New experimental measurements of the $^{16}O(p,\alpha)^{13}N$ reaction rate and its impact on SNIa models

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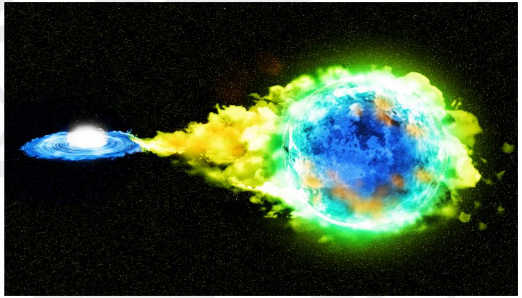
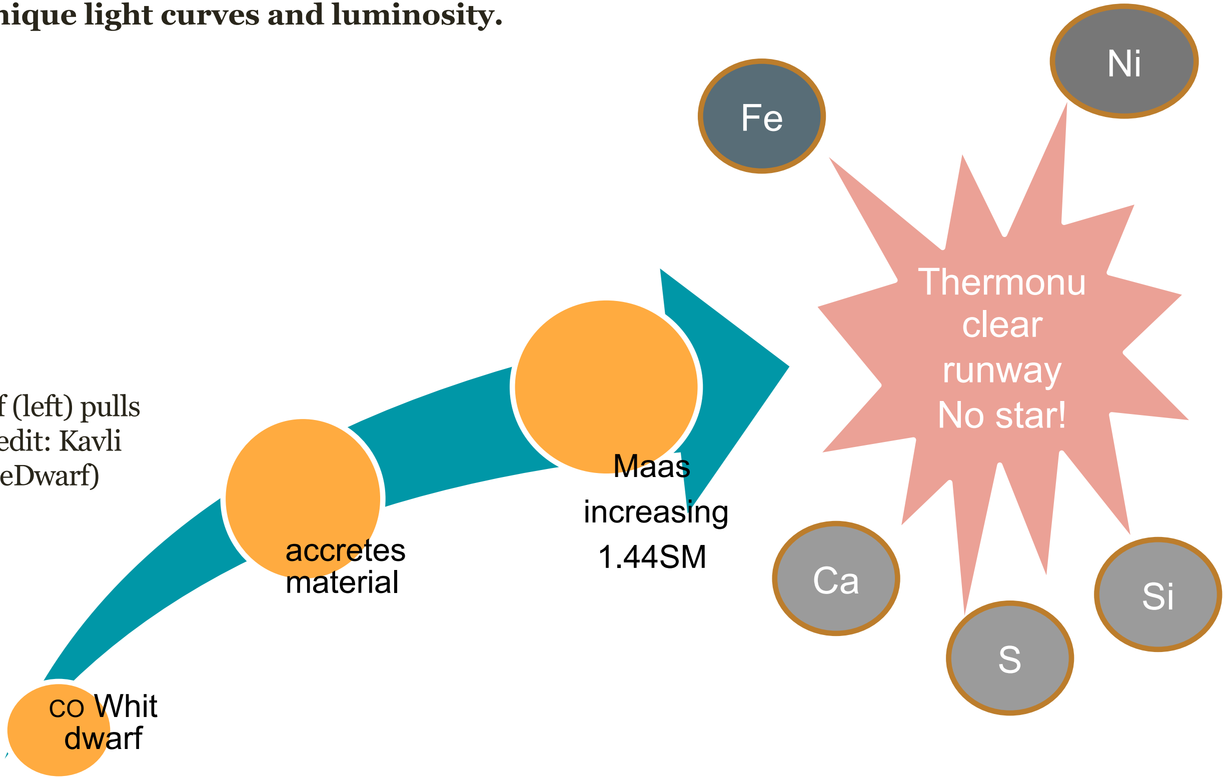
Introduction: SNIa explosion Brife

(SNIa),are known cosmic candles.
due to unique light curves and luminosity.



