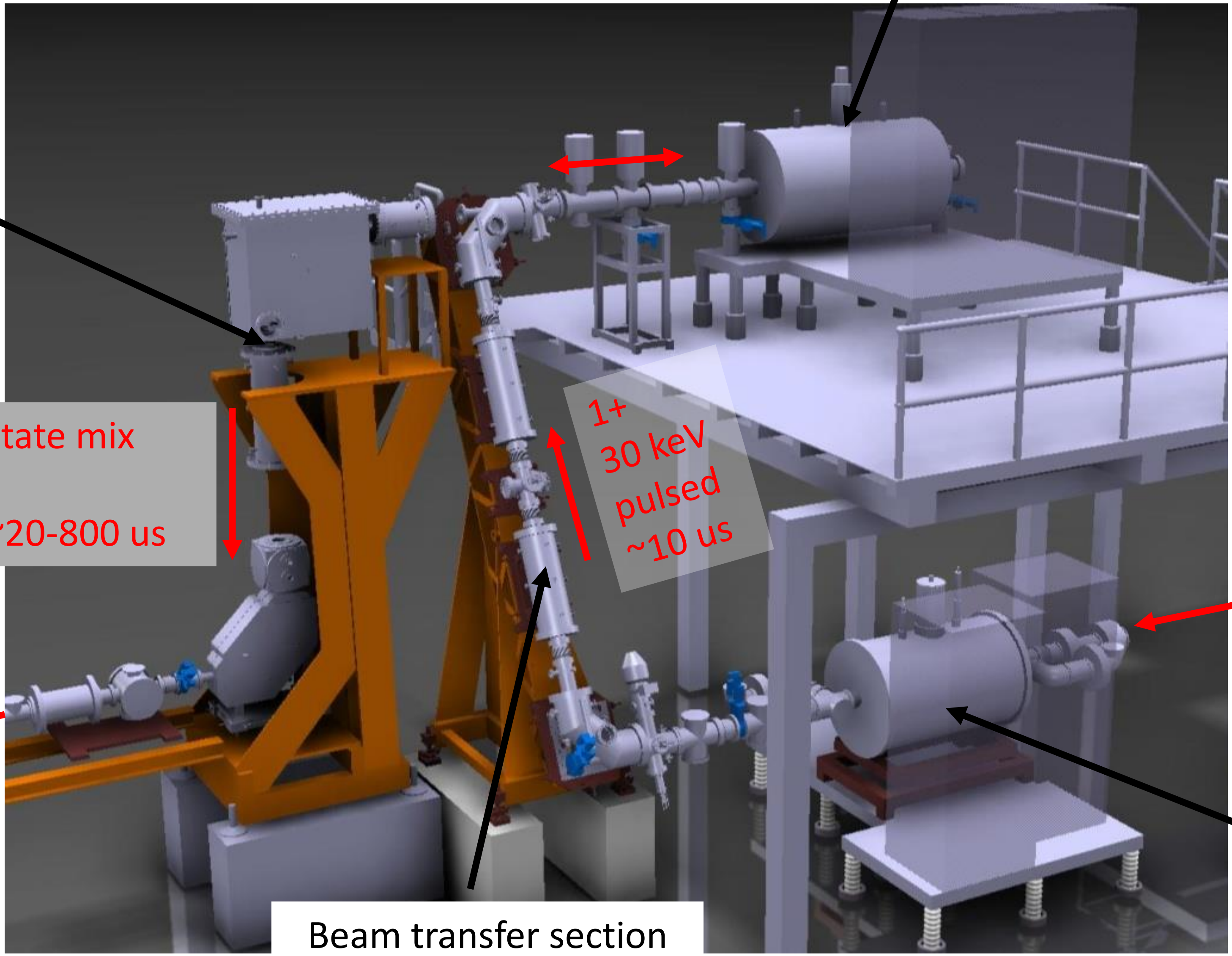
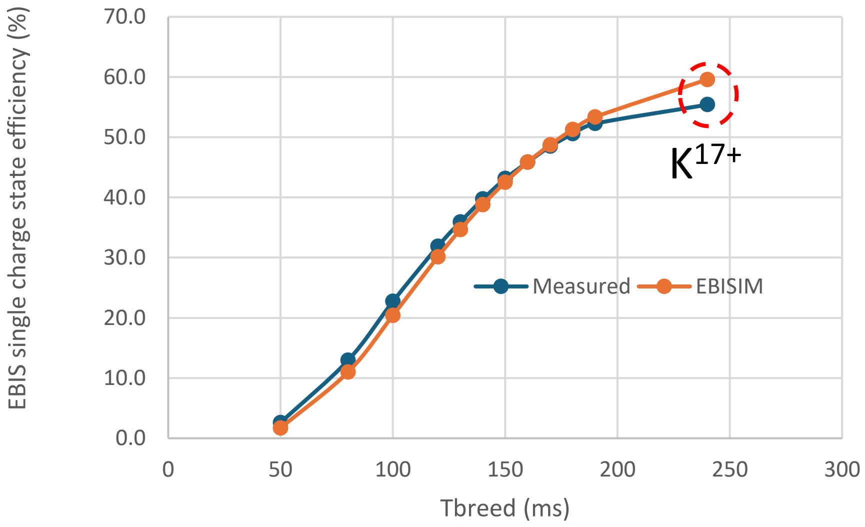
Charge breeding system



