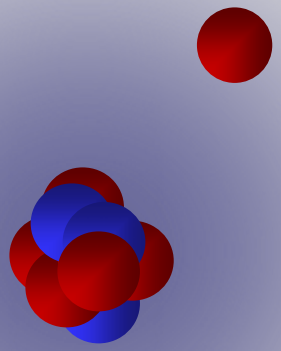
Structure at and Beyond the Neutron Dripline



Collaboration LPC-CHARISSA-DEMON

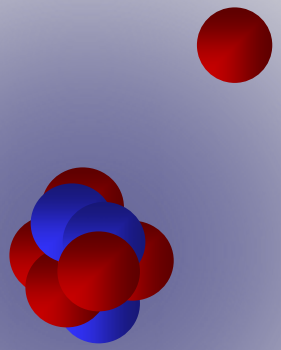
H Al Falou, FM Marqués, JL Lecouey, NA Orr, …

Structure at and Beyond the Neutron Dripline *

Motivation

Experimental Approach

"Backgrounds"



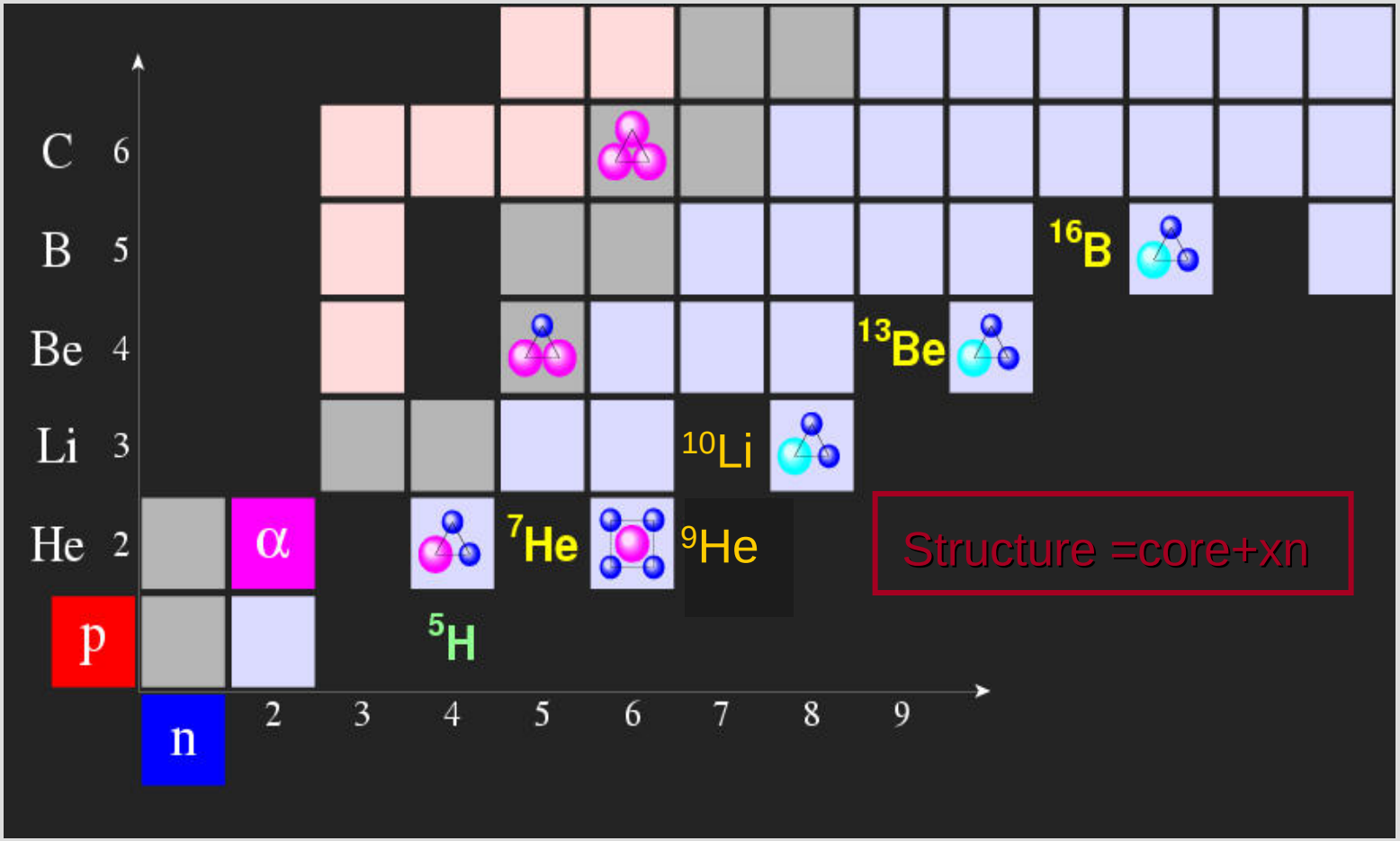
Structure of ^{7}He

N=7 : ^{10}Li & ^{9}He

Conclusions

*… "a view from the end of the beamline"

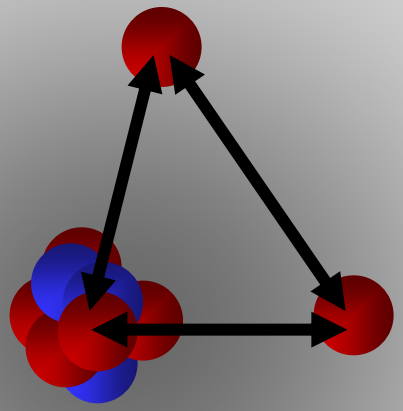
The Light Neutron-Rich Nuclei …



… driplines and beyond experimentally accessible, extreme test of models (shell model, shell model in continuum, “ab initio”, cluster, etc)

Light Unbound Neutron-Rich Systems

- *input for 3-body models*



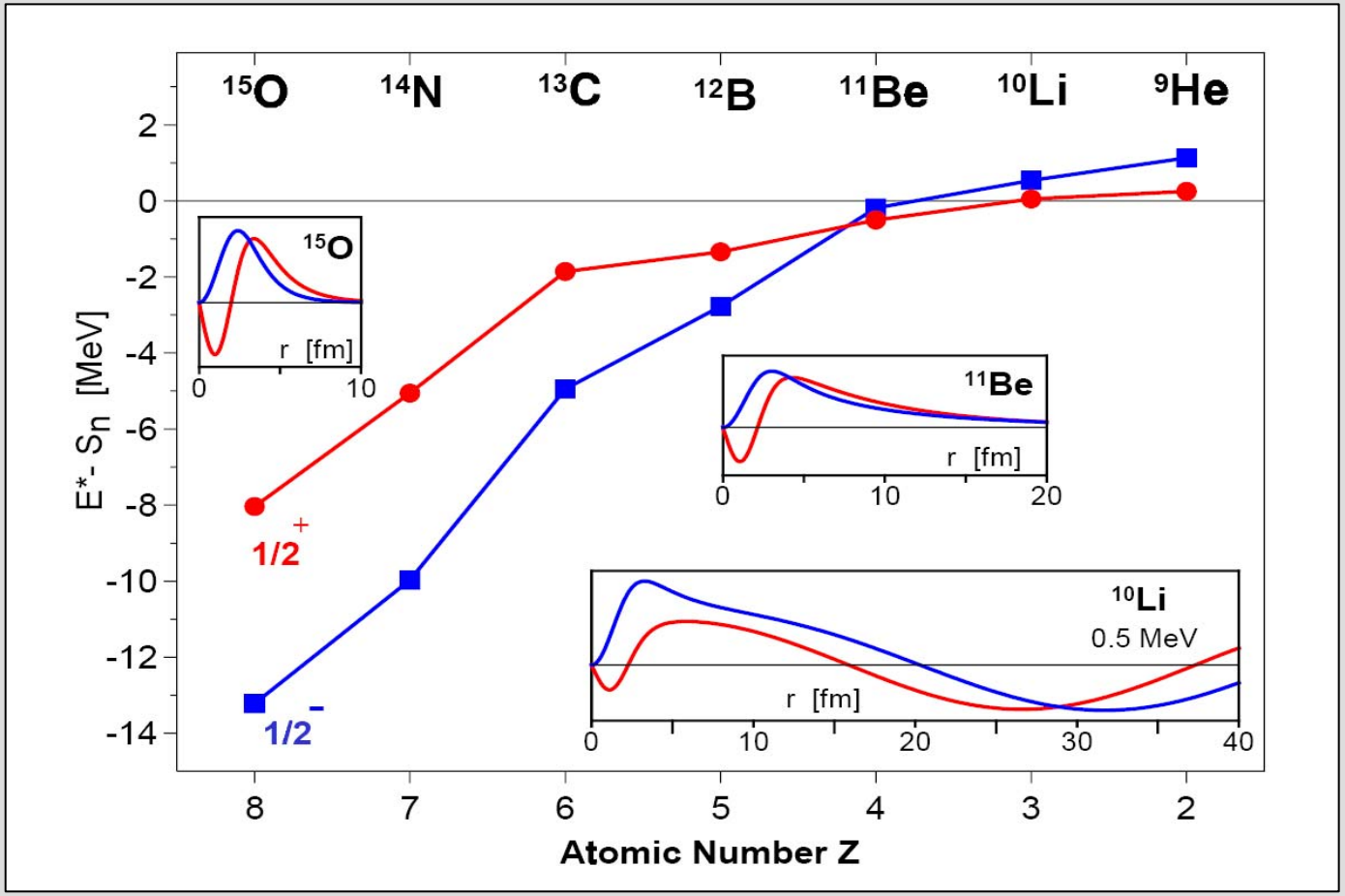
3-body systems ⇒ n-n and core-n interactions

eg. ^{11}Li : ^{9}Li-n interaction ⇒ spectroscopy of ^{10}Li

Light Unbound Neutron-Rich Systems

- *evolution of shell structure with N/Z*

... N=7 inversion

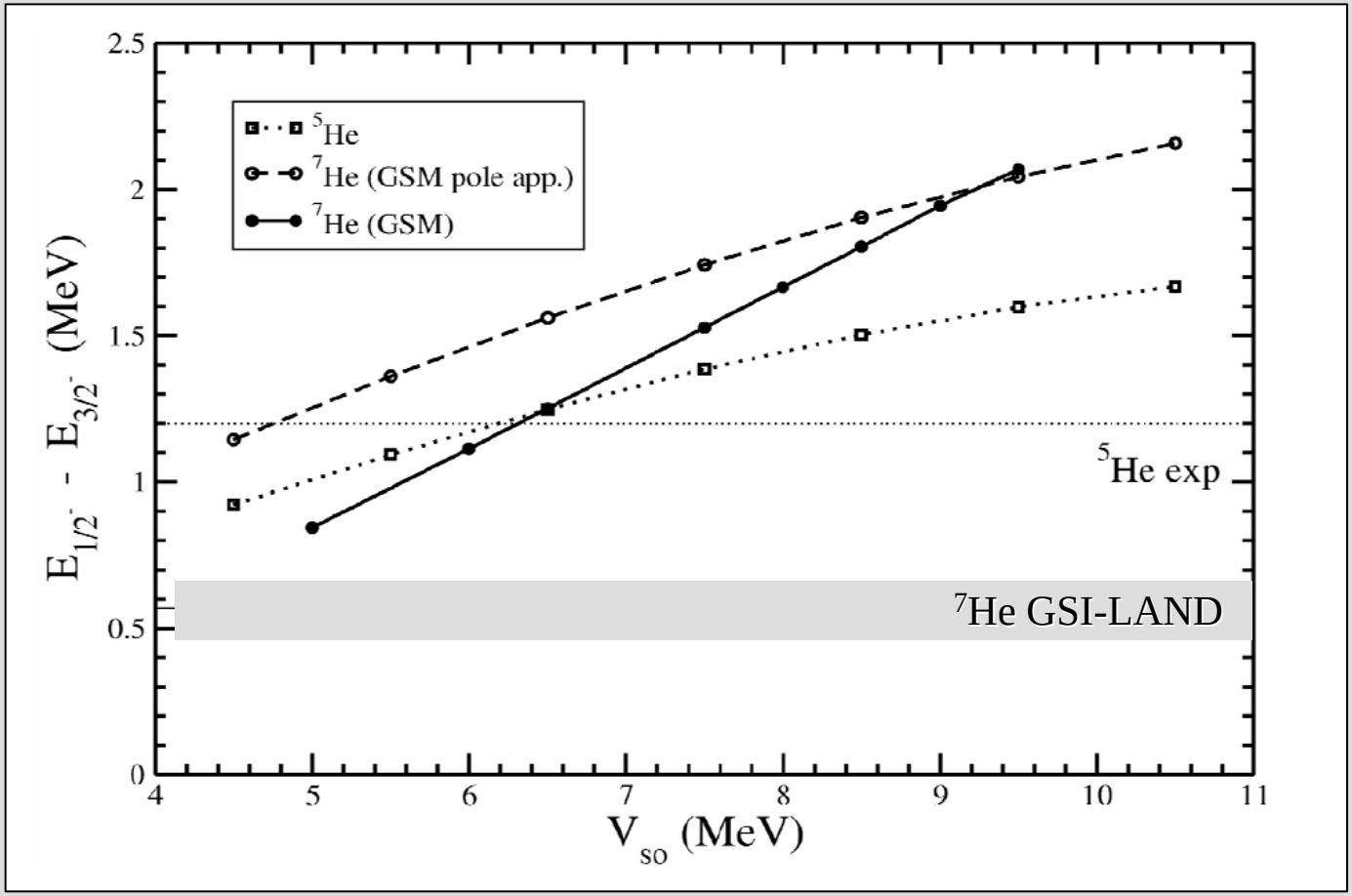


PG Hansen et al.

