S117: In-cell MNT reactions at the FRS Ion Catcher

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for the ***Super-FRS Experiment Collaboration***

47 participants, 31 institutions, 14 countries

- **Long-term goal**: establish MNT reactions with slowed-down radioactive beams at the Super-FRS to produce
  - and measure ground-state properties of heavy (A=190-260) neutron-rich isotopes
  - Supported by the supernumerary G-PAC report (February 2022)

- **S177 exploratory program**: in-cell MNT reactions with slowed-down ^{238}U beam on targets inside CSC
    - proof-of-principle measurements: 30 cross sections $^{238}U+^{64}Ni$
    - 23 new masses and 60 new cross sections: $^{238}U+^{238}U$
  - 13 main shifts scheduled: 24 – 27 May 2024, 1 shift for FRS setup

Experimental plan and objectives

1) *FRS-IC offline calibration: about 9 shifts split before and after the experiment*
   - high efficiency (purity) extraction and transport: ion sources
   - efficiency calibration with ^{252}Cf yields

2) *FRS and FRS-IC beam optimization: 3 shifts*
   - SIS18 beam $10^7 s^{-1}$ ^{238}U@500MeV/u slowed down with degrader to 12MeV/u on target
   - FRS focusing on target inside CSC, beam intensity measurement (SEETRAM & INCREASE dump)
   - extraction & transport of beam ^{238}U, range scan in CSC

3) *proof-of-principle: 3 shifts*
   - tuning of degrader, and CSC conditions with ^{238}U+^{209}Bi: α spectroscopy of ^{211}Po,^{211m}Po in DU1 and MR-TOF
   - method validation with ^{238}U+^{64}Ni: compare 30 cross sections against data from Legnaro

4) *n-rich actinides measurement with ^{238}U target: 8 shifts*
   - measure ~20 new masses and ~60 cross sections; search for new isomers

5) Total: 22 shifts (14 with beam), ~20 new masses, ~90 cross sections

Setup readiness

In-Cell Reaction System (INCREASE): SOREQ, JLU Giessen, ELI-NP, Tel Aviv University, GSI

Shortened DC cage:

– adapted to kinematics of released products

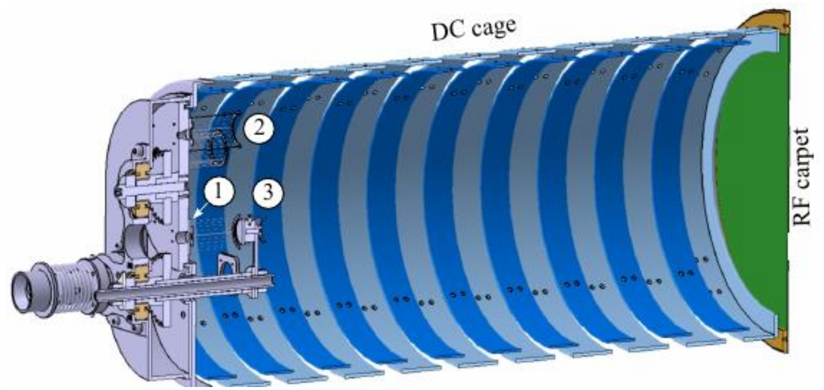
– minimum transport time ~ 7ms

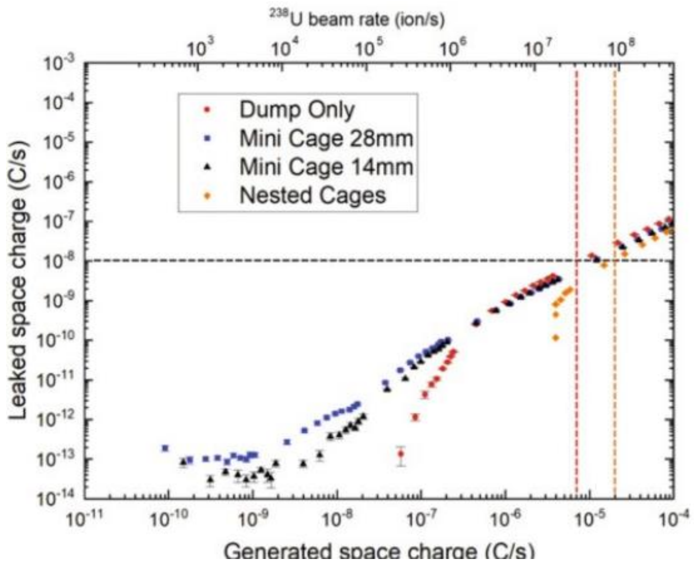
Remote controlled target wheel:

– up to 6 target positions, rotated by motor

– rotatable arm: beam dump, Si detector, attenuator

– electric cages for space charge containment

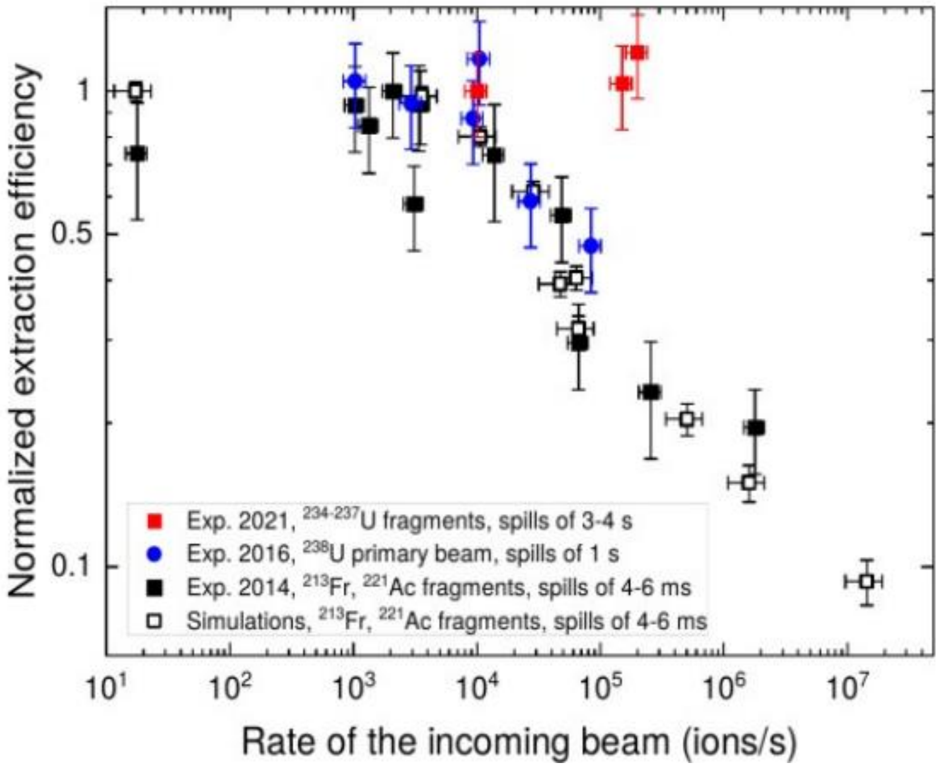




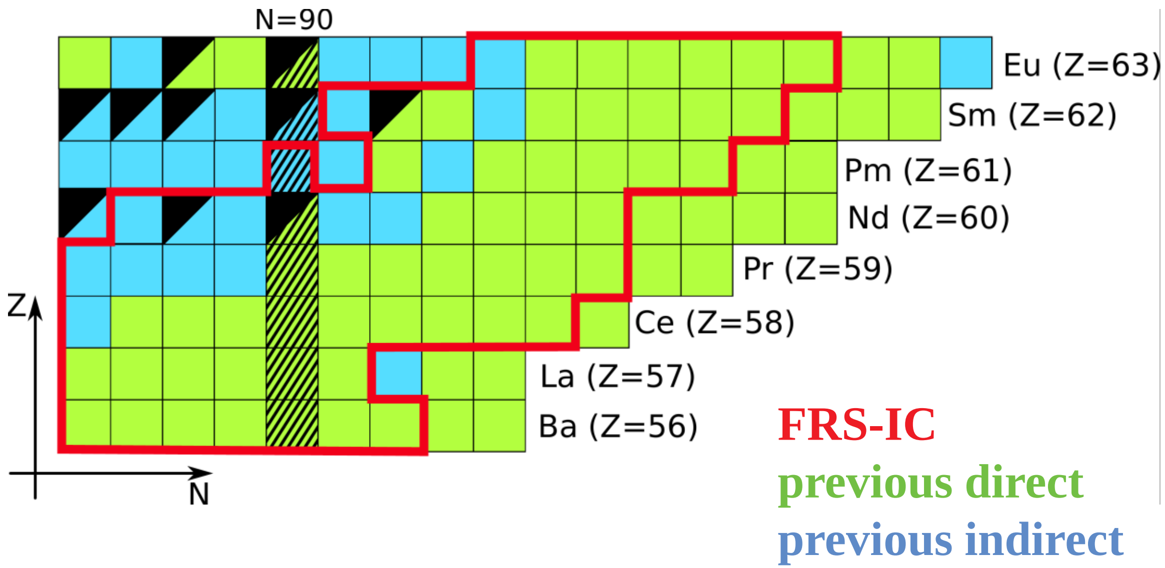
Rotaru A. et al., NIM B 512, 83 (2022)