An illustration of a Type Ia supernova, a white dwarf (left) pulls material from a nearby companion star(right). (Credit: Kavli IPMU:https://www.ipmu.jp/en/20180921-WhiteDwarf)



Intermediate mass elements nucleosynthesis in SNIa

Oxygen Burning

$^{16}_{8}O + ^{16}_{8}O \rightarrow ^{28}_{14}Si + ^{4}_{2}He$

Adding alpha particles lead to more heavier elements like (^{40}Ca, ^{32}S, Ar …) to be created. →

$$^{12}_{6}C + ^{4}_{2}He \longrightarrow ^{16}_{8}O + \gamma$$
$$^{16}_{8}O + ^{4}_{2}He \longrightarrow ^{20}_{10}Ne + \gamma$$
$$^{20}_{10}Ne + ^{4}_{2}He \longrightarrow ^{24}_{12}Mg + \gamma$$
$$^{24}_{12}Mg + ^{4}_{2}He \longrightarrow ^{28}_{14}Si + \gamma$$
$$^{28}_{14}Si + ^{4}_{2}He \longrightarrow ^{32}_{16}S + \gamma$$
$$^{32}_{16}S + ^{4}_{2}He \longrightarrow ^{36}_{18}Ar + \gamma$$
$$^{36}_{18}Ar + ^{4}_{2}He \longrightarrow ^{40}_{20}Ca + \gamma$$

Studies have shown how the oxygen burning nucleosyntheses differ with alpha:

- **lower alpha lead to more sulfur (^{32}S)production relative to calcium (^{40}Ca) .**
- **Higher alpha lead to more sulfur (^{40}Ca) production relative to calcium (^{32}S) .**

$$\boxed{M_{Ca}/M_{S} \propto X_{\alpha}^{2}}$$

(De et al. 2014)

The role of $^{16}O(p,\alpha)^{13}N$ in nucleosynthesis of SNIa

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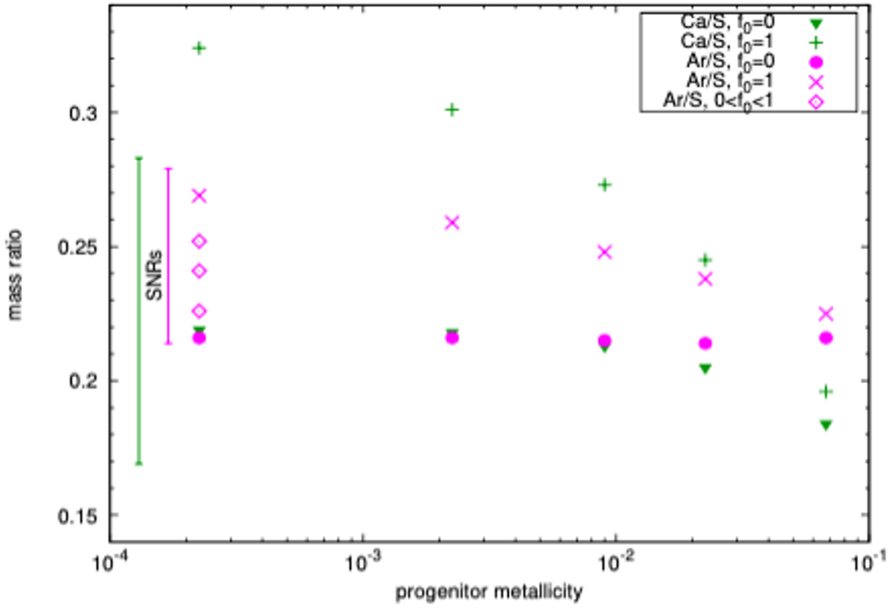
$^{16}O(p,\alpha)^{13}N \longrightarrow {}^{13}N(\gamma,p)^{12}C$

enhances the alpha , boost the $^{12}C+^{12}C$ reaction
→ building more of intermediate-mass elements..

$^{16}O(p,\alpha)^{13}N$ reaction rate depends on the proton abundance.

