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Results from the FRS Ion Catcher with projectile and fission fragments

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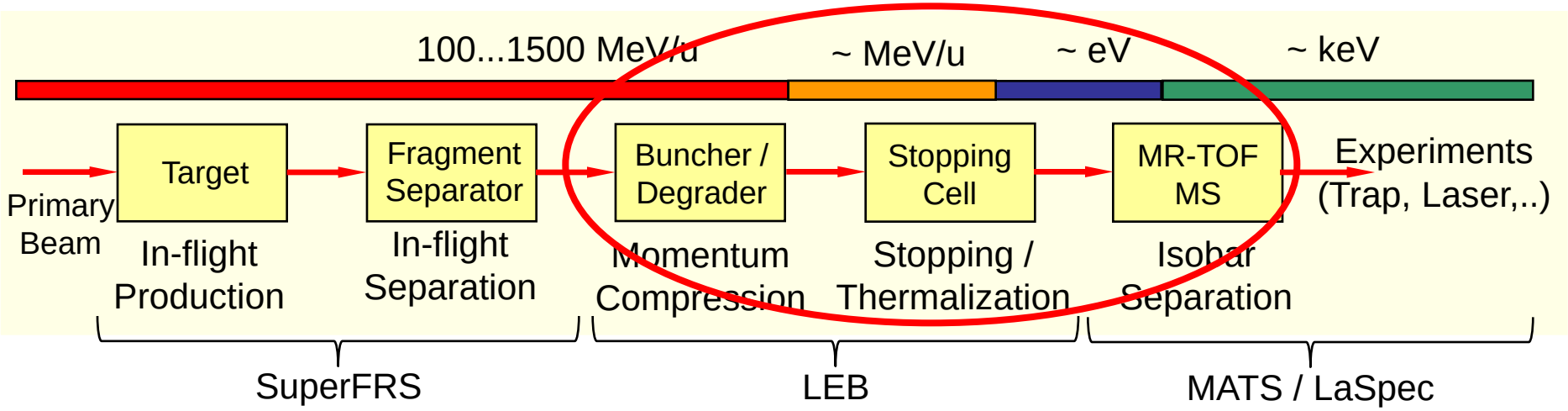
Overview

- The FRS Ion Catcher a test facility for the LEB
- Prototype of the Stopping Cell for the Super-FRS at FAIR
- Multiple-Reflection Time-of-Flight Mass Spectrometer
- Measurements at the FRS Ion Catcher in 2014
- Conclusions and Outlook

Low Energy Branch of the Super-FRS at FAIR

LEB of the Super-FRS:

universal and fast production - high selectivity - cooled exotic nuclei



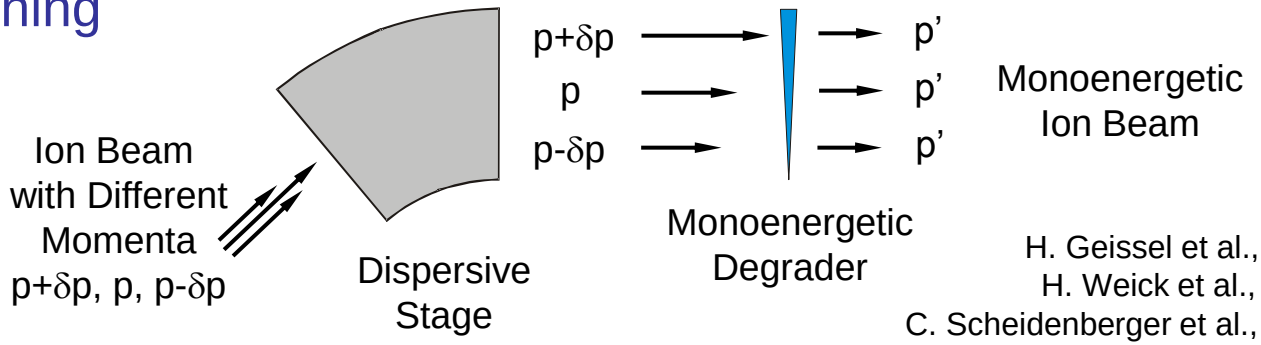
MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

LaSpec (Laser Spectroscopy)

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

Stopping Cell Principle

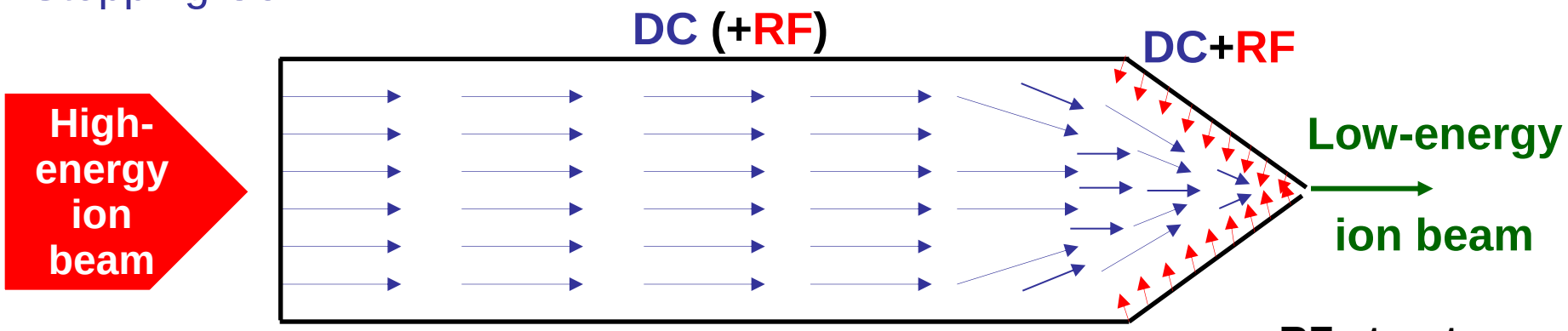
Range Bunching



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

Decreases range straggling by more than an order of magnitude
→ Enables stopping of ion produced at relativistic energies
in gas-filled stopping cells

Stopping Cell



M. Wada et al., NIM B 204 (2003) 570
G. Savard et al., NIM B 2004 (2003) 582

Converts high energy, large emittance beam in
low energy, low emittance beam

Stopping Cell Design

Cryogenic Operation

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

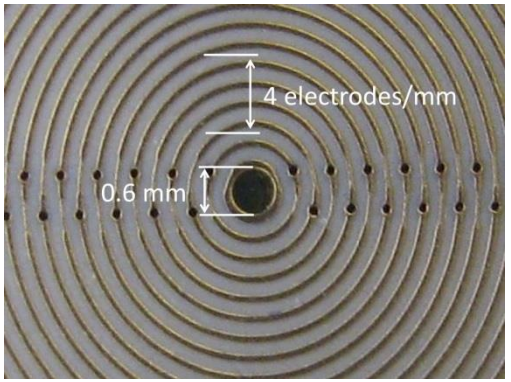
- Ultra-pure helium (freezing-out of contaminants)
  - Ideal for ion survival, 2+ charge state possible
  - No formation of molecules/adducts
- Reduced radial ion diffusion
- Reduced requirements for cleanliness → easier, more flexible construction

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 to achieve high RF repelling field (PCB-based RF carpet instead of RF funnel)

