Direct Measurement of Resonances in $^{7}Be(\alpha,\gamma)^{11}C$ With DRAGON

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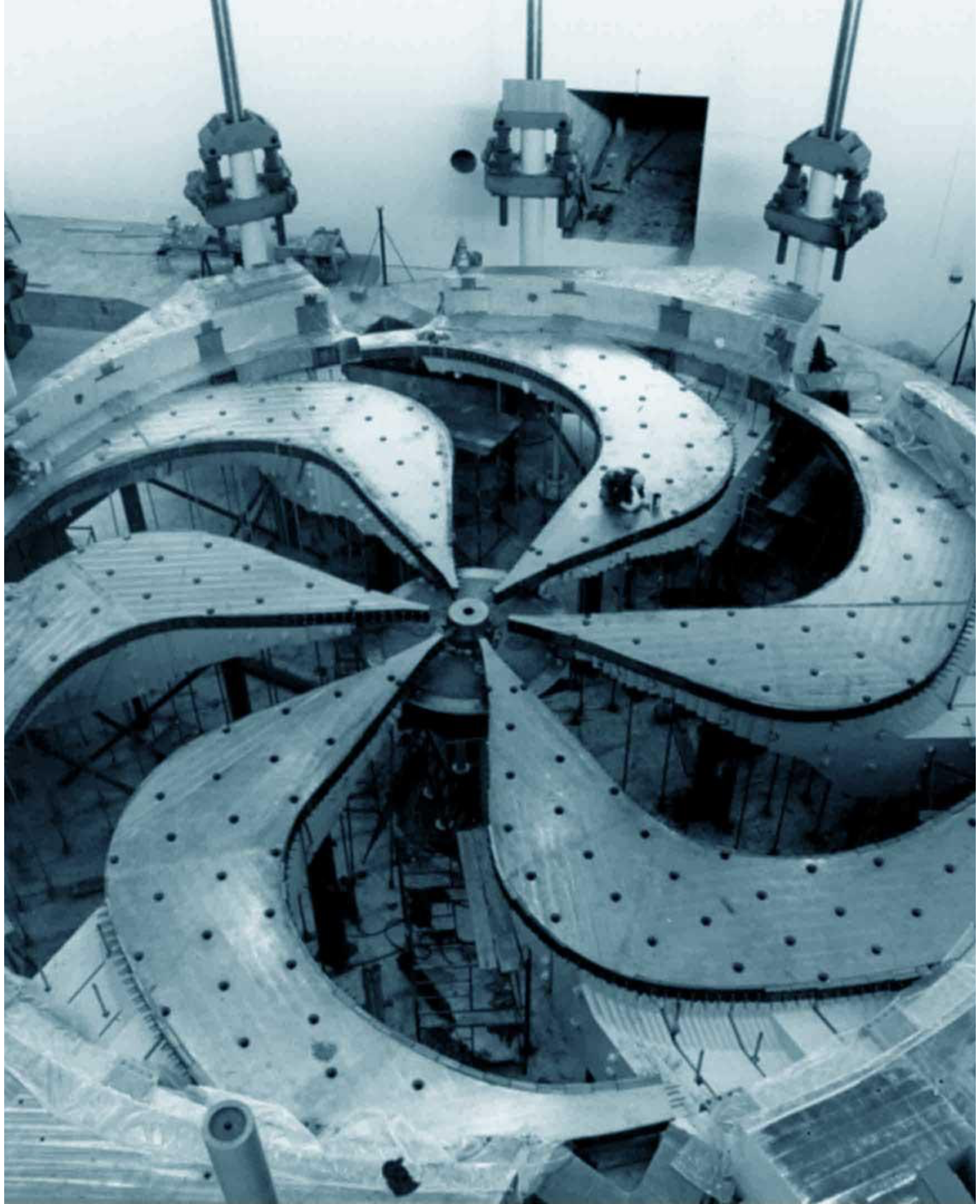
Direct Reactions with Exotic Beams

Matsue, Japan

5th June 2018



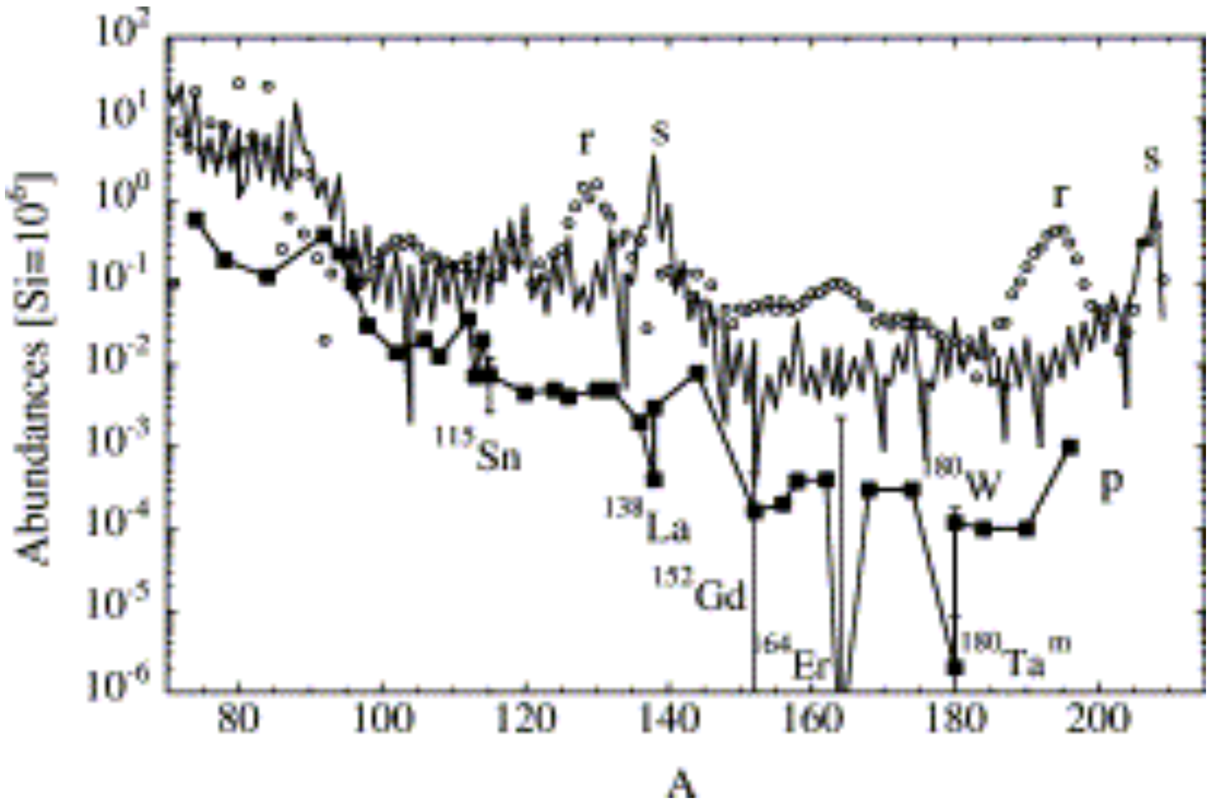
Discovery, accelerated

Outline

TRIUMF

- Motivation
- Experimental technique
- Analysis and Preliminary results
- Future plans

