Spectroscopy of $^{81}\text{Zn}$ via one-neutron transfer $^{80}\text{Zn}(d,p)$ using ACTAR TPC

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on behalf of the ACTAR-TPC collaboration

**Local contact:** L. Gaffney
Spectroscopy of $^{81}$Zn via (d,p) reaction using ACTAR TPC

**Physics case**

- N = 51 isotones: only one neutron above N = 50 shell closure
- Even Z: ground states are $5/2^+$ and the first excited states are $1/2^+$
- Excitation energies reflect the ESPE
- Tensor force drives the evolution of the ESPE
Spectroscopy of $^{81}$Zn via (d,p) reaction using ACTAR TPC

**Physics case**

- Systematics on N=51 isotones: emptying of the proton \( fp \) orbitals
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Physics case

- What is the energy of the $1/2^+_1$?
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**Physics case**

- Does the trend lead to an inversion?
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Physics case

- **Single-particle state** according to (d,p) reaction
  
  J.S. Thomas, PRC 71, 021302 (2005) and PRC 76, 044302 (2007)

- **Core-coupling** $2^+ \otimes v2d_{5/2}$ according to life-time meas.
  
  (F. Didierjean – to be published in PRC)

- Which $7/2^+$ is single-particle ($g_{7/2}$)?

![Diagram of energy levels and particle states](image_url)
Experimental method

- Accepted experiment (INTC-P-352)
  - T-REX Si detectors
    - Angular distribution of the protons
    - Between 400-keV and 1-MeV resolution
  - MINIBALL Ge array
    - Detection of the $\gamma$-rays with high resolution ($\sim$ 10 keV)
    - Limited by low efficiency for high-energy states ($7/2^+$ @ 2 MeV)
    - E2 transition might be not observed ($T_{1/2} > 10$ ns)
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Experimental set-up

• ACTAR = ACtive TARget
  Ø Gas is used as a target ...
  Ø … and to detect the reaction products.
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- **TPC = Time Projection Chamber**
  - 2D projection on the pads
  - 3rd dimension with e⁻ drift time

Courtesy of B. Mauss and A. L. Laffoley
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  - 2D projection on the pads
  - 3rd dimension with $e^-$ drift time

- **High luminosity and angular coverage** ($4\pi$)
- **Effective thickness** ~ 10 times higher than solid target but still a good resolution on the vertex.

Courtesy of B. Mauss and A. L. Laffoley
This experiment

- (d,p) transfer reaction in inverse kinematic
  - Protons mostly emitted at backward angles
- Angular distribution of the protons
  - FWHM$_\theta$ $\sim$ 1°
  - Reconstruction of the vertex: FWHM$_Q$-value $\sim$ 200 keV

Inelastic scattering experiments: $^{58}$Ni(p,p')$^{58}$Ni

Courtesy of B. Mauss and A. L. Laffoley
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This experiment

- (d,p) transfer reaction in inverse kinematic
  - Energy resolution of Si: $\sigma_E \sim 75$ keV
  - 37% of angular coverage

PhD student J. Yang
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This experiment

- **Excitation energies**
  - Using the $E_{Si}$ (75 keV)
  - Wide angular coverage
  - Separation even if $E^* \sim 100$ keV

Inelastic scattering experiments: $^6$Li($\alpha,\alpha'$$^6$Li

(d,p) with T-REX and solid target: resolution of ~ 400-1000 keV

Courtesy of B. Mauss and A. L. Laffoley
Spectroscopy of $^{81}\text{Zn}$ via (d,p) reaction using ACTAR TPC

Beam request

- Secondary beam (TAC)
  - $^{80}\text{Zn}$: $1.10^4$ pps
  - 5% of transmission, 16% of $\beta$ decay
    - $3 \times 10^3$ pps
- Target: $\text{D}_2$ (95%) + $\text{CF}_4$ (5%) @ 1 bar

- Reaction rate (Spec. factor = 0.6)

<table>
<thead>
<tr>
<th>Wave</th>
<th>Cross Section (mb)</th>
<th>Reaction rate (pph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-wave</td>
<td>37.6</td>
<td>400</td>
</tr>
<tr>
<td>d-wave</td>
<td>64.7</td>
<td>690</td>
</tr>
<tr>
<td>g-wave</td>
<td>21.8</td>
<td>230</td>
</tr>
</tbody>
</table>

