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

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[8] *ISOLDE, CERN*

ISOLDE INTC, 8th Feb, 2017

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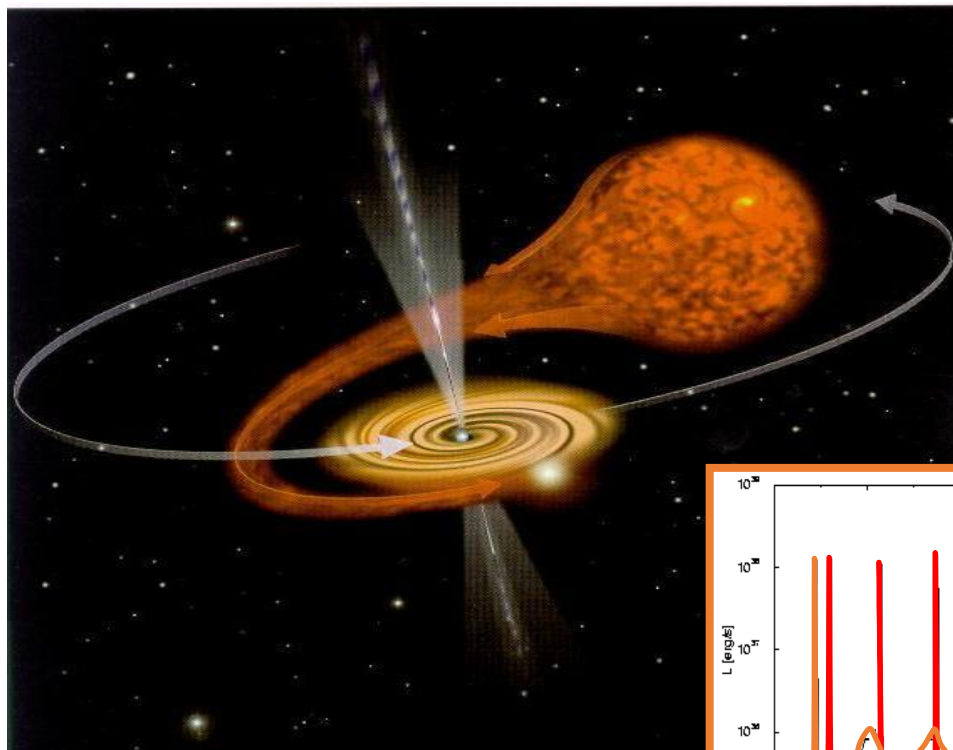
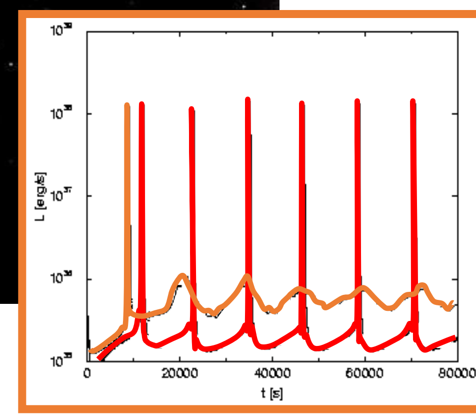
Astrophysical Motivation

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.