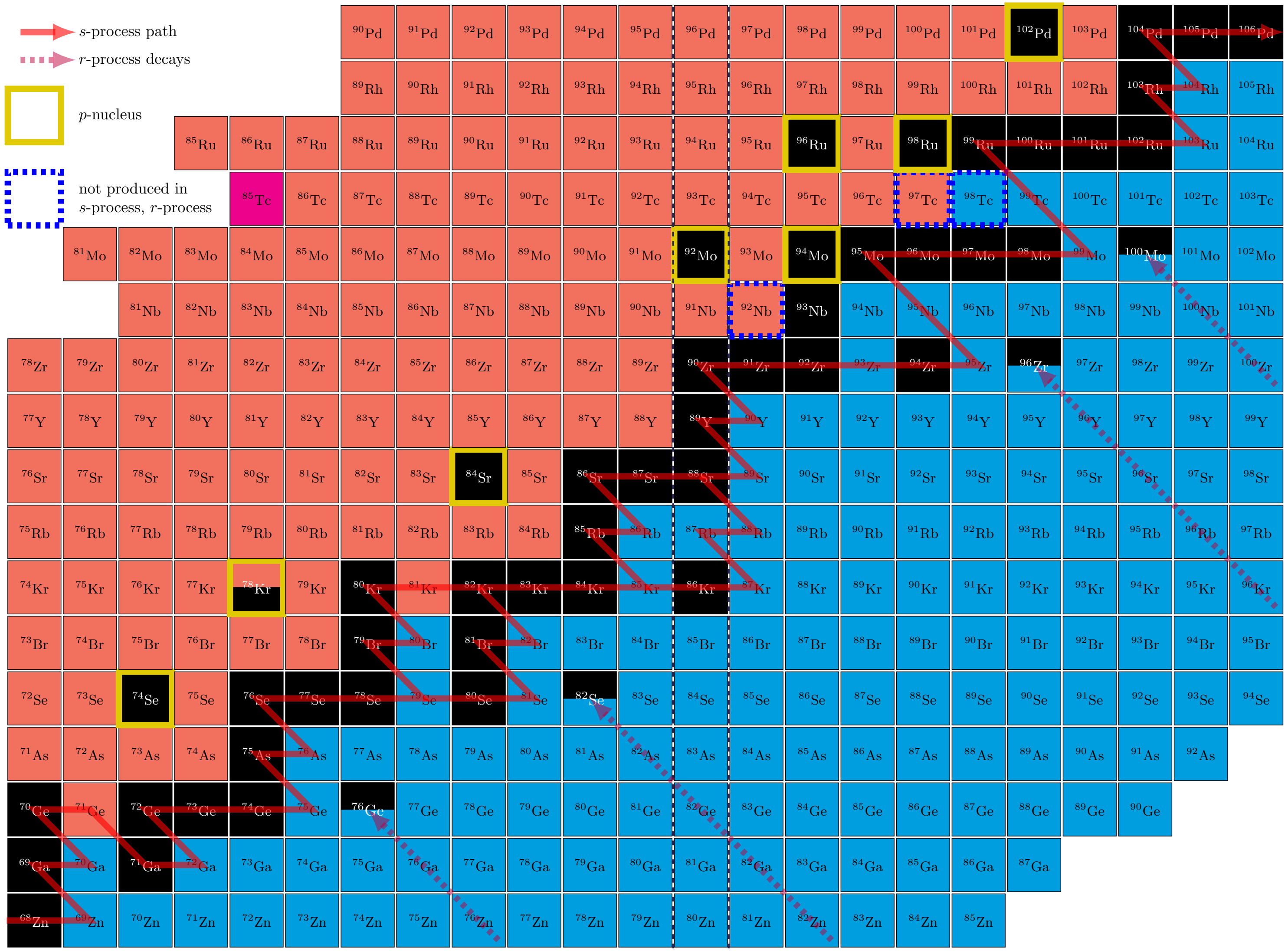
Heavy Element Nucleosynthesis



M. Arnould and S. Goriely, Phys. Rep. **384**, 1 (2003)

- Isotopic abundances of elements heavier than Fe explained by *s* - process, *r* - process and *p* - process nucleosynthesis

Heavy Element Nucleosynthesis



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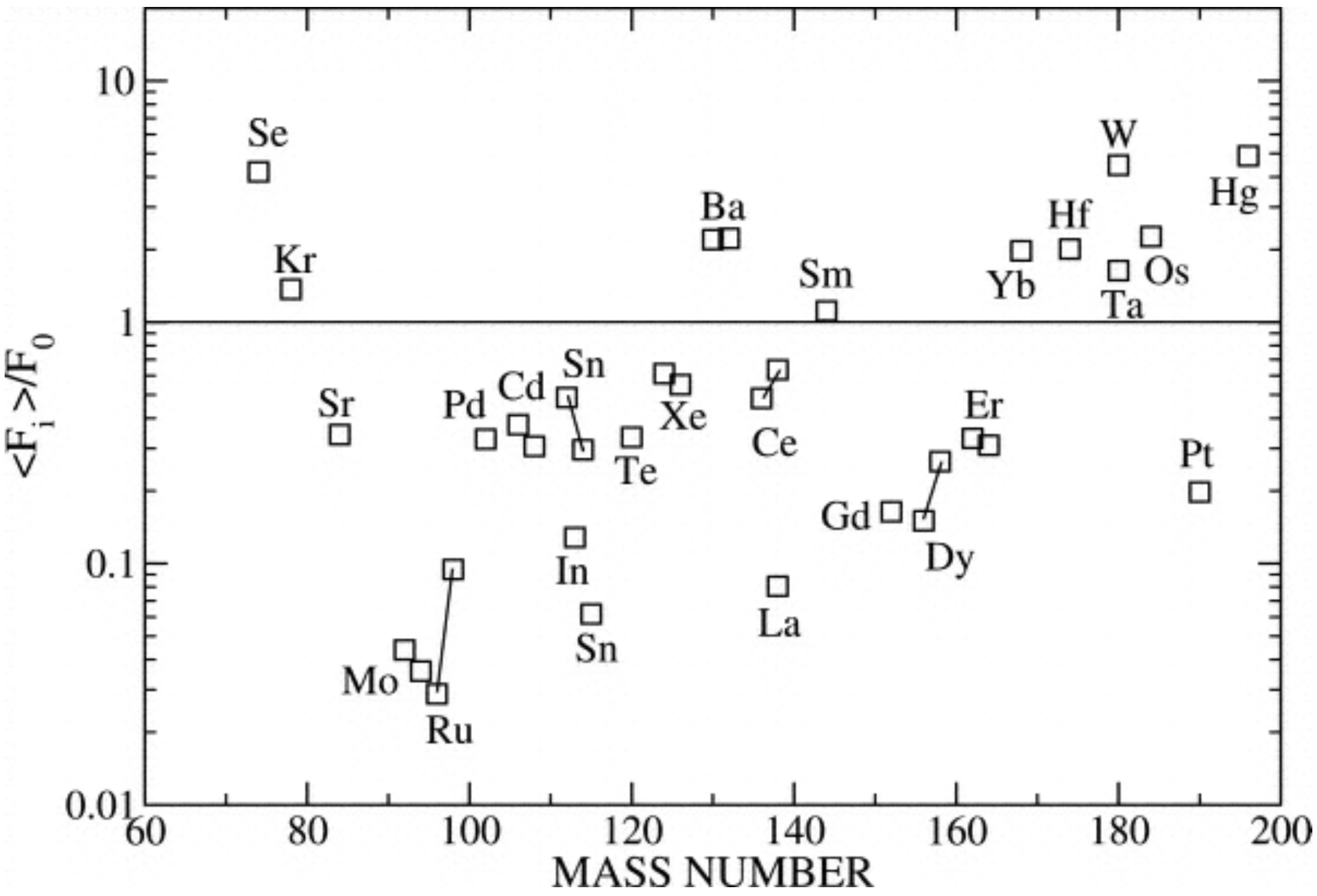
Heavy Element Nucleosynthesis



