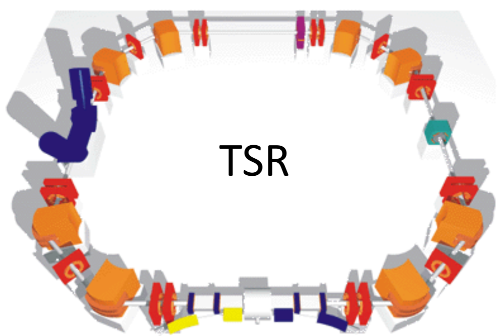
TSR@ISOLDE



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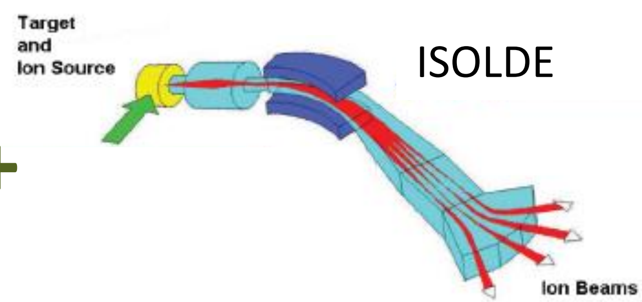


= True?

Fredrik Wenander, NUSTAR workshop 7/3-2014

High-energy and low-energy storage rings

Storage Rings for Physics with Exotic Nuclei

Easy access to highest charge states

High-energy

- **ESR @ GSI**
- **CSRe @ IMP**

- **RI-RING @ RIKEN**
- **CR @ FAIR**
- **HESR @ FAIR**

- **NESR @ FAIR**
- **RESR @ FAIR**
- **HIAF**

Low-energy

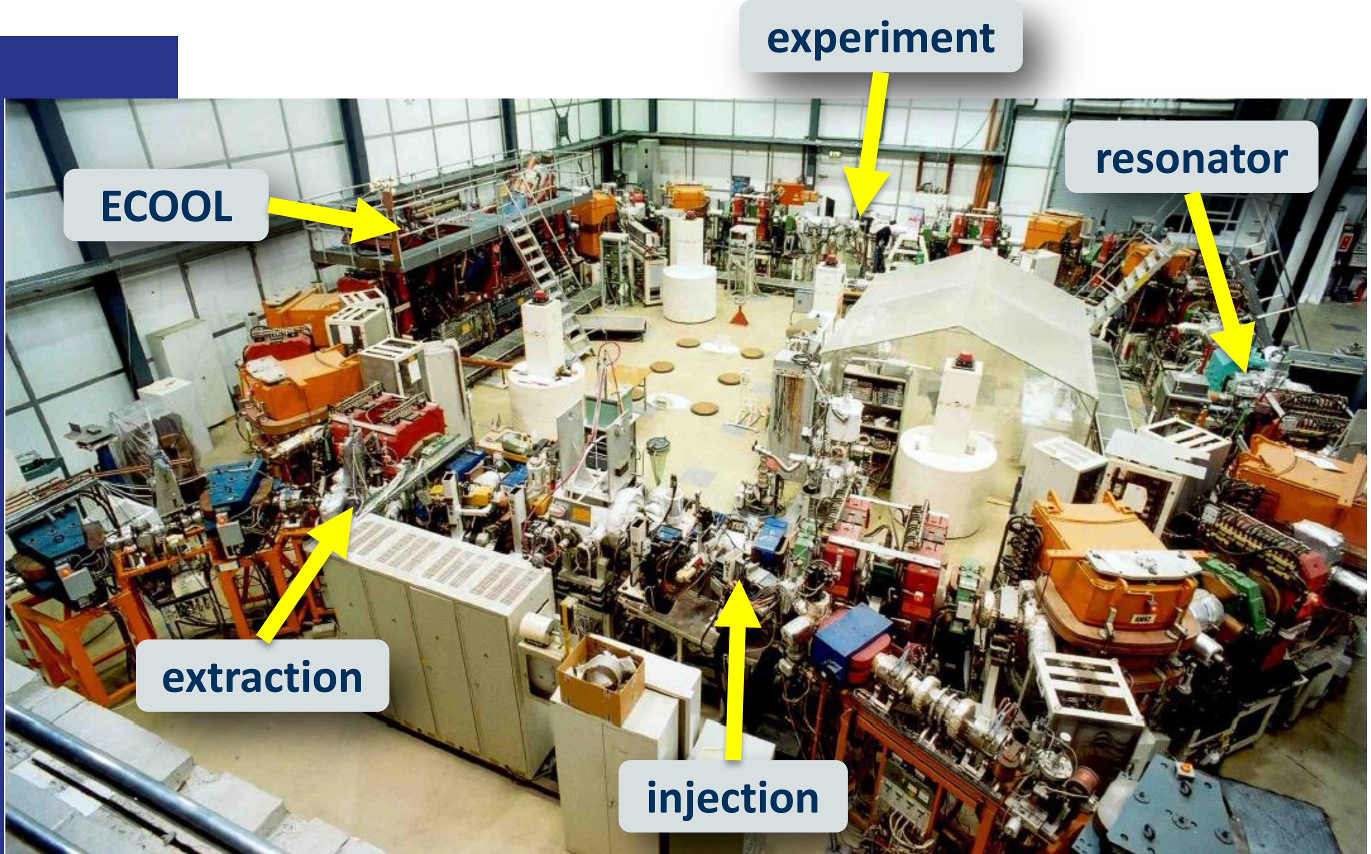
- **TSR @ ISOLDE**
- **CRYRING @ ESR**

RI beams originates from opposite side of the energy spectrum

Highly-charged ions at low-energies

Courtesy Y. Litvinov

Test Storage Rings at Heidelberg



Courtesy MPI-K

* In operation since 1988

* Mainly for atomic physics studies and accelerator development

* One nuclear physics experiment – FILTEX (internal polarized H_2 gas target)

Circumference: 55.42 m
Vacuum: ~few 1E-11 mbar
Acceptance: 120 mm mrad

Multiturn injection: mA current
Electron cooler: transverse T_{cool} in order of 1 s
RF acceleration and deceleration possible
Typical energy $^{12}C^{6+}$: 6 MeV/u

www.mpi-hd.mpg.de/blaum/storage-rings/tsr/index.en.html

A storage ring at an ISOL facility

Advantages

Compared to in-flight storage rings

- Higher intensity
- Cooler beams / Shorter cooling time

Compared to direct* beams

- Less background
  (target container, beam dump)
- Improved resolution
  (smaller beam size, reduced energy straggling in target)
- CW beam
- Luminosity increase for light beams

* reaction experiments with non-circulating, ‘thick’ target after linac

Physics programme

Astrophysics

- Capture, transfer reactions
- ^{7}Be half life

Atomic physics

- Effects on half lives
- Di-electronic recombination

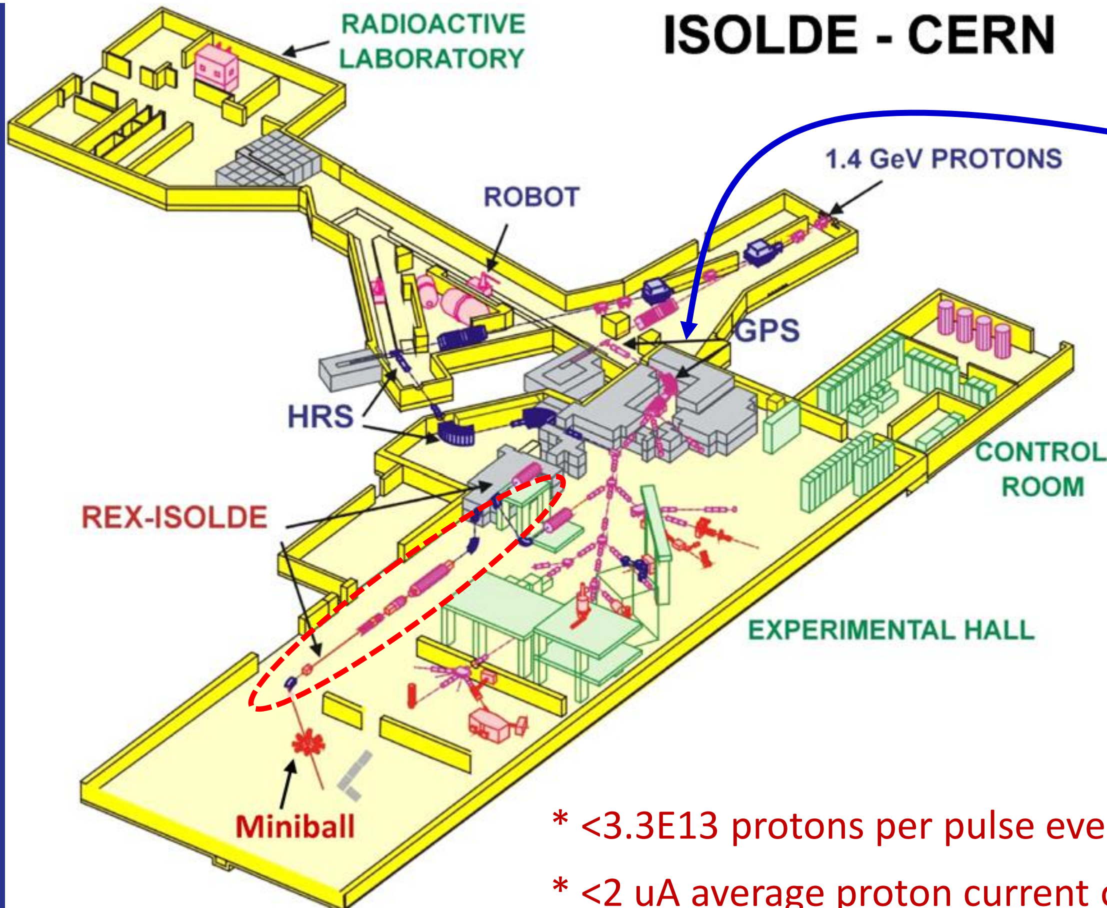
Nuclear physics

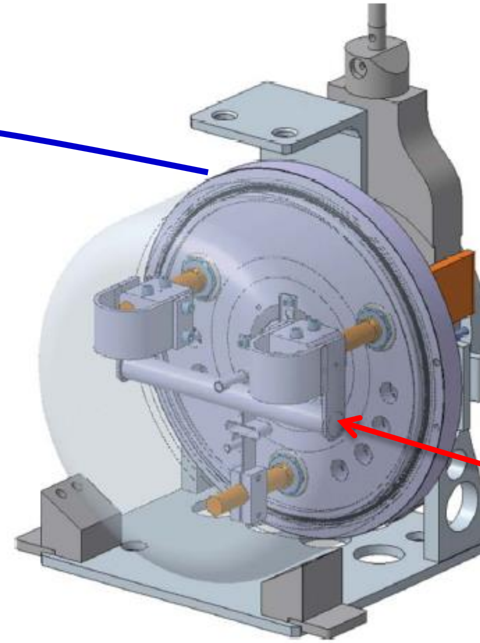
- Nuclear reactions
- Isomeric states
- Decay of halo states
- Laser spectroscopy

