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Trojan Horse particle invariance: an extensive study

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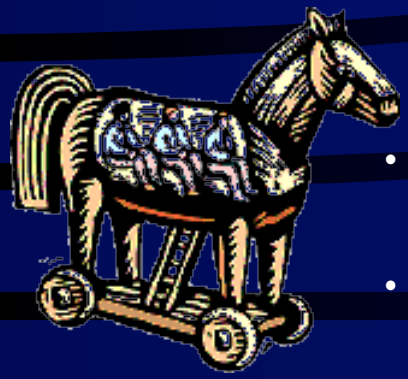
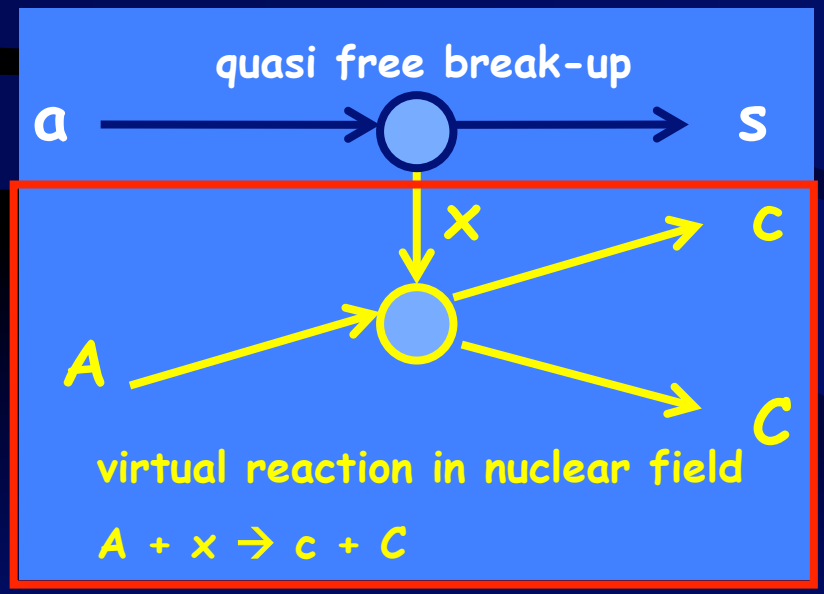
The Trojan Horse Method



- Indirect Methods can improve Nuclear Astrophysics results. Among them the Trojan Horse Method (THM).
- It allows the study of reactions of astrophysical interest like x(A,C)c at energies as low as the astrophysical ones after selection of an appropriate a(A,Cs)c reaction, induced at energies greater than the Coulomb barrier in quasi free conditions.



For QF processes the binary cross section, as a function of the three body one can be written as:

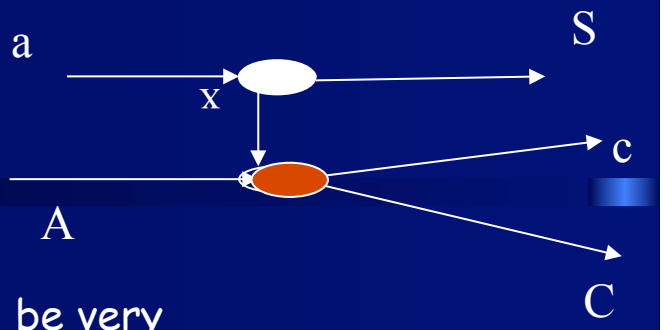
$$\frac{d^3\sigma}{dE_c\, d\Omega_c\, d\Omega_C} \propto KF\left|\Phi(p_S)\right|^2 \left(\frac{d\sigma}{d\Omega}\right)^{HOES}$$

Measured 3-body cross section

TH particle momentum distribution

2-body cross section

The incoming energy E_A of the incident particle is larger than the Coulomb barrier energy $(E_{AB})_{Coul.\ Bar.}$



$$E_A > (E_{Aa})_{Coulomb\ Barrier}$$

(This means that A and x have a non-negligible probability to be very close)

The **Trojan Horse particle** a can be brought into nuclear field

of nucleus A and while s acts as a spectator, the cluster x induces the reaction

$$A + x \rightarrow C + c$$

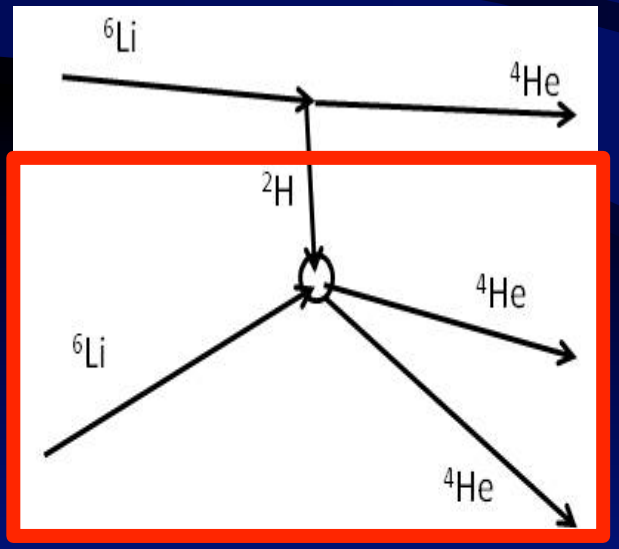
Coulomb effects and electron screening are negligible