W. Rapp et al., Astrophys. J. **653**, 474 (2006)

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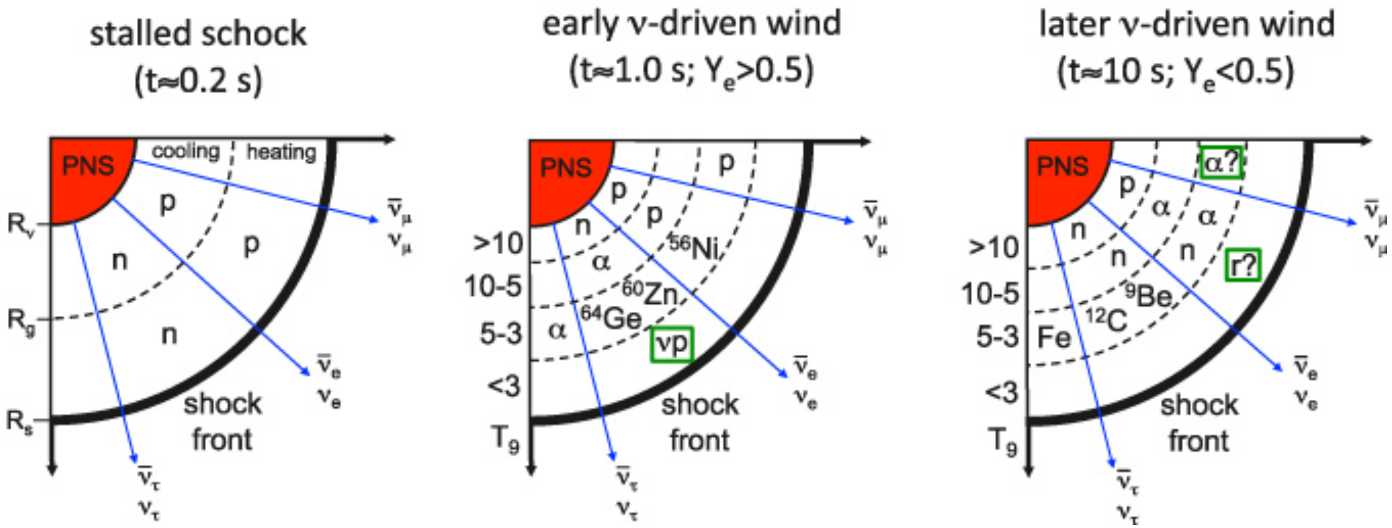
- *p* – and γ – processes under-predict abundances of several *p* – nuclei

νp-process



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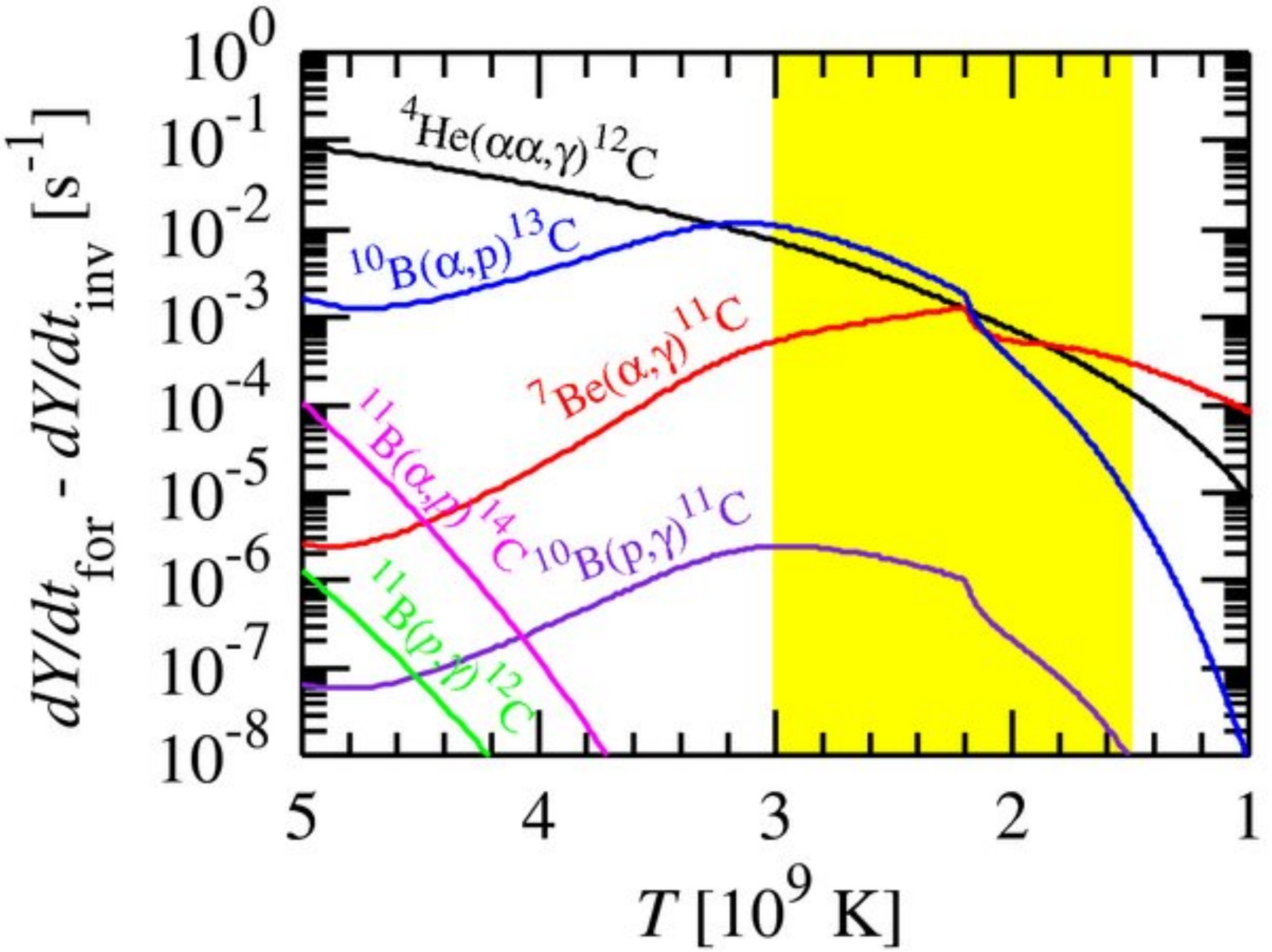
- Origin of *p* - nuclei still not fully understood
- p – and γ – processes under-predict abundances of several *p* – nuclei
- νp – process thought to occur in ejecta of CCSN, probable site of synthesis of *p* - nuclei

