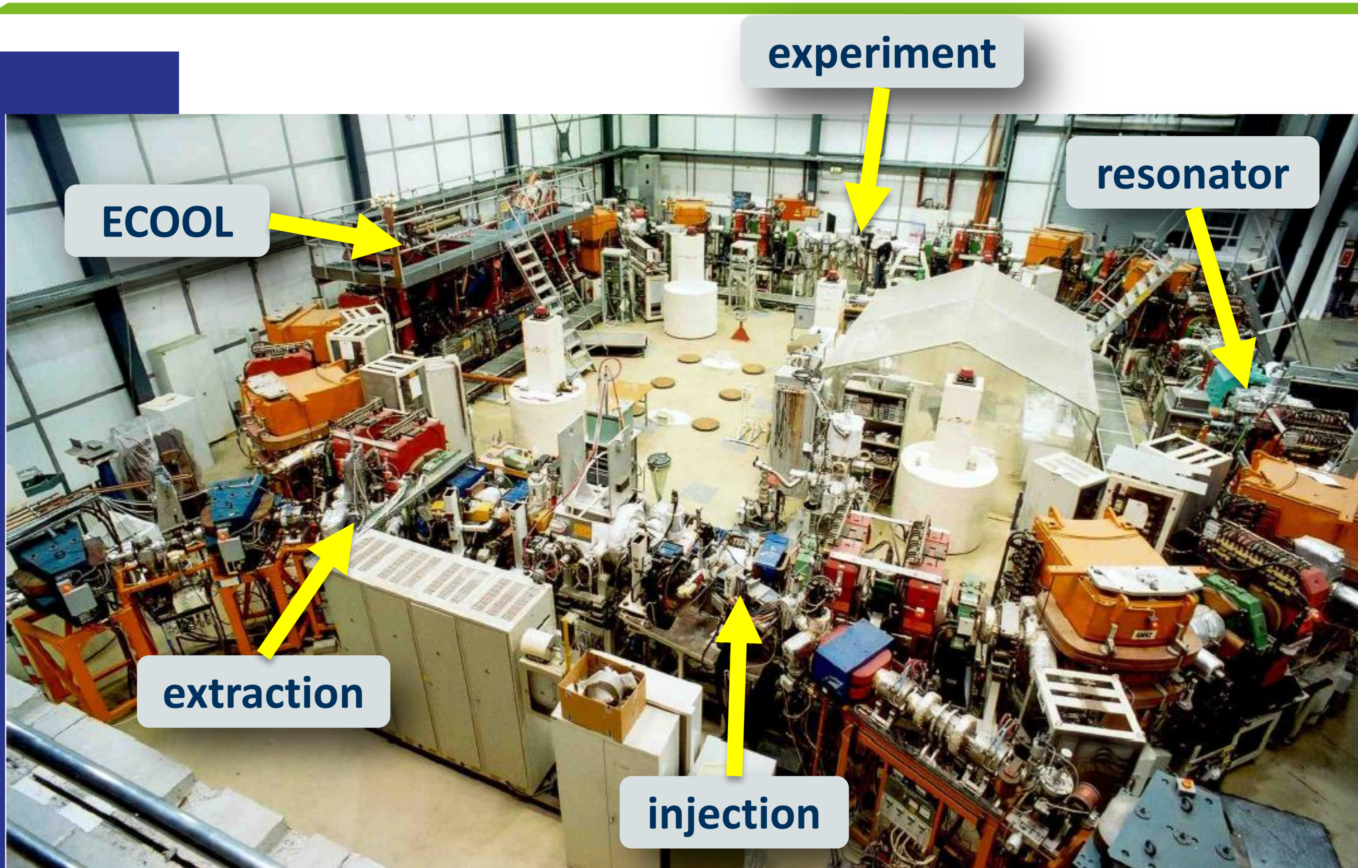
Report on technical study of TSR@ISOLDE

Outline

1. Beam-line layout
2. Storage time REXTRAP
3. Upgrade of charge breeder
4. Technical integration study
5. Conclusions

Fredrik Wenander, TSR workshop 14/2-2014

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)

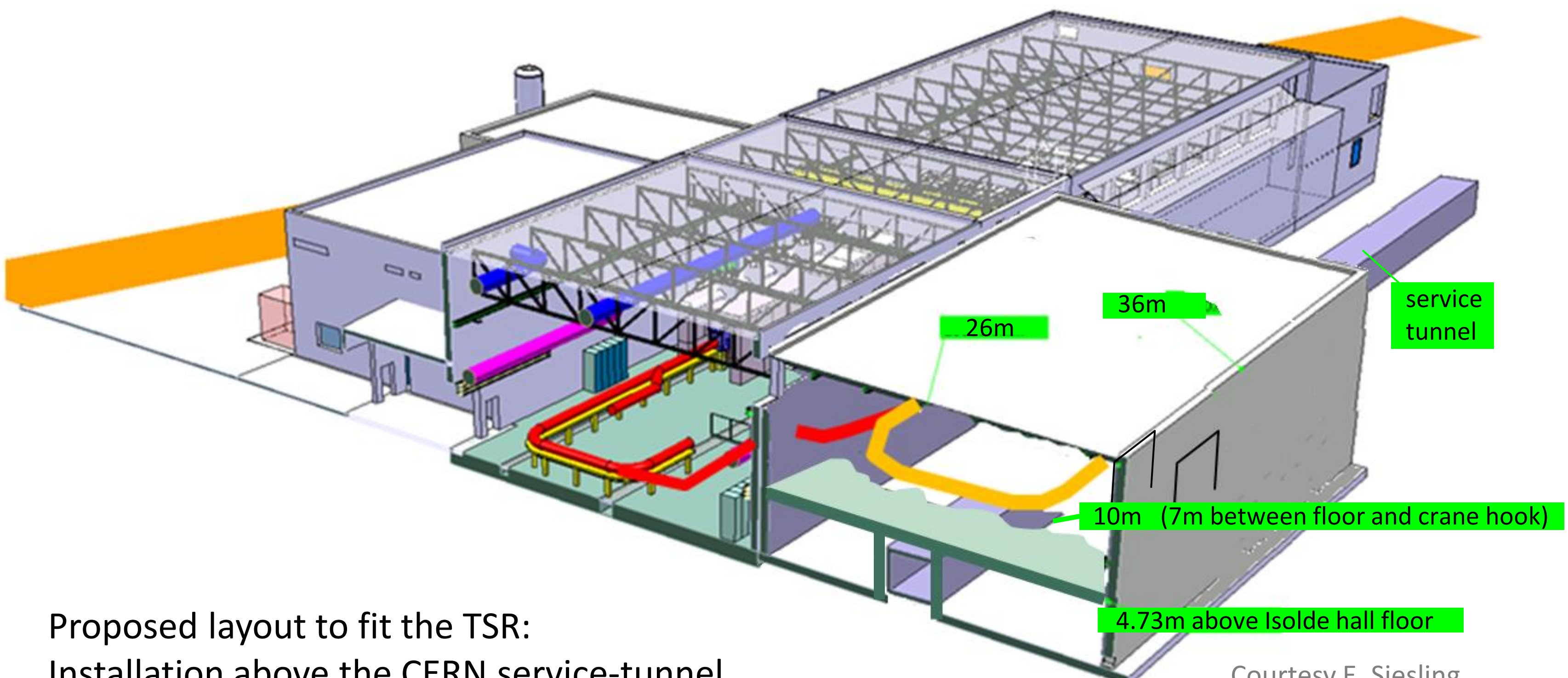
Circumference: 55.42 m
Vacuum: ~few 1E-11 mbar
Acceptance: 120 mm mrad

