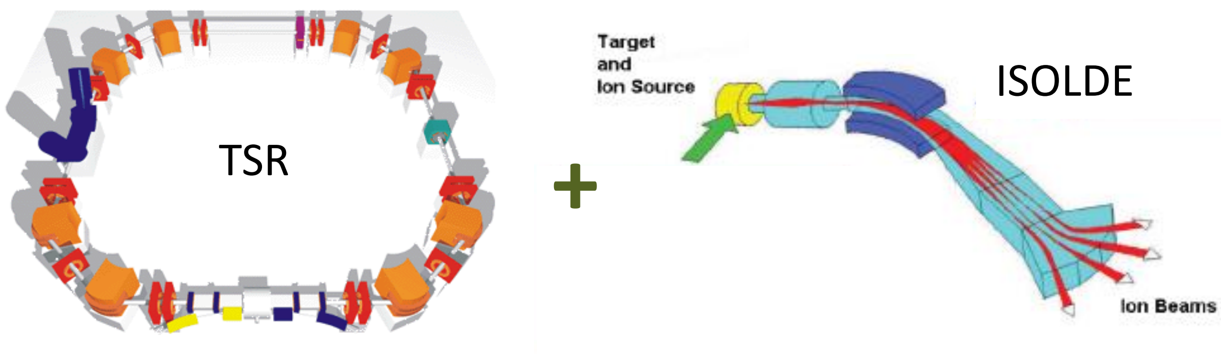
TSR ISOLDE

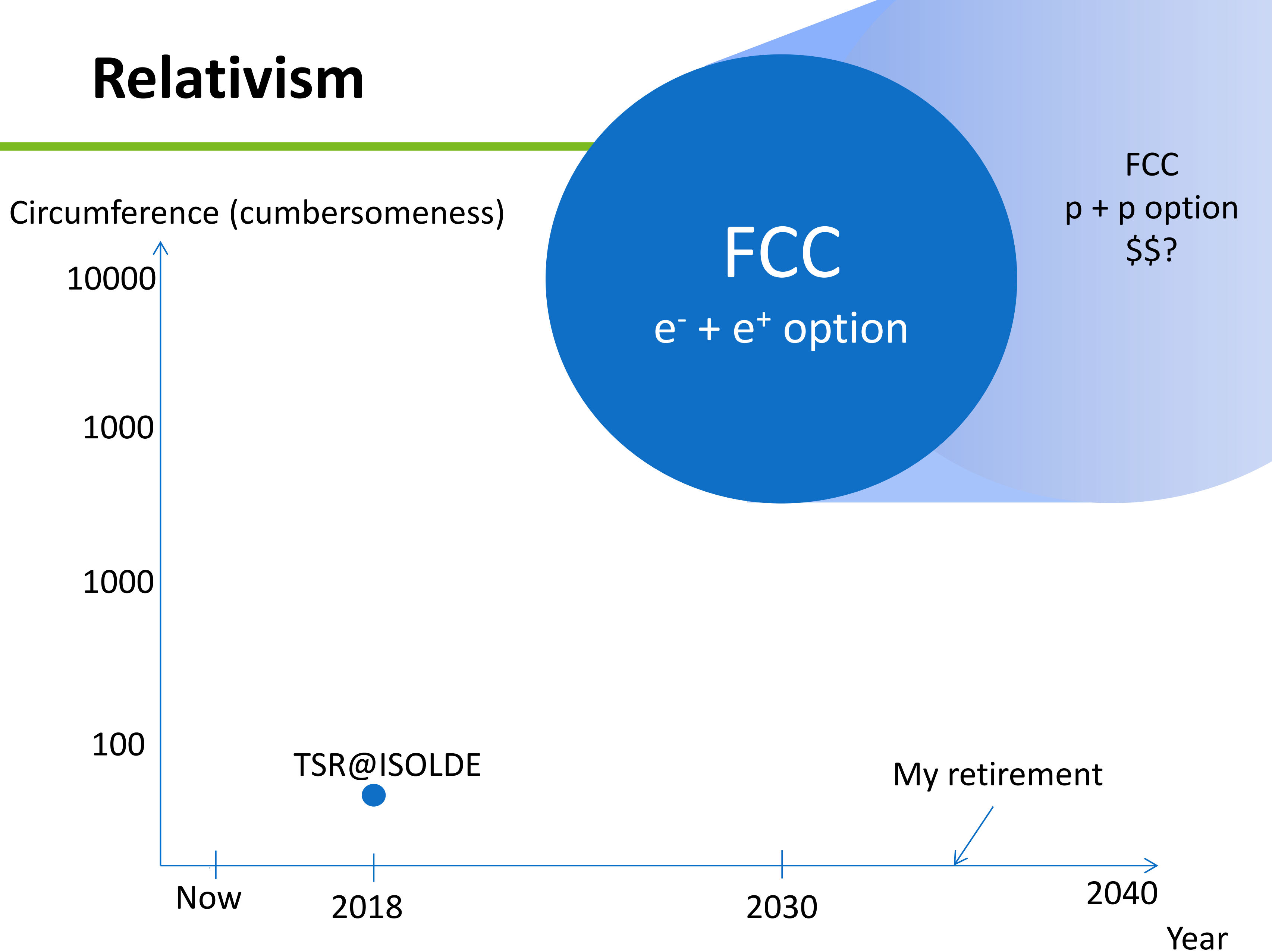


Fredrik Wenander

CATHI Review Meeting

Barcelona 23/9-2014

Relativism



The area of the dot corresponds to the cost

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

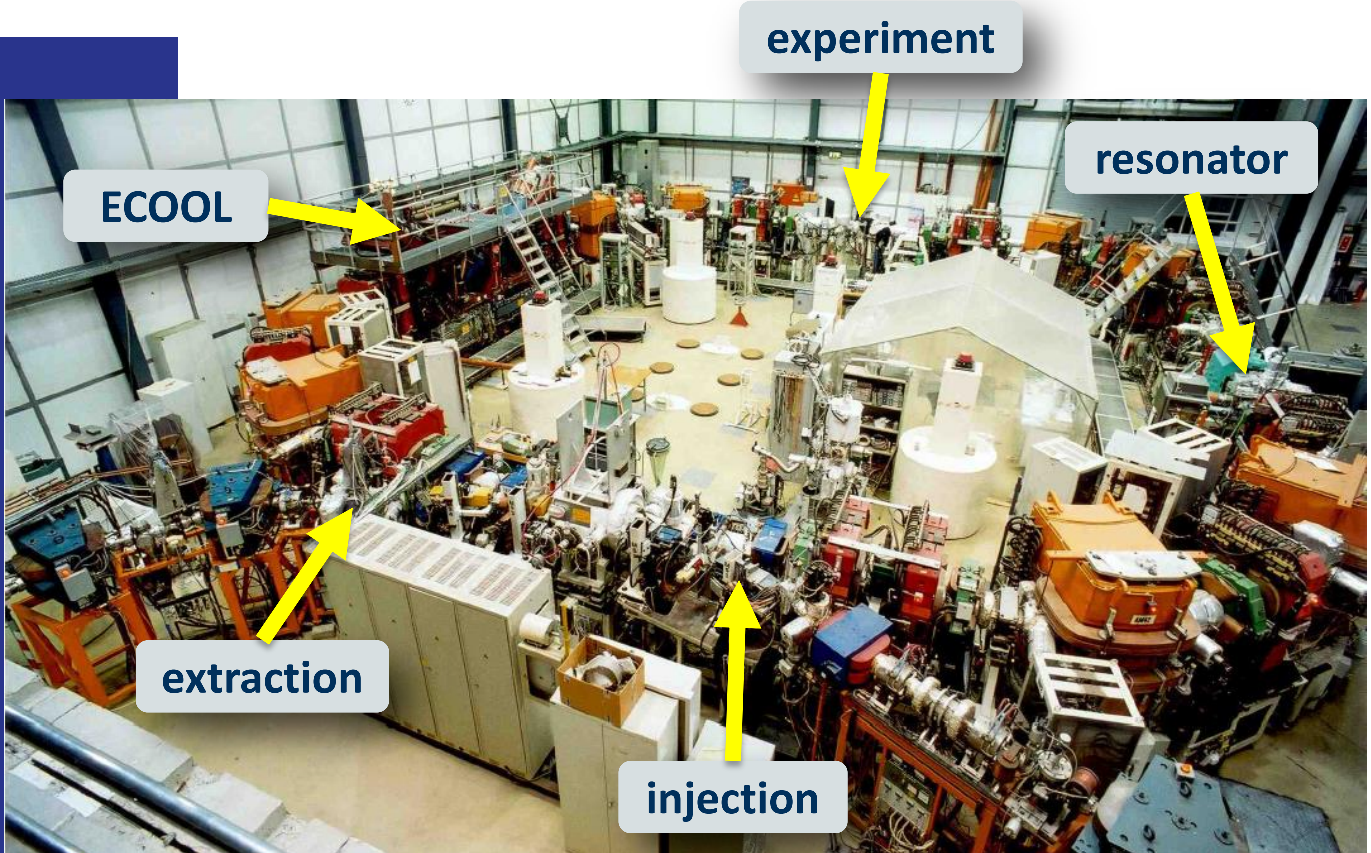