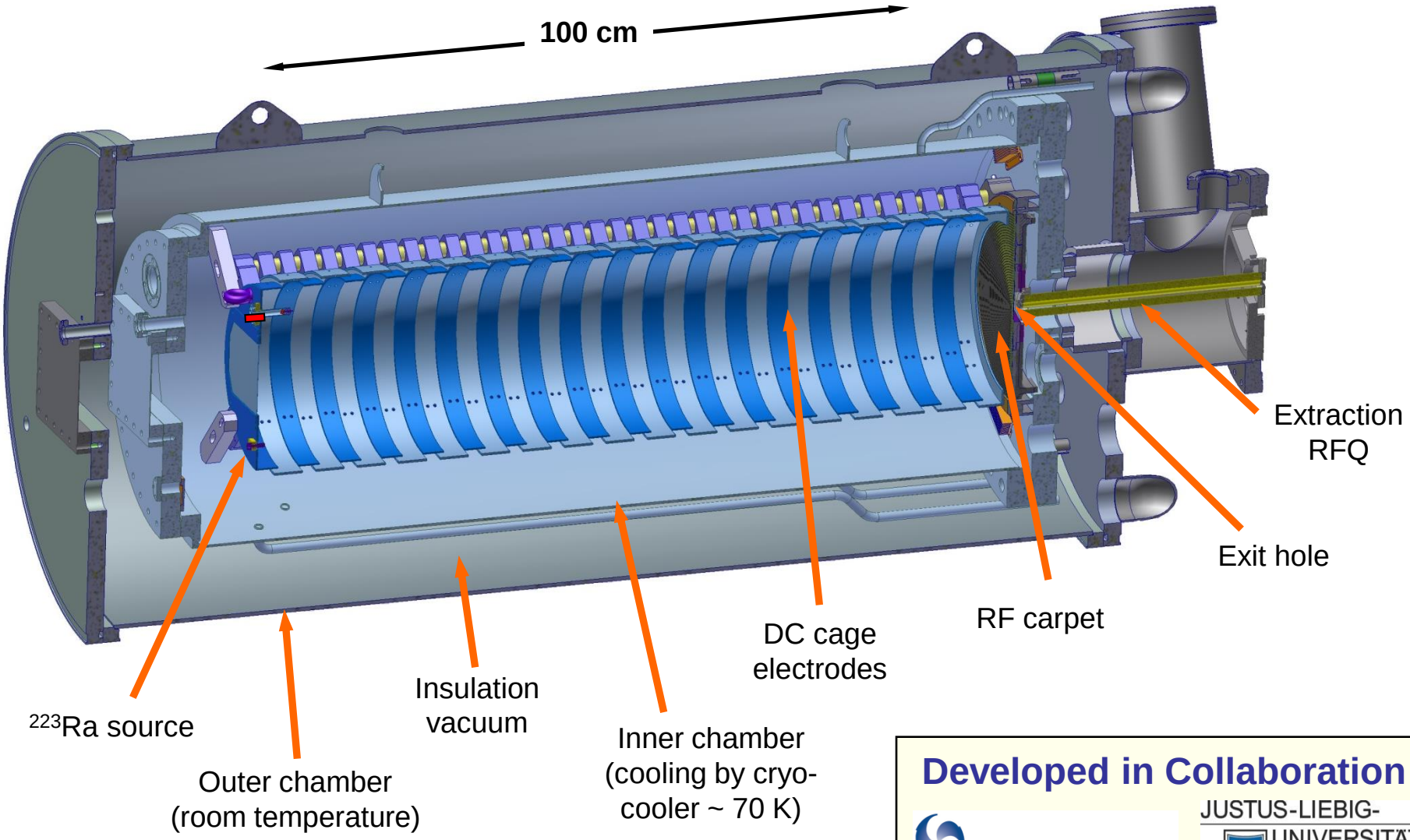
- High stopping gas densities
- Less complex construction than RF funnels



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

Diameter:	250 mm
Electrode spacing:	0.25 mm

Prototype of the Stopping Cell for the LEB



Developed in Collaboration

Kernfysisch Versneller Instituut

university of groningen

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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.

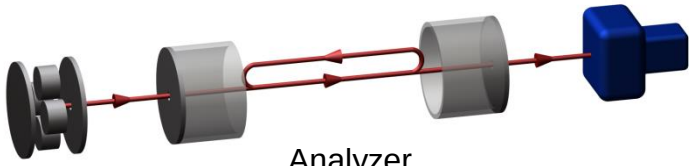
Motivation: TOF Mass Spectrometry in Nuclear Physics

Enables high performance

- Fast → access to very short-lived ions ($T_{1/2}$ ~ ms)
- Sensitive, broadband, non-scanning → efficient, access to rare ions