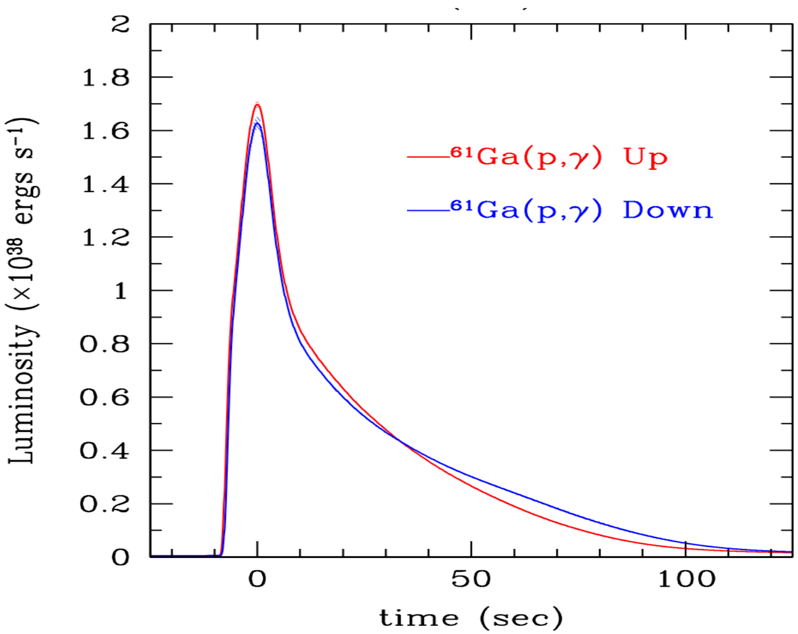




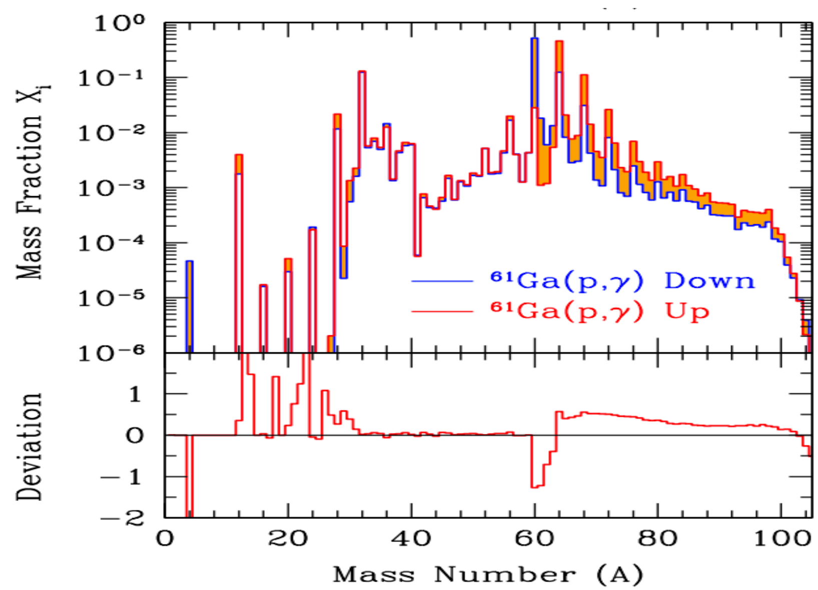
Sensitivity studies highlight the key reactions for understanding these bursts

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

Astrophysical 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).

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Astrophysical 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).

Astrophysical Motivation

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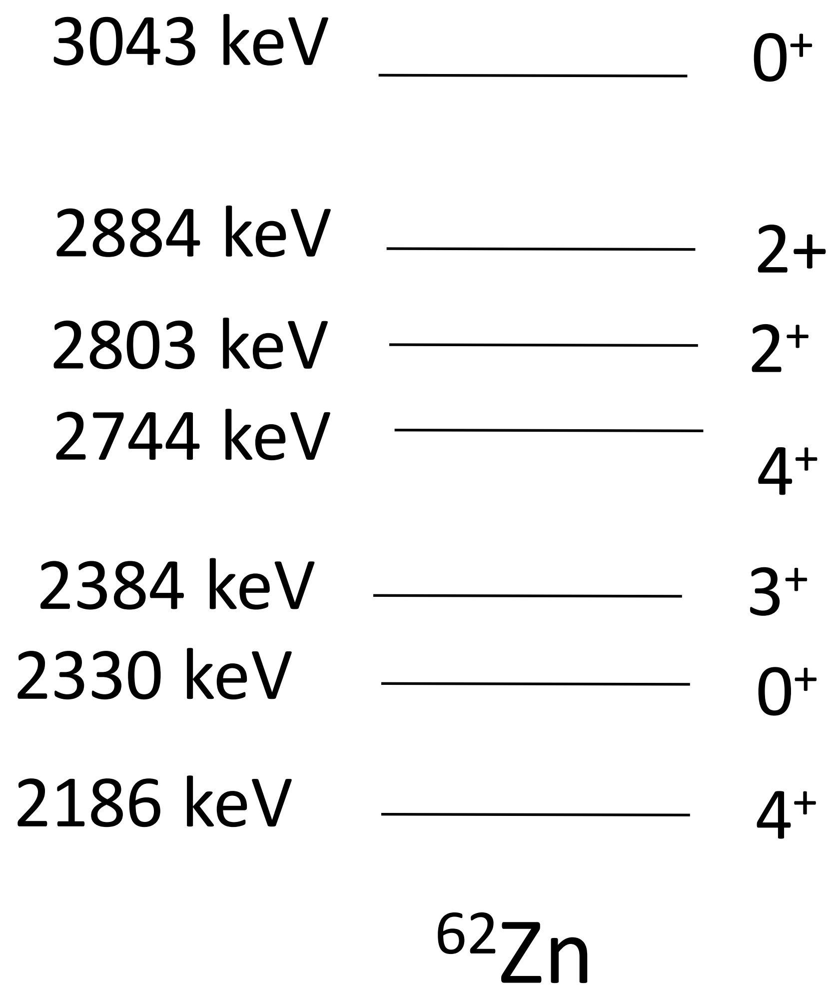
States of Interest in ^{62}Zn

