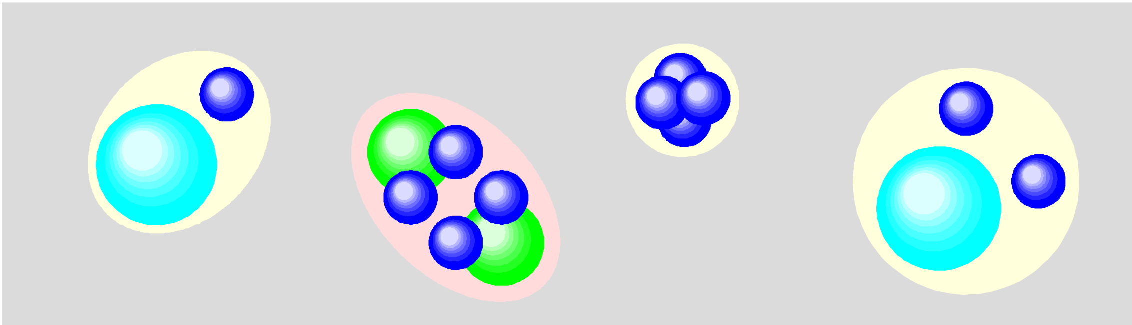
Critical Stability

5th Workshop on Critical Stability of Few-Body Quantum Systems

Erice, Italy, 13-17 October 2008

LIGHT NUCLEI IN THE CONTINUUM



F. Miguel Marqués Moreno

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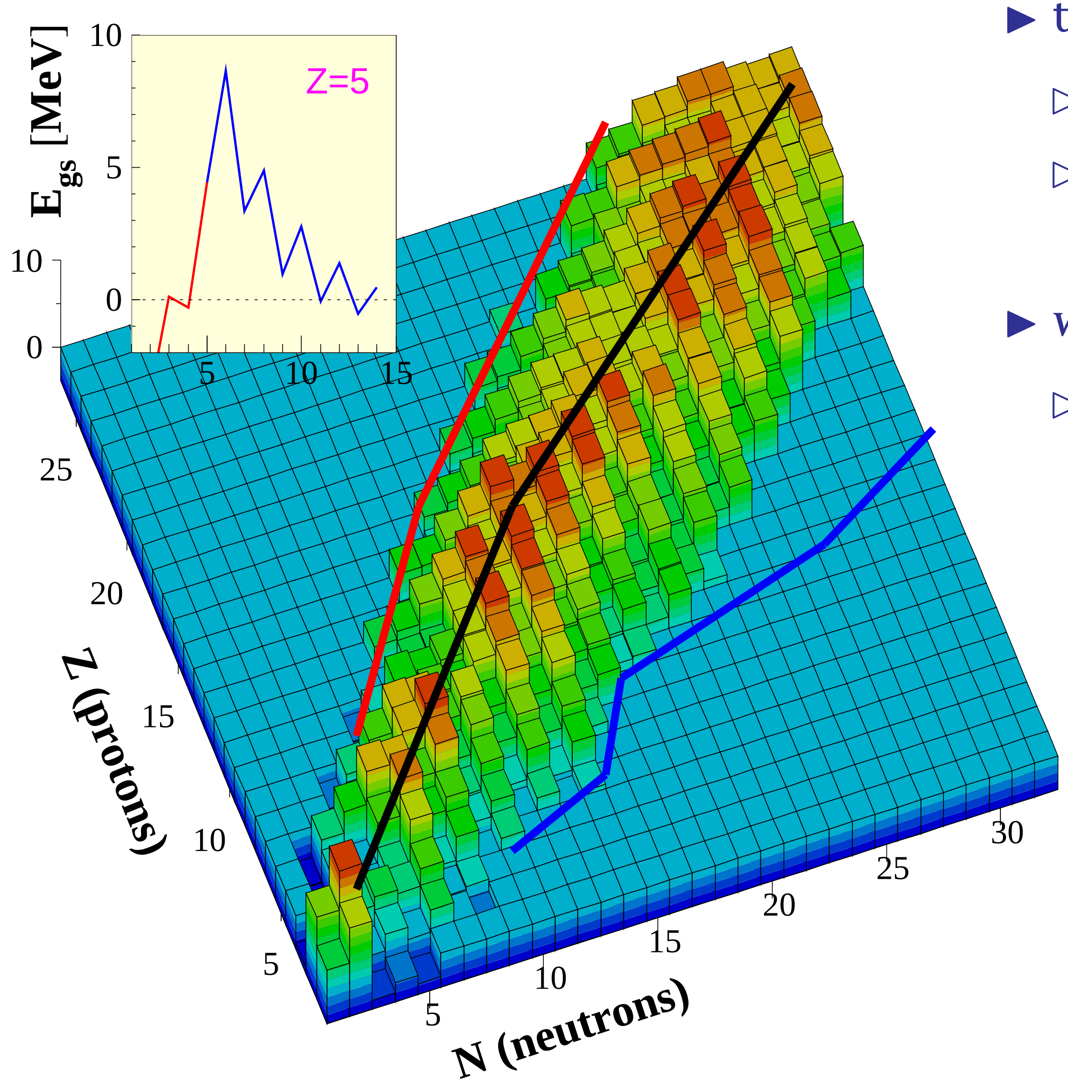
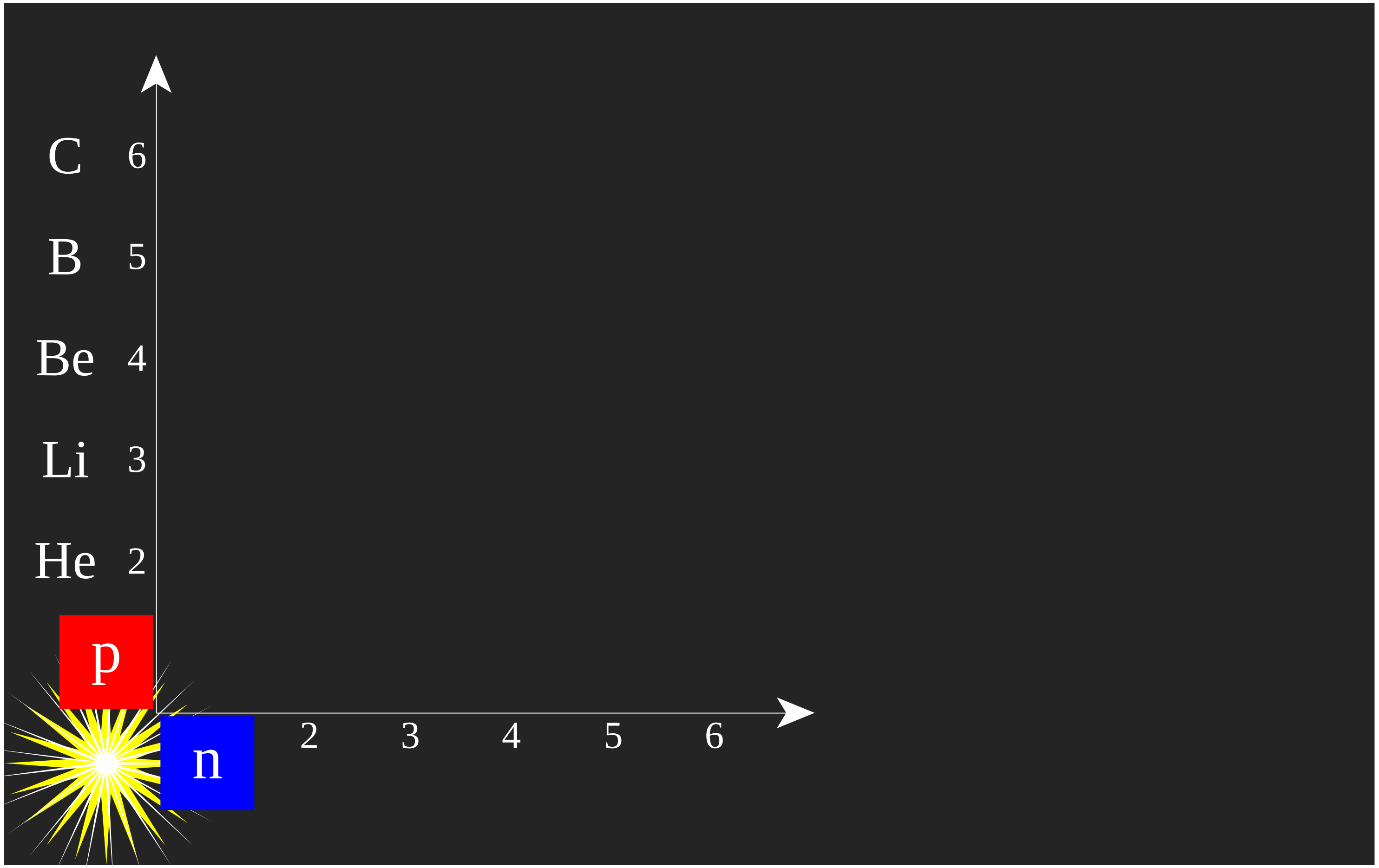
LPC-Caen [N.A. Orr, B. Laurent, H. Al Falou, A. Leprince], Surrey, Oxford, Birmingham, ULB-Bruxelles [V. Bouchat], IReS-Strasbourg, GANIL, Orsay, Göteborg, Aarhus, Madrid

nucleons in nuclei



- the valley of stability :
  - $B = Nm_n + Zm_p - M(N, Z)$
  - rather a ridge of stability …
- where are the drip lines ?
  - $E_{gs}(N, Z)$
    $= \min\left[\sum M(n_i, z_i)\right] - M(N, Z)$
- very light nuclei :
  - access to extreme (N, Z) !!!

light nuclei in the continuum



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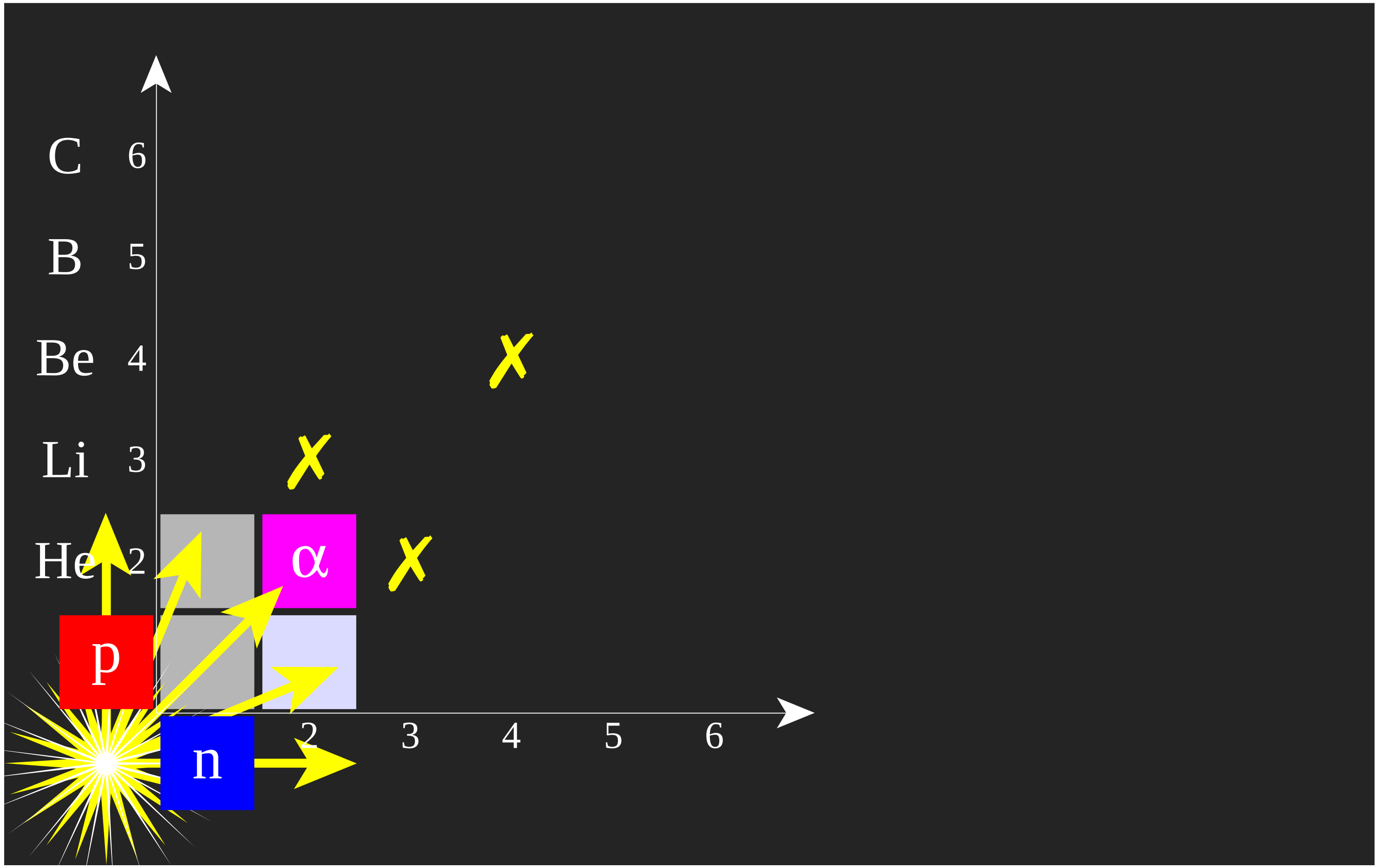

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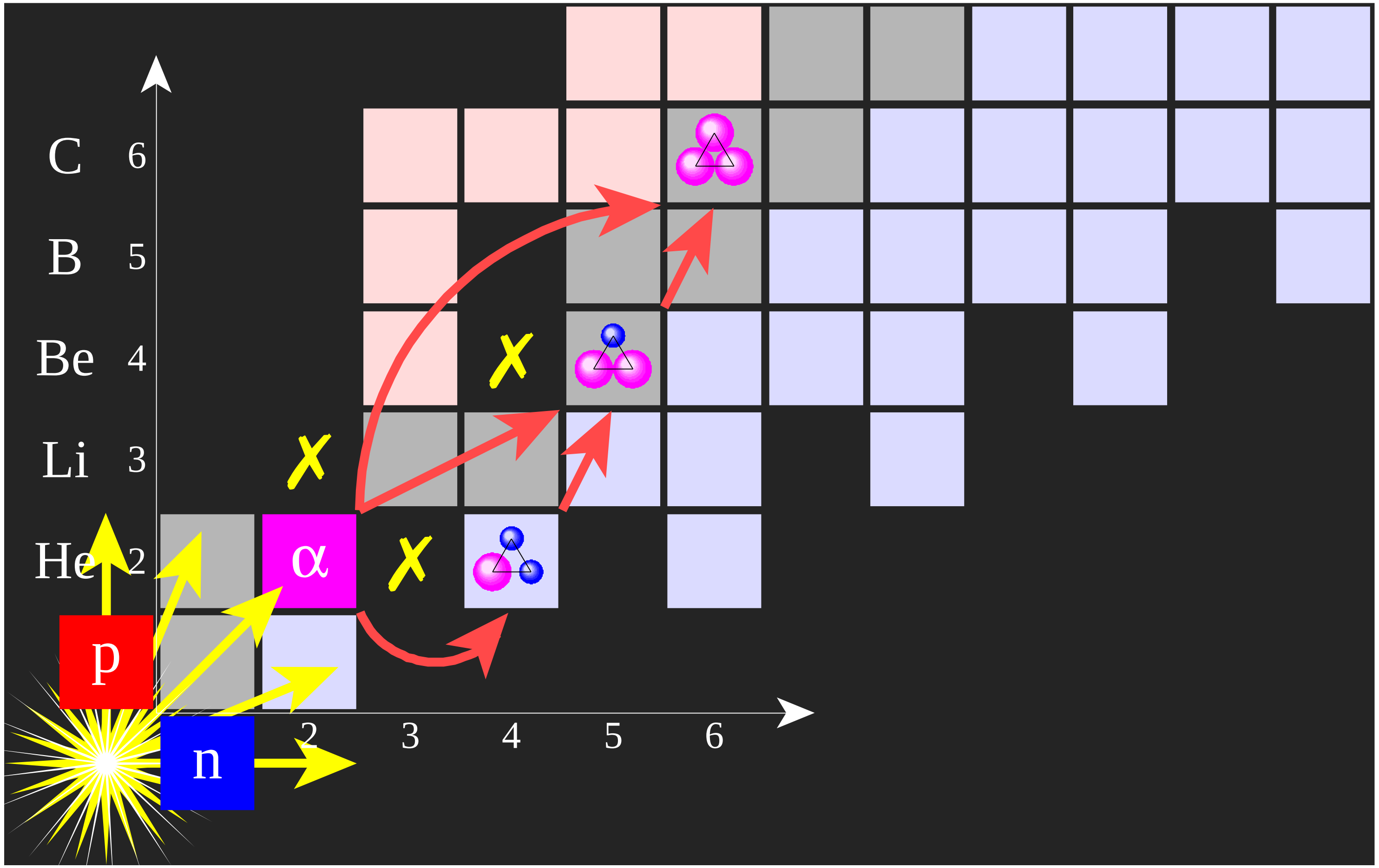

