Production of light and intermediate-mass fragments in p+Al collisions at GeV energies

Mohammad S Sabra
USRA Science and Technology Institute
NASA Marshall Space Flight Center
Huntsville, AL 35805

Introduction

- Space environment has much of cosmic rays and radiations which are dangerous for human beings and space equipment
- Spacecraft will travel through such environment, which is different from that on Earth
- Protection from space radiation is a priority to NASA, as its future plans include extended human mission in deep space

Introduction

- One of the sources of space radiations is the Galactic Cosmic Rays (GCRs) → highly energetic particles consist of every element (90% protons, 9% α-particles, 1% nuclei of heavier elements)
- When spacecraft is bombarded by GCRs, secondary nucleons, light clusters, and intermediate-mass fragments (IMFs) are produced → contribute to dose and dose equivalent received by crews inside

Motivation

- Understanding the reaction mechanism is important in improvement and development of nuclear physics codes used in space development
- We have analyzed energy spectra of nucleons (*p*, *d*, *t*), light clusters ($^{3,4,6}He$), and IMFs ($^{6,7,8,9}Li$, $^{7,9,10}Be$, $^{10,11}B$) from the interaction of ^{27}Al with protons at 1.2, 1.9, and 2.5GeV
- Calculations are done using SAPTON code

Scattering And Production Theory of Nuclei (SAPTON)

- SAPTON is a modified version of the standard statistical model.
- It has a final-state interaction between the emitted fragments
- It distinguishes itself from other models in at least one important aspect:

It includes the possibility that the fragments are being emitted the ground states, excited states, as well as in the continuum.

SAPTON (cont.)

- Energy spectra for the production of a pair of fragments $\boldsymbol{A}_1$ and $\boldsymbol{A}_2$ in cm system is s given by

$$\frac{d^2\sigma}{d\Omega dE} \propto \int \frac{T_l(\varepsilon)\rho_1(U_1)\rho_2(U_2)}{\rho_c(U_c)} dU_1 dU_2$$

where

- $T_l(\varepsilon)$ is the transmission Coefficient between the pair with relative energy ε
- ρ_1, ρ_2 are their level densities
- U_1, U_2 are their excitation energies
- ρ_c , U_c are the level density and excitation energy of the composite system

