The FRS Ion Catcher – A Facility for High-Precision Experiments With Stopped Projectile and Fission Fragments

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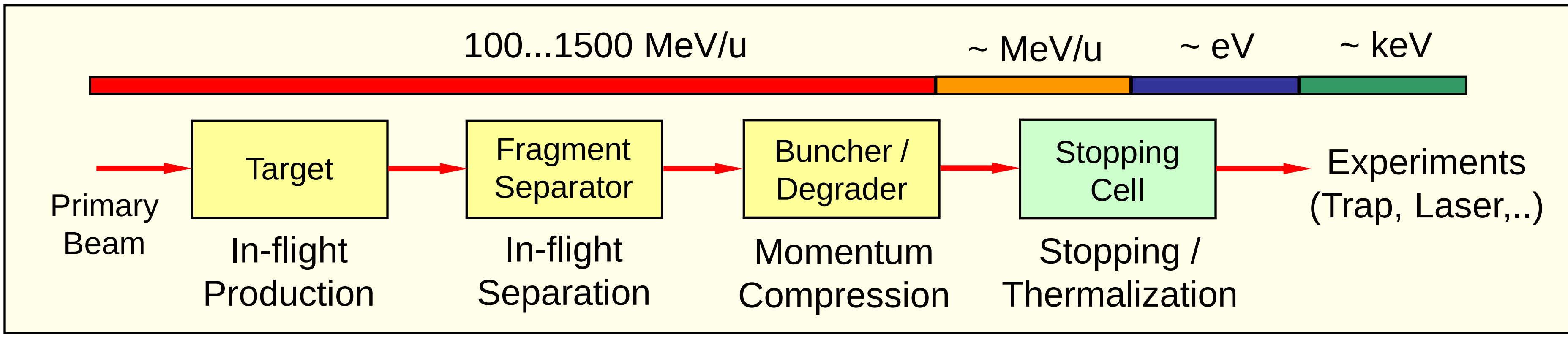
Outline

- 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 and Outlook

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

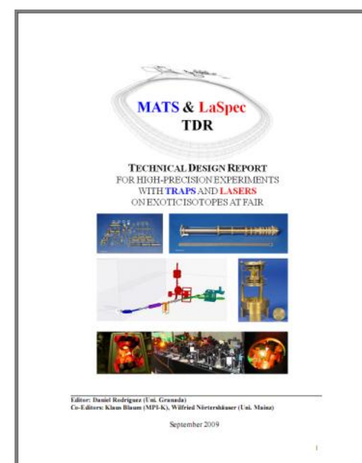


MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

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

LaSpec (Laser Spectroscopy)

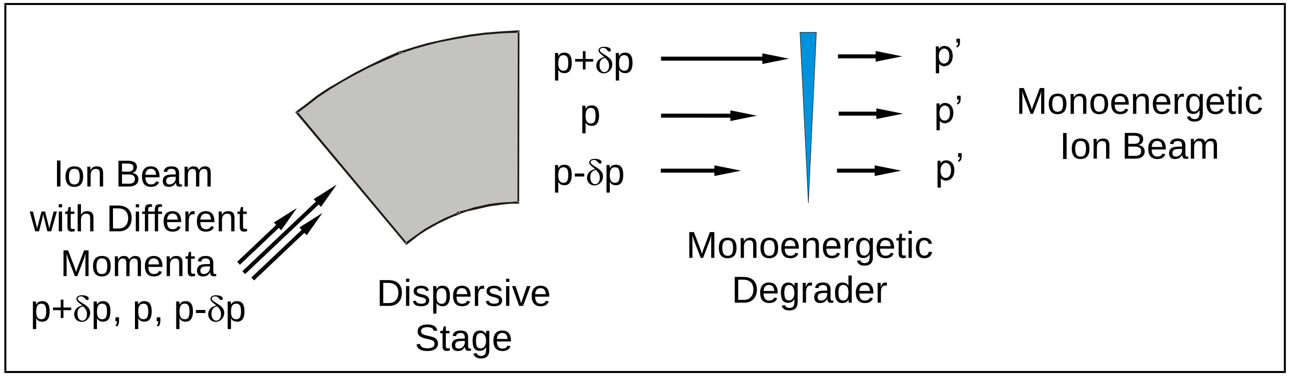
- Collinear laser spectroscopy of ions and atoms
- β-NMR
- Resonance ionization spectroscopy



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

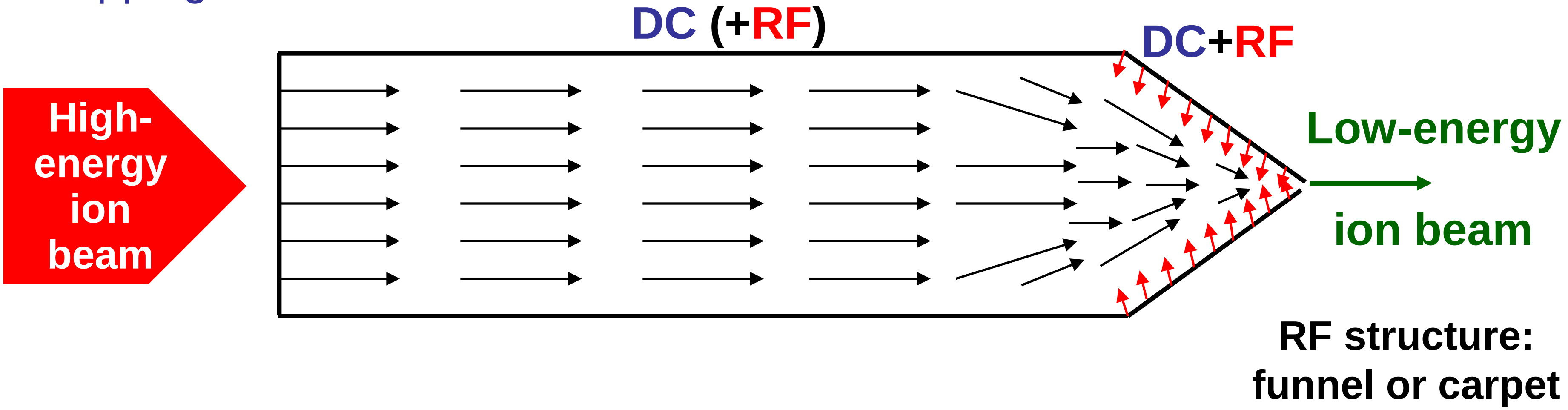
Stopping Cell Principles

Range Bunching



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

Stopping Cell



Stopping Cell Design

Cryogenic Operation

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

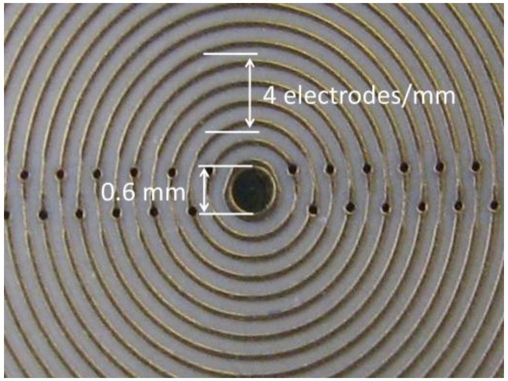
- Ultra-pure helium (freezing-out of contaminants)
  - Ideal for ion survival, 2+ charge state possible
  - No formation of molecules/adducts
- Reduced radial ion diffusion
- Reduced requirements for cleanliness → easier, more flexible construction
- Operational reliability