Light Unbound Neutron-Rich Systems

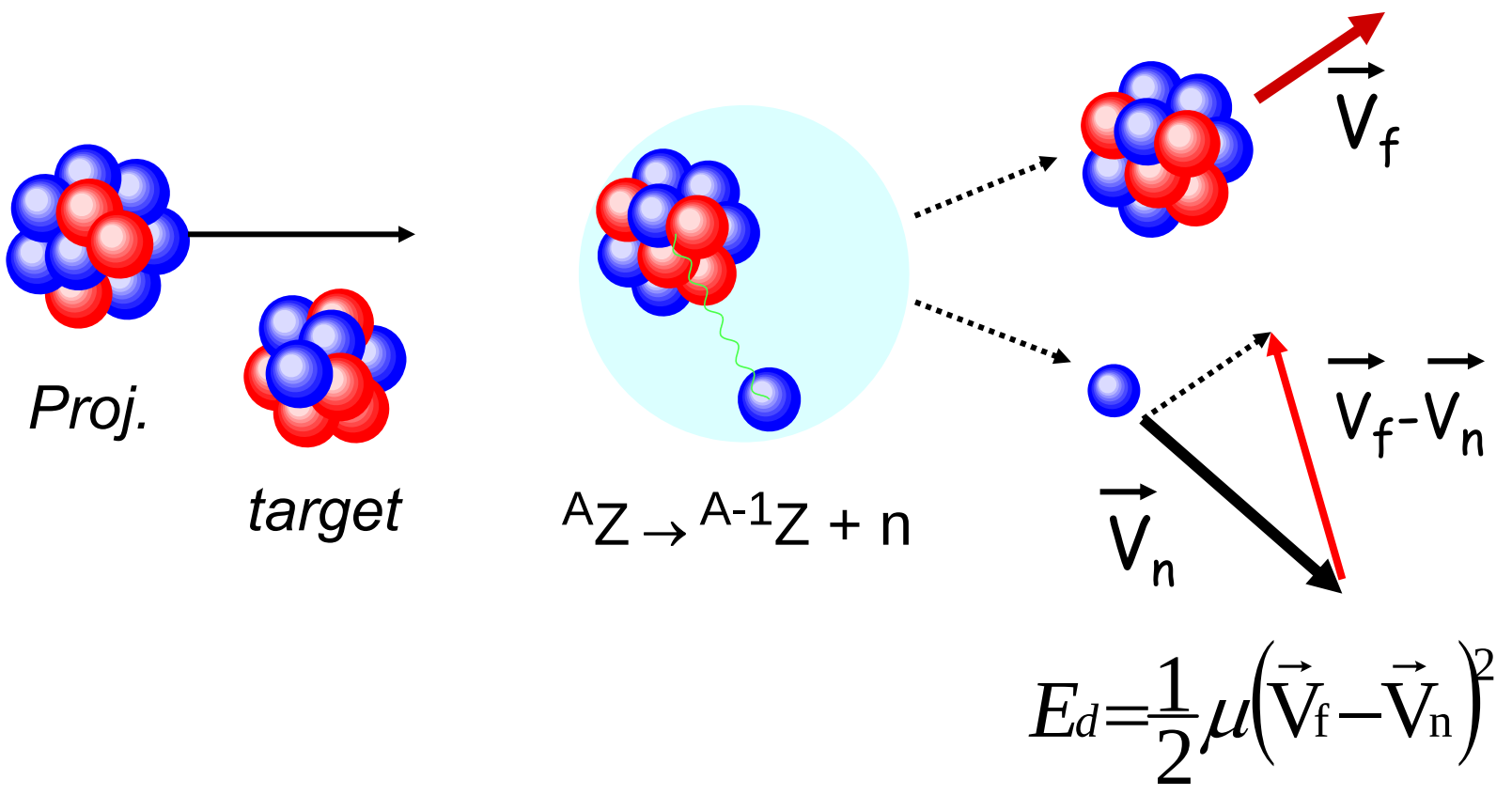
- *evolution of spin-orbit interaction with N/Z*

… ^{5}He & ^{7}He $3/2^{-} - 1/2^{-}$



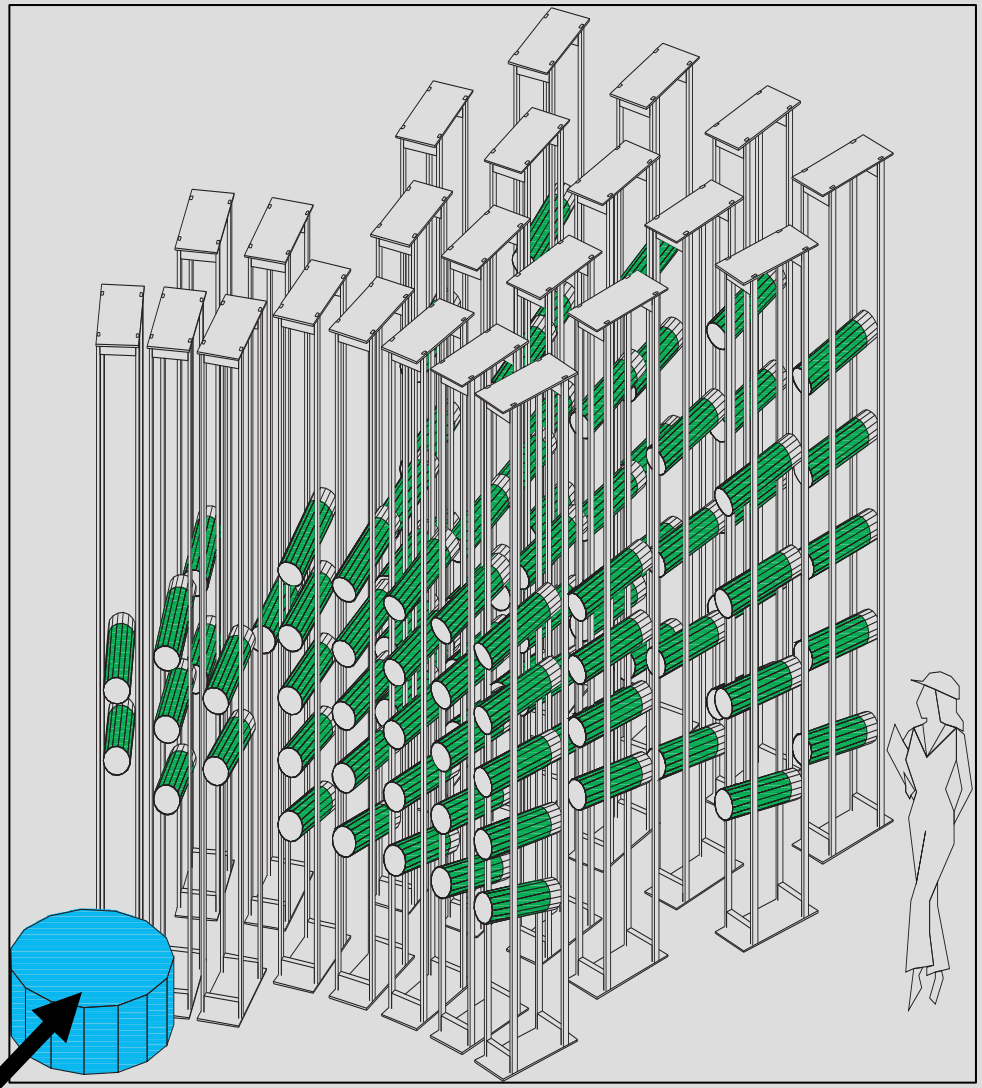
Gamow Shell Model : N Michel et al.

Experimental Approach



… breakup or "knockout" + inflight decay

Kinematically "Complete" Measurement



DEMON

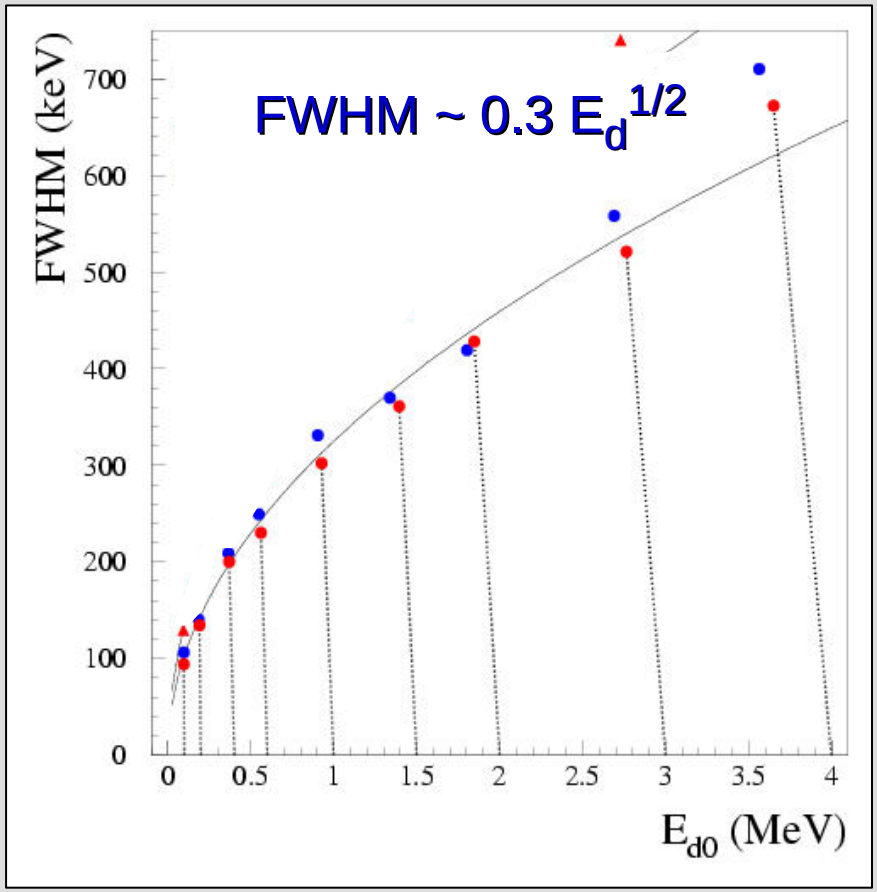
90 modules (NE213)