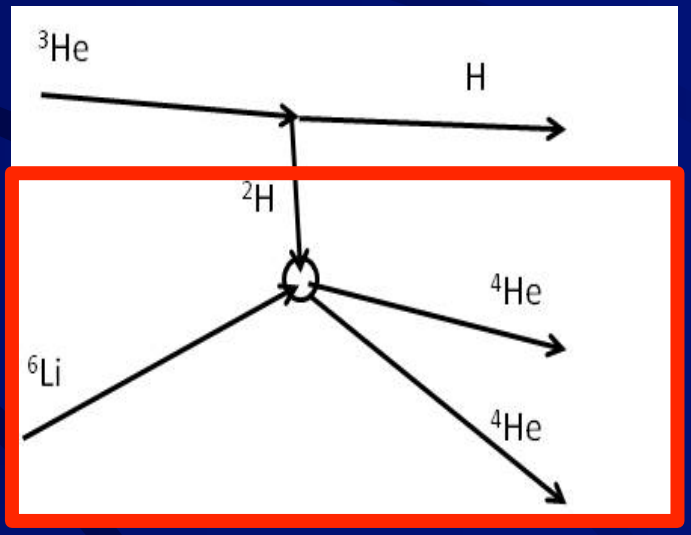
TH particle Invariance Test

The binary cross-section measured via THM should be independent from the TH particle (and also from spectator). This at least is predicted from direct reactions theory.

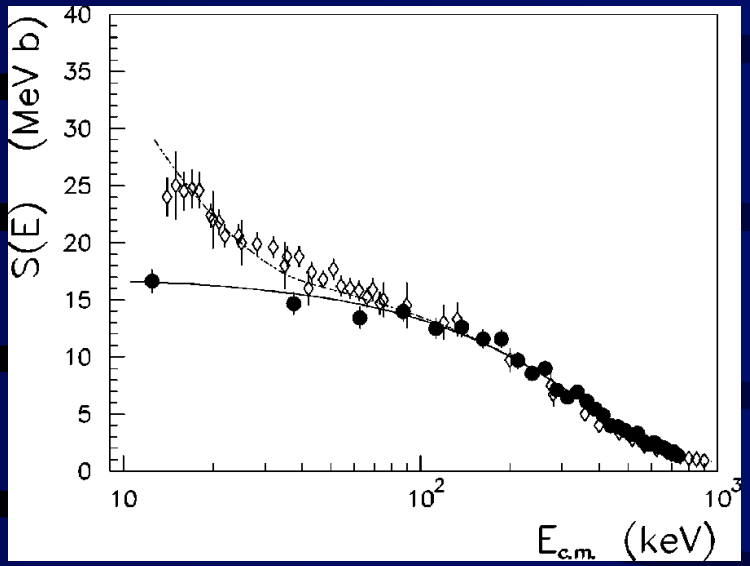
Does anything change if Trojan horse particle (or spectator) is changed?

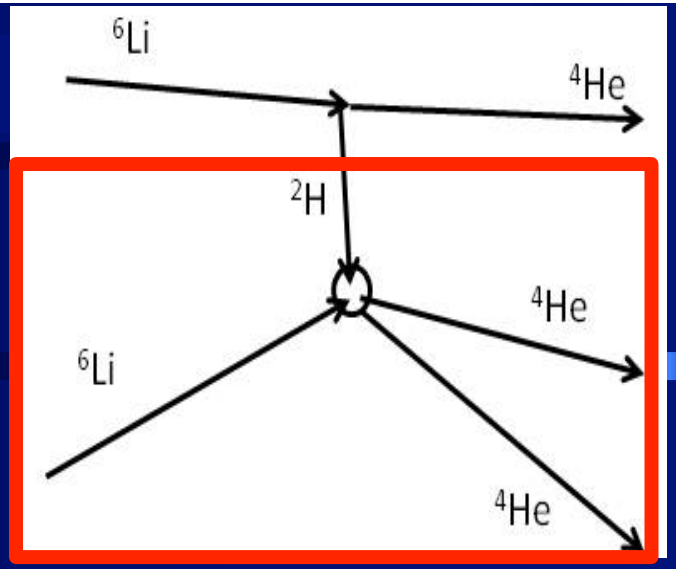
The physical case: ^{6}Li(d,a)^{4}He studied via the THM after ^{6}Li and ^{3}He break-up.





