10th Russbach School on Nuclear Astrophysics

The Trojan Horse Method as a tool for measuring nuclear reactions of astrophysical interest

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Rußbach am Paß Gschütt
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Outline

→ **Nuclear astrophysics and indirect methods**
(a few words on)

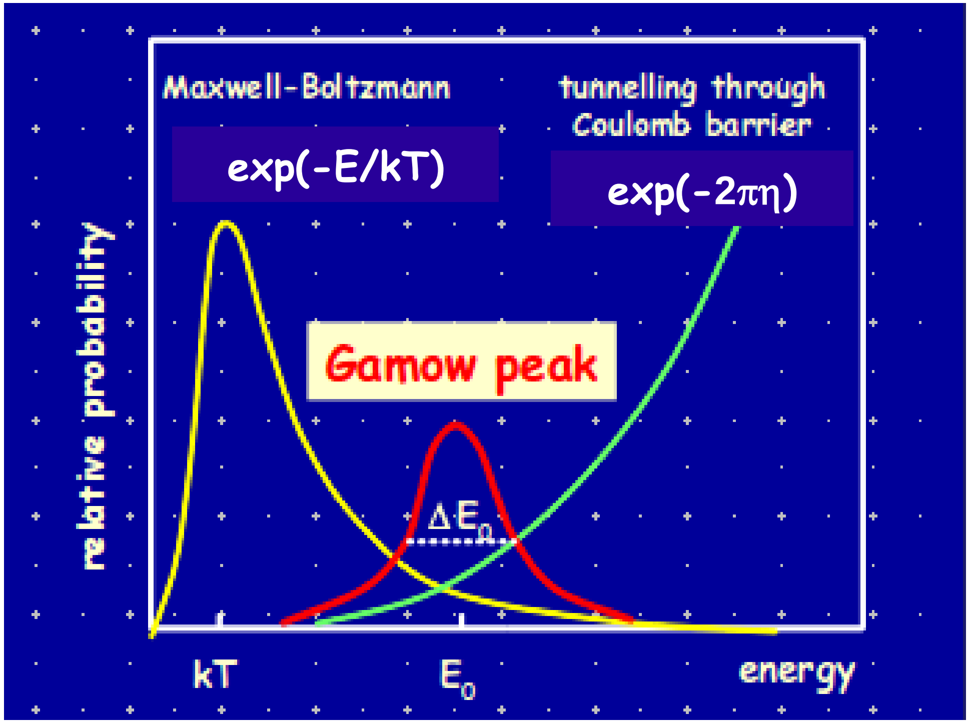
→ **The Trojan Horse Method primer**

- → **Origin of the method**
- → **Validity tests**
- → **Experimental advantages**

→ **An example of recent application: ^{18}F+p**
(if time is not gone yet)

History of Nuclear Astrophysics in short!

- Eddington, Aston, Gamow, Bethe: "energy production in stars" (1920-1939)
- Gamow introduced the Gamow factor (1928), convoluted with the Maxwell distribution this fixes the typical energy for nuclear reactions in stars



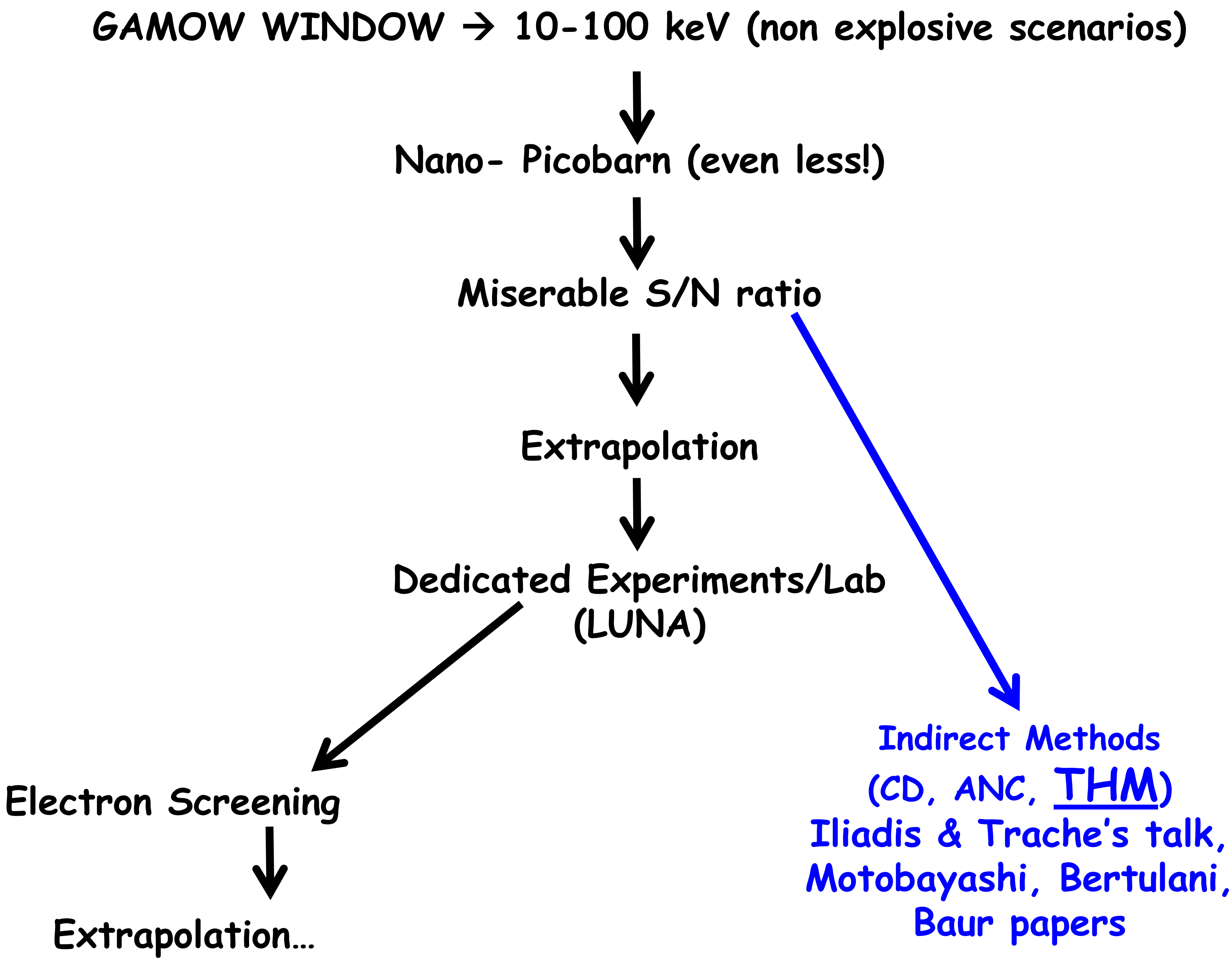
Reaction rate: $r = N_1 N_2 v \sigma(v)$

(# reactions volume^{-1} time^{-1})

$$\langle \sigma v \rangle = \left(\frac{8}{\pi\mu}\right)^{1/2} \frac{1}{(kT)^{3/2}} \int_0^\infty \sigma(E) E \exp\left(-\frac{E}{kT}\right) dE$$

See Iliadis' talk

- B^2FH: kind of formal definition of nucleosyntesis in stars (1957)


GAMOW WINDOW → 10-100 keV (non explosive scenarios)
Nano- Picobarn (even less!)
Miserable S/N ratio
Extrapolation
Dedicated Experiments/Lab
(LUNA)
Electron Screening
Extrapolation…
Indirect Methods
(CD, ANC, THM)
Iliadis & Trache's talk,
Motobayashi, Bertulani,
Baur papers

THM: a primer

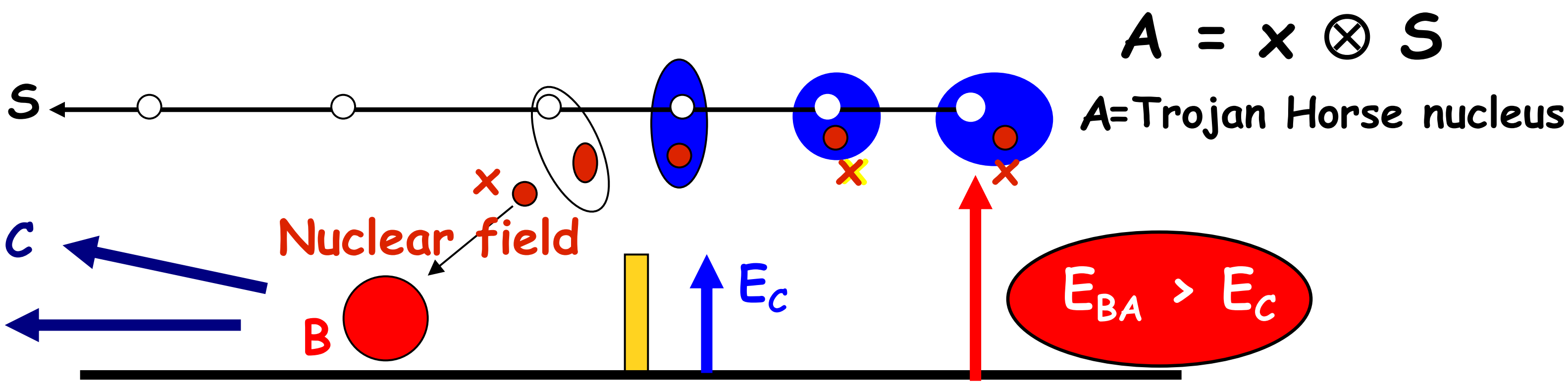
Idea: get the 2-body cross-section of the process

$$B + x \rightarrow C + D$$

At astrophysical energies from the QUASI-FREE contribution

of a 3-body reaction *(C. Spitaleri, Folgaria 1990)*

$$B + A \rightarrow C + D + S$$



E_{Bx} = interaction energy B-x

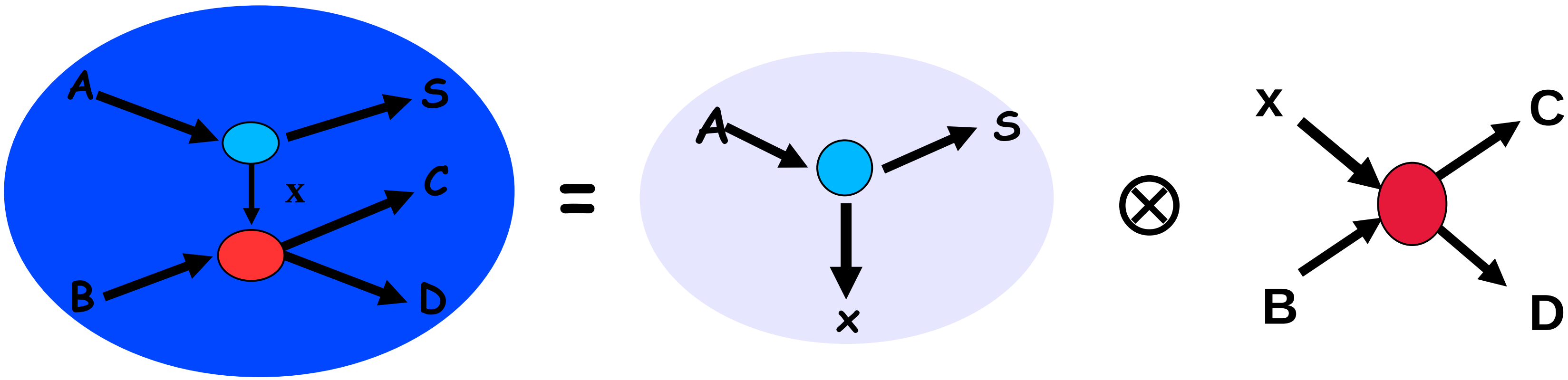
E_C = Coulomb barrier between A and B

E_{BA} = relative energy between A and B

$E_{Bx} = E_{CD} - Q_2$ P C P

Electron screening removed by construction

Assuming that a Quasi-free mechanism is dominant one can use the (PW)IA:



3-body Reaction

Virtual Decay

Virtual reaction
(astrophysical process)

$$\frac{d^3\sigma}{d\Omega_C \, d\Omega_D \, dE_{cm}} \propto KF \cdot |\Phi(P_s)|^2 \bullet \frac{d\sigma^N}{d\Omega}$$

$$E_{Bx} = E_{CD} - Q_{2b}$$

Interlude #1

(An heuristic plausibility explanation for the factorization just shown)

Where does the factorization come from?

Following a symbolic approach we can write:

$$M_{fi} = \langle d|\langle c|\langle s|\ \mathcal{M}\ |A\rangle|B\rangle$$

where $\mathcal{M}$ is the matrix element for the three body

One can rewrite M_{fi} as

$$M_{fi} = \langle d|\langle c|\langle s|M \cdot \mathbf{1}|A\rangle|B\rangle = \langle d|\langle c|\langle s|\ M\ |x\rangle\langle x||A\rangle|B\rangle$$

identity operator

Hypotesis of vertex independence:

$M = M_{vd} \otimes M_{vr}$ (compare with IA hypoteses, Chew and Wick, 1952)

then

$$M_{fi} = \langle d|\langle c|\langle s|\ M_{vd} \otimes M_{vr}\ |x\rangle\langle x|\ |A\rangle|B\rangle =$$
$$= \langle s|\langle x|\ M_{vd}\ |A\rangle\ \ \langle d|\langle c|\ M_{vr}\ |x\rangle|B\rangle$$

hence

$$\sigma_{3b} \propto \int |M_{fi}|^2\, d(PS) = \underbrace{|\langle s|\langle x|M_{vd}|A\rangle|^2}_{|\Phi(p_s)|^2} \bullet \underbrace{|\langle c|\langle d|M_{vr}|x\rangle|B\rangle|^2}_{d\sigma^N/d\Omega}$$

The missing KF factor comes from Energy-Momentum conservation.

Caveat. Particle x is associated with an internal line, a “propagator”:

$P^{\mu}\ P_{\mu} \neq m_x^{\ 2}$ **VIRTUAL PARTICLE !**

Interlude #2

Up to now no specific calculation procedure has been applied.

Only the possibility of factorizing the 3 body cross-section is really important.

Approaches used so far

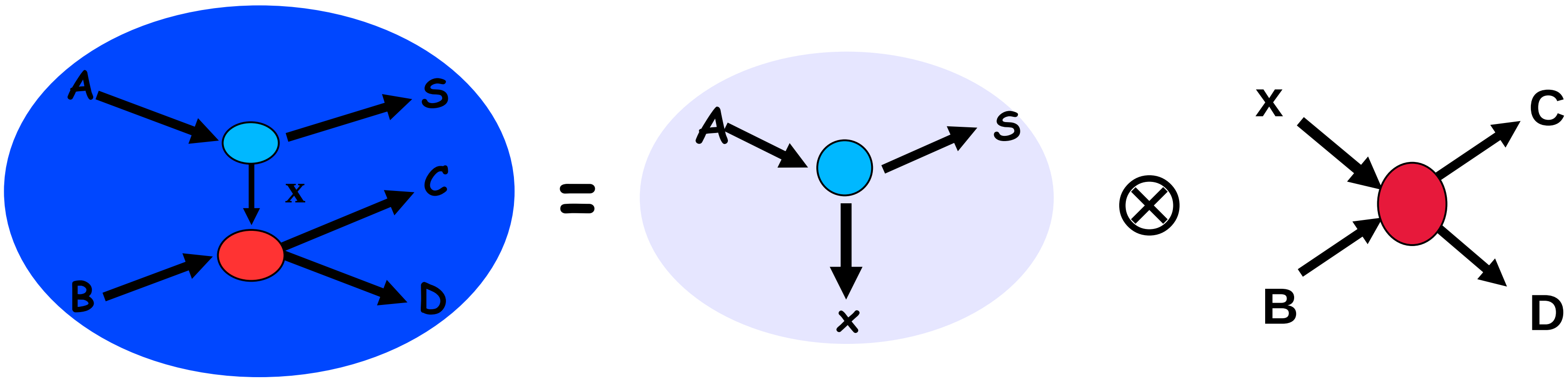
PWIA (Kondratiev)

MPWBA (Typel-Wolter)

PWIA+DWBA+many others (Mukhamedzanov+Bertulani)

«God» (the method) is one, though there are many «prophets» (theorists)!

