20-83 Long-lived isomeric states studied via mass spectrometry

Spokespersons: Dominique Curien (IN2P3), Timo Dickel (GSI)

Jianwei Zhao (GSI)

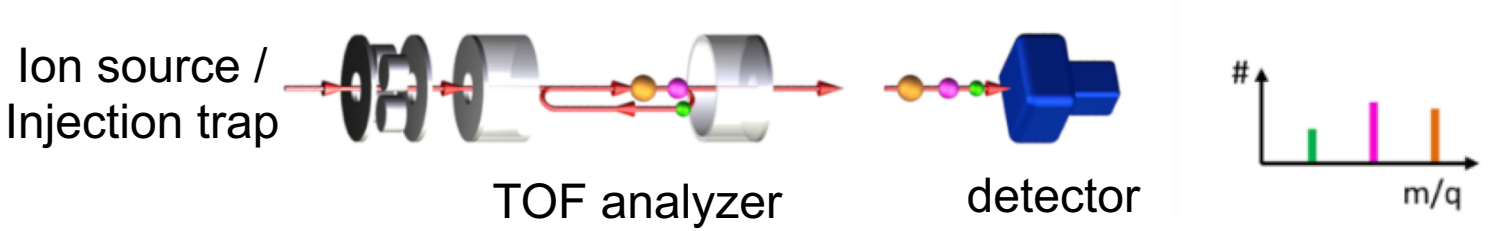
Isomers and mass spectrometry

Online and offline experiments at FRS Ion Catcher, Germany

Online experiments at TRIUMF's Ion Trap for Atomic and Nuclear Science (TITAN), Canada

- perform online & offline experiments at GSI & TRIUMF
- search for nuclear isomeric states via the mass spectrometry
- study their properties with advanced theory
- contribute to nuclear structure understanding

Multiple Reflection Time-of-Flight Mass Spectrometer (MR-TOF-MS)



H. Wollnik et al., Int. J. Mass Spectrom. Ion Processes **96** (1990) 267

Experimental challenges and dealing with them

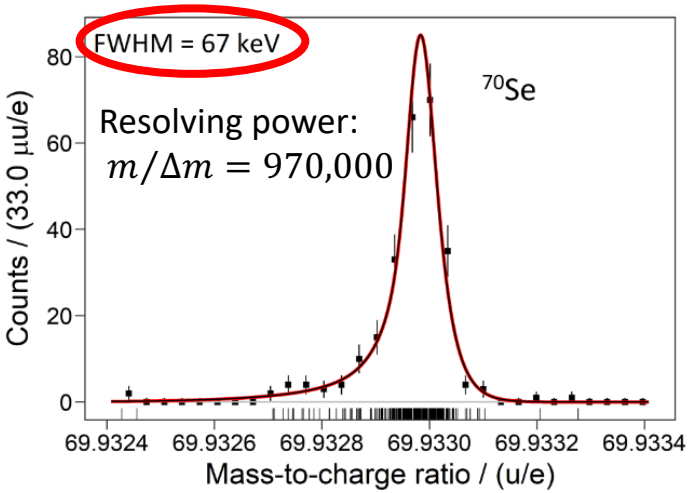
Experimental Challenges:

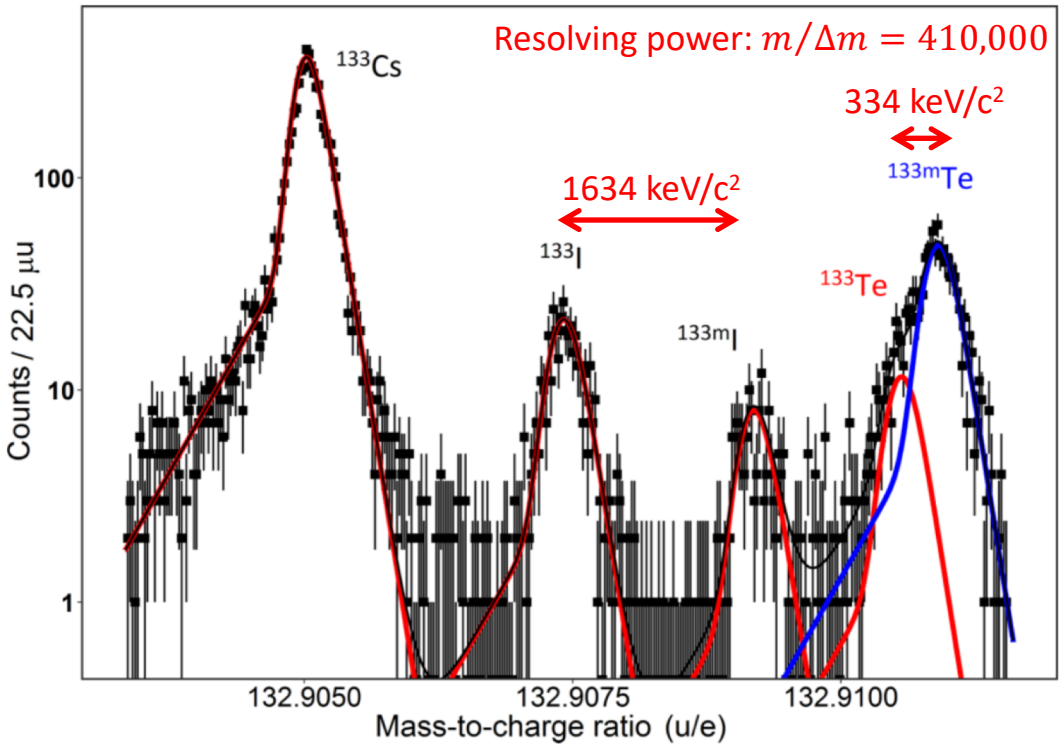
- Short half-lives (~ ms)
- Small production cross section (~ pbarn-μbarn)
- Low-lying isomeric states

Multiple Reflection Time-of-Flight Mass Spectrometer (MR-TOF-MS) :

- Online: ^{220}Ra (17.9 ms) S. Ayet *et al.*, PRC 064313
  ^{125m2}In (5 ms) C. Izzo et al., PRC 025811
- Offline: ^{215}Po (1.8 ms) A.-K. Rink, PhD thesis, JLU Gießen (2017)