Neutrino physics

The injector

ISOL basics

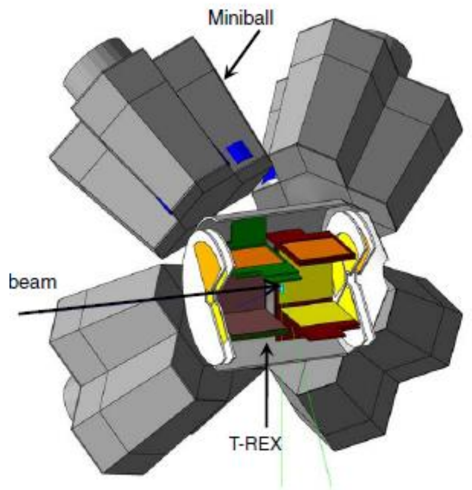




Standard ISOLDE target unit
(courtesy S. Marzari)

* <3.3E13 protons per pulse every N*1.2 s (N=1,2,3…)
* <2 uA average proton current on the target
* Target material: UCx, SiC, CaO, YO, molten Pb etc
* Material diffusion, effusion and sticking time govern the release time
* Magnetic separator

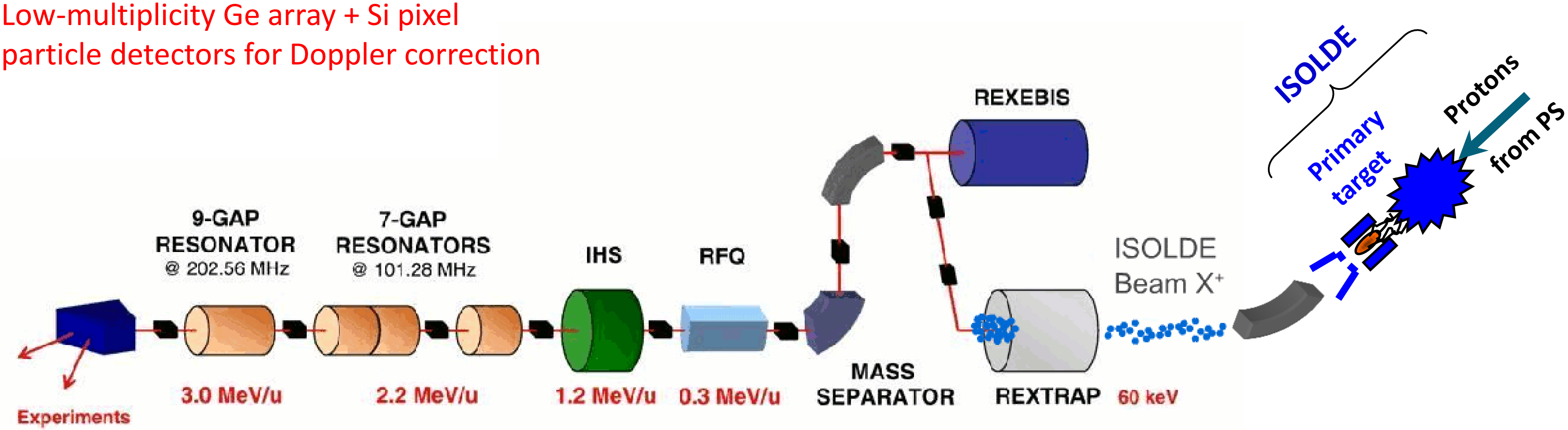
HIE-REX post-acceleration



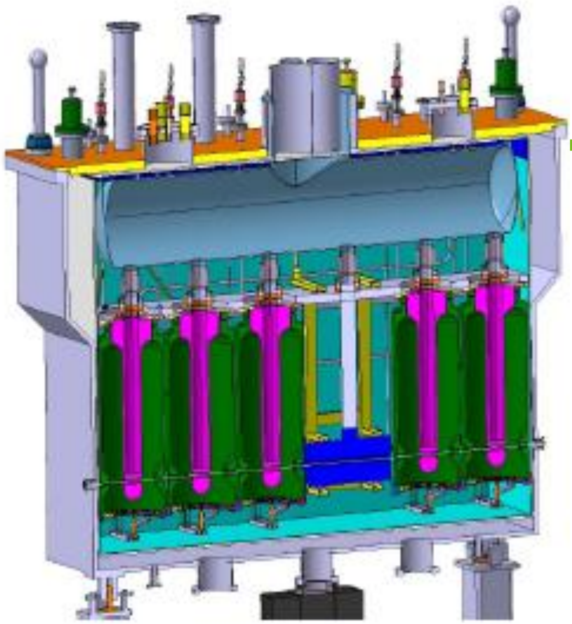
- Energy boost from 60 kV to few MeV/u
- He to U
- Few ions/s to 10^9 ions/s
- Repetition rate 2 Hz to 50 Hz

Miniball

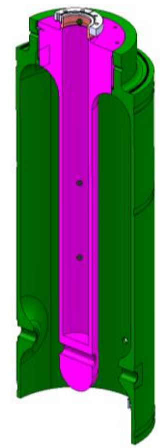
Low-multiplicity Ge array + Si pixel particle detectors for Doppler correction



HIE-REX post-acceleration



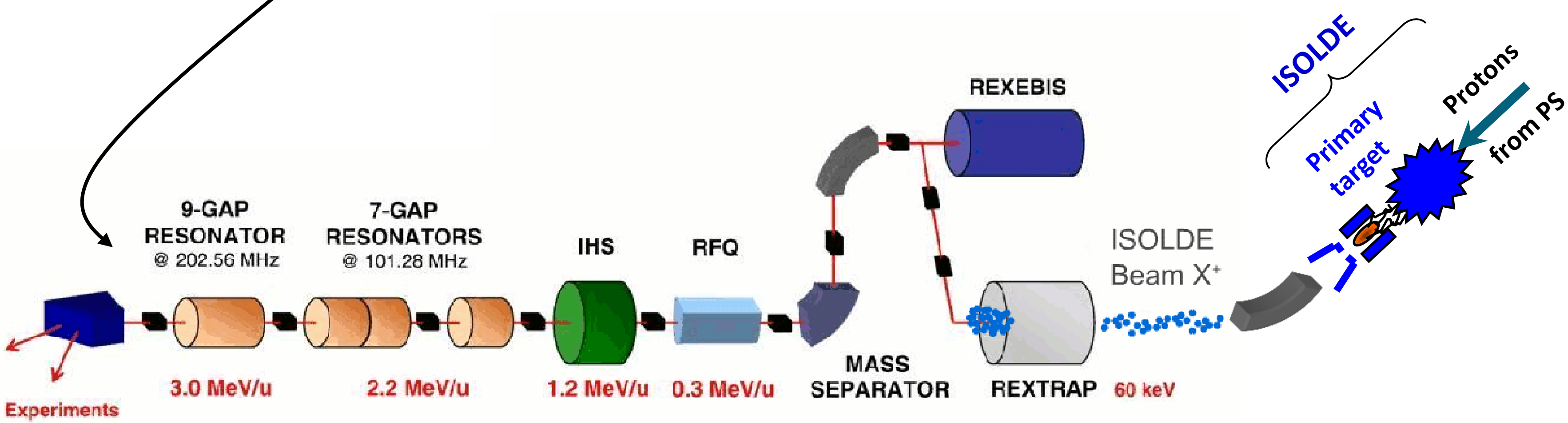
Cryostat with 5 high-β cavities and 1 SC solenoid



Nb sputtered QWR
High-β cavity

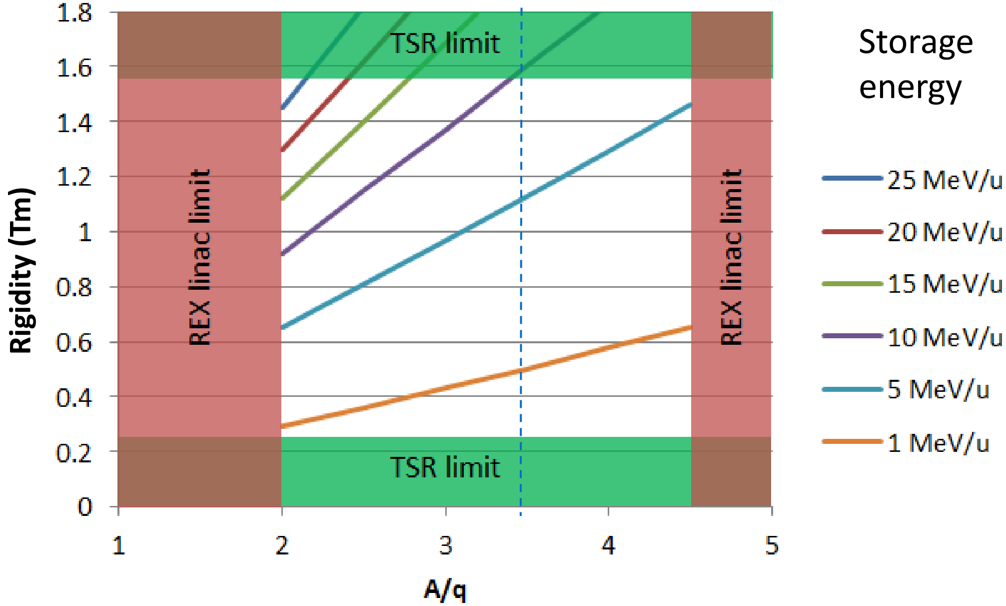
- 32 SC QWR (20 @ β_0=10.3% and 12@ β_0=6.3%)
- Energy fully variable; energy spread and bunch length are tunable. Average synchronous phase ϕ_s= -20 deg
- 2.5<A/q<4.5 limited by the room temperature cavity
- 16.02 m length (without matching section)

