II. Physikalisches Institut

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

New capabilities for mass measurements of n-rich nuclei at TITAN/TRIUMF

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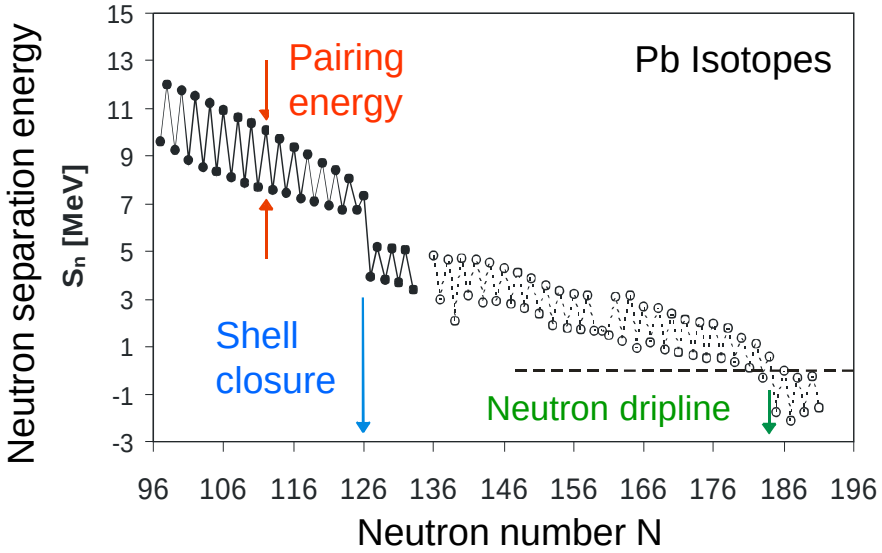
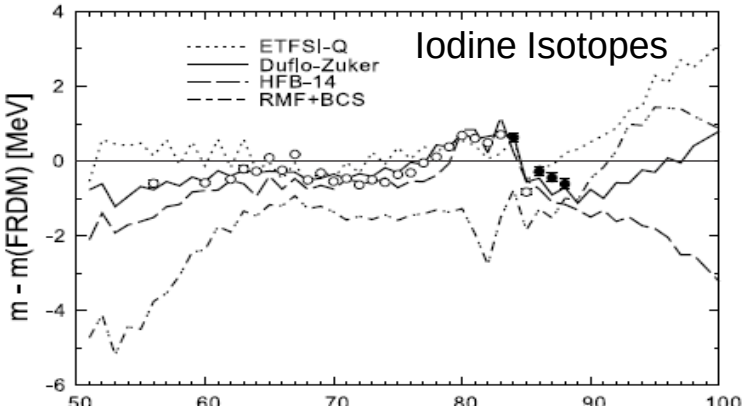
- Production of Exotic Nuclei
- The MR-TOF @ TITAN:
  - Novel Concept
  - Results
- FRS Ion Catcher
  - Isomeric Beams
- Summary

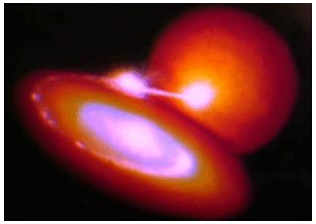
Why Mass Measurements?

