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 $1^+ \rightarrow n^+$ 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
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**Building Addition**
- N4 – beam stopping vault
- Stopped beam area
  - Relocated LEBIT
  - Laser spectroscopy
- 3 MeV/u experimental area
- Layout plan

**Other Areas**
- EBIT charge breeder
- MICHIGAN STATE UNIVERSITY
- O.Kester, LINAC2010, 09/13/2010, Slide 5
Modern ion linac:
- LEBT with multi-harmonic buncher
- Radio frequency quadrupole (RFQ)
- Superconducting RF linac
- HEBT with rebuncher

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

12 keV/u
600 keV/u

EBIT charge breeder, Q/A-separator and LEBT

238U 0.3 – 3 MeV/u
48Ca 0.3 – 6 MeV/u

Experiments

HEBT

ReA3 on the platform
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

- **Perveance**: $\sim 1.1 \mu \text{A/V}^{3/2}$
- **Simulation - TriComp**: Housing
- **1/4” cathode (Ba-dispenser)**

**Measured current:**

- **E-beam radius:**
  - $\rightarrow$ Measured beam $r_{95\%} \sim 0.58 \text{ mm}$ agrees well with $r_{\text{Herrmann}}$

**Graphs:**
- **Extraction voltage [kV]** vs. **Extracted current [mA]**
  - $\rightarrow$ Perveance $\sim 0.84 \mu \text{P}$
Injection calculation using SIMION

- Acceleration column
- Collector
- Lens
- Trap
- Barrier

60 keV

Offline ion source
Injection simulation results

**Radial energy**

**Injected beam with \( \varepsilon = 10\pi \) mm mrad**

**Ion beam**: \( A=40 \) u, \( Q=1, 60 \) keV, **Electron beam**: 5 keV
Low energy beam transport (LEBT)

- Offline Ion Source ($^{4}\text{He}^{1+}$)
- Faraday cup
- CaF viewer
- Beam transport to the RFQ:
  - Beam bunching
  - Transverse beam matching

Bunch length monitor
Emittance Scans

• RFQ transverse acceptance >
  – $\varepsilon_n = 1.0 \, \pi$-mm-mrad
  – $\varepsilon_g = 200 \, \pi$-mm-mrad (at RFQ input energy of 12 keV/u)

• Desired twiss parameters $\alpha = 0.6$ and $\beta = 0.06$ 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 + 161 MHz
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

Tuned voltage flatness at 80.374 MHz
- Tuned with plungers out
- Tuned with plungers in

Delta U in [%]
Cell number

Tuning plate
RFQ conditioning and low power beam transport

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

For details see poster THP040
ReA3 – QWRs testing

\[ \beta_{opt} = 0.041 \]

\[ \beta_{opt} = 0.085 \]

For details see poster TUP084
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 \( \lambda/4 \)
SRF-LINAC infrastructure

- Clean rooms
- Lead shield
- Diagnostic boxes
SRF-LINAC infrastructure

Clean rooms

Lead shield

diagnostic boxes
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
  - $\beta = 0.041$ module installed, hardware tests are being performed
  - $\beta = 0.085$ under construction
- Accelerated stable beams → end of 2010
- Reaccelerated beams in 2011
ReA6/ReA12

ReA3 SRF LINAC on platform

ReA3 SRF LINAC on platform

ReA12 SRF LINAC on main floor level

Experiments ReA3

Experiments ReA12

80.5 MHz 8 SRF-QWR $\beta=8.5\%$

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80.5 MHz 8 SRF-QWR $\beta=8.5\%$

Re-buncher $\beta=4.1\%$

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