Producing Huge Spin Alignment in Inelastic Excitations of Clustered Nuclei

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Introduction

In most nuclear reactions (fusion, quasi-elastic and deeply inelastic scattering) the total angular momentum is dominated by the large reservoir contained in orbital motion. It is not surprising, then, that the exit channel fragments tend to acquire an aligned spin ***perpendicular*** to the beam-axis.

After analyzing a previous experiment with ^{7}Be at MSU a huge spin alignment (~50%!) ***parallel*** to the beam-axis was found for inelastically excited ^{7}Be*[1].

We performed an analogous experiment at TAMU using ^{7}Li which also displayed a large longitudinal spin alignment. In particular we studied the reactions:

$$^7Li(J^\pi = 3/2^-) + Be/C/Al \rightarrow {}^7Li^*(J^\pi = 7/2^-) + Be/C/Al \text{ (all remaining in GS)}$$

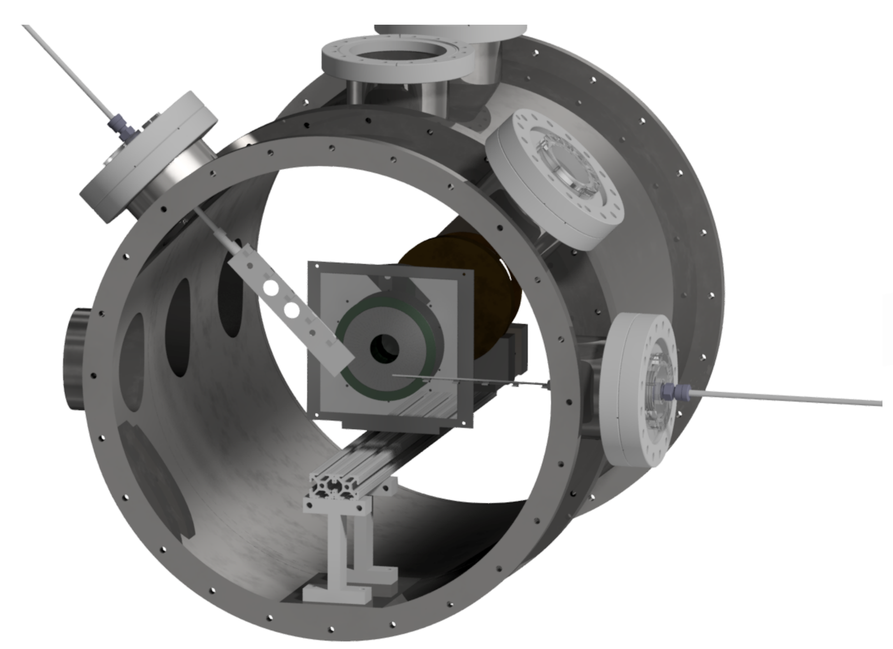
and observed a large spin-alignment ***parallel*** to the beam-axis in all cases.

Experimental Methods and Results

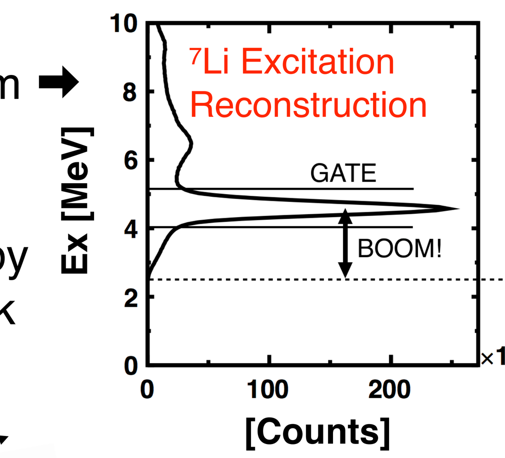
The experiment was conducted in the MARS beam line at Texas A&M in August 2015. The K500 was used to provide a primary 24 MeV/A ^{7}Li beam.

We used two Si-CsI(Tl) telescopes mounted on a rail system. One telescope array was placed at 15 cm from the target and the other at 35 cm.

