TRIGA-SPEC:
Status of the MATS and LaSpec prototype systems for the FAIR facility

Thomas Beyer
For the TRIGA-SPEC collaboration

FAIRNESS, 25.09.2014

Content:

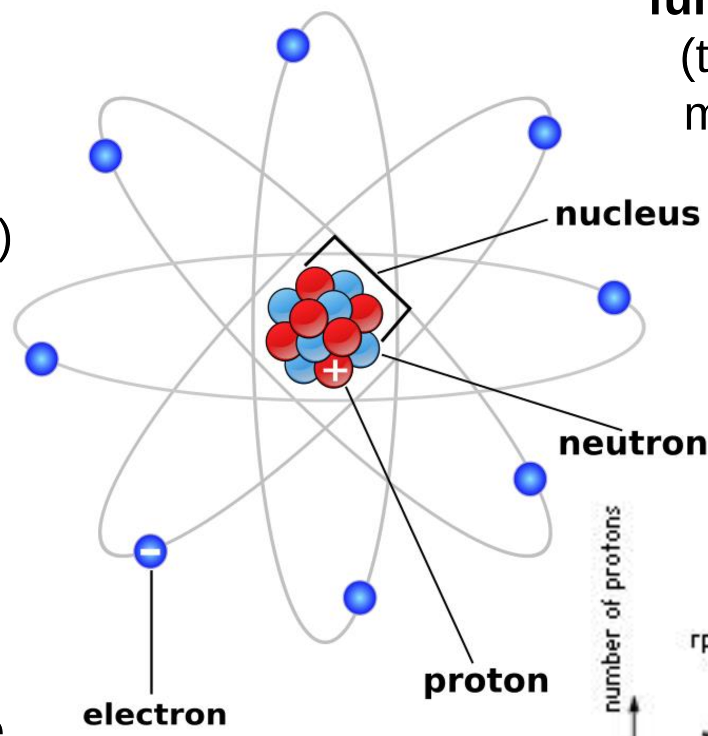
- Aims of MATS and LaSpec
- The TRIGA-SPEC experiment in Mainz
- Status and Outlook

MATS and LaSpec: Aims

- the examination of the atomic nucleus opens the door to various fields of physics

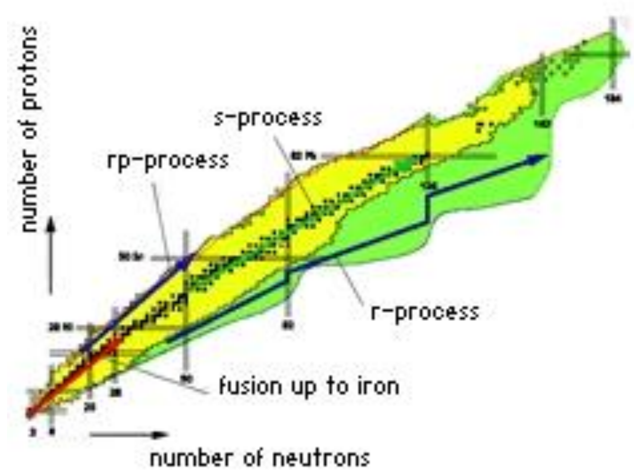
fundamental properties
(tests of nuclear mass models and formulas)

nuclear physics
(nuclear binding energies, Q-values)



astrophysics
(nucleosynthesis)

nuclear structure
(shell closure, deformation, charge radii)



MATS and LaSpec at FAIR

Rodriguez et al, Eur. Phys. J. Special Topics 183, 1–123 (2010)

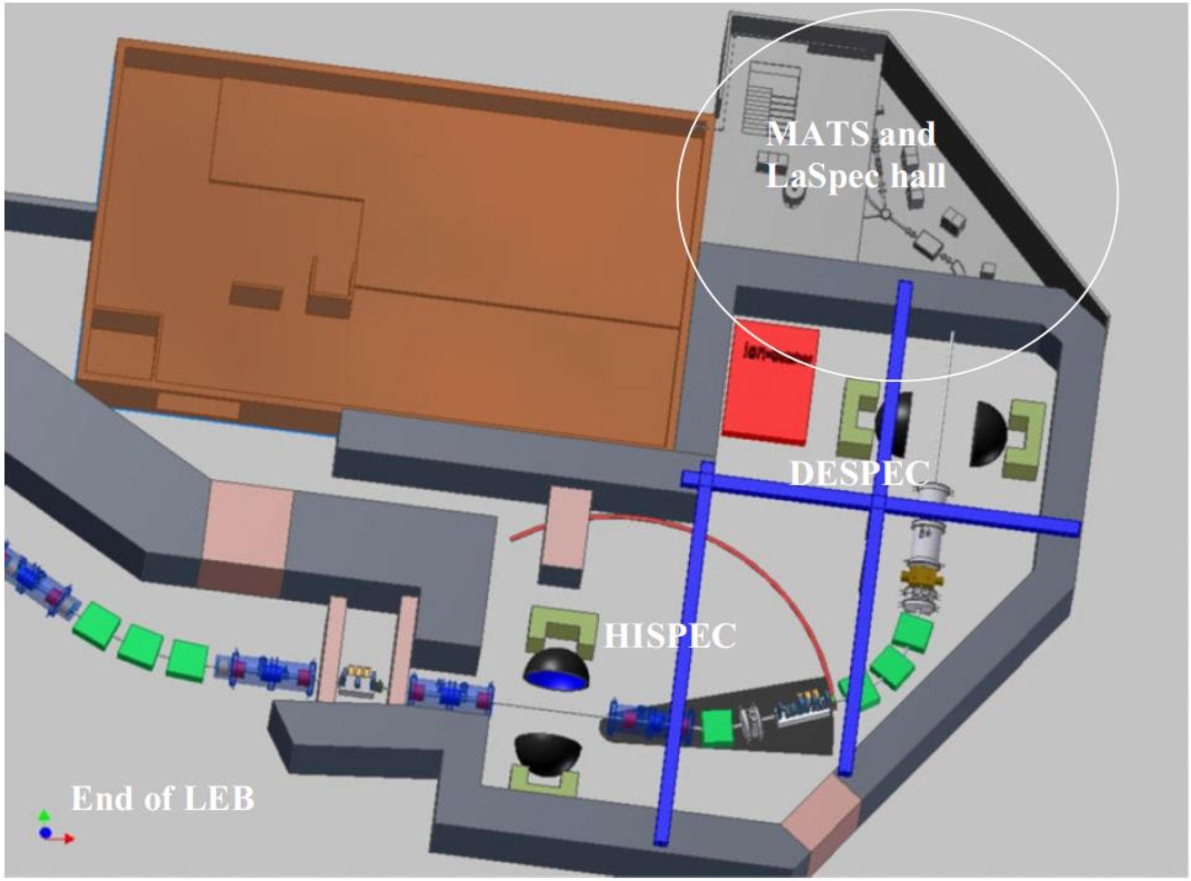
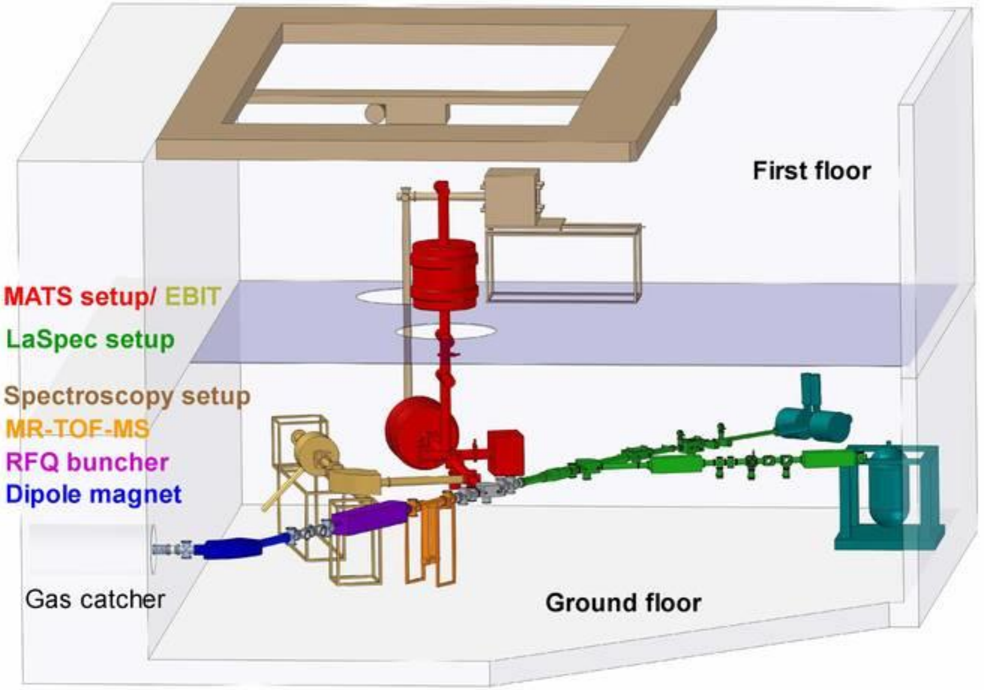


Fig. 1. End of the Low Energy Beam line of the Super FRS at the future FAIR facility.

MATS and LaSpec: Setup

- **MATS** and **LaSpec** at the future FAIR facility are part of the NUSTAR collaboration



MATS: precise **M**easurements on very short-lived nuclei using an **A**dvanced **T**rapping **S**ystem for highly-charged ions
LaSpec: **La**ser **Spec**troscopy on very short-lived nuclei

