MR-TOF as an isobar filter at ISOLTRAP

Robert Wolf
– University of Greifswald –
for the ISOLTRAP collaboration

Rare-RI Ring workshop 2011
Tokyo, Japan

- Multi-Reflection-Time-of-Flight Analyzers/Spectrometers
- ISOLTRAP
- MR-TOF Isobar Separator
    - Design and operation principle, performance
- Bradbury-Nielsen Ion Gate
    - Principle and results
- Ion-Ion Interaction Simulation for MR-TOF Analyzers
- Accumulation of Isobaric Purified Ion Ensembles
- On-line Results

http://isoltrap.web.cern.ch

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Multi-Reflection Time-of-Flight Mass Analyzers

\\ "Farvitron" in 1959

An Electrostatic Mass Spectroscope

WERNER TRETNER

Fernseh G.m.b.H., Darmstadt, Germany

- Electrostatic tube for mass analysis in UHV pressure 10^{-8}mbar
- 2 cylindrical ion mirrors separated by drift path, overall length 36mm
- Ionization via electron collision inside the mirror
- No single ion detector needed, only HF amplifier
- 50Hz spectra acquisition rate
- Mass resolving power $m/\Delta m$=20

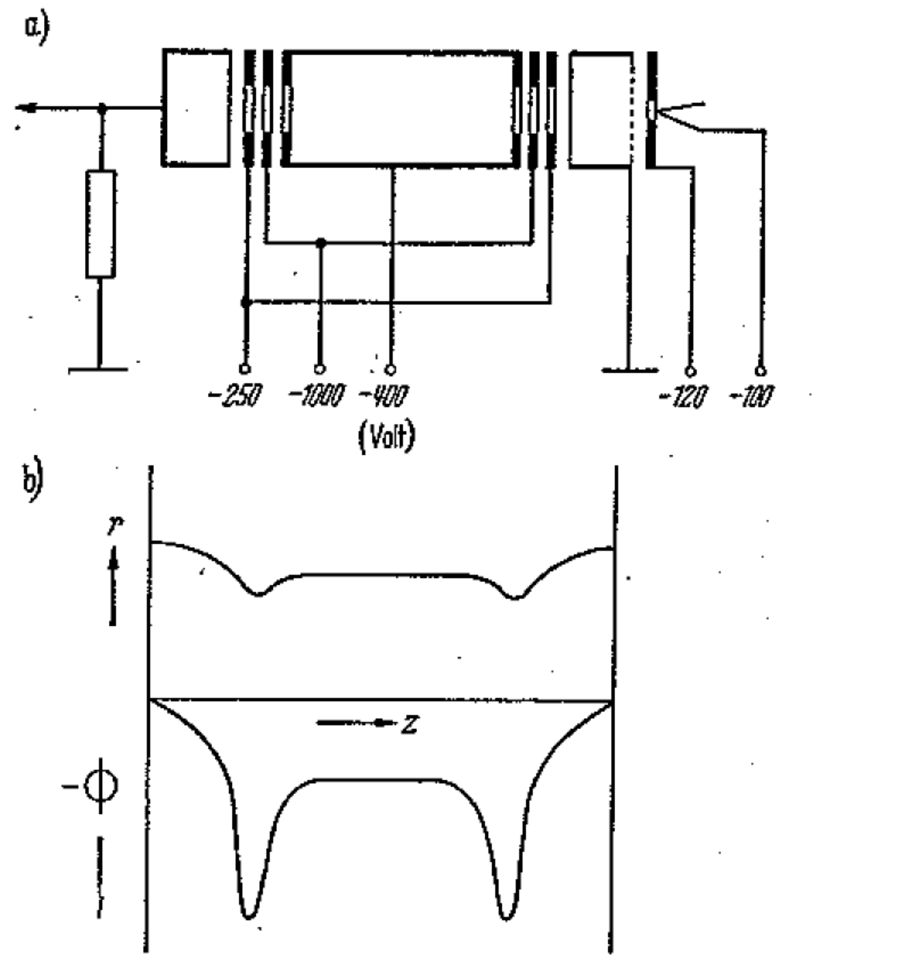
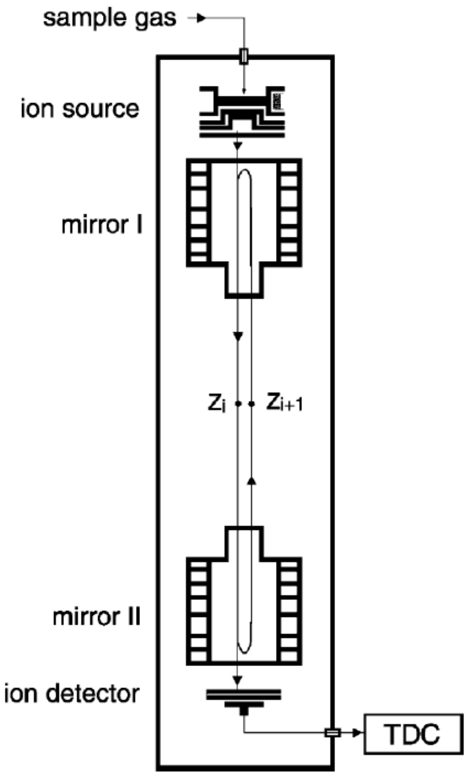


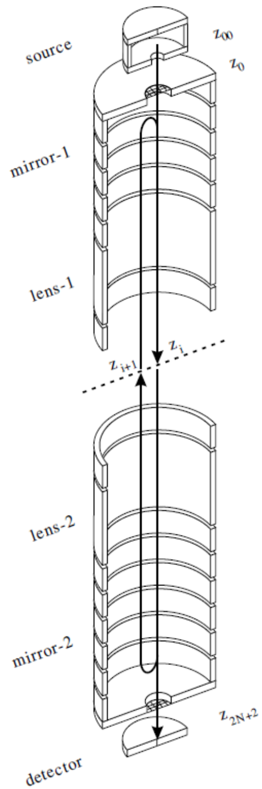
Abb. 4a u. b. a Längsschnitt durch die Elektroden der Röhre von Abb. 3. b Der Verlauf des Potentials und eine spezielle Elektronenbahn

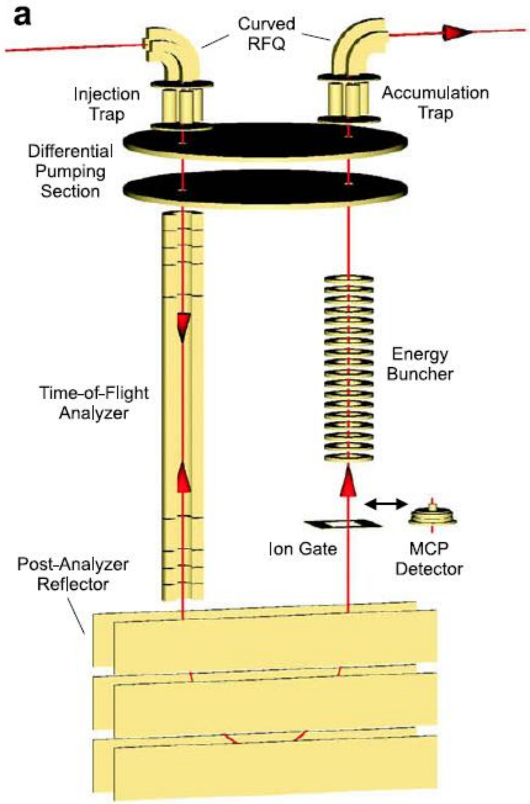
W. Tretner, Z. angew. Phys. **11**, 395 (1959)

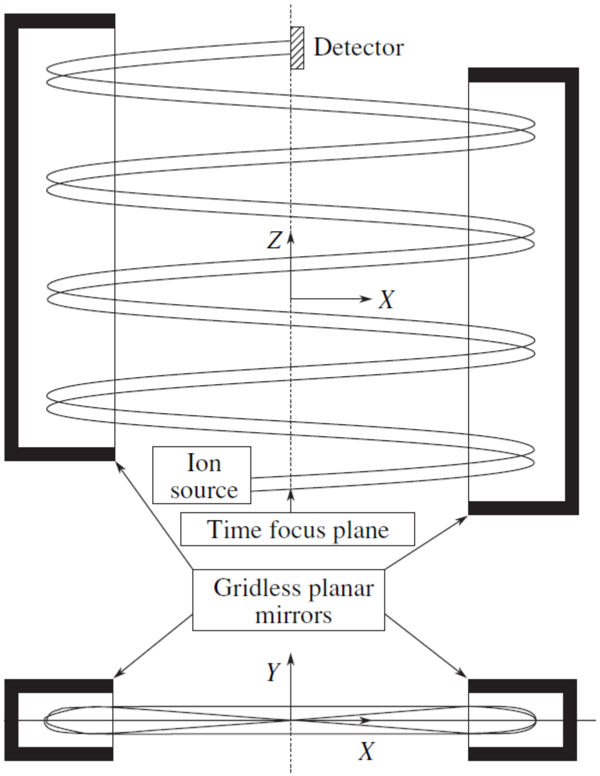
Multi-Reflection Time-of-Flight Mass Analyzers

\\ MR-ToF design









H. Wollnik and A. Casares, Int. J. Mass. Spectrom. **227**, 217 (2003)

Y. Ishida *et al.*, NIM B **219-220**, 468 (2004)
H. Wollnik *et al.*, NIM A **519**, 373 (2004)
A. Piechaczek *et al.*, NIM B **266**, 4510 (2008)

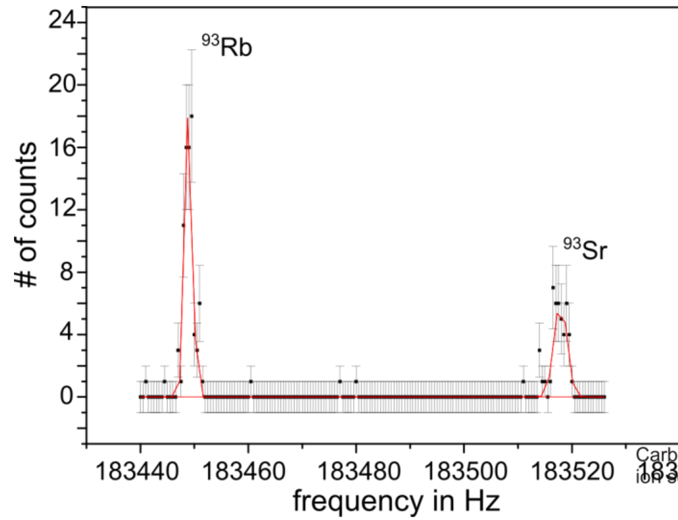
W. R. Plaß *et al.*, NIM B **266**, 4560 (2008)
W. R. Plaß *et al.*, Eur. Phys. J. Special Topics **150**, 367 (2007)

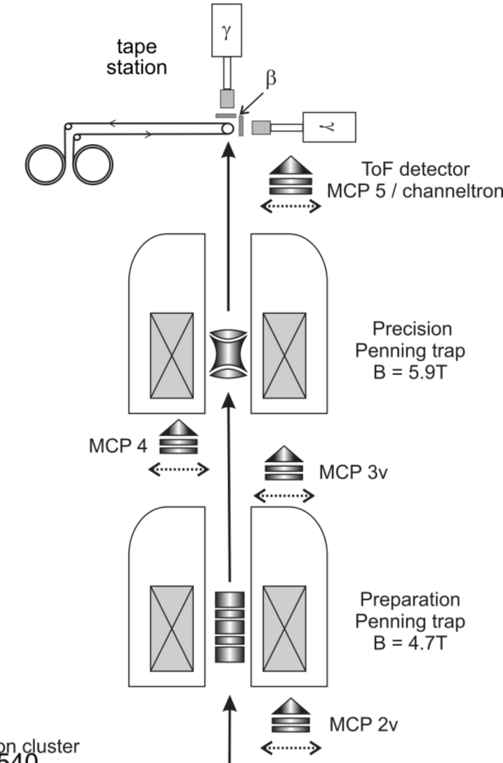
A. N. Verentchikov *et al.*, Tech. Phys. **50**, 73 (2005)

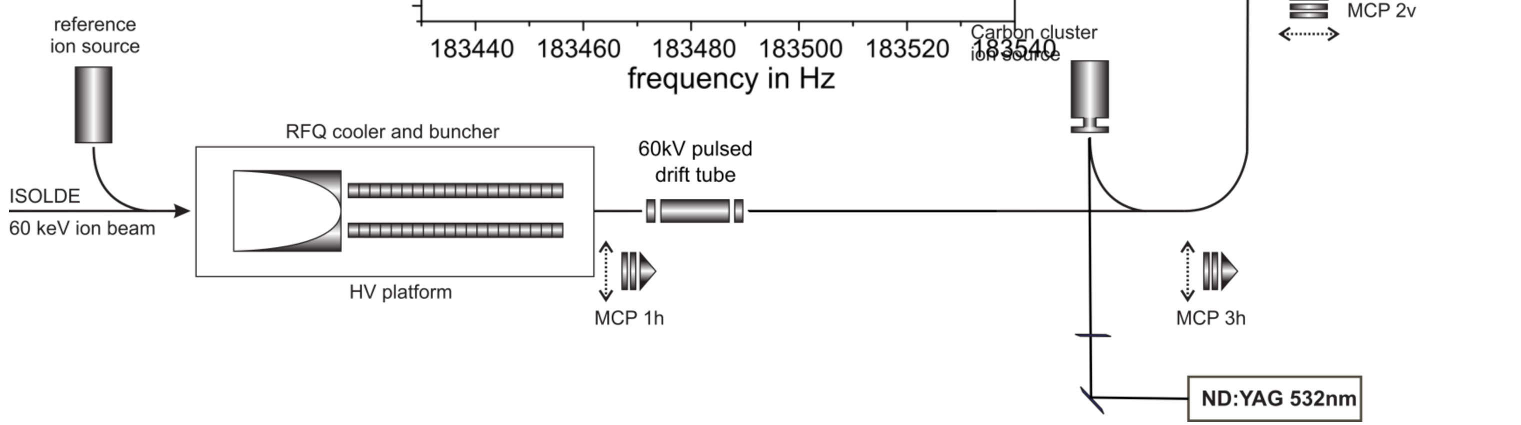
ISOLTRAP overview

\\ Setup

- Radioactive ion beam with up to 60keV from ISOLDE
- RFQ cooler and buncher[1] for accumulation and cooling
- 60keV pulsed drift tube to transfer ions between HV-cage and ground
- Preparation Penning trap for isobar cleaning, cooling with mass resolving power 10^5







[1]Herfurth *et al.*, NIM A **469**, 254 (2001)

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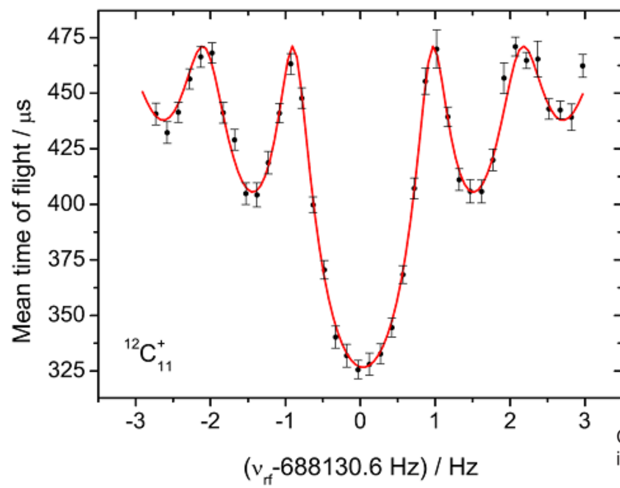
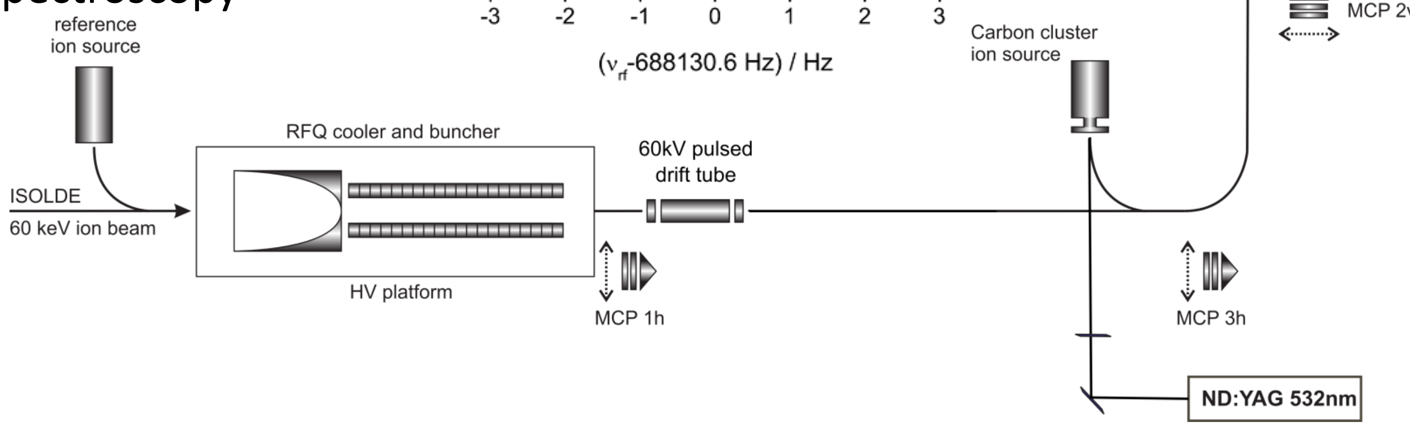
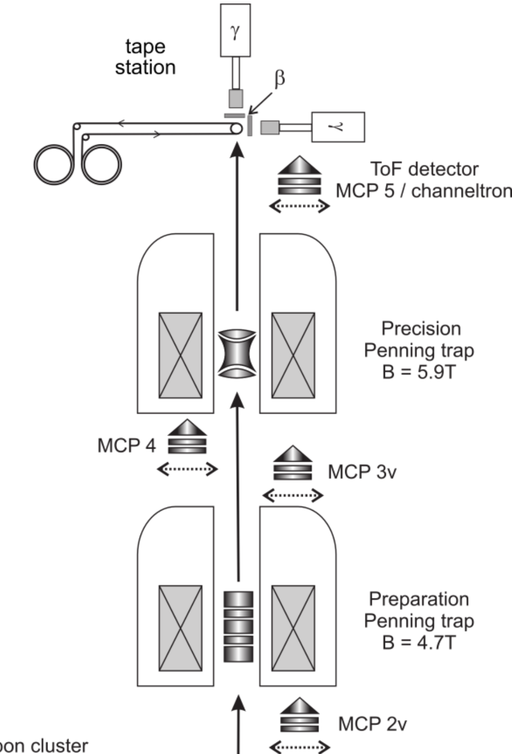
- Precision Penning trap for mass measurement
- Tape station setup for trap assisted spectroscopy







