
M. Gardner¹, A. Simons¹, C. Allwork¹,², P. Thompson¹, R. Clarke³, R. Edwards¹, J. Andrew¹.

IoP Nuclear 2009,
University of Birmingham.

¹ Plasma physics department, AWE, Aldermaston, Reading, W. Berkshire, RG7 4PR.
² Physics department, The University of Surrey, Guildford, Surrey, GU2 7XH.
³ Experimental Science Group, Rutherford Appleton Laboratory, Harwell Campus, Didcot, OX11 0QX.
Presentation outline.

- LPI and proton beam formation.
- Previous work.
- Experimental hypothesis.
- Experimental setup.
- Target selection.
- Preliminary results.
- Conclusions and future work.
Target-Normal Sheath Acceleration (TNSA).

- CPA laser pulse interacts with front surface pre-plasma.
- Hot electron population formed through coupling of laser energy to $e^-$; mechanism determined by laser irradiance.
- Electrons exit rear of target and are constrained in a “sheath” by electrostatic field set up by charge separation.
- Electric field accelerates preferentially protons from rear surface of target.
- Protons form a $\sim 30^0$ cone distributed in energy; up to $\sim 70\text{MeV}$ for Petawatt lasers.

Previous work: Vulcan Petawatt (500J, ~1ps).
HELEN Experiment: Background and hypothesis.

- Formerly experiments carried out by the group have been used to measure the activation of materials common to CPA laser environments such as optical glasses and coating components.

\[ A = \int \sigma(E) S(E) \rho x dE \]

<table>
<thead>
<tr>
<th></th>
<th>Vulcan '08</th>
<th>Measured</th>
<th>Unknown</th>
<th>“Known”</th>
<th>Known</th>
<th>Known</th>
</tr>
</thead>
<tbody>
<tr>
<td>HELEN '08</td>
<td>Measured</td>
<td>Known</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Known</td>
<td>Known</td>
</tr>
</tbody>
</table>

- Destructive proton measurement techniques have been employed to collect information on the incident proton spectrum. Repeatability assumed.

- It should be possible to obtain a measure of the proton spectrum produced during LPI by seeding main targets with additional materials and then detecting the decay of proton-induced reactions of known cross section and threshold.

- This requires careful selection of seeding materials to avoid formation of “problematic” daughter nuclei.
Experimental setup: HELEN schematic.

- Final steering mirror.
- LaBr(Ce) detector inside lead shielding.
- Chamber shielding.
- LaBr(Ce) detector inside lead shielding.
- Gamma cone (purple).
- Laser target.
- Proton cone (green).
- Detector field of view (yellow).
- Gamma cone (purple).
- Proton cone (green).
- Activation target.
- Laser target.
- Detector field of view (yellow).
- Incoming laser.

Unfocused laser beam.

Off-axis parabola.

Chamber shielding.
Experimental setup: HELEN target chamber.

- Primary (laser) target
- Final steering mirror
- Secondary activation target (Si disc)
- Shielded LaBr scintillation detector
- PTFE shielding
Material examples and selection criteria.

<table>
<thead>
<tr>
<th>Zr87</th>
<th>Zr88</th>
<th>Zr89</th>
<th>Zr90</th>
</tr>
</thead>
<tbody>
<tr>
<td>M14.0s, G1.71h</td>
<td>83.4d</td>
<td>M4.16m, G3.27d</td>
<td>51.45%</td>
</tr>
</tbody>
</table>

Isomeric state population of $^{89}\text{m}Zr$ ($E=587.82\text{keV}$). BR of 93.77% IT, 6.23% $\beta^+$. Threshold $\sim 4\text{MeV}$.

<table>
<thead>
<tr>
<th>Ga63</th>
<th>Ga64</th>
<th>Ga65</th>
<th>Ga66</th>
<th>Ga67</th>
<th>Ga68</th>
<th>Ga69</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.4s</td>
<td>2.6m</td>
<td>15.2m</td>
<td>9.5h</td>
<td>3.3d</td>
<td>67.71m</td>
<td>60.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zn63</th>
<th>Zn64</th>
<th>Zn65</th>
<th>Zn66</th>
<th>Zn67</th>
<th>Zn68</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.5m</td>
<td>48.63%</td>
<td>244d</td>
<td>27.9%</td>
<td>4.1%</td>
<td>18.75%</td>
</tr>
</tbody>
</table>

Standard $\beta^+$ decay to long-lived daughter. BR 100% $\beta^+$. Threshold $\sim 16\text{MeV}$.
Preliminary results I: Si+Y

Activation of Si and Y

- Data
- Fit
- Si-28(p,n)P-28
- Si-27 or P-29 isotopes
- Y-89(p,n)Zr-89m
- Al
- PTFE
- SS
- Background

Time (s) vs Counts/Second graph showing the decay of activated isotopes over time.
Preliminary results II: Al+Cu+Y+Zn mosaic target.

![Graph showing decay curves for various isotopes like Si27, Al26m, Ga64, Zr89m, Cu62, Ga65, Zn63, Ga66, Cu66, showing data points and fitted curves with decay times.]
Additional findings - $^{89m}$Zr population and decay.

- At early times, signal is dominated by short-lived 511keV annihilation gammas.

- At later times $^{89m}$Zr (100% I.T. @ 588keV) to $^{89}$Zr with half-life $t_{1/2}$ = 4.16m can clearly be seen.

- Unambiguous identification of isomeric population production in a CPA laser-plasma experiment.
Conclusions and future work.

- Experimental technique validated - separation and identification of ~15 components, extracted from composite half-life measurement.

- Next step is reconstruction of proton spectrum into bins defined by nuclear reaction thresholds.

- Isomer population the first explicitly observed in a CPA laser experiment.

- Future work to include sensitivity study, plus additional material and reaction selection.