DETERMINATION OF THE n-^{17}B SCATTERING LENGTH

Emeline OLIVEIRA - LPC Caen

WPCF - November 2024

Effective Range Approximation

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Case of interest: n+^{17}B

→ Neutron off exotic nuclei ?

- ➢ Both are unstable !

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EPJ Web Conf. 311, 00006 (2024)

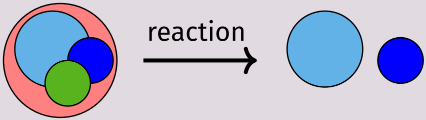
Case of interest: n+^{17}B

→ Neutron off exotic nuclei ?

➢ Both are unstable !

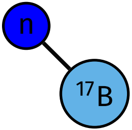
→ Knockout reaction

✔ Sudden removal



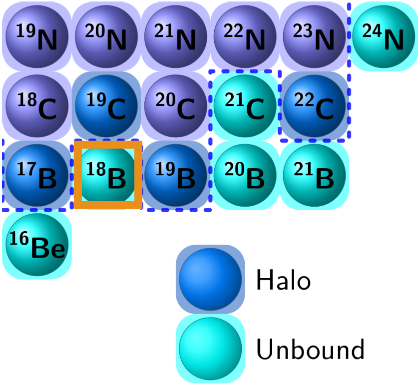
$$\sigma(k) \approx k \left| \int_0^\infty \psi_i(r) \; \varphi_k^*(r) \; r^2 dr \right|^2$$

THE STRUCTURE OF ^{18}B & ^{19}B

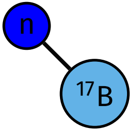


- Why n+^{17}B ?

  $(a_s, r_e) \rightarrow \delta_0 \rightarrow V(n\text{-}^{17}B)$



THE STRUCTURE OF ^{18}B & ^{19}B



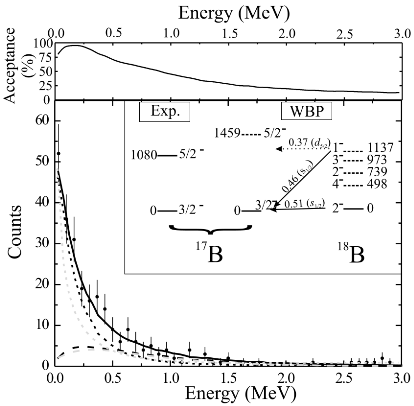
- Why n+^{17}B ?

  $(a_s, r_e) \rightarrow \delta_0 \rightarrow$ V(n-^{17}B)

- Why V(n-^{17}B) ?

  Only measure: $a_s <$ -50 fm !

Spyrou, Phy. Let. B 683 (2010)



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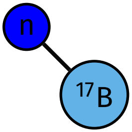
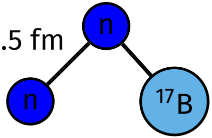


a_s = -18.5 fm



- ➤ Why n+^{17}B ?

  (a_s,r_e) $\rightarrow \delta_0 \rightarrow$ V(n-^{17}B)

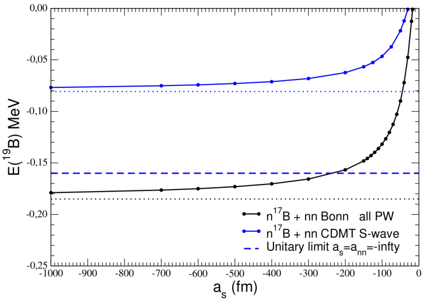
- ➤ Why V(n-^{17}B) ?

  Only measure: $a_s <$ -50 fm !

- ➤ ^{17}B+n+n: Borromean binding from two large a_s...

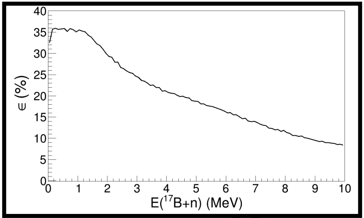
  Efimov states ?

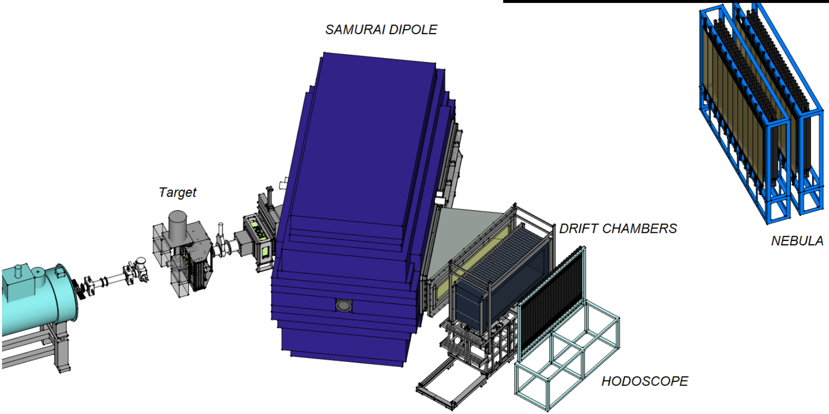
  Efimov physics ! $\frac{|a_s|}{r_e} \gg 1$



Hiyama PRC 100, 011603(R) (2019)

EXPERIMENTAL SETUP: SAMURAI DayOne (RIKEN)





