The Alto facility

S Franchoo
IPN Orsay
Alto takes central place at IPN TNA within ENSAR

March 2012: operating licence
May 2013: Alto Workshop
The Alto facility

PAC policy & new instrumentation
contribution to Spiral-2
strong local commitment

TNA
licence
Stable beams 3928 h /y
25% light ion beams 984 h
75% heavy ion beams 1964 h
RIB 360 h /y

The Alto facility
360 staff members
250 outside users (30 countries) /y
ISOL beams: $eta$-decay laser spectroscopy...

Nuclear Astrophysics: Split-Pole

Nuclear Reactions: Bacchus

Neutron source: Licorne

ISOL Line

Gamma spectroscopy: Orgam & Minorca

Clusters

The Alto facility

SALLE DE PHYSIQUE

HALL MACHINE TANDEM
“Development of the Time Dependent Recoil In-Vacuum technique for radioactive-beam geometry” (G. Georgiev, CSNSM Orsay, France)

“Probing the boundary of shape coexistence south of Z=82: Lifetime measurements of excited states in $^{170}$Os” (J. Ljungvall, CSNSM Orsay, France)

“Search for X(5) symmetry in $^{168}$W” (K. Gladnishki, University of Sofia, Bulgaria)

“Superdeformed Shell Structure in A~40 Nuclei” (E. Ideguchi, University of Osaka, Japan)
Super-deformation in $^{35,36}$S and $^{40}$Ar via $^{18}$O + $^{26}$Mg → $^{44}$Ca* 

Analysis in progress by S Go (University of Tokyo)
15-20 coax Ge + 8 Miniball triple clusters with addback

Efficiency at 1332 keV: 8.1%

Oups plunger, segmented particle detector, ...
possibility of installing a large number of \( \text{LaBr}_3 \) detectors

Up to 24 weeks of beam time available for the 2014 campaign
g factor measurements of short-lived states towards the Island of Inversion: $^{26}\text{Mg}$ and $^{28}\text{Mg}$ (G. Georgiev – CSNSM)

Shape coexistence in $^{74}\text{Se}$ studied through complete low-spin spectroscopy after Coulomb excitation (M. Zielinska – CEA Saclay)

Search for X(5) symmetry in $^{78}\text{Sr}$ (K. Gladnishki – University of Sofia)

Lifetime Measurement of $^{100}\text{Ru}$: A possible candidate for the E(5) critical point symmetry (T. Konstantinopoulos – CSNSM)

Lifetime measurements in $^{113}\text{Te}$: Determining optimal effective charges approaching the N=Z=50 doubly-magic shell closure (D. Cullen – University of Manchester)

Measurement of octupole collectivity in Nd, Sm and Gd nuclei using Coulomb excitation (P. Butler – University of Liverpool)

Single-particle structure in the second minimum. Search for high-K bands above fission isomers (G. Georgiev – CSNSM)

Spectroscopy of the neutron-rich fission fragments produced in the $^{238}\text{U}(n,f)$ reaction (J. Wilson – IPN)

~80 days beam time requested
Focused intense mono-energetic neutron source:
$10^7$ n/s/sr
$0.5 < E_n < 4$ MeV

$100$ nA $^7$Li
13-17 MeV

$^7$Li $^12$C evaporated neutrons

$E_1 = 2.8$ MeV
$E_2 = 700$ keV

Pulse Shape Analysis (PSA)
Evolution and collectivity development in the vicinity of $^{78}$Ni (D Verney)

Shape coexistence and collectivity around N=60 (A Dijon)

Spectroscopy of neutron-rich nuclei around and beyond $^{132}$Sn (R Lozeva)

Spectroscopy of neutron-rich fragments of 40<Z<50 (A Gottardo)

Spectroscopy of neutron-rich fission fragments produced in $^{238}$U(n,f) (J Wilson et al)
Transfer reactions...