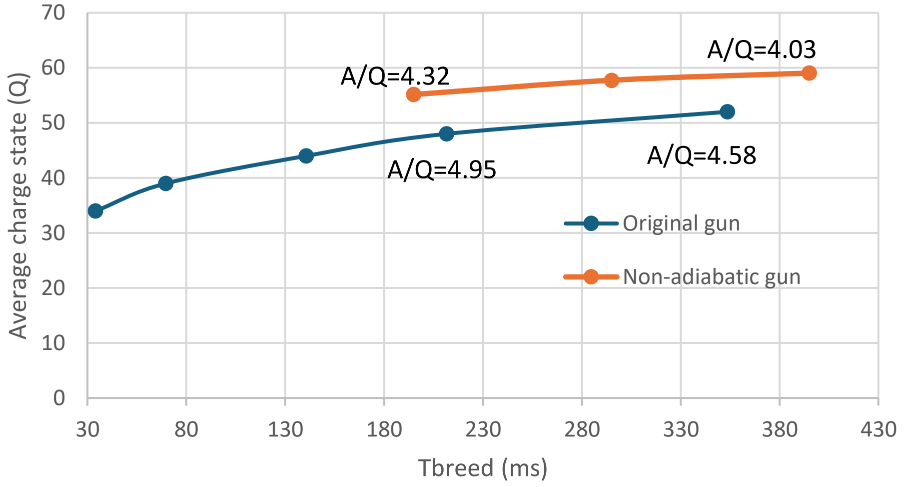
How are we doing?

With the non-adiabatic gun, installed 2020, world leading (until last week)

Stable potassium beam



Uranium beam



\+ 55% in a single charge state
\+ A/Q=2.29 => ~11.2 MeV/u

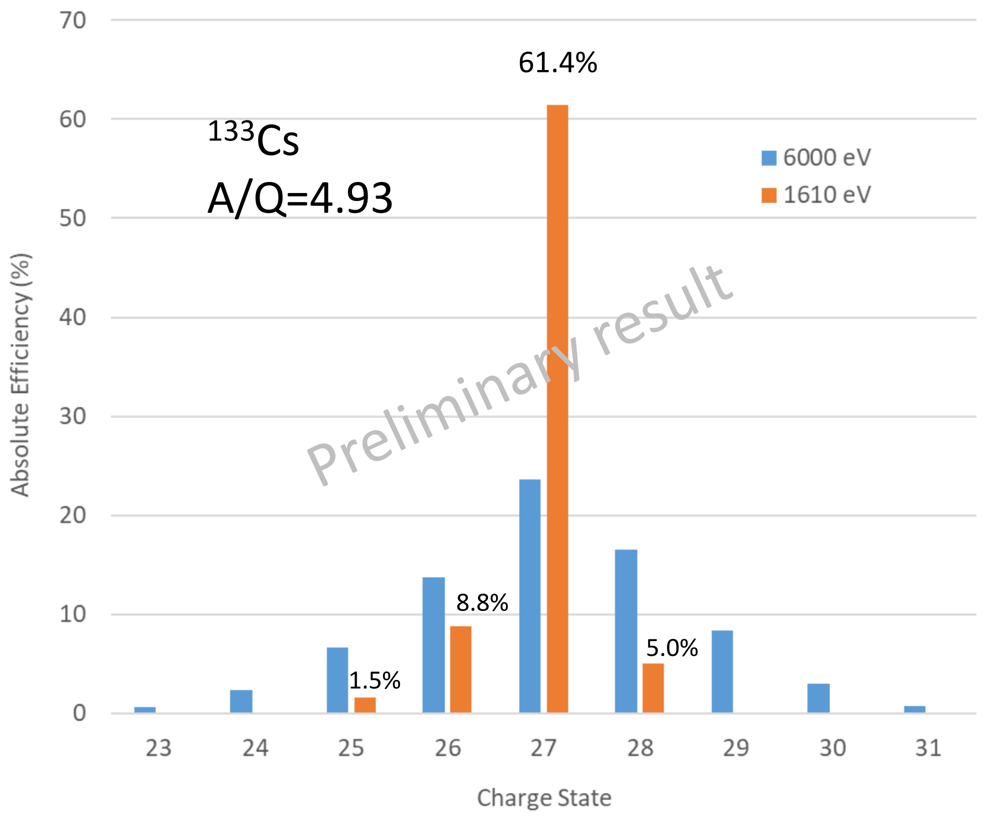
\- T_{breed}=245 ms instead of nominal 8 ms
\- Only applicable for special cases