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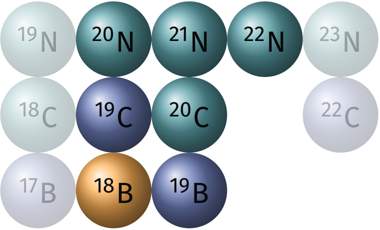
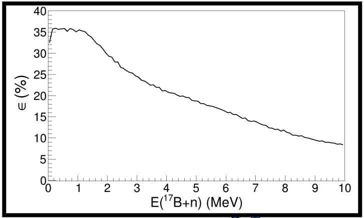
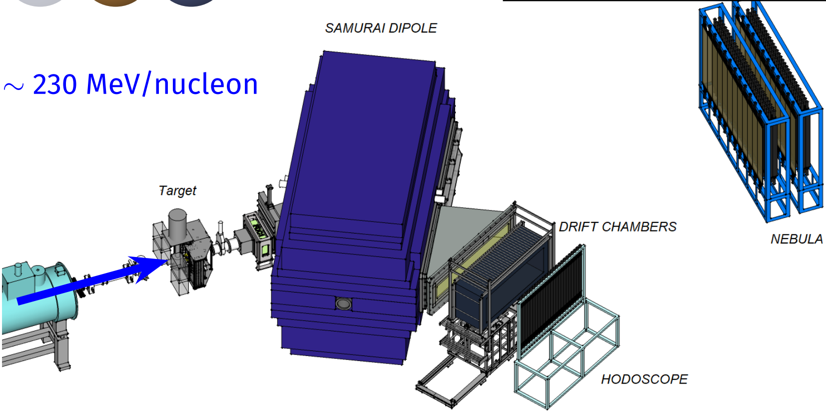




~ 230 MeV/nucleon



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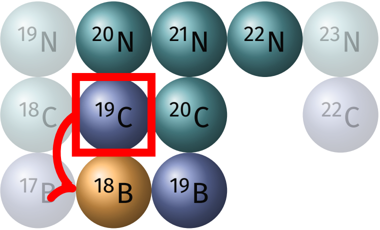
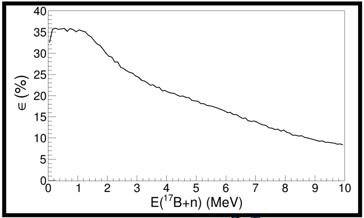
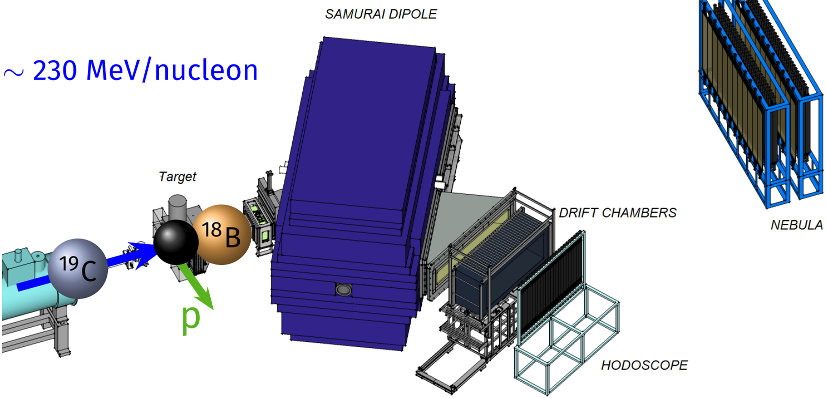




∼ 230 MeV/nucleon



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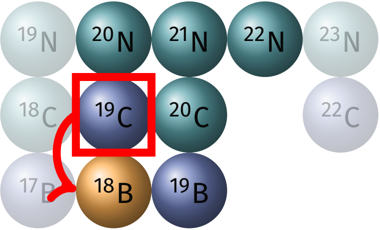

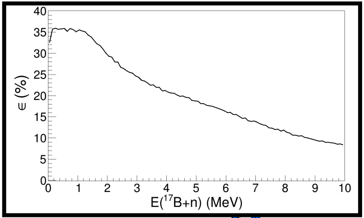

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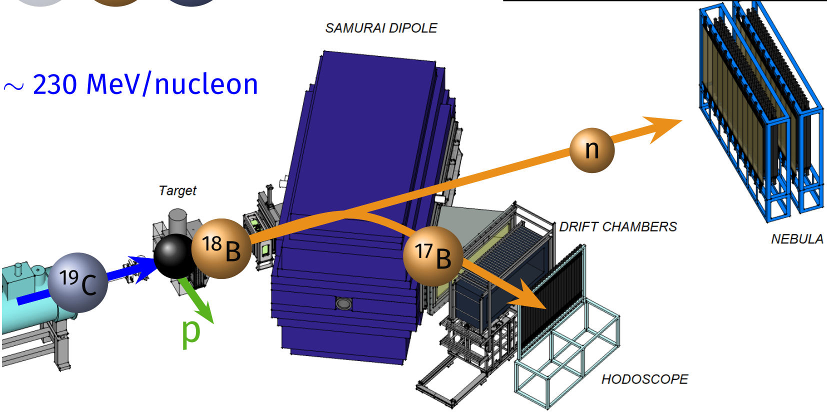
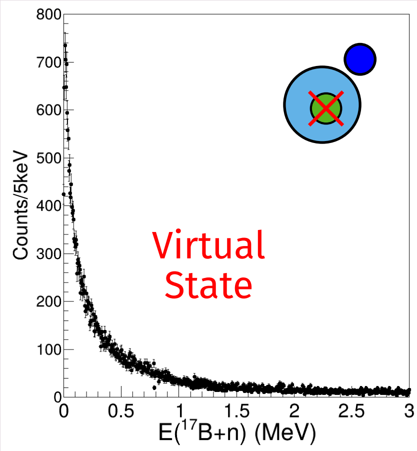
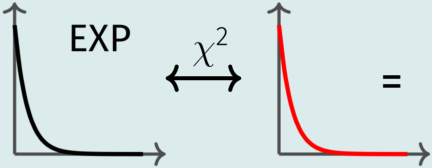
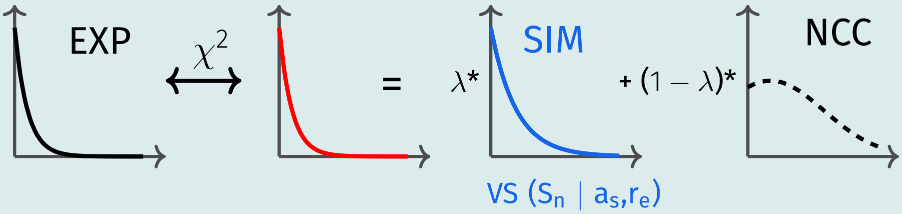