$\Rightarrow$ ToF & position

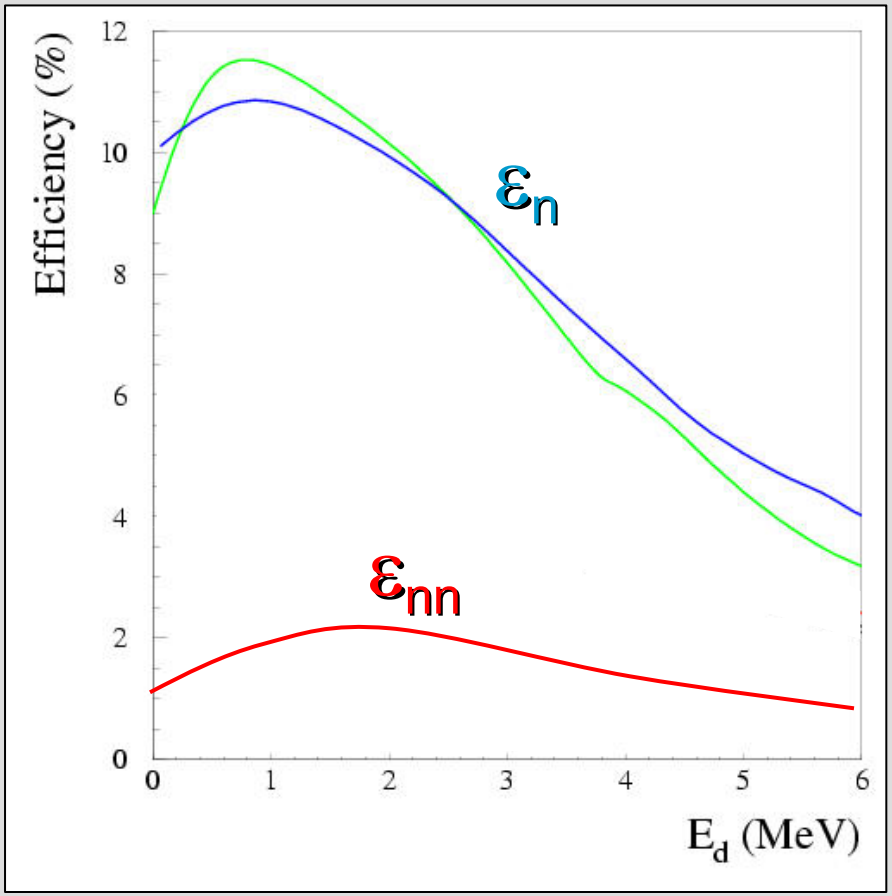
$\varepsilon_n \sim 10\%$

Experimental Response Function

Resolution



Efficiency



model distributions must be "filtered" through the simulation

JL Lecouey et al.

Reactions …

(i) 1-neutron "knockout"

$C(^{8}He,^{6}He+n)X$

(ii) 1 & 2-proton "knockout"

$C(^{11}Be,^{9}Li+n)X$, $C(^{11}Be,^{8}He+n)X$

(iii) fragmentation (-xp,-xn)

$C(^{11}Be,^{6}He+n)X$, $C(^{14}B,^{6}He+n)X$, $C(^{14}B,^{8}He+n)X$

Selection "Rules" - Sudden Approximation

(i) 1-neutron knockout $\Rightarrow$ neutron hole in proj. g.s. configuration

$C(^{8}He,^{7}He)X \rightarrow \nu p_{3/2}^{-1}$ $[\,^{8}He\ C^2S\,(\nu p_{3/2}) \approx 4\,]$

(ii) 1 & 2-proton knockout $\Rightarrow \Delta l_n = 0$ proj. valence neutron config.

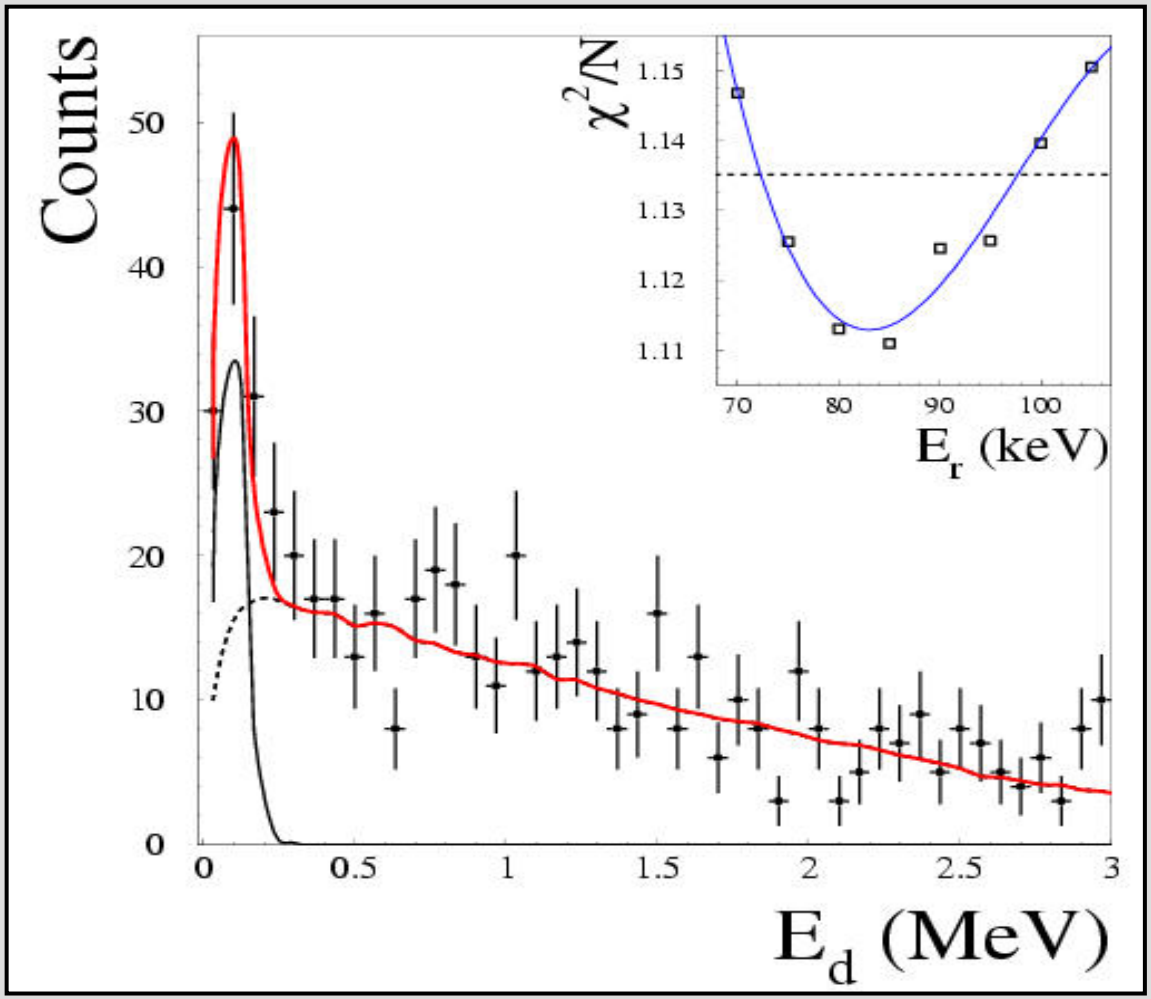
$C(^{11}Be,^{10}Li)X$, $C(^{11}Be,^{9}He)X \rightarrow \nu s_{1/2}$ $[\,^{11}Be\ C^2S\,(\nu s_{1/2}) \approx 0.8\,]$

(iii) fragmentation (-xp,-xn) $\Rightarrow$ valence neutron config. + others

$C(^{14}B,^{9}He)X \rightarrow \nu s_{1/2} + \nu p_{1/2}$

NB: for broad final states, lineshape dependent on initial state

Example : $C(^{17}C,^{15}B+n)X$ – single-proton knockout

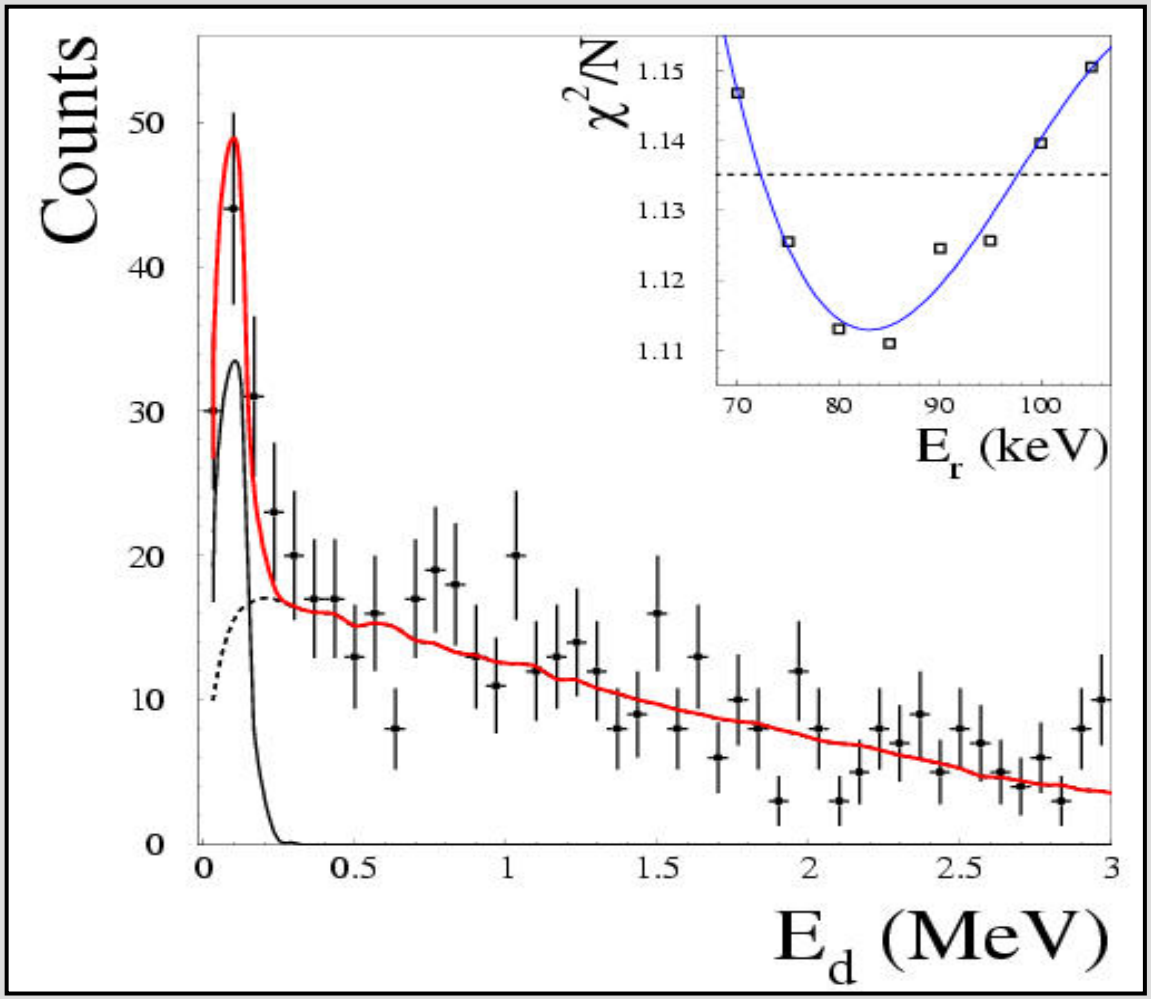


$E_r = 85 \pm 15$ keV

$\Gamma_{sp} << 100$ keV

JL Lecouey et al.