J. José and C. Iliadis, Rep. Prog. Phys. **74**, 096901 (2011)

$^7Be(\alpha,\gamma)^{11}C$ and the νp-process



S. Wanajo, H.-T. Janka and S. Kubono, Astrophys. J. **729**, 46 (2011)

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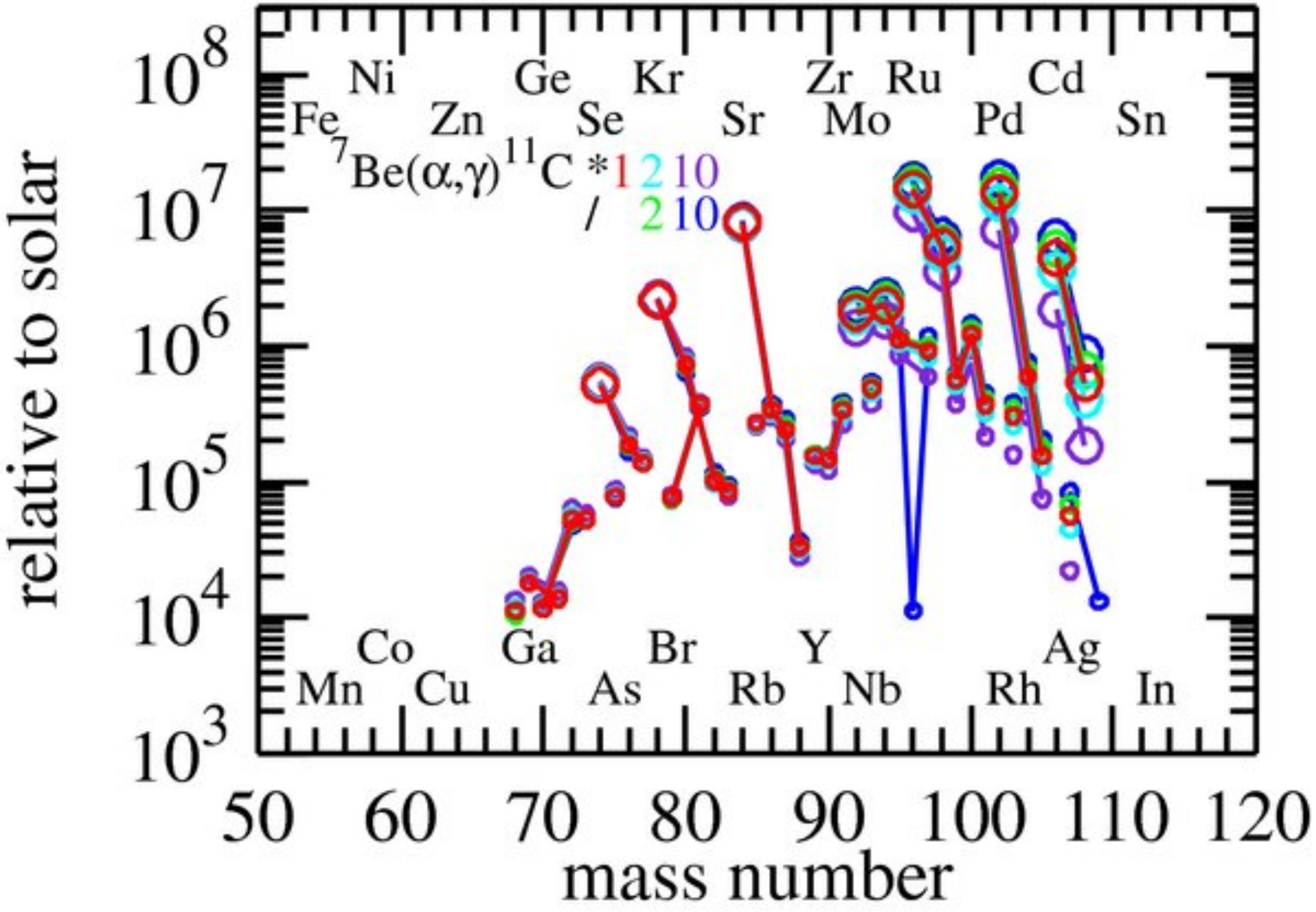
$^{7}Be(\alpha,\gamma)^{11}C$ and the νp-process



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- Recent sensitivity study found that altering $^{7}Be(\alpha,\gamma)^{11}C$ rate significantly alters *p*-nuclei abundances

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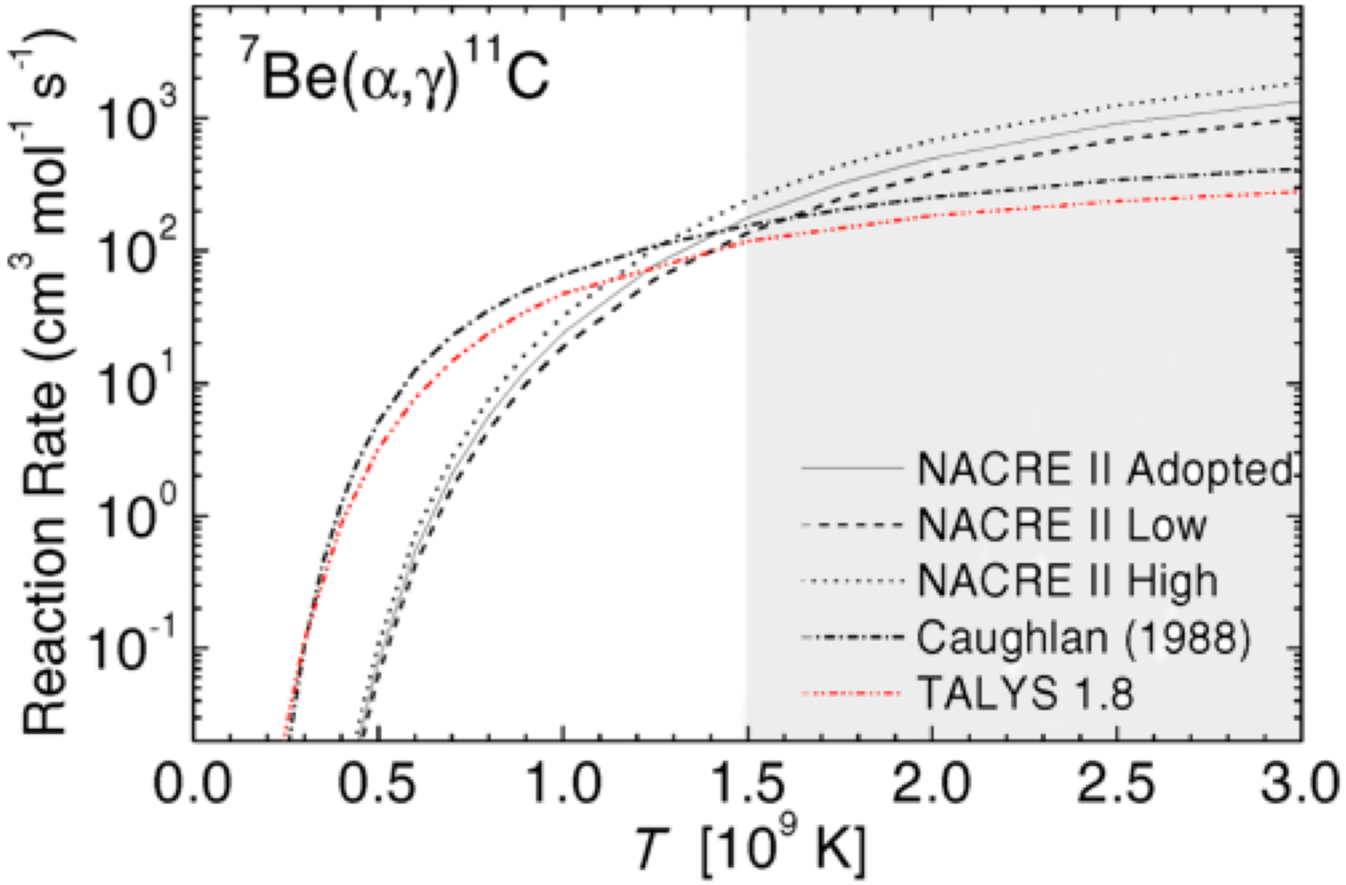
$^{7}Be(\alpha,\gamma)^{11}C$ and the νp-process



