Study of beta delayed particle emission from $^{20-21}$Mg

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EXPERIMENT IS507

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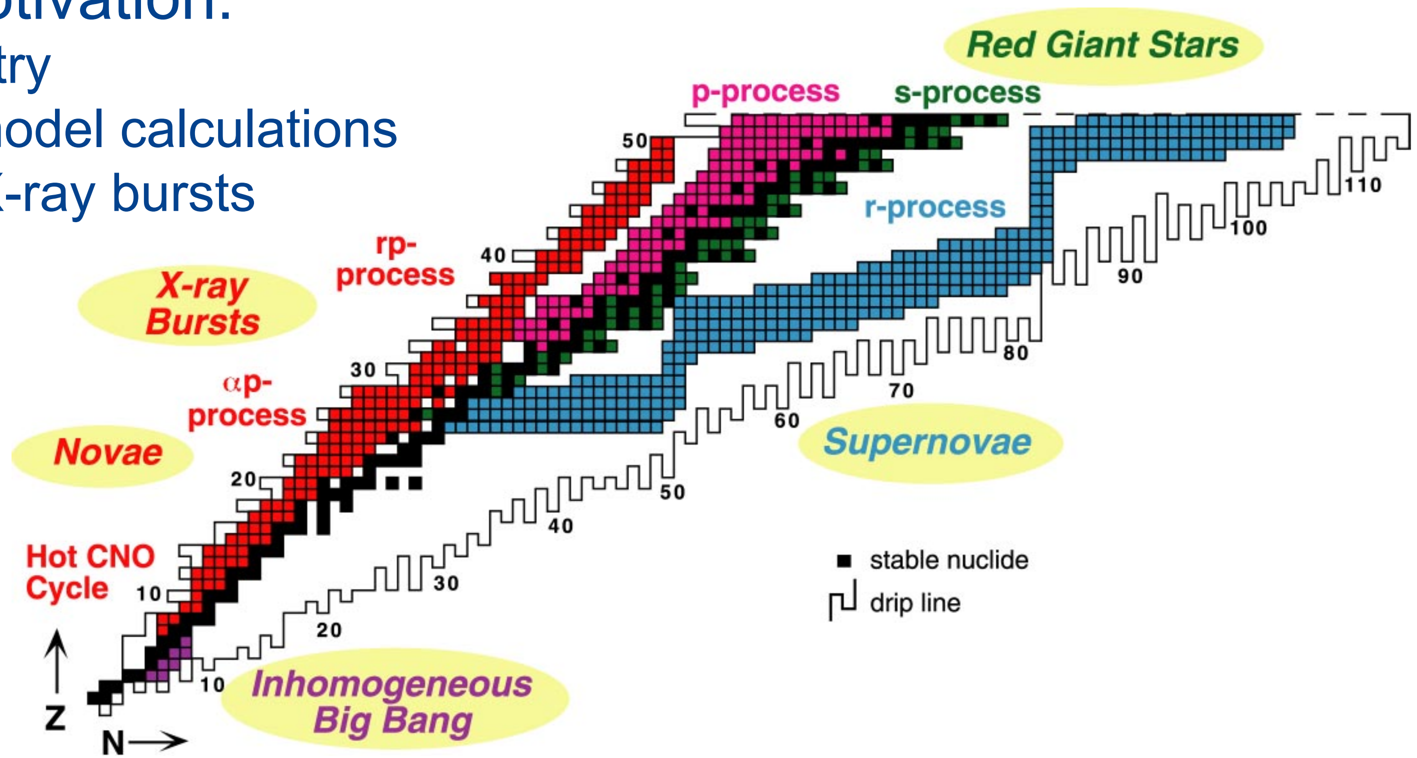
MOTIVATION I

- Threefold motivation:
- Mirror asymmetry
- Modern shell-model calculations
- Astrophysics: X-ray bursts

