FRS Ion Catcher:
First Results and Future Perspectives

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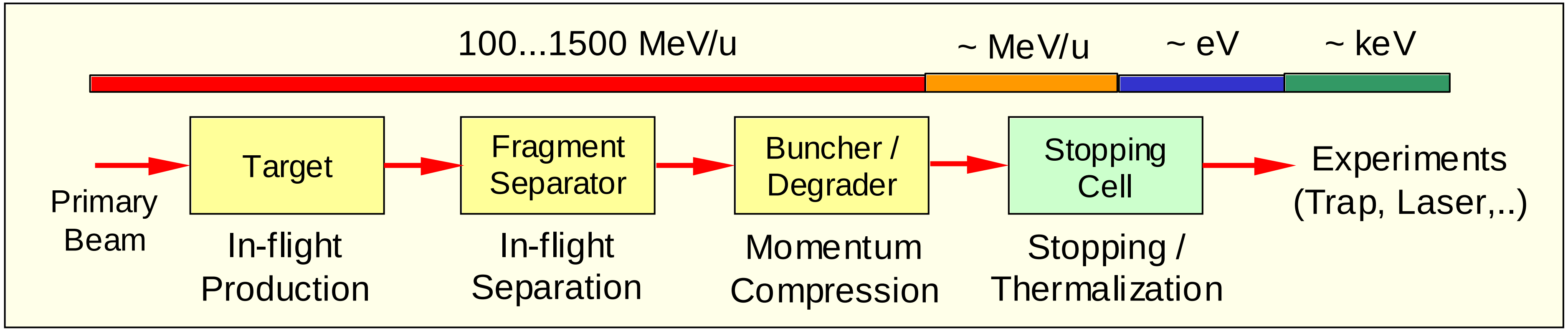
Overview

- Motivation
- Cryogenic Stopping Cell for the Super-FRS at FAIR
- Multiple-Reflection Time-of-Flight Mass Spectrometer
- On-line Commissioning at the FRS Ion Catcher at GSI
- Conclusions

Motivation: Low Energy Branch of the Super-FRS

LEB: High-precision experiments with in-flight separated exotic nuclei almost at rest, (production by projectile fragmentation / fission)

- universal and fast production
- high selectivity
- cooled exotic nuclei



Eur. Phys. J. Special Topics 183 (2010) 1

MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

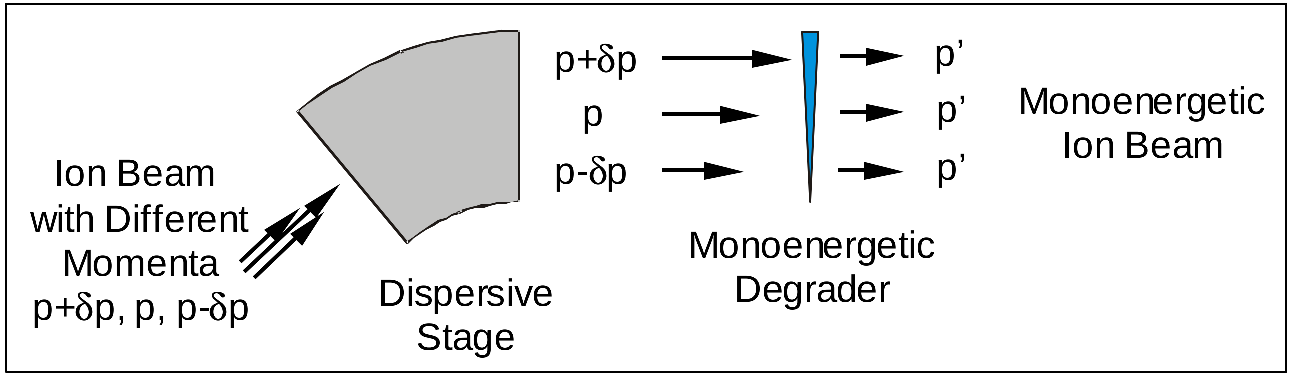
- High accuracy mass measurements
- In-trap conversion electron and alpha spectroscopy
- Trap assisted spectroscopy

LaSpec (Laser Spectroscopy)

- Collinear laser spectroscopy of ions and atoms
- β-NMR
- Resonance ionization spectroscopy

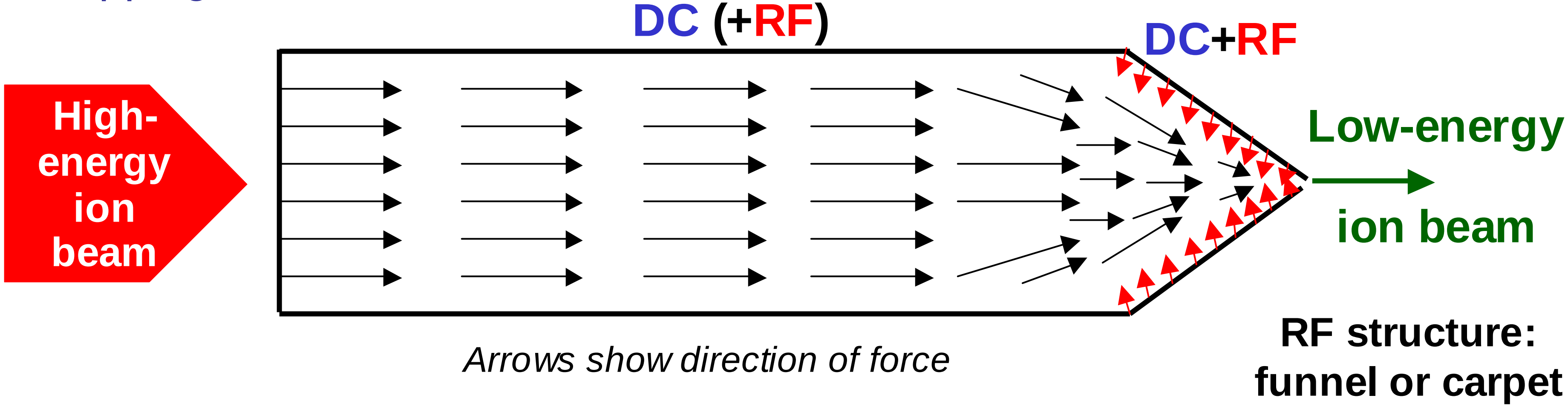
Stopping Cell Principles

Range Bunching



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

Stopping Cell



- High-energy ions stopped in noble gas
- Stopped ions transported using DC and RF fields to exit-hole
- Extraction by gas flow

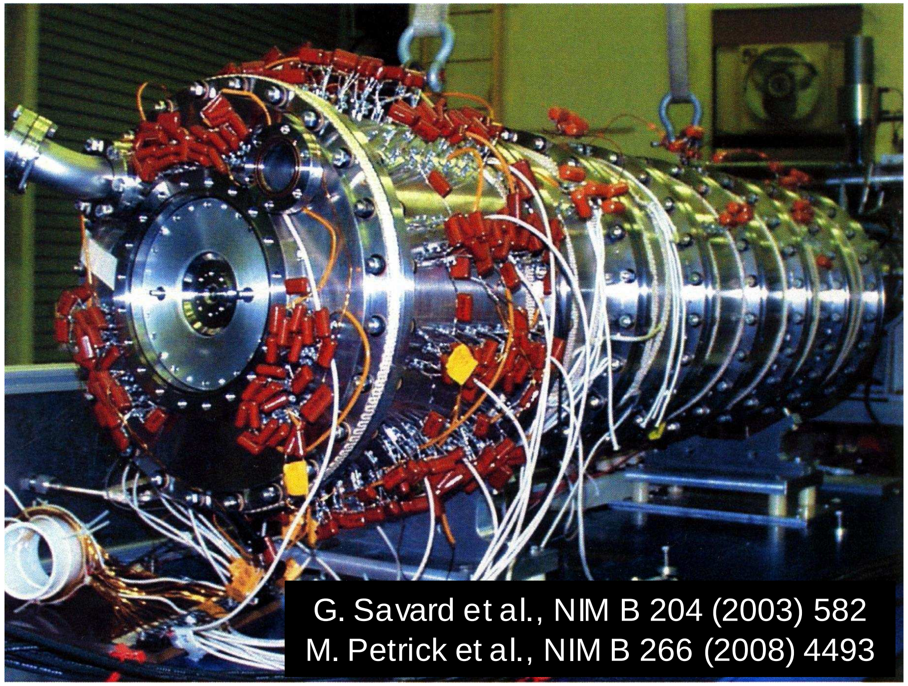
Stopping Cell for Relativistic Exotic Nuclei

