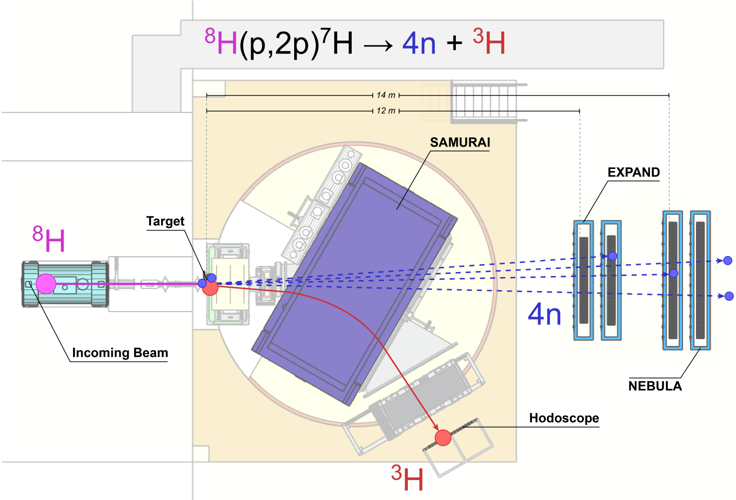
Internship Oral Defense

Multi-neutron detection for the investigation of exotic nuclei

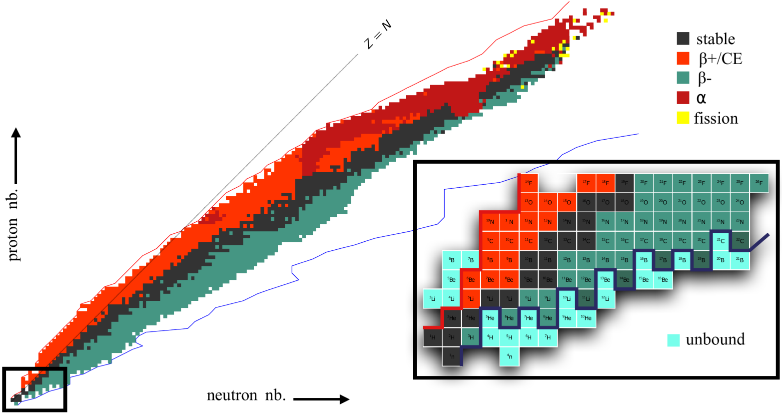
Louis LEMAIR
under supervision of Julien GIBELIN, Miguel MARQUES and Adrien MATTA