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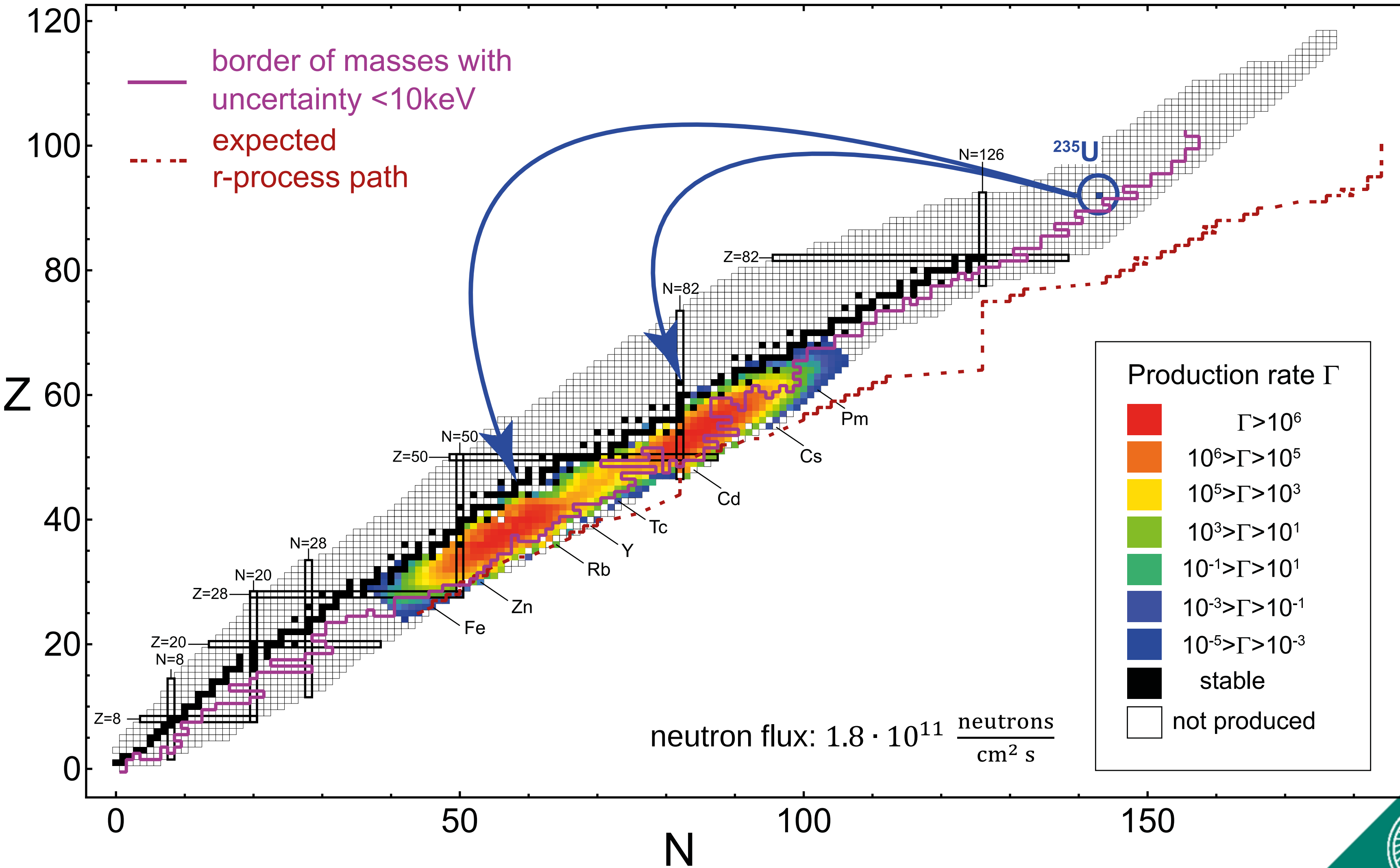
The TRIGA Mark II reactor in Mainz

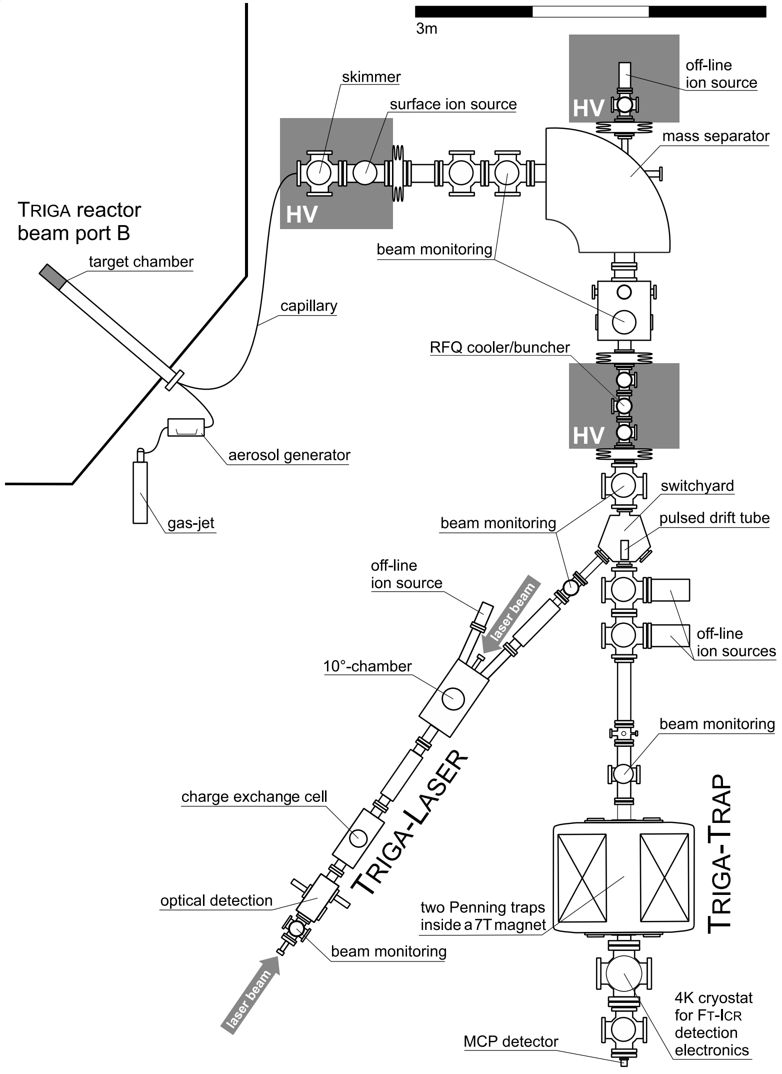
- **T**raining, **R**esearch, **I**sotopes, **G**eneral **A**tomic
- steady state mode: 100 kW_{therm}
- pulsed mode: 250 MW for 30ms
- four horizontal beam ports allow access to the reactor core