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

Beam-line layout

Building layout

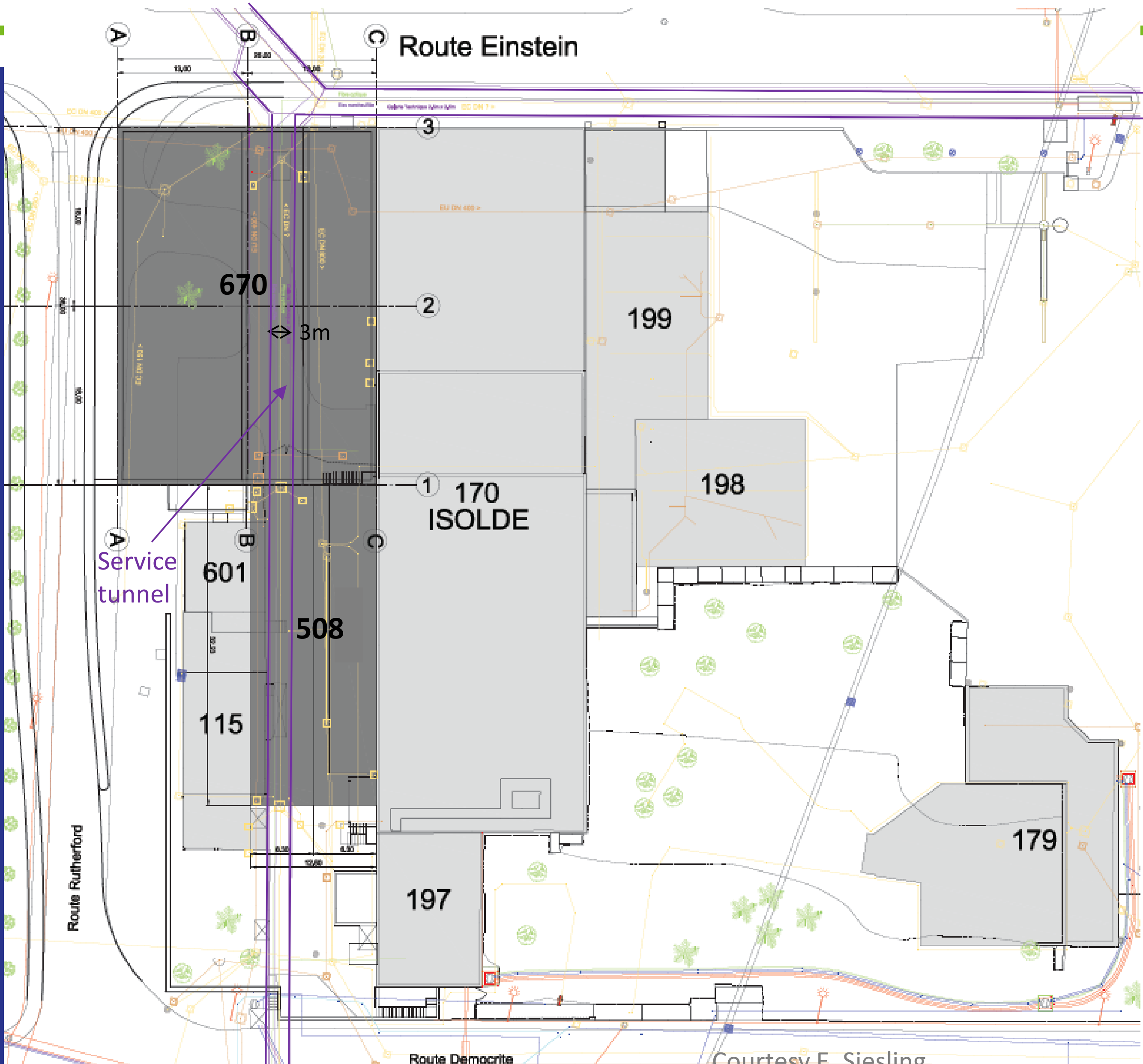
Presently at MPI-K, Heidelberg, a large hall is housing the TSR with enough space around it for experiments and equipment that need to be close to the ring. The basement underneath the ring is used for power supplies and other necessary equipment.



Courtesy E. Siesling

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

Building layout



Courtesy E. Siesling

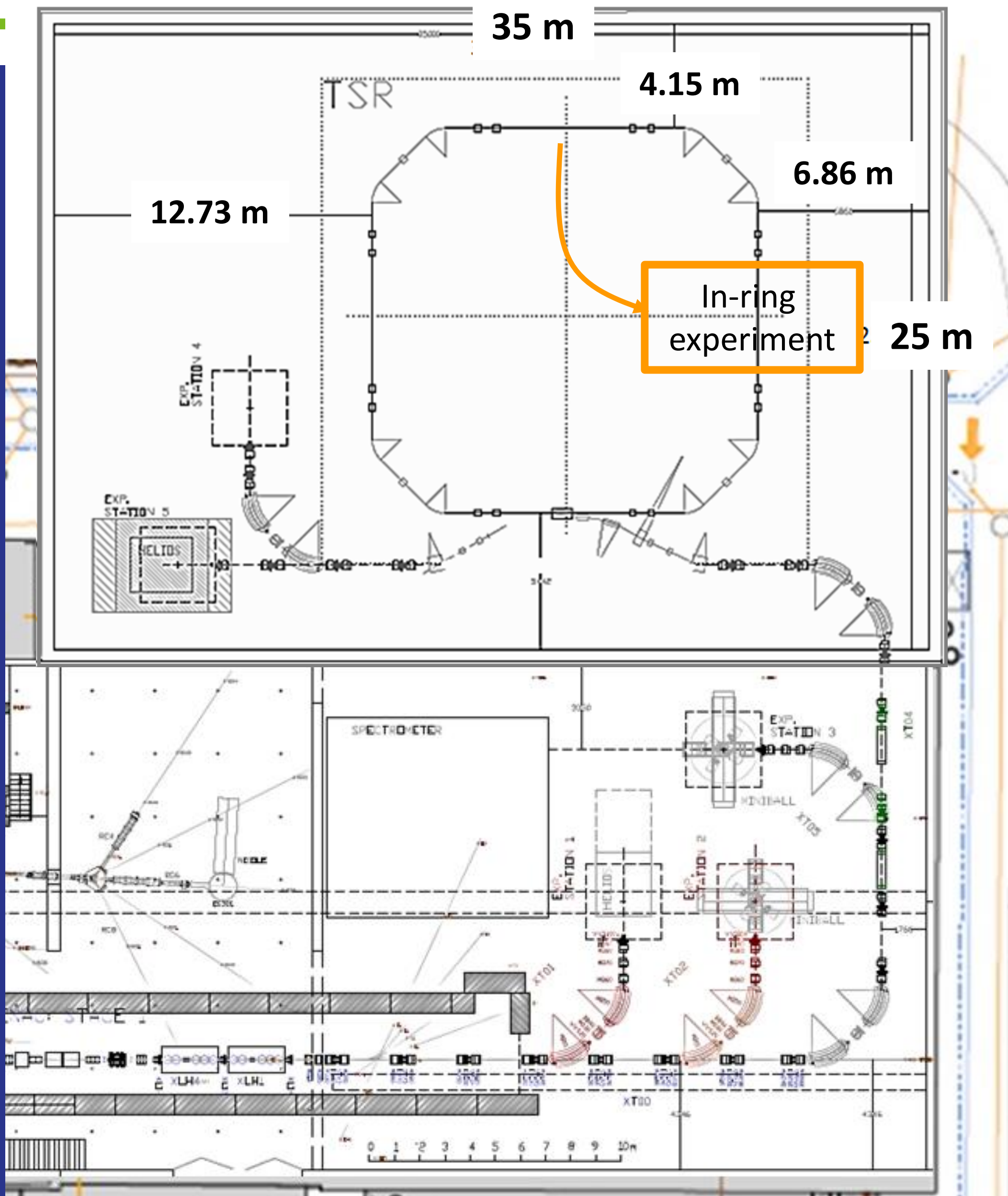
TSR building 670:
Taken in account at the construction of the new user building 508.

