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Improved results on extraction of $^{11}B(p,\alpha_0)^8Be$ S(E)-factor through the Trojan Horse Method

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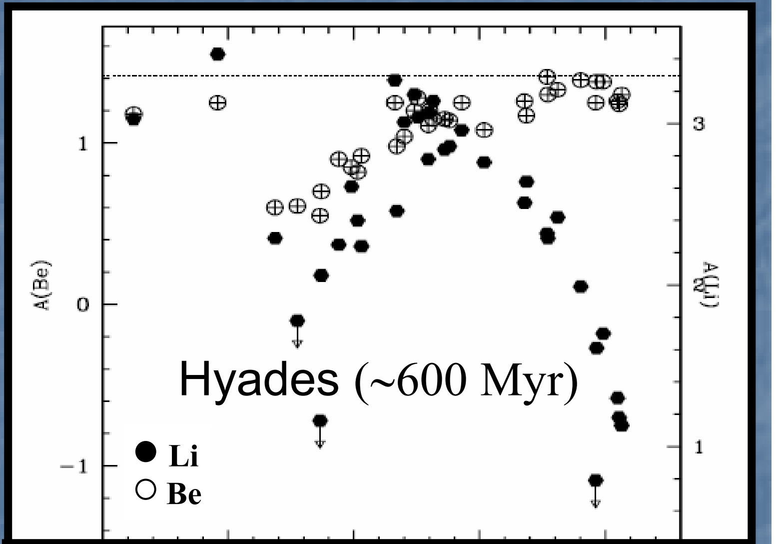
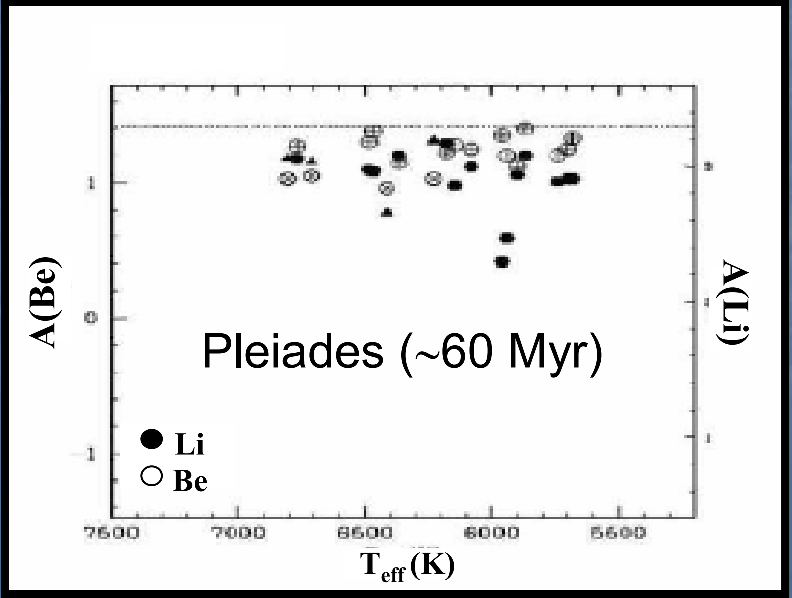
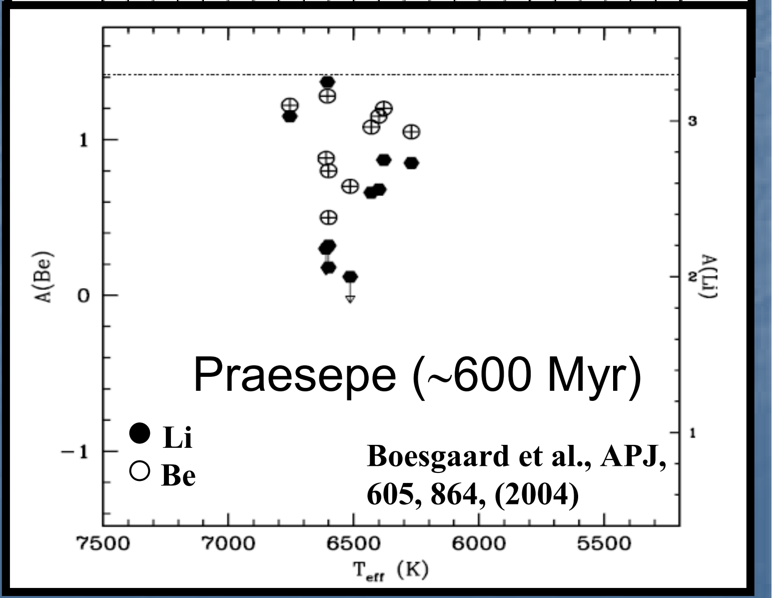
Light Elements in Astrophysics: Lithium, Beryllium, Boron (I)

- ✓ **Observational status**: Depletion in Open Clusters for stars with 5500<Teff(K)<7500.
- ✓ **Burning (p,α)** channel as the main contribution to their destruction at T_6=2.5 (Li), T_6=4 (Be), T_6=5 (B)
- ✓ **Dip di Li & Be:** the depth of the dip reflects the *nuclear fate* in the nuclear destruction zone (NDZ).
- ✓ **Li-Be & Be-B correlation** as signature of "rotation-induced" slow-mixing processes.





