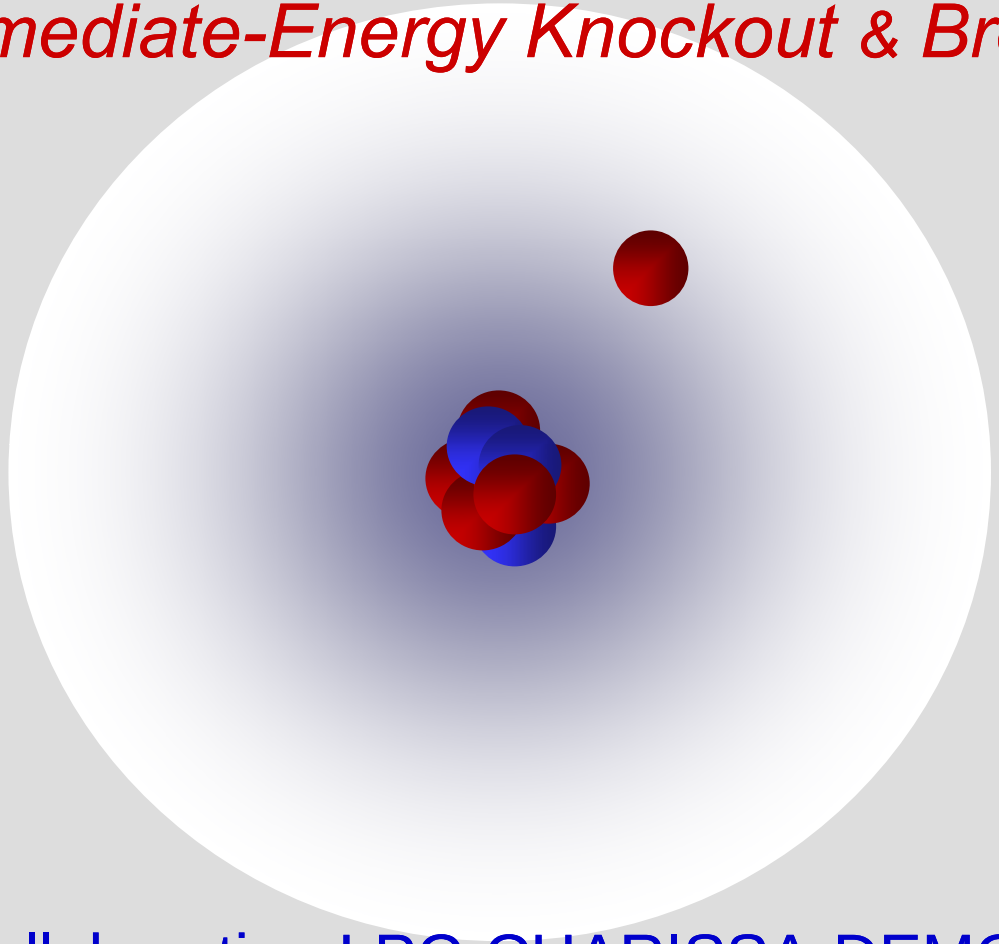
Structure Beyond the Neutron Dripline Using Intermediate-Energy Knockout & Breakup

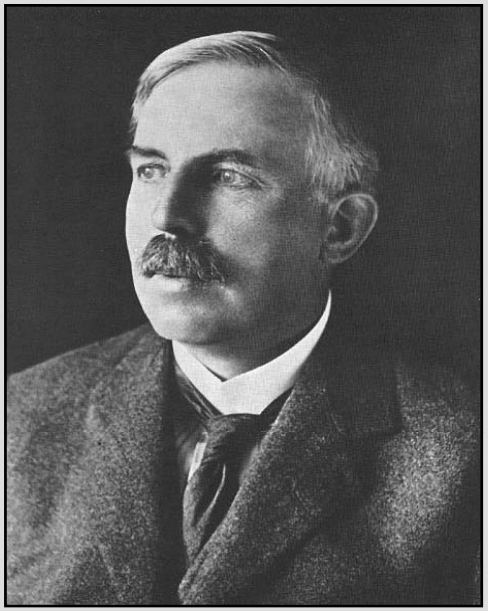


Collaboration LPC-CHARISSA-DEMON

H Al Falou, JL Lecouey, F Carstoiu, FM Marqués, NAO …

Structure & Reactions : the beginnings were Ernest …

"The Nobel Prize in Chemistry for this year (1908) has been awarded by the Royal Academy of Sciences to Ernest Rutherford, Professor of Physics at the Victoria University, Manchester (England), for his researches concerning the disintegration of elements and the chemistry of radioactive substances ... "



1871 (Nelson, NZ) – 1937 (UK)

"It was quite the most incredible event that ever happened to me in my life. It was almost as incredible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you ... "

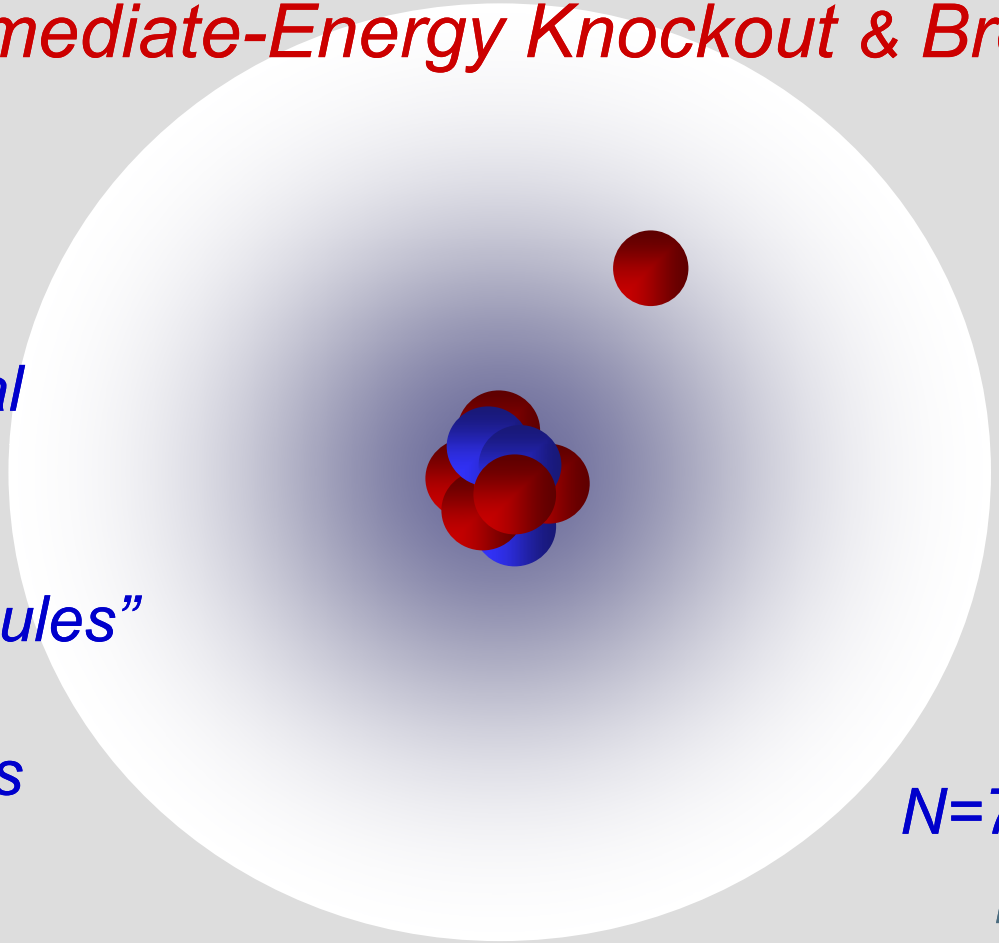
Structure Beyond the Neutron Dripline Using Intermediate-Energy Knockout & Breakup

Introduction

Experimental Approach

"Selection Rules"

