# Indirect measurements on neutron-induced reaction cross sections at storage rings

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**NECTAR: Nuclear rEaCTions At storage Rings***

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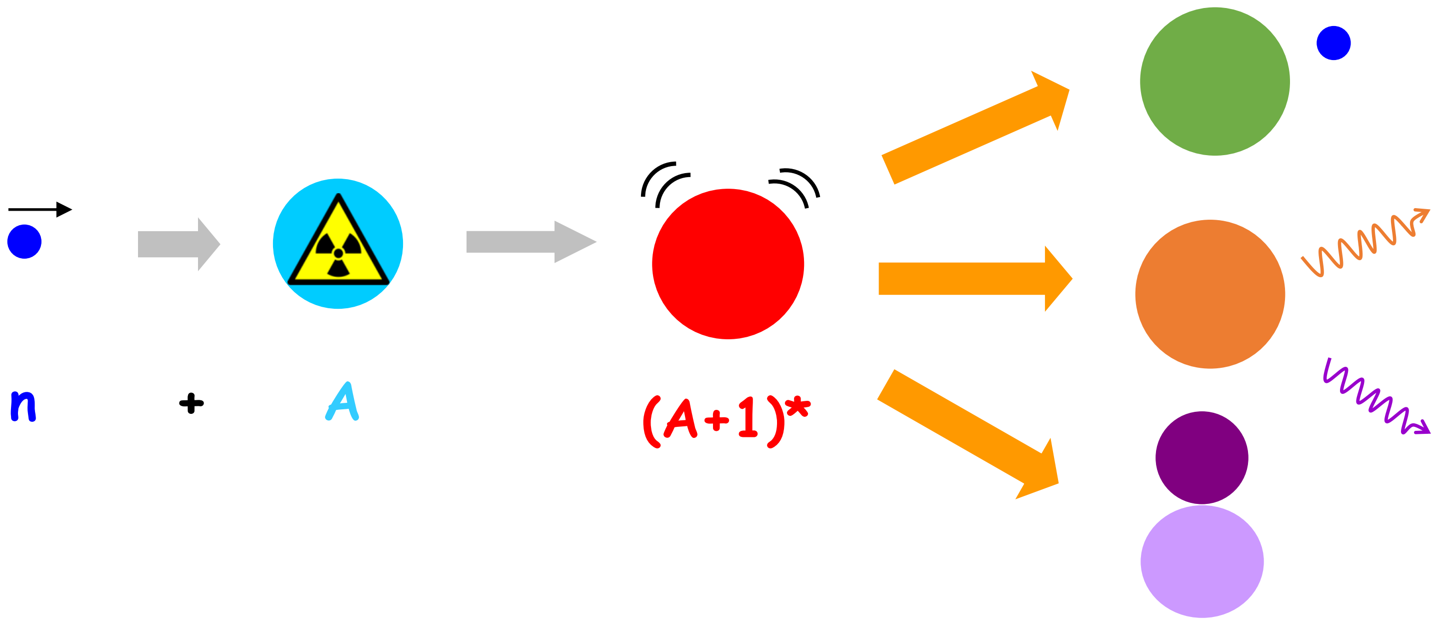
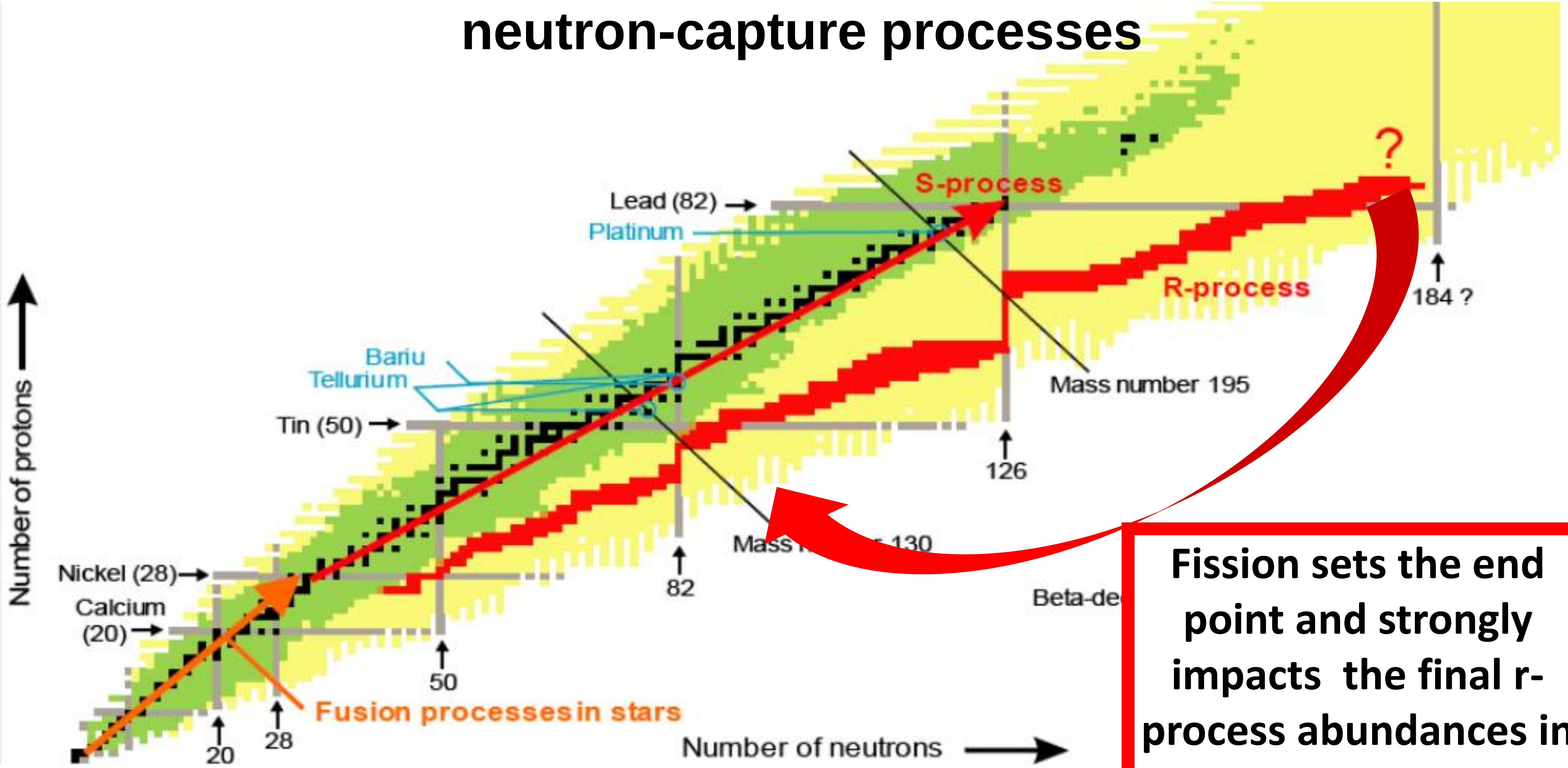
# Motivation:

