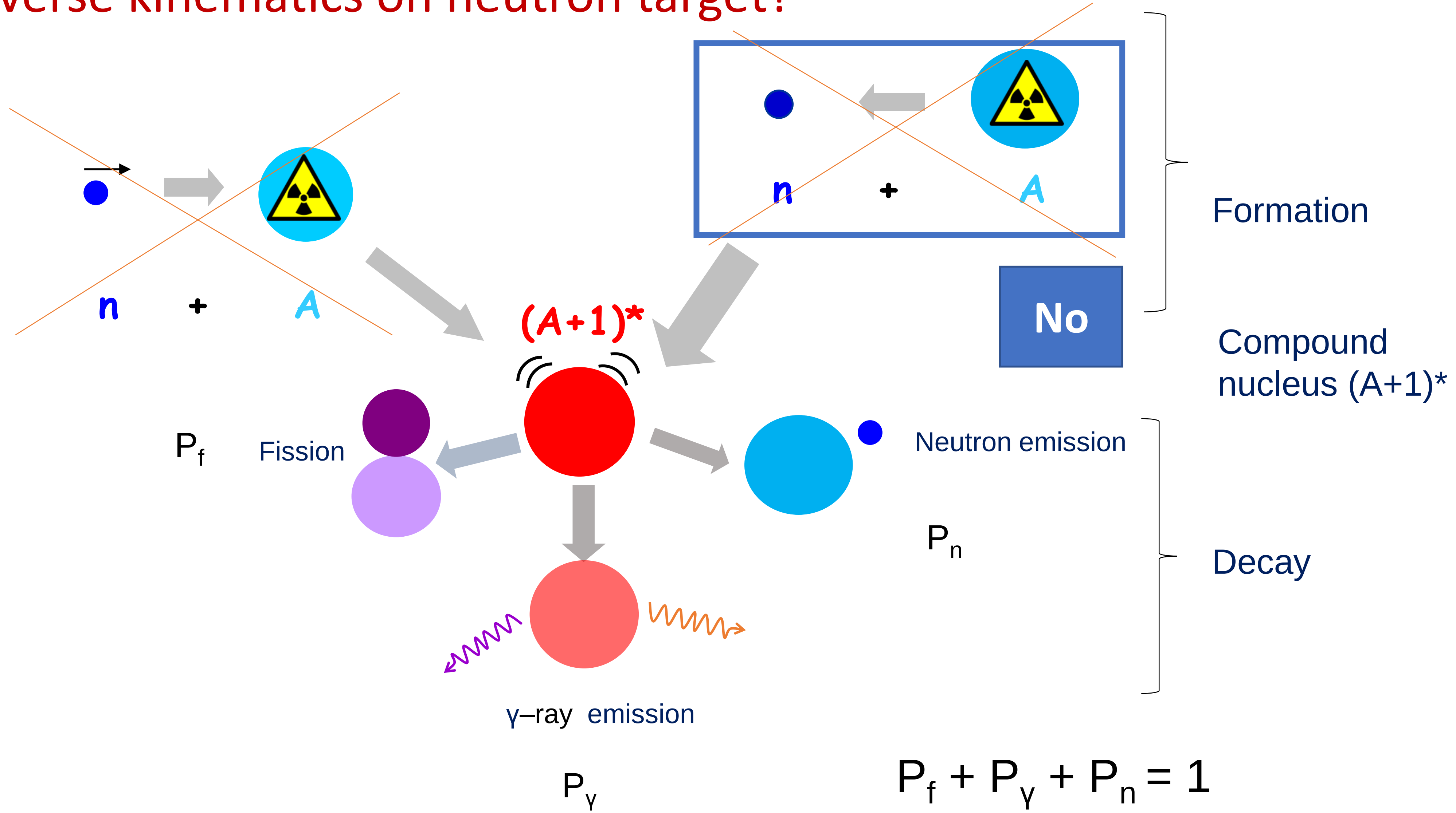

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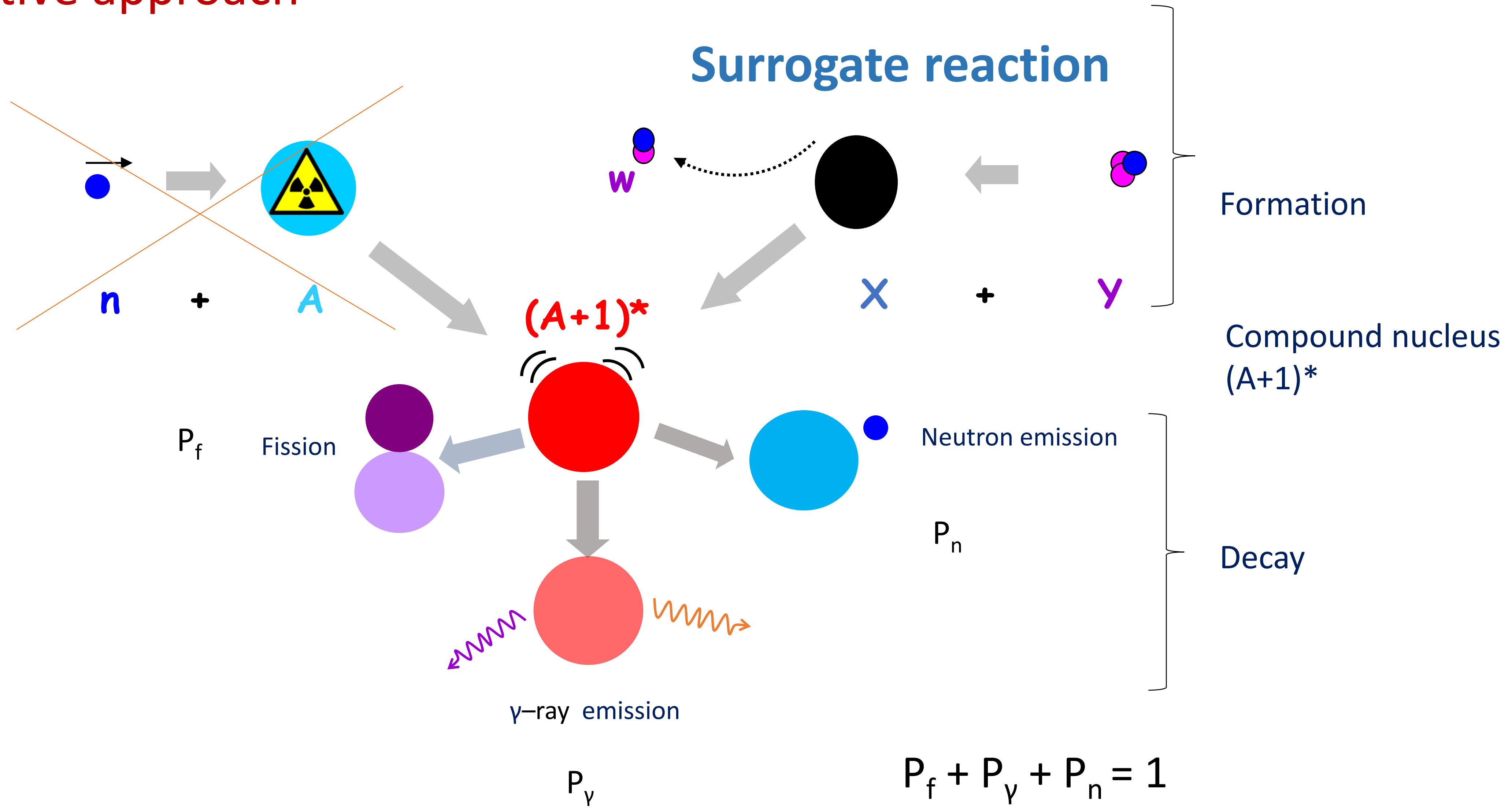
→ An alternative approach