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



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Levels of Interest

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

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

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).

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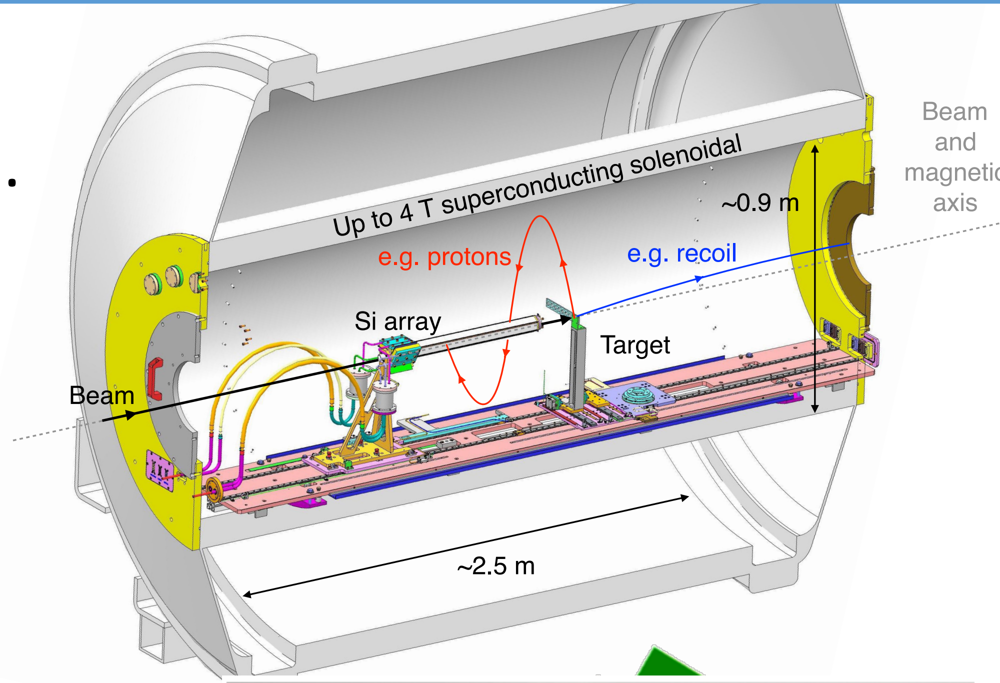
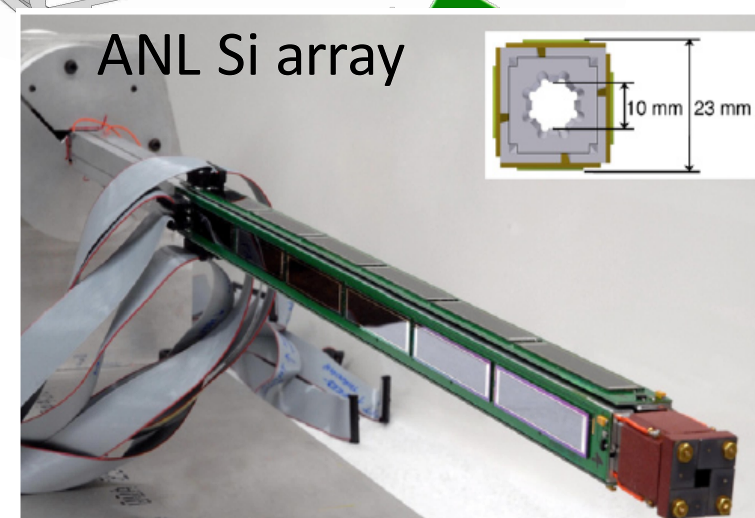
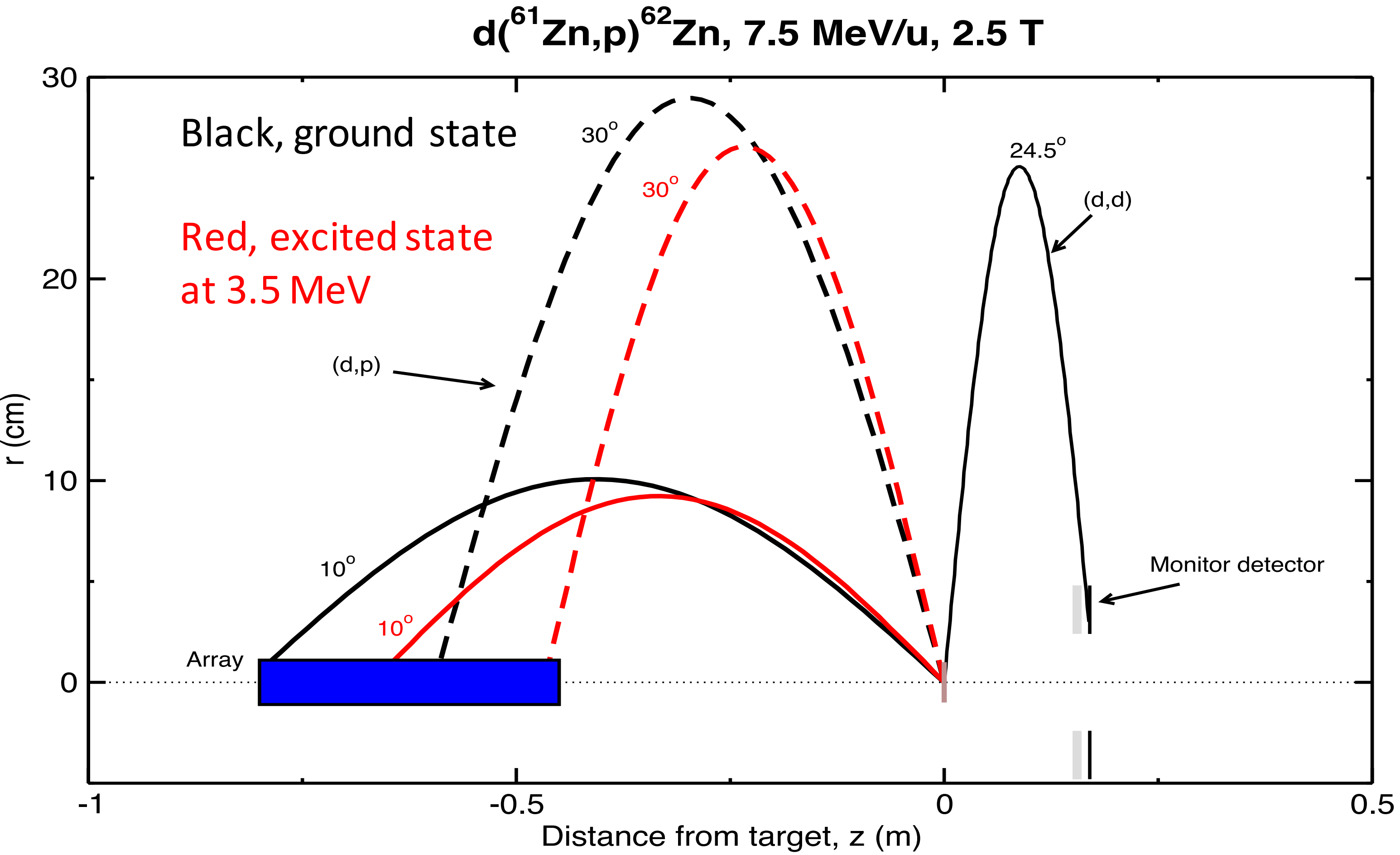
ISS – ISOLDE Solenoidal Spectrometer

- 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.





