Ion Catcher & MR-TOF-MS for NUSTAR Experiments

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for the
FRS Ion Catcher Collaboration

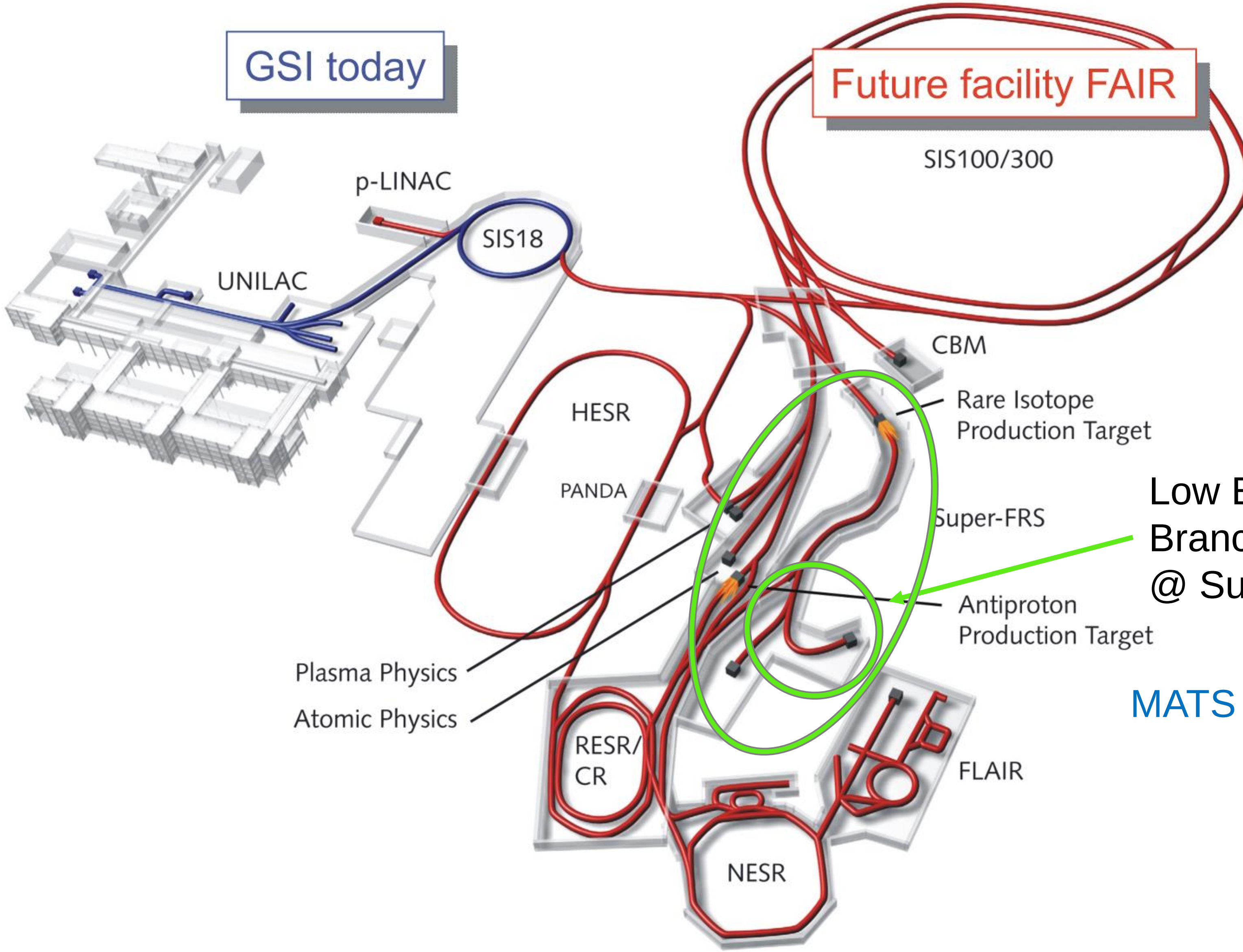
II. Physikalisches Institut, Justus-Liebig Universität Gießen

HIC 4 FAIR Detector Workshop 10.04.2015 Frankfurt/M

NUSTAR and Low Energy Branch
FRS Ion Catcher
Developments and Results

NUSTAR @ FAIR

***Nu**clear **St**ructure, **A**strophysics and **R**eactions*



Low Energy Branch (LEB) @ SuperFRS

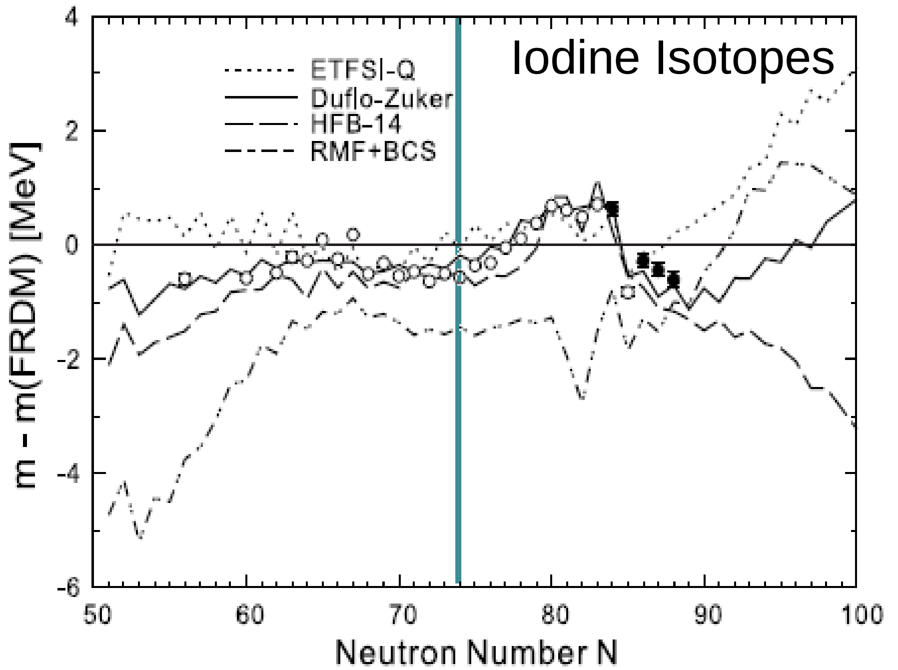
MATS & LaSpec

MATS

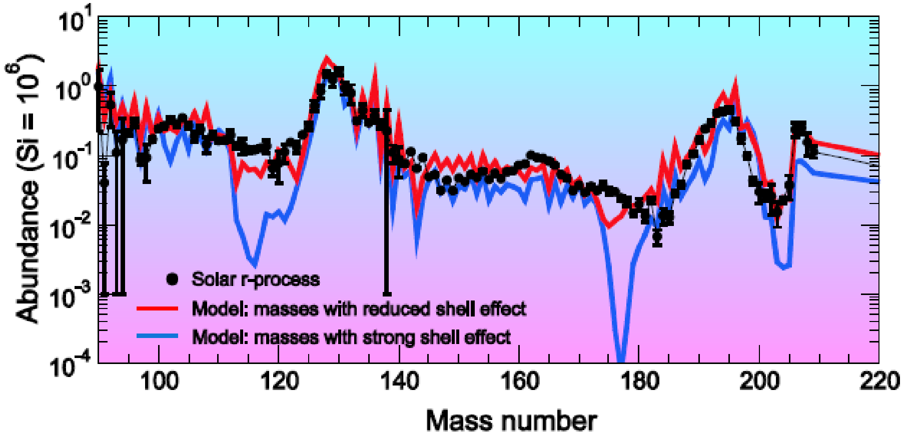
MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

D. Rodriguez et al., Eur. Phys. J. Special Topics 183 (2010) 1

- High precision mass measurements
- Spectroscopy on highly-charged ions
- In trap spectroscopy



- Nuclear structure
- Test of mass models far from stability



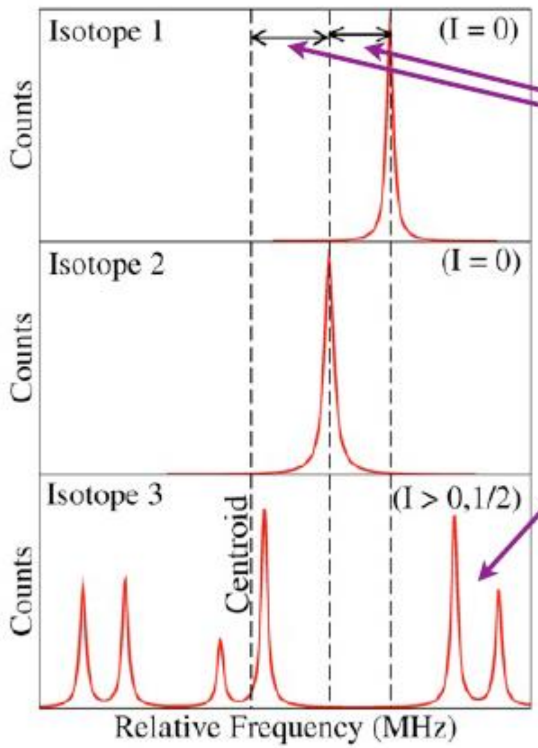
- Nuclear astrophysics
  - Explain nuclear abundances
  - Nucleosynthesis
    - e.g. r-process

D. Rodriguez et al., Eur. Phys. J.
Special Topics 183 (2010) 1

LaSpec (LAser SPECtroscopy)

- Collinear laser spectroscopy on ions
- Optical pumping and collinear laser spectroscopy on atoms

Isotope shift, hyperfine structure, charge radii and nuclear moments



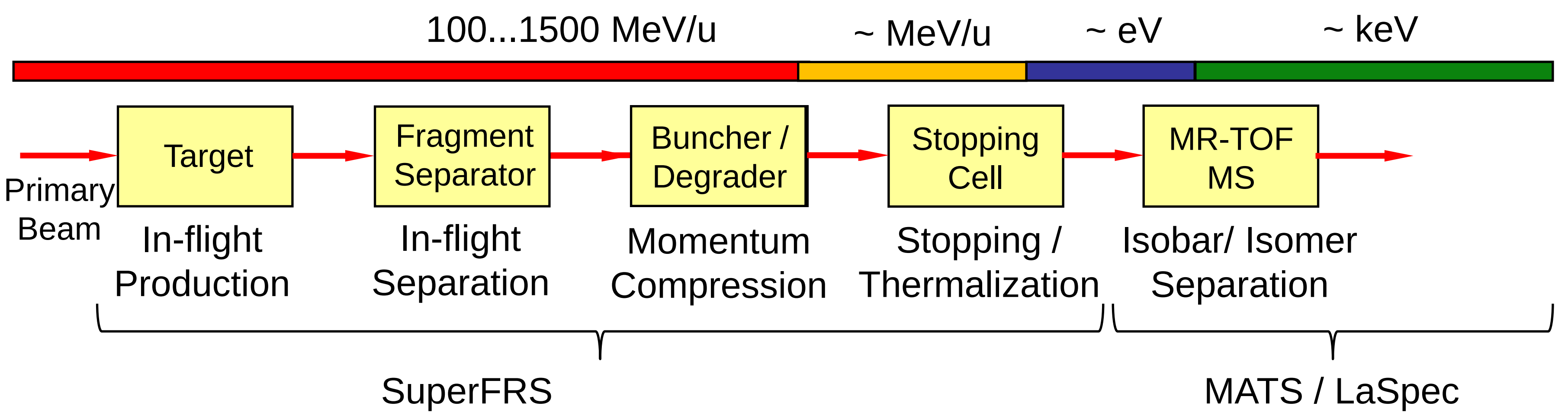
Isotope Shifts
→$\delta\langle r^2\rangle$

