Then mid 2001 - no beam accelerated yet

Meanwhile
* 9-gap cavity added
* new experimental hall
* moved Miniball
* concrete shielding

Now 2009

The refinement of REX-ISOLDE

F. Wenander
8 June 2009
Harvest incl. 2008

...and beams accelerated

Periodic Table of Elements


2009

9 experiments

171 experiments (8 h)

24 different radioactive elements and over 60 isotopes accelerated

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Machine layout

Electron beam ion source
* 1+ ions to n+
* Super conducting solenoid, 2 T
* Electron beam <0.4 A, 3-6 keV
* Breeding time 3 to >200 ms

Optional stripper for beam cleaning

Experiments

Linac
Type: normal conducting
6 accelerating cavities
Length: 11 m
Freq.: 101 MHz (202 MHz for the 9GP)
Duty cycle: 1 ms 100Hz
Energy: 300 keV/u, 1.2-3 MeV/u (variable)
A/q max.: 4.5

Penning trap
* Longitudinal accumulation and bunching
* Transverse phase space cooling
* 3 T solenoid field
  + quadratic electrostatic potential
  + RF cooling
* Buffer gas filled (5E-4 mbar)
* Cooling time ~20 ms

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REX low energy = 2-16 %
Depends on: mass, A/q, experience
Linac transmission x 0.6-0.85
A<20 ions still difficult
Heavy ions low efficiency: charge exchange? heating losses? under investigation broader CSD?

Present performance

* Trap time excluded; same as the breeding time (at least 20 ms)
* T_{breed} depends on A/q & injection condition (High efficiency -> short breeding time)
* Half-lives down to some 10 ms

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All this is standard operation...

(although manpower consuming)

...the following is over-drive
14x1.2 s

Proton bunch to ISOLDE
Proton bunch NOT to ISOLDE

Target and ion source release

Collection Cooling Bunching

RFQ cooler pulsed mode

* RFQ cooler recently installed at ISOLDE
* Before REXTRAP -> beam gymnastics
* Pulsed or CW mode

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Mass separation operation cycle

- cool down the ion cloud
- shift out the ion cloud with a dipolar excitation
- selectively re-centre the desired species
Isobaric mass resolution

Already: isobaric separation inside REXTRAP previously proven only trap, low efficiency, suppression unknown

Now: measured after the REXEBIS -> trap cooling sufficient contamination suppression 20-50 (lower limit)

Resonance curve for $^{39}$K
Mass resolution = $3.0 \times 10^{-4}$
REXTRAP + REXEBIS transmission 2.5 %
98% suppression
ISCOOL used as pre-buncher and cooler

Resonance curve for $^{133}$Cs
Mass resolution = $2.3 \times 10^{-4}$
96% suppression
From local ion source
Space charge effects > $1 \times 10^6$ ions/pulse

Frequency shifts – can be compensated for
Peak broadening -> reduced mass resolution

Mass resolution
Efficiency
Resolution

- Transmission increased a factor 10
- Depending on: mass resolution suppression factor

HRS – High Resolution Separator
$^{39}$K from RFQ cooler

Compare with 17% without mass resolution
Apart from efficiency and space charge...

1. Total cycle time 100 to 200 ms
   Limits the use of nuclides with half-lives < 100 ms
2. Setup not evident – at least 8 h; slowly gaining experience
3. Multiple peaks appearing (for single element)
4. Processes in trap not fully understood

Final test to come:
isobarically contaminated radioactive beam

Mass separation reservations

TOF after trap
NB: only one beam component (39K)

Multiple peaks sometimes visible
**Undesired for:** \(^{80}\text{Zn}\) \((t_{1/2}=537\text{ ms})\)  
– also got \(^{80}\text{Ga}\) \((T_{\text{trap}}=80\text{ ms}, \ T_{\text{breed}}=78\text{ ms})\)

**The idea:** Let easily produced elements decay in REX low-energy part prior to acceleration to provide post-accelerated beams of difficultly produced elements  
(previously used at ISOLTRAP; A. Herlert et al., New J. Phys. 7 (2005) 44)

**In-trap decay**
for better or for worse

Doppler corrected Coulex spectra (Miniball)

