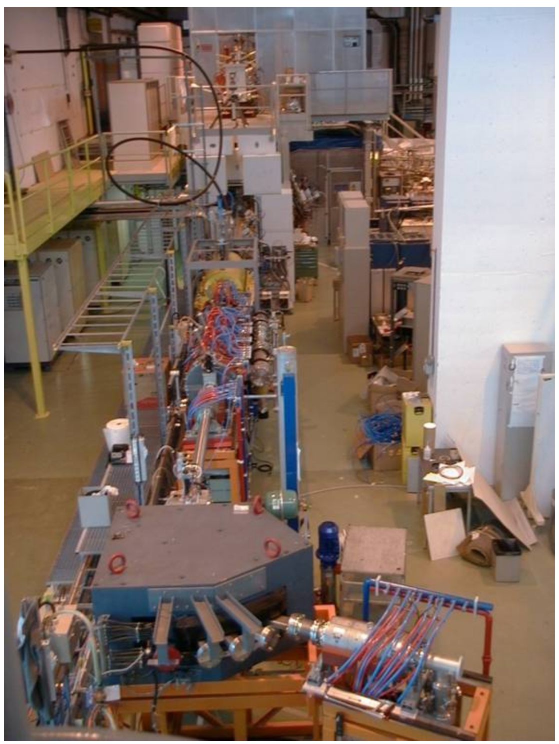
The refinement of REX-ISOLDE

ISOLDE
CERN

F. Wenander
8 June 2009

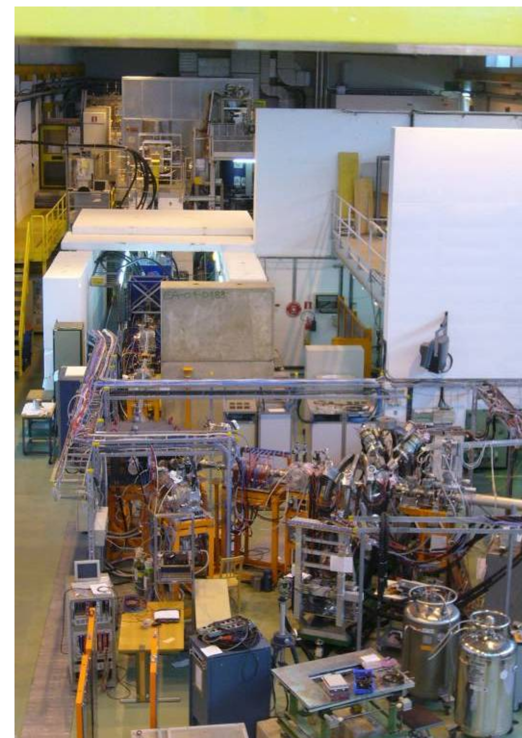
HIAT09

Then mid 2001 -
no beam accelerated yet



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

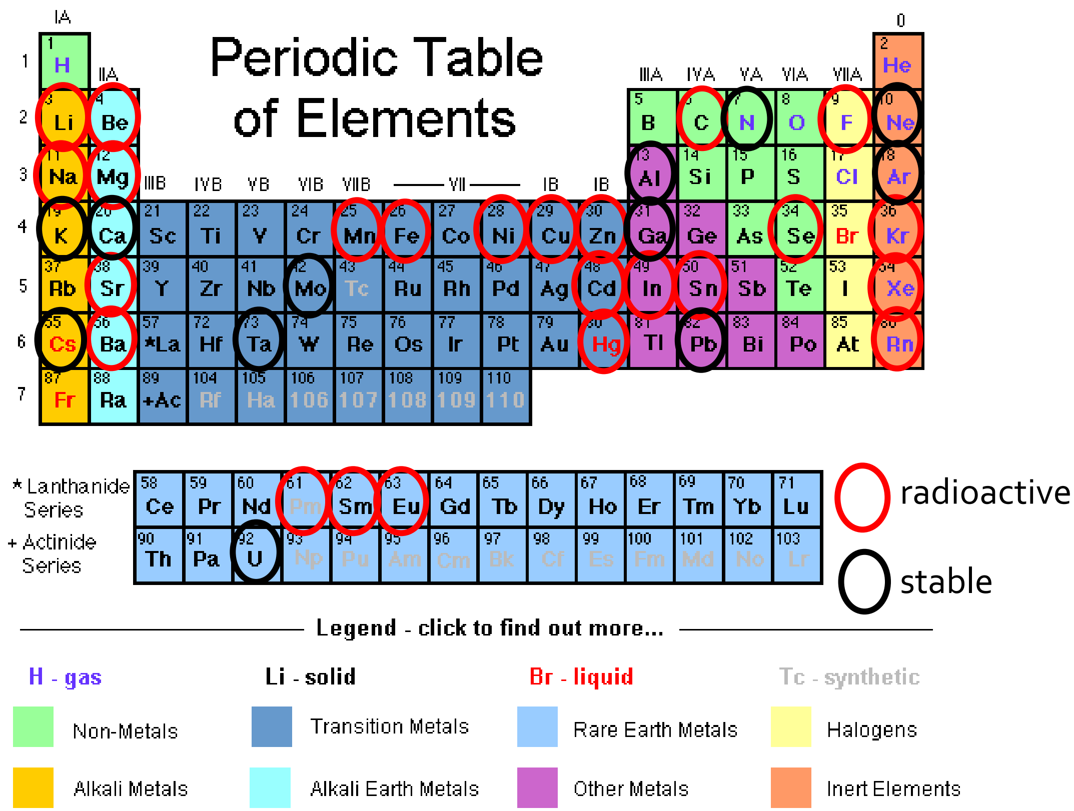
Now 2009



Harvest incl. 2008

$^{8}Li^{3+}$(2006), $^{9,11}Li^{2+}$(2004), $^{9}Li^{2+}$(2005), $^{10,11}Be^{3+,4+}$(2006), $^{11,12}Be^{3+,4+}$(2005), $^{10}C^{3+}$(2008), $^{17}F^{5+}$(2004), $^{17}F^{5+}$(2007), $^{24-29}Na^{7+}$, $^{29,31}Mg^{9+}$(2006), $^{30}Mg^{9+}$(2007), $^{30}Mg^{7+}$(2008), $^{30,31}Mg^{9+}$(2007), $^{28,30,32}Mg^{8+}$, $^{61,62}Mn^{15+}$(2008), $^{61,62}Fe^{15+}$(2008), $^{68}Ni^{19+}$(2005), $^{70}Cu^{19+}$(2008), $^{67,69,71,73}Cu^{19+,20+,20+,19+}$(2006), $^{68,69,70}Cu^{19+,20+,19+}$(2005), $^{74,76,78}Zn^{18+}$(2004), $^{80}Zn^{21+}$(2006), $^{70}Se^{19+}$(2005), $^{88,92}Kr^{21+,22+}$, $^{96}Sr^{23+}$(test), $^{96}Sr^{27+}$(2007), $^{108}In^{30+}$(2005), $^{106,108}Sn^{26+}$(2006), $^{108}Sn^{27+}$(2005), $^{110}Sn^{30+}$(2004), $^{100,102,104}Cd^{24+,25+,25+}$(2008), $^{122,124,126}Cd^{30-31+}$(2004), $^{124,126}Cd^{30,31+}$(2006), $^{138,138,140,142,144}Xe^{34+}$, $^{140,142,148}Ba^{33+,33+,35+}$(2007), $^{148}Pm^{30+}$, $^{153}Sm^{28+}$, $^{156}Eu^{28+}$, $^{184,186,188}Hg^{43+,43+,44+}$(2007), $^{182,184,186,188}Hg^{44+,44+,44+,45+}$(2008), $^{202,204}Rn^{47+}$(2008)

…and beams accelerated



2009

9 experiments

171 shifts (8 h)

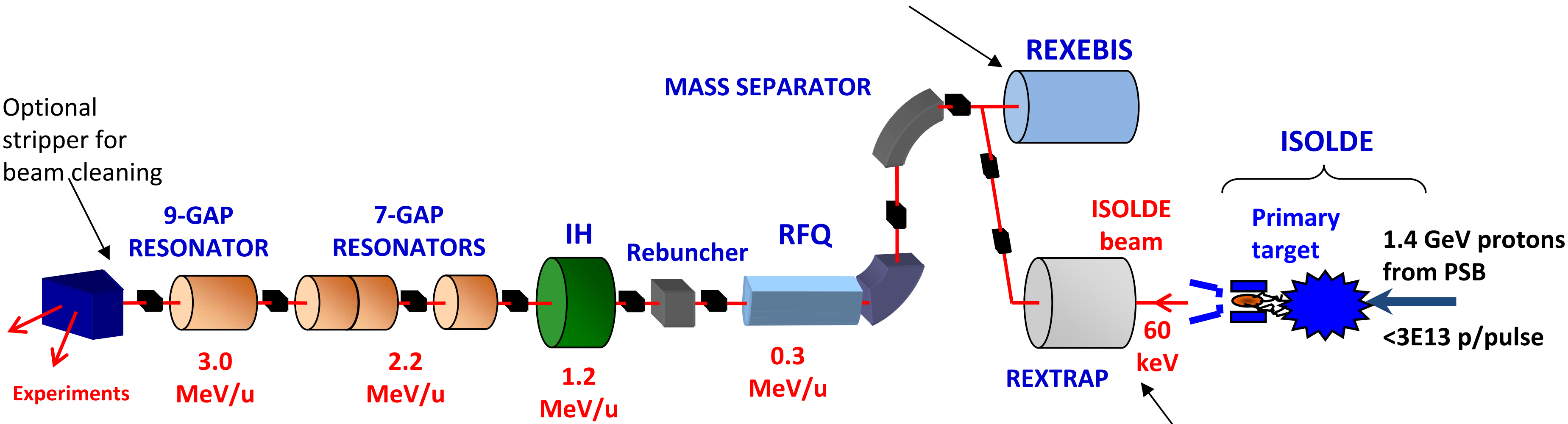
24 different radioactive elements and over **60** isotopes accelerated

