Pushing DRAGON beyond its acceptance limits: The $^{7}\mathrm{Be}(\alpha,\gamma)^{11}\mathrm{C}$ reaction

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for the DRAGON Collaboration

Nuclear Astrophysics Group
Department of Physics & Astronomy, McMaster University

Nuclear Astrophysics at Rings and Recoil Separators
Darmstadt, March 13th, 2018

The DRAGON Collaboration

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U. Greife[4] • W. Huang[2] • D. A. Hutcheon[2] • J. Karpesky[4] • A. Lennarz[2]
J. Liang[1] • M. Lovely[4] • S. N. Paneru[5] • *A. Psaltis*[1] • R. Giri[5]
C. Ruiz[2] • G. Tenkila[6] • A. Wen[6] • M. Williams[2,7]

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[5] Ohio University, [6] University of British Columbia, [7] University of York

Introduction & Motivation

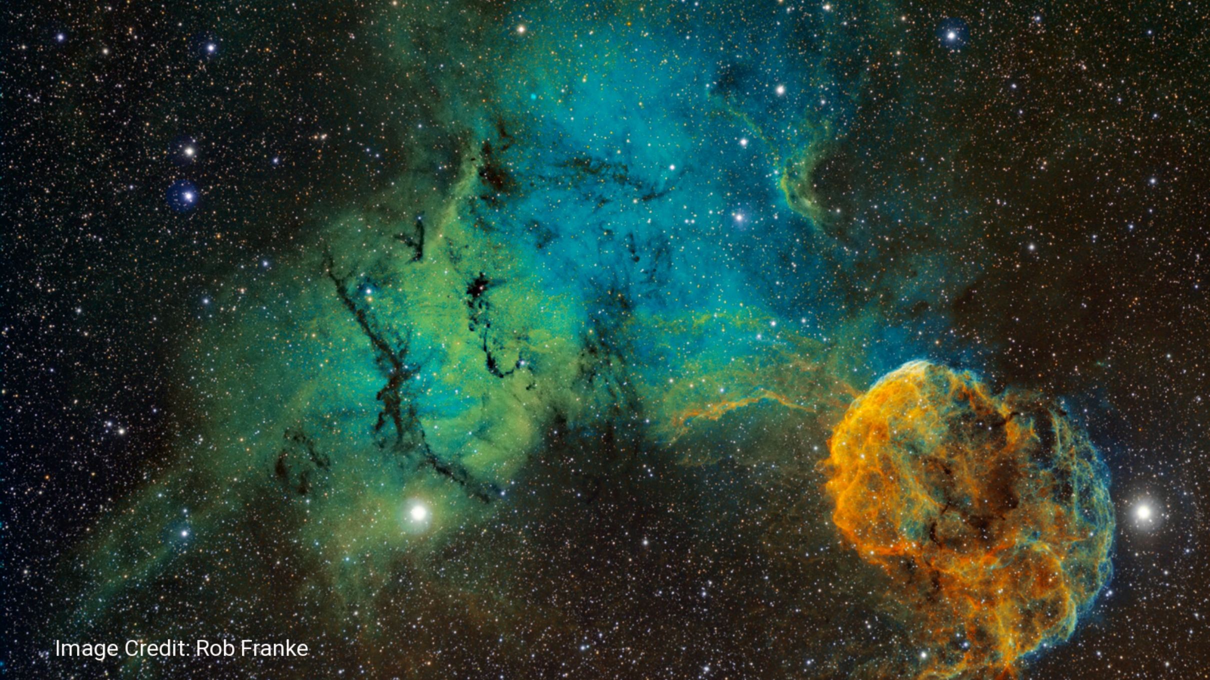


Image Credit: Rob Franke

Introduction: νp-process as the origin of *p*-nuclei

Occurs in core-collapse supernovae when **proton-rich** ejecta interact with the ν-driven wind, creating neutrons.

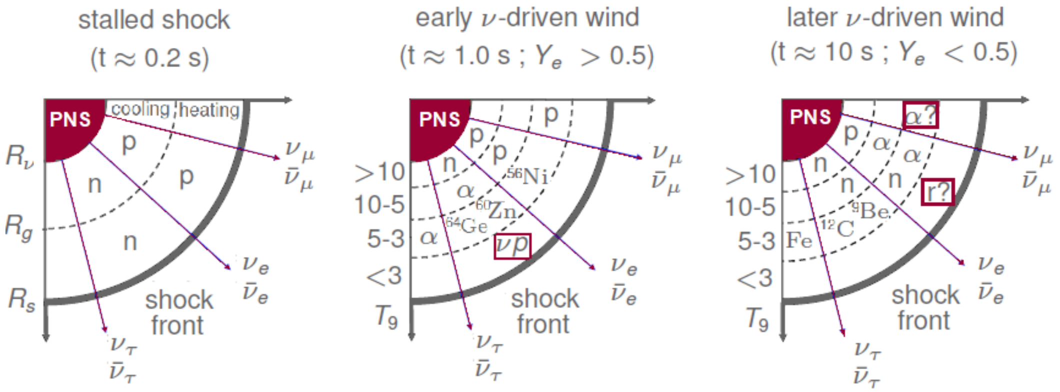
Bypasses the *rp*-process β^+ waiting-nuclei near A $\sim$ 60-70 by fast (n,p) & (p,γ) reactions, enabling the reaction flow to heavier nuclei.

Can explain the solar abundances of ^{92,94}Mo & ^{96,98}Ru.

