

ECT* workshop
'Nuclear Physics at the edge of stability'
06/07/22



Search for hydrogen 7 and its four neutron decay at RIKEN

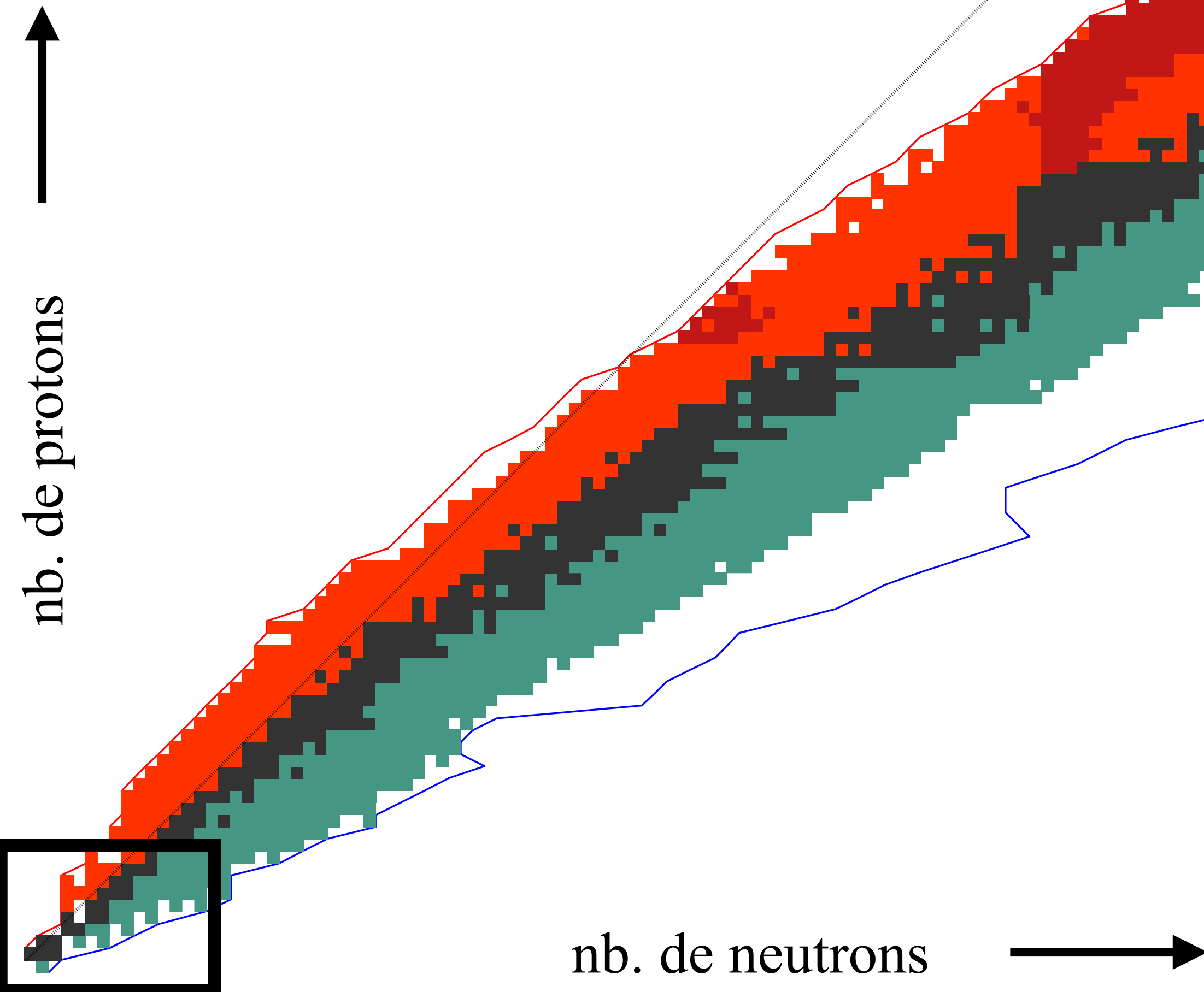
Cyril Lenain



UNIVERSITÉ
CAEN
NORMANDIE



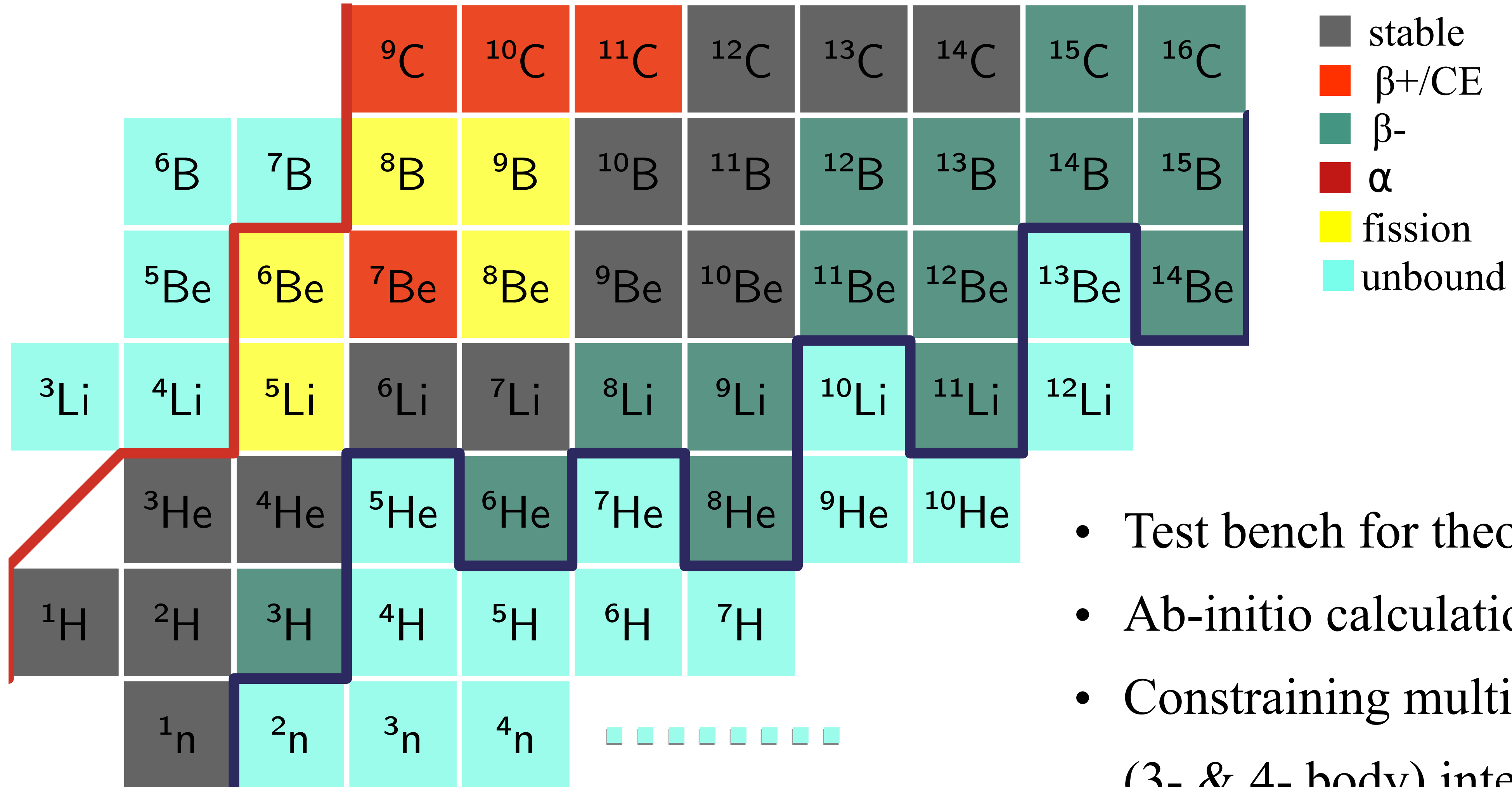
Introduction



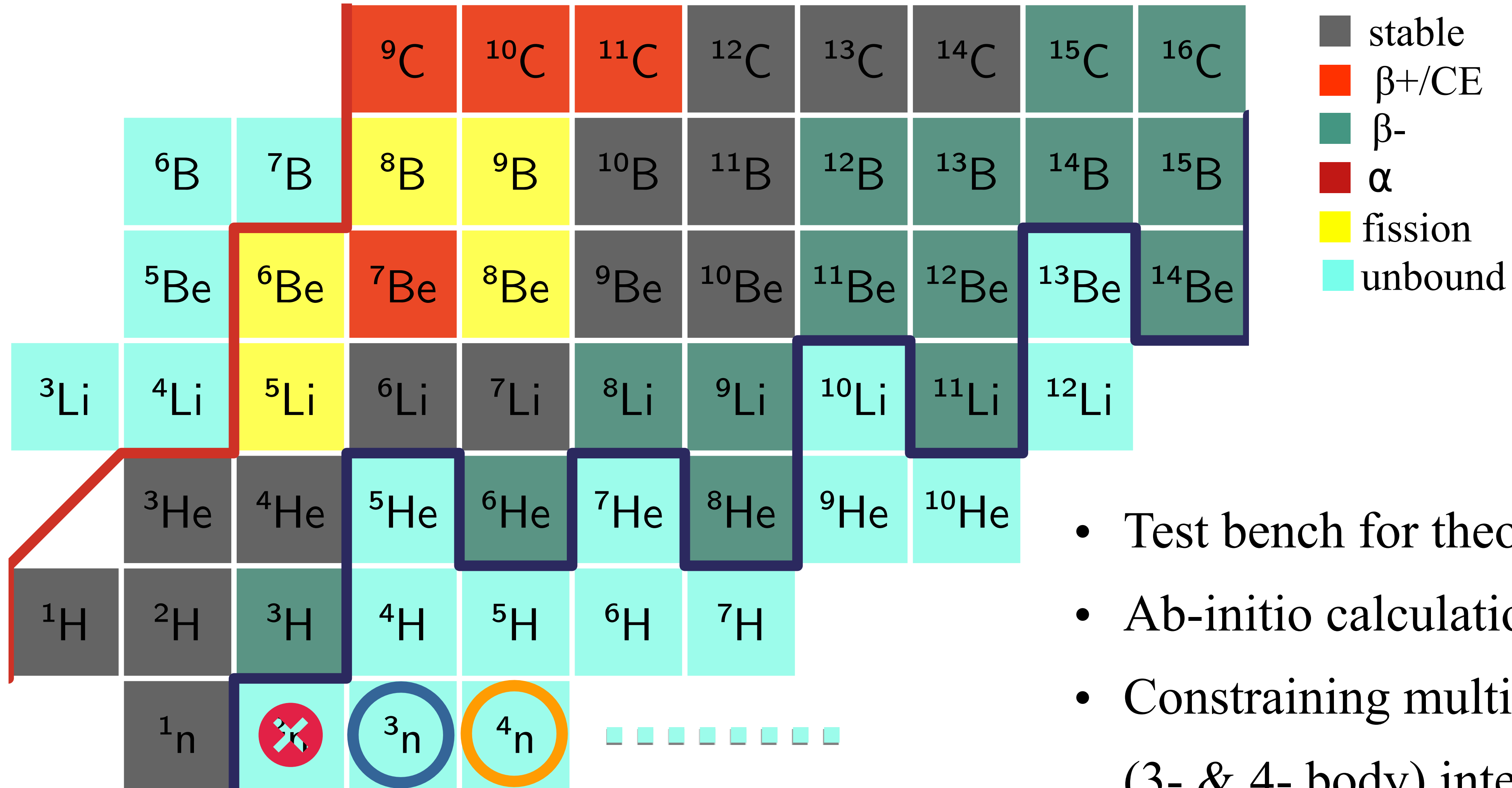
- stable
- β^+/CE
- β^-
- α
- fission

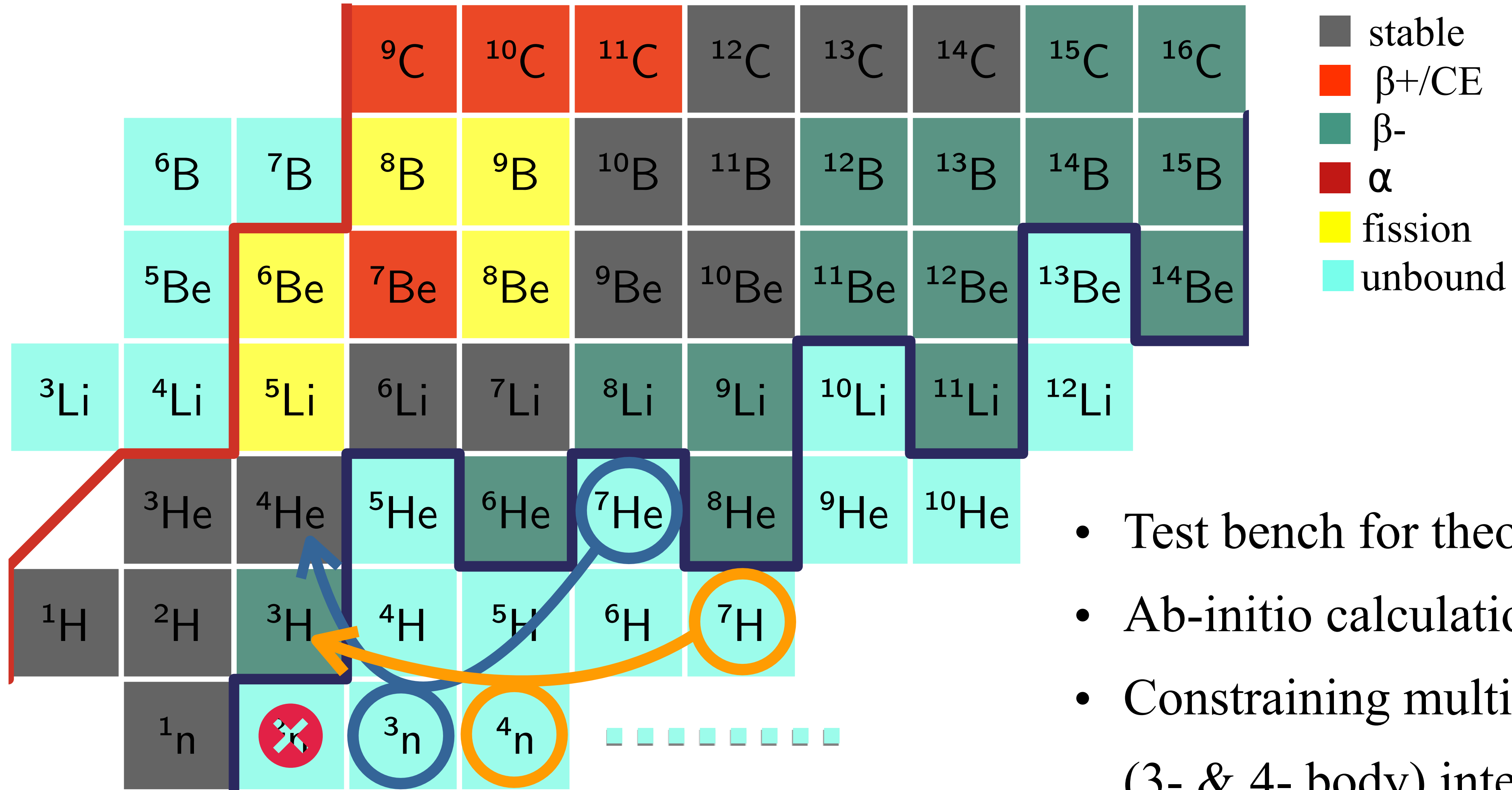
Detailed nuclide chart for elements H through F. Nuclides are labeled with their symbol and mass number (e.g., ^3Li , ^4He , ..., ^{26}F). Colors indicate stability: black for stable, orange for β^+/CE , teal for β^- , red for α , and yellow for fission. Cyan squares indicate unbound states. A blue box highlights the nuclides ^{10}Li through ^{21}C , which are unbound. A blue line traces the boundary of the nuclides.

unbound



- Test bench for theoretical models
- Ab-initio calculations tractable
- Constraining multi-neutron (3- & 4- body) interactions

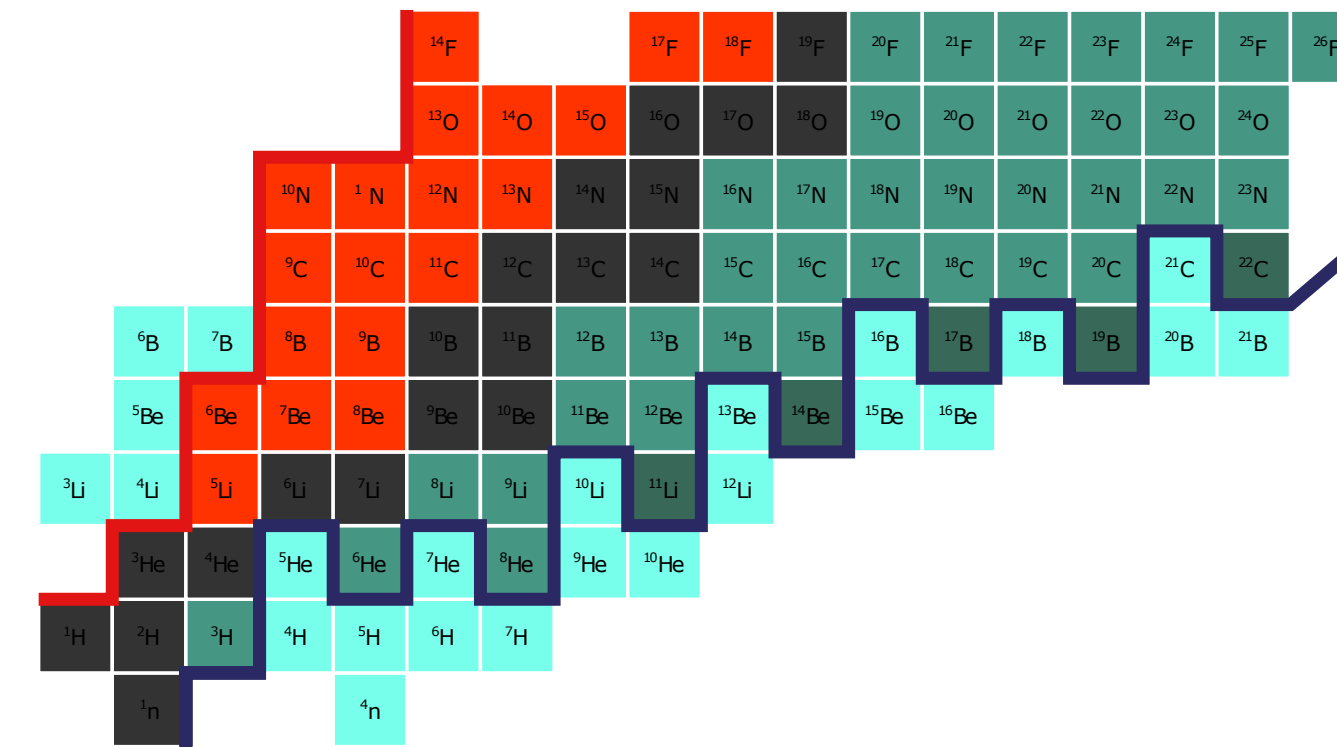
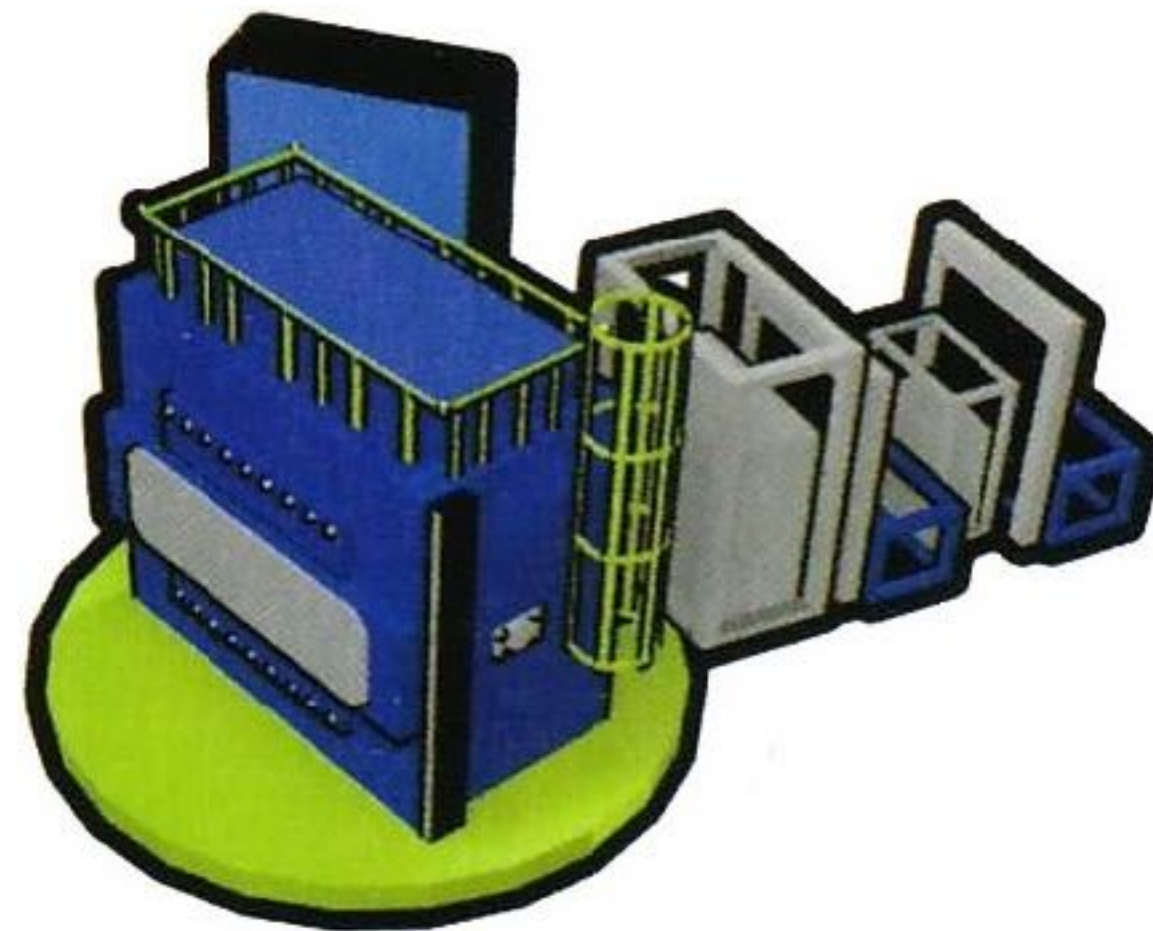




- Test bench for theoretical models
- Ab-initio calculations tractable
- Constraining multi-neutron (3- & 4- body) interactions

1. Introduction

The multineutron quest
Helium-7
Hydrogen-7

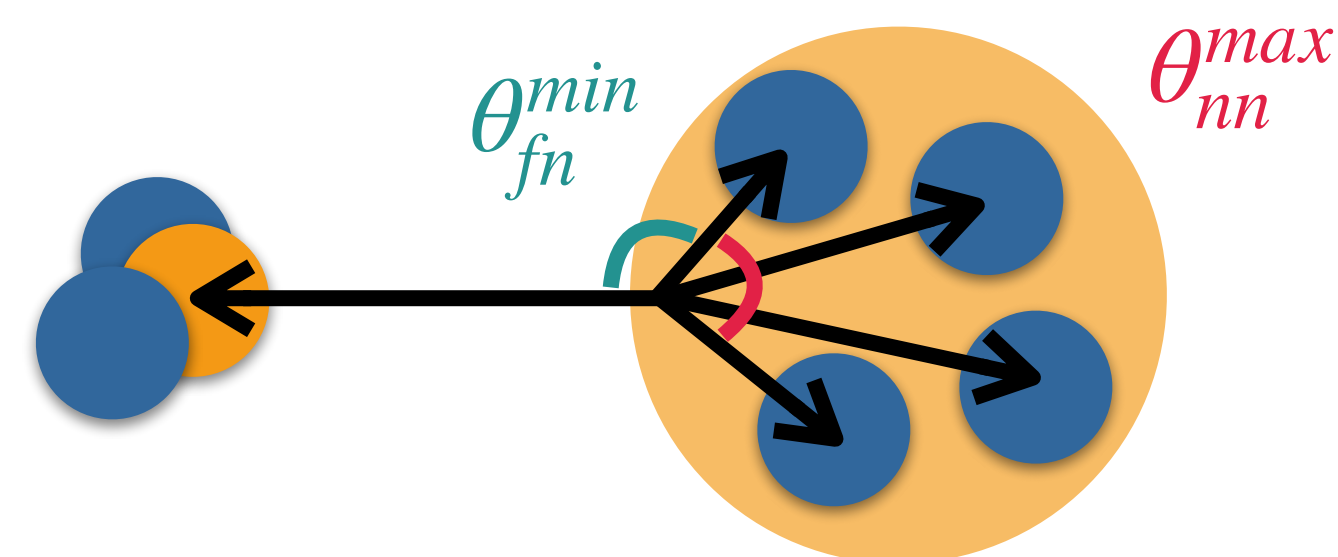


2. Samurai 34

Experimental Approach
Multineutron detection

3. First results

Helium-7 & 3n decay
Hydrogen-7 & 4n decay



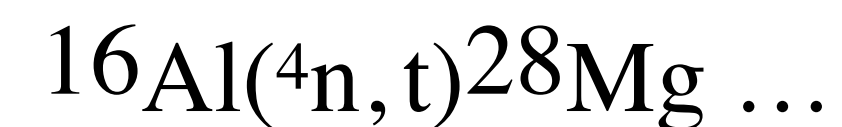
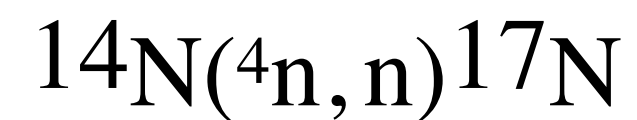
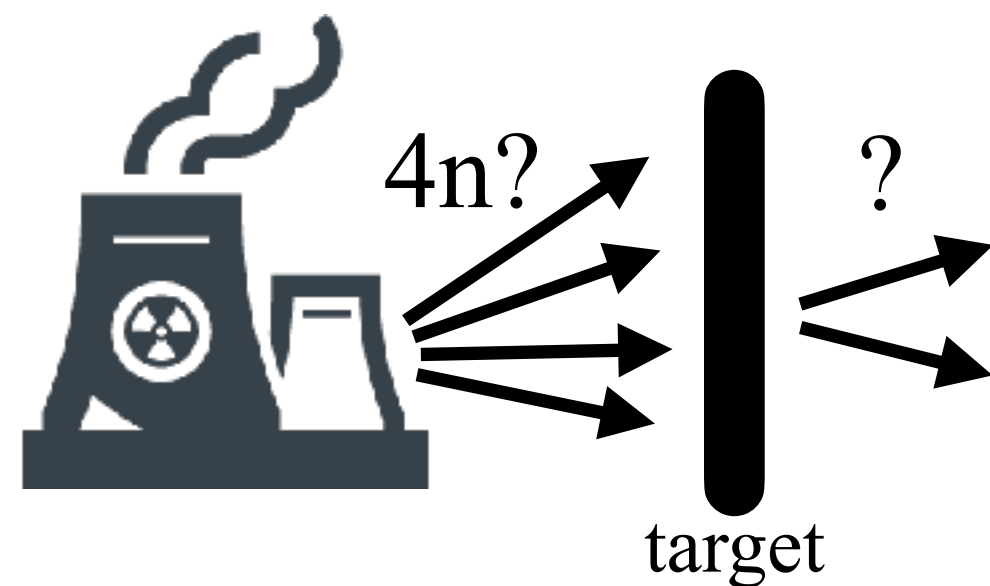
Introduction: The multineutron quest

since the 1960s ...

Where ? How ?

Extreme environnement

Lost in a large quantity of isotopes



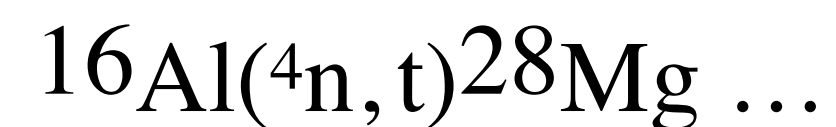
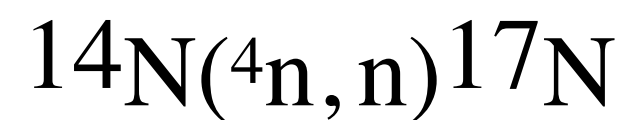
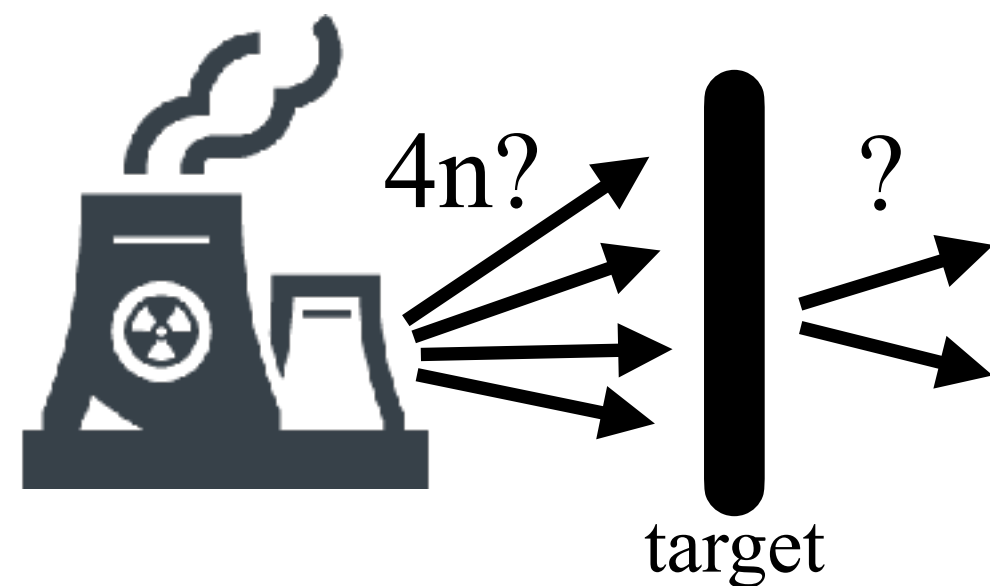
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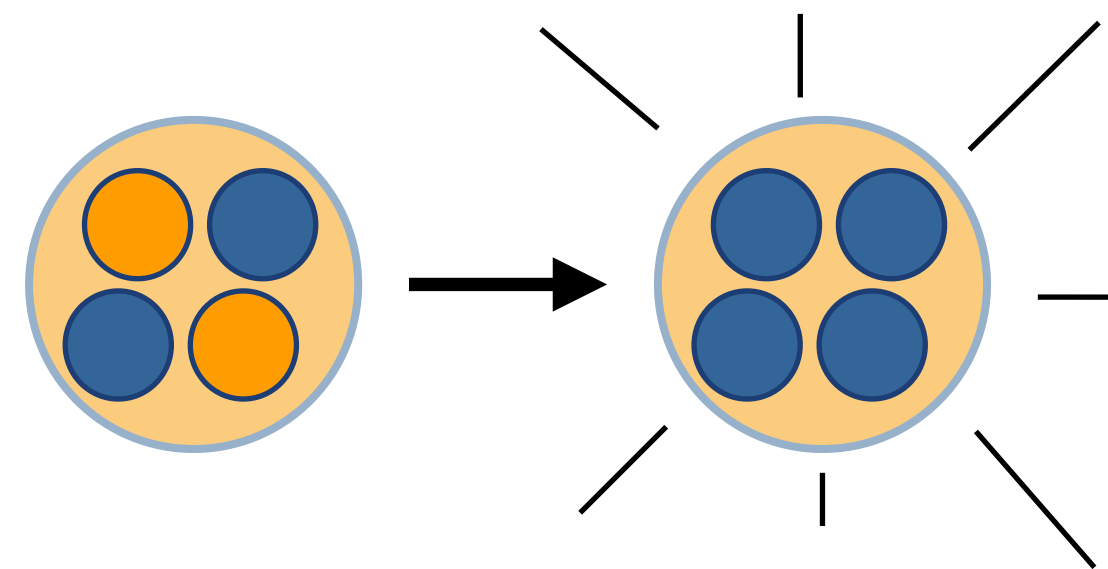
Extreme environnement

Lost in a large quantity of isotopes



Extreme reaction

Direct production



DCX, SCX ...

$$\sigma \sim 10^{-12} \text{ barn}$$

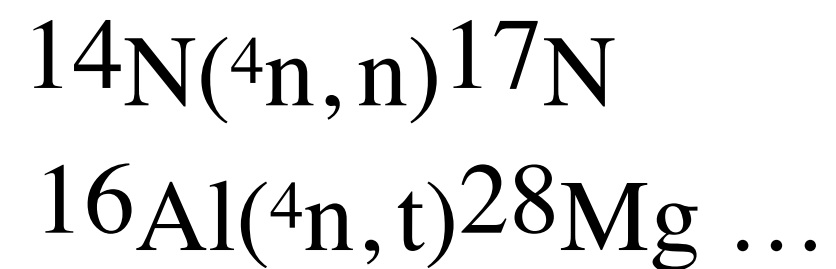
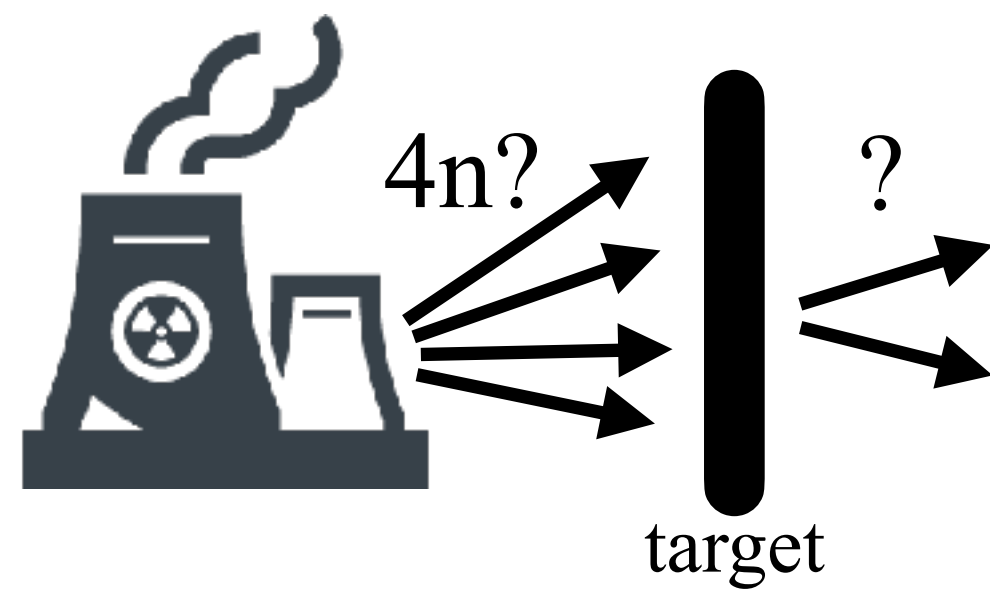
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since the 1960s ...