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.

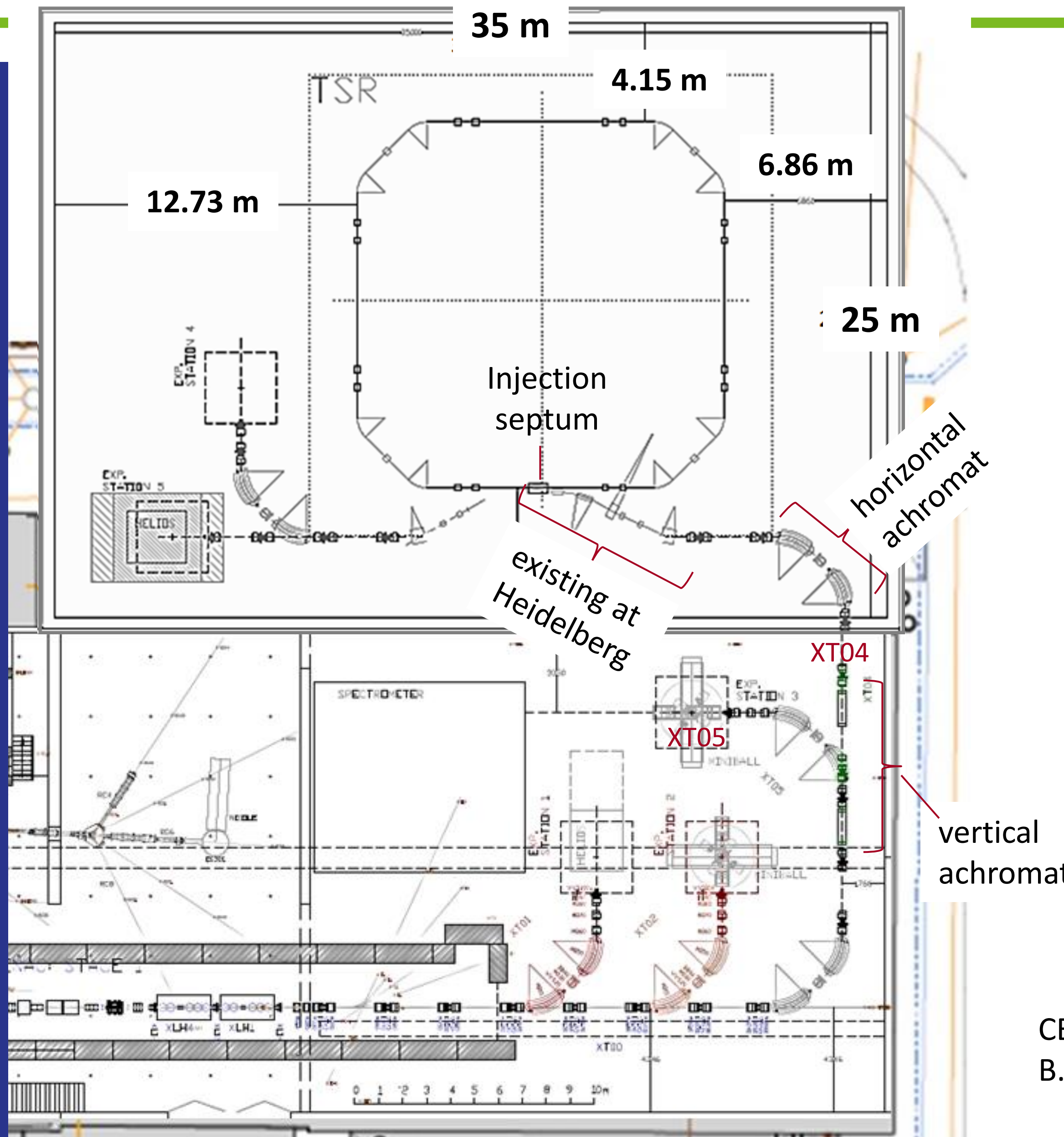
3. Standardization -> HIE-HEBT elements for inj. & ext. lines

4. Technically and beam-optically feasible

5. Two experimental stations for extracted beam

6. *No* beam-line back to ISOLDE

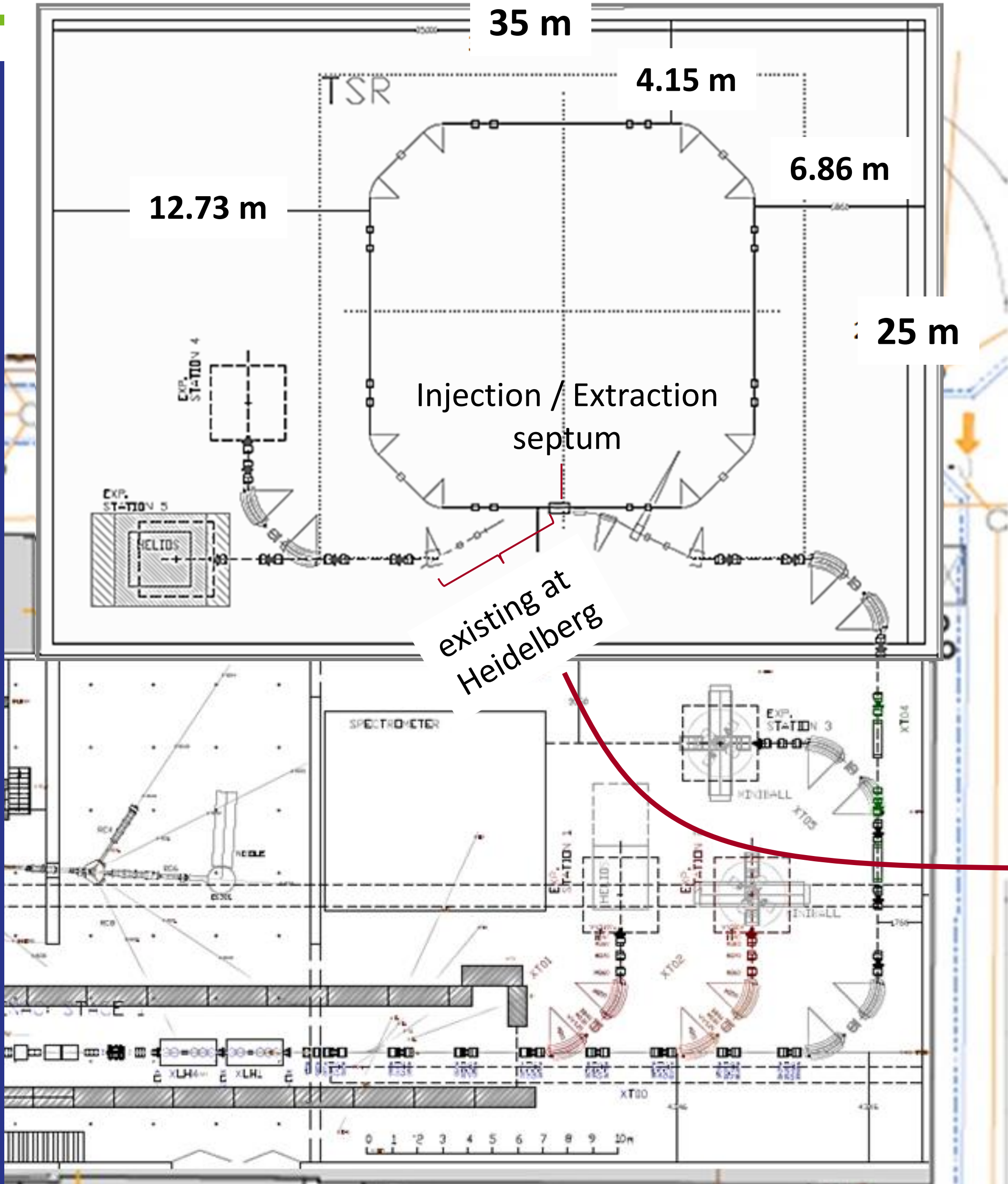
Injection line



- 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
- Additional equipment required
  - 6 dipoles
  - 19 quadrupoles singlets
  - 8 steerers
  - 10 beam diagnostics boxes