First Generation Stopping Cell (S258)

Successful proof-of-principle

Suffered from:

1. Poor stopping efficiency
2. Presence of impurities

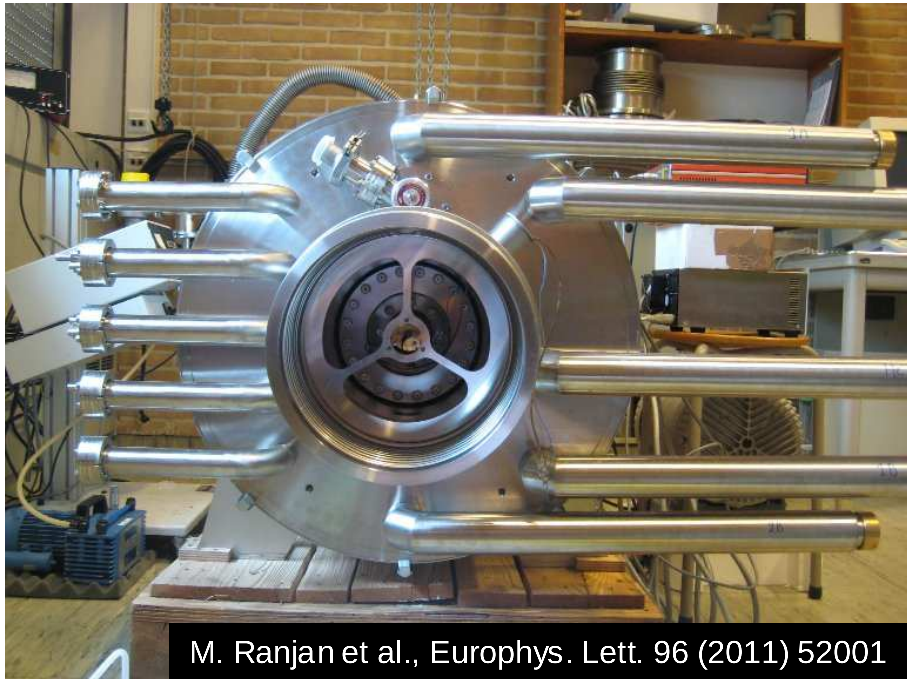


G. Savard et al., NIM B 204 (2003) 582
M. Petrick et al., NIM B 266 (2008) 4493

Second Generation Stopping Cell (S411)

Solutions now implemented:

1. High-density operation
2. Cryogenic operation



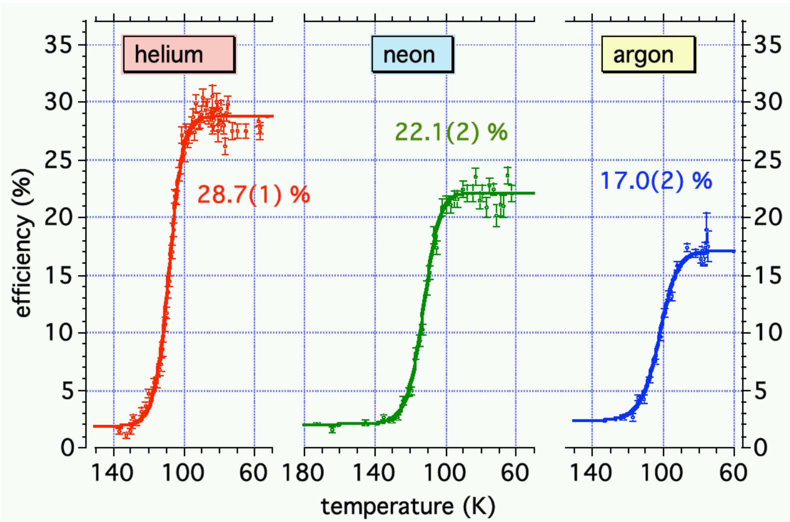
M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

Stopping Cell: Cryogenic Operation

New concept: Operate He-filled stopping cell at cryogenic temperature (~70 K)

Advantages

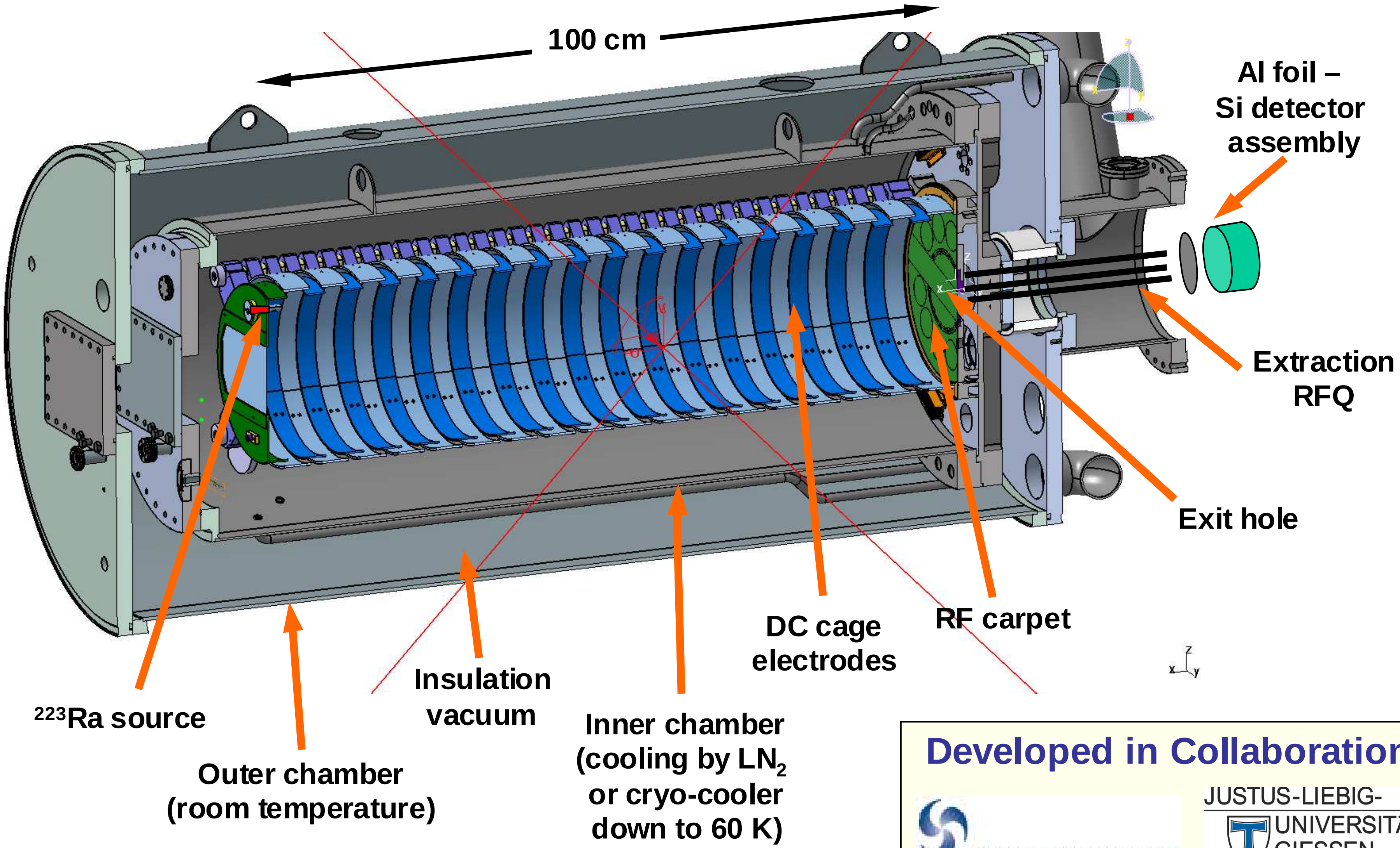
- Ultra-pure helium (freezing-out of contaminants)
  - Ideal for ion survival
  - No formation of molecules/adducts
- Reduced radial ion diffusion
- 2+ charge state (?) $\rightarrow$ shorter extraction times
- Reduced requirements for cleanliness $\rightarrow$ easier, more flexible construction
- Operational reliability



