

Experiments with ^{238}U Projectile and Fission Fragments at the FRS Ion Catcher

Jens Ebert
for the FRS Ion Catcher Collaboration

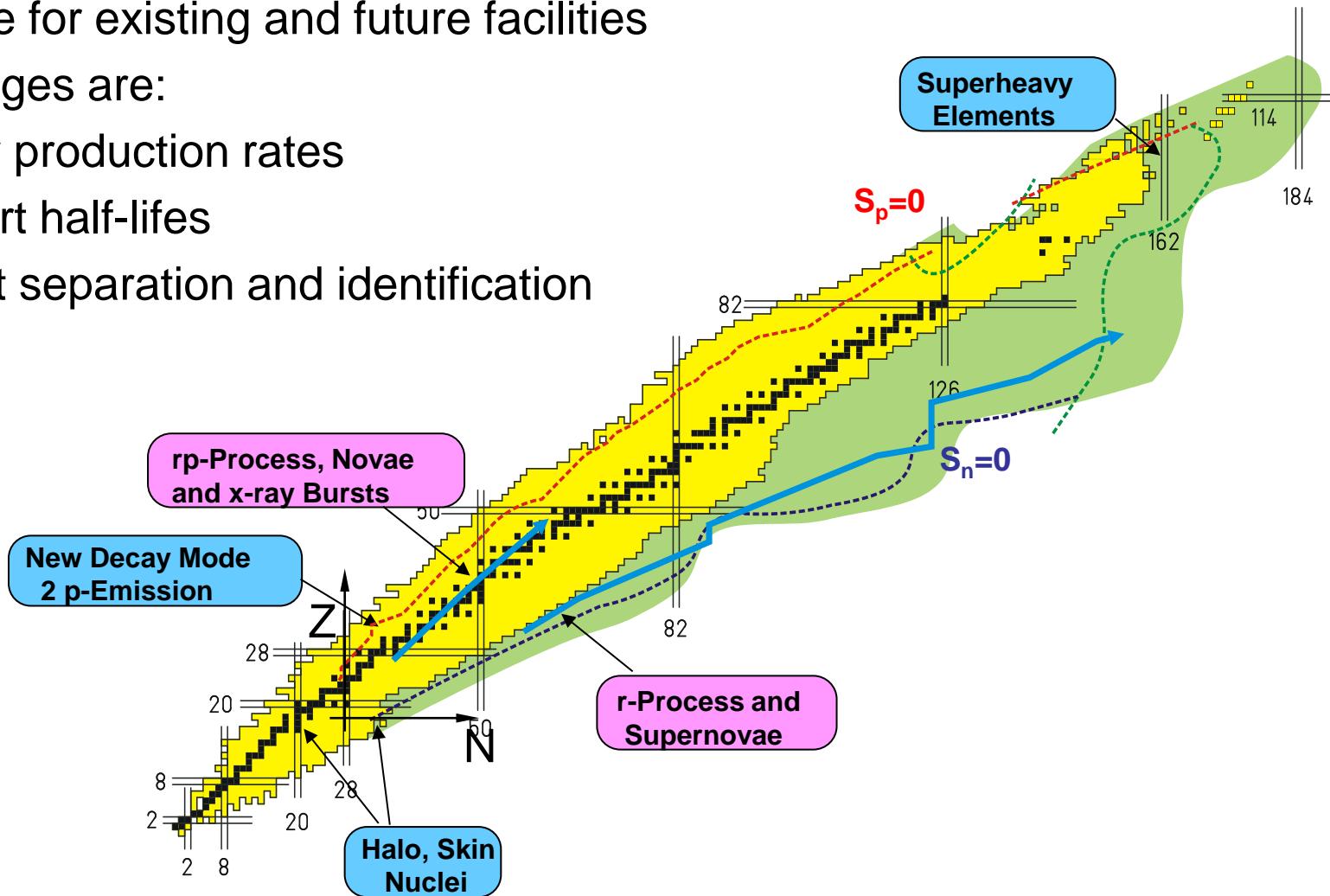
II. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany

Overview

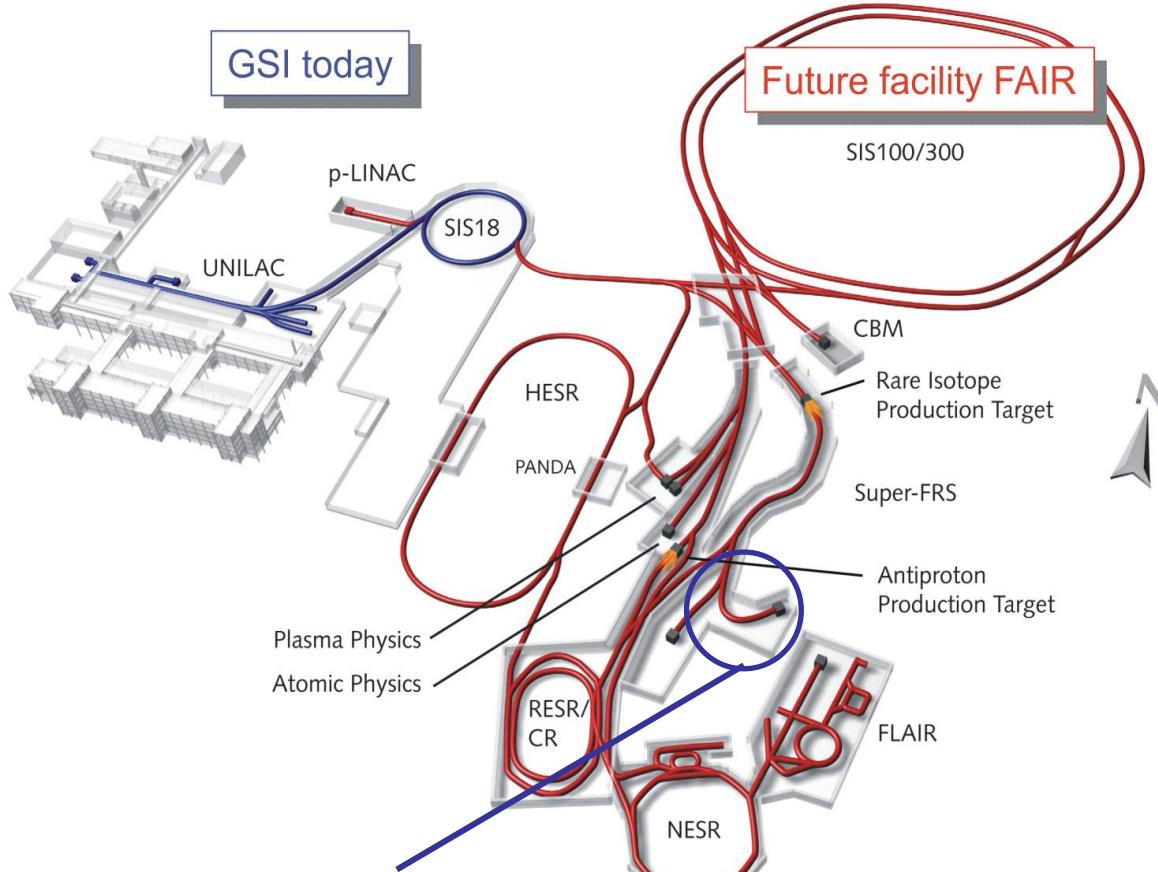
- Motivation: Experiments with Exotic Nuclei
- Setup FRS Ion Catcher
- Experimental Results
- Summary & Outlook

Experiments with Exotic Nuclei

- Exotic nuclei far away from the valley of stability are coming in reachable distance for existing and future facilities
- Challenges are:
 - Low production rates
 - Short half-lifes
 - Fast separation and identification

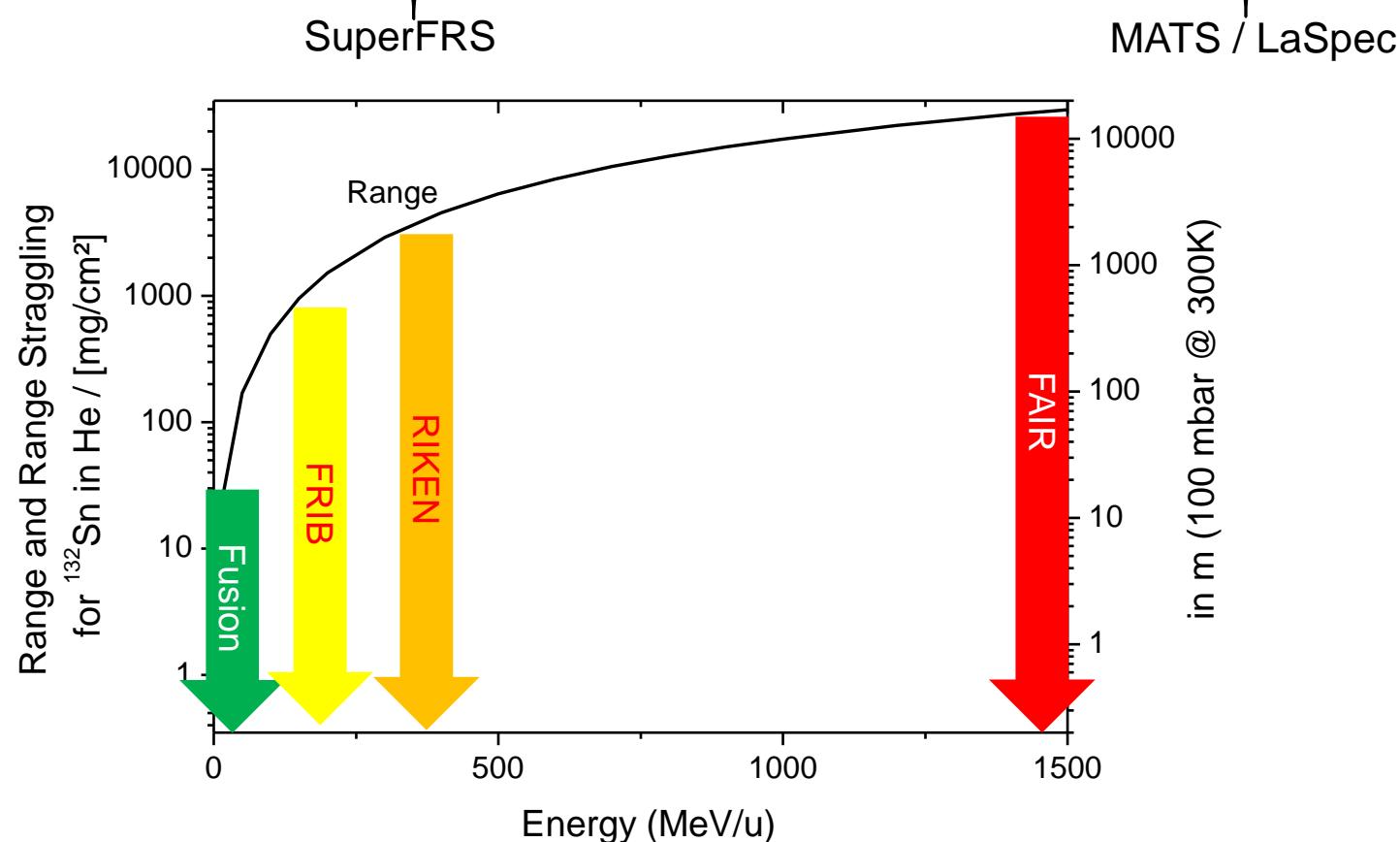
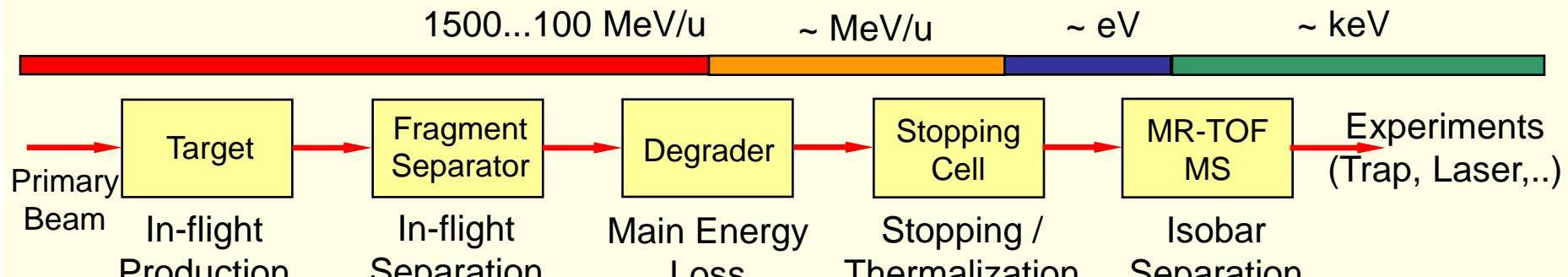