Courtesy HIE-ISOLDE Linac working group



Machine performance

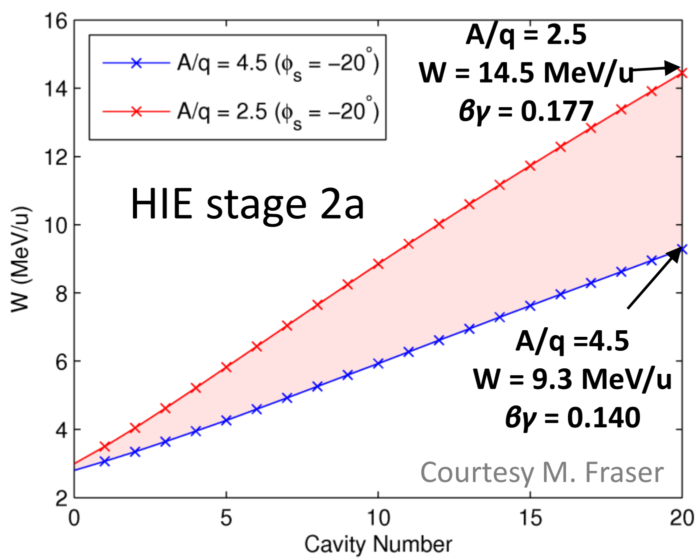
Ring beam energy



TSR magnetic rigidity range: 0.25-1.57 Tm

REX linac 2<A/q<4.5

Lifetime studies and nuclear structure studies using decay at 5 MeV/u



☺ Beam can be accelerated (and decelerated) inside the ring

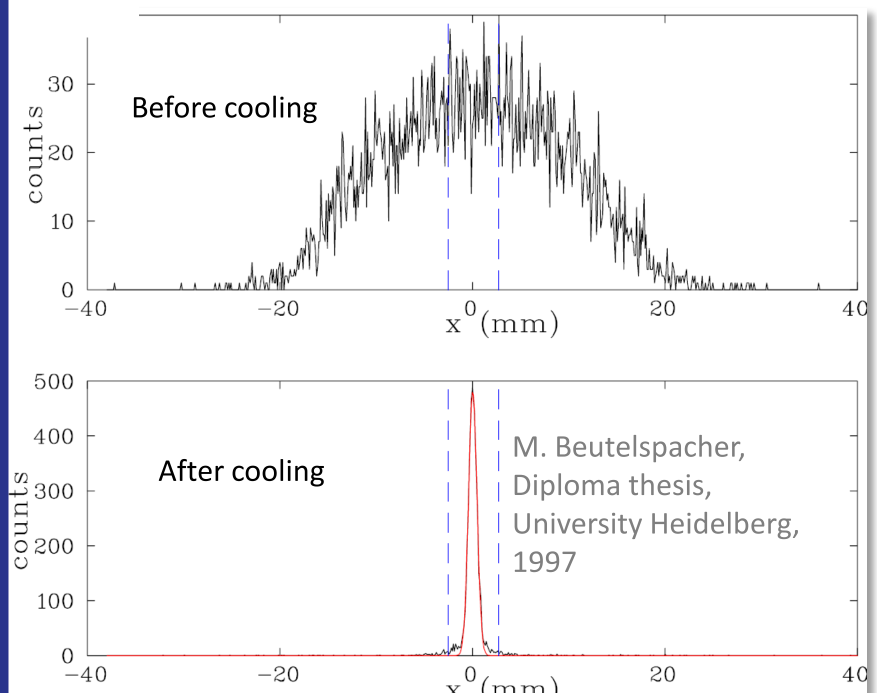
☹ Takes several seconds though

e-cooling

E-cooling needed for:

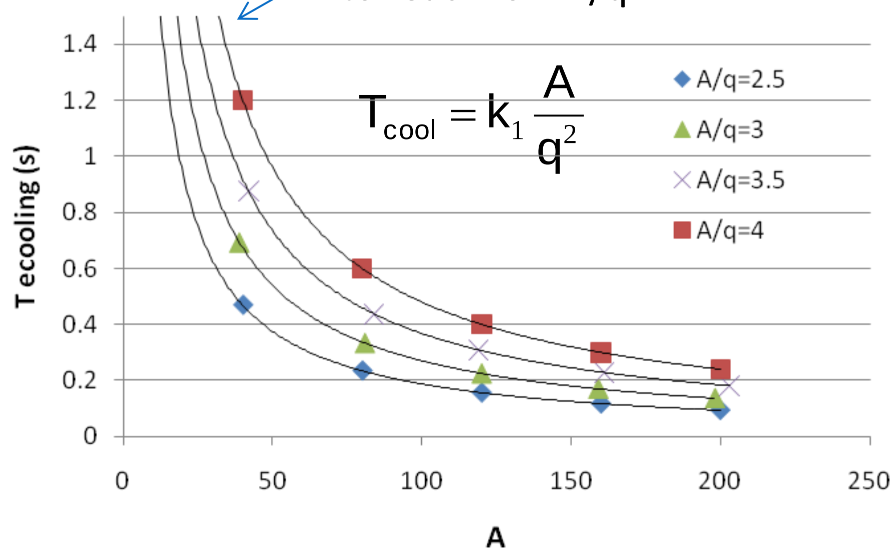
1. Reducing momentum spread
2. Stacking of multi-turn injection
3. Compensate for energy loss in target
4. Reducing beam size

$\Delta p/p$ ~ 5E-5 (rms)
$\Delta p/p$ < 1E-5 (rms) for N<1000



Radial beam extension

Light elements easiest to reach low A/q

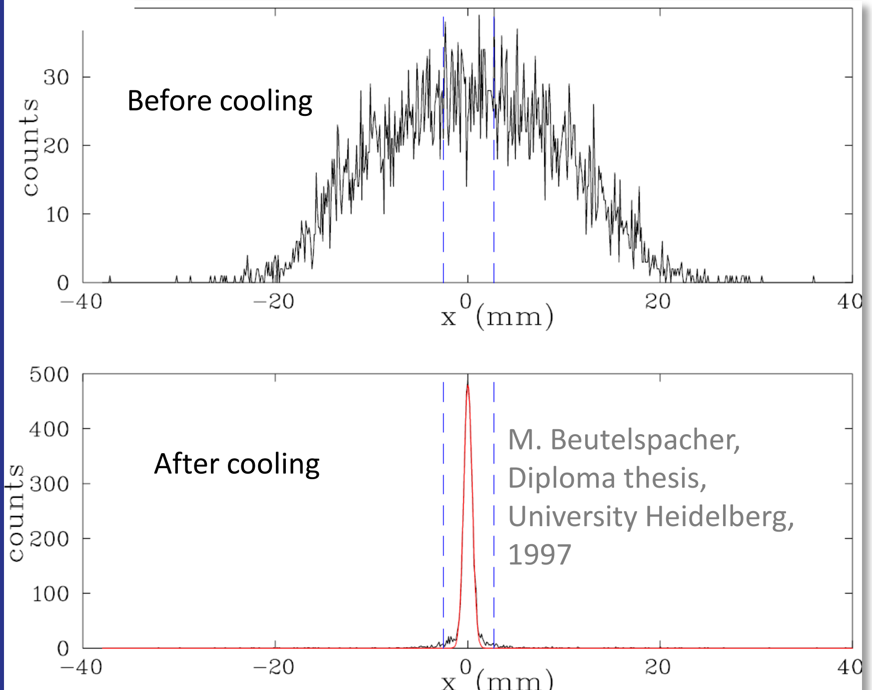


T_{cool} – horizontal cooling time for beam with large diameter

e-cooling

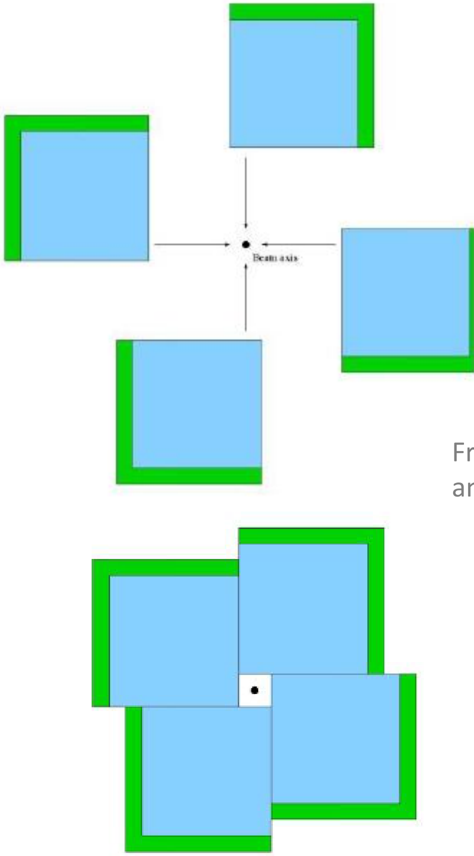
E-cooling needed for:

1. Reducing momentum spread
2. Stacking of multi-turn injection
3. Compensate for energy loss in target
4. Reducing beam size



Radial beam extension

Assembly of 4 movable DSSD positioned up- or downstream of target point



From T. Davinson and P. Woods

In-ring experiments[1]

* SAS allows for either **electron, gas-jet or no target** to be installed.
* Experimental setups installed on precision rails, moveable in and out from ring.

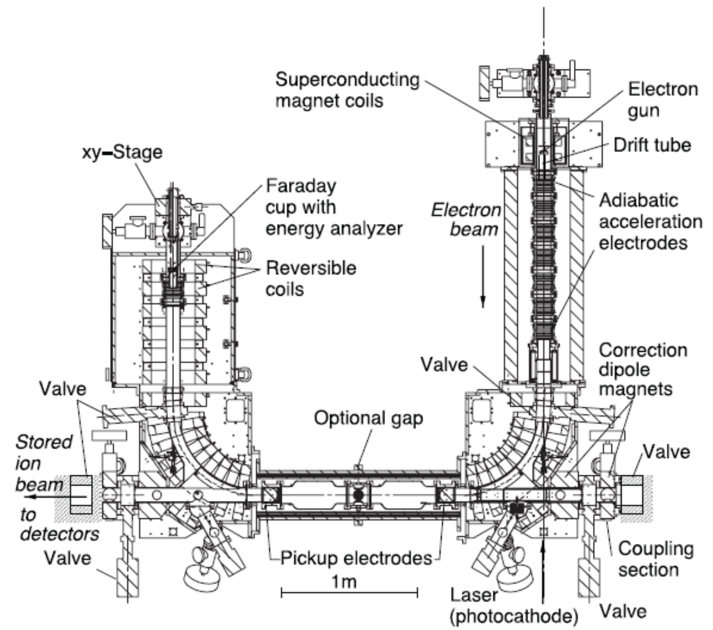


Fig. 83. ETS magnetic and vacuum system in the thermocathode configuration [170].

