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Searching for "treasures" at sub-barrier energies : the case of ^{8}B and ^{7}Be

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LAY out

- Introduction-motivation
- Previous studies
- Our study with $^{8}B+^{208}Pb$ at deep sub-barrier energies
- Recent analysis for $^{7}Be+^{208}Pb$ at deep sub-barrier energies

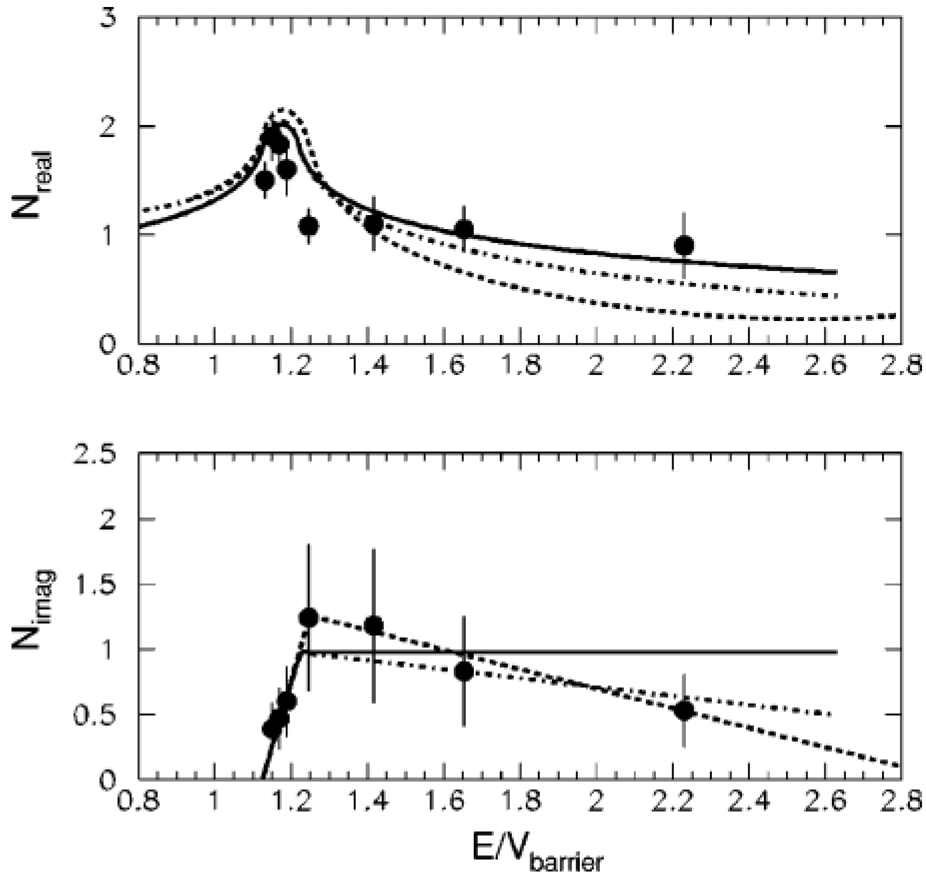
Key aspects indicating the hidden wealth of information below barrier

- Coupling channel effects visualized with an unusual behavior of the energy dependence for the optical potential
- Enhancement of fusion below barrier – or fusion hindrance at deep sub-barrier energies??

Optical potential for $^{12}C + ^{209}Bi$; the energy dependence;

Coupling channel effects at near and sub-barrier energies and the optical potential threshold anomaly

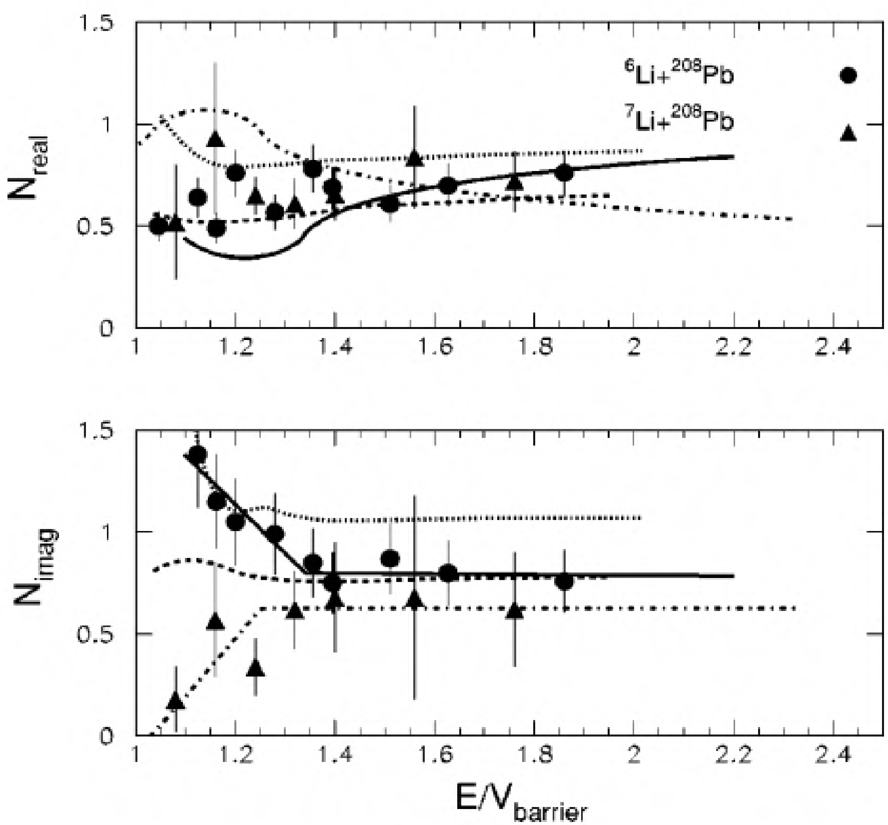
Standard behavior for stable projectiles



optical potential threshold anomaly for weakly bound projectiles

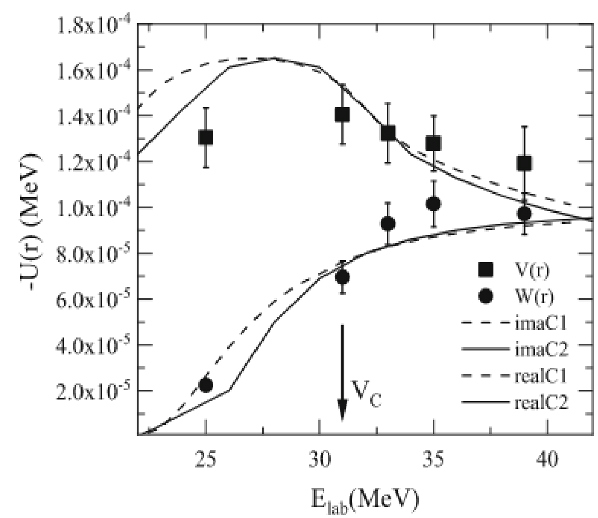
Previous information

PHYSICAL REVIEW C **69**, 054602 (2004)