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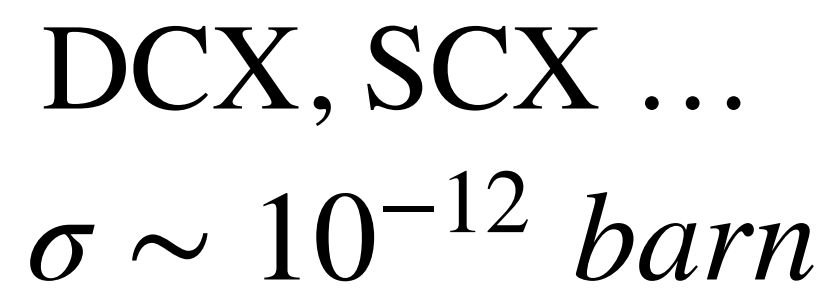
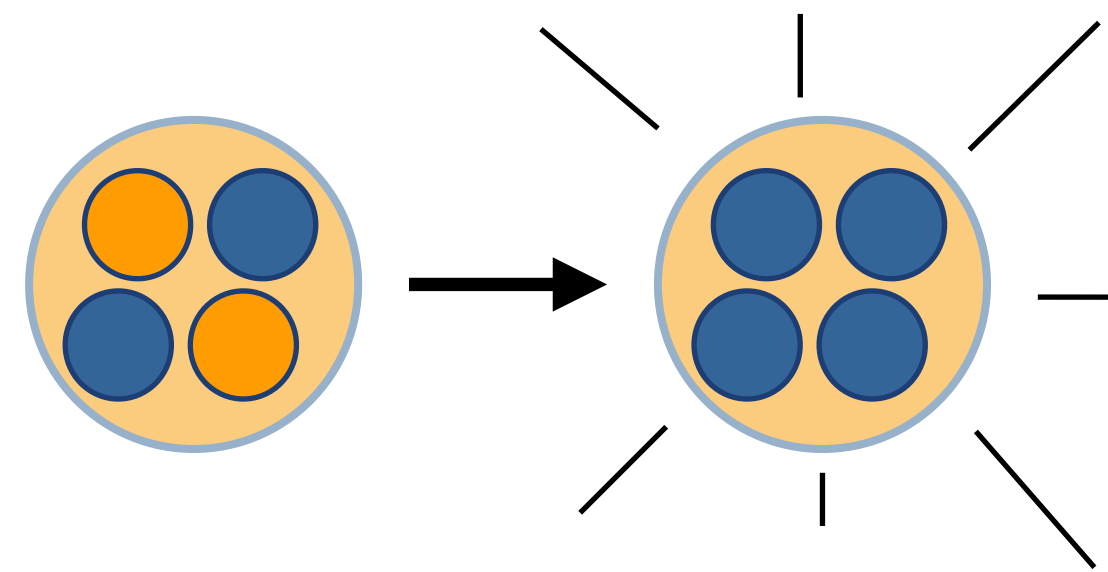
Extreme environnement

Lost in a large quantity of isotopes



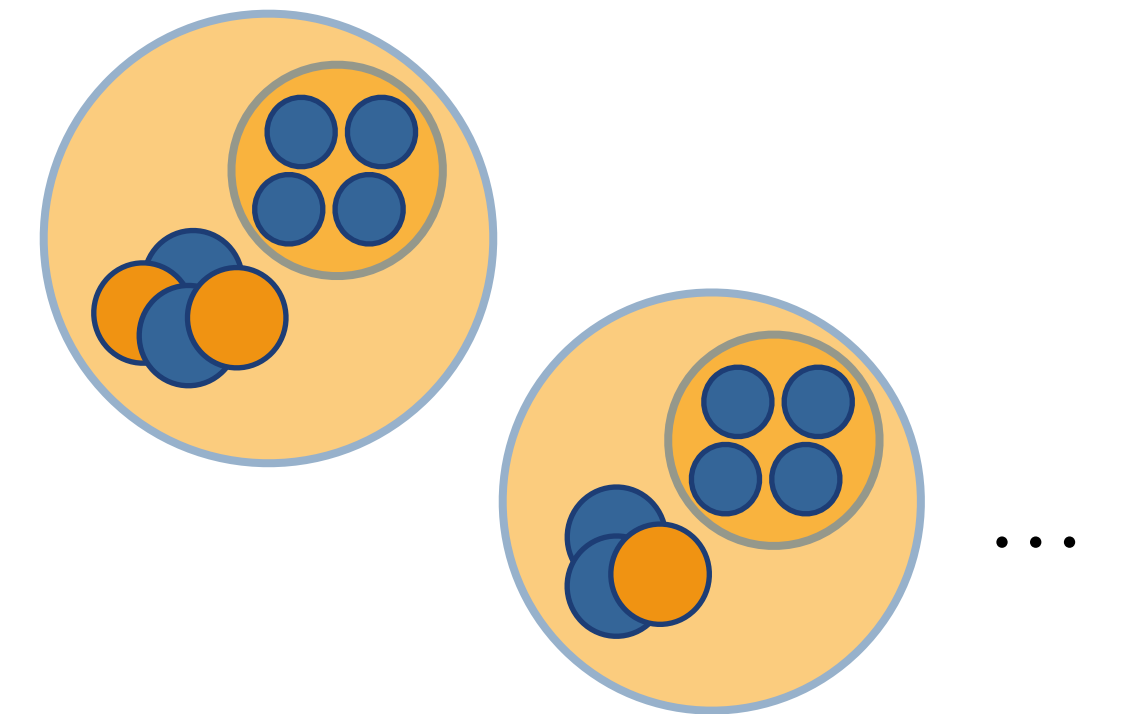
Extreme reaction

Direct production

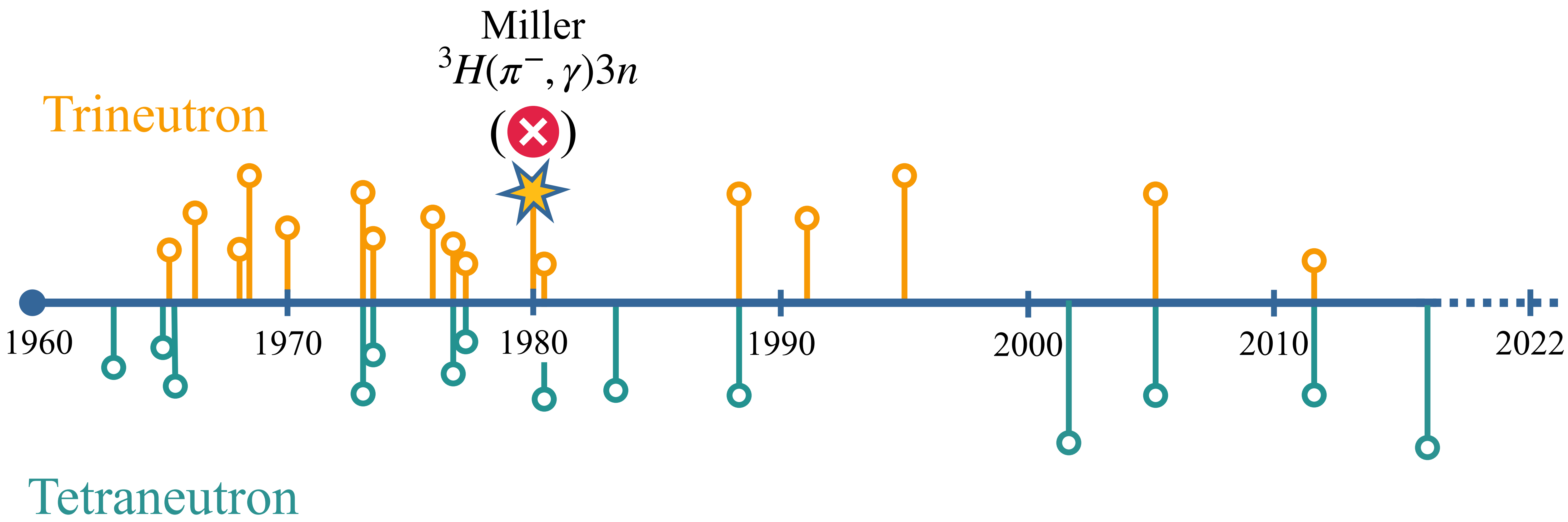


Extreme n-rich nuclei

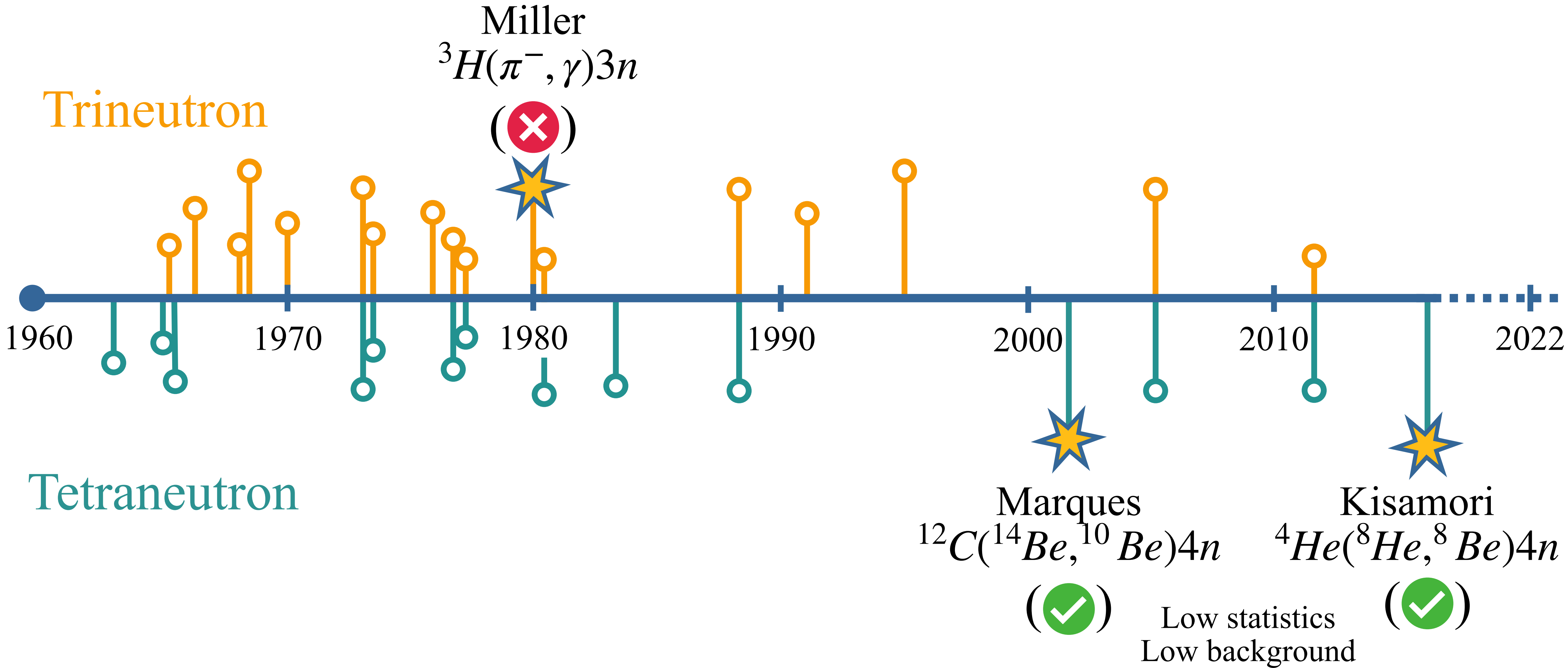
8He , 7He , $7\text{H} \dots$



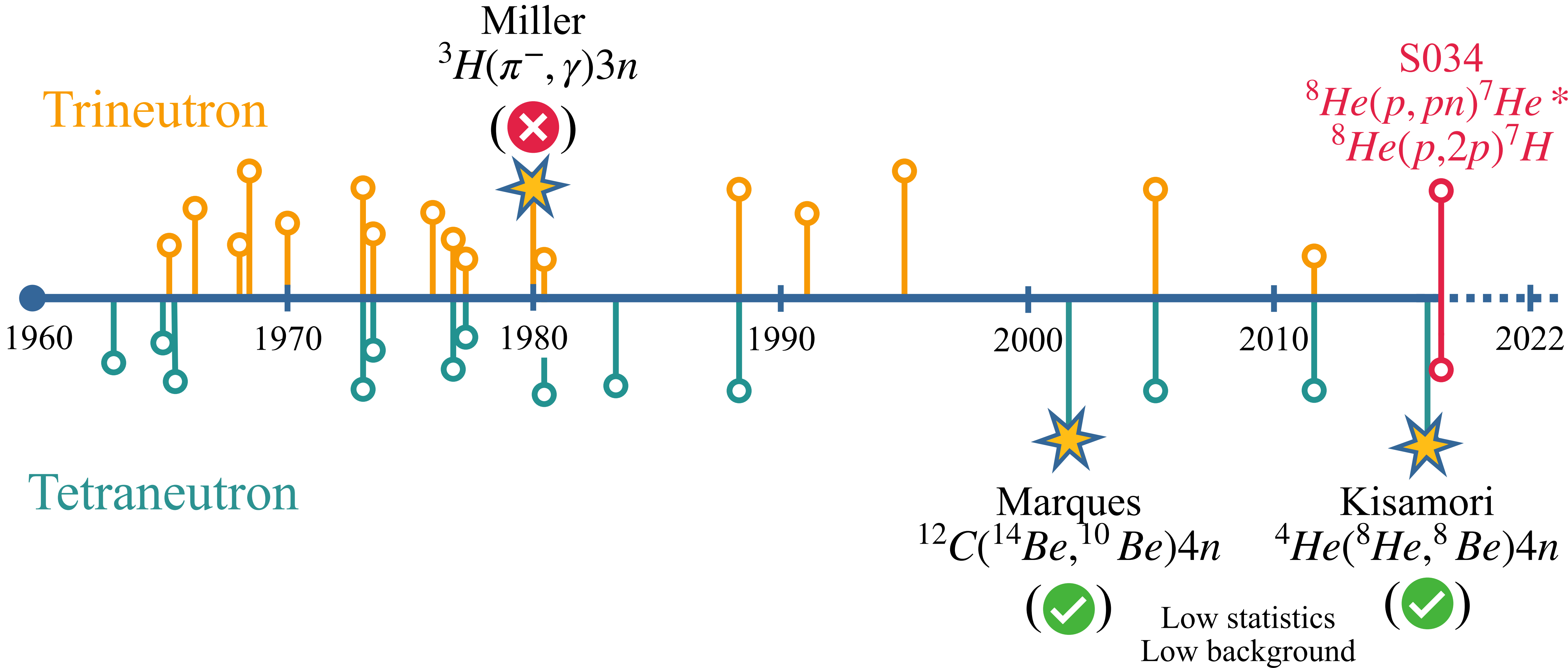
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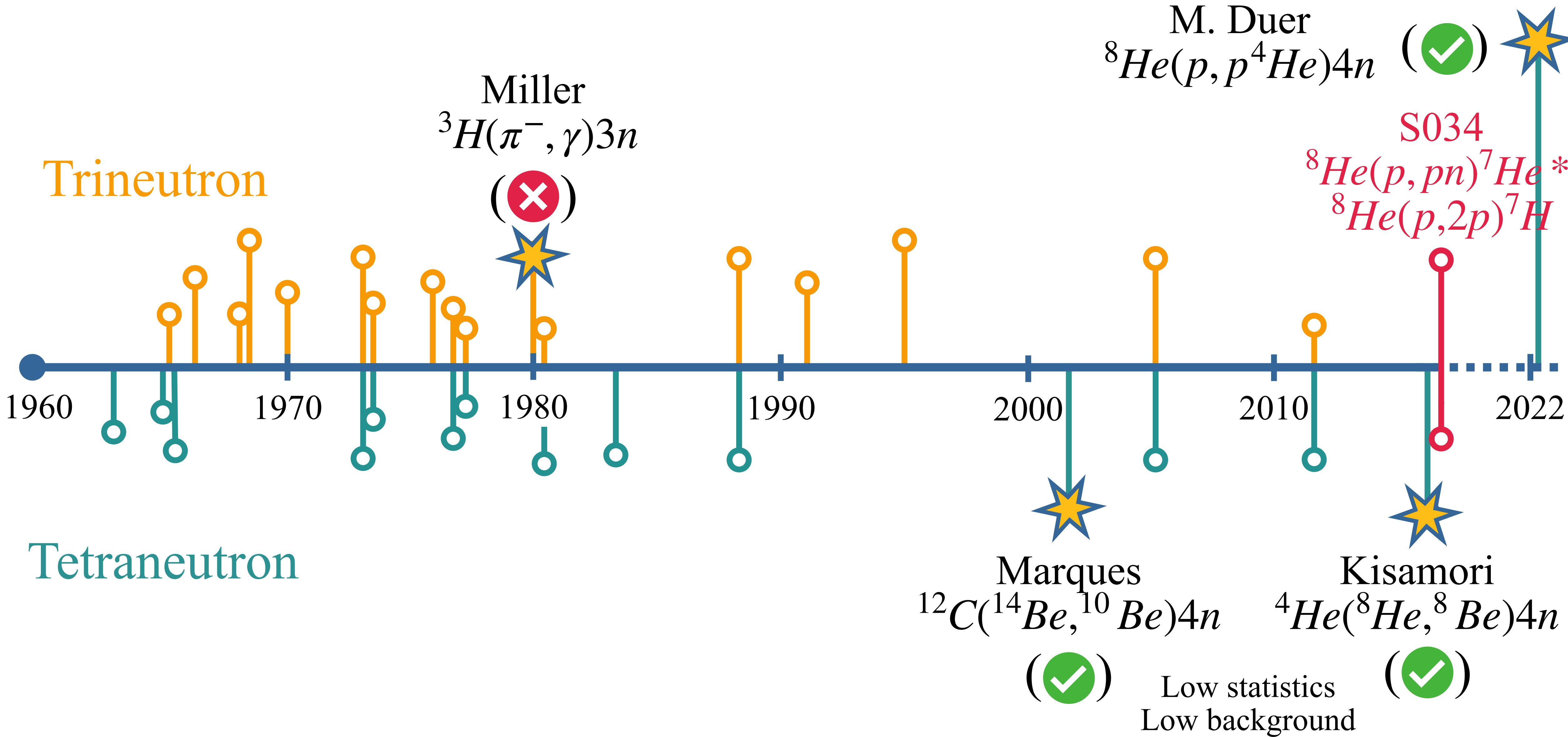
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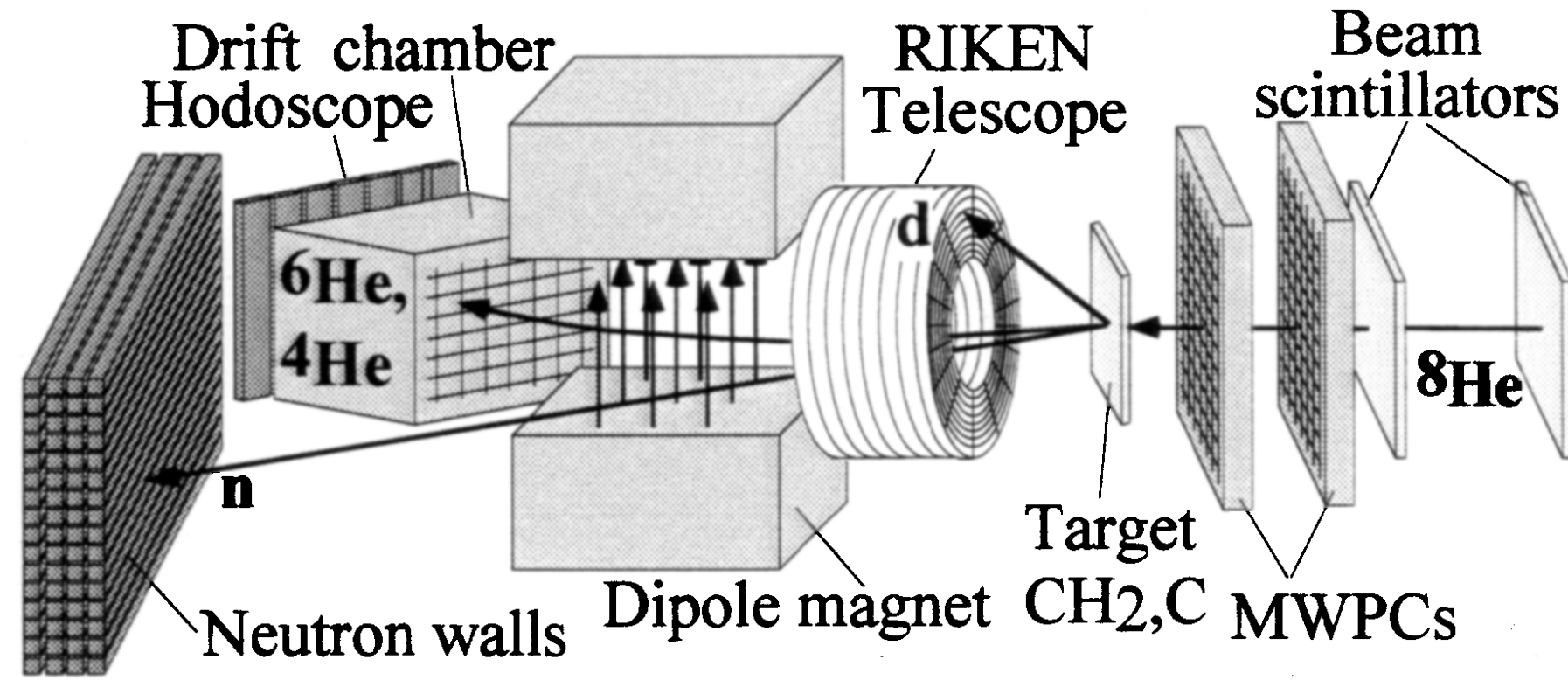
Introduction: The multineutron quest



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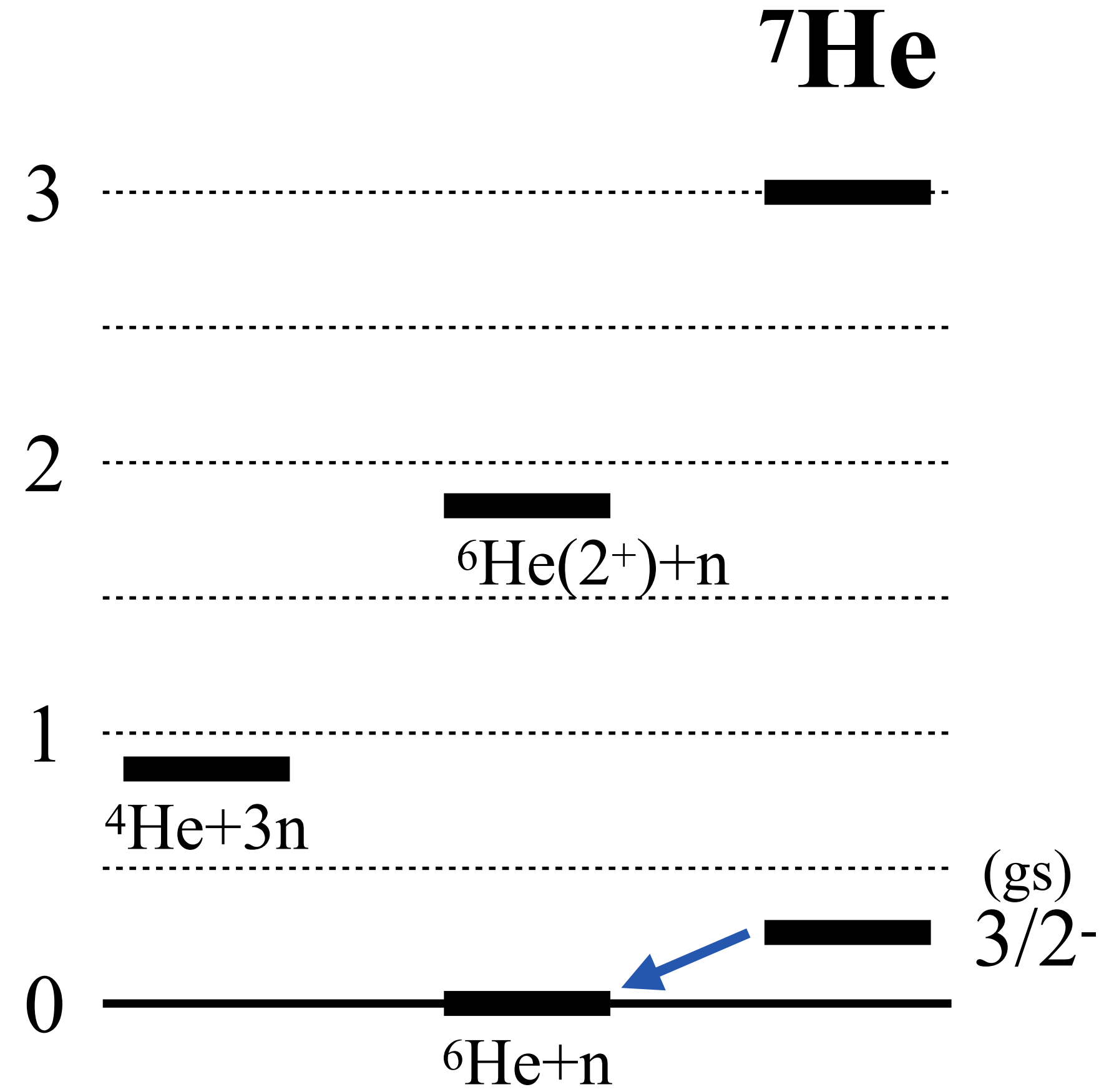
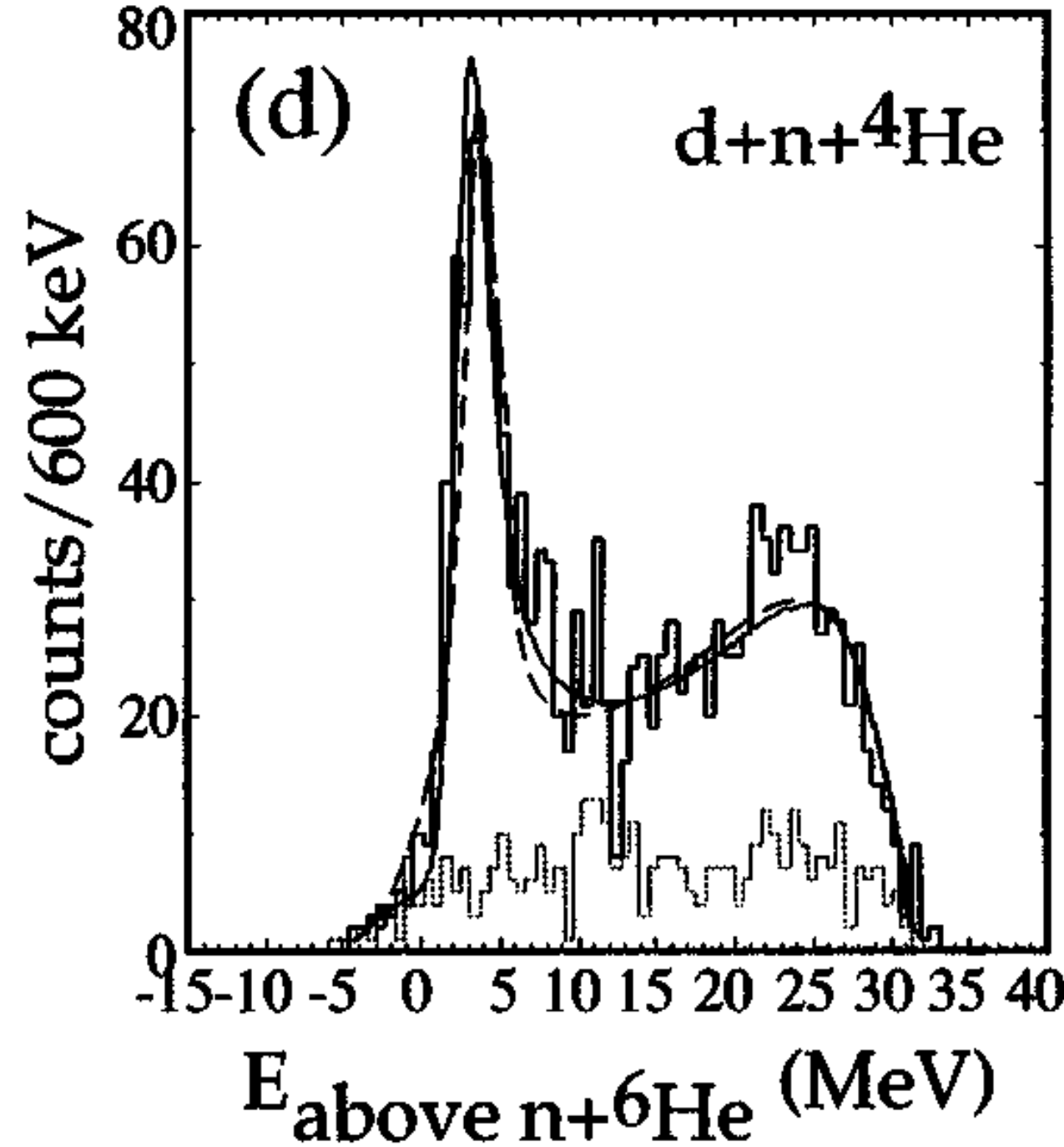
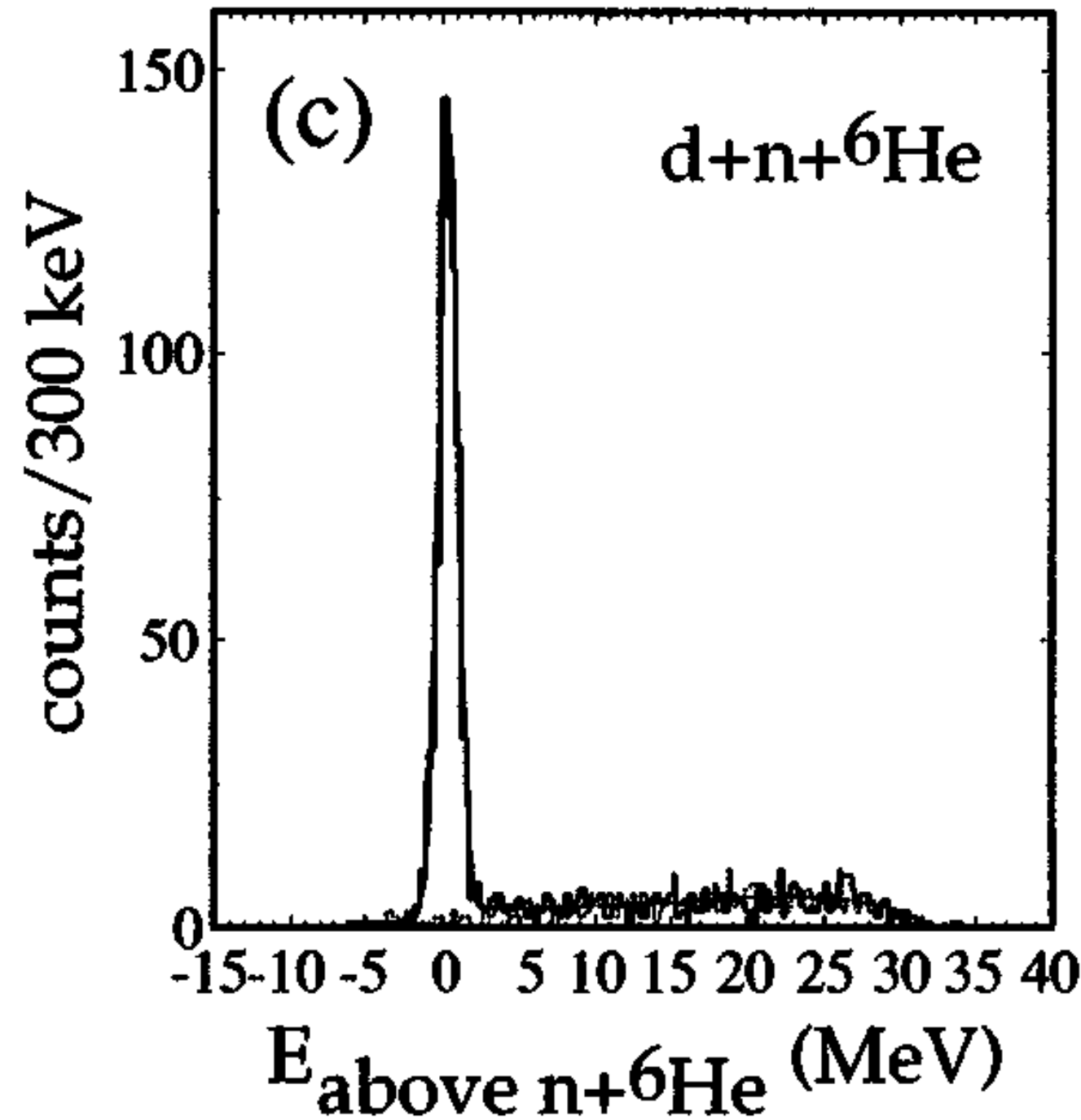


Introduction: Helium-7, state of play

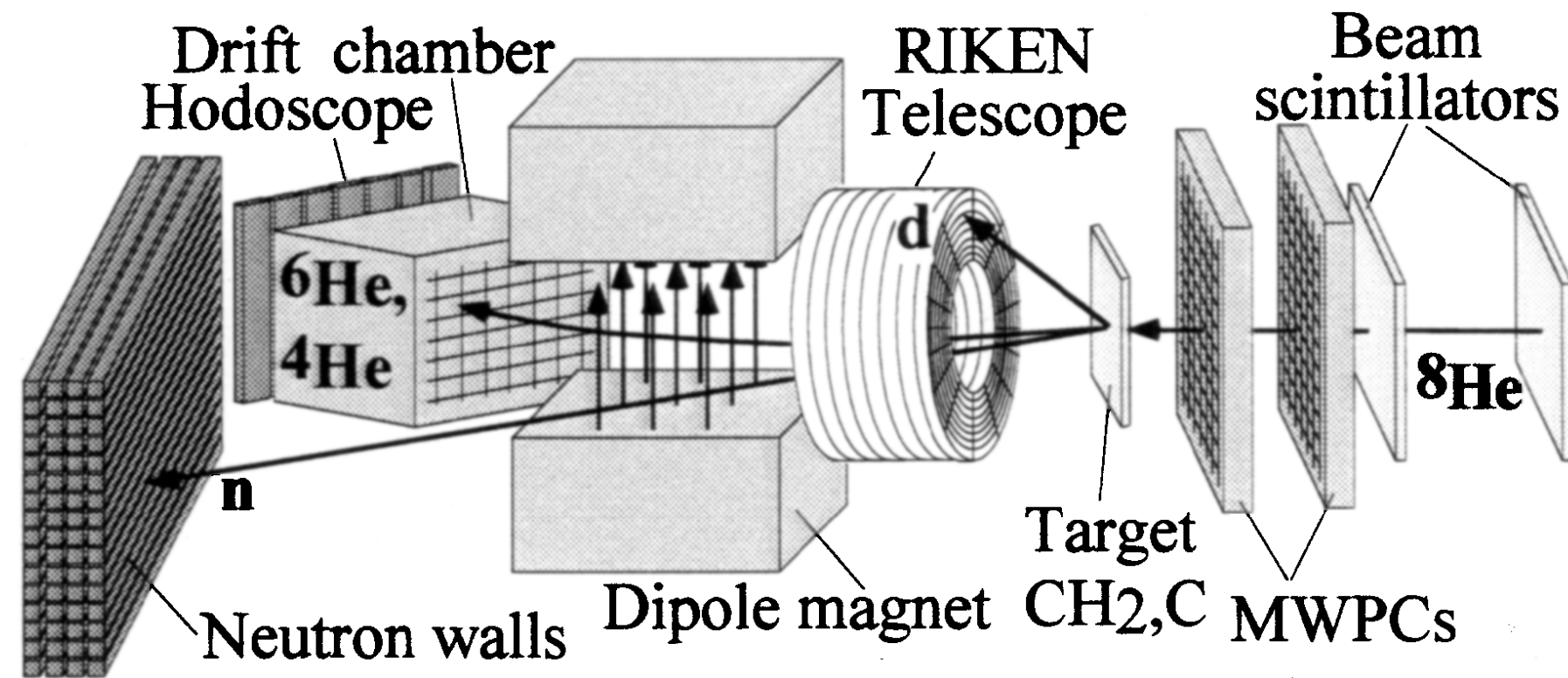


$8\text{He}(p,d)7\text{He}$

Korshennikov *et al.* PRL (1999)

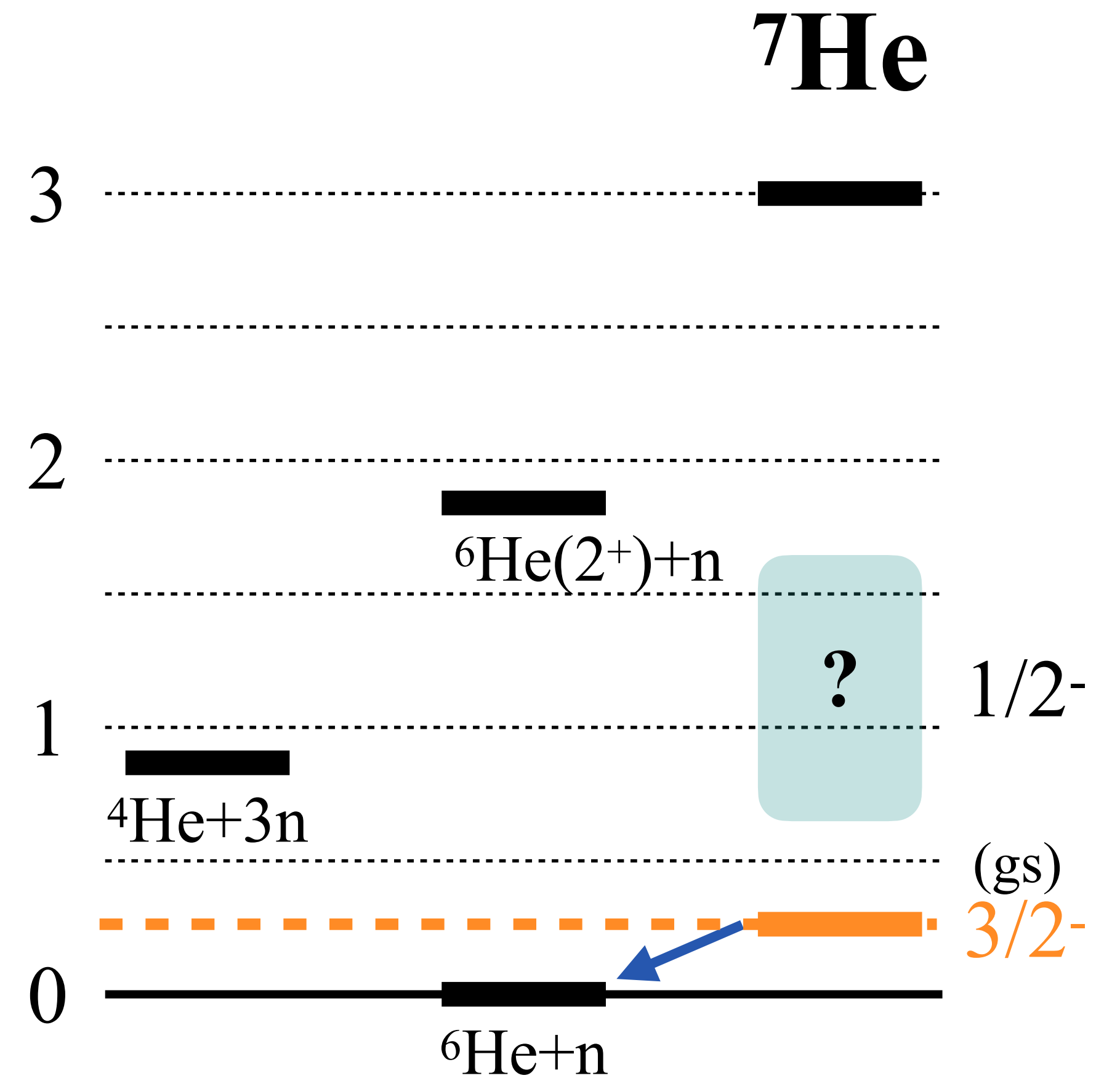
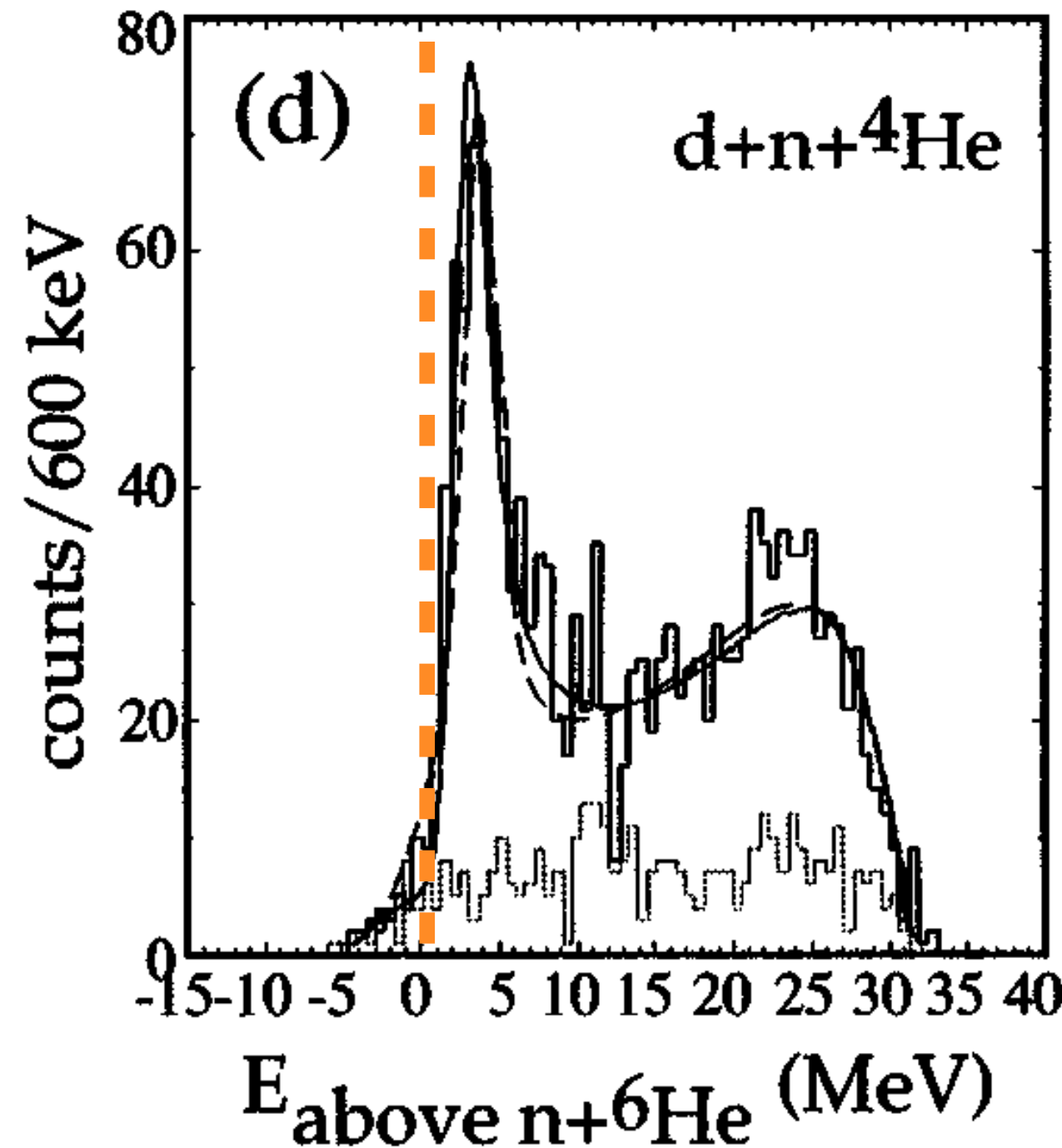
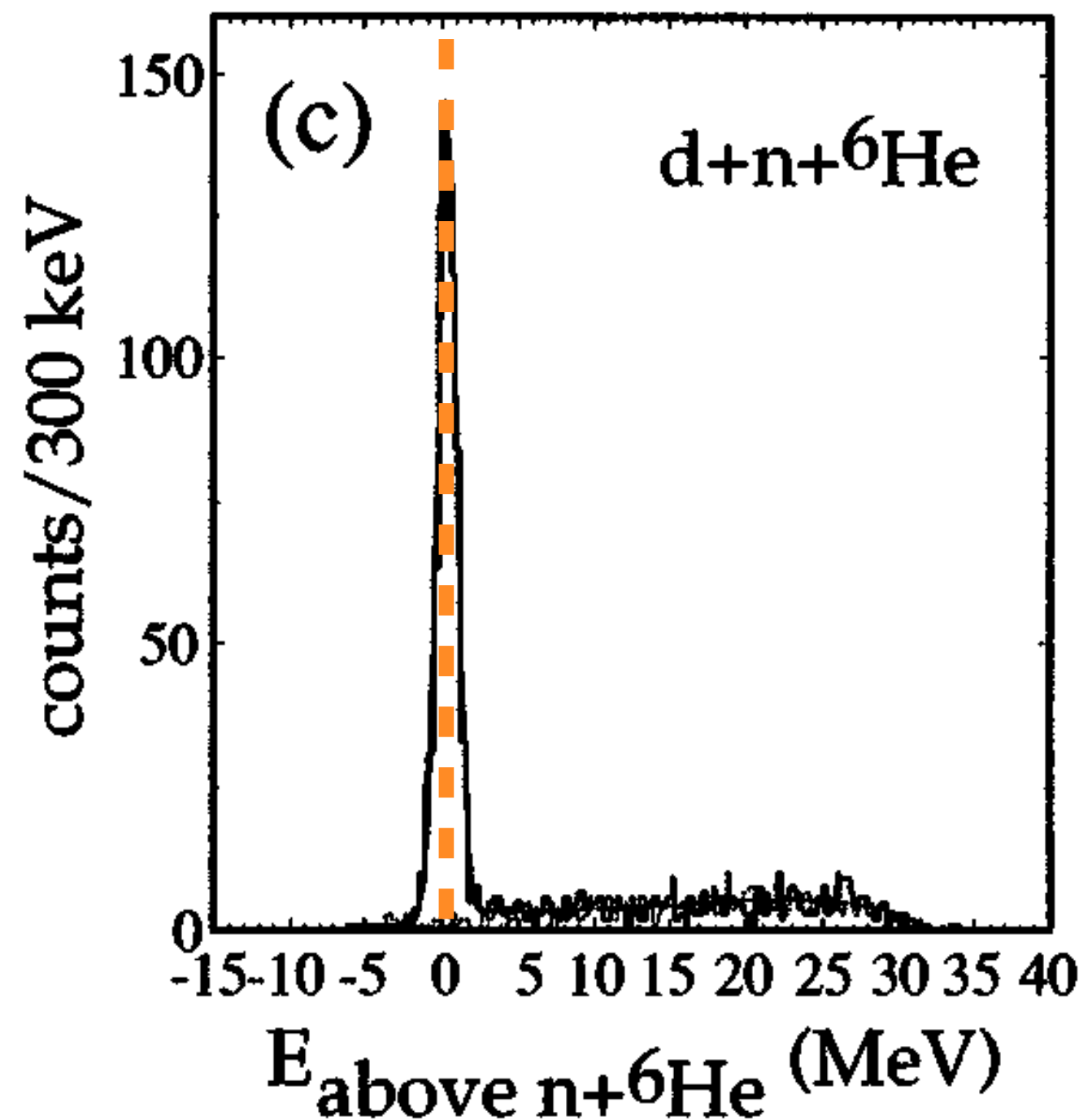