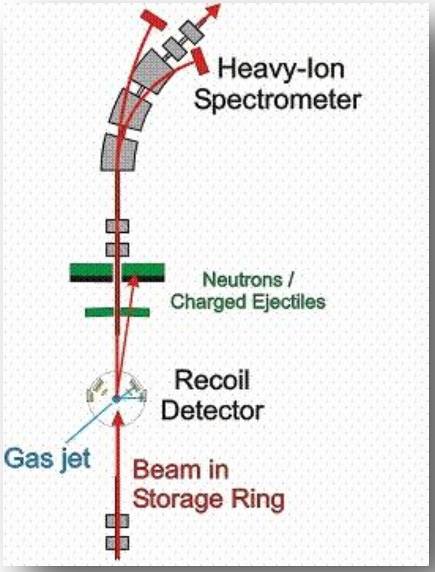
Electron target section

* Existing, delivered to CERN
* Offers an independent merged cold electron beam dedicated for collision studies

1. See M. Grieser et al., EPJ Special Topics May 2012, vol 207, Issue 1, pp 1-117

In-ring experiments[1]

* SAS allows for either **electron, gas-jet or no** target to be installed.
* Experimental setups installed on precision rails, moveable in and out from ring.



From EXL collaboration

TSR gas-jet study group being formed

Layout of the new target inlet chamber design with the existing interaction chamber and target dump system for the ESR in Darmstadt.

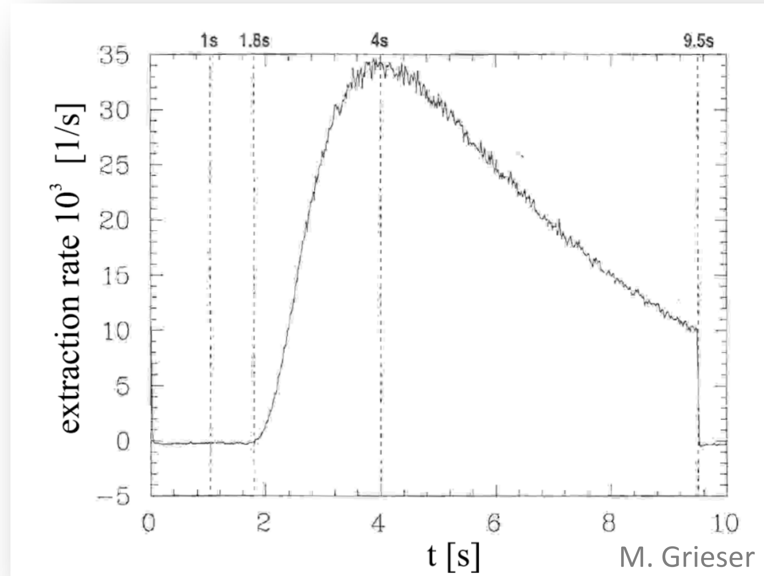
Gas-jet target

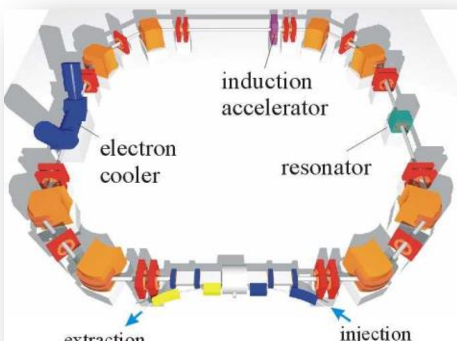
* Not existing, being studied
* Targets with thicknesses of ~ 10^{14} atoms/cm^2 for light gases as H_2, d, ^{3}He and ^{4}He

1. See M. Grieser et al., EPJ Special Topics May 2012, vol 207, Issue 1, pp 1-117

Slow extraction

- Extraction times between 0.1 s and 30 s
- Efficiency (cooled beam) ≈90%
- Properties similar to those of the cooled beam





Normal procedure for $^{12}C^{6+}$

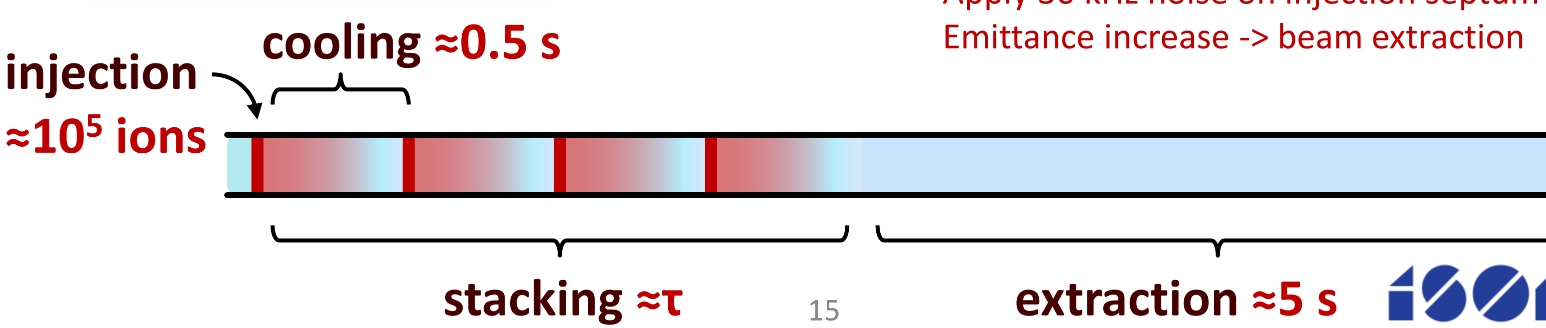
Inject at Q_x=2.64

e-cool for 1 s

Shift Q_x close to resonance 8/3

Apply 30 kHz noise on injection septum

Emittance increase -> beam extraction

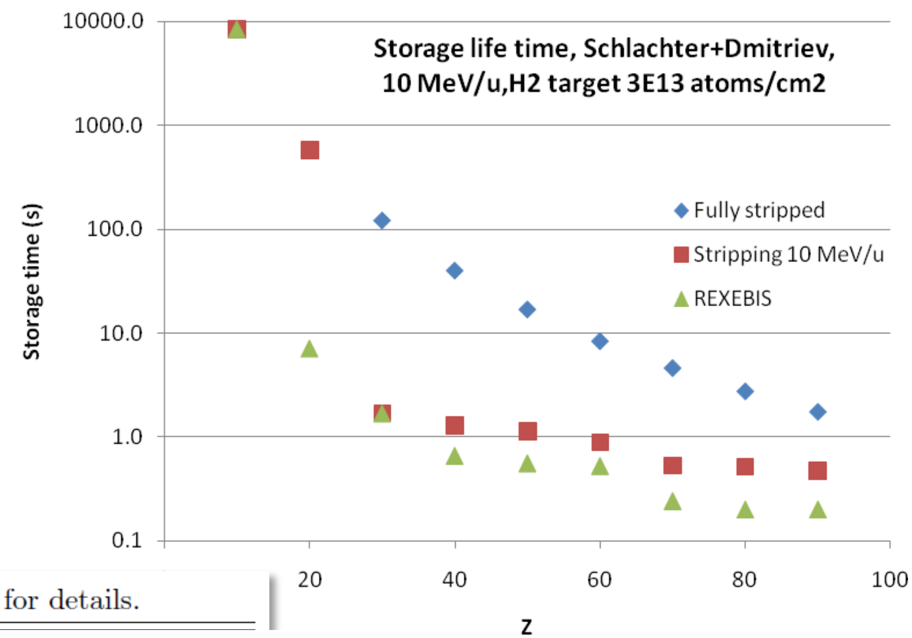


Beam life times

Survival times

* Coulomb scattering, electron capture and stripping
* Residual gas, electrons in the cooler and gas target

Internal gas target



M. Grieser et al., EPJ Special Topics May 2012, vol 207, Issue 1, pp 1-117

Table 1: Parameters of beams circulating in the TSR. See text for details.

Ion	Nuclear lifetime	Energy (MeV/u)	Cooling time	Beam lifetime in residual gas
^{7}Be 3+	(53 d)	10	2.3 s	370 s
^{18}F 9+	100 m	10	0.7 s	280 s
^{26m}Al 13+	6.3 s	10	0.5 s	137 s
^{52}Ca 20+	4.6 s	10	0.4 s	58 s
^{70}Ni 28+	6.0 s	10	0.25 s	30 s
^{70}Ni 25+	6.0 s	10	0.3 s	26 s
^{132}Sn 30+	40 s	4	0.4 s	1.5 s
^{132}Sn 45+	40 s	4	0.2 s	1.4 s
^{132}Sn 39+	40 s	10	0.25 s	7.4 s
^{132}Sn 45+	40 s	10	0.2 s	10 s
^{186}Pb 46+	4.8 s	10	0.25 s	4 s
^{186}Pb 64+	4.8 s	10	0.13 s	5 s

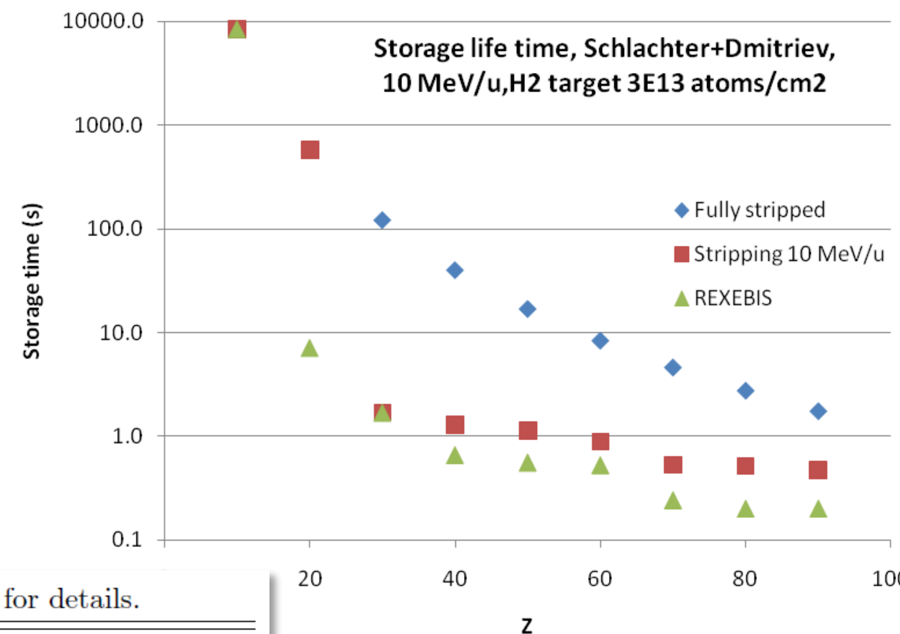
Beam life times

Survival times

* Coulomb scattering, electron capture and stripping

* Residual gas, electrons in the cooler and gas target

Internal gas target



M. Grieser et al., EPJ Special Topics May 2012, vol 207, Issue 1, pp 1-117 ↓

Table 1: Parameters of beams circulating in the TSR. See text for details.