\+ Single charge state efficiency 16-18%
\+ Beams with A/Q<4.5 attainable

\- Only valid for few ions (1E7 ions/bunch)

Latest results from ANL

Courtesy of R. Vondrasek



CARIBU EBIS operated with exceptionally low electron beam energy

Parameters for 1610 eV electron beam energy

- V_{gun}: -890 V, V_{trap}: 1141 V
- Electron beam current: 172 mA
- T_{breed}: 89 ms
- Cs+ injected: 4.3 pA

Closed atomic shell breeding

+ Very high efficiency

- Special cases
  - A/Q has to be clean
  - A/Q has to be < 4.5 for REX-ISOLDE

- Low electron beam energy → run into perveance limit → low electron beam current → longer breeding time

Aim to try on Zn beams at REX-ISOLDE this year

What can we improve?

Increase efficiency

* closed shell breeding can improve efficiency in certain cases
  - requires adjustable electron current energy
  - will complicate the setup
* total REXEBIS efficiency already ~75% => not much to gain
* REXTRAP efficiency <50%

Shorten breeding time

* increased repetition rate
* attain higher charge states within reasonable time

Beam purity

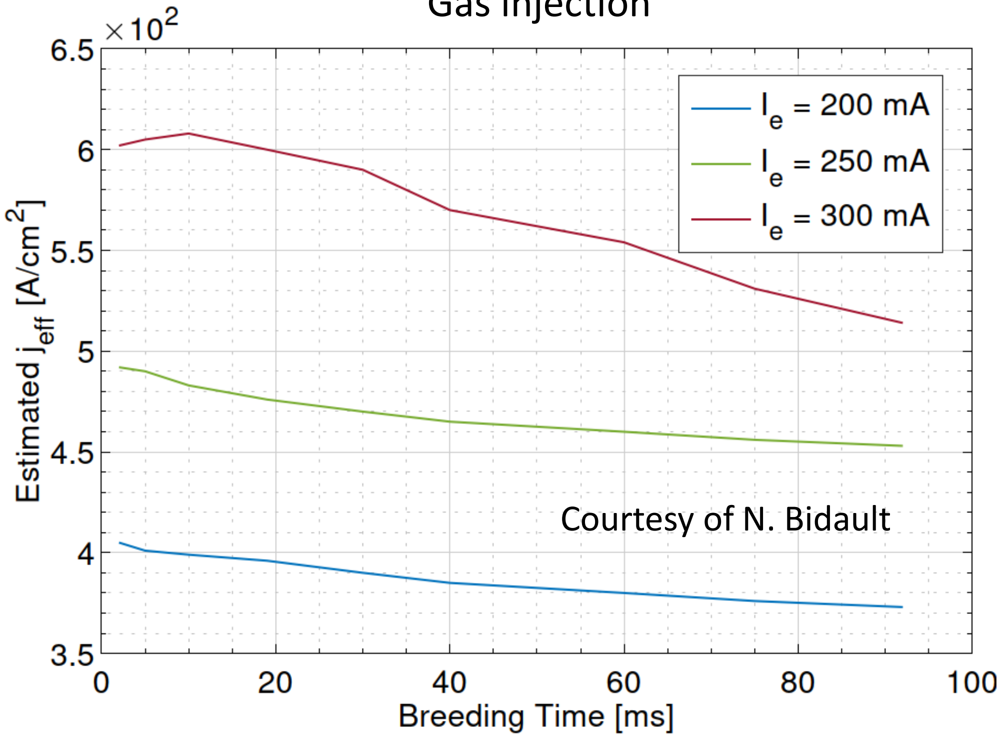
* increase number of available isotopes

Address complexity

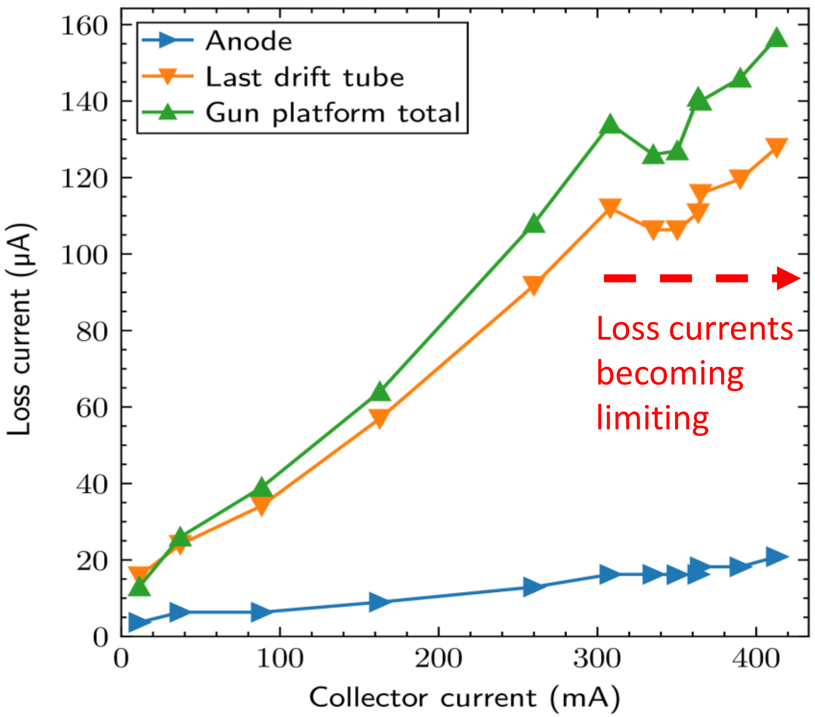
* setting up and reproducibility
* machine maintenance