νp-process is very sensitive to both **supernova dynamics** & **nuclear physics**.

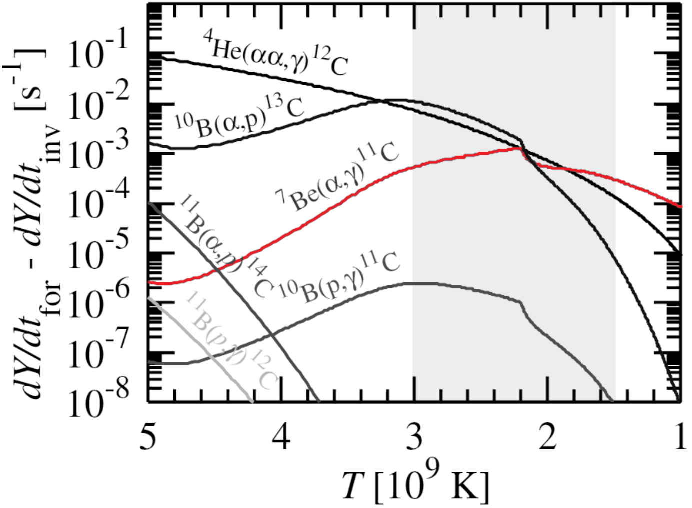
[S. Wanajo, Astrophys. J. **647**, 1323 (2006)]
[J. Pruet *et al.*, Astrophys. J. **644**, 1028 (2006)]
[C. Fröhlich *et al.*, Phys. Rev. Lett. **96**, 142502 (2006)]

νp-process in a core-collapse supernova explosion



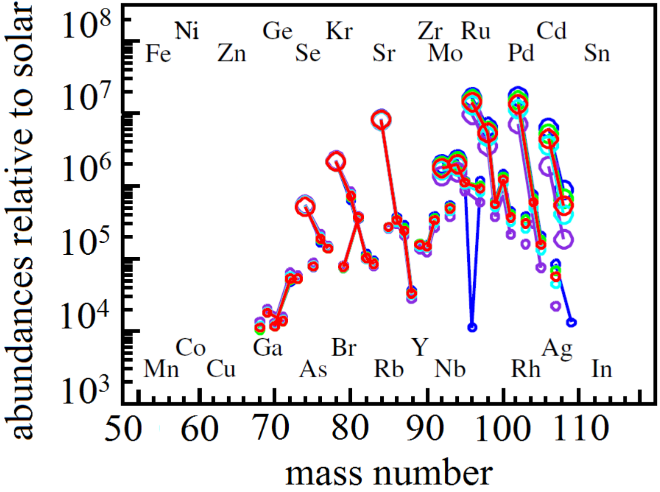
[*Adapted from*: J. José and C. Iliadis, Rep. Prog. Phys. **74**, 096901 (2011)]

$^{7}Be(\alpha,\gamma)^{11}C$ reaction can compete with 3α process



[*Adapted from*: S. Wanajo, H.-T. Janka and S. Kubono, Astrophys. J. **729**, 46 (2011)]

$^{7}Be(\alpha,\gamma)^{11}C$ can alter *p*-abundances for A∼90-110



$^{7}Be(\alpha,\gamma)^{11}C$ reaction rate:

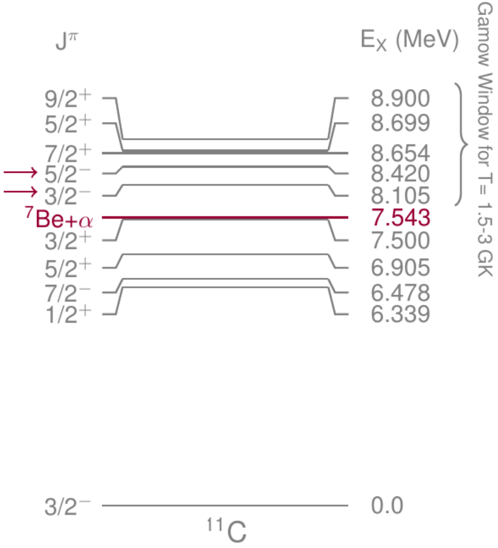
× 1 2 10

÷ 2 10

[*Adapted from*: S. Wanajo, H.-T. Janka and S. Kubono, Astrophys. J. **729**, 46 (2011)]

What we know about ^{7}Be$(\alpha,\gamma)^{11}$C

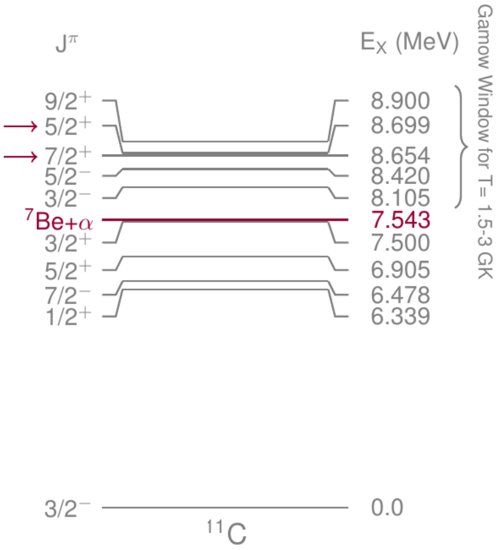
Previous work related to the ^{7}Be$(\alpha, \gamma)^{11}$C reaction



Hardie *et al.* studied the first two resonances above the α-threshold (E_x= 8.105 MeV and E_x= 8.421 MeV) with a radioactive ^{7}Be target.