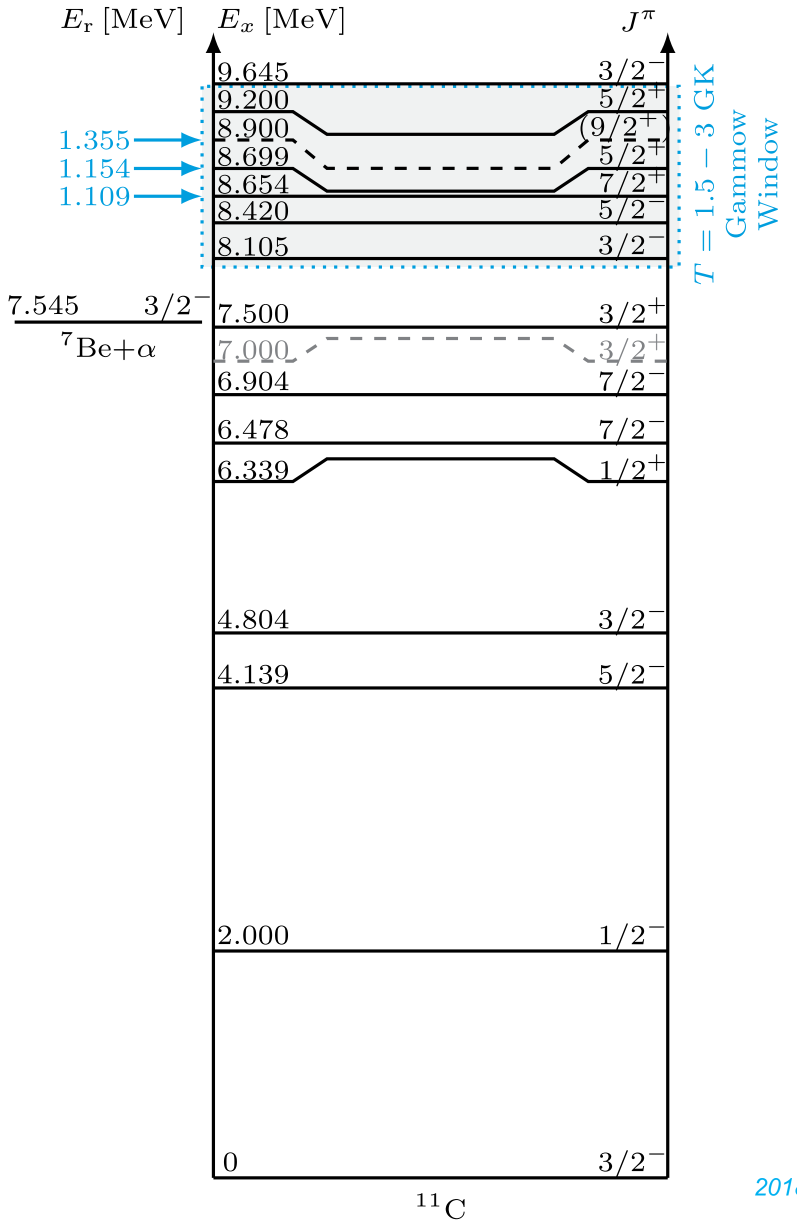
S. Goriely, S. Hilaire and A. J. Koning, Astron. Astro. **487**, 767 (2008)
Y. Xu et al., Nucl. Phys. A **918**, 61 (2013)

- $^{7}Be(\alpha,\gamma)^{11}C$ competes with 3α in breakout from *p*-*p* chain
- Recent sensitivity study found that altering $^{7}Be(\alpha,\gamma)^{11}C$ rate significantly alters *p*-nuclei abundances
- $^{7}Be(\alpha,\gamma)^{11}C$ reaction rate poorly known over temperature range of interest (1.5 – 3 GK)

Previous Measurements

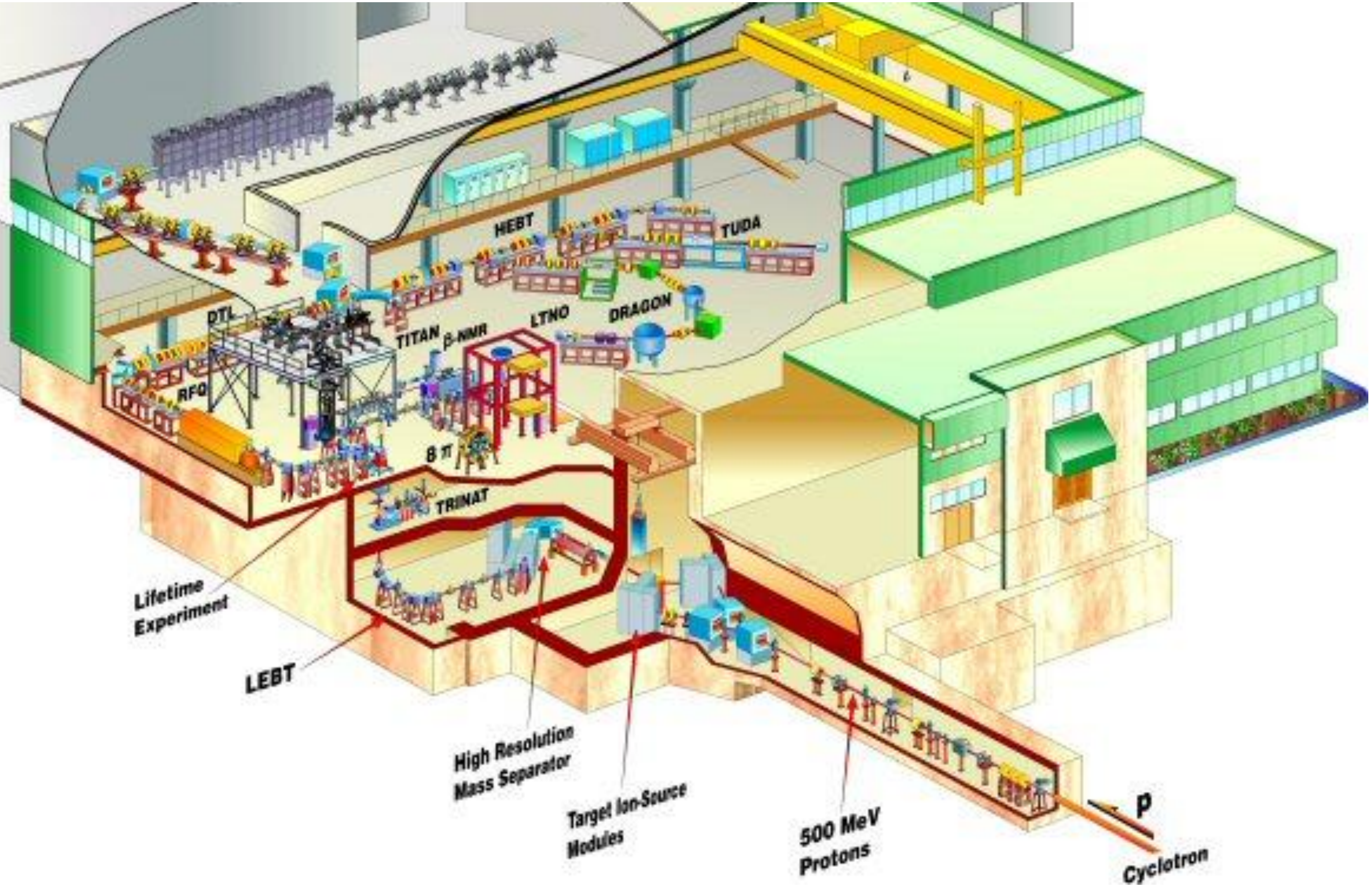
TRIUMF

E_x [MeV]	E_r [MeV]	J^π	Γ_α [eV]	Γ_p [eV]	$\omega\gamma$ [eV]
8.900[3]	1.355	(9/2$^+$)	8 keV	-	-
8.699(2)[2,3]	1.154	5/2$^+$	15(1) keV	-	-
8.654(4)[2,3]	1.109	7/2$^+$	≤ 5 keV	-	-
8.420(2)[1]	0.877	5/2$^-$	12.6(3.8)	3.1(1.3)	3.80
8.105(17)[1]	0.560	3/2$^-$	6^{+12}_{-2}	0.350(56)	0.331



[1]G. Hardie et al., Phys. Rev. C **29**, 1199 (1984)
[2]M. Wiescher et al., Phys. Rev. C **28**, 1431 (1983)
[3]H. Yamaguchi et al., Phys. Rev. C **87**, 034303 (2013)