Further info at http://isolde.web.cern.ch/ISOLDE/REX-ISOLDE/index.html

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



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

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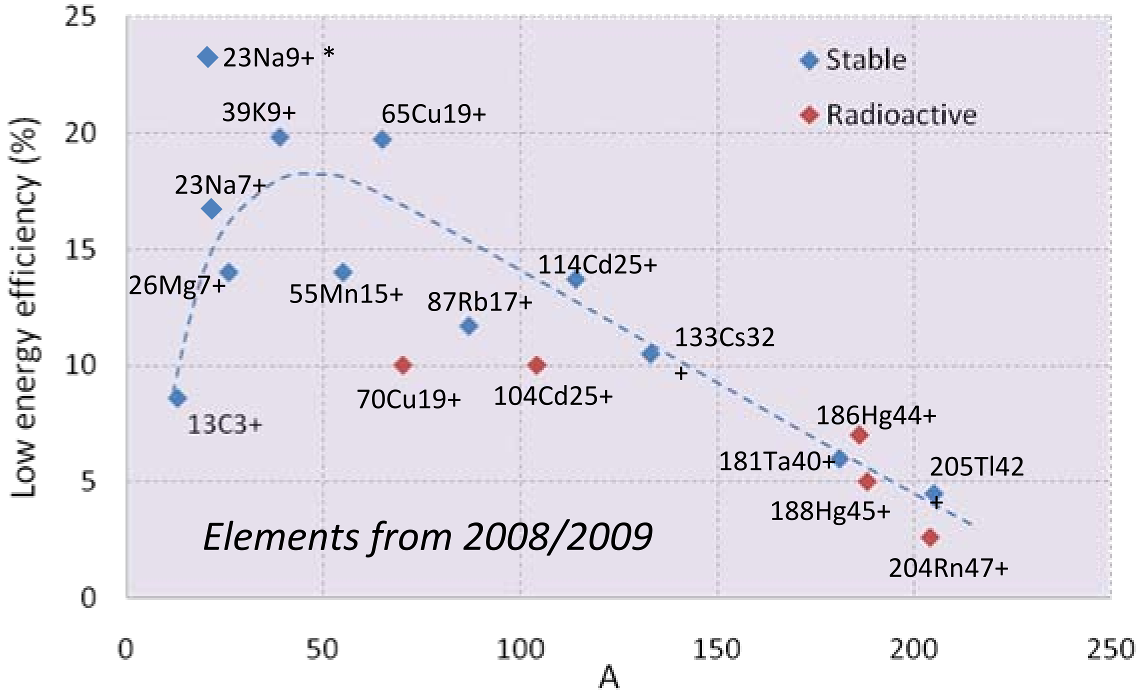
Penning trap

* 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

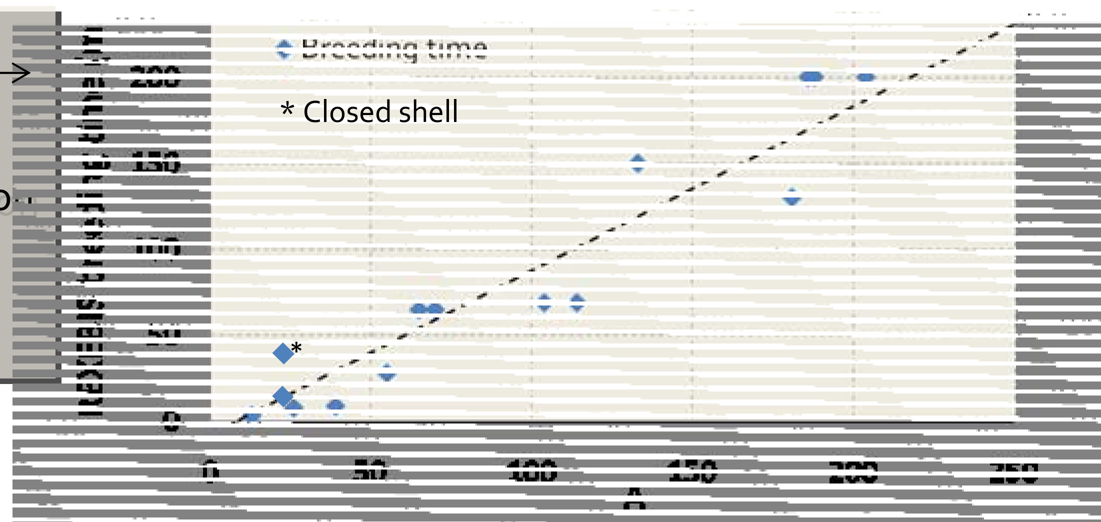
Present performance

Efficiency = Trap+EBIS+REX mass separator



* 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?

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



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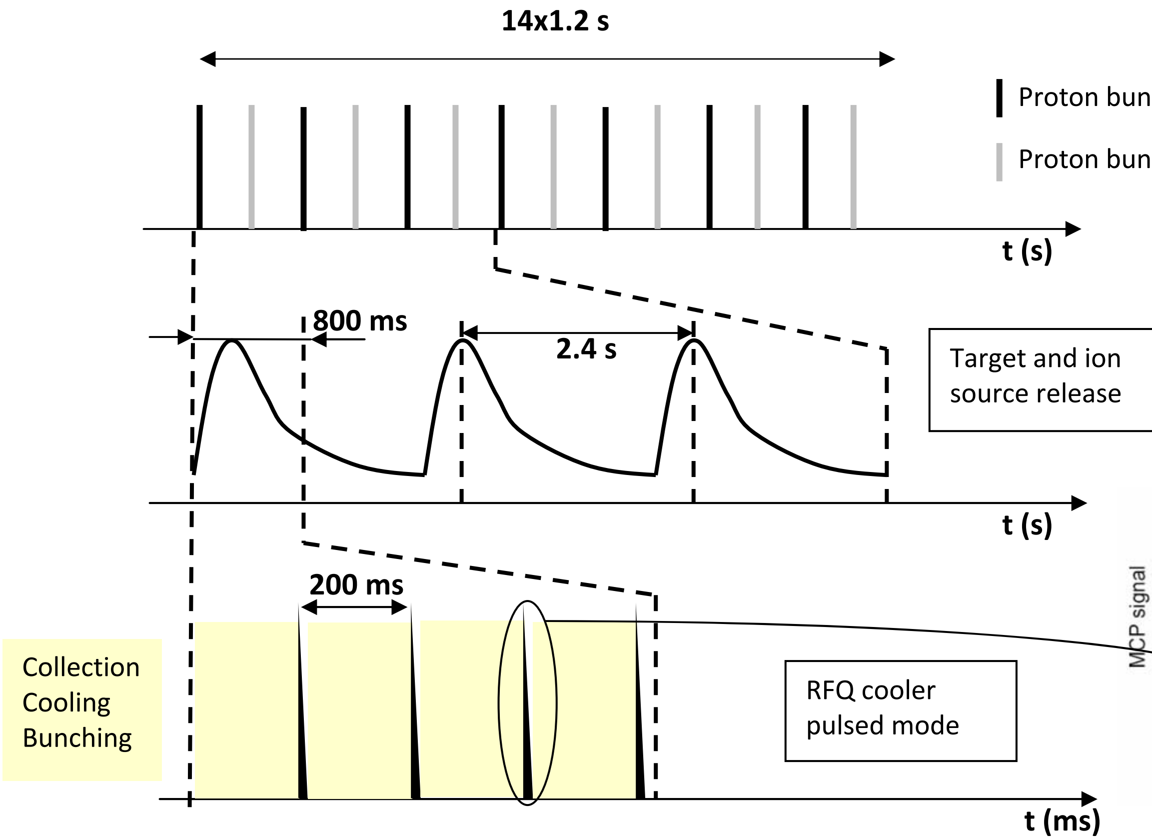
All this is standard operation…

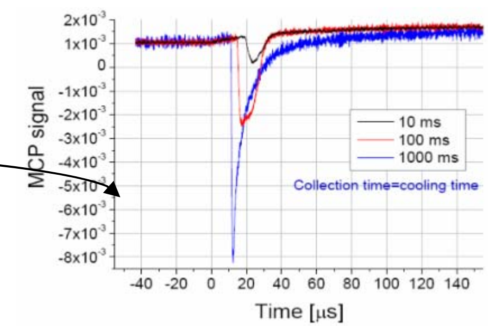
(although manpower consuming)