Assuming that a Quasi-free mechanism is dominant one can use the (PW)IA:

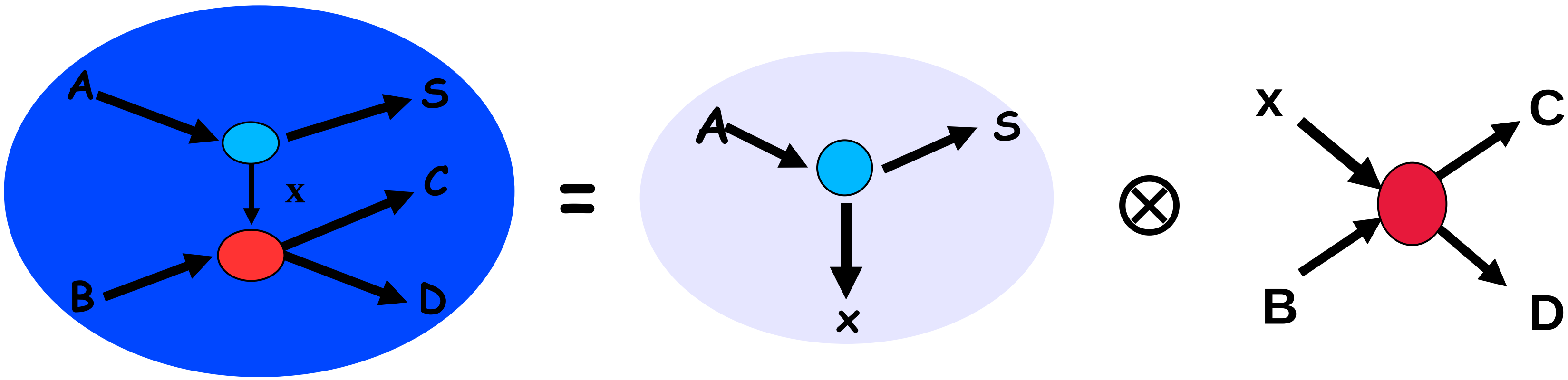


3-body Reaction — Virtual Decay — **Virtual reaction (astrophysical process)**

$$\frac{d^3\sigma}{d\Omega_C \, d\Omega_D \, dE_{cm}} \propto KF \cdot |\Phi(P_s)|^2 \bullet \frac{d\sigma^N}{d\Omega}$$

$$E_{Bx} = E_{CD} - Q_{2b}$$

By inverting the previous formula



3-body Reaction

Virtual Decay

Virtual reaction
(astrophysical process)

$$\frac{d^3\sigma}{d\Omega_C \, d\Omega_D \, dE_{cm}} \Big/ KF \cdot |\Phi(P_s)|^2 \propto \frac{d\sigma^N}{d\Omega}$$

<u>Measured at high energy</u>

<u>Calculated e.g. Montecarlo</u>

<u>Indirectly Measured</u>

$E_{Bx} = E_{CD} - Q_{2b}$

Let's summarize (in PWIA)

$$\frac{d^3\sigma}{d\Omega_c d\Omega_C dE_C} \propto KF \bullet |\Phi(p_s)|^2 \bullet \left(\frac{d^2\sigma}{d\Omega}\right)_{cm}$$

In THM becomes

$$\frac{d^3\sigma}{d\Omega_c d\Omega_C dE_C} \propto KF \bullet |\Phi(p_s)|^2 \bullet \left(\frac{d^2\sigma^N}{d\Omega}\right)_{cm}$$

2-body x-section is

coulomb barrier free!

Insensitive by definition to electron screening

$$\left.\frac{d^2\sigma}{d\Omega}\right)_{\substack{direct\\measurement}} = G_C \bullet \left(\frac{d^2\sigma^N}{d\Omega}\right)_{TH}$$

Barrier penetration coefficient

$$S(E) = e^{2\pi\eta} \cdot G_C \cdot S^N(E)$$

where

$$S^N(E) = E \cdot \sigma^N(E)$$

Nuclear Astrophysical factor

APPLICATION OF THE METHOD and tricky points

From the theoretical/phenmenological point of view

1. Selection of the three body reaction and of the Trojan Horse Nucleus depending on its cluster structure properties. *This affects the number and type of reaction mechanisms competing with the QF one and the cross section value of the QF channel itself (more in two slides)*
2. Check of the presence/dominance of the QF mechanism (impulse distribution reconstruction, study of the angular distribution, Treiman-Yang criterion)
3. Reliability of the "ingredients" used in $d^2\sigma$ derivation, e.g. of impulse distribution of the TH nucleus.
4. If one is measuring a cross section below the Coulomb barrier, then he/she has to correct the THM x-sec for penetration factor before comparing the THM results with the direct ones.

From the experimental point of view:

1) Optimization of the energy and angular resolution of the experiment to obtain the necessary resolution in the E_{xB} variable (relative energy of x-B related to the cm energy of the astrophysical process)

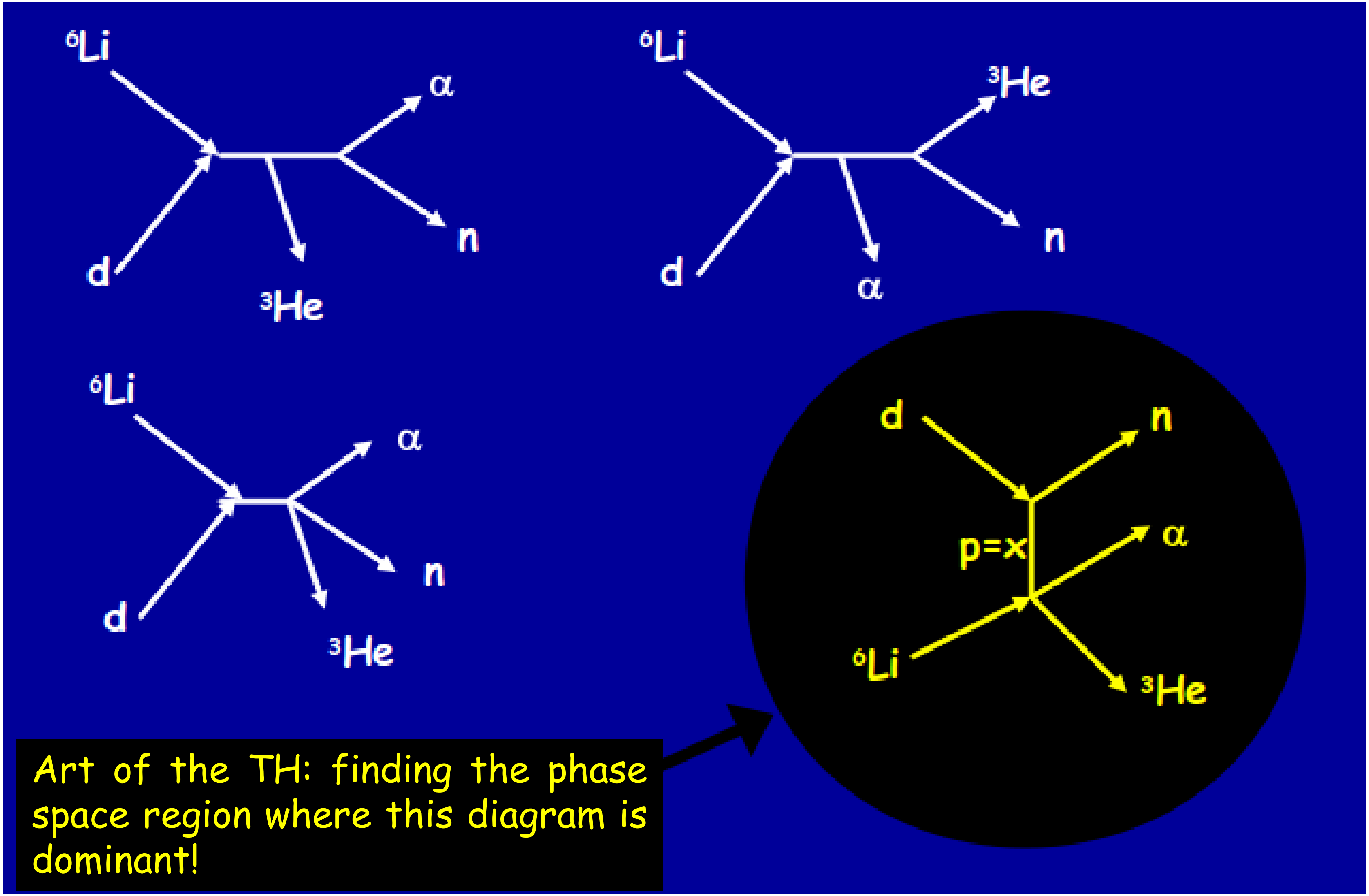
$$\Delta E_{xB} = f(\Delta E_C \ \Delta E_D \ \Delta\theta_C \ \Delta\theta_D)$$

2) Background noise suppression (this is not THM specific...) including the PHYSICAL background (see next slide)

3) Availability of direct measurements (above the region where Electron Screening effects start to show up and if possible also above the Coulomb barrier) to normalize the THM data.

PHYSICAL BACKGROUND: an example

^{6}Li+p → ^{3}He+α from ^{6}Li+d → ^{3}He+α + n



Art of the TH: finding the phase space region where this diagram is dominant!

ADVANTAGES of the Method

1) The cross sections in the experiment are typical QF processes ones (mbarn/sr) though one is measuring a nuclear reaction at astrophysical energies

2) The THM x-section is purely NUCLEAR: no suppression effect due to Coulomb barrier

3) No electron screening effect: one can get INDEPENDENT pieces of information on the electron screening potential by comparison with direct data (see RG Pizzone's talk)

4) The experimental setup is tipically simple enough

5) The THM can be extended to use QFR in studying NEUTRON induced reaction (VNM Virtual Neutron Method) (M. Gulino's talk)

IL METODO NON CADE DAL PERO…

- On the 7Li(d,αα)n Quasi-free reaction at low energy. Spitaleri, C.; Lattuada, M.; Riggi, P.; Arena, N.; Vinciguerra, D. *Lettere al Nuovo Cimento* vol. 21 issue 10 March 1978. p. 345 – 350 DOI:10.1007/BF02762995
- On the 6Li break-up in the nuclear field. Lattuada, M.; Vinciguerra, D.; Riggi, F. *Lettere Al Nuovo Cimento Series 2* vol. 21 issue 14 April 1978. p. 497 -501 DOI: 10.1007/BF02778045.
- Energy dependence of the quasi-free 9Be(3He,aa)4He reaction near the coulomb barrier. Arena, N.; Vinciguerra, D.; Lattuada, M.; Riggi, F.; Spitaleri, C. *Il Nuovo Cimento A Series 11* vol. 45 issue 3 June 1978. p. 405 - 418
- Quasi-free and sequential processes in the 9Be(3He,aa)4He Reaction at 2.8 MeV. Barbarino, S.; Lattuada, M.; Riggi, F.; Spitaleri, C.; Vinciguerra, D. *Lettere al Nuovo Cimento* vol. 25 issue 8 June 1979. p. 249 – 254 DOI: 10.1007/BF02776237.
- Quasi-free scattering and α-d clustering probability in 6Li. Calvi, G.; Lattuada, M.; Riggi, F.; Spitaleri, C.; Vinciguerra, D.; Miljanić, D. *Lettere Al Nuovo Cimento Series 2* vol. 37 issue 7 June 1983. p. 279 – 283 DOI: 10.1007/BF02752240.
- The neutron momentum distribution in 7Li and the three-body reaction7Li(d,aa)n. Lattuada, M.; Riggi, F.; Spitaleri, C.; Vinciguerra, D.; Fallica, P. G. *Il Nuovo Cimento A* vol. 72 issue 1 November 1982. p. 51 – 64 DOI: 10.1007/BF02784792.
- Excitation function of the quasi-free contribution in the 2H(Li,aa)n reaction at Eo =28—48 Mev, M. Zadro and D. Miljanic, C. Spitaleri G. Calvi, M. Lattuada, F. Riggi (Received 6 July 1988) Phys. Rev C40 (1989) 181
- Quasi-free reaction mechanism in 2H(6Li,3He a)n at Eo =21.6—33.6 MeV G. Calvi, M. Lattuada, D. Miljanic, F. Riggi, C. Spitaleri, M. Zadro Phys. Rev. C41 (1990) 1848

Treiman-Yang Criterion

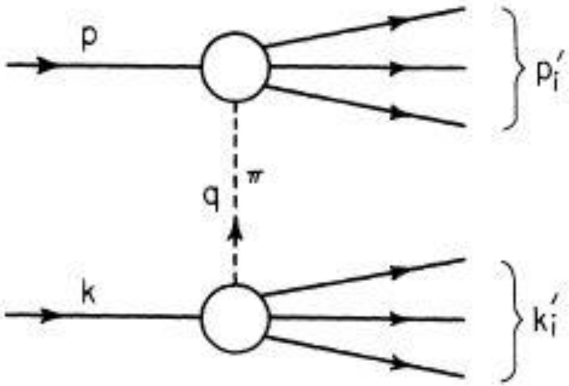


FIG. 1. Diagram for single-pion exchange.

VOLUME 8, NUMBER 3 PHYSICAL REVIEW LETTERS FEBRUARY 1, 1962

TESTS OF THE SINGLE-PION EXCHANGE MODEL

S. B. Treiman
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and

C. N. Yang
Institute for Advanced Study, Princeton, New Jersey
(Received December 14, 1961)

The differential reaction cross section $d\sigma$ is given by

$$J d\sigma = f\prod_i dp_i'\delta(p_i'^2+m_i^2)$$

$$\times\prod_j dk_j'\delta(k_j'^2+\mu_j^2)\delta(p+k-\sum p_i'-\sum k_j'). \quad (1)$$

where J is the relative current of the incident particles, f is the square of the invariant transition amplitude, and all energies are positive-definite. The crucial remark is that, on the peripheral collision picture, f has the structure

$$f = G(p, p_i')H(k, k_i'). \quad (2)$$

The implications of this restriction on the structure of f are best brought out in the reference frames in which one or another of the initial particles is at rest. Thus:

1. In the system where p is at rest (the laboratory system, if p is in fact the target particle), the differential cross section should be invariant under the simultaneous rotation of all three-vectors $\vec{p}_i'$ about the momentum vector $\vec{q}$ of the virtual meson: $\vec{q}=\vec{k}-\sum_i\vec{k}_i'=\sum_i\vec{p}_i'$. This result follows from inspection of Eqs. (1) and (2).

2. Similarly, in the system where k is at rest the differential cross section should be invariant under simultaneous rotation of all three-vectors $\vec{k}_i'$ about $\vec{q}=-\sum_i\vec{k}_i'=\sum_i\vec{p}_i'-\vec{p}$.