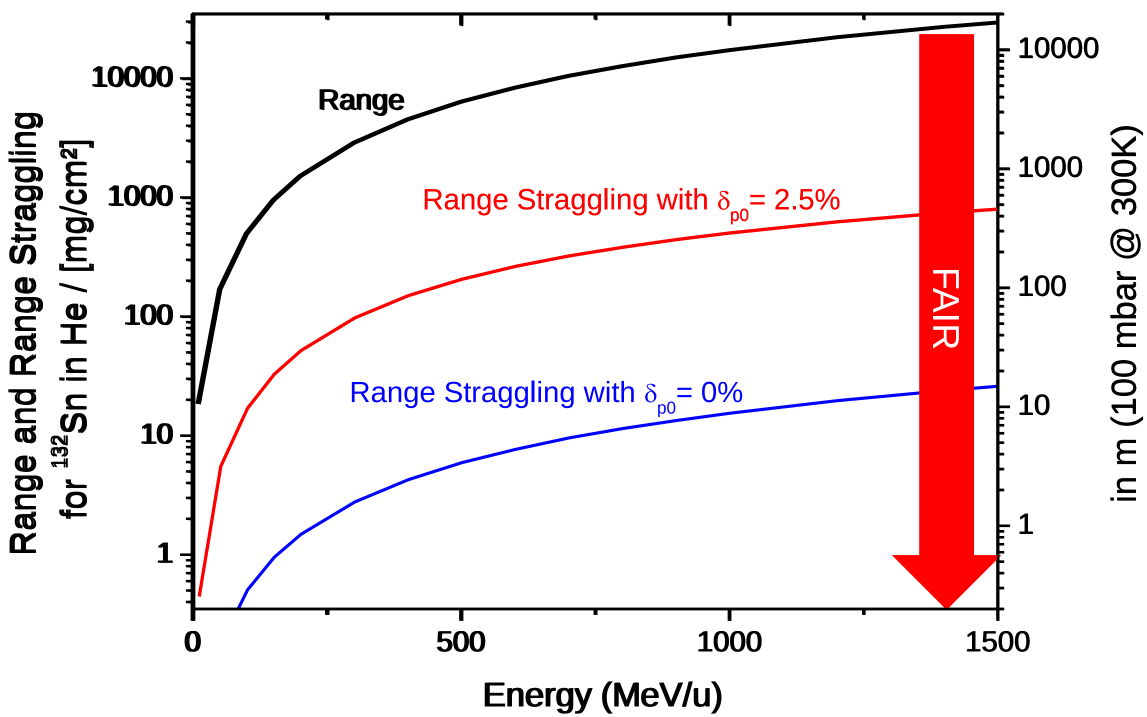
Hyperfine Structure
→ μ
→ Q_s →$\langle\beta_2\rangle$
→Nuclear Spin

shape of the nucleus

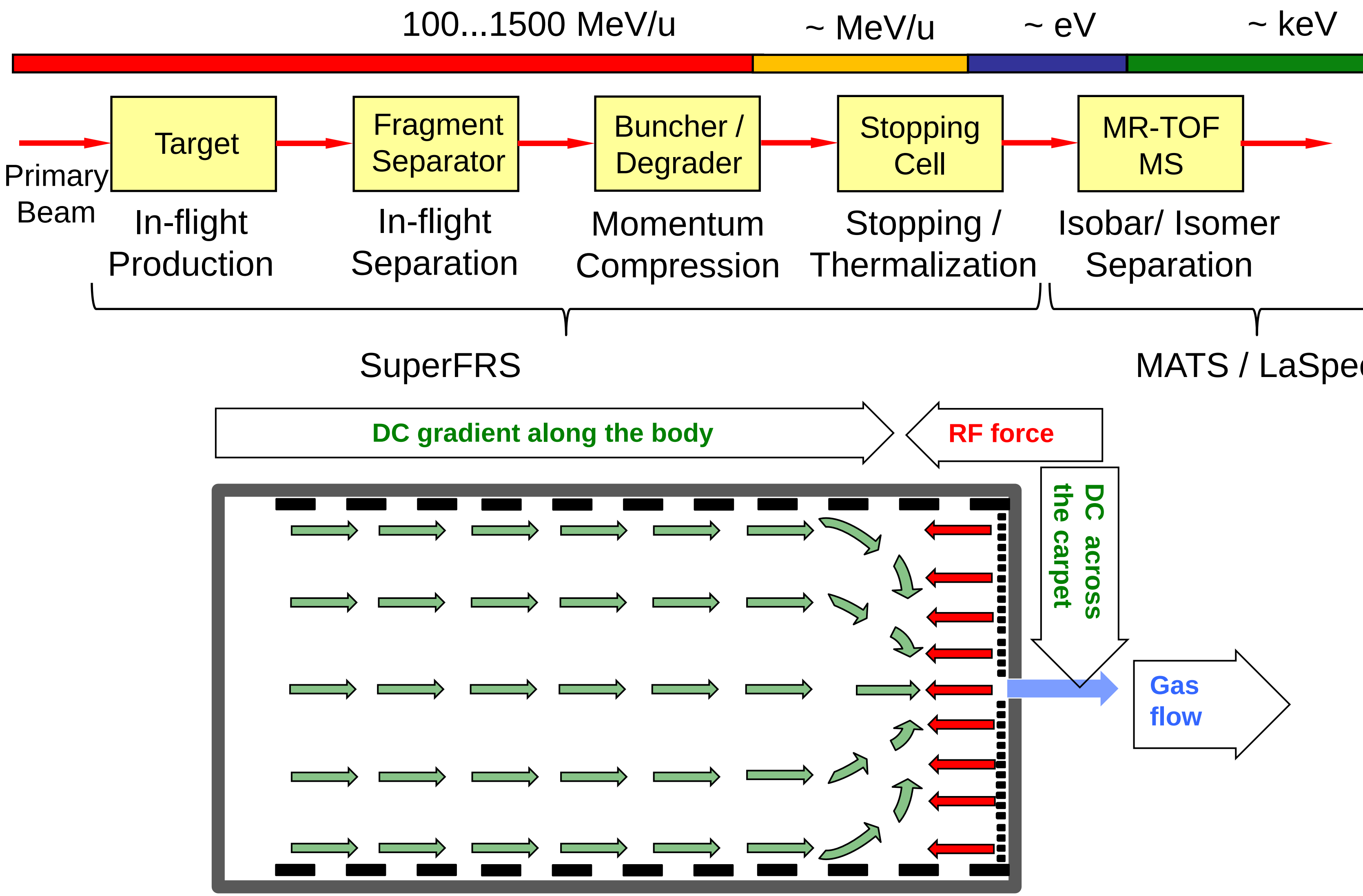
spherical   prolate (cigar shape)

LEB – from **GeV** to **keV**



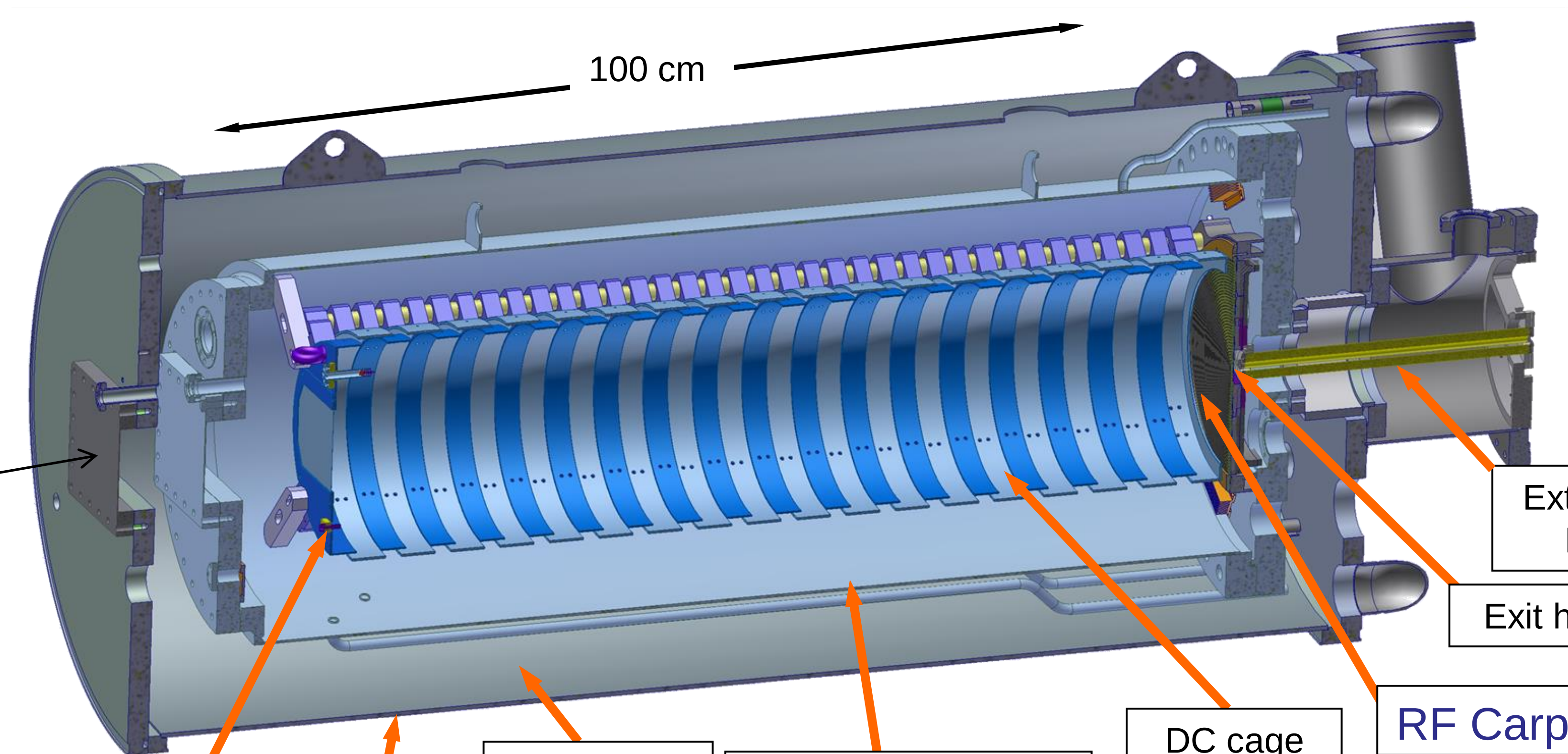


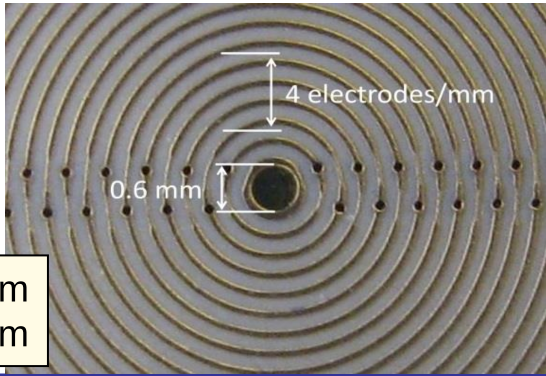
LEB – from **GeV** to **keV**



Arrows show direction of force

Cryogenic Stopping Cell





Diameter: 250 mm
Electrode spacing: 0.25 mm

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

TOF Mass Spectrometry in Nuclear Physics

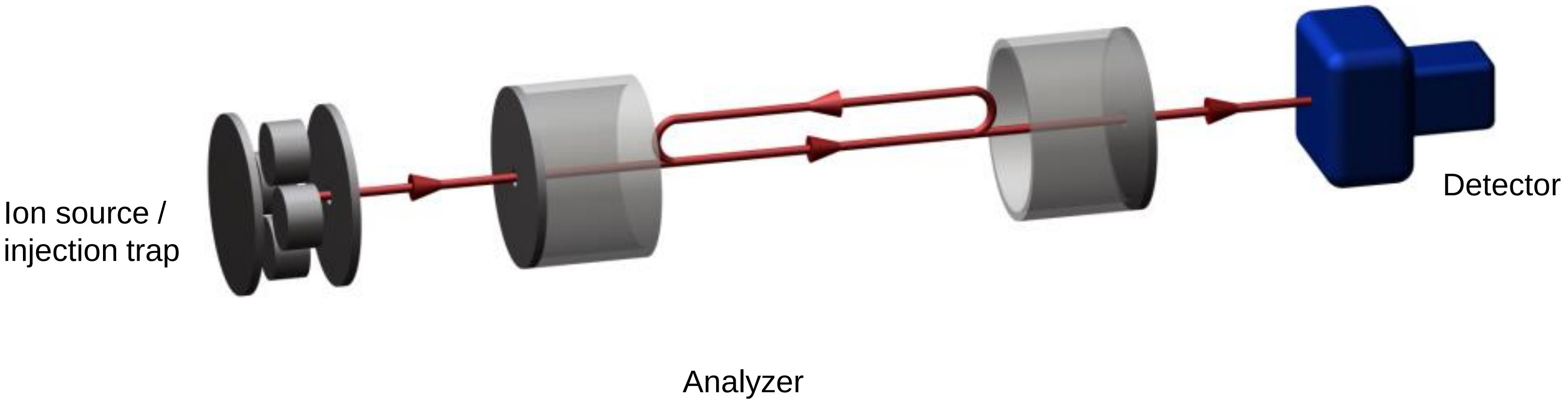
Enables high performance

Fast → access to very short-lived ions ($T_{1/2}$ ~ ms)
Sensitive, broadband, non-scanning → efficient, access to rare ions
Mass resolving power and accuracy almost mass-independent