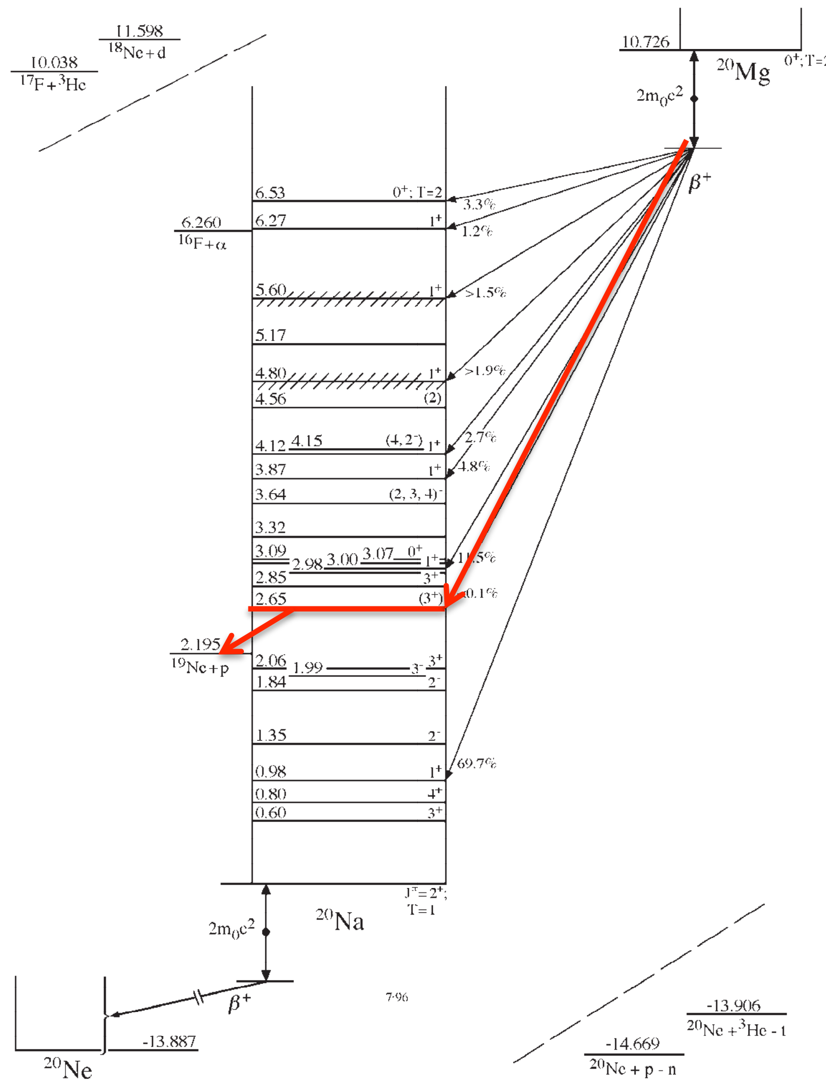


MOTIVATION II

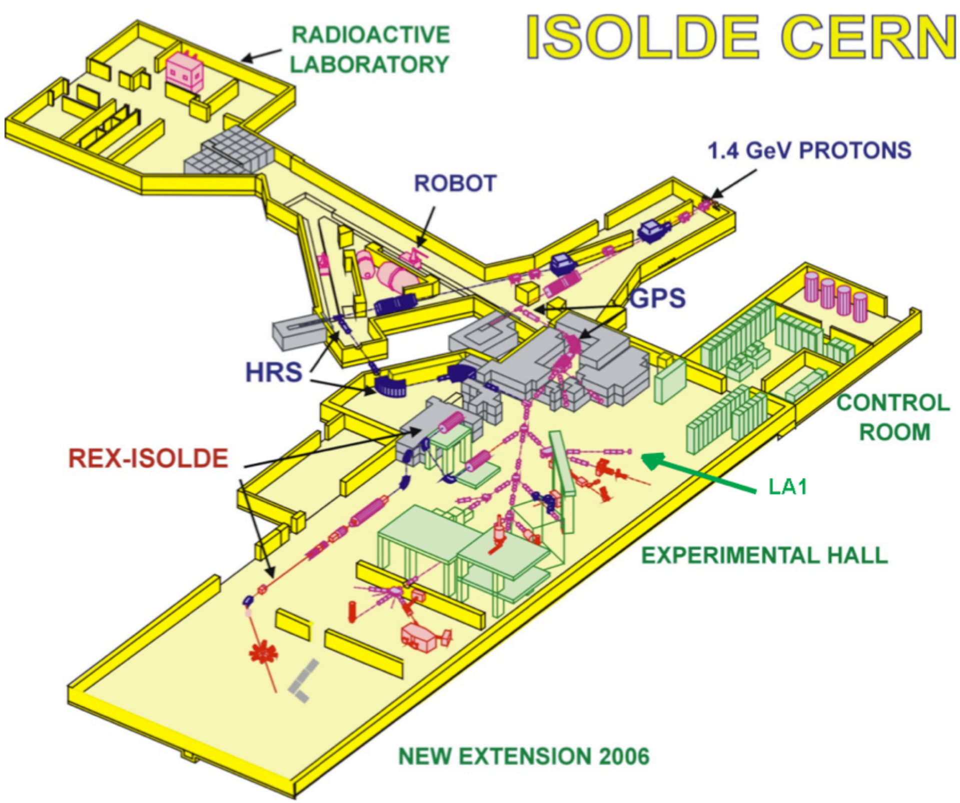
- Break out sequence from the hot CNO cycle:

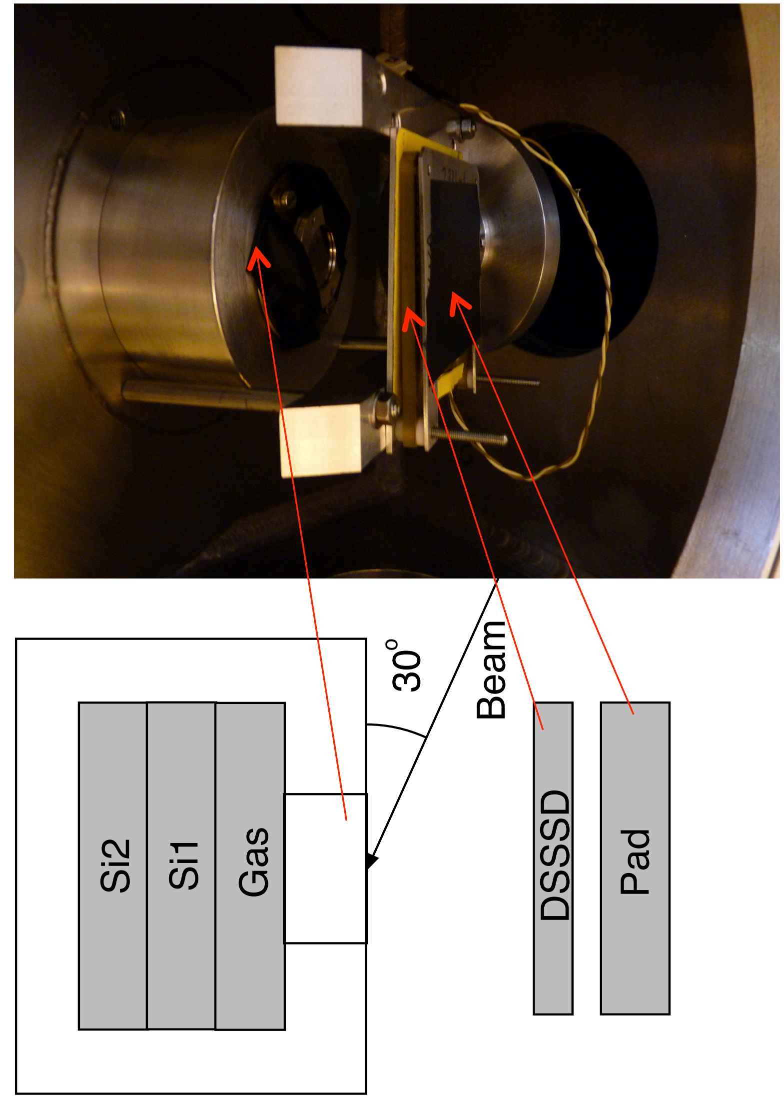
$$^{15}O(\alpha,\gamma)^{19}Ne(p,\gamma)^{20}Na$$

- Determination of Jπ for 2.645(6) MeV resonance: 1^+ or 3^+?
- Fed in beta decay of ^{20}Mg: allowed or second-forbidden?



EXPERIMENT


ISOLDE CERN
RADIOACTIVE
LABORATORY
1.4 GeV PROTONS
ROBOT
GPS
HRS
REX-ISOLDE
CONTROL
ROOM
LA1
EXPERIMENTAL HALL
NEW EXTENSION 2006