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

High-density Operation

Use RF structure with small spacing (PCB-based RF carpet) to achieve high RF repelling field

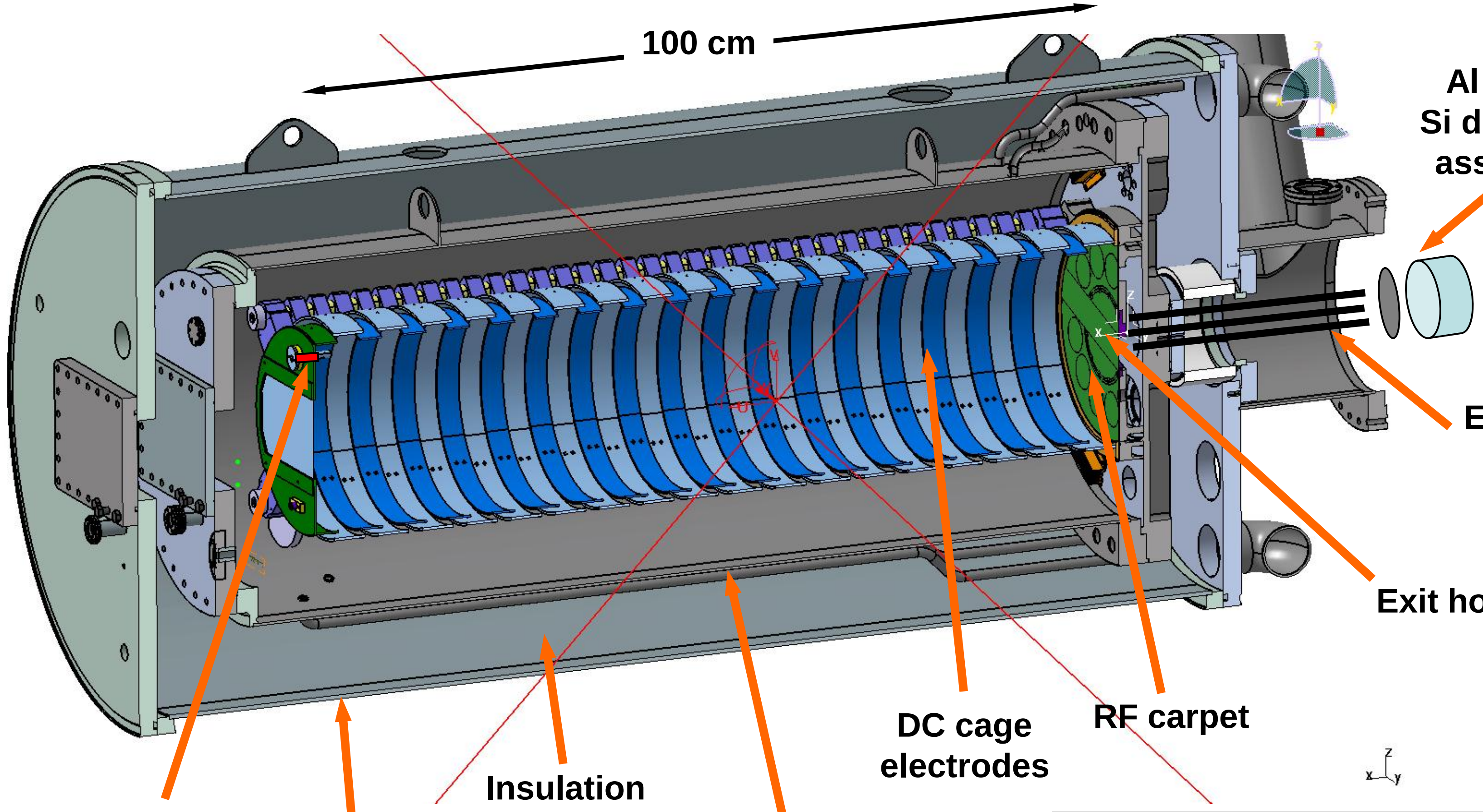
- High stopping gas densities
- Less complex construction than RF funnels



Diameter:	250 mm
Electrode spacing:	0.25 mm

M. Wada et al., NIM B 204 (2003) 570
M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

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

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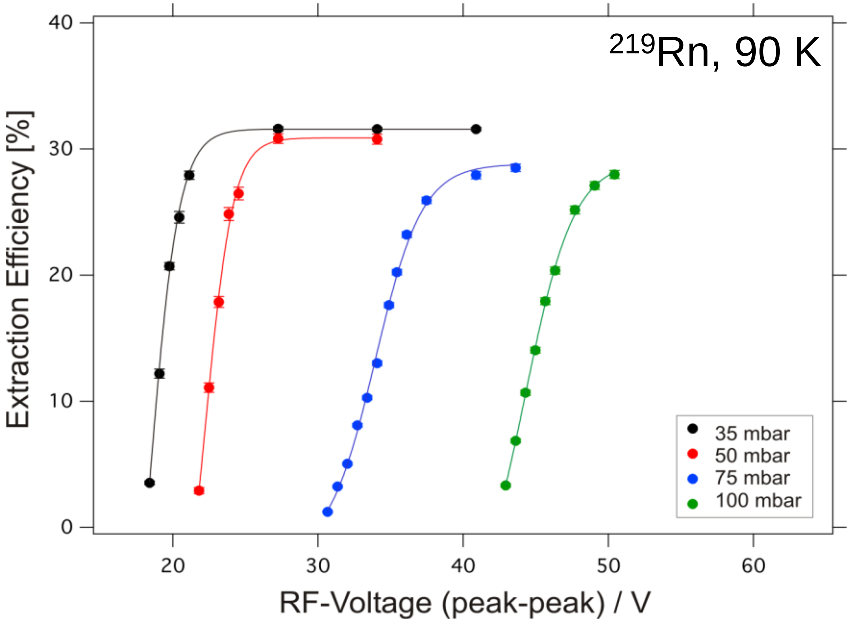
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
university of groningen
GSI

