Investigating the key *rp* process reaction ^{61}Ga(p,γ)^{62}Ge, via ^{61}Zn(d,p)^{62}Zn transfer

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ISS meeting, Manchester, 13th July, 2017

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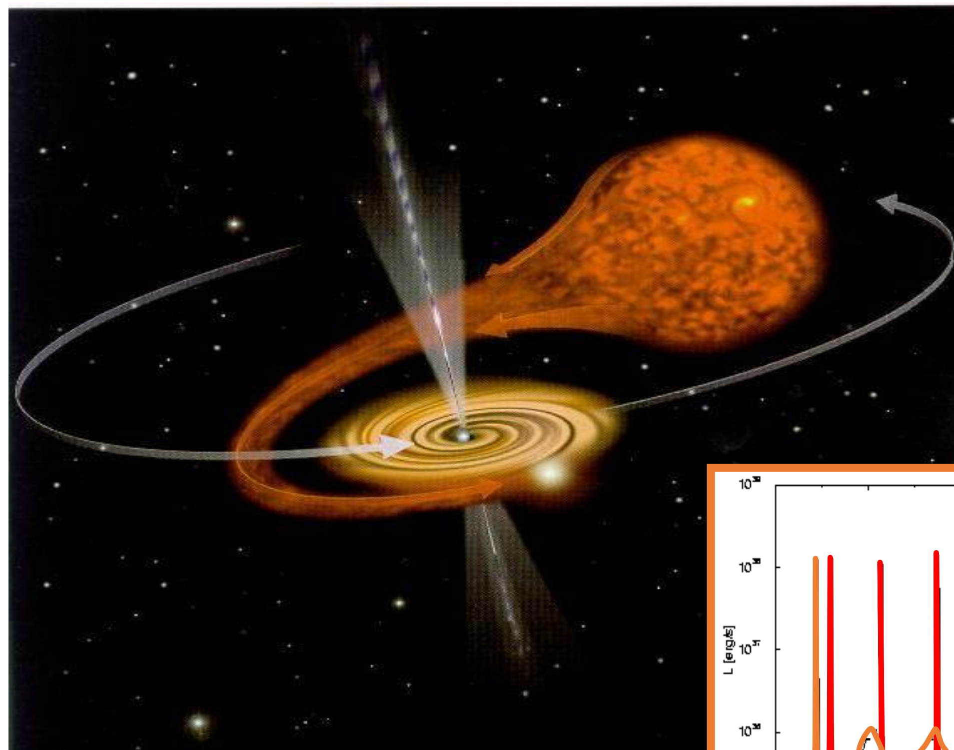
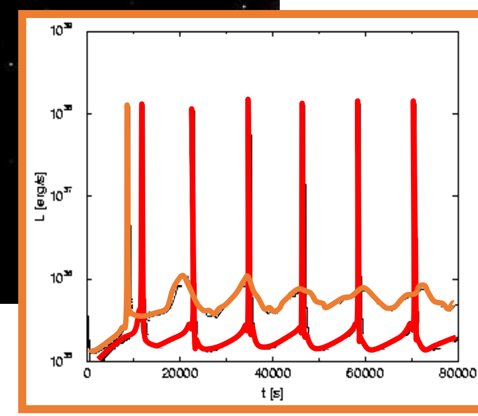
Motivation

The observation of X-ray bursts is interpreted as thermonuclear explosions in the atmosphere of a neutron star in a close binary system.

As temperature and density at the surface of the neutron star increase, the CNO cycles breakout into the *rp* process.