…the following is over-drive

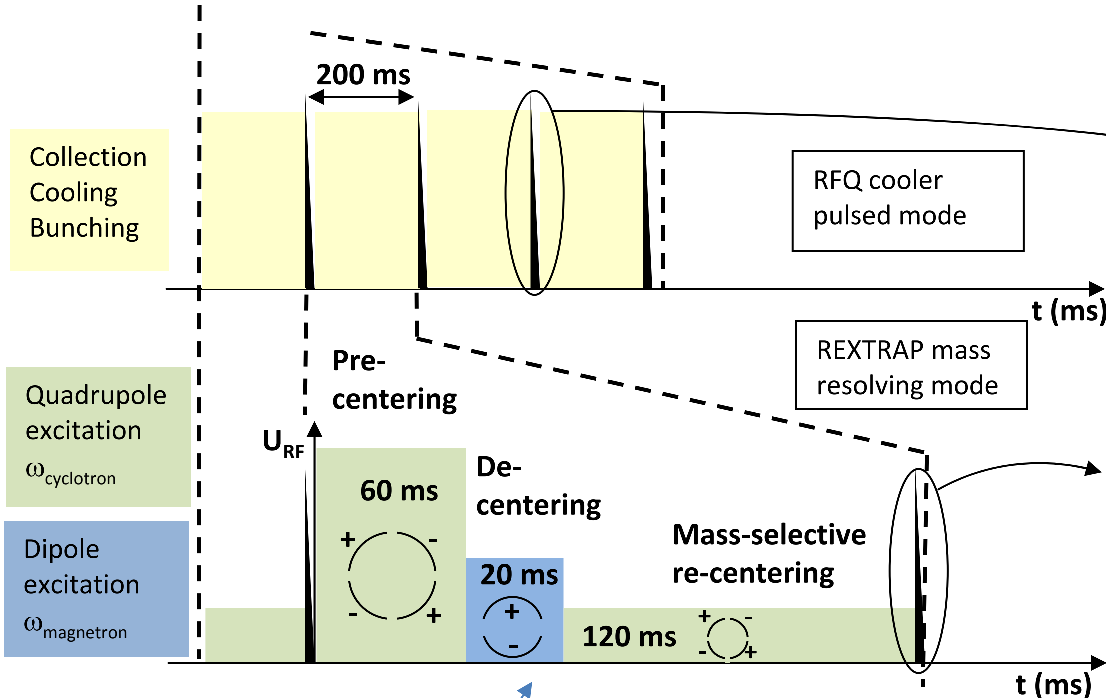
Time structure

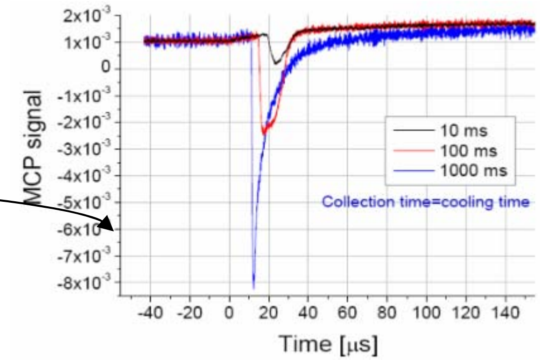
* ISOLDE
* REX

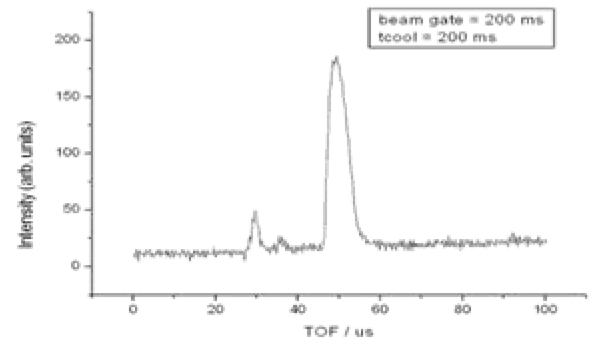


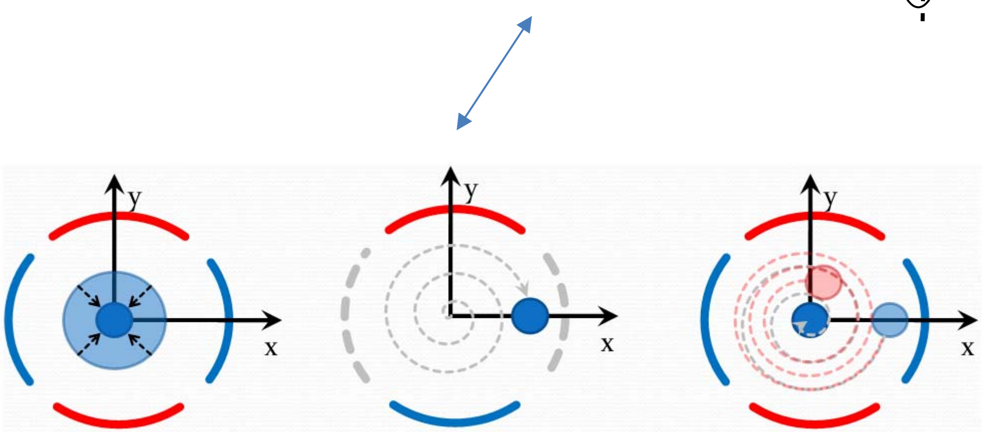


* RFQ cooler recently installed at ISOLDE
* Before REXTRAP -> beam gymnastics
* Pulsed or CW mode









Mass separation operation cycle

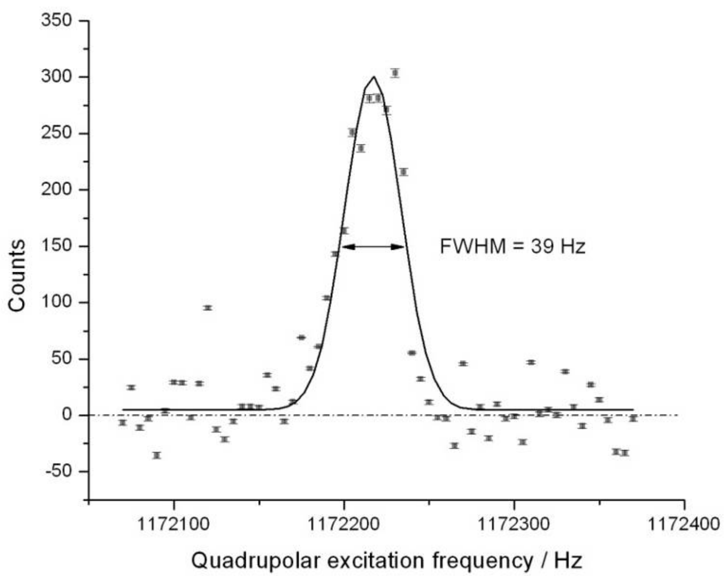
- cool down the ion cloud
- shift out the ion cloud with a dipolar excitation
- selectively re-centre the desired species

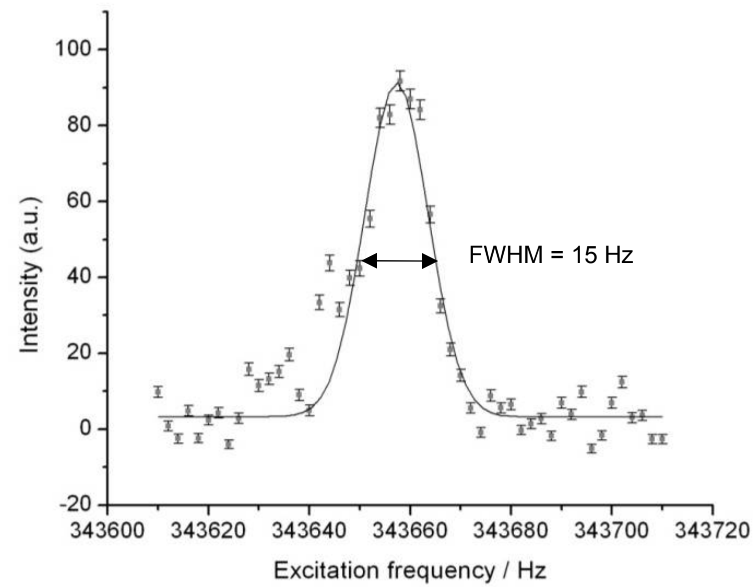
Isobaric mass resolution

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

S. Sturm, Master Thesis, Universität Heidelberg (2007)

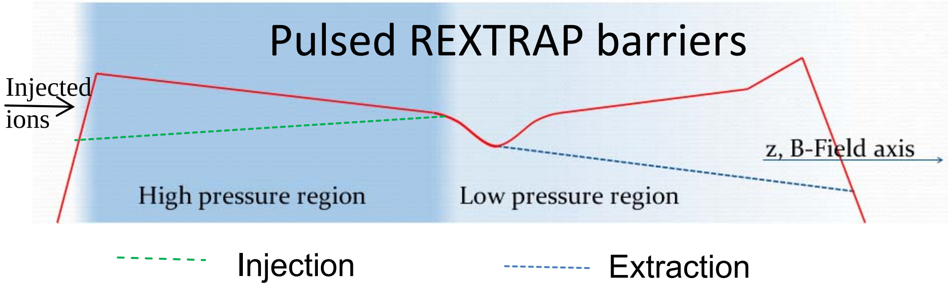
Now: measured after the REXEBIS -> trap cooling sufficient
contamination suppression 20-50 (lower limit)





Resonance curve for ^{39}**K**
Mass resolution = **3.0e4**
REXTRAP + REXEBIS transmission **2.5 %**
98% suppression
ISCOOL used as pre-buncher and cooler

Resonance curve for ^{133}**Cs**
Mass resolution = **2.3e4**
96% suppression
From local ion source

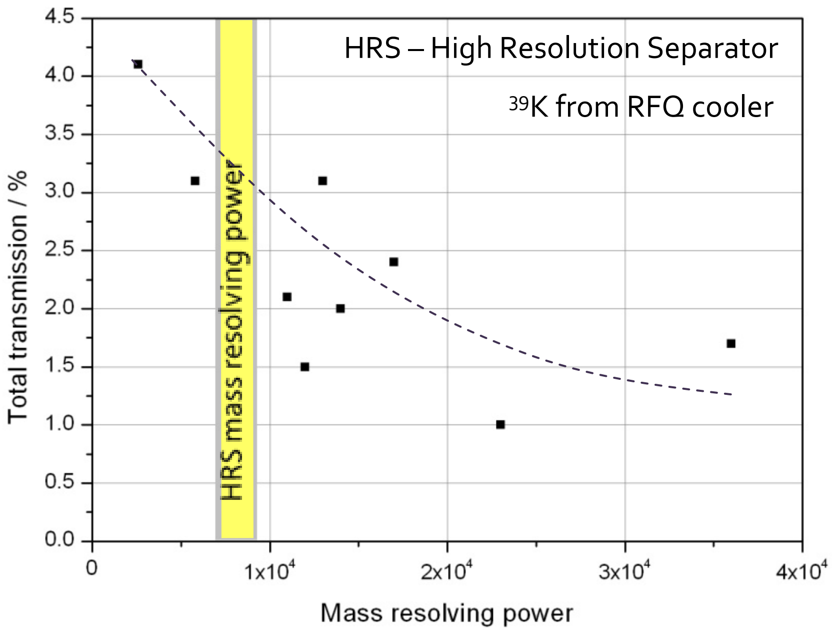


Mass resolution

Efficiency

Resolution

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



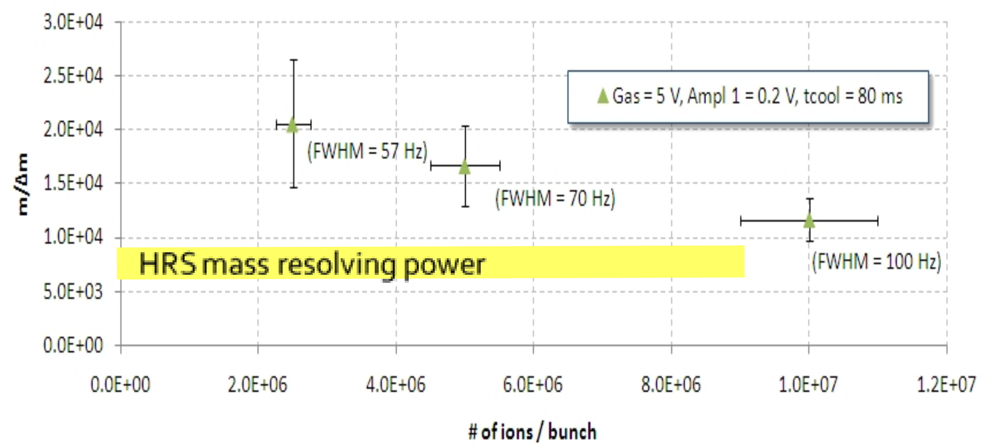
Compare with 17% without mass resolution

