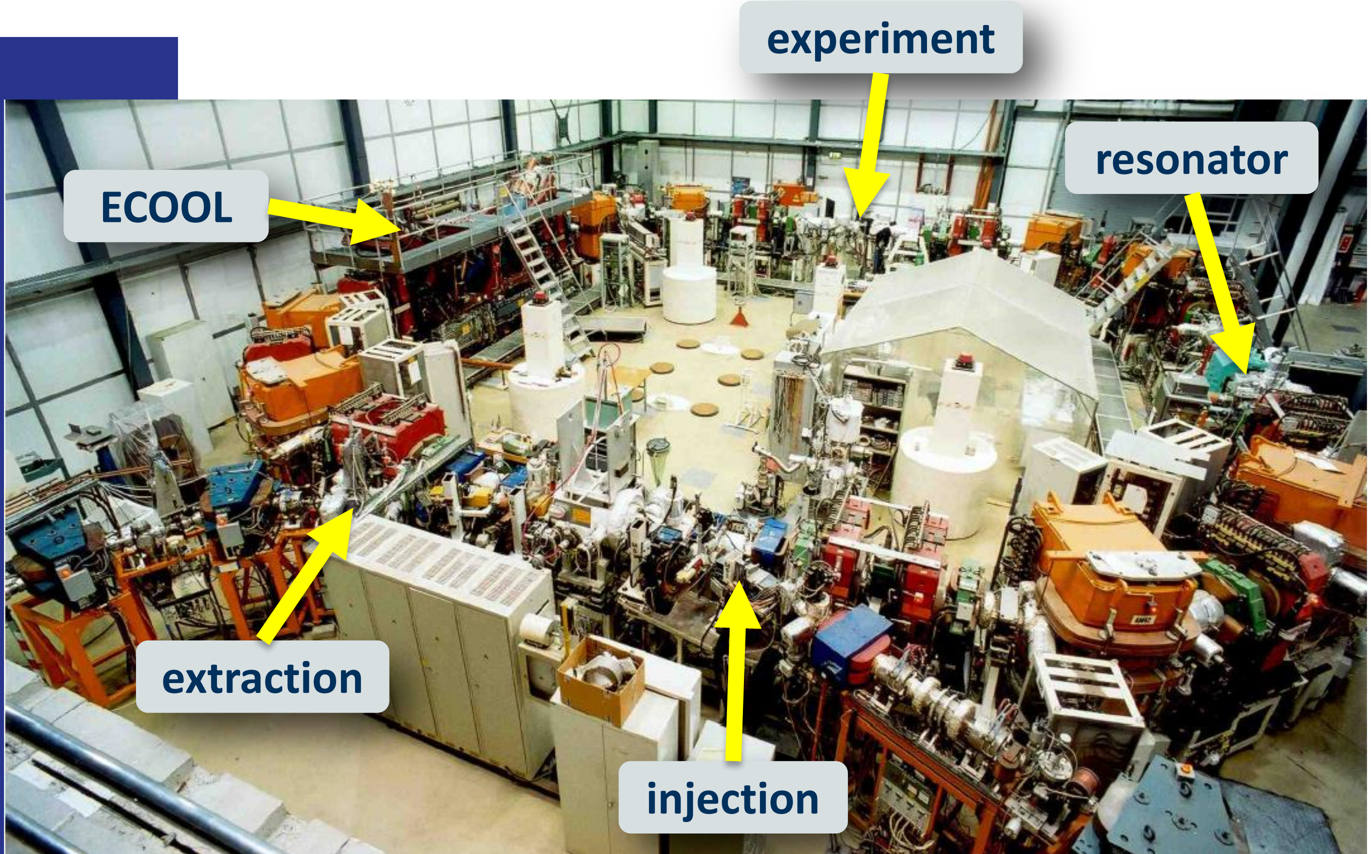
The TSR@ISOLDE
status and future prospects

Outline
1. Motivation and physics reach
2. Machine performance
3. Beam-line layout
4. Summary from integration study
5. Conclusions

Fredrik Wenander, ISOLDE workshop 26/11-2014

Test Storage Rings at Heidelberg



* 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

A storage ring at an ISOL facility

Advantages

With respect to in-flight storage rings

- Higher intensity
- Cooler beams / Shorter cooling time

With respect 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

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

Machine performance

HIE vs. TSR beam comparison

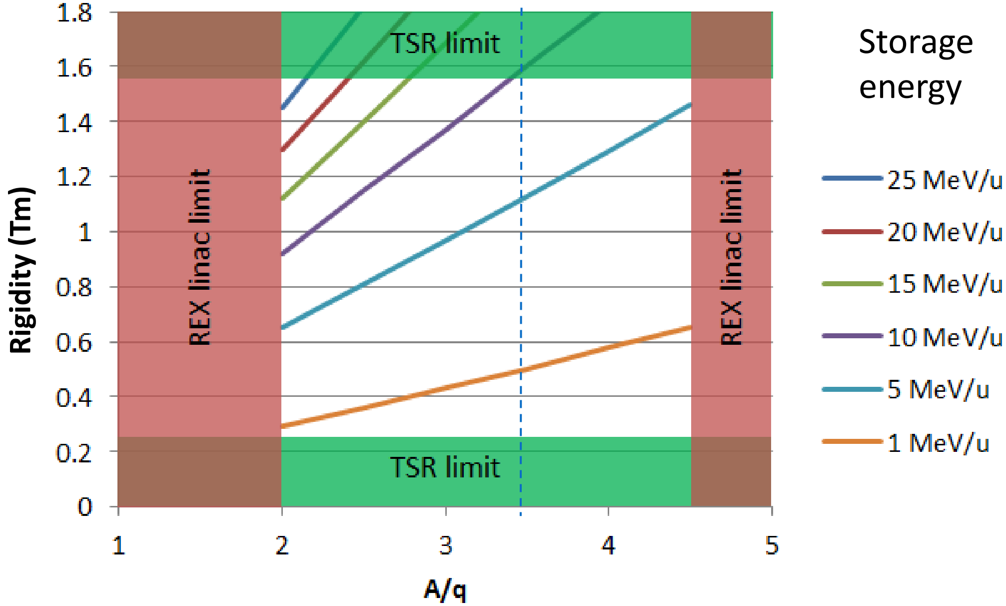
Table 2. Comparison between the main characteristics of typical reaction measurements when performed either after HIE-ISOLDE or in the TSR.

	HIE-ISOLDE	HIE+TSR	
Beam structure	macrostructure	DC	🙂 usually
Beam size	few mm	≈mm	🙂
Beam energy resolution	1.4×10^{-3}	1×10^{-4}	🙂
Transverse emittance	0.5 mm mrad	0.03 mm mrad	🙂
Loss due to beam cooling	None	(20% to 40%)[a]	☹
Beam purity	A/q contamination possible	(1 in 5000)[b]	🙂
Target z-extent	negligible	(5 mm)[c]	☹
Target thickness (background)	$\approx 100\ \mu g/cm^2$	negligible	🙂
Target purity	e.g. CH_2	pure gas	🙂
Luminosity[d]	nominal value 100	>4 for $50 < A < 200$	😐
Charge state requirement	$A/q \approx 4$	($A/q \approx$ 3-4)[e]	😐
Vacuum requirements	SHV	UHV	☹
Reaction timing	requires buncher/chopper	from beam-like detection	🙂

[a] Improvement possible – goal is 10% and 1–2 cm diameter for un-cooled beam.
[b] Improvement possible – goal is 1 in 10^4; investigate laser ionisation.
[c] Improvement possible – goal is 1 mm.
[d] The luminosity L is defined, for HIE-ISOLDE, in terms of the beam intensity I_{beam} and the target thickness T_{target}, as $L = I_{beam} \times T_{target}$. For the TSR, L also depends upon the revolution frequency f and beam lifetime τ: $L = I_{beam} \times T_{target} \times f\tau$. See also Table 1.
[e] Requires EBIS development for heavier ions.

