Nuclear structure studies with the PRISMA/CLARA setup

• Italy
  INFN LNL-Legnaro
  INFN and University Padova
  INFN and University Milano
  INFN and University Genova
  INFN and University Torino
  INFN and University Napoli
  INFN and University Firenze
  University of Camerino

• Spain
  University of Salamanca

• Romania
  NIPNE Bucharest

• France
  IReS Strasbourg
  GANIL Caen

• U.K.
  University of Manchester
  Daresbury Laboratory
  University of Surrey
  University of Paisley

• Germany
  HMI Berlin
  GSI Darmstadt
Gamma spectroscopy in grazing reactions

Thick-target experiments  R. Broda and collaborators
- Use $\gamma$-$\gamma$ cross-coincidence technique
- More than one partner/nucleus
- Only $\gamma$ rays emitted after the nucleus stop can be resolved

Thin-target experiments  PRISMA/CLARA approach
- Prompt $\gamma$-ray spectroscopy (CLARA) tagged with the identification of reaction products (PRISMA)
- Good quality Doppler correction required
The Magnetic Spectrometer PRISMA

$\Omega = 80 \text{ msr}$

$\Delta Z/Z \approx 1/60 \text{ (Measured)}$

$\Delta A/A \approx 1/190 \text{ (Measured) TOF}$

Energy acceptance $\pm 20\%$

$B\rho = 1.2 \text{ T.m}$
The CLARA Array

25 Euroball Clover detectors from the EU GammaPool

- $2\pi$ coverage
- Anti-Compton BGO shields
- High granularity
- Efficiency $\sim 3\%$
- Peak/Total $\sim 45\%$
- FWHM $\sim 0.8\%$ at $v/c \sim 10\%$

Placed at backward angles respect to the optical axis of PRISMA
The simulations of the ion transport in PRISMA (A. Latina) shown that the fringing fields of the magnetic elements have small impact on the trajectories (big magnets).

Adopted: simplified reconstruction algorithm, optimized for speed:
- Ideal magnetic elements
- All trajectories treated in the horizontal plane after the quadrupole

\[
\text{Entrance position (x,y)} \quad \text{Radius in the dipole } R \quad \text{Focal-plane position (x)}
\]

- Unique solution
- Fast convergence

- Only the magnetic fields ratio \( \frac{B_Q}{B_D} \) is needed
The absolute Time-of-Flight offset is checked/determined by looking to the Doppler correction in CLARA spectra.
PRISMA: Z, Charge states, A

Z selection

Charge state identification

Complete A and Z identification
PRISMA: efficiency and resolving power

$^{82}\text{Se}(500 \text{ MeV}) + ^{238}\text{U}$

- Projectile-like detected around 64°
- Multi-nucleon transfer
- Deep–inelastic collisions

$\text{v/c range} : 4-10\%$
$\text{Mass range} : 50-110$

Fission of $^{238}\text{U}$
Experimental production cross-sections

$^{82}\text{Se}(500 \text{ MeV}) + {^{238}\text{U}}$

Reliable production cross sections for exotic nuclei like the N=50 $^{82}\text{Ge}$ or $^{80}\text{Zn}$ are very useful when one project $\gamma$-spectroscopy experiments.
CLARA/PRISMA Campaign for the Experimental Study of Neutron-rich Nuclei

- Multi-nucleon transfer reactions with neutron-rich, stable projectiles on heavy targets
- Projectile-like reaction products are detected with PRISMA placed around the grazing angle

$^{36}\text{S}+^{208}\text{Pb}$  Medium spin - spectroscopy of Ne, Mg, and Si neutron-rich isotopes
  X.Liang, Paisley F.Azaiez, Orsay, Zs.Dombradi, Debrecen

$^{82}\text{Se}+^{238}\text{U}$  Nuclear spectroscopy of neutron rich nuclei in the N=50 region
  G.Duchene, Strasbourg, G.de Angelis, Legnaro

$^{64}\text{Ni}+^{238}\text{U}$  Spectroscopy of deformed neutron rich A ~ 60 nuclei
  S.M.Lenzi, Padova, S.J.Freeman, Manchester
Spectroscopy of the lightest $N=50$ isotones

$^{82}\text{Se}(500 \text{ MeV}) + ^{238}\text{U}$

- First observation of $\gamma$ rays from the decay of $^{81}\text{Ga}$
- The excitation energy of the $4^+$ state in $^{82}\text{Ge}$ firmly established
- First observation of the yrast levels of $^{83}\text{As}$
Spectroscopy of odd-A N=51 isotones

- First identification of yrast states in $^{85}\text{Se}$ and $^{87}\text{Kr}$

$^{82}\text{Se}(500 \text{ MeV}) + ^{238}\text{U}$
Evolution of collectivity in light N=52 nuclei