[G. Hardie *et al.*, Phys. Rev. C **29**, 1199 (1984)]

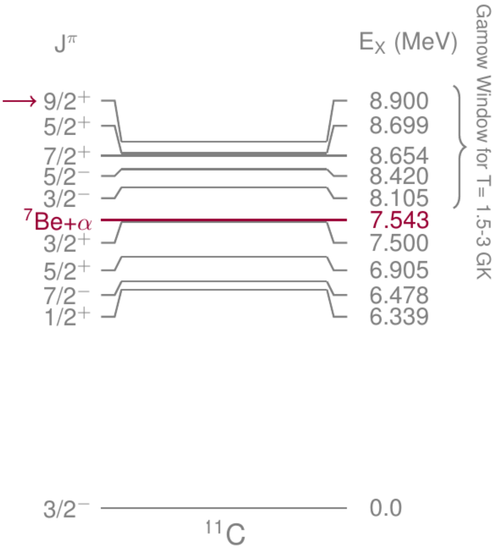
Previous work related to the ^{7}Be$(\alpha,\gamma)^{11}$C reaction



Wiescher *et al.* studied two resonances at E_x= 8.654 MeV and E_x= 8.699 MeV via the ^{10}B(p,γ) reaction, however their (α,γ) resonance strengths remain still **unknown**.

[M. Wiescher *et al.*, Phys. Rev. C **28**, 1431 (1983)]

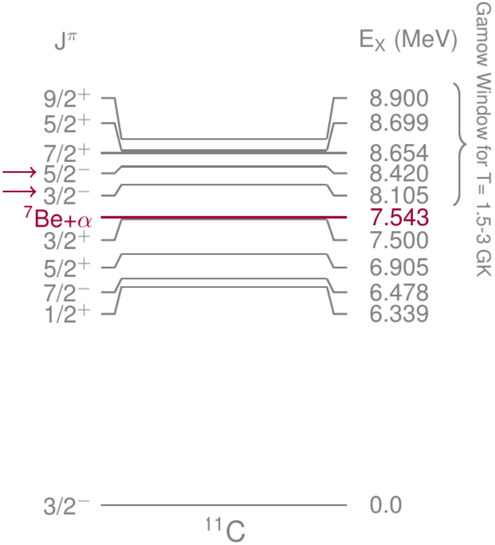
Previous work related to the ^{7}Be(α,γ)^{11}C reaction



Yamaguchi *et al.* found a **new** resonance at E_x= 8.900 MeV with inelastic scattering of ^{7}Be + α that is expected to enhance the total reaction rate of ^{7}Be(α,γ)^{11}C by 10%.

[H. Yamaguchi *et al.*, Phys. Rev. C **87**, 034303 (2013)]

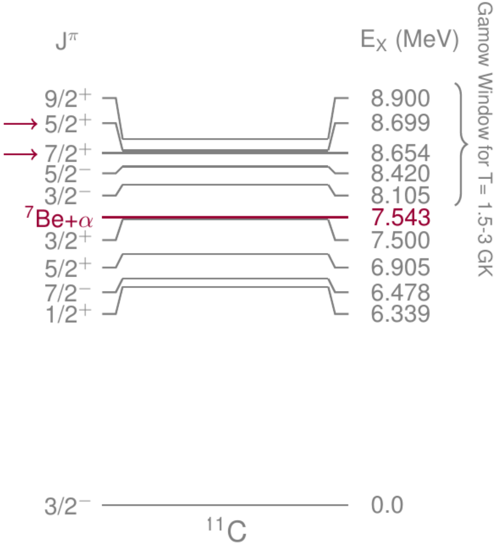
Previous work related to the ^{7}Be$(\alpha,\gamma)^{11}$C reaction



The reaction rate of $^7\mathrm{Be}(\alpha,\gamma)^{11}\mathrm{C}$ for νp-process temperatures is based on two resonances

Description of the Experiment

Objectives of the Experiment



1. First direct measurement of the E_x= 8.654 MeV & E_x= 8.699 MeV resonances. Measure their **unknown** strengths.

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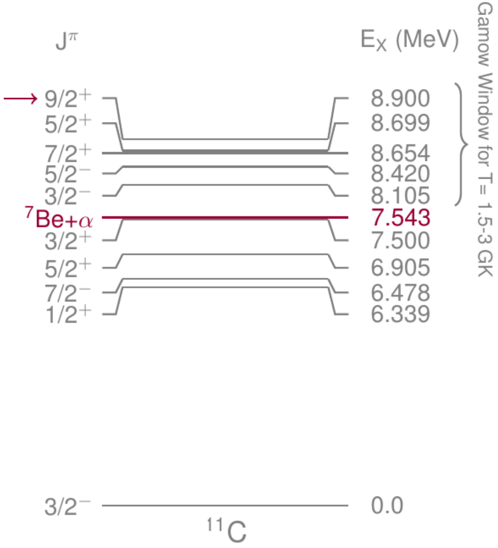

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2. Exploratory measurement of the E_x= 8.900 MeV resonance.