$^{70}\text{Zn}(d,^{3}\text{He})^{69}\text{Cu}$, P Morfouace

$^{70}\text{Zn}(^{14}\text{C},^{16}\text{O})^{68}\text{Ni}$, I Stefan

more foreseen for 2014

$^{36}\text{S}(d,p)$ & $^{36}\text{S}(^{14}\text{C},^{16}\text{O})$

O Sorlin & T Roger

... and nuclear astrophysics
Single-particle strength in neutron-rich copper
P Morfouace et al

\[ E^{(69}\text{Cu}) = 3.35 \text{ MeV} \]
\[ L = 3 (f_{7/2}) \]
\[ C^2S = 0.9 \]

\[ E^{(69}\text{Cu}) = 3.70 \text{ MeV} \]
\[ L = 4 (g_{9/2}) \]
\[ C^2S = 0.63 \]

\[ E^{(69}\text{Cu}) = 3.94 \text{ MeV} \]
\[ L = 0 (2s_{1/2}) \]
\[ C^2S = 0.15 \]

Preliminary

- resolve ambiguities from literature
- direct kinematics reference measurement for Ganil RIB experiment
Nuclear astrophysics
N De Séréville, F Hammache et al

$^{26}$Al(n,p)$^{26}$Mg and $^{26}$Al(n,α)$^{23}$Na in massive stars

Reaction: $^{27}$Al(p,p')$^{27}$Al @ 18 MeV + coincidence measurement

- Split-Pole @ 40°
- 3 DSSSDs in reaction chamber
  - $5 \times 5$ cm$^2$, 16 strips (W model)
  - backward angles
  - $d \sim 10$ cm, $\varepsilon \sim 6$

SP - DSSSDs coupling successful
- $I \sim 80 - 100$ enA (!)

Branching ratios

$\omega \gamma = \omega \Gamma_n \Gamma_i / \Gamma_{tot}$

$^{27}$Al decay modes ($E_x > 13$ MeV)

Very good beam tuning
Low background environment for DSSSDs
Low Energy Radioactive Ion Beams at Alto
D Verney et al

Electron linac
10 µA, 50 MeV

Target & ion source
5 x 10^{11} photofissions /s

Secondary beam lines

Parrne mass separator
accelerate release of Ln and other chemically reactive elements through fluorinated molecular beams

Ensar2: IPN, Cern, Ganil, GSI, INFN

Higher yields: increase UCx density up to 13 g/cm³
Control porosity
Reduce pellet thickness

Physics: B(E2) through fast timing test case $^{137,139}$Cs
B Roussière et al, EPJA 47 (2011)

Ensar Actilab: IPN, Cern, CMMO, Ganil, INFN, Univ Rennes

B Hy et al., NIM B 288 (2012) 34

IPN, CSNSM, INRNE-Sofia, Tandar-Buenos Aires
Nd:Yag pump laser (532 nm, 90 W)

2 dye lasers (540-850 nm, 8W @ 30W pump, 10 ns pulse width, 3 GHz line width)

BBO doubling units (270-425 nm, >100 mW)
2011, 2012: Gallium with two ionisation schemes
2013: Zinc with frequency tripling
2014: Off-line chamber for development of laser schemes

R. Li, D. Yordanov, IPN Orsay
V. Fedosseev, T. Day Goodacre, B. Marsh, Isolde
K. Flanagan, University of Manchester
T. Kron, K. Wendt, University of Mainz
Low Energy Radioactive Ion Beams at Alto
<table>
<thead>
<tr>
<th>Observable</th>
<th>Experimental technique</th>
<th>Physics case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy level pattern</td>
<td>( \beta \gamma )-spectroscopy</td>
<td>Evolution of (N=50) near (^{78}\text{Ni}) and (N=82) near (^{132}\text{Sn}) shell effects far from stability</td>
</tr>
<tr>
<td>Electromagnetic transitions</td>
<td>Electron conversion</td>
<td>Onset of collectivity and nature of correlations</td>
</tr>
<tr>
<td>(\delta r^2), (\mu), (Q)</td>
<td>Laser spectroscopy</td>
<td>Gross properties, shell model</td>
</tr>
<tr>
<td>(T_{1/2}) of excited levels, (B(M1), B(E2))</td>
<td>Fast timing</td>
<td>Decay heat in reactors</td>
</tr>
<tr>
<td>(P_n, P_{2n}) and (T_{1/2})</td>
<td>Neutron detection</td>
<td></td>
</tr>
<tr>
<td>g-factor and spin</td>
<td>Nuclear orientation</td>
<td></td>
</tr>
<tr>
<td>(\gamma) emission</td>
<td>Total absorption spectrometer</td>
<td></td>
</tr>
</tbody>
</table>
Bedo setup in gamma mode
4 small Exogam clovers

