A mass-purification method for REX beams

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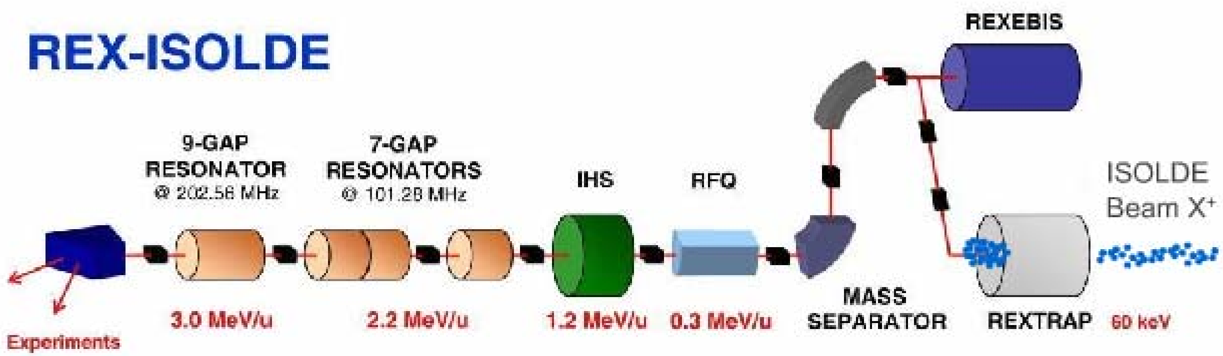
Overview

- REX-ISOLDE
  - REXTRAP
  - Penning traps
- Penning trap based mass resolving method
  - Old and new operation mode
  - Technical realisation
- Results
- Summary & Outlook

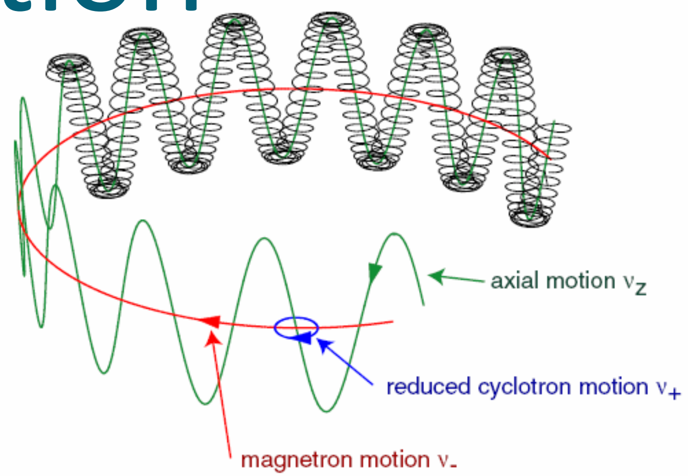
REXTRAP

- Large (d=5 cm) **Penning trap**
- 3 T magnetic field
- Bunches up to 10^9 ions
- Sideband cooling using buffer gas
- Buffer gas pressure ~ 5 10^{-4} mbar
- 10-20 ms typical bunching/cooling time in „normal“ operation (without mass separation)

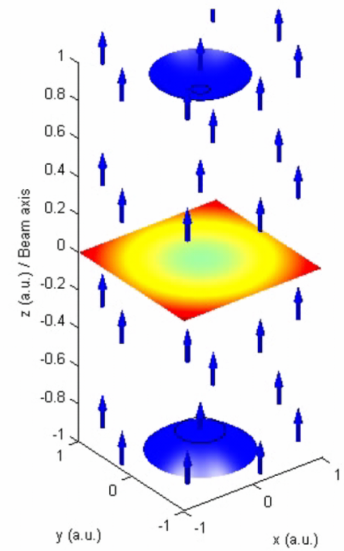


Penning trap ion motion

- The ion motion inside a Penning trap is composed of:
  - Fast **modified cyclotron** motion (~MHz)
  - Slow **Magnetron motion** (~kHz)
  - Axial harmonic motion (~50 kHz)