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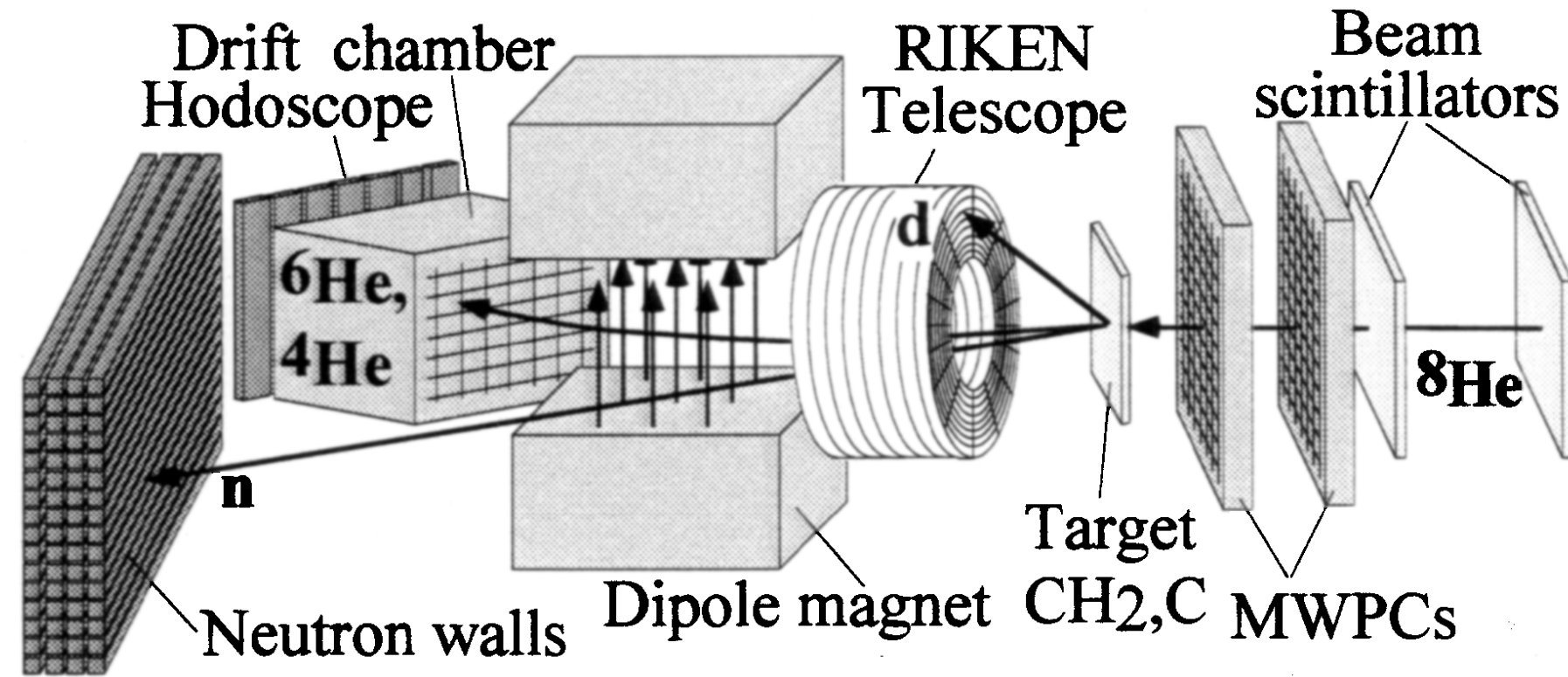


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Korshennikov *et al.* PRL (1999)

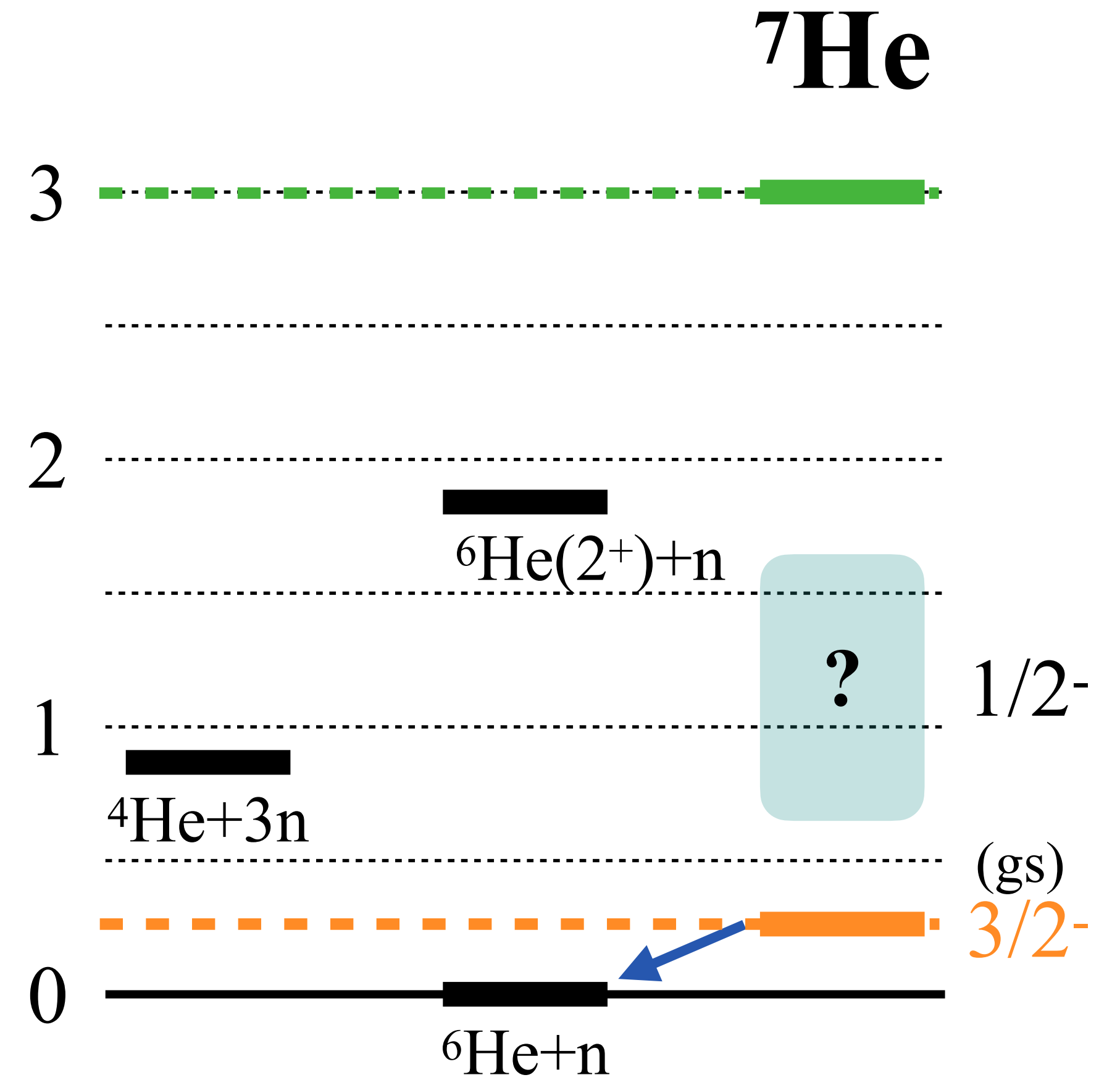
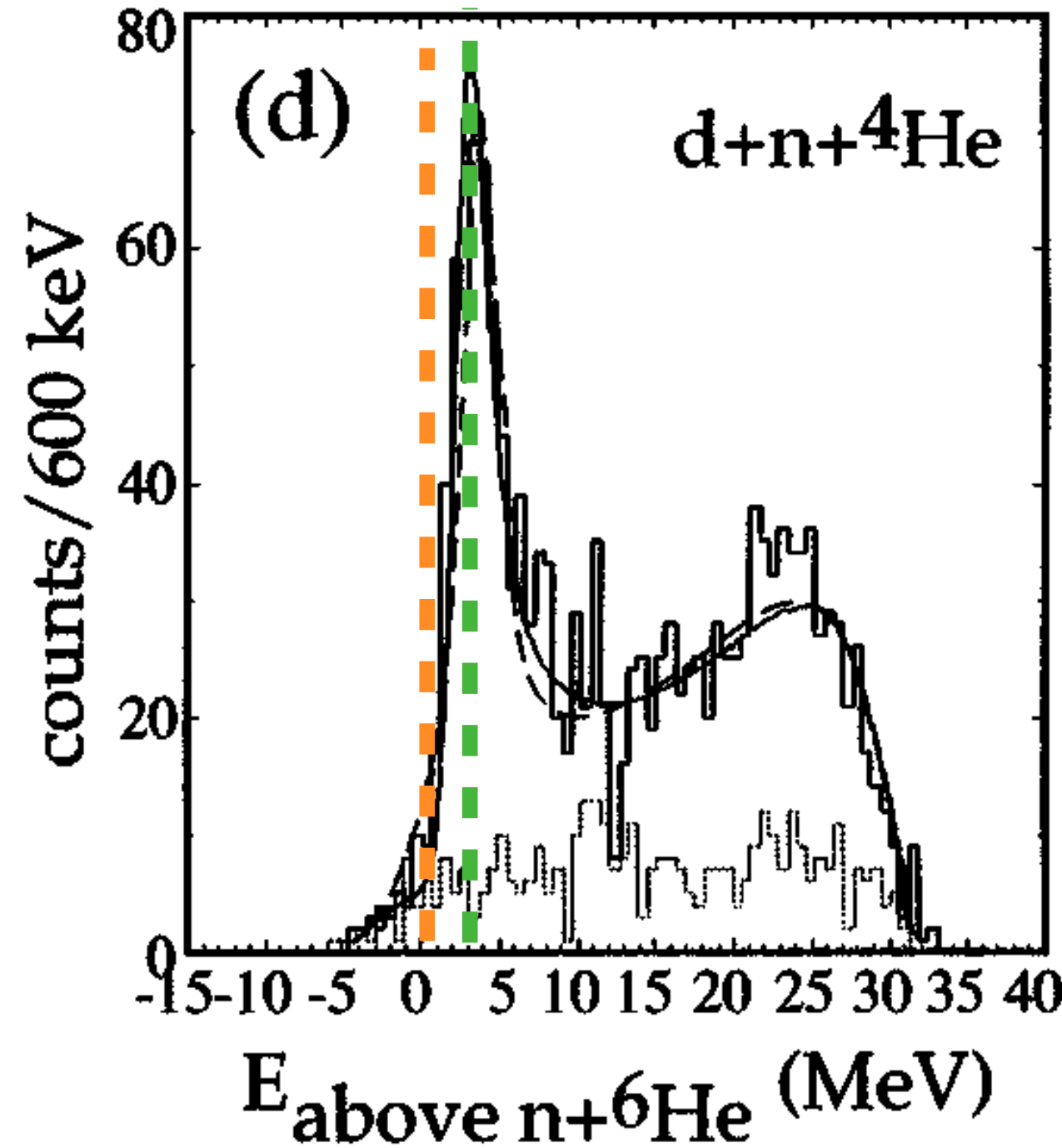
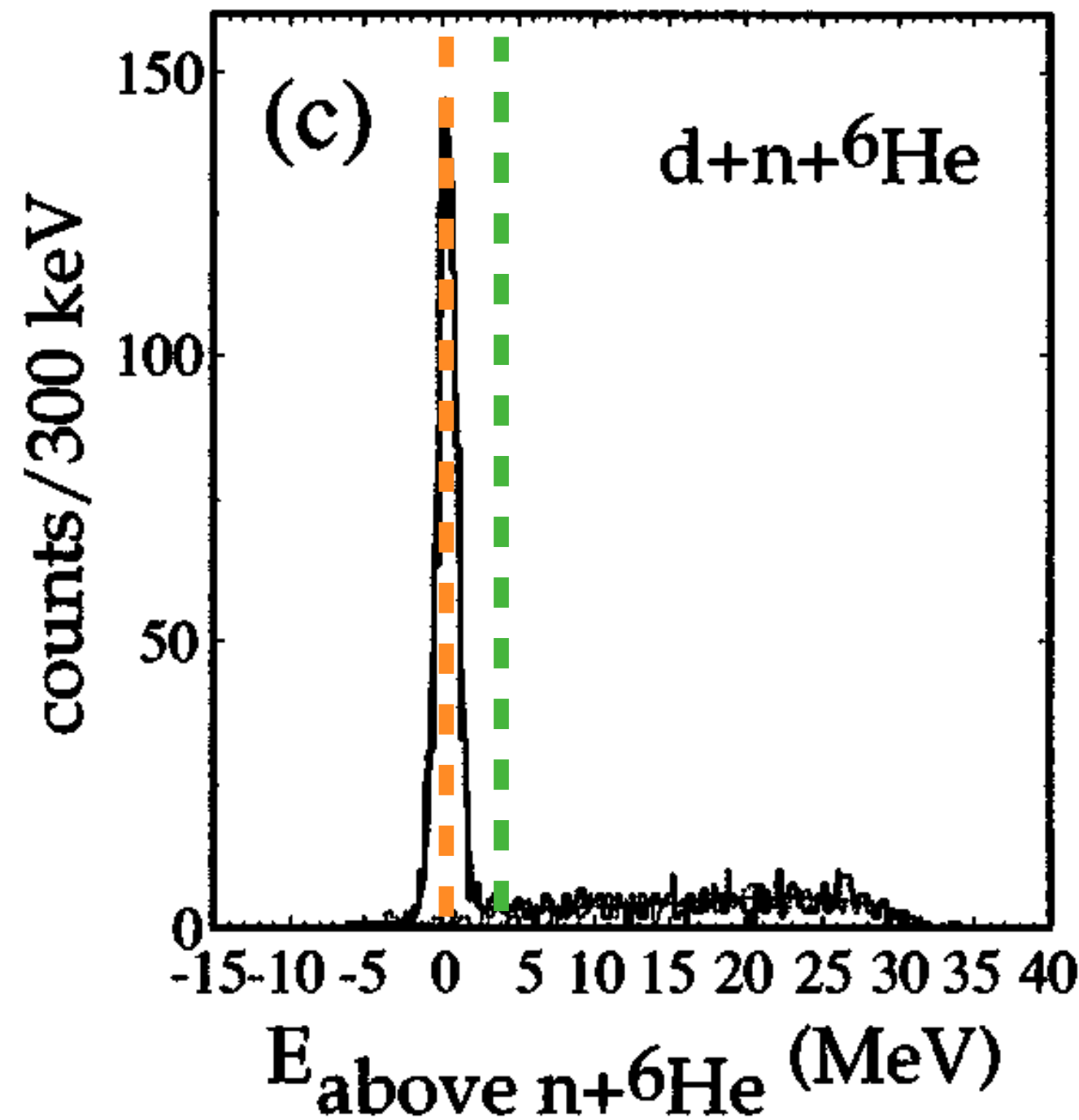


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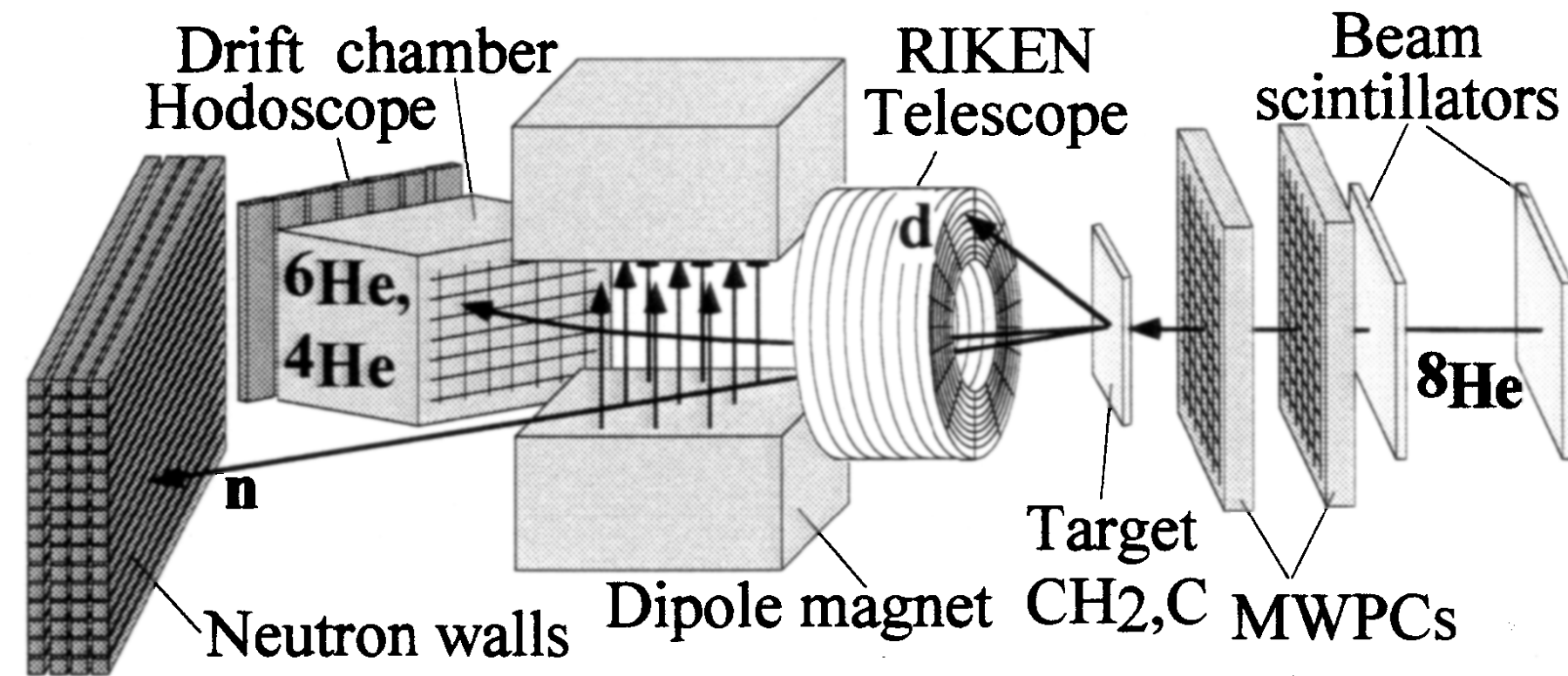


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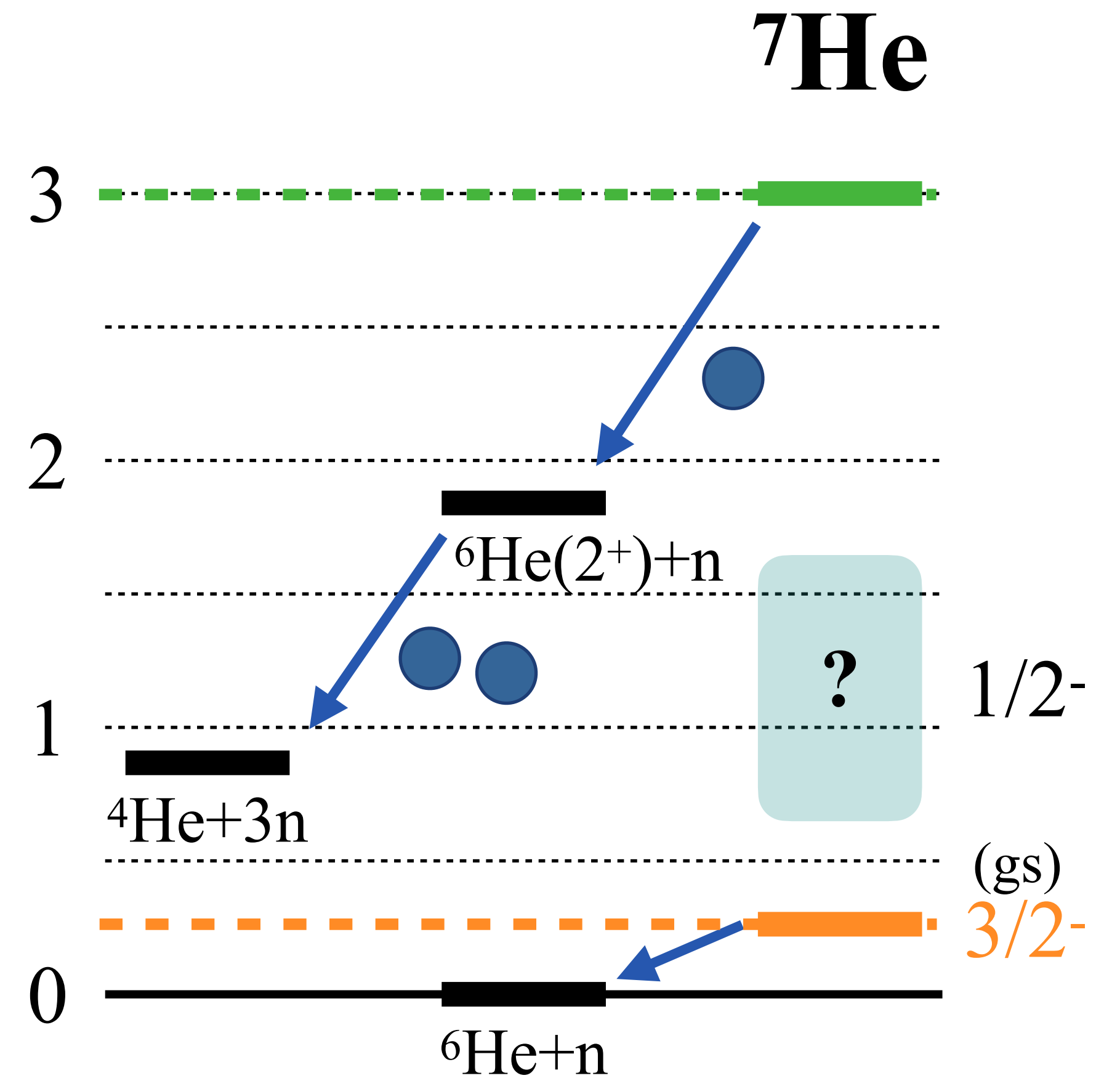
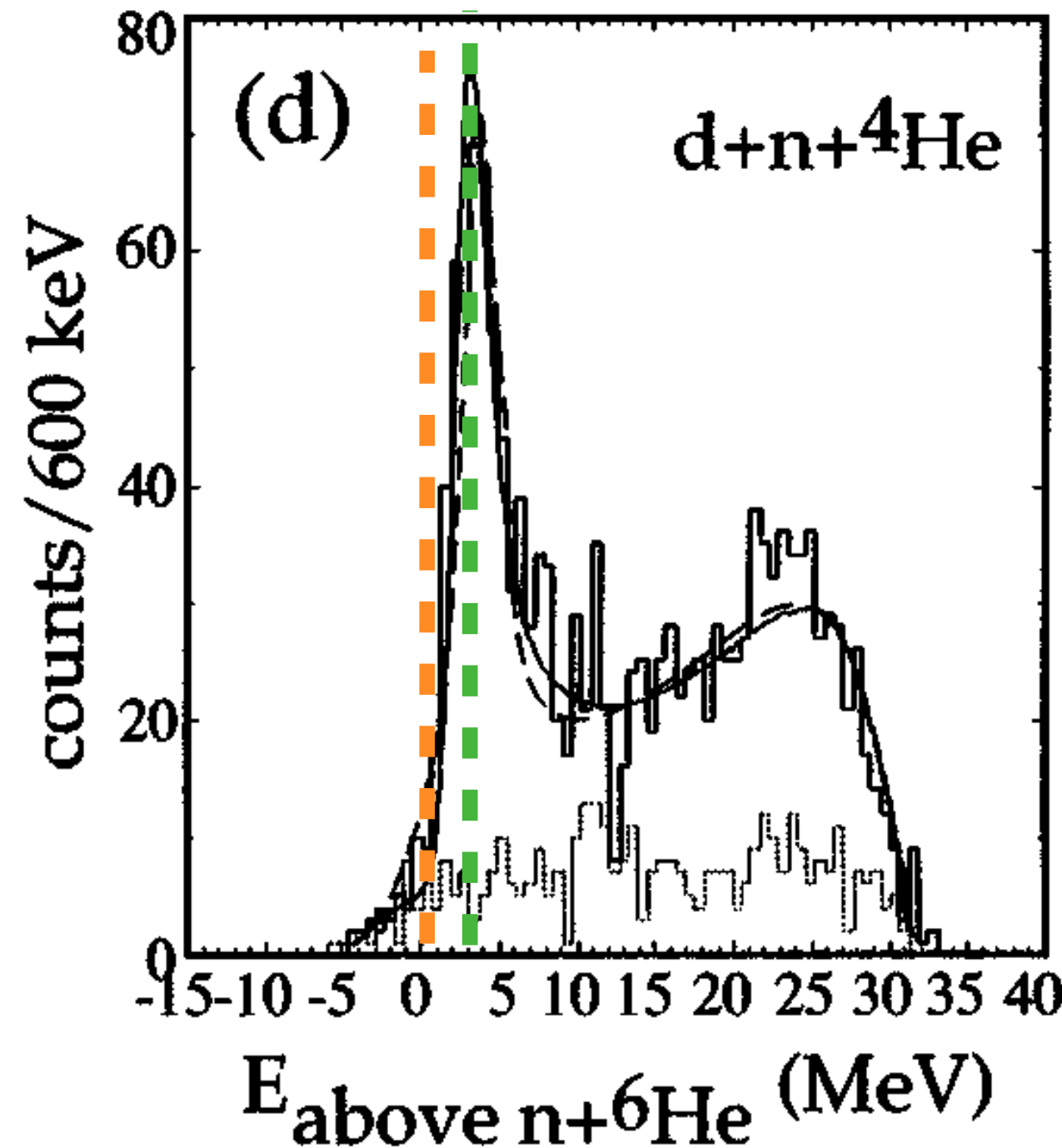
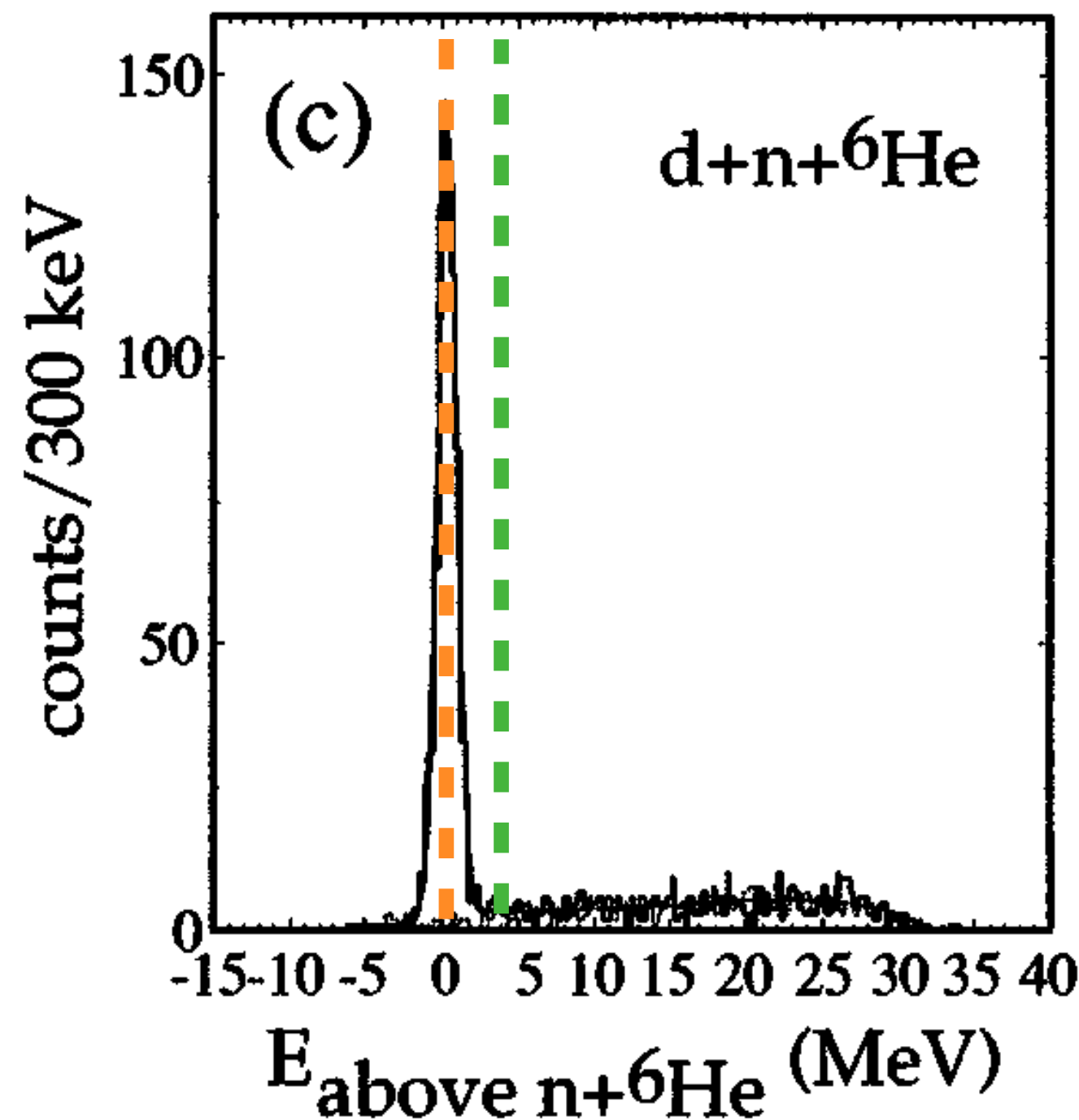


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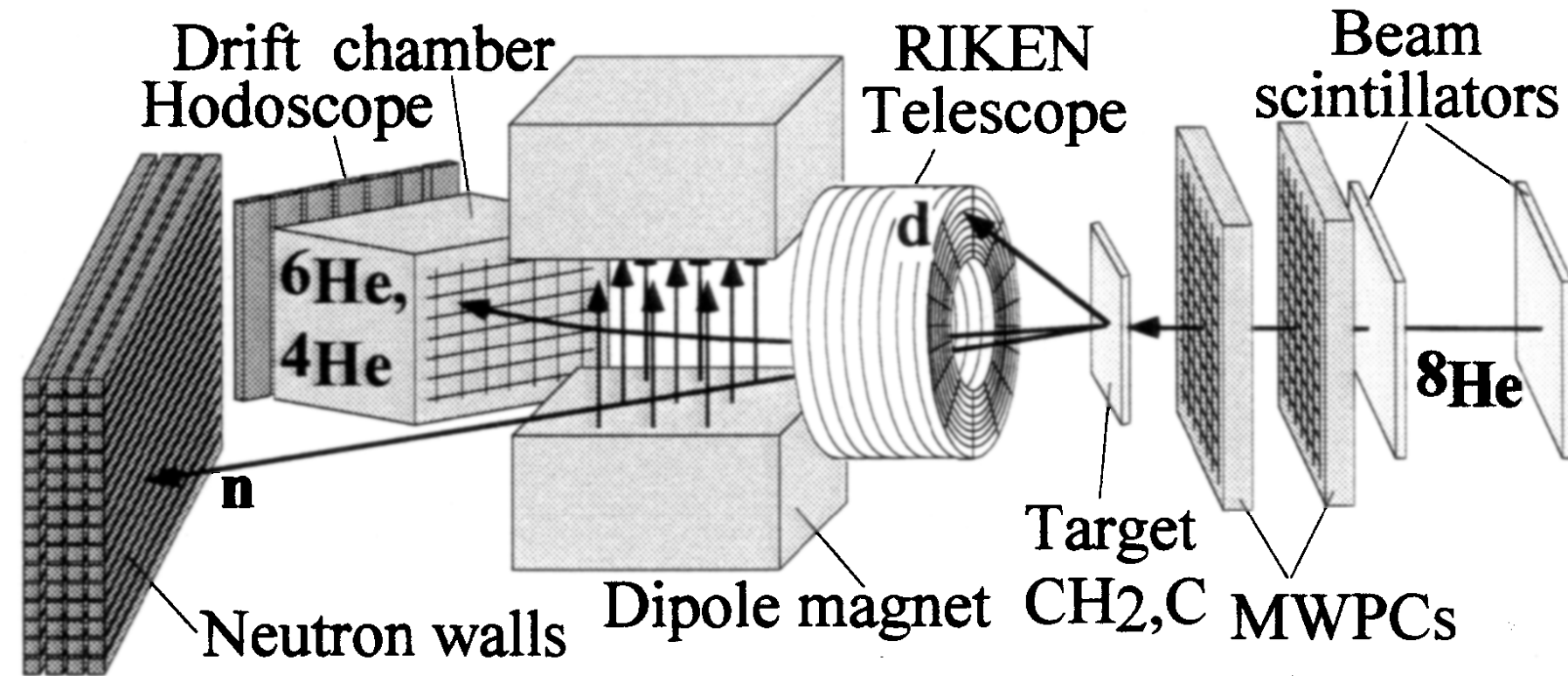


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Korshennikov *et al.* PRL (1999)