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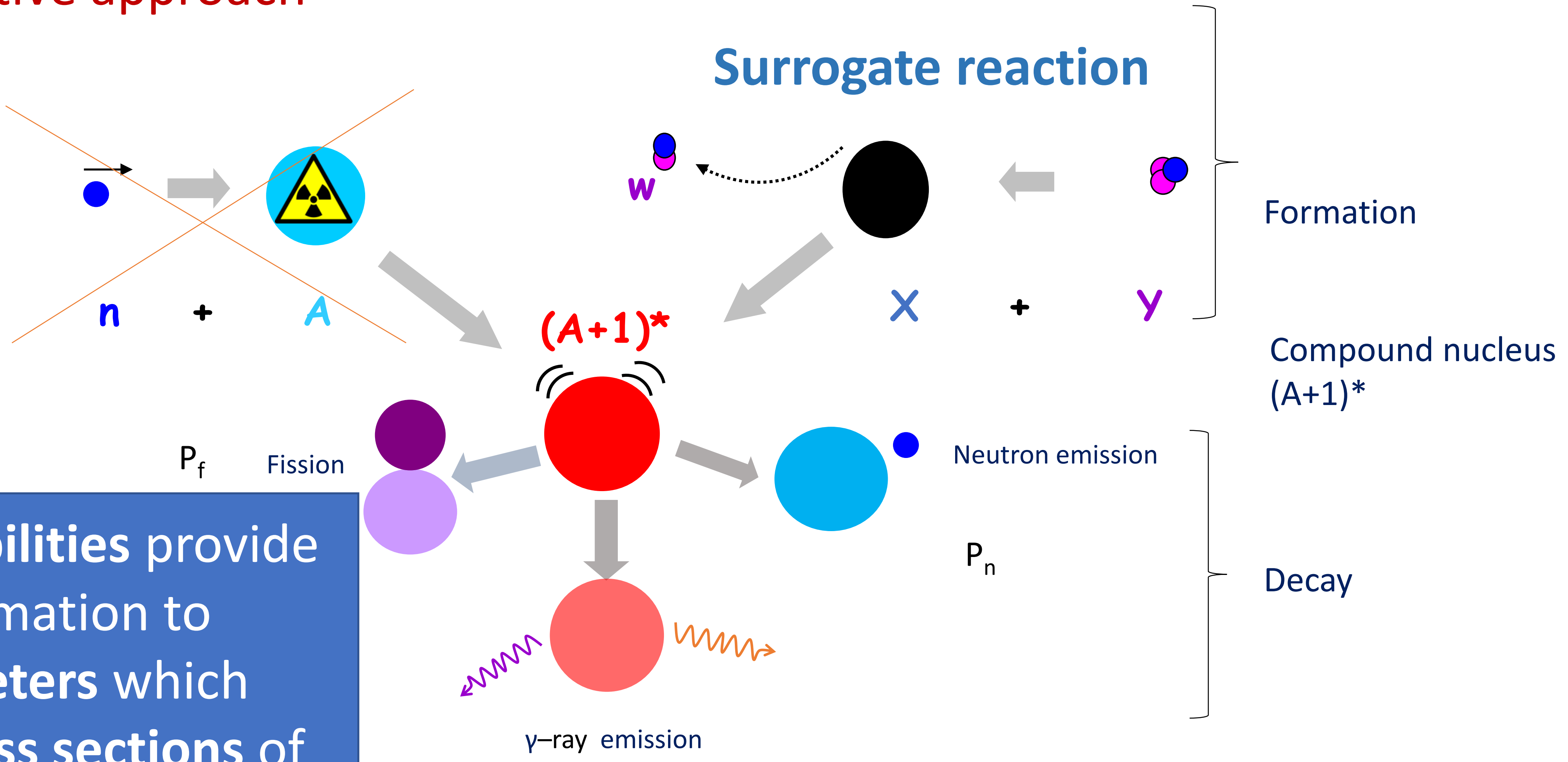
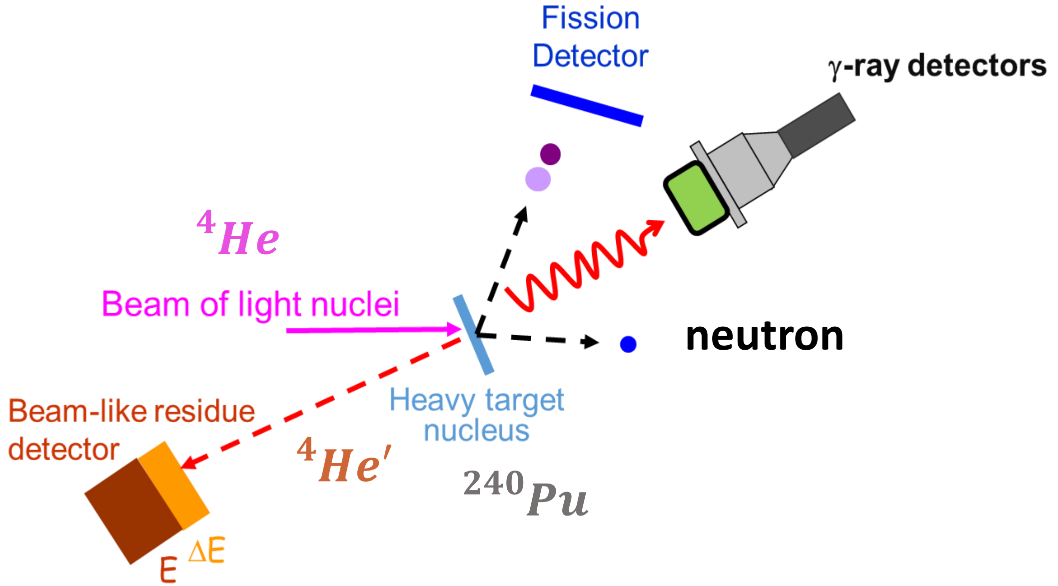


$$P_f + P_\gamma + P_n = 1$$

Decay probabilities provide key information to **Fix parameters** which constrain **cross sections** of neutron-induced reactions.