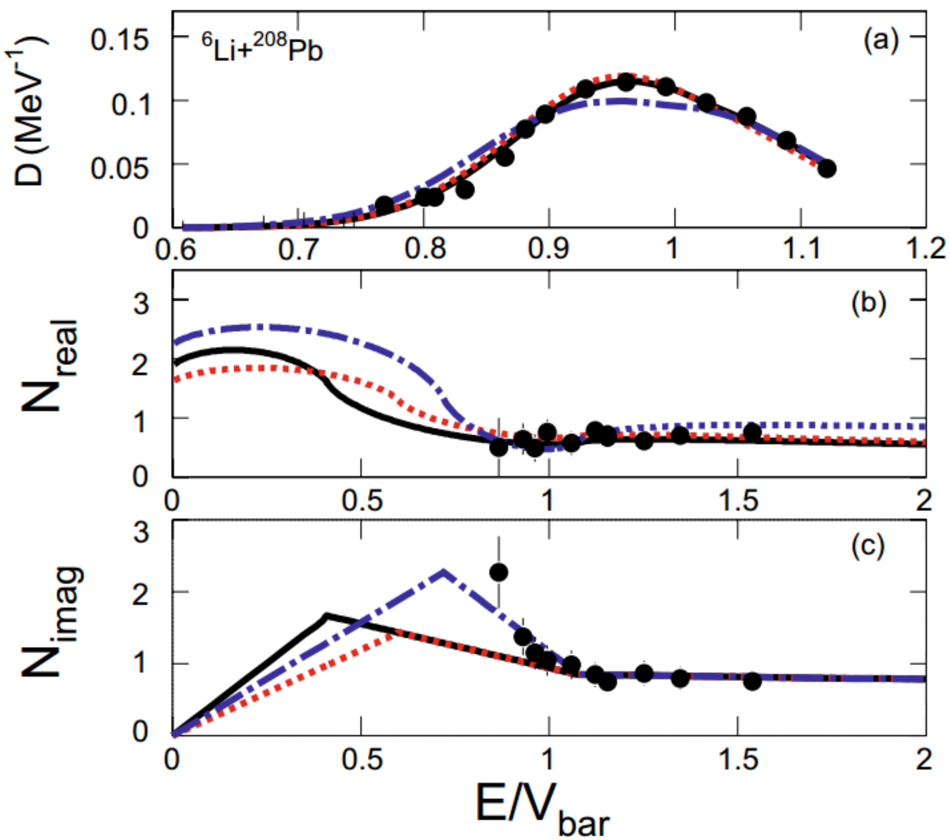
More recent information

Vardaci et al; EPJA 57,95(2021)



Data from Refs. By Keeley et al and Martel et al. NPA571,326(1994). NPA582,357(1995)

At what energy the potential drops: backscattering technique



From Zerva et al. EPJA 48,102(2012)

Unfolding the enigma of fusion at sub- and near-barrier energies for the system $^{6}Li+^{28}Si$

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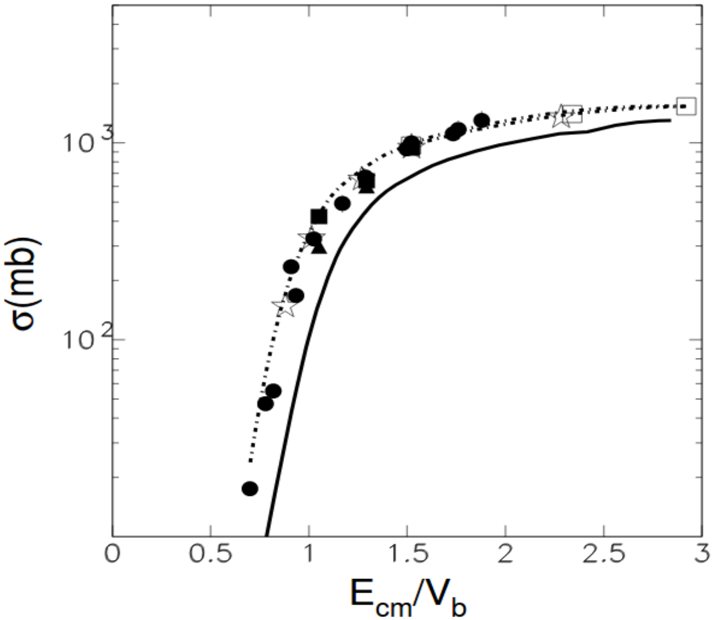
(Dated: November 23, 2007)

$E_{c.m.}$ (MeV)	σ_T(mb)	σ_F(mb)
4.94	18 ± 3	2.3±0.4(4.3)
5.35	43 ± 7	8.6±1.4(9.6)
5.5	47 ± 5	11.3±1.4(8.3)
5.76	55 ± 6	17±2(8)
6.18	98 ± 10	42±4(13)
6.5	210 ± 21	107±11(26)
7.2	325 ± 33	211±22(37)
7.41	345 ± 35	238±24(38)
8.23	493 ± 50	375±38(53)
9.05	670 ±70	524±55(73)
10.54	930±100	730±80(103)
10.7	1000±120	800±96(124)
12.2	1112±122	890±98(126)
12.4	1168±130	934±104(135)
13.2	1300±150	1040±120(155)

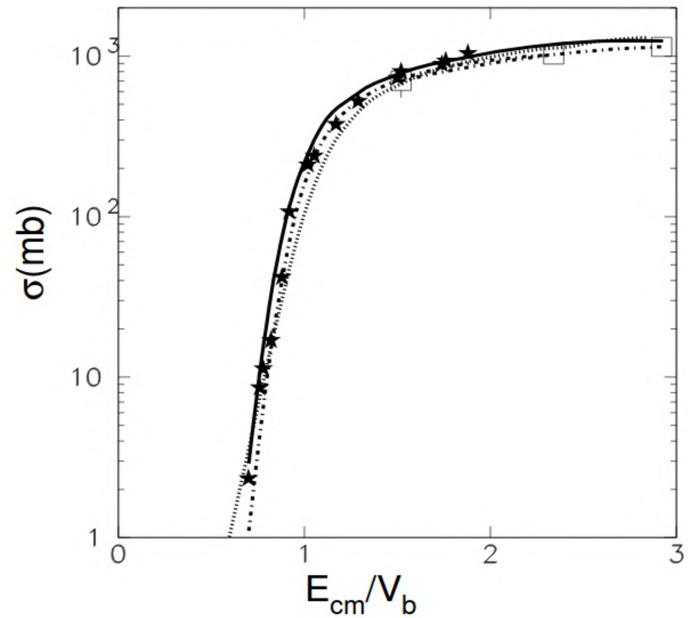
For $^{7}Li+^{28}Si$- similar work published in EPJA39,187(2009)

