REX
now also heavyweight champion

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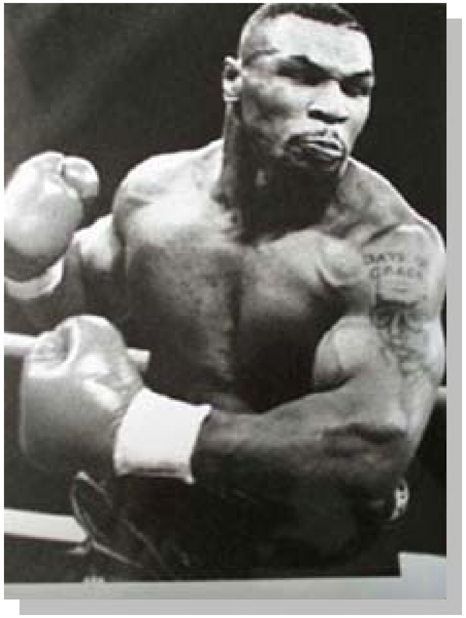
for the REX team

ISOLDE Workshop Dec 2007



Outline

1. Operation experiences 2007
2. Low energy results and hardware status
3. Linac performance and hardware modifications
4. Planned developments

REX-ISOLDE

Highlights and Hick-ups 2007

- ☺ 7/7 successful runs (accelerated beam delivered to the experiment)

  IS451, IS411, IS424, IS409, IS410, IS452, IS454

  \+ test run for BaF and SrF

- ☺ 3 new elements and 7 new radioactive isotopes post-accelerated

  $^{96}Sr^{27+}$ $^{140,142,148}Ba^{33+,33+,35+}$ $^{184,186,188}Hg^{43+,43+,44+}$

- ☺ Record heavy beams accelerated (more later)

- ☹ Beam quality not always up to expectation (more later)

- ☹ Lower efficiencies last year

	Z	N	A	q	half life	C stripper ug/cm2	stripped q	E MeV/u	breeding ms	eff. %	PSB cycle		ppp	Estimated REX yield /s
F	9	8	17	5	64.8s	50	9	2.60	18	7.5	6	12	3.0E+13	7.8E+03
Sr	38	58	96	23	1s			2.87	120	2.0				2.0E+04
Ba	56	84	140	33	12.75d			2.84	171	4.5				9.9E+06
Ba	56	86	142	33	10.7m			2.84	168	5.0				7.6E+05
Ba	56	92	148	35	610 ms			2.84	230	1.5				N/A
Hg	80	104	184	43	30.6s			2.85	170	1.7	6	12	8.0E+12	4.0E+03
Hg	80	106	186	43	1.4m			2.85	170	1.7	5	14	8.0E+12	4.0E+05
Hg	80	108	188	44	3.25m			2.85	170	1.7	5	18	8.0E+12	9.4E+05
Mg	12	19	31	9	230ms			2.99	28.5	10.0	8	19	3.0E+13	4.0E+04
Mg	12	18	30	7	335ms			2.27	15	10.0	8	19	3.0E+13	N/A
Mg	12	18	30	7	335ms			1.91	15	10.0	8	19	3.0E+13	N/A
Mg	12	18	30	7	335ms			1.56	15	10.0	18	36	3.0E+13	N/A
Mg	12	18	30	7	335ms			2.85	15	7.2	14	28	1.5E+13	1.0E+04

REX-ISOLDE

Beam comments

^{17}F – finally a success!

☺ no molecular (AlF) beam, instead atomic
^{17}F and 50 ug/cm^2 carbon stripper foil ->
$^{17}F^{5+}$ to $^{17}F^{9+}$ while ^{17}O eliminated

$^{96}Sr(F)$ - continuous injection mode into EBIS

☺ malfunctioning REXTRAP (internal discharges)
-> no bunching or cooling in REXTRAP
future operation mode with the RFQ cooler?

$^{148}Ba(F)$ – molecular sideband not always a solution

☹ molecular sideband now a standard operation
$^{148}Ba(F)^+$ beam contaminated from (mainly) $^{148}Nd(F)^+$ and $^{148}Sm(F)^+$
requires careful consideration / pre-test in the future

^{35}Ar beam to WITCH

☹ failed partly due to ^{35}Cl contamination from plasma target
(in spite of cold transfer line)
cleaning process in REXTRAP not sufficiently tested