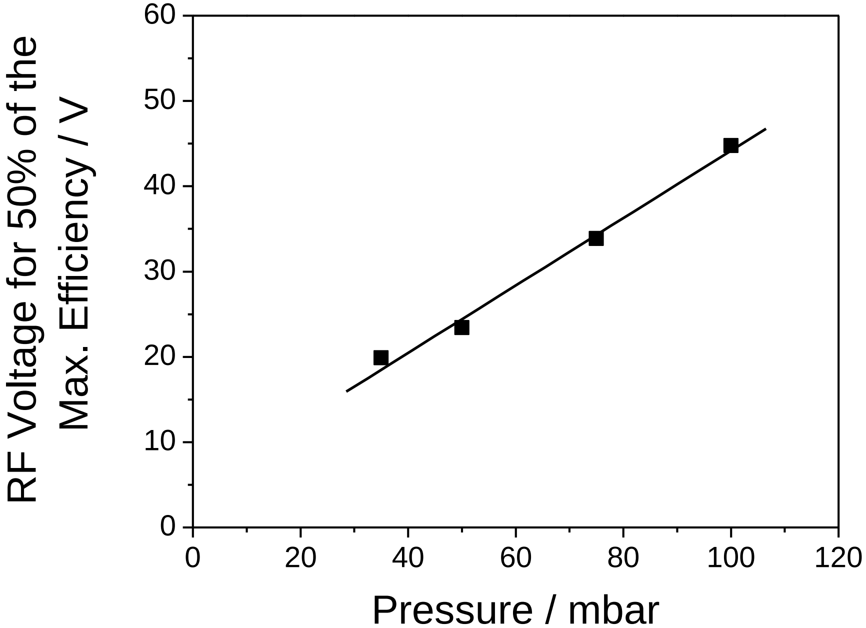
Off-line Performance Study: Efficiency



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

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

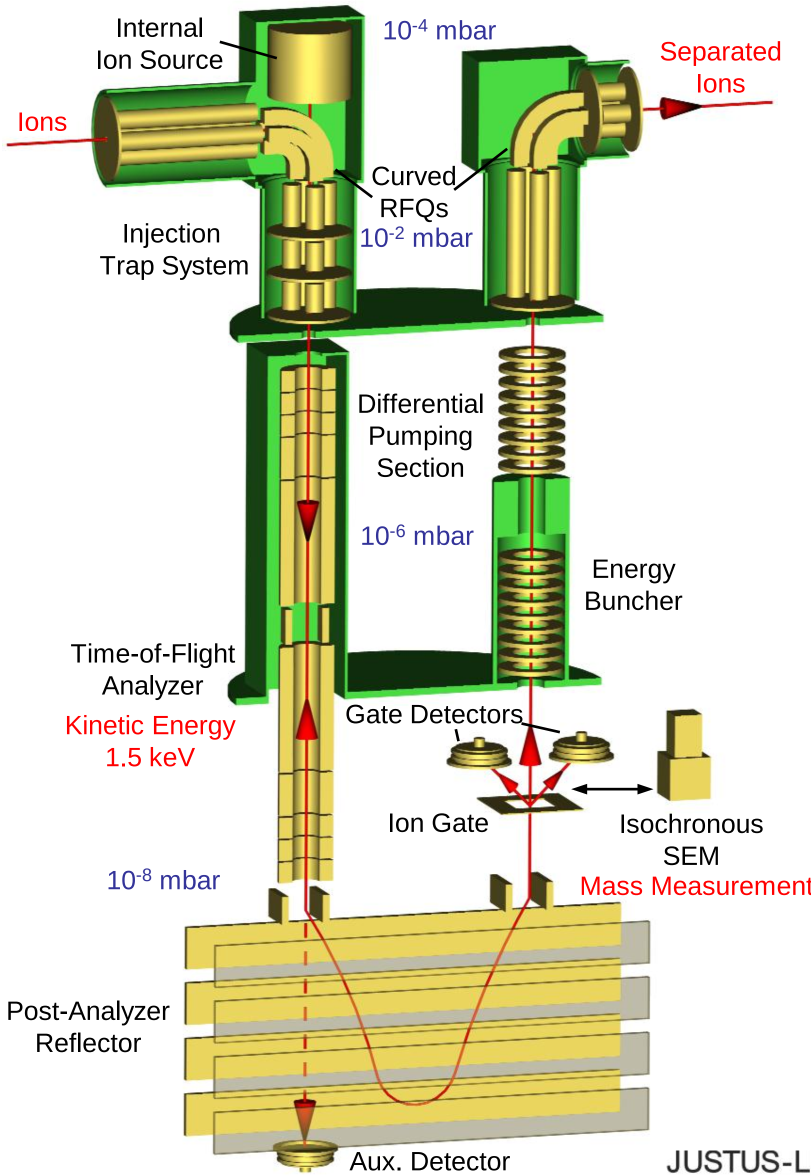
P. Dendooven et al., NIM A 558 (2006) 580
S. Purushothaman et al, NIM B 266 (2008) 4488
S. Eliseev et al., NIM B 258 (2007) 479