Sensitive, broadband, non-scanning





S. Ayet *et al.*, PRC **99** (2019) 064313
I. Mardor *et al.*, PRC **103**, 034319 (2021)

Experimental challenges and dealing with them

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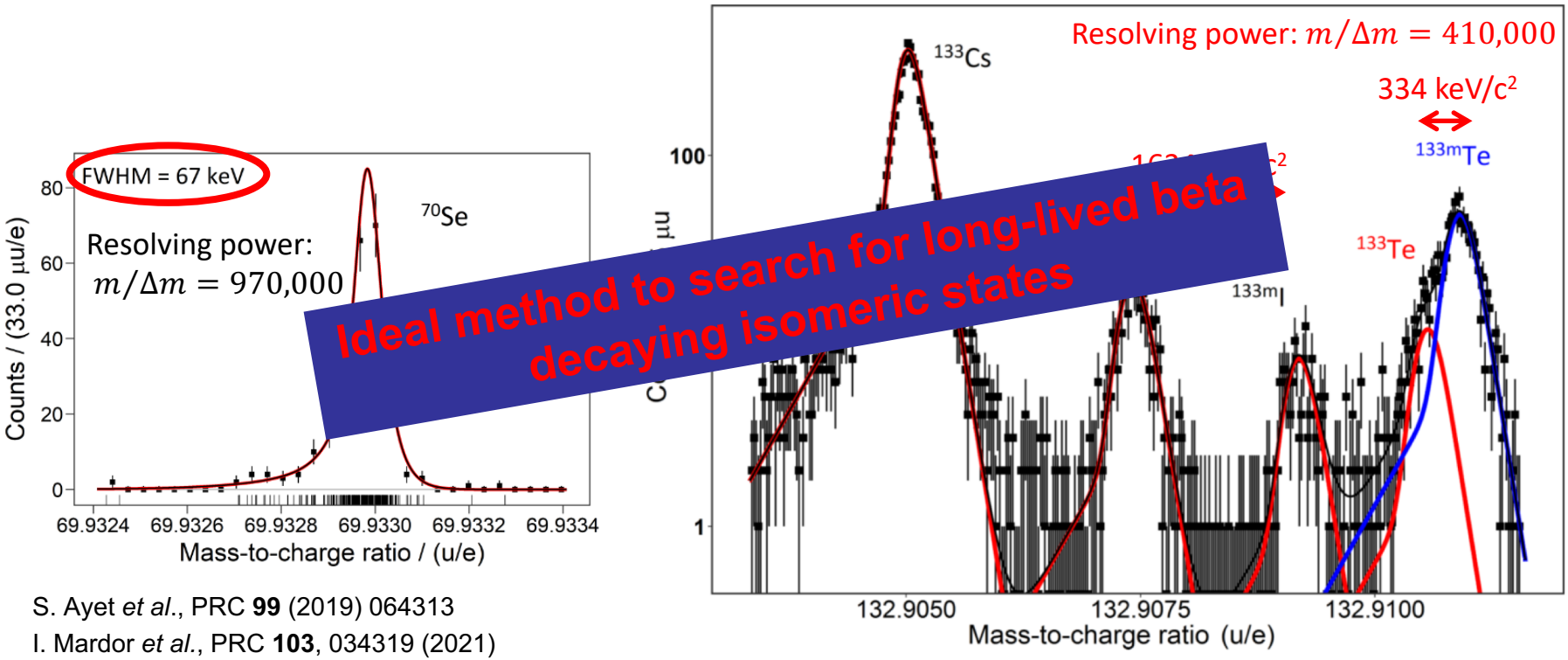
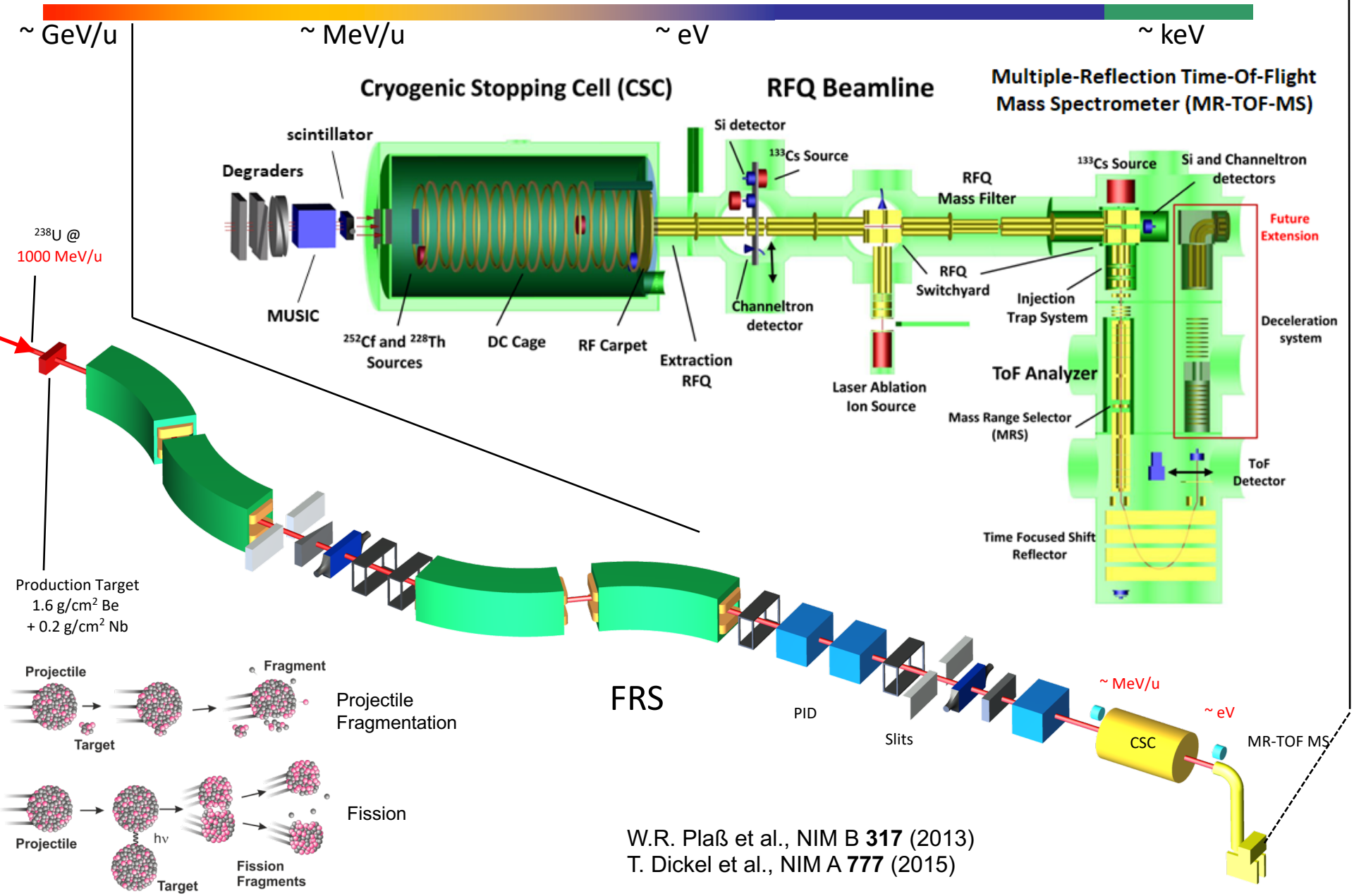


