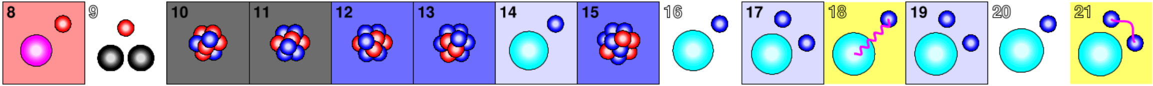
Exotic phenomena at the dripline: the most neutron-rich boron isotopes

Emeline OLIVEIRA

September 2026

The boron isotopic chain

With only five protons : wide variety of structures



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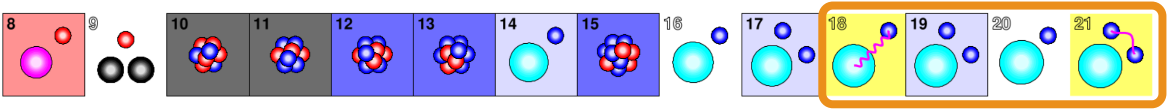

Exotic phenomena at neutron threshold :

- ^{18}B : (very) Large scattering length ? Measurable ?
- ^{19}B : Efimov Physics ?
- ^{21}B : n-n correlations, (anti)alignment ?

➠ Analysis of two experiments @ RIKEN

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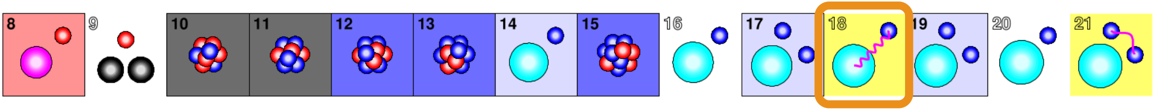

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n-^{17}B interaction

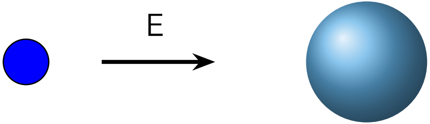
→ n-N scattering exp.

→ Important parameters ?

Low energy scattering ($\ell = 0$)

Effective range approximation

$$\varphi_k(r) \approx \frac{sin(kr + \delta_0)}{kr}, \; k = \sqrt{2\mu E} \;, \quad V = \emptyset$$



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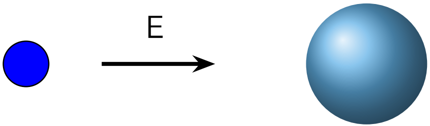

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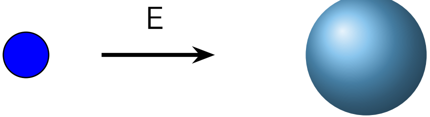

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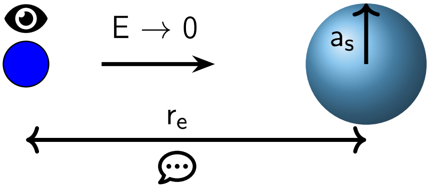

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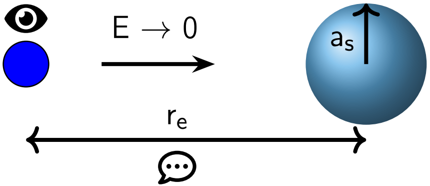

Production of the case of interest

→ Neutron off exotic nuclei ?
Unstable !

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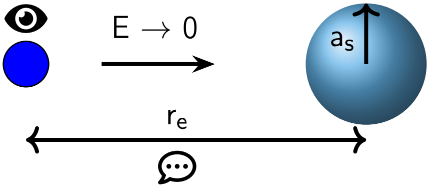
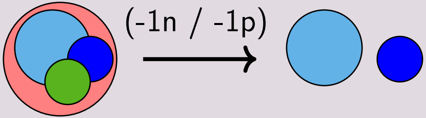


Production of the case of interest

→ Neutron off exotic nuclei ?
Unstable !

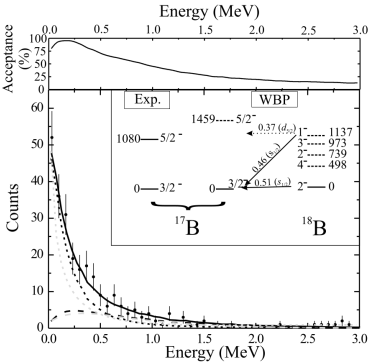
→ Knockout reaction :
Sudden approximation



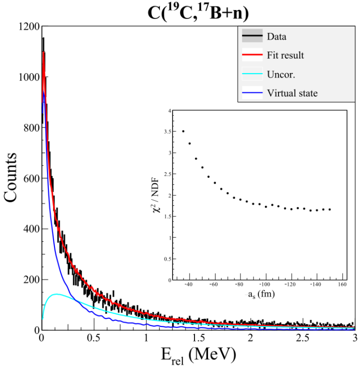
→ Container :
- similar structure
- n in an *s*-wave
- weakly bound

^{18}B structure

- Why n+^{17}B ? $(a_s, r_e) \rightarrow \delta_0 \rightarrow V(n\text{-}^{17}B)$
- Why V(n-^{17}B) ? Only a limit : $a_s <$ -50 fm !