Ion	Nuclear lifetime	Energy (MeV/u)	Cooling time	Beam lifetime in residual gas	H_2 target (atoms/cm^2)	Beam lifetime in target	Eff. target thickness (μg/cm^2)
^{7}Be 3+	(53 d)	10	2.3 s	370 s			
^{18}F 9+	100 m	10	0.7 s	280 s	1×10^{14}	236 s	31000
^{26m}Al 13+	6.3 s	10	0.5 s	137 s	5×10^{14}	23 s	4200
^{52}Ca 20+	4.6 s	10	0.4 s	58 s	5×10^{14}	9.6 s	3000
^{70}Ni 28+	6.0 s	10	0.25 s	30 s	2×10^{14}	12 s	1600
^{70}Ni 25+	6.0 s	10	0.3 s	26 s	2×10^{13}	2.1 s	60
^{132}Sn 30+	40 s	4	0.4 s	1.5 s	1×10^{12}	1.4 s	1.2
^{132}Sn 45+	40 s	4	0.2 s	1.4 s	5×10^{12}	1.6 s	7
^{132}Sn 39+	40 s	10	0.25 s	7.4 s	2×10^{12}	3.6 s	9.5
^{132}Sn 45+	40 s	10	0.2 s	10 s	5×10^{13}	1.3 s	90
^{186}Pb 46+	4.8 s	10	0.25 s	4 s	2×10^{12}	1.5 s	4
^{186}Pb 64+	4.8 s	10	0.13 s	5 s	1×10^{13}	1.7 s	20

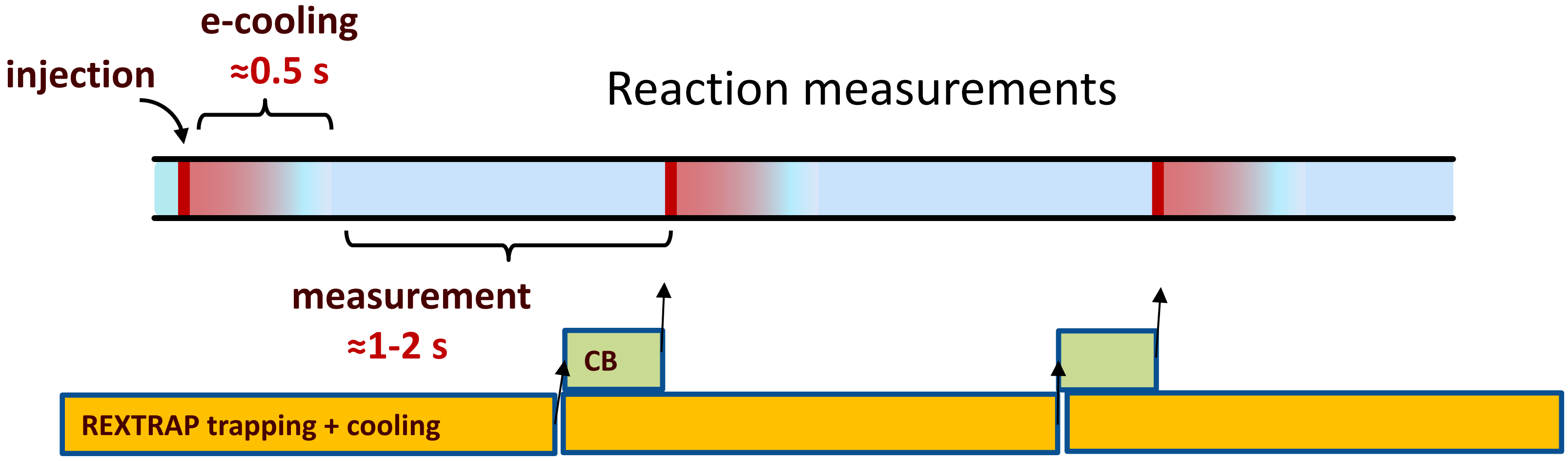
Fully stripped ions
-> improved lifetime

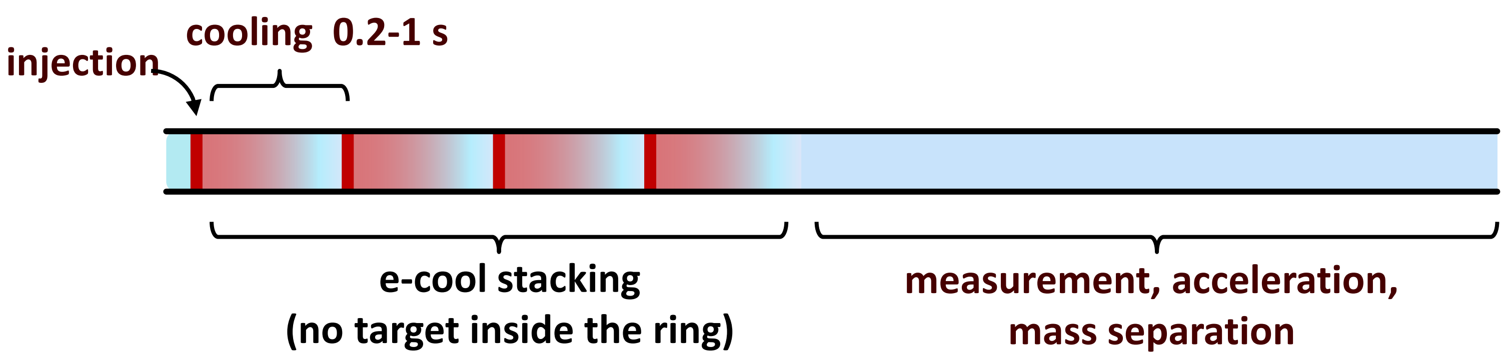
Effective target thickness:
(gas target thickness) x
(revolution frequency) x
(lifetime)

~100 ug/cm^2 for direct target

Injection rate

Reaction measurements

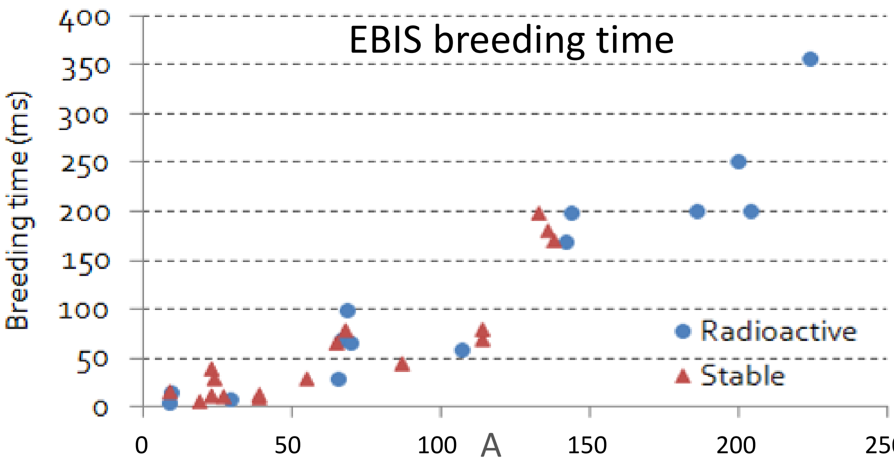




Based on R. Raabe presentation

Storage in REXTRAP essential

* Ring injection repetition rate $T_{\_rep\_rate}$ < 5 Hz
* $T_{\_rep\_rate}$ < 0.5 Hz not unusual due to e-cooling and/or in-ring beam exploitation



T_{breed} < T_{rep_rate} in many cases

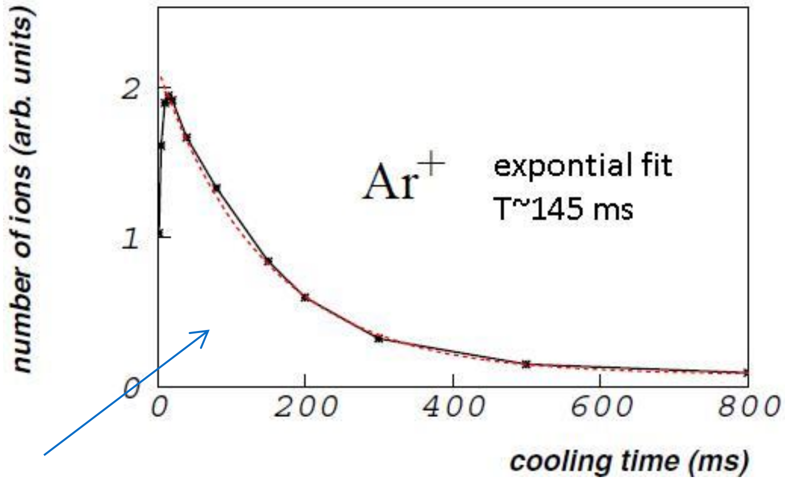
+ ample time to reach high charge states

- keep them in ~~1. REXEBIS~~ or 2. REXTRAP

q^+ dependent

Holding time in REXTRAP?