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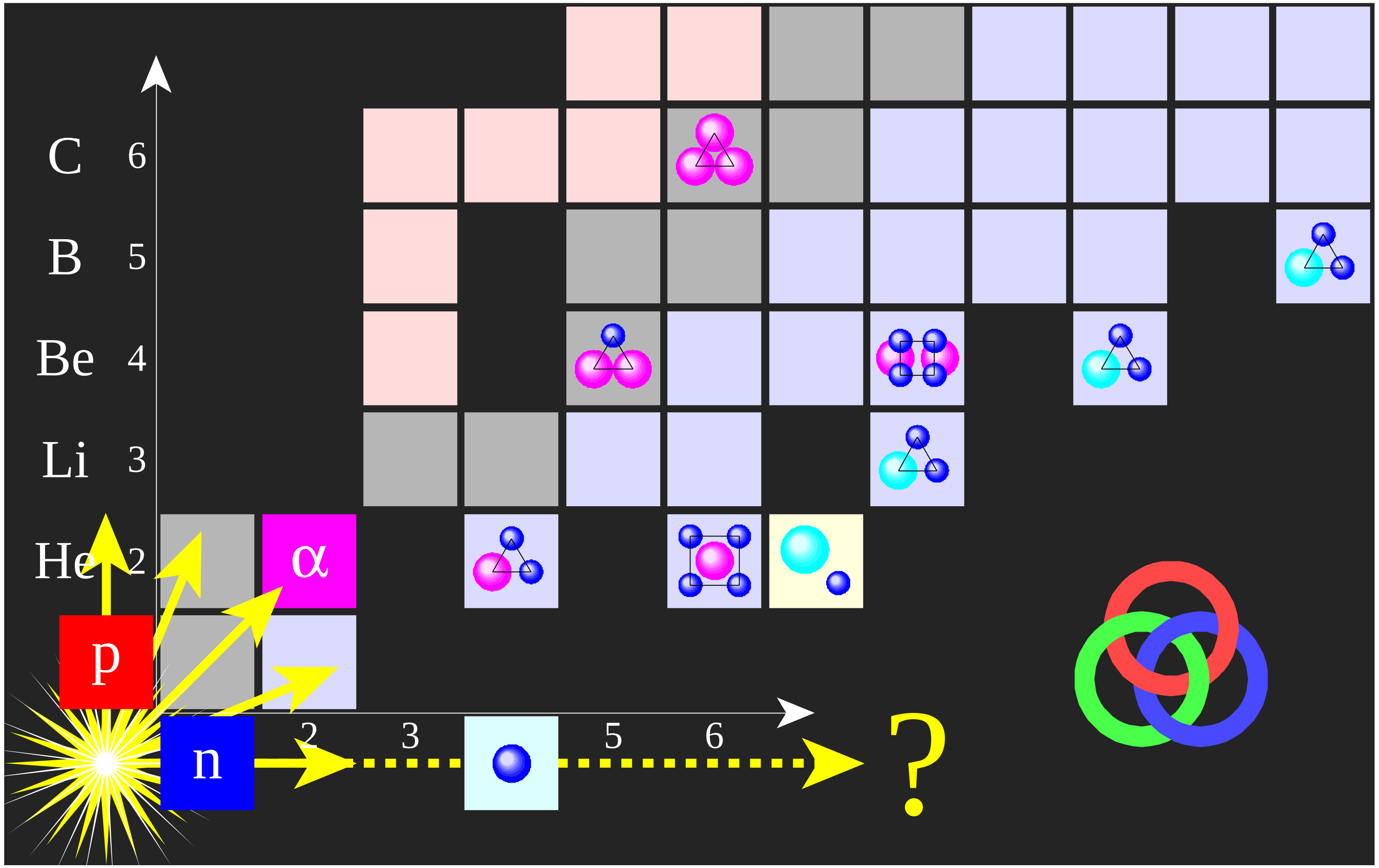

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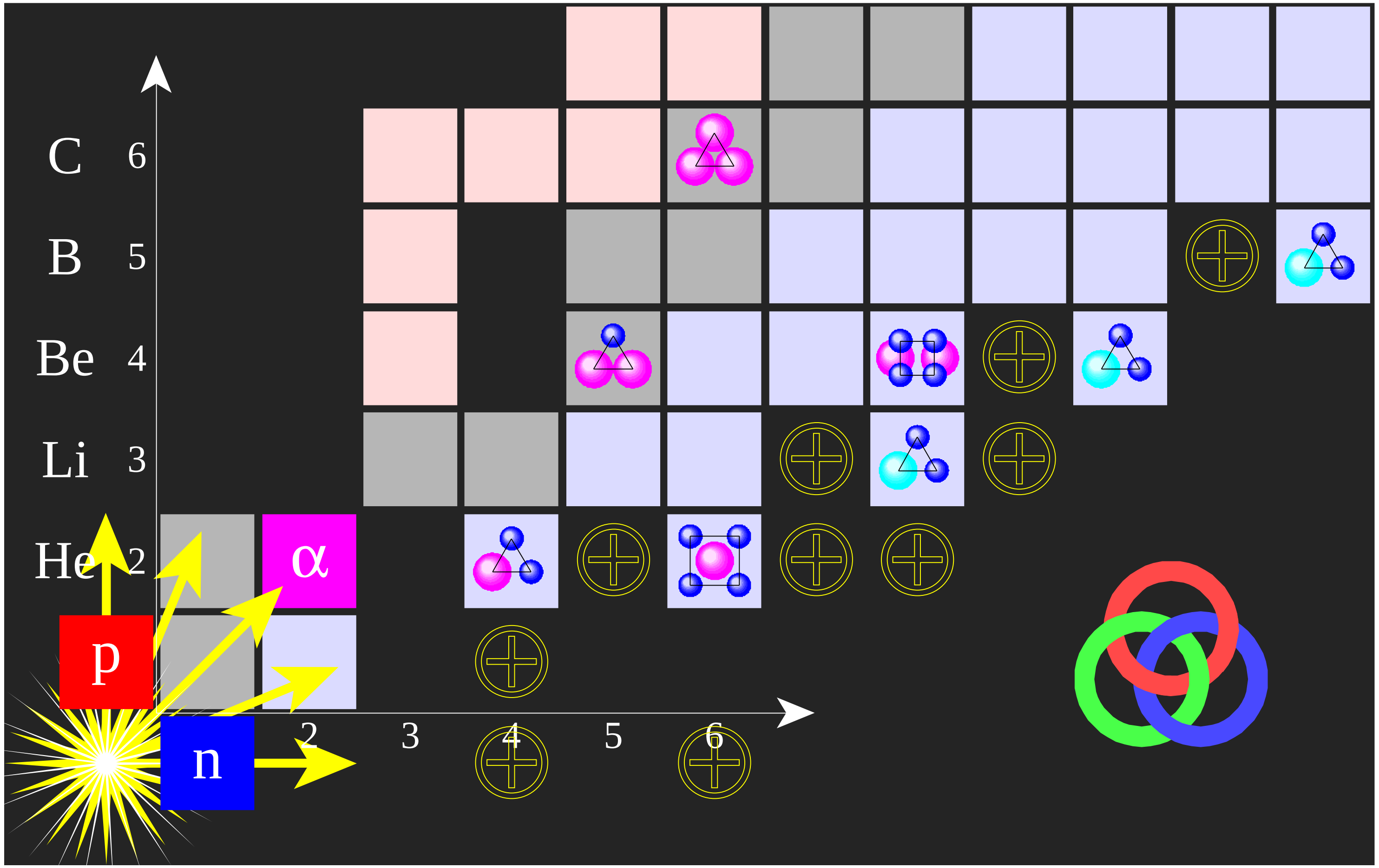


▷ breakup exp + fragment/n detectors :

⇝ unbound systems

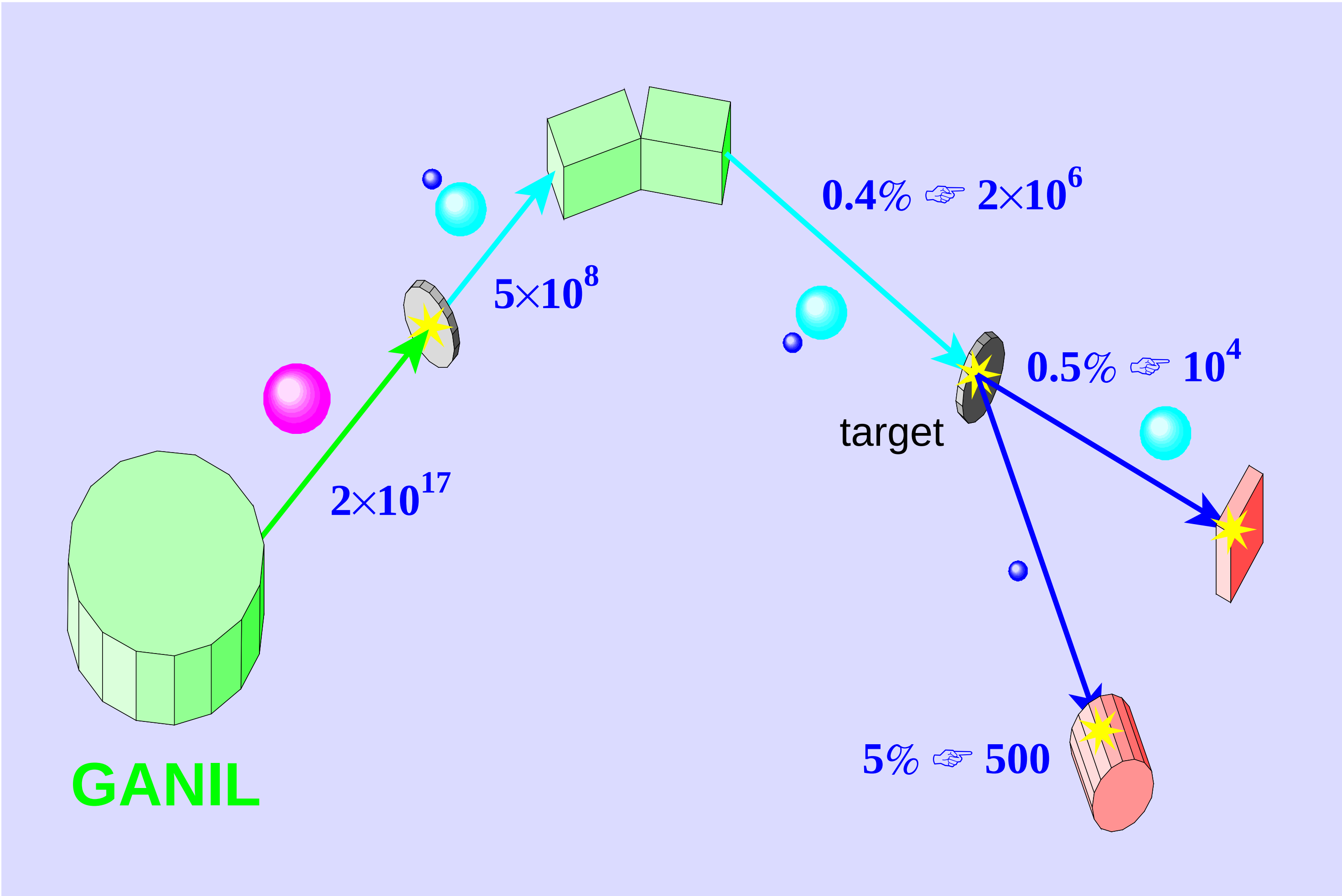
⇝ excited weakly-bound nuclei

unstable beams

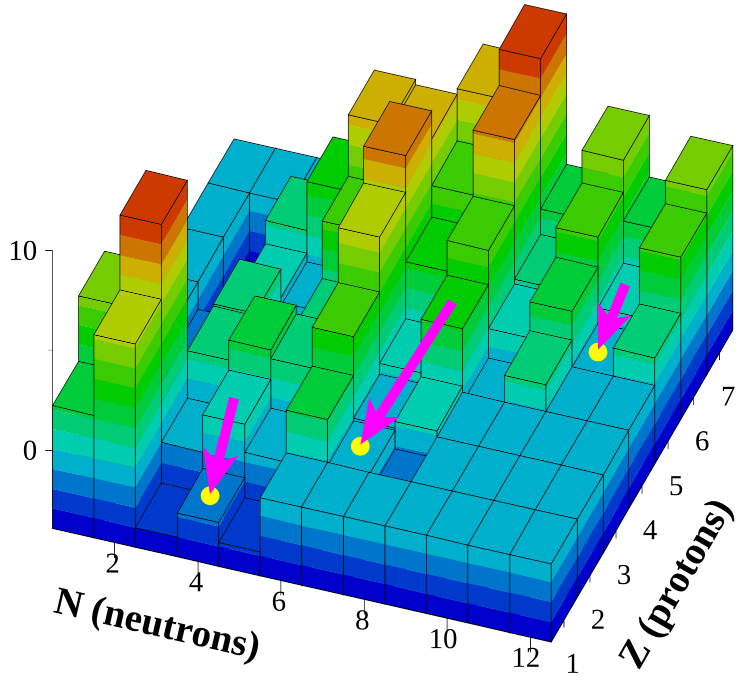
- $^{19}\mathrm{C} \longrightarrow {}^{18}\mathrm{C}+\mathrm{n}$ experiment @ GANIL :
  - add 7n to $^{12}\mathrm{C}$?? study it in less than 49 ms ???

unstable beams

- ^{19}C $\longrightarrow$ ^{18}C+n experiment @ GANIL :
  - ▷ add 7n to ^{12}C ?? study it in less than 49 ms ???