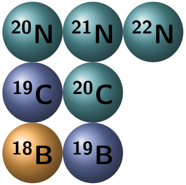


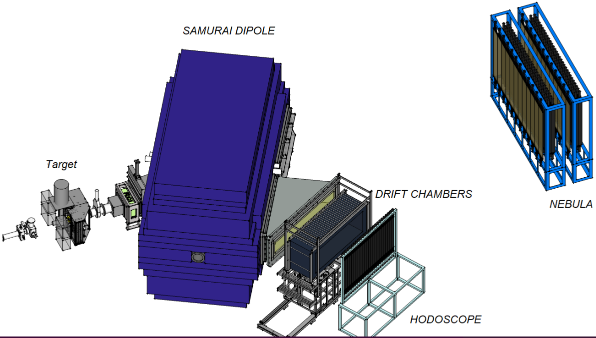
Spyrou, Phy. Let. B 683 (2010)



Leblond, PhD (2015)

Experiment @ RIKEN-RIBF - SAMURAI Collaboration (2012)





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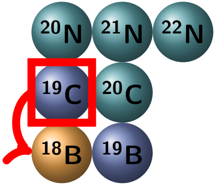
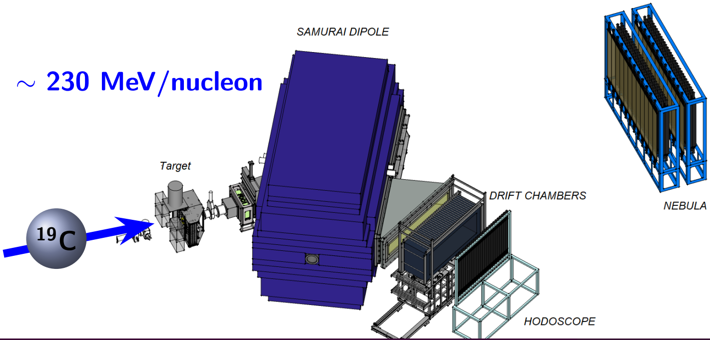


$\sim$ 230 MeV/nucleon



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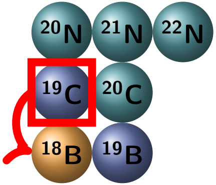

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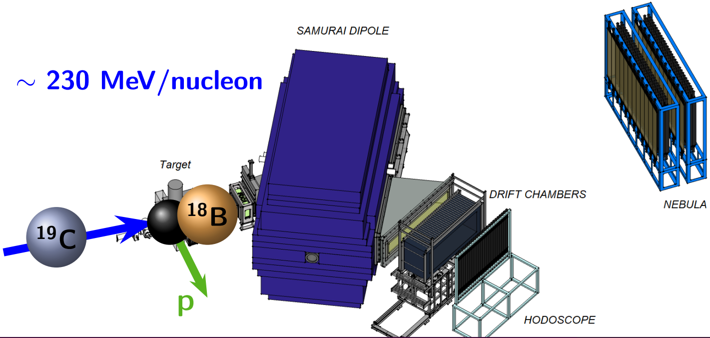

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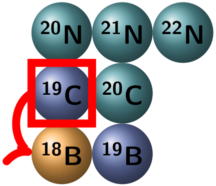

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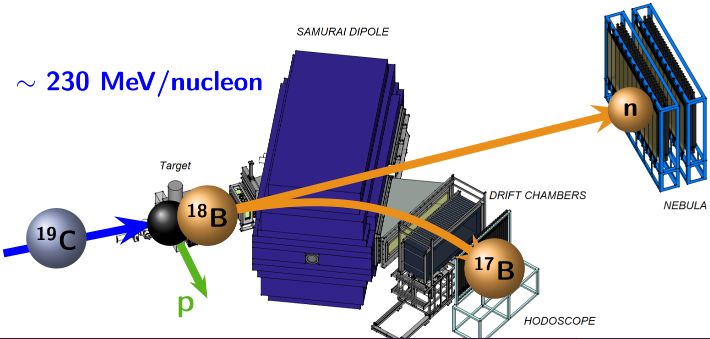
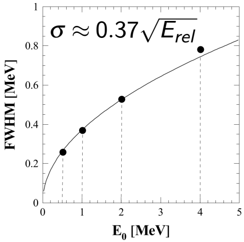
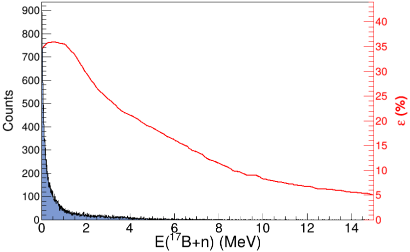
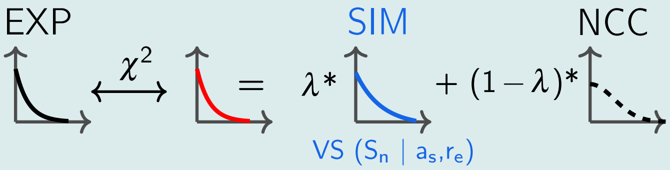