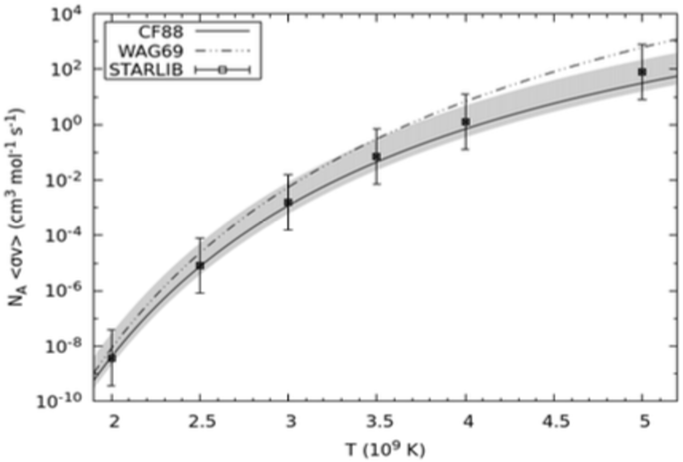
High proton available in lower metallicity progenitor!!



Theoretical mass ratios of calcium to sulfur (in green) and argon to sulfur (in magenta) from models of detonation of a 1.06 $M_\odot$ WD, as function of the progenitor metallicity, with either the standard $^{16}O(p,\alpha)^{13}N$ reaction rate ($f_0 = 1$) or the rate switched off ($f_0 = 0$). The argon-to-sulfur mass ratio for $Z = 2.25 \times 10^{-4}$ is shown as well for several other values of f_0, from bottom to top: $f_0 = 0.1$, 0.3, and 0.5. The vertical bars on the left of the figure show the range of observational mass ratios derived from measurements of X-ray emission of SNRs (Martínez-Rodríguez et al. 2017).

!->increasing Ca/S ratio related to decreasing metallicity and vice versa

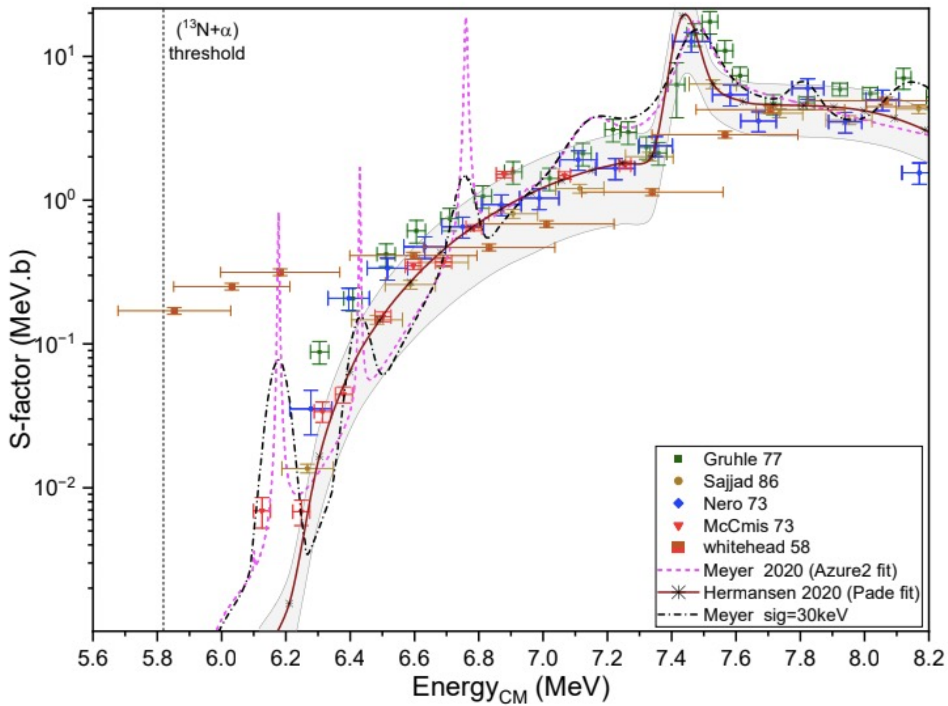
Problem of current $^{16}O(p,\alpha)^{13}N$ reaction rates



Rate of the reaction $^{16}O(p,\alpha)^{13}N$, as a function of temperature in units of 10^9 K, from different compilations: Caughlan & Fowler (1988, CF88), Wagoner (1969, WAG69), and Sallaska et al. (2013, STARLIB). The uncertainty listed in the STARLIB compilation is plotted as a vertical error bar. The shaded band shows the uncertainty on the rate as determined using measured calcium-to-sulfur and argon-to-sulfur mass ratios in SNRs (see text for details).