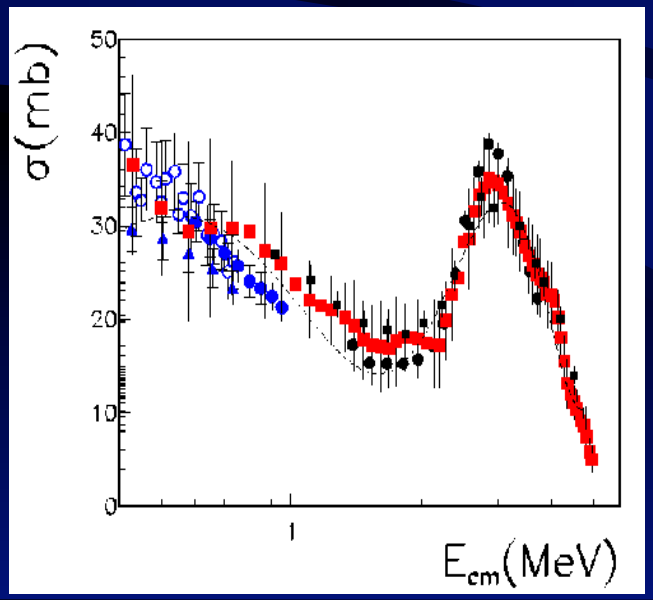
First Experiment: ^{6}Li break-up

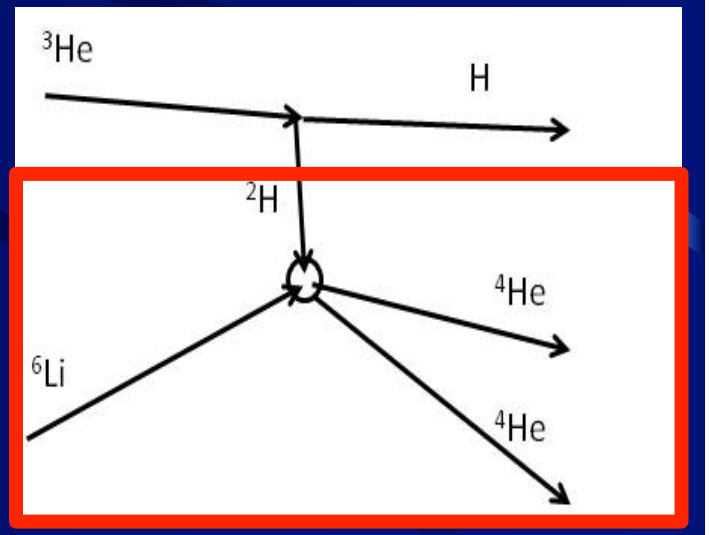




Data published in Spitaleri et al, PRC, 2001

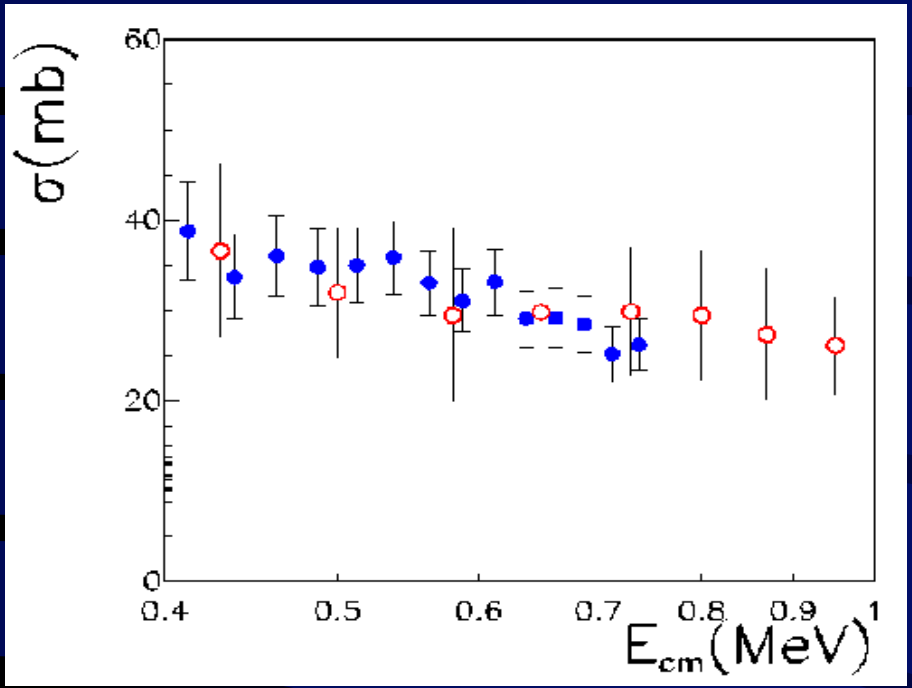
Second Experiment: ^{3}He break-up





Data published in Pizzone et al, PRC, 2011

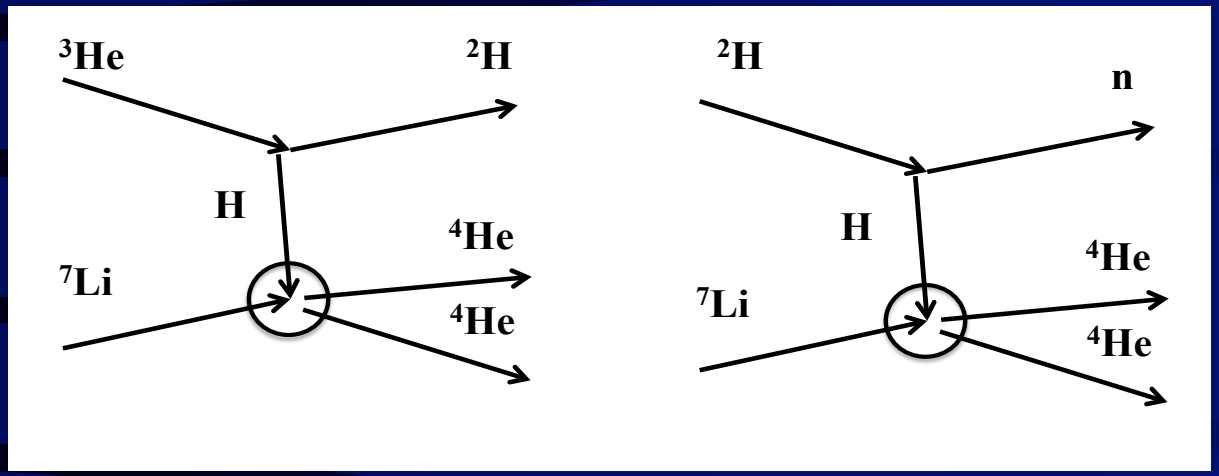
Comparison of ^{3}He and ^{6}Li break-up ✔