Experiment

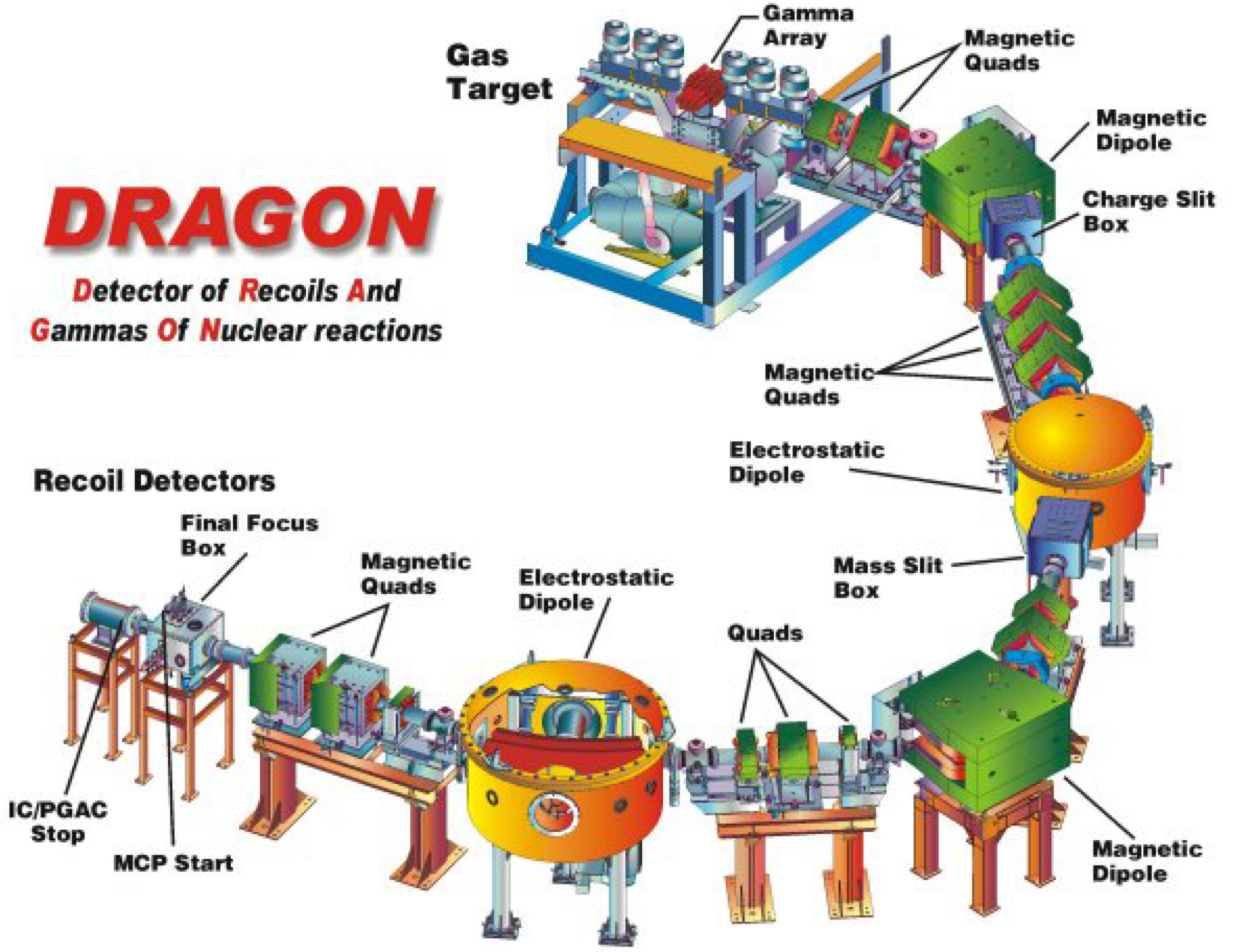


ISAC-I

- 50 μA 500 MeV $p+$ from main cyclotron
- Ta target
- A = 7 extracted from target using TRIUMF Resonant Ionization Laser Ion Source (TRILIS)
- Transported to high resolution mass separator
- Reaccelerated to 454 A keV by ISAC-I accelerators (RFQ & DTL)
- Delivered to DRAGON gas target
- $I_{avg} = 2.0(1.4)\times10^{7}$ pps

Experiment

TRIUMF

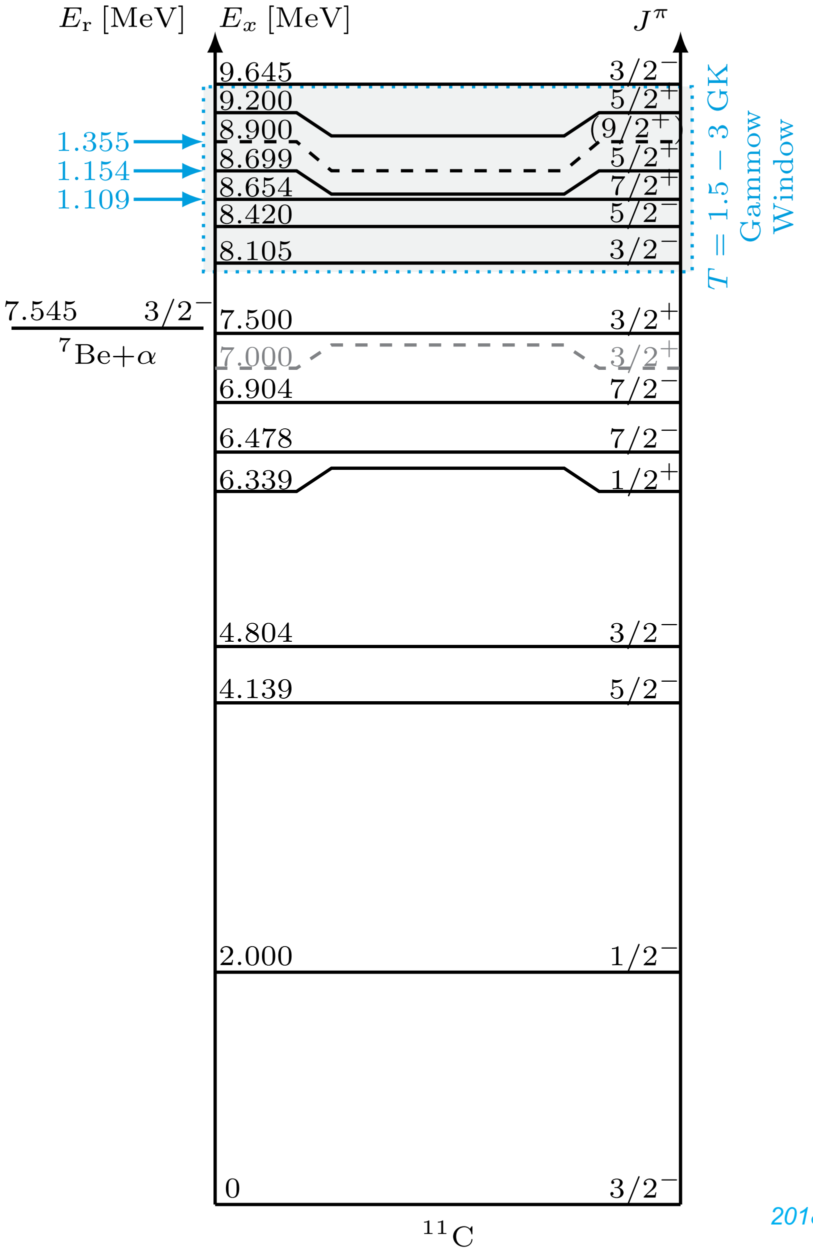


- 3 main parts:
  - Head
    - Differentially-pumped windowless gas target
    - High geometric efficiency BGO γ-ray array
      - Detects prompt γ emissions of excited recoil nuclei
  - Body
    - High-suppression electromagnetic mass separator
    - 2 stages of separation (MD, ED, MD, ED)
  - Tail
    - Suite of heavy ion detectors
    - Dual MCP for TOF
    - DSSSD, IC, or Hybrid for E-loss / deposition