Why higher electron current?

Gas injection



Electron loss currents



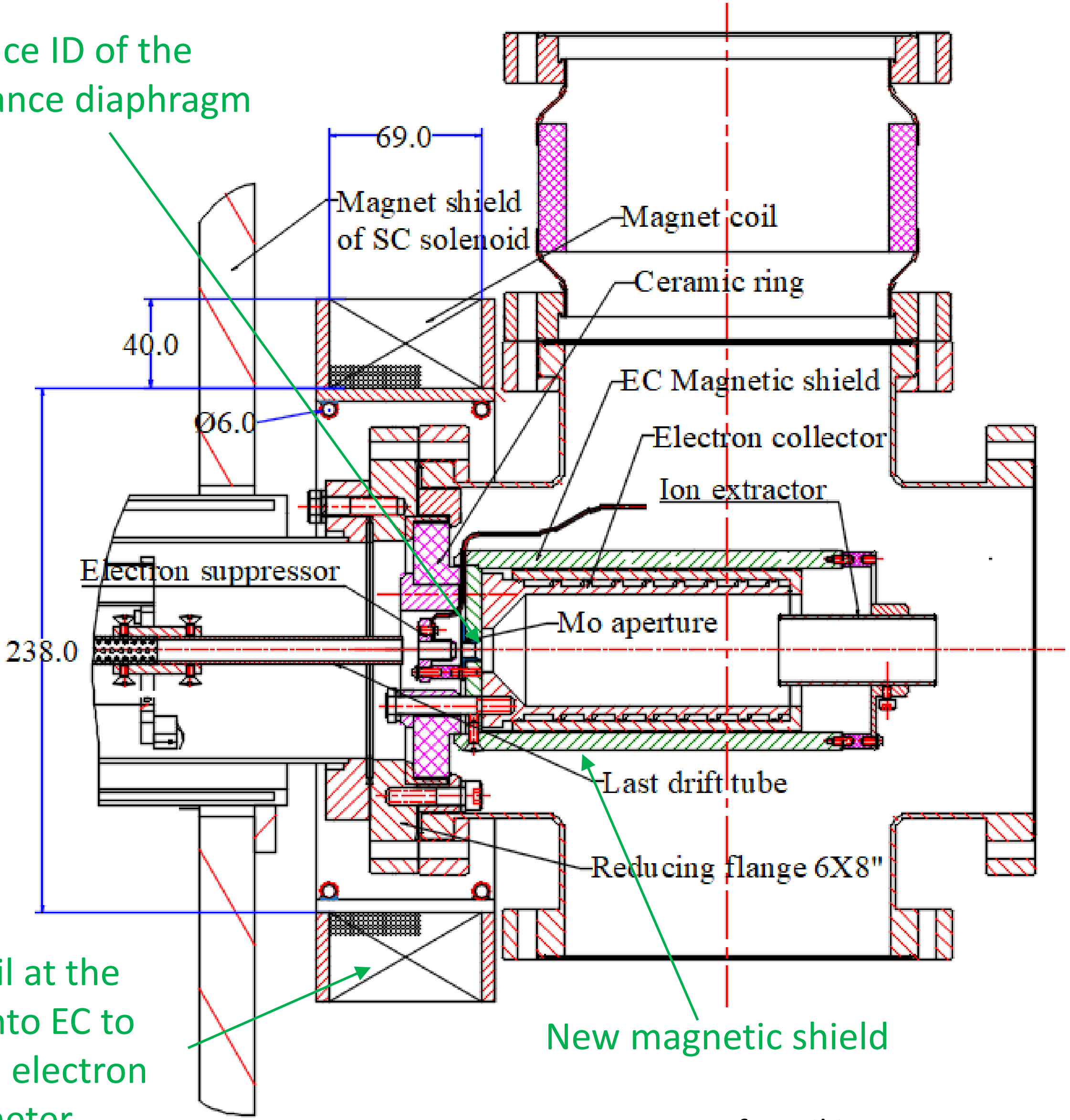
* Higher current => higher effective j_e => faster charge breeding

* Non-adiabatic electron gun designed for 500-700 mA

* Higher electron beam losses when I_e > 300 mA. Believed to be caused by back-scattered or elastically reflected electrons from the collector region.