Transport efficiency of α-decay recoil ions in a closed gas cell

P. Dendooven et al., NIM A 558 (2006) 580
S. Purushothaman et al., NIM B 266 (2008) 4488

Cryogenic Stopping Cell Design

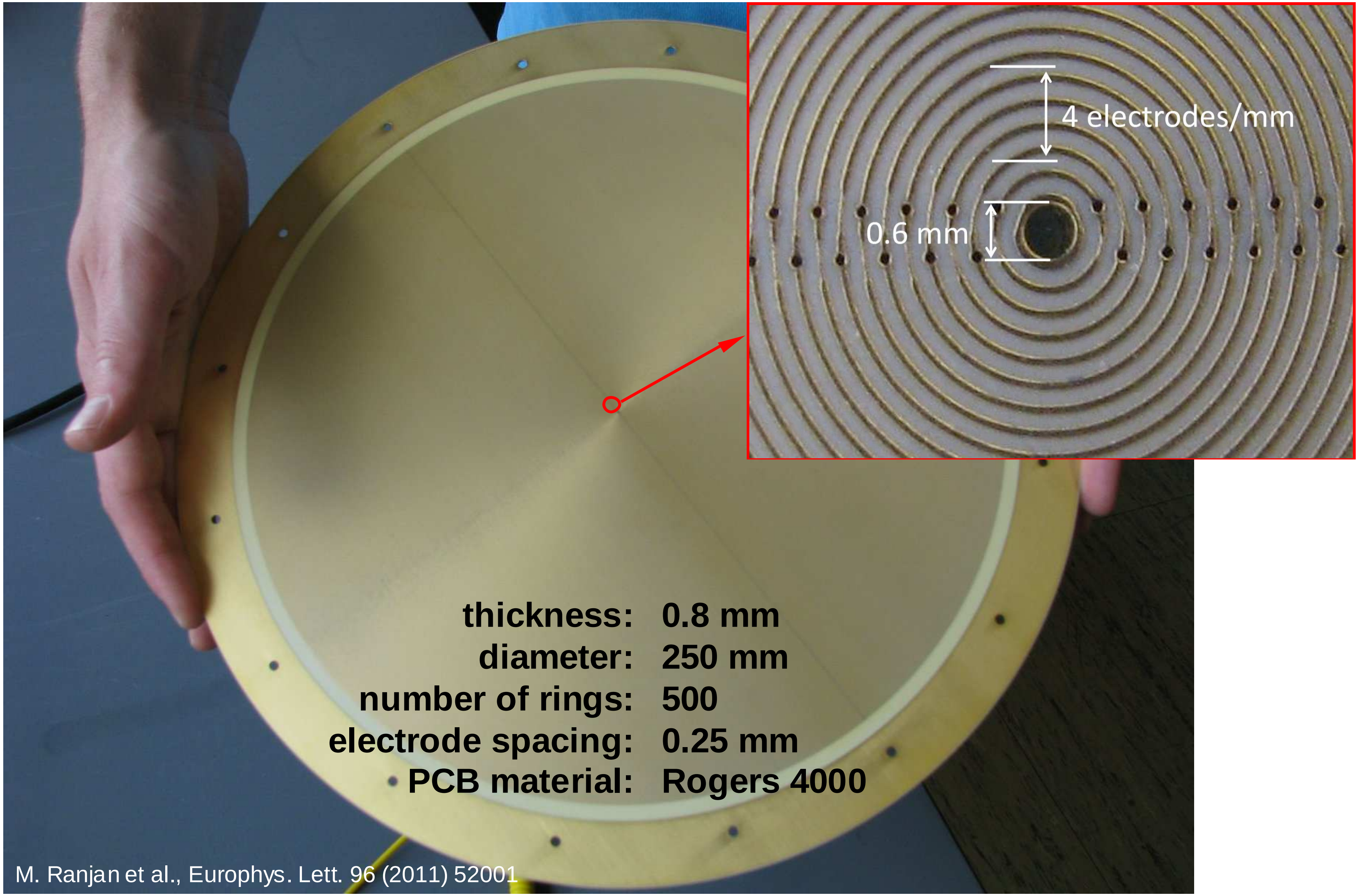


M. Ranjan et al., Europhys. Lett. 96 (2011) 52001
M. P. Reiter, Master Thesis, Justus-Liebig-Universität Gießen (2011)

Developed in Collaboration

Kernfysisch Versneller Instituut
university of groningen
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
GSI

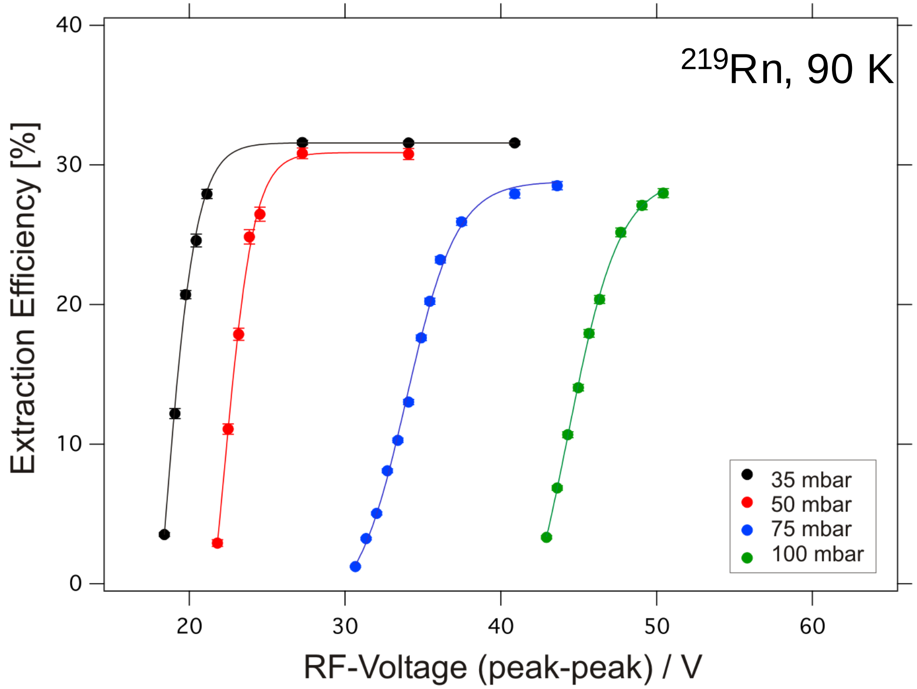
Cryogenic Stopping Cell: RF Carpet

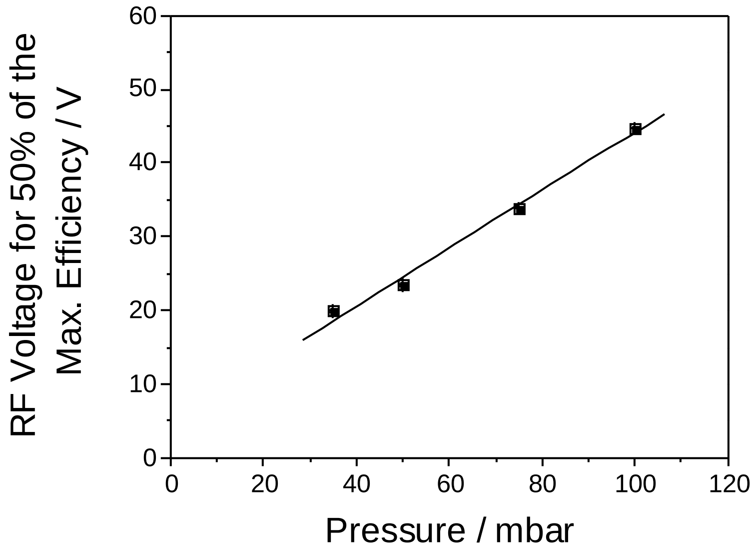


Off-line Performance Study: Efficiency

Measurement with ^{223}Ra source

S. Purushothaman et al.





Maximum survival and extraction efficiency for ^{219}Rn: ~ 30%

Value is close to the assumed efficiency value for stopping the recoils as ions

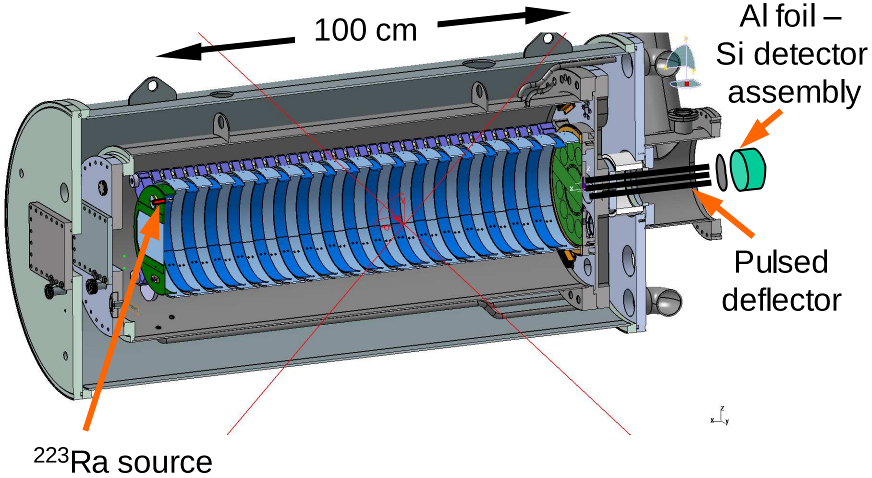
(cf. P. Dendooven at al., NIM A 558 (2006) 580; S. Purushothaman et al, NIM B 266 (2008) 4488;
S. Eliseev et al., NIM B 258 (2007) 479.)