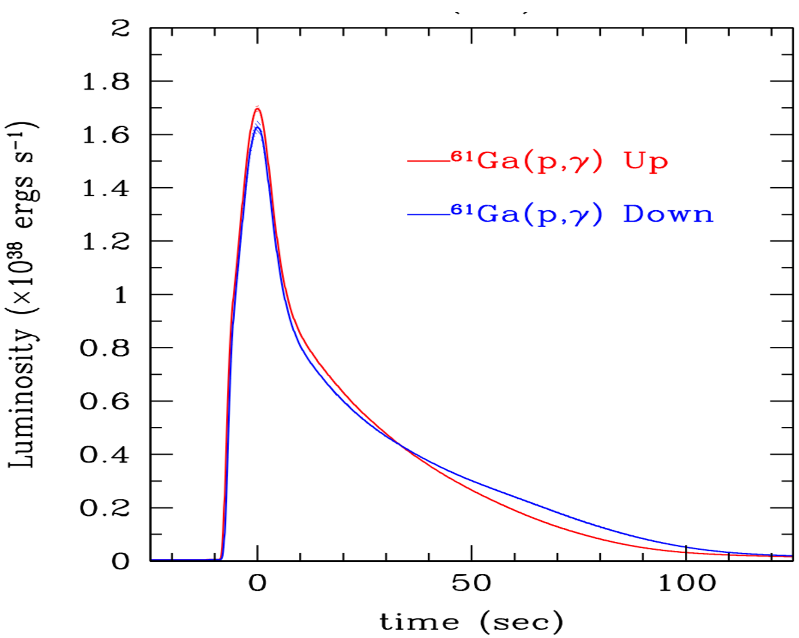




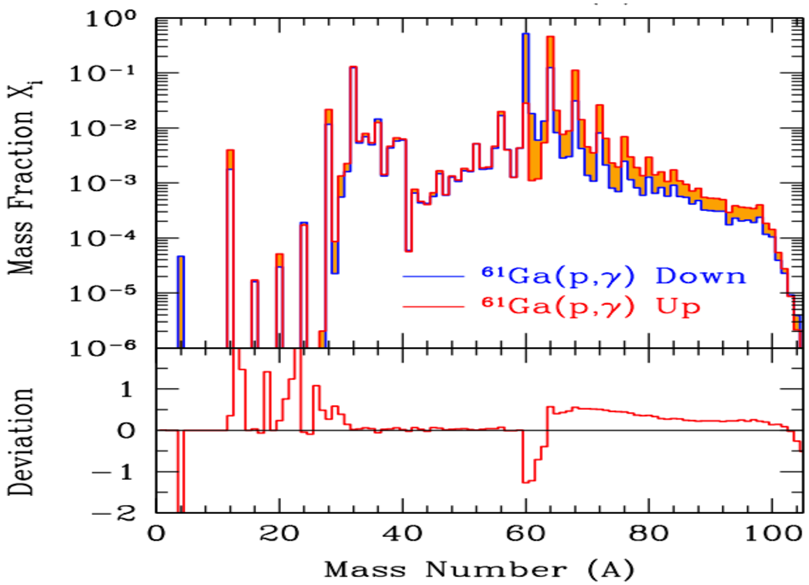
Sensitivity studies highlight the key reactions for understanding these bursts

→ $^{61}Ga(p,\gamma)^{62}Ge$ suggested as being particularly important

Motivation



Effect on the X-ray burst light curve from varying the $^{61}Ga(p,\gamma)^{62}Ge$ reaction rate within its associated uncertainties.



Effect on the final abundances from varying the $^{61}Ga(p,\gamma)^{62}Ge$ reaction rate within its associated uncertainties.

R.H. Cyburt *et al*., Astrophys. J. **830**, 2 (2016).

