TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

JUSTUS-LIEBIG
UNIVERSITÄT
GIESSEN

First application of mass selective re-trapping enables mass measurements of neutron-deficient Yb and Tm isotopes despite strong isobaric background

Moritz Pascal Reiter
Postdoctoral Fellow at TITAN

Justus-Liebig-Universität Gießen, II. Physikalisches Institut, Gießen, Germany
TRIUMF National Laboratory, Vancouver, Canada

2019/07/17

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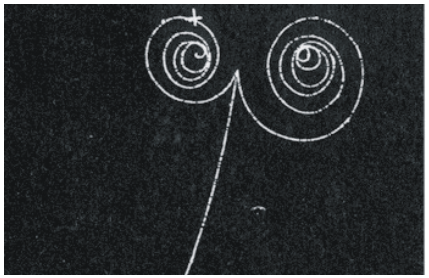
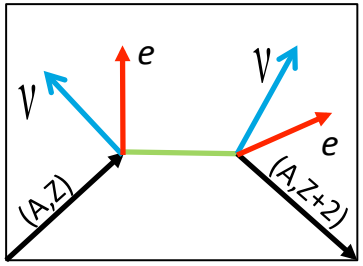
Mass Measurements for nuclear physics

Fundamental Symmetries and Interactions



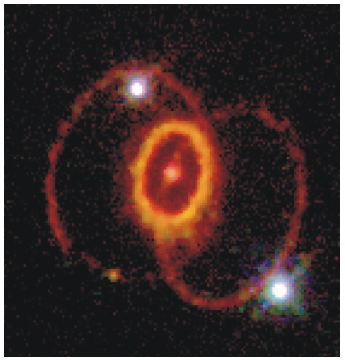
$\delta m/m \approx 10^{-9}$

Neutrino Physics



$\delta m/m \approx 10^{-9}$

Nuclear Astrophysics

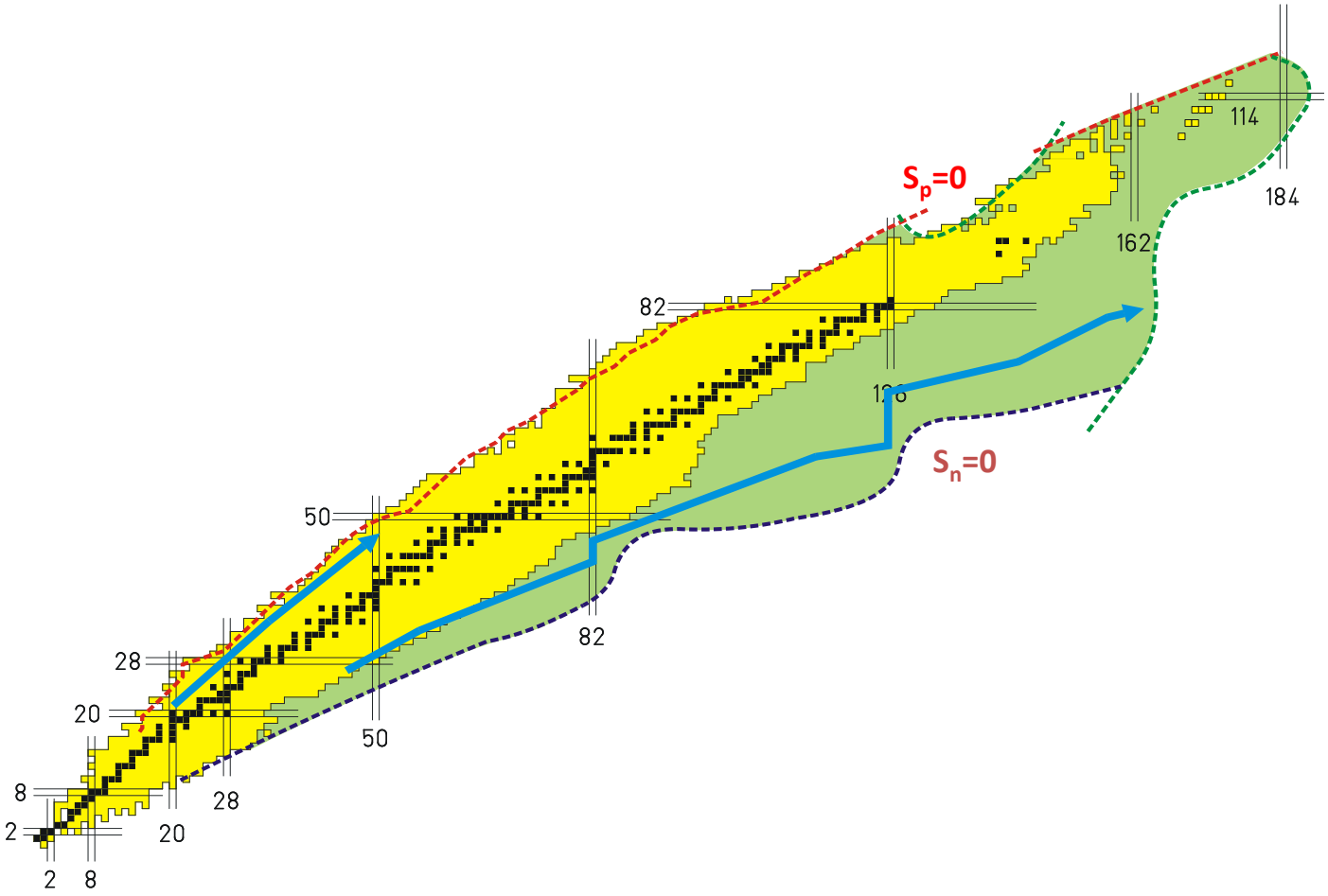


$\delta m/m \leq 10^{-7}$

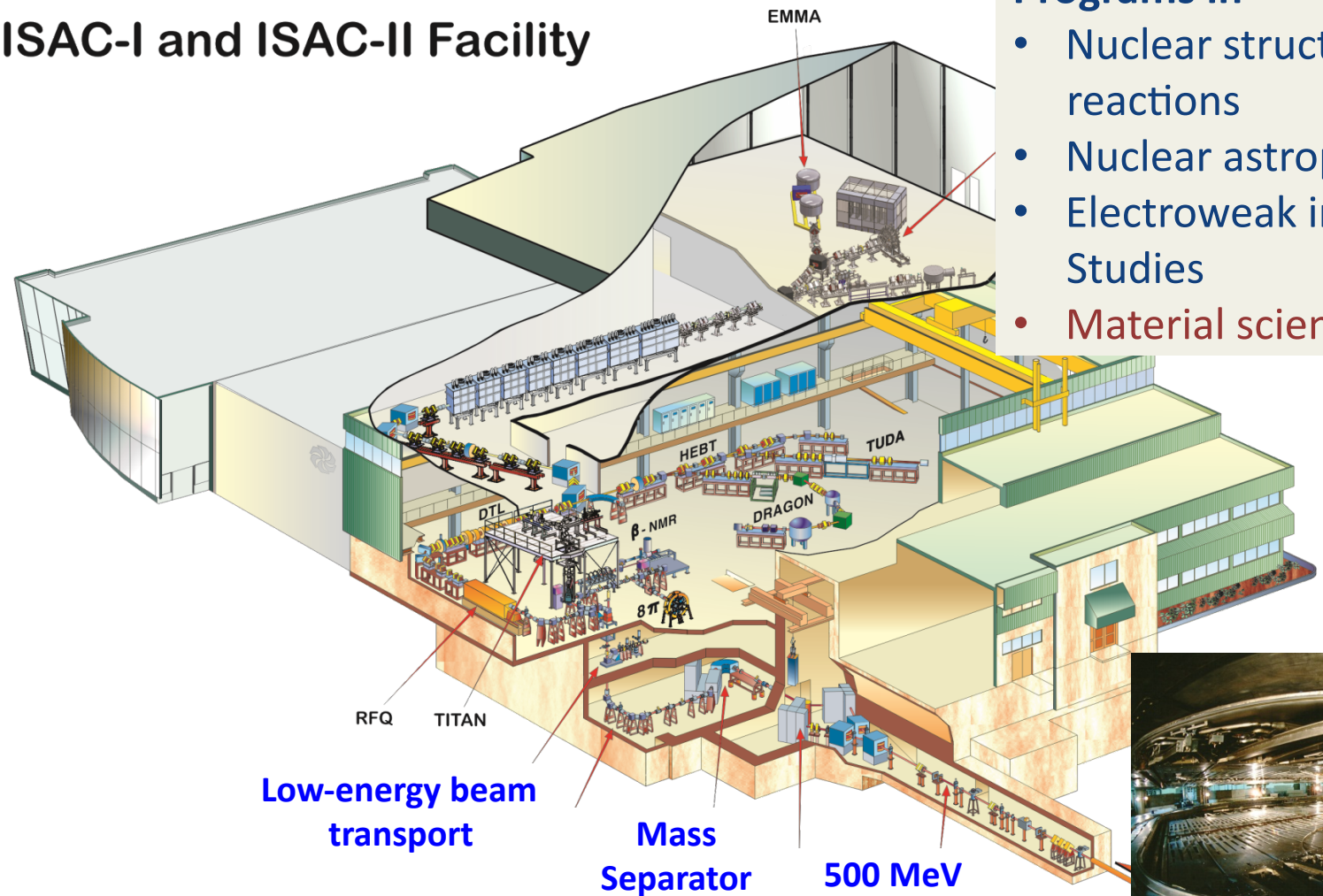
Structure of Exotic Nuclei

$\delta m/m \approx 10^{-6}$ - 10^{-7}

Mass Measurements for nuclear physics

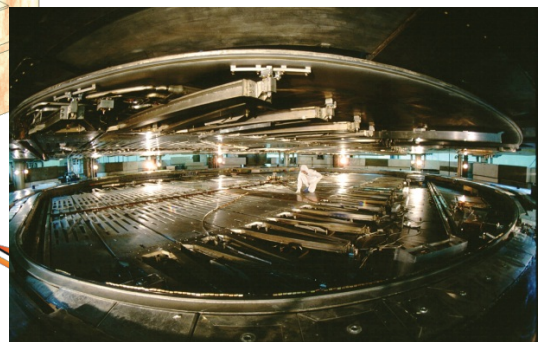


ISAC-I and ISAC-II Facility



Programs in

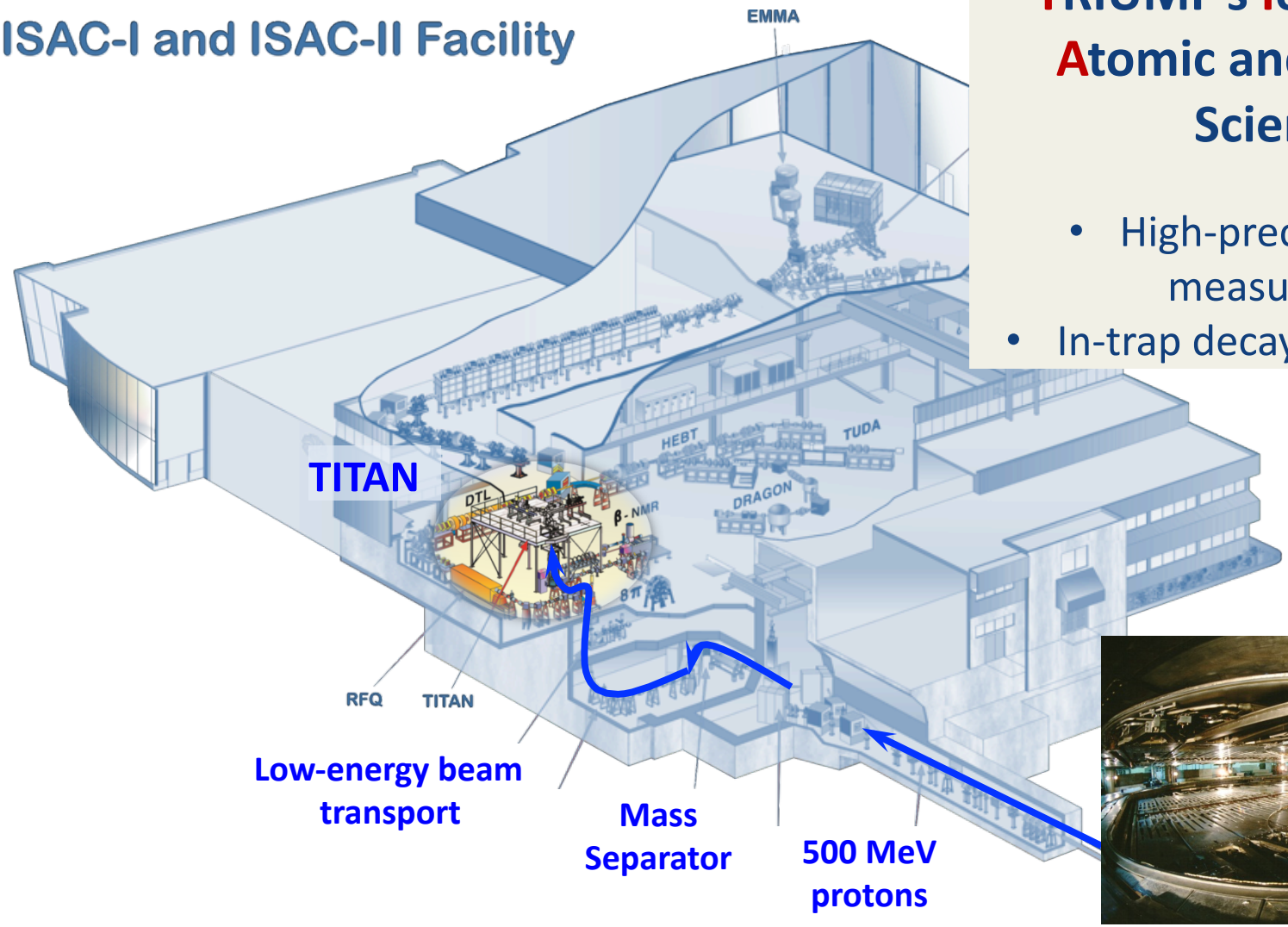
- Nuclear structure & reactions
- Nuclear astrophysics
- Electroweak interaction Studies
- Material science



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

TRIUMF's Ion Trap for Atomic and Nuclear Science

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



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MR-TOF MS:
remove isobaric contaminants and mass measurements via time-of-flight

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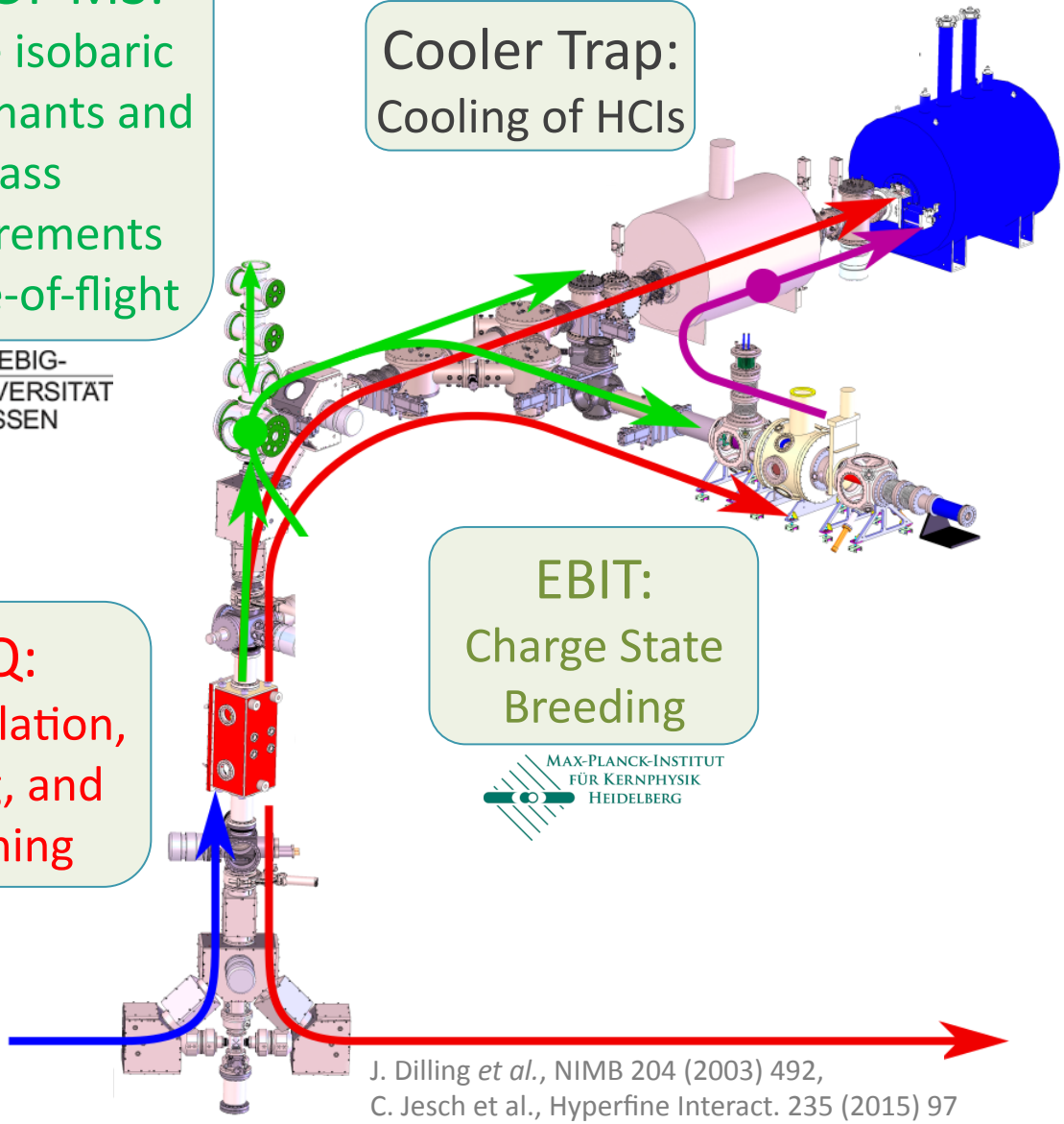
Cooler Trap:
Cooling of HCIs

MPET:
mass measurement via determination of cyclotron frequency



EBIT:
Charge State Breeding

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RFQ:
Accumulation, cooling, and bunching