WAG69: no origin
REACLIB: no uncertainty
STARLIB: statistical model

Previous measurements of $^{16}O(p,\alpha)^{13}N$ cross-section showed discrepancies on their value, and don't agree within uncertainty.



A new measurement of $^{16}O(p,\alpha)^{13}N$ Cross-section E_{cm} =5.8-6.9MeV using MUSIC

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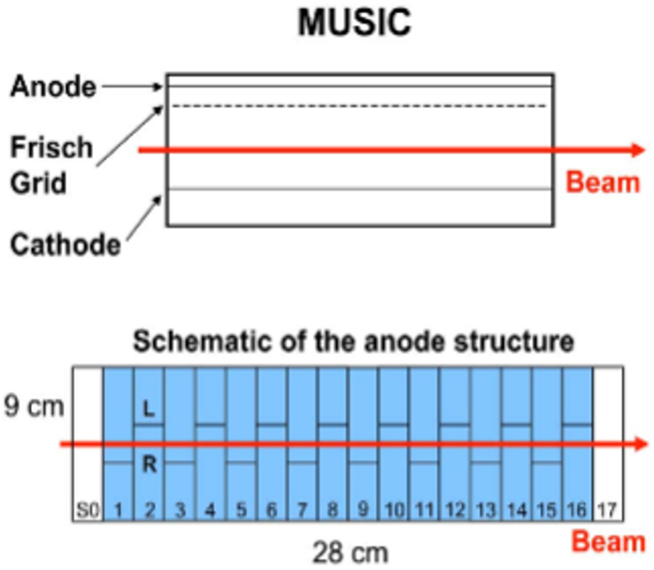
active target

Gas:
detector & target

All particles detected



Schematic of the MUSIC detector (from Ref. [5]). Upper panel: lateral view of the detector. Lower panel: anode structure, showing the 18 strips. Strips 1–16 are subdivided into non-symmetric left and right sections.

