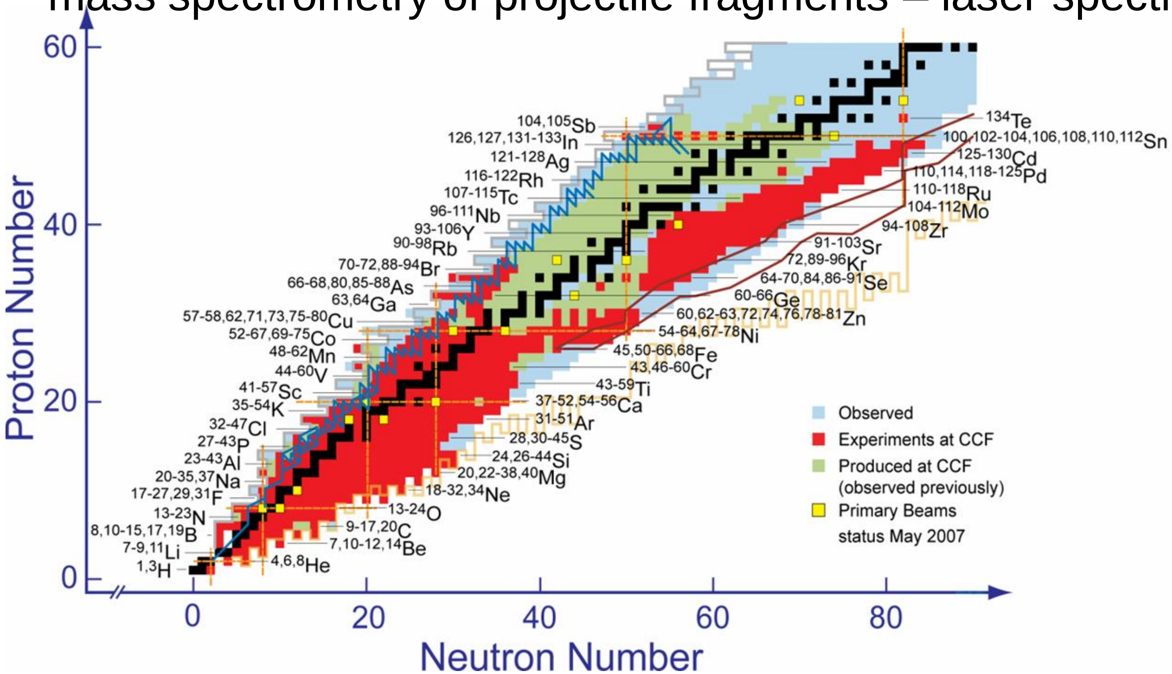
ReA3 – the rare isotope re-accelerator at MSU

- Overview and motivation
- The re-accelerator sections
  - Low beam energy section of ReA3
  - The ReA3 linac and beam transport
- Summary and outlook

Why reaccelerated beams at the NSCL?

- NSCL is a user facility based on rare isotope production by projectile fragmentation and projectile fission
  - NSCL has successful program with stopped beams – LEBIT facility for Penning trap mass spectrometry of projectile fragments – laser spectroscopy under preparation

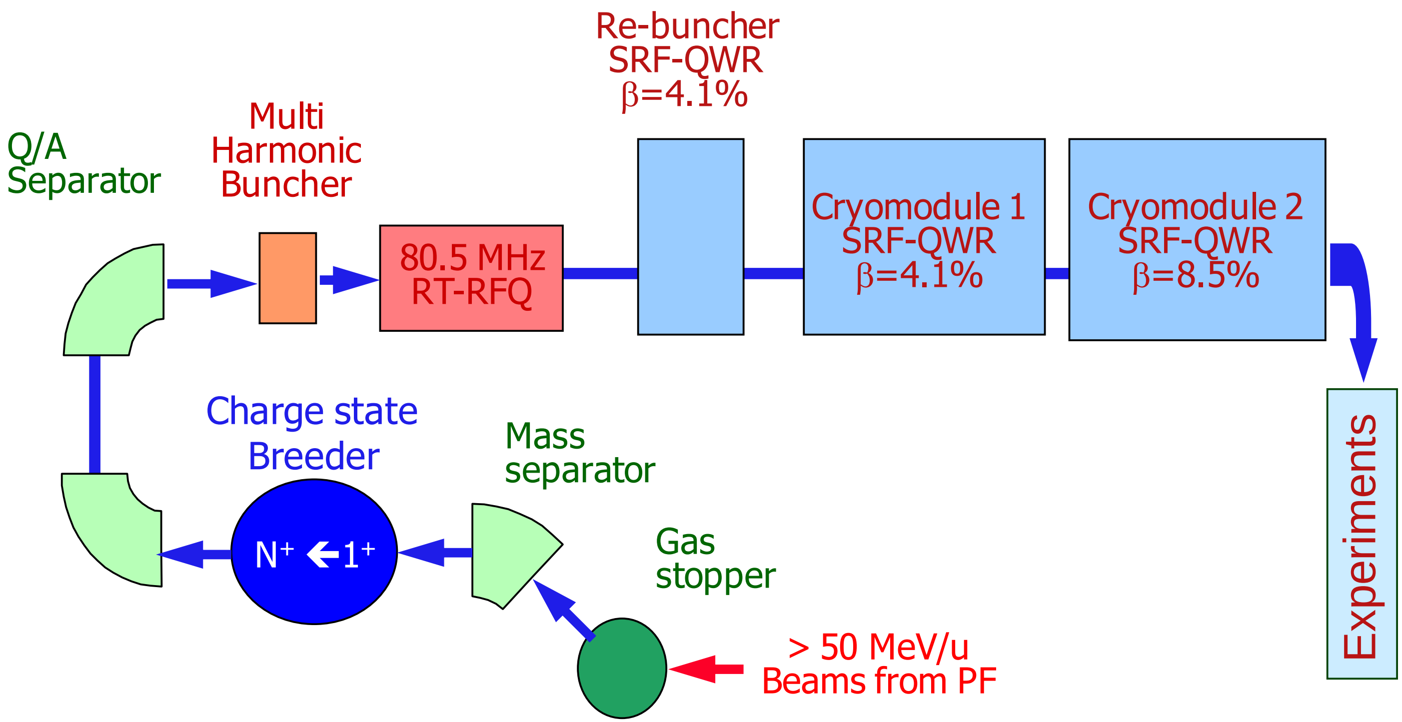


More than 900 RIBs have been made – more than 600 RIBs have been used in experiments

- ReA3 opens new science opportunities with rare isotopes produced by projectile fragmentation
  - Nuclear astrophysics: key reactions at near-stellar energies
  - Nuclear structure via Coulomb excitation or transfer reactions

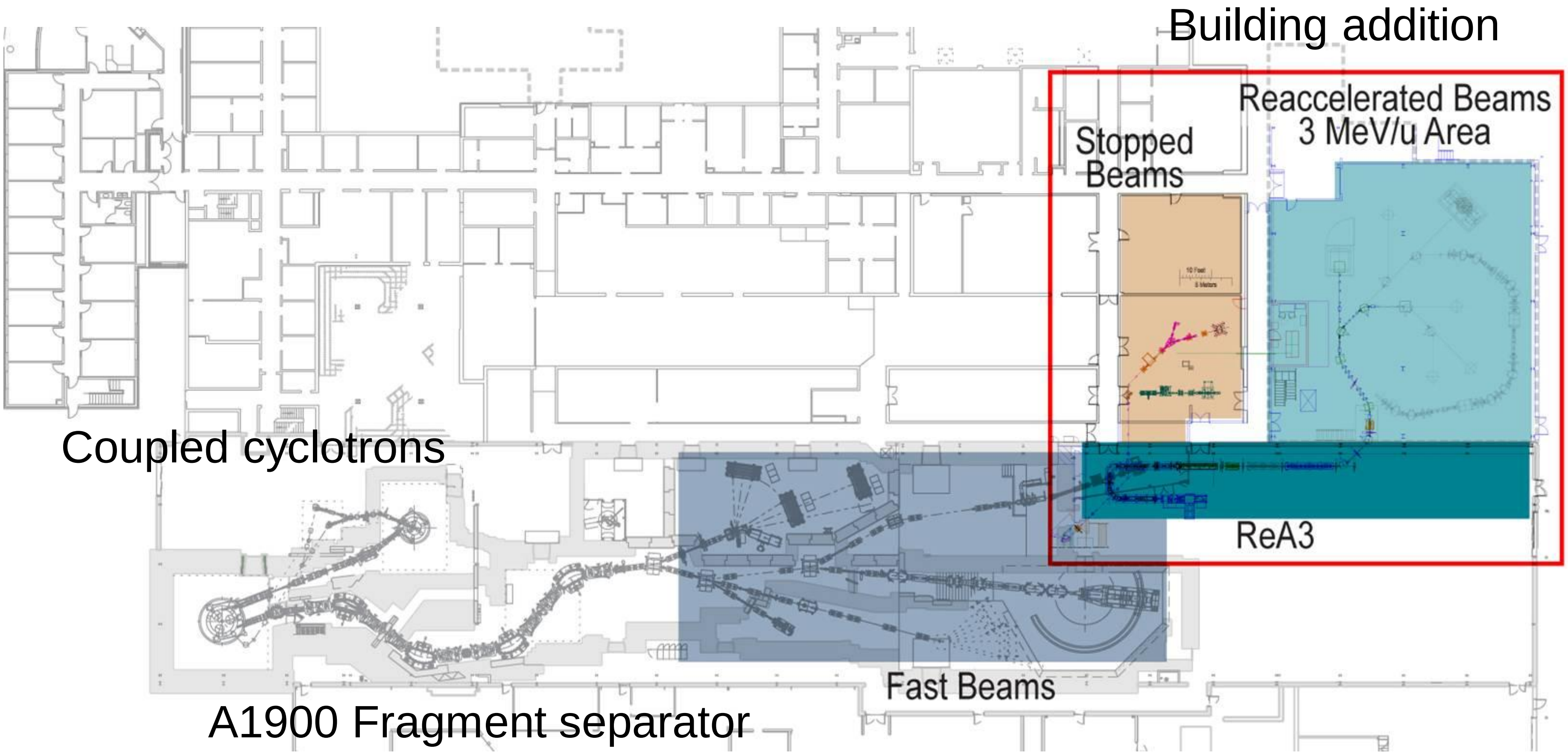
Concept and scientific motivation

- Reacceleration concept:
  - Beam stopper (linear gas stopper, cyclotron stopper or solid stopper)
  - High-intensity electron beam ion trap (EBIT) as 1+ → n+ charge breeder
  - Room temperature RFQ and Superconducting RF Quarter Wave Resonators in 3 cryomodules