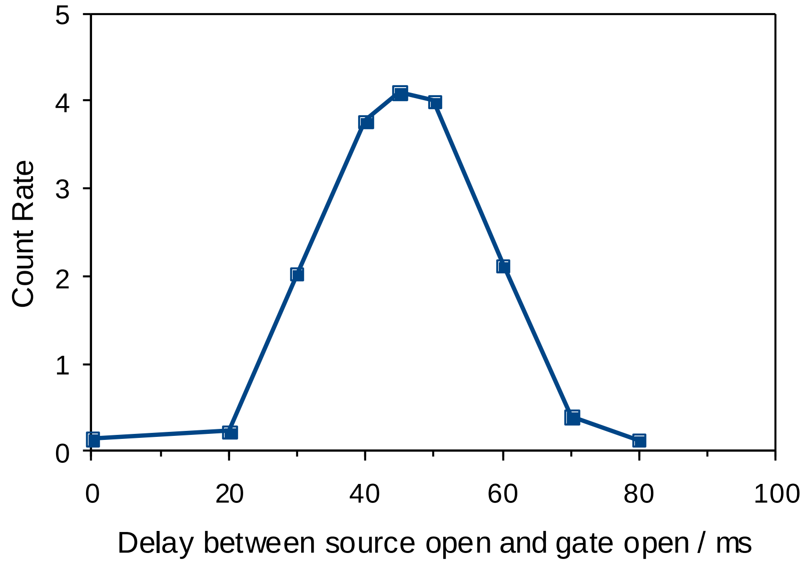
Maximum pressure reached: 100 mbar, 90 K
→ 330 mbar room-temperature equivalent; 5 mg/cm^2 (He)

In the future: RF =150 V → 1 bar room-temperature equivalent achievable

Off-line Performance Study: Extraction Time

Extraction time measurement with pulsed ^{223}Ra source





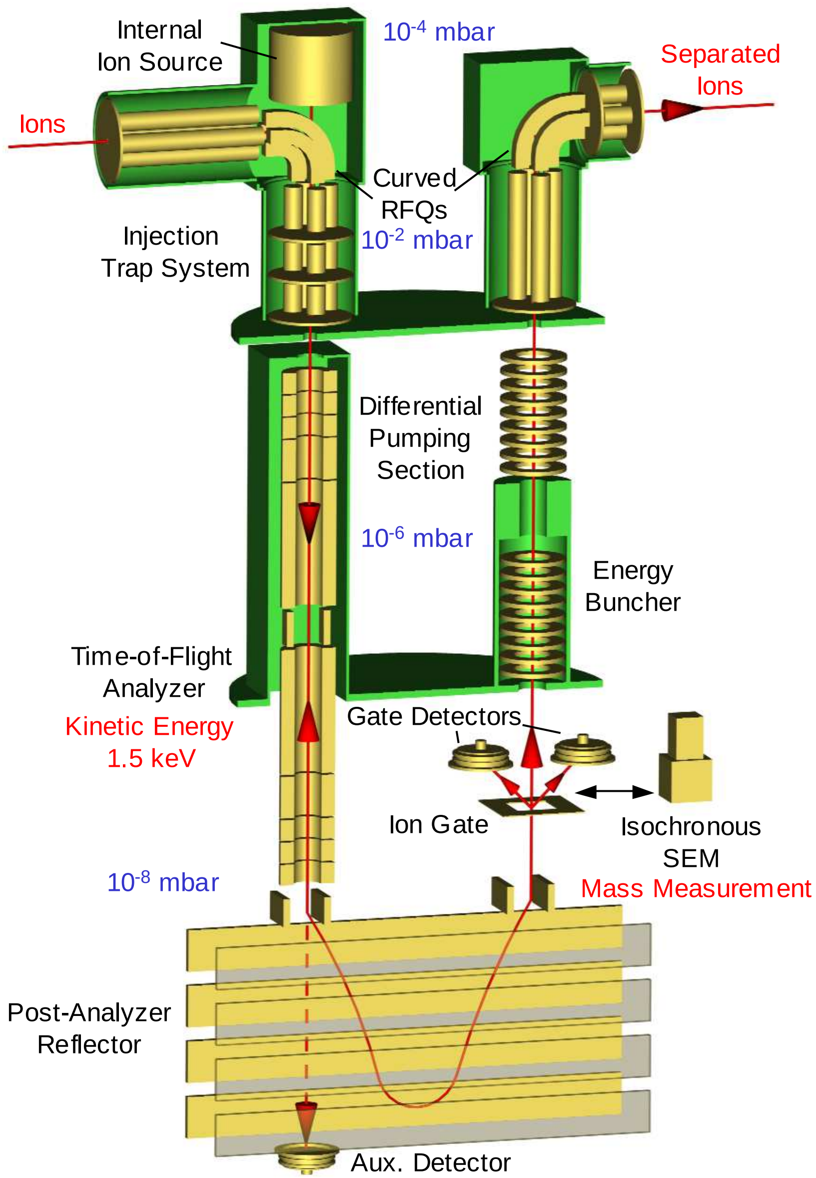
Pressure = 50 mbar, temperature = 100 K
DC field = 21 V/cm, distance = 1 m

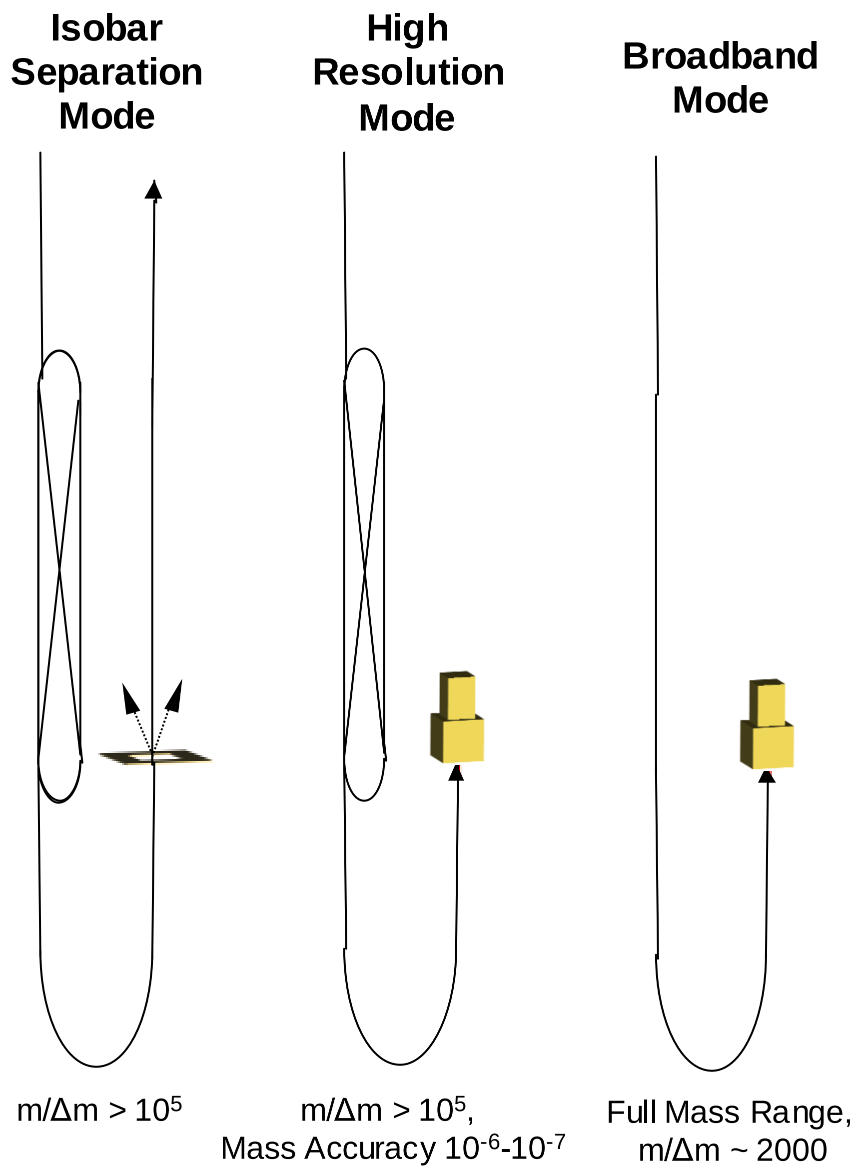
T. Dickel, S. Purushothaman, et al.