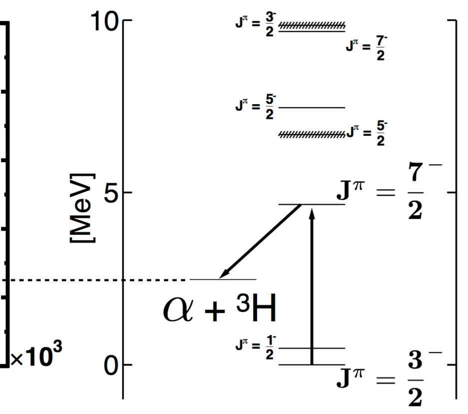
This dual-annular telescope system provided nearly complete azimuthal coverage and polar angular coverage of 1.8º to 16º, with a small gap at 5.7º.



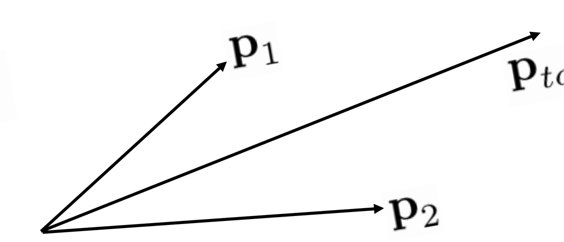
Invariant Mass (from α+t) Spectrum ➡



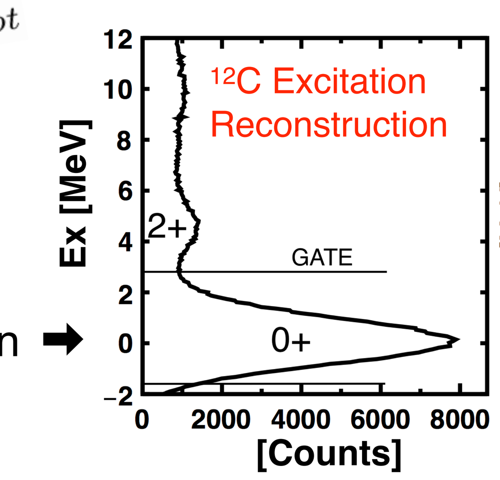
^{7}Li Level Scheme

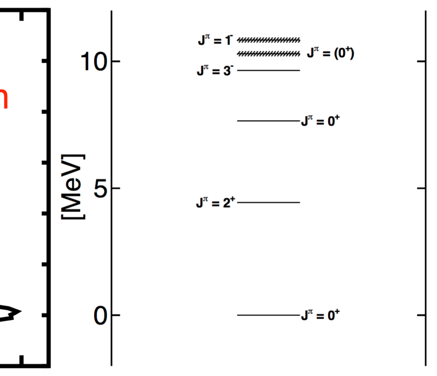


We reconstruct events by adding momentum back together.