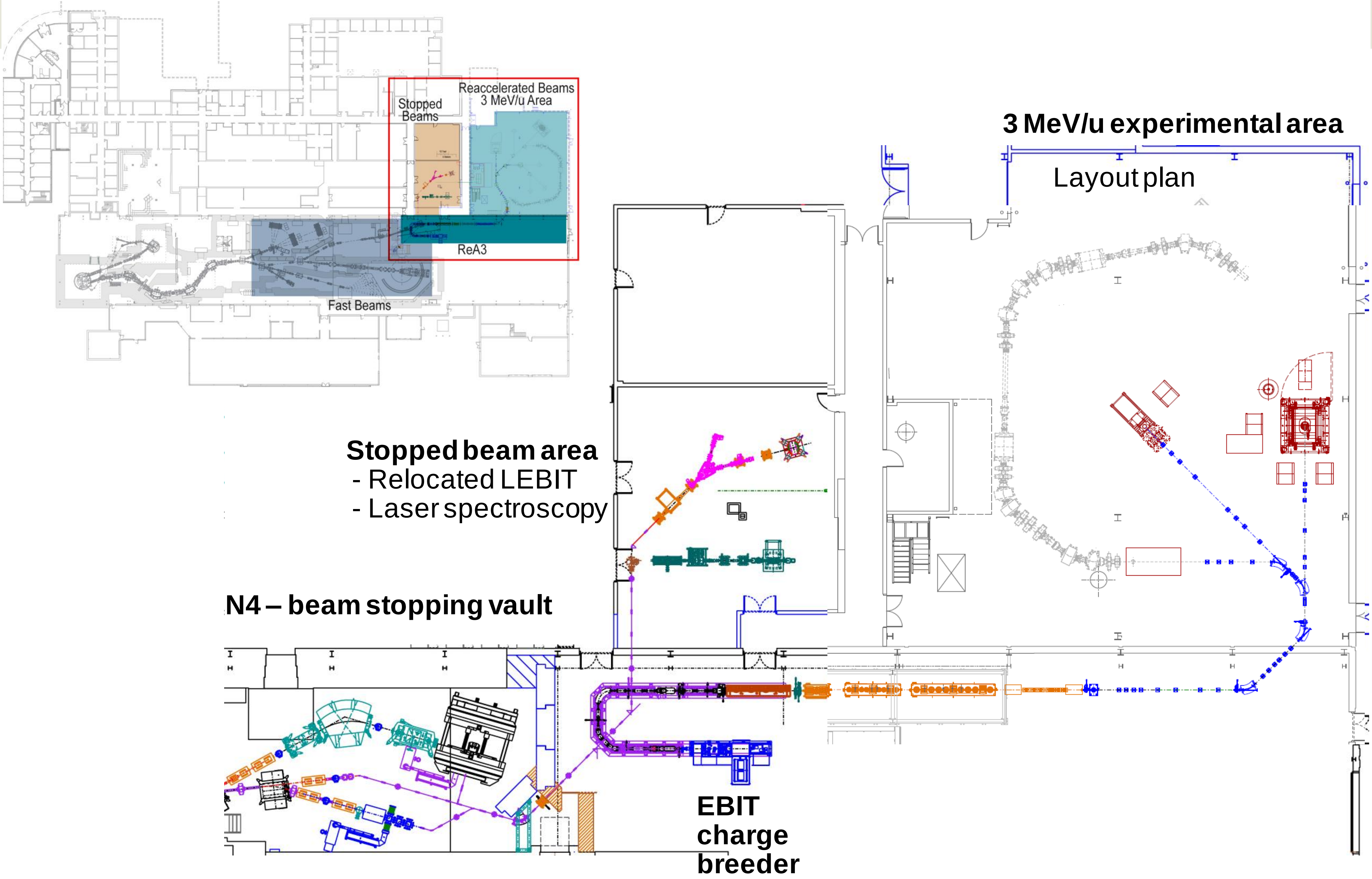


ReA3 at the Coupled Cyclotron Facility

- Coupled cyclotrons primary beams : ~ 150 MeV/u
  secondary beams with E < 100 MeV/u
- ReA3 beams : 0.3 - 3 MeV/u for Q/A=1/4 rare isotope beams

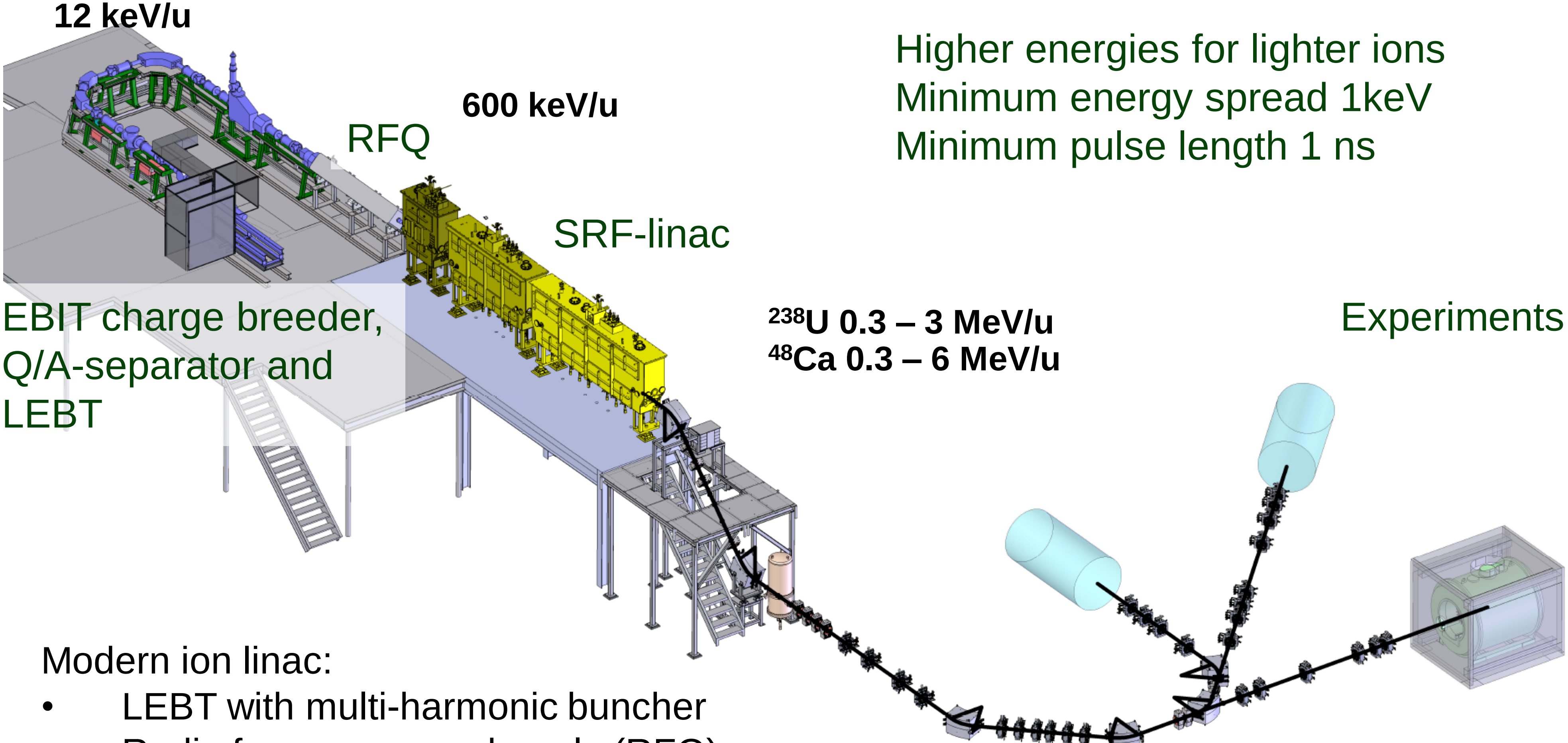


ReA3 at the Coupled Cyclotron Facility



ReA3 on the platform

Higher energies for lighter ions
Minimum energy spread 1keV
Minimum pulse length 1 ns



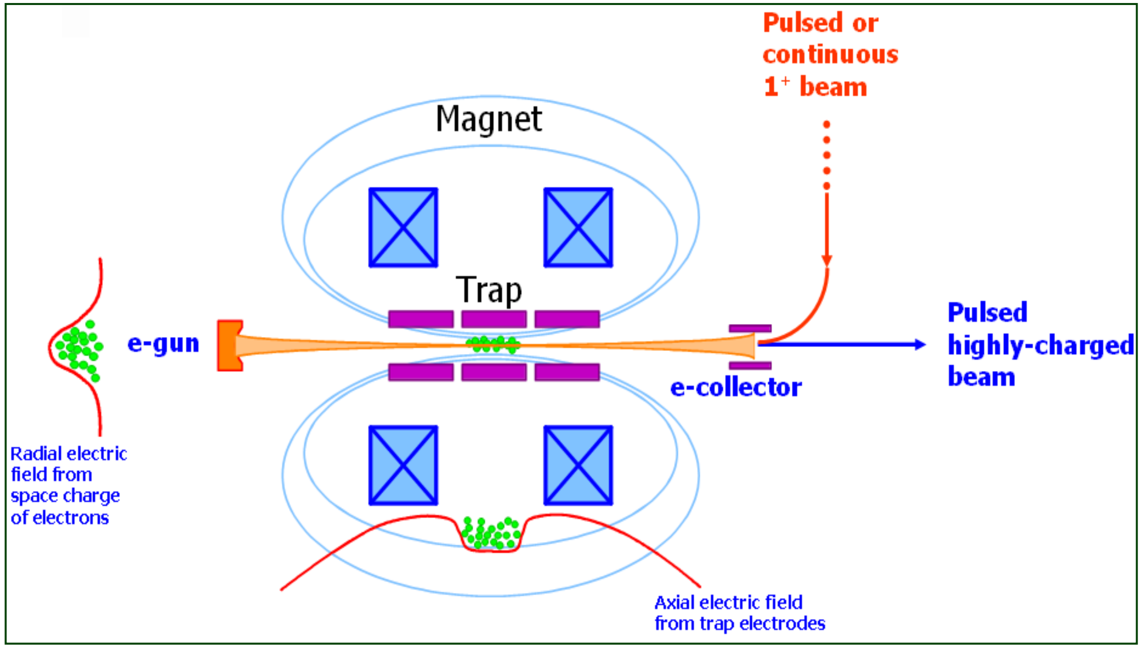
Modern ion linac:

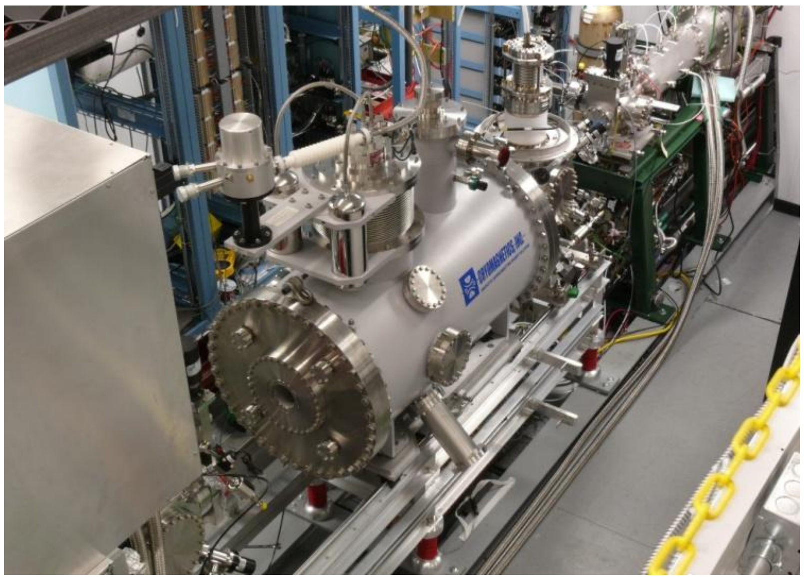
- LEBT with multi-harmonic buncher
- Radio frequency quadrupole (RFQ)
- Superconducting RF linac
- HEBT with rebuncher

ReA3 platform

ReA3 – EBIT charge breeder

- Unique features:
  - Continuous injection of ions
    - » high capture rate
  - Variable extraction duty cycle
    - » μs pulse to quasi-continuous
  - Short breeding time (<10 ms)
  - High efficiency
    - > 50% in a single charge state

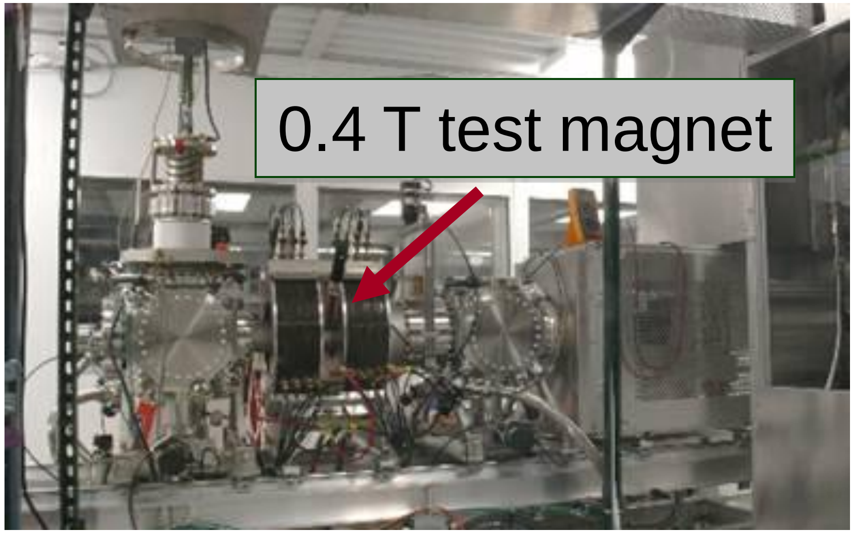


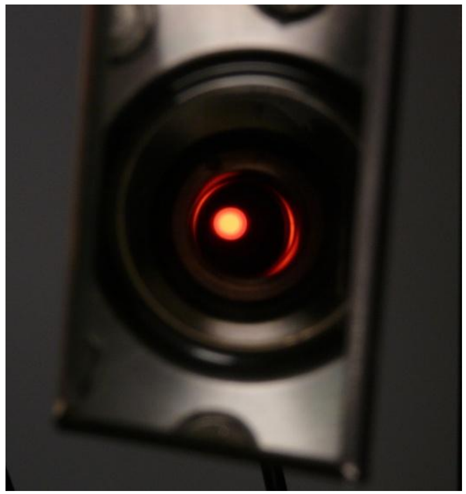


EBIT installation will be completed in October,
Simulations are performed to optimize performance,
Injection tests end of 2010!