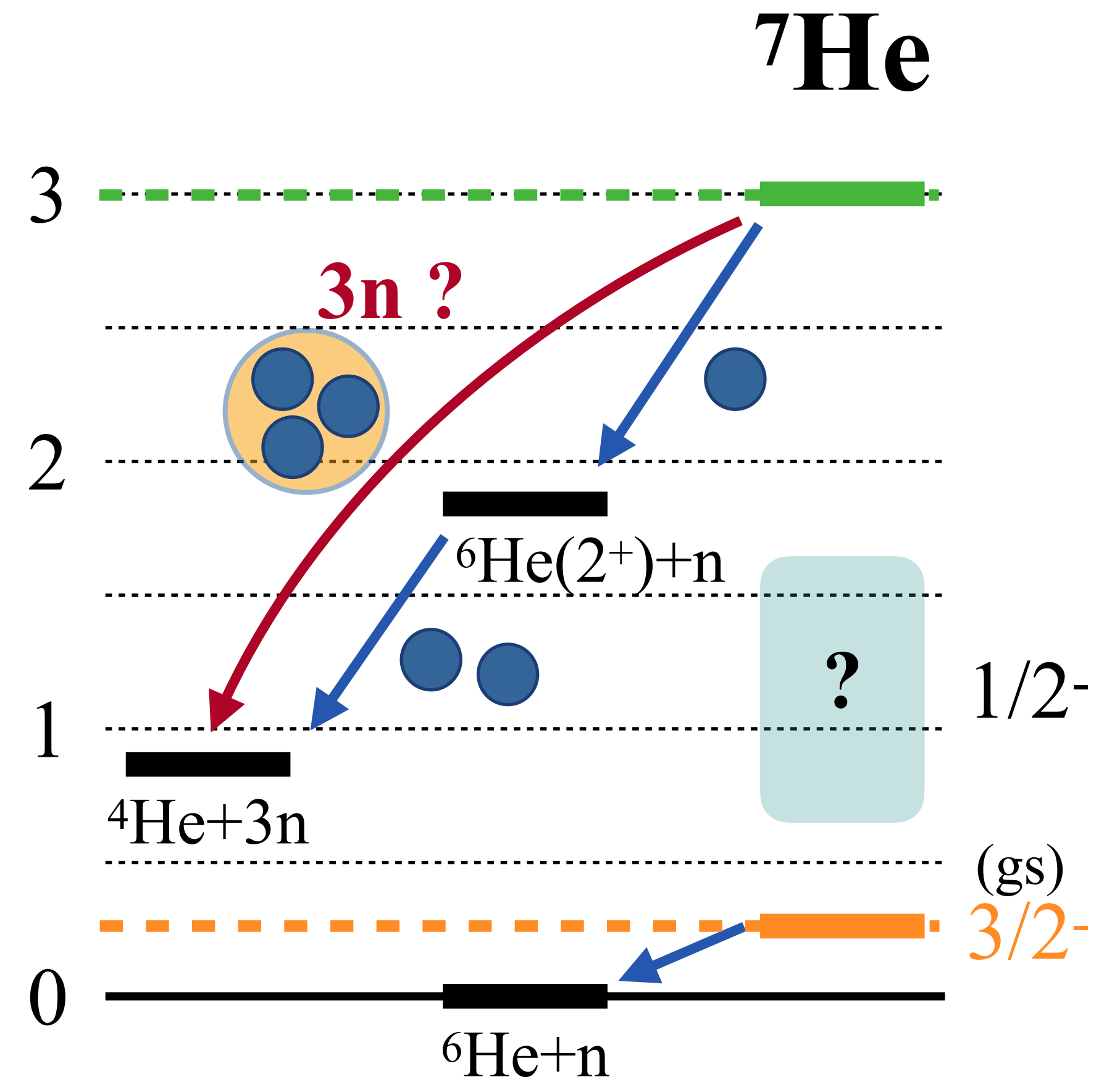
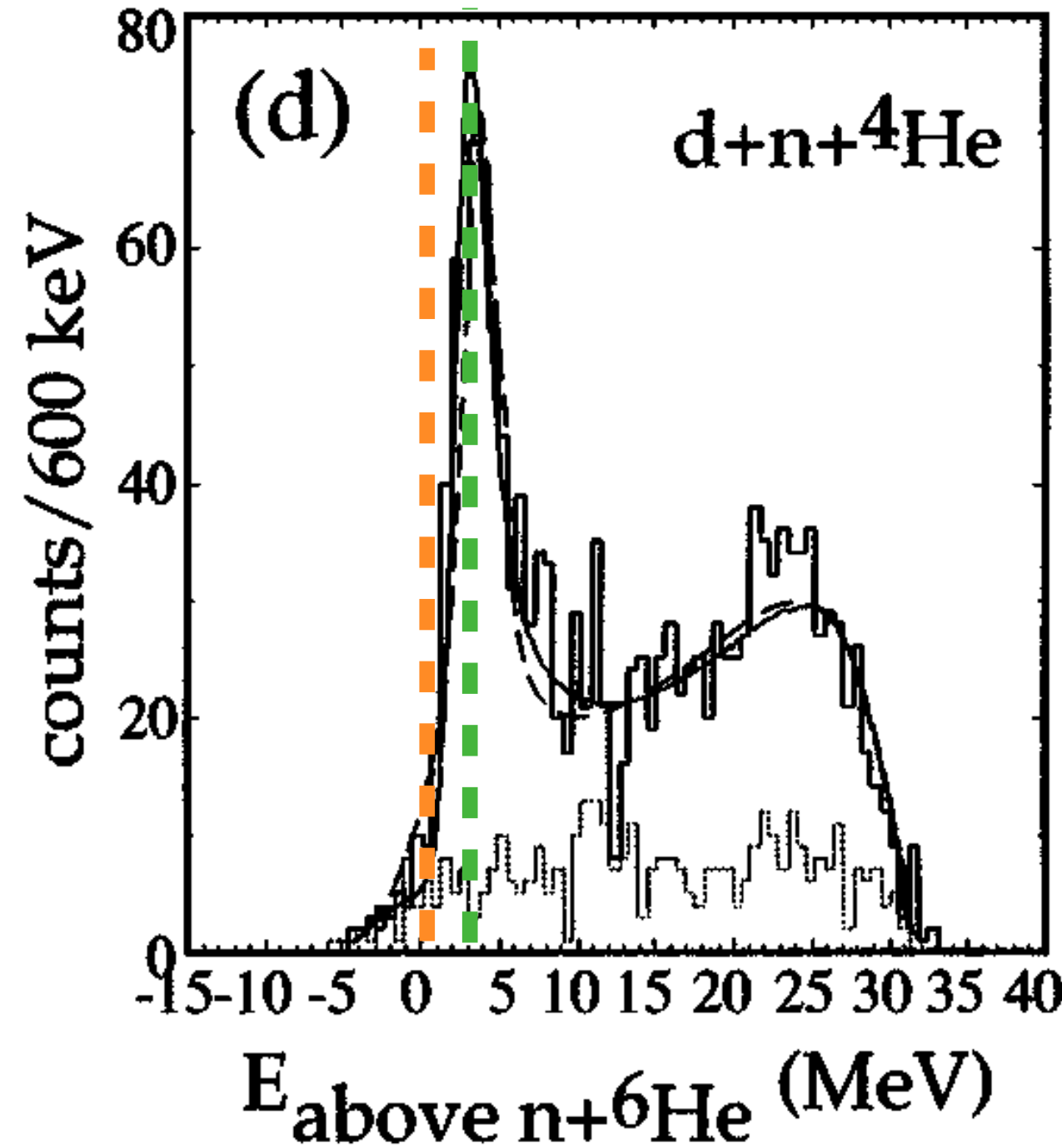
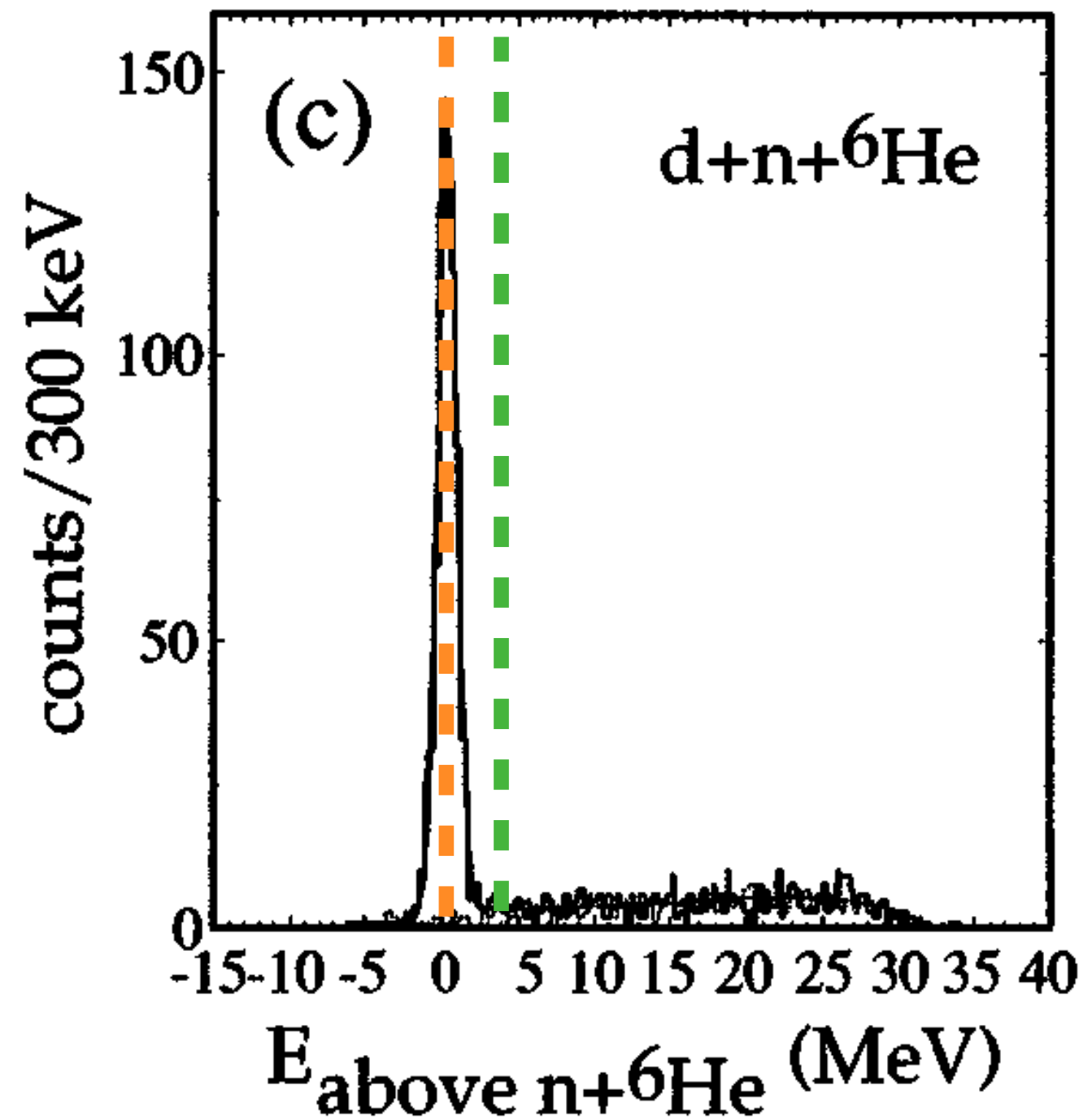


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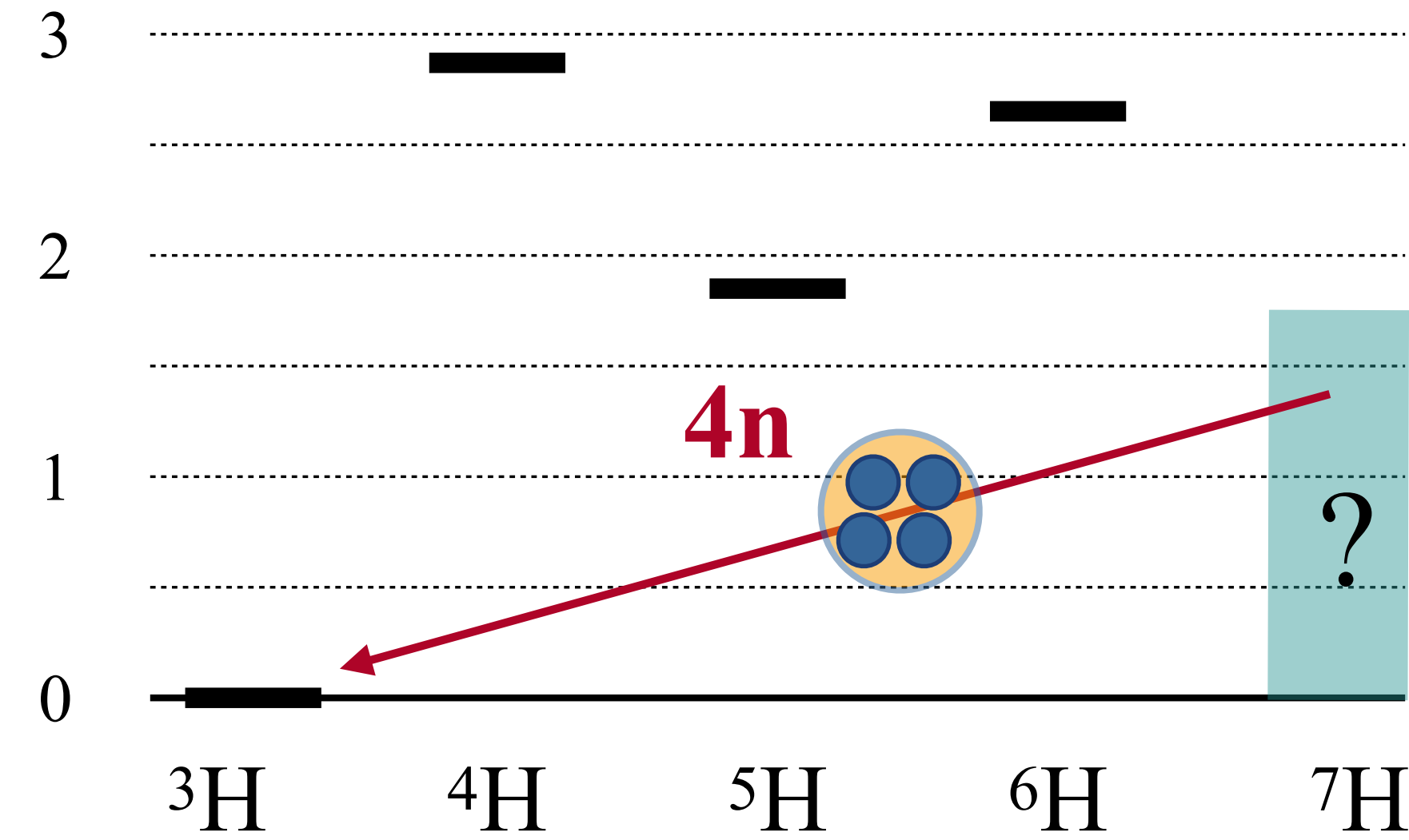


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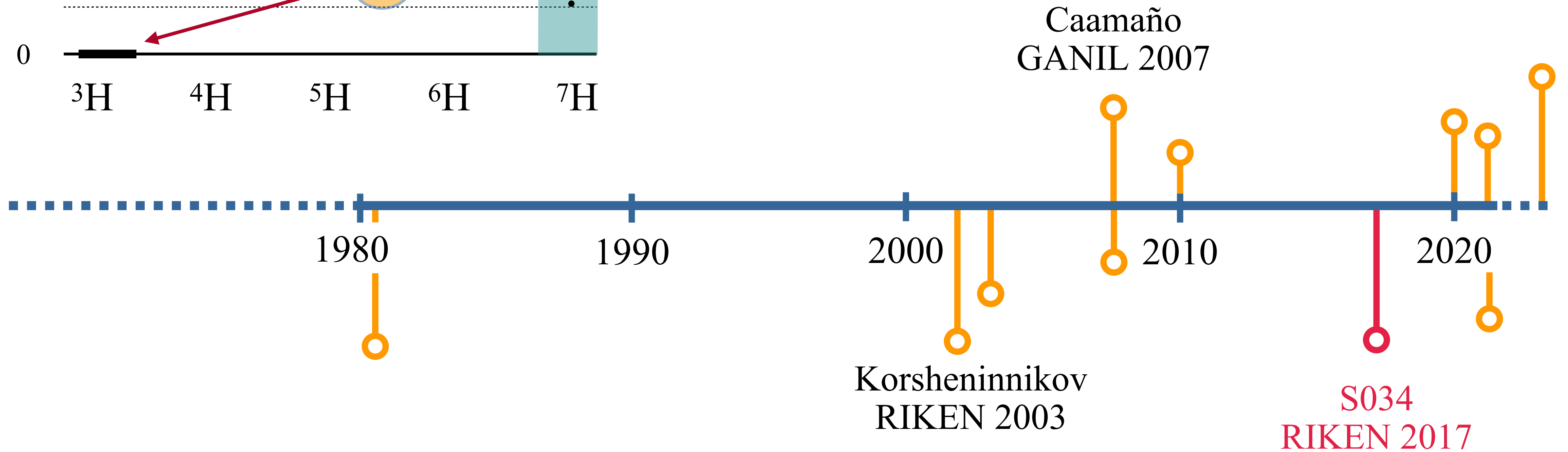
Korshennikov *et al.* PRL (1999)



Introduction: Hydrogene-7, state of play

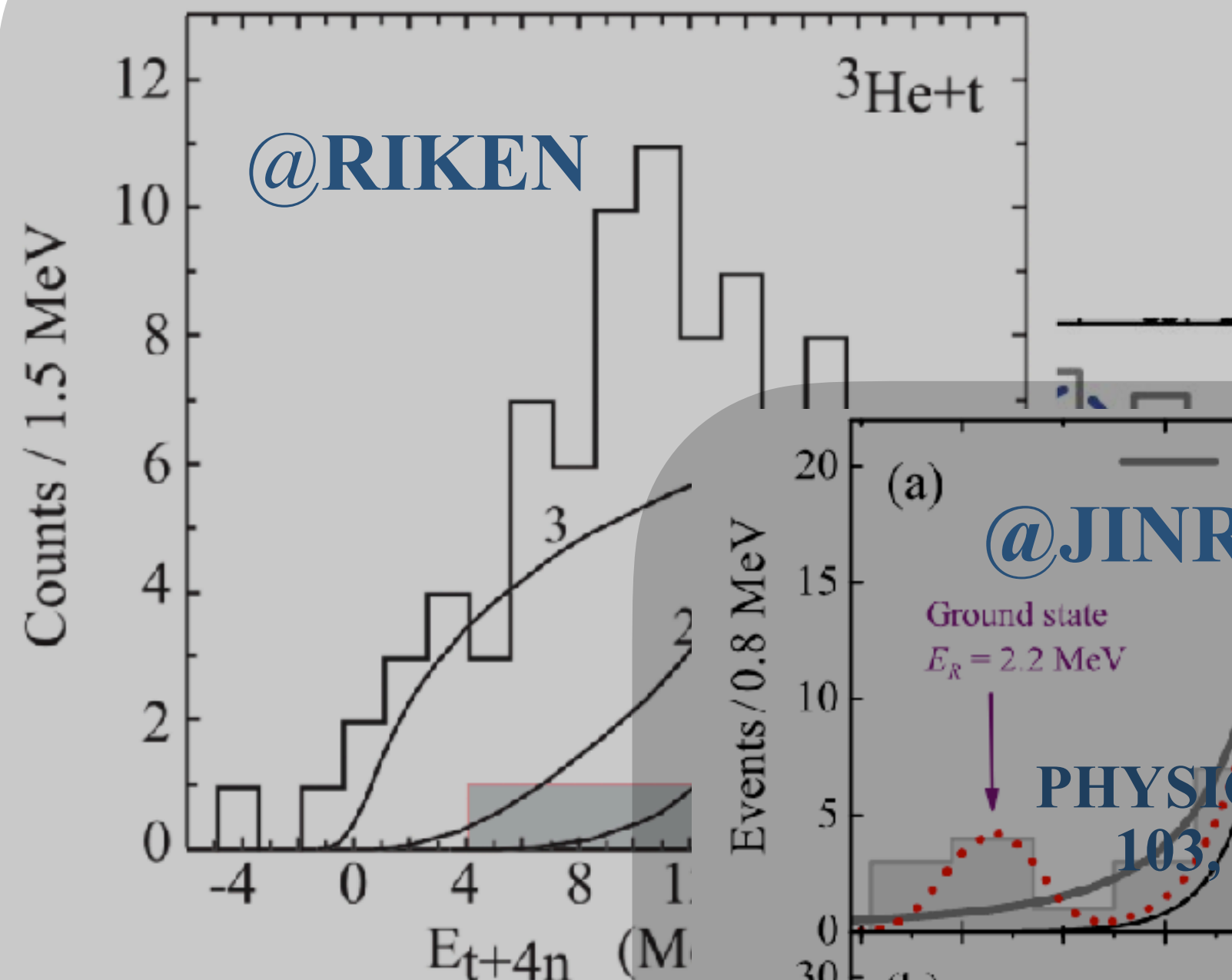


^7H a hot but difficult topic ...

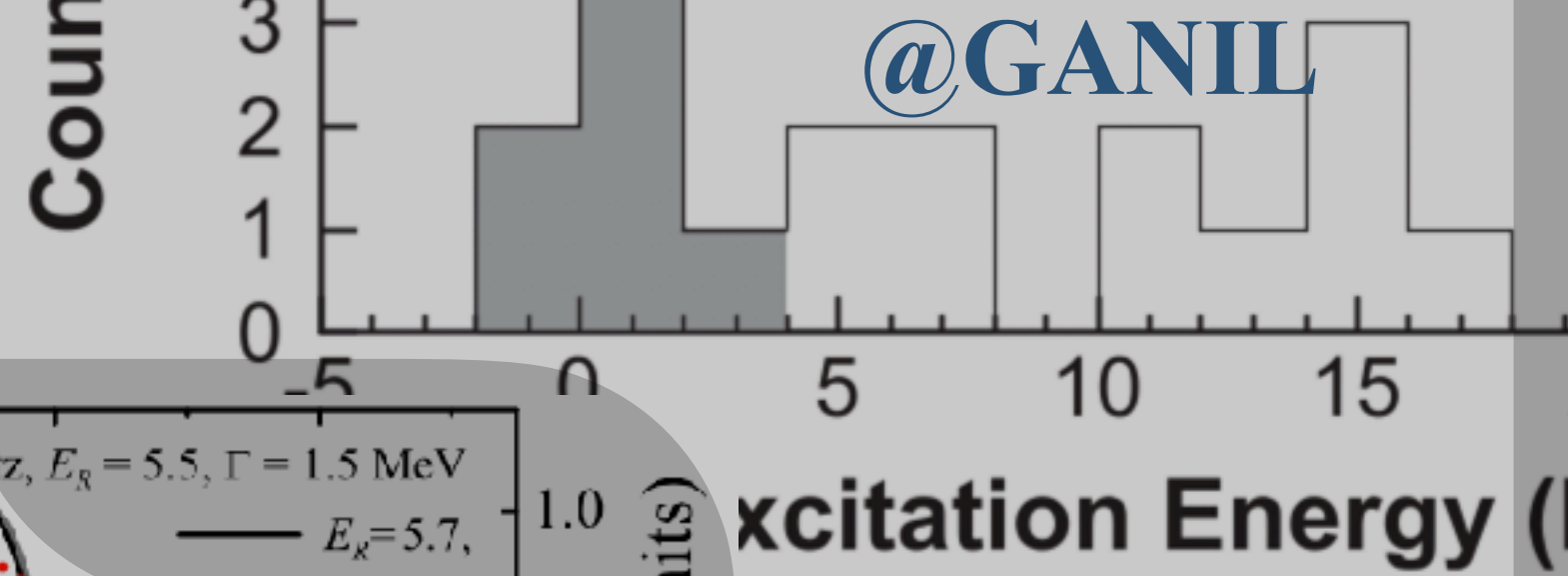


Introduction: Hydrogene-7, state of play

PHYSICAL REVIEW C 81, 064606 (2010)



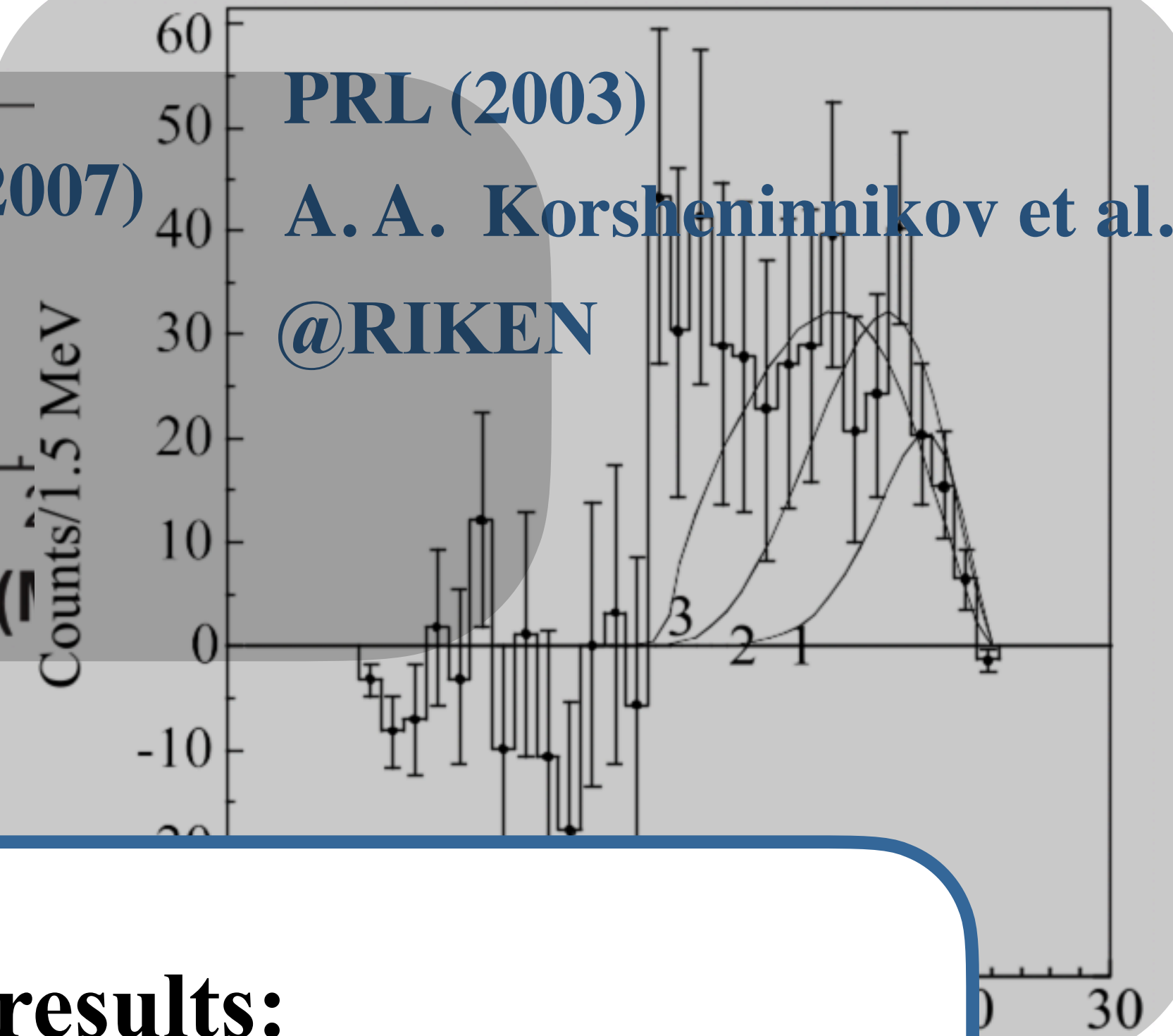
PRL 99, 062502 (2007)



PRL (2003)

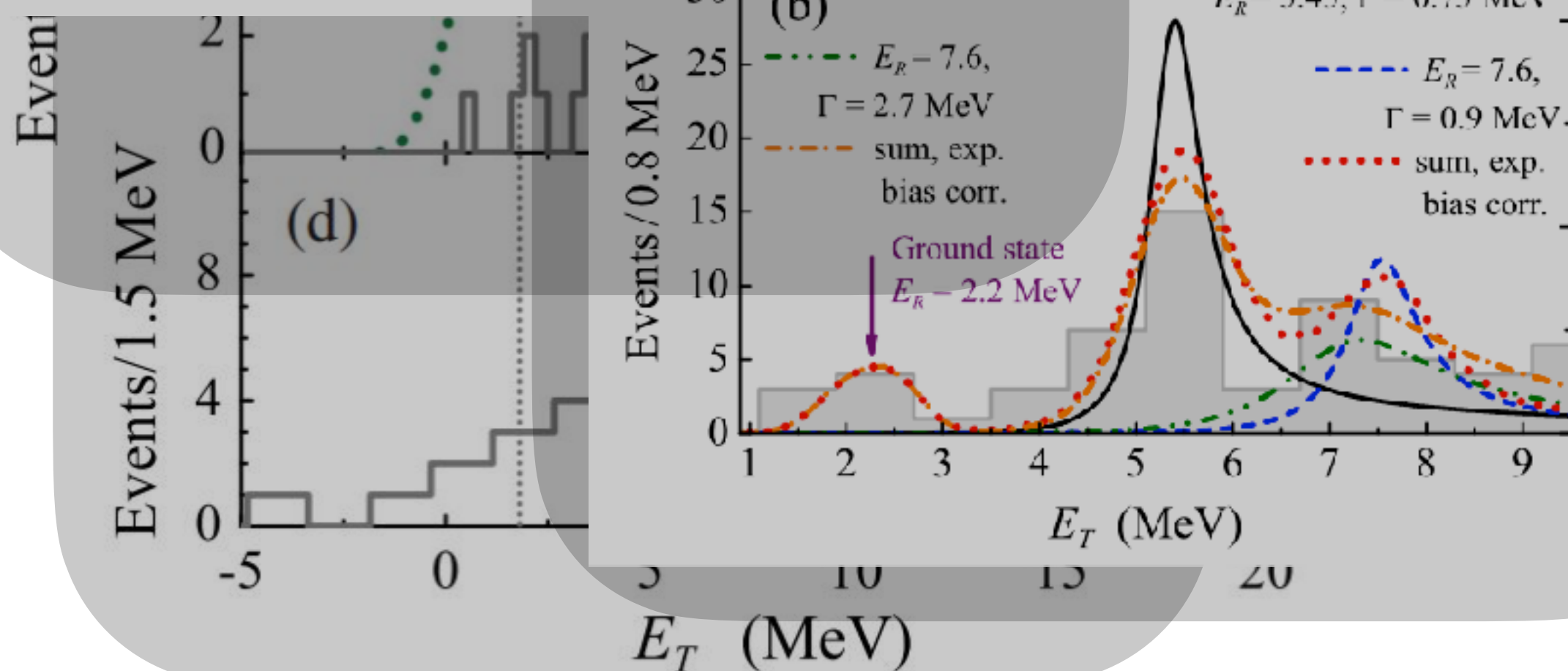
A. A. Korshennikov et al.

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@JINR

PHYSICAL REVIEW C 103, 044313 (2021)



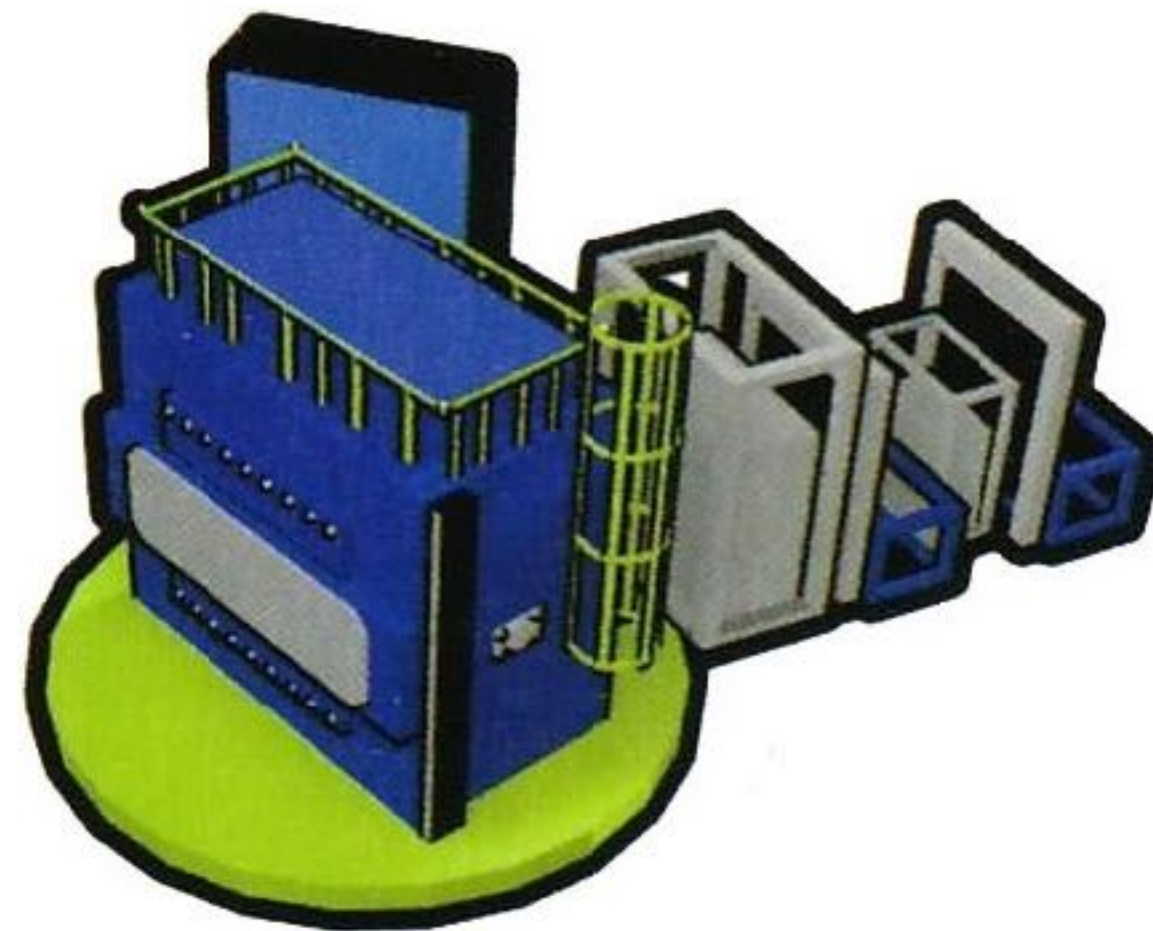
Contradictory results:

- Low statistics
- Low signal to background
- Limited resolution $\sim 2-3$ MeV
- Missing mass (no neutron detection)

→ Better experiments needed

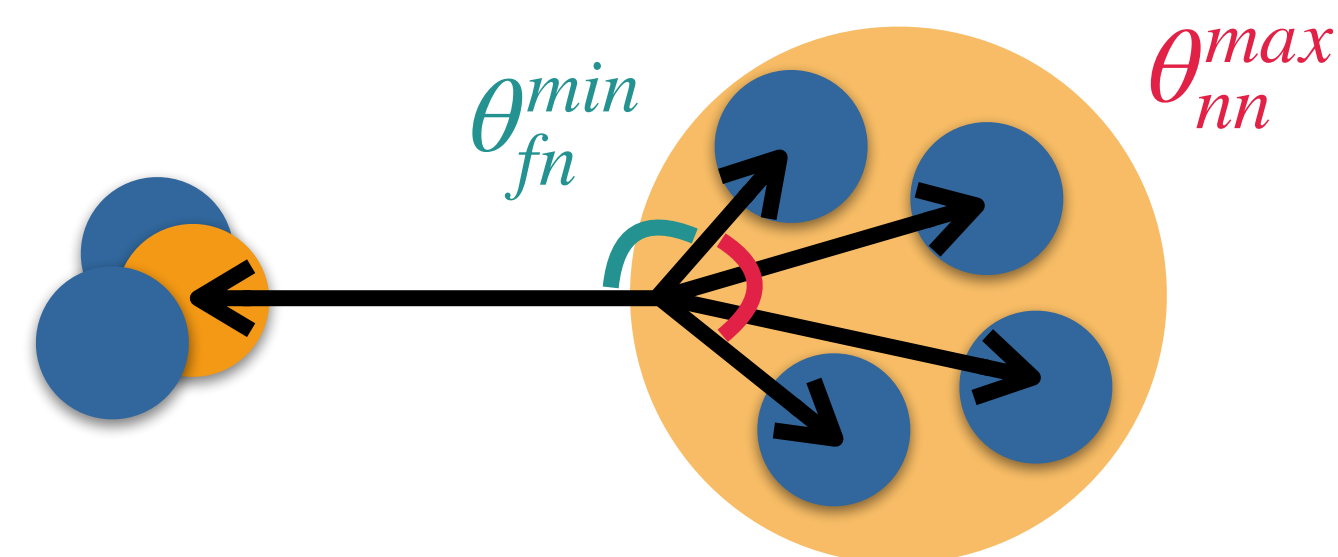
1. Introduction

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Helium-7
Hydrogen-7



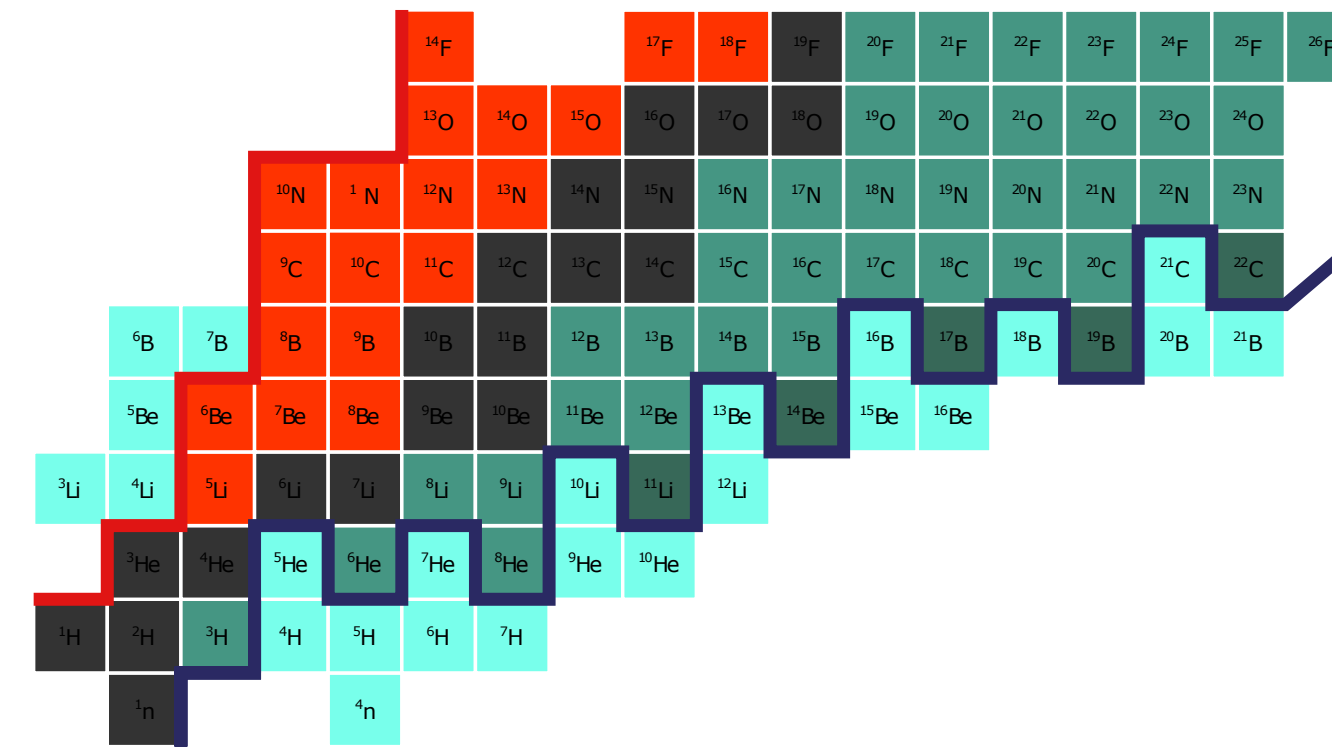
2. Samurai 34

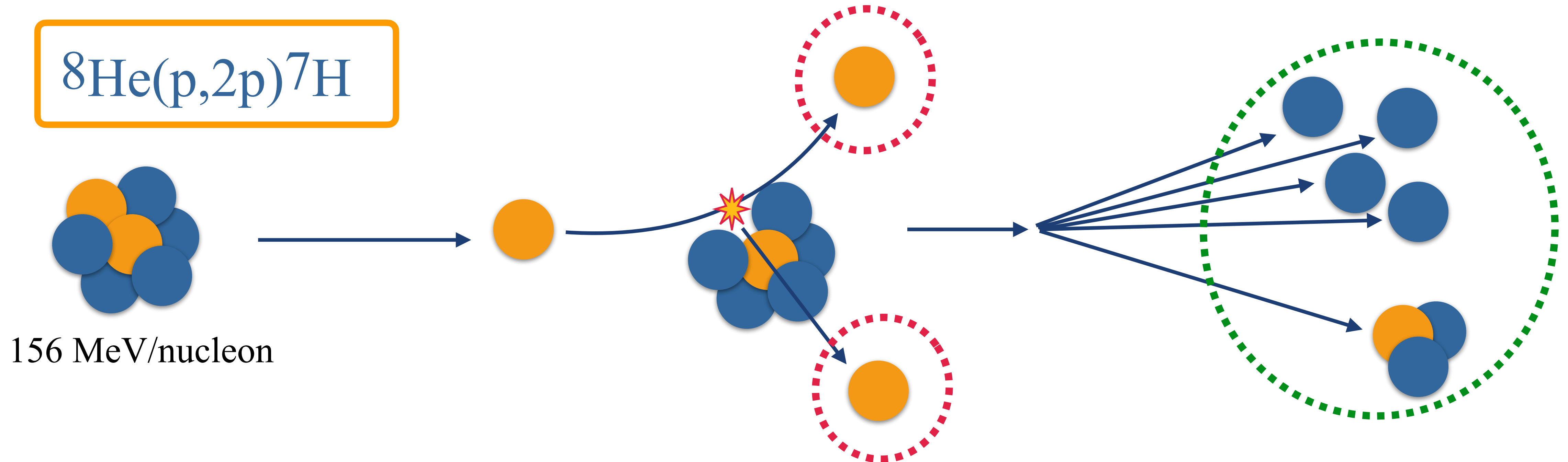
Experimental Approach
Multineutron detection