BACKGROUND: $C(^{17}C,^{15}B+n)X$ – single-proton knockout



$E_r = 85 \pm 15$ keV

$\Gamma_{sp} << 100$ keV

+

uncorrelated

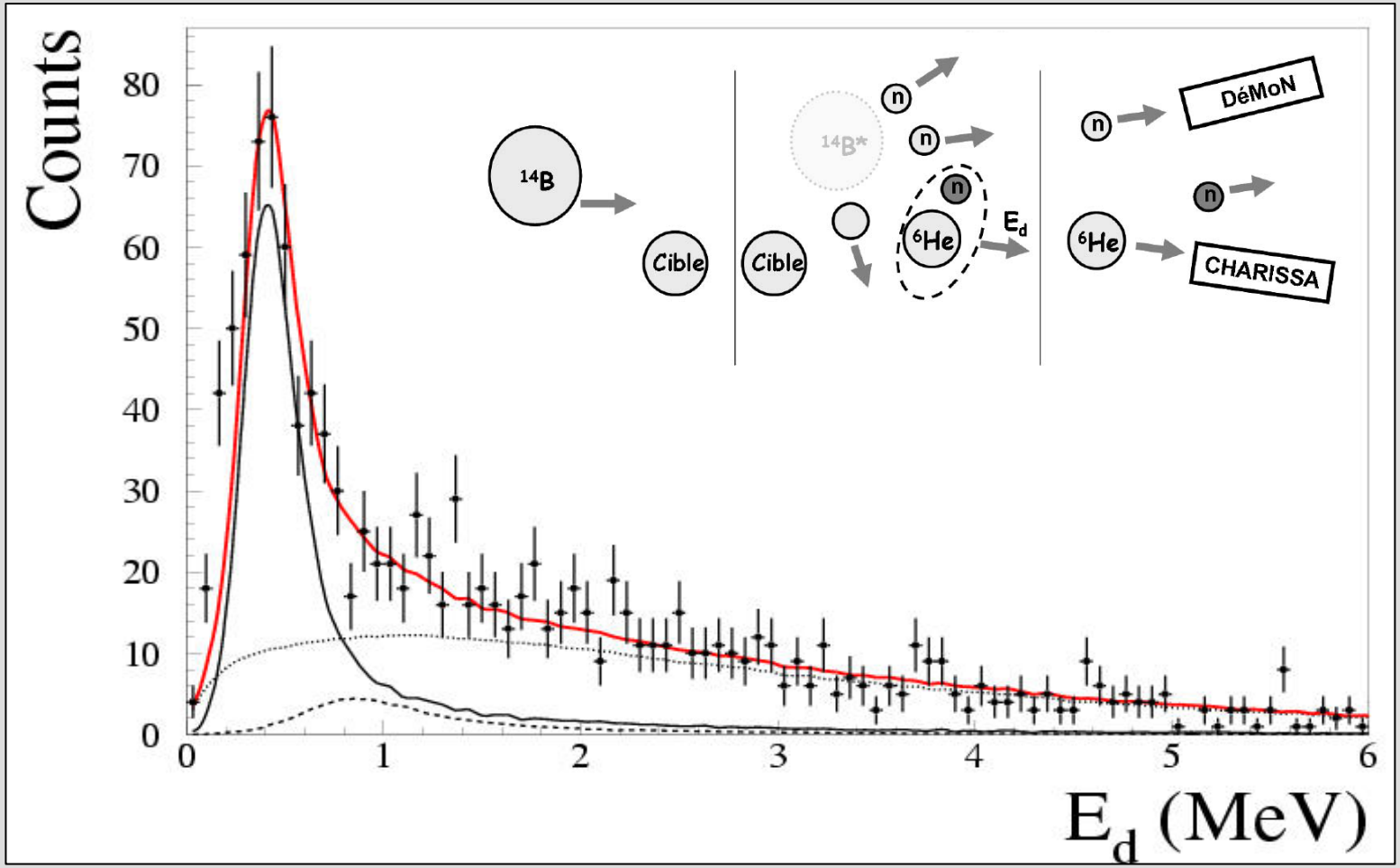
$^{15}B+n$ distribution

… "background" ≡ non-resonant continuum

NB: uncorrelated or event-mixed distribution

JL Lecouey et al.

BACKGROUND : $C(^{14}B,^{6}He+n)X$ – fragmentation



"background" ≡ neutrons evaporated from PLF + continuum

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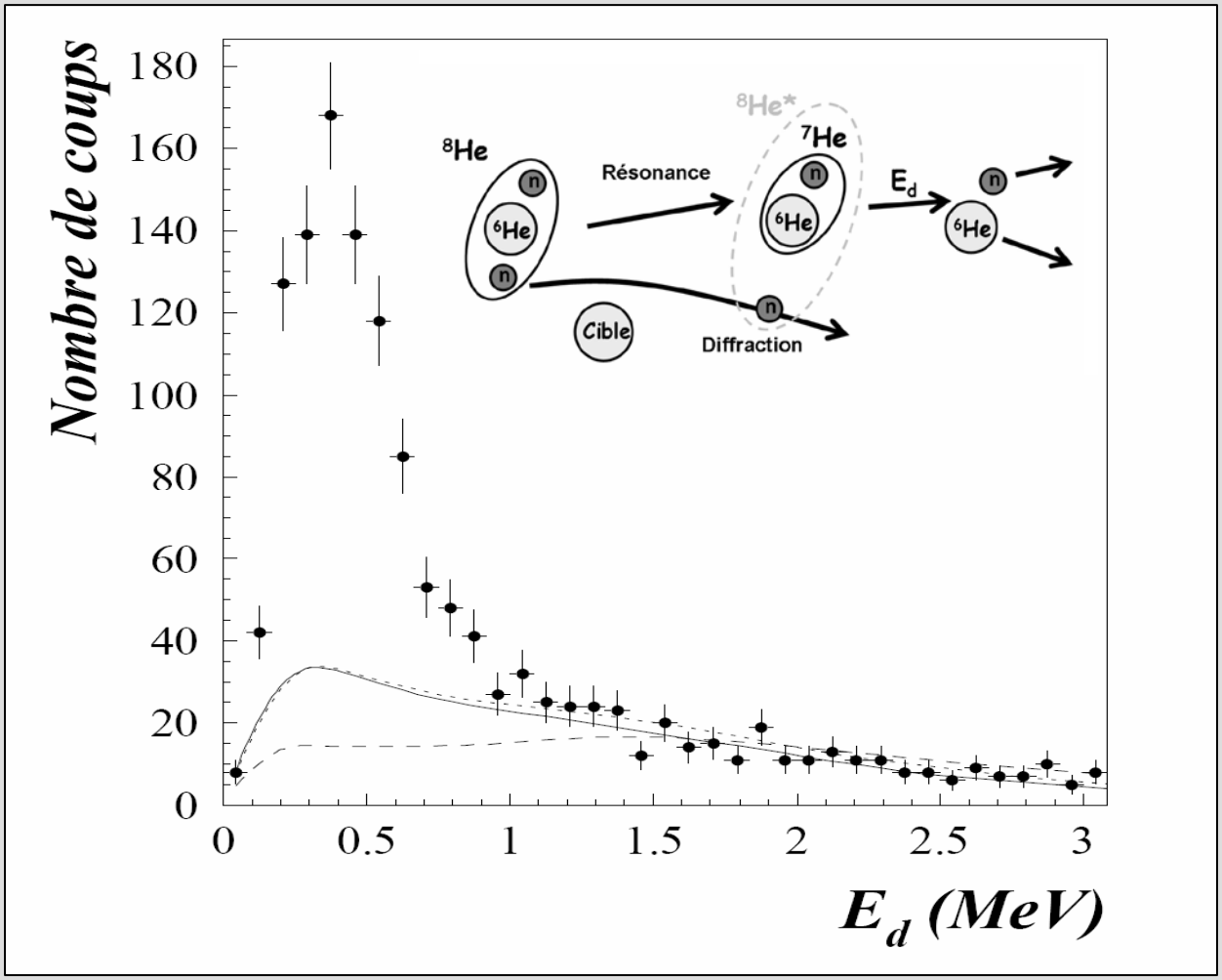
BACKGROUND : $C(^8He,^6He+n)X$ – halo dissociation



"background" ≡ neutrons from sequential breakup + continuum

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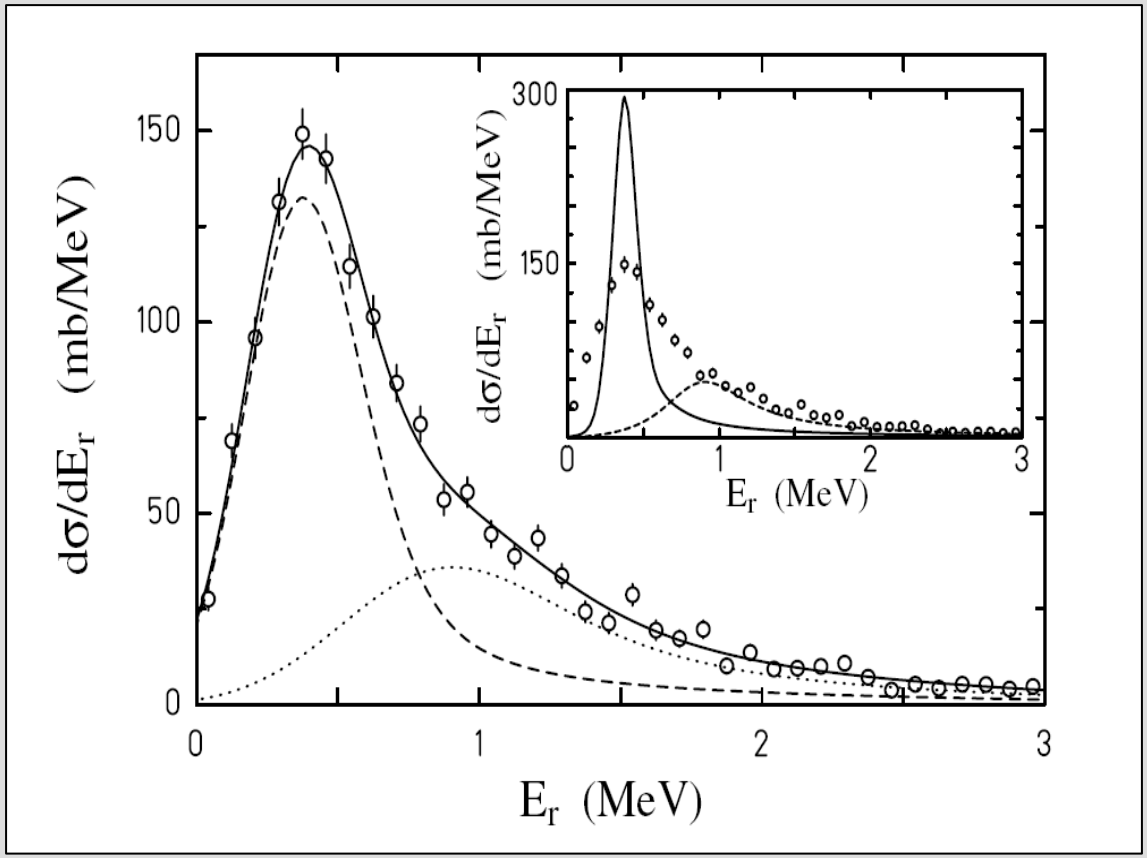
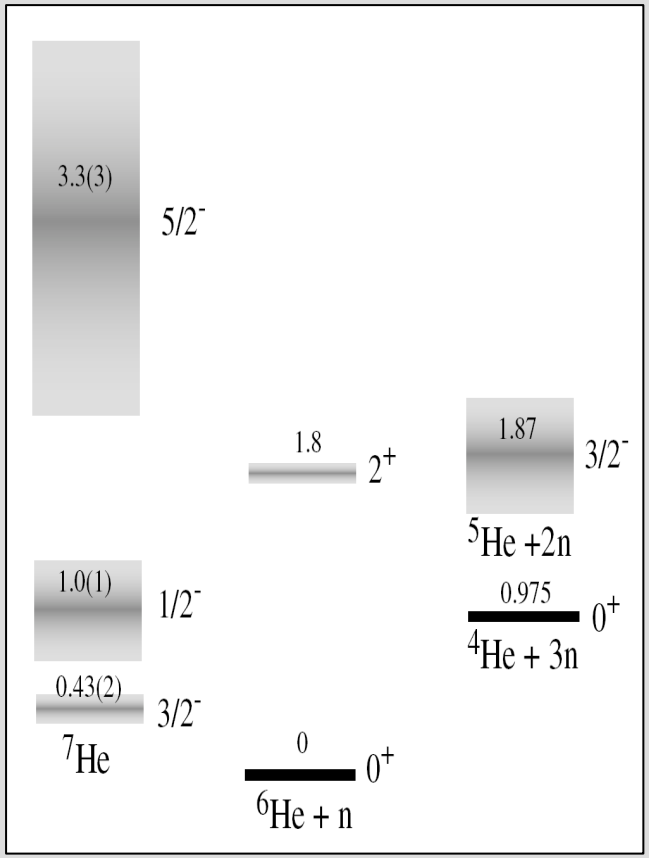
^{7}He : $C(^{8}He,^{6}He+n)$ @ 240 MeV/nucleon