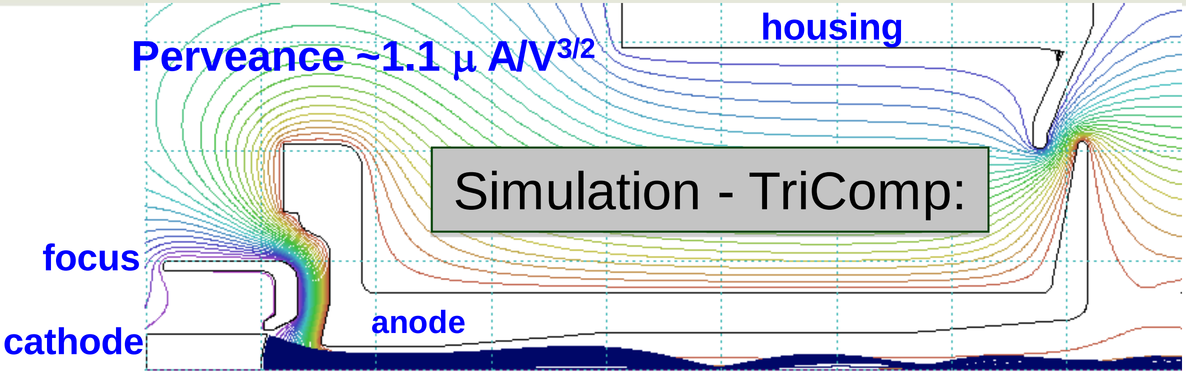
EBIT electron beam tests

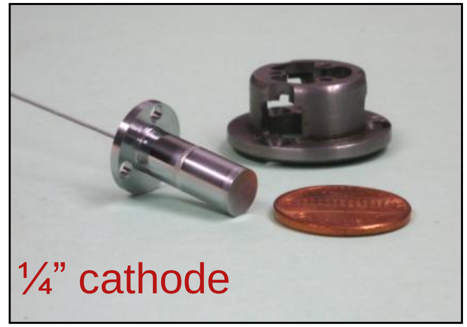
- Measurements of electron beam diameter
- High current tests with 0.9 A with negligible losses on the electrodes
- Electron beam simulation compared with measured beam properties



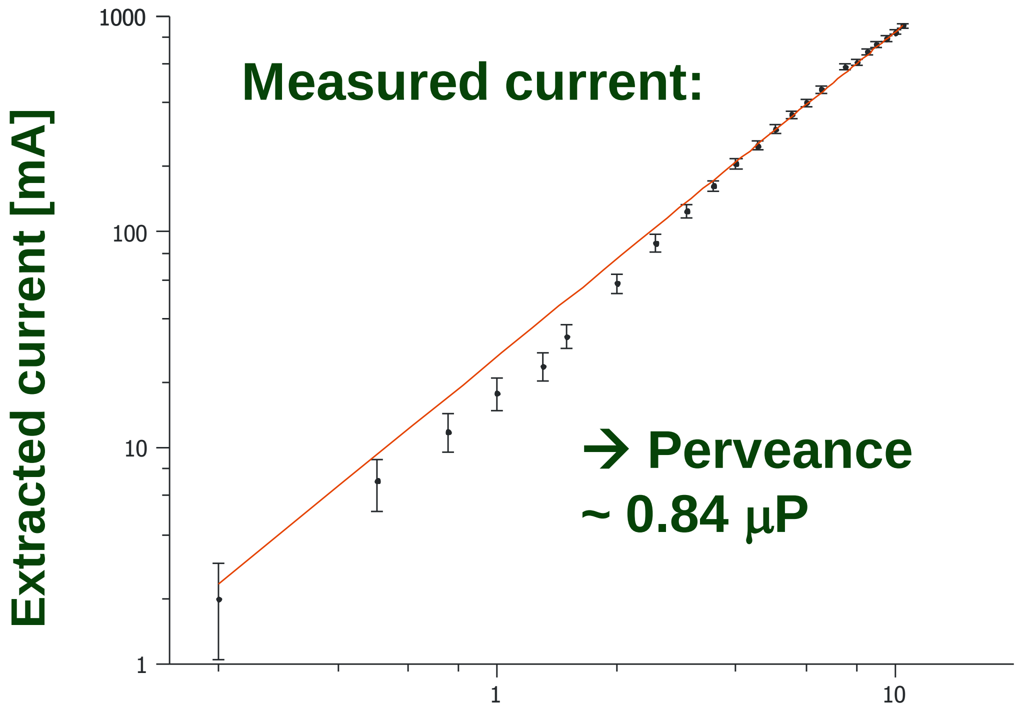


Tests with ‘mama’ cathode

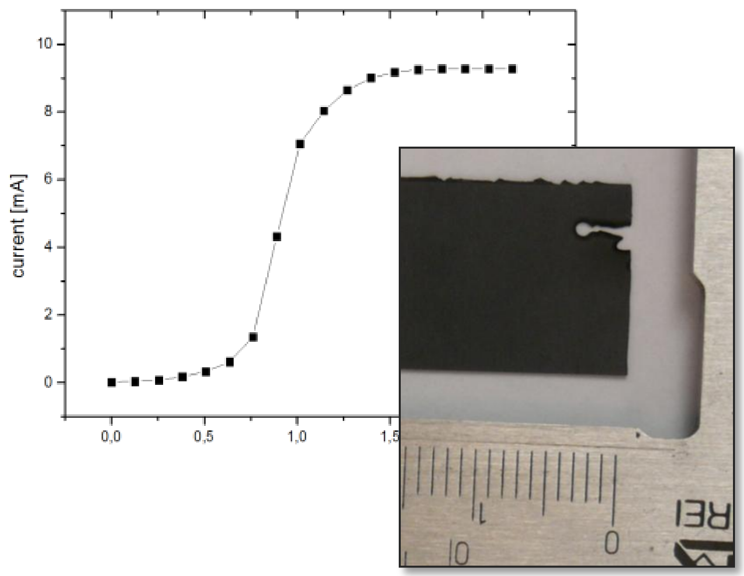




(Ba-dispenser)

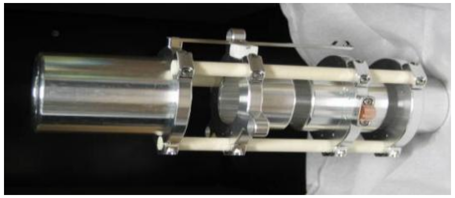


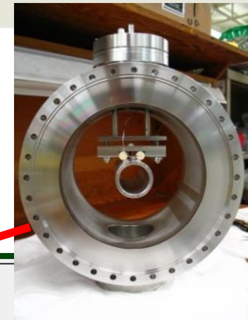
E-beam radius:



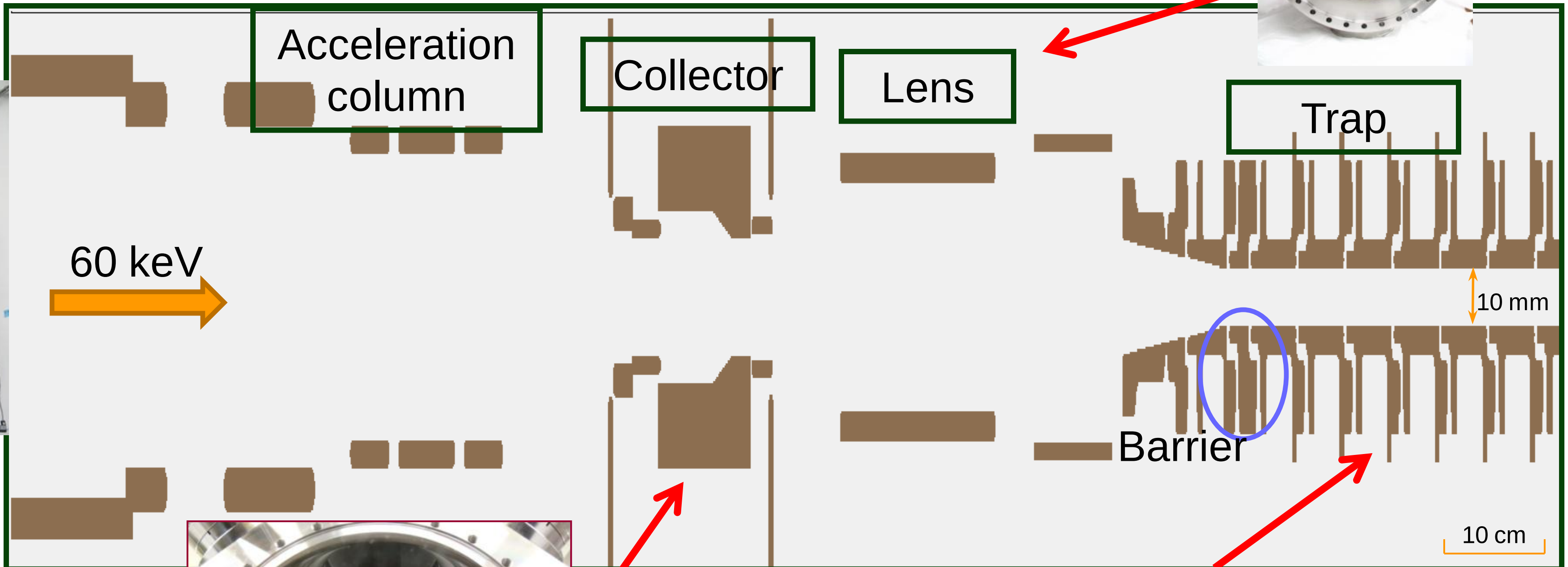
→ Measured beam $r_{95\%}$ ~ 0.58 mm agrees well with $r_{Herrmann}$