Nuclear Structure

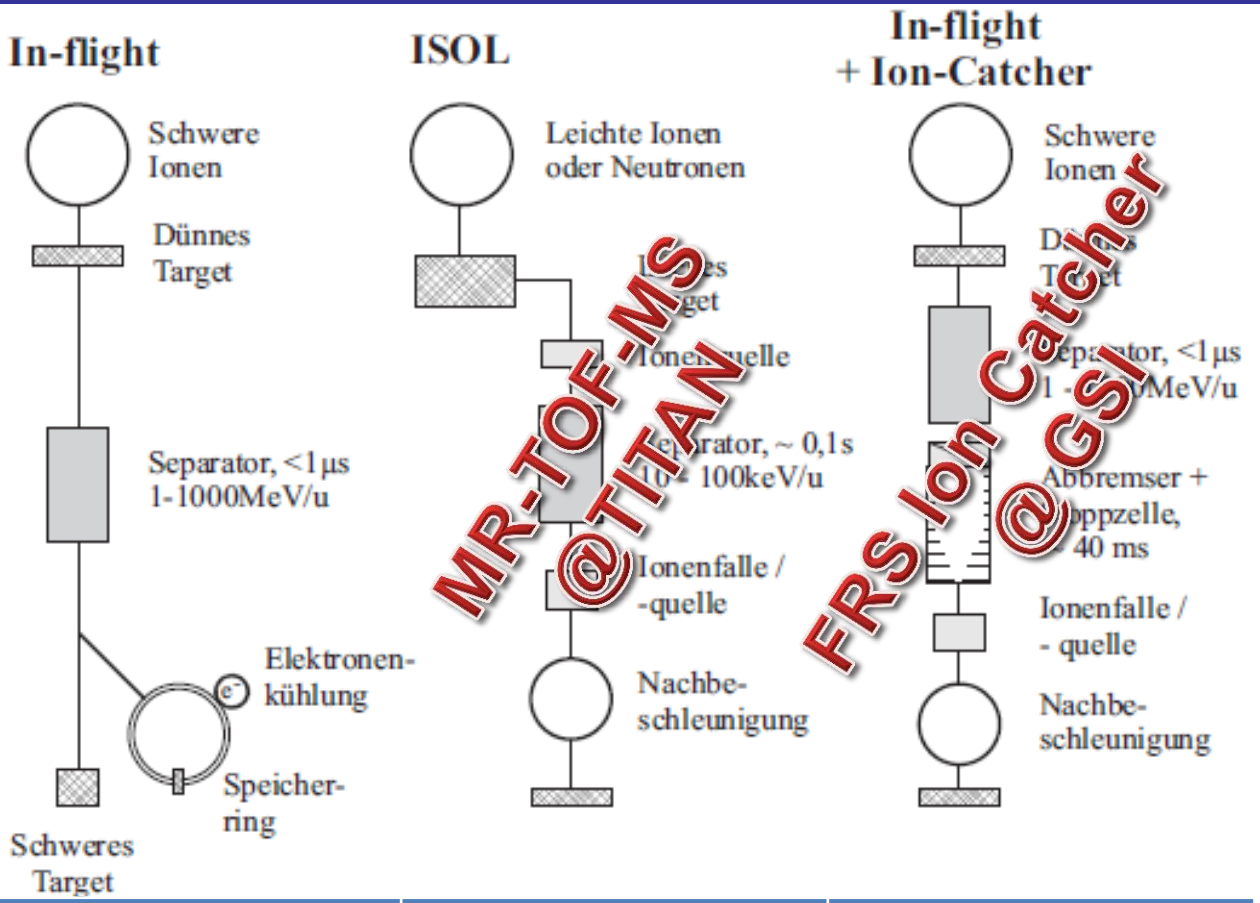




Nuclear Astrophysics

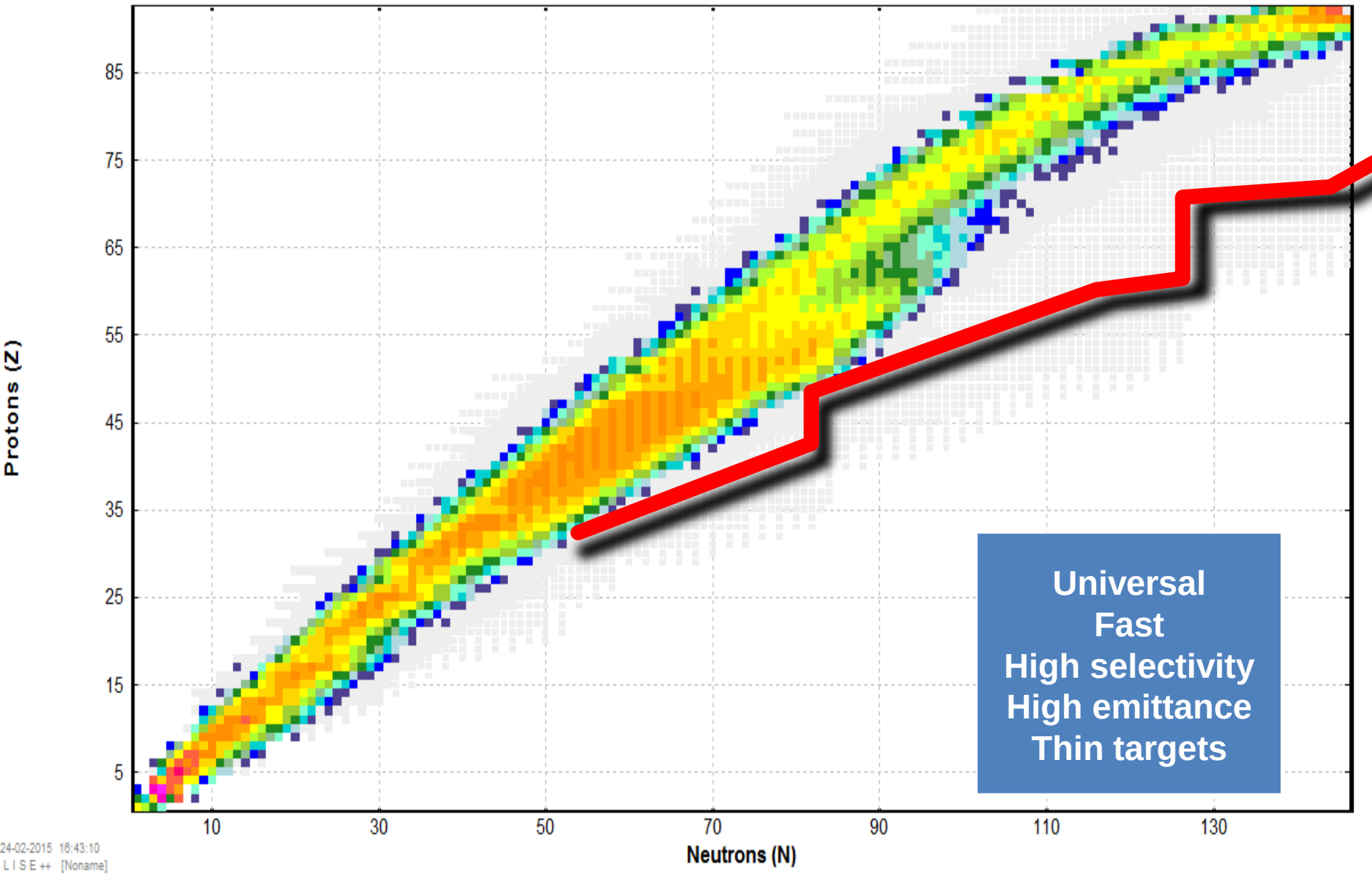


Production of Exotic Nuclei

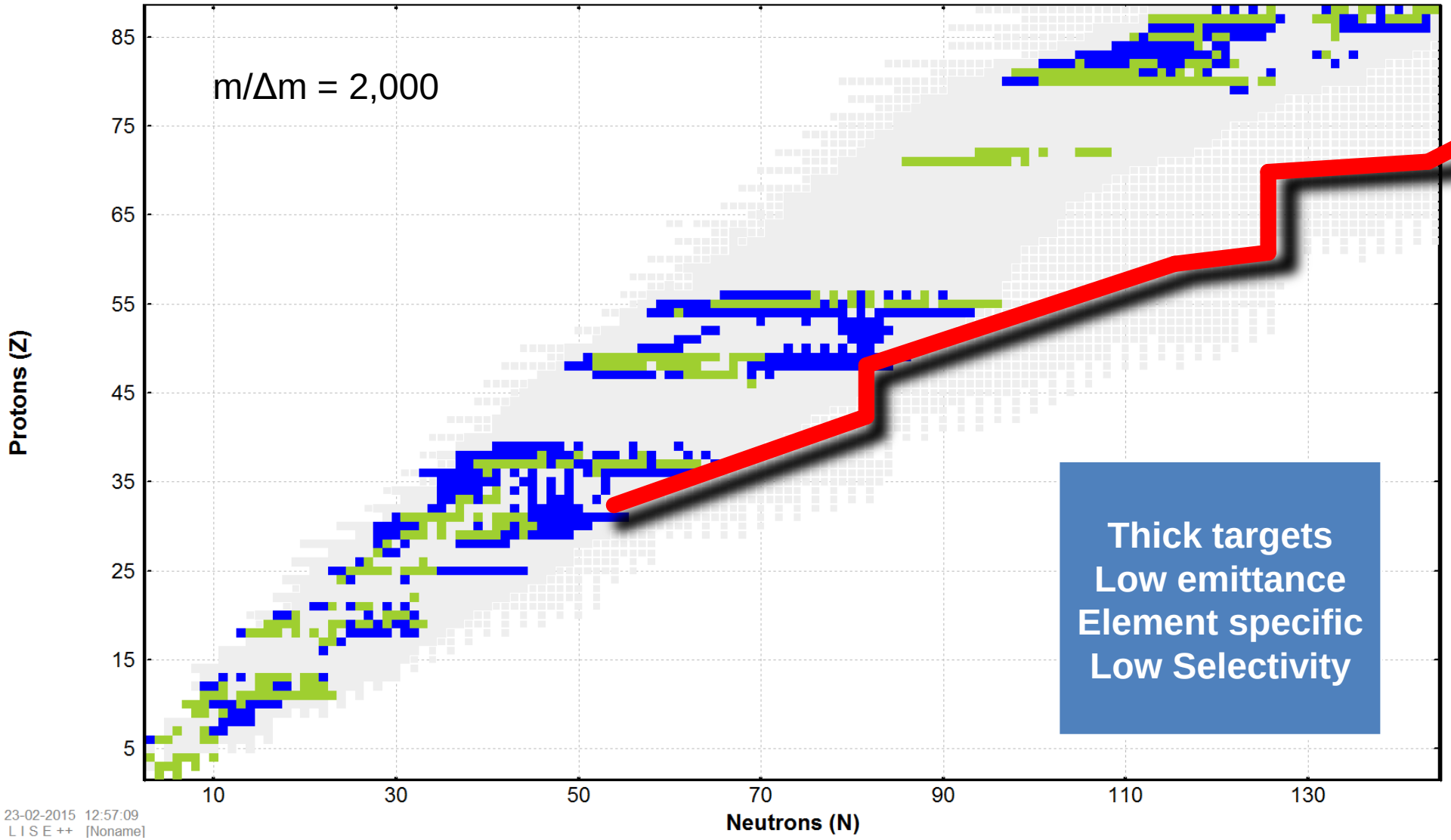


Universal **Fast** **High selectivity** **High emittance** **Thin targets**	**Thick targets** **Low emittance** **Element specific** **Low Selectivity**	**Universal** **Fast** **High selectivity** **Low emittance** **Thin targets**

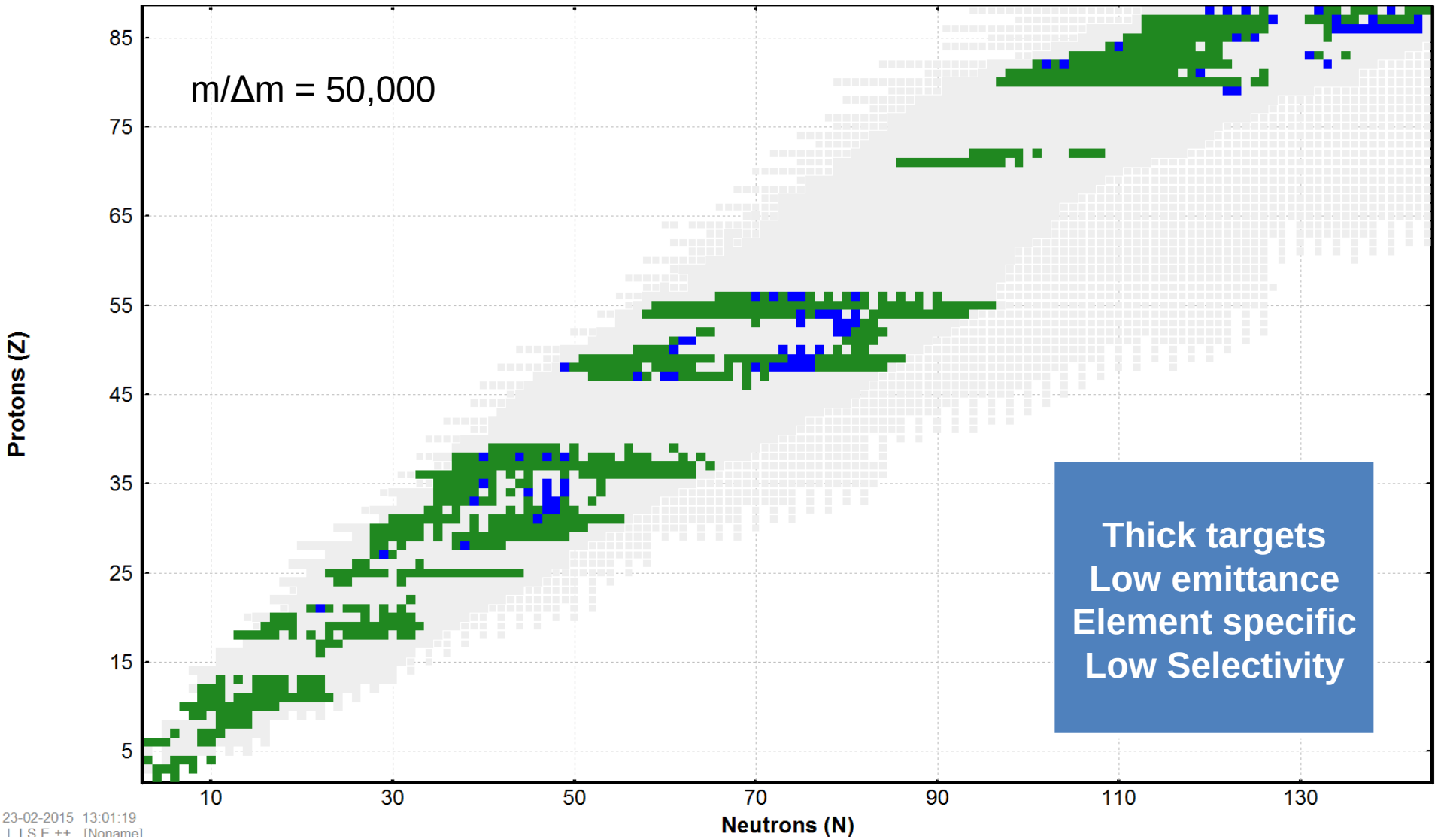
Production of Exotic Nuclei: In-flight



Production of Exotic Nuclei: ISOL

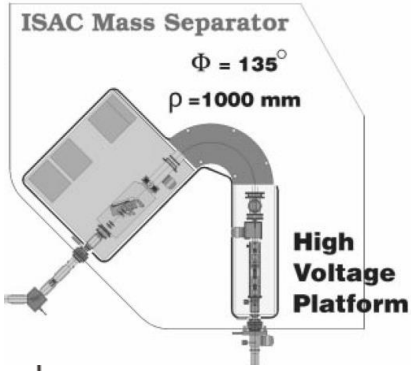


Production of Exotic Nuclei: ISOL

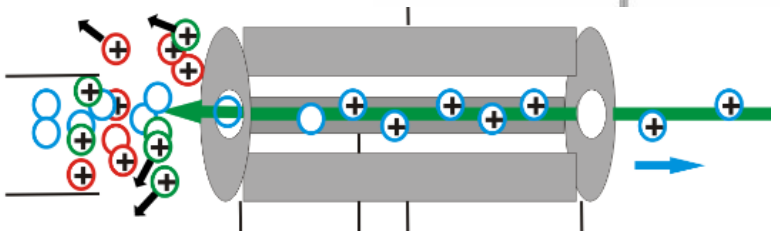


Possible Solutions for Isobaric Contaminations

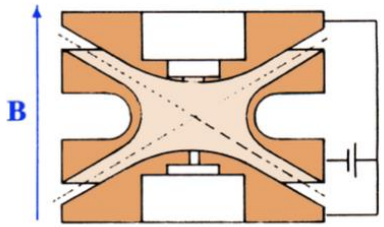
- Magnetic Separator
  - low resolving power (~2000)



- Ion Guide/Trap Resonant Laser Ionization Source
  - Element specific
  - Low efficiency: ~%

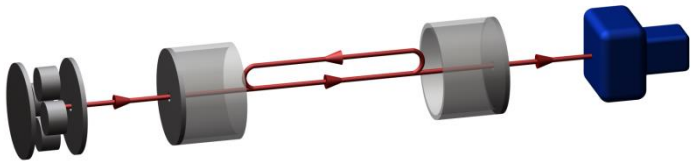


- Mass-sellective Cooling in Penning trap
  - High mass resolving power
  - Low ion capacity (<1000 ions/s) and long separation time (>100ms)



Penning trap
DC plus magnetic field

- MR-TOF-MS
  - Fast (~ms)
  - Universal
  - High ion capacity and mass resolving powe



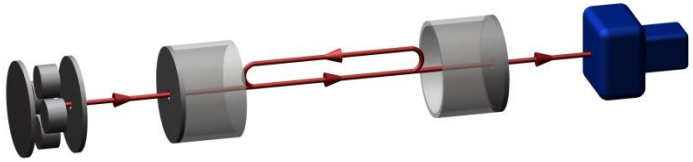
Motivation: TOF Mass Spectrometry in Nuclear Physics

Enables high performance

- Fast → access to very short-lived ions ($T_{1/2}$ ~ ms)
- Sensitive, broadband, non-scanning → efficient, access to rare ions
- Mass resolving power and accuracy almost mass-independent

Conventional TOF-MS achieve medium mass resolving power only
→ Solution to achieve high mass resolving power and accuracy:

Multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS)



