The ^{19}F(p,α) reaction studied via Trojan Horse Method

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Galactic fluorine: stellar production sites

- ^{19}F abundance is very sensitive to physical condition in stars
- stellar production sites: **AGB stars**, type II supernovae (SNe II), Wolf-Rayet (W-R) stars

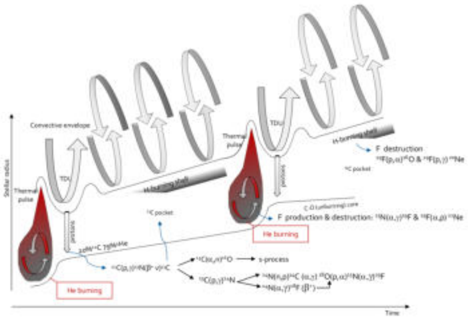

Figure 1: Temporal evolution of the internal structure of an **AGB star** [1] shows complex reaction network dependant on the physical condition in stars, which proceed throught radiative burning in **H-shell** and convective burning in He-shell via *thermal pulses*. Degenerative core is made of carbon and oxygen.

^{19}F - complex production network in **AGB** stars:

- production through series of p,n,α,γ reactions with ^{14,15}N and ^{13}C in H-rich environment
- main destruction channels are (α,p) in He-burning shell and (p,α) & (p,γ) in H-burning shell

[1] S. Palmerini et al. (2019) J.Phys.Conf.Ser.1308, 012016 and ref. therein

Galactic fluorine: direct vs. indirect measurements

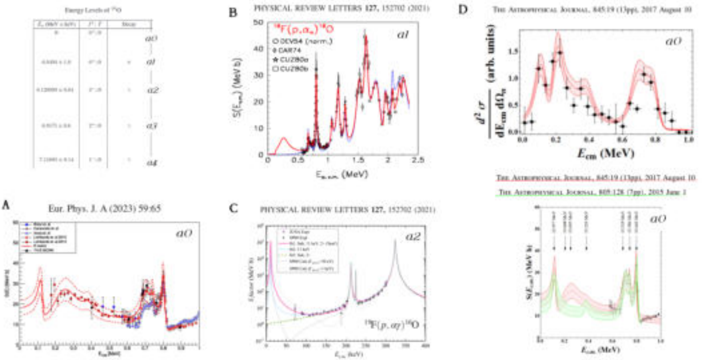

Figure 2: left+middle:(direct data) **A** Guardo et al. (2023) measurement of ^{19}F(p,α_0)^{16}O channel, **B** Lombardo et al. (2019) measurement of ^{19}F(p,α_π)^{16}O channel, **C** Zhang et al. (2021) measurement of ^{19}F(p,α_γ)^{16}O channel, right:(THM data) **D** Indelicato et al. (2017) measurement of ^{19}F(p,α_0)^{16}O channel (up), overlapped with La Cognata et al. (2015) results (down).

[B] Guardo, G.L. et al. (2023) E.P.J.A, 59:65, **[B]** Lombardo, I. et al. (2019) P.R.C 100, 044307, **[C]** Zhang, L. et al. (2021) P.R.L.127, 152702, **[Da]**, Indelicato, I. et al. (2017), ApJ 845, 19 **[Db]** La Cognata, M. et al. (2015), ApJ 805, 805:128 (7pp)

Experiment at INFN-LNS in Catania

Measurement:

- performed at INFN-LNS (Catania)
- 6 $\times$ silicon Position Sensitive Detectors
- 2 $\times$ Ionization Chambers filled with Isobutane gas at $\sim$**52.5mbar**

Ingredients:

- ^{19}F beam (55MeV)
- CD_2 target ($\sim$ 100 μg/cm^2)
- ^{2}H used as **THM nucleus** due to p $\otimes$ n cluster structure (l=0, $p_s \propto 0$)

Method:

- selection of the proper quasi-free contribution of the ^{19}F(d,α^{16}O)n reaction to measure ^{19}**F(p,α)^{16}O** reaction

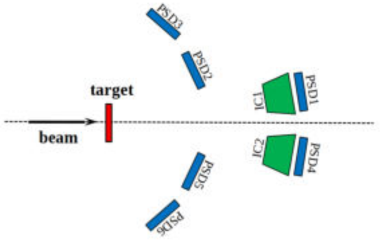

Figure 3: Experimental setup used at INFN-LNS for complete kinematic measurement of the ^{19}F(d,α^{16}O)n reaction optimised for QF conditions.