## Need for neutron-induced reaction cross sections of short-lived nuclei




**Essential for astrophysics and applications!**

# Synhtesis of heavy elements: slow and rapid neutron-capture processes

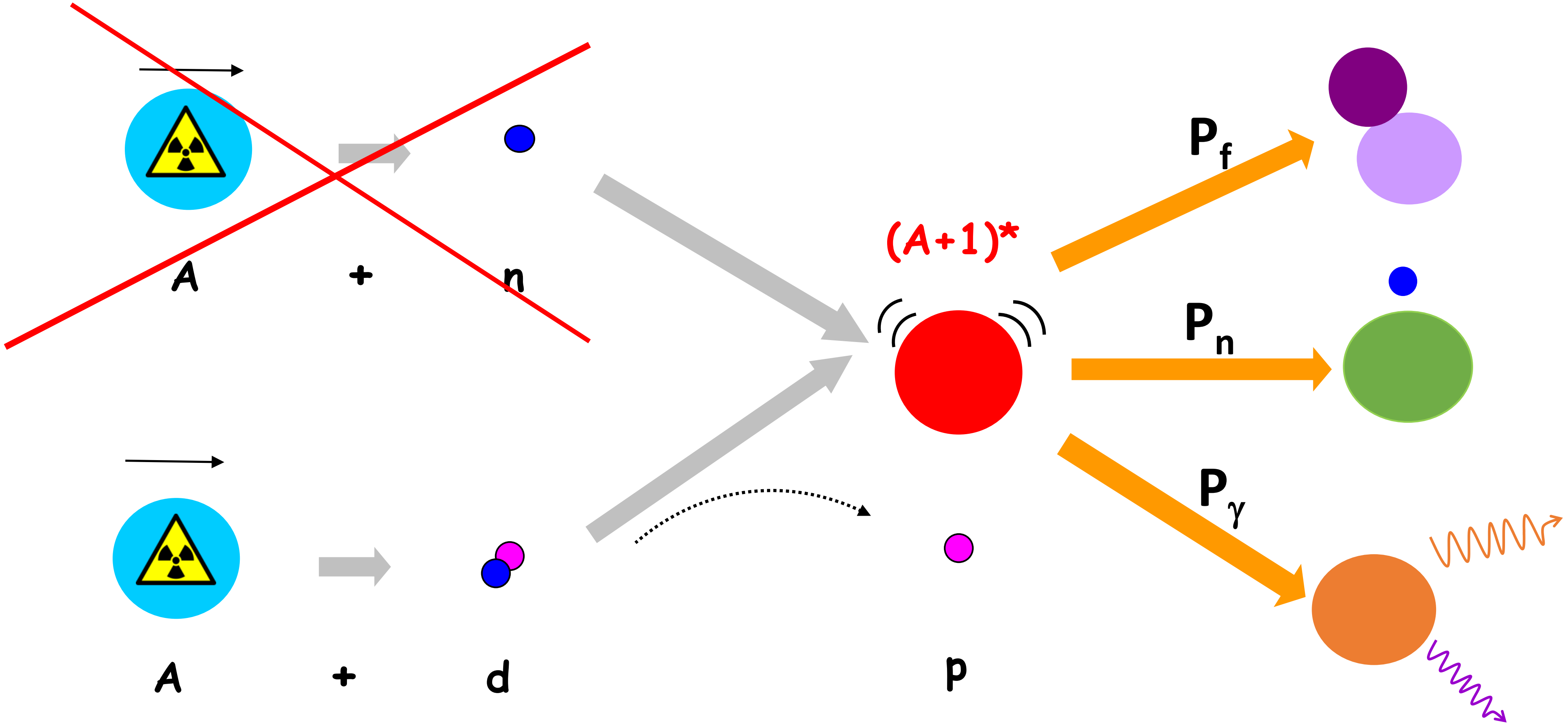



**Fission sets the end point and strongly impacts the final r-process abundances in neutron-star mergers!**

**Very difficult or even impossible to measure with standard techniques →difficulty to produce and handle the needed targets!**

**Complicated to calculate due to the difficulty to describe the de-excitation process.**

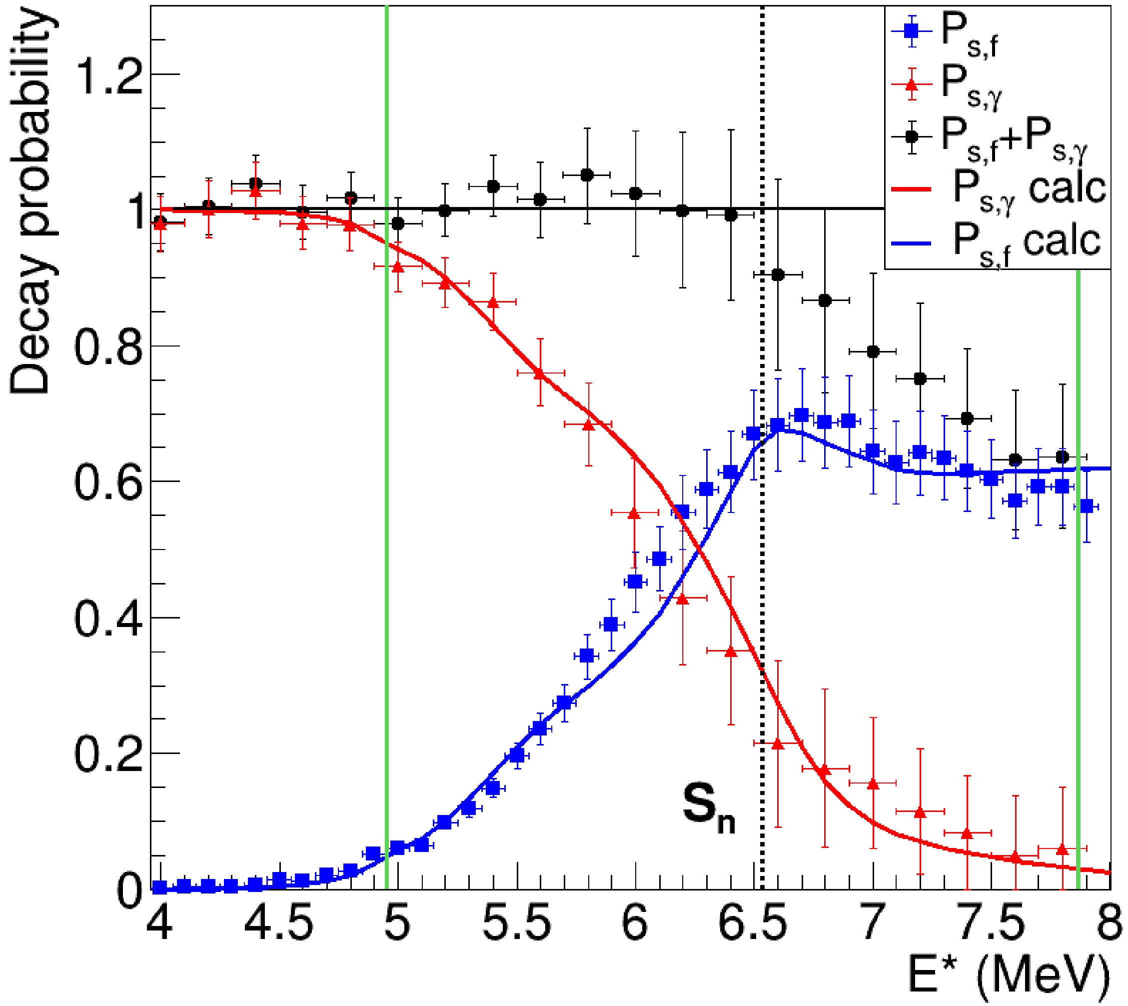
# Surrogate-reaction method in inverse kinematics




Decay probabilities as a function of excitation energy are precious observables to constrain models and provide much more accurate predictions for neutron-induced cross-sections of nuclei far from stability.