- $^{60}Ni^+$ and $^{87}Rb^+$ kept for >1.5 s
- 3E7 ions/s injected
- Additional losses <20%



P. Delahaye et al., Nucl Phys A746 (2004) 604

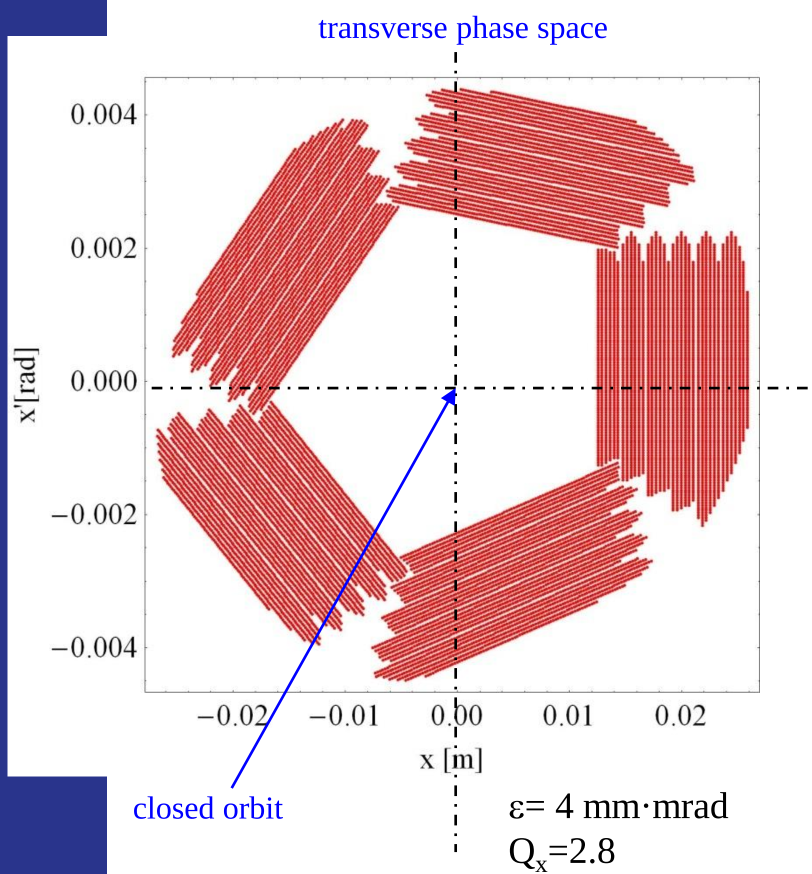
Concerns

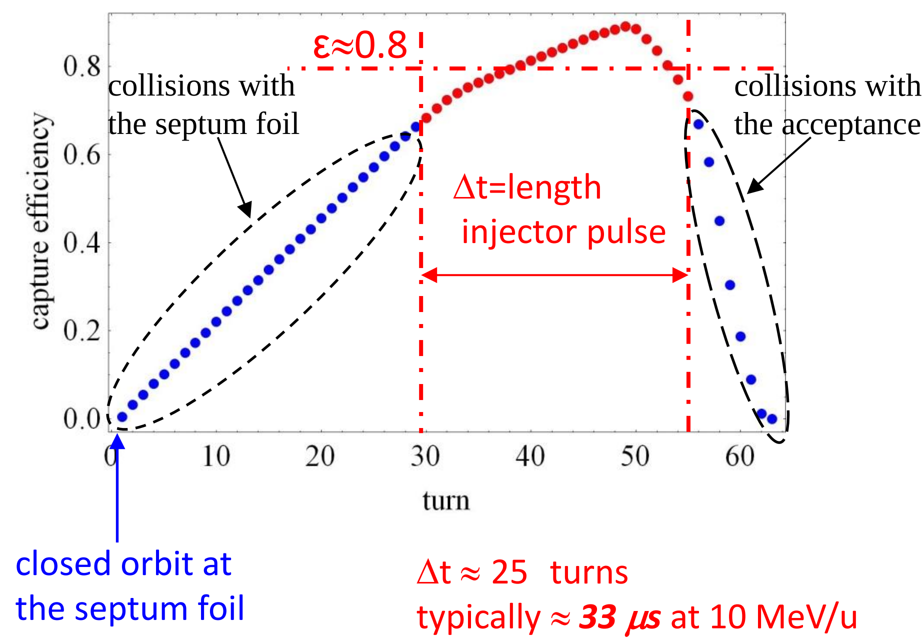
- Short-lived ions
- Space-charge effects (ω_c changes; eff. decrease)
- Noble gases and ions with high I.P. such as F, Cl, Br

Ring injection time

- ***High injection efficiency of outmost importance***
- ***Multi-turn injection***

Slide from M. Grieser

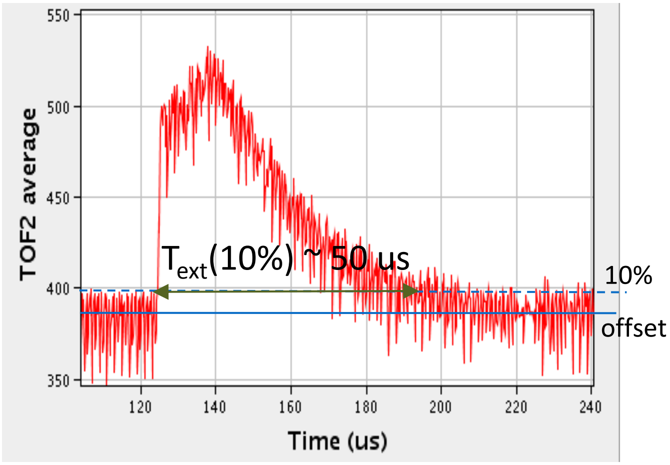




Δt ≈ 25 turns
typically ≈ ***33 μs*** at 10 MeV/u

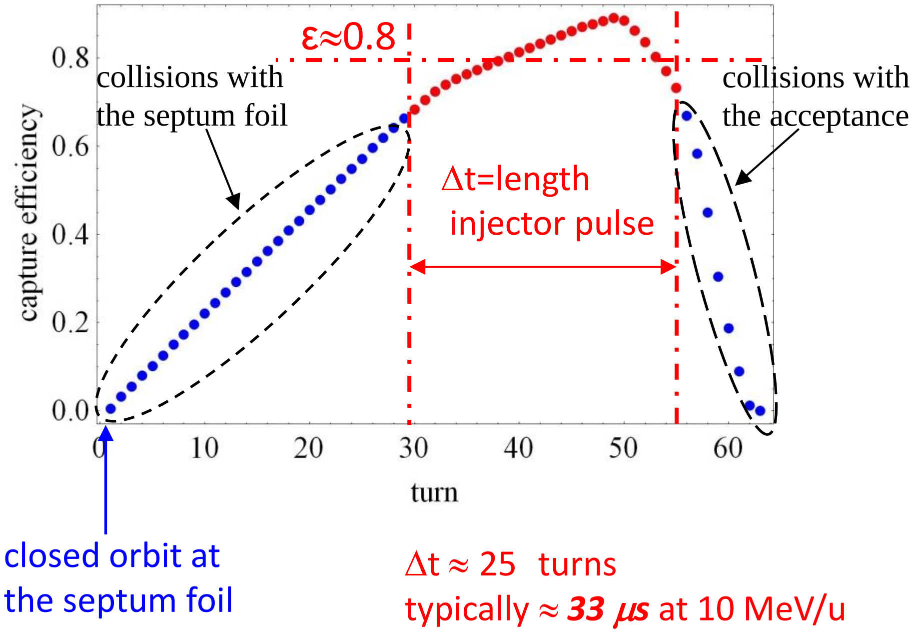
Ring injection time

- ***High injection efficiency of outmost importance***
- ***Multi-turn injection***



TOF after REX charge breeder

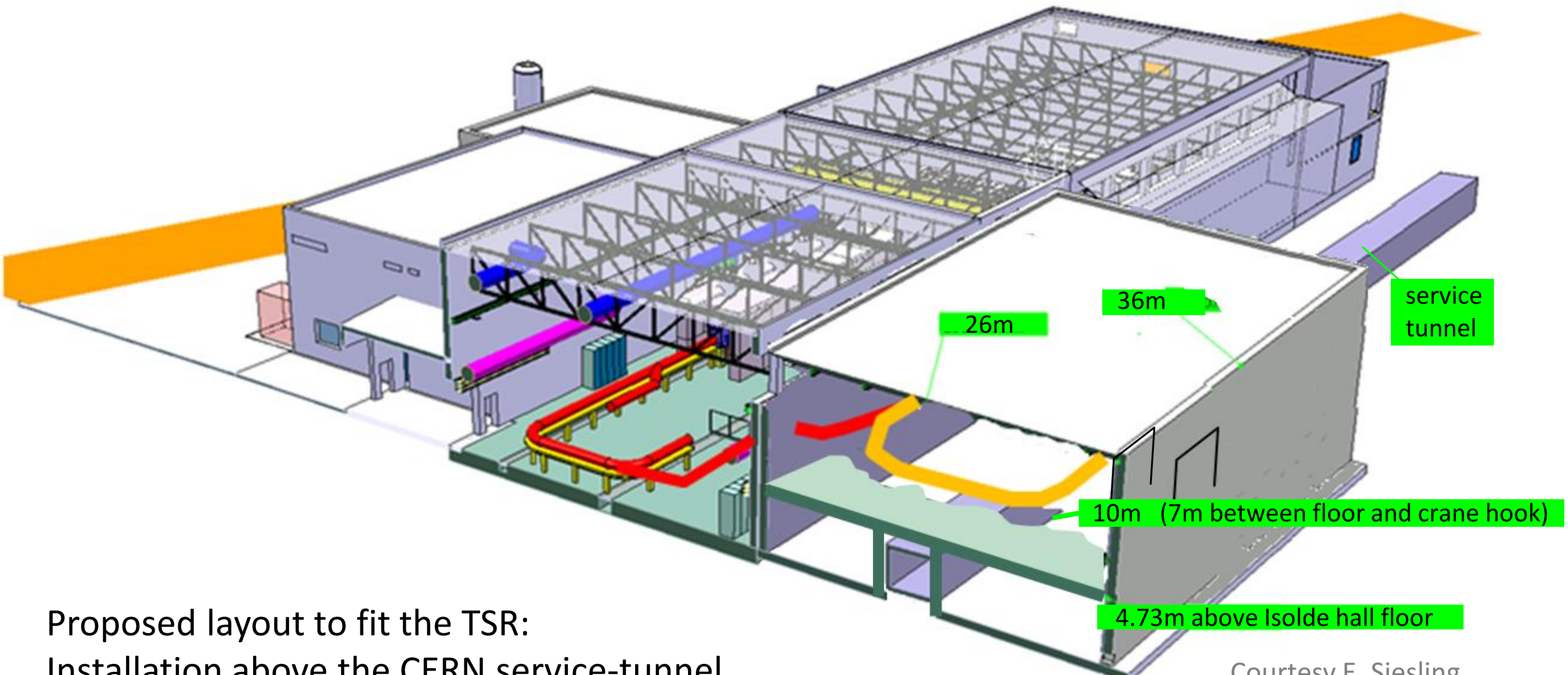
Adapt EBIS $T_{extraction}$
to fit beam pulse into
transverse acceptance