30°
Beam
Si2
Si1
Gas
DSSSD
Pad

^{21}MG BETA DECAY

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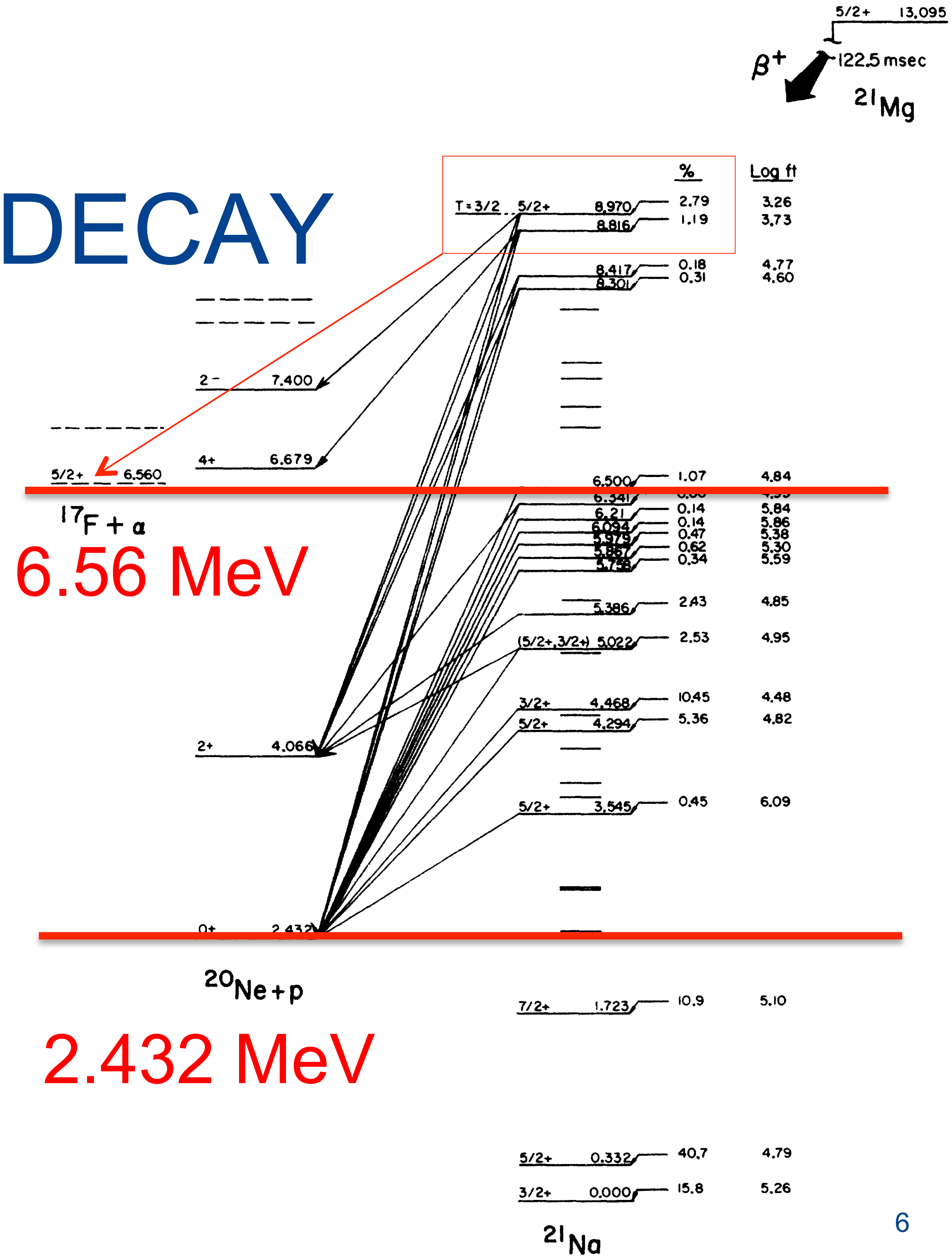
^{21}MG – KNOWN DECAY

- ^{21}Mg is a well known proton emitter
- Used for proton calibration
- Delayed alpha emission energetically allowed:
  - Q_a(8827 keV) = 2267 keV
  - Q_a(8976 keV) = 2416 keV



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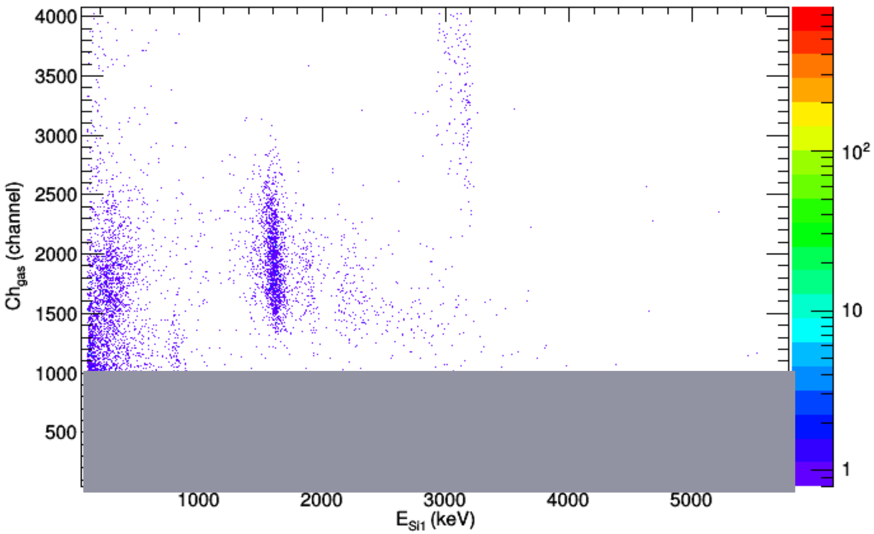
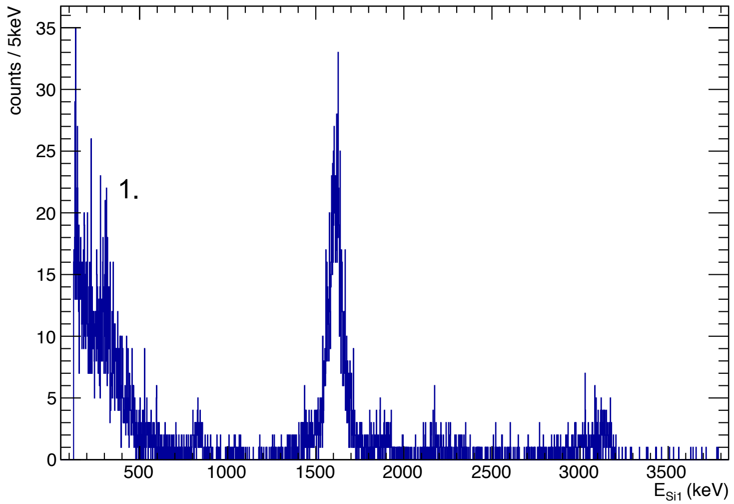
$$^{21}Mg \rightarrow \beta + {}^{21}Na \rightarrow p + {}^{20}Ne \rightarrow \alpha + {}^{16}O$$
$$\downarrow$$
$$^{17}F + \alpha$$