# Benchmark:

# 4He+240Pu→4He'+240Pu*⇔n+239Pu→240Pu*




**First simultaneous measurement of $P_f$ and $P_\gamma$!**

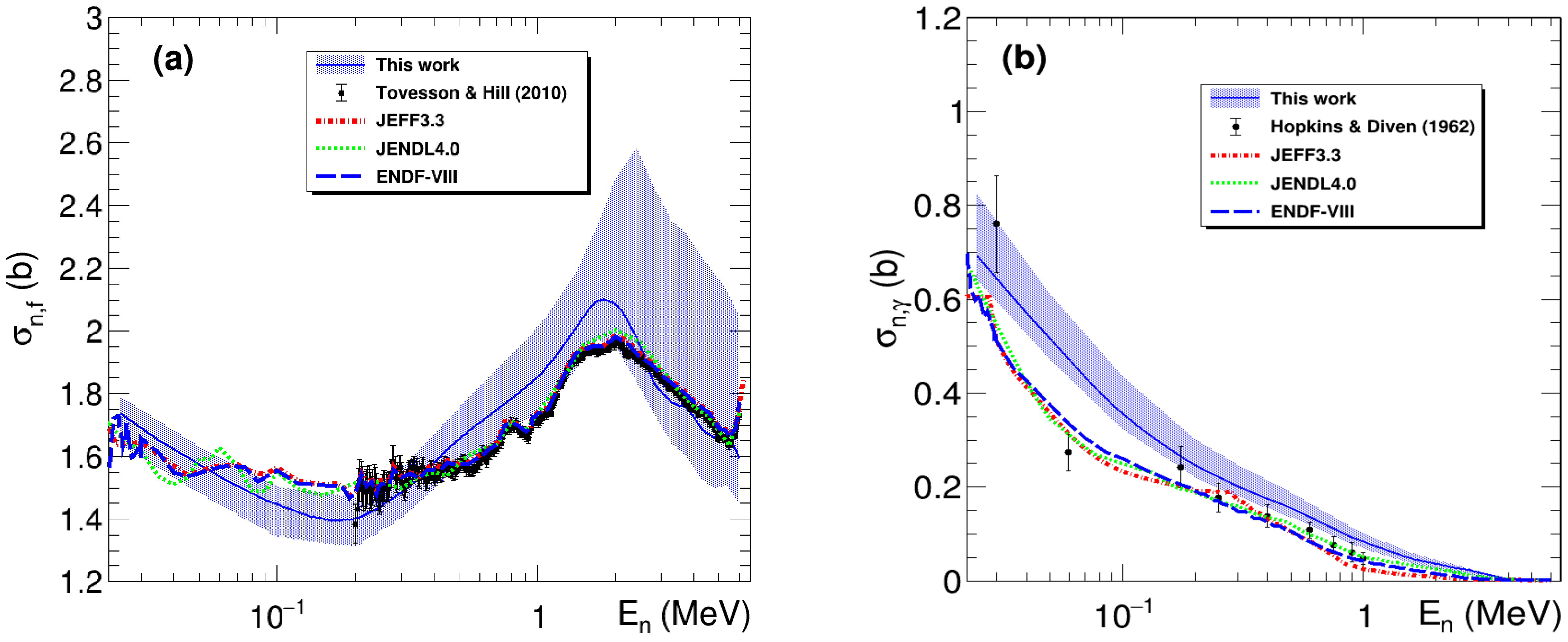
**Stringent test of experimental method!**