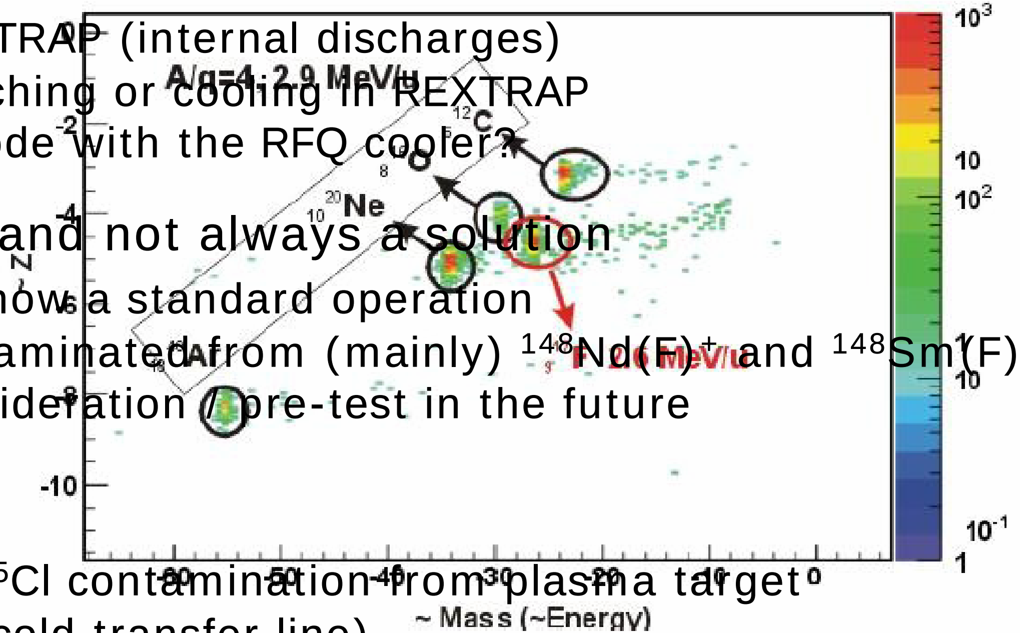
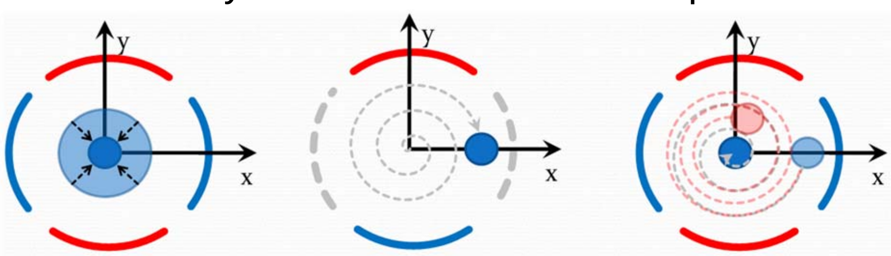


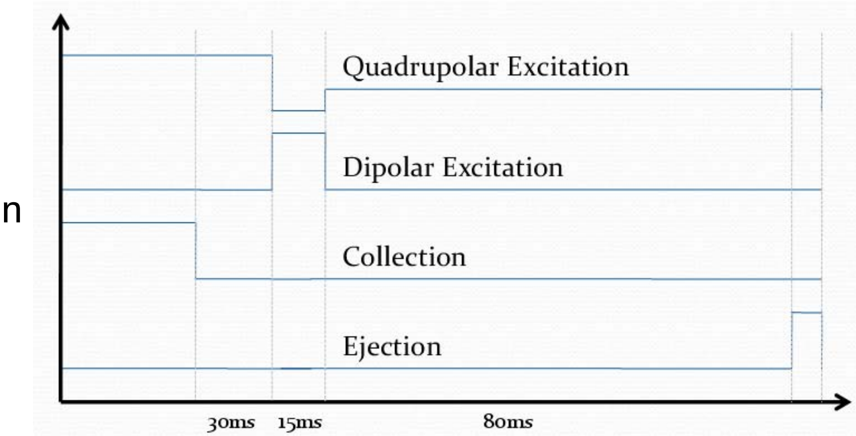
Figure 1 : Bragg spectrum taken with stable beam (A/q=4, 2.9 MeV/u) and with radioactive beam 17F(9+) at 2.6 MeV/u.

Isotopic mass separation in REXTRAP

Operation cycle for mass selection mode

- cool down the ion cloud (normal operation) then close the trap and stop collection
- shift out the ion cloud with a dipolar excitation
- selectively re-centre the desired species



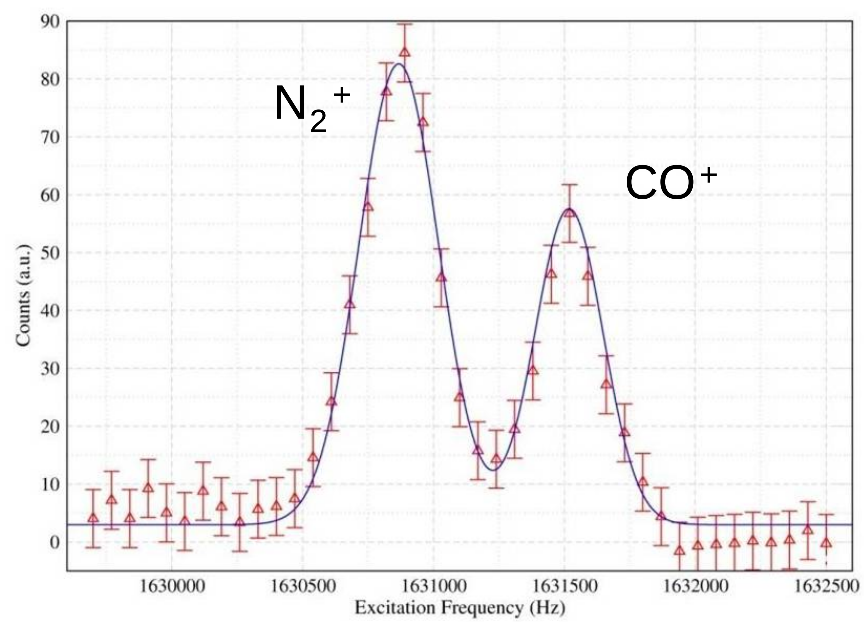


* Attainable mass resolving power 3E4

* Necessary excitation time ~100 ms (compare with lifetime)

