

Study of beta delayed particle emission from ^{21}Mg

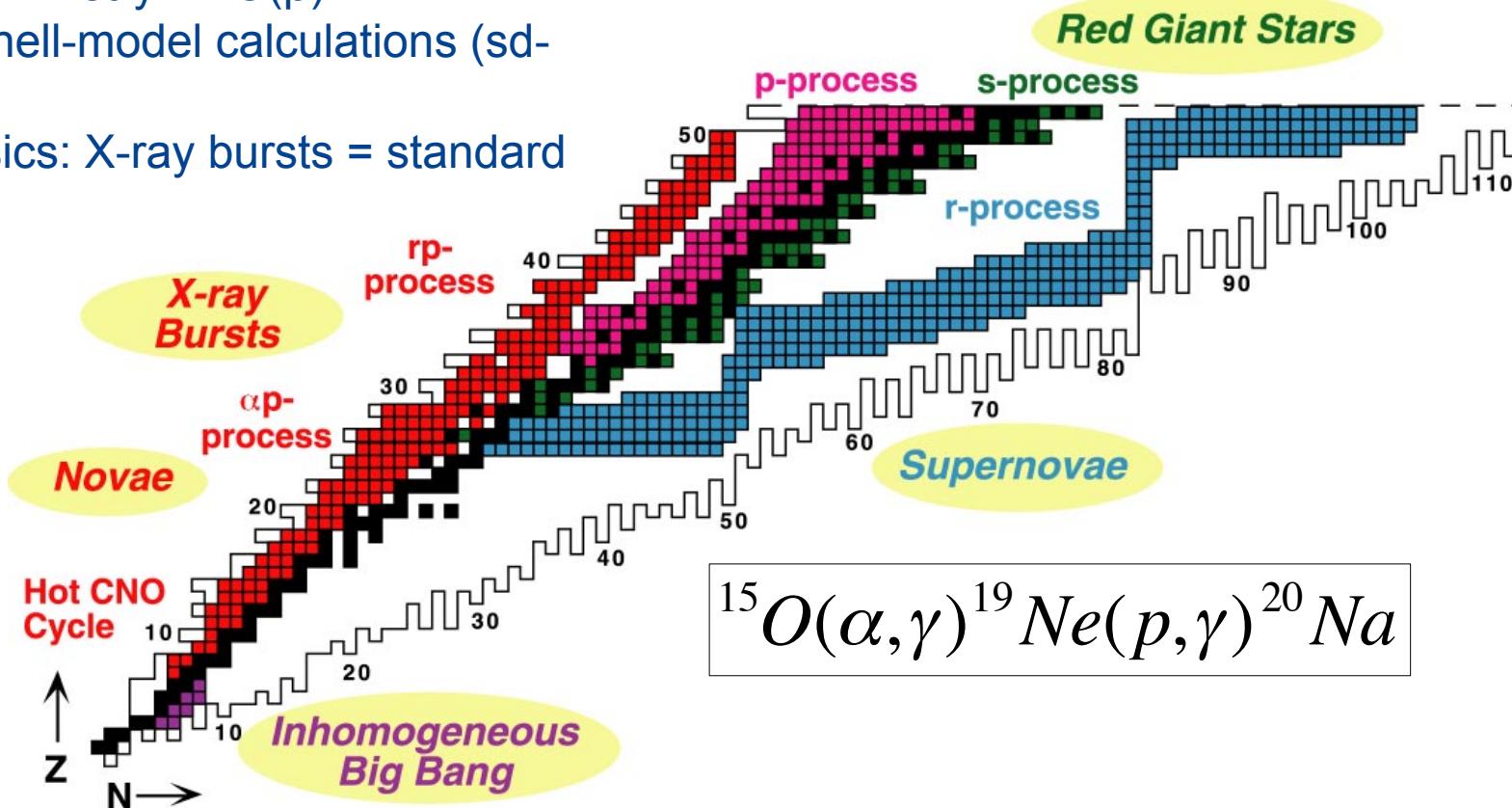
MORTEN VINTHER LUND
AARHUS UNIVERSITY
ON BEHALF OF IS507 COLLABORATION

VERSITET

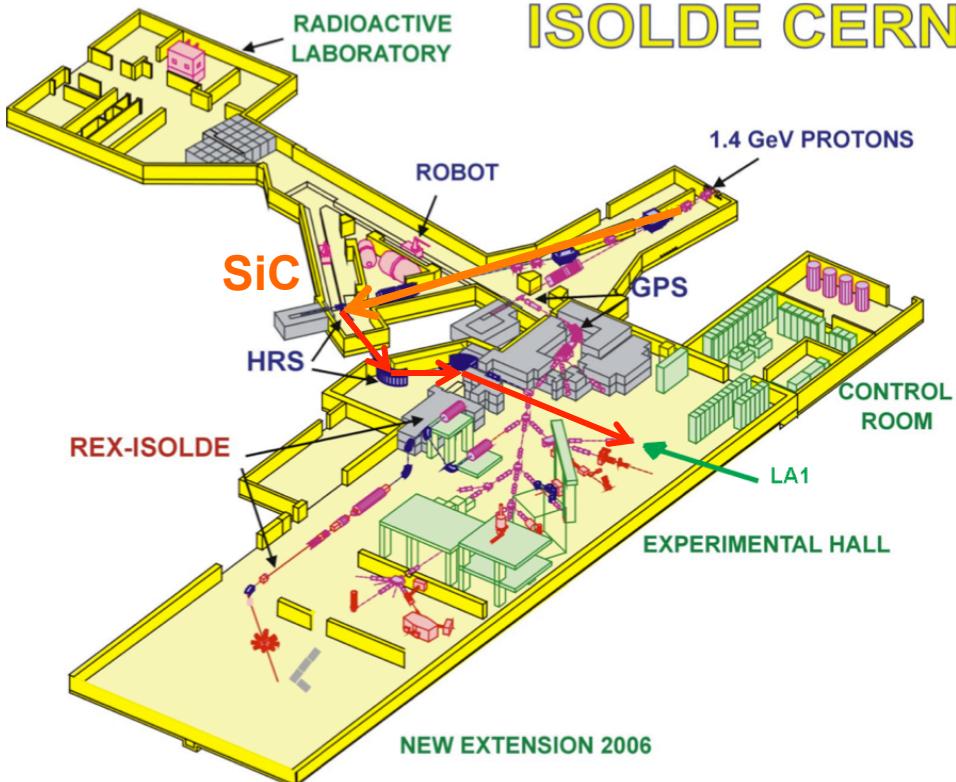
MOTIVATION ^{20}MG

Threefold motivation:

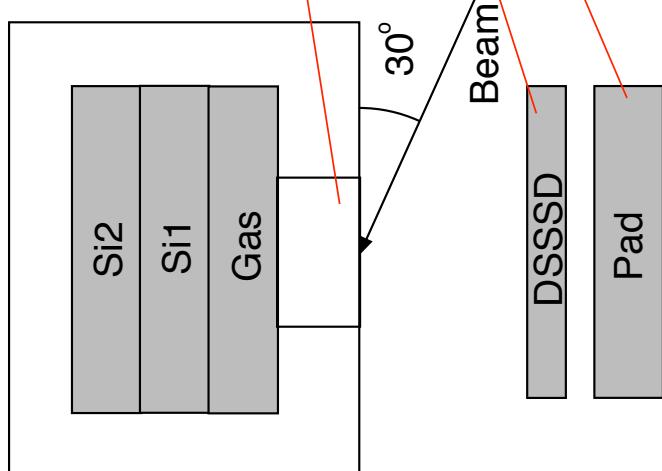
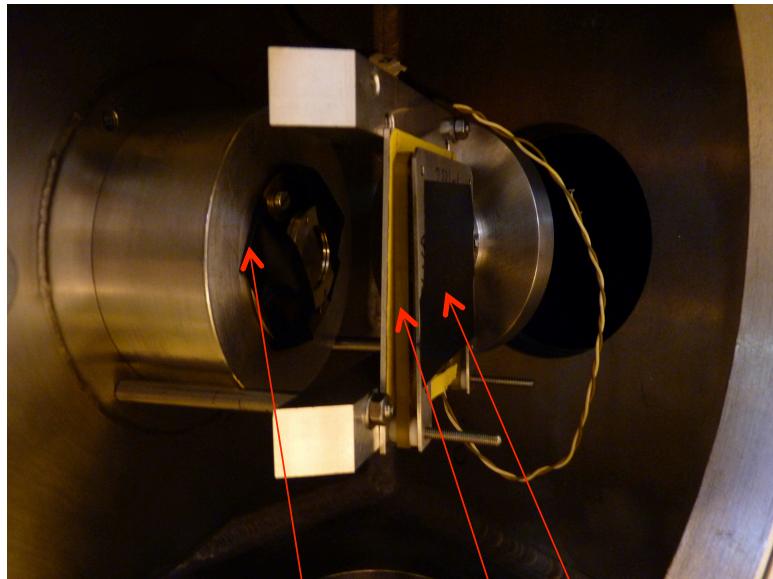
1. Mirror asymmetry - $^{20}\text{O}(\beta)^{20}\text{F}$
2. Modern shell-model calculations (sd-shell)
3. Astrophysics: X-ray bursts = standard candles