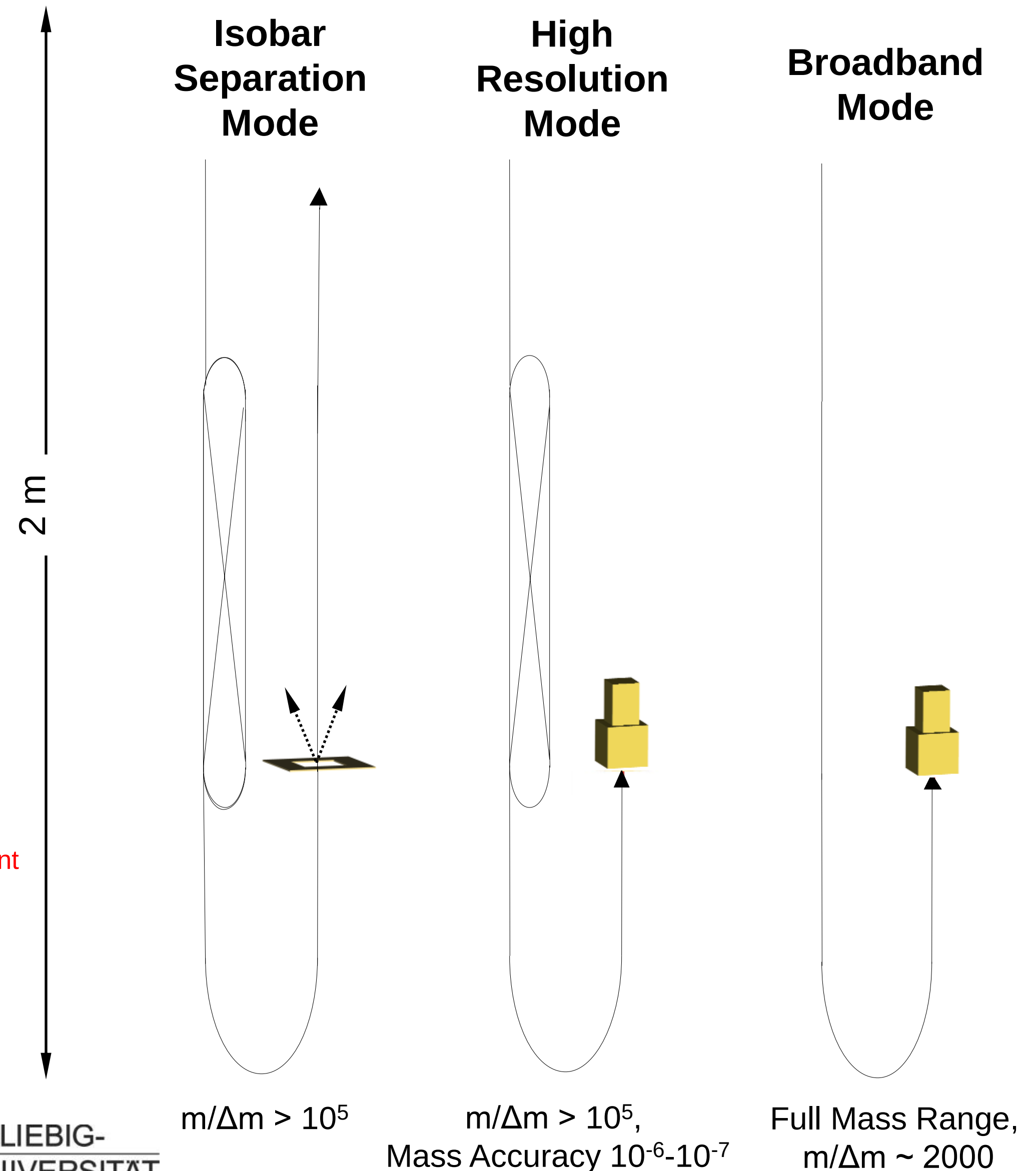


Maximum pressure reached:
- 100 mbar at 90 K
- 330 mbar room-temperature equivalent
- 5.5 mg/cm^2 (He)

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

Multiple-Reflection Time-of-Flight Mass Spectrometer





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

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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

Repetition Rate

up to 400 Hz

Transmission efficiency

up to 70%

Ion Capacity

$> 10^{6}$ ions / s

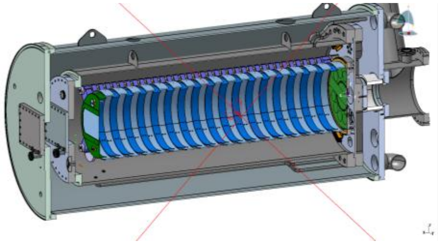
Dynamic Range

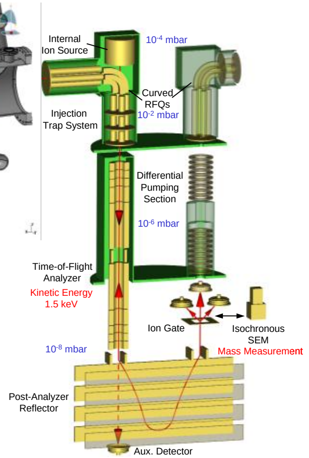
$> 10^{4}$

Further performance improvements are underway.

FRS Ion Catcher

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





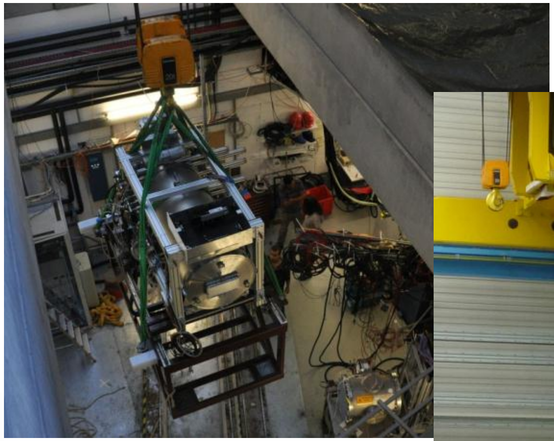
W.R. Plaß et al., GSI Scientific Report 2010 (2011) p. 137

FRS Ion Catcher

- Test facility 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
  - ….

