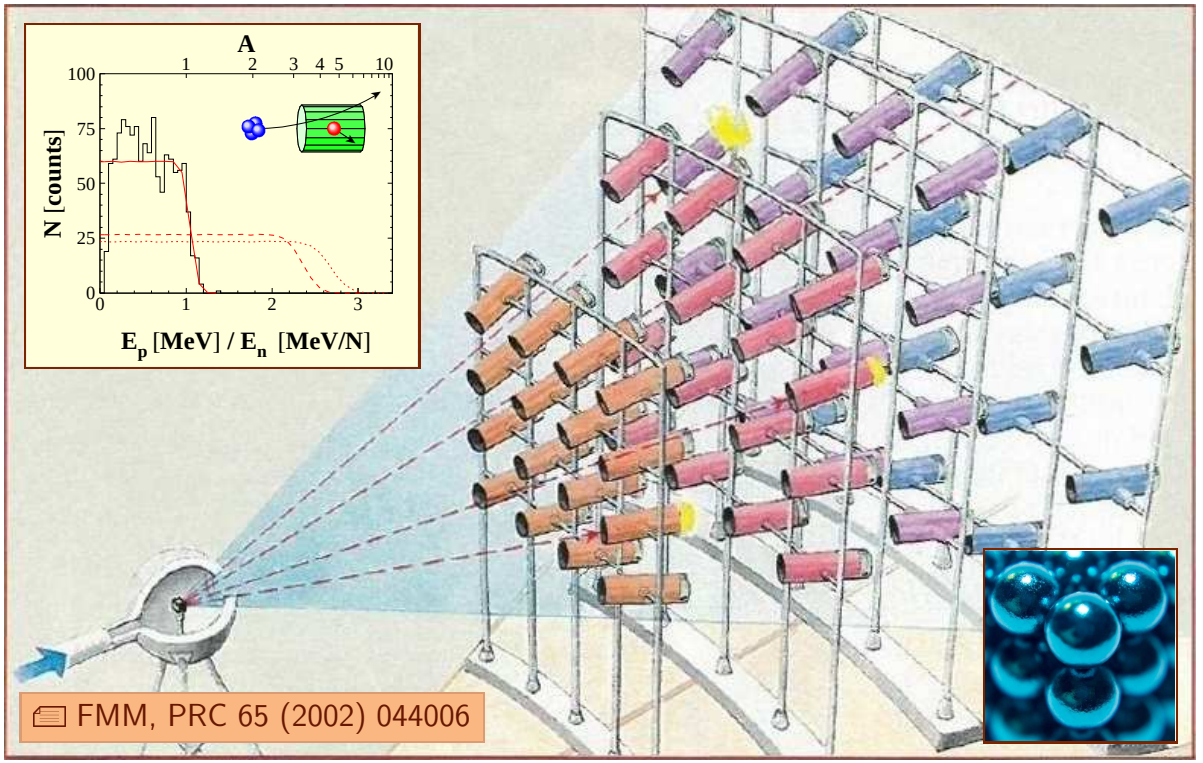
25th European Conference on
Few-Body Problems in Physics

Johannes Gutenberg University Mainz (31/07–4/08/2023)

The story behind the first 4n signal



F.M. Marqués

lpc caen
Laboratoire de physique corpusculaire

Old libraries (before XXI century)

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- spend time reading 'anything'
- no predefined filters & alerts
- exposure to other ideas/fields
- away from computers: think ...

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$\Rightarrow$ source of new ideas !

What the ... ???

Eur. Phys. J. A 4, 5–7 (1999)

THE EUROPEAN PHYSICAL JOURNAL A
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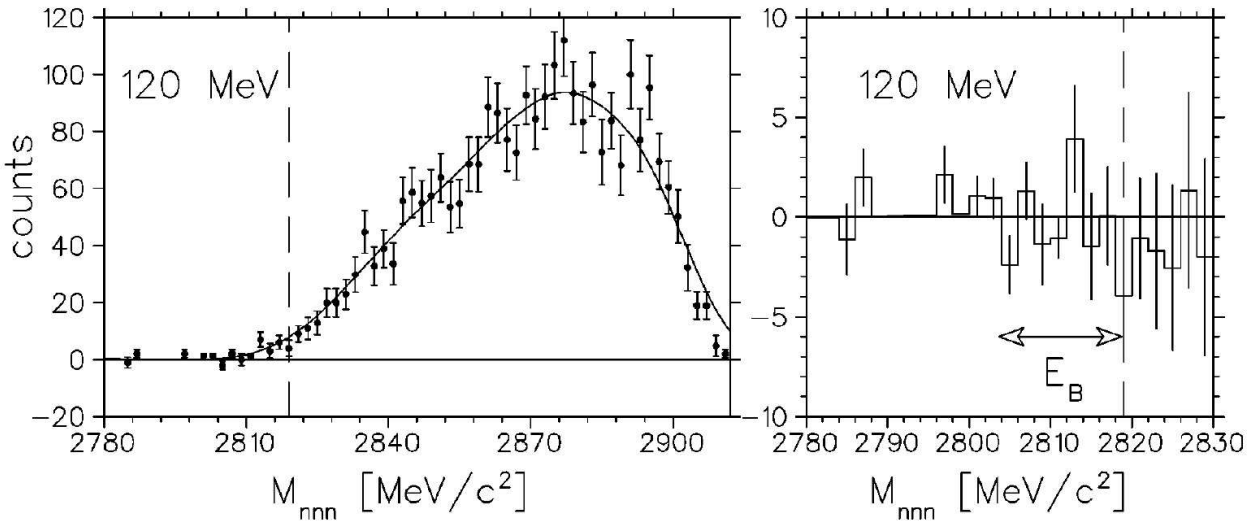
Short note

Search for a bound trineutron with the ^{3}He(π^-,π^+)nnn reaction

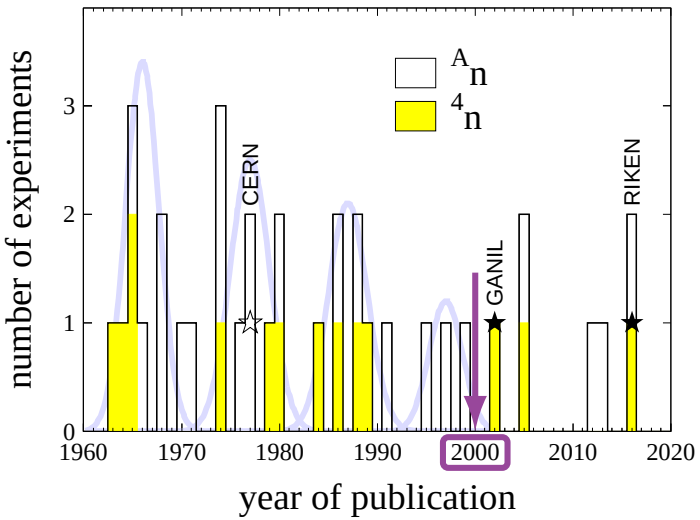
J. Gräter[1], P. A. Amaudruz[2], R. Bilger[1], P. Camerini[3], J. Clark[4], H. Clement[1], E. Friedman[5], L. Felawka[2], S.N. Filippov[6], E. Friagiacomo[3], Yu. K. Gavrilov[6], E. Gibson[7], N. Grion[3], G.J. Hofman[8a], B. Jamieson[8], T.L. Karavicheva[6], M. Kermani[8b], E.L. Mathie[9], R. Meier[1], G. Moloney[4], D. Ottewell[2], J. Pätzold[1], O. Patarakin[10], K. Raywood[2], R. Rui[3], M. Schepkin[11], M.E. Sevior[4], G.R. Smith[2], H. Staudenmaier[12], R. Tacik[9], G. Tagliente[8], G.J. Wagner[1], M. Yeomans[9]

Abstract. A search for the production of a bound trineutron state has been performed using the reaction ^{3}He(π^-,π^+)nnn at incident pion energies of 65, 75, and 120 MeV. No evidence for the existence of the ^{3}n was found, and an upper limit for the production cross section of approximately 30 nb/sr (2σ confidence level) was obtained.



Experimental program since 1960s !

FMM & Carbonell, EPJA 57 (2021) 105



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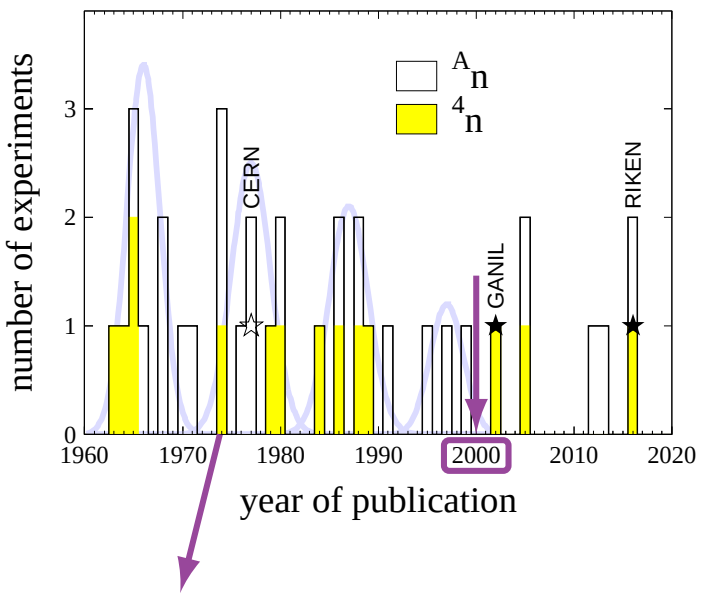
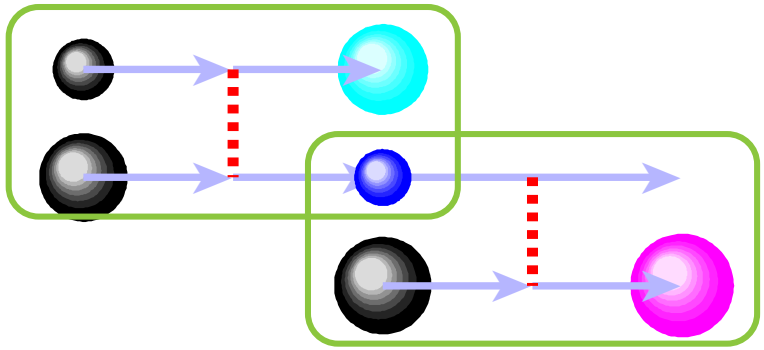
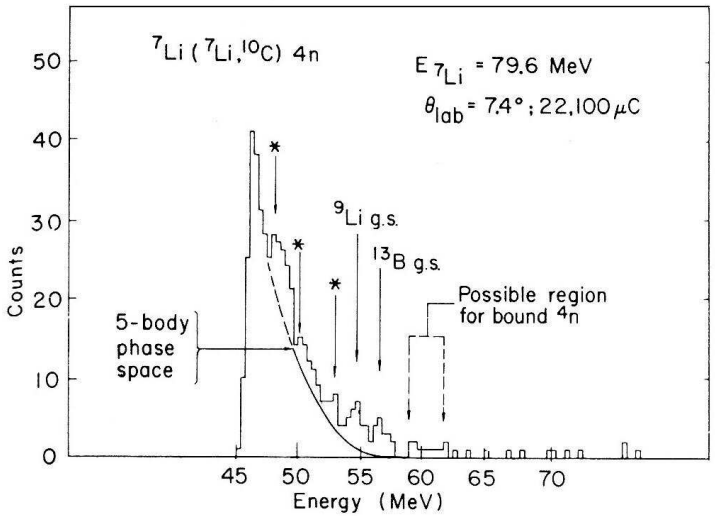


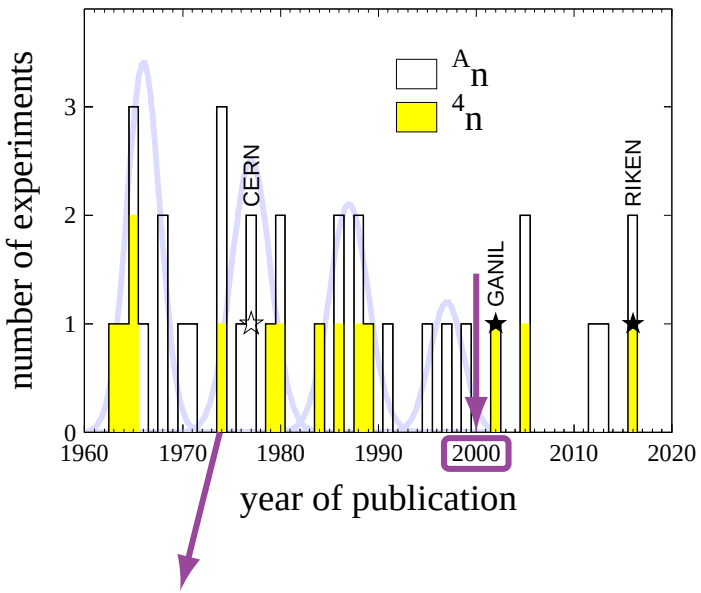


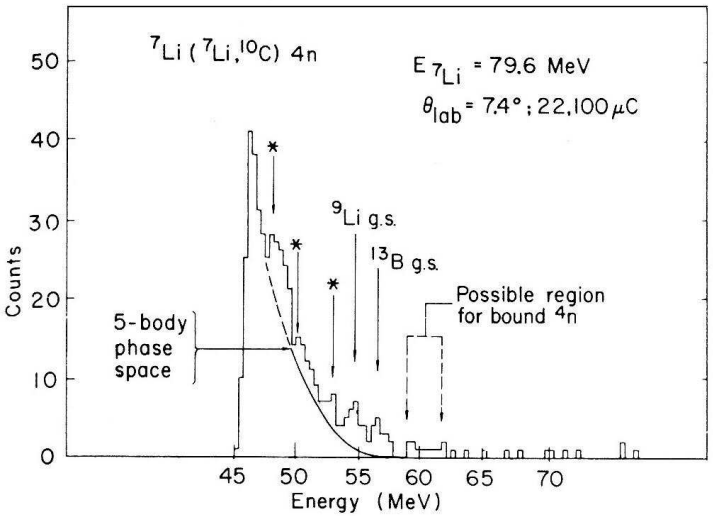


⇨ XX : cross-sections & backgrounds ...

Experimental program since 1960s !

FMM & Carbonell, EPJA 57 (2021) 105





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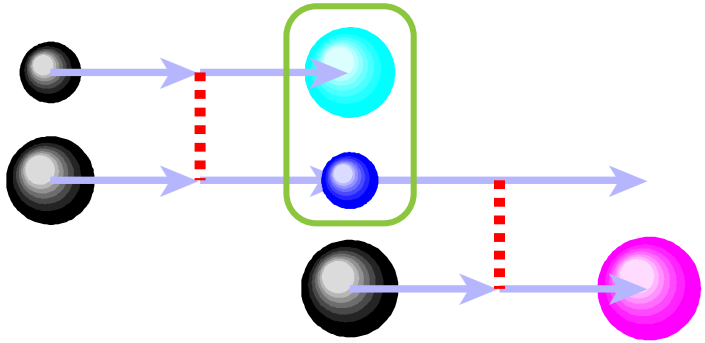
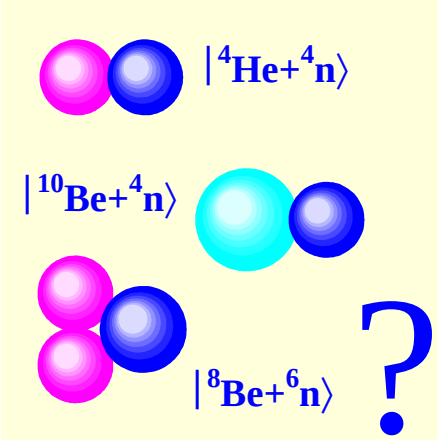


- What else could we do ?