Introduction

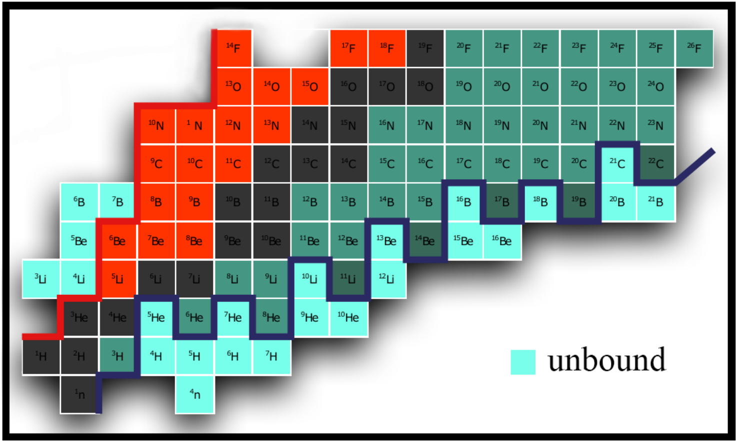


Scientific Context

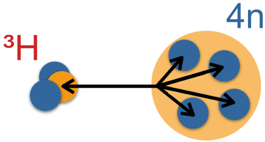
Nuclear Stability



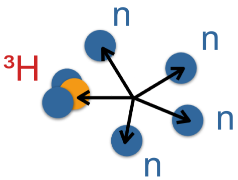
Nuclear Stability



Multi-Neutron Systems



Bound System



Unbound System

Multi-Neutrons Detection

Direct Method

- Better energy resolution

Multi-Neutrons Detection

Direct Method

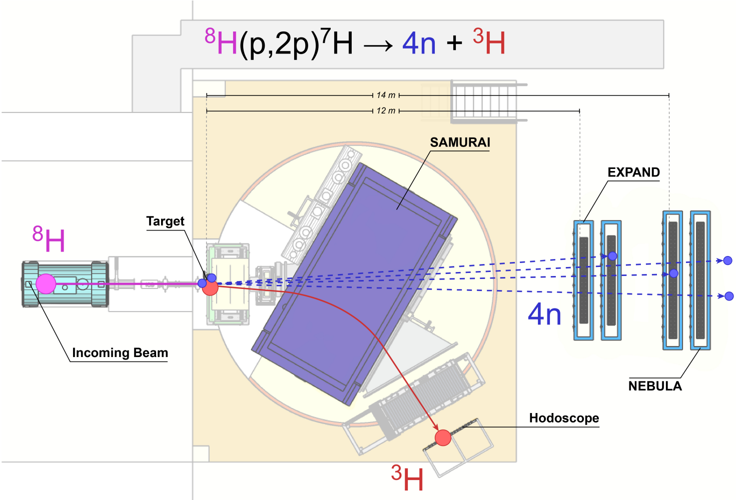
- Better energy resolution
- Direct access to neutrons

Multi-Neutrons Detection

Direct Method

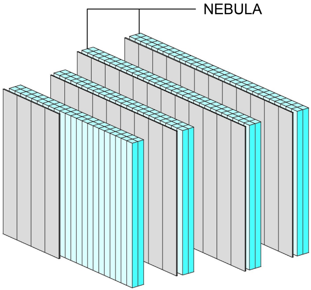
- Better energy resolution
- Direct access to neutrons
- Very low efficiency

Setup



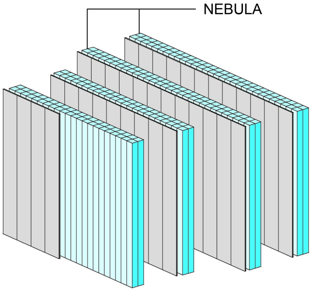
$^8H(p,2p)^7H \rightarrow 4n + {}^3H$
14 m
12 m
SAMURAI
EXPAND
Target
^8H
4n
Incoming Beam
NEBULA
Hodoscope
^3H

NEBULA / EXPAND



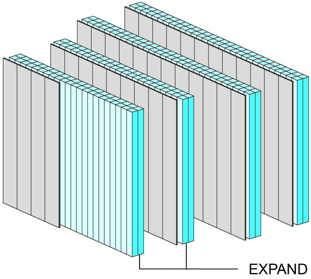
- C, H composed plastics

NEBULA / EXPAND



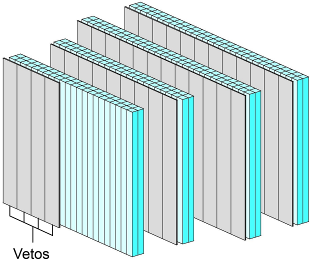
- C, H composed plastics
- 120 bars for NEBULA

NEBULA / EXPAND



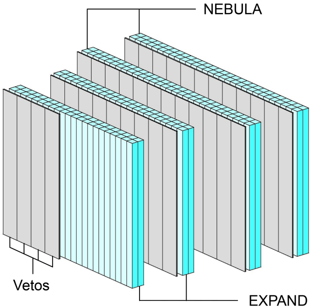
- C, H composed plastics
- 120 bars for NEBULA
- 90 bars for EXPAND

NEBULA / EXPAND



- C, H composed plastics
- 120 bars for NEBULA
- 90 bars for EXPAND
- Vetoes to track charged particles

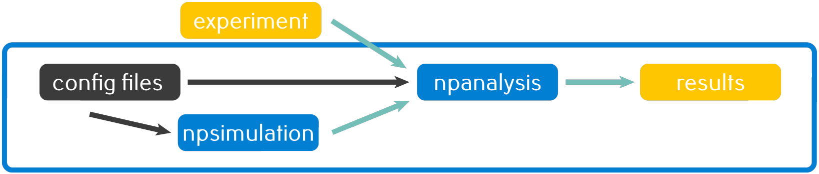
NEBULA / EXPAND



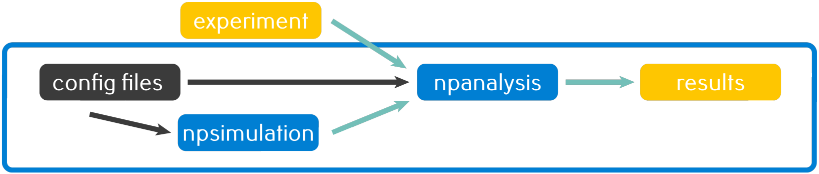
- C, H composed plastics
- 120 bars for NEBULA
- 90 bars for EXPAND
- Vetoes to track charged particles
- Frames to hold the system