- **TSR @ ISOLDE**
- **CRYRING @ ESR**

TSR 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

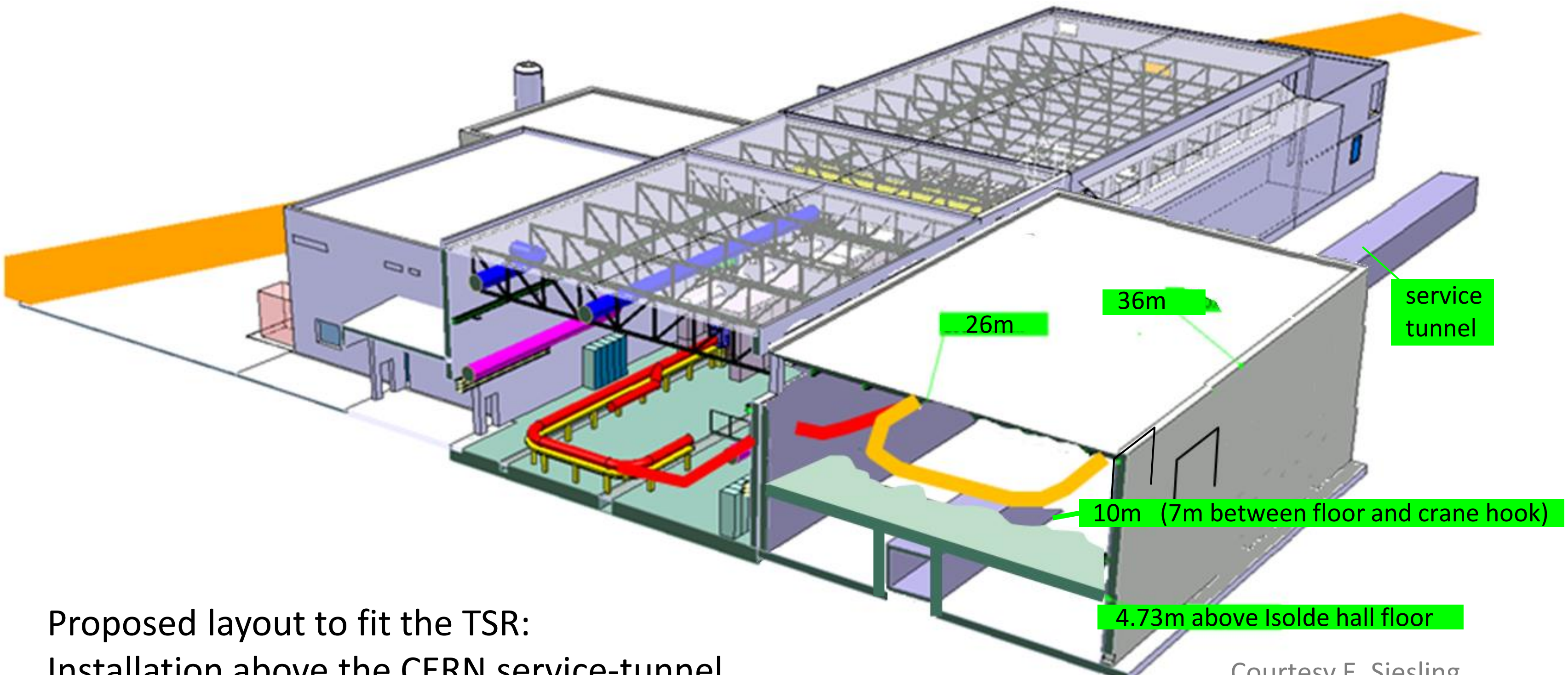
Nuclear physics

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

Neutrino physics

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.



