Spectroscopy with the Clover array and the PRISMA magnetic spectrometer

Structure of Moderately n-rich nuclei by multinucleon transfer and deep-inelastic collisions

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for the EUROBALL & PRISMA2 collaborations

- The PRISMA magnetic spectrometer: Description and status.
- Coupling the Clover Array to PRISMA.
- Multi-nucleon transfer and deep-inelastic collisions as tools to study the structure of n-rich nuclei
- Perspectives.
The PRISMA magnetic spectrometer
PRISMA specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid angle</td>
<td>≈ 80 msr</td>
</tr>
<tr>
<td>Energy acceptance</td>
<td>± 20%</td>
</tr>
<tr>
<td>Resolving power</td>
<td>p/Δp = 2000</td>
</tr>
<tr>
<td>Mass resolution</td>
<td>1/300 (via TOF)</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>1/1000 (via TOF)</td>
</tr>
<tr>
<td>Z resolution</td>
<td>≤ 1/60</td>
</tr>
<tr>
<td>Mass energy product</td>
<td>ME/q² = 70 MeV amu</td>
</tr>
<tr>
<td>Kinematic correction</td>
<td>via software</td>
</tr>
<tr>
<td>Aberrations correction</td>
<td>via software</td>
</tr>
<tr>
<td>Dispersion</td>
<td>4 cm/%</td>
</tr>
<tr>
<td>Count rate capability</td>
<td>up to 2x10⁵ s⁻¹</td>
</tr>
</tbody>
</table>
The Spectrometer Detectors

Position sensitive MCP

10 sections Multiwire PPAC

S. Beghini et al. LNL annual Report 2000 pg. 163

10 x 4 sections Ionization Chamber

G. Montagnoli et al. LNL annual Report 2000 pg. 165
The Spectrometer Detectors

10 sections Multiwire PPAC

Position sensitive MCP

S. Beghini et al. LNL annual Report 2000 pg.163
10 x 4 sections Ionization Chamber

G. Montagnoli et al. LNL annual Report 2000 pg.165
Status and tests of PRISMA

$^{58}\text{Ni} + ^{197}\text{Au}$
185 MeV
(target thickness
1.5 mg/cm$^2$)

105 MeV $^{32}\text{S} + ^{64}\text{Ni}$

32/12$^+$
32/11$^+$
33/12$^+$
31/12$^+$

105 MeV $^{32}\text{S} + ^{64}\text{Ni}$
$\theta_{ab} = 68^0$

190 MeV $^{58}\text{Ni} + ^{197}\text{Au}$
$\theta_{ab} = 90^0$
$\Delta(A/q)/A/q = 1/200$

240 MeV $^{58}\text{Ni} + ^{124}\text{Sn}$
$\theta_{ab} = 90^0$
FWHM = 1/90
The Prisma - Clover array setup

- 24 to 25 Clovers setup
- Efficiency $\sim 3\%$
- Peak/Total $\sim 50\%$
- Position $\theta = 104^\circ-156^\circ$
- FWHM $\sim 10$ keV for $E_\gamma = 1.3$ MeV at $v/c = 10\%$
Collimator with 4 removable elements allow the beam line to follow the rotation of PRISMA

Clover array design

Clover detectors placed, with respect to the PRISMA entrance, at:

- $\theta = 102.9^\circ$
- $\theta = 128.6^\circ$
- $\theta = 141.4^\circ$
- $\theta = 154.3^\circ$
- $\theta = 180.0^\circ$
Clover Array Frame designed by the University of Manchester and Daresbury Laboratory
Polarization measurements with the Clover array

The Clover composite detectors constitute a high sensitivity and efficiency Compton polarimeter

\[ A = \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \]

EUROBALL III Polarization Sensitivity

- Monte Carlo simulation
- Experimental PCO

Raffi et al. NIM A 391 (97) 461
Lifetime measurements with the Clover array at Prisma

- Recoil Shadow anisotropy method:
  Based on the array-collimator geometry.
  Lifetimes ranging from ~0.5 to ~20 ns.