Motivation

TABLE 19

SUMMARY OF THE MOST INFLUENTIAL NUCLEAR PROCESSES, AS COLLECTED FROM TABLES 1–10

Reaction	Models Affected
$^{12}C(\alpha, \gamma)^{16}O$[a]	F08, K04-B2, K04-B4, K04-B5
$^{18}Ne(\alpha, p)^{21}Na$[a]	K04-B1[b]
$^{25}Si(\alpha, p)^{28}P$	K04-B5
$^{26g}Al(\alpha, p)^{29}Si$	F08
$^{29}S(\alpha, p)^{32}Cl$	K04-B5
$^{30}P(\alpha, p)^{33}S$	K04-B4
$^{30}S(\alpha, p)^{33}Cl$	K04-B4,[b] K04-B5[b]
$^{31}Cl(p, \gamma)^{32}Ar$	K04-B1
$^{32}S(\alpha, \gamma)^{36}Ar$	K04-B2
$^{56}Ni(\alpha, p)^{59}Cu$	S01,[b] K04-B5
$^{57}Cu(p, \gamma)^{58}Zn$	F08
$^{59}Cu(p, \gamma)^{60}Zn$	S01,[b] K04-B5
$^{61}Ga(p, \gamma)^{62}Ge$	F08, K04-B1, K04-B2, K04-B5, K04-B6
$^{65}As(p, \gamma)^{66}Se$	K04,[b] K04-B1, K04-B2,[b] K04-B3,[b] K04-B4, K04-B5, K04-B6
$^{69}Br(p, \gamma)^{70}Kr$	K04-B7
$^{75}Rb(p, \gamma)^{76}Sr$	K04-B2
$^{82}Zr(p, \gamma)^{83}Nb$	K04-B6
$^{84}Zr(p, \gamma)^{85}Nb$	K04-B2
$^{84}Nb(p, \gamma)^{85}Mo$	K04-B6
$^{85}Mo(p, \gamma)^{86}Tc$	F08
$^{86}Mo(p, \gamma)^{87}Tc$	F08, K04-B6
$^{87}Mo(p, \gamma)^{88}Tc$	K04-B6
$^{92}Ru(p, \gamma)^{93}Rh$	K04-B2, K04-B6
$^{93}Rh(p, \gamma)^{94}Pd$	K04-B2
$^{96}Ag(p, \gamma)^{97}Cd$	K04, K04-B2, K04-B3, K04-B7
$^{102}In(p, \gamma)^{103}Sn$	K04, K04-B3
$^{103}In(p, \gamma)^{104}Sn$	K04-B3, K04-B7
$^{103}Sn(\alpha, p)^{106}Sb$	S01[b]

A. Parikh, J. Jose, F. Moreno and C. Iliadis, Astrophys. J. Suppl. Ser. **178**, 110 (2008).

Motivation

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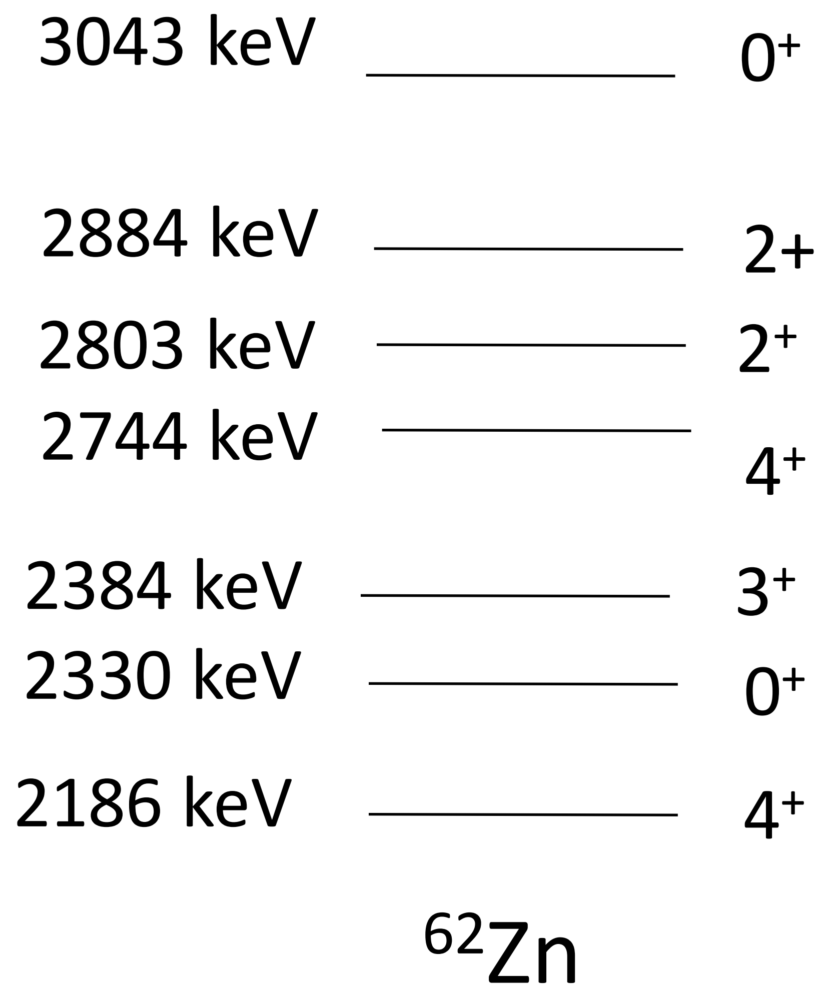
States of Interest in ^{62}Zn