Methods

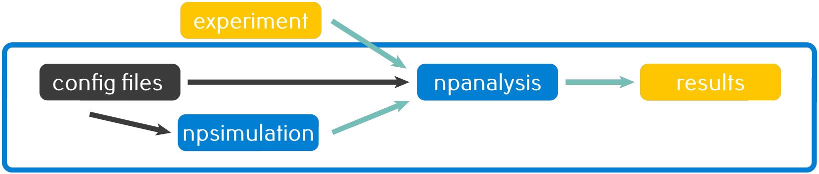
- Geant4 and Root based framework



- Geant4 and Root based framework
- LPC-lead Collaboration

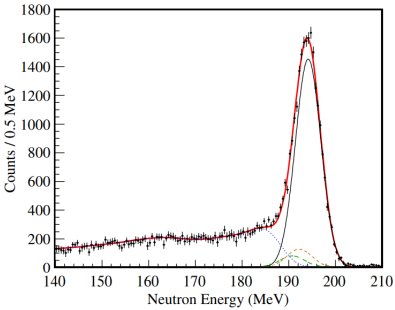


- Geant4 and Root based framework
- LPC-lead Collaboration
- Simulation and Analysis



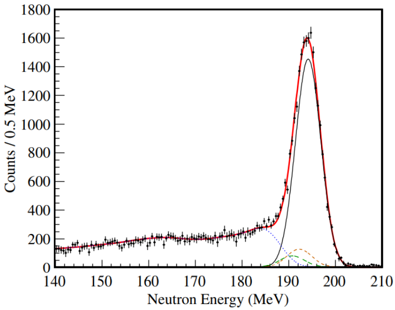
First Step:
Mono-energetic neutrons

Reference



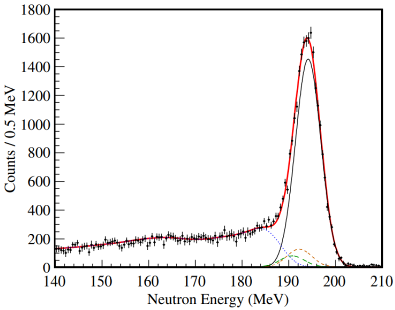
- $^{7}\text{Li}(\text{p},\text{n})^{7}\text{Be}(\text{g.s.} + 0.43\,\text{MeV})$

Reference



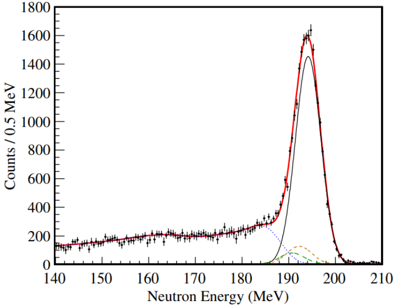
- $^{7}Li(p,n)^{7}Be(g.s. + 0.43\,\mathrm{MeV})$
- Small forward angles

Reference



- ^{7}Li(p, n)^{7}Be(g.s. $+$ 0.43 MeV)
- Small forward angles
- Mono-energetic neutrons at 194 MeV

Reference



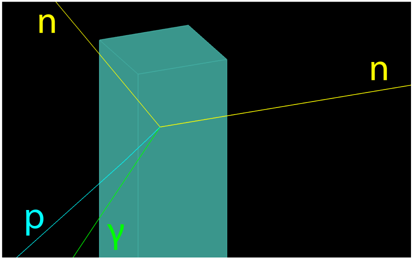
- $^{7}Li(p,n)^{7}Be(g.s. + 0.43\,\mathrm{MeV})$
- Small forward angles
- Mono-energetic neutrons at 194 MeV
- Empirical Efficiency 32.5%

Simulation Steps

- Implementing geometry
- Selecting processes
- Implementing Energy to Light conversion
- Verifying cross-talk rejection algorithms

