The accelerators at LNS – INFN and diagnostics aspects of the radioactive beams

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LNS lay-out: accelerators and experimental halls

EXCYT facility: ISOL radioactive ion beams

Energy ranges: 10keV ÷ 300keV

Tandem 15MV

FRIBs: in-flight fragment separator

Radioactive beams at the Cyclotron energies

EXCYT: Exotics at the Cyclotron and Tandem
Superconducting Cyclotron

- Strong focusing three-sector machine \( K_b = 800 \) and \( K_f = 200 \)
- Superconducting Nb-Ti coils cooled down to 4.2 K in an LHe bath.
- Magnetic field at the center ranges from 2.2 to 4.8 T
- Operational range of the radio frequency between 15 and 48 MHz
- Two ECR ion sources: SERSE and CAESAR
  - SERSE is a highly performing superconducting source, producing beams with high charge states and intensities much higher than room temperature sources
  - The CAESAR is a conventional ECR ion source for lighter ions with moderate charge states

2011 activity (2665 hours)

- 32% Nuclear Physics
- 20% Catana (protontherapy for eye melanoma)
- 48% Applications

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Superconducting Cyclotron

$^4\text{He}$ 80 MeV/a.m.u.

$^{112}\text{Sn}$ 43.5 MeV/a.m.u.

<table>
<thead>
<tr>
<th>$^A\text{X}$</th>
<th>$\text{E (MeV/a.m.u.)}$</th>
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<tr>
<td>$^2\text{D}^+$</td>
<td>35,62,80</td>
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<tr>
<td>$^3\text{H}^+$</td>
<td>30,35,45</td>
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<tr>
<td>$^4\text{He}$</td>
<td>25,80</td>
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<tr>
<td>$^{10}\text{B}$</td>
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<td>$^{12}\text{C}$</td>
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<td>$^{13}\text{C}$</td>
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<td>$^{14}\text{N}$</td>
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<td>$^{15}\text{O}$</td>
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<td>$^{48}\text{Ca}$</td>
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<td>$^{64}\text{Ni}$</td>
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<tr>
<td>$^{68,70}\text{Zn}$</td>
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<td>$^{78}\text{Kr}$</td>
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</tr>
<tr>
<td>$^{208}\text{Pb}$</td>
<td>10</td>
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High Voltage Tandem 15 MV

• operating range 2.5 – 15 MV
• charging system based on the belt
• SF6 insulating gas (6 atm)
• transmission next to 90% 
• pre-injection voltage up to 450 kV
• well suitable for nuclear astrophysics
• used as a booster for ISOL beams (EXCYT)

2011 activity
(1810 hours)

96%
Nuclear Physics

4%
Applications

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The Excyt ISOL facility

beam intensities up to now: $10^4$ pps – $10^5$ pps

$E=0.2$ MeV/A $\div$ 7 MeV/A

10 keV – 300 keV
FRIBS: In-flight production of radioactive beams
Diagnostics for low intensity radioactive beams
Low energy (>10 keV) beam imaging with CsI(Tl) screens

CsI(Tl) is an insulator and gets charged-up

High light yield of CsI(Tl) ~ 65000 photons/MeV

Tandem injector

- Protons $E=44$ keV, $I=20$ pA
- Protons $E=170$ keV, $I=30$ fA
- $^{109}$Ag$^+$, $E=170$ keV, $I=0.5$ pA
- $^{16}$O$^+$, $E=50$ keV, $I=1.5$ pA
Diagnostic device for EXCYT Low Energy RIBs

- Photomultiplier
- Plastic scintillator BC 408
- CsI (Tl) plate
- mylar tape 6 μm
- tape transport system
- metallic grid tungsten wires
- step motor
Beam diagnostics in the EXCYT beam line

Sensitivity for beam imaging

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

Imaging of Stable (pilot) beams

- Imaging of radioactive beams
- Beam rate measurement
- Decay curve reconstruction
Ultra-thin CsI(Tl) Scintillating screens

test with protons at LNS 180 keV, 5 pA
CsI(Tl) ultra-thin scintillator (3 microns) standard video CCD

test with protons at LNS 20 keV, 700 pA
CsI(Tl) ultra-thin scintillator (3 microns) standard video CCD
Scintillating screens for very low beam intensity with a cooled CCD still camera

- Screen = CsI(Tl)
- Beam = protons
- $E = 50\text{keV}$
- $I \approx 5\text{pA}$
- $t_{\text{exposure}} = 60\text{s}$

- Screen = CsI (TI)
- Beam = protons
- $E = 200\text{keV}$
- $I \approx 2.5\text{fA}$
- $t_{\text{exposure}} = 20\text{s}$
Radiation damage in CsI(Tl) screens

scintillating light vs. fluence for a 100keV $^{16}$O beam

A 1mm thick screen was continuously irradiated for 6 h. A set of pictures was acquired while verifying that in the mean time the overall beam intensity was constant at the reference value of 1.3 pA. The light efficiency drops to 10%.
Micro-beam diagnostics: the SFOP

SFOP
Scintillating Fiber Optic Plate

- Tb doped glass fibres
- Fibre diameter = 10 μm
- Light decay time = 4 ms
- Space resolution = 20 μm
- Sensitivity < 10^5 pps (Li @52 MeV)
- Plate thickness = 1mm, 2mm, ...