→ Experiment T_{extr} ~ 45 ms
Theory (K_0=15 cm²/Vs) T_{extr} ~ 47 ms

Scaled mean extraction time (extraction from middle of cell) T_{extr} ~ 23 ms

Multiple-Reflection Time-of-Flight Mass Spectrometer





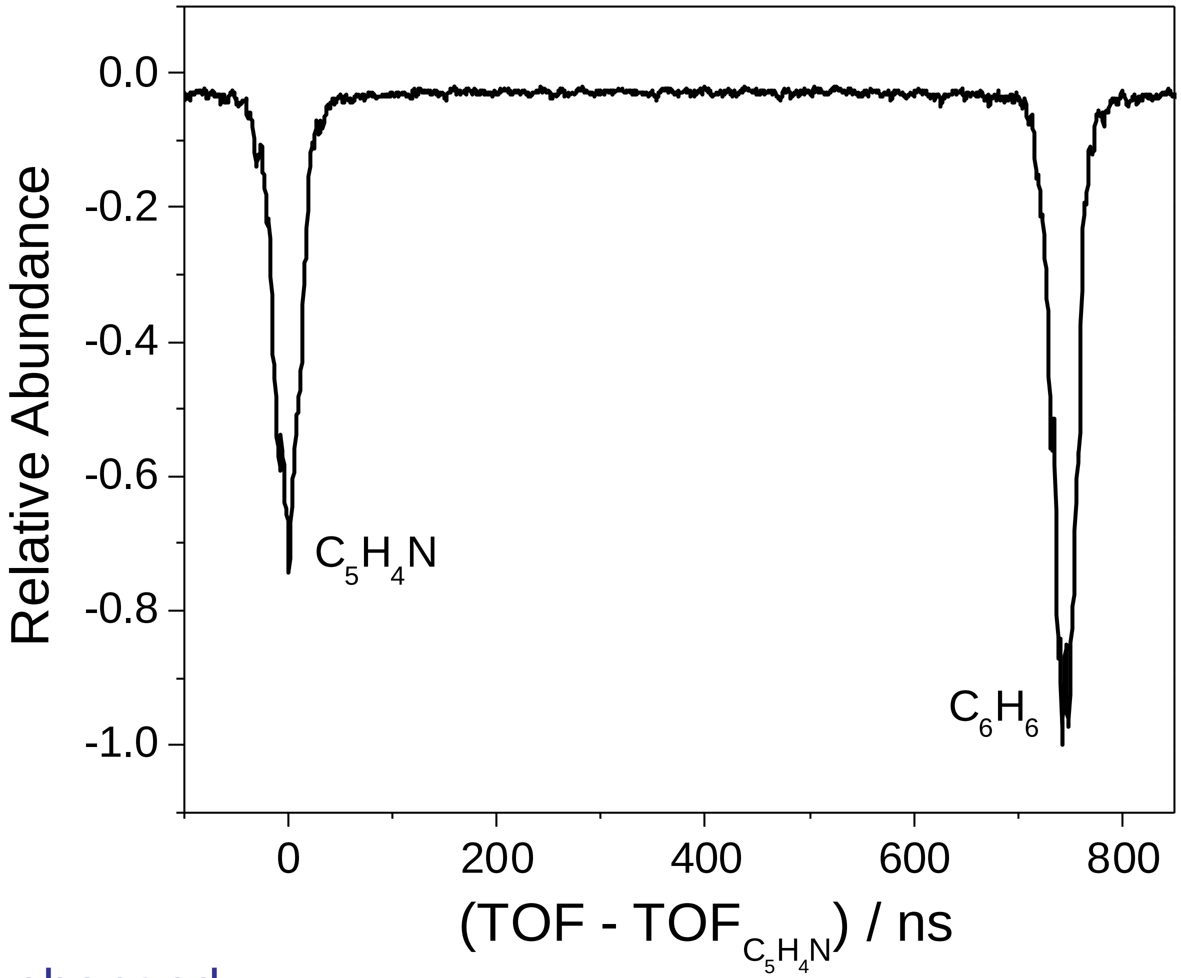
W.R. Plaß et al., NIM B 266 (2008) 4560

MR-TOF-MS: Mass Resolving Power

Isobar doublet at mass 78 u

- pyridine fragment (C_5H_5N)
- benzene (C_6H_6)

256 Turns, $TOF_{C_5H_4N}$ = 9.2 ms, $m/\Delta m$ = 160,000



No re-tuning, only delays changed

Data taken within 6 minutes

T. Dickel

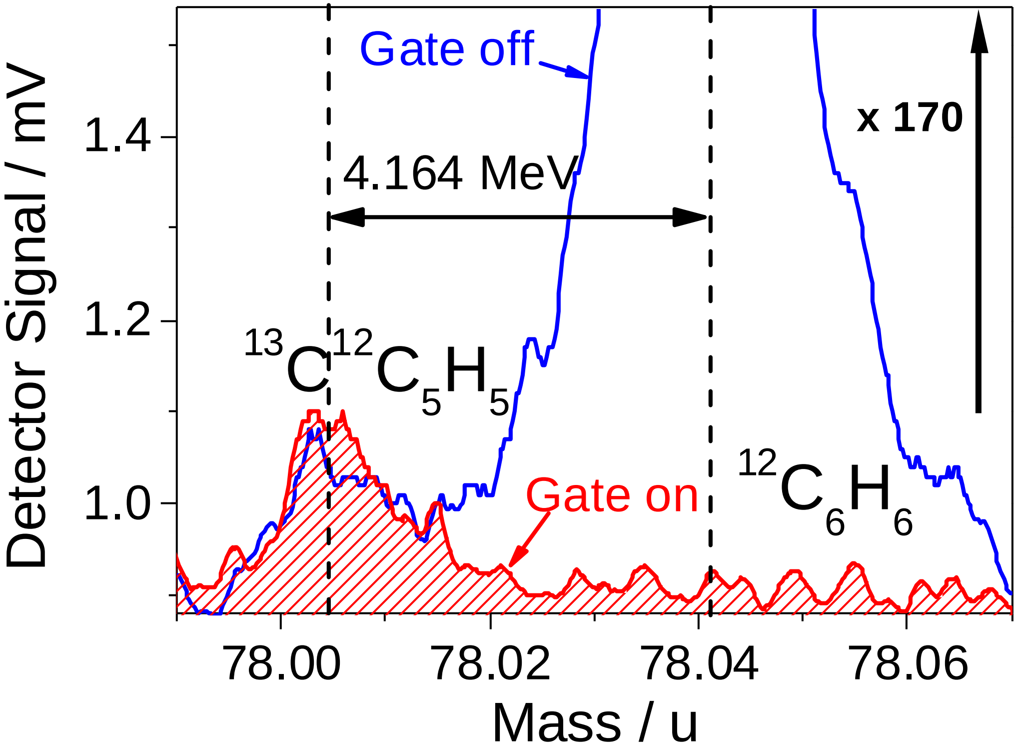
MR-TOF-MS: Isobar Separator

Combination of MR-TOF-MS and Bradbury-Nielsen Gate yields powerful isobar separator

- Proposed in 2005 (W.R. Plaß et al.)
- First demonstrated in 2006 W.R. Plaß et al., NIM B 266 (2008) 4560

Isobar separation demonstrated for C_6H_6 and $^{13}C^{12}C_5H_5$

- Intensity ratio 170:1
- Δm = 4 mu
- up to 10^4 ions/cycle $\rightarrow 10^6$ ions/s



T. Dickel, PhD Thesis Justus-Liebig-Universität Giessen, 2010

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
Mass Measurement Accuracy	$\sim 10^{-7}$
Measurement Duration	~10 ms
Sensitivity	~10 ions
Mass Range	Broadband: ~% - full
Transmission efficiency	up to 70%
Ion Capacity	$> 10^6$ ions / s
Dynamic Range	$> 10^4$

World-wide unique combination of performance characteristics, ideally suited for the LEB of the Super-FRS

Further performance improvements are underway..