<table>
<thead>
<tr>
<th>(T_{\text{trap}})</th>
<th>(T_{\text{breed}})</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>200-1100 ms</td>
<td>28 ms</td>
<td>no Fe detected at Miniball</td>
</tr>
<tr>
<td>300-1100 ms</td>
<td>298 ms</td>
<td>(57(7)%) Fe detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>agrees with predictions</td>
</tr>
</tbody>
</table>

Tested first time at REX-ISOLDE with \(^{61}\text{Mn}\) \((T_{1/2}=675\text{ ms}; \ 1.7\times10^6\text{ atoms/s})\)
Mn -> Fe in-trap decay

Why not working in REXTRAP?
SIMION simulations show that 90% of the recoiling daughter ions are trapped in REXTRAP

Fraction of daughter depends on
1. $X^+ \rightarrow \beta^+ \rightarrow X^0$   $X^+ \rightarrow \beta^- \rightarrow X^{++}$
2. half-life + trapping and breeding time
3. ion recoil energy and distribution
   (Fermi vs Gamow–Teller decay)
4. trapping potentials (trap and EBIS)
5. Auger and shake-off effects
6. $n^+$ recombination time

M. Beck, ‘WITCH internal report…’, 7 May 2007
Future in-trap decay applications

* Choice: decay in trap or in EBIS

* Prefer decay in trap to EBIS
  - No linac A/q rescaling
  - No disturbing residual A/q-peaks
  - No ion losses due to electron heating

New!

<table>
<thead>
<tr>
<th>Daughter</th>
<th>Mother</th>
<th>$T_{1/2}$ mother</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}$B</td>
<td>$^{12}$Be</td>
<td>23.6 ms</td>
</tr>
<tr>
<td>$^{33,34,35}$Si</td>
<td>$^{33,34,35}$Al</td>
<td>54, 60, 150 ms</td>
</tr>
<tr>
<td>Ti</td>
<td>Sc</td>
<td></td>
</tr>
<tr>
<td>$^{61,62,63}$Fe</td>
<td>$^{61,62,63}$Mn</td>
<td>710, 880, 250 ms</td>
</tr>
<tr>
<td>$^{98-103}$Zr</td>
<td>$^{98-103}$Y</td>
<td>0.23 s to 3.75 s</td>
</tr>
</tbody>
</table>

Prospective new beams for REX-ISOLDE produced with β- in-trap decay.

Limitations
- Good yield from ISOLDE
- Reasonable $T_{1/2}$ mother: 10 ms to 2 s
- $\beta^-$ decay -> daughter $2^+$ or $n^+$ charged
- $\beta^+$ decay -> daughter neutral or $n^+$
- Daughter recoil energy limited trapping potentials in trap (100-200 V) and EBIS (300-400 V)

Further test in July
Polarized beams

Induced Nuclear Polarization using Multi Tilted Foils

* Polarization - ion - surface interactions (no bulk - effects influences)

* Atomic polarization $\rightarrow$ nuclear polarization

* Nuclear polarization degree $P_I$:
  higher polarization level at higher $I$ (nuclear spin)
  faster "saturation" at lower $I$ (fewer foils needed)
  strong velocity dependence

Previously shown for $^{51}$V
$P_I > 10(1)\%$ at $\beta = 4.6\%$

Physics
* Transfer reactions
* Decay spectroscopy

First tests with $^{27}$Na $5/2^+$
or Coulex $^{23}$Ne $3/2^+$

M. Hass et al., NPA 414, 316 (84)
Mobile tilted foil setup

Modular foil stack
1. Adjust intermediate foil distance with spacers
2. Adjust number of foils
3. Adjust beam inclination angle
4. Ladder with three different foil configurations

Aperture size
- first version 20*14 mm
- second version 30 to 35 mm large axis

Foil type
- laser ablated C, 4 ug/cm² from TU Munich
- pA beam flux -> no life-time problems

Goal – parameter scan

possible positions
1. Tilted foil -> charge state distribution
   -> low overall efficiency
   (or install foils after all magnetic elements)

2. Post-acceleration after polarization?
   Noble-gas like charge states

3. Beam energy for optimal polarization
   should coincide with charge state
distribution for magic number

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K. SHIMA et al., Atomic data and nuclear data
    tables, 1992, vol. 51, n°2, pp. 173-241

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Equilibrium charge fraction of ion after passage
through a carbon foil as function of exit energy

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* β-NMR setup from HMI Berlin

* To be installed after the linac
   -> beam energy 0.3 to 3 MeV/u

* nuclear structure (moments, reactions ...)
nuclear methods in the solid-state physics
biophysics etc. ...