Conventional TOF-MS achieve medium mass resolving power only

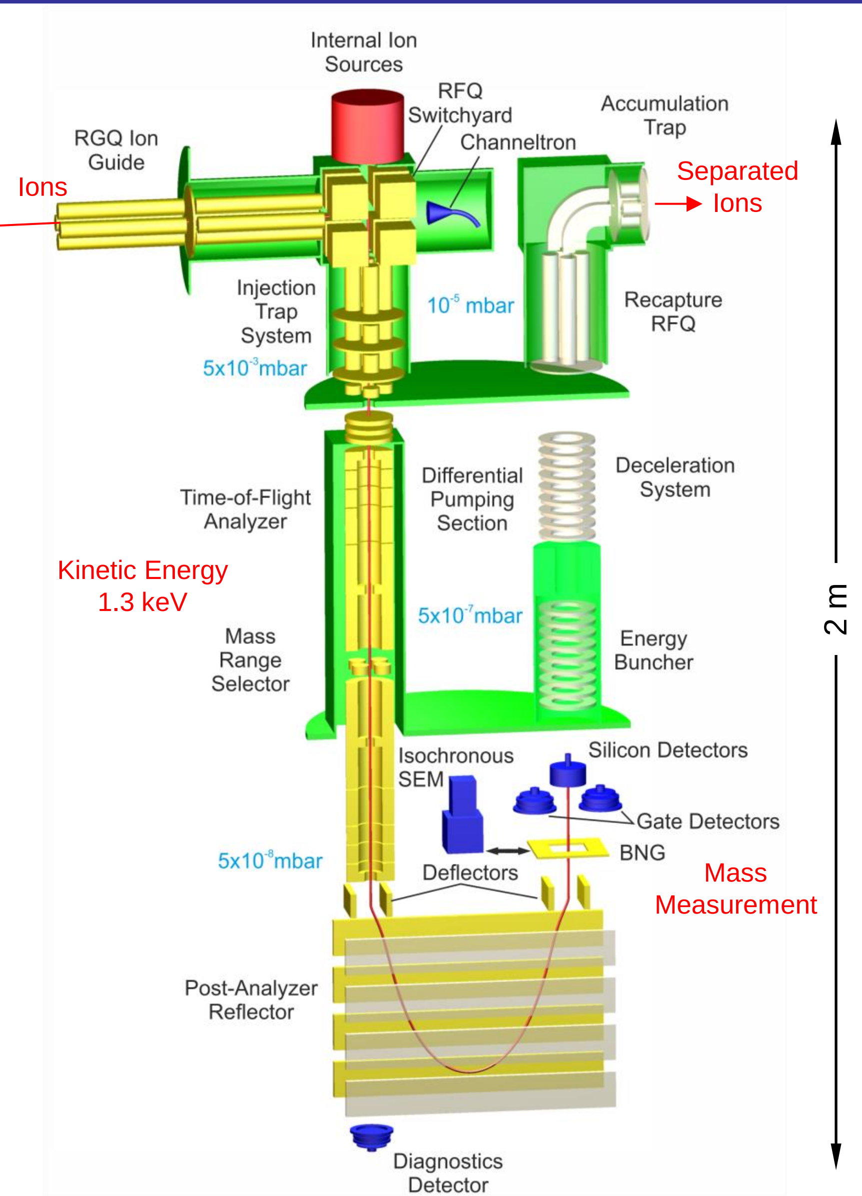
→ Solution to achieve high mass resolving power and accuracy:

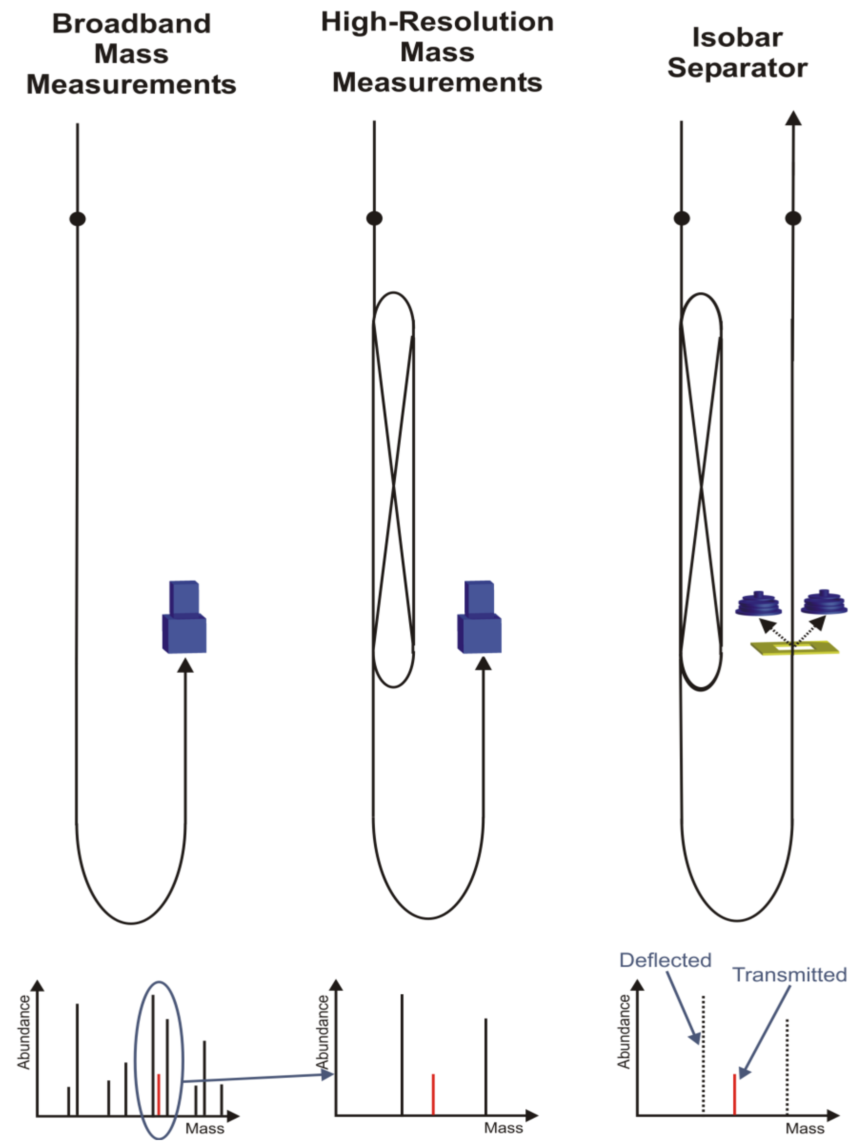
Multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS)



H. Wollnik et al., Int. J. Mass Spectrom. Ion Processes 96 (1990) 267

Multiple-Reflection Time-of-Flight Mass Spectrometer





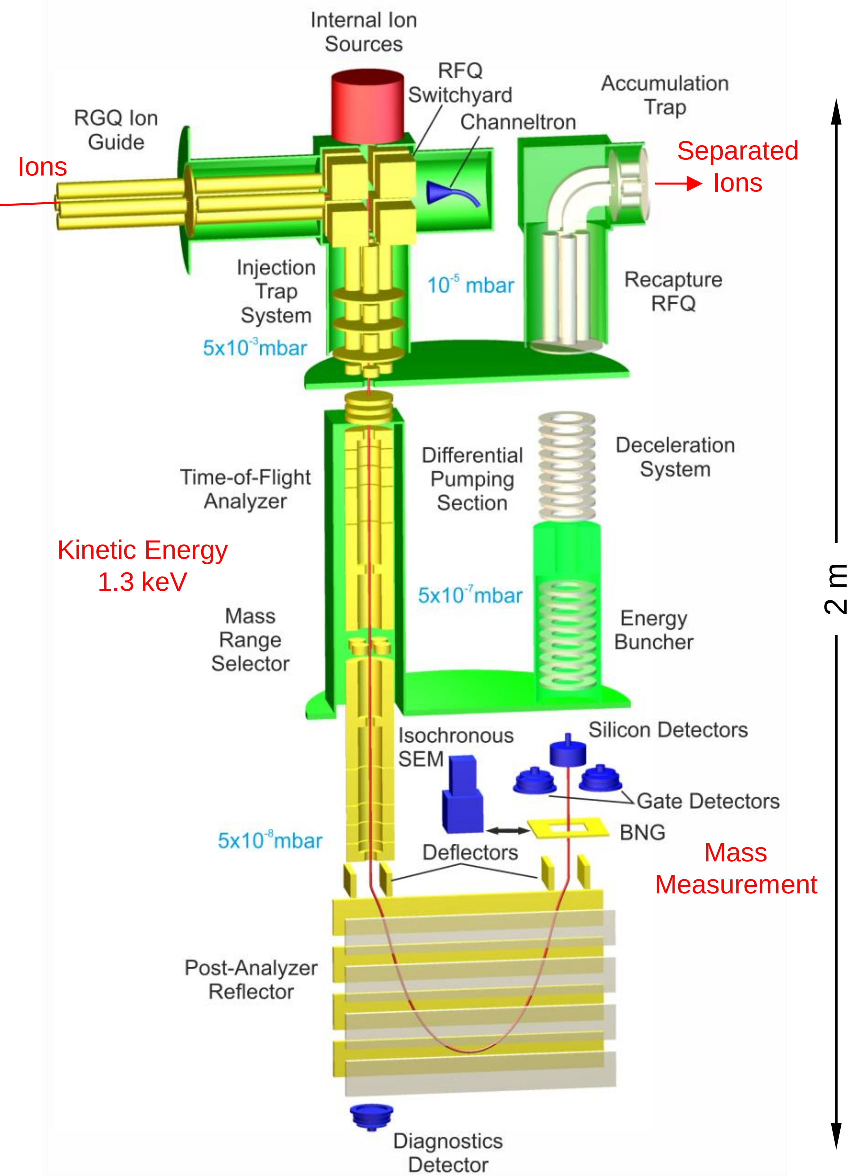
Full Mass Range, $m/\Delta m \sim 10^3$-10^4

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

$m/\Delta m > 10^5$

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., Int. J. Mass Spectrom. (2015), http://dx.doi.org/10.1016/j.ijms.2015.01.002

Multiple-Reflection Time-of-Flight Mass Spectrometer



Mass Measurement Accuracy

~10^{-7}

Transmission efficiency

up to 70%

Sensitivity

~10 ions

Isobar separator with high ion capacity

>10^6 ions/s

W.R. Plaß et al., Int. J. Mass Spectrom. 394 (2013) 134
T. Dickel et al., NIM A 777 (2015) 172 - 188
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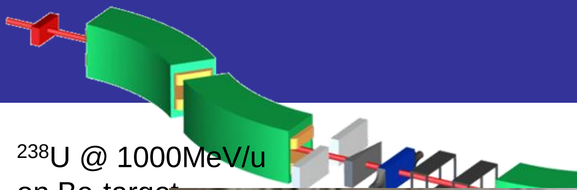
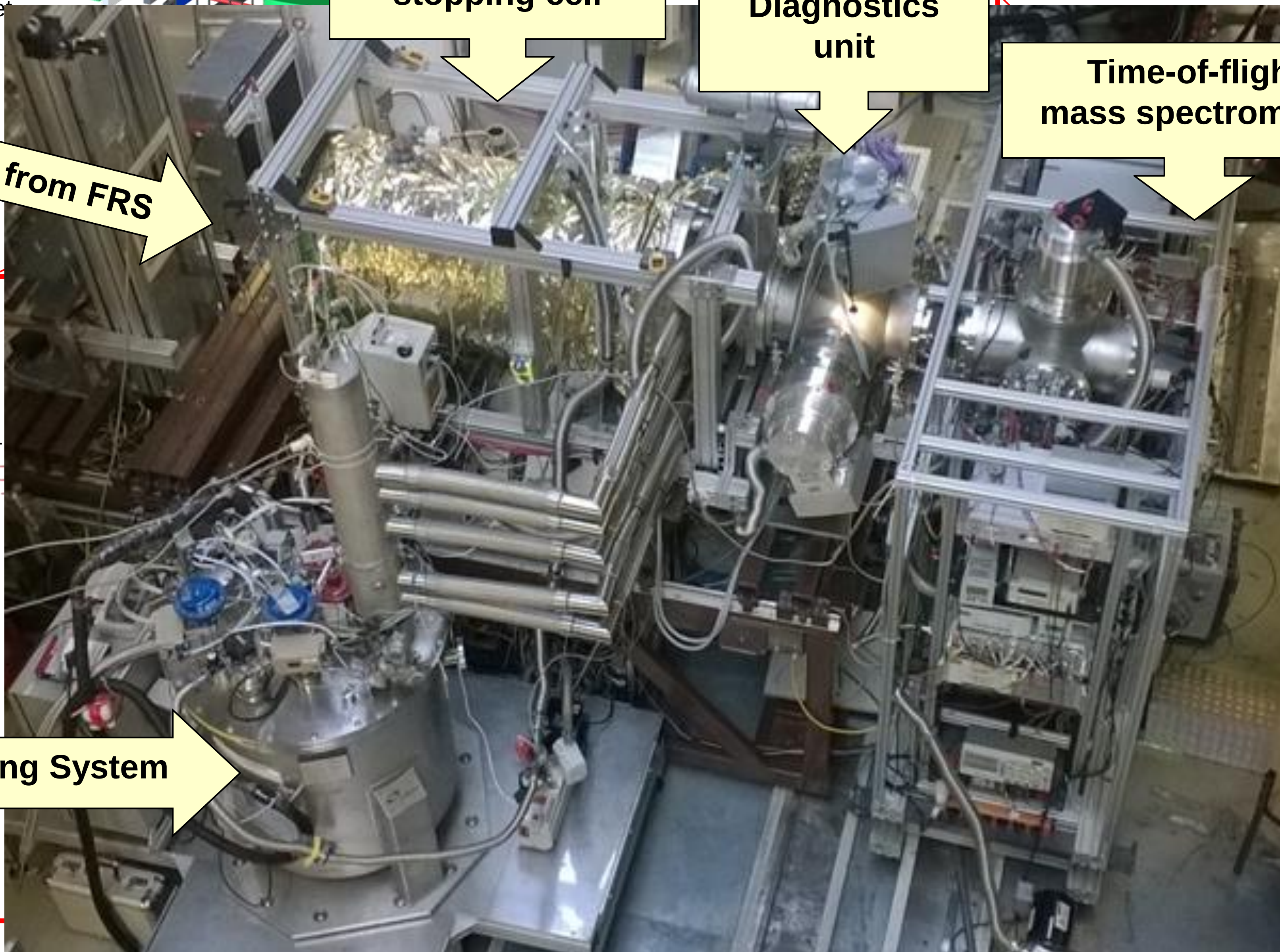
FRS Ion Catcher