3

array of 18 anode

Filtering background

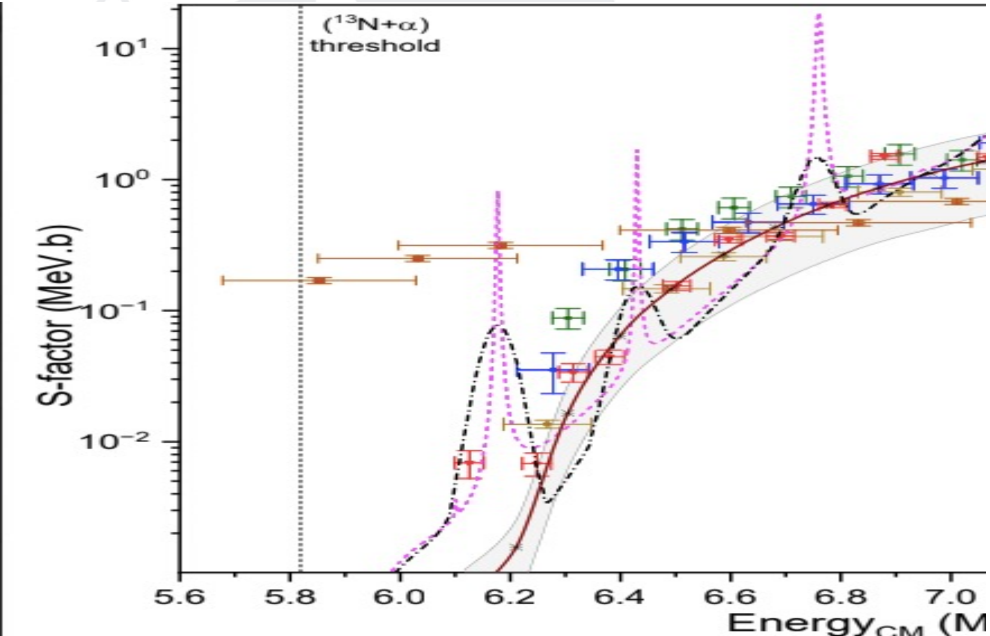
Single Beam wide Ecm range

- **Each ion travels in the detector loses energy in increments across these strips.**
- **Each particle has its own pattern in losing Energy**
- **Eloss (ΔE) $\propto Z$**

MUSIC experimental setup for $^{16}O(p,\alpha)^{13}N$

- **Inverse kinematics**
- **136-MeV 16O beam Energy**
- **pure methane gas at 700Torr.**

- **Covers a centre of mass energy range of ~5.8-6.9 MeV, with a 275-keV resolution.**



- methane pressure 716,88 (GHS calibration)
- error from strip width (15.8 cm)

Results

Strip	Ecm (MeV)	Error (MeV)
1	6.91231	0.133371
2	6.64159	0.137352
3	6.36252	0.141721
4	6.07425	0.146548
5	5.77578	0.151917
6	5.46593	0.157939
7	5.14323	0.16476
8	4.8059	0.172572
9	4.45168	0.181643
10	4.07768	0.192353
11	3.68006	0.205267
12	3.25353	0.221264
13	2.79045	0.241818
14	2.27897	0.269664
15	1.69854	0.310762
16	1.00705	0.380732

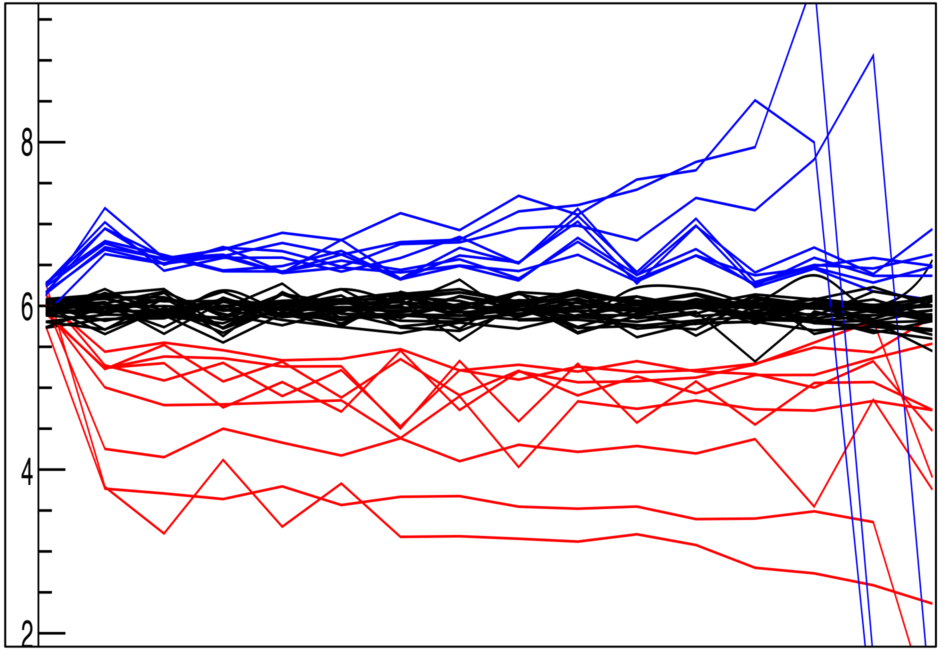
Beam Normalization and events Categorizing:

1- background events: excluded.