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

Extraction lines

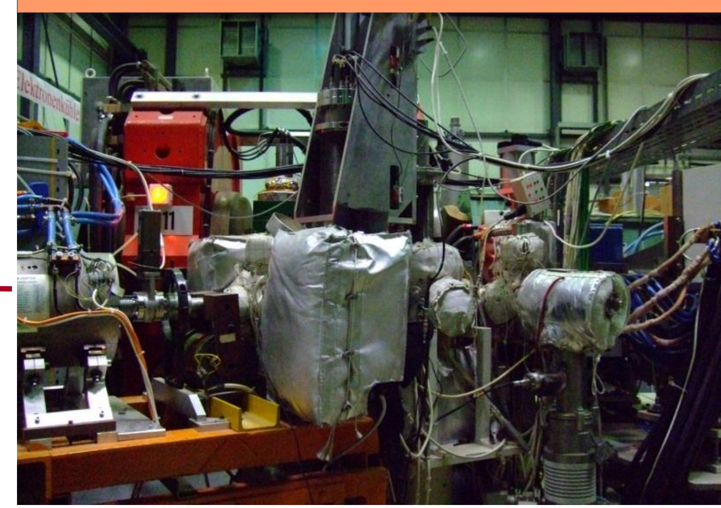


* Tentative layout for two experimental stations.

* Tolerated stray magnetic field at ring from experiments
$\int B_{stray} ds < 10^{-4}\ Tm$

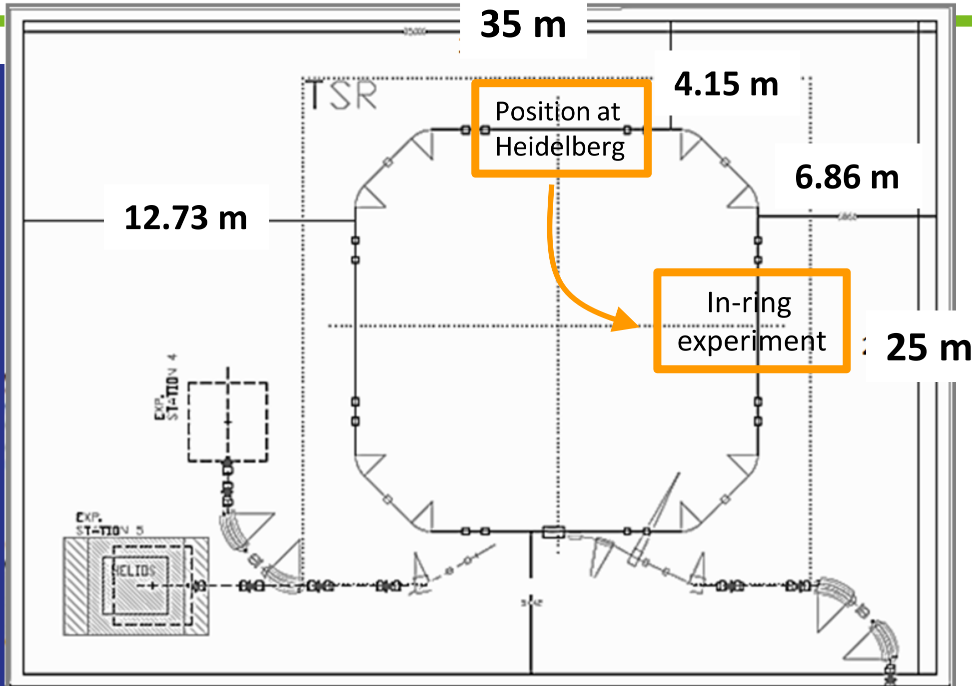
* Beam optics study initiated.

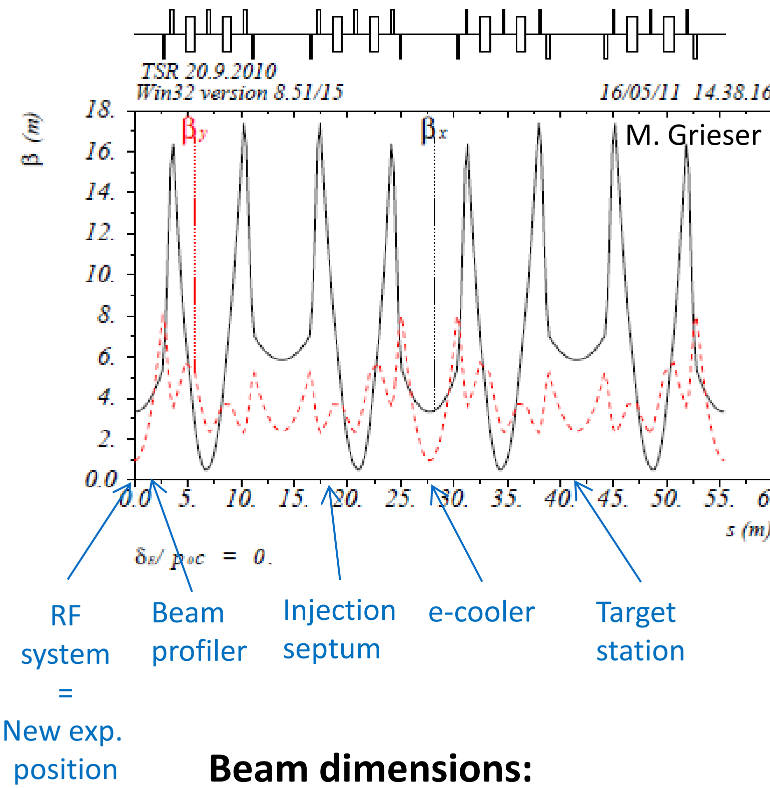
**** Awaiting feedback from physics community.***



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:

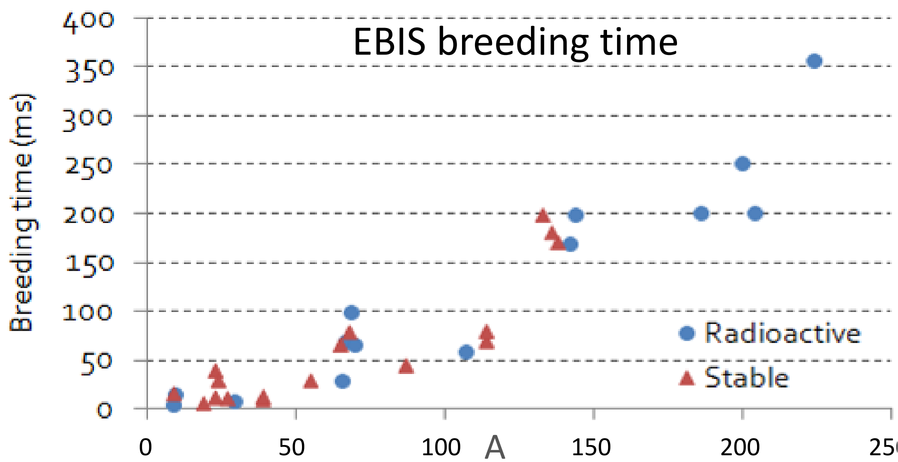
$$x_{\max} = \sqrt{\varepsilon_x \cdot \beta_x}$$

☹ **Rearrangement of optics lattice required**

Storage time in REXTRAP

Storage time REXTRAP?