^{238}U @ 1000MeV/u
on Be-target



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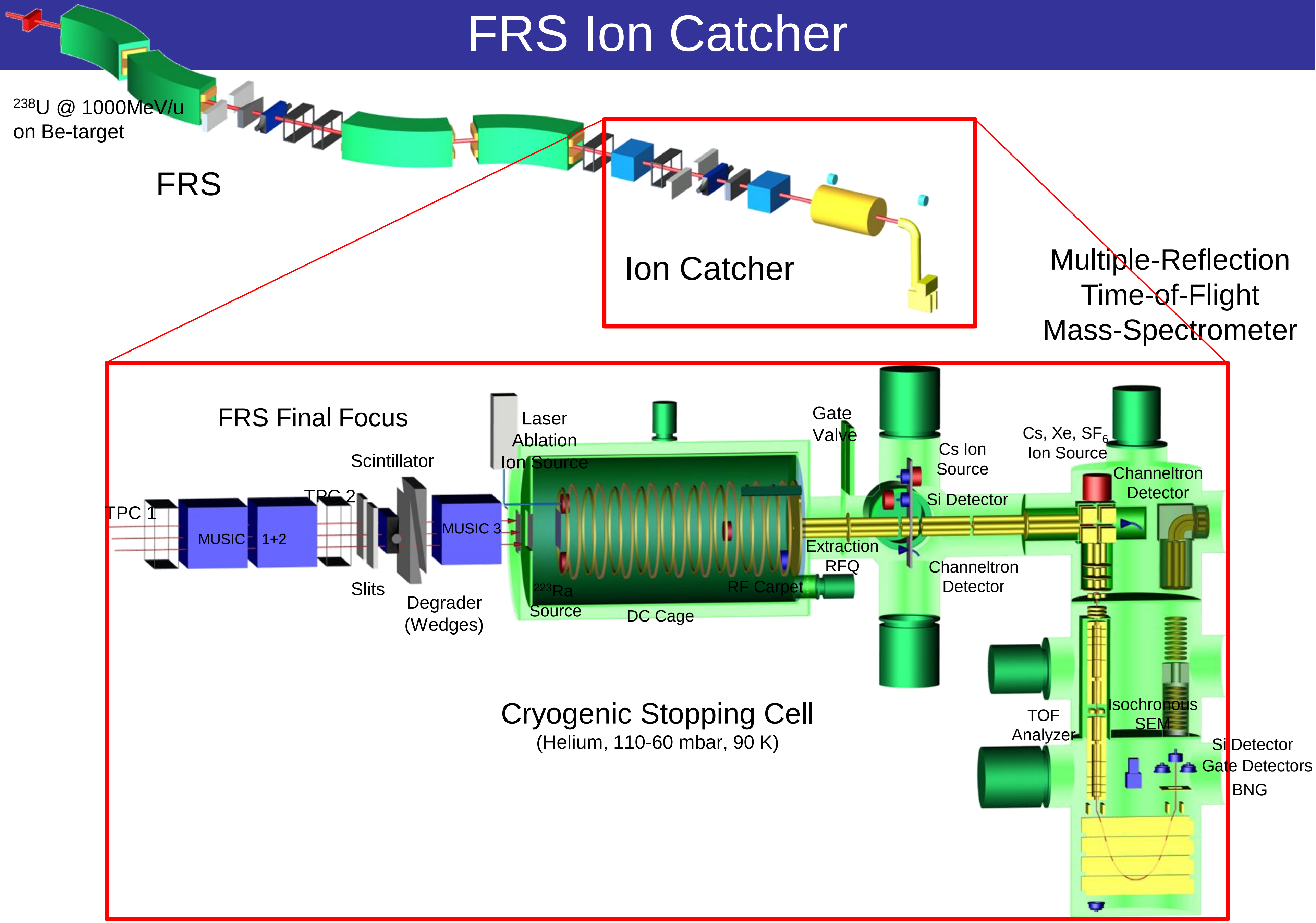
meter

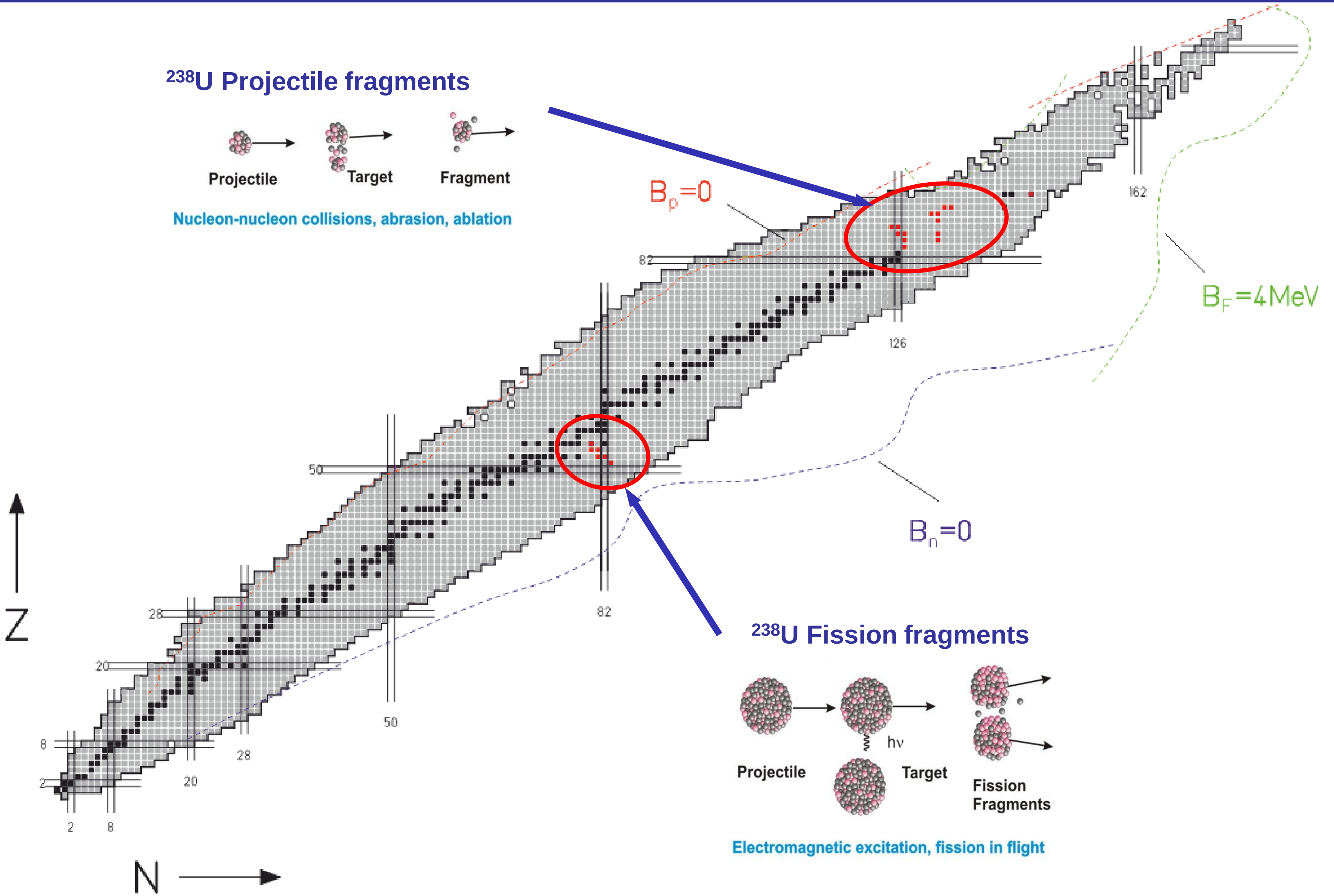
T

Detector
e Detectors
BNG

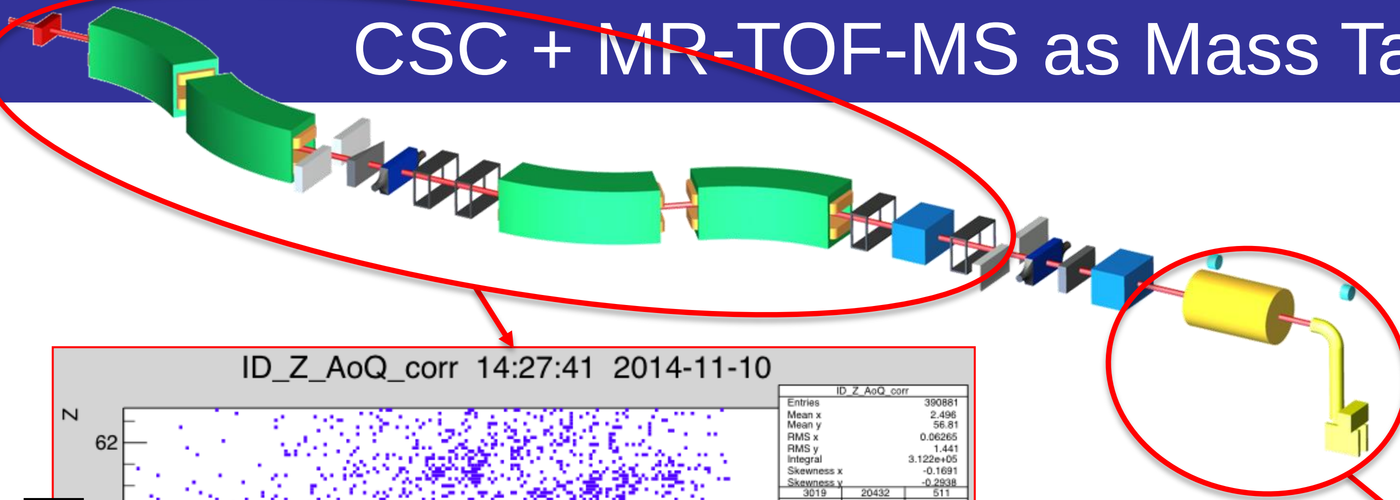


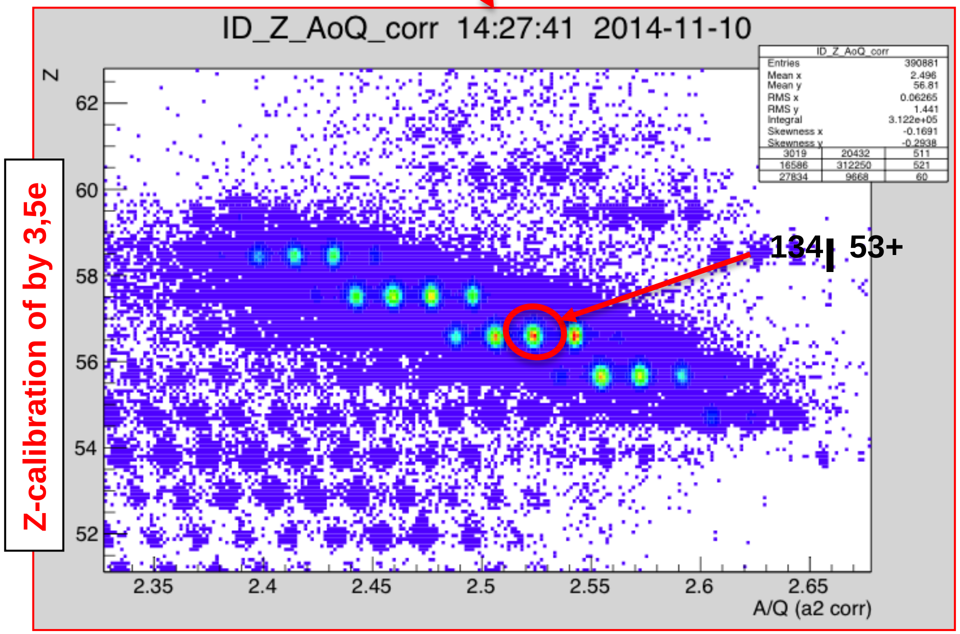
^{238}U @ 1000MeV/u
on Be-target
FRS
Ion Catcher
Multiple-Reflection
Time-of-Flight
Mass-Spectrometer
FRS Final Focus
Laser
Ablation
Ion Source
Gate
Valve
Cs Ion
Source
Cs, Xe, SF_6
Ion Source
Channeltron
Detector
Scintillator
TPC 2
TPC 1
MUSIC 1+2
MUSIC 3
Si Detector
Extraction
RFQ
Channeltron
Detector
Slits
Degrader
(Wedges)
^{223}Ra
Source
RF Carpet
DC Cage
Cryogenic Stopping Cell
(Helium, 110-60 mbar, 90 K)
TOF
Analyzer
Isochronous
SEM
Si Detector
Gate Detectors
BNG