J. Dilling *et al.*, NIMB 204 (2003) 492,
C. Jesch et al., Hyperfine Interact. 235 (2015) 97

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GANIL Spiral2
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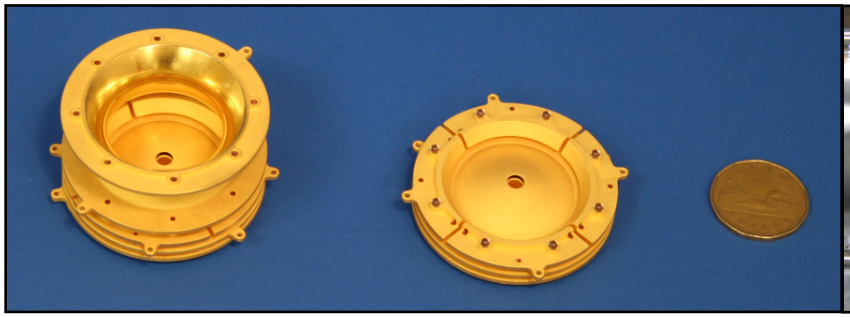
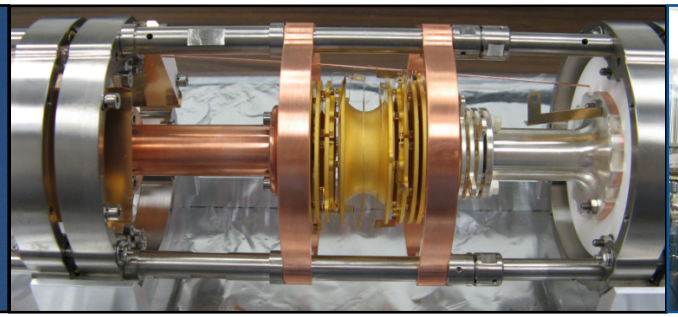
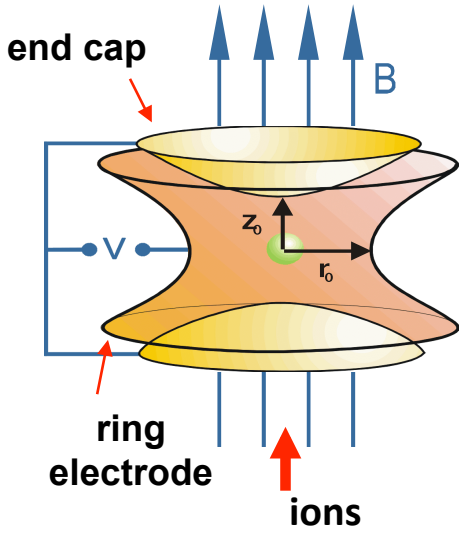
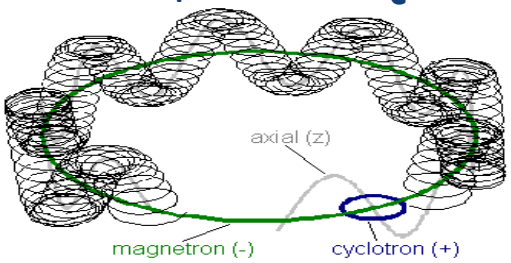
Measurement Penning Trap



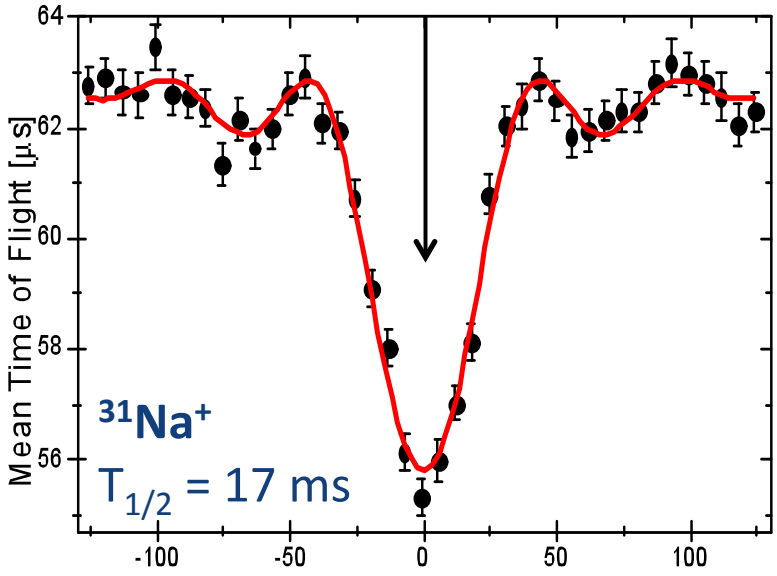




$\nu_+ + \nu_- = \nu_c$



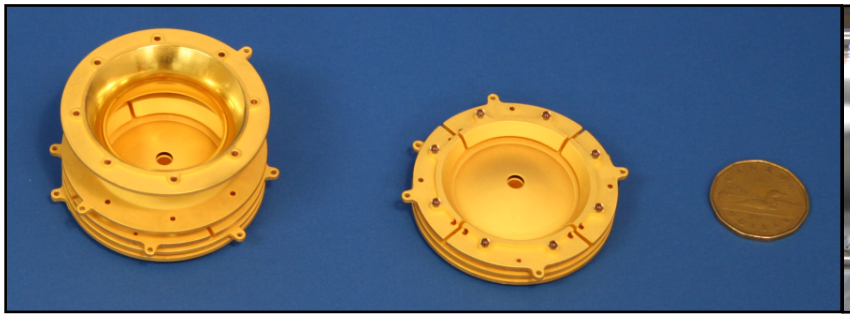
$2\pi\nu_c = (qe/\mathbf{m}) \cdot B$

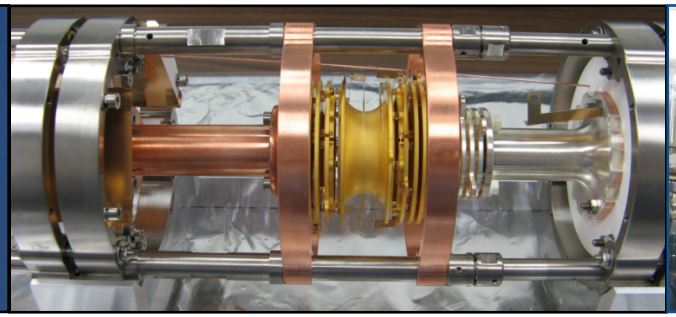


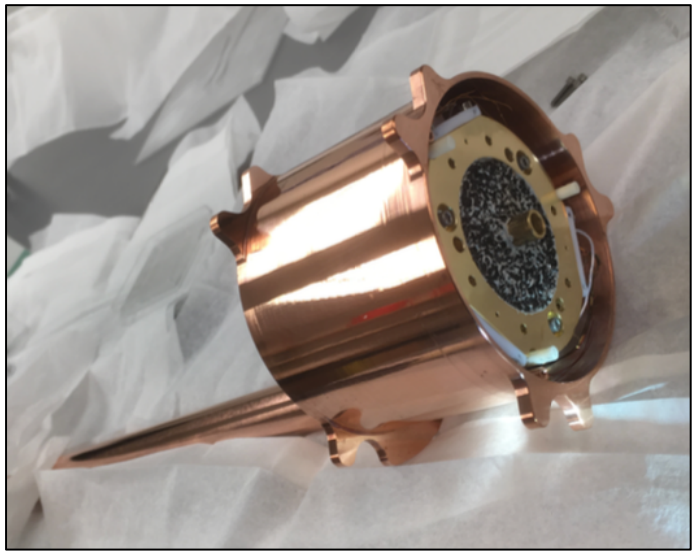
- TOF-ICR technique
  - Fast measurement preparation
    Using Lorentz steerers (LEBIT-NSCL) R. Ringle IJMS 263 (2007) 38-44
  - → Fast and robust measurements: $T_{1/2}$ < 9 ms (^{11}Li)
  - → High precision technique ≥ 10^{-9}

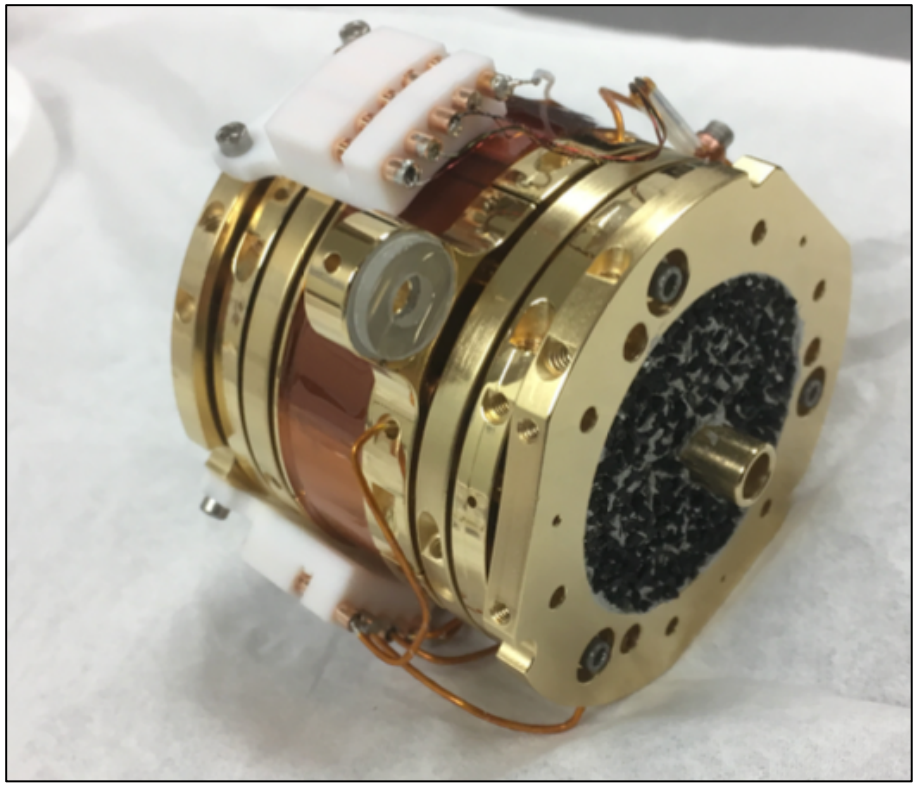
M. Brodeur *et al.*, PRC **80** (2009) 044318 , M. Brodeur *et al.*, IJMS **20** (2012) 310, A. Chaudhuri et al., PRC 88 (2013) 054317

Measurement Penning Trap









- Cryo-upgrade of MPET
  - better vacuum (10^{-2} mbar)
  - longer storage time
  - enable Phase Imaging Technique
    → higher precision

E. Leistenschneider PhD thesis (2019) to be defended

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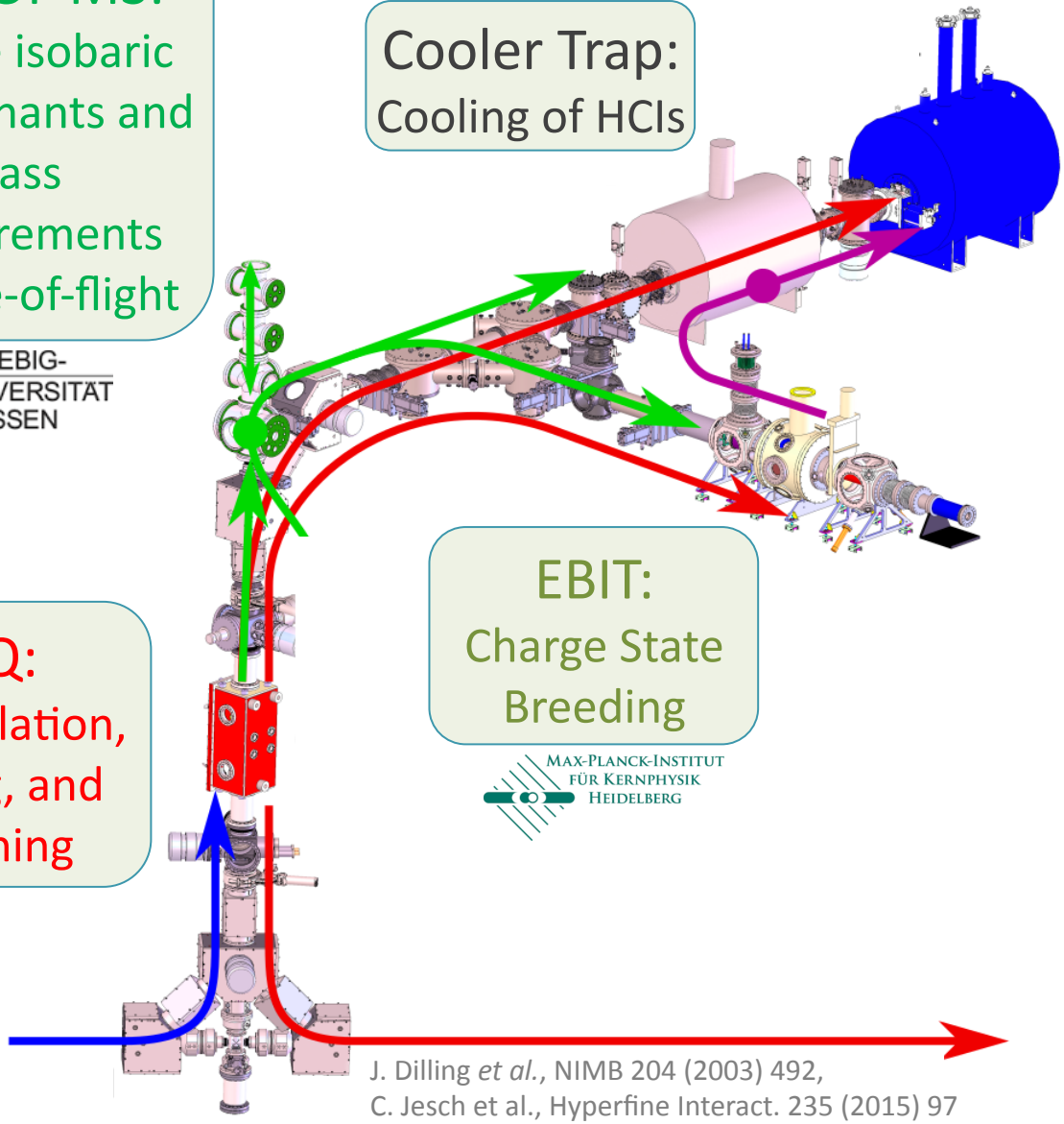

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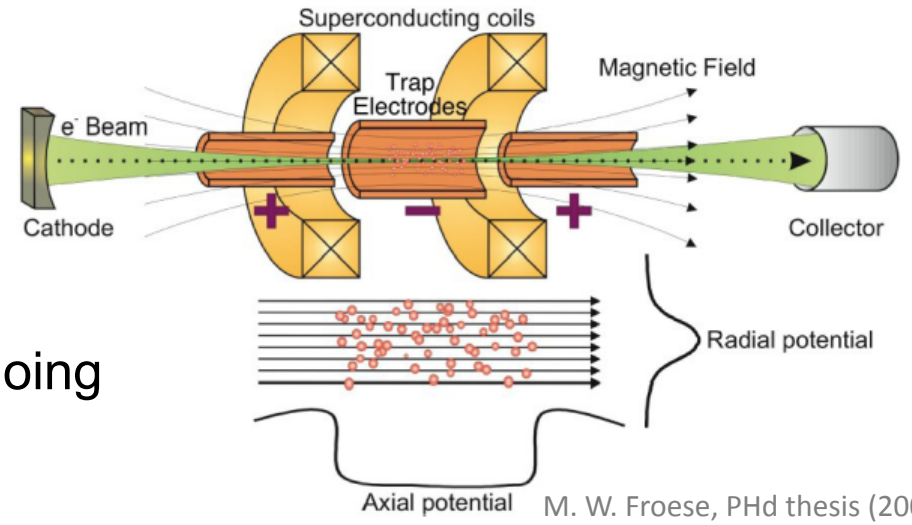
Electron Beam Ion Trap

- Charge breeding by electron impact ionization
  - e-beam parameters
    - Upgraded to 65 kV
    - Typical current ~100 mA
      → upgrade e-gun to 5 A ongoing

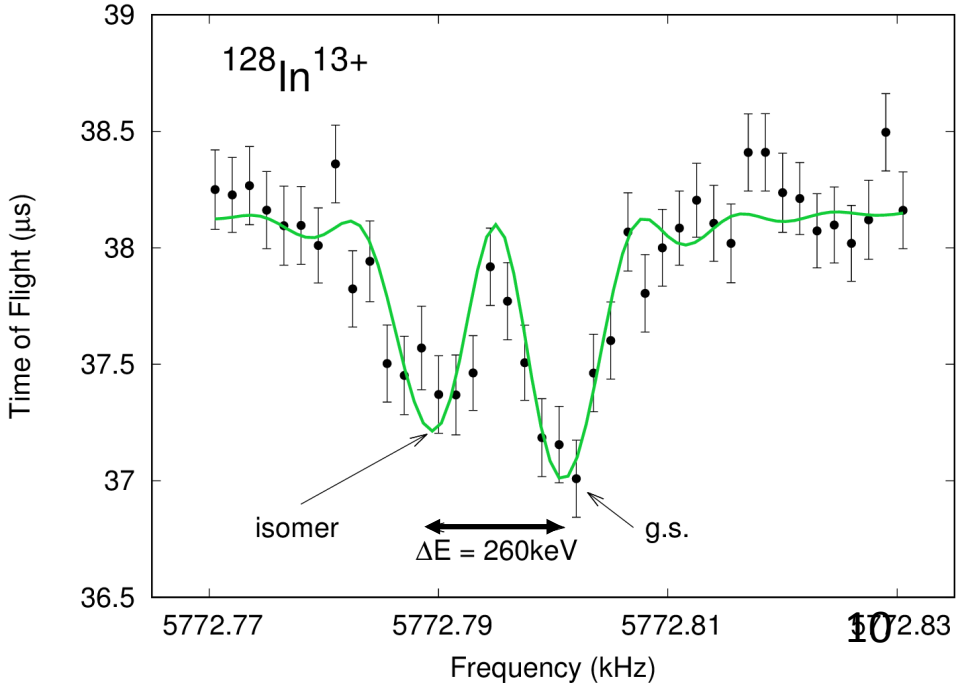


M. W. Froese, PHd thesis (2006)

- HCI boost in resolving power and precision using conventional TOF-ICR technique

$$\frac{\delta m}{m} \propto \frac{m}{qBT_{rf}\sqrt{N_{\mathrm{ions}}}}$$

  - e.g. neutron-rich In isotopes
    - Resolving power
      ~ 1 million at 100ms @13+