Backgrounds



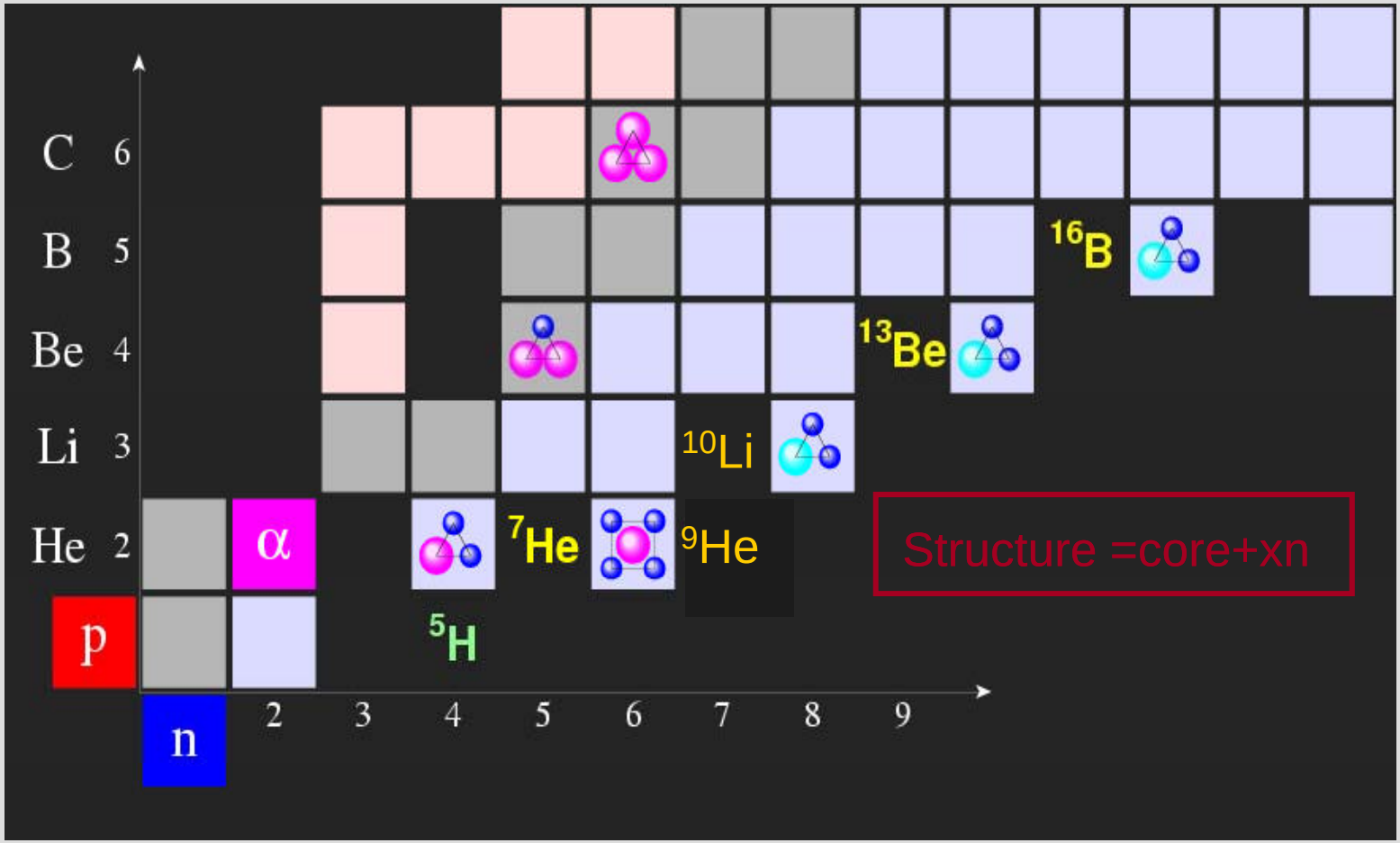
N=7 : ^{10}Li & ^{9}He

[N=9 : ^{13}Be]

Conclusions & Perspectives

See also Kondo-san ^{13}Be, Joe Finck ^{24}O(2^+)

The Light Neutron-Rich Nuclei …



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

***LPC Programme** : H Al Falou LPCC 07-03, G Normand LPCC 04-03, JL Lecouey LPCC 02-03*

Strategy …

"Fast" nucleon (proton) removal $\Rightarrow \Delta\ell_{(n)} = 0$ *

IFF proj. structure known $\Rightarrow$ *deduce structure of A-1 system*
(core^{-1} $\otimes$ *valence nucleon)*

$\rightarrow$ *Proton removal (*S_p*~15 MeV) from very neutron-rich beams*

$\Rightarrow$ *systems beyond dripline – observe frag.+ n FSI*

* *M Zinser et al., PRL* ***75*** *(1995) 1719*
L Chen et al. PLB ***505*** *(2001) 21*

Issues : Reaction ↔ Structure …

- *Weakly bound valence neutron*

  $\Rightarrow$ *possible relaxation of* $\Delta\ell_n = 0$

  $\rightarrow$ *frag. recoil induced by proton removal*

  $\rightarrow$ *scattering of valence neutron*

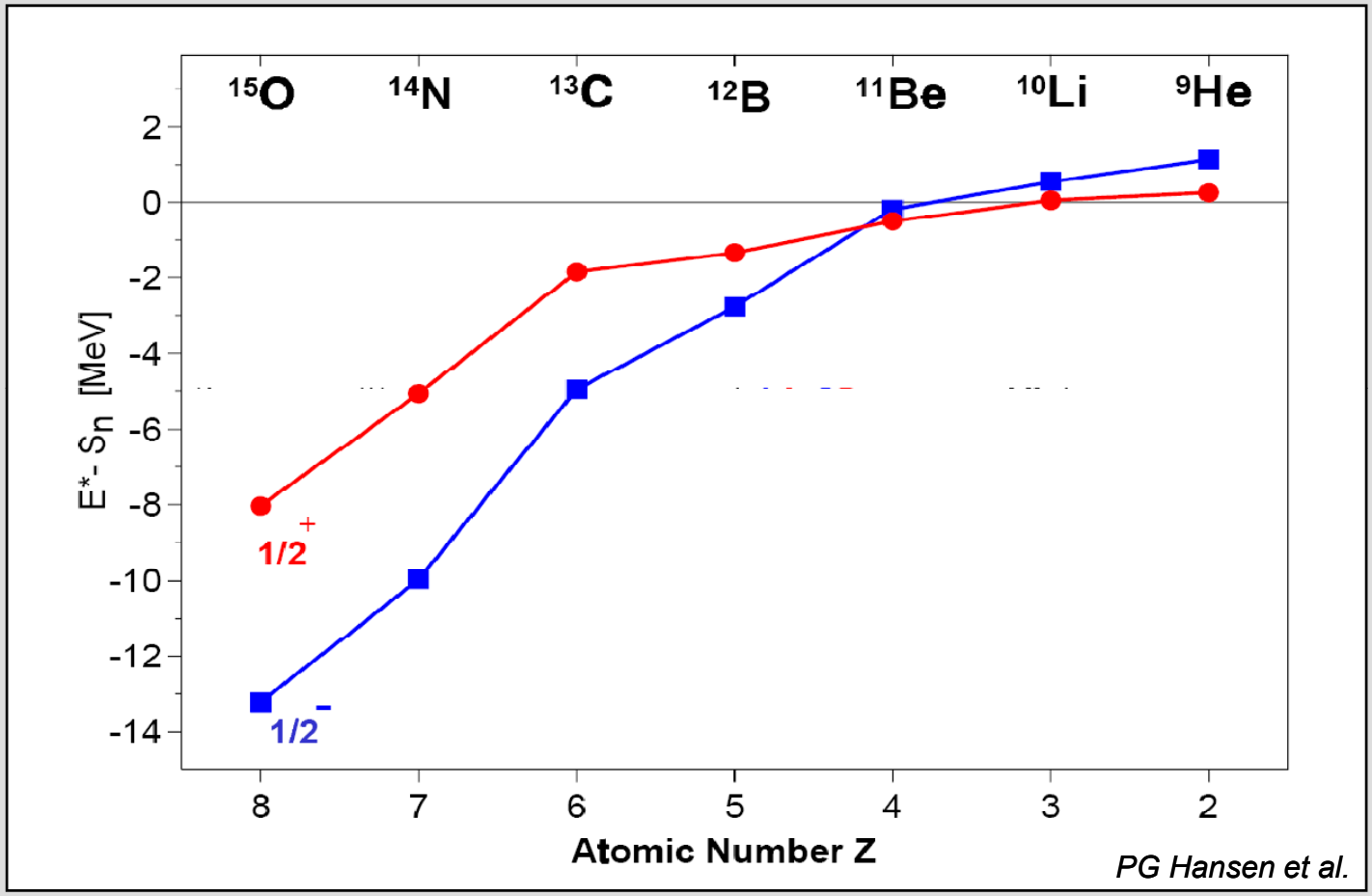
VALIDATE approach using ^{11}*Be beam* (S_n = 0.5 MeV)

- *In parallel explore evolution of N=7 g.s. parity inversion*

  $\Rightarrow$ *test of structure models & input for*

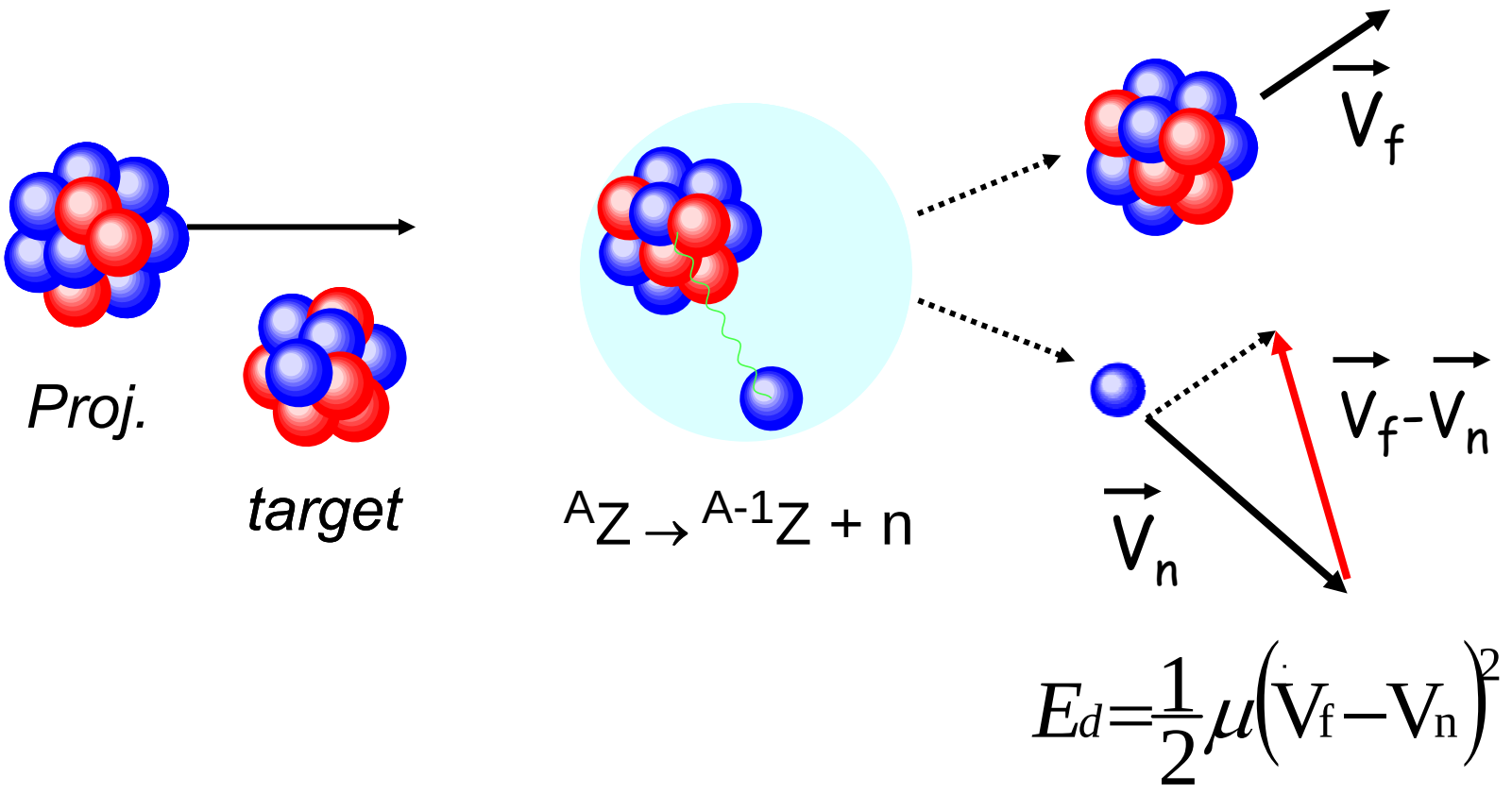
  for 3-body modelling of ^{10}*He,* ^{11}*Li*

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



… ^{10}Li & ^{9}He ??