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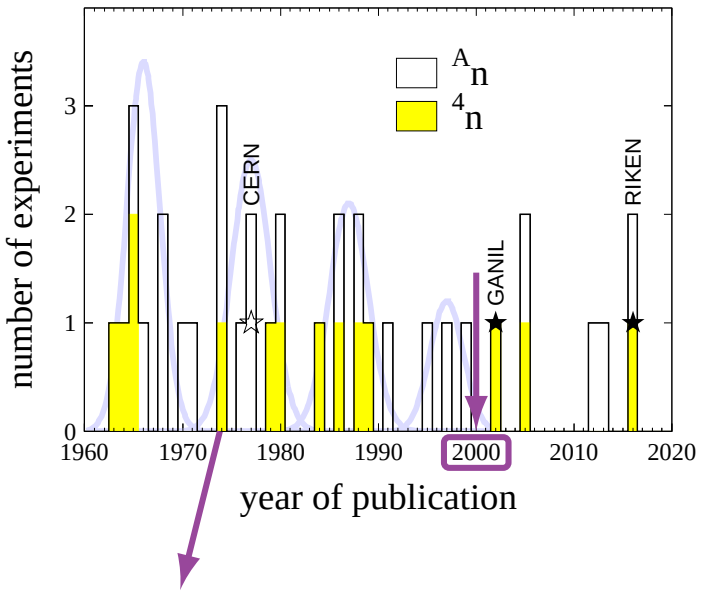

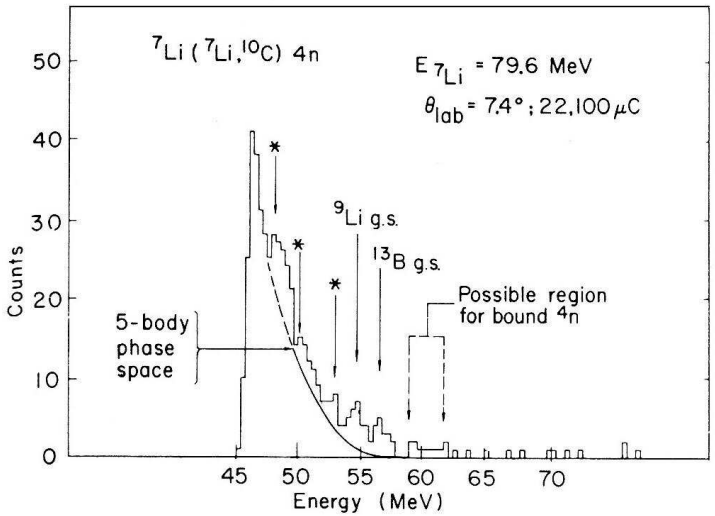

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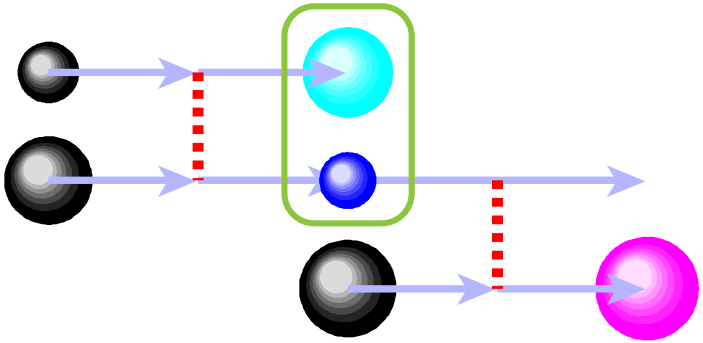

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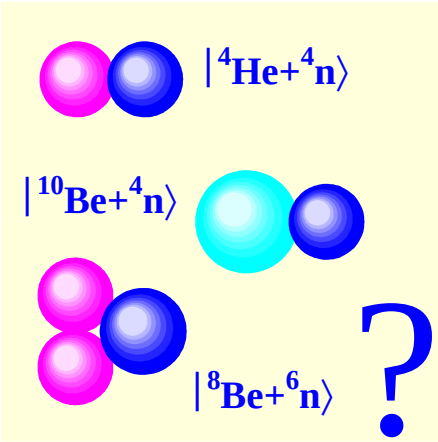
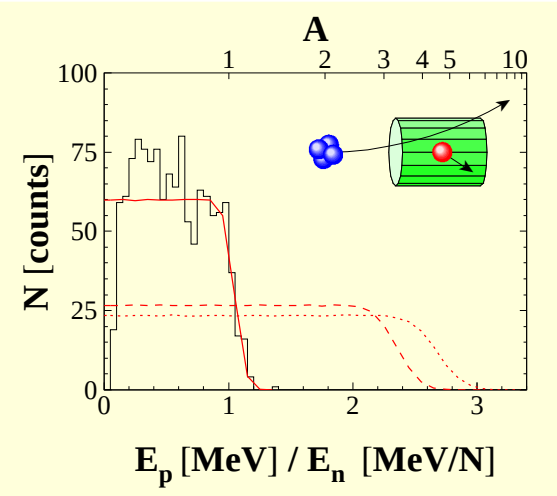


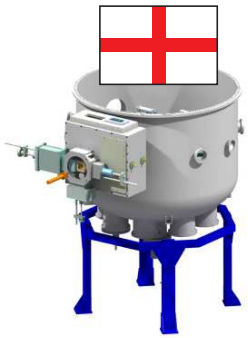


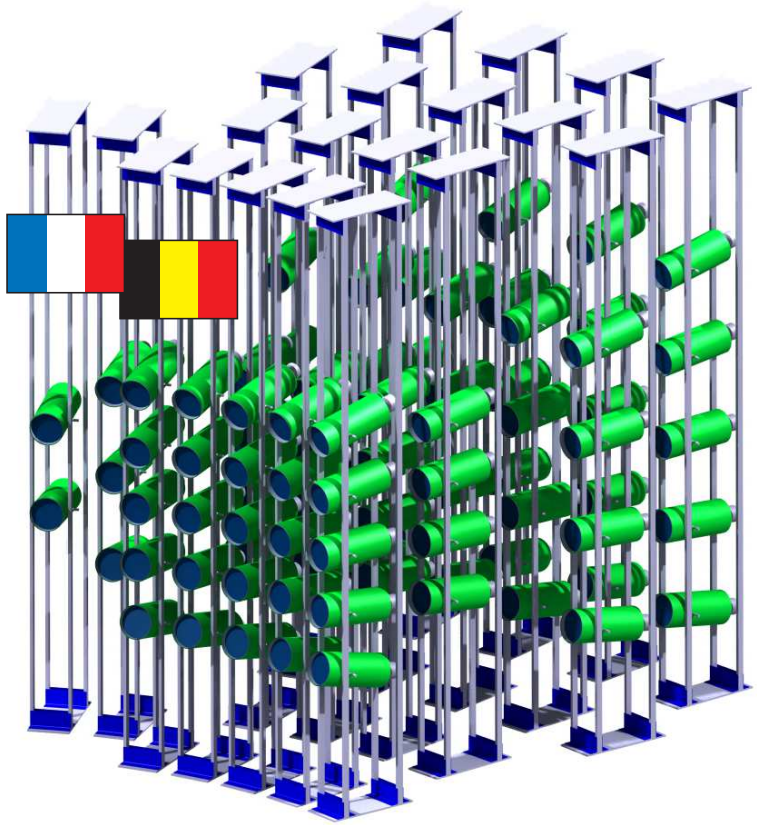
Chadwick, Nature 129 (1932) 312

Are you kidding me ?!?

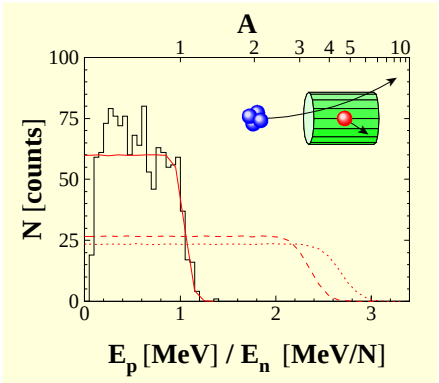
Show first that it may work ...

- "Halo" campaign @ GANIL : *(1997)*





- $^{14}\mathrm{Be} \xrightarrow{(\mathrm{C})} {}^{12}\mathrm{Be} + \underline{1n}$:



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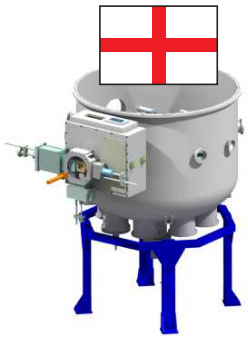

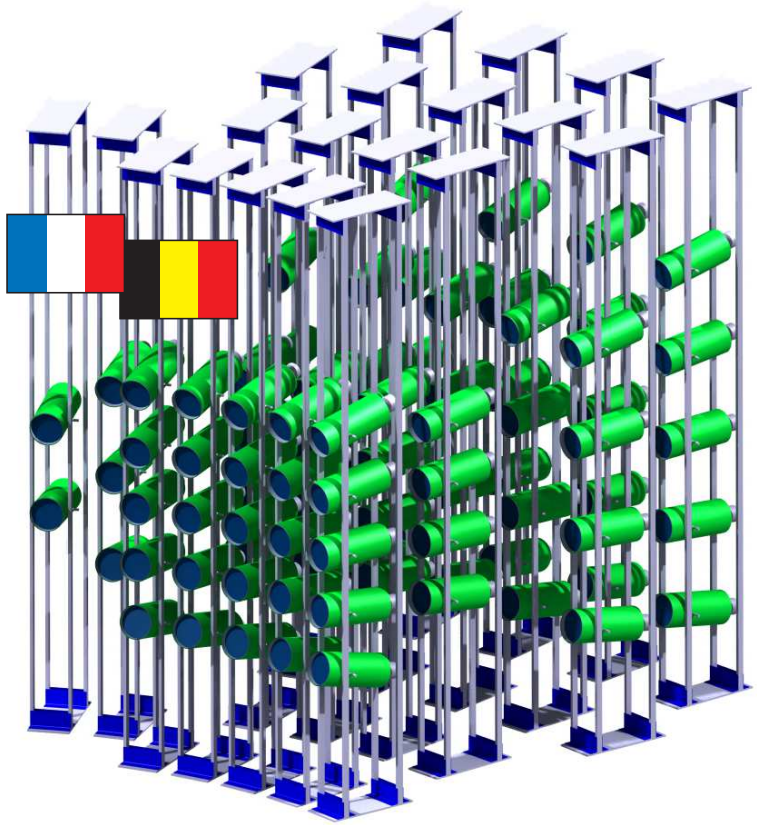

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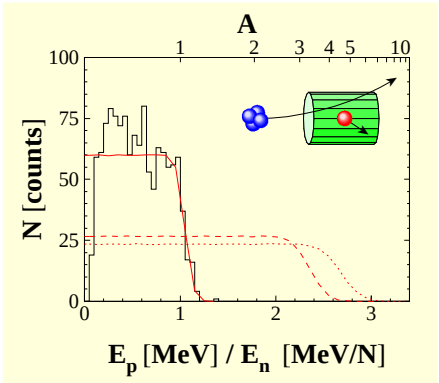
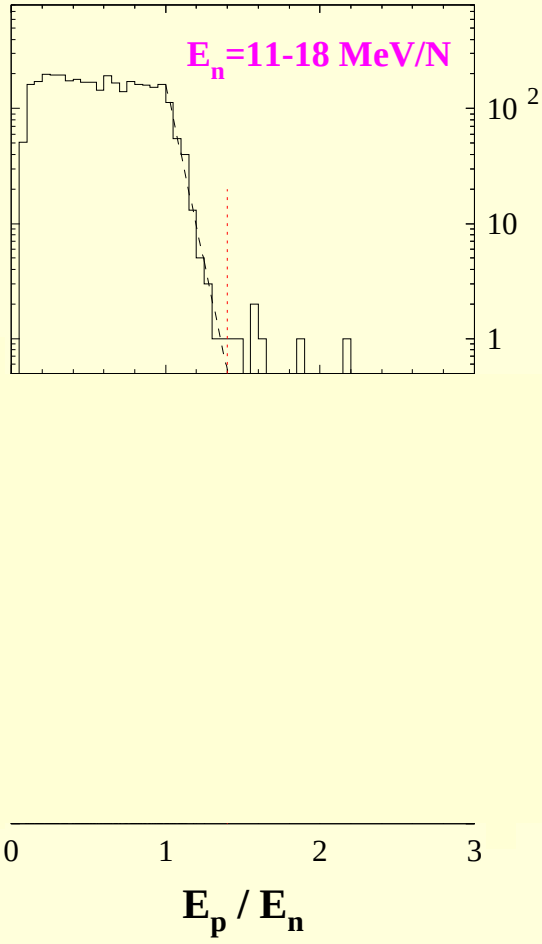


^{14}Be(C) $\rightarrow$X+n



✘ $\sim$1% background ?

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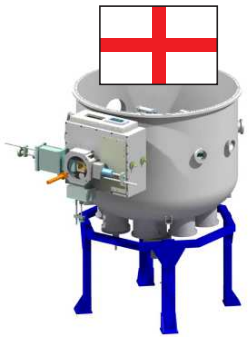