M. C. Simon Phyisca Scripa (2012)
C. Babcock et al., PRC 97 (2018) 024312

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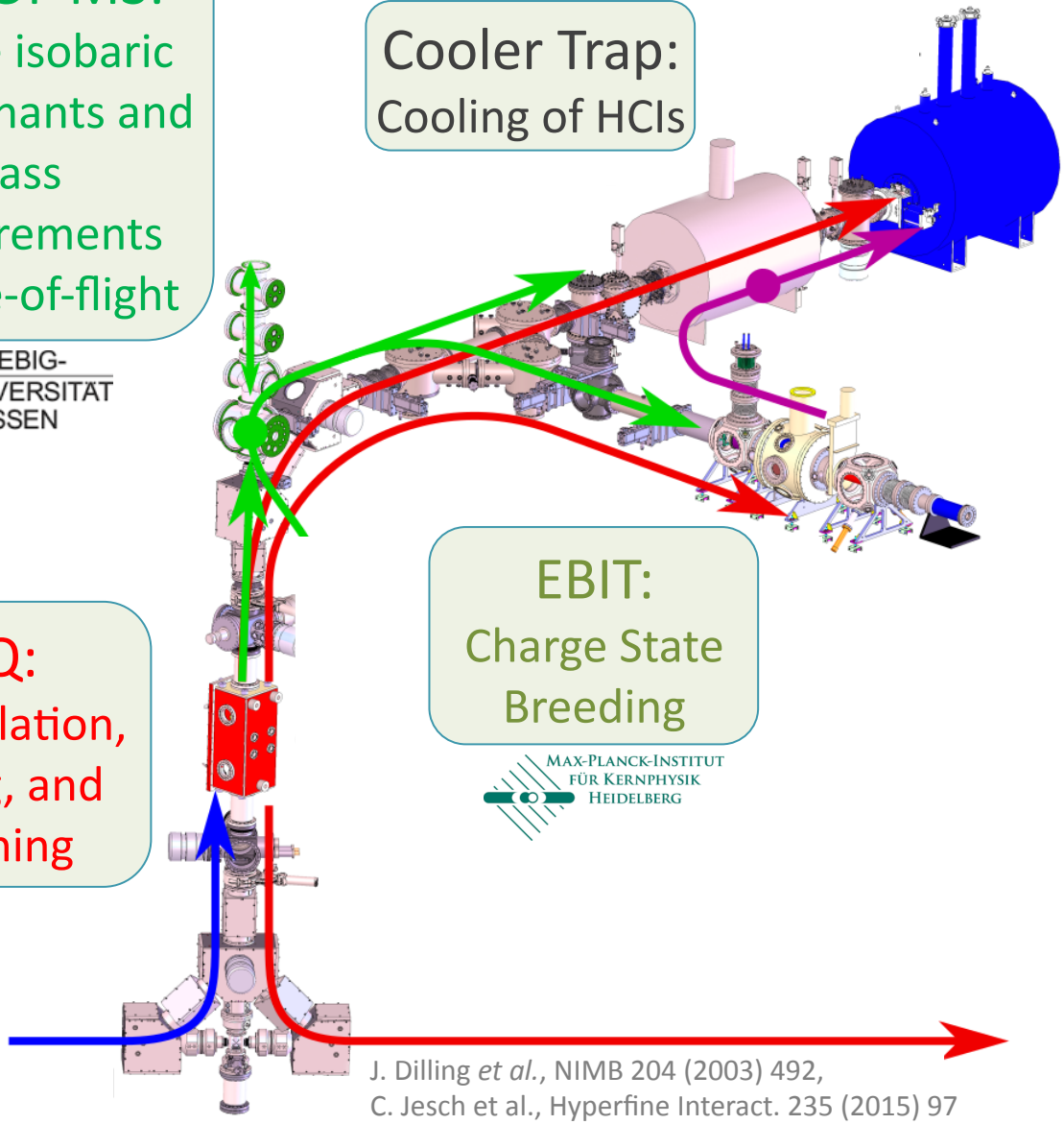

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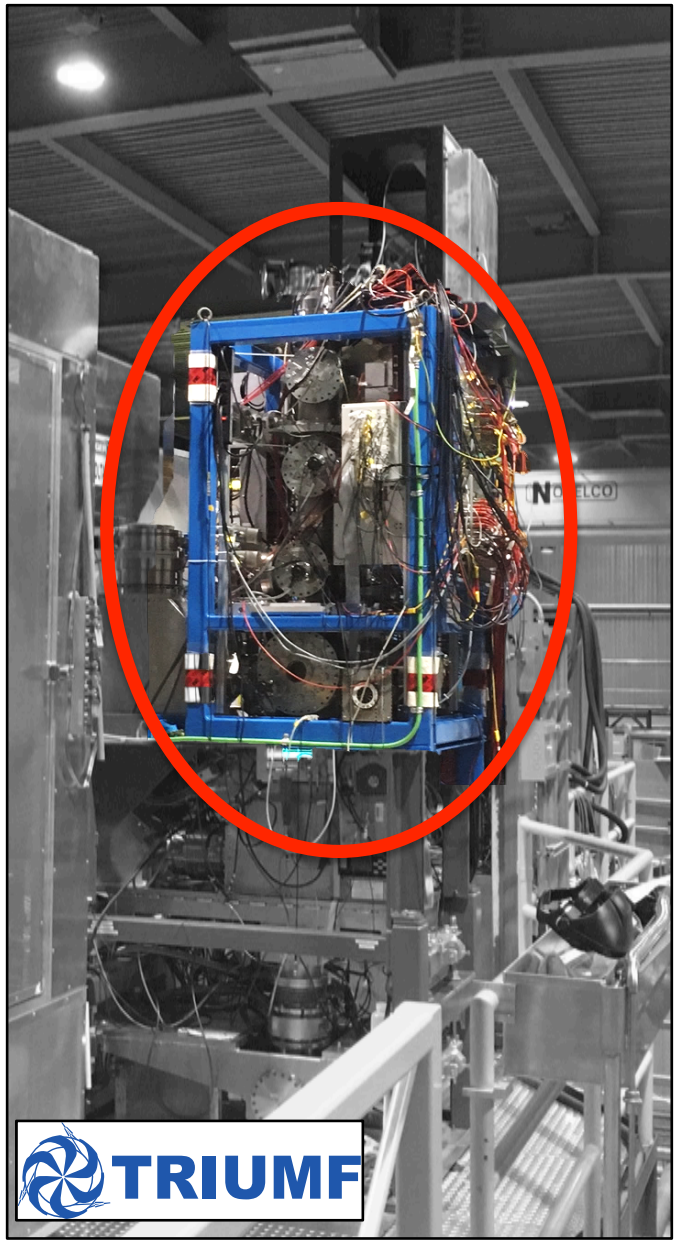
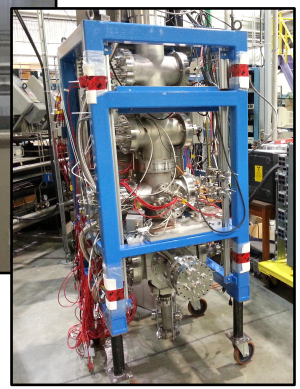
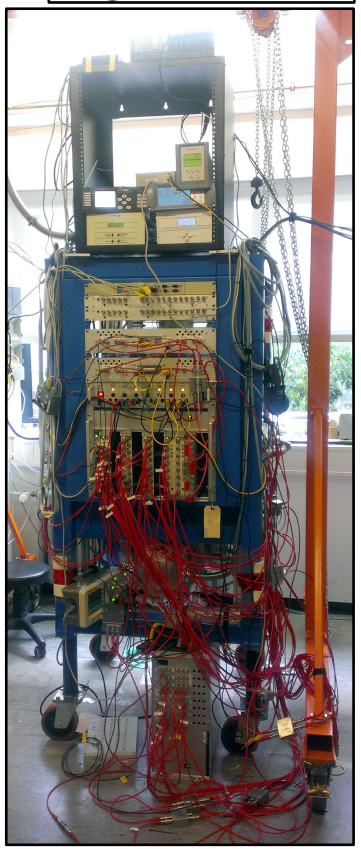
Multiple-Reflection Time-Of-Flight Mass Spectrometer



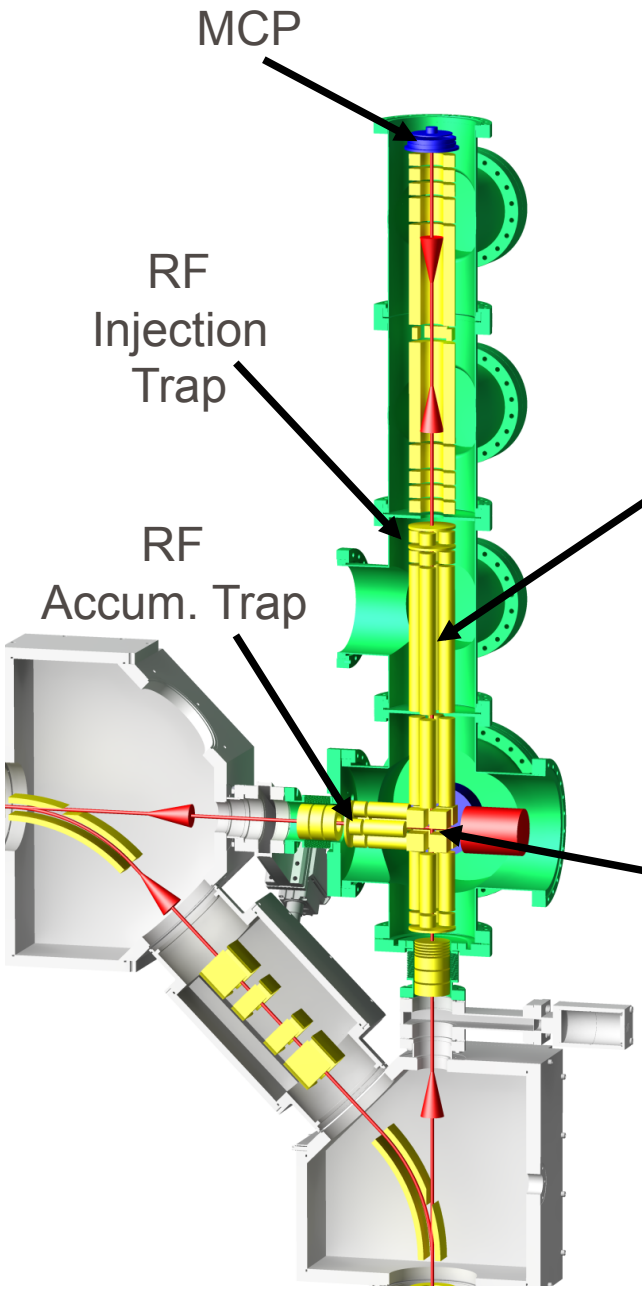




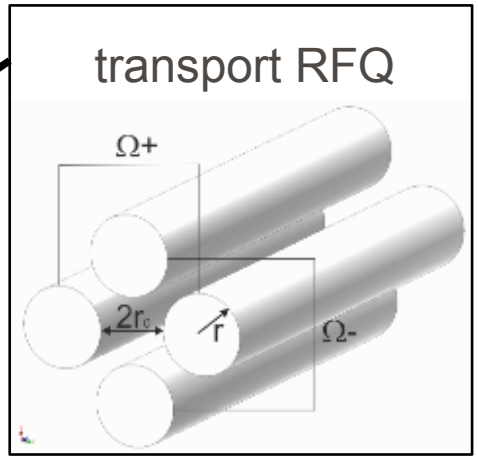
History of the project

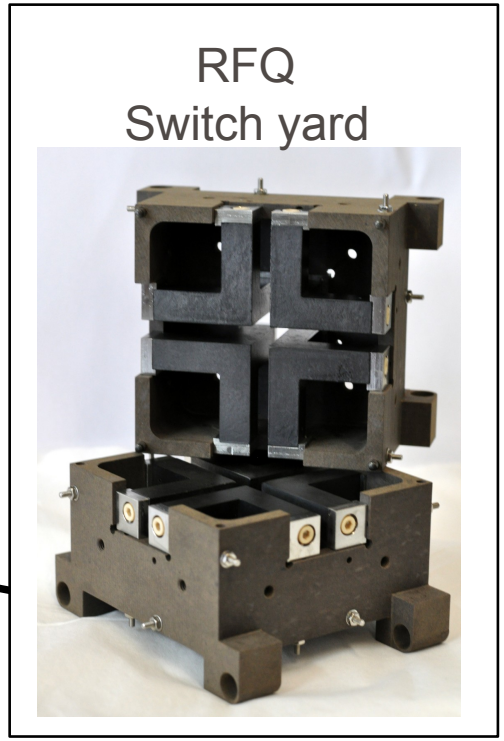
- Design and constructed at University of Giessen (2014)
  (Phd Thesis C. Jesch)
- Offline commissioning at TRIUMF (2016)
- Installation at TITAN late April (2017)
  - Routine operation since

Multiple-Reflection Time-Of-Flight Mass Spectrometer



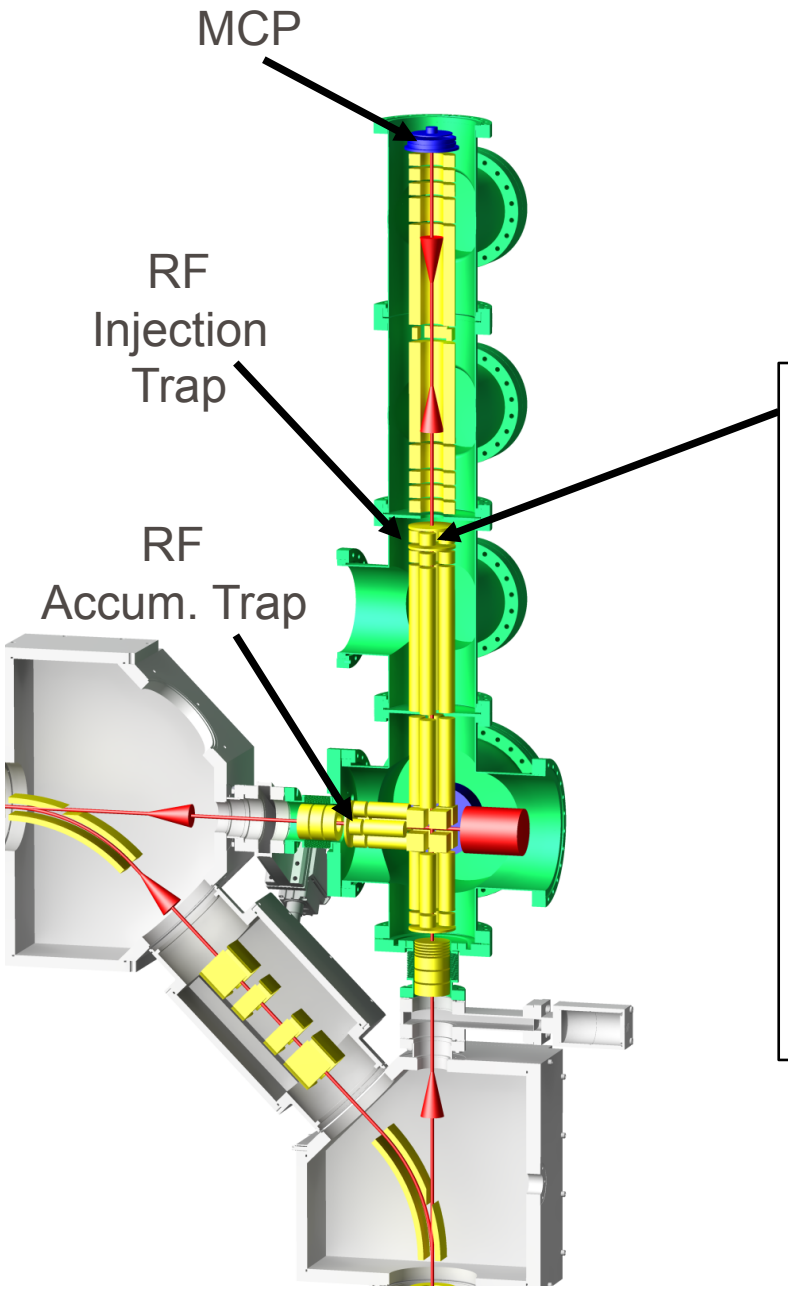
- Low energy transport system for beam preparation
  - Gas filled RFQ
  - RFQ Switchyard





C. Jesch et al., Hyperfine Interact. 235 (2015) 97
W. Plass et al., Phys. Scr. T166 (2015) 014069

Multiple-Reflection Time-Of-Flight Mass Spectrometer



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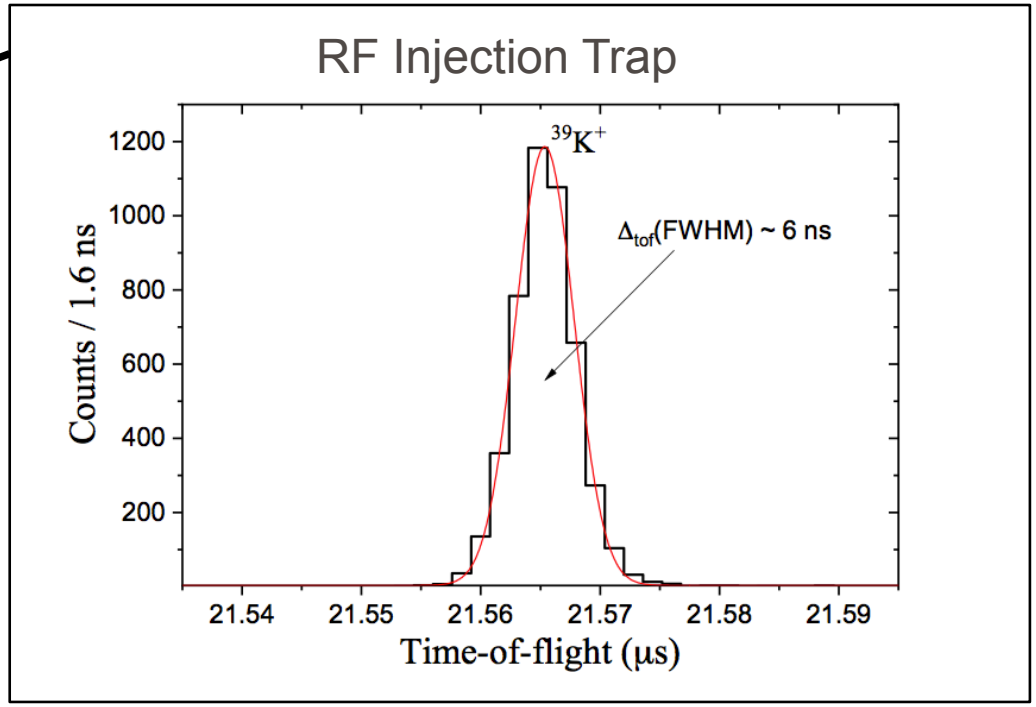