ANALYSIS:

N.V. (a1o4 & o1a4), X.Su (a2o4) and G.G.Rapisarda (o1a5)

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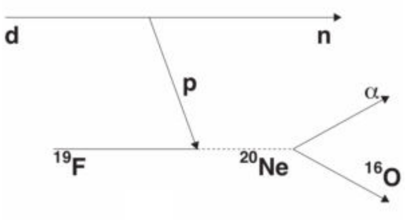


Figure 4: Schematic diagram of the ^{19}F(d,α^{16}O)n **QF** reaction. The upper vertex describes the virtual decay of the THM-nucleus ^{2}H into the participant **p** and spectator **n**, while the ^{19}F(p,α)^{16}O reaction that takes place in the lower vertex.

Experimental details: PSD energy & position signal

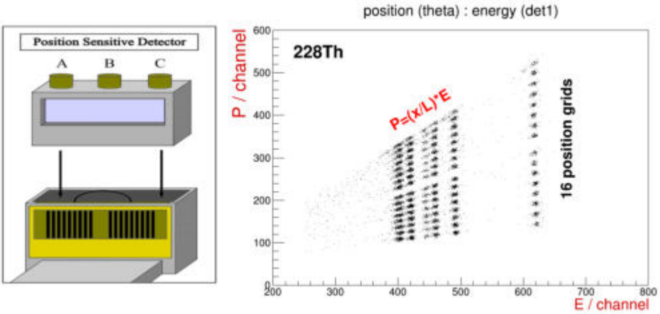


Figure 5: **P**osition vs. **E**nergy spectrum of the (**PSD**) detector for the ^{228}Th α-source with 16 position grids used for calibration of the detector.

CALIBRATION PROCEDURE

16 individual **P/E** peaks for each α and elastics (^{197}Au,^{12}C) beam energy

$\rightarrow$ one **a**(θ) and **b**(θ) set of calibration parameters for **E/P** per detector

Experimental details: PSD+IC calibration

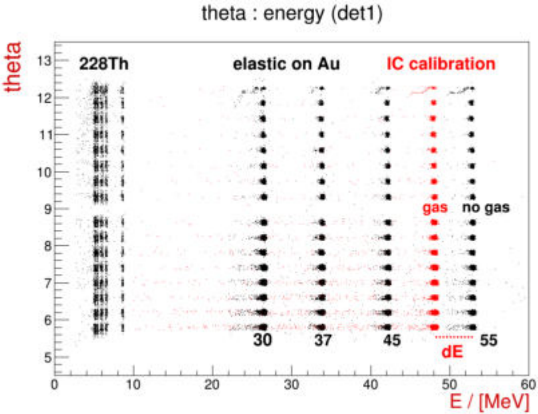


Figure 6: **T**heta vs. **E**nergy spectrum of the (**PSD**) detector for the ^{228}**Th** α-source and elastics ($E_{^{16}O}$=55,45,37,30 MeV) on ^{197}**Au** target. Elastic scattering on ^{12}**C** target omitted here, but was used in the calibration of PSD's.

Experimental details: data (reaction products) selection

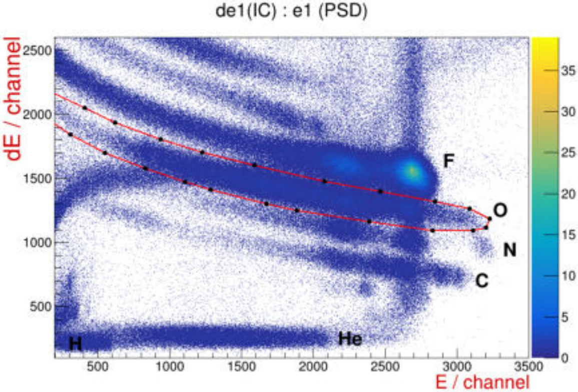


Figure 7: Δ**E** vs. **E** spectrum with graphical cut to select ^{16}**O** in detector-1. With the "gate" on ^{16}**O**, α was selected in detector-4. For detectors 2 & 5 α's were selected via kinematical conditions (X.Su - *Russbach'18* and G.G.R. analysis).