* Efficiency / Intensity limitations <10% few pA or 10^5-10^6 ions/bunch

* Need evaluation during realistic runs – 1 extra shift setup time with protons



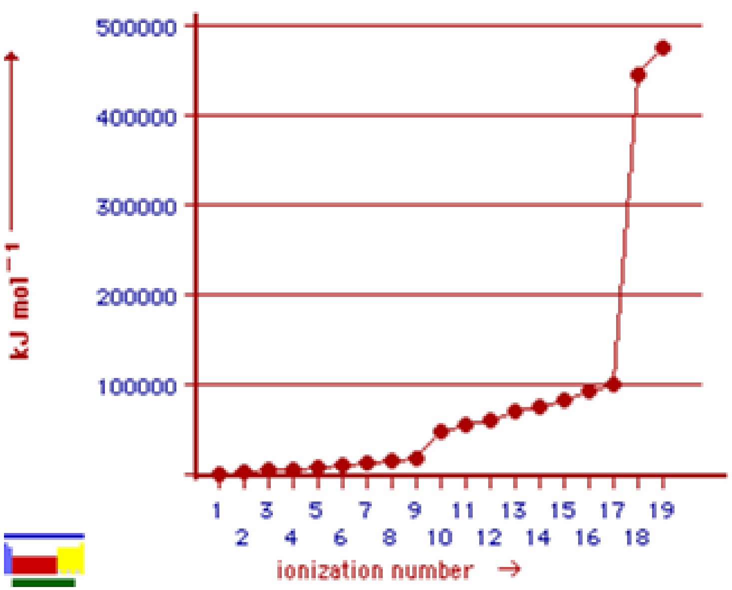
Closed shell breeding

The idea

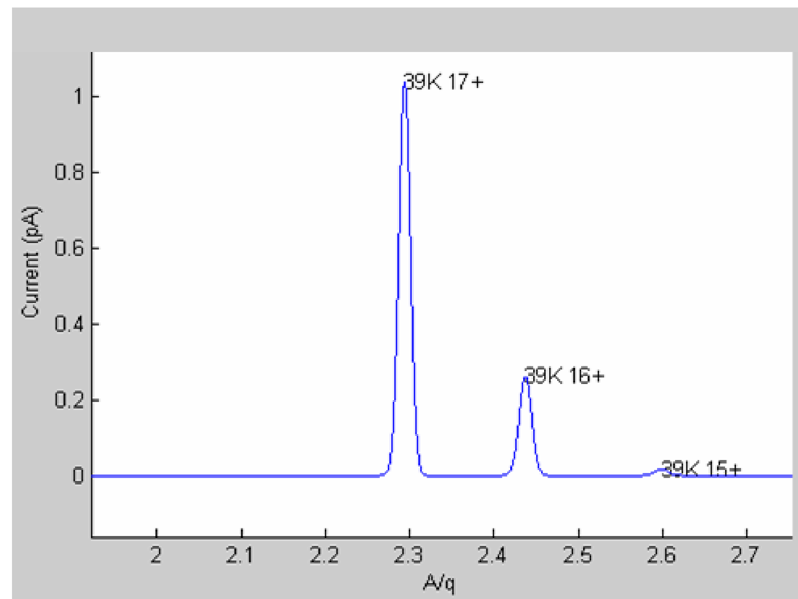
* use atomic shell gaps to reach 100% efficient charge breeding
* adjust EBIS electron beam energy < ionisation potential
* breed long and force ions into one charge state

Limitations

* only elements with shell gap around 2 – 5 keV
* competing processes (radiative recombination, evaporative ion losses)

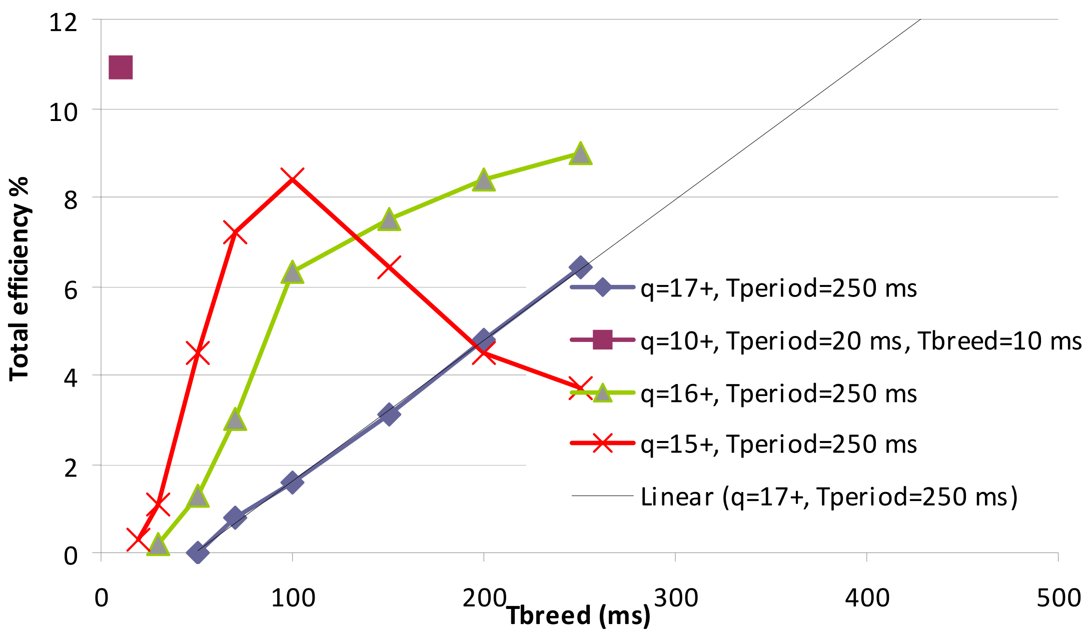


1st	418.8
2nd	3052
3rd	4420
4th	5877
5th	7975
6th	9590
7th	11343
8th	14944
9th	16963.7
10th	48610
11th	54490
12th	60730
13th	68950
14th	75900
15th	83080
16th	93400
17th	99710
18th	444870
19th	476061



Simulation: I_e=300 mA, E_e=4500 eV,
T_{breed}=250 ms, j_e=130 A/cm², K^+ ions injected

Closed shell breeding cont'd



Tested with:

$^{39}K^{17+}$

Shell structure: 2.8.8.1

I_e=300 mA

E_e=4500 eV

Results

* Longer breeding time (i.e. lower j_e(effective)) than expected

  radiative recombination?

  evaporative ion losses?