* 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

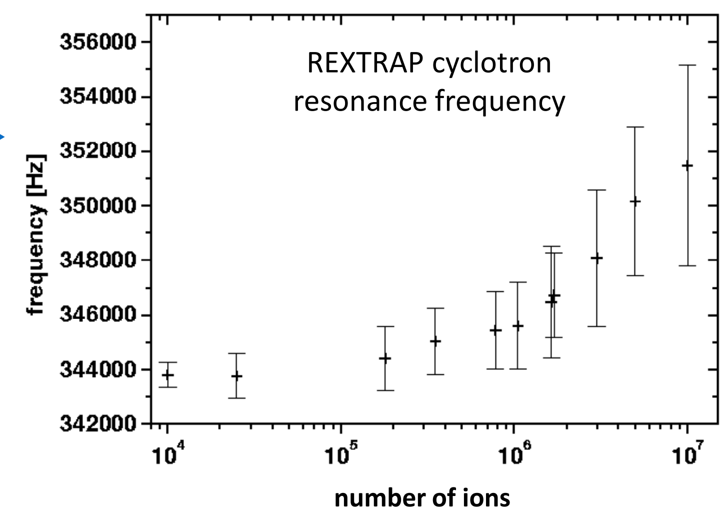
- keep them in ~~1. REXEBIS~~ or 2. REXTRAP

q^+ dependent

We know that space-charge effects

modifies ω_c (can be adapted for)

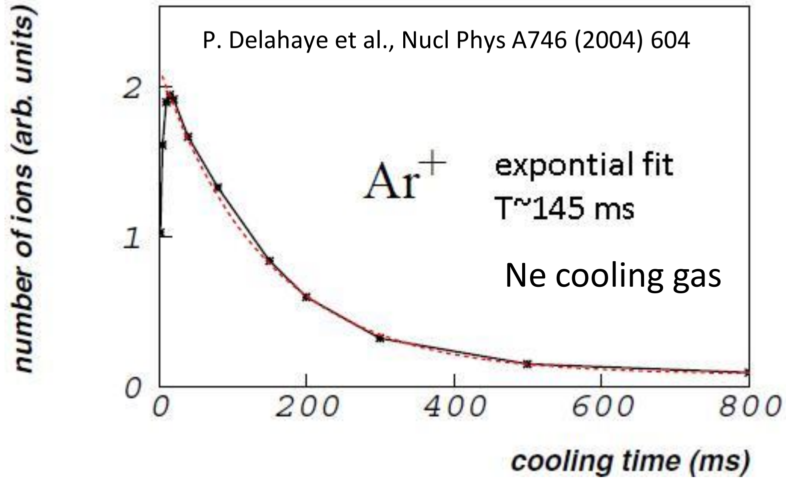
transmission efficiency decreases



Holding time in REXTRAP?

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

Storage time REXTRAP?



The concerns

A. Short-lived ions

B. Noble gases and ions with high ionization potential such as F, Cl, Br

Reason?

Charge exchange with buffer-gas

C. Trapping efficiency in REXTRAP of *radioactive* ions

WITCH experiment has recorded storage times for ^{35}Ar of 0.7 * $\tau_{1/2}$

(space-charge dependent?)

Vague memory of similar effects in REXTRAP

Reason?

Shake-off electrons cause radiative and di-electronic recombination?

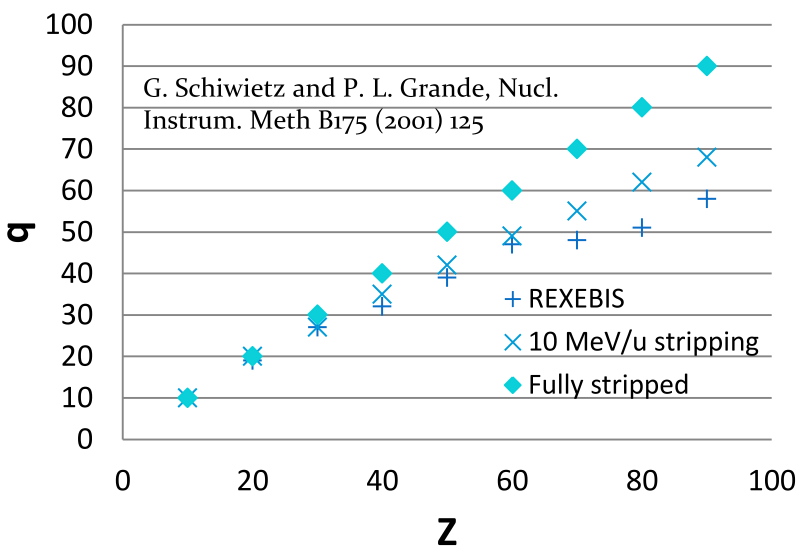
Tests with radioactive ions foreseen for the summer 2014

Charge breeder upgrade

Charge states out of REX

- Rigidity TSR
- Storage lifetimes
- Cooling times
- Experiments

All benefit from high q



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

REXEBIS 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	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

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

☹ But some experiments might require:
* Fully stripped to Z~70
* Few-electron system, e.g. for Th/U

TSR@ISOLDE implications for the HEC^2

Experiment	Species	State	Char breeder requirements
Astrophysical p-process capture	Zn through* Yb	bare	E_e~150 keV, J_e ~1-2x10^4 A/cm^2 ***
Atomic effects on nuclear half-lives	Cu Sn Tl **	H/Li-like	E_e~100 keV, J_e ~1-2x10^4 A/cm^2 ***
DR on exotic ions	Lu U Th	Li/Na-like	E_e~100 keV, J_e ~1-2x10^4 A/cm^2 ***
Atomic data for supernova explosions	Fe Si	1$^+$ to H-like	Not limiting any charge state
Atomic data for fusion research	W	q>22	Not limiting till H-like Courtesy A. Shornikov