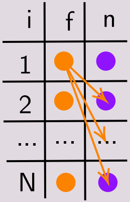
Parameters characterisation method

χ^2 minimisation



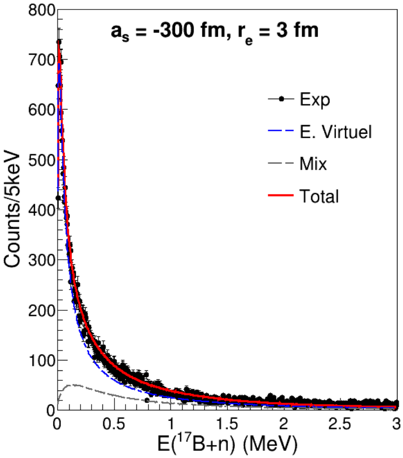
Non-Correlated Contribution

EXP
- ➤ ^{18}B (^{17}B+n)
- ➤ ^{17}B & n ⟶ Mixing



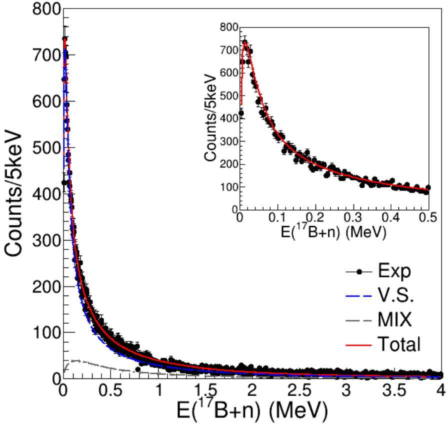
✔ Shape

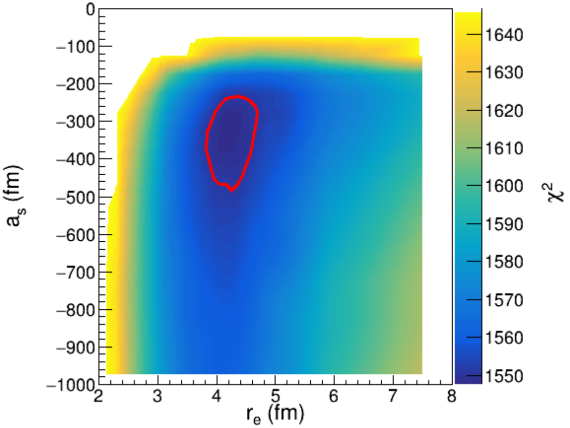
✔ Measured events



Results at nuclear/atomic scale ?

$$a_s \approx -350^{+90}_{-160}\ \text{fm}\ ,\ r_e \approx 4.1^{+0.5}_{-0.3}\ \text{fm}$$





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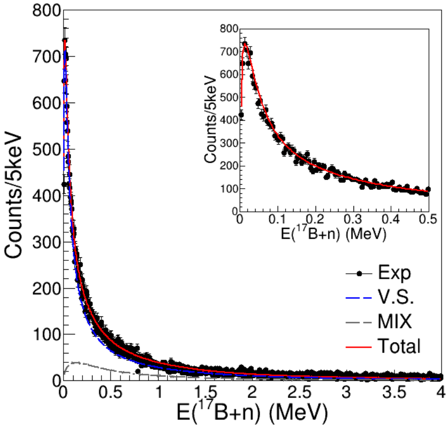
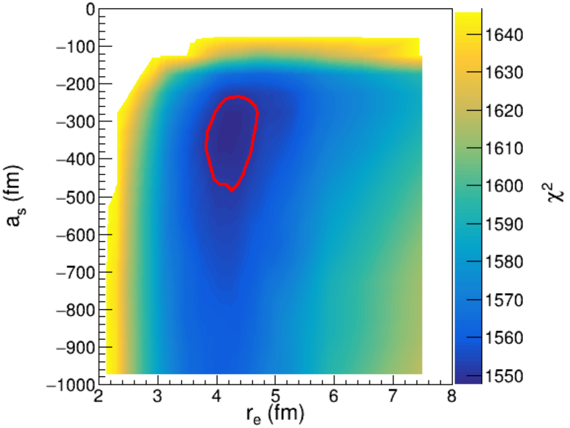
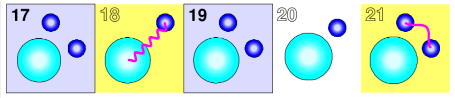
$$E \approx \hbar/2\mu a_s^2 = 180^{+150}_{-90}\ \text{eV (AME)}$$



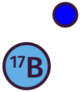


Two-neutron emission: ^{21}B

With only 5 protons ?



