Accelerators for the Advanced Exotic Beam Facility

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Physics Division
Content

- Facility for Radioactive Ion Beams (FRIB)
  - Short introduction to the current status
  - Major differences from RIA
- Heavy-ion Driver Accelerator
  - Impact of the R&D and prototyping on the design, expected performance and cost
  - Accelerator lattice and beam parameters
- Current R&D related to the FRIB
  - Super CARIBU (Post Accelerator)
  - Test of the liquid Li stripper
  - Beam diagnostics
- Conclusion
Layout of the FRIB at ANL – 200 MeV/u, 400 kW

Color code:
Black = existing facility
Blue+ green = AEBL baseline
Red = Low-cost upgrade
**FRIB includes**

- Heavy-ion driver linac capable of producing 400 kW beams
  - All ion species
  - Uranium 200 MeV/u
  - Protons 580 MeV
- Production area
  - Fragment separator and gas cell
  - Two ISOL targets (can be excluded from the baseline due to the cost)
- Post-accelerator
  - Charge breeder + RFQ
  - ATLAS
- Experimental systems
  - In-flight fragmentation area
  - All ATLAS instruments
  - Stopped beams facility
  - Astrophysics facility
## FRIB vs RIA

<table>
<thead>
<tr>
<th></th>
<th>RIA</th>
<th>FRIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC (actual dollars)</td>
<td>$1.1B</td>
<td>$550M</td>
</tr>
<tr>
<td>Driver linac</td>
<td></td>
<td>Superconducting CW linac</td>
</tr>
<tr>
<td>Total voltage</td>
<td>1400 MV</td>
<td>833 MV</td>
</tr>
<tr>
<td>Uranium energy</td>
<td>400 MeV/u</td>
<td>200 MeV/u</td>
</tr>
<tr>
<td>Protons</td>
<td>1000 MeV</td>
<td>580 MeV</td>
</tr>
<tr>
<td>Beam power (kW)</td>
<td>400 kW</td>
<td>400 kW</td>
</tr>
<tr>
<td>Post-accelerator</td>
<td>Low-q injector + ATLAS</td>
<td>Charge breeder + ATLAS</td>
</tr>
<tr>
<td>In-flight experimental facility</td>
<td>yes</td>
<td>limited</td>
</tr>
<tr>
<td>Gas catcher</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Number of ISOL targets</td>
<td>4</td>
<td>1 or 2</td>
</tr>
<tr>
<td>Intensity of ISOL RIBs</td>
<td>High</td>
<td>Same as RIA</td>
</tr>
<tr>
<td>Multi-user capability</td>
<td>Extensive</td>
<td>Limited</td>
</tr>
</tbody>
</table>
Heavy-ion Driver Linac and Production Complex, R&D

- Advanced ECR ion source (LBNL)
- Prototyping of the Front end for a High Intensity Heavy Ion linac
  - 2Q-LEBT
  - 57 MHz cw RFQ
- SRF technology
  - Higher gradients
  - Higher quality – lower cryogenic load
  - Lower microphonics
- High-power targets and strippers
  - 15 µm liquid lithium film required for the stripping has been demonstrated
  - Liquid lithium fragmentation target has been demonstrated
- Beam dynamics
  - Code development
  - Linac design, large scale simulations on supercomputers
  - Large acceptance fragment separators
VENUS ECR ion source data, LBNL (Berkeley)

- Uranium 6 µA is sufficient for 400 kW with the following two-charge-state LEBT

Uranium (6 µA)

Bismuth (8 µA)
Multi-q ion beam studies at ANL

- Permanent Magnet ECR on 100 kV platform voltage
- Achromatic bending system to extract and combine multi-q beams
- Electrostatic focusing
Multi-q beam in the 2Q-LEBT

- We are extracting more than \(\sim 1\) p\(\mu\)A of Bismuth in each charge state 20+ and 21+.
100% transmission of two-charge state beam

- Beam profiles (X-, Y-) taken by rotating wire (slightly non-linear reading) at the end of beamline
Combining of two charge states of Bismuth ions