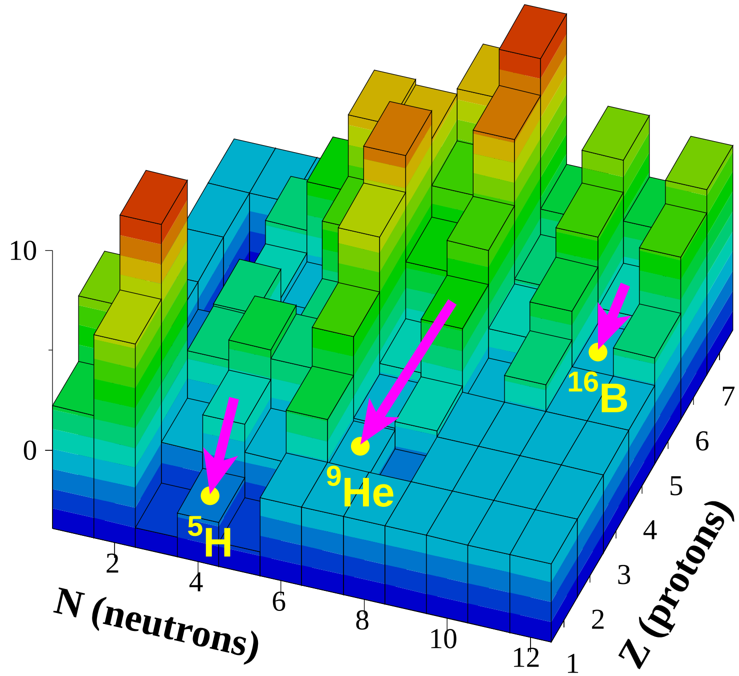
mapping the seabed



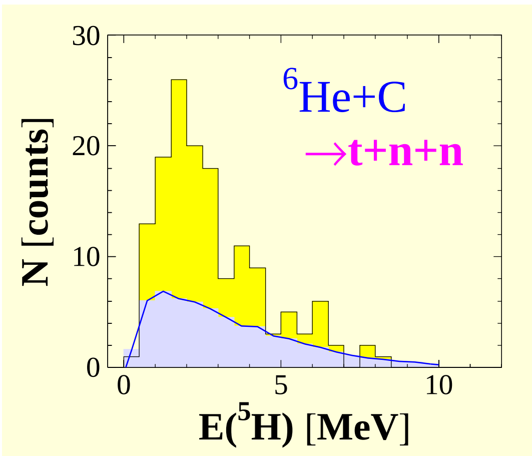
▶ how to dive below the surface ?

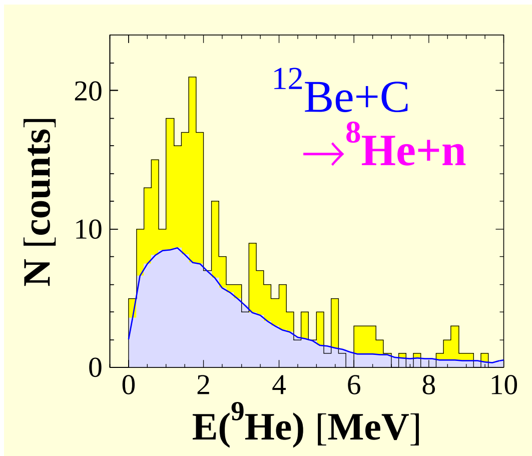
▷ strip nucleons from a beam !

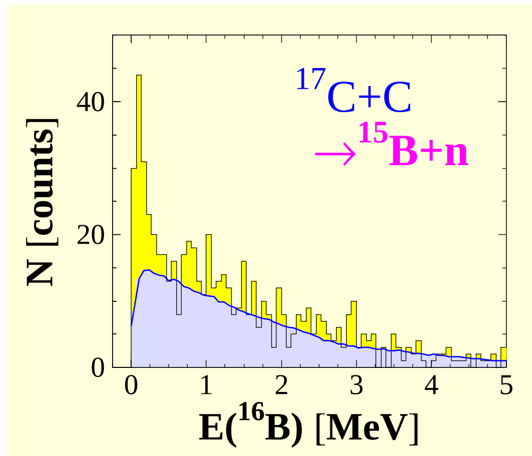
mapping the seabed



- how to dive below the surface ?
  - ▷ strip nucleons from a beam !
- how to find a "nucleus" ?
  - ▷ look for energy levels ...

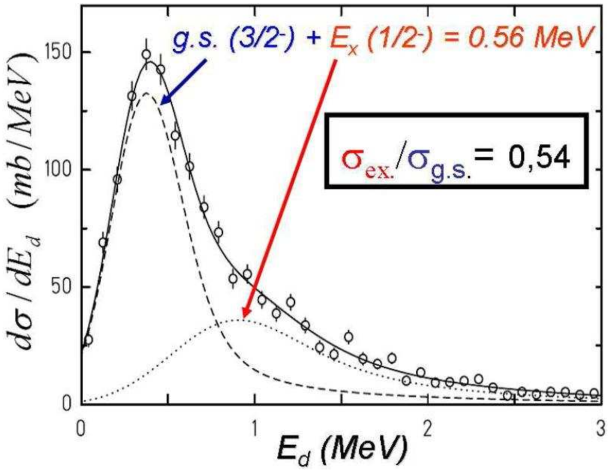






7He : a well-known nucleus ? [Al Falou]

- C(^{8}He,^{6}He+n)X @ 240 and 15 MeV/N :



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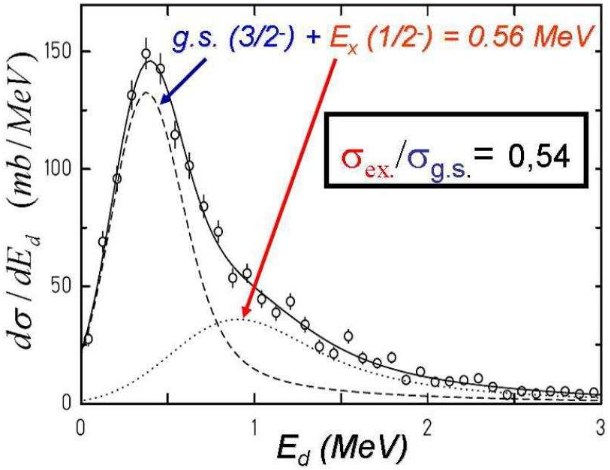

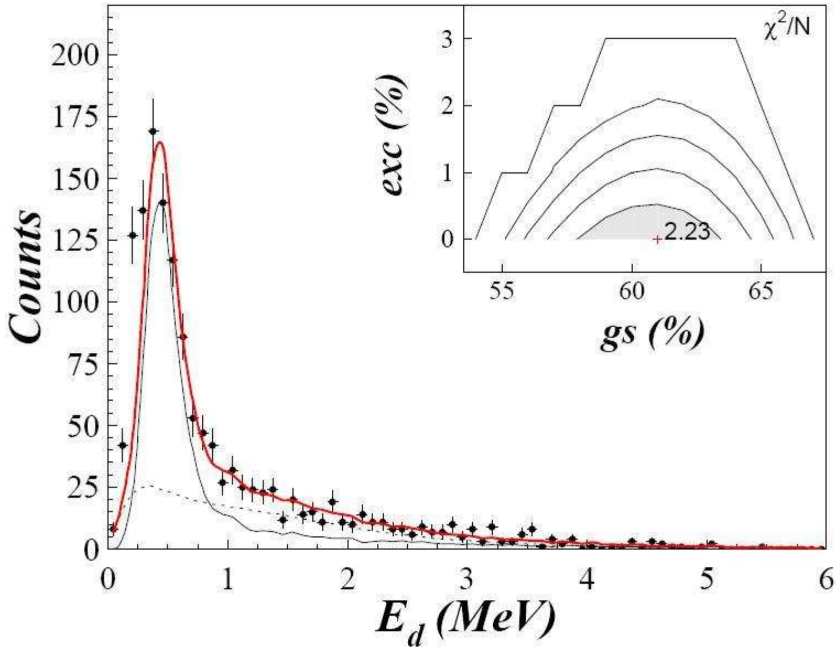

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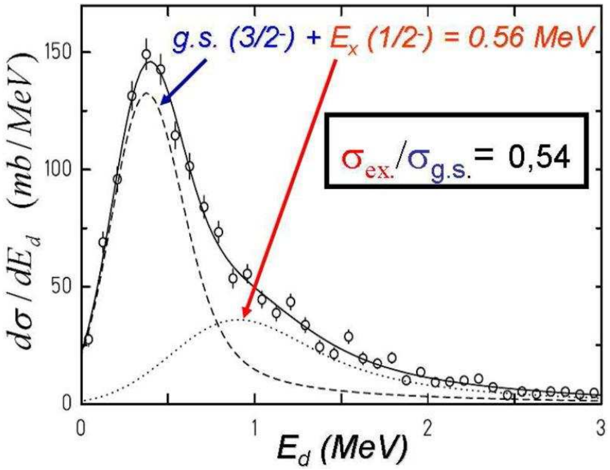
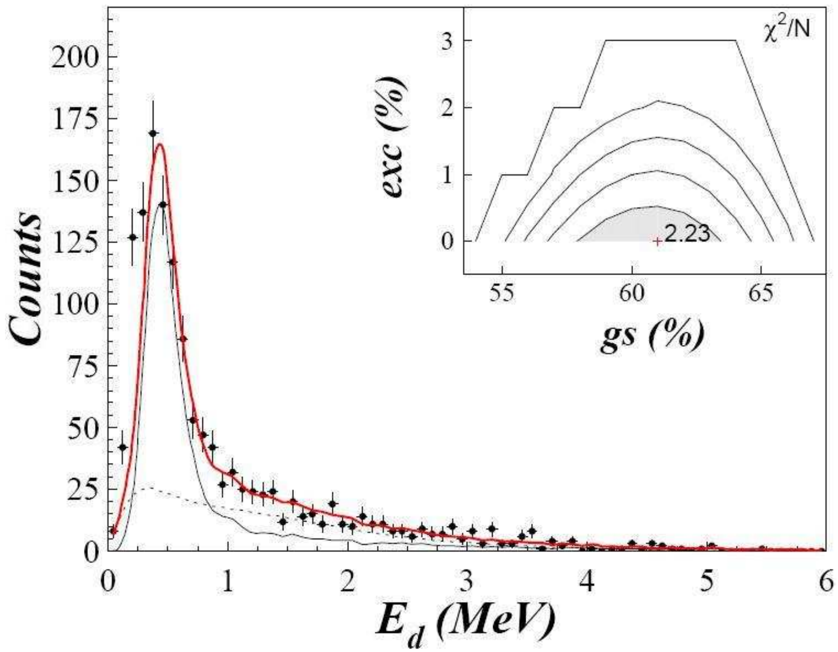
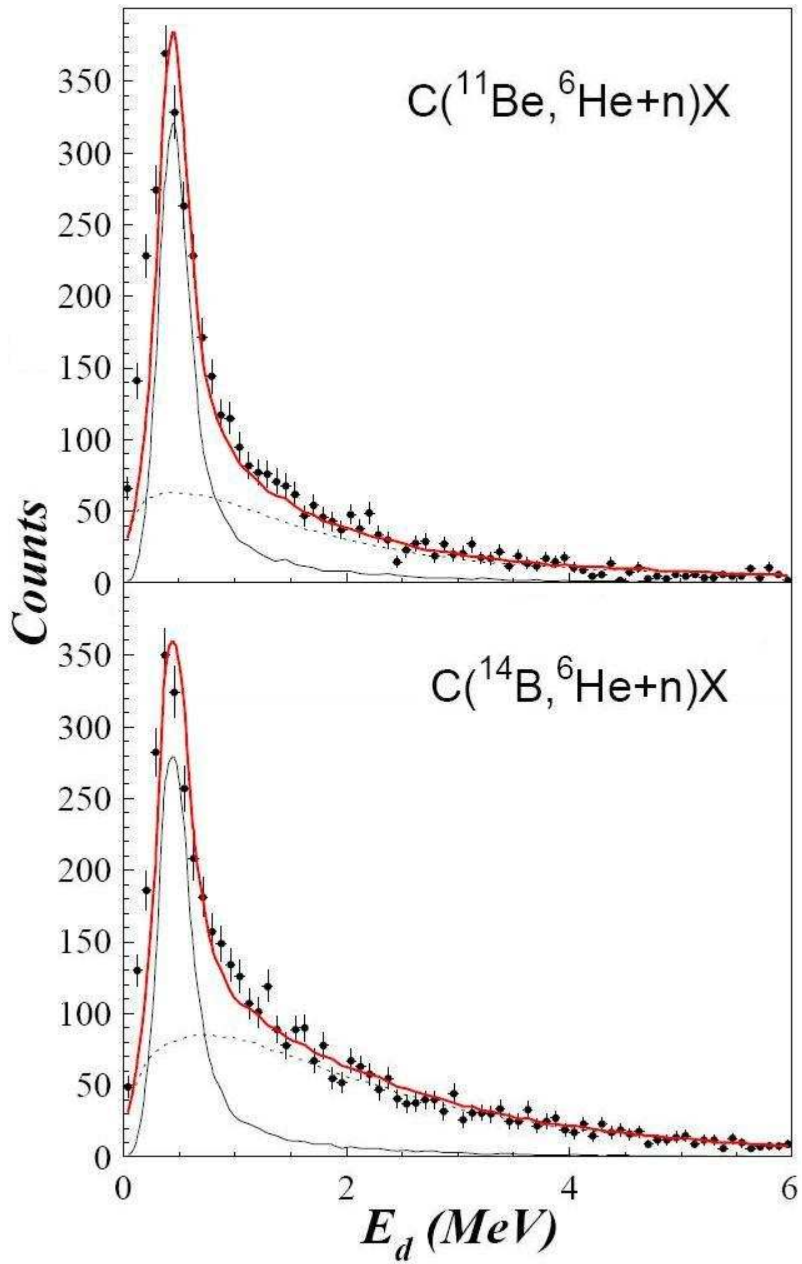
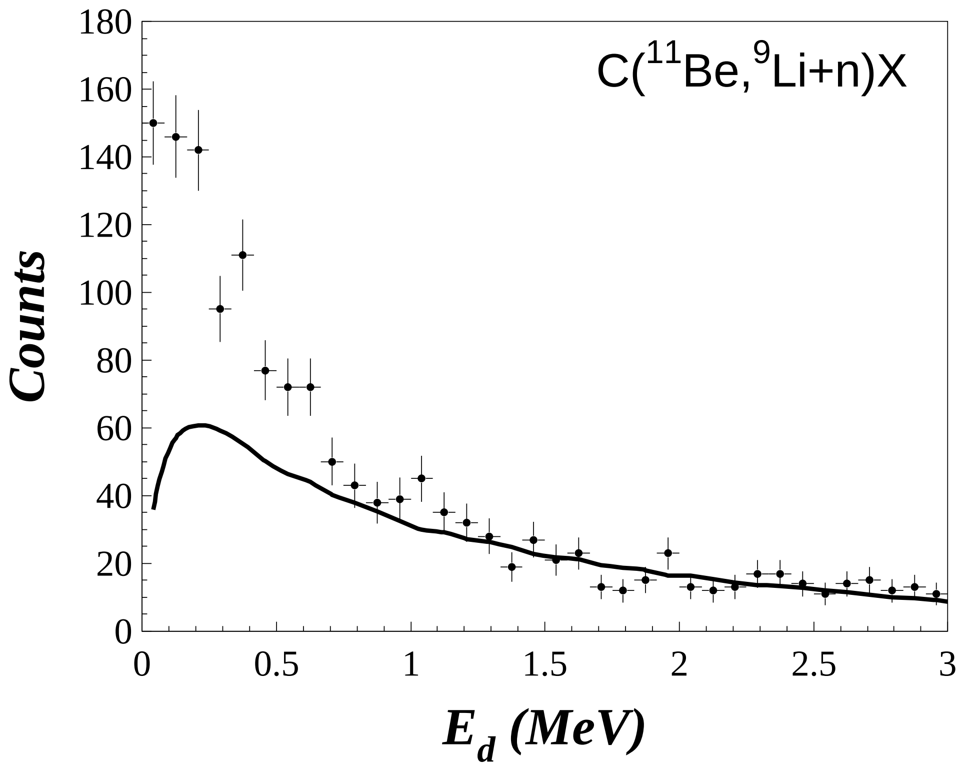