Ideal method to search for long-lived beta decaying isomeric states

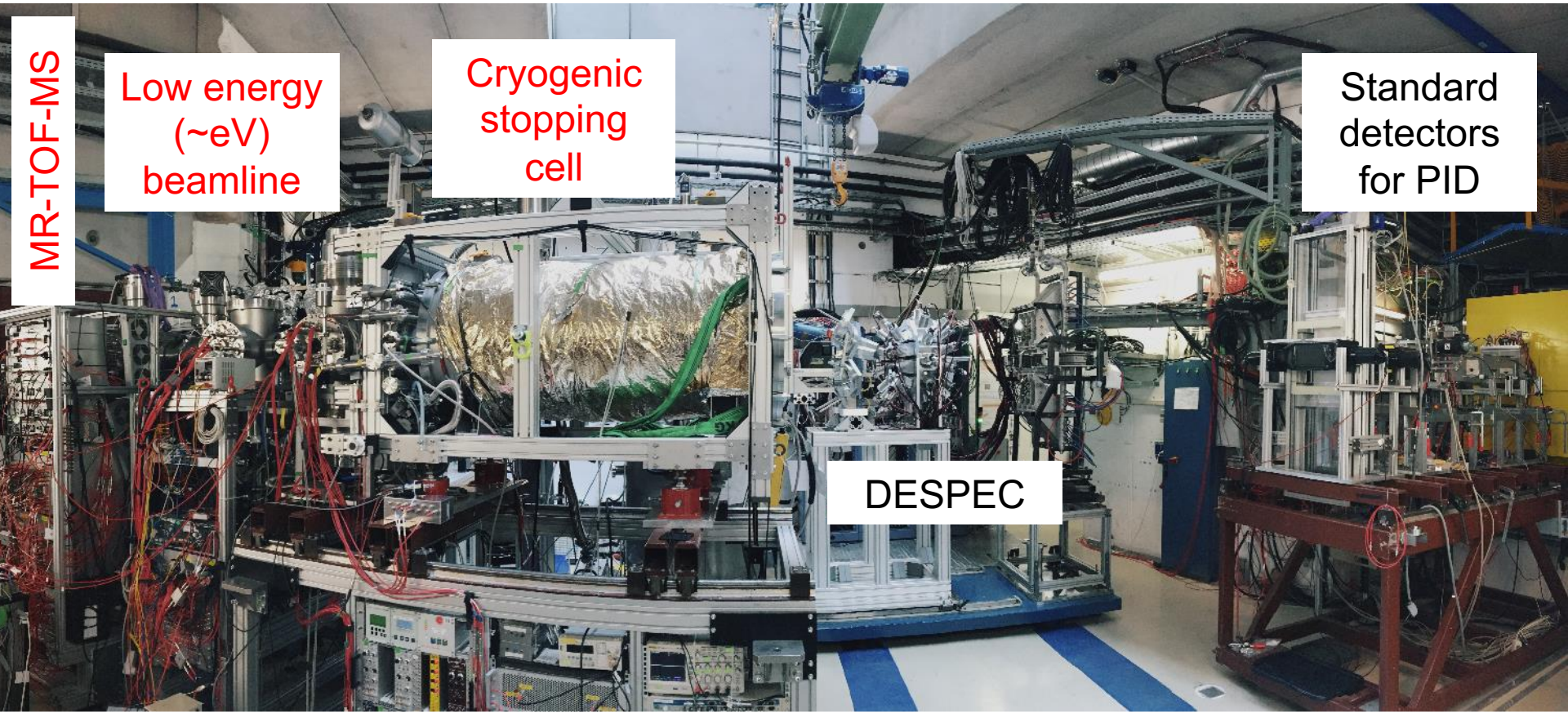
S. Ayet *et al.*, PRC **99** (2019) 064313
I. Mardor *et al.*, PRC **103**, 034319 (2021)

FRS Ion Catcher: Test Facility for the LEB@SuperFRS



W.R. Plaß et al., NIM B **317** (2013)
T. Dickel et al., NIM A **777** (2015)

FRS Ion Catcher



I. Miskun et al., IJMS 459 (2021) 116450
W.R. Plaß et al, Hypefine Inter. 241 (2020) 1
E. Haettner et al., NIM A 880 (2018) 138
S. Purushothaman et al., IJMS 421 (2017) 245
W. R. Plaß et al., Phys. Scr. T166 (2015) 014069
W.R. Plaß et al., Int. J. Mass Spectrometry **394** (2013)

F. Greiner et al., NIM B 463 (2020) 324
M.P. Reiter et al., NIM B 376 (2016) 240
M. Ranjan et al., NIM A 770 (2015) 87
S. Purushothaman et al., EPL 104 (2013) 42001
M. Ranjan et al., Europhys. Lett. 96 (2011) 52001
W.R. Plaß et al., NIM B **266** (2008)

The first and second joint publications

Physics Letters B 802 (2020) 135200

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Isomer studies in the vicinity of the doubly-magic nucleus ^{100}Sn: Observation of a new low-lying isomeric state in ^{97}Ag

Christine Hornung [a,*], Daler Amanbayev [a], Irene Dedes [b], Gabriella Kripko-Koncz [a], Ivan Miskun [a], Noritaka Shimizu [c], Samuel Ayet San Andrés [a,d], Julian Bergmann [a], Timo Dickel [a,d], Jerzy Dudek [e,b], Jens Ebert [a], Hans Geissel [a,d], Magdalena Górska [d], Hubert Grawe [d], Florian Greiner [a], Emma Haettner [d], Takaharu Otsuka [f], Wolfgang R. Plaß [a,d], Sivaji Purushothaman [d], Ann-Kathrin Rink [a], Christoph Scheidenberger [a,d], Helmut Weick [d], Soumya Bagchi [a,d,g], Andrey Blazhev [h], Olga Charviakova [i], Dominique Curien [e], Andrew Finlay [j], Satbir Kaur [g], Wayne Lippert [a], Jan-Hendrik Otto [a], Zygmunt Patyk [i], Stephane Pietri [d], Yoshiki K. Tanaka [d], Yusuke Tsunoda [c], John S. Winfield [d]

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[f] RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
[g] Saint Mary's University, NS B3H 3C3 Halifax, Canada
[h] Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany
[i] National Centre for Nuclear Research, Hoża 69, 00-681 Warszawa, Poland
[j] TRIUMF, BC V6T 2A3 Vancouver, Canada

PHYSICAL REVIEW LETTERS 127, 112501 (2021)

Mass Measurements of Neutron-Deficient Yb Isotopes and Nuclear Structure at the Extreme Proton-Rich Side of the $N = 82$ Shell

Sönke Beck [1,2,*], Brian Kootte [3,4], Irene Dedes [5,6], Timo Dickel [1,2], A. A. Kwiatkowski [3,7], Eleni Marina Lykiardopoulou [8,3], Wolfgang R. Plaß [1,2], Moritz P. Reiter [1,3,9], Corina Andreoiu [10], Julian Bergmann [1], Thomas Brunner [11], Dominique Curien [12], Jens Dilling [3,8], Jerzy Dudek [12,6], Eleanor Dunling [3,13], Jake Flowerdew [14], Abdelghafar Gaamouci [15], Leigh Graham [3], Gerald Gwinner [4], Andrew Jacobs [8,3], Renee Klawitter [3], Yang Lan [8], Erich Leistenschneider [8,3], Nikolay Minkov [16], Victor Monier [3], Ish Mukul [3], Stefan F. Paul [3], Christoph Scheidenberger [1,2,17], Robert I. Thompson [14], James L. Tracy, Jr. [3], Michael Vansteenkiste [3], Hua-Lei Wang [18], Michael E. Wieser [14], Christian Will [1], and Jie Yang [6,18]

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[8] Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z1, Canada
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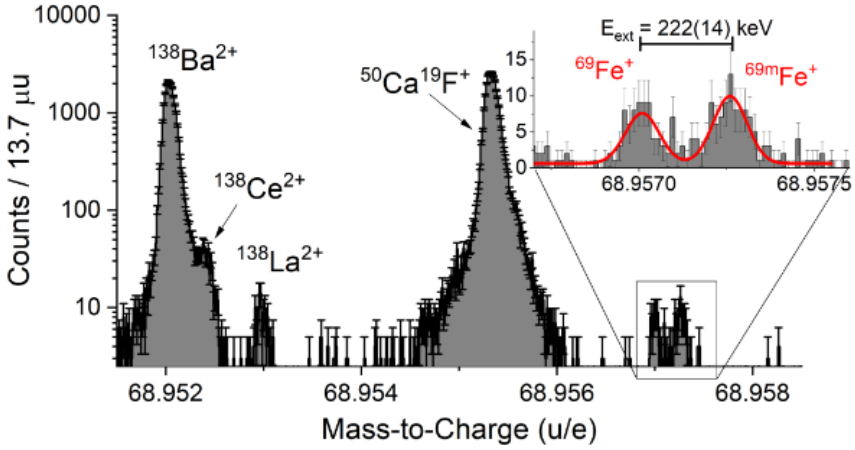
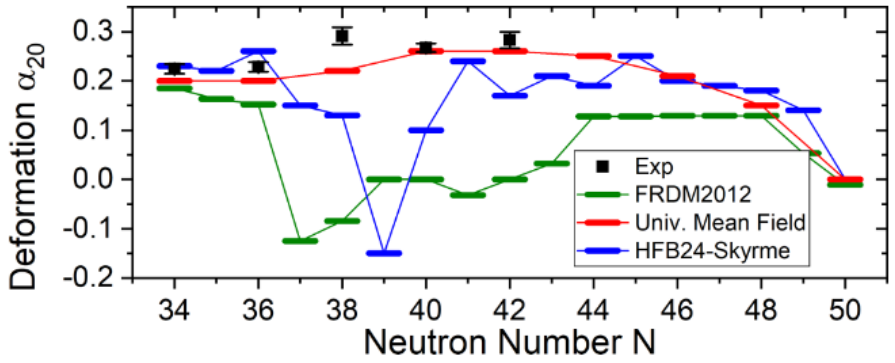
[11] Physics Department, McGill University, H3A 2T8 Montréal, Québec, Canada
[12] Université de Strasbourg, CNRS, IPHC UMR 7178, F-67 000 Strasbourg, France
[13] Department of Physics, University of York, York YO10 5DD, United Kingdom
[14] Department of Physics and Astronomy, University of Calgary, Calgary, Alberta T2N 1N4, Canada
[15] Faculté de Physique, University of Science and Technology Houari Boumediene, BP 32, El Alia, 16111 Bab Ezzouar, Algiers, Algeria
[16] Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria
[17] Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung, Campus Gießen, 35392 Gießen, Germany
[18] School of Physics and Microelectronics, Zhengzhou University, Zhengzhou 450001, China