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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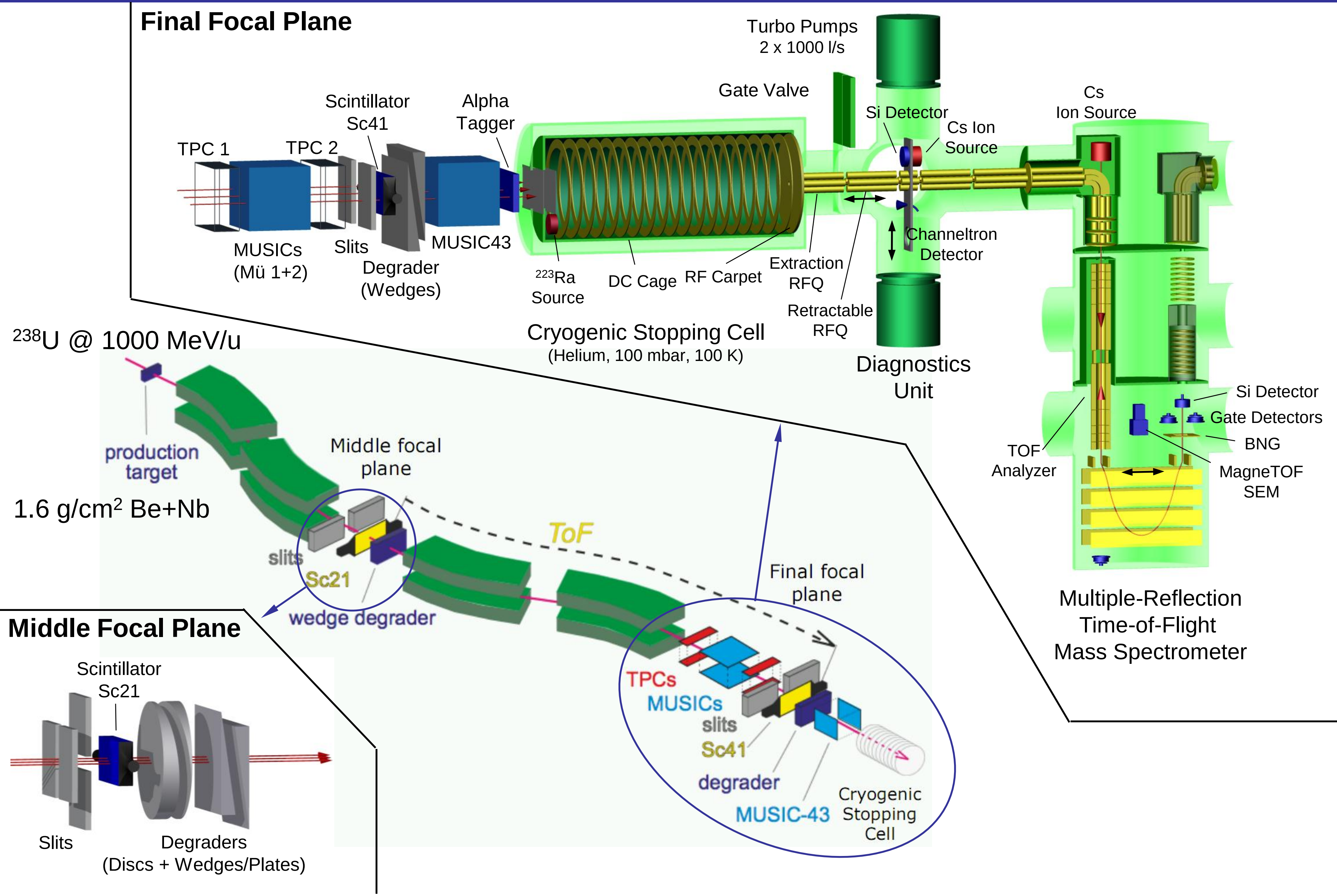
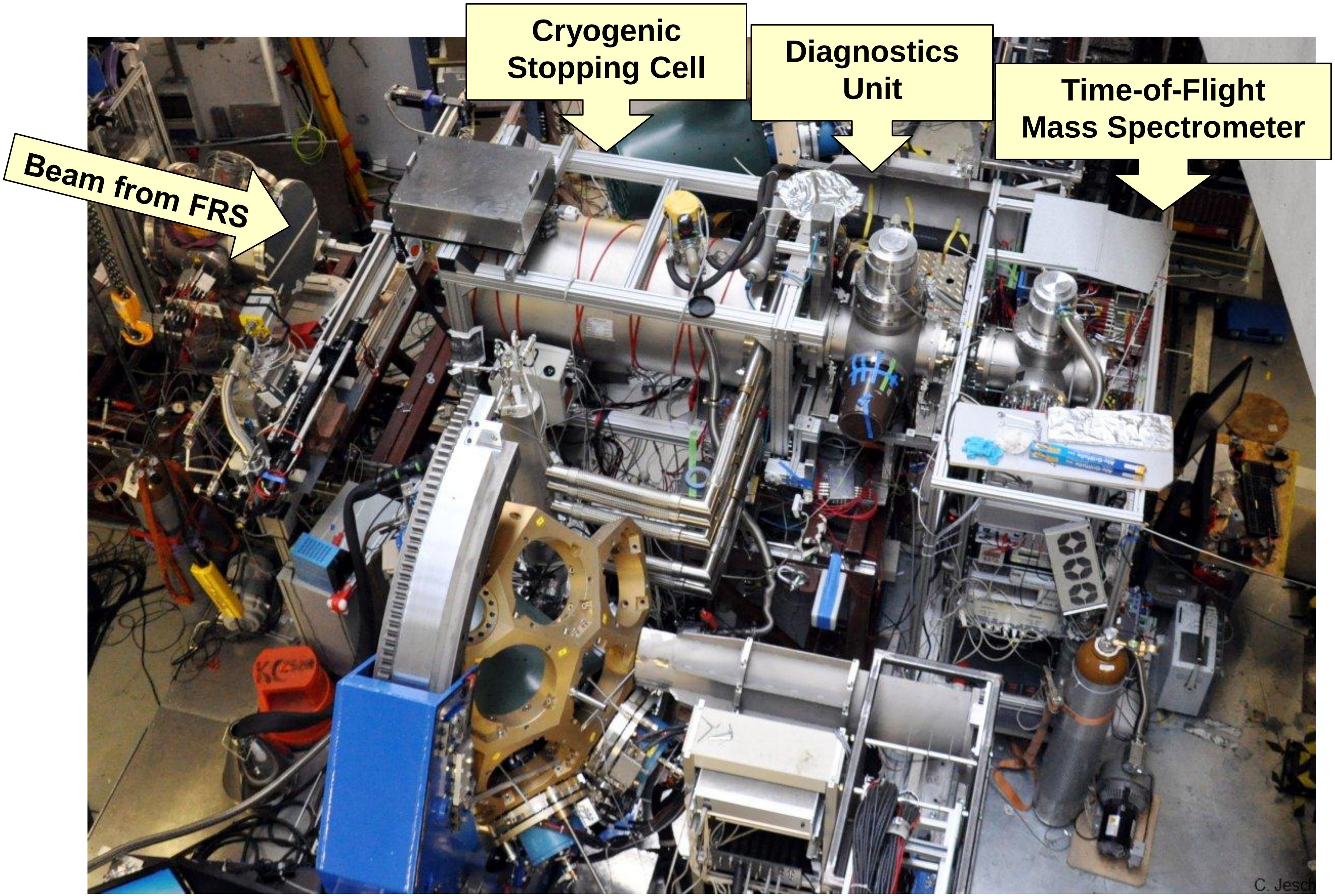
FRS Ion Catcher Experiment in Oct. 2011 / Jul. 2012

