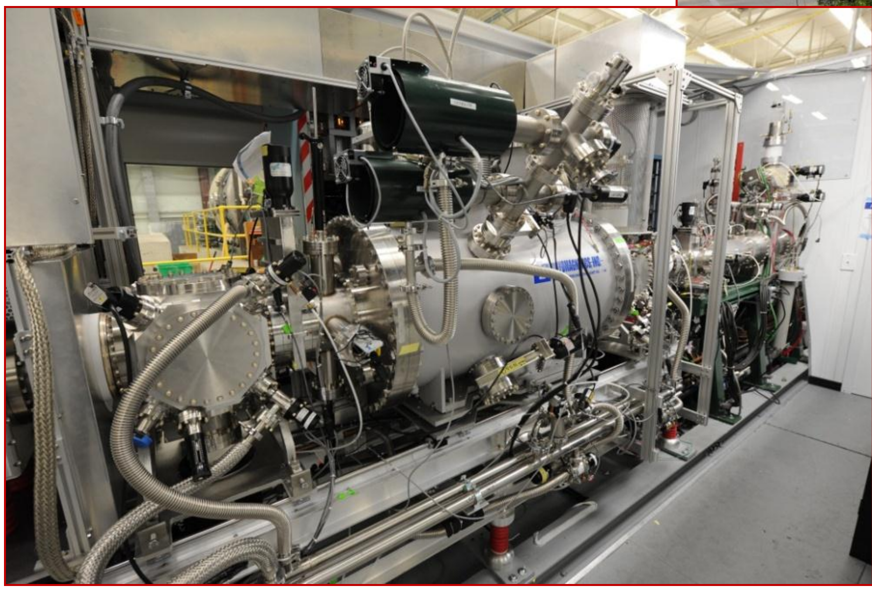
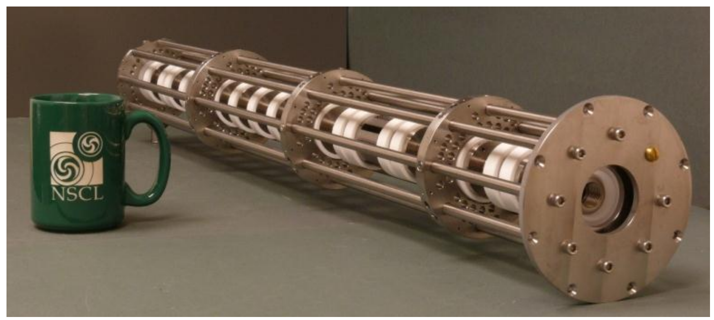
The EBIS/T charge breeder in the NSCL re-accelerator ReA

The NSCL EBIT within ReA

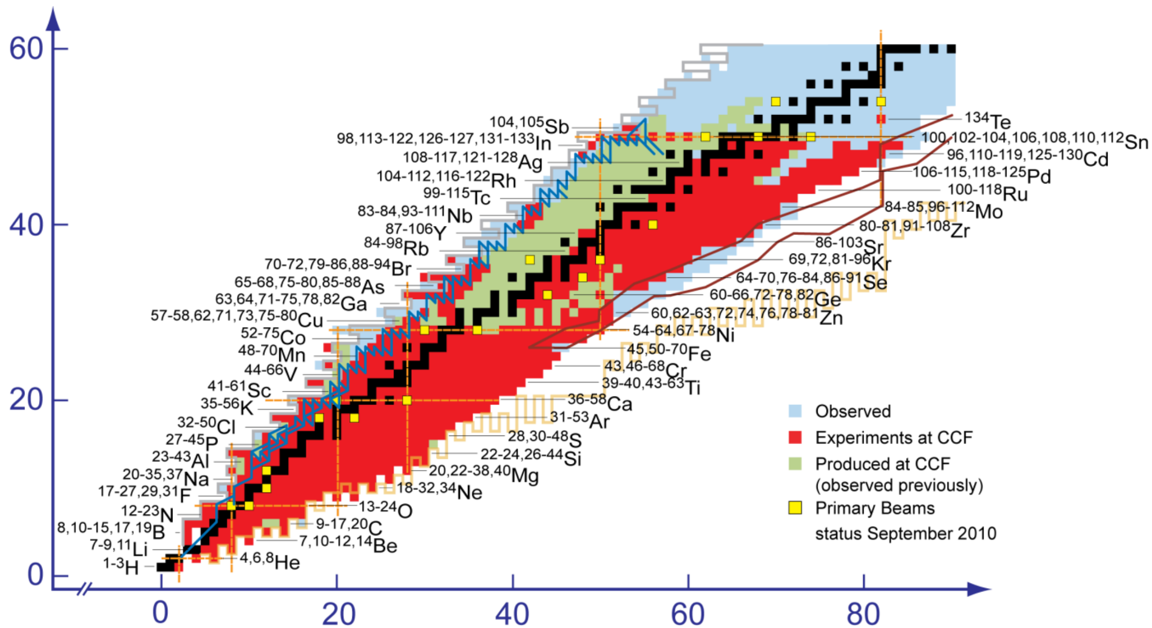
- Stopping / EBIT / LINAC
- EBIT
  - commissioning results,
  - status
  - outlook





Why reaccelerated beams at the NSCL?

NSCL: User facility, RIB production by projectile fragmentation and fission



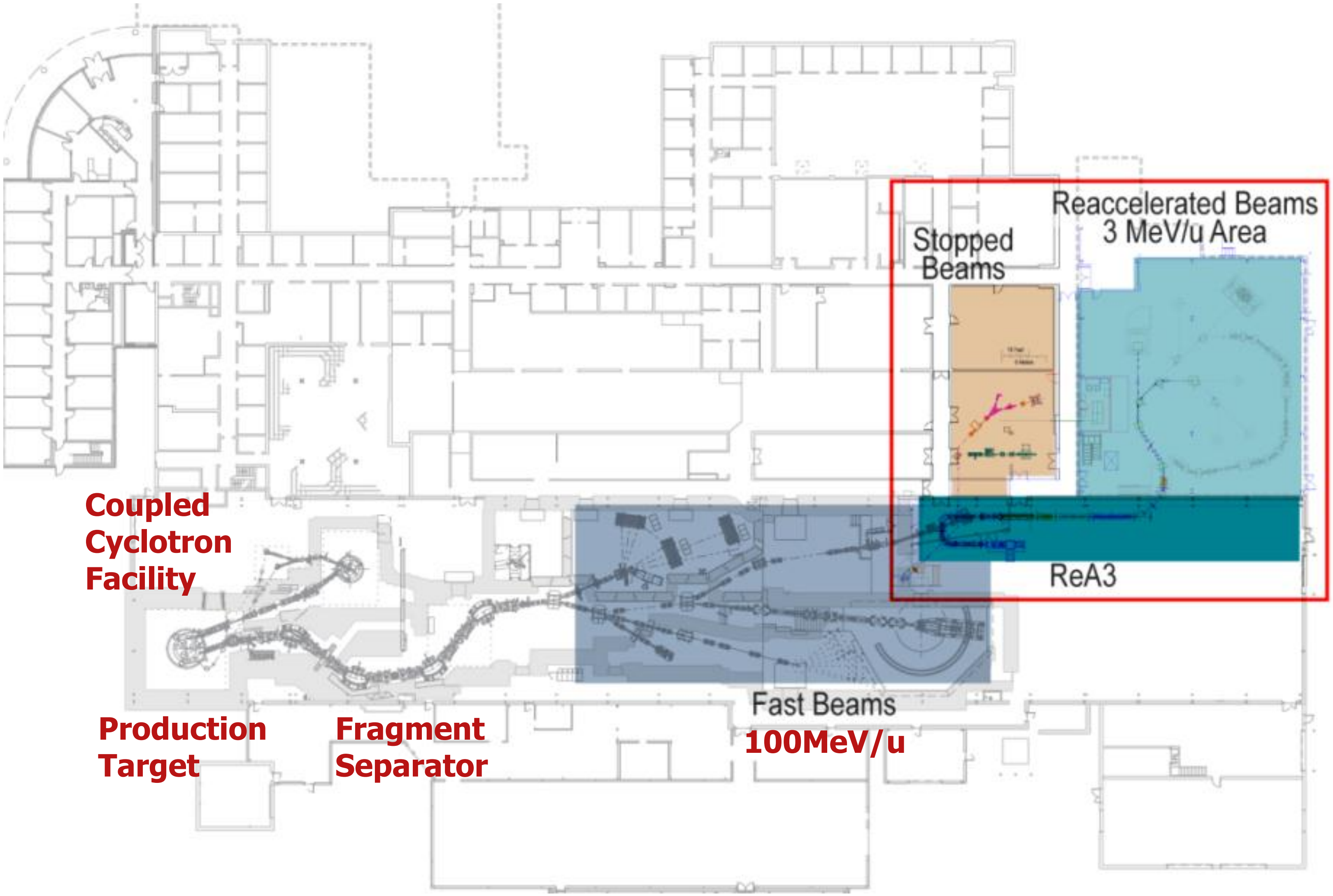
> 1000 RIBs made
> 830 RIBs used in experiments

- NSCL has successful program with stopped beams
- LEBIT facility for Penning trap mass spectrometry of projectile fragments
- laser spectroscopy under preparation

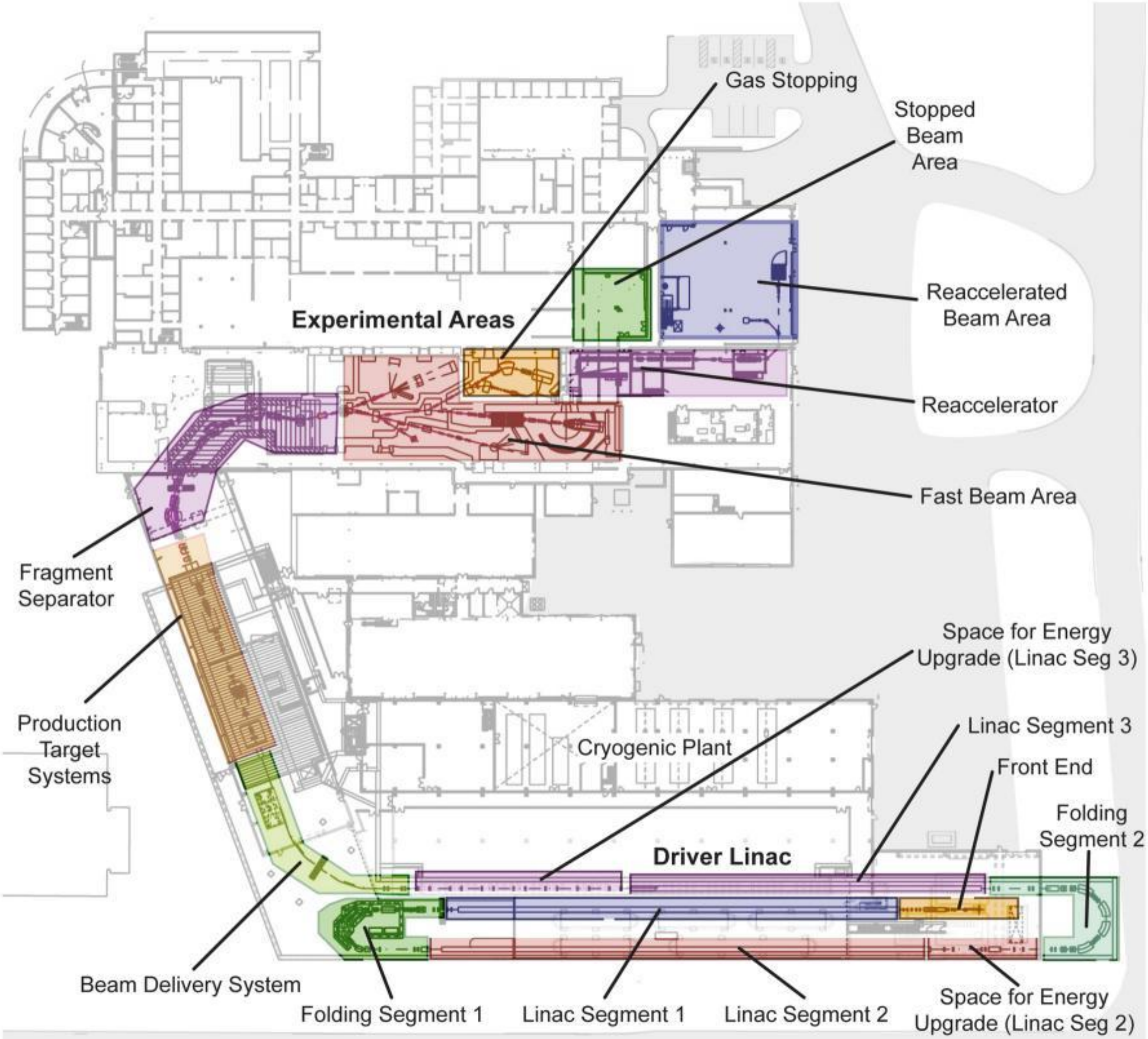
→ ReA, new science opportunities with rare isotopes from projectile fragmentation

- Nuclear astrophysics: key reactions at near-stellar energies
- Nuclear structure via Coulomb excitation or transfer reactions

NSCL: Fast , slow and reaccelerated beams



Facility for Rare Isotope Beams - FRIB



NSCL: 2kW coupled-cyclotron driver

→

FRIB: up to 400kW LINAC driver

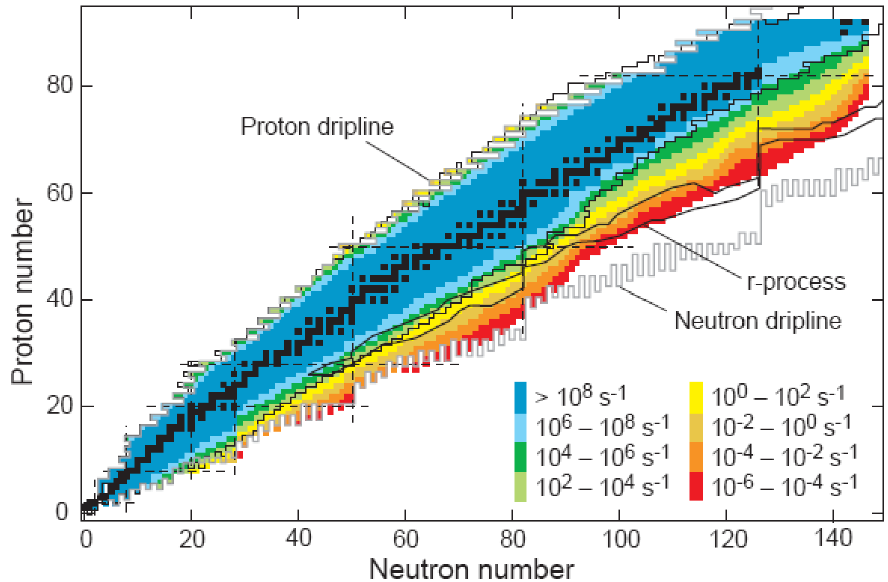
- Fast, stopped and reaccelerated beams

Expect start in 2018+

Capability:

- RIB production, in-flight technique, primary beams:
  up to 400 kW, 200 MeV/u (Uranium)
- Fast, stopped and reaccelerated beams
- Upgrade options:
  - Energy 400 MeV/u for uranium
  - ISOL production – Multi-user capability

Rates:



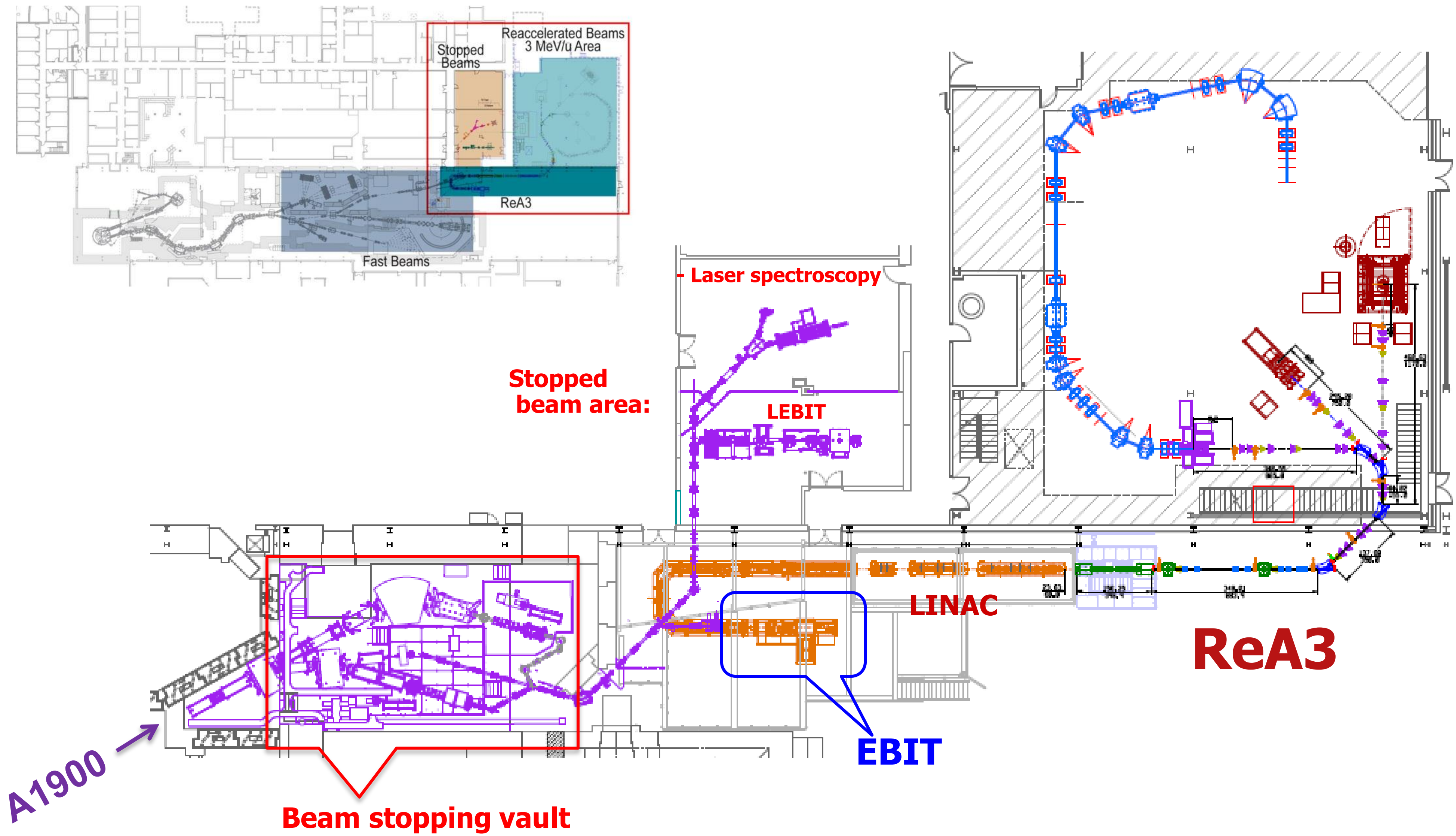
- more than 1000 new isotopes at useful rates
- High fraction of the reaccelerated beams projected to be available at 10^6 to 10^8/sec
- Special cases, e.g., ^{15}O will have $2x10^{10}$/s

Ready for Civil Construction

- Utility relocation and site preparation activities:

Web cams at www.frib.msu.edu

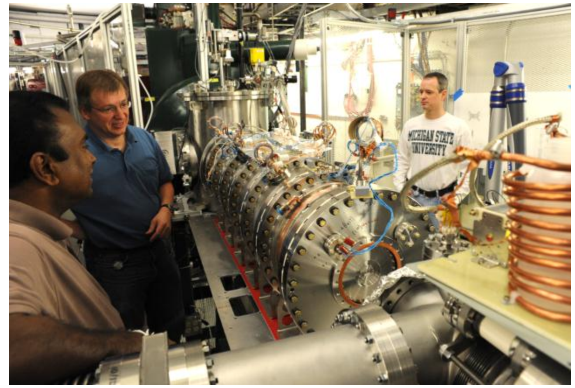
From fast to not-so-fast



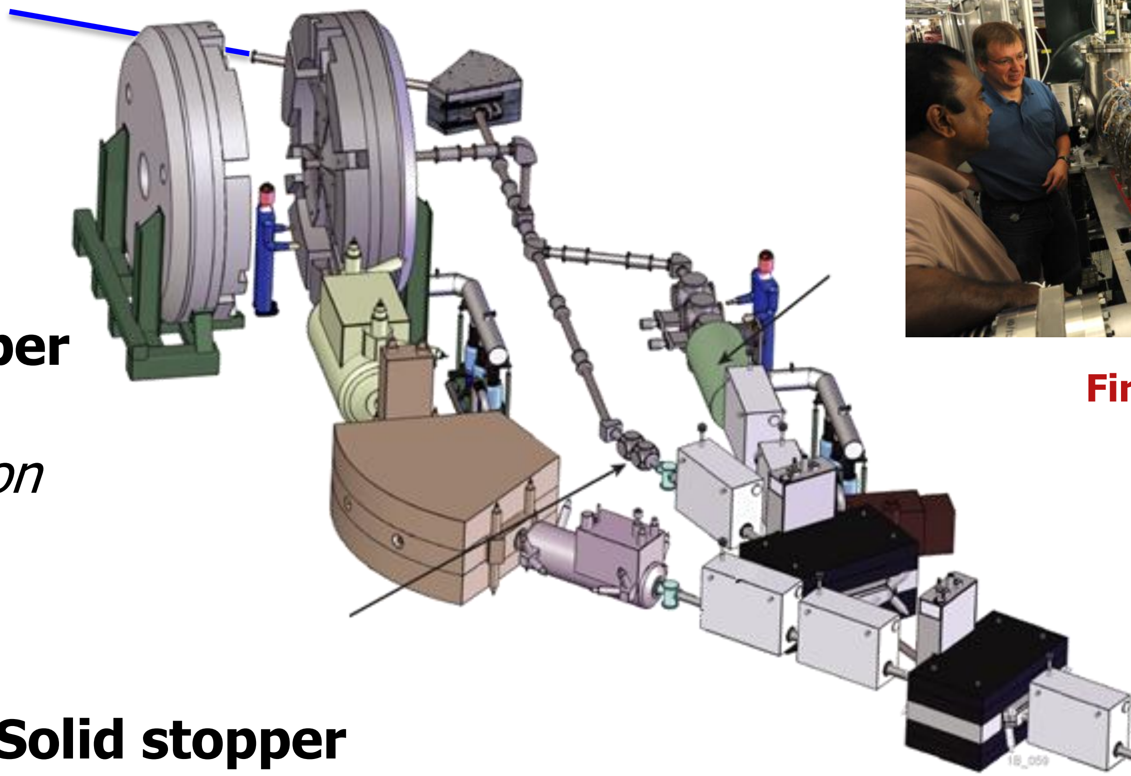
120 MeV/u → (Fully stripped) STOP → (1+) 60 keV → (1+) 12 keV/u EBIT → (n+) 3 MeV/u and more

Stopper options:

- **Large linear gas stopper → ReA3**
  - Low-pressure with RF carpets
  - Collaboration with ANL (FRIB R&D)



First tests: Today!

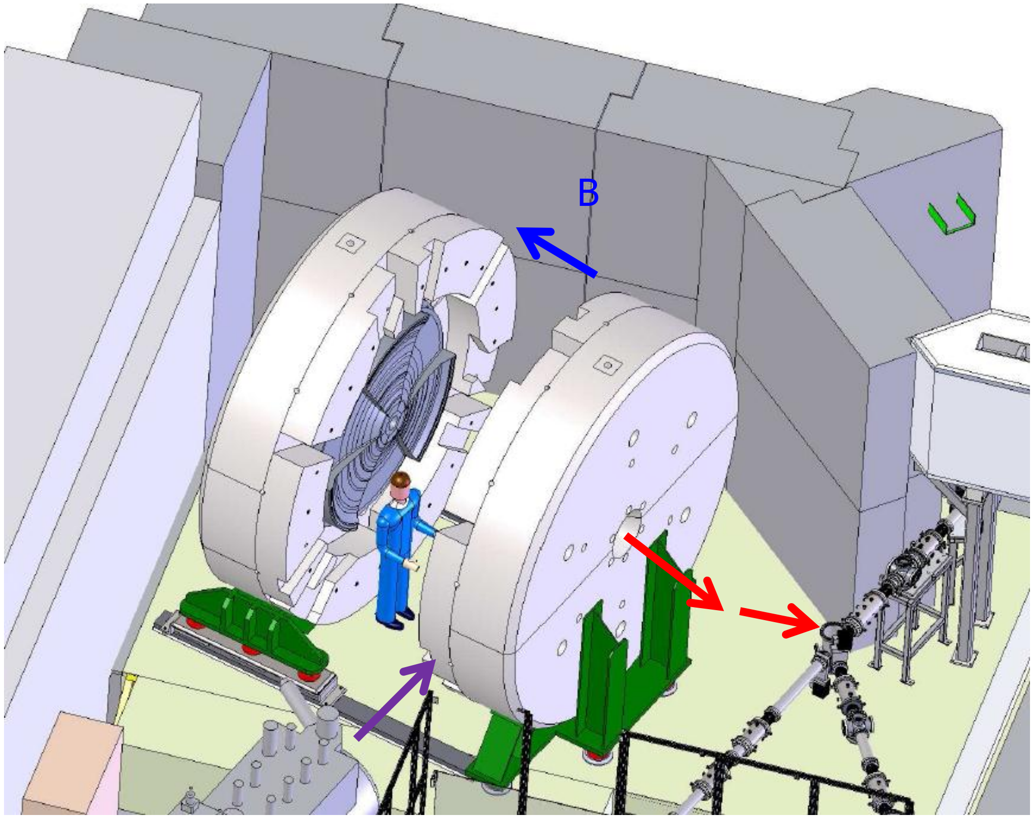


- **Cyclotron stopper**
  Funded by NSF
  Under construction

- **Solid stopper**

→ For special elements and very high beam rates
Example: ^{15}O, I >10^{10}/s

Cyclotron stopper



High efficiency even for light ions
Long stopping range !

High intensity → FRIB
Large stopping volume !

Fast extraction < 50ms
Low pressure

Clean beams
Cryogenic chamber

How?

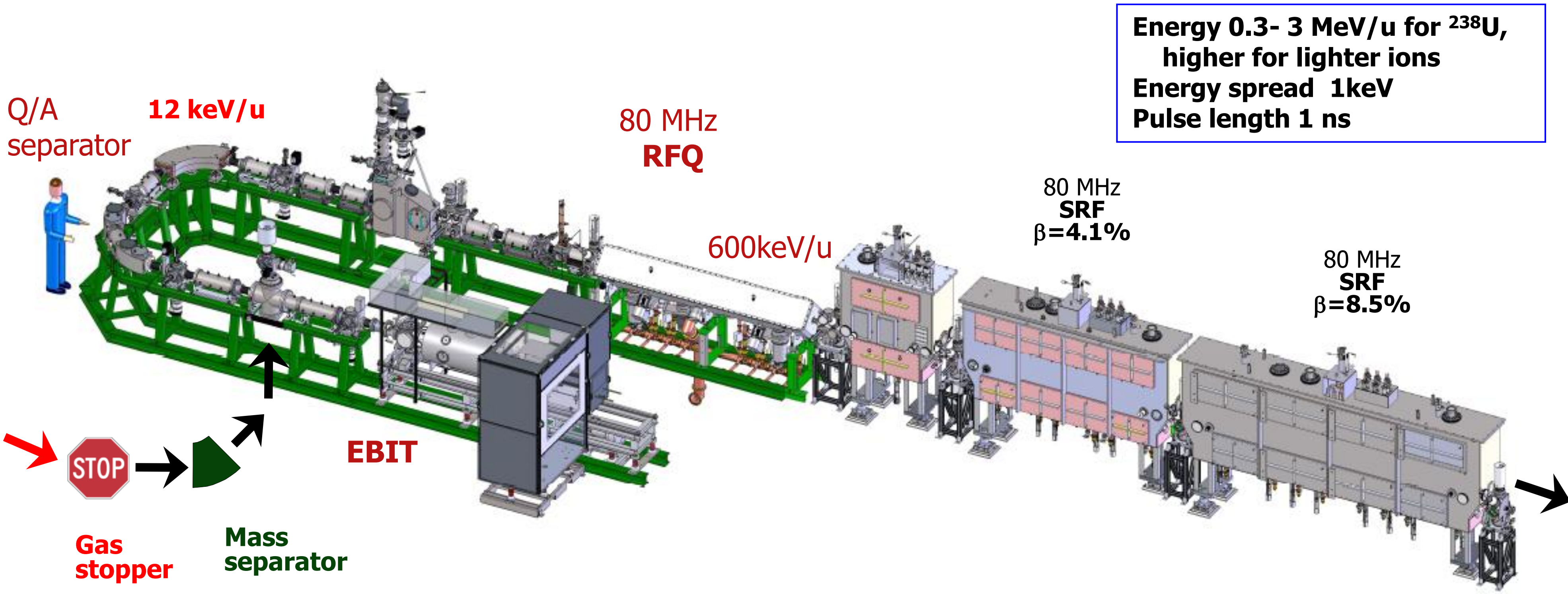
- **Magnetic field, <2.6T**
  - 'wind up' trajectory in central chamber
    → confinement in radial direction
  - Cyclotron-type **sector field**:
    → axial focusing

- **Low-pressure gas:**
  ions lose energy, spiral towards axis

-Use **RF ion guiding techniques** (carpets)
  to move ions to on-axis exit

Now in construction!