^{21}MG – ALPHA SPECTRUM





1. ^{21}Na (?? MeV) ➔ ^{20}Ne (5.621 MeV) + p ➔ ^{16}O (gs) + a

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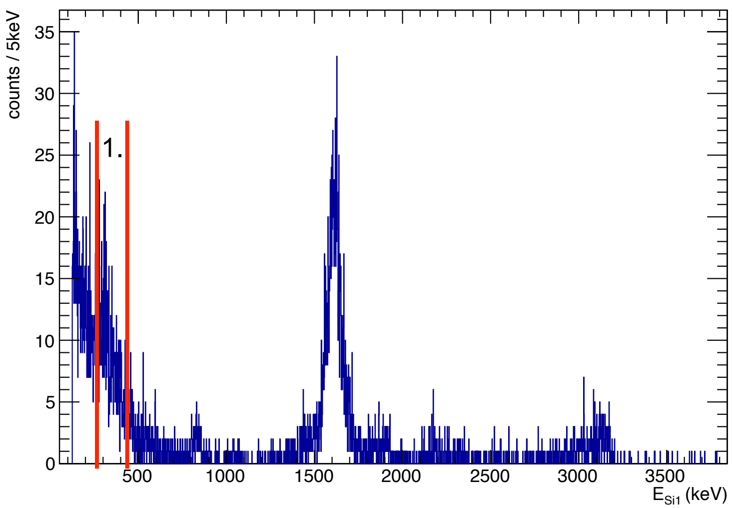
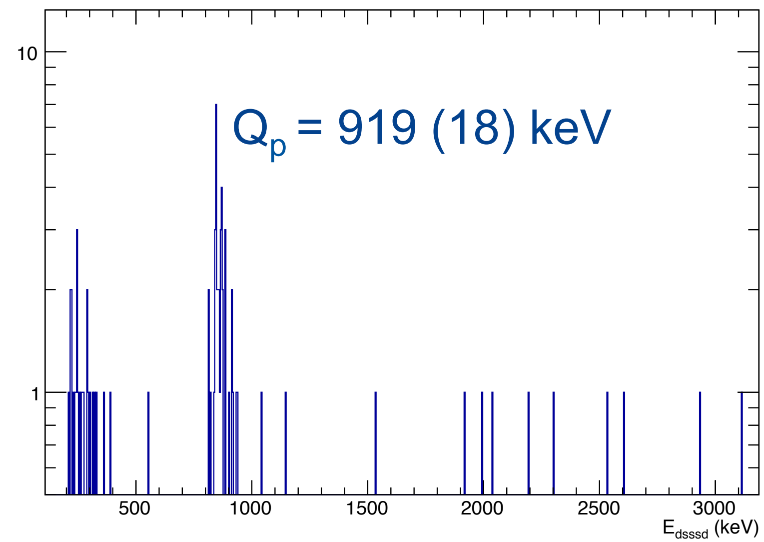
$$^{21}Mg \rightarrow \beta + {}^{21}Na \rightarrow p + {}^{20}Ne \rightarrow \alpha + {}^{16}O$$
$$\downarrow$$
$$^{17}F + \alpha$$

^{21}MG – ALPHA SPECTRUM





1. ^{21}Na (8.976 MeV) ➔ ^{20}Ne (5.621 MeV) + p
   ➔ ^{16}O (gs) + a

$$E(^{21}Na) = (919+5621+2432)\ keV = 8972\ (18)\ keV$$

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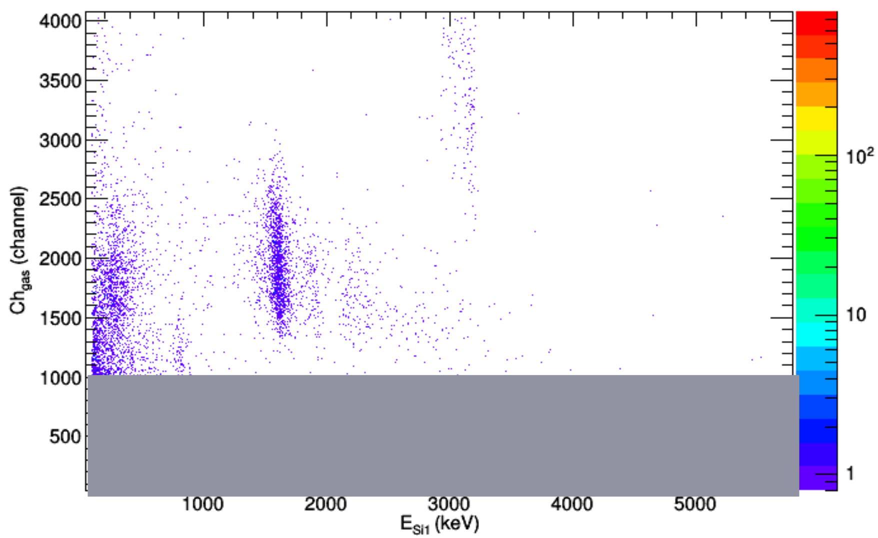
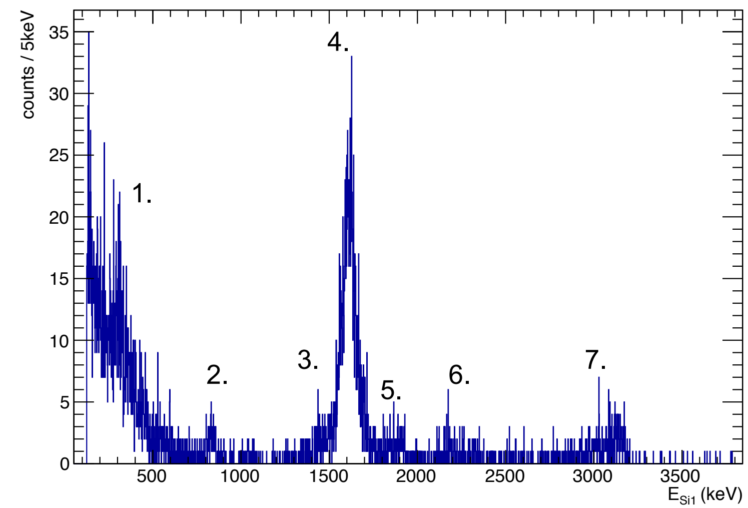
$$^{21}Mg \rightarrow \beta + {}^{21}Na \rightarrow p + {}^{20}Ne \rightarrow \alpha + {}^{16}O$$
$$\downarrow$$
$$^{17}F + \alpha$$

^{21}MG – ALPHA SPECTRUM





1. ^{21}Na (8.976 MeV) ➔ ^{20}Ne (5.621 MeV) + p ➔ ^{16}O (gs) + a
2. Proton tail
3. ^{21}Na (8.827 MeV) ➔ ^{17}F (gs) + a
4. ^{21}Na (8.976 MeV) ➔ ^{17}F (gs) + a
5. ??
6. ??
7. ^{148}Gd