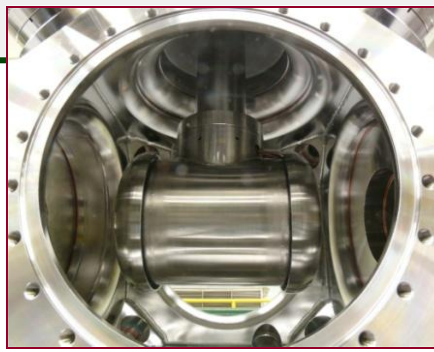
Injection calculation using SIMION

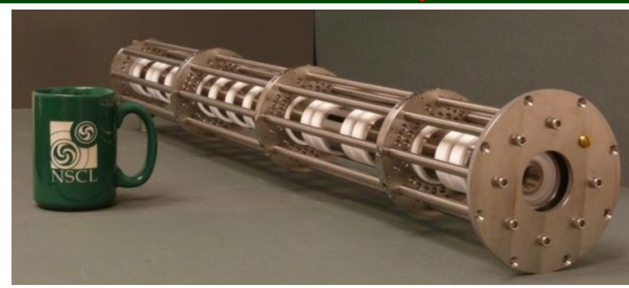




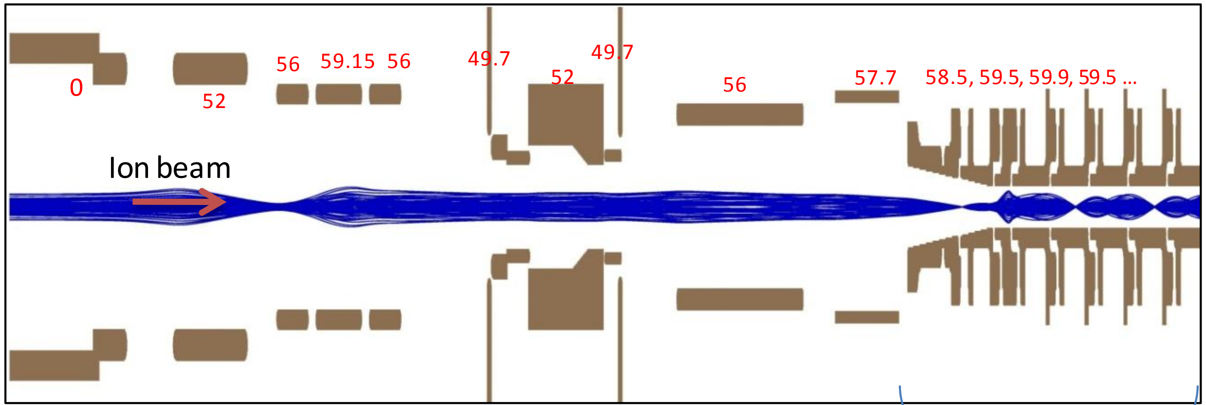
Offline ion source







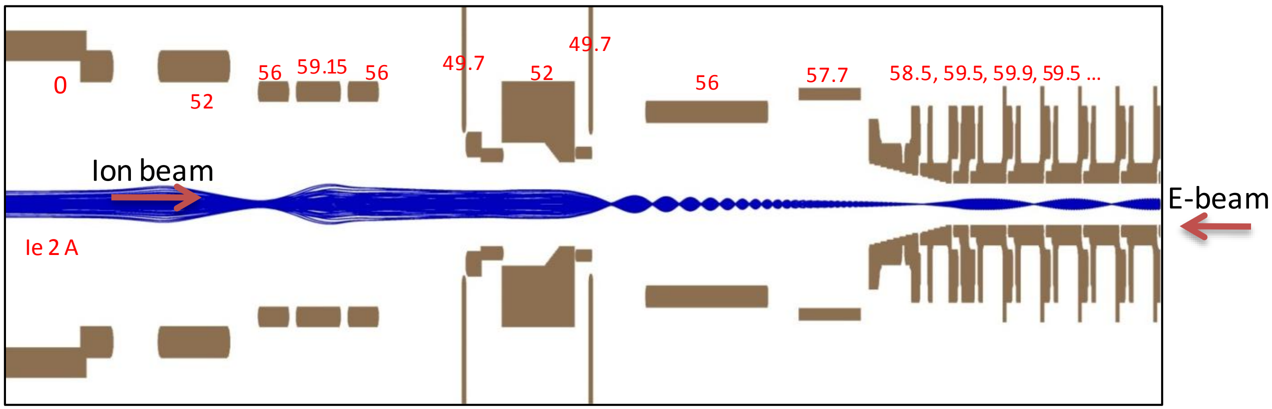
Injection simulation results



No electron beam

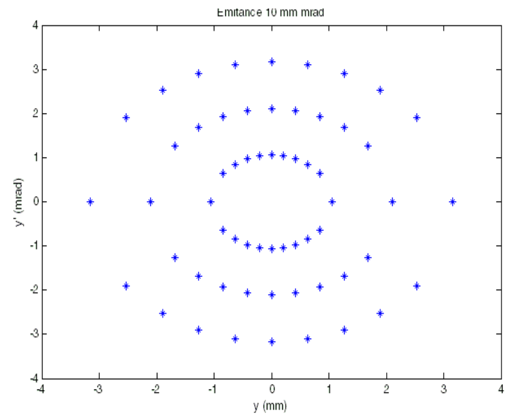
Collector

Trap

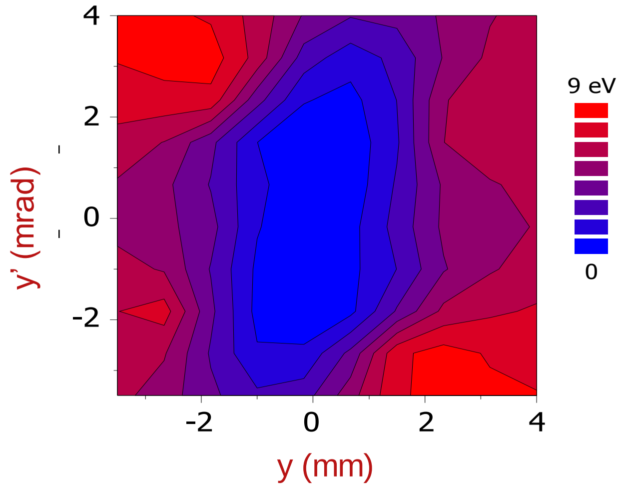


With electron beam 2 A

Injected beam with ε = 10π mm mrad

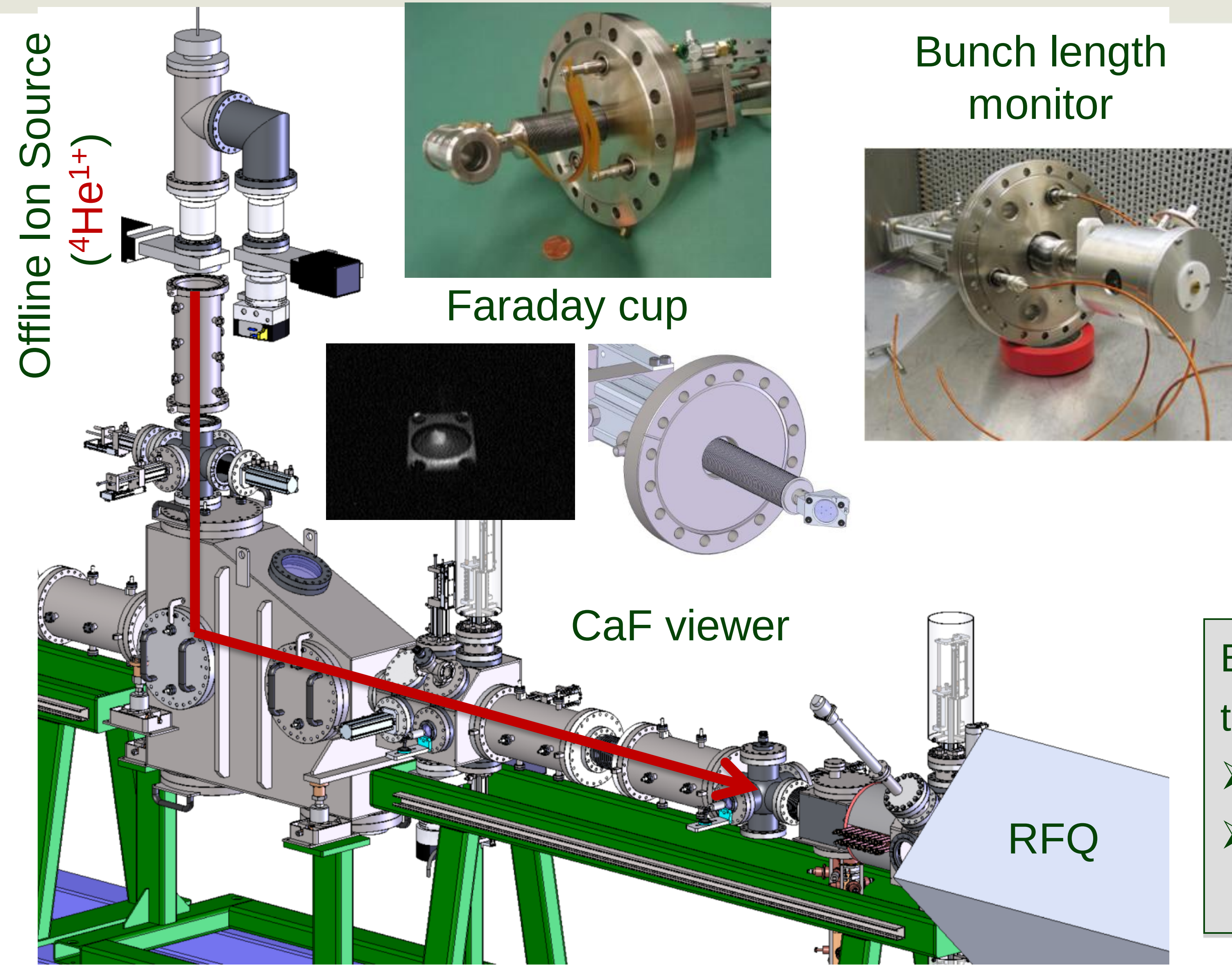


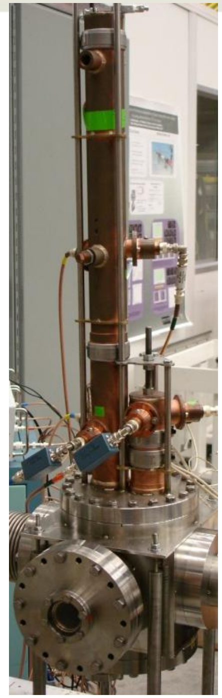
Radial energy



Ion beam: A=40 u, Q=1, 60 keV, **Electron beam**: 5 keV

Low energy beam transport (LEBT)



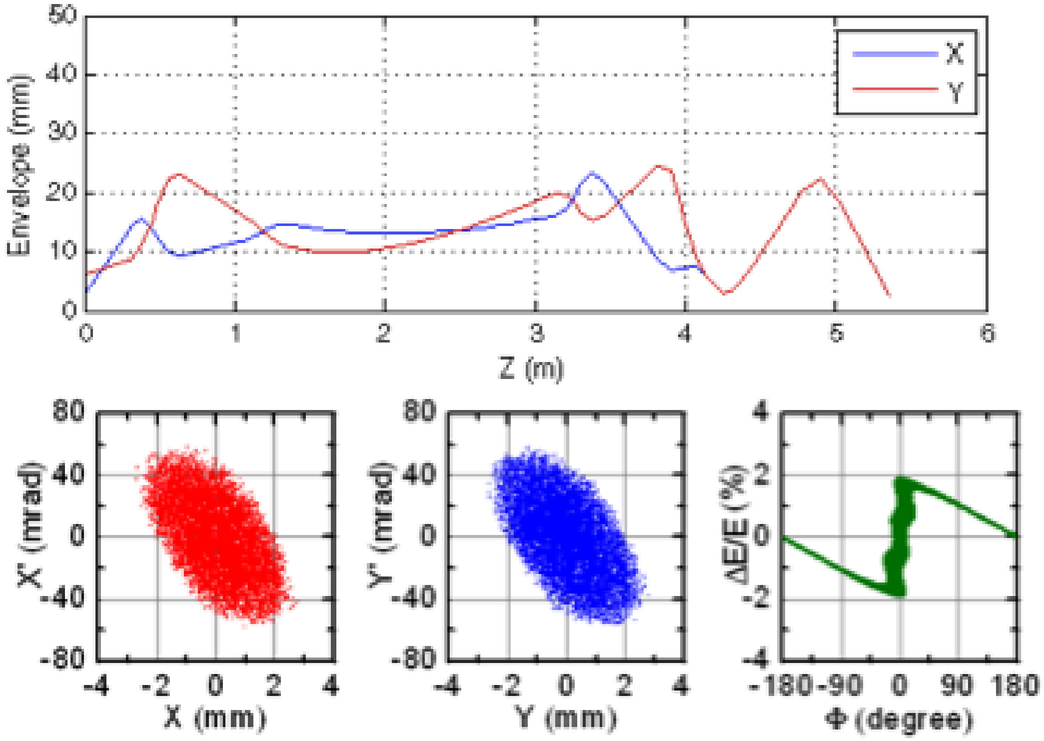


Beam transport to the RFQ:

- Beam bunching
- Transverse beam matching

Emittance Scans

- RFQ transverse acceptance >
  - ε_n = 1.0 π-mm-mrad
  - ε_g = 200 π-mm-mrad (@ RFQ input energy of 12 keV/u)
- Desired twiss parameters α = 0.6 and β = 0.06 m
  - Measured beam emittances fit into RFQ transverse acceptance



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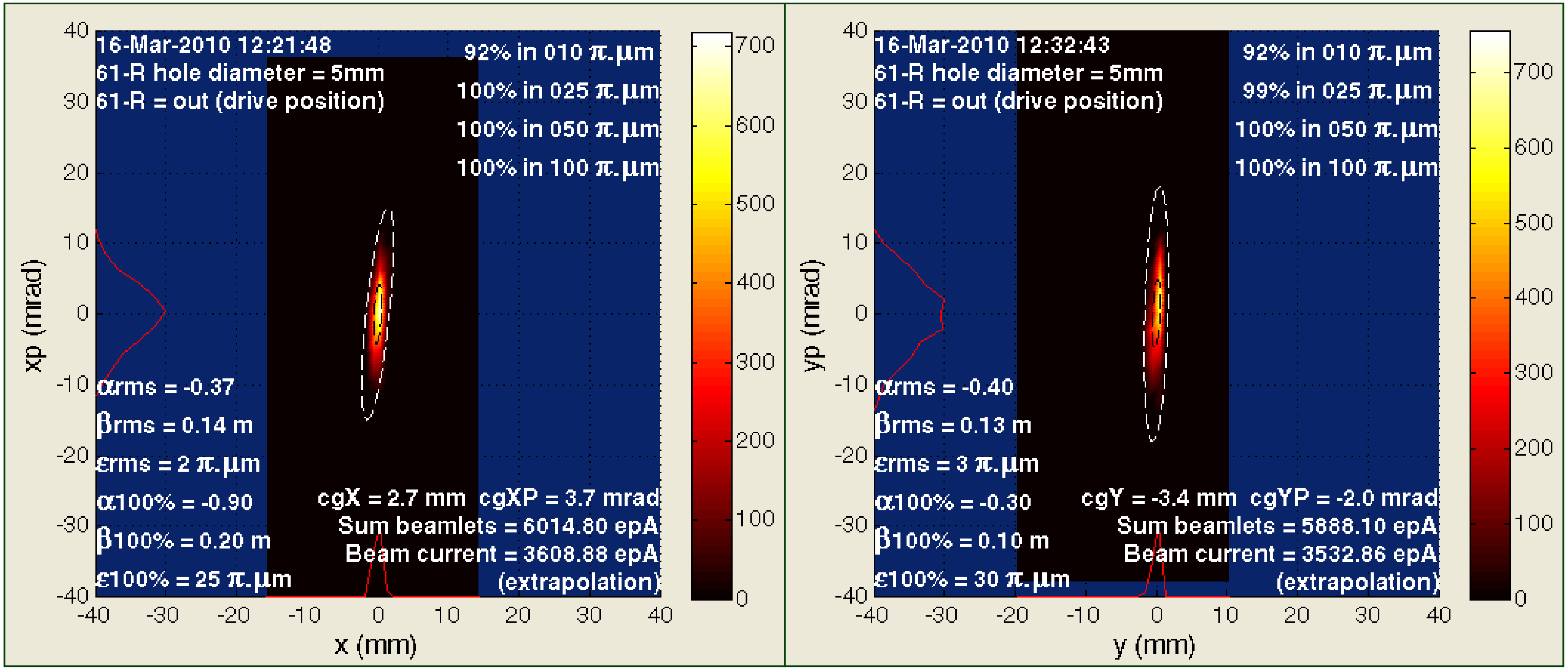
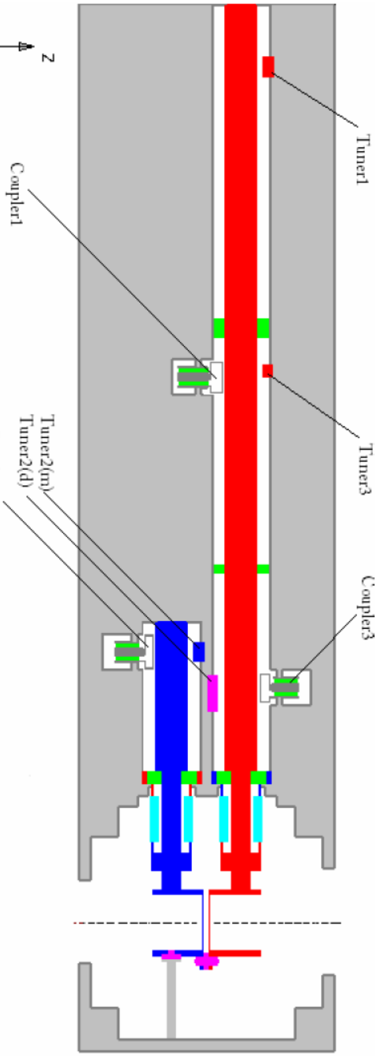
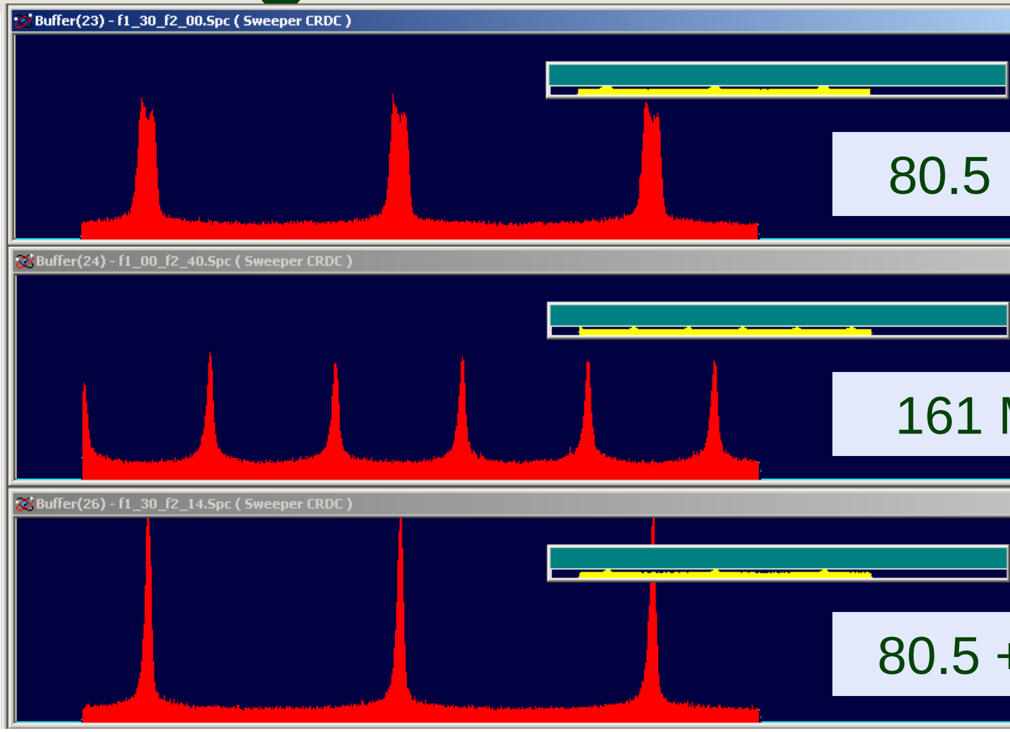


Multi Harmonic Buncher (MHB) test with timing wire detector

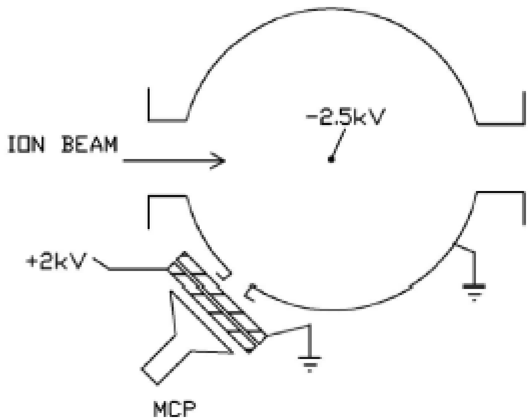


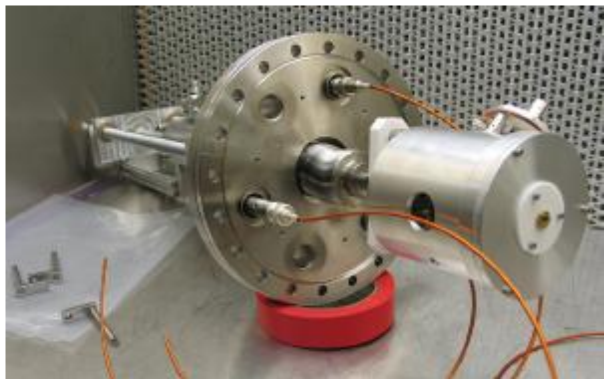


80.5 MHz

161 MHz

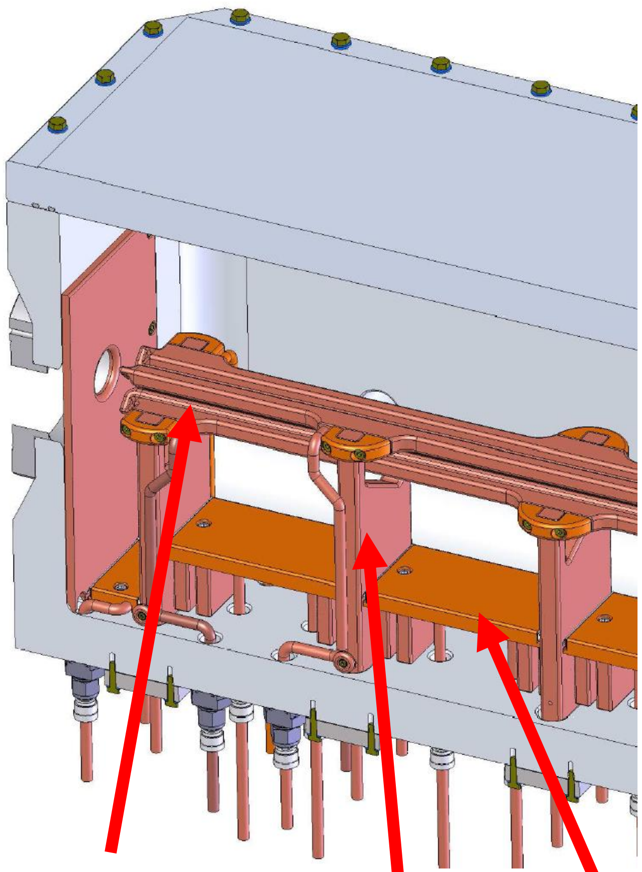
80.5 + 161MHz





NSCL
FRIB
U.S. Department of Energy Office of Science
National Science Foundation
Michigan State University
MICHIGAN STATE UNIVERSITY