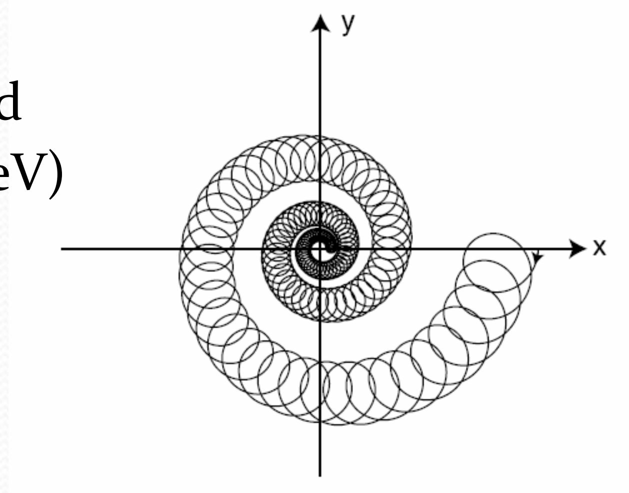


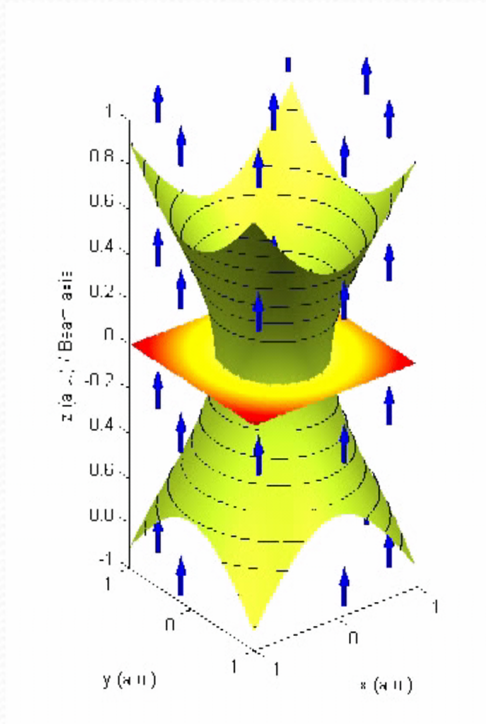
- Since the magnetron motion does have a negative energy/radius-dependance its radius increases as the ions loose energy to the buffer gas
- Coupling both motions at their **sum frequency ω_c** in a buffer gas filled trap allows to decrease both radii and thus to shrink and cool the cloud



Sideband Cooling

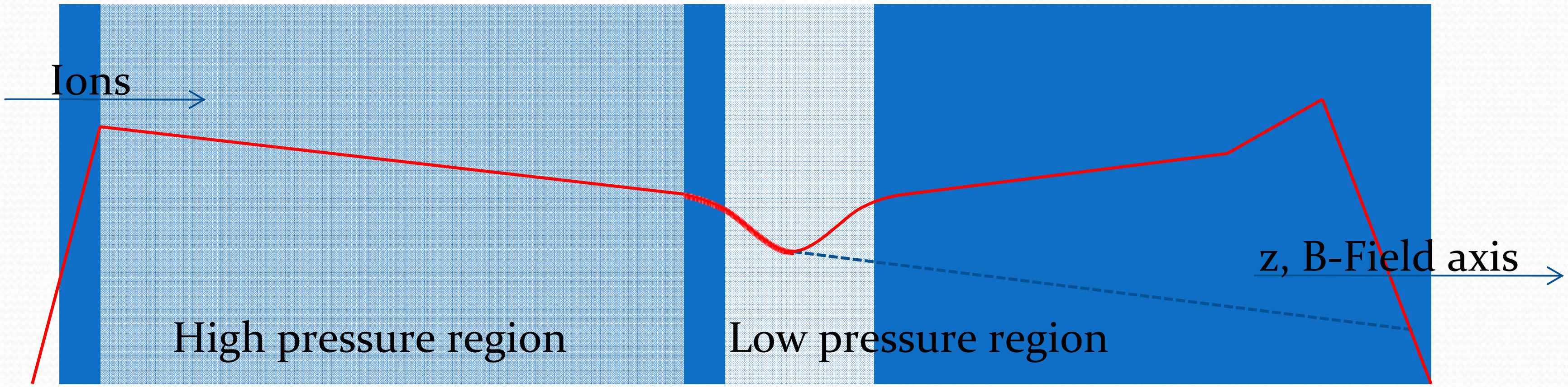
- After some time the ion cloud is cooled axially by the buffer gas into the harmonic region of the trap potential
- Here a strong azimuthal quadrupolar excitation at ω_c is applied until the cloud is small enough to be ejected through the 5 mm diaphragm
- Doing so results in a reduction of the occupied space & phase-space volume
- The emittance is reduced (~ 10 π mm mrad @ 30keV)