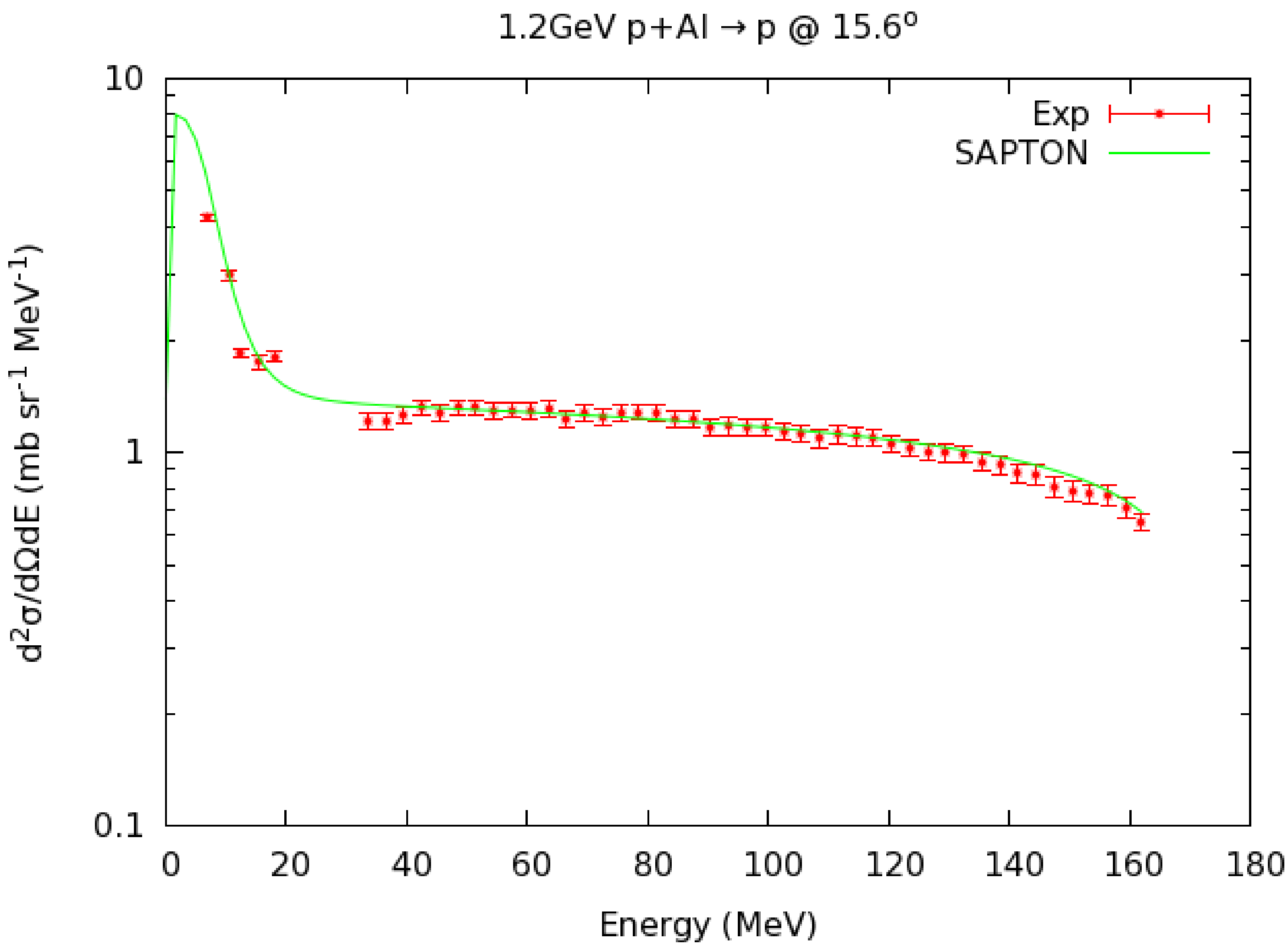
Transmission Coefficient $T_l(\varepsilon)$

- $T_l(\varepsilon)$ represents the final-state interaction between the fragments in the exit channel
- It is calculated from a realistic complex optical potential

