Radioactive Ion Beams at LNS-Catania

by Luciano Calabretta

on behalf of the EXCYT and FRIBs projects
Mainly used for Nuclear Physics and Astrophysics experiments

- Irradiation of biological tissue, superconducting materials,
- Radiation hardness
- Cultural heritage
- Protontherapy

Tandem
$V_{\text{max}} < 13 \text{ MV}$

Superconducting Cyclotron
$8 < E < 80 \text{ MeV/n}$
Cyclotron is also used as driver for production of radioactive beams, both IFF and ISOL methods being exploited.
EXCYT: the mass separator

HRS $(M/\Delta M)_{2nd} \approx 20000$ II$^{nd}$ stage

2 magnets (90°) and a quadruplet of 4 electrostatic quadrupoles

1st platform: Target + ion source + preseparator $(M/\Delta M) \approx 180$ 18 magnet and a quadruplet of 4 electrostatic quadrupoles

2nd platform: CEC and Mass separator 1$^{st}$ stage $(M/\Delta M) \approx 2000$. PS and service for the two H.V. platforms
The Target-ion source complex of EXCYT

Positive surface ionization source

Light ions Primary Beam 100÷500 W

TARGET

L. Calabretta, COLLIGA meeting Paris, 23-24 November '09
LEBI: Low Energy Beam Imager / Identifier

exit slit
preseparator

Intermediate slit
1st stage

entrance slit
1st stage

exit slit
2nd stage

Intermediate slit
2nd stage

Quartz

LEBI: Low Energy Beam Imager / Identifier
The device can be placed at three different positions, depending on the application.

1) Stable (pilot) beams hit directly the CsI(Tl) scintillating plate to produce the 2D profile.

2) RIBs are implanted onto a thin mylar tape placed in front of the CsI(Tl) plate to avoid its contamination. The emitted radiation (mainly $\beta$ and $\gamma$ rays) crosses the plate producing the light spot.

3) RIBs can be implanted also on a large plastic scintillator, used for counting and spectroscopy of beta particles emitted from the radionuclides.
Sensitivity for beam imaging

- $E_{\text{threshold}} = 5$ keV
- $I_{\text{stable beam}} = 10^4$ pps/mm$^2$
- $I_{\text{radioactive beam}} \sim 10^3$ pps/mm$^2$
- resolution $< 1$ mm

Energy range
$10$ keV ÷ $300$ keV
Position sensitive silicon detectors (PSSD)

- Beam intensity measurement
- Beam energy spectra
- 2D beam profile monitor
- Identification of the beam particles ($\Delta E - E$) by adding a thin silicon detector to obtain a telescope configuration

Beam profile monitor based on a pair of scintillating fibers

Fibres diameter: 300–500 µm

Plastic fibers for low intensity
Glass fibers for higher current

size: 50 x 50 mm²
Diagnostics for High Energy (Tandem) RIBs

Short term upgrading: Provide the long beam lines (Magnex and Chimera) with low intensity diagnostics

Image of a matrix holes $\phi=5$ mm

Early test of beam imaging
Experiments performed with EXCYT

BIGBANG
Measurement of the $^8\text{Li}(\alpha,n)^{11}\text{B}$ cross section in the energy range 1.5~0.5 MeV, down to the Gamow peak. Key reaction in the inhomogeneous Big-Bang model, *Physics Letters B* 664 (2008) 157-161
*APJ* 706:L251–L255, 2009 December 1

RCS
Measurement of the $^8,^9\text{Li} + ^{28}\text{Si}$ reaction cross section near barrier energies to measure the size of unstable Li isotopes, *Active target*, Analysis in progress

RSM
Measurement of the $\alpha$-$^8\text{Li}$ elastic scattering excitation functions in reverse kinematics, aimed at studying backward angle resonances associated with cluster configurations of $^{12,13}\text{B}$, *carried out with $5 \cdot 10^4$ pps on target*

MAGNEX-RIB
Exploratory attempt to investigate $^8\text{He}$ states using the $^8\text{Li}(^7\text{Li},^7\text{Be})^8\text{He}$ charge exchange reaction, $2 \cdot 10^5$ pps required, feasible after Beam line will be equipped with diagnostics and with a 200 W on the production target
**Production:** at least 3 times the value found with the previous cylinder target

A factor 1.4 after the Charge Exchange Cell (CEC) vs. the first commissioning

When Tandem transmission and transport to the experimental area reach the values of 70% and 95% respectively, and with a primary beam power of **200 watt ± 2 • 10^5 pps** on target are expected.
Increasing the Cyclotron beam intensity from present 100 → 500 Watt

Short term upgrading: a primary beam power of 500 watt

Before going beyond 150 watt it is wise to look for a further increase of the present extraction efficiency 63% ± 80% (500W)

Use of phase slits exploiting the phase-radius correlation given by

$$\Delta E = - \Delta \phi \int \sin \phi \, dE$$

The source-cyclotron transmission needs to be improved, the injection efficiency being ~15%.