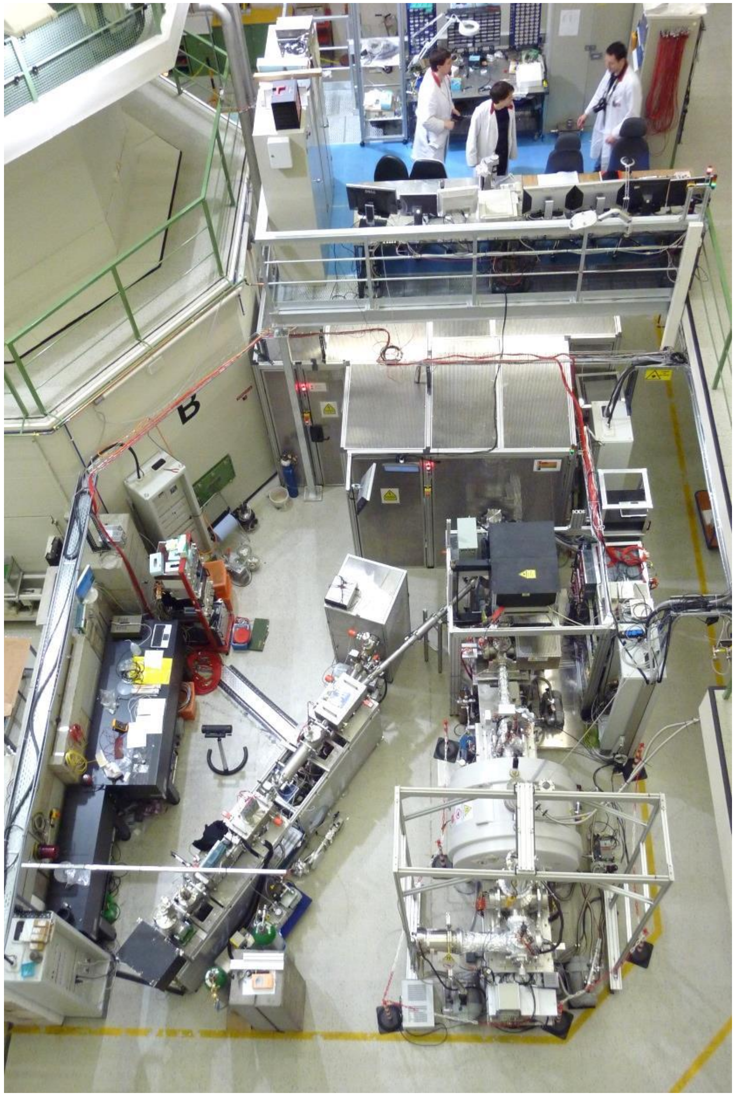
TRIGA reactor: production rates

neutron-induced fission of an actinide target, e.g. ^{235}U or ^{249}Cf

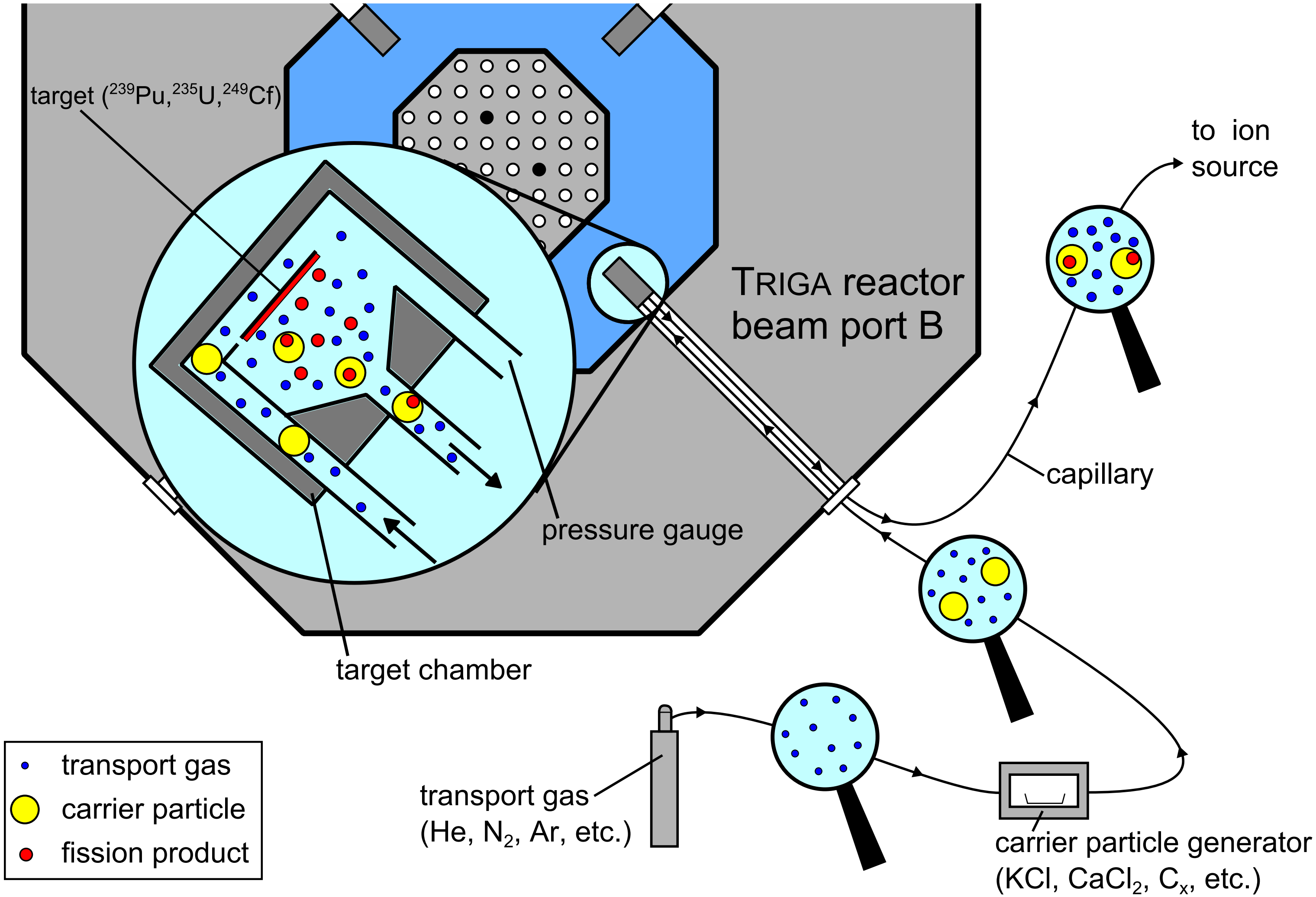


Prototype systems at TRIGA-SPEC

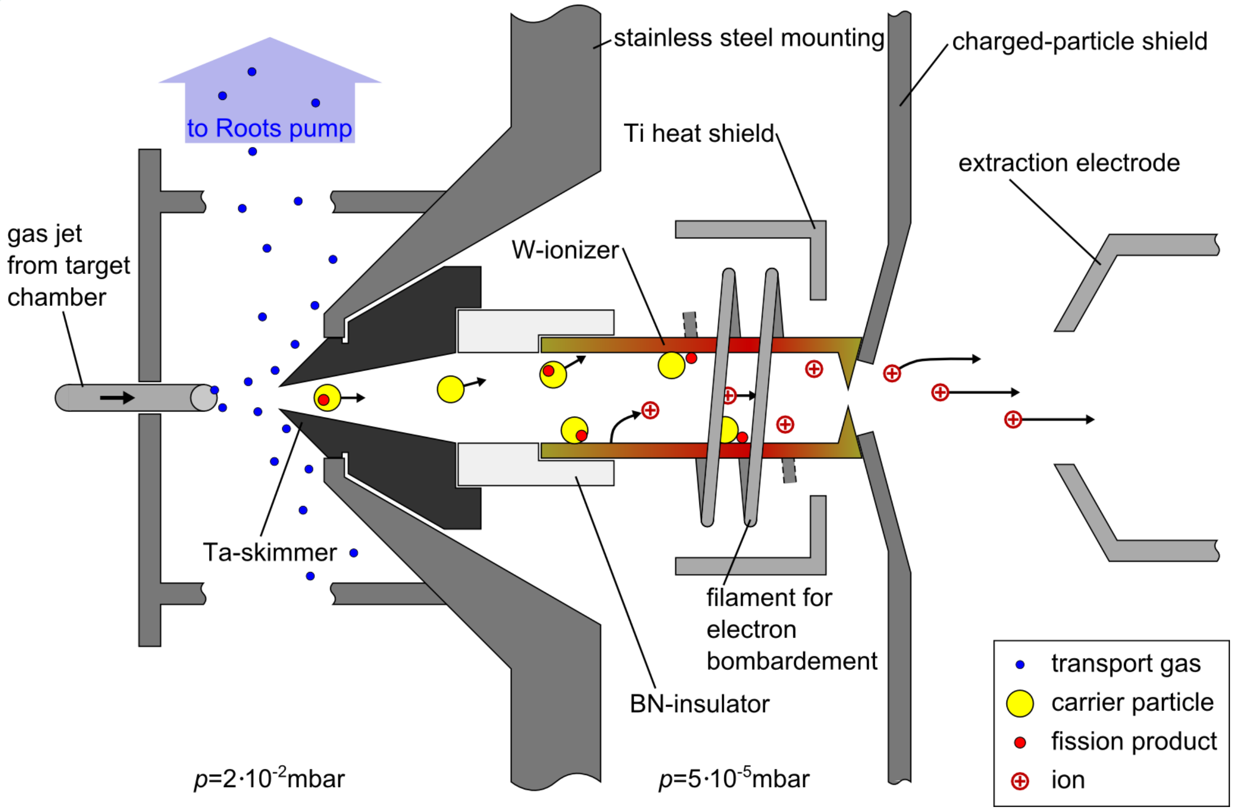




Extraction of the fission products

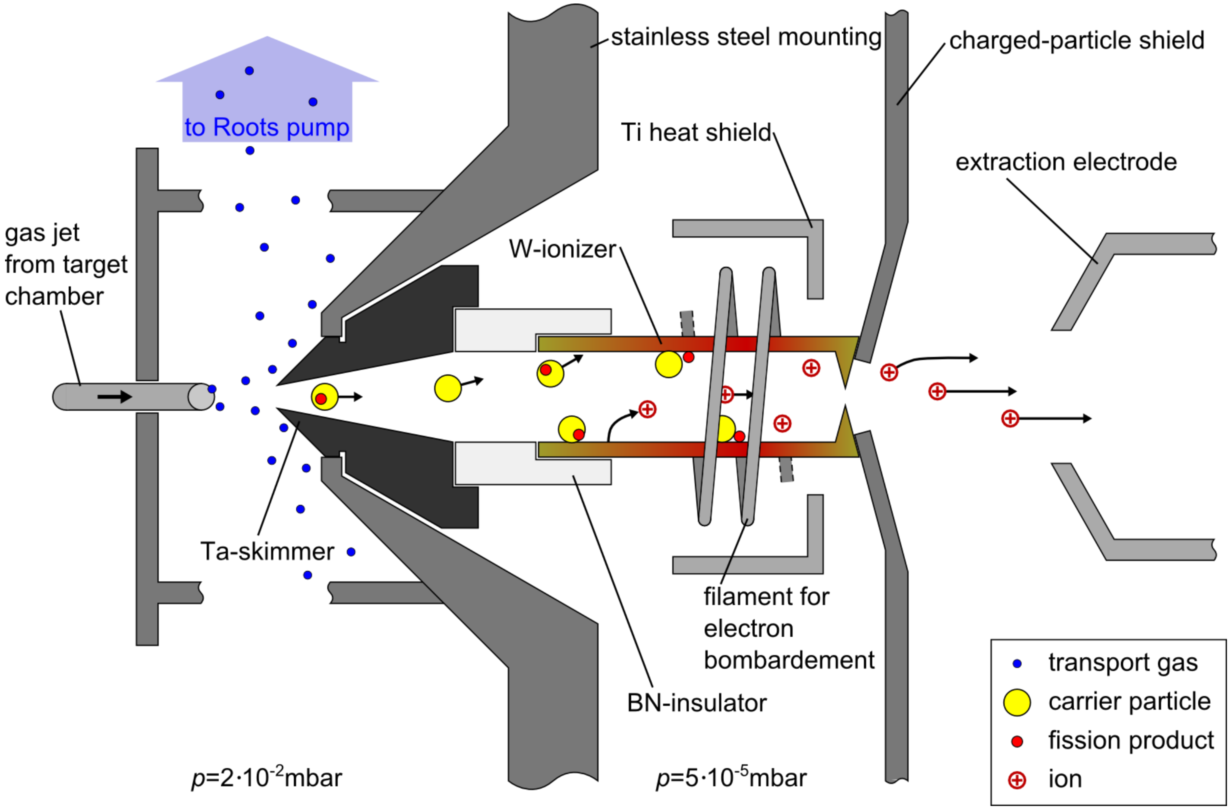


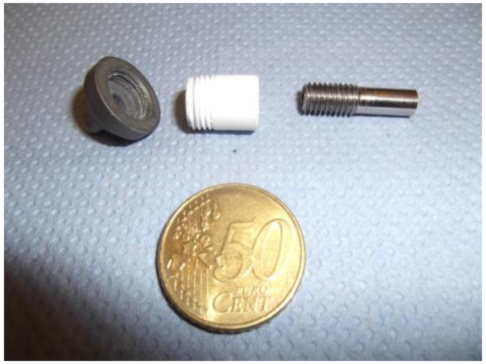
Ionization of the fission products



- a skimmer strips away the light carrier gas
- the carrier particles enter the ionizer (efficiency ~15%)
- they break up and release the fission products

Ionization of the fission products





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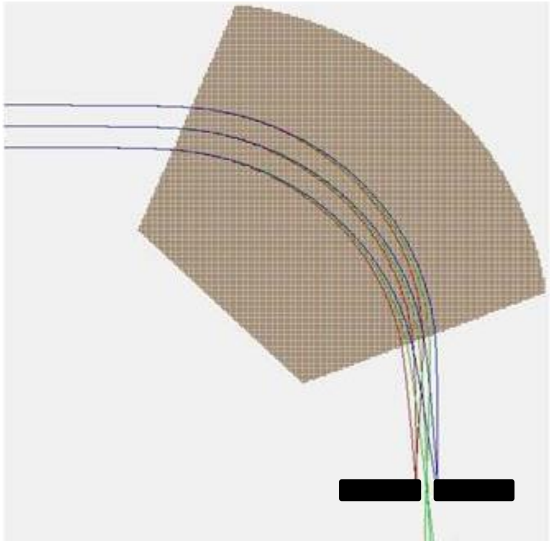
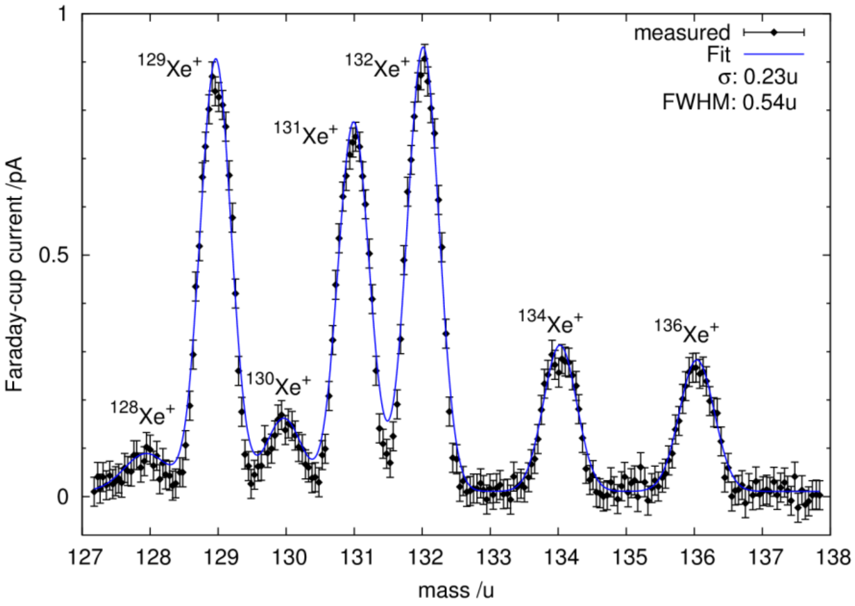
Mass separation in a dipole magnet