RT 4-rod RFQ ReA3

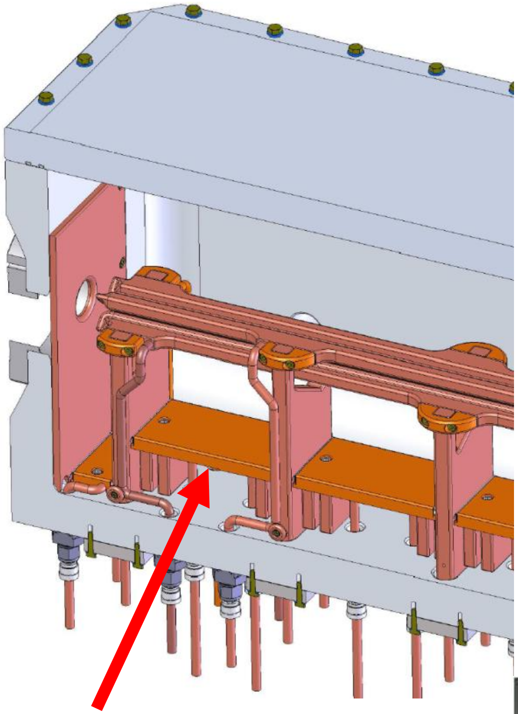


New design:

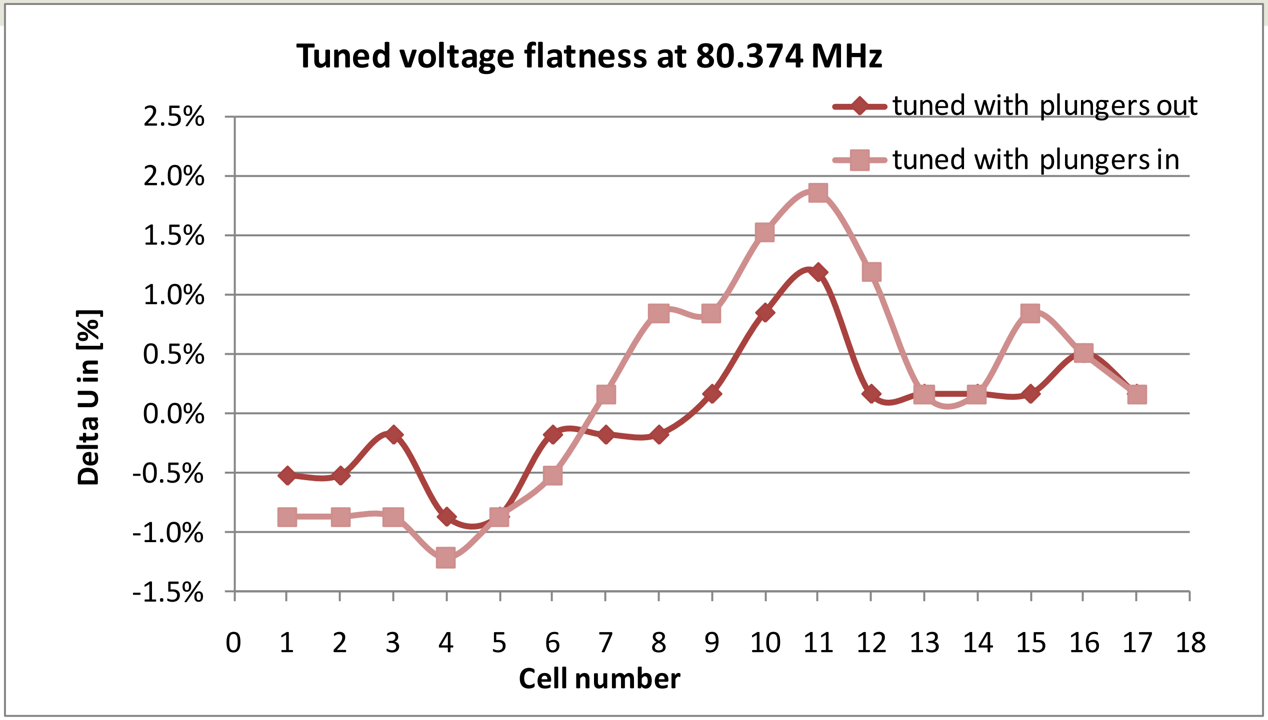
- Al-tank (no copper plating required)
- Simple adjustment of tuning plates, no alignment required
- High power operation

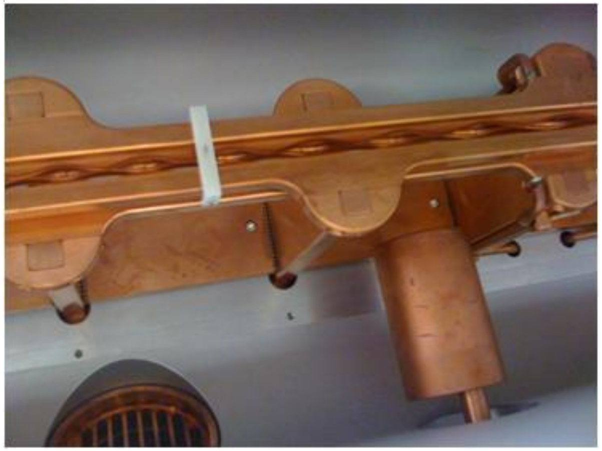
RFQ installed in beam line,
Conditioning started,
Beam tests in September 2010!

Flatness tuning



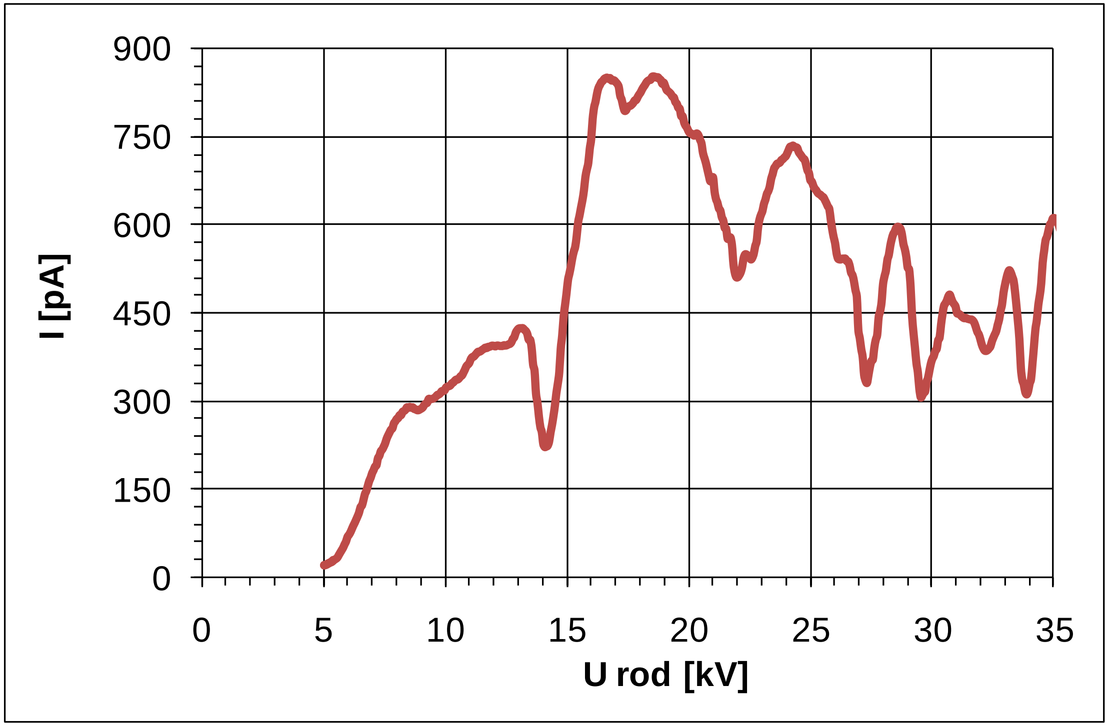
tuning plate



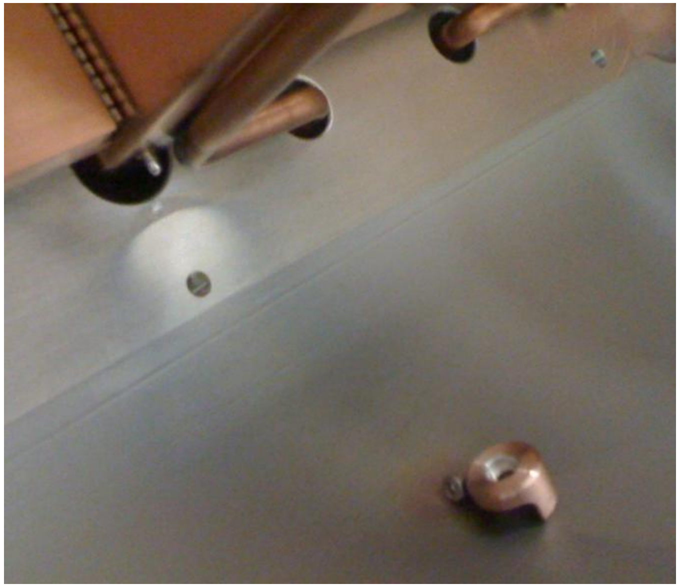


RFQ conditioning and low power beam transport

RFQ data:	
Shunt impedance Z:	210 kΩm
Q value:	4400
U_{rods} (A/q=4):	70 kV
P_{rf} (A/q=4):	78 kW



- High power conditioning up to 55 kW (with minor losses of equipment ☹)
- Pulsed conditioning up to 80 kW
- Beam transmission measured in transport mode



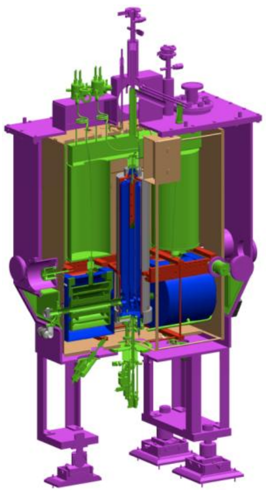
ReA3 SRF-cryomodules

ReA3 -

- 3 ReA3 Cryomodules
- 15 cavities
- 2 cavity types (QWR)
  - Beta=0.041 & 0.085
  - Same as FRIB design
- 8 solenoids
  - Same as used in FRIB