Experiments with Exotic Nuclei

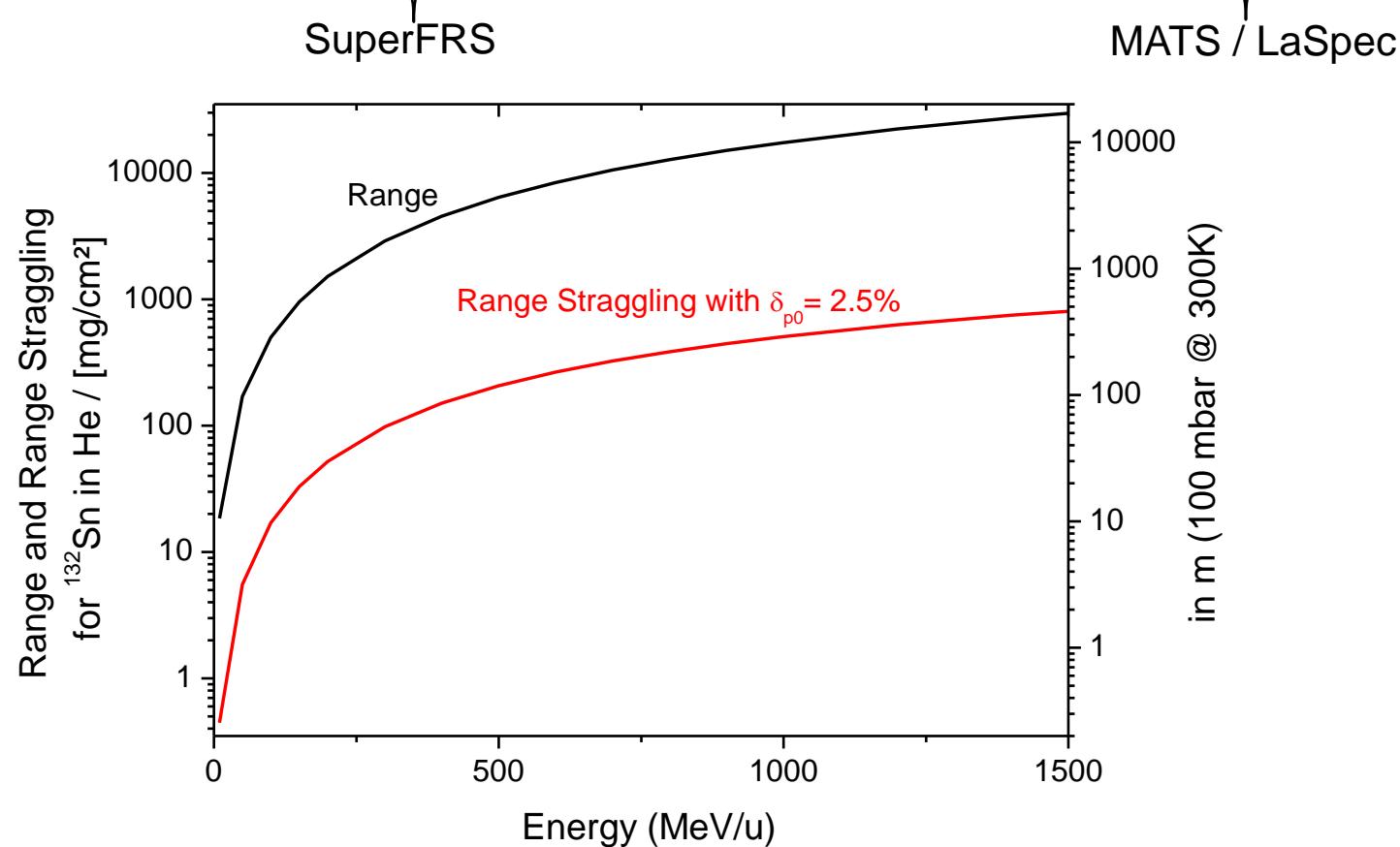
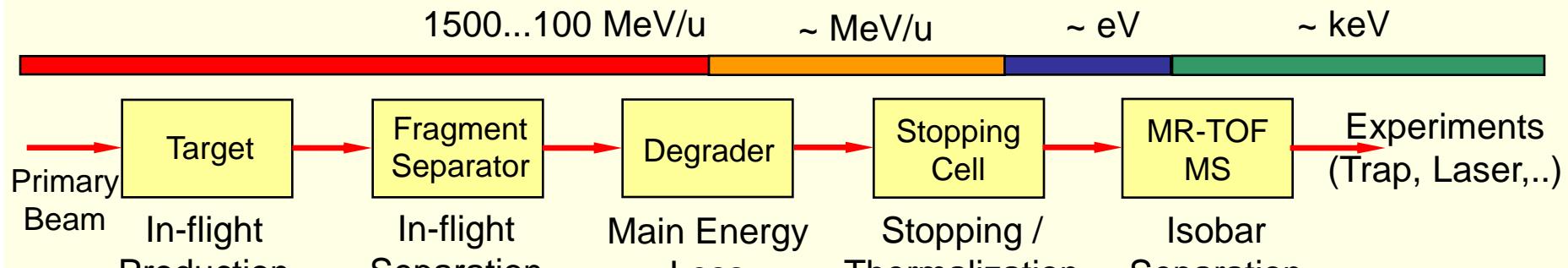


- Experiments at the Low Energy Branch (LEB) at FAIR combine the advantages of in-flight production and established ISOL high precision measurement techniques
 - MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly-charged ions)
 - LaSpec (LAser SPECtroscopy)

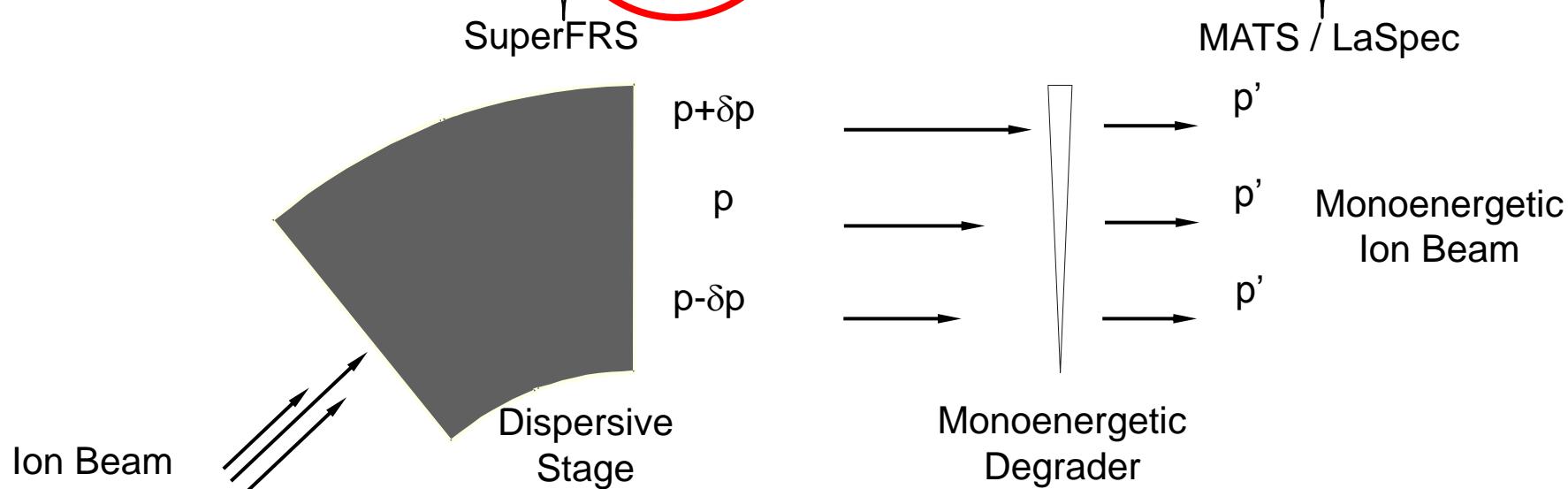
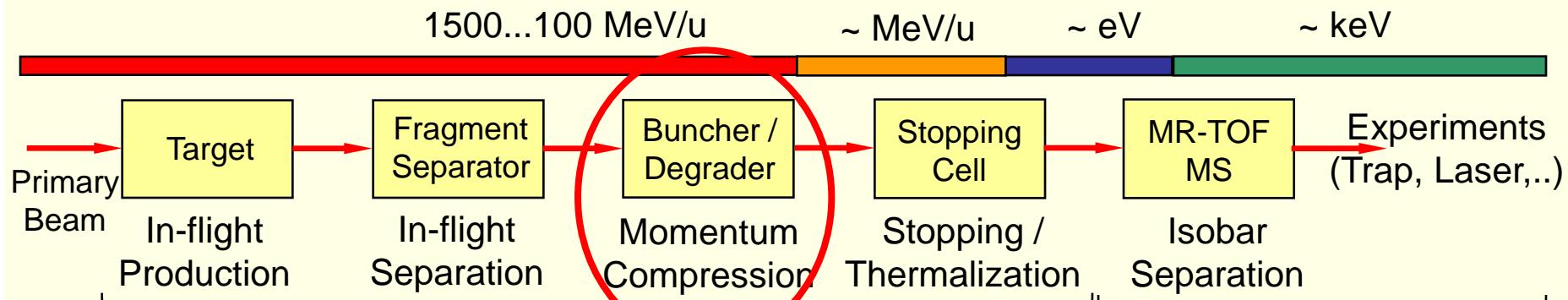
LEB: Challenges