- the dipole magnet separates ions via $\frac{m}{q}$
- by using a small (vertical) slit after the magnet, only one isobaric line passes through

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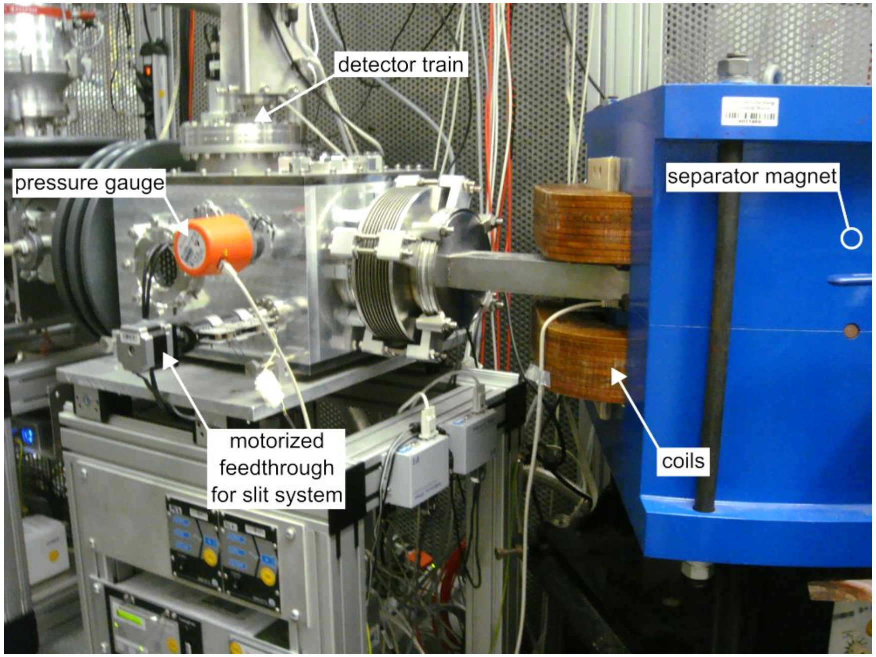

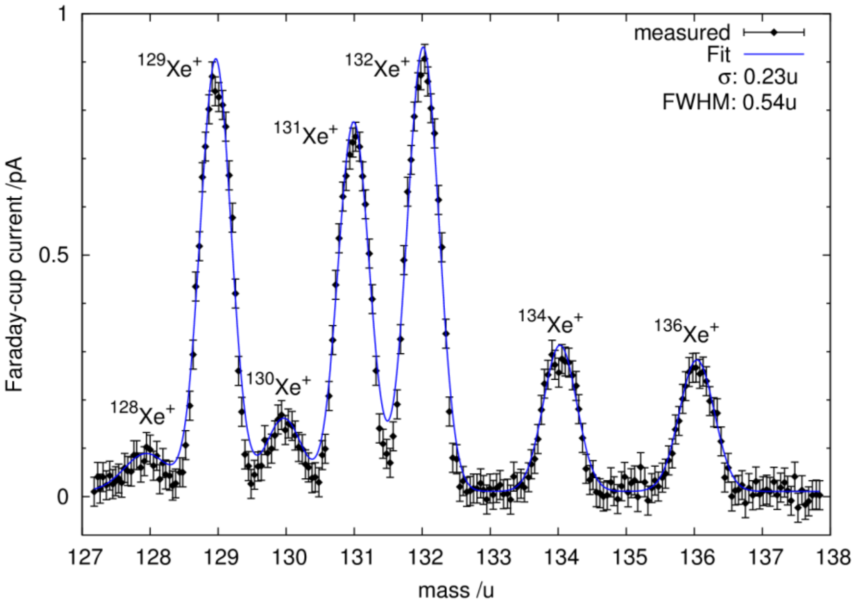

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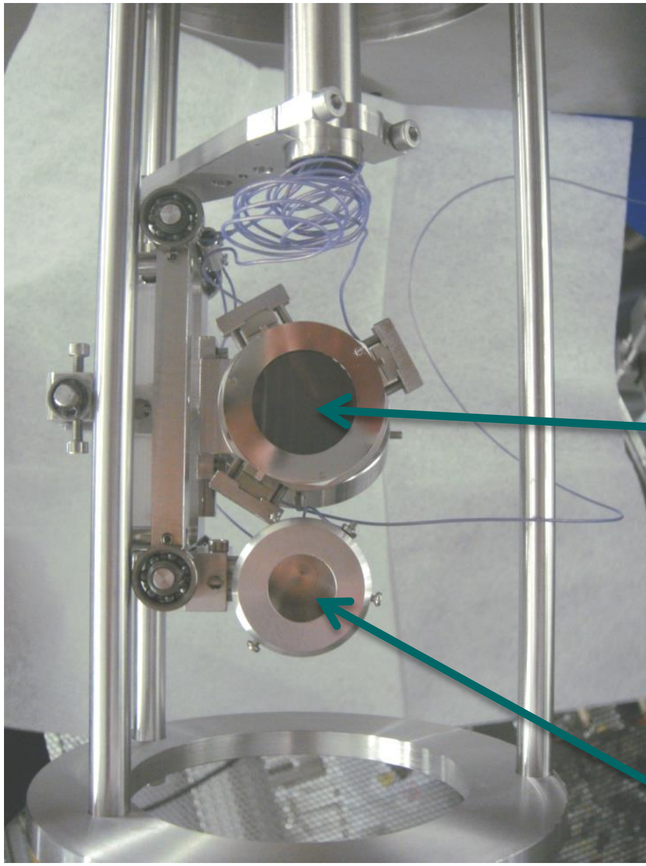
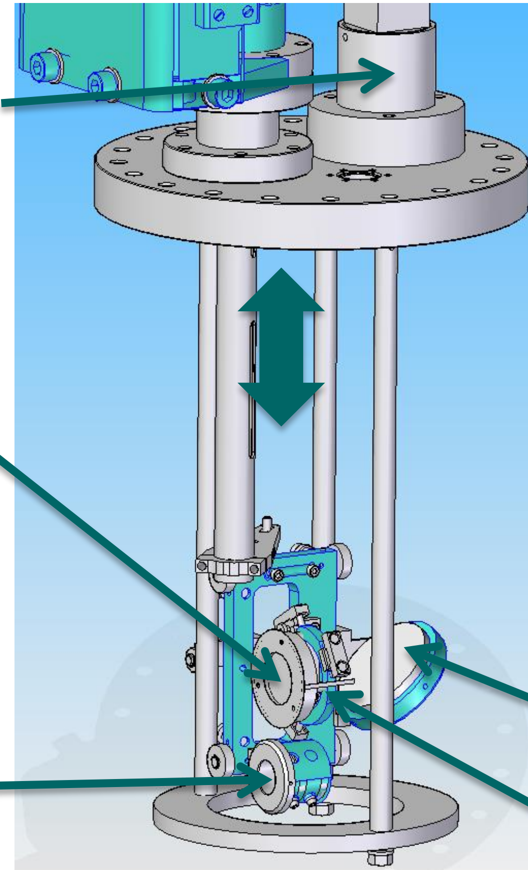
Tools for beam diagnosis

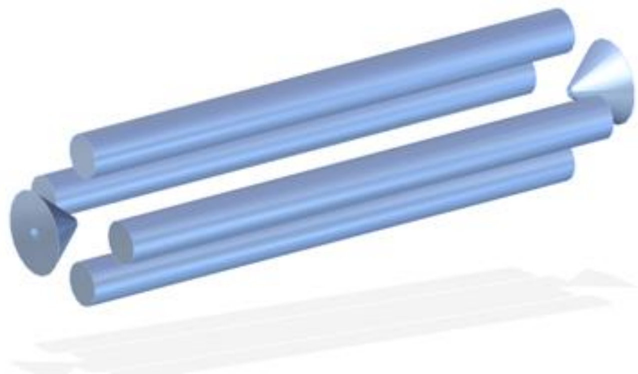


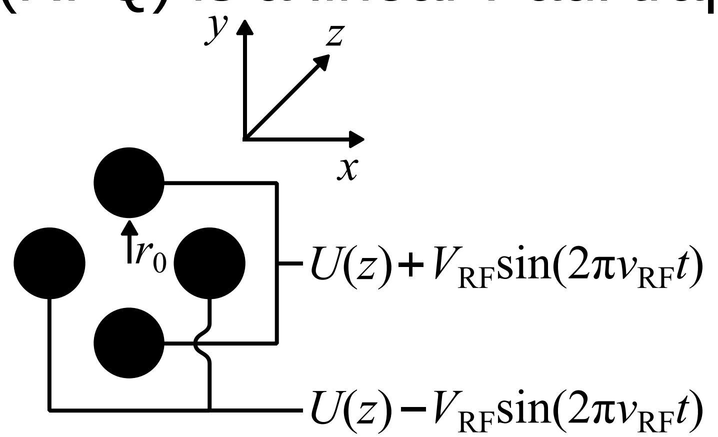


Faraday cup	microchannel plate	phosphor screen
• ion current • ion number in bunches (with charge amplifier)	• Single-ion counter (time-resolved)	• visual detection • beam shape, diameter