New electron collector design

Reduce ID of the entrance diaphragm



Magnet coil at the entrance into EC to control the electron beam diameter.

New magnetic shield

Courtesy of A. Pikin

Aim to reduce elastically reflected electrons from the collector region

Installed at TwinEBIS

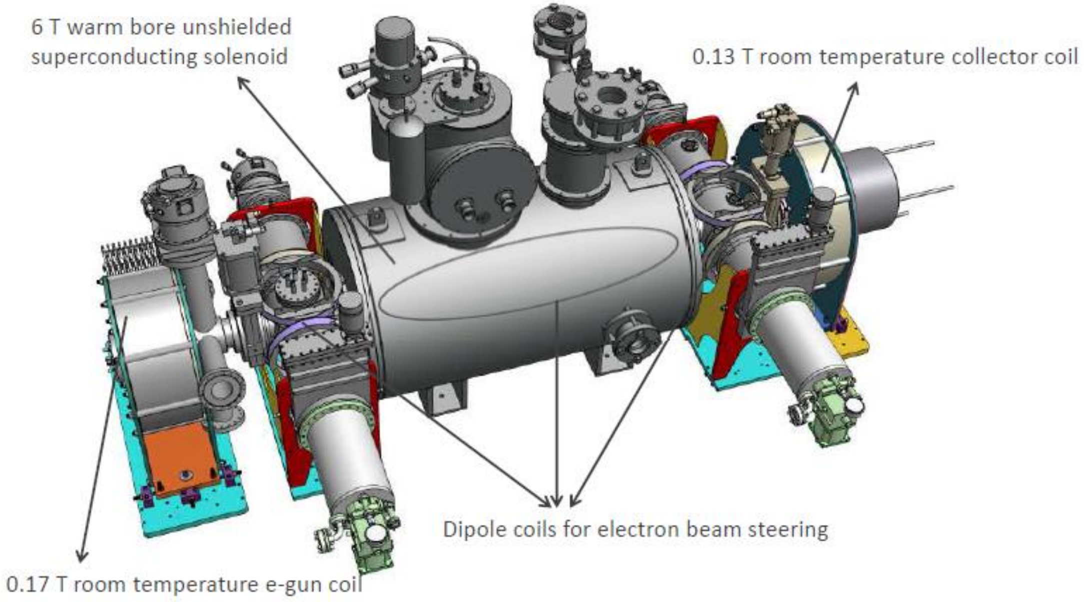
Testing foreseen summer/autumn 2024

5 T EBIS upgrade – RT version

Use proven concept like CARIBU at ANL, US
(originally based on RHIC concept, BNL)

Though, with different gun as a copy of CARIBU has only a similar current density as REXEBIS

- Controllable current density
- Maximum possible electron current density providing a stable electron-ion system in the ion trap
- Current at least 1.0 A, ability to go to 2.0 A for boosting efficiency of trapping and confining ions in the trap
- Backup solution: present non-adiabatic electron gun, operated at 500 mA instead of present 200-300 mA



No details ironed out

5 T EBIS upgrade – RT version

Benefits	Risks and Drawbacks
+ Address aging solenoid issue + Eliminate need for a technician performing coolant filling + Faster breeding -> higher repetition rate + Consistent better breeding efficiency + Option with very fast extraction	- Delayed magnet delivery; magnet teething problems - Maintenance of cryo-cooler - Stray magnetic fields from a stronger EBIS magnet – what is the effect on beam transport and is shielding technically possible? - Available space at the REXEBIS platform very limited - Degraded vacuum due to higher electron beam current, power deposition and 10 kV on drift tubes - Electron beam problems Electron reflection from collector region Instabilities - Longer activation time for dispenser cathode in case of vacuum venting - Design is heavily relying on VISC Alexander Pikin