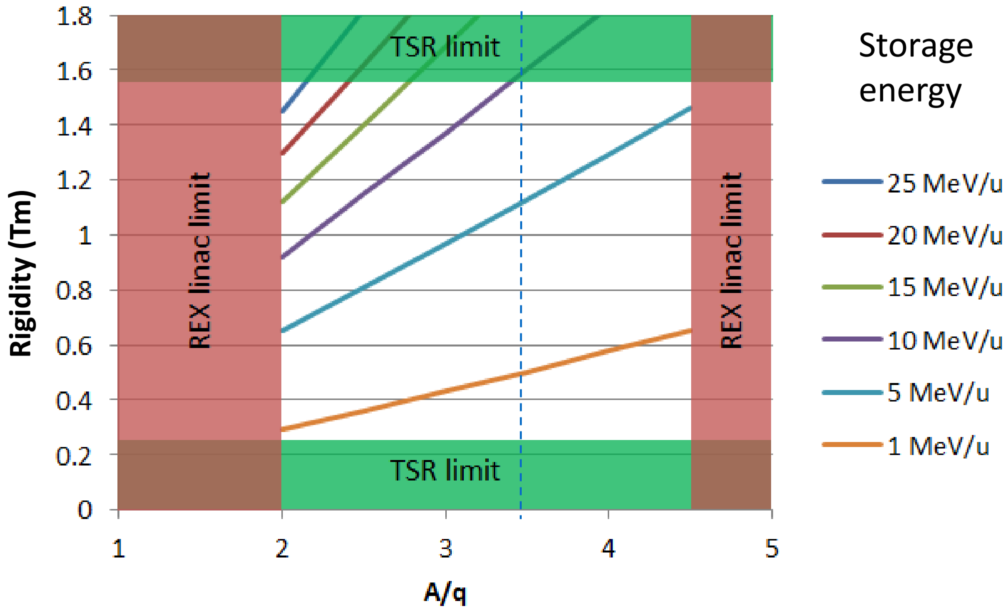
Courtesy E. Siesling

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

ISOLDE

Machine performance

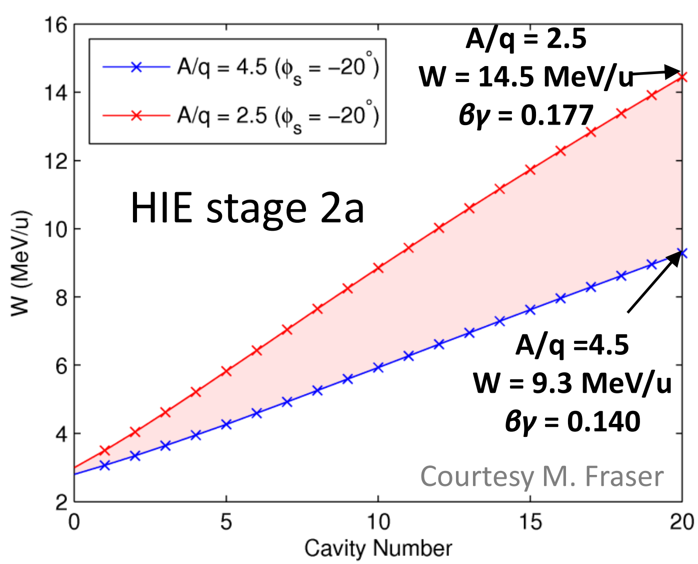
Ring beam energy



TSR magnetic rigidity range: 0.25-1.57 Tm

REX linac 2<A/q<4.5

5 MeV/u sufficient for lifetime and nuclear structure studies



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

☹ Takes several seconds though

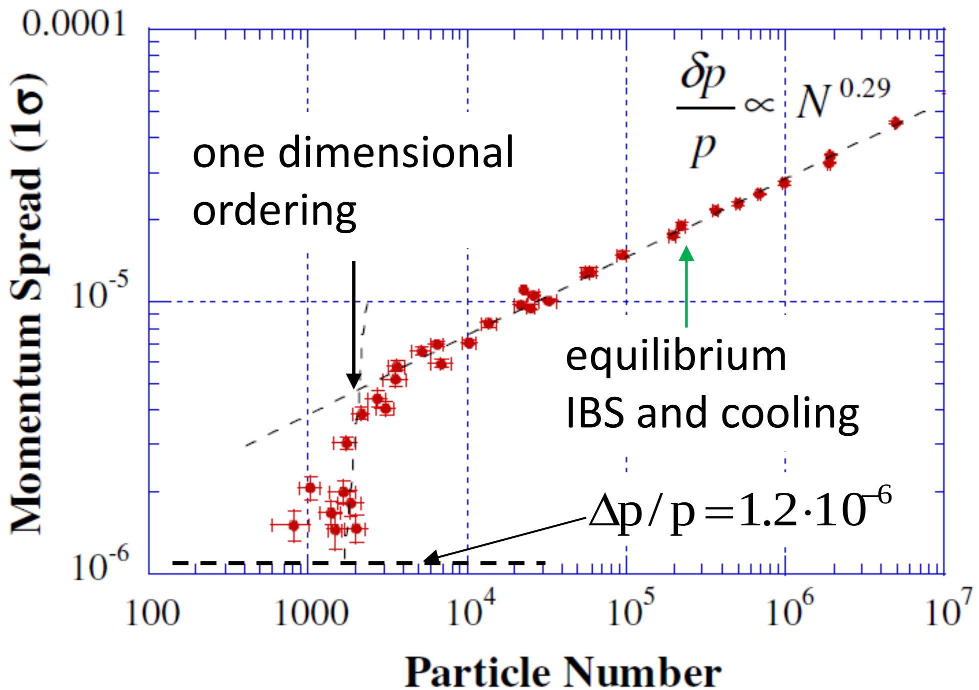
e-cooling

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

Δp/p ~ 5E-5 (rms)
Δp/p < 1E-5 (rms) for N<1000

HIE-ISOLDE Δp/p ~ 1E-3 (rms)