Experimental Approach



Fast nucleon removal from projectile with known structure
+ inflight decay of unbound system

(Approx.) Selection Rules …

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

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

→ well adapted to probing low-lying s-wave strength

(ii) fragmentation (-xp,-xn) ⇒ valence neutron config. + others / population via neutron-decay of N+1 system

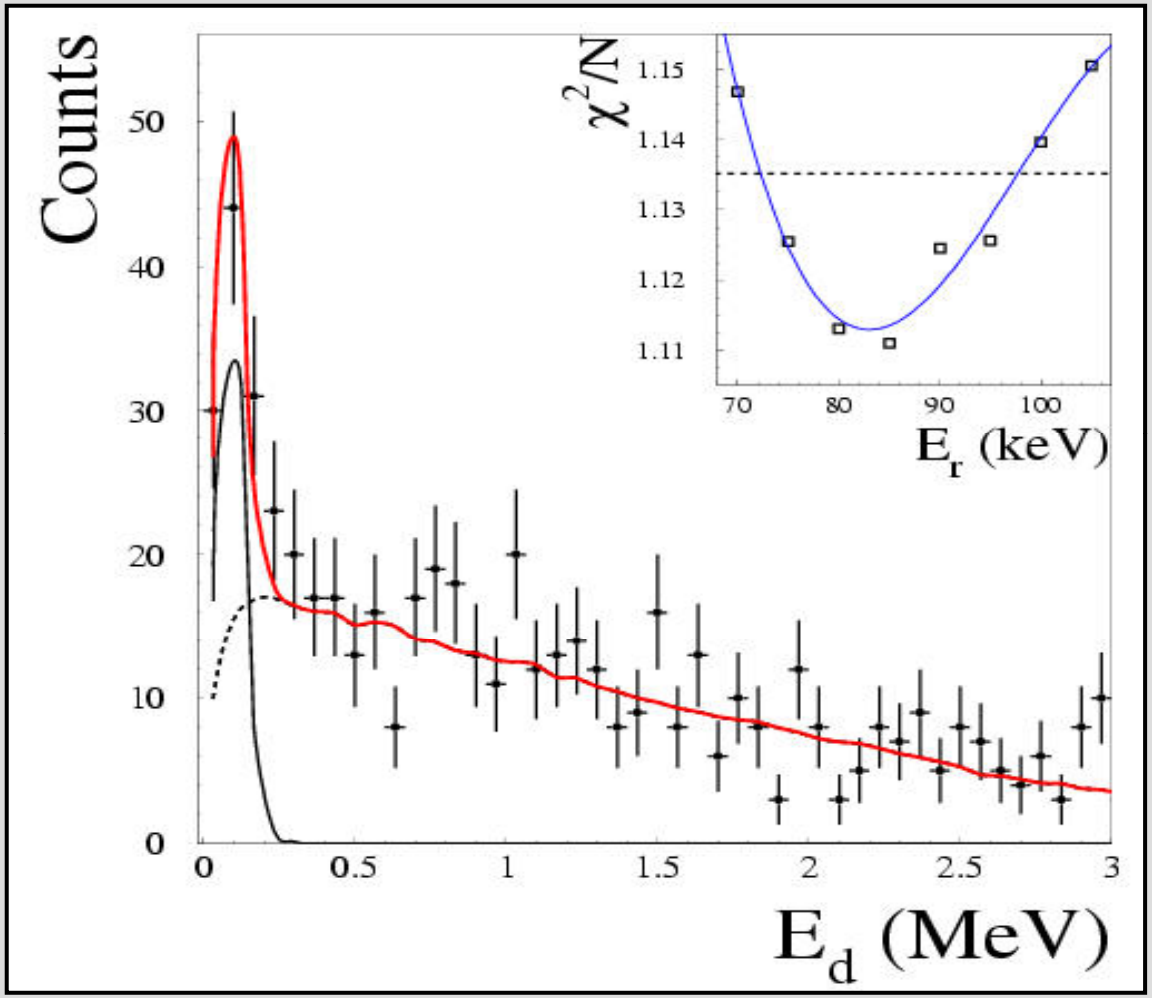
$C(^{14}B,^{10}Li)X$, $C(^{14}B,^{9}He)X \rightarrow \nu s_{1/2} + \nu p_{1/2} + \ldots$

→ CAVEAT*: decay of narrow low-lying resonances in N+1,2,… systems

Note - E_d lineshape dependent on initial state (esp. for broad final states)