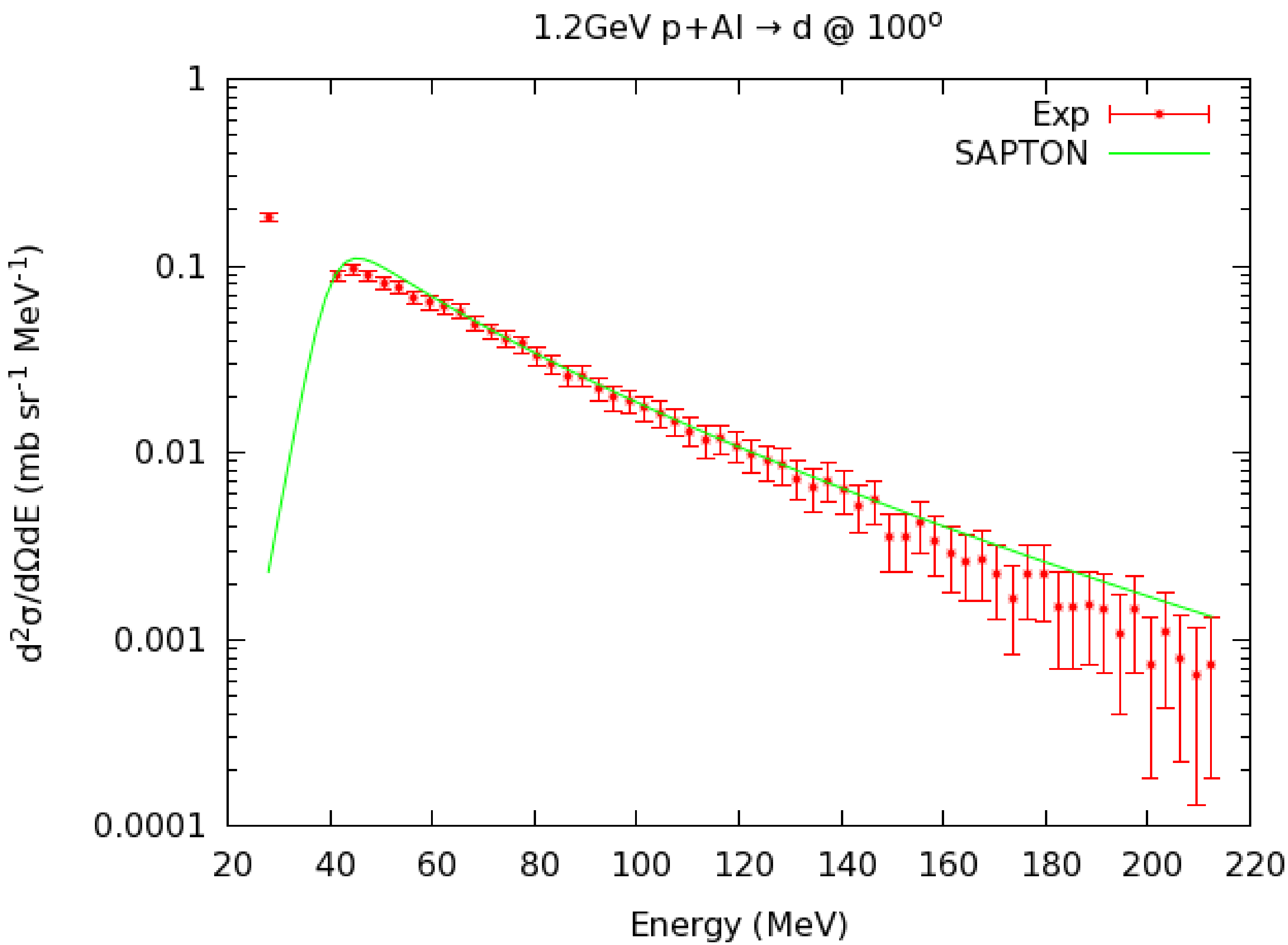
$$T_l(\varepsilon) = 1 - |S_l|^2$$

- The existence of such potential governs the dynamics of the fragmentation process entirely by dividing it into various reaction channels according to various relative angular momentum *l*-values (which are related to the impact parameter)
- This allows fragments to be emitted in ground, excited states, as well as in the continuum → fragments might be unstable while detected (similar to fission-like process)
- Other models → fragments are emitted in their ground states.