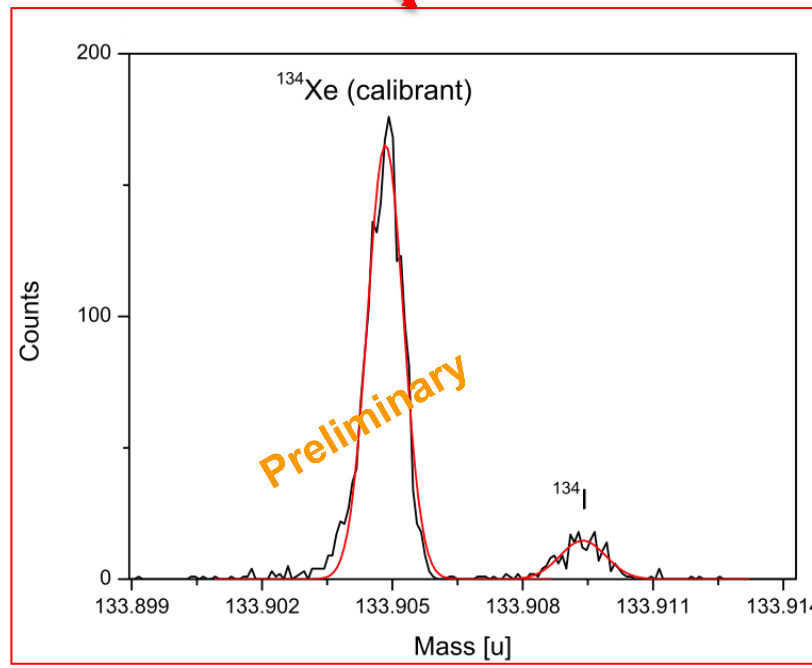
Commissioning Experiments



CSC + MR-TOF-MS as Mass Tagger







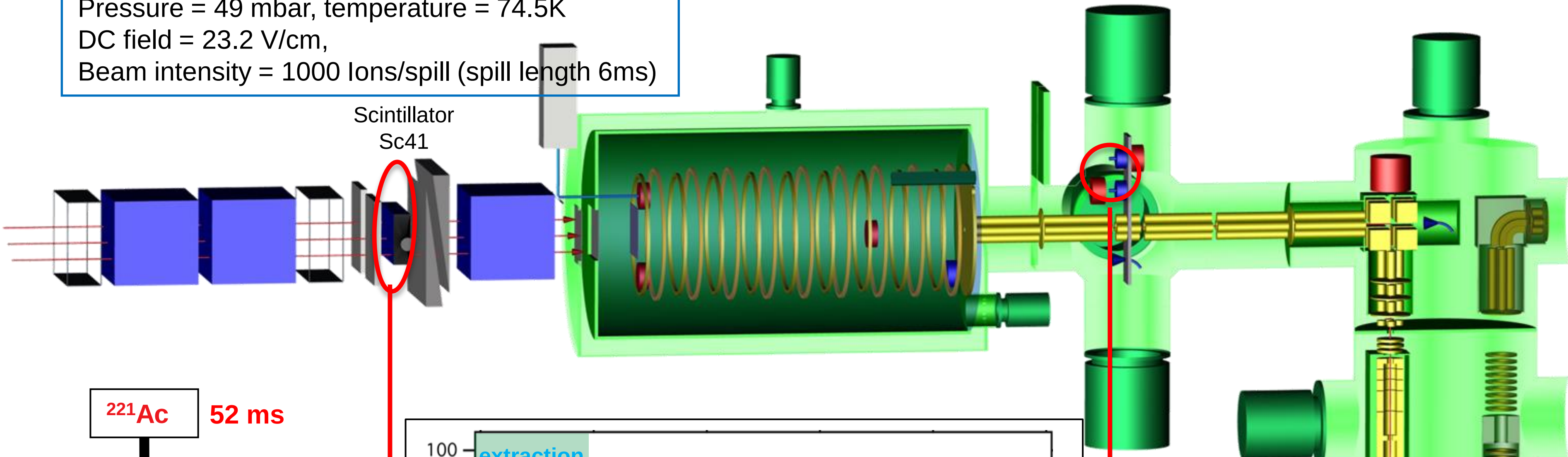
FRS identification may not always be accurate

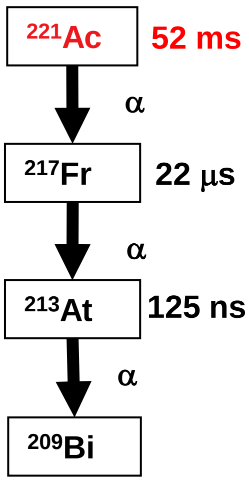
MR-TOF-MS as mass tagger

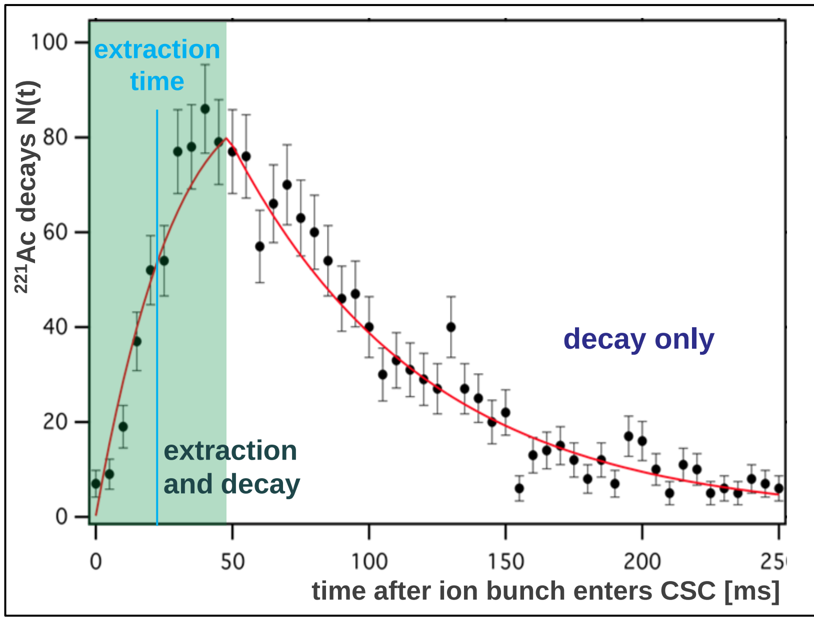
Universal and fast technique (~20 min)

FRS Ion Catcher Results: Extraction Time (^{221}Ac)

Pressure = 49 mbar, temperature = 74.5K
DC field = 23.2 V/cm,
Beam intensity = 1000 Ions/spill (spill length 6ms)







Scintillator time stamps

t (ms)

Si detector timing output

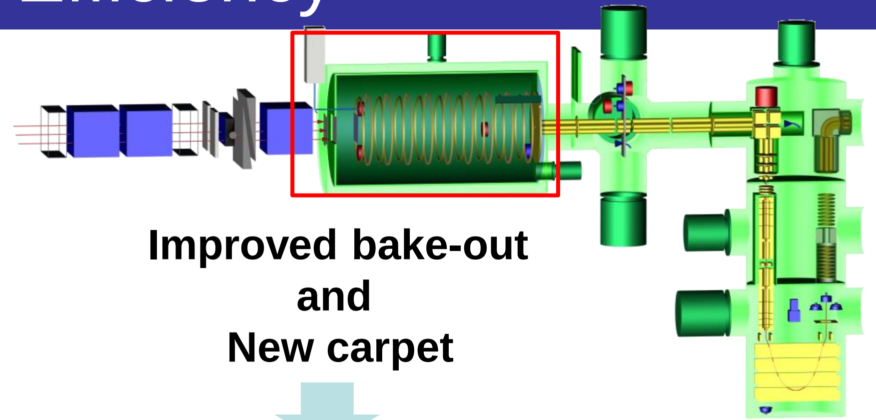
time after ion bunch enters CSC [ms]

extraction time

- **off-line: ~ 25 ms**
- **on-line: ~ 24 ms**
- **Theory** (K_0=17.5 cm^2/Vs): **~ 27.5 ms**

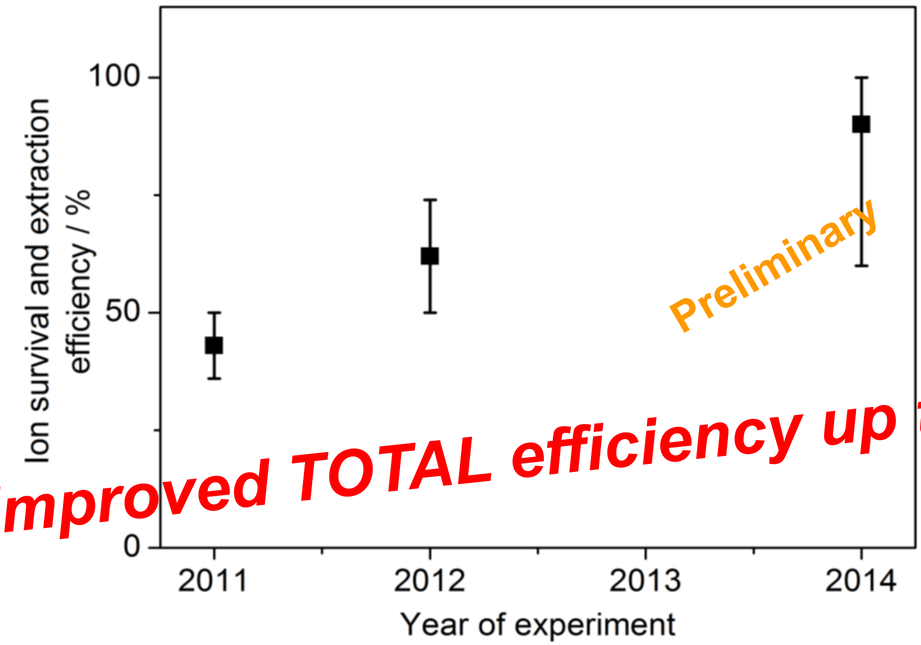
Purushothaman S. et al, EPL 104 (2013) 42001

Improved Total Efficiency



Carpet with improved electrical desgin

Now: Higher RF-amplitude possible and lower temperatures



Improved TOTAL efficiency up to 30%

Improved bake-out and New carpet

↓

better cleanliness

↓

Higher ion survial and extraction efficiency (eg. ^{223}Th)

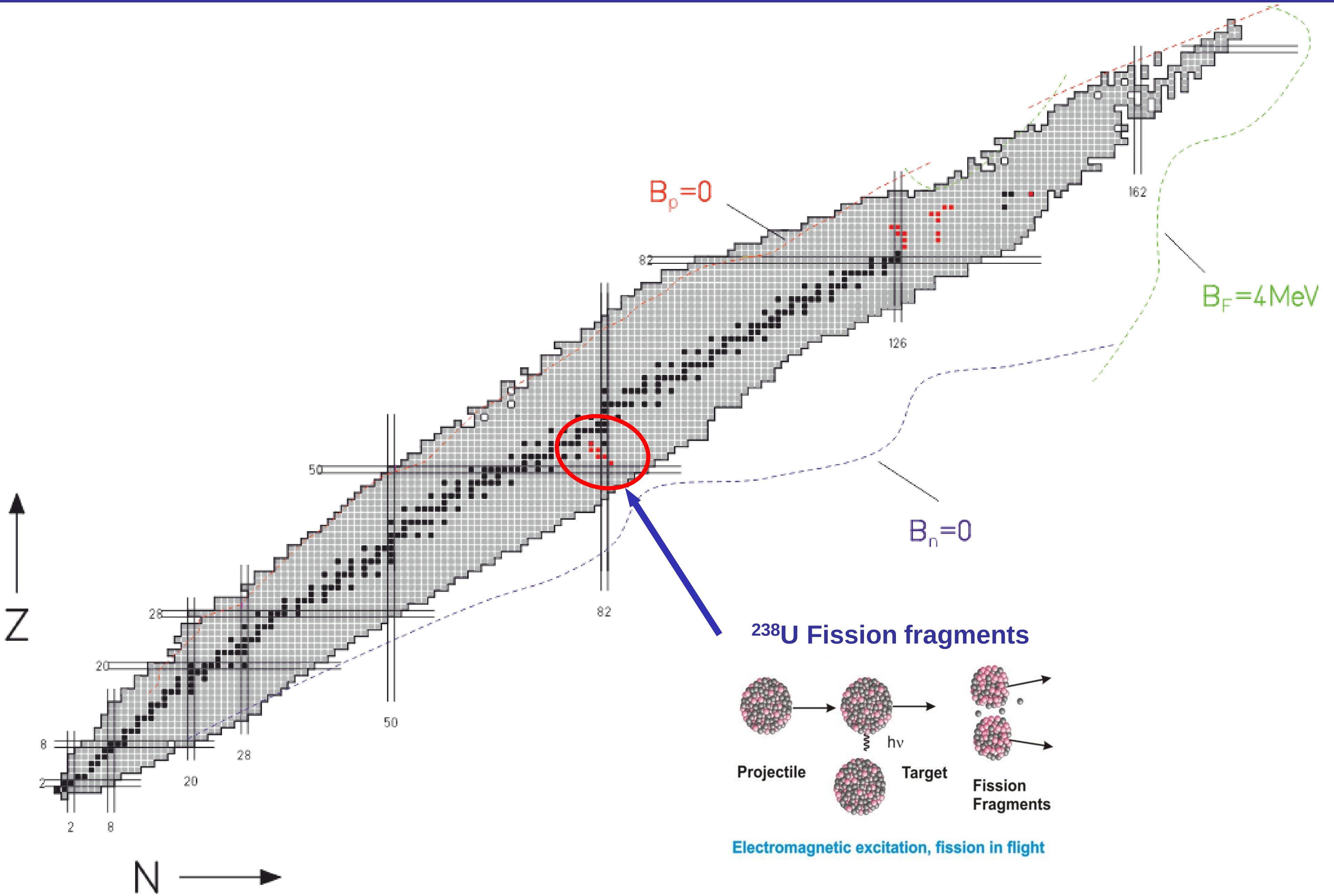
Higher differential pumping

↓

Higher areal density
Higher stopping efficiency

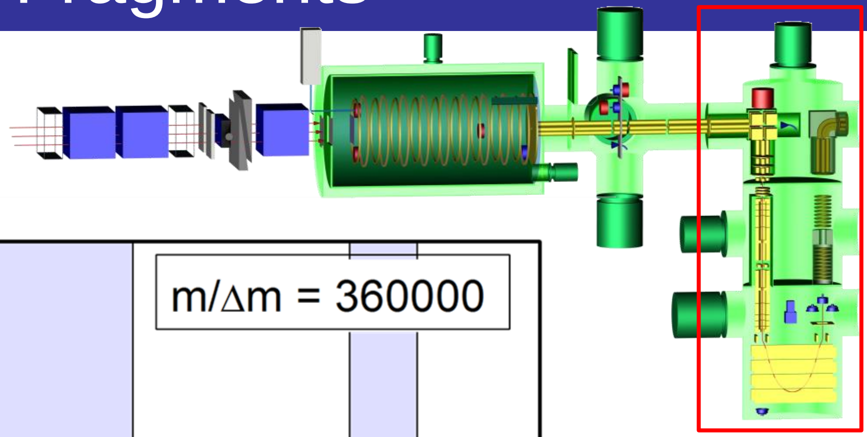
***2012:* 3.1 mg / cm²**
***2014:* 6.3 mg / cm²**

