Challenges and ideas for the absorption of the **relic neutrino**

PTOLEMY collaboration meeting
6-8 November

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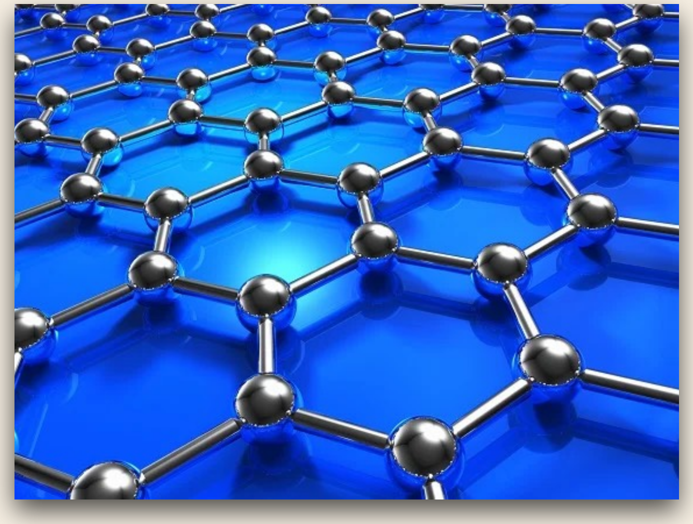
UNIVERSITÀ DI ROMA

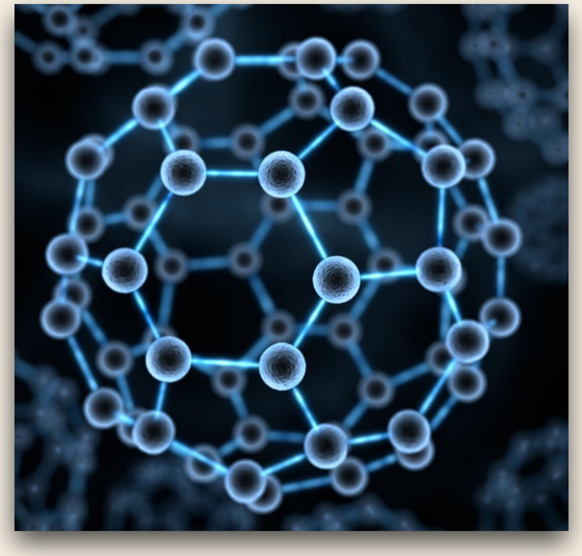
Overview

- **Graphene** and relic neutrinos don't seem to get along



- How would the electron spectra vary if we changed the **substrate**?

- First results from **fullerenes**



Relic neutrinos

Why is it important to detect relic neutrinos?

- Decoupled from ordinary matter just **1 second** after the Big Bang

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Weinberg: **neutrino absorption**!

[Weinberg, 1962 Phys. Rev. 128 1457]

CNB detection in vacuum

Decay

$$\mathrm{T} \longrightarrow {}^{3}\mathrm{He}^{+} + e^{-} + \bar{\nu}_e$$

$$\nu_e + \mathrm{T} \longrightarrow {}^{3}\mathrm{He}^{+} + e^{-}$$

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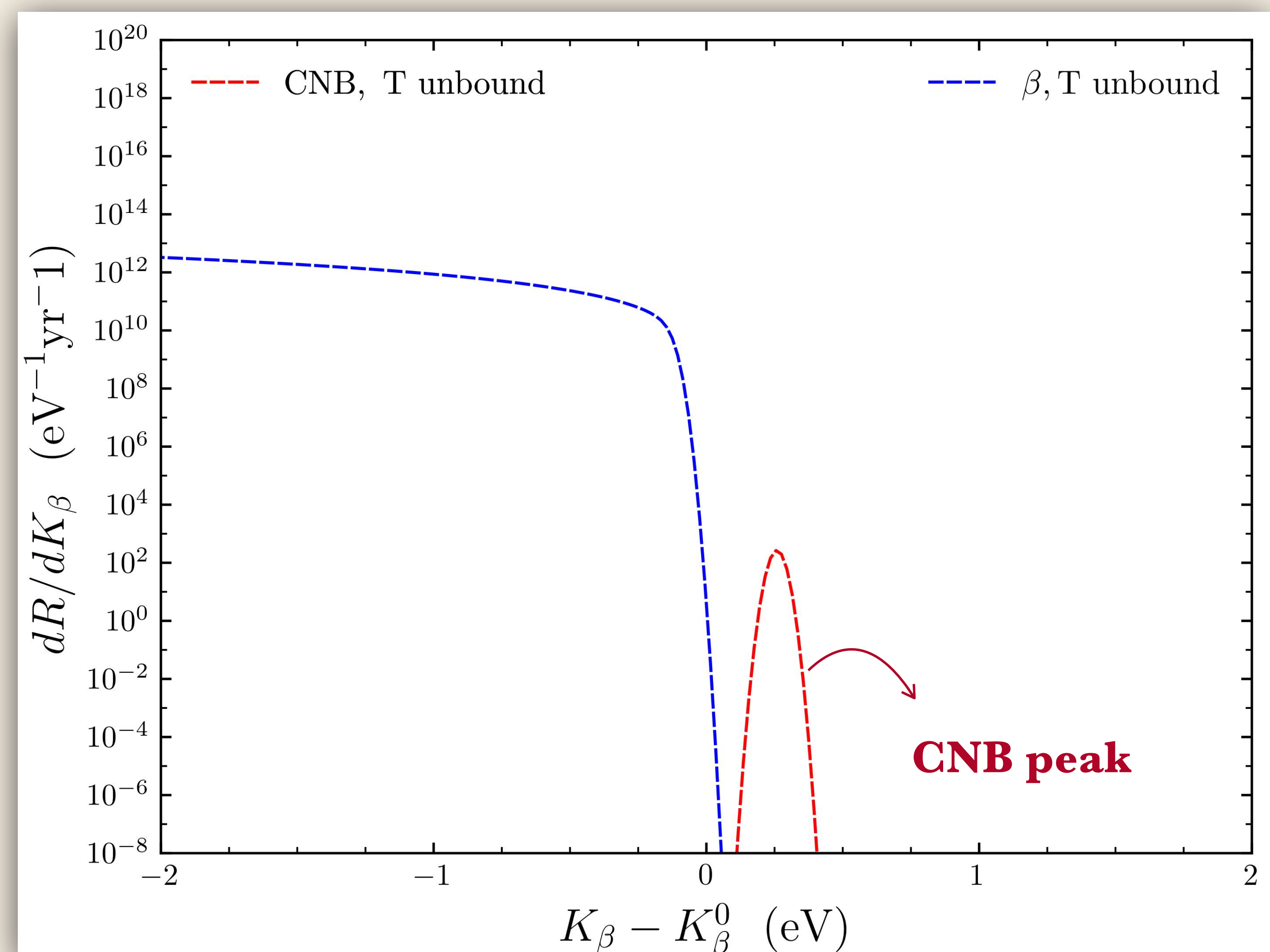

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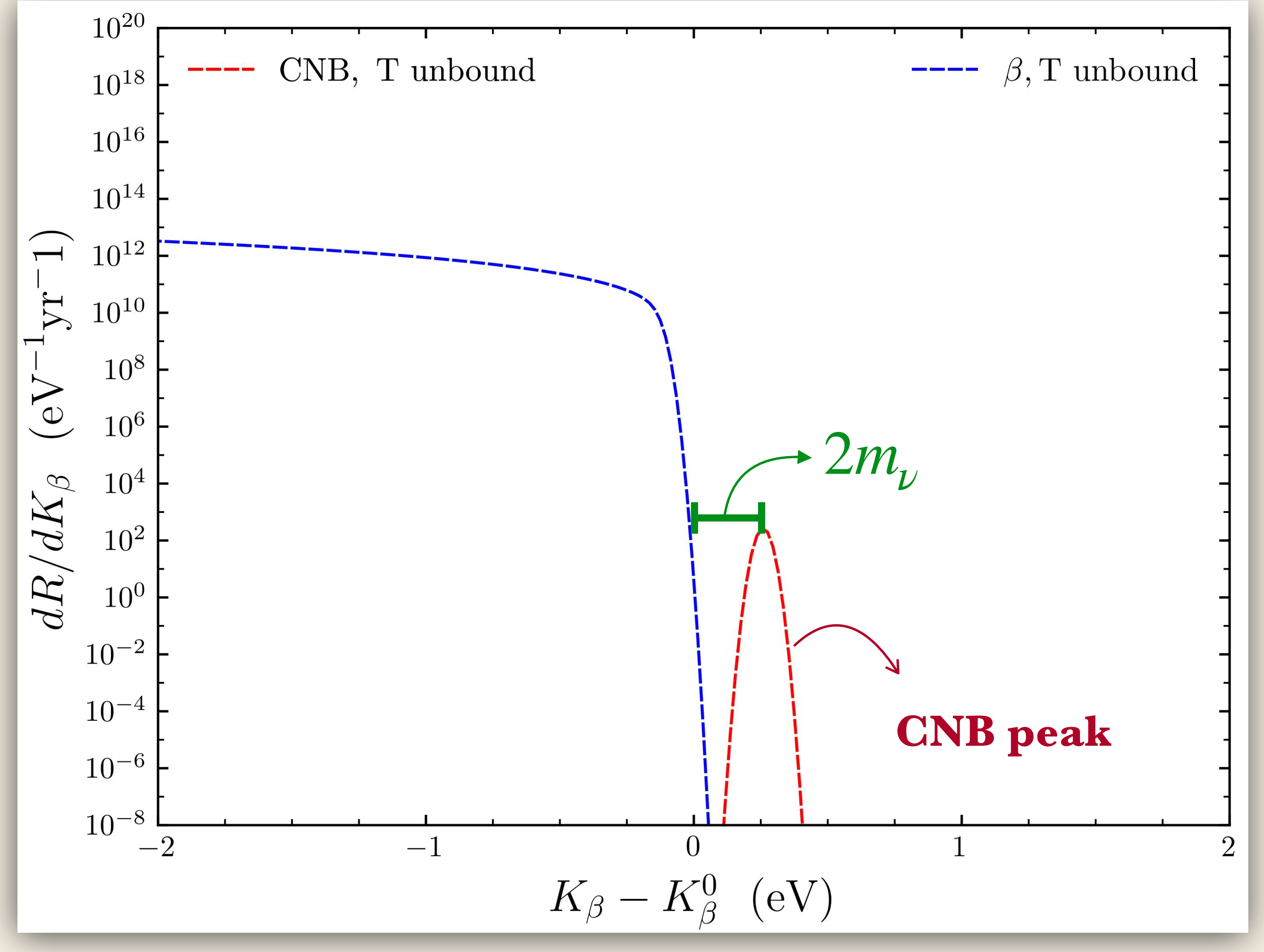

- What do we need?

1) Enough **events** per year
2) Good **energy resolution**

PTOLEMY with graphene

- What does graphene bring on the table? (potentially)
  1. **100 g** of tritium
  2. Energy resolution of **50 meV**

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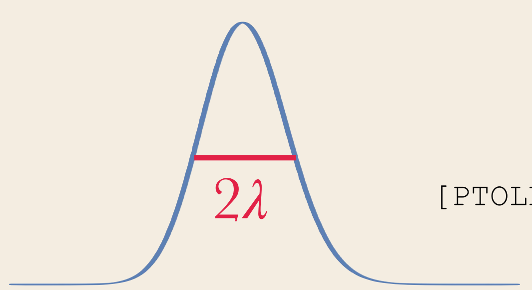
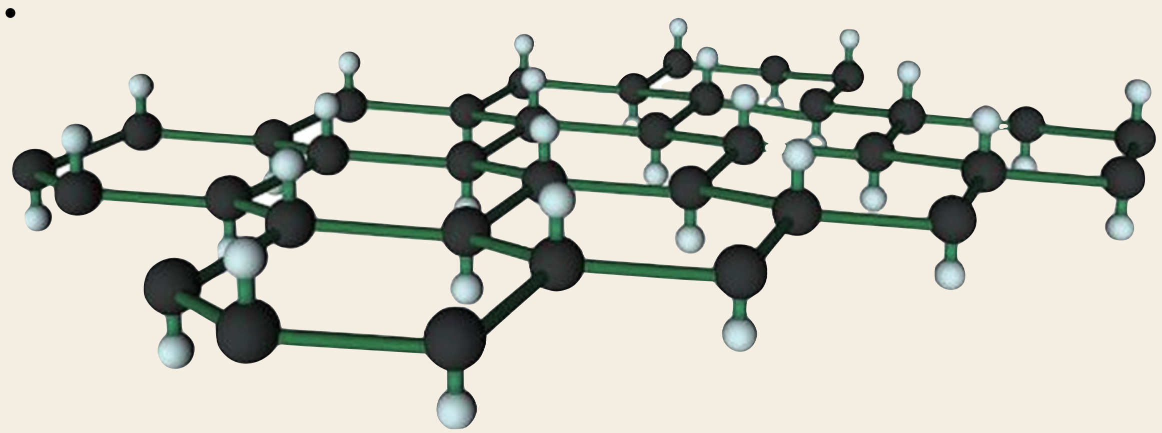
- How to describe tritium **initial state**?

$$\Psi_T(\vec{x}) \propto e^{-\vec{x}^2/2\lambda^2}$$

Localization
$\lambda \simeq 0.08$ Å



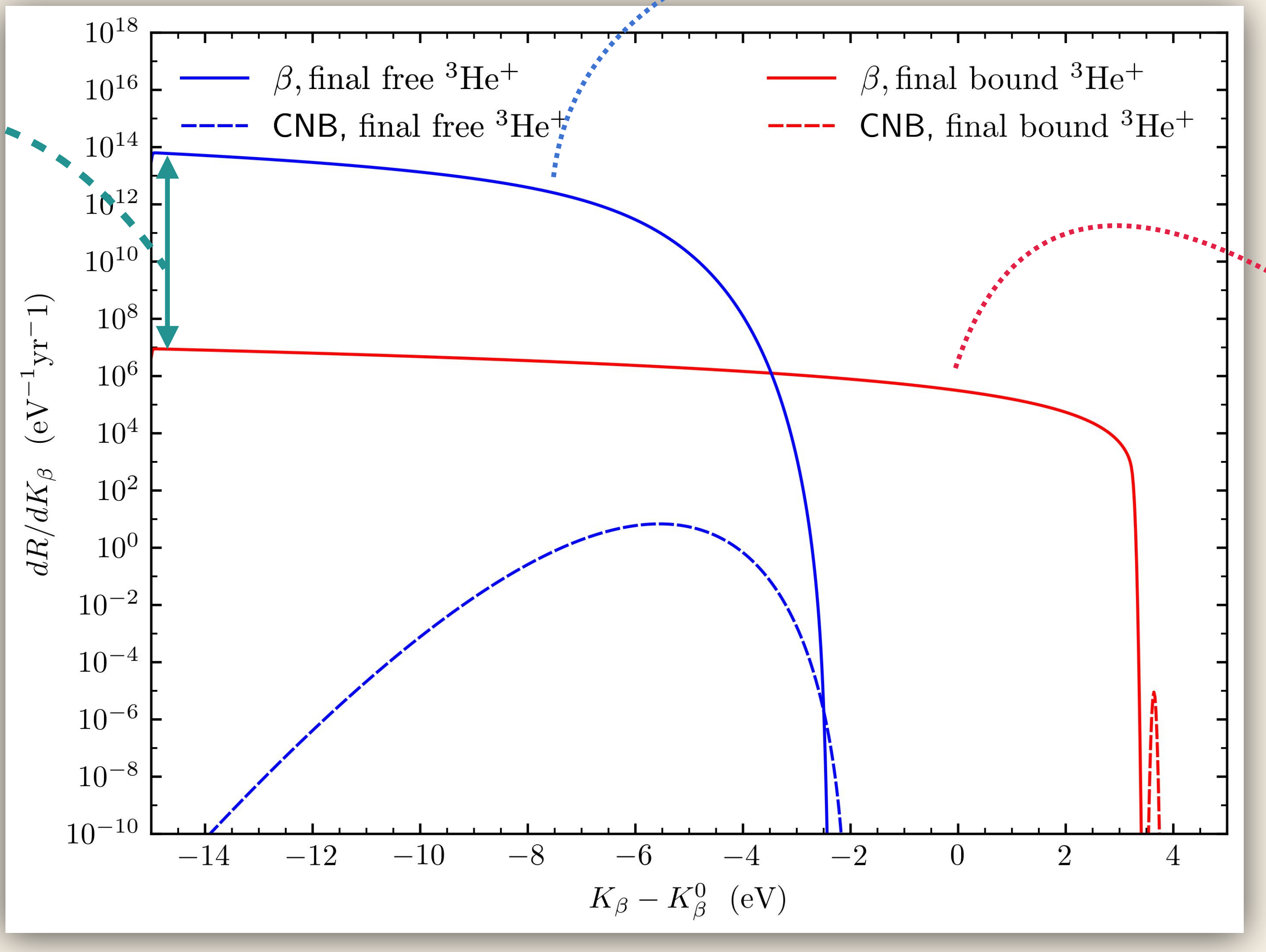
[PTOLEMY — PRD 2022, 2203.11228]