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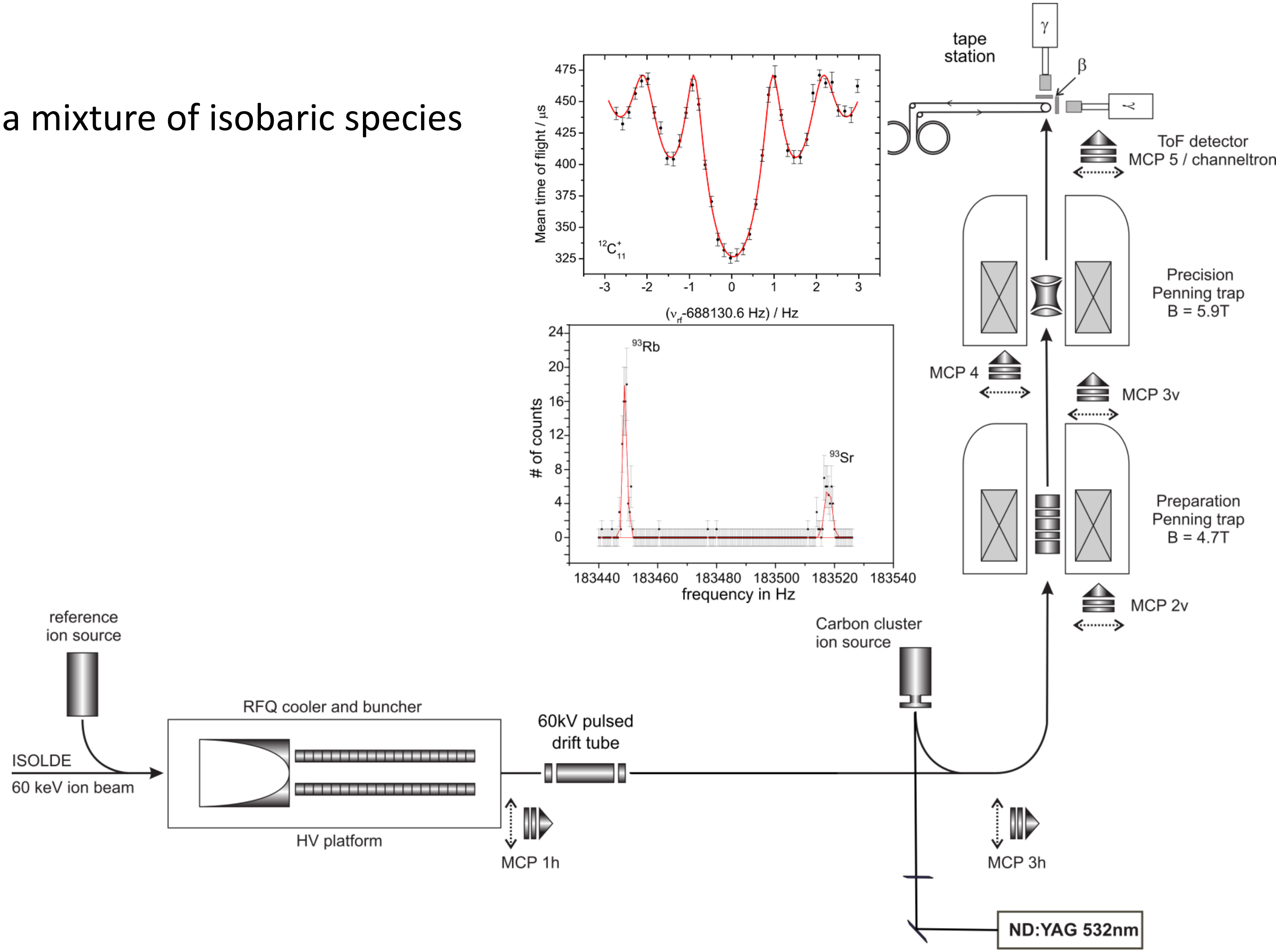
\\ Setup

- ISOLDE delivers a mixture of isobaric species

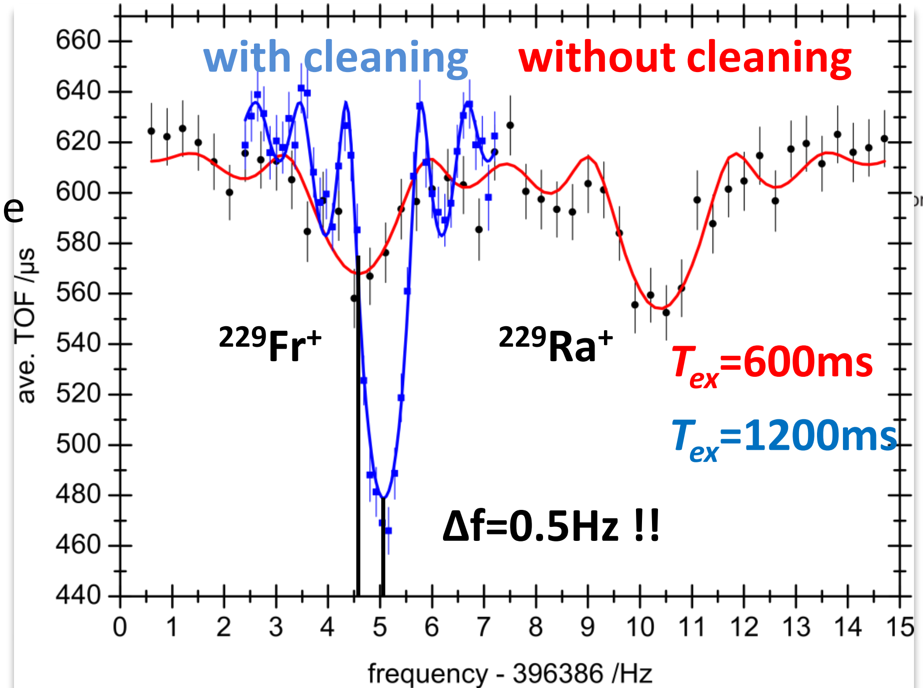


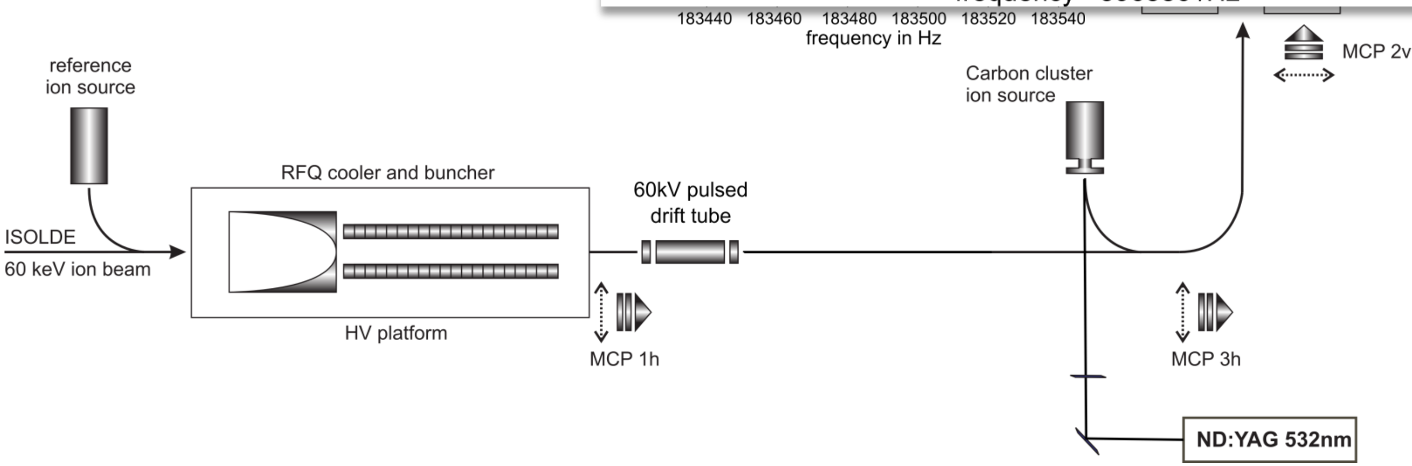
ISOLTRAP overview

\\ Setup

- ISOLDE delivers a mixture of isobaric species
- frequency shifts due to contaminated ensemble

→ **Incorrect mass values**





ISOLTRAP overview

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- ISOLDE delivers a mixture of isobaric species
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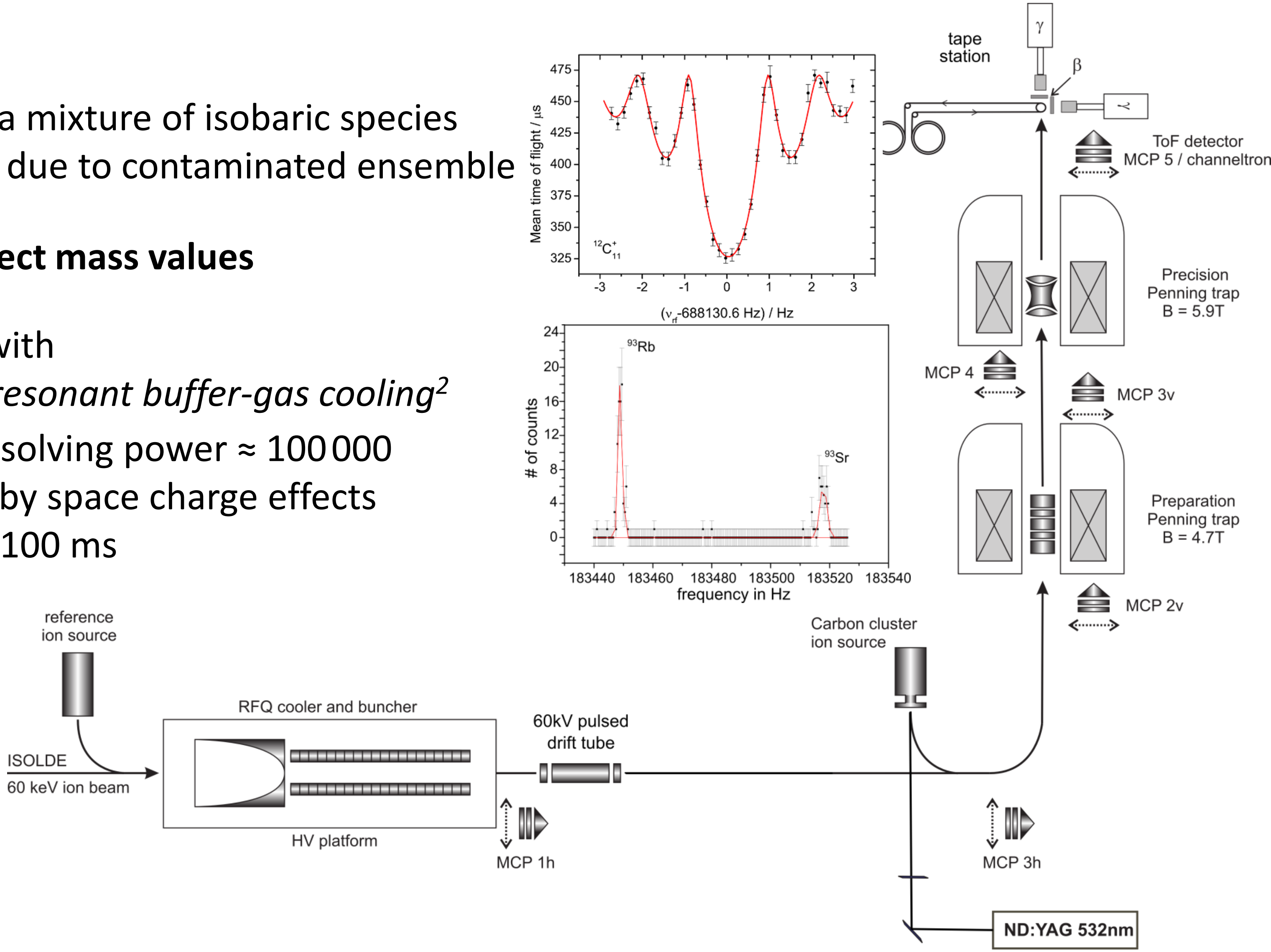
→ **Incorrect mass values**

- RIB is purified with *mass-selective resonant buffer-gas cooling*[2]
    - mass resolving power ≈ 100 000
    - limited by space charge effects
    - several 100 ms



[2]Savard *et al.*, Phys. Lett. A **158**, 247 (1991)

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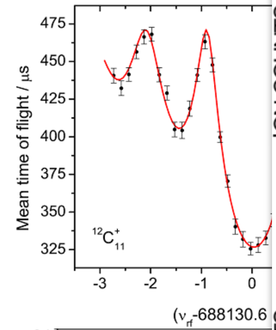
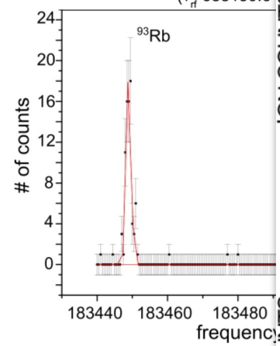
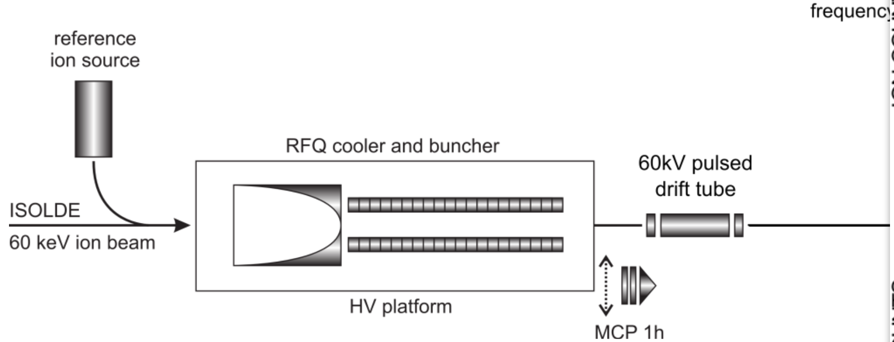
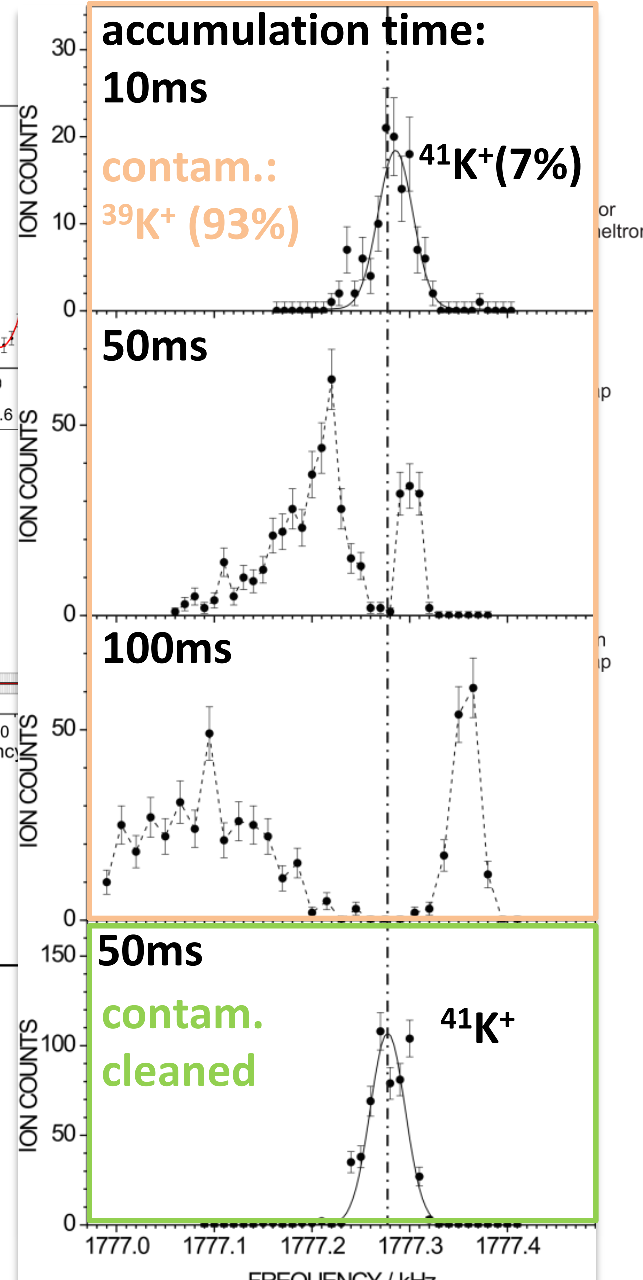






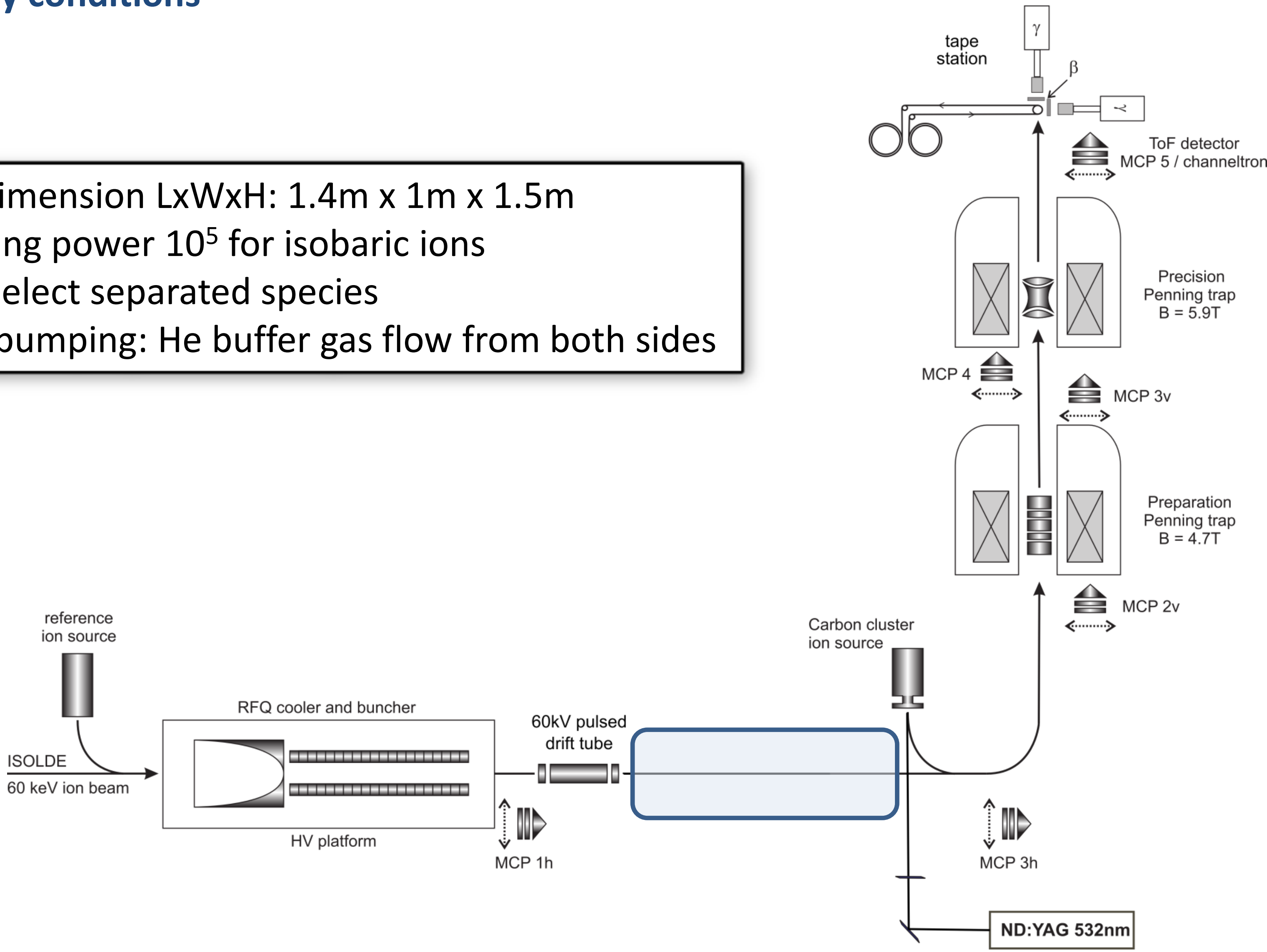
Schweikhard *et al.*, Eur. J. Mass Spectrom. **11**, 457 (2005)