800
700
600
500
400
300
200
100
0
Counts/5keV
0
0.5
1
1.5
2
2.5
3
E(17B+n) (MeV)
Virtual State

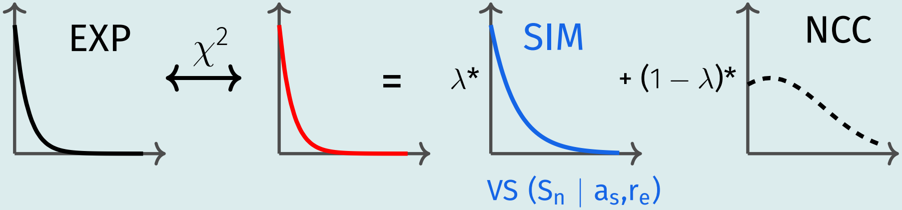
Minimization



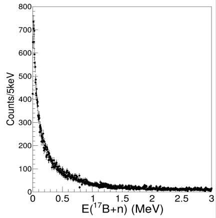
Minimization



Minimization

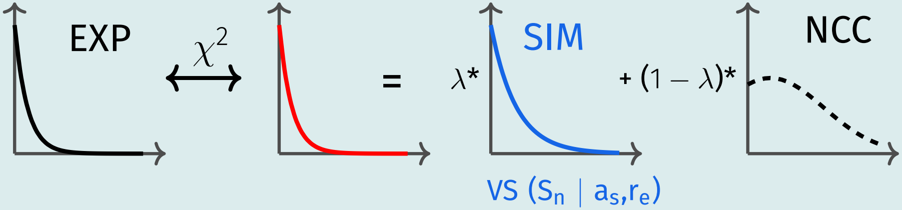


Non-correlated contribution

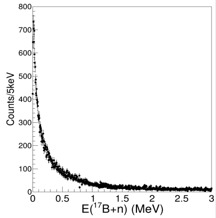


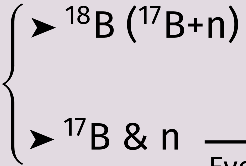
- ➤ ^{18}B (^{17}B+n)
- ➤ ^{17}B & n

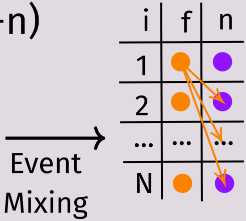
Minimization



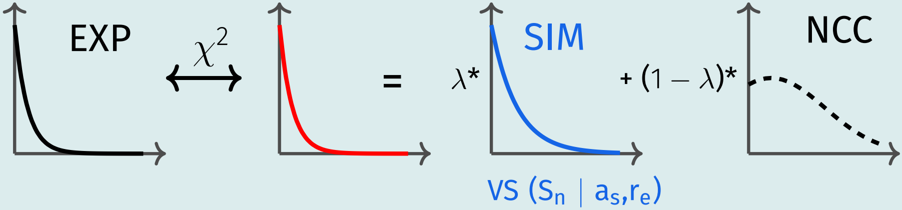
Non-correlated contribution







Minimization



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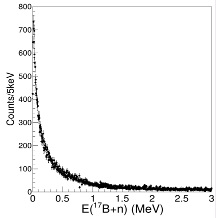
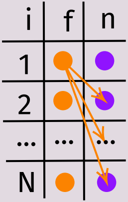


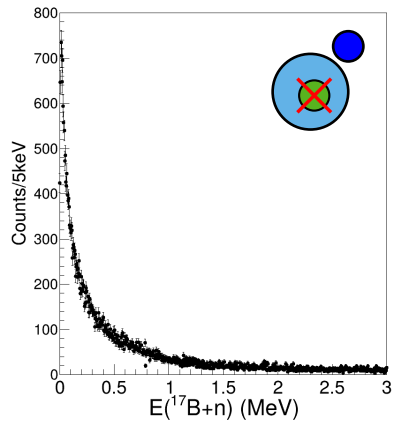
- ➤ ^{18}B (^{17}B+n)
- ➤ ^{17}B & n ⟶ Event Mixing



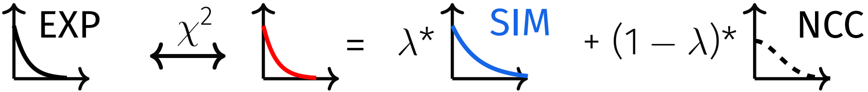
✔ Shape

✔ Measured events

Fit Example

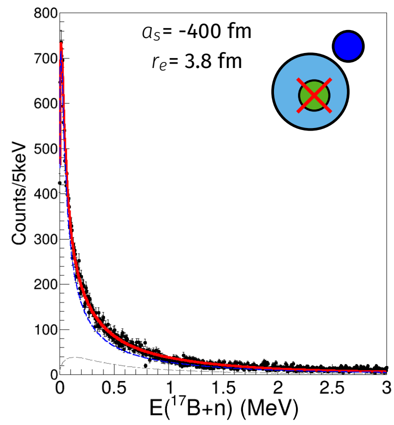


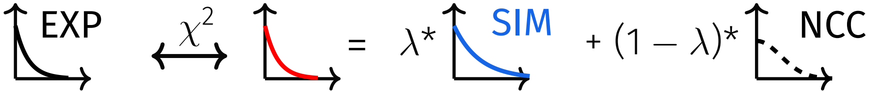
Counts/5keV
800
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
E(^{17}B+n) (MeV)