LEB: Challenges



LEB: Momentum Compression



Ion Beam with Different Momenta
 $p+\delta p$, p , $p-\delta p$

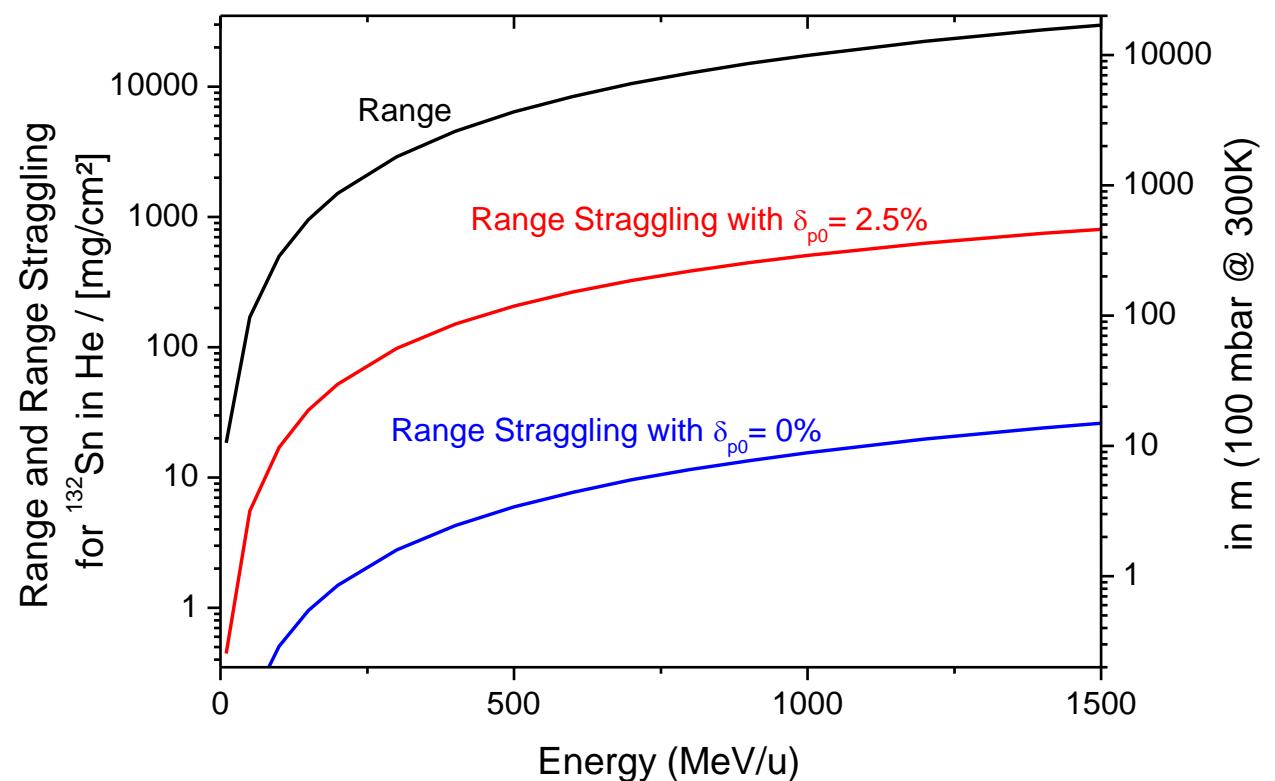
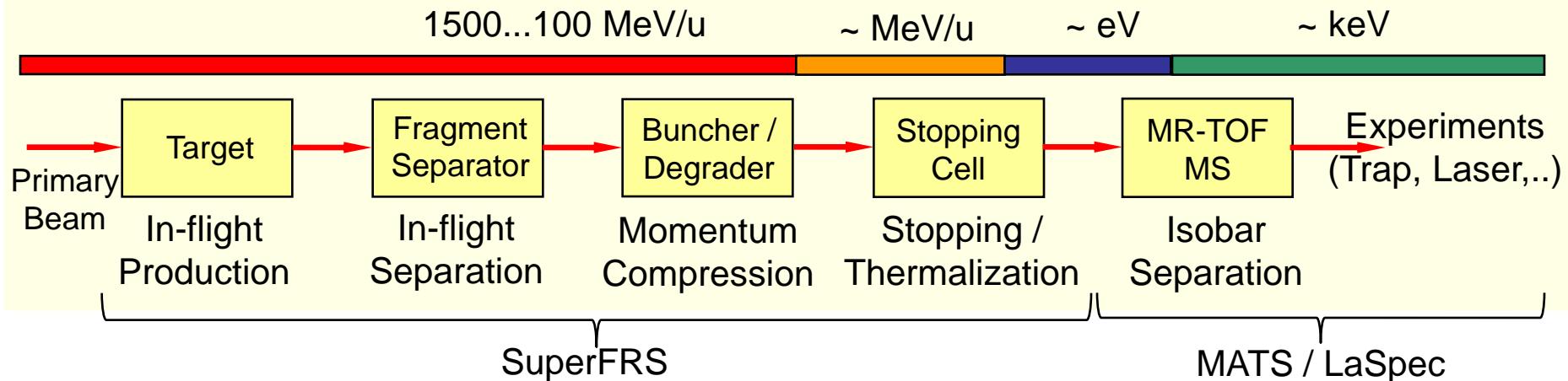
- Ion beam is spatially separated by its momentum in a dispersive stage
- Monoenergetic degrader reduces momentum spread
- Allows stopping in realistic amount of material

H. Geissel et al., NIM A 282 (1989) 247

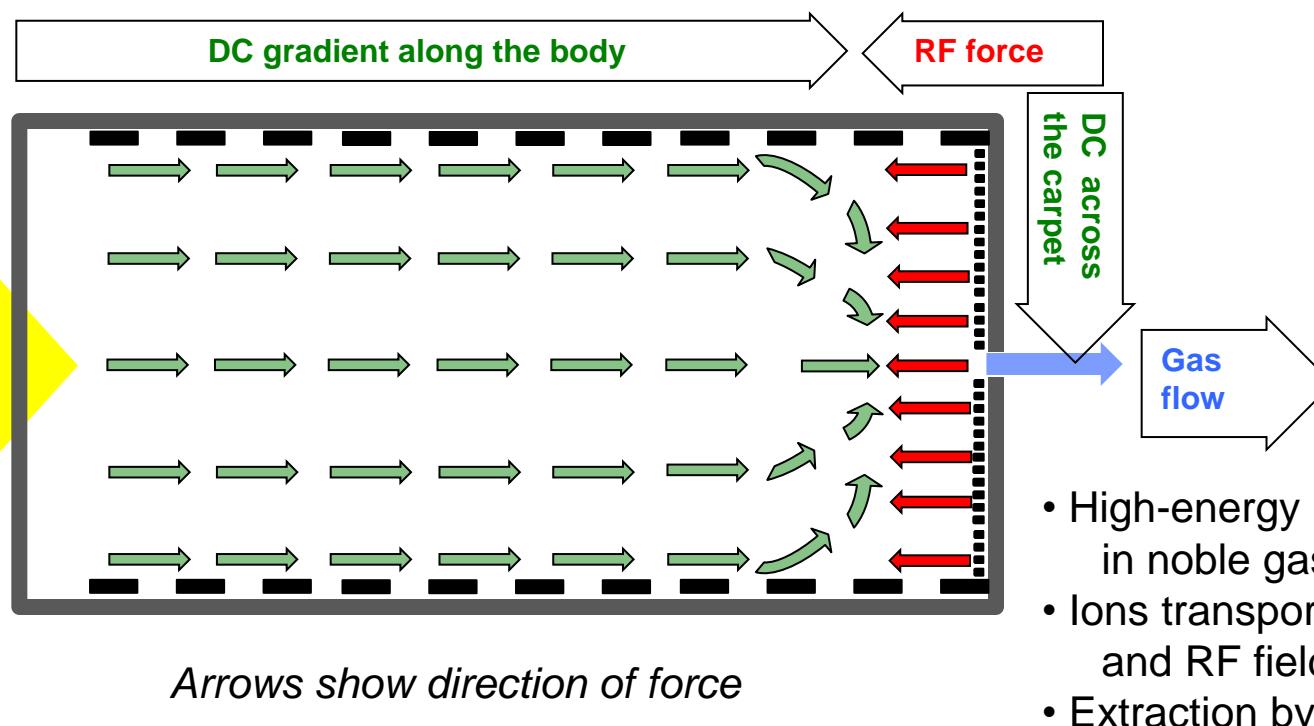
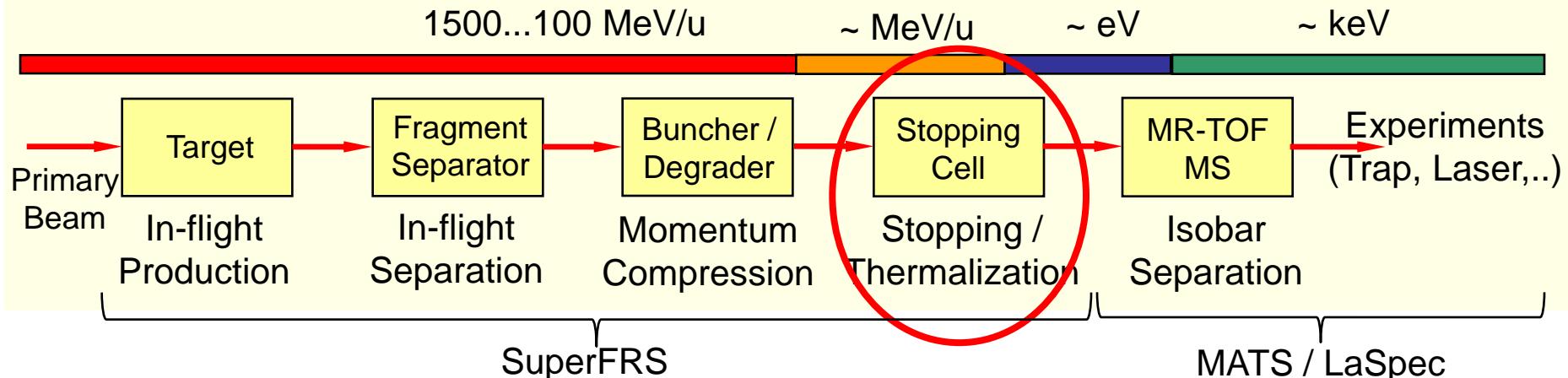
H. Weick et al., NIM B 164 (2000) 168