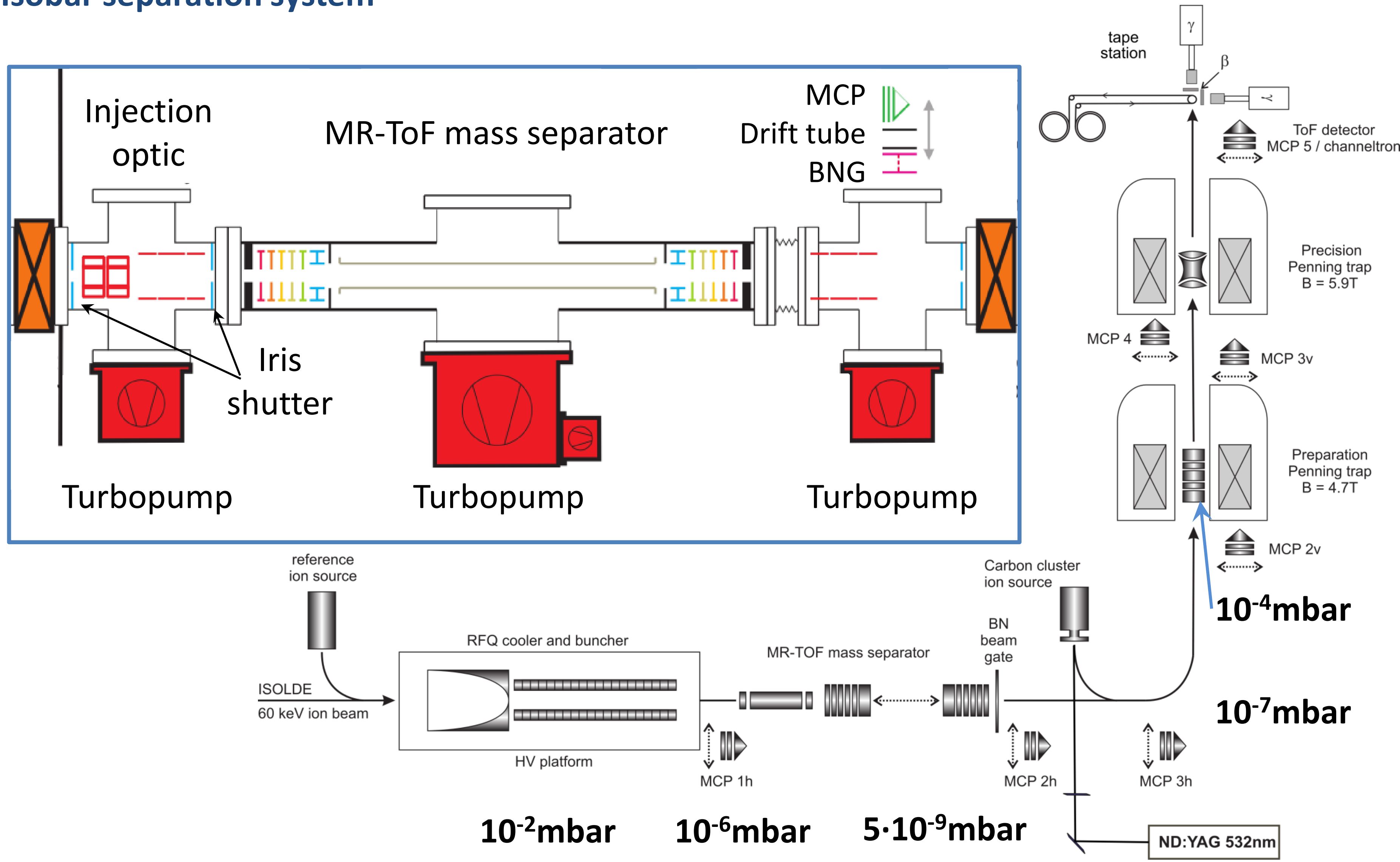
[2]Savard *et al.*, Phys. Lett. A **158**, 247 (1991)

\\ MR-ToF boundary conditions

- Maximum dimension LxWxH: 1.4m x 1m x 1.5m
- Mass resolving power 10^5 for isobaric ions
- Ion gate to select separated species
- Differential pumping: He buffer gas flow from both sides



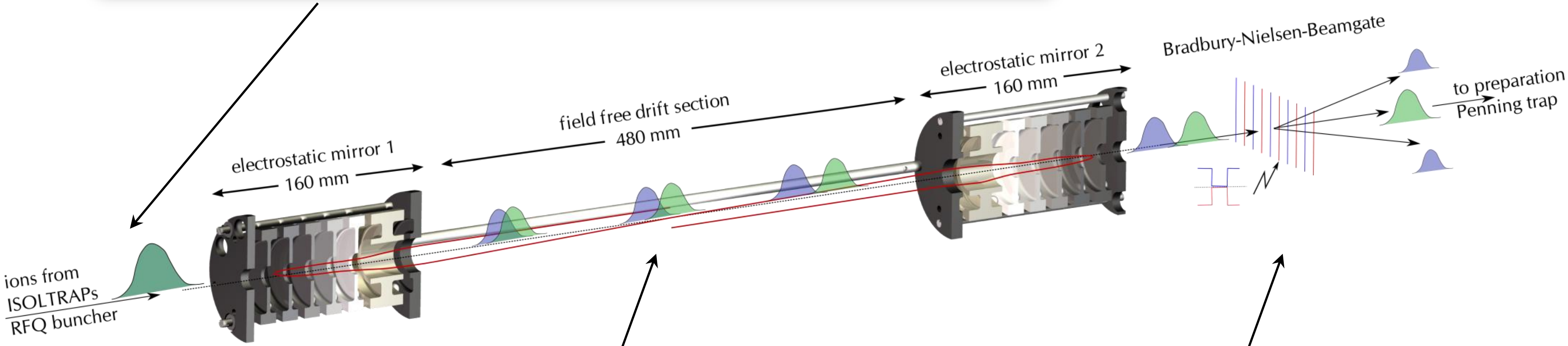
\\ Isobar separation system



MR-ToF isobar separator

\\ Isobar purification principle

RFQ-Buncher
- ion pulses from RFQ-buncher with time width Δt≈60ns
- relative kinetic energy $\Delta E_{kin}/E_{kin}$≈5%



MR-ToF isobar separator[3]
- mean kinetic energy E_{kin}=2.1keV
- time-of-flight separation due to different m/q

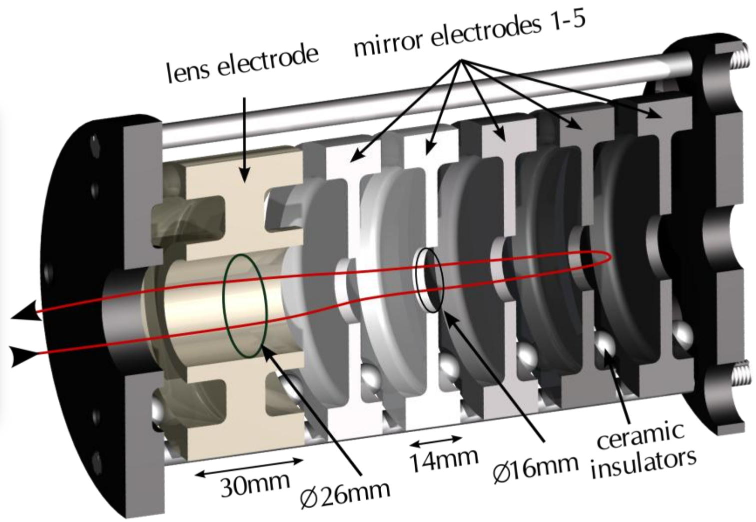
Bradbury-Nielsen ion gate (BNG)[3,4]
- selection of wanted species
- further transport to first Penning trap

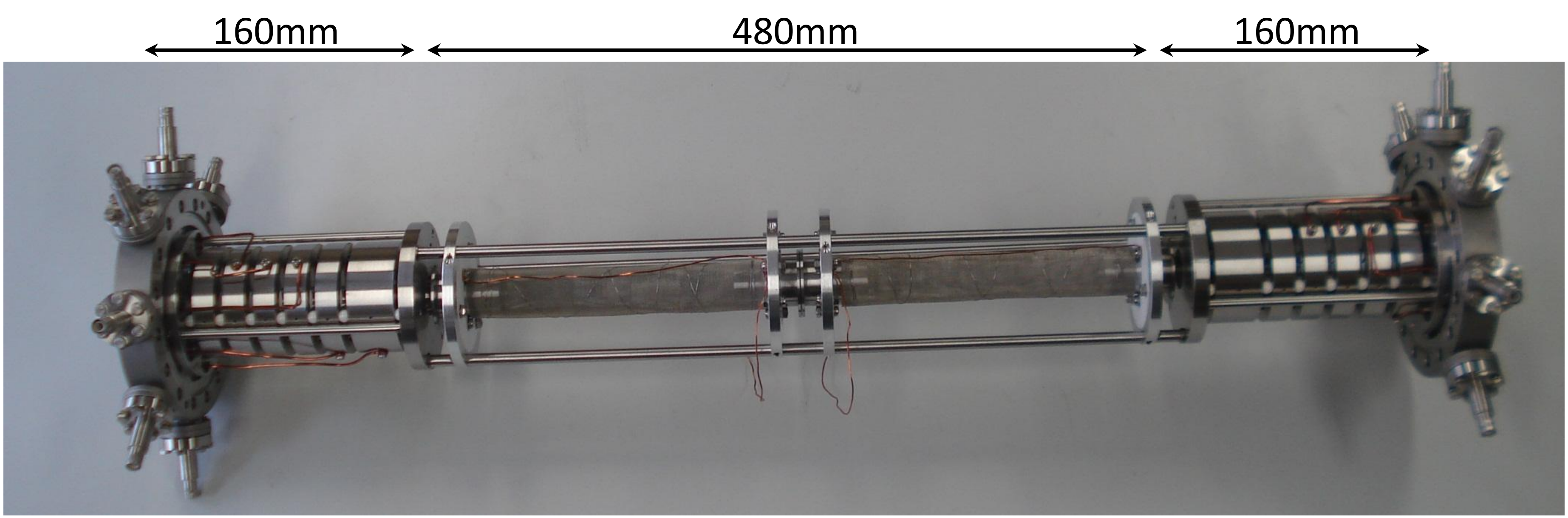
[3]Plass *et al.*, NIM B **266**, 4560 (2008)
[4]Bradbury and Nielsen, Phys. Rev. **49**, 388 (1936)

MR-ToF isobar separator

\\ MR-ToF device

- Stack of 6 electrodes per mirror, length 160mm
- Pulsed drift tube between mirrors
- Overall length 800mm
- Symmetrically connected to high precision power supplies, ripple/noise ≈ 10mV



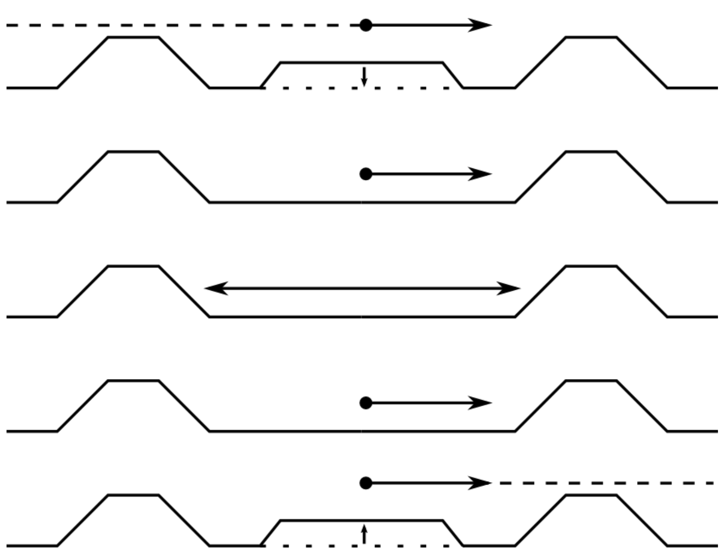


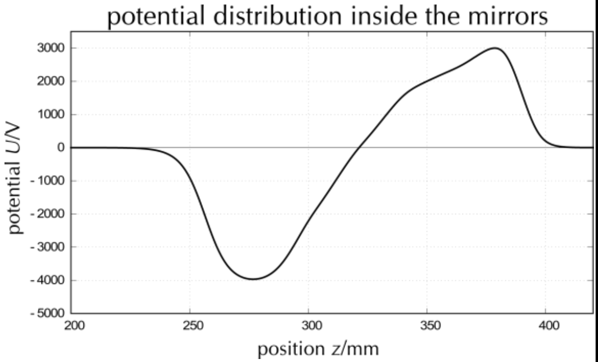
MR-ToF isobar separator

\\ MR-ToF details: technical overview

2 electrostatic ion mirrors: 6 electrodes, inner and outer shielding

- electrostatic mirrors -> no switching
- pulsed drift tube to capture and eject ions
- drift tube potential: set time focus on the detector/Bradbury-Nielsen ion gate





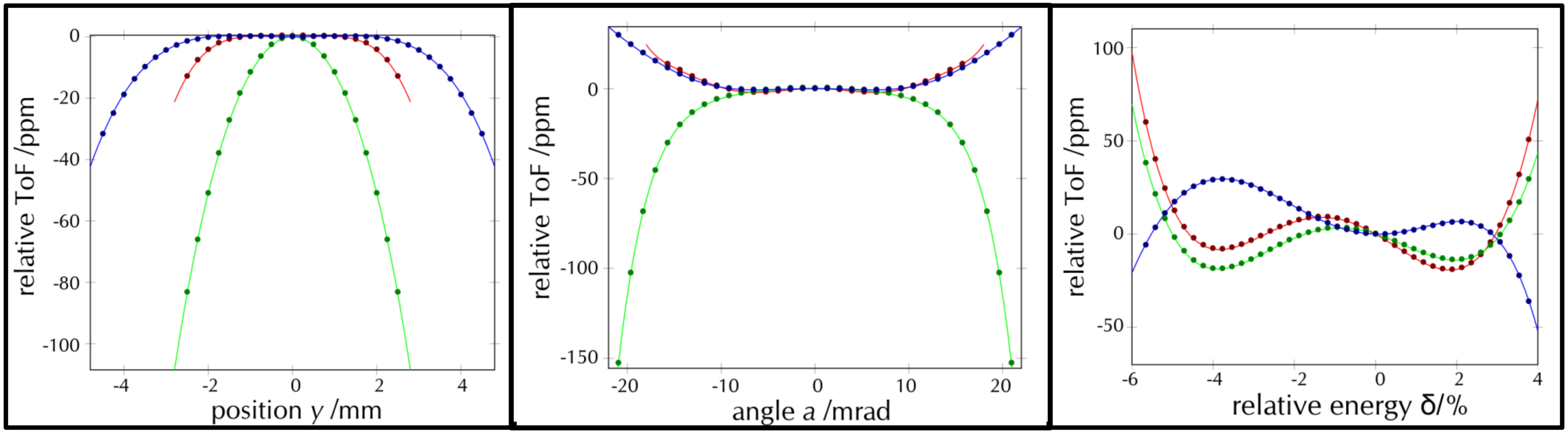
potential distribution:

compensate spatial and energetic distribution from ion source

\\ MR-ToF details: potential optimisation

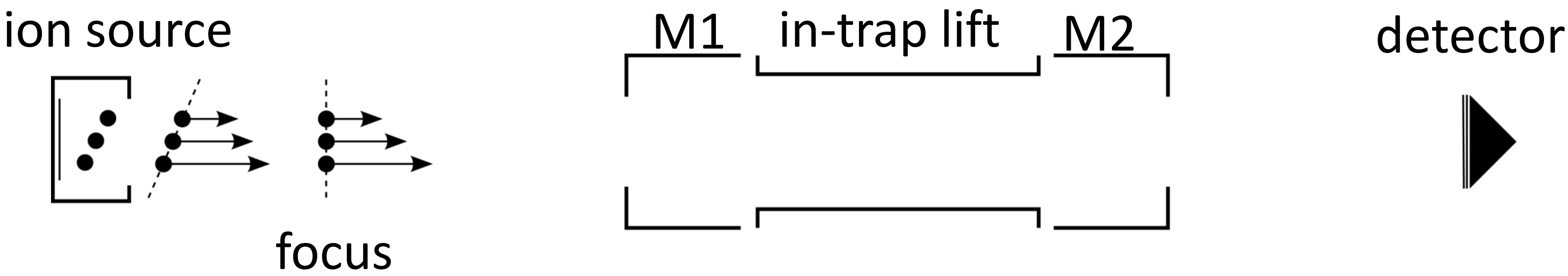
Optimizing 6 mirror electrodes for lowest ToF deviations and stable orbits:

- mirror voltages in kV range, precision $<10^{-4}$ -> 10^{24} potential combination
- Nelder-Mead simplex[5] optimization algorithm to find ToF deviation minima[6]
- using SIMION, consistency between simulation and experiment sufficient



[5]Nelder and Mead, Computer Journal **7**, 308 (1965)
[6]Wolf *et al.*, Hyperfine Interact., **199**, 115(2011)

\\ MR-ToF details: in-trap potential lift time focussing



Wolf *et al.*, submitted to Rev. Sci. Instrum. (2011)

MR-ToF isobar separator

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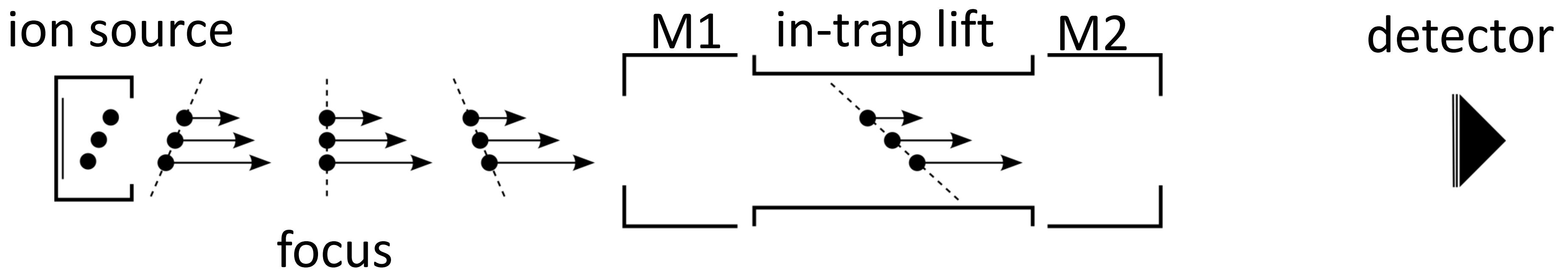