* Charge breeding efficiency lower than normal breeding

  (for reasonable breeding times)

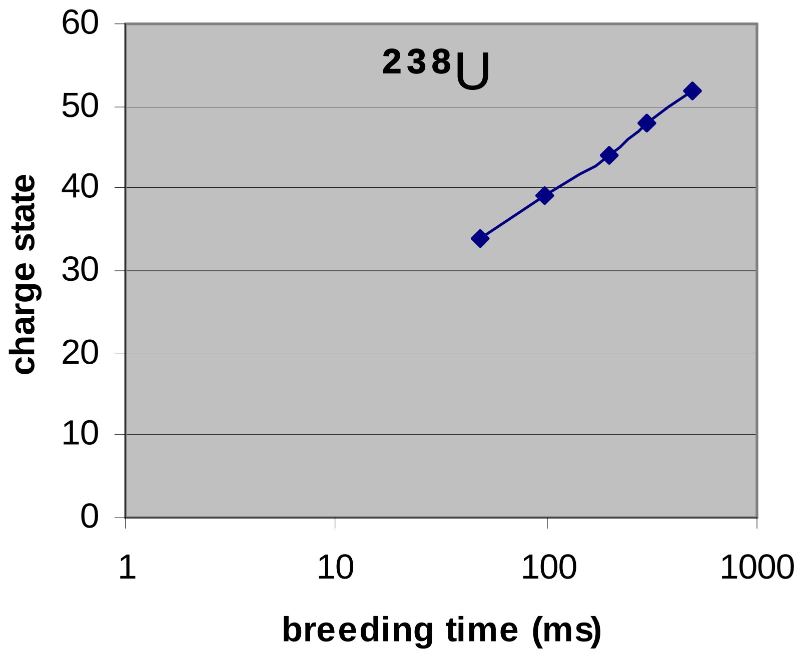
* Not an alternative for REX (except possibly for light ions)

REX-ISOLDE

Heavy beams

* REX breeder system initially designed for A<50

* Last year - proven that A~200 can be reached in some cases



* $T_{breeding}$ for $^{238}U^{52+}$ is 498 ms
add to this 500 ms cooling in the trap

* $T_{breeding}$ can possibly be reduced to 400 ms

* REXTRAP+REXEBIS efficiency 4.3%

☺ REX low energy stage now covers A=7 to 238

This year

* $^{238}U^{56+}$, A/q=4.25, T_{breed}=500 ms

* accelerated through the Linac (without 9-gap)

* very low efficiency since not optimised

REX-ISOLDE

Heavy beams cont’d

Accelerated radioactive ^{184,186,188}Hg to 2.8 MeV/u
helped by the fact that we were running neutron deficient nuclei

What is limiting?

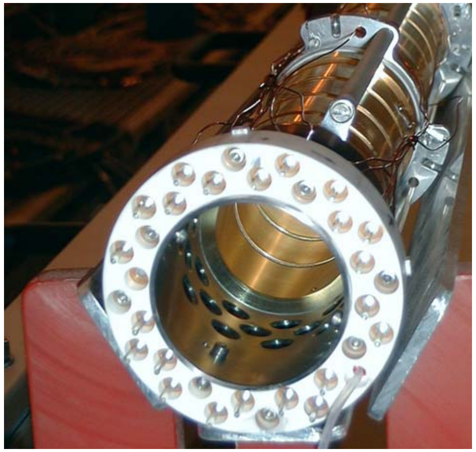
* Hardware limits
  Linac requires A/Q<4.5
  weak electron beam inside the EBIS

* Inherent problems with
  long breeding times (lumped extraction -> use slow extraction)
  low efficiency for heavy elements
    - poor ion confinement inside the EBIS
    - distribution over several charge states
  critical beam setup

REX-ISOLDE

Low energy problems

* Discharges inside the REXTRAP
  due to deposits on insulators
  partly repaired, to be rebuilt this shutdown



* REXTRAP control system stopped
  Windows patch update suspected

* Difficult start-up of the EBIS
  an ice-plug in the cryostat
  poorly performing cathode
  thereafter running smoothly

* And of course the usual / unusual:
  Beam diagnostics problems; Running in problems with new control system; Mechanical problems with tuners; Broken pumps; Large N-peaks in EBIS spectrum; Anti-resonance in trap cyclotron freq scan etc etc

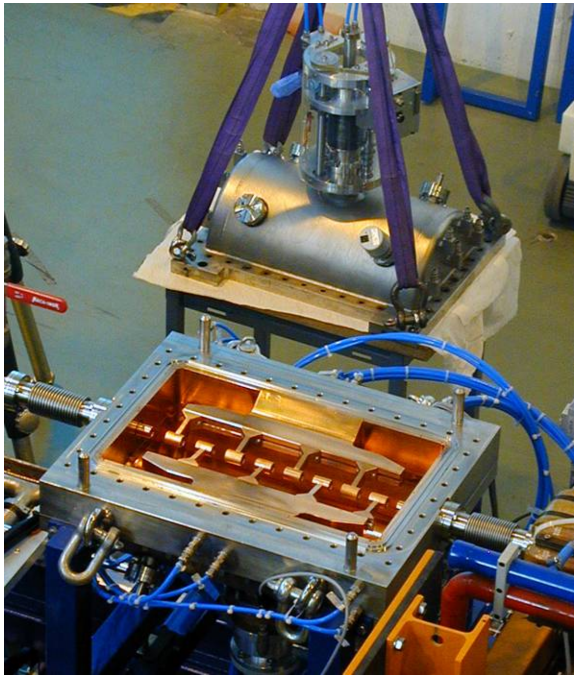
Too much power in the 9-gap!