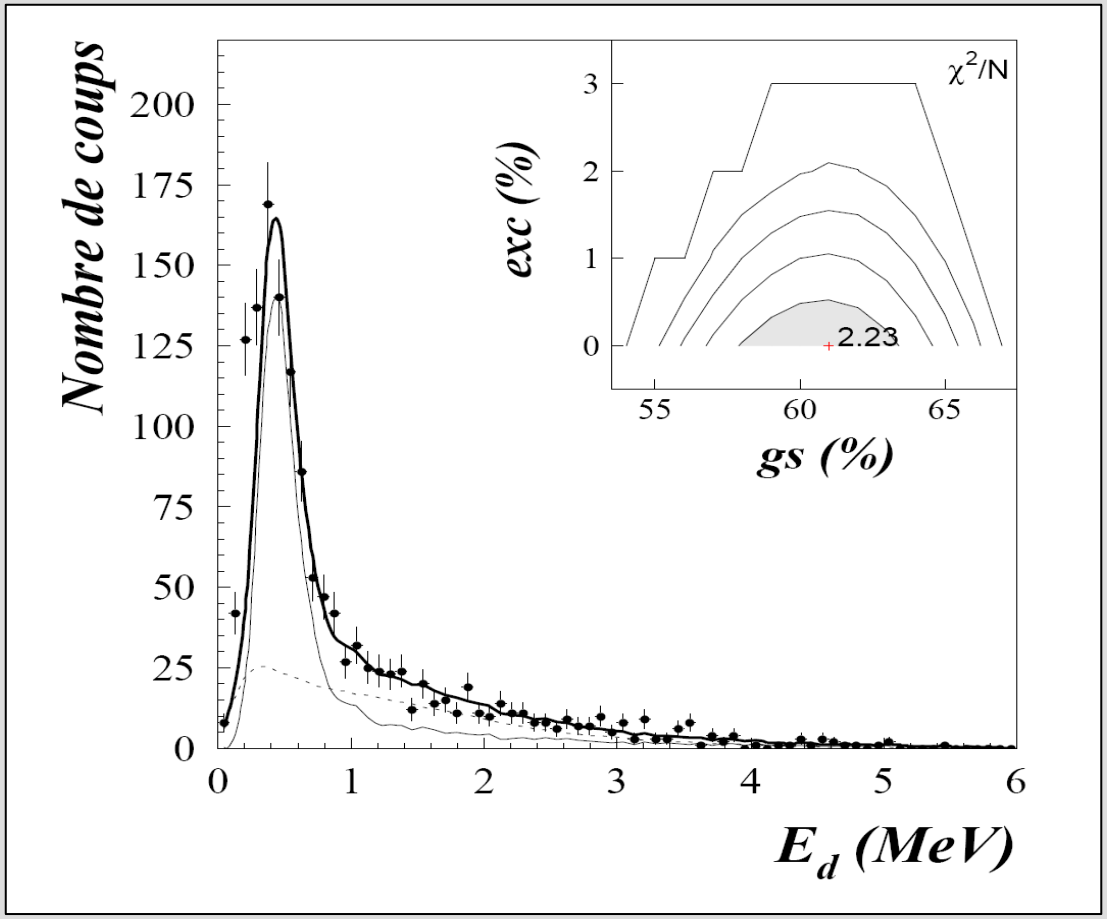


$g.s.\ (3/2^-) + E_x\ (1/2^-) = 0.56 \pm 0.10$ MeV, $\Gamma = 0.75 \pm 0.08$ MeV

small $3/2^- - 1/2^-$ splitting $\Rightarrow$ significant decrease in V_{SO} [??]

LAND Collaboration, M Meister et al. PRL (2002)

^{7}He : $C(^{8}He,^{6}He+n)$ @ 15 MeV/nucleon

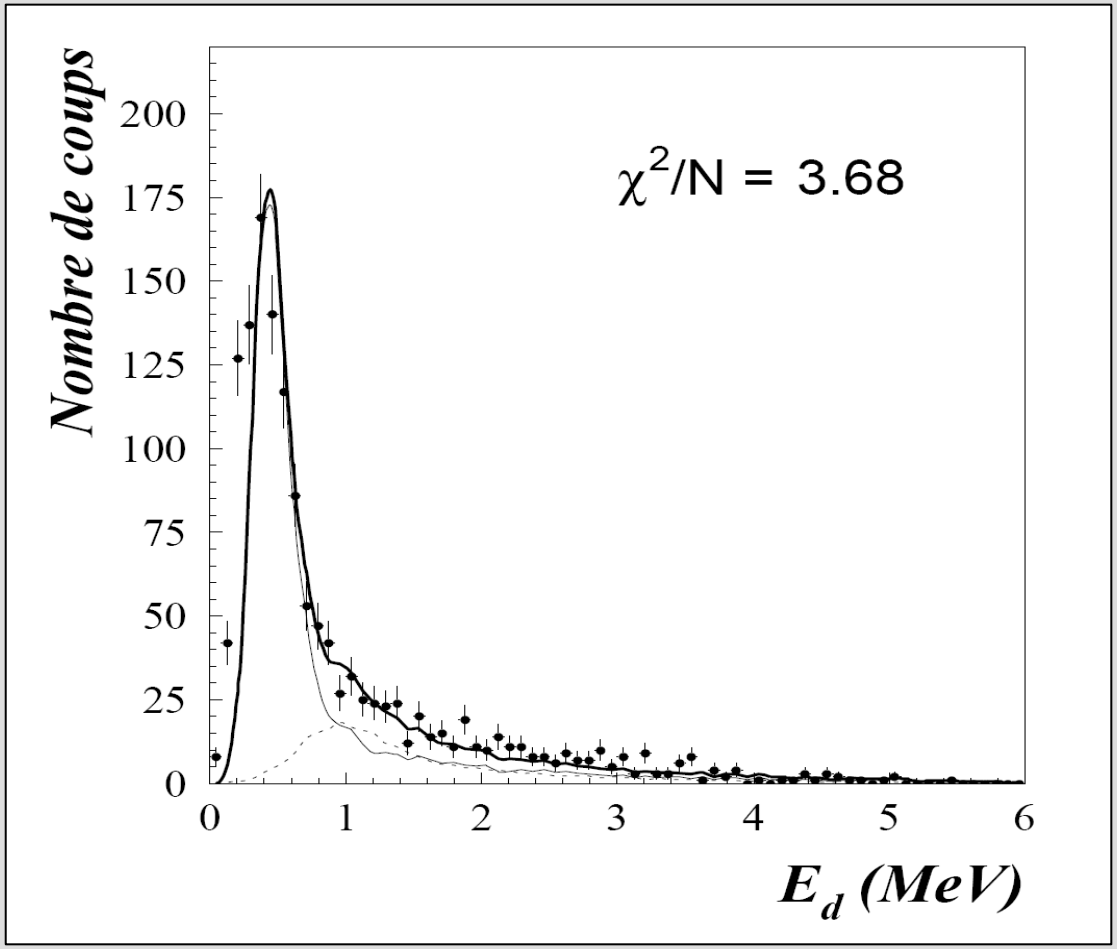


g.s. [$E_r(3/2^-)$ = 0.44 MeV, Γ = 0.16 MeV] + background

$\Rightarrow$ NO evidence for excited state

H Al Falou et al.

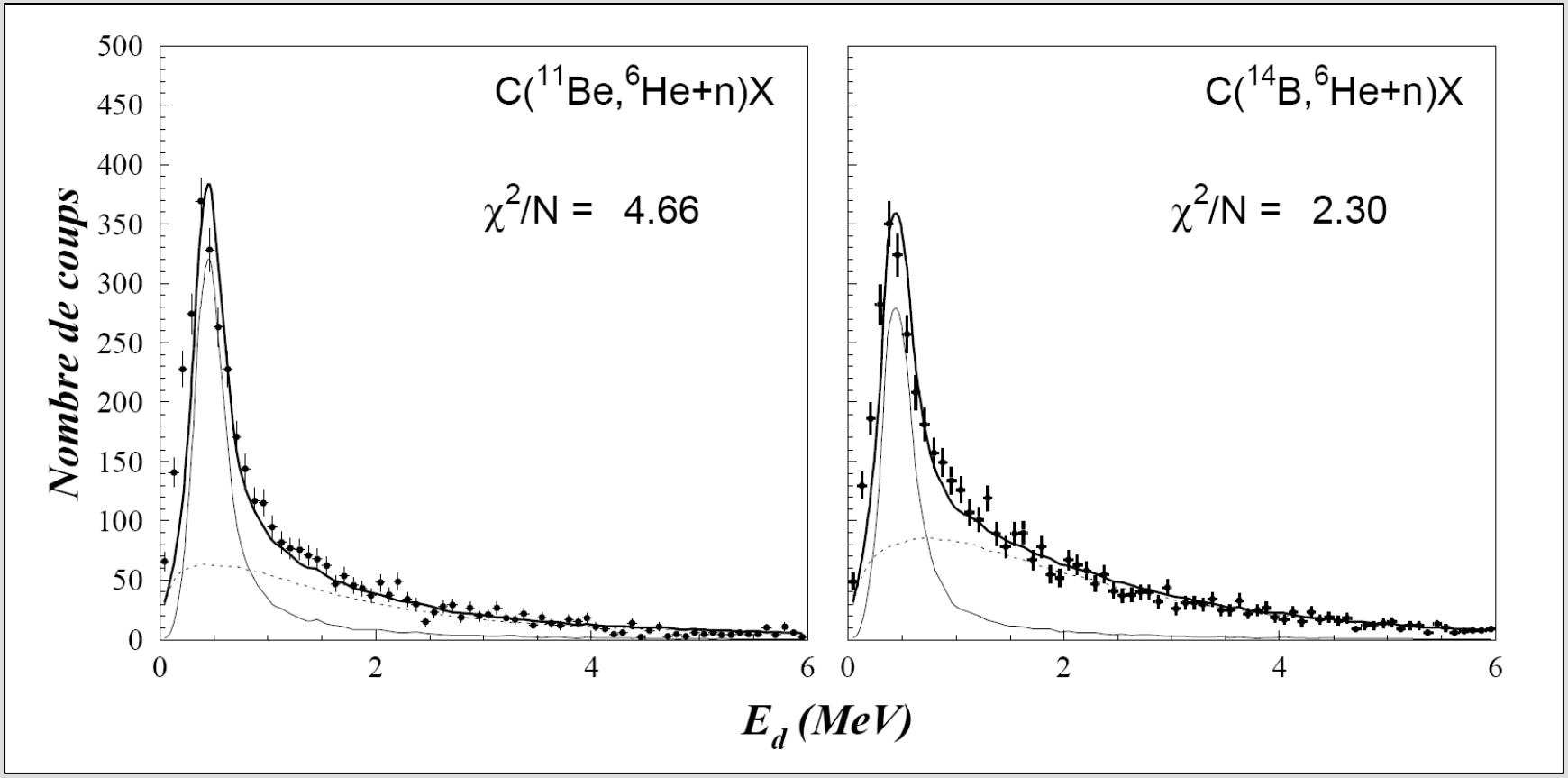
^{7}He : $C(^{8}He,^{6}He+n)$ @ 15 MeV/nucleon



g.s. + E_x ($1/2^-$) = 0.56 MeV, Γ = 0.75 MeV + NO background

H Al Falou et al.