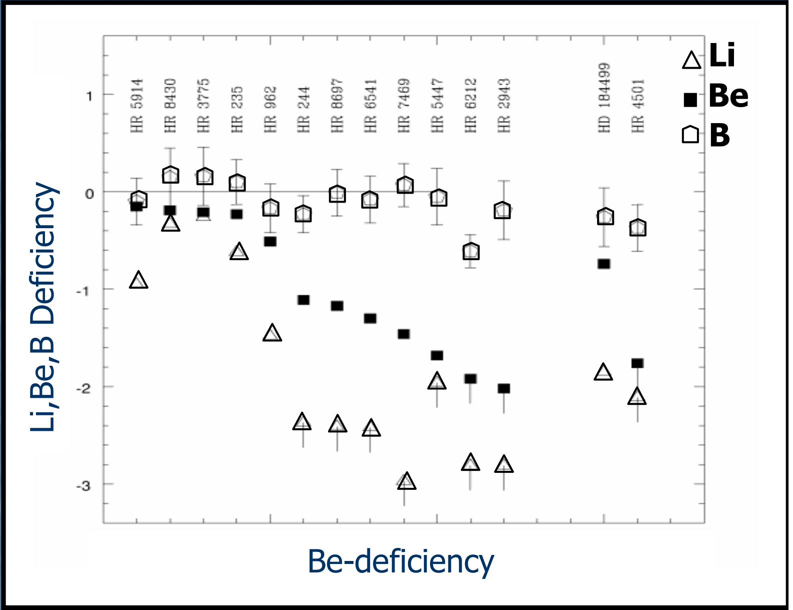


Boesgaard et al., APJ, 605, 864, (2004)

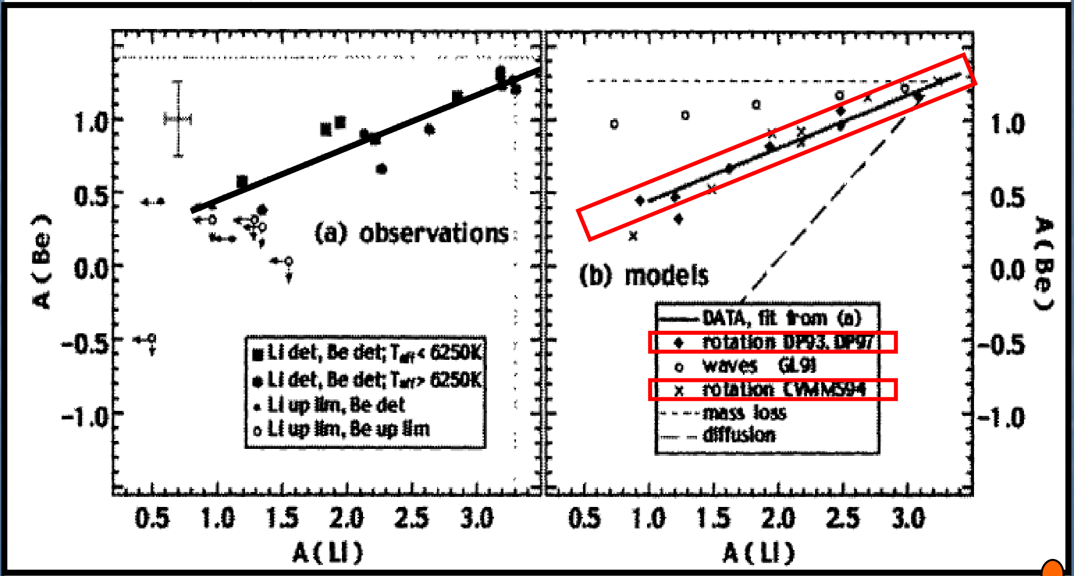
Light Elements in Astrophysics: Lithium, Beryllium, Boron (II)

✓ *Observational Status*

Light elements Li, Be and B abundances are showed as the Be-deficinecy varies for low-metallicity young star (5800<Teff (K)<6500, $M_* \sim 1M_o$).



Deliyannis C.P., ASP Conference series, Vol. 198, 2000

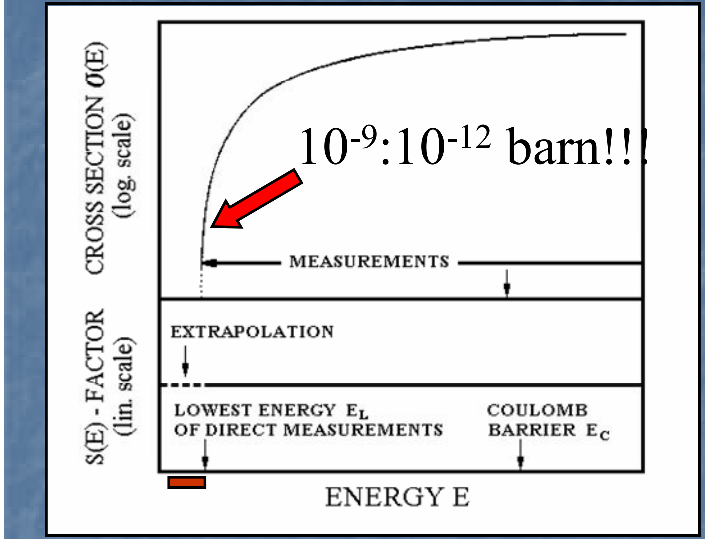


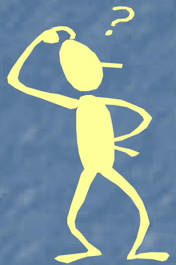
✓ *Theoretical Models*

The lithium and berylllium deficiency and the boron observational trend are in agrrement with “non-standar mixing process (*slow-mixing cess*” in stellar interior mainl gere y rotation (Stephens et 97 Boesgaard et al. 19