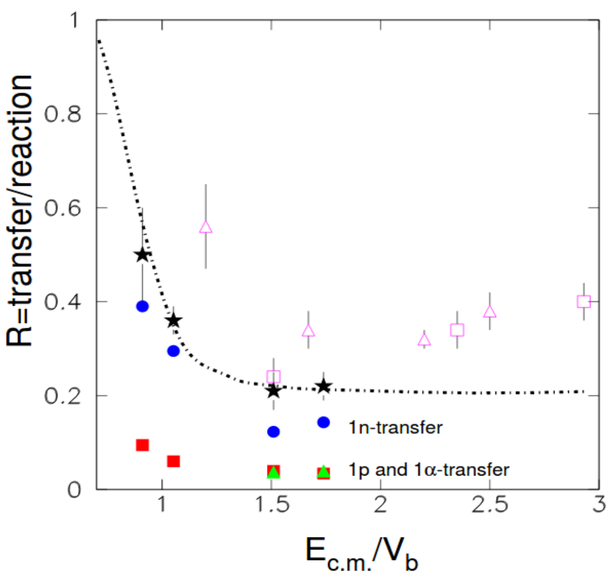
$^{6}Li+^{28}Si$

TOTAL



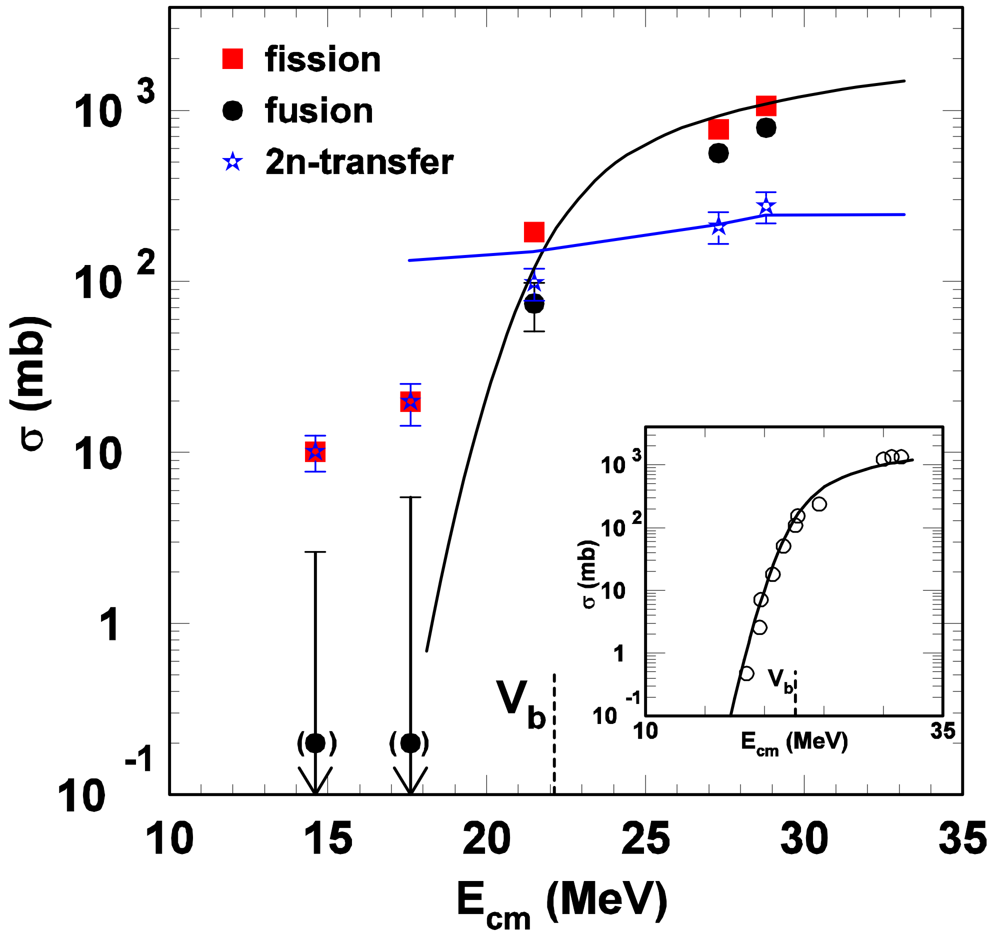
FUSION





← Direct to total

key reaction → $^{6}He + ^{238}U$



Fission is used as a tracer of fusion

M Trotta et al, PRL84,2342(2000)

R. Raabe et al., Nature 431,823(2004)

N. Keeley, R. Raabe, N. Alamanos, J.L. Sida; Progress in Nuclear Physics 59, 579 (2007).

Fusion 8He + 197Au

Lemasson et al.
PRL103,232701(2009)

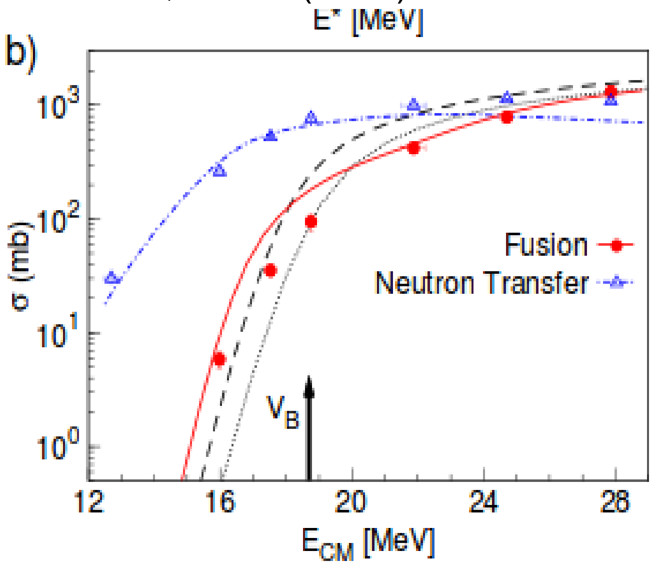
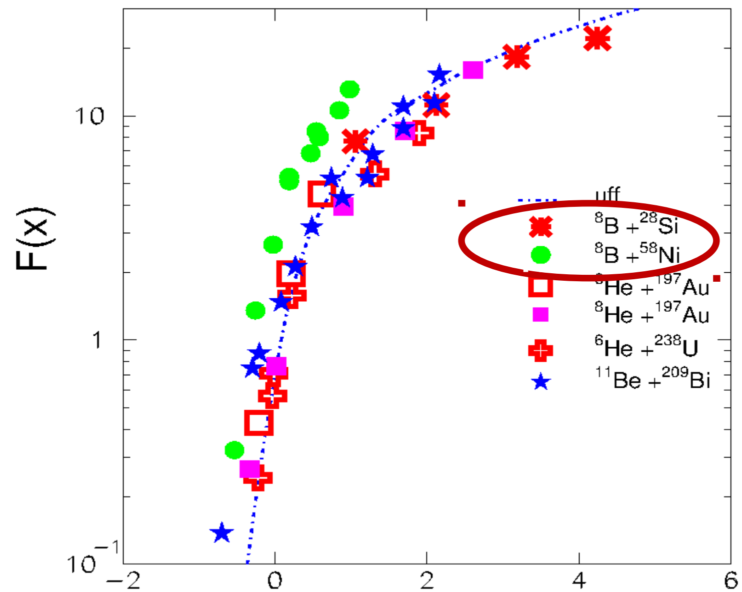


Fig. 2. (a) Cross sections for evaporation residues as

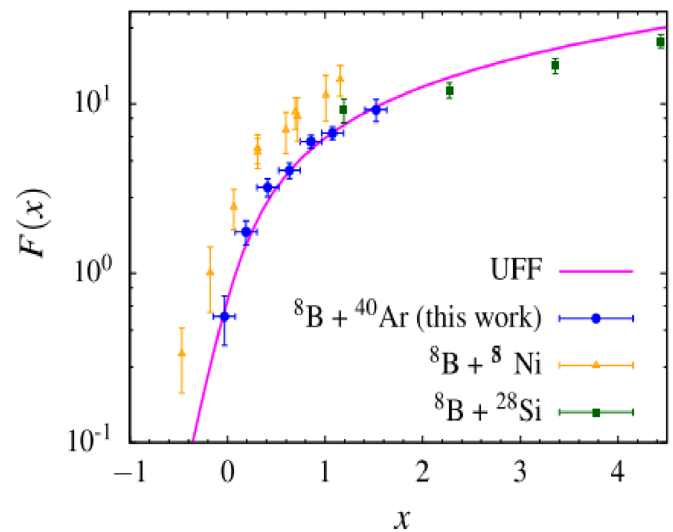
Reduced fusion for various weakly bound exotic projectiles

Pakou et al, PRC87,014619(2013)



8B+58Ni
Notre Dame
PRL107,092701(2011)

Zamora et al; Phys. Lett. B 816, 136256(2021).



Two key issues

- Predictions of Ratios direct to total reported in Ref: **EPJA 51,55 (2015)**
- CDCC calculations for $^{8}B+^{208}Pb$, reported in Ref **Prog.Part. Nucl. Phys. 63, 396 (2009)**

Paulo Gomes
Rev. C 71, 017601 (2005).