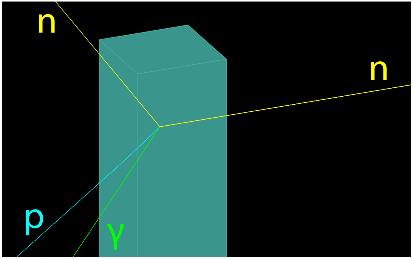
Results & Discussion

Retrieved Neutron Energy



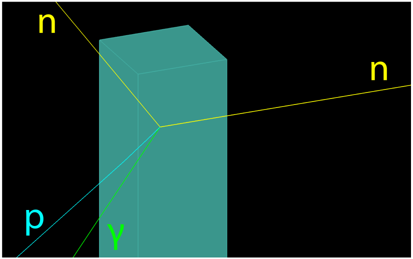
- High energy $\Longrightarrow$ Inelastic

Retrieved Neutron Energy



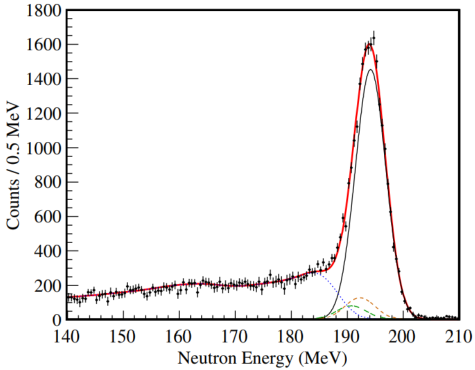
- High energy $\Longrightarrow$ Inelastic
- High energy $\Longrightarrow$ Elastic

Retrieved Neutron Energy



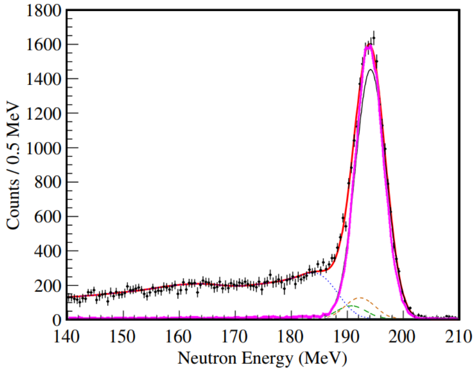
- High energy $\Longrightarrow$ Inelastic
- High energy $\Longrightarrow$ Elastic
- Low energy $\Longrightarrow$ Elastic

Retrieved Neutron Energy



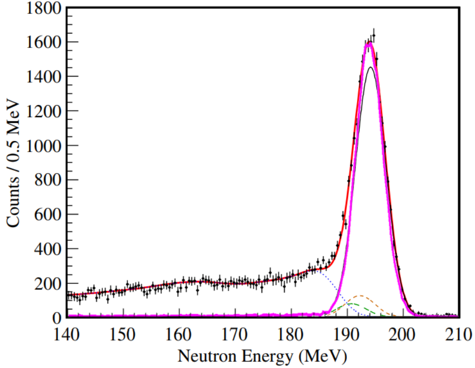
- Energy retrieved from TOF and Hit Position

Retrieved Neutron Energy



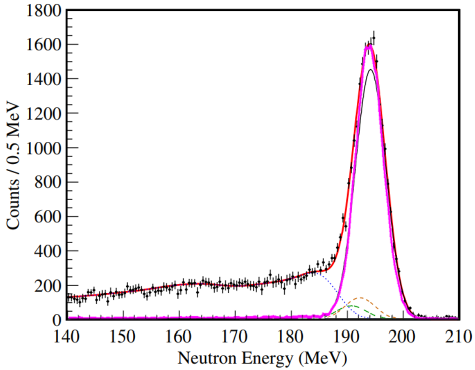
- Energy retrieved from TOF and Hit Position

Retrieved Neutron Energy



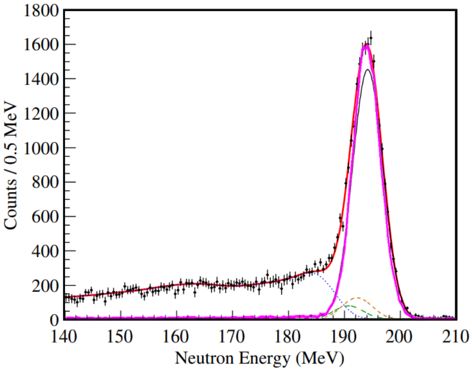
- Energy retrieved from TOF and Hit Position
- Neutrons at 194 MeV, with σ=0.5 MeV