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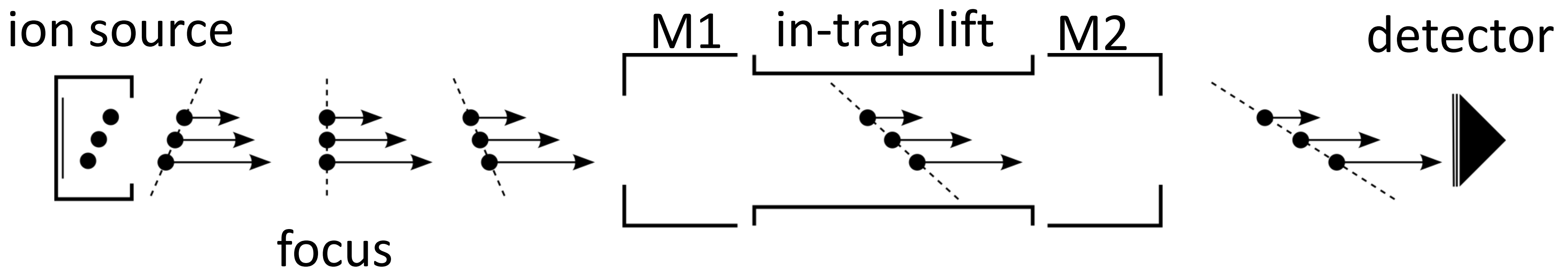

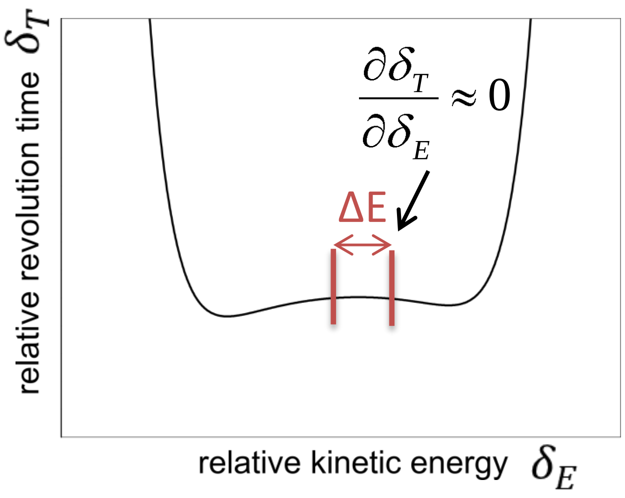

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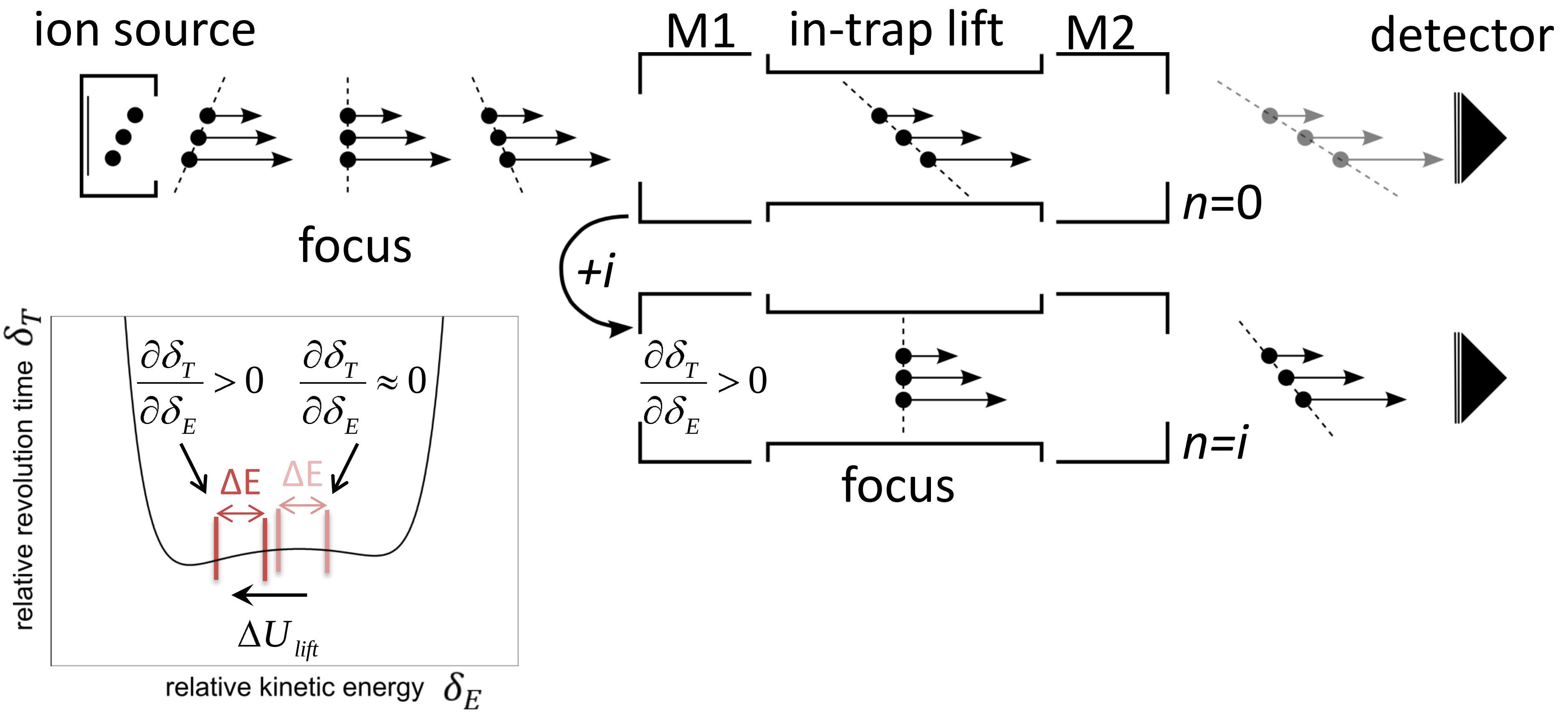

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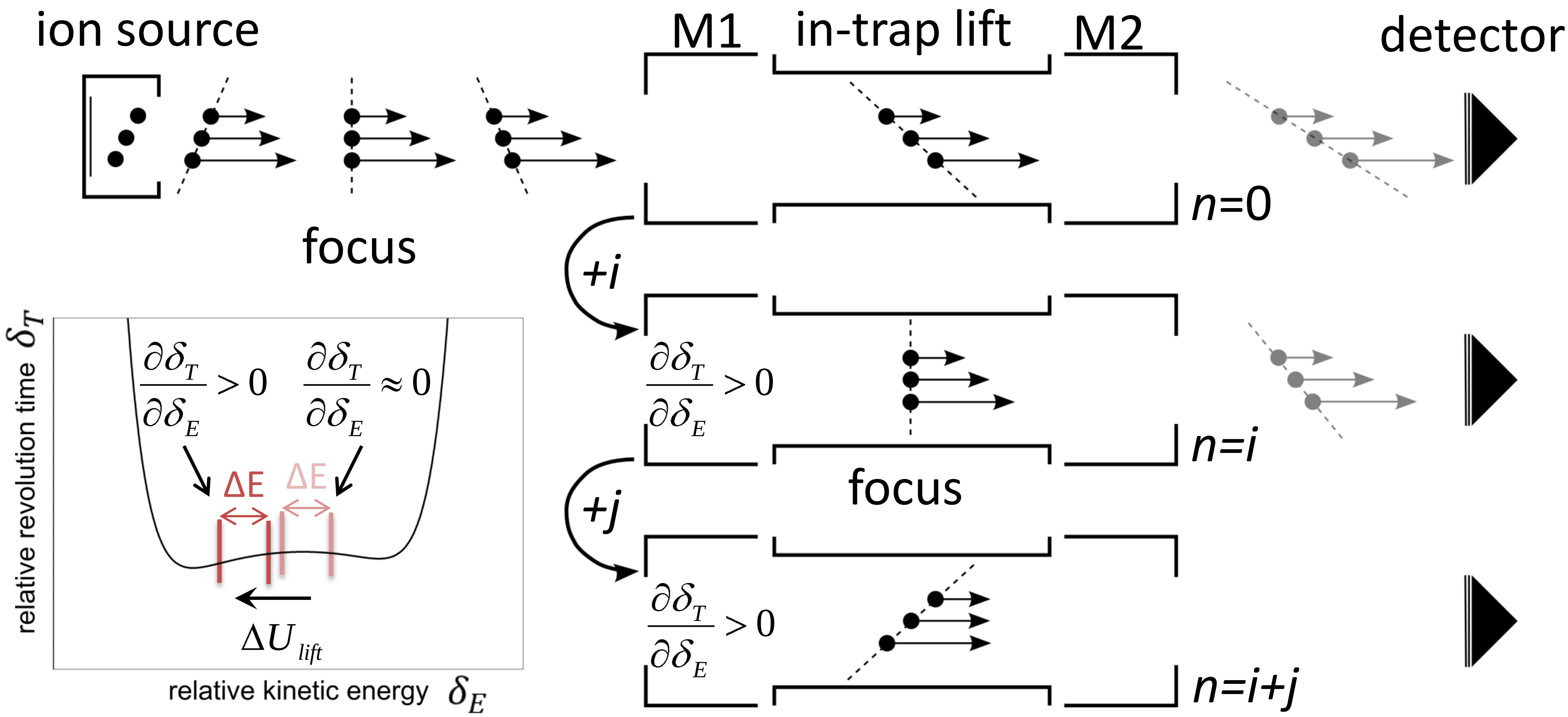

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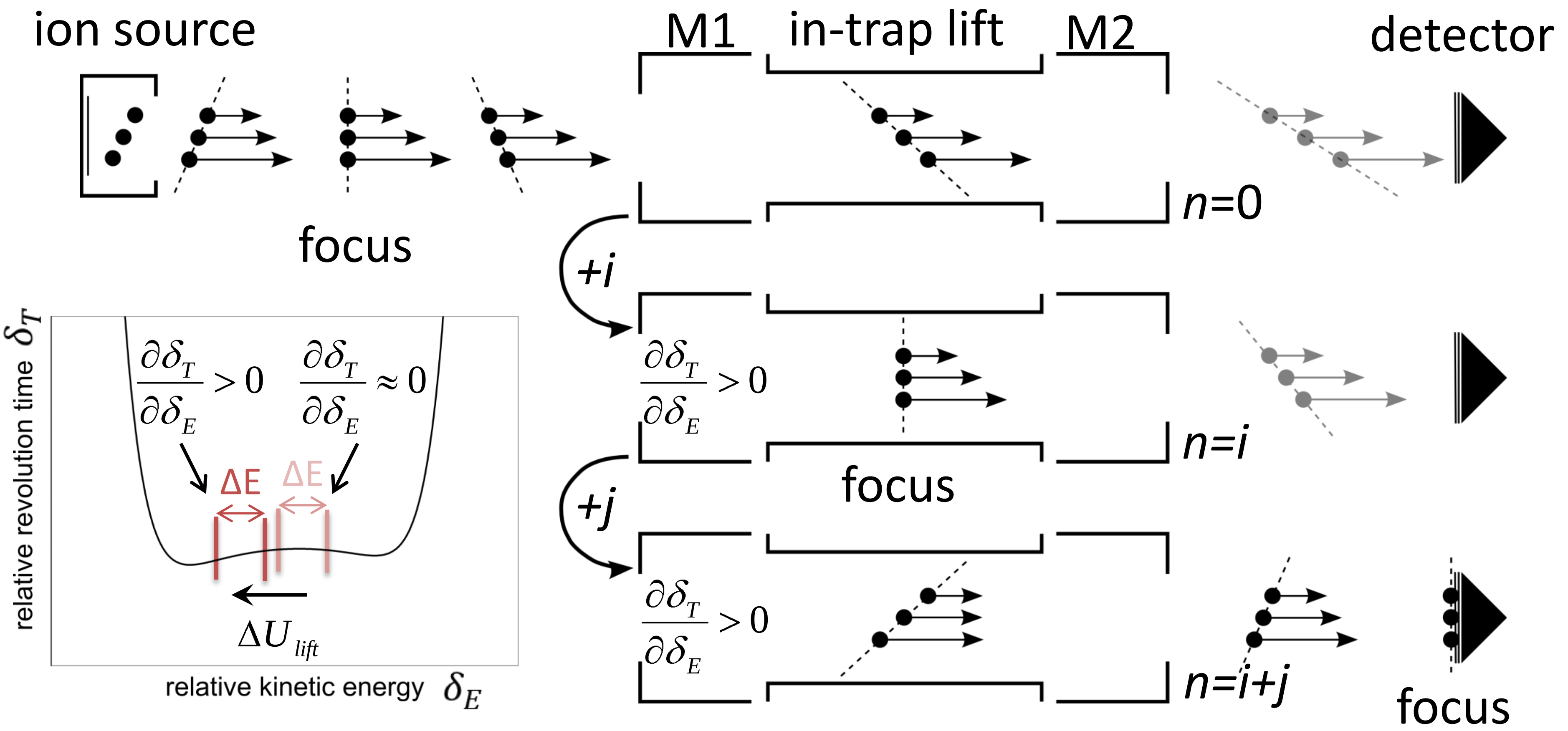

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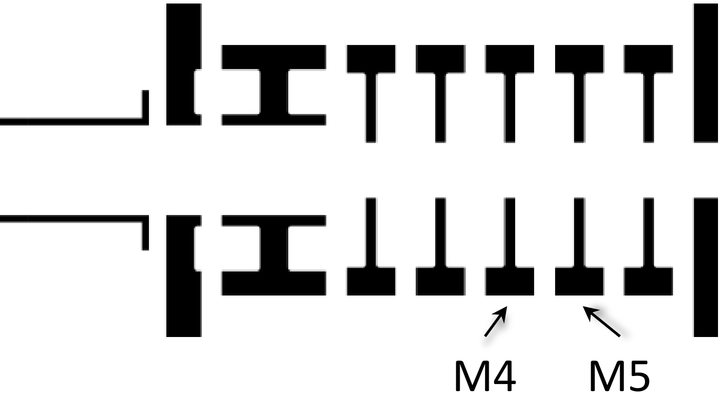
MR-ToF isobar separator