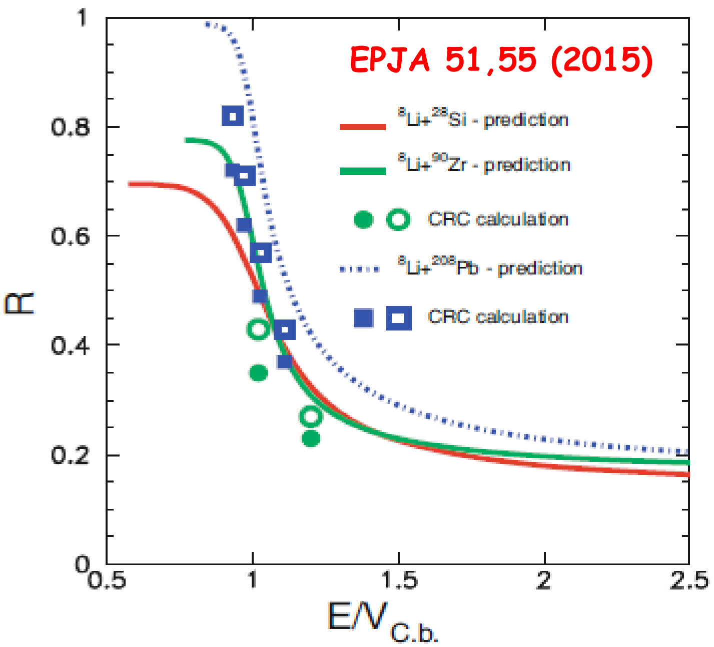
$$R = \frac{F(x) - F(0)}{F(x)}$$

F(x) reduced total reaction cross section
F(0) reduced fusion cross section

Reduction based to the Wong cross section

$$\sigma_F^W = R_B^2 \frac{\hbar\omega}{2E_{c.m.}} \ln\left[1 + \exp\left(\frac{2\pi(E_{c.m.} - V_B)}{\hbar\omega}\right)\right],$$

$$\sigma_F \rightarrow F(x) = \frac{2E_{c.m.}}{\hbar\omega R_B^2}\sigma_F,$$

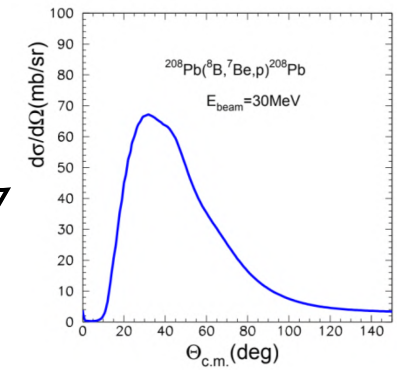


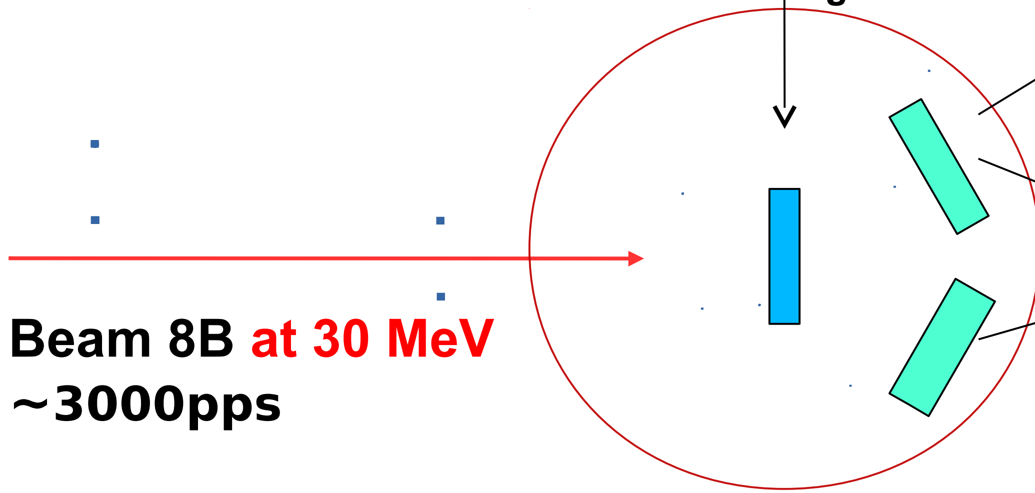
BREAKUP of $^{8}B+^{208}Pb$

Experimental set up

Pb target
1.5mg/cm2

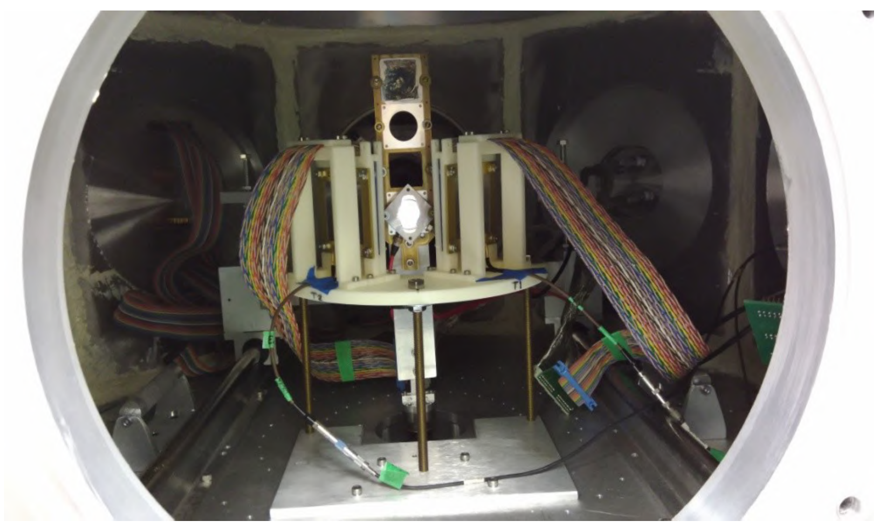
7Be
fragments
Energy
profile





Beam 8B at 30 MeV
~3000pps

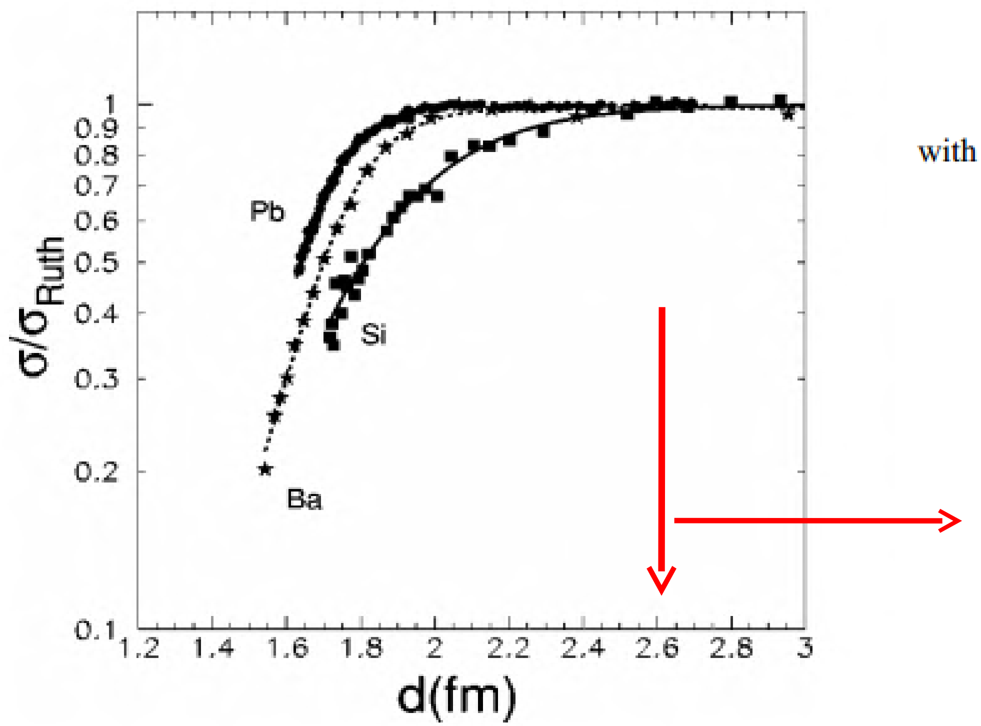
Two telescopes
DE 20 microns
E   150 microns
AT
+- 20 to 70 degrees
from



SIMAS (Sistema Mvil de Alta Segmentacin) array of the LEMA (Laboratorio Nacional de Espectrometra de Masas con Aceleradores)

Is it really low this energy at 30 MeV ??