- The first measurements

<table>
<thead>
<tr>
<th>Charge State</th>
<th>X</th>
<th>Y</th>
<th>Rms Emittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>20+</td>
<td>19π</td>
<td>16π</td>
<td>17π mm-mrad</td>
</tr>
<tr>
<td>21+</td>
<td>17π</td>
<td>20π</td>
<td>20π mm-mrad</td>
</tr>
<tr>
<td>20+ and 21+</td>
<td>22π</td>
<td>38π</td>
<td>22π mm-mrad</td>
</tr>
</tbody>
</table>

Beam current
- 20+: 20 eμA
- 21+: 24 eμA
- 20+ and 21+: 44 eμA

Beam current in 3 charge states (19+, 20+, 21+)=63 eμA
Prototyping of 2q 57 MHz CW RFQ, q/A=33/238 → 1
Required for the high intensity heavy-ion driver

Pre-brazed assembly

Coupling loop

Fabrication technology:
High-T furnace brazing, OFE copper

Vane tip alignment is better than 50 microns
The 57.5 MHz RFQ was successfully tested

- Stable operation in wide dynamic range of rf power
  - Limiting voltage is higher than 91 kV
- Q-factor: Simulation = 9300, Measured = 8860 95% of theoretical value
- 4-meter length RFQ will provide 300 keV/u beams of ions
- Cooling: 2 chillers with total 40 G/min water flow
**RFQ options**

- Conventional RFQ with build-in adiabatic bunching
- RFQ + Multi-Harmonic Buncher
Main function is to form a low longitudinal emittance at sub-harmonic frequency
ATLAS MHB, 12.125 MHz

- Simulated and measured bunch intensity distribution
- Forms very low Longitudinal emittance
- Capture efficiency is 80%
Voltage gain per cavity in the SC section
### FRIB Driver Linac - SC Resonator Configuration

- Input of uranium 33+ and 34+ at beta = 0.0254

<table>
<thead>
<tr>
<th>Beta</th>
<th>Type</th>
<th>Freq</th>
<th>Length</th>
<th>Esurf</th>
<th>Eacc</th>
<th># Cav</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.031</td>
<td>FORK</td>
<td>57.5</td>
<td>25</td>
<td>22.4</td>
<td>5.60</td>
<td>3</td>
</tr>
<tr>
<td>0.061</td>
<td>QWR</td>
<td>57.5</td>
<td>20</td>
<td>27.5</td>
<td>9.29</td>
<td>21</td>
</tr>
<tr>
<td>0.151</td>
<td>QWR</td>
<td>115.0</td>
<td>25</td>
<td>27.5</td>
<td>8.68</td>
<td>48</td>
</tr>
</tbody>
</table>

**STRIッPER**

<table>
<thead>
<tr>
<th>Beta</th>
<th>Type</th>
<th>Freq</th>
<th>Length</th>
<th>Esurf</th>
<th>Eacc</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.263</td>
<td>HWR</td>
<td>172.5</td>
<td>30</td>
<td>27.5</td>
<td>9.45</td>
</tr>
<tr>
<td>0.393</td>
<td>2SPOKE</td>
<td>345.0</td>
<td>38.1</td>
<td>27.5</td>
<td>9.17</td>
</tr>
<tr>
<td>0.500</td>
<td>3SPOKE</td>
<td>345.0</td>
<td>65.2</td>
<td>27.5</td>
<td>9.55</td>
</tr>
<tr>
<td>0.620</td>
<td>3SPOKE</td>
<td>345.0</td>
<td>80.9</td>
<td>27.5</td>
<td>9.26</td>
</tr>
</tbody>
</table>

**Subtotal**

- 72
- 134
- 206

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**Total Cavity Count = 206**
Cryomodules: rectangular, ATLAS type

- Separated cavity and cryostat vacuum
- QWR, HWR

- Spoke resonators

\[ \text{Beam} \quad 8.6 \text{ m} \]

\[ \text{Beam} \quad 5.80 \text{ m} \]
SC Solenoids

- 9 Tesla solenoids, 30 mm and 40 mm bore

Steering coil

Solenoid

Bucking coil

FNAL Solenoid

Surface: Magnetic flux density norm [T]
Contour: Magnetic potential, z component [V/m]
ATLAS upgrade & FRIB Prototype Cryomodule Assembly
Liquid Lithium stripper