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

Applications in nuclear physics

- Direct mass measurements of exotic nuclei

C. Scheidenberger et al., Hyperfine Interact. 132 (2001) 531

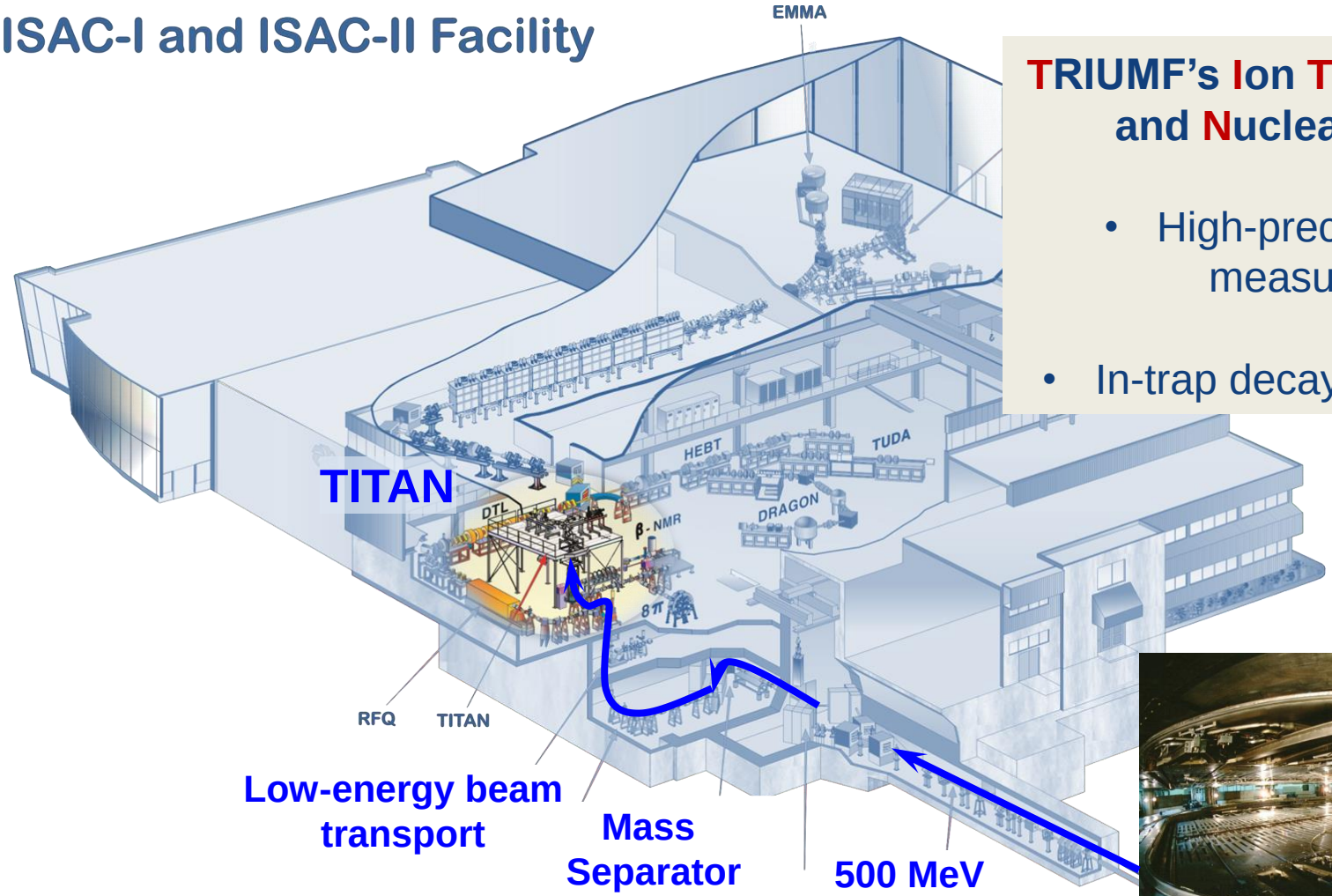
- High-resolution isobar separator

W.R. Plaß et al., NIM B 266 (2008) 4560

- Diagnostics measurements: Monitor production, separation and low-energy beam preparation of exotic nuclei

W.R. Plaß et al., Int. J. Mass Spectrom. 394 (2013) 134

TRIUMF's Ion Trap for Atomic and Nuclear Science



TRIUMF's Ion Trap for Atomic and Nuclear Science

- High-precision mass measurements
- In-trap decay spectroscopy

ISOL facility with **highest primary beam intensity** (100 μA, 500 MeV p)

TRIUMF

TRIUMF's Ion Trap for Atomic and Nuclear Science

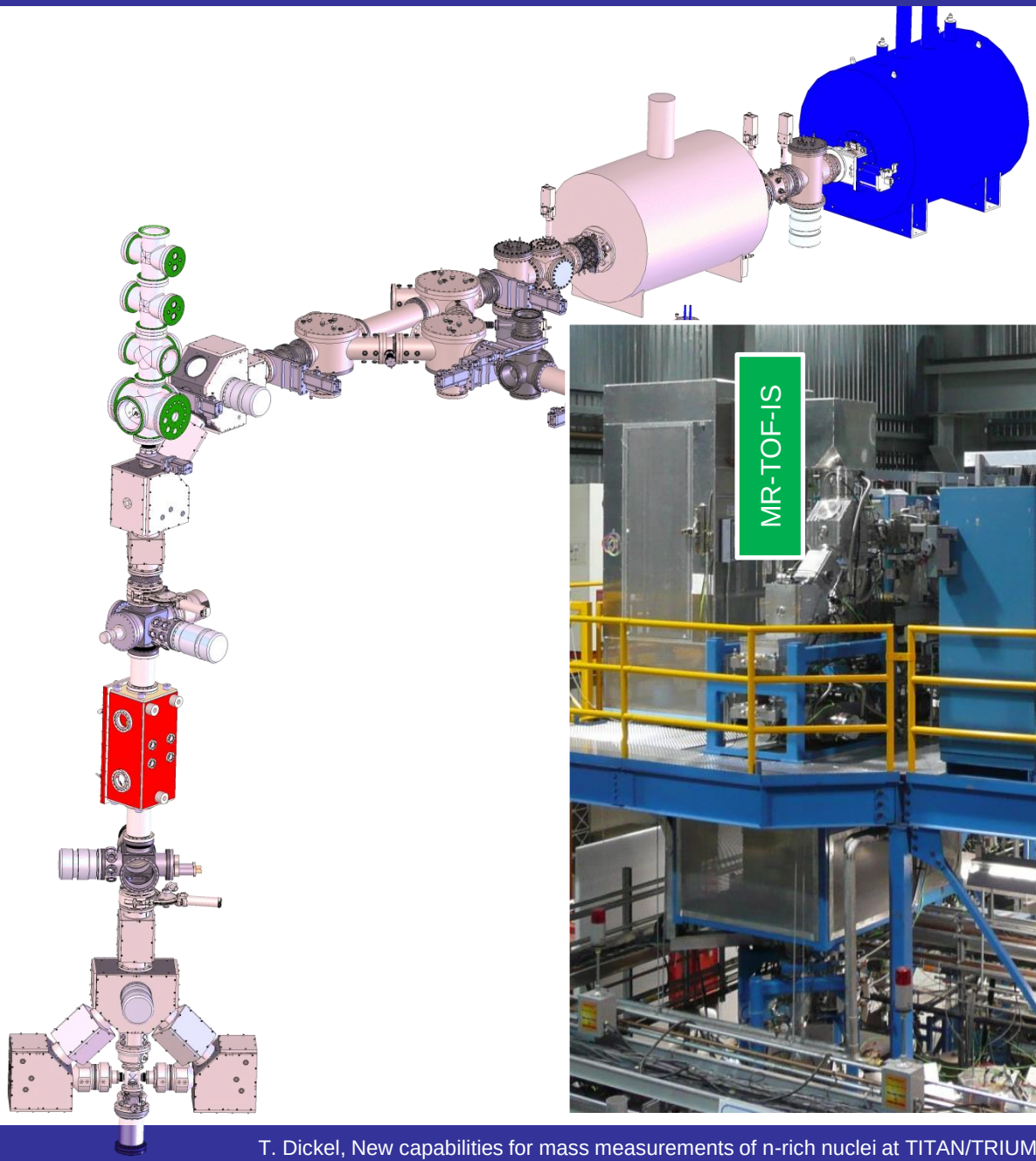
RFQ: Accumulation, cooling, and bunching