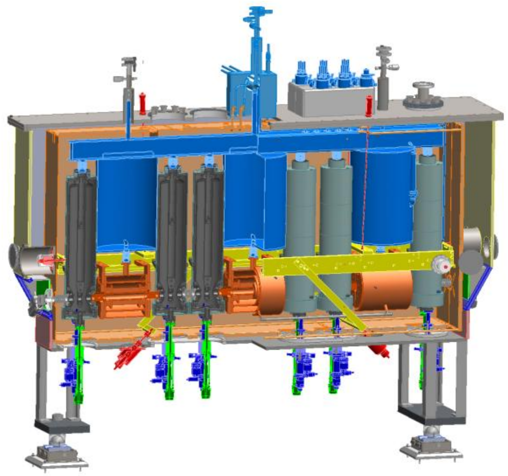
First two cryomodules completed, third in progress to be completed Q2FY2011

re-buncher

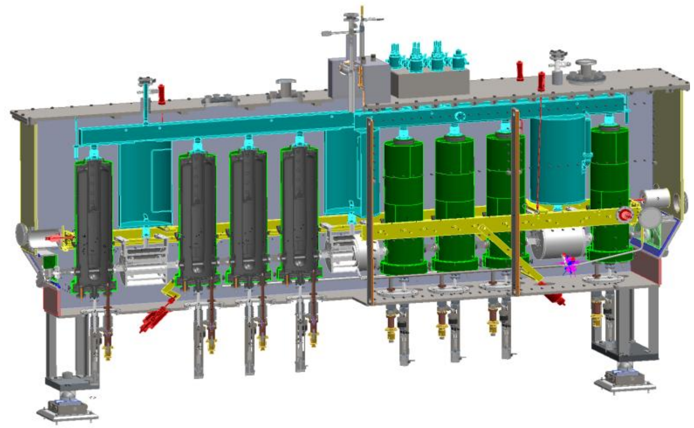


For details see poster THP040

β = 0.041 module

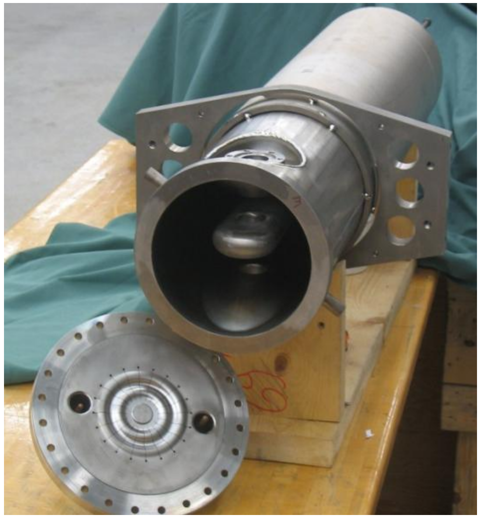


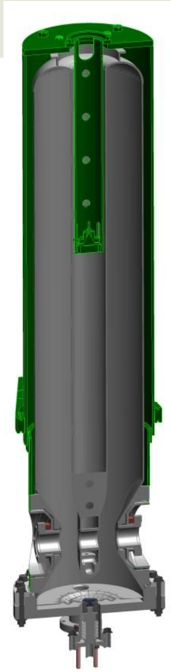
β = 0.085 module



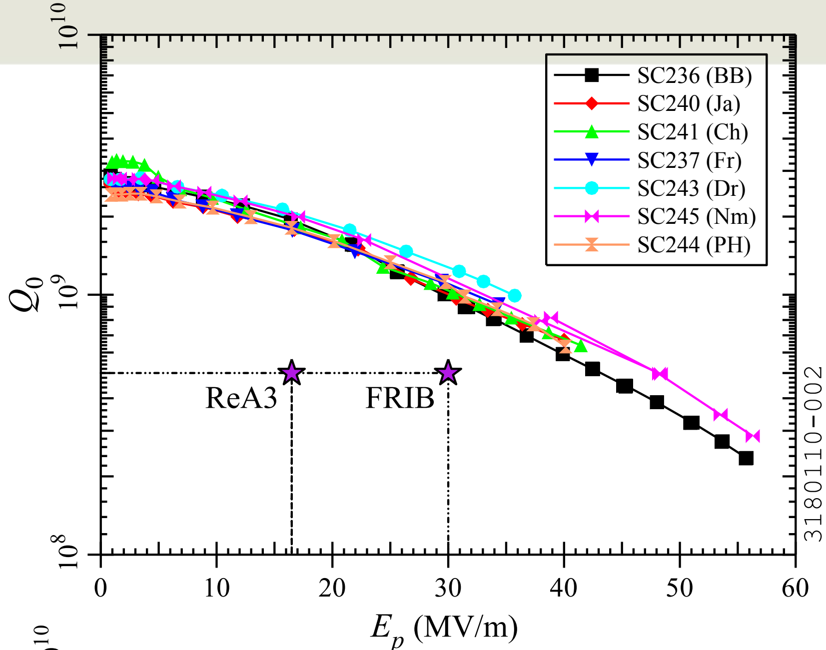
ReA3 – QWRs testing

$\beta_{opt}=0.041$

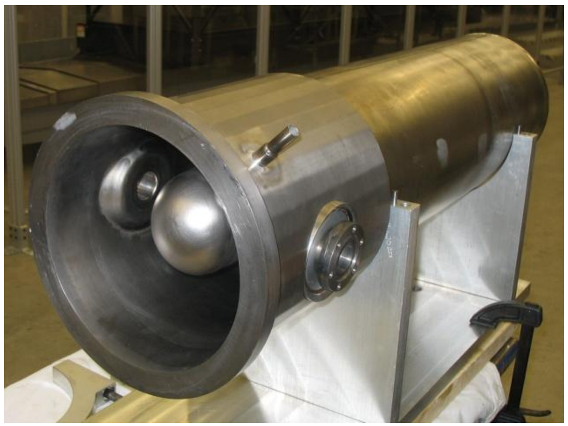


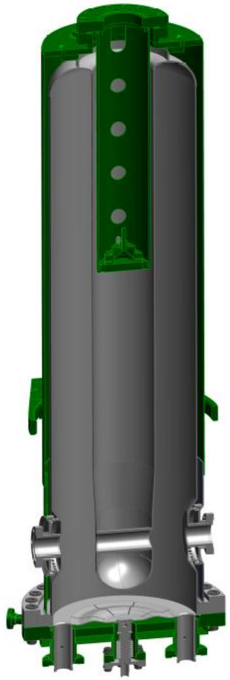


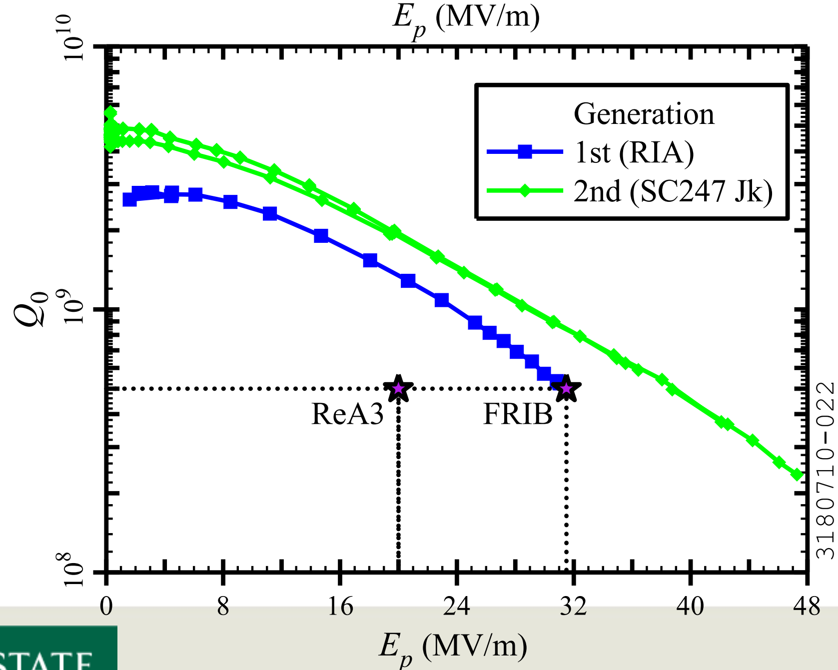
For details see poster TUP084



$\beta_{opt}=0.085$







ReA3 – SRF component tests

Test of systems in the modules:

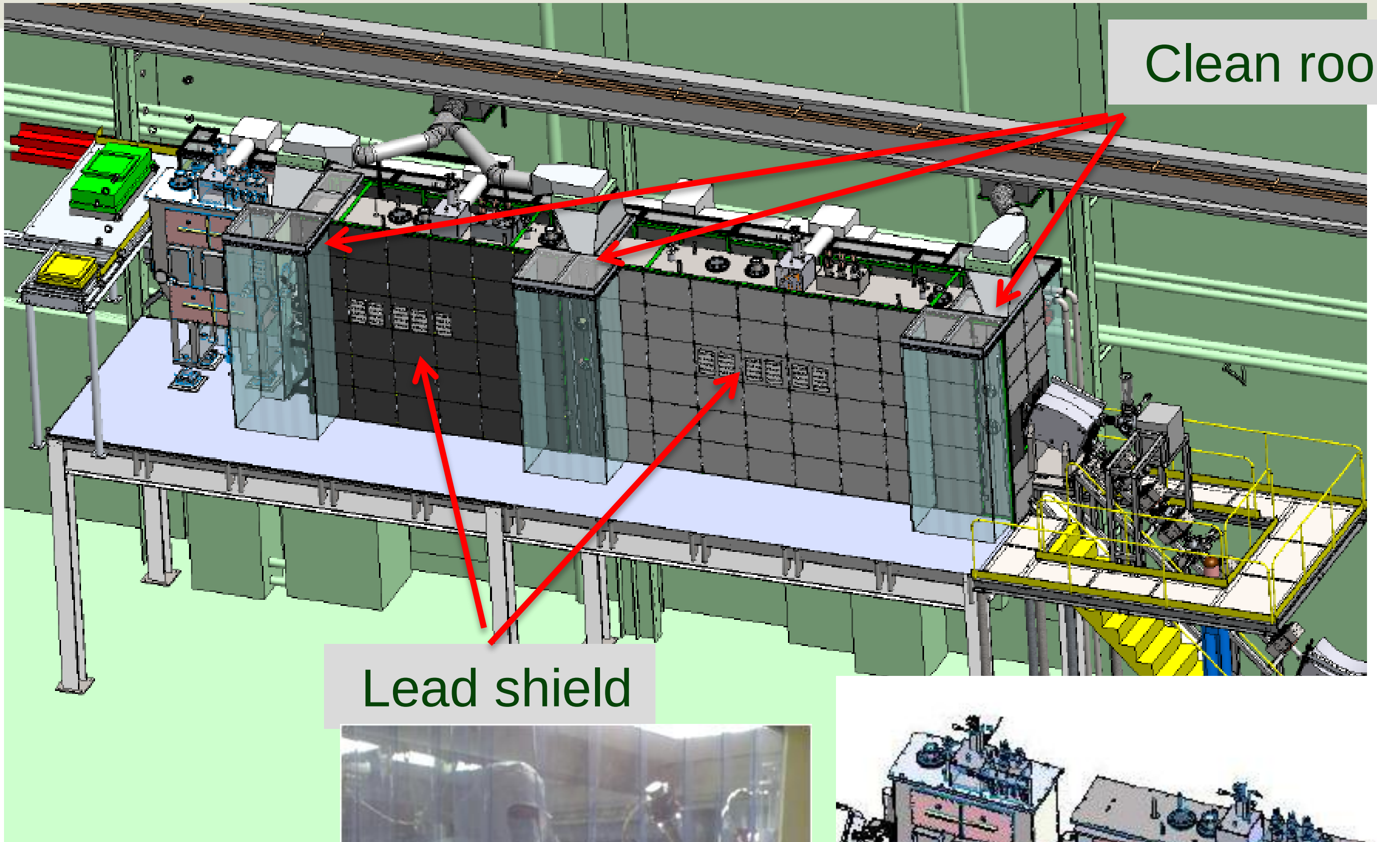
- Power coupler conditioning and operation
- Magnetic shielding
- Low level rf
- Damping of microphonics
- Q versus E_z measurements
- Determination of static heat load
- Multipacting analysis