^{18}B : Very large scattering length, $a_s = -350$ fm !



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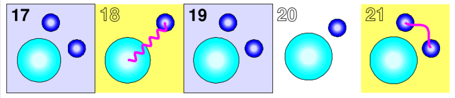

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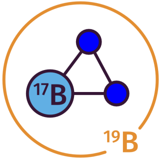
Universality !



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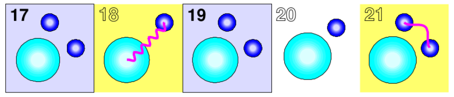

^{18}B : Very large scattering length, $a_s = -350$ fm !

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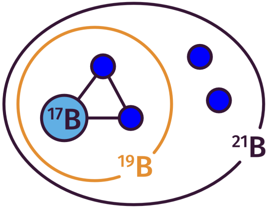
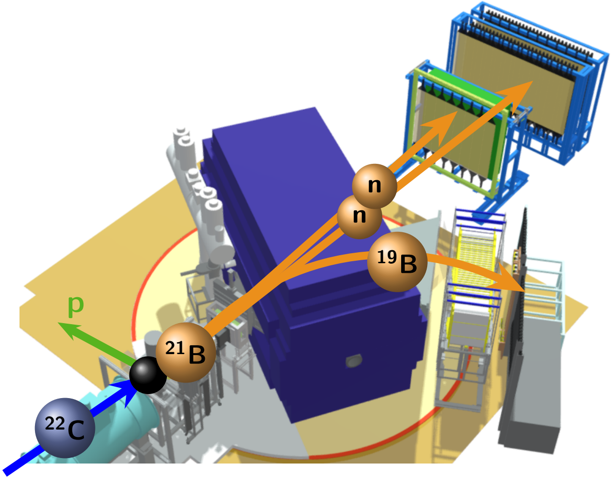
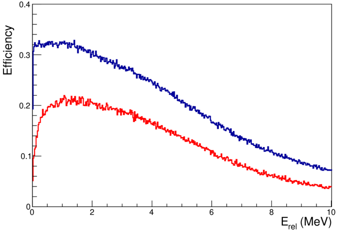
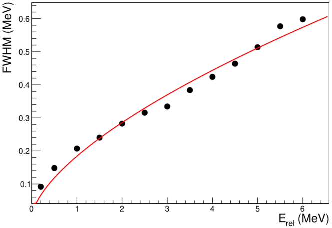
^{21}B : Direct two-neutron emission : n-n correlations ?



Experiment @ RIKEN-RIBF - SAMURAI Collaboration (2016)





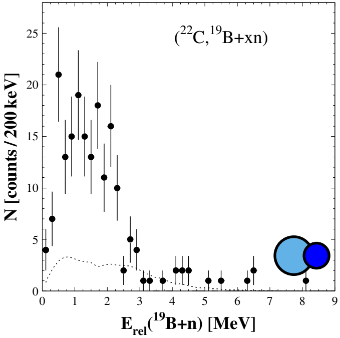


The heavier isotope: ^{21}B

S04 : ^{21}B first observation

- Direct : plateau ^{19}B+n $\rightarrow$ 3 P.S.
- Fit ^{19}B+n : E$= 2.47 \pm 0.19$ MeV

Leblond, PRL 121, 262502 (2018)



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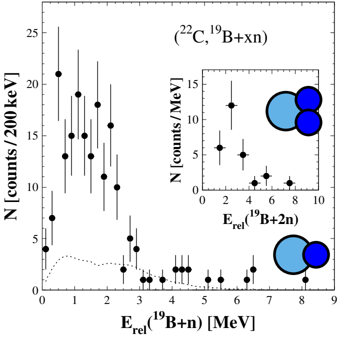

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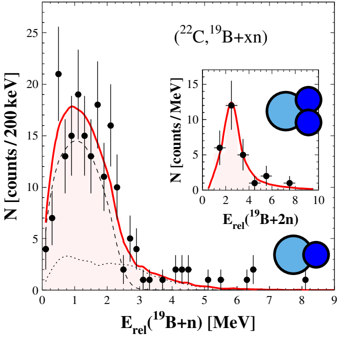