Results from graphene

- Final **bound states** are suppressed

$$d\Gamma_F \propto e^{-\lambda^2|\vec{p}_\beta + \vec{p}_{He}|^2}$$



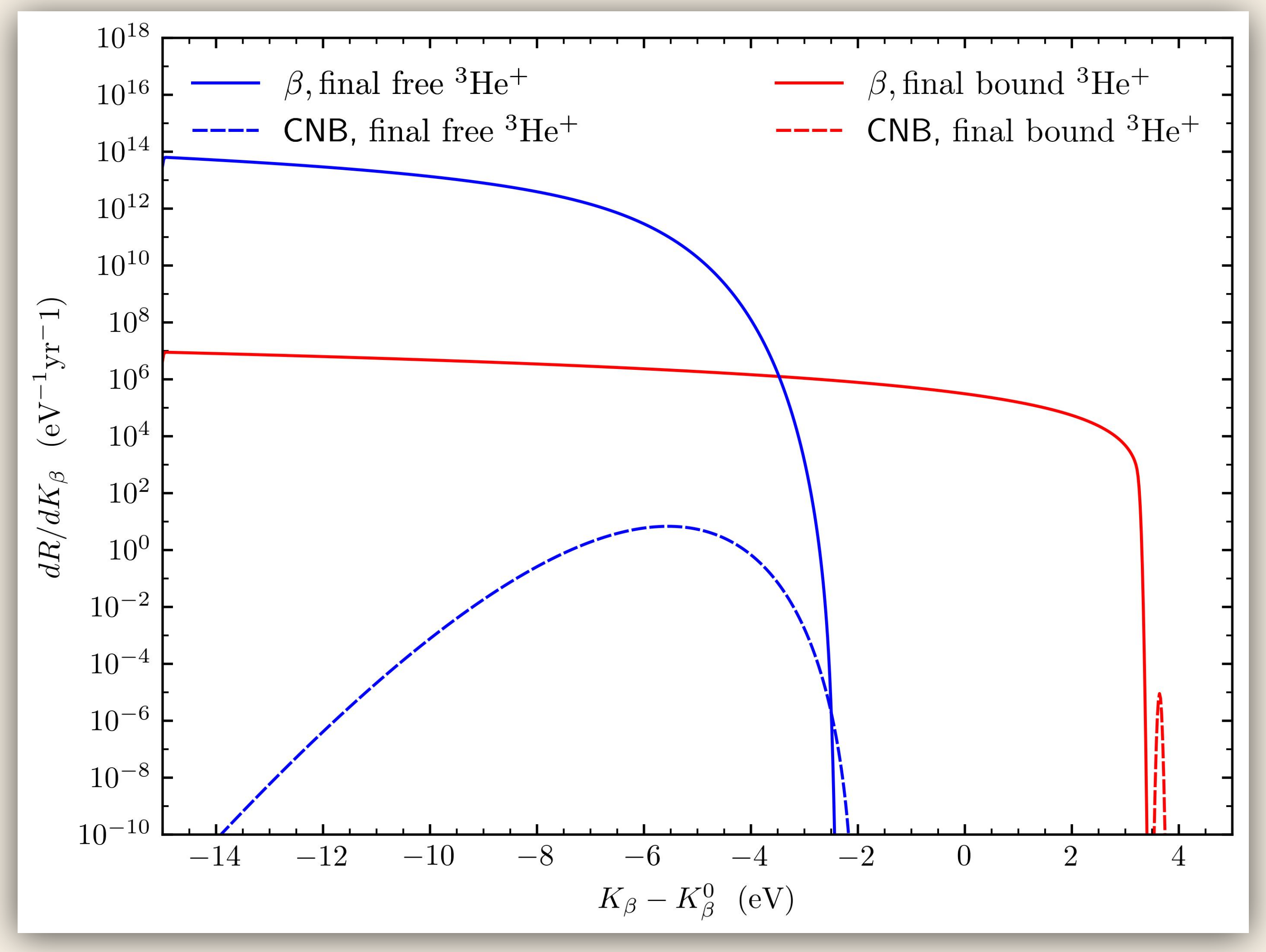
Suppression of $\sim 10^{-7}$

$$d\Gamma_B \propto e^{-\frac{\lambda^2 p_\beta^2}{2}}$$

$\lambda p_\beta \simeq 6$ at endpoint

Results from graphene

- How good is graphene to **detect CNB**?



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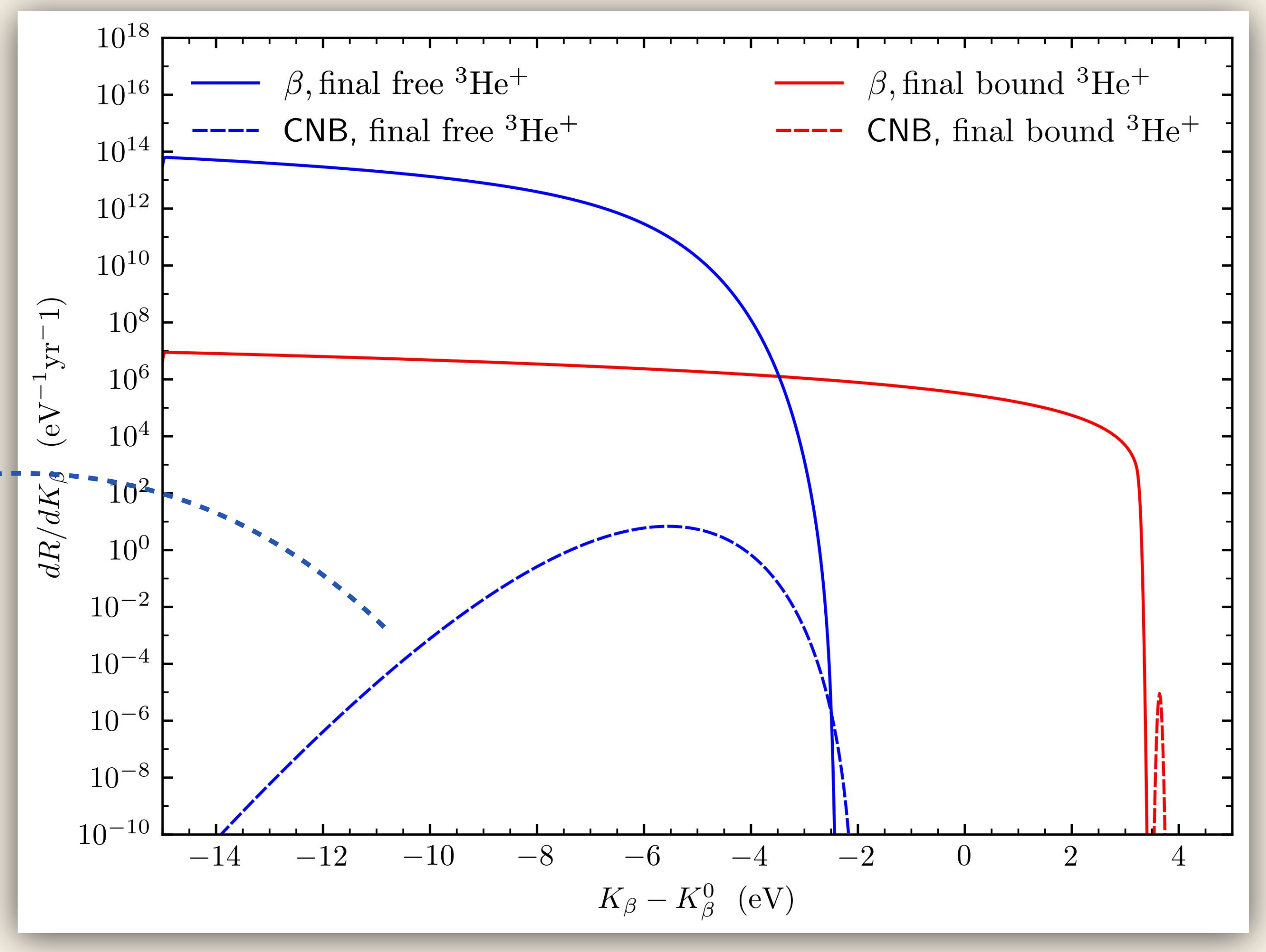
Obscured CNB peak



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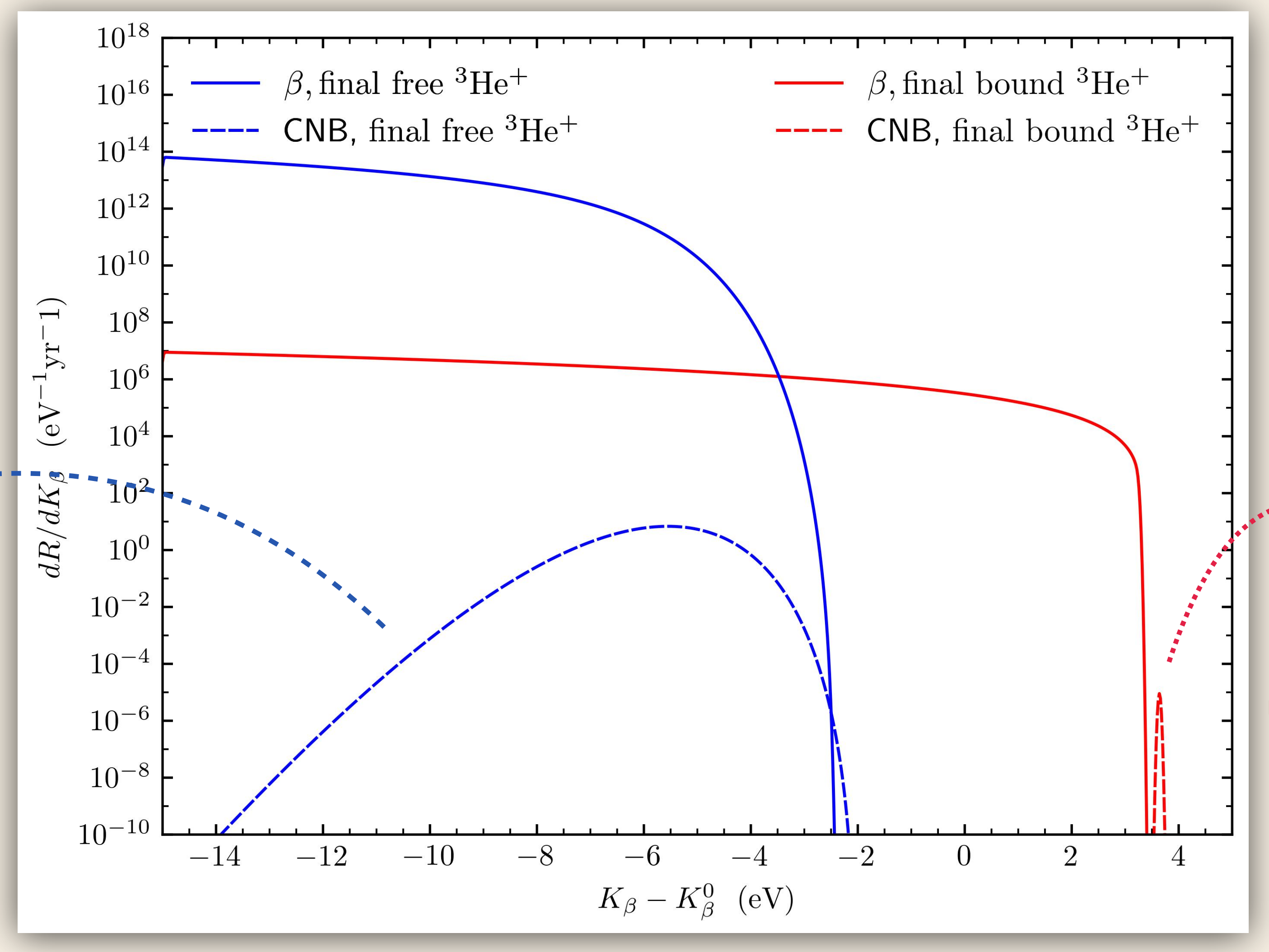

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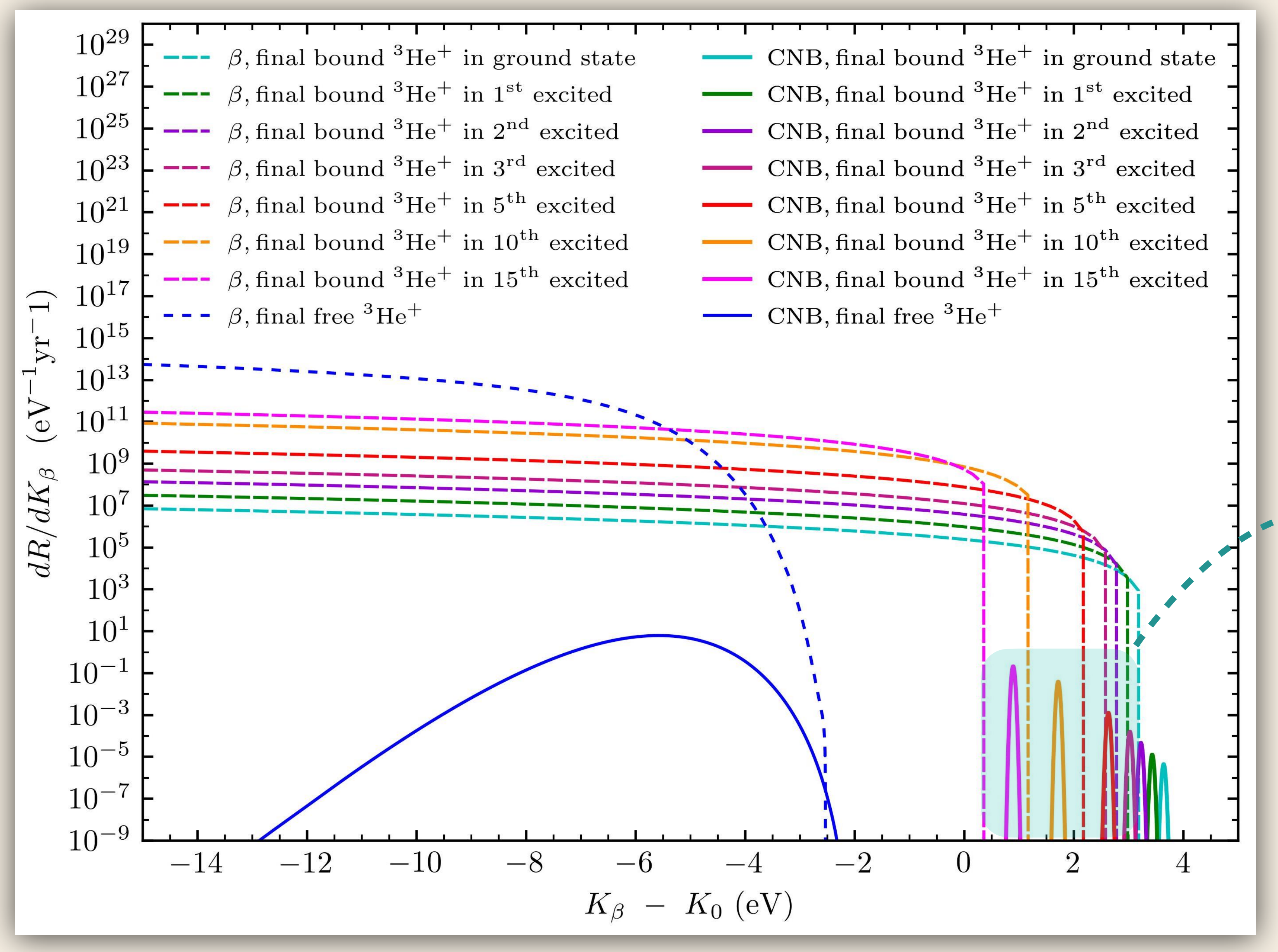
Results from graphene

- What about final excited bound states?



Stronger peaks, but **obscured**!

Need to change substrate

- What would change if we used **another substrate**?