10Li : initial state dependence [Al Falou]

► C(^{11}Be,^{9}Li+n)X @ 35 MeV/N :



▷ non-resonant continuum

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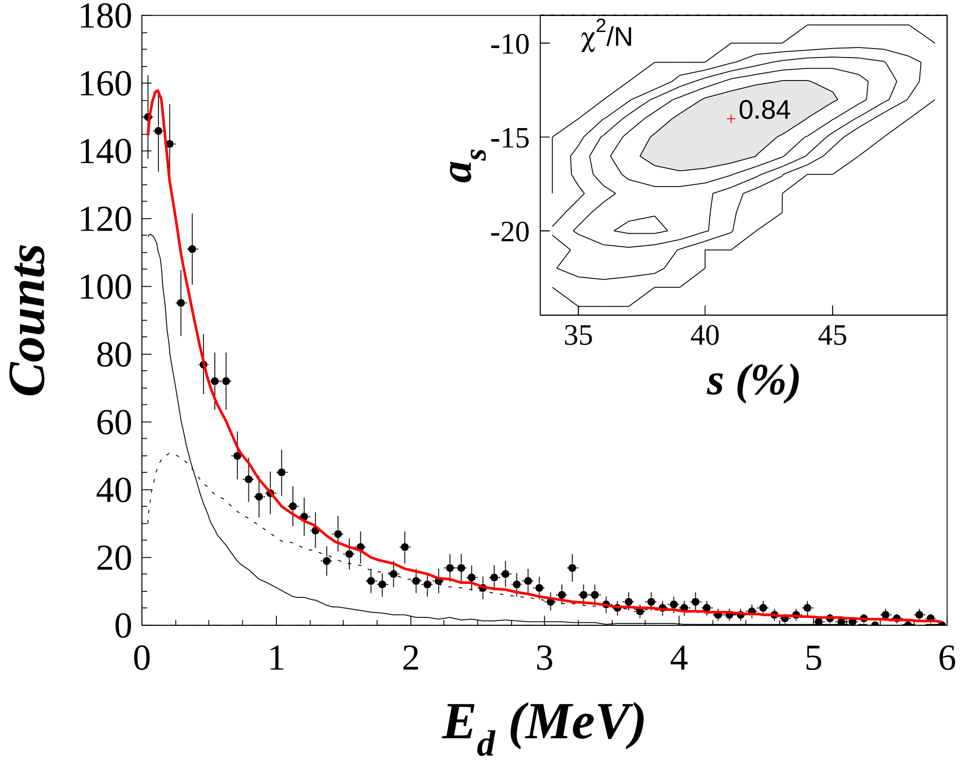

- ▷ non-resonant continuum
- ▷ plus s-wave : $a_s = -14 \pm 2$ fm

  [^{11}Be : $C^2S(\nu s_{1/2}) \sim 0.8$]

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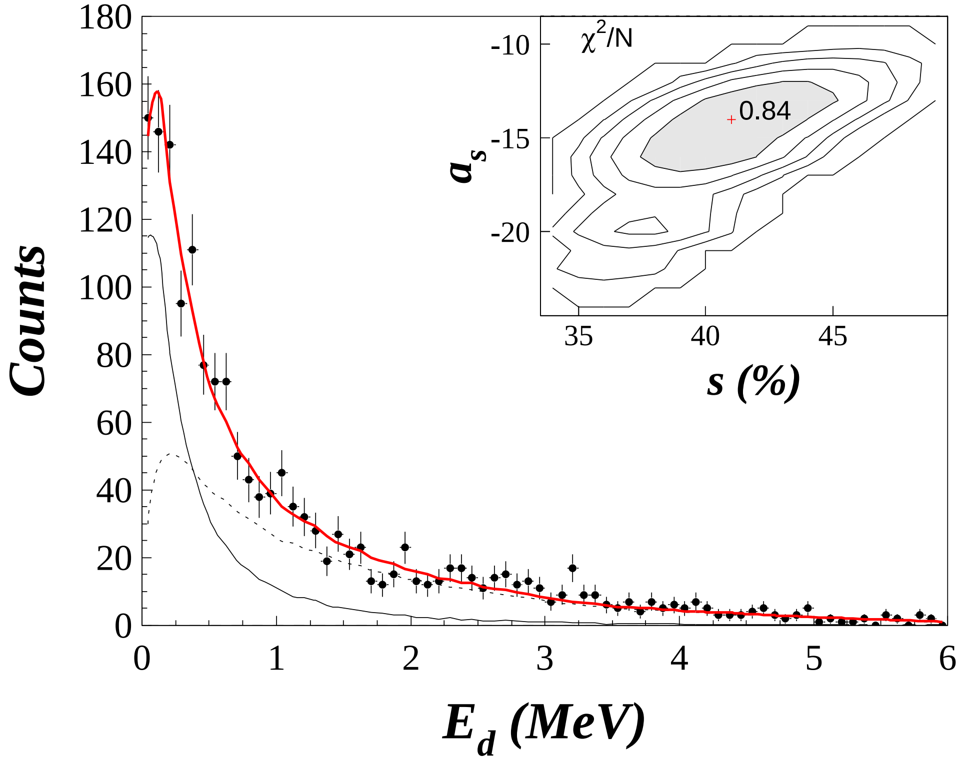

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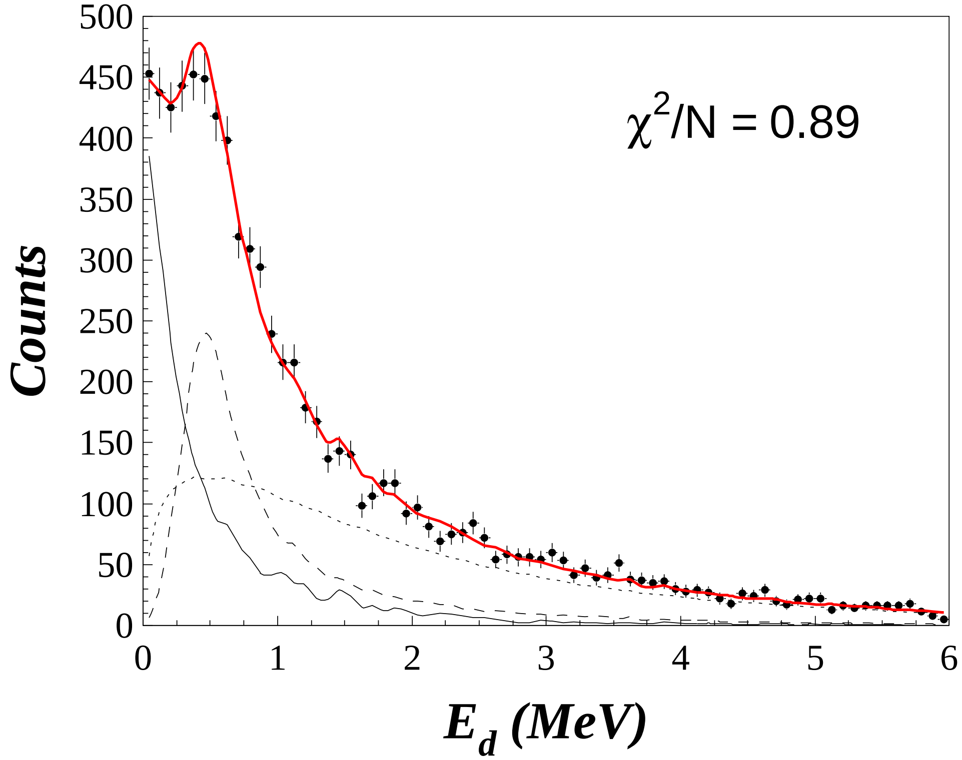


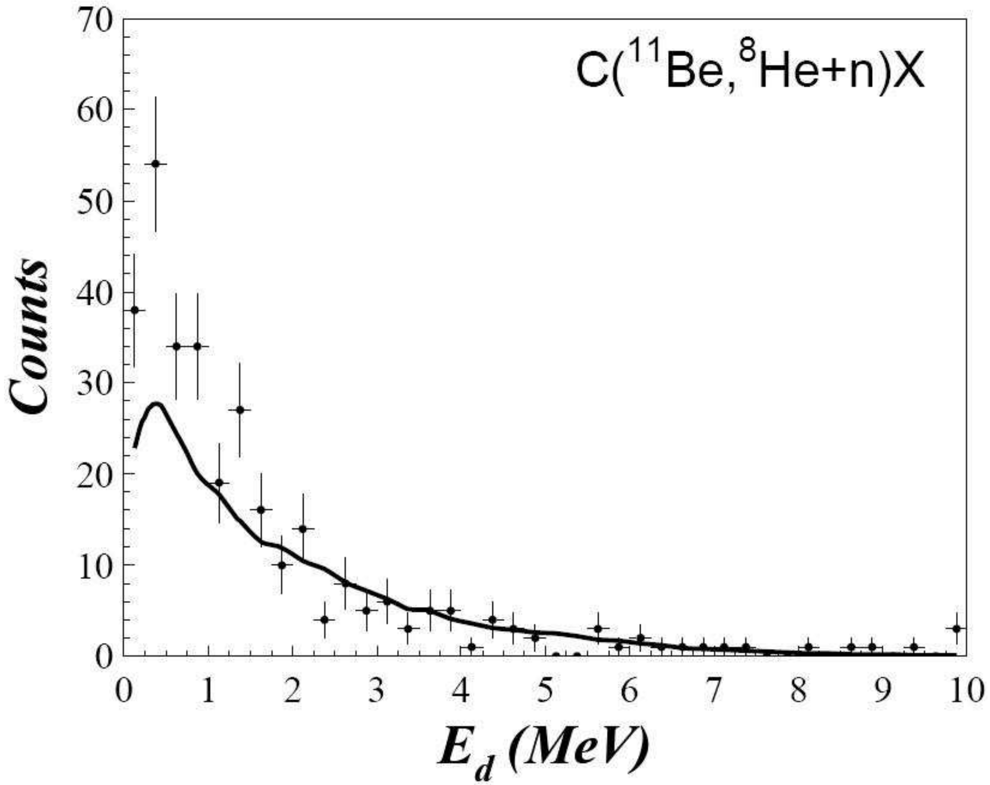
▷ non-resonant continuum

▷ plus $a_s = -14$ fm

▷ plus p-wave : $(E, \Gamma) \sim 500$ keV

9He : almost unknown [Al Falou]

- C(^{11}Be,^{8}He+n)X @ 35 MeV/N :



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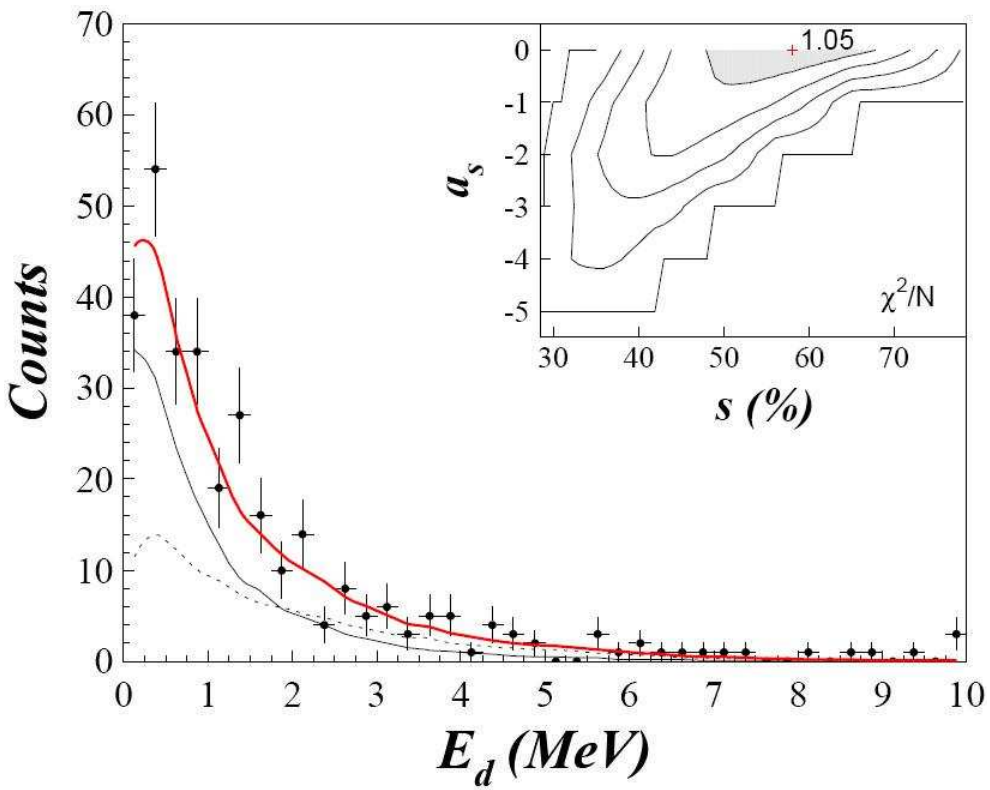