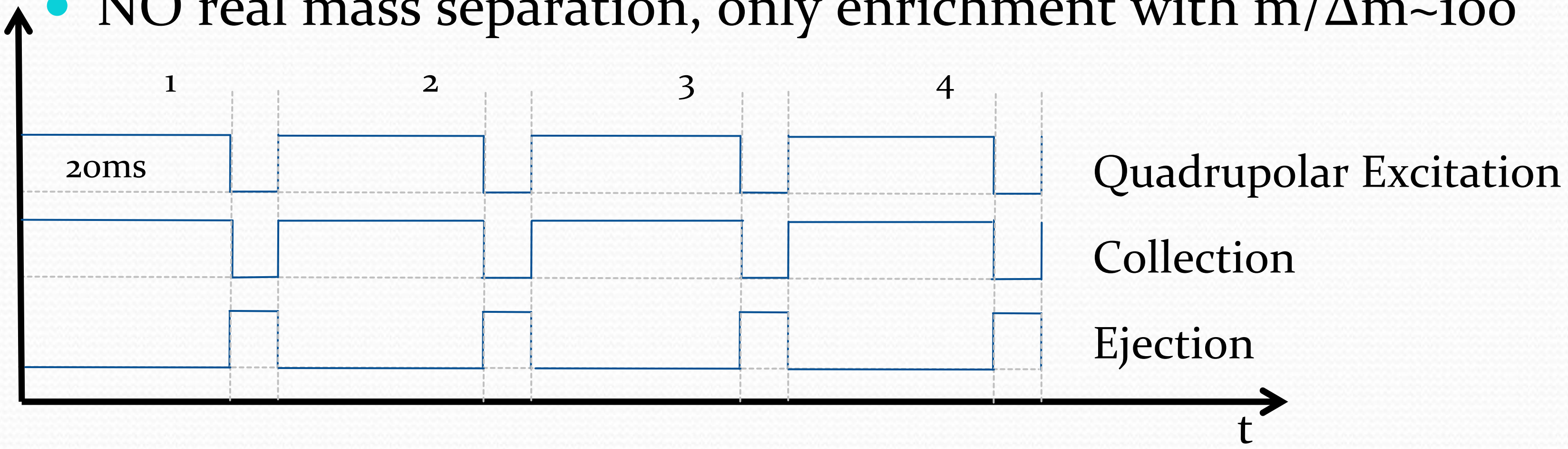
Trapping process

- Ions are injected with energies slightly higher than injection potential
- Electrostatic reflection at the backside of the trap
- Energy loss due to buffer gas collisions prevent reflected ions from escaping over the injection potential



Normal operation cycle

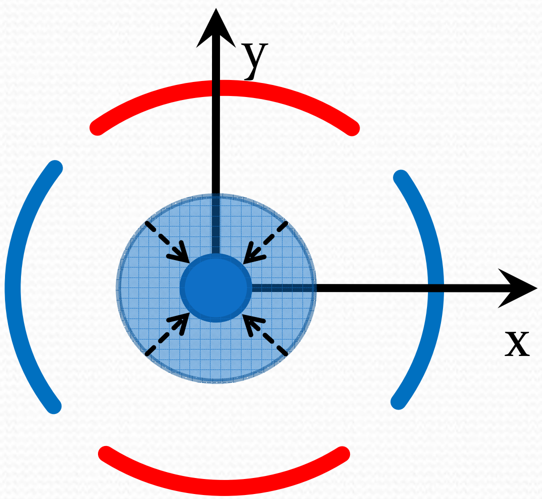
- Strong azimuthal quadrupolar excitation couples magnetron and cyclotron motion to allow for a decrease of both radii
- Relatively high gas pressure gives good efficiency (~50%)
- Strong excitation allows fast repetition rate (50-100 Hz)
  - Allows use with very short lived nuclides
  - Gives high current throughput
- NO real mass separation, only enrichment with m/Δm~100