EXPERIMENT IS507



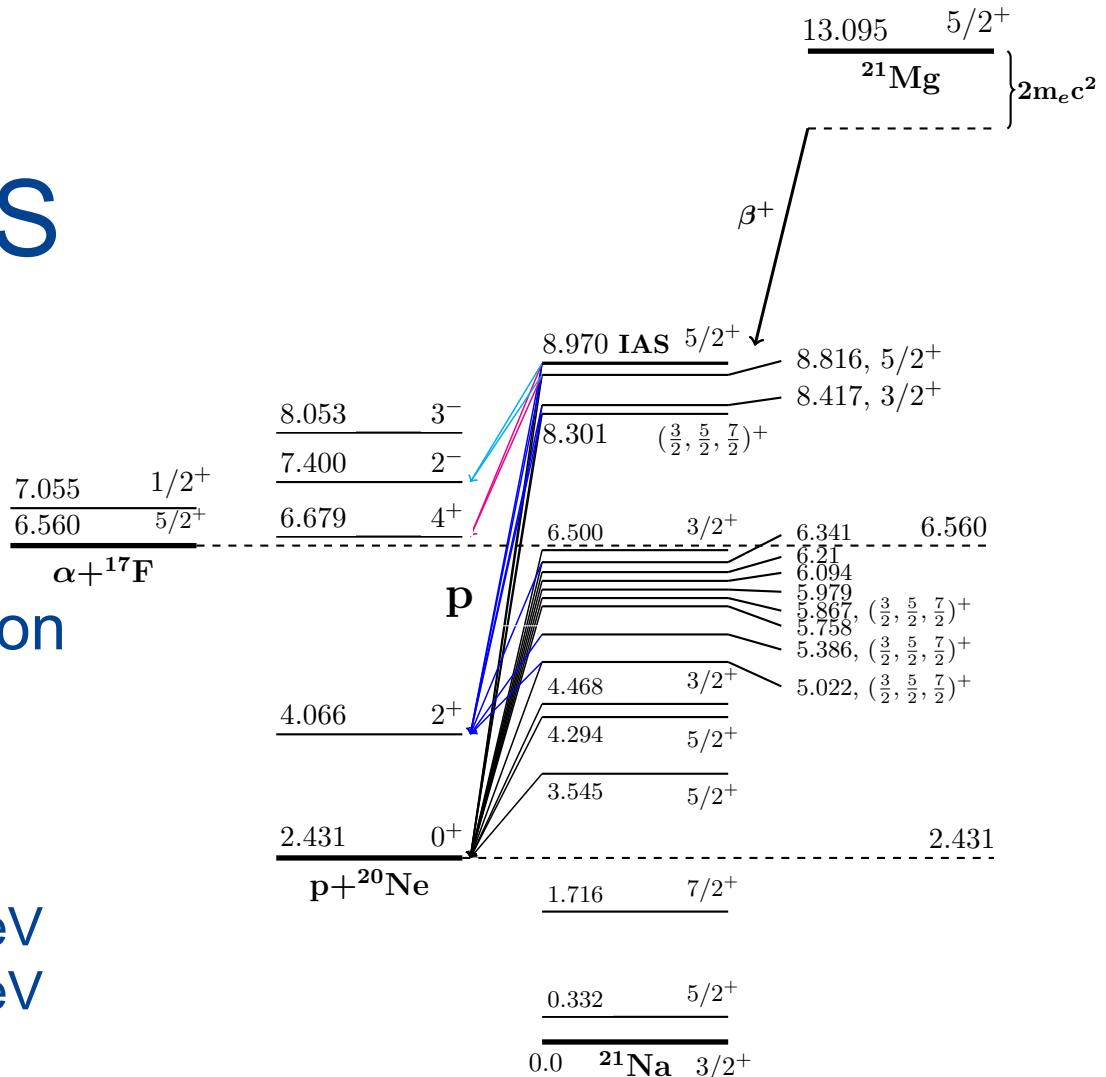
ISOLDE CERN



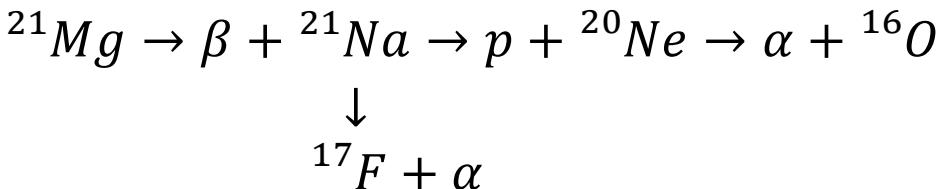
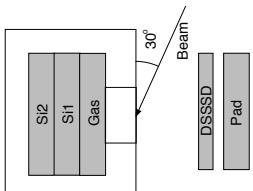
^{21}Mg BETA DECAY

^{21}Mg – STATUS

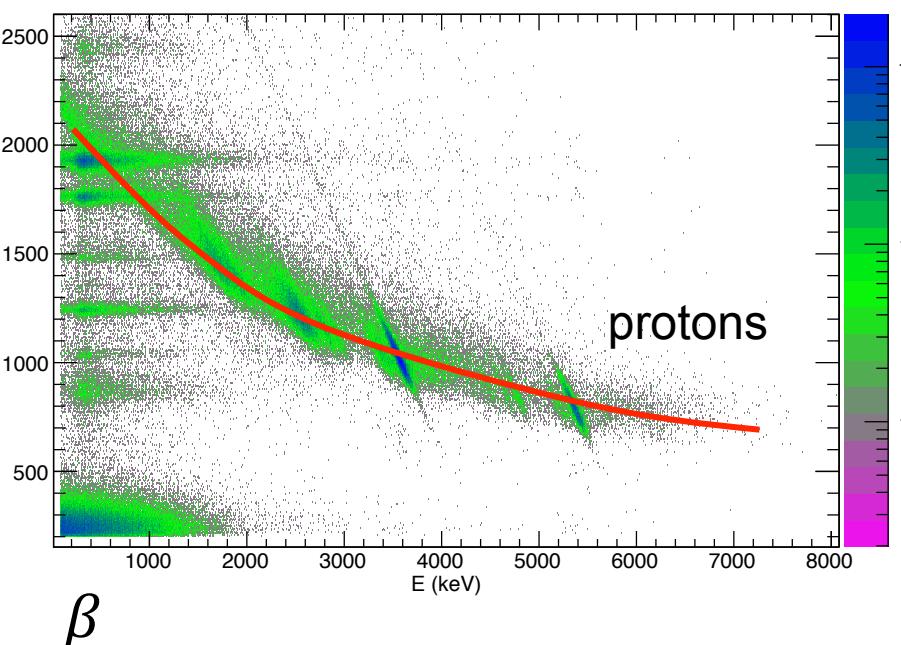
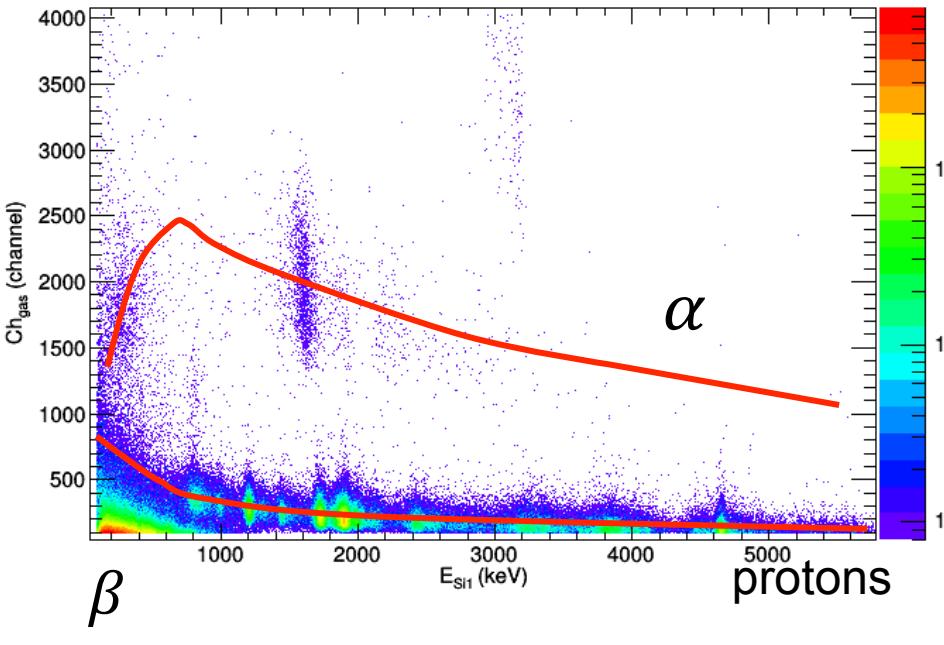
- › ^{21}Mg is a well known proton emitter
- › Used for proton calibration
- › Delayed alpha emission energetically allowed:
 - › $Q_a(8816 \text{ keV}) = 2256 \text{ keV}$
 - › $Q_a(8970 \text{ keV}) = 2410 \text{ keV}$