* The 200 MHz amplifier can now provide full power
  106 kW, 100 Hz, 1 ms on dummy load

* Several runs have used the 9-gap at high power in 2007

$^{31}Mg^{9+}$	3.0 MeV/u	84 kW / 33 Hz
$^{30}Mg^{7+}$	2.9 MeV/u	88 kW / 50 Hz
$^{96}Sr^{23+}$	2.9 MeV/u	89 kW / 8 Hz

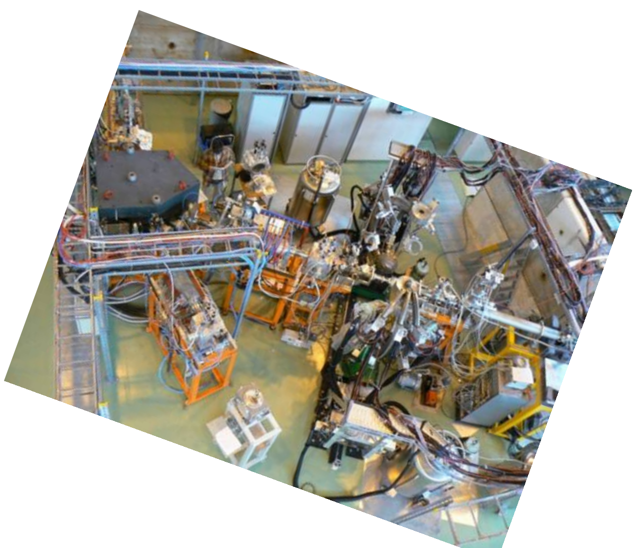
* New practical limit
  9-gap cavity cooling
  -> max 4.5 kW average



Thanks to AB/RF and Berdermann

REX-ISOLDE

Mini-move installation finished

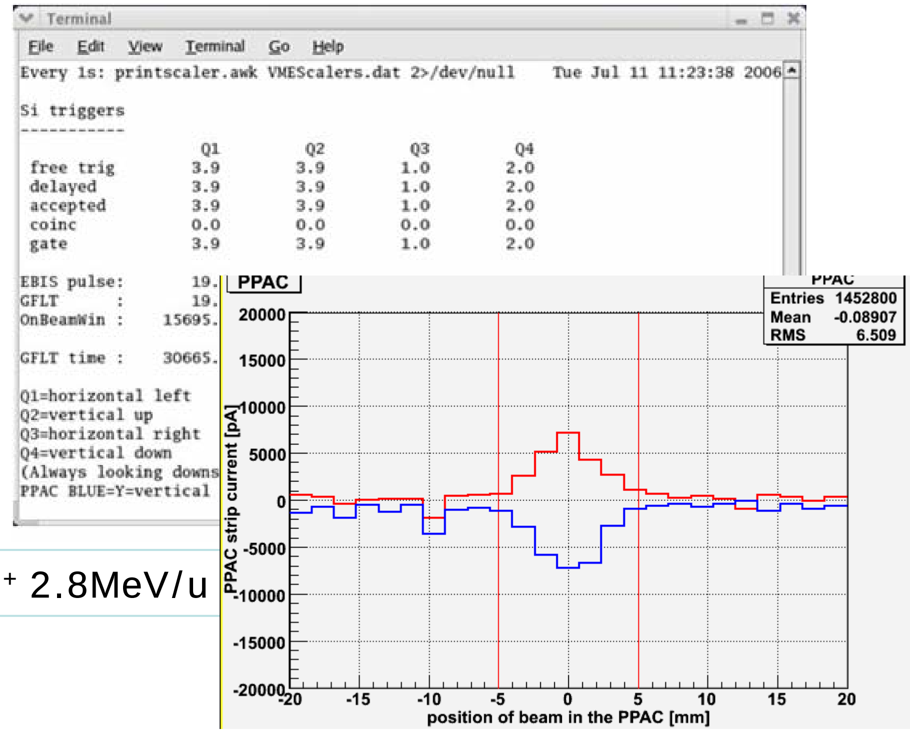


- Easier beam tuning at Miniball (more knobs, better steering)
- Increased distance and extra shielding for the X-ray background
- Realignment of the beamlines (including, 9-gap, bender, collimators...)
- Installation of reference points in the new hall for alignment
- One new beam diagnostics box installed and operational

Improved beamspot?