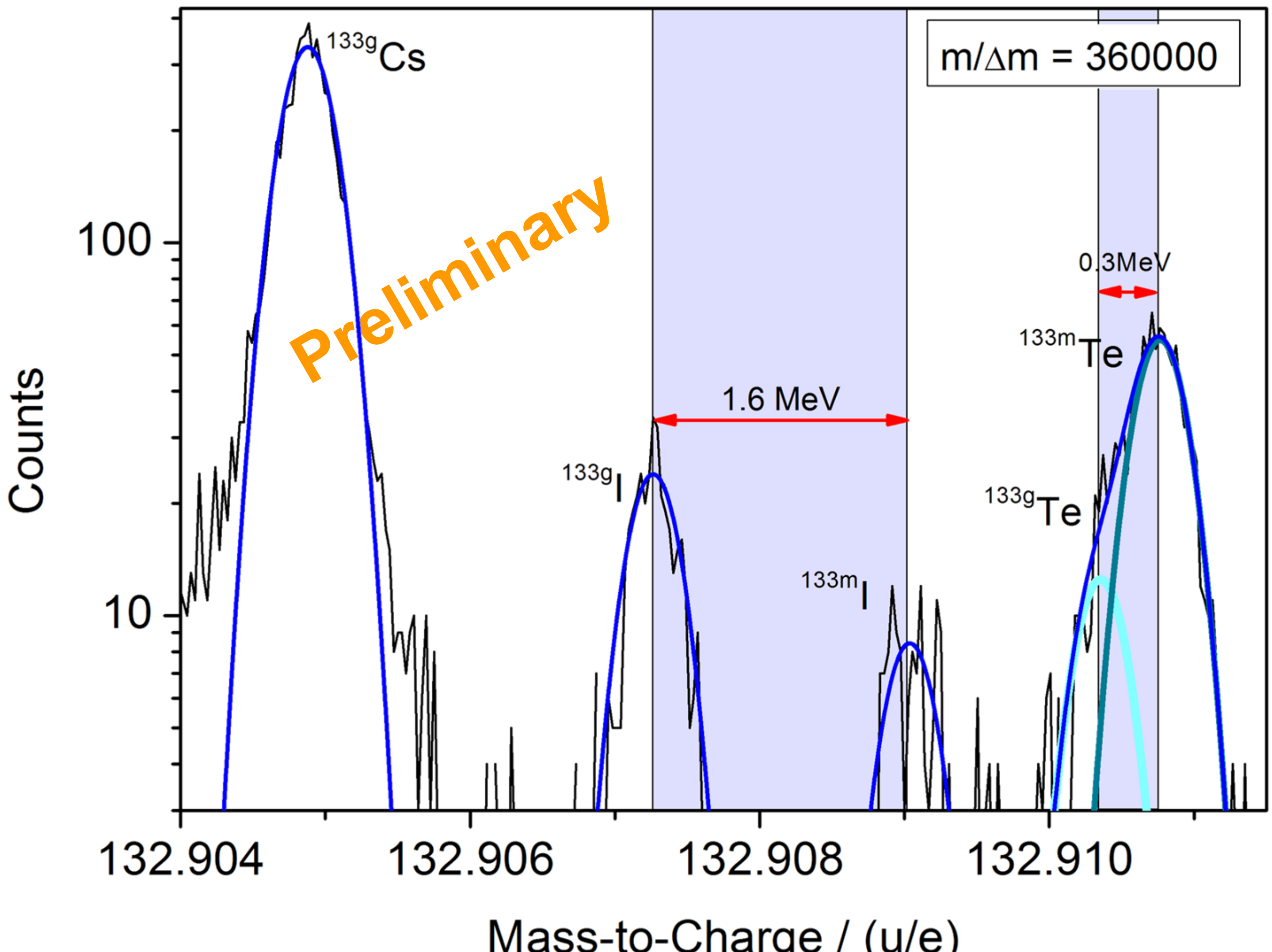
Commissioning Experiments



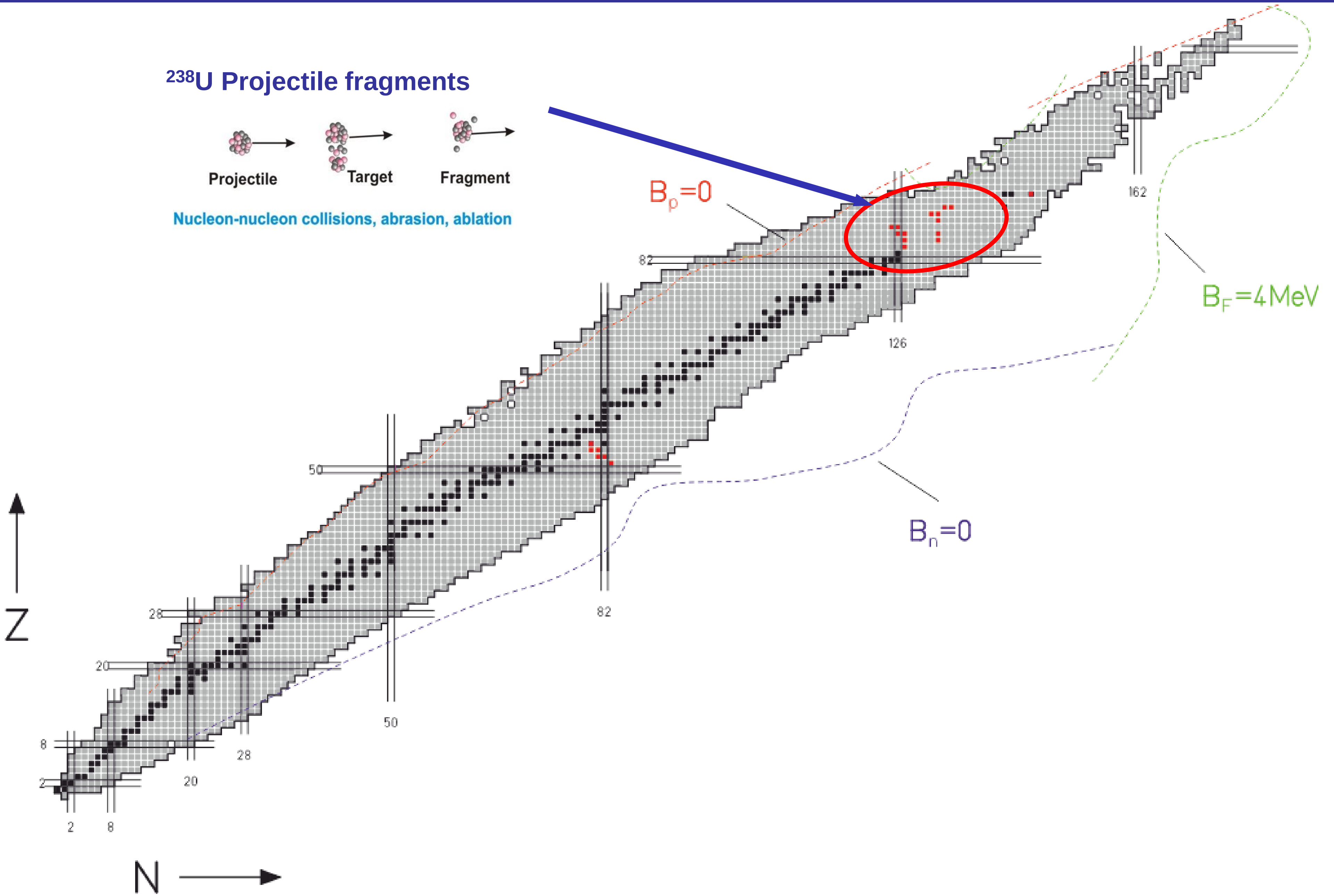
Uranium Fission Fragments

Thermalising and extracting **fission fragments** the first time



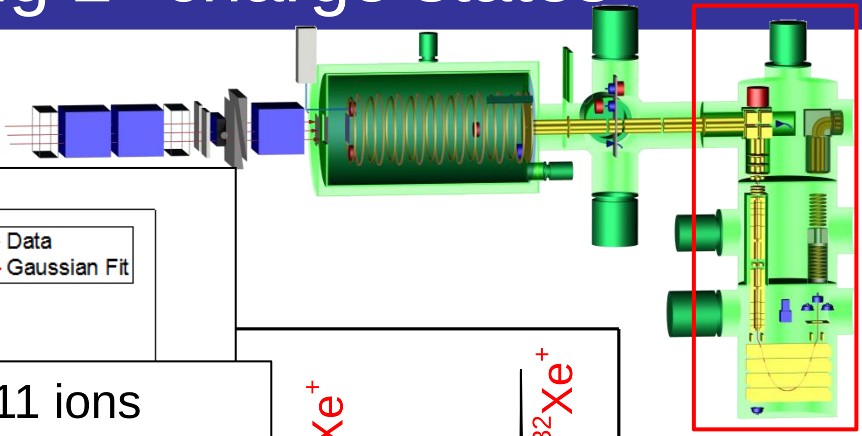


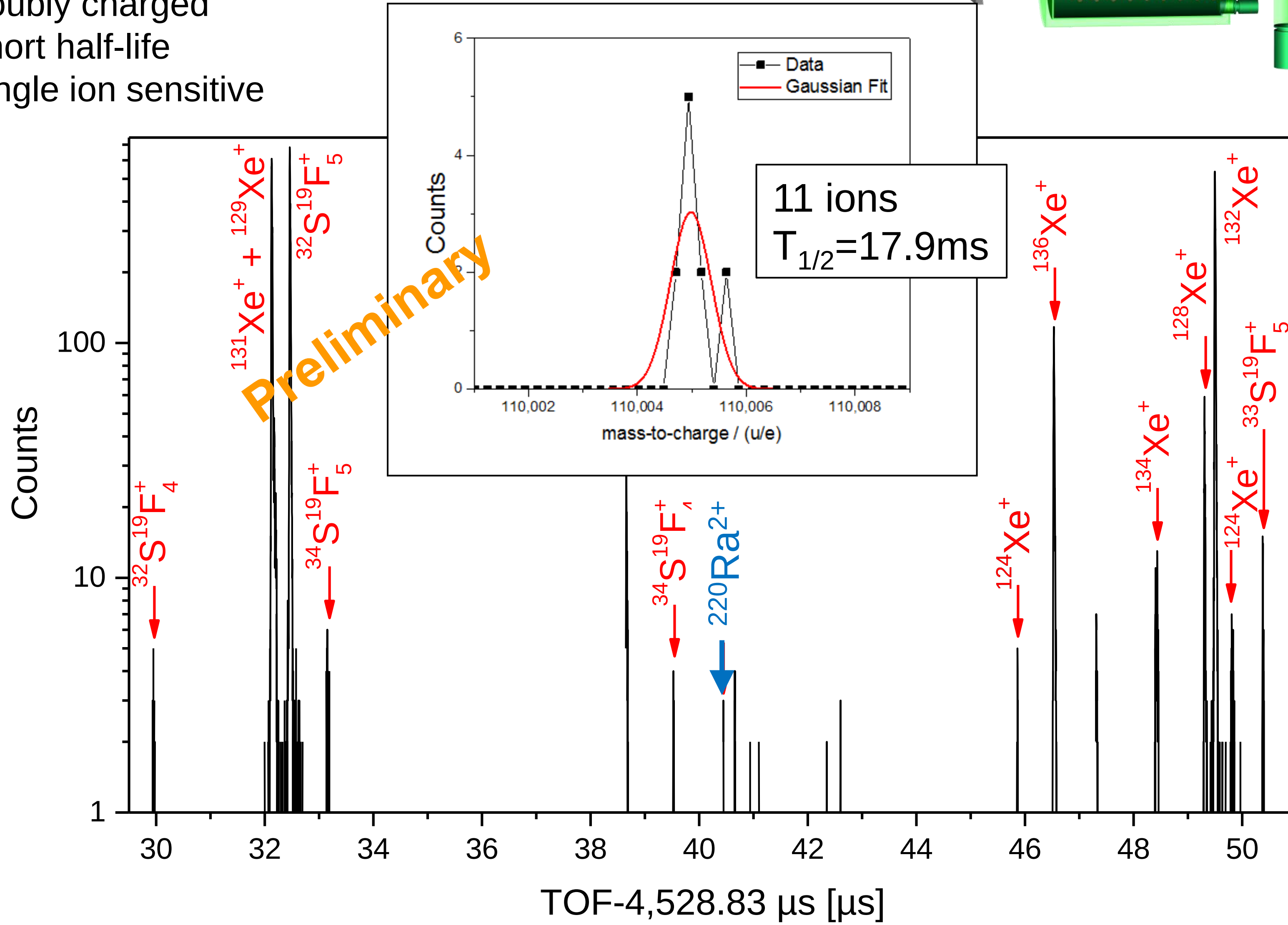
Commissioning Experiments



Extracting and measuring 2^+ charge states

Mass window ~ **30 u**
Mass resolving power ~ **120000**
Doubly charged
Short half-life
Single ion sensitive