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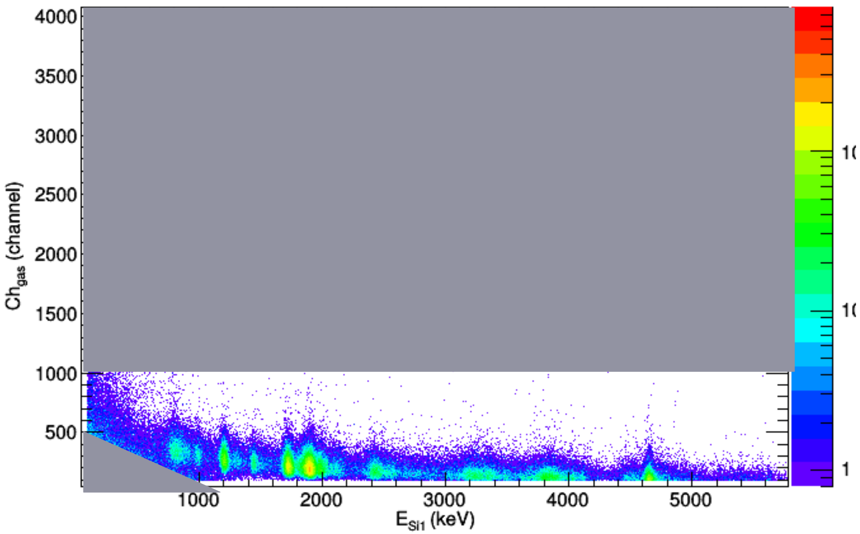
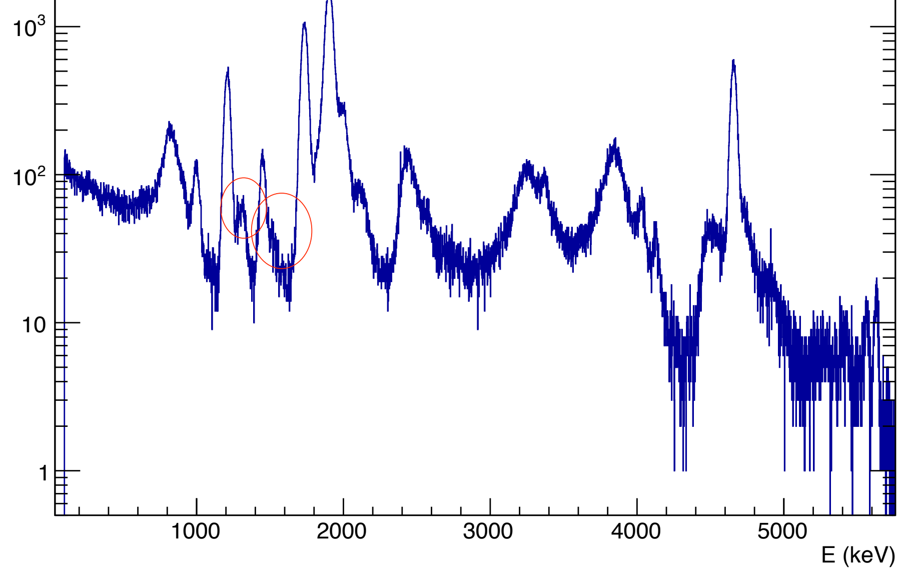
$$^{21}Mg \rightarrow \beta + {}^{21}Na \downarrow {}^{20}Ne + p$$