ReA3

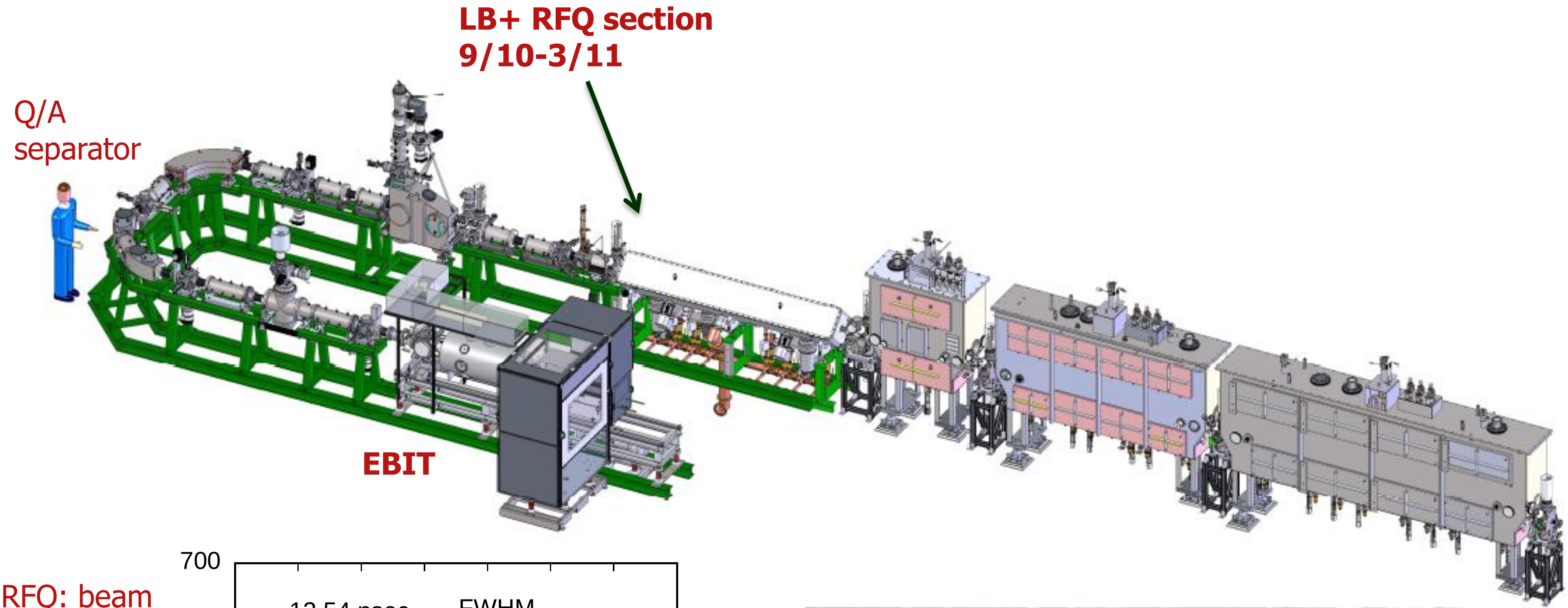


- **Gas stopping** of RIBs from fast fragmentation or in-flight fission
- High-intensity **EBIT** for charge breeding ($1^+ \rightarrow q^+$)
- Compact **linear accelerator**: MHB, RFQ + SRF modules
- expandable **space** for experiments

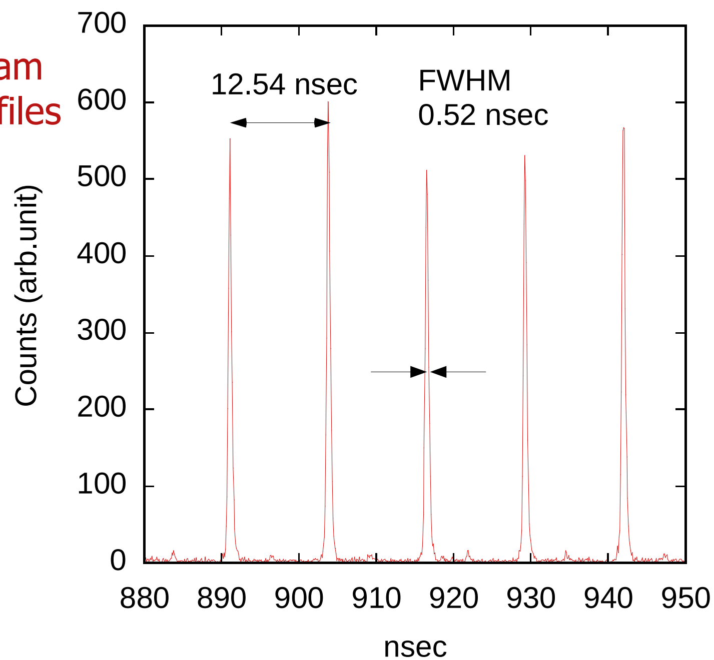
- ReA3: funded, ReA6, ReA12 proposed

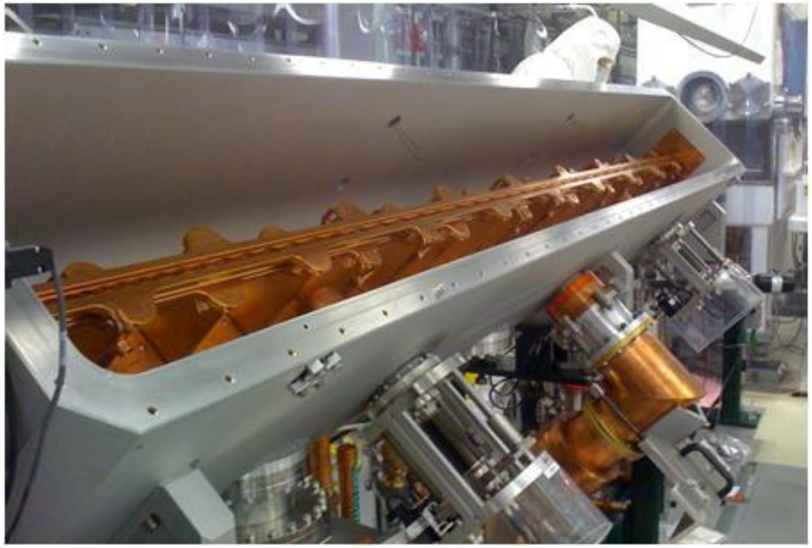
→ **Compact, cost-efficient, highly efficient, expandable**

ReA commissioning, RFQ

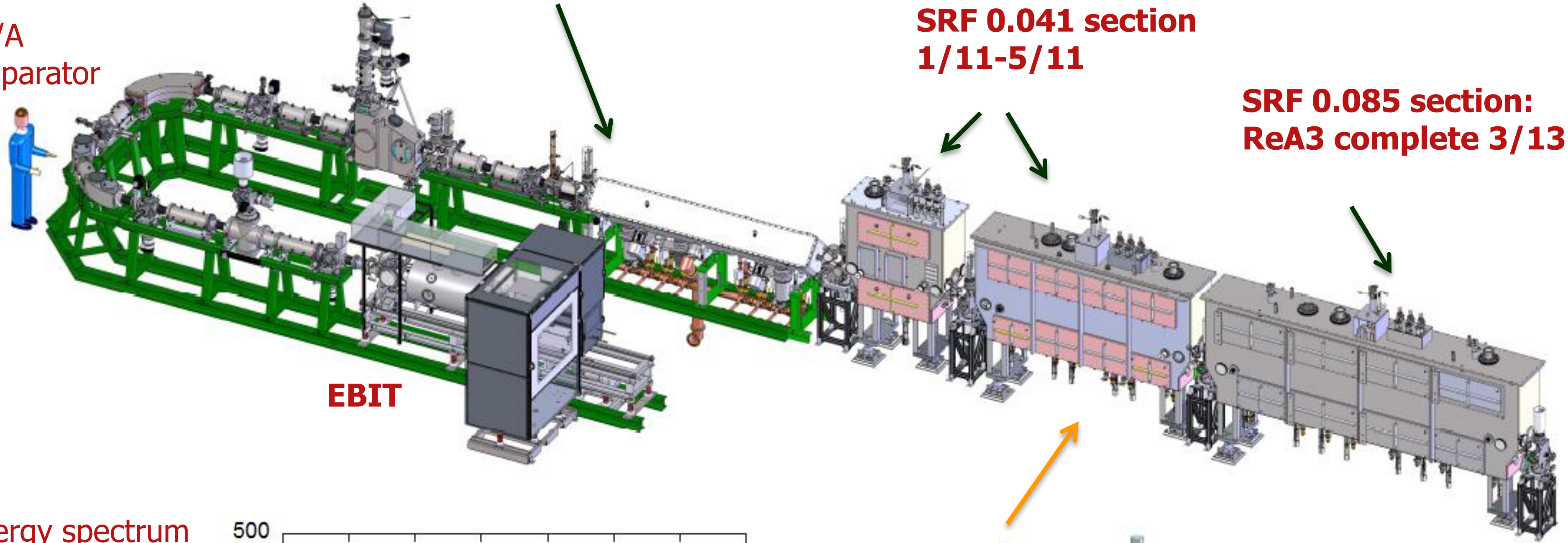


RFQ: beam time profiles

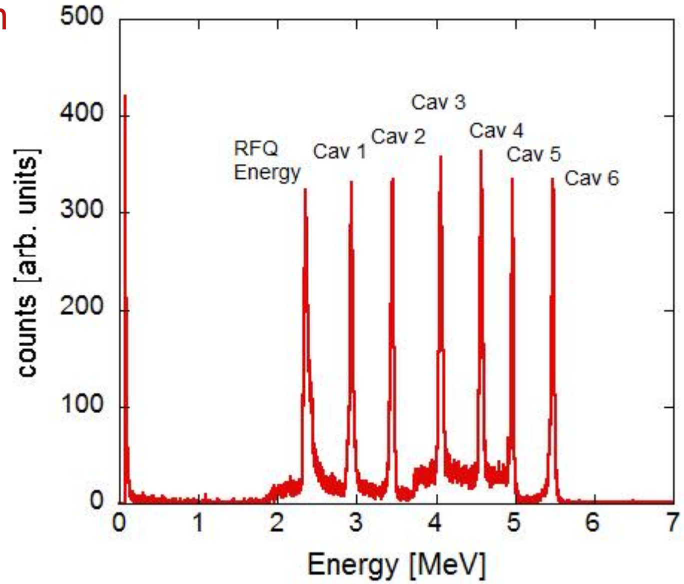


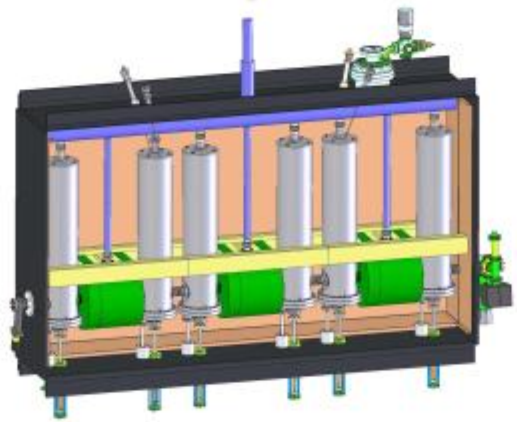


ReA commissioning, SRF modules



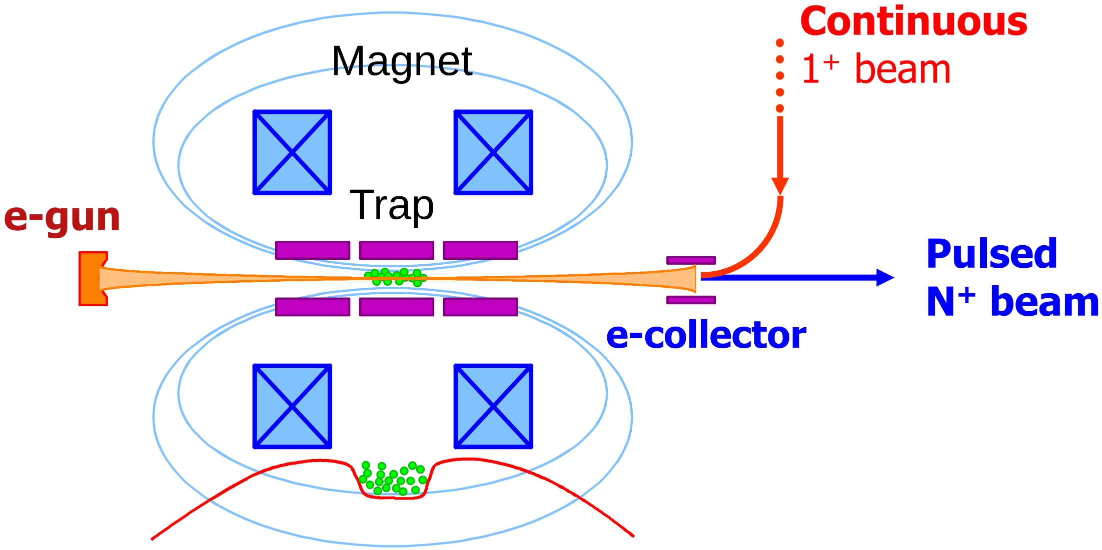
Energy spectrum after CM2





Cryo-module #2

ReA3 – EBIS/T charge breeder



Expected performance
- Efficiency > 50%
- Beam rates > 10^9/s
- Variable duty cycle
- Clean beams
- **Breeding time to q/A>0.25 < 50 ms**