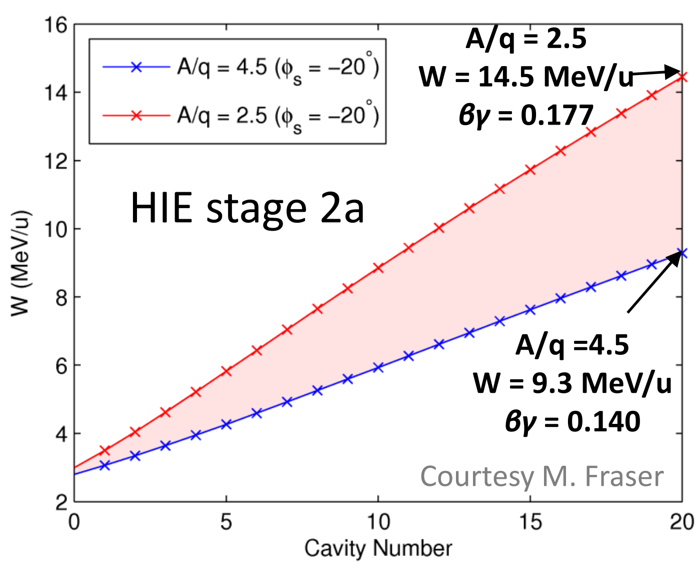
Taken from Eur. Phys. J. Special Topics 207 1-117 (2012)

Ring beam energy



TSR magnetic rigidity range: 0.25-1.57 Tm

REX linac 2<A/q<4.5



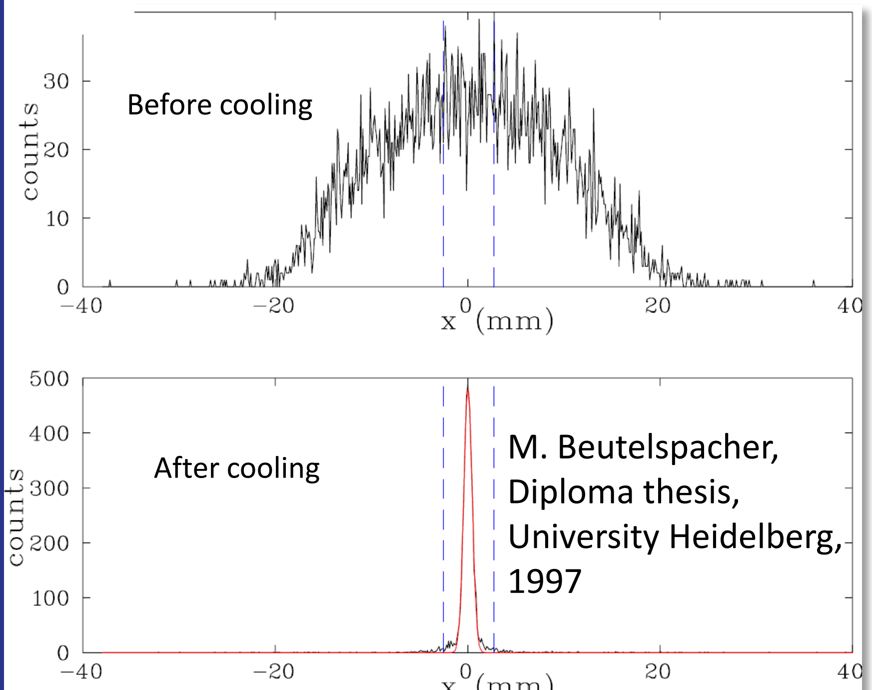
☺ Beam can be accelerated (and decelerated) inside the ring

☹ Takes several seconds though

e-cooling

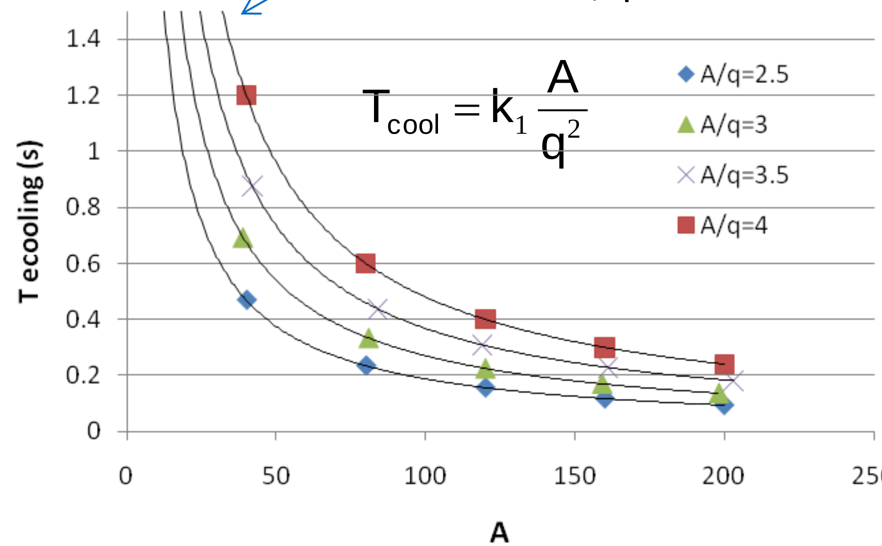
E-cooling needed for:

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



Radial beam extension

Light elements easiest to reach low A/q



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

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.

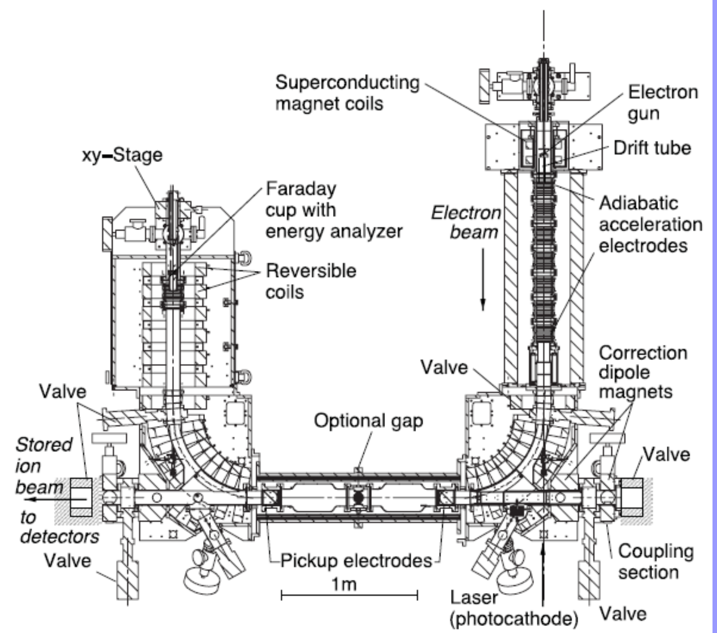


Fig. 83. ETS magnetic and vacuum system in the thermocathode configuration [170].

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

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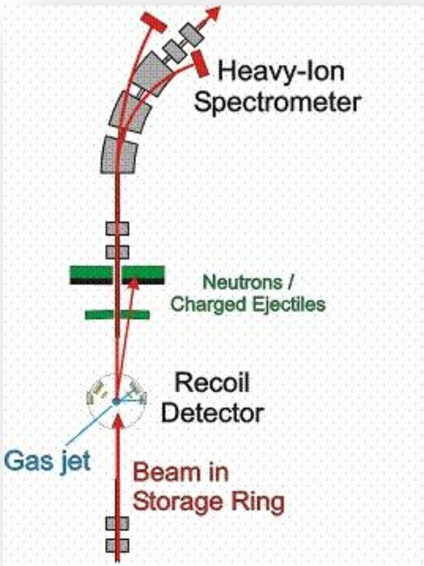
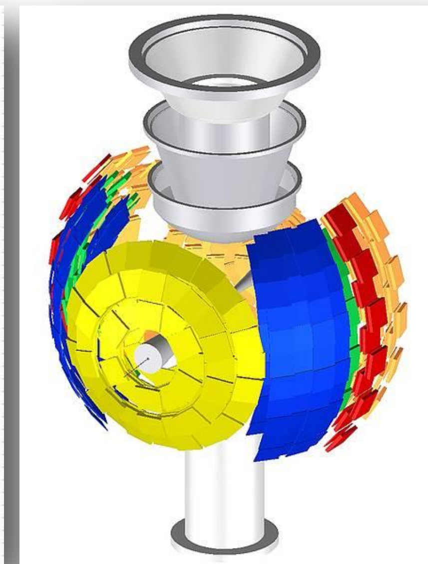




Layout of the new target inlet chamber design with the existing interaction chamber and target dump system for the ESR in Darmstadt.