It is easy to prove that the above two tests are exhaustive for fixed incoming energy. There are

PHYSICAL REVIEW C VOLUME 24, NUMBER 4 OCTOBER 1981

Treiman-Yang criterion as a test of the pole approximation in the $^9Be(^3He,\alpha\alpha)^4He$ reaction

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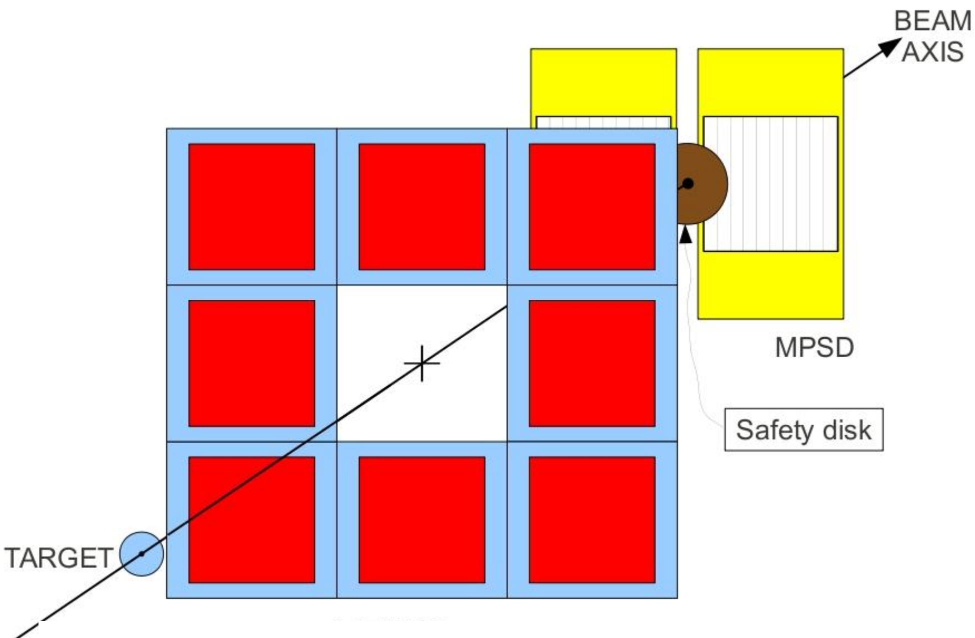
Istituti di Fisica dell'Università di Catania, Catania, Italy
(Received 26 March 1981)

The $^9Be(^3He,\alpha\alpha)^4He$ reaction has been studied at low incident energy to test the predictions of the pole approximation. Treiman-Yang distributions have been deduced from the measured differential cross sections for a wide range of the Treiman-Yang angle and of the spectator momentum. The data are consistent with the isotropic distribution predicted by

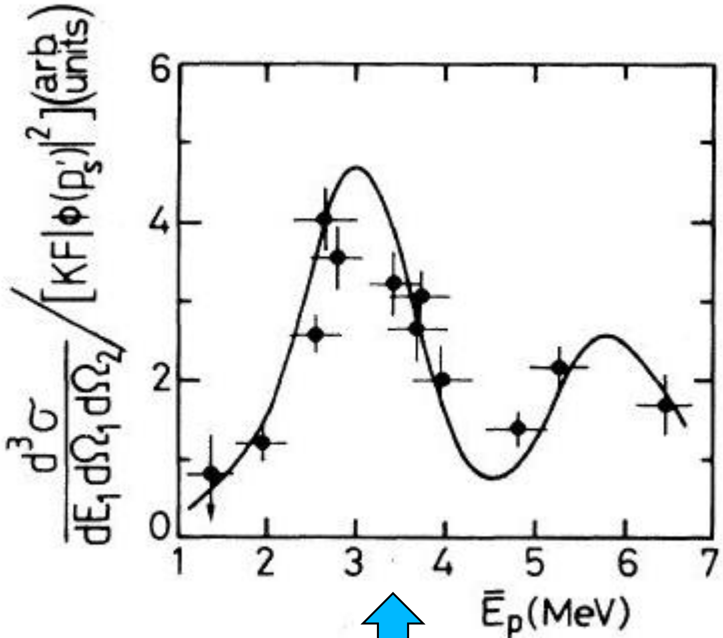
No satisfactory theoretical explanation has been given so far, to our knowledge, to justify the existence of QF processes at such low energies. However, the high Q of the reaction (19.09 MeV) is responsible for high momenta ($\approx$ 300 MeV/c) transferred to the outgoing particles. This is the case also for $(\pi^+,2n)$ and $(\pi^-,2p)$ reactions with low energy pions which have been reported for many years as showing evidence for QF processes.

Apart from the well known difficulties (Sec. I) of describing the QF process at low energies in the PWIA or even in the DWIA, one may argue which kind of information can be obtained by a more detailed study of the TY distribution. A higher resolution in θ_{TY} and spectator momentum, in addition to a better statistics would be highly desirable in order to measure significant deviation from the prediction of the pole approximation.



Super-ASTRHO (SuperA)

Two body cross sections from QFR with three body in the final state (above the Coulomb barrier)

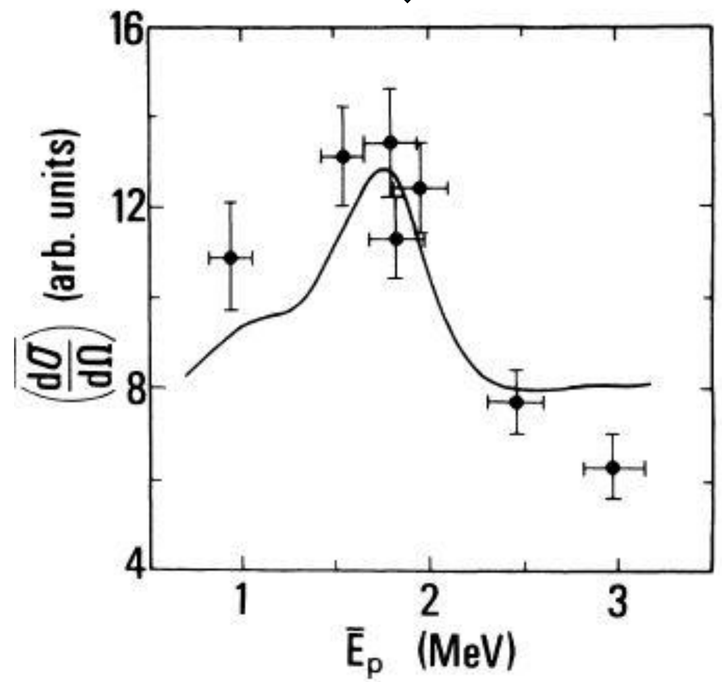


7Li+p → a + a
from
7Li+d → a +a +n

M. Zadro and D. Miljanic, C. Spitaleri G. Calvi, M. Lattuada, F. Riggi (Received 6 July 1988) Phys. Rev C40 (1989) 181

G. Calvi, M. Lattuada, D. Miljanic, F. Riggi, C. Spitaleri, M. Zadro Phys. Rev. C41 (1990) 1848

6Li+p → a + 3He
From
6Li+d → a +3He +n



THE ASTROPHYSICAL JOURNAL, 457:855–858, 1996 February 1

INDIRECT INVESTIGATION OF THE $d + {}^6\mathrm{Li}$ REACTION AT LOW ENERGIES RELEVANT FOR NUCLEAR ASTROPHYSICS

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Received 1995 April 11; accepted 1995 August 4

ABSTRACT

The indirect investigation of low-energy charged-particle reactions relevant for nuclear astrophysics is considered, employing statistical tensor analysis. Data from the quasi-free contribution to the ${}^6\mathrm{Li}({}^6\mathrm{Li}, 2\alpha){}^4\mathrm{He}$ reaction at projectile energies above the Coulomb barrier are analyzed in order to extract the excitation function of the ${}^6\mathrm{Li}(d, \alpha){}^4\mathrm{He}$ reaction at very low relative energy. The results are compared with an astrophysical factor extracted from the free-reaction cross section data. The limits of the method are discussed.

Subject headings: nuclear reactions, nucleosynthesis, abundances

First THM paper

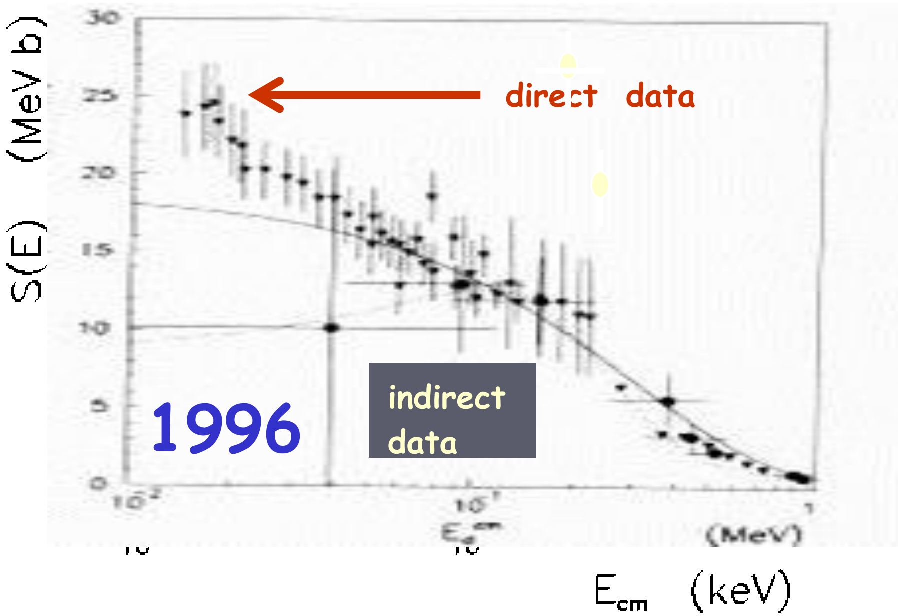
1. INTRODUCTION

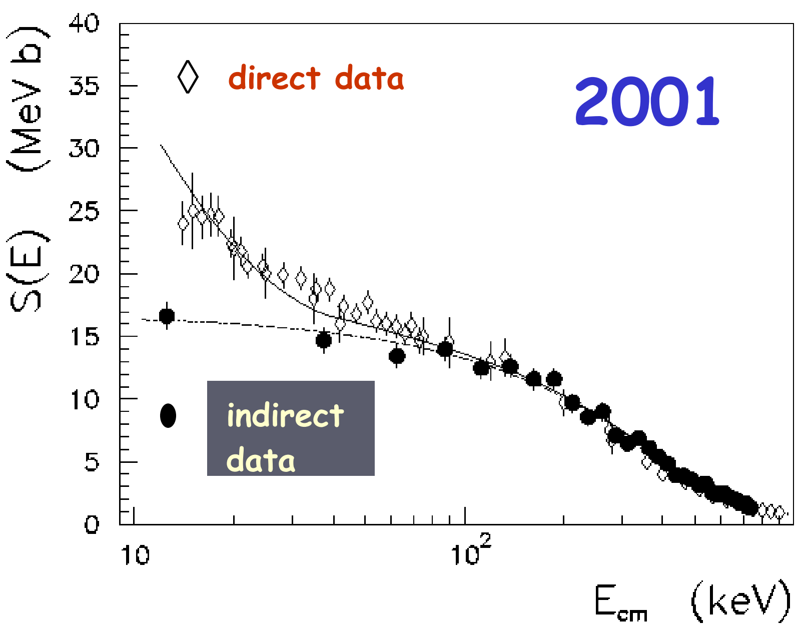
The study of nuclear reactions at very low bombardment energies, corresponding to stellar temperatures, is a significant support for an understanding of the astrophysical nuclear processes as well as for the description of stellar evolution and the abundance of various nuclides observed in the universe (Engstler et al. 1992). The calculated production rate of the elements depends strongly on the available experimental data. The eventual presence of unpredicted nuclear cross section resonances is particularly important to understanding the nuclide production through the stellar-burning chains. It is well known that the main difficulty of direct measurement comes from the very small value of the cross sections, which is due to the very high ratio of the Coulomb barrier to the incident energy. For this reason, very often the extraction of the astrophysical *S*-factor at the relevant energies is performed by extrapolation of experimental information taken at higher energies. This procedure implies an assumption of a theoretical

dominant at some particular kinematical conditions. At these conditions, the scattering process is considered to be well described by the pseudo–Feynman diagram of Figure 1. The target nucleus ${}^6\mathrm{Li}$ is assumed to disintegrate into the clusters α_s and d; α_s is then considered to be a spectator to the ${}^6\mathrm{Li}(d, \alpha)\alpha$ virtual reaction that proceeds within the region of the nuclear interaction. This description allows direct comparison of the triple-differential cross section $d^3\sigma/(dE_1\, d\Omega_1\, d\Omega_2)$ of the ${}^6\mathrm{Li}({}^6\mathrm{Li}, 2\alpha)\alpha_s$ reaction with the cross section for the ${}^6\mathrm{Li}(d, \alpha)\alpha$ nuclear process. Using the distorted wave impulse approximation, we express the triple-differential cross section, measured in an α_1-α_2 coincidence experiment, through the nuclear part of the two-body reaction cross section as (see Chant & Roos 1977 and references therein):

$$\frac{d^3\sigma}{dE_1\, d\Omega_1\, d\Omega_2} = \mathrm{KF}|\Phi_{p_{12}}(p_s)|^2 \frac{d\sigma^N}{d\Omega}\,, \qquad (1)$$

where KF is a kinematical factor. The distorted, spectator





Tandem- Athens (re-analisys)

E_{beam}=3-7 MeV

Cherubini et al. ApJ. 457 (1996) 855, THM

Engstler et al. 1992

Tandem Zagreb – IRB

E_{beam}= 5 MeV

● **Musumarra et al.:**
Phys. Rev.C 64,(2001),068801

◊ **Engstler et al.** PLB 279,20, (1992)

S_0=16.9 MeVb

For applications to LiBeB abundances problem of these see Lamia's talk

Optimization of the «ingredients» of the method

PHYSICAL REVIEW C 71, 058801 (2005)

Impulse distribution of α+d in ^{6}Li

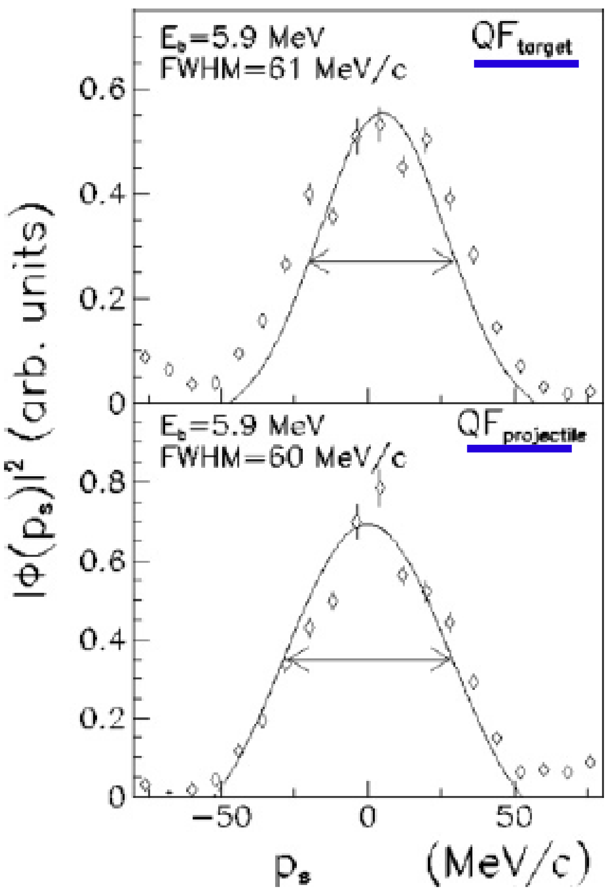


FIG. 1. Experimental momentum distribution for the α particle inside ^{6}Li derived according to the guidelines given in the text for the ^{6}Li(^{6}Li, αα)^{4}He reaction. The upper and lower parts refer to the target and projectile breakup cases, respectively.