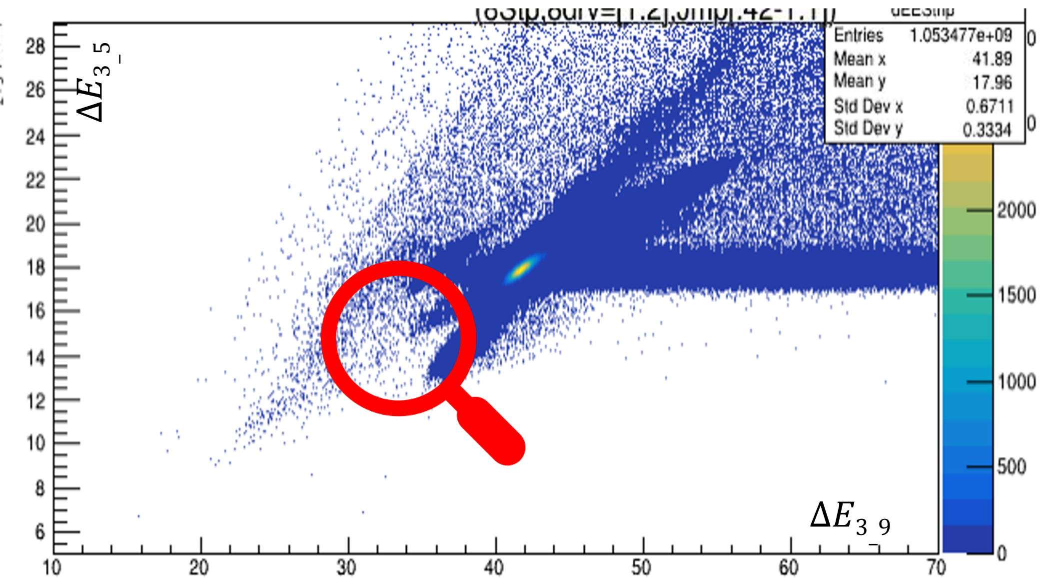
2-Beam events: Normalized Eloss= 6±0.147

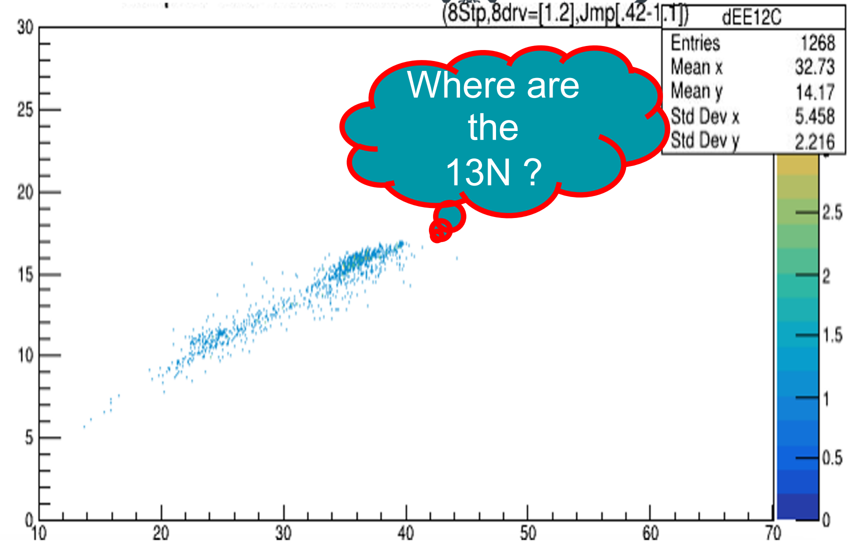
3-Jumps on the Eloss:

- Higher events: event with Eloss > 6+2(0.147) → resulted from Ions heavier then beam(potentially 25Mg, 26Al…).
- Lower events: event with Eloss < 6-2(0.147) → resulted from Ions Lighter then beam (potentially 13N, 11B, 12C…).