Distance of closest approach



Pakou-Rusek Phys. Rev C

$$D = d(A_1^{1/3} + A_2^{1/3}) = \frac{1}{2} D_0 \left(1 + \frac{1}{\sin(\theta/2)}\right)$$

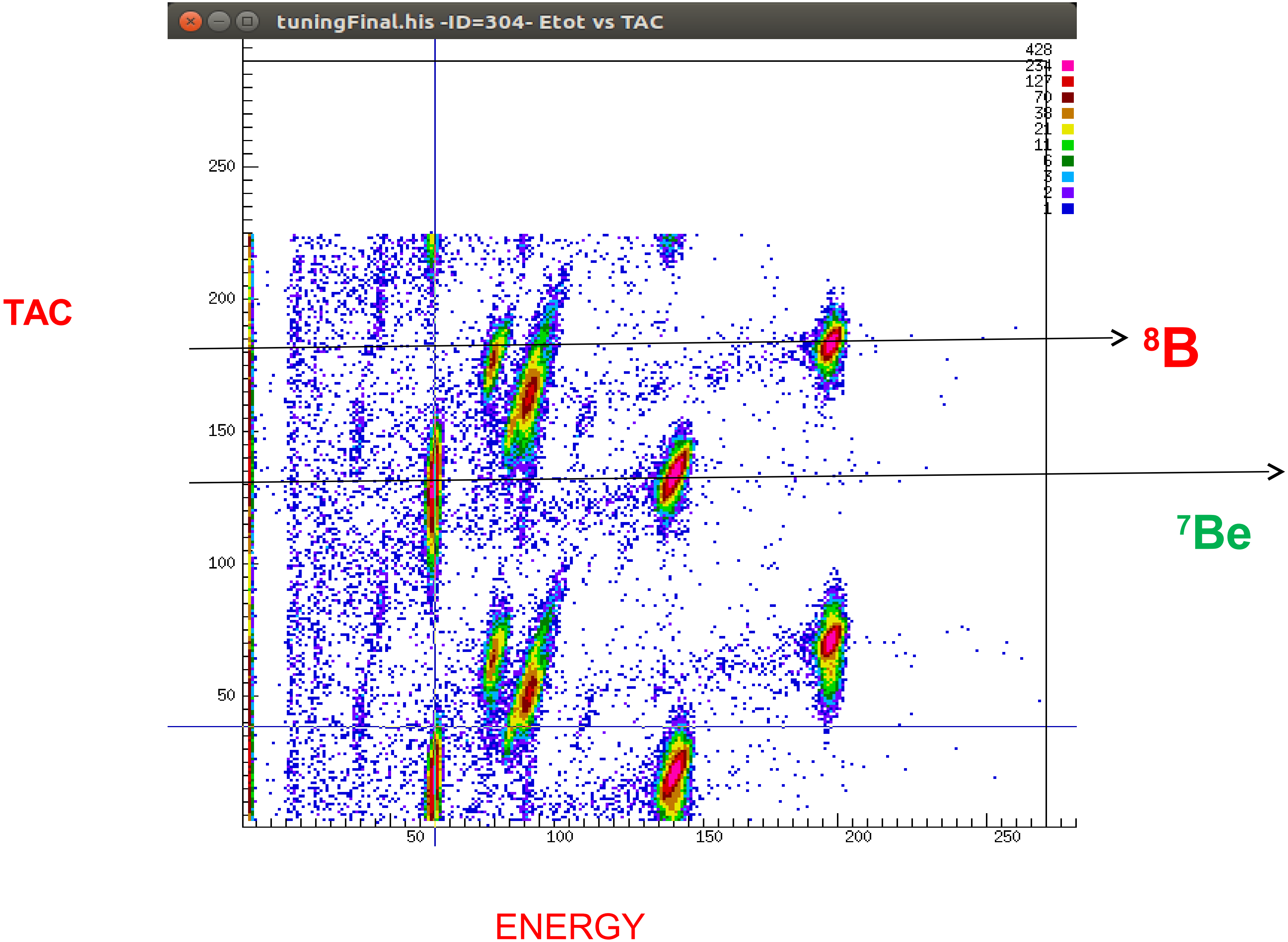
with

$$D_0 = \frac{Z_1 Z_2 e^2}{E_{\text{c.m.}}}$$

Θ =30 to 70 deg
d= 2.6 to 2.9 fm

D=20.5 to 22.8 fm

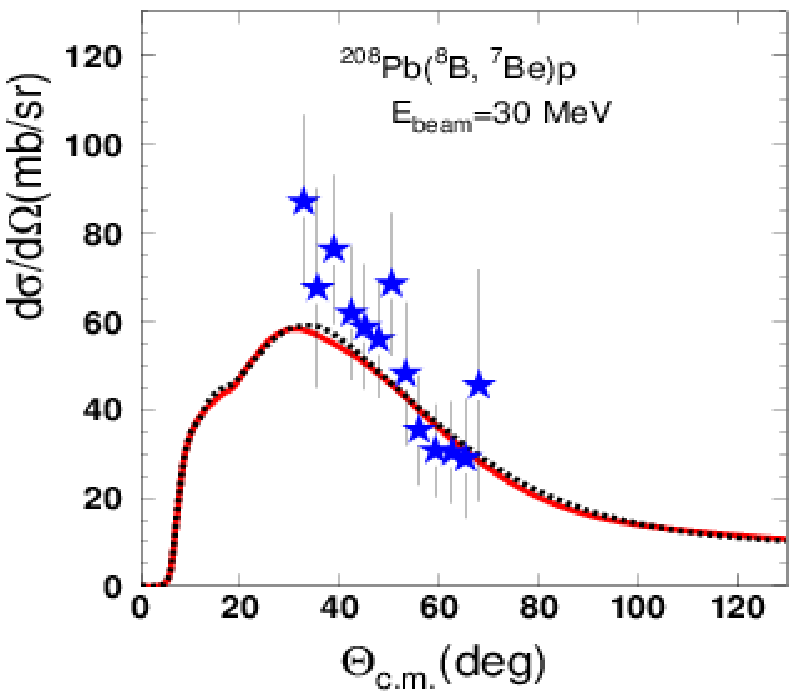
To be compared with
R=R1+R2~**10fm**



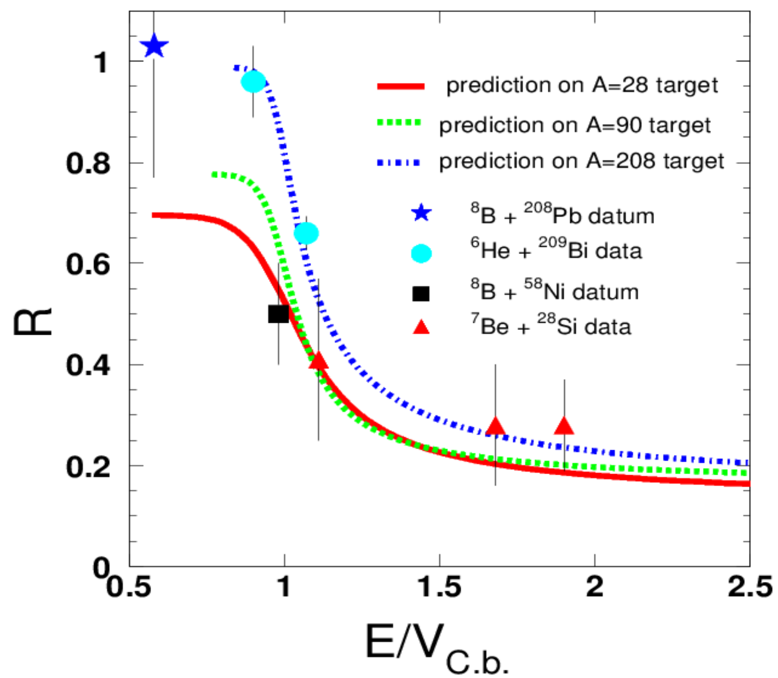
tuningFinal.his -ID=304- Etot vs TAC
TAC
ENERGY
^{8}B
^{7}Be
428
234
127
70
38
21
11
6
3
2
1
250
200
150
100
50
50
100
150
200
250