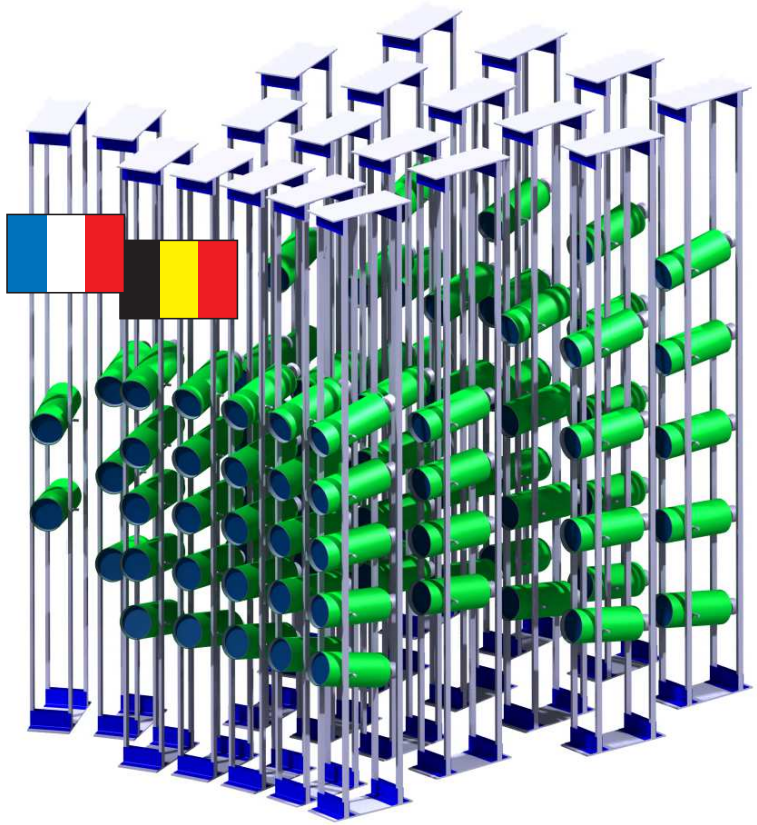

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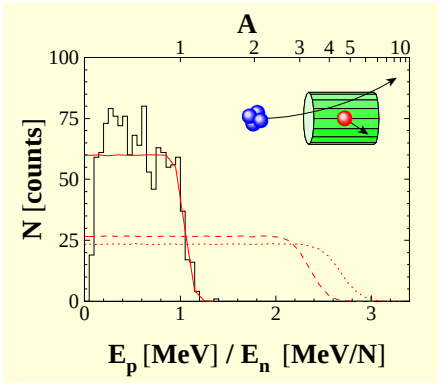
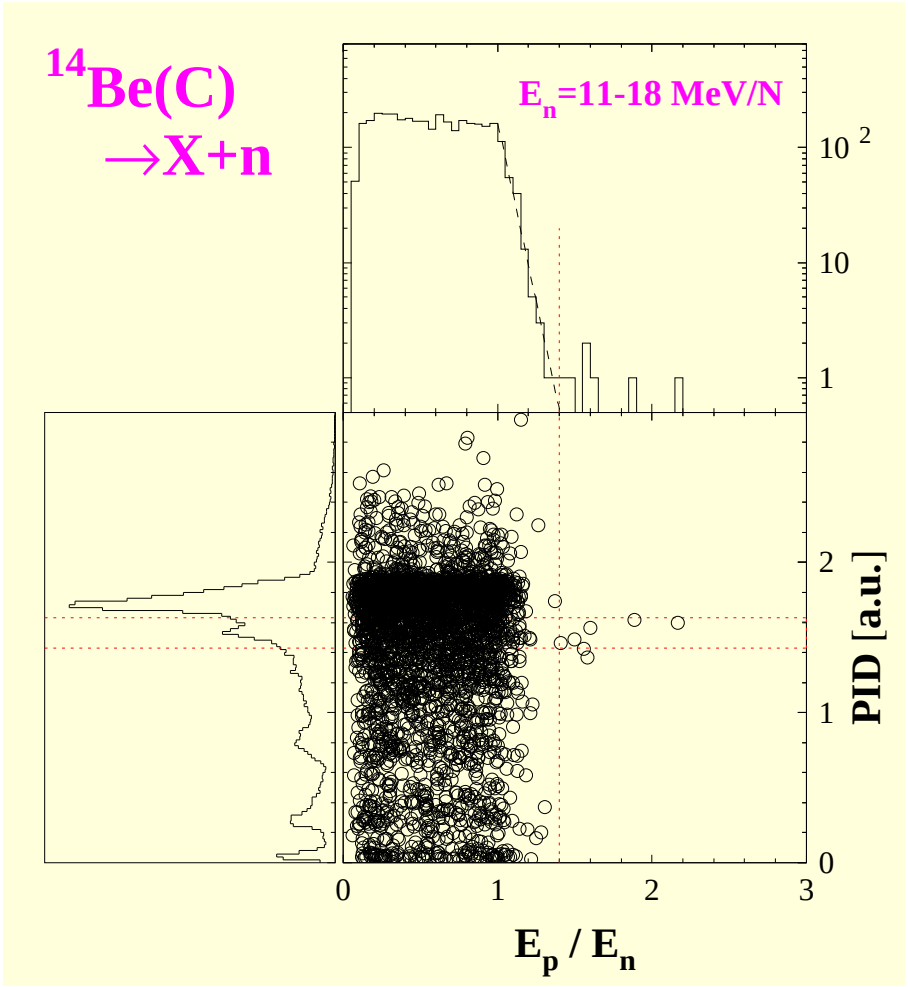
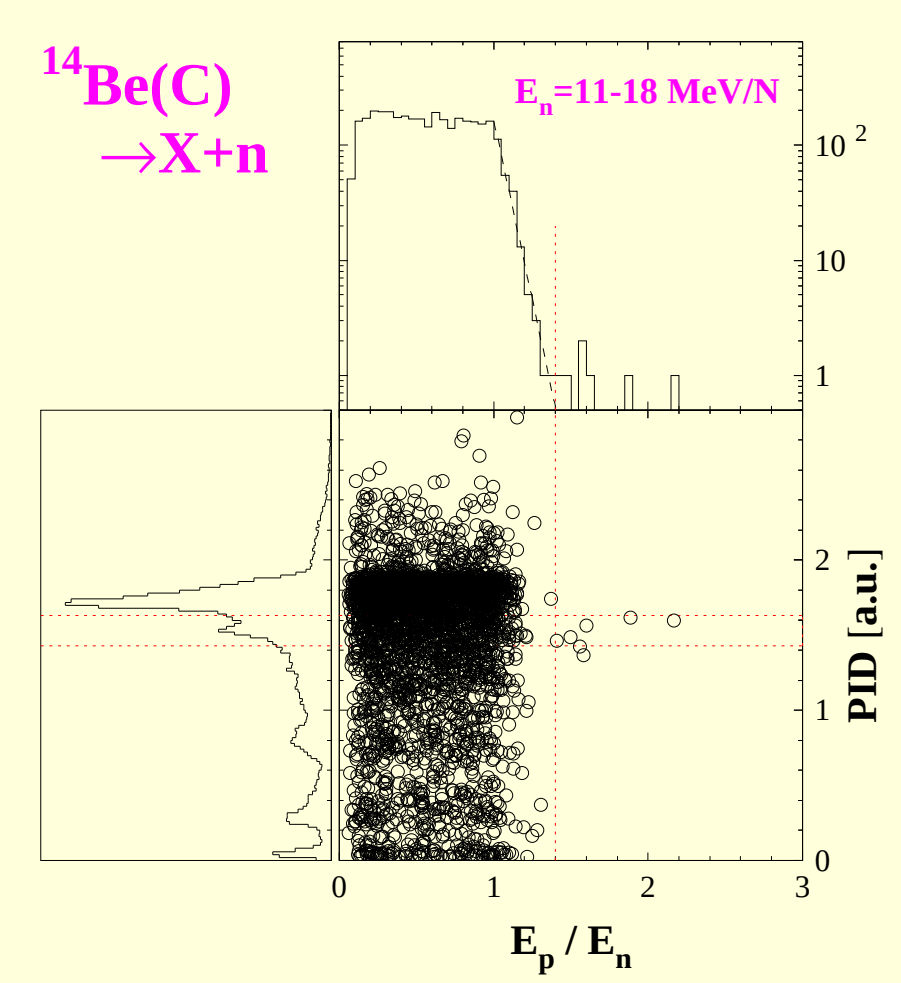




- ✘ $\sim$1% background ?
- ✔ very strong correlation ! $^{10}\mathrm{Be} + {}^{4}\mathrm{n}$???

(May 17, 2001)

Is it really the –4n channel ?



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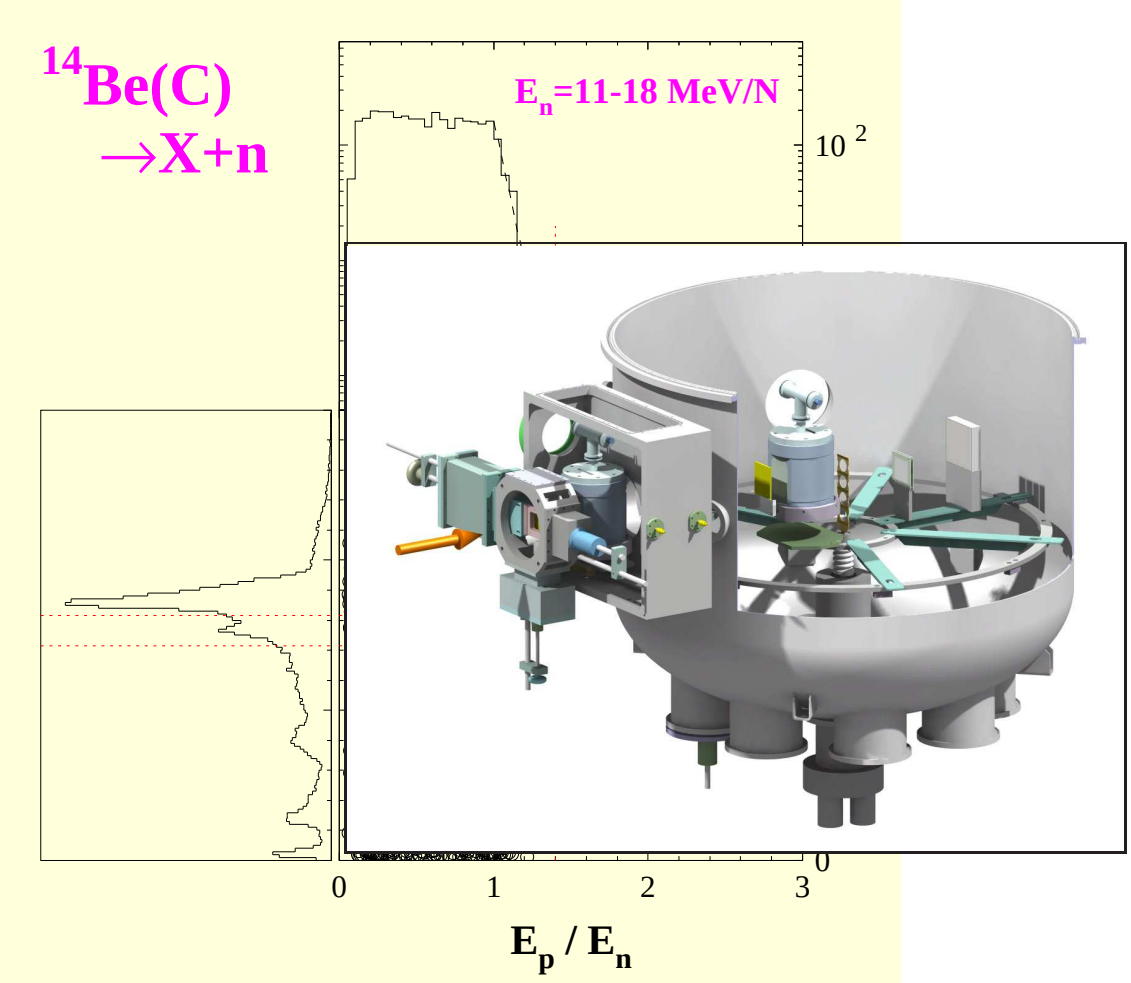

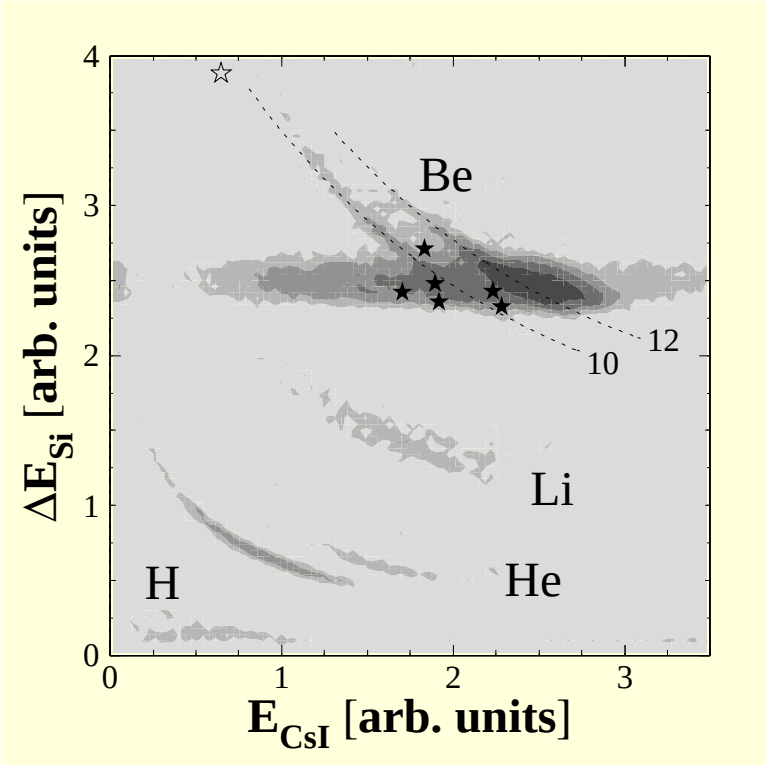

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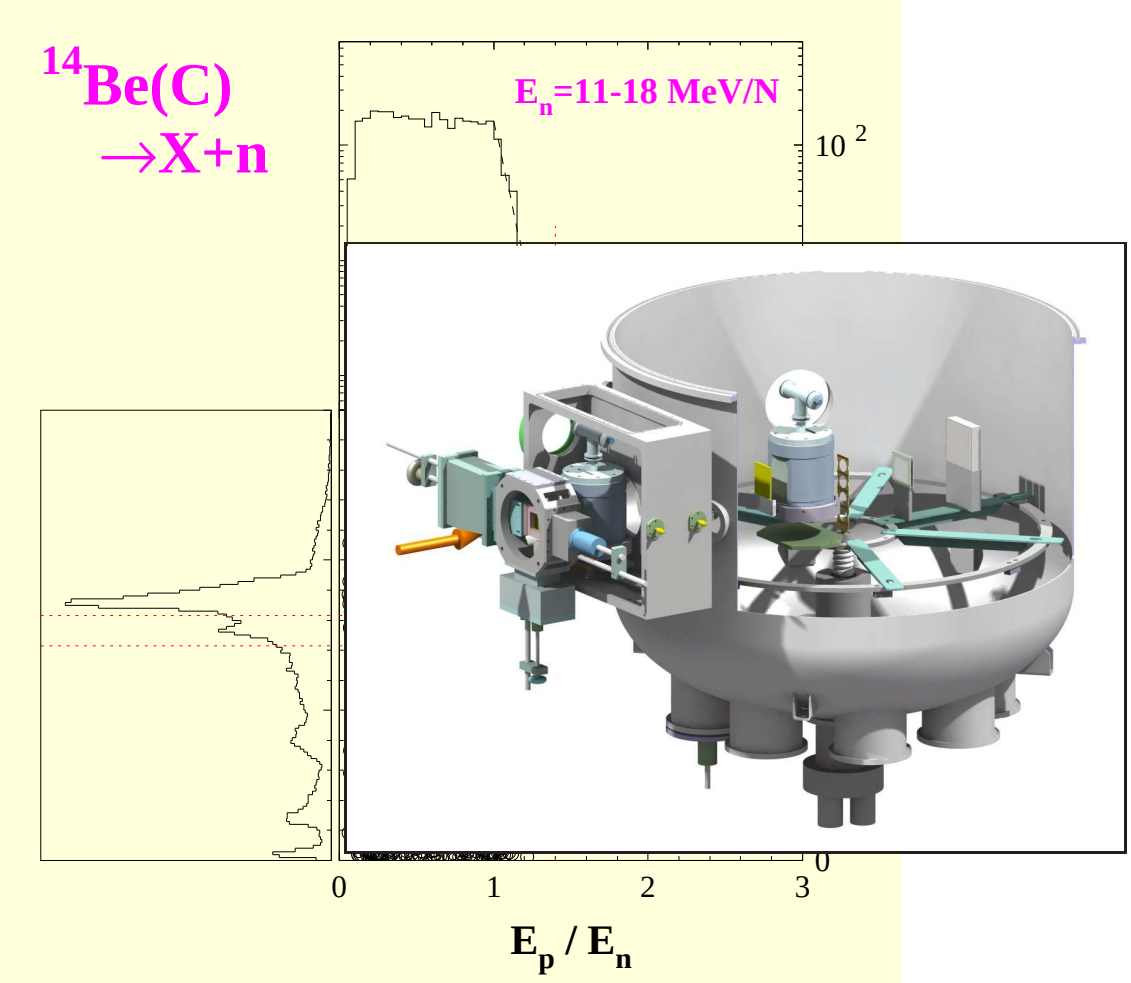
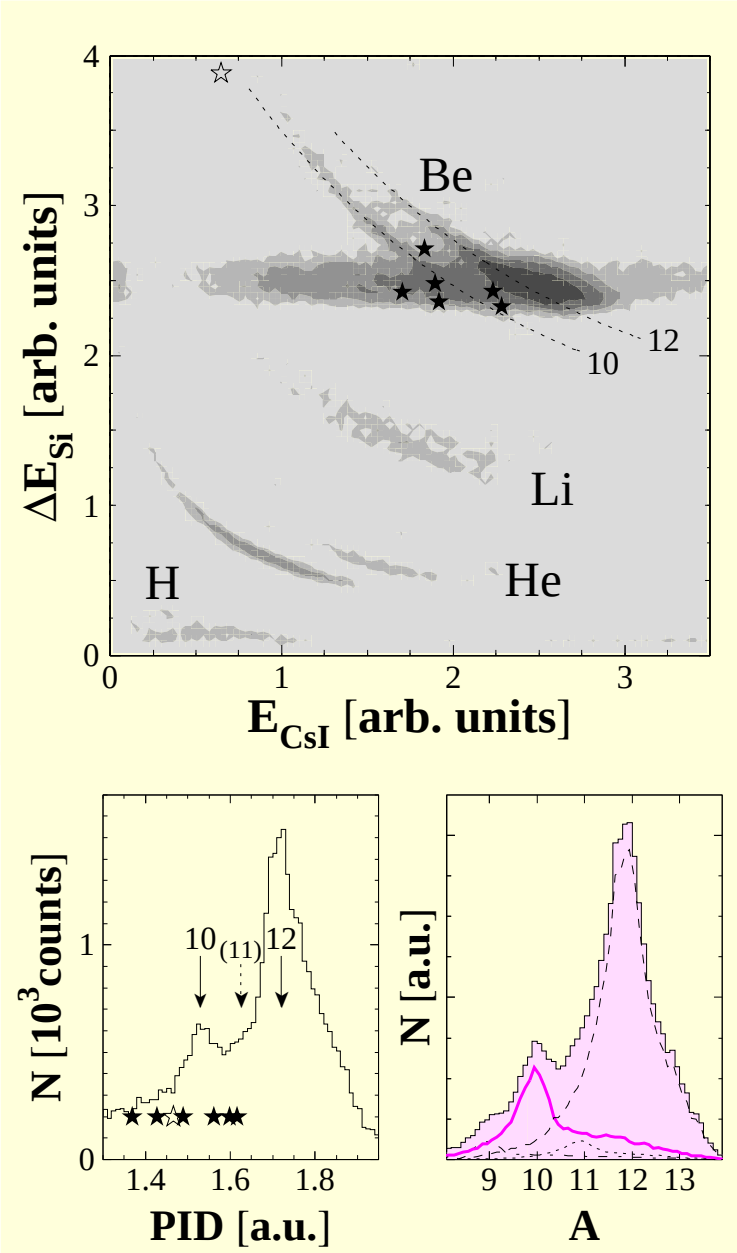
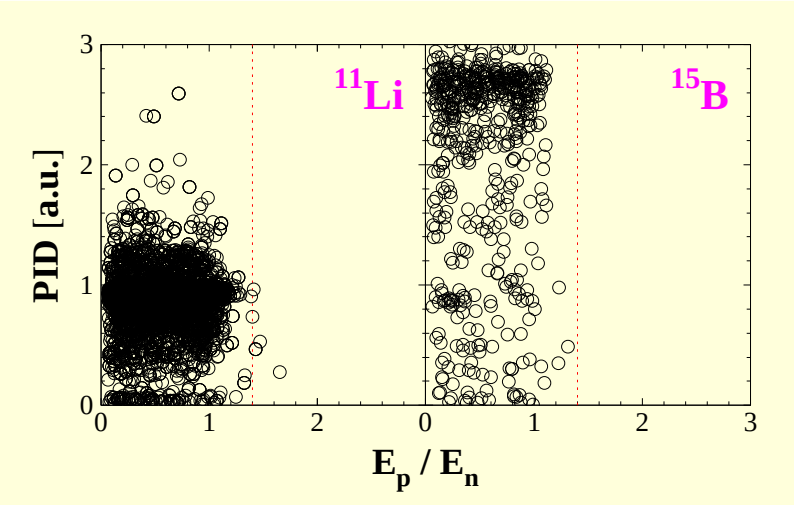




⇨ looks like : ^{14}Be $\xrightarrow{(C)}$ ^{10}Be + ^{4}n

On the detection of neutron clusters ?