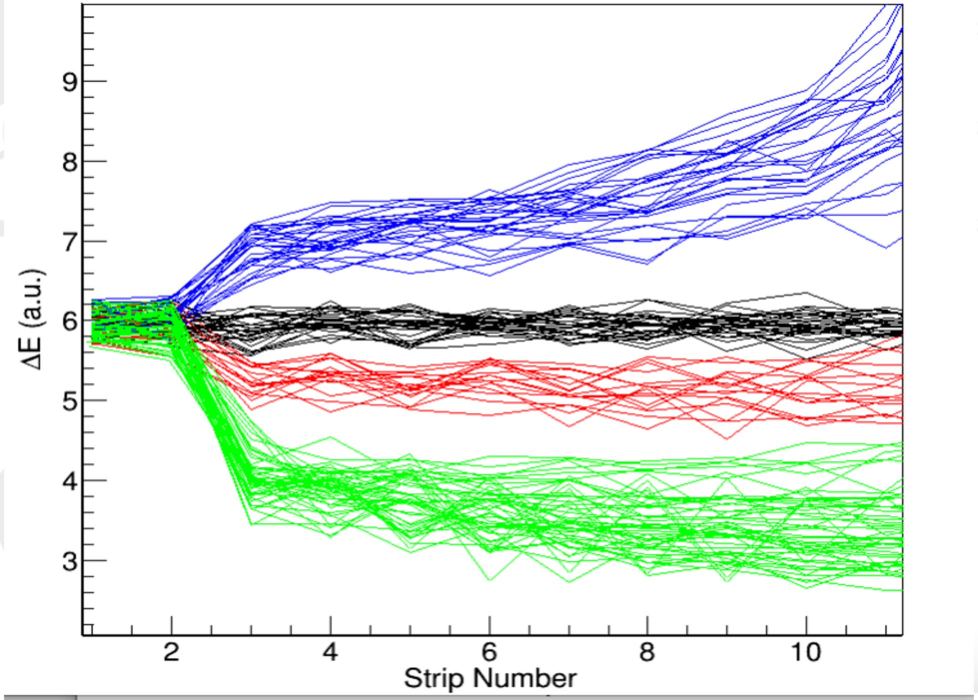
Strip analysis and events counting

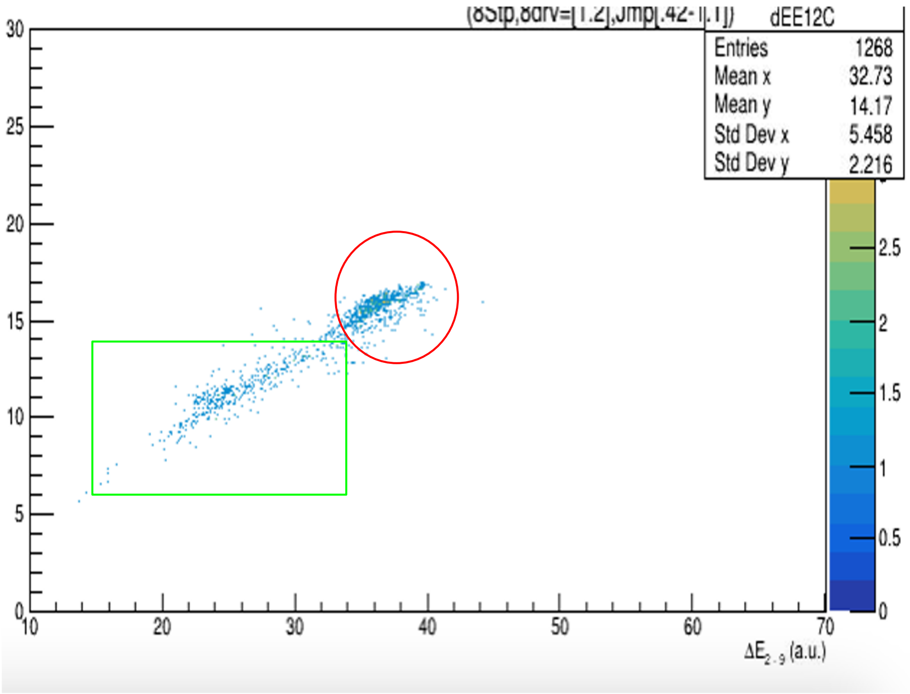




Strip3 unfiltered events (left) compared to the events with Eloss-Only- Lower than the beam (right)