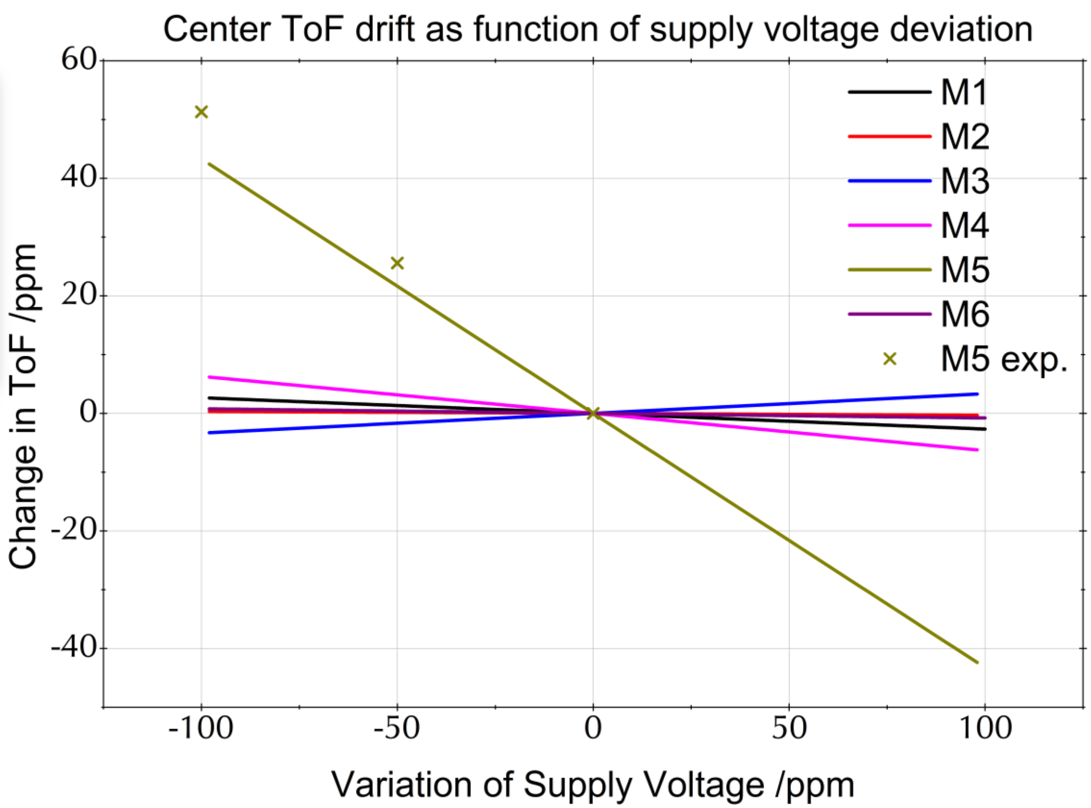
\\ MR-ToF details: voltage stability

mirror electrode 5: turn around point

$$\text{center drift} = \frac{0.5\text{ppm(ToF)}}{1\text{ppm(V)}}$$

- limiting long-term stability
- mass resolving power





MR-ToF isobar separator

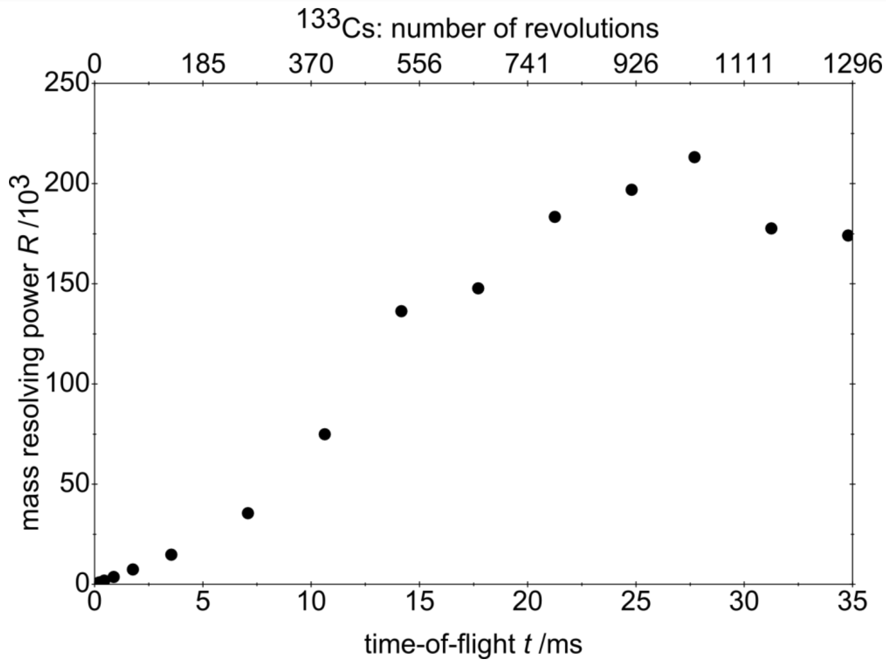
\\ MR-ToF off-line results

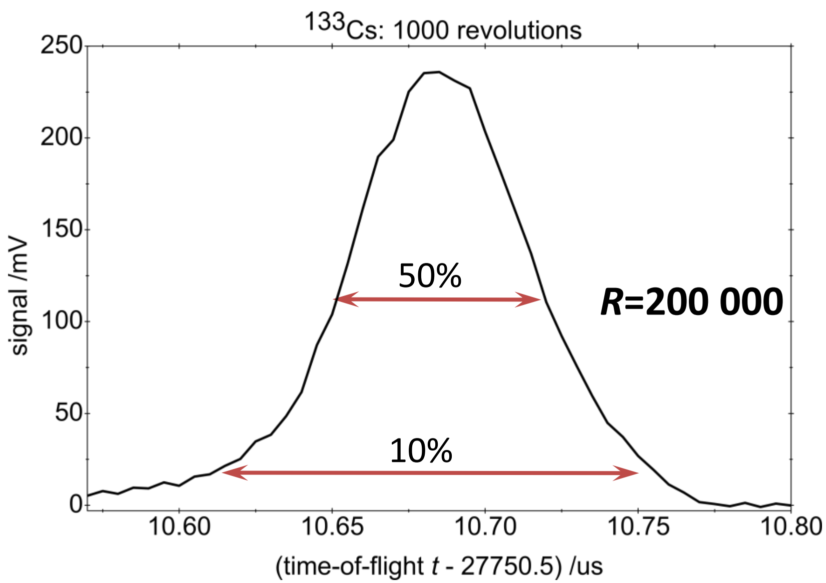
Mass resolving power

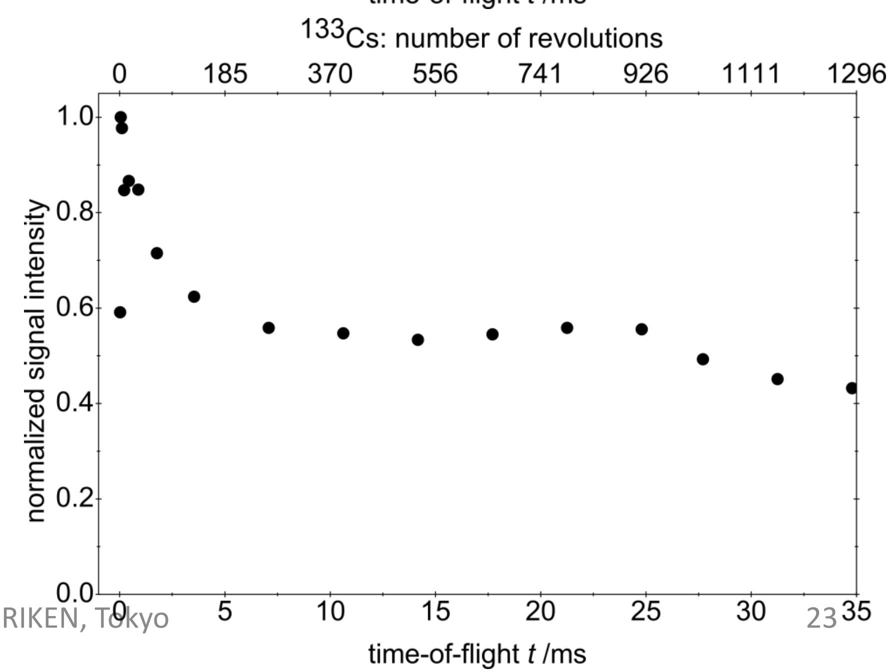
- $R_{50\%}$=200 000
- $R_{10\%}$=100 000

Transmission 50%

- phase space selection
- mechanical imperfections
- magnetic field
- background pressure



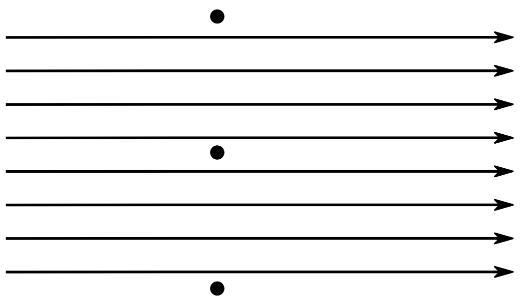


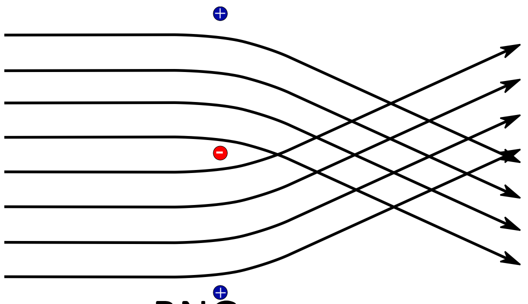


Bradbury-Nielsen ion gate

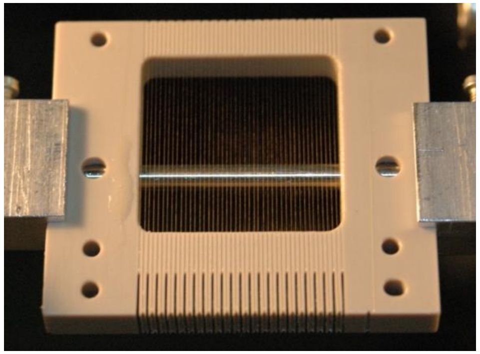
\\ Principle of operation

- ideal deflector if high time resolution is need
- time resolution depends on wire distance and speed of pulsers

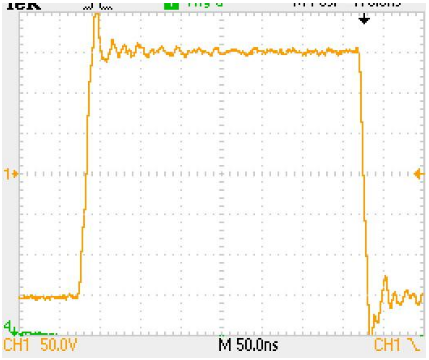




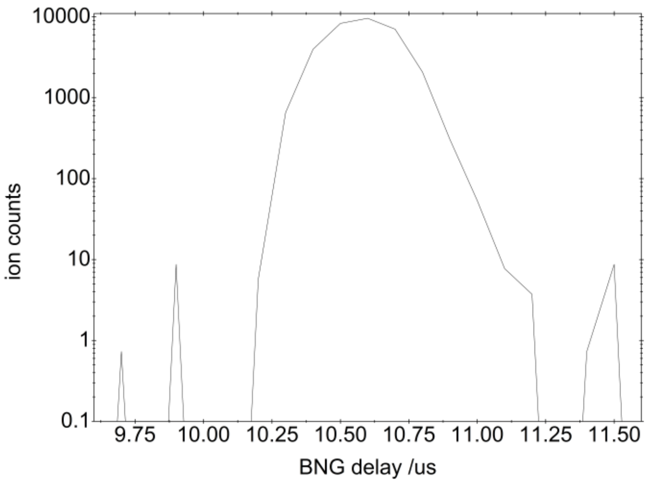
- 10µm diameter gold-plated tungsten wire
- wire distance 0.5mm
- woven on PEEK, contacted by adhesives



- RF Power MOSFETs push-pull configuration
- rise/fall times 7ns @ 500V



Reduction of 4 orders of magnitude possible



Coulomb interaction

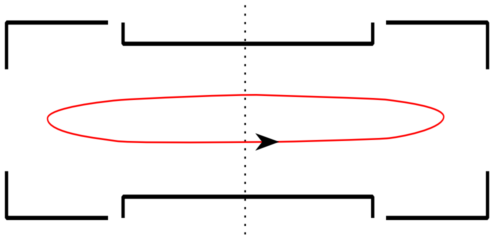
- Trajectory calculation with Coulomb interaction – no approximations/scaling for interaction
- Using PC graphics card for parallelism, NVIDIA CUDA and SIMBUCA[7]

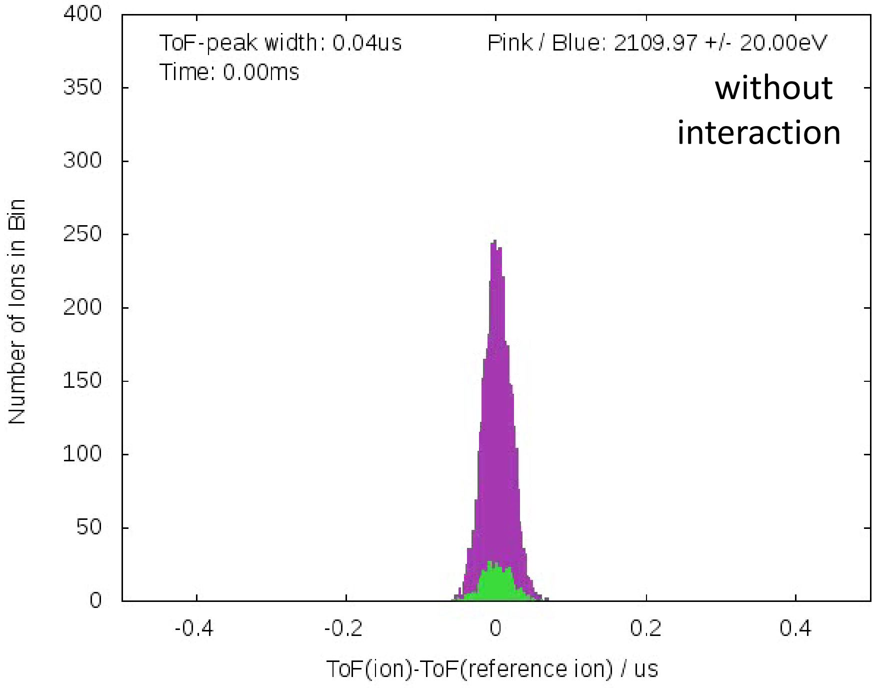
Recording spectrum in middleplane every revolution

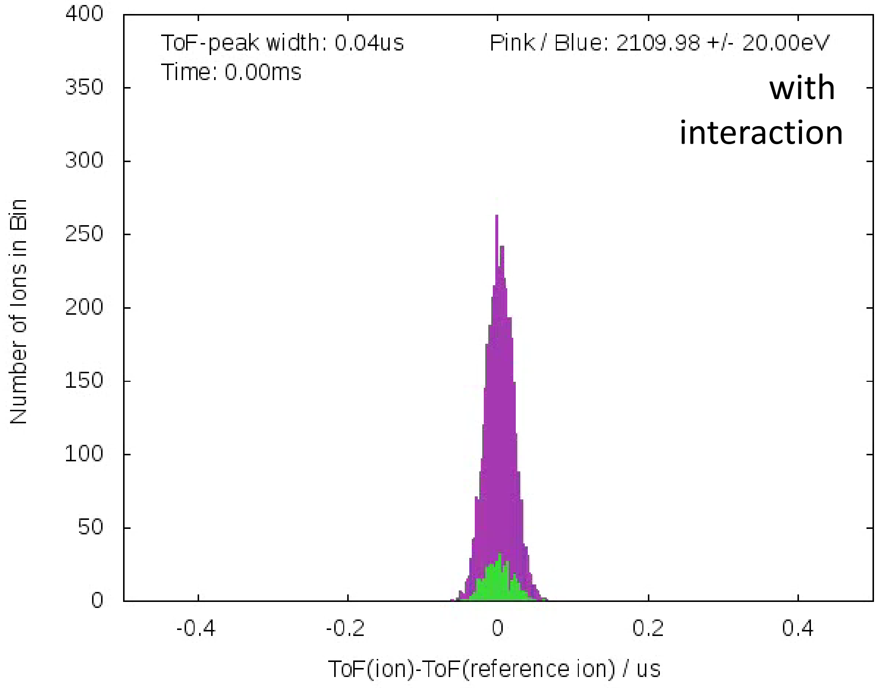
2 species: purple & green(4500:500), m/Δm=10000

E_{nom}=2110eV, ΔE_{FWHM}=20eV, $\Delta x,y,z_{std}$=1mm

$$\frac{\partial \delta_T}{\partial \delta_E} > 0$$







[7]S. van Gorp et al., NIM A **638,** 192 (2011)

Simulations by M. Rosenbusch, Greifswald

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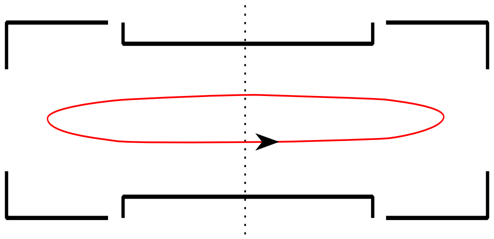

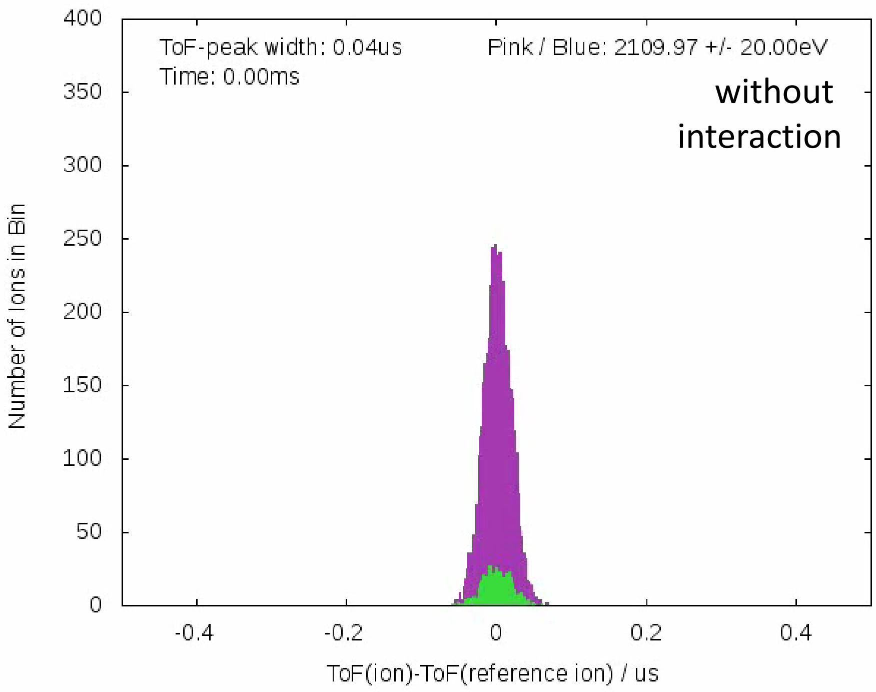

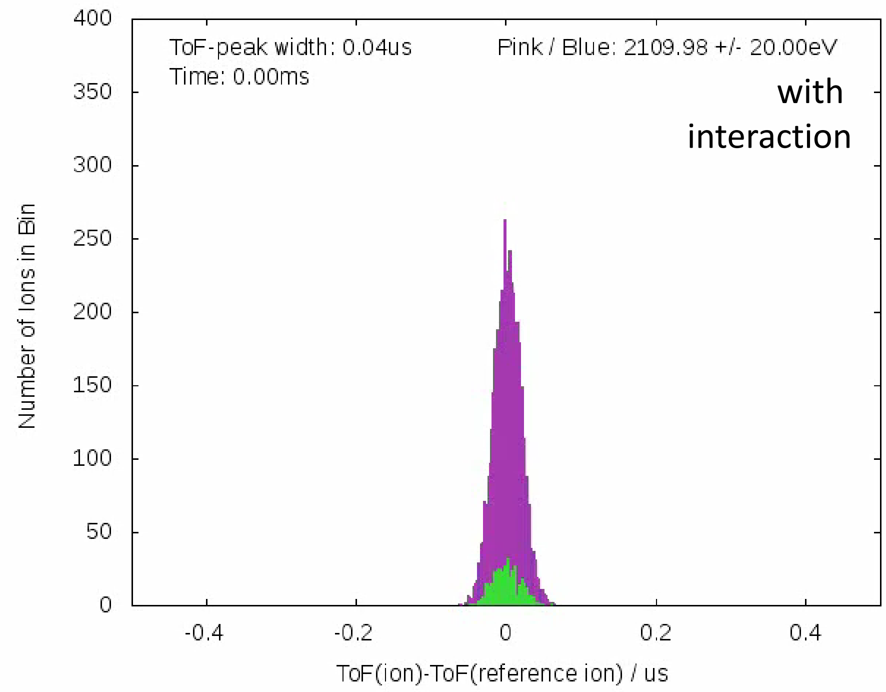

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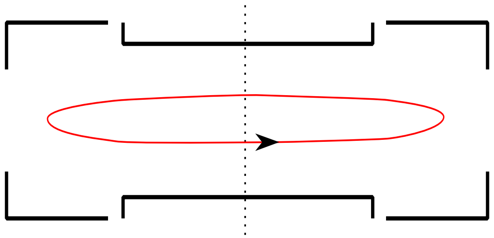
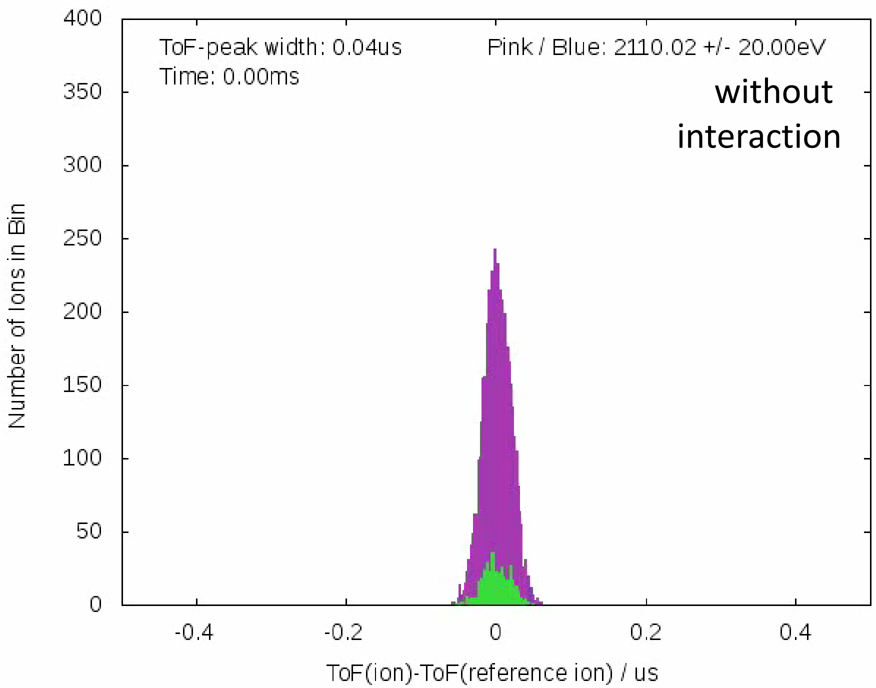
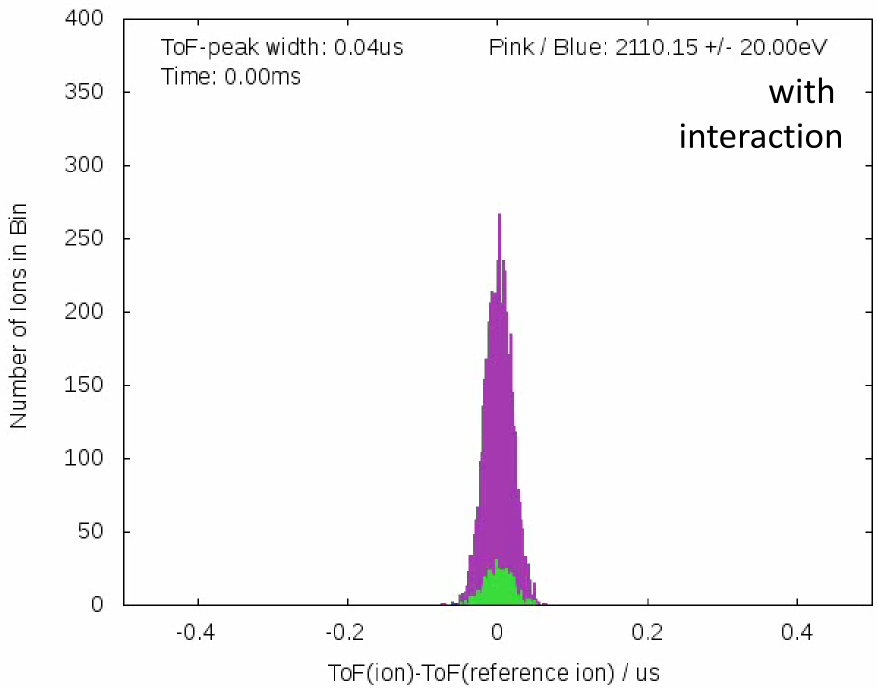




