Study of the crucial nuclear reaction $^{14}O(\alpha, p)^{17}F$ in X-ray bursts

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1. Introduction

(Status and Puzzles)

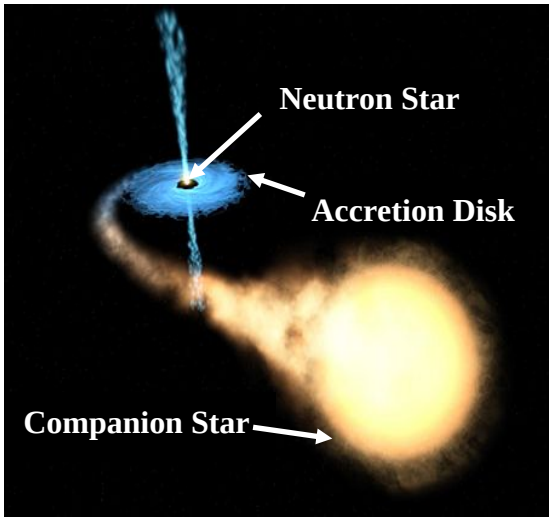
1.1 Astrophysical Site and Process

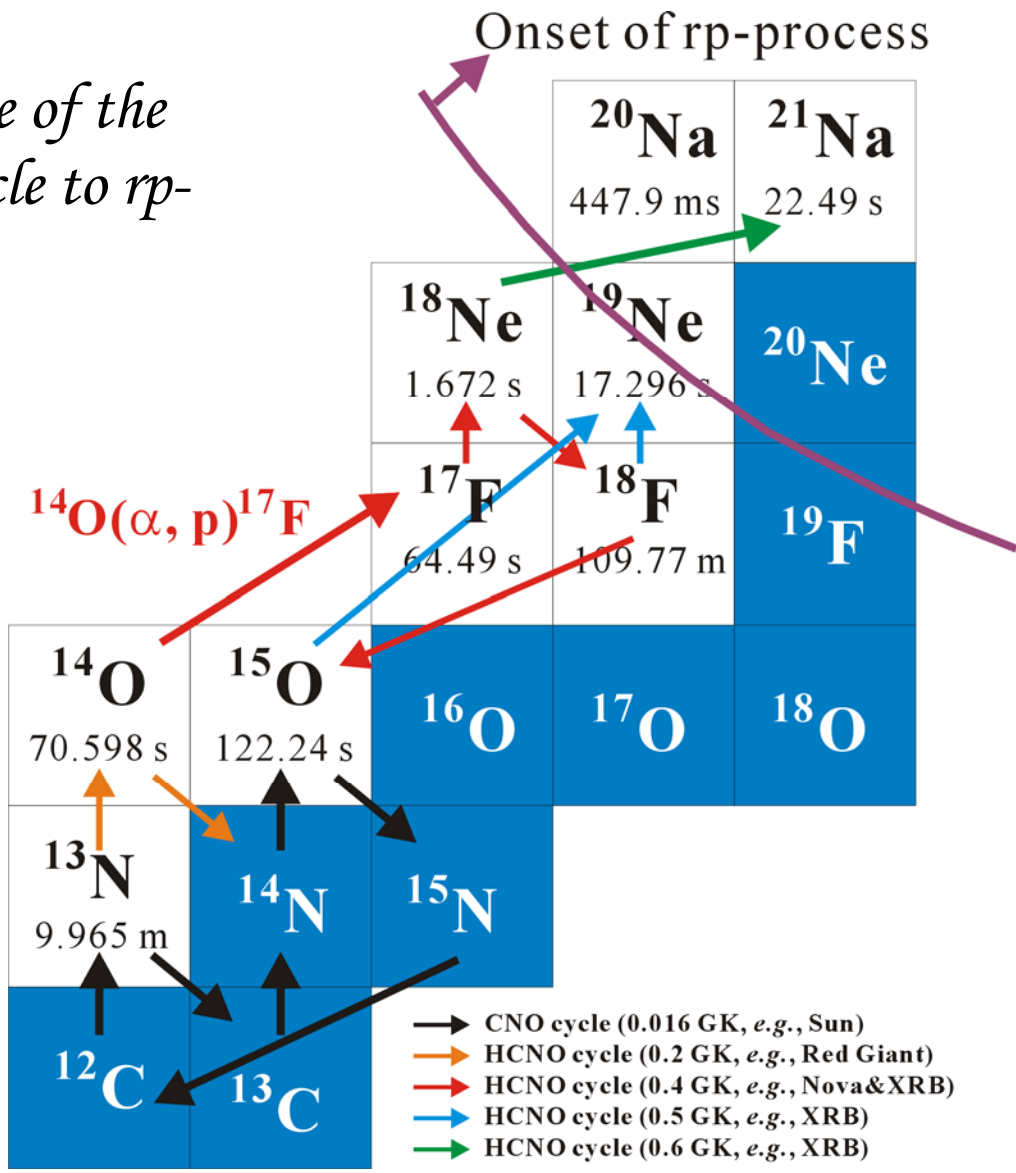
- *Theoretical prediction:*

  $^{14}O(\alpha,p)^{17}F$ is, most probable, one of the breakout reactions (from HCNO cycle to rp-process) in x-ray bursts.

- *Present Status:*

  Its reaction rate hasn't been determined very well yet.





1.2 Thermonuclear Reaction Rate

- *Definition: how fast a reaction takes place*
- *Formula: reaction rate can be written as:*

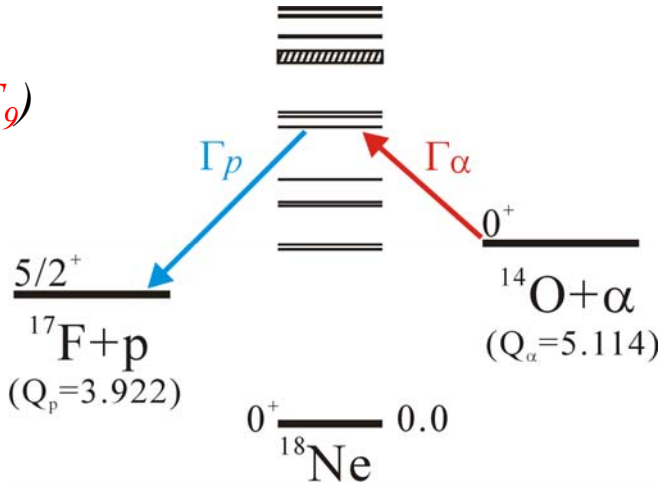
$$N_A \langle \sigma v \rangle = N_A \left(\frac{8}{\pi\mu}\right)^{1/2} \left(\frac{1}{kT}\right)^{3/2} \int \sigma(E) E \times e^{\left(-\frac{E}{kT}\right)} dE \quad (\mathrm{cm^3 s^{-1} mole^{-1}})$$

- *For single narrow resonance, reaction rate can be written as*

$$N_A \langle \sigma v \rangle_{res} = N_A (2\pi/\mu kT)^{3/2} \hbar^2 \omega\gamma * \exp(-E_{res}/kT)$$
$$= 1.5394 \times 10^{11} (\mu T_9)^{-3/2} \omega\gamma * \exp(-11.605 * E_{res}/T_9)$$

($\omega\gamma$ in unit of eV, E_{res} in MeV, rate in $\mathrm{cm^3\ s^{-1}\ mol^{-1}}$)

Where
$\omega = (2J_r+1) / [(2J_1+1)*(2J_2+1)]$ = statistical factor,
$\gamma = \Gamma_{in} * \Gamma_{out} / \Gamma_{tot}$,
$\omega\gamma$ is the "resonance strength".