- Other beam particles :



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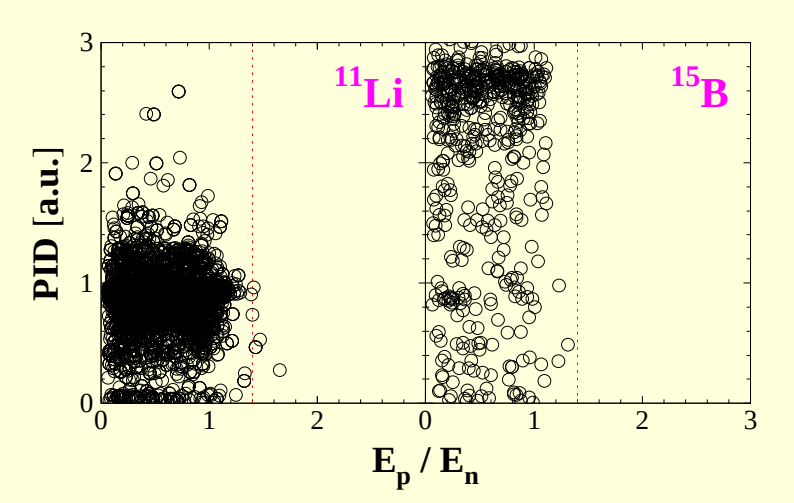

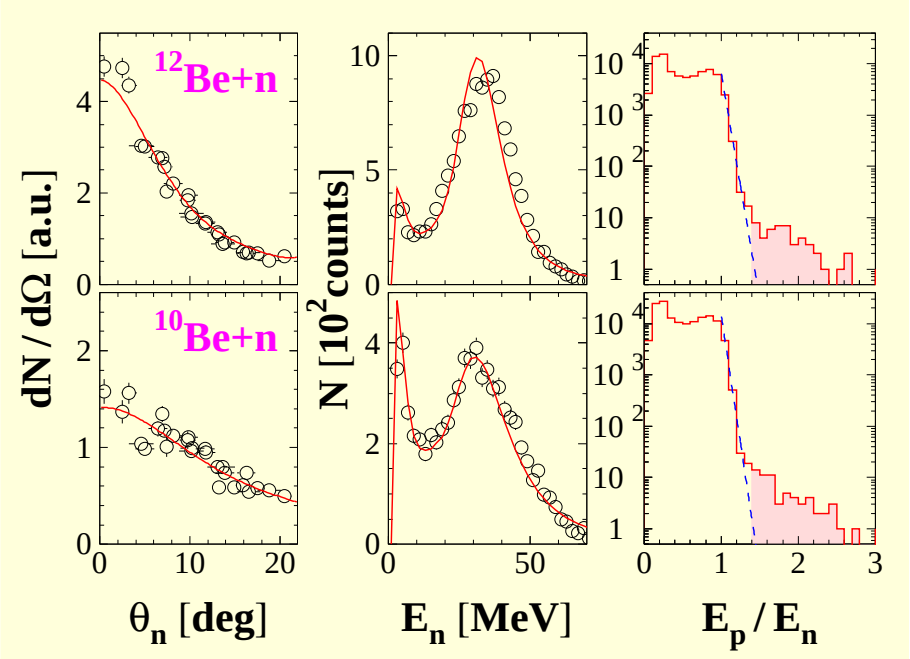

- Estimated pileup $(x\mathrm{n})$:

channel	$N_{2n}^{(12)}$	$N_{2n}^{(sim)}$	$N_{2n}^{(nn)}$	N_{2n}^{exp}
$(^{11}\mathrm{Li}, \mathrm{X})$	< 6.0	~ 3.3	< 7.0	4
$(^{15}\mathrm{B}, \mathrm{X})$	< 0.5	~ 0.3	< 0.9	0
$(^{14}\mathrm{Be}, ^{12}\mathrm{Be})$	–	0.8	< 1.2	0
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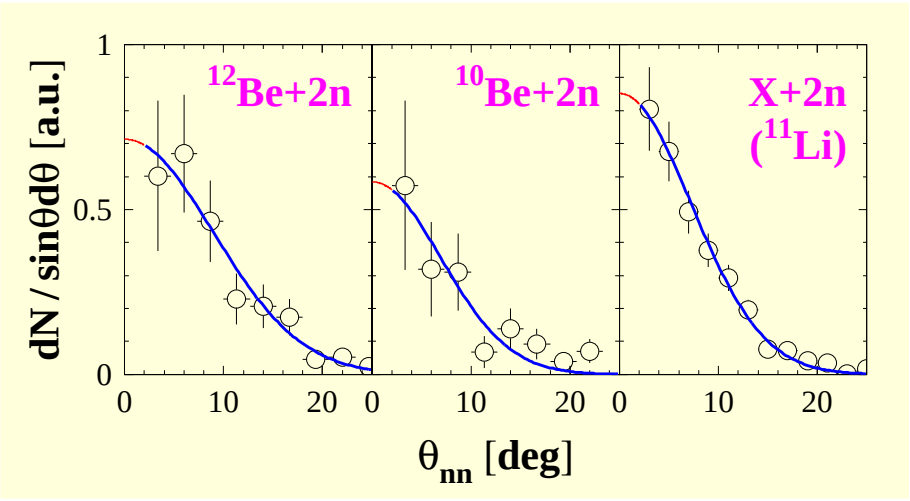

→ 2.5σ : "On the detection of neutron clusters"

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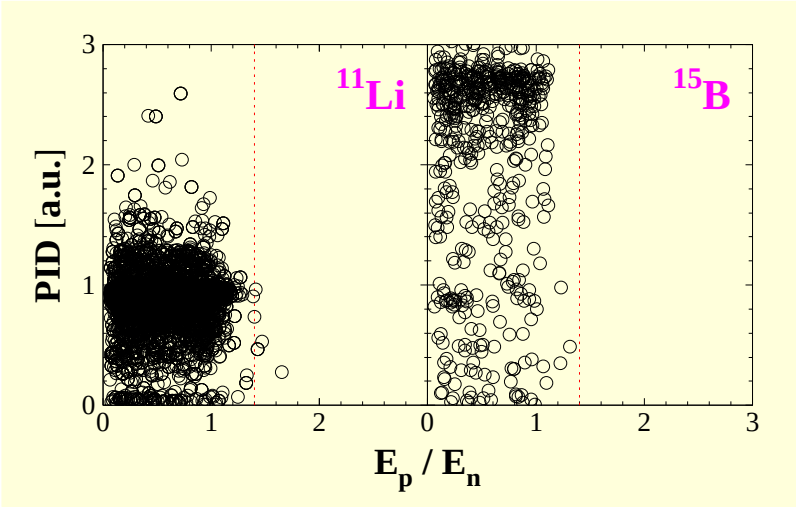

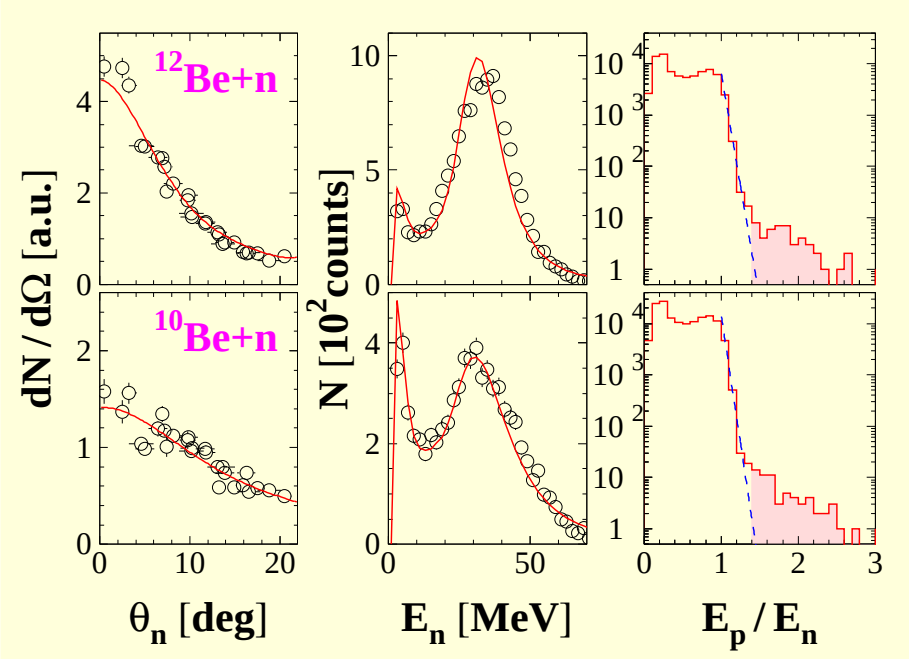

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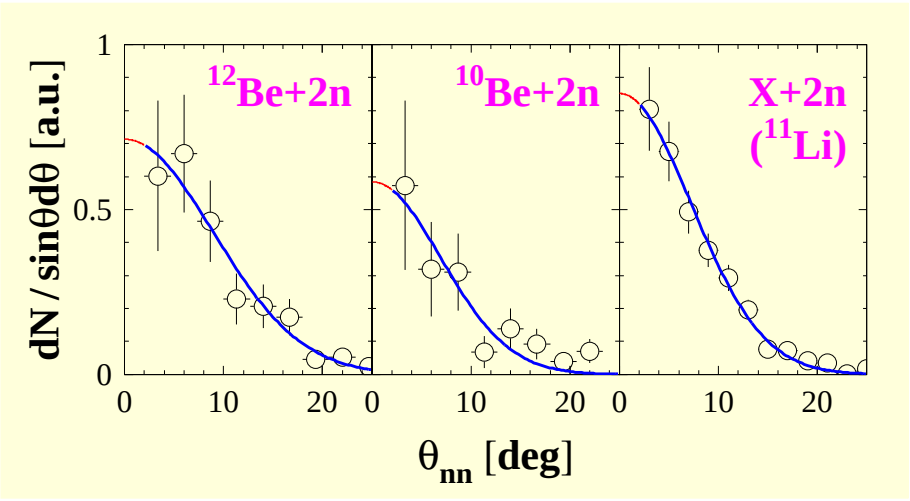

→ 2.5σ : ~~On the~~ "Detection of neutron clusters"

FMM, PRC 65 (April 1, 2002) 044006

Impact on the media

PHYSIQUE

Atome : le noyau pur

Un noyau atomique ne contient aucun proton. Une stupéfiante découverte à confirmer

Les physiciens devront-ils revoir leur théorie sur le fonctionnement de l'atome ? Une équipe internationale, dirigée par des chercheurs du Laboratoire de physique corpusculaire du CNRS à Caen (Calvados), vient en effet d'annoncer l'existence d'un objet que l'on ne devrait pas trouver dans la nature : un tétraneutron, un noyau atomique constitué de quatre neutrons. Sans le moindre proton ! La nouvelle risque de faire du bruit. Et pas seulement chez les spécialistes du nucléaire. Car elle contredit tout ce qui est aujourd'hui enseigné dans les manuels du secondaire. Découvert en 1911 par Ernest Rutherford, au cœur de l'atome, le noyau est en effet défini comme un assemblage de neutrons et de protons. Selon les règles établies par les physiciens, la quantité des premiers varie et peut même être nulle. Le nombre de protons détermine quant à lui la nature même de l'atome. Ainsi, si l'or s'appelle or, c'est que son noyau contient 79 protons. Si l'hydrogène porte son nom, c'est qu'il n'en contient qu'un... Dès lors, on comprend la surprise suscitée par l'existence du tétraneutron. Pour débusquer cette étrange entité, les chercheurs de l'expérience, baptisée E 295, ont précipité, à une vitesse de l'ordre de celle de la lumière, des atomes de béryllium massif sur une cible de carbone. Le choc aurait créé, durant quelques milliardièmes de seconde, un noyau à quatre neutrons. Reste à confirmer la découverte : cet objet du troisième type n'aurait jusqu'ici été observé que six fois. ●

GANIL

Montage de l'expérience, au Ganil, à Caen, grâce à laquelle a été découvert le tétraneutron.

Vahé Ter Minassian

88 ● L'EXPRESS 9/5/2002

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88 ● L'EXPRESS 9/5/2002

L'elemento zero

Sembra una botte...
...ma è un rivelatore di neutroni (Tonneau pour neutrons retardés) presso l'acceleratore Ganil di Caen, in Francia.

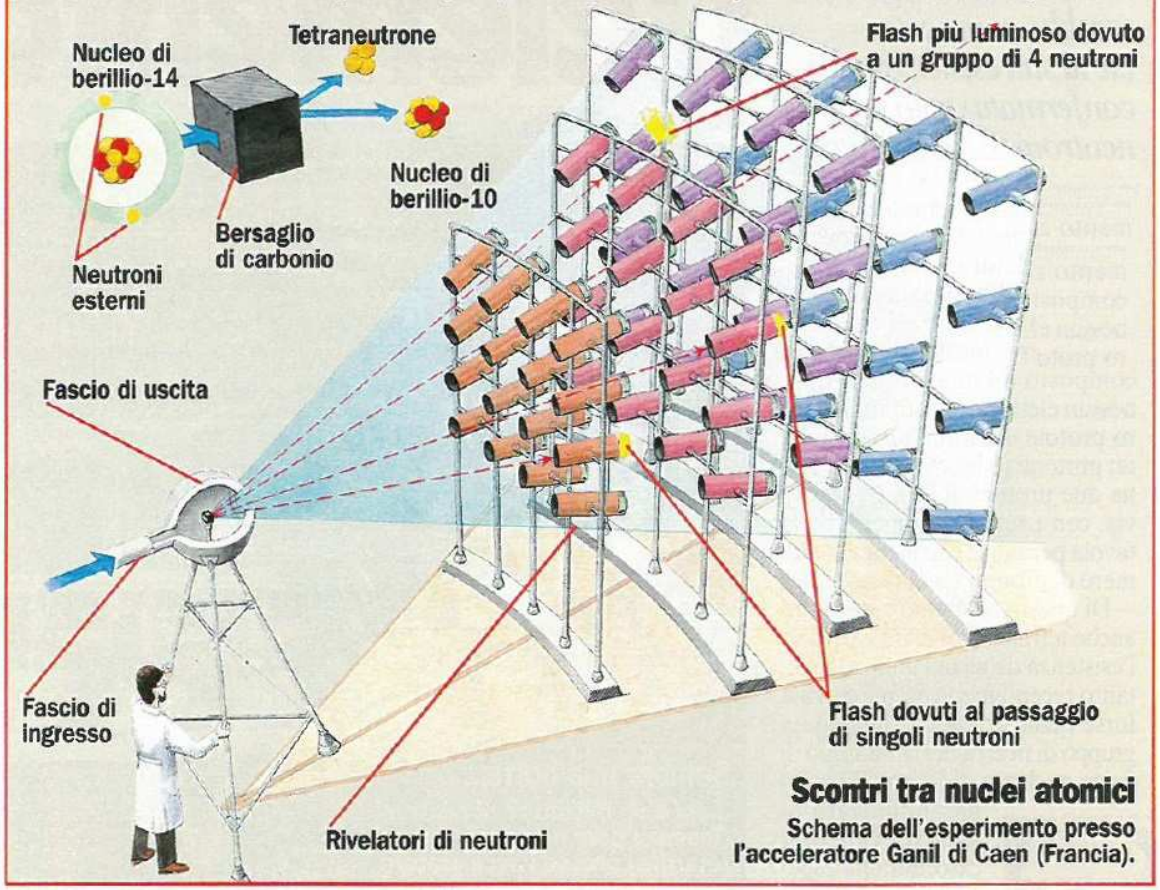
Impact on the media

PHYSIQUE

Atome : le noyau pur

Come si produce l'elemento zero

Ecco come funziona l'esperimento. Si accelera un fascio di nuclei di berillio-14, un isotopo dell'elemento berillio (che ha la particolarità di essere avvolto da una coppia di neutroni), e lo si fa scontrare con un bersaglio di carbonio. In seguito all'impatto, i nuclei di berillio-14 si spezzano in nuclei di berillio-10 e 4 neutroni. **Tutti insieme** I 4 neutroni, registrati da rivelatori che producono flash luminosi, dovrebbero sparpagliarsi in più direzioni. Per 6 volte, però, sono arrivati tutti insieme, come se fossero una sola particella.



Scontri tra nuclei atomici
Schema dell'esperimento presso l'acceleratore Ganil di Caen (Francia).

...mme un as- | 79 protons. Si l'hy-
e de ne
...otons. S
s établi
...hysicie
des pr
peut m
e. Le n
...ns déte
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GANIL

...en,
...neutron.