Experimental details: calibration vs. calculation for dE

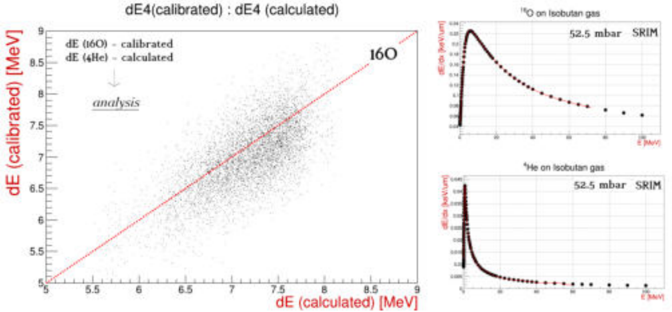


Figure 8: (left) Comparison spectrum for **ΔE** - IC4 (X_{length}=50mm, isobutane gas at ~52.5 mbar) for ^{16}O energy loss calculated with SRIM (x) vs. calibration (y). (right) Calculation in **SRIM** for dE/dx in isobutane gas at 52.5 mbar ($\rho \propto P$).

◦ for final results calibrated value was used for ^{16}O and calculated for ^{4}He ◦

Analysis: identification of the exit channel

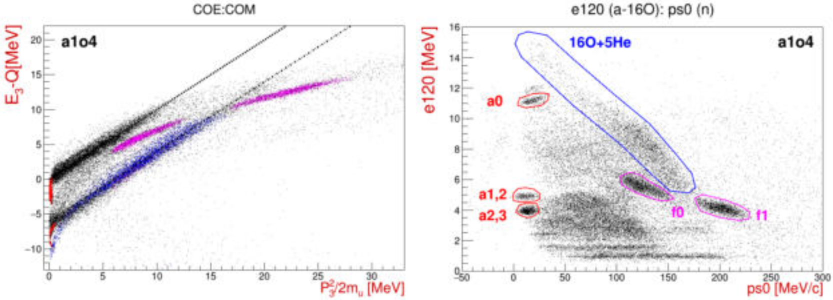
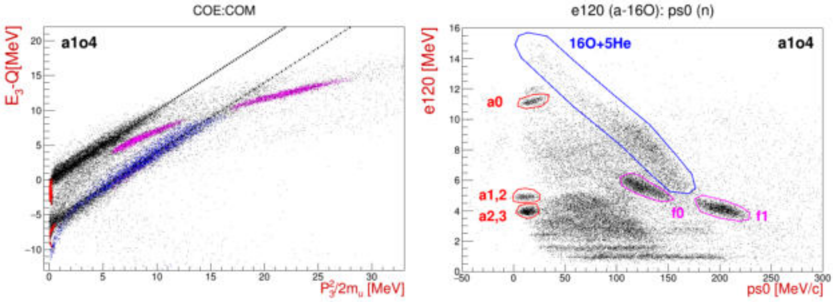


Figure 9: (left) The "Romano" plot [⊗] correlates COE and COM without assumption of the exit channel, which can be identified via slope of the data locus for undetected nucleus $\sim$ **1/A**$_3$. The intercept on the y-axis indicates **-Q** value.(right) Relative energy "e12" of detected pair of nuclei (^{16}O$+\alpha$) versus the momentum of the spectator "ps" (n) for 3-body quasi-free reaction. (*note*) No channel-ID cuts on these plots, so $\alpha_0, \alpha_{1,2}, \alpha_{3,4}$ are all present.

e12 $\propto$ **f**(E$_1$,θ_1,E$_2$,θ_2), straight line locus in e12 $\sim$ resonance in compound nucleus (^{20}Ne)

[⊗] Costanzo, E. et al. (1990) N.I.M.A, 295, 373

Analysis: identification of the exit channel



- **THM** reaction of interest:

$$^{19}\text{F}+\mathbf{d}\rightarrow\ ^{20}\mathbf{Ne}^{*}+\text{n}_s \rightarrow (^{16}\text{O}+\alpha_{0,1,2,3,4})_{\text{detected}}+\text{n}_s$$

- reaction proceeds through the ground state of ^{5}He:

$$^{19}\text{F}+\mathbf{d} \rightarrow\ ^{16}\text{O}+^{5}\mathbf{He} \rightarrow (^{16}\text{O}+\alpha)_{\text{detected}}+\text{n}$$

- $\propto$ 1% of ^{1}H in CD_2 target - 2-body reactions

$$^{19}\text{F}+\mathbf{p} \rightarrow (^{16}\text{O}+\alpha_{0,1,2\ldots})_{\text{detected}}$$