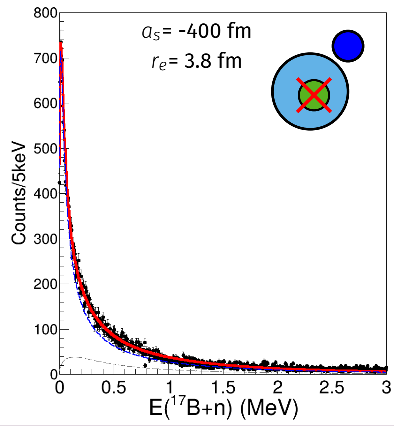
EXP
χ^2
= λ*
SIM
+ (1 − λ)*
NCC

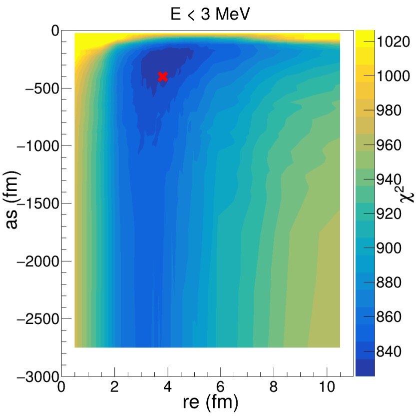
Fit Example

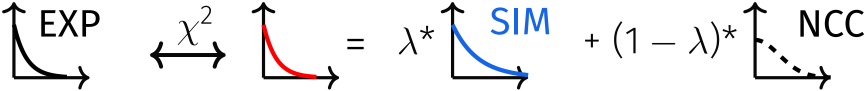

a_s= -400 fm
r_e= 3.8 fm
Counts/5keV
E(^{17}B+n) (MeV)
0
100
200
300
400
500
600
700
800
0
0.5
1
1.5
2
2.5
3


EXP
χ^2
=
λ*
SIM
+ $(1-\lambda)$*
NCC

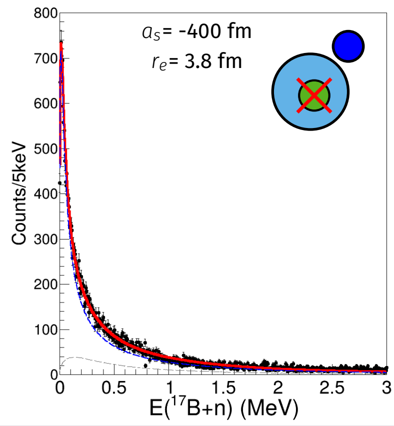
Fit Example

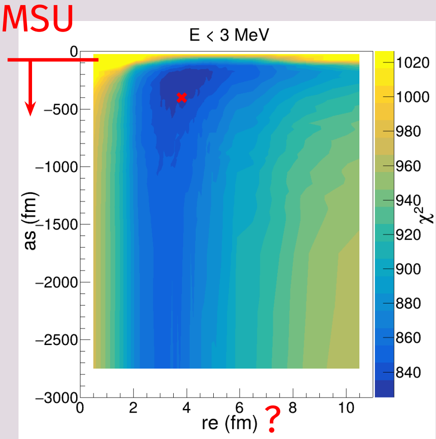

a_s= -400 fm
r_e= 3.8 fm
Counts/5keV
E(^{17}B+n) (MeV)
0
100
200
300
400
500
600
700
800
0
0.5
1
1.5
2
2.5
3

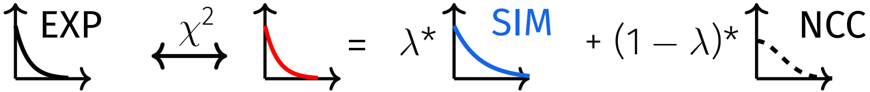

E < 3 MeV
as (fm)
re (fm)
χ^2
0
−500
−1000
−1500
−2000
−2500
−3000
0
2
4
6
8
10
1020
1000
980
960
940
920
900
880
860
840


EXP
χ^2
=
$\lambda*$
SIM
+ $(1-\lambda)*$
NCC

Fit Example


a_s= -400 fm
r_e= 3.8 fm
Counts/5keV
E(^{17}B+n) (MeV)
800
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3

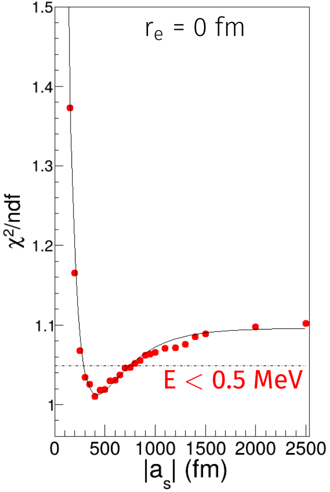

MSU
E < 3 MeV
as (fm)
re (fm)
?
χ^2
0
−500
−1000
−1500
−2000
−2500
−3000
0
2
4
6
8
10
1020
1000
980
960
940
920
900
880
860
840


EXP
χ^2
=
$\lambda *$
SIM
$+ (1 - \lambda) *$
NCC

PARAMETERS SENSITIVITY

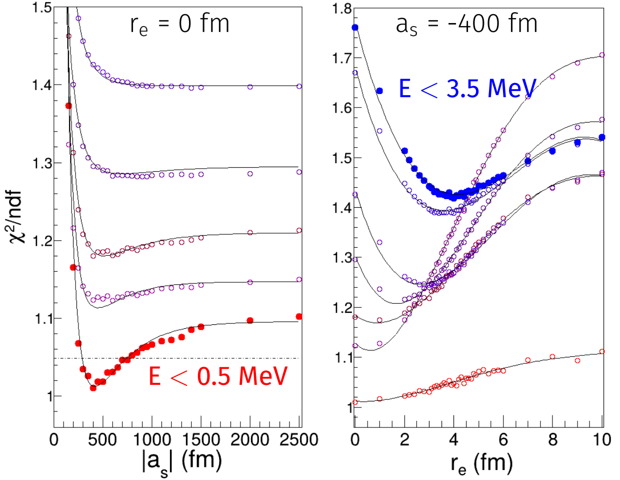
$$k\cot(\delta_0) = \frac{-1}{a_s} + \frac{r_e}{2}k^2 + \mathcal{O}(k^4)$$