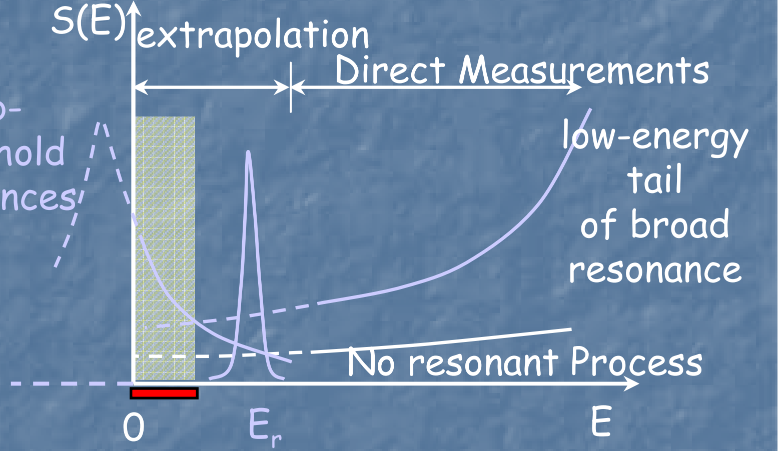
Direct Measurements in Nuclear Astrophysics and related difficulties

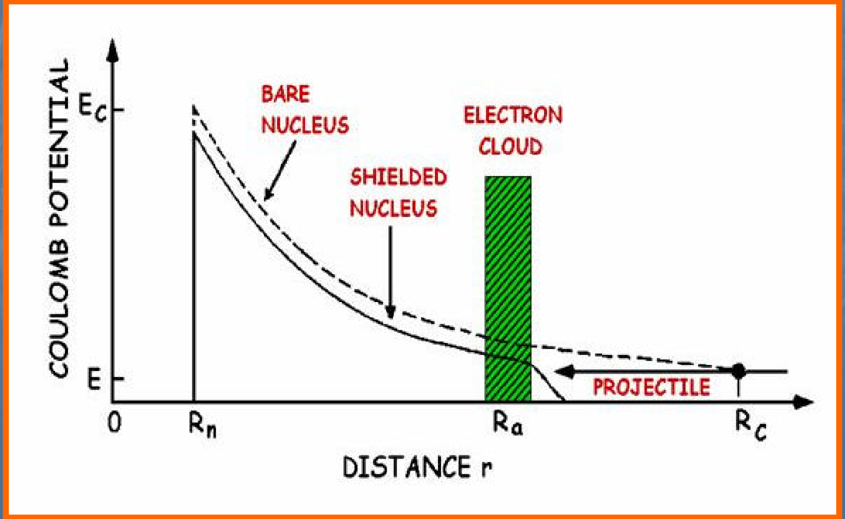
AstroFIsica Nucleare

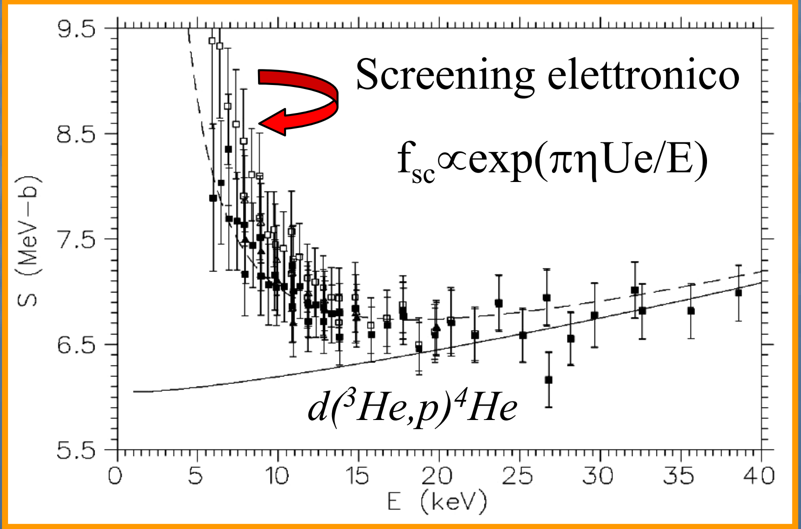




$$S(E) = E\sigma(E)\exp(2\pi\eta)$$







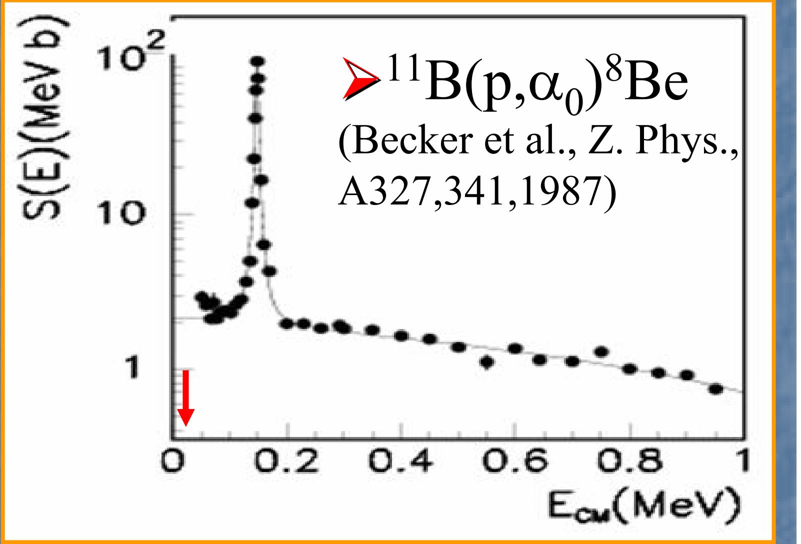
From Stars to the laboratory:
direct measurements of ^{11}B(p,α)^{8}Be reaction

✓ **By considering the typical temperatures of some 10^6 K at which burning (p,α) reactions typically occur for boron isotopes in stellar environments, the Gamow peak is at about**

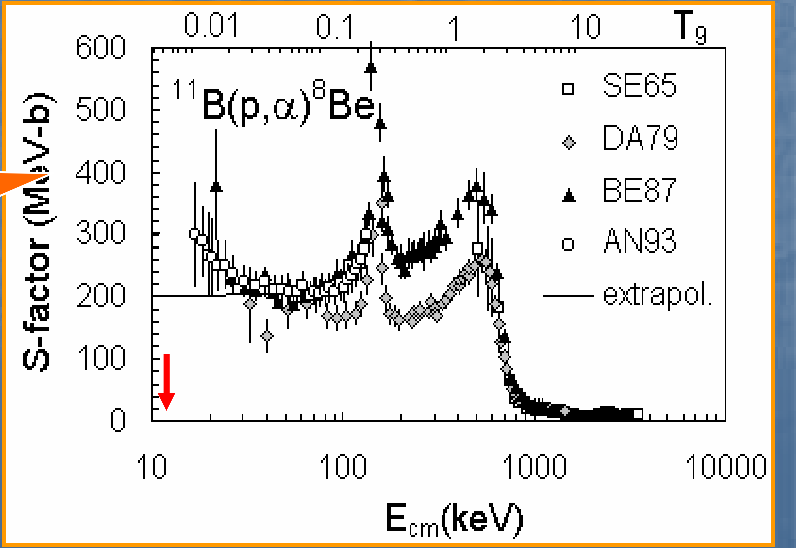