Courtesy of D. Verney
Spectroscopy of $^{81}$Zn via (d,p) reaction using ACTAR TPC

**Beam request**

- **Efficiency**
  - Reconstruction: ~ 90%
  - Si detectors: $\Omega$ ~ 37%

- **Reaction rate** (Spec. factor = 0.6)

<table>
<thead>
<tr>
<th></th>
<th>Cross Section (mb)</th>
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<th>Part. detected (pph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-wave</td>
<td>37.6</td>
<td>400</td>
<td>130</td>
</tr>
<tr>
<td>d-wave</td>
<td>64.7</td>
<td>690</td>
<td>230</td>
</tr>
<tr>
<td>g-wave</td>
<td>21.8</td>
<td>230</td>
<td>75</td>
</tr>
</tbody>
</table>
Spectroscopy of $^{{81}}$Zn via (d,p) reaction using ACTAR TPC

Beam request

- **10 shifts** for $^{{80}}$Zn(d,p)$^{{81}}$Zn with LASER ON

<table>
<thead>
<tr>
<th></th>
<th>Cross Section (mb)</th>
<th>Reaction rate (pph)</th>
<th>Part. detected (pph)</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-wave</td>
<td>37.6</td>
<td>400</td>
<td>130</td>
<td>11 K</td>
</tr>
<tr>
<td>d-wave</td>
<td>64.7</td>
<td>690</td>
<td>230</td>
<td>18 K</td>
</tr>
<tr>
<td>g-wave</td>
<td>21.8</td>
<td>230</td>
<td>75</td>
<td>6 K</td>
</tr>
</tbody>
</table>

- $^{{80}}$Ga will represent ~20% of the beam
- **5 shifts** with LASER OFF
  - No contaminants
- **2 shifts** for the beam and detector tuning

We require a total of **12 shifts**
Spectroscopy of $^{81}\text{Zn}$ via (d,p) reaction using ACTAR TPC
Spectroscopy of $^{81}$Zn via (d,p) reaction using ACTAR TPC

Back up slides
Spectroscopy of $^{81}$Zn via (d,p) reaction using ACTAR TPC

**Beam request – TAC feedback**

<table>
<thead>
<tr>
<th>INTC-P-904</th>
<th>Actar</th>
<th>21</th>
<th>$^{60}$Zn</th>
<th>ACTAR</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCx-quartz v1.0-Ta n conv 3$^4$ n conv 1.4$^4$5 targ in DB 1e5/uC requested 2006: UC329, 45%Ga, 20%Rb, 110$^4$80Zn/uC UC542 (2015) $^{80}$Zn – 1.2E3 /uC (lower estimate Laser on/off beta activity ratio: 1.2) 2016 UC584 ca 5e4/uC $^{80}$Zn: no impurities. A yield of 5e4 can be delivered/guaranteed (lower than quoted in the proposal): physics still feasible?</td>
<td>ACTAR needs clearance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0$^0$Zn done before A/q=80/21 Rb and Zn mass markers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If 3 CMS are ok, then 7MeV/u ok.</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Two times less intensity
- But no contaminants
- Still feasible with 10 shifts
- No shift with LASER OFF ?
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Time line of ACTAR TPC project
Spectroscopy of $^{81}$Zn via (d,p) reaction using ACTAR TPC

Beam request for $l=4$

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<td>37.6</td>
</tr>
<tr>
<td>d-wave</td>
<td>64.7</td>
</tr>
<tr>
<td>g-wave</td>
<td>13.4 / 21.8</td>
</tr>
</tbody>
</table>

7/2$^+$ @ 2 MeV is most probable to be a single-part. state, according to F. Didierjean
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**Additional setup**

- Si thicknesses …
  (12cm of gas mixture included)

We need about 5 mm of Si … or Si + NaI (2cm) (all available)

Ep > 15.7 MeV escapes 1.5 mm of Si
(DSSD of Leuven available soon)

Ep < 6 MeV don’t escape 0.6 mm of Si
(20 detectors of 0.7 mm available)
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Kinematic lines

![Graph showing energy vs. angle for different states and excitation energies](image)

- $E^* = 100\text{ keV}$
- $E^* = 300\text{ keV}$

KU LEUVEN
Kinematic lines

- Wide range of angles allows to determine the excitation energy
  - If $E^* \sim 100$ keV: forward $\theta_{lab}$
  - If $E^* > 250$ keV: difference above the Si resolution

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