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

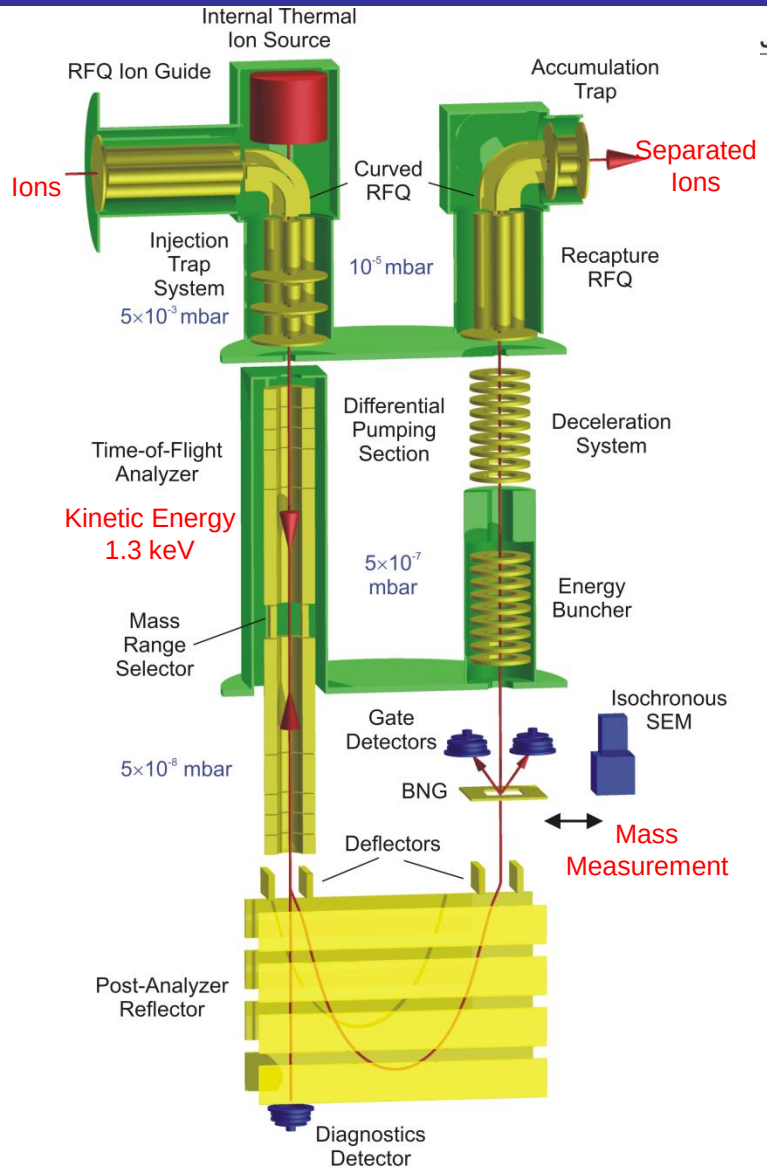
- High-resolution isobar separator

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

Multiple-Reflection Time-of-Flight Mass Spectrometer



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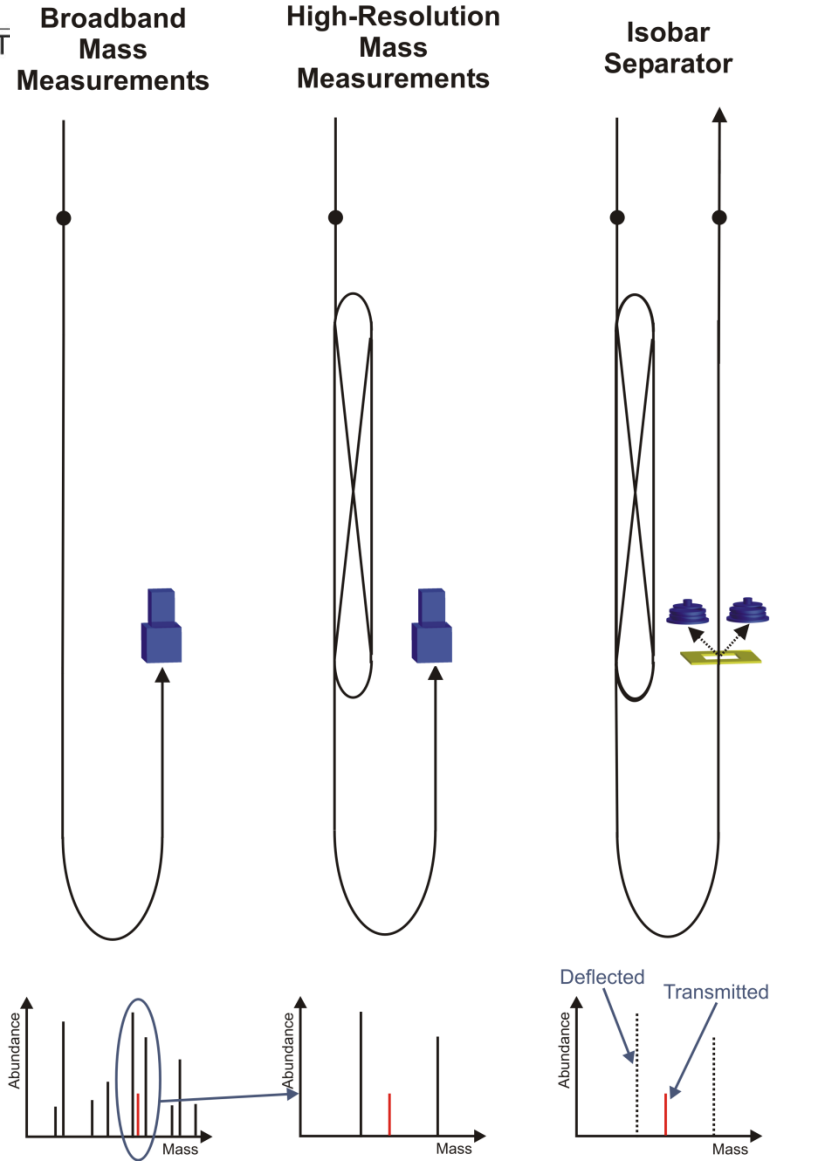


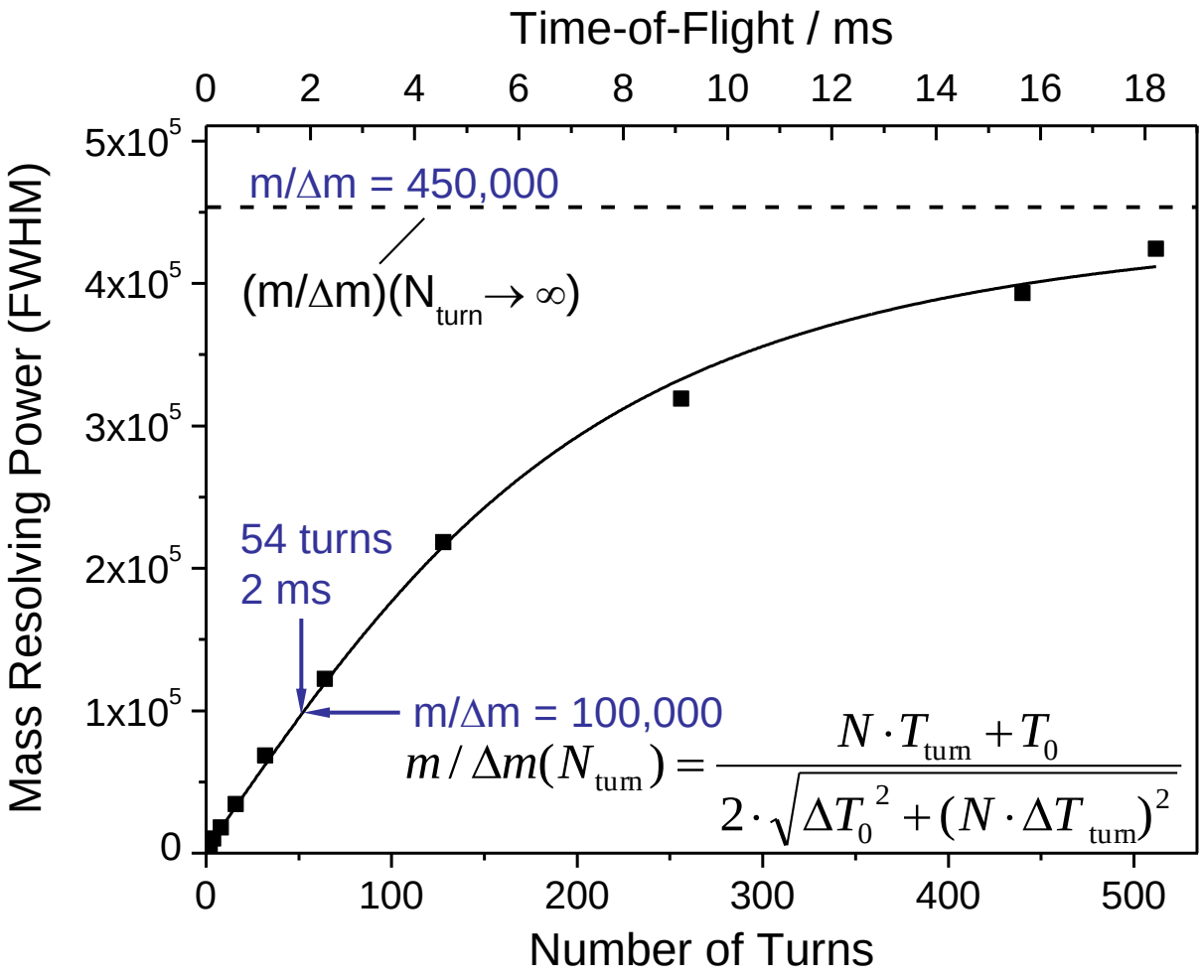
W.R. Plaß et al., Int. J. Mass Spectrom. 394 (2013) 134
T. Dickel et al., NIM A 777 (2015) 172 - 188
M. I. Yavor et al., IJMS (2015) in press