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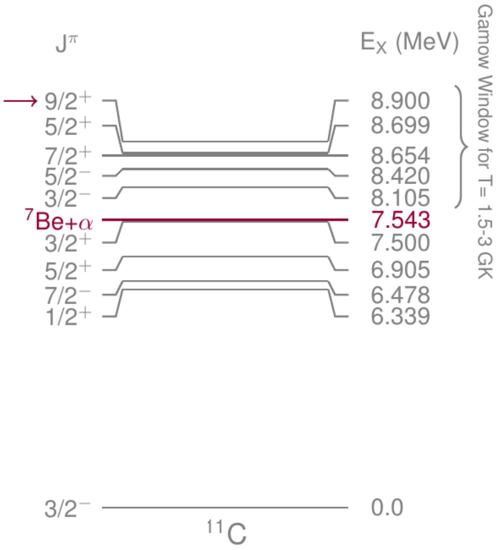

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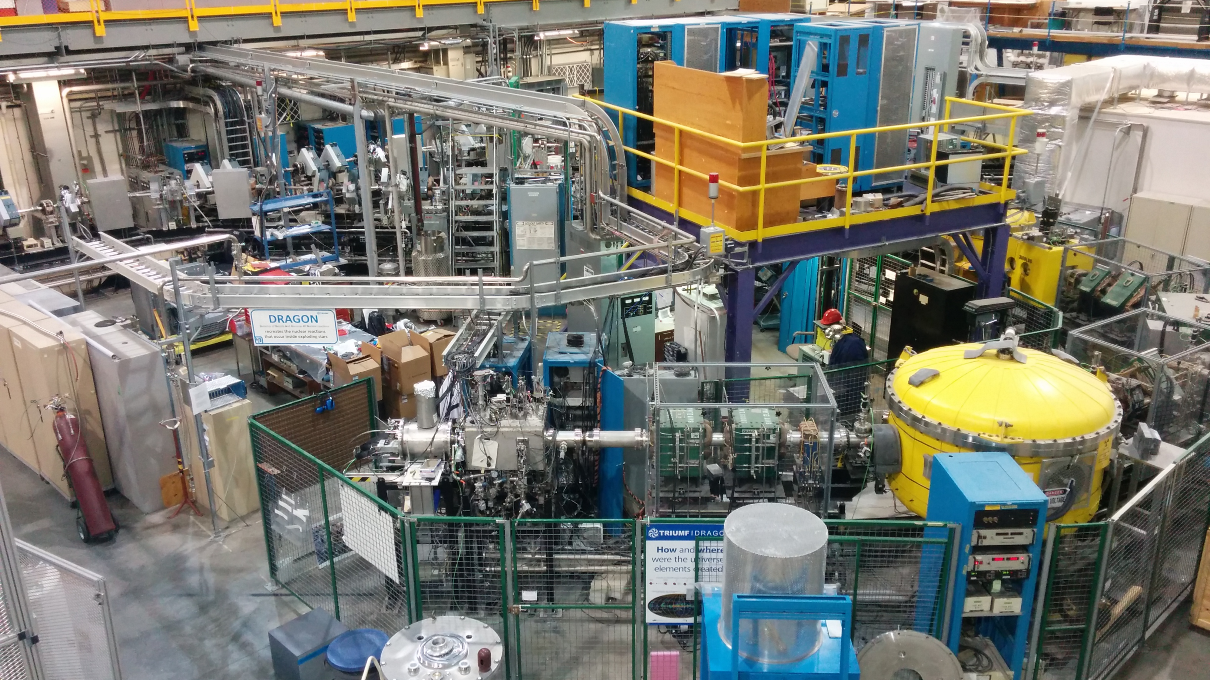
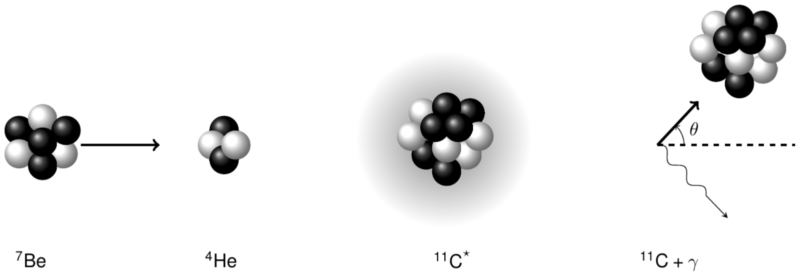
Improve the reaction rate for
$^{7}\mathrm{Be}(\alpha,\gamma)^{11}\mathrm{C}$
at νp-process temperatures


DRAGON
recreates the nuclear reactions
that occur inside exploding stars
TRIUMF I DRAGO
How and where
were the universe
elements created

Inverse Kinematics Reactions - Momentum Cone



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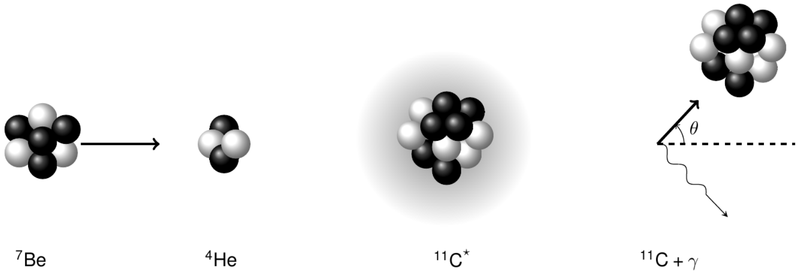