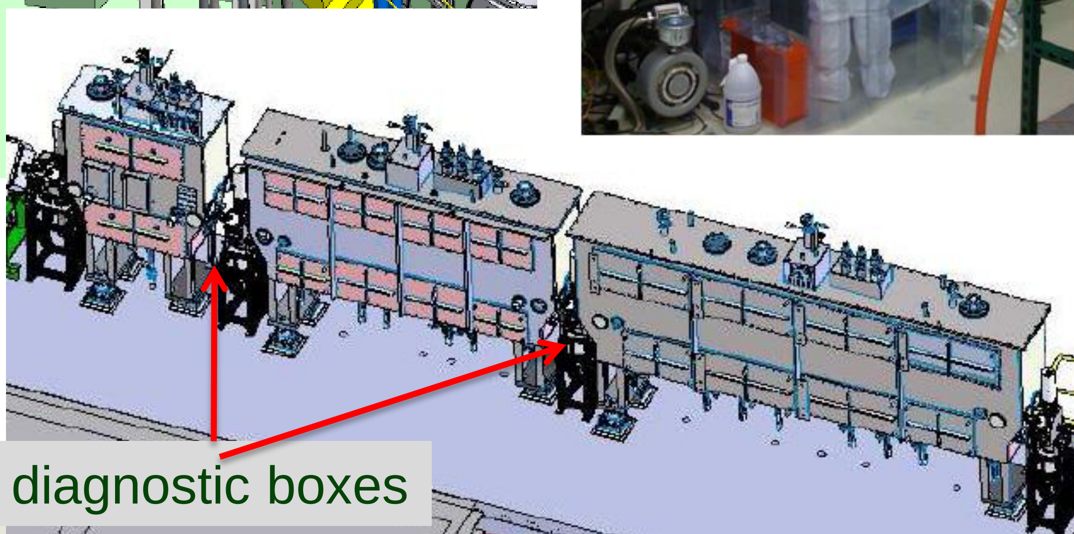
For details see poster THP039 THP092

Magn. Shielding tests

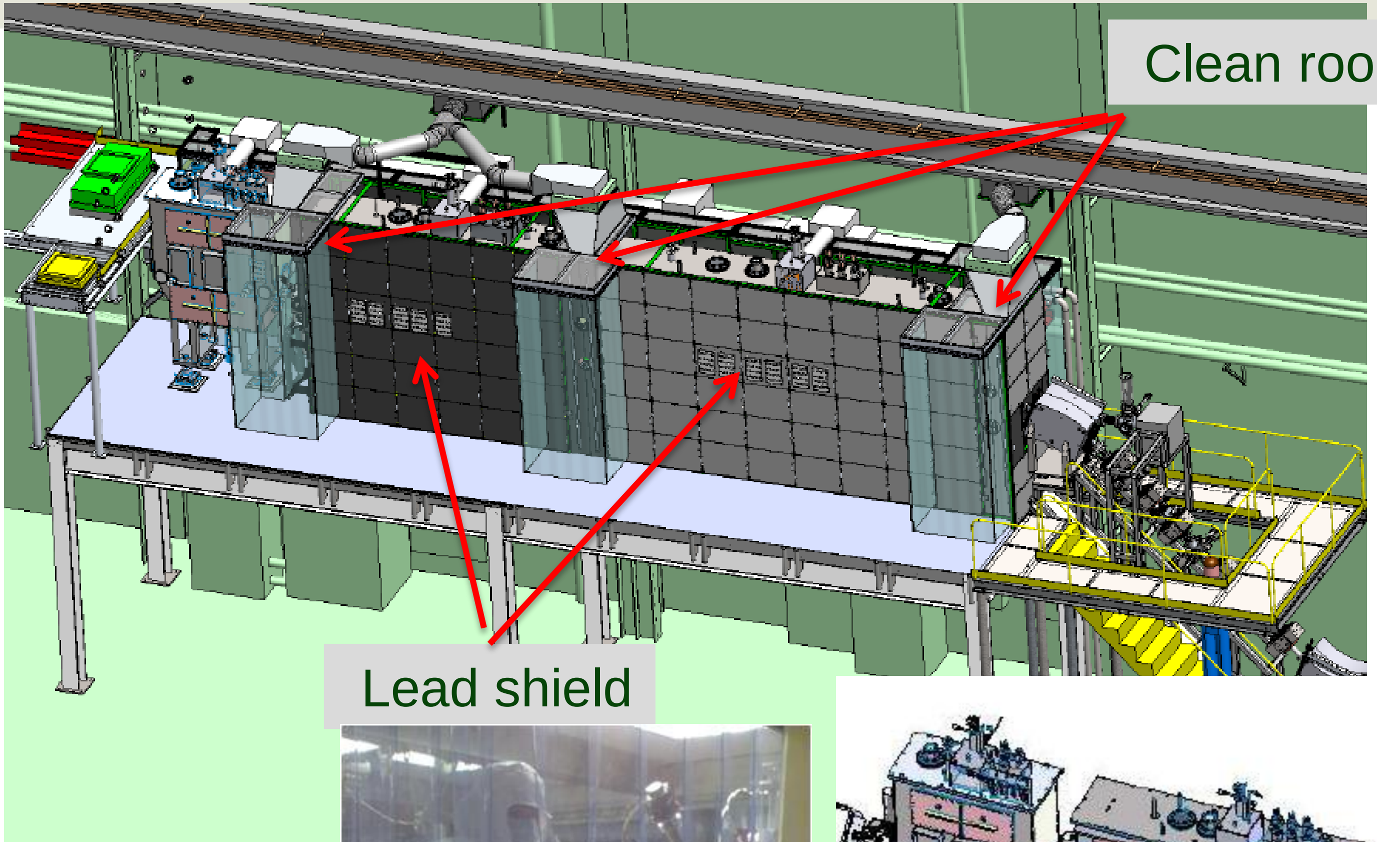
ReA3 Coupler for λ/4

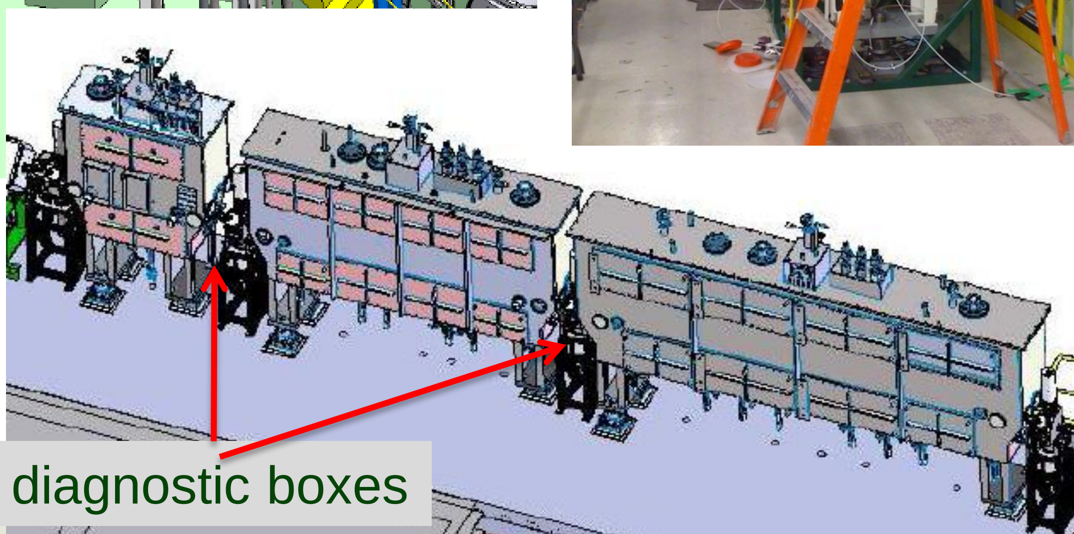
SRF-LINAC infrastructure





SRF-LINAC infrastructure

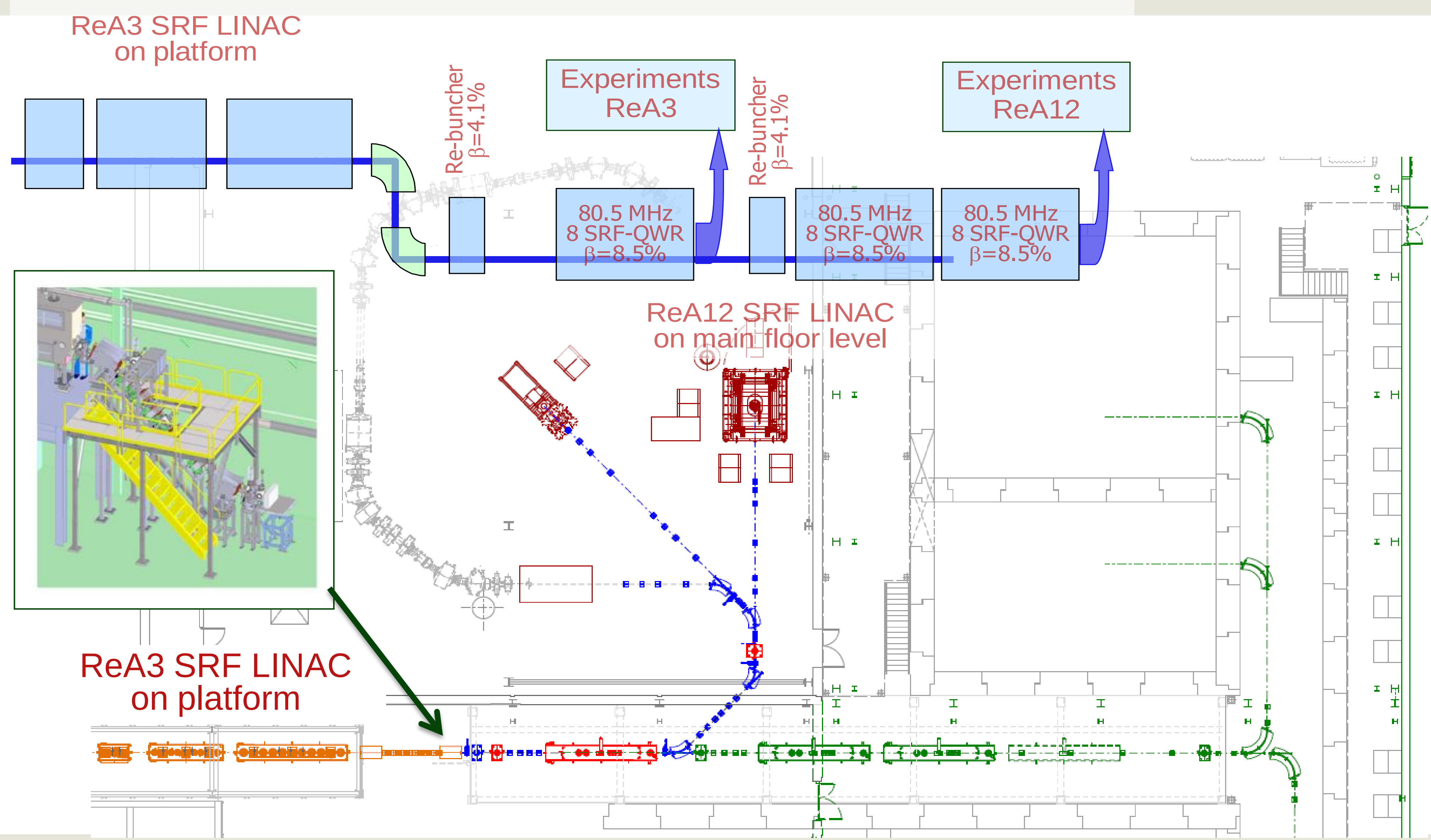




Summary ReA3 status

- Test of EBIT electron beam system done, magnet commissioned, assembly ongoing → first operation October
- Q/A-separator beam commissioning completed
- LEBT beam commissioning is presently performed
- RFQ tuning completed, conditioning ongoing, first beam tests in early September 2010
- SRF-linac:
  - re-buncher rf-tests completed, first beam tests in conjunction with RFQ beam commissioning
  - β = 0.041 module installed, hardware tests are being performed
  - β = 0.085 under construction
- Accelerated stable beams → end of 2010
- Reaccelerated beams in 2011

ReA6/ReA12



ReA3 SRF LINAC
on platform
Re-buncher
β=4.1%
Experiments
ReA3
80.5 MHz
8 SRF-QWR
β=8.5%
Re-buncher
β=4.1%
80.5 MHz
8 SRF-QWR
β=8.5%
Experiments
ReA12
80.5 MHz
8 SRF-QWR
β=8.5%
ReA12 SRF LINAC
on main floor level
ReA3 SRF LINAC
on platform