Measurement done with 7 MeV **protons** at the LSR storage ring, Kyoto University

T. Shirai et al. PRL 98, 204801 (2007)

e-cooling

E-cooling needed for:

1. Reducing momentum spread
2. Stacking of multi-turn injection
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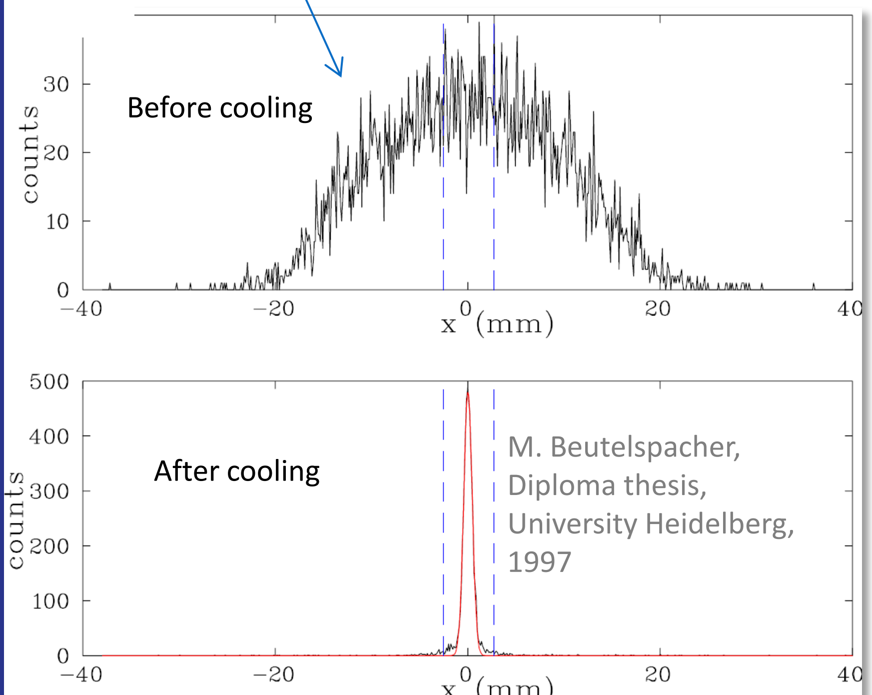
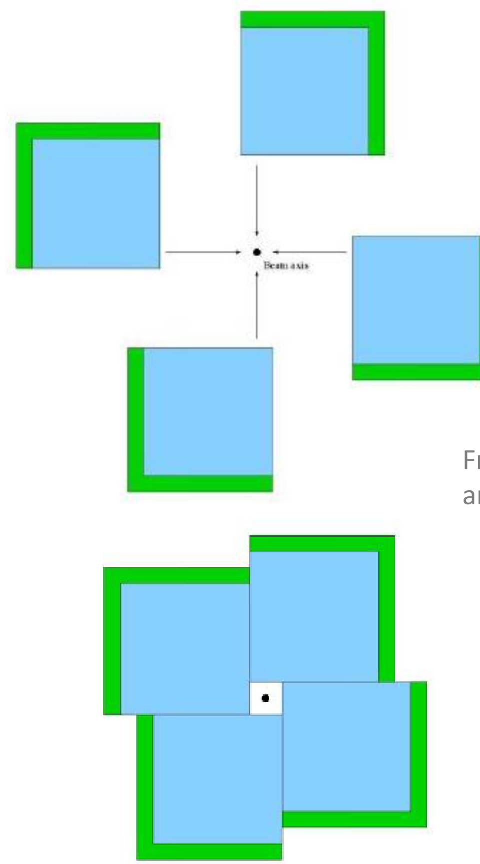
4. Reducing beam size



Radial beam extension

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



From T. Davinson and P. Woods

e-cooling

E-cooling needed for:

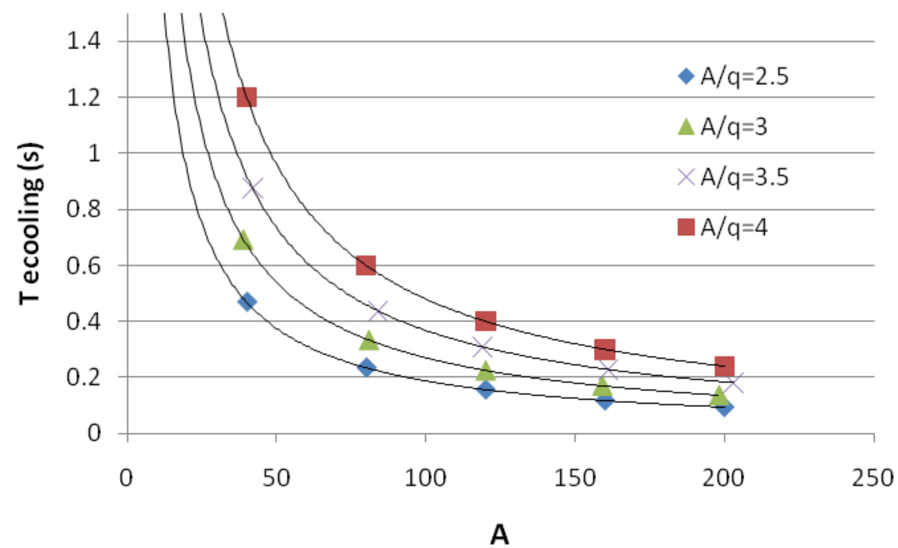
1. Reducing momentum spread
2. Stacking of multi-turn injection
3. Compensate for energy loss in target
4. Reducing beam size

$$T_{cool} \approx \frac{A}{q^2} \cdot 3s$$

in the velocity range
0.03<ß<0.16

ion	T_{cool} (s)	nuclear τ_n (s)	fraction of particles left after cooling
$^{8}B^{3+}$	2.7	0.77	3 %
$^{10}C^{4+}$	1.9	19.3	90 %
$^{16}C^{4+}$	3	0.747	2 %