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



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

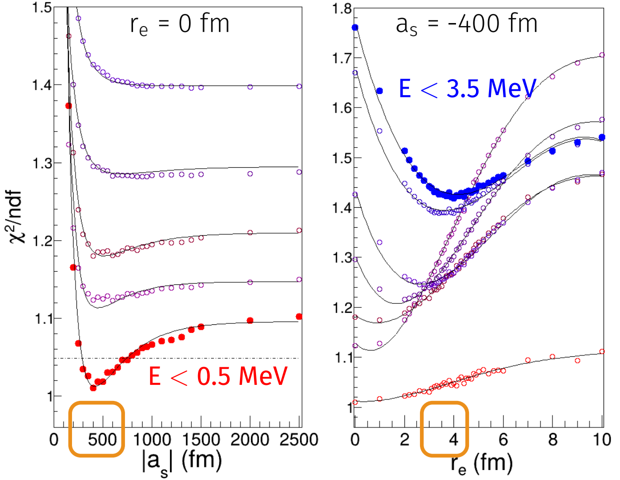
$(k, E) \ll$ ⟶ $(k, E) \gg$



PARAMETERS SENSITIVITY

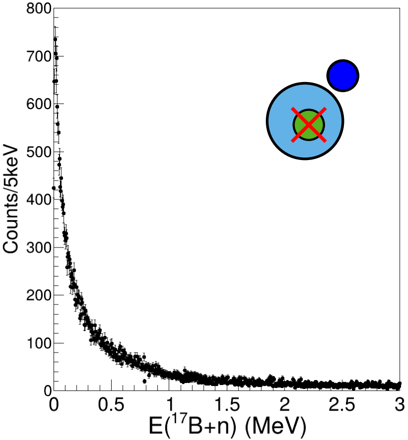
$$k\cot(\delta_0) = \frac{-1}{a_s} + \frac{r_e}{2}k^2 + \mathcal{O}(k^4)$$

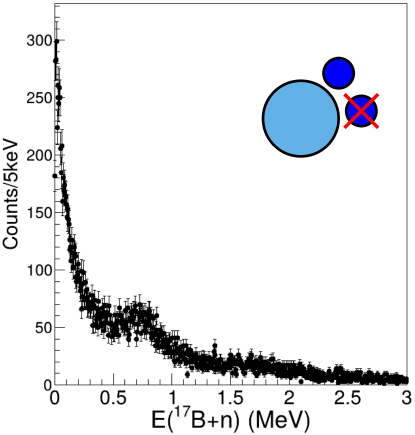
$(k, E) \ll$ ⟶ $(k, E) \gg$



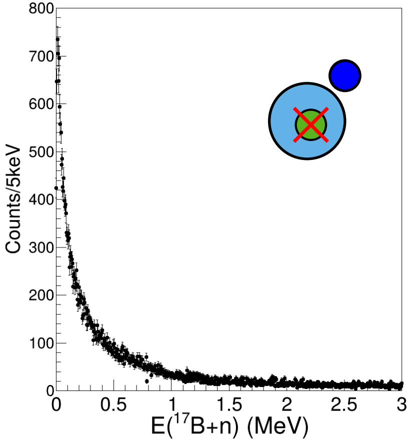
$$\frac{|a_s|}{r_e} \approx 100 \,!$$

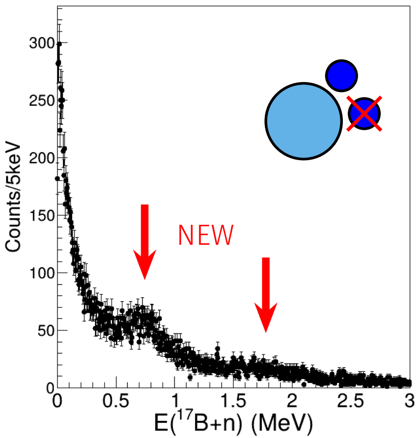
EXPLORATION OF ^{19}B CHANNEL





EXPLORATION OF ^{19}B CHANNEL





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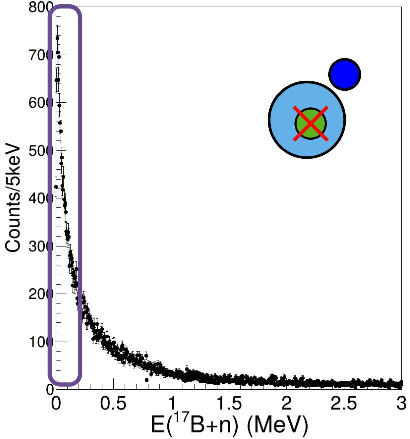
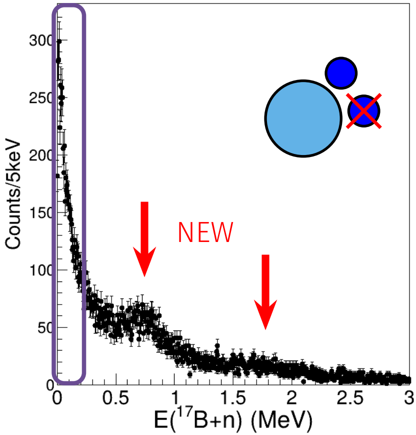
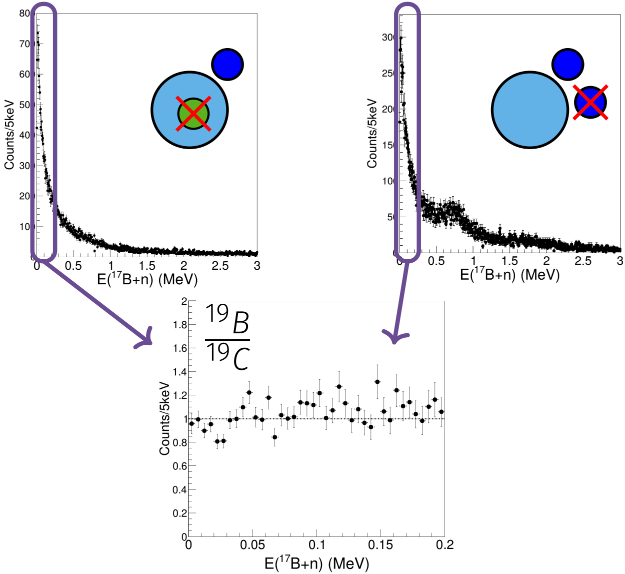