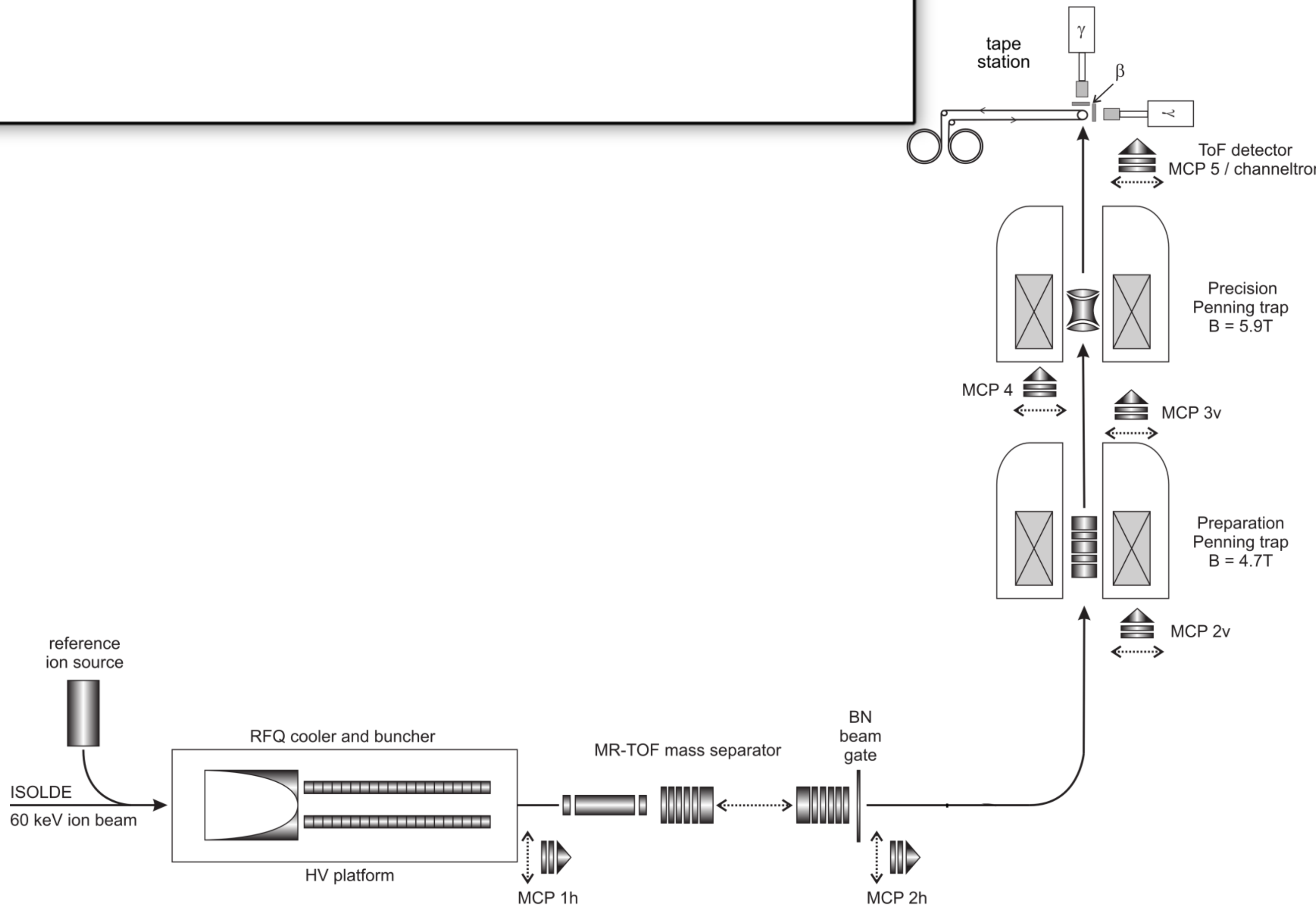


[7]S. van Gorp et al., NIM A **638,** 192 (2011)

Simulations by M. Rosenbusch, Greifswald

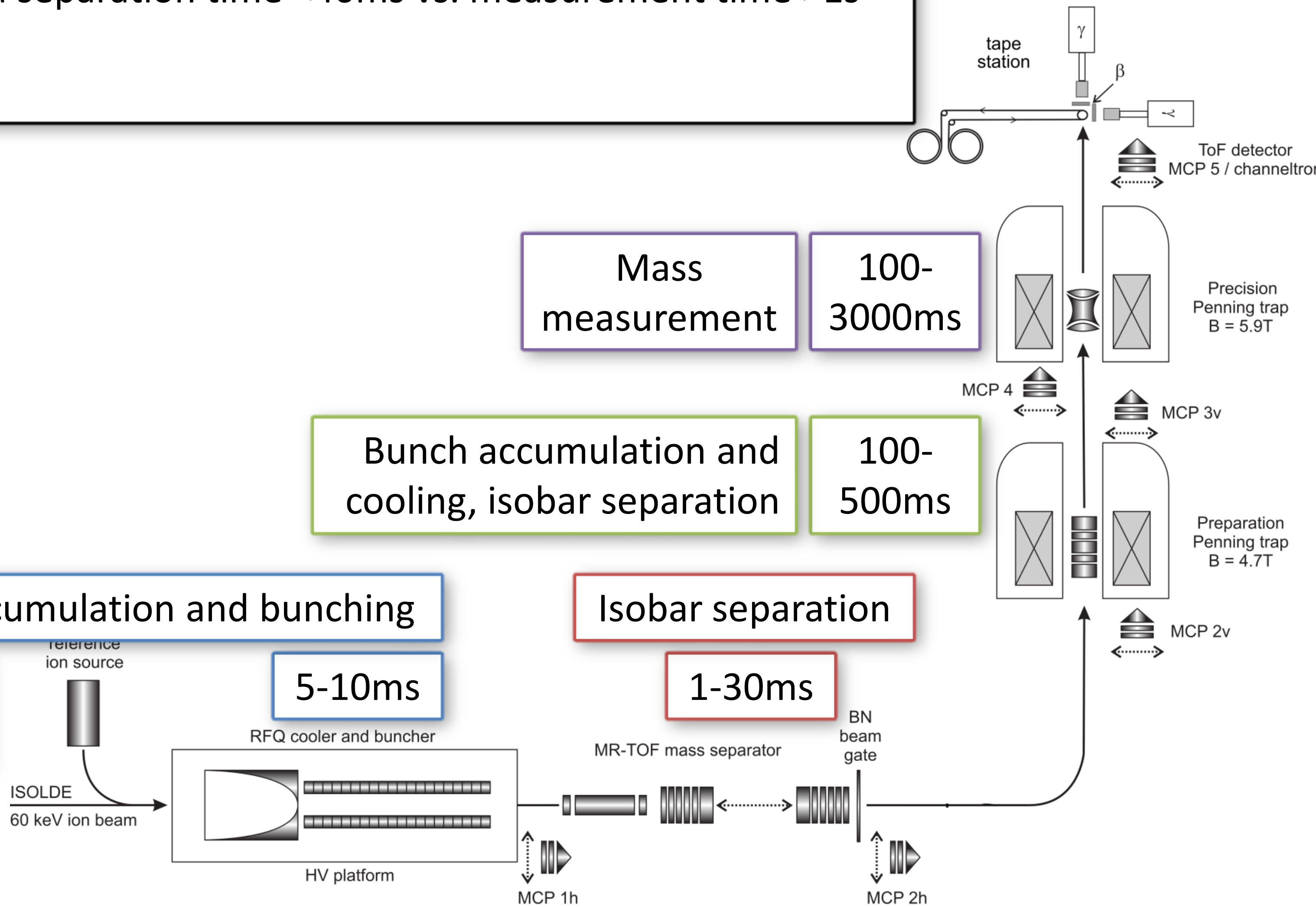
Preparation Penning trap stacking

- limited number of ions in MR-TOF, possibly <1000



Preparation Penning trap stacking

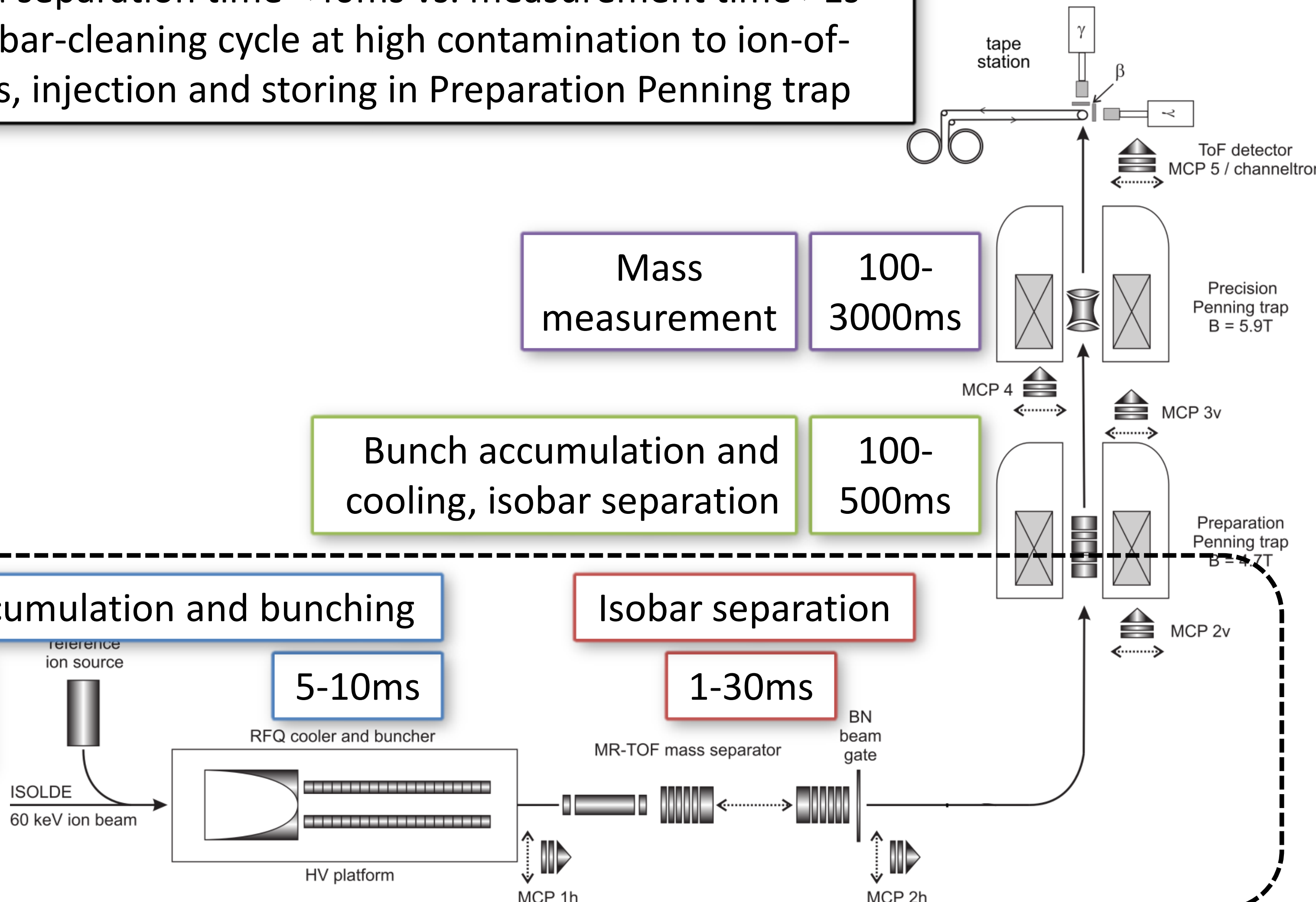
- limited number of ions in MR-TOF, possibly <1000
- bunching and separation time <40ms vs. measurement time >1s



Mass measurement	100-3000ms
Bunch accumulation and cooling, isobar separation	100-500ms
Isobar separation	1-30ms
Beam accumulation and bunching	0.001-1000ms
	5-10ms

Preparation Penning trap stacking

- limited number of ions in MR-TOF, possibly <1000
- bunching and separation time <40ms vs. measurement time >1s
- ➢ repetitive isobar-cleaning cycle at high contamination to ion-of-interest ratios, injection and storing in Preparation Penning trap



Mass measurement	100-3000ms
Bunch accumulation and cooling, isobar separation	100-500ms
Beam accumulation and bunching	0.001-1000ms; 5-10ms
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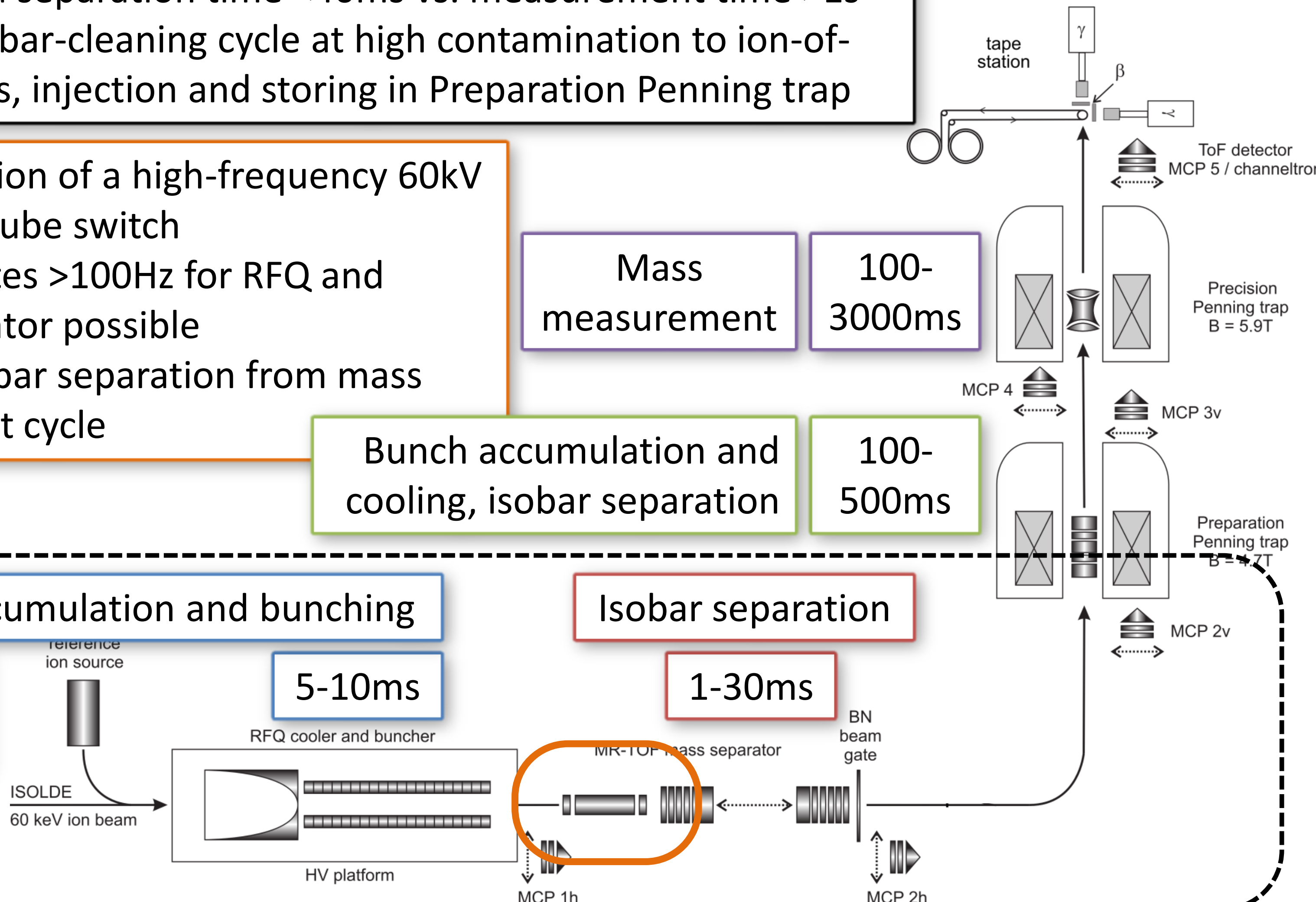
Preparation Penning trap stacking

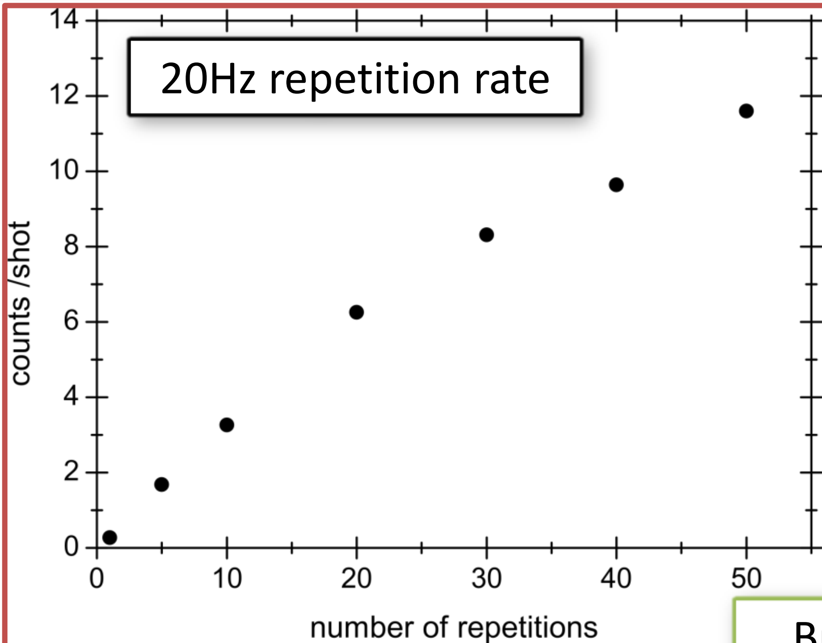
- limited number of ions in MR-TOF, possibly <1000
- bunching and separation time <40ms vs. measurement time >1s
- ➢ repetitive isobar-cleaning cycle at high contamination to ion-of-interest ratios, injection and storing in Preparation Penning trap

- implementation of a high-frequency 60kV pulsed drift-tube switch
- ➢ repetition rates >100Hz for RFQ and isobar separator possible
- ➢ decouple isobar separation from mass measurement cycle

Mass measurement	100-3000ms
Bunch accumulation and cooling, isobar separation	100-500ms
Beam accumulation and bunching	0.001-1000ms / 5-10ms
Isobar separation	1-30ms