▷ non-resonant continuum

▷ plus s-wave : $a_s > -3$ fm

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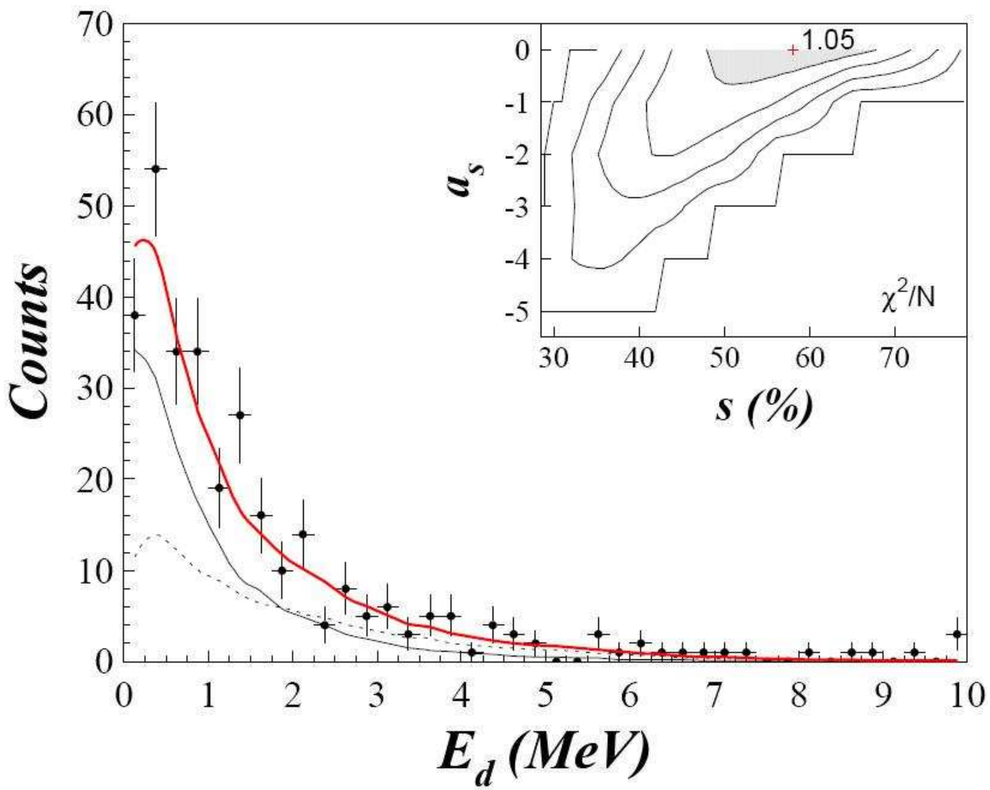

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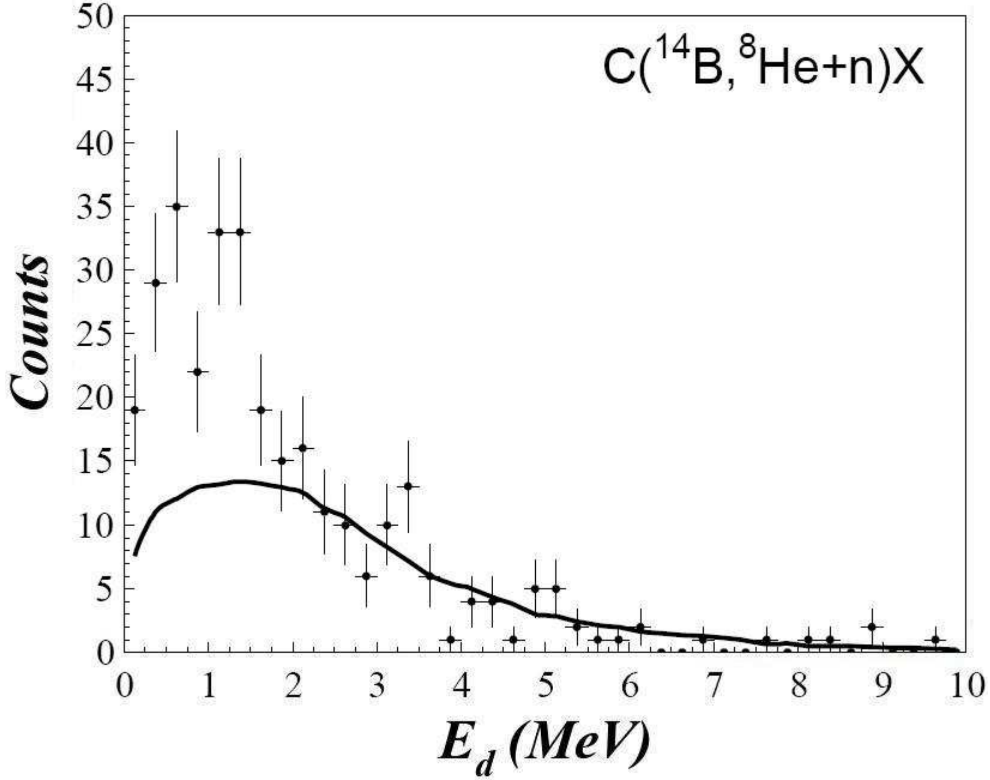

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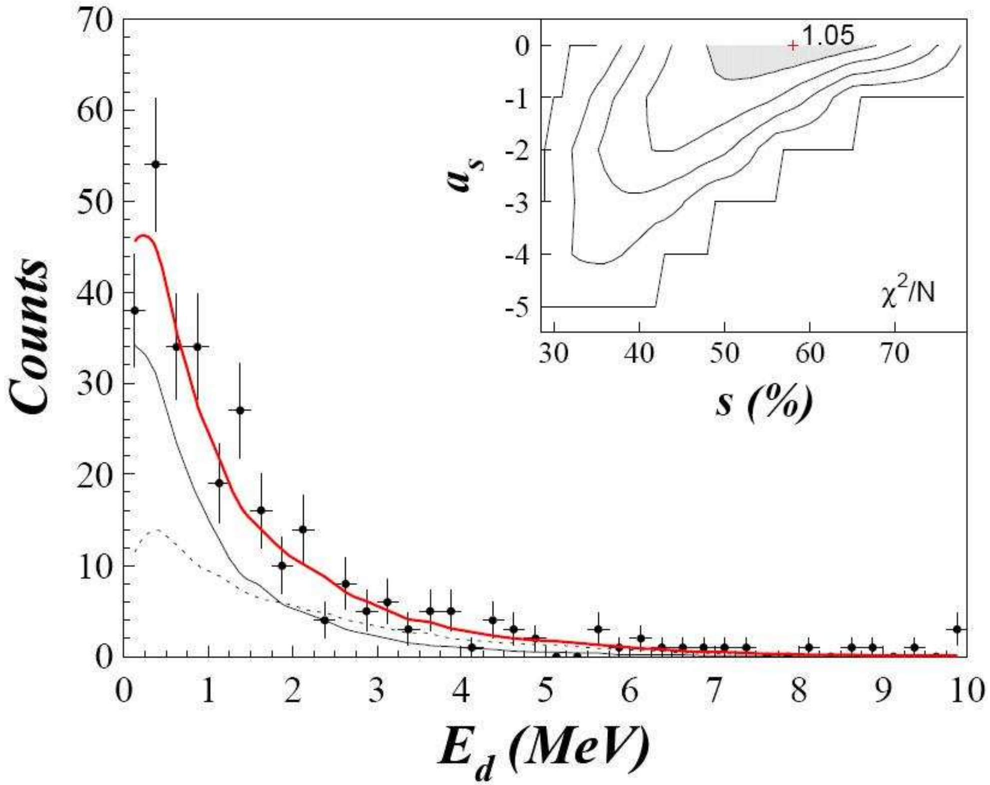

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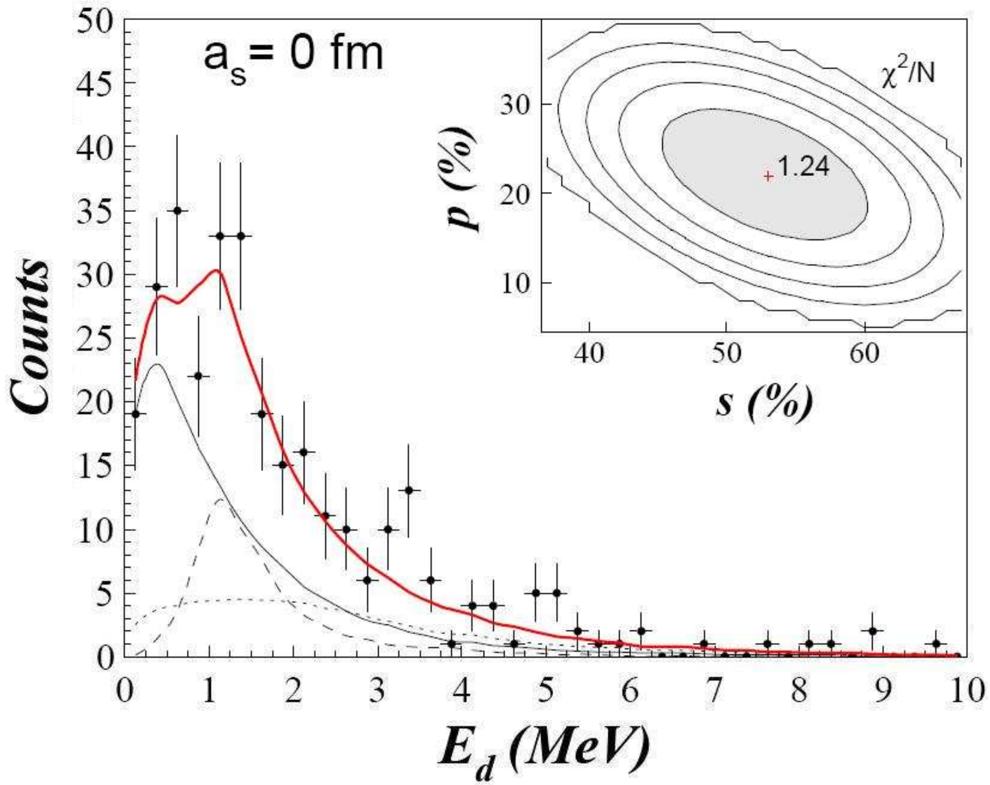
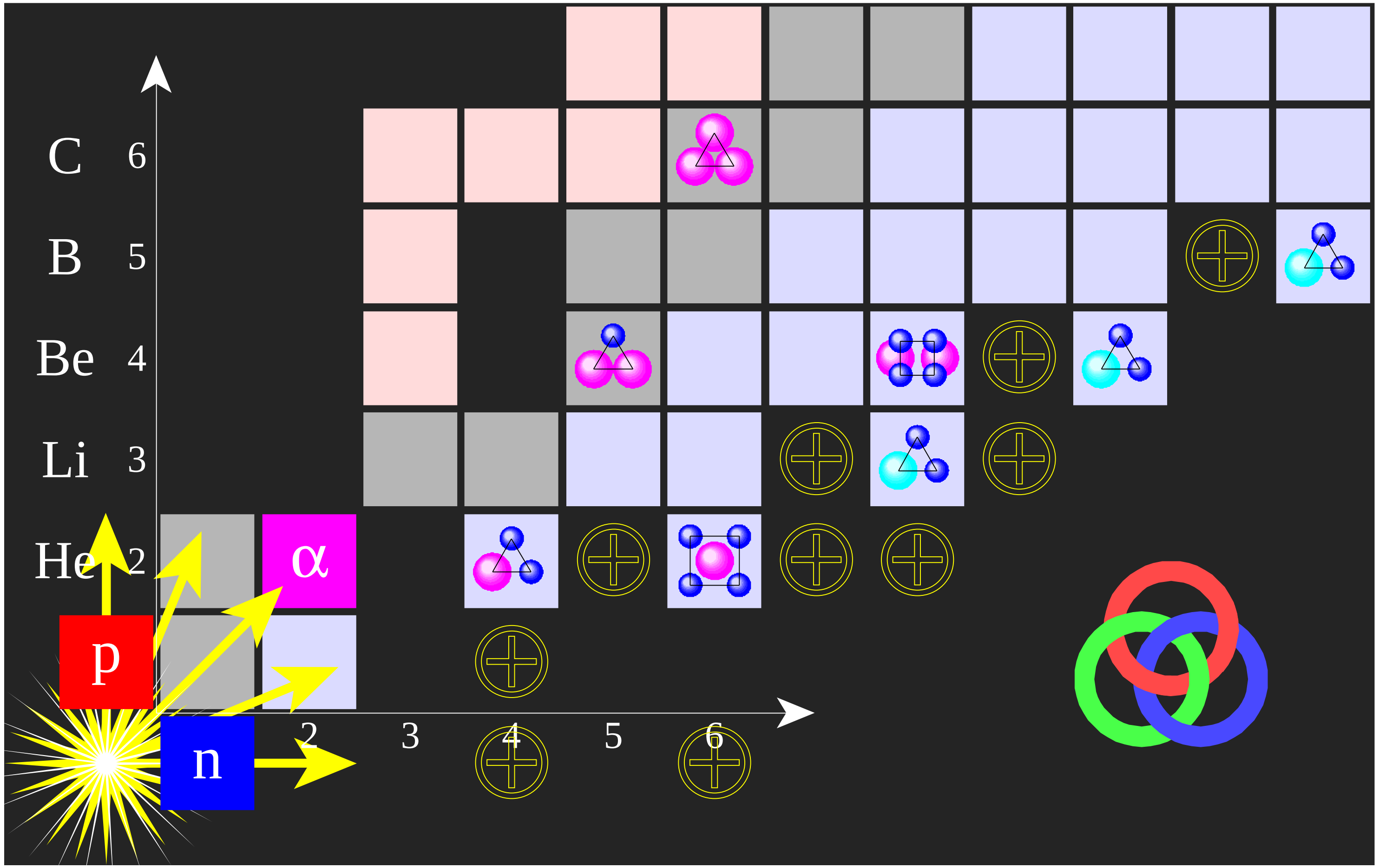


▷ non-resonant continuum

▷ plus $a_s = -3$ fm

▷ plus p-wave : $(E, \Gamma) \sim 1$ MeV

light nuclei in the continuum



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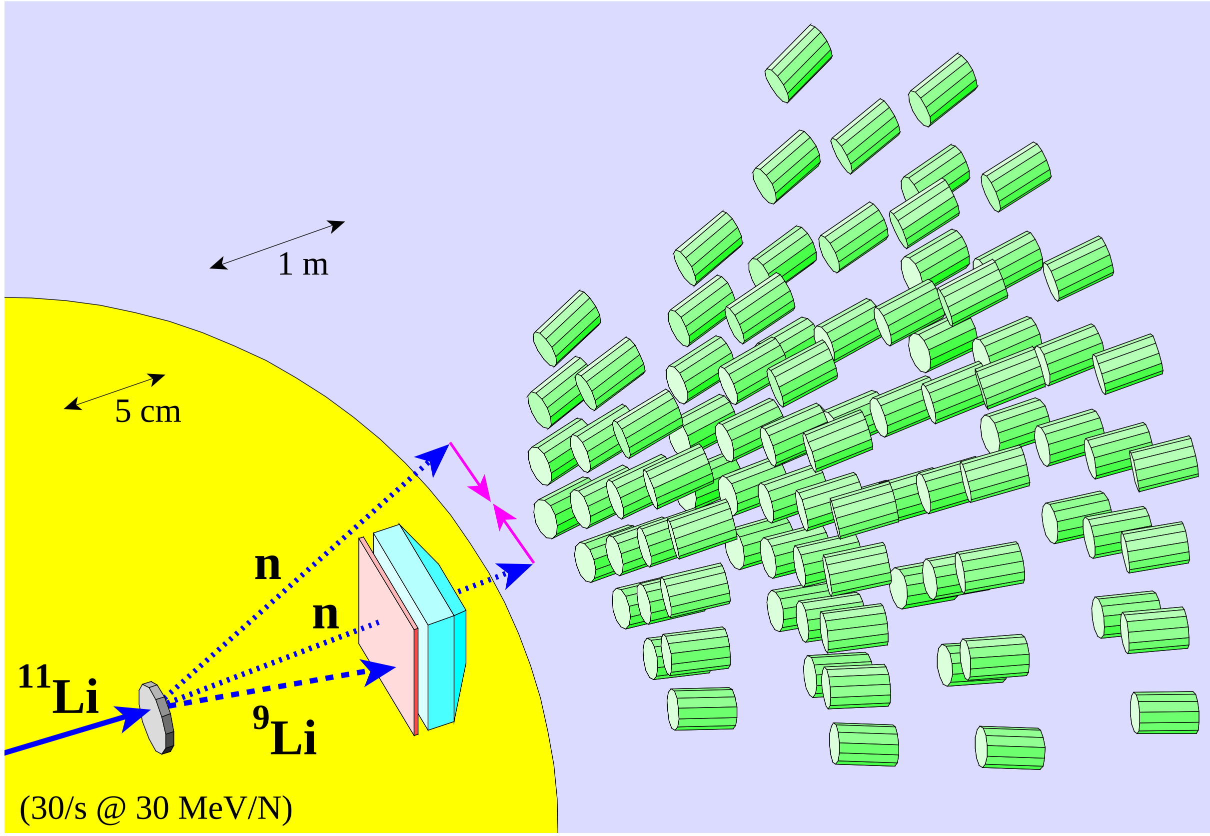
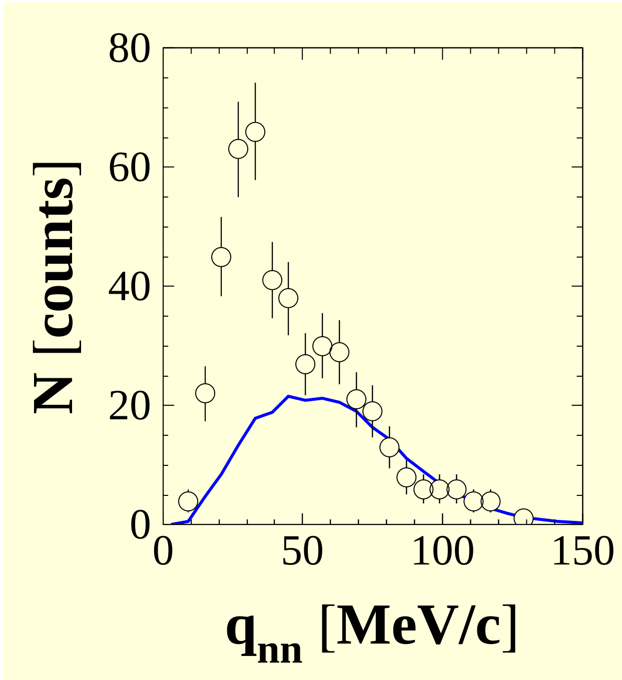
3-body continuum