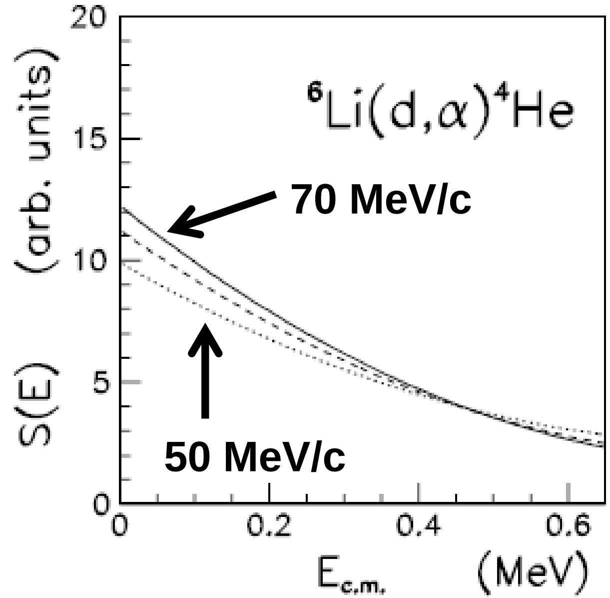
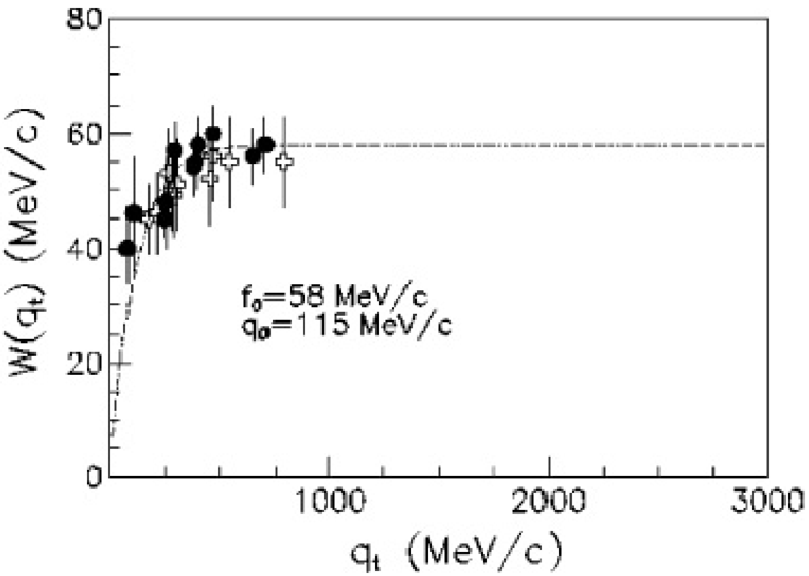


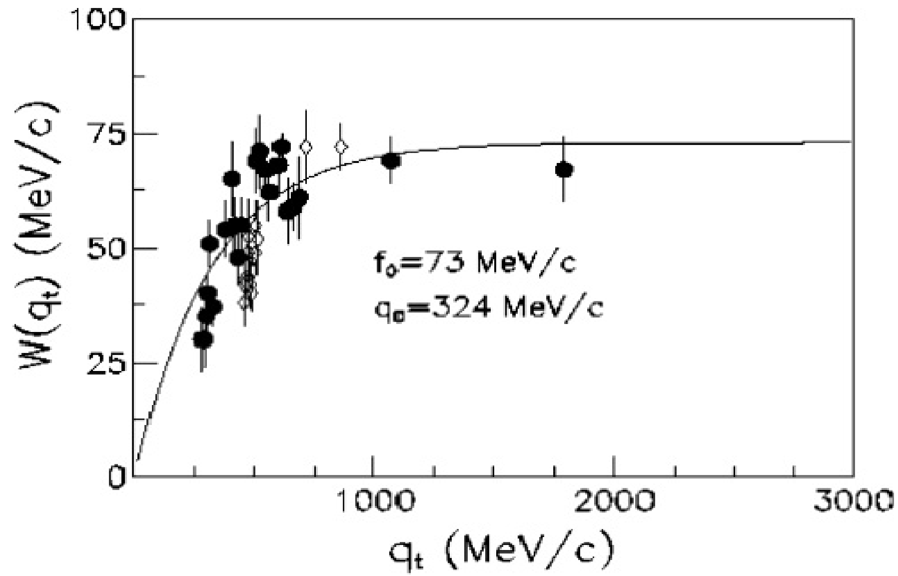
FIG. 3. Experimental ^{6}Li(d, α)^{4}He $S(E)$ factor, extracted via the THM, for different choices of the $w(q_t)$ for the α momentum distribution inside ^{6}Li. The solid line represents the case of $w(q_t)$ = 70 MeV/c, the dashed line is for $w(q_t)$ = 61 MeV/c, and dotted line is for $w(q_t)$ = 50 MeV/c.

Dependence of the final result from the impulse distribution width

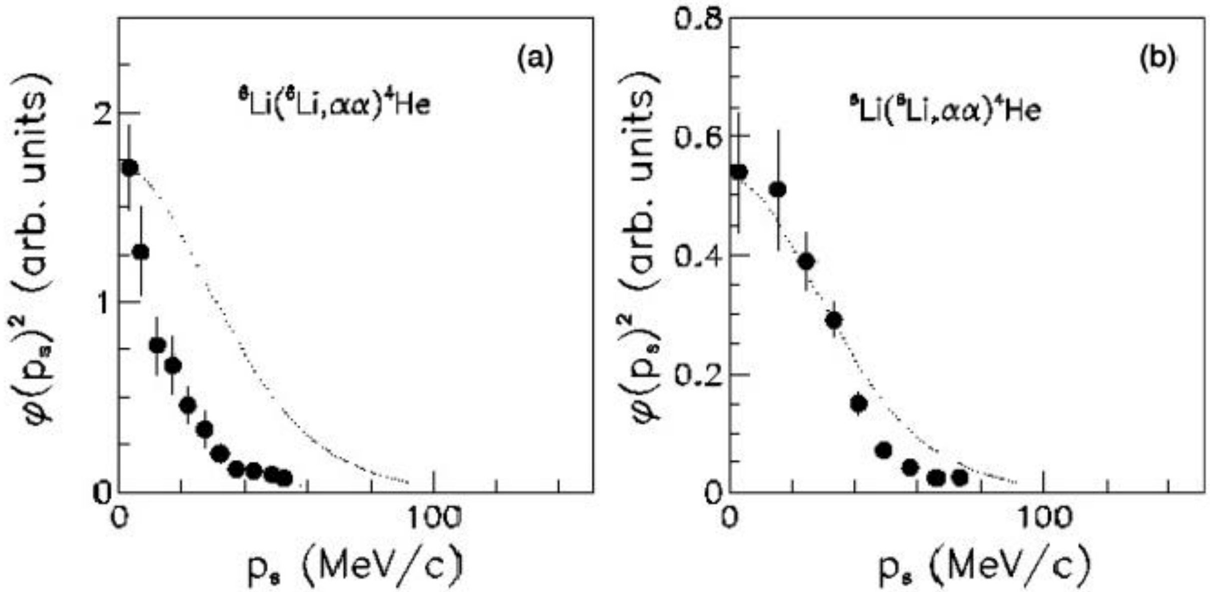
(IN)dependence from theTrojan Horse nucleus also verified

Optimization of the «ingredients» of the method



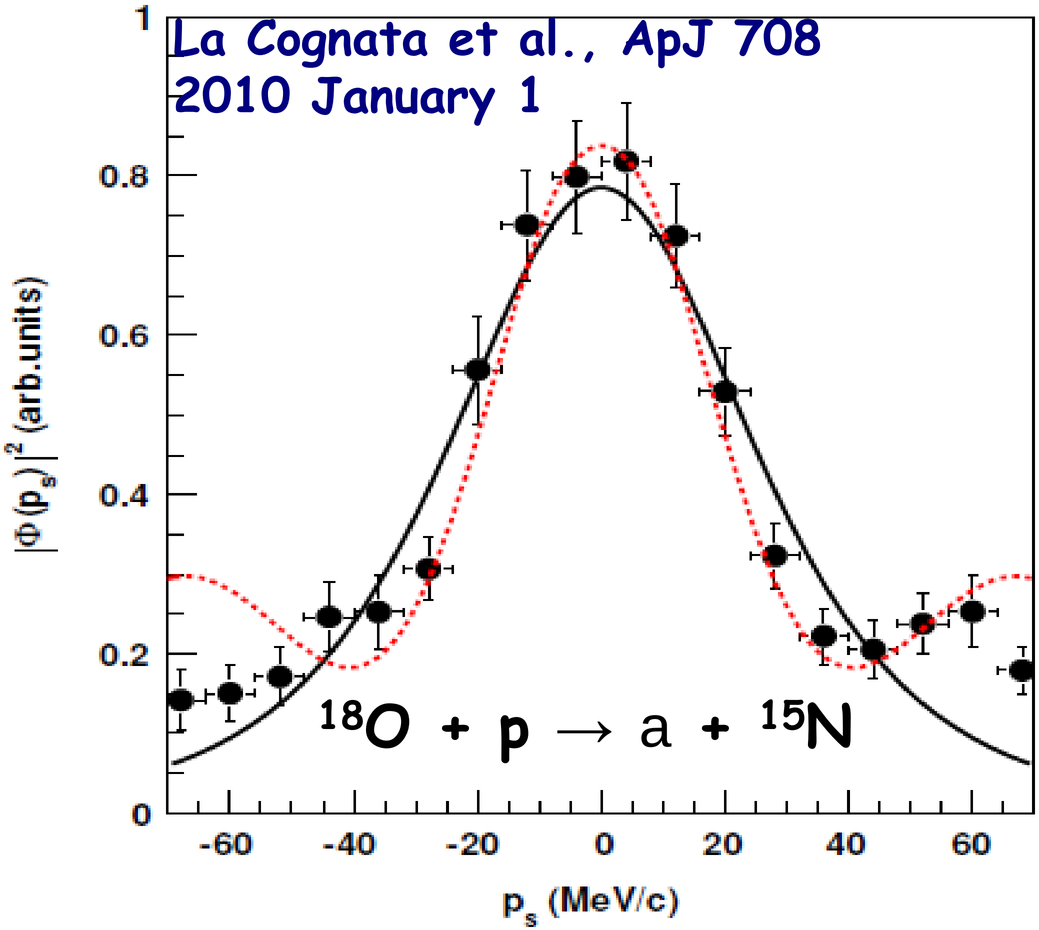


$$\mathbf{q}_t^{QF} = m_x \sqrt{\frac{1}{m_A m_B}}\, \mathbf{p}_A$$



RG Pizzone et al Phys Rev C 80, 025807 (2009)

Comparison of PWIA-DWBA approches



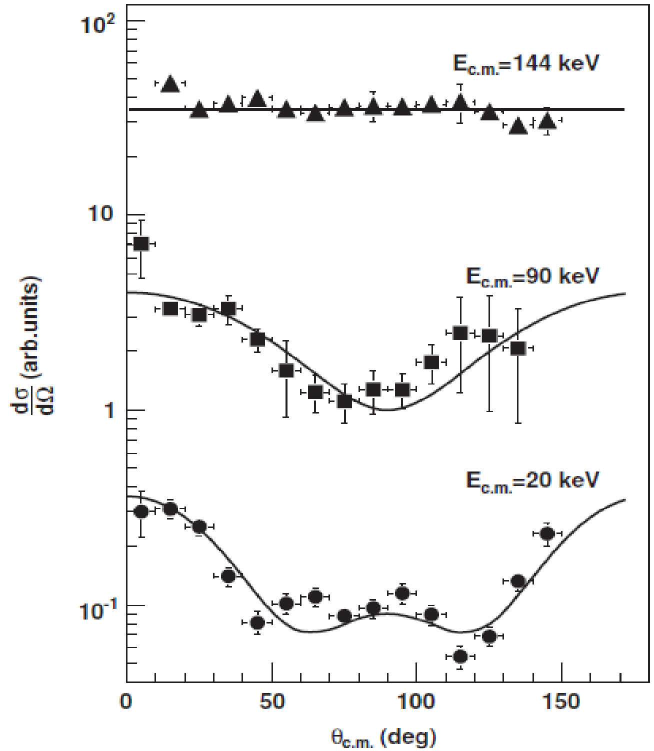
FRESCO

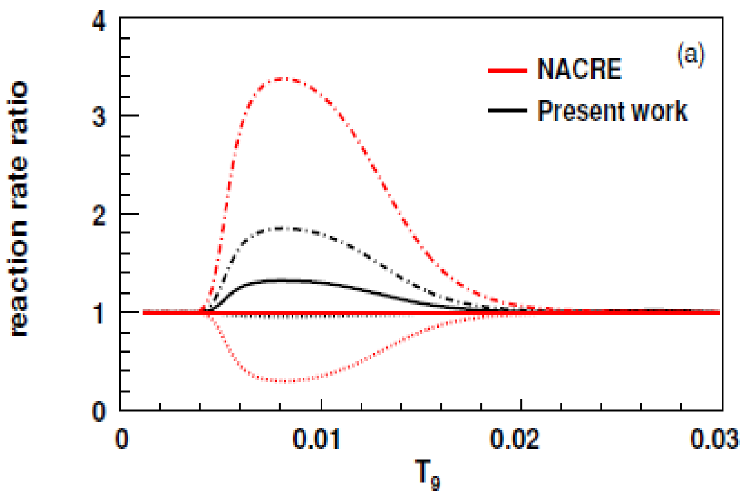
Hultén function for deuton

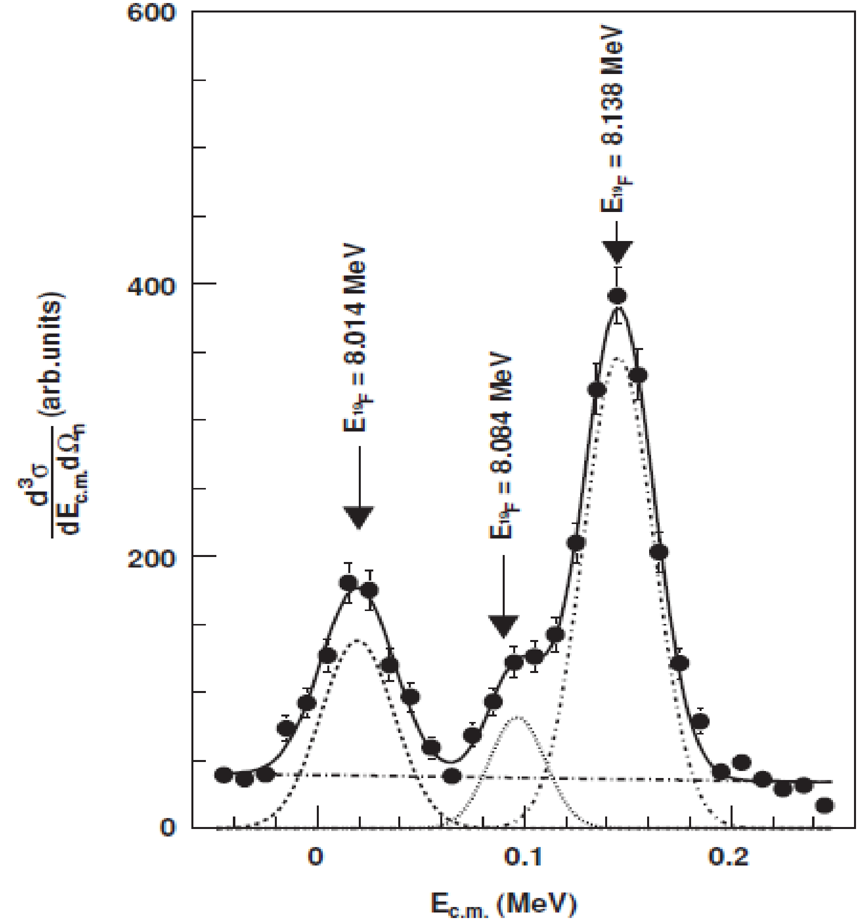
a= 0.2317 fm^{-1}
b= 1.202 fm^{-1}

$$\Phi(p_s) = \frac{1}{\pi}\sqrt{\frac{ab(a+b)}{(a-b)^2}}\left[\frac{1}{a^2+p_s^2} - \frac{1}{b^2+p_s^2}\right]$$

Check of angular distributions







$^{18}O + p \rightarrow \alpha + {}^{15}N$

La Cognata et al., PRL 101 (2008)

La Cognata et al., ApJ 708 2010 January 1

p-p SCATTERING from $p+d \rightarrow p+p+n_s$

Jackson & Blatt question, Rev. Mod. Phys., 22 (1950), p. 77, is the "smoking gun" of THM!