DRAGON's Acceptance: 22 mrad

vs

$^7\mathrm{Be}(\alpha,\gamma)^{11}\mathrm{C}$: $\sim$ **43 mrad**

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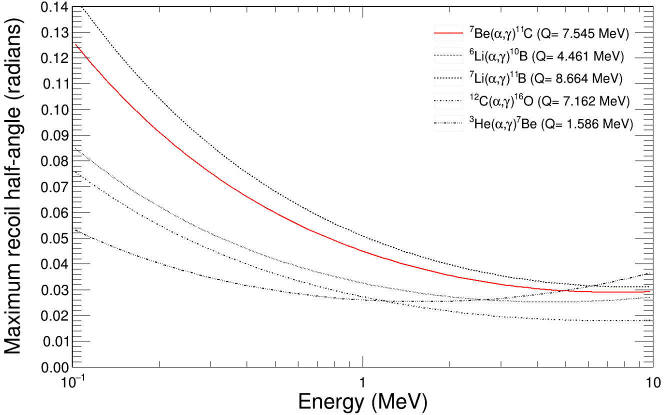

[C. Ruiz *et al.*, Eur. Phys. J. A **50**, 99 (2014)]

$$\theta \simeq \arctan\left(\frac{Q+E}{\sqrt{2\frac{m_1}{m_2}\left(m_1+m_2\right)E}}\right)$$

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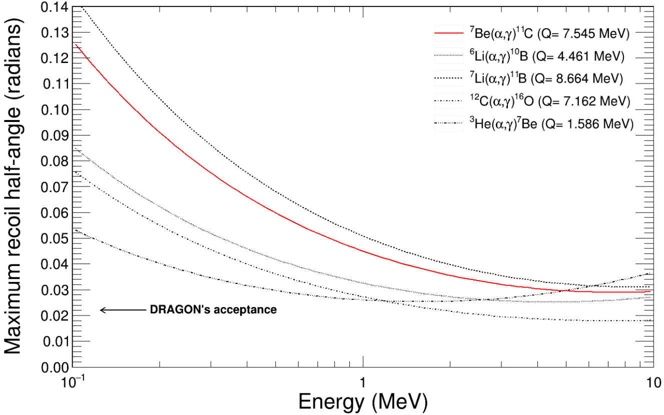

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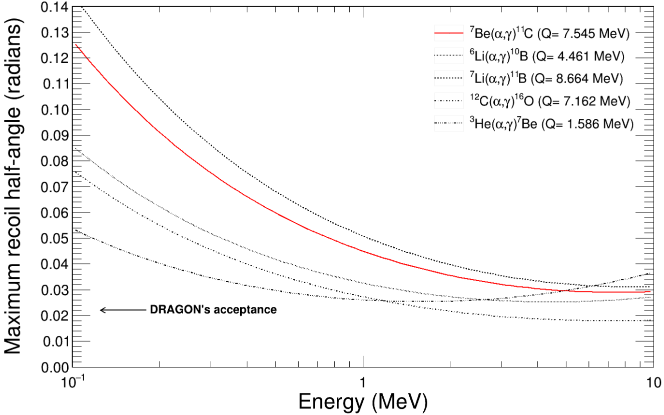

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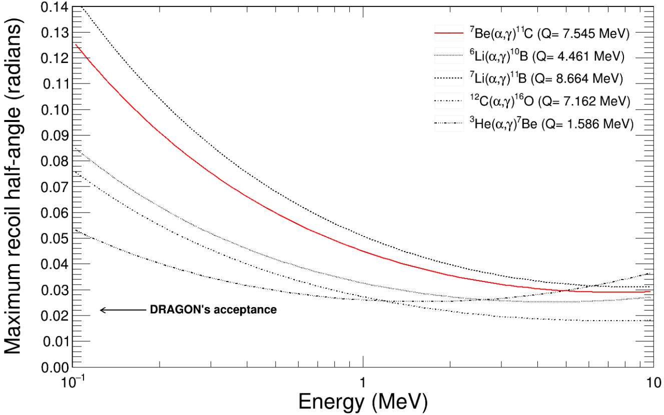

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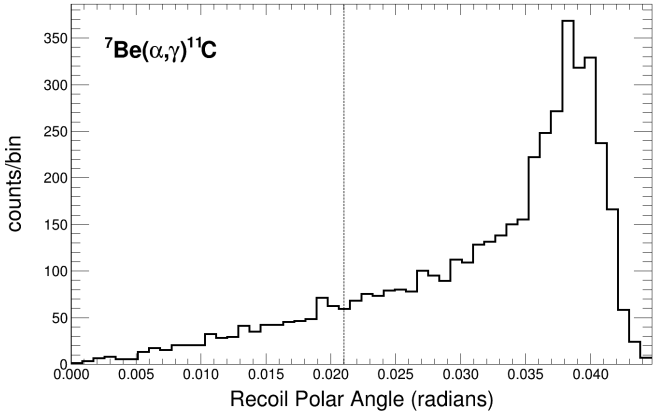
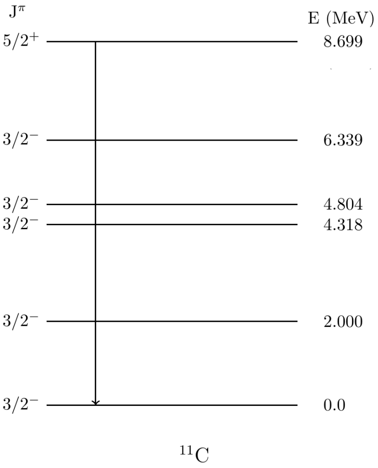
Effect of γ-ray branching ratios to recoil angle θ