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PHYSIQUE

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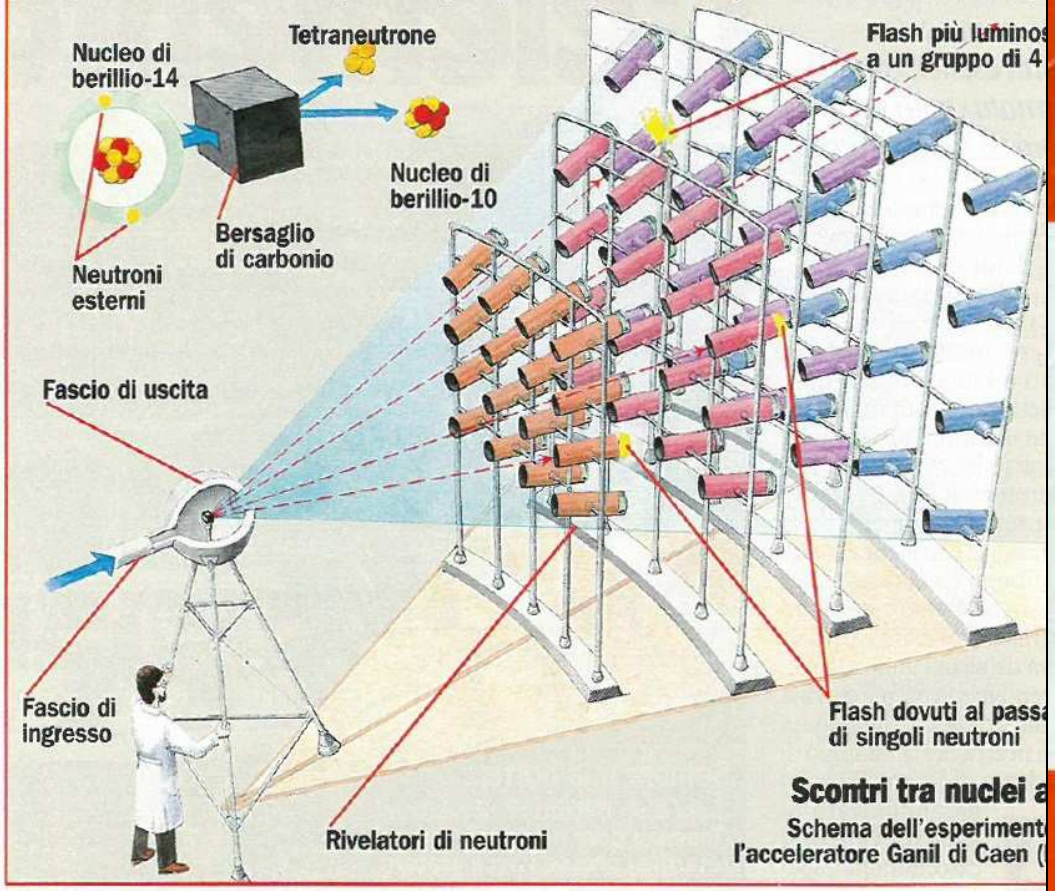
Come si produce l'elemento zero

Ecco come funziona l'esperimento. Si accelera un fascio di nuclei di berillio-14, un isotopo dell'elemento berillio (che ha la particolarità di essere avvolto da una coppia di neutroni), e lo si fa scontrare con un bersaglio di carbonio. In seguito all'impatto, i nuclei di berillio-14 si spezzano in nuclei di berillio-10 e 4 neutroni.

Tutti insieme

I 4 neutroni, registrati da rivelatori che producono flash luminosi, dovrebbero sparpagliarsi in più direzioni. Per 6 volte, però, sono arrivati tutti insieme, come se fossero una sola pa



Scontri tra nuclei a

Schema dell'esperiment
l'acceleratore Ganil di Caen (

88 ● L'EXPRESS 9/5/2002

...mme un as- | 79 protons. Si l'hy-
...e de ne
...otons. S
...s établi
...hysicie

L'elemento zero

NewScientist

the global science and technology weekly | 20 October 2012

NEW! US JOBS SECTION

ELEMENT ZERO?

Theory says it can't exist, but experiments have found a new type of matter...

SWEETNESS AND MIGHT
Awesome power of the glycome

CHAD'S ANCIENT APE
Is this really the missing link?

LATEST NEWS
NASA's new vision emerges
Row over 'turning rivers around'
New scare links food to blindness

Impact on the media

PHYSIQUE

Atome : le noyau pur

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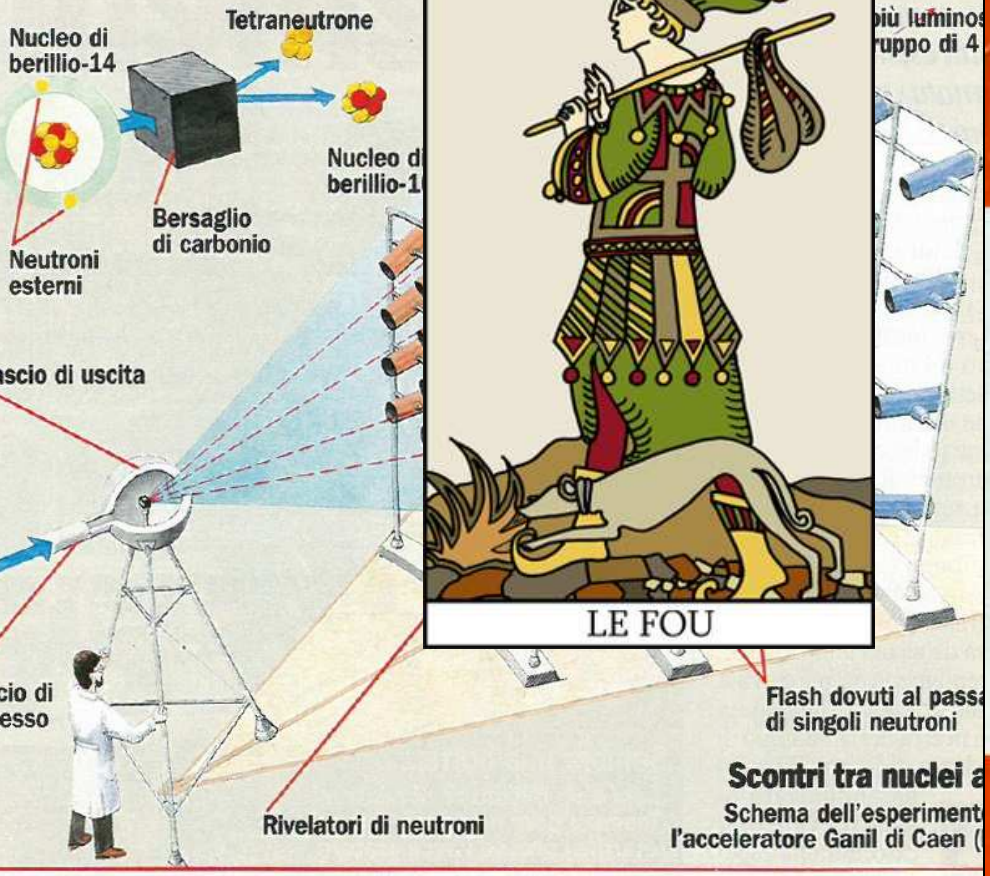


Scontri tra nuclei a

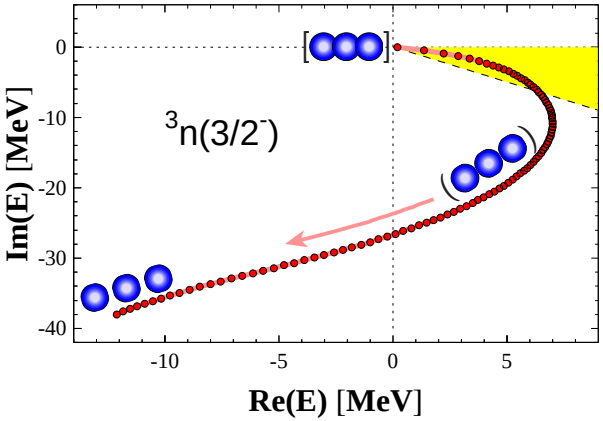
Schema dell'esperiment l'acceleratore Ganil di Caen (

88 ● L'EXPRESS 9/5/2002

Impact on theory

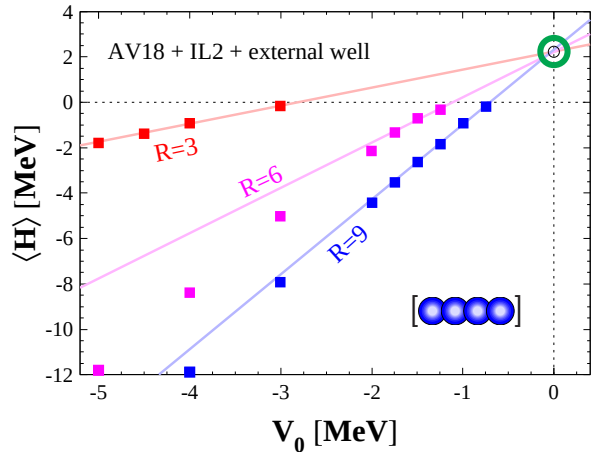
Hemmdan, PRC 66 (2002) 054001

"3n resonances close to the physical region will not exist"



Pieper, PRL 90 (2003) 252501

"the resonance, if it exists at all, must be very broad"



Sherrill, PRC 69 (2004) 027601 : (^{4}n,p) elastic ?

Impact on theory : resonance ?

Hemmdan, PRC 66 (2002) 054001

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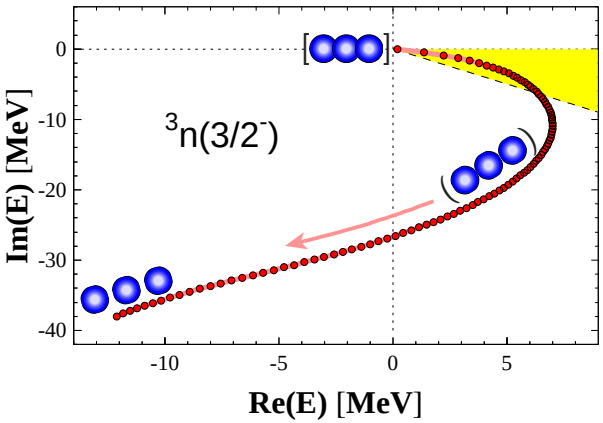

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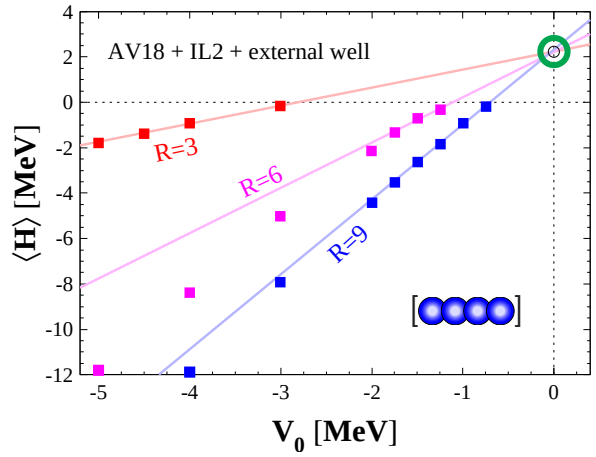
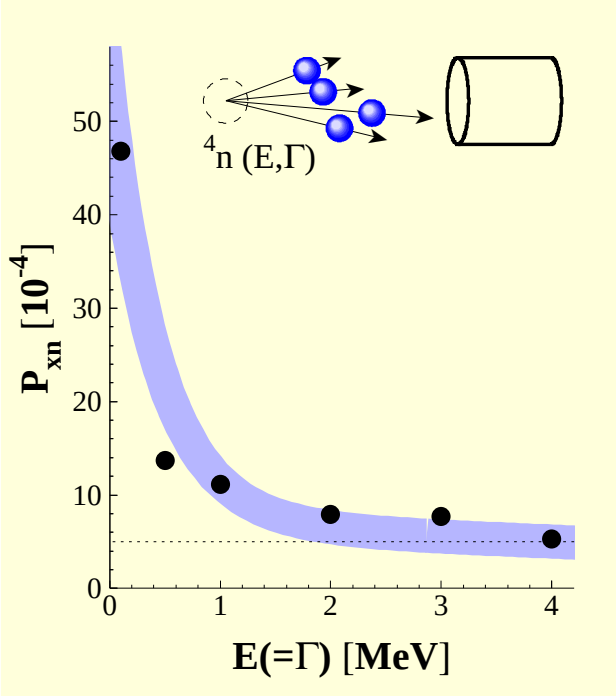


Sherrill, PRC 69 (2004) 027601 : (^{4}n,p) elastic ?

- Candidate evts compatible with :
  - (^{4}n,p) breakup
  - $E_R(^4n) \lesssim 2$ MeV !



FMM, arXiv:nucl-ex/0504009

→ picky referee : *"No new data"* !

→ involved in confirmation attempts ...

Impact on Wikipedia !

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Tetraneutron *(October 25, 2002)*

12 languages

Article Talk | Read Edit View history Tools

From Wikipedia, the free encyclopedia

A **tetraneutron** is a hypothetical stable cluster of four neutrons. The existence of this cluster of particles is not supported by current models of nuclear forces.[1] There is some empirical evidence suggesting that this particle does exist, based on a 2001 experiment by Francisco-Miguel Marqués and co-workers at the Ganil accelerator in Caen using a novel detection method in observations of the disintegration of beryllium and lithium nuclei.[2] However, subsequent attempts to replicate this observation have failed.

Further work[3] in 2019 suggests potentially observable consequences in neutron star crusts, if the tetraneutron exists.

As detailed at the end of this article, subsequent observations from different ion beam experiments are consistent with short-lived four neutron states with some binding.

Marqués' experiment [edit]

As with many particle accelerator experiments, Marques' team fired atomic nuclei at carbon targets and observed the "spray" of particles from the resulting collisions. In this case the experiment involved firing beryllium-14, boron-15 and lithium-11 nuclei at a small carbon target, the most successful being beryllium-14. This isotope of beryllium has a nuclear halo that consists of four clustered neutrons; this allows it to be easily separated intact in the high-speed collision with the carbon target.[2] Current nuclear models suggest that four separate neutrons should result when beryllium-10 is produced, but the single signal detected in the production of beryllium-10 suggested a multineutron cluster in the breakup products; most likely a beryllium-10 nucleus and four neutrons fused together into a tetraneutron.

Since Marqués' experiment [edit]

A later analysis of the method used in the Marqués' experiment suggested that at least part of the orginal analysis was flawed[4] *(July 10, 2005)*

Impact on Wikipedia !

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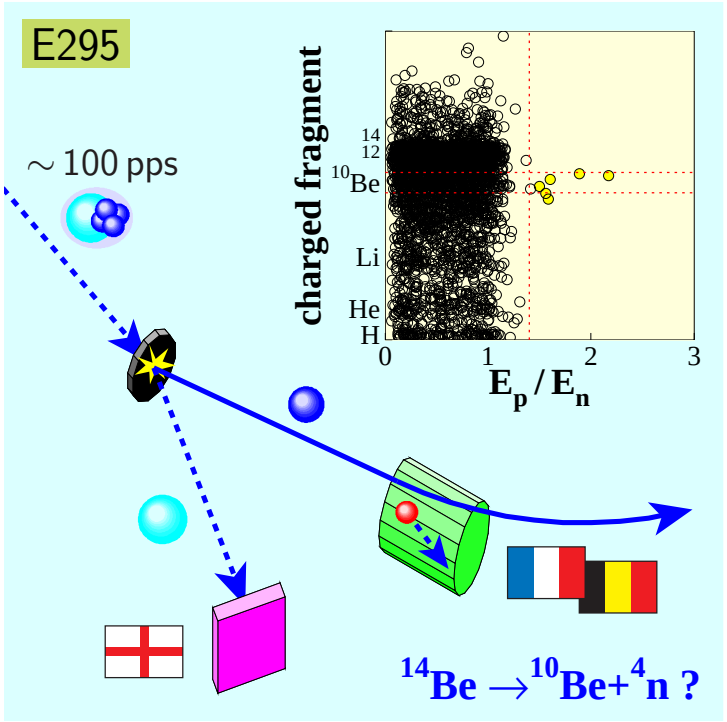
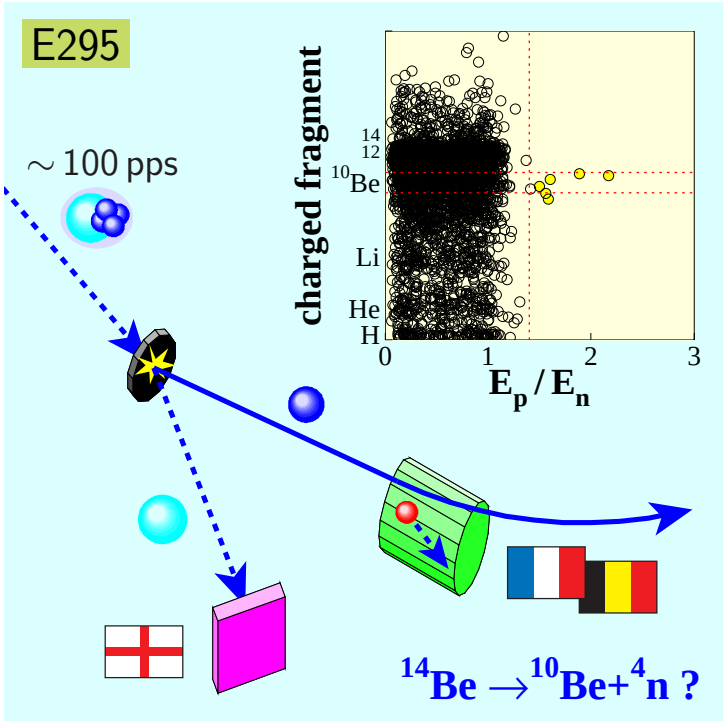
the detection mechanism was unlikely[4] but the suggestion was refuted,[5]

New experiments @ GANIL ...