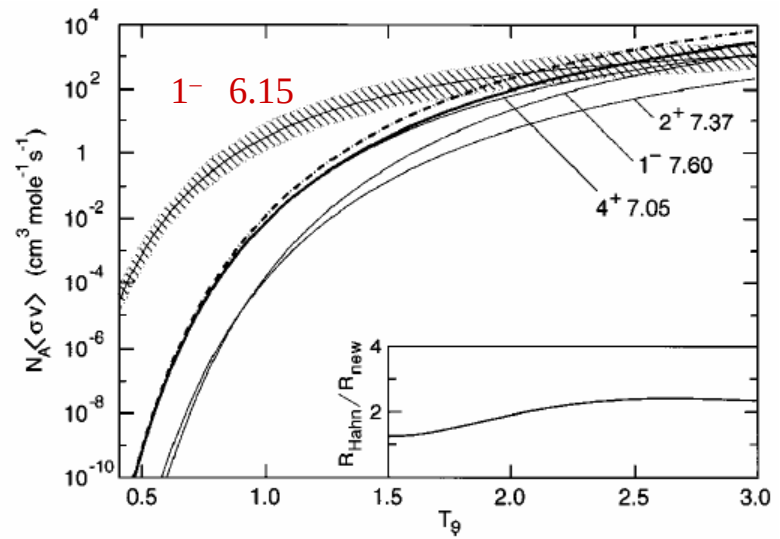
- *For multiple resonances, total rate is*

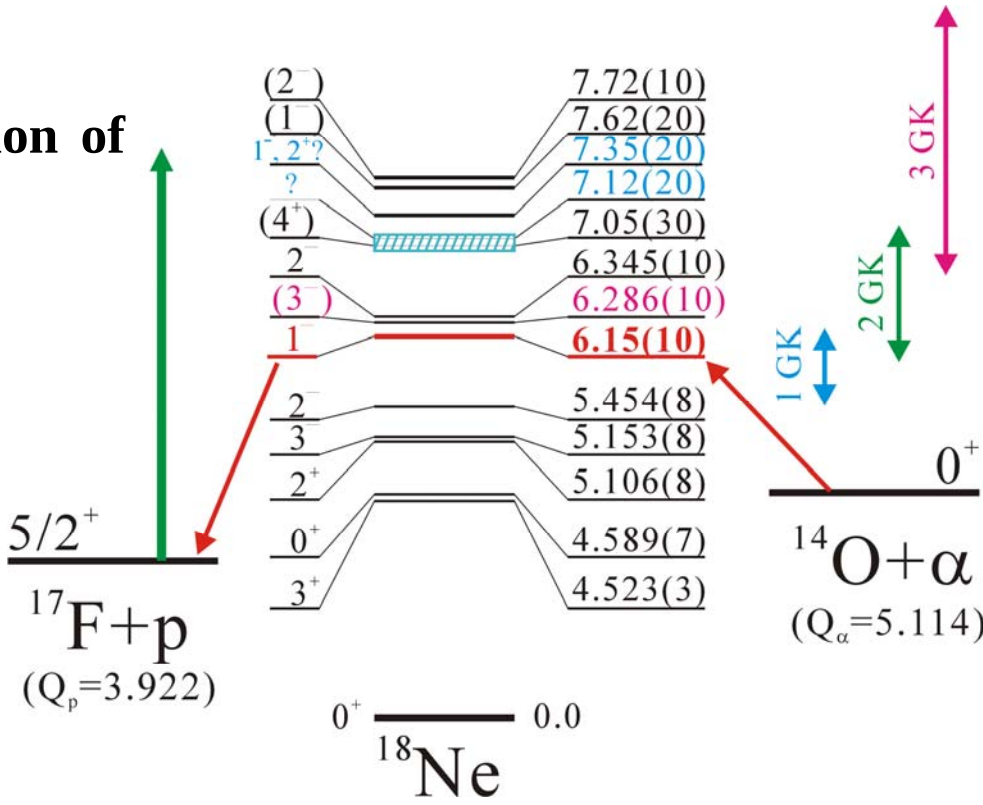
$$N_A \langle \sigma v \rangle_R = 1.5394 \times 10^{11} \left(\frac{1}{\mu T_9}\right)^{3/2} \sum_i (\omega\gamma)_i \exp\left(-\frac{11.605 E_R^i}{T_9}\right)$$

1.3 Experimental goal

- **To determine resonant properties of unbound states in ^{18}Ne (E_R, J_R, Γ_α)**

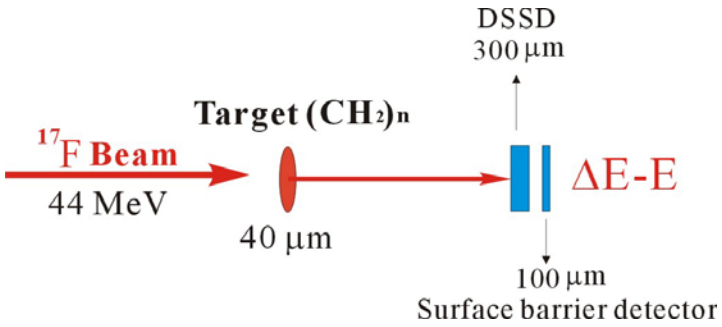
- **To address astrophysical implication of the ^{14}O(α,p)^{17}F reaction**





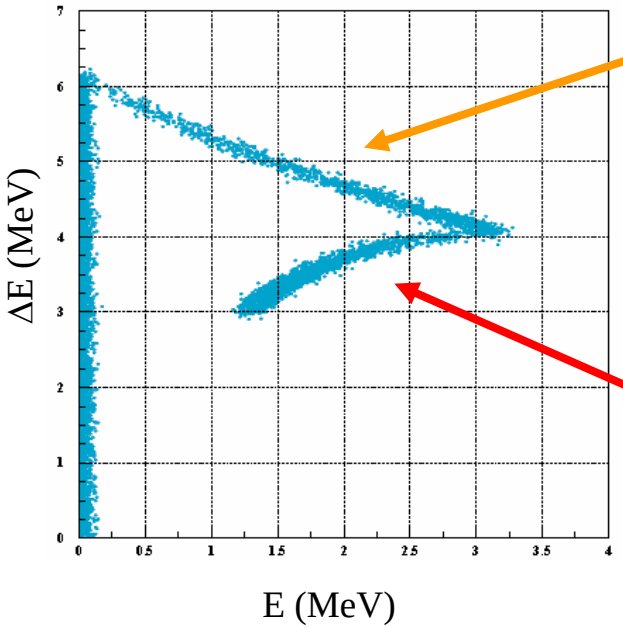
***refs.:* Harss et al., PRC 65 (2002) 035803**