<table>
<thead>
<tr>
<th></th>
<th>Uranium energy on the stripper</th>
<th>17 MeV/u</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Stripper material</td>
<td>Lithium film</td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>0.511 g/cm³</td>
</tr>
<tr>
<td>3</td>
<td>Thickness</td>
<td>1.12 mg/cm² or 22 µm</td>
</tr>
<tr>
<td>4</td>
<td>U average energy loss from SRIM code</td>
<td>0.51 MeV/u</td>
</tr>
<tr>
<td>5</td>
<td>Central charge state</td>
<td>79</td>
</tr>
</tbody>
</table>

A jet of 15 µm liquid lithium film was demonstrated
Liquid Lithium Thin Film

- Liquid Li thin film system
SRIM results, $10^6$ particles

SRIM = Stopping Range of Ions in Matter
by J.F. Ziegler, J.P. Biersack and U. Littmark

15 mg/cm$^2$ Carbon foil

monochromatic input beam
$W_{\text{in}} = 85$ MeV/u
$\Delta W = 3.29$ MeV/u
$\sigma_W = 17.5$ keV/u
$\sigma_T = 0.5$ mrad
SRIM results, $10^6$ particles, angle=$\sqrt{x'^2 + y'^2}$

- Fluctuation of the film thickness can result in large longitudinal emittance growth.
Post-stripper chicane and beam collimation
Set-up for measurement of thin film thickness

- Measurement of electron beam current attenuation behind a thin foil

![Diagram showing components of the set-up: Faraday Cup, Calibrated foils, Gridded el.static lens, 30-keV electron gun, Bending magnet.](image-url)
Machine errors

- Large-statistic beam dynamics simulations including all known errors
  - Static errors are corrected for each simulation seed
  - Dynamic errors are not correctable
- Most studies have been performed for Uranium beam
  - 2 charge states from the ECR
  - 5 charge states after the stripper

Table 2: Typical values of misalignment and RF errors.

<table>
<thead>
<tr>
<th>Error</th>
<th>Value</th>
<th>Distr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol. end displacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short (20-25 cm)</td>
<td>0.15mm (max)</td>
<td>Uniform</td>
</tr>
<tr>
<td>Long 1 (32-50 cm)</td>
<td>0.2 mm (max)</td>
<td></td>
</tr>
<tr>
<td>Quad. end displacement</td>
<td>0.15mm (max)</td>
<td>Uniform</td>
</tr>
<tr>
<td>Quad. rotation (z-axis)</td>
<td>5 mrad (max)</td>
<td>Uniform</td>
</tr>
<tr>
<td>Cav. end displacement</td>
<td>0.5 mm (max)</td>
<td>Uniform</td>
</tr>
<tr>
<td>Cav. field jitter error</td>
<td>0.5 % (rms)</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Cav. phase jitter error</td>
<td>0.5° (rms)</td>
<td>Gaussian</td>
</tr>
</tbody>
</table>
**Beam parameters in the driver linac (all errors are included)**

- Large statistics simulations:
  - Generate 200 different linacs with random static errors
  - Apply correction to static errors in each linac
  - Simulate 0.5M particles with dynamic errors through each linac
  - Detect lost particles

---

No correction is applied in X- and Y-

Correction is applied in X- and Y-
X-, Y- and $\phi$-profiles along the Linac, large statistics simulations, 200 seeds each with 200k particles
Larger errors

Figure 9: Left: Phase space plots for \((1^\circ,1\%)\) RF errors (top) and \((2^\circ,2\%)\) (bottom). Right: Beam loss in Watts/m along the linac for \((1^\circ,1\%)\) RF errors (top) and \((2^\circ,2\%)\) (bottom).
Proton beam dynamics in the RIA driver linac