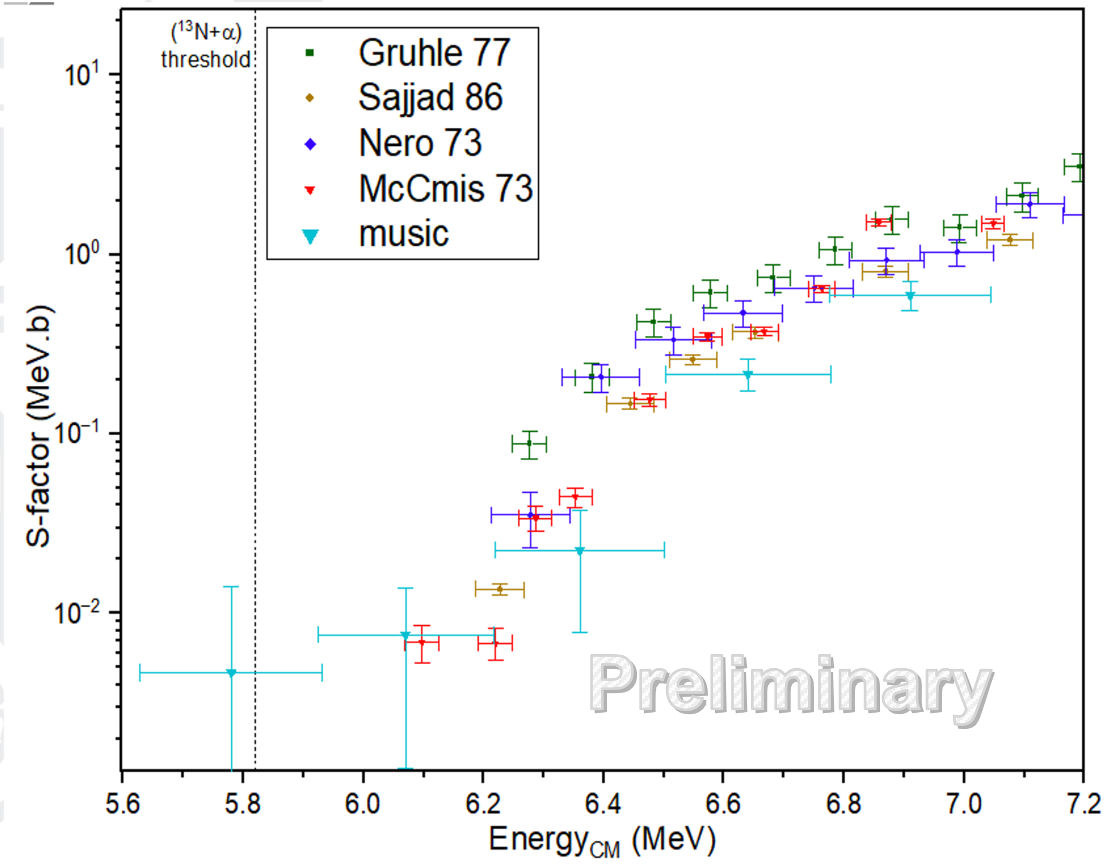
Traces and dE-dE identification





Strip 2 traces compared to the dEE plot shows how the blob in red consistance with the red lined in the traces.. And for the green traces, the scatter of the events is reflected on the grean traces .

Cross-secion calculation



Summary

- The $^{16}O(p,\alpha)^{13}N$ reaction can give hents on the metallicity of the SNIa progenitor.
- Previous rates poorly constrained.
- The New cross section measurement with MUSIC provides promises to refine our models of SNIa with reliable rate and meaningful uncertainty.
- Calculating the new rate, after refining the data.
- Helps bridging the gap between theory and observational data have a deeper understanding of SNIa synthesis and progenitor.

Thanks

A. Laird [1], H. Jayatissa[2], N. de Séréville[3],
M. Avila[2], C. Fougères[3], B. Kay[2], S. Chakraborty[1],
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