▶ the halo of ^{11}Li : $\ddot{\bigcirc} \leftrightarrow$?





▷ $\sigma(q) \equiv \Omega(q) \times C_{nn}\,\{\psi(r_{nn}), a_{nn}\}$:

$\rightsquigarrow$ $\sigma(q)$ is measured

$\rightsquigarrow$ event mixing provides $\Omega(q)$ …

3-body continuum

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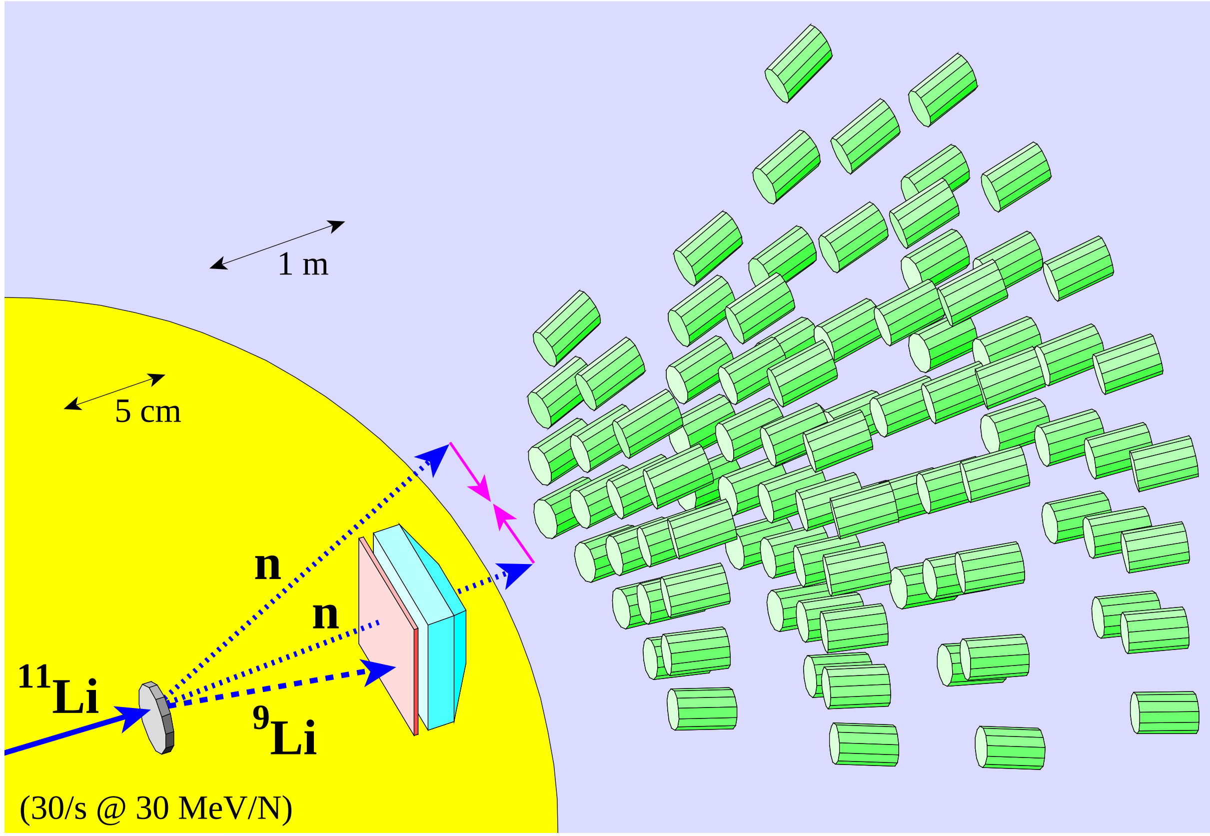

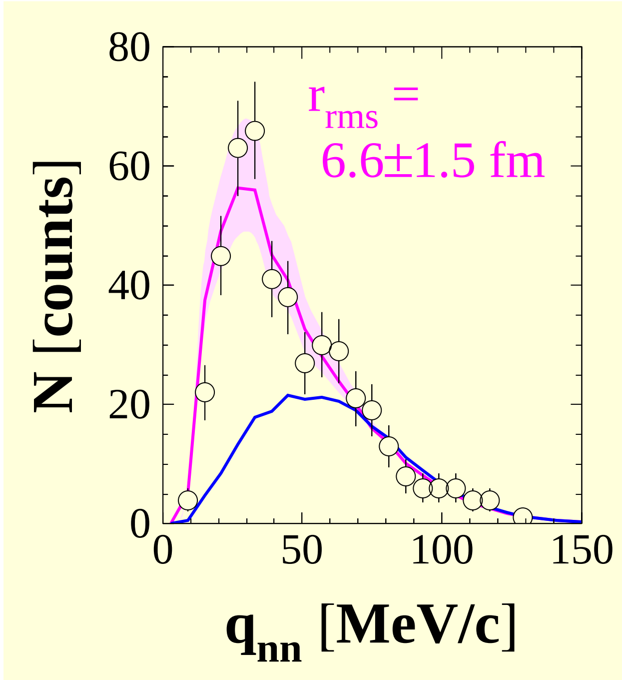

▹ $\sigma(q) \equiv \Omega(q) \times C_{nn}\{\psi(r_{nn}), a_{nn}\}$:

⇝ $\sigma(q)$ is measured

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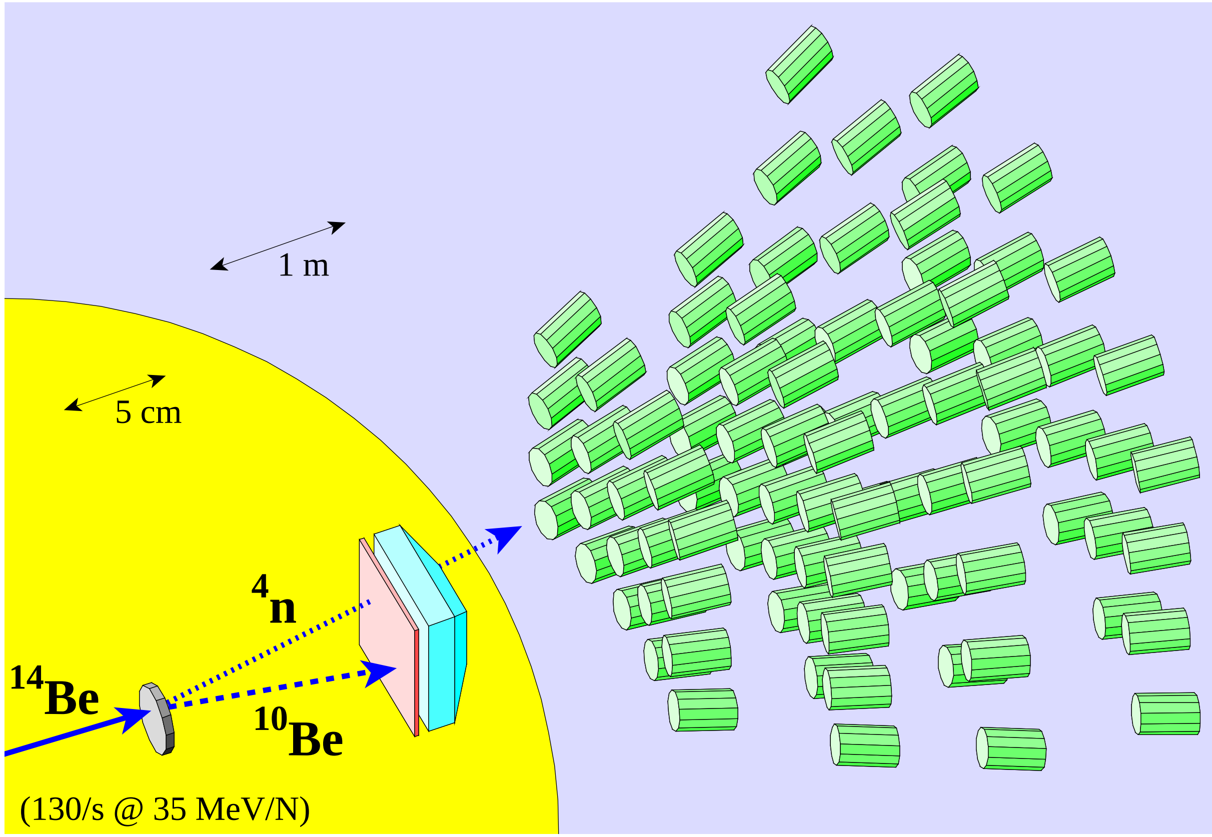
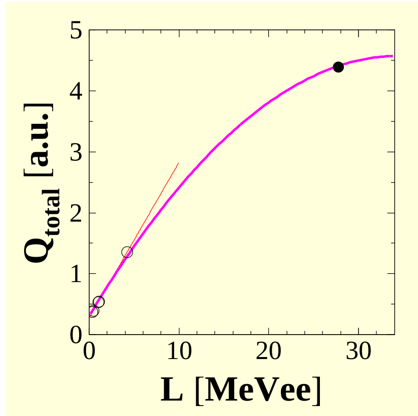
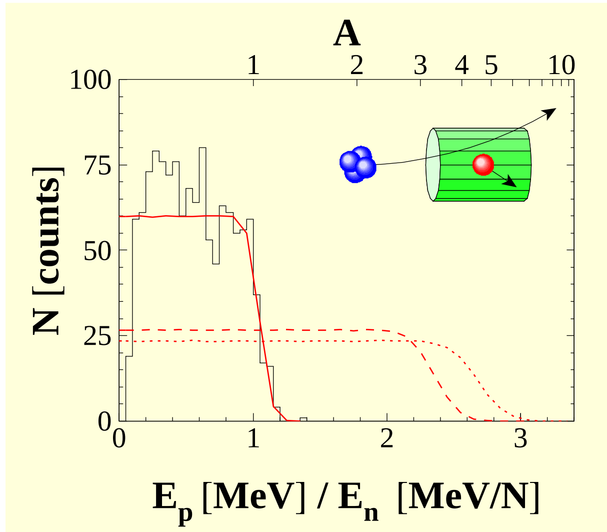
4-body continuum ?

▶ $|{}^{14}\mathrm{Be}\rangle \equiv a\,|{}^{10}\mathrm{Be} + {}^{4}\mathrm{n}\rangle + \cdots$



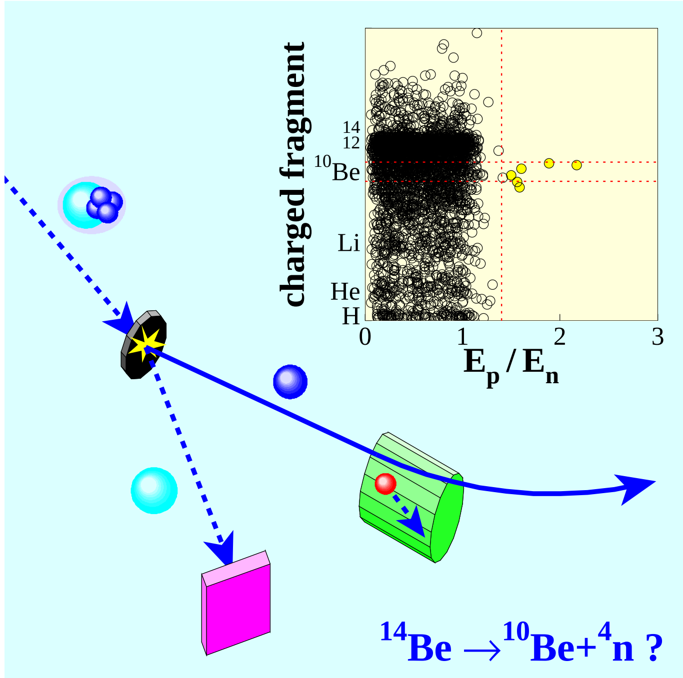




▷ effective + clean + sensitive !!!