**Accurate determination of model parameters!**

**R. Perez Sanchez, BJ et al., Phys. Rev .Lett. 125 (2020) *122502***

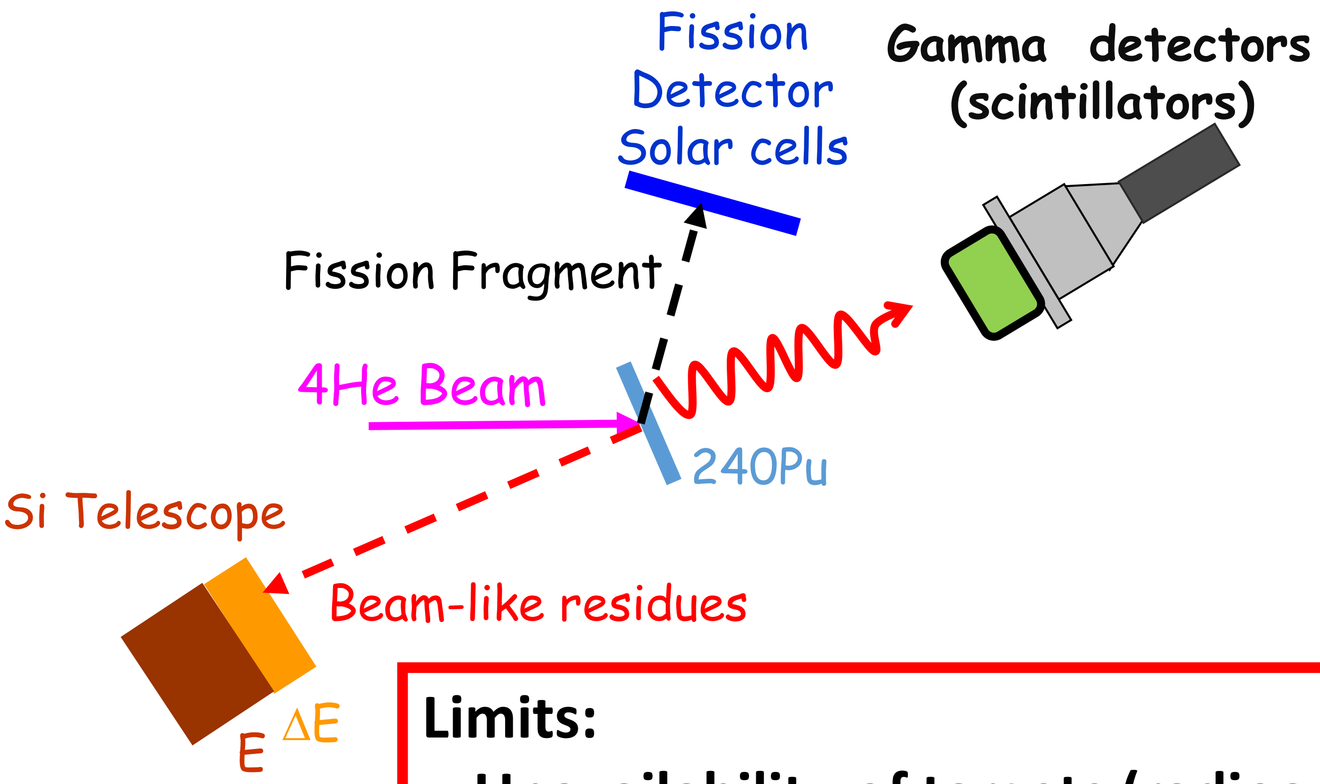
# First simultaneous determination of neutron-induced fission and capture cross sections