* After Z=60 the abundance of bare state will drastically drop

** Only Li-like Tl with acceptable abundance

*** Assumed an injection repetition rate of 1 Hz

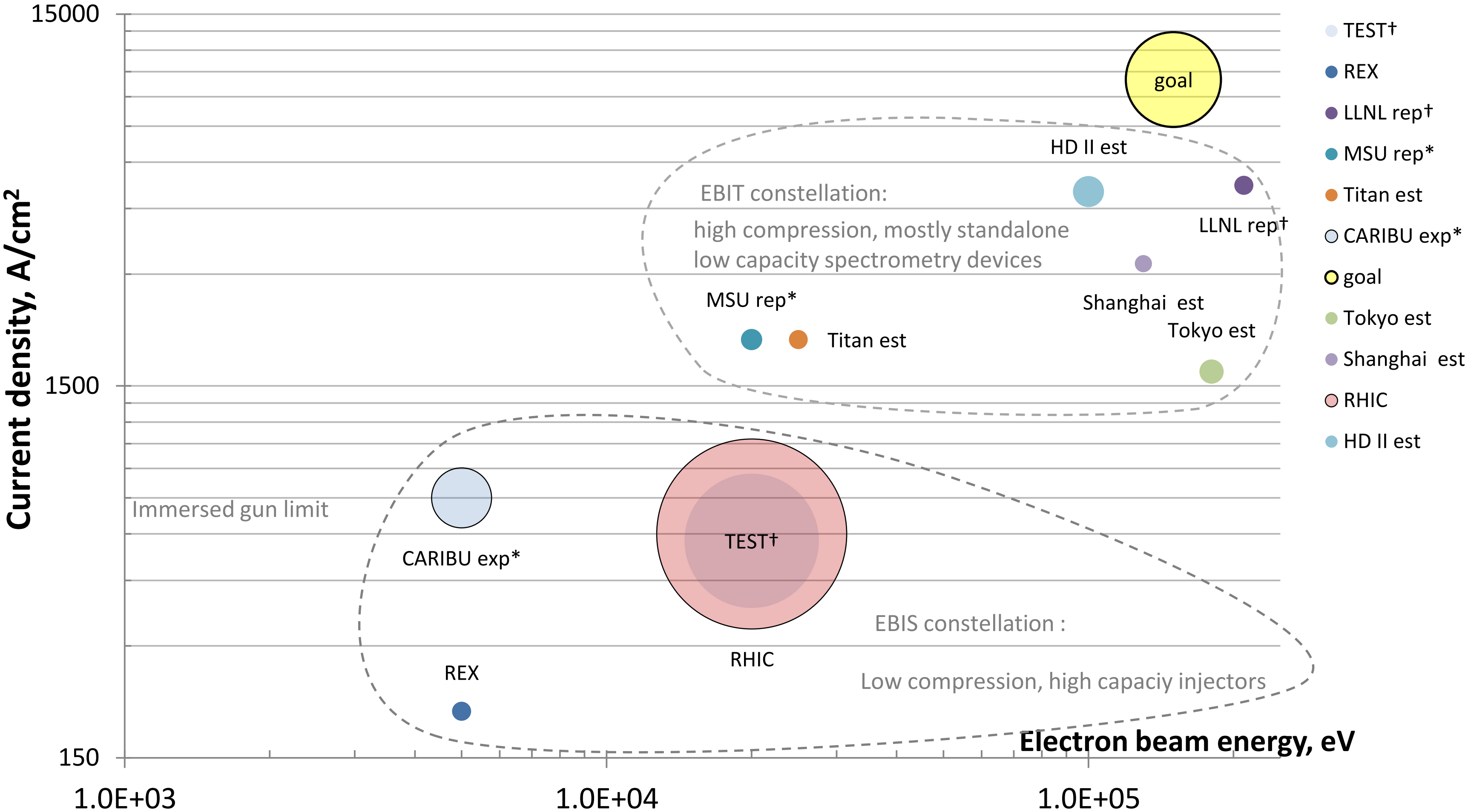
Need a very different breeder

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
Trap pressure (mbar)	~10^{-11}	~10^{-11}
Ion-ion cooling needed	YES	NO
Extraction time (us)	<30	>50

* Capacity of 10^8 primary ions needs current I_e >3 A ,
Transverse acceptance ~ 34 µm (REXEBIS) needs I_e ~ 4-5 A

No such breeders available



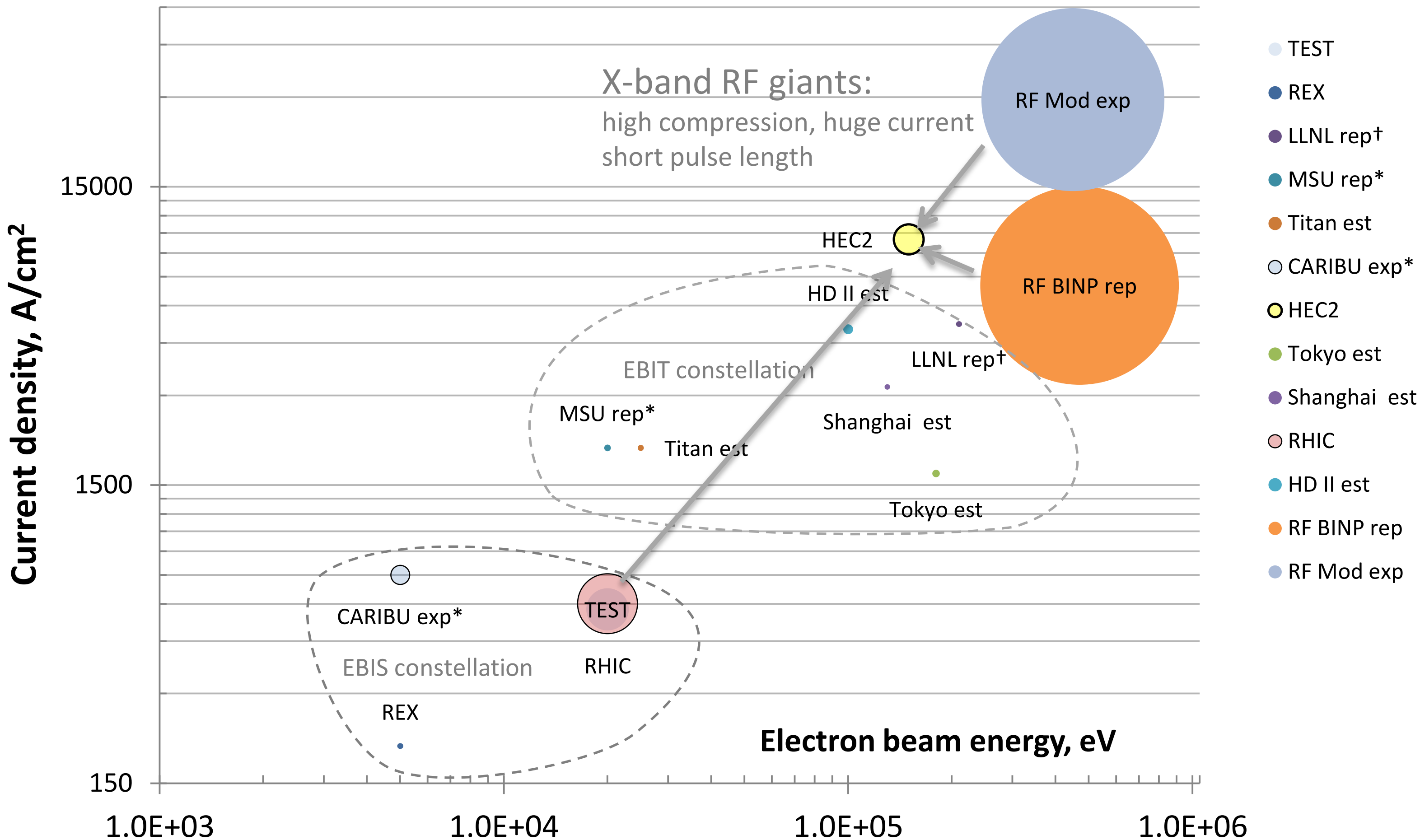
rep - reported, est - estimated, * - in commissioning phase † - discontinued

Bubble size represents electron current

Courtesy A. Shornikov

Good news

we not alone in the upper right corner!



Bubble size represents electron current

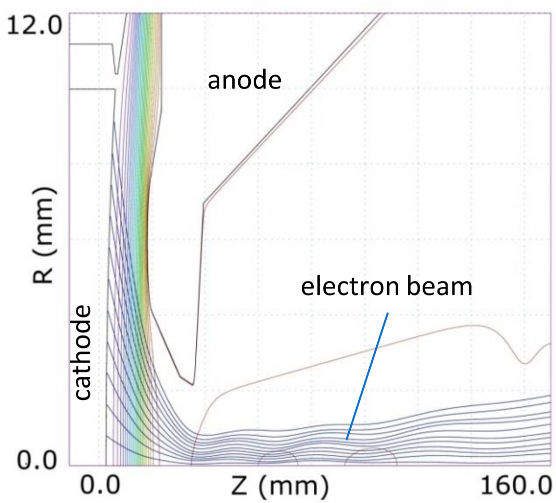
Courtesy A. Shornikov

How we are addressing them

High Energy Current and Compression (HEC^2) electron gun project
Requirements compared to simulations