New operation cycle

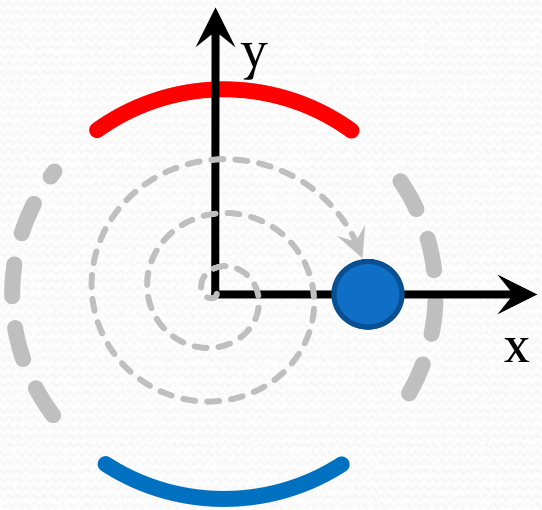
(1)

Shrinking the cloud using an (almost) mass independent, strong quadrupolar cooling



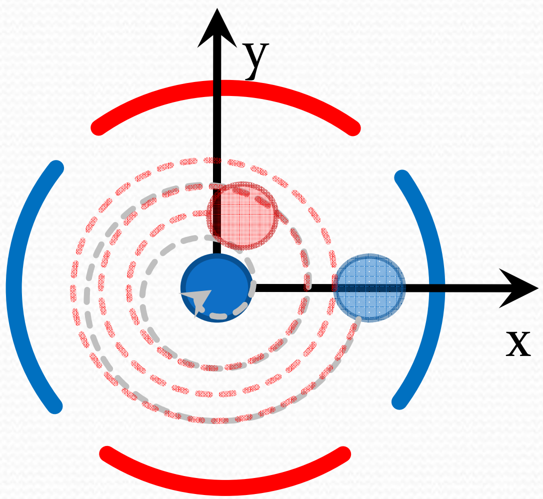
(2)