Setup readiness

In beam experiment S530 fission isomers:
T. Dickel et al. (2021)
– faster (shorter, higher DC): τ~7ms
– high rate: >$10^5 s^{-1}$ (exp.), 10^7-$10^8 s^{-1}$ (sim.)
– broadband and element independent



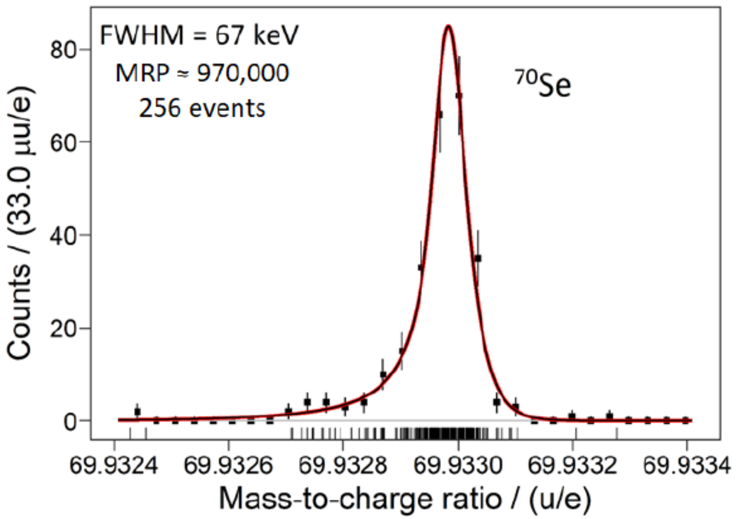
Offline experiment ^{252}Cf s.f.:
I. Mardor et al. (2020-2022)
– several experimental runs using ^{252}Cf source
– first time simultaneous direct measurement of 69 masses
– data shown here: tof~9ms, m/Δm~320,000



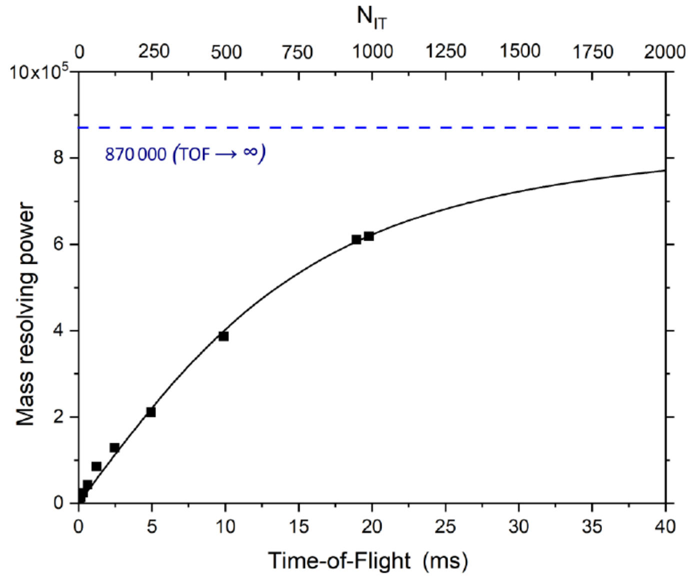
Setup readiness

MR-ToF upgrades:
– m/Δm~10^6 obtained
– fast: half lives ~1ms
– non-scanning device: tens of FFs measured simultaneously

I. Mardor et al., PRC 103, 034319 (2021)



S. Ayet San Andrés et al., PRC 99, 064313 (2019)



FRS-IC operation modes: fragmentation behind FRS + in-cell 252Cf s.f., MNT

future at SuperFRS: combine both!