MPET: mass measurement via cyclotron frequency determination

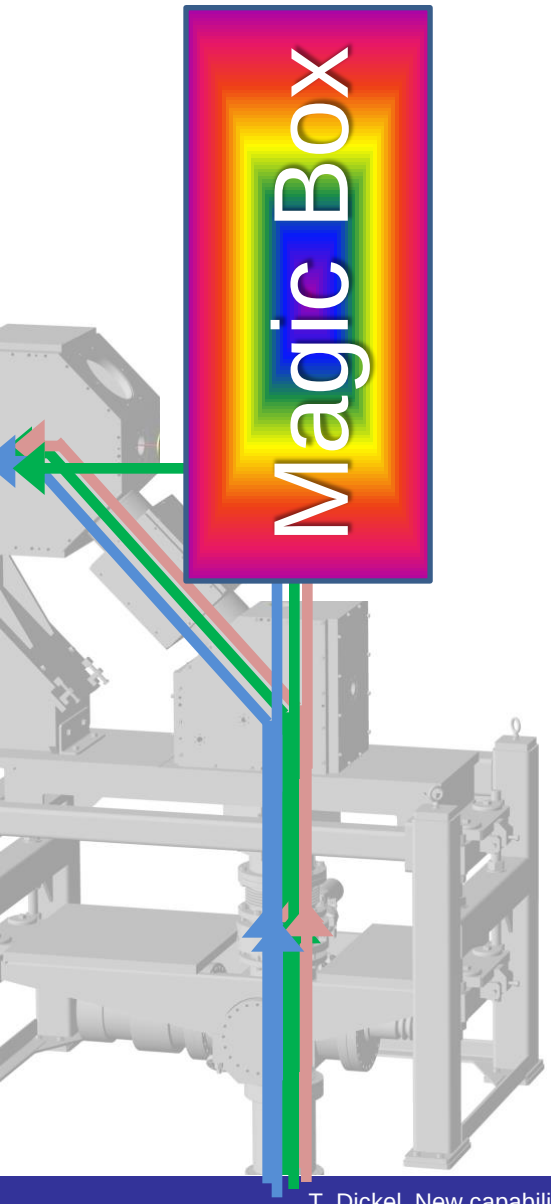
EBIT: ms charge breeding

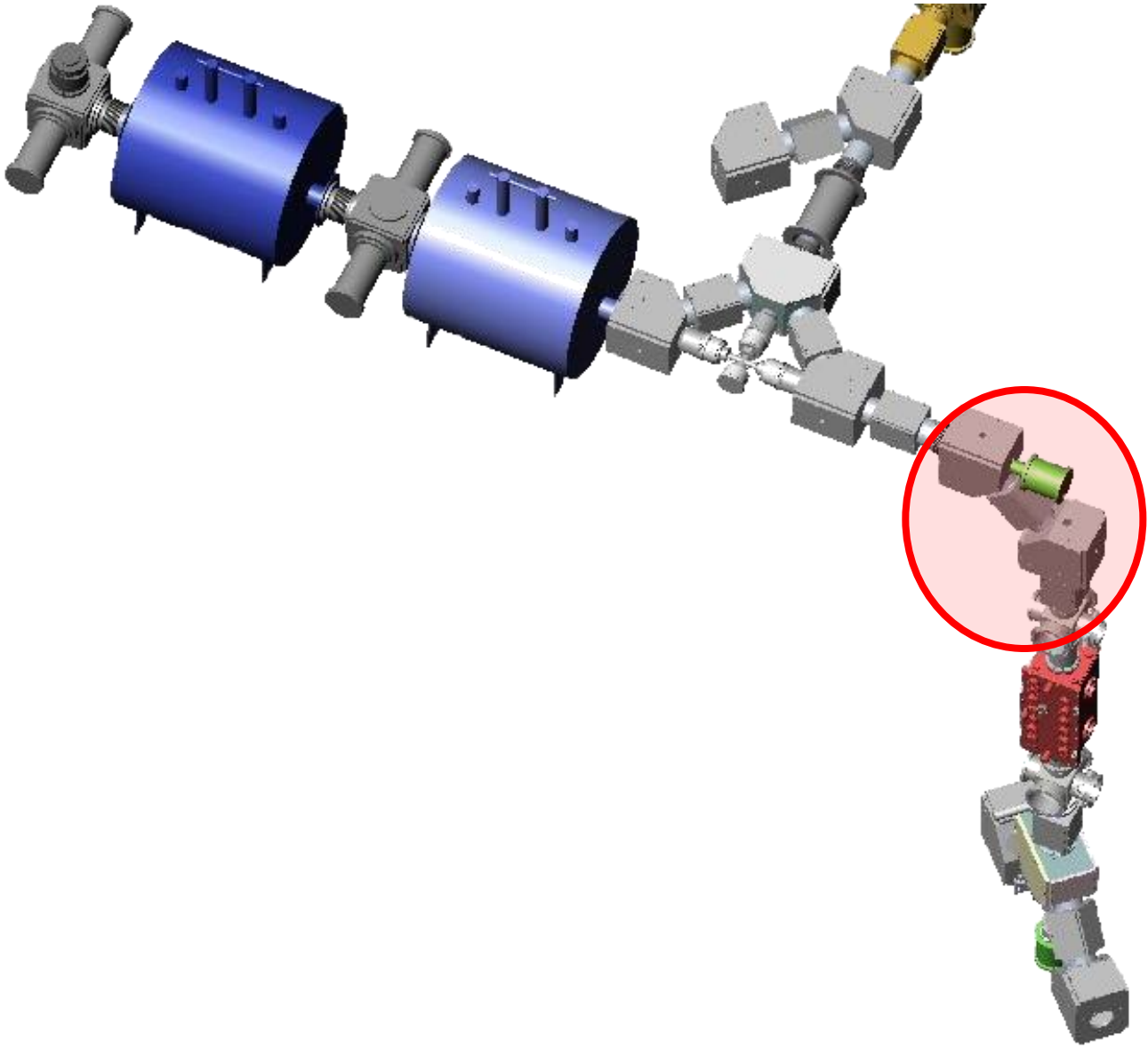
J. Dilling *et al.*, NIMB **204** (2003) 492