Shifting the cloud from the center with a mass independent dipolar excitation

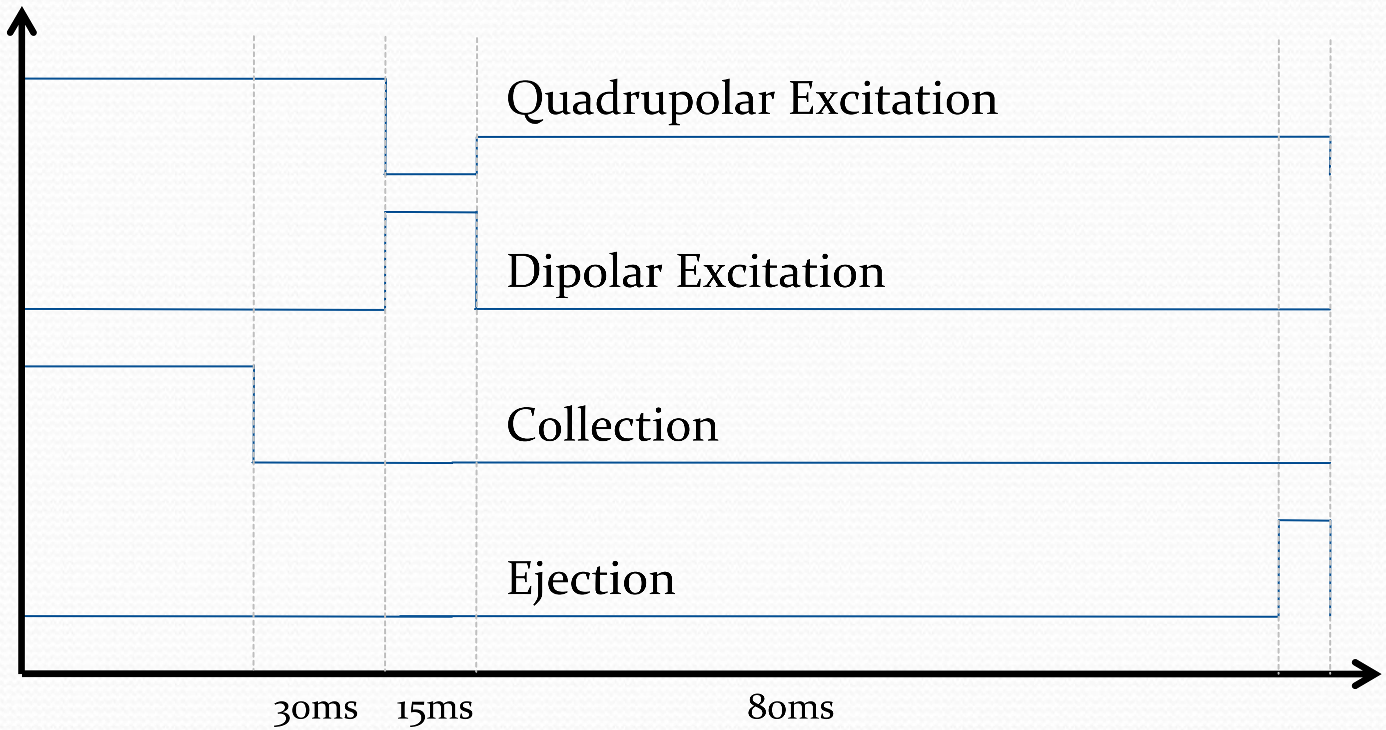


(3)

Recentering selectively only the mass of interest



New operation cycle (2)



- Much longer cycle time: ~100ms + Collection time

Increasing resolution

- The attainable resolution depends mainly on the following factors:
  - Amplitude of the recentering excitation
  - Duration of the recentering excitation
  - Size and shape of the cloud after the first cooling
  - Accuracy of the static fields

Increasing resolution (2)

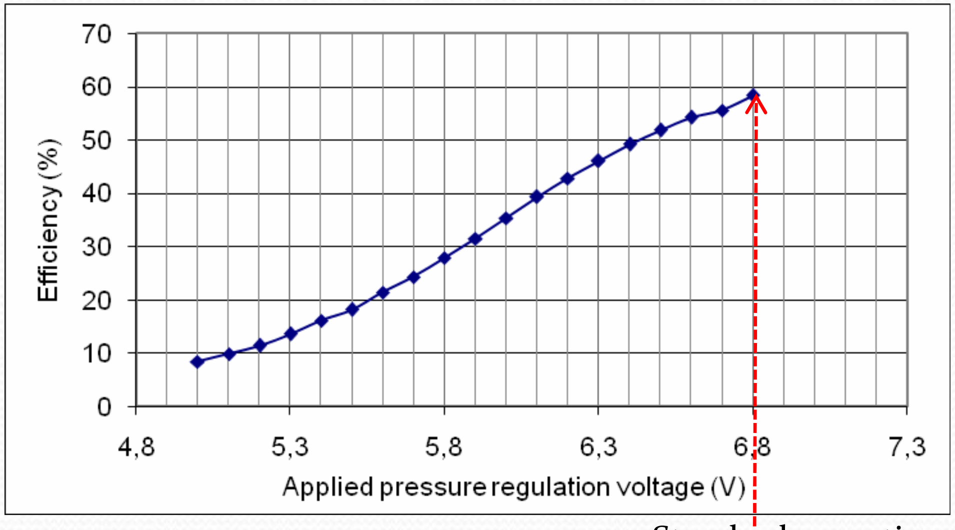
- The static fields were optimized using a SIMION® model of the electrodes
- The remaining parameters (Amplitude,Duration) are not independent
- The minimum duration of the excitation is given by the Fourier limit:

$$\delta\omega \propto \frac{1}{T} \Rightarrow R = \frac{m}{\delta m} \approx \frac{\omega}{\delta\omega} \propto \omega T$$

- Setting the duration of the excitation fixes the amplitude

Increasing resolution (3)

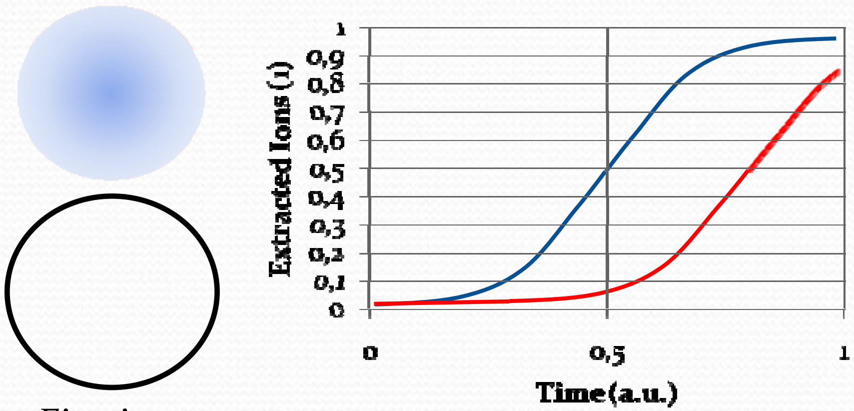
- The resolution increases with decreasing amplitude
- But the buffer gas pressure sets a lower amplitude limit
- Decreasing the gas pressure means decreasing efficiency
- Efficiency will depend on (asked) resolution !