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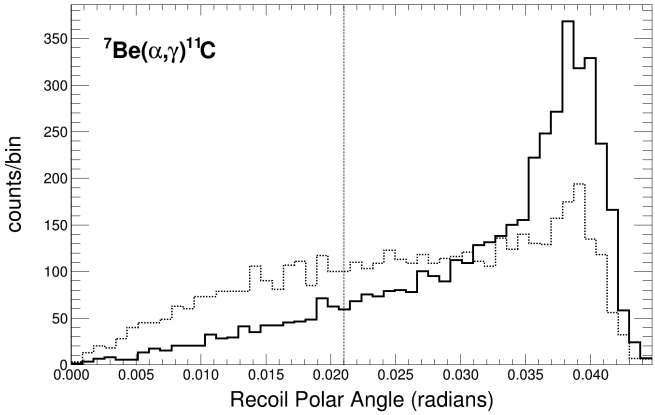
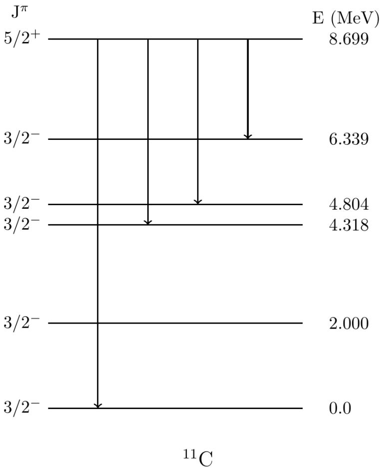
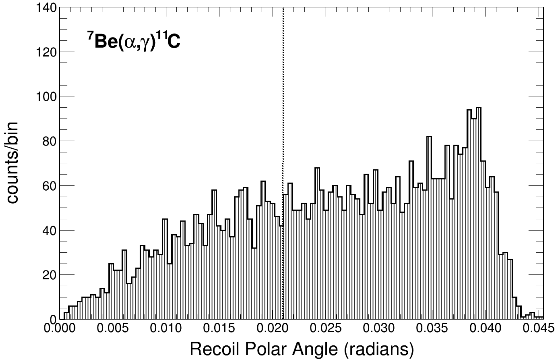




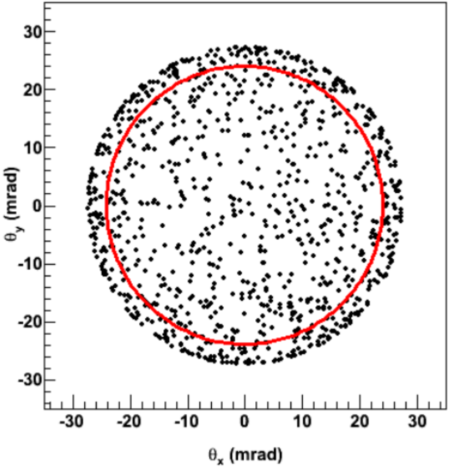
Effect of γ-ray angular distribution to recoil angle θ



Uniform Distribution

$W(\theta) = 1$

Effect of γ-ray angular distribution to recoil angle θ



[L. Gialanella & D. Schürmann, PoS (ENAS 6), 058 (2013)]

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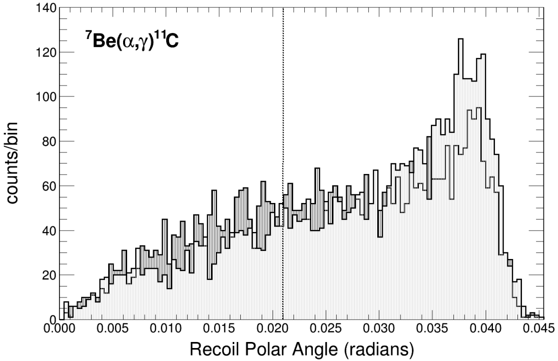

Dipole Distribution

$$W(\theta) = \frac{3}{8\pi}\left(1 - \cos^2\theta\right)$$

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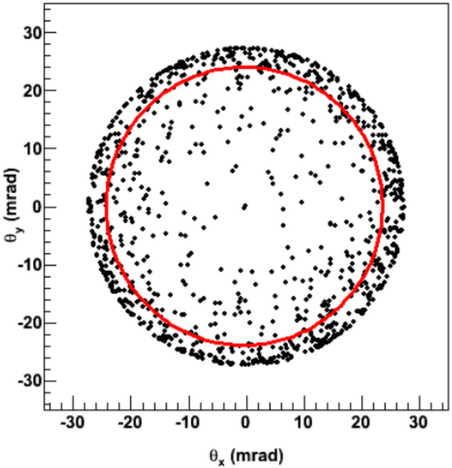

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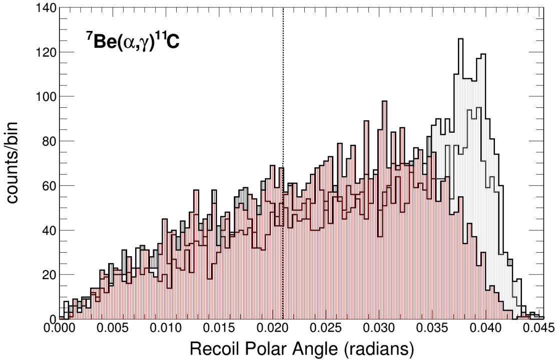