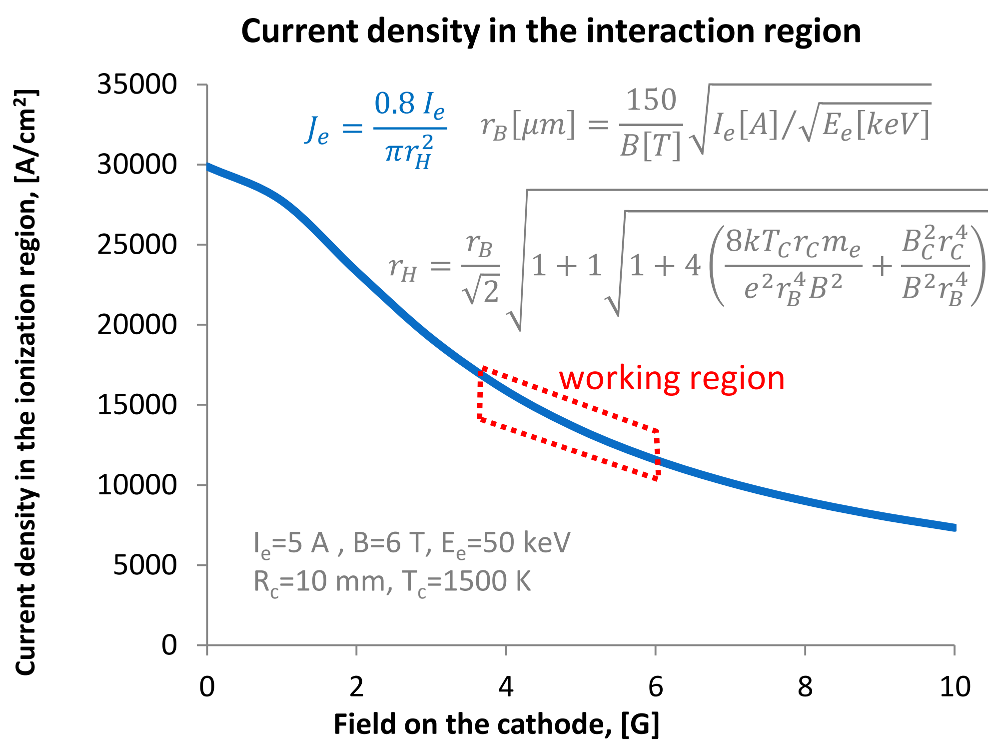
Matching two focusing systems

Very laminar electron flow,
high electrostatic compression



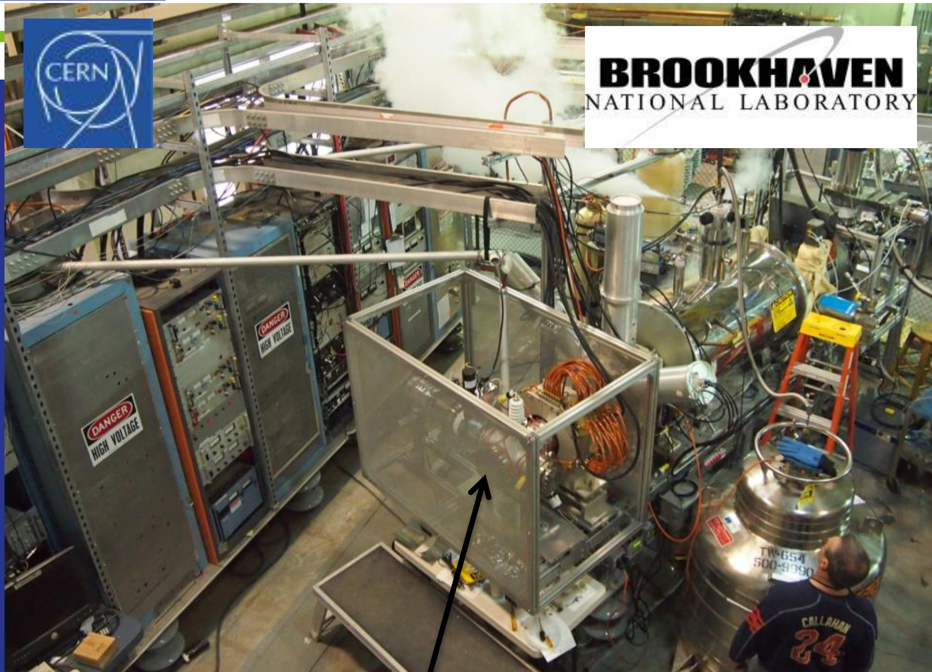
A. Pikin, E. N. Beebe, and D. Raparia, Rev. Sci. Instr. 84 033303 (2013)

Influence of B field leaking



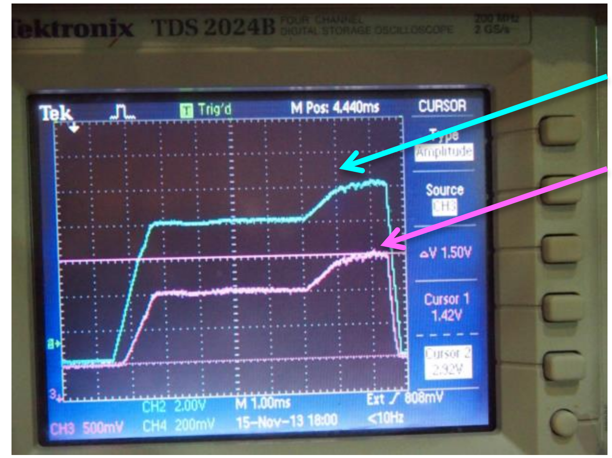
HEC^2 designed at BNL is now a collaborative effort between BNL and CERN

HEC^2 prototype tests at BNL



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

First beam time – 08.11.2013-15.11.2013



Anode voltage

Extracted current (1V=1A)

Scenario	E_e, keV	I_e, A	J_e, kA/cm^2
HEC^2 ultimate spec	150	5	10-20
Test stand limit *as is*	40	2.2	5
Achieved in 1-st run	30	1.54	tba

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

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

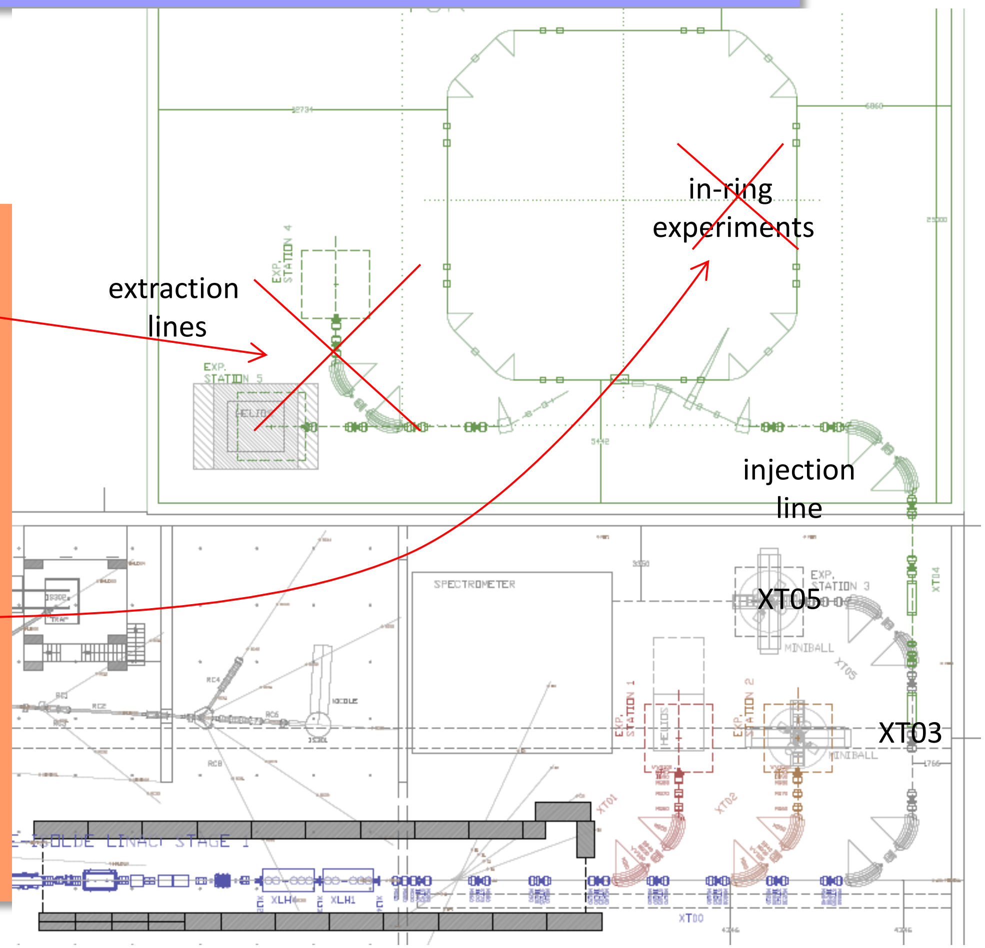
1. Study covers the injection line from HIE-ISOLDE to TSR and the associated costs.