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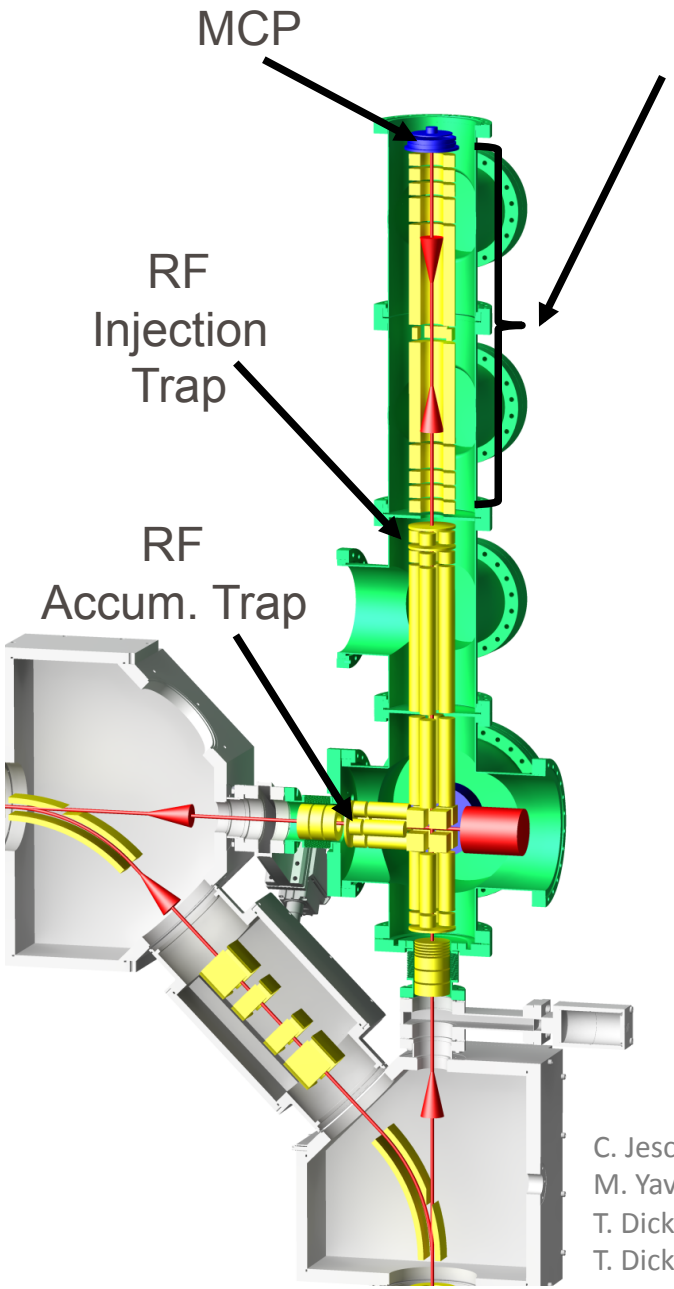
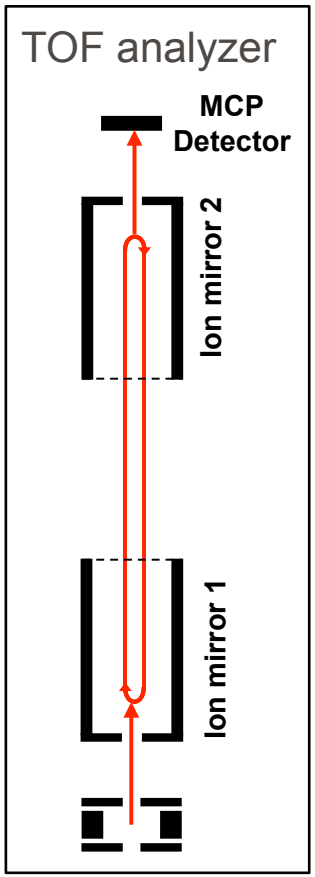
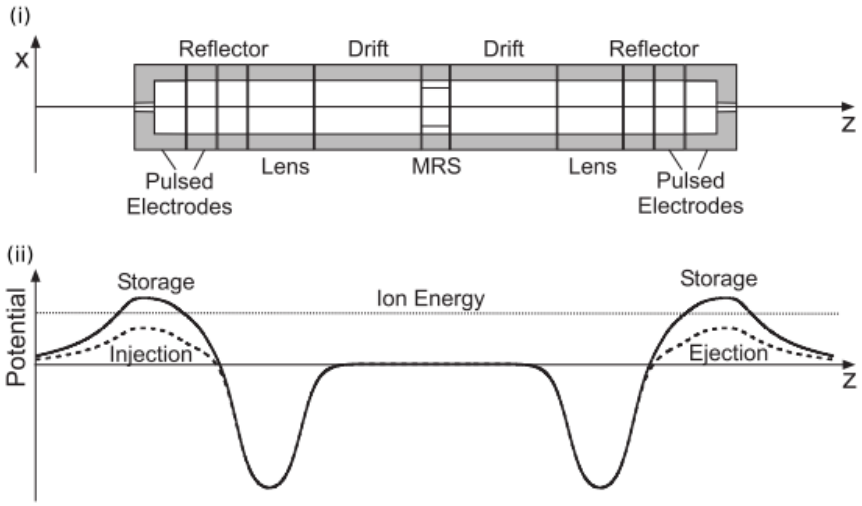


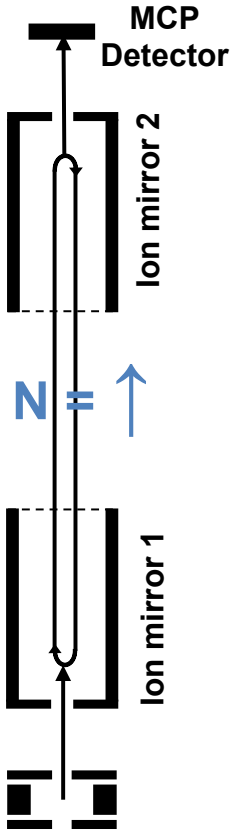


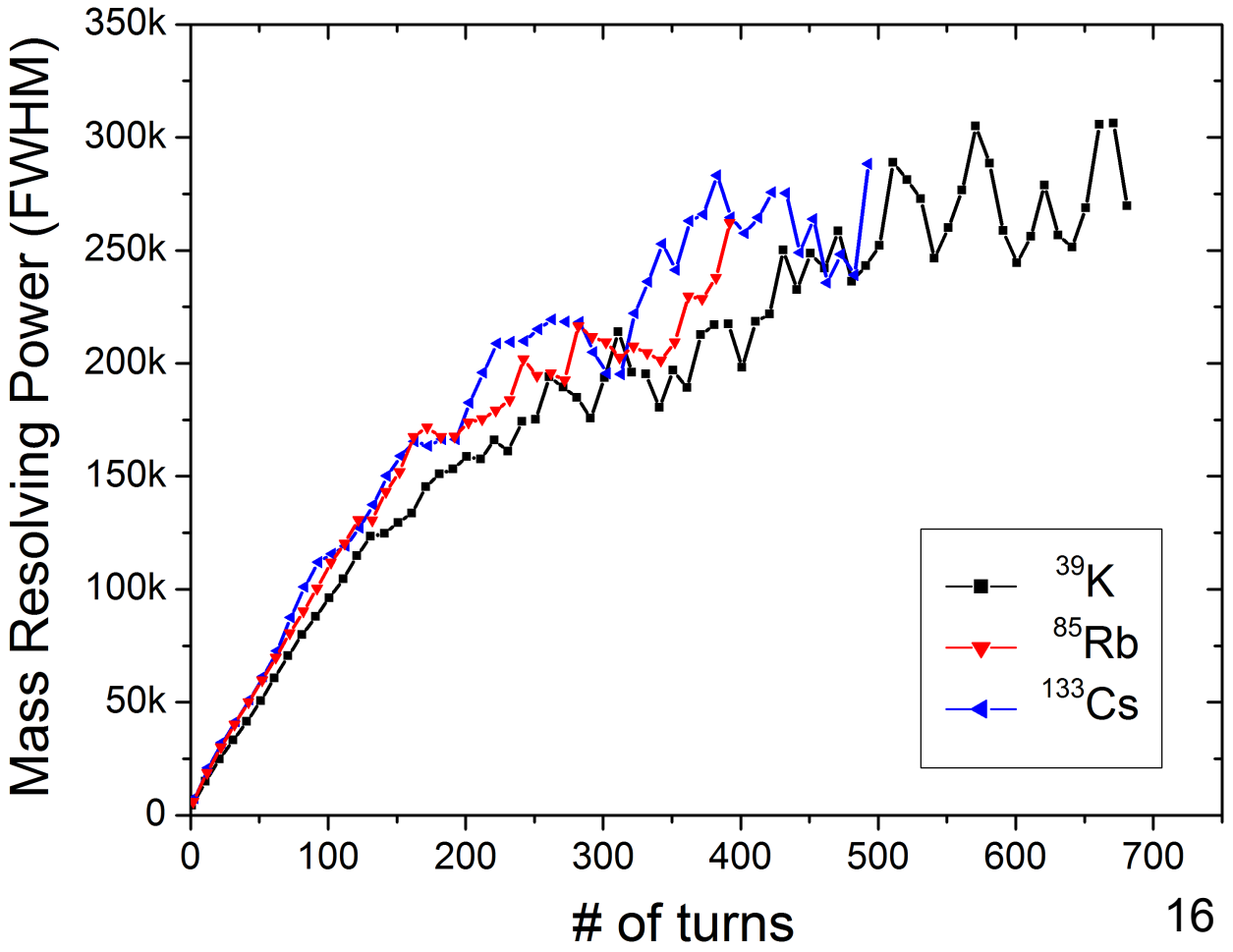
- Measurement of mass-to-charge ratio by measurement of time-of-flight
  - Isochronous electrostatic ion mirrors
  - Time Focus Shift (TFS) method



C. Jesch et al., Hyperfine Interact. 235 (2015) 97
M. Yavor et al., Int. J. Mass Spec. 381 (2015) 1-9
T. Dickel et al., J. ASMS 28 (2017) 1079
T. Dickel et al., IJMS 412 (2017) 1-7

- Beam/sample composition
  - MR-TOF allows fast changing of time-of-flight (number of multiple-reflections)
  - High resolution mode (Resolving power ~ 200k)





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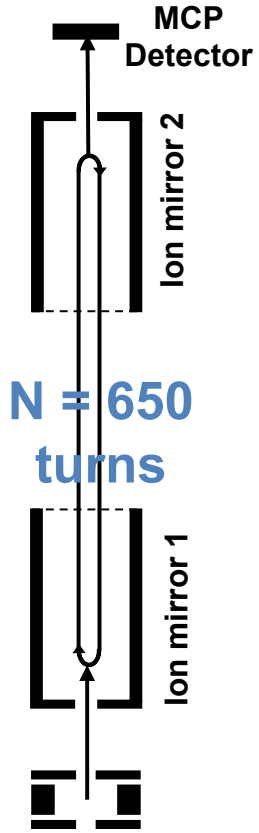
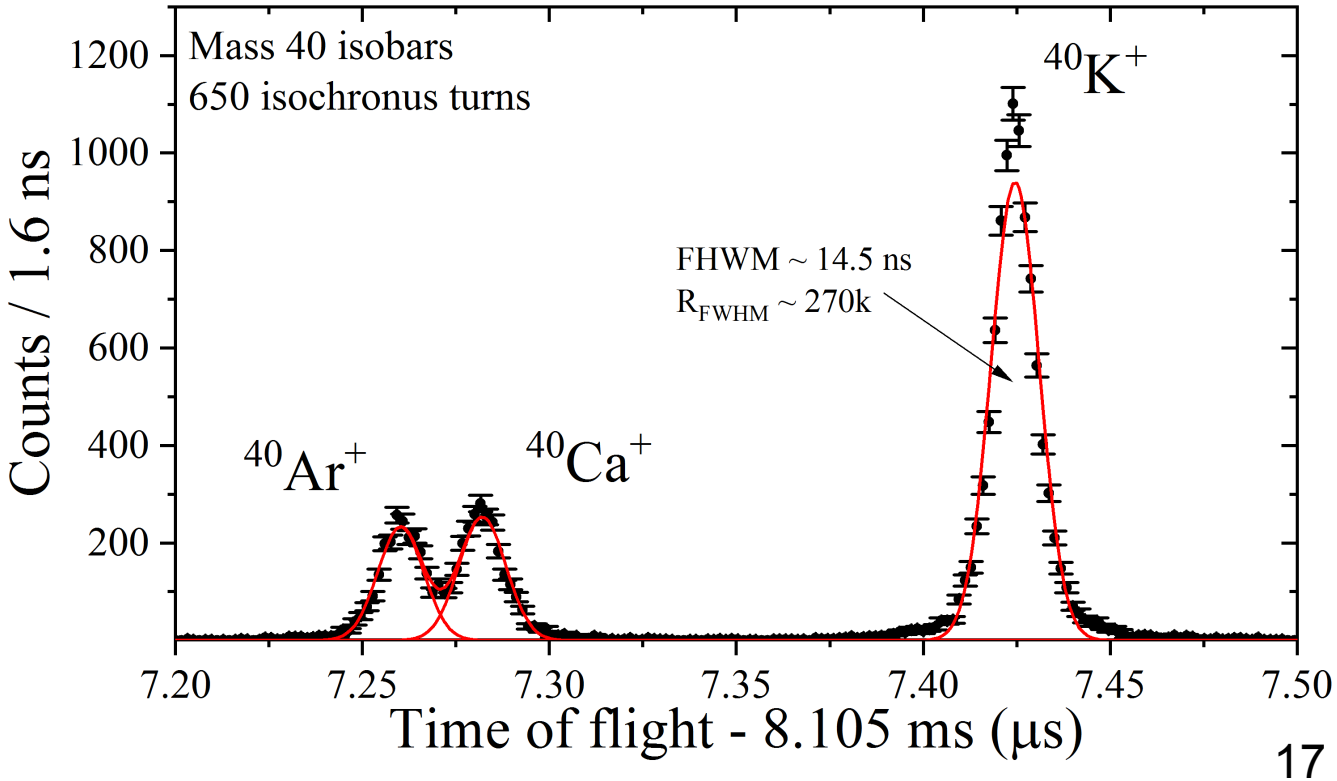
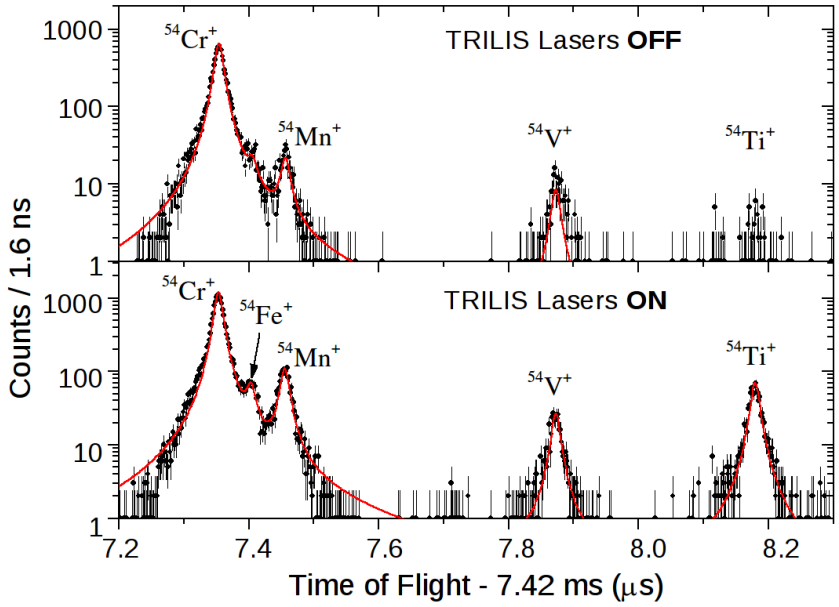
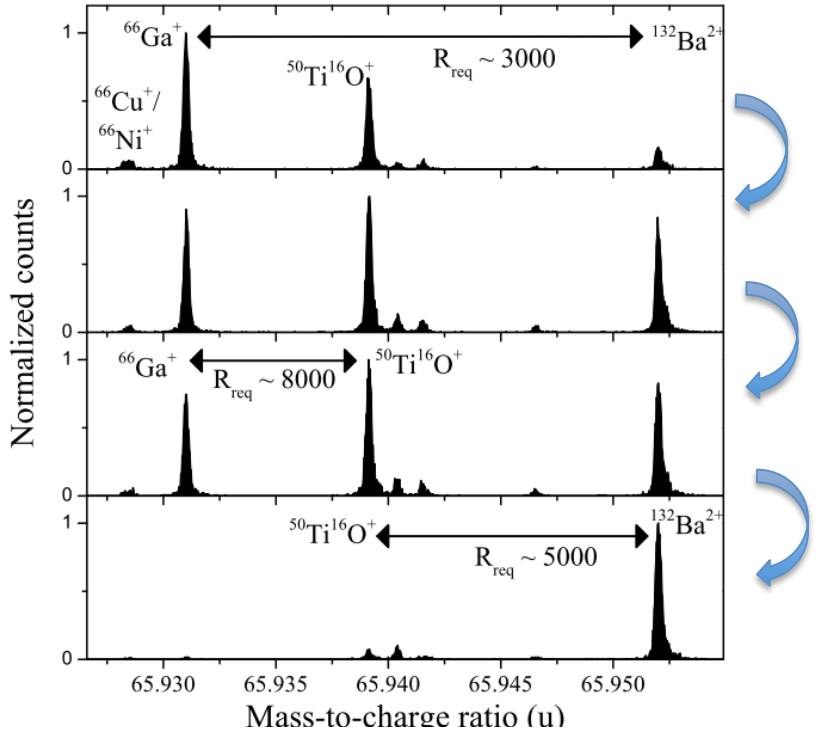


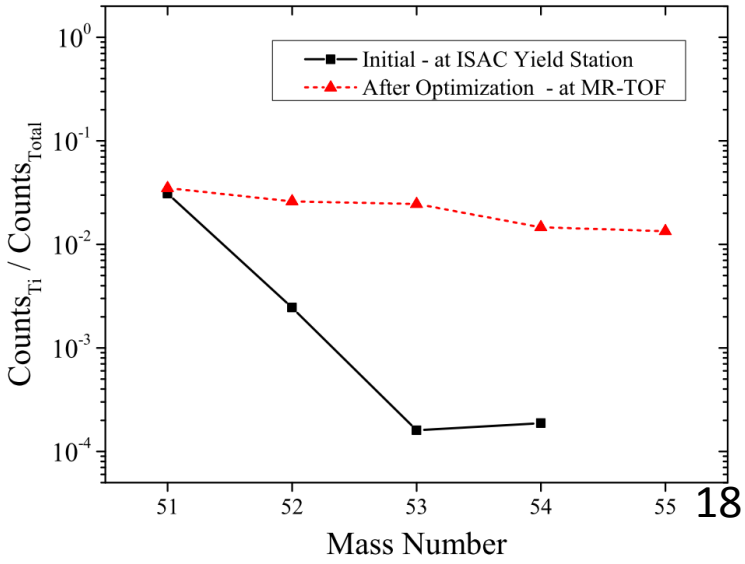


Multiple-Reflection Time-Of-Flight Mass Spectrometer

- Make use of MR-TOF-MS for:
  - Laser On/OFF validation of the time-of-flight identification
  - Fine adjustment of ISAC mass separator
    - ~ 1 order of magnitude cleaner beams