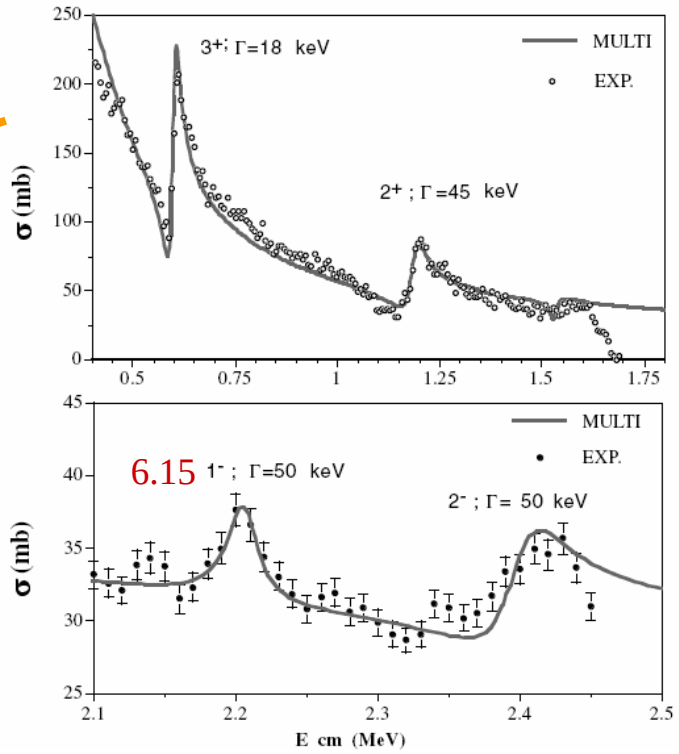
1.4 Puzzles from Gomez's experiment



- ***The telescope cannot stop the protons with higher energy (>7.5 MeV).***

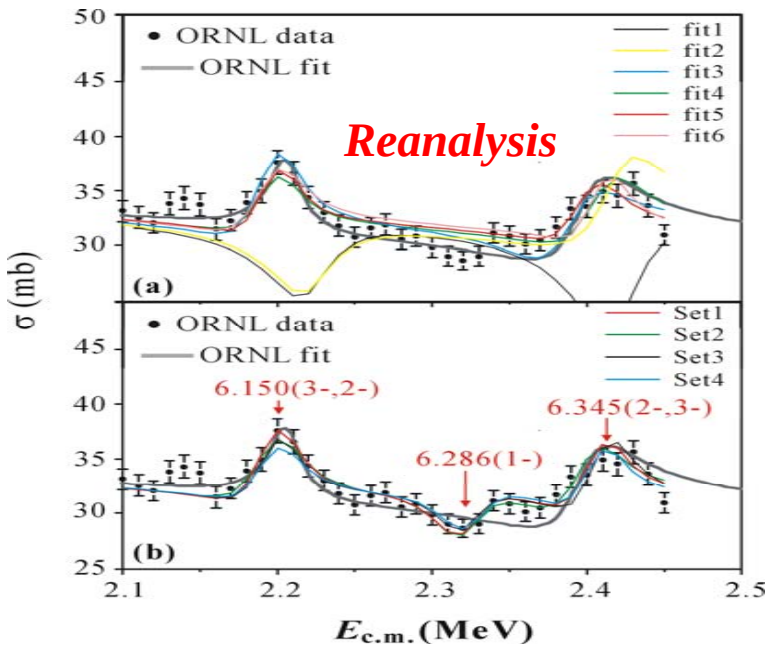
Thick target technique @ HRIBF

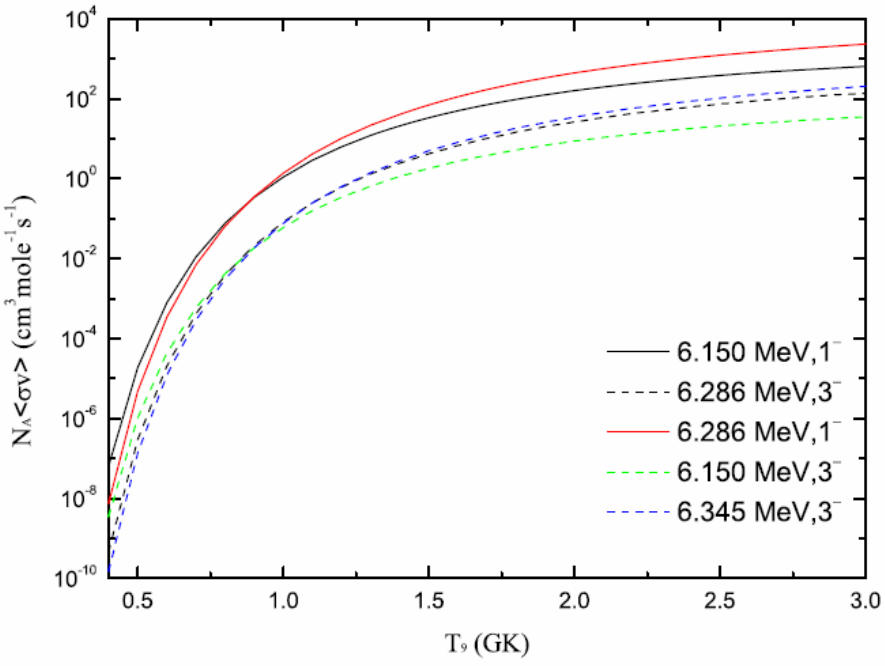




refs.: ***J. Gómez del Campo et al., PRL 86 (2001) 43***

1.4 R-Matrix reanalysis





According to the reanalysis, 1^- assignment for the 6.15 MeV is impossible for the observed peak structure.