Tritium would be localized differently

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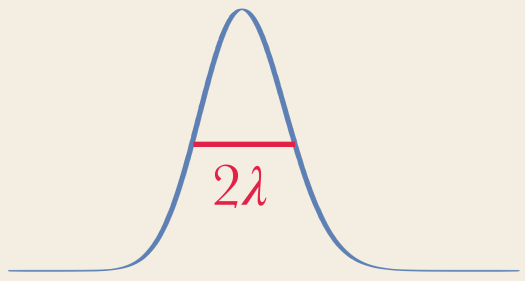

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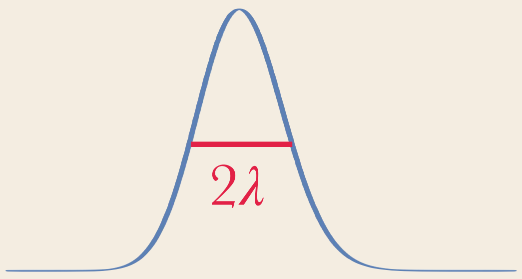
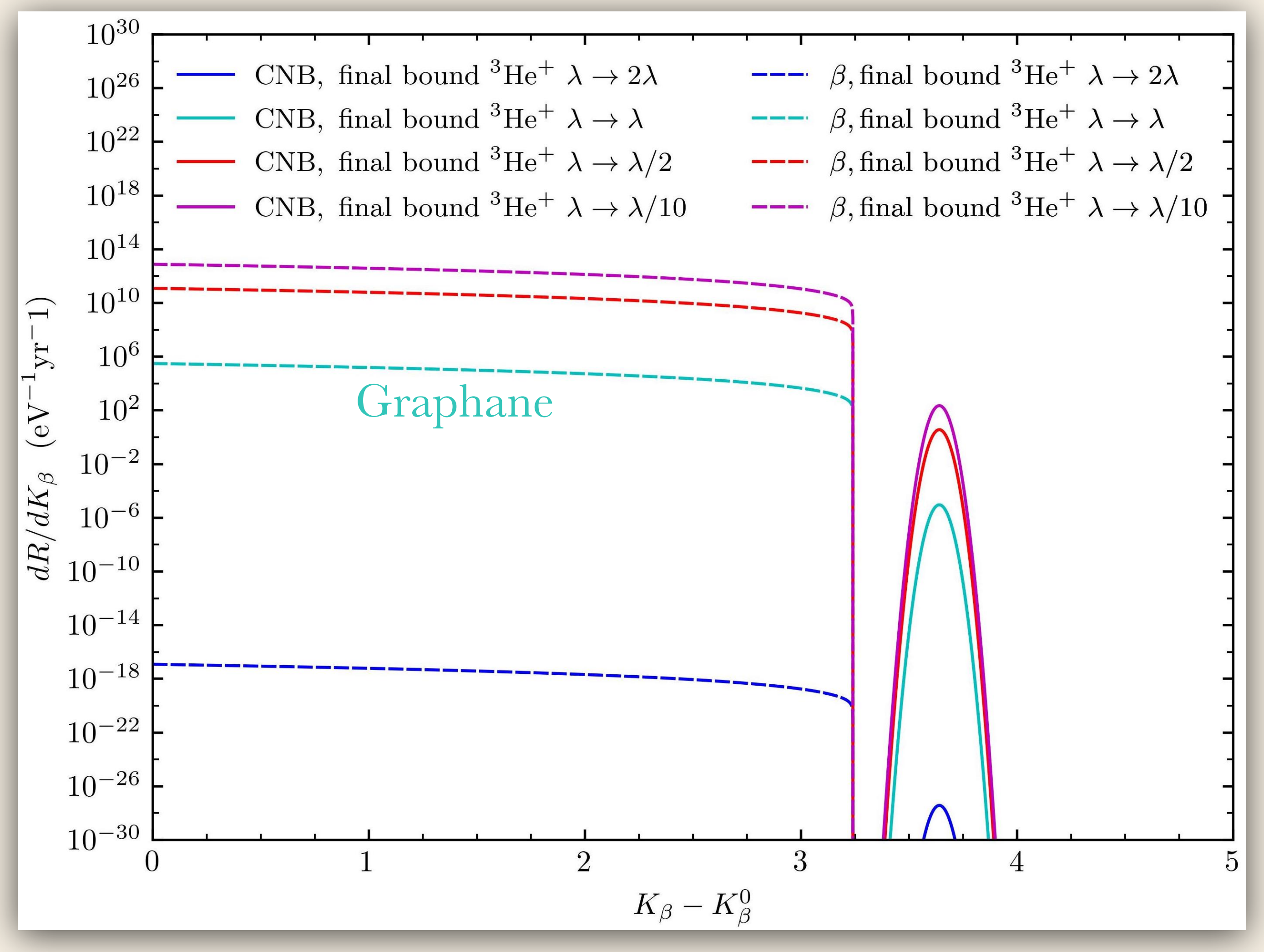


- Let's see how electron spectra change varying λ

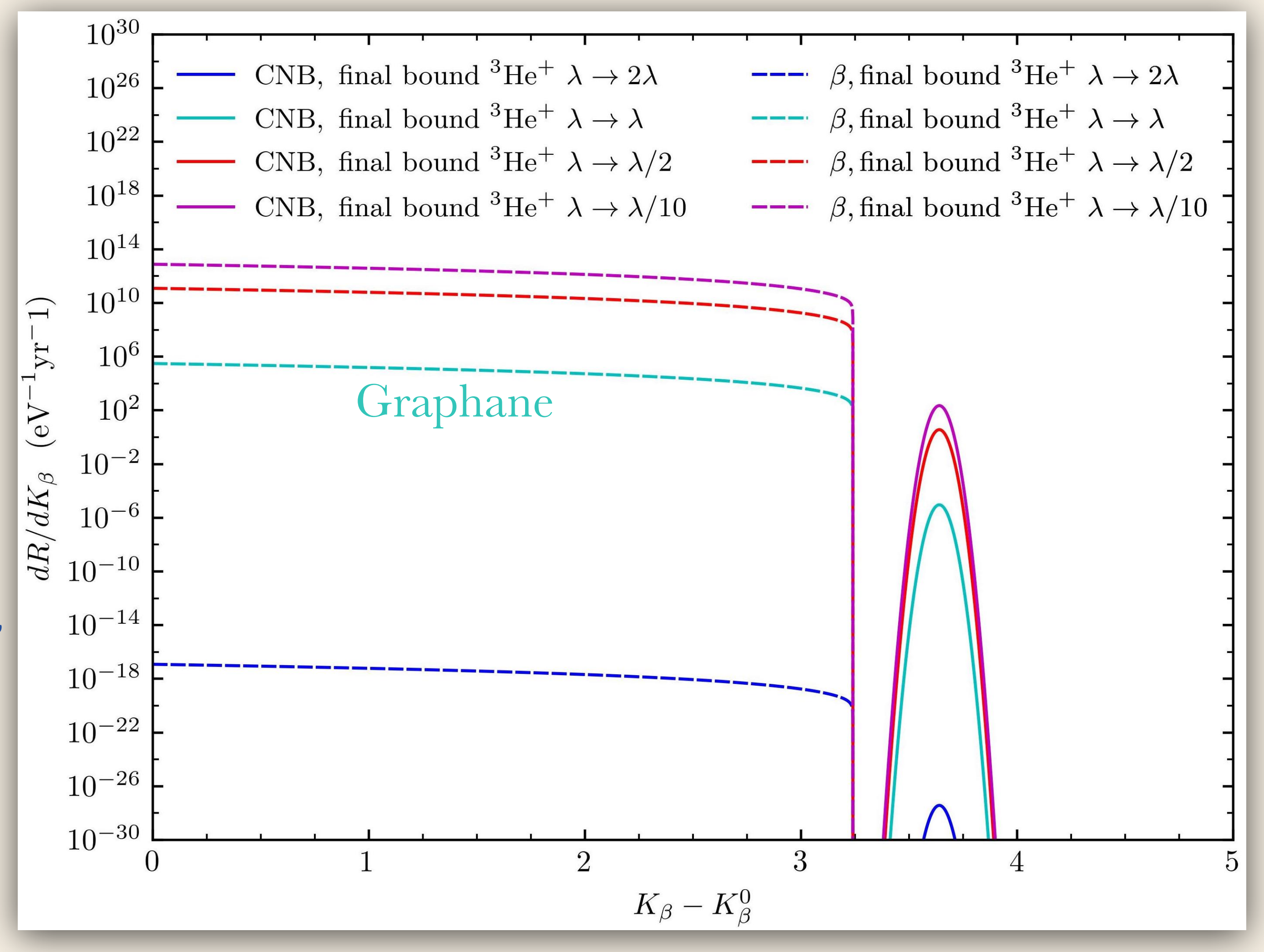
Bound states varying λ



Bound states varying λ

Delocalization brings **suppression**

$$d\Gamma_B \propto e^{-\frac{\lambda^2 p_\beta^2}{2}}$$



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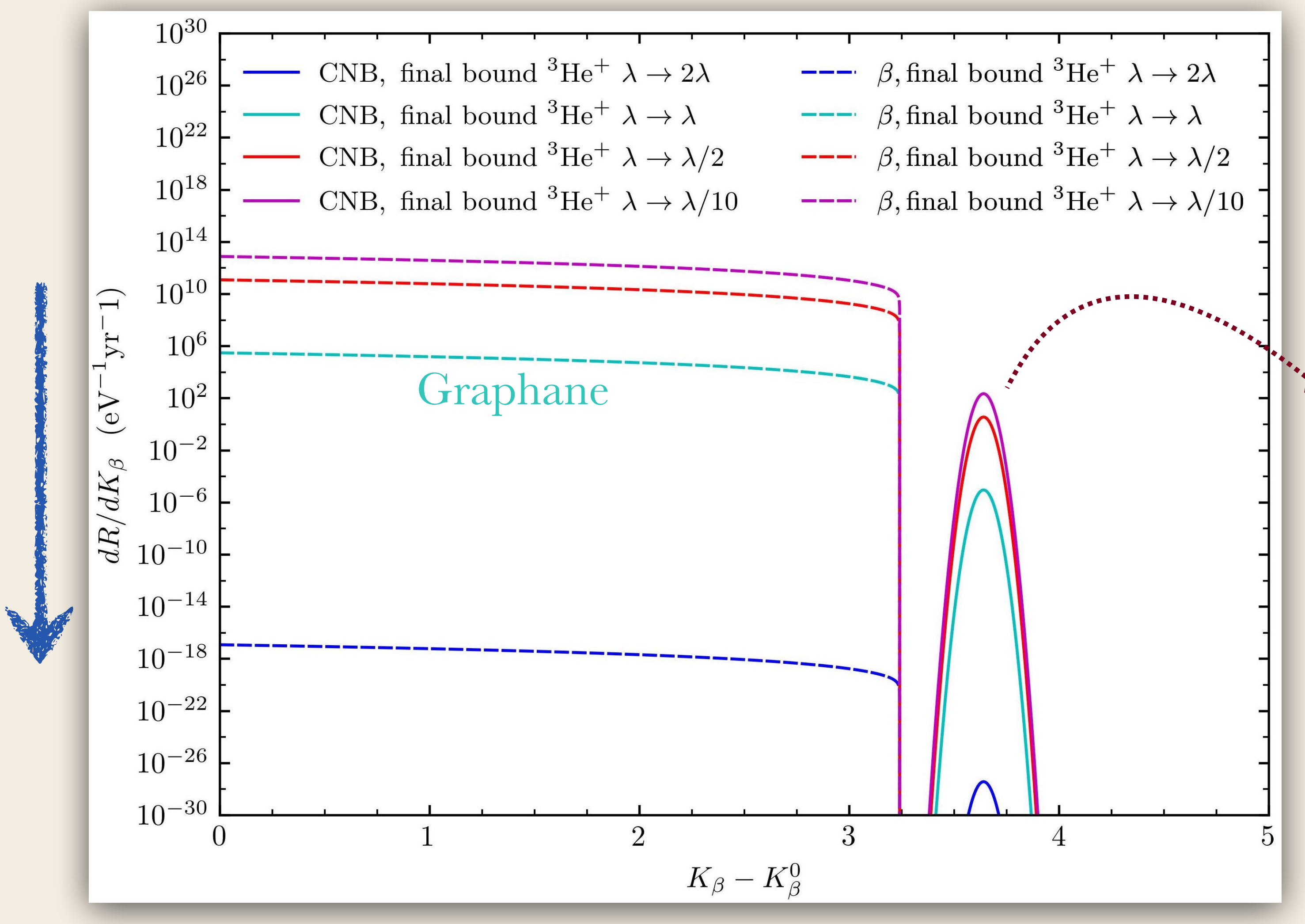

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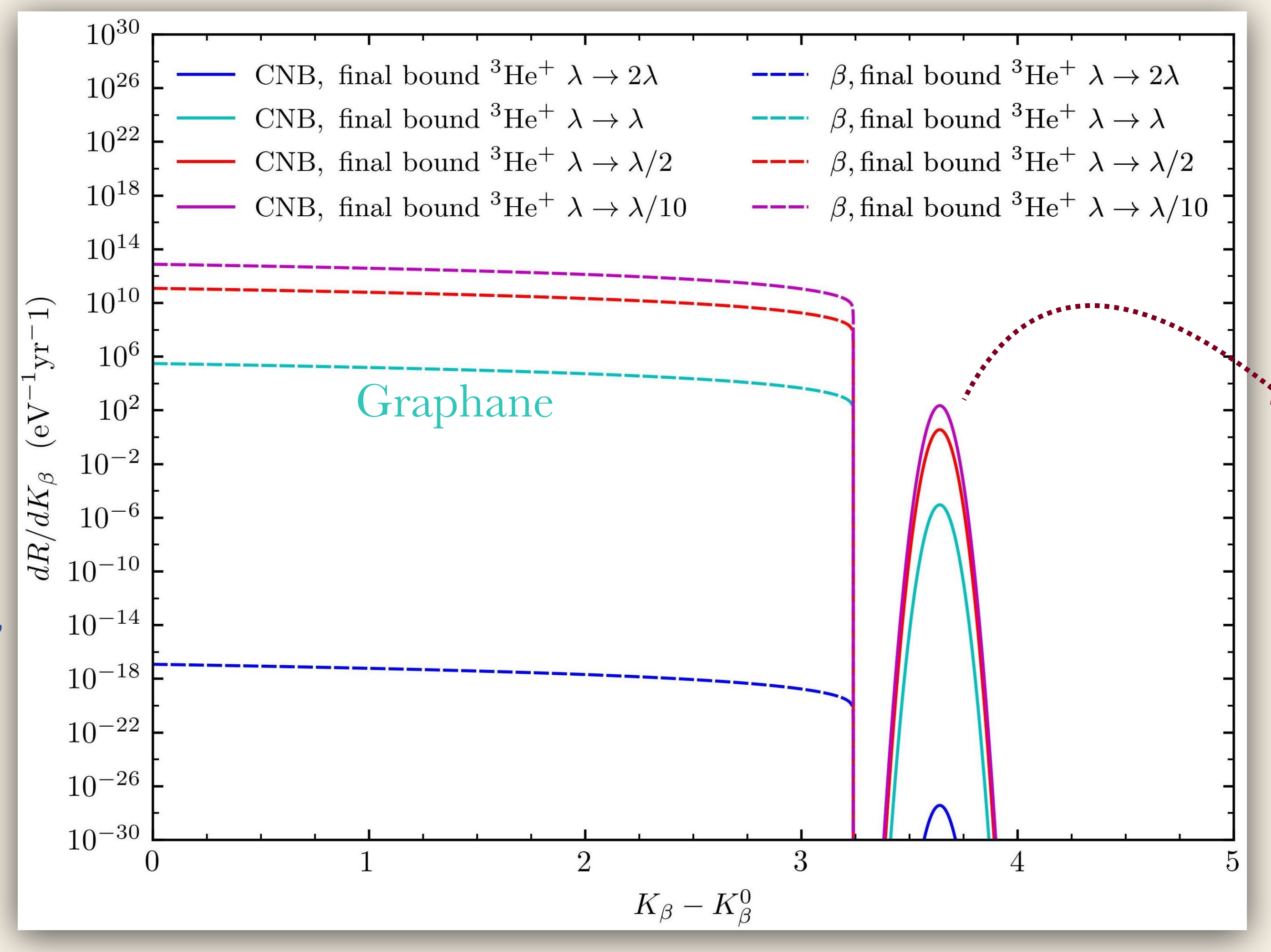