Beam-line layout

Building layout

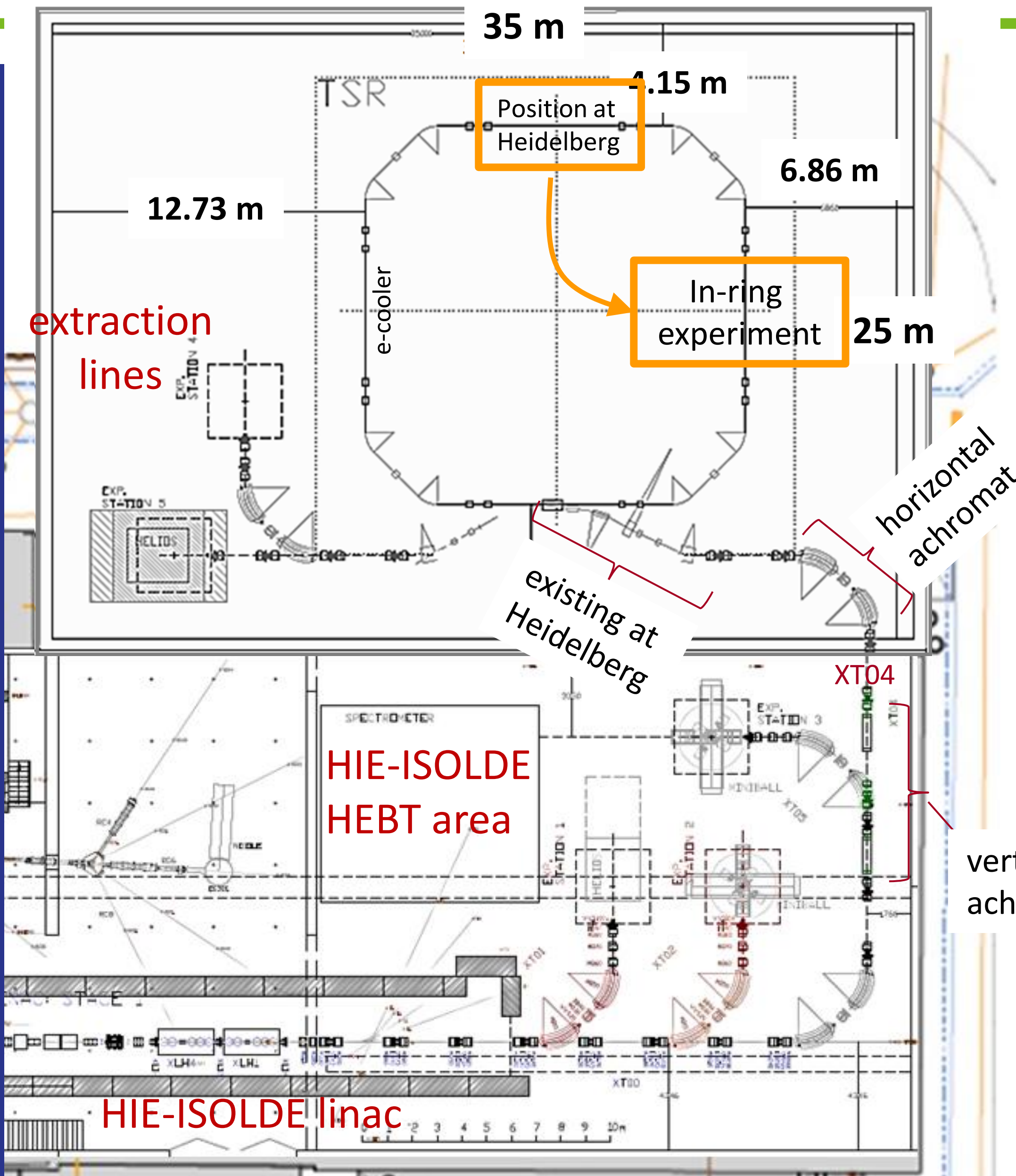
Presently at MPI-K, Heidelberg, a large hall is housing the TSR with enough space around it for experiments and equipment that need to be close to the ring. The basement underneath the ring is used for power supplies and other necessary equipment.



Courtesy E. Siesling

Proposed layout to fit the TSR:
Installation above the CERN service-tunnel
Tilted beam-line coming up from the machine.

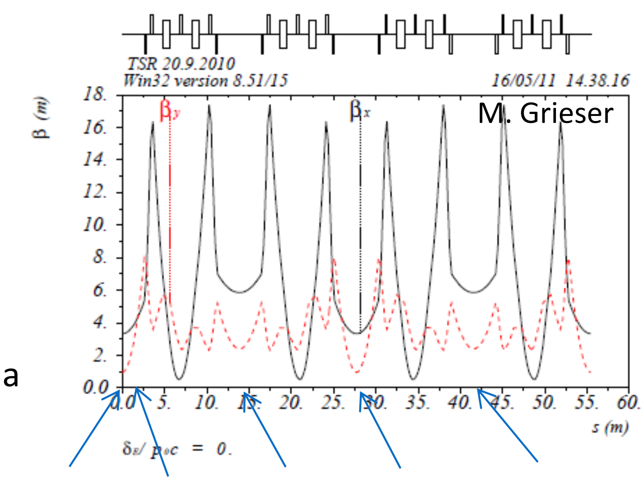
Beam-line layout



1. Achromatic injection line
   * Links HIE-ISOLDE to TSR ring via XT04
   * Considers HIE-ISOLDE and TSR floor level difference of 4.73 m

2. Standard HIE-EBIT elements

3. Tentative layout for two experimental stations.



Heidelberg layout

Charge breeder upgrade

Charge states out of REX

Benefits from high q

- Rigidity TSR
- Storage lifetimes
- Cooling times
- Experiments

Charge breeding times for a selection of elements of relevance for TSR@ISOLDE experiments

Ion	Z	q	A/q	Breeding time (ms)
^{7}Be	4	3	2.33	20
^{18}F	9	9	2	100
^{70}Ni	30	25	2.33	350
^{132}Sn	50	39	3.38	700 *
^{182}Pb	82	53	3.43	1000 *
^{182}Pb	82	64	2.84	EBIS upgrade needed

* to be tested

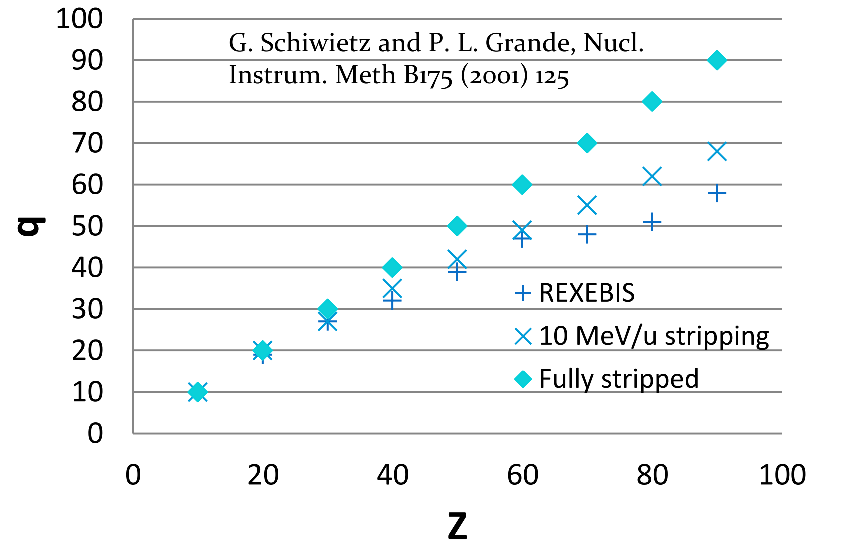
☺ REXEBIS charge breeder capable of producing sufficiently low A/q (or beam rigidity for < 10MeV/u) for most elements

Charge states out of REX

☹ But some experiments might require:

* Fully stripped to Z~60

* Few-electron system, e.g. for Th/U

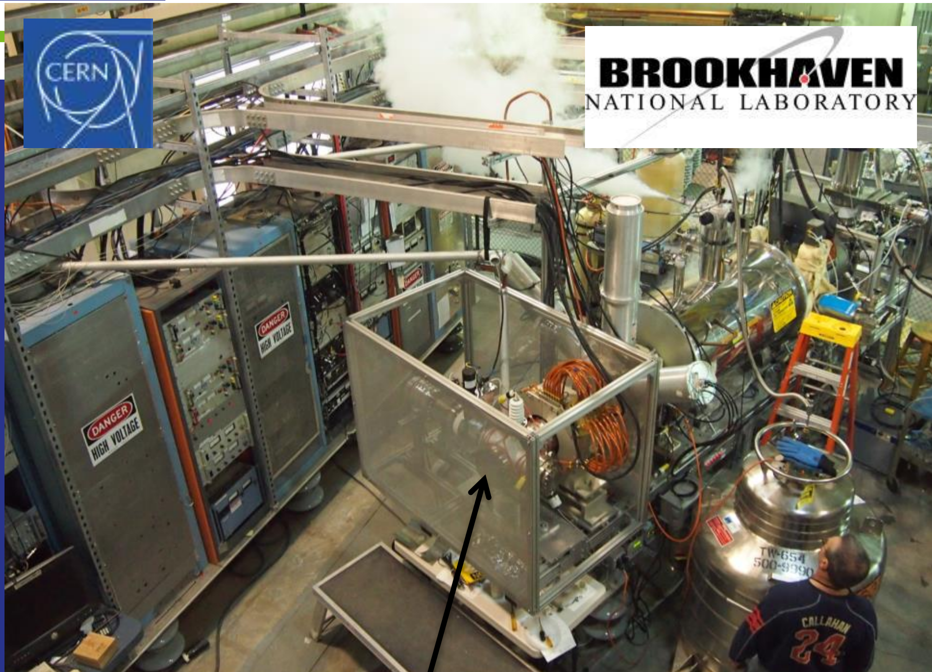


Estimated attainable charge states in REXEBIS and after stripper foil as a function of ion Z

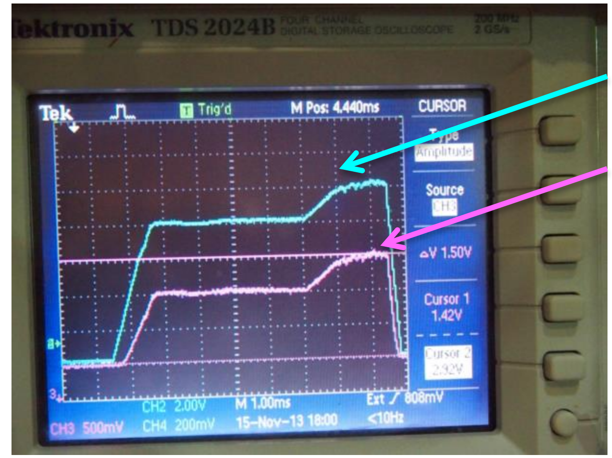
Design parameters HIE-ISOLDE / TSR@ISOLDE breeder