The Gomez *et al.* data and the R-Matrix fit are questionable.

refs.: ***J.J. He et al., arXiv:1105.5882v1.***

2. Experiment

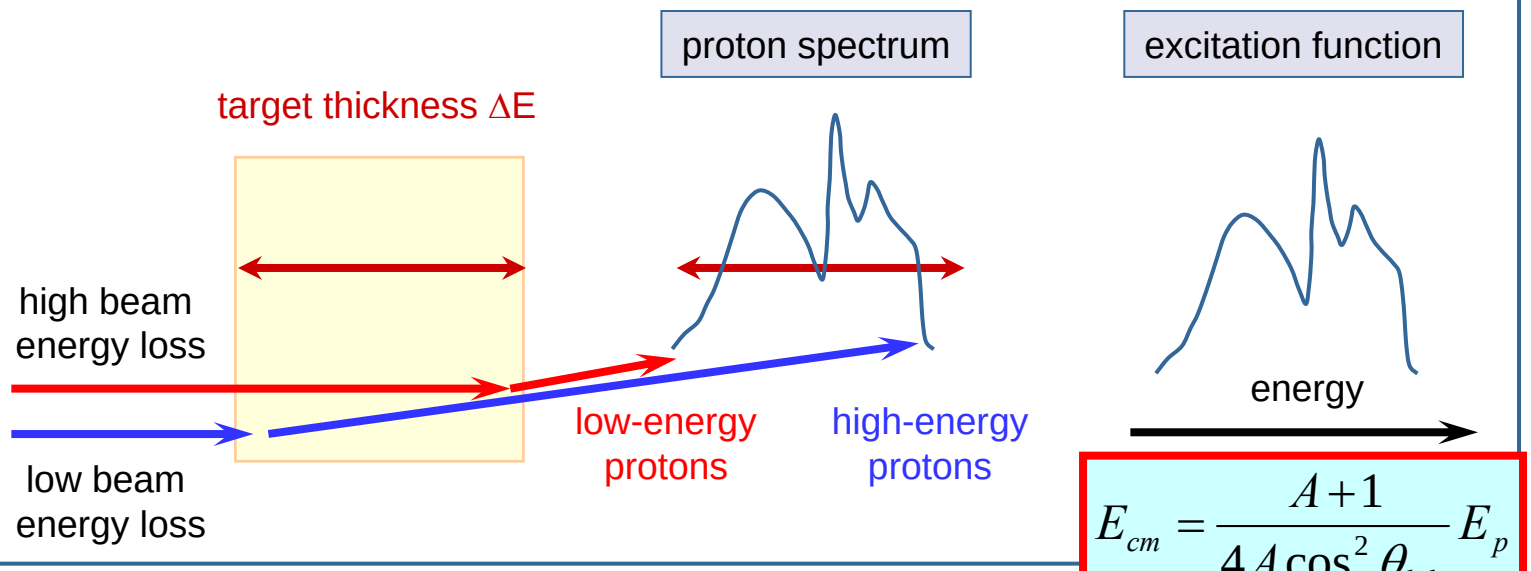
(Study of the Resonant Elastic Scattering of ^{17}F+p via thick-target method)

2.1 Methodology

Resonant elastic scattering of $^{17}F+p$

Principle of thick-target technique

inverse kinematics + suitably thick target (*e.g.*, $(CH_2)_n$, H_2) + proton detection