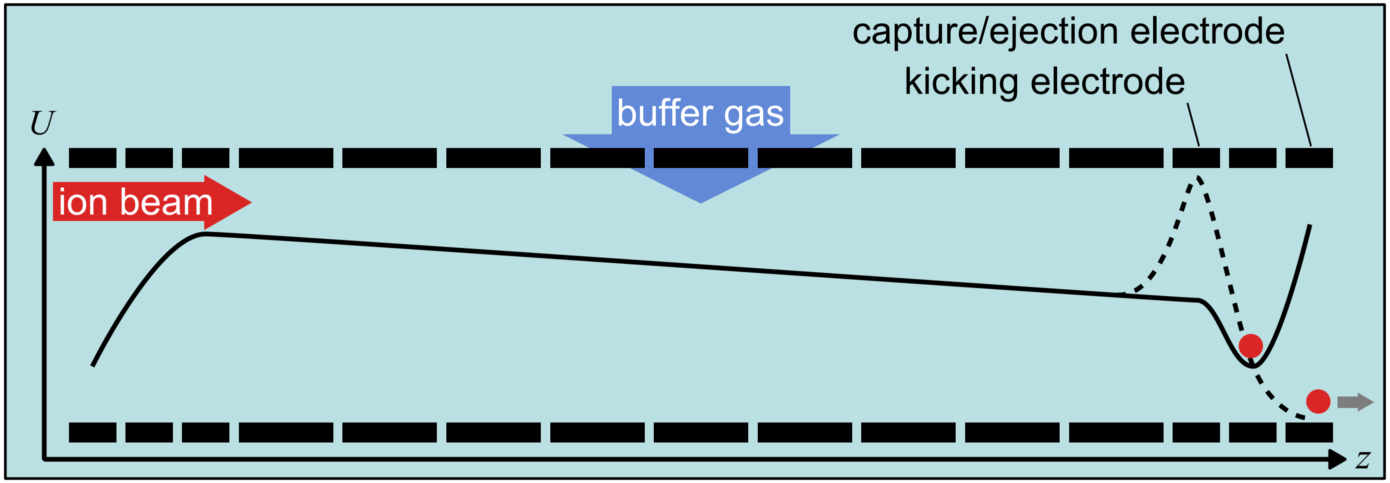
RFQ cooler/buncher: principle

- a radio-frequency quadrupole (RFQ) is a linear Paul trap

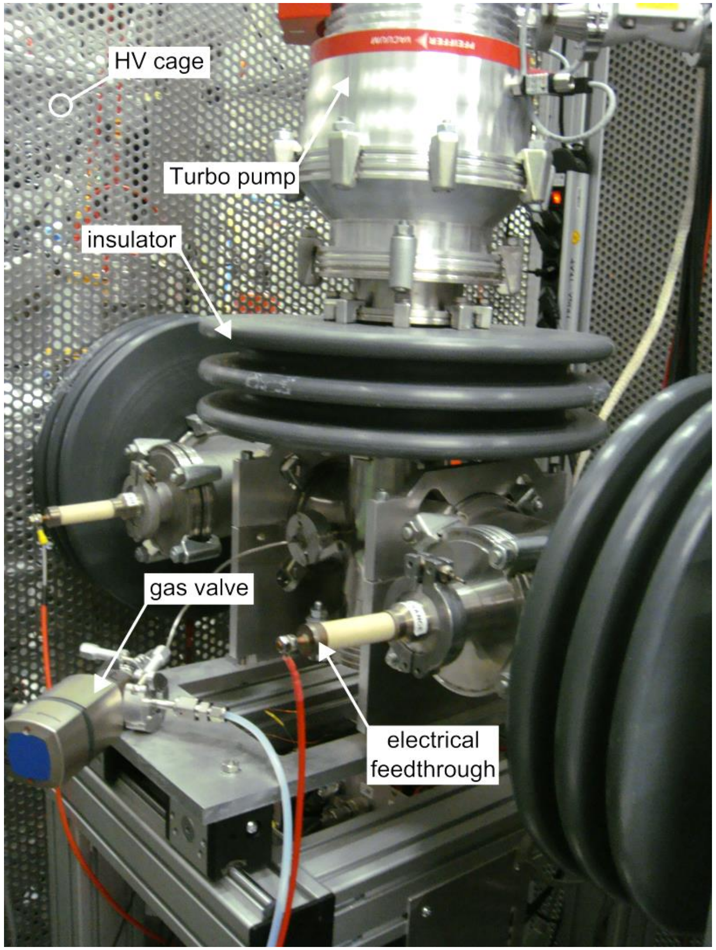




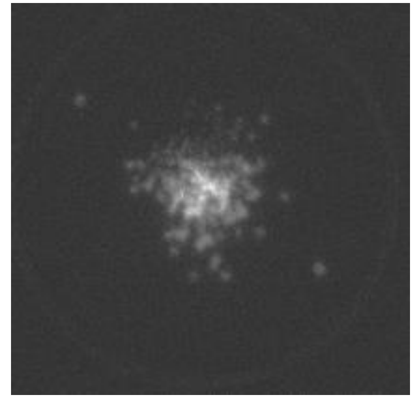
- axial trapping is achieved by segmented rods



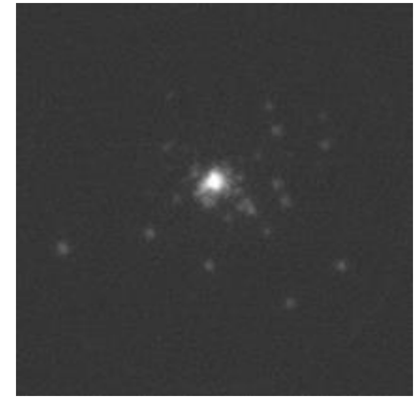
RFQ cooler/buncher: operation modes



continuous



without buffer gas

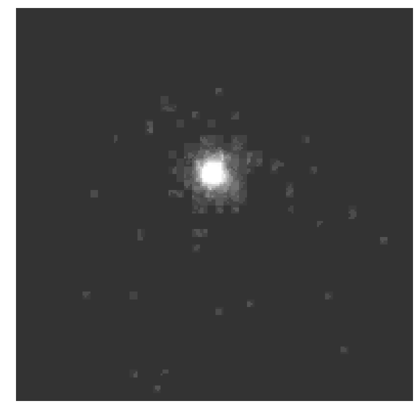


with buffer gas

(phosphor screen captures)

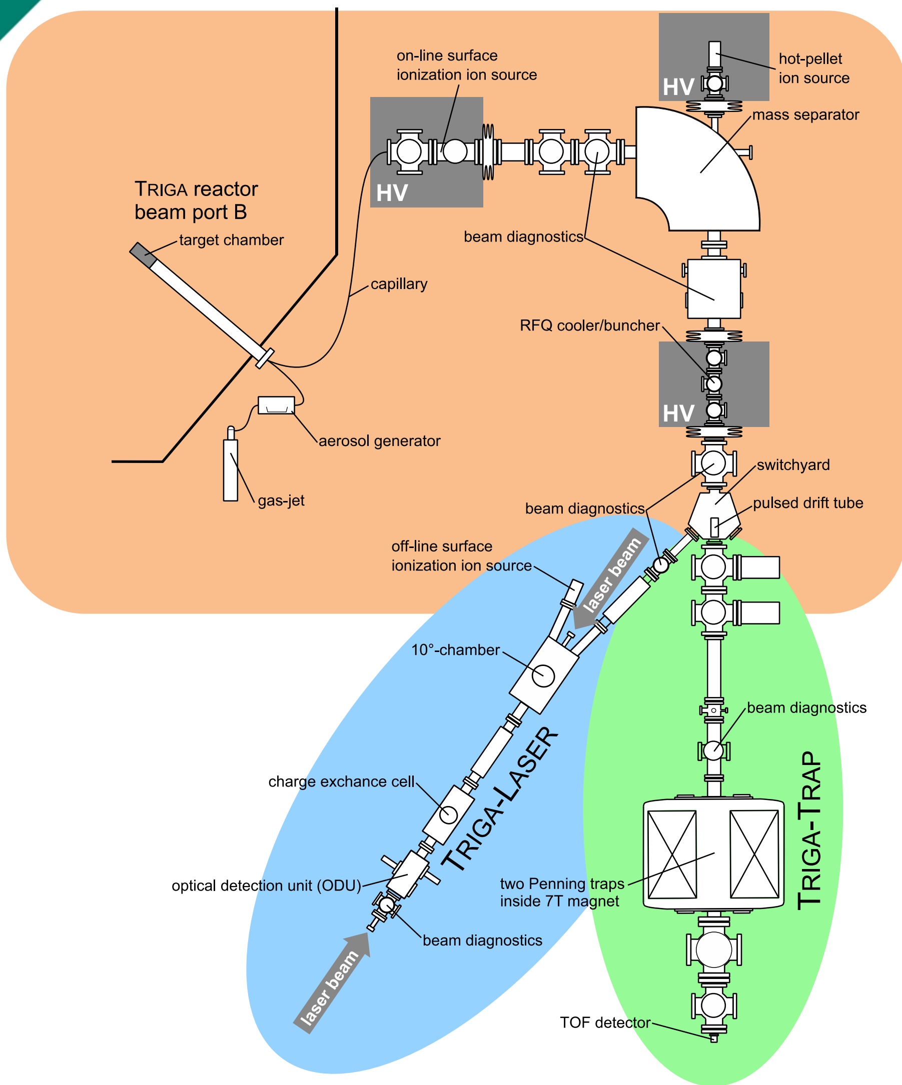
bunched

all the time…



once: short bright pulse

TRIGA-SPEC: experiments



Ion beam preparation transfer line

- provide bunches of cooled radioactive ions

Collinear laser spectroscopy

- probe the properties of atoms and ions through the interaction of their electronic shell with an applied laser field
- Isotopic shifts in the Ca D2 line[1]

Penning-trap mass spectrometer

- high-precision mass measurements
- Cd, Pd masses and Q-values[2]
- Am, Pu, Cf masses[3]

[1] in preparation

[2] Smorra et al, Phys. Rev. C, 85:027601 (2012)

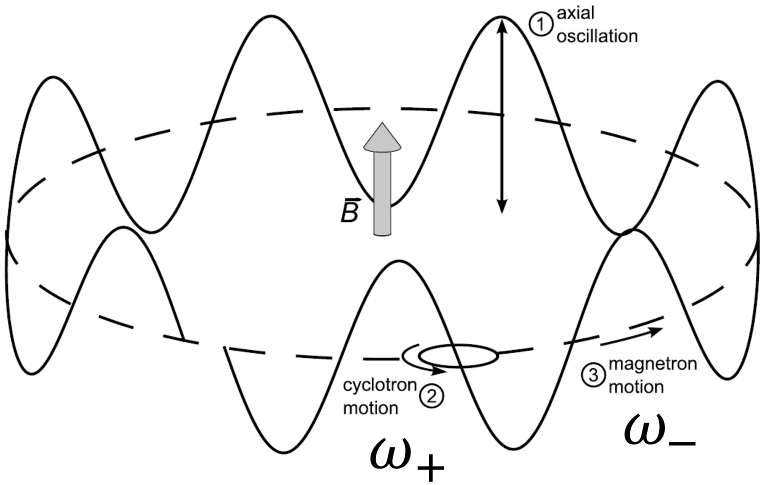
[3] Eibach et al, Phys. Rev. C, 89:064318 (2014)