Phys. Rev. C 102, 031601(R)(2020)

Direct = breakup



Direct to total



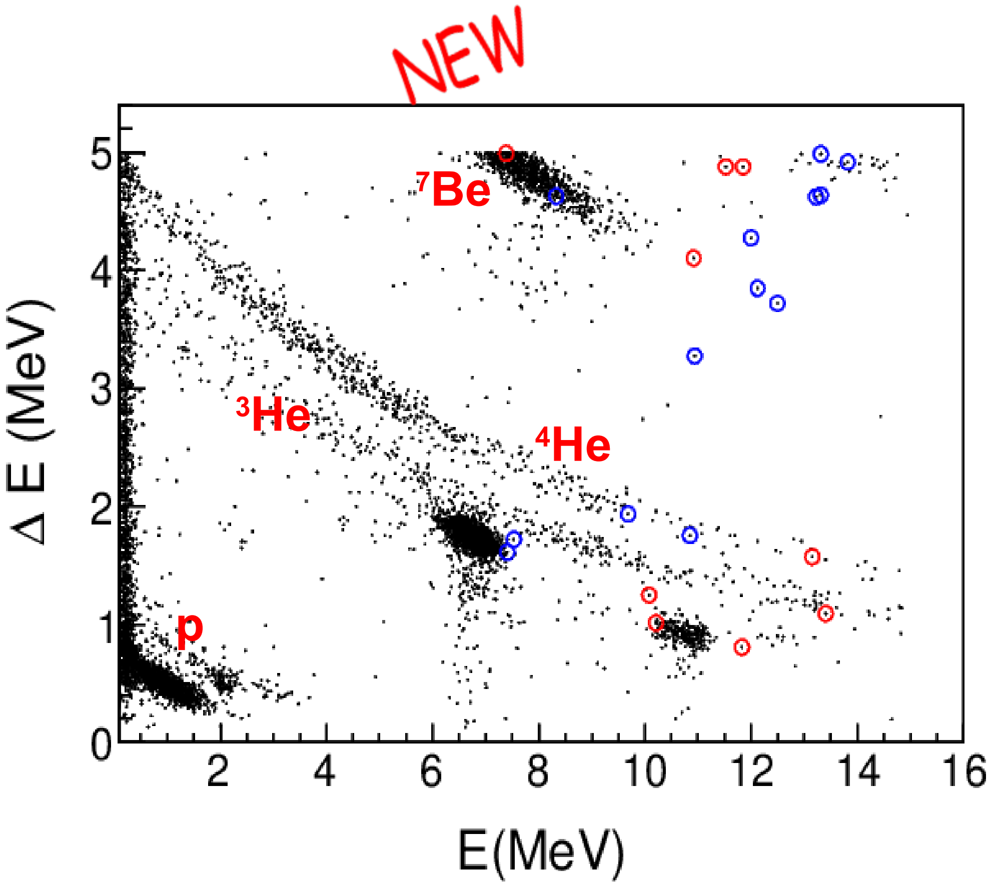
σ_{break}=325±84 mb

the lack of measured total reaction cross section value does not allow the confirmation of a fusion hindrance