$$E_0=1.22(Z^2_x Z^2_y \mu T_6^2)^{1/3}\ \text{keV} \approx 10\ \text{keV}$$

Only extrapolations are possi le o w- energies direct data be use on screening and Coulom penetrab ty effects

THM application!!!!!!

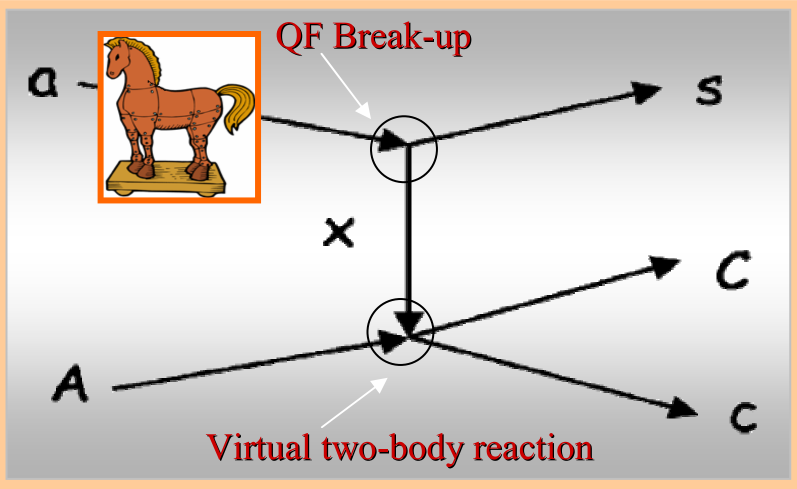


➢^{11}B(p,α$_0$)^{8}Be (Becker et al., Z. Phys., A327,341,1987)



The Indirect Methods: Trojan Horse Method

✓ The THM allows to extract a charged particles two-body cross section x(A,C)c at astrophysical energies by selecting the quasi-free (QF) contribution of a suitable three body reaction a(A,Cc)s performed at energies well above the Coulomb barrier.