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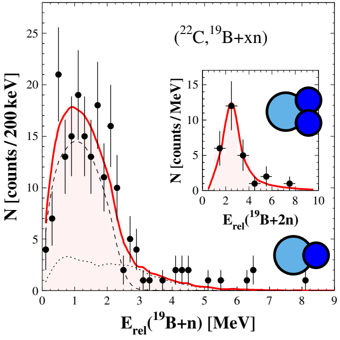
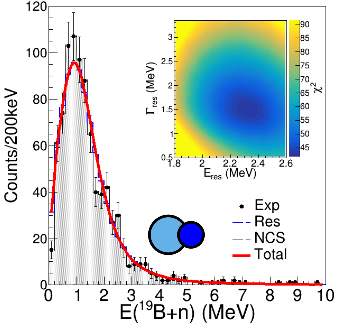
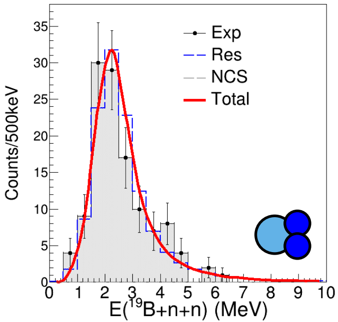
S36 : beam intensity + NeuLAND
- Better precision : E$=2.30\pm0.16$ MeV
- Study of n-n correlations ...

Leblond, PRL 121, 262502 (2018)







Exotic two-neutron emission ?

Dalitz Plot

- n-n and f-n correlations
- Normalized energies ε_{nn}, ε_{fn}

$$\varepsilon = \frac{E_{rel}(2\ bodies)}{E_{rel}(3\ bodies)}$$

- Phase space : flat

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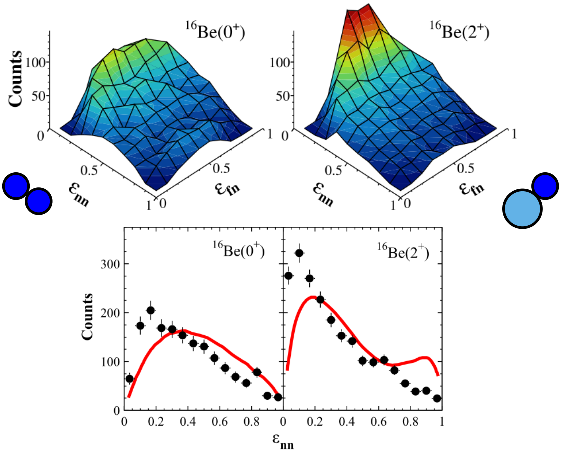
- Phase space : flat

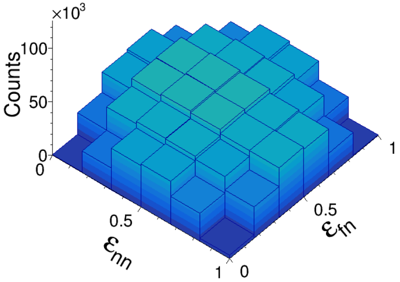
Demonstration with ^{16}Be

- ^{14}Be+n+n from ^{17}B
- Direct 2n decay
- Strong enhancement at $\varepsilon_{nn} \to 0$
- Typical example

Monteagudo, PRL 132, 082501 (2024)

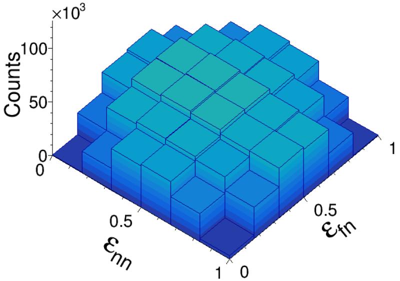


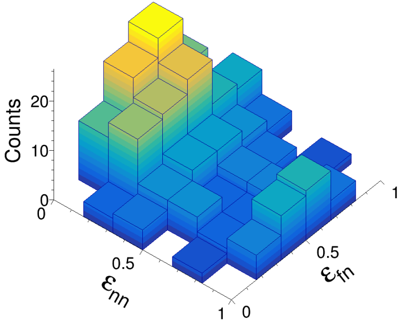
Decay of $^{21}B \rightarrow {}^{19}B+n+n$



Decay of ^{21}B $\rightarrow$ ^{19}B+n+n

- Strong n-n correlations
- Strong decrease $\varepsilon \sim 0.6$
- Origin : structure of ^{21}B !
- Theoretical calculations in progress...