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

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

$m/\Delta m > 10^5$

MR-TOF-MS: Mass Resolving Power



Mass Measurement Accuracy

~10^{-7}

Transmission efficiency

up to 70%

Sensitivity

~10 ions

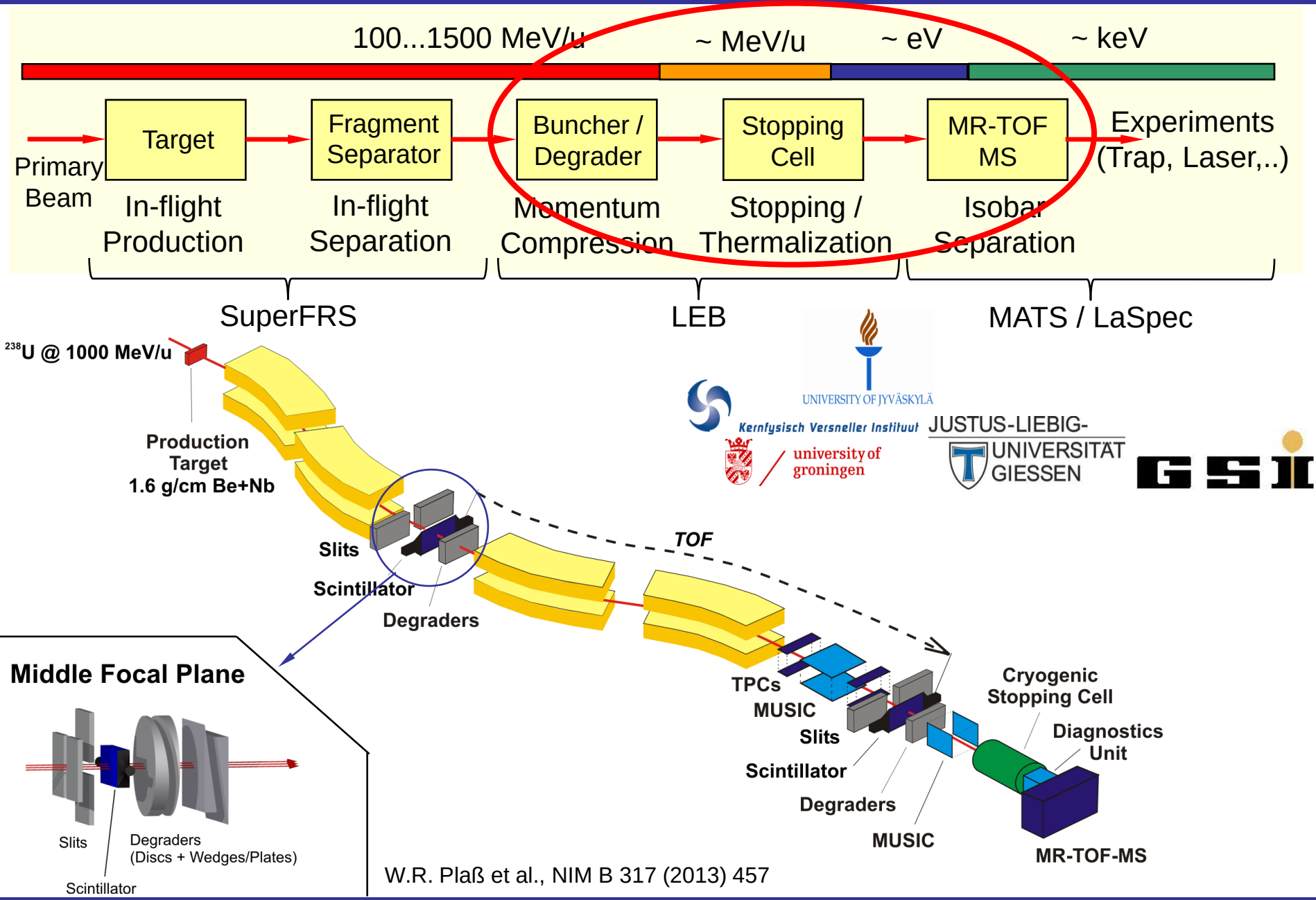
Isobar separator with high ion capacity

>10^6 ions/s

World-wide unique combination of performance characteristics!

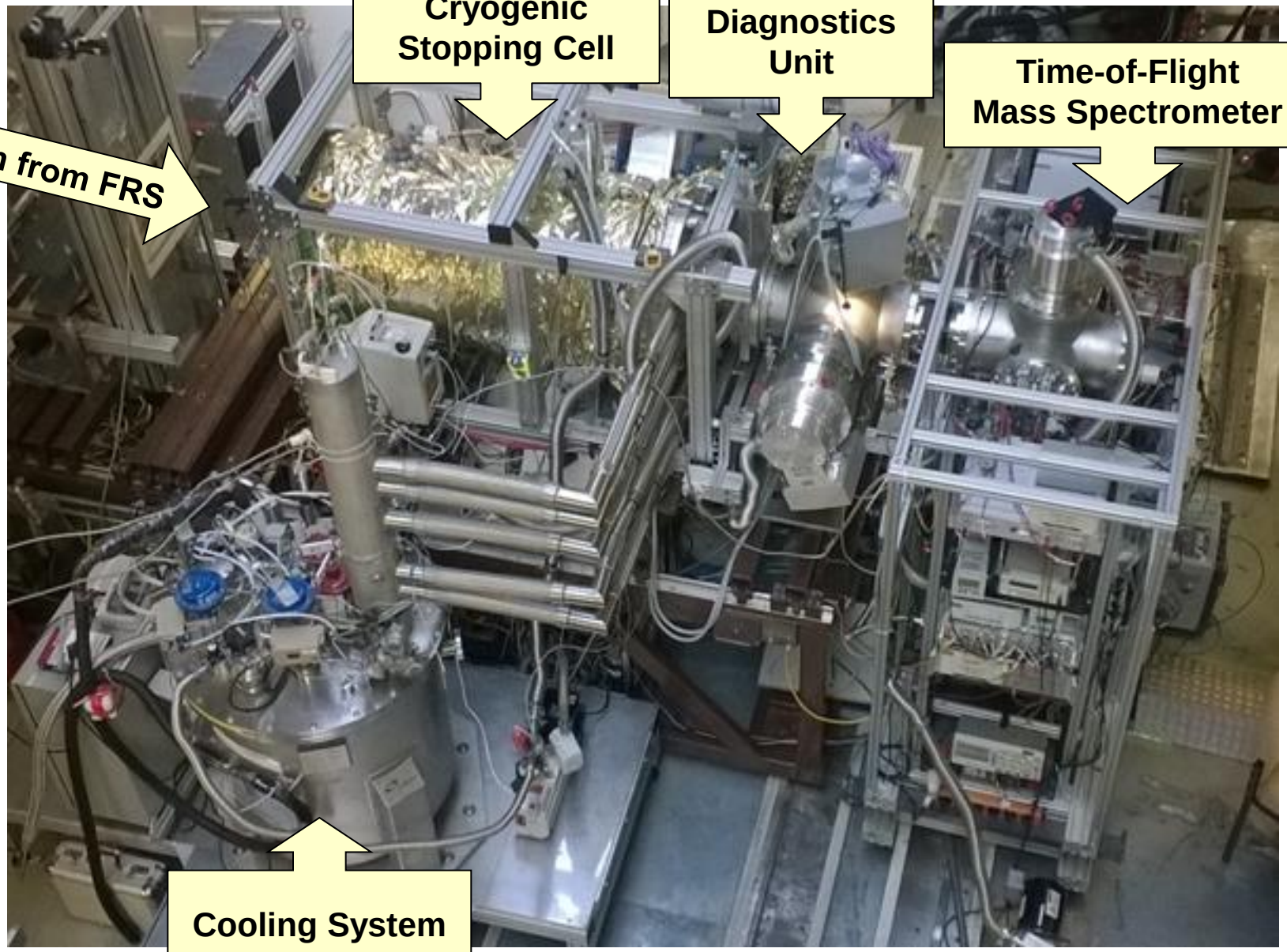
$^{133}Cs^+$, Ion kinetic energy 1.3 keV