Surrogate reaction experiments, in direct kinematics

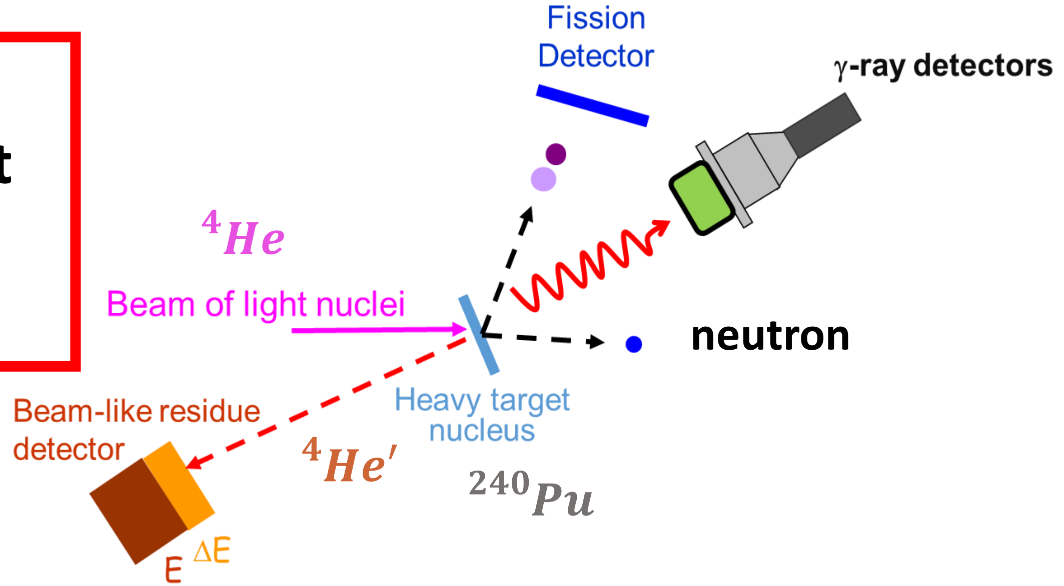


R. Perez Sánchez, B. Jurado et al., PRL 125, 122502 (2020)

Surrogate reaction experiments, in direct kinematics

Limitations:

- **Target radioactivity, contaminants and target support**
- **P_γ efficiency**
- **P_n: low-energy neutrons and efficiency**



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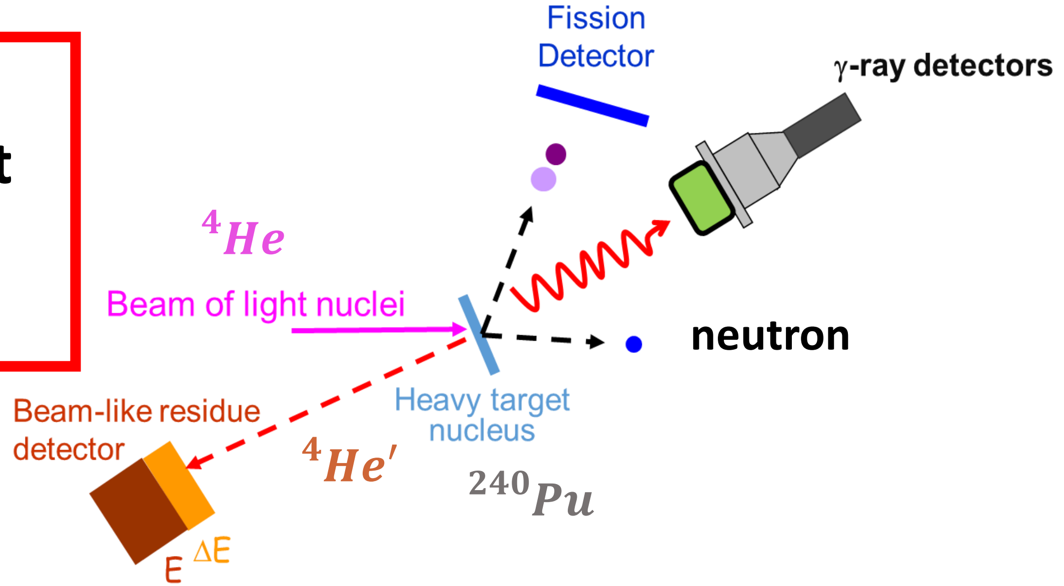

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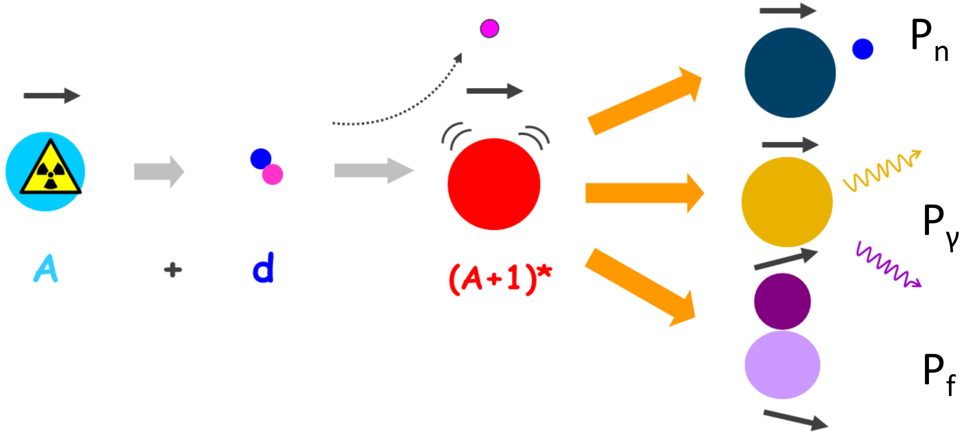
..Surrogate reactions in inverse kinematics

Advantages:

- **Access to very short-lived nuclei**
- **Detection of heavy residues (high efficiency)**



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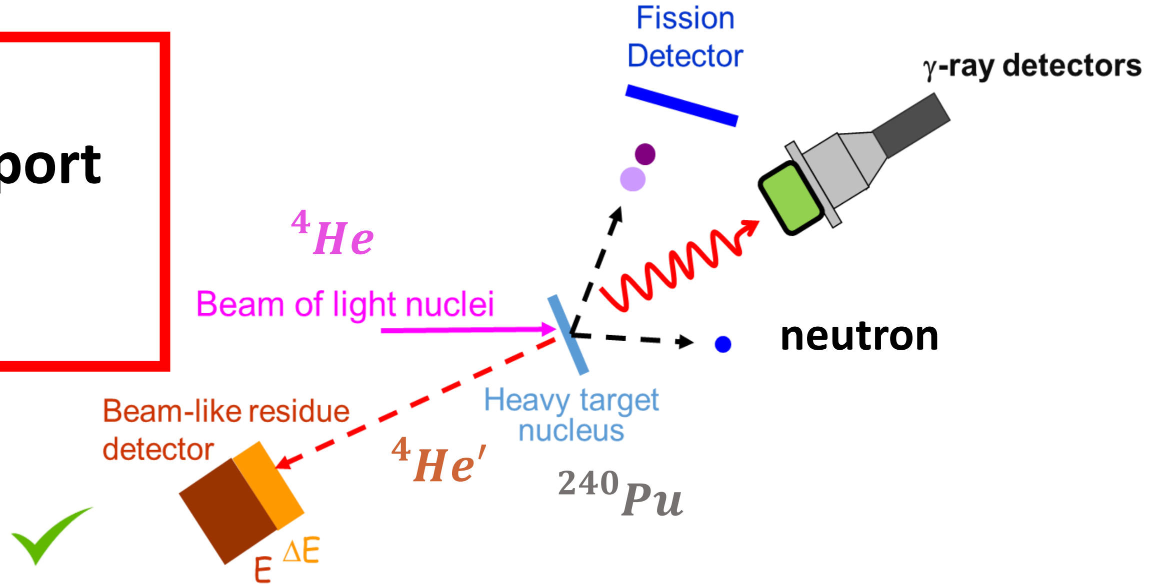