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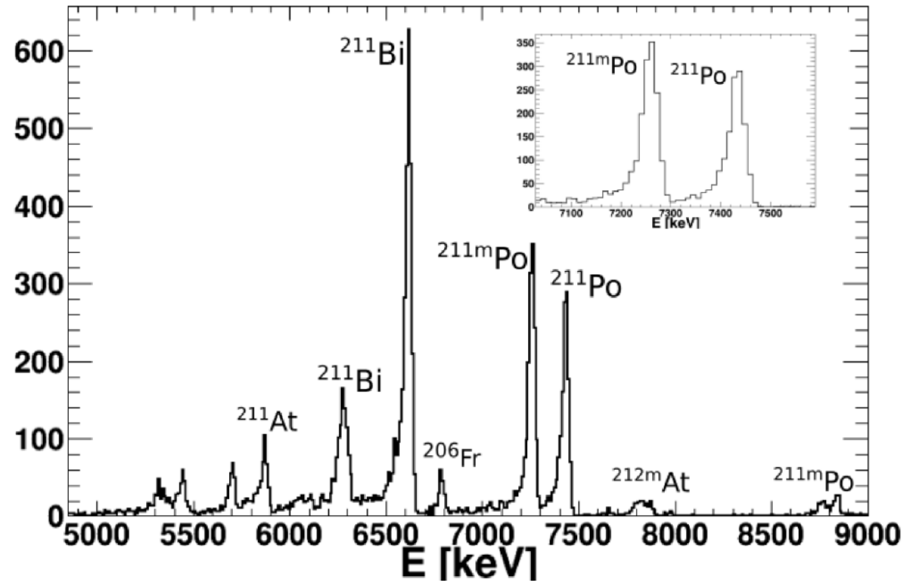
Beam optimization and CSC tuning

Beam optimization:
– beam slowing down from 500 MeV/u to 6 MeV/u (^{64}Ni) and 12 MeV/u (^{238}U/^{209}Bi)
– beam focusing on the target inside the CSC
– beam intensity measurement: SEETRAM (FRS) + INCREASE beam dump current
+ extracted charge on channeltron detector in beamline
– procedures important for future reactions with FRS secondary beams

CSC tuning:
– extract beam ions to DU1 & MR-ToF
– short ^{238}U+^{209}Bi run: MNT test case (Jyväskylä)

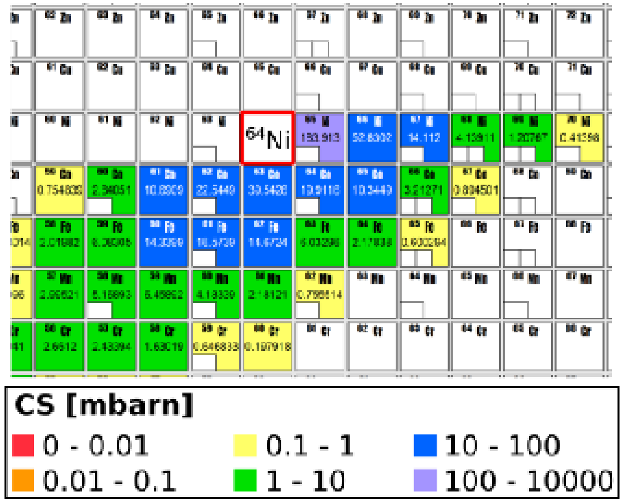
α spectroscopy of ^{211}Po,^{211m}Po
1n+1p transfer TLF
α-decay of fragments on DU1 Si-detector