Space charge effects > 1E6 ions/pulse

Frequency shifts – can be compensated for

Peak broadening -> reduced mass resolution

Limit includes stable contaminants



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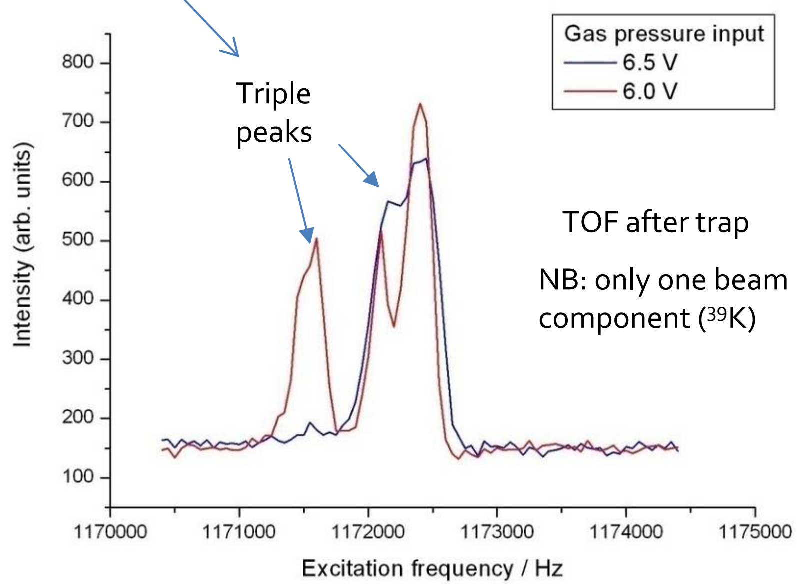
Mass separation

reservations

Apart from efficiency and space charge…

1. Total cycle time 100 to 200 ms
   Limits the use of nuclides with halflives < 100ms
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



Multiple peaks sometimes visible

Final test to come:
isobarically contaminated radioactive beam

Undesired for: ^{80}Zn ($t_{1/2}$=537 ms)
– also got ^{80}Ga (T_{trap}=80 ms, T_{breed}=78 ms)

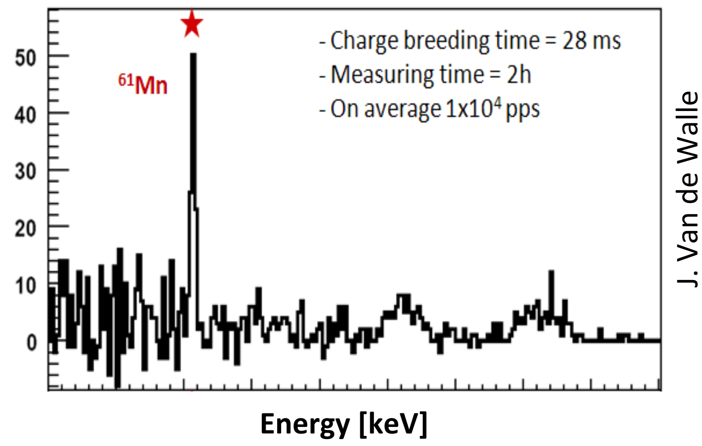
In-trap decay

for better or for worse

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

Doppler corrected Coulex spectra (Miniball)

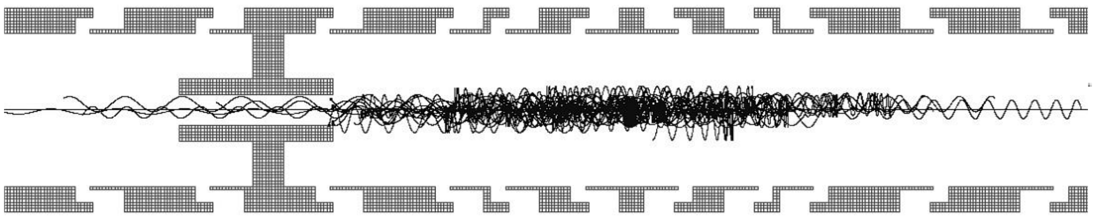


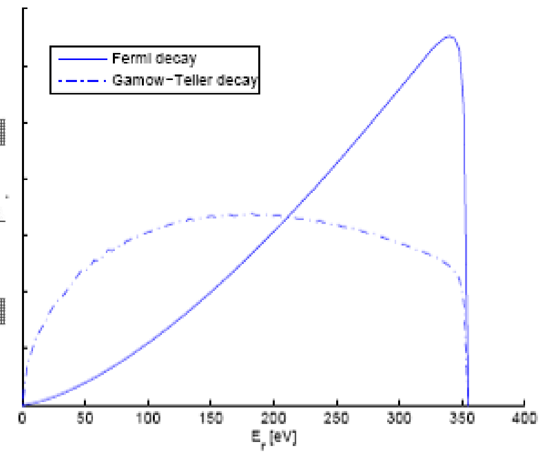
Tested first time at REX-ISOLDE with ^{61}Mn ($T_{1/2}$=675 ms; 1.7x10^{6} atoms/s)

T_{trap}	T_{breed}	**Result**
200-1100 ms	28 ms	no Fe detected at Miniball
300-1100 ms	298 ms	57(7)% Fe detected agrees with predictions

Mn -> Fe in-trap decay

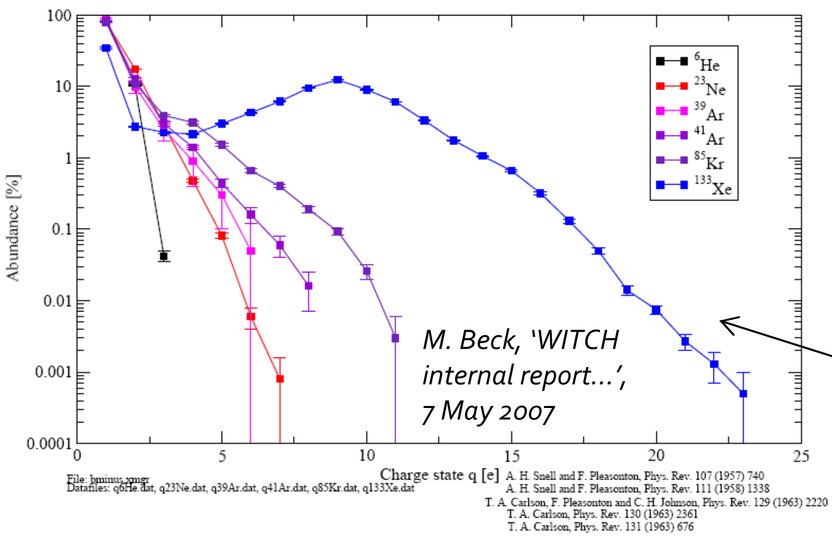
Why not working in REXTRAP?
SIMION simulations show that 90% of the recoiling daughter ions are trapped in REXTRAP





Example of a recoil energy distribution function.

F. Ohlsson's Diploma thesis Chalmers university of Technology 2007



M. Beck, 'WITCH internal report…', 7 May 2007

Fraction of daughter depends on

1. $X^+ \to \beta^+ \to X^0$ $X^+ \to \beta^- \to X^{++}$
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

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

Further test in July

New!

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

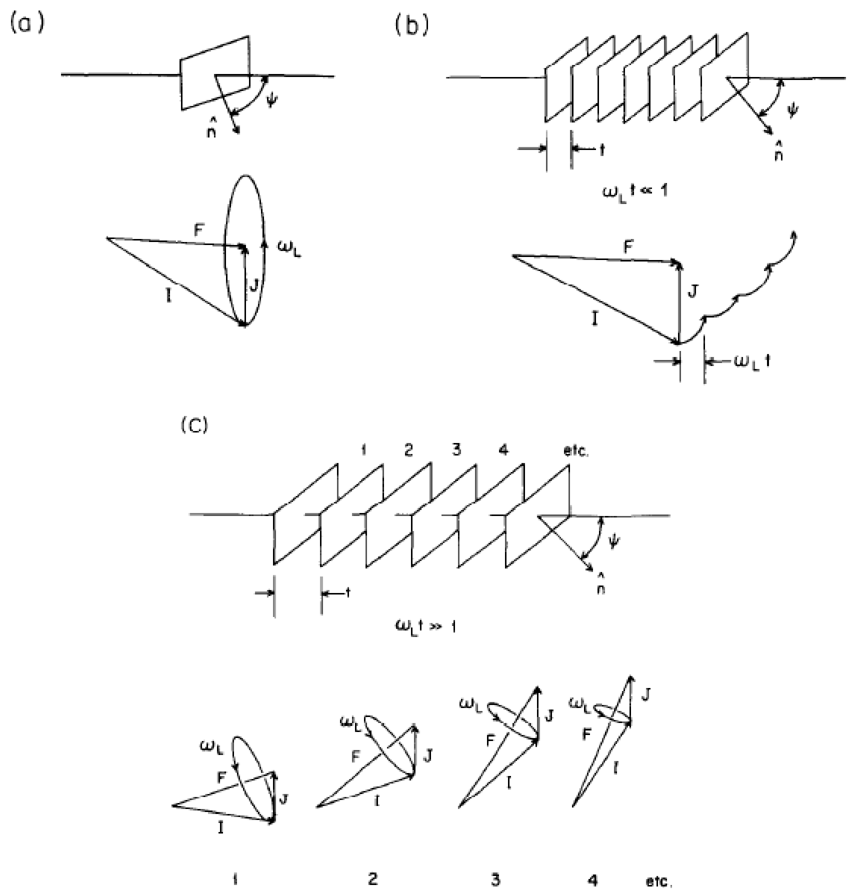
Prospective new beams for REX-ISOLDE produced with β- in-trap decay.