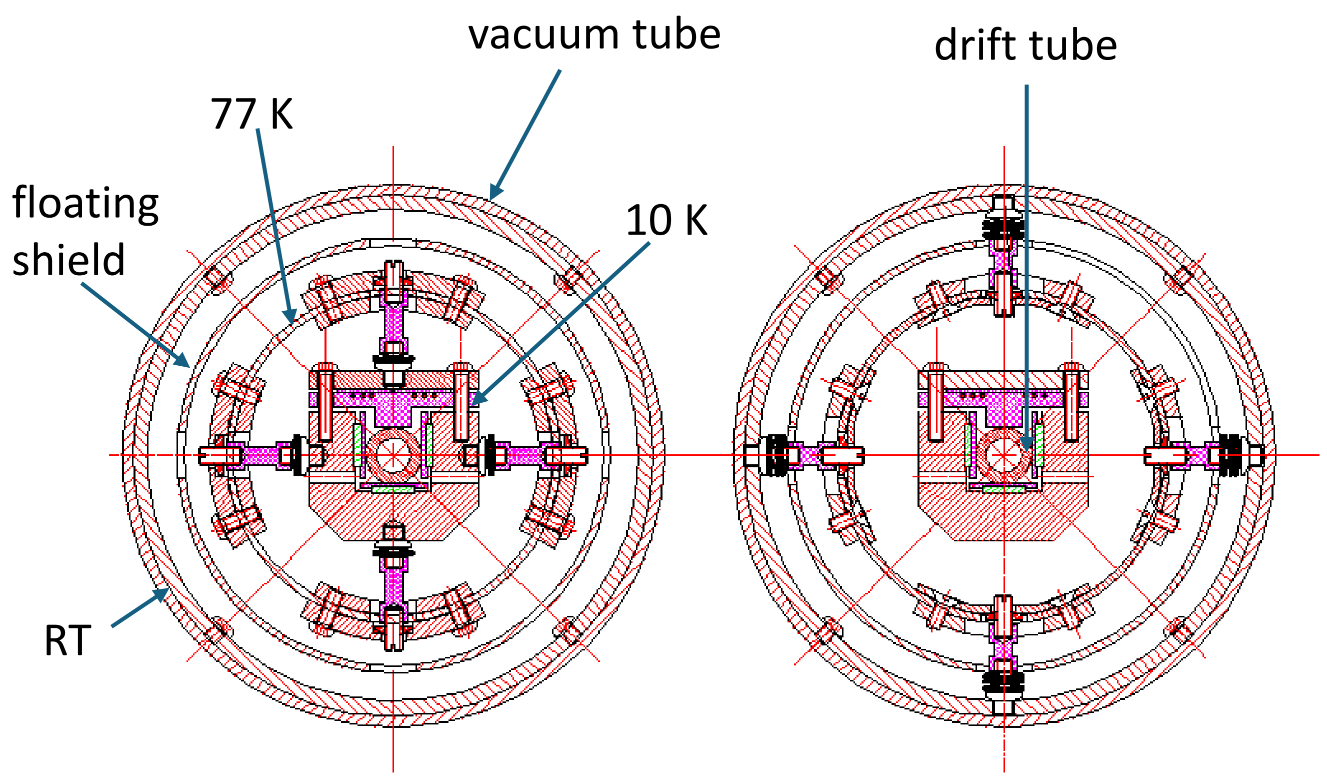
Hardware cost (kCHF)	Manpower (FTE)	Timeline
~1.5 MCHF (solenoid >30% of the total cost)	**14**	Estimated project time **>5 years**

FW estimate

Motivates/requires complete off-line test before installation

5 T EBIS upgrade – cryogenic version

Focus on vacuum
- => less residual gas contamination
- => better breeding performance
- => make use of A. Pikin’s exceptional experience