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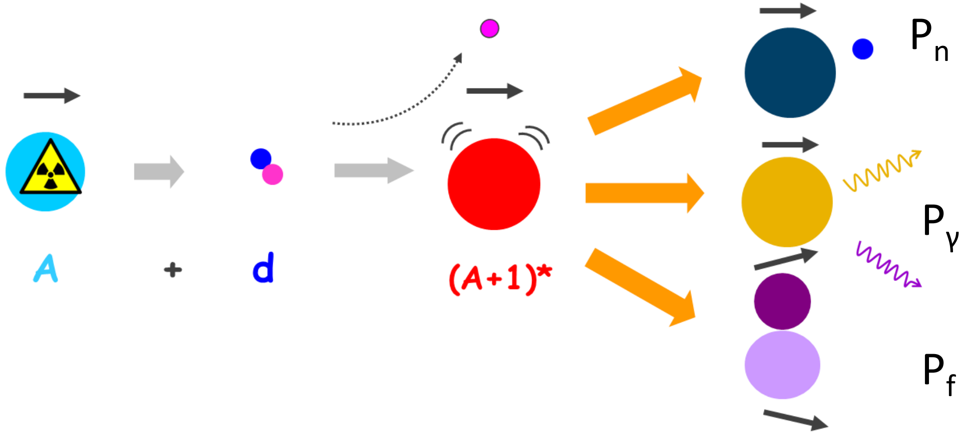

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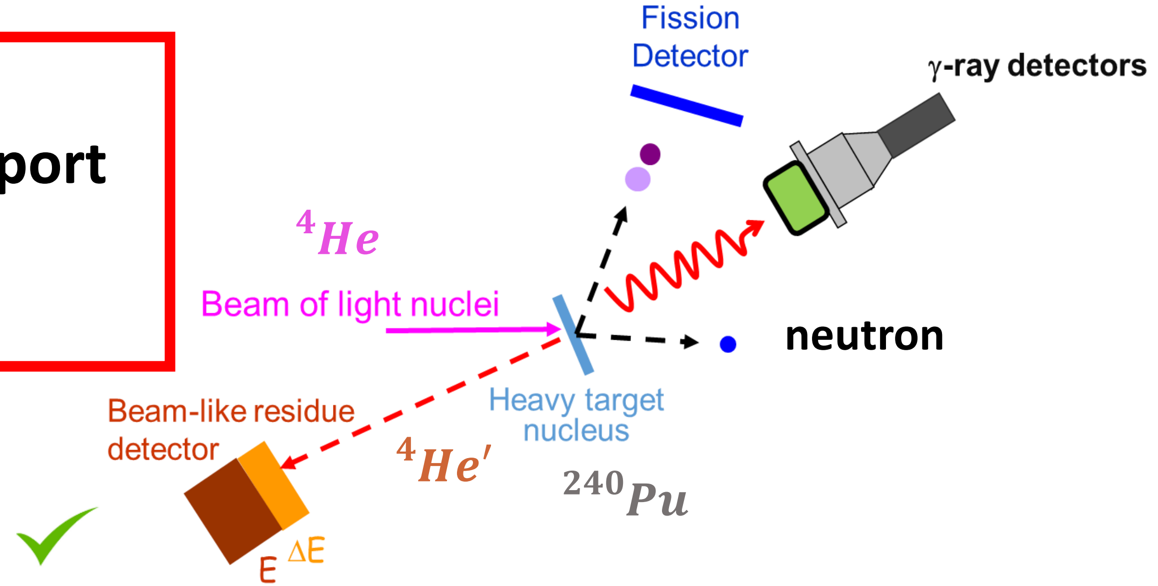

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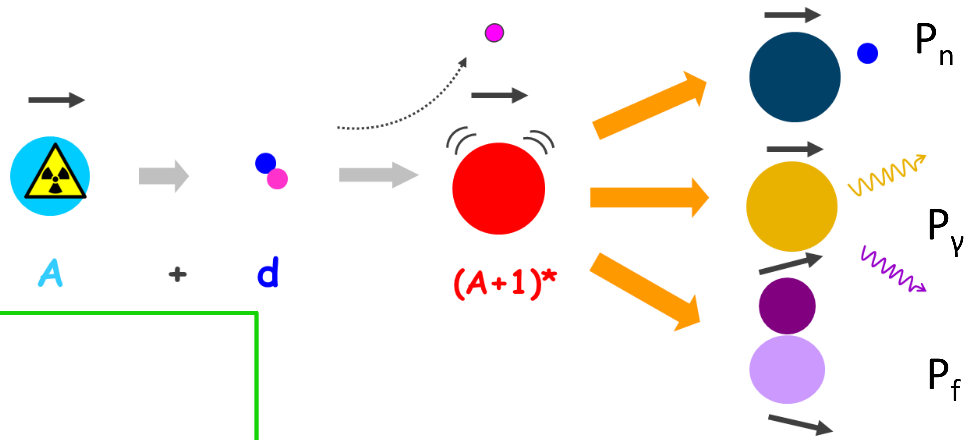
Large E-loss and straggling due to target effects
E*~ few 100 keV needed...



Experiments at storage rings of GSI/FAIR

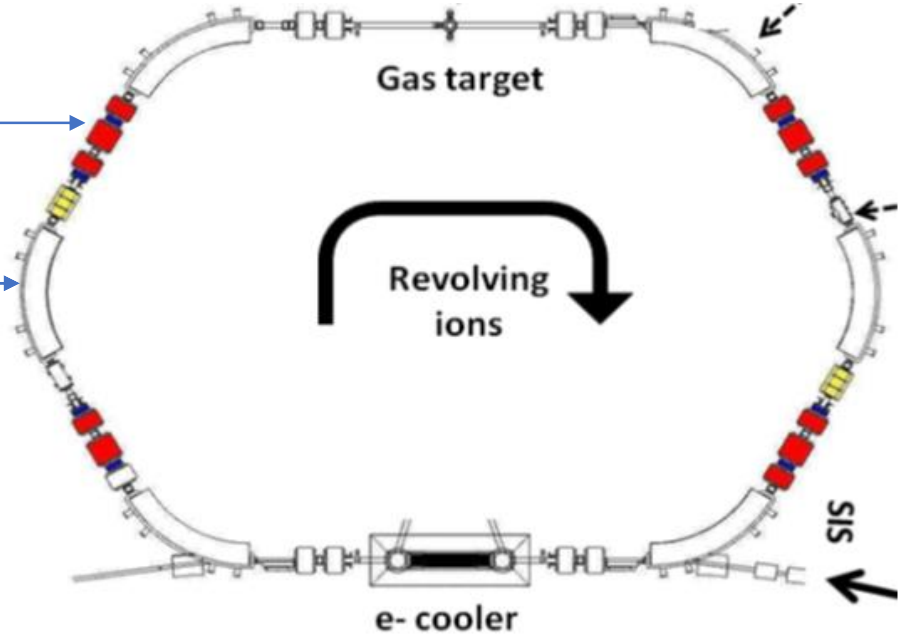
Advantages:

- Excellent excitation energy resolution possible through low-density gas jet target and electron cooling.
- Frequency compensates for thin target.
- No target contaminants or window.