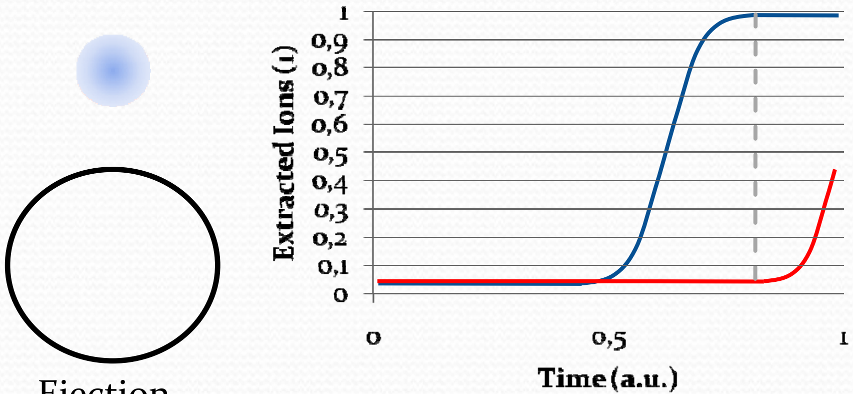
Standard operation region

Initial cooling and cloud shape

- Decreasing the initial cloud size
  - Can potentially increase resolution BUT
  - results in increasing Space charge issues
  - Cloud collisions and interactions become harder and can inhibit mass selection
- Effects depend on mass difference
- Limit on the number of ions in the trap !