How to Integrate the MR-TOF-MS in the TITAN Beamline

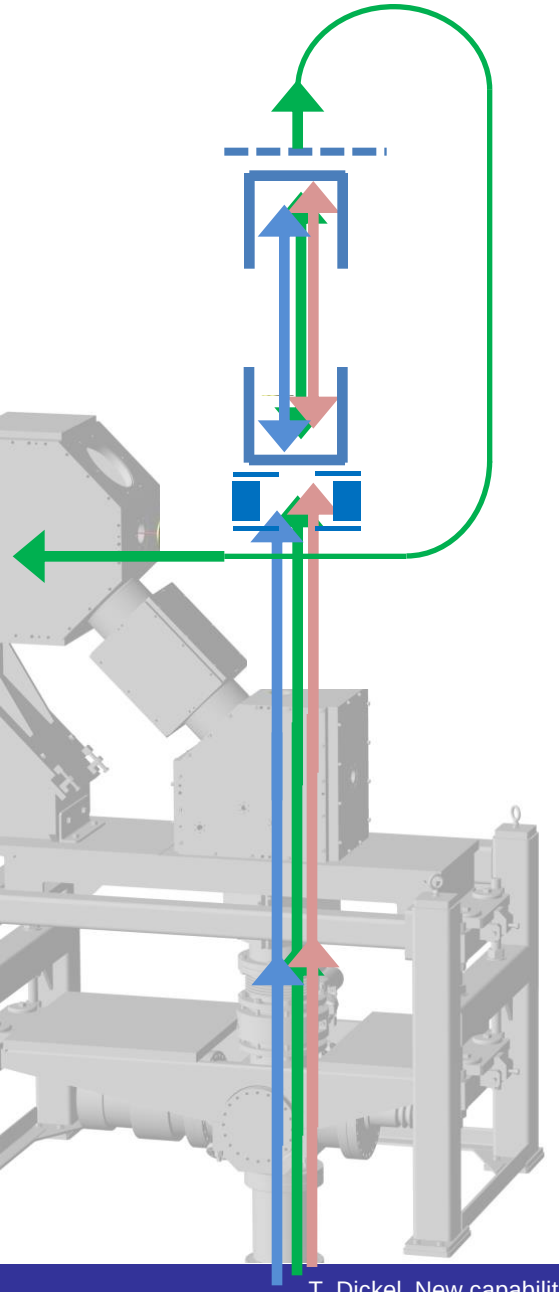


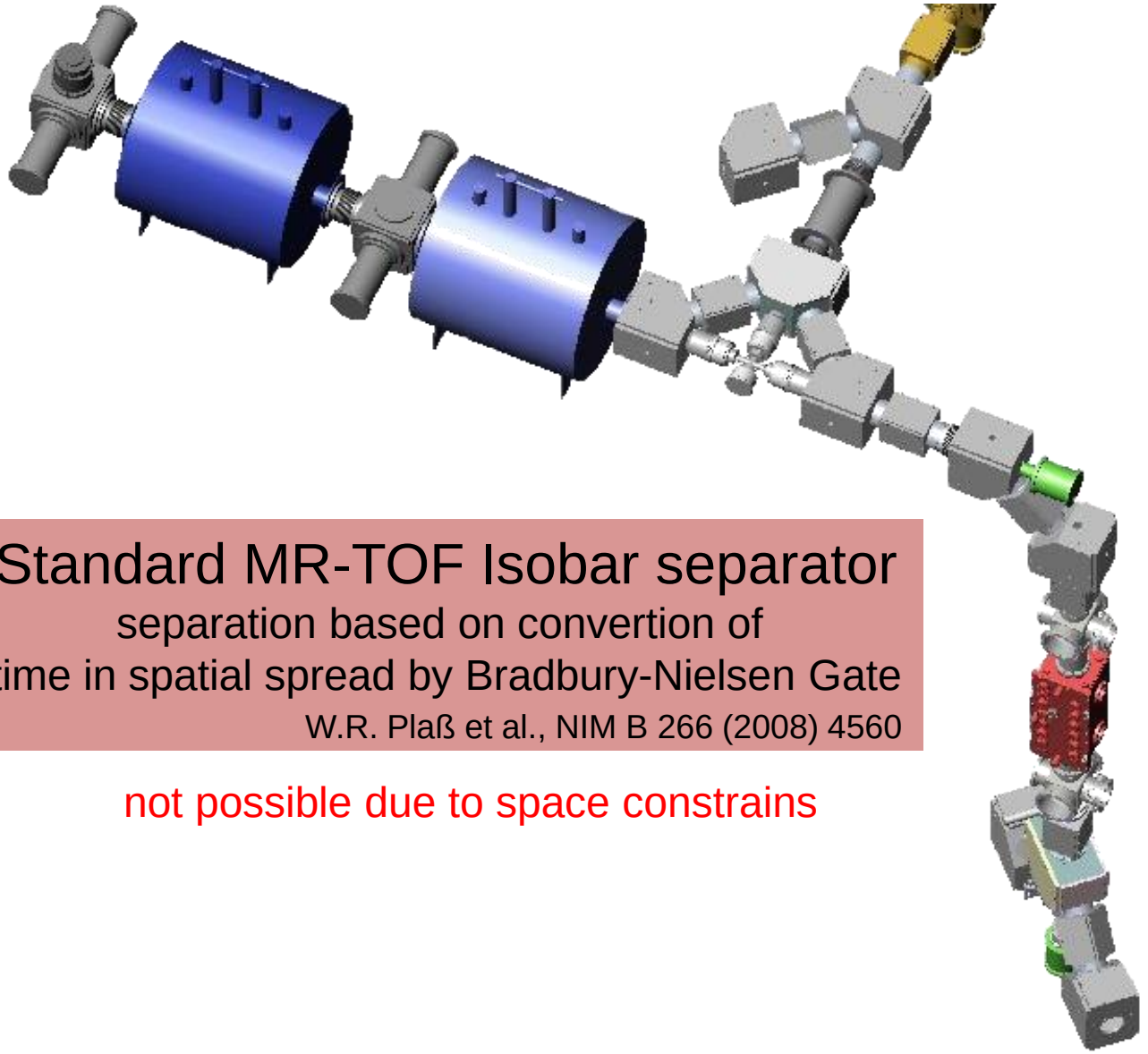
Conceptual Desgin





Conceptual Desgin





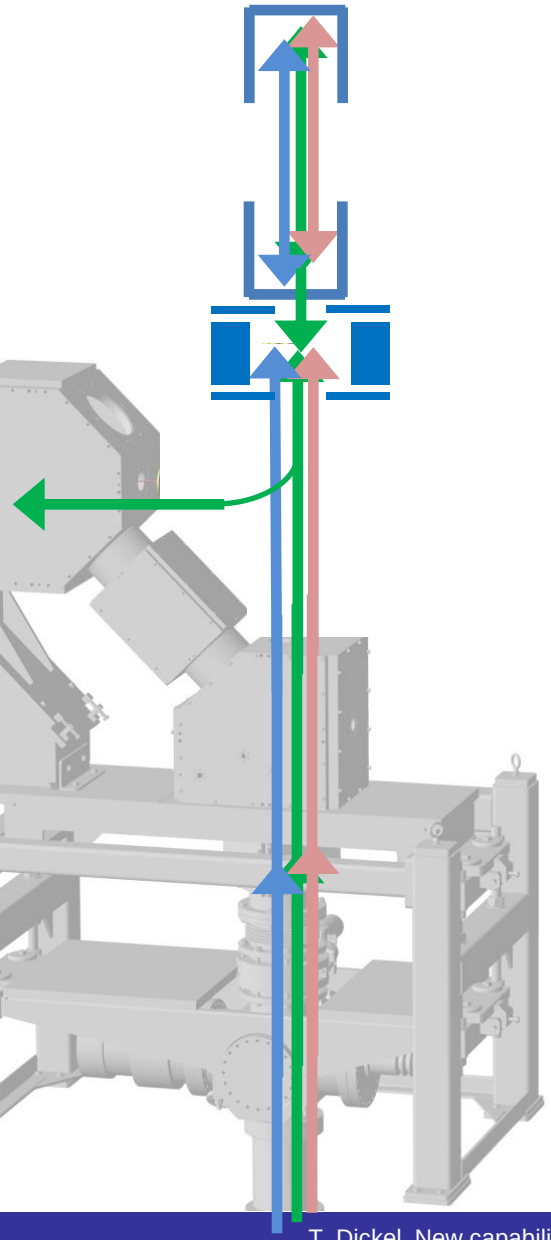
Standard MR-TOF Isobar separator

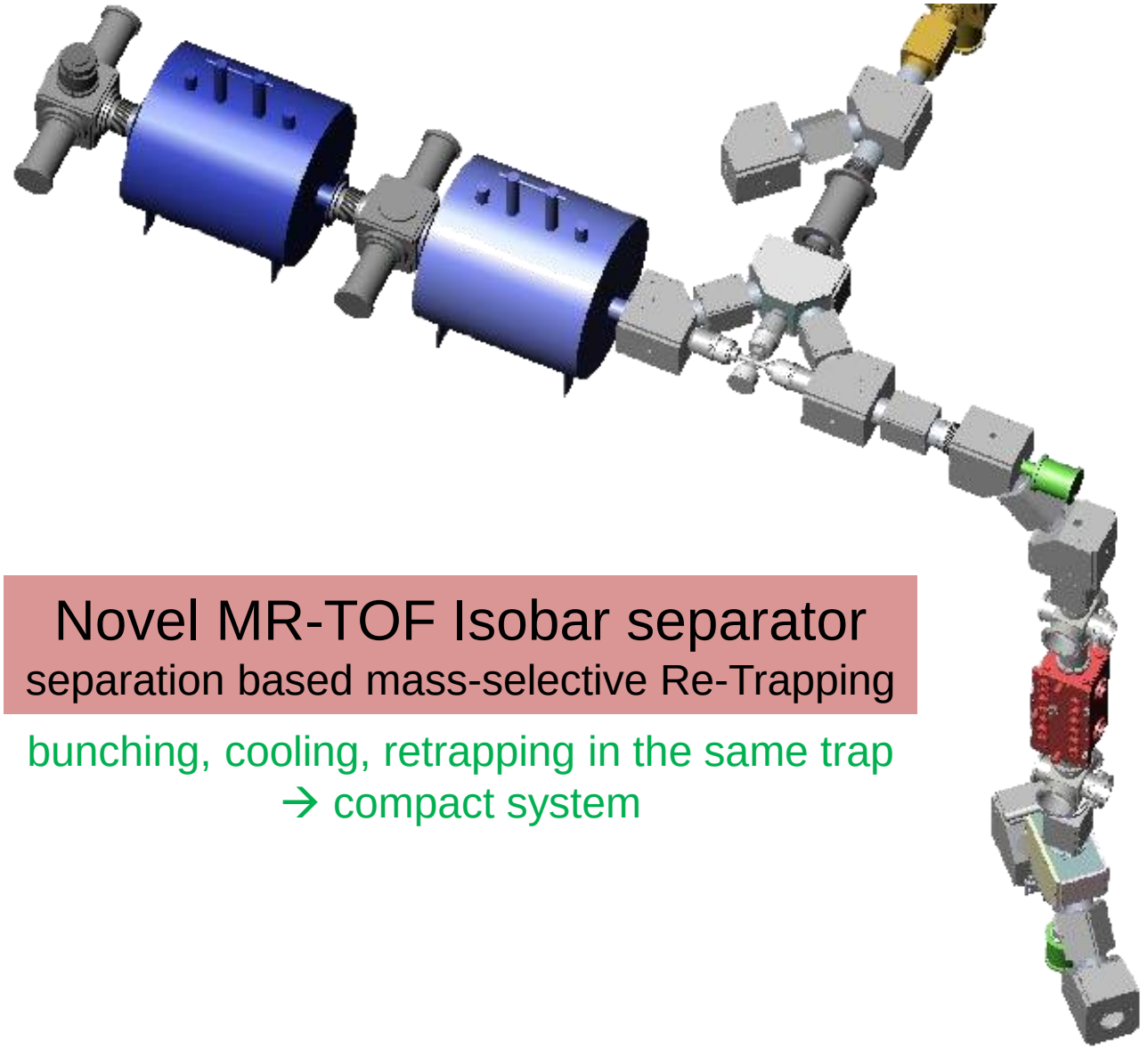
separation based on convertion of
time in spatial spread by Bradbury-Nielsen Gate