3. First results

Helium-7 & 3n decay
Hydrogen-7 & 4n decay



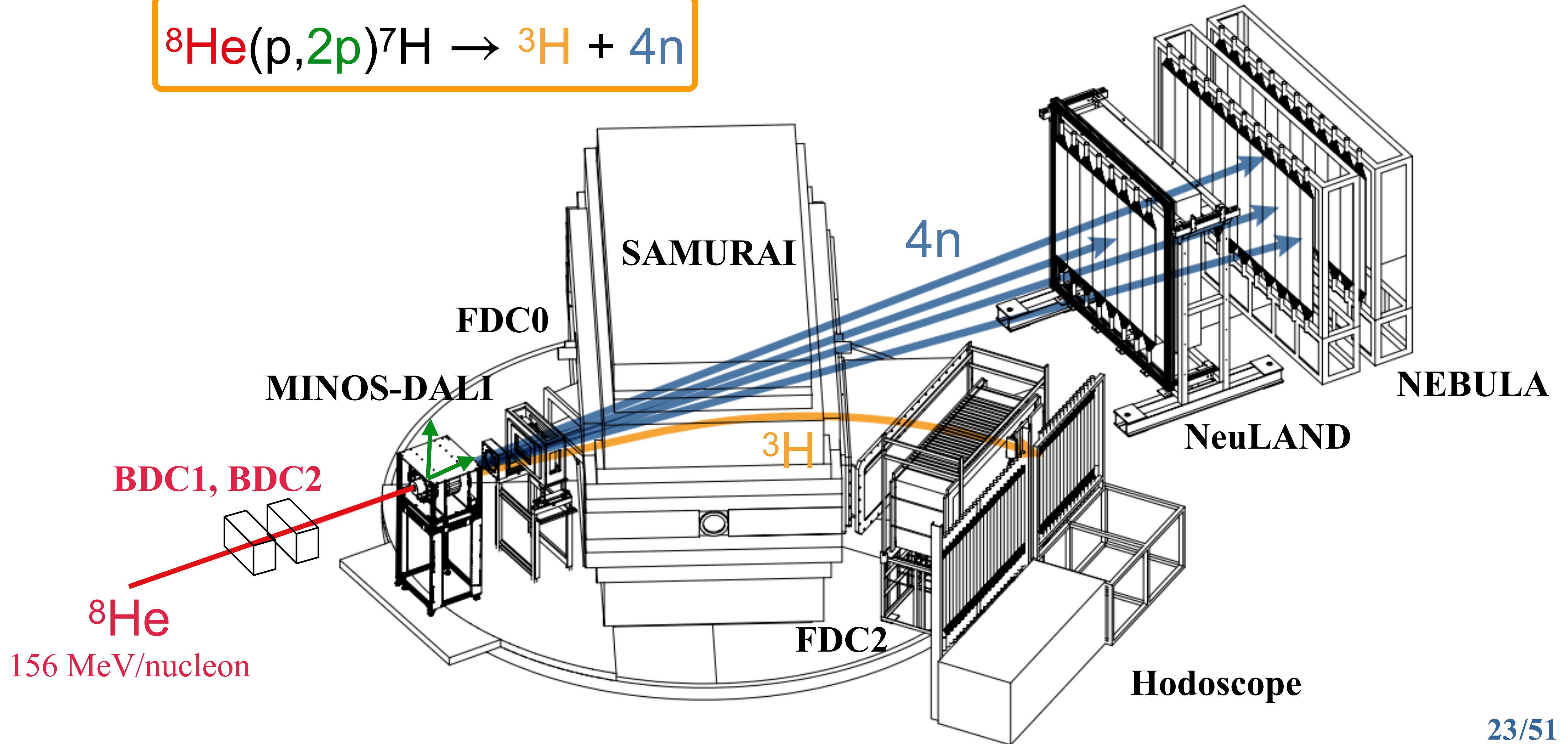


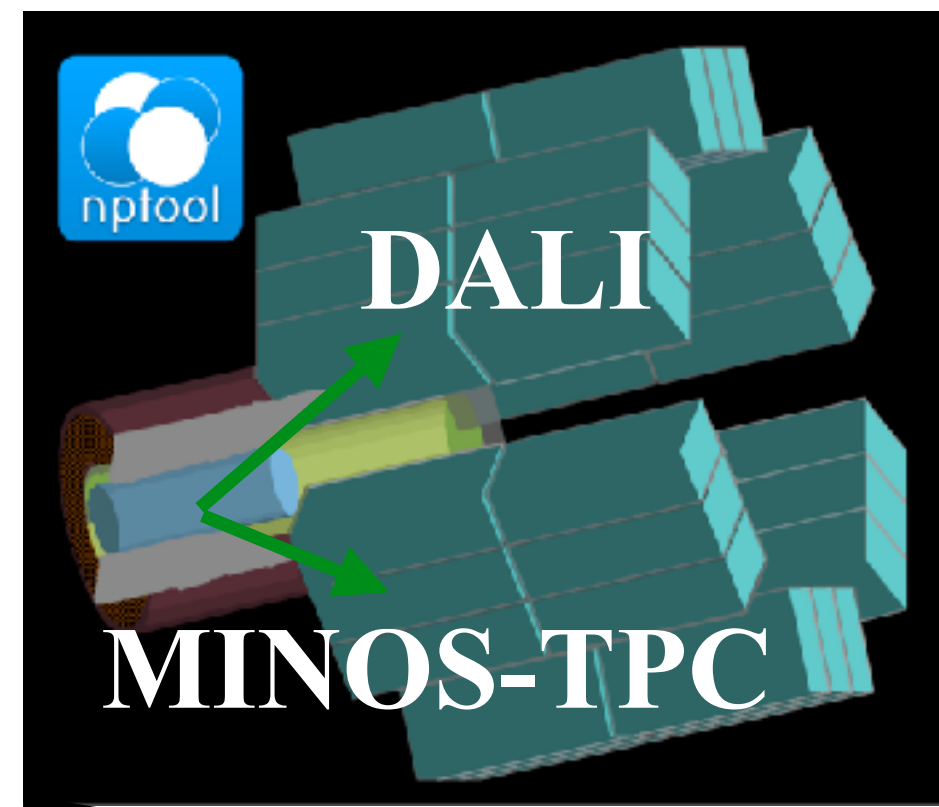
Complete kinematics :

Invariant mass FWHM ~ 0.1 MeV: main goal

Missing mass FWHM ~ 7 MeV: complementary cross-check

SAMURAI 34 : a challenging setup

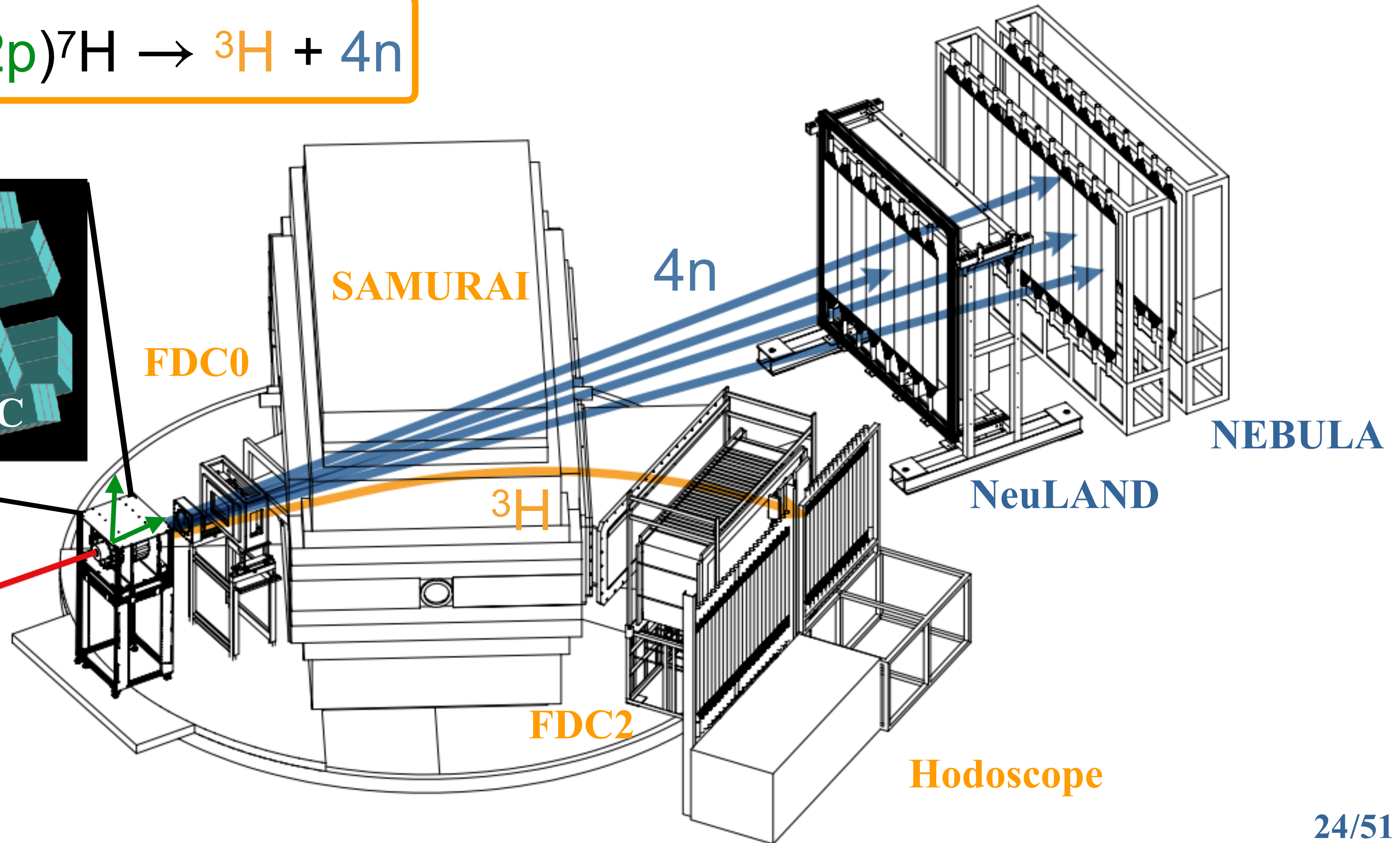




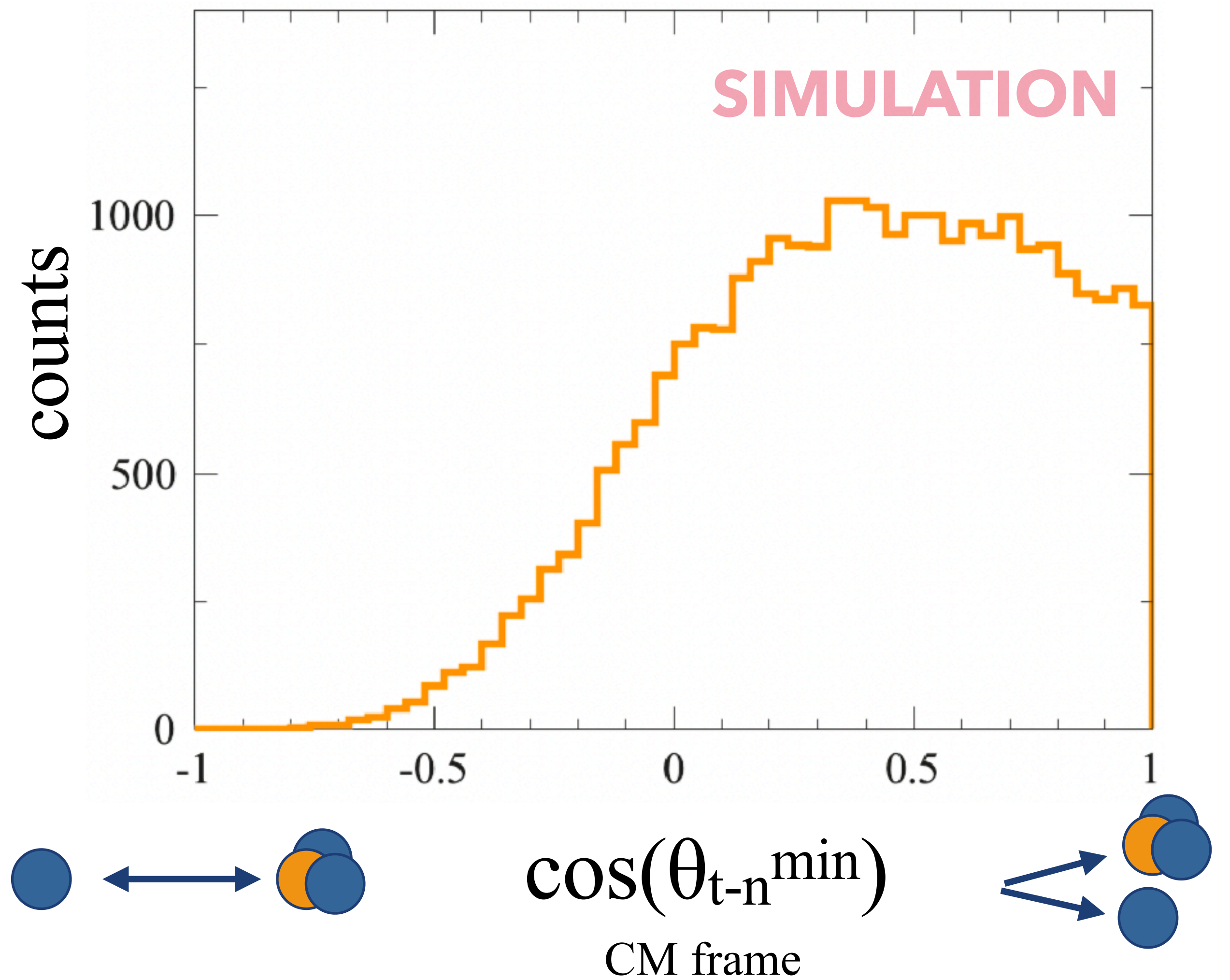
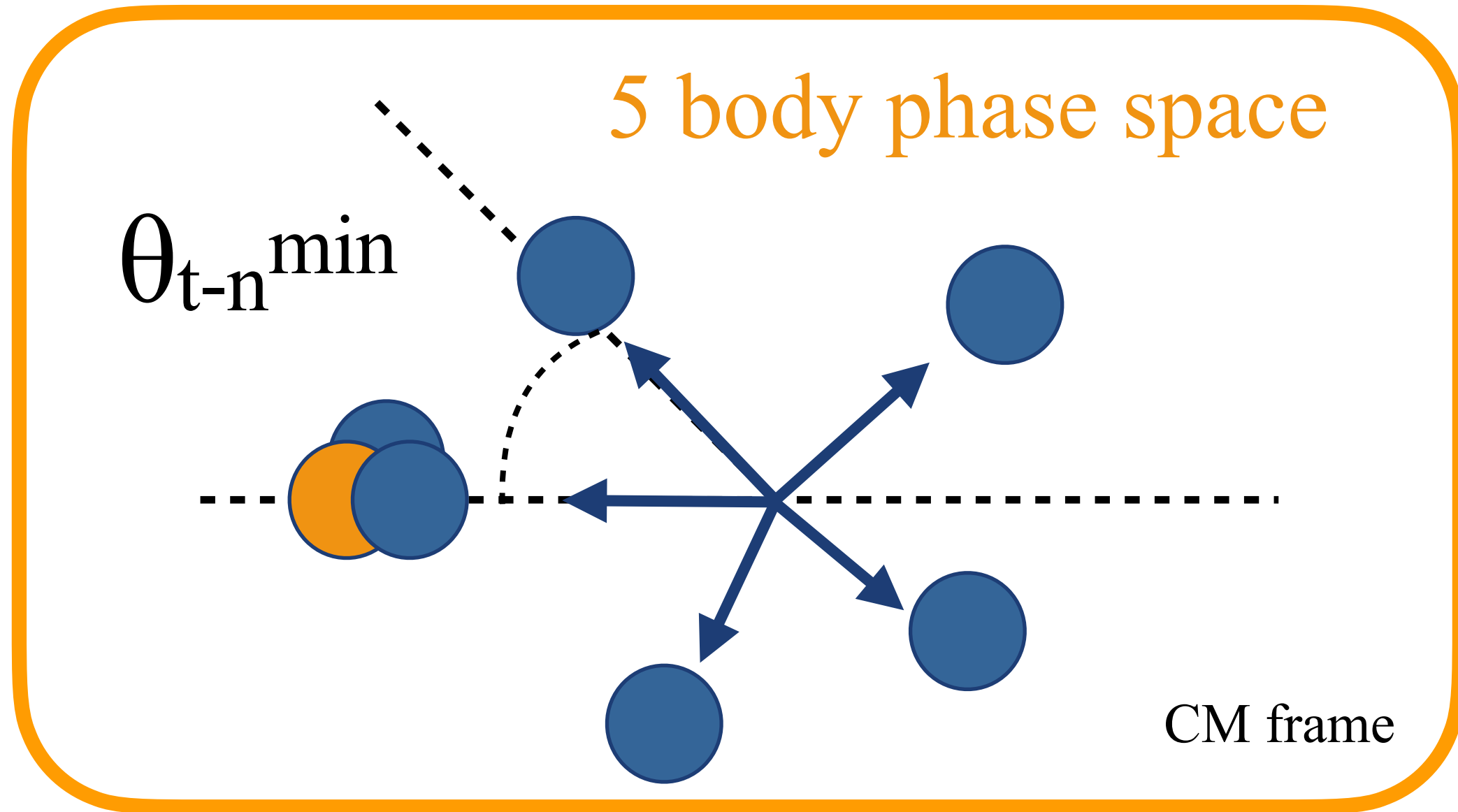
BDC1, BDC2

${}^8\text{He}$

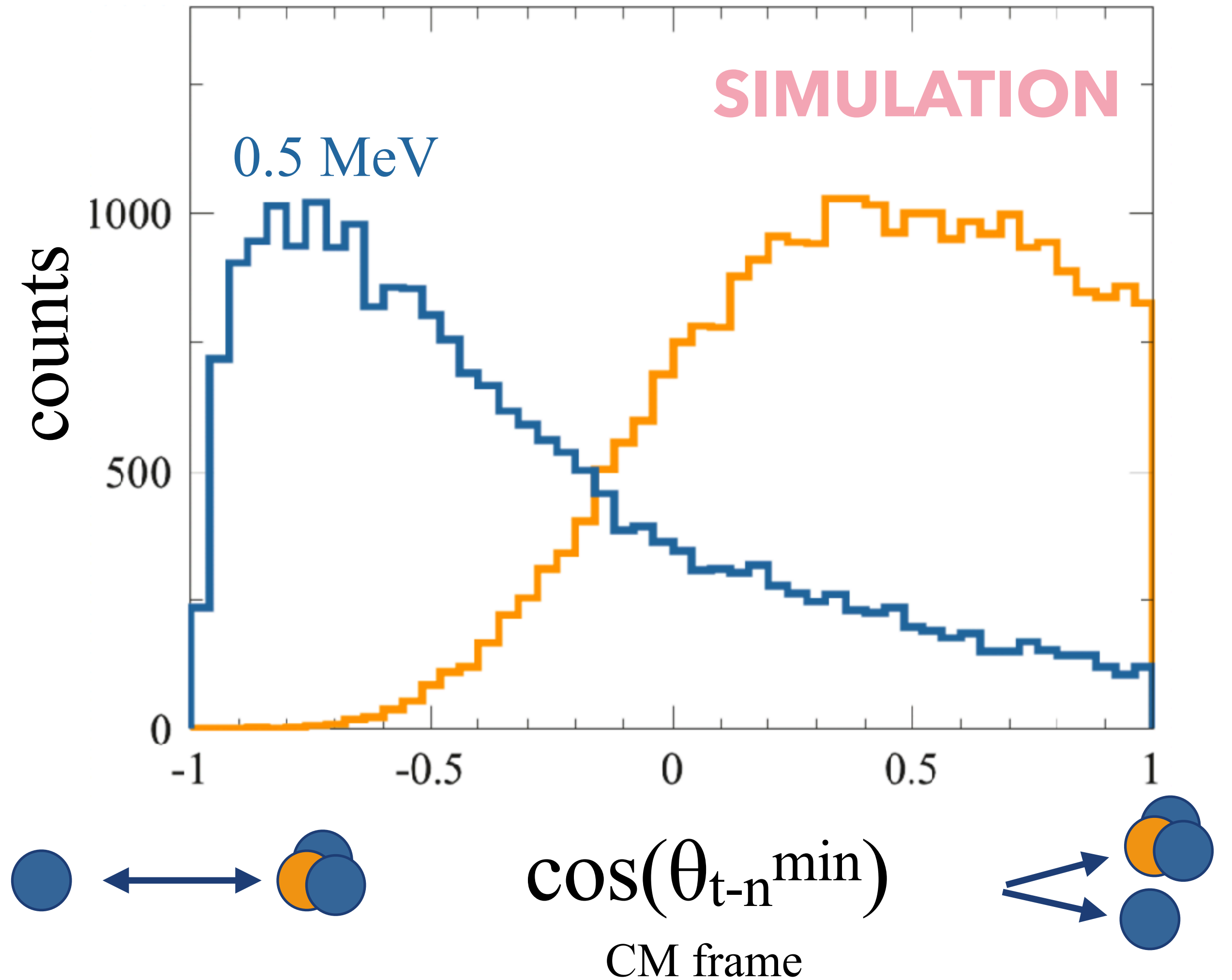
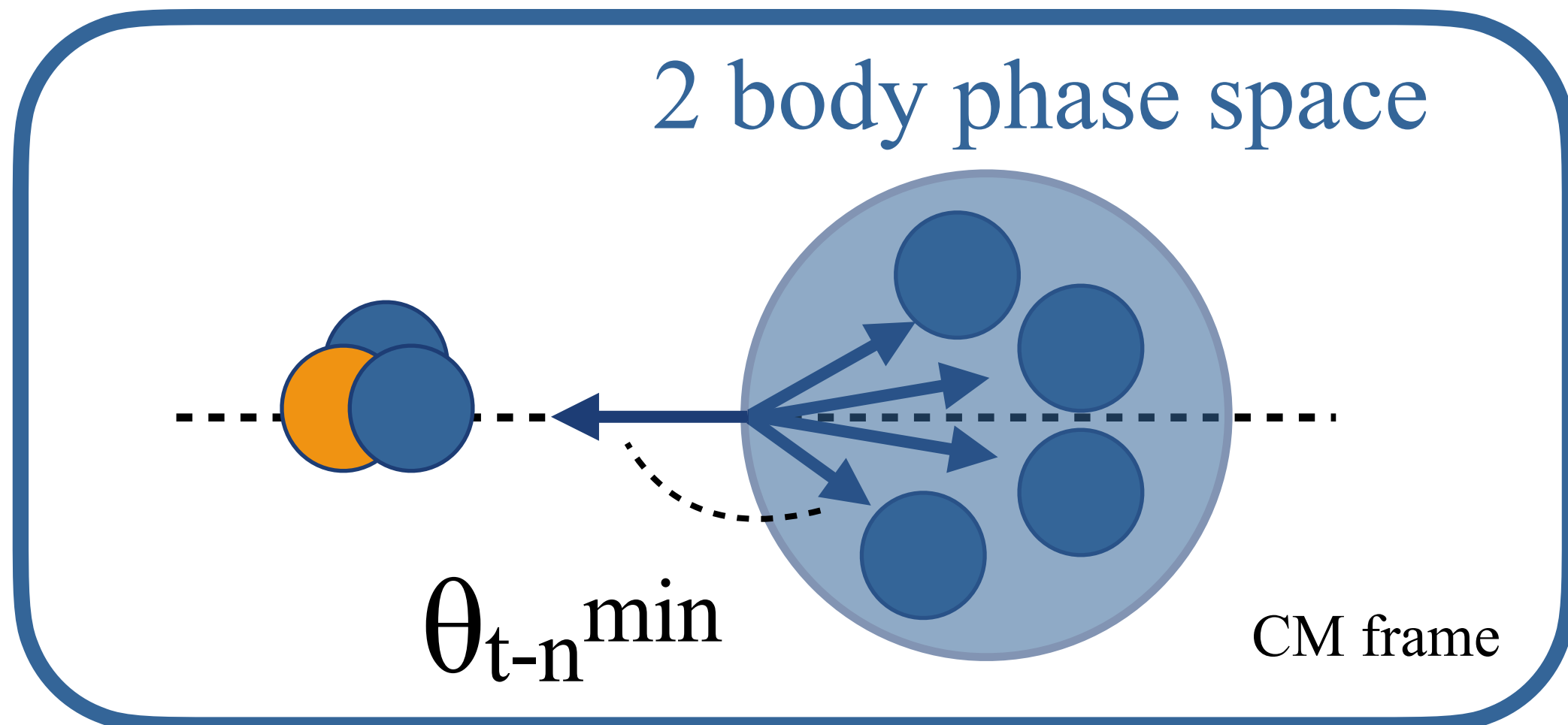
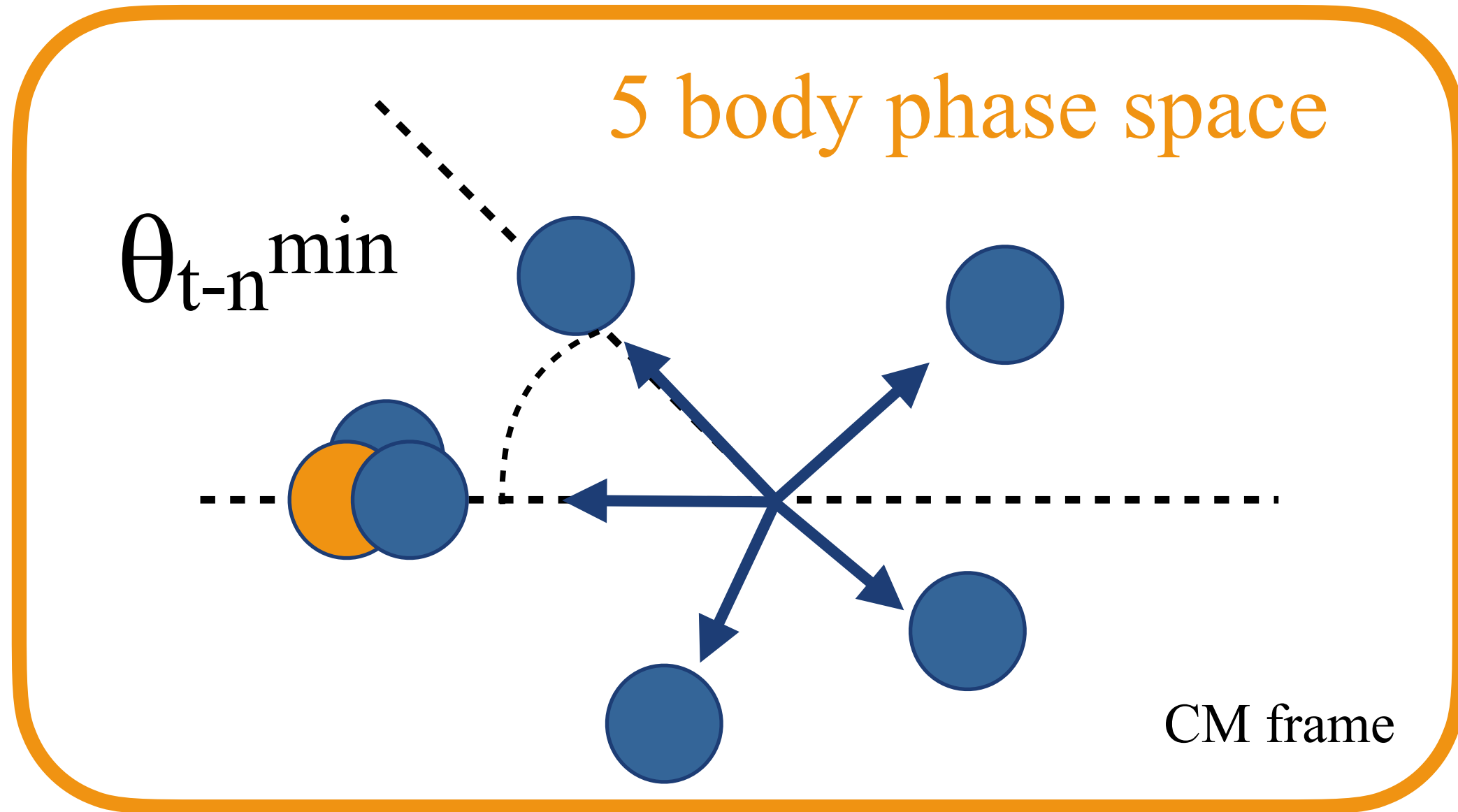
156 MeV/nucleon



Samurai 034: Tetraneutron emission ?

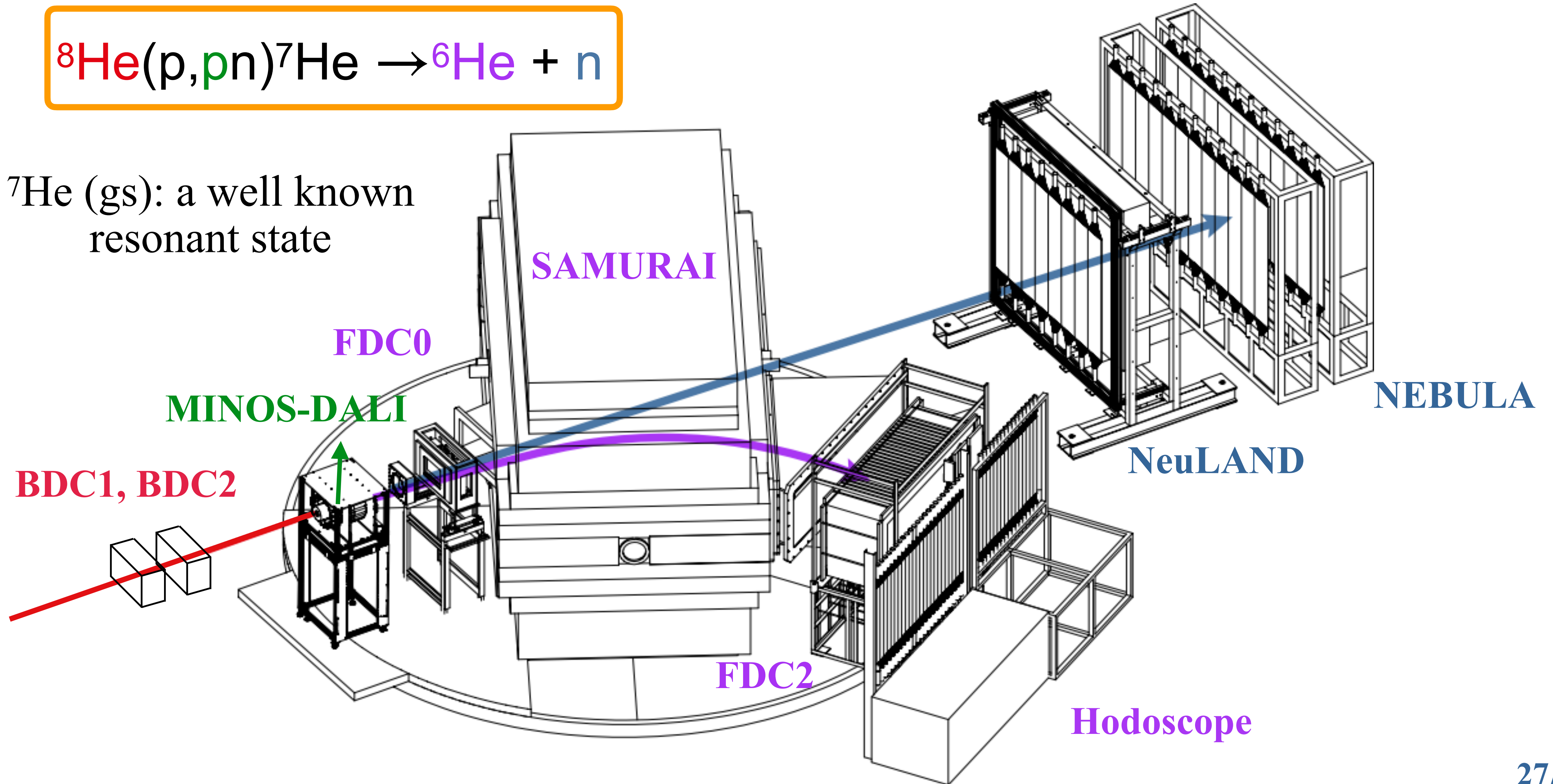


Samurai 034: Tetraneutron emission ?

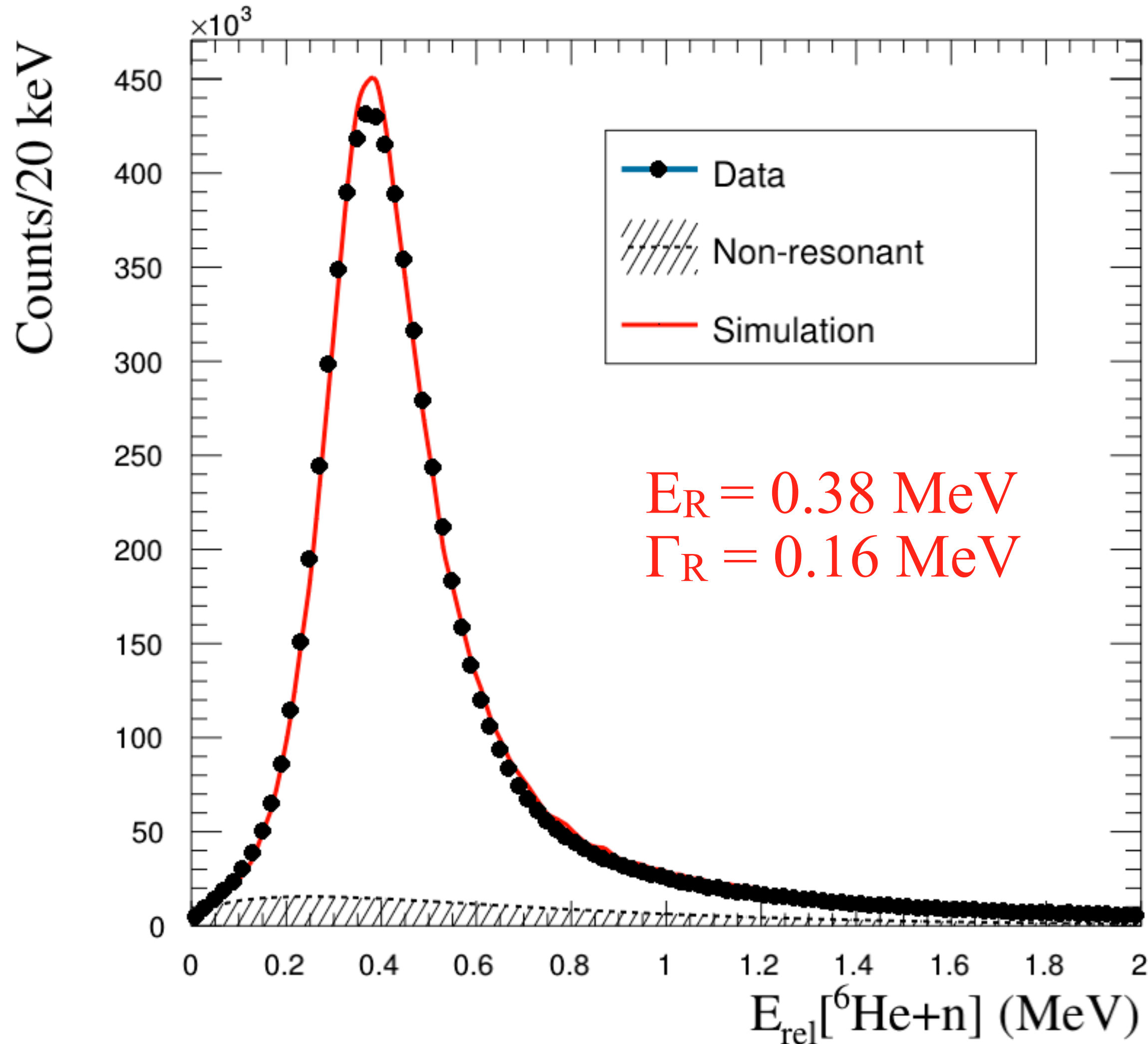




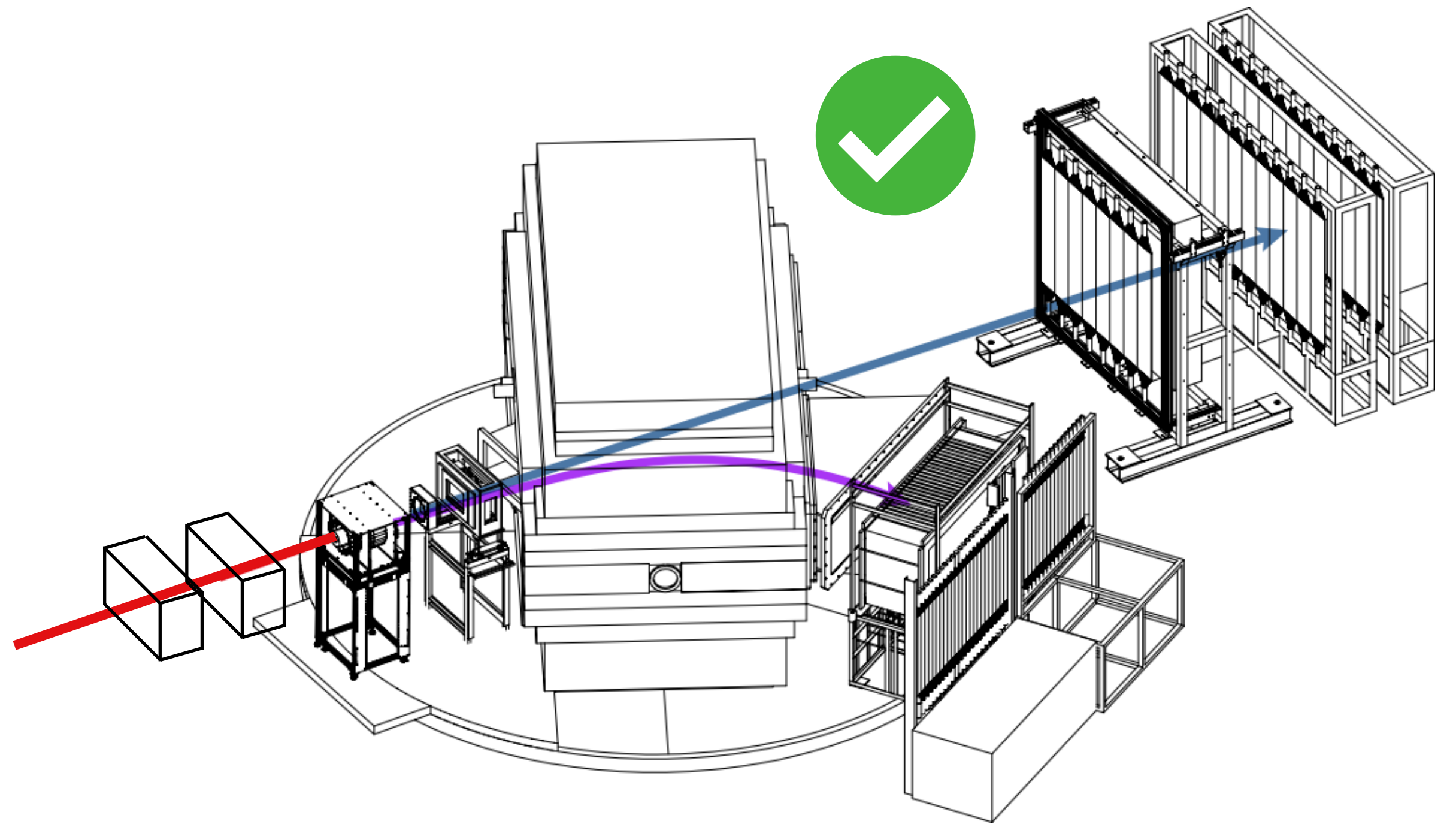
${}^7\text{He}(\text{gs})$: a well known resonant state



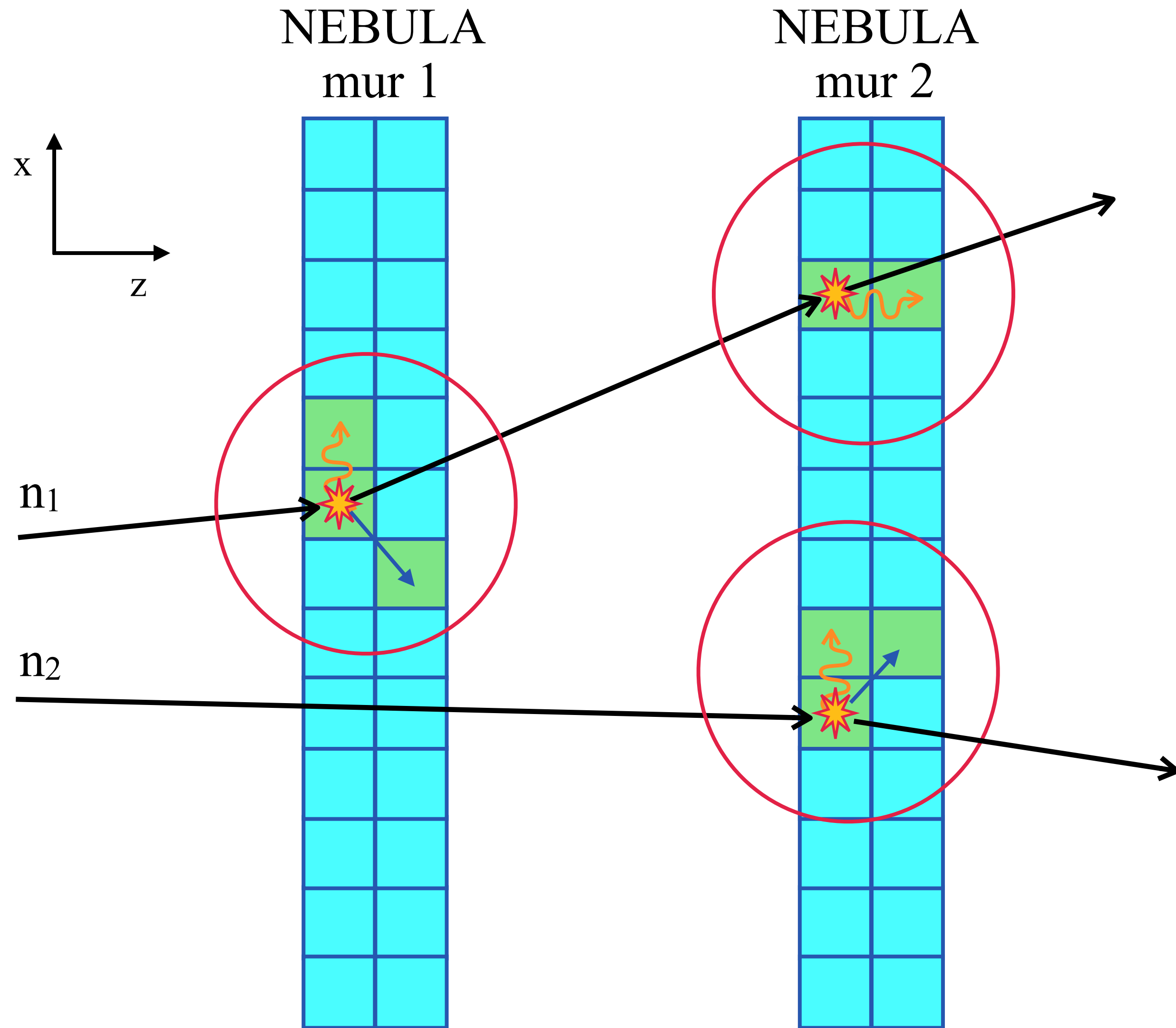
Samurai 034: ${}^7\text{He}(\text{gs})$, benchmark '1n'