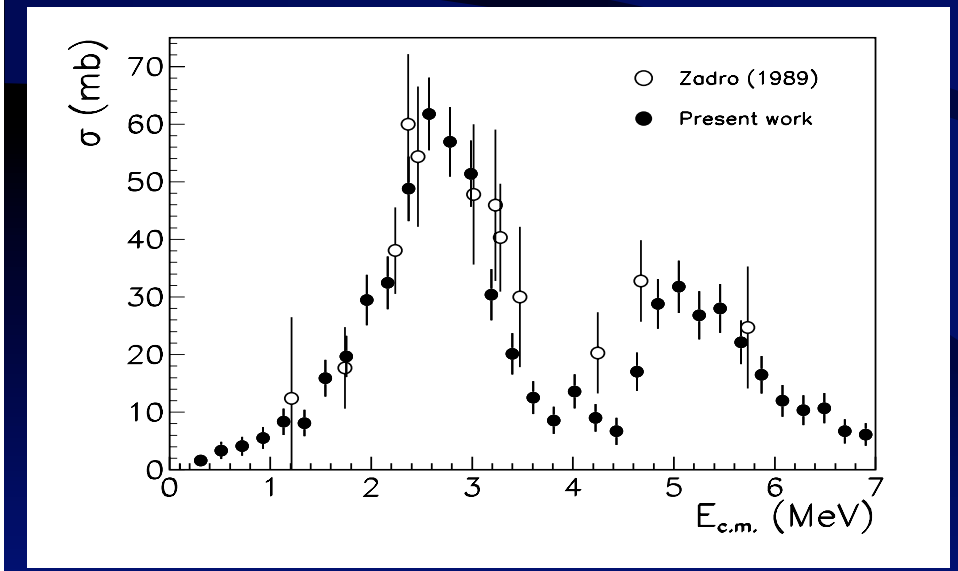
Data from ^{3}He and ^{6}Li break-up
Were compared and they agree within
Experimental errors

Blue: ^{6}Li break-up
Red: ^{3}He break-up

Second Evidence: $^{7}Li(p,a)^{4}He$



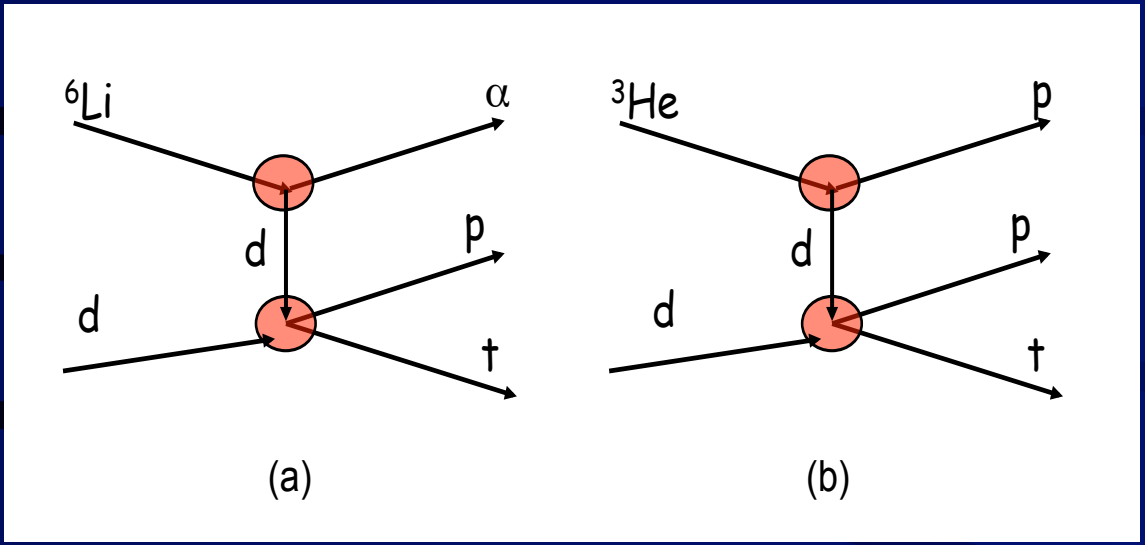
^{3}He breakup ^{2}H breakup



The $^{7}Li(p,a)^{4}He$ reaction was studied after ^{3}He and ^{2}H break-up.
The two data sets are compared above, showing that we have a good Agreement within experimental errors also in this case.