(Sep 2001) E378 * $^{14}\mathrm{Be} \xrightarrow{(C)} {}^{10}\mathrm{Be} + {}^{4}\mathrm{n}$

New experiments @ GANIL ...



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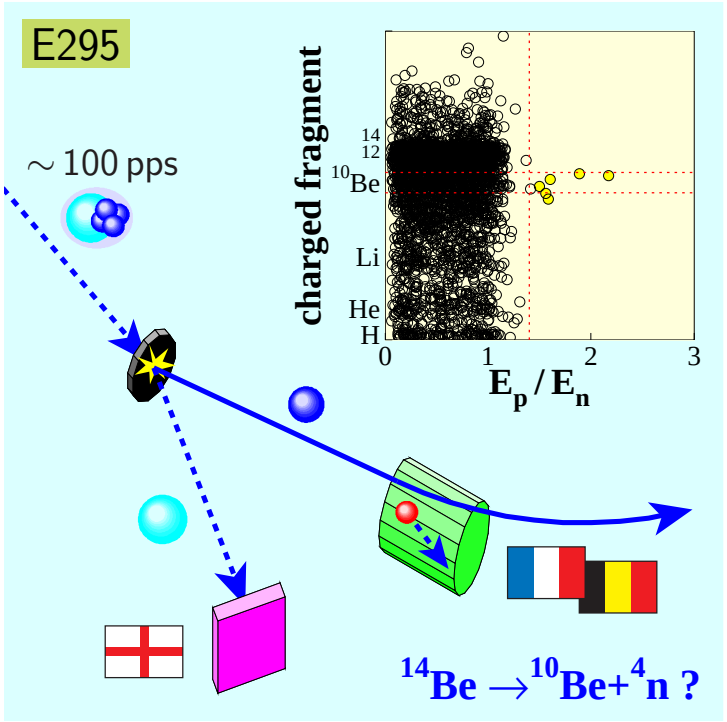

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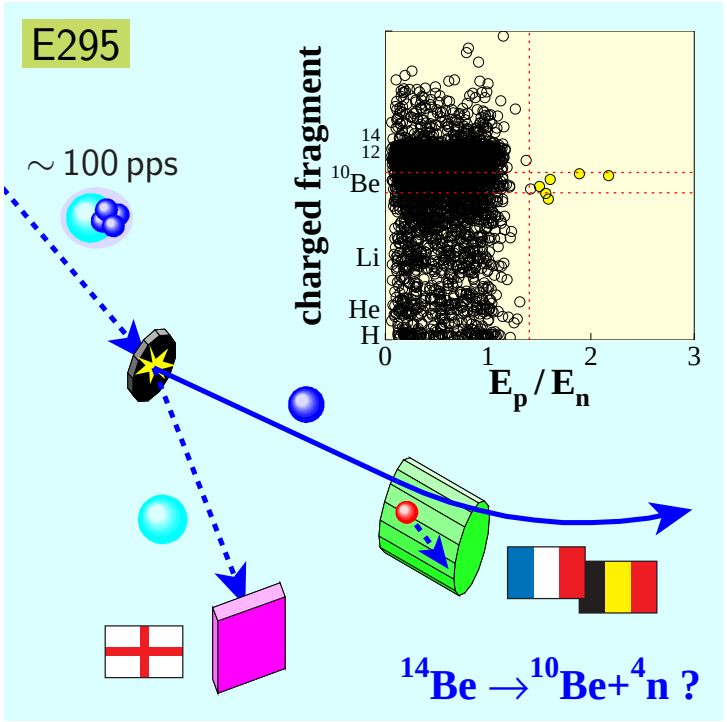
New experiments @ GANIL ...



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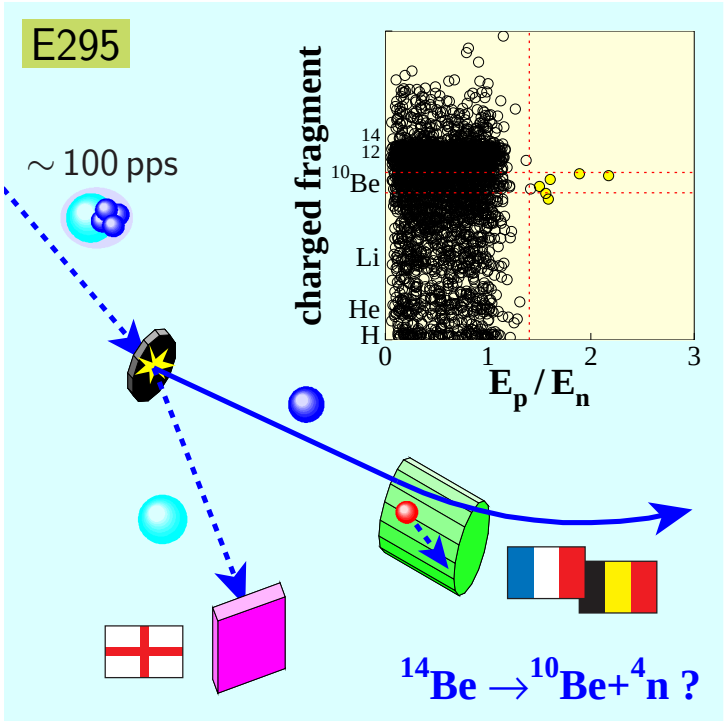

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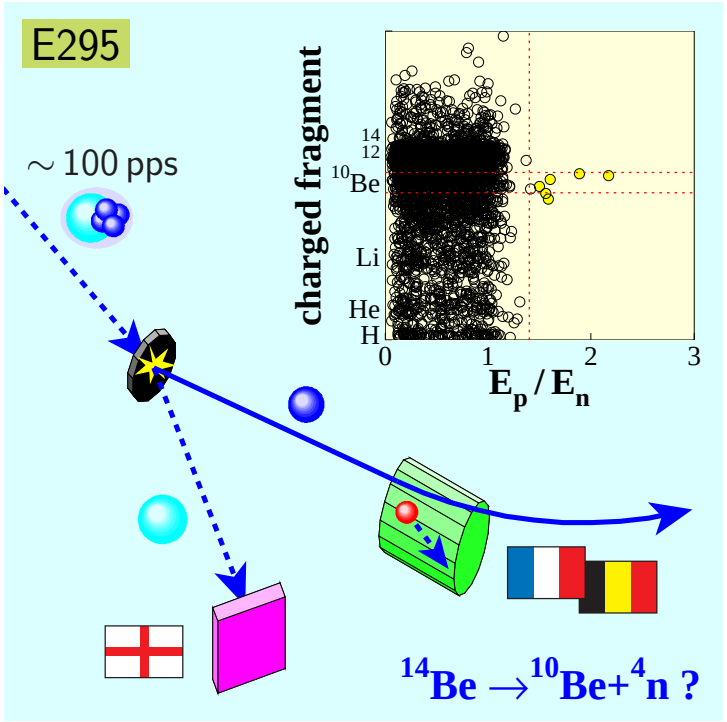
New experiments @ GANIL ...



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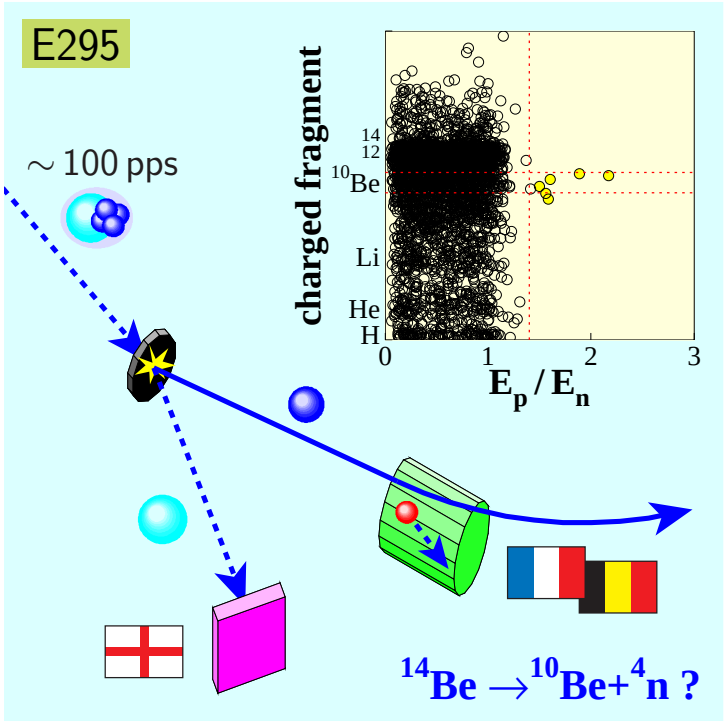

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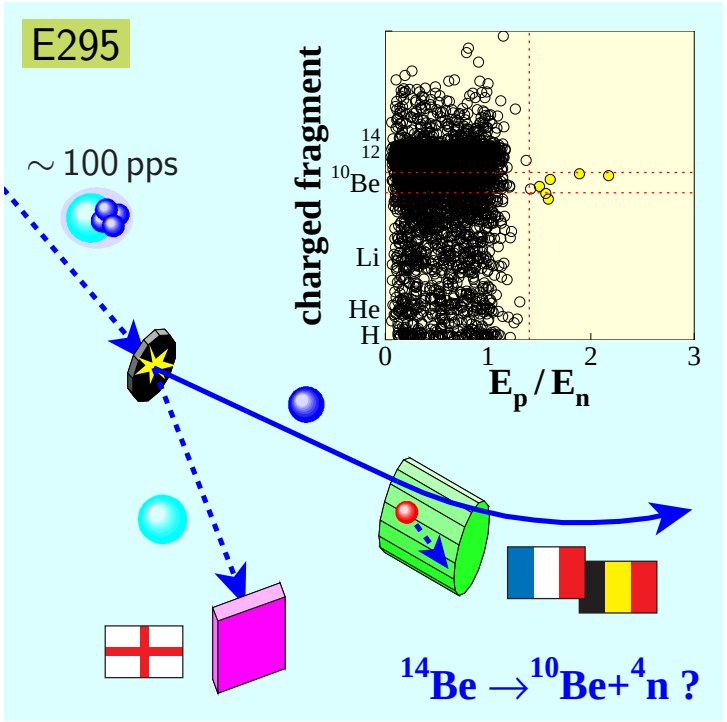
(Apr 2006)	E483	^{15}B	$\xrightarrow{(C)}$	^{14}Be* → ^{4}n

⇨ program on hold ...

New experiments @ GANIL ... and RIKEN



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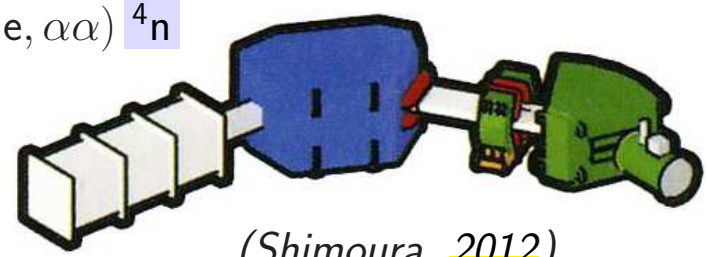
(Apr 2006)	E483	^{15}B	$\xrightarrow{(C)}$	^{14}Be* → ^{4}n

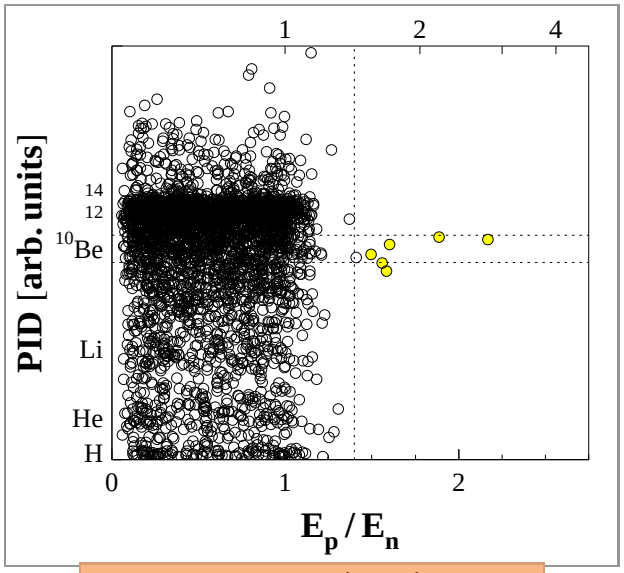
⇨ program on hold ... starts @ **RIKEN** !

^{4}He (^{8}He, $\alpha\alpha$) ^{4}n



(Shimoura, 2012)

A long homestretch

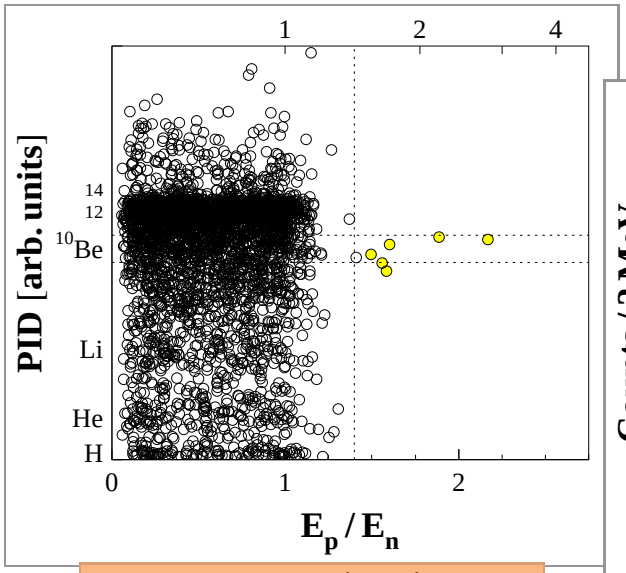


FMM, PRC 65 (2002) 044006

FMM, arXiv:nucl-ex/0504009

$E(4n) \sim [-1,+2]$ MeV (2.5σ)

A long homestretch



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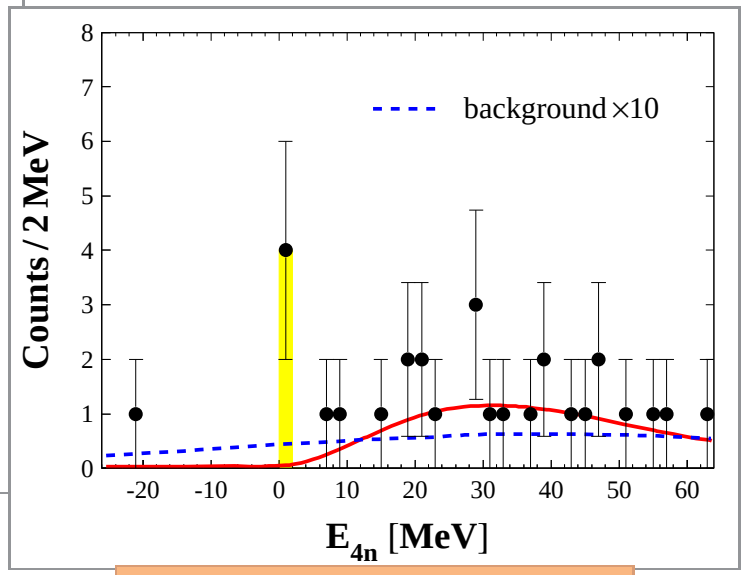
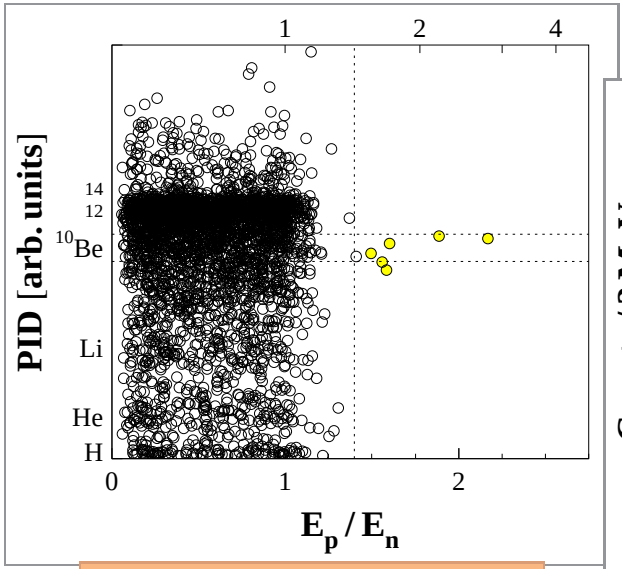


Kisamori, PRL 116 (2016) 052501

$E(4n) = 0.8 \pm 1.3$ MeV (4.9σ)