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

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

Beam life times

Survival times

* Coulomb scattering, electron capture and stripping

* Residual gas, electrons in the cooler and gas target

Internal gas target

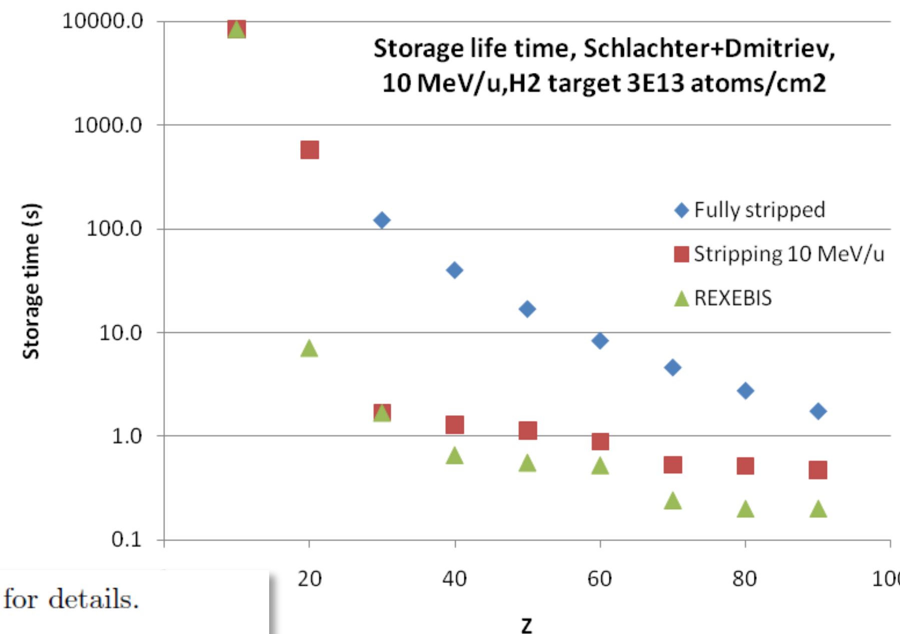
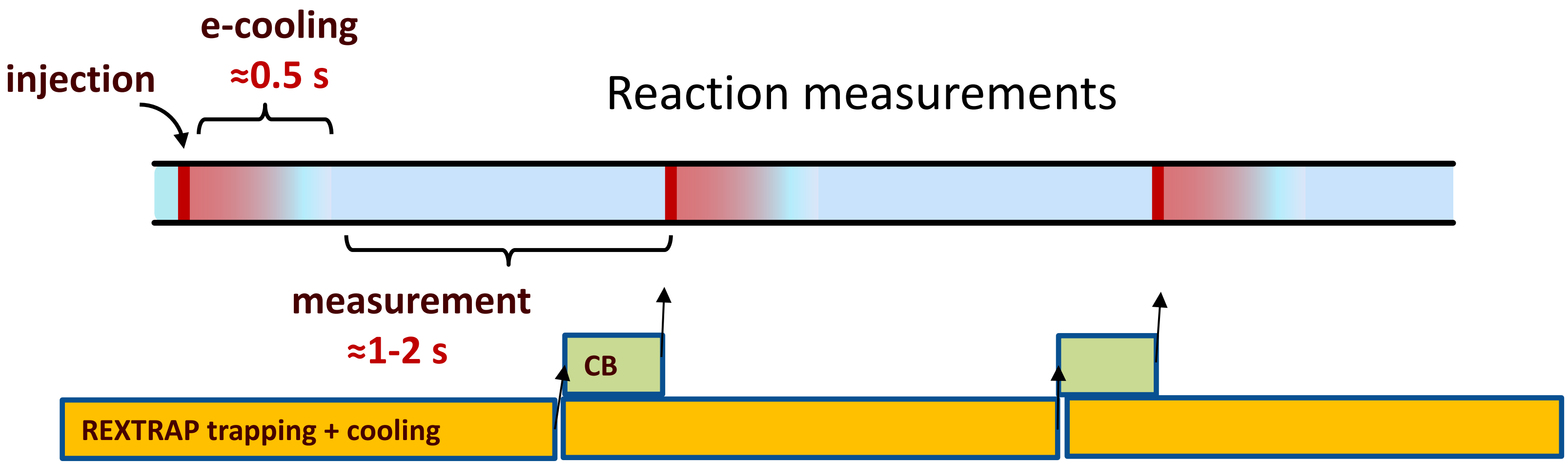


Table 1: Parameters of beams circulating in the TSR. See text for details.

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

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

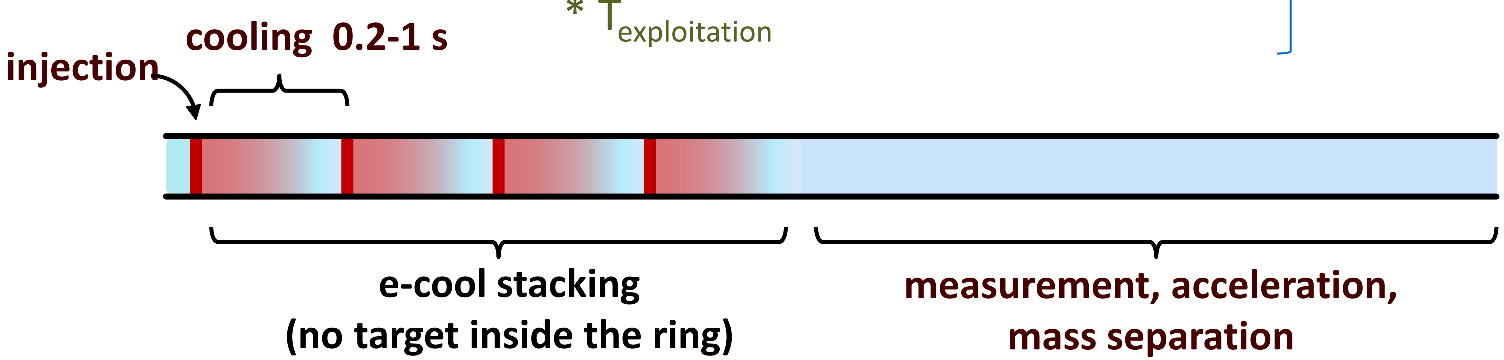
Injection rate



Repetition rate limitations

* T_{ramp} bumper magnets (max 5 Hz)
* $T_{e\text{-}cool}$
* T_{breed} in EBIS
* $T_{exploitation}$