$S_n(^{19}C)$ = 580 ± 90 keV

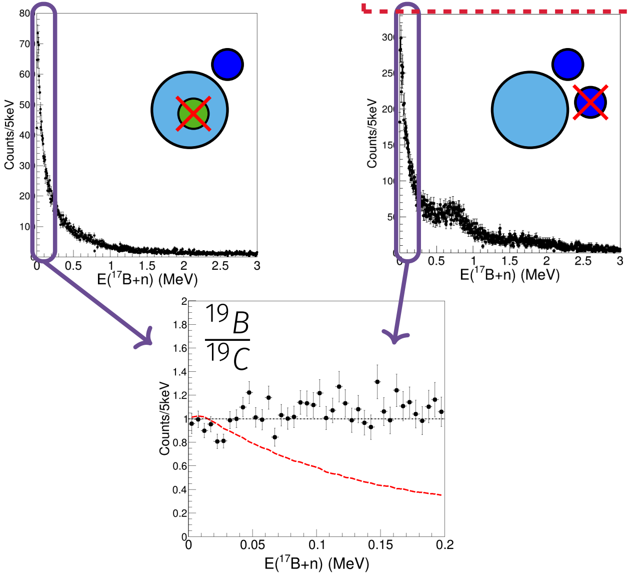
$S_n(^{19}B)$ = 90 ± 560 keV



EXPLORATION OF ^{19}B CHANNEL

$S_n(^{19}C) = 580 \pm 90$ keV

$S_n(^{19}B) = 90 \pm 560$ keV



EXPLORATION OF ^{19}B CHANNEL

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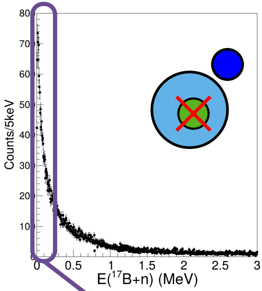
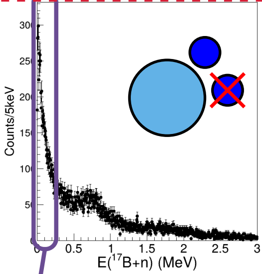
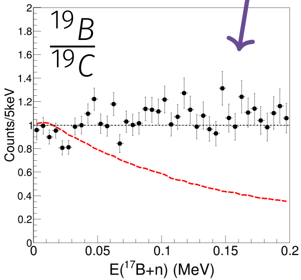


$S_n(^{19}B) = 90 \pm 560$ keV



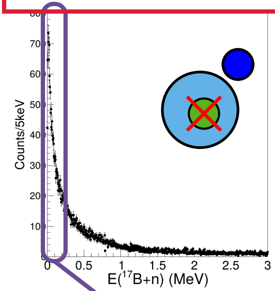


➢ $S_n(^{19}B) \sim 0.5$ MeV ?

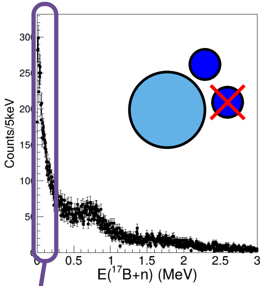
Cook PRL 124, 212503 (2020)

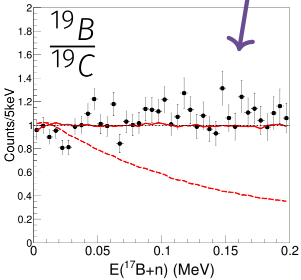
EXPLORATION OF ^{19}B CHANNEL

$S_n(^{19}C) = 580 \pm 90$ keV



$S_n(^{19}B) = 90 \pm 560$ keV





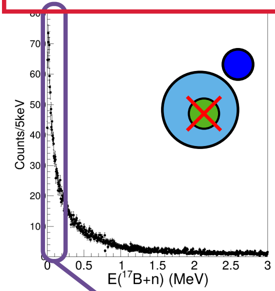
➢ $S_n(^{19}B) \sim 0.5$ MeV ?

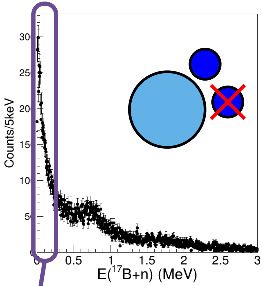
Cook PRL 124, 212503 (2020)

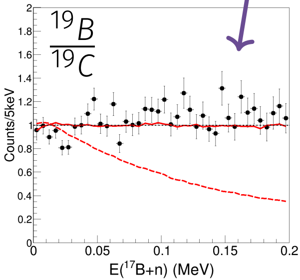
EXPLORATION OF ^{19}B CHANNEL

$S_n(^{19}C)$ = 580 ± 90 keV

$S_n(^{19}B)$ = 90 ± 560 keV







➢ $S_n(^{19}B) \sim 0.5$ MeV ?

Cook PRL 124, 212503 (2020)

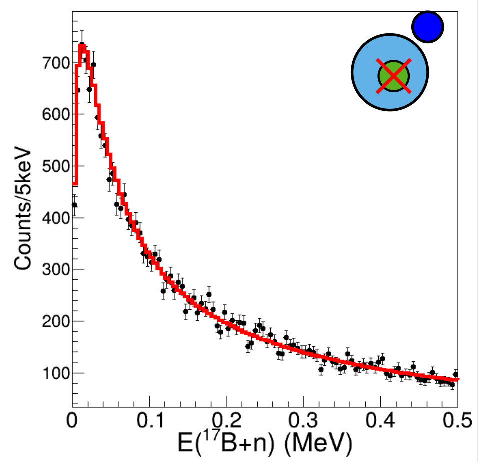
Re-estimation of $S_n(^{19}B)$?