Bedo setup in neutron mode
Dubna neutron detector Tetra

fast timing
B Roussière

LaBr₃

up to 5 Ge detectors $\varepsilon = 5\%-6\%
4\pi \beta$ trigger
BGO anti-Compton

~90 $^3\text{He}$ tubes
borated polyethylene shielding
4π neutron detector of $^{3}$He counters $\varepsilon = 63\%$
4π beta detector
1 Ge detector

D Testov, PhD thesis
Tetra and Bedo in alternating mode

dipole on: towards Bedo

dipole off: towards Tetra
mid-shell Ln $\beta\gamma$ fast-timing
Roussière et al.

n-rich Sb and Te $\beta\gamma$ and $\beta n$
Li et al.

$^{132}$Sn region $\beta\gamma$ and $\beta n$
Didierjean et al.
Lozeva et al.

n-rich Se $\beta\gamma$ and $\beta n$
Kurtukian-Nieto et al.

n-rich Ge $\beta\gamma$ and $\beta n$
Duchêne et al.

N=50 $\beta\gamma$
Etile et al.
Astier et al.
laser spectroscopy in the Sn region:
ground and isomeric state properties of $^{110-126}$Ag and $^{128-133}$In
β-decay of polarised $^{121-126}$Ag and $^{128-133}$In

- more accurate theoretical lifetimes of the $N=82$ isotones below $^{129}$Ag
- shell quenching vs deformation
- shell effect in radii
Lino: Laser-induced nuclear orientation
D Yordanov et al

- polarisation by optical pumping
- $\mu$ & $Q$ from nuclear magnetic resonance
- $\beta$-delayed spectroscopy of laser-polarized beams

$\beta$ detection

$\gamma$ detection

permanent magnets

electromagnet

RF coil

guiding-field coils

laser beam

ion beam

$|I+1\rangle$ $|I-1\rangle$ $|I\rangle$

$\pm I/(I+1)$ $\mp 1$ $\mp 1/(I+1)$

$\beta$ asymmetry for Gamow-Teller transitions

post-acceleration

nuclear magnetic resonance

$h\Delta\nu \sim g, Q$

hyperfine structure

$D_2$

$3^2 S_{1/2}$

$3^2 P_{3/2}$

$F=1$

$F=2$

$F=0$

$F=1$

optical pumping

$3^2 S_{1/2}$

$3^2 P_{3/2}$

$F=1$

$F=2$

$F=0$

$F=1$
CSNSM off-line validation
Rejuvenation of the dilution cryostat
Letters of intent received

Preparation at the Alto site
Structure and platforms
Faisceaulogie and beam line design

CSNSM Orsay
LPSC Grenoble
IPN Orsay
INM Paris
University of Tennessee
University of Maryland
University of Oxford
University of Novi Sad
Proposed roadmap at Alto:

- **Phase 1 (2014-2015):** install the Valencia-Surrey \textit{TAS@ALTO (12 BaF}_2\text{)} at the \textit{existing beam line}, for nuclei of interest that could be easily selected.
- **Phase 2 (2014-2016):** more challenging cases that the \textit{laser ion source} for selection, in parallel with development of a \textit{dedicated TAS beam line}.
- **Phase 3:** \textit{synergy with Bedo and Tetra} for βn emitters and more exotic isotopes. Common measurement campaigns with complementary beam lines?