Theory by IPHC (J. Dudek et al.)

- ^{97m}Ag ($1/2^-$) was discovered (the **first isomer** found by MR-TOF-MS)
- better understanding of the isomeric structures around ^{100}Sn
- reach the proton drip line of Yb with MR-TOF-MS
- isomeric state systematics of the N=81 isotones

Third joint publication: mapping the N = 40 island of inversion





- MR-TOF-MS mass-selective retrapping for neutron-rich Fe isotopes
  → signal-to-noise ratios ~ 10^{-4} for high-precision mass measurements
- a long-lived isomer ^{69m}Fe ($T_{1/2}$>100 ms) newly discovered
- mean-field calculations of deformations in the N=40 island of inversion
- establish a deformation maximum point in the Fe isotopic chain

W.S. Porter *et al.* PRC 105(2022)L041301

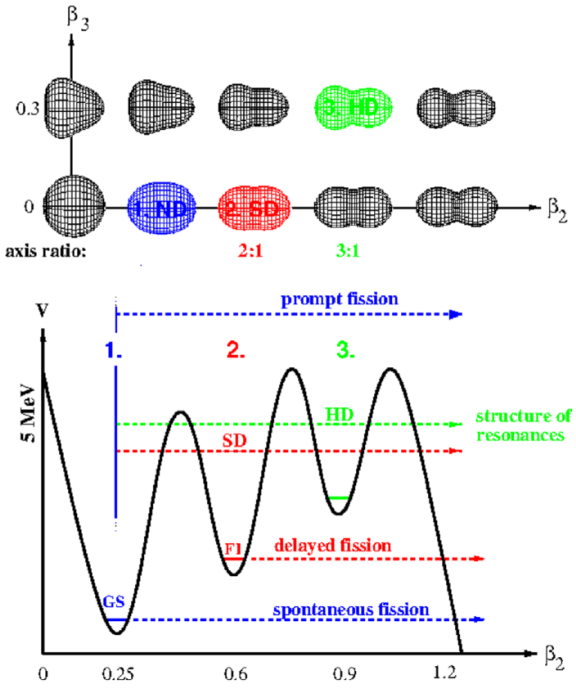
Experiment for fission isomer study

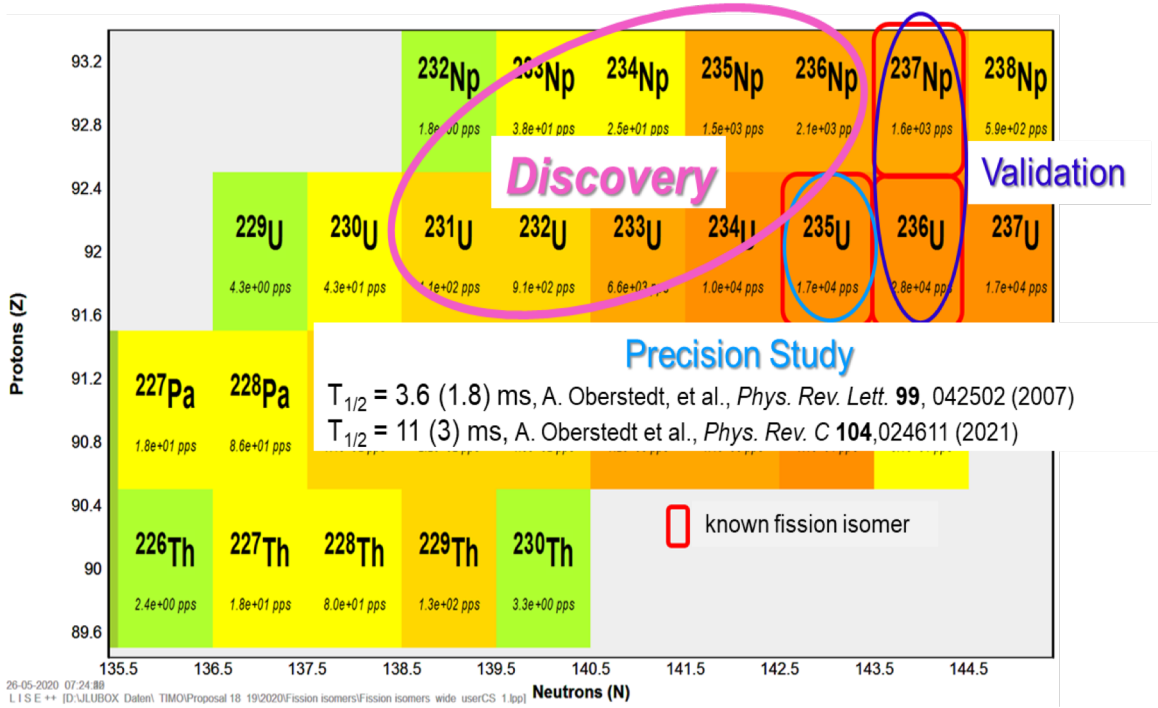
S530 @GSI: "Fission isomer studies with the FRS" (*T. Dickel et al.*)

(Superdeformed) second minimum in potential energy surface appears in actinides → fission isomers.

Ideal testing ground for strongly deformed low-spin nuclei and shell corrections in very heavy systems.

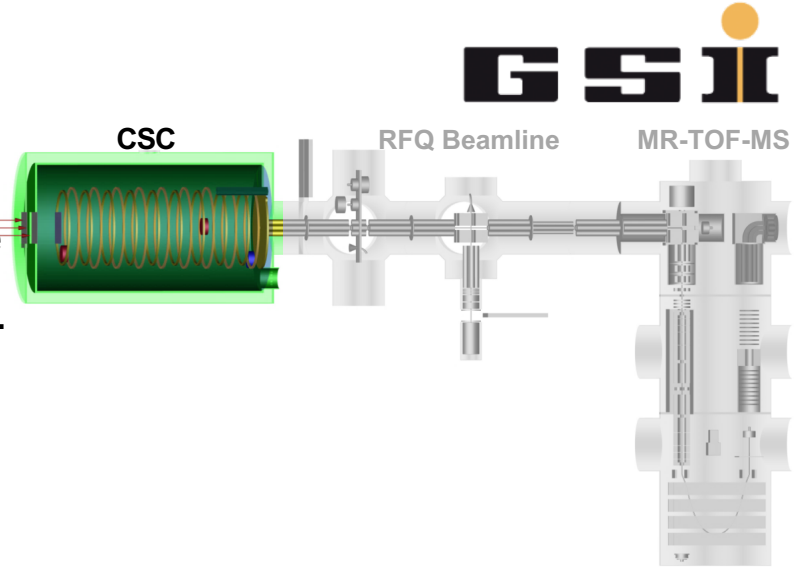
- Fission isomer population with ^{238}U projectile fragmentation
- ^{235f}U, U and Np isotopes that are so far not well studied
- Data analysis ongoing.