Retrieved Neutron Energy



- Energy retrieved from TOF and Hit Position
- Neutrons at 194 MeV, with σ=0.5 MeV
- Kinetic Energy at 56% of c

Retrieved Neutron Energy



- Energy retrieved from TOF and Hit Position
- Neutrons at 194 MeV, with σ=0.5 MeV
- Kinetic Energy at 56% of c
- First neutron only

Efficiency

- Experimental 32.5 %

Efficiency

- Experimental 32.5 %
- Reference Simulation 33.7%

  Simulation Results:

Efficiency

- Experimental 32.5 %
- Reference Simulation 33.7%

  Simulation Results:
- Without Vetoes 38%

Efficiency

- Experimental 32.5 %
- Reference Simulation 33.7%

  Simulation Results:
- Without Vetoes 38%
- With Vetoes but without Veto Filter 41.2%

Efficiency

- Experimental 32.5 $\pm 0.3(stat) \pm 0.9(syst)\%$
- Reference Simulation 33.7%

Simulation Results:

- Without Vetoes 38%
- With Vetoes but without Veto Filter 41.2%
- With Veto Filter 33.2%

Conclusion & Perspectives

Conclusion

- Implementing geometry
- Selecting processes

Conclusion

- Implementing geometry ✓
- Selecting processes

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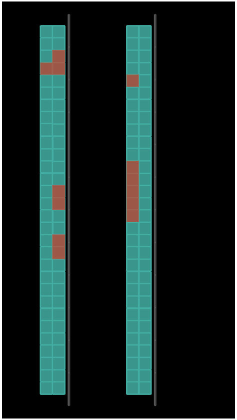
Conclusion

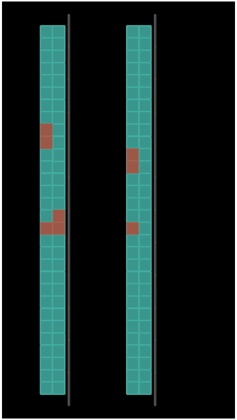
- Implementing geometry ✓
- Selecting processes ✓
- Implementing Energy to Light conversion

Conclusion

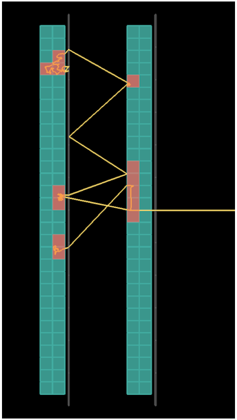
- Implementing geometry ✓
- Selecting processes ✓
- Implementing Energy to Light conversion
- Verifying cross-talk rejection algorithms

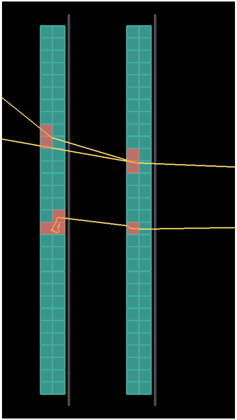
Perspectives





Perspectives





Bibliography

[1] Björn Jonson. “Light dripline nuclei”. In: *Physics Reports* 389.1 (2004), pp. 1–59. ISSN: 0370-1573. DOI: https://doi.org/10.1016/j.physrep.2003.07.004. URL: https://www.sciencedirect.com/science/article/pii/S0370157303003259.

[2] Y Kondo, T Tomai, and T Nakamura. “Recent progress and developments for experimental studies with the SAMURAI spectrometer”. In: *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 463 (2020), pp. 173–178.

[3] T Kobayashi et al. “SAMURAI spectrometer for RI beam experiments”. In: *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 317 (2013), pp. 294–304.

[4] IN2P3. *LPC Caen, Chronologie*. 2021. URL: https://50ans.in2p3.fr/timeline-lpc-caen/.

[5] Physical Science Division - CEA. *The Valley of Stability*. 2011. URL: https://youtu.be/UTOp_2ZVZmM.

[6] Rene Brun. *What does ROOT stand for?* 1998. URL: https://root.cern.ch/root/roottalk/roottalk98/0718.html.

[7] Inc. Digital Science & Research Solutions. *List of article citing NPTool*. 2022. URL: https://app.dimensions.ai/discover/publication?or_subset_publication_citations=pub.1047376487.

[8] Cyril Lenain. “Etude des décroissances multi-neutron des isotopes lourds d’hélium et d’hydrogène”. PhD thesis. Normandie Université, 2021.