W.R. Plaß et al., NIM B 266 (2008) 4560

not possible due to space constrains

First Novel Concept: Mass Selective Re-Trapping



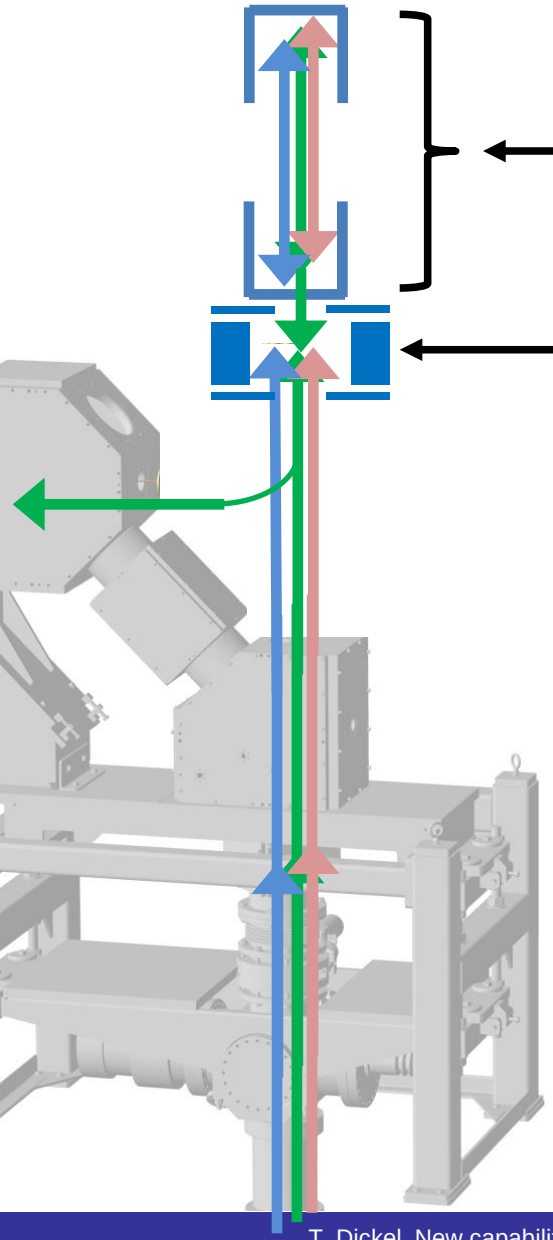


Novel MR-TOF Isobar separator

separation based mass-selective Re-Trapping

bunching, cooling, retrapping in the same trap
→ compact system

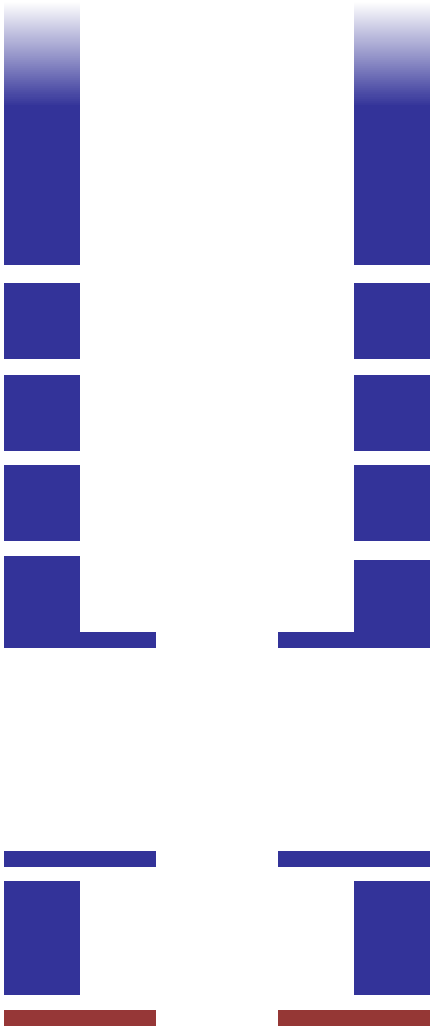
MR-TOF-MS @ TITAN



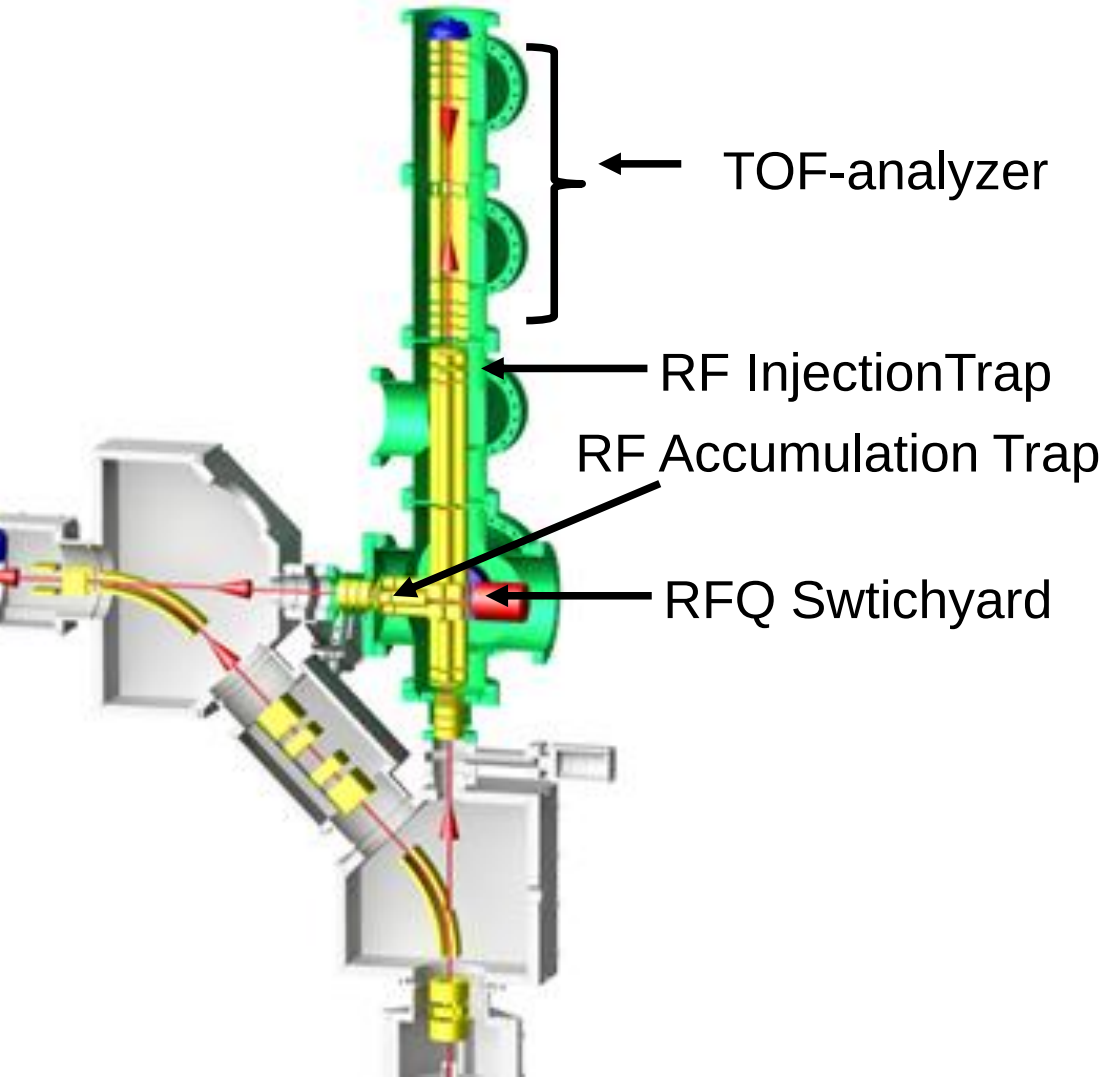
TOF-analyzer

RF trap

Separation Mechanism

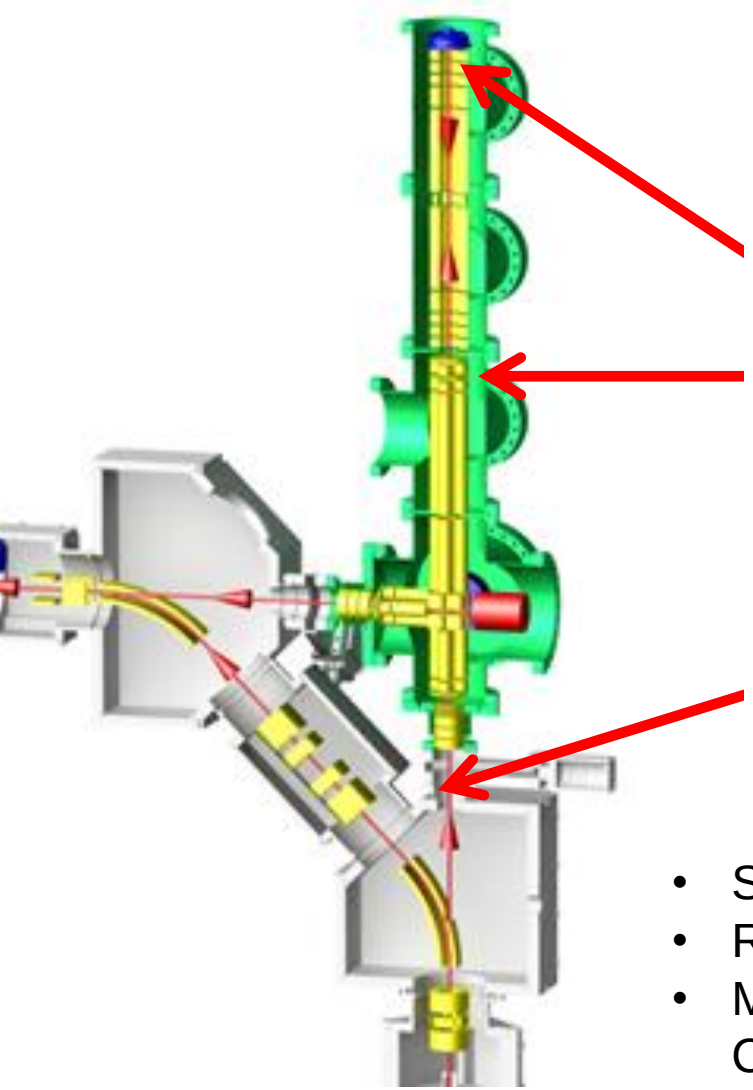


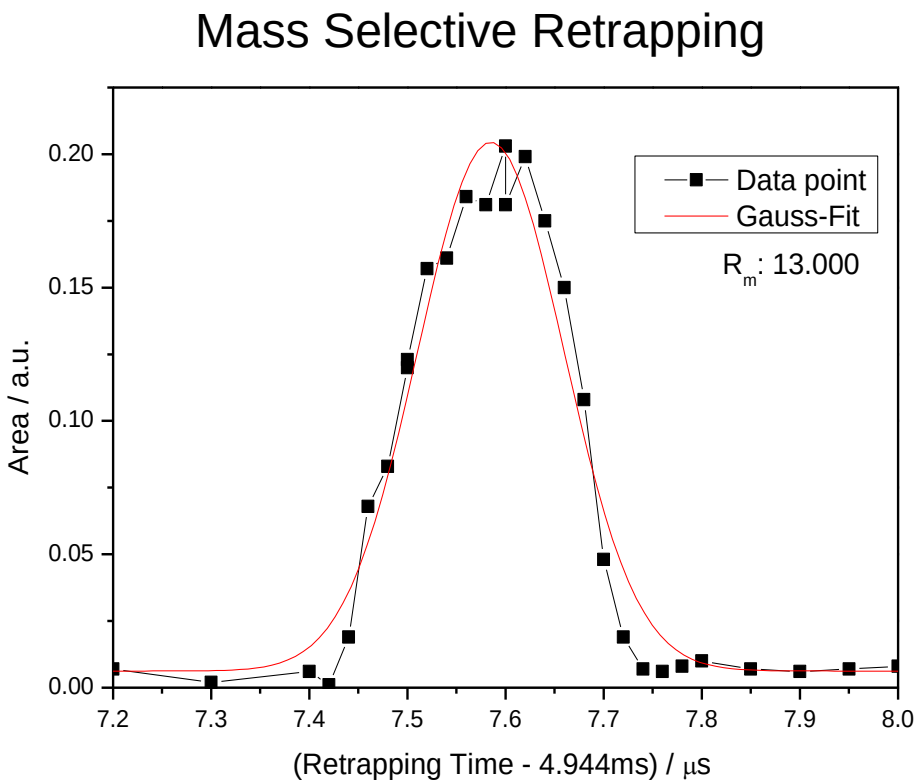
From Giessen to Vancouver



On the TITAN platform

Early Commissioning of the MR-TOF-MS for TITAN



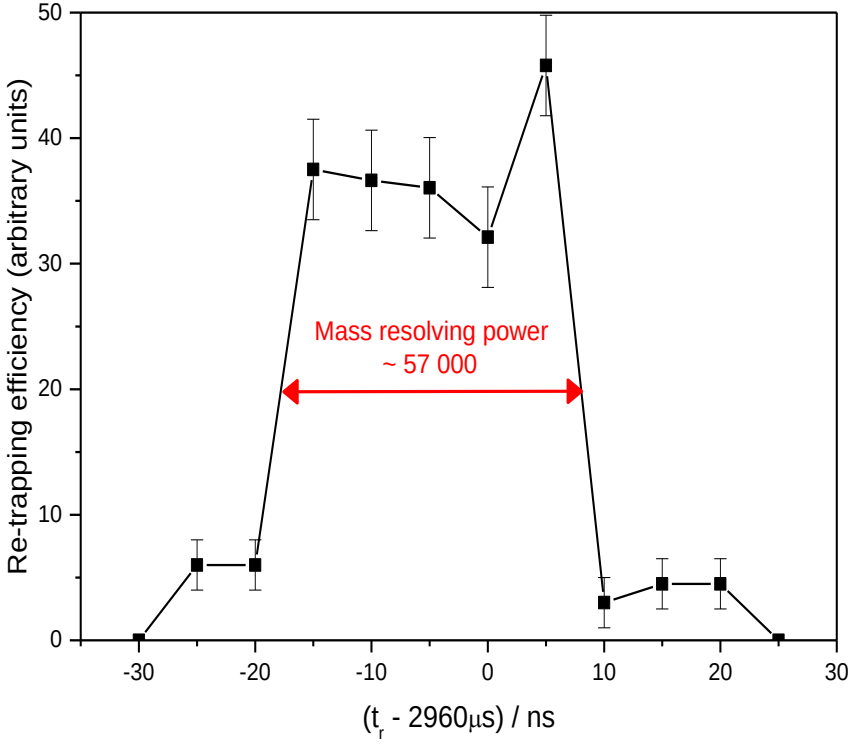


- Shipped as assembled device to TRIUMF
- Running again within days
- Measurements shown were done with additional Cs source mounted to instrument inlet and internal MCP detector
- Full insatllation in the TITAN beamline underway