* See Kondo-san $^{14}Be^* \rightarrow {}^{12}Be+n$

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



$E_r = 85 \pm 15$ keV

$\Gamma_{sp} << 100$ keV

+

uncorrelated

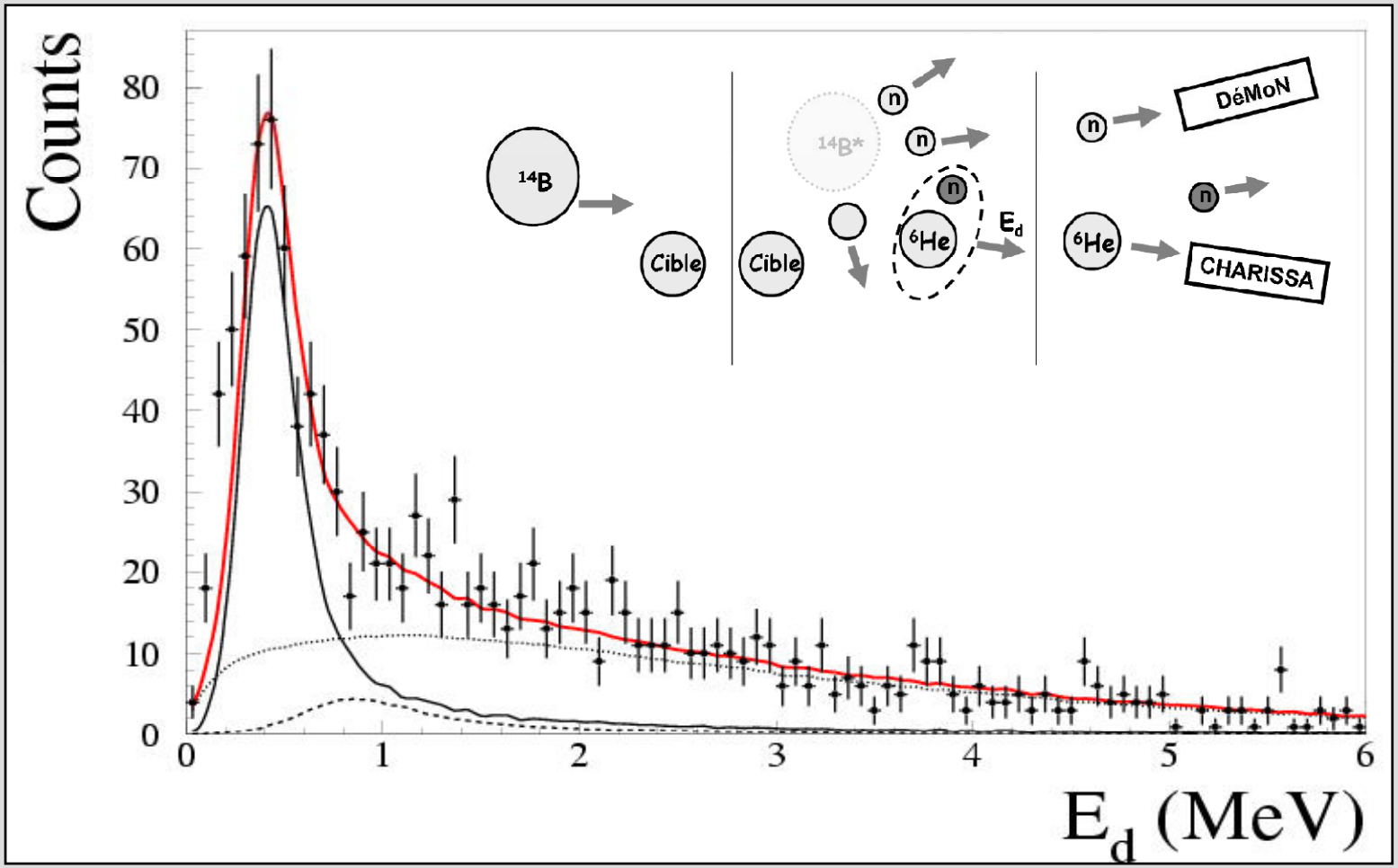
$^{15}B+n$ distribution

*"background" ≡ non-resonant continuum ↔ event-mixed distribution **

* *ie., uncorrelated fragment-neutron pairs*

JL Lecouey et al, nucl-ex/0802.4225
JL Lecouey, Few-Body Systems 34 (2004) 21

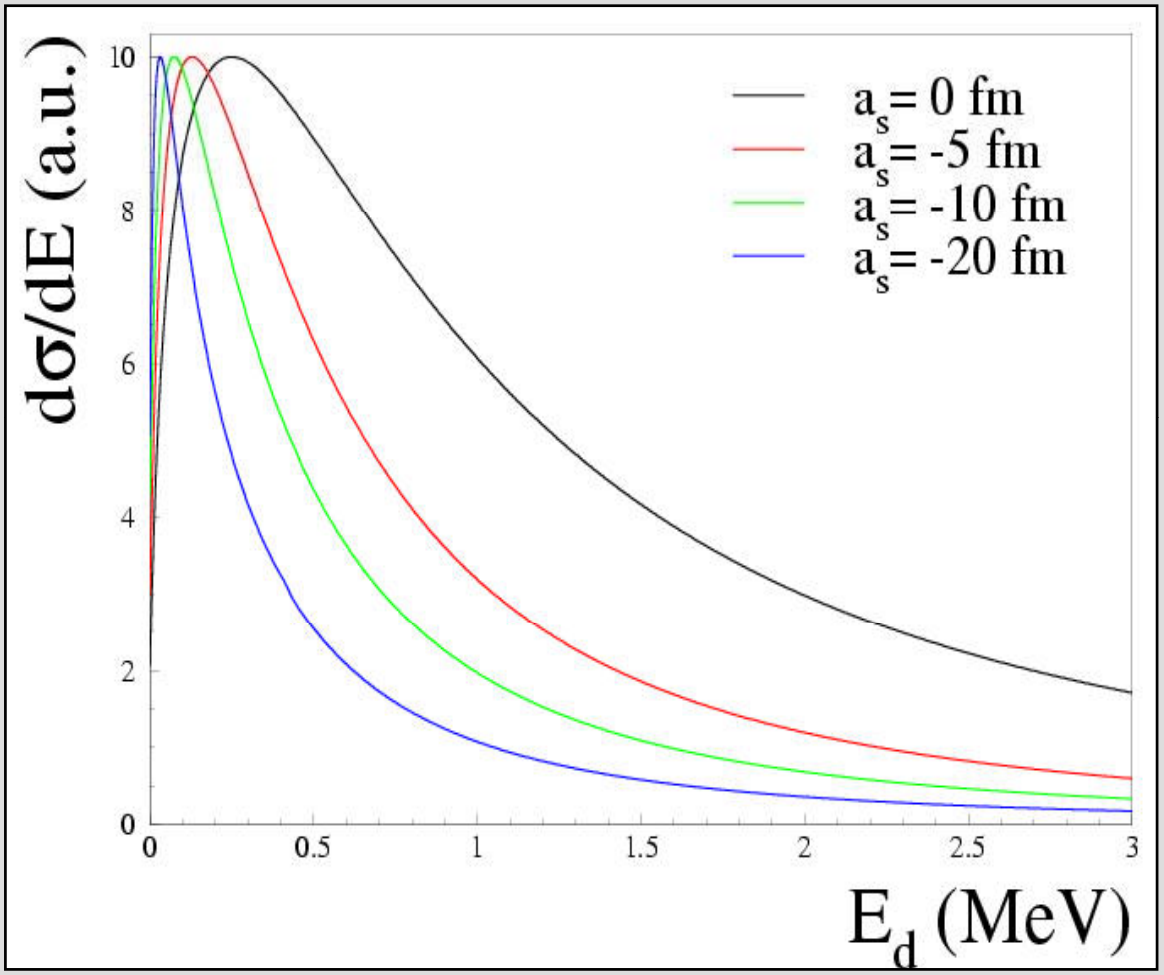
BACKGROUND : $C(^{14}B,^{6}He+n)X$ – fragmentation



"background" ≡ sequential neutron decay/evaporation from PLF + continuum

JL Lecouey, LPCC T 02-03.