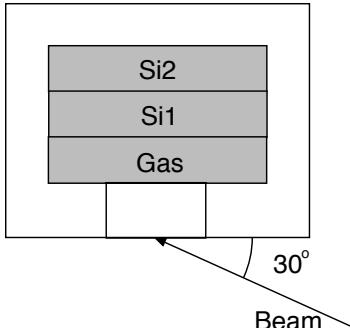
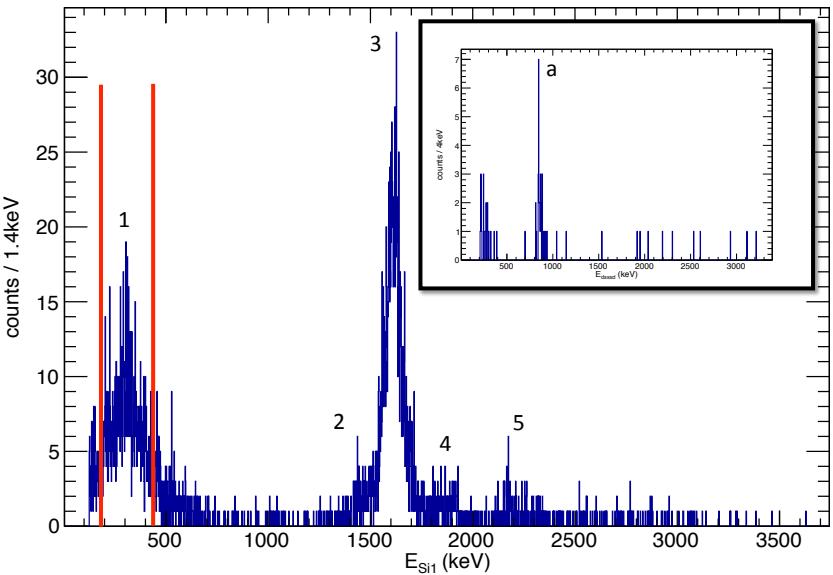
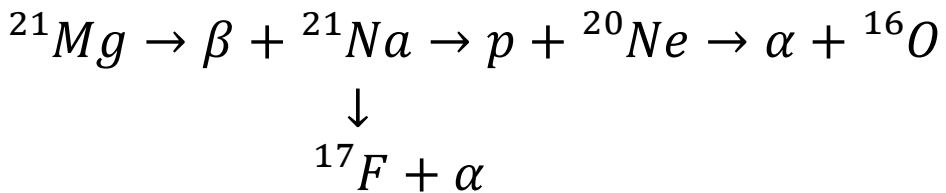
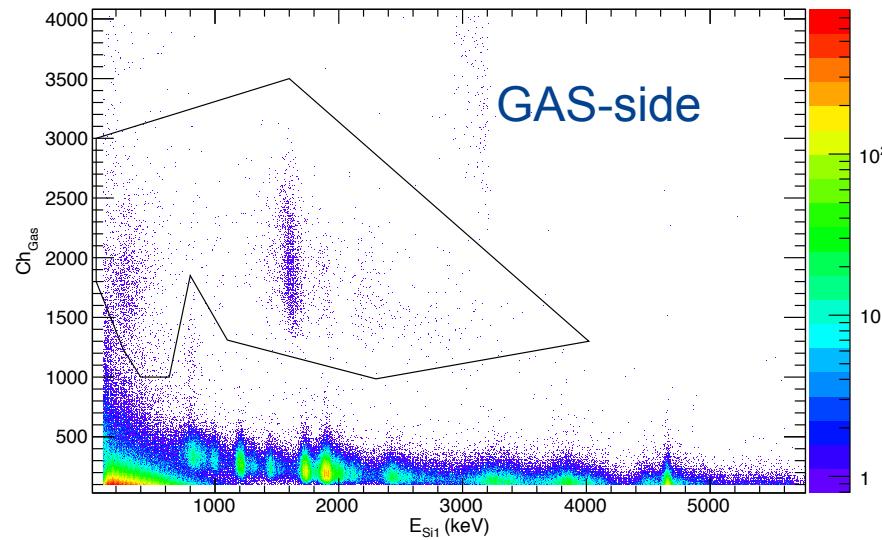
Sextro et al. (1973)



$^{21}\text{MG} - \Delta E\text{-}E$ DATA



^{21}Mg – ALPHA'S

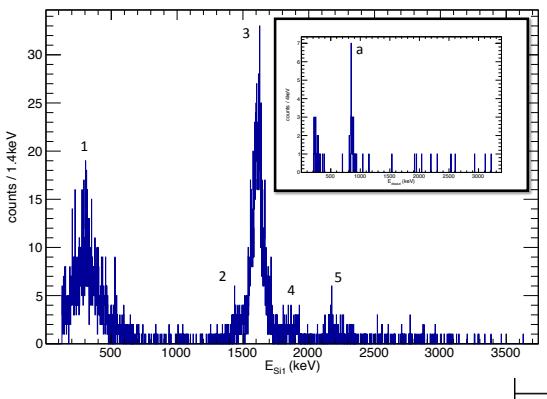


Decay modes observed:

- 4 $\beta\alpha$ (nr. 2, 3, 4, and 5)
- 1 $\beta\bar{\nu}\alpha$ (nr. 1)

$$^{21}Mg \rightarrow \beta + ^{21}Na \rightarrow p + ^{20}Ne \rightarrow \alpha + ^{16}O$$

^{21}Mg – ALPHA SPECTRUM



$\beta\alpha$ -decay mode:

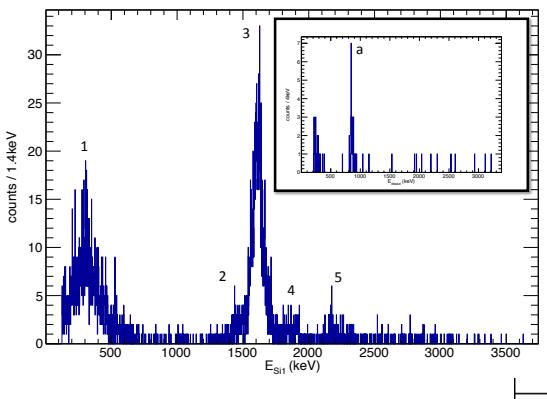
- Only seen in 9C and ^{17}Ne before

			C128	C129	C130	C131	C132	C133	C134	C135	C136	C137	C138					
			S26 <10 NS	S27 21 MS	S28 125 MS	S29 187 MS	S30 1.178 s	S31 2.572 s	S32 95 ms	S33 0.75 s	S34 4.21 s	S35 87.98 d	S36 0.02 s	S37 505 MS				
			P24	P25 <10 NS	P26 20 MS	P27 270.3 MS	P28 4.142 s	P29 2.468 K	P30 1.00	P31 14.262 D	P32 25.34 D	P33 12.43 s	P34 47.3 s	P35 P36 56.8 s				
			Si22 29 MS	Si23 >200 NS	Si24 102 MS	Si25 222 MS	Si26 224 s	Si27 4.16 s	Si28 2.232 K	Si29 4.68 s	Si30 3.087	Si31 1.973 M	Si32 1.72 Y	Si33 Si34 6.322 s				
			Al21 <35 NS	Al122 50 MS	Al123 0.47 s	Al124 2.053 s	Al125 7.185 s	Al126 71.700 Y	Al127 1.00	Al128 2.2414 K	Al129 6.56 K	Al130 3.60 s	Al131 644 MS	Al132 33 MS				
			Mg19	Mg20 90.8 MS	Mg21 122 MS	Mg22 11.317 s	Mg23 11.317 Y	Mg24 78.99	Mg25 10.00	Mg26 1.11	Mg27 94.95 K	Mg28 20.815 H	Mg29 1.30 s	Mg30 955 MS	Mg31 230 MS			
			Na17	Na18 <10 NS	Na19 447.9 MS	Na20 22.49 s	Na21 2.6219 Y	Na22 1.00	Na23 14.912 H	Na24 9.91 s	Na25 1.072 s	Na26 1.072 s	Na27 301 MS	Na28 30.5 MS	Na29 44.9 MS	Na30 48 MS		
			Ne15	Ne17 102.2 MS	Ne18 17.22 S	Ne19 17.22 S	Ne20 0.01	Ne21 0.27	Ne22 9.25	Ne23 37.24 S	Ne24 3.38 K	Ne25 6.22 MS	Ne26 0.197 s	Ne27 32 MS	Ne28 17 MS	Ne29 200 MS	Ne30 >200 NS	Ne31 >200 NS
			F14	F17 64.49 s	F18 10.00	F19 1.00	F20 11.163 s	F21 4.198 s	F22 4.23 s	F23 2.23 s	F24 0.34 s	F25 59 MS	F26 1.90 MS	F27 <10 NS	F28 <10 NS	F29 <10 NS		
			O13	O14 8.9 MS	O15 70.606 S	O16 122.24 S	O17 99.769	O18 0.008	O19 26.91 s	O20 13.51 s	O21 3.42 s	O22 2.25 s	O23 0.23 s	O24 61 MS	O25 <10 NS	O26 <10 NS		
			N12	N13 11.000 MS	N14 9.965 M	N15 0.366	N16 7.13 s	N17 4.175 s	N18 624 MS	N19 200 MS	N20 142 MS	N21 87 MS	N22 18 MS	N23 >200 NS	N24 <10 NS			
			C9 126.5 MS	C10 1.255 s	C11 20.30 K	C12 0.85	C13 1.11	C14 5730 Y	C15 2.449 s	C16 0.747 s	C17 193 MS	C18 95 MS	C19 49 MS	C20 14 MS	C21 <10 NS	C22 >200 NS		
			B8 770 MS	B9 1.98	B10 0.02	B11 20.20 K	B12 17.36 K	B13 12.3 MS	B14 9.87 MS	B15 <10 NS	B16 5.08 MS	B17 <10 NS	B18 <10 NS	B19 >200 NS				
			Be5	Be7 52.9 D	Be9 1.00	Be10 1.51000 Y	Be11 1.381 S	Be12 21.3 MS	Be14 4.35 MS									
			He3 0.0000137	He4 99.999863	He6 106.7 MS	He8 119.0 MS												
			H1 99.985	H2 0.015	H3 12.33 Y													
1			N1 10.24 M															
0																		

