University of Padova

Beihang University

Measurement of the cross section for the reaction $p + {}^{19}F \rightarrow {}^{16}O + {}^{4}He$ in the range of astrophysical interest

18th Russbach School on Nuclear Astrophysics

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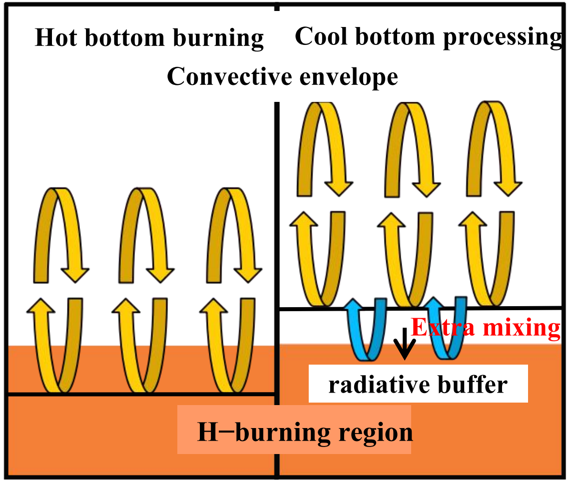
CONTENTS

1 Background

He-burning shell of **Asymptotic Giant Branch** (AGB) stars is one of the major contributors to fluorine in galaxy.

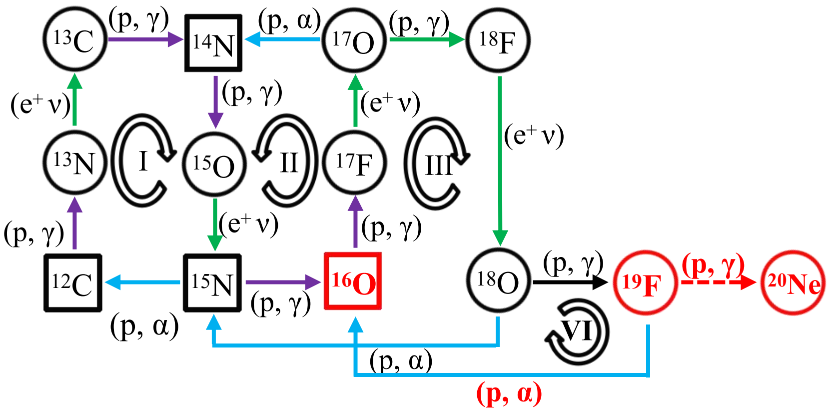
The observed fluorine abundances cannot be explained by current AGB models.

It seems that the fluorine produced in the He-rich intershell can be carried to the surface by extra mixing effects.



In **population III stars**, the breakout possibility from the CNO cycles depends on the reaction rates of the $^{19}F(p,\gamma)^{20}Ne$ and $^{19}F(p,\alpha)^{16}O$.

The enhancement of this (p,γ)/(p,α) rate ratio by a factor of 8 or more could possibly solve the Ca production problem.



In order to investigate these problems, the major fluorine destruction channel $^{19}F(p,\alpha)^{16}O$ should be studied.

1 Background

^{19}F (p,α_0)^{16}O

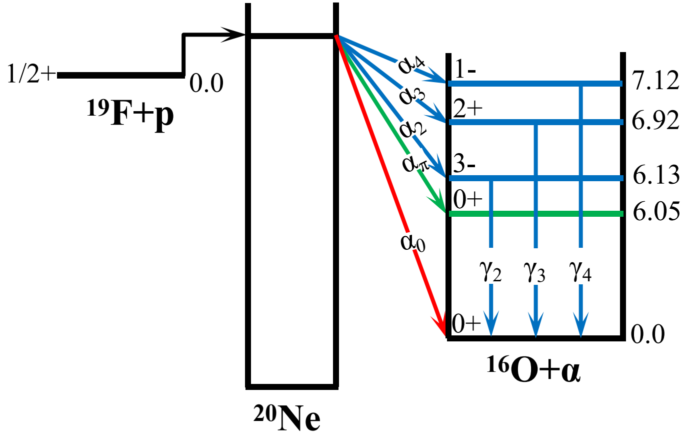
Trojan Horse Method (THM) measurement in the energy region $0 < E_{cm} < 1$ MeV (La Cognata et al. 2011, La Cognata et al. 2015, Indelicato et al. 2017).