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

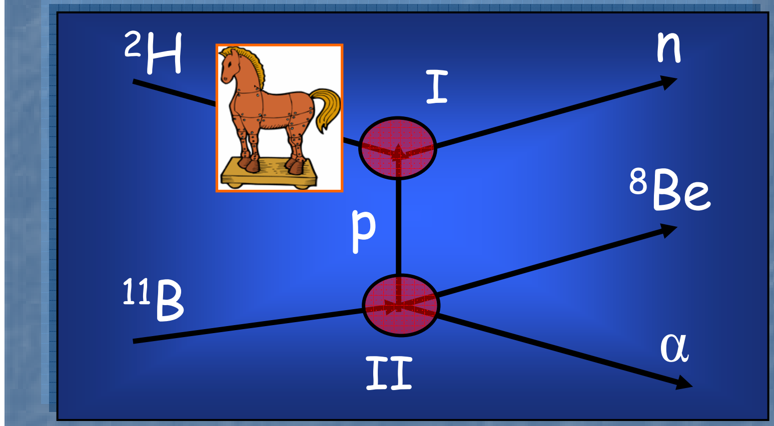
(I) 2-body data free of Coulomb suppression and electron screening effects;

(II) validity test, introduction of penetrability function and normalization to direct data are needed!!!

The explored energy region E_{cm} goes from $0 < E_{cm} < 1$ MeV by using only one value for the energy beam!!!

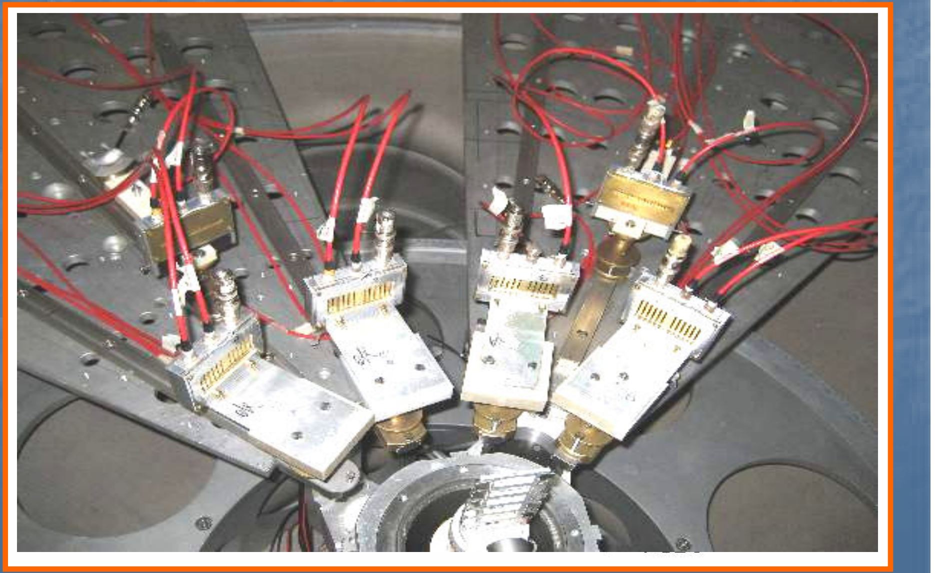
no estrapolation for A(x,c)C in the energy window relevant for astrophysics

Indirect study of the $^{11}B(p,\alpha_0)^8Be$ reaction through $^2H(^{11}B,\alpha_0{}^8Be)n$ by means of the THM



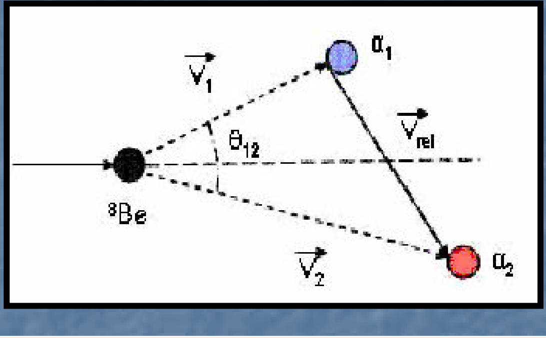
- ✓ Study of the $^{11}B(p,\alpha)^8Be$ reaction (Q=8.59 MeV) through $^2H(^{11}B,\alpha^8Be)n$ 3-dody reaction (Q=6.36 MeV, E_{coul}= 1.3 MeV);
- ✓ The deuteron is used like Trojan Horse nucleus. The momentum distribution of intercluster motion inside the deuteron is known from indipendent experiments.

- ☐ The experiment was performed at LNS (Tandem & Camera2000) in two different runs on December 2002 and April 2007 ;
- ☐ $E_{beam}(^{11}B)$=27 MeV & $I_{beam}(^{11}B)$=2-5 nA;
- ☐ Target thickness CD_2 ~190 μg/cm^2;
- ☐ Displacement of the detectors around the whole *QF-angular* range.

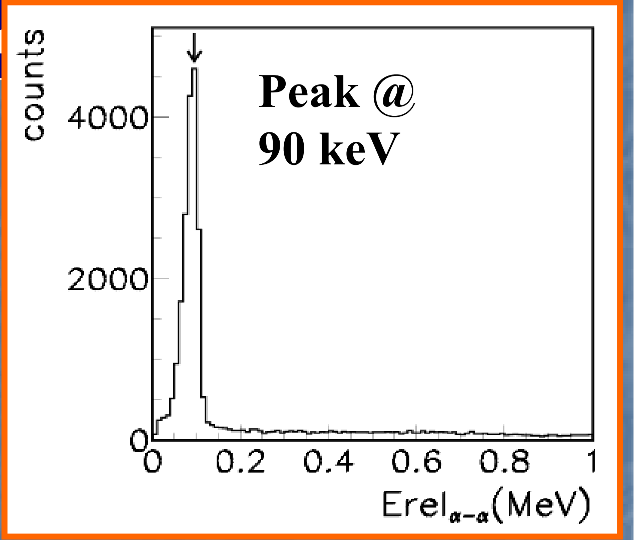


Determination of ^{8}Be and selection of the three-body channel $^{2}H(^{11}B,\alpha_0{}^{8}Be)n$: 2007 Exp