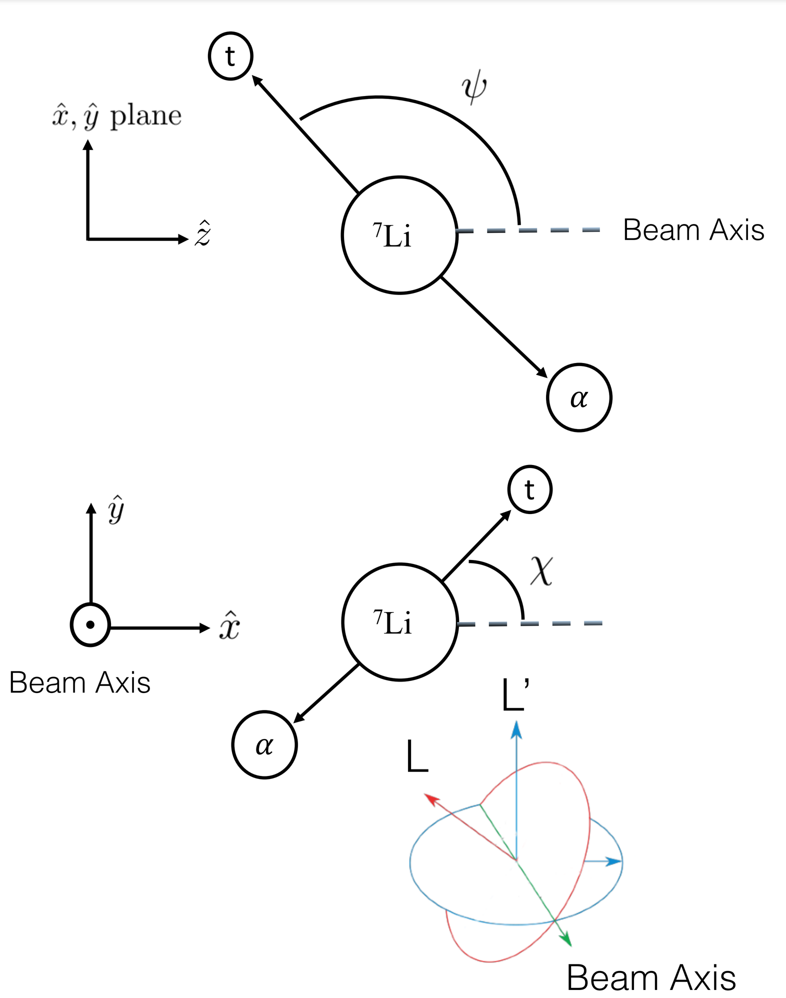
^{12}C Level Scheme





Extracted Target Excitation ➡ (from 2-body kinematics)

Measuring Alignment

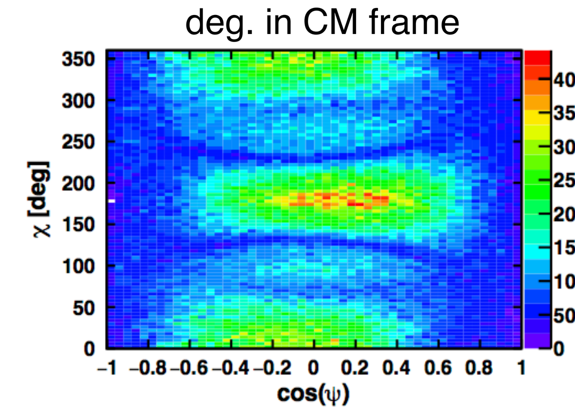


If reaction product's spin is aligned ***perpendicular*** to the beam axis fragments from its decay will be preferentially emitted in a plane *containing* the beam-axis (cos(ψ) = ±1). This is not observed.

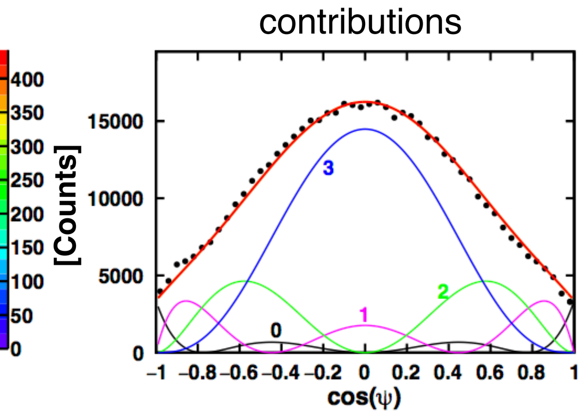
If the reaction product's spin is aligned ***parallel*** to the beam axis fragments from he decay will be preferentially emitted in the x-y plane (cos(ψ) = 0). This is observed.

Standard theory of angular correlations says the distribution will be dictated by Legendre Polynomials *weighted* by the outgoing magnetic substate density matrix. In the inelastic excitation studied here (conducted at intermediate energy) the produced ^{7}Li* fragments are highly aligned ***parallel*** the beam axis.