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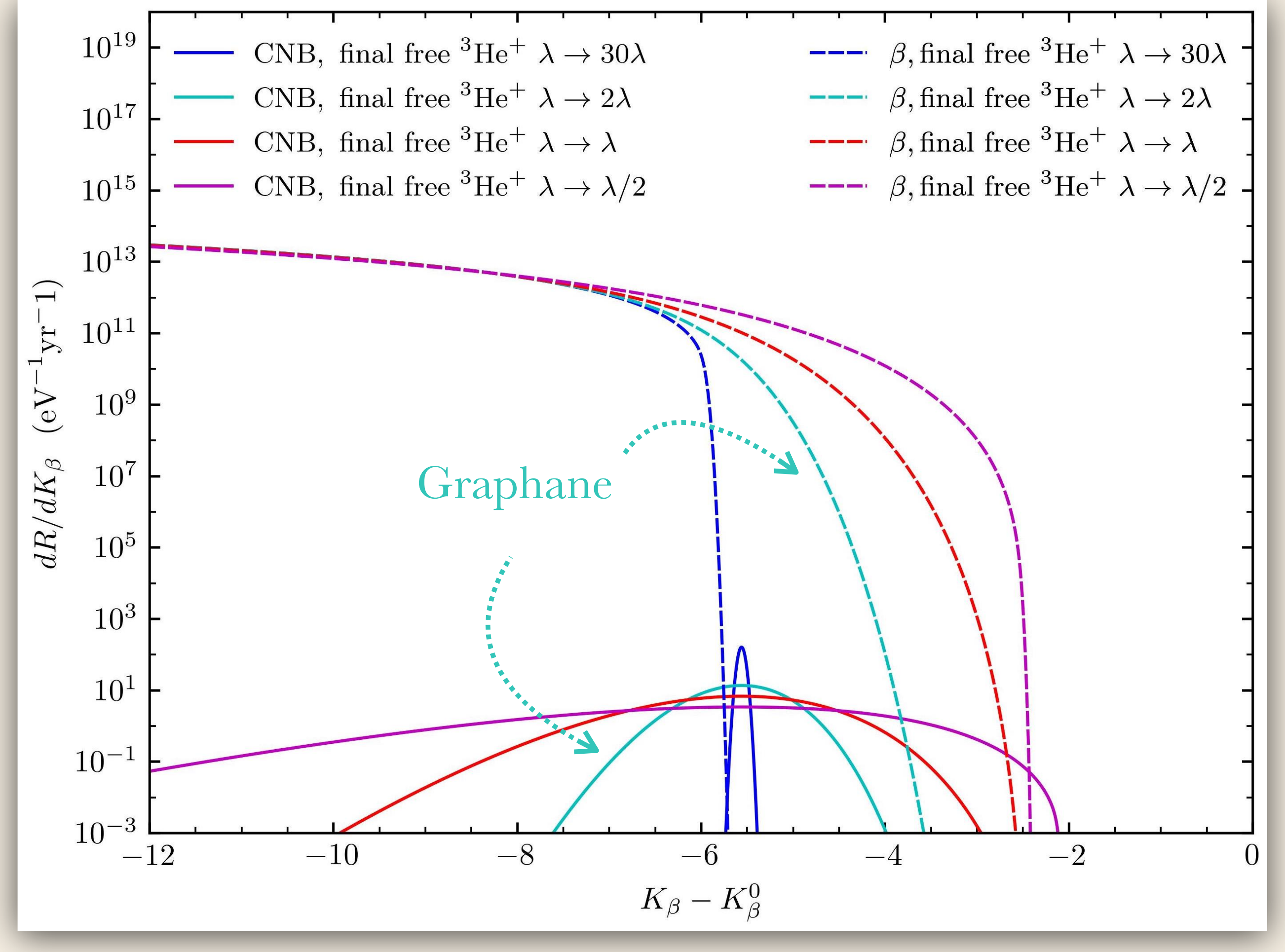
Strategy n.1: decrease λ → **Very difficult** in condensed matter physics

Free states varying λ

- Distortion on the rates as λ is decreased



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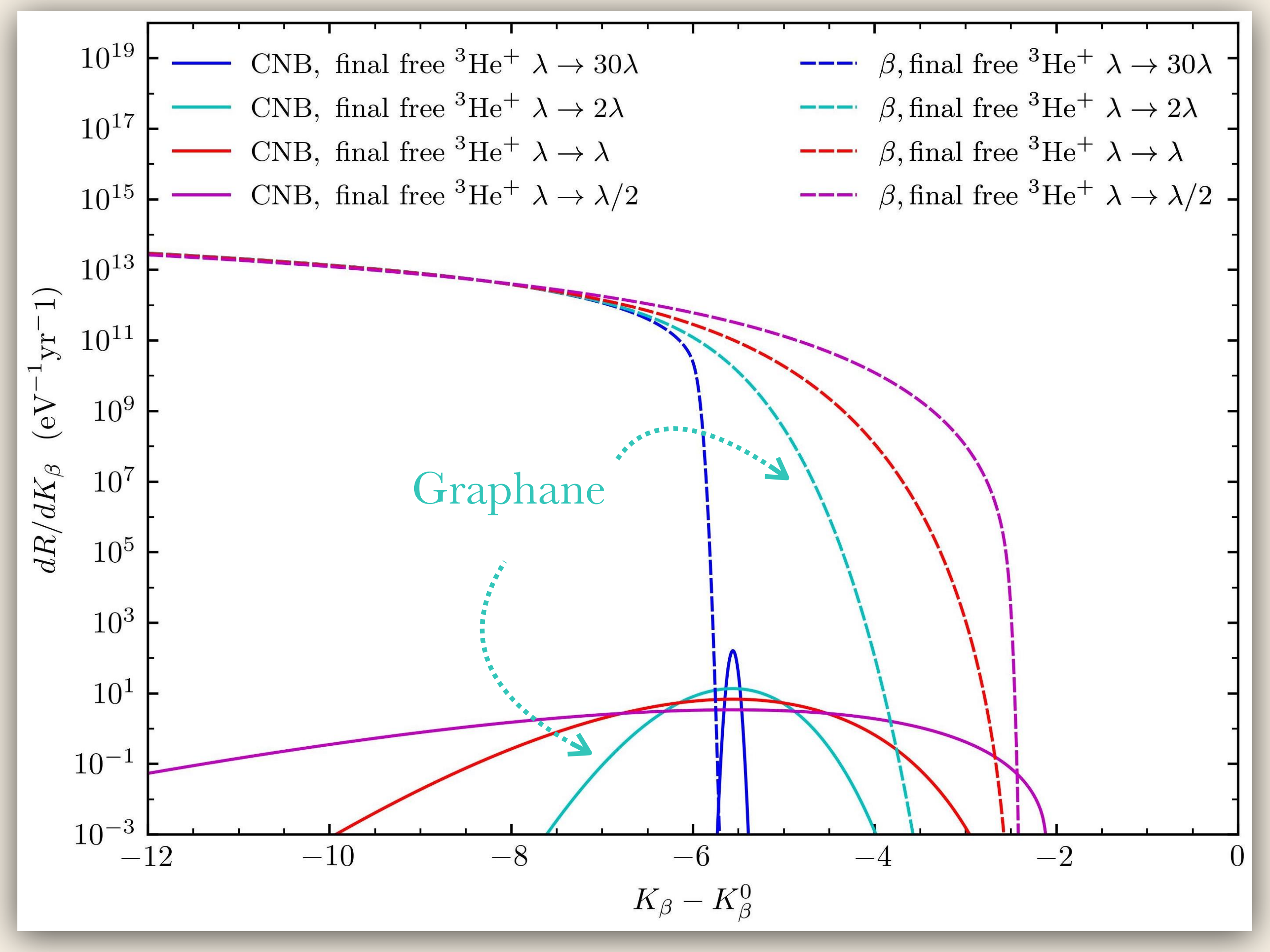
Heisenberg
uncertainty principle

$$\Delta K_\beta \simeq \frac{p_\beta}{m_{^3\mathrm{He}^+}\Delta x_\mathrm{T}}$$



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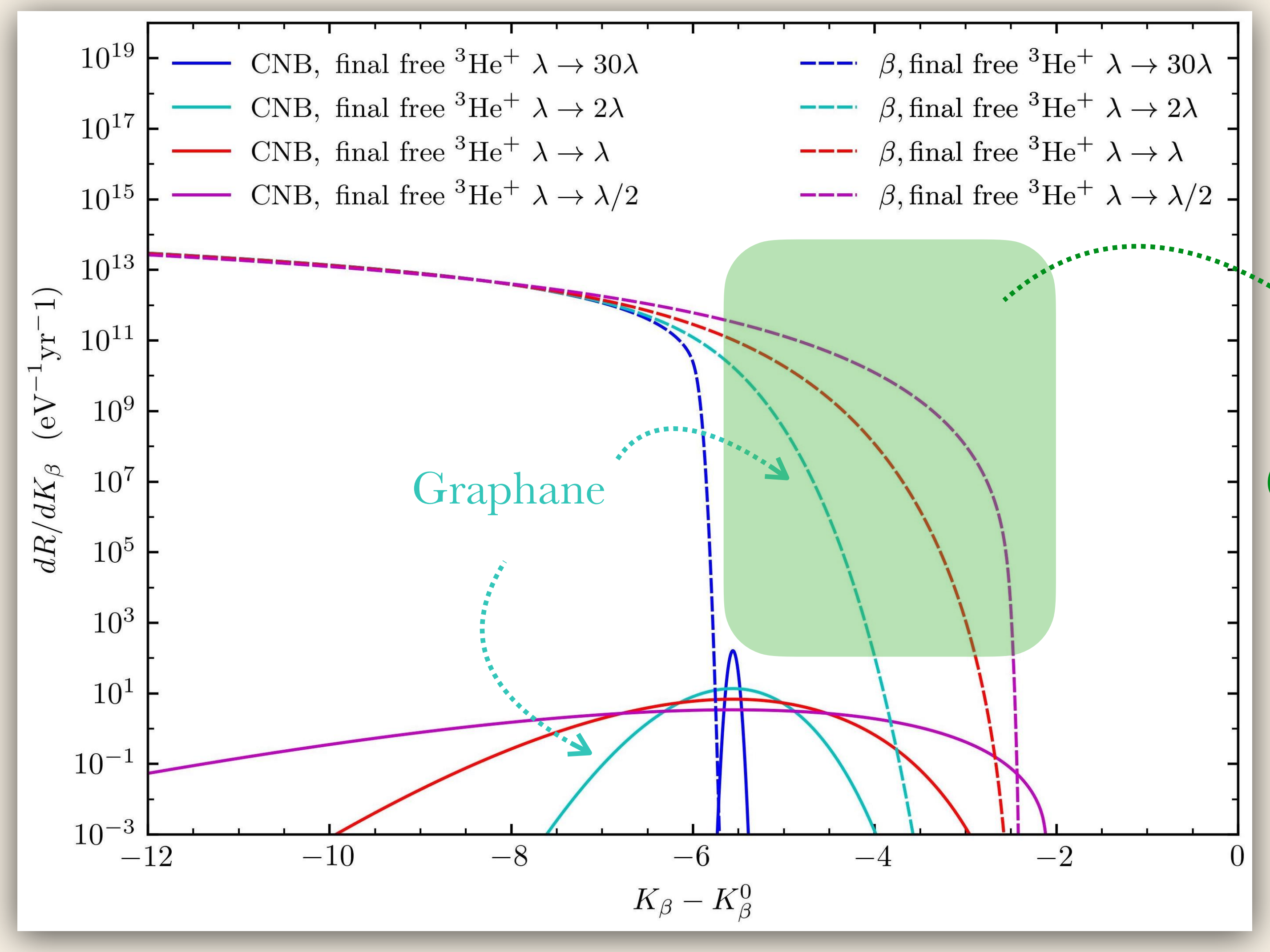


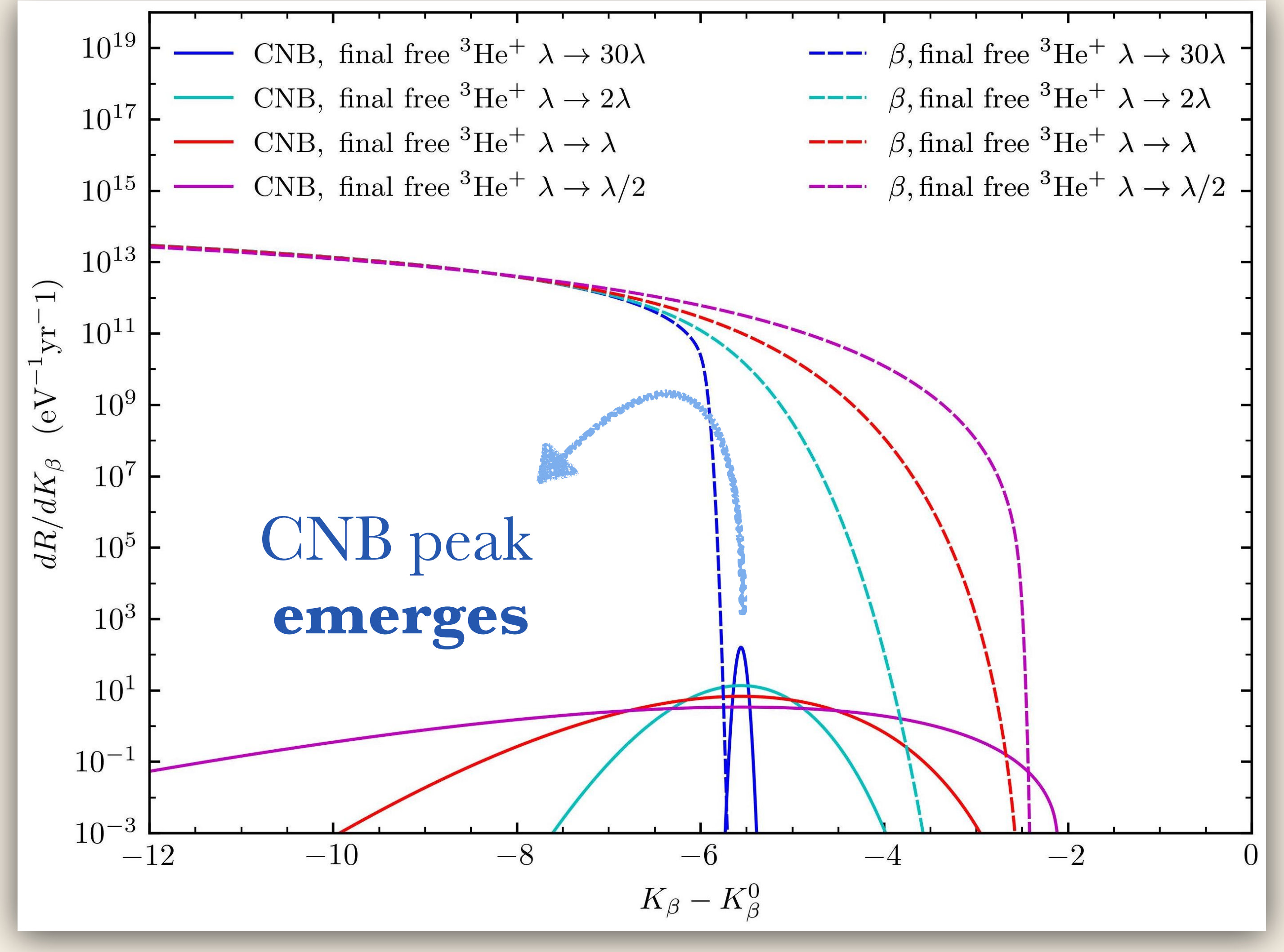
Beta decays obscure CNB signals beneath

Free states varying λ

- What would happen if we increased λ?