- Differential Plunger method (to be developed):
  Needs a degrader foil at different distances form target.
  Lifetimes ranging from ~1 ps to ~1 ns.

- RFD method:
  Developed at the Krakow Recoil Filter Detector.
  Based on the line shape analysis of the Doppler shifted lines
  and the change of momentum introduced by the straggling of the
  products in the target.
  Needs an accurate position sensitive detector as the PRISMA
  start MCP.
  Lifetimes ranging from ~50 fs to ~1 ps.
  P.Bednarczyk, W.Meczynski, J.Styczen et al.
Recoil Shadow Anisotropy Method

Angles for the Ge crystals of the Clover array ring:

$\theta = 106^\circ$

$\theta = 98^\circ$

E.Gueorguieva et al. NIM A 474 (2001) 132
Recoil Shadow Anisotropy Method

Angles for the Ge crystals of the Clover array ring:

\[ \theta = 106^\circ \]
\[ \theta = 98^\circ \]
A short lifetime determination with RFD

The range of measured lifetimes can be chosen by a selection of the target thickness.

68 MeV $^{16}$O + 0.8 mg/cm$^2$ $^{30}$Si; 
Recoil transit time 0.4 ps

$45$Sc; 3110 keV 40 fs
$45$Ti; 3013 keV 200 fs
$42$Ca; 3219 keV > 4 ps

In the measurement ranging from 40 to 800 fs could be determined.

P. Bednarczyk, W. Meczynski, J. Styczen et al.
Deep Inelastic and Multi-nucleon transfer

- Both are binary reactions with the mass of the products in a narrow distribution around the projectile and target masses.

**DIC**

- Present at energies well above the Coulomb barrier are the transition between QE/grazing and fragmentation.
- Most of the beam energy is absorbed in the process, the reaction products emerge with low kinetic energy

**QE-Transfer**

- Occurs at energies around the Coulomb barrier.
- Population of Multiparticle-Multihole states with limited excitation energy and therefore limited particle evaporation.
Deep Inelastic

QE Multi-nucleon Transfer

R.J. McDonald et al.
Multi-nucleon transfer: production of moderately n-rich nuclei

$^{64}\text{Ni} (390\text{MeV}) + ^{238}\text{U}$

L. Corradi et al.
Production of n-rich nuclei by multi-nucleon transfer

Experiment by L. Corradi et al. to be published
Theory by G. Polarollo et al.

$L^58\text{Ni}$ (345 MeV) + $^{208}\text{Pb}$

LNL - PISOLO Experiment
Neutron rich Ni isotopes spectroscopy by DIC

$^{64}\text{Ni} \ (275\text{MeV}) + ^{130}\text{Te}$

$^{76}\text{Ge} \ (635\text{MeV}) + ^{198}\text{Pt}$

(h_{11/2}}^2) alignments

86Kr (395MeV) + 110Pd

I.Y. Lee et al.

rotational structures in n-rich Yb isotopes

48Ca (250MeV) + 176Yb

S.J. Asztalos et al.

Spin yields in DIC

154Sm (1GeV) + 208Pb

High Spin studies with deep-inelastic reactions
### Table

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Mass Number</th>
<th>Decay Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa221</td>
<td>221</td>
<td>235</td>
<td>α, EC</td>
</tr>
<tr>
<td>Pa223</td>
<td>223</td>
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<tr>
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<td>Th230</td>
<td>230</td>
<td>246</td>
<td>α, EC, β</td>
</tr>
<tr>
<td>Th232</td>
<td>232</td>
<td>248</td>
<td>α, EC, β</td>
</tr>
</tbody>
</table>

### Diagram

232Th + 136Xe  833MeV

Gammasphere at LBNL

J.F.C Cocks et al.