See: Pizzone et al. PRC 2011 & Zadro et al PRC 1989

Third evidence d(d,p)t

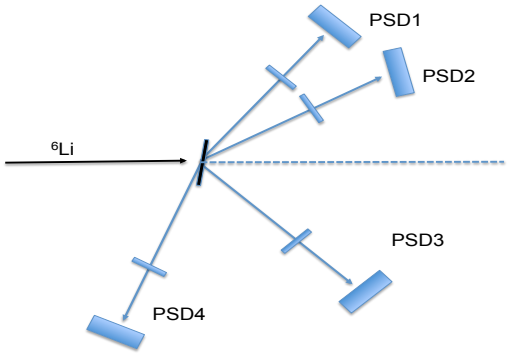


?

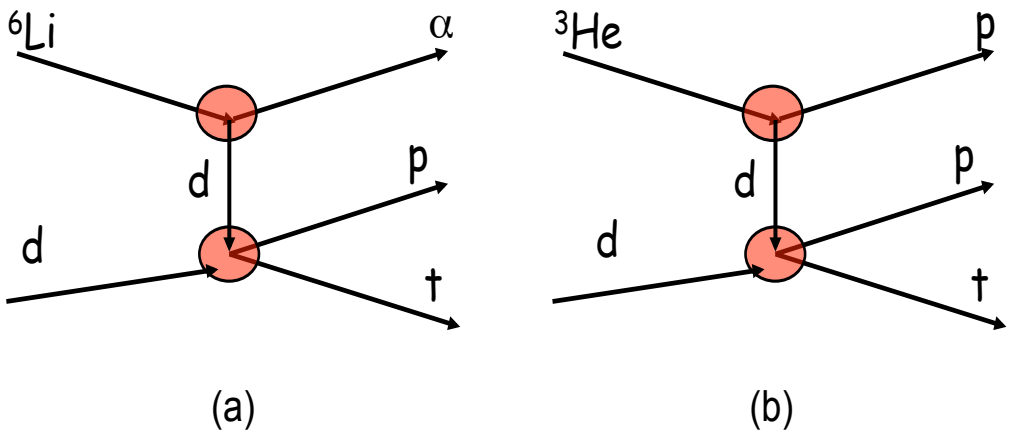
The d(d,p)t reaction was studied and its cross section measured after The break-up of ^{3}He (process (b), see ref. Tumino et al. Phys.Lett.B 2011)
Does the spectator invariance holds also in this case?
We thus suggest an experiment via ^{6}Li break-up following the break-up scheme (a).
The experiment was performed in Dynamitron Tandem Laboratorium (Bochum)

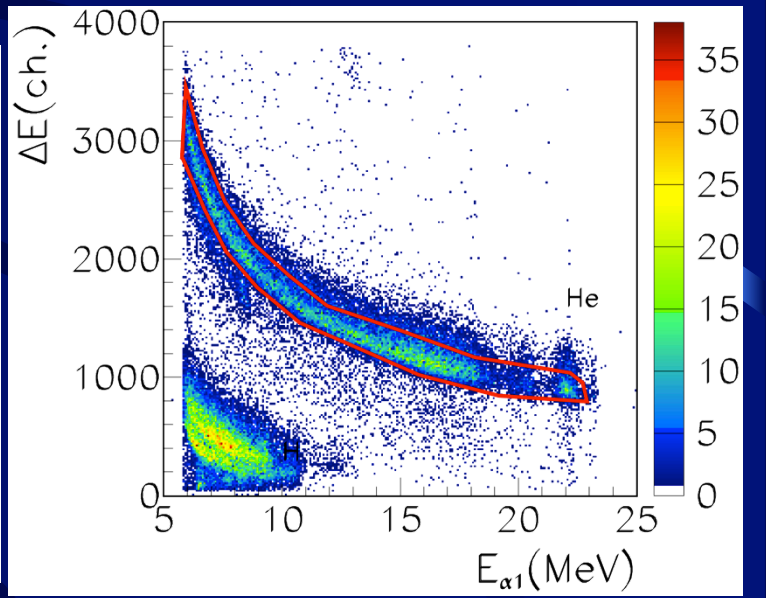
The experiment

Detector	angular range (deg)
PSD_1	42-54
PSD_2	18-28
PSD_3	42-54
PSD_4	105-115



A preliminary run was performed (Rinollo et al. 2006) and an upgraded experimental setup was Used.





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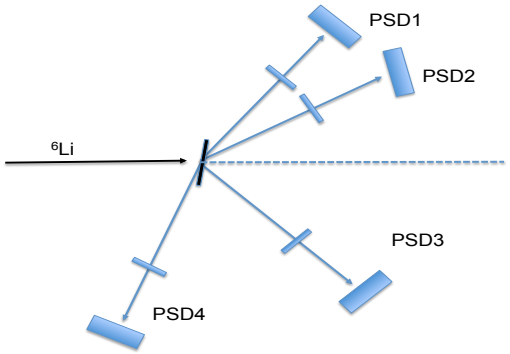