1	H1 99.985	H2 0.015	H3 12.33 Y
0			N1 10.24 M

$$^{21}Mg \rightarrow \beta + ^{21}Na \rightarrow p + ^{20}Ne \rightarrow \alpha + ^{16}O$$

²¹MG – ALPHA SPECTRUM

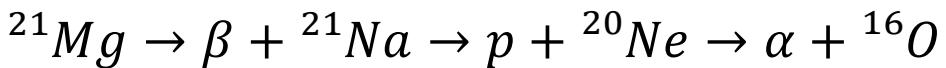


Beta-decay mode:

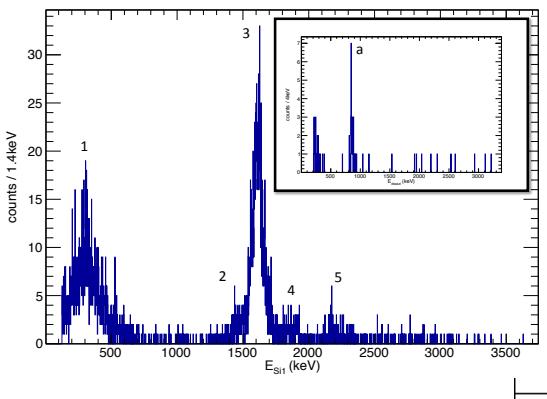
- Only seen in ${}^9\text{C}$ and ${}^{17}\text{Ne}$ before
 - Known to be energetically possible in ${}^{13}\text{O}$ also – not observed in β -decay

N10		N12 11.000 MS	N13 9.965 K	N14 9.965	N15 0.366	N16 7.13 S
C9 126.5 MS	C10 12.255 S	C11 20.390 K	C12 9.989	C13 1.11	C14 5.930 Y	C15 2.449 S
B8 77.0 MS	B10 19.8	B11 80.2	B12 20.200 MS	B13 17.36 MS	B14 12.3 MS	
Be7 53.9 D	Be9 1.00	Be10 15.0000 Y	Be11 13.81 S	Be12 21.3 MS		
Li6 7.7	Li7 9.9 AL	Li8 9.98 MS	Li9 17.83 MS		Li11 8.5 MS	Li12 4.0 MS
He3 0.000137	He4 99.99963	He6 80.67 MS		He8 11.90 MS		
H2 0.0015	H3 12.35 Y					
N1 1024 X						

	C128	C129 -20 NS	C130 -30 NS	C131 -50 MS	C132 -70 MS	C133 -2.51 S	C134 -1.5264 S	C135 7.577	C136 -30.0000 Y	C137 24.23	C138 -57.24 M
S26 -10 MS	S26 -10 MS	S27 21 MS	S28 125 MS	S29 187 MS	S30 1178 S	S31 2.572 S	S32 9502	S33 0.75	S34 4.21	S35 87.38 D	S36 0.02
P24	P25 -30 NS	P26 20 MS	P27 260 MS	P28 270.3 MS	P29 4.142 S	P30 2.408 M	P31 100	P32 14.262 D	P33 25.543	P34 12.43 S	P35 47.3 S
Si22 29 MS	Si23 -20 NS	Si24 102 MS	Si25 220 MS	Si26 2.234 S	Si27 4.16 S	Si28 92.230	Si29 4.693	Si30 1.087	Si31 157.3 M	Si32 1.72 Y	Si33 6.332 S
Al21 -35 NS	Al22 50 MS	Al23 0.47 S	Al24 2.053 S	Al25 7.185 S	Al26 71.7000 Y	Al27 100	Al28 2.2414 M	Al29 6.56 M	Al30 3.60 S	Al31 644 MS	Al32 33 MS
Mg19	Mg20 -20 MS	Mg21 122 MS	Mg22 3.97	Mg23 11.317 S	Mg24 78.99	Mg25 100	Mg26 1.01 M	Mg27 94.95 M	Mg28 20.915 H	Mg29 1.30 S	Mg30 335 MS
Na17	Na18	Na19 -40 NS	Na20 447.9 MS	Na21 22.49 S	Na22 2.611 Y	Na23 100	Na24 14.2912 H	Na25 51.1 S	Na26 1.072 S	Na27 30.5 MS	Na28 44.9 MS
Ne15	Ne17 -102 MS	Ne18 -72 MS	Ne19 17.22 S	Ne20 0.47	Ne21 0.27	Ne22 925	Ne23 37.24 S	Ne24 3.38 M	Ne25 62.2 M	Ne26 0.197 S	Ne27 32 MS
F14		F17 64.49 S	F18 -10 M	F19 100	F20 11.163 S	F21 4.198 S	F22 423 S	F23 2.23 S	F24 0.34 S	F25 59 MS	F26 190 MS
O13 -8.58 MS	O14 70.626 S	O15 122.24 S	O16 0.776	O17 0.058	O18 0.020	O19 25.91 S	O20 13.51 S	O21 3.42 S	O22 2.25 S	O23 82 MS	O24 61 MS
N12 -11.000 MS	N13 9.965 M	N14 9.965 M	N15 0.366	N16 7.13 S	N17 4.173 S	N18 624 MS	N19 142 MS	N20 87 MS	N21 18 MS	N22 -200 NS	N23 -52 NS
C11 20.39 M	C12 0.869	C13 1.11	C14 5730 Y	C15 2.449 S	C16 0.747 S	C17 193 MS	C18 95 MS	C19 49 MS	C20 14 MS	C21 -30 NS	C22 -200 NS
B10 19.8	B11 80.2	B12 20.20 MS	B13 17.36 MS	B14 12.3 MS	B15 9.97 MS	B16 -150 JS	B17 518 MS	B18 -26 NS	B19 -200 NS		