Proton separation energy in ^{62}Ge is 2053(145) keV

- uncertainty from mass data

Mirror energy differences from theory

Rate expected to be dominated by low-spin states



States of Interest in ^{62}Zn

The Spectroscopic factor (C^2S) is directly related to the proton widths and, hence, the resonance strengths.

$$\omega\gamma = \omega\frac{\Gamma_p\Gamma_\gamma}{\Gamma_p + \Gamma\gamma} \approx \omega\frac{\Gamma_p\Gamma\gamma}{\Gamma_\gamma} \approx \omega\Gamma_p. \qquad \Gamma_p = C^2S\Gamma_{sp}$$

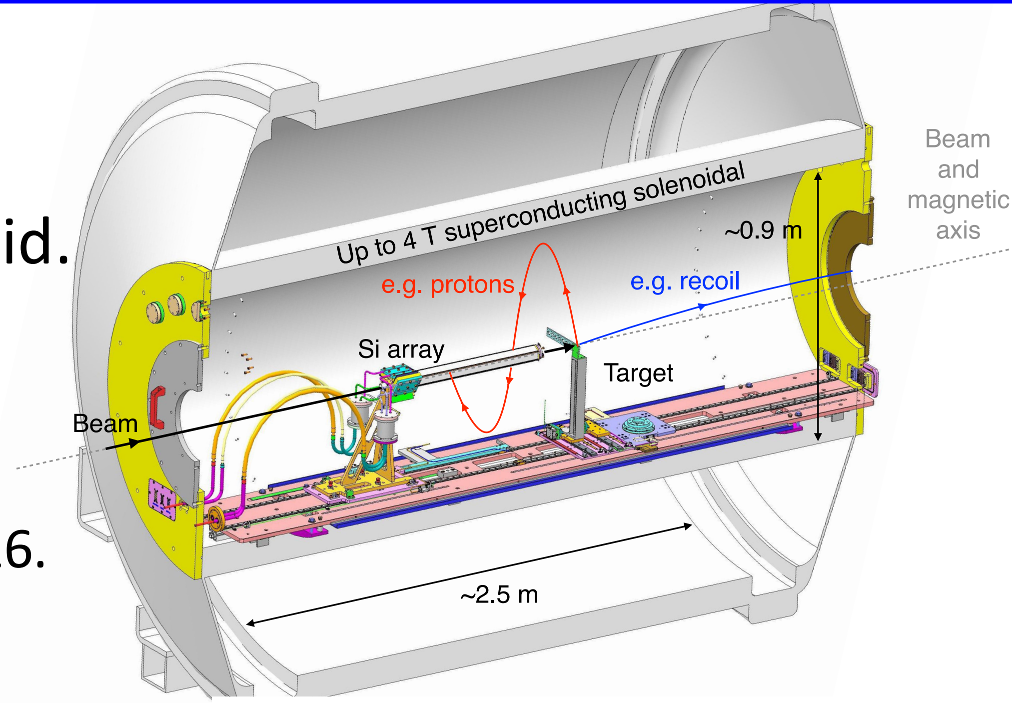
Will be extracted from the proton yields with the ADWA code TWOFNR. Recent success for the astrophysically important ^{27}Al-^{27}Si system. V. Margerin et al., PRL **115** 062701 (2015)