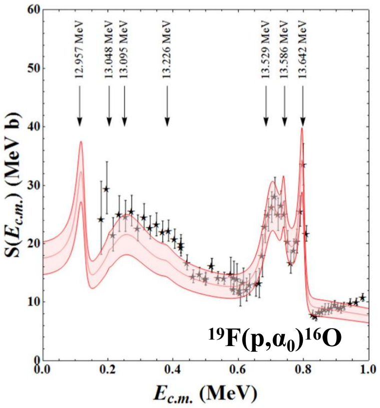
Direct measurement in the energy region $0.2 < E_{cm} < 1$ MeV (Lombardo et al. 2013, Lombardo et al. 2015).

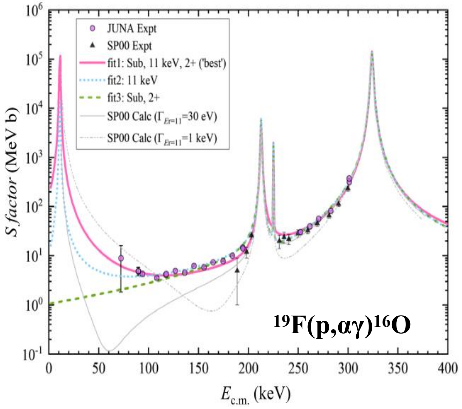
^{19}F(p,$\alpha\gamma$)^{16}O

Direct measurement in the energy region $72.4 < E_{cm} < 344$ keV (Zhang et al. 2021).

The ^{19}F(p,α)^{16}O reaction rate is the sum over the rate for the (p,α_0), (p,α_π) and (p,αγ) channels, but the (p,α_π) channel has never been measured experimentally in the energy range of interest.

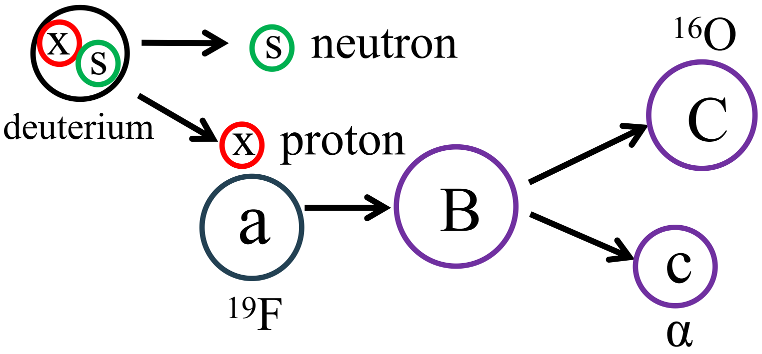






2 Experiment

Quasi-free breakup mechanism



$A = x \oplus s$: Trojan Horse nucleus

x: Participant nucleus

s: Spectator nucleus

The cross section of two body reaction should be normalized using data from direct measurements.

Trojan Horse Method

Quasi-free breakup selection

$$a + A \longrightarrow C + c + s$$

$$\Downarrow$$

$$a + x \longrightarrow C + c$$

The quasi-free kinematical condition:

the relative momentum of s and x is zero

The beam energy is compensated by the $x \oplus s$ binding energy:

$$\mathbf{E_{cm} = E_{aA} - B_{xs}}$$

E_{aA} is the beam energy in the center-of-mass system.

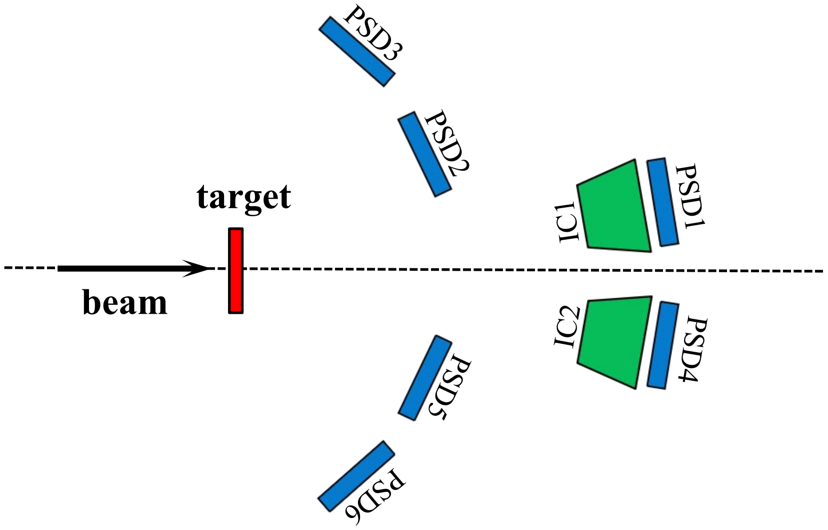
B_{xs} is the binding energy for the x–s system.