Low energy scattering

- Formalism
- Exotic nuclei (& n) unstable
- **n-^{17}B** case: ^{18}B & ^{19}B
  - ➢ **scattering lenght**

Exp. program @ RIKEN

- Luminosity $\otimes$ Acceptance:
  - ➢ **effective range**
- Multiple channels: (a_s, r_e)
  - ➢ $\frac{|a_s|}{r_e} \sim$ 100 !
- Measure of ^{19}B mass ?
- First resonances in ^{18}B

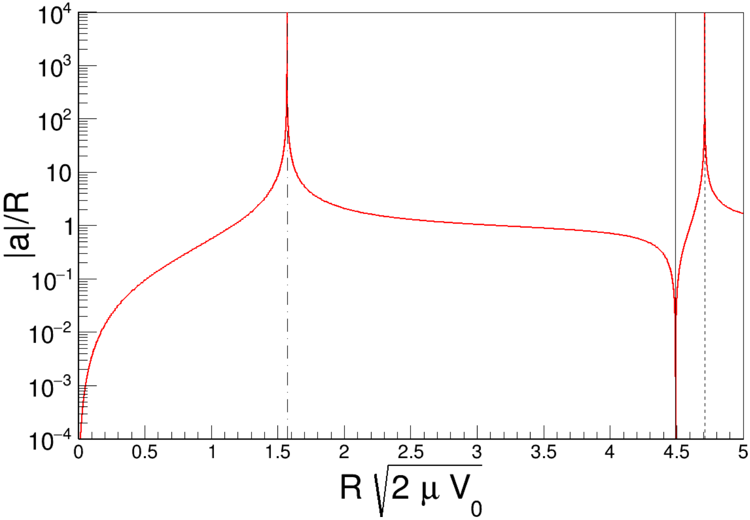


DETERMINATION OF THE n-^{17}B SCATTERING LENGTH

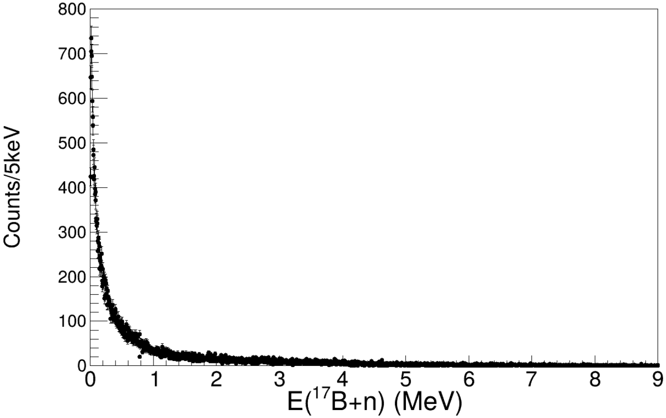
Emeline OLIVEIRA - LPC Caen

WPCF - November 2024

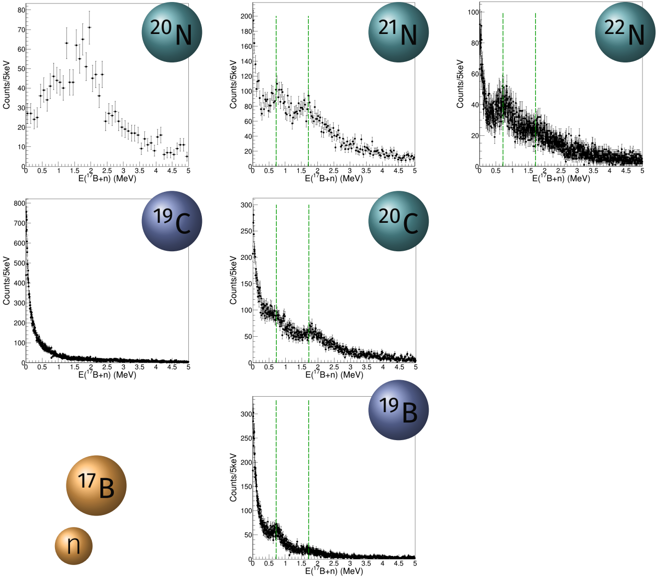
Particle off square well



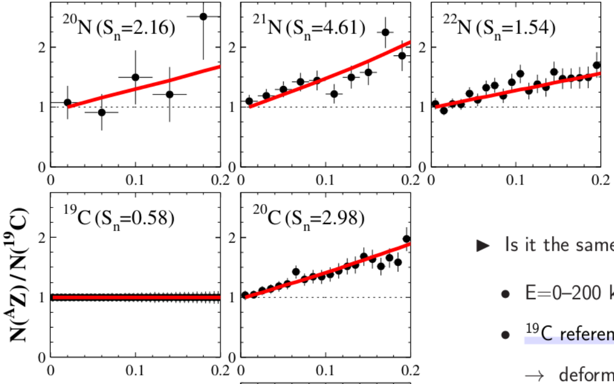
Relative Energy: ^{19}C channel



Relative energy for every channel



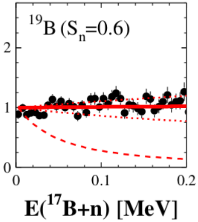
Effect of the intial state



$S_n(^{19}\text{C}) = 580(90)$ keV

$\sim 600(200)$???

$S_n(^{19}\text{B}) = 90(560)$ keV



- Is it the same virtual state ?
  - E=0–200 keV (no other resonances)
  - ^{19}C reference ('pure' state)
    - → deformation increases with S_n
  - $\psi_i(\text{n})_{\text{SW}}$ for $(a_s, r_e) = (-600{,}4)$ fm
    - → consistent with same state !
    - → description of container effects
    - → very sensitive to $S_n(^{19}\text{B})$!!!