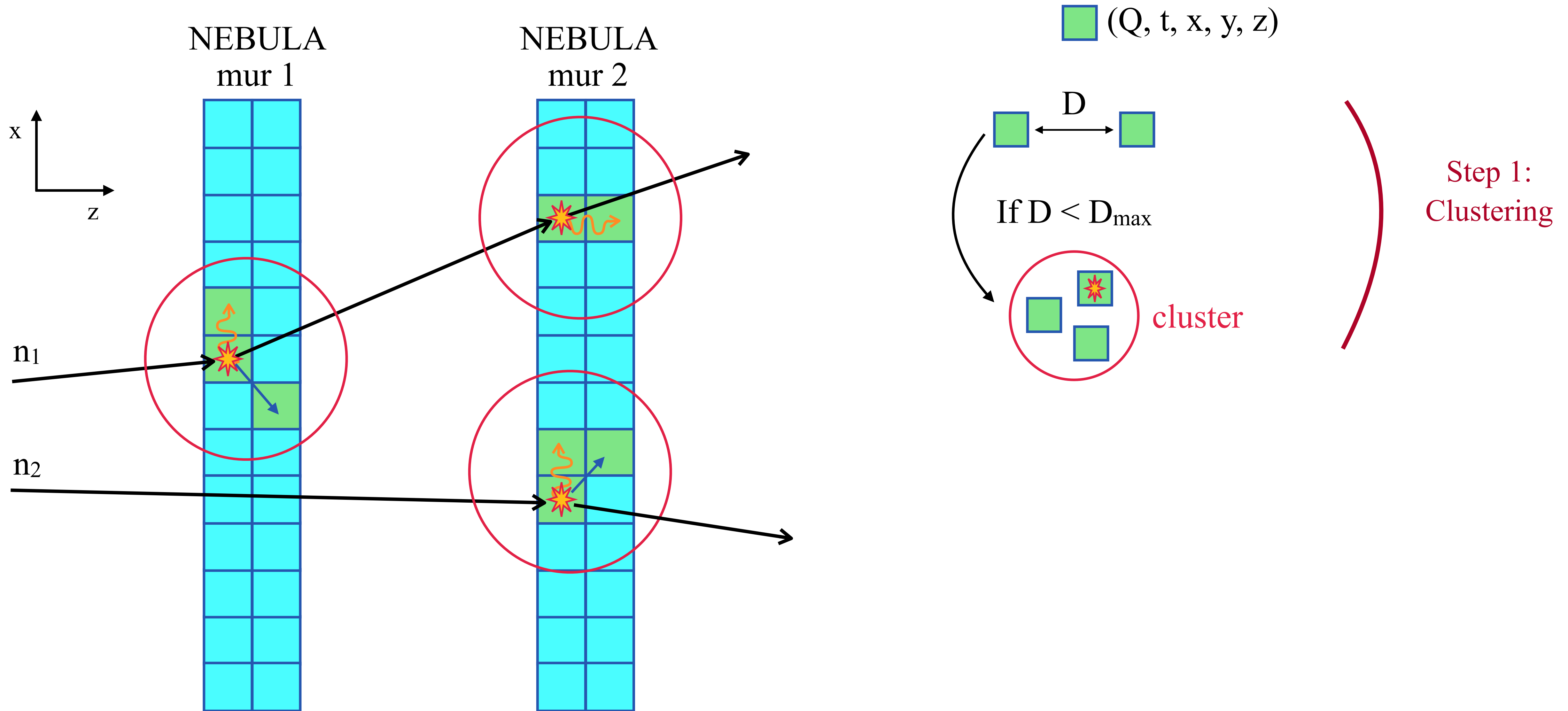
- (E_R, Γ) in agreement with literature
- Validated analyses & response function



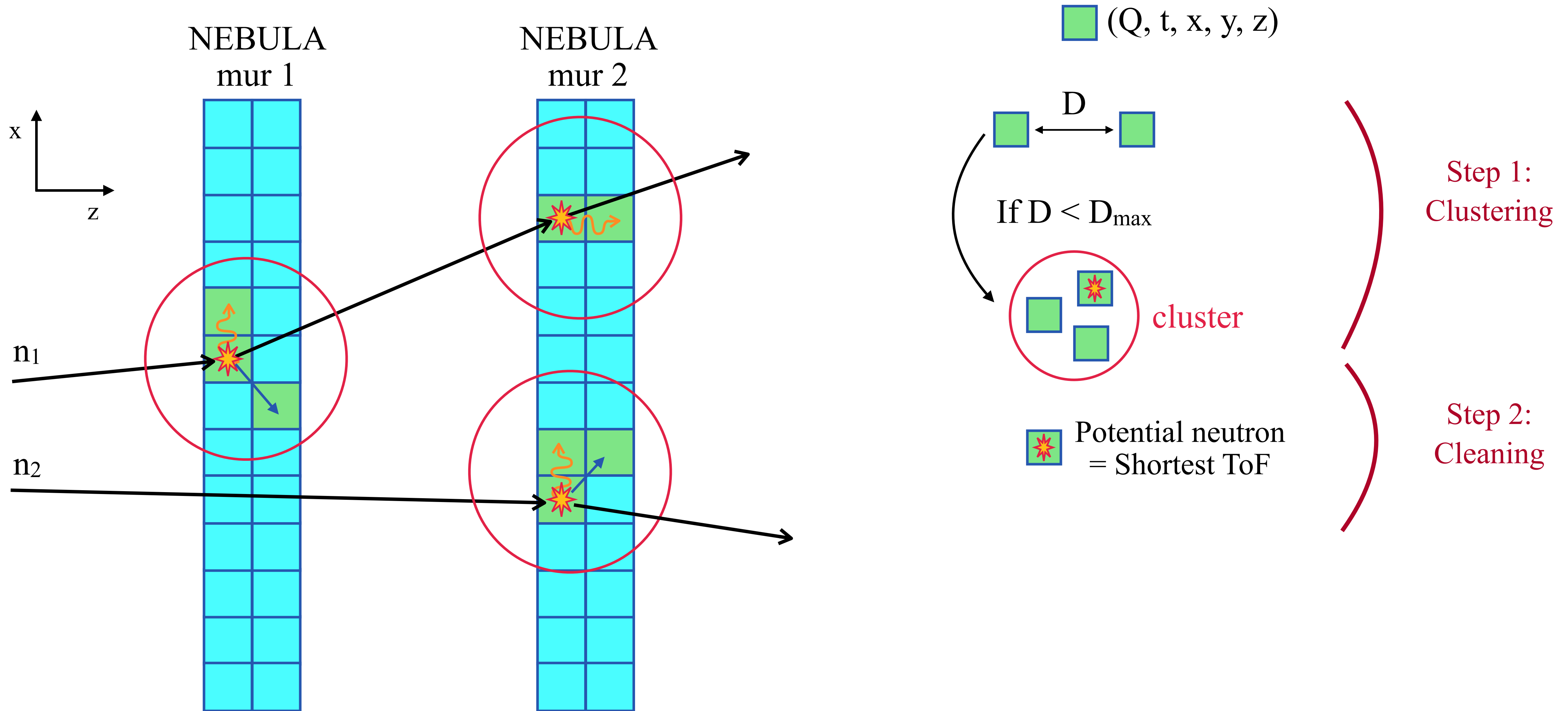
Absence of ${}^6\text{He}+n$ excited state !



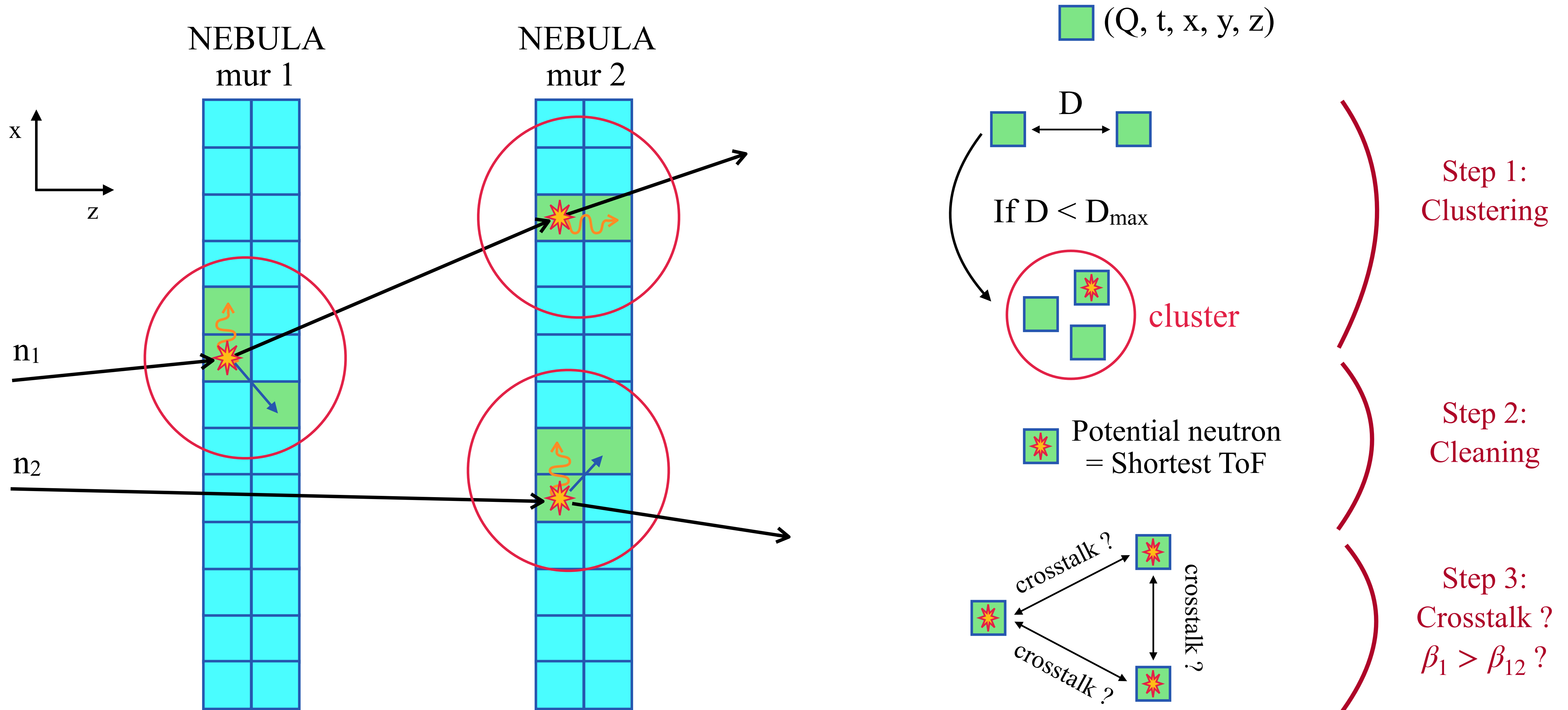
Samurai 034: Multineutron, crosstalk rejection

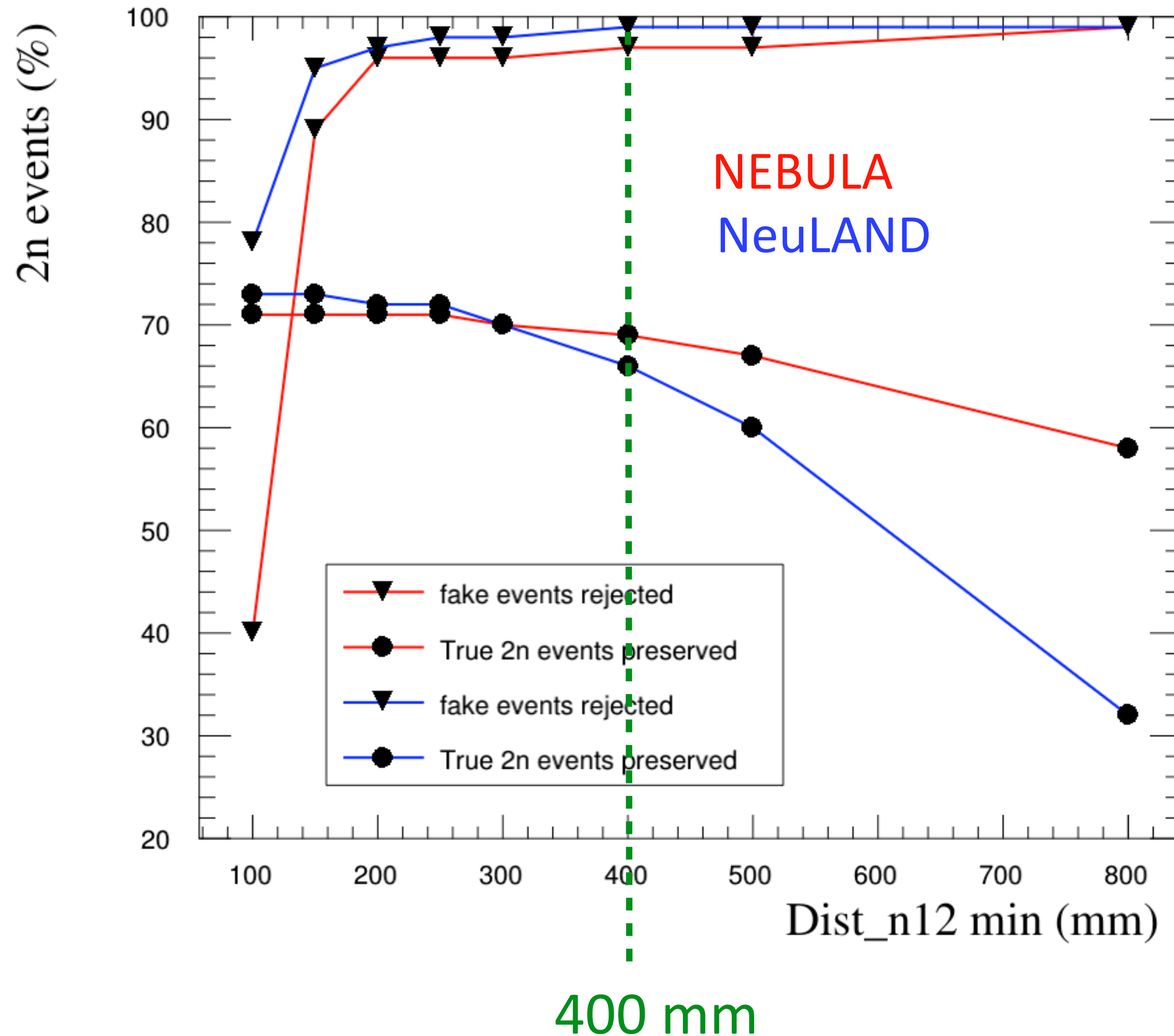


Samurai 034: Multineutron, crosstalk rejection



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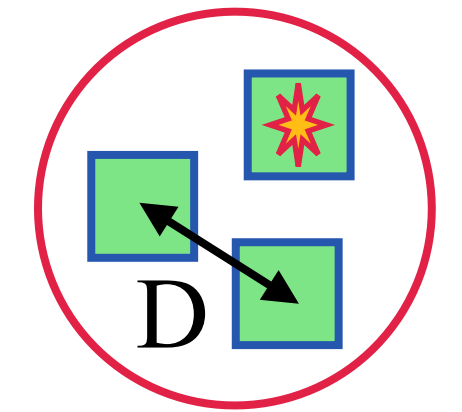




Optimization

Step 1: Clustering

$$D_{\max} = 400 \text{ mm}$$



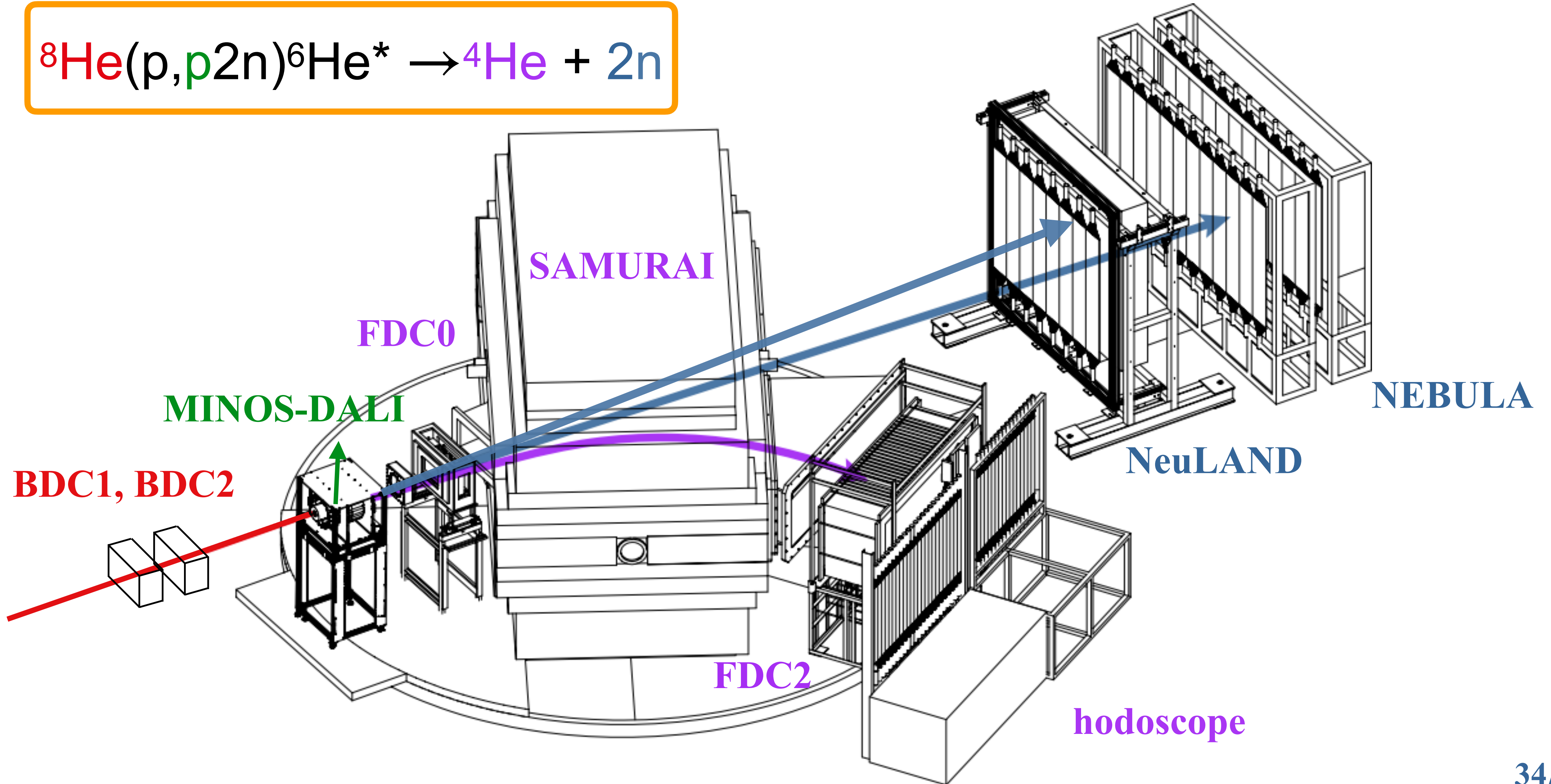
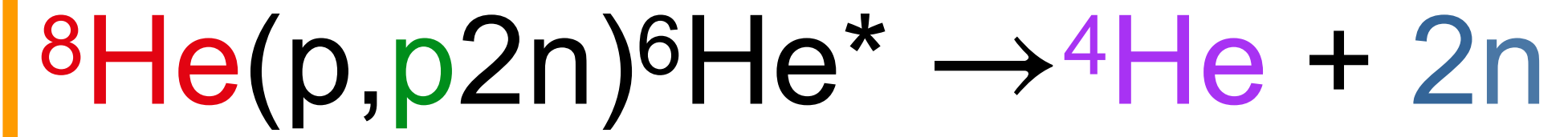
Step 2: Cleaning

Step 3: Crosstalk test $\beta_1 > \beta_{12}?$

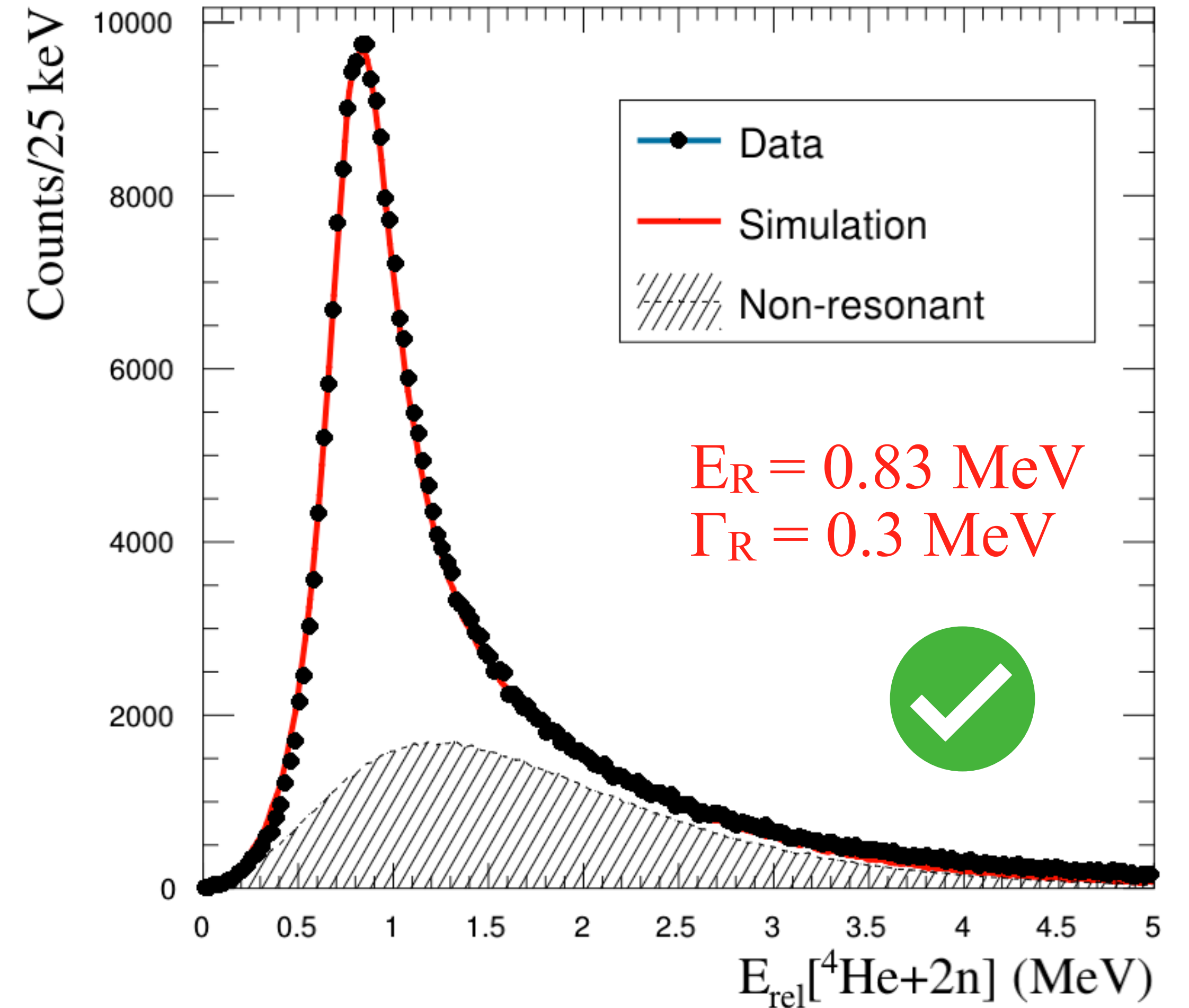
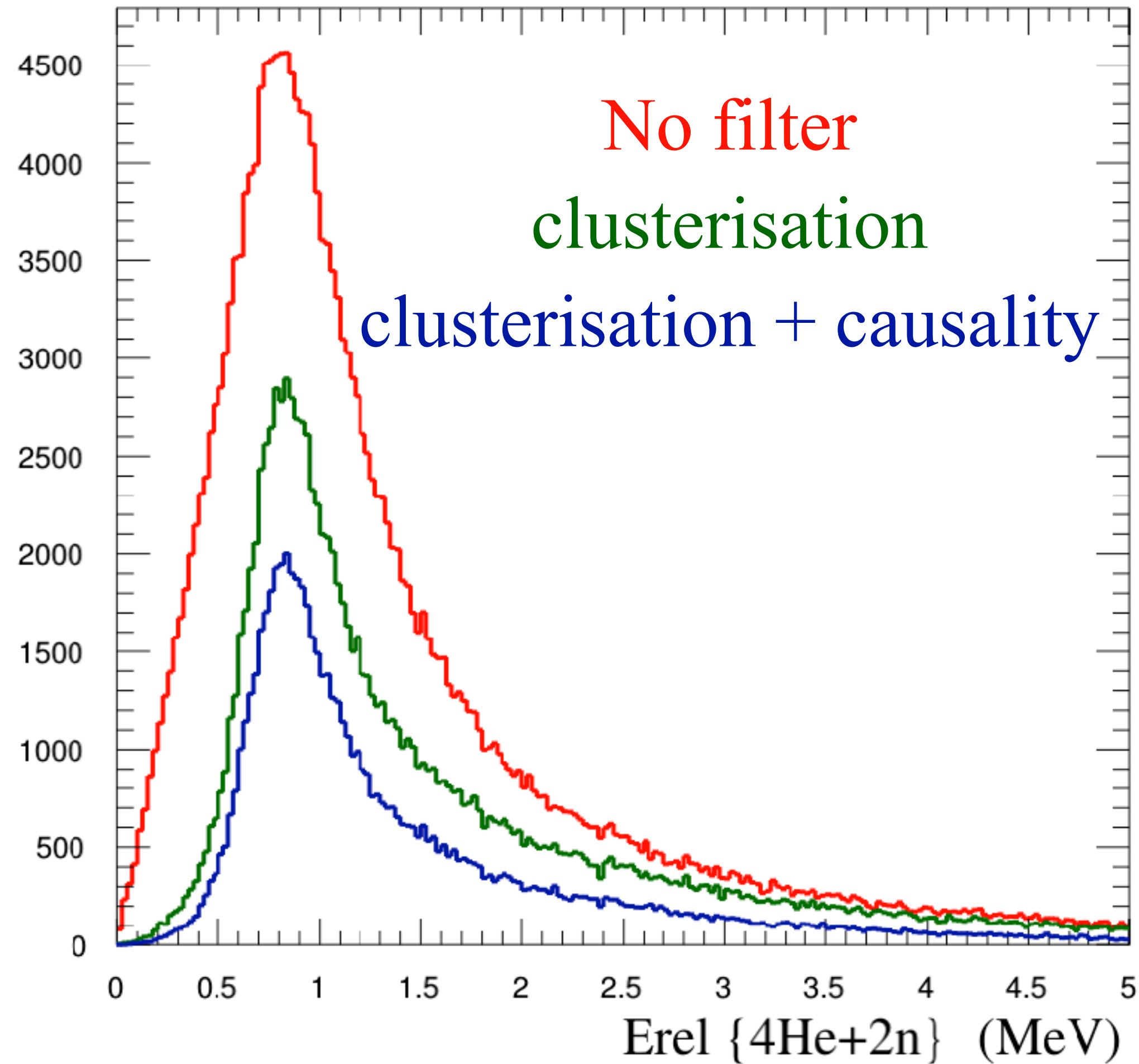


Fake events rejected: 98%
True 2n events rejected: 34%

Samurai 034: ${}^6\text{He}^*(2^+)$, benchmark '2n'

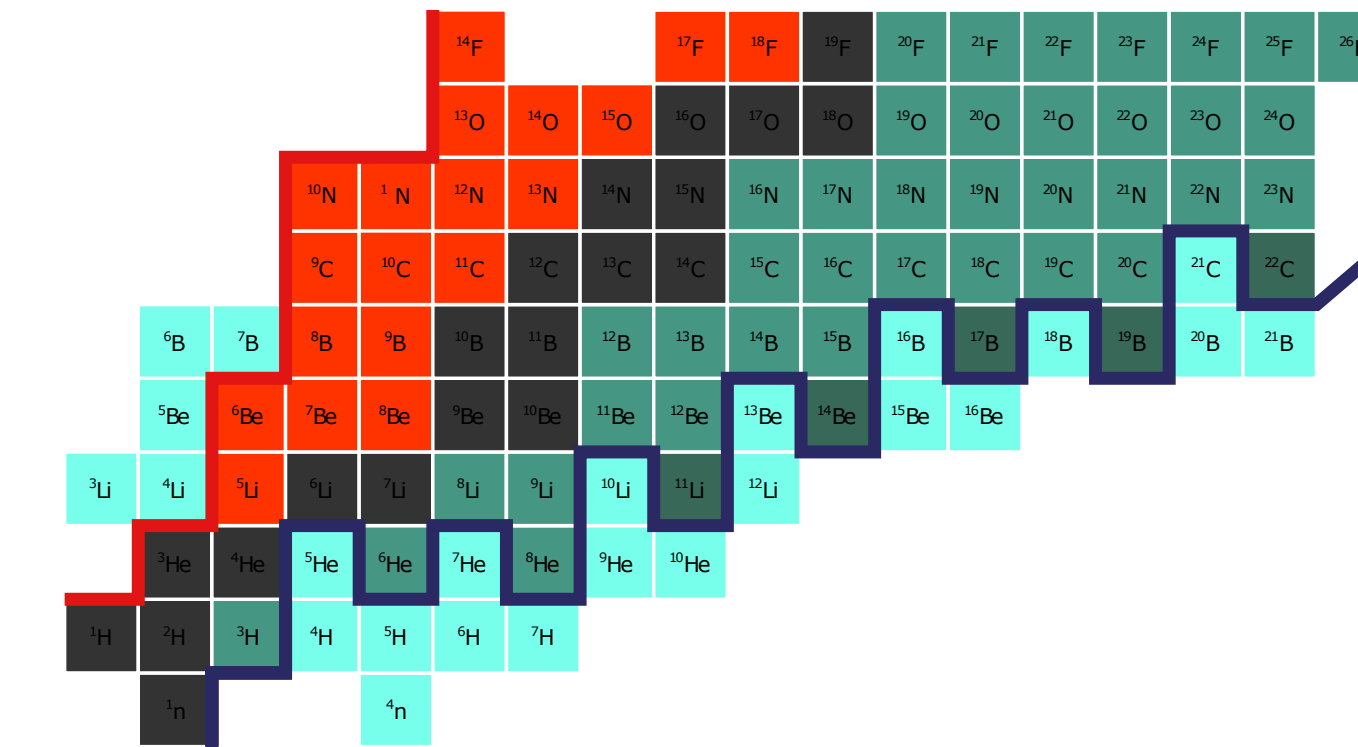
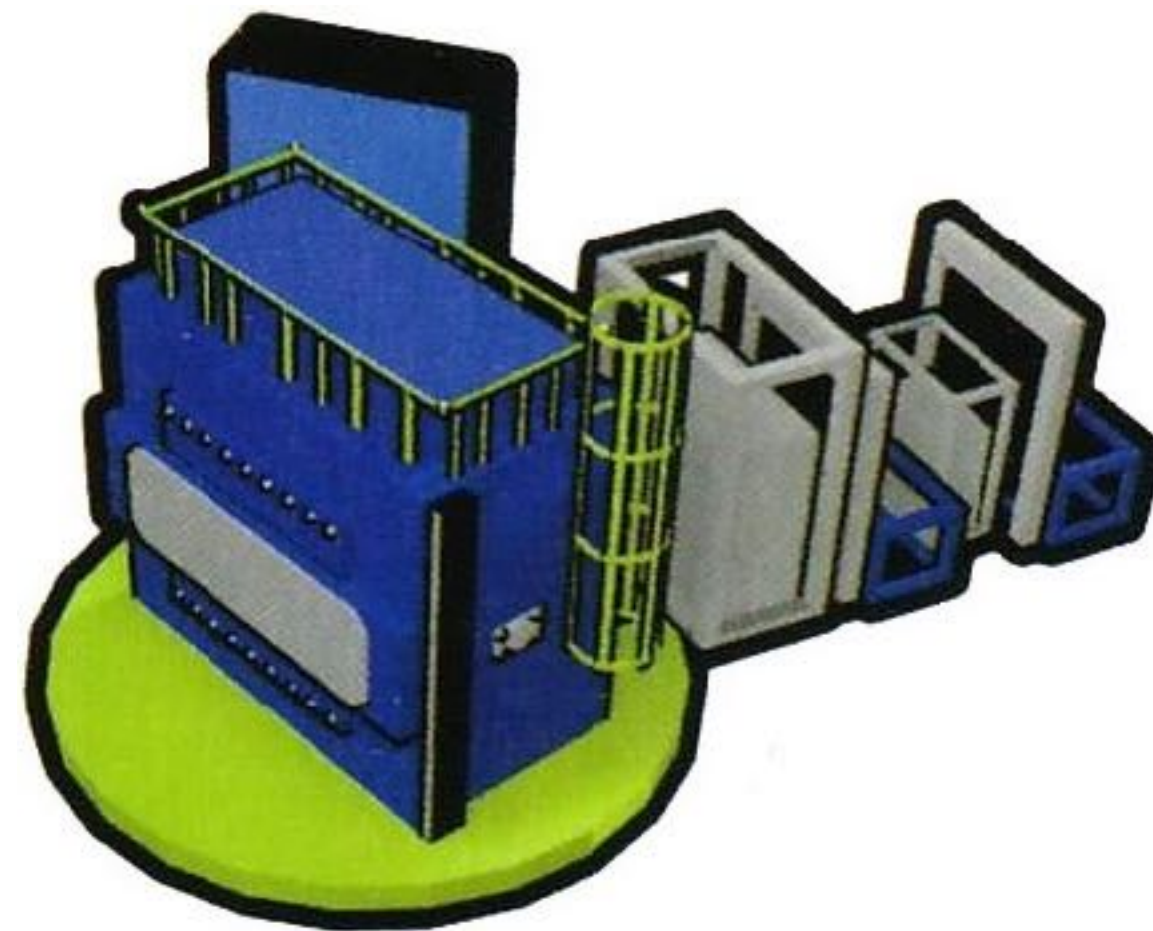


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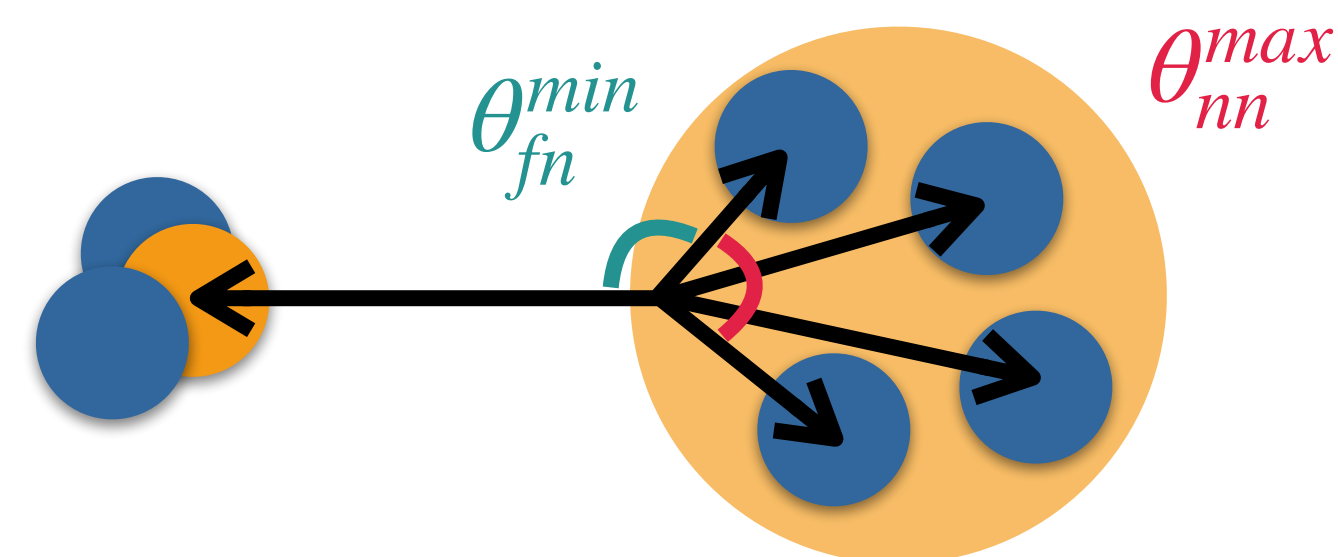