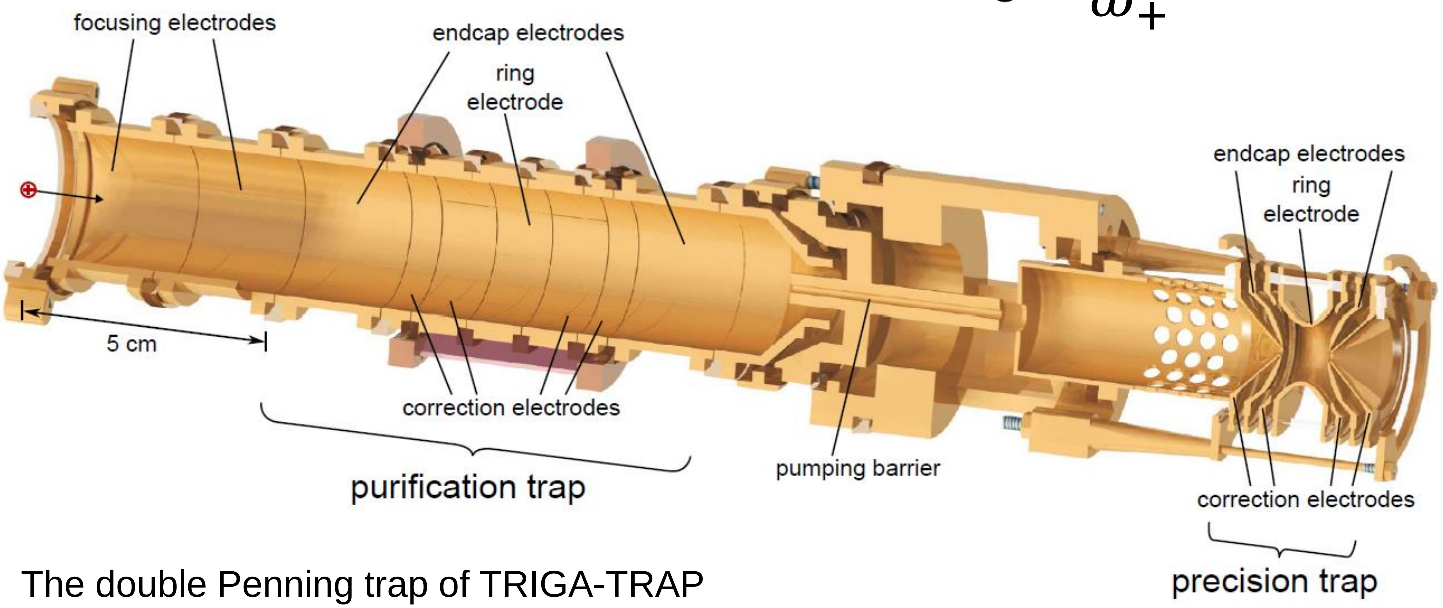
Penning-trap mass spectrometry

Principle idea:

measure the mass of an ion by its cyclotron frequency in a magnetic field $\boldsymbol{B}$

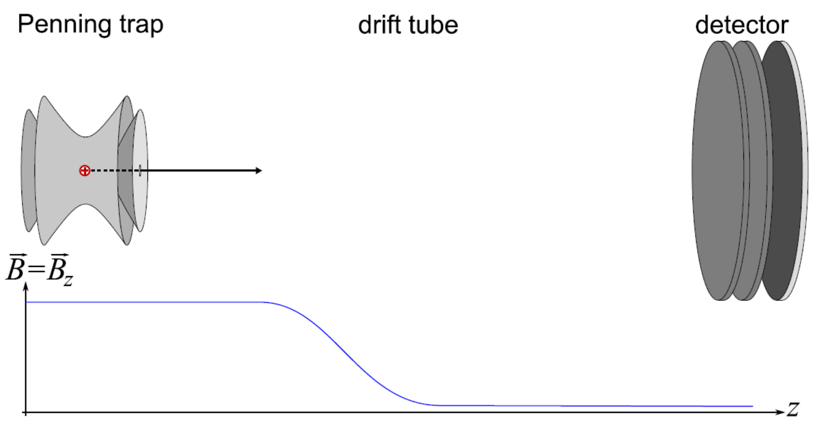
$$\omega_c = \frac{q}{m} B \qquad \omega_c = \omega_+ + \omega_-$$



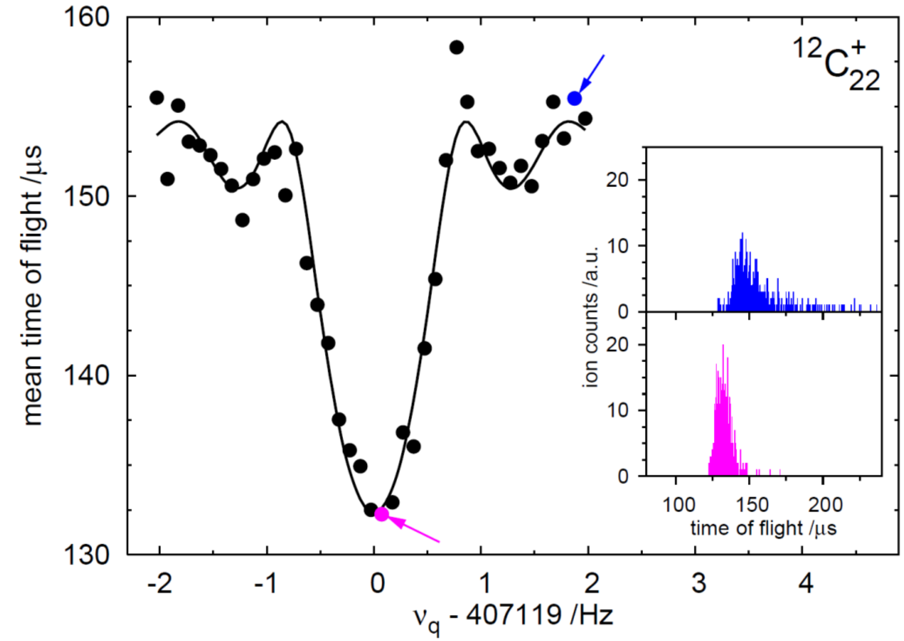


The double Penning trap of TRIGA-TRAP

Penning-trap mass spectrometry



$$\vec{F}_{\nabla B} = -\vec{\mu}\left(\vec{\nabla}\vec{B}\right) \propto r^2\omega$$



Time-of-flight ion cyclotron resonance (TOF-ICR):

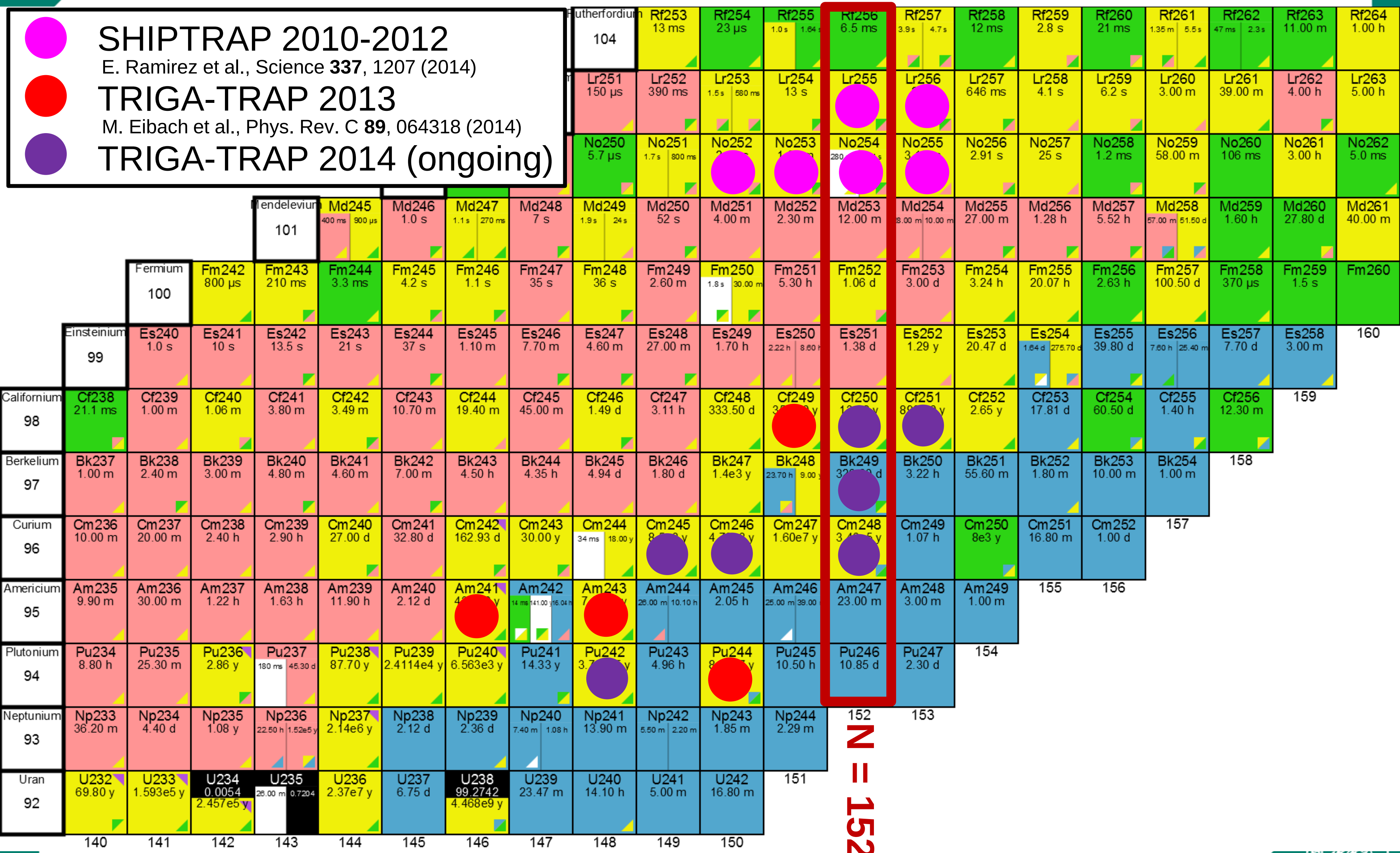
- the ions' cyclotron frequency is excited
- after ejection, excited ions receive an extra "kick"
- excited ions show the shortest TOF