C(^{11}Be,^{6}He+n) & (^{14}B,^{6}He+n) @ 35 MeV/nucleon

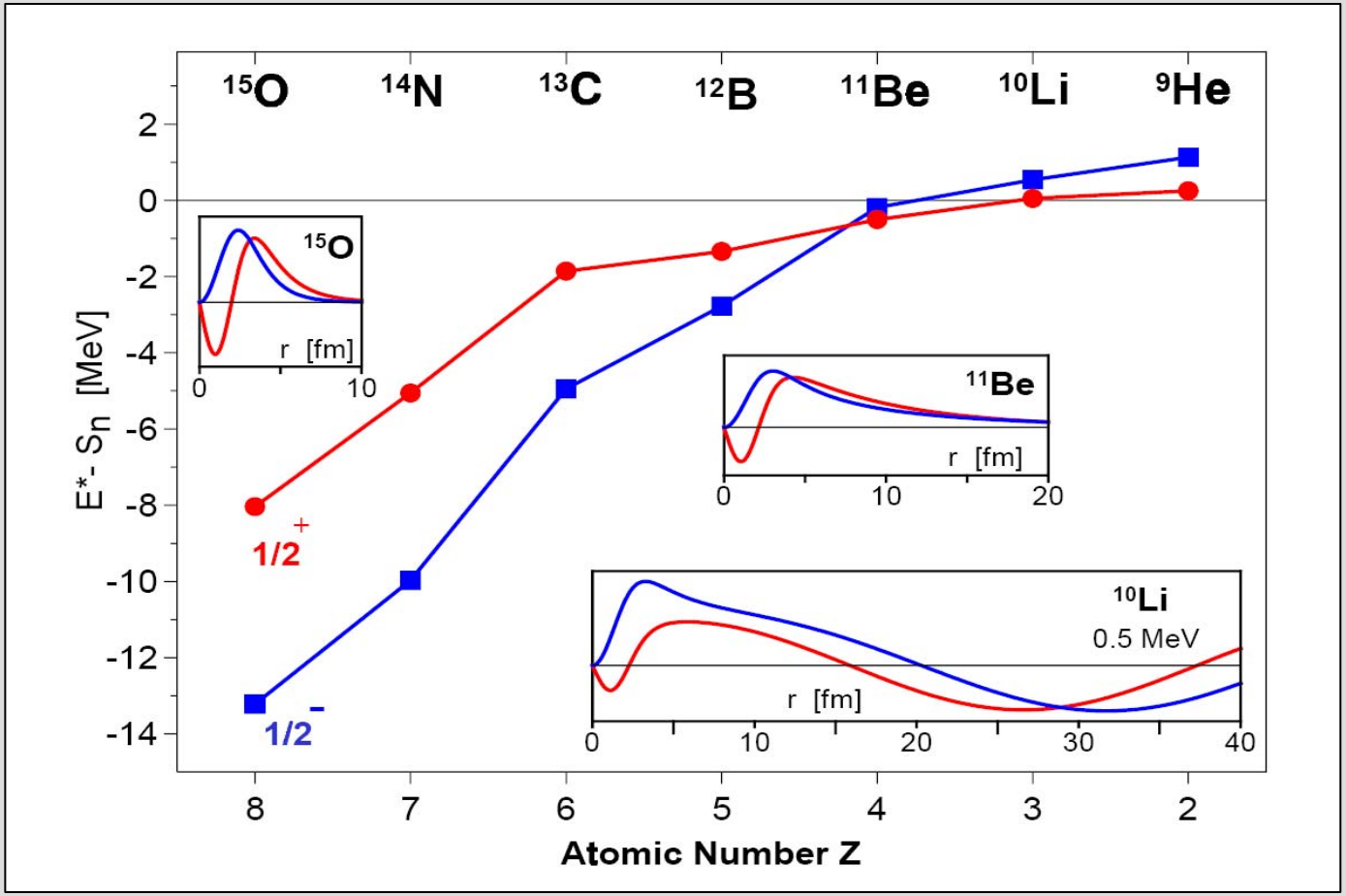


g.s. [E_r (3/2$^-$) = 0.44 MeV, Γ = 0.16 MeV] + background

$\Rightarrow$ NO evidence for excited state

H Al Falou et al.

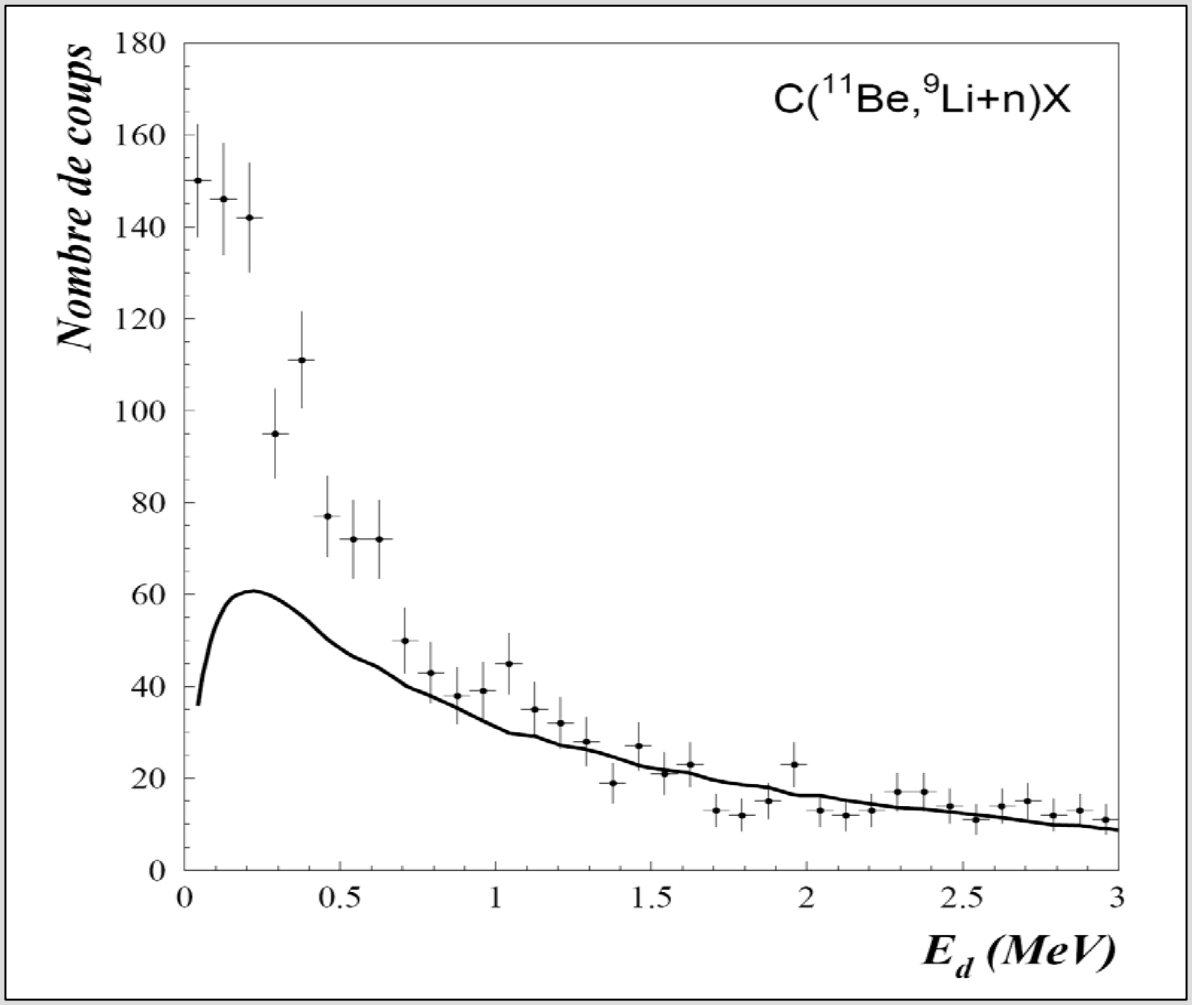
N=7 $1/2^-$ – $1/2^+$ Level Inversion



… ^{10}Li & ^{9}He ??

PG Hansen et al.

^{10}Li : C(^{11}Be,^{9}Li+n) @ 35 MeV/nucleon

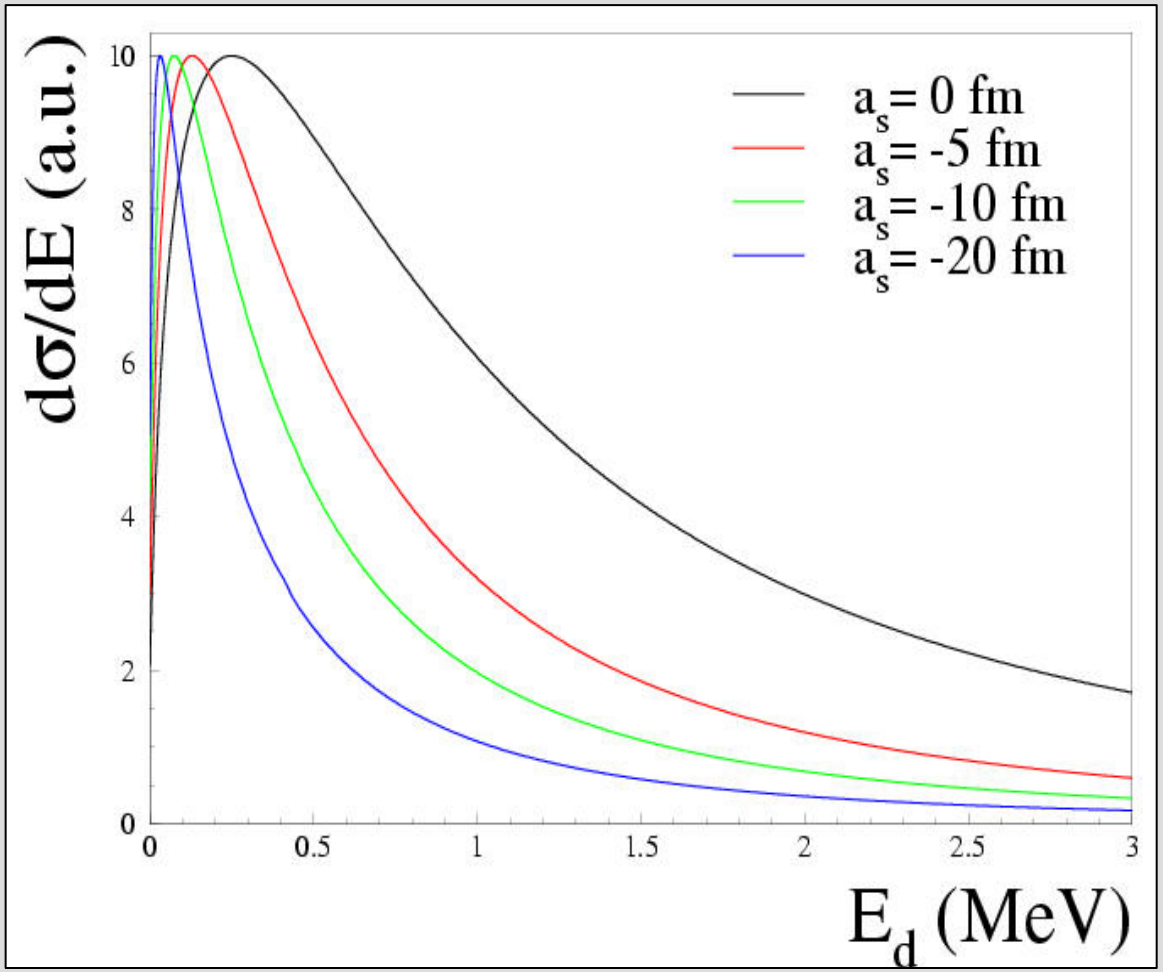


background/non-resonant continuum*

* normalised for comparison at high Ed

H Al Falou et al.