First observation of the $4^+ \sim 2^+$ transition in $^{86}$Se

The systematic of R(4/2) ratio in N=52 even-even nuclei indicates an increase of collectivity going towards lower Z
Spectroscopy around N=32 shell closure

$^{64}\text{Ni}(404 \text{ MeV}) + ^{238}\text{U}$

First identification of yrast states in heavy odd-A Vanadium isotopes $^{55}\text{V}$ and $^{57}\text{V}$

- N=32 shell closure previously observed in $^{52}\text{Ca}$ and $^{54}\text{Ti}$
Predicted shell closures at $N=32$ and $N=34$

- First experimental observation of the $1\pi f_{7/2}$ band in $^{55,57}\text{V}$
- The predicted shell closure at $N=34$ is not confirmed by experimental data
Onset of deformation towards $N=40$

First identification of $4^+$ and possibly $6^+$ states in $^{64}\text{Fe}$

The onset of deformation towards $N=40$ is confirmed by experimental data

Shell-model calculations predicts that the $\nu g_{9/2}$ orbit has strong influence on the structure of even-even Fe isotopes with $N=38$

The experimental $R(4/2)$ ratio indicates a structure change for $N=38$

$^{64}\text{Ni}(404 \text{ MeV}) + ^{238}\text{U}$

$\nu g_{9/2}$ region
Spectroscopy of heavy Cr isotopes

$^{64}\text{Ni}(404 \text{ MeV}) + ^{238}\text{U}$

First observation of $\gamma$ rays from the yrast levels of $^{58}\text{Cr}$
γ-softness in heavy Cr and Fe isotopes

- The $R(4/2)$ ratio in Fe isotopes is very close to the value of 2.50 specific to γ-soft rotors
- The $R(4/2)$ ratio in Cr isotopes is increasing towards the same value

The $R(4/2)$ of $^{58}\text{Cr}$ has exactly the value predicted for E(5) critical point
58\(^{\text{Cr}}\): A shape phase transition critical point?

- The excitation energies for all states in the yrast band of 58\(^{\text{Cr}}\) are very close to the predictions of the E(5) symmetry.
- Several large-scale Shell-Model results are also in good agreement with the E(5) solution.

Experimental B(E2) values are needed to firmly demonstrate the existence of E(5) symmetry in 58\(^{\text{Cr}}\).

Collectivity above N=20 shell closure

$^{36}\text{S} (230\text{MeV}) + ^{208}\text{Pb}$

First identification of yrast states in $^{34,36}\text{Si}$ and $^{40}\text{S}$

$^{40}\text{S}$

β decay

NSCL-MSU
(1)

GANIL
(2)

CLARA/PRISMA

(1) J.A. Wigner et al.
Phys. Rev C 64(2001)064318

(2) D. Sohler et al.

N. Marginean  Fusion06
γ-softness in heavy S isotopes

Analytic IBA formulas

Realistic effective charge $q_{\text{eff}} = 0.2 \times Z$

The level scheme and B(E2) value suggest a significant degree of γ-softness in $^{40}\text{S}$
Development projects:
Differential plunger with CLARA/PRISMA

Collaboration with IKP-Köln

- Consists in having an energy degrader at fixed distance after the target
- The gamma rays emitted before or after the recoil passes the degrader will have different Doppler shifts
- The lifetimes will be obtained from the intensity ratio before/after degrader

$^{60}\text{Fe} - $ simulation based on existing experimental data

Before degrader

After degrader

$2^+ \ ? \ 0^+ \ 4^+ \ ? \ 2^+$

$V' < V$

$\gamma$

Degrader

CLARA

Target

PRISMA
Development projects: Position-sensitive MCP array DANTE

Collaboration with FLNR Dubna

- Variable-position MCP array, allowing complete covering of the grazing angle
- Will compensate the low level of statistics of $\gamma$-PRISMA coincidences

$\gamma$-PRISMA: identification

$\gamma$-$\gamma$-DANTE: build the level scheme

Talk of J.J. Valiente Dobon
On the second half of 2007, the clover array CLARA will be replaced with the AGATA demonstrator

- 5 triple-clusters
- 36-fold segmented crystals
- 540 segments

Talk of E. Farnea
Higher intensity beams: PIAVE/ALPI

- Test beams of $^{22}$Ne and $^{40}$Ar were already successfully delivered.
- Higher beam intensities and heavier projectiles will become available with the entrance of PIAVE/ALPI complex in routine operation.
Summary

- Spectroscopy with quasi-elastic multi-nucleon transfer and deep-inelastic collisions, using the CLARA-PRISMA setup and the medium-mass and heavy beams from LNL, provides valuable structure information on moderately n-rich nuclei.

- Further developments include:
  - the possibility to measure lifetimes with CLARA/PRISMA setup
  - higher granularity and $\gamma$ detection efficiency (AGATA demonstrator)
  - More statistics for $\gamma$-recoil coincidences (DANTE)
  - Higher intensities and heavier beams (PIAVE/ALPI)