^{252}Cf spontaneous fission studies@ FRS Ion Catcher

^{252}Cf spontaneous fission source (37kBq) mounted in the inner chamber of CSC:



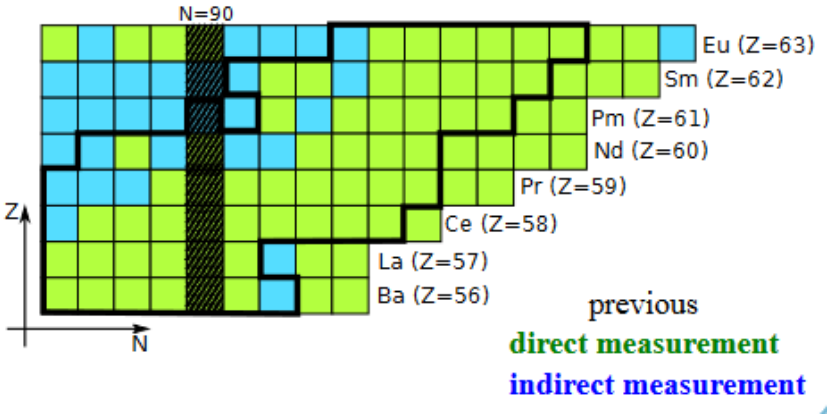
- in-cell produced ions over a broad mass range
- few hundred detected fission products per sec.

→ systematics of spontaneous fission
- → independent fission yields
- → isomer-to-ground ratios

- Shape phase transition at N=90

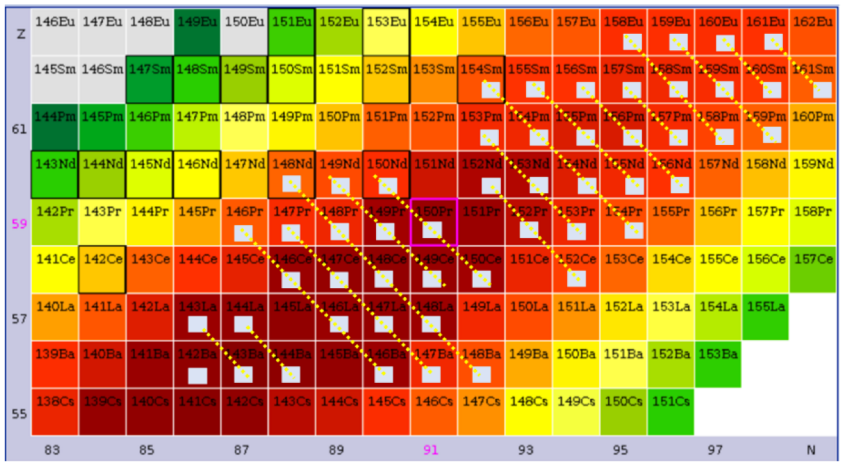
- first time simultaneous measurement of ~ 70 masses
- first time direct mass measurement of 15 nuclei

broadband!



A. Spataru et al, Bulg. J. Phys. 48 (2021) 535

- Independent isotopic fission yields



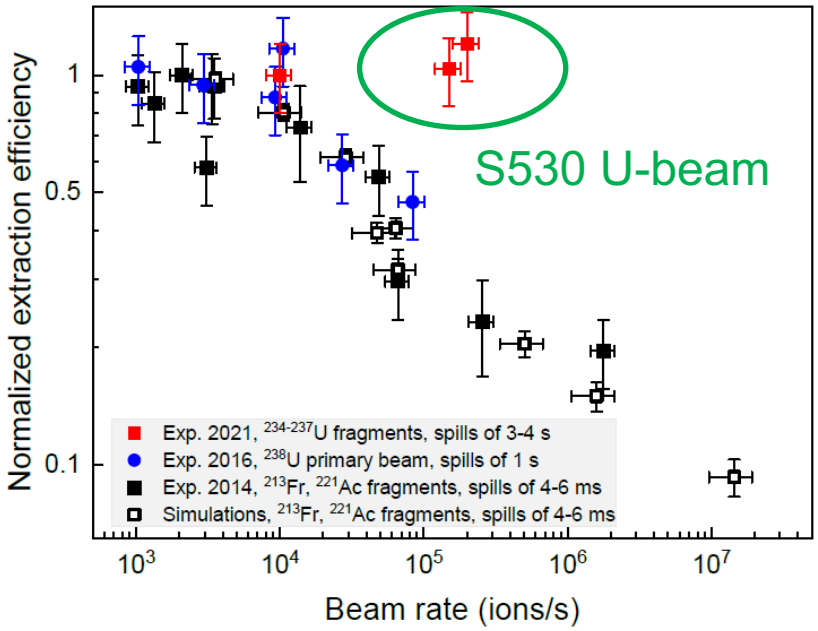
Y. Waschitz, ND 2022 proceeding submitted

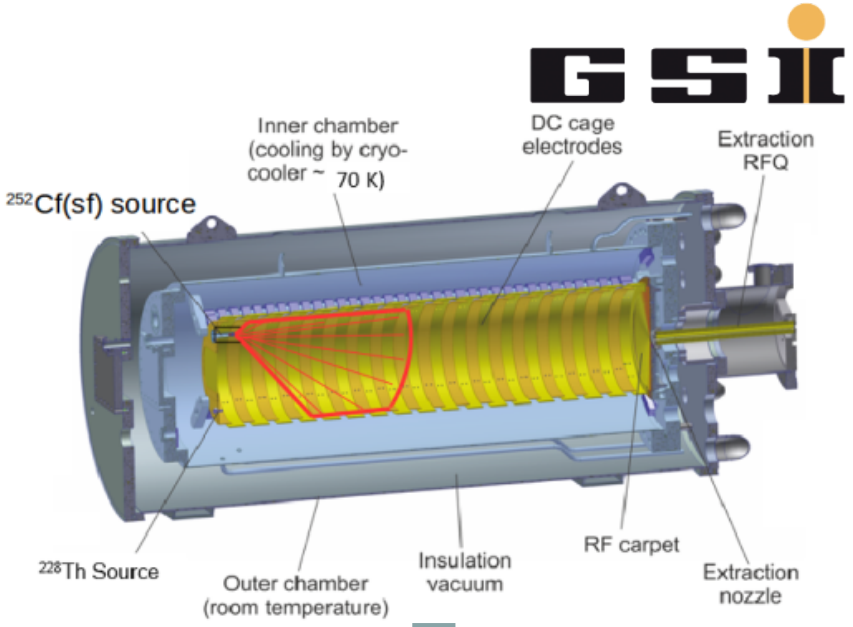
I. Mardor *et al.*, EPJ Web Conf. 239 02004 (2020)