↓

Quantum uncertainty decreases



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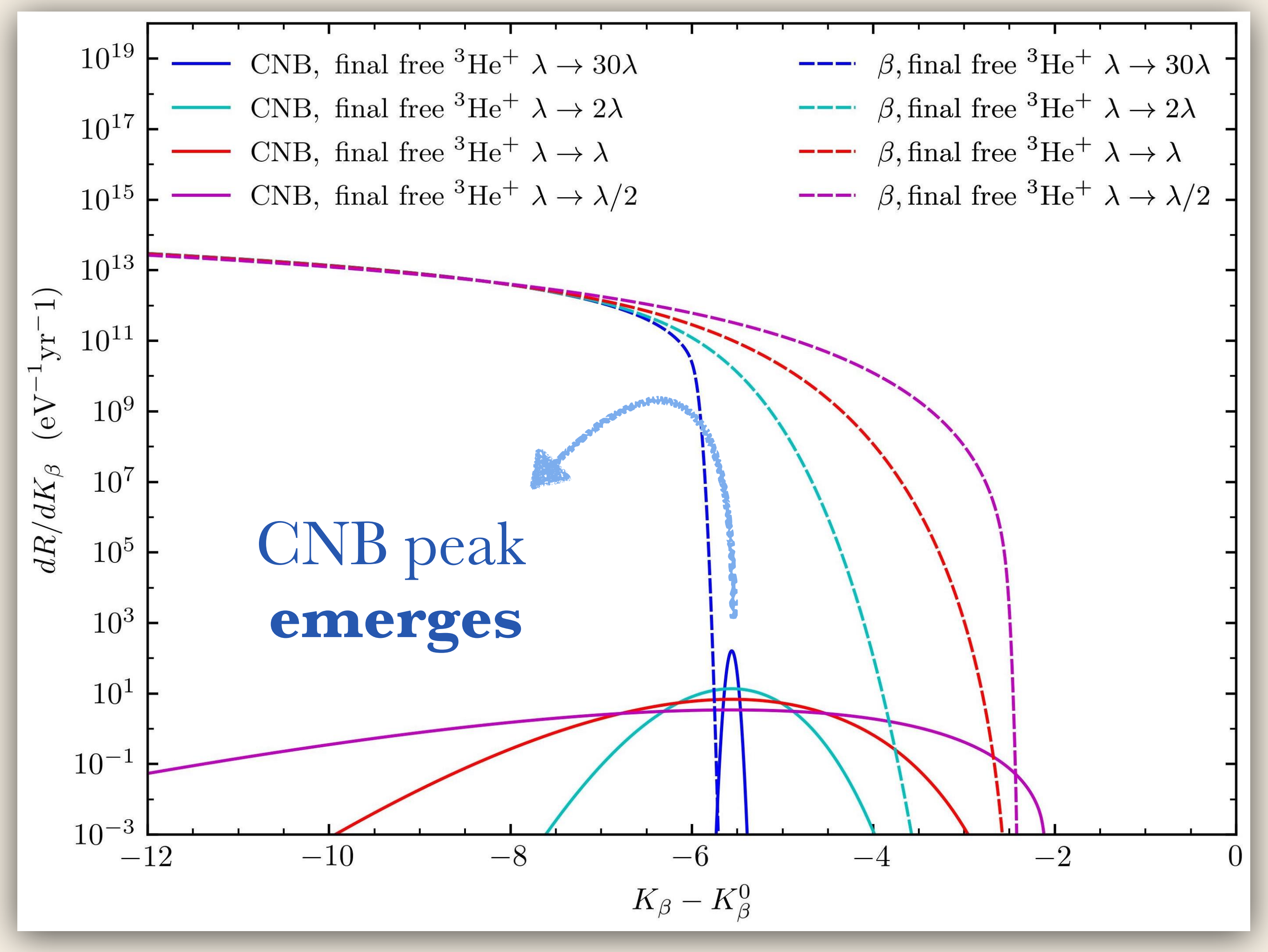
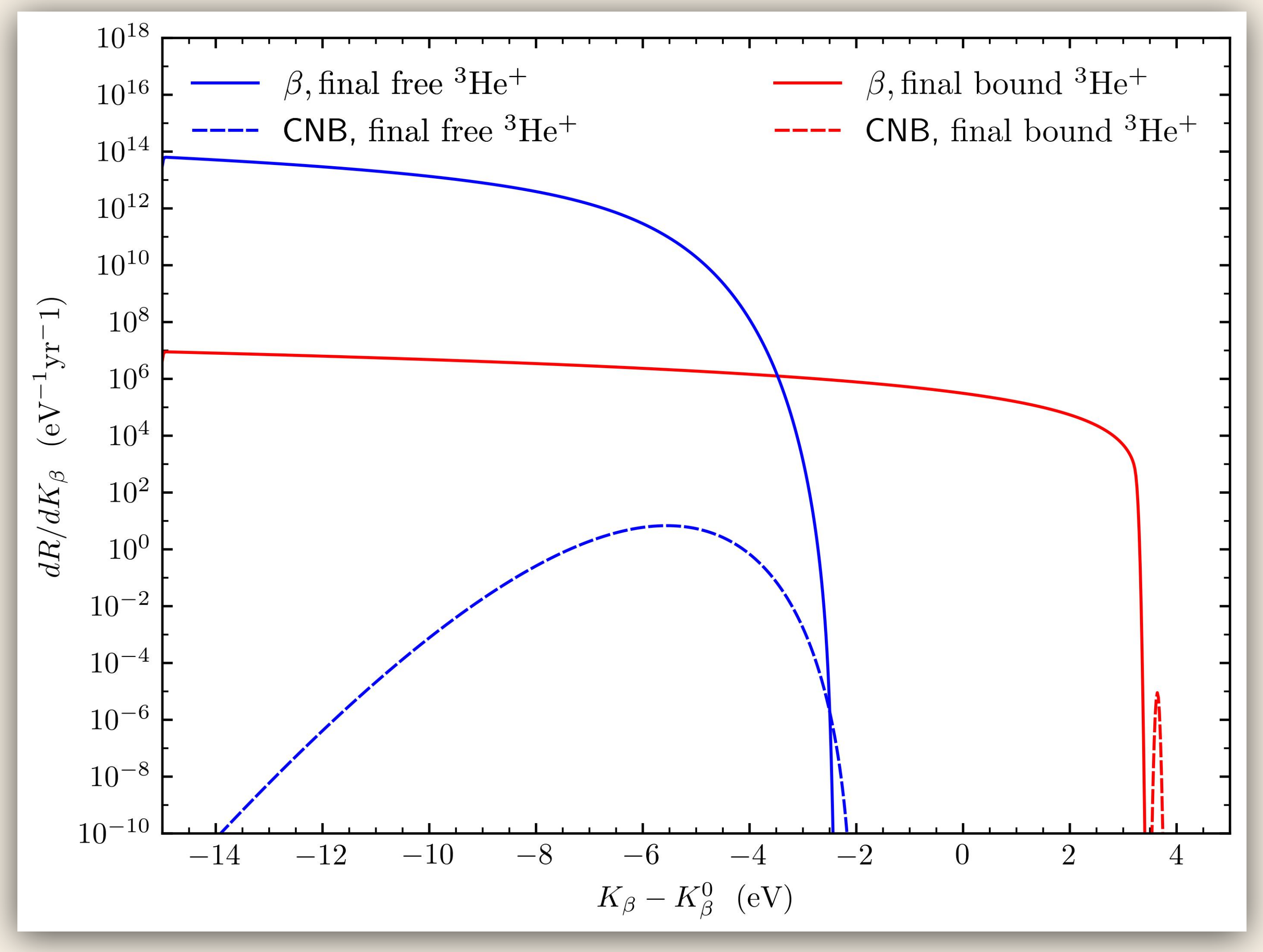


Strategy n.2: increase λ

Moral of the story

- How to make CNB detection possible?



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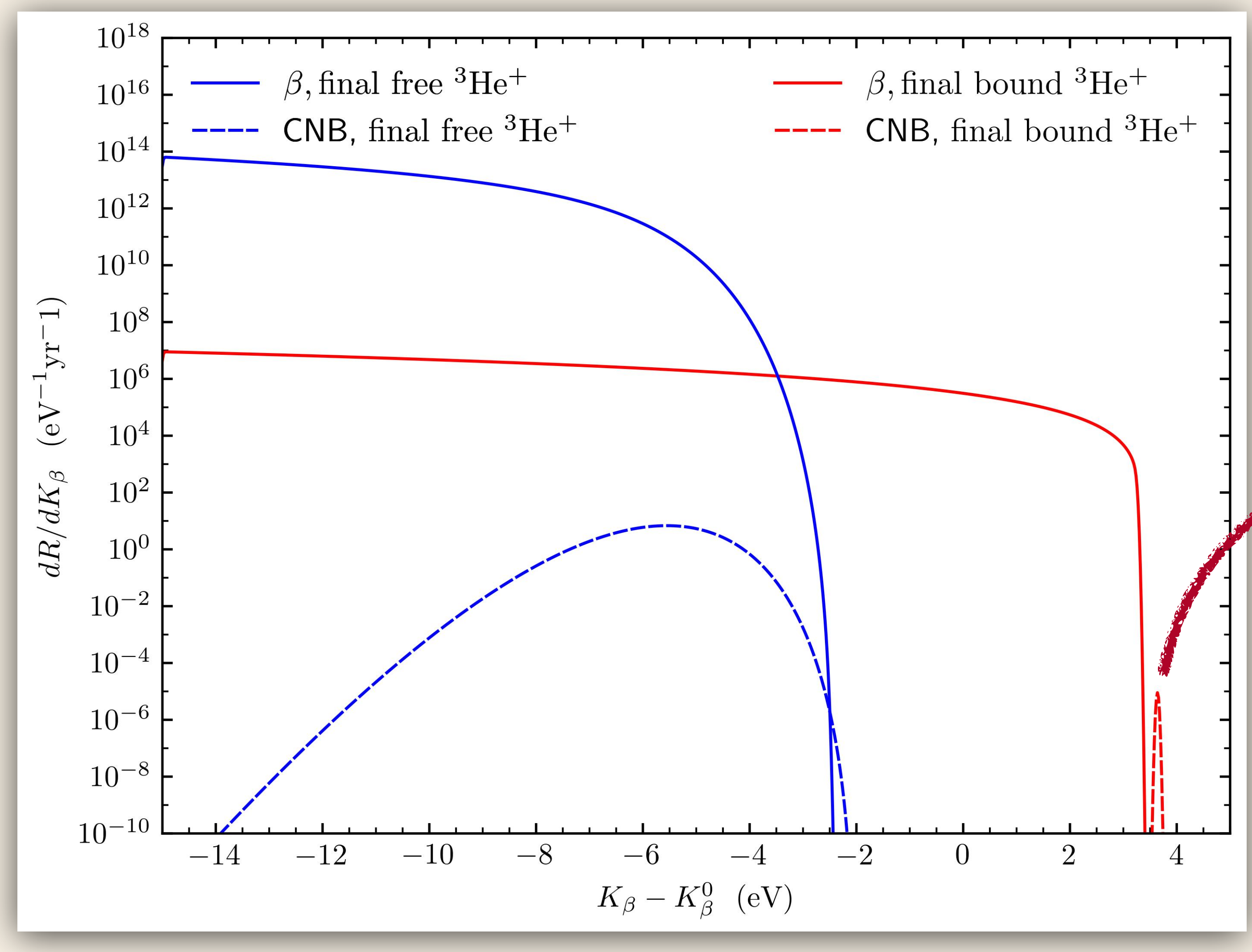

Strategy n. 1:
Localize tritium to increase CNB peak intensity

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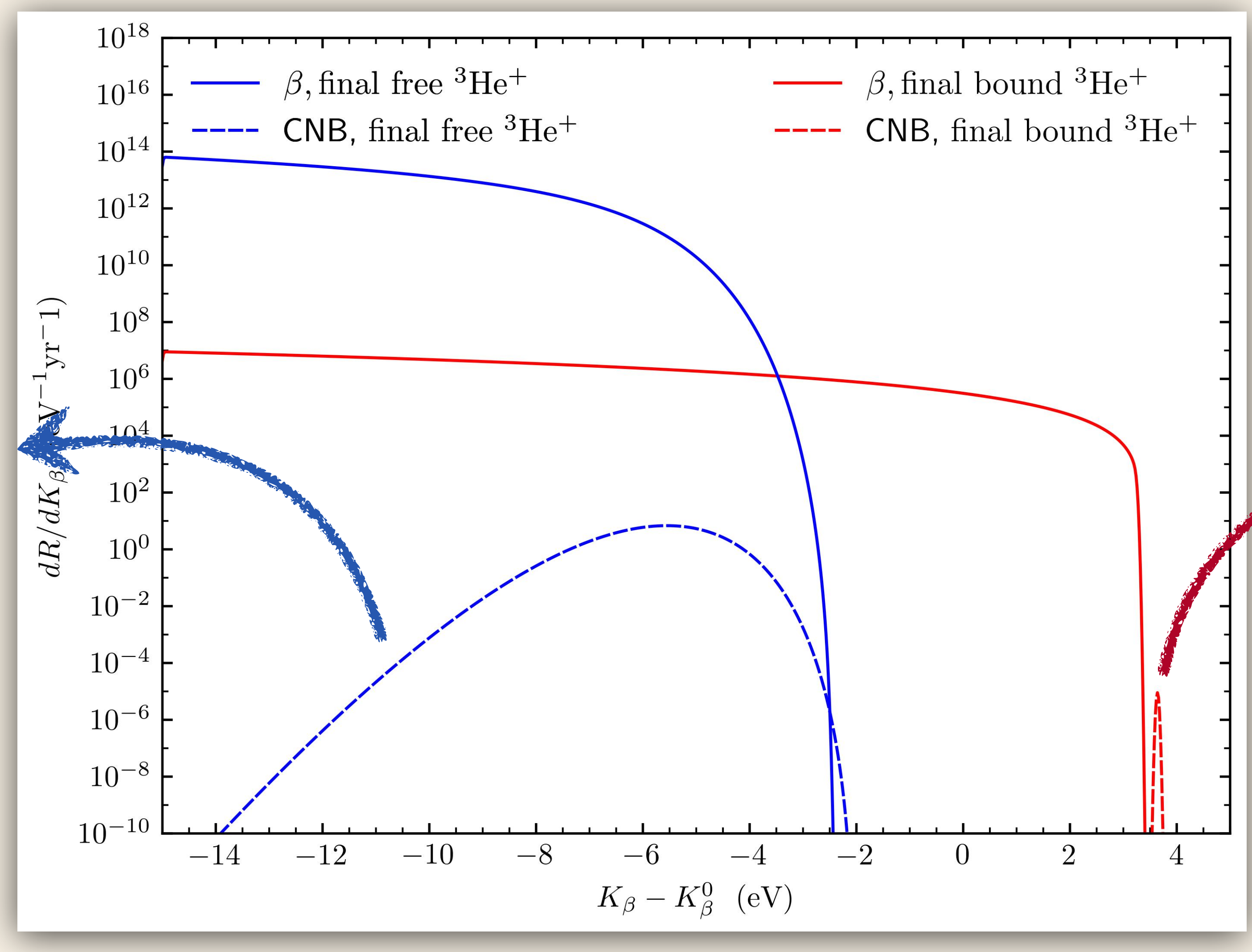
- How to make CNB detection possible?