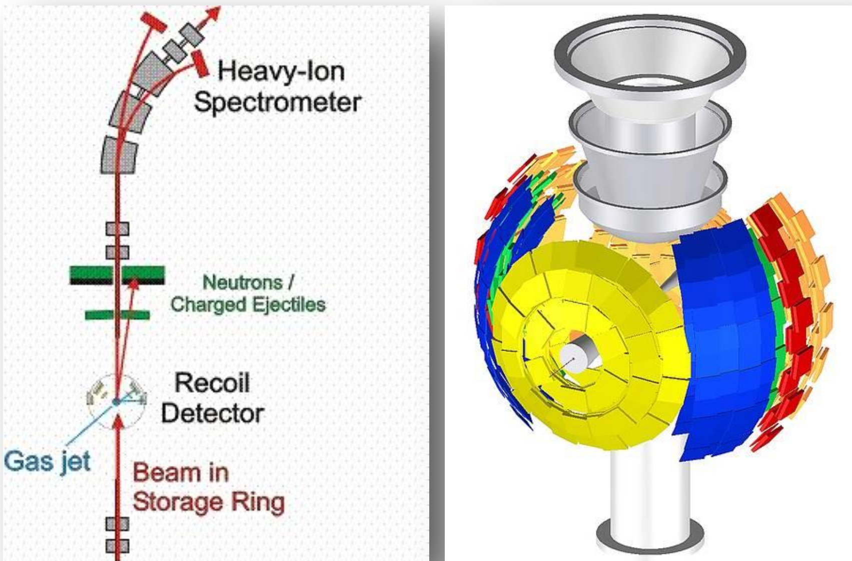
Proposed ions for laser spectroscopy



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.



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.

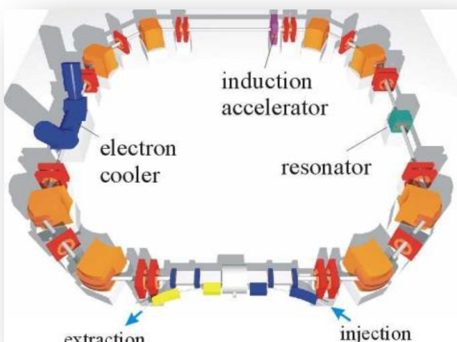
Gas-jet target

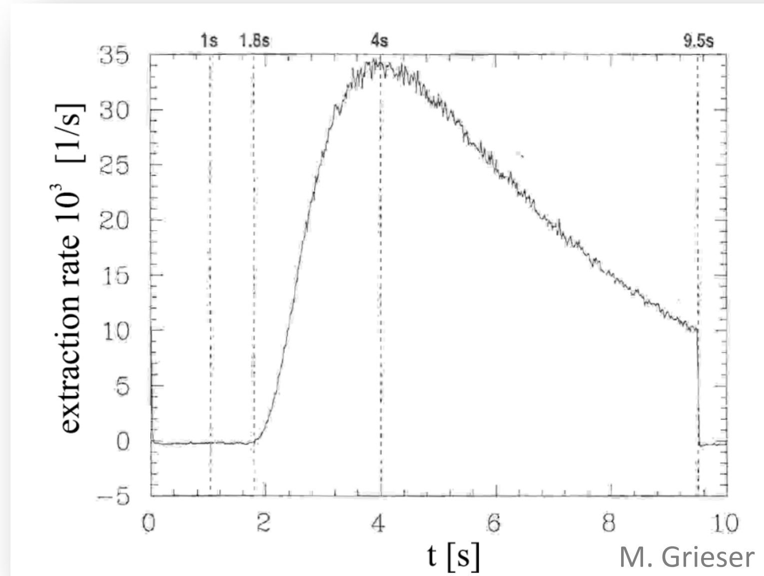
* Not existing, being studied
* Targets with thicknesses of ~ 10^{14} atoms/cm^2 for light gases as H_2, d, ^3He and ^4He