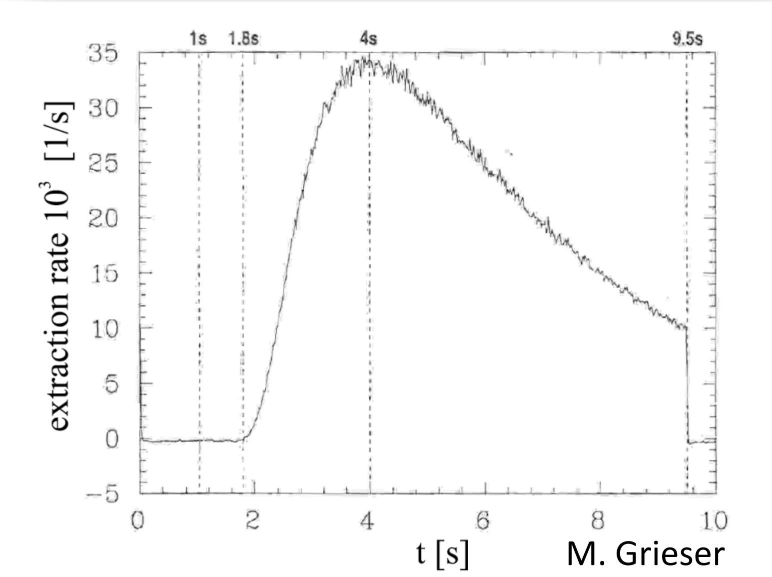
$0.2 < T_{period} < ??$

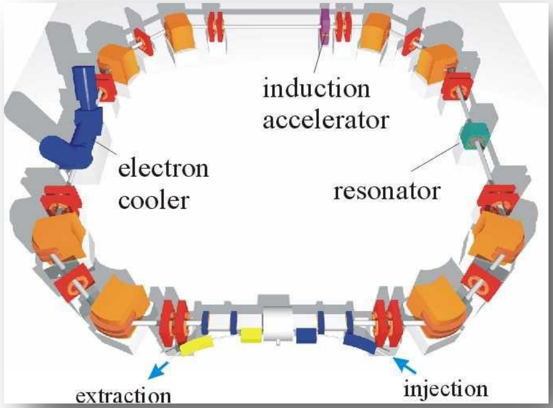


Based on R. Raabe presentation

Slow extraction

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

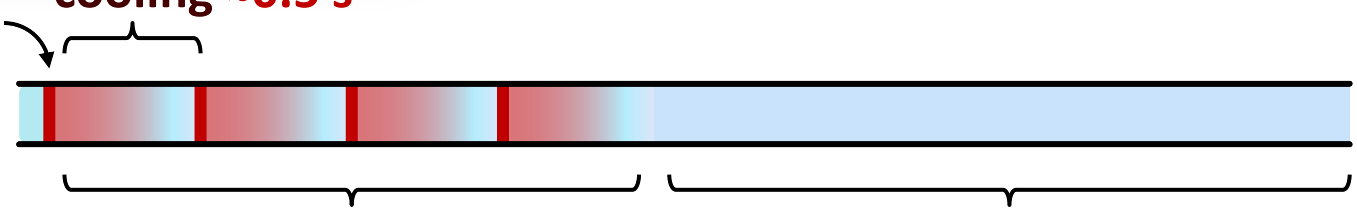




Use for external experiments (HELIOS…)

injection ≈10^5 ions

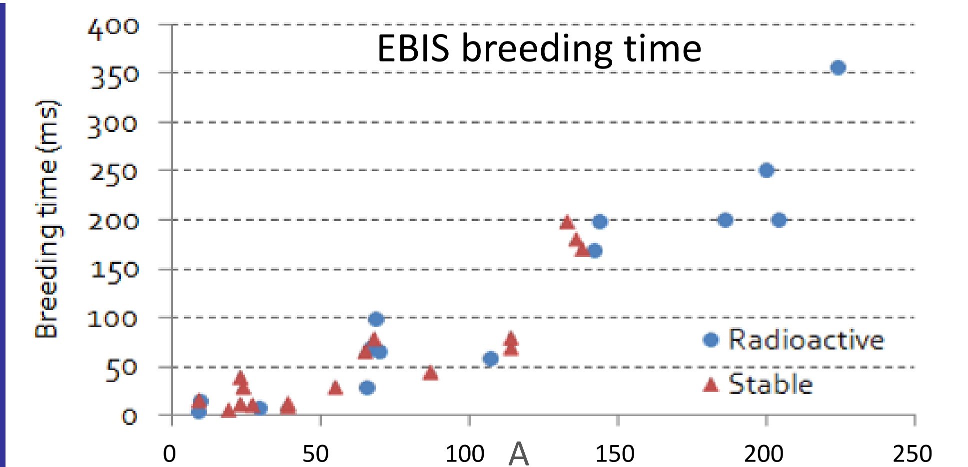
cooling ≈0.5 s



stacking ≈τ

extraction ≈5 s

REX repetition rate vs e-cooling rate



$T_{breed} < T_{rep\_rate}$ in many cases

+ ample time to reach high charge states

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

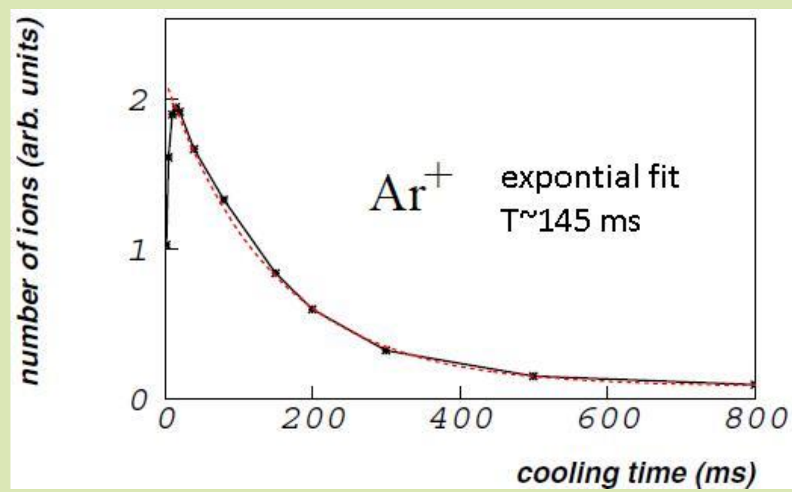
q^+ dependent

Holding time in REXTRAP?

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

Worries

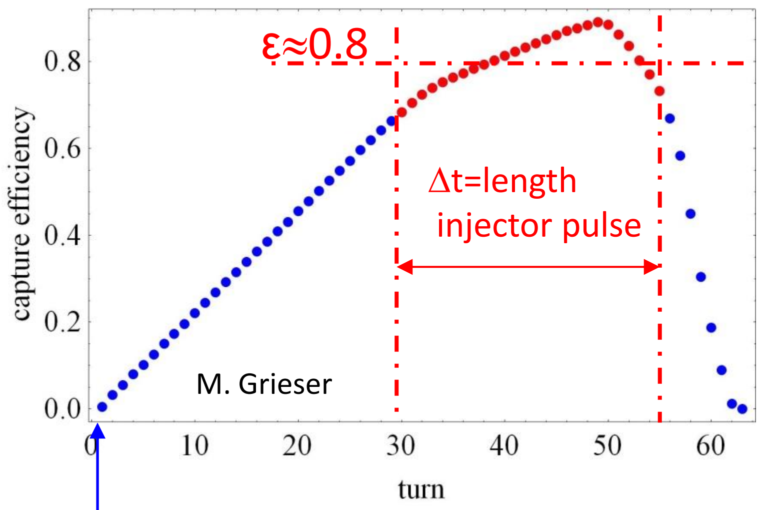
- Short-lived ions
- Space-charge effects (ω_c changes; eff. decrease)
- Noble gases and ions with high I.P. such as F, Cl, Br



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

Ring injection time

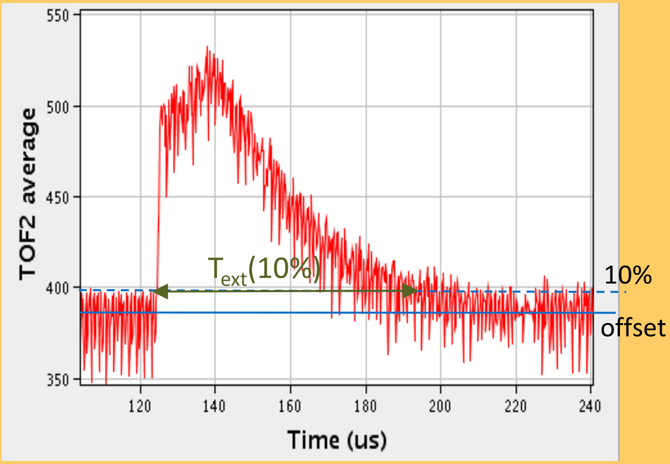
High injection efficiency of outmost importance



closed orbit at the septum foil

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

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



TOF after REX mass separator

* Investigation started
(see F. Wenander TSR workshop 2012)

* TwinEBIS could be used for optimization

If we reach $T_{extraction}$ <30 us
=> More efficient injection
=> Smaller initial beam size
=> Faster cooling

Attainable charge states

- Rigidity TSR
- Storage lifetimes
- Cooling times
- Experiments

REXEBIS breeding times for a selection of elements of relevance for TSR at 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	30	4.4	120
^{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

☹ But some experiments might require:
* Fully stripped to Z~60
* Few-electron system, e.g. for Th/U

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

Design parameters HIE-ISOLDE / TSR@ISOLDE breeder

	Charge breeder	REXEBIS
Electron energy [keV]	150	5
Electron current [A]	2-5	0.2
Electron current density [A/cm^2]	1-2x10^4	100

* On-going tests of HEC^2 gun at BNL.