^{21}MG – PROTON SPECTRUM

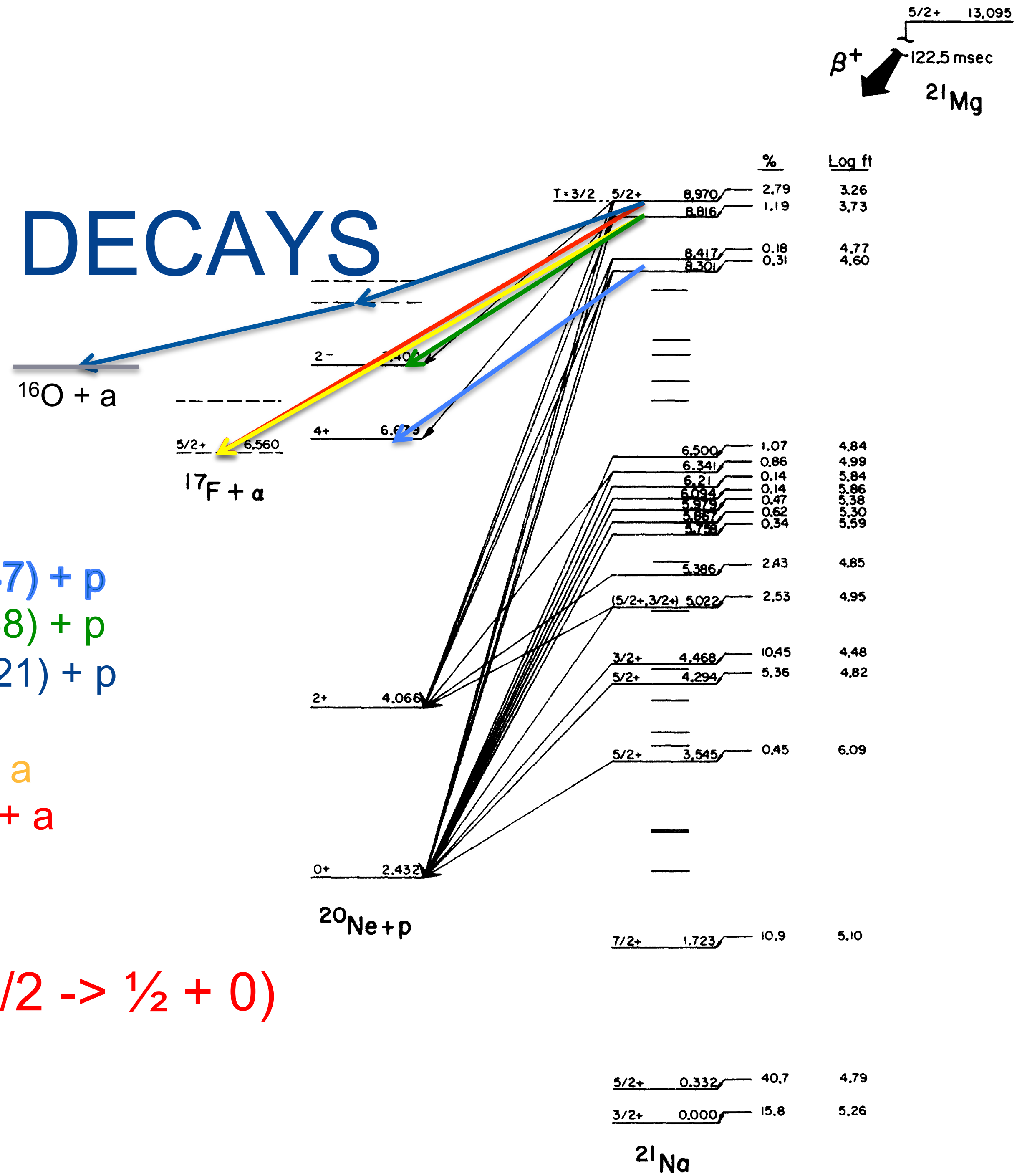




Q_p = 1416 (6) keV : ^{21}Na(8827) ➔ ^{20}Ne(4968) + p

Q_p = 1626 (17) keV : ^{21}Na(8303) ➔ ^{20}Ne(4247) + p

^{21}MG – NEW DECAYS

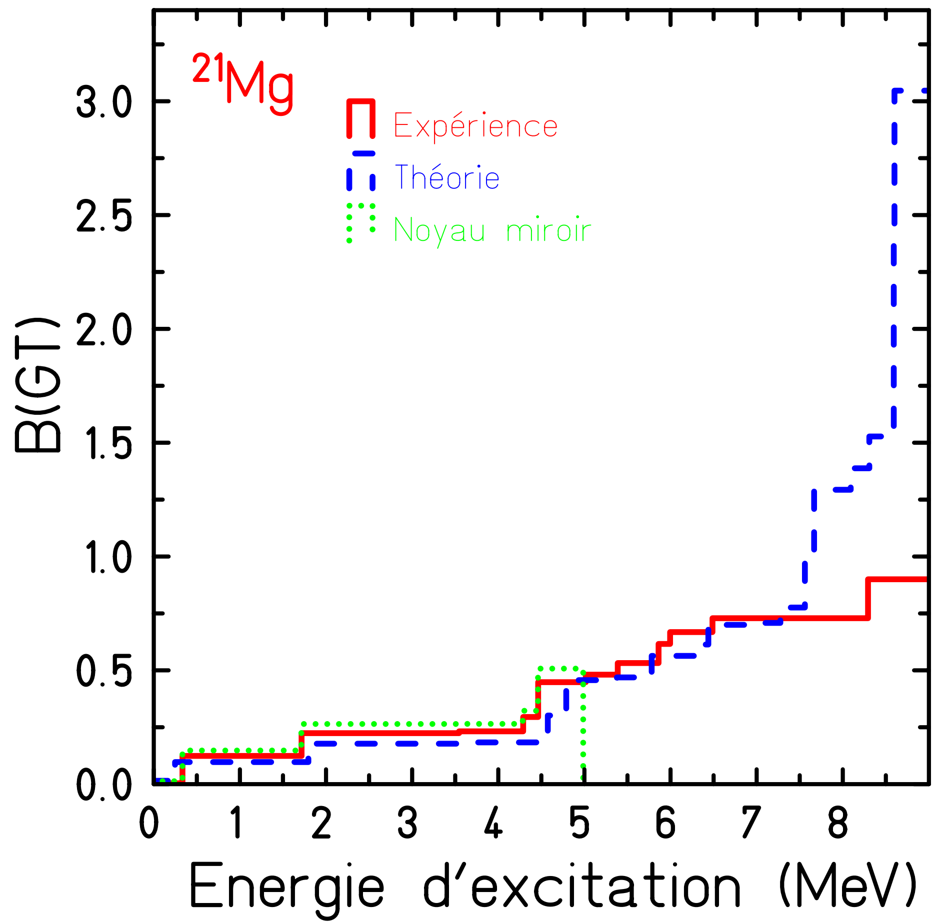


1. ^{21}Na(8303) ➔ ^{20}Ne(4247) + p
2. ^{21}Na(8827) ➔ ^{20}Ne(4968) + p
3. ^{21}Na (8976) ➔ ^{20}Ne (5621) + p
   ➔ ^{16}O (gs) + a
4. ^{21}Na (8827) ➔ ^{17}F (gs) + a
5. ^{21}Na (8976) ➔ ^{17}F (gs) + a

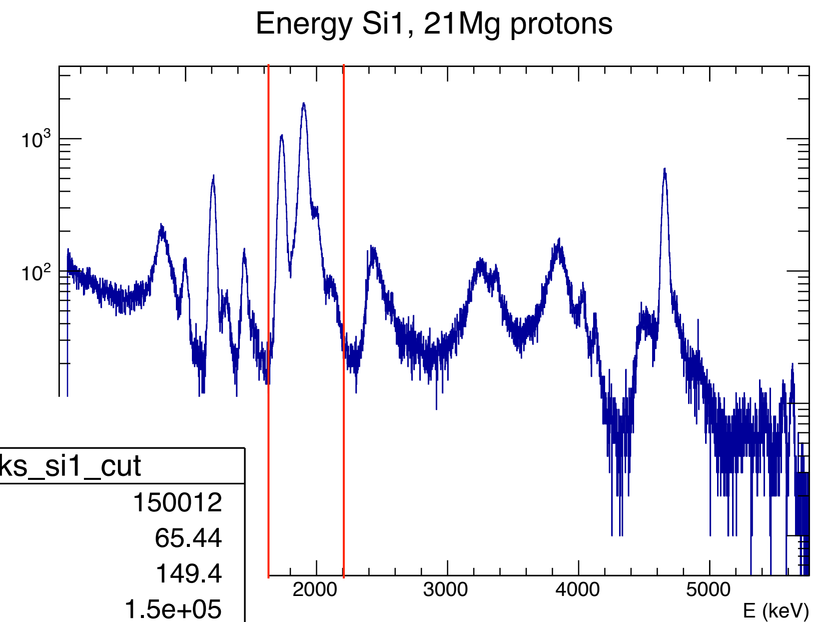
5.: Isospin mixing (3/2 -> ½ + 0)