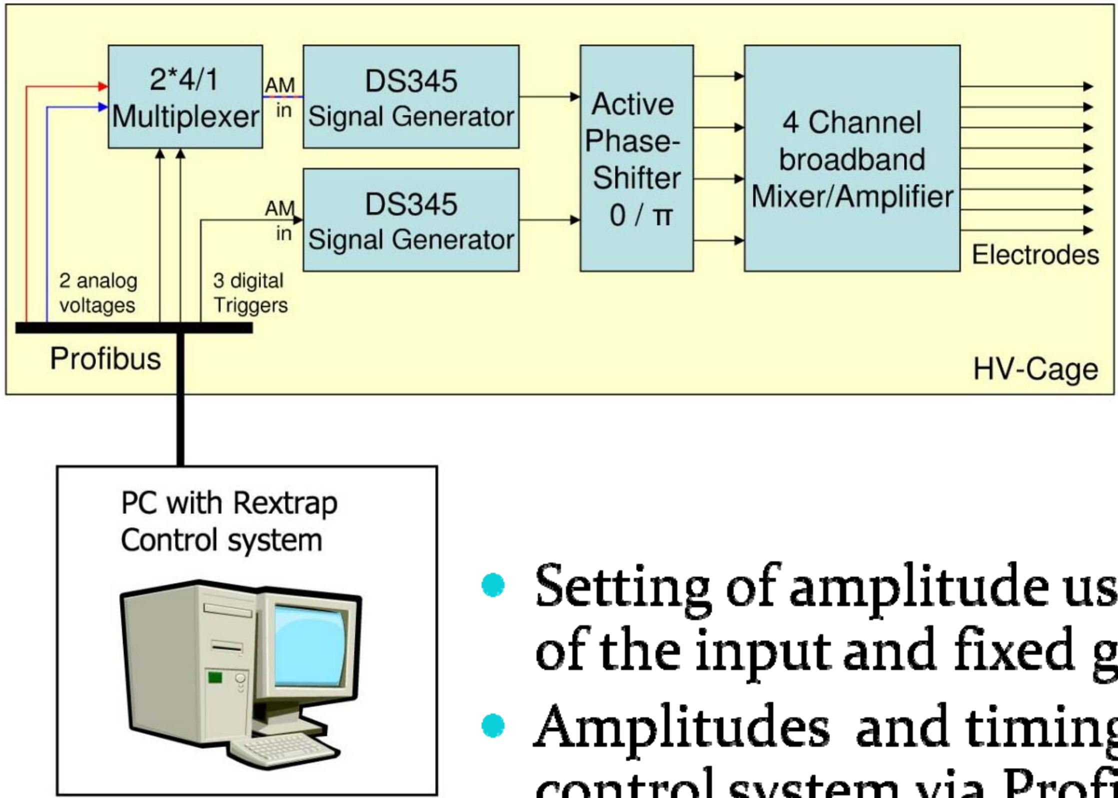


Ejection
diaphragm



Ejection
diaphragm

Setup



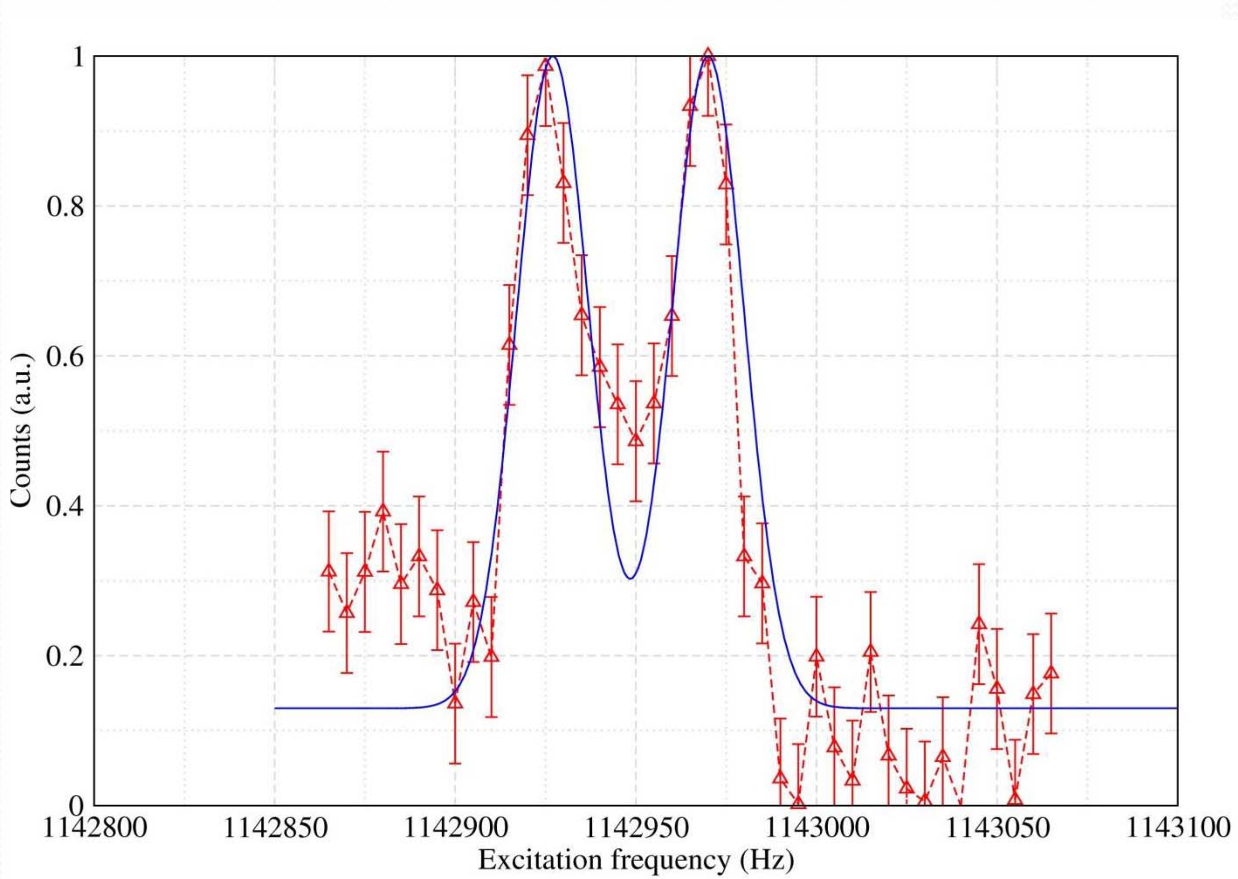
- RF-Amplifier design with 4 impedance matched power output channels (Up to 1.5A/30V_{pp} @ 15MHz)
- Electronic signal mixing in the amplifier

- Setting of amplitude using amplitude modulation of the input and fixed gain
- Amplitudes and timing can be set from the control system via Profibus
- System is fully **compatible with old settings** !