Quadrupole Distribution

$$W(\theta) = \frac{15}{8\pi}\left(1 - \cos^2\theta\right)\cos\theta^2$$

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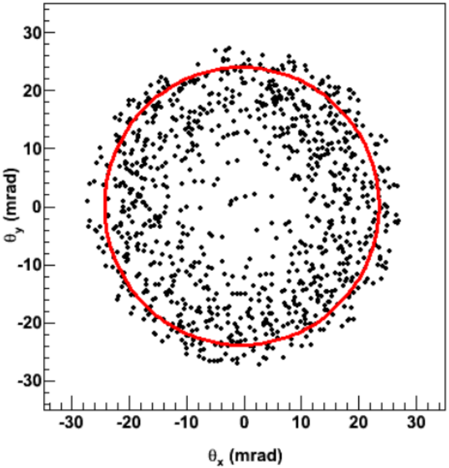

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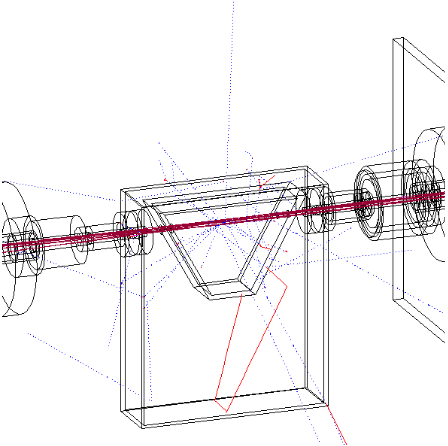
Testing the DRAGON: GEANT simulations



The **transmission** of the recoils and the **efficiency** of the BGO array of DRAGON were studied with the `GEANT3` toolkit.

[Dario Gigliotti, M.Sc. Thesis, Univ. of Northern British Columbia, (2004)]

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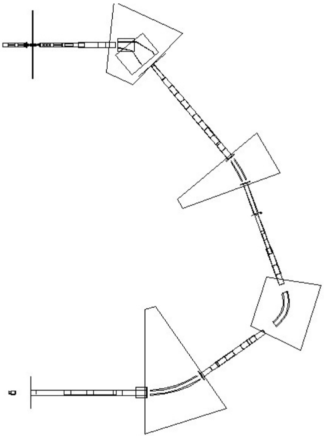

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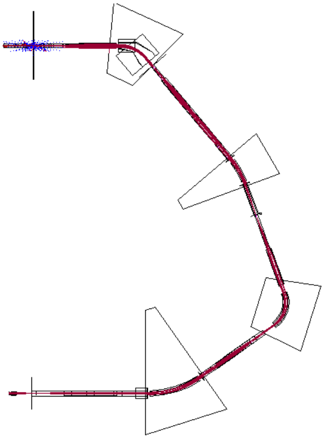

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^{6}Li(α, γ) reaction
E_x= 5.920 MeV resonance
as benchmark 60% transmission

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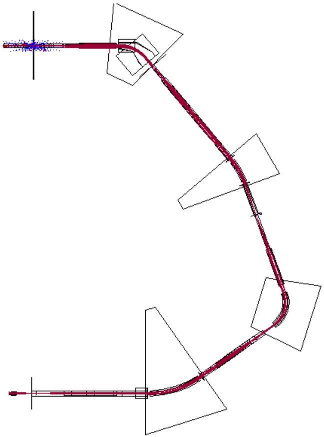

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Recoil transmissions:
27% for E_x= 8.654 MeV resonance
18% for E_x= 8.699 MeV resonance

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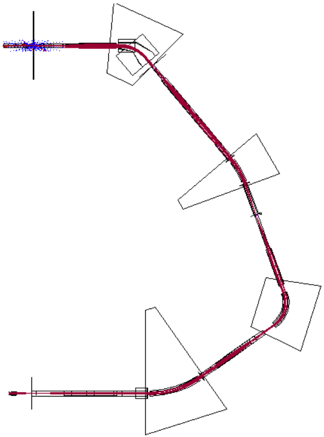
Testing the DRAGON: GEANT simulations



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50% BGO array efficiency
&
70% recoil detection efficiency

[Dario Gigliotti, M.Sc. Thesis,
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Beamtime during Schedule 132

Stable Beam Week - Aug. 25 - Sept. 1

^{6}Li: Studied a resonance at E_x= 5.920 MeV (E_r= 1459 keV, E_b= 612 keV/u) with known $\omega\gamma$ as a benchmark to study DRAGON's acceptance.

Stable Beam Week - Aug. 25 - Sept. 1

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^{7}Li: Run only at two ^{7}Be energies (E_b= 437.5 & 431.6 keV/u) for isobaric contaminant measurements.