- To reduce the cost we like to avoid additional injector for light ions
- Main issues:
  - The driver linac is optimized for the heaviest ions. Must be retunable for protons and other light ions.
  - 200 MeV/u Uranium and 580 MeV protons
  - Space charge effects of low-energy (14 keV/u) pre-bunched proton beams upstream of the RFQ:

\[
K = \frac{q}{A} \frac{I\lambda}{20\sqrt{5}\pi \varepsilon_0 m_e c^3 \gamma^3 \beta^2}
\]

\[
K \sim \frac{q}{A} I \frac{K_P}{K_U} = \frac{1}{33} \cdot \frac{0.8}{0.25} = 23
\]
Beam quality in the longitudinal phase space after the RFQ

Fraction of particles outside of a given longitudinal emittance as a function of the emittance.

- Simulation of proton beam does not show any losses along the linac
RF power requirement

- CW operation
- Beam loading is high: from 0.6 kW to 5.2 kW
- Microphonics require some additional rf power
- For high reliability of the facility operation, all cavities should be supplied by fast tuners (piezo- or magnetostrictive).
- Power specifications to the amplifiers is:

<table>
<thead>
<tr>
<th>f, MHz</th>
<th>57.5</th>
<th>115</th>
<th>172.5</th>
<th>345</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power, kW</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Δf/2, Hz</td>
<td>~30</td>
<td>~30</td>
<td>~25</td>
<td>from 27 to 48</td>
</tr>
</tbody>
</table>
Summary of the R&D

- 400 kW is possible for all beams including uranium at 200 MeV/u with
  - Advanced ECR source capable of producing required beam intensity
  - Acceleration of multiple-charge-state beams

- SRF R&D in recent years resulted in
  - Significant reduction of the number of SC cavities and RF amplifiers; We need just 206 SRF cavities (+1 rebuncher) to obtain 833 MV for the driver linac in the velocity range from 0.025c to 0.6c
  - Significant reduction of the cryogenic load due to demonstrated low residual resistance (or high quality) of SC cavities. Operation at 2.1K is more efficient
  - Shorter accelerator tunnel and smaller support building;
  - Significant cost reduction of the low-q post-accelerator by applying high gradient SC cavities in the velocity range 0.014c to 0.046c
  - RIA-type SC spoke cavities are being developed and used for the FNAL proton driver in pulsed regime
Summary of the R&D (cont’d)

- Large-scale beam dynamics simulations at BlueGene/L supercomputer at ANL
  - No beam losses except in the designated area
  - Excellent quality of multiple-charge state beams
  - The driver linac delivers a CW sequence of bunches into the target
    - ~1 nsec bunch width with repetition rate of 57.5 MHz.
    - Energy spread ≤ 0.5%
    - Can be focused on the production target less than 1 mm in diameter if necessary.

- One stripper at 17 MeV/u results in optimal linac lattice
  - Substantially simplifies Linac design and operation
  - High power dissipation on the stripper is removed by liquid lithium film
Recent and current R&D

- Complete Assembly and test of the ATLAS Cryomodule
  - 12.5 MV/m accelerating fields are demonstrated (FRIB spec = 8.7 MV/m)
- Design of the Super-CARIBU post-accelerator
- Minimize cavity count in the high-energy section of the AEBL driver linac
- Electrodynamics, structural and thermal optimization of SRF cavities
  - Four types of interdigital four-gap cavities for SuperCARIBU and AEBL
  - Two types of triple-spoke cavities for the AEBL
- Liquid lithium film tests with ~0.5 kW low energy bunched proton beam;
  Thickness measurements of the liquid lithium film using 30 kV electron beam
- Development of a bunch length detector with resolution of several picoseconds
CARIBU

- $^{252}$Cf fission source
- Gas cell
- Isobar separator, ~20000
- Charge breeder
- ATLAS
### Yields for Representative Species