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

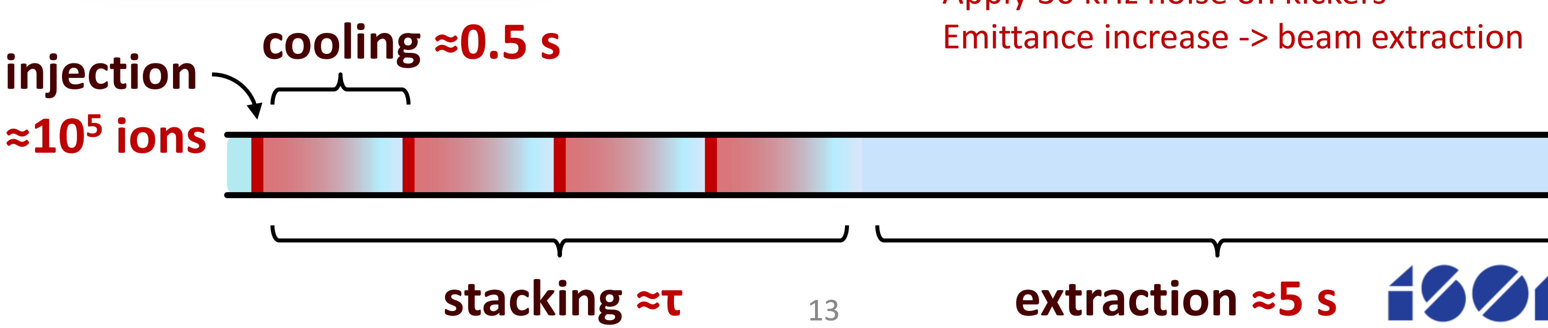
Slow extraction

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



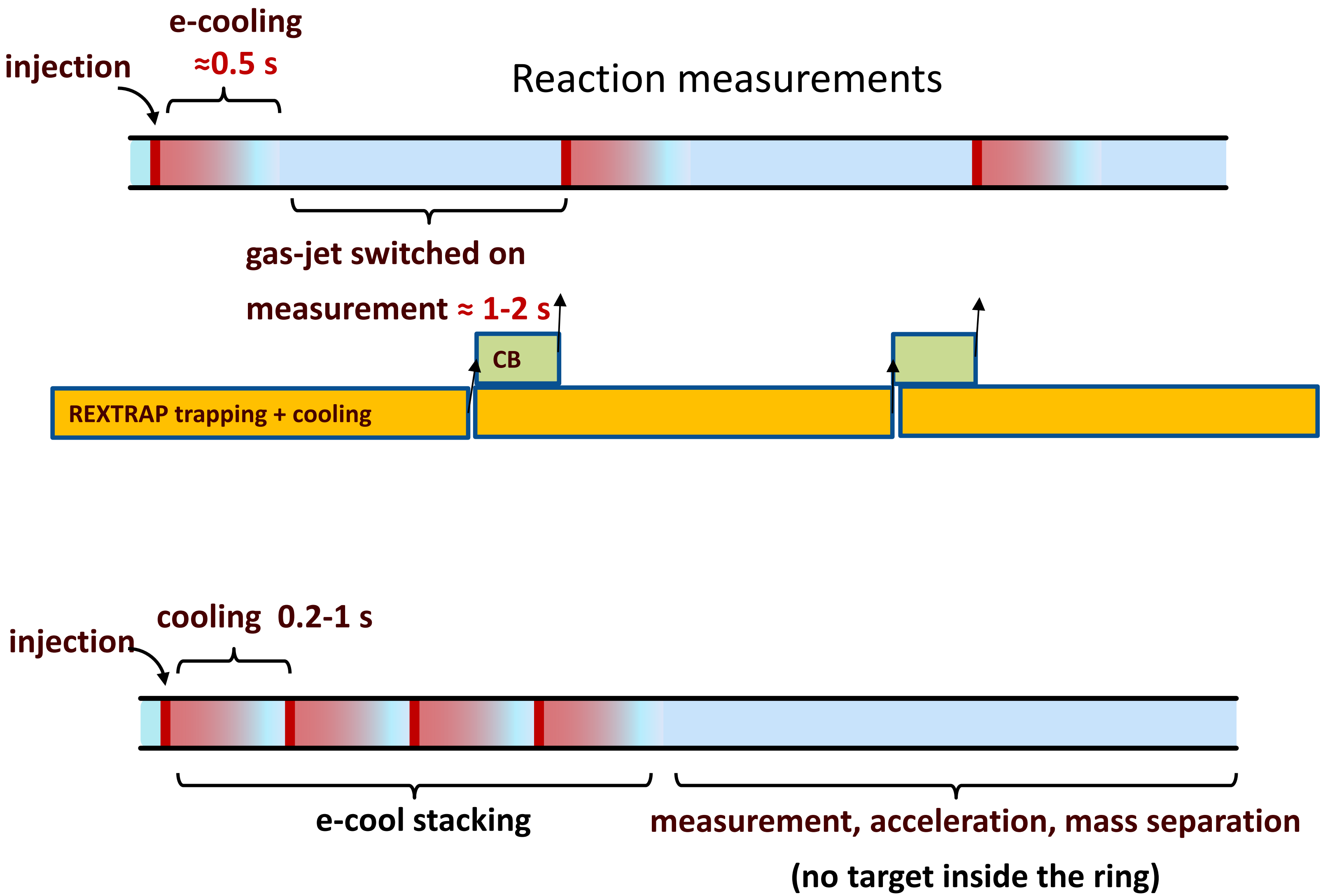


Normal procedure for $^{12}C^{6+}$
- Inject at Q_x=2.64
- e-cool for 1 s
- Shift Q_x close to resonance 8/3
- Apply 30 kHz noise on kickers
- Emittance increase -> beam extraction



Many different ways of operating the machine

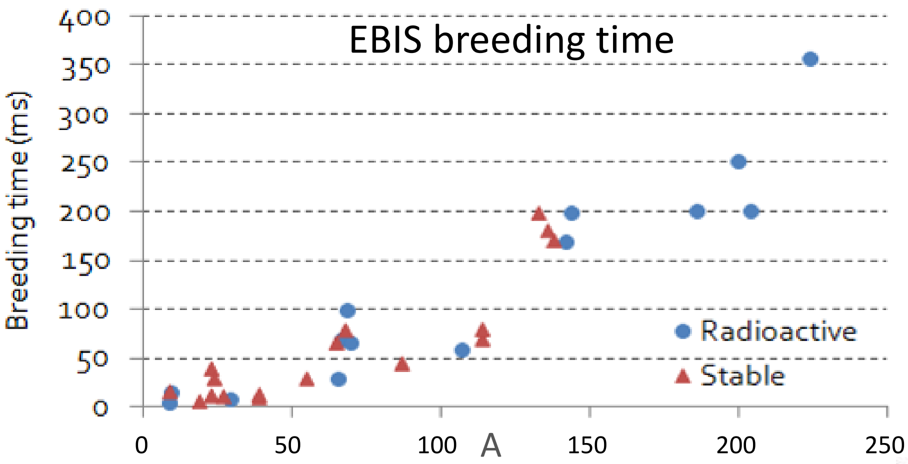
Injection rate



Based on R. Raabe presentation

Storage in REXTRAP essential

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



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

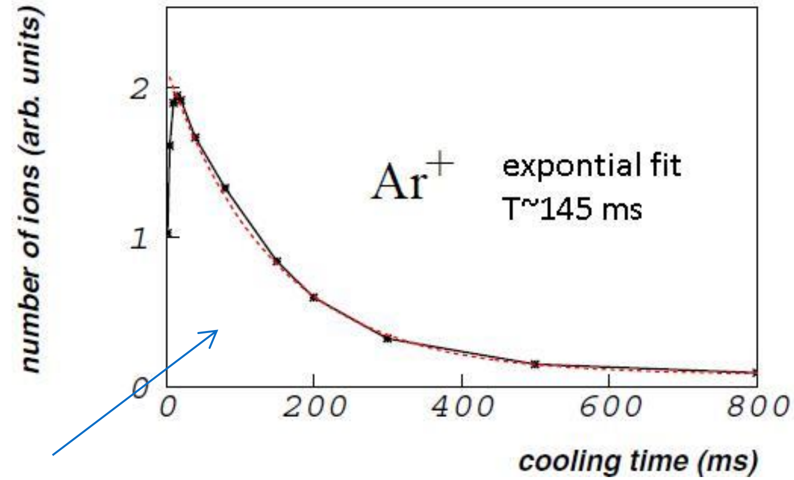
+ ample time to reach high charge states