➢ Challenge: UHV of the ring (P ~ $10^{-11} – 10^{-12}$ mbar)

Quadrupole magnet

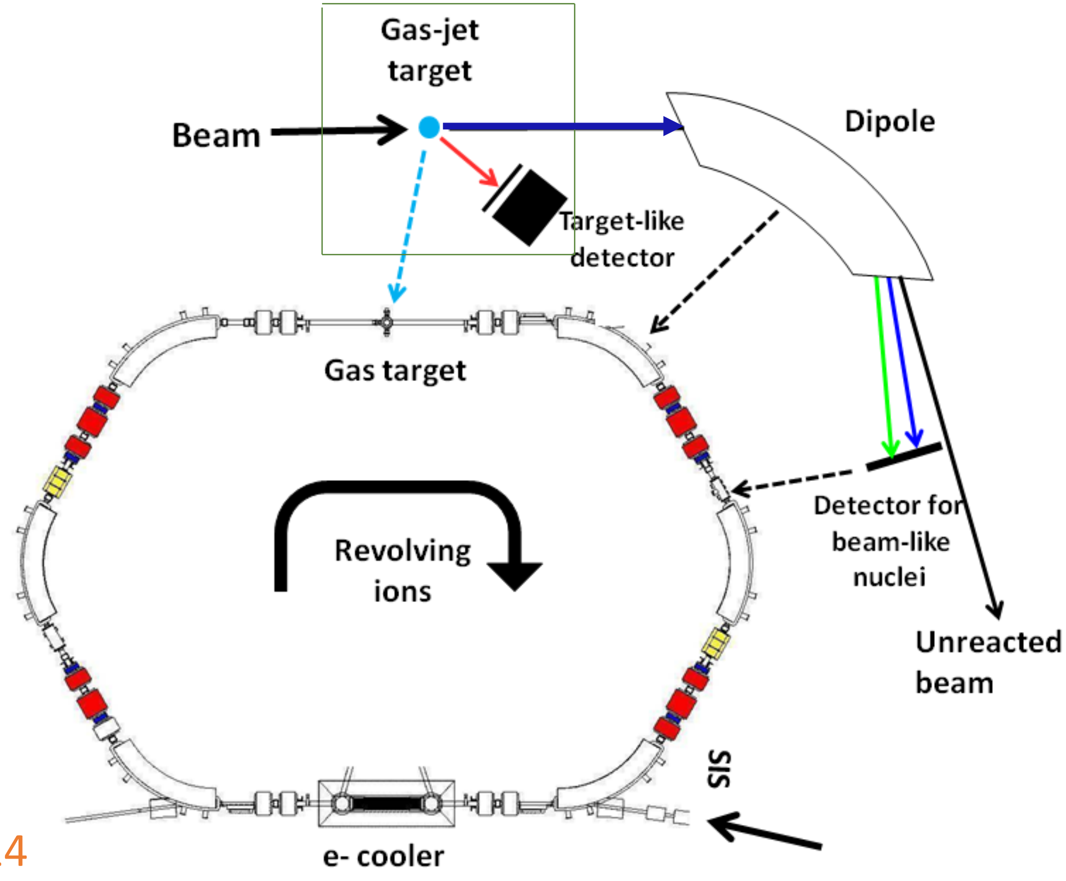
Dipole magnet



The ESR storage ring at GSI

NECTAR Proof-of-Principle (PoP) experiment – June 2022

- Beam of ^{208}Pb at E_{beam} = 30 AMeV on ^{1}H gas jet target
- $^{208}Pb(p,p')^{208}Pb^*$ reaction, measure $^{208}Pb^* \rightarrow {}^{208}Pb+\gamma$ (P_γ) and $^{208}Pb^* \rightarrow {}^{207}Pb+n$ (P_n)



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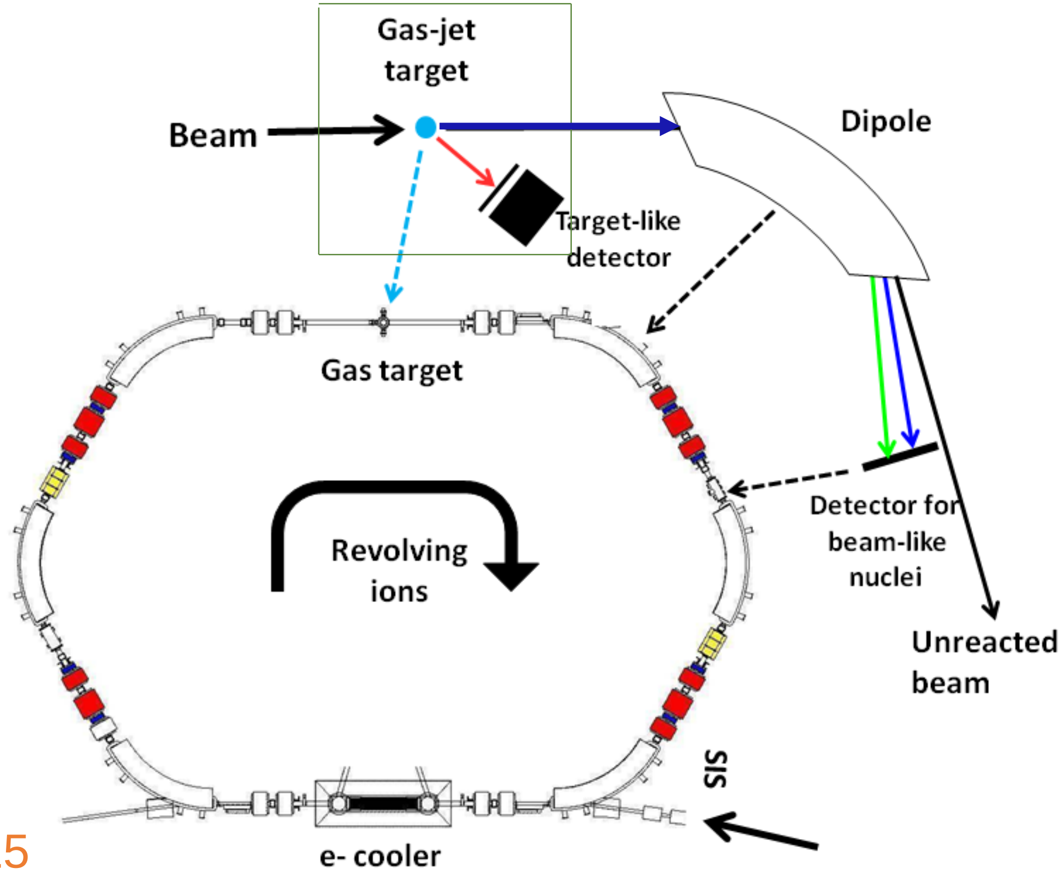