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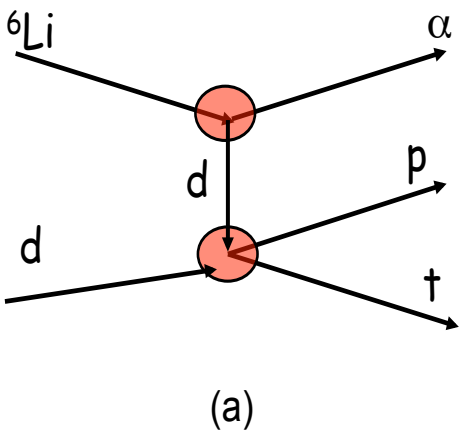
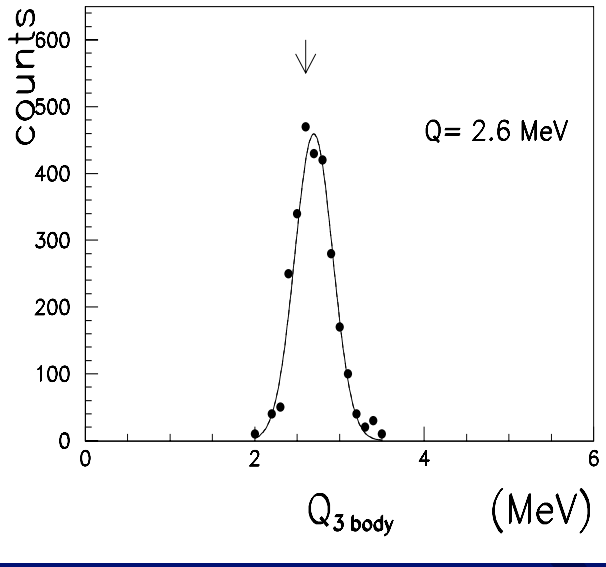
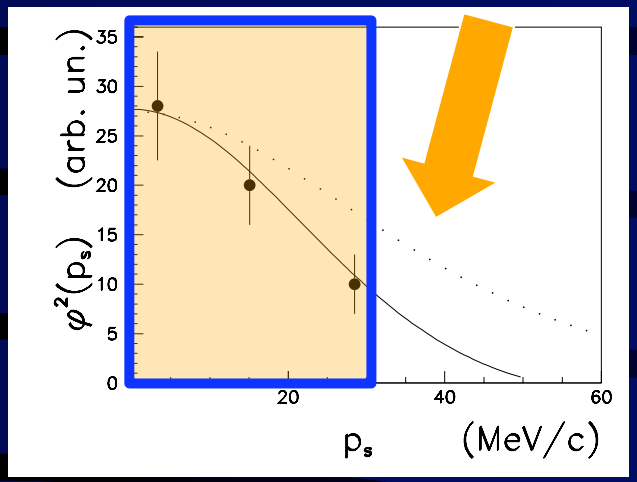


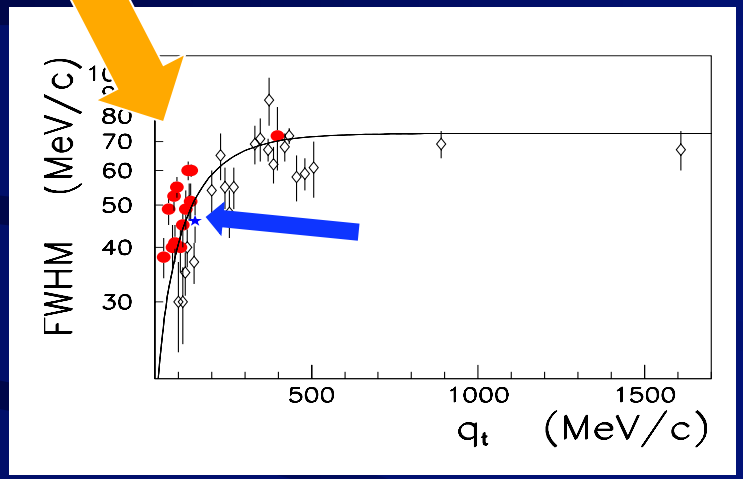


The 3-body reaction of interest was selected after particle identifications, kinematic cuts and Q-value reconstruction