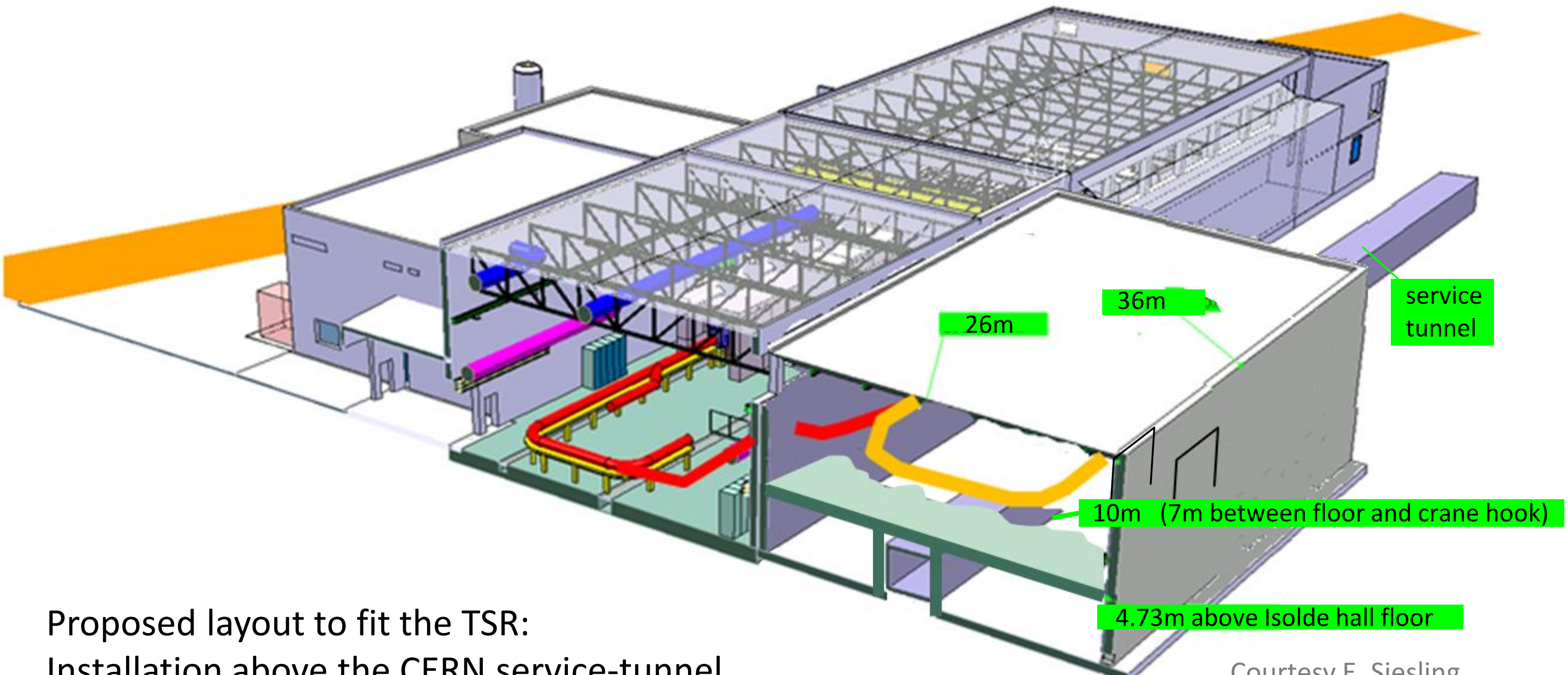
* So far 1.5 A at 30 keV

Talk by A. Shornikov

Beam-line layout

Building layout

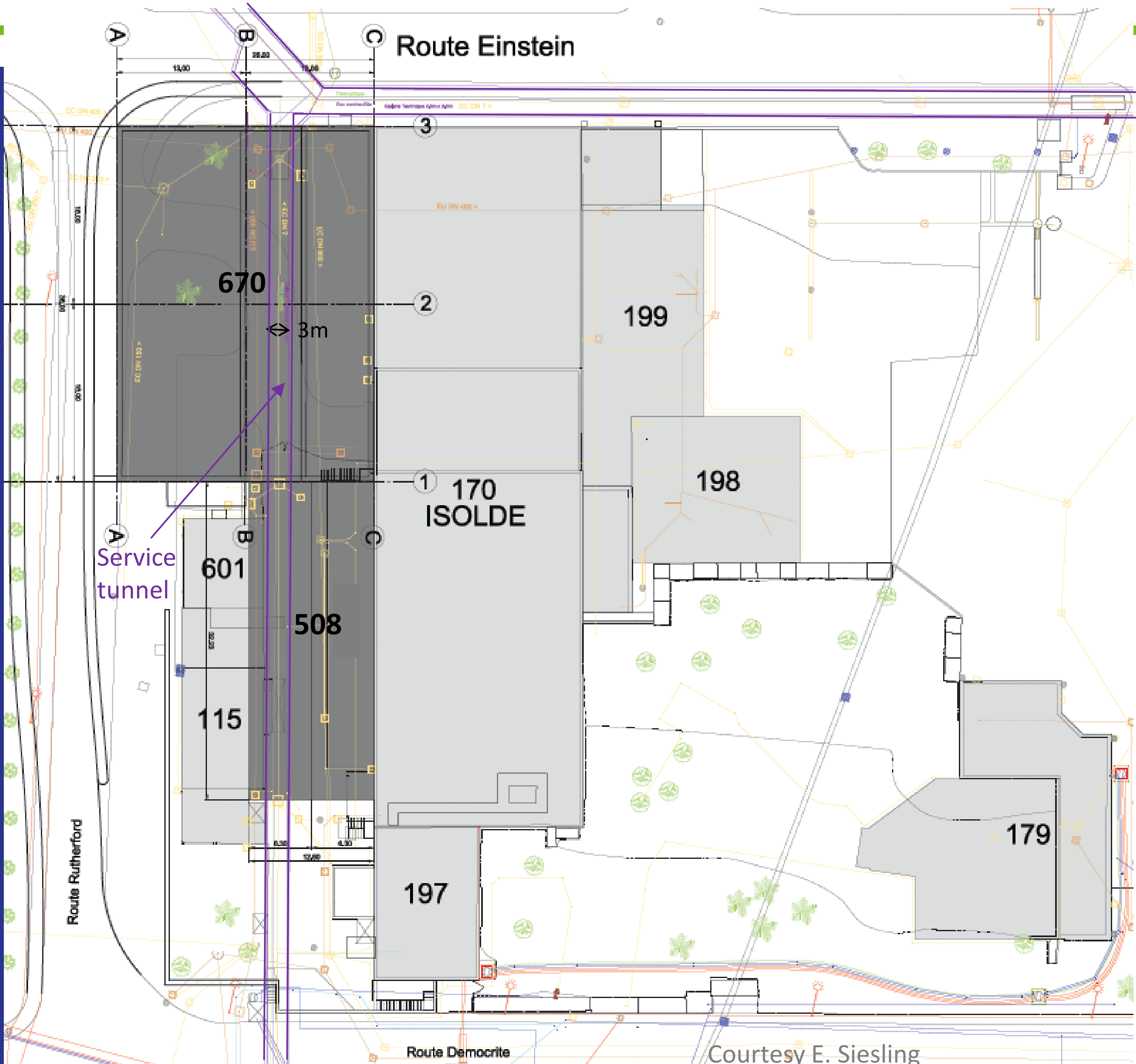
Presently at MPI-K, Heidelberg, a large hall is housing the TSR with enough space around it for experiments and equipment that need to be close to the ring. The basement underneath the ring is used for power supplies and other necessary equipment.