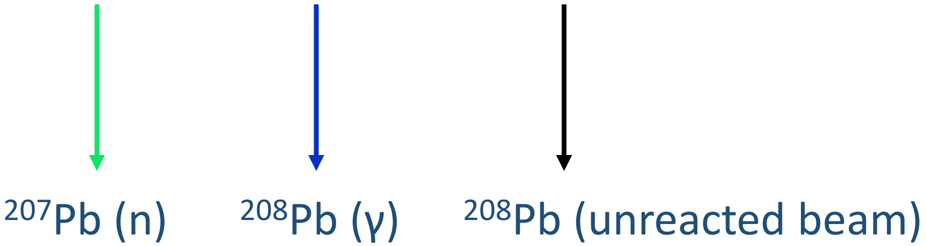

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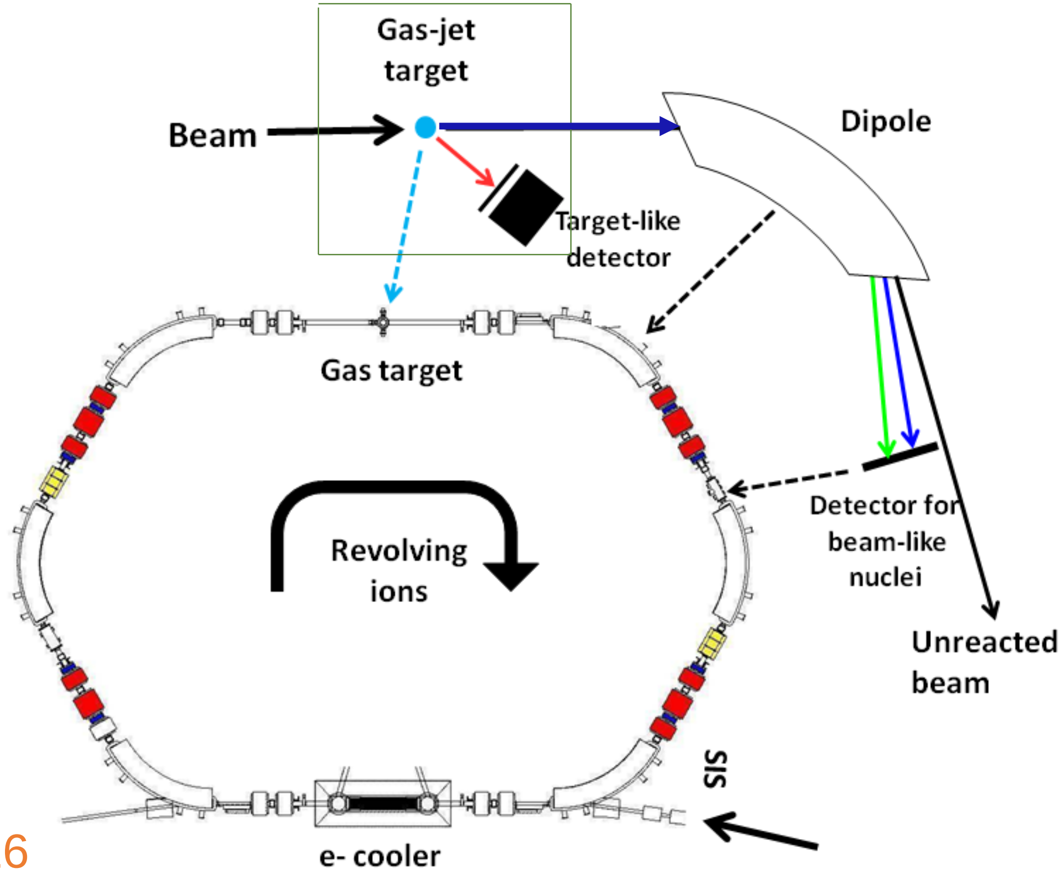
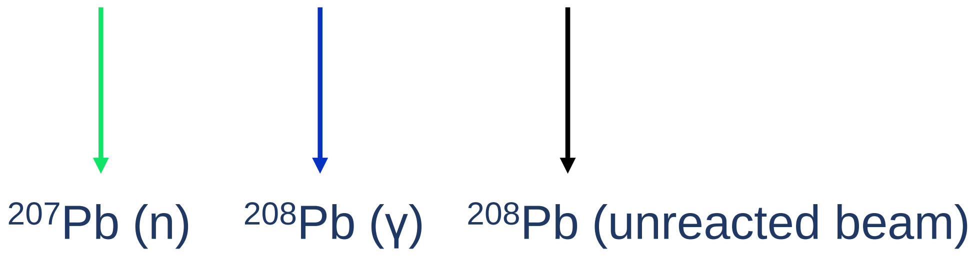


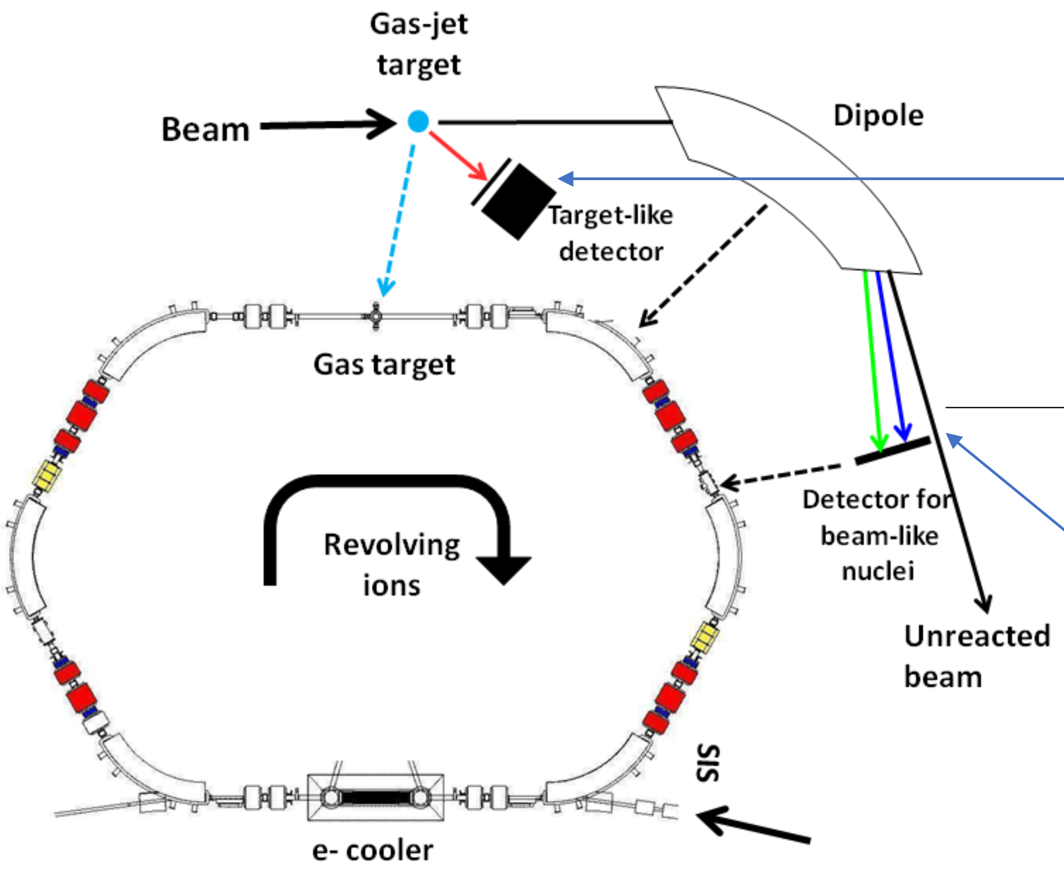


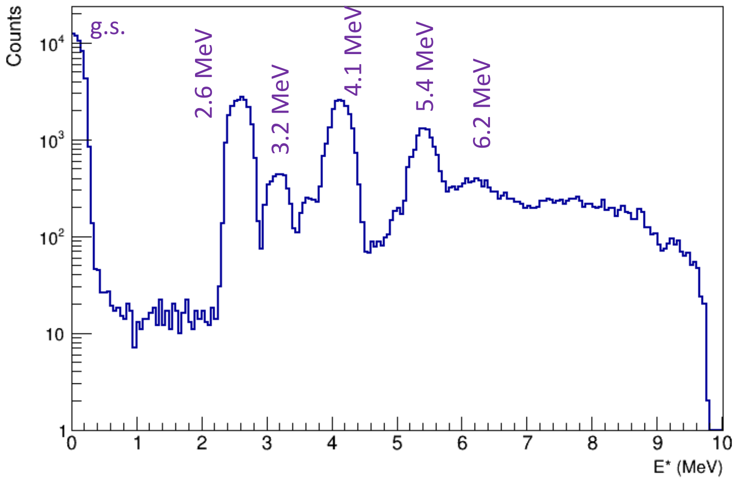
$$P_\gamma(E^*) = \frac{N_\gamma(E^*)}{N_p(E^*).\,\varepsilon(E^*)}$$