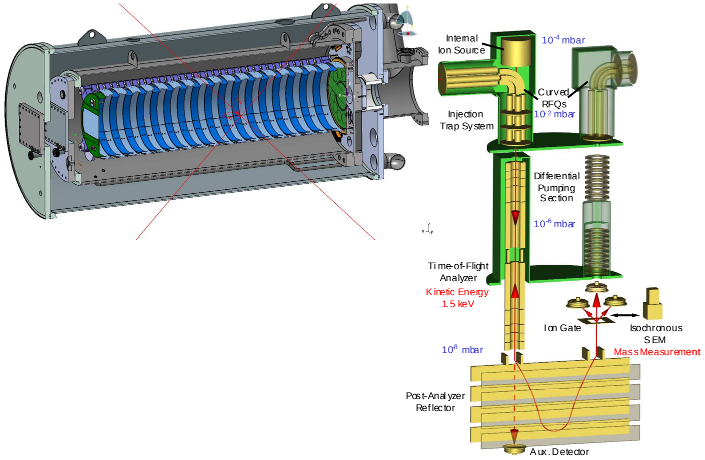
T. Dickel

FRS Ion Catcher

Fragment separator FRS at GSI is the ideal instrument for testing Super-FRS developments

FRS Ion Catcher

- Test bench for the cryogenic stopping cell and the MR-TOF-MS
- Potential for high-precision experiments with stopped projectile and fission fragments
  - Direct mass measurements
  - Mass-selected decay spectroscopy
  - ….



W.R. Plaß et al., GSI Scientific Report 2010 (2011) p. 137

Challenges

- Limited space at the final focal plane
- Setup cannot be installed permanently
- Short setup times
- Limited amount of beam time

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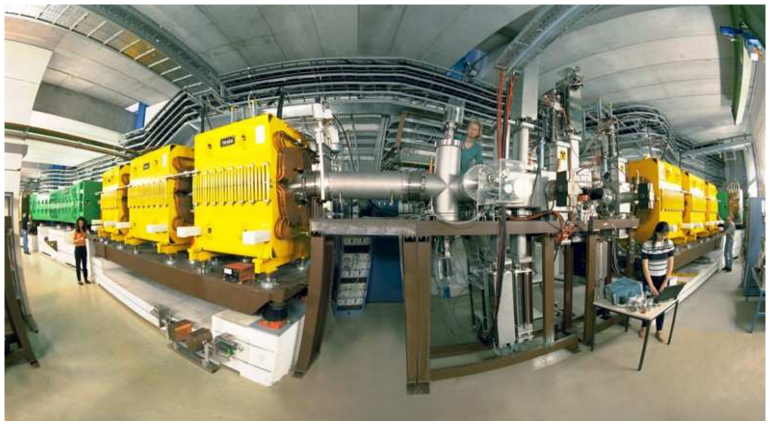
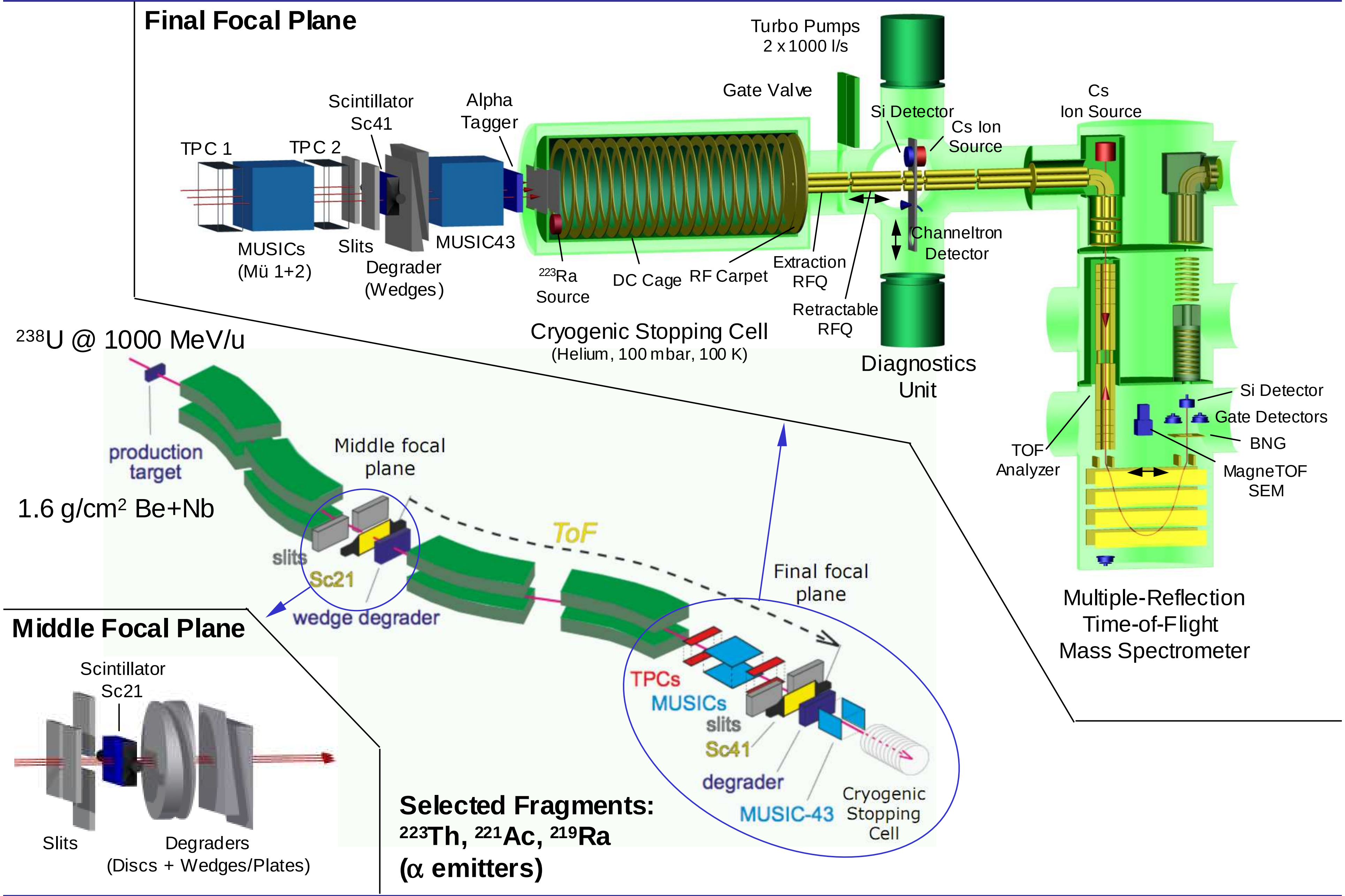


Projectile Fragment Separator FRS

FRS Ion Catcher Experiment in October 2011



Selected Fragments:
^{223}Th, ^{221}Ac, ^{219}Ra
(α emitters)