Courtesy E. Siesling

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

Building layout



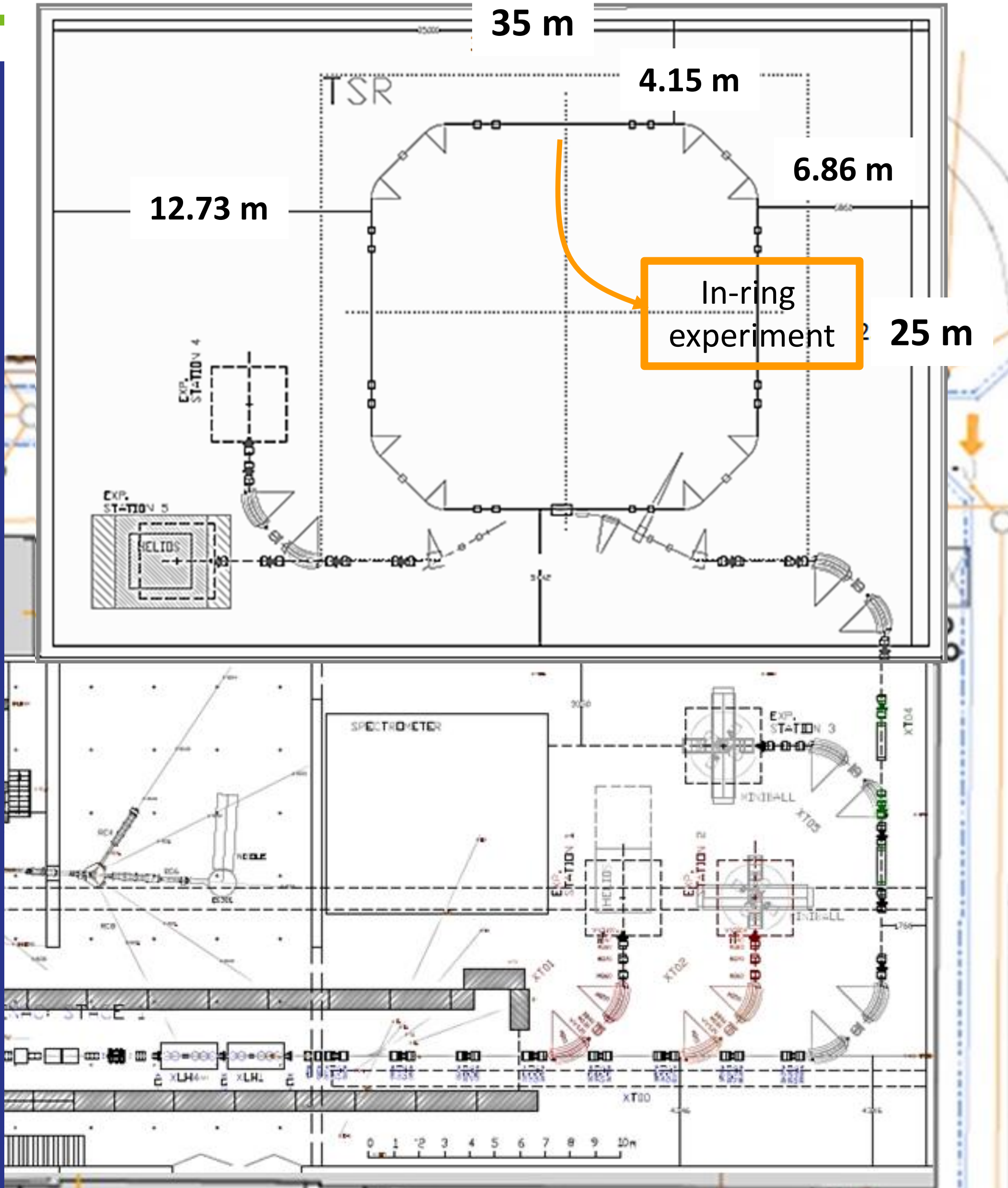
TSR building 670:
Taken in account at the construction of the new user building 508.

Water station:
Water station and cooling tower to be integrated in the ISOLDE area.

Roads:
Adaptation of the Route Rutherford and corner with Route Einstein. Move of the ramp giving access to the premises to the Route Democrite side.

CERN service tunnel:
Construction above the tunnel creating two separate basements to house TSR equipment racks and power supplies.

Beam-line layout



Numerous updates

1. Larger hall dimensions 25*35 m^2

2. Ring position shifted
-> more space for in-ring exp.

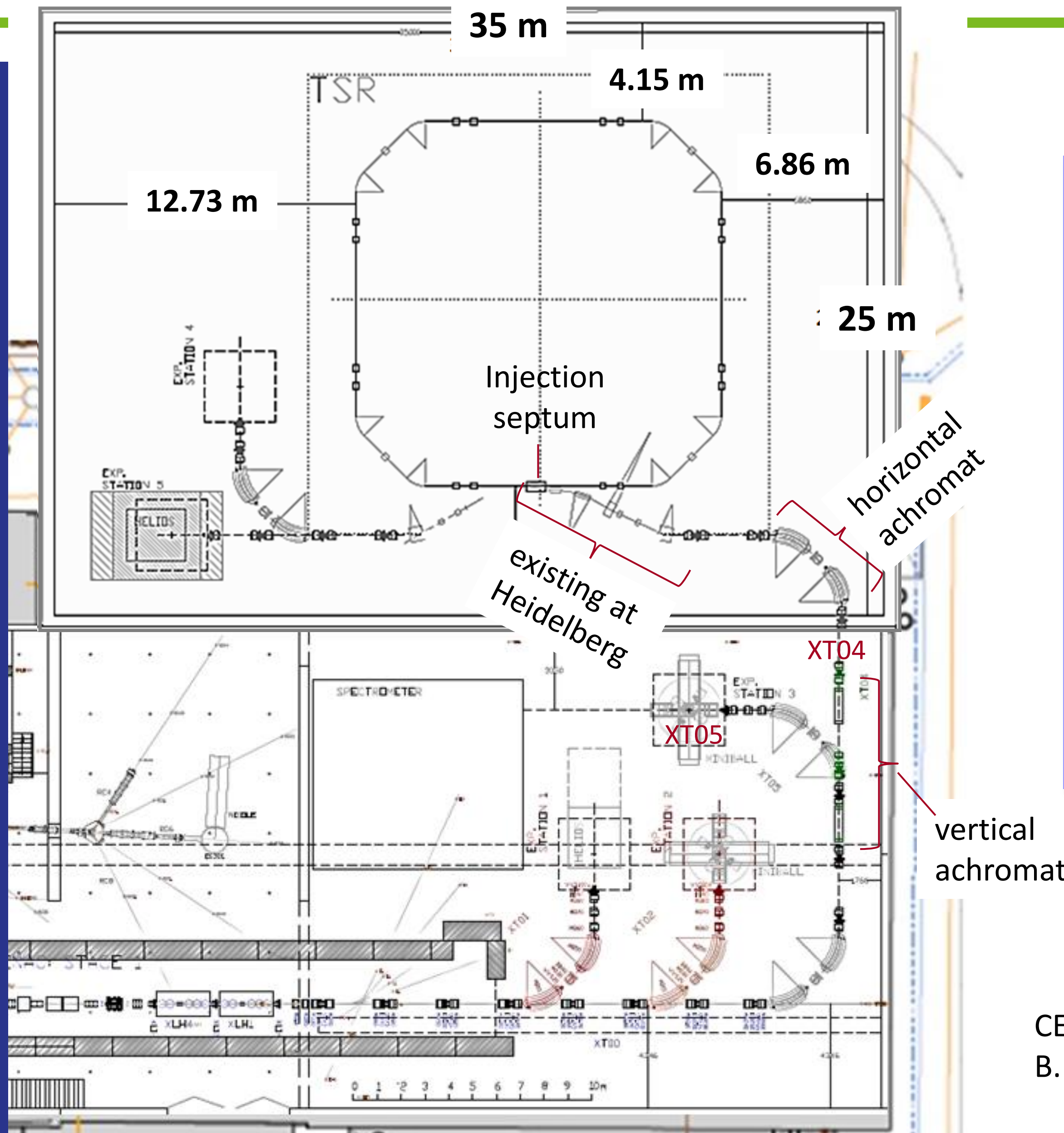
3. Standardization -> HIE-HEBT elements for inj. & ext. lines