	Upgrade	REXEBIS
Electron energy [keV]	150	5
Electron current [A]	2-5	0.2
Electron current density [A/cm^2]	1-2x10^4	100
Trapping region pressure (mbar)	~10^{-11}	~10^{-11}
Ion-ion cooling needed	YES	NO
Extraction time (us)	<30	>50

HEC^2 prototype tests at BNL



First beam time – 08.11.2013-15.11.2013



Prototype gun design by BNL, built by CERN being tested at BNL by joint team at BNL TEBIS

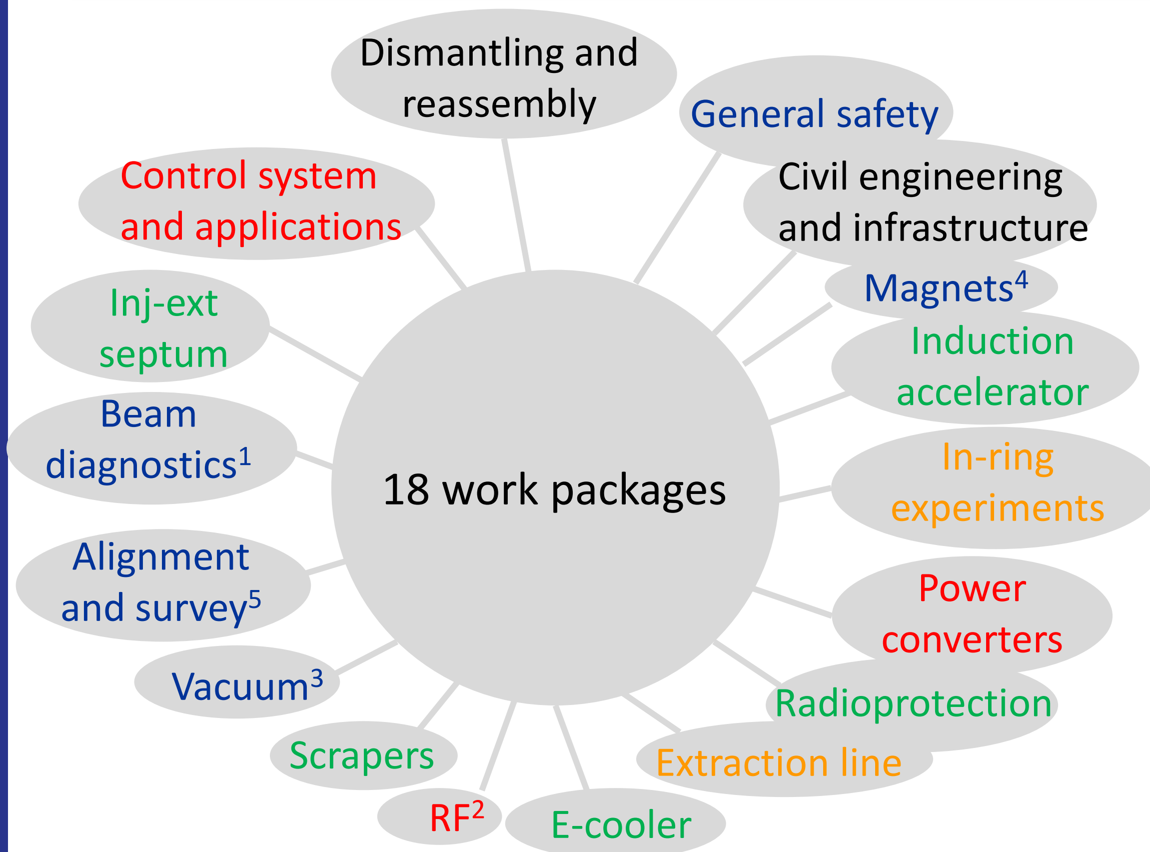
Scenario	E_e, keV	I_e, A	J_e, kA/cm^2
HEC^2 ultimate spec	150	5	10-20
Achieved in 1-st run	30	1.54	tba
REXEBIS	5	0.4	0.2

* These activities supported by HIE-ISOLDE design study will continue in 2014
* Hopefully a continuation within ENSAR2

Technical integration study

Technical integration study

Two approaches 1. CERN homologation (full-fledged ‘standardization’)
2. Keep-system-as-is (low-budget option with minimal changes)



1. Obsolete electronics
   Improve sensitivity
2. Change for Finement® type
3. Exchange bakeout system
4. Improve electrical safety
5. External targets on elements

Red: fully replaced
Blue: complemented and improved
Green: accepted or minor upgrades
Orange: not part of costing

Recommendations by CERN specialists

Technical integration study - conclusions

- ✓ The radiological concern of importing the ring is minimal.
- ✓ Well advanced civil engineering plan with associated infrastructure exists.
- ✓ No technical show stoppers for the implementation – standard solutions identified.

CERN integration proposal

a. First cost and manpower estimate believed to be conservative. *However, no contingency included.*

b. Most CERN groups have insisted on hardware changes and CERN standardization and discourage a 3 years transition period.

Total cost and manpower for transfer and integration into a CERN facility:

15.2 MCHF 27.5 FTE (man year)

Keep-system-as-is

a. Would need to keep all subsystems as they are since many are interlinked with the control system.

b. Would have limited / no support by CERN groups; longer dependence on MPIK Heidelberg.

The approximate cost and manpower need for the Keep-system-as-is scenario are:

11.8 MCHF 17.1 FTE (man year)

The cost saving might appear low. Reasons:
** The main cost drivers are the injection line, buildings and infrastructure.*
** Some spares, complementing parts and replacement parts are absolutely necessary.*
** Includes the mandatory electrical protection of magnets connections.*
** Includes sensitivity improvement of the beam diagnostics.*

NB. The figures have not been considered the CERN management

Past, present and future

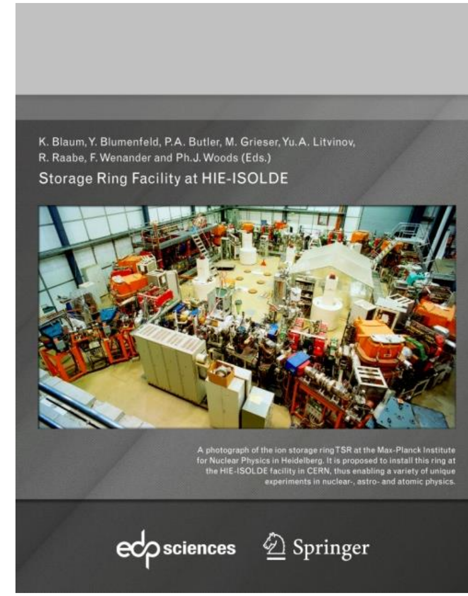
* TSR@ISOLDE workshop at MPI-K Heidelberg 28-29/10 2010 evaluated the future for TSR

* LoI to the ISOLDE and Neutron Time-of-Flight Committee

  http://cdsweb.cern.ch/record/1319286/files/INTC-I-133.pdf

* TSR at ISOLDE technical design report

  M. Grieser et al., EPJ Special Topics May 2012, vol 207, Issue 1, pp 1-117



* Approved by CERN Research board, May 2012

  "The installation of TSR, as an experiment to be included in the HIE-ISOLDE programme, was approved by the Research Board. The timescale will be defined once the study of its Integration has been completed."

* Presentation of the integration study to the CERN Research Board Nov 2013

* TSR@ISOLDE workshop at CERN 14/2-2014

* The CERN Council will take the final decision

  Aim to be part of CERN Mid Term Planning 2014

ISOLDE

Eur. Phys. J. Special Topics 207, 1-117 (2012)

K. Blaum, Y. Blumenfeld, P.A. Butler, M. Grieser, Yu.A. Litvinov, R. Raabe, F. Wenander and Ph.J. Woods (Eds.)

Storage Ring Facility at HIE-ISOLDE

TSR@ISOLDE Collaboration:
129 scientists from 47 institutions in 19 countries

A photograph of the ion storage ring TSR at the Max-Planck Institute for Nuclear Physics in Heidelberg. It is proposed to install this ring at the HIE-ISOLDE facility in CERN, thus enabling a variety of unique experiments in nuclear-, astro- and atomic physics.

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THE EUROPEAN PHYSICAL JOURNAL
SPECIAL TOPICS

Review

Storage ring at HIE-ISOLDE

Technical design report

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C. Scheidenberger[22,3,a], S. Schippers[13], D. Schneider[43], R. Schuch[44], D. Schwalm[1,45], L. Schweikhard[46], D. Shubina[1], E. Siesling[5], H. Simon[3,a], J. Simpson[36], J. Smith[8], K. Sonnabend[29], M. Steck[3,a], T. Stora[5], T. Stöhlker[47,48,3,a], B. Sun[37], A. Surzhykov[2], F. Suzaki[49], O. Tarasov[31], S. Trotsenko[48], X.L. Tu[32], P. Van Duppen[4], C. Volpe[50], D. Voulot[5], P.M. Walker[5,20], E. Wildner[5], N. Winckler[1], D.F.A. Winters[3,a], A. Wolf[1], H.S. Xu[32], A. Yakushev[3,a], T. Yamaguchi[49], Y.J. Yuan[32], Y.H. Zhang[32], and K. Zuber[51]

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[a] The members of the GSI Helmholtzzentrum für Schwerionenforschung will exploit the synergies with the FAIR physics program and concentrate on R&D activities relevant for FAIR.

General conclusions

- TSR matches the HIE-ISOLDE characteristics
- TSR and ISOLDE would be a nice couple, with:
  - broad range of elements and isotopes
  - wide energy range
  - e-cooled beams
  - several tools for beam manipulation and detection
- A storage ring at an ISOL facility: a unique instrument

  First storage ring with ISOL-facility!
- The technical aspects of the integration have been studied
- Now awaiting response from the management…

Thanks for your attention!

Credits to

M. Grieser MPI-K

Experimentalists K. Blaum, P. Butler, R. Raabe, Y. Litvinov, P. Woods…

TSR@ISOLDE collaboration

CERN support groups