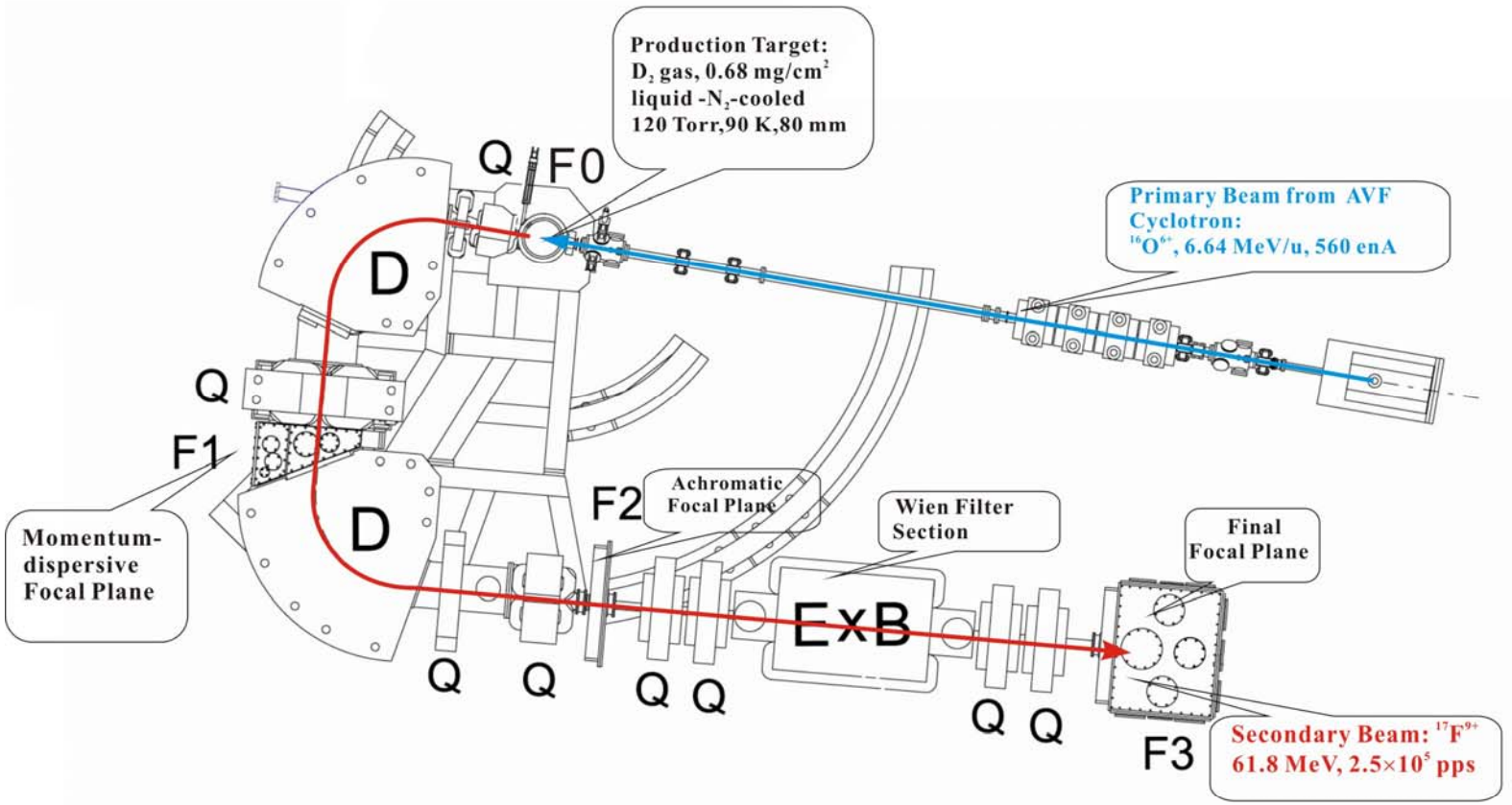


$$E_{cm} = \frac{A+1}{4A\cos^2\theta_{lab}} E_p$$

$$E_x = E_{cm} + Q$$

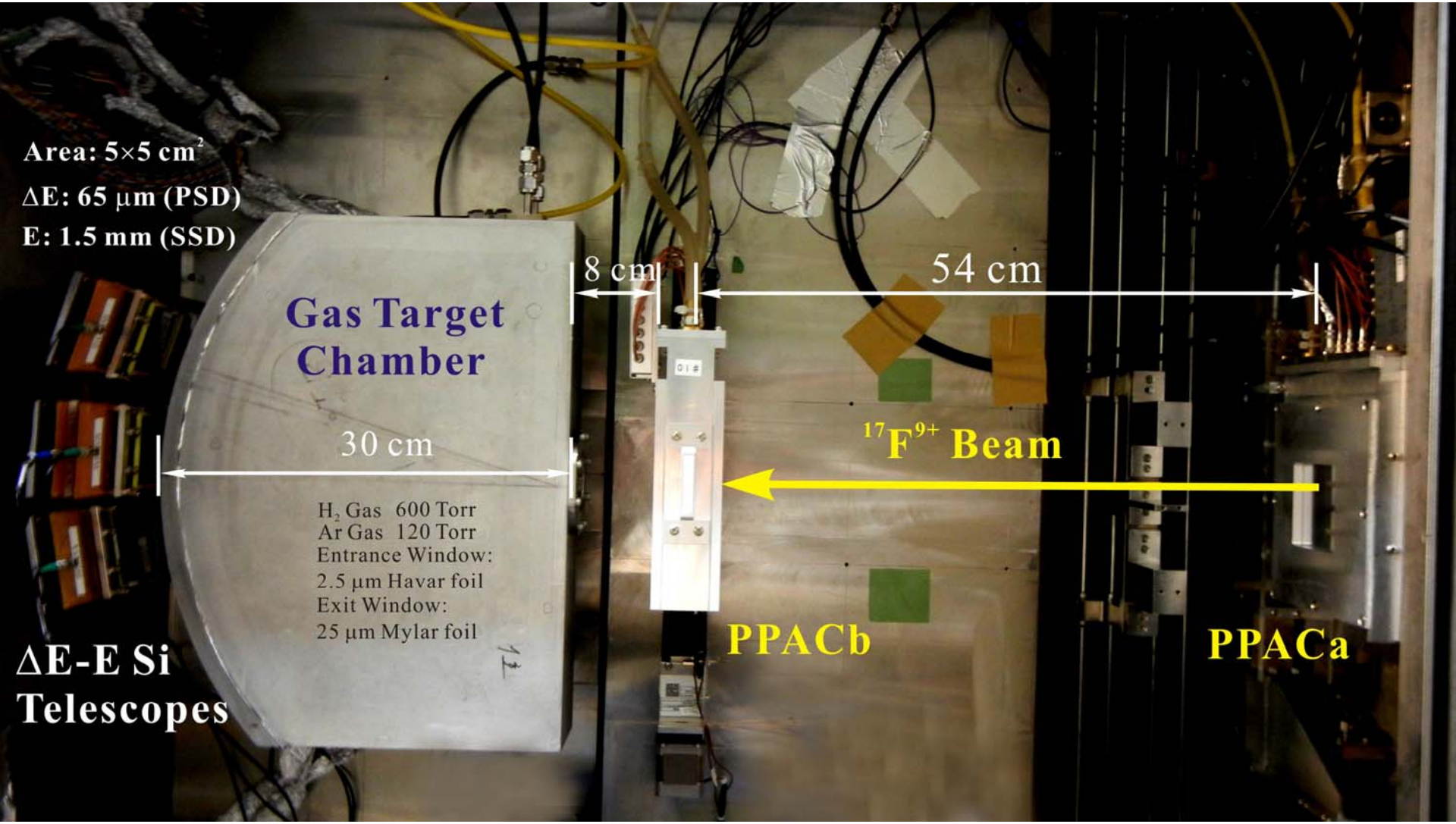
protons undergo little energy loss, little kinematics variation, little straggling → retain information on resonance shape

2.2 Experiment layout @ CRIB



CNS Radioactive Ion Beam separator (CRIB)