FRS Ion Catcher a Test Facility for the LEB



W.R. Plaß et al., NIM B 317 (2013) 457

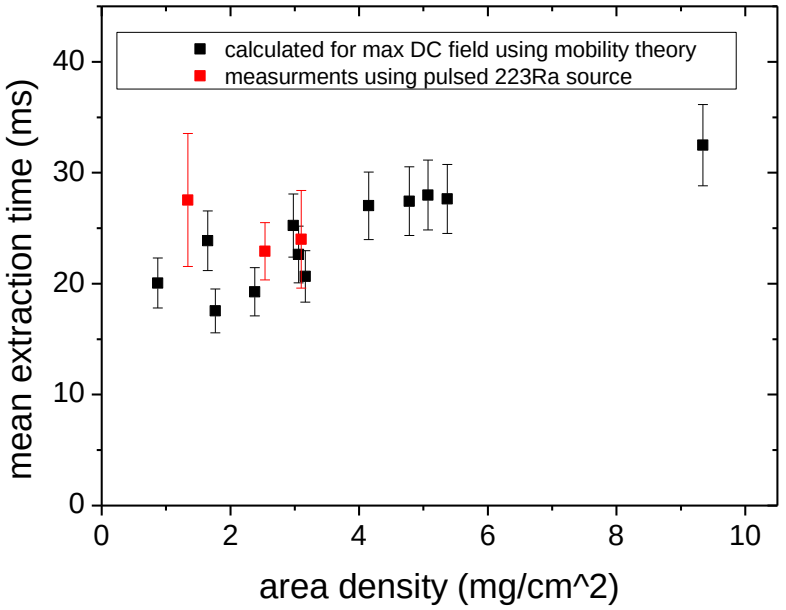
Setup at the FRS Ion Catcher at GSI



Systematic Investigations

Extraction time:

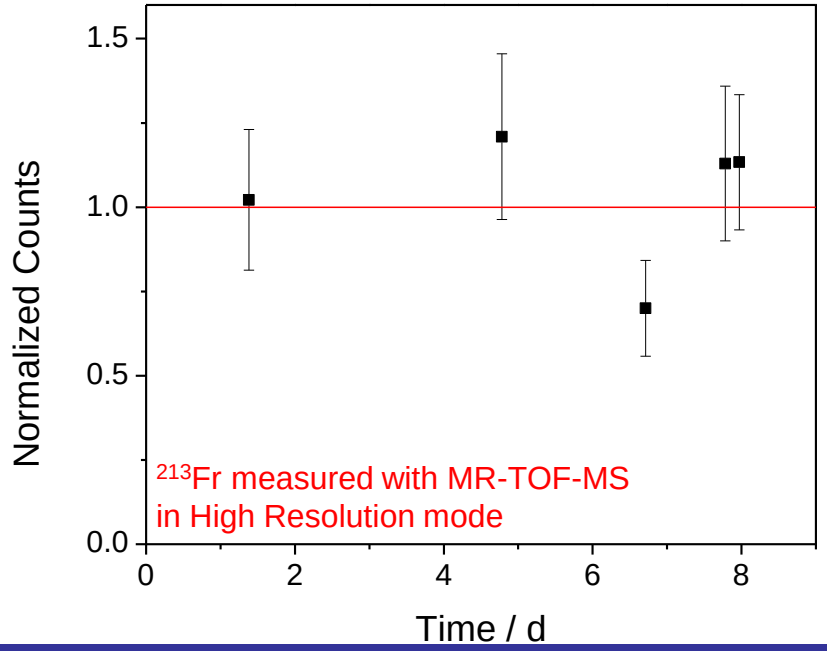
- Extraction time independent of areal density
- given by mechanical desgin of stopping cell



Stability of operation:

from production to mass measurement

Stable over one week beam time

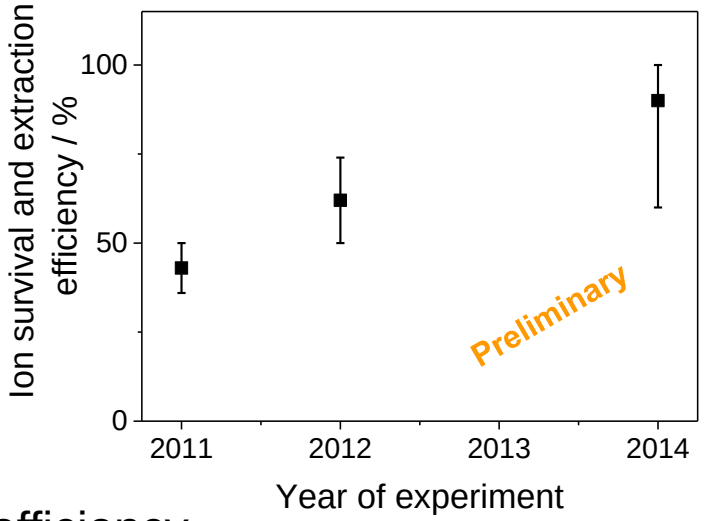


Improved Total Efficiency

- Carpet with improved electrical desgin:
  - Higher RF-amplitude possible and lower temperatures

Year	Max. RF-amplitude	Temperature of RF coil
2012	80 Vpp	270 °K
2014	140 Vpp	150 °K

- Improved bake-out + New carpet
  → better cleanliness
    → Higher ion survial and extraction efficiency (eg. ^{223}Th)

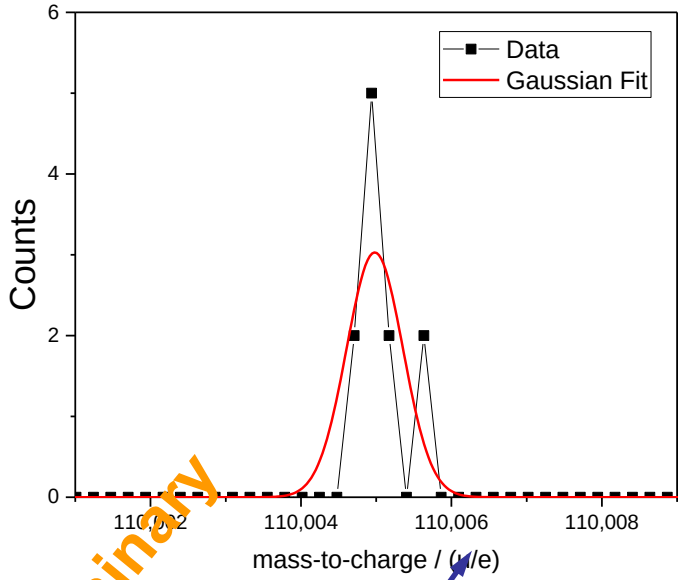


- Higher differential pumping
  → Higher areal density → Higher stopping efficiency
  2012: 3.1 mg / cm²
  2014: 6.3 mg / cm²

