ORNL Instrumentation Development for Astrophysics Measurements

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ATLAS Workshop
7/13/19
• $^3$He beam experiments with GODDESS
  • Previous experiments
    • $^{19}$F($^3$He,$t$)$^{19}$Ne
    • $^{40}$Ca($^3$He,$\alpha$)$^{39}$Ca
  • ($\alpha,p$) reactions with gas jets
    • Previous measurements with JENSA
    • SOLSTISE for HELIOS and SOLARIS
Recipe for Reaction Rate Calculations

• Resonance Strengths
  • Typically need one of $\Gamma_p$, $\Gamma_\alpha$, $\Gamma_\gamma$
  • Need $J^\pi$ of excited states in compound nucleus

• Excitation energies
  • Reducing uncertainty important - affects reaction rate exponentially:

$$N_A(\sigma v)_r = \frac{1.5399 \times 10^{11}}{T^3} \left( \frac{M_0 + M_1}{M_0 M_1} \right)^{3/2} \times \sum_i (\omega \gamma)_i \exp \left( -\frac{11.605 E_i}{T} \right)$$

• Interference?
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• Interference?
GODDESS Summary

• ORRUBA + Gretina/Gammasphere

• Previous Experiments:
  (Gammasphere)
  • $^{95}\text{Mo}(d,p)^{96}\text{Mo}$
  • $^{134}\text{Xe}(d,p)^{135}\text{Xe}$
  • $^{19}\text{F}(3\text{He},t)/$
    $^{40}\text{Ca}(3\text{He},\alpha)$
  (Gretina)
  • $^{56}\text{Fe}(p,p')$
  • $^{30}\text{P}(d,p)^{31}\text{P}$
  • $^{134}\text{Te}(d,p)^{135}\text{Te}$
$^3\text{He}$ Beams with GODDESS

\( ^{19}\text{F}(^{3}\text{He},t)^{19}\text{Ne} \) for \( ^{18}\text{F}(p,\alpha)^{15}\text{O} \)

- \( ^{18}\text{F}(p,\alpha)^{15}\text{O} \) important for nova nucleosynthesis.
- Interference between \( 3/2^+ \) states near \( S_p \) and resonance at \( E_x \sim 7 \text{ MeV} \)
- Found gamma rays for two potential \( 3/2^+ \) states in \( ^{19}\text{Ne} \) – resonances in \( ^{18}\text{F}(p,\alpha)^{15}\text{O} \)

\[
\begin{align*}
&6927, 7/2^- \\
&6891, 3/2^- \\
&6383, 5/2^- \\
&6787, 3/2^- \\
&6592, 9/2^- \\
&6554, 7/2^- \\
&6527, 3/2^- \\
&6500, 11/2^- \\
&6497, 3/2^- \\
&6429, 1/2^- \\
&6330, 7/2^- \\
&6282, 5/2^- \\
&6255, 1/2^- \\
&6110, 9/2^- \\
&6088, 3/2^- \\
&6070, 7/2^- \\
&5107, 5/2^- \\
&4682, 5/2^- \\
&4648, 13/2^- \\
&4556, 3/2^- \\
&4549, 5/2^- \\
&4377, 7/2^- \\
&4032, 9/2^- \\
&3998, 7/2^- \\
&3908, 3/2^- \\
&2779, 9/2^- \\
&1554, 3/2^- \\
&1458, 3/2^- \\
&1345, 5/2^- \\
&197, 5/2^- \\
&109, 1/2^- \\
&0, 1/2^- 
\end{align*}
\]
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• $^{38}$K($p$,γ)$^{39}$Ca important at endpoint of nova nucleosynthesis – disagreement between theory and observation.
• Previously studied directly with DRAGON and via $^{40}$Ca($^{3}$He,α) at TUNL.
• 23 new $^{39}$Ca transitions found including three potential resonances for $^{38}$K($p$,γ)
(α,p) reactions with SOLSTISE
(SOLenoid and Supersonic Target In Structure Experiments)
(α,p) Reactions and Nucleosynthesis

• (α,p) reactions important reactions for αp-process and astrophysical sites like XRBs, Type Ia SN, etc.
• Not easy to measure, especially on radioactive nuclei where He target needed.
• Gas target (jet/cell) necessary for many of these:

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</tr>
</tbody>
</table>

a Up (U) or down (D) variation that has the largest impact
b $M_{LC}^{(t)}$ in units of $10^{17}$ ergs/g/s
$(\alpha,p)$ Reactions with JENSA

- $^{14}\text{N}(\alpha,p)$ – first inverse kinematics experiment with gas jet.
- Large level spacing in $^{18}\text{F}$, nice test case:
  \[ E_{19}, E^{(14}\text{N}) = 1296 \text{ keV/u} \]

- $^{56}\text{Ni}(\alpha,p)$ – performed for time inverse
- $^{59}\text{Cu}(p,\alpha)$ – important in XRBs.

- Density of states also not an issue here because $p_0$ dominates.
Many of these experiments could be improved in a solenoid especially if the level density is higher.

SOLSTISE (gas jet + HELIOS/SOLARIS)

Jet currently being tested at ORNL/simulations in progress (more at LECM).
Advantages of \((\alpha, p)\) with SOLSTISE

- Potentially less elastic scattering – less DAQ dead time and higher beam rates for more statistics.

- Kinematic compression in inverse kinematics not an issue: in \(A=30-40\) region solenoid may especially be useful due to high density of states.

Design considerations:

- Investigating different nozzle designs
  - Gas jet “sheet” or smaller (~1 mm) jet to improve position resolution?
    - For high level densities that can’t be resolved in silicon, thicker jet may be more useful for increased statistics.
  
- Gas jet “sheet” would also be useful for RAISOR beams/beams with larger spot size.
• GODDESS has had successful measurements using stable $^3$He beams
  • $^{19}$F($^3$He,$t$) & $^{40}$Ca($^3$He,$\alpha$)

• Some astrophysics measurements may require new target technologies (SOLSTISE)
  • SOLSTISE will be particularly useful for ($\alpha$,p)
  • JENSA has already had some success
  • Solenoid may solve some issues present in regular inverse kinematics experiments (kinematic compression, etc)…
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