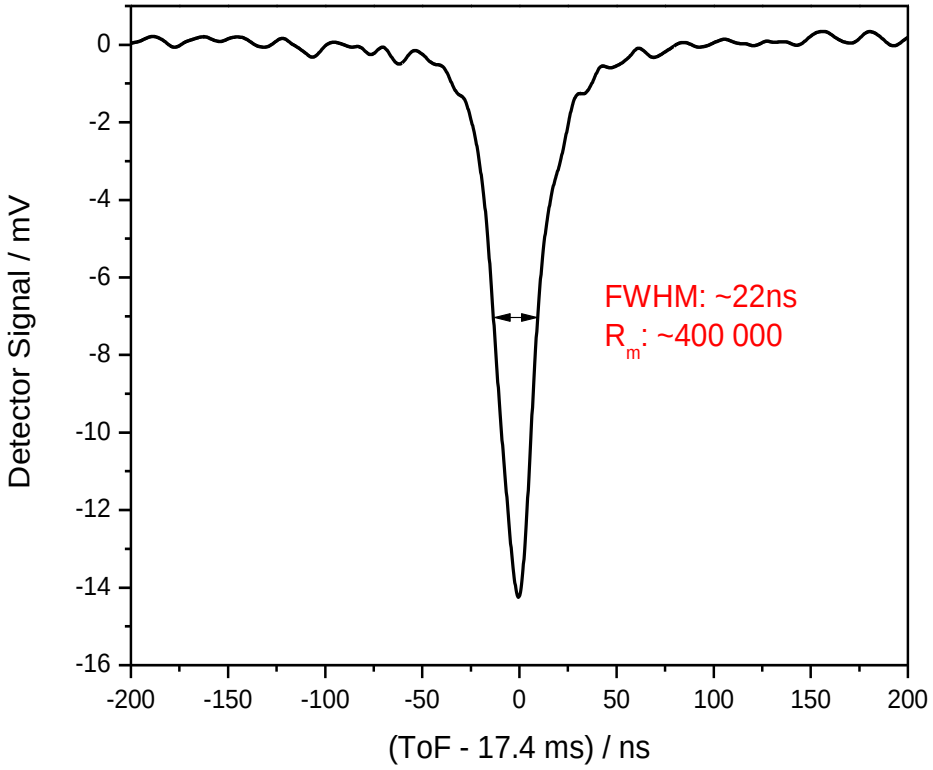
PhD thesis C. Jesch

What is Possible: Results from the Prototype

Mass Selective Retrapping



Mass Resolving Power

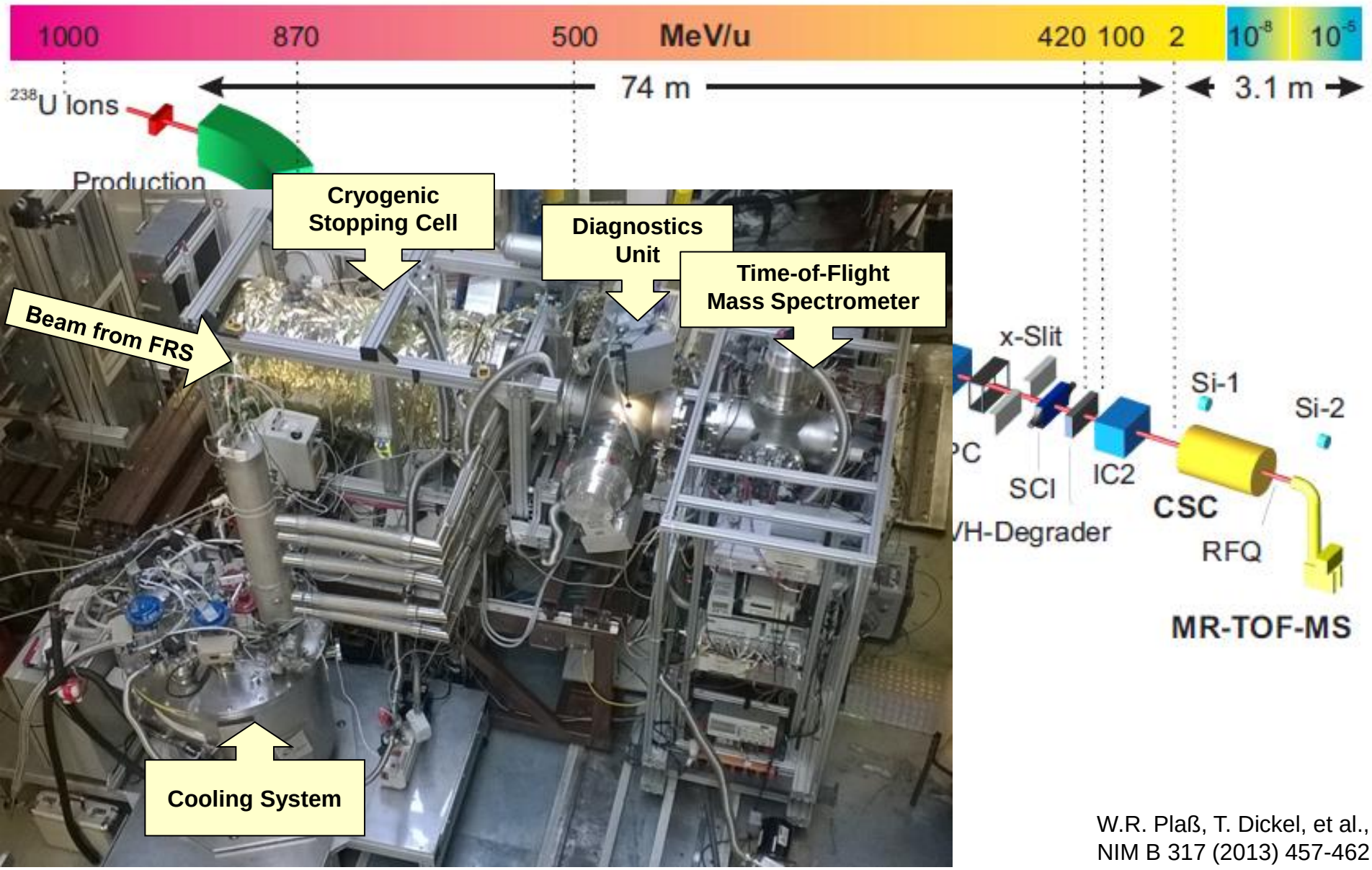


Isobarically clean beams of almost all nuclei produced at ISOL facilities can be provided.

Mass measurement of many short-lived low-lying isomeres becomes possible

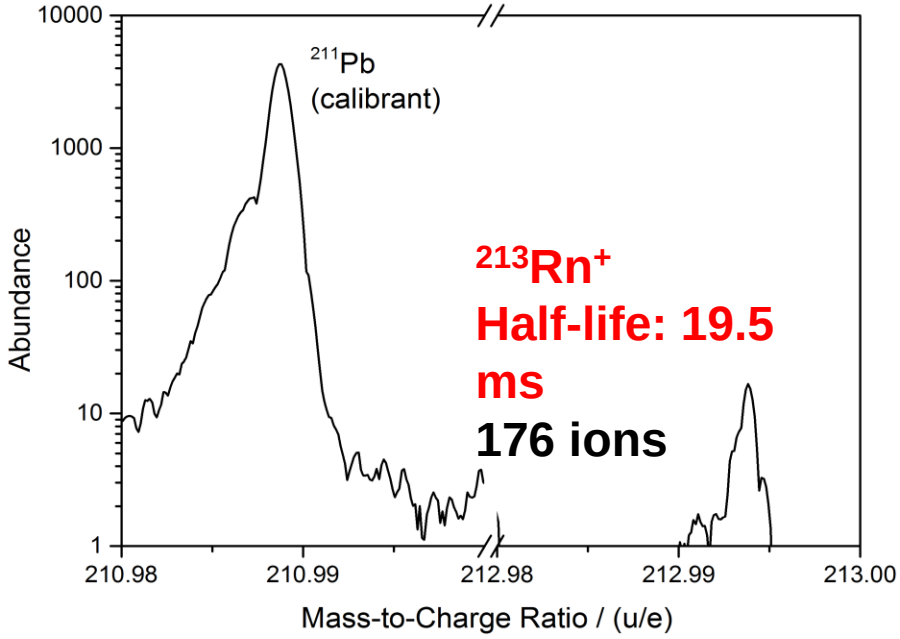
PhD thesis J. Lang

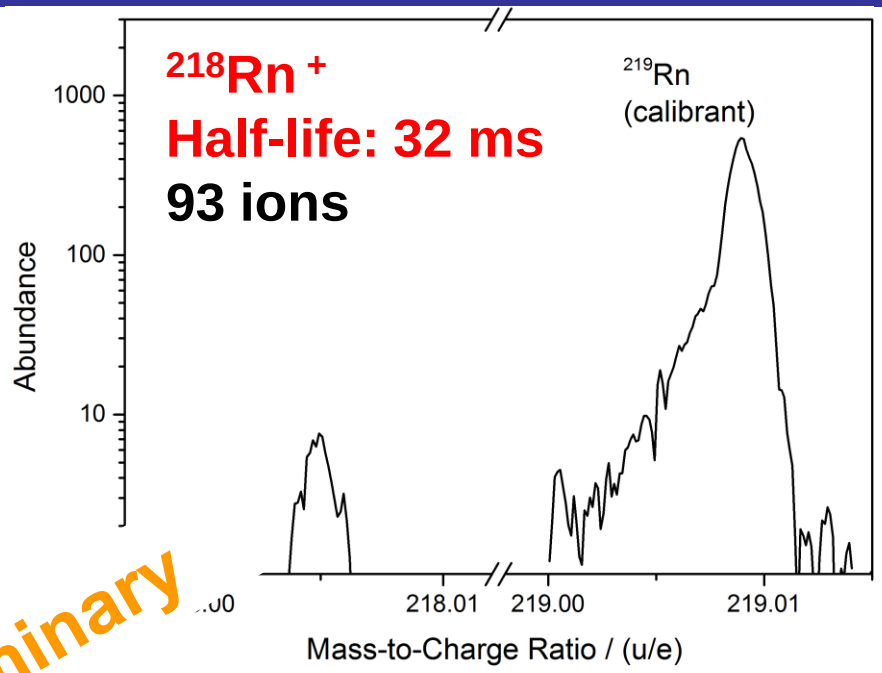
FRS Ion Catcher



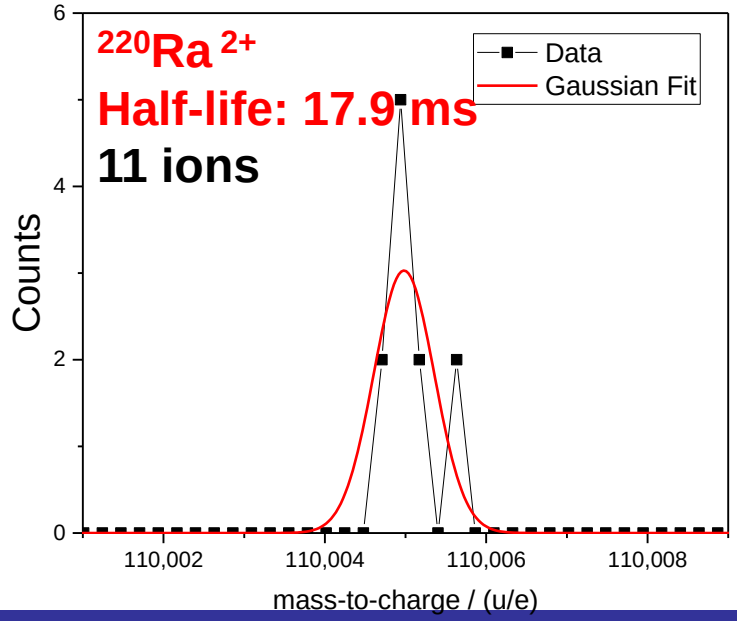
W.R. Plaß, T. Dickel, et al.,
NIM B 317 (2013) 457-462

Mass Measurement: Uranium Projectile Fragments





Preliminary

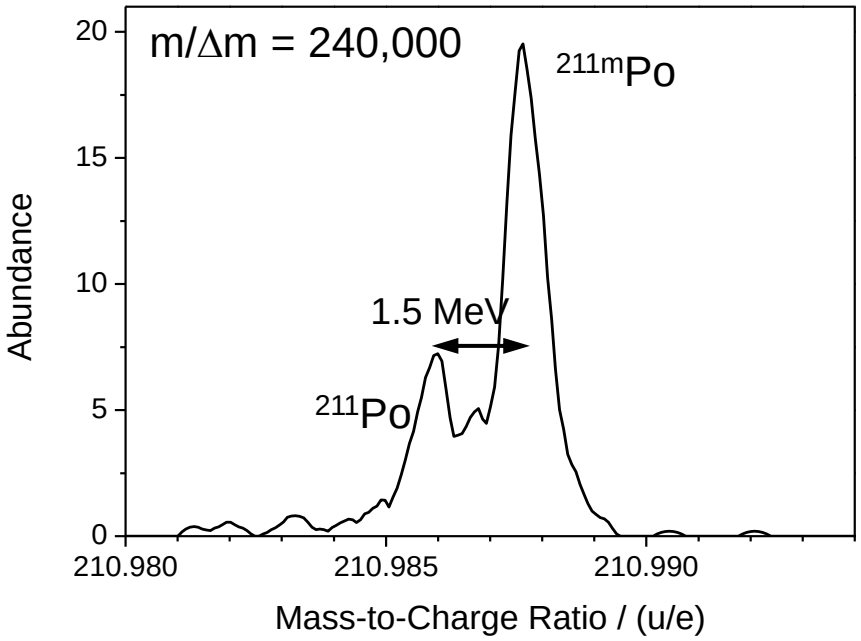


Mass resolving power
~ 175,000

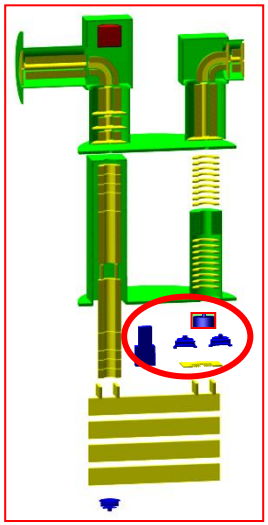
Mass measurements performed at an ion rates as low as 5 detected ions/hour