Latest improvements on CSC: INCREASE and DC-cage

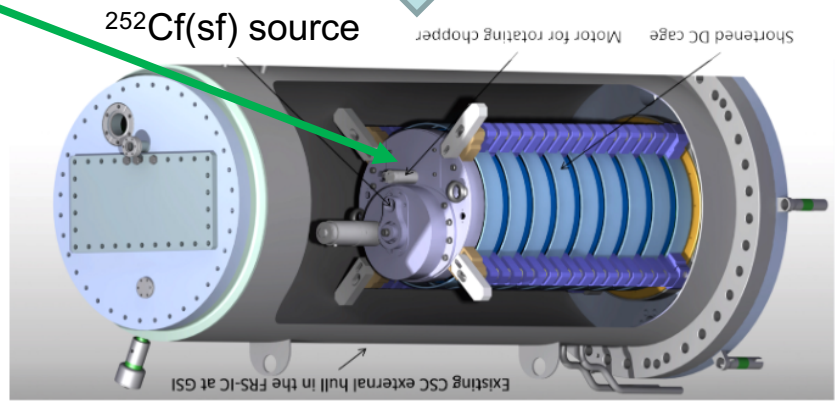
^{252}Cf spontaneous fission source

- source mounted in axis with INCREASE
  - → large acceptance (FFs rate x5)
- short DC-cage
  - → short extraction time (10-20 ms)
  - → higher rate capability (~2x10^5 ions/s)





INCREASE



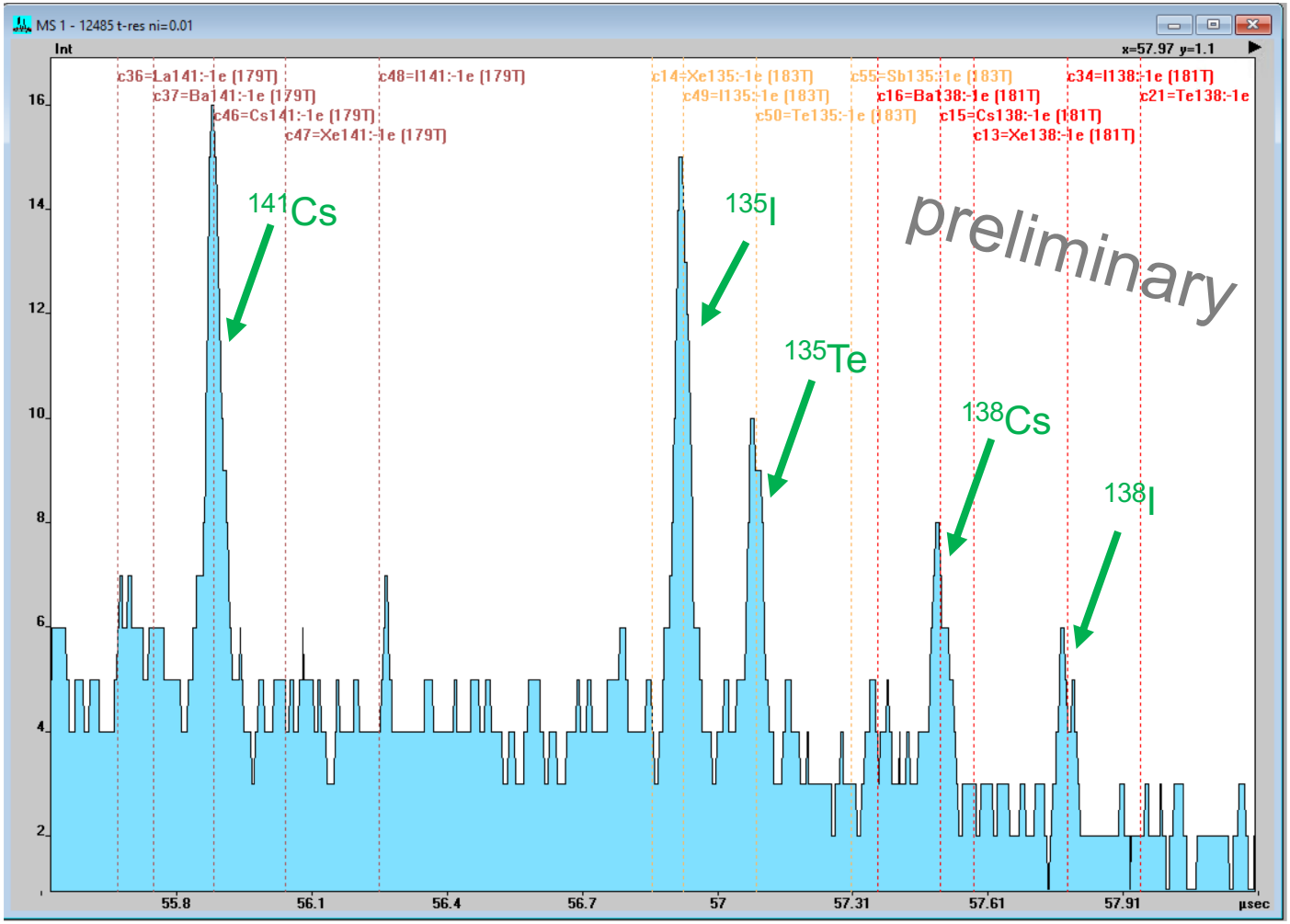
A. Roratu et al, NIMB 512,83 (2022)

Y. Waschitz, ND 2022 proceeding submitted

^{252}Cf spontaneous fission studies 2022

First spectrum from the October engineering run:

- fission fragments from ^{252}Cf source seen: e.g. ^{138,141}Cs, ^{135,138}I, ^{135}Te



Time of flight

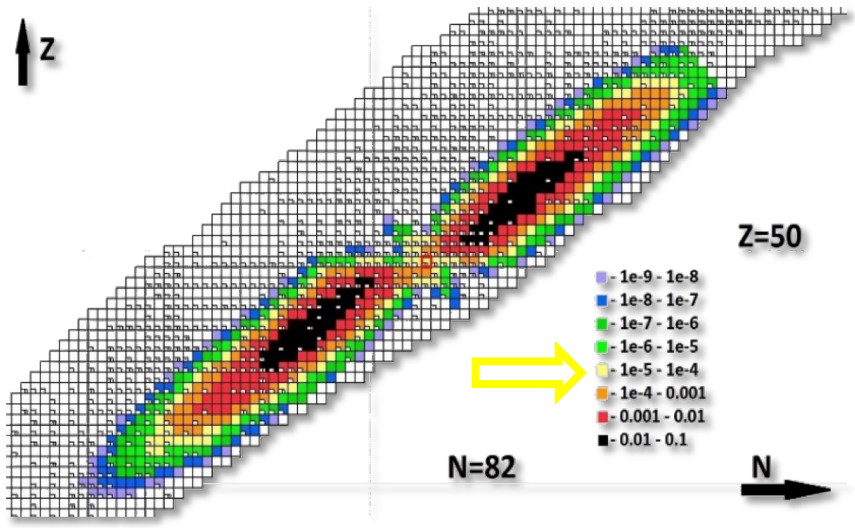
Plans for 2023: ^{252}Cf spontaneous fission studies

The coming run in December:

- aim to reach isotopic fission yields as low as $1x10^{-5}$ (10 times lower)