C. Scheidenberger et al., NIM B 204 (2003) 119

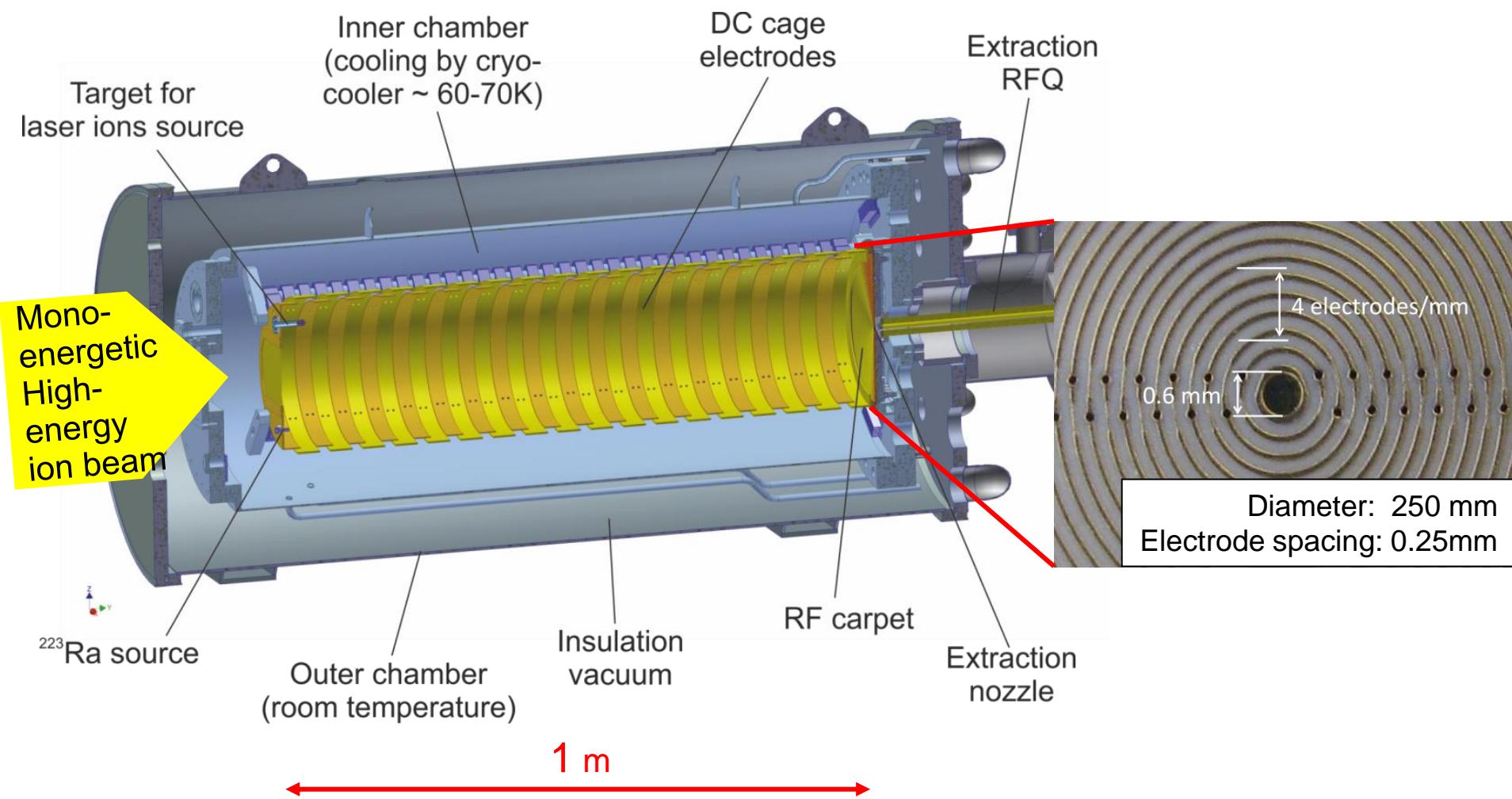
LEB: Challenges



LEB: Stopping and Thermalization



Prototype for the LEB Stopping Cell



M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

W.R. Plaß et al., Nucl. Instrum. Methods B 317 (2013) 457

M. Ranjan et al., Nucl. Instrum. Methods A 770 (2015) 87

Developed in Collaboration

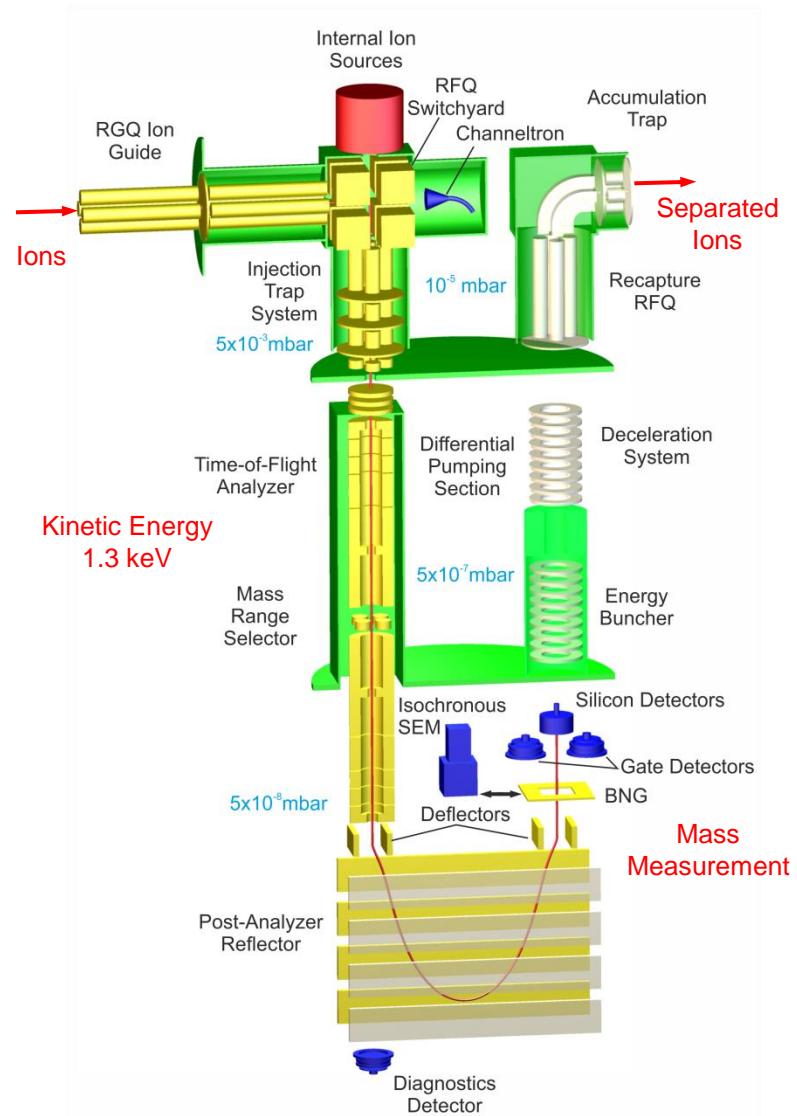
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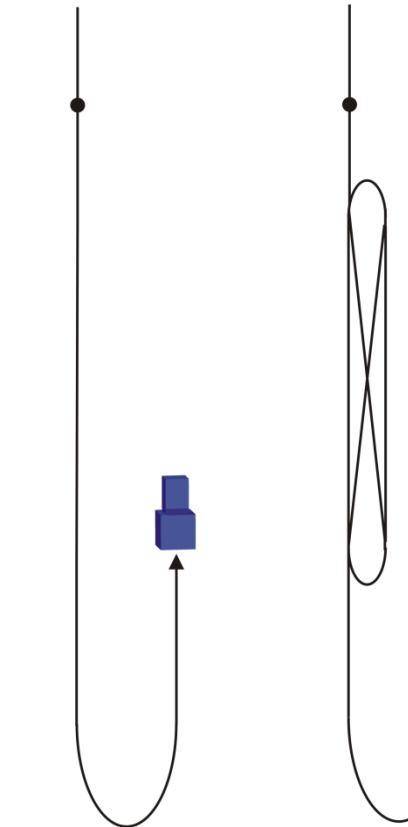
UNIVERSITÄT
GIESSEN

GSI

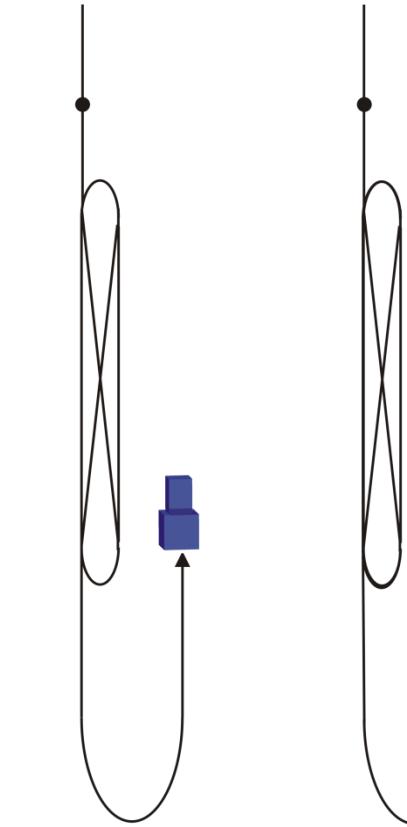
Multiple-Reflection Time-of-Flight Mass Spectrometer



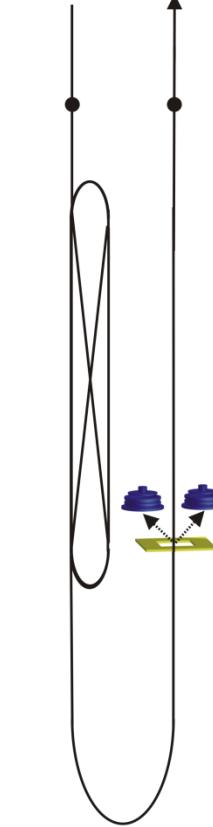
Broadband Mass Measurements



High-Resolution Mass Measurements



High-Resolution Mass Separator



Full Mass Range,
 $m/\Delta m \sim 10^5-10^6$,
 $m/\Delta m \sim 10^3-10^4$

$m/\Delta m > 10^5$
Mass Accuracy $\sim 10^{-6}-10^{-7}$

Performance Characteristics of the MR-TOF-MS

Universal mass spectrometer and mass separator
(works for all elements, stable and unstable ions)