Proof-of-principle: $^{238}U+^{64}Ni$

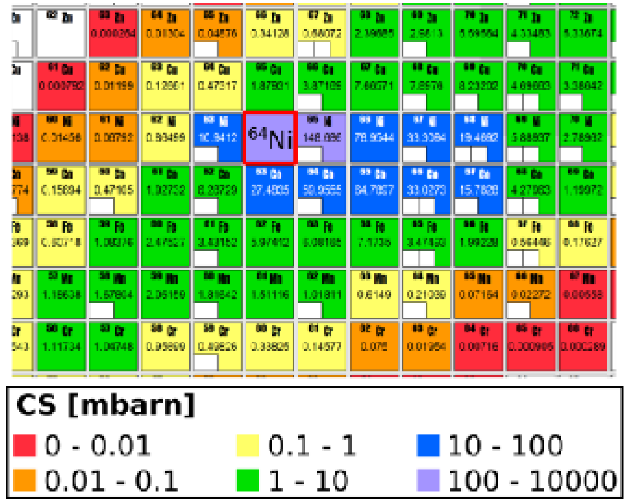
L. Corradi et al.
Phys. Rev. C 59, 261 (1999)

Measurements



A. V. Karpov, V. V. Saiko
Phys. Rev. C 96, 024618 (2017)

Langevin-type model

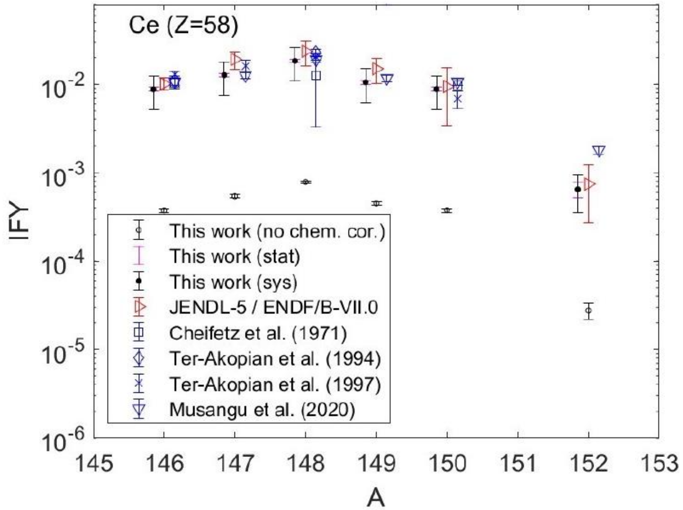


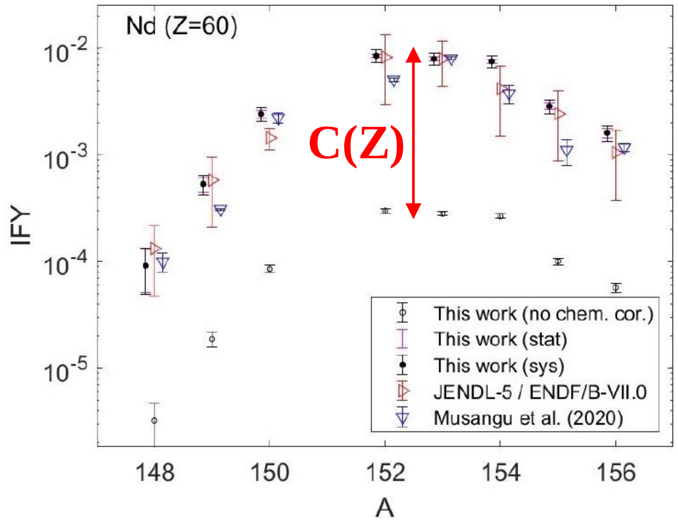
Compare against cross sections for ^{64}Ni at 6 MeV/u on ^{238}U at Legnaro

- full $^{238}U+^{64}Ni$ simulations
- use ^{252}Cf IFY method in MNT case: ^{252}Cf IFY needed in same conditions!
- optimal FRS-IC cleanness: minimize C(Z)!

$$\sum_{Z} IFY(N,Z)_{exp}^{N+Z=A} \cdot C(Z) = frac(FY_{lit}(A)) \cdot FY_{lit}(A)$$