* Shorter set-up times and easier optimisation of the beamspot at MB

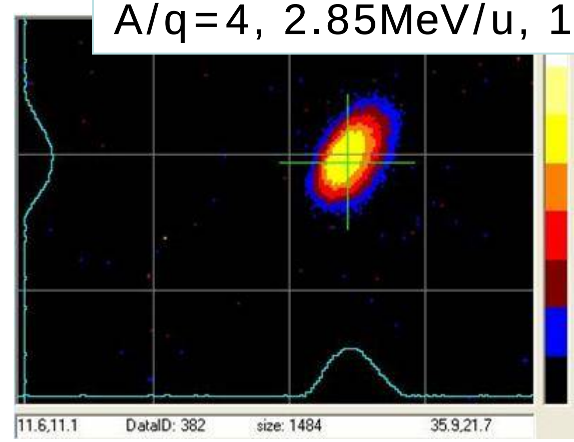
* No quantitative measurement yet (emittance measurement needed)



$^{22}Ne^{6+}$ 2.8MeV/u

Beam profile on PPAC and count rate with an empty target frame for a stable beam (several pA)

A/q=4, 2.85MeV/u, 17pA



Beam profile after the linac at max energy for a stable Ne beam

X-ray background at Miniball

☹ The background is still present in MB's spectra

better shielding and longer distance

higher amplifier power

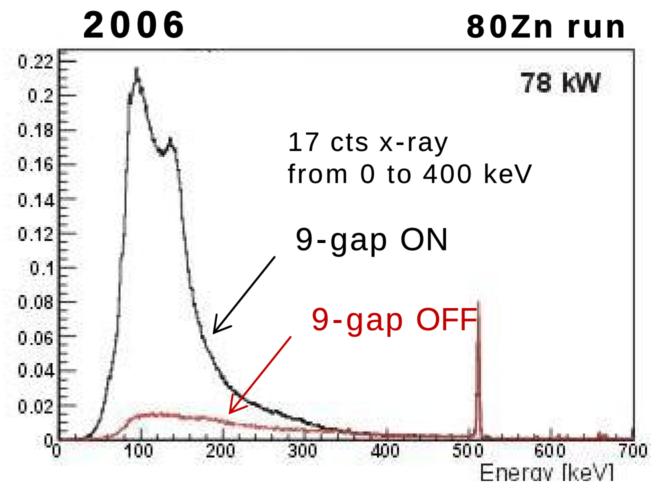
☺ The x-ray background is strongly reduced above 100 keV

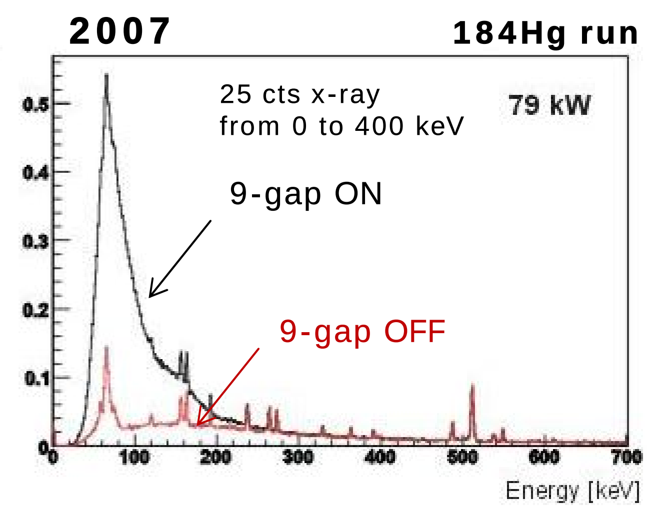
☺ The source of background is identified: mainly due to X-rays on axis and Compton scattering in the bender/beamline

Foreseen

- new shielding for the 9-gap and IHS
- lead collimators and mobile screens on the beamline after the 9-gap

Thanks to Jarno and Emanuel





Linac problems

Discharges in the IHS and buncher cavities

-> problematic for the higher A/q (max 60 kW in the IHS)

-> will be addressed during shutdown

Transport in the new beamline is too sensitive

(need steering, does not scale very well)

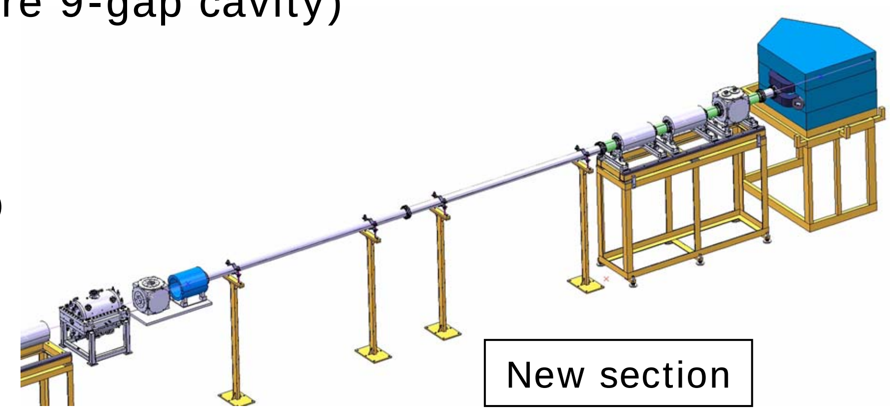
-> could be improved by modifying the optics (move one of the quadrupoles)

-> install proper magnetic steerers

-> realign the rest of the linac (before 9-gap cavity)

Possible charging-up problems in the electrostatic QP before the RFQ

-> under study...