Scattering/Virtual s-Wave States



a_s = 0 fm no FSI ; a_s << 0 fm stronger FSI

JL Lecouey, thèse

Initial State Dependence of Unbound States

- *sudden approximation*

$\Rightarrow$ *neutron configuration of projectile preserved* ($\Delta l_n = 0$)

$$a(k)=\int_0^\infty r^2 dr\, \varphi_k^*(r)\psi_0(r)$$

Final unbound state

$$|\varphi\rangle = |fragment\rangle \otimes \nu|\ell j\rangle$$

Initial bound state

$$|\psi_0\rangle = |A-1\rangle \otimes \nu|\ell j\rangle$$

Decay Energy

$$\frac{d\sigma}{dE_d} \alpha \sqrt{E_d}\,|a(k)|^2$$

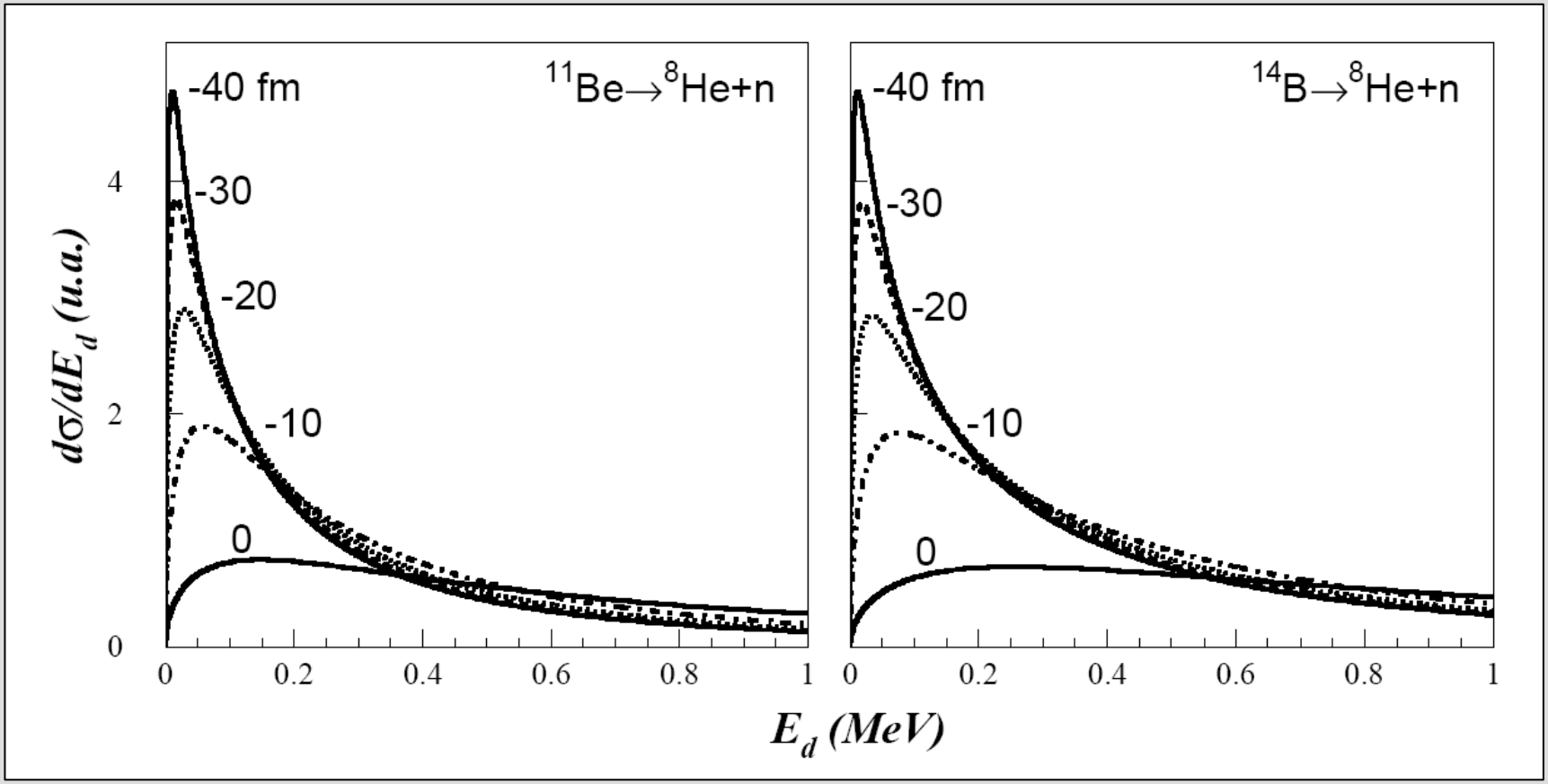
Simulation

Comparison to data

(χ^2)

G Bertsch et al., PRC (1998), L Chen et al. PLB (2001)

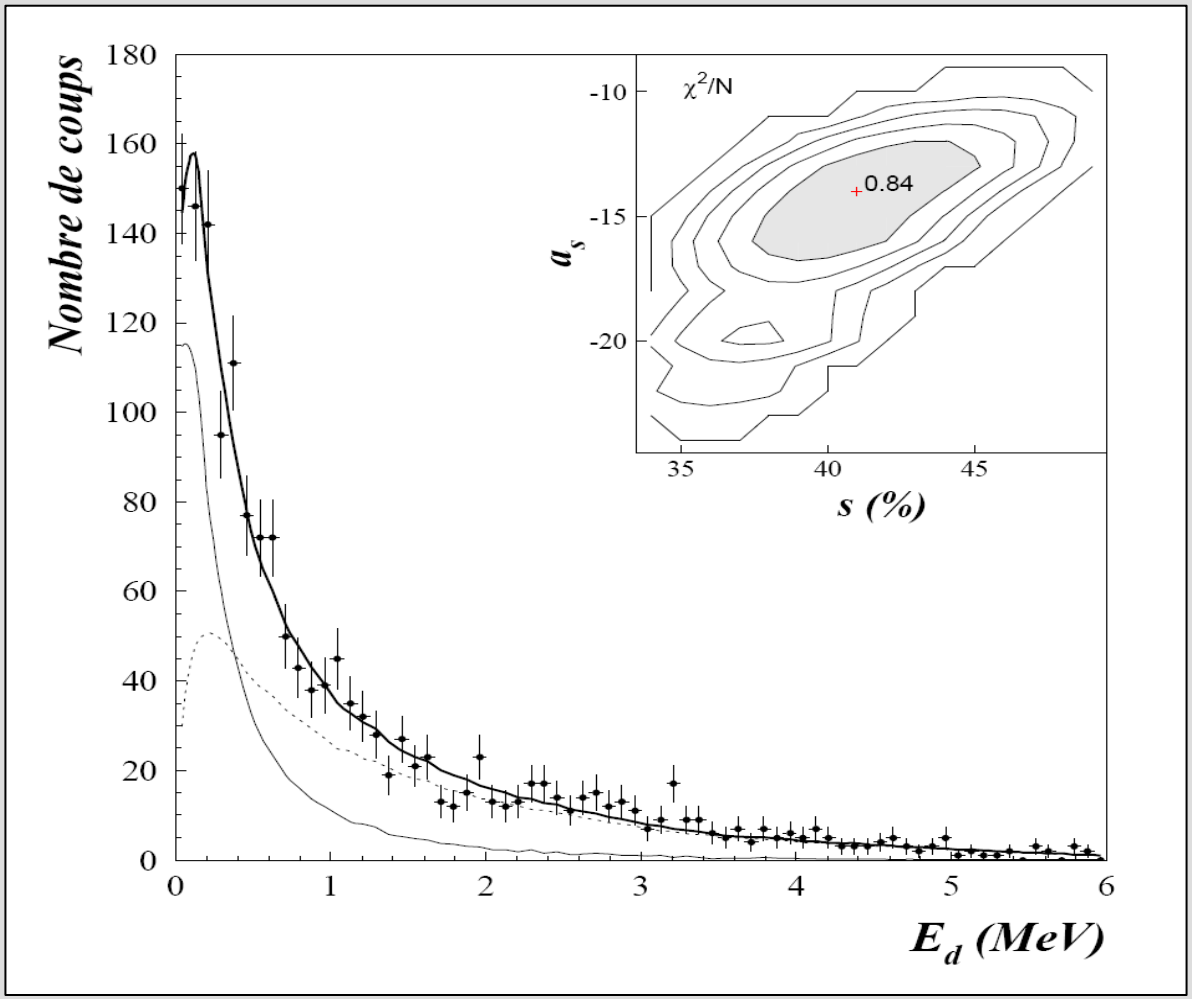
Initial State Dependence of Virtual s-States



a_s = 0 fm no FSI ; a_s << 0 fm stronger FSI

JL Lecouey, thèse

^{10}Li : C(^{11}Be,^{9}Li+n) @ 35 MeV/nucleon

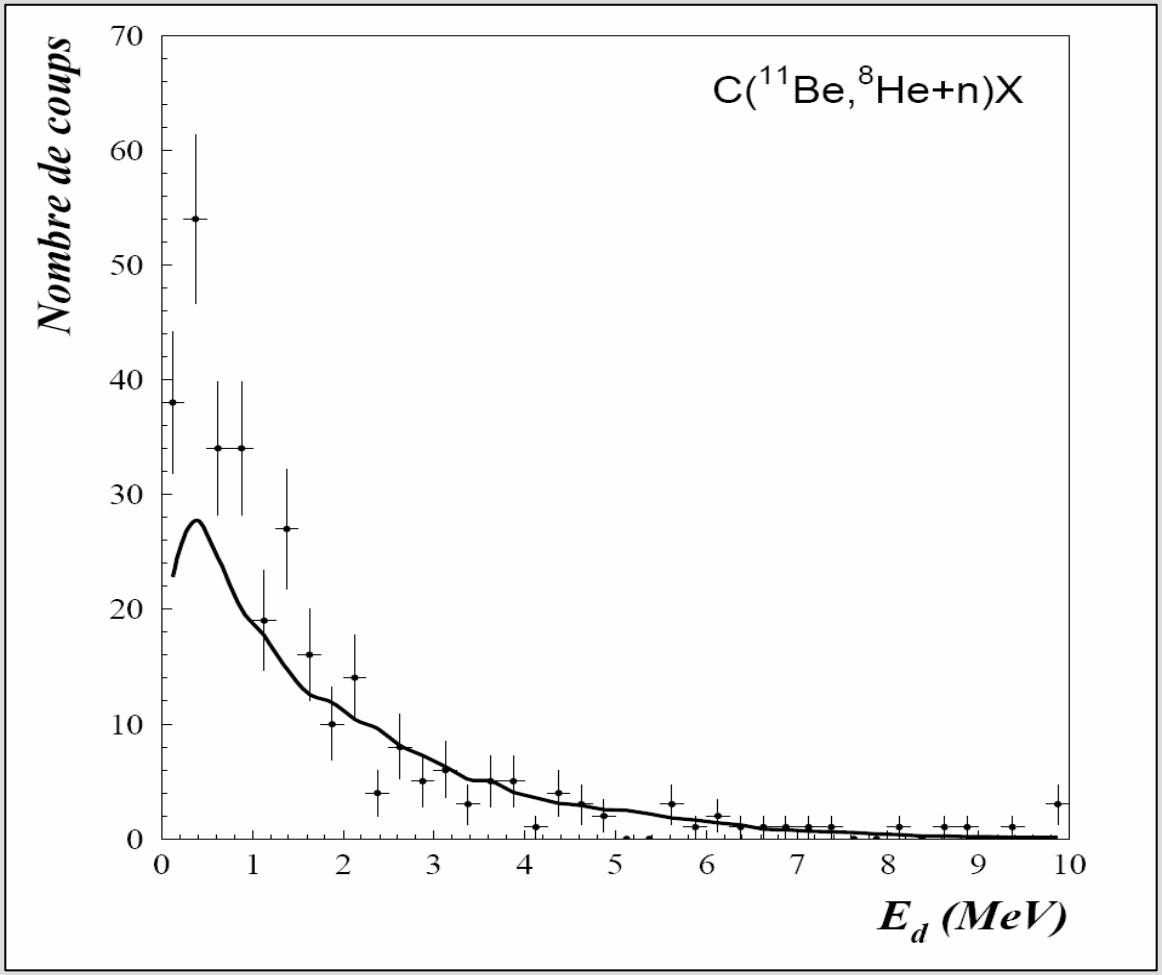


a_s = 14±2 fm + non-resonant continuum

NB: p-wave resonance E_d > ~0.6 MeV

H Al Falou et al.