Mass Resolving Power

600,000

Repetition Rate

up to 500 Hz

Mass Measurement Accuracy

down to 10^{-7}

Transmission efficiency

up to 70%

Measurement Duration

2...20 ms

Ion Capacity

$> 10^6$ ions / s

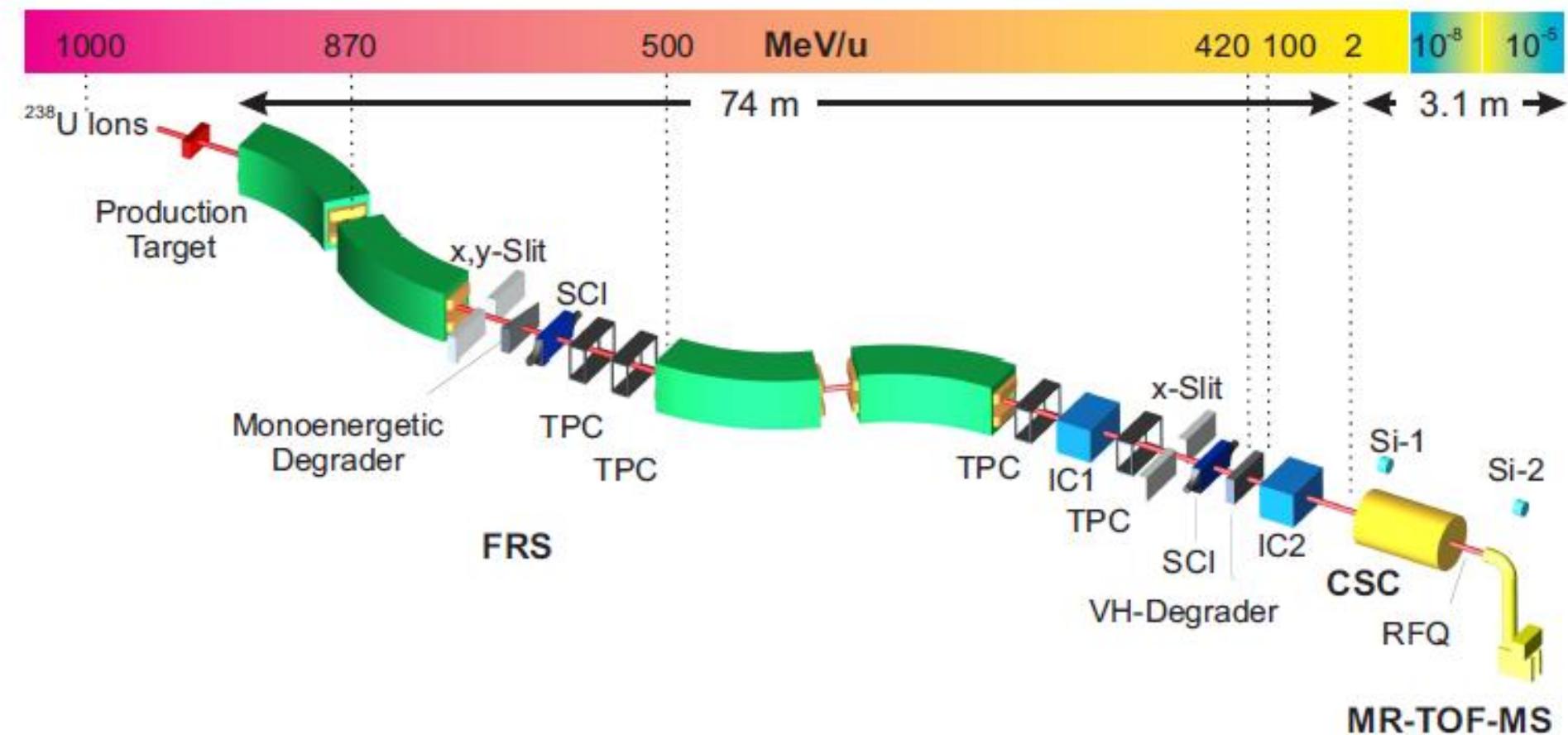
Ions required for mass measurement

~ 10 ions

Dynamic Range

$> 10^4$

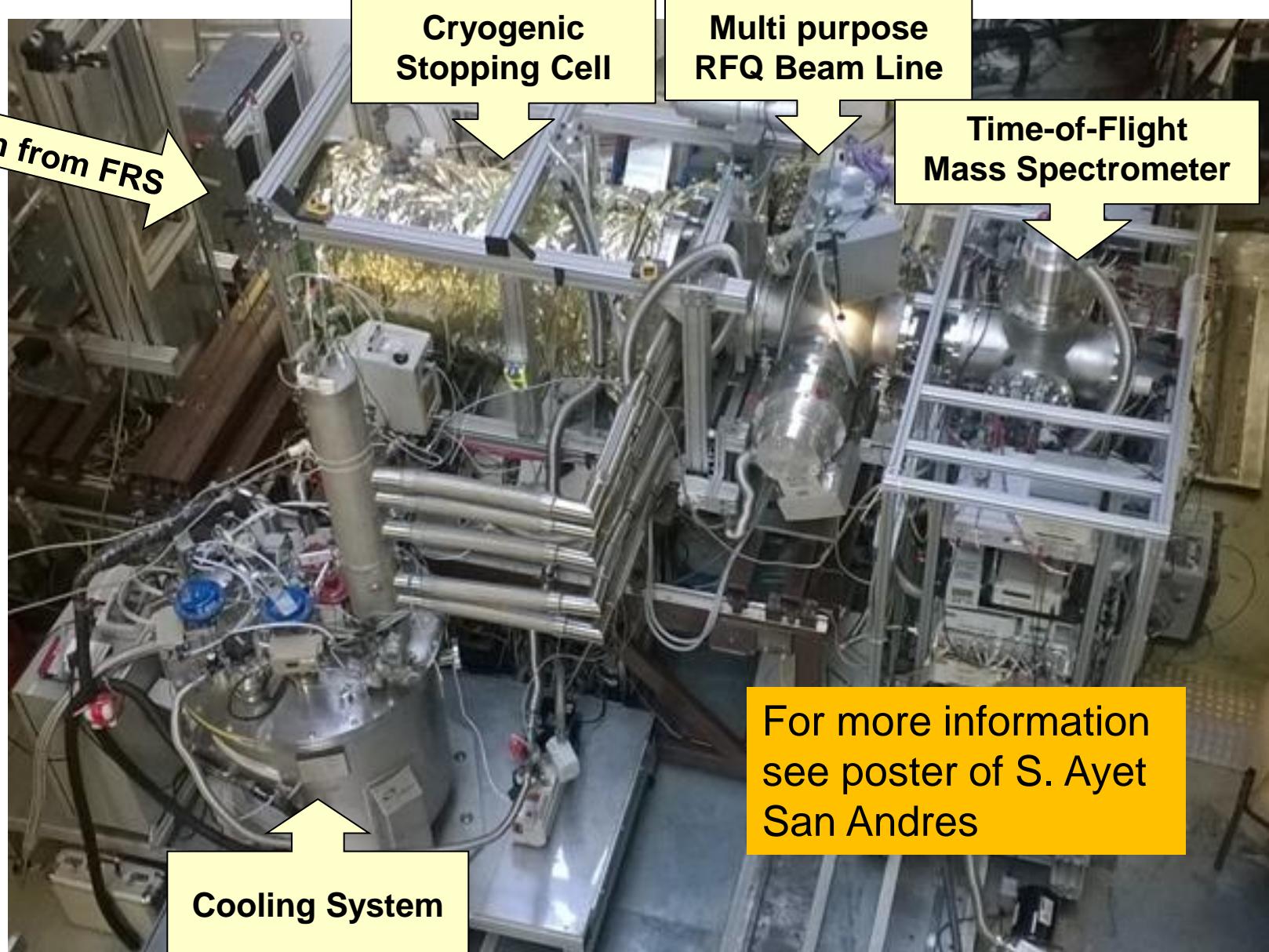
FRS Ion Catcher: A Test Bench for the LEB



W.R. Plaß, et al., Nucl. Instrum. Methods B 317 (2013) 457-462

J. Ebert, Experiments with ^{238}U Projectile and Fission Fragments at the FRS Ion Catcher, EURORIB'15, Hohenroda, Germany, June 7 -12, 2015

Setup FRS Ion Catcher at GSI



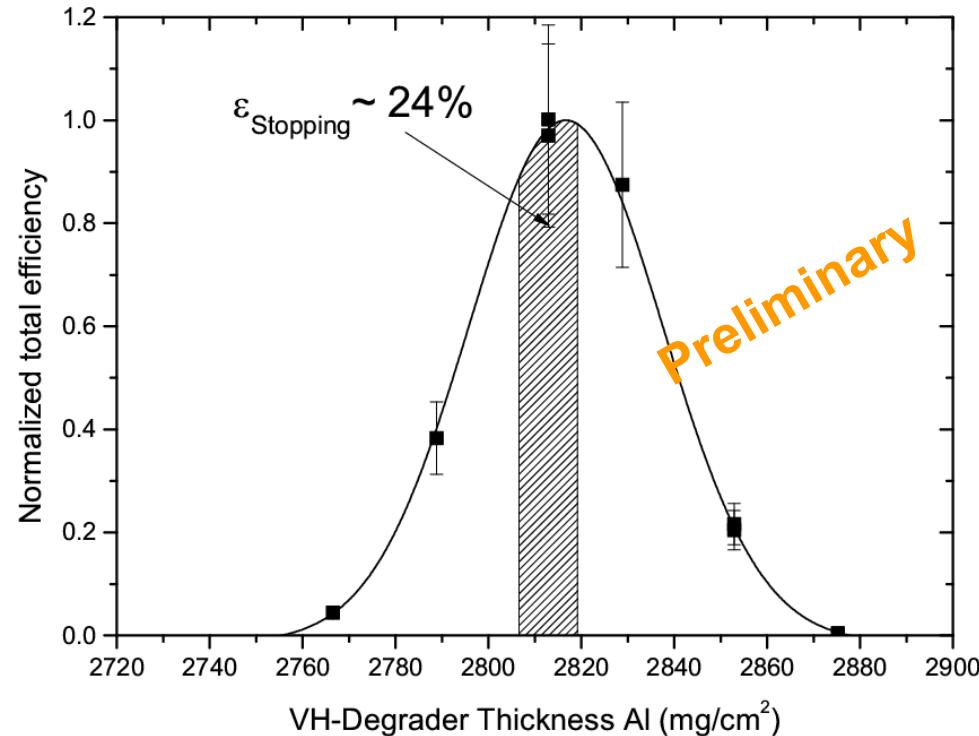
Efficiency of the CSC

- Efficiency measurement

$$\mathcal{E}_{total} = \mathcal{E}_{stopping} \times \mathcal{E}_{extraction}$$

- High areal density of 6.3 mg / cm^2 results in a stopping efficiency of $\sim 20\text{-}30\%$ for relativistic projectile fragments with 1GeV/u
- Ion survival and extraction efficiency e. g. for ^{223}Th : 80 - 100 %)