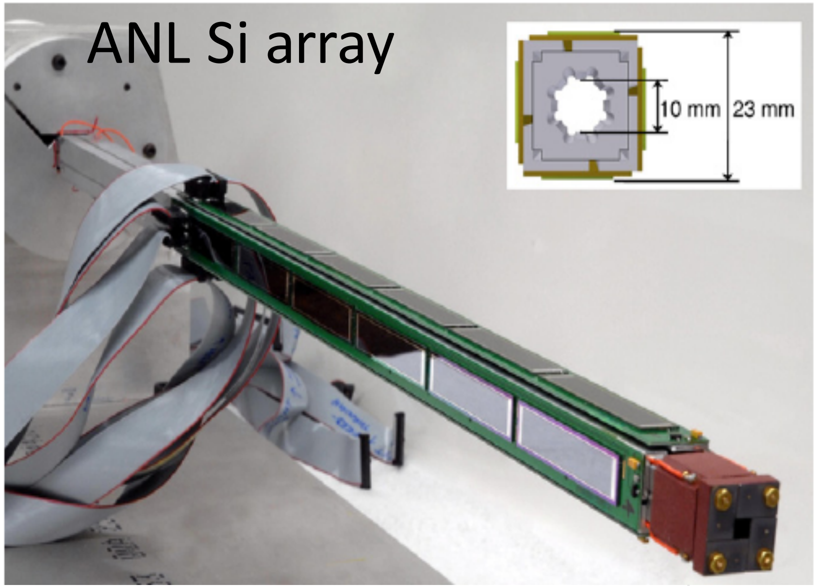
C^2S of mirror analog states are expected to agree within 20%

N. K. Timofeyuk, R. C. Johnson, and A. M. Mukhamedzhanov, PRL **91**, 232501 (2003)
N. K. Timofeyuk, P. Descouvemont, and R. C. Johnson, Eur. Phys. J. A **27**, 269 (2006).