Preparation Penning trap stacking – ^{179}Lu



Ratio:
1:1400
^{179}Lu : ^{163}Dy^{16}O

Mass measurement

1200ms

Bunch accumulation and cooling, isobar separation

460ms

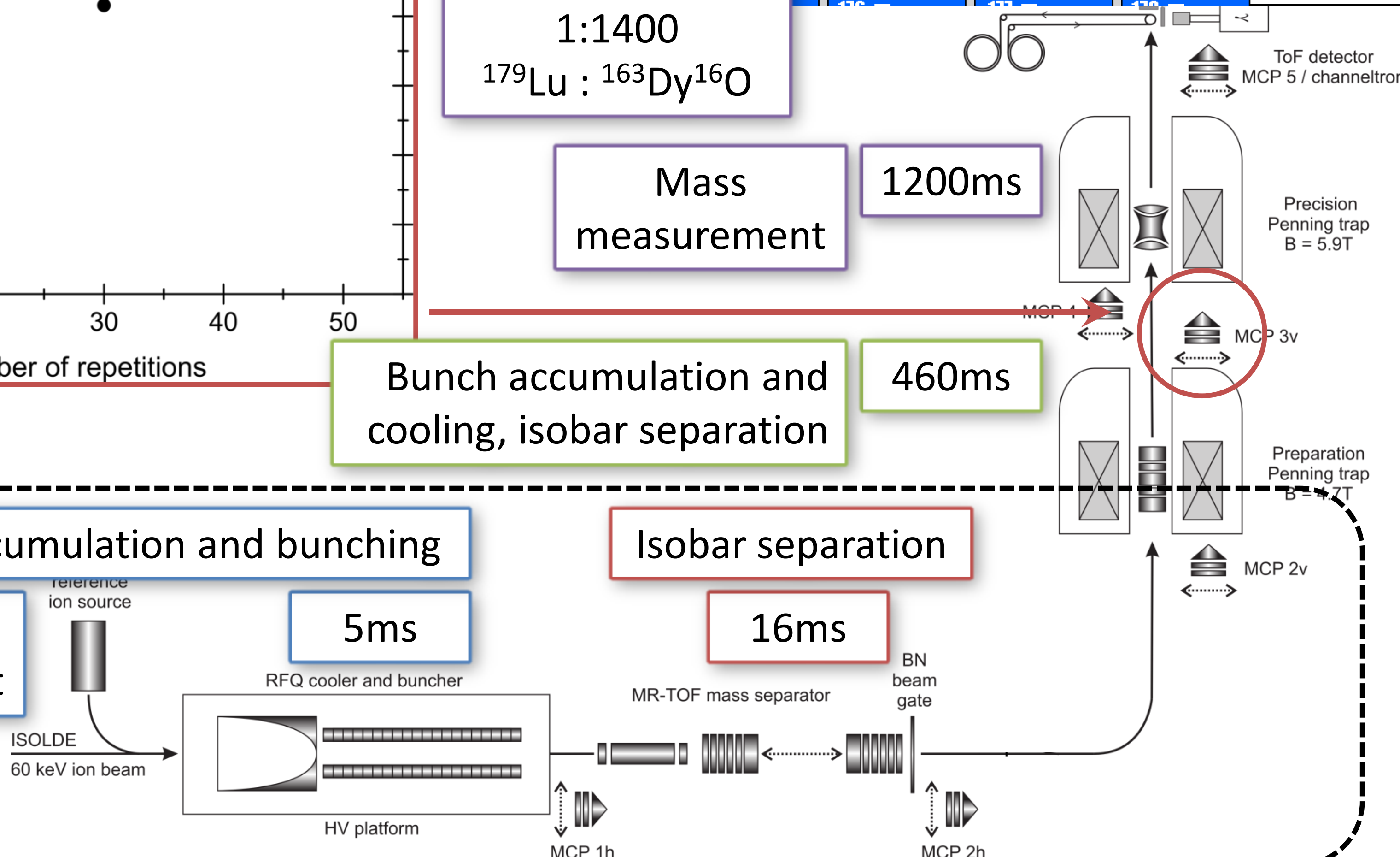
Beam accumulation and bunching

0.1ms+ 30ms wait

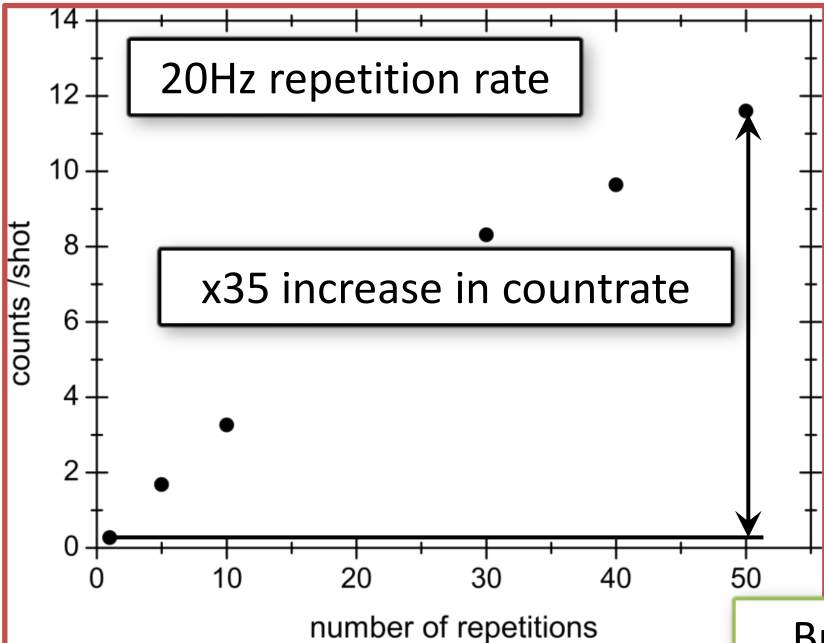
5ms

Isobar separation

16ms



Preparation Penning trap stacking – ^{179}Lu



Ratio:
1:1400
^{179}Lu : $^{163}Dy^{16}O$

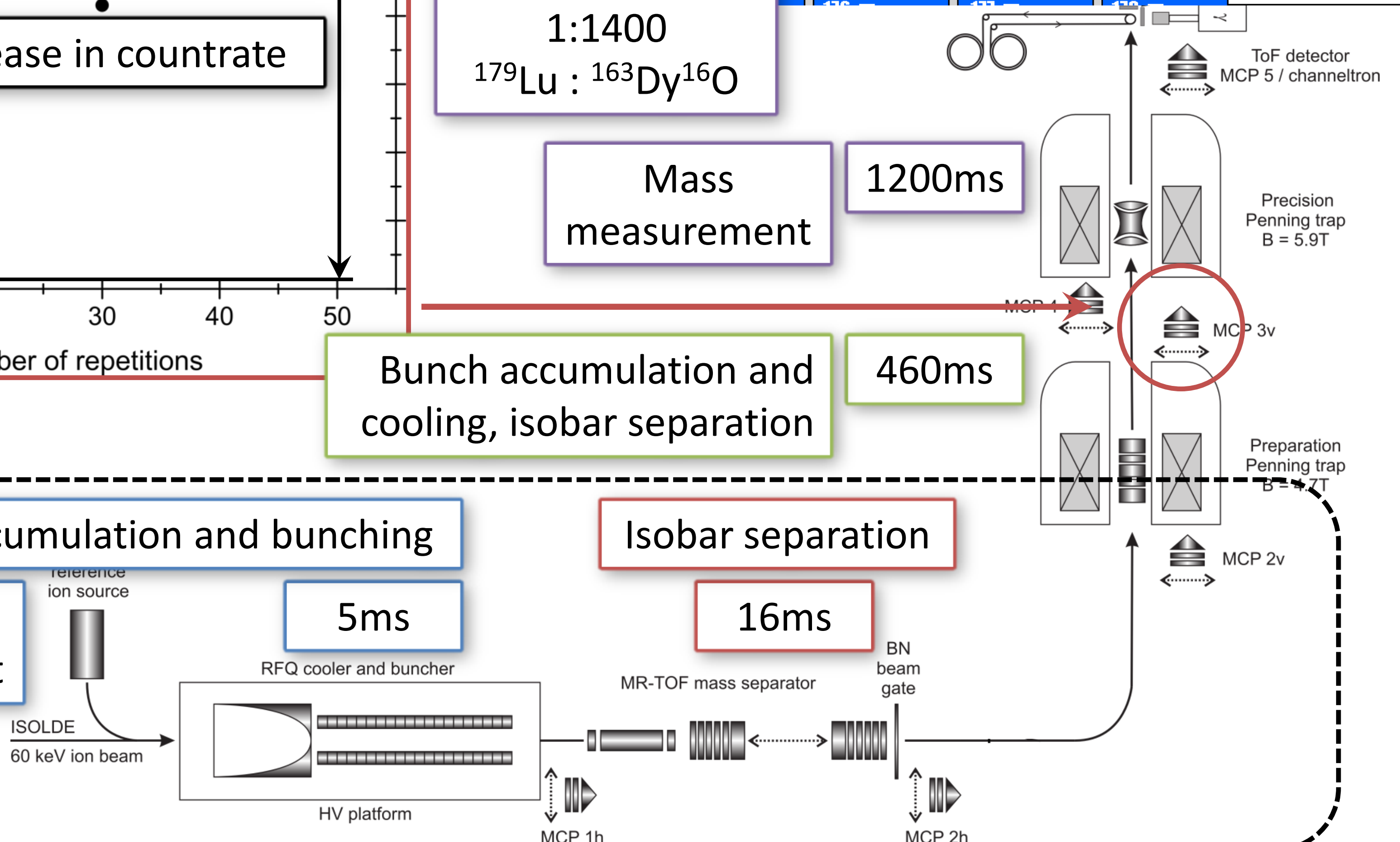
Mass measurement | 1200ms

Bunch accumulation and cooling, isobar separation | 460ms

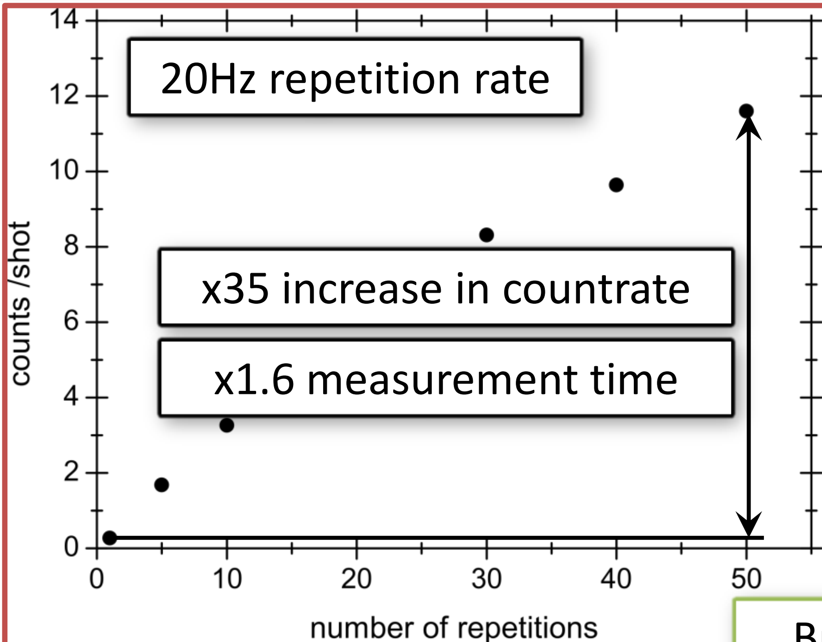
Beam accumulation and bunching

0.1ms+ 30ms wait | 5ms

Isobar separation | 16ms



Preparation Penning trap stacking – ^{179}Lu



Ratio:
1:1400
^{179}Lu : ^{163}Dy^{16}O

Mass measurement | 1200ms

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Beam accumulation and bunching

0.1ms+ 30ms wait | 5ms

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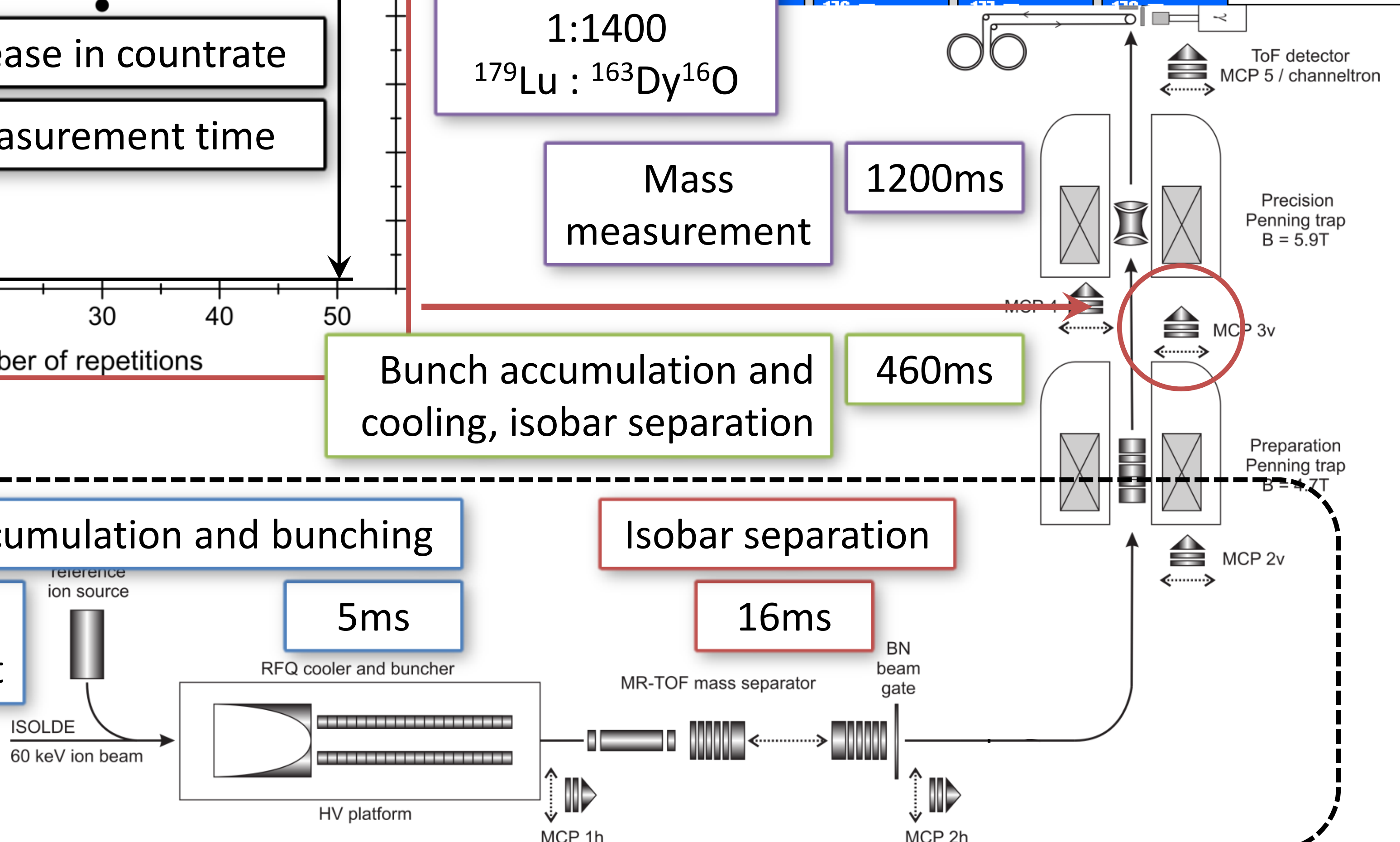
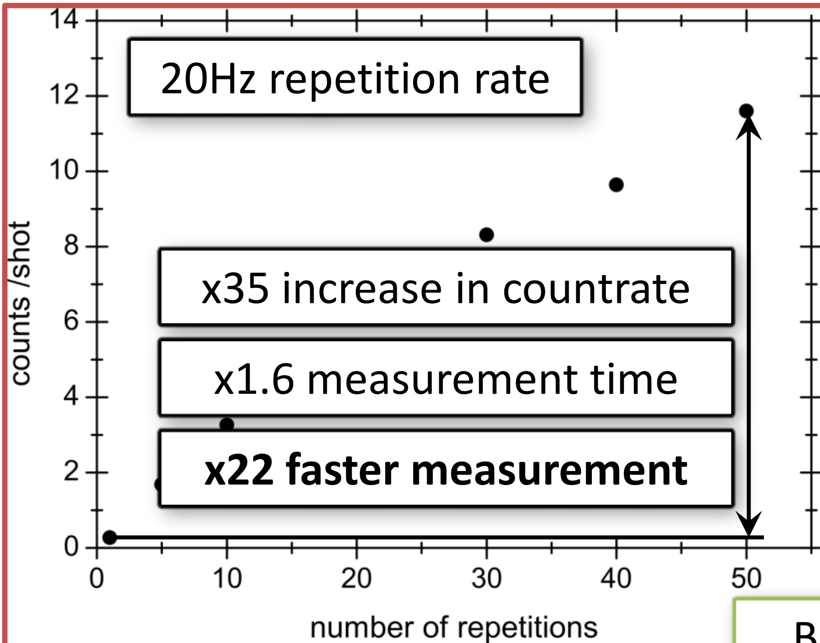