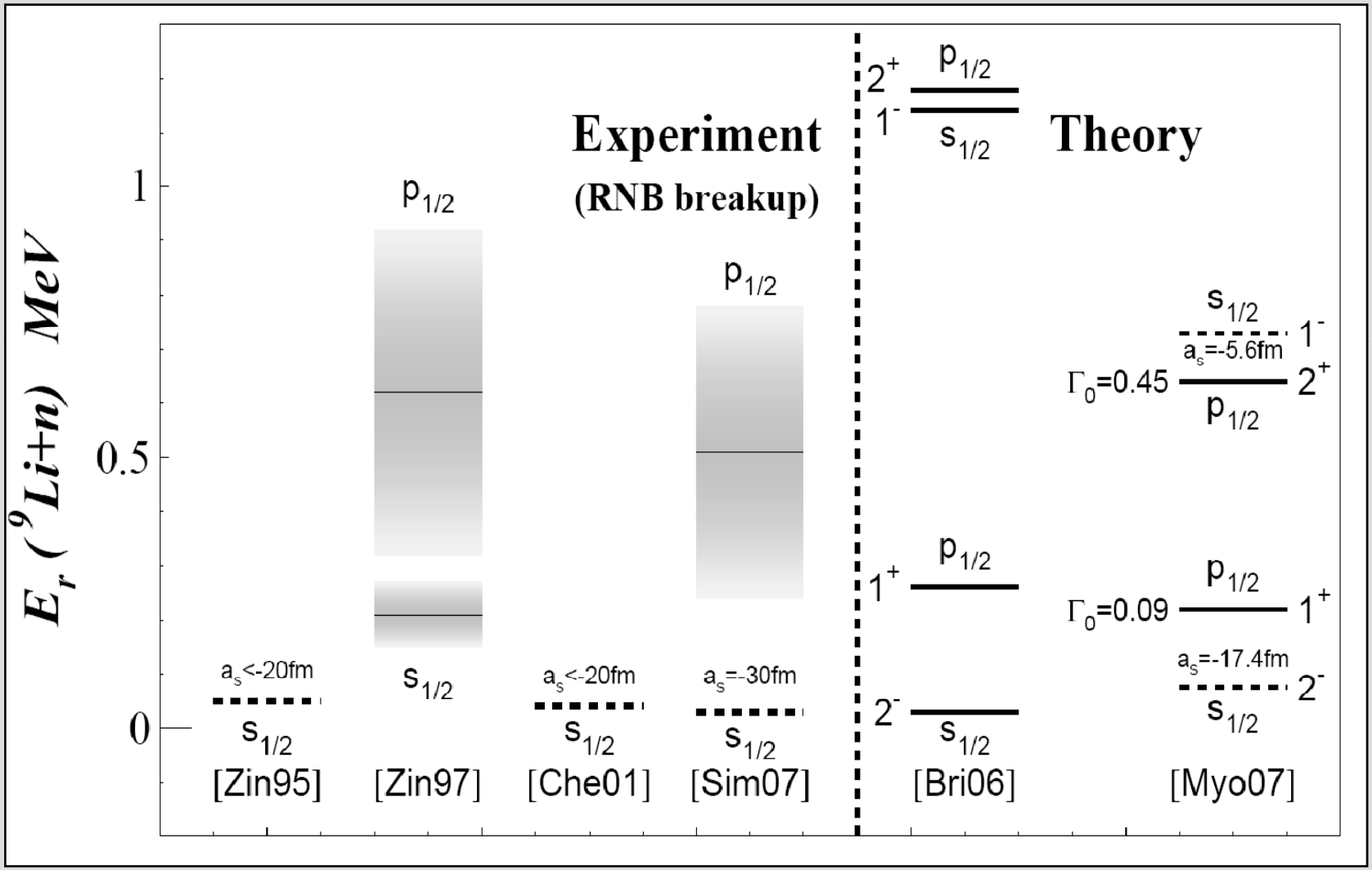
Scattering/Virtual s-wave States



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

Note - *final lineshape E_d(frag+n) depends on projectile*

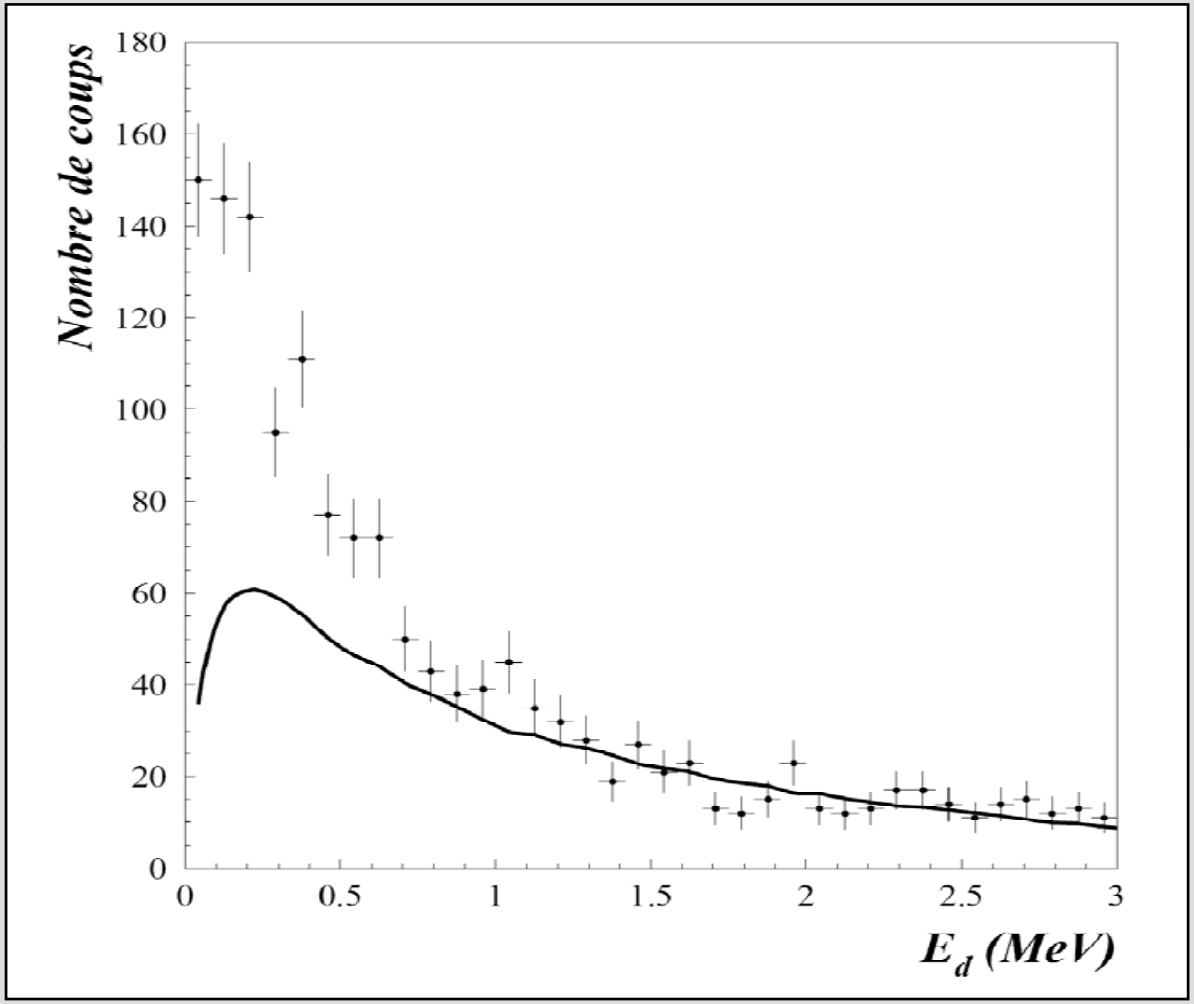
^{10}Li : Low-Lying Level Scheme *



* "Partial" – also d(^{9}Li,p) ; new LAND-GSI etc

..... s-virtual $E_r \sim \hbar^2 / 2a_s$

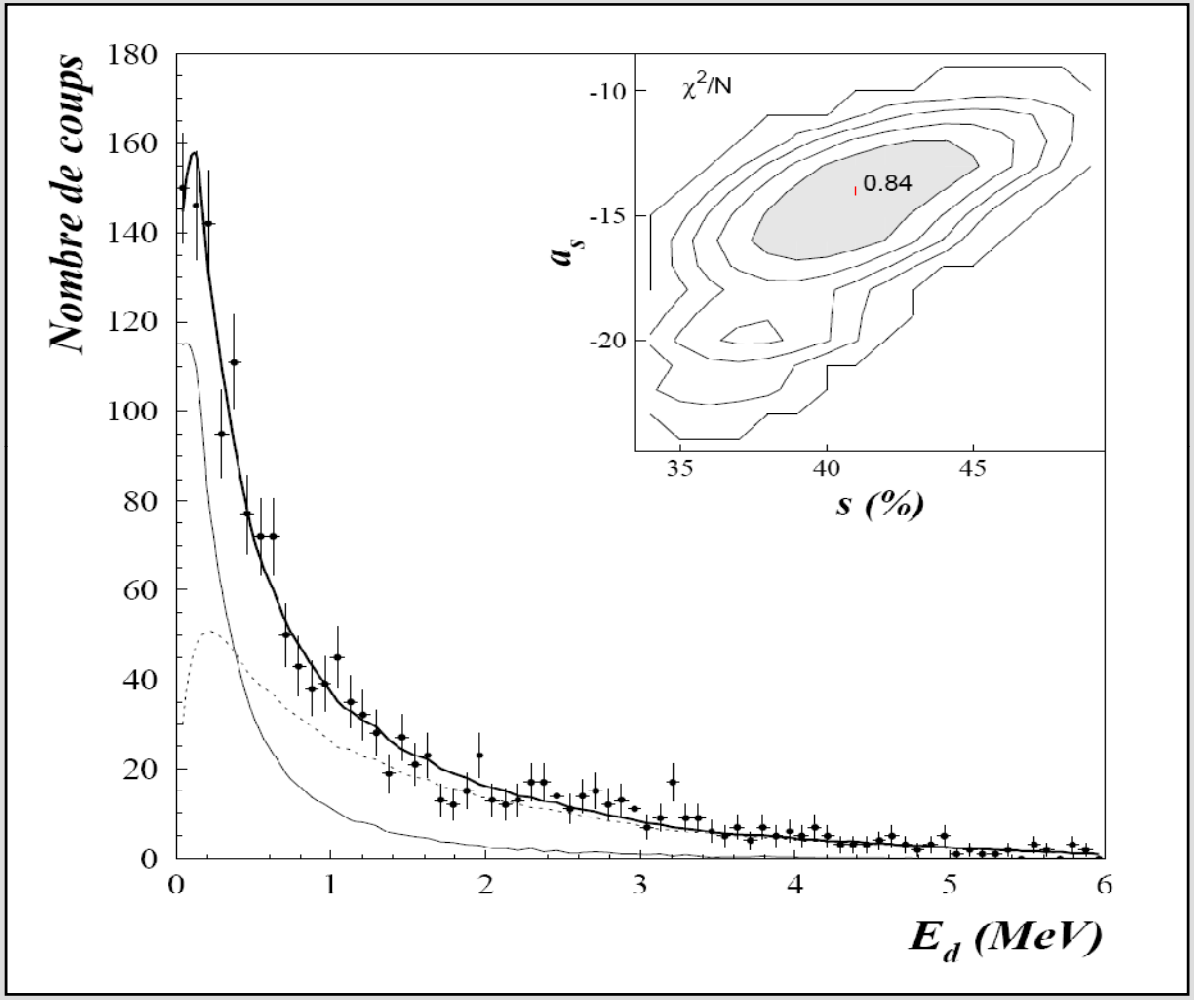
^{10}Li : $C(^{11}Be,^{9}Li+n)$ @ 35 MeV/nucleon [-1p]



uncorrelated / event-mixed distribution *

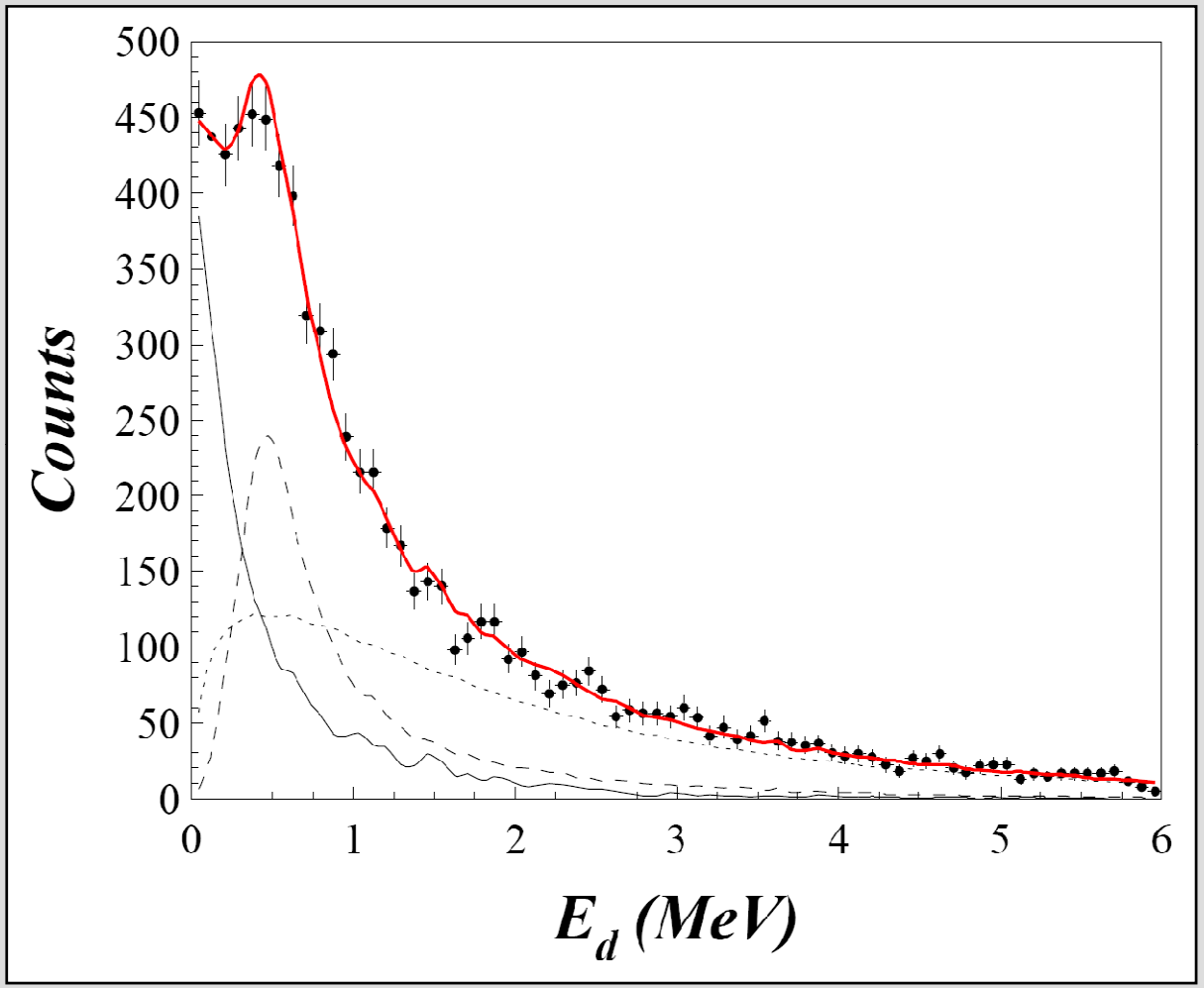
* *normalised for comparison at high E_d*