$$P_\gamma + P_n = 1$$

Simulation results for PoP experiment

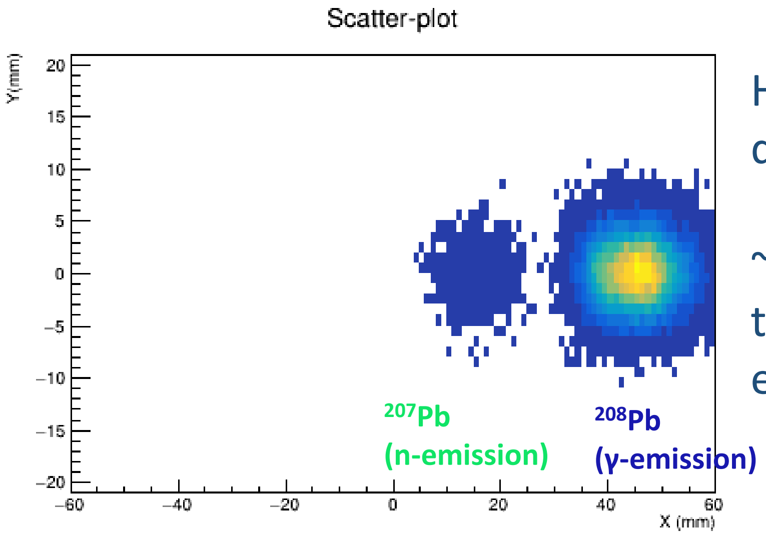
Simulations by M.Sguazzin





Target residue detection

σE* ~ 200 keV

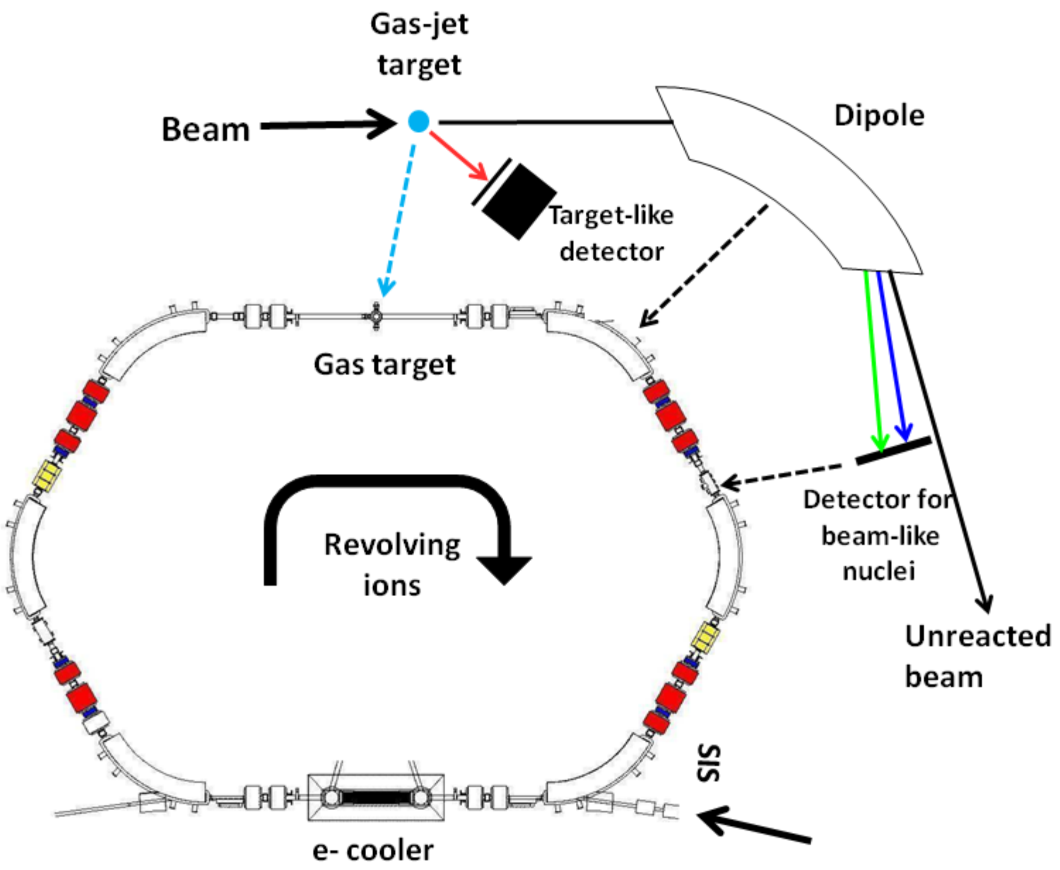


Heavy residue detection

~100% transmission efficiency

Outlook:

- NECTAR PoP experiment – coming to ESR@GSI June 2022
- NECTAR experiments featuring fission detection ca. 2024



1st full experiment:

^{238}U + d at E = 10 AMeV.