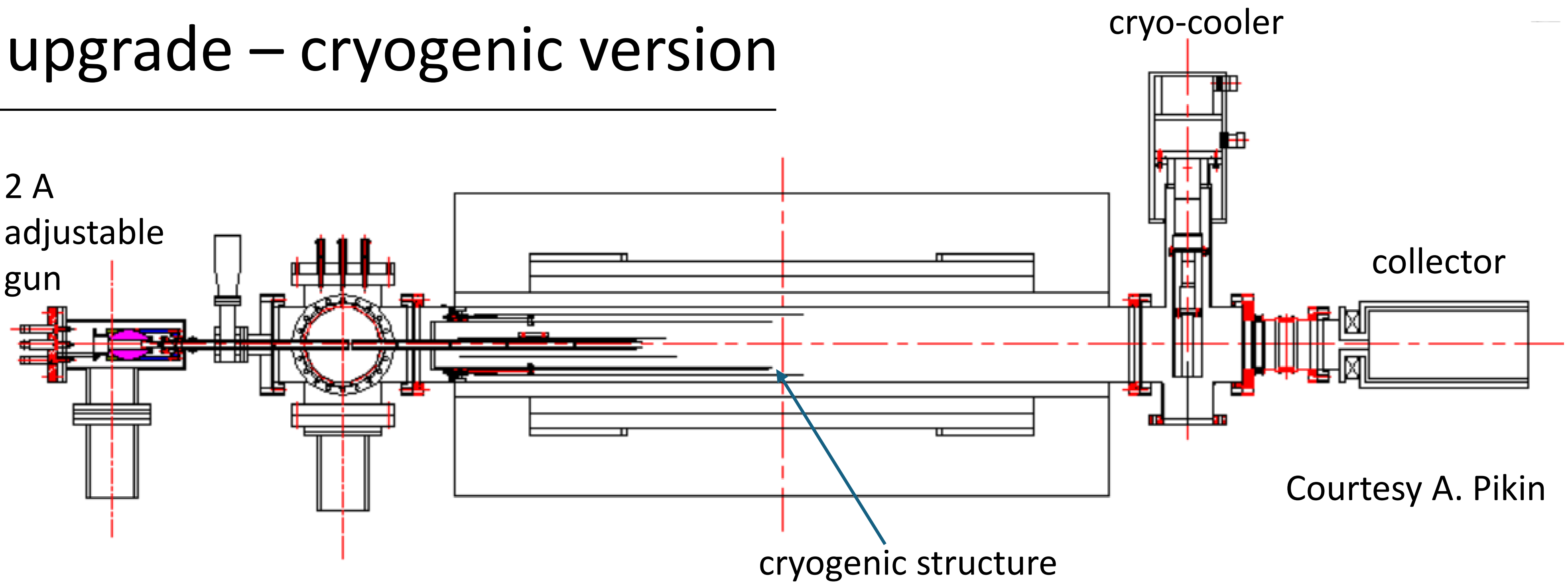


Courtesy A. Pikin

Transverse cross-sections of the cold drift structure

Cold drift tube structure
“Easy” and fast getting ultra high vacuum in EBIS

5 T EBIS upgrade – cryogenic version



Courtesy A. Pikin

* 5 T unshielded solenoid with cryocooler (identical to RT concept)
* 2 A controllable current density gun (identical to RT concept)
* Warm bore, large ID=205 mm for vacuum and HV leads
* Includes independent cold drift tube structure
* Cryocoolers (Sumimoto) => no weekly coolant refillings
* Automatically contains built-in vacuum separation

- Physical envelope – fit onto the platform?
- New untested concept!

Summary

Low-intensive, incremental improvements on-going

Design of a cryogenic “paradigm-shift” device being pursued

An upgrade requires major resources in terms of money and manpower and a critical mass

Off-line testing is necessary, so a 5-year’s time-line is minimum

Backup slides

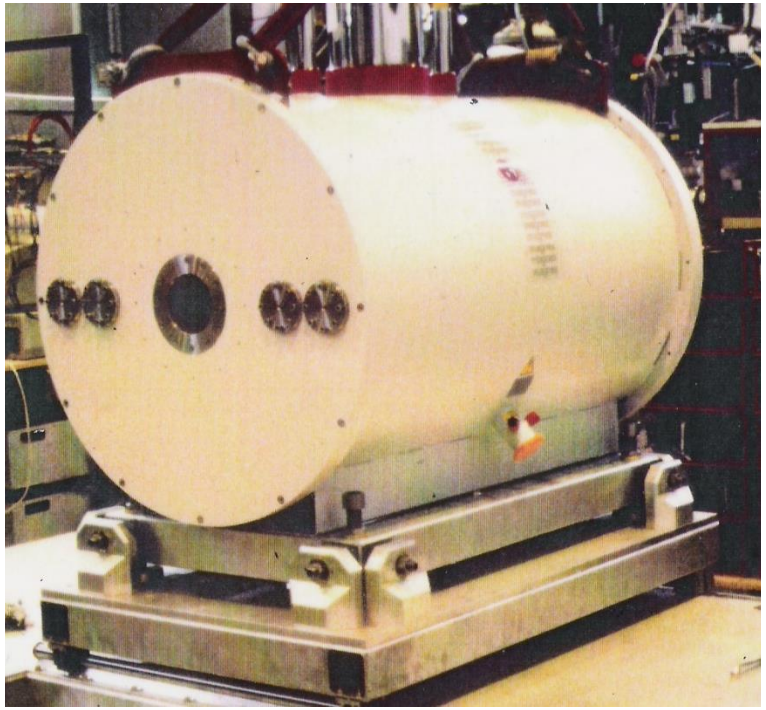
REXTRAP concerns

1. REXTRAP solenoid – consolidation request pending
   * 26 years old, no spare
   * limited knowledge about de- and re-energization

2. REXTRAP efficiency
   * < 50%, losses at the injection side
   * poor efficiency for light elements (A<10)

3. REXTRAP operation
   * difficult to set up, numerous elements and parameters

4. REXTRAP reliability
   **** increasing problems with internal discharges / beam disturbance***
   * until now mitigated by lowering critical voltages
   * not identified the exact reasons despite several dedicated MDs and internal inspections



Complete renovation during LS3?

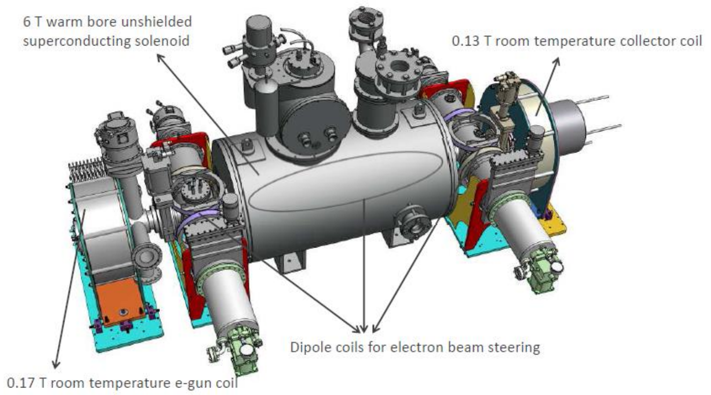
Exchange for an RFQ cooler-buncher

First phase of a 5 T system

Deliverables

* Electron beam and ion beam simulations
* Engineering simulations (vacuum, heat, magnetic fields)
* Production of the electron gun
* Tests of electron gun at TwinEBIS
* Detailed design of complete system (stage before production drawings)
* Design specification of external parts