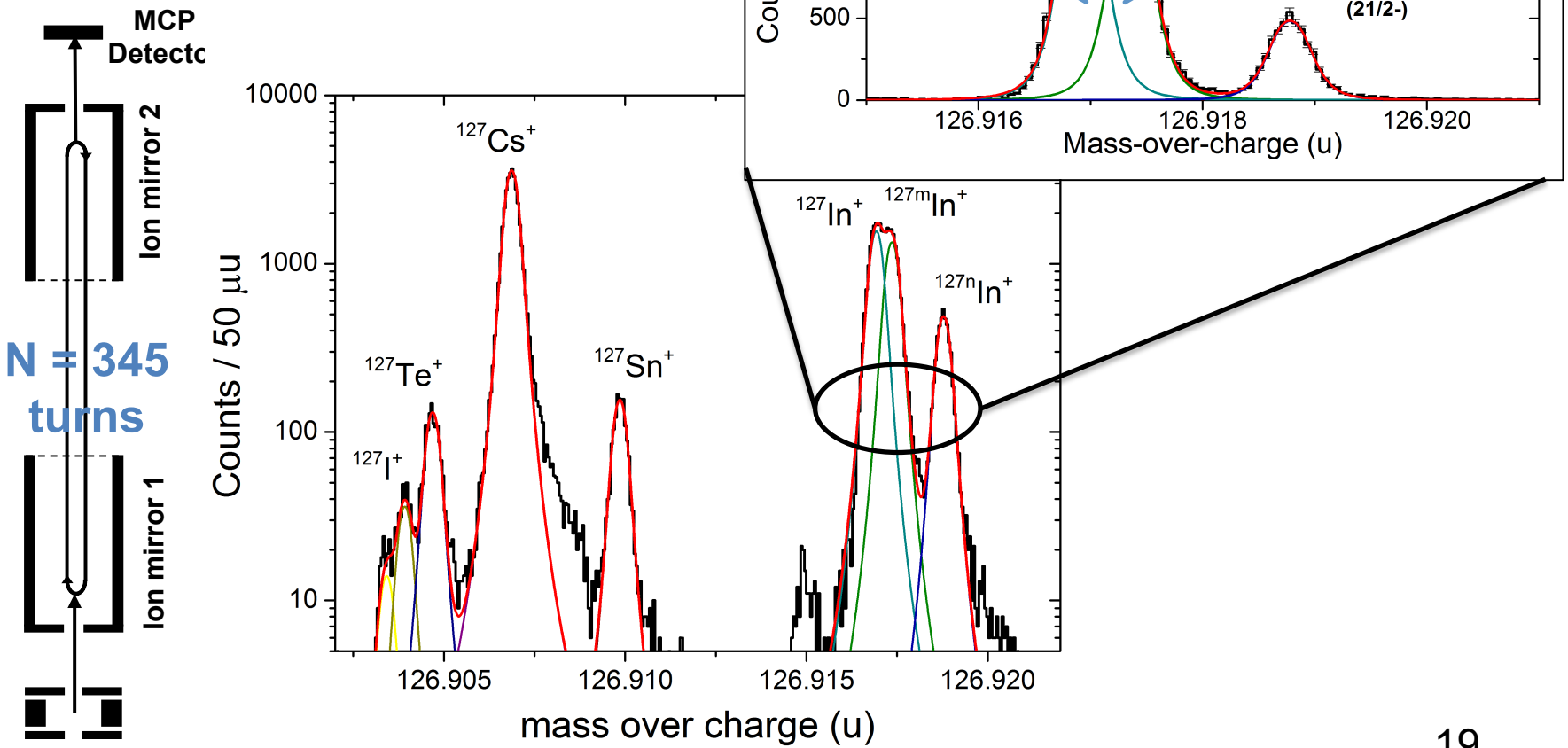




E. Leistenschneider et al., PRL 120 (2018) 062503
M.P. Reiter et al., PRC 98 (2018) 024310

Multiple-Reflection Time-Of-Flight Mass Spectrometer

- Beam/sample composition
  - High resolution mode (Resolvi
  - Fast measurements (time-of-fl



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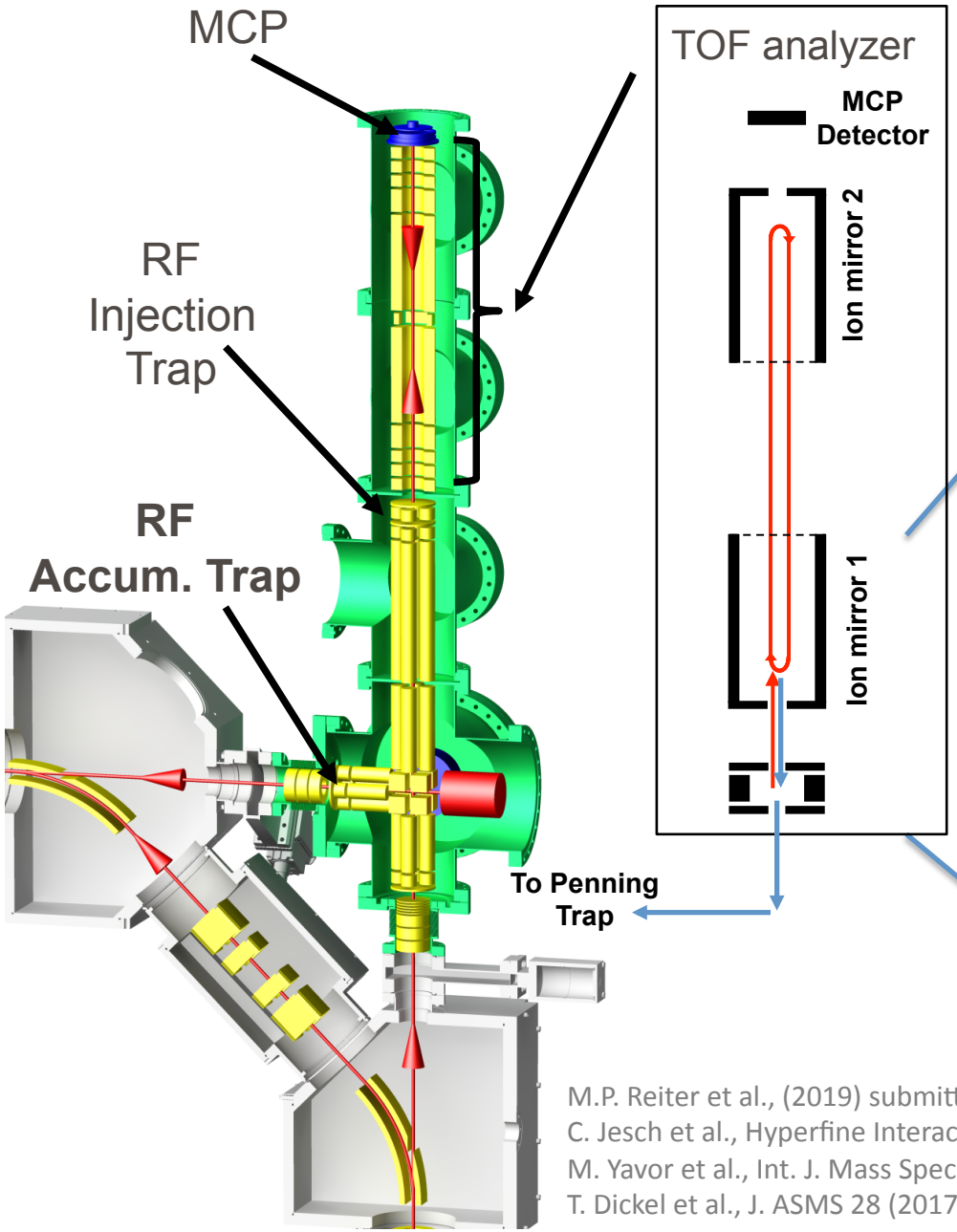
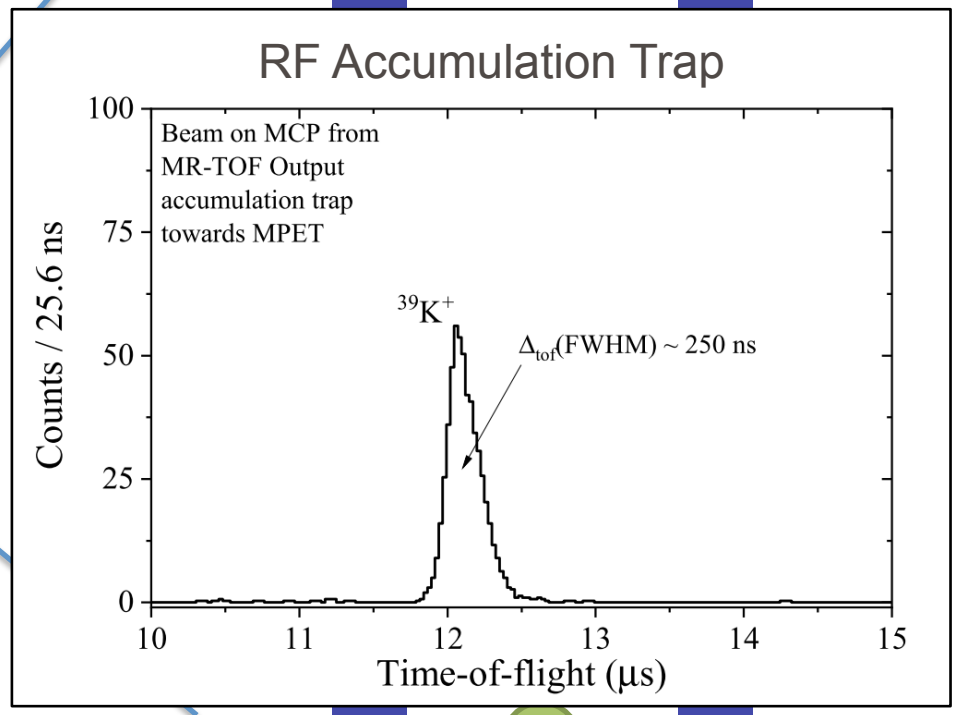


Isobar separation

– Mass-Selective Re-Trapping



M.P. Reiter et al., (2019) submitted to NIM
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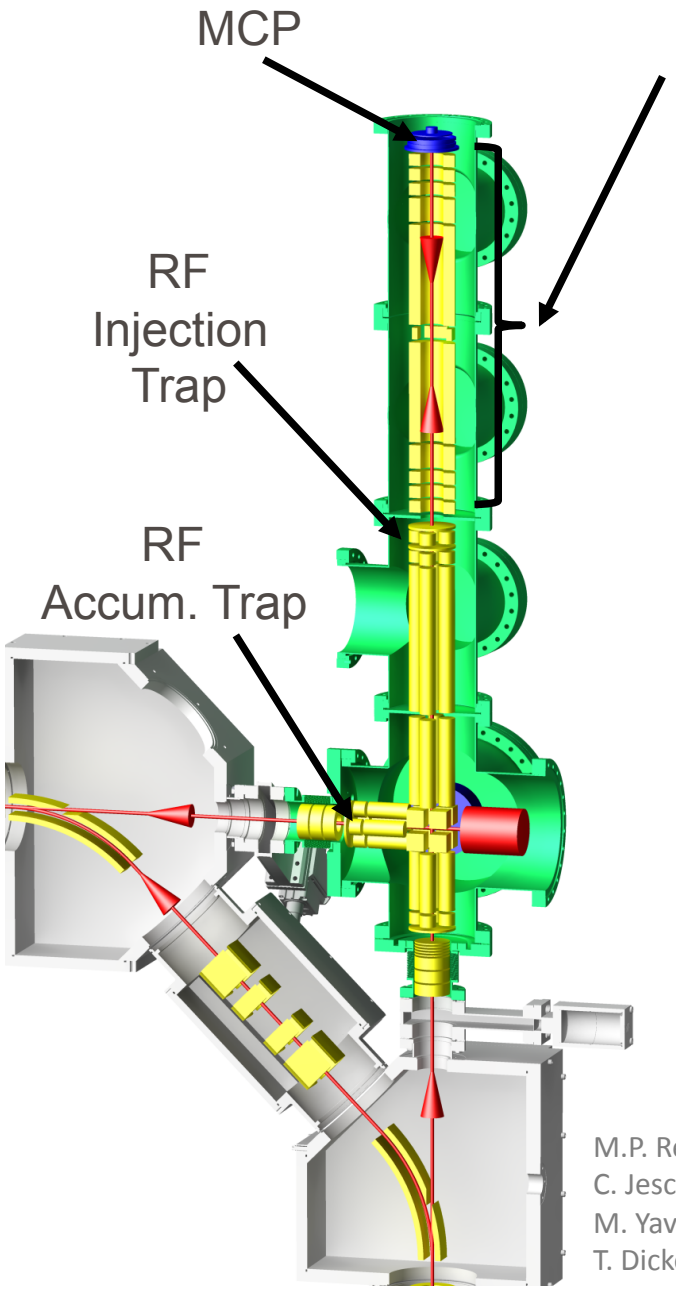
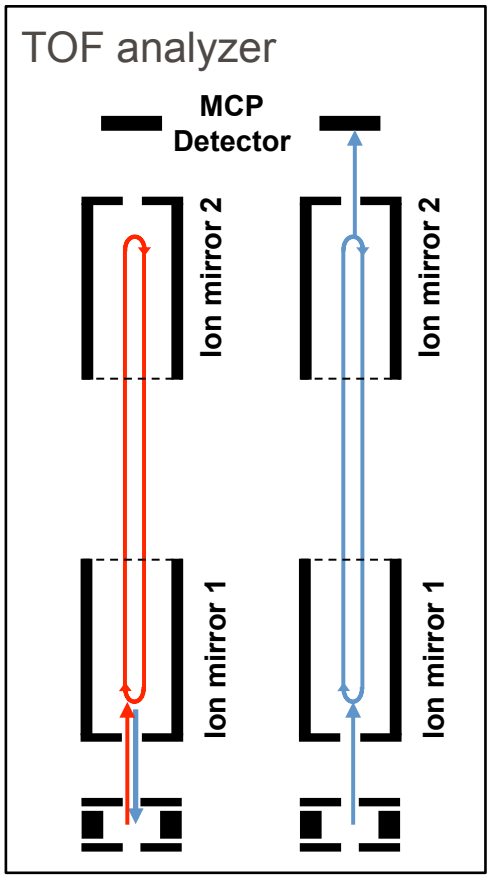




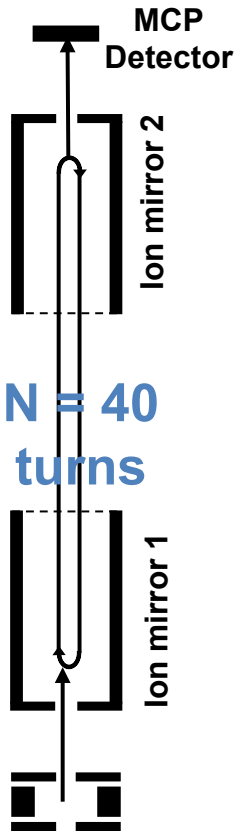
Isobar separation

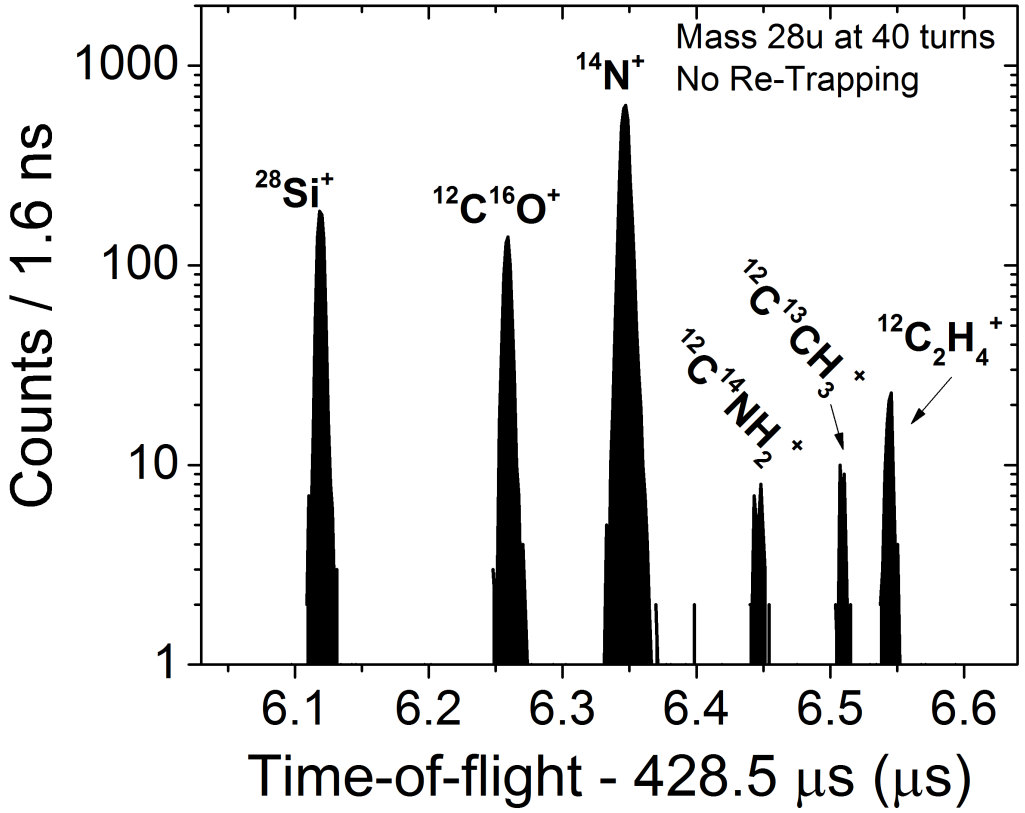
- Mass-Selective Re-Trapping
- Rate capability up to ~ $5*10^4$ to 10^5 pps
- Suppression ~ 10^4
- Separation power 80k

- **Operate is its own high resolution isobar separator**

M.P. Reiter et al., (2019) submitted to NIM
C. Jesch et al., Hyperfine Interact. 235 (2015) 97
M. Yavor et al., Int. J. Mass Spec. 381 (2015) 1-9
T. Dickel et al., J. ASMS 28 (2017) 1079

- First commissioning with stable beam from ISAC in May
  Demonstrate:
  - Isobar separation using mass selective re-trapping with suppression of ~ 10^4 at R~ 25.000