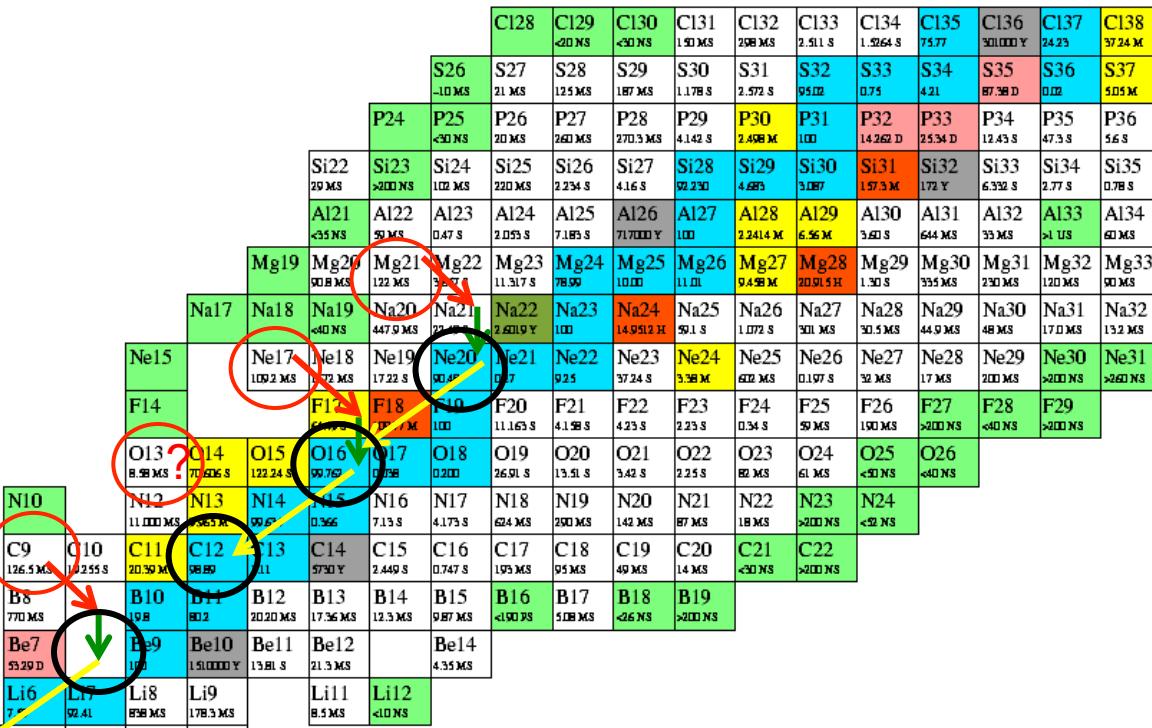
^{21}Mg – ALPHA SPECTRUM

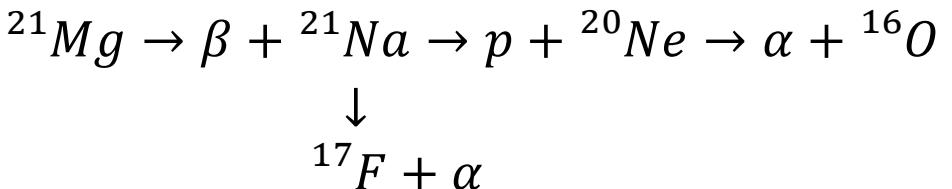
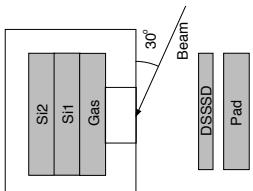


$\beta\alpha$ -decay mode:

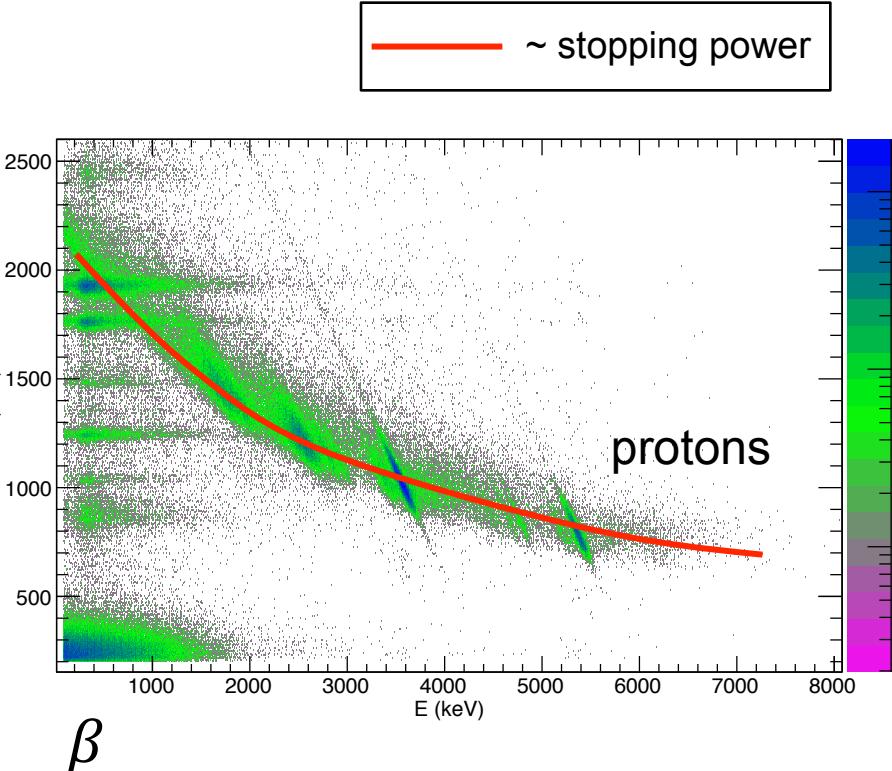
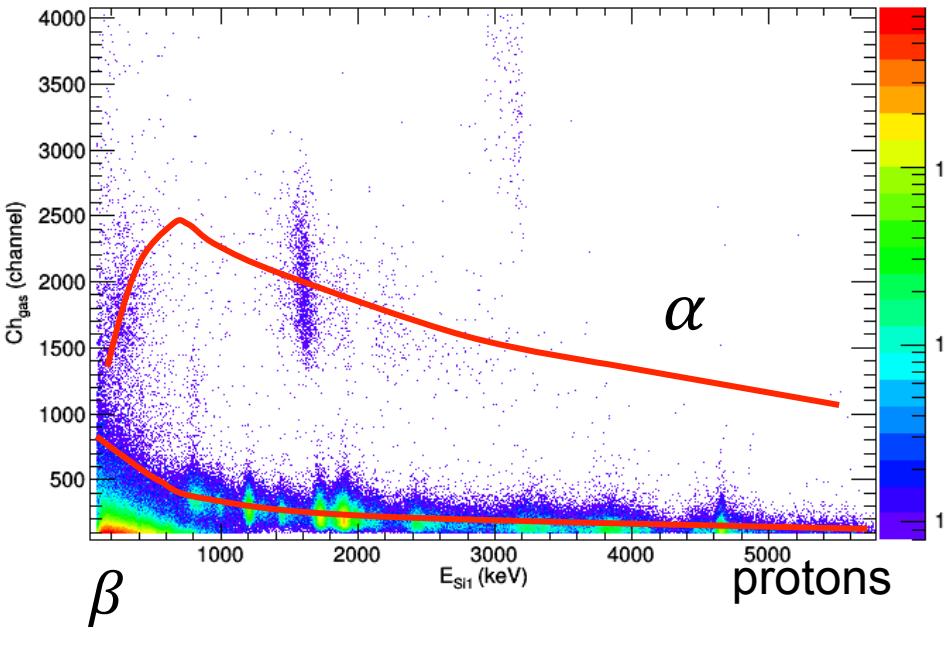
- Only seen in 9C and ^{17}Ne before
- Known to be energetically possible in ^{13}O also – not observed in β -decay
- Systematics: βp -decay to an alpha-conjugate nuclei, low-mass
- Alpha-conjugates are more stable hence making $S_p(i^*\alpha + p)$ and S_α low

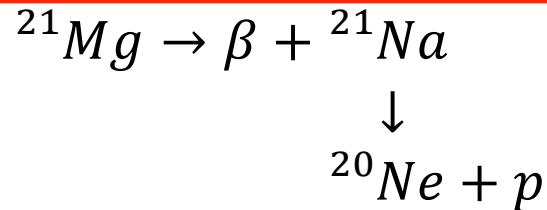
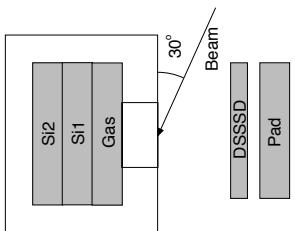
1	H1 99.985	H2 0.015	H3 12.33 Y
0	N1 10.24 M		



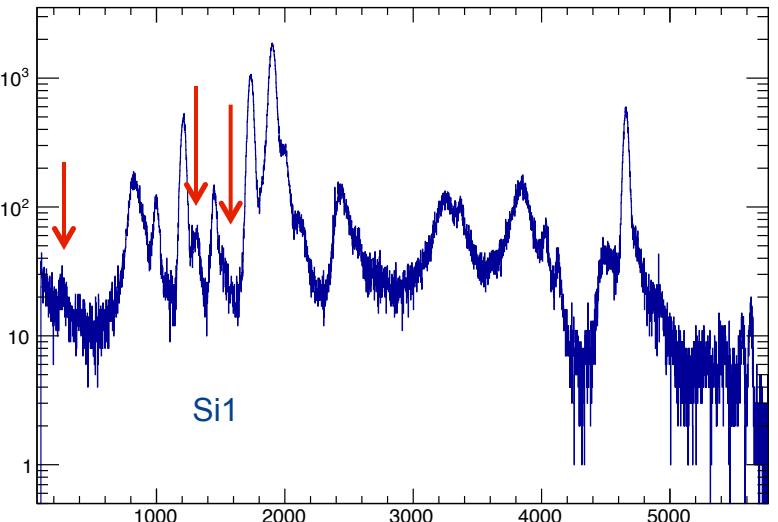


$^{21}\text{MG} - \Delta E\text{-}E$ DATA





${}^{21}Mg$ – PROTON SPECTRUM

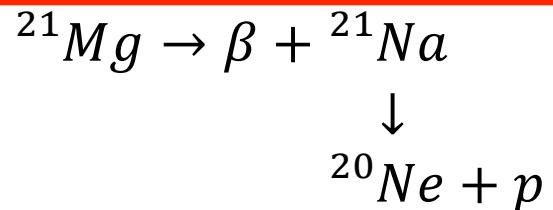
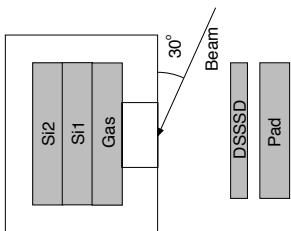