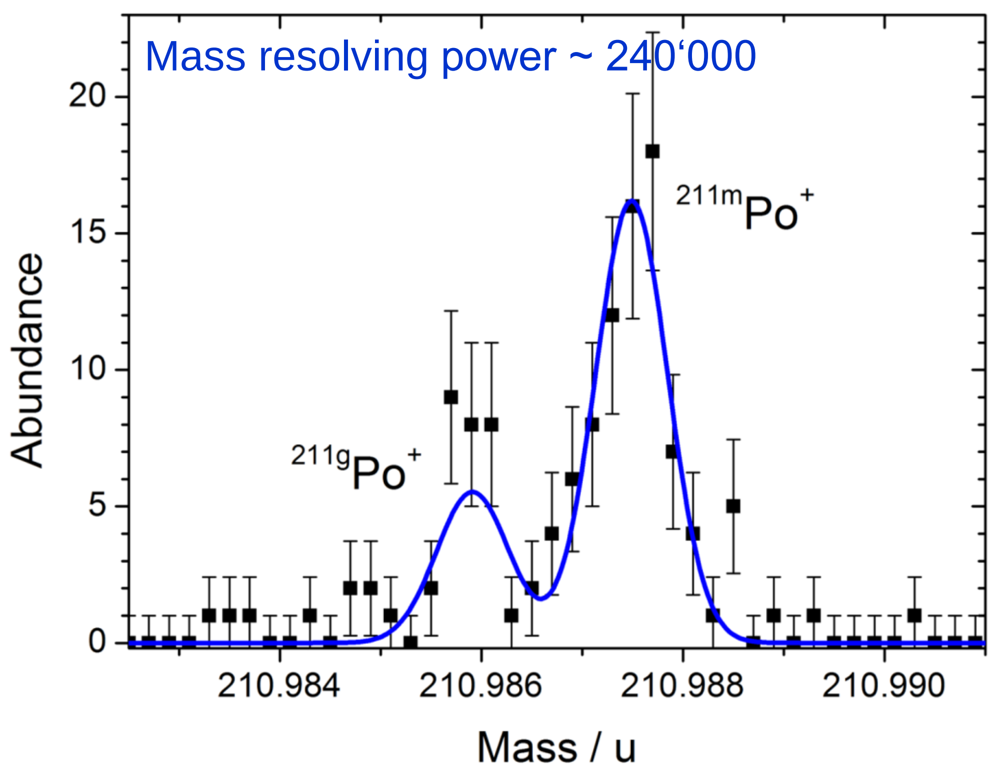


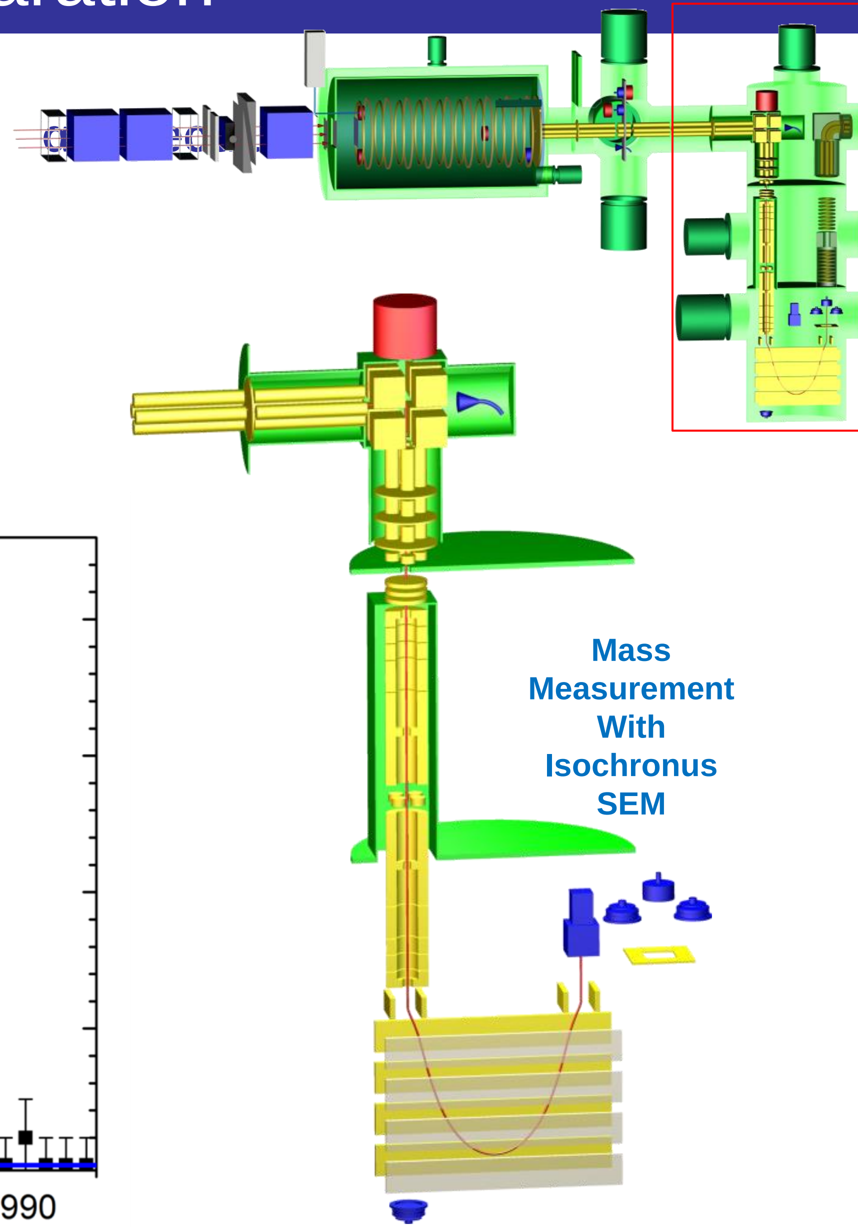


Step 1

Measurement of excitation energy
→1472 ± 120keV (lit. 1462 ± 5keV)

Measurement of ground-to-isomer ratio
→ 2.5(0.8)

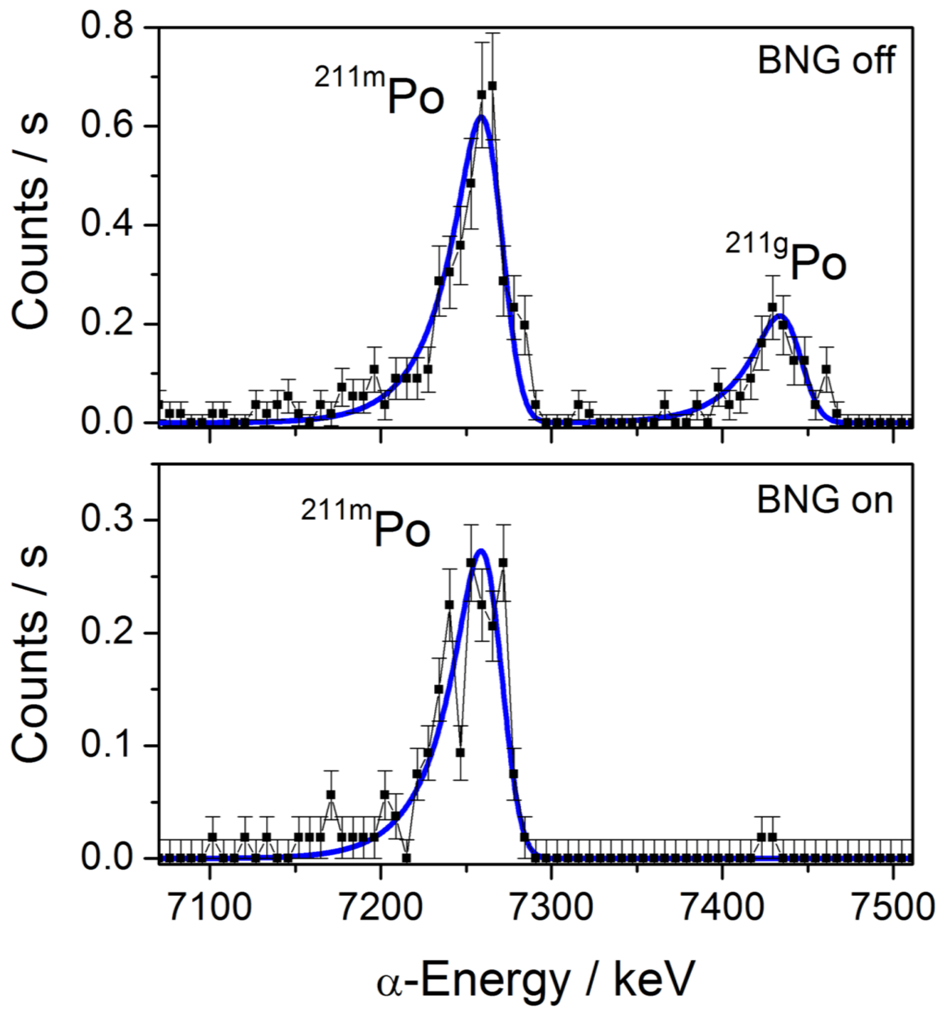


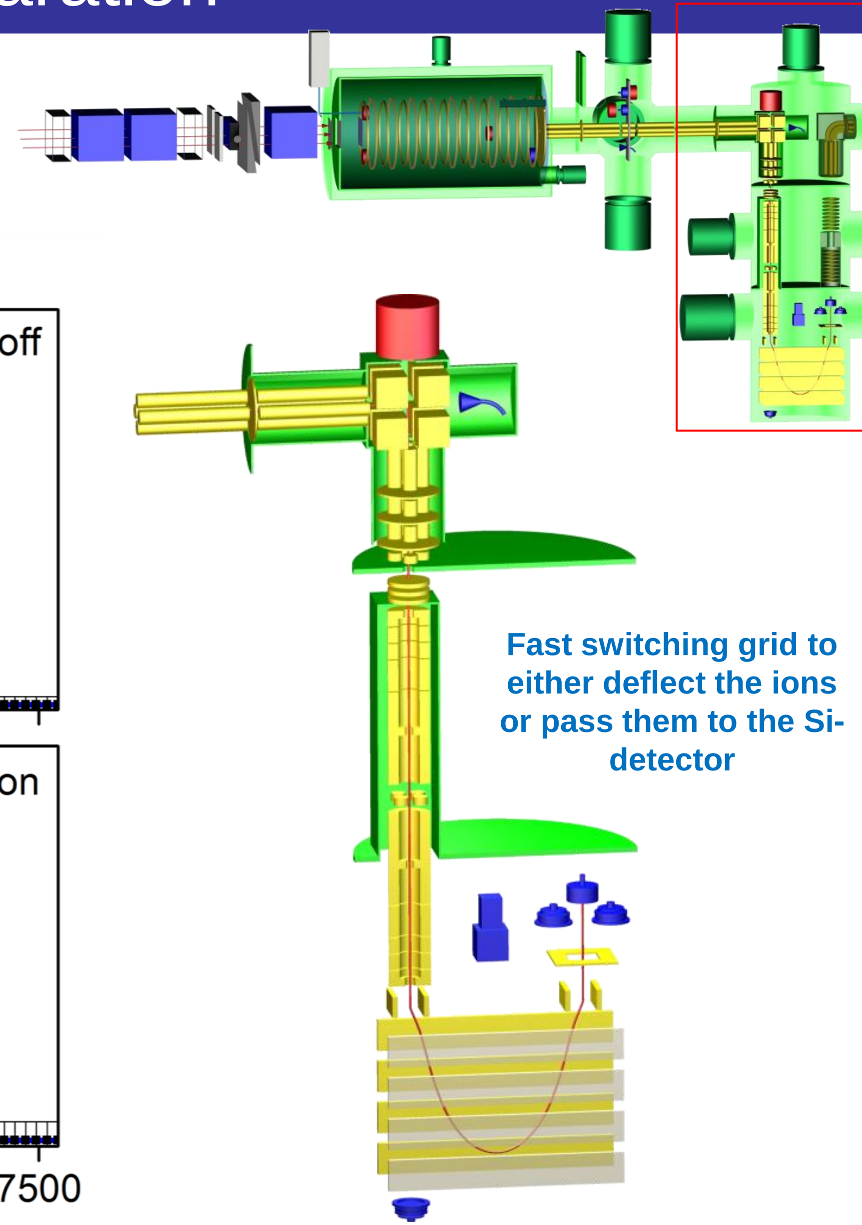


T. Dickel et al., PL B (2015)

Step 2

Spatial separation with an ion Gate





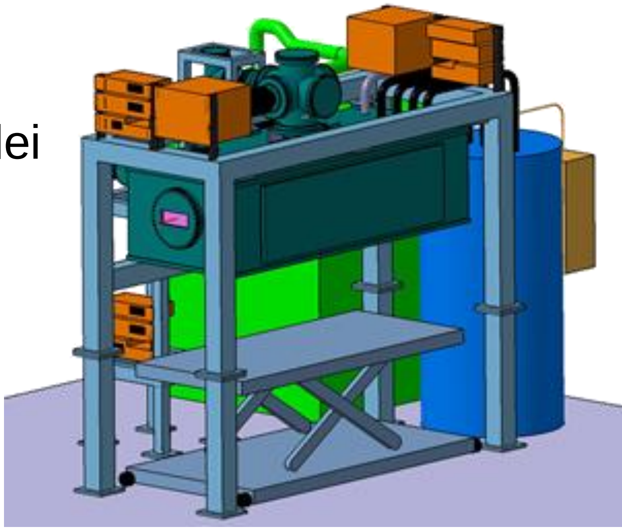
T. Dickel et al., PL B (2015)