- First commissioning with stable beam from ISAC in May
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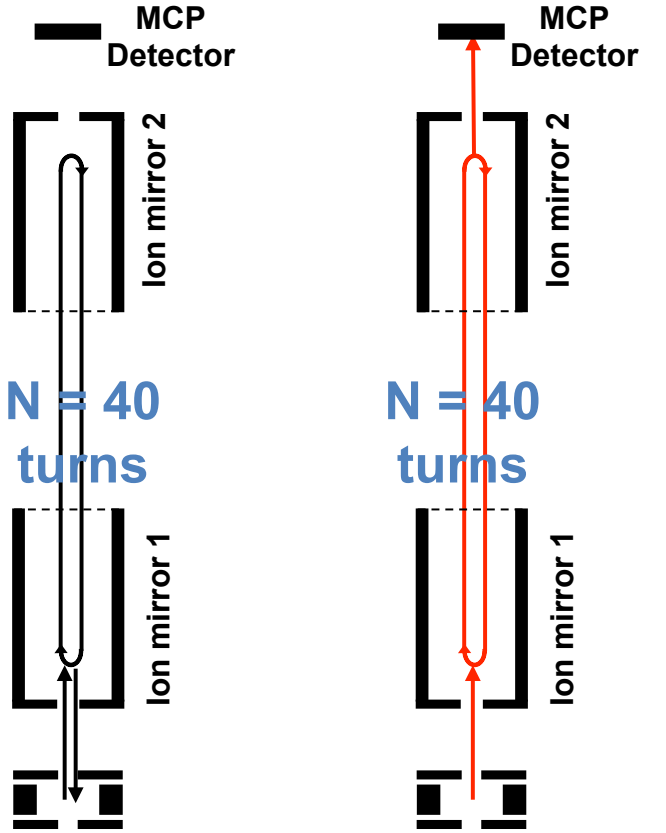
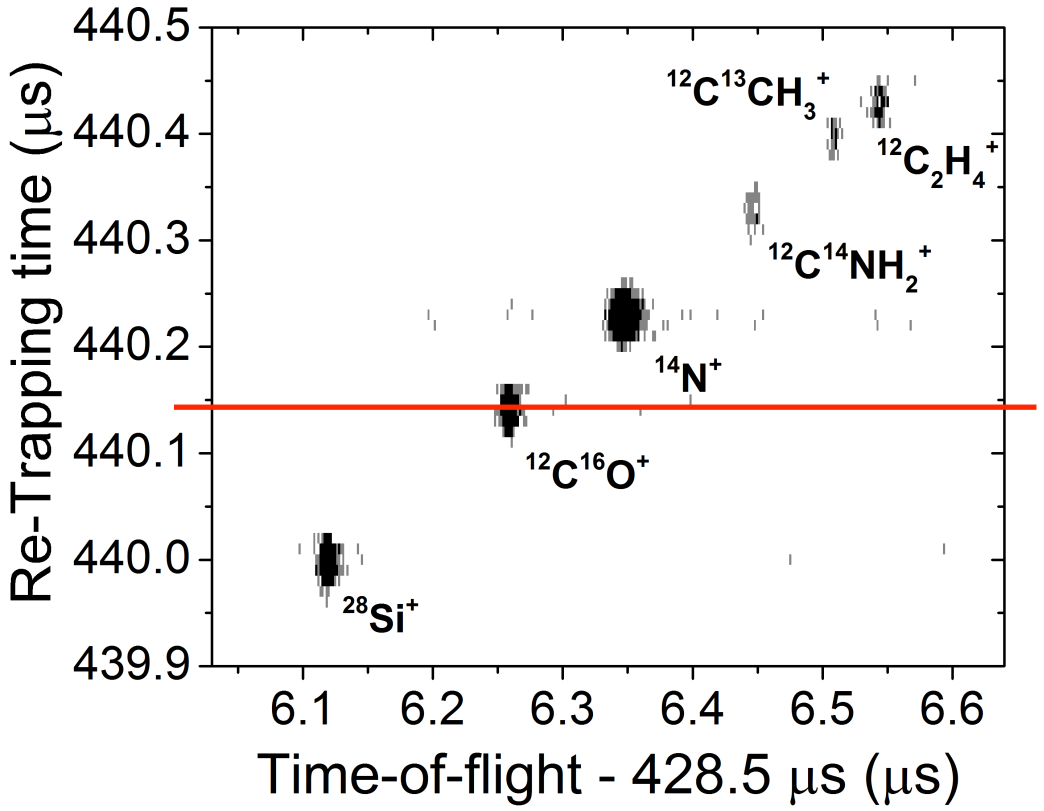
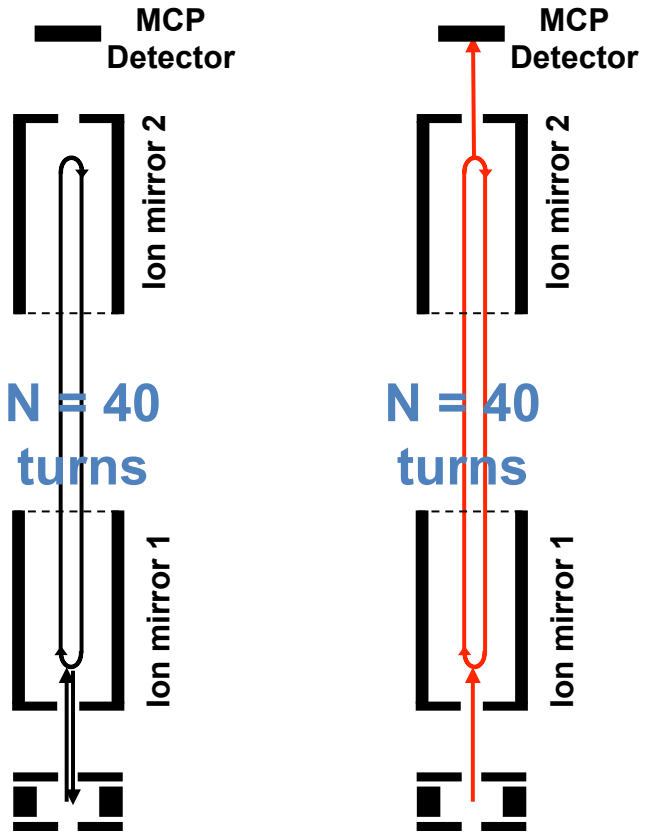
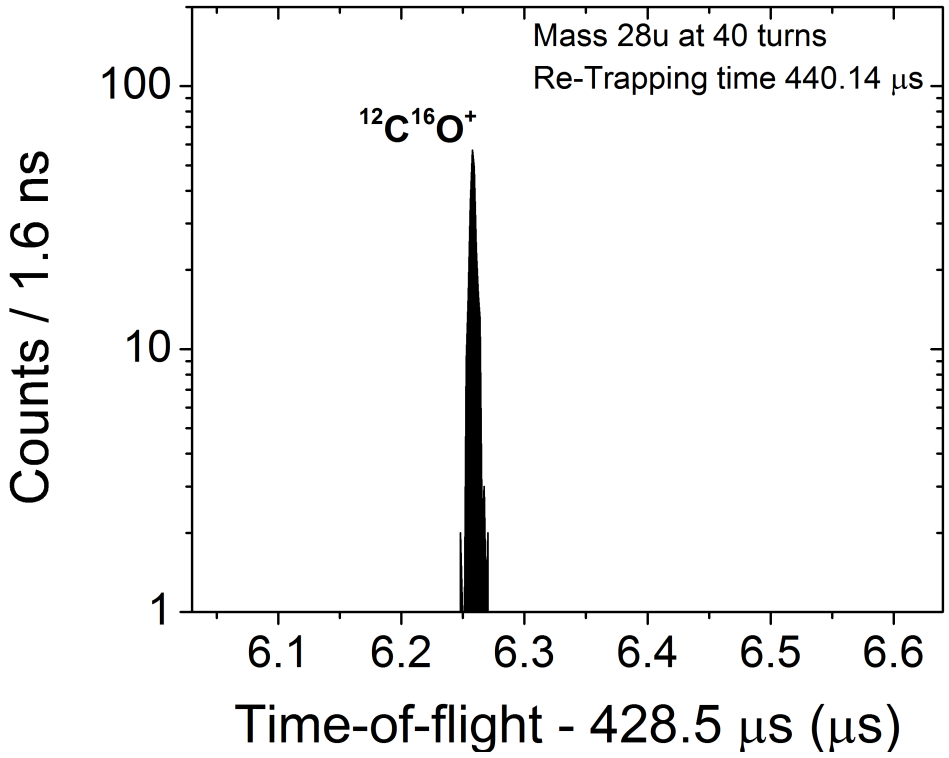


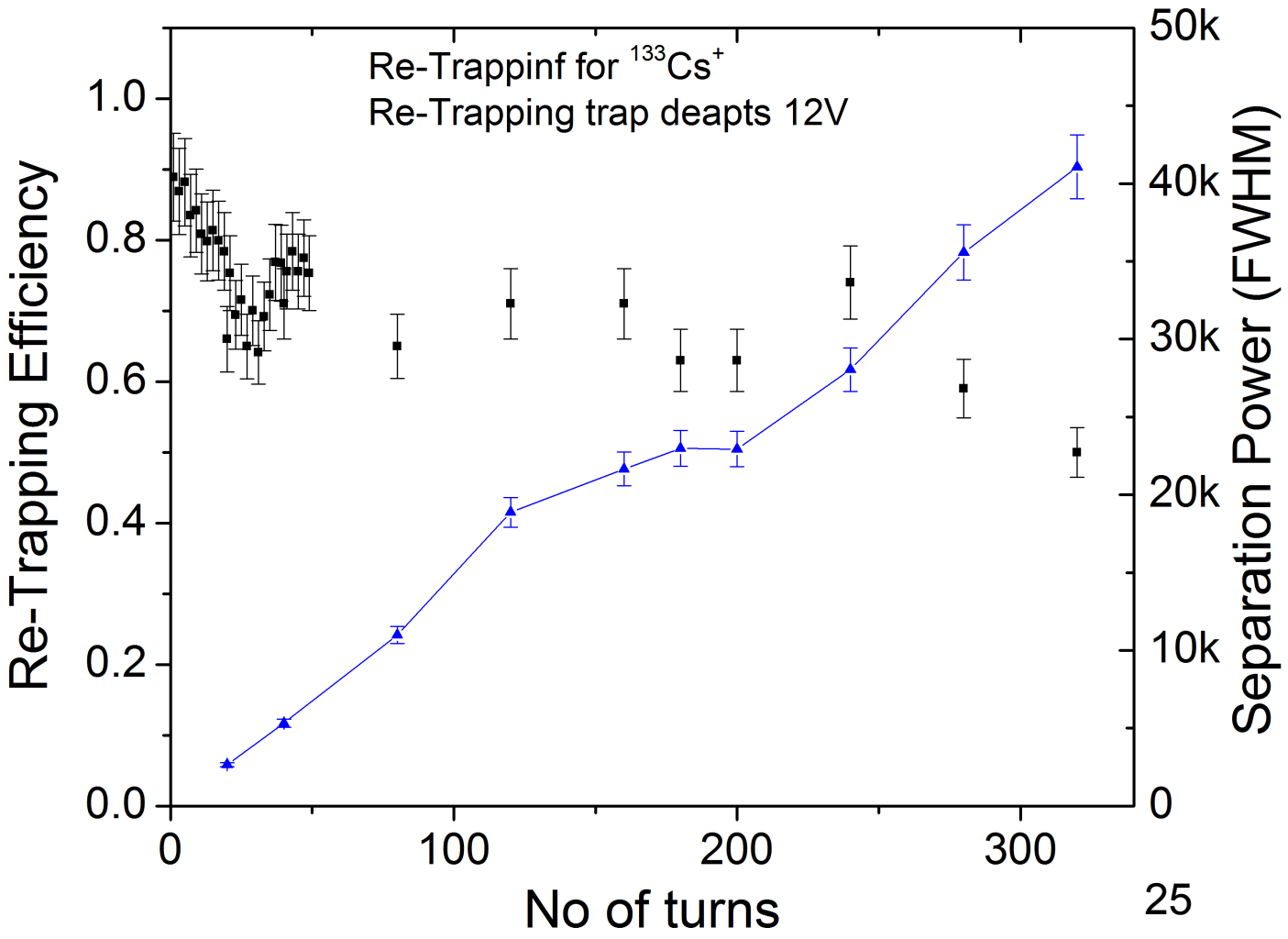


- First commissioning with stable beam from ISAC in May
  Demonstrate:
  - Isobar separation using mass selective re-trapping with suppression of ~ 10^4 at R~ 5.000

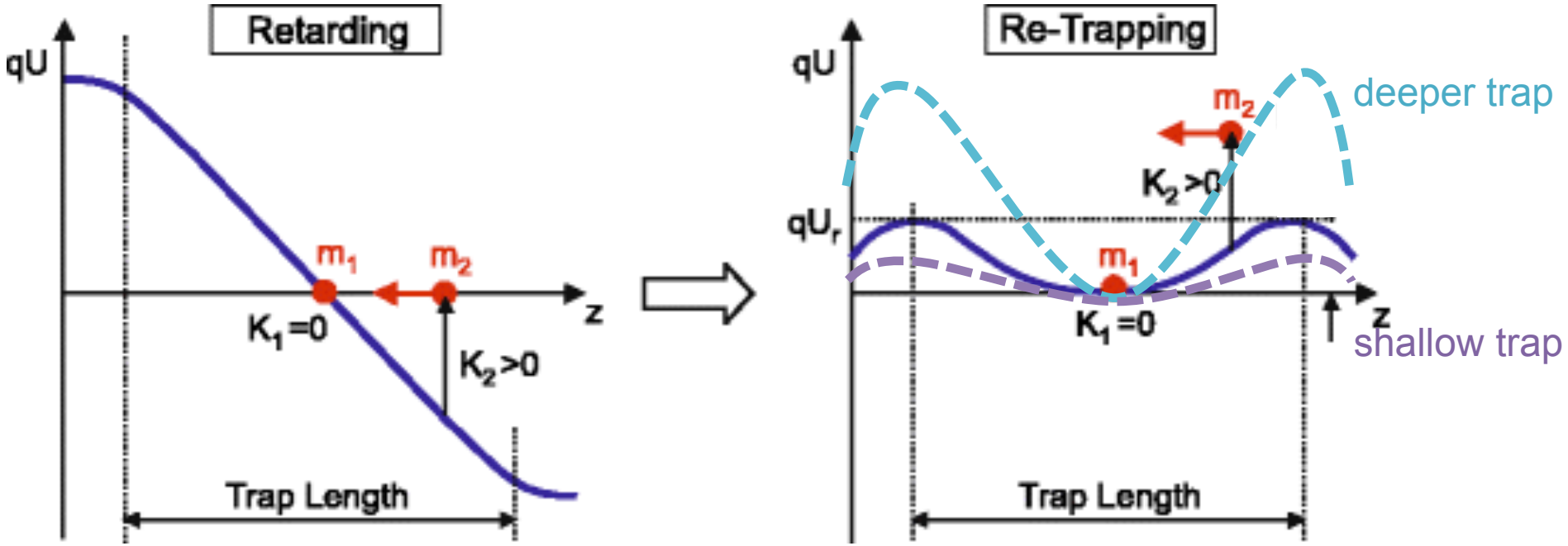




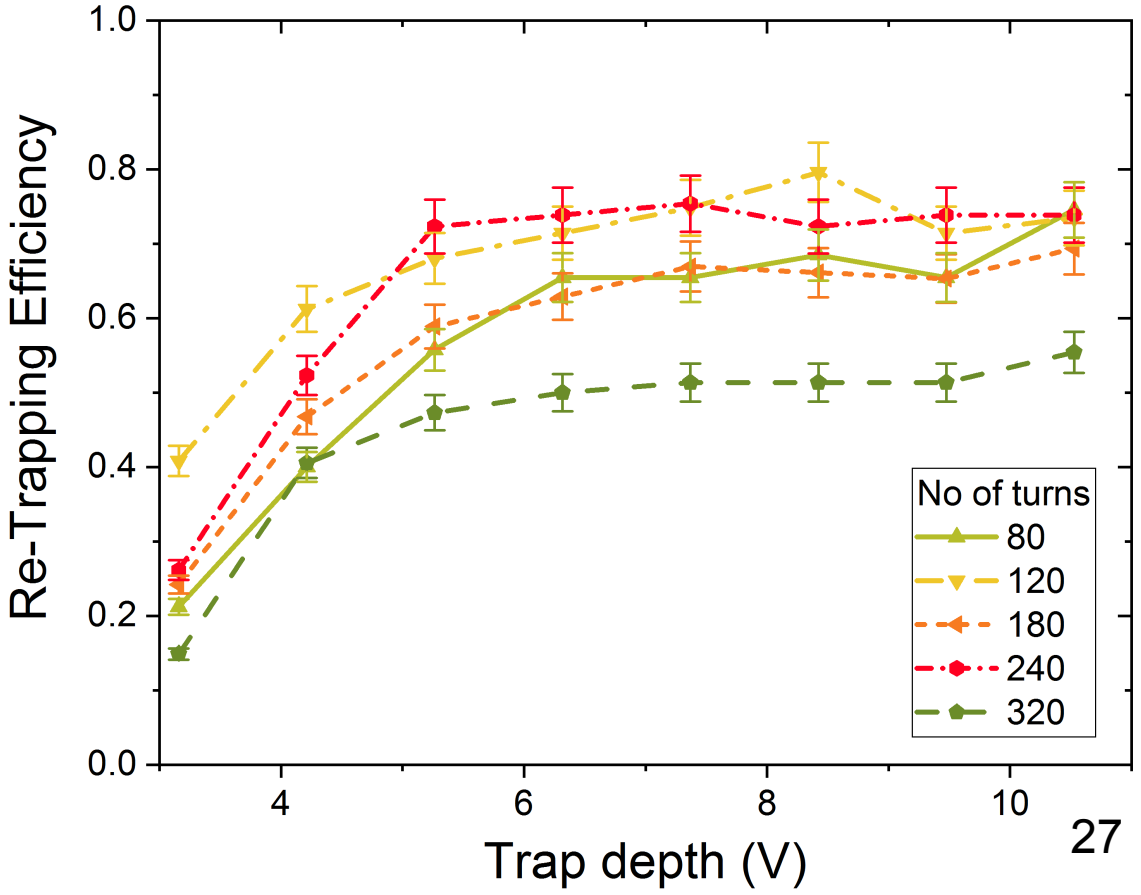
- First commissioning with stable beam from ISAC in May 2017
- Two ways to increase selectivity
  - longer flight times



- First commissioning with stable beam from ISAC in May 2017
- Two ways to increase selectivity
  - longer flight times
  - shallow trap for re-trapping
    - comparable to closing slits at a magnetic mass separator



- First commissioning with stable beam from ISAC in May 2017
- Two ways to increase selectivity
  - longer flight times
  - shallow trap for re-trapping
    - too shallow trap results in efficiency loss