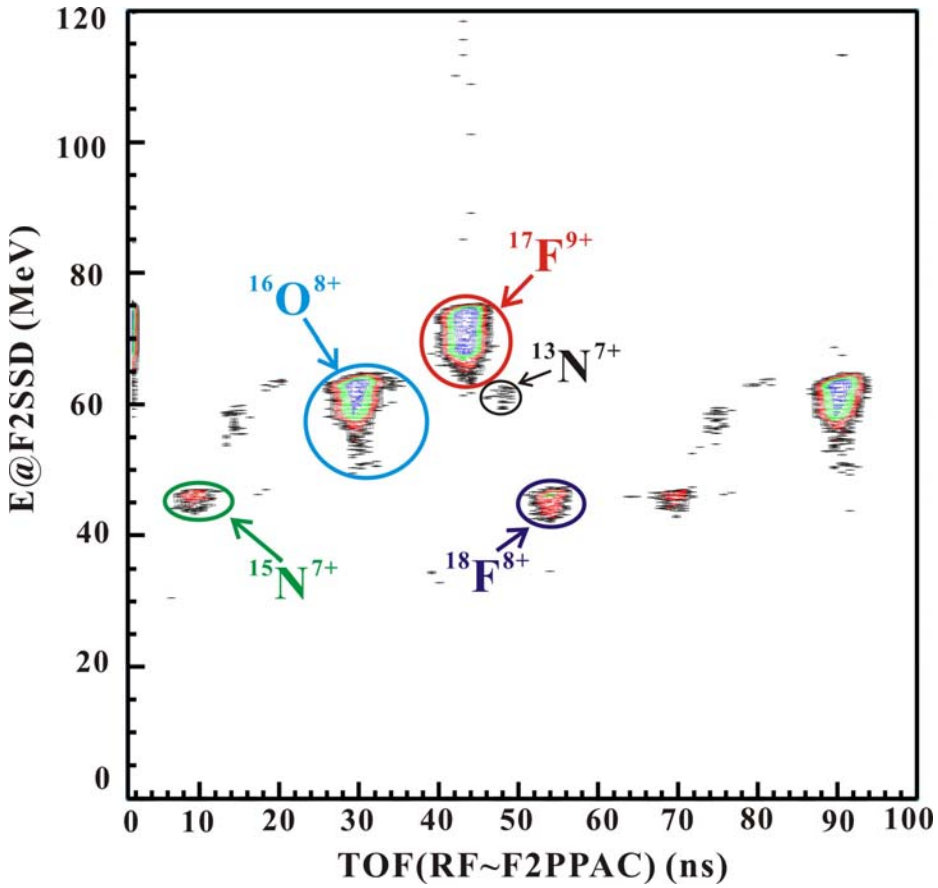
2.3 Measurement setup

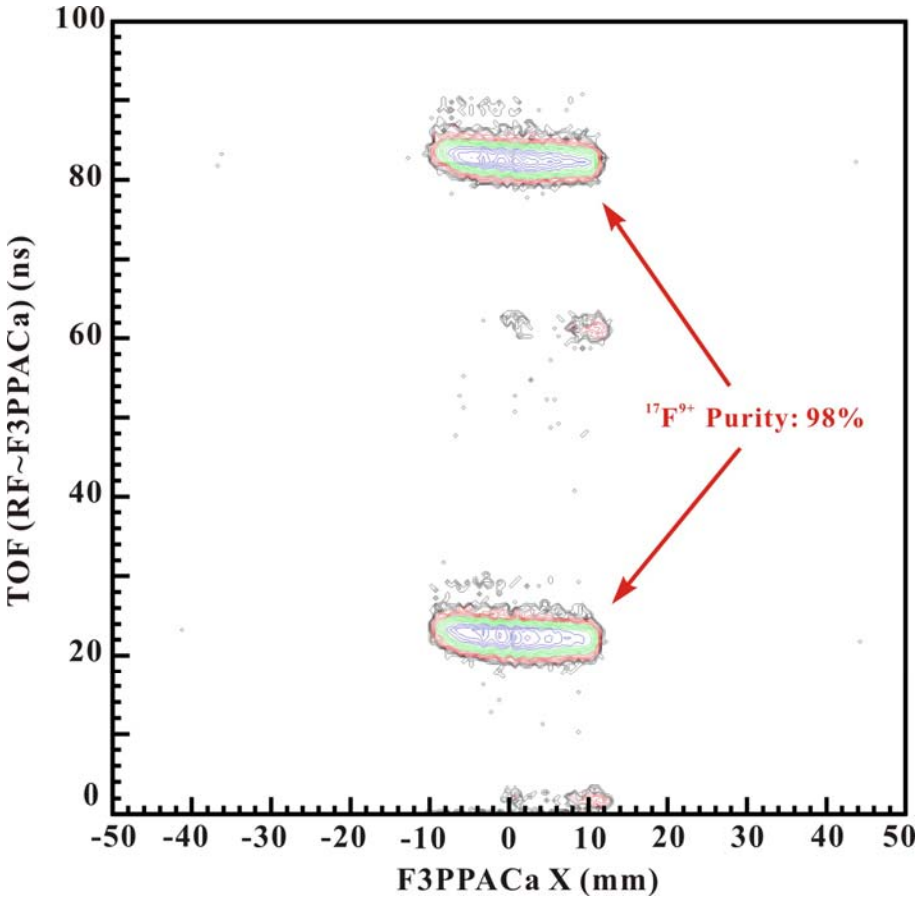


2.4 Identification of RIBs

TOF technique

→ can identify the $^{17}F^{9+}$ beam particles clearly !

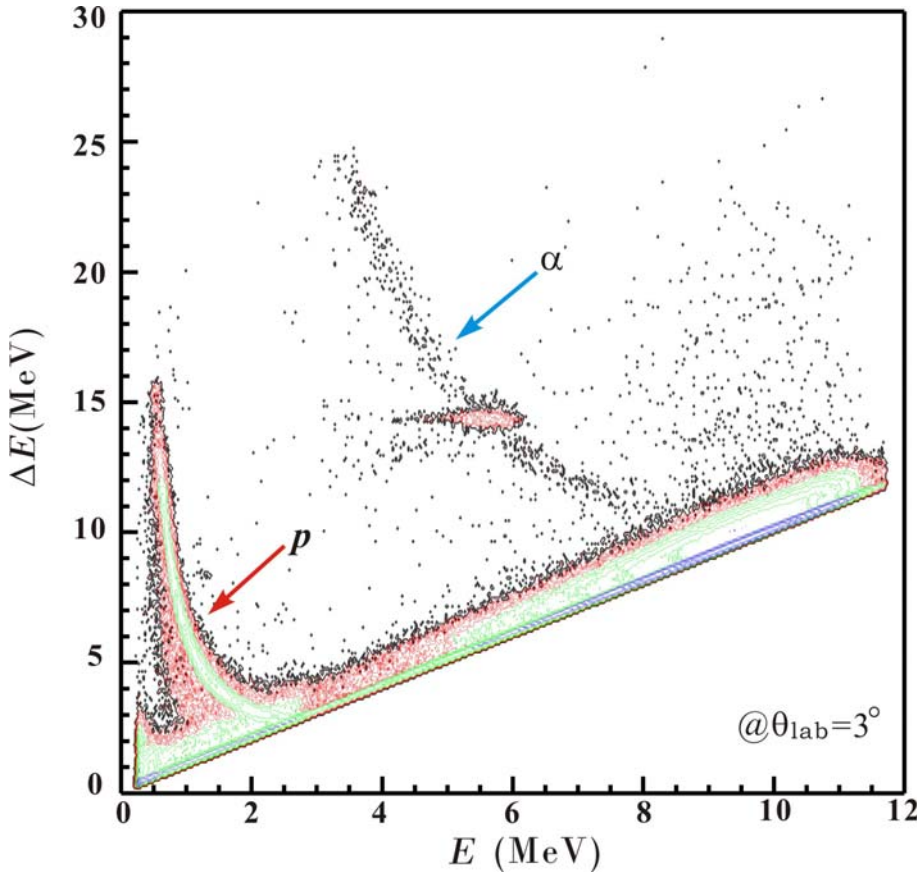


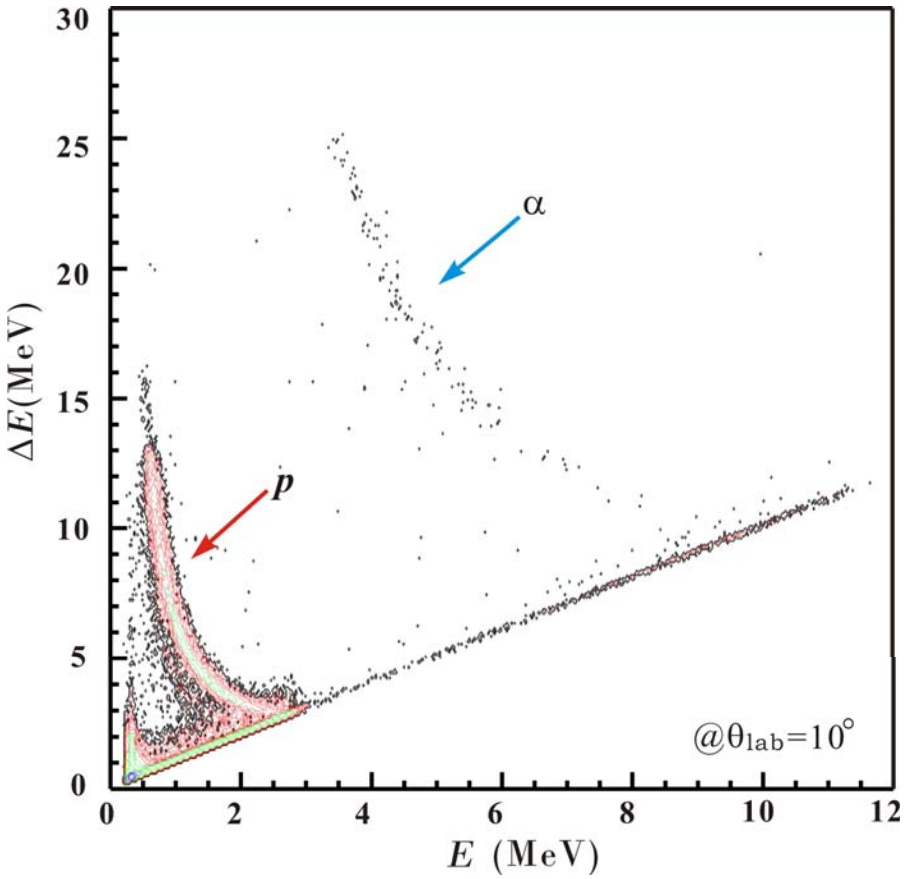


2.5 Identification of recoiled particles

ΔE-E technique

→ can identify the recoiled particles (p & α) clearly!