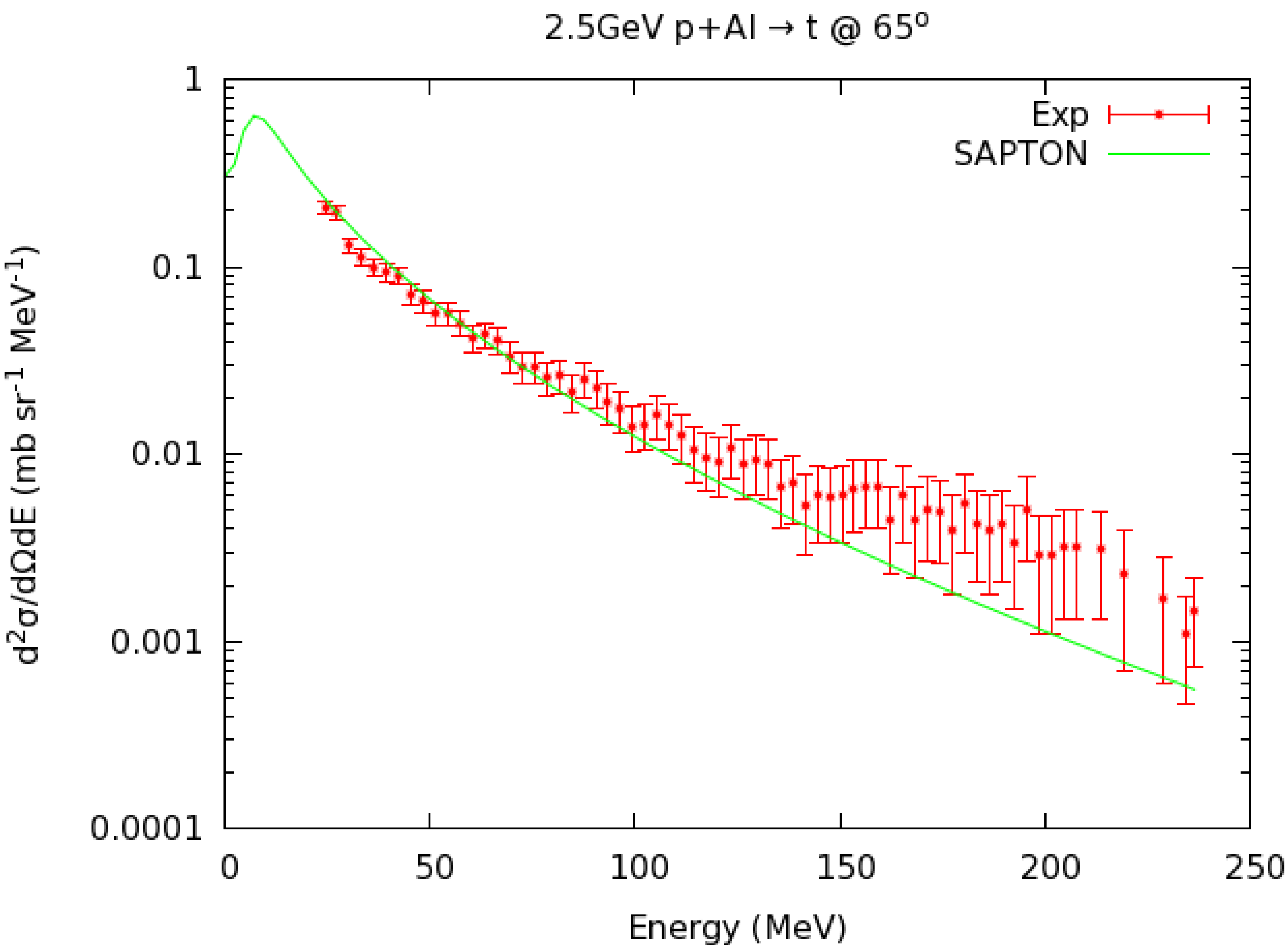
Theory vs Experiment



Theory vs Experiment



Theory vs Experiment



Conclusions

- SAPTON reproduces energy spectra for H-isotopes reasonably well compared to data
- In SAPTON, these nucleons are emitted in all possible states with a most probable energy (ε_{prob}) controlled by nuclear potential in the exit channel ($V_N + V_C$)
- Surface coalescence stage plays a significant role in IMFs production
- While most simulation codes ignore such stage, SAPTON employs such stage using different impact parameters (*l*-values)

Future work

- Calculate production cross-sections for Li, Be and B isotopes in p+Al reaction at 1.2, 1.9, and 2.5GeV
- Invesitigate charge and mass distribution of fragments as a function of proton incident energy.

Thank You!

Questions?

Scaling Potential

- The potential between the outgoing fragments A_1 and A_2 is represented by a complex molecular potential

$$V_N(r) = V(r) + iW(r)$$

where

$$V(r) = \frac{V_o}{1 + e^{(r-R_o)/a_o}} + V_1 e^{-\left(\frac{r}{R_1}\right)^2} + V_c(r)$$

$$W(r) = V_2(1 + C_1\varepsilon + C_2\varepsilon^2)e^{-\left(\frac{r}{R_2}\right)^2}$$

V_o, R_o, R_1, R_2, R_C are functions of A_1 and A_2.