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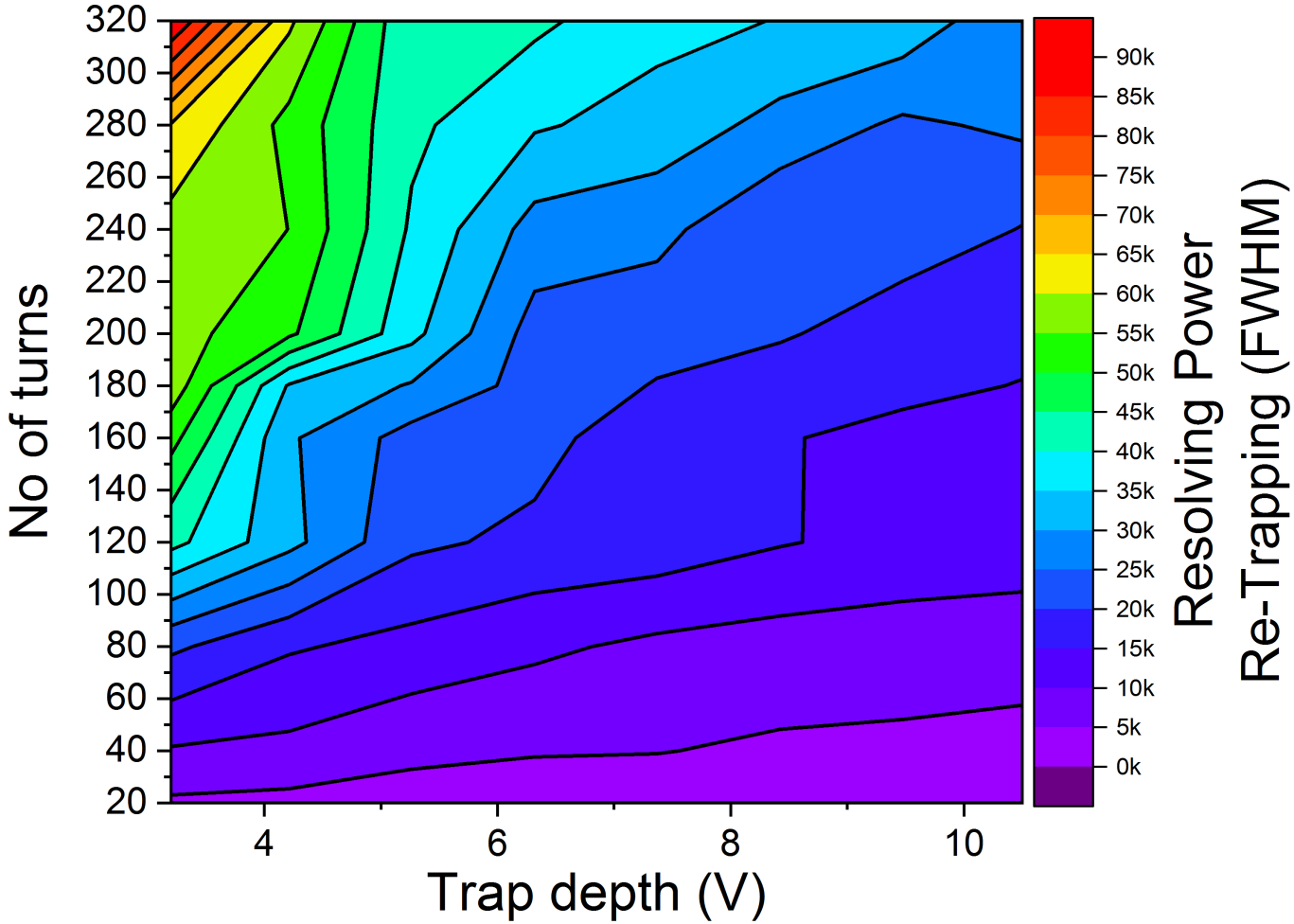
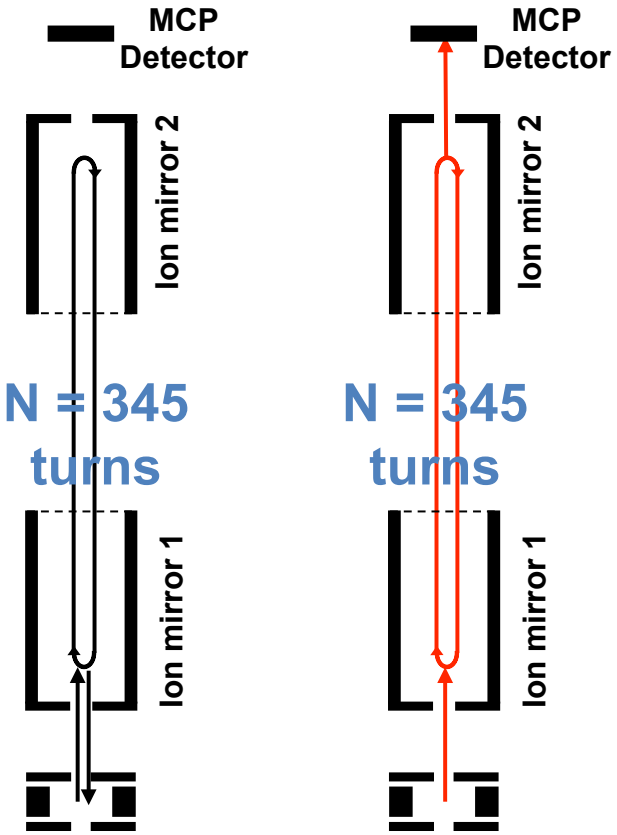
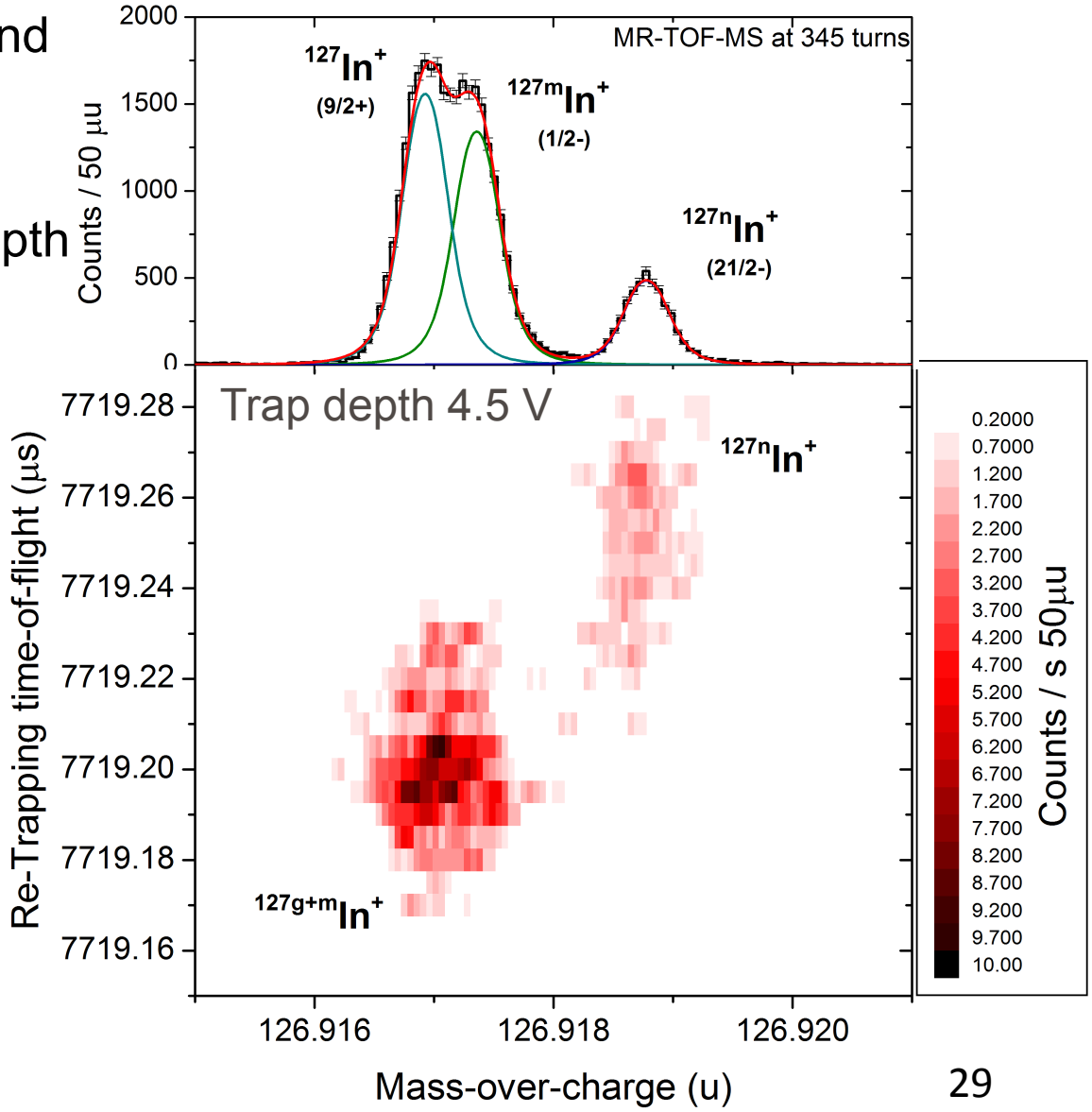


Multiple-Reflection Time-Of-Flight Mass Spectrometer

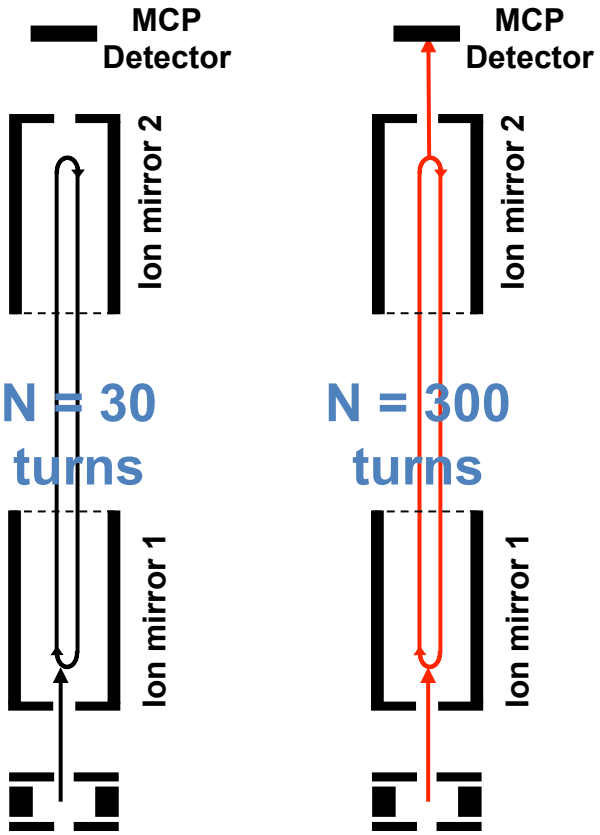
- High-resolution example
  - e.g. separation of ground and isomeric states
    - At E_X ~ 1.5 MeV
    - Using 4.5 V trap depth

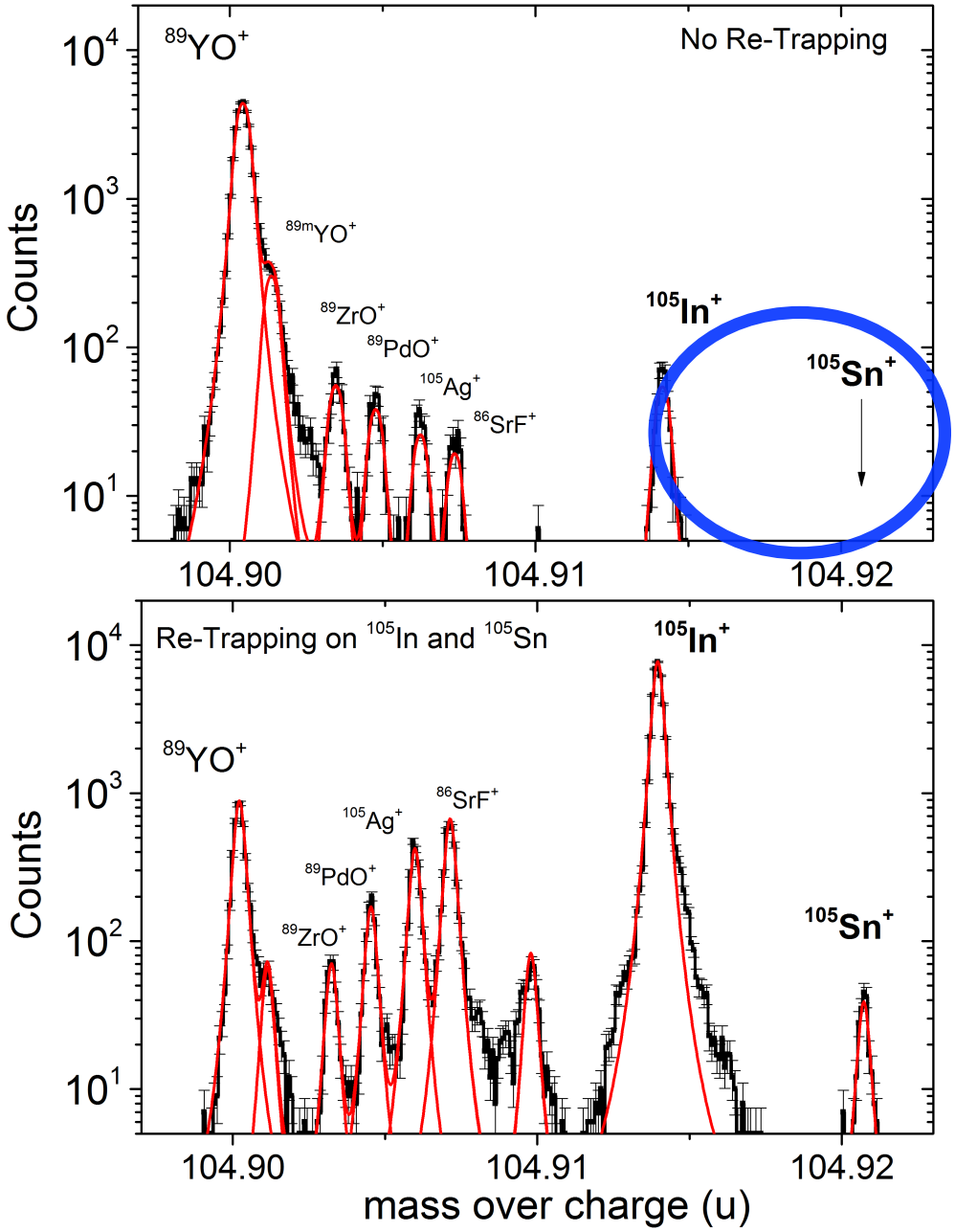




Multiple-Reflection Time-Of-Flight Mass Spectrometer

- High-intensity example
  - e.g. separation of ^{105}Sn
    ^{105}Sn Yield ~ 1pps,
    background ~ 10^6pps
    - deep trap, low No of turns

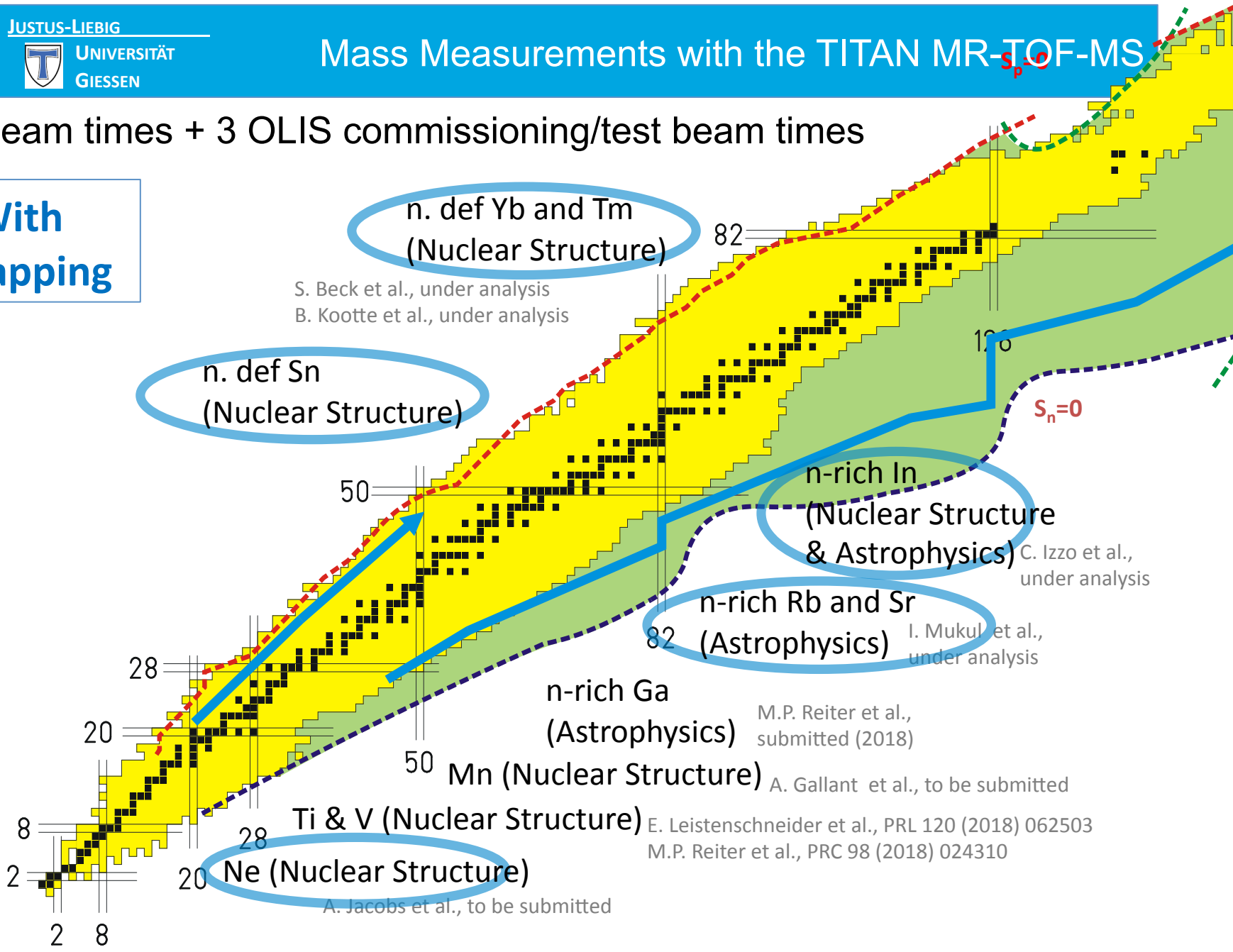




Mass Measurements with the TITAN MR-TOF-MS

- 8 RIB beam times + 3 OLIS commissioning/test beam times

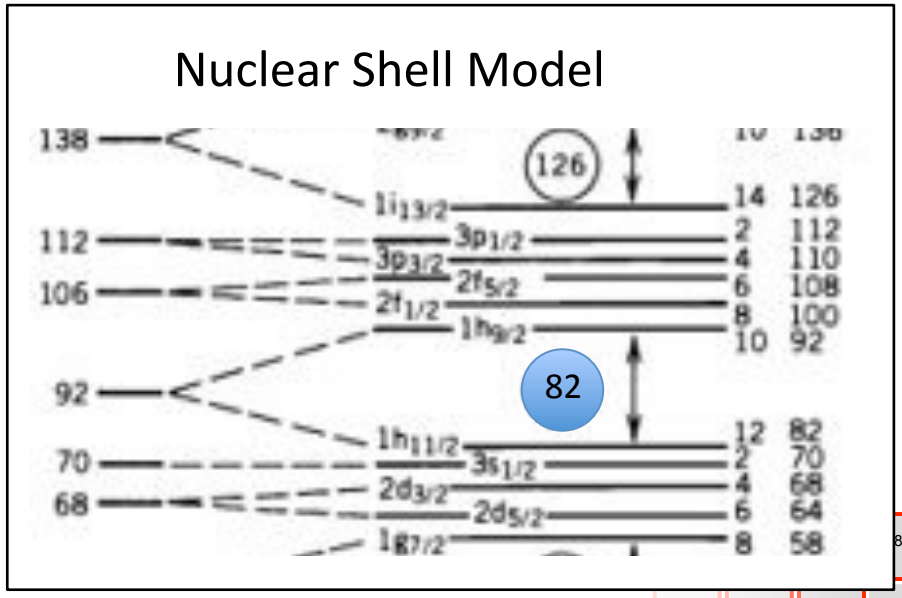
5 With Re-Trapping

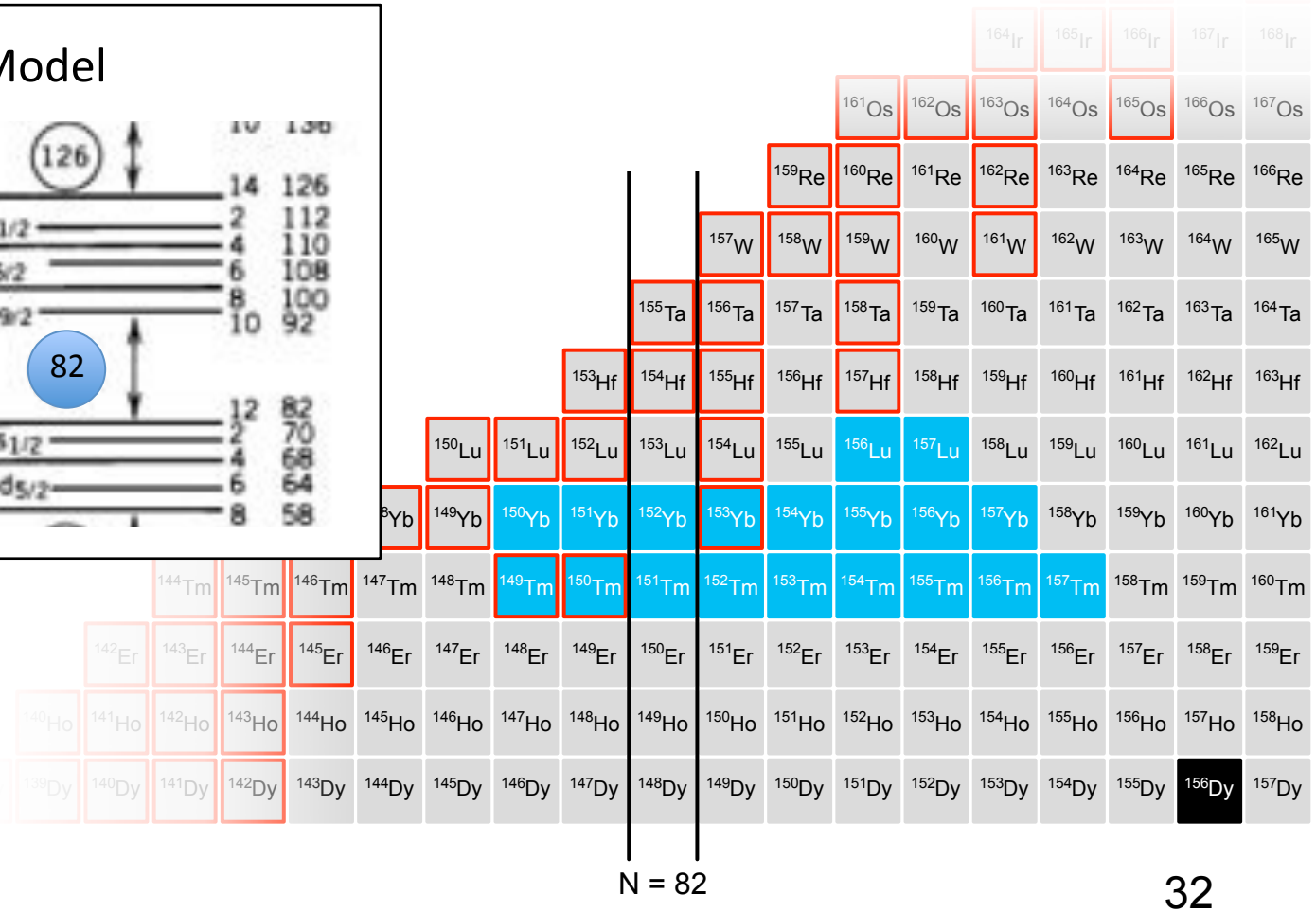


Mass measurements of neutron-deficient lanthanides

- N = 82 shell closure far from valley of stability
- Nuclear structure close to the proton dripline
- Possible proton and 2-proton emitters