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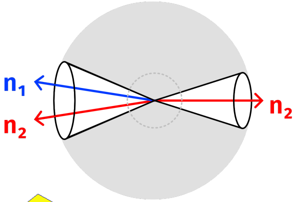
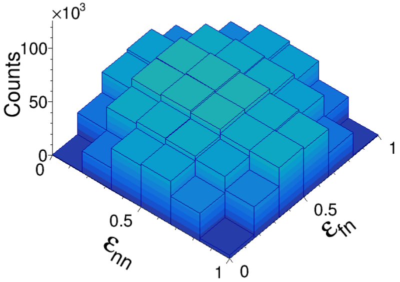
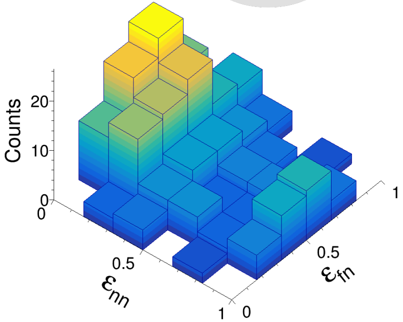
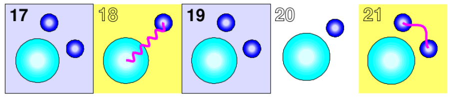






Conclusions and Outlook

With only 5 protons ?



^{18}B : Atomic scale ?
$a_s \approx -0.35$ pm, $r_e \approx 4.1$ fm, $E \approx 180$ eV !

^{19}B : $|a_s|/r_e \sim 100 \rightarrow$ Efimov Physics !

^{21}B : n-n correlations,
(anti)alignment in the decay ?
$\rightarrow$ Structure effect !

Outlook

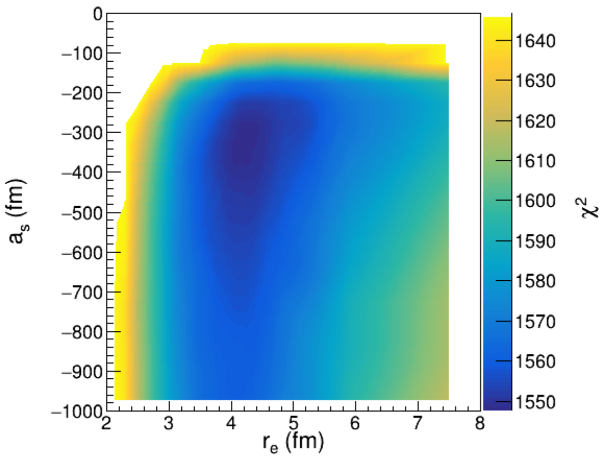
^{18}B :
- Systematic uncertainties
- Spin dependent scattering lengths ?

^{19}B : $\sim$ 0.5 MeV more bound
$\rightarrow$ Bound excited states ?
Efimov states ?

^{21}B :
- Not only n-n FSI
- Theoretical description

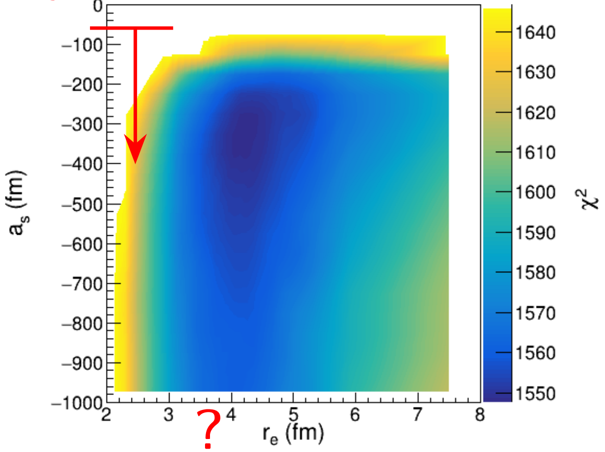
Why only in ^{21}B ?

