FRIBs
past, present, and future of radioactive ion beams (RIBs) produced In-Flight @ LNS

... remembering Giovanni Raciti

Why RIBs are important?
How to reach the Driplines
FRIBs: from an exciting idea to a real facility
The Upgrade
Looking Through the keyhole of nature

At the moment we are limited in our view of the atomic nucleus

Why RIBs are important?

M. Thoennessen RIA School 2003
Looking Through the keyhole of nature

Why RIBs are important?
Why RIBs are important?

~ The nature of Nuclear Matter and strong interaction
~ Limits of nuclear existence
~ Astrofisical question: The origin of elements \( \rightarrow \) Nucleosynthesis, rp-process
~ Fundamental interaction and symmetry: test of Standard Model

Physics with Radioactive Ion Beams

Nova Cigny 1992

"Ci atammantiri i manu!"
How to reach the Driplines

Primary Projectile

STABLE

Heavy ion accelerator

Projectile Fragmentation: In-Flight method

9Be

Projectile Fragment

RADIOACTIVE

Thin production target

Fragment separator

Radioactive ion beam

Experiment
“Part of the CS extraction line can be used as a Fragment Separator“

Superconducting Cyclotron

Some Primary Stable Beams
12C @ 60 AMeV
20Ne @ 45 AMeV
40Ar @ 40 AMeV
......

Production Target
9Be 500 um
......

Fragment Separator

Prod. Target
D1
Q1 Q2 Q3
D2
Q4 Q5 Q6
Q7 Q8 Q9
Degrader

FRIBs Cocktail

G. Raciti et al.
NIM B 266 (2008) 4632
The Tagging Idea

"Identify, event-by-event, in charge, mass and energy each ion of the RIBs cocktail selected by the fragment separator, before it interacts with the secondary target."

FRIBs: from an exciting idea to a real facility
The Tagging Idea

“The tagging technique allows to perform simultaneous (same primary beam, target and reaction target) experiments”

FRIBs: from an exciting idea to a real facility
Making ideas become reality

Two-proton decay
nucleus → two protons + (nucleus − 2)

Intensity Interferometry
• Astronomy
• Particle Physics
• Liquid -Gas Phase Transition

Proton-Proton correlation function

First Experimental Evidence of 2He Decay from 18Ne Excited States
G. Raciti et al., PRL 100, 192503 (2008)

FRIBs: from an exciting idea to a real facility

“la fisica su quattro cosi e u baddu”
“New quadrupoles in the fragment separator will increase the total acceptance by a factor 10 and rates of the order of $10^5 - 10^6$ ions/sec can be achieved” Varenna, 2003

New FRS setup

New production target
- Mobile target
- H$_2$O Cooling
- Power up to 300 Watt

New diagnostic detectors

L. Calabretta
New RIBs

Rates measured in front of the CHIMERA detector (March 2011)

G. Cardella et al.

The Upgrade
# Yields Summary

<table>
<thead>
<tr>
<th>Beam</th>
<th>Primary Beam</th>
<th>Setting</th>
<th>Intensity with old FIBS (kHz/100W)</th>
<th>Intensity (kHz/100W) March 2011</th>
<th>Intensity (kHz/100W) END 2011</th>
<th>Foreseen Yield (kHz/100W) END 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>16C</td>
<td>180 55MeV/A</td>
<td>11Be</td>
<td>9</td>
<td>59</td>
<td>&gt;120</td>
<td></td>
</tr>
<tr>
<td>17C</td>
<td>180 55MeV/A</td>
<td>11Be</td>
<td>6</td>
<td>6</td>
<td>&gt;12</td>
<td></td>
</tr>
<tr>
<td>13B</td>
<td>180 55MeV/A</td>
<td>11Be</td>
<td>4.5</td>
<td>37</td>
<td>&gt;80</td>
<td></td>
</tr>
<tr>
<td>11Be</td>
<td>180 55MeV/A</td>
<td>11Be</td>
<td>2</td>
<td>11</td>
<td>&gt;20</td>
<td></td>
</tr>
<tr>
<td>10Be</td>
<td>180 55MeV/A</td>
<td>11Be</td>
<td>3</td>
<td>9</td>
<td>&gt;60</td>
<td></td>
</tr>
<tr>
<td>9Li</td>
<td>180 55MeV/A</td>
<td>11Be</td>
<td>3</td>
<td>9</td>
<td>&gt;20</td>
<td></td>
</tr>
<tr>
<td>14B</td>
<td>180 55MeV/A</td>
<td>12Be</td>
<td>1.2</td>
<td>3</td>
<td>&gt;3</td>
<td></td>
</tr>
<tr>
<td>12Be</td>
<td>180 55MeV/A</td>
<td>12Be</td>
<td>2</td>
<td>5</td>
<td>&gt;5</td>
<td></td>
</tr>
<tr>
<td>9Li</td>
<td>180 55MeV/A</td>
<td>12Be</td>
<td>2.7</td>
<td>6</td>
<td>&gt;5</td>
<td></td>
</tr>
<tr>
<td>6He</td>
<td>180 55MeV/A</td>
<td>12Be</td>
<td>4.7</td>
<td>12</td>
<td>&gt;20</td>
<td></td>
</tr>
<tr>
<td>11Be</td>
<td>13C 55 MeV</td>
<td>11Be</td>
<td>10</td>
<td>&gt;50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12B</td>
<td>13C 55 MeV</td>
<td>11Be</td>
<td>20</td>
<td>&gt;100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37K</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>50</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35Ar</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>35</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36Ar</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>50</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37Ar</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>12</td>
<td>&gt;25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33Cl</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>6</td>
<td>&gt;10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34Cl</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>25</td>
<td>&gt;50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35Cl</td>
<td>36Ar 42 MeV</td>
<td>34Ar</td>
<td>26</td>
<td>&gt;50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18Ne</td>
<td>20Ne 35 MeV</td>
<td>18Ne</td>
<td>9</td>
<td>&gt;50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17F</td>
<td>20Ne 35 MeV</td>
<td>18Ne</td>
<td>3</td>
<td>&gt;20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21Na</td>
<td>20Ne 35 MeV</td>
<td>18Ne</td>
<td>20</td>
<td>&gt;100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

G. Cardella et al. [www.lns.infn.it](http://www.lns.infn.it) – IFEB@LNS
“Our death is not an end if we can live on in our children and the younger generation. For they are us, our bodies are only wilted leaves on the tree of life.”

A. Einstein