Limitations

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

Polarized beams

Induced Nuclear Polarization using Multi Tilted Foils



M. Hass et al., NPA 414, 316 (84)

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

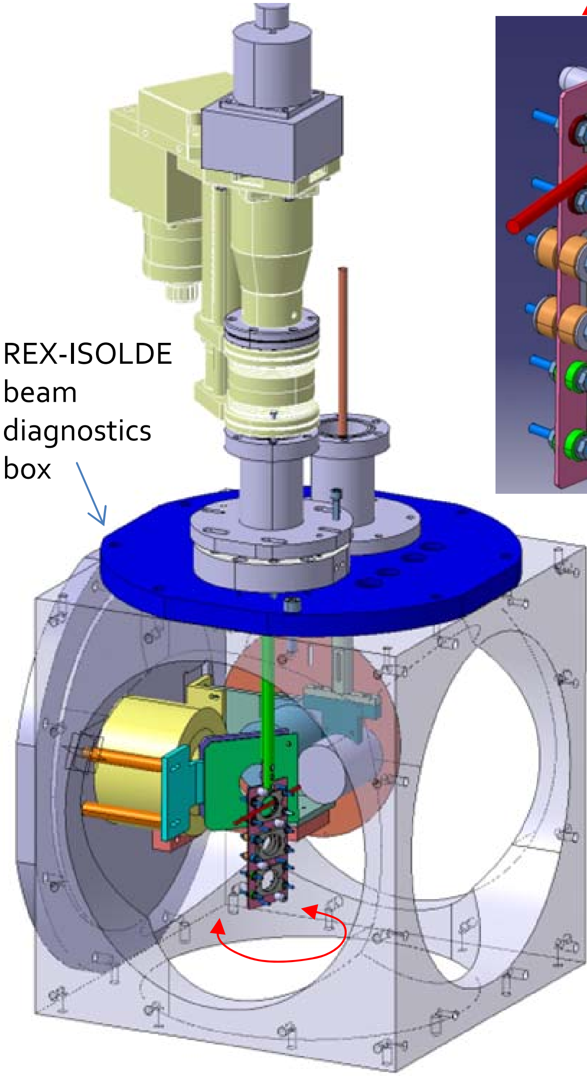
* Atomic polarization → nuclear polarization

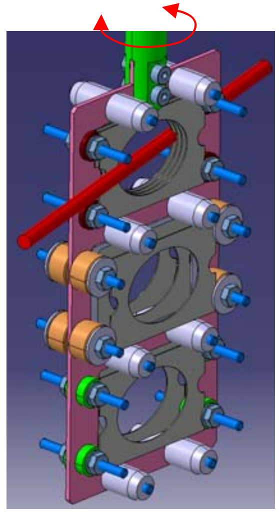
* Nuclear polarization degree P_I:
  higher polarization level at higher I (nuclear spin)
  faster "saturation" at lower I (fewer foils needed)
  strong velocity dependence

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

Physics
* Transfer reactions
* Decay spectroscopy

First tests with ^{27}Na $5/2^+$
or Coulex ^{21}Ne $3/2^+$





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

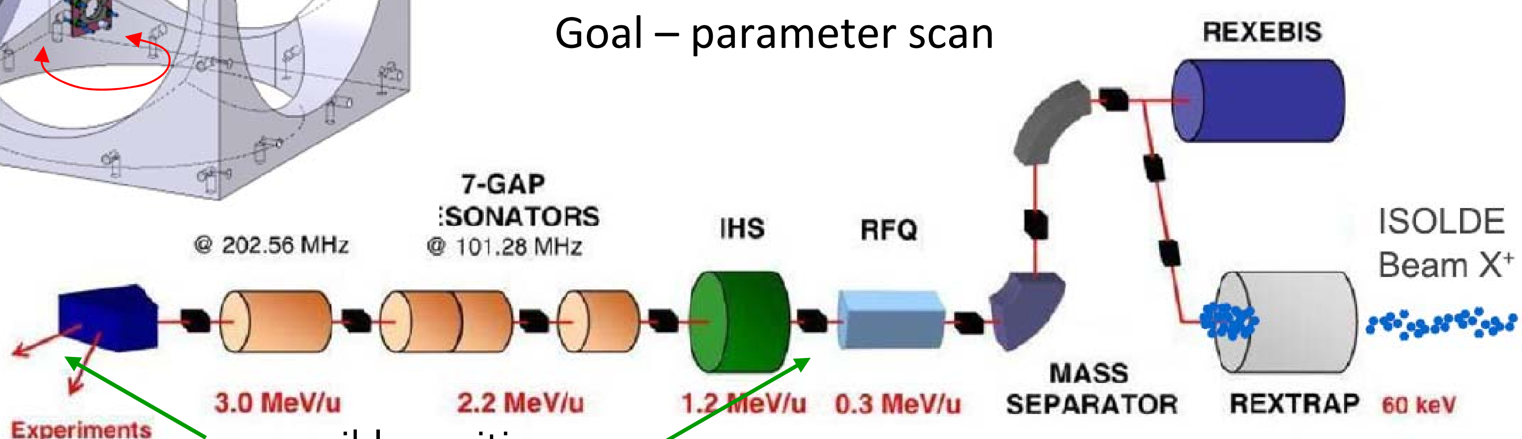
Aperture size

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



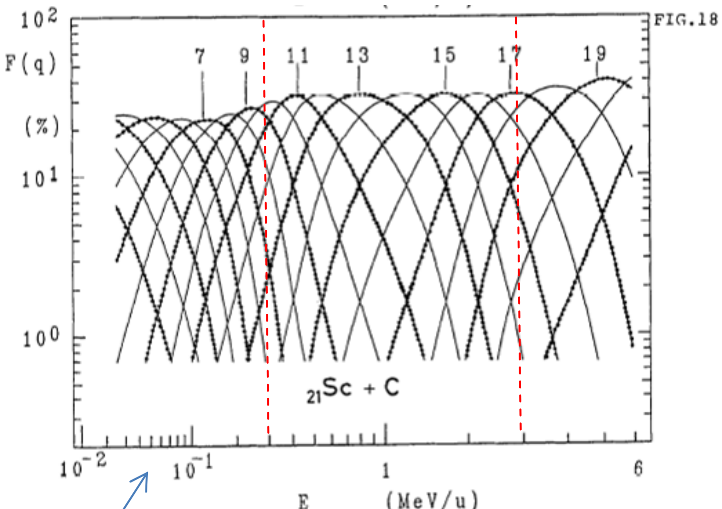
Constraints and Alternatives

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

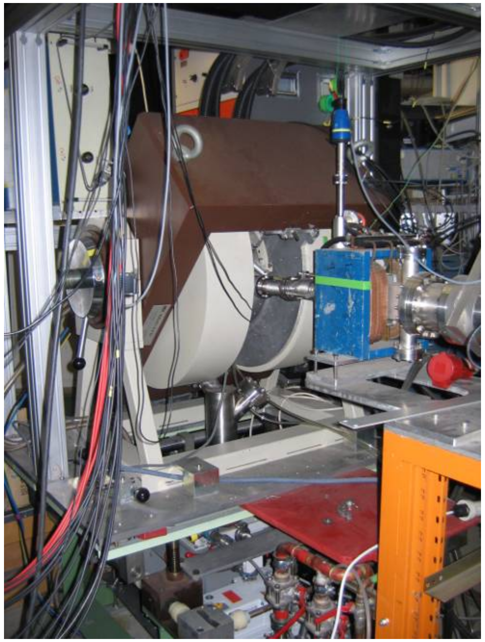
2. Post-acceleration after polarization?
   Noble-gas like charge states

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

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



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



* β-NMR setup from HMI Berlin

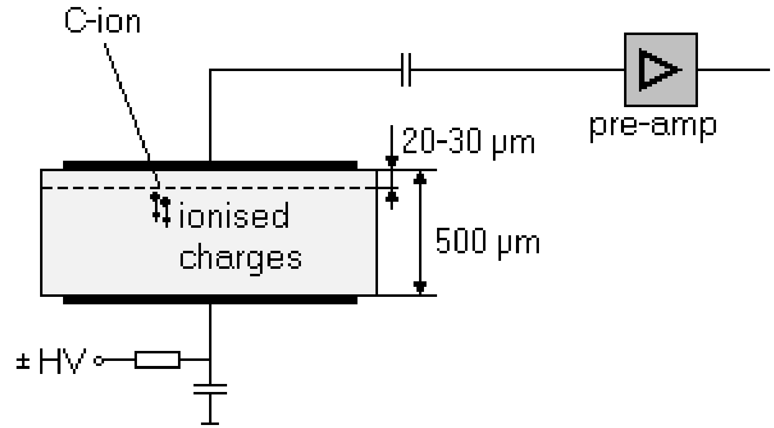
* To be installed after the linac
  -> beam energy 0.3 to 3 MeV/u