A long homestretch



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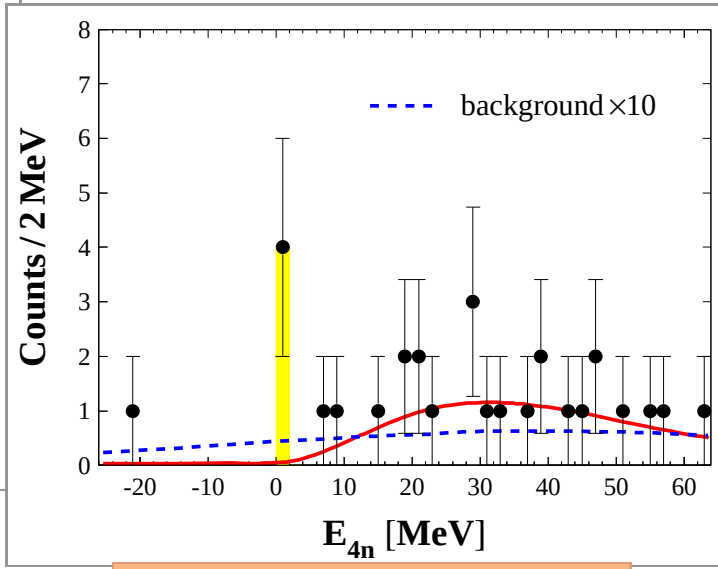

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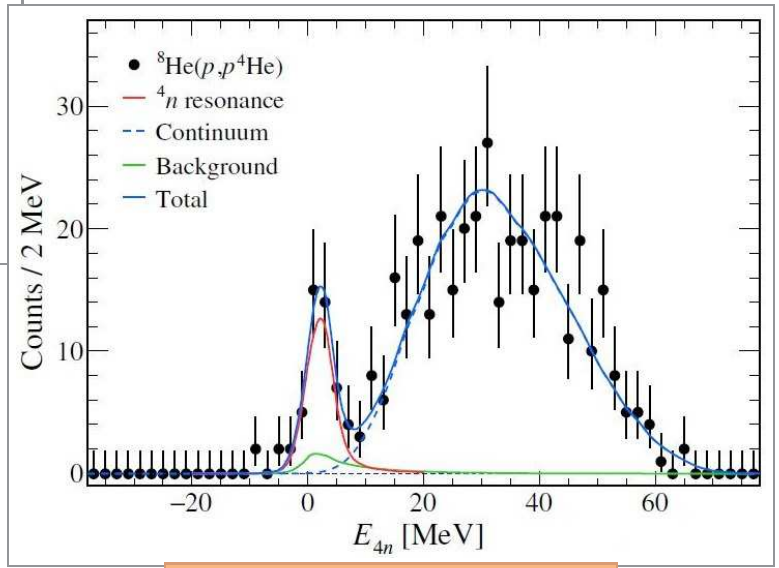
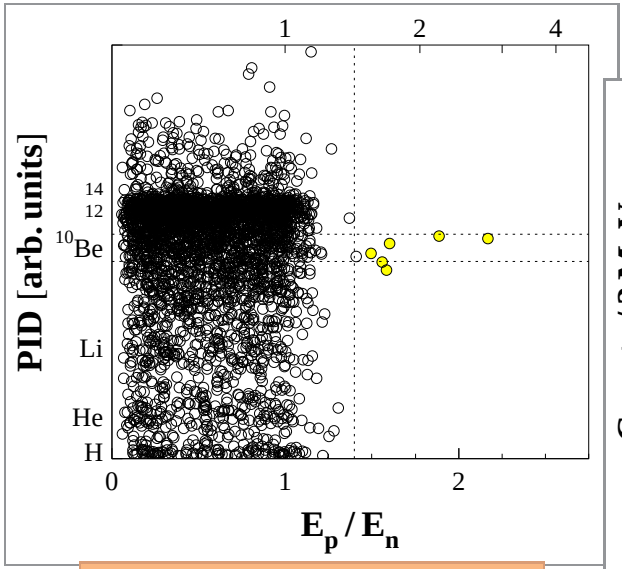


Duer, Nature 606 (2022) 678

$E(4n) = 2.4 \pm 0.6$ MeV ($\gg 5\sigma$)

A long homestretch



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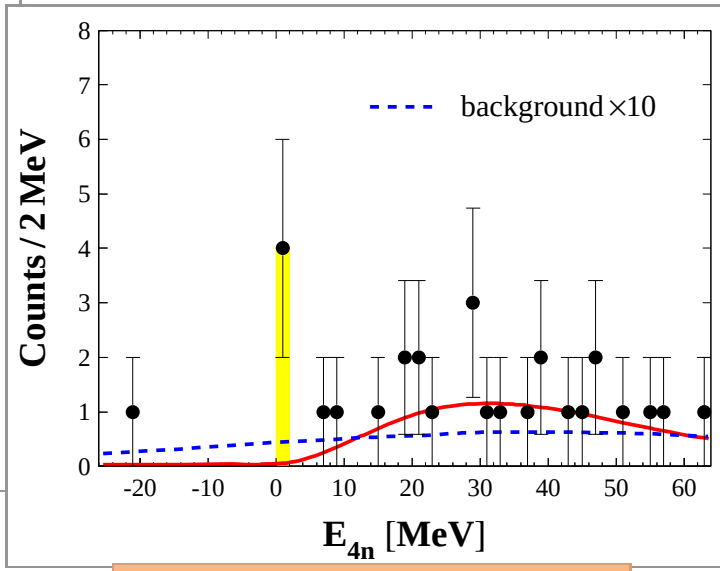

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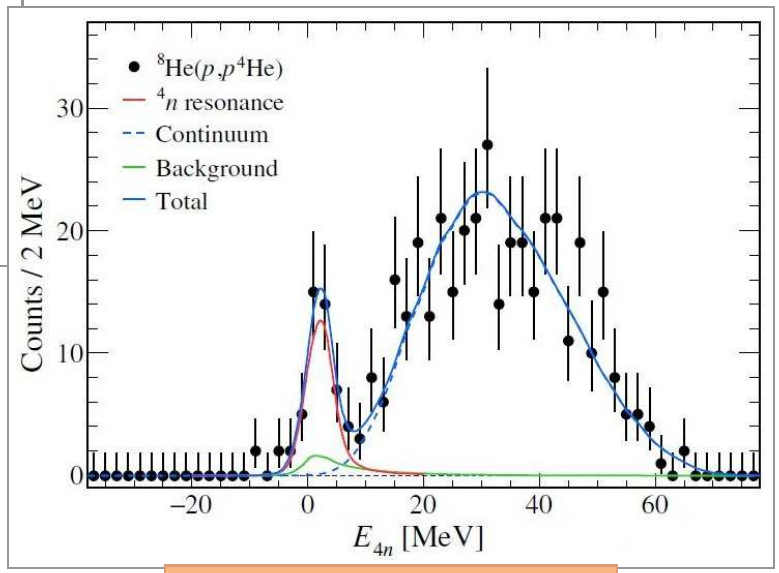

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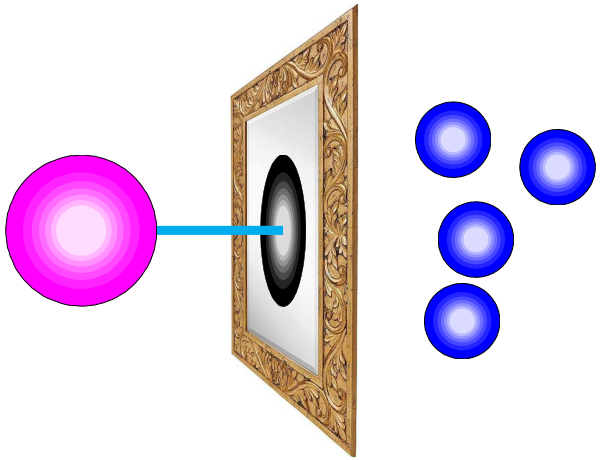

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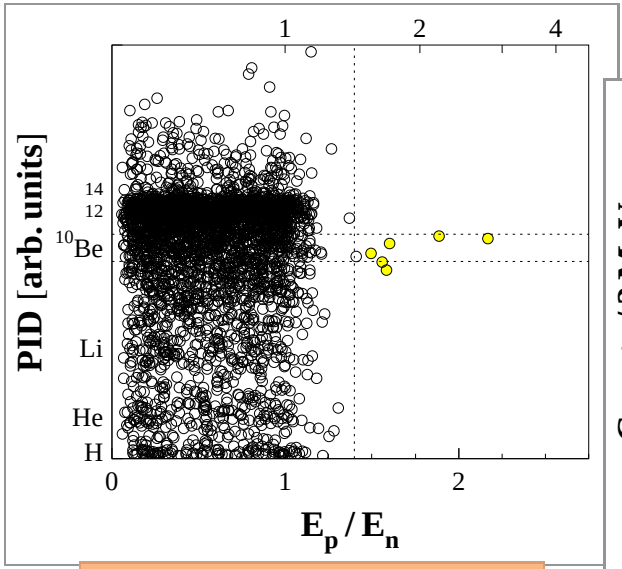

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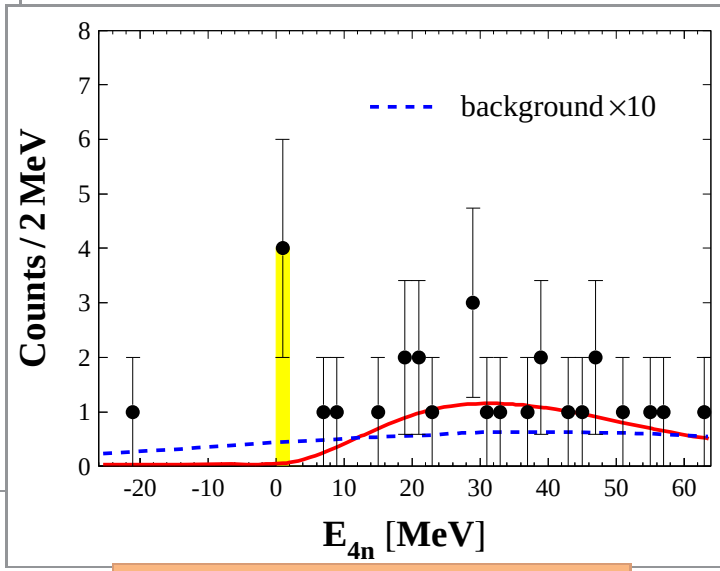

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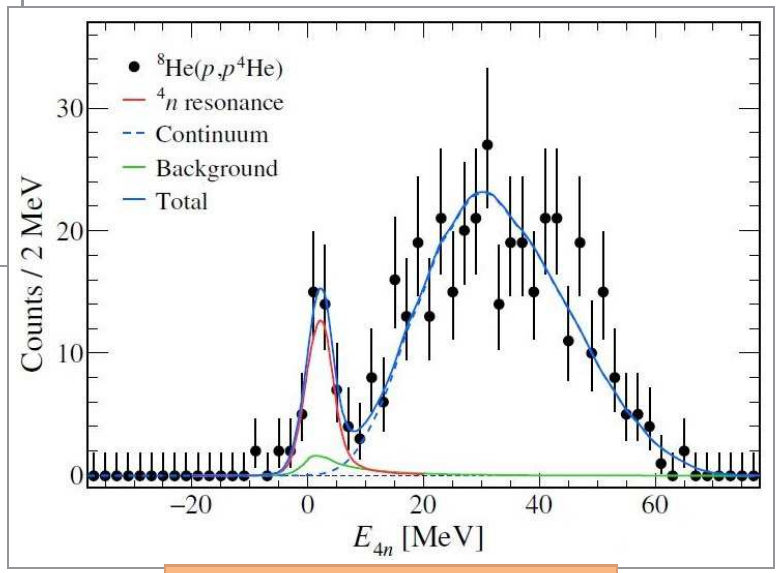

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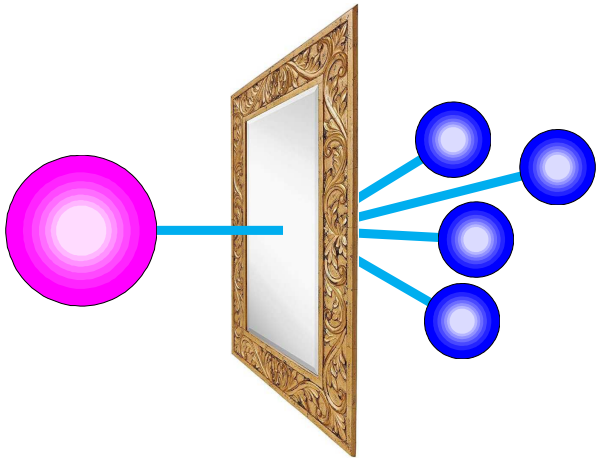
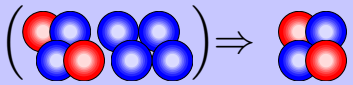
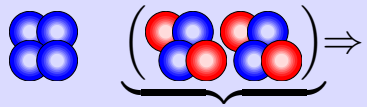
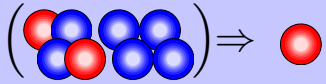
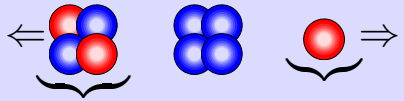
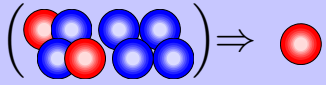
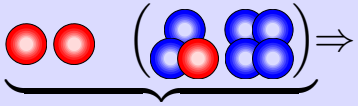


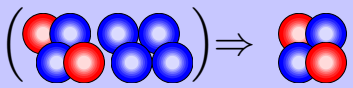
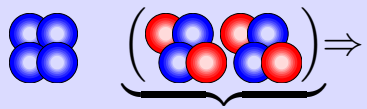
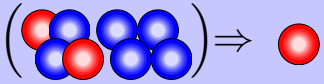
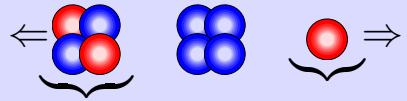
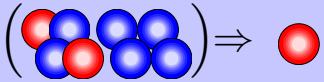
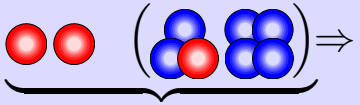
Tetraneutron campaign @ RIKEN

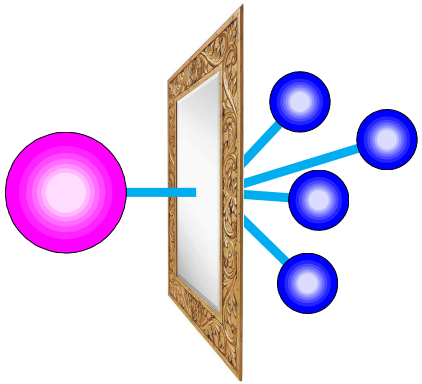
- Three experiments : same beam (^{8}**He**) & energy (150–200 MeV/N) ?