ALPI Output Energy

- Tandem (G-F) (1-10 pnA)
- PIAVE+Alpi (40-200 pnA)

E/A [MeV/u]

0 10 20 30

0 50 100 150 200 250

Tandem

New Injector

XTU Tandem

Piave

Alpi

Experimental halls

PIAVE RFQ
Multinucleon transfer and DIC in the $^{132}$Sn region

- Topics: residual interactions: SPE and TBME, core and particle-core excitations, high spin with DIC
- $^4p$ transfer estimated $\delta\sigma/\delta\Omega \sim 100$ to 500 $\mu$b/sr, Ge efficiency $\sim 3\%$.
  Prisma acceptance $\sim 80$ msr.
  Beam: 10 pnA $^{134,136}$Xe.
  Target 300 mgr/cm$^2$ $^{208}$Pb or $^{238}$U.
  $\gamma$-Multiplicity 5: 10 to 50 $\gamma-\gamma$-Prisma coin./hour

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The $^{78}$Ni region

- Topics: residual interactions at the Z=28 N=50 shell closure. High spin with DIC
- Estimated cross sections:
  - For -4p transfer $\delta \sigma/\delta \Omega \sim 10$ to 100 $\mu$b/sr
  - For -6p transfer $\delta \sigma/\delta \Omega \sim 1$ to 10 $\mu$b/sr.
  - Ge efficiency ~3%. Prisma acceptance ~80msr
  - Beam intensity 10 pnA ($^{76}$Ge, $^{80}$Se, $^{82}$Se, $^{86}$Kr)
  - 300mCr/cm$^2$ $^{208}$Pb target
  - $\gamma$-Multiplicity 5
  - -4p channels: 1 to 10 $\gamma$-$\gamma$-Prisma coin./hour
  - -6p channels: 0.1 to 1 $\gamma$-$\gamma$-Prisma coin./hour

Xiangdong Ji and B.H. Wildenthal

The N=50 Shell closure

R.C. Nayak

- Investigation of the shell closure evolution at the magic number N=50. Seniority scheme conservation towards Z=28

\[ { }^{64}\text{Ni (390MeV)} + { }^{238}\text{U} \]

L.Corradi et al.

- Cross section estimates:
  - for \(-4p\) transfer \(\delta\sigma/\delta\Omega \sim 10 \text{ to } 100 \mu\text{b/sr}\)
  - for \(-2p+2n\) transfer \(\delta\sigma/\delta\Omega \sim 1 \text{ mb/sr}\)

- Ge efficiency \(\sim 3\%\)
  - Prisma acceptance \(\sim 80\text{msr}\)
  - Beam intensity \(10\text{pnA (}{ }^{82}\text{Se,}{ }^{86}\text{Kr)}\)
  - \(300\mu\text{gr/cm}^2\) \(^{238}\text{U}\) target, \(\gamma–\text{Multiplicity 5}\)
  - \(-4p\) channels: \(1 \text{ to } 10 \gamma–\gamma\)-Prisma coin./hour
  - \(-2p+2n\) channels: \(100 \gamma–\gamma\)-Prisma coin./hour
Cross Section Calculations (GRAZING code)

G. Pollarolo

\[^{82}\text{Se} + ^{124}\text{Sn} \ E_{\text{LAB}} = 380 \ \text{MeV}\]

\[
\begin{array}{ccc}
\sigma \ (\text{mb}) & 10^{-3} & 10^{-2} & 10^{-1} & 10^{0} & 10^{1} & 10^{2} & 10^{3} \\
\text{Ge} (-2p) & 75 & 80 & 85 \\
\text{As} (-1p) & 75 & 80 & 85 \\
\text{Se} (0p) & 75 & 80 & 85 \\
\end{array}
\]

MASS NUMBER
Deformation in light neutron rich nuclei

\[ \beta_2 \text{ range } -0.5 \text{ - } 0.85 \]

R. Rodriguez-Guzman et al.
Neutron Skin Oscillations: Pygmy Resonance


Use of DIC to study GDR


Conclusions

- Structure studies in moderately n-rich nuclei with the Clover array at PRISMA
- Preliminary dates for the arrival of the Clover detectors to LNL ~15 July 2003
- Commissioning of the Clover array October 2003
- Commissioning of ALPI spring 2003
The PRISMA-Clover Array collaboration

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

• France
  IReS Strasbourg

• Germany
  HMI Berlin

• Romania
  Horia Hulubei NIPNE Bucharest

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

• Spain
  University of Salamanca