Mapping the N=152 deformed shell closure

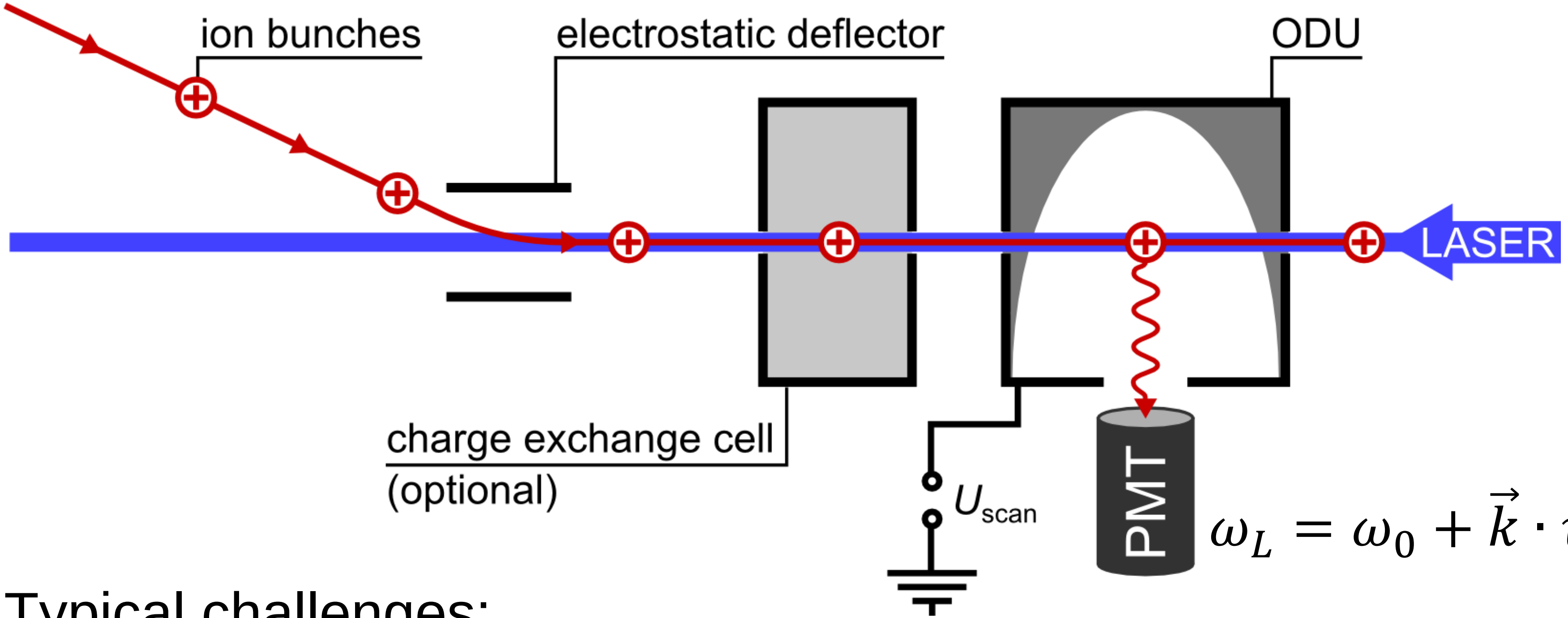
SHIPTRAP 2010-2012
E. Ramirez et al., Science **337**, 1207 (2014)

TRIGA-TRAP 2013
M. Eibach et al., Phys. Rev. C **89**, 064318 (2014)

TRIGA-TRAP 2014 (ongoing)



Collinear laser spectroscopy



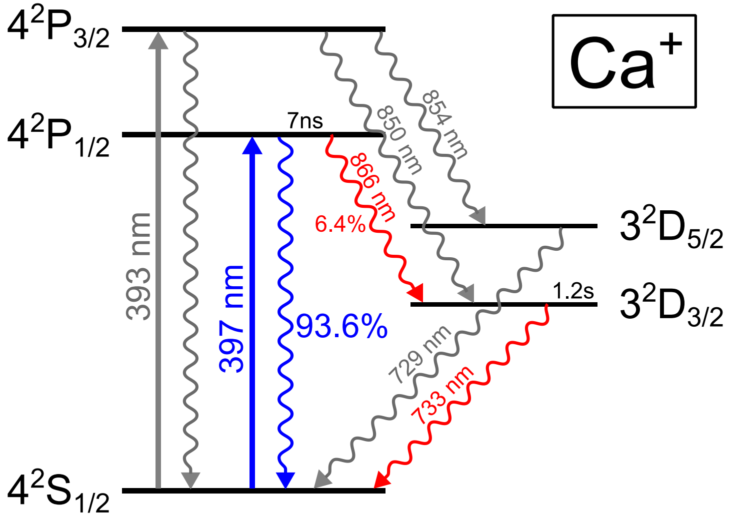
$$\omega_L = \omega_0 + \vec{k} \cdot \vec{v}$$

Typical challenges:

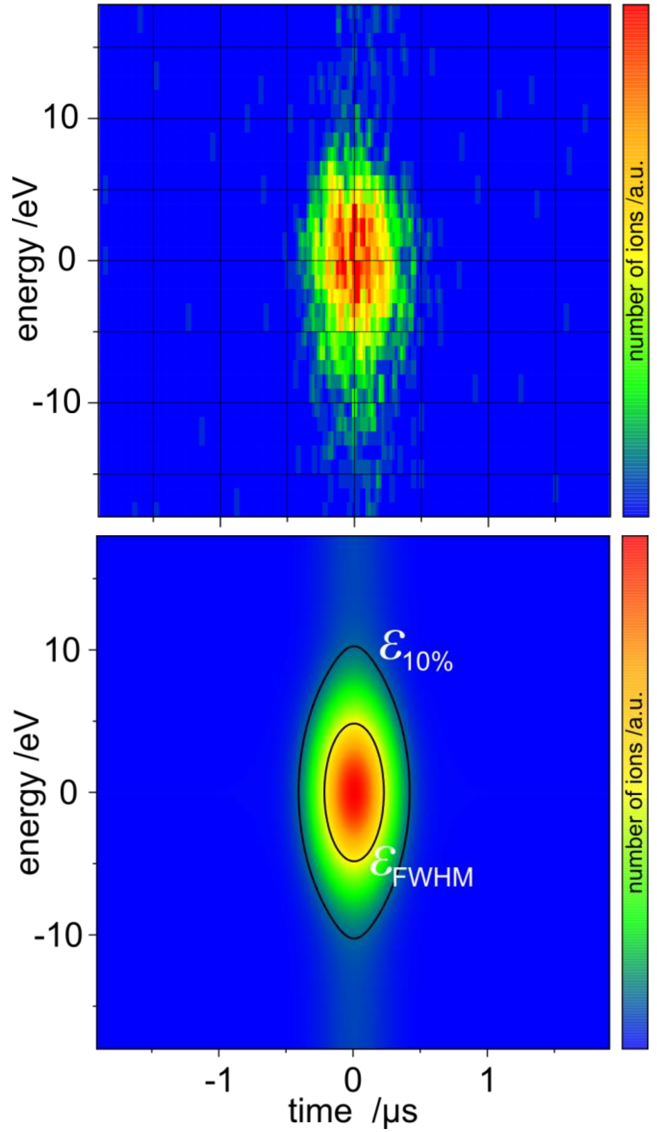
- stray light reduction (mirror geometry)
- background suppression (ion-photon coincidence detection)
- line width reduction (electrostatic acceleration)

Commissioning of the ion beam preparation

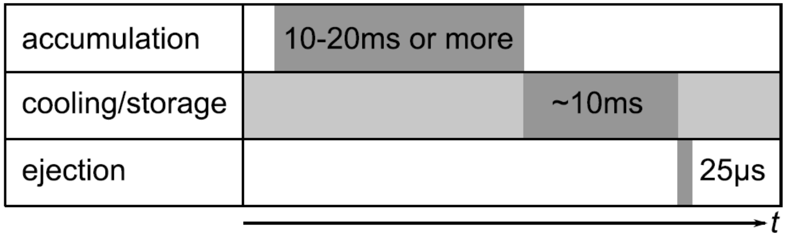
Ca^+ bunch is probed by time-resolved resonant laser spectroscopy at 397nm

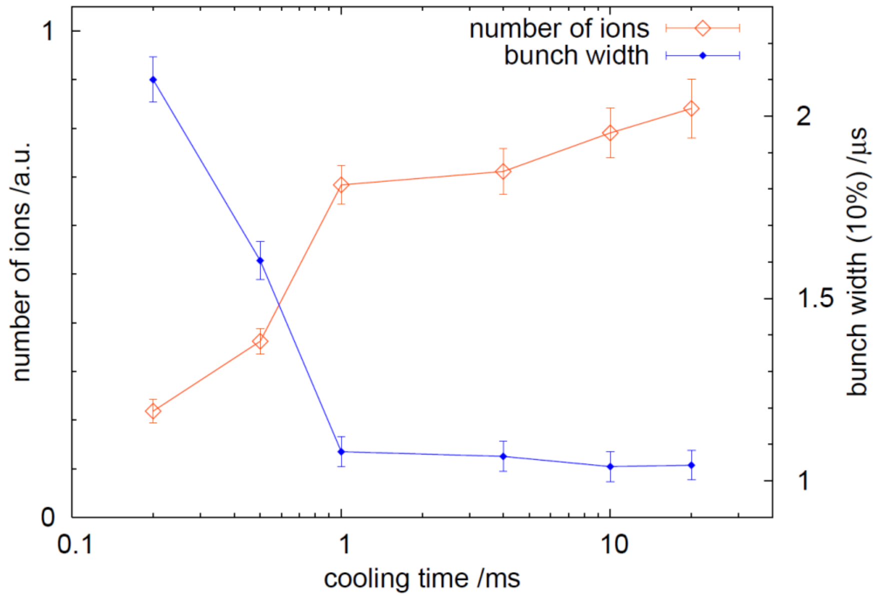


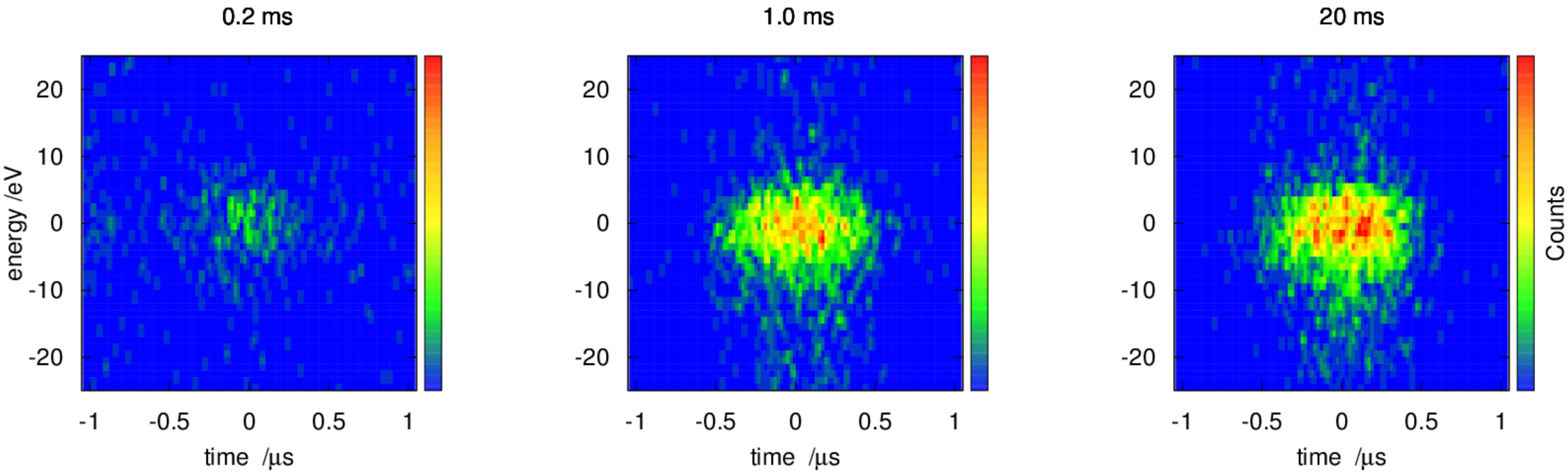
the result is the longitudinal emittance ε (in units of eV*µs)