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

Diamond detector tests

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

- 2nd phase
- TOF
- cavity phase measurements

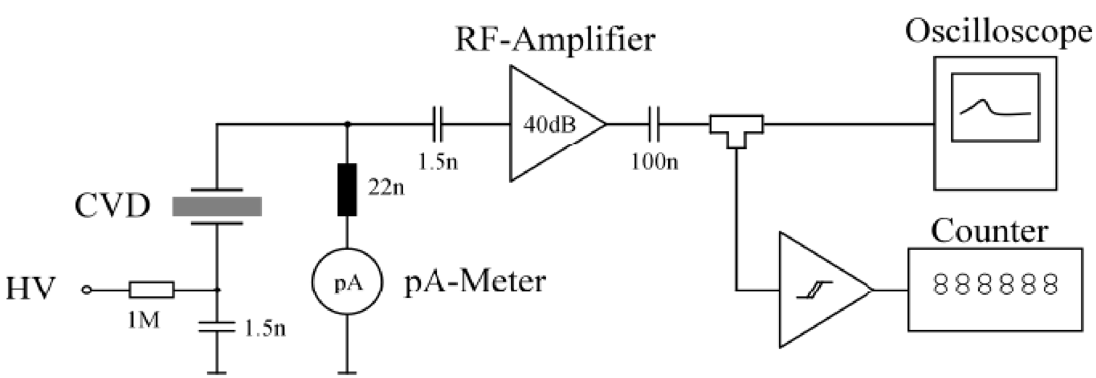


Test 'outsourced' to:
E. Griesmayer, ATLAS/CERN and
Bergoz Instrumentation, St Genis, France

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

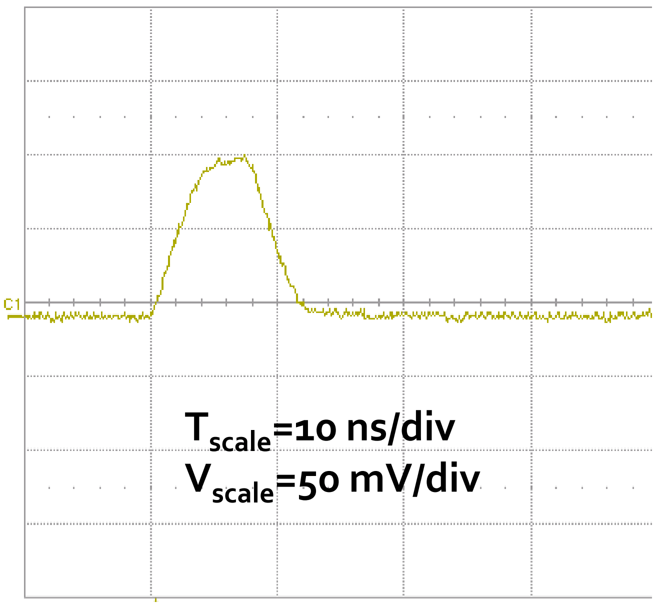
Manufacturer: Diamond Detectors Ltd
own contact layers



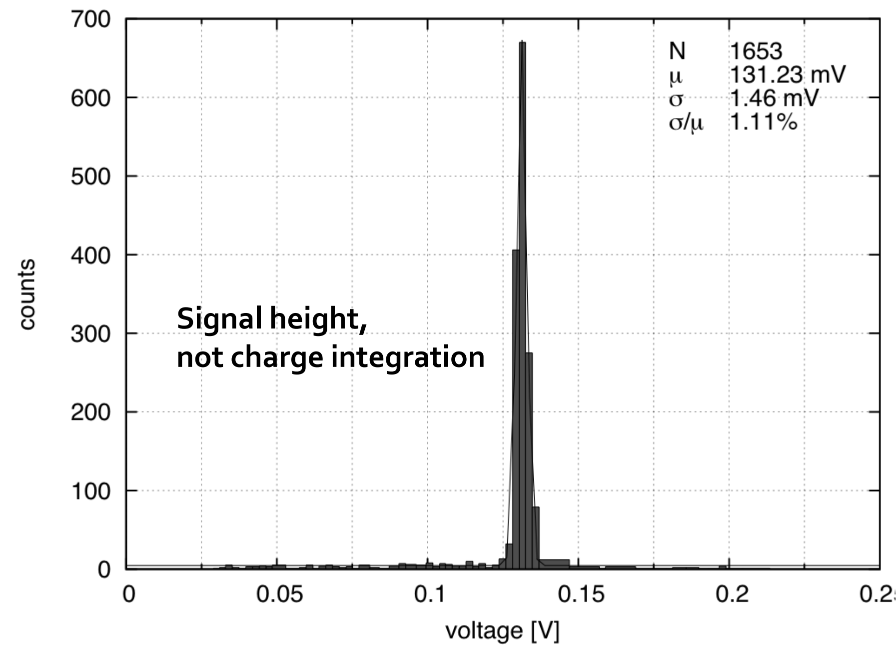
sCVD results

+ 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 mm²

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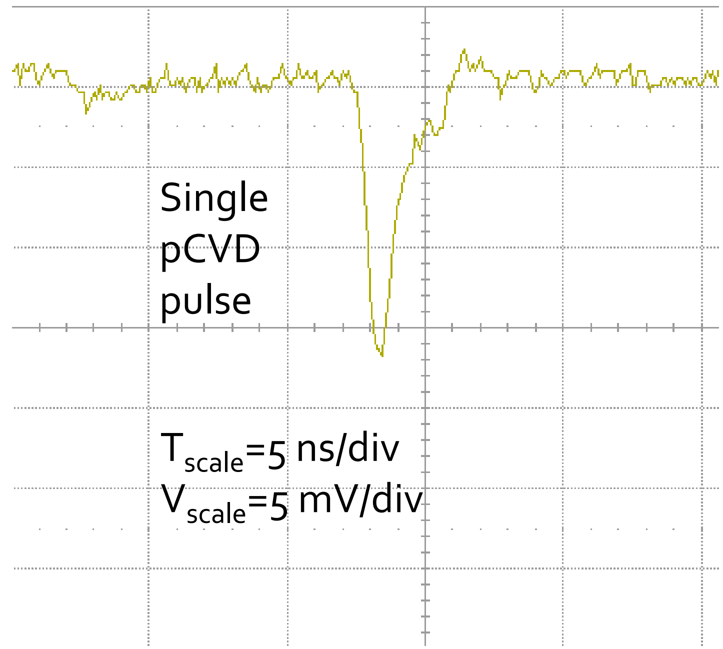
pCVD results

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
*…

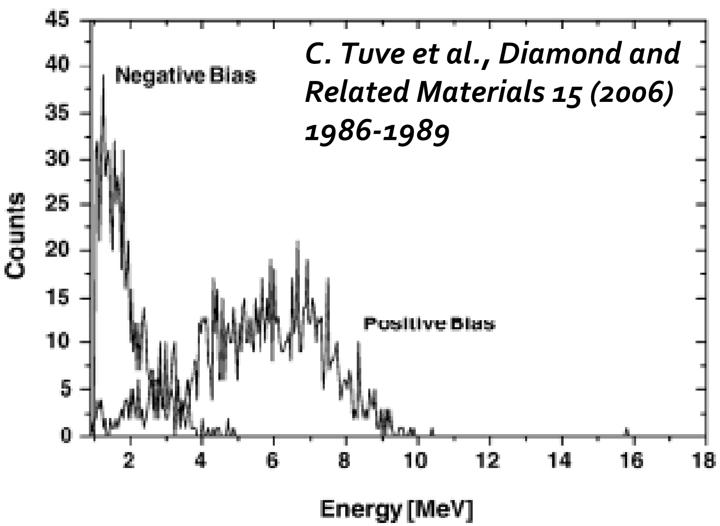


Fig. 1. Energy spectrum of a pCVD diamond detector (50 μm thick; V_{bias} = ±50 V) for ^{12}C of 16.2 MeV.

'High-Resolution Energy and Intensity…'.
E. Griesmayer et l., CERN BE Note, 2009 , tbp

Last word

Stable $^{23}Na^{+}$ cw from HRS

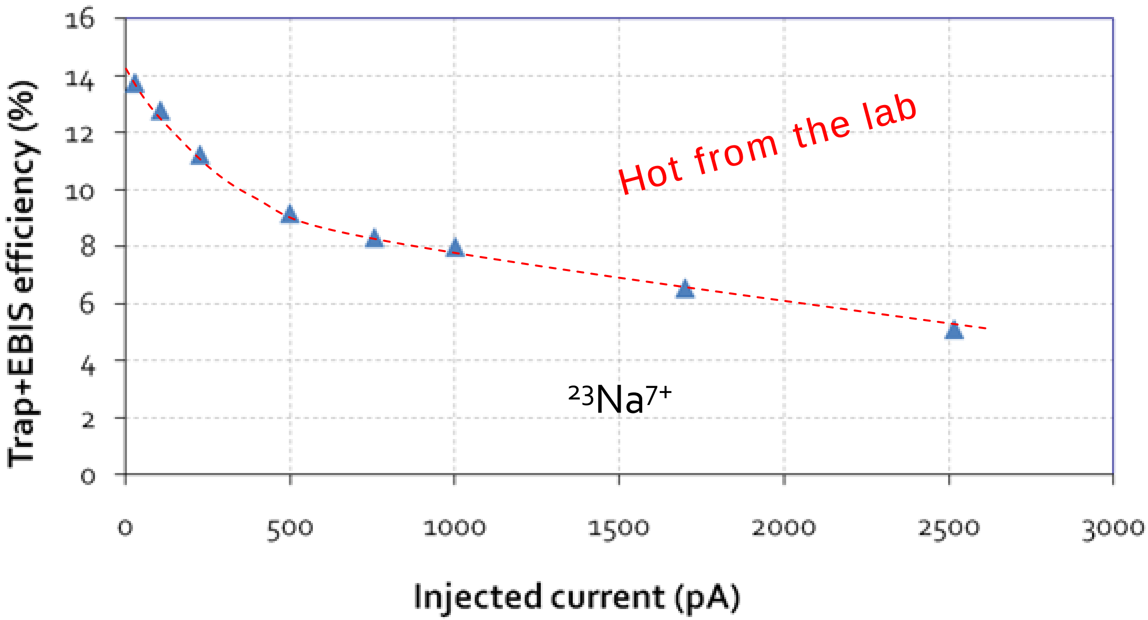
T_{period}=20 ms

$T_{breeding}$=11-13 ms

Modest ebeam current

Only adjusted ω_c

NB! M. Pasini talk on HIE-ISOLDE



Repetition rate 50 Hz:

2.5 nA ->

1.5E10 ions/s ->

3E8 ions/pulse

with > 5% eff

Worse for RI

discharges

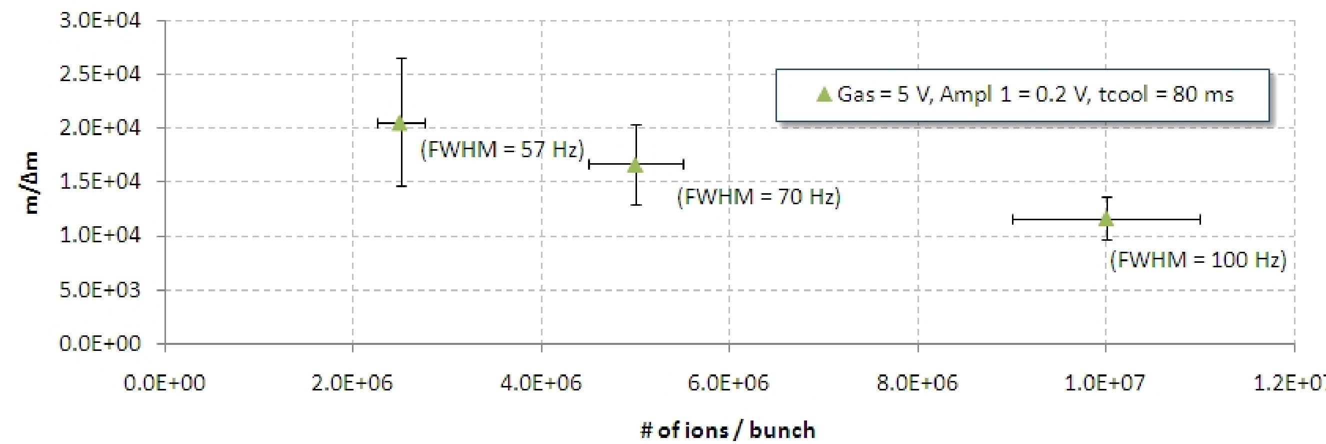
recombination

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

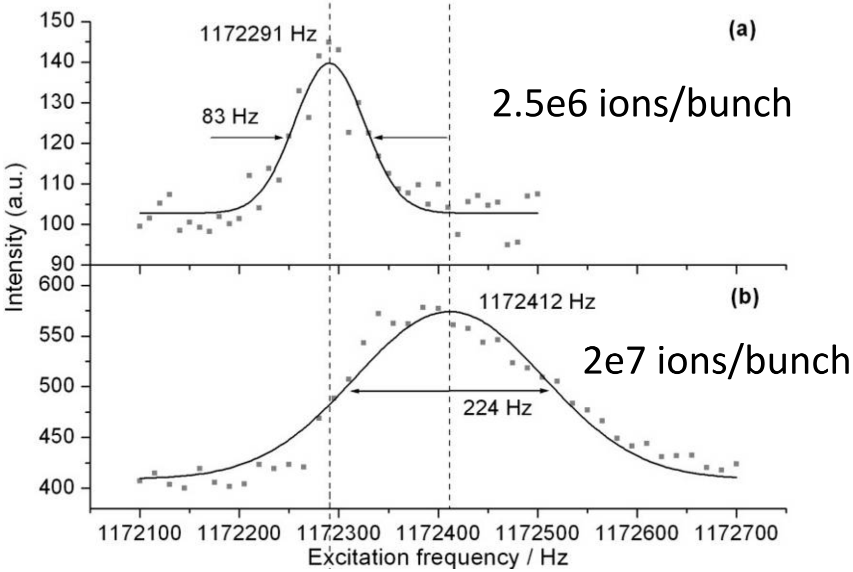
Wait for the 2nd generation!

Mass separation in REXTRAP - Space-charge effects

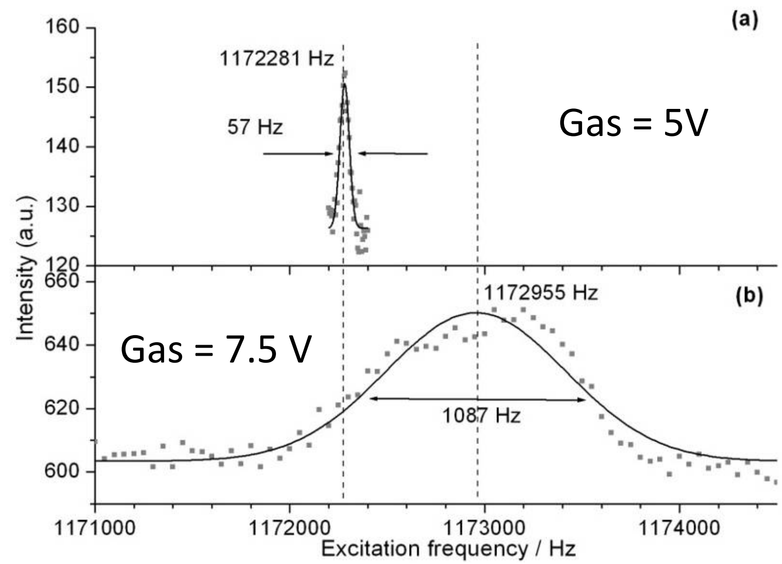
- Frequency shifts
- Peak broadening



Gas pressure control = 5 V



2.5e6 ions/bunch



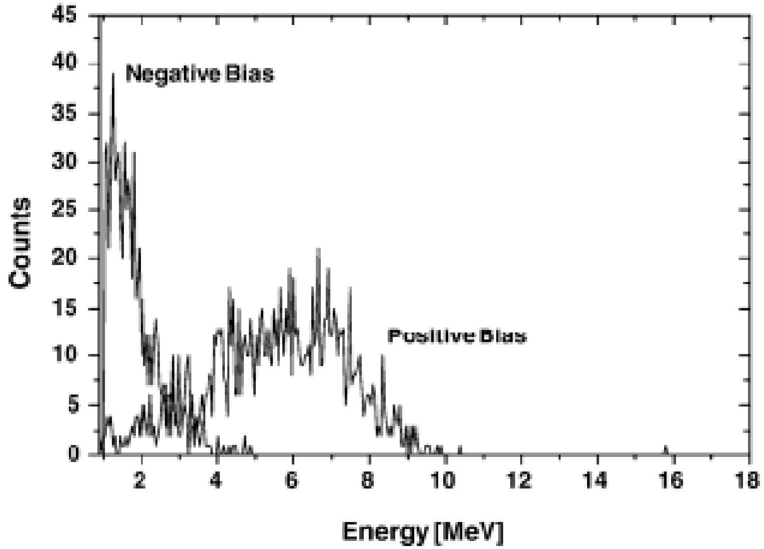


Fig. 1. Energy spectrum of a pCVD diamond detector (50 µm thick; $V_{bias} = \pm 50$ V) for ^{12}C of 16.2 MeV.

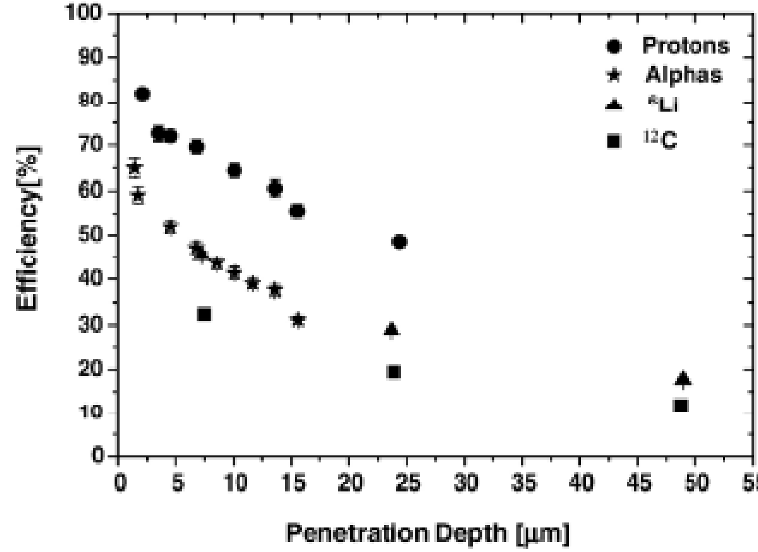


Fig. 3. The same data as Fig. 2, in positive polarity, not corrected for pulse height defect.