Total efficiency up to 30%



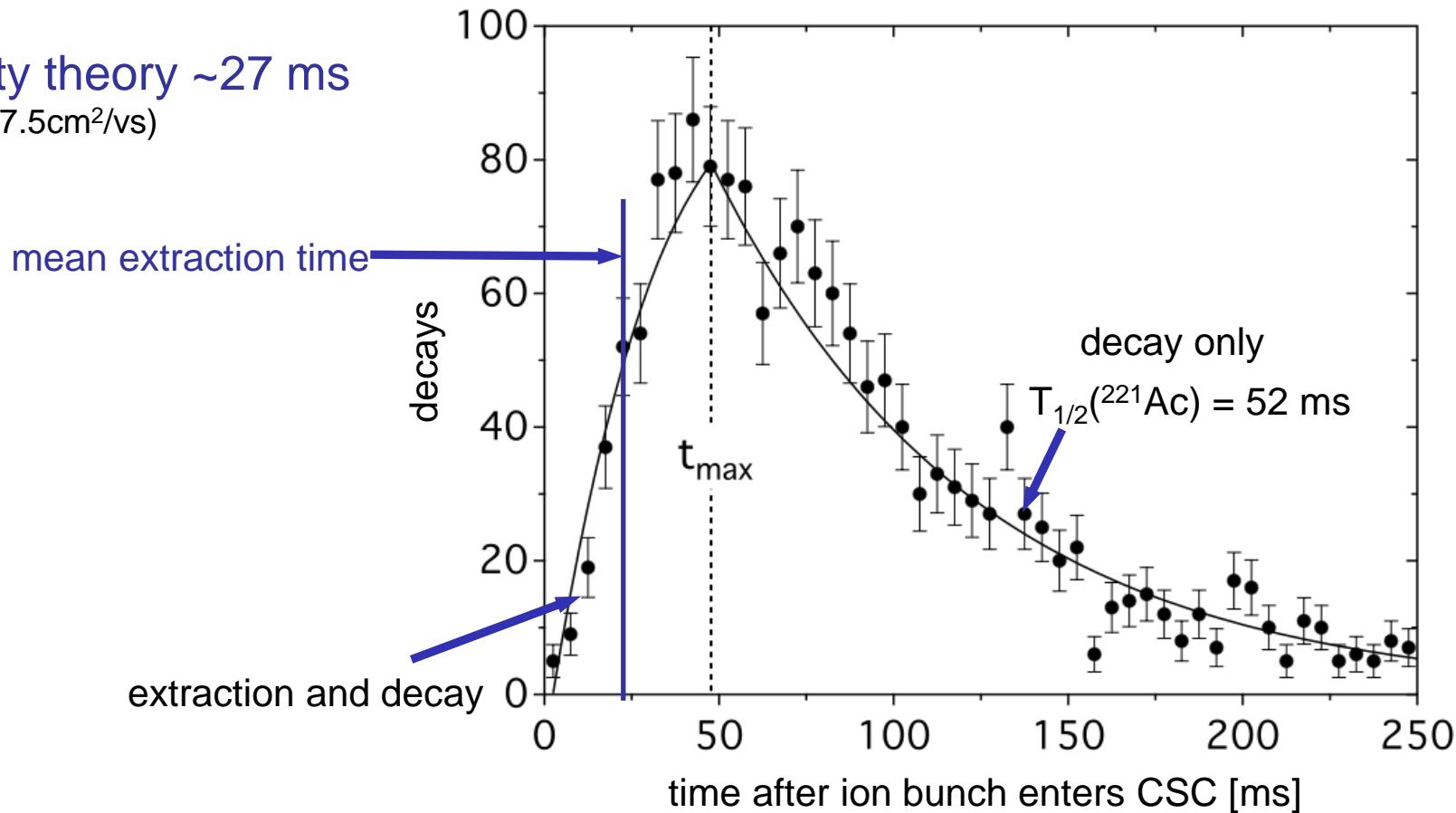
M. P. Reiter et al.

Extraction Time of the CSC

- Meassurment of extraction time with short spills (spill length 4-6 ms)
 - Projectile fragment ^{221}Ac
 - Pressure = 49 mbar @ 74.5 K

Mean extraction time ~ 24 ms

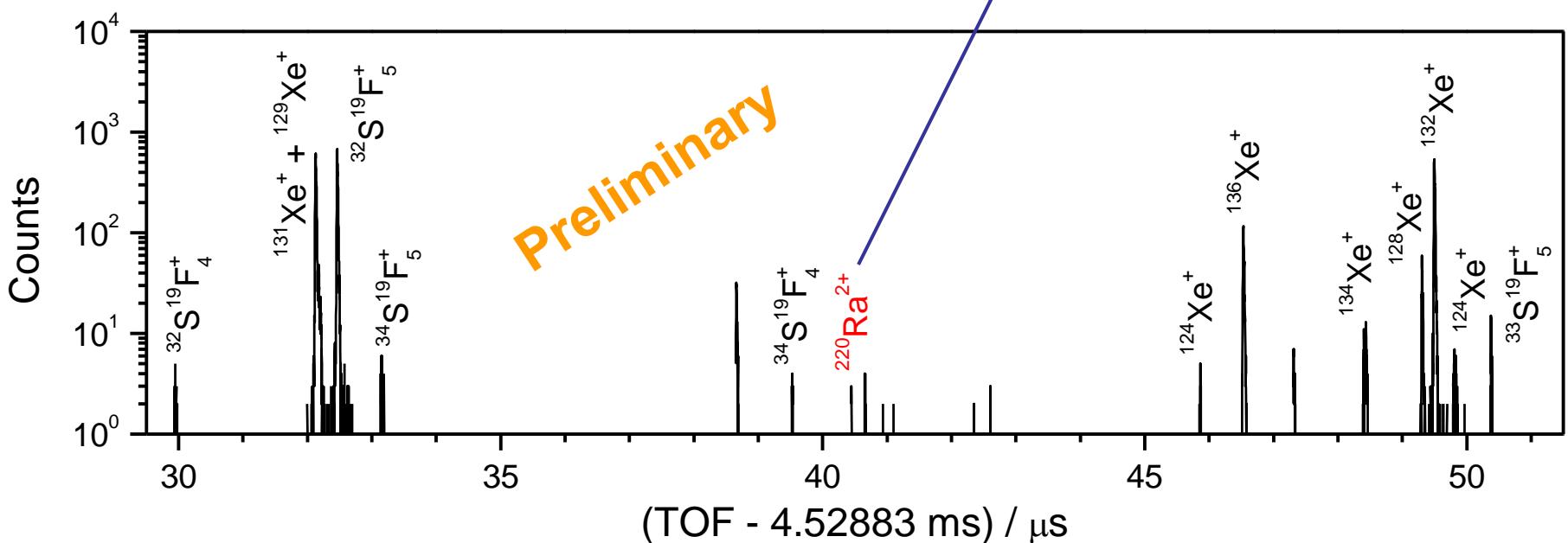
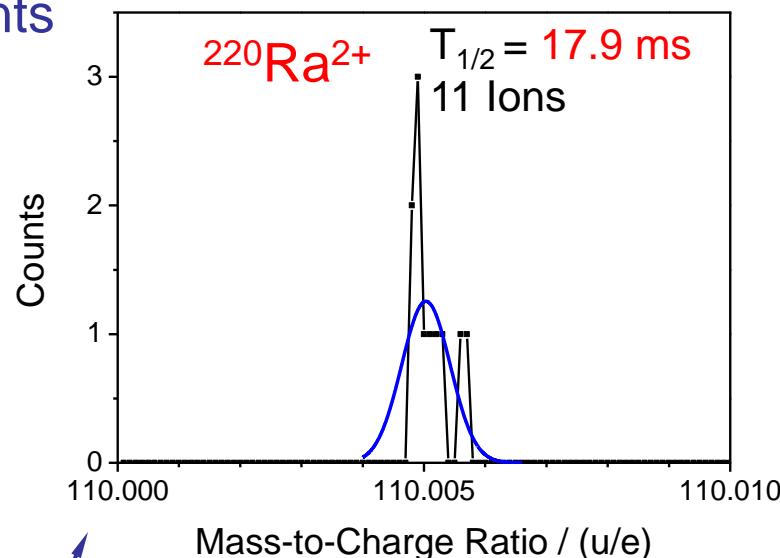
Mobility theory ~ 27 ms
($K_0=17.5\text{cm}^2/\text{vs}$)