Development schedule - low energy

1. Beam preparation with RFQ cooler

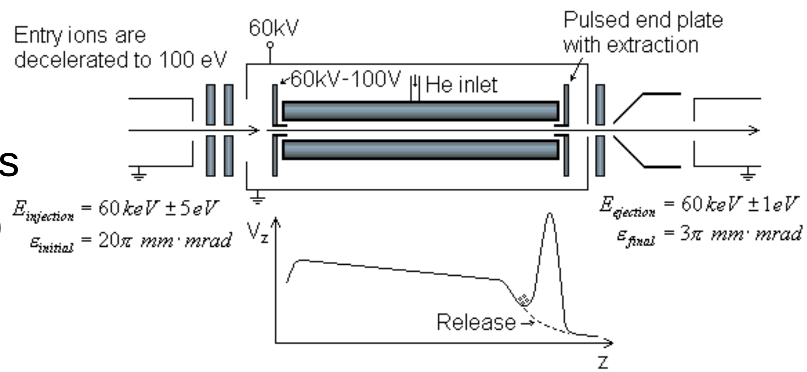
☺ try continuous injection into EBIS

(high intensity beams)

☺ equalize beam energies from plasma sources

(see also separate project by P. Suominen)

☹ difficult to replace reliable REXTRAP



2. Beam development - C, N and O beams

molecular/atomic beams from MINIMONO ECRIS

two tests failed 2007

uncertain outcome (large stable beam contaminations from the ECR)

3. Try CeB_6 cathode in EBIS

higher electron beam current?

longer life-time?

4. On-line mass resolving tests with REXTRAP

Development schedule - Linac

1. Preparation for HIE REX

   * transverse emittance at 1.2, 2,2 and 3 MeV/u

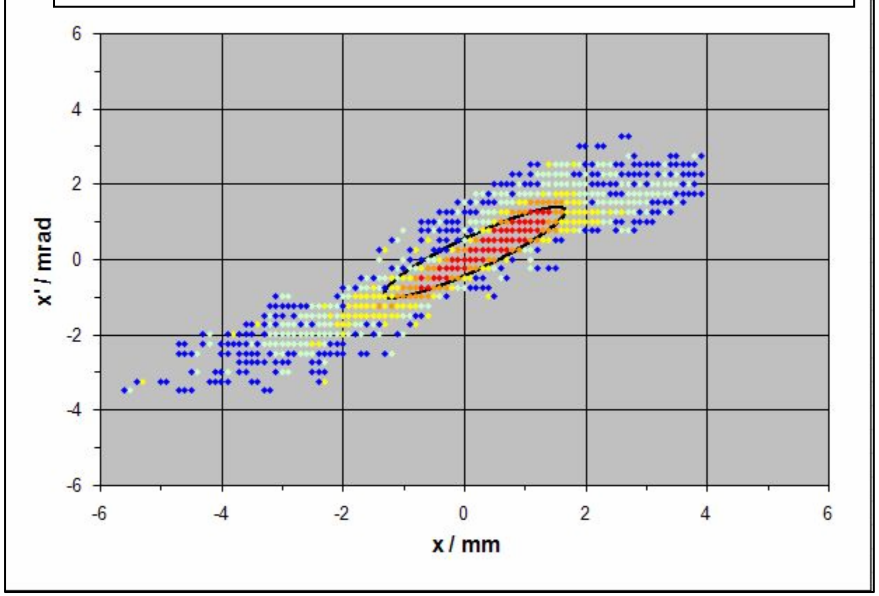
     (follow up last year’s measurements)

   * bunch length measurements

     (recuperated a Bunch Length and Velocity Detector)

   * ΔE, energy gain vs power etc

Emittance in Y after 2.5m drift
RMS = 0.051 π.mm.mrad normalised @ 2.2MeV/u



2. Accelerated polarised beams

   * use tilted foil

   * beam physics requests?