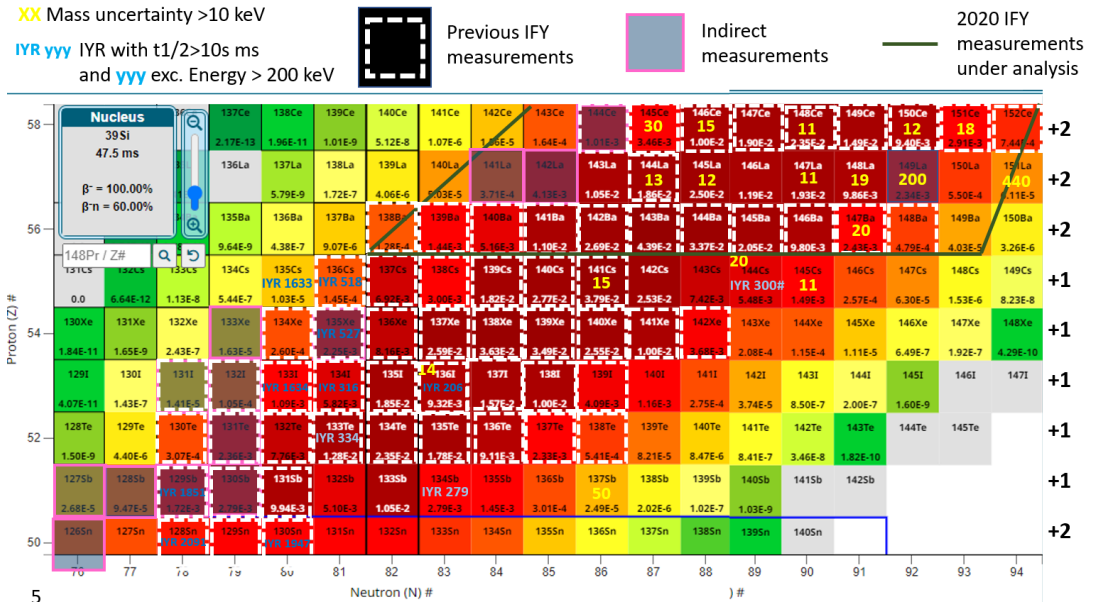
Physics goals:

- tetrahedral magic nuclei around ^{144,146}Ba
- spontaneous fission fragments (Z=51-58)
  - → independent fission yields
  - → isomer-to-ground state ratios



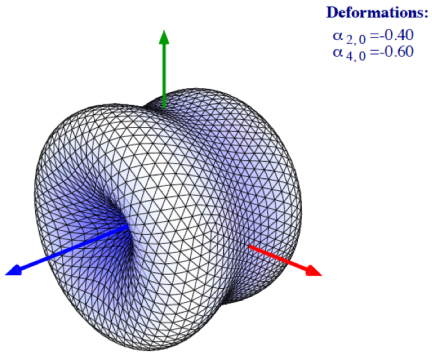
Plan 2023:

- two runs are planed
  - low fission peak (e.g., Zr)

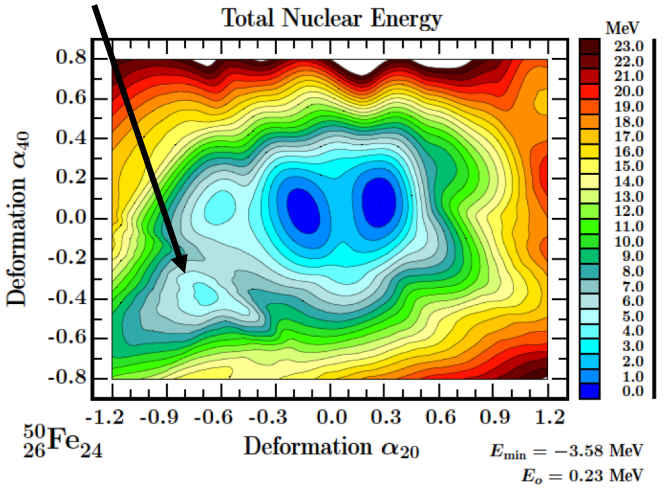


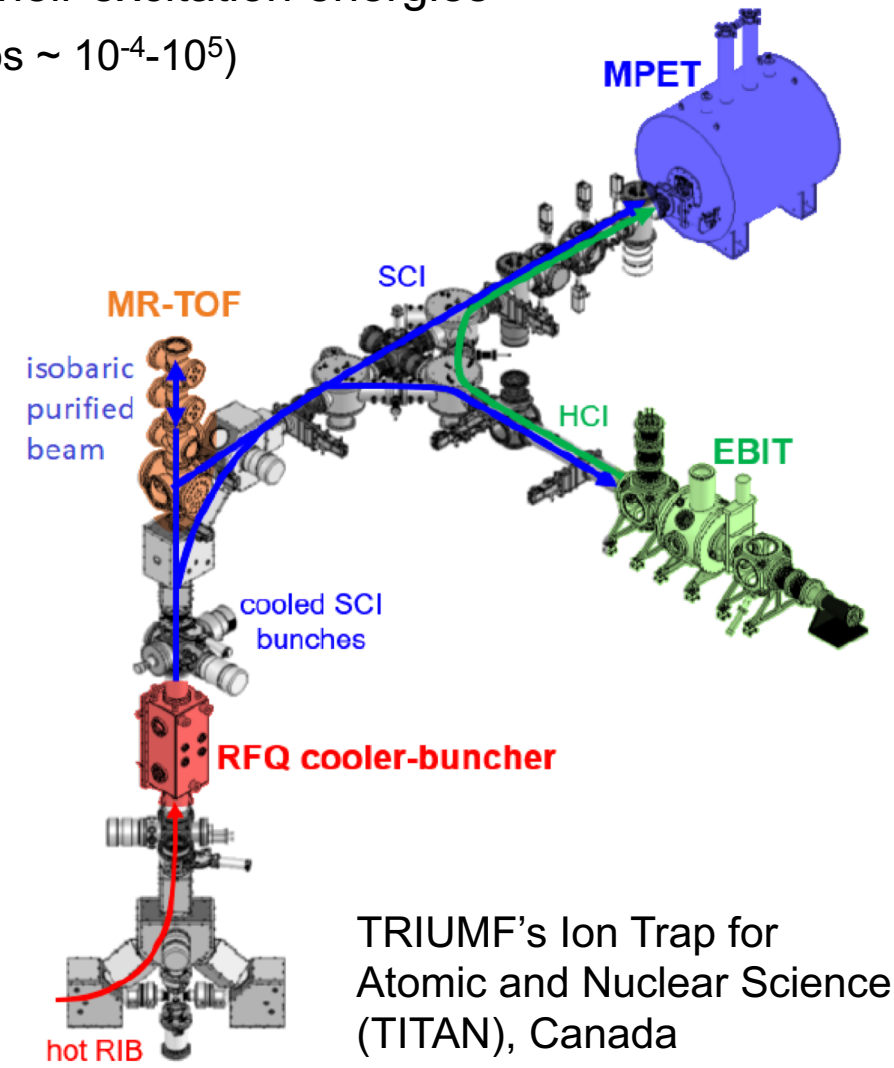
Plans for 2023: Toroidal isomer studies at TITAN

- toroidal shape isomers predicted in even-even Fe & Cr isotopes
- MR-TOF-MS: isomers's existence and their excitation energies
  - → high sensitivity (signal-to-backgroud ratios ~ 10^{-4}-10^{5})
  - → high mass resolving power ~ 6×10^{5}



toroidal shape isomers (mean-field theory by IPHC)





TRIUMF's Ion Trap for Atomic and Nuclear Science (TITAN), Canada

Summary

3 joint publications (PLB, PRL, PRC)

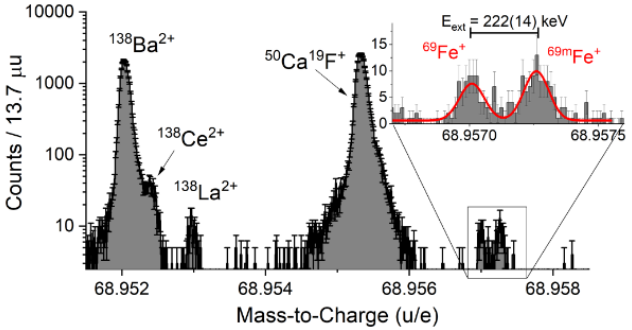
- long-lived isomers (^{97m}Ag, ^{69m}Fe) are discovered
- isomeric state systematics of the N=81 isotones
- mapping the N = 40 island of inversion