Mass Measurements: Uranium Projectile Fragments

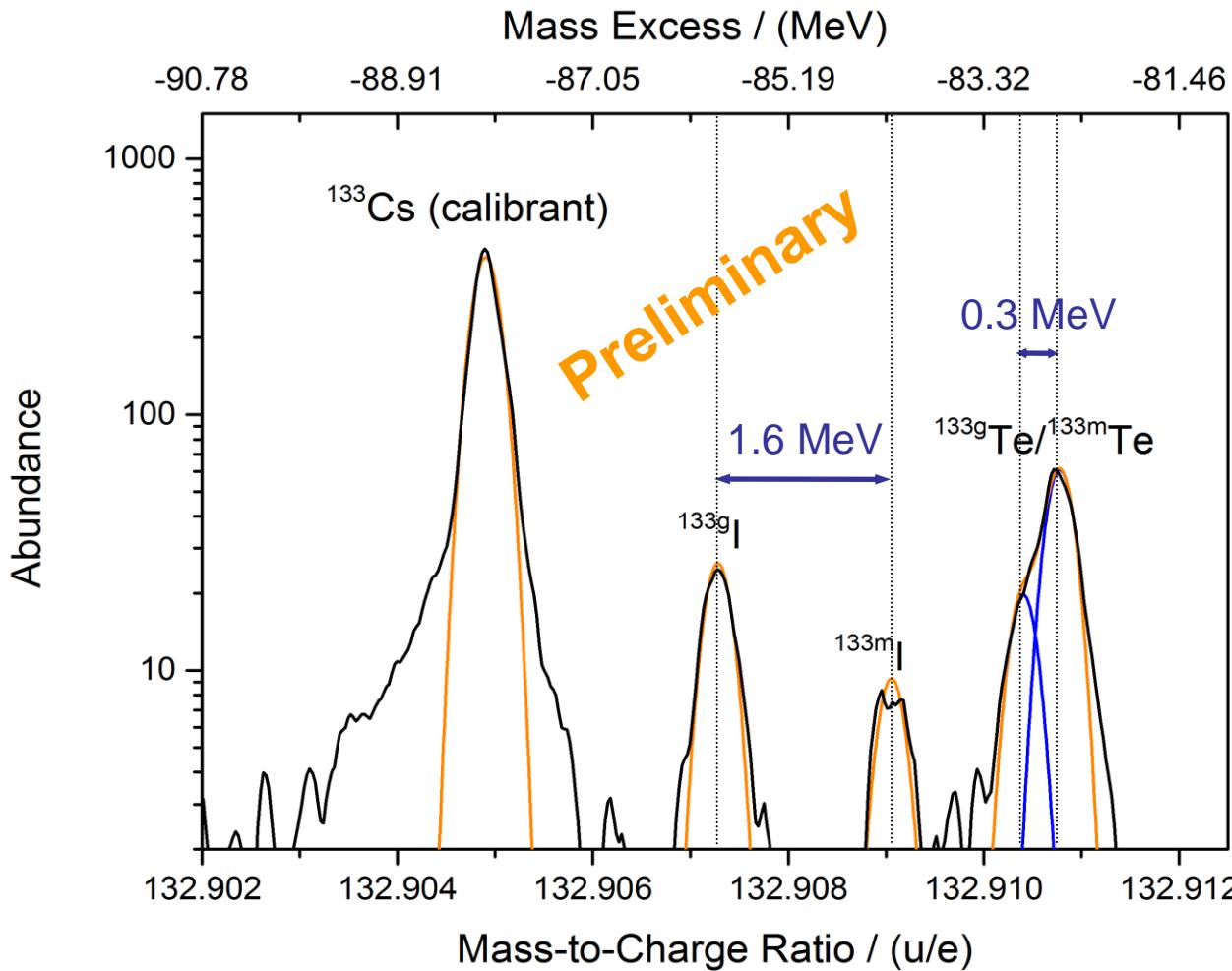
- Mass measurement of ^{238}U projectile fragments produced at 1000 MeV/u

- Mass window of ~ 30 amu
- Doubly charged ion
- Mass resolving power (FWHM)
 ~ 120000
- Access to ms half-lives
- Very high sensitivity



Mass Measurements: Uranium Fission Products

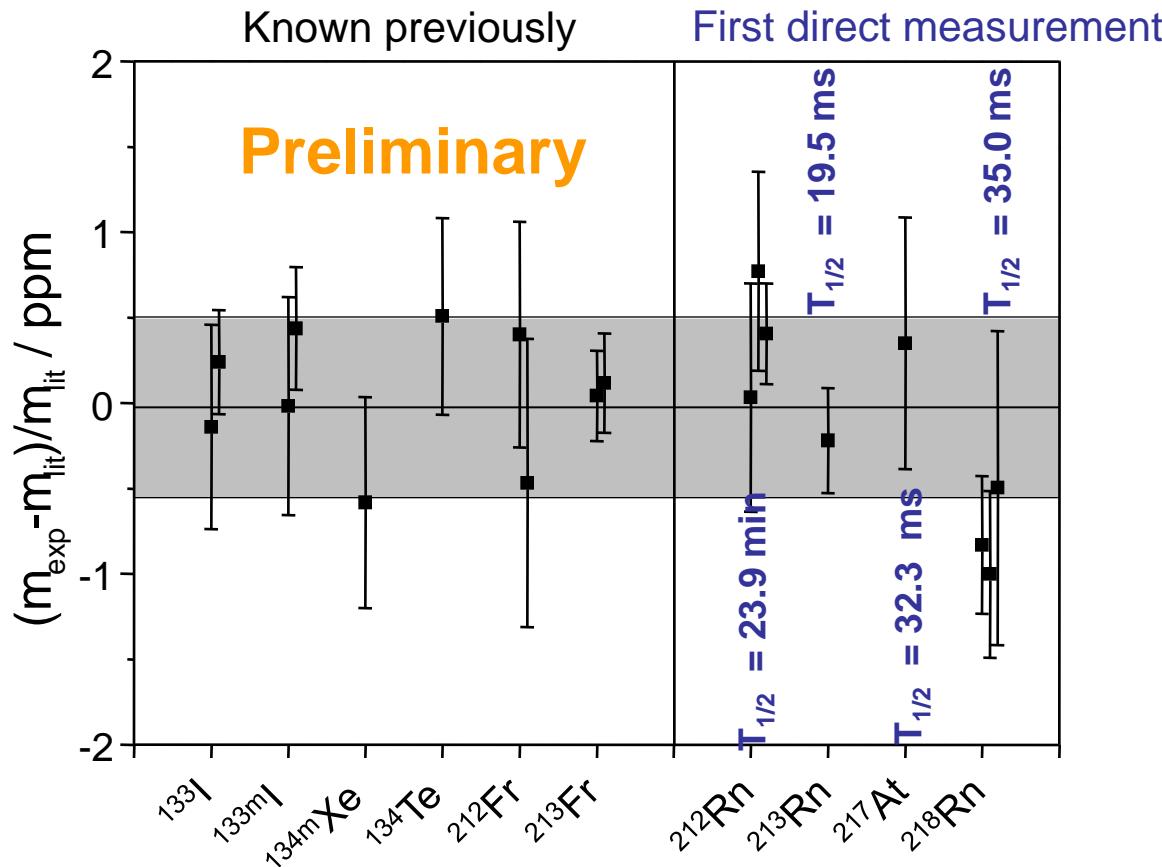
- Mass measurement of ^{238}U fission products produced at 1000 MeV/u
 - Mass resolving power (FWHM) ~ 360000
 - Identification of low-lying isomers



S. Ayet et al.

Results: Mass Measurement Accuracy

First results (here: same-turn number, non-overlapping peaks)



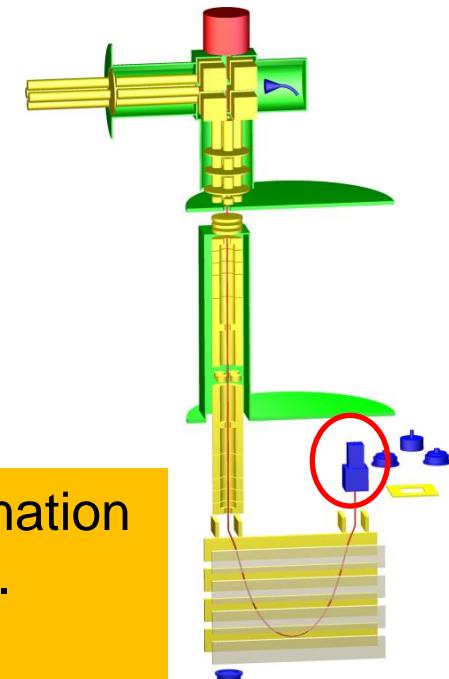
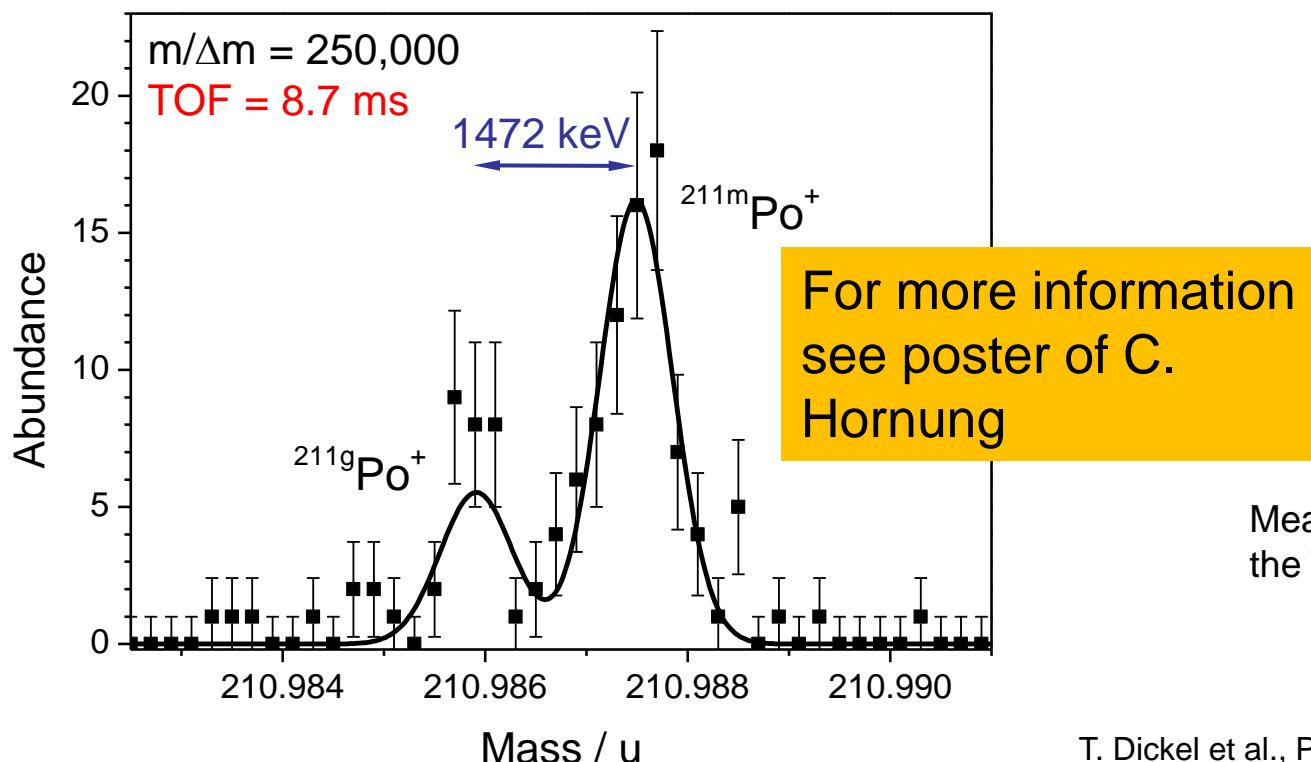
Mean deviation from literature: $-0.03 \text{ ppm} \pm 6 \text{ keV}$ @ mass 213 amu

Mean uncertainty: $0.5 \text{ ppm} \pm 100 \text{ keV}$ @ mass 213 amu

Residual systematic uncertainty: $0.2 \text{ ppm} \pm 40 \text{ keV}$ @ mass 213 amu

Measurement and Separation of Isomers

- First measurement of isomer-to-ground state ration
 - Identification of ^{211}gPo and ^{211}mPo by using PID detectors in the FRS, by alpha decay on Si detector and by mass spectrometry
 - Measurement of excitation energy:
 (1472 ± 120) keV Lit.: (1462 ± 5) keV
 - Measured ratio: (2.5 ± 0.8)