   * need external / your assistance

Time – a scarce resource

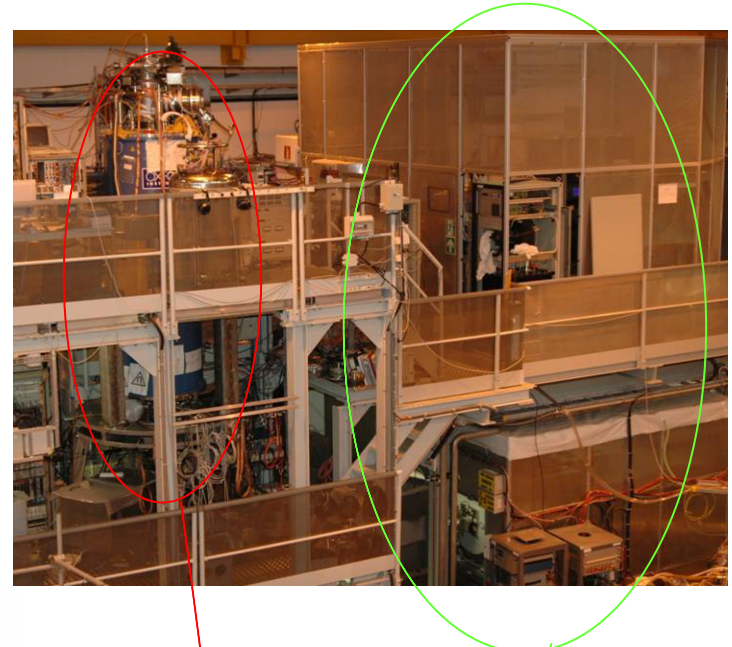
Setup time is a bottleneck

* extended REX setup time foreseen
* no night-time setups any longer

1. Parallel beams through CAO line

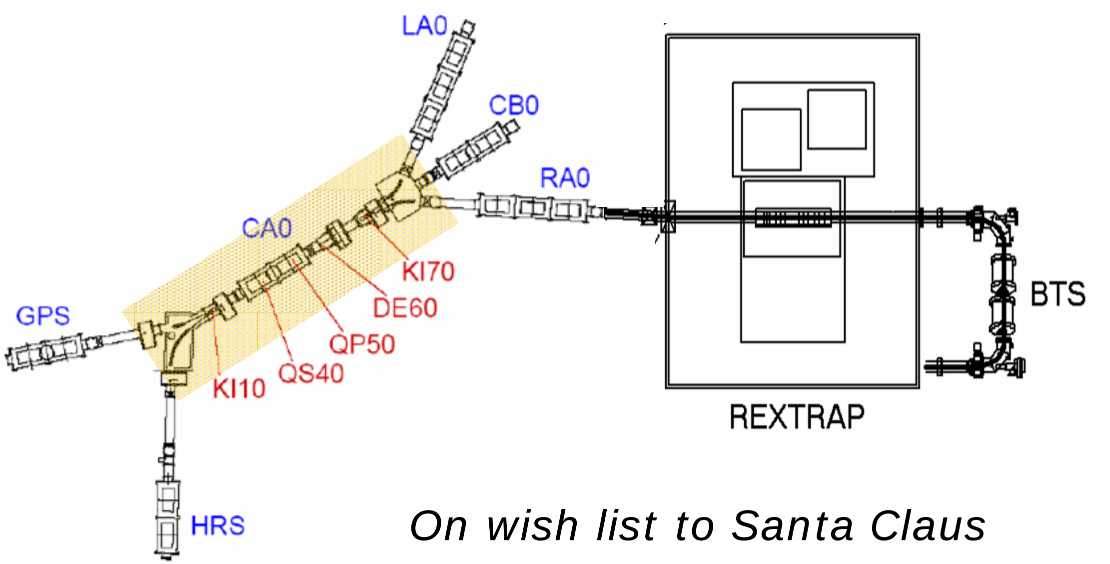
Technical feasibility study

T. Giles, sec 7.2 in ‘HIE-ISOLDE: the technical options’, CERN 2006



2. WITCH B-field

Possible to run REX with WITCH B-field on in non-critical situations (not during physics runs or beam set-up)



On wish list to Santa Claus

REX-ISOLDE

Some Practical News

For the users:

for machine details from each run, summary found at:
www.cern.ch/ISOLDE, click on REX-ISOLDE, bottom first page

report from weekly ISOLDE Technical meeting:
www.cern.ch/ISOLDE, click on Committees & Meetings

Operational changes:

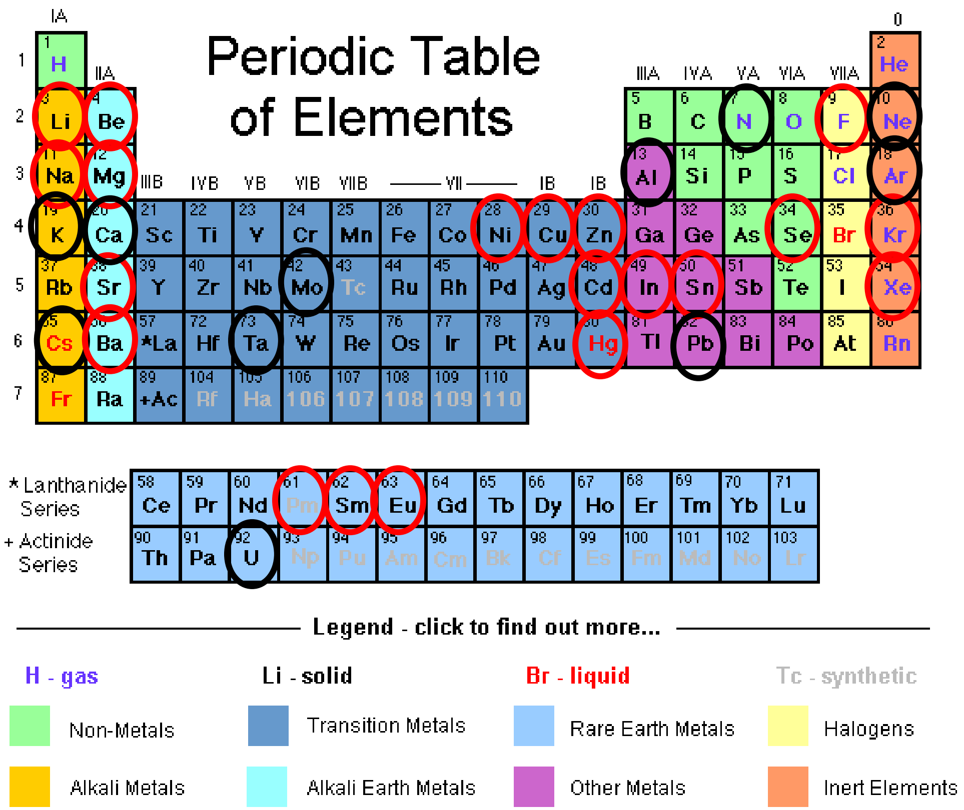
1. Transition of operation started 2007, will continue 2008
   liberate Didier (fellow) for HIE REX activities
2. Two weeks REX course for ISOLDE operators autumn 2007
3. Matteo Pasini (AB/RF) joins as Linac specialist
4. Longer scheduled setup-time foreseen for 2008
5. Specialist supervision scheme or not?

Students for mass resolving tests, in-trap decay and polarised beams most welcome!

REX-ISOLDE

The REX smörgåsbord...

^{8,9,11}Li
^{10,11,12}Be
^{17}F
^{24,25,26,27,28,29}Na
^{28,29,30,31,32}Mg
^{68}Ni
^{67,68,69,70,71,73}Cu
^{74,76,78,80}Zn
^{70}Se
^{88,92}Kr
^{96}Sr
^{122,124,126}Cd
^{108}In
^{106,108,110}Sn
^{138,140,142,144}Xe
^{140,142,148}Ba
^{148}Pm
^{153}Sm
^{156}Eu
^{184,186,188}Hg



53 radioactive isotopes of 20 elements

A selection of charge bred stable elements