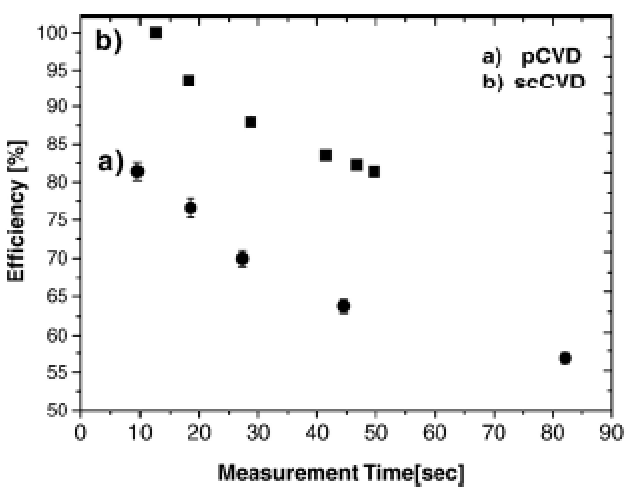


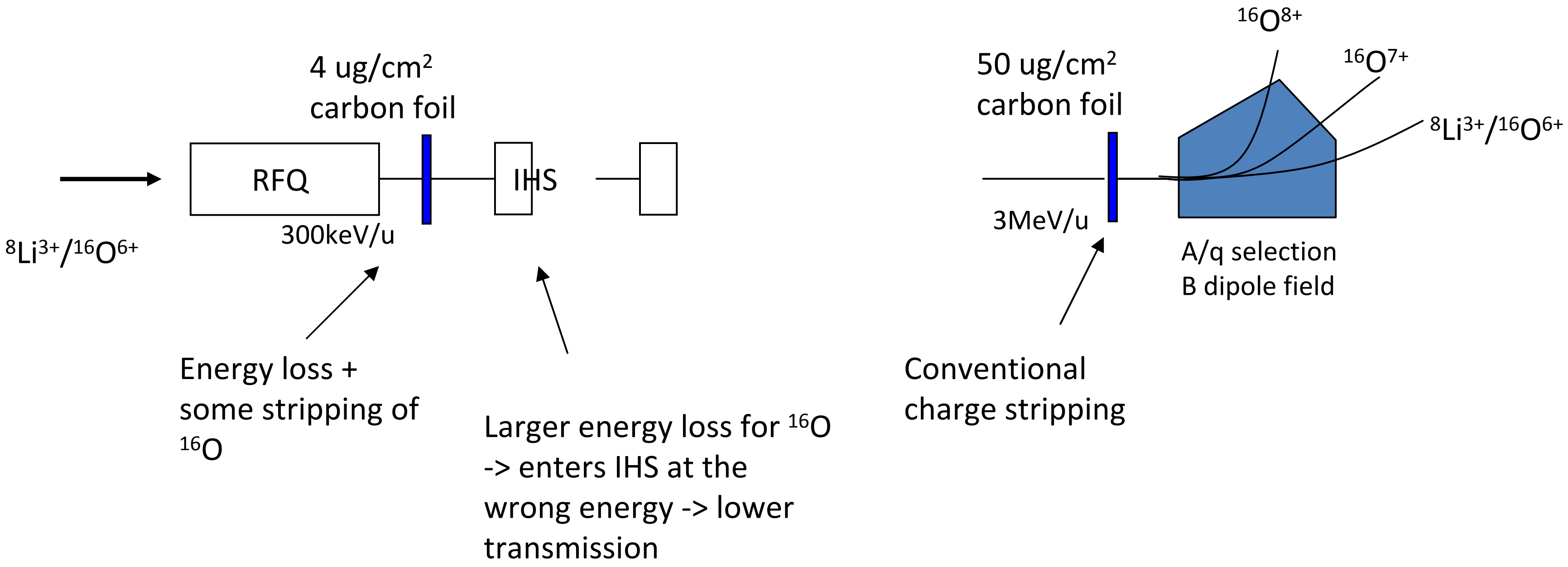
Fig. 6. Time dependence of pulse heights produced during a measurement of charge collection efficiency with protons of E_{inc}=1.5 MeV. a) for a pCVD; b) for a scCVD.

C. Tuve et al., Diamond and Related Materials 15 (2006) 1986-1989

Did we have the same for the energy measurement?

Double stripping

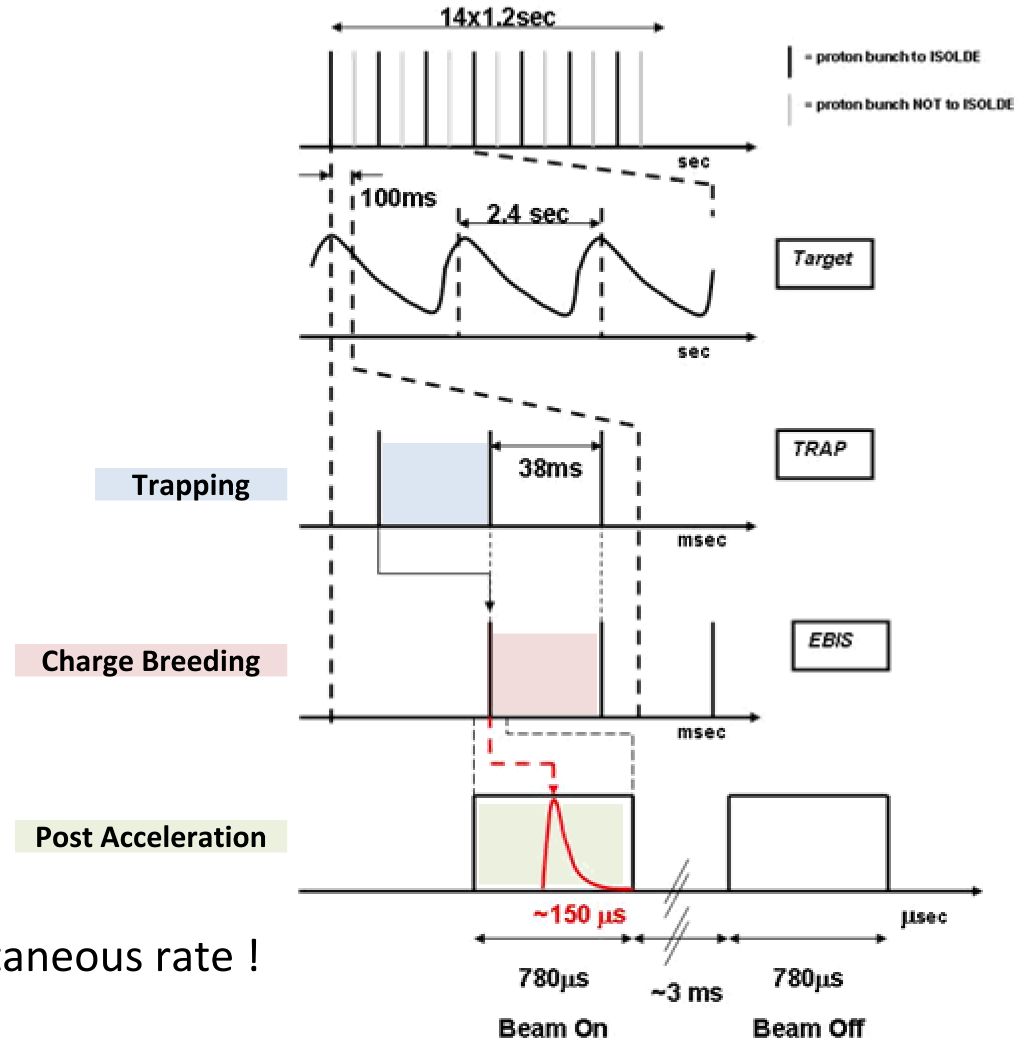
Can we make use of the different energy loss through a stripping foil to eliminate selectively heavy contaminant? (8Li run Oct. 2006)



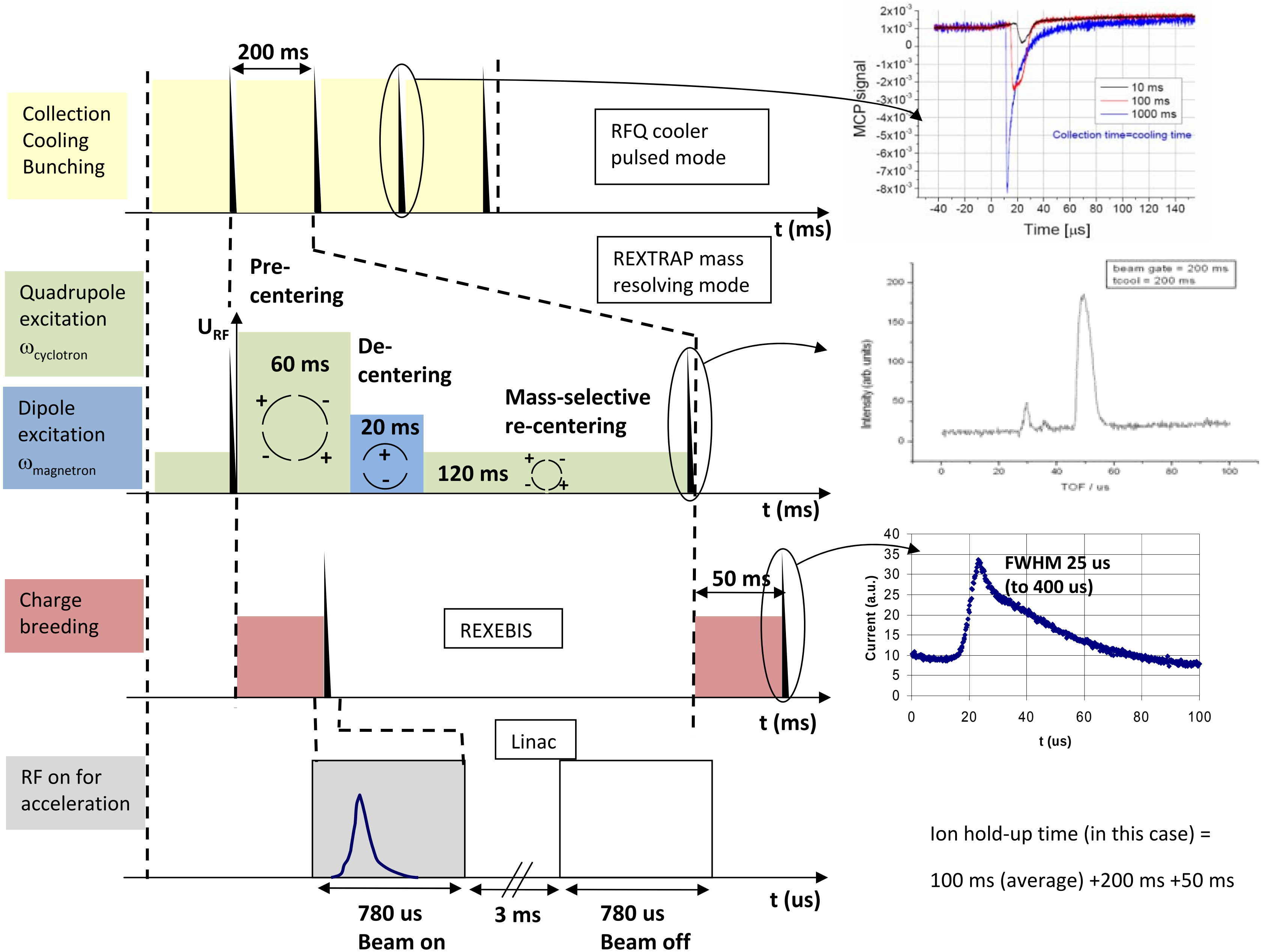
- $^{8}Li/^{16}O$ ratio increased by a factor 13 (expected a factor 3 with single stripping foil)
- Beam intensity decreased by a factor 3 -> can only be used in case of sufficiently intense beams

Time Structure

1 shift at REX = 19 min actual measuring time



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



Ion hold-up time (in this case) =

100 ms (average) +200 ms +50 ms