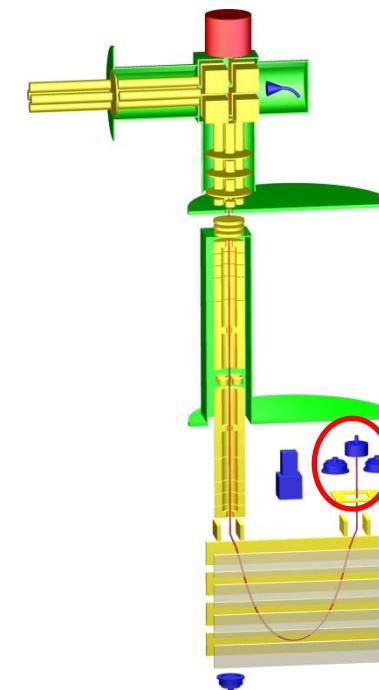
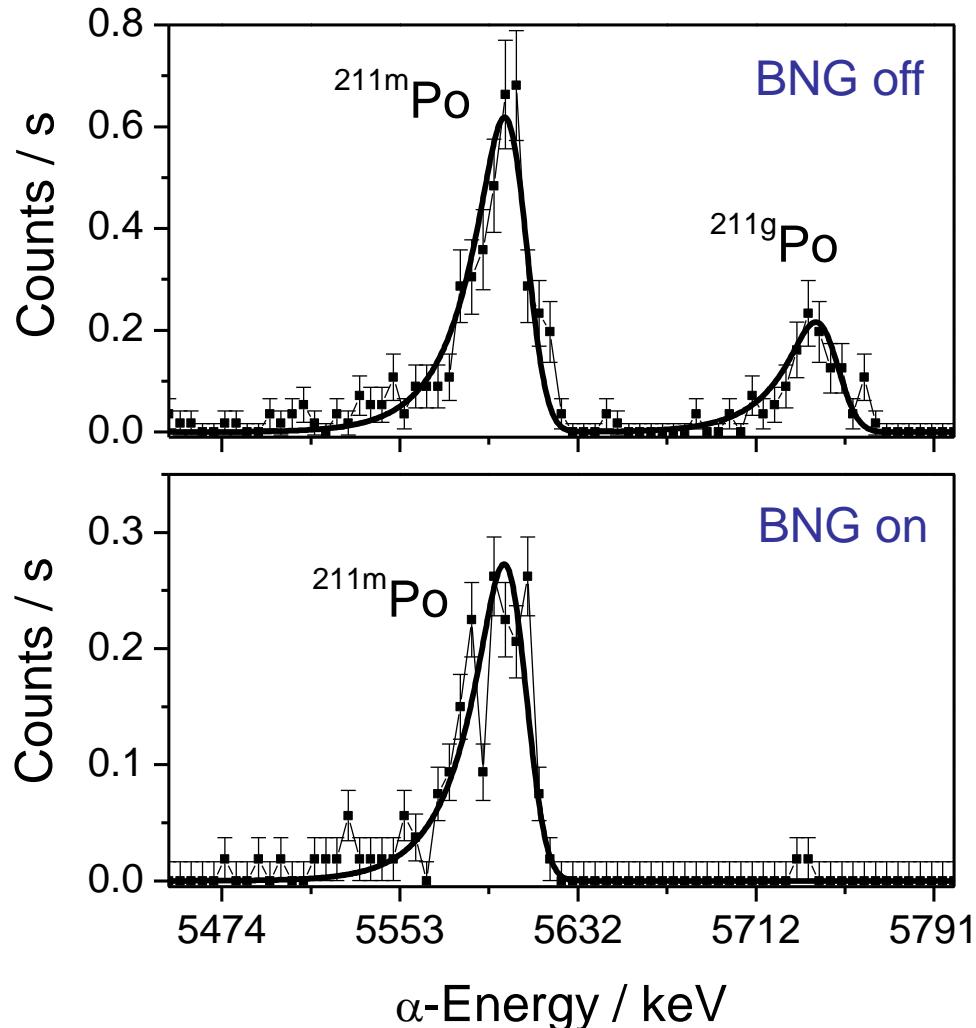
Measurement using
the TOF detector

T. Dickel et al., Phys. Lett. B 744 (2015) 137

Measurement and Separation of Isomers

First spatial separation of ground state and isomeric state in a MR-TOF-MS

- Proof-of-principle: production of isomerically clean beams by MR-TOF-MS
- MR-TOF-MS suitable to measure Isomers



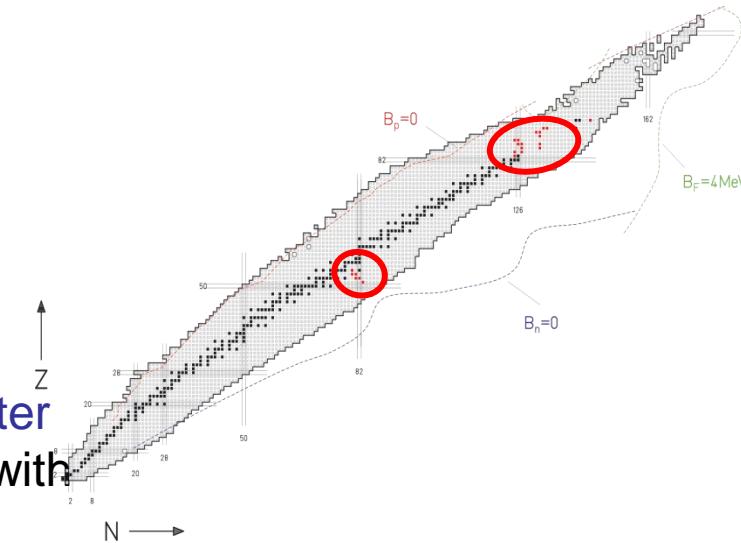
Separation using the
Bradbury-Nielsen gate,
measurement using
the Si detector

T. Dickel et al., Phys. Lett. B 744 (2015) 137

Summary & Outlook

Summary

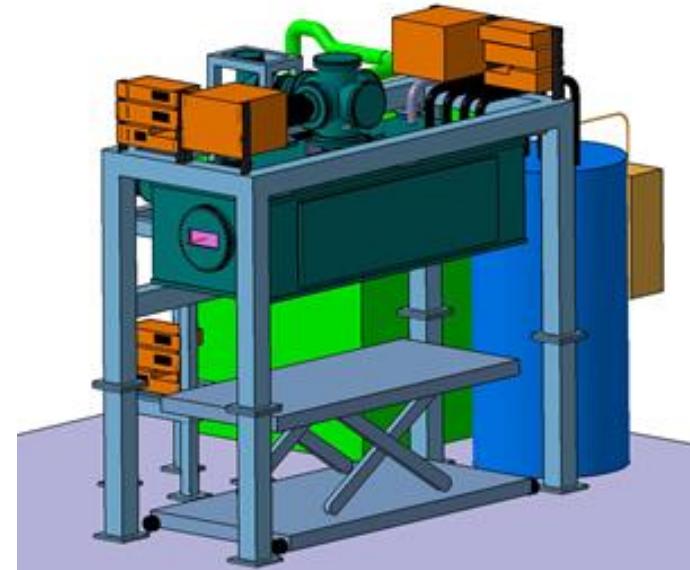
- Cryogenic Stopping Cell
 - Total efficiency up to 30%
 - Mean extraction time ~ 24 ms
- Multiple-Reflection Time-of-Flight Mass Spectrometer
 - Mass measurement of short-lived nuclides with mass accuracy of 0.5 ppm
 - Isotope with half-life of only 17.9 ms measured
 - First spatial separation of ground state and isomeric state in a MR-TOF-MS



Outlook

Conceptual design of the final cryogenic stopping cell for the LEB

- x5 higher areal density
- x5 faster extraction
- Higher intensity capabilities $\sim 10^7$ U/s



Acknowledgements

FRS Ion Catcher / S411 Collaboration

F. Amjad², S. Ayet², J. Bergmann¹, P. Dendooven³, T. Dickel^{1,2}, M. Diwisch¹, J. Ebert¹, A. Estrade², F. Farinon², H. Geissel^{1,2}, F. Greiner¹, E. Haettner², F. Heiße², C. Hornung¹, C. Jesch¹, N. Kalantar-Nayestanaki³, R. Knöbel², J. Kurcewicz², J. Lang¹, W. Lippert¹, I. Miskun², I. Moore⁴, I. Mukha², C. Nociforo², M. Petrick¹, M. Pfuetzner², S. Pietri², A. Pikhtelev⁵, W.R. Plaß^{1,2}, I. Pohjalainen⁴, A. Prochazka², S. Purushothaman², M. Ranjan³, M.P. Reiter¹, A.-K. Rink¹, S. Rinta-Antila⁴, C. Scheidenberger², M. Takechi², Y. Tanaka², H. Weick², J.S. Winfield², X. Xu^{1,2}, M.I. Yavor⁶

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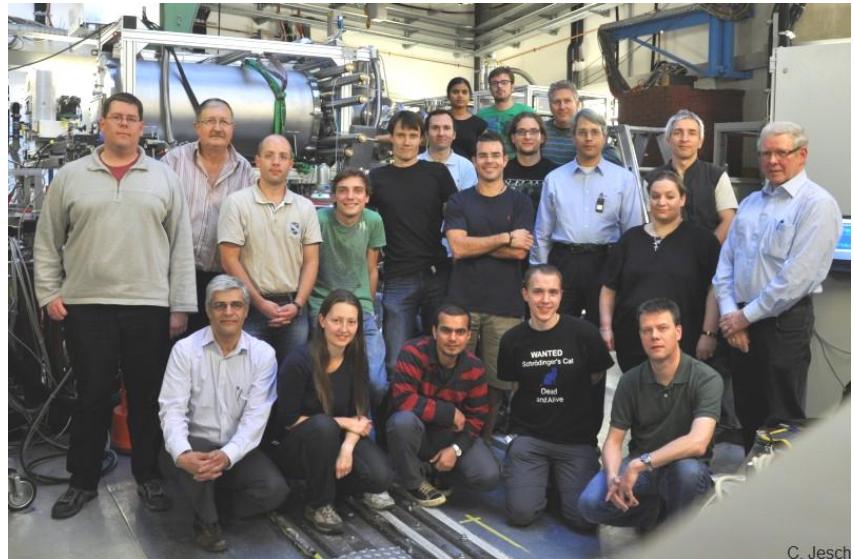
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Funding:

BMBF (05P12RGFN8), State of Hesse (HMWK) (LOEWE focus AmbiProbe, LOEWE Center HICforFAIR), HGS-HIRe, JLU Giessen and GSI (JLU-GSI strategic Helmholtz partnership agreement)



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