▷ saturation (sensitive to low E_p) …

4n candidate events



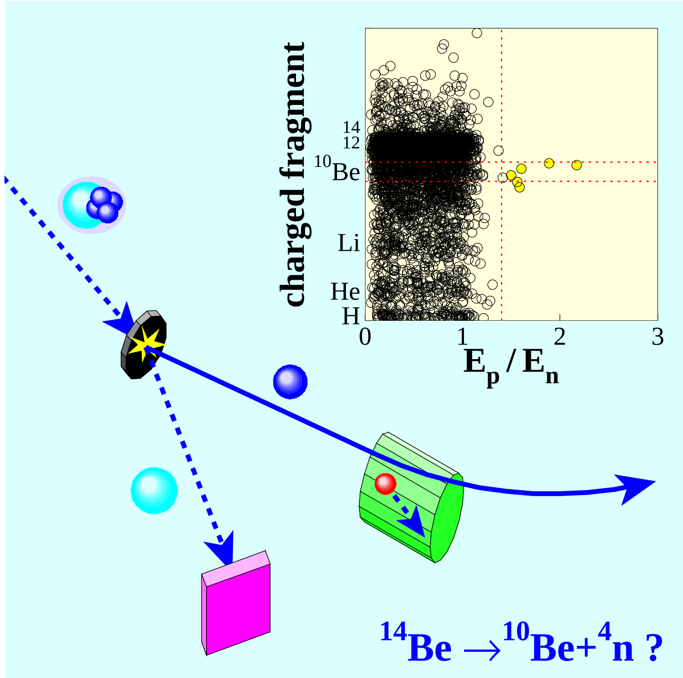
$$^{14}\mathrm{Be} \xrightarrow{(\mathrm{C})} {}^{10}\mathrm{Be} + {}^{4}\mathrm{n} \quad ('01, '02)$$

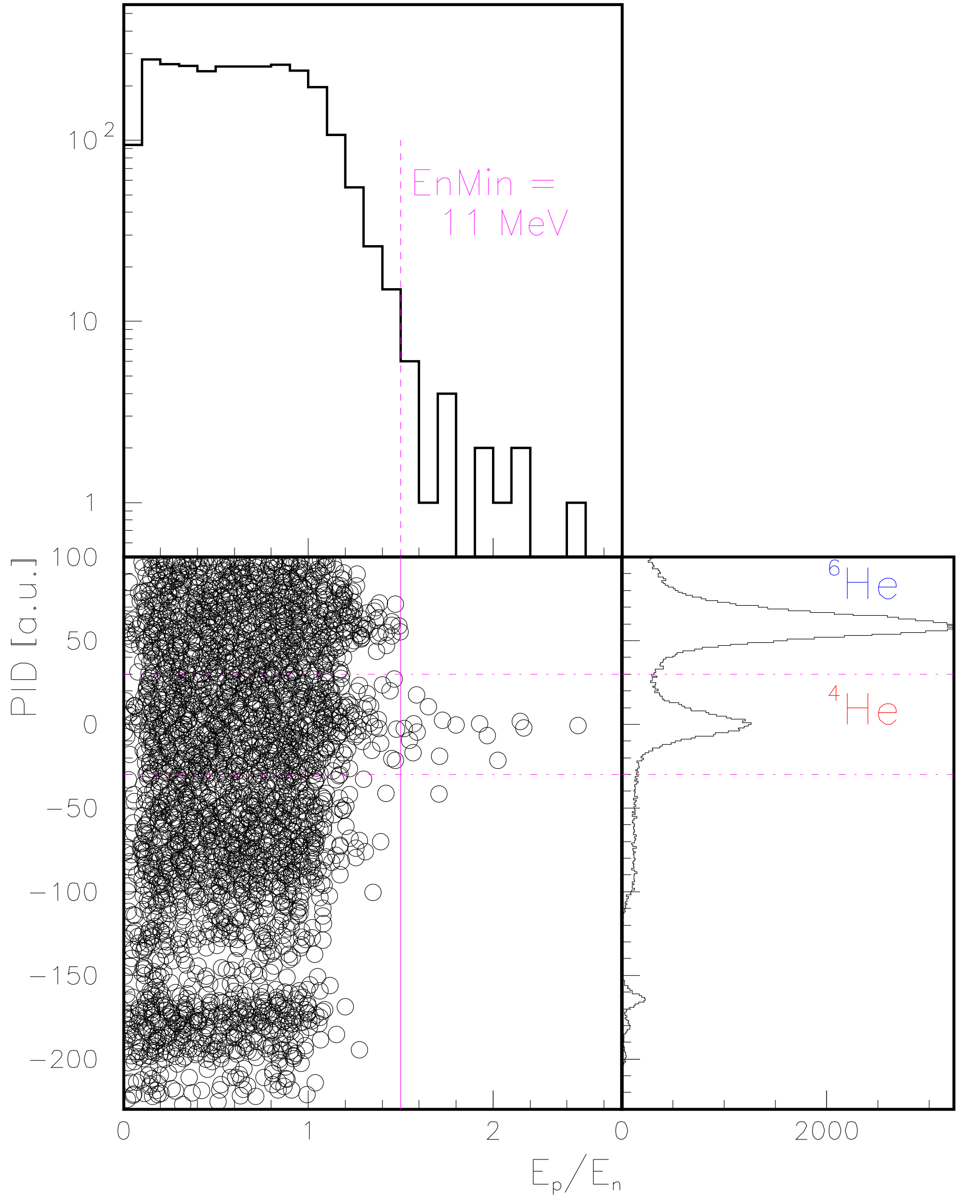
$$^{8}\mathrm{He} \xrightarrow{(\mathrm{C})} {}^{4}\mathrm{He} + {}^{4}\mathrm{n} \quad ('02)$$

$$^{12/14}\mathrm{Be} \xrightarrow{(\mathrm{C})} 2\alpha + {}^{4/6}\mathrm{n} \quad ('02)$$

$$^{8}\mathrm{He} \xrightarrow{(d)} {}^{4}\mathrm{He} + d\ [+{}^{4}\mathrm{n}] \quad ('04)$$

4n candidate events [Bouchat, preliminary]





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preliminary conclusions & outlook

- unbound nuclei [Al Falou] :
  - ^{7}He : no excited state ...
  - ^{10}Li : $a_s \sim -14$ fm + p-wave
  - ^{9}He : $a_s \sim -3$ fm + p-wave ?

    $\rightsquigarrow$ N = 7 s/p inversion

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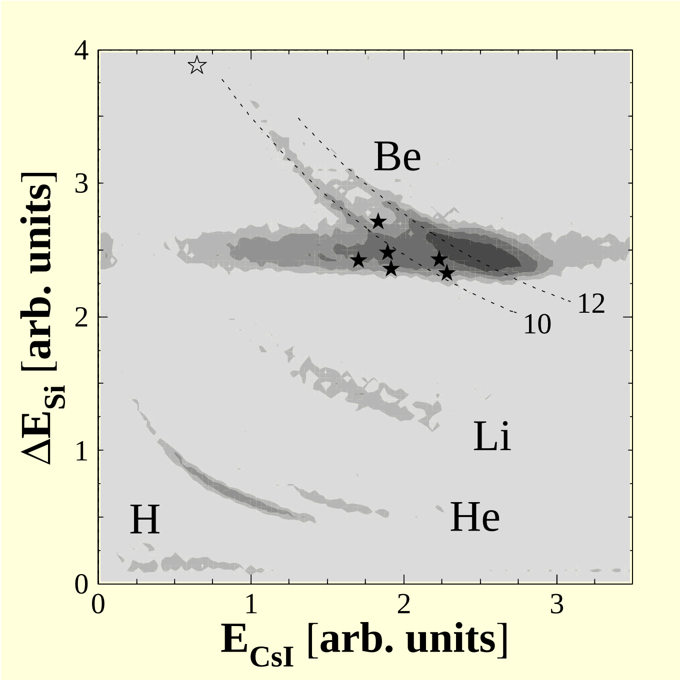

- DEMON @ GANIL '06 [Leprince] :

$$^{15}\text{B} \xrightarrow{(\text{C})} \ldots$$

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- DEMON @ GANIL '06 [Leprince] :

$$^{15}\mathrm{B} \xrightarrow{(\mathrm{C})} \ \ldots$$

  - ^{10}Li, ^{9,10}He, ^{12}Li
  - $^{14}\mathrm{Be}^{*} \longrightarrow {}^{12}\mathrm{Be}+\mathrm{nn}$

    $\longrightarrow {}^{10}\mathrm{Be}+{}^{4}\mathrm{n}$

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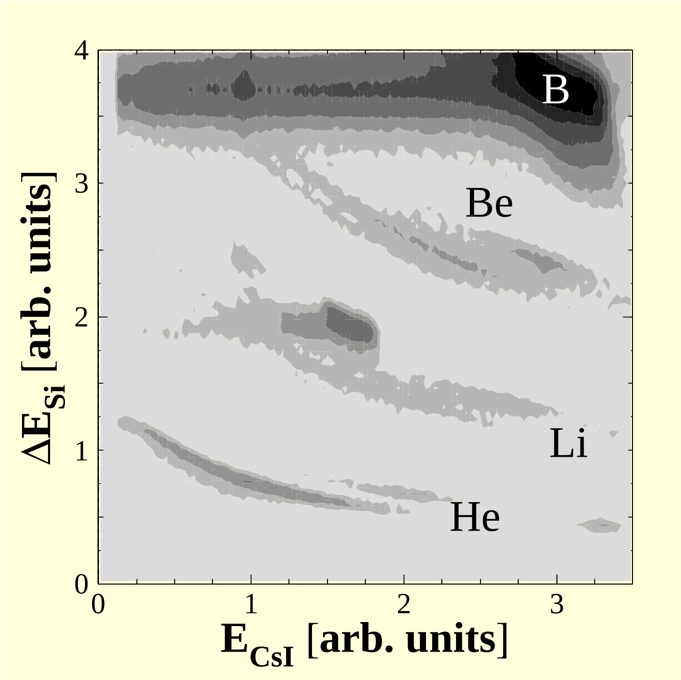
  ⇝ clean Be identification



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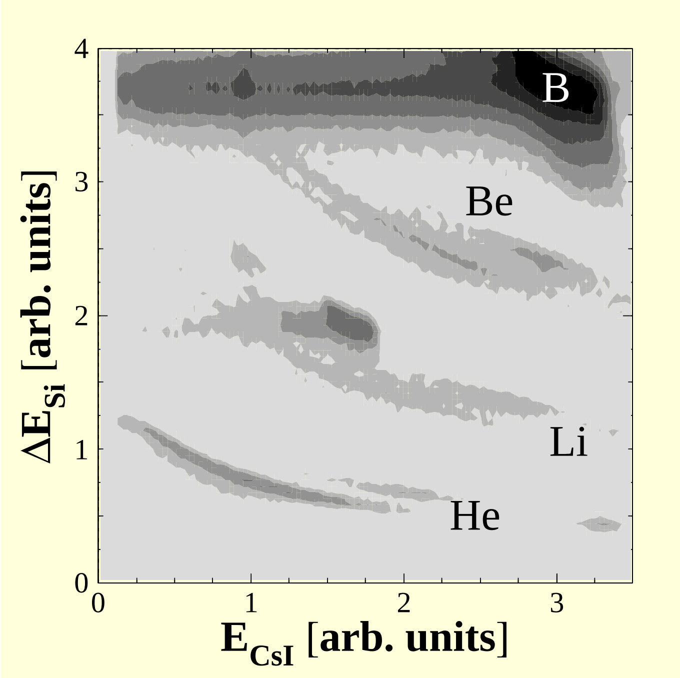


▶ β-delayed neutrons ?

▷ ^{11}Li [$Q_{\beta 2n} = 13$ MeV]

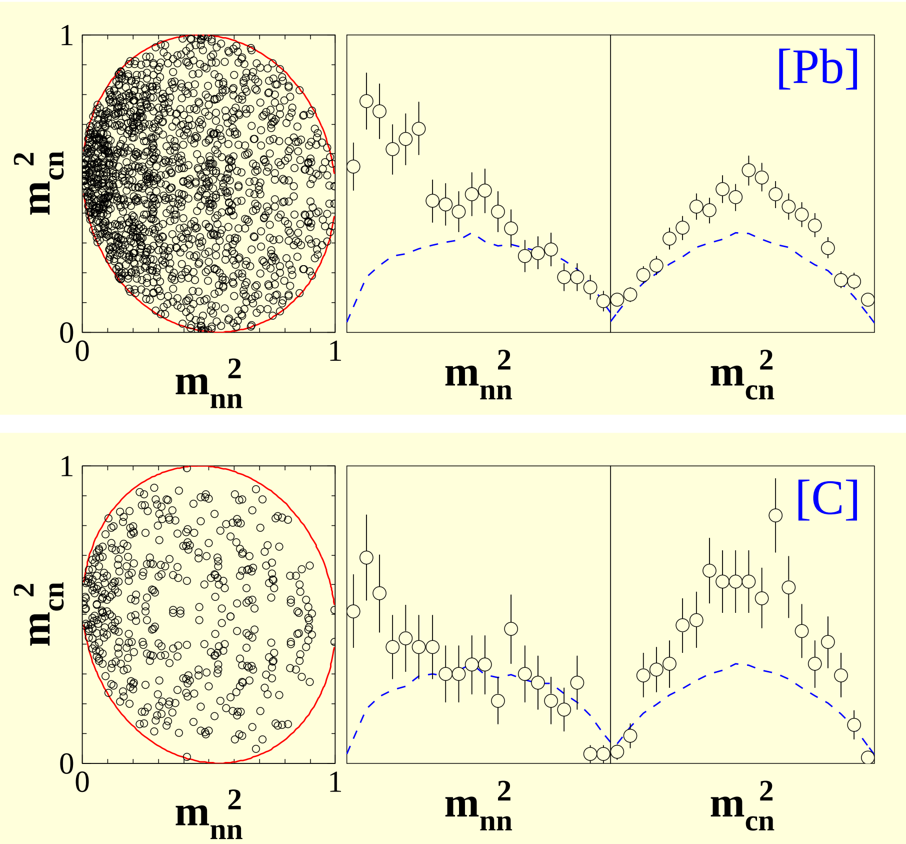
▷ ^{17}B [$Q_{\beta 4n} = 9$ MeV]

▷ ^{19}B [$Q_{\beta 4/6n} \sim 17/8$ MeV]
[$S_{4n} \sim 2$ MeV !!!]