Plane Wave Impulse Approximation:

$$\frac{d\sigma_{ax}^{HOES}}{d\Omega} \propto \frac{\dfrac{d^3\sigma}{dE_c d\Omega_c d\Omega_C}}{KF\left|\Phi(\vec{p}_s)\right|^2}$$

Experimental Set-Up

Laboratori Nazionali del Sud (LNS) - INFN



Goal: ^{16}O and α coincidence measurement

Beam: ^{19}F

Beam Energy: 55 MeV

Target: CD_2

Target Thickness: 0.1 mg/cm^2

Detectors:

6 Position Sensitive Detectors (PSD)

2 Ionization Chambers (IC)

△E-E Telescope (IC - PSD)

(for Oxygen Identification)

Position and Energy Calibration

- Elastic scattering of ^{16}O on ^{197}Au E = 30, 37, 45, 55 MeV;
- Elastic scattering of ^{16}O on ^{12}C E = 30, 37, 45, 55 MeV;
- Reaction of ^{19}F on CD_2 E = 30 MeV;
- An α (^{228}Th) radioactivity source.

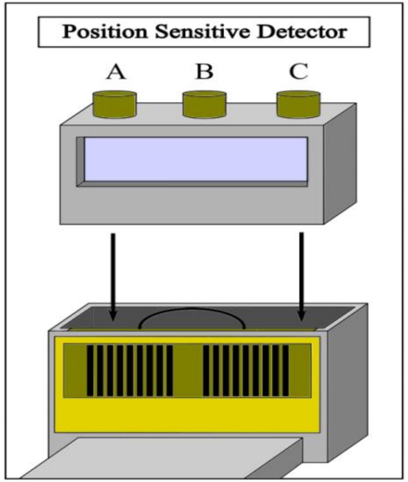
Position Calibration:

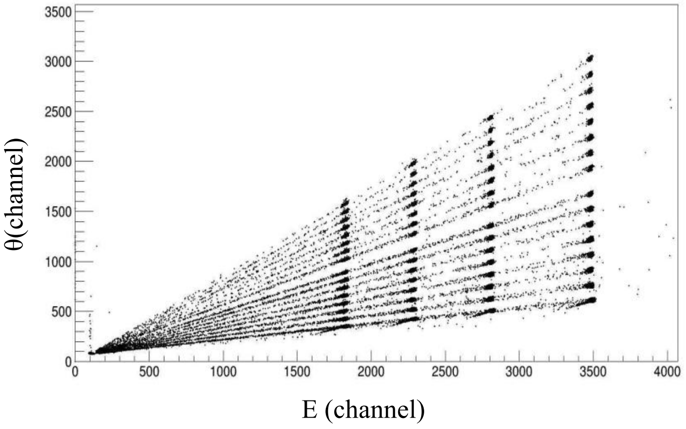
$$x = \frac{p - p_0}{e - e_0} \qquad \theta = \theta_0 + \arctan[c_1(x - x_0)]$$

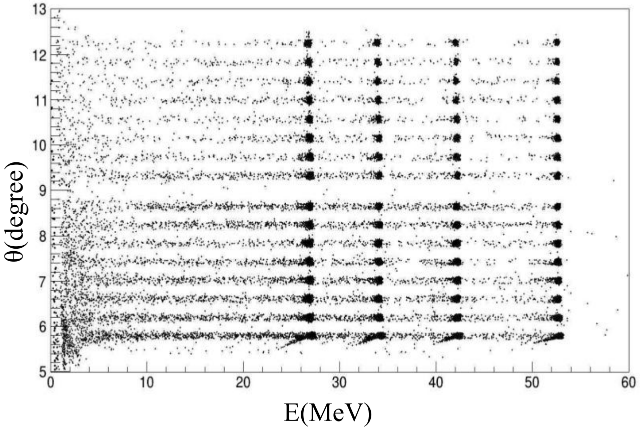
Energy Calibration:

$$E_{MeV} = a + bE_{channel}$$

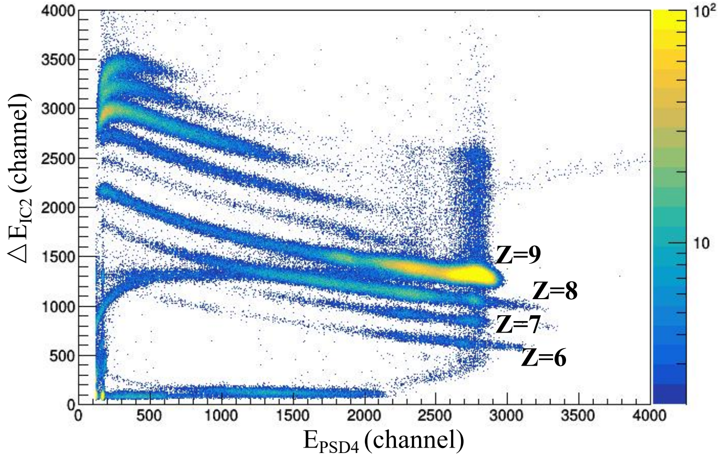
$$E_{MeV} = (a + bE_{ch})[1 + c_3(\theta - \theta_0)]$$



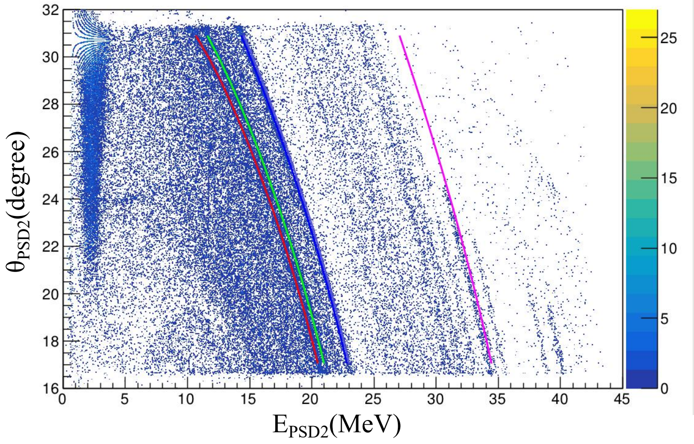




Reaction Channel Selection

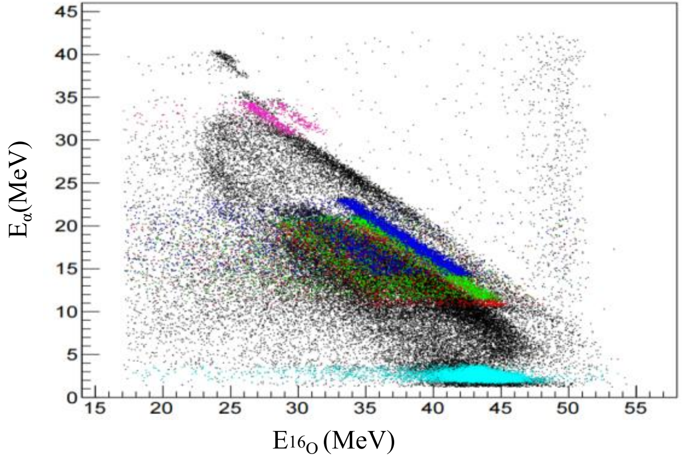


Graphical selection of $Z = 8$ (Oxygen isotopes) events in $\triangle$E-E spectrum.



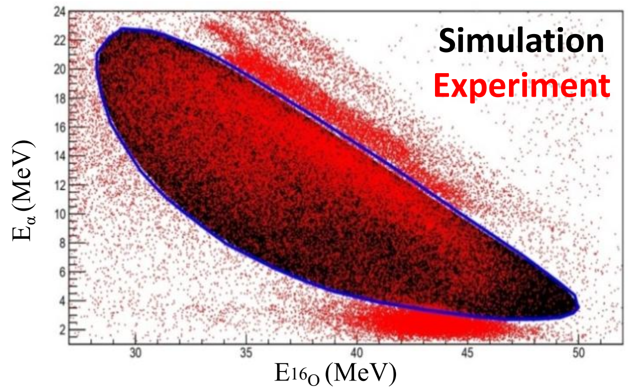
Two-body reaction: $p + {}^{19}F \rightarrow \alpha_0 + {}^{16}O$
$p + {}^{19}F \rightarrow \alpha_\pi/\alpha_2 + {}^{16}O$
$p + {}^{19}F \rightarrow \alpha_3 + {}^{16}O$
$p + {}^{19}F \rightarrow \alpha_4 + {}^{16}O$