4. Technically and beam-optically feasible

5. Two experimental stations for extracted beam

6. *No* beam-line back to ISOLDE

Injection line

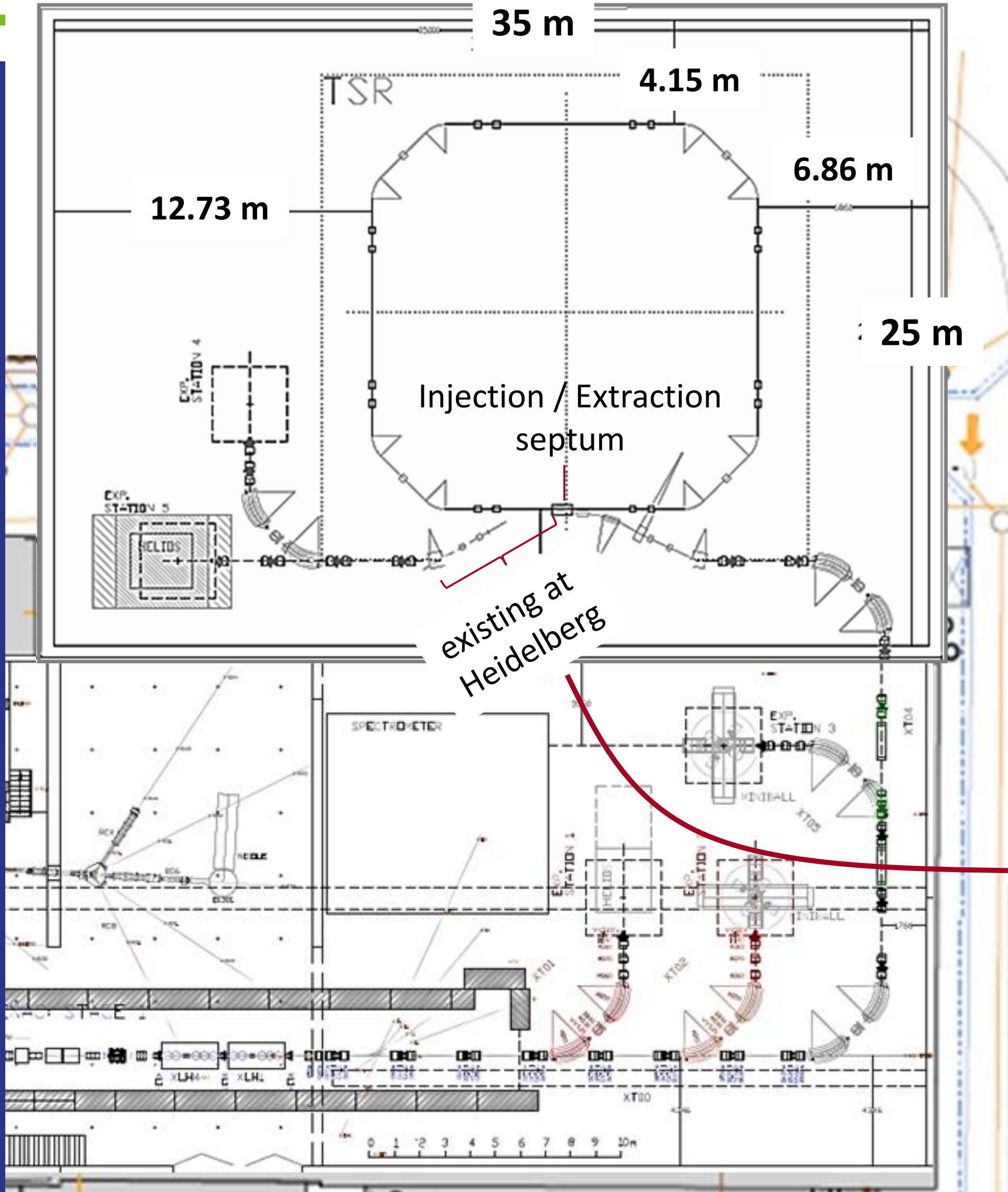


- Links HIE-ISOLDE to TSR ring via XT04
- Considers HIE-ISOLDE and TSR floor level difference of 4.73 m
- Includes the move of the experimental station XT03 to the XT05 position (pink)
- Additional equipment required
  - 6 dipoles
  - 19 quadrupoles singlets
  - 8 steerers
  - 10 beam diagnostics boxes

CERN input: A. Parfenova, D. Voulot, B. Goddard, M. Fraser

ISOLDE

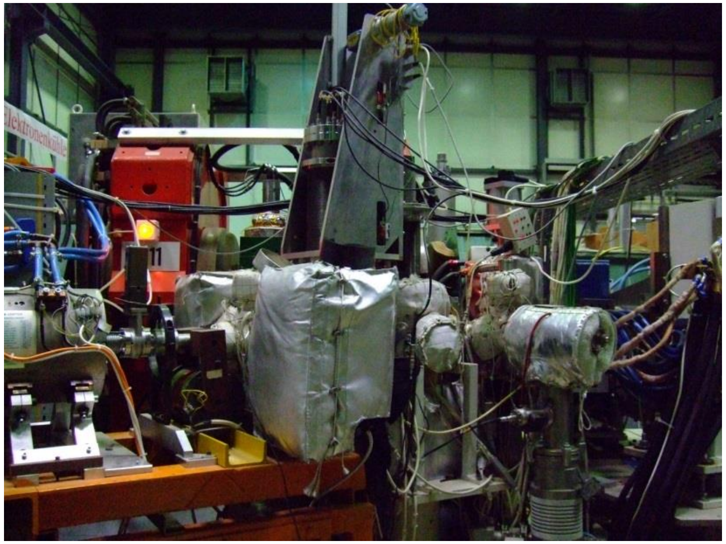
Extraction lines



* Tentative layout for two experimental stations.

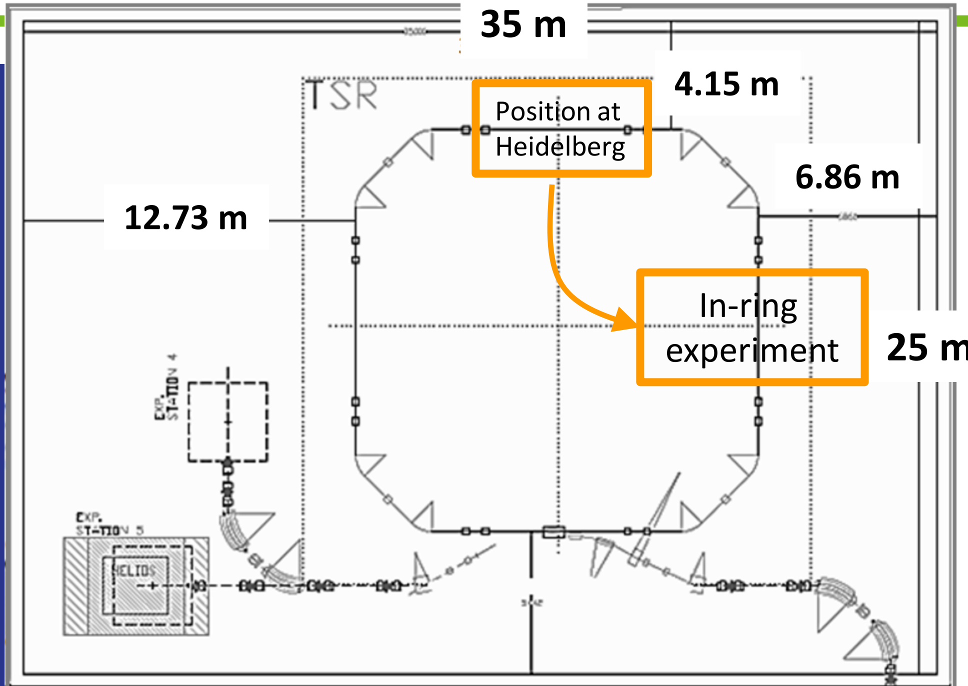
* Beam optics study initiated.