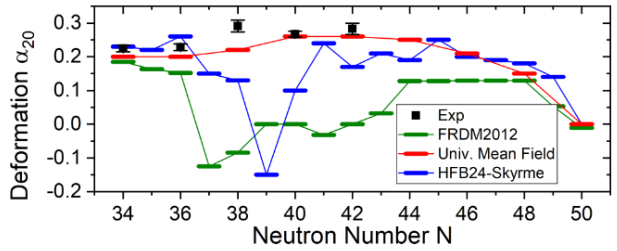
Experiments in progress

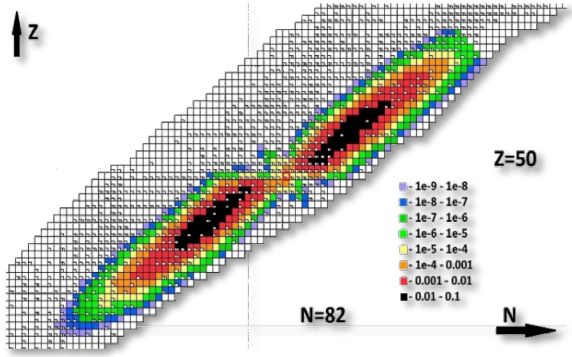
- online experiment for fission isomer study
- offline experiments with ^{252}Cf fission source

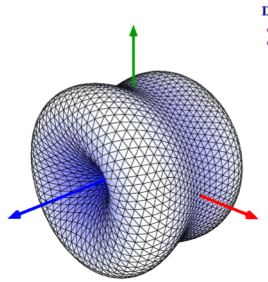
Time used in 2022

- 15/15 days to GSI 6/10 days to IPHC









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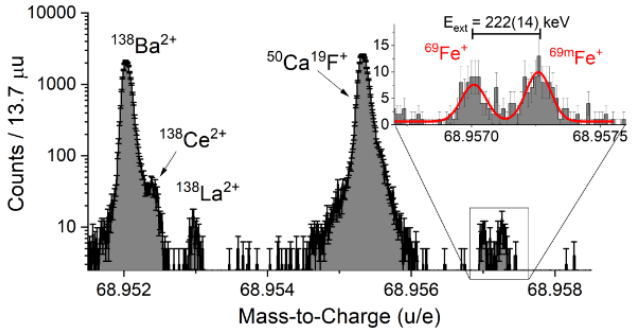
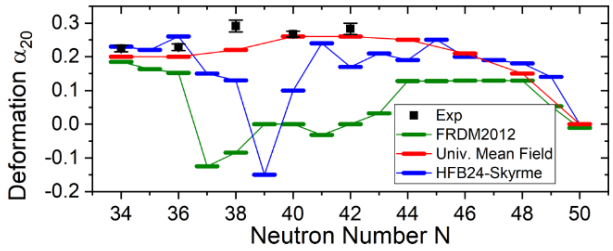
Plans in 2023

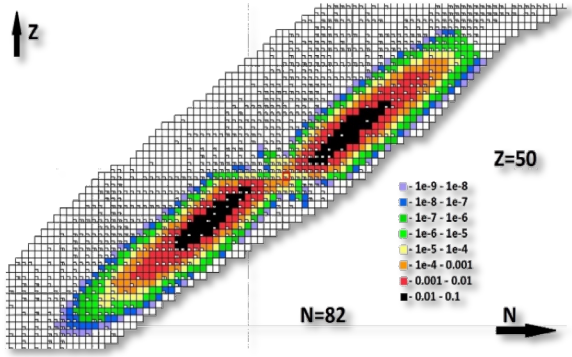
- Joint experiments with ^{252}Cf source @GSI
  - tetrahedral-symmetry nuclei
  - fission product yield distributions & isomeric yield ratios
- Toroidal isomer studies @TITAN

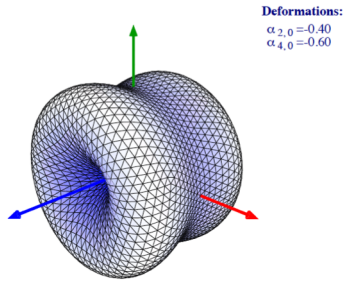
Time requested

- 20 days to GSI: two experiments
- 8 days to IPHC: data analysis & interpretation



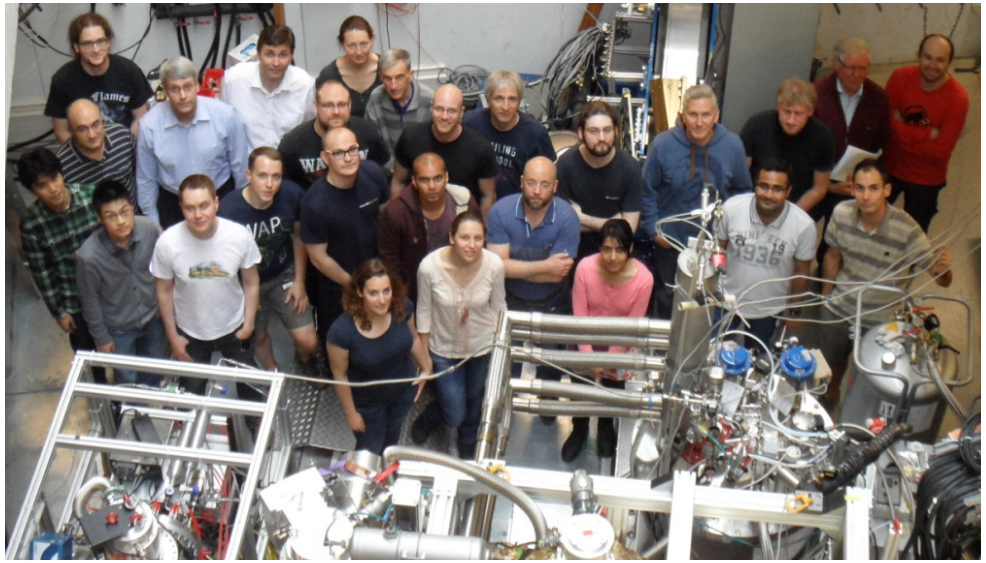




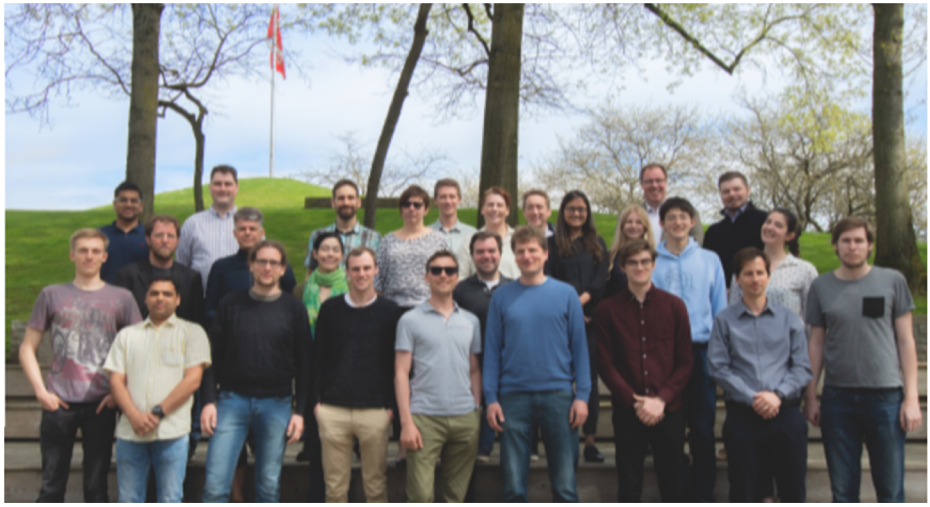


Acknowledgements

FRS Ion Catcher Collaboration



TITAN Collaboration



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KEK Wako Nuclear Science Center
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