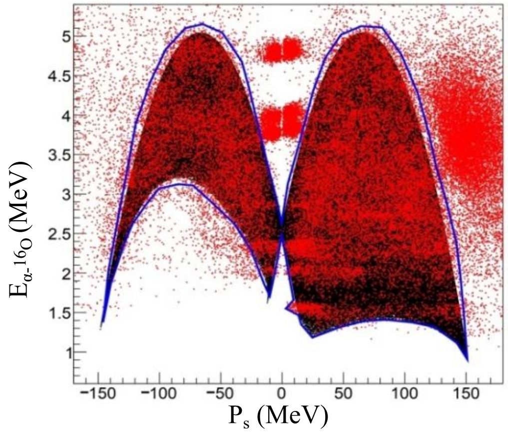
Three-body reaction: $p + {}^{19}F \rightarrow \alpha_0 + {}^{16}O$
$p + {}^{19}F \rightarrow \alpha_\pi /\alpha_2 /\alpha_3/ \alpha_4 + {}^{16}O$



3 Data Analysis

Reaction Channel Selection



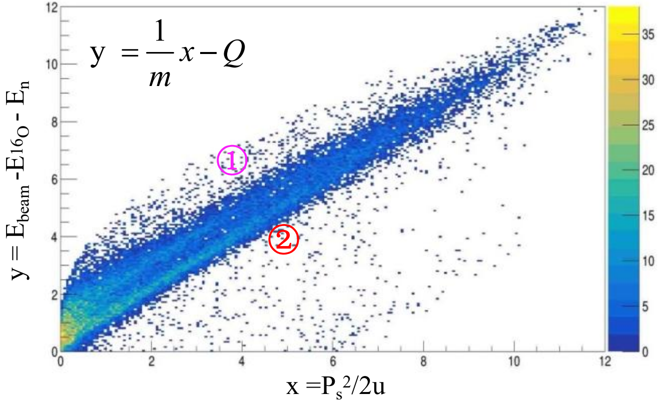


Comparison with simulation

Selection in E_α- $E_{^{16}O}$ and $E_{\alpha-^{16}O}$- P_s

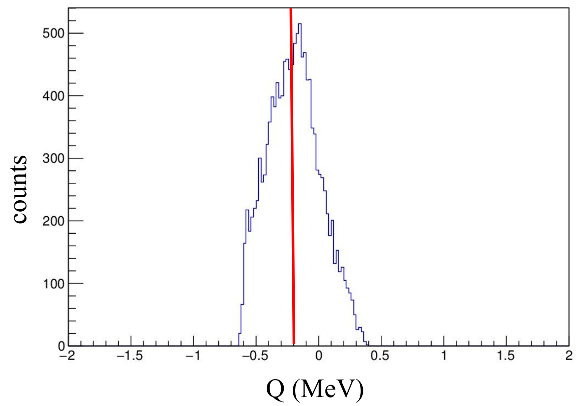
Select the three-body reaction channel

Reduce the background



① the line of (p, α_3) and (p, α_4) channels

② the line of (p, α_π) and (p, α_2) channels



4 Summary

- The $^{19}F(p,\alpha)^{16}O$ reaction was measured by the Trojan Horse Method based on the quasi-free breakup process of $d(^{19}F,\alpha^{16}O)n$.
- The position and energy calibration of PSDs were performed by means of the α radioactivity source and elastic scattering of ^{16}O on the ^{12}C and ^{197}Au target.
- The oxygen isotope was identified in △E-E spectrum.
- The kinematic locus of three-body reaction $d(^{19}F,\alpha^{16}O)n$ was identified and the $(p,\alpha_\pi/\alpha_2)$ and $(p,\alpha_3/\alpha_4)$ channels were separated by $y = (1/m)x - Q$ plot.
- Resonant states were observed in the relative energy spectrum and will be subject of detailed investigation in the coming months.

ASFIN Collaboration

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AsFiN

Thanks for your attention!