Isomeric Beams

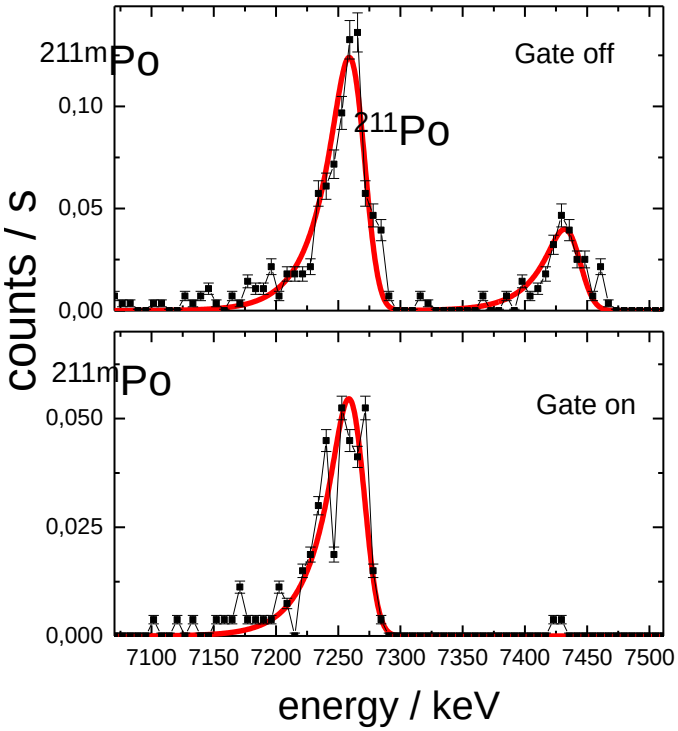
Measurement of isomers



- Identification of ^{211}Po and ^{211m}Po
- Measurement of excitation energy
- Measurement of isomeric ratio

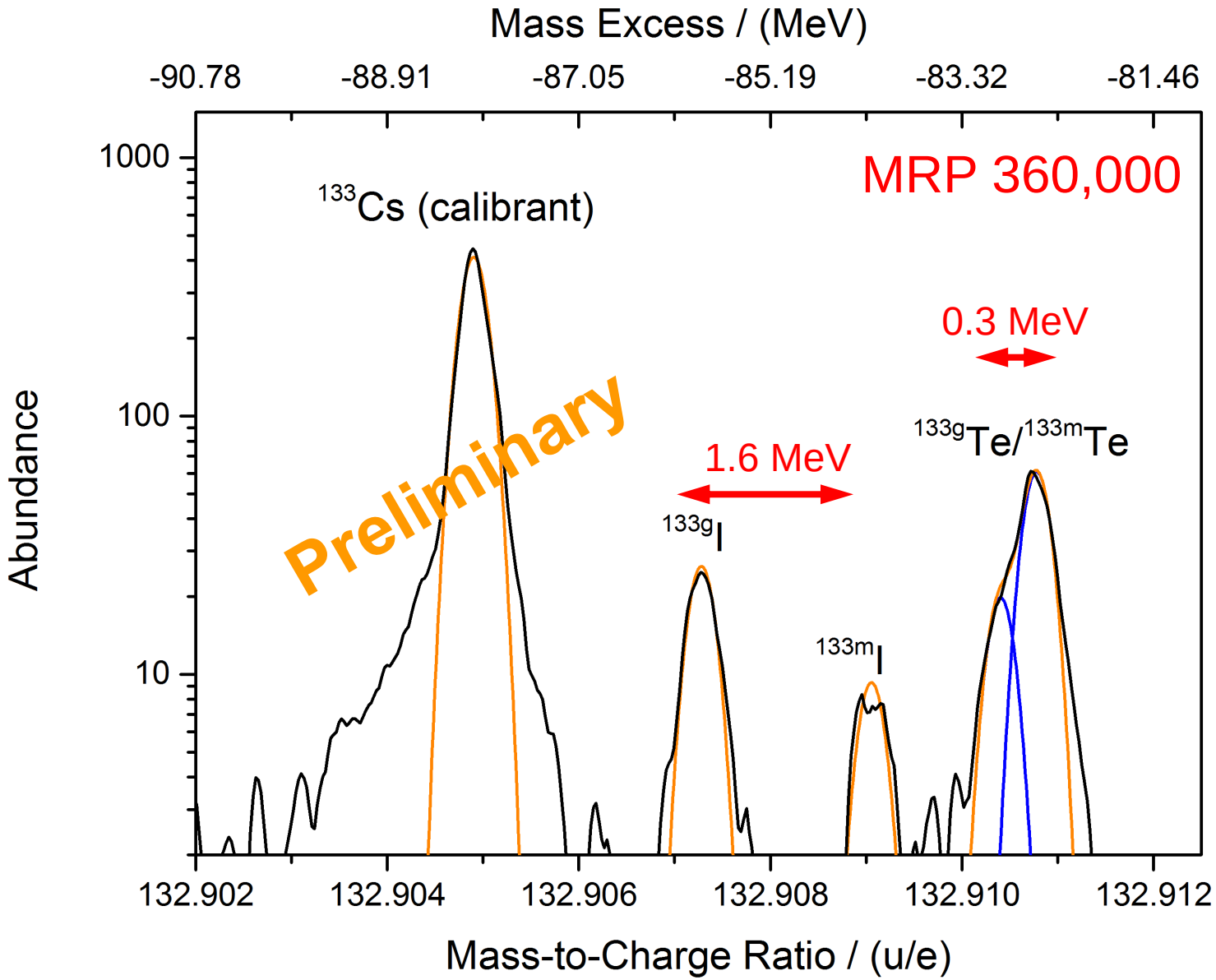


Spatial separation of ground state and isomeric state



- Separation using the ion gate of the MR-TOF-MS
- Proof-of-principle: production of isomerically clean beams

Mass Measurement: Uranium Fission Fragments

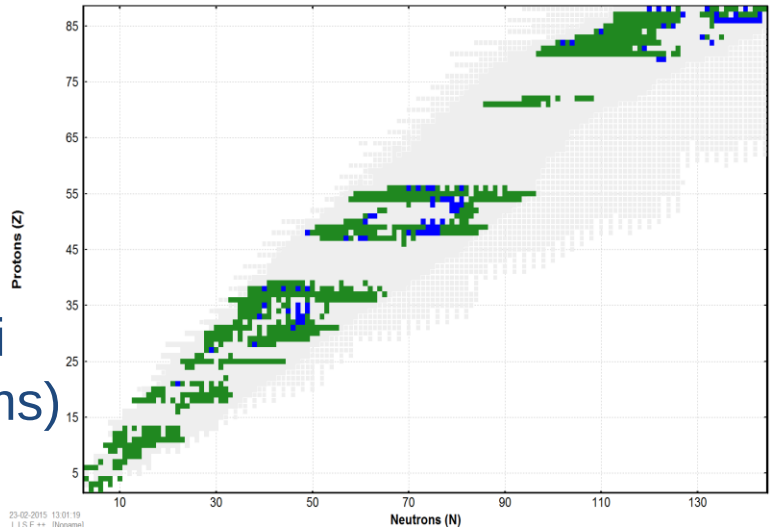


Summary and Outlook

MR-TOF-MS open new possibilities at ISOL and In-Flight facilities

ISOL / MR-TOF@TITAN:
isobar separation with „zero space in the beamline“
only possible due to novel concepts

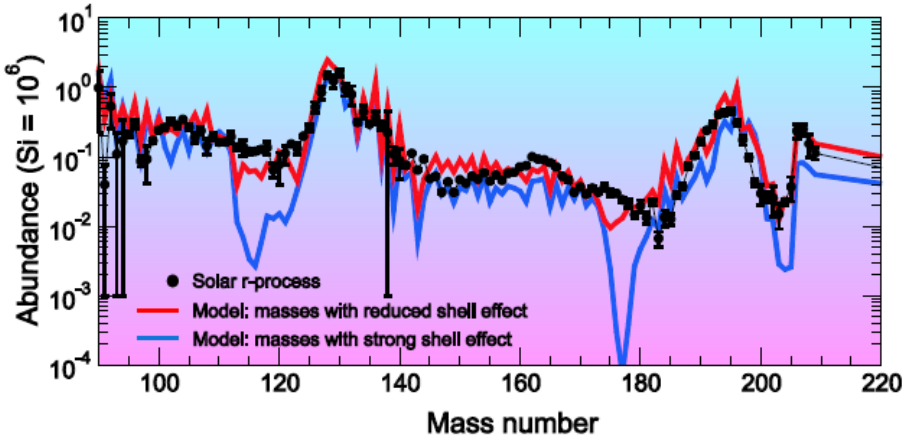
- Mass selective retrapping
- enables access to more than 350 nuclei
- enables access to short-lived nuclei (~ms)



Envisaged Experiments

- Nuclear astrophysics, nuclear structure, fundamental interactions:
- n-rich Ca,K,Sc: appearance of N=32,34 shell closure?
- $^{98\text{-}101}$In: V_{ud}, rp-process
- r-process: Kr, Sr, Rb, Xe Cs
- ^{130}Cd,In: N=82 shell gap,
  shell evolution

New Ideas?

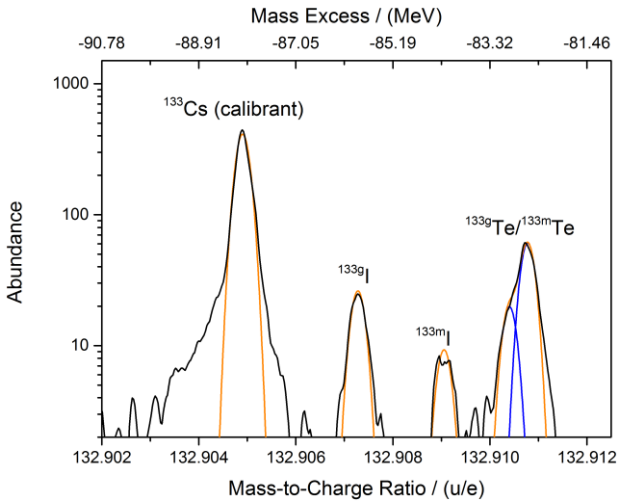


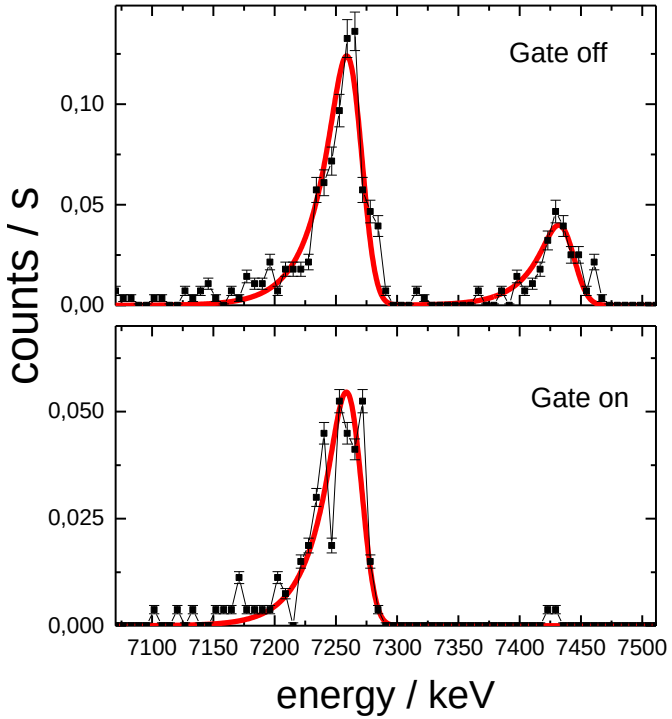
Summary and Outlook

MR-TOF-MS open new possibilities at ISOL and In-Flight facilities

In-Flight / FRS Ion Catcher:

- Universal and fast
- Highest Resolving Power
- Isomeric Beams





Importance of Isomers in Astrophysics?

Acknowledgements

TRIUMF

2 GSI

1 JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

5 UNIVERSITY OF JYVÄSKYLÄ

3 Kernfysisch Versneller Instituut

university of groningen

FRS Ion Catcher / S411 Collaboration

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