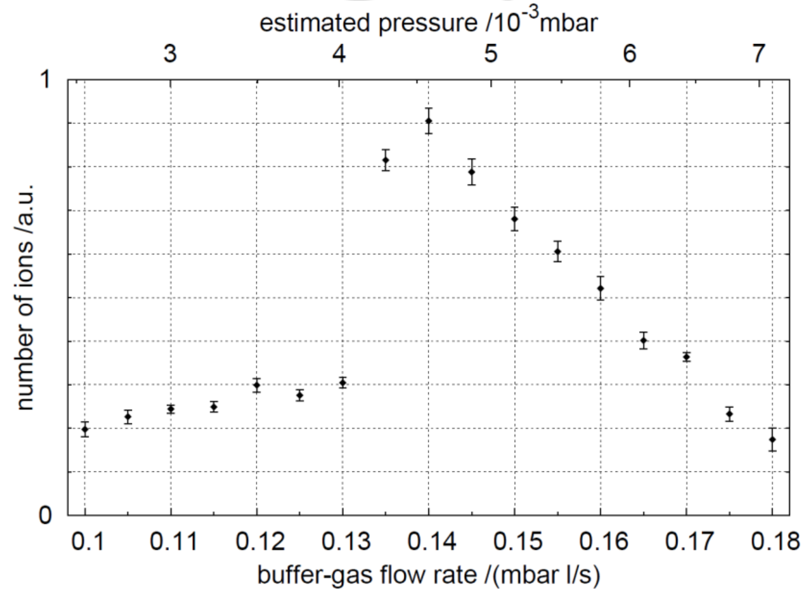
Optimization of the cooling time

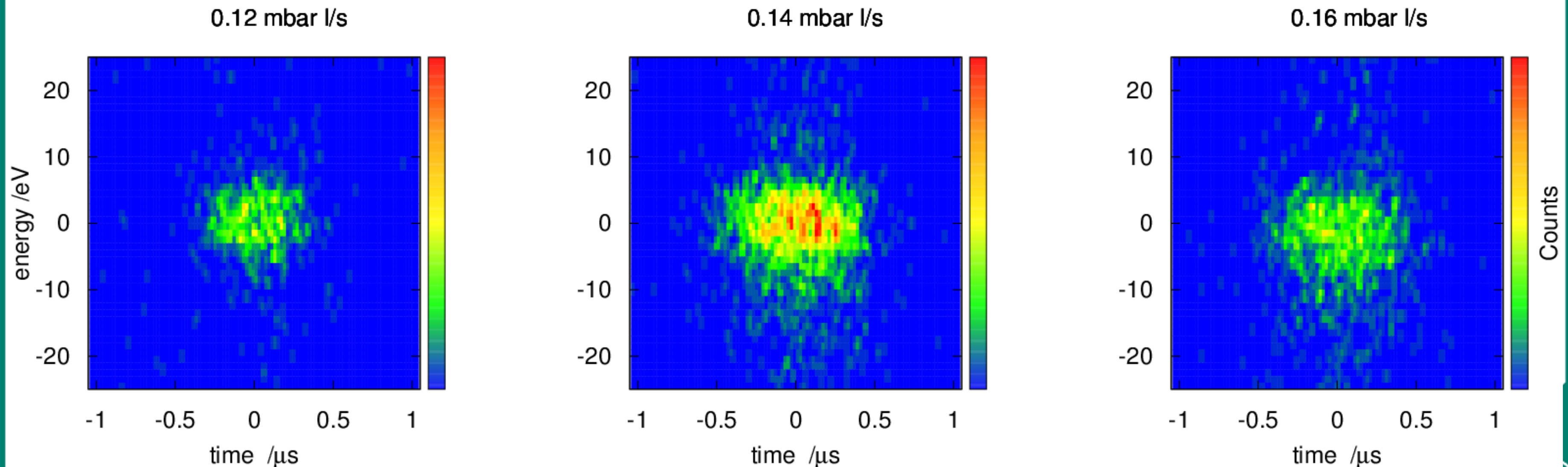






Optimization of the buffer gas pressure

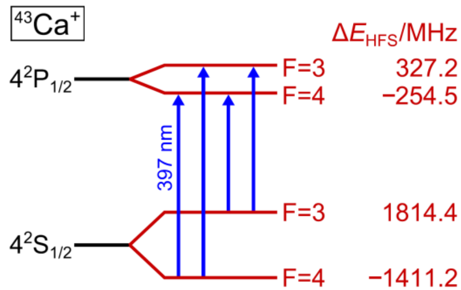


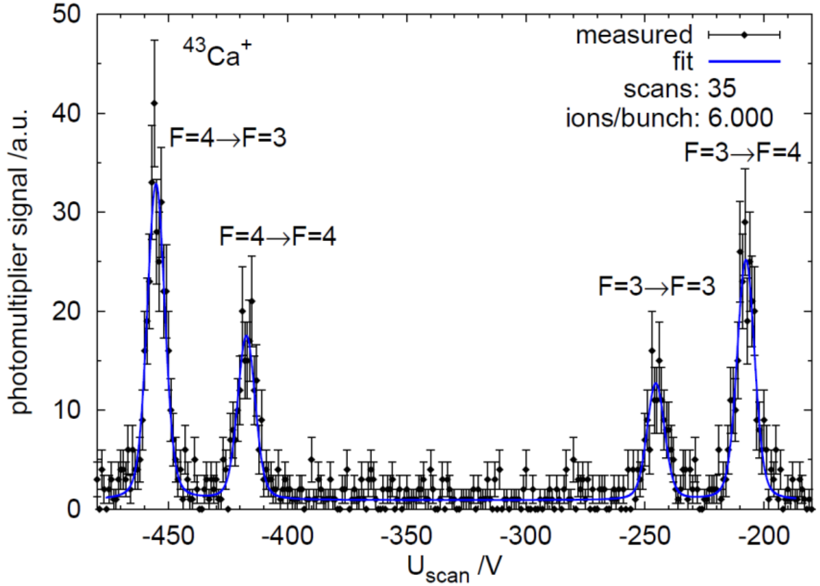


Operation of the complete setup

Ions created in the online source were sent to…

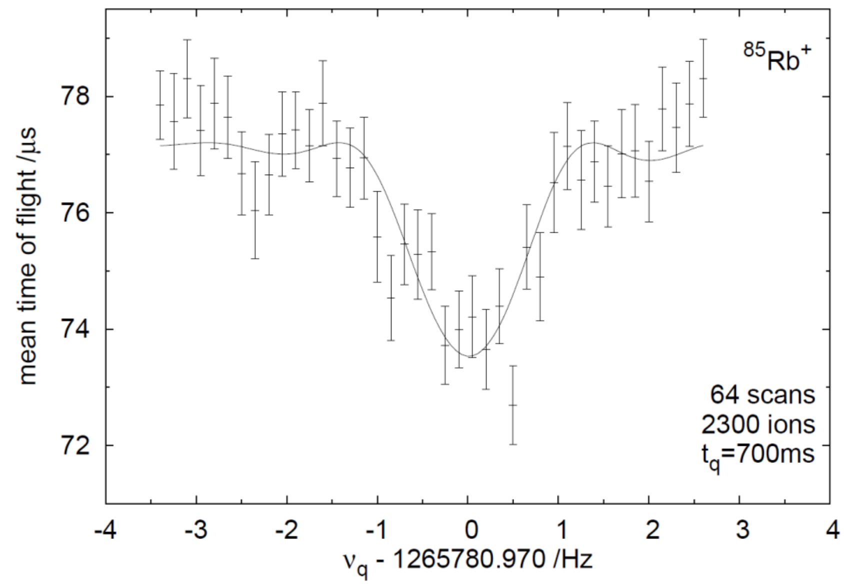
(a) TRIGA-LASER





to resolve the hyperfine structure of $^{43}Ca^{+}$

(b) TRIGA-TRAP



for a cyclotron-frequency measurement of $^{85}Rb^{+}$

Outlook

TRIGA-SPEC is fully connected and functional \ö/

The next steps include:

- Measurement of a radioactive nuclide (e.g. ^{91}Rb)
- Efficiency improvements to reach the rare candidates
  – Bigger actinide target (12-fold increase in production)
  – Aerodynamic lens to improve skimmer efficiency (15% -> 65%)
- Implementation of new techniques
  – Plasma ion source for the ionization of refractories
  – FT-ICR detection at TRIGA-TRAP
  – Two-step laser excitation at TRIGA-LASER

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Thank you for listening!

- Group members:

Christian Smorra
Martin Eibach
Szilard Nagy

Prof. Klaus Blaum

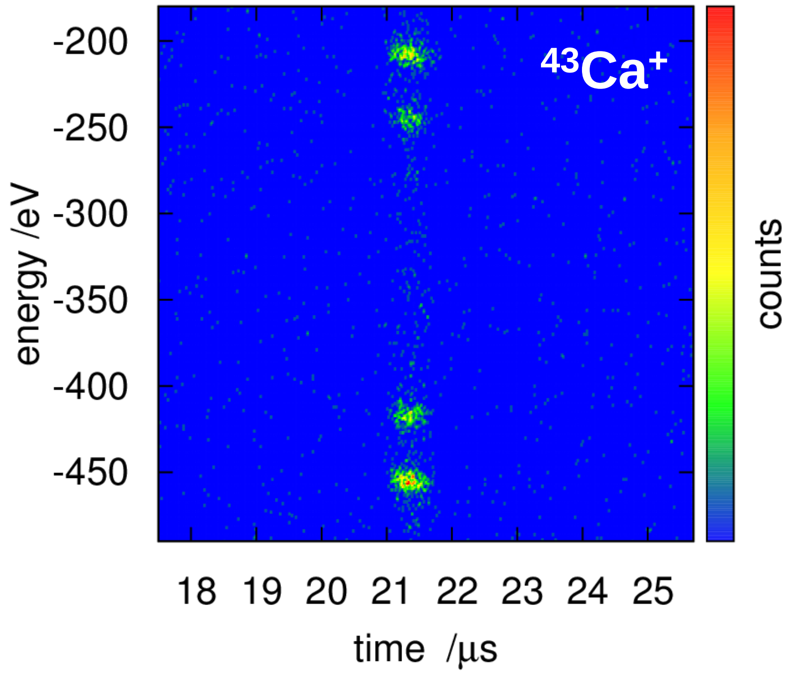
Simon Kaufmann
Christian Gorges
Christopher Geppert

Prof. Wilfried Nörtershäuser

Jessica Grund
Dennis Renisch

Prof. Christoph E. Düllmann

Fabian Schneider
Michael Block
Klaus Eberhardt



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