Non Correlated Contribution

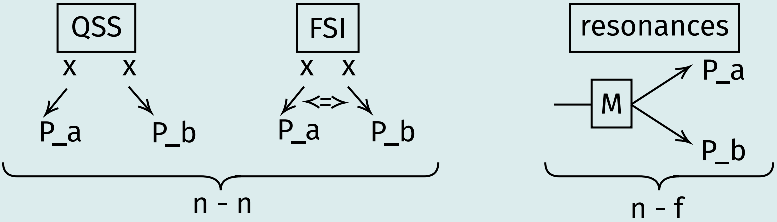
Non correlated events

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

If (a,b) emitted together: $\frac{d^2\sigma}{dP_a dP_b} = \frac{d\sigma}{dP_a}\frac{d\sigma}{dP_b} \times C(P_a, P_b)$

$C(P_a, P_a)$? $\rightarrow \frac{d\sigma}{dP_a}\frac{d\sigma}{dP_b}$

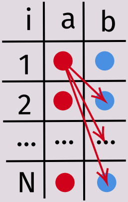
Mechanisms modifying (P_a, P_b)



Non Correlated Contribution

Event Mixing

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

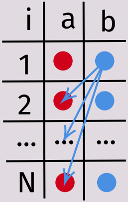


$$\frac{d\sigma_\otimes}{dP_a} = \int \frac{d^2\sigma}{dP_a dP_b} dP_b = \frac{d\sigma}{dP_a} \int C(P_a, P_b) \frac{d\sigma}{dP_b} dP_b$$

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

Event Mixing

Independent particles → virutal pairs → E_{rel}



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

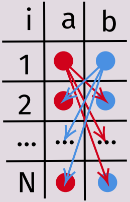
$$= \frac{d\sigma}{dP_a} \langle C \rangle (P_a)$$

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

Non Correlated Contribution

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

Event Mixing

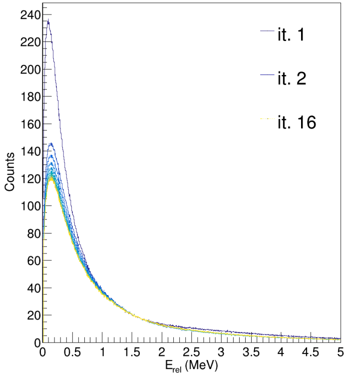


Figure: All distribution of event mixing procedure

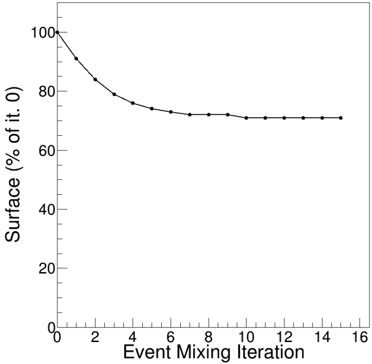
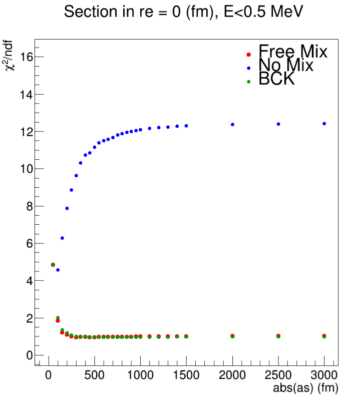
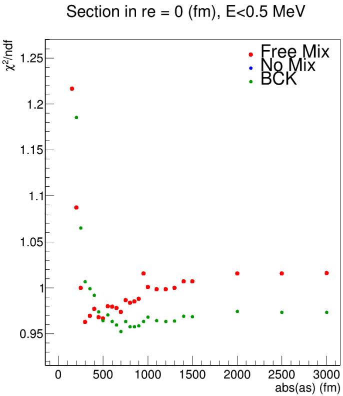


Figure: Convergence of the event mixing procedure

Non Correlated Contribution





Non-Correlated Distribution

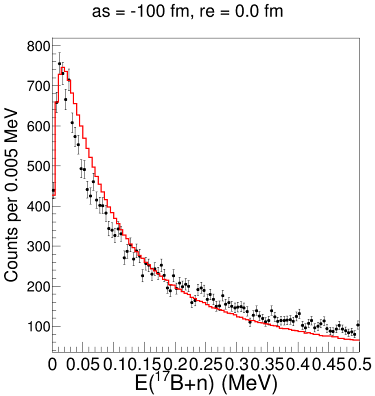


Figure: Best Fit without Mix, χ^2 = 4.57

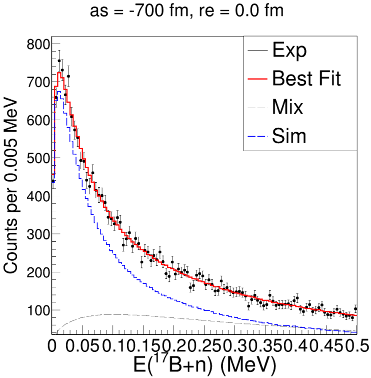


Figure: Best Fit with simulated Mix, χ^2 = 0.95

Induced long-range interaction

→ Effective interaction is mediated between two particles by the third particle moving back and forth between the two. It is thus possible for the three particles to feel their influence at **distances much larger than the range of interactions**, typically up to **distances on the order of the scattering length**.

Discrete scale invariance

→ **infinite series of bound states**, the Efimov trimers, whose properties such as size and energy are related to each others' by a scale transformation with a **universal scaling factor**.

Borromean binding

When the interaction is not strong enough to support a two-body bound state, it may nonetheless support one, up to infinitely many, Efimov trimers. This possibility of **binding N particles, while the N-1 subsystems are unbound** is called 'Borromean' binding.

Alignment

$\text{Min}(\langle E_{rel} \rangle)$ $\langle \beta_n - \beta_f \rangle = 0$ $\left\langle P_z^f(n) \right\rangle = 0$ $\text{Max}(E_{rel})$