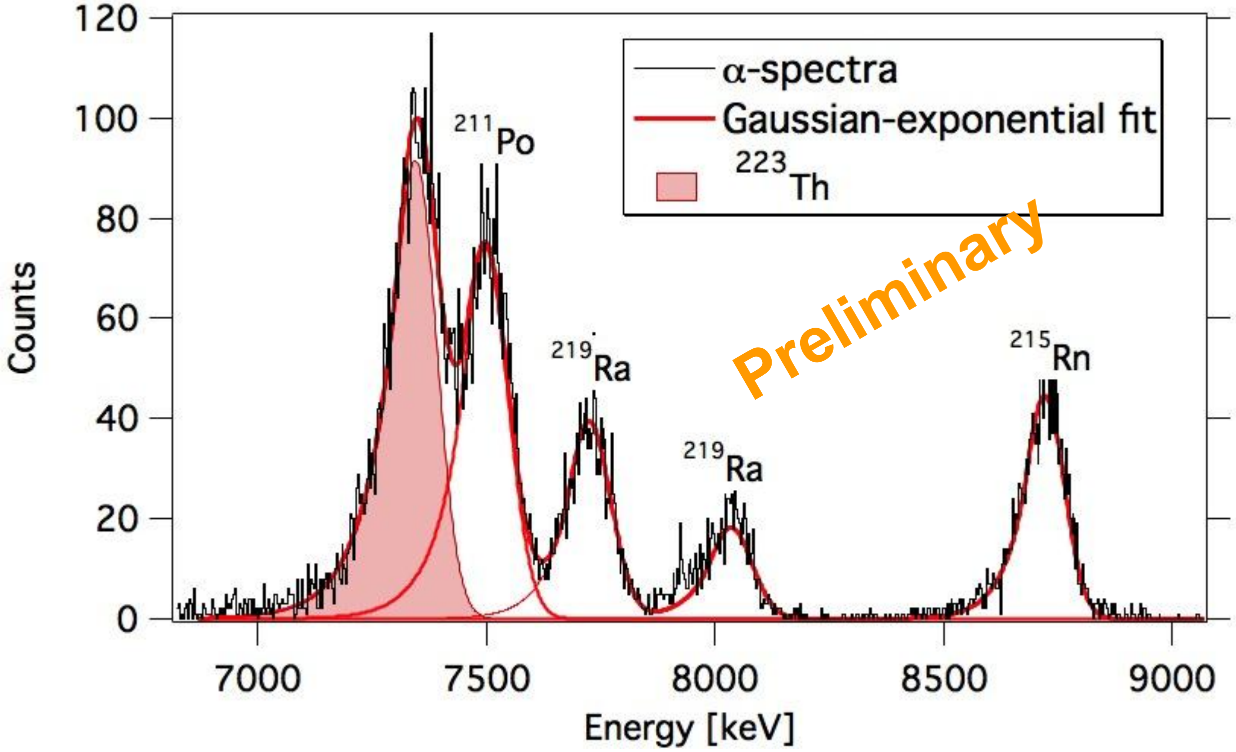


Setup at the FRS Ion Catcher

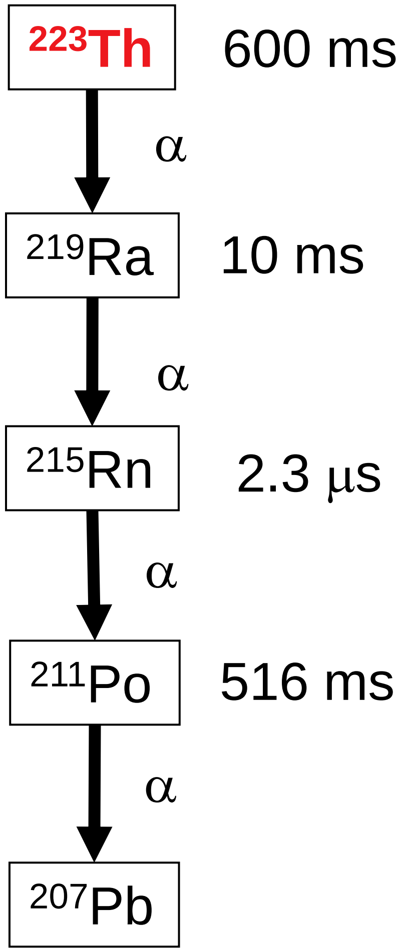


Stopping Cell Performance

Si detector spectrum of extracted projectile fragments



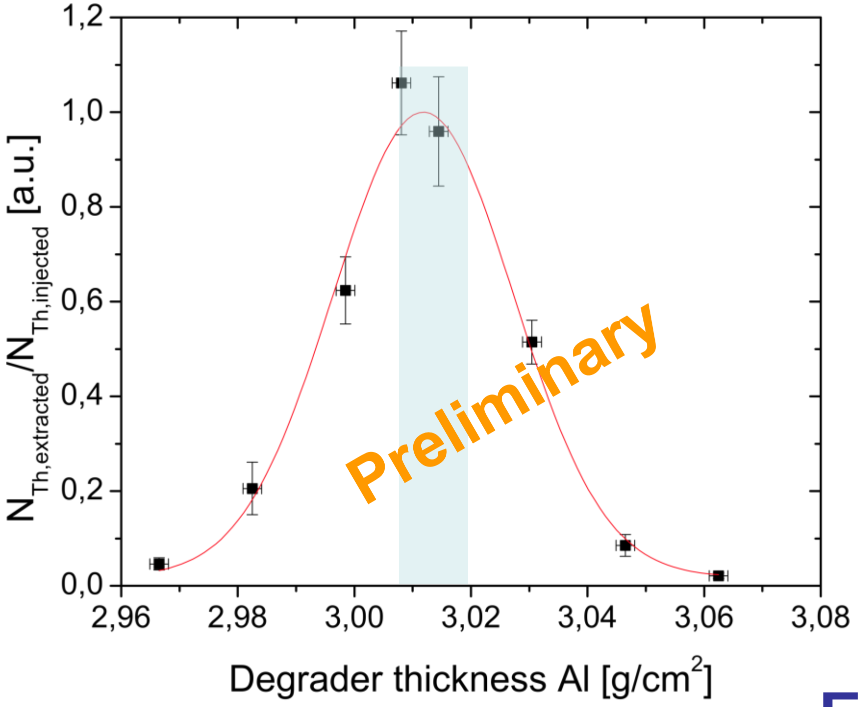
extracted as 2+



First on-line operation of a cryogenic stopping cell for exotic nuclei

Stopping and Extraction Efficiencies

Range distribution of ^{223}Th



- Range distribution:
  - σ = 15 mg/cm^2 (Al)
  - σ = 7.5 mg/cm^2 (He)
- Stopping cell: 100 mbar, 100 K
  - → Areal density: 5 mg/cm^2 (He)
  - → corresponds to ~ 300 mbar at room temperature