Beam transport along the injection line is now being considered.
FRIBs: in-Flight Radioactive Ions Beams productions

20 beam line: efficiency≈ 90% vs. FRIBs exit

Transport efficiency from FRIBs to Ciclope Room ≈ 20%

Transport efficiency from FRIBs to Chimera Room ≈ 50%
The idea was to identify event-by-event the produced ions with minor modifications of their characteristics:

- Charge and mass identification \((Z,A)\)
- Position \((x,y)\) and Energy measurements

**G. Raciti BeamTagging**

Secondary beam “cocktail”

First tagging detector \((\Delta E, TOF, X', Y')\)  
(16x16 strips)

Second tagging detector \((X'', Y'')\)

Secondary reaction target
In-flight production of radioactive beams (FRIBs)

Detector used in FRIBs, for monitoring the beam and tagging the particles

Ne\textsuperscript{20}+Be @ 45 AMeV

L. Calabretta, COLLIGA meeting, Paris, 23-24 November '09
Multi-strip silicon detector, beam monitor

16x16 X-Y strips
5 x 5 cm²

Multi-hit Probability
$10^6 \uparrow \ 87\%$
$10^5 \uparrow \ 15\%$
$10^4 \uparrow \ 2\%$

Next Detector
24x24 X-Y strips
2.4 x 2.4 cm²
The measured angular distributions cannot discriminate between direct or two step emission of $2p$ or $^2\text{He}$ emission.

Laboratory reference system
Search for DI-PROTON DECAY of excited states of $^{18}\text{Ne}$

$^{18}\text{Ne}$ beam produced at 35MeV/u by projectile fragmentation

The 6.15 MeV level populated by Coulomb excitation (E1 transition) by interaction on lead target

Proton energy and angle correlations $\hat{E}$ di-proton emission?
Momentum and angle correlation for $E^* = 6.15$ MeV

- 250 enA of $^{20}$Ne primary beam
- 60 kHz of secondary beam on the tagging detector
- $\approx 5$ kHz of $^{18}$Ne (9% of the total secondary beam)

$(66 \pm 9)\%$ direct three-body

$(3 \pm 2)\%$ virtual sequential

$(31 \pm 7)\%$ $^2$He decay

G. Raciti et al., PRL 100, 192503, 2008
Upgrading of the beam line extraction
2 order beam envelope

\[ X_i = +/- 3 \text{ mm} \quad \theta_i = +/- 3 \text{ mrad} \]

\[ Y_i = +/- 2 \text{ mm} \quad \phi_i = +/- 7.5 \text{ mrad} \]

\[ \Delta P/P = +/- 0.5\% \]
FRIBs, New beam line optic

2 order beam envelope

\[ X_i = \pm 3 \text{ mm} \quad \theta_i = \pm 16 \text{ mrad (±1)} \quad (16/3 = 5.3) \]

\[ Y_i = \pm 2 \text{ mm} \quad \phi_i = \pm 30 \text{ mrad (±2)} \quad (30/7.5 = 4) \]

\[ \Delta P/P = \pm 1\% \quad (1/0.5 = 2) \]
**Acceptance in the transverse space and in momentum for present and upgraded FRIBs line, beam spot $\phi=2\div4$ mm**

<table>
<thead>
<tr>
<th></th>
<th>(x,x’') Acceptance [mm.mrad]</th>
<th>(y,y’') Acceptance [mm.mrad]</th>
<th>Momentum Acceptance $\Delta P/P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today FRIBs line</td>
<td>$3x3=9\pi$</td>
<td>$2 \times 7.5=15\pi$</td>
<td>0.5 %</td>
</tr>
<tr>
<td>New FRIBs line</td>
<td>$1x16=16\pi$</td>
<td>$1x30=30\pi$</td>
<td>1 %</td>
</tr>
<tr>
<td>Gain factor</td>
<td>5.33</td>
<td>4</td>
<td>2</td>
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**Acceptance for the main LNS transport lines**

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<tbody>
<tr>
<td>FRIBs+20 line</td>
<td>$3x10=30\pi$</td>
<td>$2x20=40\pi$</td>
<td>0.7 %</td>
</tr>
<tr>
<td>Chimera, Magnex</td>
<td>$10x4=40\pi$</td>
<td>$5 \times 4=20\pi$</td>
<td>0.8 %</td>
</tr>
<tr>
<td>Medea, Ciclope</td>
<td>$3x3=9\pi$</td>
<td>$3 \times 3=9\pi$</td>
<td>0.5 %</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td><strong>42!</strong></td>
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<td><strong>Expected yield Gain</strong></td>
<td>29 $\div$ 12</td>
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<td><strong>Gain factor</strong></td>
<td><strong>5.33</strong></td>
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<tr>
<td><strong>Expected yield Gain</strong></td>
<td><strong>1.9 msr</strong></td>
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**Gain 42!**
Power released on the target about 20÷30% of incident beam power

Up to now maximum beam power was 150 W on a spot of 1 cm²

In future the beam power will be 500 W on a spot of 4 mm²

Power density 3100 W/cm², but power released on target ≈ 125 W

A rotating target will be mandatory

A study, to build a LISE like solution, will start on next month

We have to satisfy the request to remove the target from the beam line in a simple way and short time
Dedicated to our friend Giovanni Raciti
1-1-'49, † 19-8-'09
Two types of 2p emission:
- ground-state emission
  • long lived: $^{45}$Fe, $^{48}$Ni, $^{54}$Zn
  • short lived: $^{6}$Be, $^{12}$O, $^{16}$Ne, $^{19}$Mg
- emission from excited states
  • $\beta$ delayed: $^{22}$Al, $^{31}$Ar, ...
  • others: $^{14}$O, $^{18}$Ne, $^{17}$Ne

To be measured:
• proton energies
• proton-proton angle

In two-proton emitter the one-proton emission must be forbidden

The mass of the Z-even two-proton emitter smaller than the mass of the odd-Z one-proton daughter
The measured angular distributions cannot discriminate between direct or two step emission of \(2p\) or \(^2\)He emission.