Analysis: QC of the data :: 2-body reactions

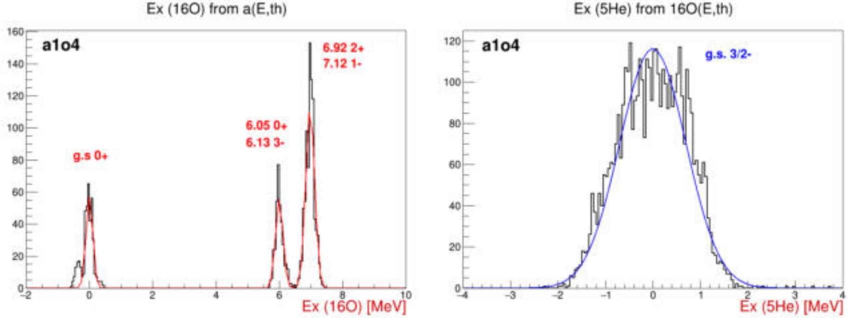


Figure 10: left: Excitation energy of the ^{16}O, calculated from the (E,θ) of detected α. right: Excitation energy of the ^{5}He, calculated from the (E,θ) of detected ^{16}O nuclei. Both data are coming from α+^{16}O coincidences in front detectors: 1+4.

for B(T,a)x reaction, Ex(x) $\propto$ $\mathbf{f}$(Q,E_a,θ_a)

Analysis: QC of the data :: α_0 channel

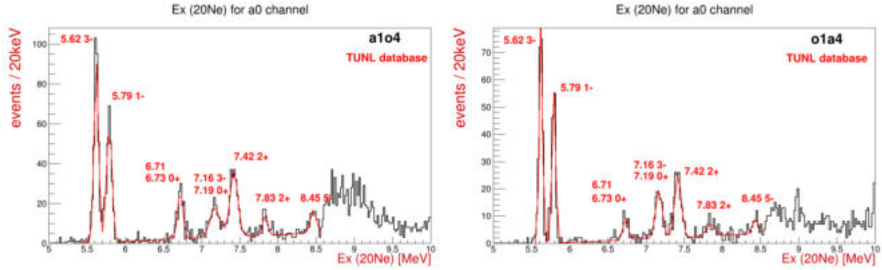


Figure 11: Excitation energy of the ^{20}Ne nucleus from the ^{19}F(d,^{16}Oα)n reaction. left: a1o4 coincidence, right: o1a4 coincidence.

Ex(^{20}Ne) $=$ E12$_{\text{relative energy}}$ $+$ E$_{\text{decay treshold}}$; for ^{20}Ne tresholds are 4.73 MeV for α_0, while it's 4.73+6.05 MeV for α_1, 4.73+6.13 MeV for α_2 ...

Analysis: comparison with MC simulations :: $\alpha_{1,2}$ channel

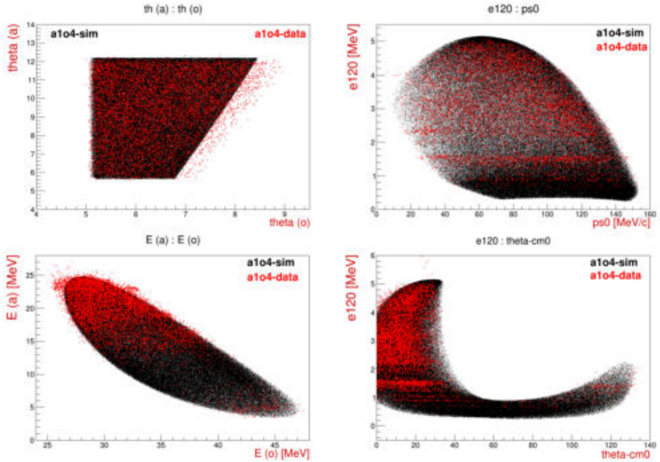
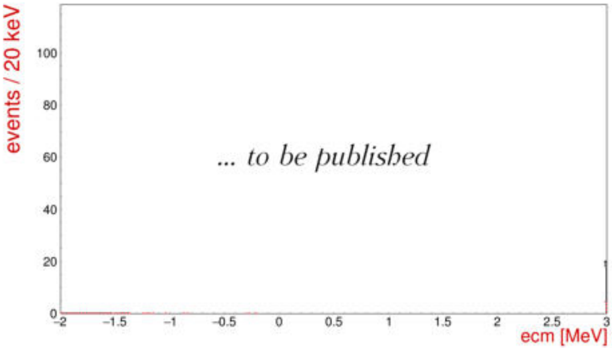


Figure 12: Comparison of the relevant distributions for **a1o4 data** and realistic **MC simulations** (*phase space*). Good agreement among the two is particularly important for the $\theta_{\mathbf{CM}}$ and **ps** (*momentum of the spectator*) distributions.

Results: $\alpha_{1,2}$ channel



Thank you for the attention!

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