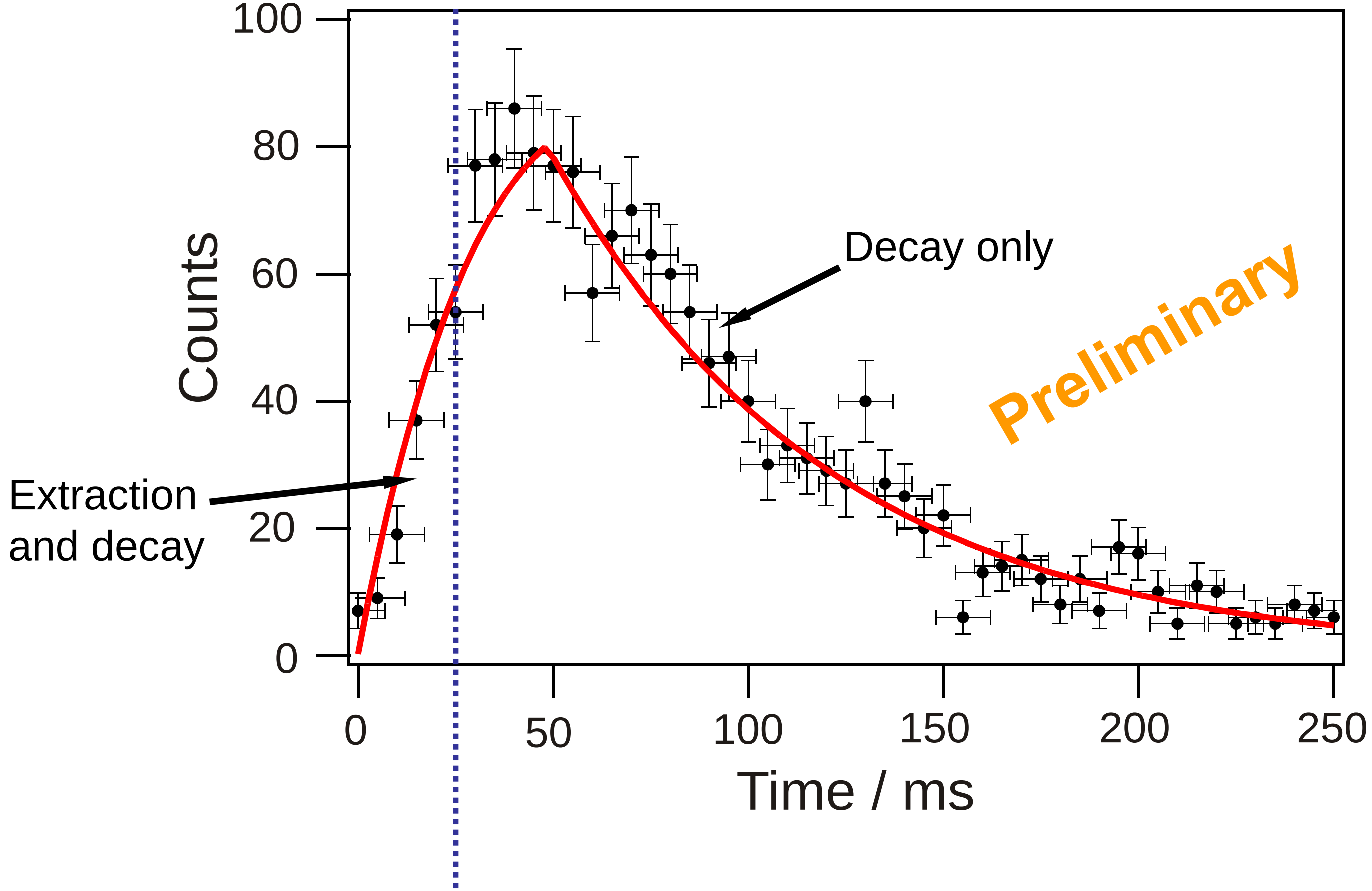
Efficiencies

	^{223}Th
Stopping efficiency	(27 ± 3)%
Survival and extraction efficiency	(43 ± 9)%
Total efficiency	(12 ± 2)%

Preliminary

Extraction Time

Extraction of ^{221}Ac ($T_{1/2}$ = 52 ms)



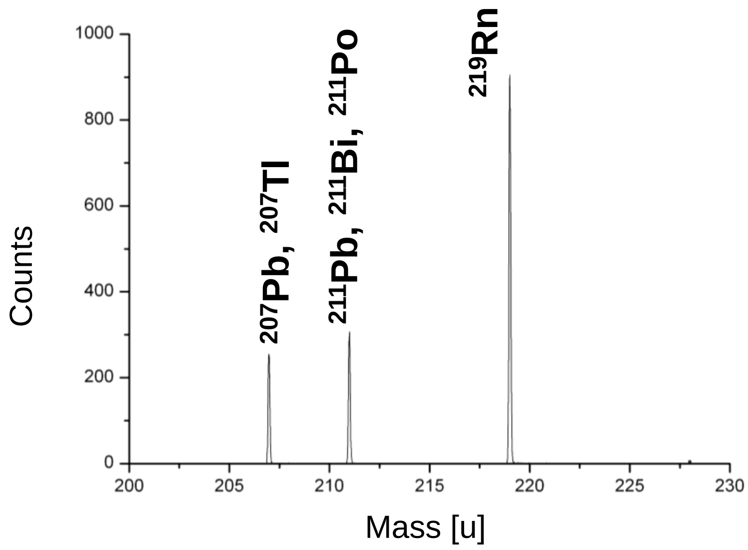
Pressure = 50 mbar,
Temperature = 75 K
DC field = 23 V/cm