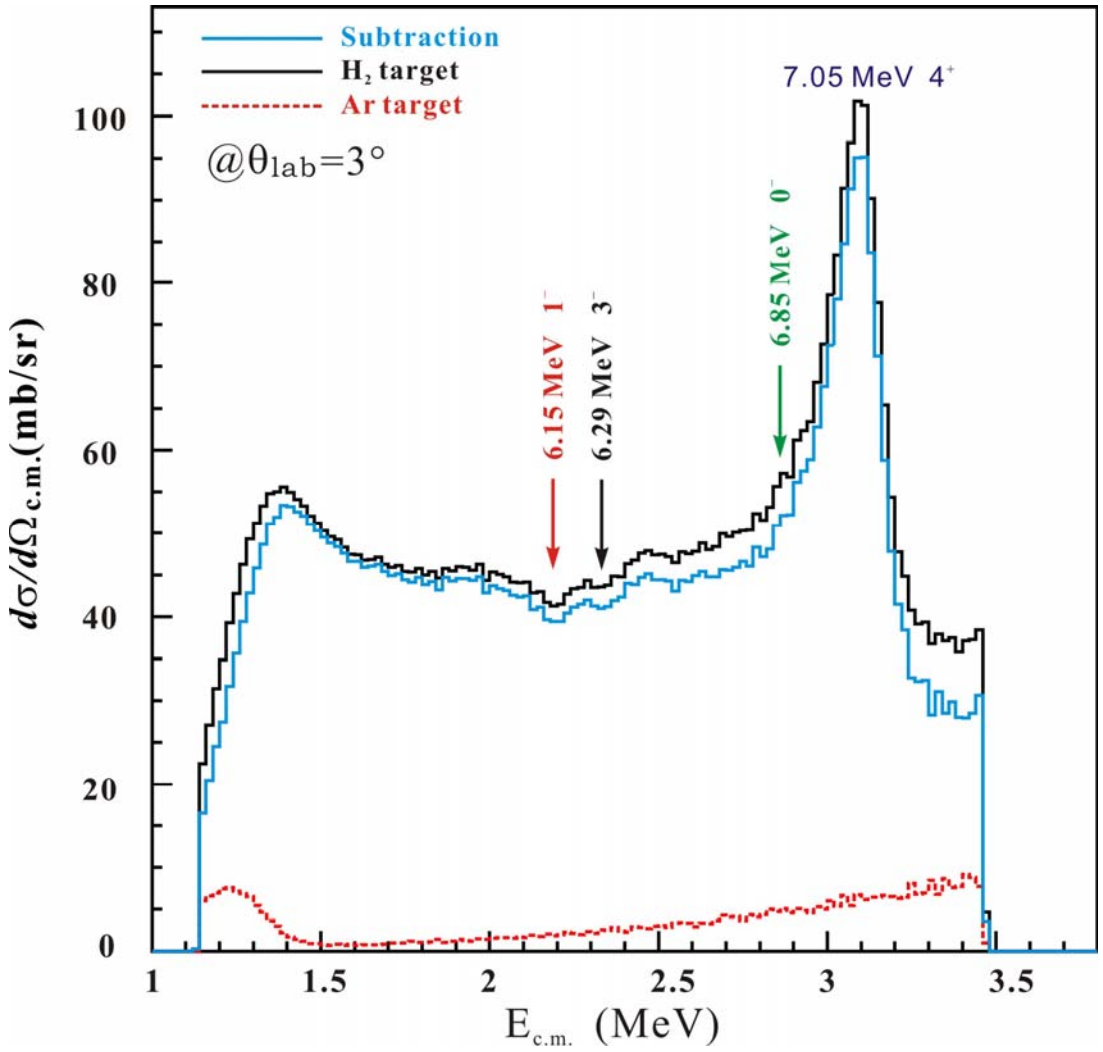


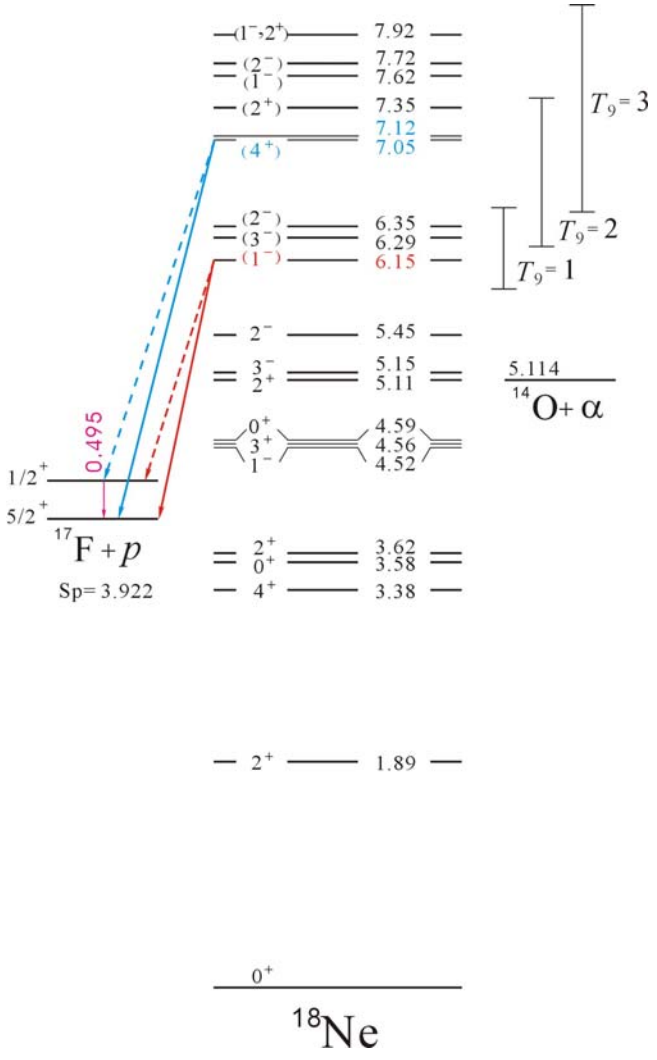


3. Preliminary Results

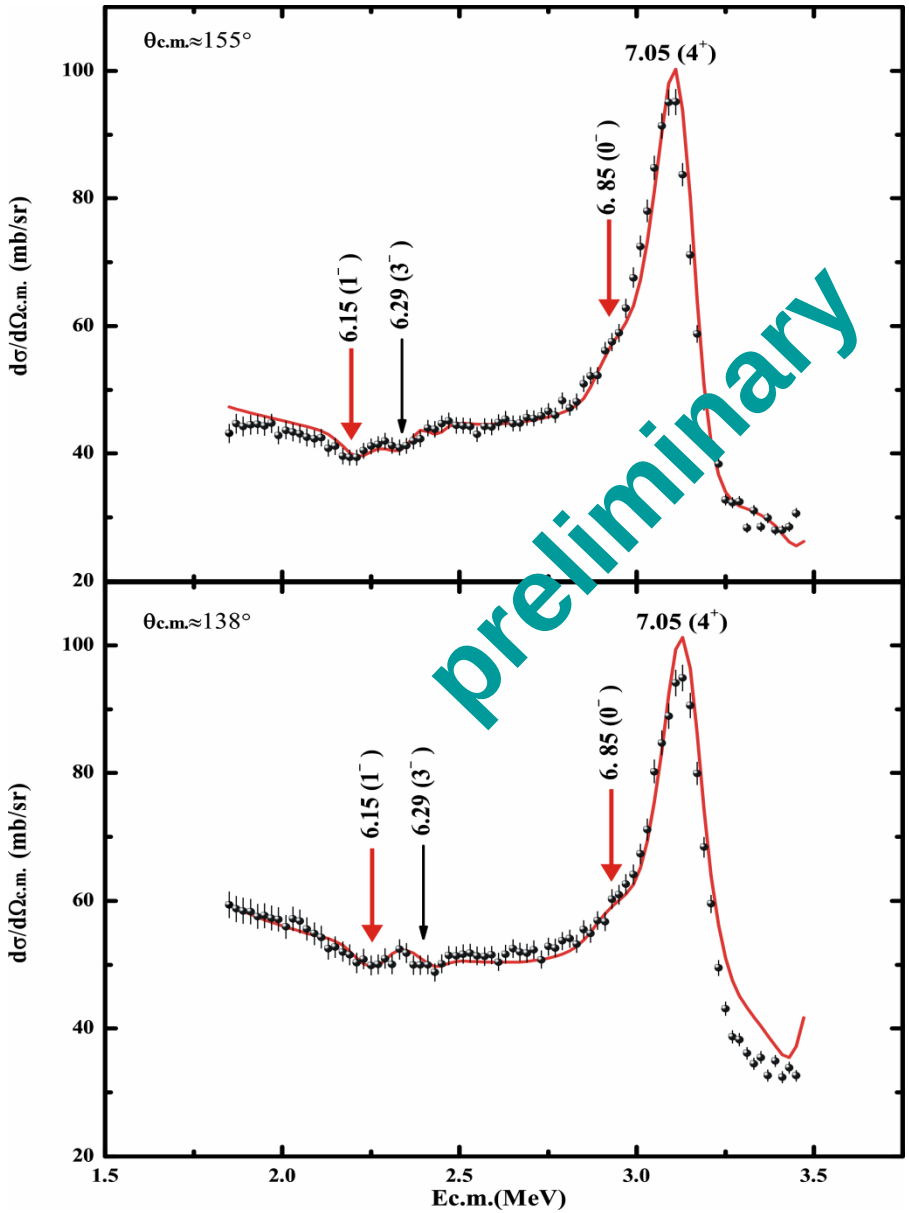
(Excitation function and R-matrix analysis)

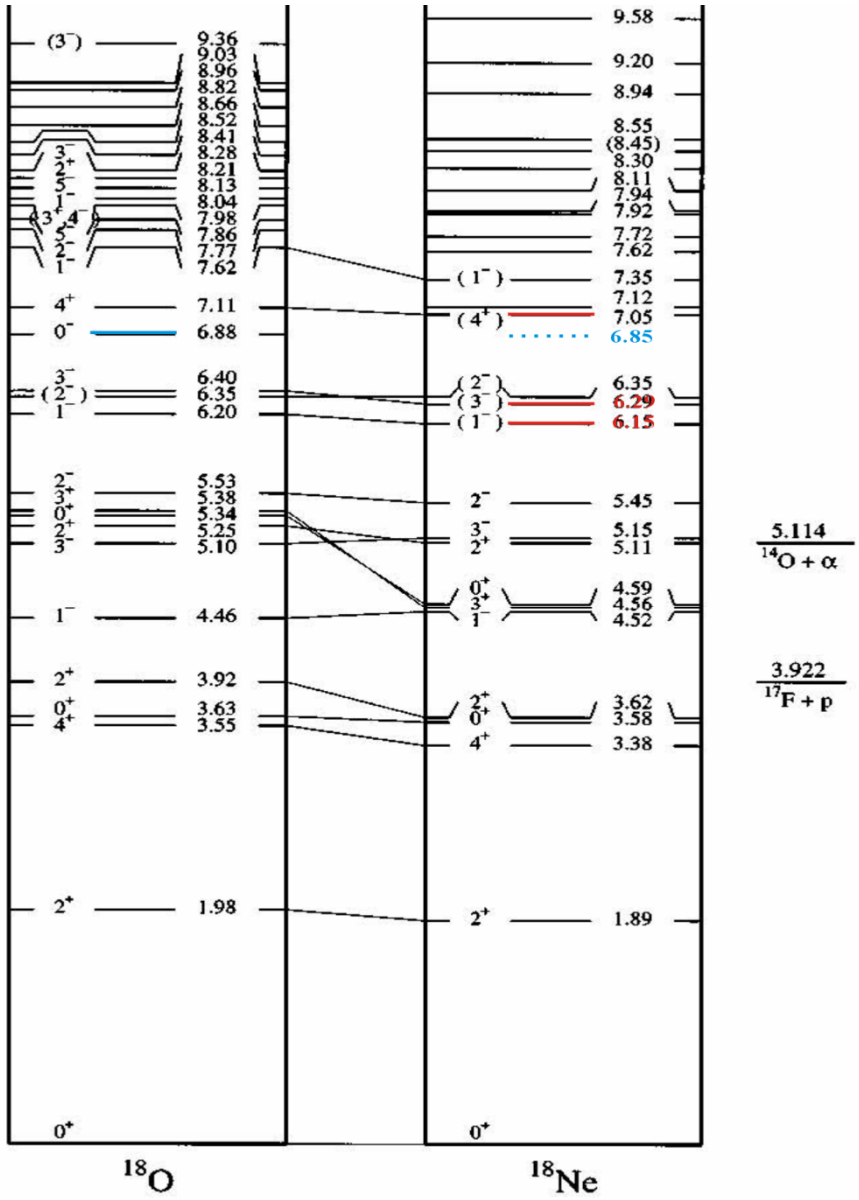
3.1 Excitation function





3.2 R-matrix analysis





4. Summary

1. Proton resonant scattering of ^{17}F+p was successfully performed.

2. The astrophysically crucial state 6.15-MeV in ^{18}Ne was observed as a spin-parity assignment of 1^- with high statistics. The confirmation of 1^- on a firm ground clarified this previous discrepancy.

3. The 1^- assignment with high statistics in this work firmly keeps the significant position of 6.15 MeV state.

4. A new state was observed at E_x = 6.85 MeV with a tentative spin-parity assignment of 0^- which could be the missing mirror state of 6.88-MeV, 0^- in ^{18}O.


Thank you for your attention!