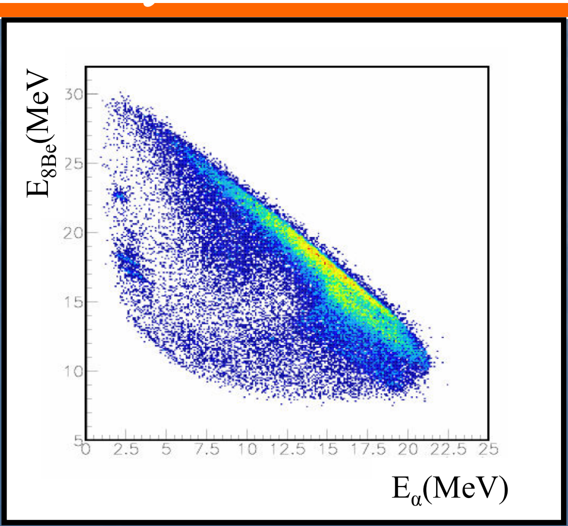
Alpha-decay of ^{8}Be(g.s.) in 2 alphas ($Q_{dec} \sim 90$ keV) detecetd in coincidence on DPSD (Dual Position Sensitive Detecto



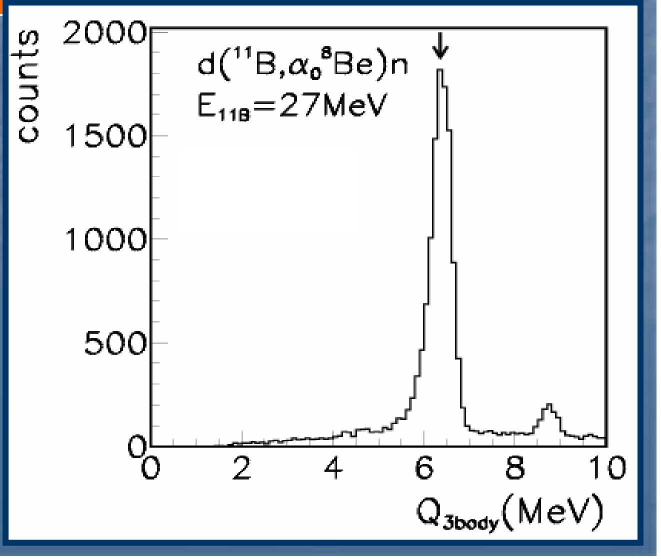
Off-line reconstruction of relative energy for alfa-decay of 8Be(g.s.)



3-body kinematical locus: selection of channel



Q-value peak for the 3-body reaction (Q_{th}=6.36 MeV)



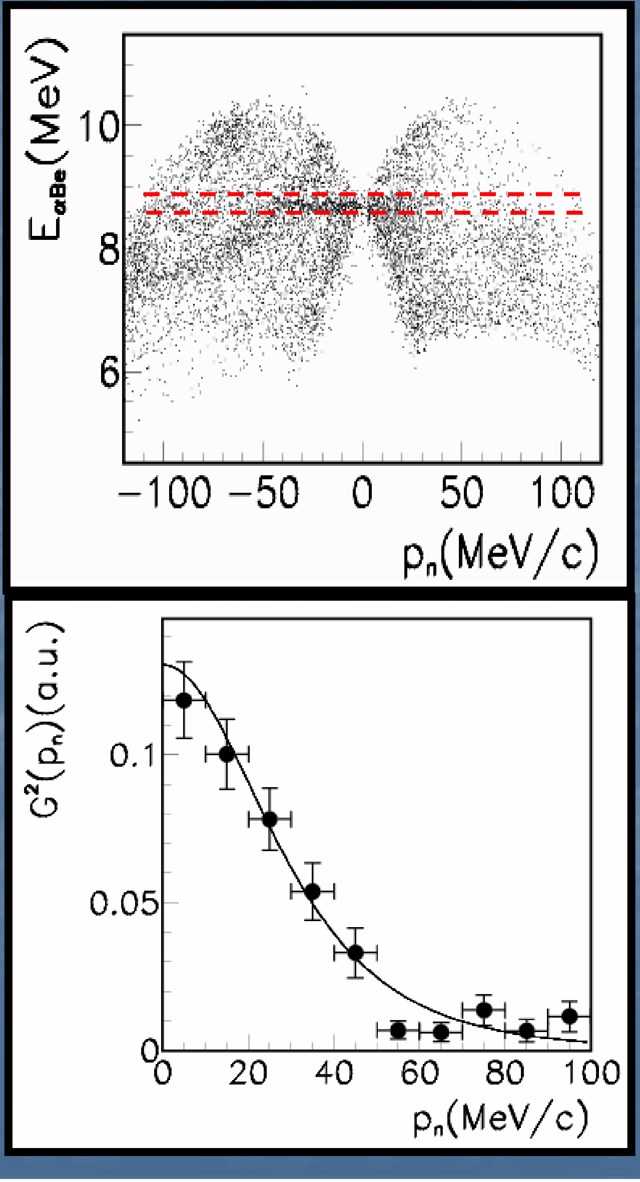
Selection of the QF-mechanism:
Experimental Momentum Distribution

- ✓ A further and necessary experimental check is to study the experimental neutron momentum distribution.