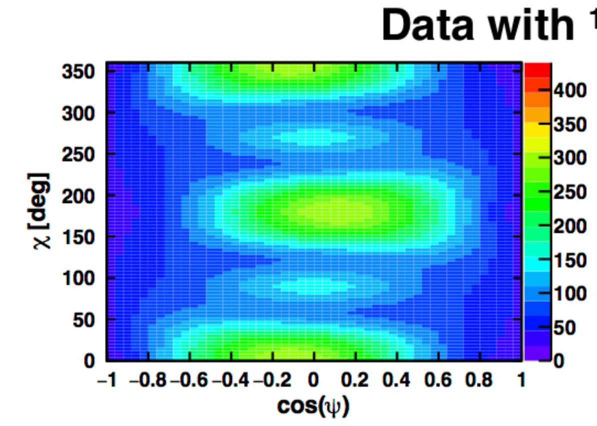
Angular Correlations for 5-15 deg. in CM frame



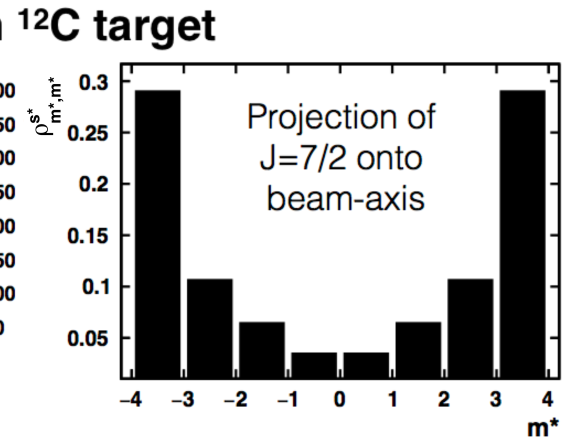
Legendre Polynomial contributions



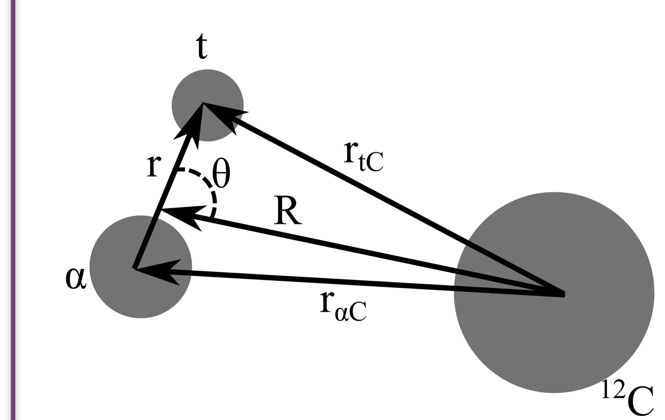
Data with ^{12}C target

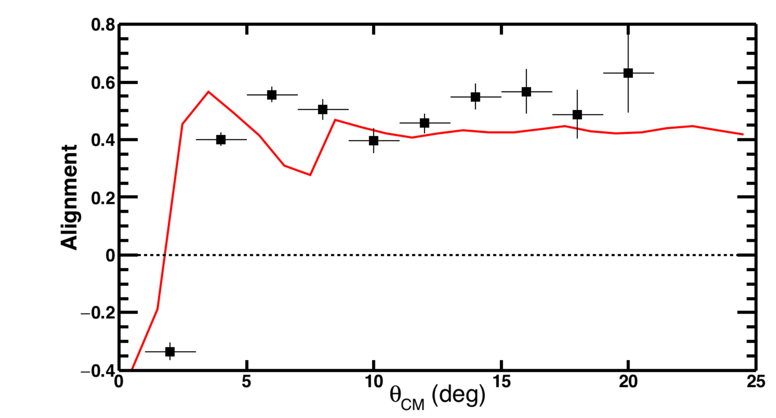


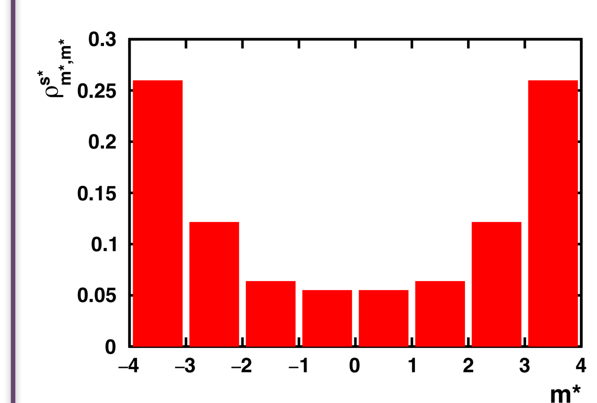
Density Matrix Fit



Cluster Model Calculations







Diagonal elements of FRESCO generated density matrix.