# $n + {}^{239}Pu \rightarrow {}^{240}Pu^*$




R. Perez Sanchez, BJ et al., Phys. Rev .Lett. 125 (2020) 122502

# Setup for the measurement of fission and gamma-emission probabilities in direct kinematics



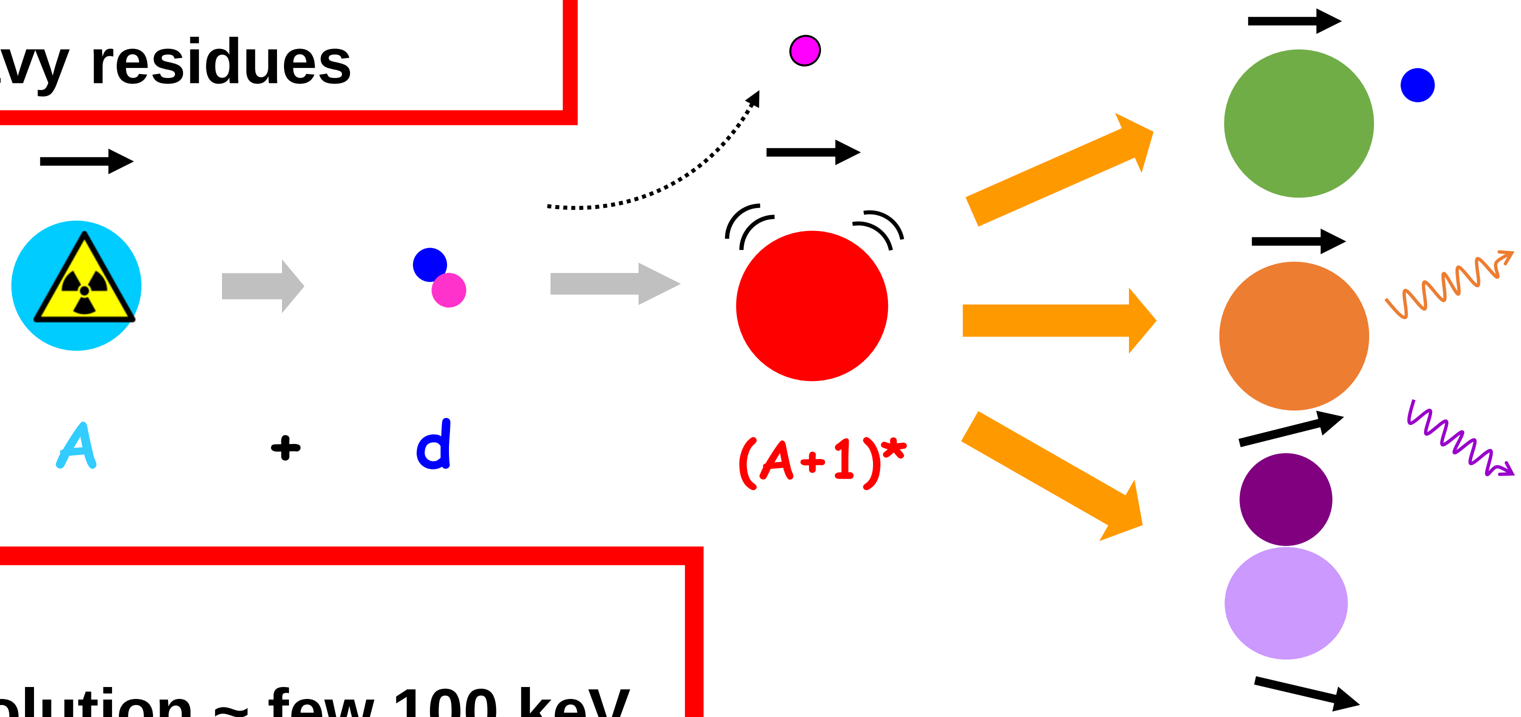

**Limits:**

- **Unavailability of targets (radioactive samples)**
- **Target contaminants and target support**
- **$P_{\gamma}$ : discrimination of γ's from fission fragments, very low detection efficiency**
- **$P_n$: measurement of low-energy neutrons and neutron efficiency**