Strategy n. 2:
Delocalize tritium in order to:

1. Make CNB peak emerge from beta decay events



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Moral of the story

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Strategy n. 2:
Delocalize tritium in order to:

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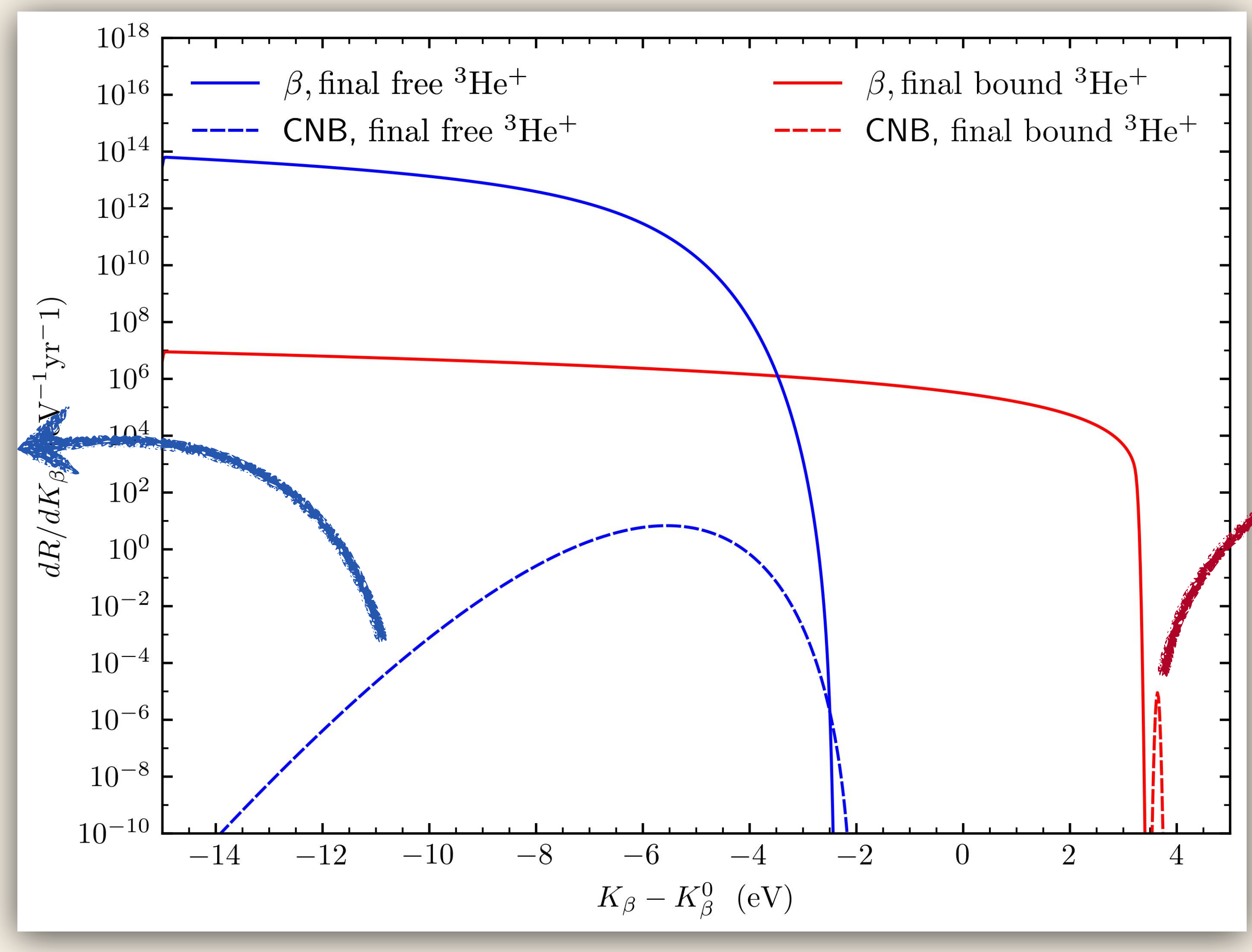
2. Make bound events hugely suppressed



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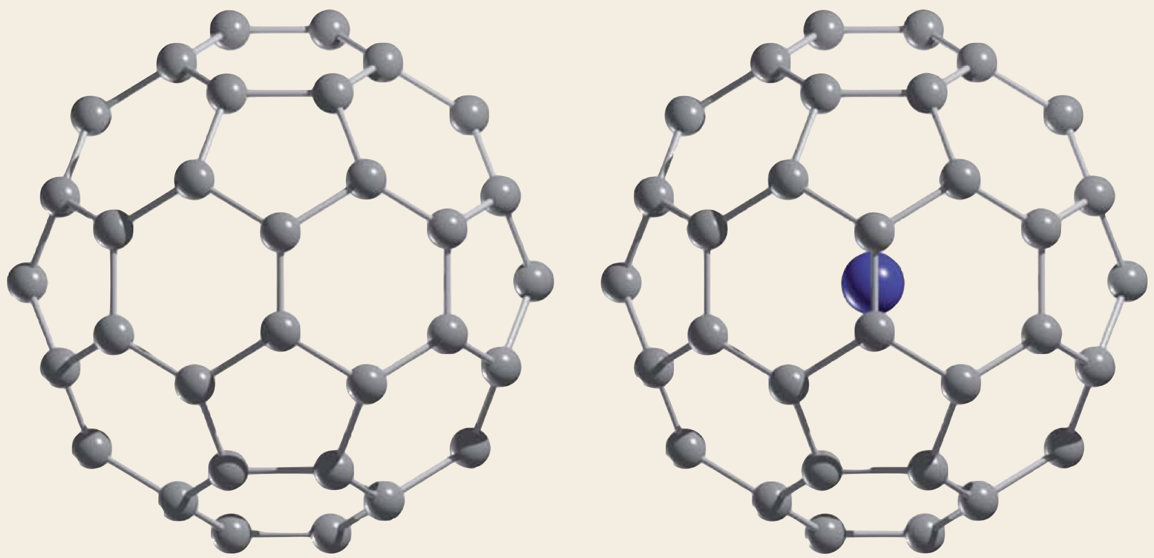
Fullerenes

- We studied the C_{60} molecule



[Jalife et al., Chem. Sci., 2020, 11, 6642-6652]

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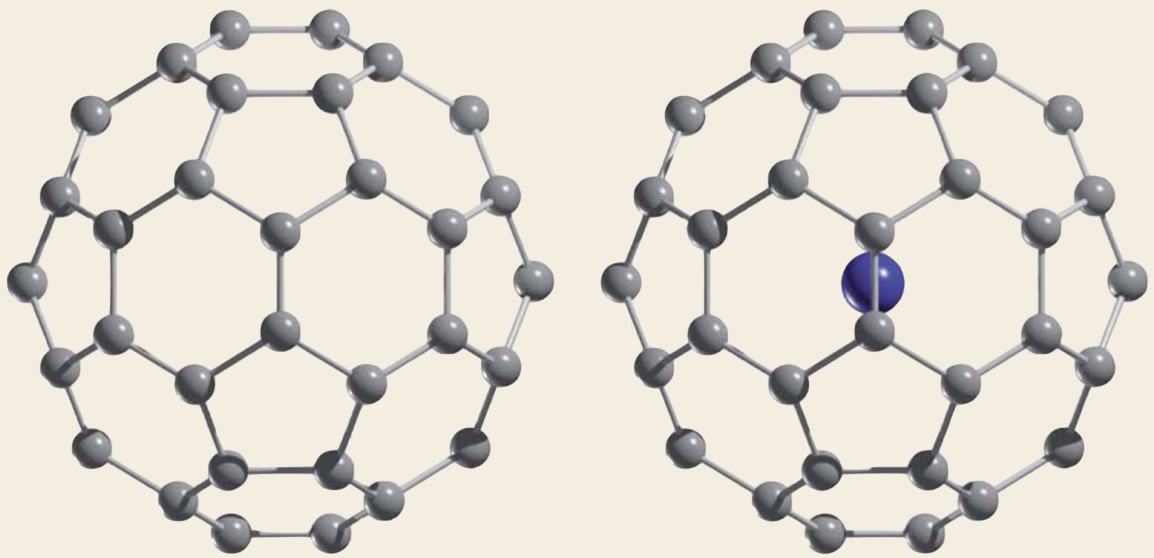

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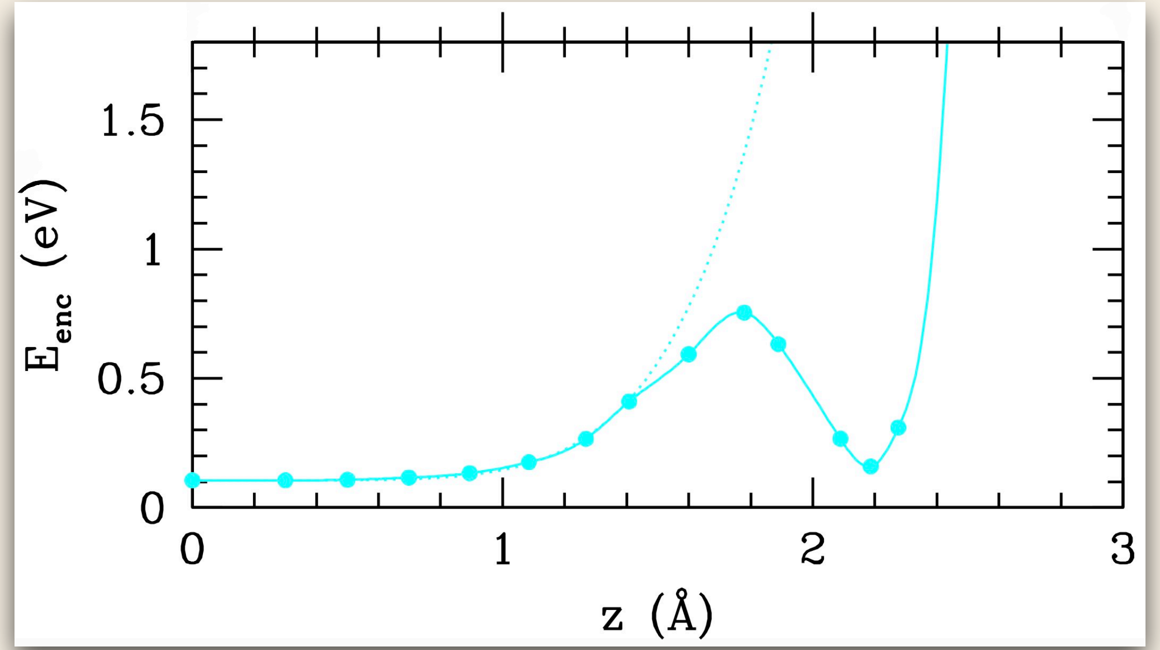
- **Assumptions**:

1) Spherical symmetry

$$V(r) = a_6 r^6 + a_8 r^8$$

2) Binding energy of 1 eV

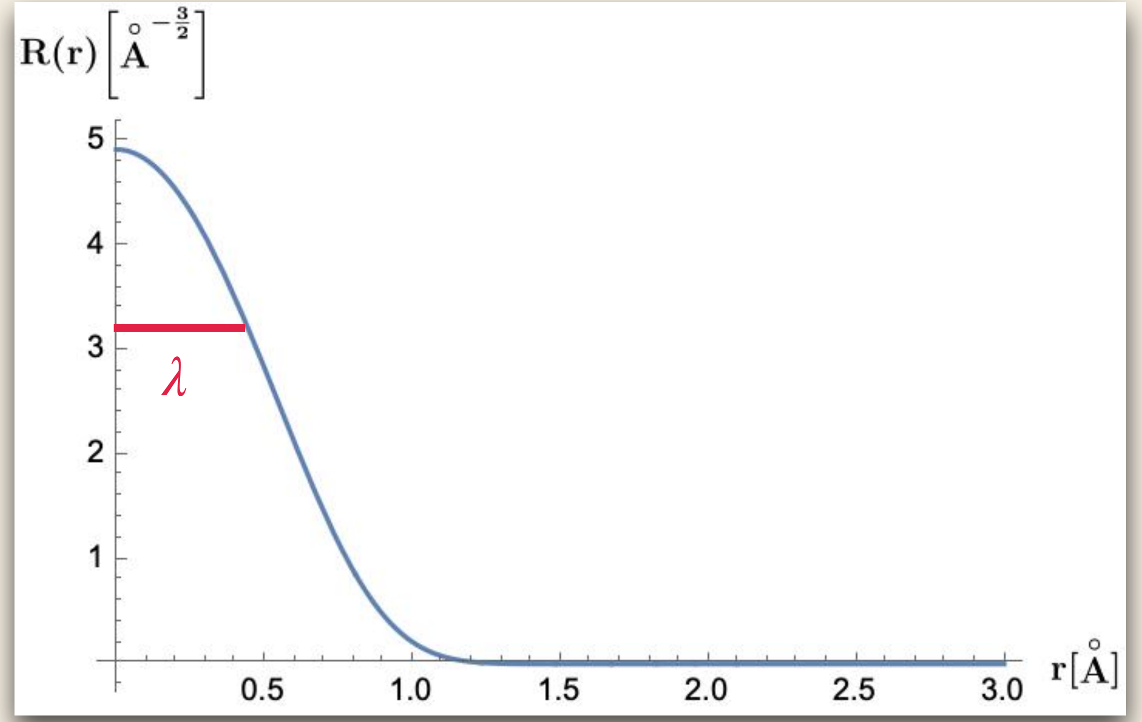


[Tozzini, Menichetti - Private communication]

Effects of C_{60}

- T is more **delocalized**: $\lambda \simeq 0.44$ Å

(with graphane $\lambda \simeq 0.08$ Å)



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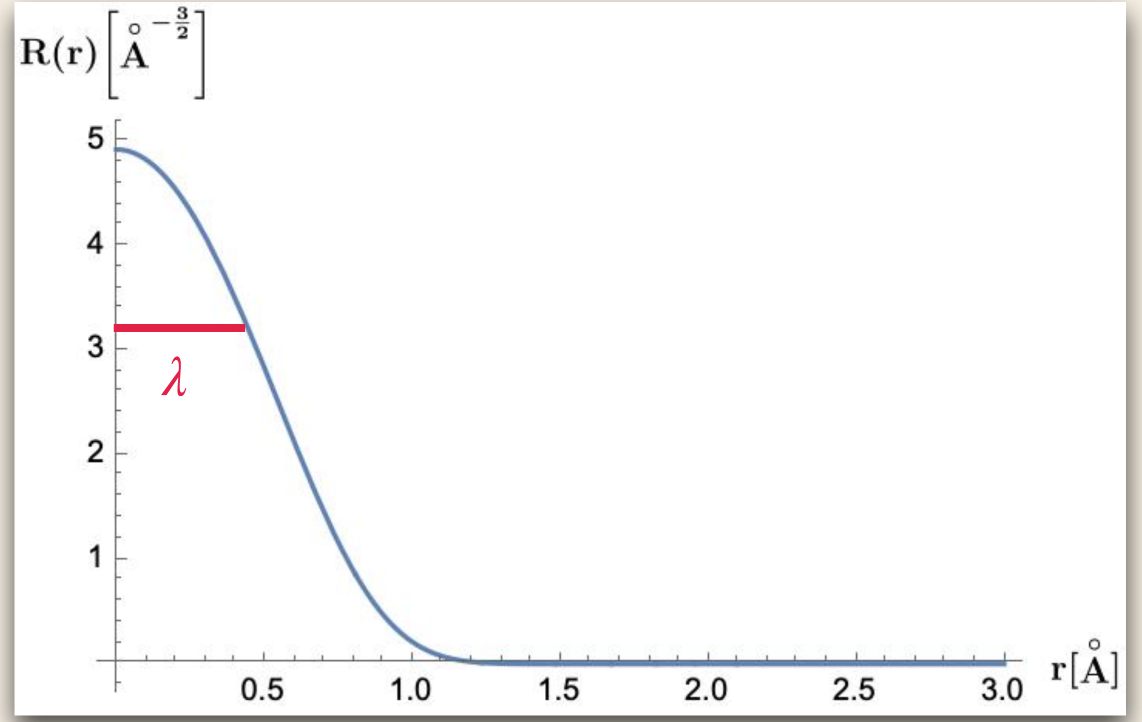

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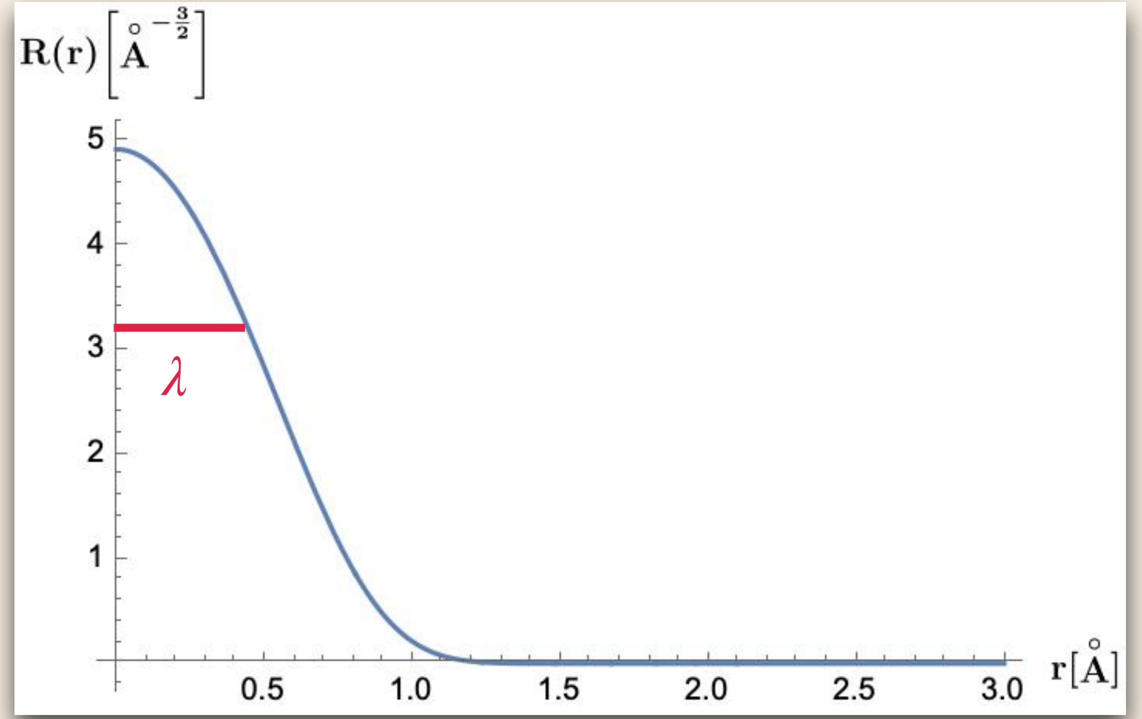

- Final **bound** $^3He^+$: events are even more suppressed: $\lambda p_\beta \simeq 31$

- Final **free** $^3He^+$: does the CNB peak emerge from background of beta decay events?