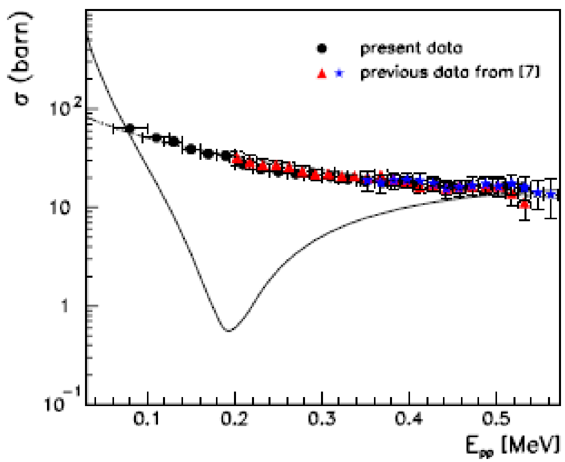


FIG. 3 (color online). THM two-body cross section (black dots from present experimental work, red triangles, and blue stars from previous work [7]) vs E_{pp}. Solid line represents the theoretical OES $p-p$ cross section calculated as explained in the text. The dashed-dotted line is the HOES cross section calculated using Eq. (3).

Tesi Laurea G.G. Rapisarda (2005)

Tumino et al. PRL 98, 252502 (2007)

PRL 98, 252502 (2007) PHYSICAL REV

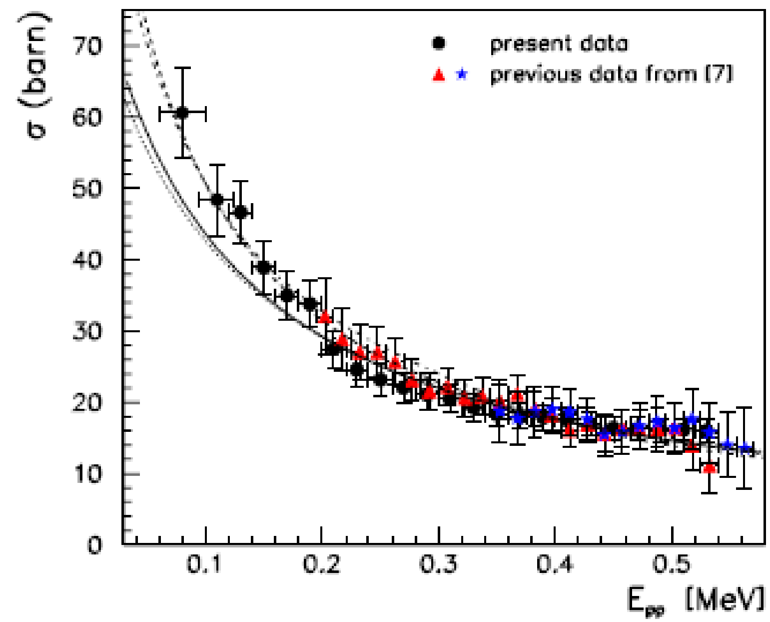
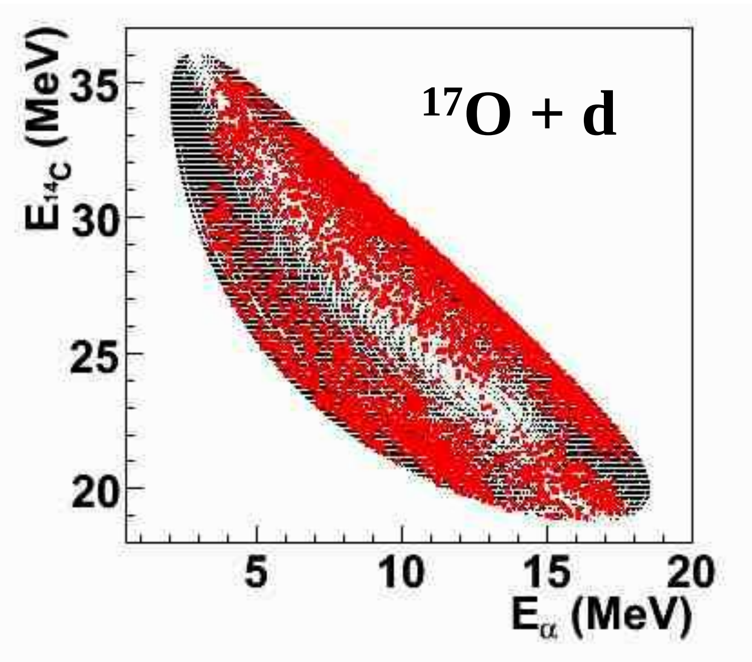


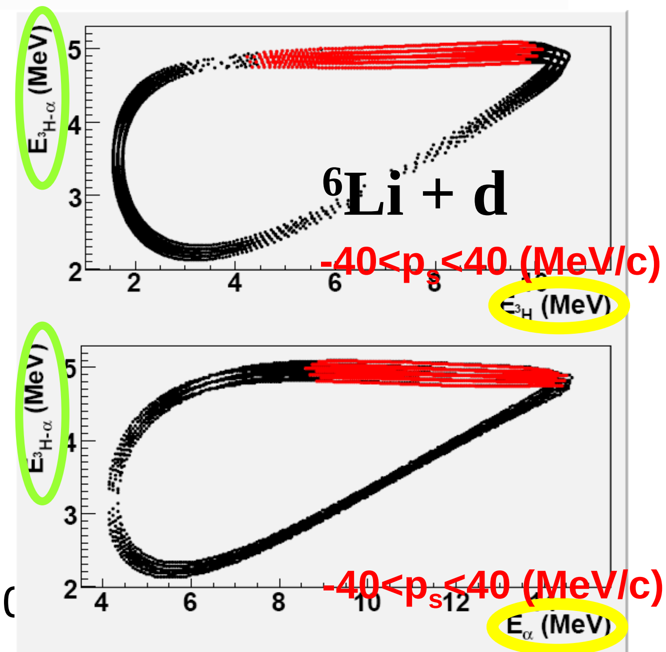
FIG. 4 (color online). THM two-body cross section (black dots from present experimental work, red triangles, and blue stars from previous work [7]) vs $p-p$ relative energy E, compared with the on-shell $n-n$ (solid line), $p-n$ (dashed line), and pure nuclear $p-p$ (dotted line) ones. The HOES calculated cross section is also reported as the dashed-dotted line.

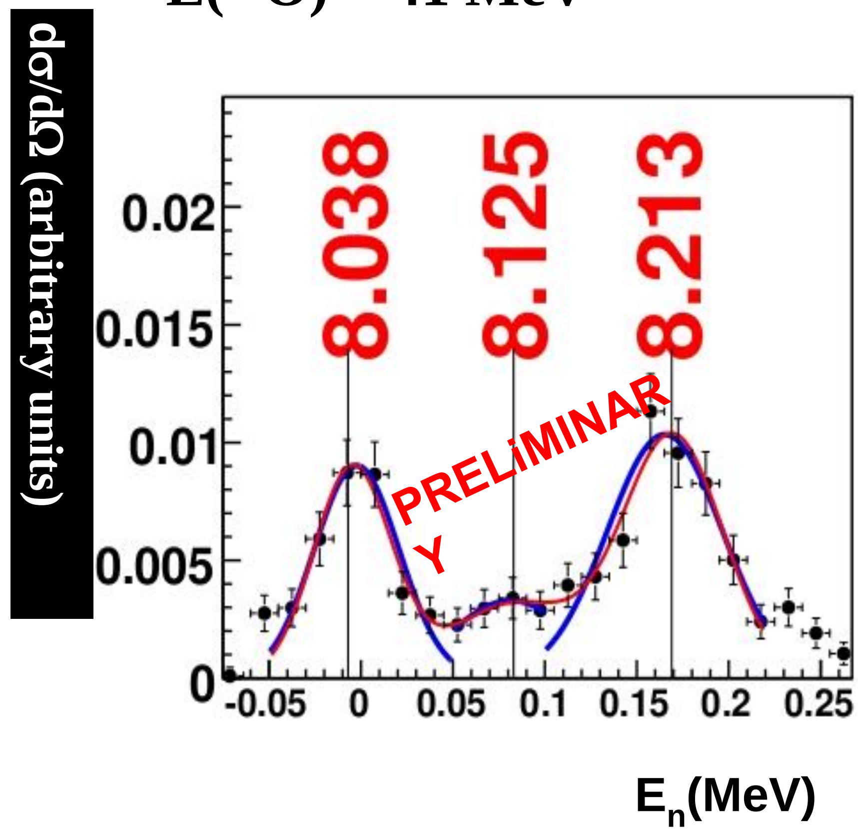
Magnifying glass effect



V N M: $^{17}O(n,\alpha)^{14}C$ via
$^{17}O + d \to \alpha + ^{14}C + p$
A parasitic experiment...

Performed @ LNS, Catania
$E(^{17}O) = 41$ MeV





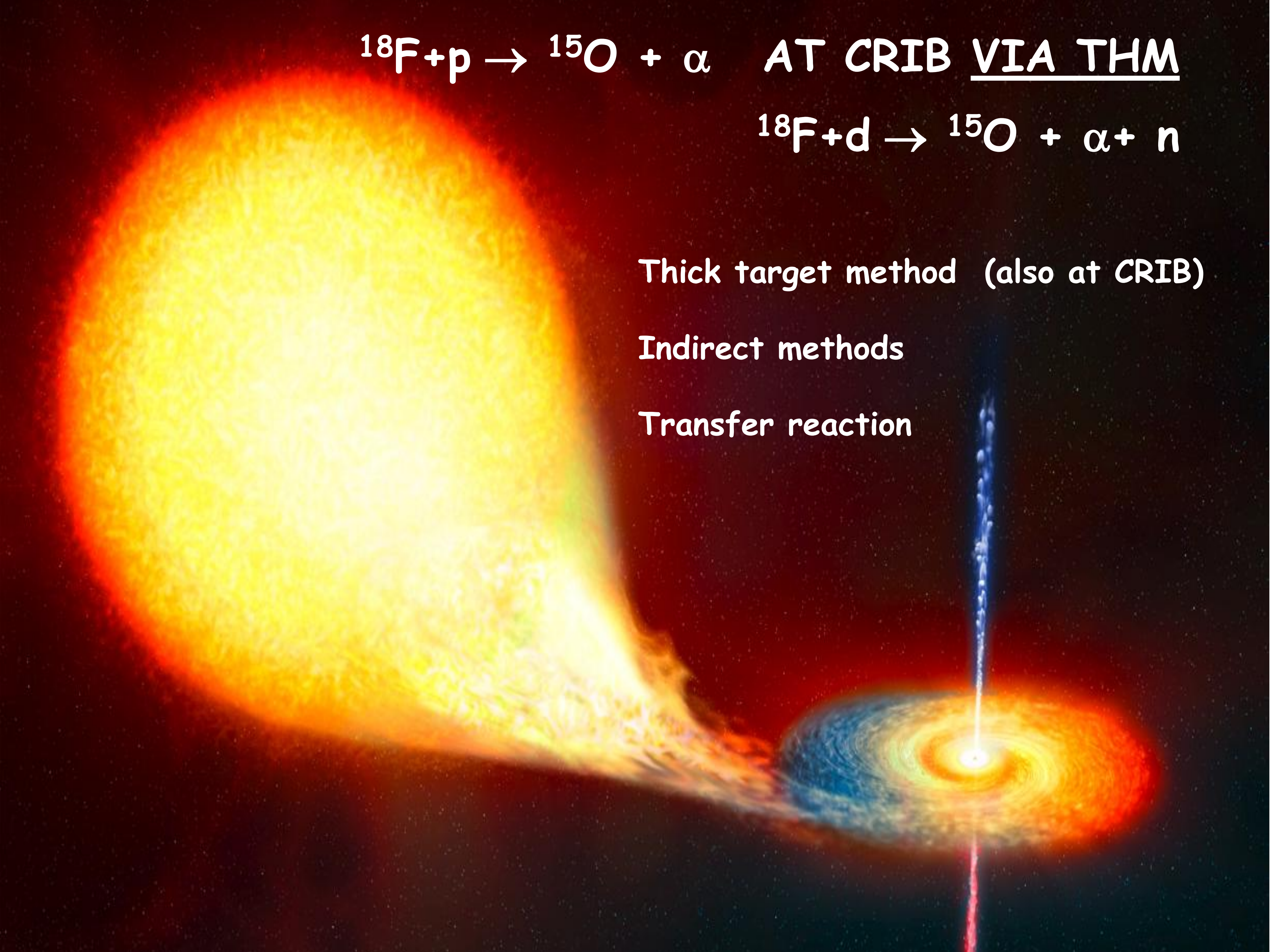
$^{18}F+p \rightarrow {}^{15}O + \alpha$ AT CRIB VIA THM

$^{18}F+d \rightarrow {}^{15}O + \alpha + n$

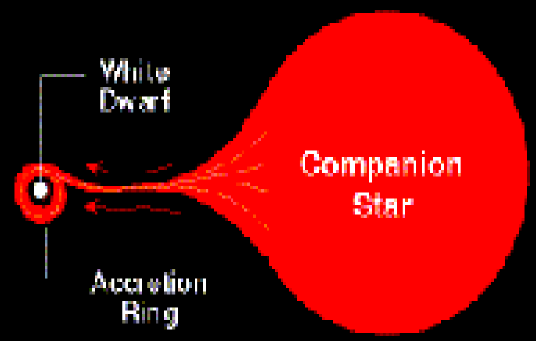
Thick target method (also at CRIB)