Preparation Penning trap stacking – ^{179}Lu



20Hz repetition rate

x35 increase in countrate

x1.6 measurement time

x22 faster measurement

Ratio:
1:1400
^{179}Lu : ^{163}Dy^{16}O

Mass measurement — 1200ms

Bunch accumulation and cooling, isobar separation — 460ms

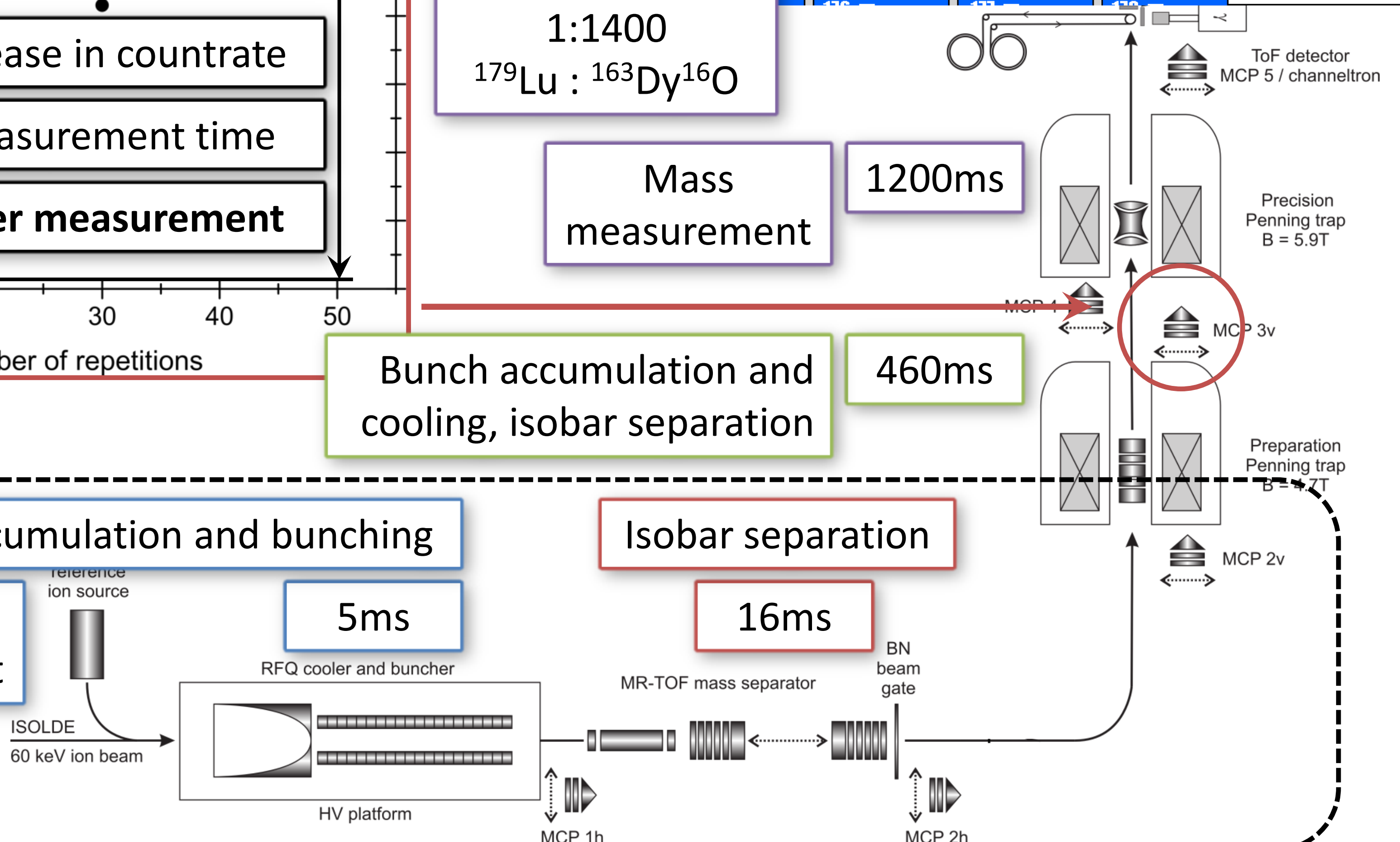
Beam accumulation and bunching

0.1ms+ 30ms wait

5ms

Isobar separation

16ms



Preparation Penning trap stacking – Short half-life <500ms

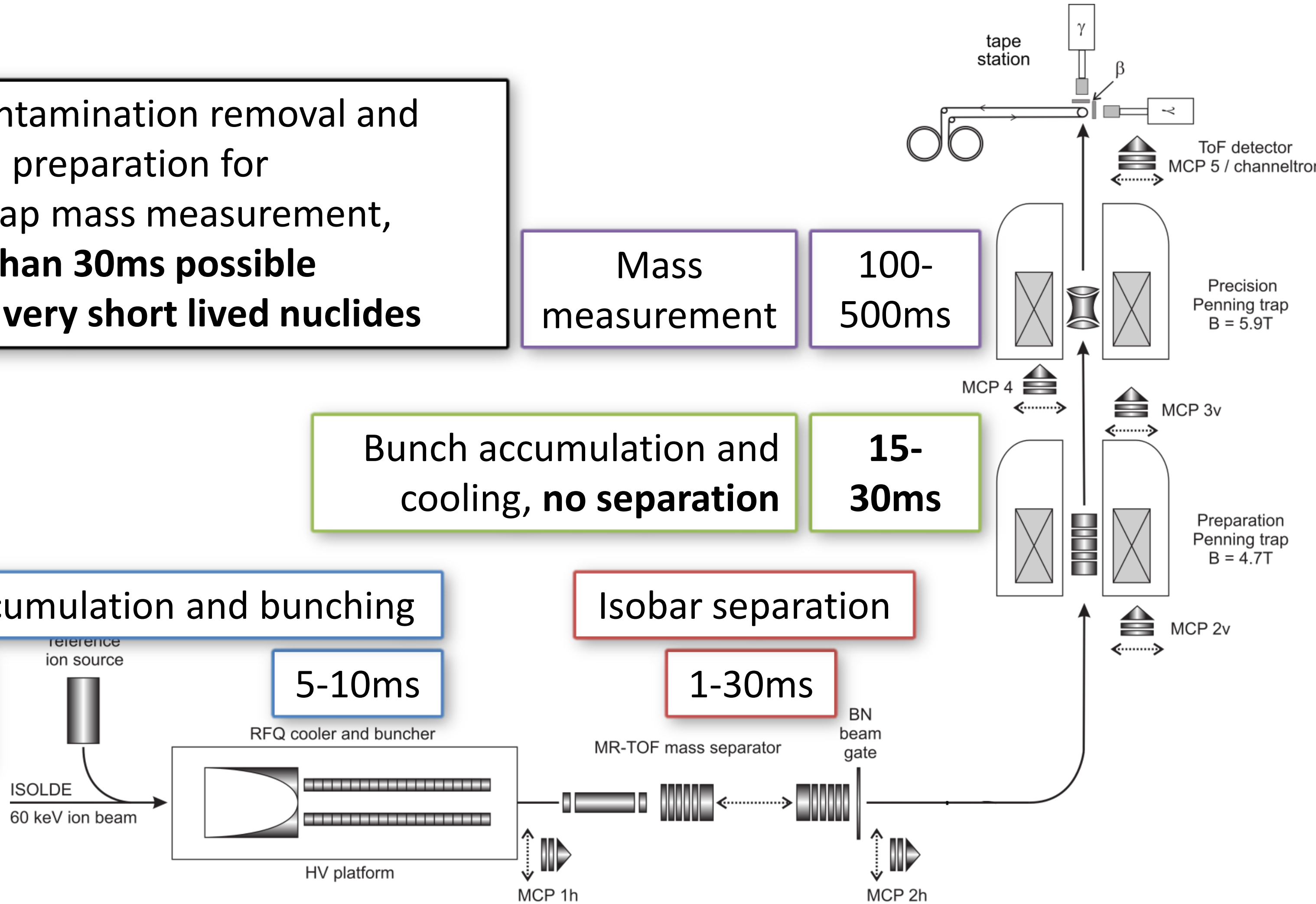
Very fast contamination removal and ion preparation for Penning trap mass measurement, **less than 30ms possible**
-> access to very short lived nuclides

Mass measurement | 100-500ms

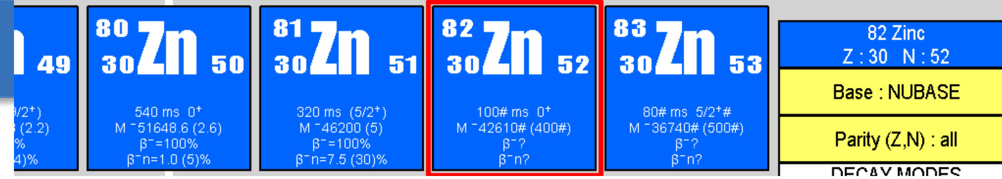
Bunch accumulation and cooling, **no separation** | **15-30ms**

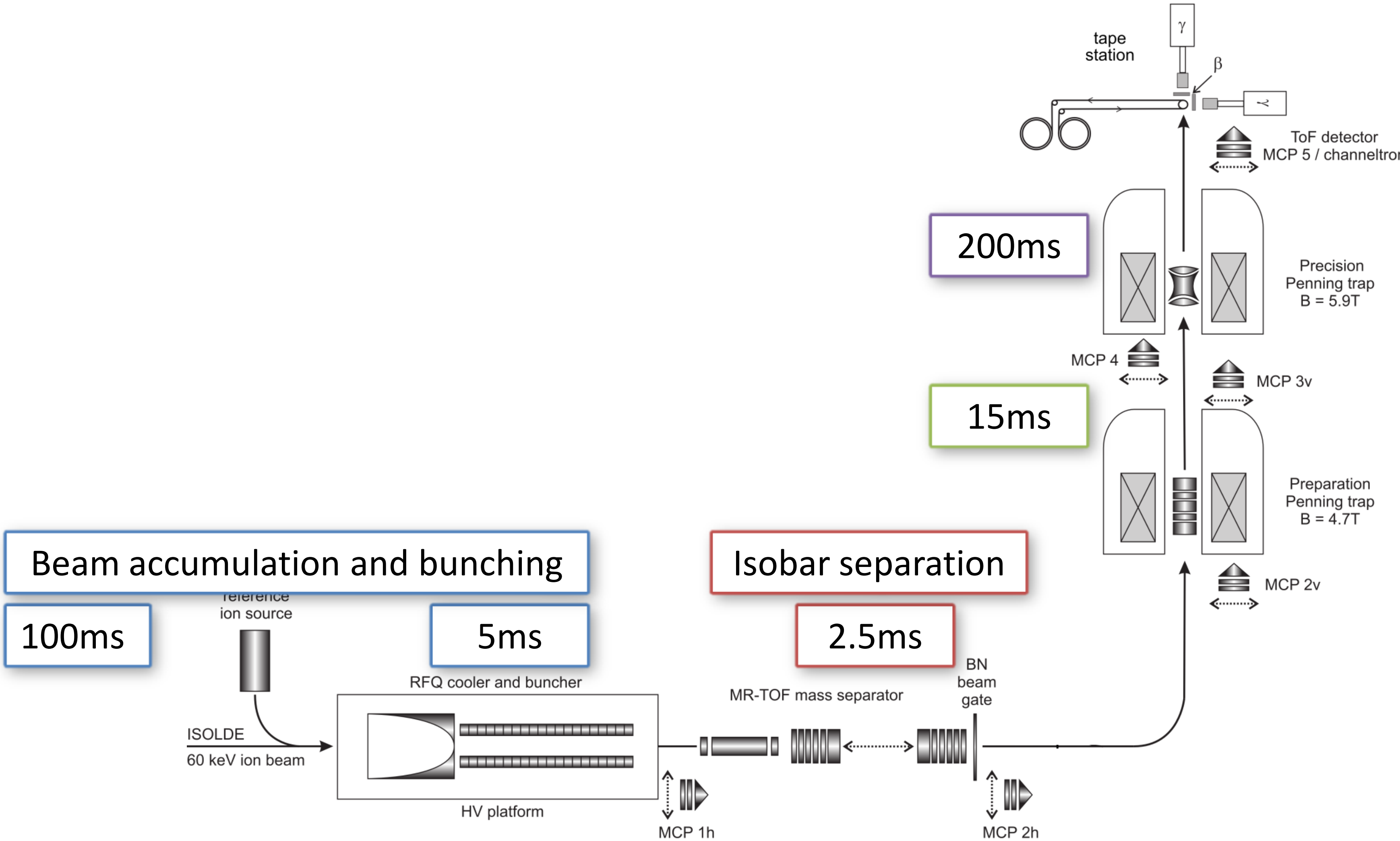
Beam accumulation and bunching | 0.001-100ms | 5-10ms

Isobar separation | 1-30ms

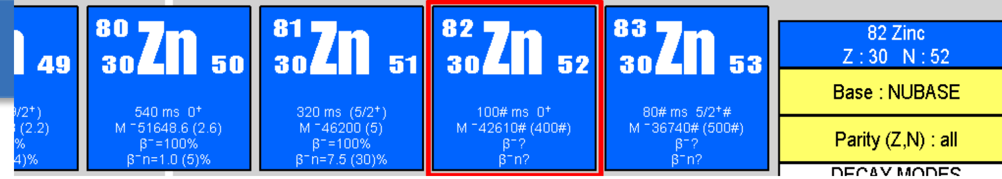


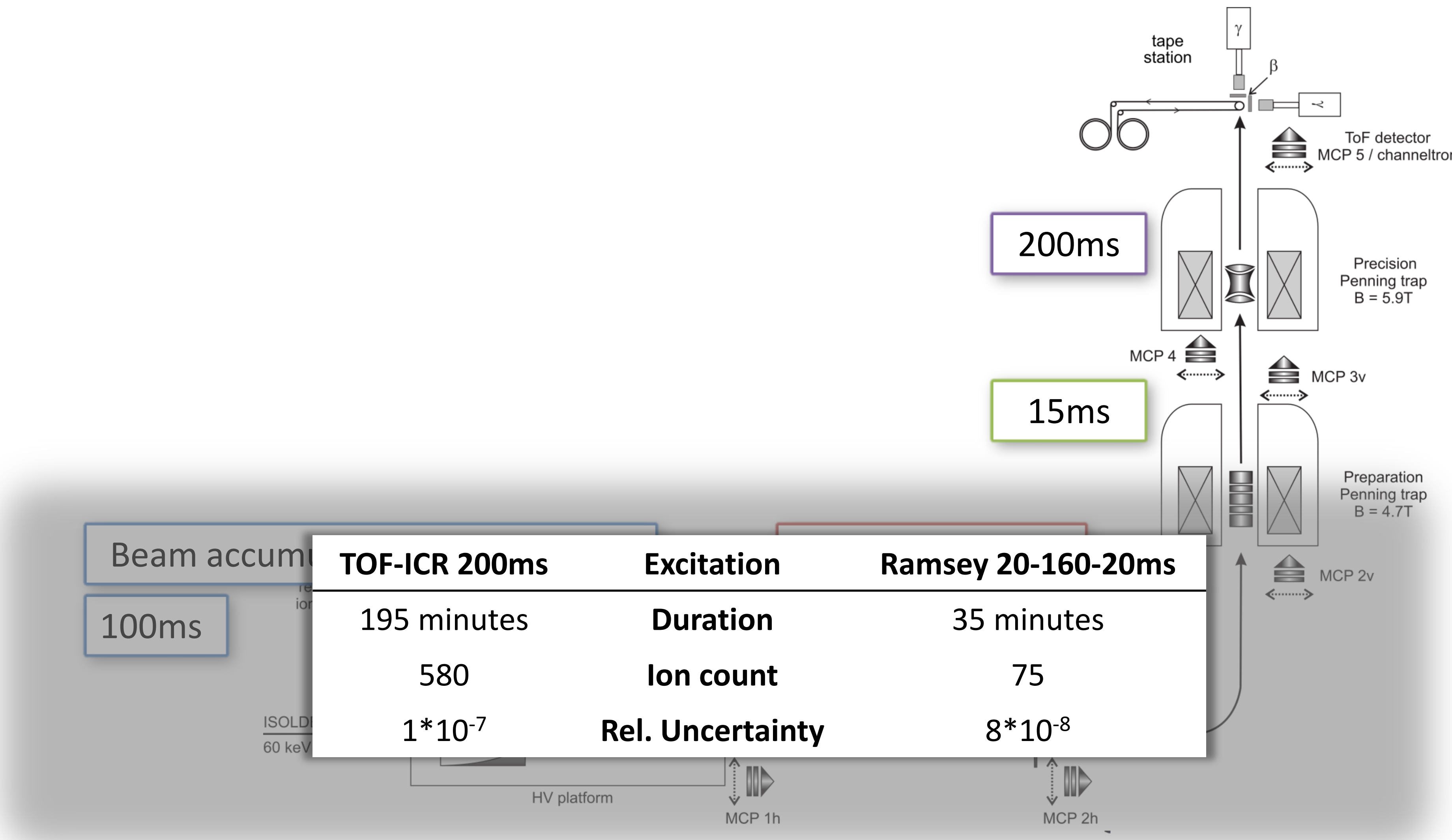
First ^{82}Zn mass measurement





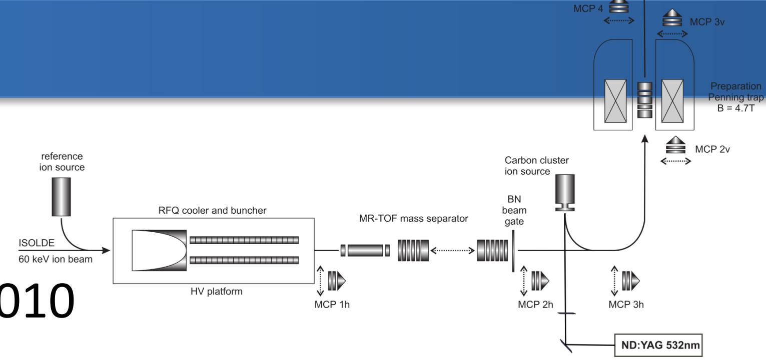
First ^{82}Zn mass measurement



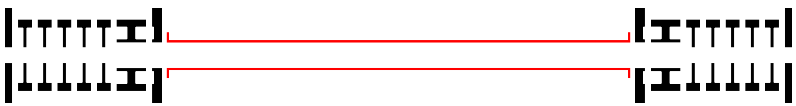


TOF-ICR 200ms	Excitation	Ramsey 20-160-20ms
195 minutes	**Duration**	35 minutes
580	**Ion count**	75
$1*10^{-7}$	**Rel. Uncertainty**	$8*10^{-8}$

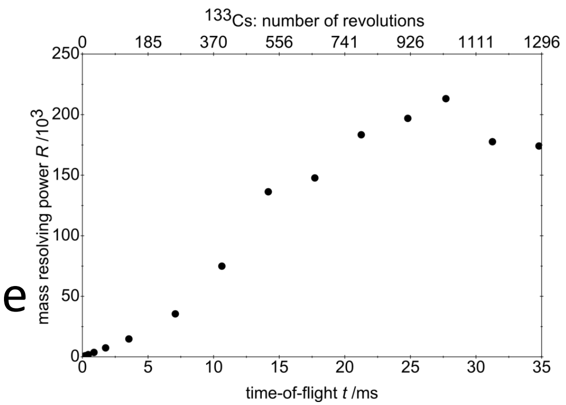
Summary



- Isobar separation with MR-ToF device and BNG successfully implemented at ISOLTRAP System continuously used in on-line runs since 2010



- Pulsed drift tube technique developed to control ion injection/ejection and time focus



- Ideal conditions: mass resolving power of 200 000
  Normal conditions: mass resolving power of 100 000

- Suppression of contaminant ions by 4 orders of magnitude

- Stacking technique implemented to increase number of separated ions per second

- Successful Penning-trap mass measurement of ^{82}Zn and determination of half-life

Thanks to…

ERNST MORITZ ARNDT UNIVERSITÄT GREIFSWALD — M. Breitenfeldt*, G. Marx, M. Rosenbusch, L. Schweikhard, F. Wienholtz

MAX-PLANCK-GESELLSCHAFT, MAX-PLANCK-INSTITUT FÜR KERNPHYSIK — K. Blaum, Ch. Böhm, Ch. Borgmann, R. B. Cakirli, S. Eliseev, S. Kreim

GSI — D. Beck, F. Herfurth, J. Kluge, E. Minaya-Ramirez, D. Neidherr

UNIVERSITÉ PARIS-SUD 11 — G. Audi, D. Lunney, V. Manea, S. Naimi**, M. Wang

ISOLDE — T. E. Cocolios, A. Herlert***, M. Kowalska

TECHNISCHE UNIVERSITÄT DRESDEN — J. Stanja, K. Zuber

MICHIGAN STATE UNIVERSITY — S. George, S. Schwarz

*WITCH Trap (@CERN), Leuven, Belgium
**SLOWRI Team, RIKEN, WAKO, Japan
***FAIR GmbH, Darmstadt, Germany

SPONSORED BY THE
Federal Ministry of Education and Research

Thanks also to
M. Eritt, UIP Heidelberg
Group of D. Zajfman, WIS Rehovot
T. Dickel, W. R. Plaß, JLU Giessen
M. I. Yavor, RAS St. Petersburg

http://isoltrap.web.cern.ch

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