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**Wish list - 1st phase**
- current amplification
- beam profiler / beam position
- <1 pA beam intensity
- <0.5% energy measurement

**- 2nd phase**
- TOF
- cavity phase measurements

**Test ‘outsourced’ to:**
E. Griesmayer, ATLAS/CERN and Bergoz Instrumentation, St Genis, France

**Diamond detector tests**

- **pCVD**, 10x10 mm², 500 um thick plated with square 8x8 mm² Al electrodes thickness of 25 nm
- **sCVD**, 5x5 mm², 500 um thick plated with 3 mm diameter Au electrodes thickness of 500 nm

Manufacturer: Diamond Detectors Ltd
own contact layers

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sCVD results

+ Very low noise level (< 1mV)
  -> Noise discrimination easy

+ Particle counting up to 1E4 part/s
  (duty factor => ~1E7 part/s)

Single pulse example, +500 V bias
Pulse height 109 mV
Pulse width 7.7 ns

+ ~1% energy resolution $^{12}$C$^4+$ 1.9 MeV/u
  sCVD with 1000 V bias

- Cases with worse resolution
  Solved with polarity change
  Space charge? Charge trapping?

- Expensive – 3 kCHF for 5x5 mm$^2$

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pCVD results

1. fluctuating leakage current (tens pA to nA)  
   -> current amplification mode not viable
2. signal height polarity and time dependent  
   -> counting problems
3. signal size decreases with beam loading / time  
   -> position tuning difficult; always better at fresh pixel  
   -> counting problems

 Reasons?  
* charge trapping  
* polarization  
* structural defects  
* contact layer  
* ...


Fig. 1. Energy spectrum of a pCVD diamond detector (50 µm thick; $V_{bias} = \pm 50$ V) for $^{10}$C of 16.2 MeV.

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‘High-Resolution Energy and Intensity...’  
E. Griesmayer et l., CERN BE Note, 2009, tbp
Wait for the 2\textsuperscript{nd} generation!

Thanks to A. Gustafsson, D. Voulot, J. Van de Walle, R. Scrivens, E. Griesmayer, T. Aumeyr...

Repetition rate 50 Hz:
- 2.5 nA →
- 1.5E10 ions/s →
- 3E8 ions/pulse
  with > 5\% eff

Worse for RI discharges recombination

Last word

NB! M. Pasini talk on HIE-ISOLDE

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Mass separation in REXTRAP - Space-charge effects

- Frequency shifts
- Peak broadening

![Diagram showing mass separation effects with gas pressure control and ion counts]

Did we have the same for the energy measurement?
Double stripping

Can we make use of the different energy loss through a stripping foil to eliminate selectively heavy contaminant? (8Li run Oct. 2006)

- 8Li/16O ratio increased by a factor 13 (expected a factor 3 with single stripping foil)
- Beam intensity decreased by a factor 3 -> can only be used in case of sufficiently intense beams
Time Structure

- Bunched beam: high instantaneous rate! ⇒ deadtime ...
- Good signal/background ...

1 shift at REX = 19 min actual measuring time
Collection Cooling Bunching

RFQ cooler pulsed mode

REXTRAP mass resolving mode

Collection time = cooling time

Ion hold-up time (in this case) =
100 ms (average) + 200 ms + 50 ms

Quadrupole excitation \( \omega_{\text{cyclo}} \)

Dipole excitation \( \omega_{\text{mag}} \)

Pre-centering

De-centering

Mass-selective re-centering

Linac

RF on for acceleration

Charge breeding

REXEBIS

780 us Beam on

780 us Beam off

Beam on 780 us

Beam off 3 ms

FWHM 25 us

(400 us)

Linac

Cyclotron

Magnetron

RFQ

RFQ cooler pulsed mode

Pre-centering

De-centering

Mass-selective re-centering

REXEBIS

RF on for acceleration

Charge breeding

REXEBIS