Parameters sensitivity

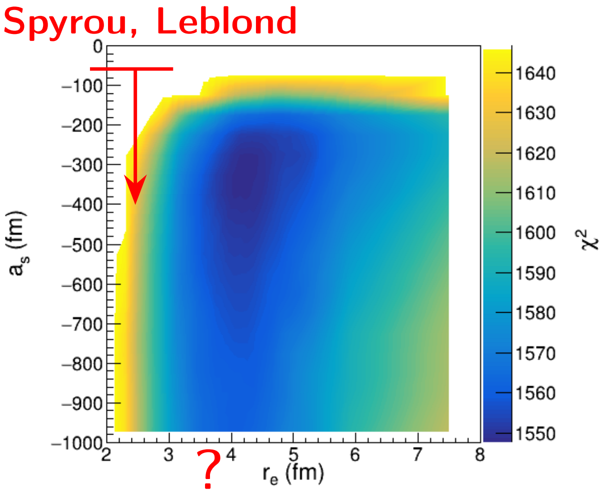


Parameters sensitivity

Spyrou, Leblond



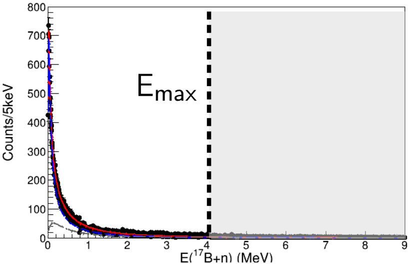
Parameters sensitivity

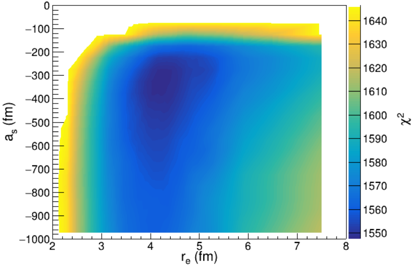


$$k\cot(\delta_0) = \frac{-1}{a_s} + \frac{r_e}{2}k^2 + \mathcal{O}(k^4)$$

$(k,E) \ll$ $(k,E) \gg$

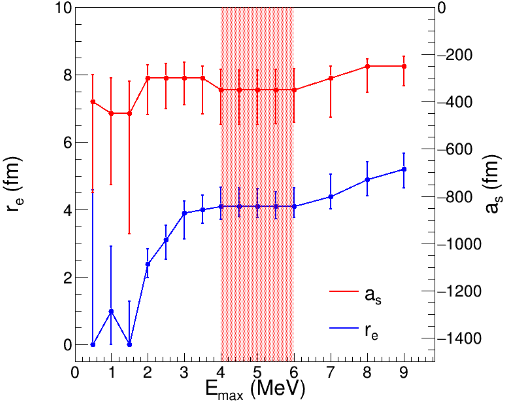
Parameters sensitivity



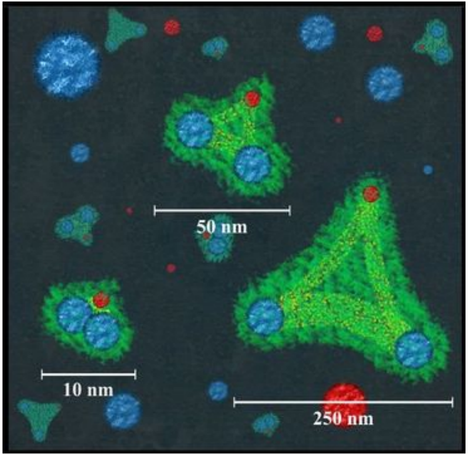


$$k\cot(\delta_0) = \frac{-1}{\boxed{a_s}} + \frac{\boxed{r_e}}{2}k^2 + \mathcal{O}(k^4)$$

$(k, E) \ll$ $(k, E) \gg$



Annexe: Physique Efimov (PRL 112, 250404 (2014))



"The size of successive trimers is larger by λ, while their binding energy is smaller by λ^2"

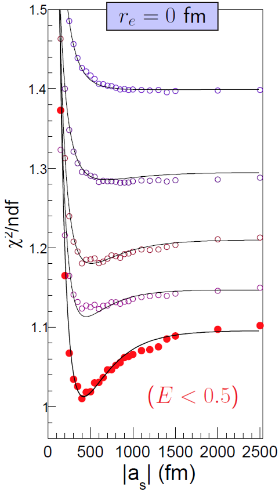
effective $1/R^2$ potential

- infinite number of bound states
- discrete scaling symmetry

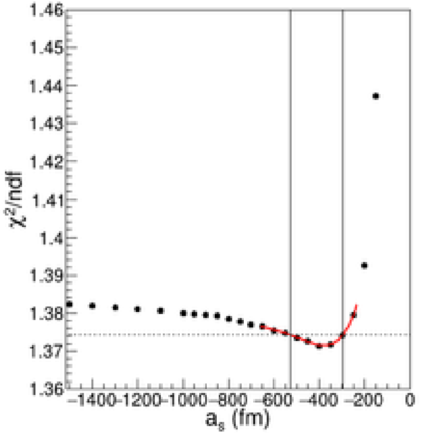
$$\psi_n(R) = \psi_{n-1}(\lambda R)$$

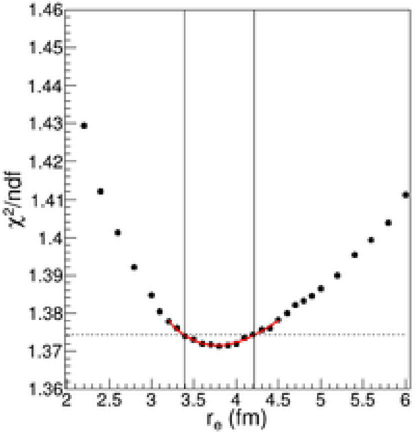
$$E_n = \lambda^{-2} E_{n-1}$$

Annexe: dépendance à la gamme d'énergie du fit (coupe $r_e = 0$)