^{10}Li : $C(^{11}Be,^{9}Li+n)$ @ 35 MeV/nucleon [-1p]



s-wave [a_s = -14±2 fm] + non-resonant continuum

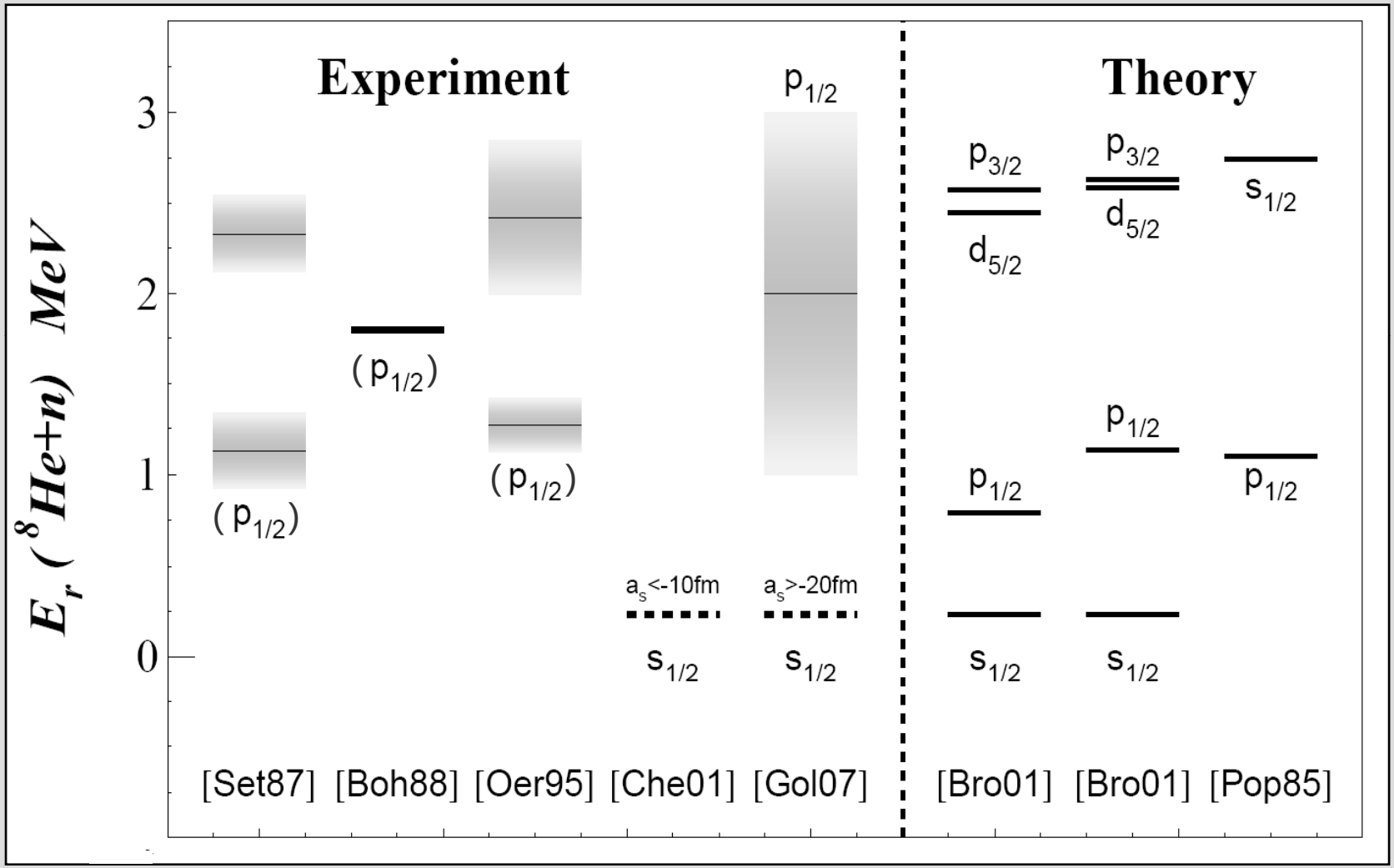
^{10}Li : $C(^{14}B,^{9}Li+n)$ @ 35 MeV/nucleon [-2p,-2n]



s-wave [a_s << -14 fm] + p-wave [E_r = 0.51, Γ_0 = 0.50 MeV] + background

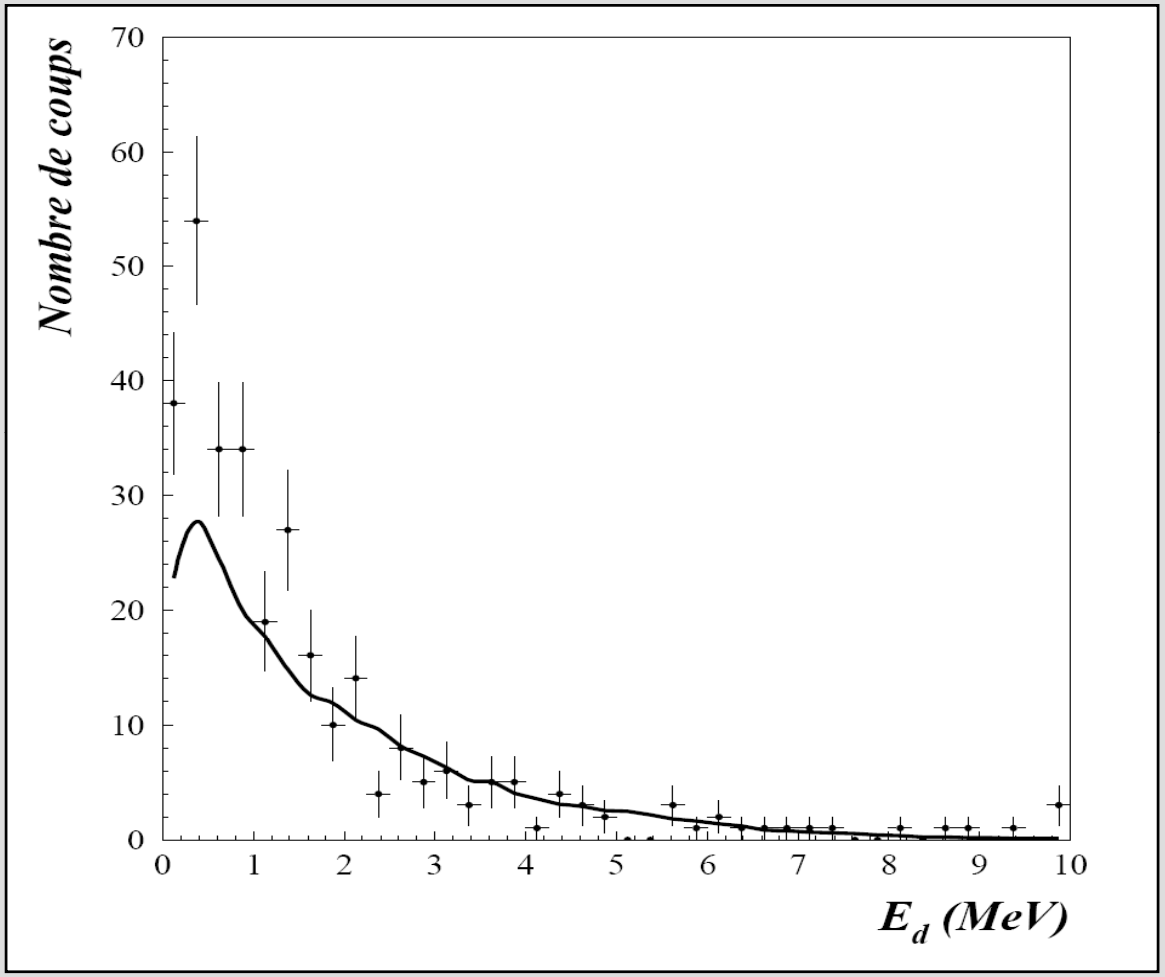
[Decay of $^{11}Li^*$ & ^{12}Li … ?]

^{9}He : Low-Lying Level Scheme *



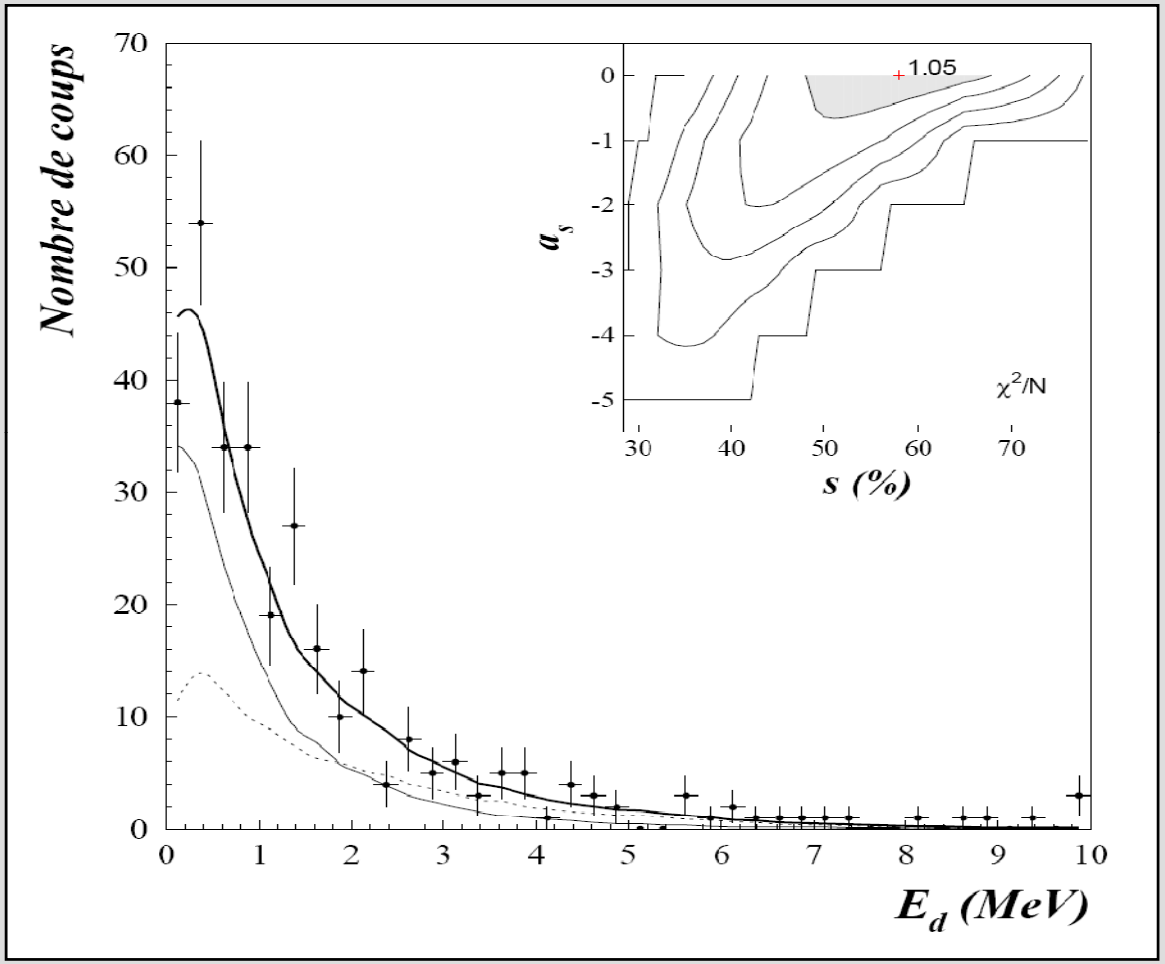
* Also IAS expts (see Wolfi's talk) ; GANIL-MUST (d,p) under analysis ; LAND-GSI