σ_{break}^{cdcc}=300mb

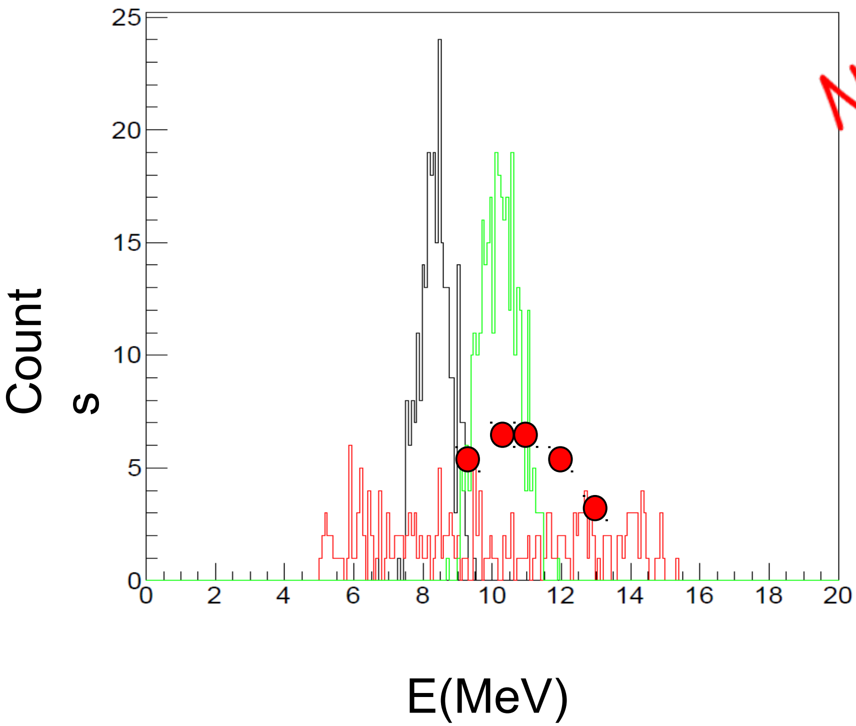
Σ_{tot}^{cdcc} =316mb

$^{7}Be+^{208}Pb$ at 22.5 MeV

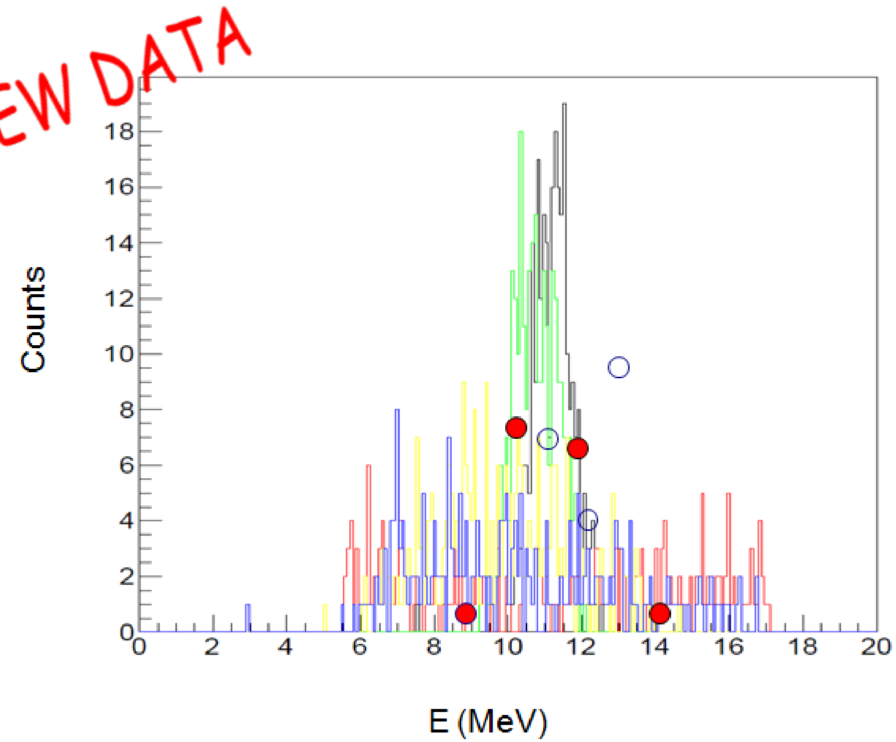


$^{7}Be+^{208}Pb$ at 22.5 MeV

^{3}He -production



^{4}He -production



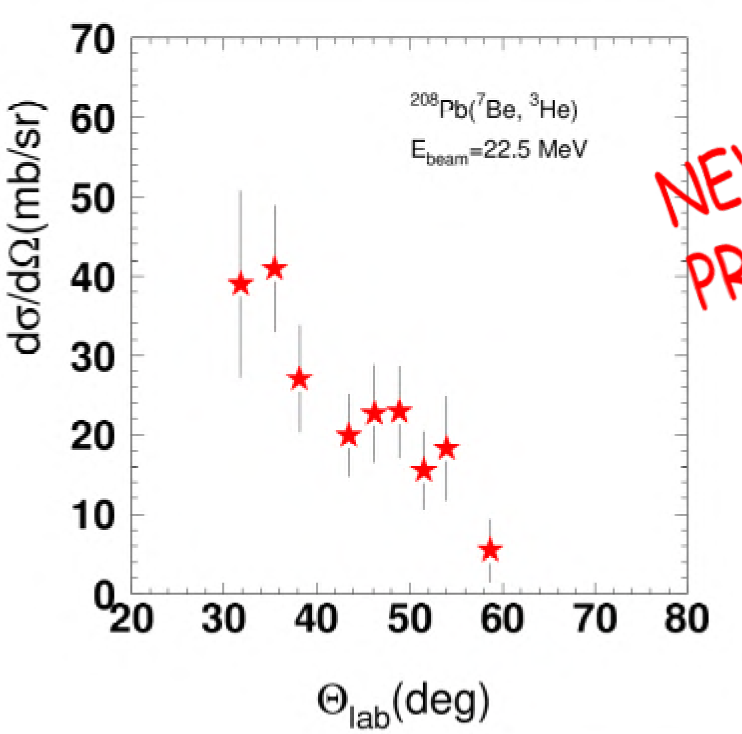
Data: red dots

Simulation : black line breakup, green line 4He(3He)-transfer

Simulation by Angel Santzez Benitez

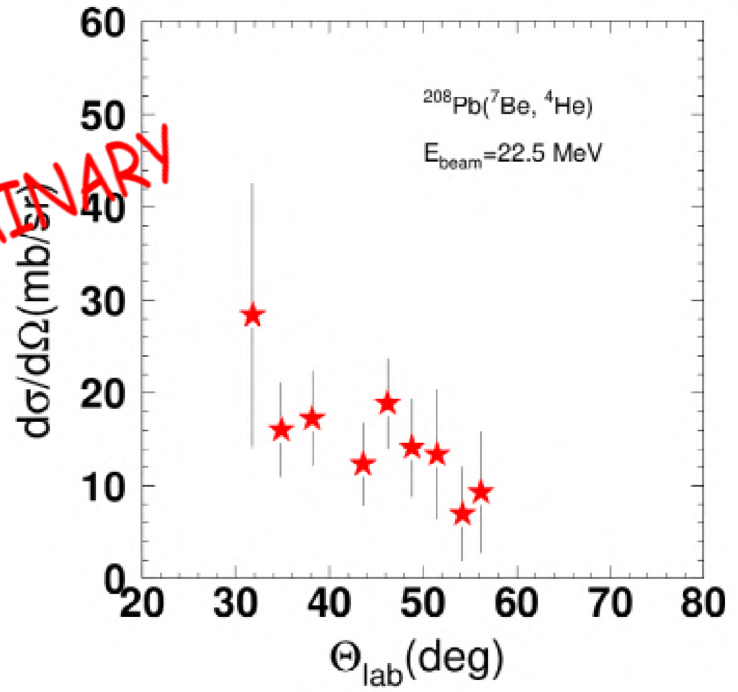
$^{7}Be+^{208}Pb$ at 22.5 MeV

^{4}He -production



NEW-
PRELIMINARY

^{3}He -production

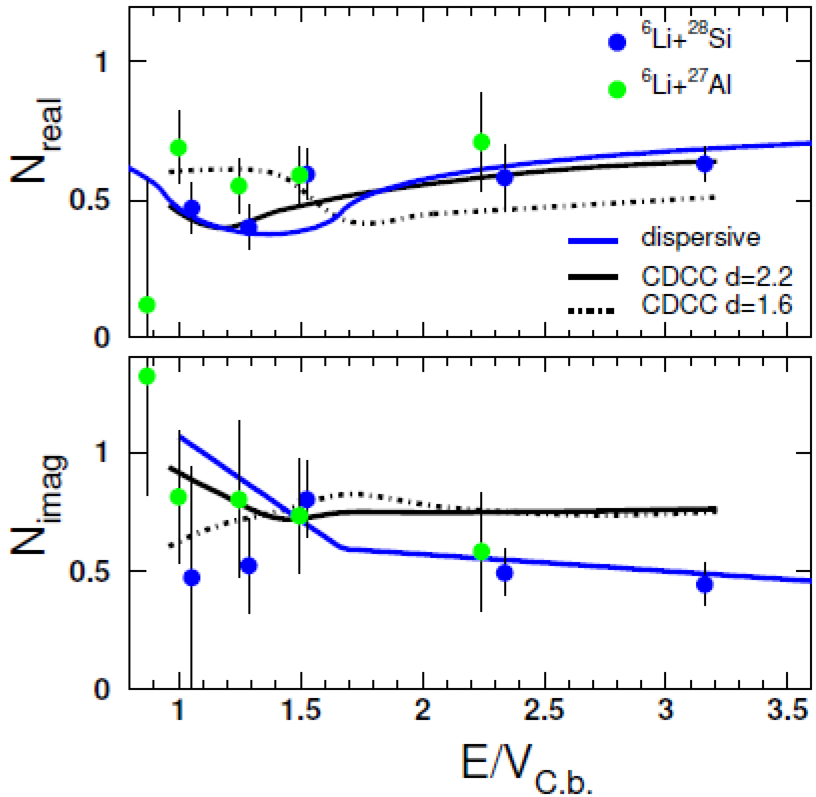


conclusions

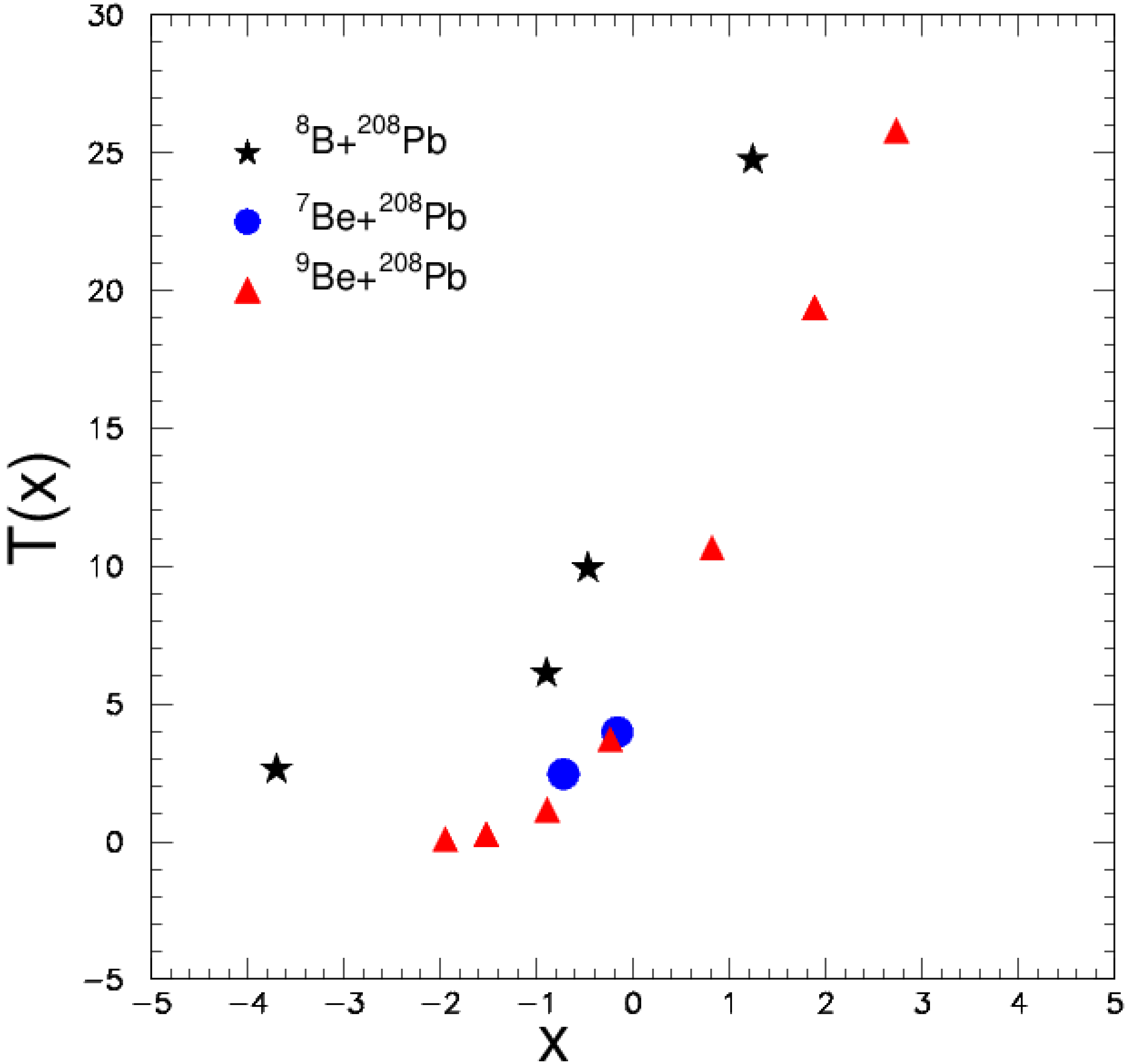
- We have presented a brief review for the observation of strong direct reaction channels at sub and deep sub –barrier energies