Indirect methods

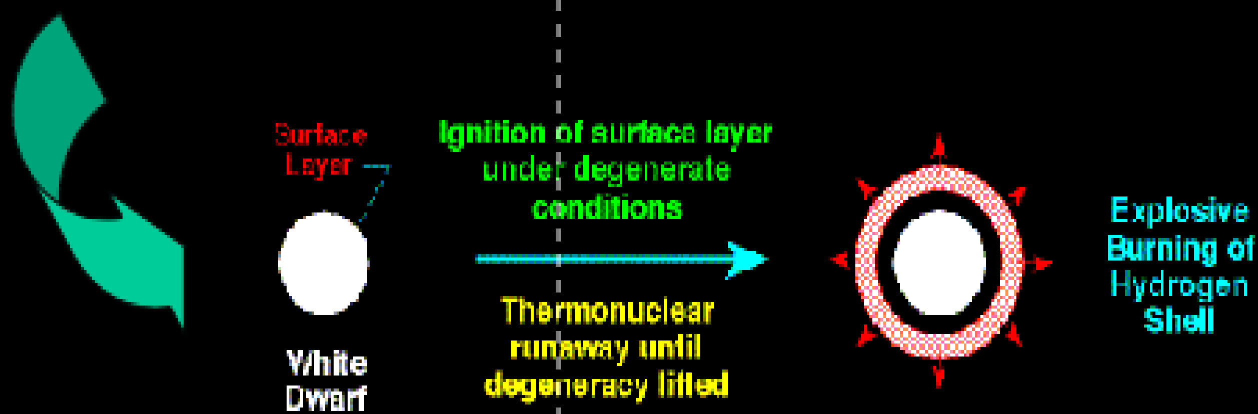
Transfer reaction



$^{18}F(p,\alpha)^{15}O$



Thin hydrogen surface layer accumulated on white dwarf through accretion ring



Observed γ- rays come from e^+e^-

e^+ come from ^{18}F decay mostly

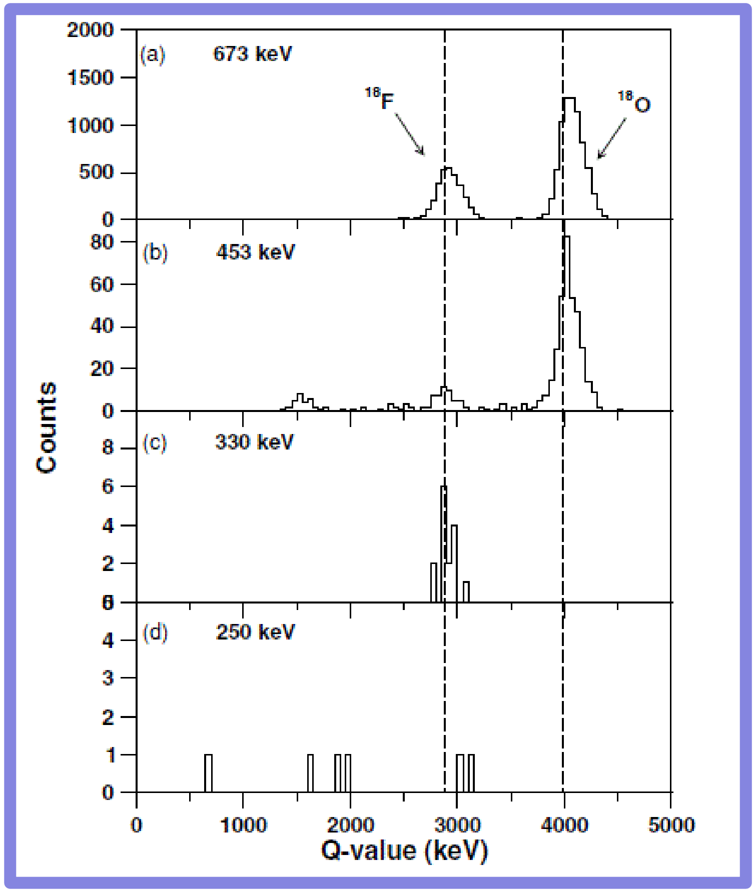
At novae temperatures (100 - 500 keV) ^{18}F can be mainly destroyed by

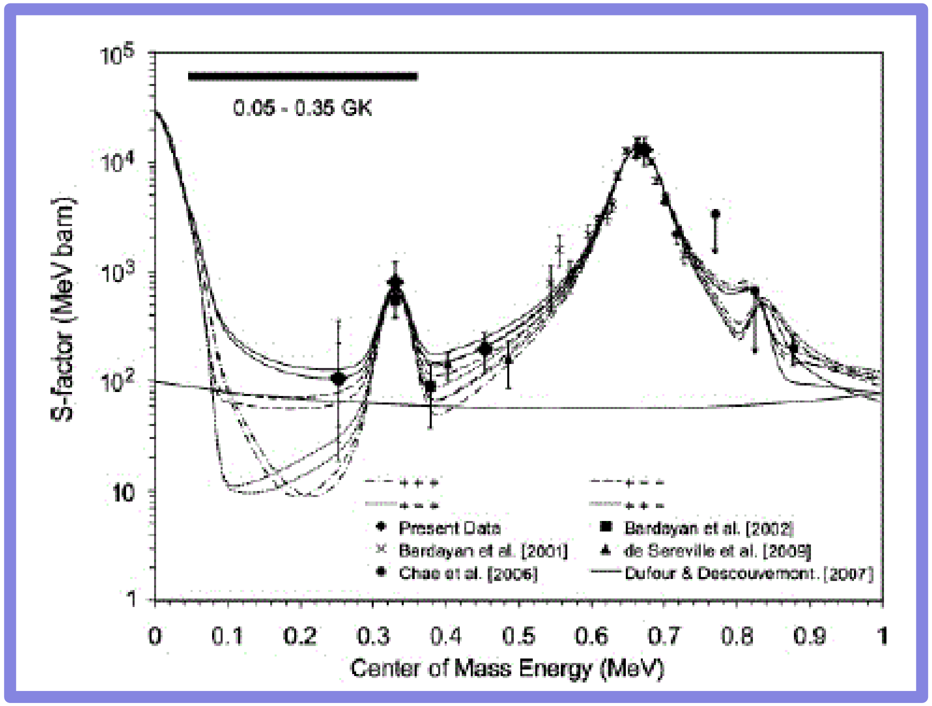
$^{18}F(p,\alpha)^{15}O$

For the star energetics this are peanuts!

STATE OF THE ART DIRECT EXPERIMENT

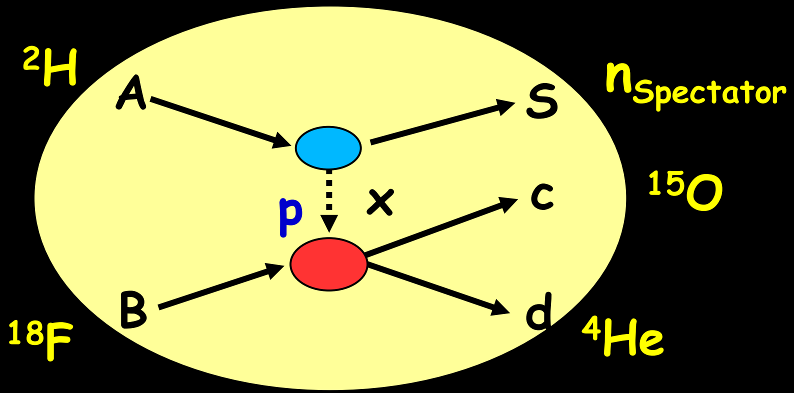
TRIUMF DATA



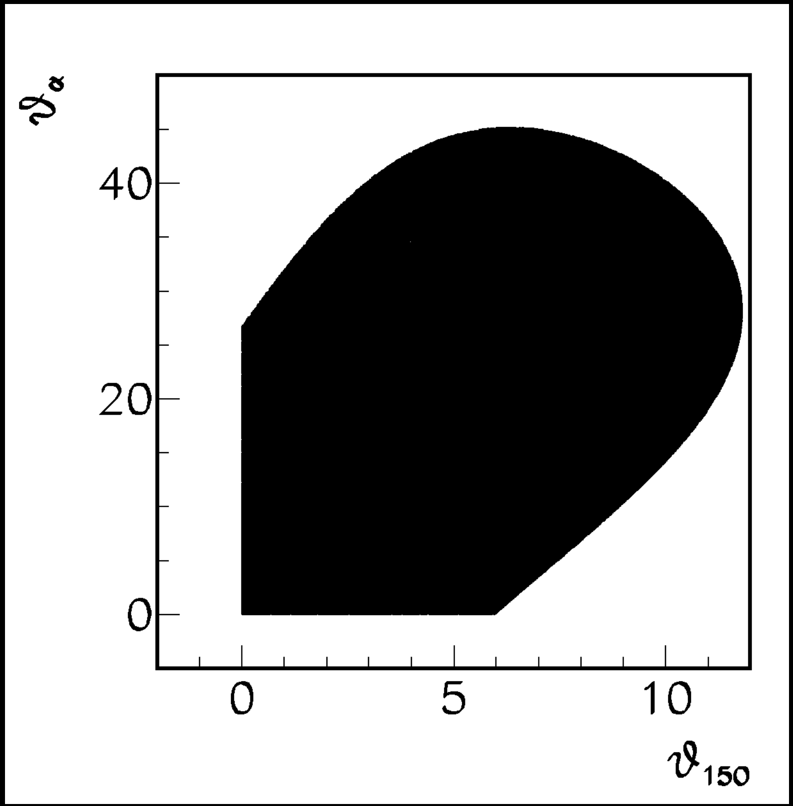


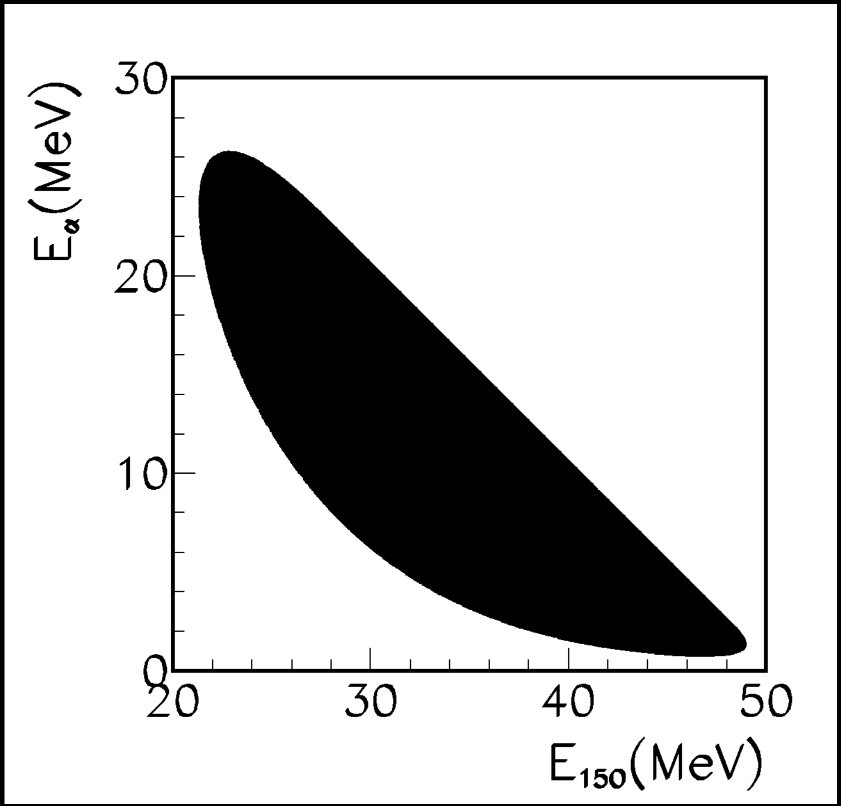
C. E. Beer et al. PHYSICAL REVIEW C 83, 042801(R) (2011)

THM Experiment kinematics… needs all!