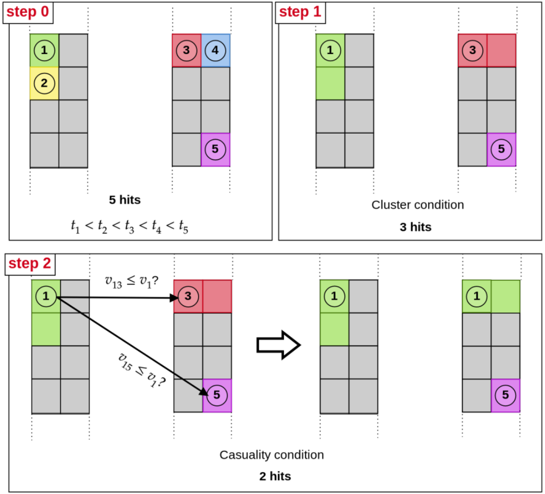


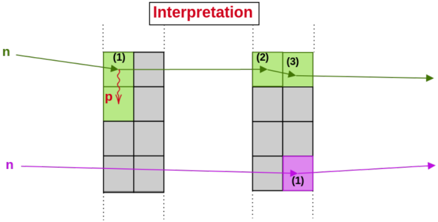
Annexe: détermination avec un fit $(a_s, r_e) = (-400,3.8)$fm



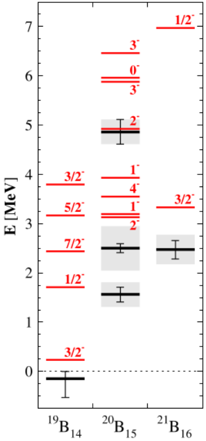


Annexe: Rejet de la Diaphonie (crosstalk)

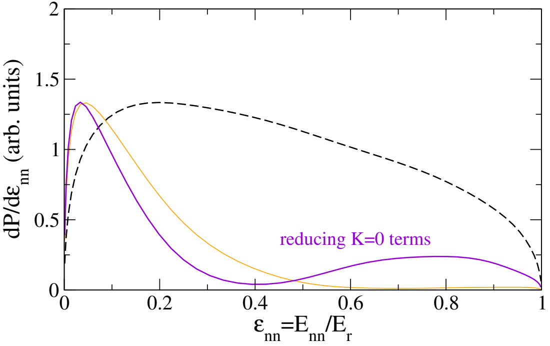




Annexe: Prédiction Shell Model $^{19,20,21}B$ (PRL 121, 262502 (2018))



Annexe: Description théorique du ^{21}B par J. Casal



- Three body modeling, incorporating a realistic description of the decay.
- ^{21}B wave function in the continuum based on standard Jacobi coordinates for three-body systems
- Hyperspherical formulation where K is the hypermomentum that defines the effective barrier in the hyperradial coupled-channels system.

Annexe: Formules du mélange d'événement (1/2)

Evenements non corrélés

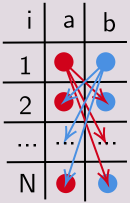
Particules indépendentes : $\begin{cases} a \\ b \end{cases} \Rightarrow \begin{cases} P_a \\ P_b \end{cases} \Rightarrow \frac{d\sigma}{dP_a}\frac{d\sigma}{dP_b}$

Si (a,b) émises ensemble : $\frac{d^2\sigma}{dP_a dP_b} = \frac{d\sigma}{dP_a}\frac{d\sigma}{dP_b} \times C(P_a, P_b)$

Annexe: Formules du mélange d'événement (2/2)

Event Mixing

Independent particles $\rightarrow$ virutal pairs $\rightarrow$ E_{rel}



$$\frac{d\sigma_\otimes}{dP_a} = \int \frac{d^2\sigma}{dP_a dP_b} dP_b = \frac{d\sigma}{dP_a} \int C(P_a, P_b) \frac{d\sigma}{dP_b} dP_b$$

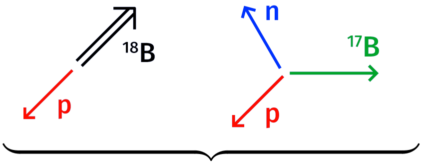
$$= \frac{d\sigma}{dP_a} \langle C \rangle (P_a)$$

$$\frac{d\sigma_\otimes}{dP_b} = \frac{d\sigma}{dP_b} \langle C \rangle (P_b)$$

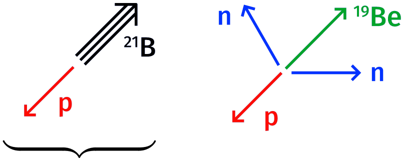
if $\langle C \rangle (P) \gg 1 \Rightarrow C(P_a, P_b) \geq \dfrac{d^2\sigma / dP_a dP_b}{(d\sigma_\otimes / dP_a)(d\sigma_\otimes / dP_b)}$

Annexe: Partitions - événements non corrélés

décroissance du ^{18}B :



décroissance du ^{21}B :



décroissance du ^{16}Be :