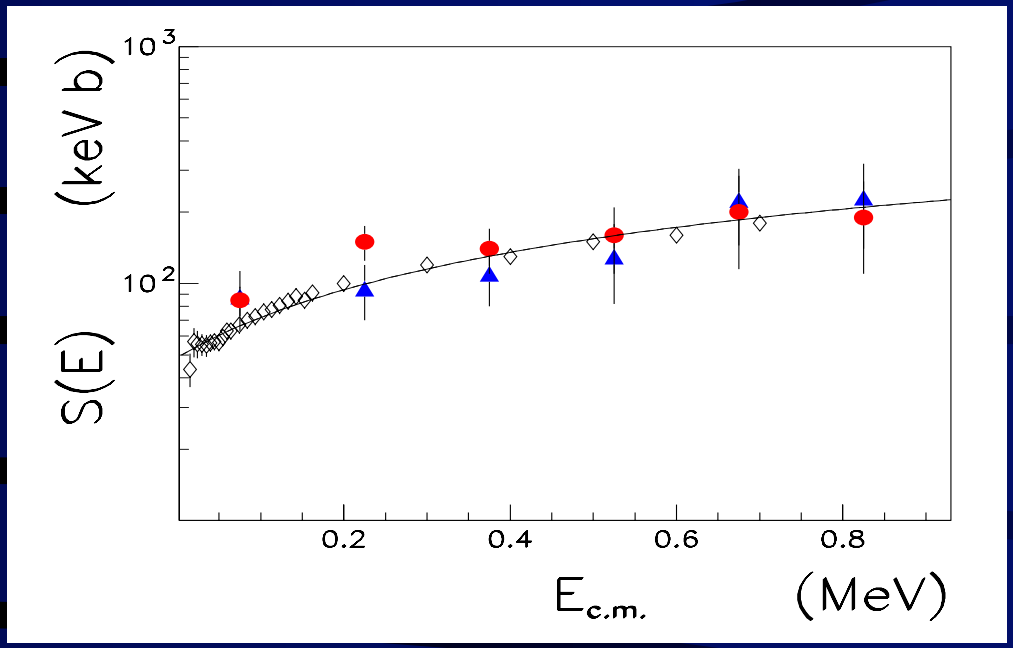
QF mechanism selection

All steps of the standard THM Analysis were carried successfully on (see Pizzone et al. PRC 2013) and the momentum distribution extracted

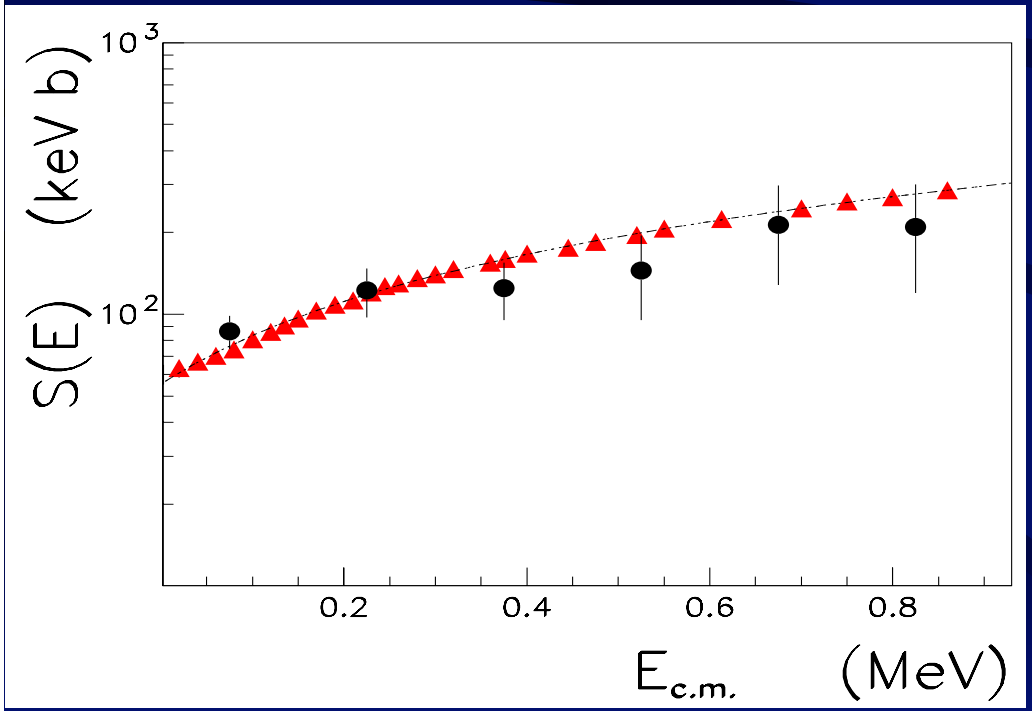




Evidences of QF mechanism are found and only events with p_s<30 MeV/c were selected for the following analysis, according to THM prescriptions.

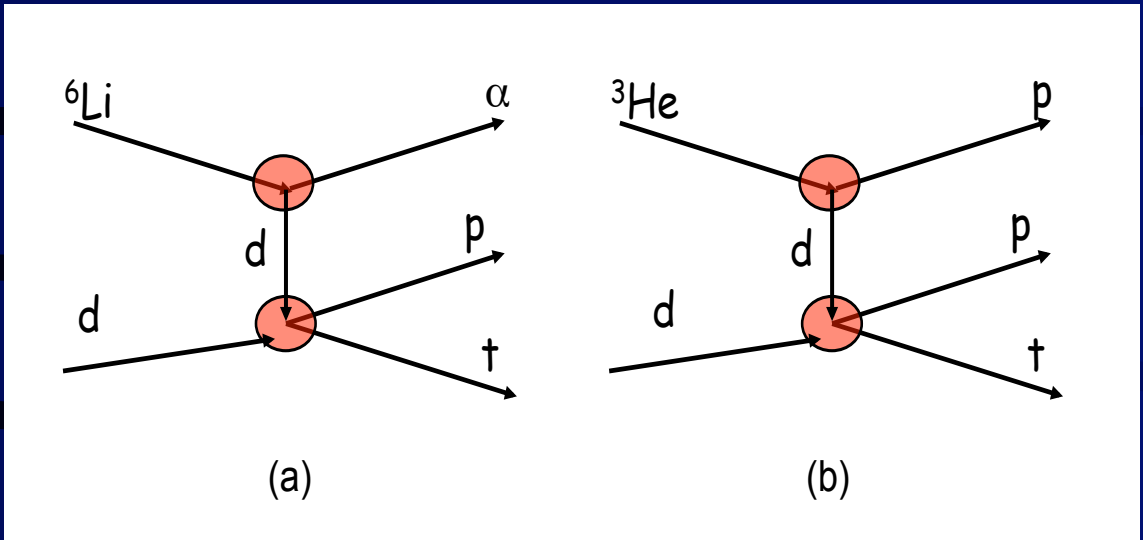


Present data from ^{6}Li break-up (red) compared with THM data from Rinollo et al. Normalized to direct data (Krauss Et al.,1987)
A good agreement shows up.