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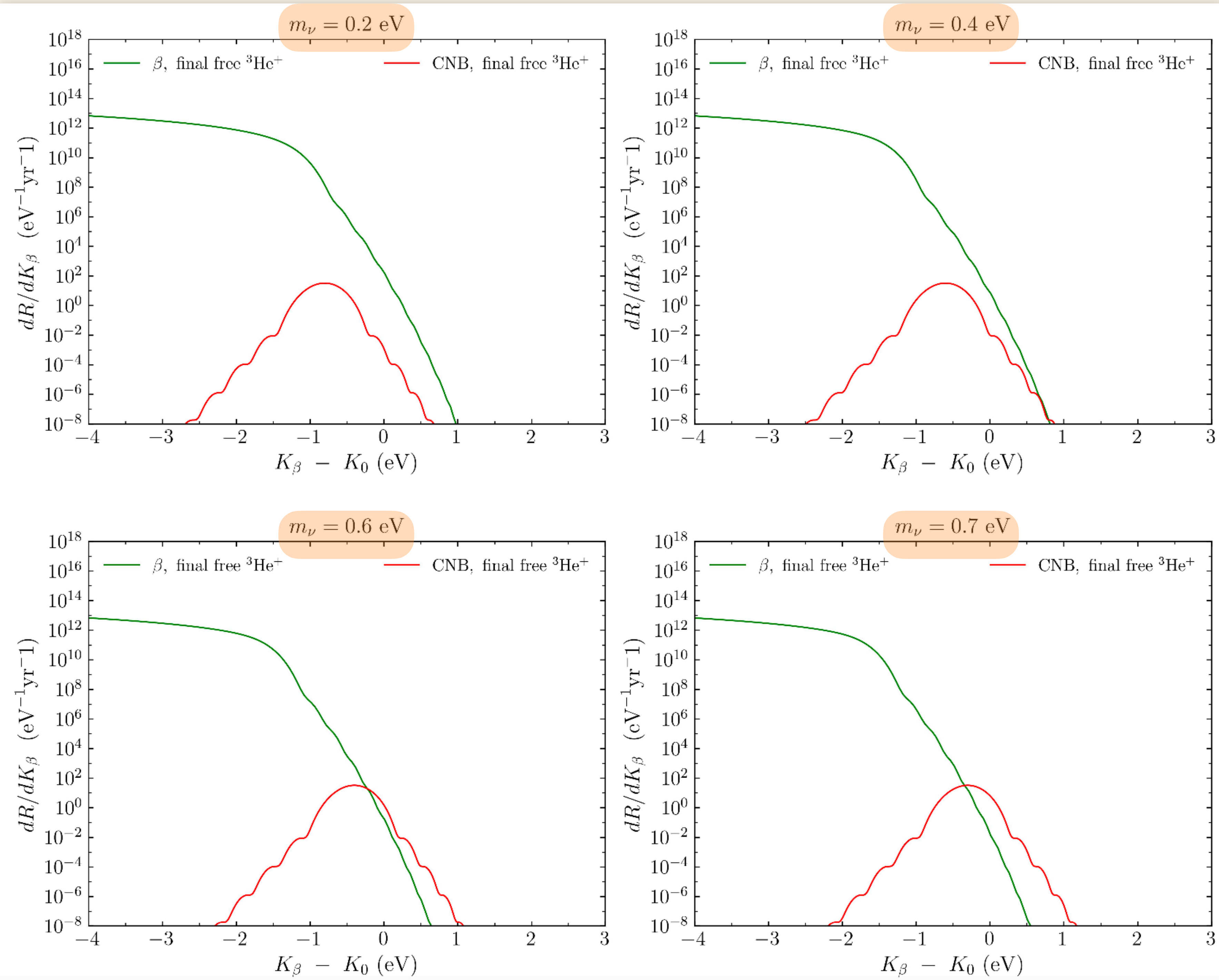

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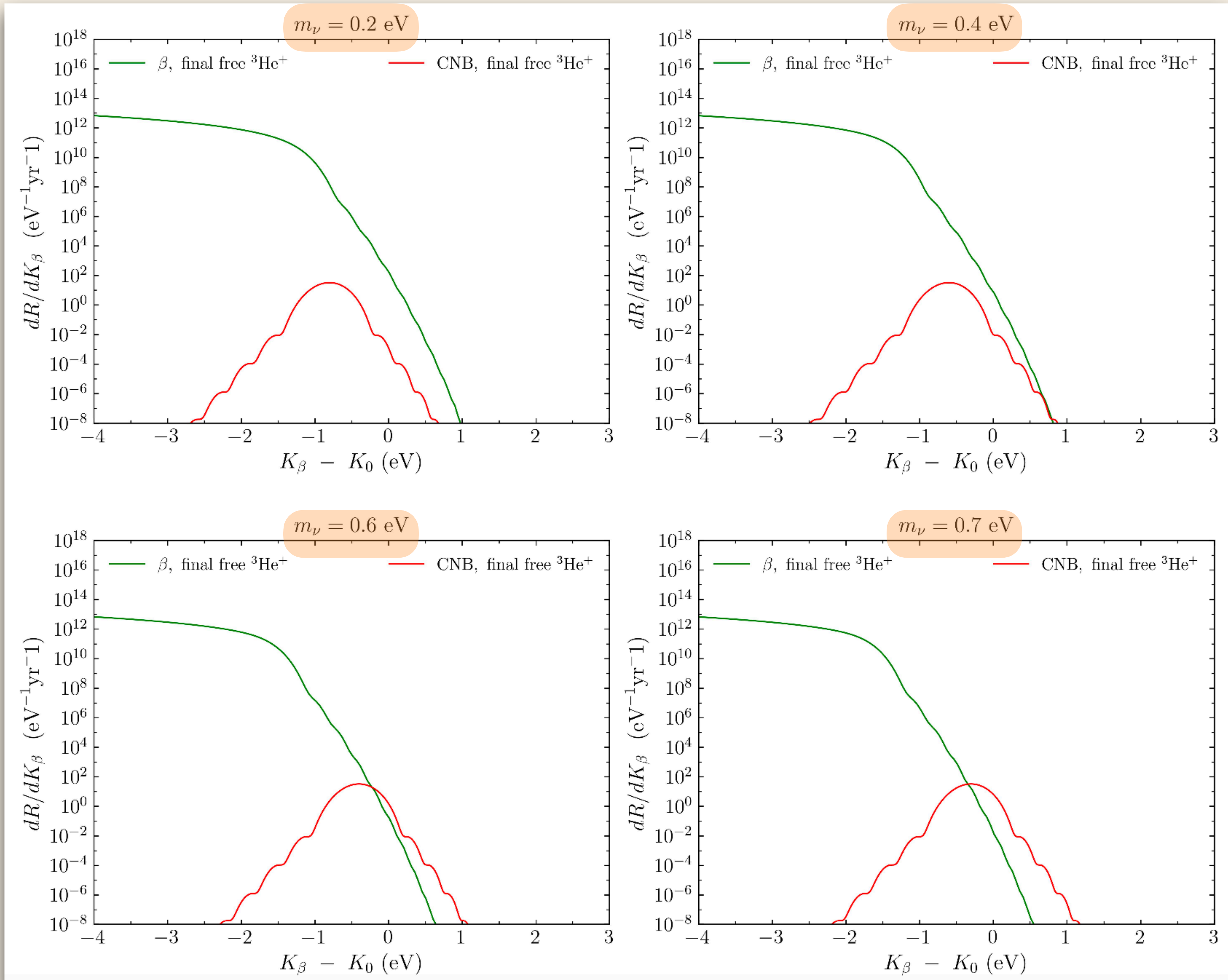

CNB peak becomes more visible as m_ν increases…

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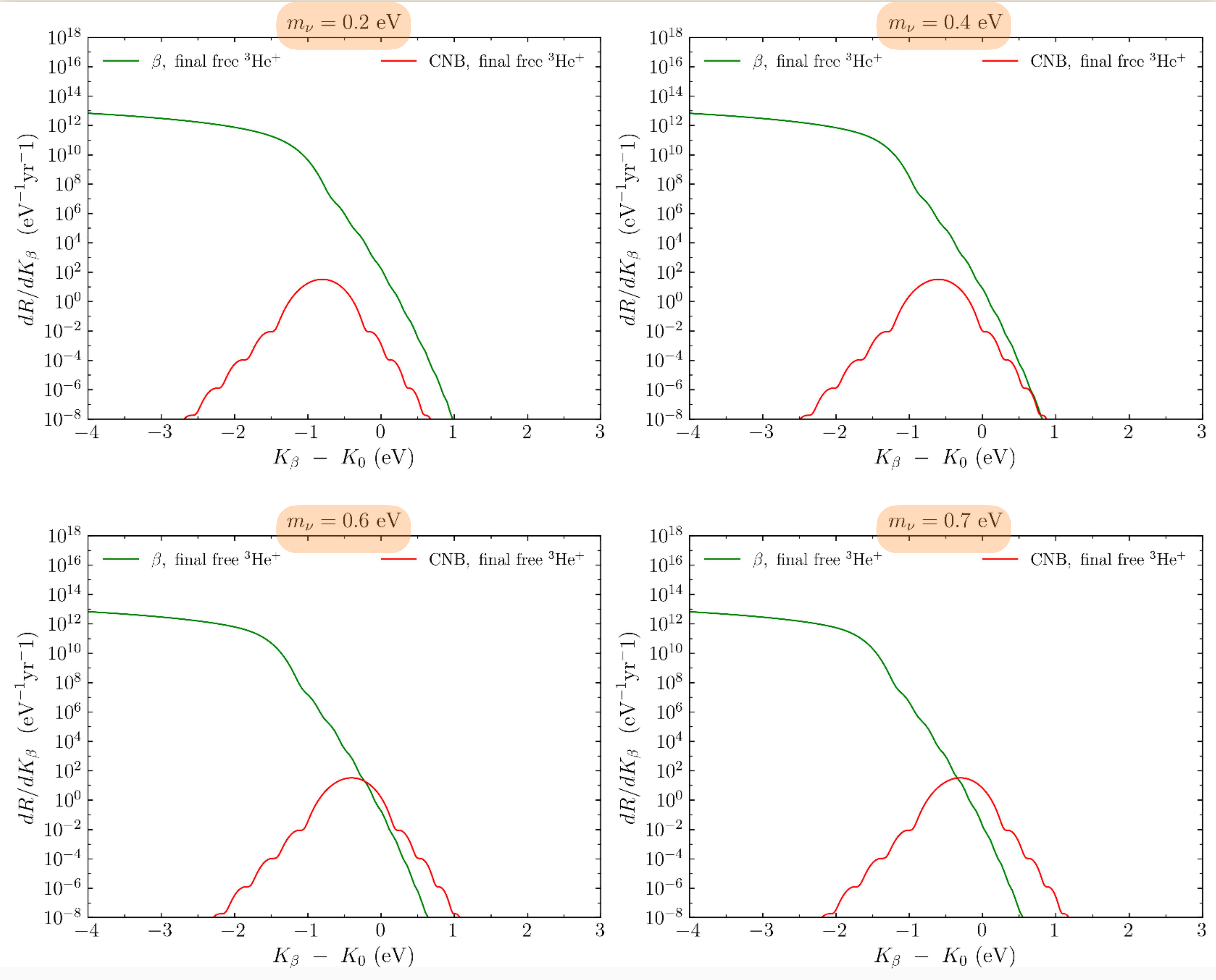

CNB peak becomes more visible as m_ν increases...

... but emerges only for $m_\nu \gtrsim 0.6$ eV

What if we expanded C_{60}?

- C_{60} doesn't delocalize tritium enough

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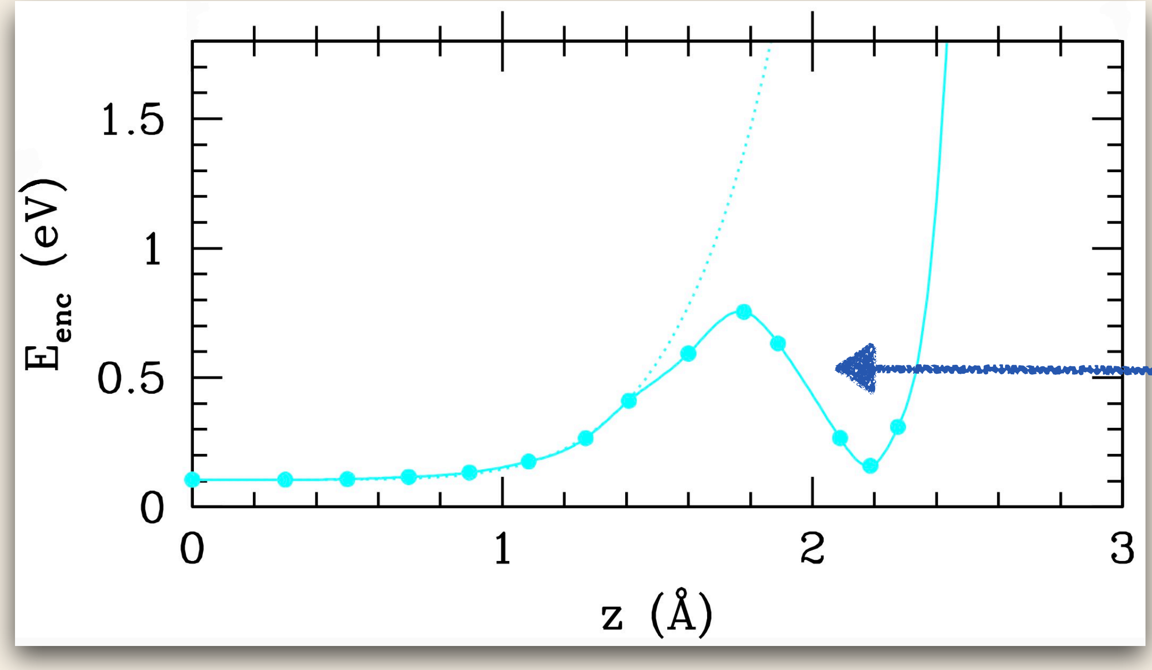

[Tozzini, Menichetti - Private communication]

In the lab, this could be achieved by flattening the potential hill

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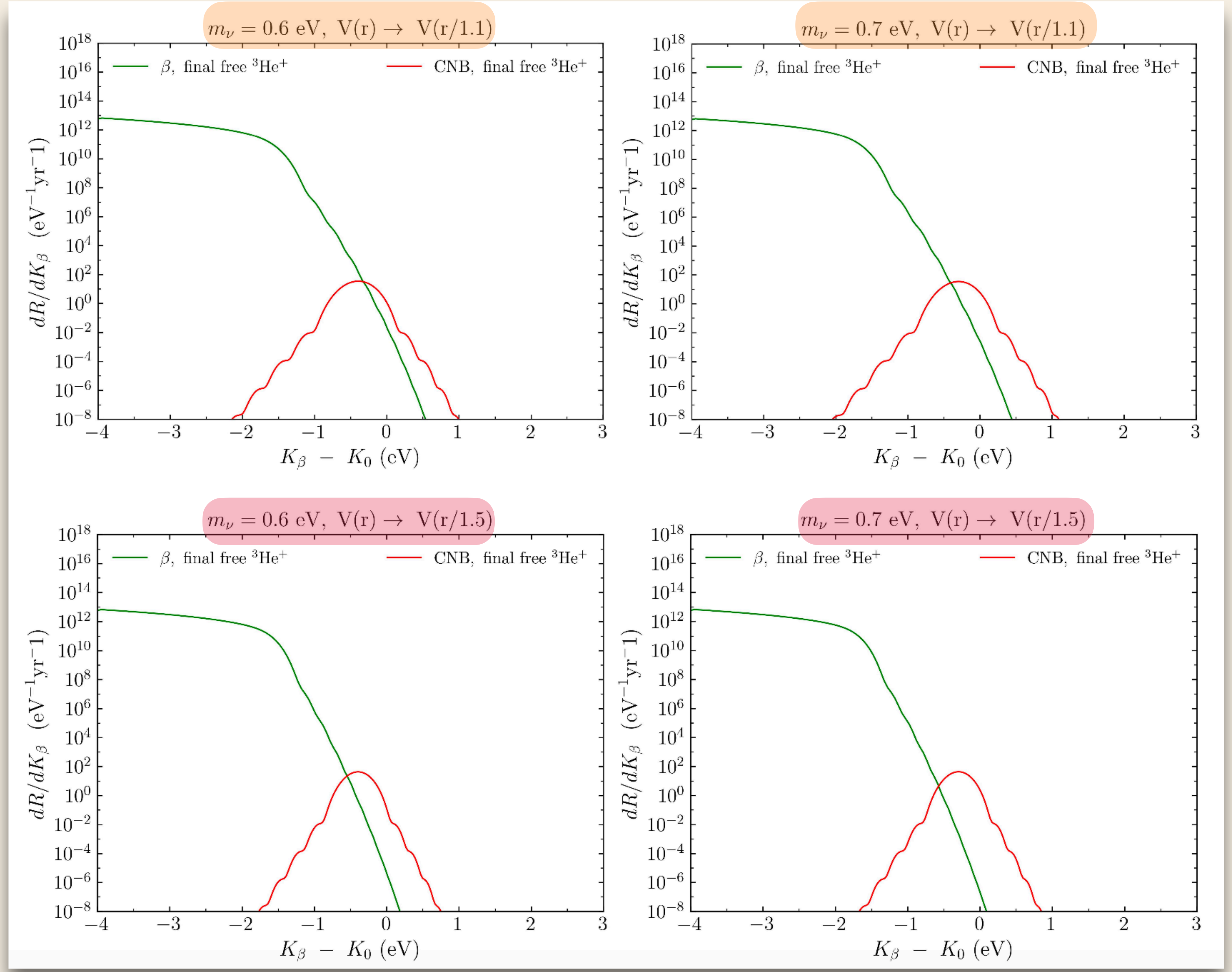