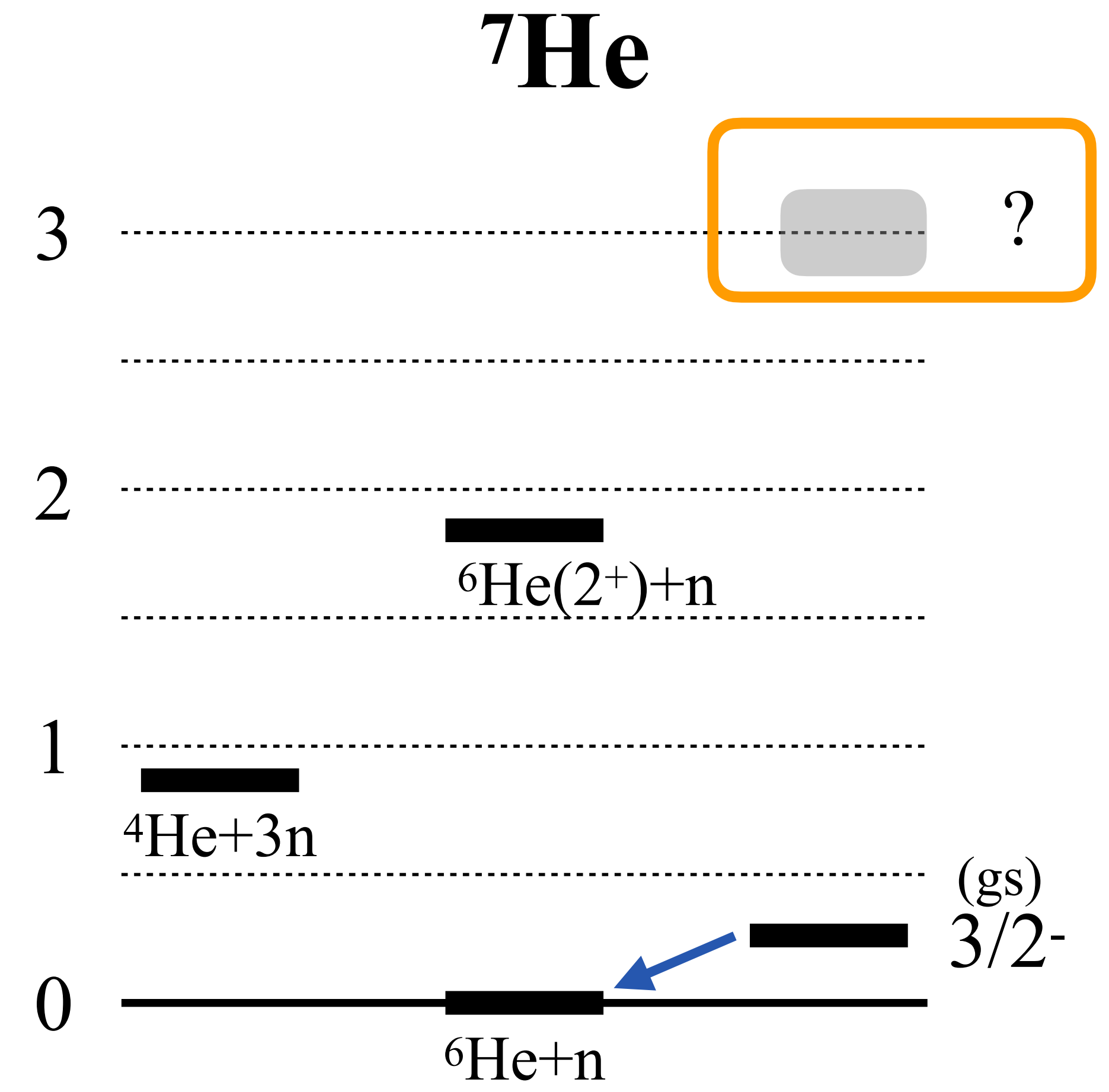
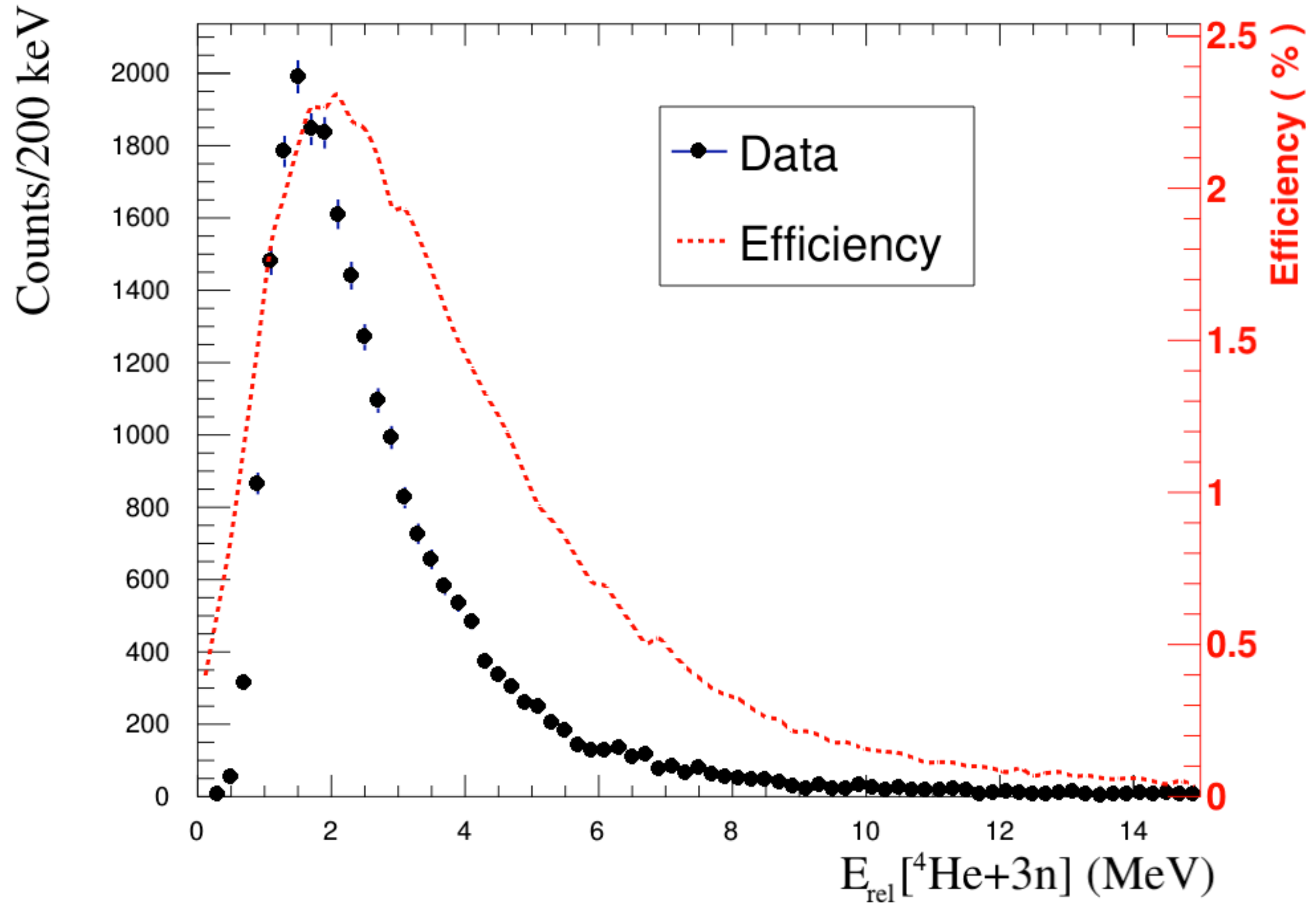
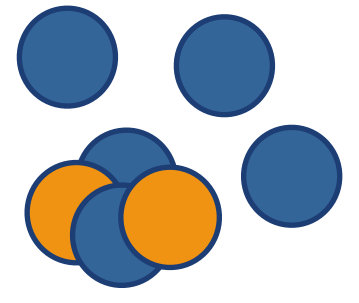
2. Samurai 34

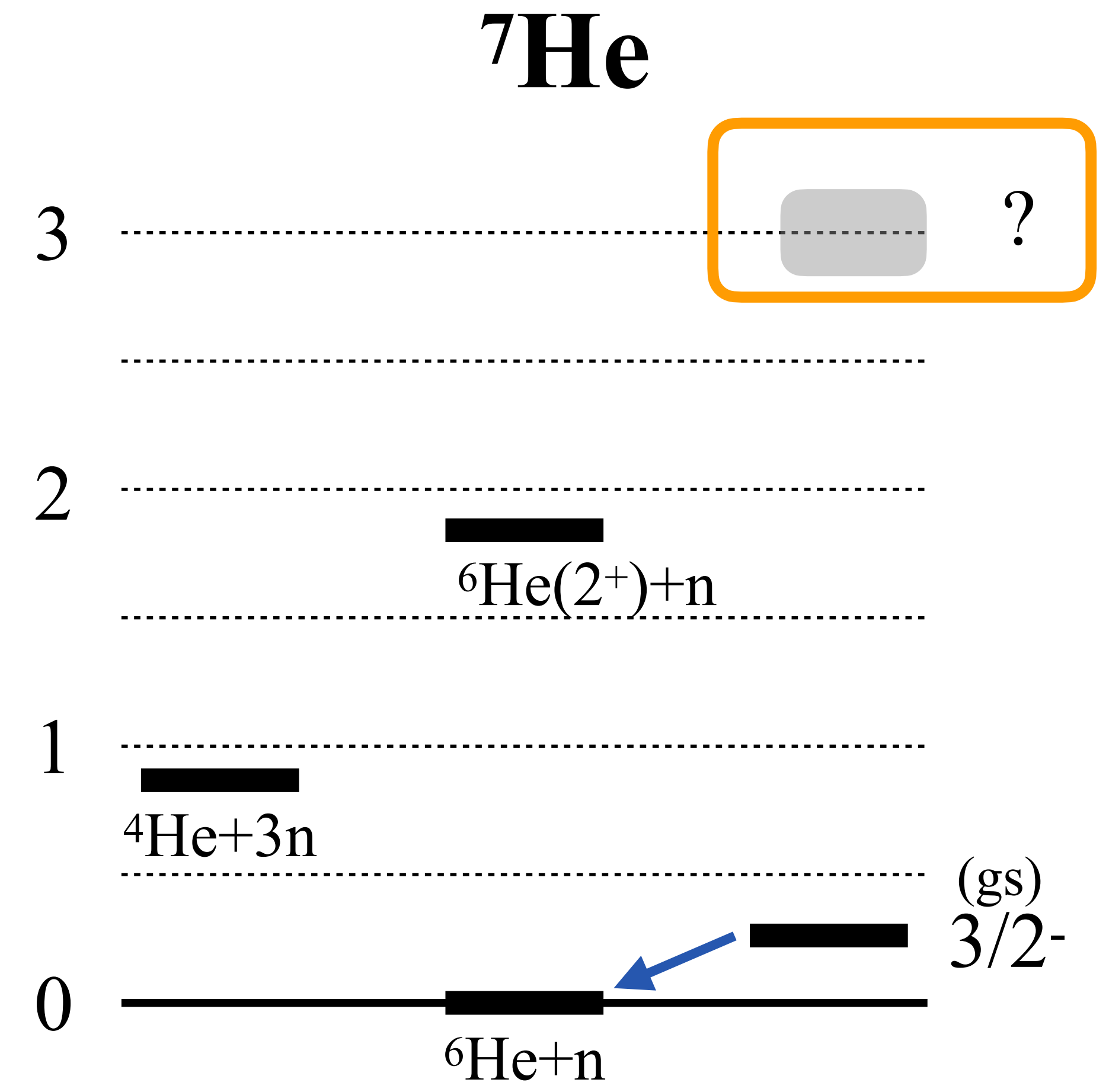
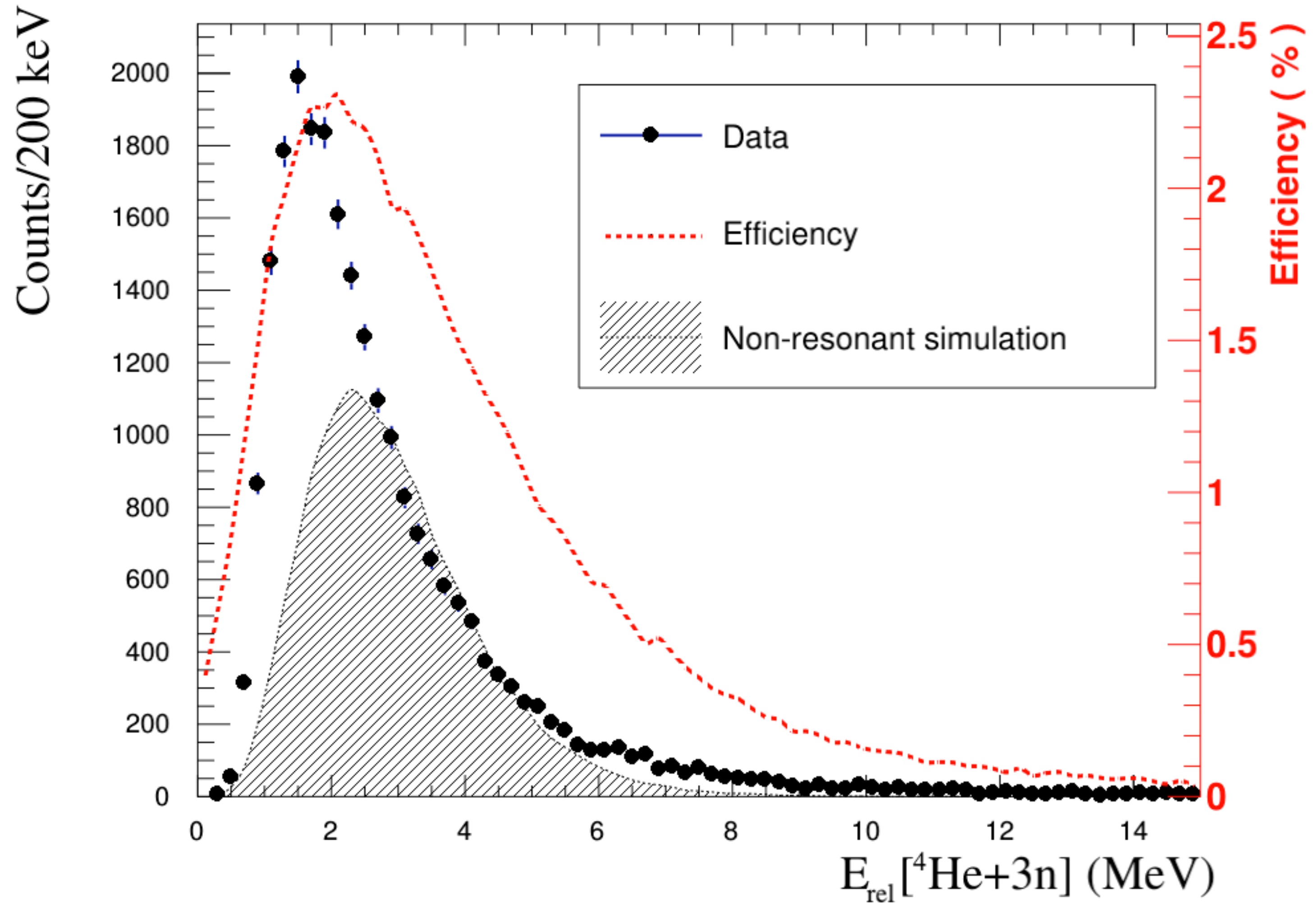
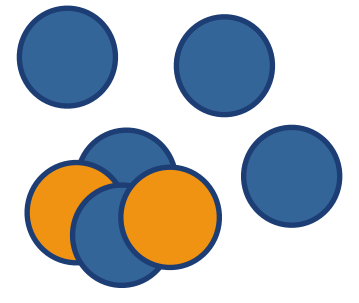
Experimental Approach
Multineutron detection

3. First results

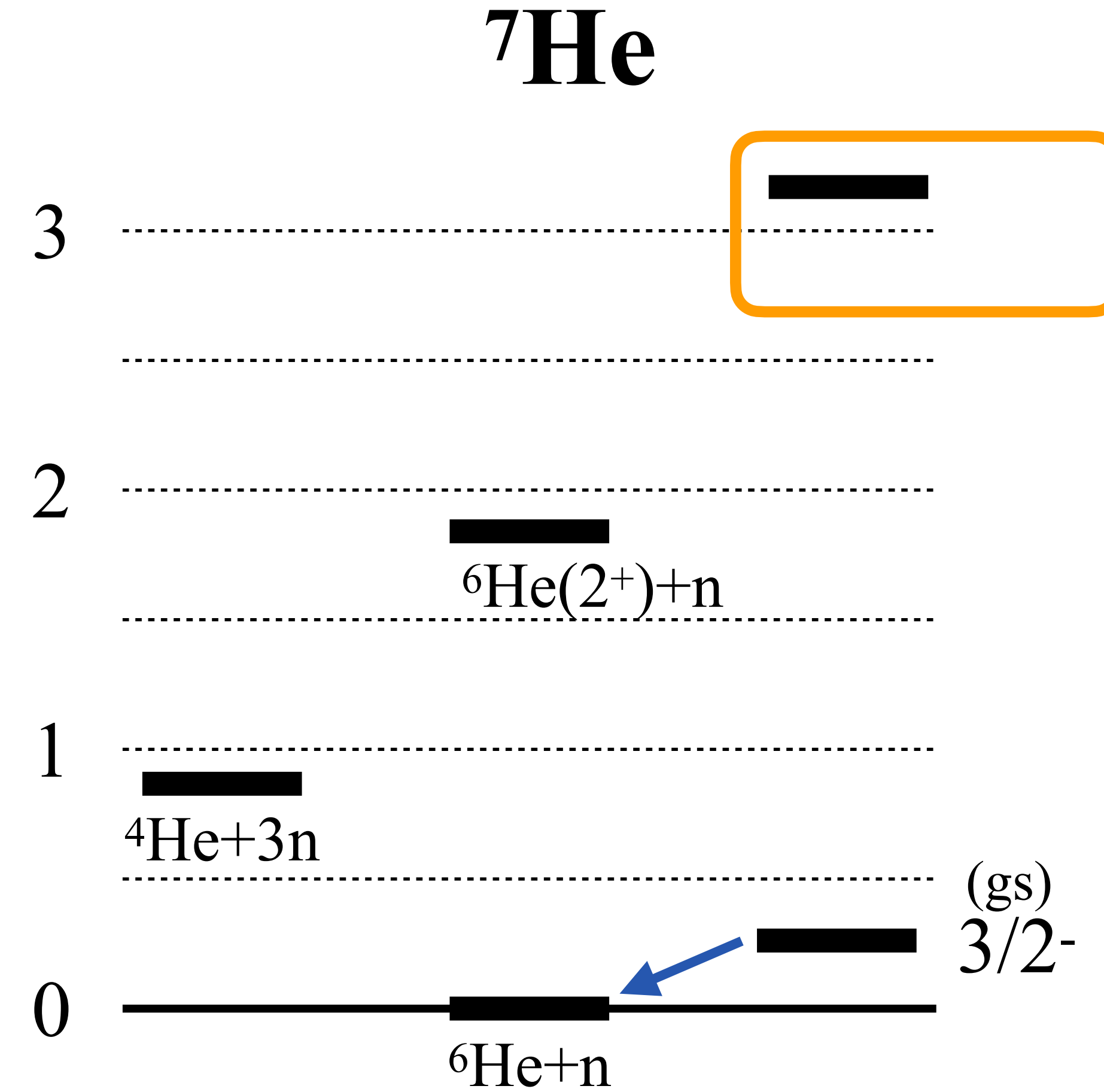
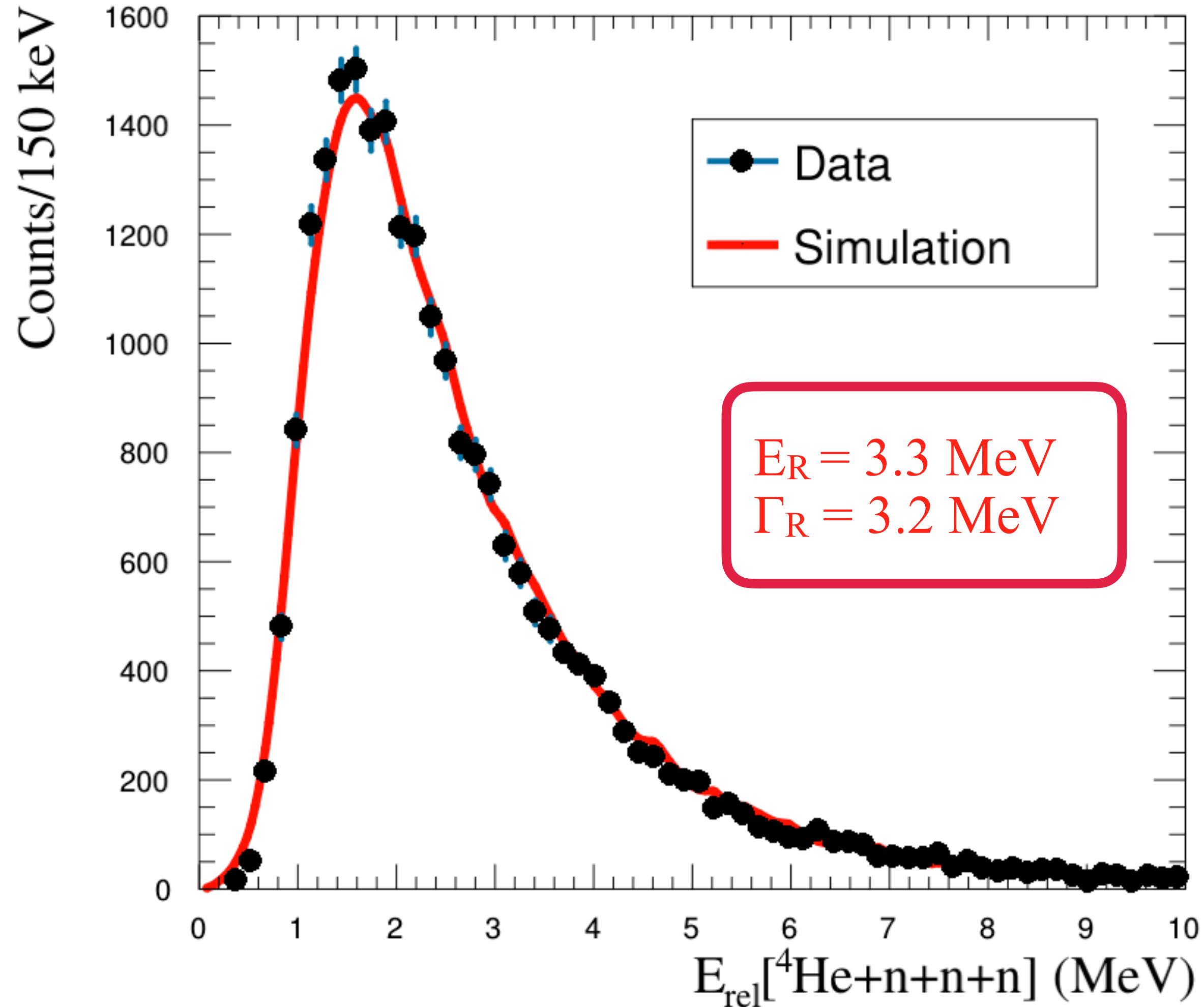
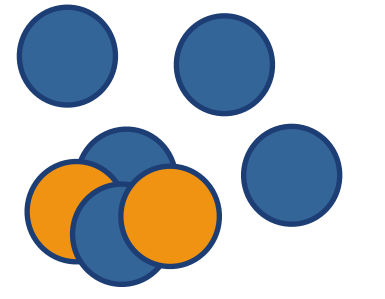
Helium-7 & 3n decay
Hydrogen-7 & 4n decay



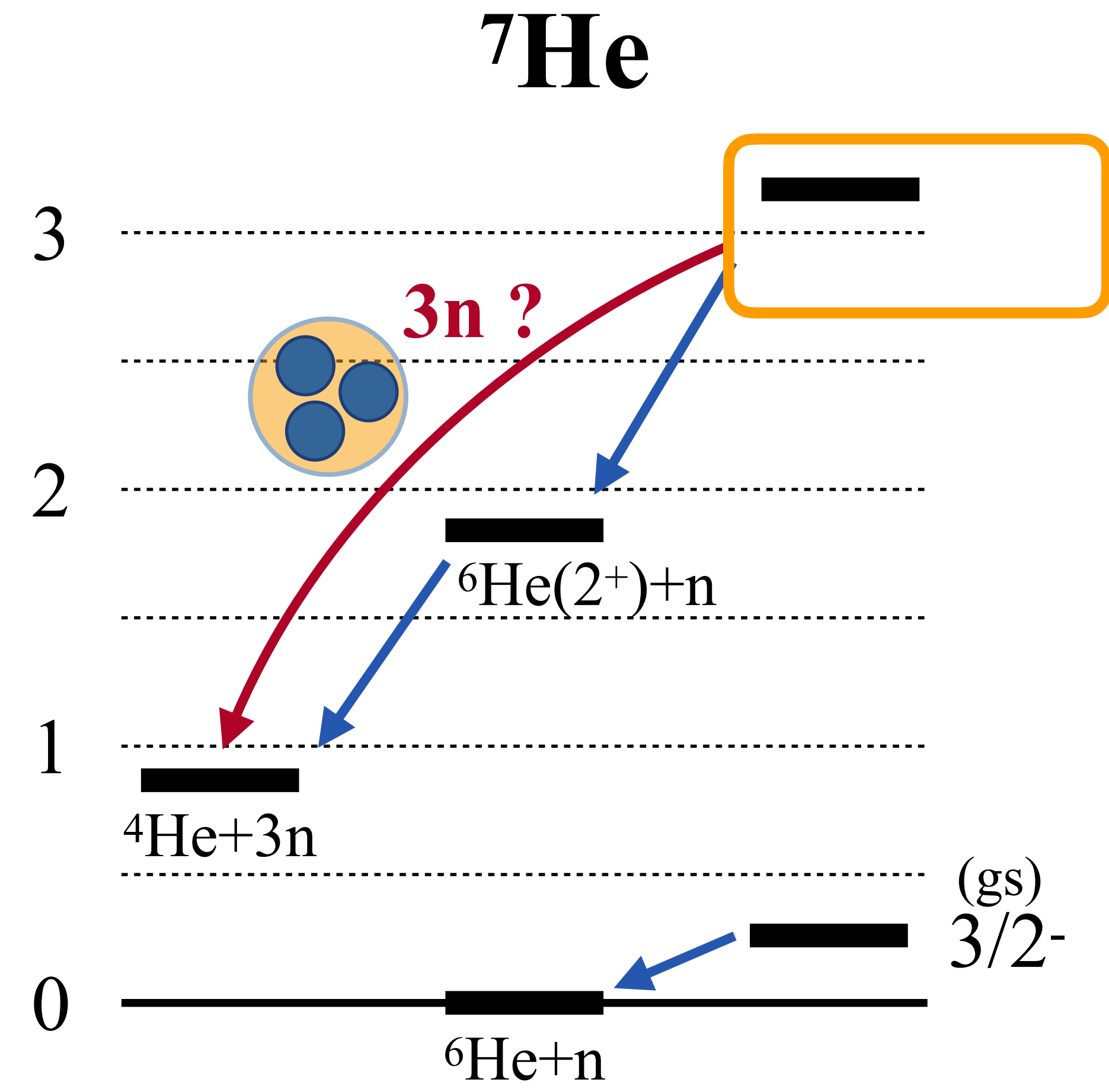
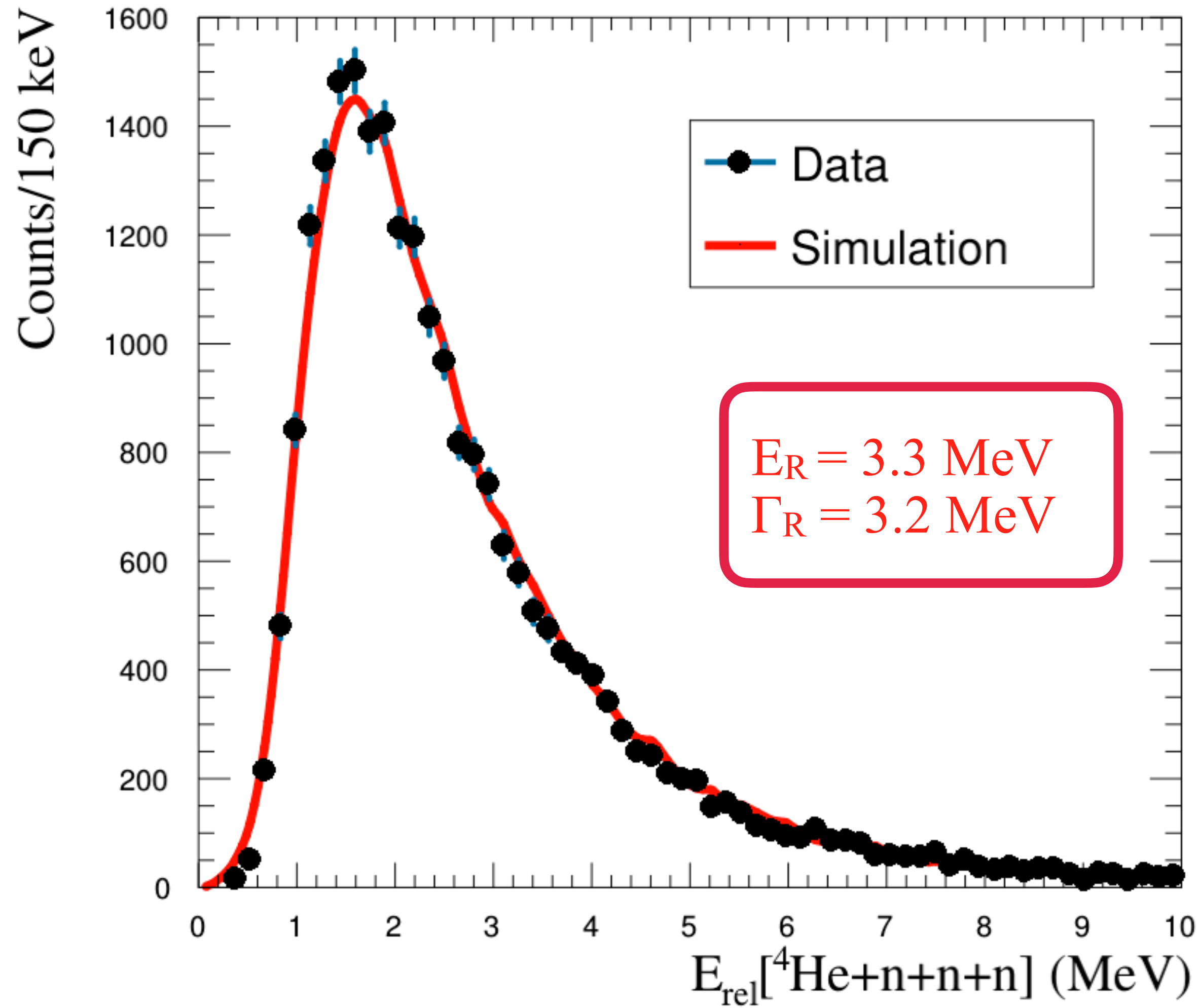
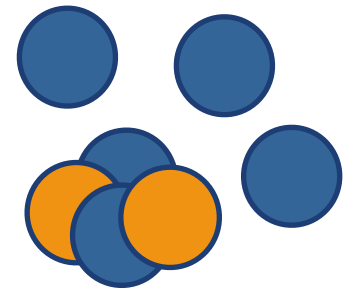




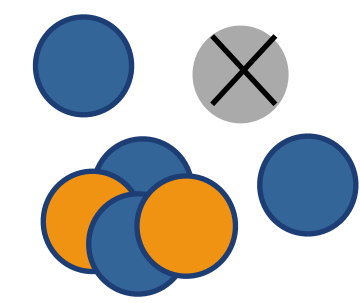
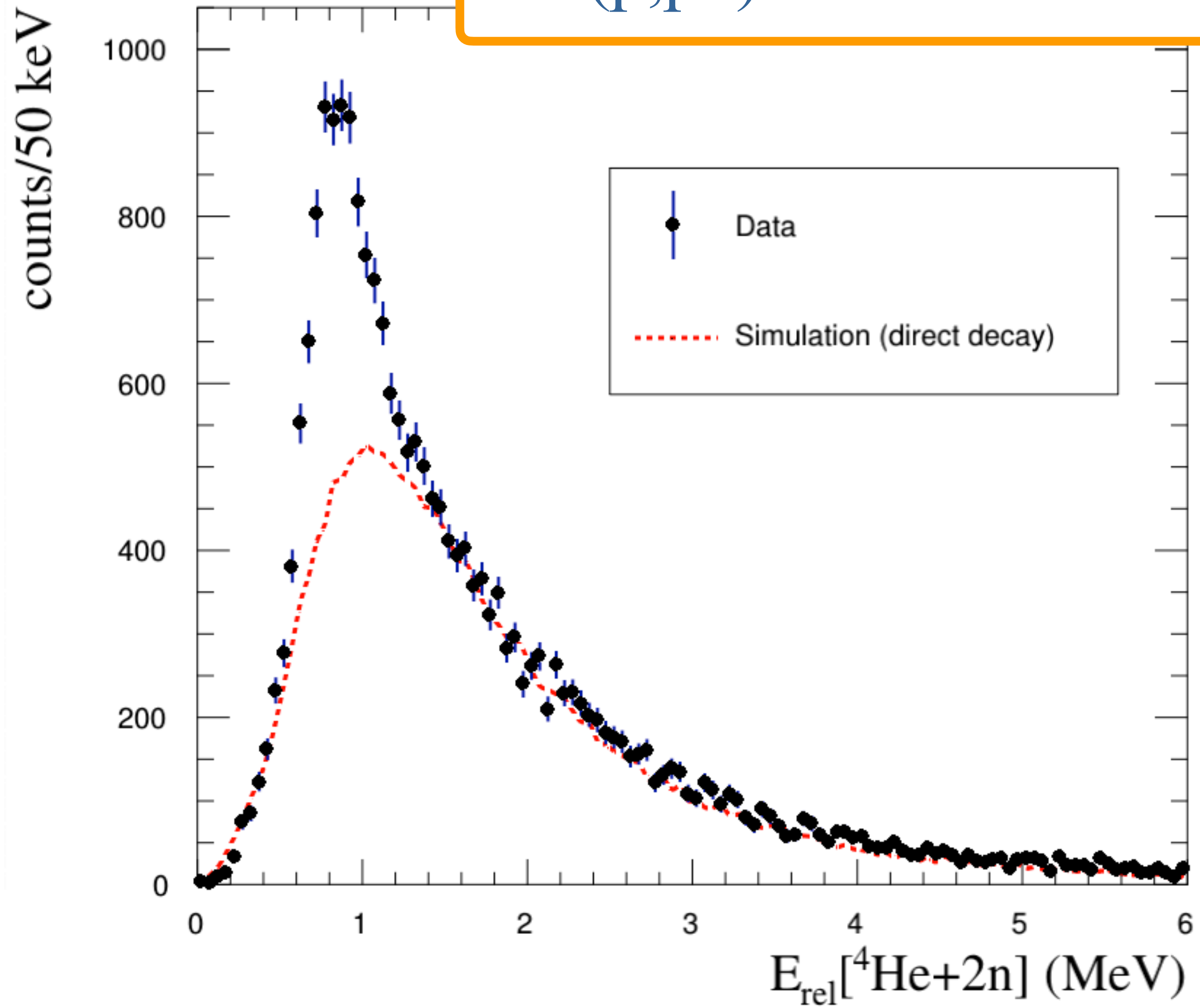
Results : Helium-7



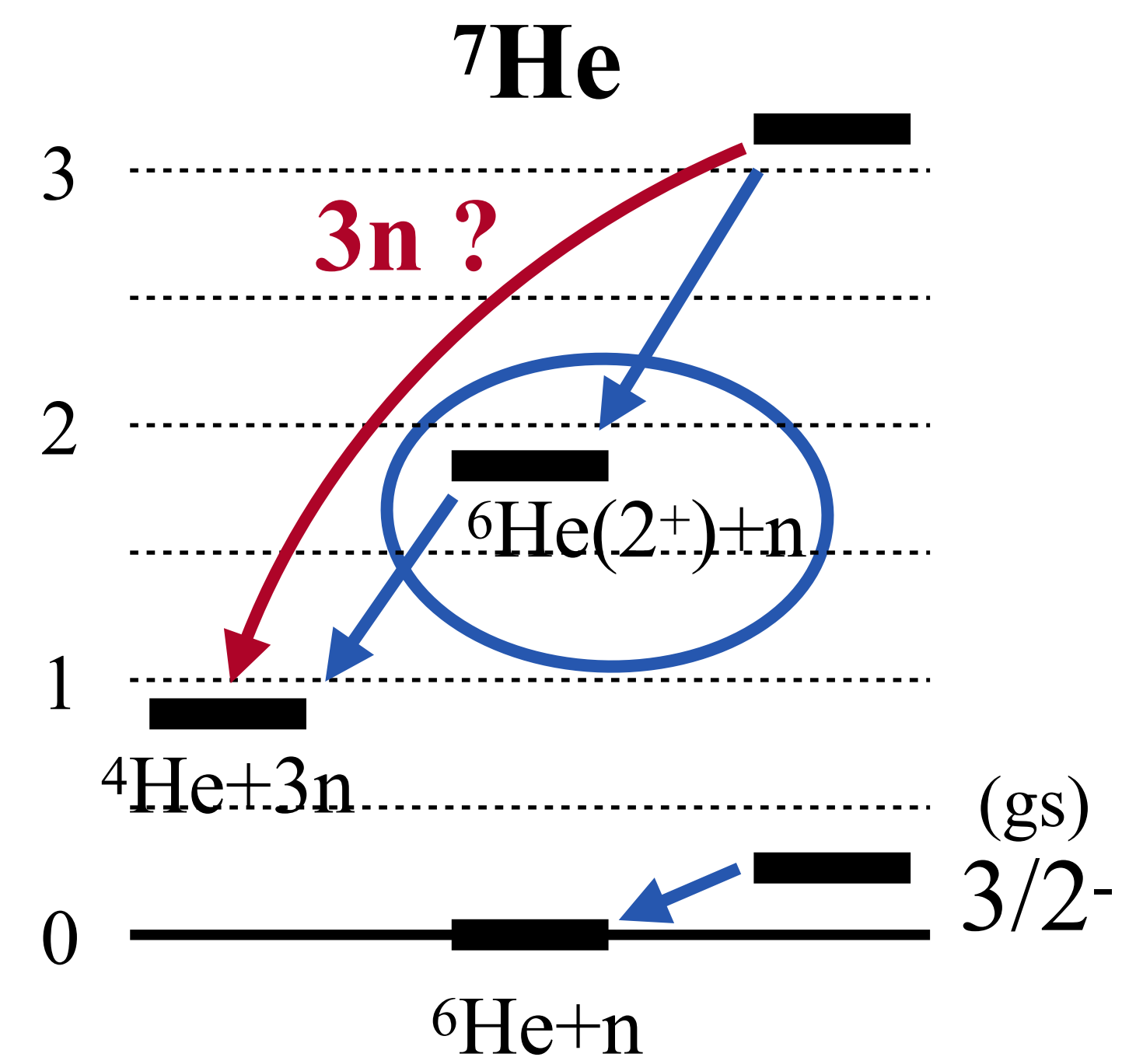
Results : Helium-7



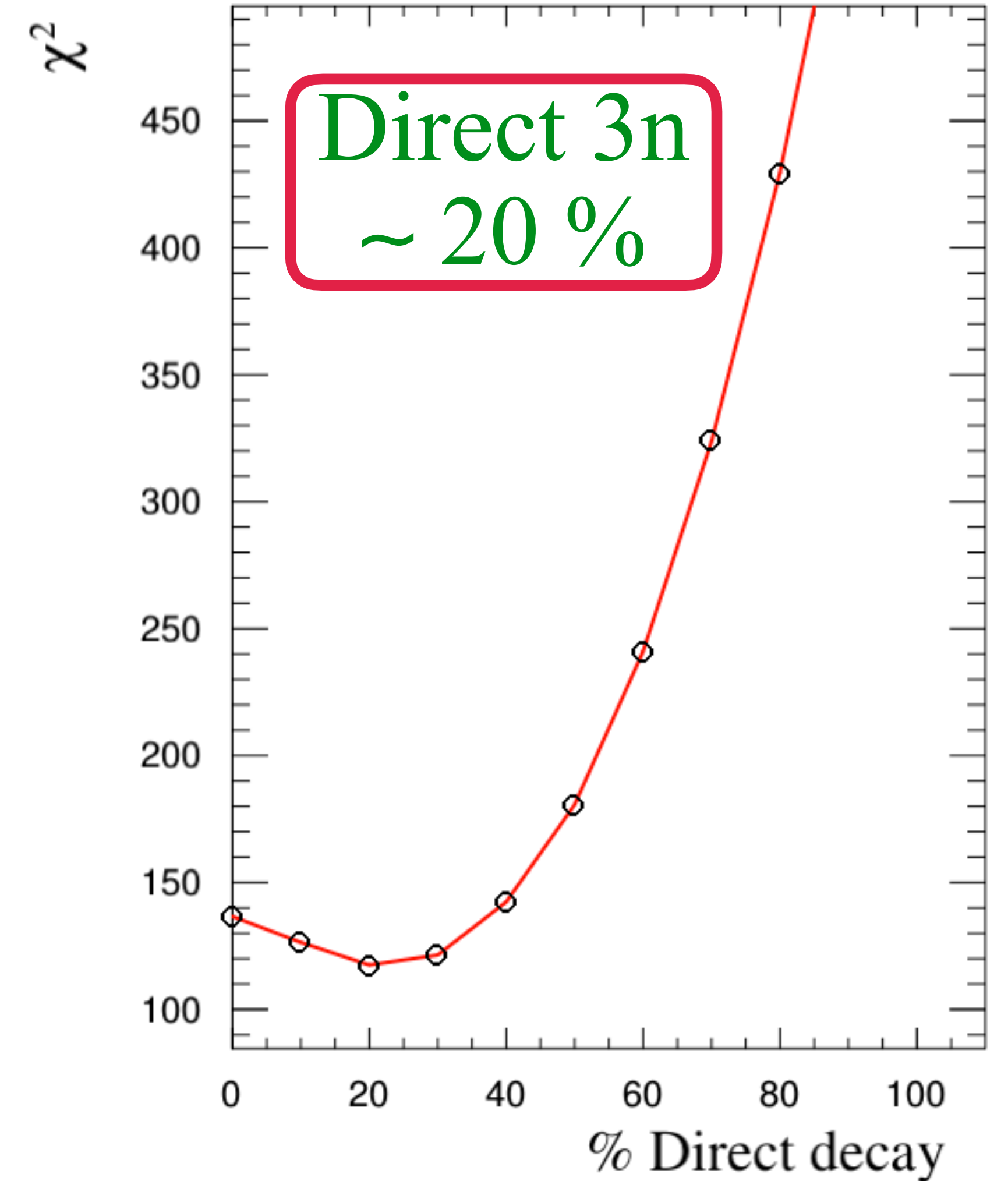
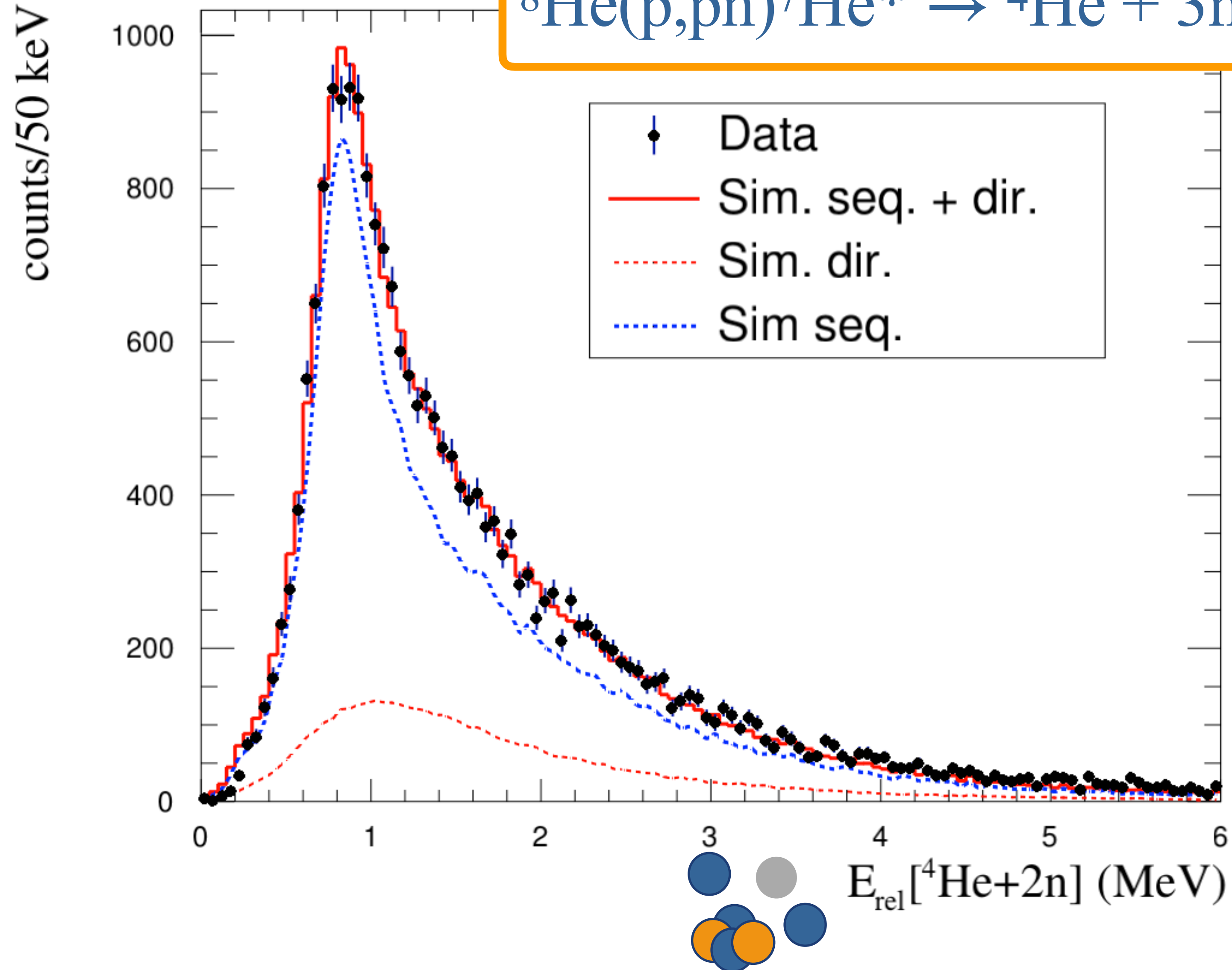
Results : Helium-7 decay