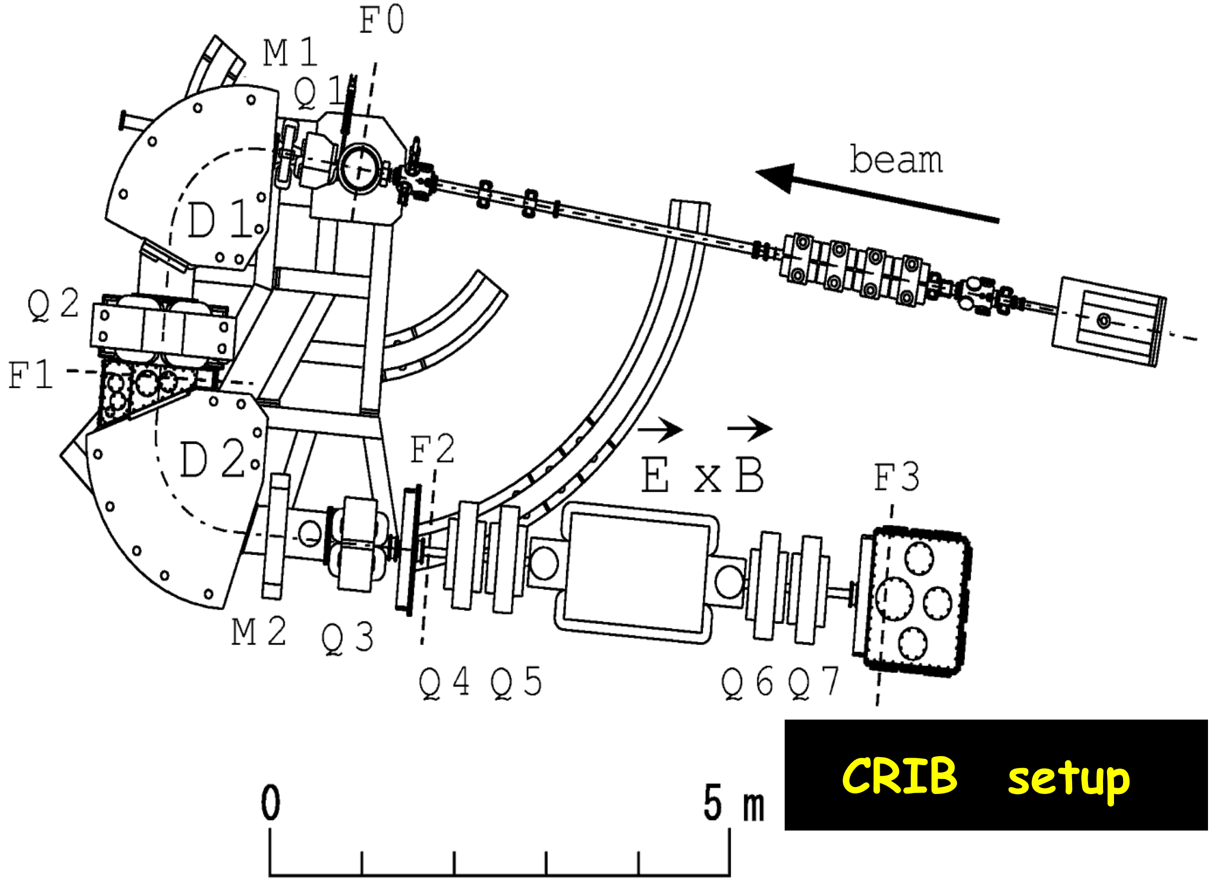


$E(^{18}F) = 50$ MeV





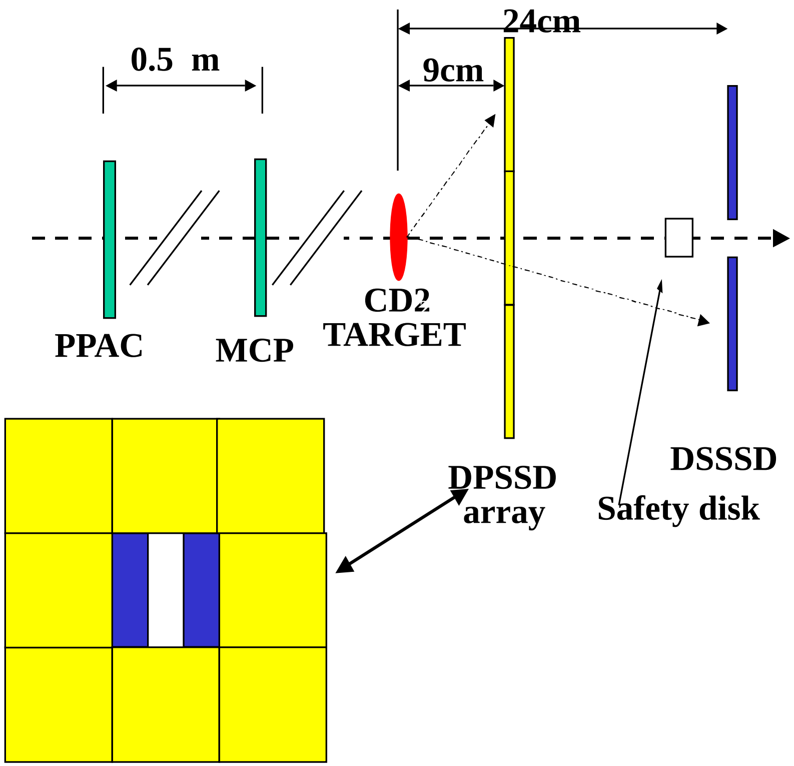
BEAM PRODUCTION AT CRIB

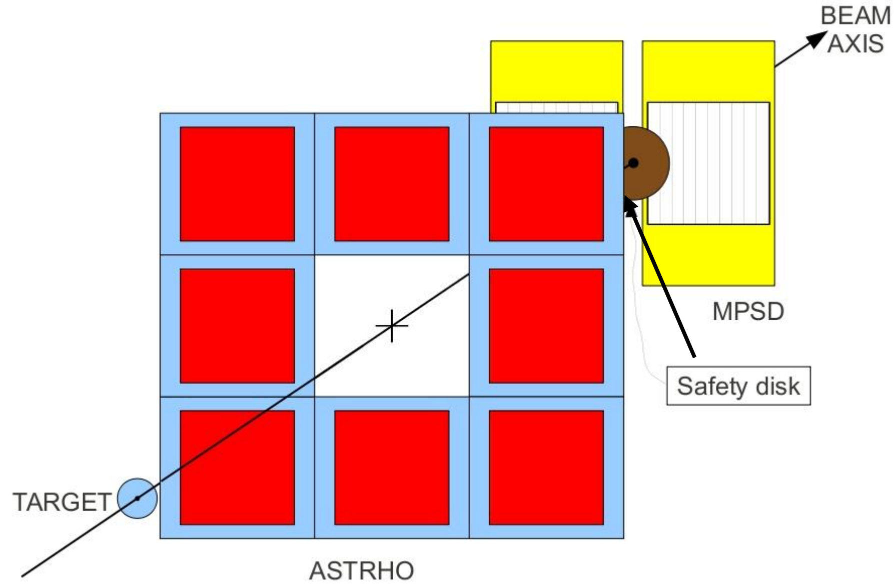


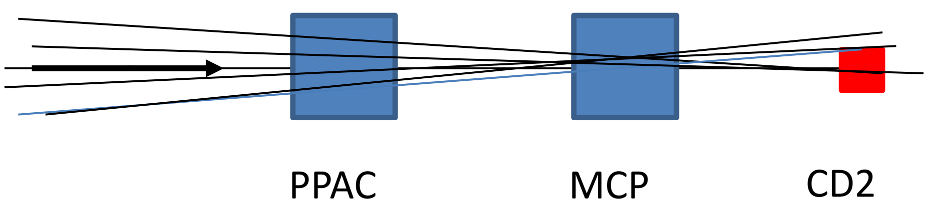
1. Two beam production tests performed (Nov 2005, June 2006)
2. 3*10^5 pps obtained, 10^6 pps within the capabilities of the machine
3. Beam purity > 98%
4. Normalization and deffinitionof the beam particle by particle (PPACs)

EXPERIMENTAL SETUP

(other then CRIB.....)

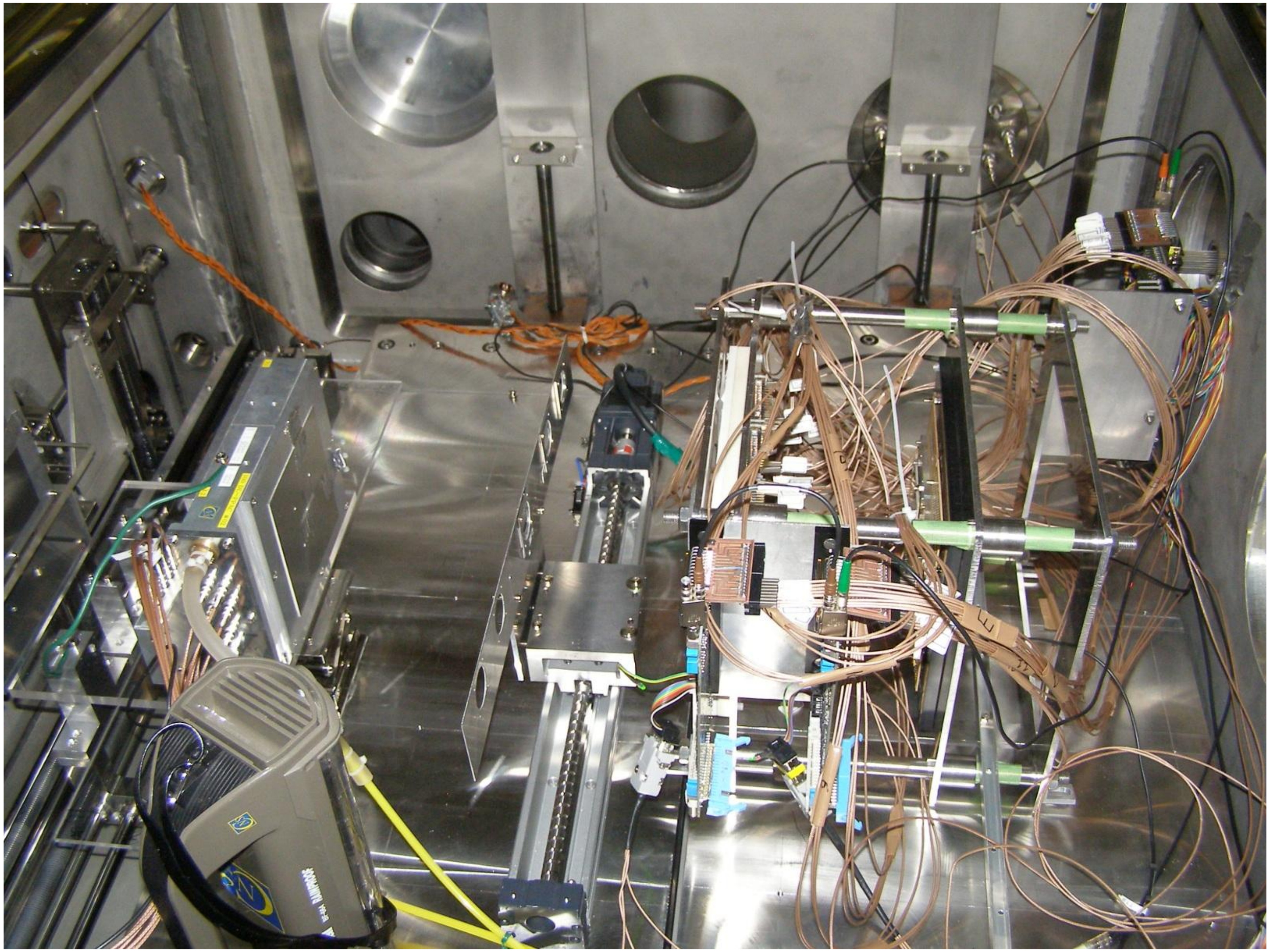




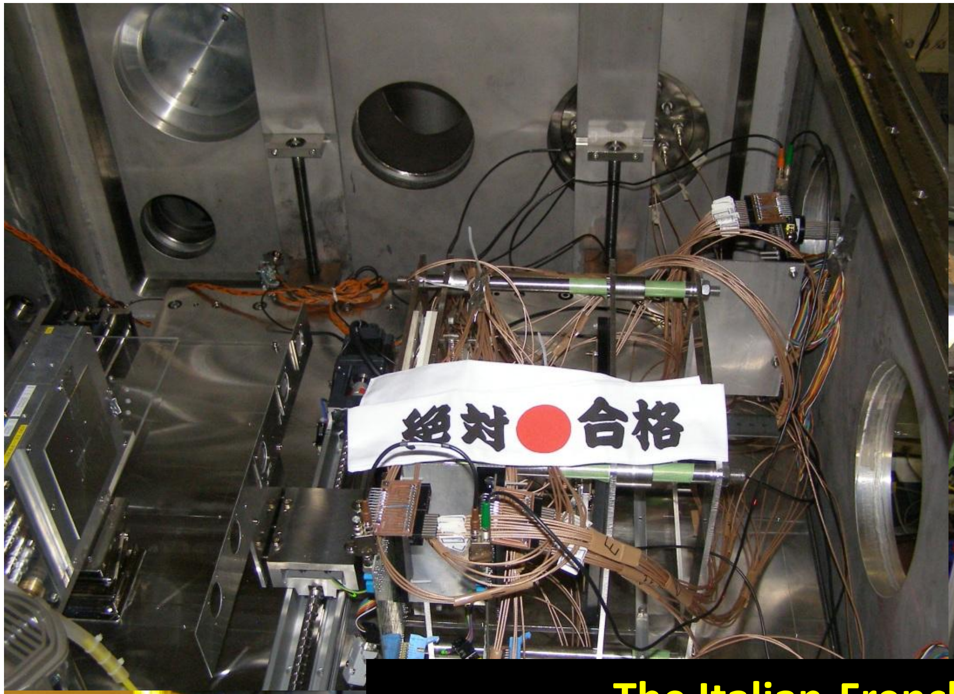


particle by particle beam reconstruction

ASTRHO:
Array of Silicons for TRojan HOrse



How ASTRHO looks like in reality
(before PPAC explosion...)



The Italian-French-Japanese connection


Q-VALUE SPECTRUM

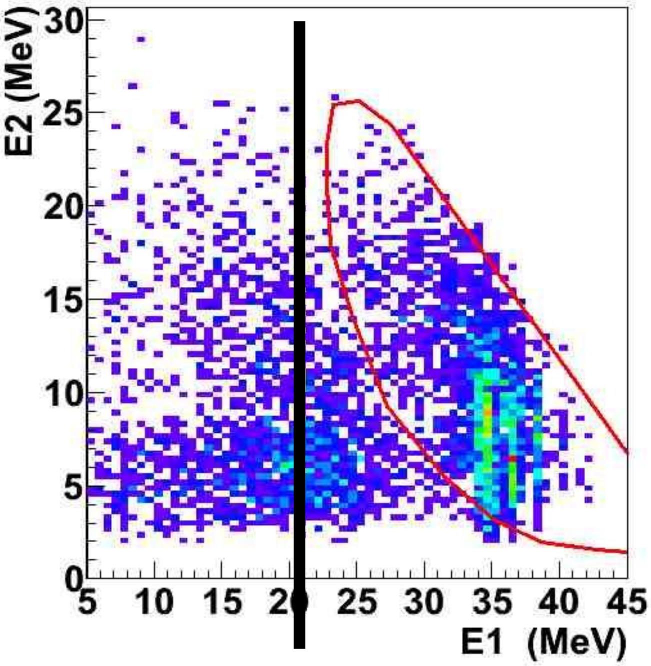
$^{18}F+d \rightarrow ^{15}N+\alpha+p$ @ q=4.194

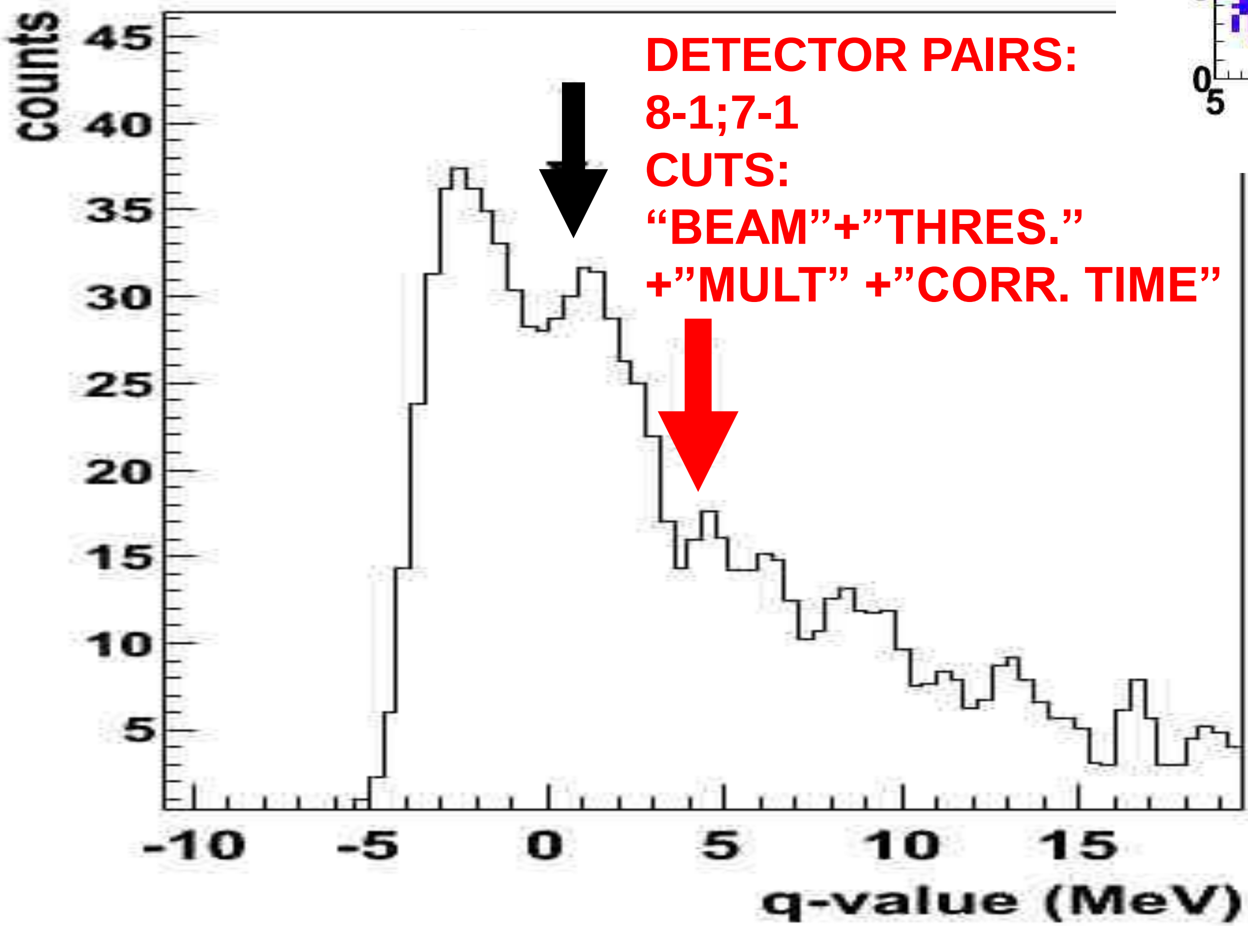
$^{18}F+d \rightarrow ^{15}O+\alpha+n$ @ q=0.658

$^{18}F+d \rightarrow ^{18}O+p+p$ @ q=0.213

$^{18}F+d \rightarrow ^{18}F+p+n$ @ q=-2.225

VNM+RIB!!!