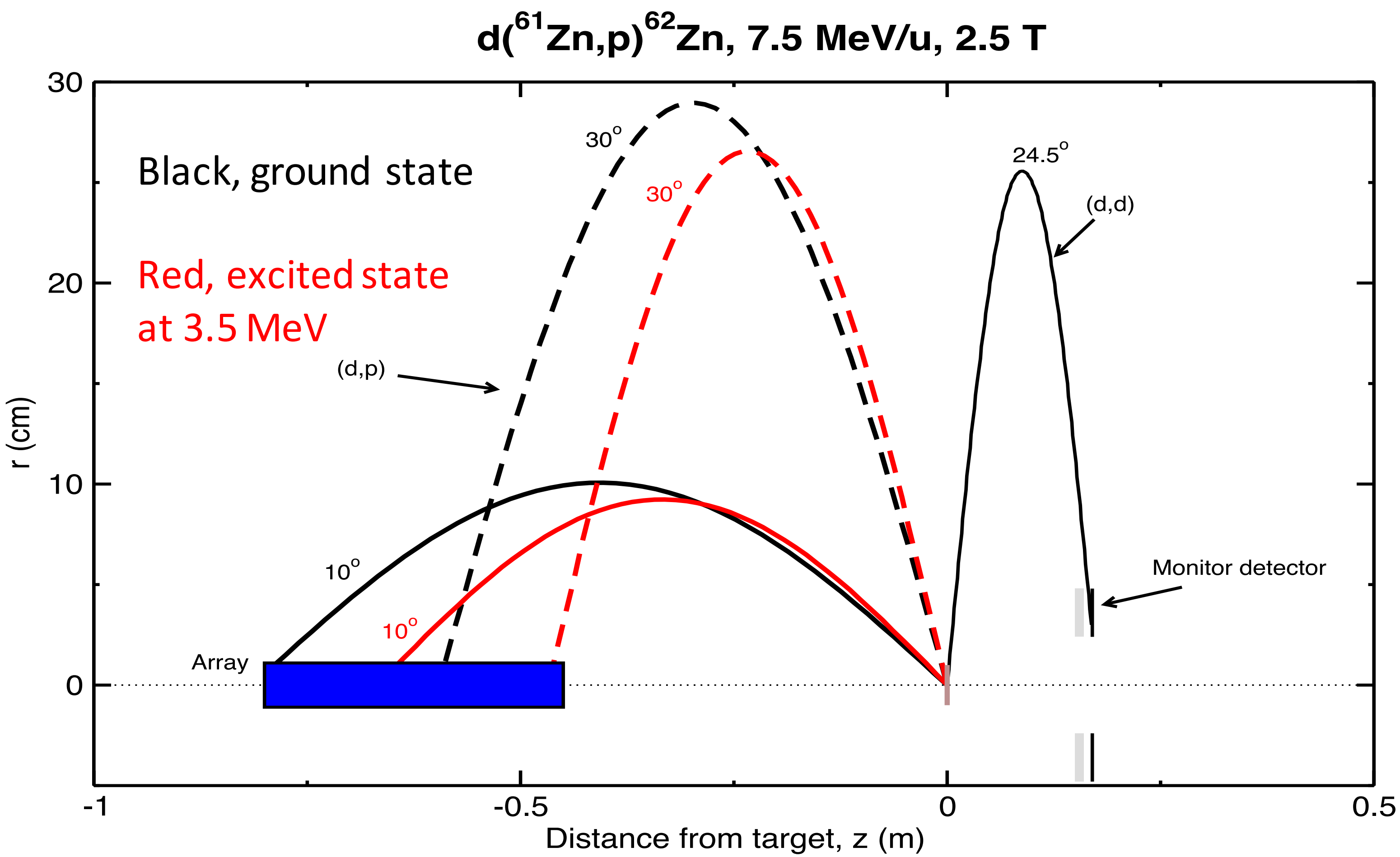
ISS – ISOLDE Solenoid Spectrometer

- 4T superconducting solenoid.
- Obtained as MRI magnet from Brisbane.
  - Arrived @ CERN in April 2016.
- Dedicated to transfer reactions with HIE-ISOLDE.
- New Si array designed and under construction (ready after LS2).
  - First experiments with ANL array.