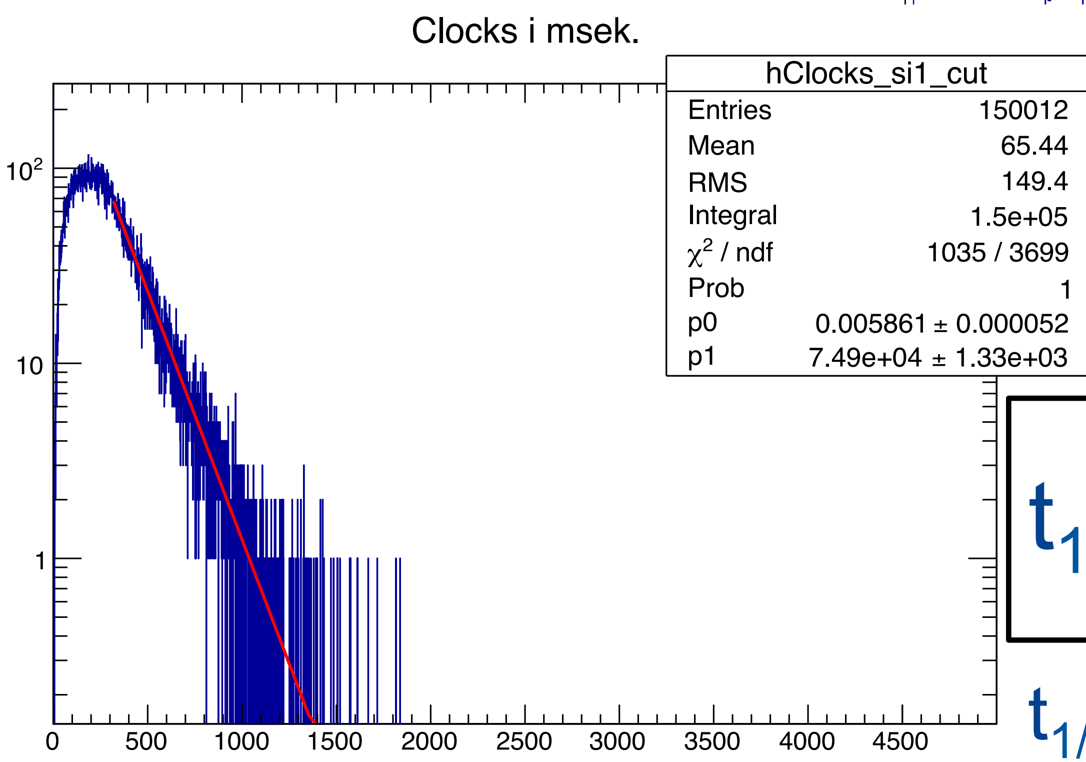
B(GT) DISTRIBUTION

- From dissertation of Jean Charles Thomas, Bordeaux
- Theory by B. A. Brown
- Next step!



^{21}MG – HALF-LIFE





$t_{1/2} = 118\ (1)$ ms

$t_{1/2}(\text{ref}) = 122\ (3)$ ms

^{20}MG BETA DECAY

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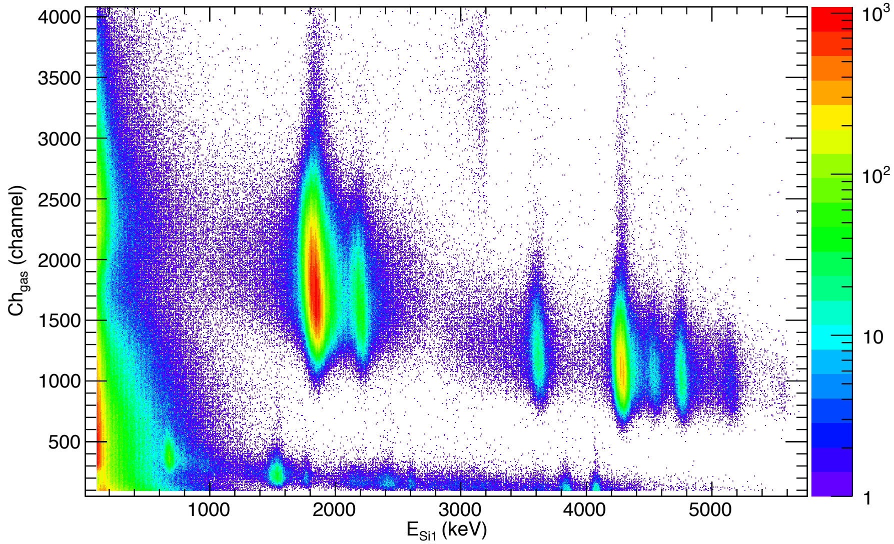
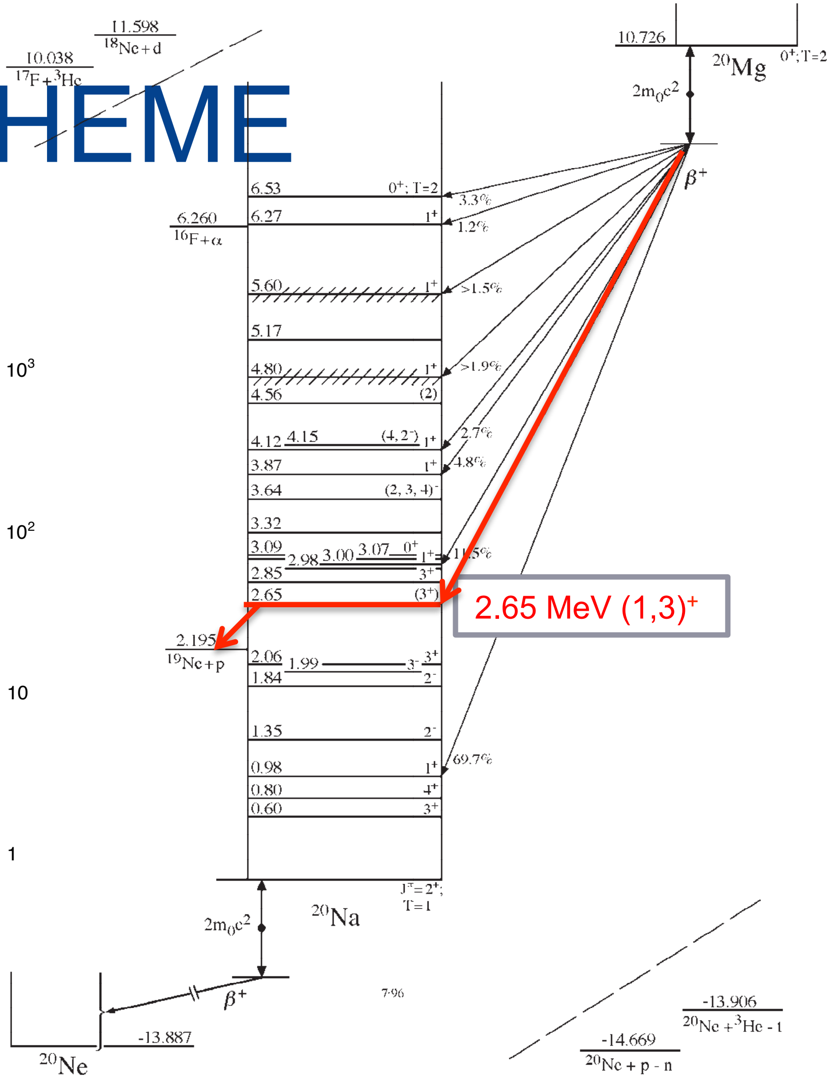
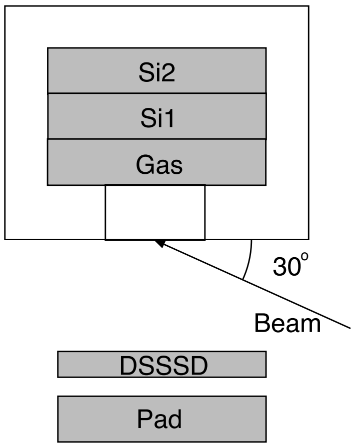
^{20}MG DECAY SCHEME