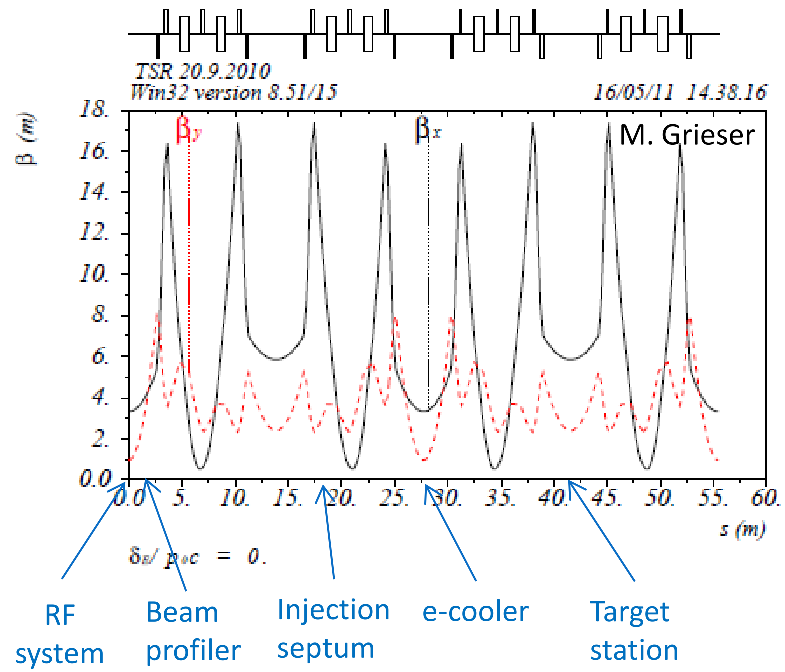
**** Awaiting feedback from physics community.***



CERN input: A. Parfenova, D. Voulot, B. Goddard, M. Fraser

Position of in-ring experiment





Benefits of change

1. Smaller β-function

smaller beam size

lifetime increase with in-ring target

2. Small dispersion in the RF region

beam position independent of beam energy

easy to hit the target

3. Advantageous for storage of multiple charges

avoid betatron oscillations and beam losses

Beam dimensions:

$$x_{\max} = \sqrt{\varepsilon_x \cdot \beta_x}$$

☹ **Rearrangement of optics lattice required**

Technical integration study

Technical integration study

* Study group E. Siesling, E. Piselli, F. Wenander

Mandate - a report covering the following aspects should be prepared:

An inventory of all equipment to be brought to CERN for installation.

Initial estimates for the infrastructure needed for the ring and it's transfer lines. This should include the overall space, power, cooling and safety needs. It should not include a detailed design of these systems.

For each system a brief study of the equipment to be installed should be undertaken after discussion with the experts in Heidelberg and the concerned CERN groups. This study should include:

- The issues associated with the integration of the equipment into the CERN accelerator environment.
- The spare situation for the equipment together with any issues or recommendation concerning additional spares.
- A radiological assessment of the equipment in collaboration with RP.
- The control system presently used for the system and whether the control hardware must be replaced to meet CERN standards.
- Any specific costs associated with the initial installation, or the modification to meet CERN standards should be estimated.

* Study running Sep 2012 to Aug 2013

Technical integration study

Assumptions and limitations

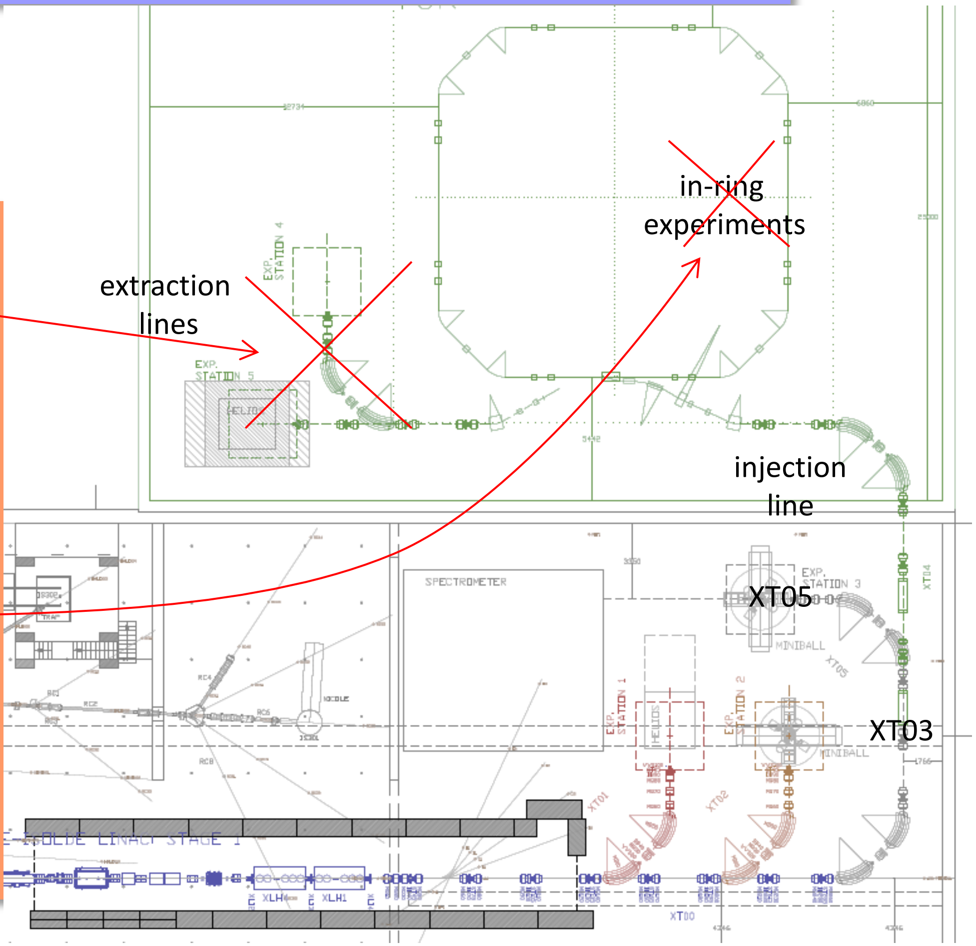
1. Study covers the injection line from HIE-ISOLDE to TSR and the associated costs.

2. Assumes that a 3rd beam line XT03 exists, which is modified to TSR.

1. Study does not cover the cost of extraction line(s); only presents possible layouts.

2. Study does not cover in-ring experiments
   electron target
   gas-jet target

6. Study does not cover an upgrade of REXEBIS which is needed for some physics cases.



Technical integration study

* Divided into 18 work packages.
* Full equipment inventory.
* TSR elements evaluated by CERN specialists -> CERN recommendations.
* In general a positive response and supportive response from the CERN groups.

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

* Preliminary results presented at IEFC 31/7-2013.
* Final report to Director of accelerators and Department leaders 28/8-2013.
* Full presentation (140 pages) and executive summary (15 pages) can be obtained upon request (from F. Wenander).

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. The CERN support groups claim that the cost of some WPs can be reduced if the allocated budget so requires. *However, no contingency included.*

b. Most CERN groups have insisted on hardware changes and CERN standardization and discourage a 3 years transition period with temporary solution as that would inflate the costs.

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.

c. Power converters, vacuum, magnets, RF and e-cooler could in principle be imported as such.

d. Improved electrical ring safety is mandatory if the ring is imported as is.

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

11.8 MCHF 17.1 FTE (man year)

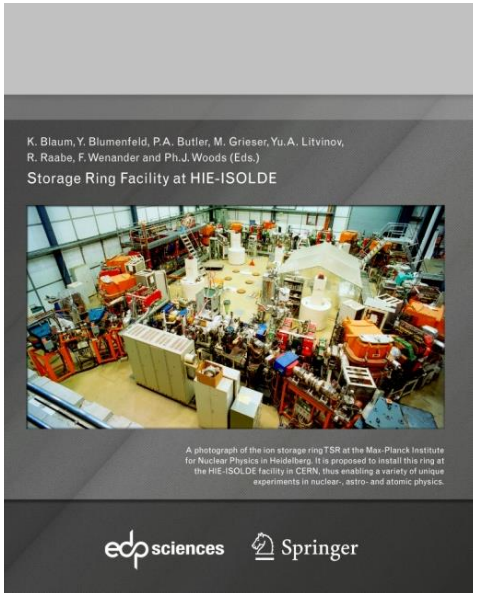
The cost saving might appear low. Reasons:
** The main cost drivers are the injection line, buildings and infrastructure.*
** Some spares, complementing parts and replacement parts are absolutely necessary.*
** Includes the mandatory electrical protection of magnets connections.*
** Includes sensitivity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

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."

* Technical integration study; report submitted to CERN management 28/8-2013

* Presentation of the project to the CERN Research Board by K. Blaum 27/11-2013

* TSR@ISOLDE workshop at CERN 14/2-2014 (registration open)

General conclusions

- A storage ring at an ISOL facility: a unique instrument
  First storage ring with ISOL-facility!
- Possibilities in atomic, nuclear, astro- and neutrino physics
- TSR matches the HIE-ISOLDE characteristics
- The technical aspects of the integration have been studied
- Now awaiting response from the management…