=> prepared for launching production and procurement of external parts



Cost (kCHF)	Manpower (FTE)	Involved groups	Time span	Benefits (compared to Full 5 T EBIS upgrade)	Risks and Drawbacks (compared to Full 5 T EBIS upgrade)
<200	**~4.5**	BE-ABP, TE-VSC, EN-MME, TE-MSC, TE-CRG, SY-BI, SY-STI	2 years (After finished first phase, expect 4.5 years until operational system)	+ Assure fully successful and optimal design concept before committing + Reduced initial peak workload	- Later final implementation - Postpones addressing old REX and TwinEBIS solenoids

5 T EBIS upgrade – RT version

Tasks

1. Preparatory studies	2. Hardware procurement and preparation	3. Installation an tests
Principal investigator / project management Electron and ion beam simulation electron gun design (laminarity, compression) electron collector design (e- reflection, energy deposition ion injection acceptance / phase space matching / trapping ion extraction simulation error studies beam optics for 1+ ion injection branch at test bench Theoretical studies instabilities ion breeding performance Concept studies and engineering simulations evaluate and decide on design concepts vacuum simulations heat dissipation gun and collector stray magnetic field for turbo pumps	Magnet specification and follow-up of production process acceptance testing incl. field measurement Mechanical design and production of manufacturing drawings Integration Design and production of HV gas feed breaks Installation cooling water and compressed air Ordering, medication and installation of larger motor-generator Installation of vacuum system, incl. controls Installation of PSU, incl. low-level controls Gas injection Ordering and installation HV platform + racks HV cage modification Timing, Controls, Function generation Beam diagnostics (incl. test bench)	Assembly Controls applications Preparation of test bench ion extraction line separator magnet external 1+ ion source beam diagnostics (emittance meter and TOF) Commissioning tests at test bench gun collector electron beam transmission tests as function of current and B-fields characterisation of gas injected ions ion injection tests and characterisation of the breeding performance Final installation and commissioning

Hardware cost (kCHF)	Manpower (FTE)	Involved groups	Timeline
~1.5 MCHF (solenoid >30% of the total cost)	**14**	BE-ABP, TE-VSC, EN-MME, TE-MSC, EN-ACE, TE-CRG, SY-EPC, EP-DT, BE-CSS, BE-CEM, SY-BI, BE-OP, SY-STI, BE-GM	Estimated project time **>5 years**

NB! Once operational, a spare solenoid would be needed

Tentative group assignment and estimations by FW

Goals

A. Higher ion charge
=> reach higher beam energy
=> of use in storage ring?

B. Shorter breeding time
=> reach shorter $t_{1/2}$
=> higher repetition rate
(less instantaneous extracted peak current)

C. Higher efficiency
=> shorter data taking time
=> reach more exotic isotopes /reactions

D. Less residual contaminants
=> increase number of available isotopes

E. Higher beam intensities
=> not sure there's a need?

F. Slower ion extraction
=> lower instantaneous beam rate

G. Faster ion extraction
=> of interest for ISS?

H. Easier maintenance
=> allow long-lived high intensity beams

I. Reliability
=> allow long-lived high intensity beams

Present Limits / Problems

Increased e-beam losses >200 mA
due to back-scattered electrons in the collector?

REXTRAP requires 20 ms cooling time
in principle not a problem as long as REX linac in place

Optimal efficiency at around electron beam 200 mA
not finding the right settings
or aperture focusing limitation

2 T limits the magnetic beam compression
limits the charge breeding time

Poor ion result with Brillouin compression
would have provided very fast breeding

Limited range of electron beam energy
practically limited to ~8 keV
varying the energy affects the injection/extraction conditions
alas, can't reach very higher charge states

REXTRAP efficiency very poor for light ions
believed that the injection and trapping is poor

Limited RF pulse length in REX linac
pulses >1.5 ms from EBIS not transported

Complex machines +radioactive
difficult to maintain

Machine modifications

(in order of complexity ↓)

Increase injection aperture at REXTRAP
C+, 2 weeks, YETS2023

BJUT cathode
B+ D- I-, 2 months, YETS2023?

Ion pumps at REXEBIS
D+ I+, LS3

Upgraded electron collector
B+ C? D? I?, 1 year, LS3

Adjustable 2 A gun
A? B+ C+ D? H-, 2 years, LS3

RFQ cooler-buncher
C+ E+ H+ I?, >3 years

Multi-Reflection TOF
D+ H- I-, >3 years, requires RFQ-CB

New EBIS
A+ B+ C+ D- H- I?, >5 years