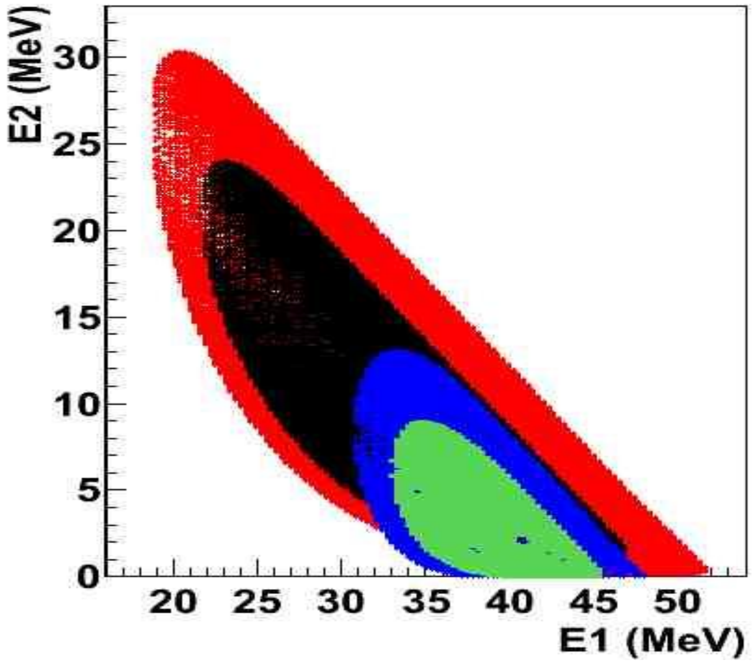


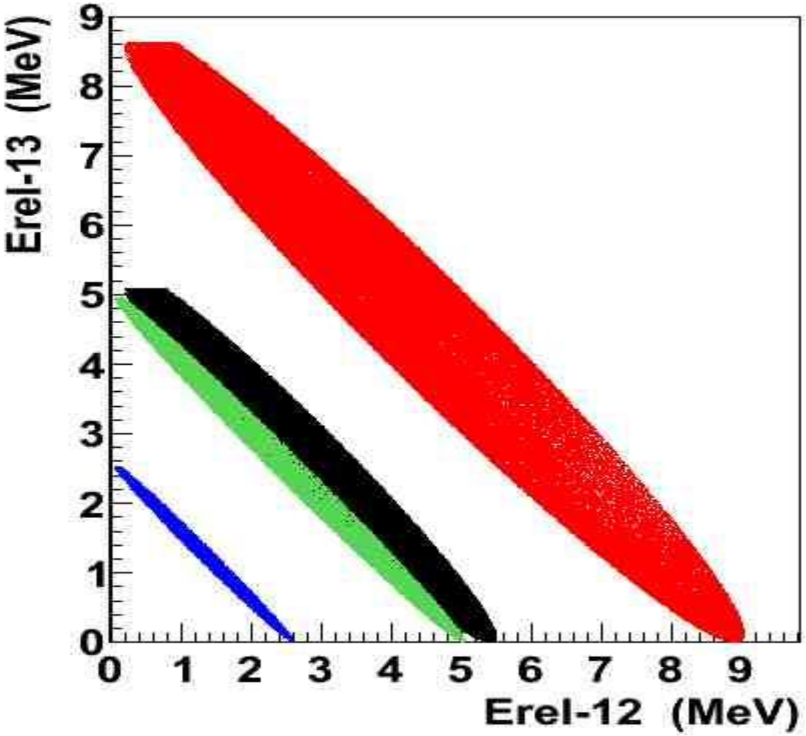


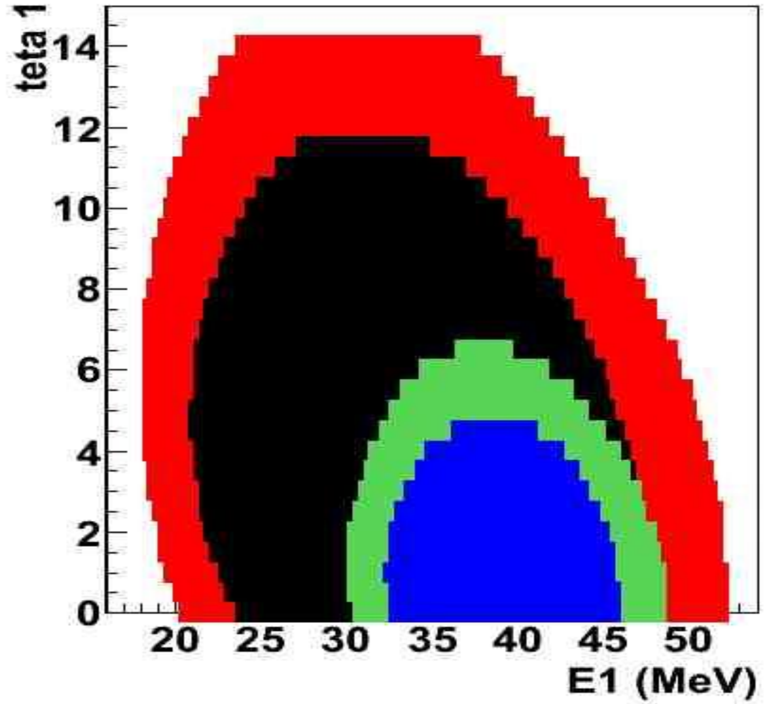
DETECTOR PAIRS:
8-1;7-1
CUTS:
“BEAM”+”THRES.”
+”MULT” +”CORR. TIME”

EVENT SELECTION

Red : $^{18}F + d \rightarrow$ $^{15}N + \alpha + p$
Black: $^{18}F + d \rightarrow$ $^{15}O + \alpha + n$
Blue: $^{18}F + d \rightarrow$ $^{18}F + p + n$
Green: $^{18}F + d \rightarrow$ $^{18}O + p + p$
"1"+"2"+"3"

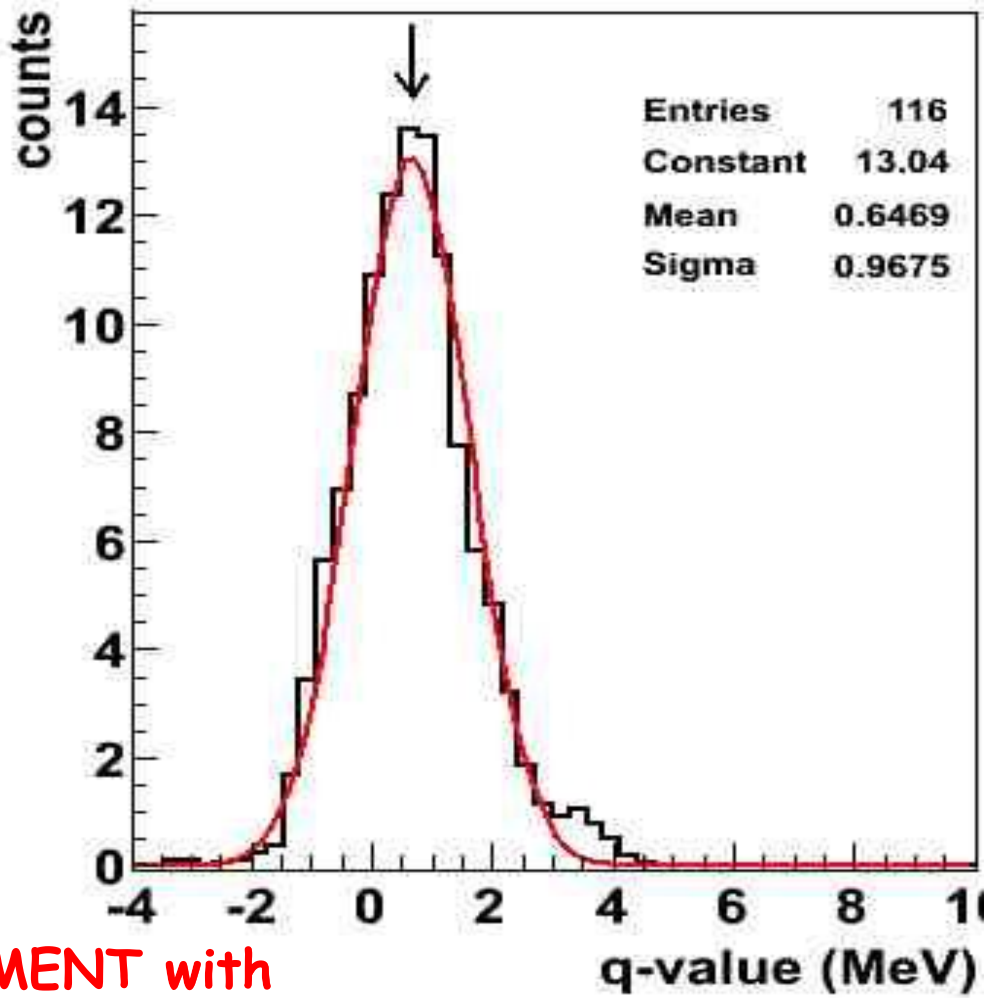






Q-VALUE SPECTRUM

Previous cuts + Erel-Erel correlation +E-Theta correlation

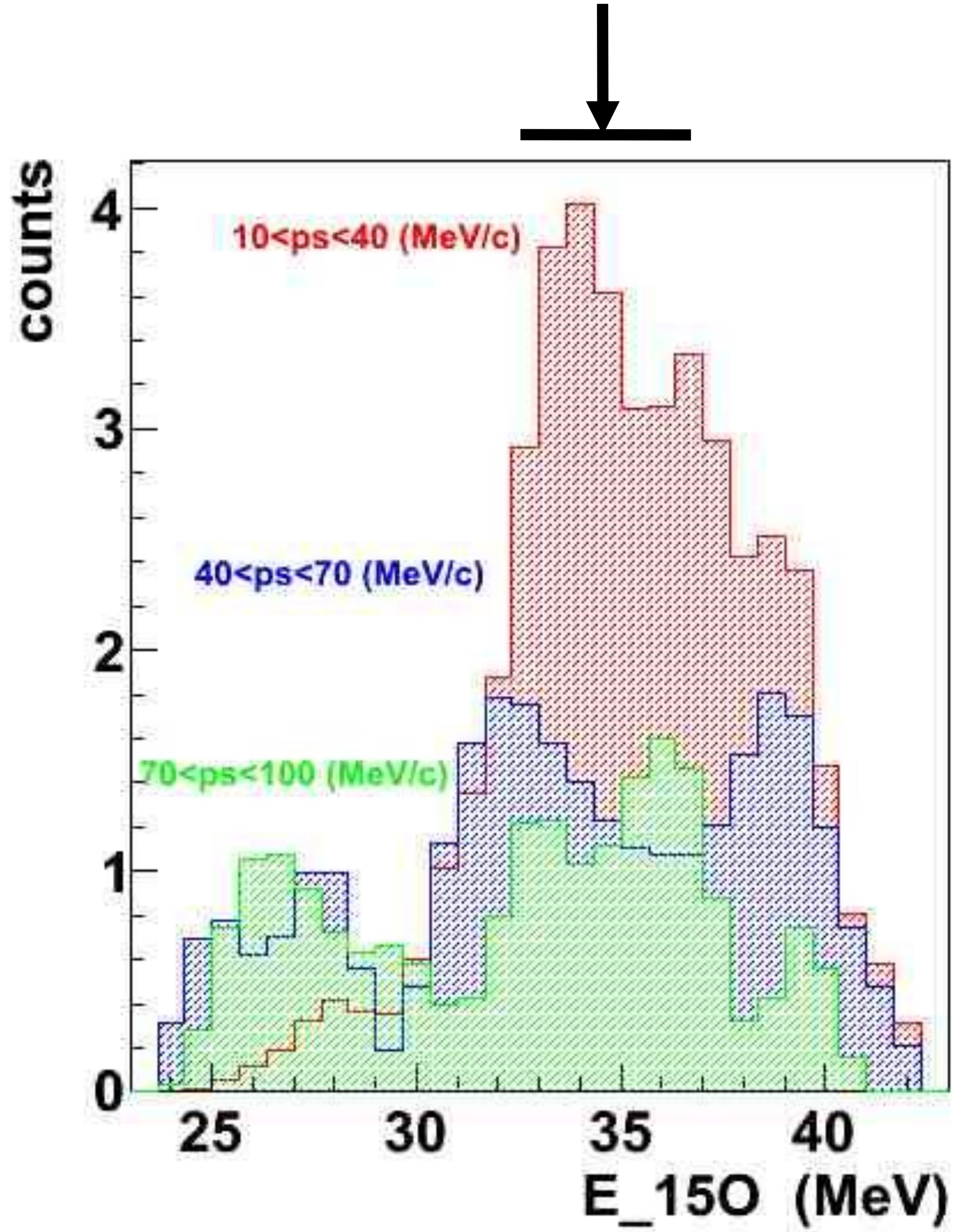


GOOD AGREEMENT with

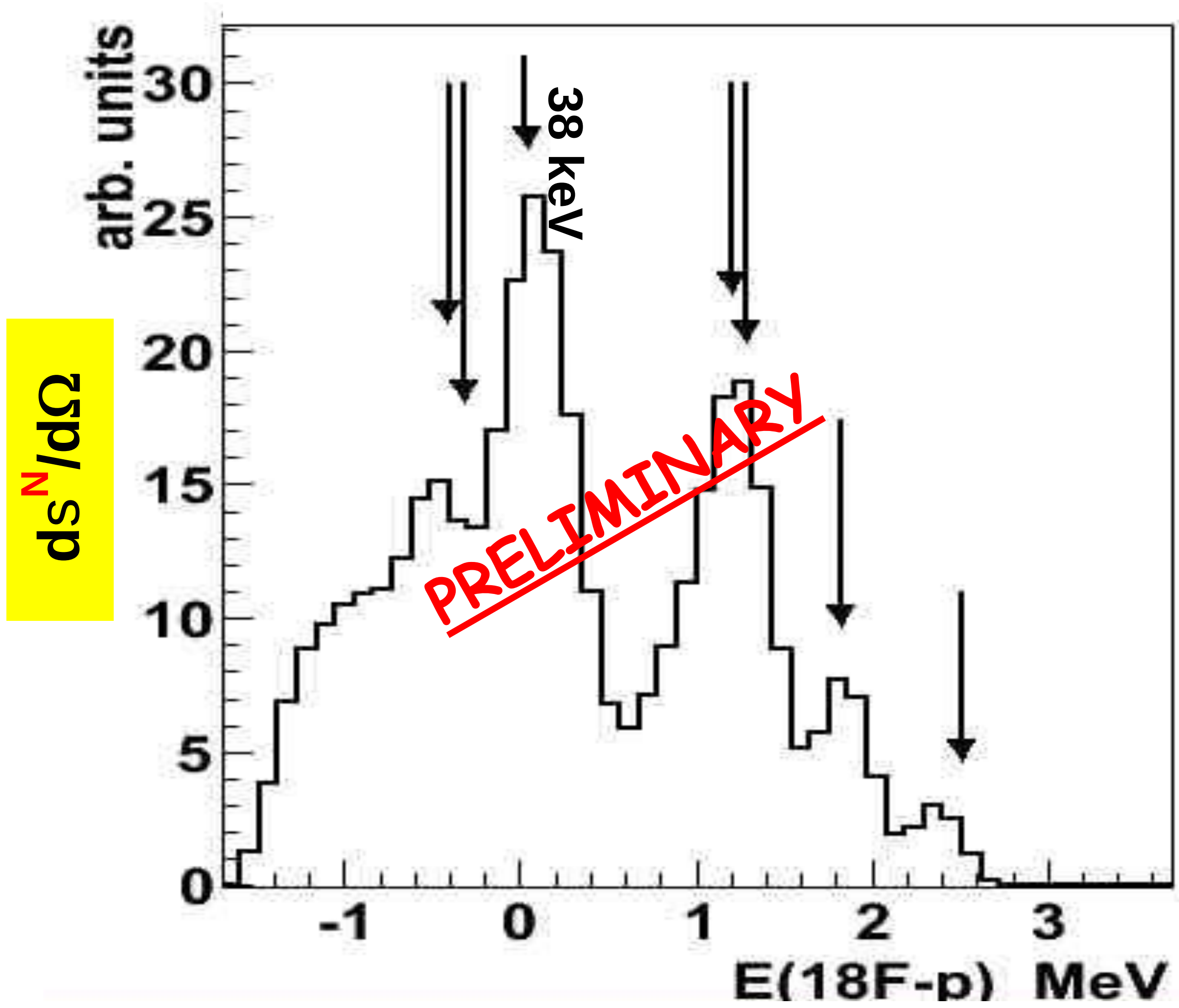
Q-value expected position (0.658 MeV)

And energy beam profile (exp. Sigma 0.8 MeV)

HINTS FOR QF MECHANISM



BARE NUCLEUS CROSS SECTION



FIRST TROJAN HORSE MEASUREMENT WITH RIBs !!!