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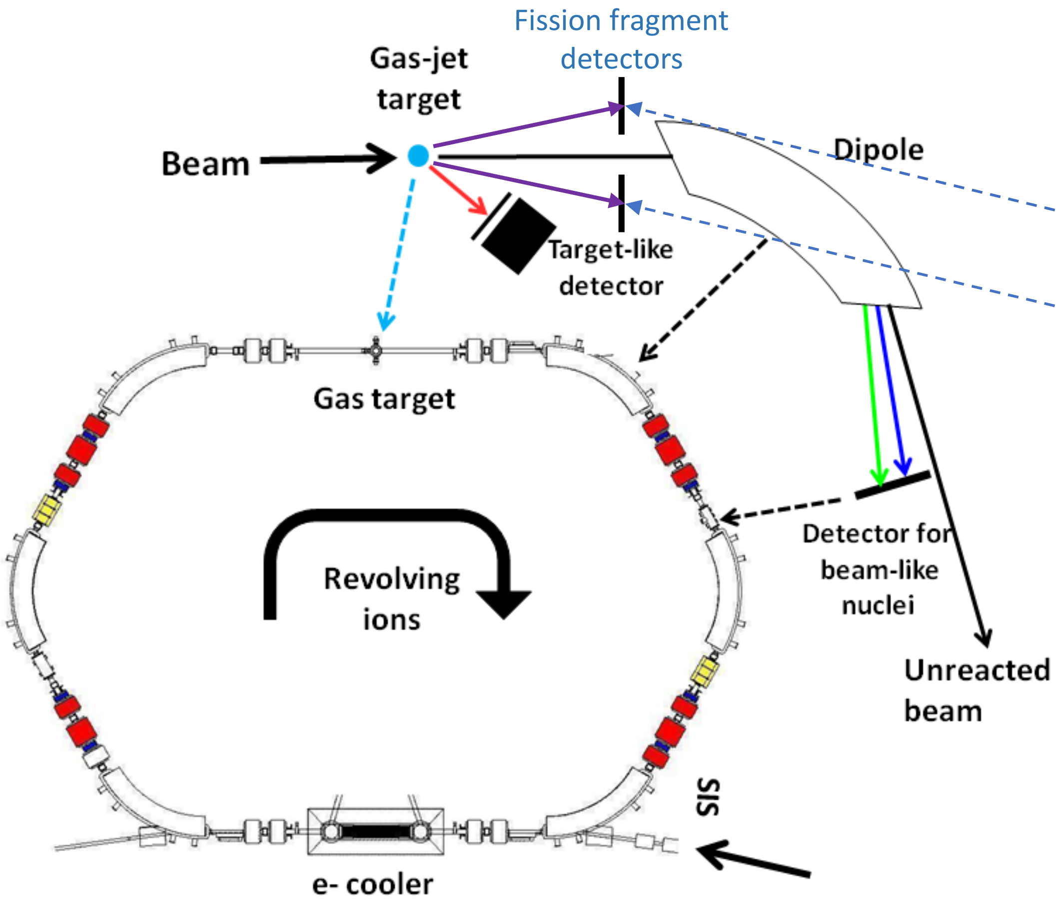

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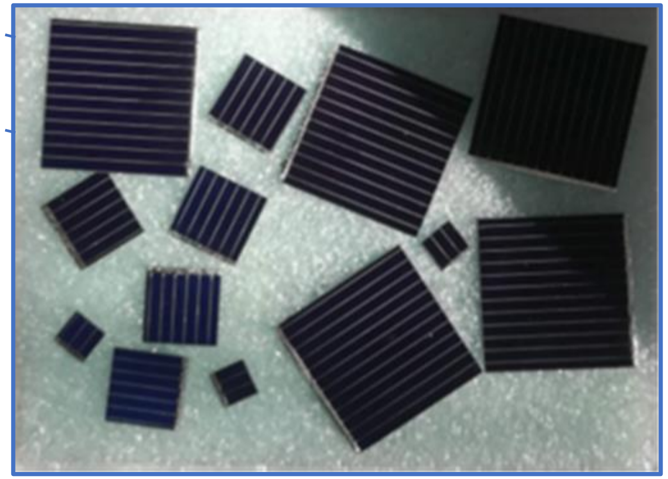

Solar cells

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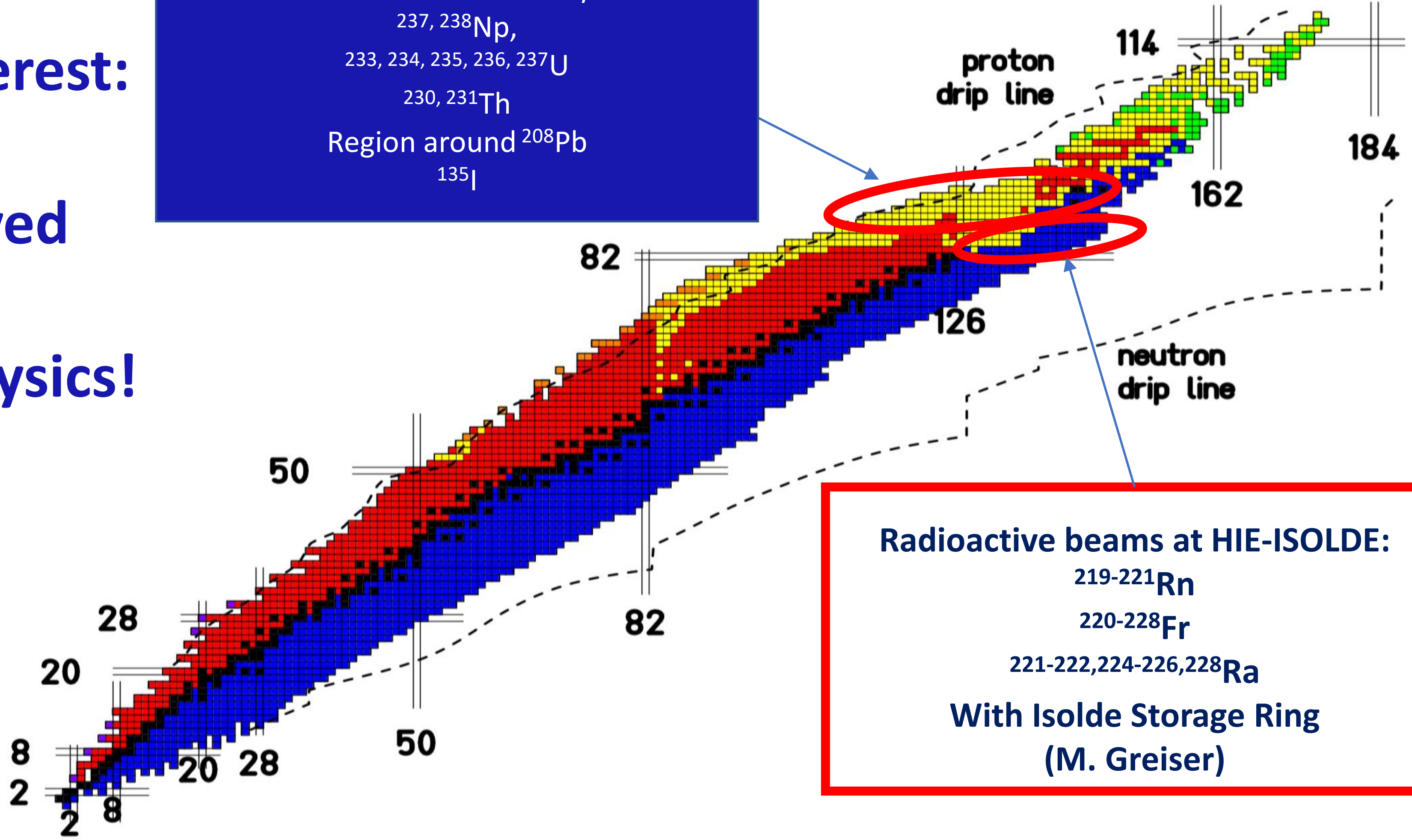
- Isotopic chains of interest:
- I, Pb, U, Th, Np etc.
- Multitude of short-lived nuclei
- Years and years of physics!

Radioactive beams at GSI/FAIR:
$^{237,\,238}$Np,
$^{233,\,234,\,235,\,236,\,237}$U
$^{230,\,231}$Th
Region around ^{208}Pb
^{135}I



Radioactive beams at HIE-ISOLDE:
$^{219\text{-}221}$Rn
$^{220\text{-}228}$Fr
$^{221\text{-}222,224\text{-}226,228}$Ra
With Isolde Storage Ring
(M. Greiser)

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The NECTAR Collaboration

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M. Gerbaux
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Thank you for listening! To be continued..