Holding time in REXTRAP

$^{60}Ni^{+}$ and $^{87}Rb^{+}$ kept for >1.5 s

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

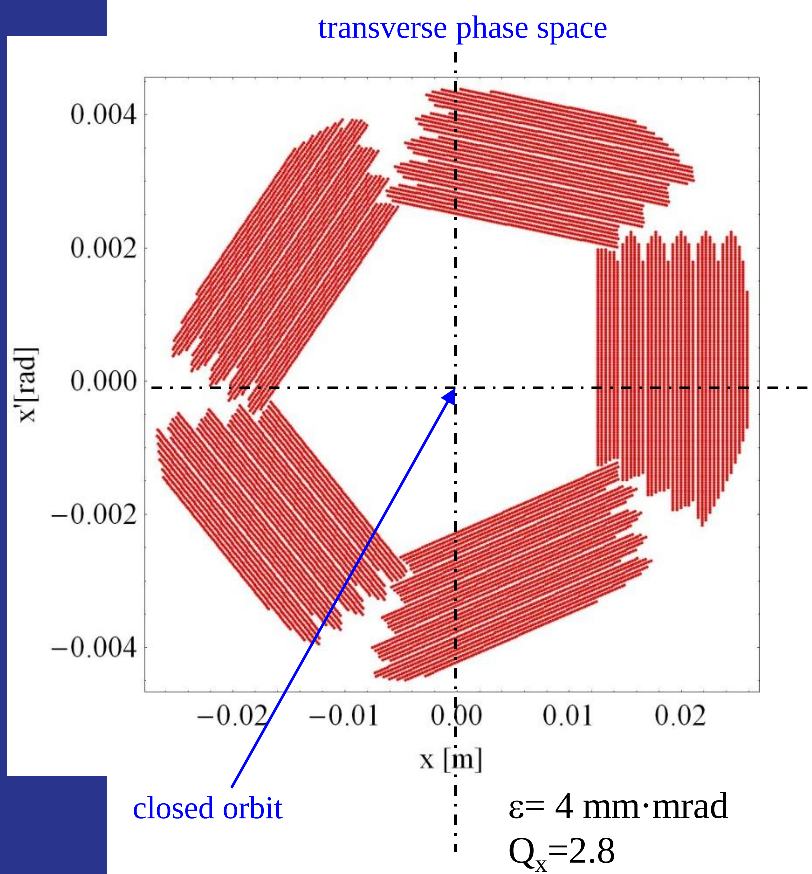


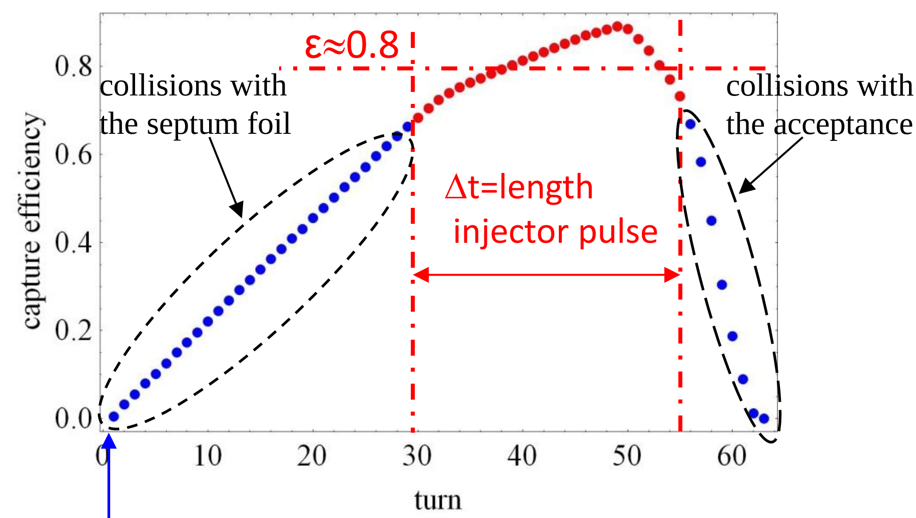
P. Delahaye et al., Nucl Phys A746 (2004) 604