Averaged THM data (black) compared with data arising from ^{3}He breakup (Tumino et al.,2011)
A good agreement shows up
Proving also in this case the Trojan Horse particle invariance.

Third evidence d(d,p)t



- The Trojan Horse particle is found also in the d(d,p)t case. Data from ^{3}He and ^{6}Li break-up agree within experimental errors showing also in this case the spectator invariance (also referred to as pole invariance).

Concluding Remarks

- The spectator invariance was experimentally tested in three cases:

  d(d,p)t both from ^{6}Li and ^{3}He break-up;

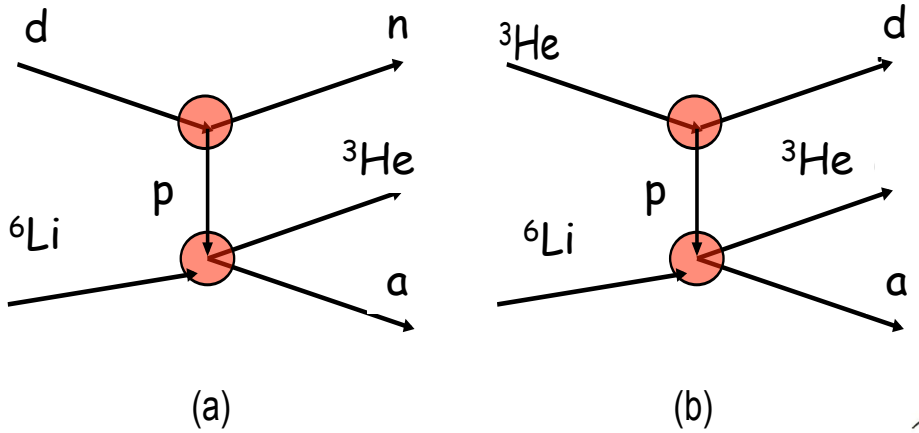
  ^{7}Li(p,a)^{4}He both from ^{3}He and d break-up;

  ^{6}Li(d,a)^{4}He both from ^{6}Li and ^{3}He break-up.

- Evidences confirm prediction from direct mechanisms theory
- Further experimental studies are required for other precesses, e.g. ^{6}Li(p,a)^{3}He

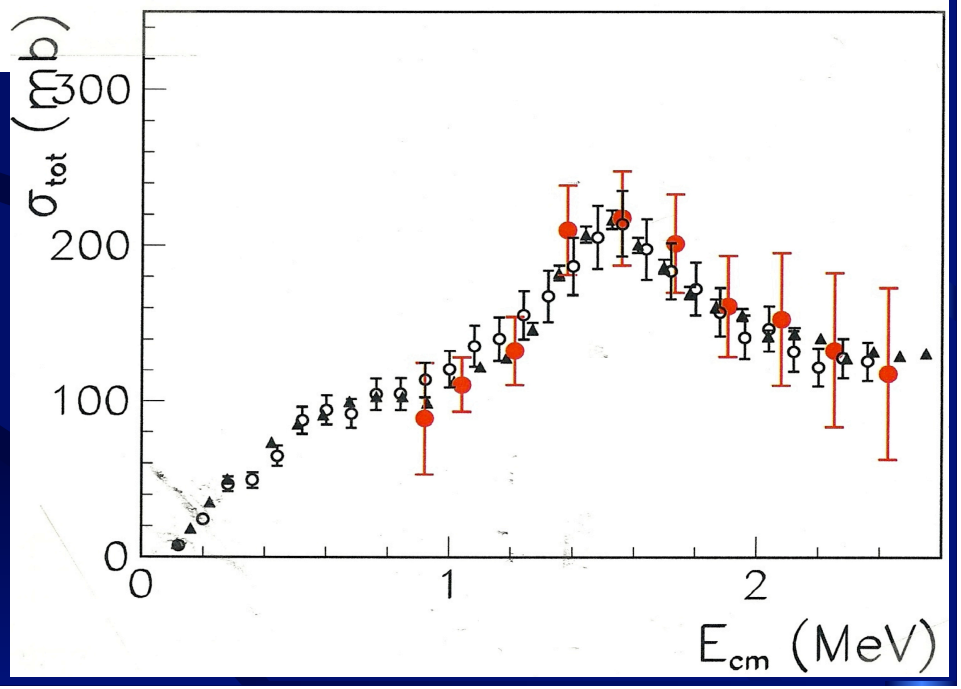
Preliminary data on $^{6}Li(p,a)^{3}He$

E_{beam}=25 MeV @ Rez (Praha), LiF target



First evidences show results consistant with other reactions

Red: ^{3}He break-up
Black: d break-up
Empty: Direct data
(Elwyn 1979)



COLLABORATION

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