Experimental Details



10° < θ_{CM} < 30° => protons emitted at backward lab angles

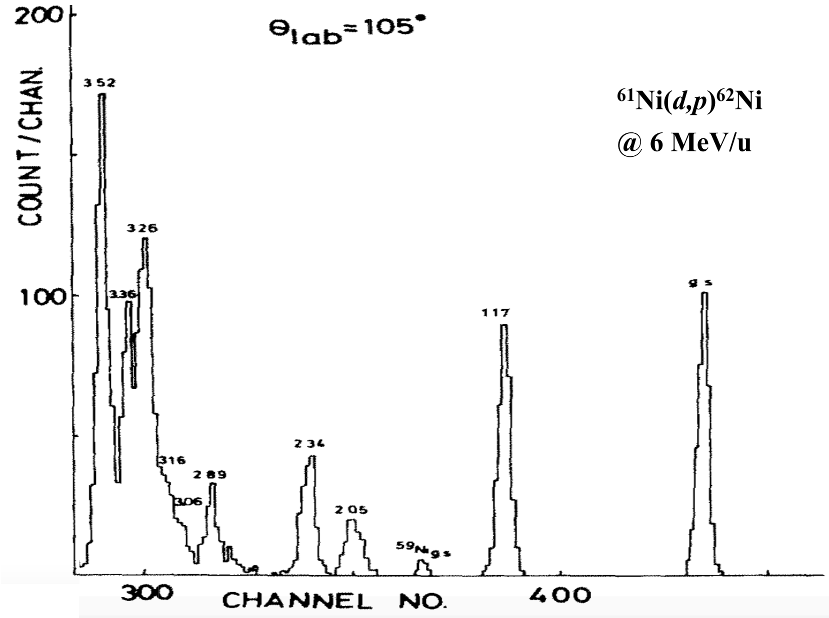
Proton energies ~10 MeV

Beam composition

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

Ga contamination to be suppressed with RILIS ionisation of Zn

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



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

Summary of Beam Time Request

To study the ^{61}Zn(d,p)^{62}Zn reaction for the first time as a probe of the key rp process reaction, ^{61}Ga(p,γ)^{62}Ge.

Obtained spectroscopic factors will be used to determine the properties of proton-unbound levels in ^{62}Ge, therefore, placing the first ever constraints on the key ^{61}Ga(p,γ)^{62}Ge reaction in X-ray burst environments.

Complementary to the two previously approved proposals for the ISOL Solenoid Spectrometer.

We request a total of 21 shifts with a 457.5-MeV ^{61}Zn beam (7.5 MeV/u) at a minimum intensity of 4 x 10^5 pps in order to perform the experiment.

Thank you very much!

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ISOLDE INTC, 8th Feb, 2017

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Timeline of ISS events

2017 →

Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb	Mar.
Delivery						Design and construction of Si array -->					
		Safety files									
						Vacuum tests					
									LN_2		
										He	
										Energize	
										Move to ISOLDE	

← 2016 →

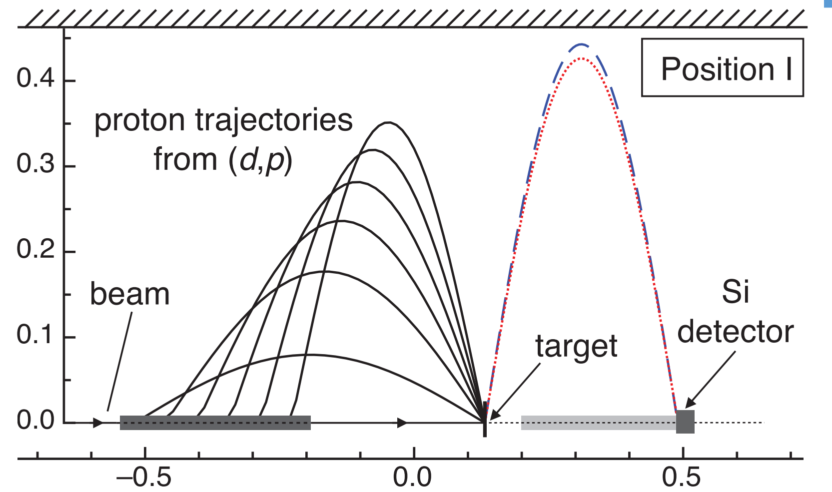
Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
array -->				HIE-ISOLDE campaign				
	Coupling to XT02							
		Shielding -->						
		Field mapping -->						