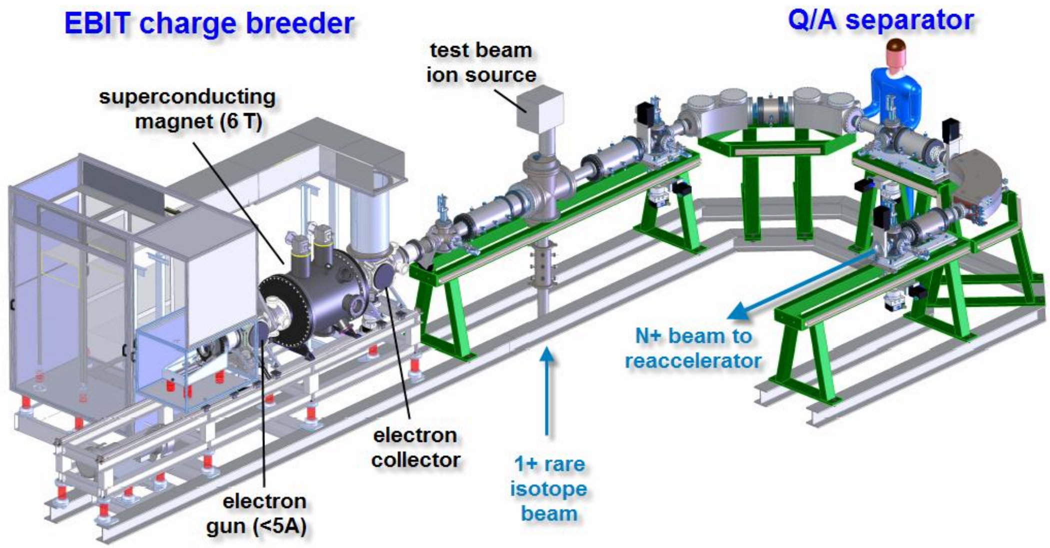
EBIT: Key design parameters:
- **I_e= 0.5 … 5 A, E_e < 30keV**
- **current density: up to ~10^4 A/cm^2**
- magnetic field: up to 6 T

In Collaboration with

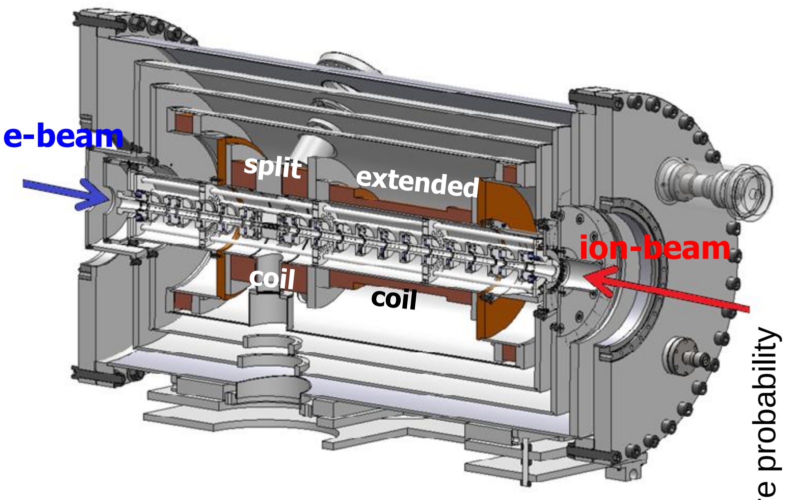
Max-Planck-Institut für Kernphysik — J. R. Crespo López-Urrutia

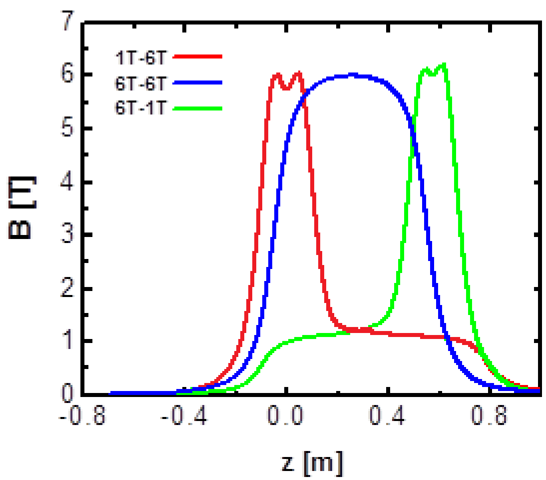
GSI — O. Kester

TITAN ISAC-TRIUMF — J. Dilling



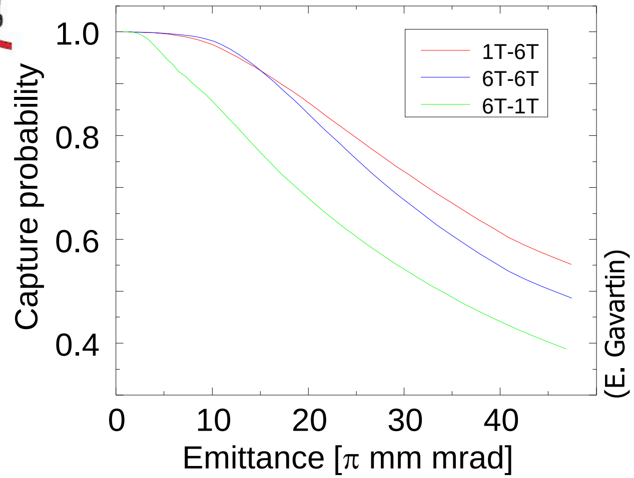
EBIS/T design – hybrid trap

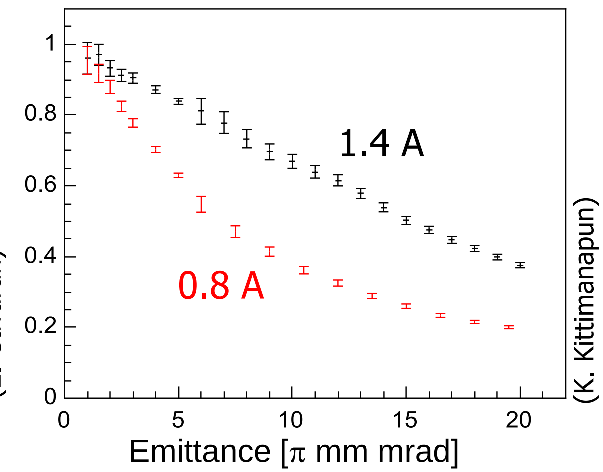




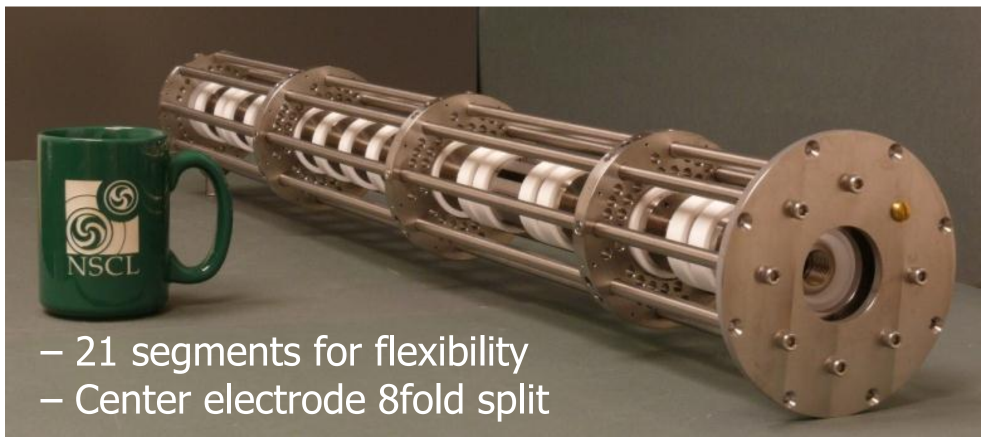
- **Continuous-beam injection:**
  Moderate compression + large e-beam current
  + long trap → good acceptance
- **High** compression → fast breeding

➔ Two regions with different field strength





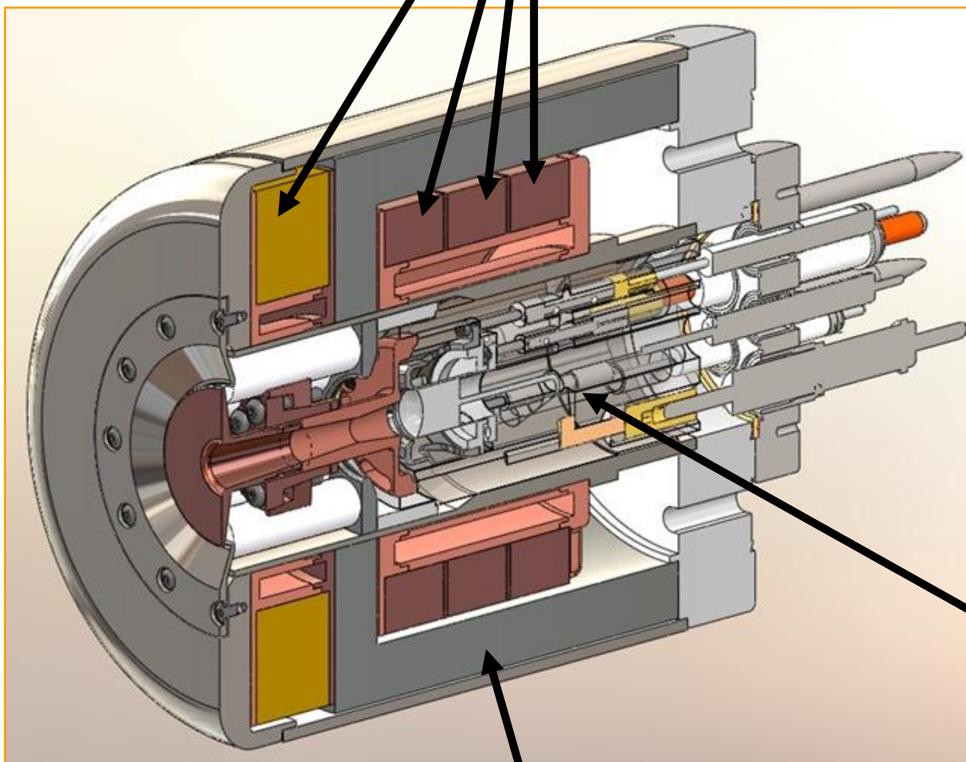
Trap: ~ 0.8m long

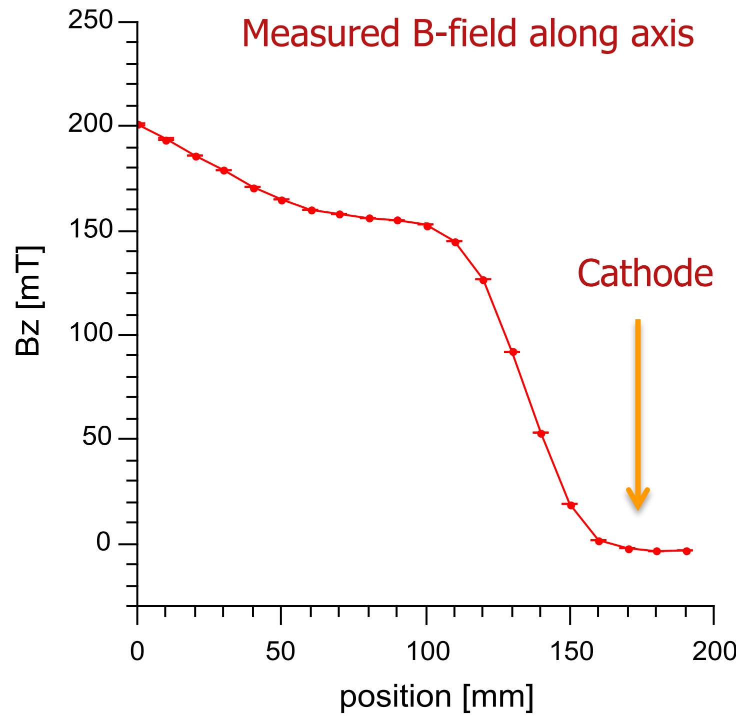


The electron gun

Flexibility by modular design - shape electric & magnetic fields as needed

Bucking coils
- 3 inside iron shield → ~ 60 G per A
- 1 at front → ~ 120 G per A





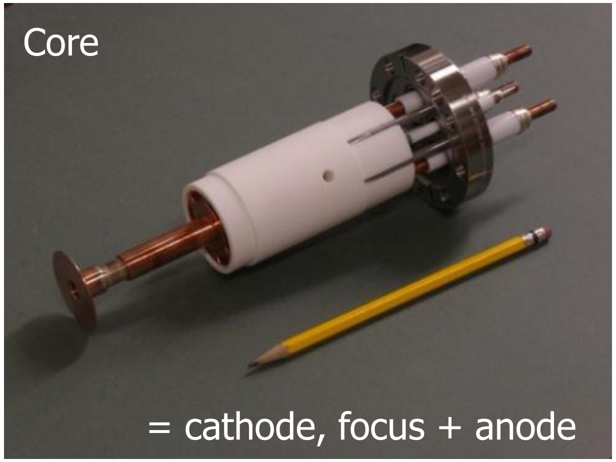
Core
= cathode, focus + anode assembly comes out through front

Soft-iron shield

Two cathode options:
1.4 A(1.1μP) / 2.4 A (1.8μP)