→ Improved total efficiency up to 30%
Factor 2 higher than 2012

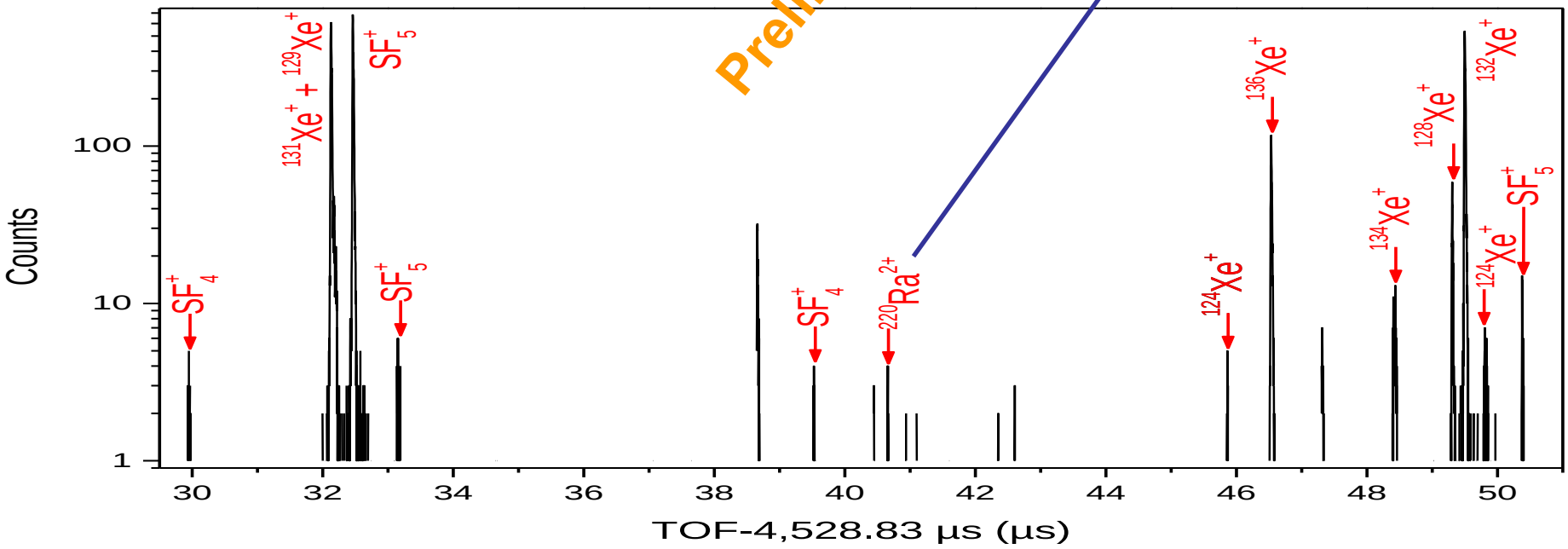
Mass Measurement: Uranium Projectile Fragments

- Mass window of ~ 30 u
- Mass resolving power ~ 120,000
- Doubly charged
- Shortest half-life
- Highest sensitivity



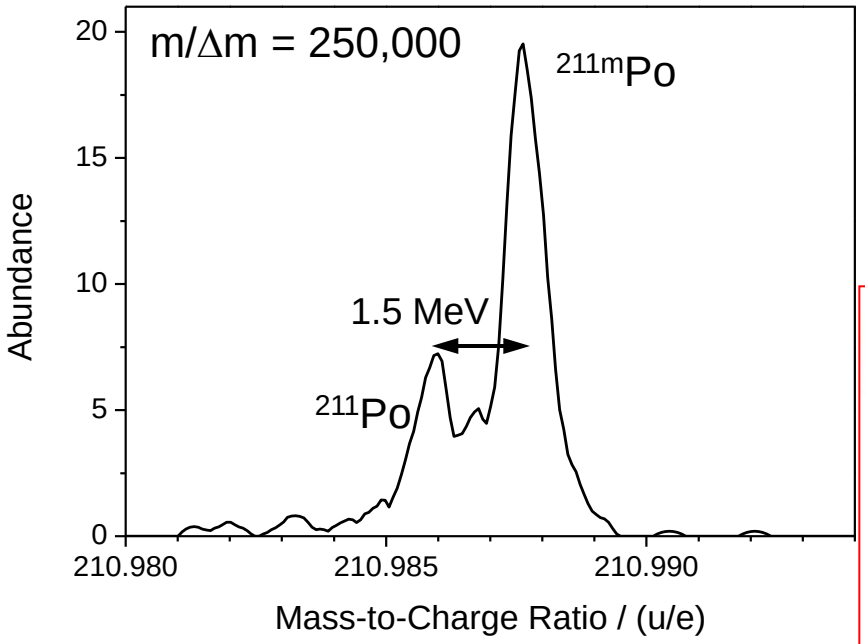
$^{220}Ra^{2+}$
Half-life: 17.9 ms
11 ions