In parallel, new detector developments combining higher resolution with efficiency such as \textit{LaBr}_3 or \textit{CeBr}_3 for Alto then Spiral-2.
Initiate the physics for Spiral-2 at Ganil: Desir, S3, NFS
► niche with stable beams
► R&D on Isol & RIB
► low-energy physics programme based on photofission
► R&D and physics at Alto pave the way to Spiral-2 at Ganil: initiate physics program, train new generation of isol physicists, develop instruments and methodologies
<table>
<thead>
<tr>
<th>Clusters &amp; ion-matter interaction</th>
<th>Nuclear physics</th>
<th>R&amp;D</th>
</tr>
</thead>
</table>
Outgoing Neutron kinematic curves

7Li energy
Photo-fission based isol facility

- e-LINAC
  - 10 µA 50MeV
- TIS vault
  - ~5.10^11 fissions/s
- PARRNe mass separator
- secondary beam lines
- BEDO beta decay
- identification station
$^{81}\text{Zn} \rightarrow ^{81}\text{Ga} \beta$ decay

no evidence for neutron 
excitations at low energy in
$^{81}\text{Ga}$: $N=50$ is effective

Deep inelastic at Legnaro
G. De Angelis et al. NPA 787 (2007)

observé en décroissance $\beta$
à Orsay (PARRNe)
D. Verney et al PRC 76 (2007)

Oak Ridge,
Ga → ^{84}\text{Ge} \, \beta \, \text{decay}

\textbf{Ga: hot-plasma ionisation (1 \, \mu\text{A} \, \text{deutons})}

\textbf{Ga: surface ionisation (2-4 \, \mu\text{A} \, \text{electrons})}
M. Lebois et al, PRC 80, 044308 (2009)
B. Tastet et al, PRC 87, 054307 (2013)

\textbf{Ga: laser ionisation (10 \, \mu\text{A} \, \text{electrons})}
D. Testov et al, to be published

\textbf{Zn: hot plasma ionization}
(1 \, \mu\text{A} \, \text{deutons})
Verney et al, PRC 76, 054312 (2007)

\textbf{Zn: laser ionisation}
(10 \, \mu\text{A} \, \text{electrons})
^{82}\text{Zn} \rightarrow ^{82}\text{Ga} \, \text{A. Etilé et al.}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{diagram.png}
\caption{\textbf{Ga → ^{84}\text{Ge} \, \beta \, \text{decay}}}
\end{figure}
Two long lived isomers in $^{84}$Ga

low-spin state
$\pi 1f_{5/2} \otimes \nu 2d_{5/2}$

high-spin state
$\pi p_{3/2} \nu d_{5/2}$

J. S. Thomas PRC 76, 044302 (2007)
D. Verney et al PRC 76, 054312 (2007)
Progress in the instrumentation of the secondary beam lines

POLAREX

Low Temperature Nuclear Orientation

Angular distribution depends on spins of the nuclear states, transition multipolarities, total magnetic field and temperature.

AND Nuclear Magnetic Resonance

The good frequency -> magnetic moment
-> Hyperfine structure
-> Nuclear thermometer

Verney – IPN Orsay
INPC 2013 – Firenze – 2-7 May 2013
Progress in the instrumentation of the secondary beam lines
TAS: Total Absorption Spectroscopy program

TAS Technique

Pandemonium effect**:

Due to the use of Ge detectors to measure the decay schemes: lower efficiency at higher energy

→ underestimate of β branches towards high energy excited states: overestimate of the high energy part of the FP β spectra

Solution: Total Absorption Spectroscopy (TAS)
Big cristal, $4\pi \Rightarrow$ A TAS is a calorimeter!

- 12 BaF$_2$ covering $\sim 4\pi$
- Detection efficiency of γ ray cascade $\sim 100$
- Si detector for β

Picture from A. Algora


TAGS developed by the Valencia team (Spain, B. Rubio, J.L. Tain, A. Algora et al.) : Proceedings of the Int. Conf. For nuclear Data for Science and technology (ND2013)
Progress in the instrumentation of the secondary beam lines
TAS: Total Absorption Spectroscopy program

Observable: beta feeding => beta strength

Statement of the problem:
Relation between TAS data and the $\beta$-intensity distribution:

$$d_i = \sum_j R_{ij} f_j$$

An ideal TAS would give directly the $\beta$-intensity $I_\beta$, which is linked with the $\beta$-strength $S_\beta$:

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}} \quad \left[ s^{-1} \right]$$

- Spectrum must be clean
- Response must be accurately known
- Solution of inverse problem must be stable

Deconvolution (Inverse problem) algorithms
Monte Carlo simulations
+ Nuclear statistical model