Collimator = 150 μm
Primary beam current = 30 pA

50x50x2 mm³ SFOP

Glasses are reported in ref. [5].
Mathematically the optical transfer function of an image system is derived from the brightness attenuation of a sine reference. The result is obtained by the two-dimensional Fourier transform.
Scintillating screens for very low beam intensity with a cooled CCD still camera

- Screen = SFOP
- Beam = protons
- $E = 200\text{keV}$
- $I \approx 50\text{fA} \ [5\text{pA}/100]$
- $t_{\text{exposure}} = 20\text{s}$

- Screen = SFOP
- Beam = protons
- $E = 200\text{keV}$
- $I \approx 2.5\text{fA} \ [5\text{pA}/2000]$
- $t_{\text{exposure}} = 20\text{s}$
screen = CsI
beam = protons
E = 50keV
I ≈ not measurable
t_{exposure} = 60s
toward single particle imaging....!!!

beam attenuated through a fine mesh, pitch ≈ 0.1mm
Microchannel Plate (MCP) for beam imaging

Beam hits the MCP

Deflection of Low Energy Beams

- 300 keV protons/antiprotons/H⁺ ions: < 0.1 mm
- 20 keV protons: < 1 mm
- 20 keV antiprotons/H⁻ ions: 3–5 mm
MCP for beam imaging
(proton beam with the Tandem injector at LNS)

Proton beam 180 KeV
Intensity < 0.1 pA

different MCP gains

Foil / Mesh Assembly

- Nickel mesh:
  - 80 wires/inch (~3 wires/mm)
  - 25 micron thick wires
  - 293 micron hole size
  - 85% transmission

- Aluminium foil:
  - 25 micron thick

Foil voltage

Image FWHM [mm]

Foil voltage [kV]

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MCP for beam imaging with a mask

different beam steering

Further studies
- SEM/MCP sensitivity
- radiation hardness
- reliability/robustness

Damage to the MCP/Phosphor

After a few days
Diagnostics for accelerated RIBs

Plastic scintillators for beam intensity measurements

Position sensitive silicon detectors (PSSD)
- 2D beam profile monitor
- beam energy spectra
- identification of the beam particles ($\Delta E - E$)

Beam profile monitor (FIBBS) based on a pair of scintillating fibre scanning the beam
Position Sensitive Silicon Detectors

Real time beam imaging. Fast acquisition system based on VME modules

particle position reconstructed by 4 signals from the PSSD corners. Spatial resolution 1 – 2 mm

intensity range: a few pps to $10^4$ pps
1D beam scanning

This technique consists of scanning a beam with scintillating fibres, in order to produce the 1D intensity distribution.

Light collection efficiency at one end: ≈3.5%

- Light yield is of the order of 10000 photons/MeV. For charged particles is lower (quenching).
  - Plastic scintillating fibre: fast (3ns), not rad-hard, $L_{at} \approx 3.5m$, $\lambda \approx 435nm$
  - Tb-glass scintillating fibre: slow (4ms), rad-hard, $L_{at} \approx 10cm$, $\lambda \approx 550nm$
  - Ce-glass scintillating fibre: fast (40ns), not rad-hard, $L_{at} \approx 2cm$, $\lambda \approx 400nm$
FIBBS (Fibre Based Beam Sensor)

Fibres diameter: $300 \div 500 \mu m$
Glass fibres for intensity over $10^6$ pps
Plastic fibres for lower intensity
Conclusions

we are moving for developing a compact diagnostic device based on MCP and silicon detectors, in order to measure beam intensity, beam shape, time of flight and energy loss for ion identification (beam tagging)

Thanks to the colleagues working in beam accelerators and ion sources!
Thank you for your attention
Use of the Cyclotron and Tandem beams in 2011

**Cyclotron**

- **2665 h**
- **32%** Nuclear Physics
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- **48%** Applications

**Tandem**

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EXCYT beam diagnostics: LEBI
Low Energy Beam Imager-Identifier

A complex diagnostics station that combines several techniques for beam detection and identification

- CsI(Tl) plate + CCD camera for direct imaging of stable beams
- CsI(Tl) plate + CCD camera for beta-ray imaging of implanted RIBs
- Plastic scintillator + PMT for radioactive decay counting of implanted RIBs (determination of $T_{1/2}$)
- Gamma detectors for RIBs spectroscopic fingerprinting
Accelerators and facilities at LNS

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<80MeV/amu

Tandem 15MV

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