^{9}He : $C(^{11}Be,^{8}He+n)$ @ 35 MeV/nucleon [-1p]



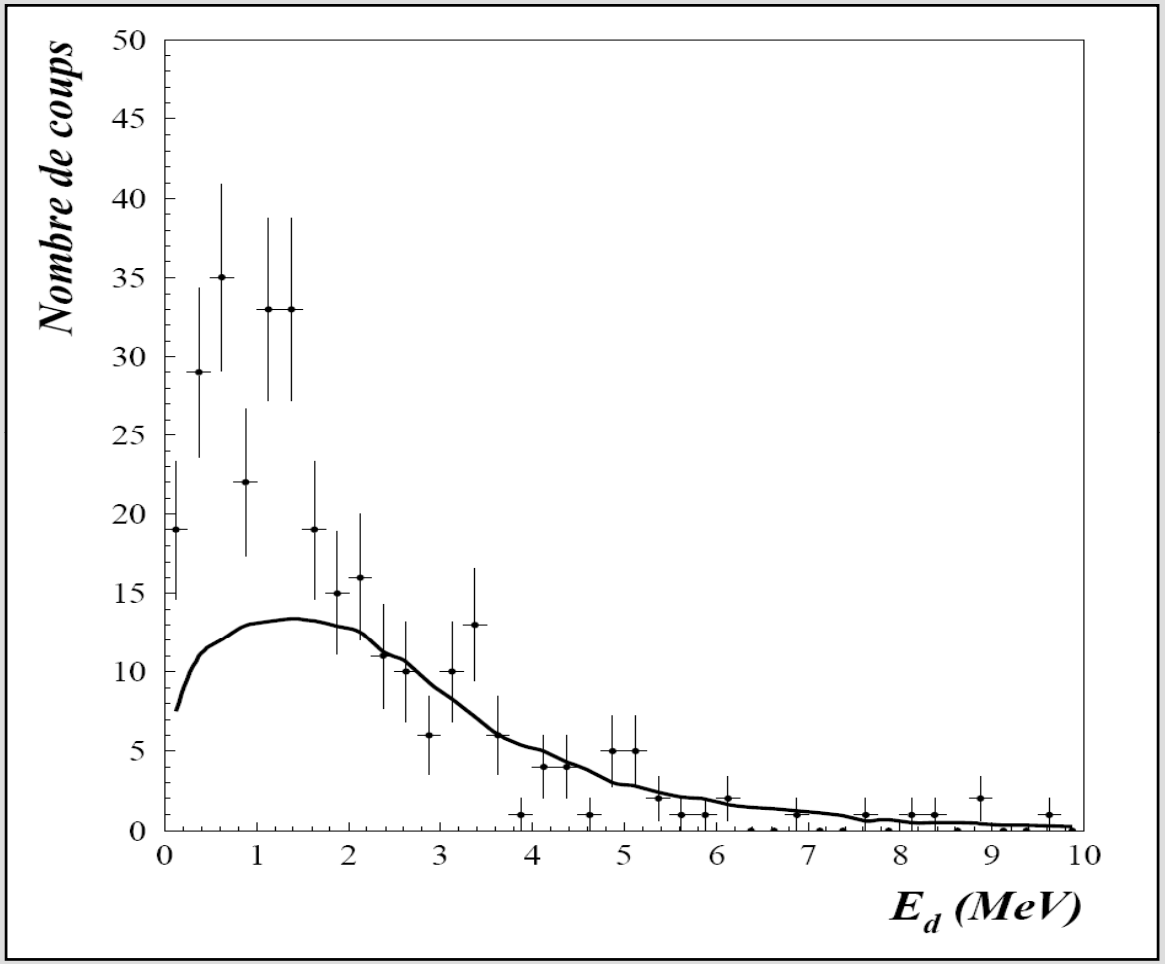
uncorrelated distribution/event mixed distribution

^{9}He : $C(^{11}Be,^{8}He+n)$ @ 35 MeV/nucleon [-1p]



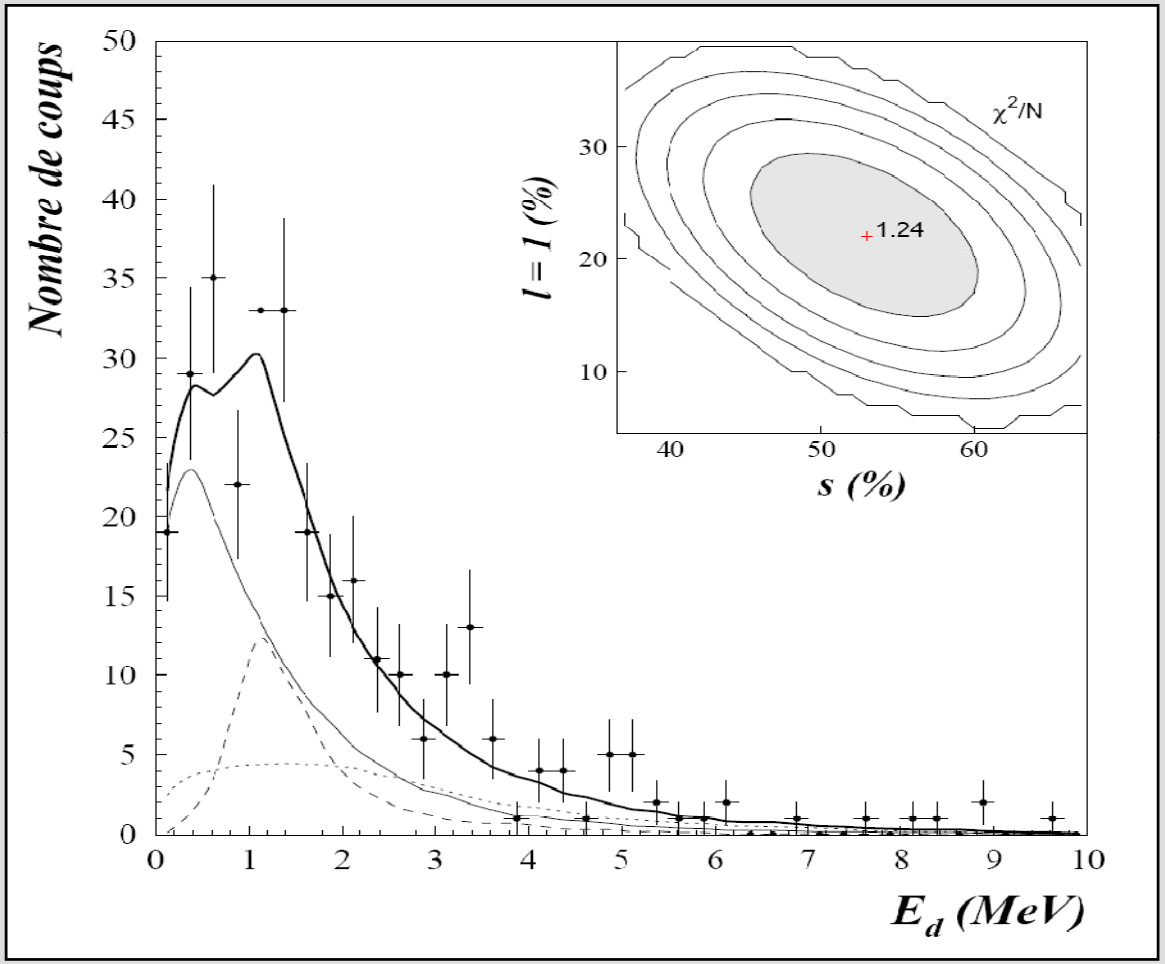
s-wave [a_s = -3 ~ 0 fm (3σ)] + non-resonant continuum

^{9}He : $C(^{14}B,^{8}He+n)$ @ 35 MeV/nucleon [-3p,-2n]



uncorrelated distribution/event mixed distribution

^{9}He : $C(^{14}B,^{8}He+n)$ @ 35 MeV/nucleon [-3p,-2n]



s-wave [a_s = -3 ~ 0 fm] + p-wave [E_r = 1.2, Γ_0 = 1.0 MeV] + background

[Decay of ^{10}He & ^{11}He … ?]

Conclusions & Perspectives

- ^{11}Be proton knockout suggests that selection rule valid

  $\Rightarrow$ spectroscopy possible beyond the dripline using knockout from RNB …

→ ^{10}Li : low-lying s-wave strength (a_s = -14±2 fm)

low-lying p-wave resonance (E_r = 0.5 MeV)

$\Rightarrow$ N= 7 inversion confirmed

[but … $\pi p_{3/2} \otimes \nu s_{1/2}$, $\nu p_{1/2}$, $\nu d_{5/2}$]

→ ^{9}He : low-lying s-wave strength ($a_s \approx 0$ fm) + $E_x \approx 1.2$ MeV

(l>0) $\Rightarrow$ N= 7 inversion … ??

[FSI << ^{9}Li+n ? *]

- EXPT: higher resolution & statistics improved neutron detection & I_B

* confirmed by recent LAND-GSI work

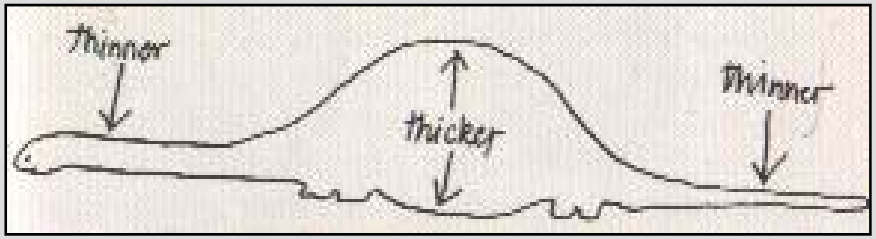
Conclusions & Perspectives

- *validity of s-wave virtual states ??*

  eg., deformed ^{9}Li & ^{12}Be cores

  [MCAS ??]