**Advantages of Inverse kinematics:**

**-Access to very short-lived nuclei**

**-Detection of heavy residues**



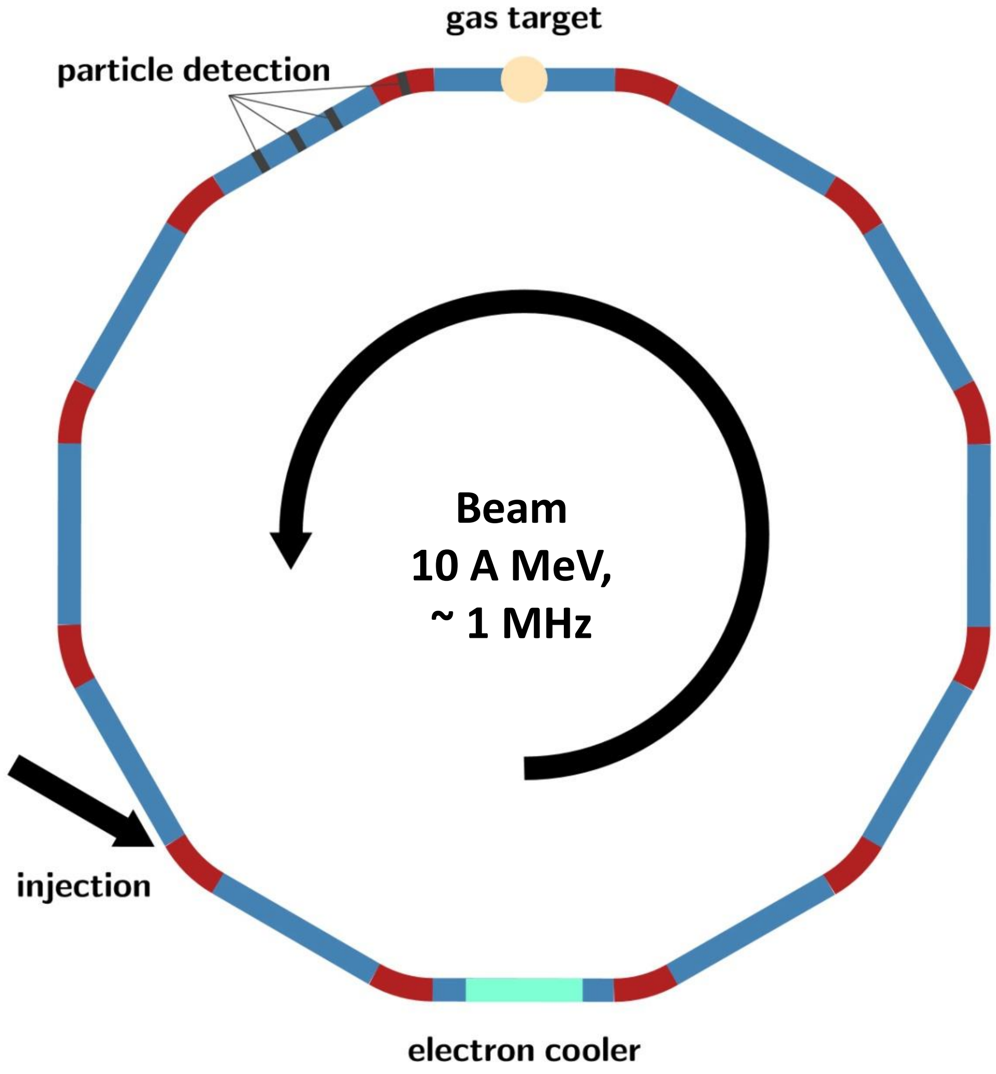

**BUT!**

- **Required E* resolution ~ few 100 keV, $E^*=f(E_{beam}, E_{target\_like}, \theta)$**
- **Target contaminants and target windows have to be avoided**

# STORAGE RINGS!

# Advantages of heavy-ion storage rings

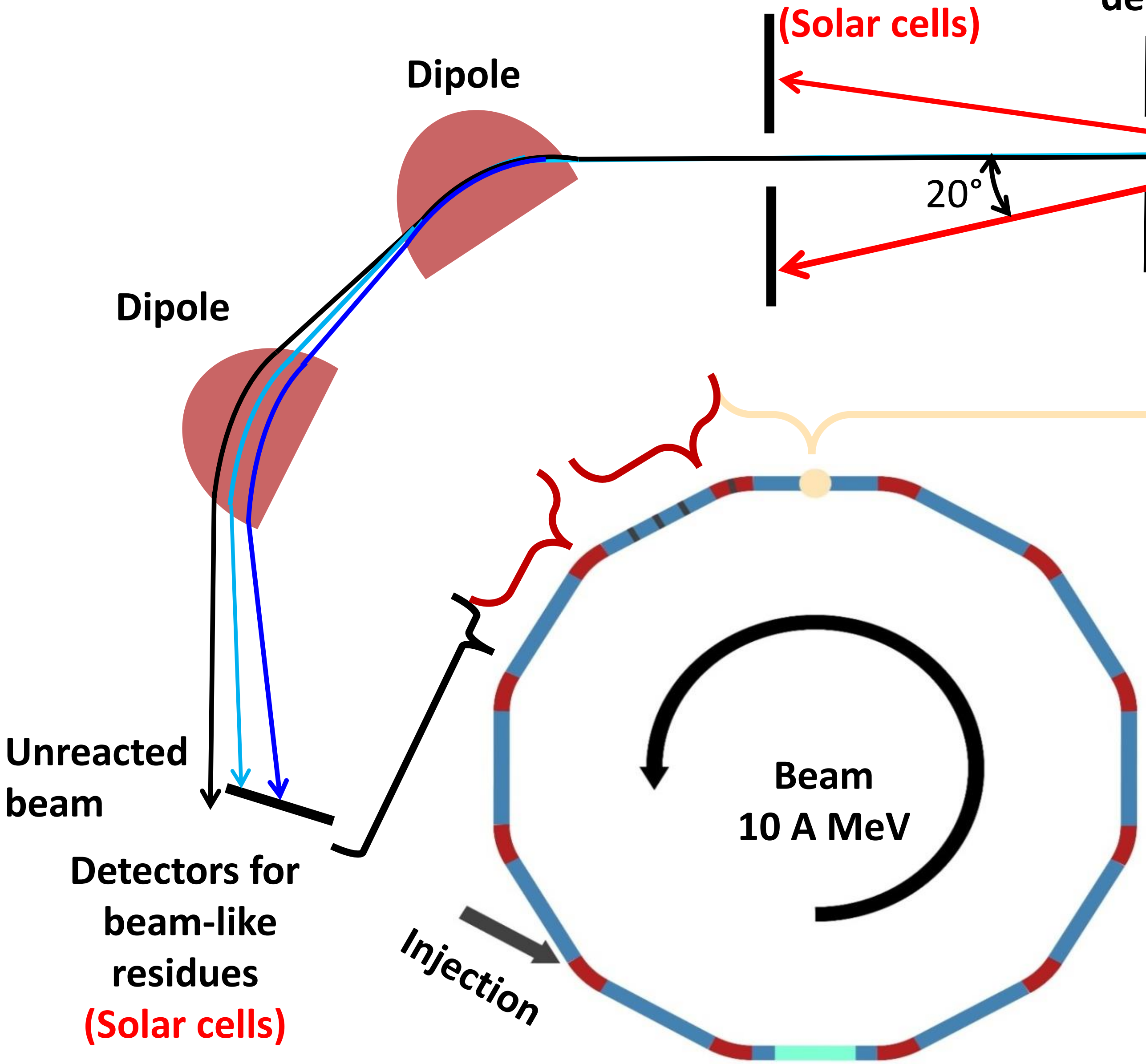
The CRYRING at GSI/FAIR




- Use of ultra-thin in-ring gas-jet targets ~$10^{13}/cm^2$. Effective target thickness increased by ~$10^6$ due to revolution frequency (at 10 A MeV)
- Beam cooling → Excellent energy and position resolution of the beam, maintained after each passage through the target, negligible E-loss & straggling effects
- High-quality, pure, fully-stripped beams and pure, ultra-thin, windowless targets→ unique!