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).

Work package key actions and CERN recommendations

Work package	*Key action / recommendation*
Civil engineering and infrastructure	* Initial study performed for building and services.
Alignment	* Do the alignment using external targets instead of in beam line as at Heidelberg.
Control system and applications	* Replace existing control system; use CERN CO infrastructure and separate the equipment control for different groups.
Magnets	* Keep the magnets but perform a refurbishment, install electrical protection and external targets.
Power supplies and HV installations	* Refuse all existing power supplies and equipment and use standard HIE-ISOLDE / LHC / CERN general solutions.
Vacuum	* Accept most material, complement with spares and replace bakeout system.
Beam diagnostics	* Accept most instruments; replace electronics; improve sensitivity for Schottky, FC and beam profile measurement.
RF	* Exchange all RF equipment for copies of ELENA/AD; use a Finemet® type cavity.
E-cooler	* Accept e-cooler as is; refurbish magnets and HV equipment.

Work package key actions and CERN recommendations

Injection-extraction septum	* Accept septum as is; complement HV supplies and HV equipment.
Scrapers	* Remove as presently not used and keep for possible use in the future.
Induction accelerator	* Accept as is; no real CERN expertise.
TSR injection line	* Follow HIE-ISOLDE design layout; optics study performed.
Extraction lines	* Beam optics study in progress.
In-ring experiments	* Outside the scope of this study.
General safety	* The missing electrical protection of magnet connections has the highest priority.
Radioprotection	* No activation of the machine has been measured and there should be little concern for importing the ring. Future operation conditions similar to HIE-ISOLDE linac.
Dismantling and Reassembly	* Bulk of dismantling and transport covered by TSR@ISOLDE collaboration; reassembly mainly done by each work package; integration important as outdated or incomplete drawings.

Cost and manpower summary for CERN proposal

Work package description	Material cost kCHF incl FSUs	FTE (man months)	Comments
1. Alignment and Survey	155	3	Alignment, survey, fiducialisation, laser scanning
2. Beam diagnostics	1061	56	Includes sensitivity improvement to meet ISOLDE requirements. Incl. spares.
3. Civil engineering and infrastructure	*7684*	36	Includes building, crane, HVAC, water station, electrical transformer, DC cabling and electrical infrastructure, compressed air, fire detection, controlled access, porch door
4. Control system and applications	0	20	Hardware covered by equipment groups. Manpower requested from BE-OP
5. Dismantling and Reassembly	64	53	Includes dismantling, transport/handling, reassembly, integration, project management. Transport cost covered by TSR@ISOLDE collaboration.
6. E-cooler	70	6	Alignment assistance from WP1
7. Extraction line	n.a.	n.a.	Not part of the costing
8. General safety	0.7	7.5	Protection of current leads for magnets covered by WPs 6,13
9. Induction accelerator	0	0.5	Associated tasks and costs covered by WPs 1,5,13,14
10. Injection line	0	3	Associated tasks and costs covered by WPs 1,2,3,4,8,11,13,14,18 Manpower to recalculate matching parameters, optimize multiturn injection
11. Injection-extraction septum	51	2.75	+7 kCHF if spare parts are added
12. In-ring experiments	n.a.	n.a.	Not part of the costing
13. Magnets	2310	52.8	Spares are included
14. Power supplies	2510	46.8	+542 kCHF if spares are added
15. Radioprotection	100	0.5	Disposal cost will only be inferred by operation conditions at CERN
16. RF	254.2	27.6	Spares are included
17. Scrapers	2	1	Removed , evaluated off-line and stored for possible future use
18. Vacuum	954.7	13.2	+329 kCHF and 5 man months for full vacuum control +418.5 kCHF for fixed cabling for vacuum bakeout

Cost, manpower and risk summary Keep-system-as-is

Work package description	Cost savings (kCHF)[1]	FTE (man months)[2]	Risk[3]	Comments
1. Alignment and Survey	-170	3	1	Cost savings comprise the redundant alignment targets in different WP. Manpower only covers the injection line, the ring alignment is covered by WP5.
2. Beam diagnostics	-375	20	3	Includes cost and manpower for sensitivity improvement to meet ISOLDE requirements. Installation manpower covered by WP5.
3. Civil engineering and Infrastructure	0	36	n.a.	No risk factor as CERN standard.
4. Control system and applications	+50	8	4	Extra cost for replacement of obsolete/broken equipment. Manpower only covers the injection line and minor upgrades; the ring related manpower is covered by WP5.
5. Dismantling and Reassembly	0	87	n.a.	NB! WP comprises manpower contributions from different CERN support groups (mechanical and electrical technicians, construction engineer, physicists etc).
6. E-cooler	-40	0	2	Manpower covered in WP5.
7. Extraction line	n.a.	n.a.	n.a.	Not part of the study.
8. General safety	0	7.5	1	The risk factor would have been 5 if protection of the current leads were to be omitted. See ref. [1], for explanation.
9. Induction accelerator	0	0	1	Associated tasks and costs covered by WPs 5,14.
10. Injection line	0	3	n.a.	Associated tasks and costs covered by WPs 1,2,3,4,8,11,13,14,18. Specified manpower used to recalculate matching parameters and optimize multiturn injection. No risk factor as CERN standard.
11. Injection-extraction septum	-18	0	2	Manpower covered by WP5.
12. In-ring experiments	n.a.	n.a.	n.a.	Not part of the study.
13. Magnets	-1000	30	2	Large cost savings from recuperated quadrupole and dipole magnets to be used for the injection line. Specified manpower for ordering of injection line magnets.
14. Power supplies	-1500	5	3	Installation partly covered by WP5. Specified manpower for ordering of injection line power converters. Higher risk factor if repair responsibility is not taken on by EPC.
15. Radioprotection	0	0.5	n.a.	No risk factor as CERN standard.
16. RF	-150	0	3	Manpower covered by WP5.
17. Scrapers	0	0	1	No action, scrapers stored.
18. Vacuum	-215	5.25	2	Most of the bakeout equipment kept. Limited spares in general. Installation partly covered by WP5. Specified manpower for ordering of injection line vacuum equipment.

1. These values indicate the reduction in cost compared to the CERN integration proposal. Negative value = saving; Positive value = increased expense.
2. These values indicate the required manpower for the Keep-system-as-is, not the reduction in manpower compared to the CERN integration proposal.
3. 1 – low risk, 5 – high risk.

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.*

General conclusions

* The technical aspects of the integration have been studied. No technical show stoppers identified.

* Cost and manpower analysis of the integration has been performed.

* Request feedback from the user community about the layout of the extraction lines and experimental setups.

* Tests of charge breeder upgrade on-going. Concept promising but a long way to go!

* Influence of radioactive decay on the storage time inside REXTRAP to be investigated.