- *realistic structure + reaction modelling needed (lineshape and cross section) including non-resonant continuum + other backgrounds …*



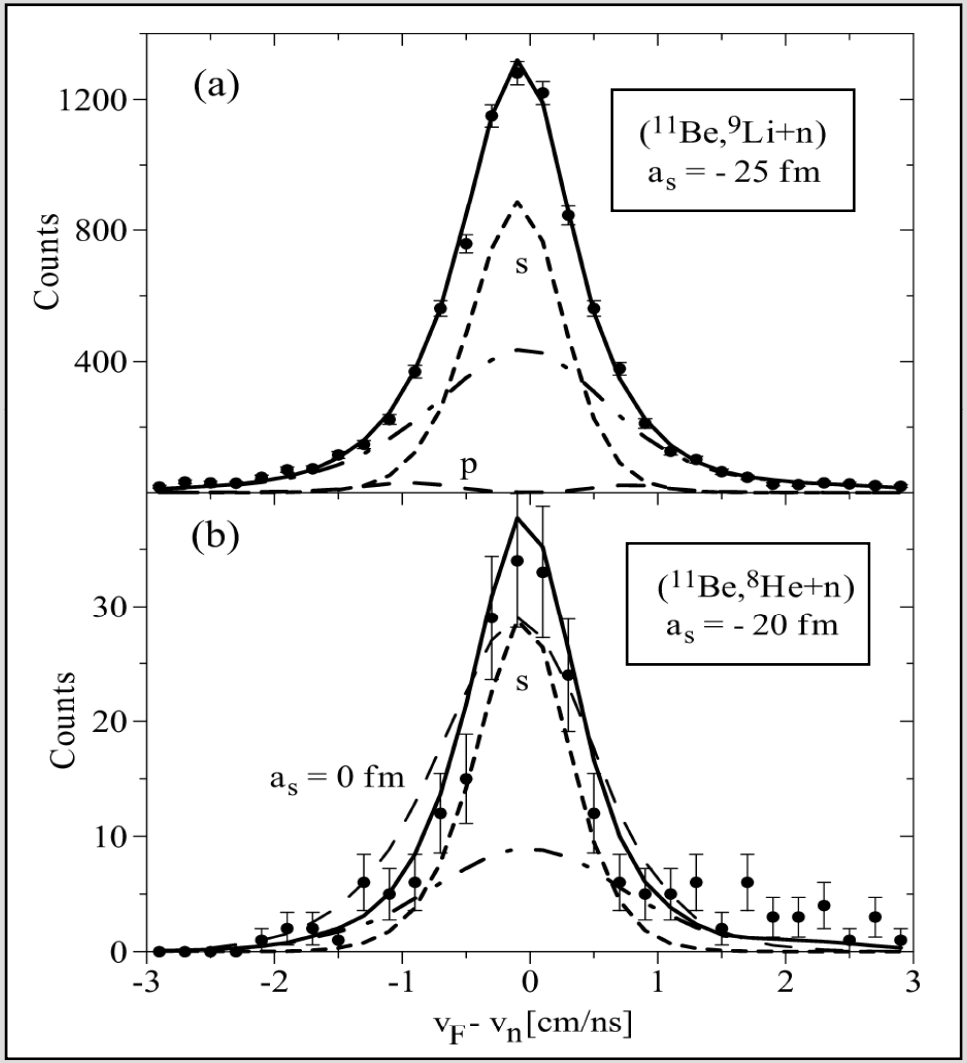
- *first step – estimate frag. recoil effects*
- *valence neutron scattering (approx. free neutron scattering ?)*

Mea Culpa …*

… the true antipode of Queenstown

** on behalf of WNC*

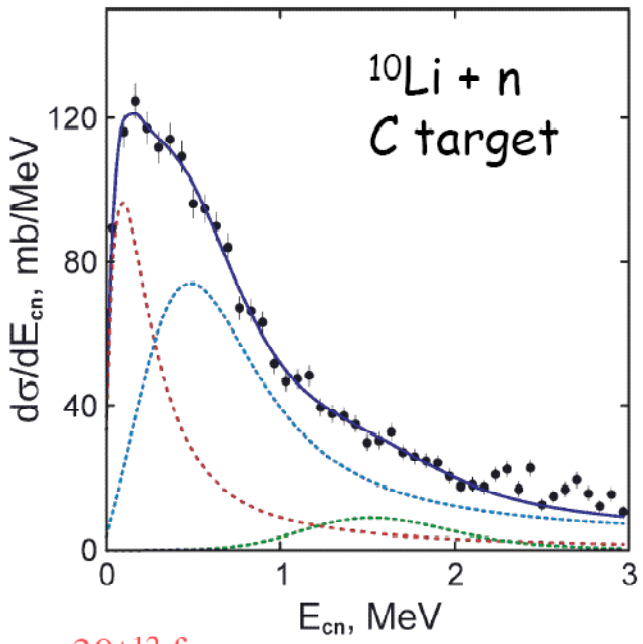
$^{10}Li,^{9}He$: Be($^{11}Be,^{9}Li+n$) & Be($^{11}Be,^{8}He+n$)



MSU L Chen et al., Phys. Lett. B (2001)

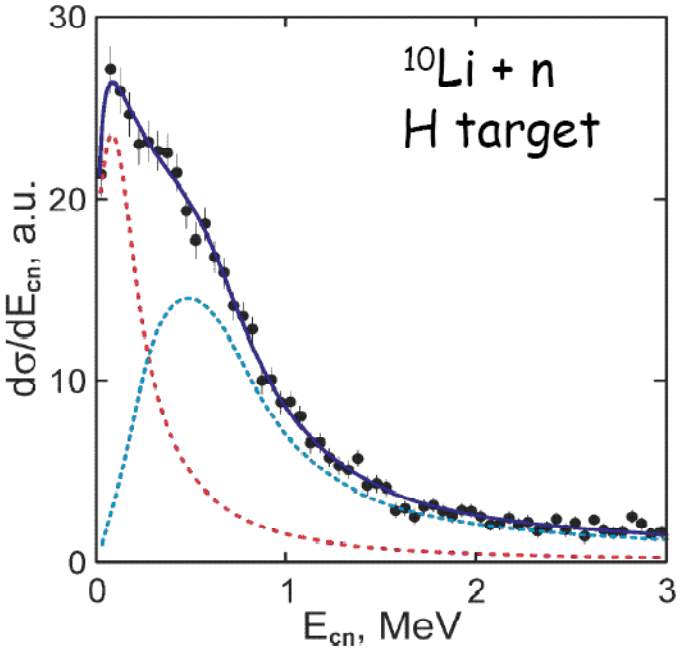
^{10}Li : H,C(^{11}Li,^{9}Li+n)

H. Simon, M. Meister *et al.*
Nucl. Phys. A791 (2007) 267



$a = -30^{+12}_{-31}$ fm
$E_r = 0.510(44)$ MeV, $\Gamma = 0.54(16)$ MeV
$E_r = 1.486(88)$ MeV, $\Gamma < 2.2$ MeV

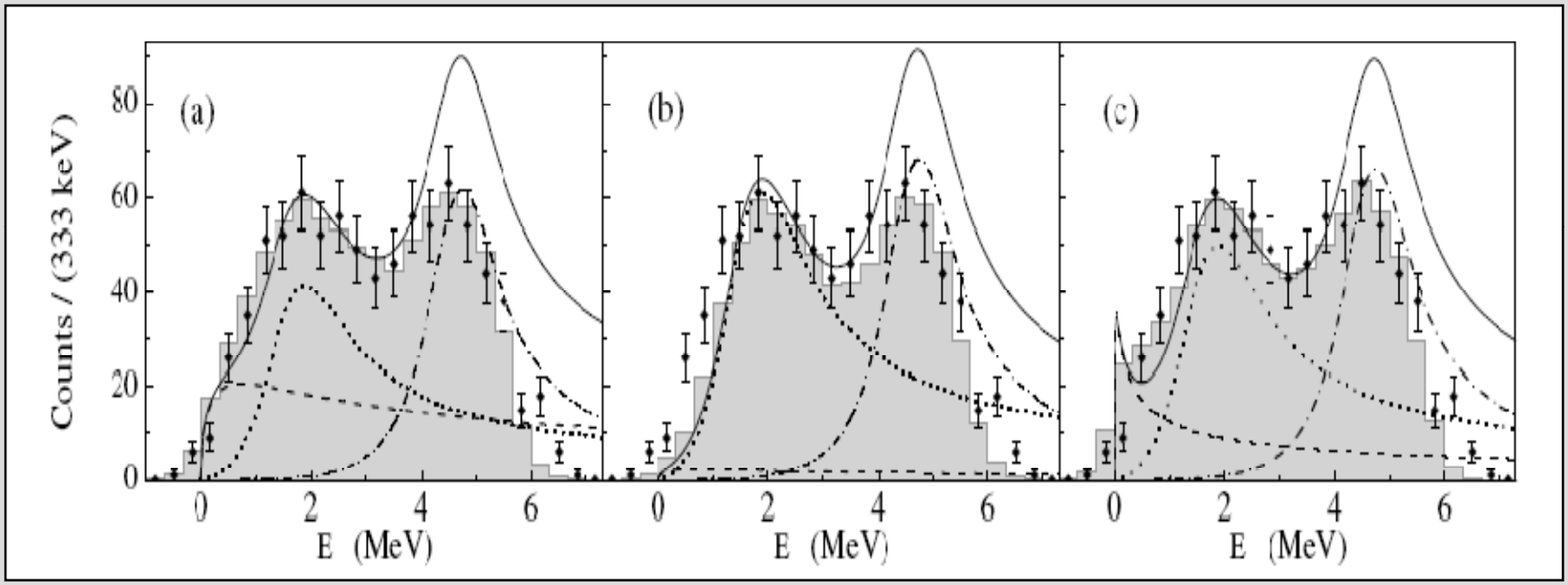
Present work



$a = -22(5)$ fm
$E_r = 0.566(14)$ MeV, $\Gamma = 0.548(30)$ MeV

LAND-GSI: Aksyutina et al. PLB (2008)

^{9}He : $d(^{8}He,p)$ @ 25 MeV/nucleon



MS Golovkov et al., PRC76 (2007)