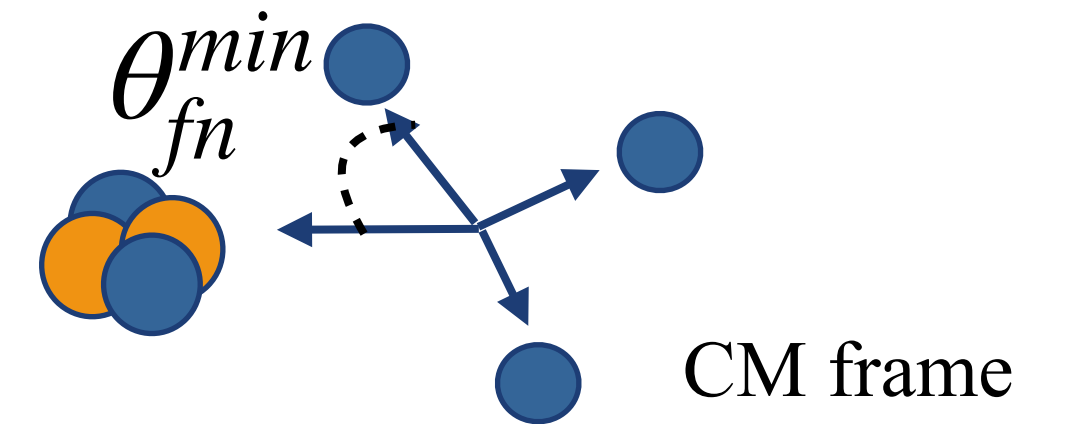
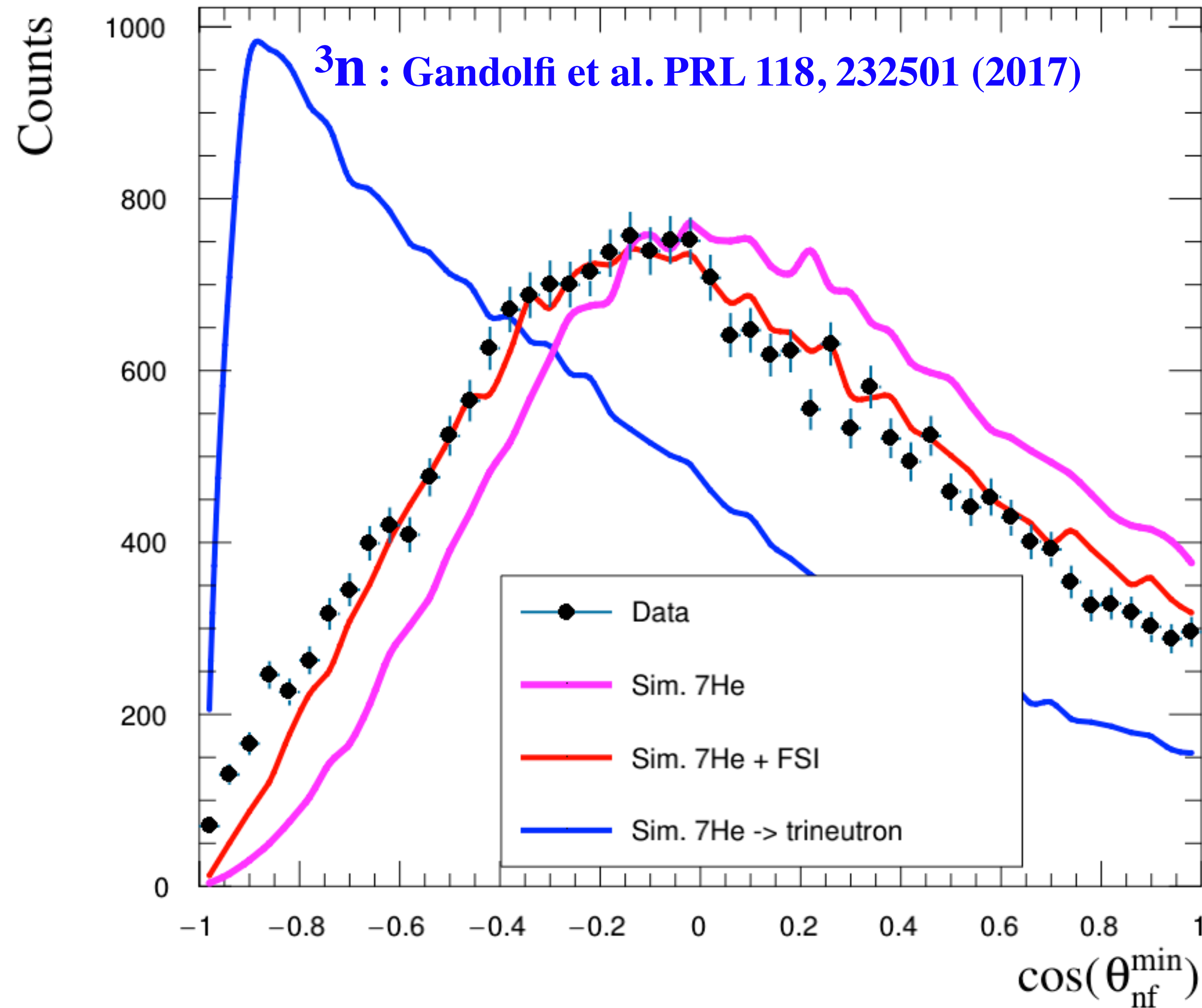
Direct decay does not reproduce data
 → 2 step decay



Results : Helium-7 decay

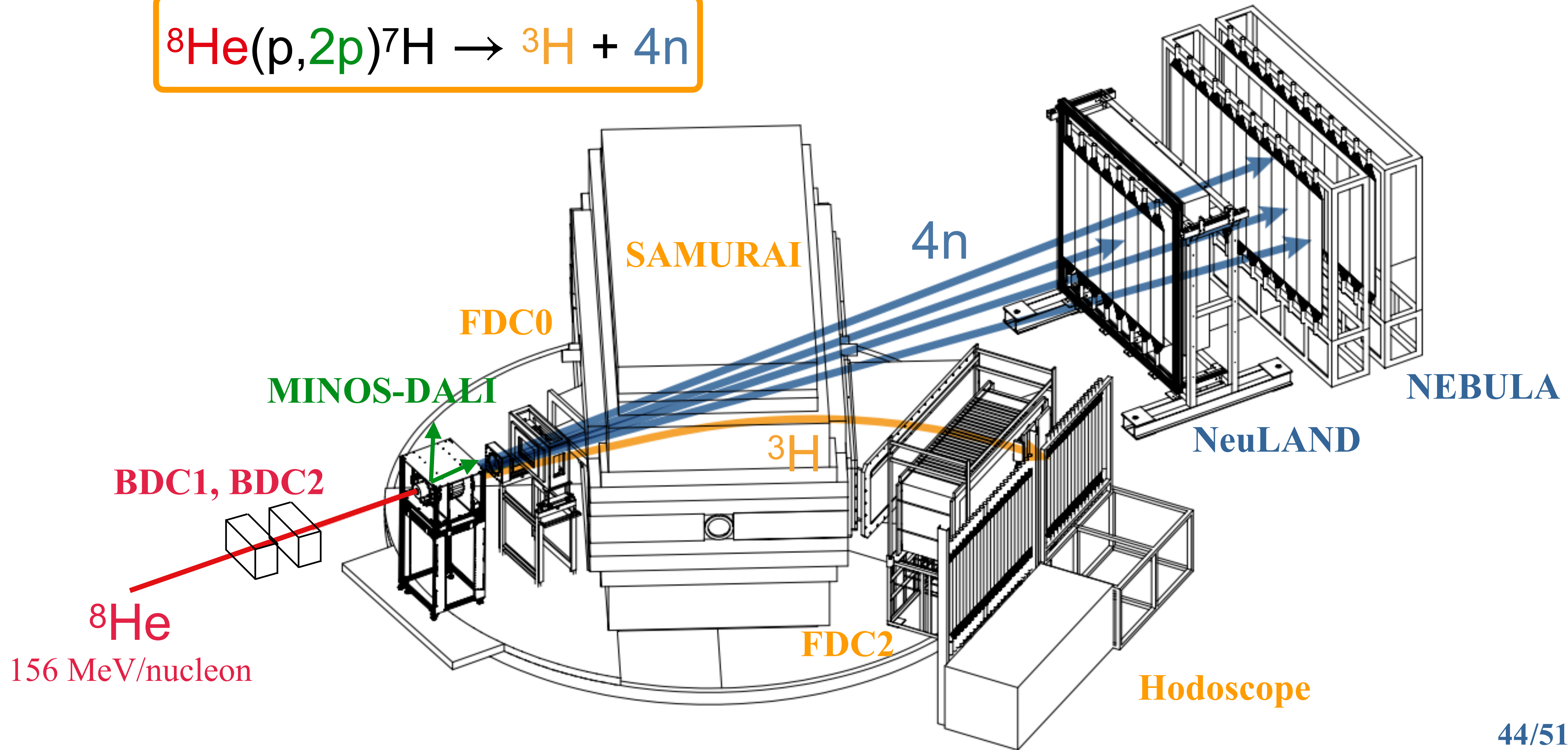
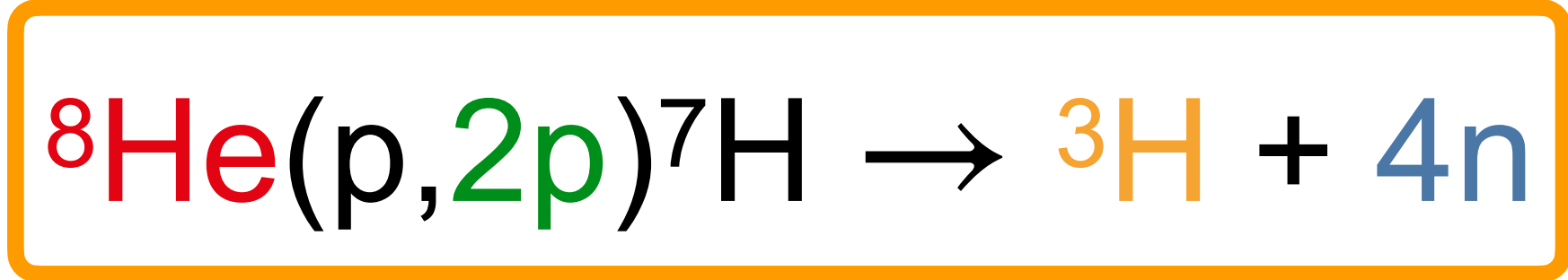


Results: Helium-7 decay, angular correlations

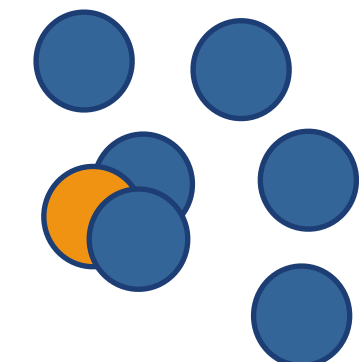
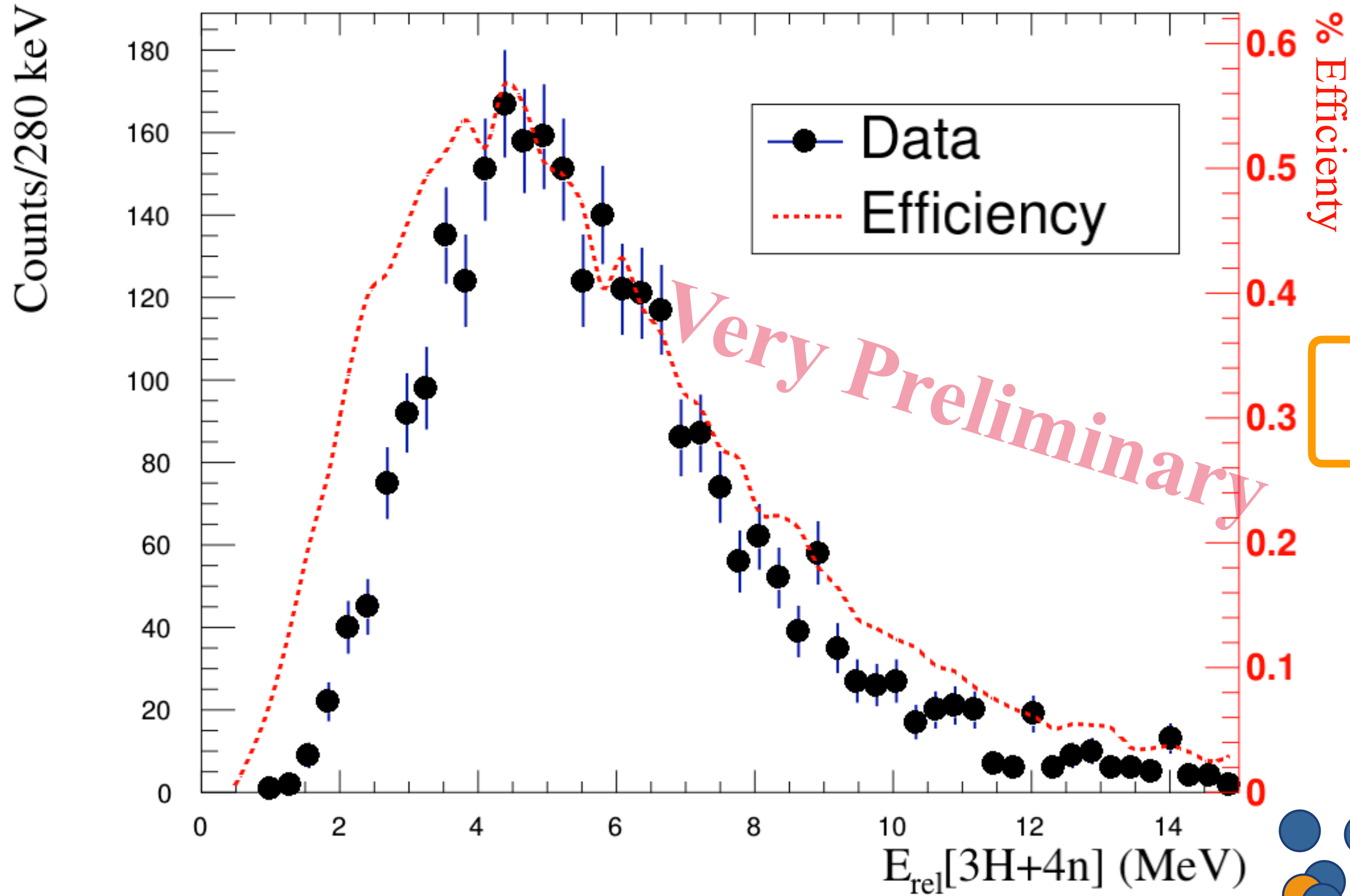


no trineutron signal in 3n emission

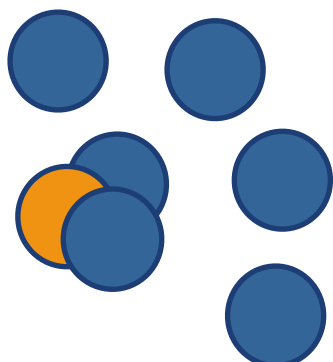
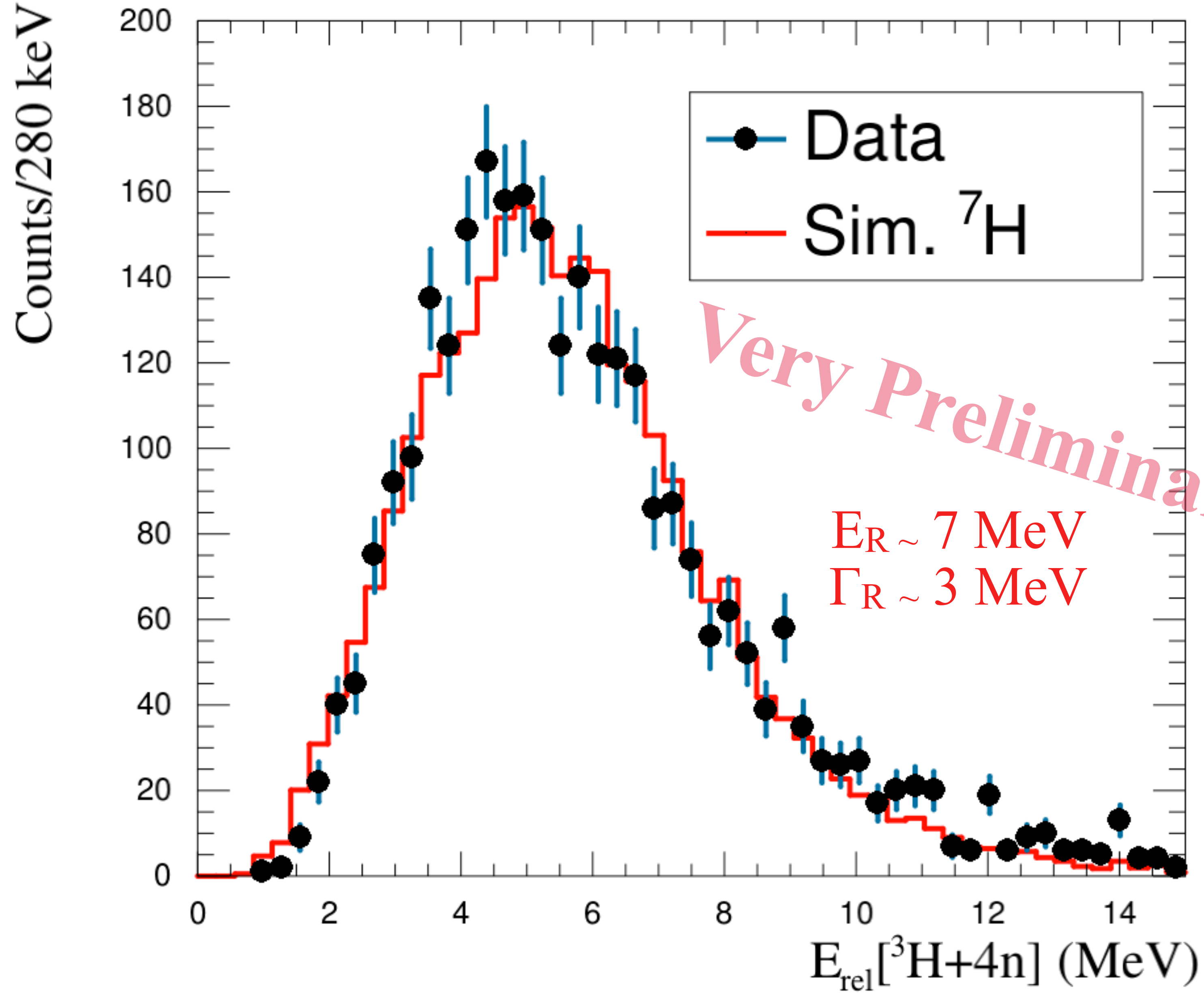
Results: Hydrogen-7

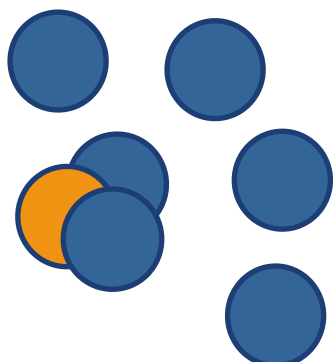
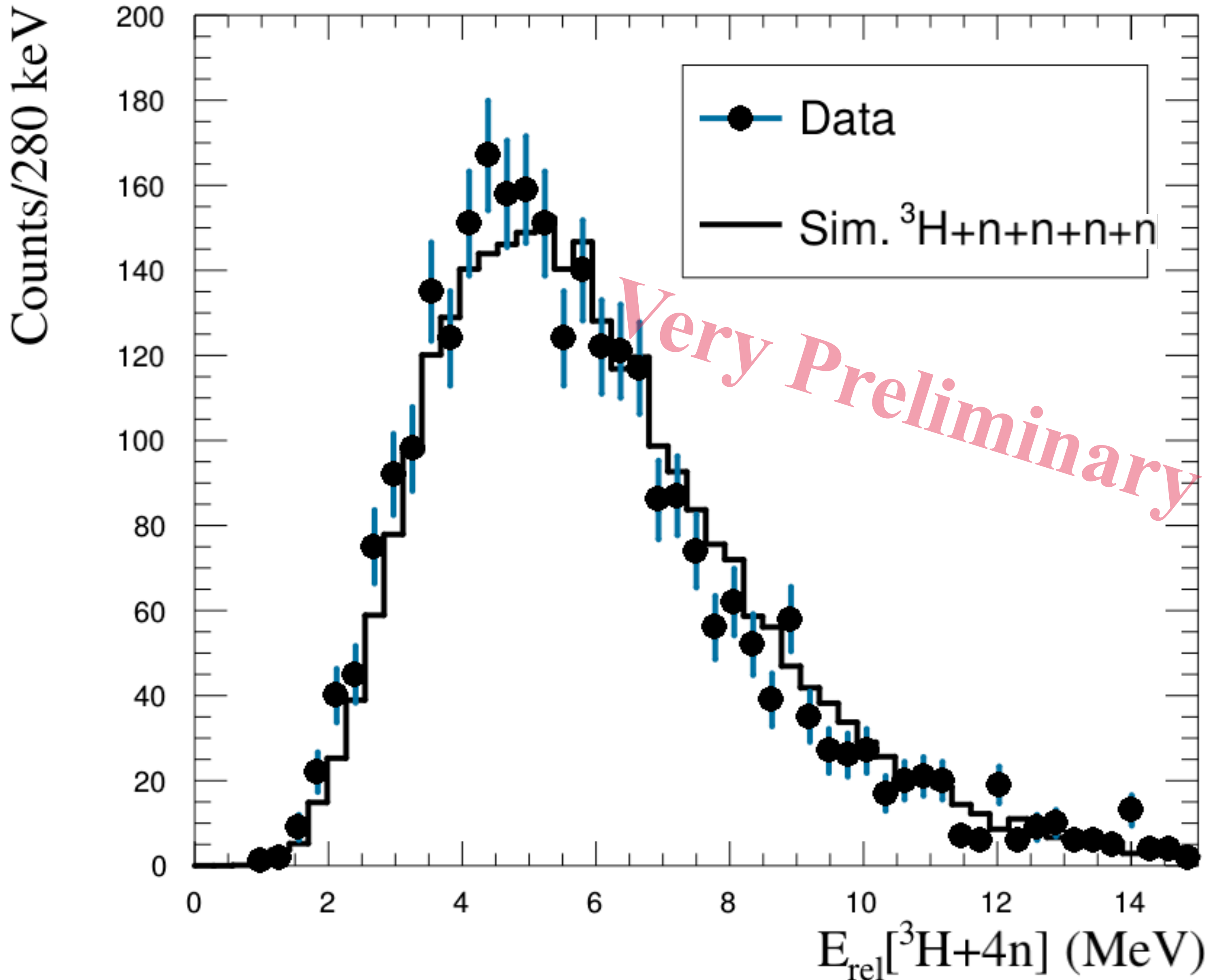


Results: Hydrogen-7

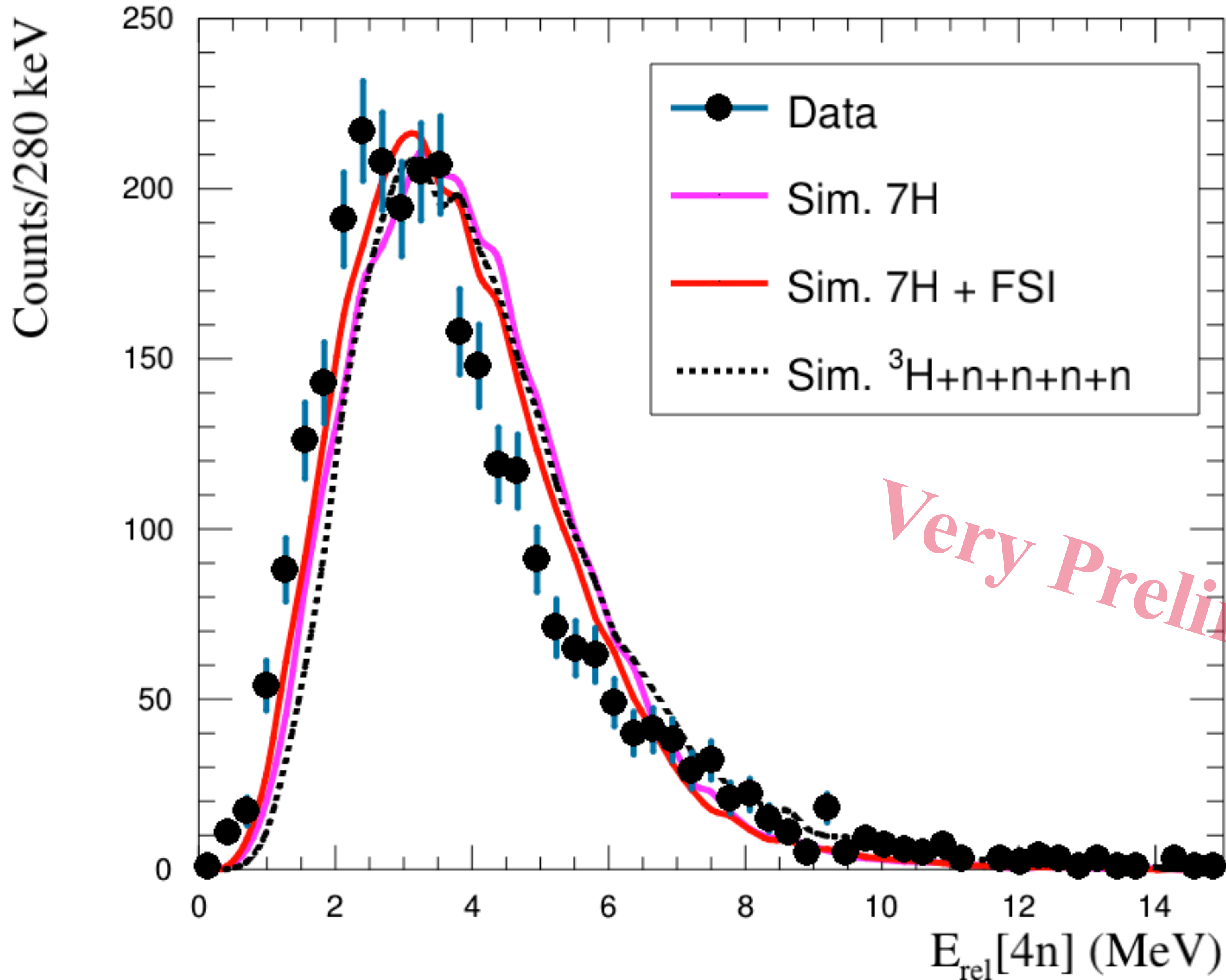


Results: Hydrogen-7



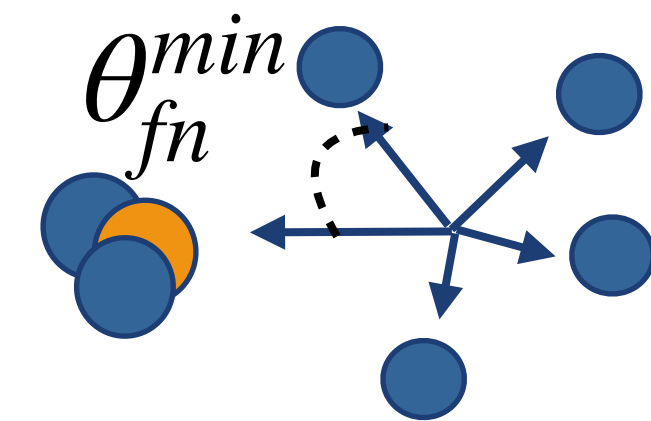
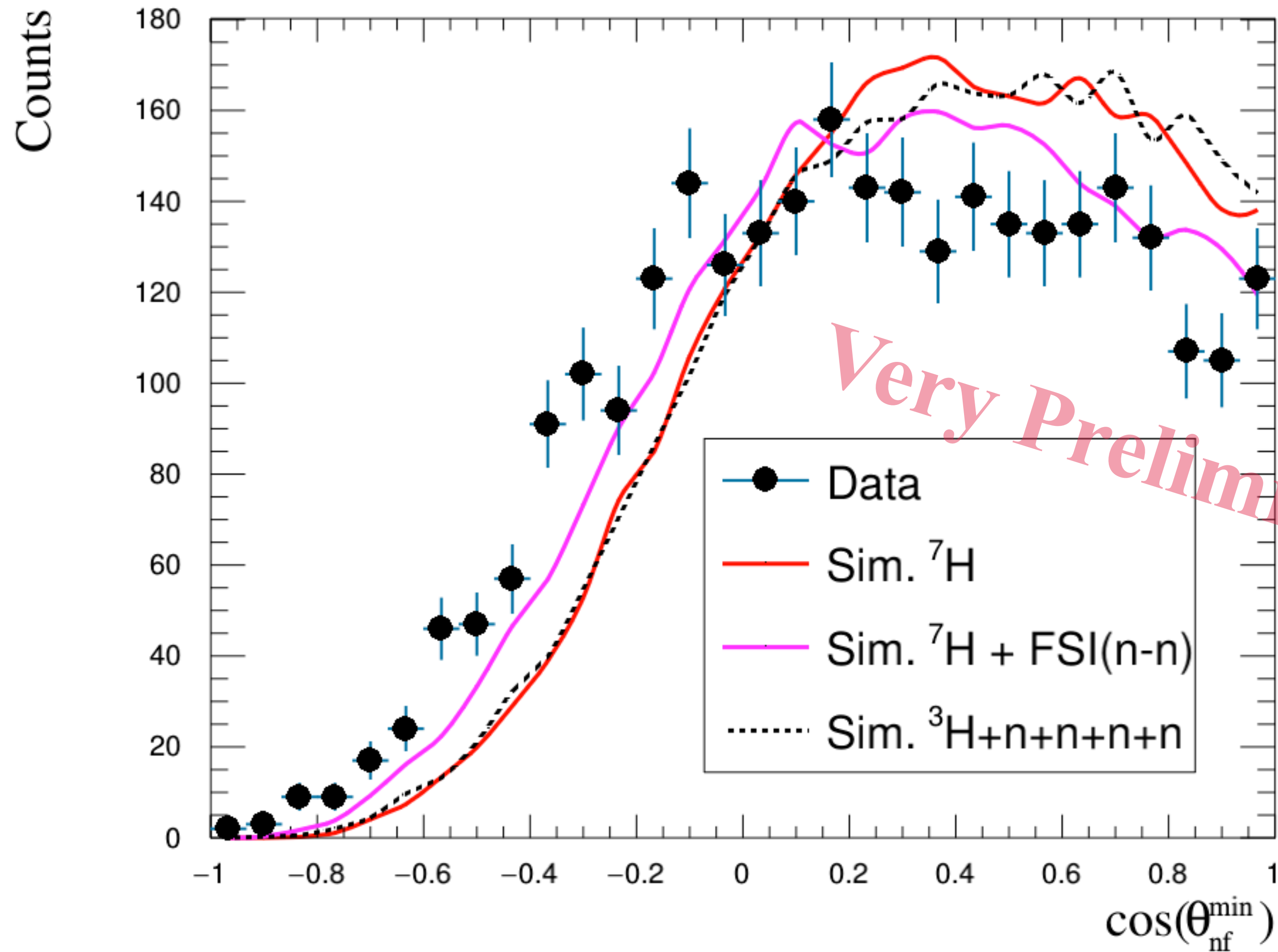


Results: Hydrogen-7 decay, neutron correlations



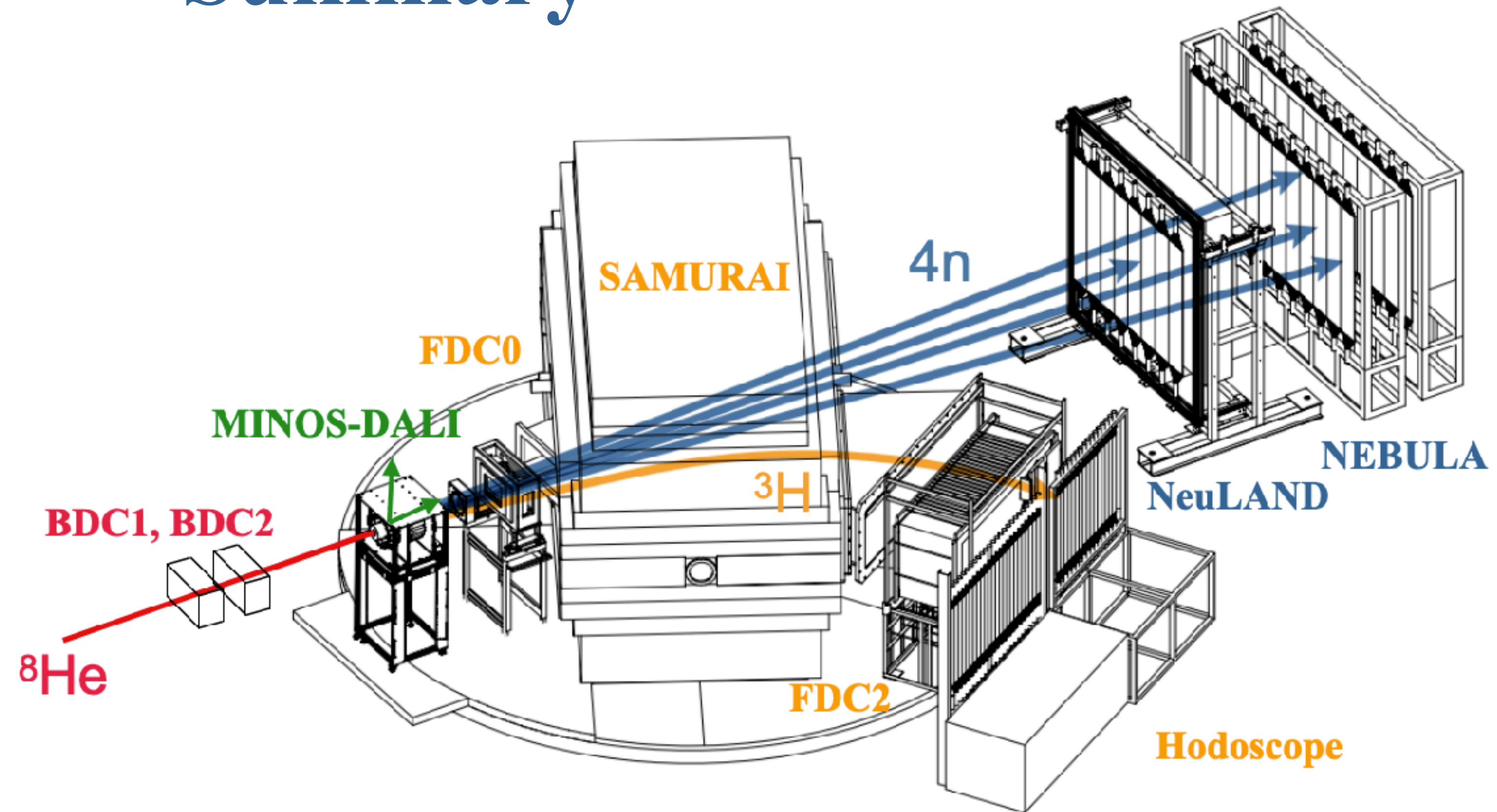
Very Preliminary

Results: Hydrogen-7 decay, angular correlations



SAMURAI 34 experiment

- High intensity beam
- High luminosity target
- High multi-neutron efficiency



Two techniques IM & MM:

- Multi detectors (DC, TPC, Neutron walls, Spectrometer)
- Analysis algorithms (tracking, crosstalk...)
- Simulations of different detectors (MINOS-TPC, DALI, NeuLAND/NEBULA)
- Setup validation on physics: ^7He g.s. & $^6\text{He}^*$

${}^7\text{He}$ & ${}^3\text{n}$:

- Clear absence of any (${}^6\text{He}+\text{n}$) excited state
- First observation of ${}^7\text{He}^*$ by IM measurement
- First observation of **direct 3n** emission ? (To be confirmed)
- No significant **trineutron** signal

${}^7\text{H}$ & ${}^4\text{n}$:

- First high acceptance+resolution+statistics experiment
- Observation of broad structure at $E({}^7\text{H}) \sim 7$ MeV
- No clear sign of any resonant-like structure ... ?