Ring injection time

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

Slide from M. Grieser

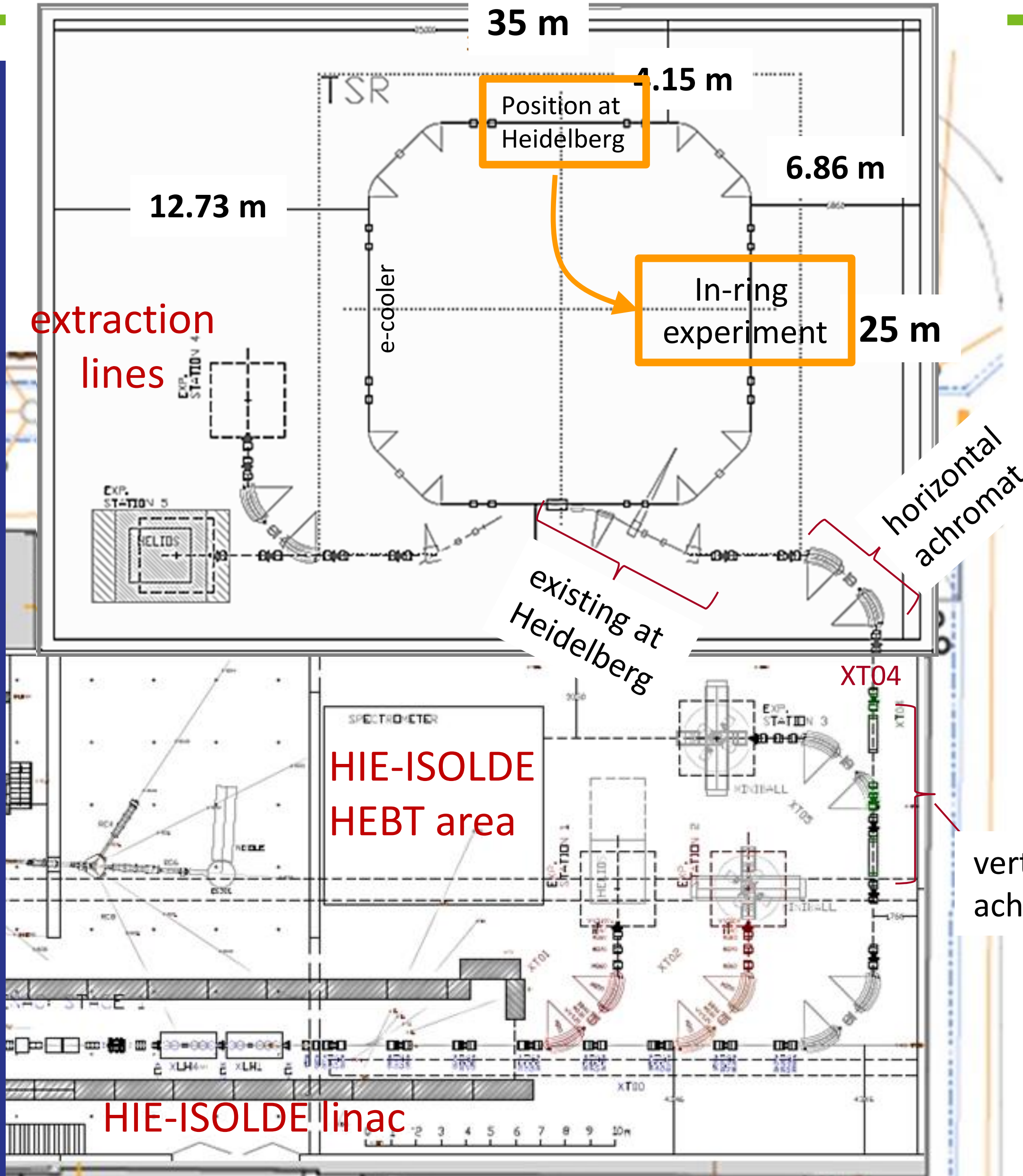




Δt ≈ 25 turns
typically ≈ ***33 μs*** at 10 MeV/u

Beam-line layout

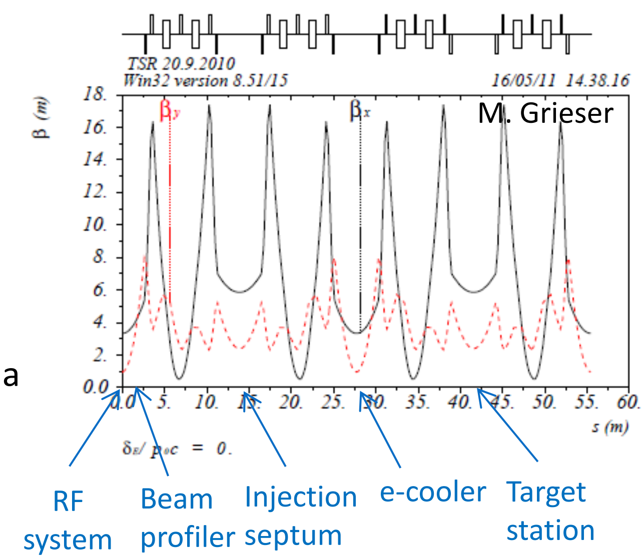
Beam-line layout



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

REXEBIS 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

Benefits from high q

- Rigidity TSR
- Storage lifetimes
- Cooling times
- Experiments

☹ But some experiments might require:

* Fully stripped to Z~60

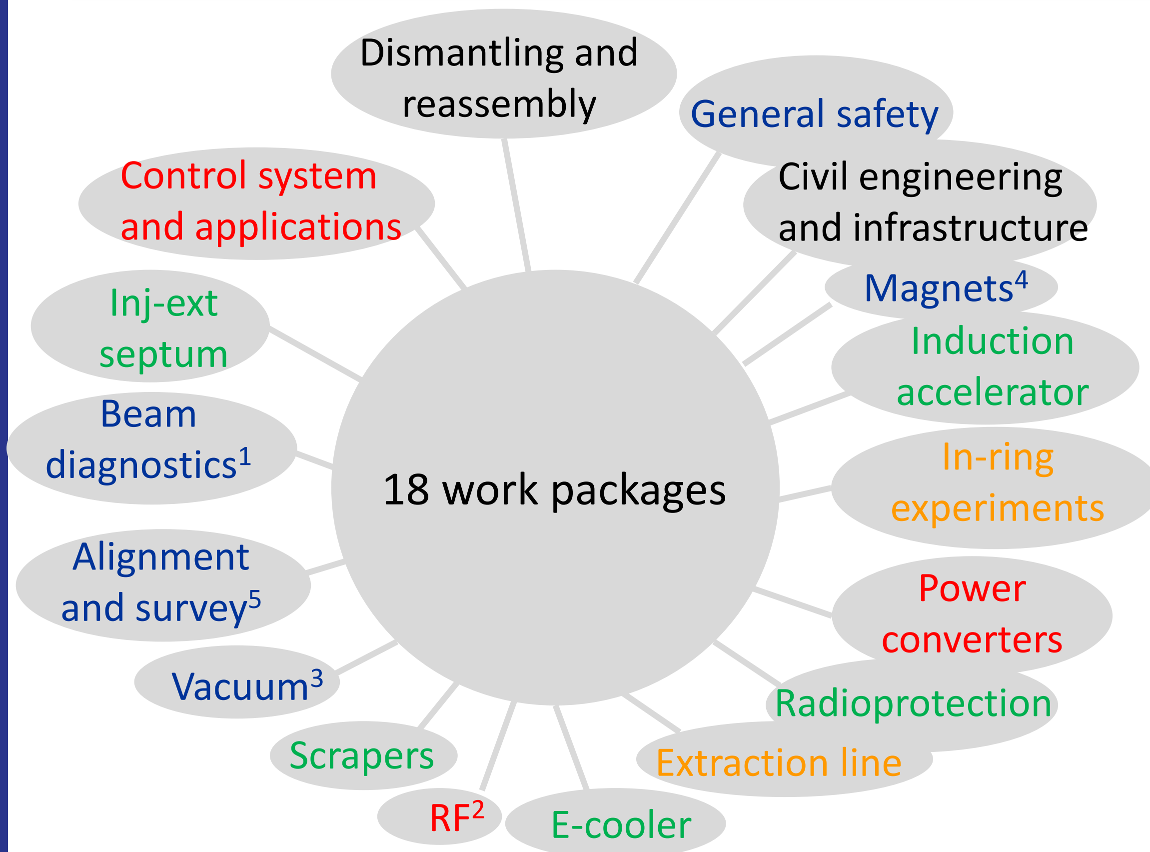
* Few-electron system, e.g. for Th/U

Addressed by HEC[2] EBIS
see A. Shornikov's talk

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 for scenario 1

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

ISOLDE

General conclusions

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

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

TSR@ISOLDE

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