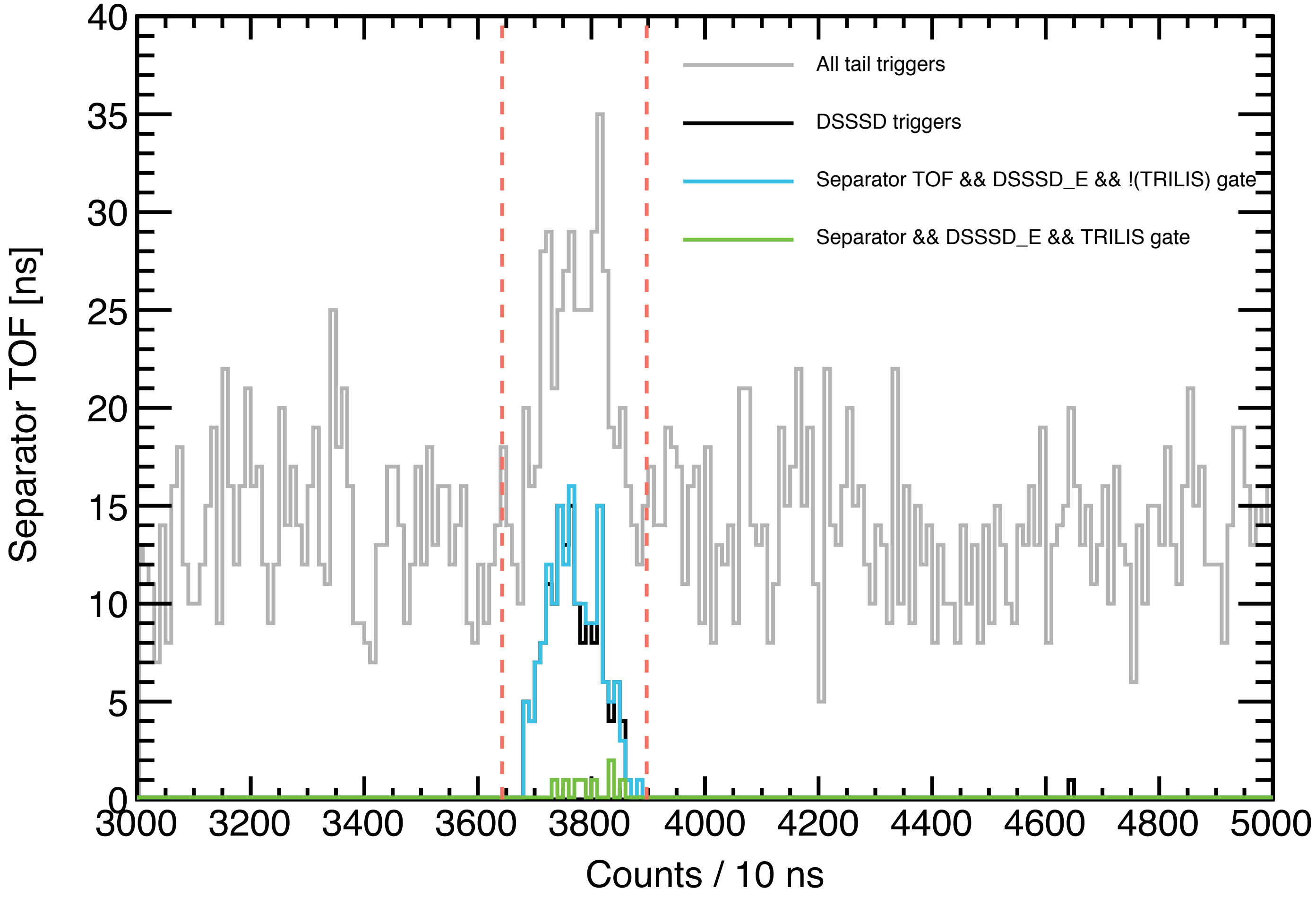
Experiment

TRIUMF

- Performed $^{6,7}\mathrm{Li}(\alpha,\gamma)^{10,11}\mathrm{B}$ yield measurements for background / acceptance characterization
- Performed Yield measurements of E_r = 1.155 MeV and E_r = 1.109 MeV resonances

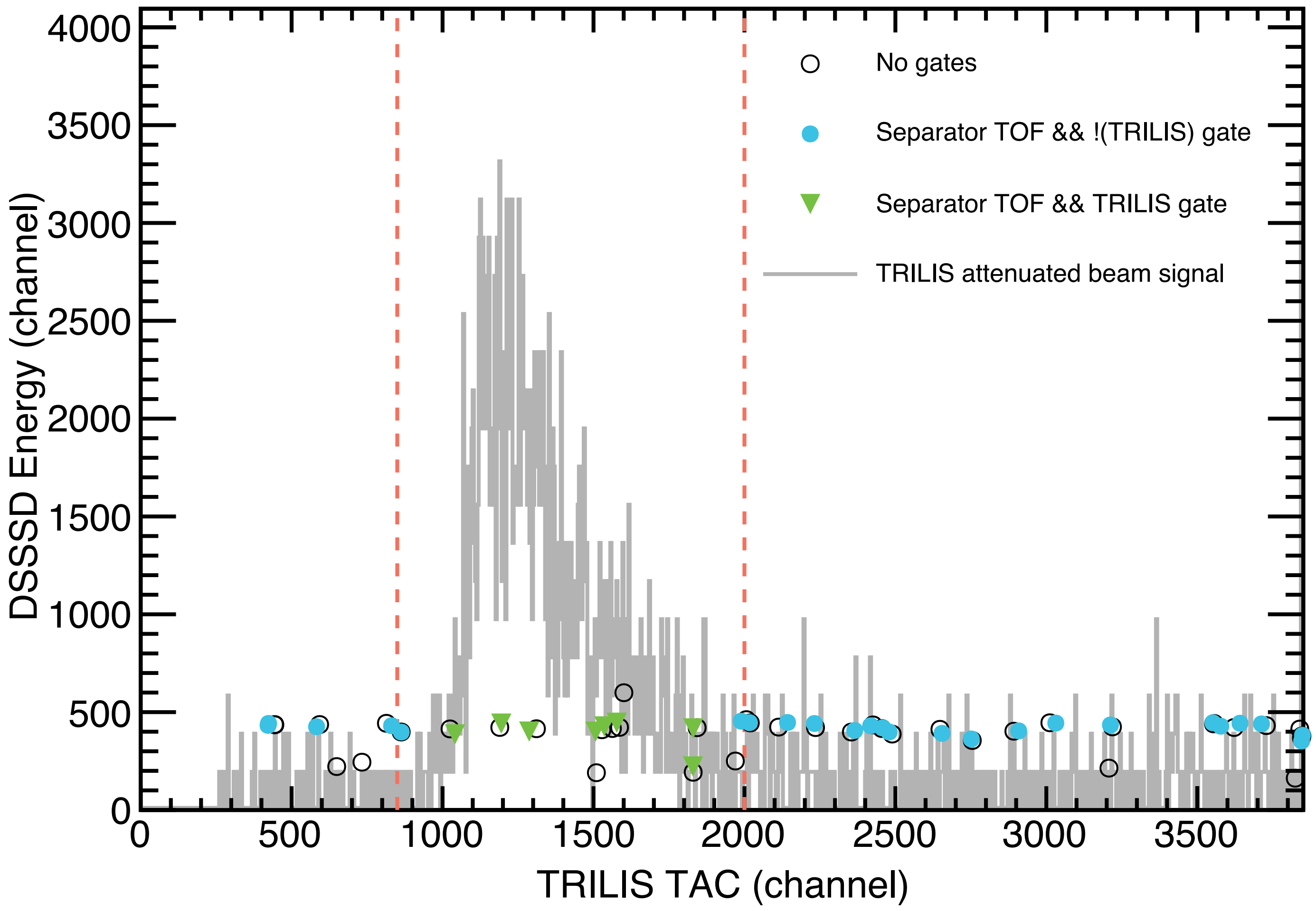


Analysis



- E_r = 1.155 MeV
- Candidate recoils identified via TOF between coincident γ and heavy ion signals