Calculated beam intensities for a 1 Ci $^{252}\text{Cf}$ fission source using expected efficiencies.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life (s)</th>
<th>Low-Energy Beam Yield (s$^{-1}$)</th>
<th>Accelerated Beam Yield (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{104}\text{Zr}$</td>
<td>1.2</td>
<td>6.0x10$^5$</td>
<td>2.1x10$^4$</td>
</tr>
<tr>
<td>$^{143}\text{Ba}$</td>
<td>14.3</td>
<td>1.2x10$^7$</td>
<td>4.3x10$^5$</td>
</tr>
<tr>
<td>$^{145}\text{Ba}$</td>
<td>4.0</td>
<td>5.5x10$^6$</td>
<td>2.0x10$^5$</td>
</tr>
<tr>
<td>$^{130}\text{Sn}$</td>
<td>222.</td>
<td>9.8x10$^5$</td>
<td>3.6x10$^4$</td>
</tr>
<tr>
<td>$^{132}\text{Sn}$</td>
<td>40.</td>
<td>3.7x10$^5$</td>
<td>1.4x10$^4$</td>
</tr>
<tr>
<td>$^{138}\text{Xe}$</td>
<td>846.</td>
<td>9.8x10$^6$</td>
<td>7.2x10$^5$</td>
</tr>
<tr>
<td>$^{110}\text{Mo}$</td>
<td>2.8</td>
<td>6.2x10$^4$</td>
<td>2.3x10$^3$</td>
</tr>
<tr>
<td>$^{111}\text{Mo}$</td>
<td>0.5</td>
<td>3.3x10$^3$</td>
<td>1.2x10$^2$</td>
</tr>
</tbody>
</table>
**SuperCARIBU**

- Was designed as a part of the future FRIB
- SuperCARIBU is a significant upgrade of CARIBU capabilities by:
  - Using low-Q acceleration and stripping to gain factors of 5 to 8 in efficiency
  - Providing increased experimental space for stopped beam and astrophysics beam experiments,
  - Increasing the source fission rates, for example by using Cf-254 as the source material.
The floor plan proposed for SuperCARIBU.

- (A) high voltage platform
- (B) low-Q (1/238) RFQs
- (C) gas stripper
- (D) Hybrid RFQ (q/A=1/66)
- (E) low-Q SC linac (q/A=1/66)
- (F) carbon stripper foil
- (G) final SC linac section prior to ATLAS.

Final energy is 1.0 MeV/u to 1.7 MeV/u

General properties of the low-q injector
  - 92% transmission (acceleration efficiency) for masses \( \leq 66 \)
  - \(~45\%\) transmission for masses \( 228 \geq A > 66 \)
Overall efficiency of the RIB linac ($W \geq 10$ MeV/u)

- Gas stripper, 7 keV/u and 22 keV/u
- Carbon stripper, 1 MeV/u to 1.7 MeV/u
**Basic parameters of the low-q RFQ**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duty cycle</td>
<td>100% (CW)</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>12.125 MHz</td>
</tr>
<tr>
<td>Vane length</td>
<td>226 cm</td>
</tr>
<tr>
<td>Average radius</td>
<td>0.7 cm</td>
</tr>
<tr>
<td>Input beta</td>
<td>0.0009267</td>
</tr>
<tr>
<td>Charge-to-mass ratio</td>
<td>≥1/238</td>
</tr>
<tr>
<td>Design inter-vane voltage</td>
<td>82 kV</td>
</tr>
</tbody>
</table>

0.4 keV/u
A 12-MHz split-coaxial CW RFQ for the S-Caribu Project, \( \text{U}^{1+} \)

- The same tank as for \(^{136}\text{Xe}^{1+}\) RFQ
- Design of vanes is significantly modified

**Diagram:**
- **Beam**
- **WEIGHT** = 585 #
- **VANES INSTALLED INTO END FLANGE VIA SHRINK FIT**
A 12-MHz CW RFQ for the S-Caribu Project, U^{1+}

- Cavity assembly

4 tie rods are used for the assembly
**SC Linac for \( \frac{1}{6} \leq \frac{q}{A} \leq \frac{1}{66} \) from 75 keV/u to 1.0 MeV/u**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type-I</th>
<th>Type-II</th>
<th>Type-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (MHz)</td>
<td>48.5</td>
<td>48.5</td>
<td>72.75</td>
</tr>
<tr>
<td>( \beta_G )</td>
<td>0.017</td>
<td>0.026</td>
<td>0.038</td>
</tr>
<tr>
<td>Aperture diameter (cm)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Number of cavities</td>
<td>6</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