Installation at the FRS

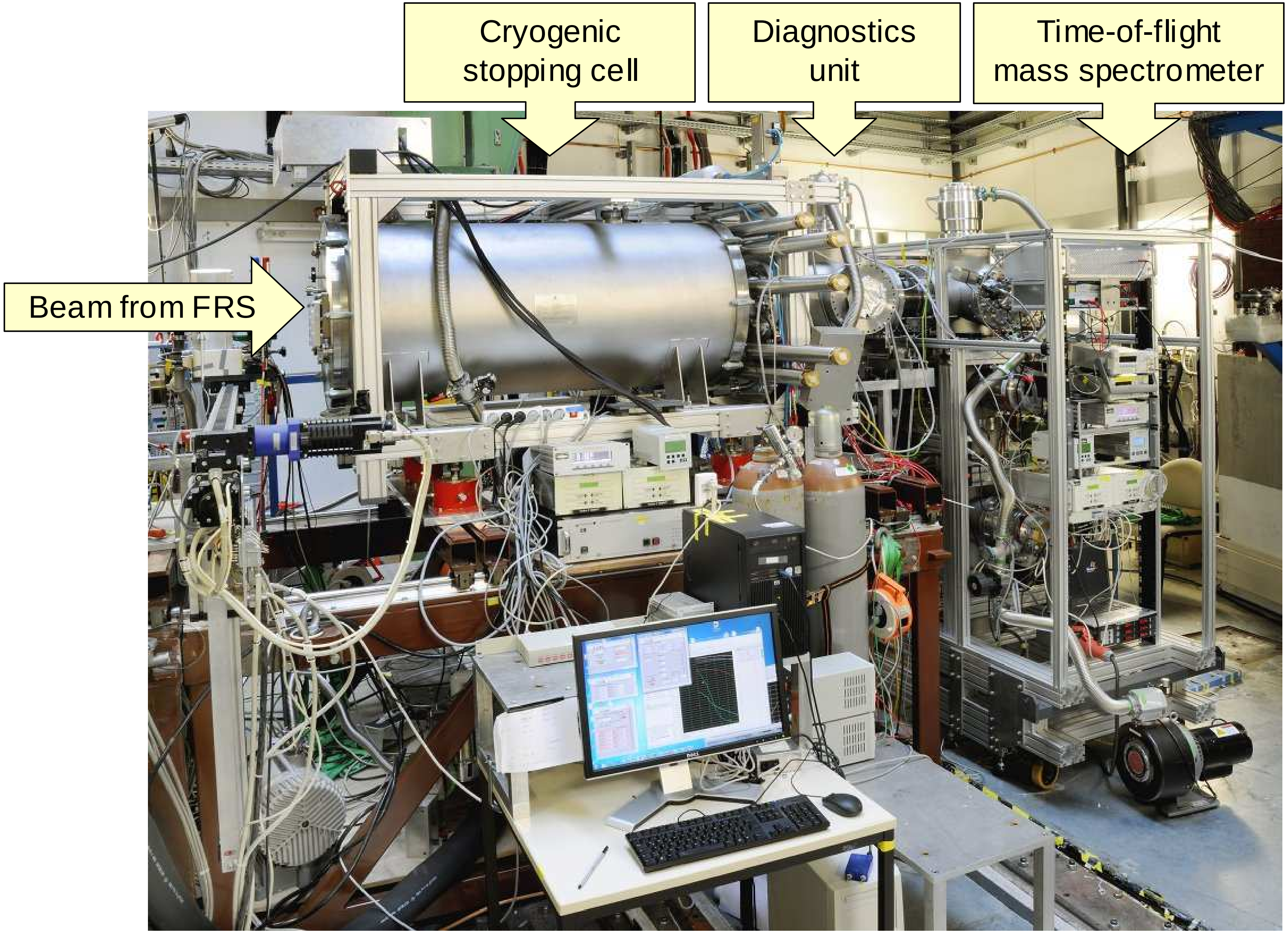
Transport of stopping cell and MR-TOF-MS from off-line location to FRS

The components just fit into the available space at the final focal plane of the FRS

Time between MR-TOF-MS spectra at the offline location and the FRS: 4 hours!

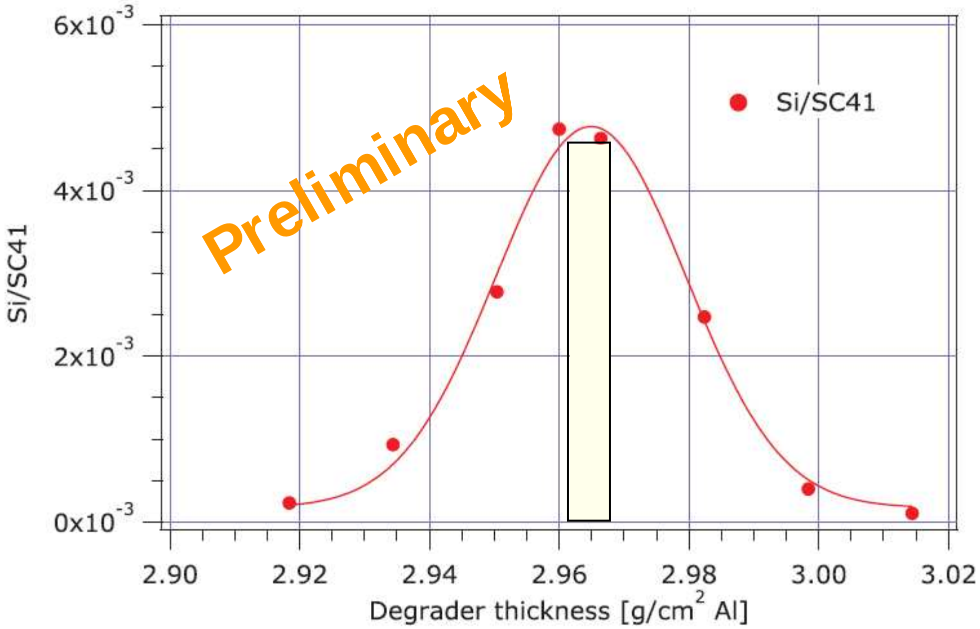
First mobile high-performance MS

FRS Ion Catcher Setup



Range Distribution and Stopping Efficiency

Range distribution of ^{223}Th

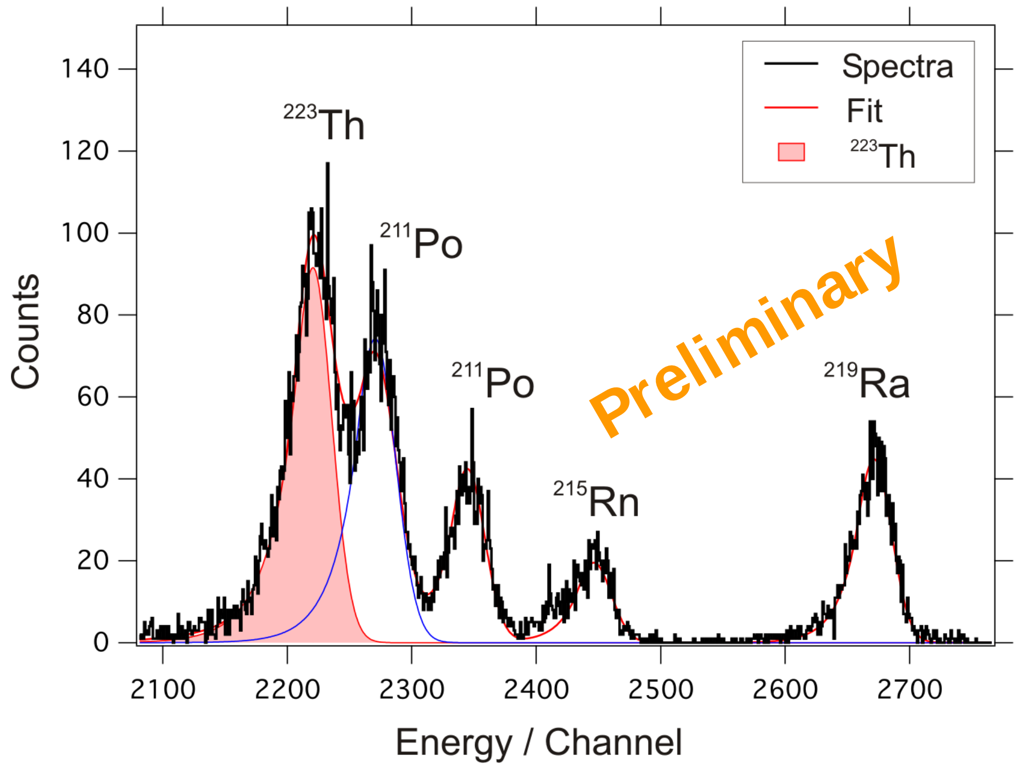


- Range distribution: σ = 14 mg/cm^2 (Al) $\rightarrow$ σ = 11 mg/cm^2 (He)
- Stopping cell gas density: 100 mbar, 100 K $\rightarrow$ 0.05 mg/cm^3
  Areal weight of stopping cell: 5 mg/cm^2 (He)

Stopping efficiency = ~16%   (Preliminary)