⇝ ^{11}Li planned @ GANIL '09

3-body correlations

- ^{14}Be [FMM et al, PRC 64 (2001) 061301] :
  - ▷ decay $\longrightarrow$ ^{12}Be+nn
  - ▷ Dalitz plots (core-n vs n-n) :



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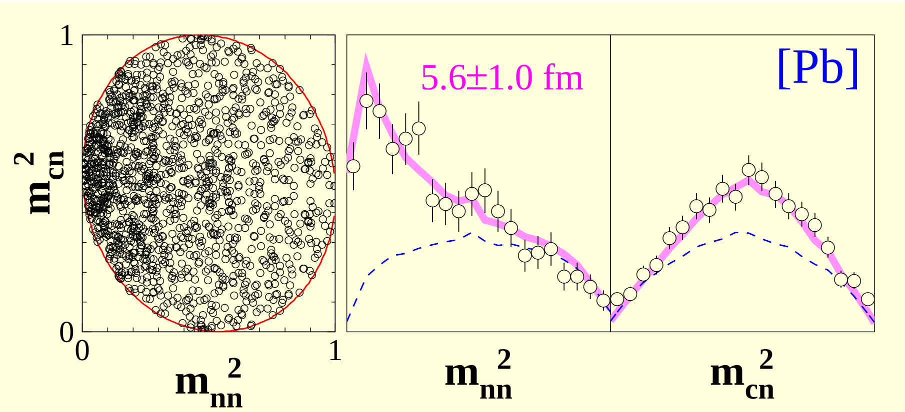
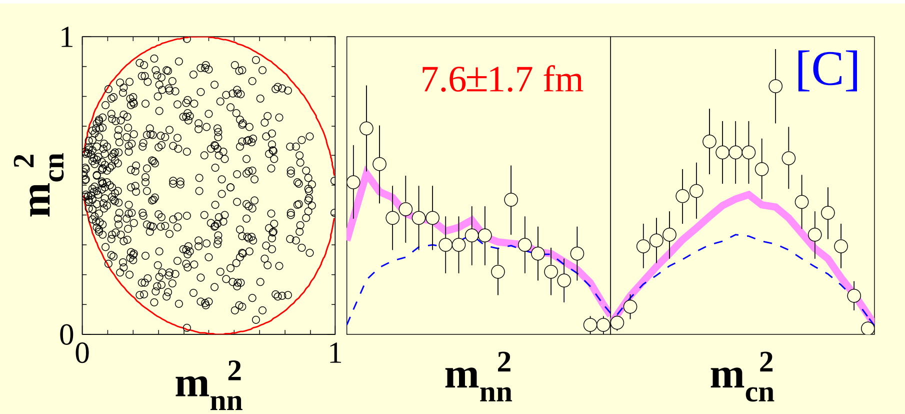
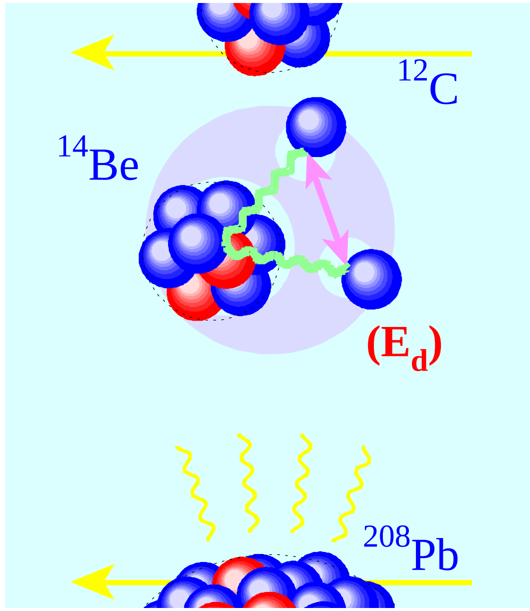
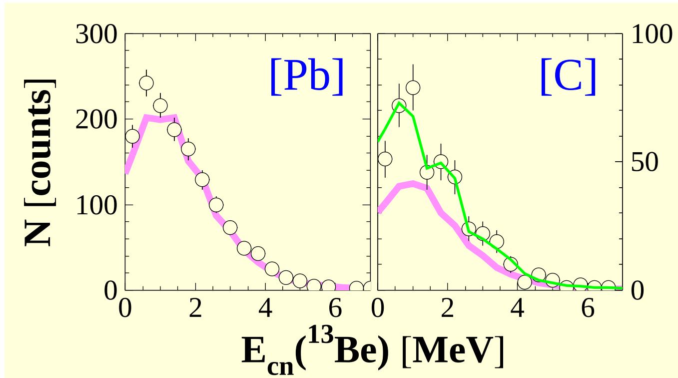




$\rightsquigarrow$ r_{nn}[C] $>$ r_{nn}[Pb] ???

- ▶ core-n resonances :



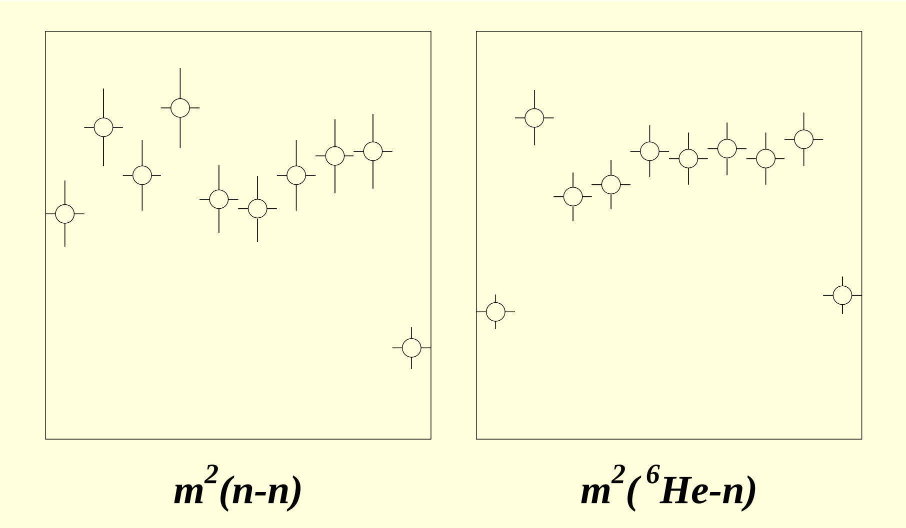


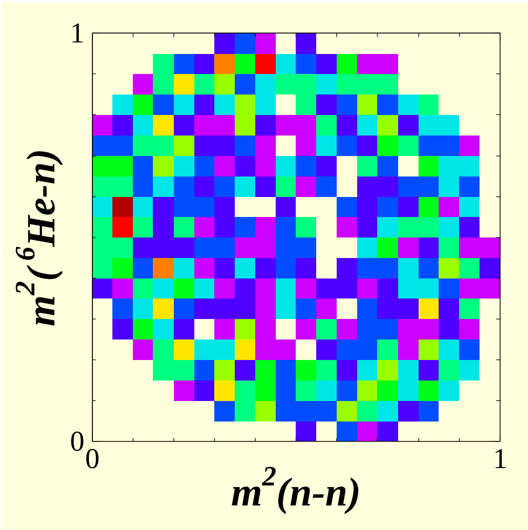
$\rightsquigarrow$ $r_{nn}^{rms} = r_{nn}$[Pb] !

$\rightsquigarrow$ E_{cn} + $\langle\tau_{cn}\rangle \lessapprox$ 400 fm/c !

femto+chronometer [Laurent]

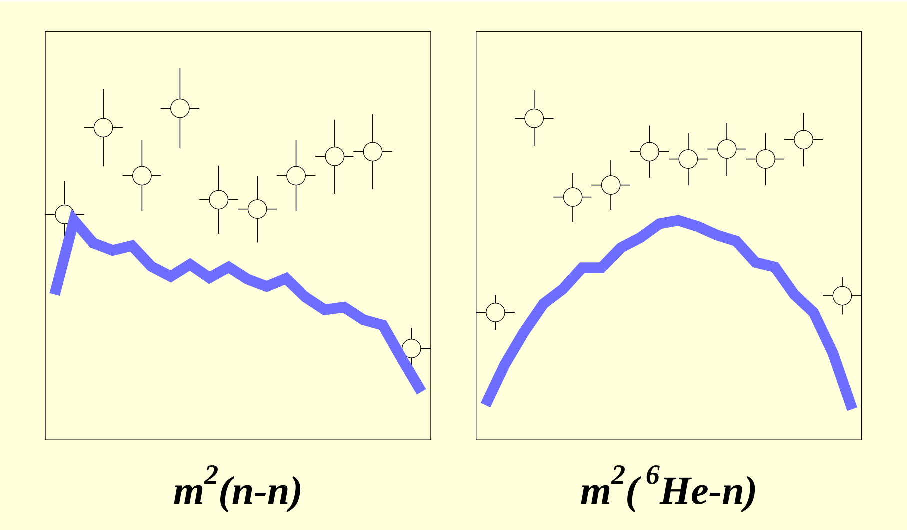
- $^8He^* \xrightarrow{(C)} {}^6He + nn$:

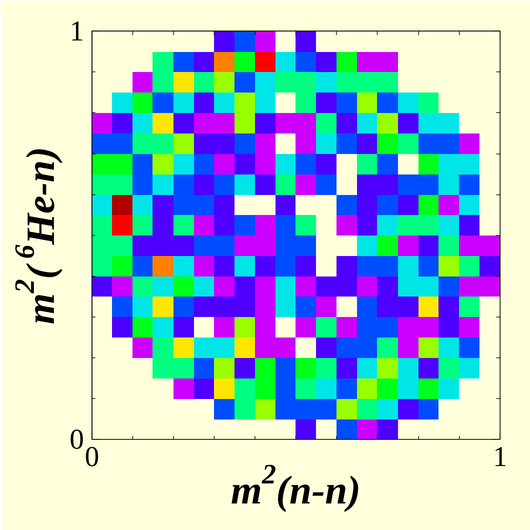




femto+chronometer [Laurent]

- $^{8}\mathrm{He}^{*} \xrightarrow{(\mathrm{C})} {}^{6}\mathrm{He}+\mathrm{nn}$:

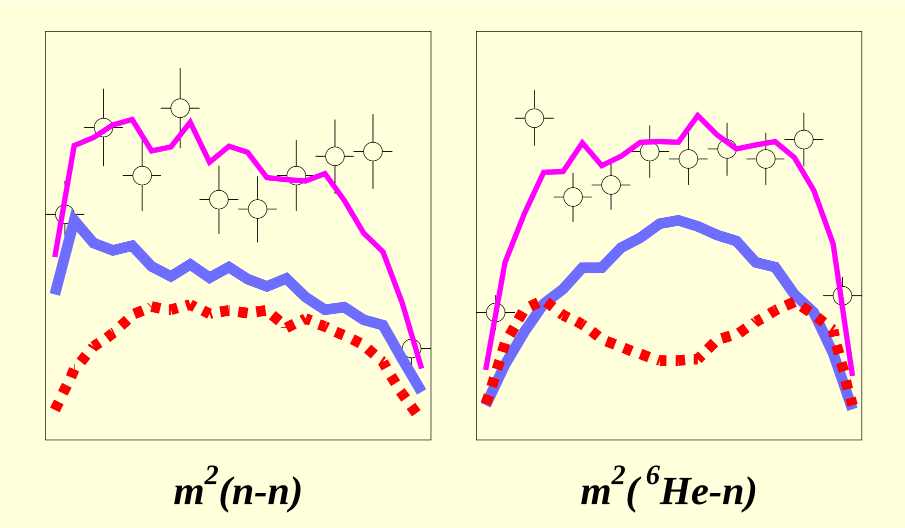


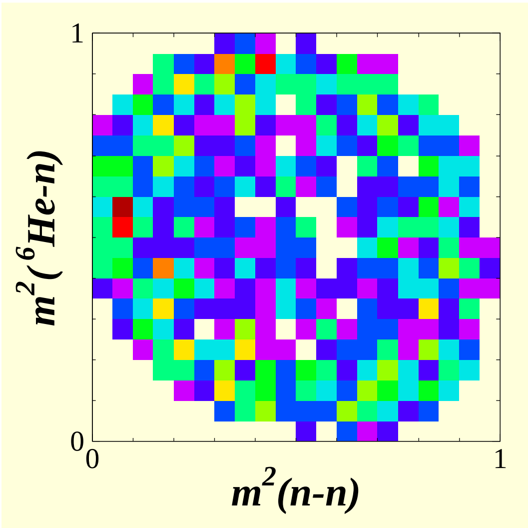


[60%] $\longrightarrow {}^{6}\mathrm{He}+\mathrm{nn}\ _{[C_{nn}(r_0)]}$

femto+chronometer [Laurent]

- ^{8}He$^* \xrightarrow{(C)} {}^6$He+nn :



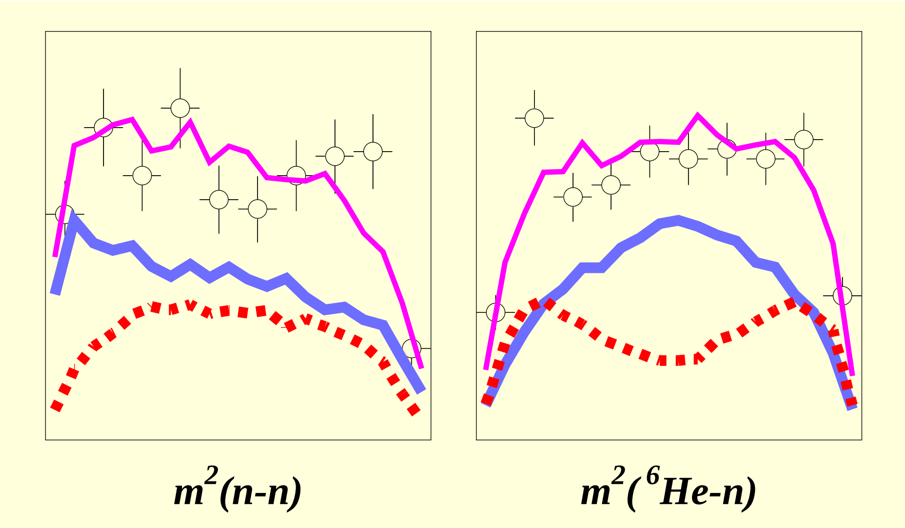


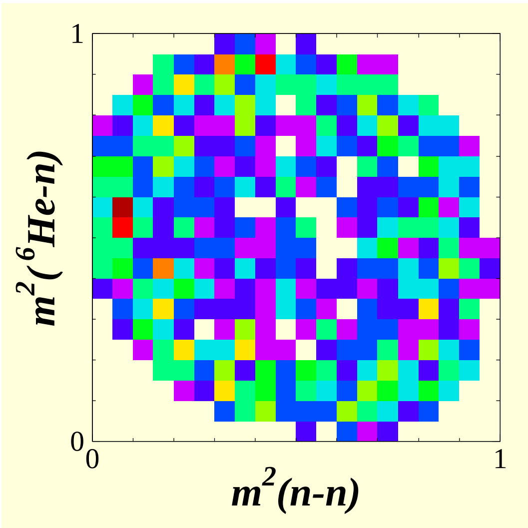
[60%] $\longrightarrow {}^6$He+nn $[C_{nn}(r_0)]$

[40%] $\longrightarrow {}^7$He+n $\xrightarrow{\tau} {}^6$He+nn $[C_{nn}(r_0,\tau)]$

femto+chronometer [Laurent]

▸ $^{8}\mathrm{He}^{*} \xrightarrow{(C)} {}^{6}\mathrm{He}+nn$:

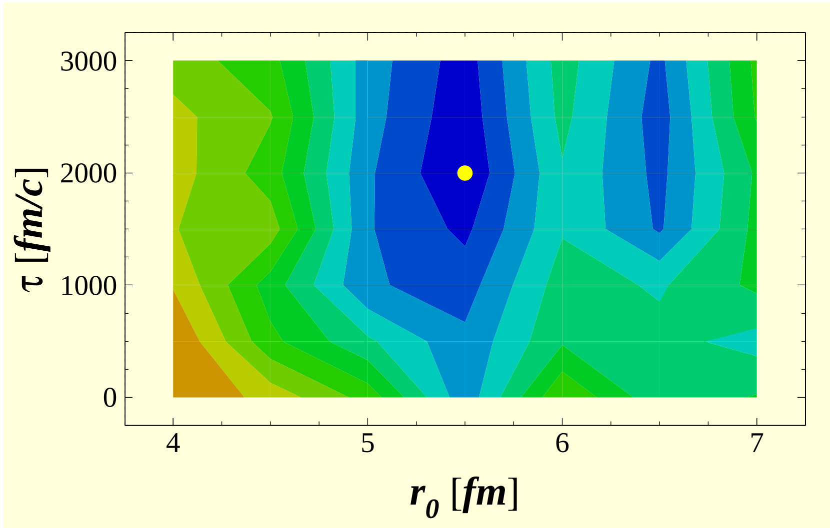




[60%] $\longrightarrow {}^{6}\mathrm{He}+nn$ $[C_{nn}(r_0)]$

[40%] $\longrightarrow {}^{7}\mathrm{He}+n \xrightarrow{\tau} {}^{6}\mathrm{He}+nn$ $[C_{nn}(r_0,\tau)]$

▸ how sensitive to τ ?



$\rightsquigarrow \tau = 2000 \pm 500$ fm/c

[same order than $\Gamma(^{7}\mathrm{He})$]