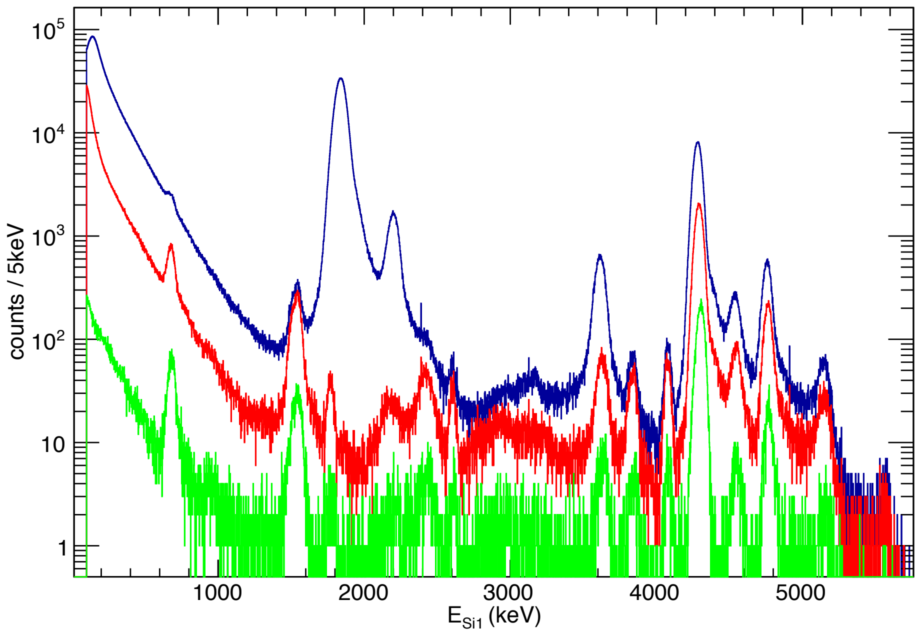




^{20}NA RESONANCE – J^{P}?



- 1^{+} or 3^{+}
- Proton, Q = 450keV
- Blue: full spectrum
- Red: gate on gas (100-1000)
- Green: Cut on Si2 (E=0) and Pad (E>0)



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PERSPECTIVES

- B_{β}(2,65MeV) < 0,02%
- In-flight method
- Small beta response
- Can't separate α's and protons
- Beta summing

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ELSEVIER

β-Delayed proton-decay study of ^{20}Mg and its implications for the ^{19}Ne(p, γ)^{20}Na breakout reaction in X-ray bursts

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ABSTRACT

Under astrophysical conditions of high temperature and density, such as for example found in X-ray bursts, breakout can occur from the hot CNO cycles into the rapid proton capture process. A key breakout route is via the sequence ^{15}O(α,γ)^{19}Ne(p, γ)^{20}Na. The ^{19}Ne(p, γ)^{20}Na reaction rate is expected to be dominated by a single resonance at 457(3) keV. The identity of the resonance has been under discussion for a long time, with $J^{\pi} = 1^+$ and 3^+ assignments suggested. In this study of the β-delayed proton decay of ^{20}Mg we report a new, significantly more stringent, upper limit on the β-decay branch to this state of 0.02% with a confidence level of 90%. This makes a 1^+ assignment highly unlikely and favours a 3^+ assignment for which no branch is expected to be observed. The 3^+ state is predicted to have a significantly higher resonance strength, and to produce a proportionately higher ^{19}Ne(p, γ)^{20}Na reaction rate in X-ray burst conditions.

1. Introduction

In explosive astrophysical phenomena in which temperatures in excess of 0.5 GK are achieved, such as X-ray bursts, it is possible to breakout from the β-limited hot CNO cycles into the rp process, a series of rapid proton capture reactions synthesizing proton-rich nuclei potentially up to the Sb–Te mass region [1,2]. It is expected that the reaction sequence ^{15}O(α,γ)^{19}Ne(p, γ)^{20}Na provides the main link between the two processes, with its strength determining the conditions for ignition of the X-ray burst and the recurrence rate [3,4]. As such, extensive efforts have been made to determine both the ^{15}O(α,γ)^{19}Ne and ^{19}Ne(p, γ)^{20}Na astrophysical reaction rates (see Ref. [4] for a recent discussion of the former reaction). Under X-ray burst conditions, the ^{19}Ne(p, γ)^{20}Na reaction is thought to be dominated by the contribution of a single low-energy resonance ~450 keV above the proton-emission threshold energy of 2190.1(11) keV in ^{20}Na [5]. The identity of this resonance, and hence its inferred strength, has remained a matter of intense debate for over two decades. Direct measurements of the strength have been attempted using radioactive beams of ^{19}Ne [6–10], but so far only an upper limit of 15 meV with a 90% confidence level has been determined [10].

Lamm et al. [11] studied the ^{20}Ne(^{3}He, t)^{20}Na charge exchange reaction, and from a DWBA analysis made a 1^+ (spin and parity, J^{π}) resonance assignment for the state at an excitation energy ~2650 keV in ^{20}Na, pairing it with a 1^+ level at an energy of 3173 keV in ^{20}F. However, Clarke et al. [12] studied both the ^{20}Ne(^{3}He, t)^{20}Na and ^{20}Ne(t, ^{3}He)^{20}F charge exchange reactions and found the angular distributions to be incompatible with these being analogue states. Rather, they noted a good agreement could be obtained with a known 3^+ level at 2966 keV in ^{20}F [12]. Similarly, a study of the ^{20}Ne(p, n)^{20}Na reaction made a 3^+ assignment for the ~2650 keV state in ^{20}Na [13]. Arguing from a shell model perspective, Fortune et al. [14] pointed out that a large Coulomb energy shift is required for the ~2650 keV level which can only be achieved for states with a large $2s_{1/2}$ component, and is only satisfied by the 3^+ level in this excitation energy region of ^{20}F. The 1^+ state at 3173 keV in ^{20}F is suggested as having a $(sd)^6p^{-2}$ configuration which would not exhibit a significant Coulomb energy shift, whereas the known 1^+ state at 3488 keV is considered to have much too large a shift relative to the ~2650 keV level in ^{20}Na [15]. For a 3^+ assignment, Fortune et al. derived a lower limit on the resonance strength of 16 meV [14], tantalizingly close to the experimental upper limit of 15 meV [10]. In contrast, taking a 1^+ assignment, a value for the strength of 6 meV has been estimated [9], which is more clearly compatible with the upper limit

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THANK YOU!

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