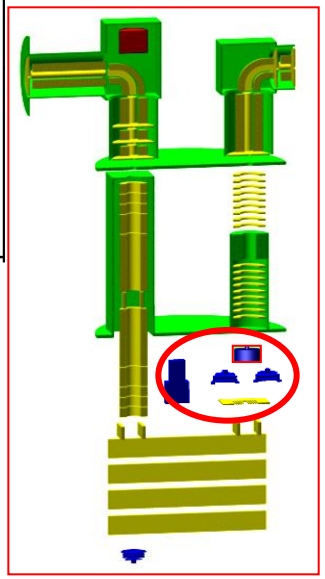
Preliminary



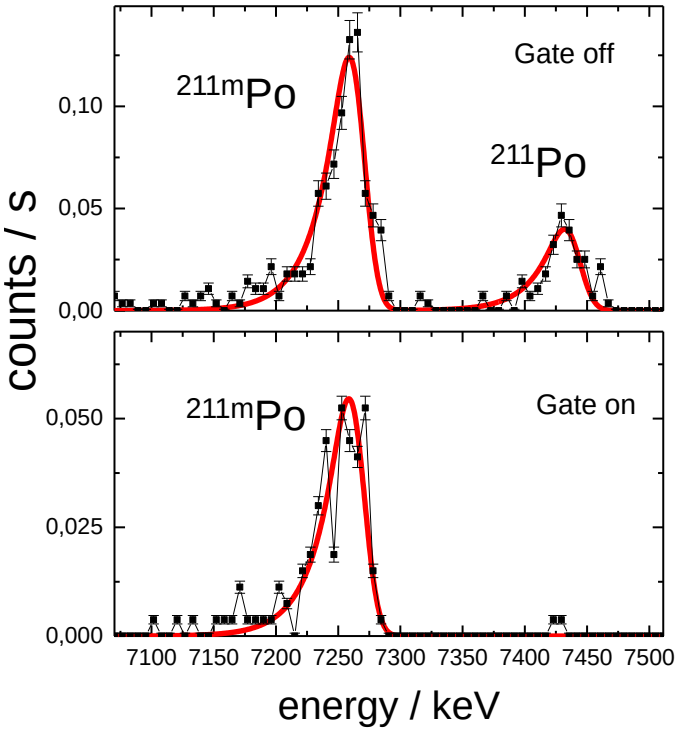
Measurement and Separation of Isomers

Measurement of isomers





Spatial separation of ground state and isomeric state

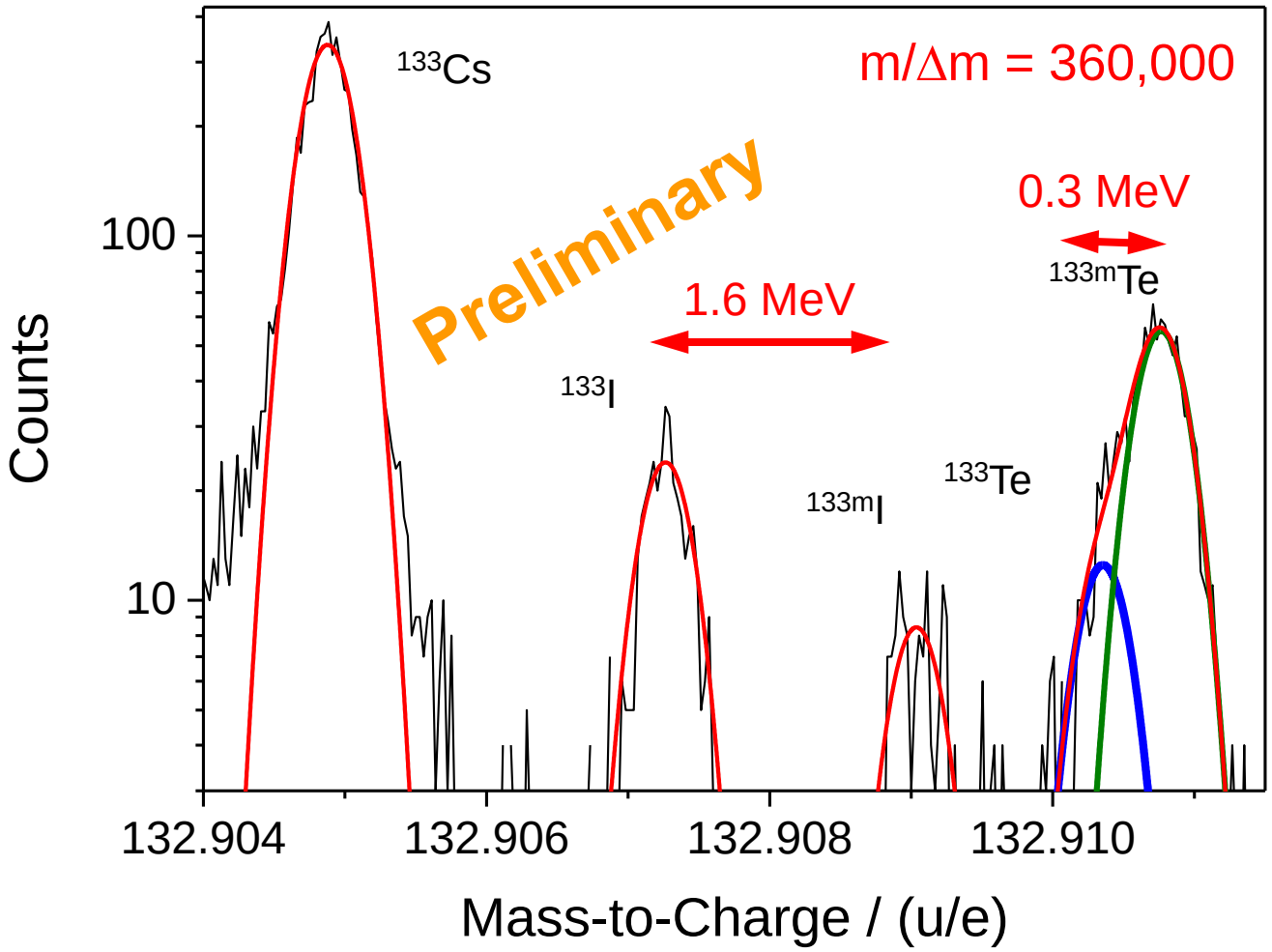


- Identification of ^{211}Po and ^{211m}Po
- Measurement of excitation energy
- Measurement of isomeric ratio

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

Mass Measurement: Uranium Fission Fragments

- Mass measurement of uranium fission products produced at 1000 MeV/u
- MR-TOF-MS will enable efficient search and measurement of new isotopes and isomers