I. Mardor et al., EPJ Web of Conferences 239 (2020)
Y. Waschitz et al., EPJ Web of Conferences





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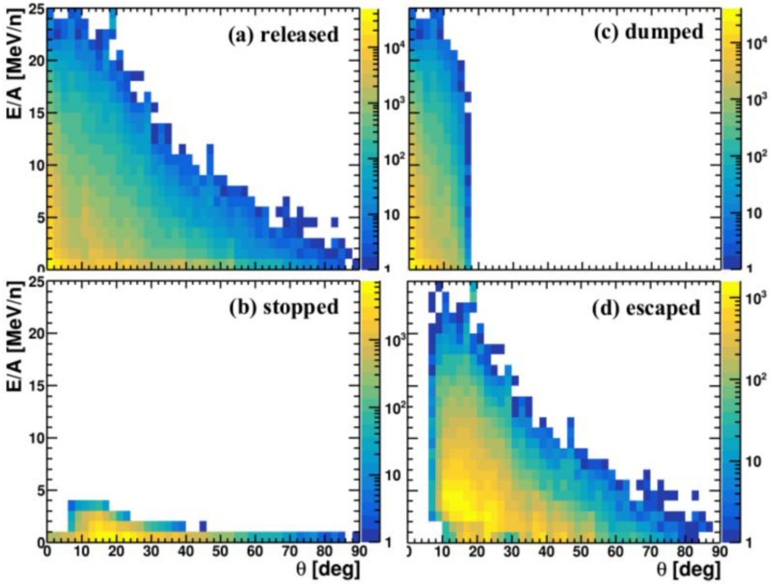
Super-FRS EC

Neutron rich actinides: $^{238}U + ^{238}U$

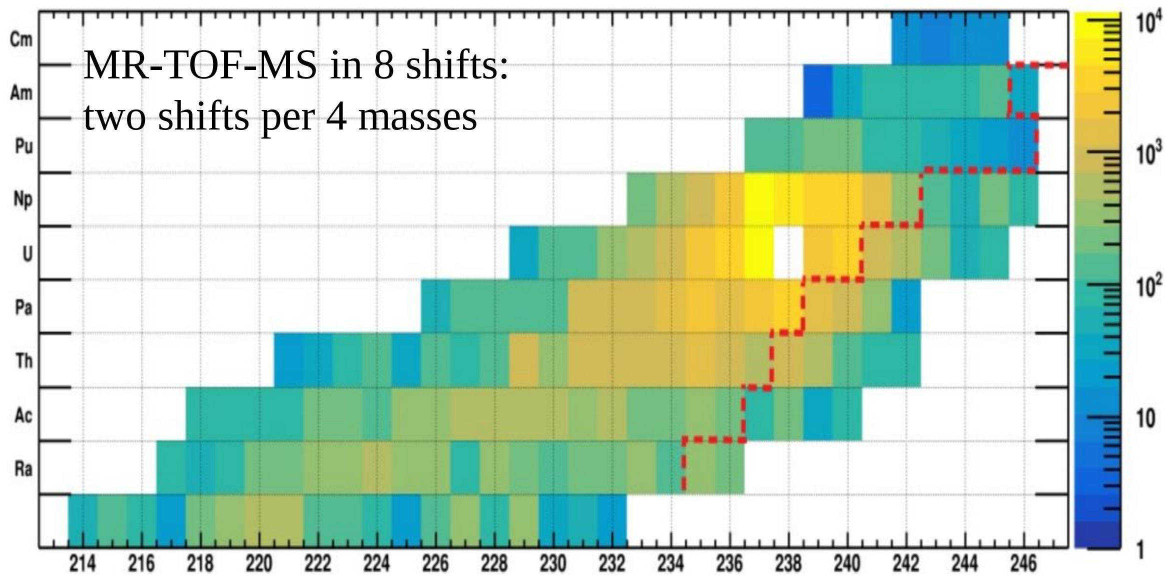
Geant4 simulations with Langevin cross sections
– maximum rate of stopped fragments: optimal $^{238}UO_2$ target 40 μm
– for a $10^7 s^{-1}$ beam, a MR-ToF measurement limit of 20 counts, and 4 mass numbers/measurement:

simulation predicts 23 new masses (Ra-Np) with A=235-246 in 8 shifts



Fragment kinematics
at release in CSC gas

Stopping efficiency ~20%



Dashed line: NUBASE2021 limit

T. Niwase et al., PRL 130, 132502 (2023):
^{241}U measured at KISS in ^{238}U at 10.75 MeV/n on ^{198}Pt

THANK YOU!

and the ***Super-FRS Experiment Collaboration***