Analysis



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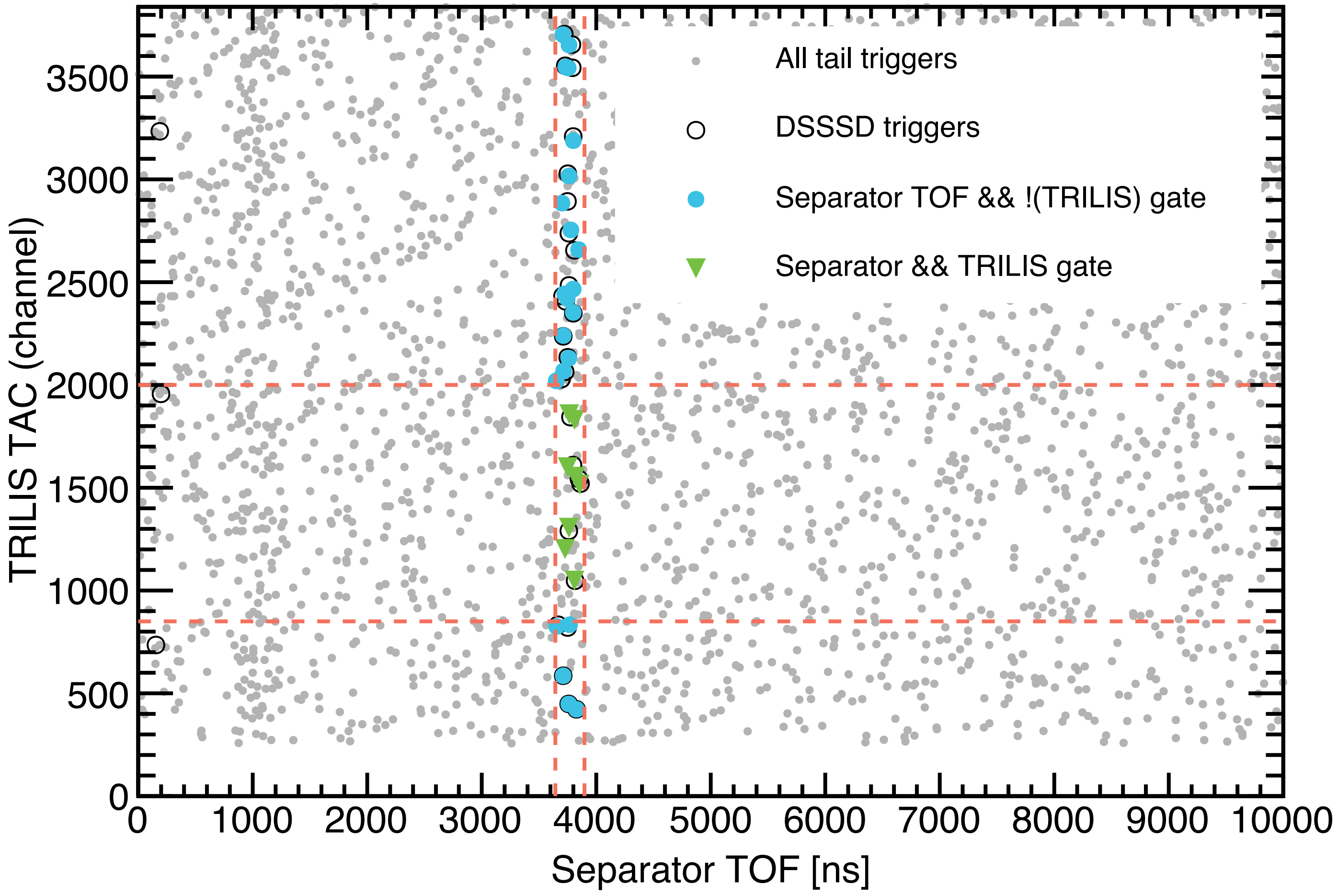
- Gating on TRILIS signal provides further discrimination of ^{11}C / ^{11}B

Analysis



- E_r = 1.155 MeV
- Candidate recoils identified via TOF between coincident γ and heavy ion signals
- Gating on TRILIS signal provides further discrimination of ^{11}C / ^{11}B
- 8 candidate ^{11}C recoils pass gates on Separator TOF, TRILIS, E_{BGO}, E_{DSSSD}

^{7}Li Contamination

TRIUMF

- $\frac{(m_{^7Be} - m_{^7Li})}{m_{^7Be}} = 0.00013 \rightarrow$ expect significant ^{7}Li contamination
- Average ^{7}Li / ^{7}Be ratio = 520:1
- Observed total of 172 candidate recoil events (signal + bg region)
- Given detection efficiencies, number or signal / bg events and ratio of signal / bg regions yields an upper limit[1] of 15 detected ^{11}C recoils (given detection efficiencies and ratio of signal / bg regions)

$$Y = \frac{N_{rec}}{N_b \eta_{DRA}} = 6.39\times10^{-11}$$

→ Preliminary (1 – σ) upper limit (E_r = 1.155 MeV resonance)

$$\omega\gamma = \frac{2\,Y_\infty}{\lambda_r^2} \frac{m_{^7Be}}{m_{^7Be} + m_\alpha} \epsilon_{lab} = 0.64 \text{ eV}$$

[1]W. A. Rolke et al., Nucl. Instrum. Meth. A **551**, 493 (2005)

Future Plans

- Further analysis of current data

  → upper limits on E_r = 1.155 MeV and E_r = 1.109 MeV resonances
- Post-experiment ^{7}Be beam development on UC_x target yielded intensities as high as 2.4×10^8 pps
  - Suggests use of pure SiC target could yield intensities ~10^9 pps
  - Possible to post-strip in HEBT beamline at these intensities

    → pure ^{7}Be on target by selecting q = 4
  - Reperform previous measurements of E_r = 1.109 MeV and E_r = 1.155 MeV resonances with pure ^{7}Be on target
  - Probe possible existence of E_r = 1.355 MeV resonance

Summary

TRIUMF

- ^{7}Be(α,γ)^{11}C reaction rate impacts isotopic abundances of *p*-nuclei in νp-process nucleosynthesis
- 2 resonances in ^{7}Be(α,γ)^{11}C were directly measured with DRAGON E_r = 1.155 MeV and E_r = 1.109 MeV
  - Preliminary (1 – σ) upper limit 0.64 eV(E_r = 1.155 MeV resonance)
- Beam Development suggests use of pure SiC target could yield a background-free measurement

Thank You!

A. Psaltis[1], D. Connolly[2], A. A. Chen[1], B. Davids[2,3], N. Esker[2], G. Gilardy[4], R. Giri[5], U. Greife[6], W. Huang[7], D. A. Hutcheon[2], J. Karpesky[6], A. Lennarz[2], J. Liang[1], M. Lovely[6], S. Paneru[5], C. Ruiz[2,9], G. Tenkila[8], M. Williams[2,10]

[1]McMaster University
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[9]University of Victoria
[10]University of York