Stopping Cell Extraction Efficiency

Si detector spectrum of extracted projectile fragments



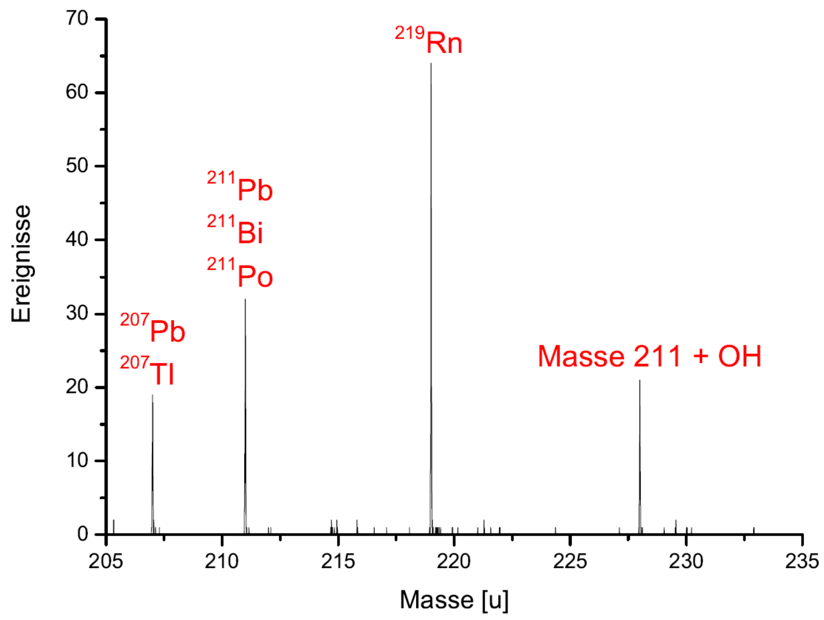
First on-line operation of a cryogenic stopping cell

Efficiencies for ^{223}Th (preliminary)

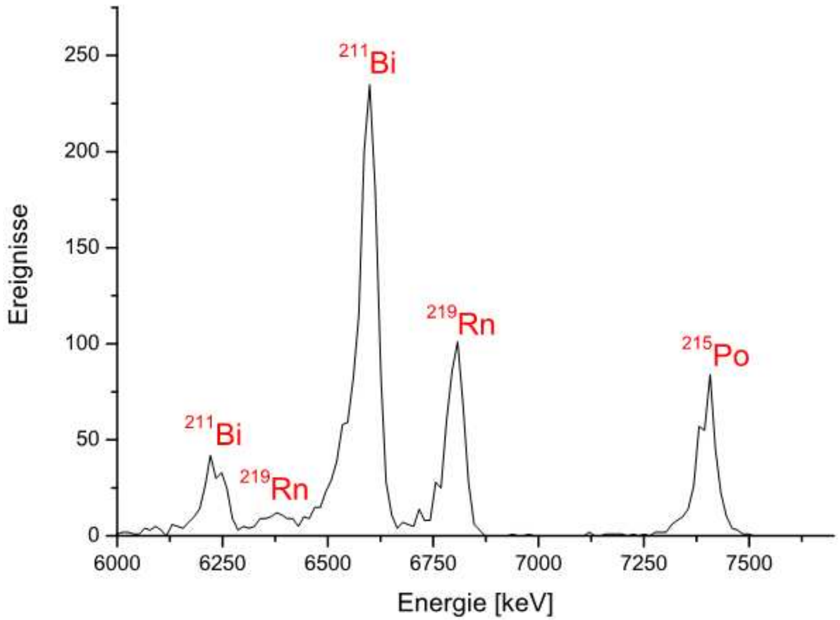
- Overall efficiency ~ 8%
- Survival and extraction efficiency ~ 50%

Measurement with the MR-TOF-MS

Measurement with ^{223}Ra source

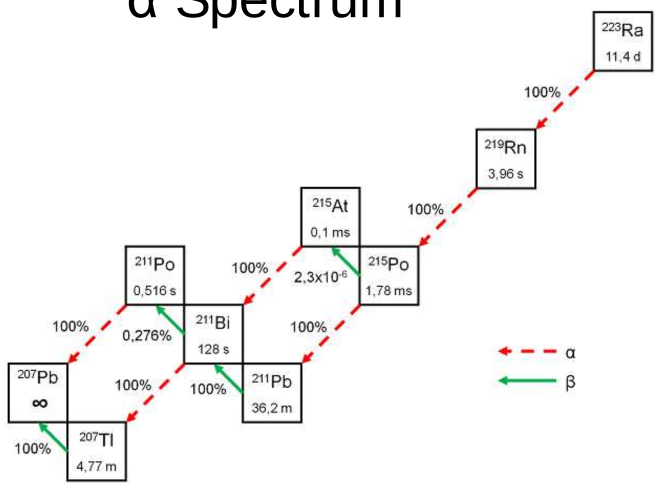


Mass Spectrum



α Spectrum

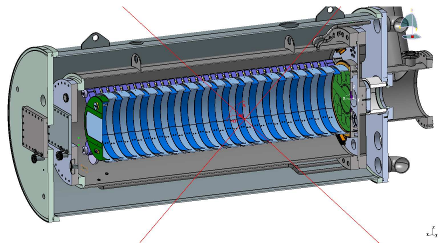
Broadband mass spectrometry is a necessity for quick and reliable operation of a stopping cell



J. Ebert, Master Thesis, Justus-Liebig-Universität Gießen (2011)

Conclusions

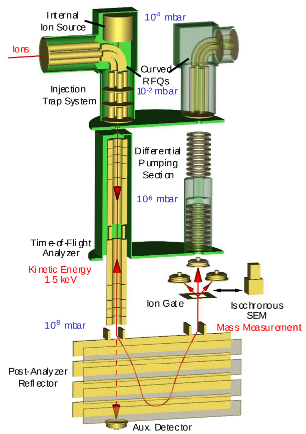
Stopping cell for the Super-FRS and the FRS Ion Catcher



- Cryogenic, high density operation
- Commissioned off-line and on-line
- Preliminary performance values:
  Stopping efficiency ~ 16%, survival and extraction efficiency ~ 50%
  Extraction time ~ 20 ms

High-performance multiple-reflection time-of-flight mass spectrometer

- Direct mass measurements
- High-resolution mass separator
- Diagnostics tool: identification and quantification
- World-wide unique combination of performance characteristics, ideally suited for current and next generation facilities



Outlook

Next steps

- Commission cryo-cooler based cooling system for the stopping cell
- Systematic study of the cryogenic stopping cell (intensity limitations and temperature / cleanliness)
- Mass measurements with the MR-TOF-MS
- Increase stopping efficiency even further (higher densities)

Acknowledgements

FRS Ion Catcher / S411 Collaboration

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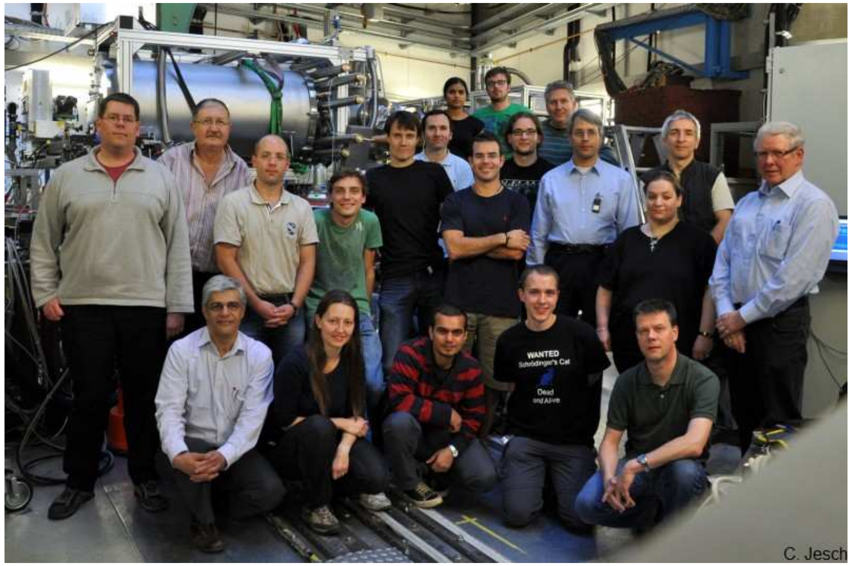

C. Jesch

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