- ✓ Comparison between the experimental data (black points) and the theoretical Hulthén wave function ($a=0.2317\ \mathrm{fm}^{-1}$, $b=1.202\ \mathrm{fm}^{-1}$):

$$|\Phi(\vec{p}_n)|^2 = \frac{1}{2\pi}\sqrt{\frac{ab(a+b)}{(a-b)^2}}\left[\frac{1}{a^2+p_n^2} - \frac{1}{b^2+p_n^2}\right]$$

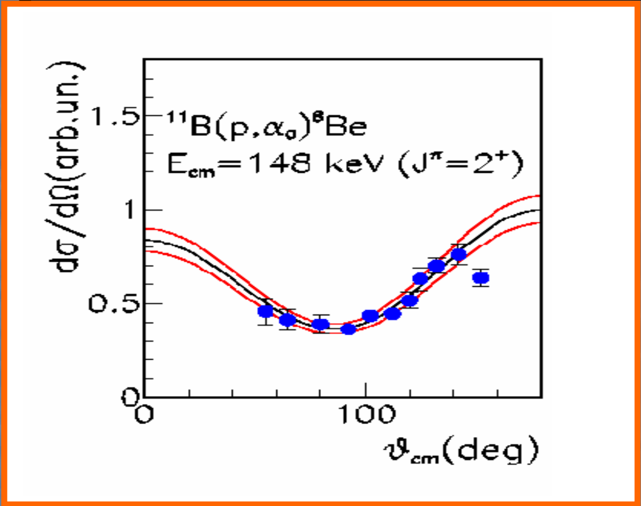
Necessary condition for the application of the Trojan Horse!!



- ✓ QF-hypothesis satisfyed

- ✓ THM application

$^{11}B(p,\alpha_0)^8Be$ angular distributions & S(E)-factor. Comparison between Exp 2007 – Exp 2002



- **S(E)-extraction**

S(E) = E*P$_l$σ^N(E)*exp(2πη)

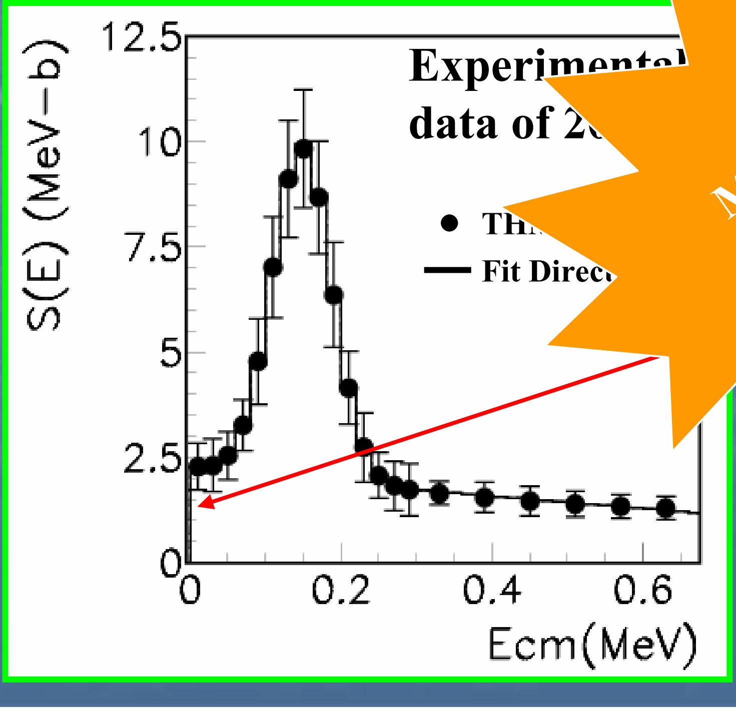
- ***APPROACH:***

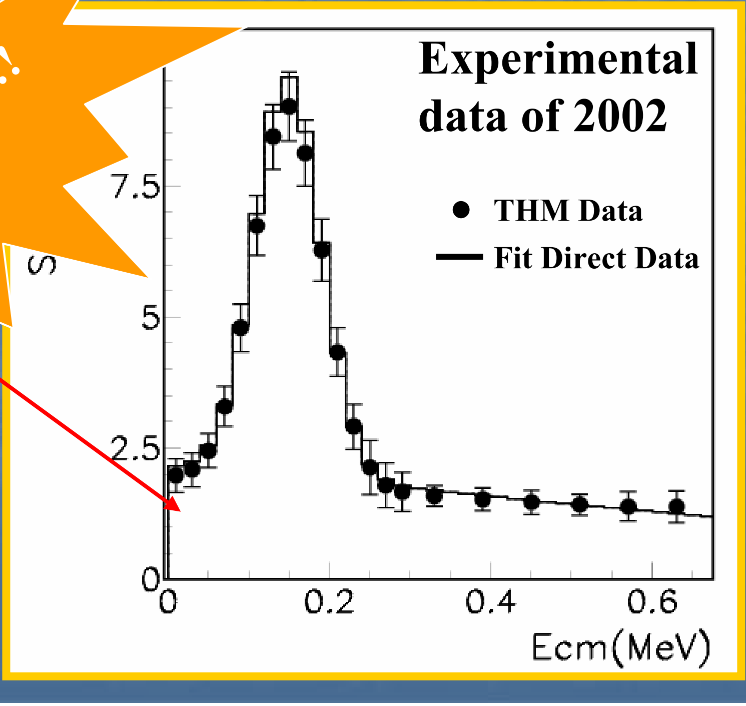
-^{9}Be (SD) subtraction;