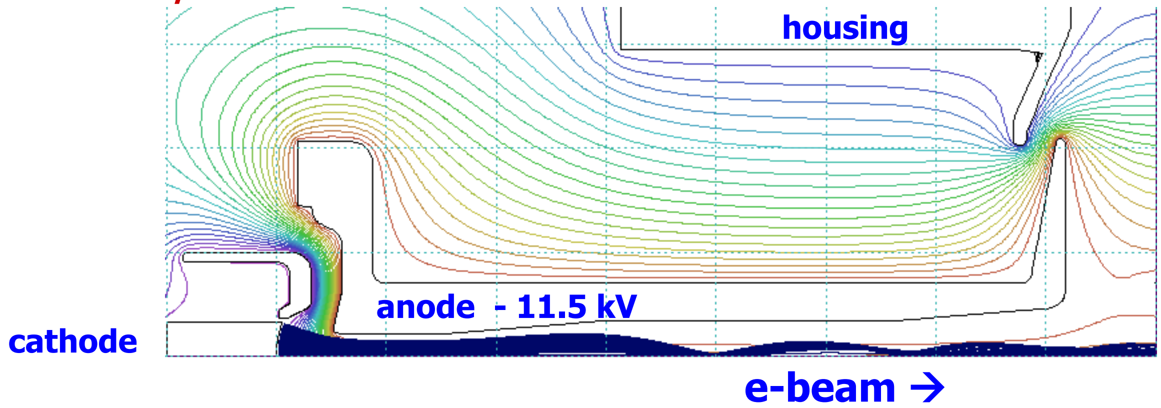
Two cathode assemblies

The electron gun

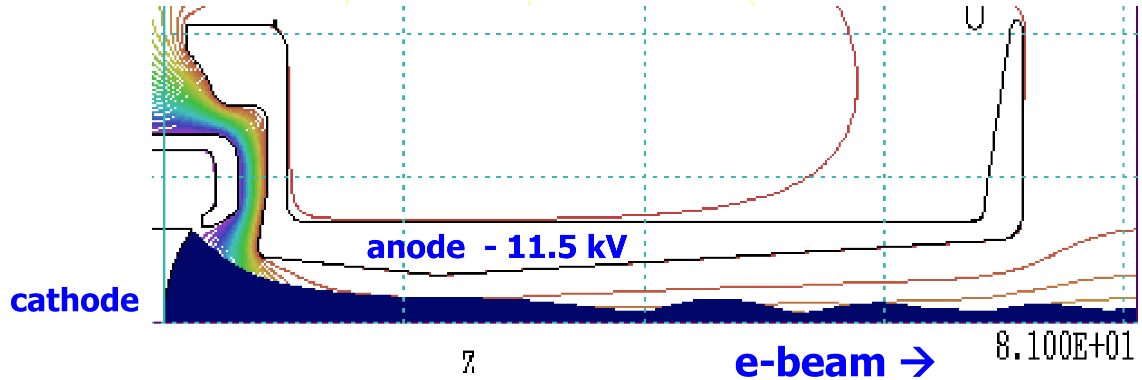


Simulation of extracted beam:
Challenge: Space charge + injection into magnetic field

1/4" - cathode: 1.4 A



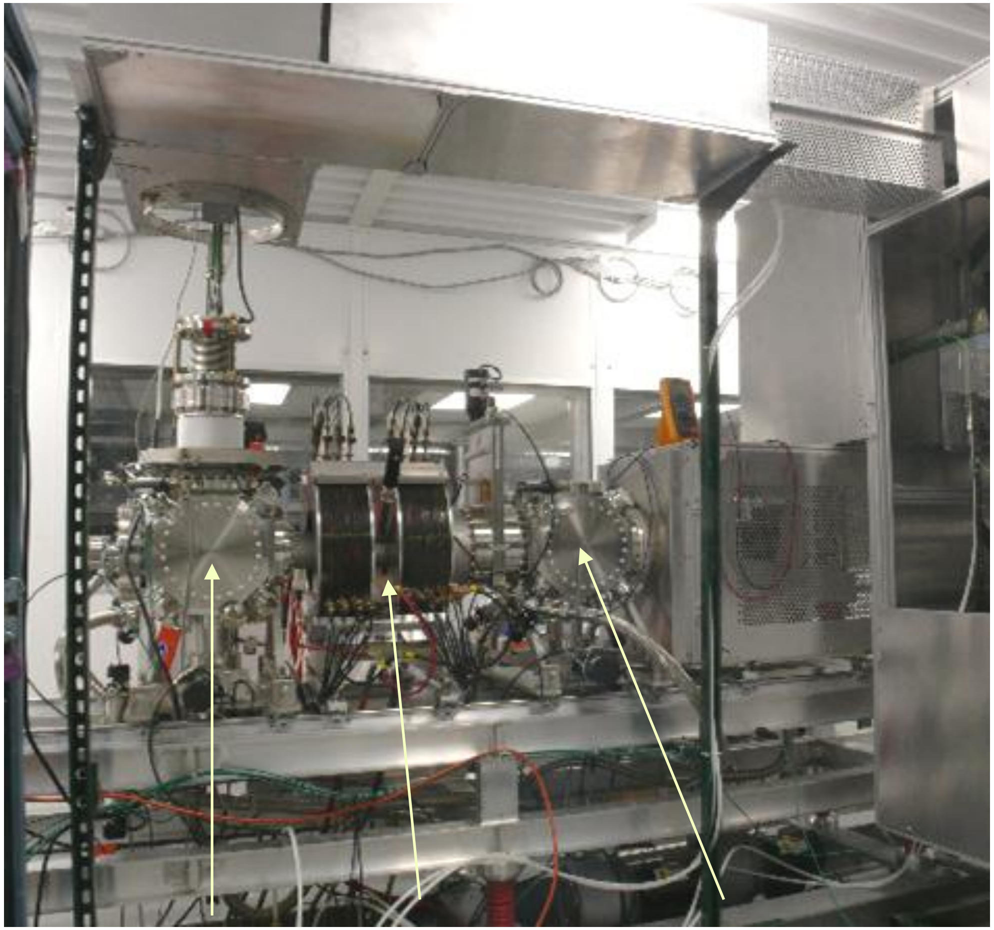
1/2" - cathode: 2.4 A



Calculations for injection into 0.4T test magnet …

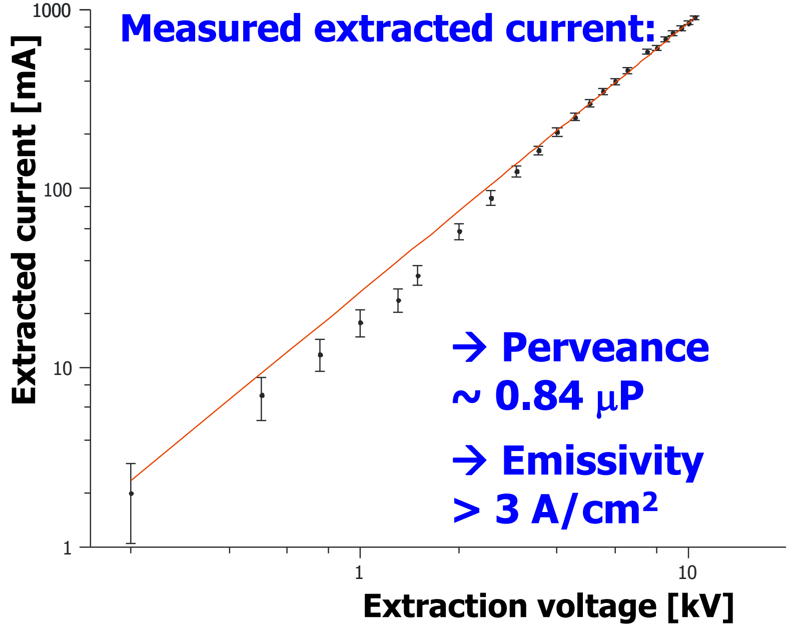
Commissioning of e-gun and collector

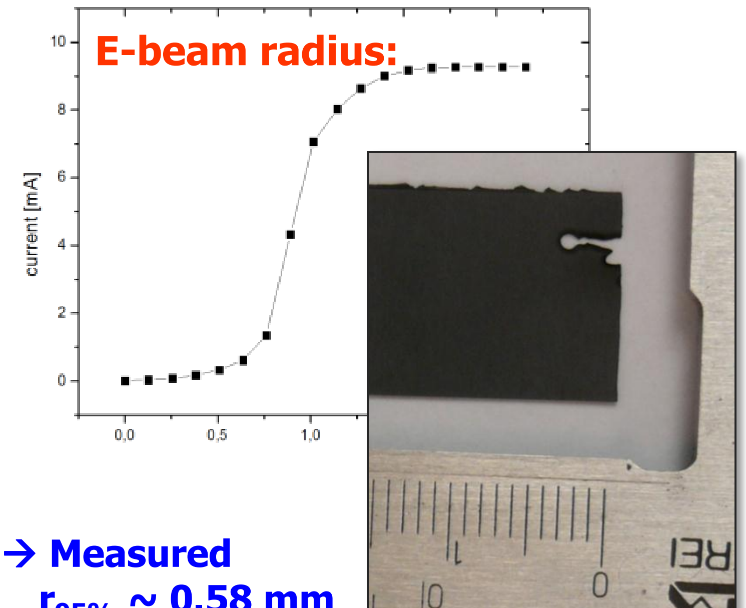
… with a 0.4 T RT coil



collector test coil e-gun

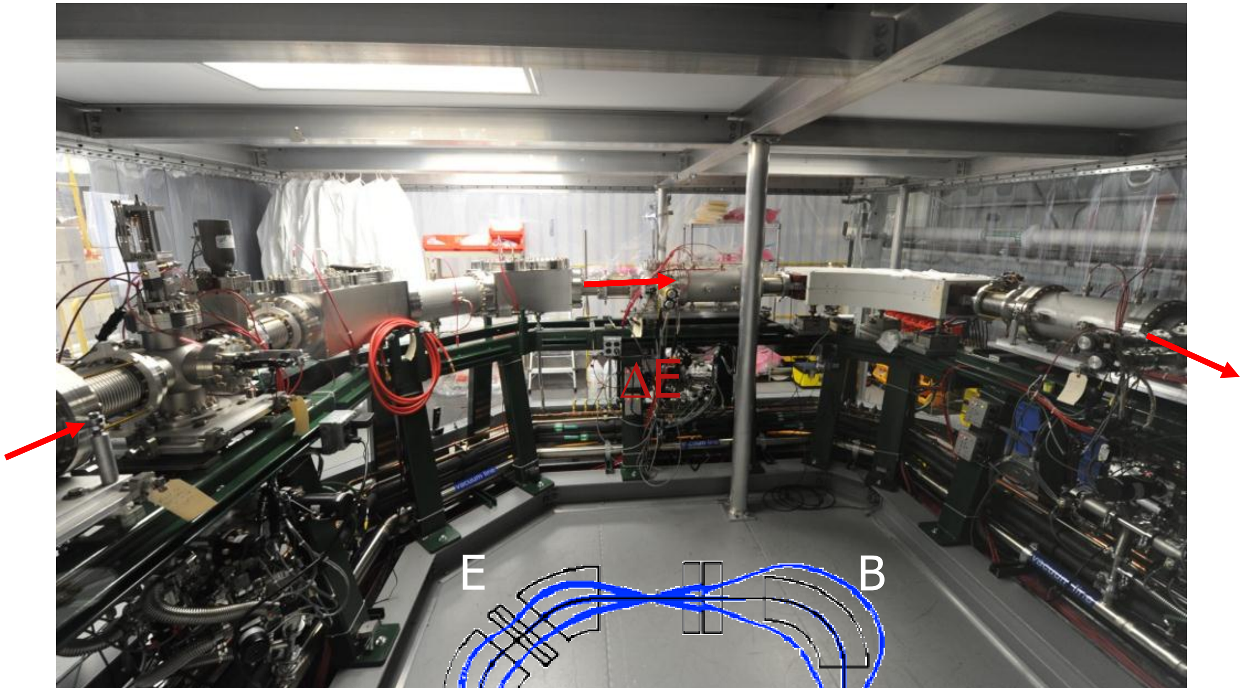
… with provision to insert C-foil

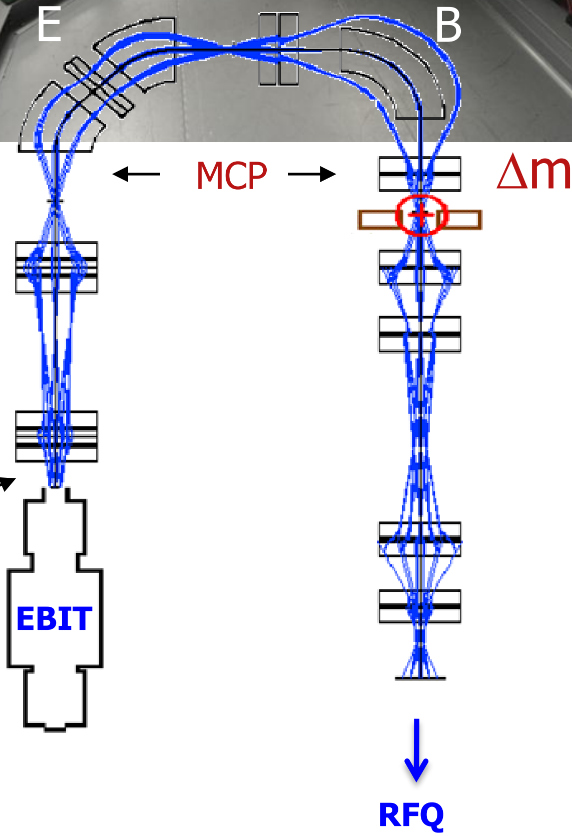




→ Measured $r_{95\%}$ ~ 0.58 mm agrees well with $r_{Herrmann}$

Commissioning of the Q/A separator



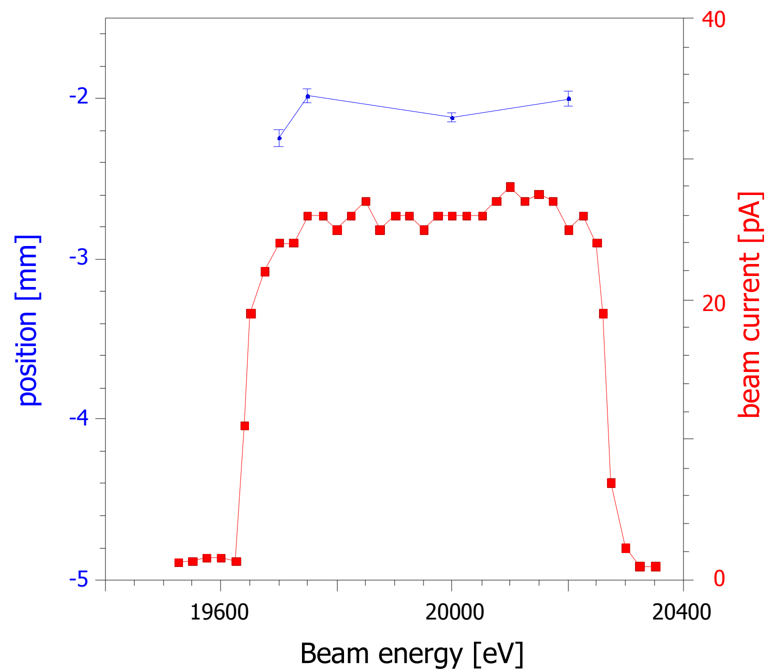


For commissioning just a temp ion source (alkali/He-discharge)

