Experimental Nuclear Physics activity in Spain

(B. Rubio- IFIC Valencia)

Barcelona, Madrid, Santiago, Sevilla-Huelva, Valencia

- Exotic Nuclei
- Hadron reactions at intermediate energy
- Neutron Time of Flight

All projects supported by the Spanish “Particle and Large Accelerators National Programme”
EXOTIC NUCLEI

Madrid, Sevilla-Huelva, Santiago, Valencia
Proton emission, neutron emission and fission define an Island of about 6000 possible nuclei which might exist somewhere in our Universe. On our planet, 265 stable plus 60 radioactive nuclei are synthesised in our laboratories. About 3000 are synthesised in our laboratories.
Producing nuclei far from stability

**ISOL METHOD (ISOLDE)**

1 GeV p

**IN FLIGHT METHOD (GSI)**

1 GeV \times A
In beam investigations of nuclei around doubly-magic $^{100}$Sn using stable and radioactive ion beams
(Dresden-Köln-Madrid-Valencia)

- **REX-ISOLDE: study of halo systems**
  - Characterise the unbound nuclei $^7$He and $^{10}$Li
  - Study the transition from weakly bound systems to the continuum.
  (Aarhus-Darmstadt-Göteborg-Madrid-Moscow)
  - Signatures of dipole polarizability in the halo nuclei $^6$He and $^{11}$Li.
  (Huelva-Madrid-Santiago-Sevilla-Valencia)

- **β- delayed multi-particle breakup**
  (Aarhus-Göteborg-Jyväskylä-Madrid)

2 staff
3 postdocs
3 students
Multi particle breakup - IEM

- β-delayed particle emission - ISOLDE
  - $^9\text{C} \rightarrow ^9\text{B}^* \rightarrow p + \alpha + \alpha$
  - $^9\text{Li} \rightarrow ^9\text{Be}^* \rightarrow n + \alpha + \alpha$
  - $^{12}\text{N} \rightarrow ^{12}\text{C}^* \rightarrow \alpha + \alpha + \alpha$
  - $^{12}\text{B} \rightarrow ^{12}\text{C}^* \rightarrow \alpha + \alpha + \alpha$
  - CERN-IS361 done
  - (In preparation)

- Reaction studies - CMAM tandem
  - $^3\text{He} + ^6\text{Li} \rightarrow ^9\text{B}^* \rightarrow \alpha + \alpha + p$
  - $^d + ^7\text{Li} \rightarrow ^9\text{Be}^* \rightarrow \alpha + \alpha + n$
  - $^p + ^{11}\text{B} \rightarrow ^{12}\text{C}^* \rightarrow \alpha + \alpha + \alpha$
  - $^3\text{He} + ^9\text{Be} \rightarrow ^{12}\text{C}^* \rightarrow \alpha + \alpha + \alpha$
  - Jyväskylä done

Feed states of definite spin & parity
Defined by the Q-value
Clean the operator is known
F & GT transitions feed states of well defined spin

Selection rules ⇒ Feeds many different states
Energy window ⇒ Limited by the accelerator energy
Feeding mechanism ⇒ Not trivial, resonance or direct reactions.
Isospin ⇒ Depends on beam and target chosen

- 2 DSSSD telescope ultra thin window, design IEM
- 64 +8 electronic channels
- Data acquisition system FERA-CAMAC
Madrid Tandetron: 5MV electrostatic accelerator

Terminal voltage $V_T$: 0,1 – 5 MV  
Voltage ripple $\Delta V/V = 10^{-4}$  

Ion-sources:  
- Duoplasma  
- Sputter  

→ all elements available

Final energy: $V_T^*(Q+1)$  
Q=charge state

Beam current: 1-10 $\mu$A

Accelerator working since september 2002. 
Sevilla-Huelva research program

- EXPERIMENTS TO MEASURE DIPOLE POLARIZABILITY OF HALO NUCLEI $^6$He AND $^{11}$Li

- EXPERIMENTS IN THE CNA 3MV TANDEM ACCELERATOR

- (THEORETICAL SUPPORT TO THE COLLABORATION)

2 staff \{ SEVILLA

2 staff
1 student \{ HUELVA

Strong involvement of the theory group
Reactions with radioactive nuclei:

**Dipole polarizability of halo nuclei**

Dipole polarizability included

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One important aspect which differentiates weakly bound nuclei from normal is the Coulomb dipole polarizability. The strong Coulomb field of the target distort the $^6\text{He}$ ($^{11}\text{Li}$) projectile, so that the $^4\text{He}$ ($^9\text{Li}$) core is pushed away from the target while the *halo neutrons* remain unaffected by the Coulomb field.
CNA (Centro Nacional de Aceleradores) SEVILLA

Participants: University of Sevilla-CSIC(Research Council)-Junta de Andalucía (Local administration)