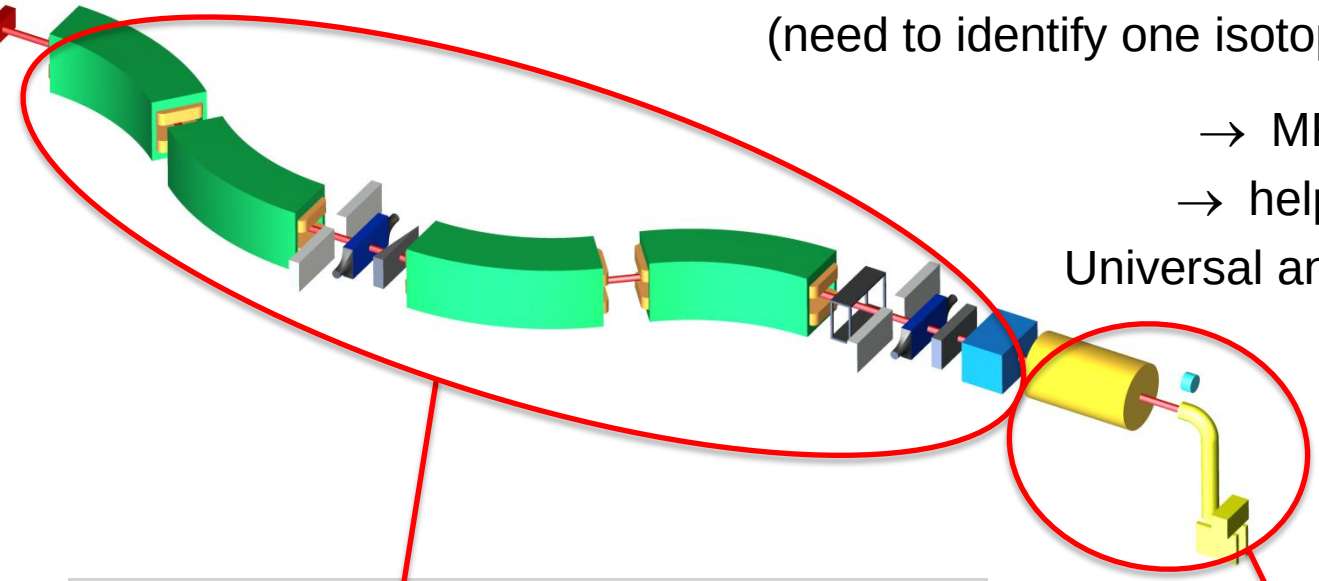
CSC + MR-TOF-MS as Mass Tagger

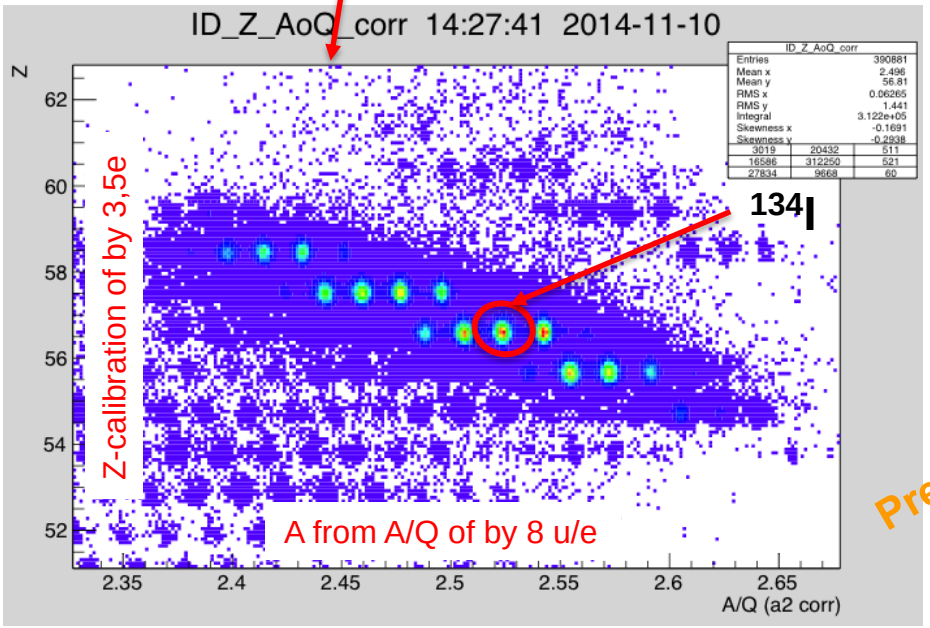
FRS identification may not always be accurate
(need to identify one isotope in the identification plot)

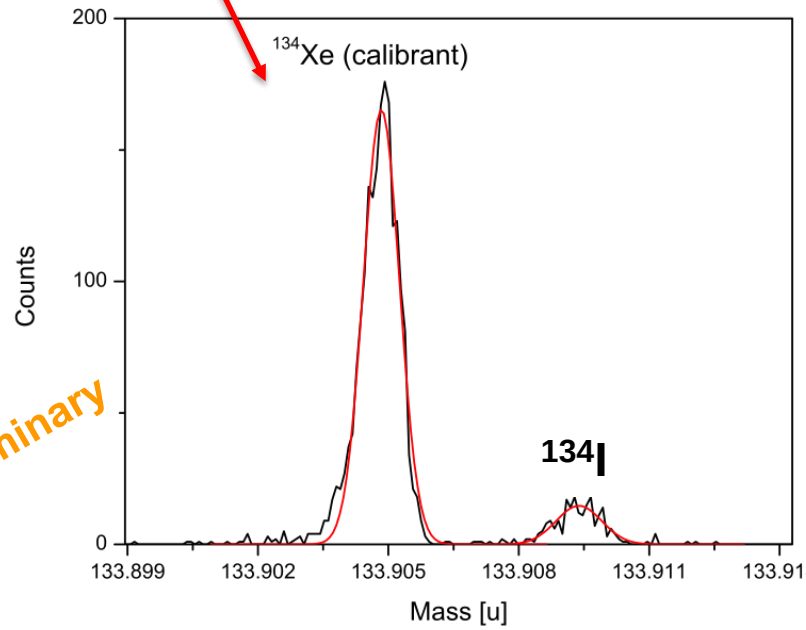
→ MR-TOF-MS as mass tagger

→ helped to correctly identify ^{134}I

Universal and fast technique (~20 min)



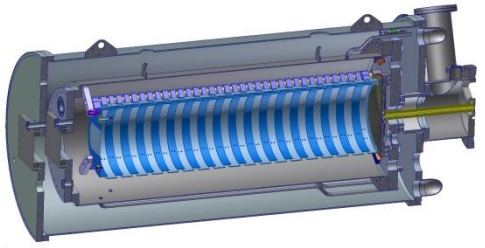




Preliminary

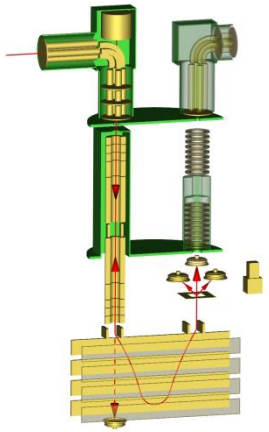
Conclusions and Outlook

(Prototype)Stopping cell for the Super-FRS and the FRS Ion Catcher



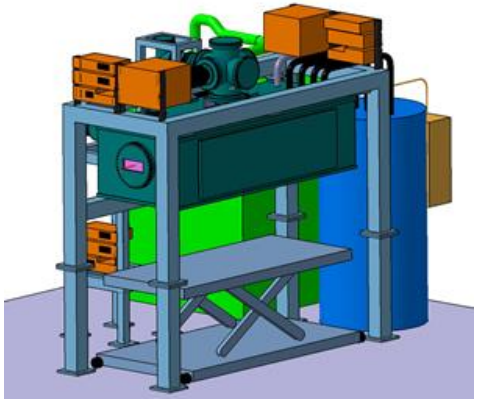
- Cryogenic, high density operation, suitable for exotic nuclei produced at relativistic energies
- Unprecedented efficiencies for relativistic ions
  Access to short life times (extraction time ~ 25 ms)

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



- High-accuracy mass measurements at m/Δm up to ~ 450,000
  Harvest of 6 shifts of beam time:
  ≥ 8 first direct mass measurements,
  e.g. ^{220}Ra ($T_{1/2}$ = 17.9 ms, 11 ions only)
- Powerful tool for the measurement of isomers:
  Identification, excitation energies, isomeric ratios
- High-resolution mass separator for isobars and isomers
- Diagnostics tool: identification and quantification

Development of the future stopping cell for the Super-FRS



- Higher areal densities
- Shorter extraction times
- Higher rate capabilities

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], F.Heiße[2], C.Hornung[1], C. Jesch[1], N. Kalantar-Nayestanaki[3], R. Knoebel[2], J. Kurcewicz[2], J. Lang[1], W.Lippert[1], I. Miskun[2], I. Moore[4], C. Nociforo[2], A. Pikhtelev[5], M. Petrick[1], M. Pfuetzner[2], W.R. Plaß[1,2], S. Pietri[2], I. Pohjalainen[4], 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], X.Xiaodong[1,2], M.I. Yavor[6]

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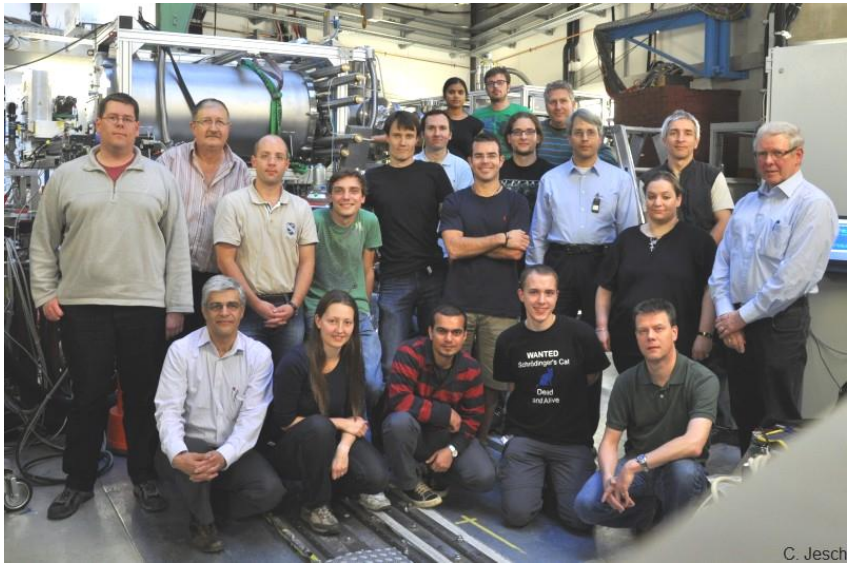

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