ISS – ISOLDE Solenoid Spectrometer

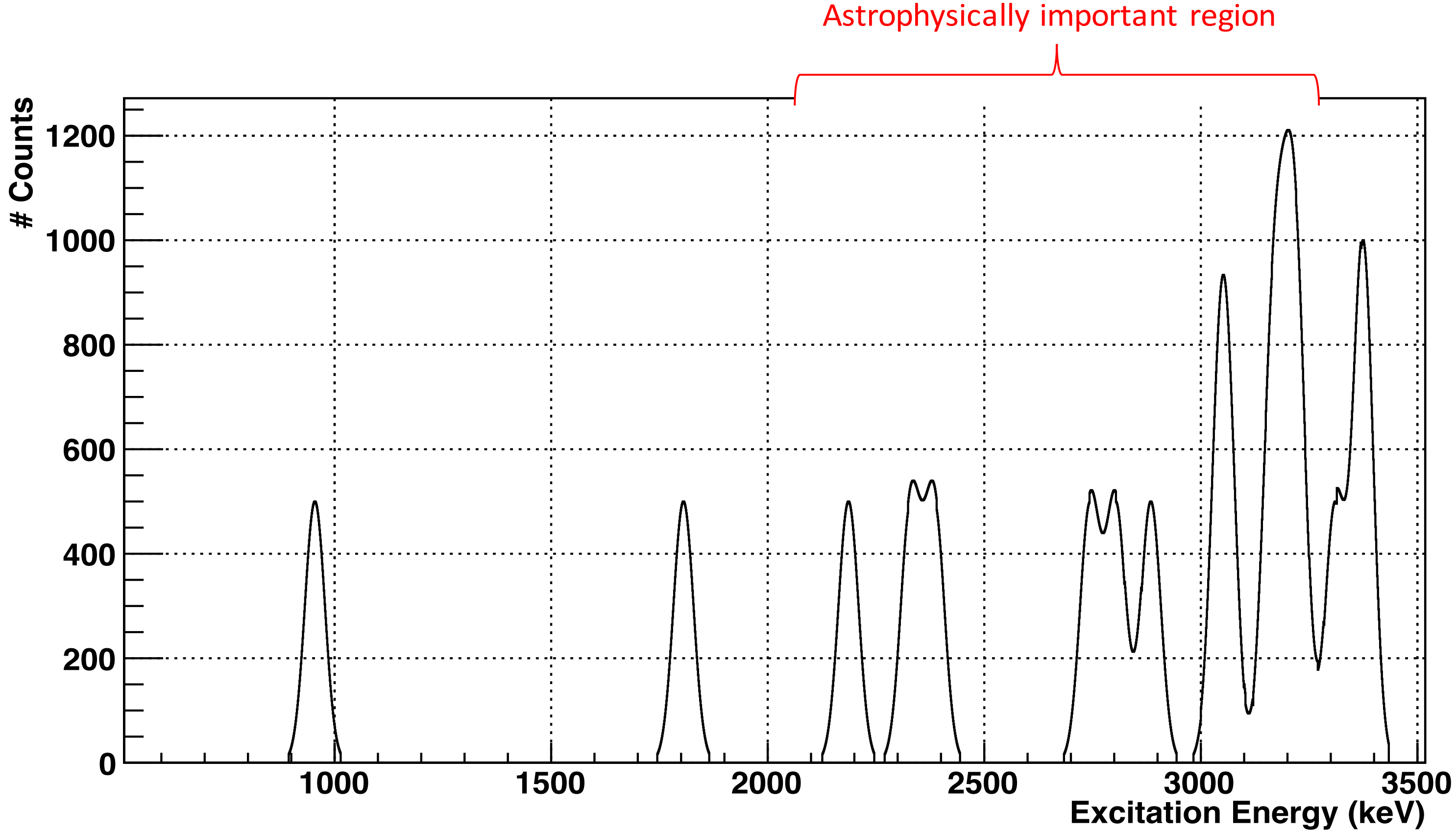


$10° < \theta_{CM} < 30°$ => protons emitted at backward lab angles

Proton energies ~10 MeV

ISS – ISOLDE Solenoid Spectrometer

Know ^{62}Zn level scheme folded with 75-keV resolution obtained with HELIOS type device and detectors



$10° < \theta_{CM} < 30°$ => protons emitted at backward lab angles

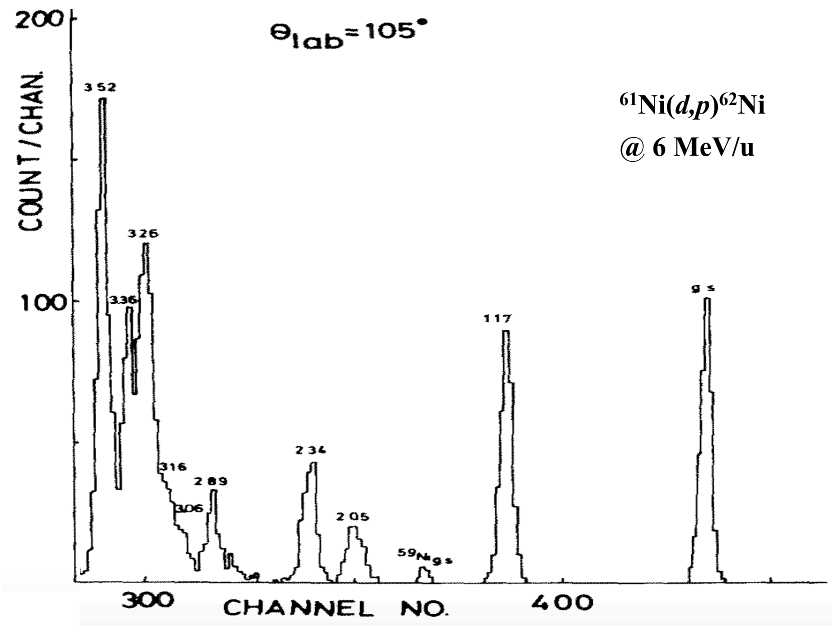
Proton energies ~10 MeV

ISS – ISOLDE Solenoid Spectrometer

7.5 MeV/u ^{61}Zn beam of minimum intensity 4 x 10^5 pps (ZrO_2 target)

Ga contamination to be suppressed with RILIS ionisation of Zn

Stable ^{61}Ni contaminant highlighted in TAC meeting, known spectrum. See below.



Problems from transfer on light elements from EBIS charge breeder?

O. Karban *et al.*, Nucl. Phys. **A366**, 68 (1981).

‘Feedback’ from the INTC

“The presented physics case is certainly of great interest”

BUT

"the proposal is premature considering that the instrument to be used will not be available in 2017 and furthermore two proposals for the same setup have already been approved in 2016"

Extensions and other reactions of Astrophysical Interest

- With beam intensities > 10^5 pps can look for p-γ coincidences with a suitable array.

- (d,p) reactions on the neutron-rich isotopes as a surrogate for neutron-capture reactions

- New beams of neutron-deficient isotopes becoming available with ZrO_2 targets.
  - Transfer around ^{56}Ni ($t_{1/2}$ = 6 days), rp-process waiting point?
  - Germanium/ gallium isotopes along the rp-process path

Thank you very much!

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