3 MV, 20 μA, operative since 1998

Ion beam analysis:
RBS, PIXE, NRA, Channeling, ERD

Material sciences
Archaeometry
Enviroment

Nuclear Physics
Nuclear Medicine

12 Investigators
5 Tecnicians
2 administ.
Univ. Santiago research programme

Production and structure of neutron-rich nuclei

- Residual nuclei production in spallation reaction (GSI)
- Production and $\beta$-decay investigation of heavy neutron-rich isotopes (GSI)
- Nuclear structure studies of medium-mass neutron-rich isotopes (GANIL)
- Nuclear structure at the neutron drip-line (light neutron-rich isotopes) (GSI)

1 staff
2 postdocs
4 students
Production and $\beta$-decay investigations of heavy neutron-rich isotopes

Collaboration: GSI, Santiago, Orsay, Bordeaux

Example:

Production of heavy neutron-rich isotopes: Cold fragmentation
✓ only protons are abraded and no neutron evaporated

Approaching the r-process path
Gamma spectroscopy group at IFIC

2 staff
2 postdocs
2 students

Research
Beta decay studies with Total Absorption Techniques (GSI, ISOLDE, Jyvaskyla)
Nuclear structure at extreme values of spin and isospin (Legnaro, Strasbourg)
Reactions with radioactive beams (Ganil)

Ge arrays

NaI, BaF
Example: Beta decay, far from stability, large energy window

TAS at GSI

Mass Separator beam
Operating

(Warsaw, GSI, St. Petersburg, Valencia)

Lucrecia at ISOLDE

Mass sep.
Radioactive Beam
Operating

(Madrid, Strasbourg, Surrey, Valencia)

Under development at IFIC

180 k€
(Valencia, Surrey)

n $\gamma$ discrimination
Hadron Reactions at Intermediate Energy

IFIC
2 staff
2 postdocs
1 student

TAPS

Univ. Santiago
2 staff
2 student

HADES
Collisions at intermediate energies

- Accelerators: KVI Groningen, GANIL (50, 200MeV/u)
- TAPS Collaboration (384 BaF)
- Measurements of hard photon and subthreshold pion production in heavy ion collisions (i.e. Ar + Au 25 MeV/U, Π°)
- Dynamics of heavy ion reactions
Collisions at relativistic energies

- Accelerator: SIS (Darmstadt GSI) (1GeV/u)
- Measurement of particle production at relativistic energies (TAPS Collaboration)
- Hadron Properties in Nuclear Matter (Hades Collaboration: measurement of $\omega$, $\rho$, $\varphi$ mass in the nuclear medium)
- Development of high energy pion beams (Hades Collaboration)
Development of high energy pion beams (Hades Collaboration)

Primary beam → Be (Prod. target) → Hodoscope → Hades Target

Time and position of the pions
Recent News:

Spain will (probably) enter the Isolde collaboration

GSI new project approved in February 2003: 675 M€ if 25% of the cost by foreign partners
A New International Accelerator Facility for Research with Ion- and Antiproton Beams at GSI

Scientific program

- Nuclear Structure Physics and Nuclear Astrophysics
  - Structure of exotic nuclei far off stability;
  - Nuclear synthesis in stars and star explosions;
  - Fundamental interactions and symmetries

- Hadron Physics with Antiproton Beams
  - Quark gluon structure and dynamics of “strong” interacting particles;
  - Origin of the confinement and mass of hadrons

- Physics of Nuclear Matter
  - Studies of hadronic matter at high densities;
  - Phase transitions in quark matter;
  - Properties of neutron stars

- Plasma Physics

- Atomic Physics and Applied Science

Special Properties

- Intense, fast cooled energetic beams of exotic nuclei
- Cooled antiproton beams up to 15 GeV
- Internal targets for high-luminosity in-ring experiments

COSTS

- Buildings and Infrastructure: 225 M €
- Accelerator: 265 M €
- Experiments / Detectors: 185 M €
- Total: 675 M €
Measurement of high quality neutron reaction cross sections: \((n,f)\), \((n,\gamma)\), \((n,xn)\), ..., of key interest in Nuclear Technology (ADS, transmutation), Nuclear Astrophysics and Basic Nuclear Physics

\(^{235}\text{U}(n,f)\)

\(^{232}\text{Th}(n,\gamma)\)
Construction of a neutron Time Of Flight facility at CERN: high instantaneous flux (10^6 n/bunch), low duty cycle (10^{-8}), wide energy range (1eV-250MeV), (good resolution) long flight path (185m).

Operative since 2002
Implementation of advanced instrumentation: fission (PPAC, Ionization Chamber), capture ($^{6}C_6D_6$ detectors, BaF$_2$ calorimeter), neutron multiplication (Ge detectors), monitoring (MicroMegas, Si detectors, BF$_3$ counters), data acquisition system (Flash ADC).
END
Producing nuclei far from stability

Isol method (from Isolde): spallation of target

ISOLDE

Protons 1 GeV
Heavy target
THICK

stopped
Ionised & mass separated

In flight method: fragmentation of projectile

GSI

Heavy projectile 1 GeV per nucleon.

Mass separated
Stopped & Detected