Design parameters:

- 12 keV/u, A/Q = 2 to 5
- ε_n = 0.6 π mm mrad
- R > 100, verified
- mass dispersion 10mm/%, verified
- Achromatic: dE > ±0.2%

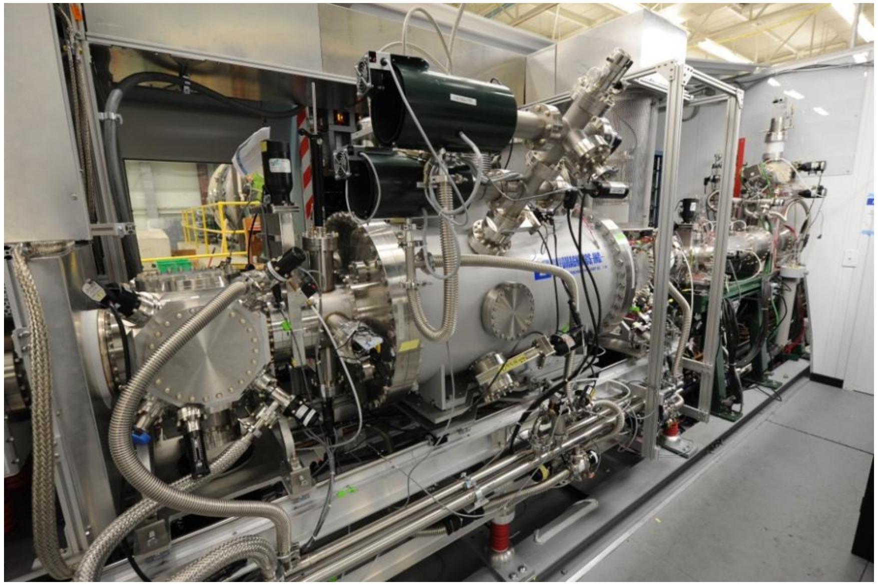
Energy acceptance:

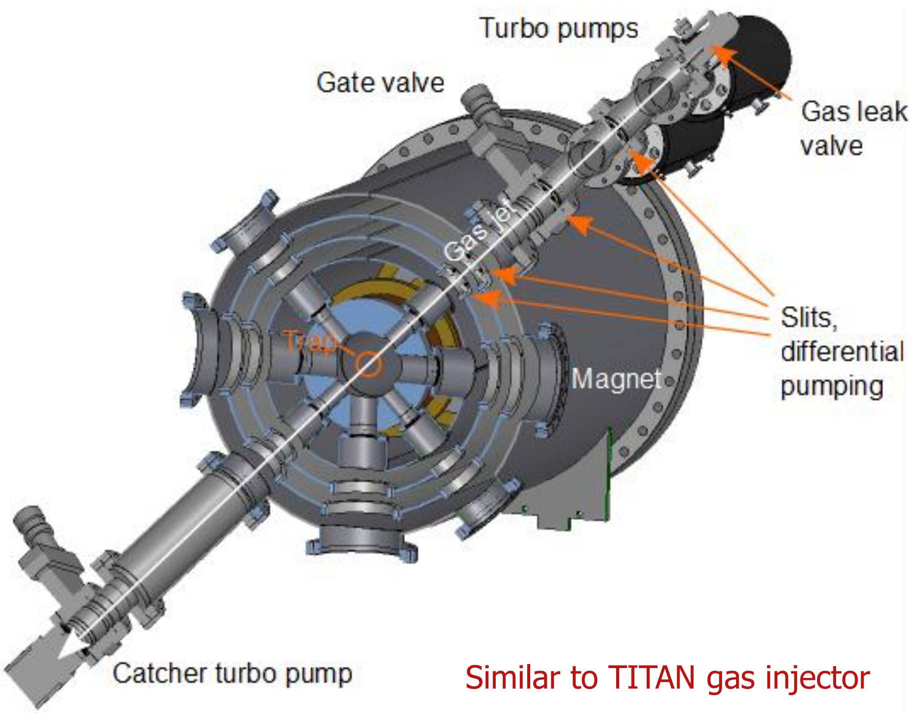


→ accepted E-spread ~±1.5 %

Beam optics:
M. Portillo

Charge-breeding of Ne ions from the gas injector

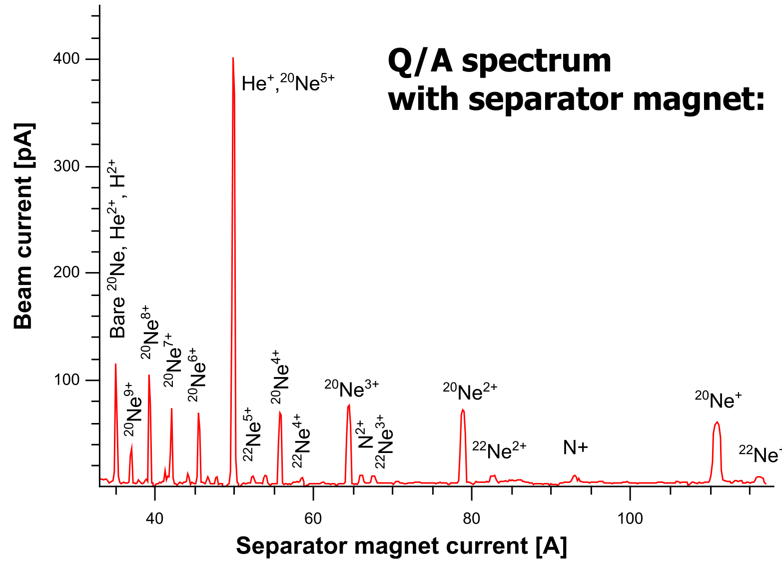




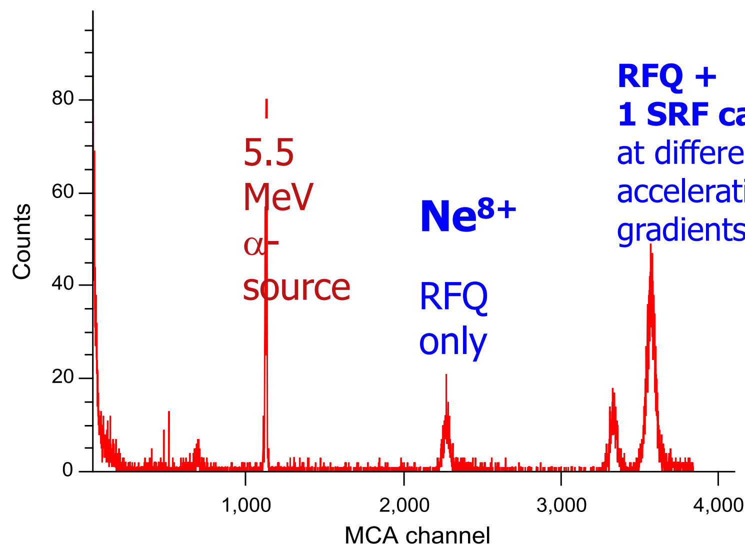
Similar to TITAN gas injector

June/July 2011: First breeding & Q/A scan of Neon

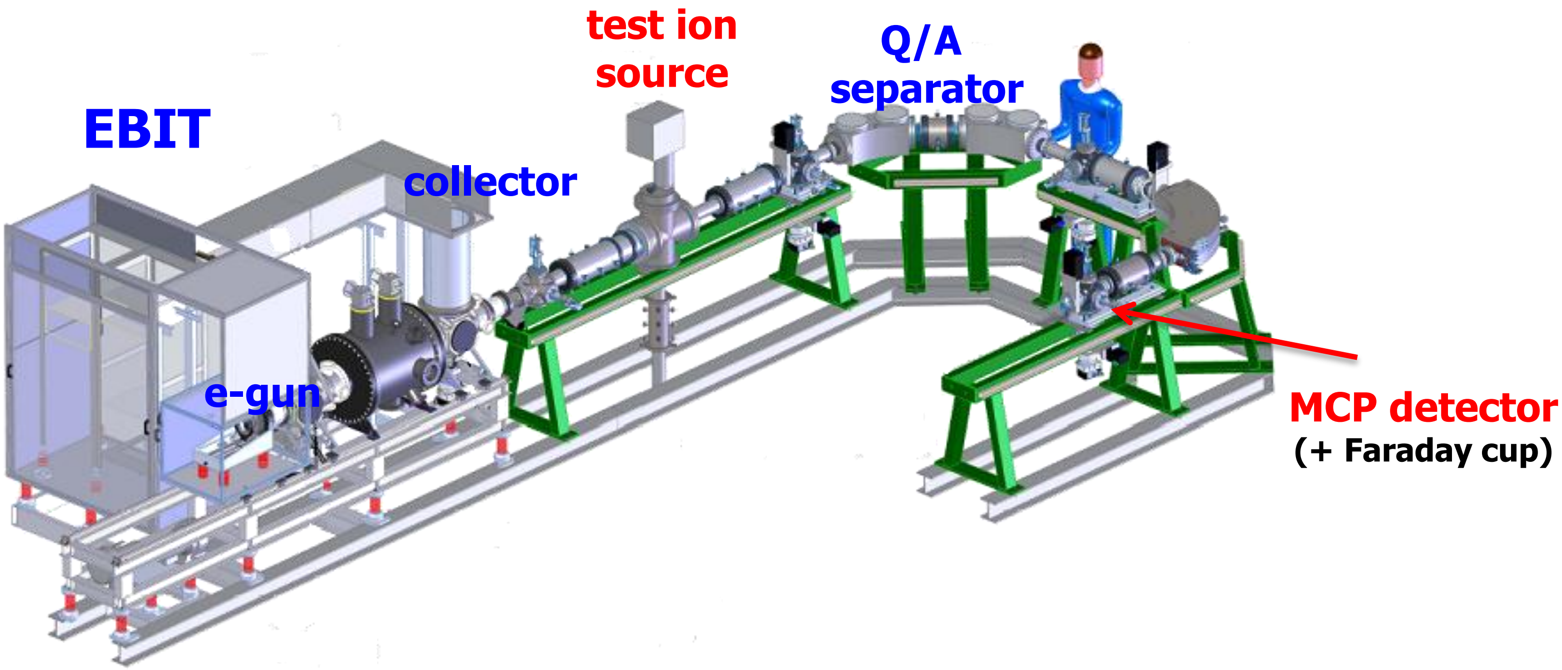
- 'Leaky mode' + pulsed extraction
- 2T field, 15 keV, 36mA electrons, 30kV extraction



Accelerated Ne^{8+}: Energy spectrum



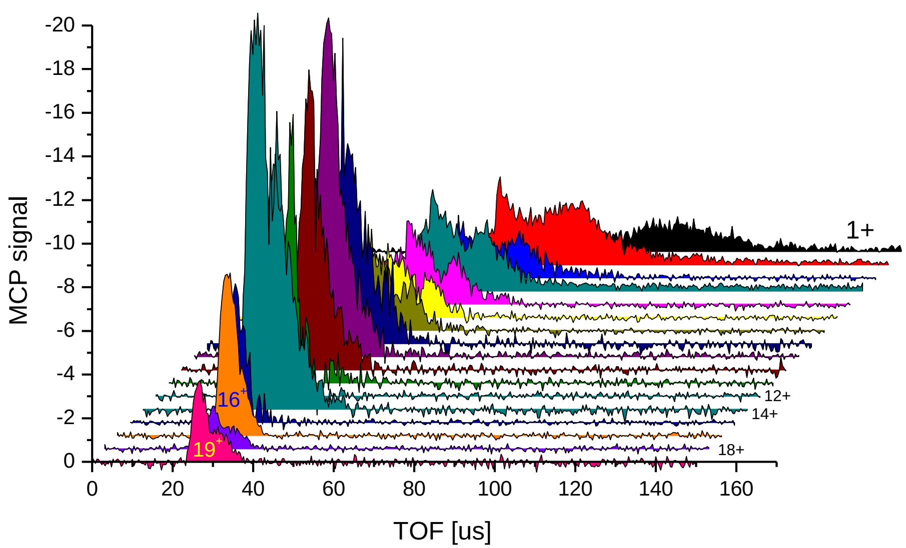
Charge-breeding of alkali ions from the test ion source



Since Fall 2011:

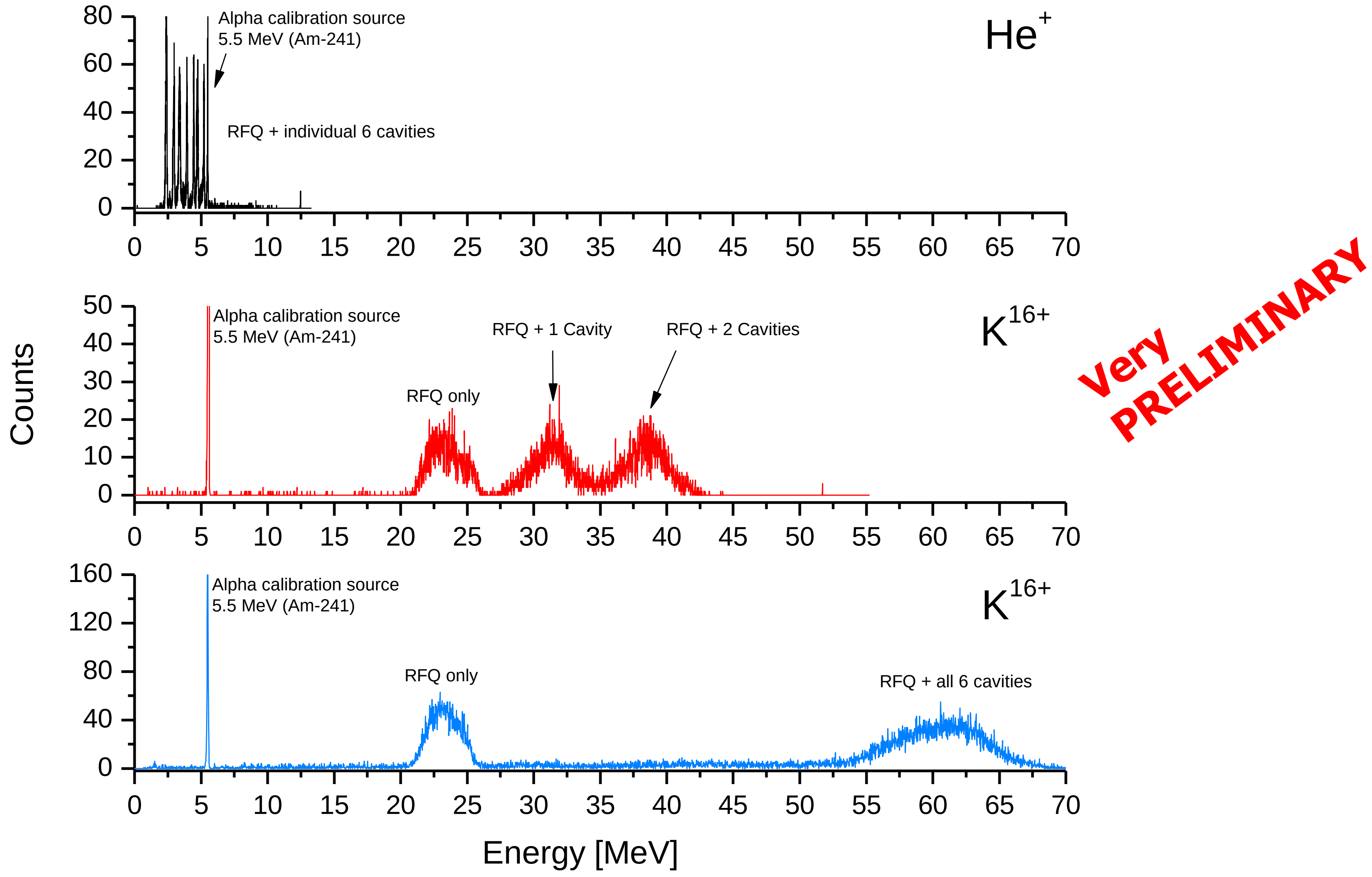
Capture and charge-breeding of External ions

TOF spectra for Q/A-separated K charge states:



Electron current: 88 mA
Electron energy: 16.5 keV
Ion energy: 15 kV*q
Injected ion current: 18 pA

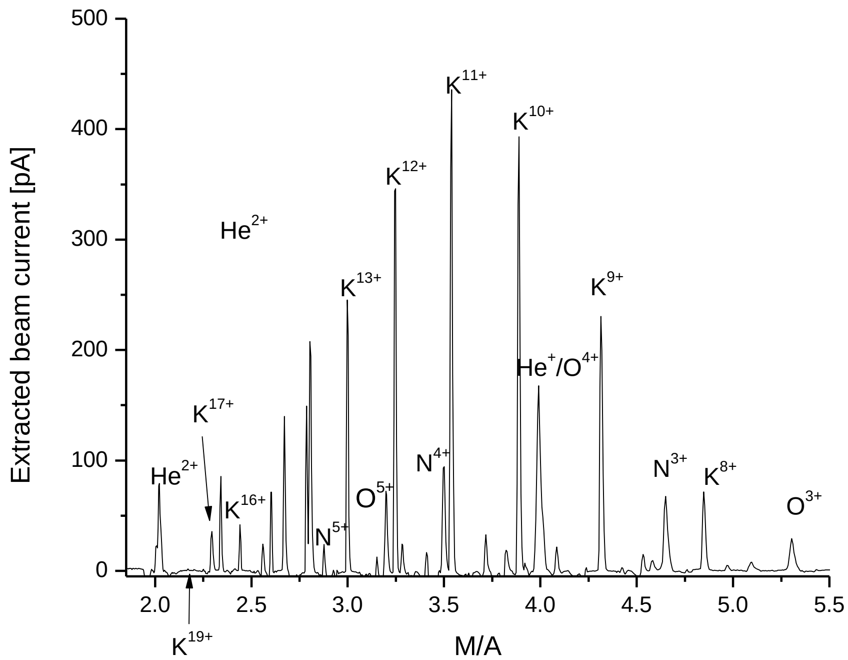
Accelerated alkali ions from the test ion source



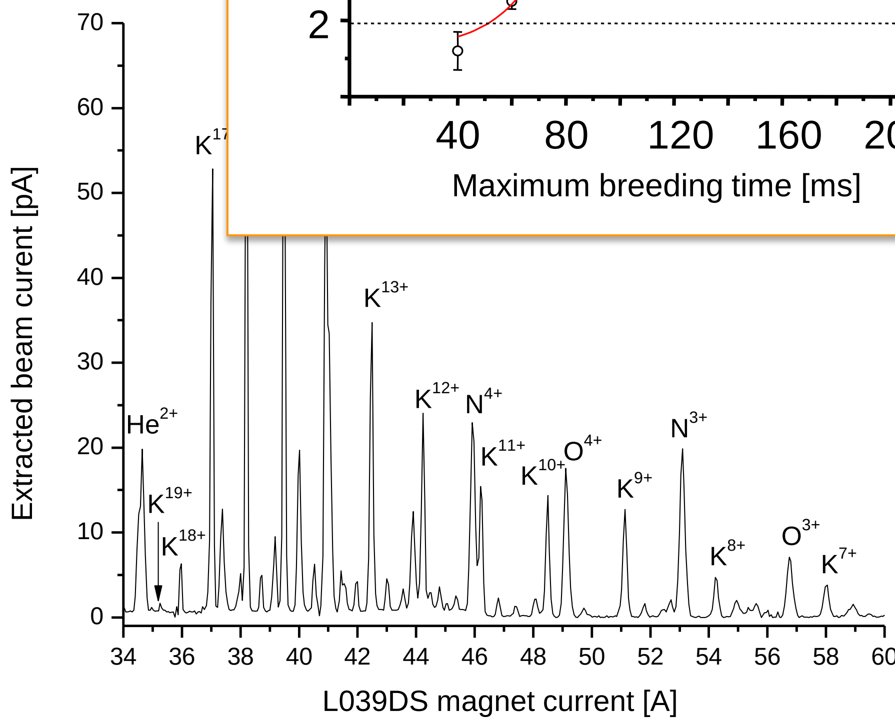
Breeding time

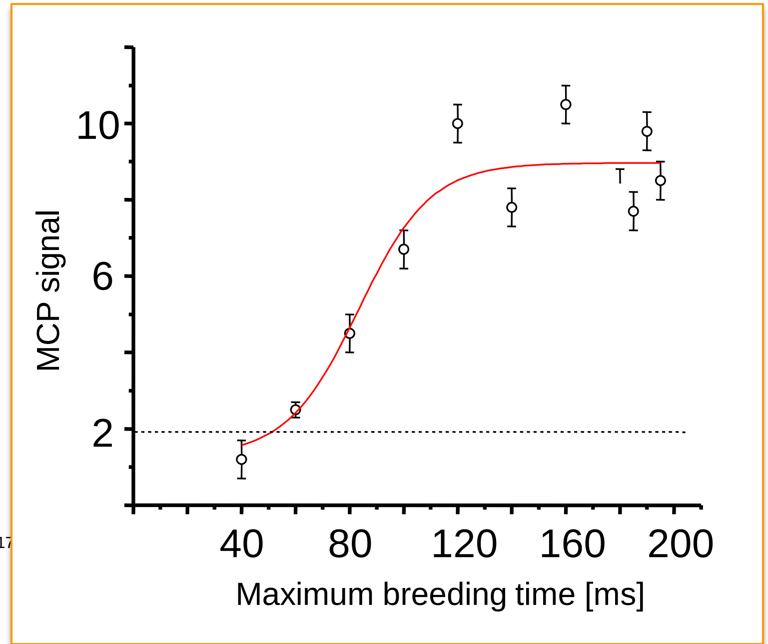
Q/A spectra with K from test ion source:

K^+ beam current: ~10 nA
I-beam energy: ~29keV * q
100 mA electron beam



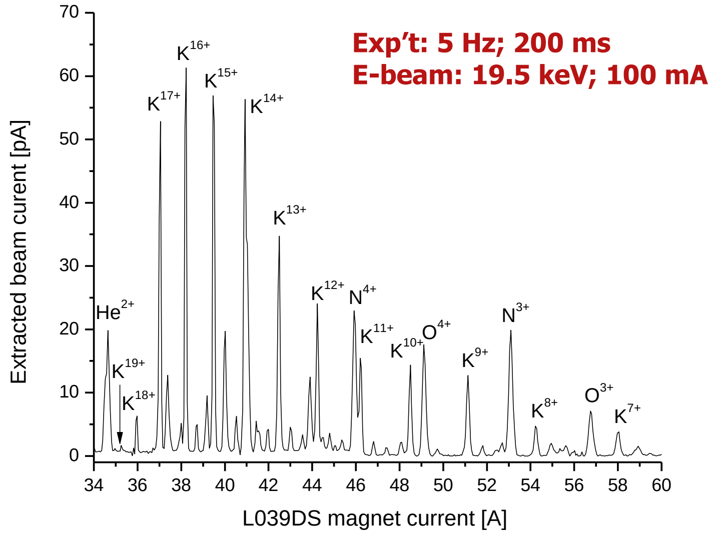
20 Hz extraction rate
→ up to 50ms breeding time