$$Q_p = 394 (5) \text{ keV} : {}^{21}Na(4468) \rightarrow {}^{20}Ne(1633) + p$$

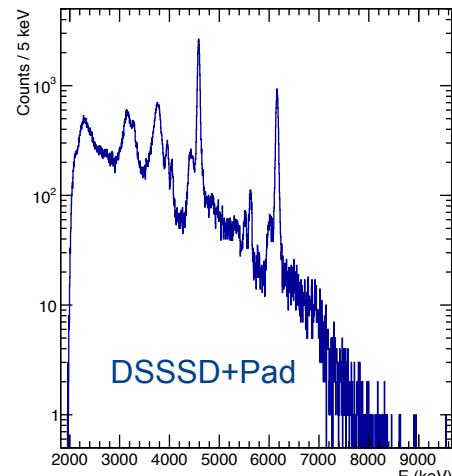
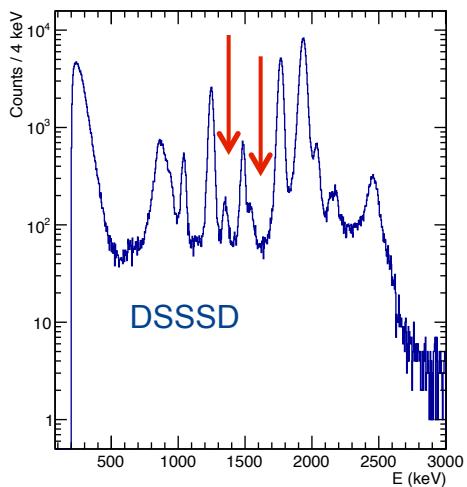
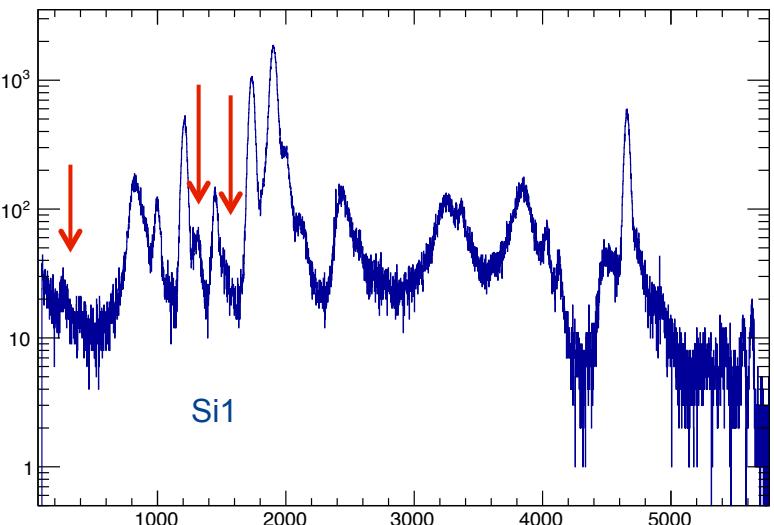
$$Q_p = 1416 (6) \text{ keV} : {}^{21}Na(8827) \rightarrow {}^{20}Ne(4968) + p$$

$$Q_p = 1626 (17) \text{ keV} : {}^{21}Na(8303) \rightarrow {}^{20}Ne(4247) + p$$

$$S_p({}^{21}Na) = 2431 \text{ keV}$$



^{21}Mg – PROTON SPECTRUM



$$Q_p = 394 (5) \text{ keV} : ^{21}\text{Na}(4468) \rightarrow ^{20}\text{Ne}(1633) + p$$

$$Q_p = 1416 (6) \text{ keV} : ^{21}\text{Na}(8827) \rightarrow ^{20}\text{Ne}(4968) + p$$

$$Q_p = 1626 (17) \text{ keV} : ^{21}\text{Na}(8303) \rightarrow ^{20}\text{Ne}(4247) + p$$

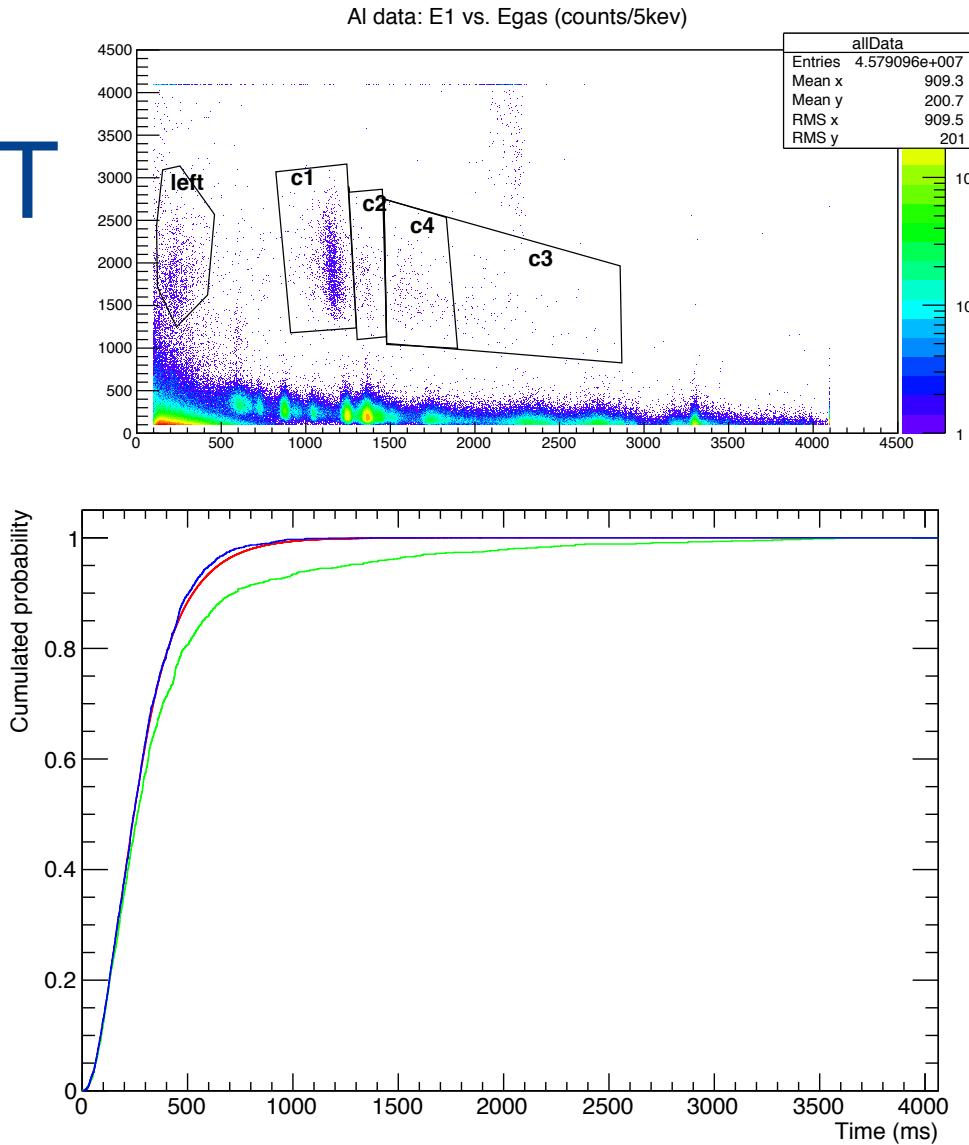
$$S_p(^{21}\text{Na}) = 2431 \text{ keV}$$

²¹MG – TIME TEST

Method:

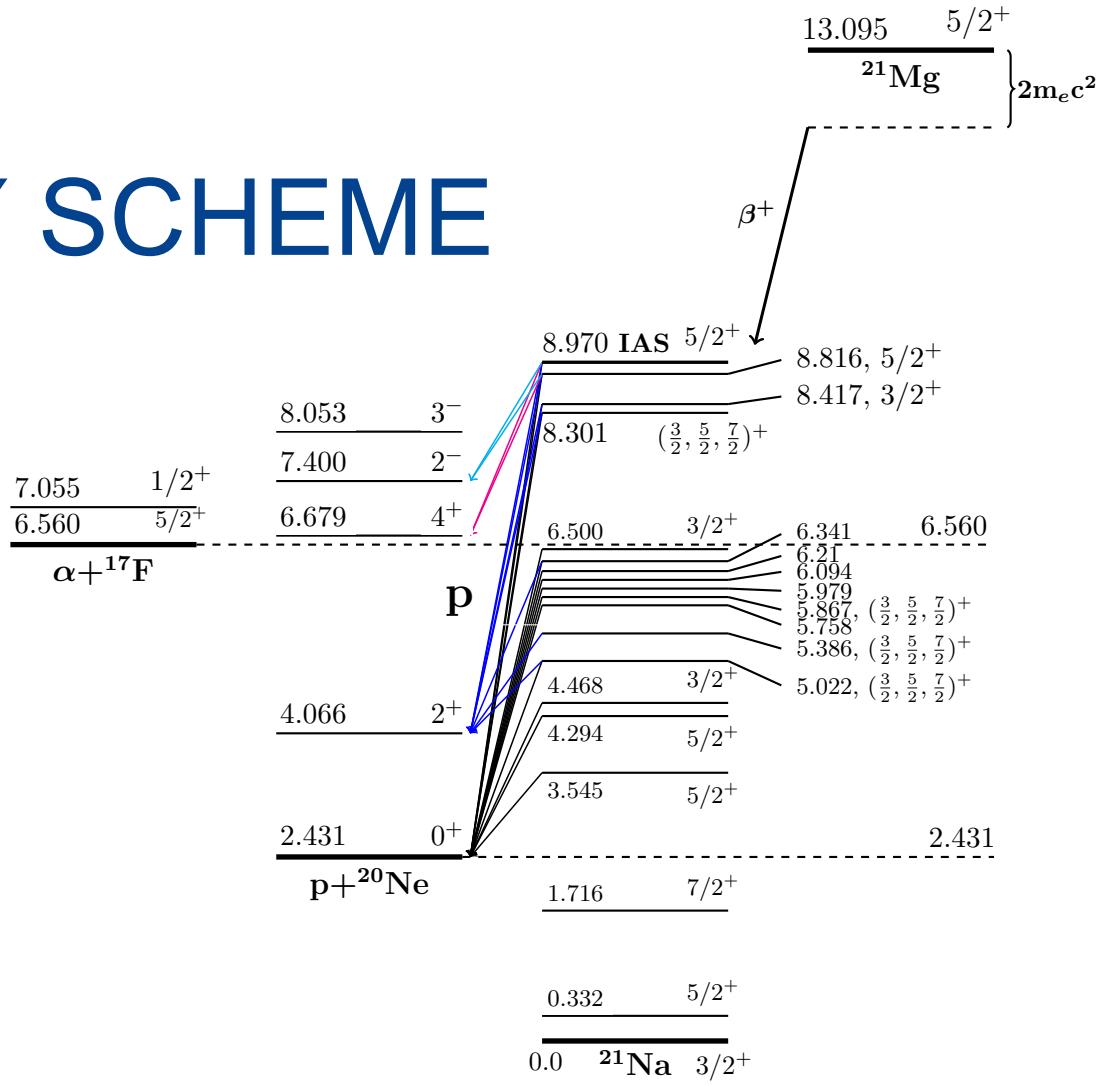
- Use 3 different statistical tests: Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling
- All quantify the vertical difference between the reference distribution and the distribution in question
- MC simulation to get confidence limits

- Reference distribution from protons, excluding lowest energy
- Left region (1 of 3 tests positive to $>5\%$, 2 of 3 $<5\%$)
- Central region, c1, (positive all, $>25\%$ significance)



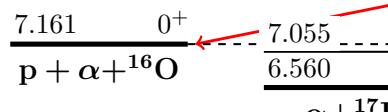
^{21}Mg – DECAY SCHEME

- Decay scheme mainly based on Sextro et al. from 1973 seem unlikely:
 - new $^{20}\text{Ne}(p,p)$ scattering experiments
 - Sextro et al. introduced new resonances not seen again
- New tentative interpretation based on:
 - new knowledge of resonance widths
 - new knowledge of J^P
 - energy considerations

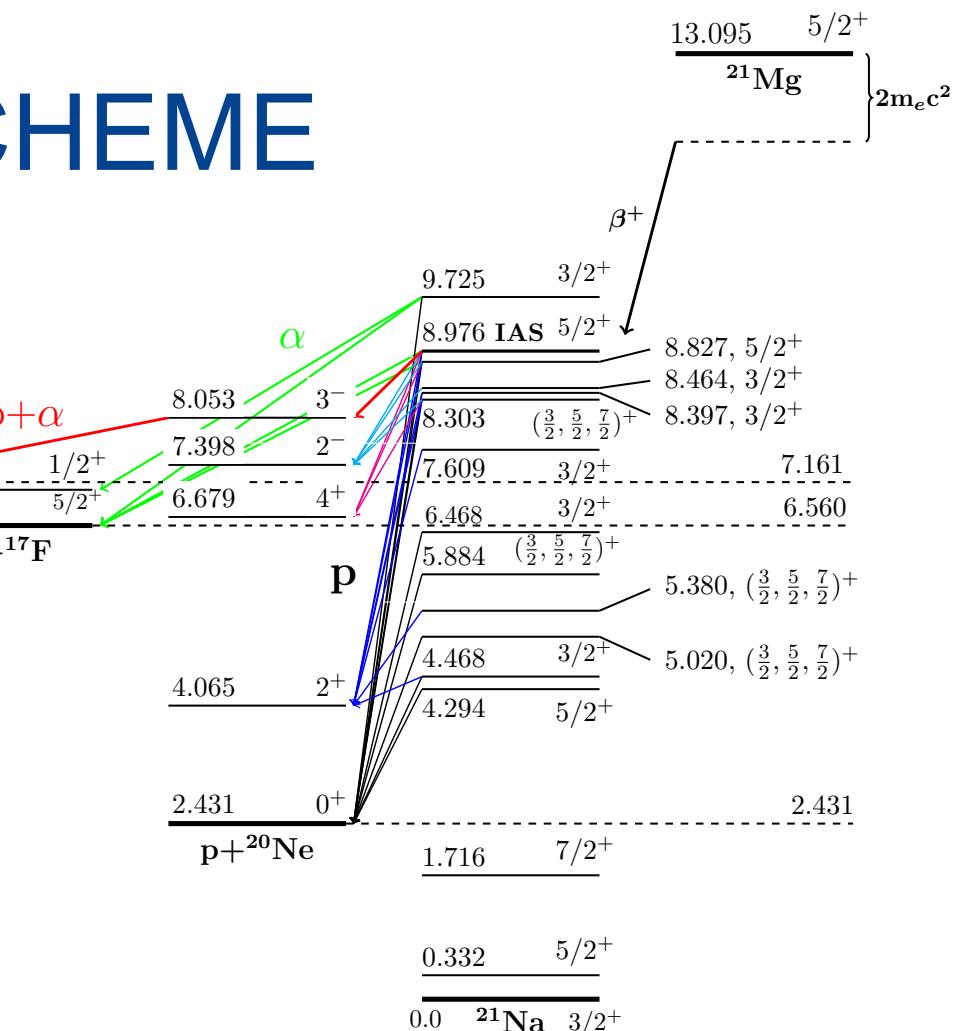


^{21}Mg - DECAY SCHEME

NEW TENTATIVE DECAY SCHEM



- New beta-delayed proton-alpha branch (first measurement)
- New beta-delayed alpha branches (first measurement)
- New tentative interpretation of decay scheme – need gamma's to pin it down completely (future experiment@IDS)



Only showing beta fed resonances.

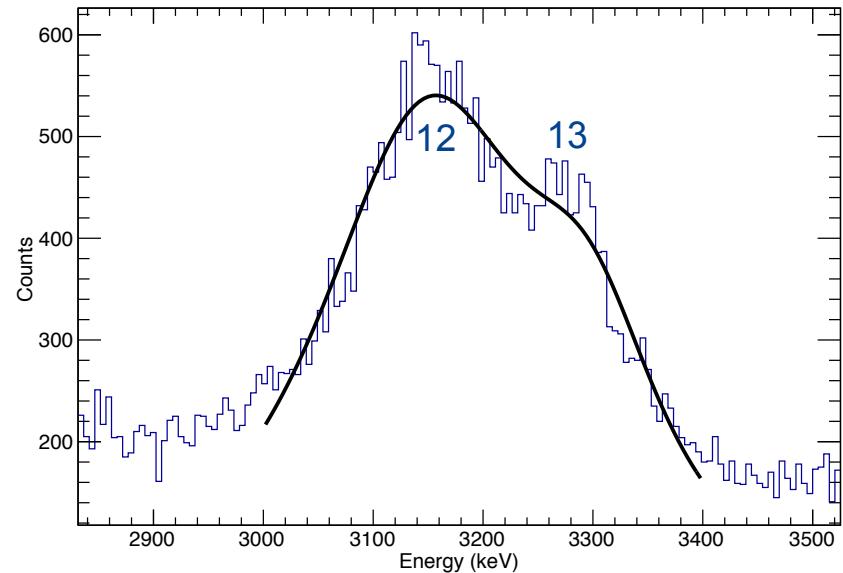
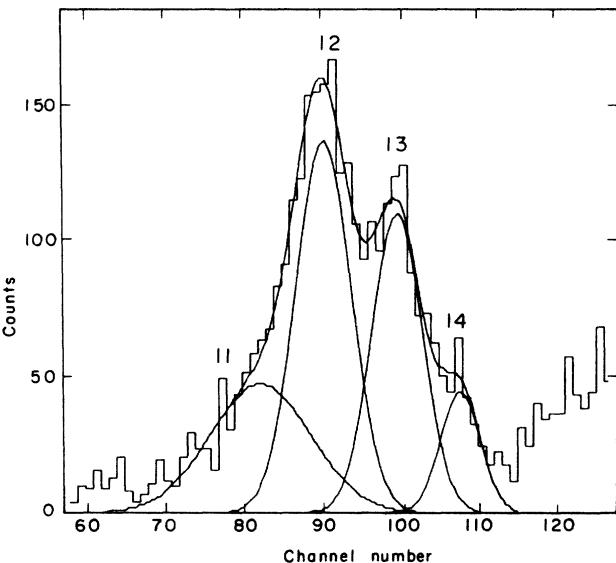
ON BEHALF OF THE IS507
COLLABORATION.