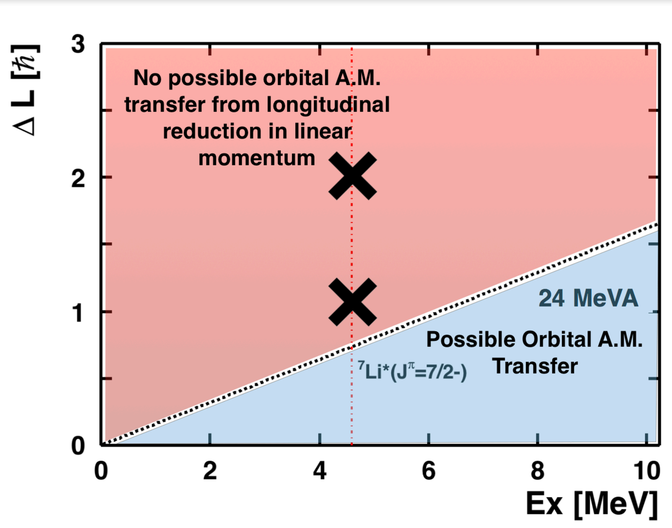
The reaction code FRESCO, exercised with a three-body (cluster) model, was able to reproduce the alignment (black = data) and its angular distribution.

To understand the physics that generates the longitudinal alignment, a dissectible 3-body reaction code was written.

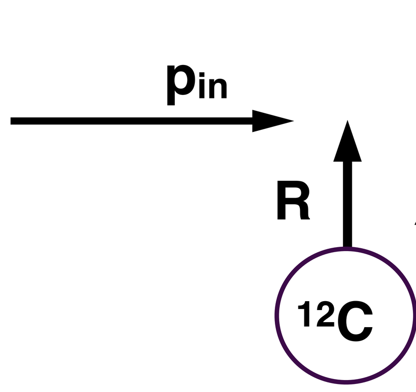
Alignment Mechanism

$$|T_{m_i,m_f}|^2 \approx \langle J_i, m_i\,;\, \mathbf{K}, M \mid J_f, m_f\rangle^2 \langle L_g, 0\,;\, \mathbf{K}, M \mid L_g, M\rangle^2$$

$$M = m_f - m_i$$

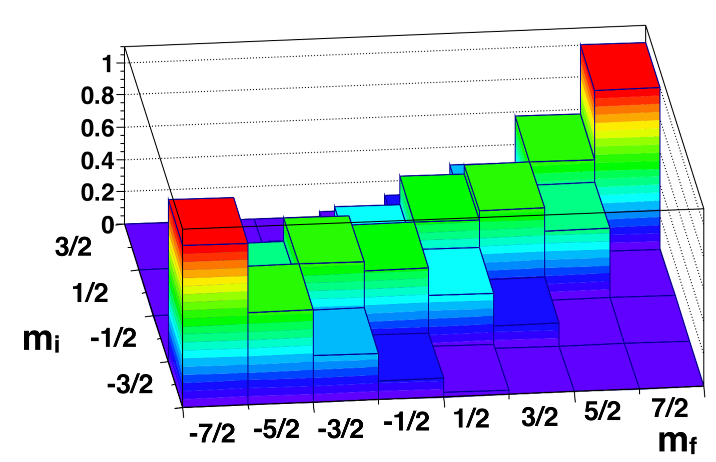


Increased *J* of the projectile *cannot* come from longitudinal reduction in linear momentum. Reaction plane must *tilt*.