First Results

- System was first tested in December 06 with stable beam from ISOLDE targets
- 2 different isobarically impure beams:
  - $^{40}K/^{40}Ca$ requiring the maximum resolution of 4.5 10^4
  - $^{28}N_2/^{28}CO$ molecular beam requiring $m/\Delta m=3000$
- Both beams were resolved
- No suppression-factor measurement possible since no radioactive beam was available

First Results (2)



Approximately FWHM ≈ 25Hz ⇒ MRP ≈4.5 10^4

Approximately 0.8 pA ^{40}K & 2.8 pA $^{28}N_2$ & 1.5 pA ^{28}CO

Efficiency is below 5%

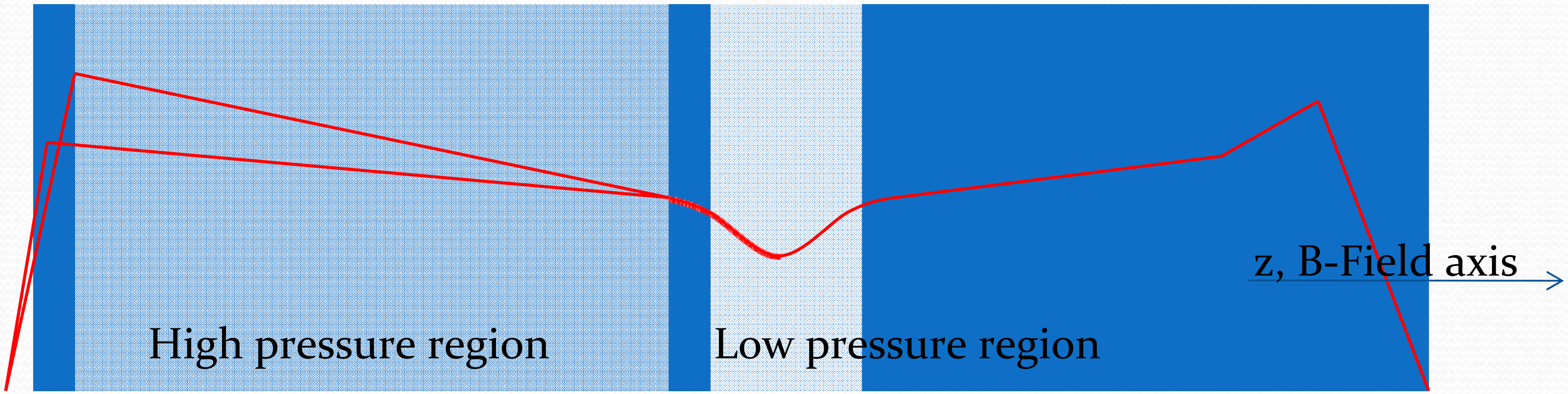
2.5%

Limitations

- Throughput
  - Limited due to space-charge
  - Long cycle time (100ms) means more ions/bunch (10^5-10^6)
  - Depends on asked resolution, but is always in the order of 1 pA or ~10^6 10^7 ions/s
- Efficiency
  - Mainly limited due to injection losses resulting from low gas pressure
  - Depends on asked resolution
  - Might improve with bunched injection
  - Depending on the element, long cycle times cause losses due to charge-exchange
  - In the order of 10%
- Cycle time
  - Limits the use to nuclides with halflives > 100ms

Bunched injection

- Collection window cannot be open during the selection process
- Resulting beam and/or time losses could be overcome by introducing a bunched injection
- A device downstream of Rextrap is pre-bunching the DC beam (ISCOOL)
- Injection into REXTRAP has to be synchronized with the bunch arrival
- Physical length of the bunch in the trap potential has to be comparable to the REXTRAP dimension
- Feasibility depends mainly on the energy-spread of the ions from ISCOOL



Summary

- A new high resolution mass separation system for REX-ISOLDE was implemented and evaluated at REXTRAP
- The maximum attainable resolution is about $R=4.5\ 10^4$, thus a factor of 10 better than HRS
- Limitations in throughput still allow use for experiments with high demand in beam purity but low demand in intensity
- More work has to be done in order to use bunched injection and to evaluate the suppression factor