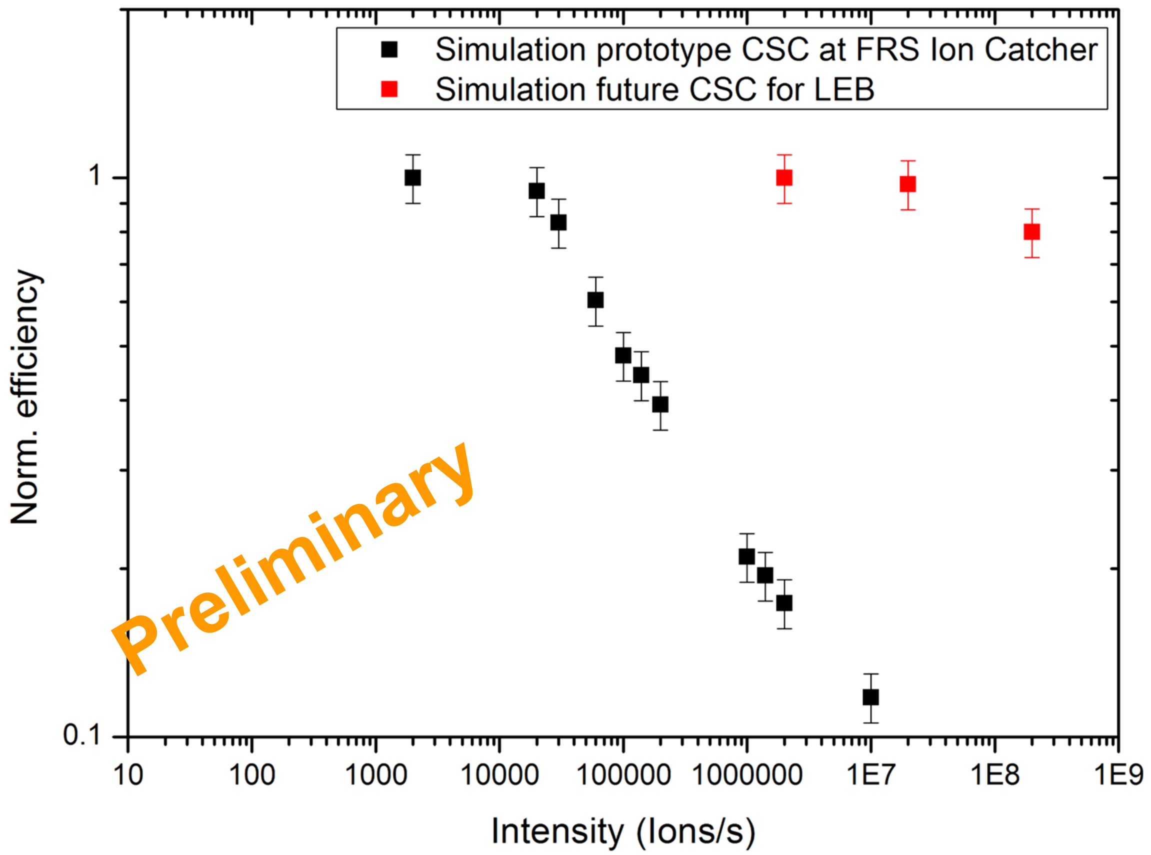
Future Stopping Cell

New challenges

Higher requirements to stop the ions

Due to higher beam intensities and more exotic nuclei

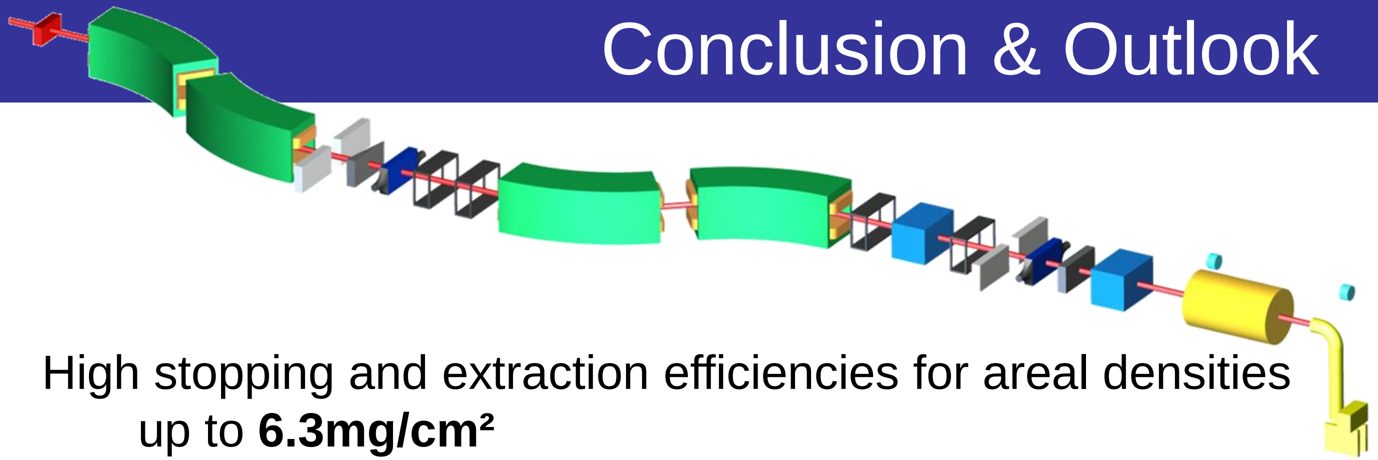


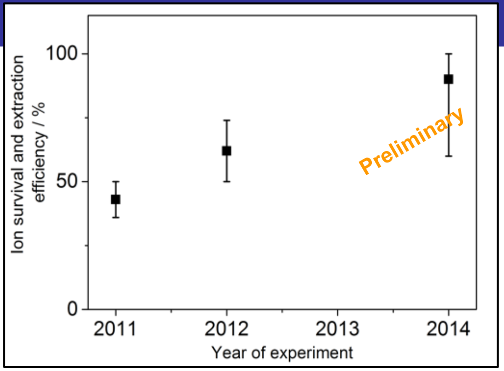


With future design:

5x higher areal density
5x faster
10^3 higher rates

Conclusion & Outlook

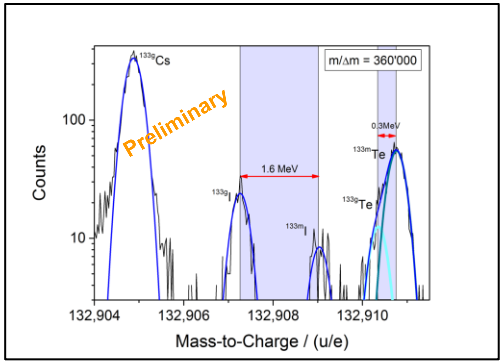




High stopping and extraction efficiencies for areal densities up to **6.3mg/cm²**

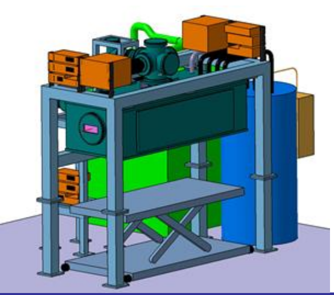
Successful stopping of fission and projectile fragments With total efficiencies of ~**30%**

Fast extraction times (**$^{220}Ra^{2+}$,17.9ms**)

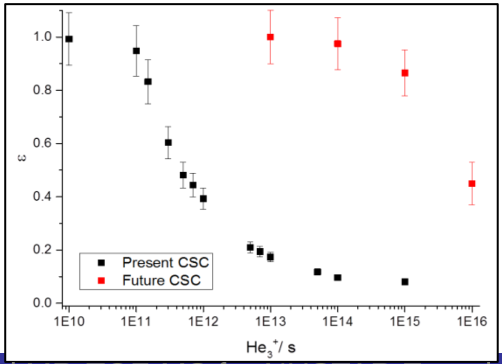


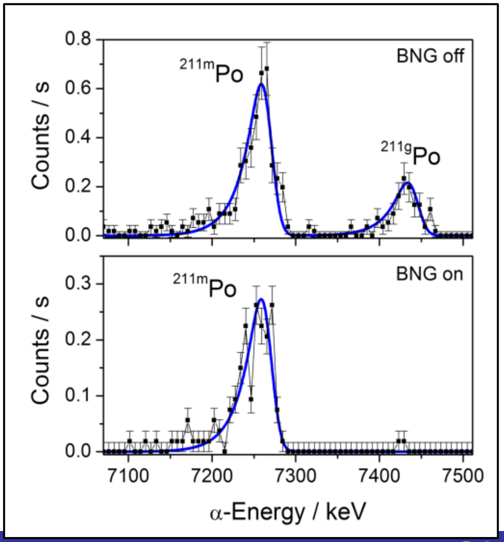
High mass resolving power enables spatial separation of isomer states

Cryogenic Stopping Cell for the Super-FRS Low Energy Branch is design



5x higher areal density
5x faster
10^3 higher rates





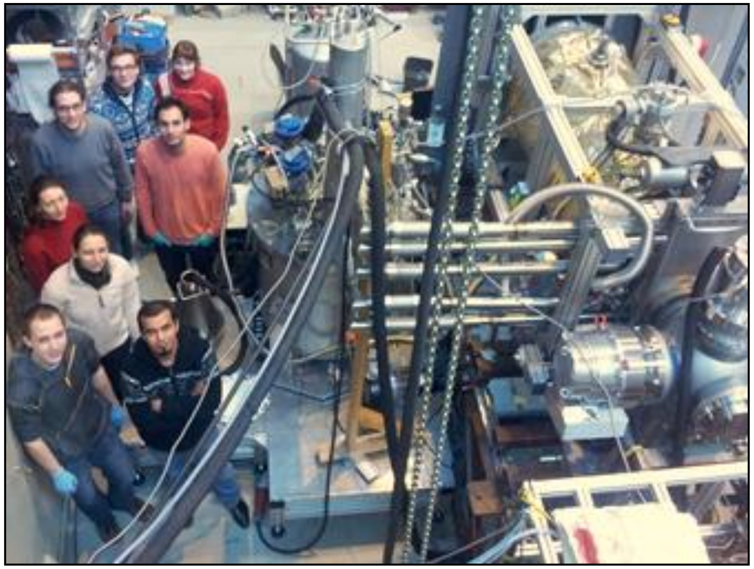
Acknowledgement

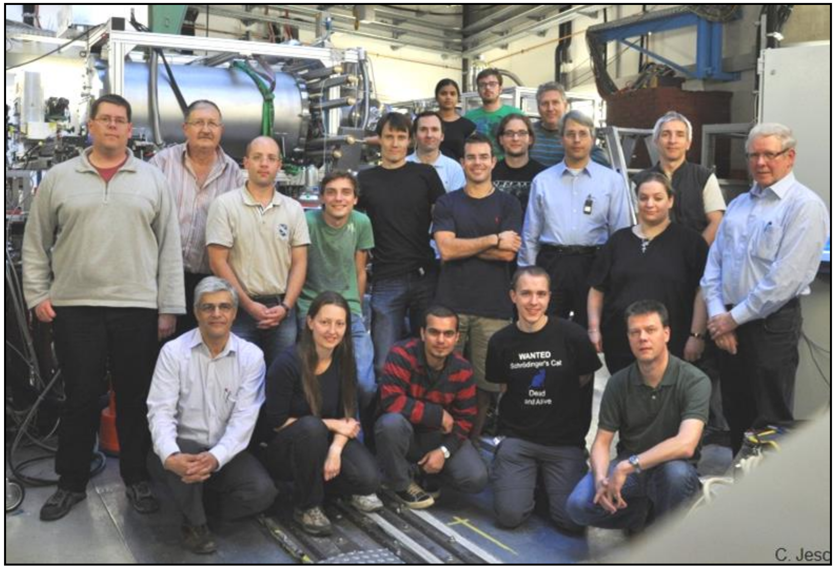
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

GSI

university of groningen
kvi - center for advanced radiation technology

UNIVERSITY OF JYVÄSKYLÄ





FRS Ion Catcher / S411 Collaboration

F. Amjad[2], S. Ayet[2], J. Bergmann[1], P. Dendooven[3], T. Dickel[1,2], 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], I. Mukha[2], C. Nociforo[2], M. Petrick[1], M. Pfuetzner[2], S. Pietri[2], A. Pikhtelev[5], W.R. Plaß[1,2], 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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HESSEN Hessisches Ministerium für Wissenschaft und Kunst

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