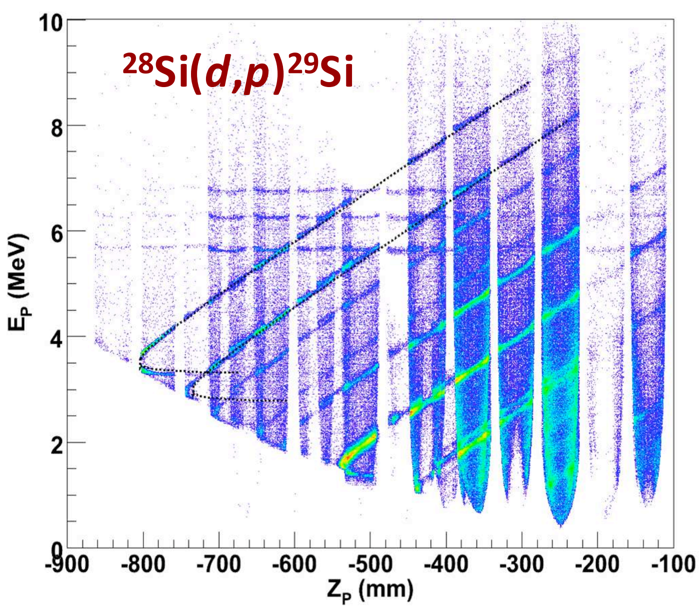
← 2017 →

- First experiments in 2018, before LS2.
- Delivery of stable beams at end of 2017?

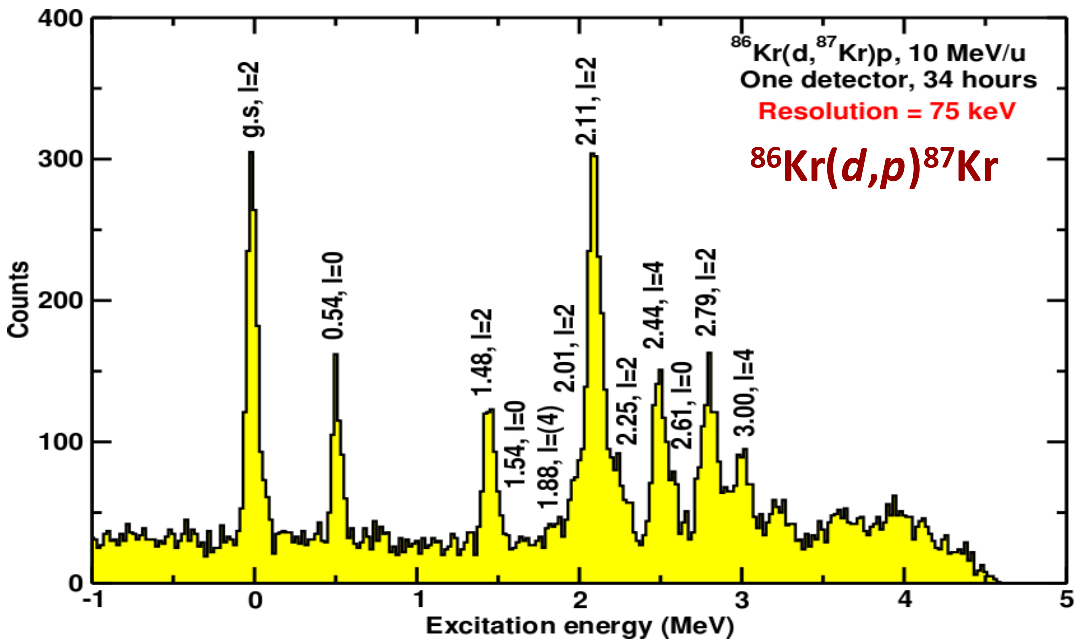
HELIOS @ ANL

- Demonstrated in multiple experiments with 12 < *A* < 136.
- Resolution of 75 keV achieved.
  - In-flight beams ~100 keV.
- Array to be used with ISS@ISOLDE.





J. C. Lighthall *et al.* NIMA **622** (2010) 97



D.K. Sharp *et al*, Phys.Rev.C **87** 014312 (2013)