- For ^{8}B reacting with the heavy Pb target the dominance of breakup at deep sub-barrier energies is evident and this tops the total reaction cross section according to predictions due to systematic. A fusion hindrance is not however confirmed. Strong boron beams are necessary for a direct fusion measurement

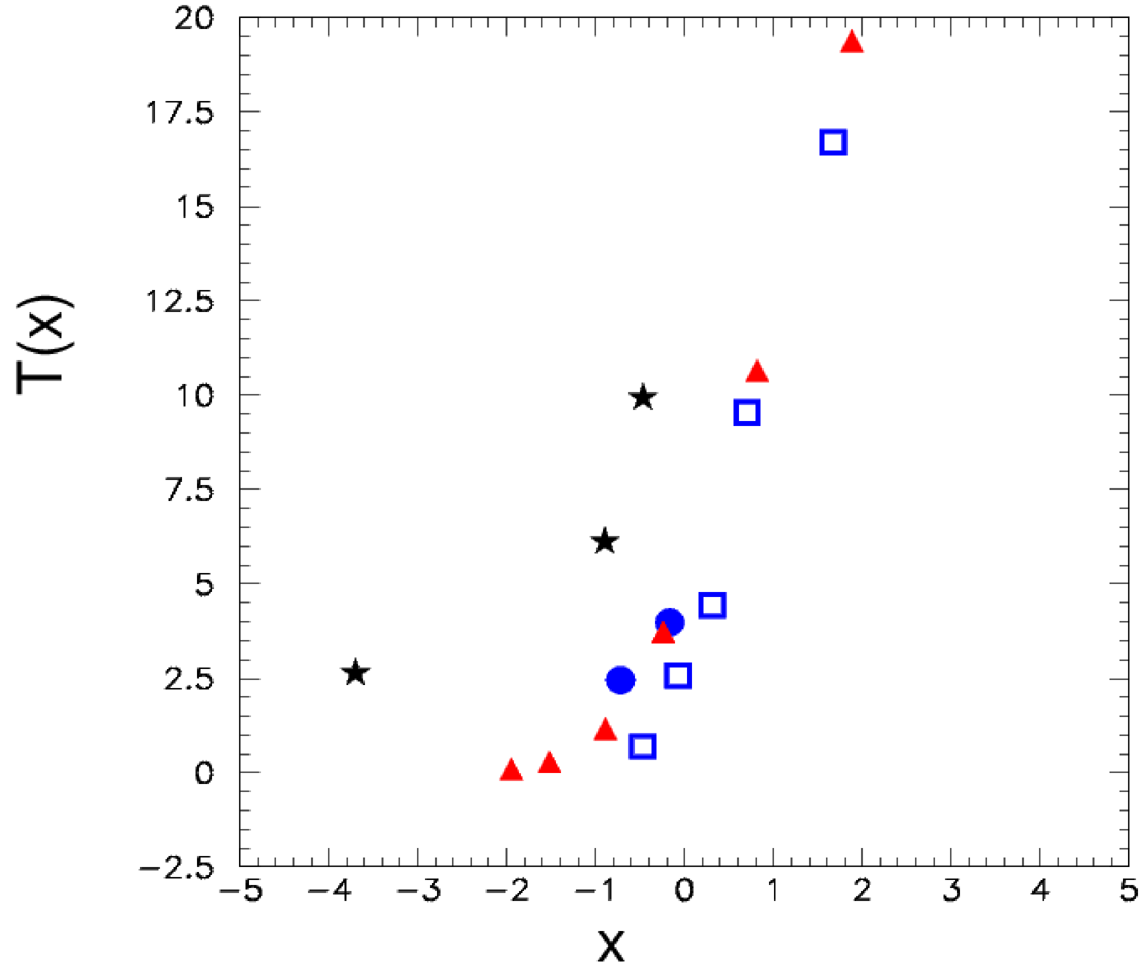
- New results for the production of large ^{4}He and ^{3}He yields have been reported. For $^{7}Be+^{208}Pb$ at deep sub-barrier energies. For ^{3}He, it is clear that the reaction products are due to ^{4}He transfer and not due to elastic breakup



^{6}Li+^{28}Si
^{6}Li+^{27}Al
dispersive
CDCC d=2.2
CDCC d=1.6
N_real
N_imag
E/V_C.b.
0
0.5
1
1.5
2
2.5
3
3.5



$^{8}B+^{208}Pb$
$^{7}Be+^{208}Pb$
$^{9}Be+^{208}Pb$
T(x)
X
30
25
20
15
10
5
0
−5
−5
−4
−3
−2
−1
0
1
2
3
4
5



T(x)
20
17.5
15
12.5
10
7.5
5
2.5
0
−2.5
−5
−4
−3
−2
−1
0
1
2
3
4
5
x