**Challenge: Detectors in Ultra-High Vacuum ($10^{-11}$-$10^{-12}$ mbar)!**

# Set-up at the CRYRING




**Beam:** $10^7$-$10^8$ stored $^{238}U^{92+}$ at 11 A meV

See talk by M. Sguazzin on solar cells!

CRYRING:

- Simultaneous measurement of fission, γ- and n-emission probabilities with high precision!
- E* resolution ~200 keV!
- Detection efficiencies close to 100% for all reaction products!

Storage rings are the only instruments where all this can be achieved!

# Time line of NECTAR and beyond…

2022 | 2023 | 2024 | 2025

**Jan 2021**
**Start!**

March 2021
Solar cell studies at GANIL
**See talk by M. Sguazzin!**

June 2022
Proof of principle Experiment at ESR of GSI/FAIR

Possibly additional solar cells tests at GANIL?

Commissioning of setup at CRYRING
&
Main experiment

Data analysis and interpretation

**Dec 2025**
**End…**

**Beyond 2025, radioactive beams:**

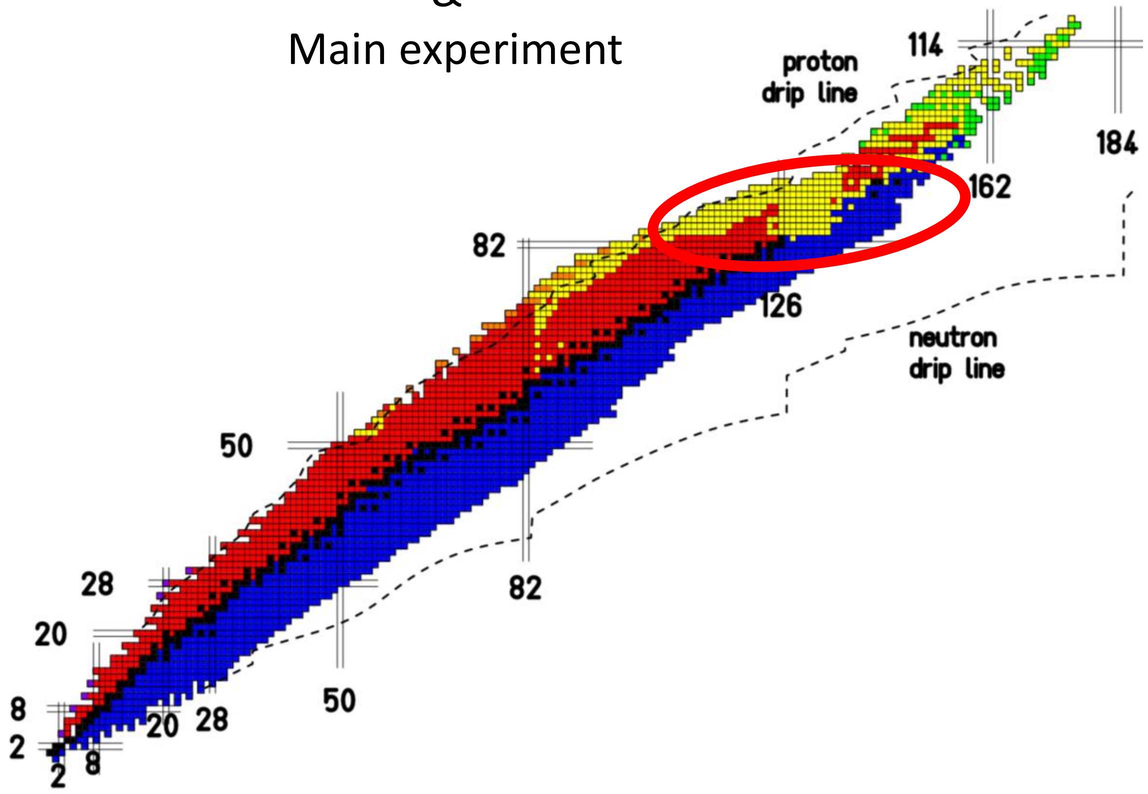
**GSI/FAIR**

**$^{237, 238}$Np, $^{233,234, 235, 236, 237}$U, $^{230, 231}$Th**

**Unexplored region, pre-actinides and actinides around shell N=126**

**ISOLDE STORAGE RING**

**$^{219\text{-}221}$Rn, $^{220\text{-}228}$Fr, $^{221\text{-}222,224\text{-}226,228}$Ra, etc.**



# Collaboration

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