Mean extraction time T_{extr} = 24 ms

Theory (K_0=15 cm^2/Vs) T_{extr} = 27 ms

Cleanliness of the Stopping Cell

Broadband mass spectrum taken with the MR-TOF-MS

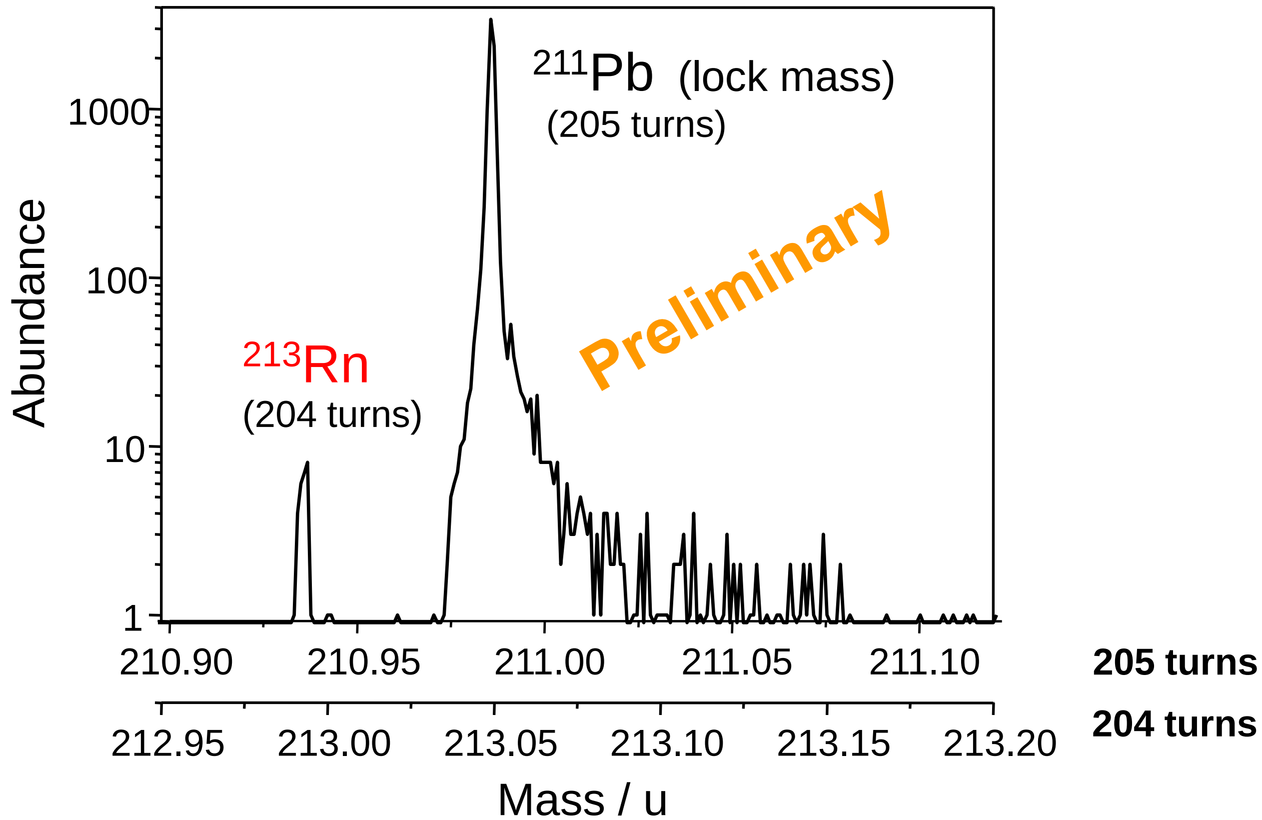


- Molecular contaminants / adduct formation are not a problem for the cryogenic stopping cell
- Broadband mass spectrometry is a necessity for quick and reliable operation of a stopping cell

MR-TOF-MS Mass Measurements

Mass measurements of A = 211 and A = 213 isobars

Example: ^{213}Rn ($T_{1/2}$ = 19.5 ms)

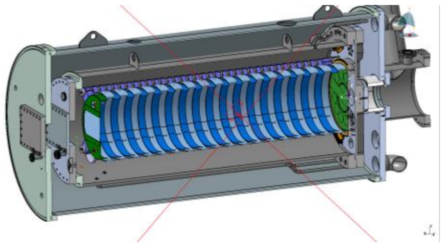


First direct mass measurements of projectile fragments with an MR-TOF-MS

Conclusions and Outlook

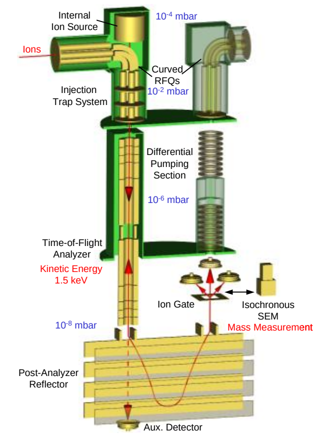
Stopping cell for the Super-FRS and the FRS Ion Catcher

- Cryogenic, high density operation, suitable for exotic nuclei produced at relativistic energies
- Commissioned off-line and on-line
- Preliminary performance values:
  Stopping efficiency ~ 27% (^{223}Th),
  Survival and extraction efficiency ~ 43%
  Extraction time ~ 25 ms



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

- First direct mass measurements of projectile fragments
- High-resolution mass separator
- Diagnostics tool: identification and quantification



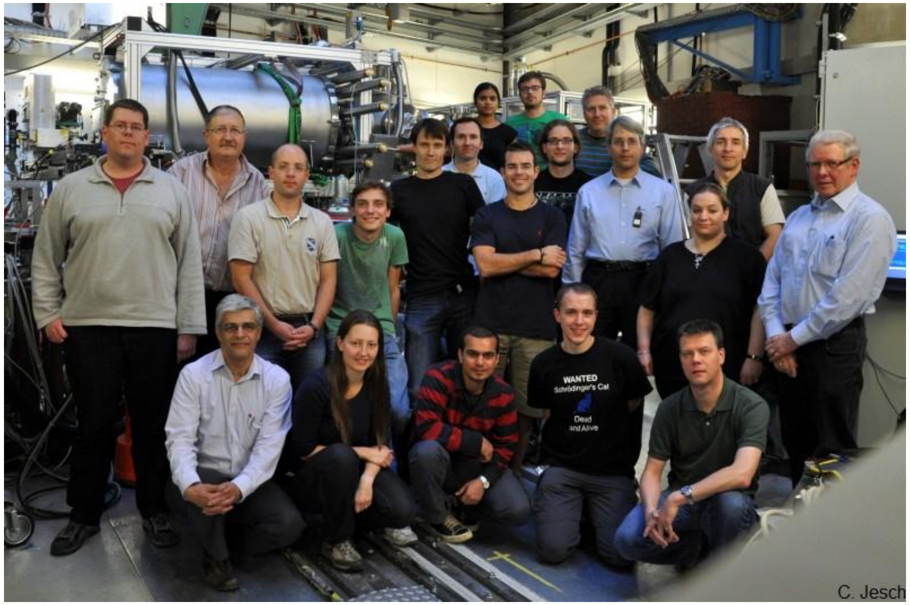
Further planned performance enhancements

- Stopping cell: Even higher densities
- MR-TOF-MS: Mass resolving power > 10^6 ($\rightarrow$ isomers?!)

Acknowledgements

FRS Ion Catcher / S411 Collaboration

F. Amjad[2], S. Ayet[2], T. Dickel[1,2], P. Dendooven[3], M. Diwisch[1], J. Ebert[1], A. Estrade[2], F. Farinon[2], H. Geissel[1,2], F. Greiner[1], E. Haettner[1], C. Jesch[1], N. Kalantar-Nayestanaki[3], R. Knoebel[2], J. Kurcewicz[2], J. Lang[1], I. Moore[4], C. Nociforo[2], M. Petrick[1], M. Pfuetzner[2], W.R. Plaß[1,2], S. Pietri[2], A. Prochazka[2], S. Purushothaman[2], M. Ranjan[3], M.P. Reiter[1], A.-K. Rink[1], S. Rinta-Antila[4], C. Scheidenberger[2], M. Takechi[2], Y. Tanaka[2], H. Weick[2], J.S. Winfield[2], M.I. Yavor[5]



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