$$\Delta p = \frac{\Delta L}{R} = \sqrt{\frac{E_{CM}}{2\mu}} - \sqrt{\frac{E_{CM} - Ex}{2\mu}}$$

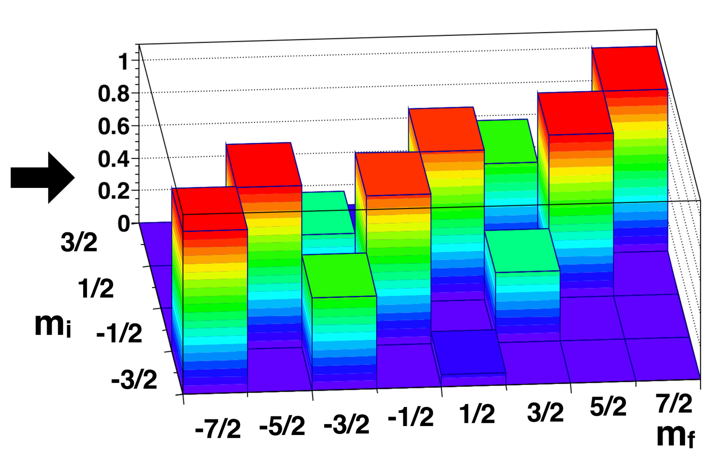
CG for initial spin projection to final spin projection via K = 2 quadrupole transition ➡ ***huge*** "spin-up".



$$\langle 3/2, m_i\,;\, \mathbf{2}, M \mid 7/2, m_f\rangle^2$$

×

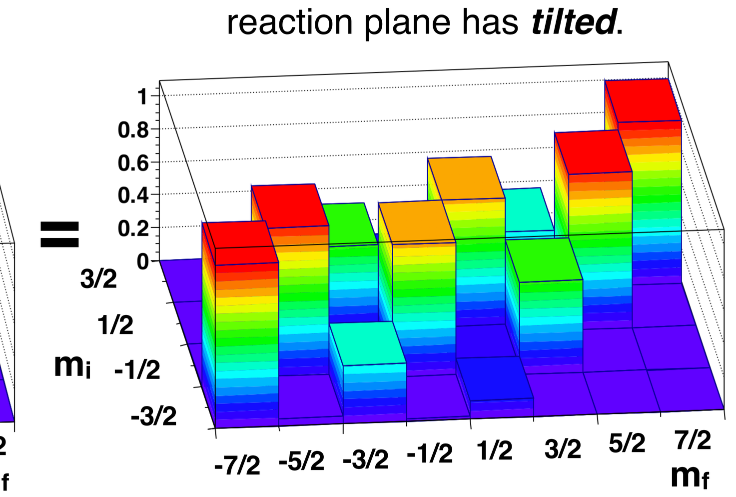
CG for K = 2 change in the *orientation* of the reaction orbital angular momentum for one L-wave, near the grazing value of L_g = 35.



$$\langle 3/2, m_i\,;\, \mathbf{2}, M \mid 7/2, m_f\rangle^2 \langle 35, 0\,;\, \mathbf{2}, M \mid 35, M\rangle^2$$

=

The entrance and exit L-waves are the same *but* the projection has changed, i.e. the reaction plane has ***tilted***.



Full FRESCO Calculation of T-Matrix

Conclusion

^{7}Li ground state is well described as an α + t with ℓ = 1 internal orbital motion, and the J^π = 7/2$^-$ state with ℓ = 3. The inelastic excitation is almost exclusively a quadrupole transition and the reaction "spins up" ^{7}Li along the beam-axis (i.e. +3/2 → +7/2, -3/2 → -7/2).

The large beam energy and small excitation energy forces the reaction plane to *tilt* (ΔL = 0, M = ± 2) because of angular momentum and excitation energy matching.

Additional findings suggest coherent L-wave mixing washes out the oscillations of alignment in angle expected for a single L-wave.

References: [1] R.J. Charity et al., PRC **91**, 024610 (2015)