Voltage gain per cavity, \( W_{in}=75 \text{ keV/u} \)

![Graph showing voltage gain per cavity](image-url)
End-to-end simulations, \( q/A = 1/66 \), from \( 0.4 \text{ keV/u} \) to \( 1.0 \text{ MeV/u} \)
4-gap cavities for the S-CARIBU
4-gap cavity

- Multipacting studies – ANALYST (STAAR)
- Helium pressure – MWS, ProE, ANSYS
- Mechanical tuner – MWS, ProE, ANSYS

Paper accepted for publication in PRSTAB
4-gap SC cavities can provide 10 MV/m

- Minimize ratio $E_{peak}/E_{acc}$ and $B_{peak}/B_{acc}$
- Minimized df/dp
- Improve structural stability

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>ATLAS</th>
<th>Type-I</th>
<th>Type-II</th>
<th>Type-III</th>
<th>Type-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh-points</td>
<td></td>
<td>385K</td>
<td>626K</td>
<td>2M</td>
<td>2M</td>
<td>2M</td>
</tr>
<tr>
<td>$E_{PEAK}$</td>
<td>MV/m</td>
<td>5.04</td>
<td>3.76</td>
<td>3.41</td>
<td>3.48</td>
<td>3.61</td>
</tr>
<tr>
<td>$B_{PEAK}$</td>
<td>Gauss</td>
<td>117</td>
<td>42</td>
<td>43</td>
<td>55</td>
<td>48</td>
</tr>
<tr>
<td>Length, $L_c$</td>
<td>cm</td>
<td>24.6</td>
<td>17</td>
<td>26</td>
<td>26</td>
<td>26.4</td>
</tr>
<tr>
<td>W</td>
<td>mJ</td>
<td>221</td>
<td>72</td>
<td>150</td>
<td>118</td>
<td>149</td>
</tr>
<tr>
<td>G</td>
<td>Ω</td>
<td>13.8</td>
<td>11.5</td>
<td>18.1</td>
<td>25.1</td>
<td>20.9</td>
</tr>
<tr>
<td>$R/Q_0$</td>
<td>Ω</td>
<td>900</td>
<td>1309</td>
<td>1486</td>
<td>1254</td>
<td>1298</td>
</tr>
<tr>
<td>$\beta_G$</td>
<td></td>
<td>0.025</td>
<td>0.017</td>
<td>0.026</td>
<td>0.038</td>
<td>0.031</td>
</tr>
<tr>
<td>Height</td>
<td>cm</td>
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<td>139.5</td>
<td>131.3</td>
<td>80.8</td>
<td>107.3</td>
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<tr>
<td>Diameter</td>
<td>cm</td>
<td>30.48</td>
<td>23.54</td>
<td>37.0</td>
<td>37.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Frequency</td>
<td>MHz</td>
<td>48.5</td>
<td>48.5</td>
<td>48.5</td>
<td>72.75</td>
<td>57.5</td>
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</table>
**X-ray based bunch length detector with several psec time resolution**
Conclusion

- A 400 kW 200 MeV/u reaccelerated rare isotope facility can be built for about half the cost of RIA.

- Vigorous R&D and prototyping of the FRIB technical systems resulted in
  - Significant reduction of the estimated cost
  - Extended scientific reach by improved production and collection of rare isotopes

- FRIB technologies are robust; the project can proceed with minimal risk

- Superconducting technology is only option for CW ion accelerators
  - NC accelerator is required in the front end

- Low-Q injector provides predictable, reliable high yields of rare isotopes including short-lived isotopes and will be the upgrade path from the FRIB

- We observe significant impact of the RIA technology on accelerator projects worldwide
  - FNAL is interested in pulsed 8-GeV SC linac for H-minus beam based on ILC technology ("Project X")
  - GANIL
  - TRIUMF
  - SARAF, Soreq