THANK YOU FOR YOUR
ATTENTION!

^{21}MG – DECAY SCHEME

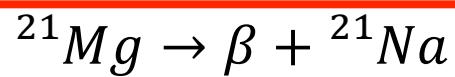
Analysis levels:

- 0th order: Gaussian fit
- 1st order: detector response convoluted with a Breit-Wigner resonance lineshape
- 2nd order: includes also interference

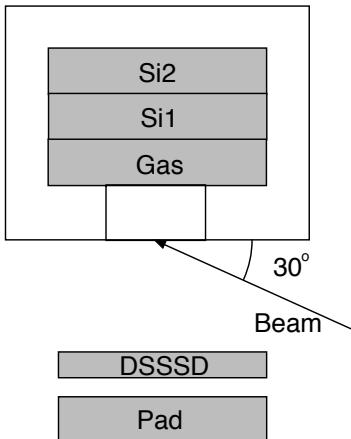
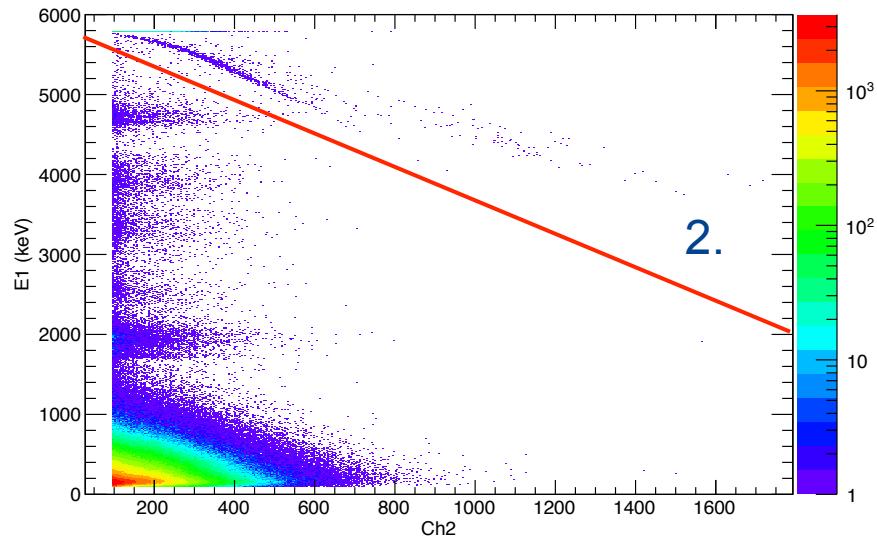
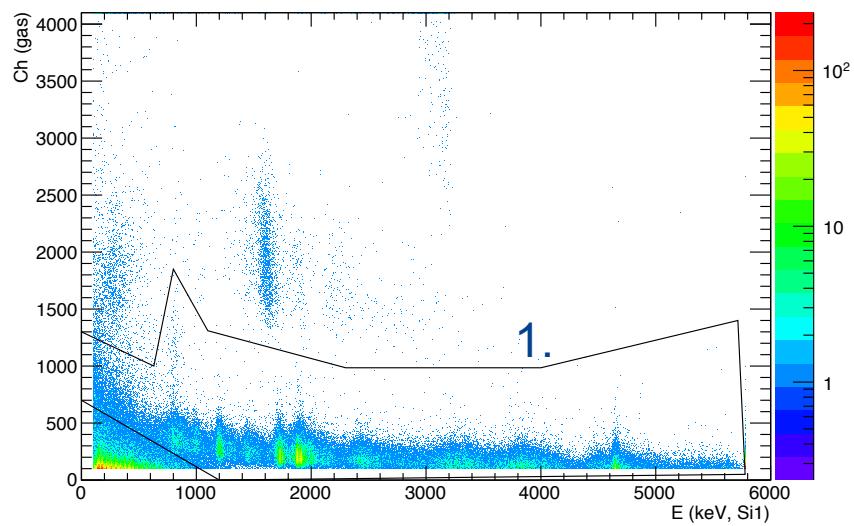


Results:

- In general less proton branches are needed
- Levels only seen by Sextro et al. disappear
- The fitted B.W. widths in agreement with scattering results (when bigger than resolution)



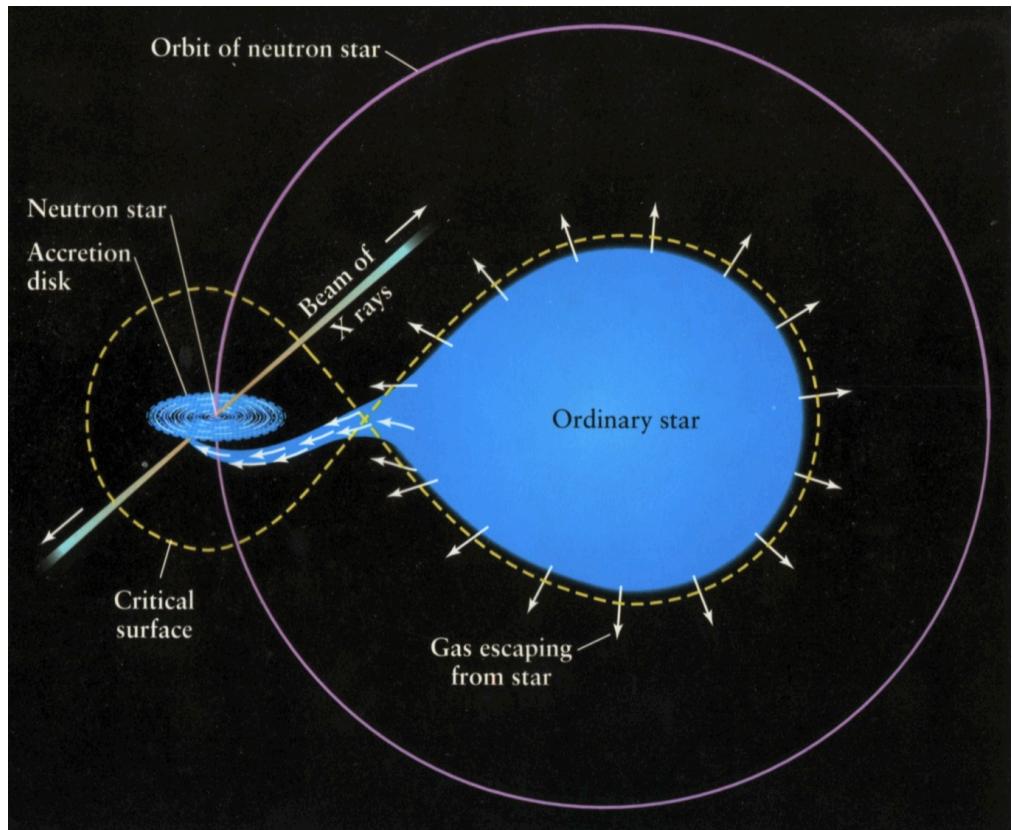
^{21}Mg – PROTON SPECTRUM



1. Remove alpha particles, beta's and recoils
2. Remove punch-through protons

TYPE 1 X-RAY BURST

- Binary star-system: neutron star + light pop. 2 star
- Transfer of material to the neutron star = X-ray emission due to high T
- Explosive H and He burning (HCNO and break-out to A>20)
- Burst time: seconds to minutes
- Time between bursts: hours to days



MOTIVATION II

- Break out sequence from the hot CNO cycle:

$$^{15}\text{O}(\alpha, \gamma)^{19}\text{Ne}(p, \gamma)^{20}\text{Na}$$
- Determination of $J\pi$ for 2.645(6) MeV resonance: 1^+ or 3^+ ?
- Fed in beta decay of ^{20}Mg : allowed or second-forbidden?