^{A}X extrapolated masses





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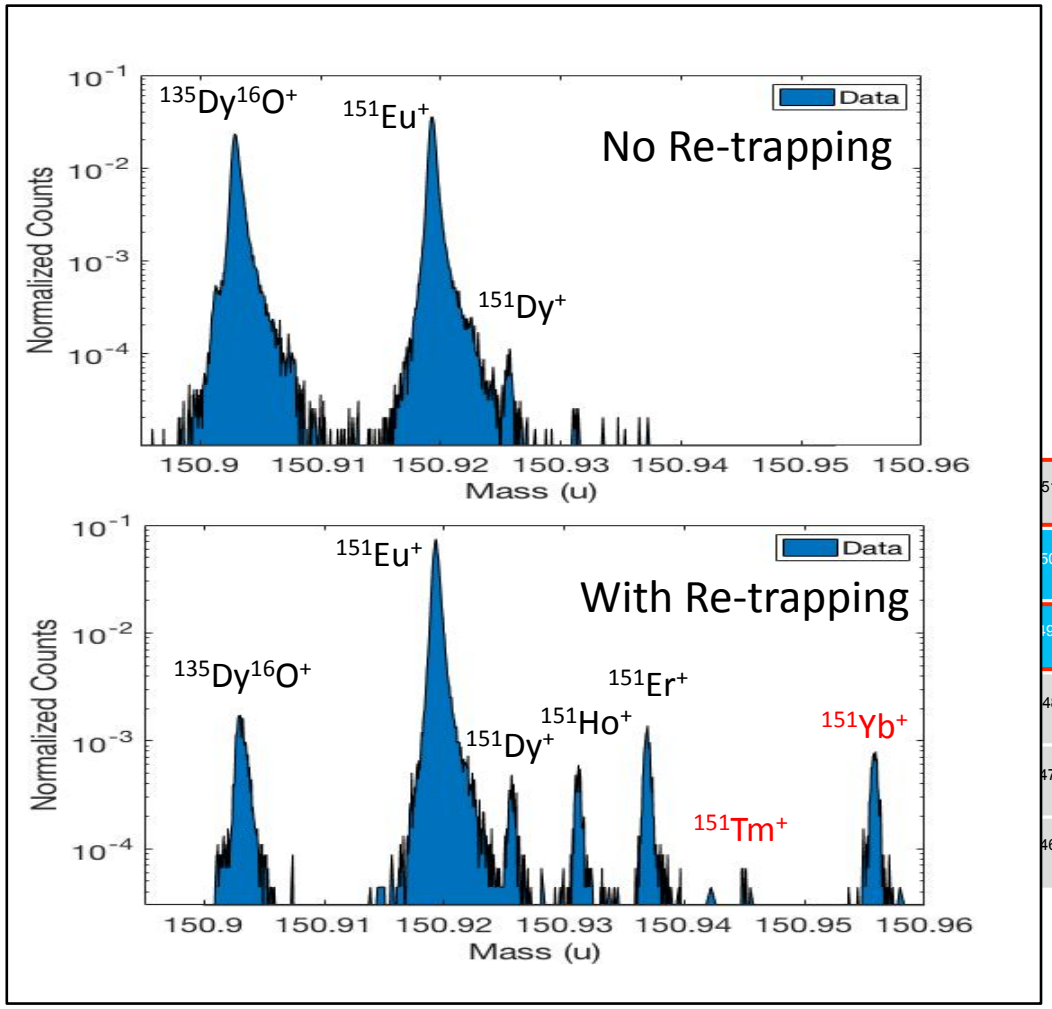
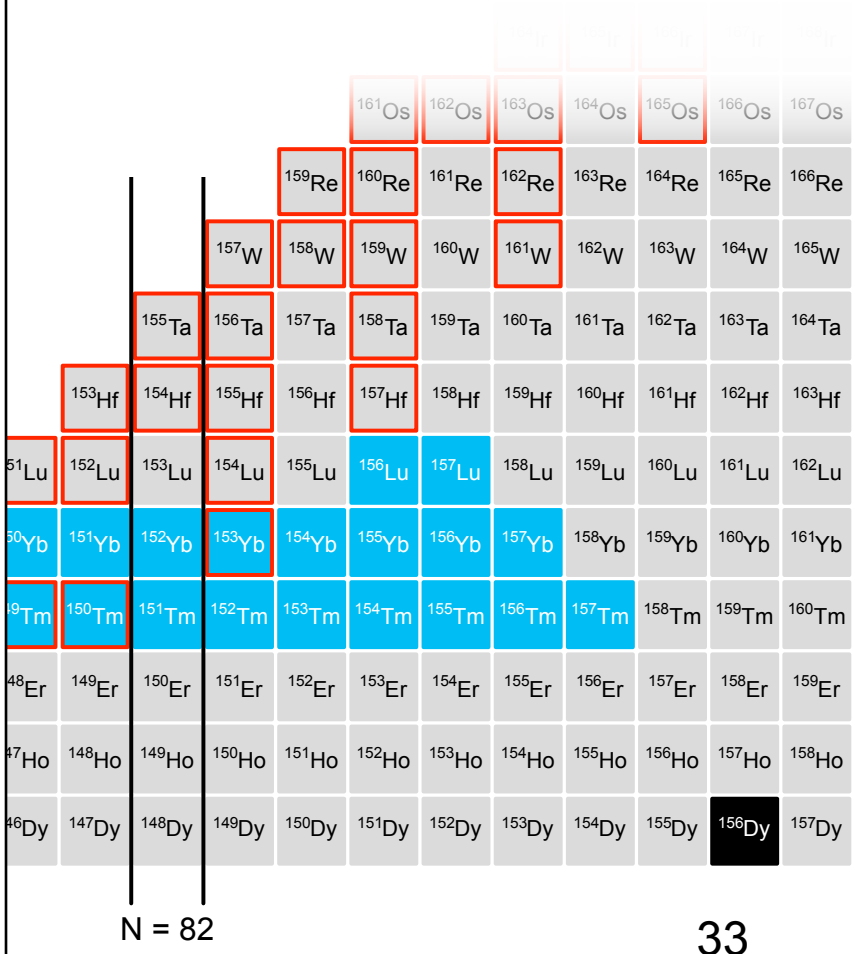
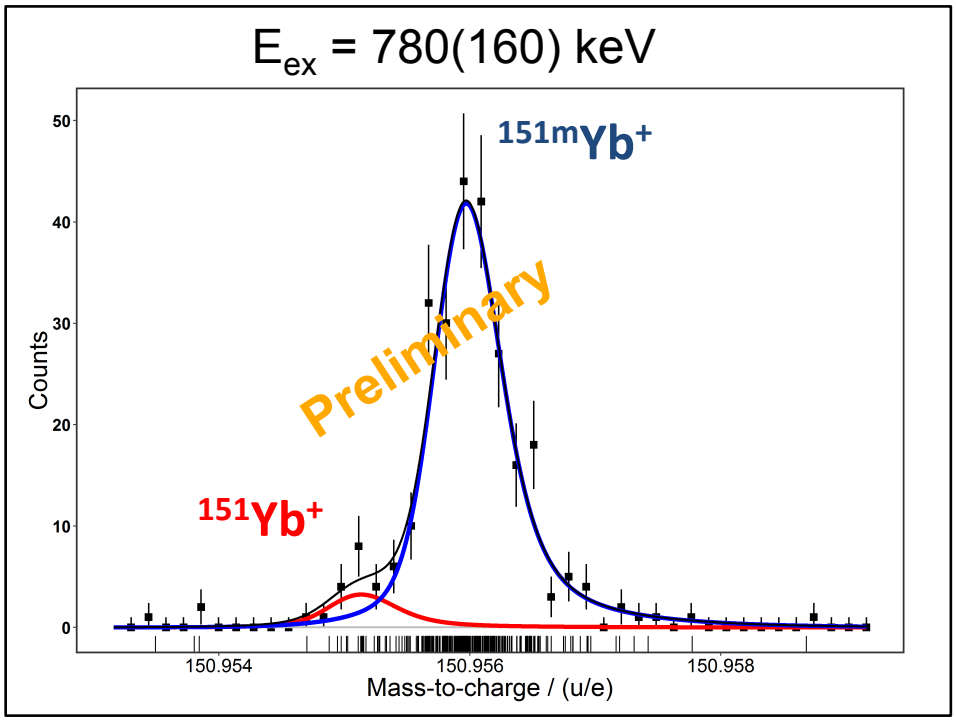


^{A}X extrapolated masses

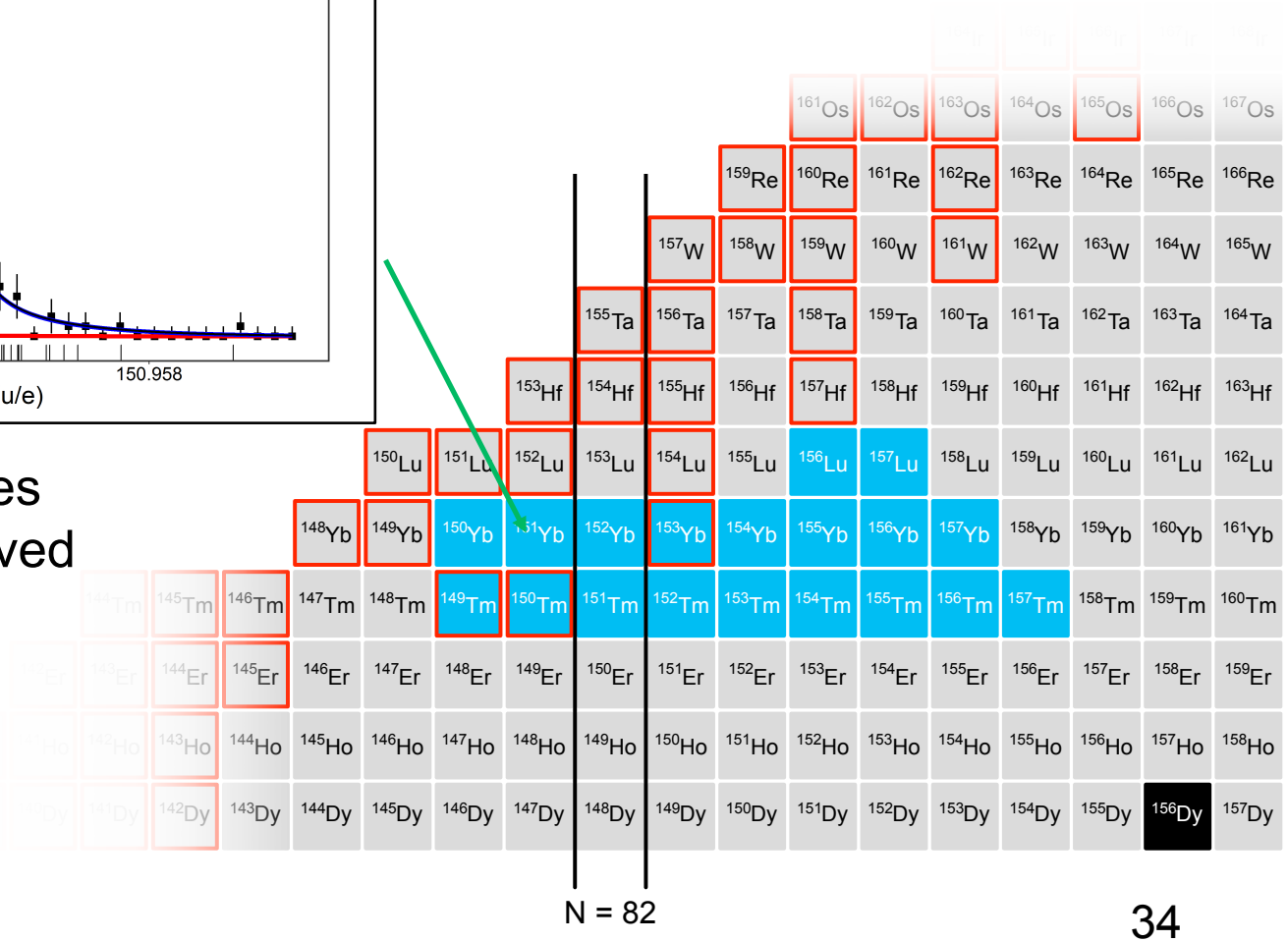


Nuclear structure close to the proton dripline

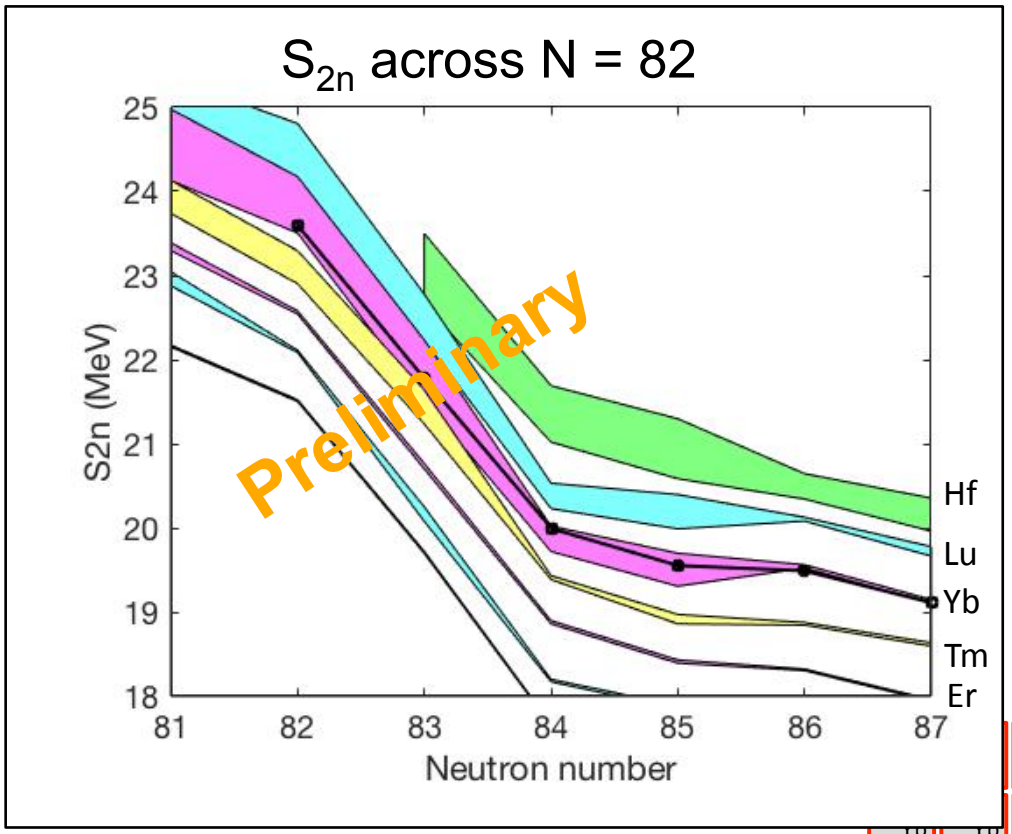


Excitation energy agrees with systematics observed for lighter even-Z N=81 nuclides

^{A}X extrapolated masses



N = 82 shell closure far from valley of stability



Confirm N = 82 shell closure in neutron-deficient Yb isotopes

N = 82

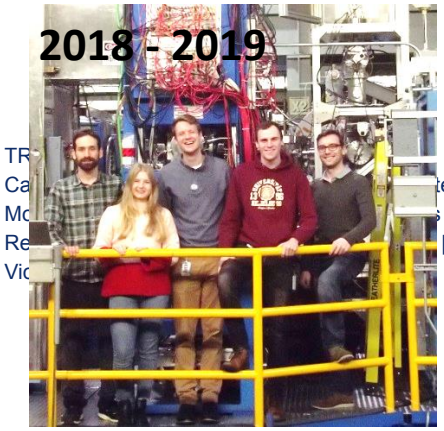
Conclusion and Outlook

- MR-TOF-MS has been a beautiful extension to TITAN experiment
  - improves capabilities for
    - short-lived,
    - low production
    - high background species
  - mass-selective re-trapping has been fully established for RIB experiments

- TITAN is rapping up many technical upgrades of the facility
  - MR-TOF-MS commissioning
  - Cryogenic Penning Trap upgrade + phase imagining technique under way
  - EBIT charge breeding upgrade
  - EBIT HPGe upgrade underway

→ Preparations to operate all traps hand in hand during experiments end of this year

MR-TOF Students



TITAN Collaboration

Thank you!
Merci!

FRS Ion Catcher Collaboration

University of Manitoba

University of Calgary

SFU

McGill

Max-Planck-Institut für Kernphysik Heidelberg

Justus-Liebig-Universität Giessen

University of Victoria

Colorado School of Mines

University of Notre Dame

UBC

Westfälische Wilhelms-Universität Münster

university of groningen

kvi - center for advanced radiation technology

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