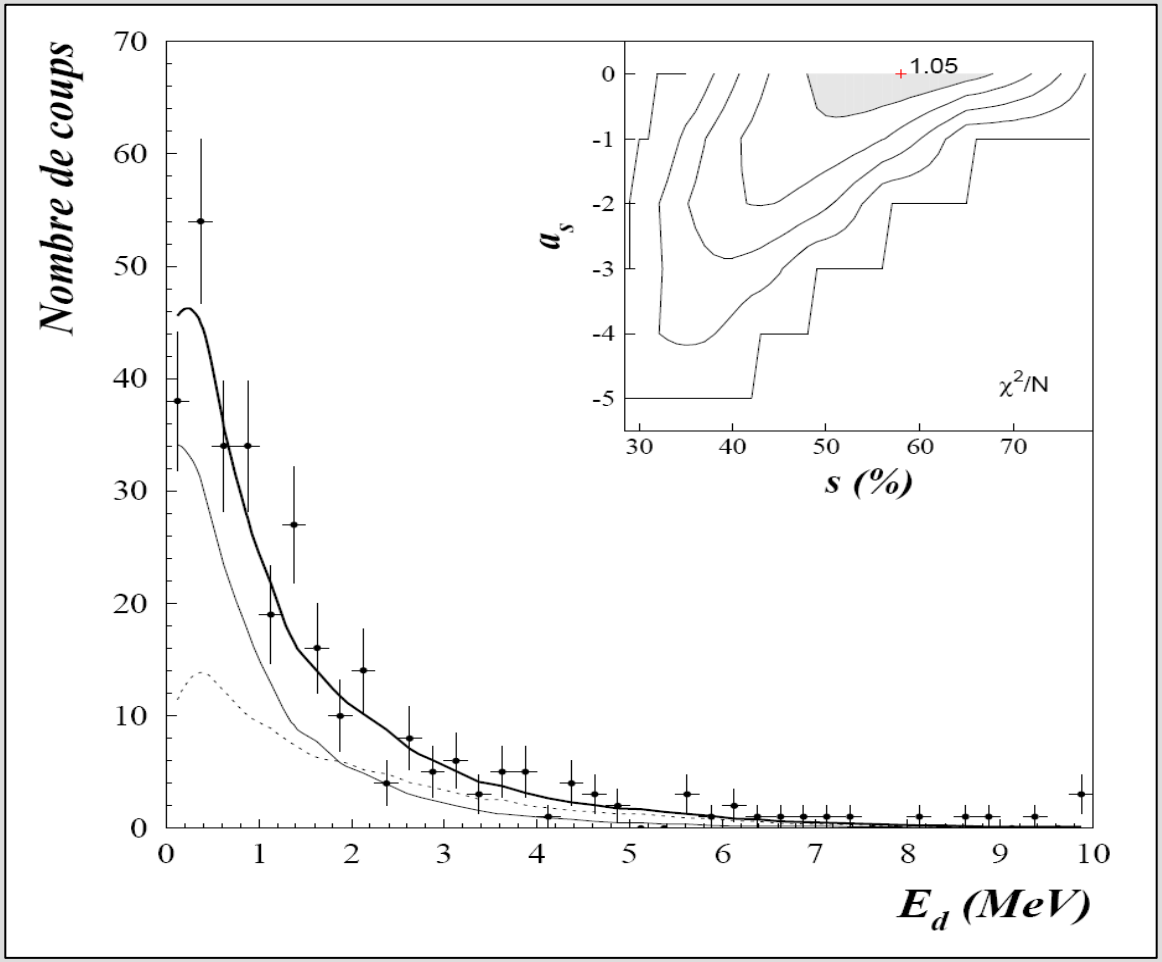
^{9}He : C(^{11}Be,^{8}He+n) @ 35 MeV/nucleon



background/non-resonant continuum

H Al Falou et al.

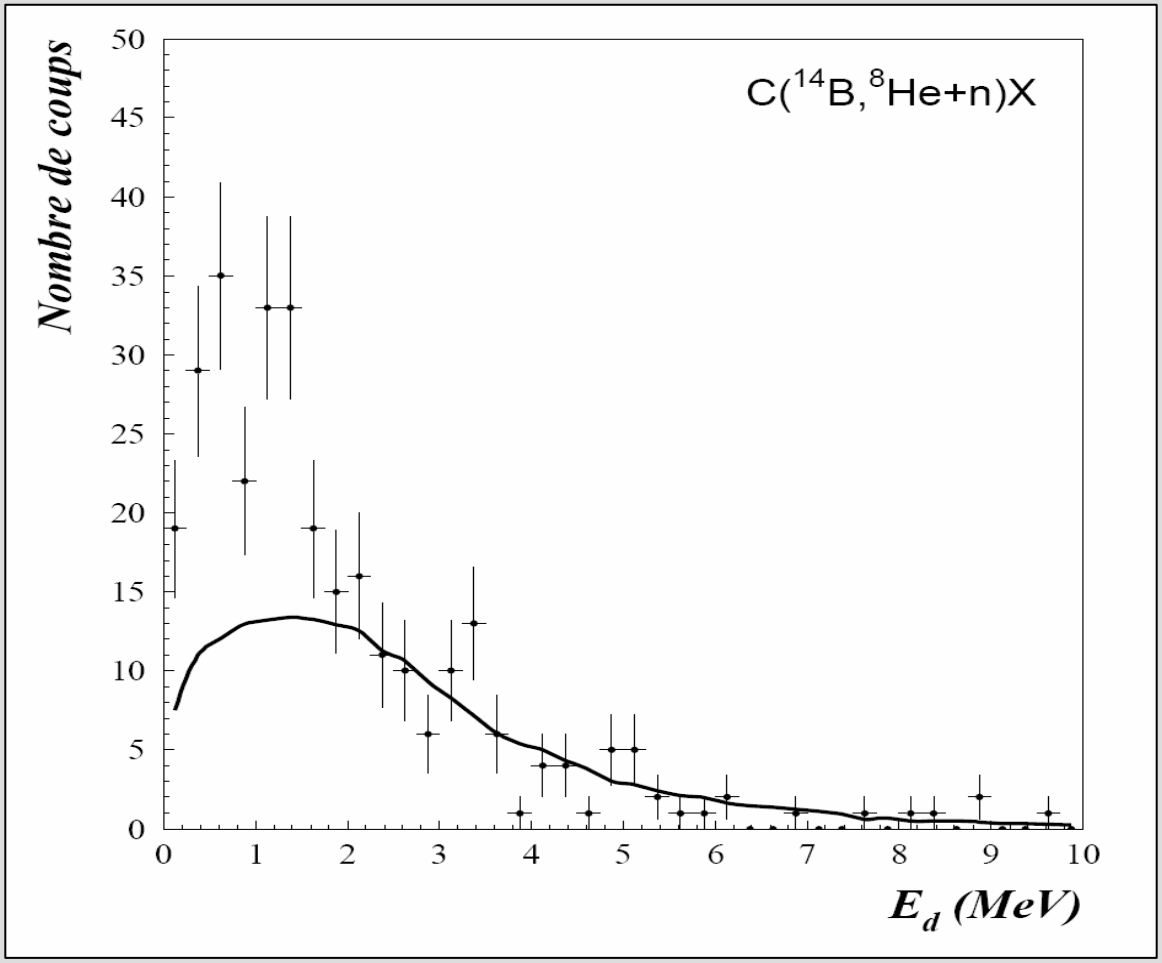
^{9}He : $C(^{11}Be,^{8}He+n)$ @ 35 MeV/nucleon



$a_s = 0 \sim -3$ fm (3σ) + non-resonant continuum

H Al Falou et al.

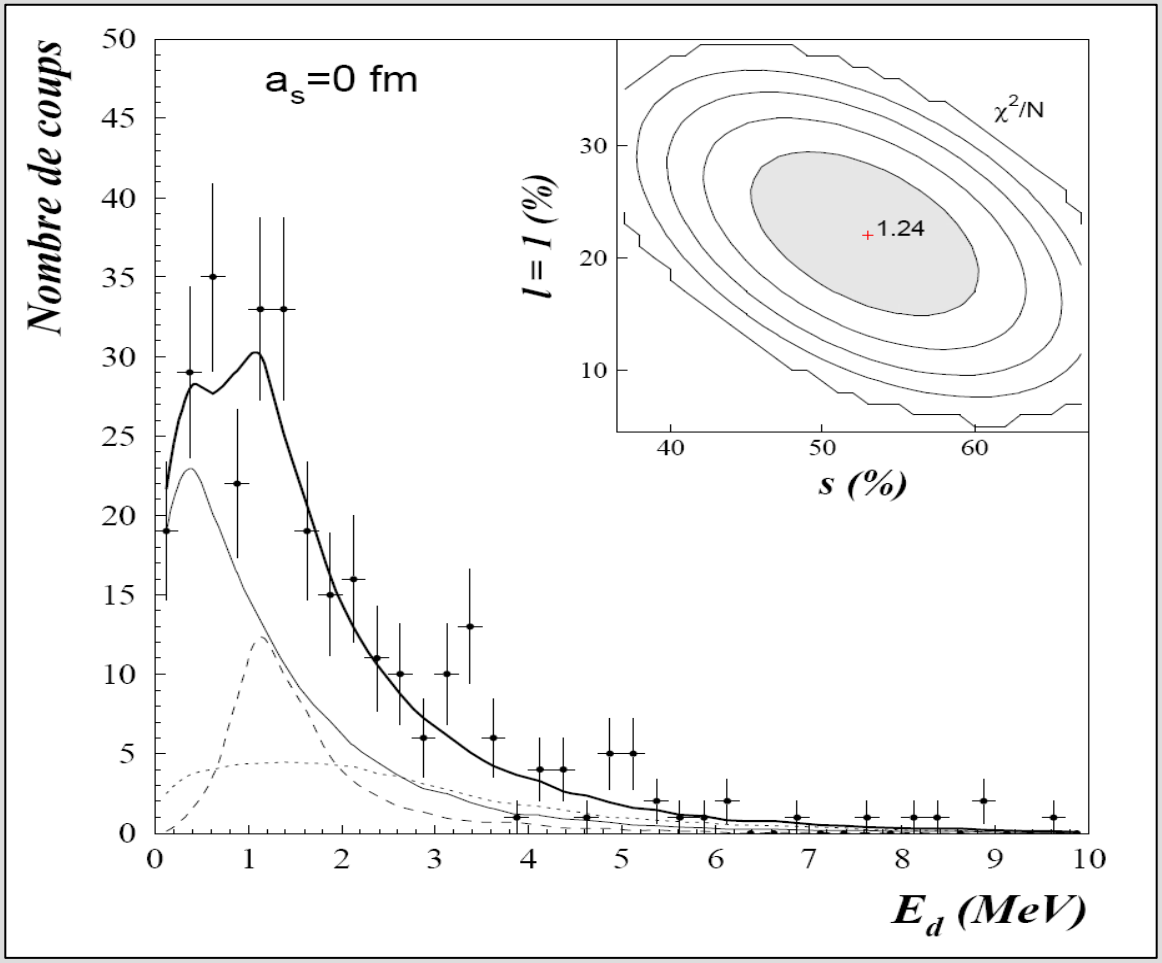
^{9}He : C(^{14}B,^{8}He+n) @ 35 MeV/nucleon



background/non-resonant continuum

H Al Falou et al.

^{9}He : $C(^{14}B,^{8}He+n)$ @ 35 MeV/nucleon



$a_s \approx 0$ fm + E_r = 1.2 MeV (l=1) + non-resonant continuum

H Al Falou et al.

Conclusions & Perspectives

- *low-lying spectroscopy of light systems beyond the neutron dripline using breakup of RNB …*

→ ^{7}He : no evidence for low-lying spin-orbit partner of g.s.
[^{6}He core excitations]

→ ^{10}Li : low-lying s-wave strength (a_s = -14±2 fm)
⇒ N= 7 inversion confirmed
[but … $\pi p_{3/2} \otimes \nu s_{1/2}$]

→ ^{9}He : low-lying s-wave strength ($a_s \approx 0$ fm) + $E_x \approx 1.2$ MeV (l>0)
⇒ N= 7 inversion … ??
[FSI << ^{9}Li+n ??]

- *more realistic structure + reaction modelling needed …*
… including non-resonant continuum + other backgrounds