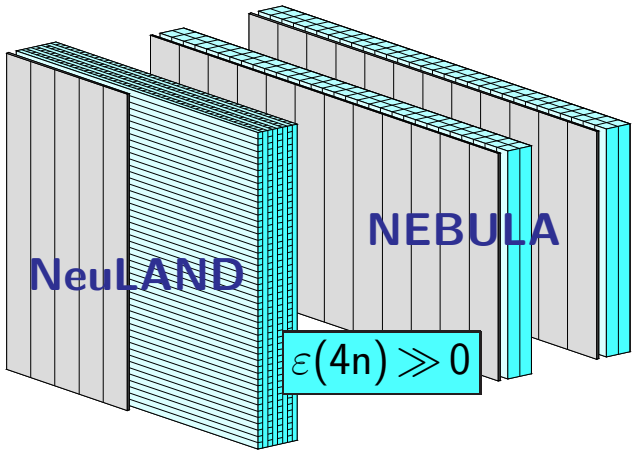
reaction	initial state	final state	σ	results
('16) ^{4}He $(^{8}$He, $\alpha\alpha)$ ^{4}**n** Shimoura, NP1512-SHARAQ10			nb	$N_{evt} \sim 10$ s ^{4}n : E, Γ
('17) ^{8}He (p,pα) ^{4}**n** Paschalis, NP1406-SAMURAI19			μb	$N_{evt} \sim 1000$ s ^{4}n : E, Γ
('17) ^{8}He (p,2p) $\{^{3}$**H**$+^{4}$**n**$\}$ FMM/Yang, NP1512-SAMURAI34			**mb**	$N_{evt} \sim$ **10,000** s ^{4}n & ^{7}H : E, Γ, Ω

Tetraneutron campaign @ RIKEN

- Three experiments : same beam (^{8}**He**) & energy (150–200 MeV/N) ?

reaction	initial state	final state	σ	results
('16) ^{4}He $(^{8}$He, $\alpha\alpha)$ ^{4}**n** Shimoura, NP1512-SHARAQ10			nb	$N_{evt} \sim 10$ s ^{4}n : E, Γ
('17) ^{8}He (p,pα) ^{4}**n** Paschalis, NP1406-SAMURAI19			μb	$N_{evt} \sim 1000$ s ^{4}n : E, Γ
('17) ^{8}He (p,2p) $\{^{3}$**H**$+^{4}$**n**$\}$ FMM/Yang, NP1512-SAMURAI34			**mb**	$N_{evt} \sim$ **10,000** s ^{4}n & ^{7}H : E, Γ, Ω





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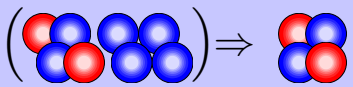
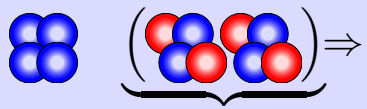
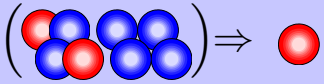
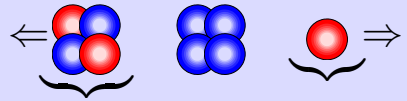
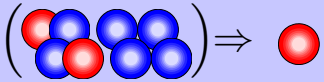
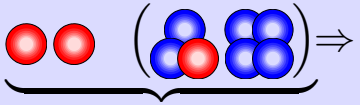
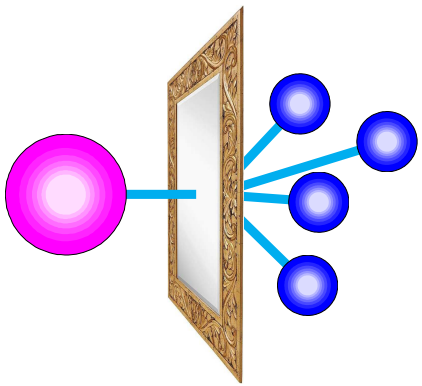
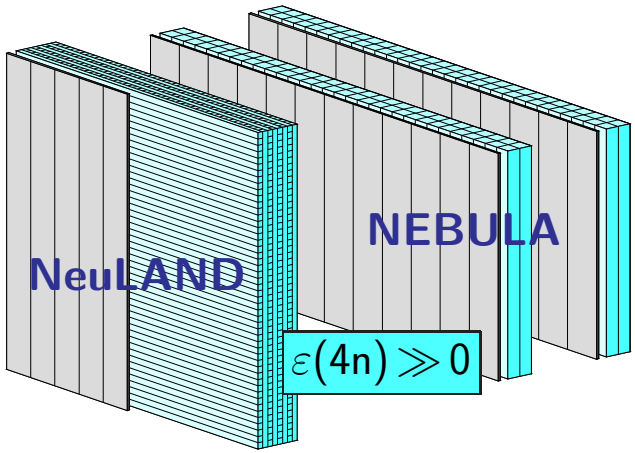
('16) ^{4}He $(^{8}$He, $\alpha\alpha)$ ^{4}**n** Shimoura, NP1512-SHARAQ10			nb	$N_{evt} \sim 10$ s ^{4}n : E, Γ
('17) ^{8}He (p,pα) ^{4}**n** Paschalis, NP1406-SAMURAI19			μb	$N_{evt} \sim 1000$ s ^{4}n : E, Γ
('17) ^{8}He (p,2p) $\{^{3}$**H**$+^{4}$**n**$\}$ FMM/Yang, NP1512-SAMURAI34			**mb**	$N_{evt} \sim$ **10,000** s ^{4}n & ^{7}H : E, Γ, Ω

^{8}He (p,2p) ^{7}H $\rightarrow$ ^{3}H + ^{4}n ?

^{8}He (p,pn) ^{7}He* $\rightarrow$ ^{4}He + ^{3}n ?

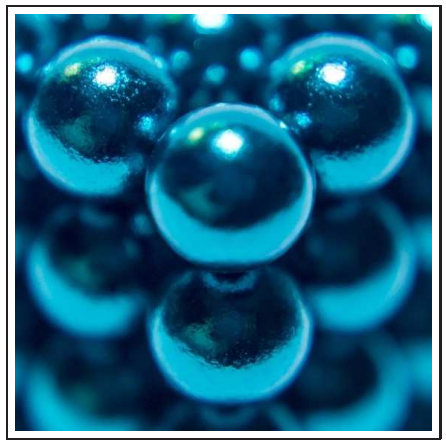
^{8}He (p,p') ^{8}He* $\rightarrow$ ^{4}He + ^{4}n ?





Summary & Conclusion

- Importance of new ideas
- Understanding problematics
- Risk of being taken for a fool !
- Relationships with the media
- Stories are not linear successes !
- Link between experiment & theory



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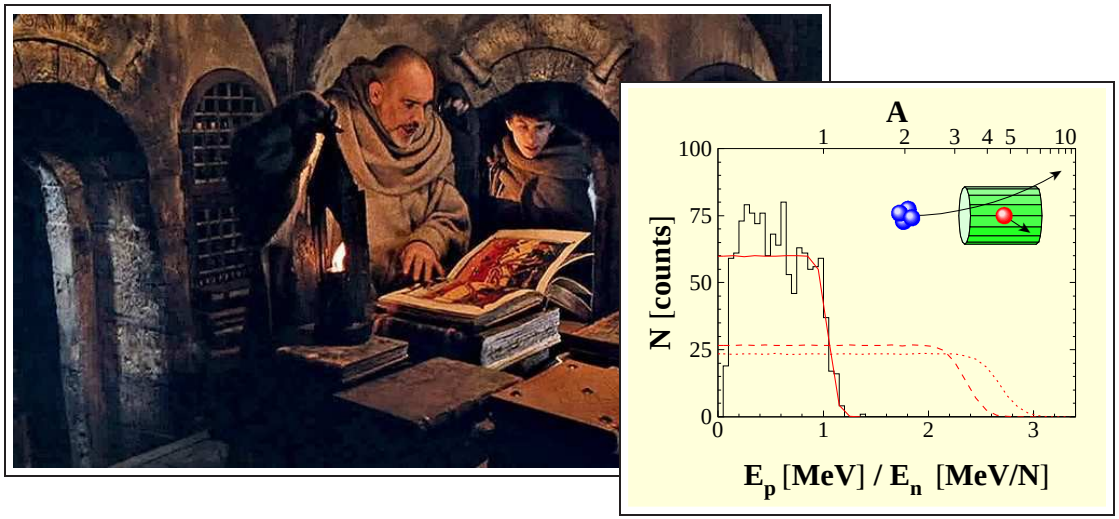

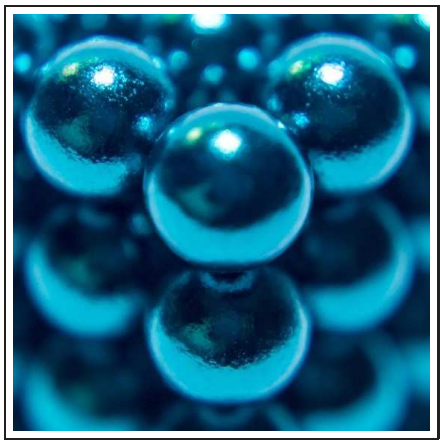

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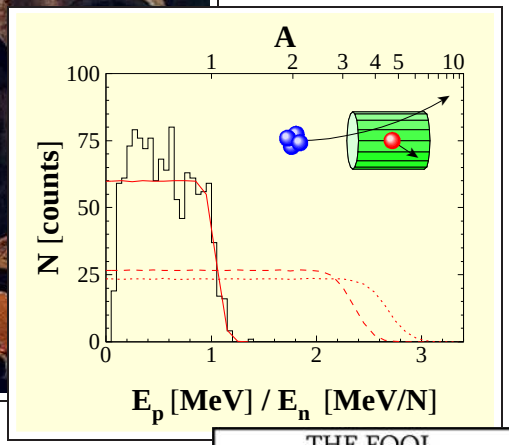

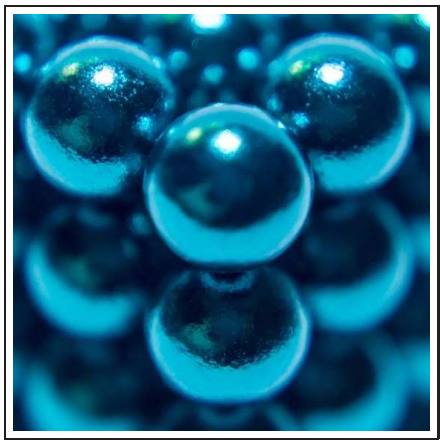

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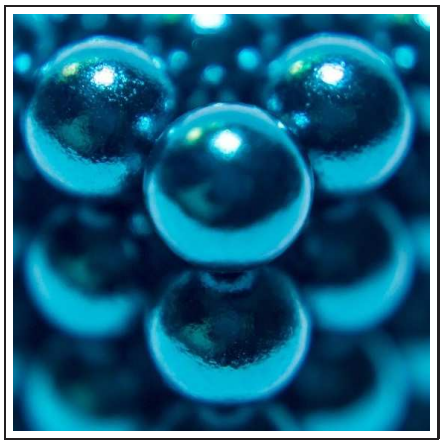

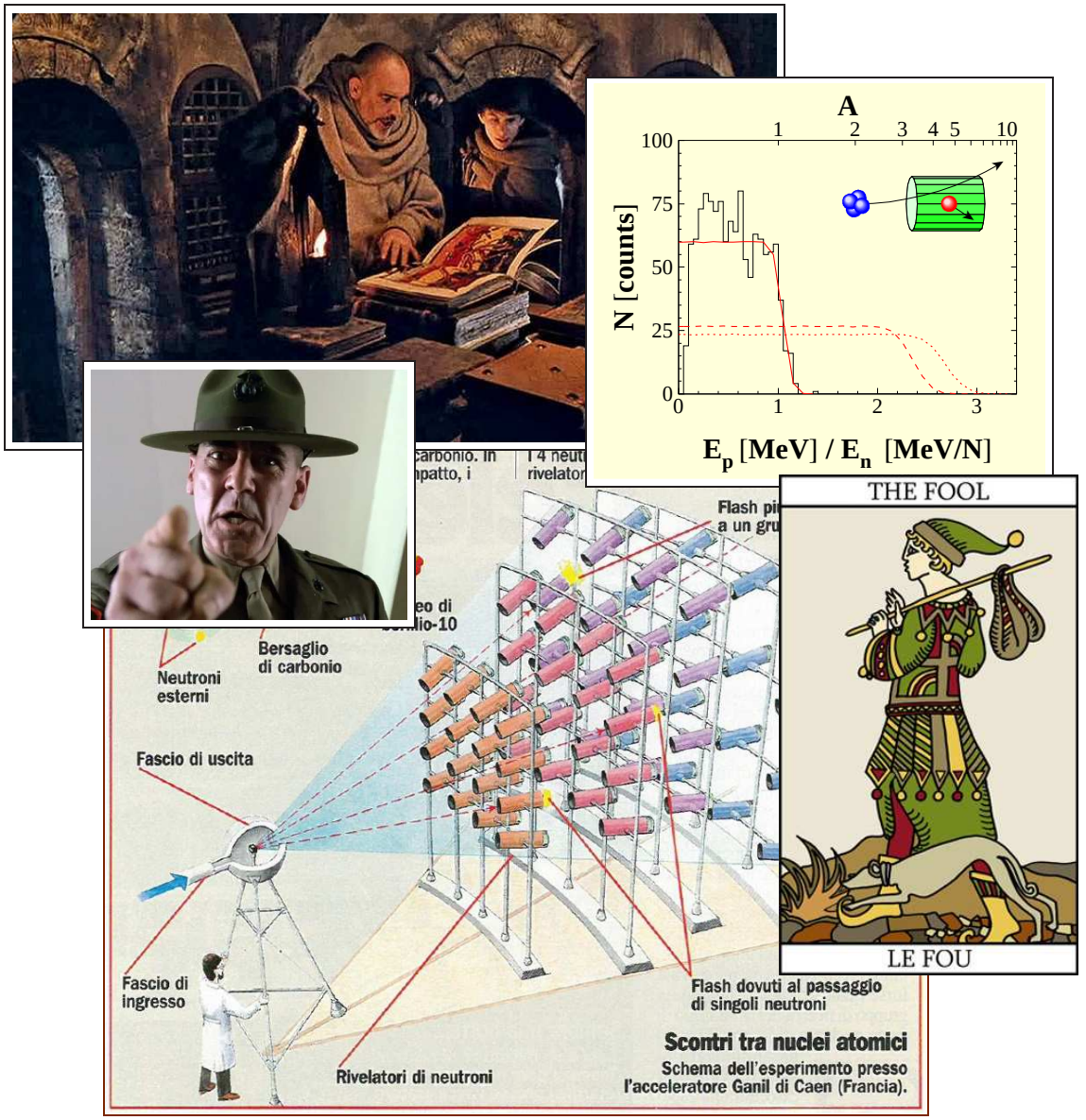

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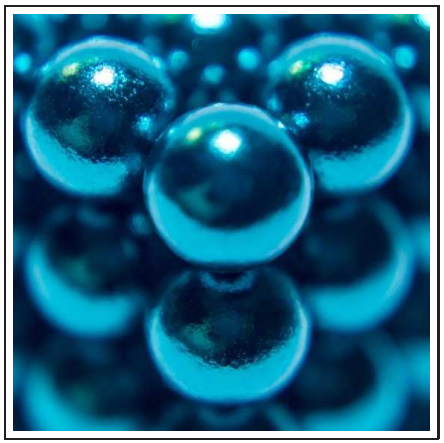

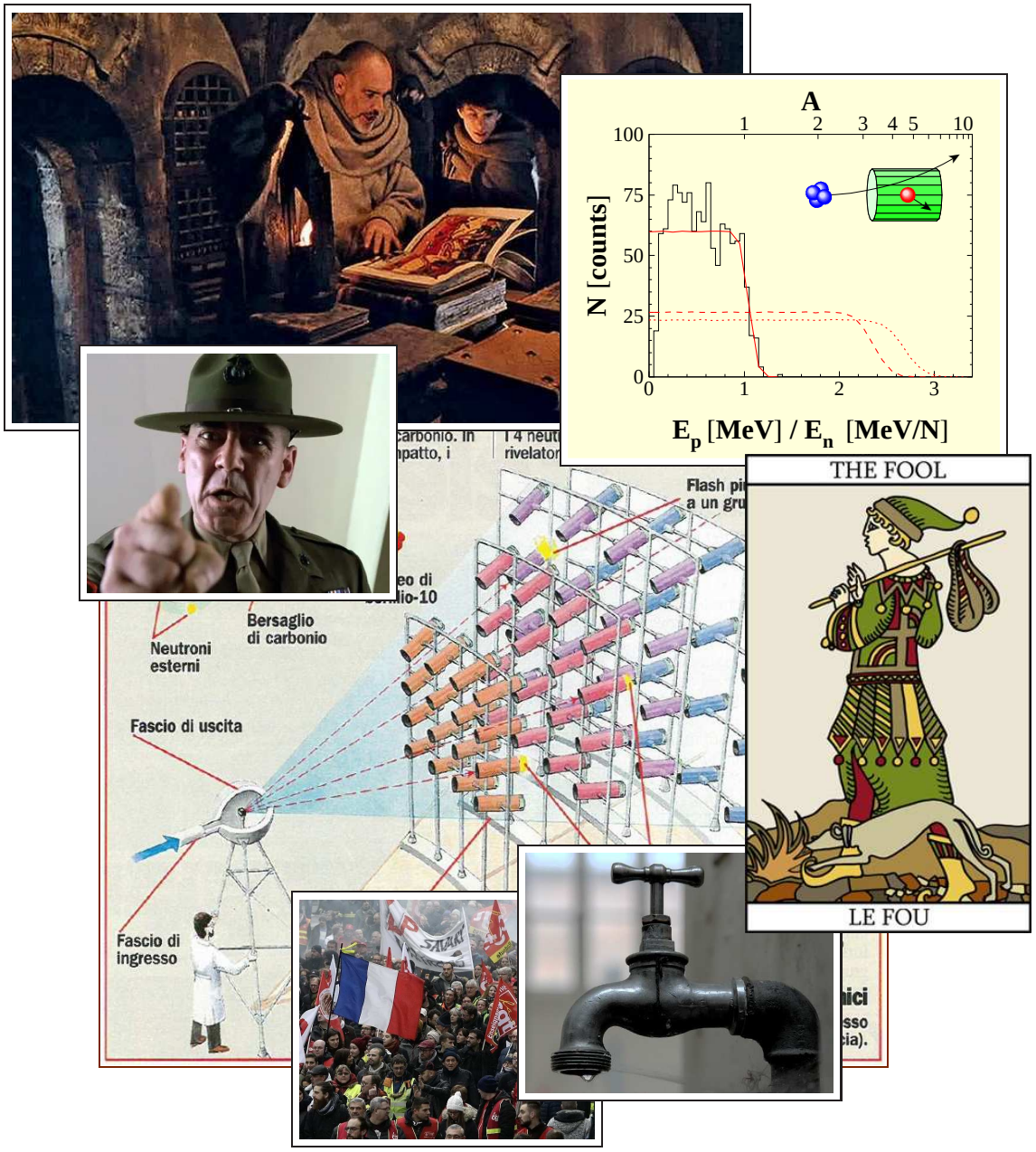

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