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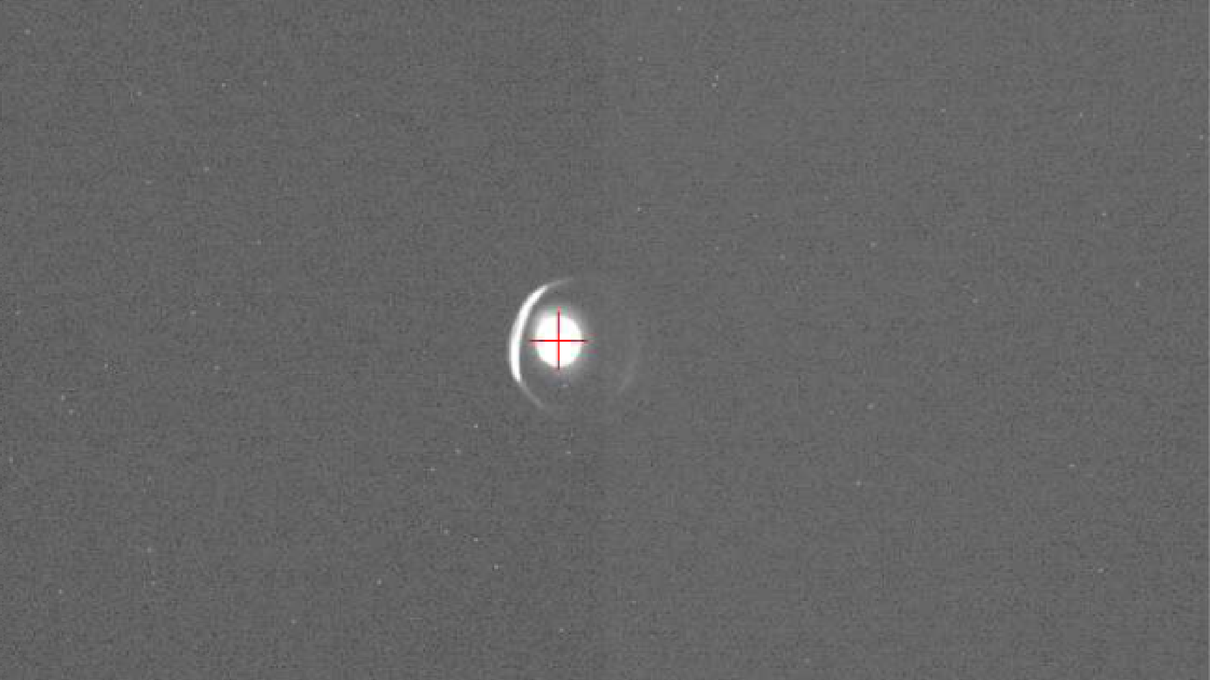
Not enough time for all ^{7}Li energies and ^{12}C CSD measurements.



Radioactive Beam Week - Sept. 2-11

^{7}Be:^{7}Li ratio was worse than 1:500 for most of the time and intensity close to 1×10^{7} pps.

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TRILIS TAC signal was used to determine the ^{7}Be content of the beam.

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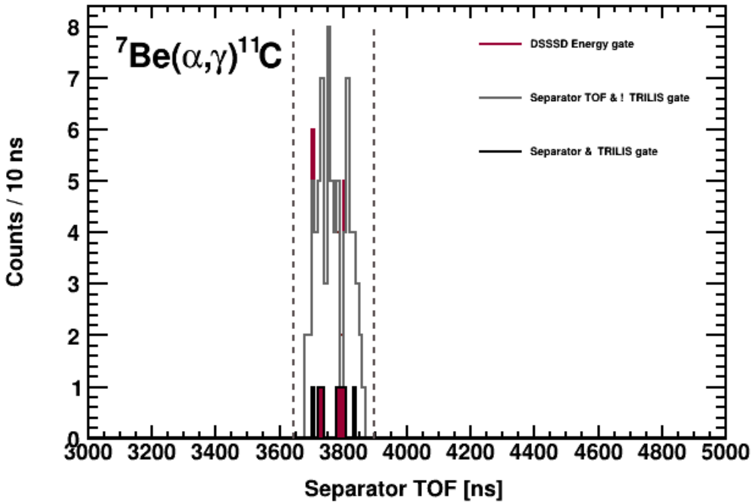
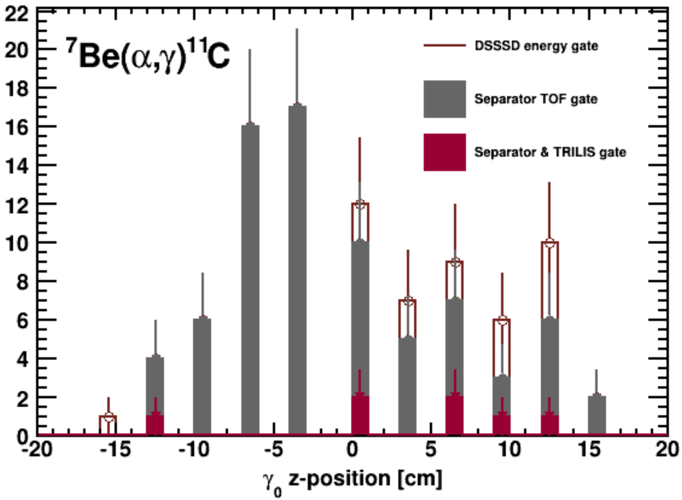
The resonance at E_x= 8.654 MeV was studied for a very short time, and most of the week was spent on the E_x= 8.699 MeV. Not enough time for the E_x= 8.900 MeV resonance.

Really Preliminary Results

Really Preliminary Results - Separator TOF



Really Preliminary Results - BGO γ Hit Pattern



Future Plans (the rest of my PhD)

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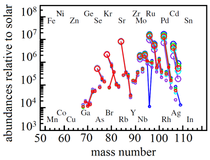
- Study of the $^{10}B(\alpha, p)^{13}C$ with TUDA (?)

Summary

1. νp-process is very **sensitive** to few nuclear reactions and $^{7}Be(\alpha,\gamma)^{11}C$ can **alter** some nuclear inputs.



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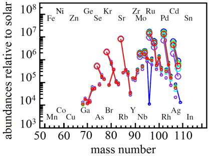
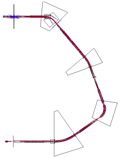


2. DRAGON can **successfully** handle reactions with large momentum cones.



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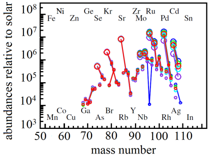

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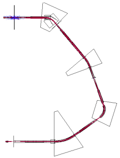

3. There is still a lot of work to be done!