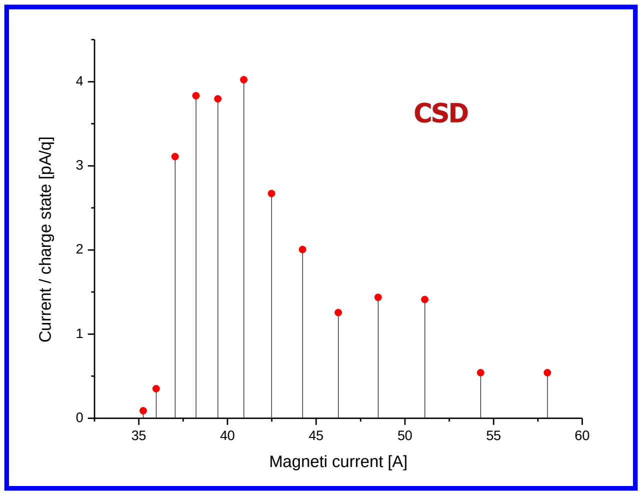


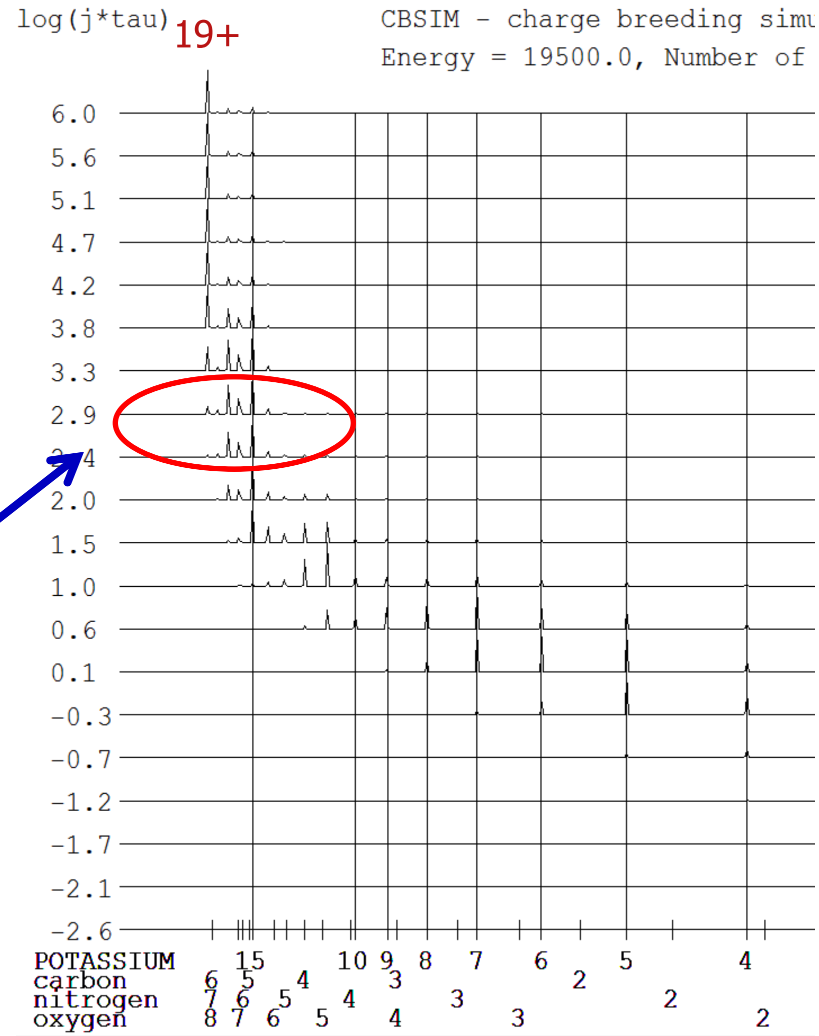


5 Hz extraction rate
→ up to 200ms breeding time

Charge state distributions, CBSIM, j



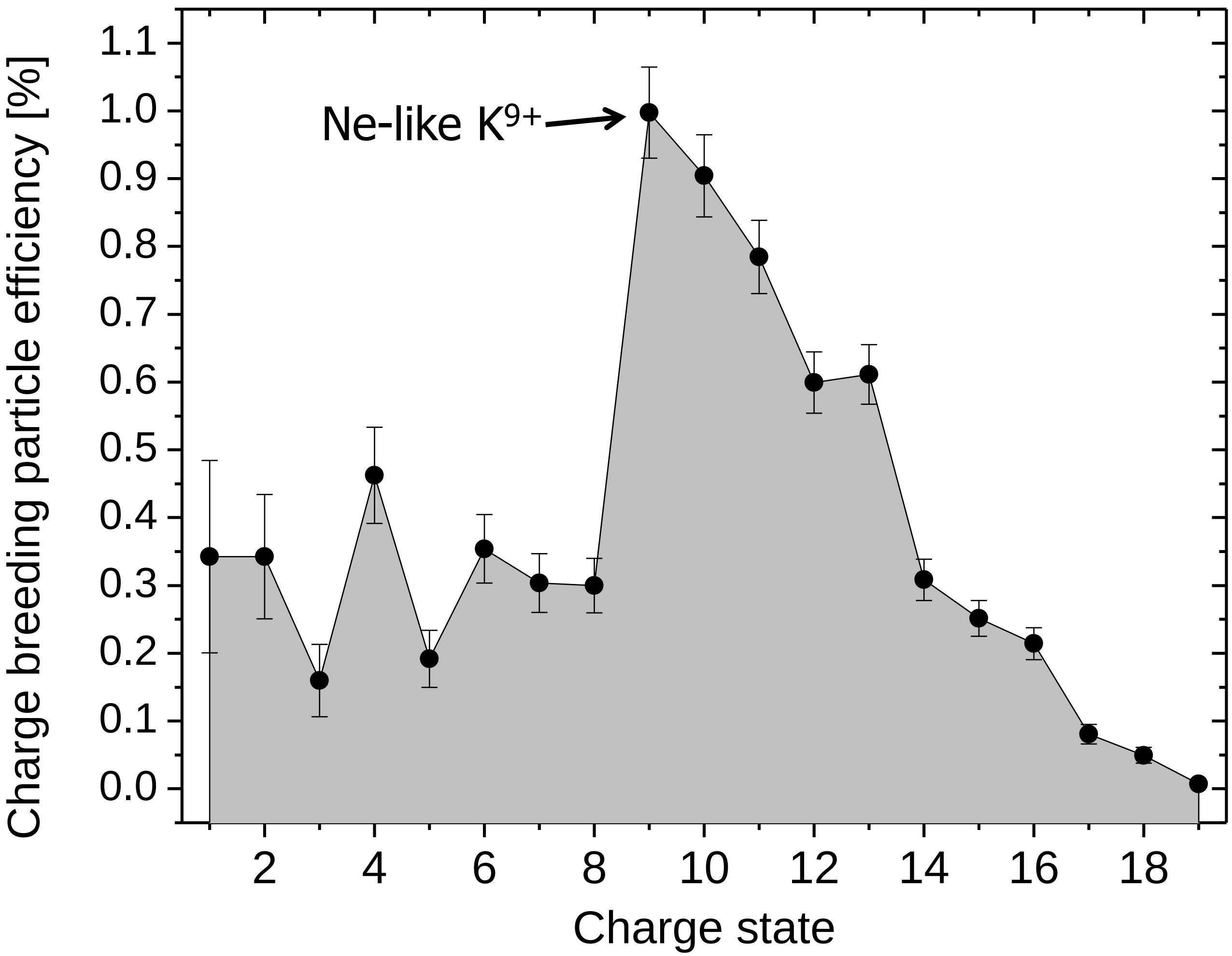




CBSIM code (Becker/Kester):
Log(j*t) ~ 2.4
Using residual gas …
Exp't · **j~1000 A/cm2** (3 T, average)
t~250 ms

Efficiency ?

Preliminary charge breeding efficiency in single charge states



Magnet config.: 4 T–2 T
Breeding time: 200 ms (5 Hz)
E-beam current: **100 mA**
E-beam energy: 19.5 keV

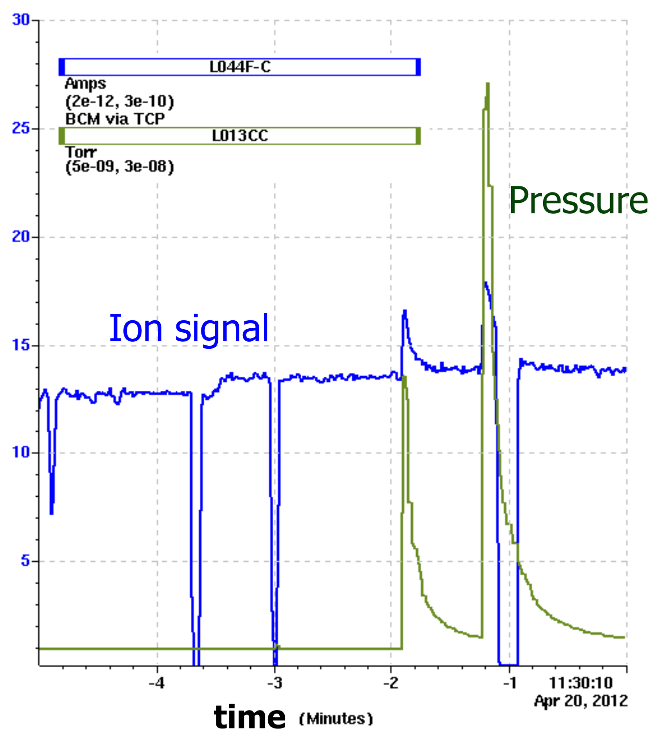
Total capture efficiency: 7.5%

Simulation total eff.: 15 ± 5 %

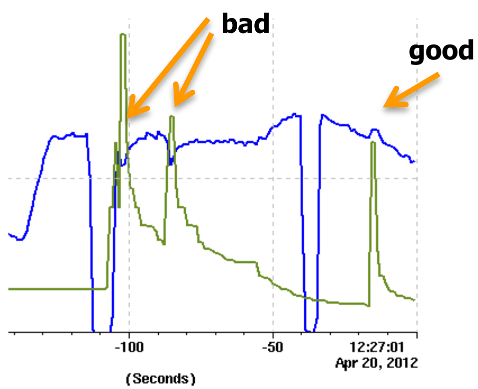
Larger efficiencies with 1 A !

Ion cooling with He

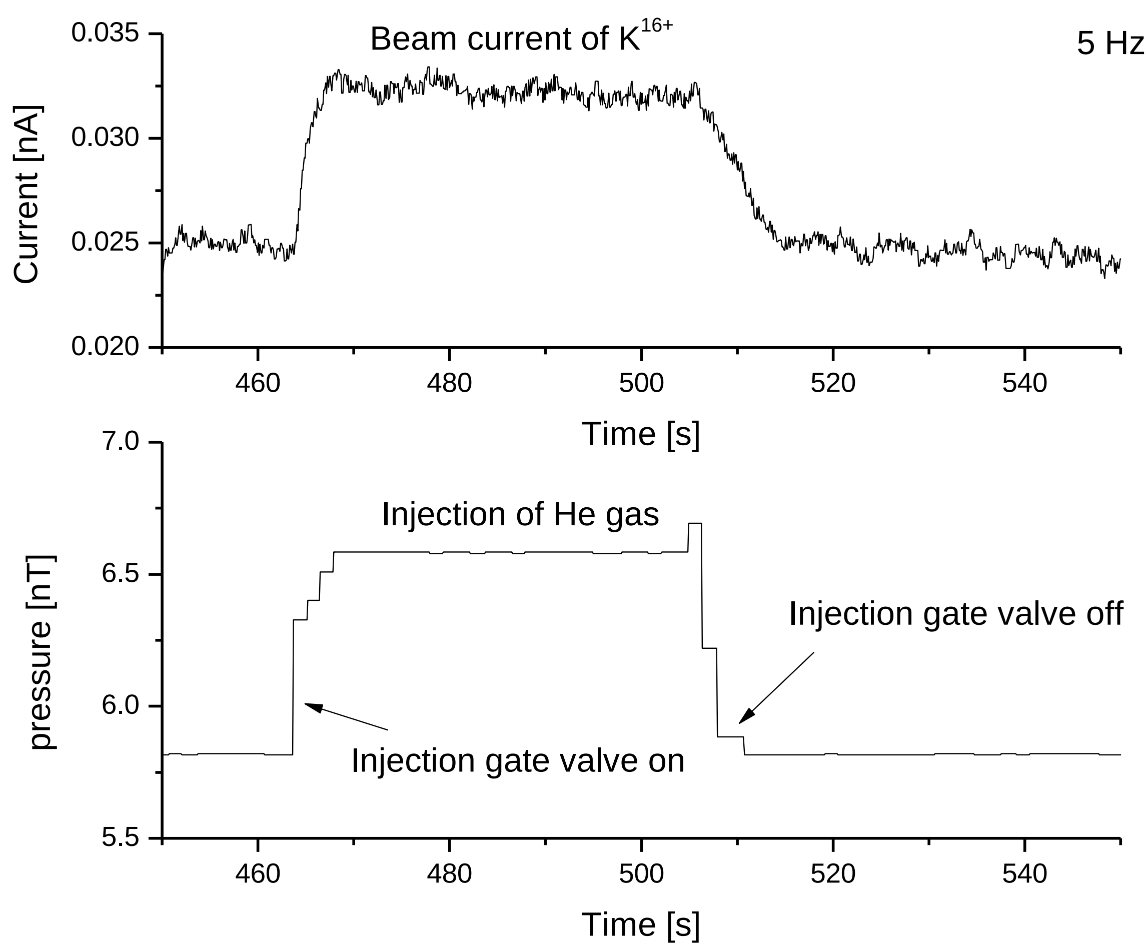
He pressure bursts …
and effect on K^{16+} production:



Another example:

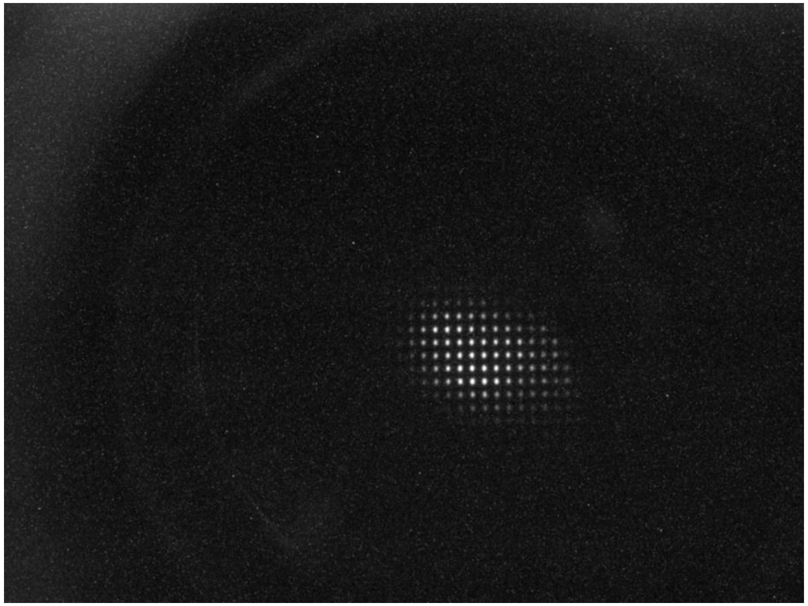


Remember the gas injector … add He deliberately!



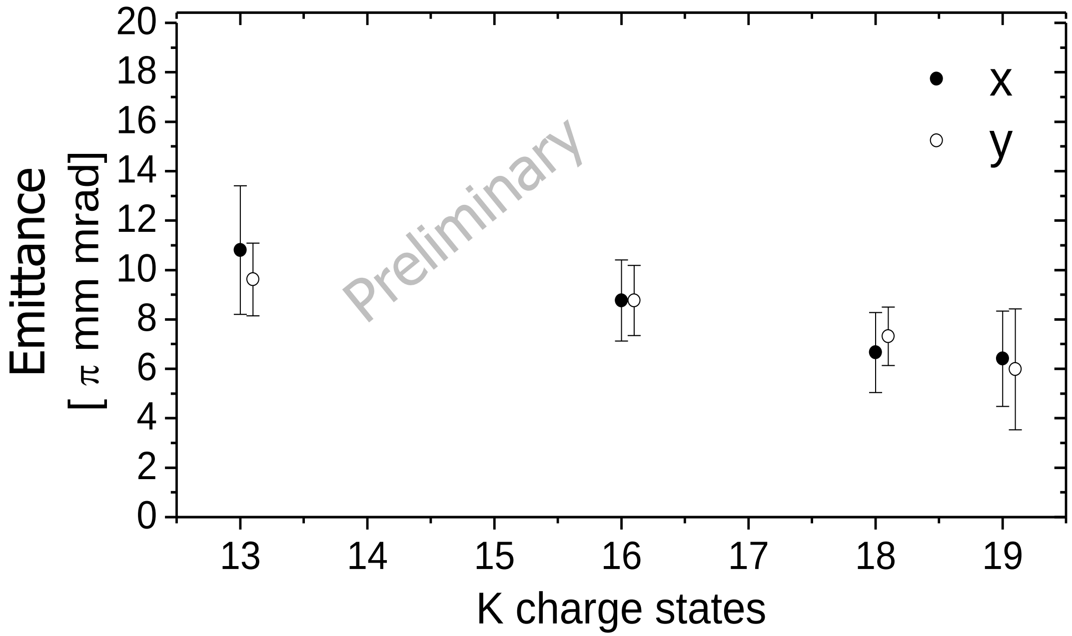
First stab at emittance …

K^{18+} beam on the Pepperpot meter



Ion beam energy: 29.223 kV * q
Electron beam current: 100 mA

Emittance *vs* charge state



EBIT: First accelerated charge-bred ions with EBIT-RFQ-SRF
To do: Reached 250mA, but → increase I !

ReA3:

2011: Accelerated highly-charged beams

2012: First test with RIB

2013: Complete ReA3, limited user program

Thanks to …

MICHIGAN STATE UNIVERSITY

NSCL

Max-Planck-Institut für Kernphysik

GSI

G. Bollen, *K. Kittimanapun*, ***A. Lapierre,*** D. Leitner … and MANY MANY MORE
J. R. Crespo López-Urrutia
O. Kester

Thanks for listening!

What do we like / what did we learn ?

Electron gun:
- Modular ! → Swap out insert
- Gate valve separating from SC magnet
- High compression not easy

Magnet:
- Flexible field
- 4K trap
- LHe-buffered cryostat, cooled by 1.5W pulse-tube cooler
- Shared vacuum of trap & shields (not coils!) – He bursts!
- Perhaps too long a distance from magnet to e-gun / collector

Collector:
- Burned out v.1 … → added T-interlock
- v.2: changed water connections … so far working well
- Vacuum shared with trap, no gate valve
- Hard to adjust position (HV)

Other:
- FC / MCP diagnostics: Both between e-gun/trap and outside collector
- Need to switch 60kV to 20kV … 48kV. No good solution yet for 100Hz
- Failed 60kV DC isolation transformer
- Failed pulsed 60kV isolation transformer
- … more to come!