- Normalization between 400-600 keV's;

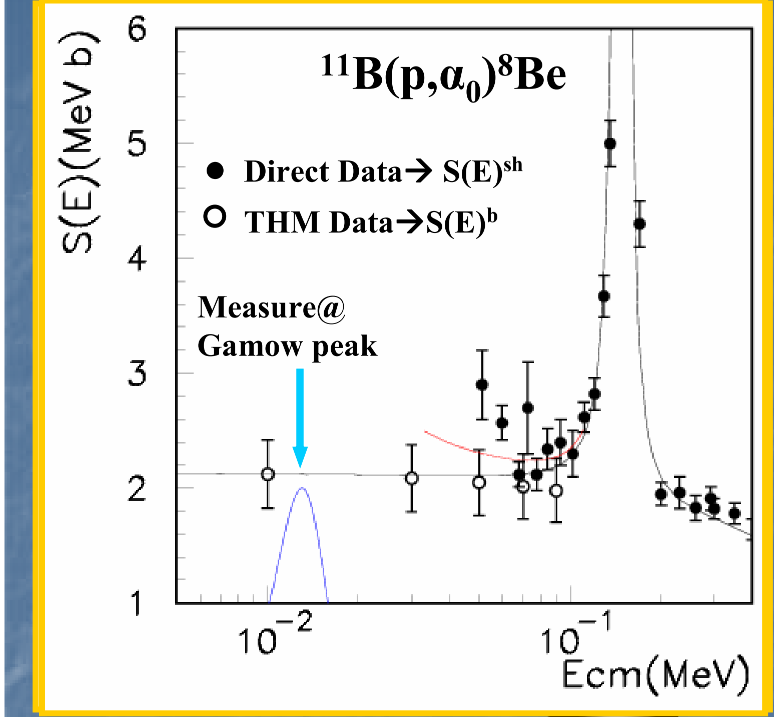
- Separatio[illegible] between resonant l=1 (16.106 MeV ^{12}C) and [illegible] resonant l=0 contribution

Measurement @ Gamow peak!!!!





Final results, discussion & perspectives



- S(E)-extraction

$$\underline{S(E) = E*P_l\sigma^N(E)*exp(2\pi\eta)}$$

The experimental Fit on THM data leads to

$$S(E)^{THM}_{NR}=2.14-1.85*E+0.89*E^2\ \text{(MeV b)}$$

DATA	*S(E) VALUEs*	*REFERENCEs*
THM 2007-2002	2.15±0.28 MeV b	Present Work.
THM 2002 (new approach)	2.2±0.3 MeV b	Lamia et al., N. Cimento, 2009
Extrapolations	2.10±0.13 MeV b	Becker et al., Z.Ph.327, 341, 1987
PRC, 2004	0.41±0.09 MeV b	Spitaleri et al., Phy.Rew.C, 2004

Final results, discussion & perspectives

- Non resonant reaction rate ("Nuclear Physics of Stars", Iliadis C., 2007)

$$N_A \langle \sigma v \rangle = \frac{C1}{T_9^{2/3}} e^{-C_2/T_9^{1/3}} \left(1 + C_3 T_9^{1/3} + C_4 T_9^{2/3} + C_5 T_9 + C_6 T_9^{4/3} + C_7 T_9^{5/3}\right) \quad (cm^3 mol^{-1} s^{-1})$$

$$C_1 = 7.8324 \times 10^9 \left(Z_0^2 Z_1^2 \frac{M_0 M_1}{M_0 + M_1}\right)^{1/6} S(0) \sqrt{\frac{M_0 + M_1}{M_0 M_1}}$$

$$C_2 = 4.2475 \left(Z_0^2 Z_1^2 \frac{M_0 M_1}{M_0 + M_1}\right)^{1/3}$$

$$C_3 = 9.810 \times 10^{-2} \left(Z_0^2 Z_1^2 \frac{M_0 M_1}{M_0 + M_1}\right)^{-1/3}$$

$$C_4 = 0.1220 \frac{S'(0)}{S(0)} \left(Z_0^2 Z_1^2 \frac{M_0 M_1}{M_0 + M_1}\right)^{1/3}$$

$$C_5 = 8.377 \times 10^{-2} \frac{S'(0)}{S(0)}$$

$$C_6 = 7.442 \times 10^{-3} \frac{S''(0)}{S(0)} \left(Z_0^2 Z_1^2 \frac{M_0 M_1}{M_0 + M_1}\right)^{2/3}$$

$$C_7 = 1.299 \times 10^{-2} \frac{S''(0)}{S(0)} \left(Z_0^2 Z_1^2 \frac{M_0 M_1}{M_0 + M_1}\right)^{1/3}$$