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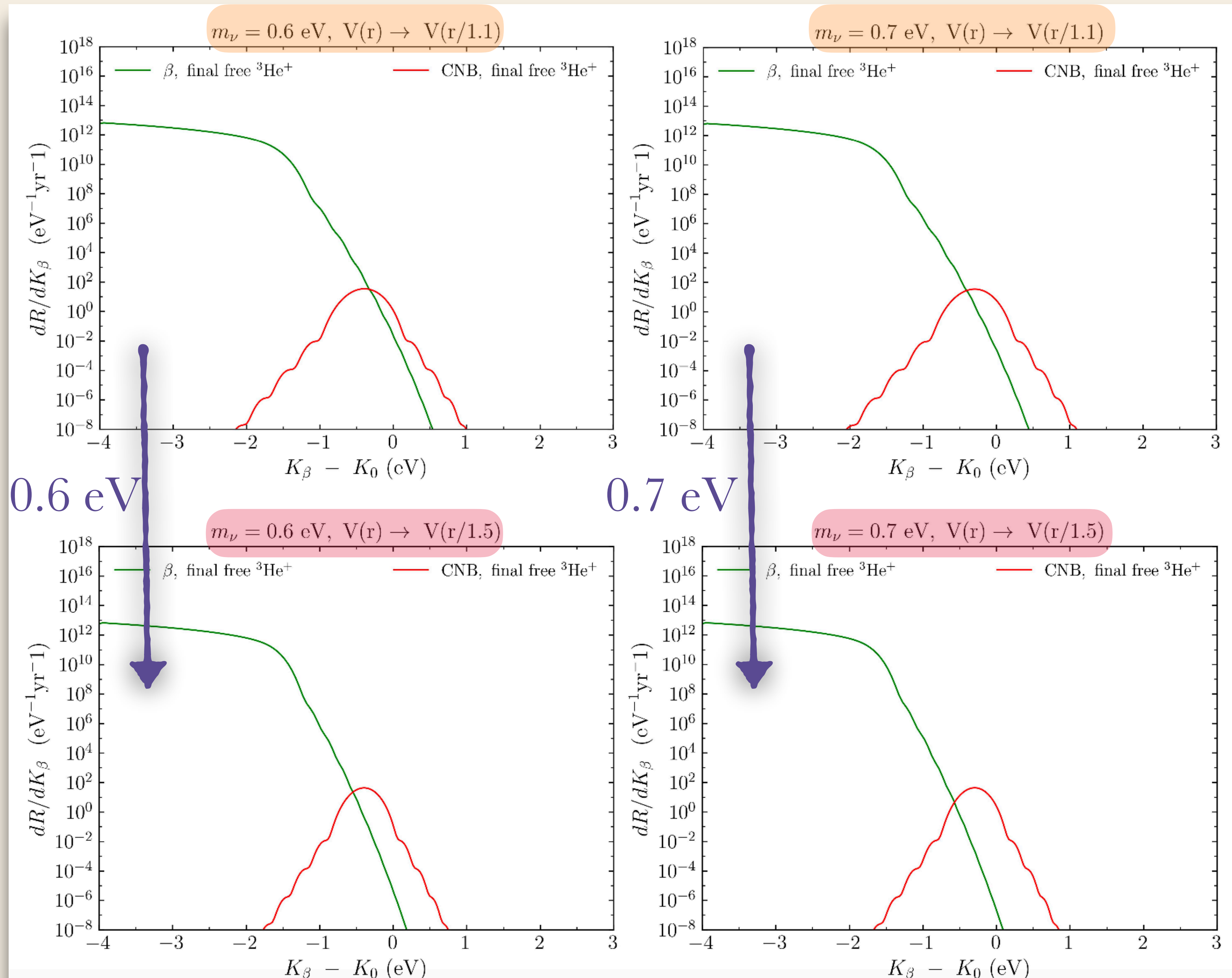

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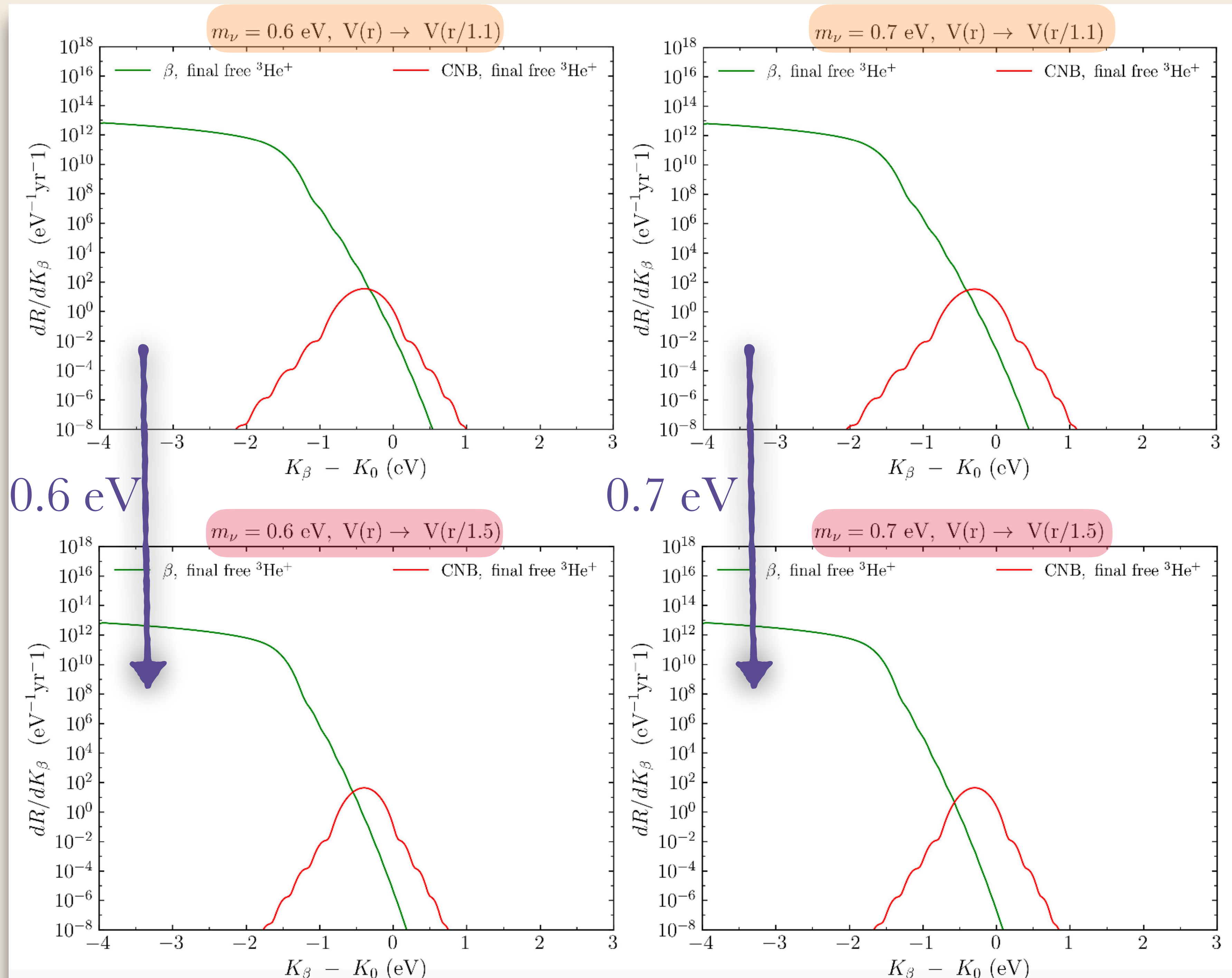

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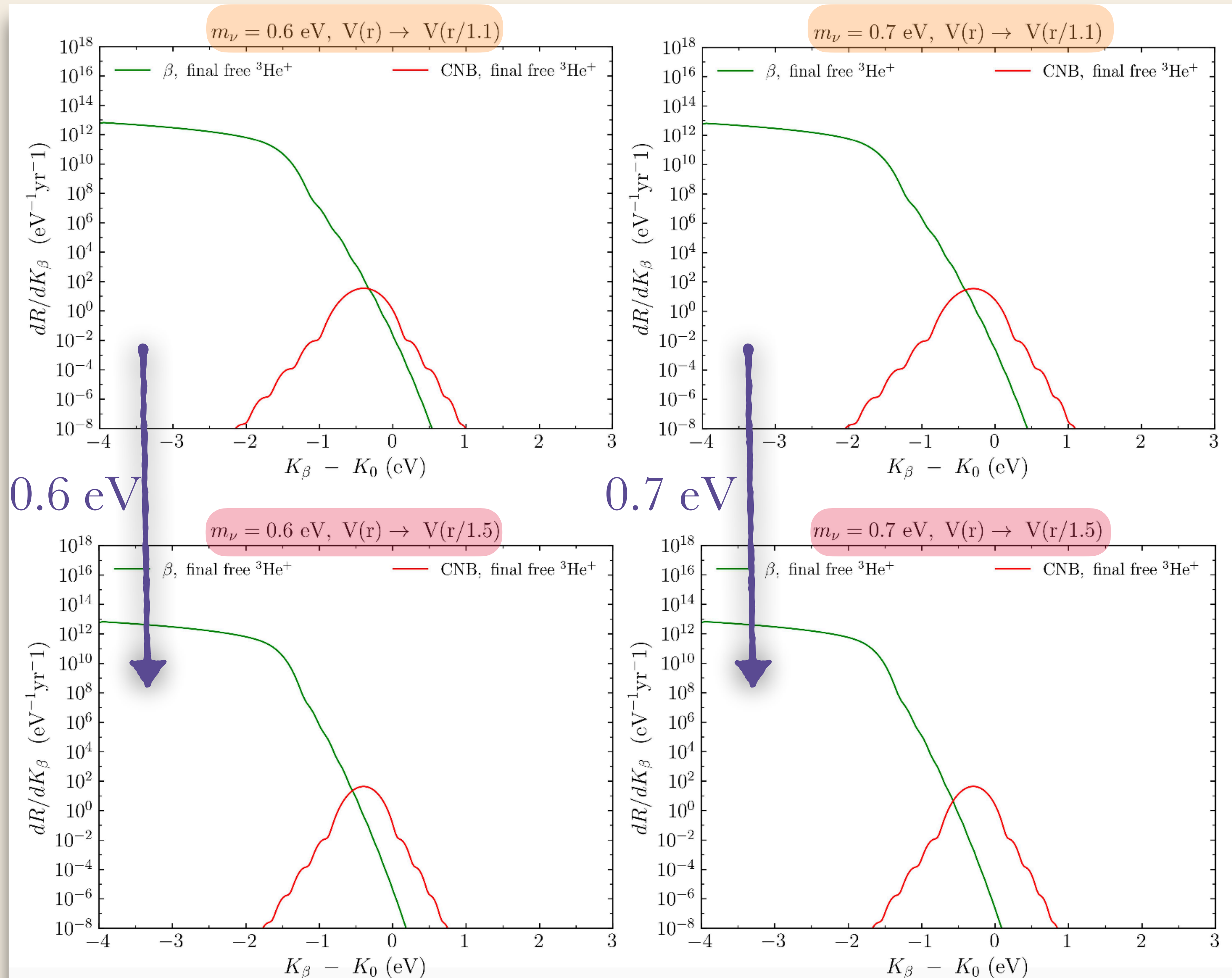

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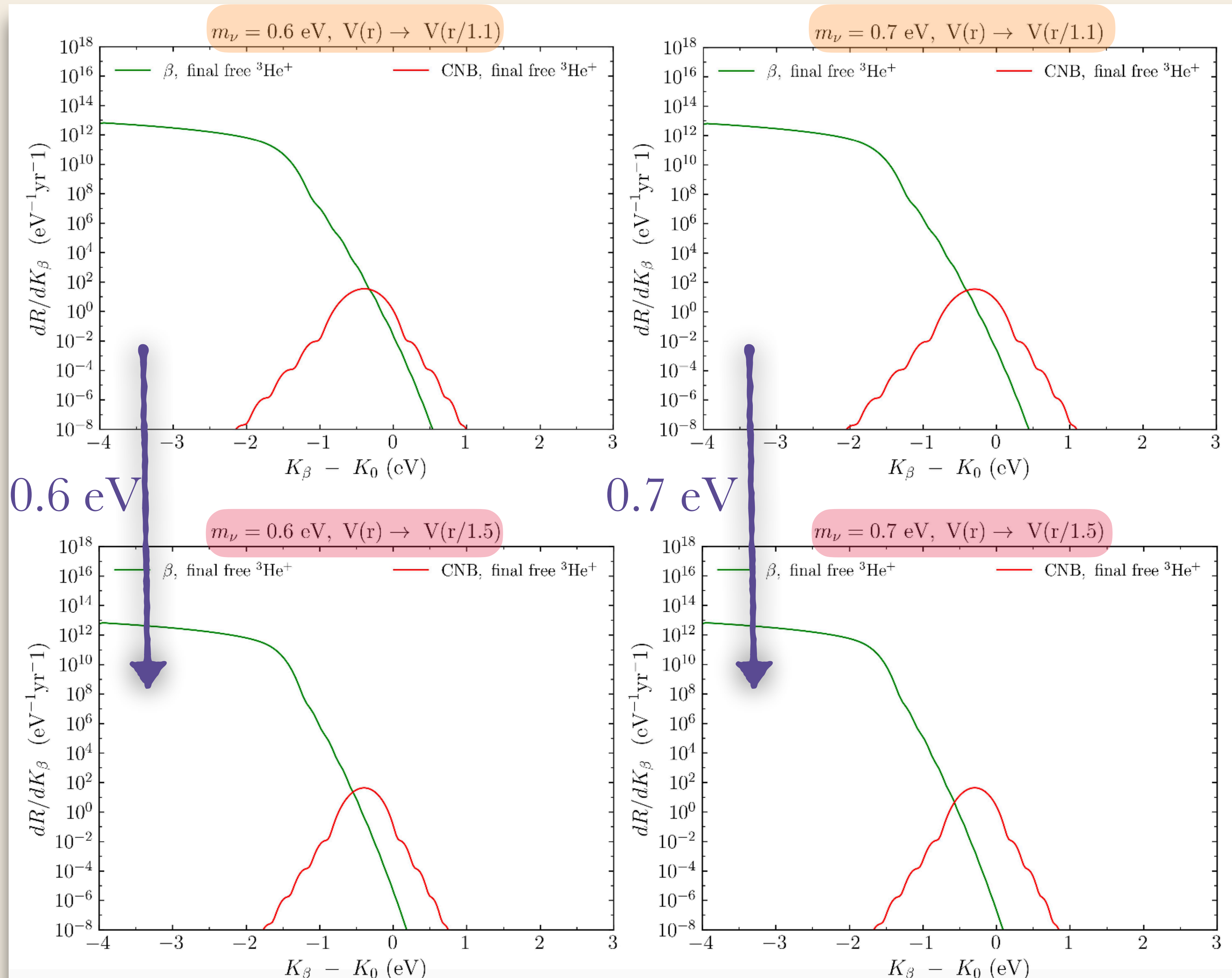

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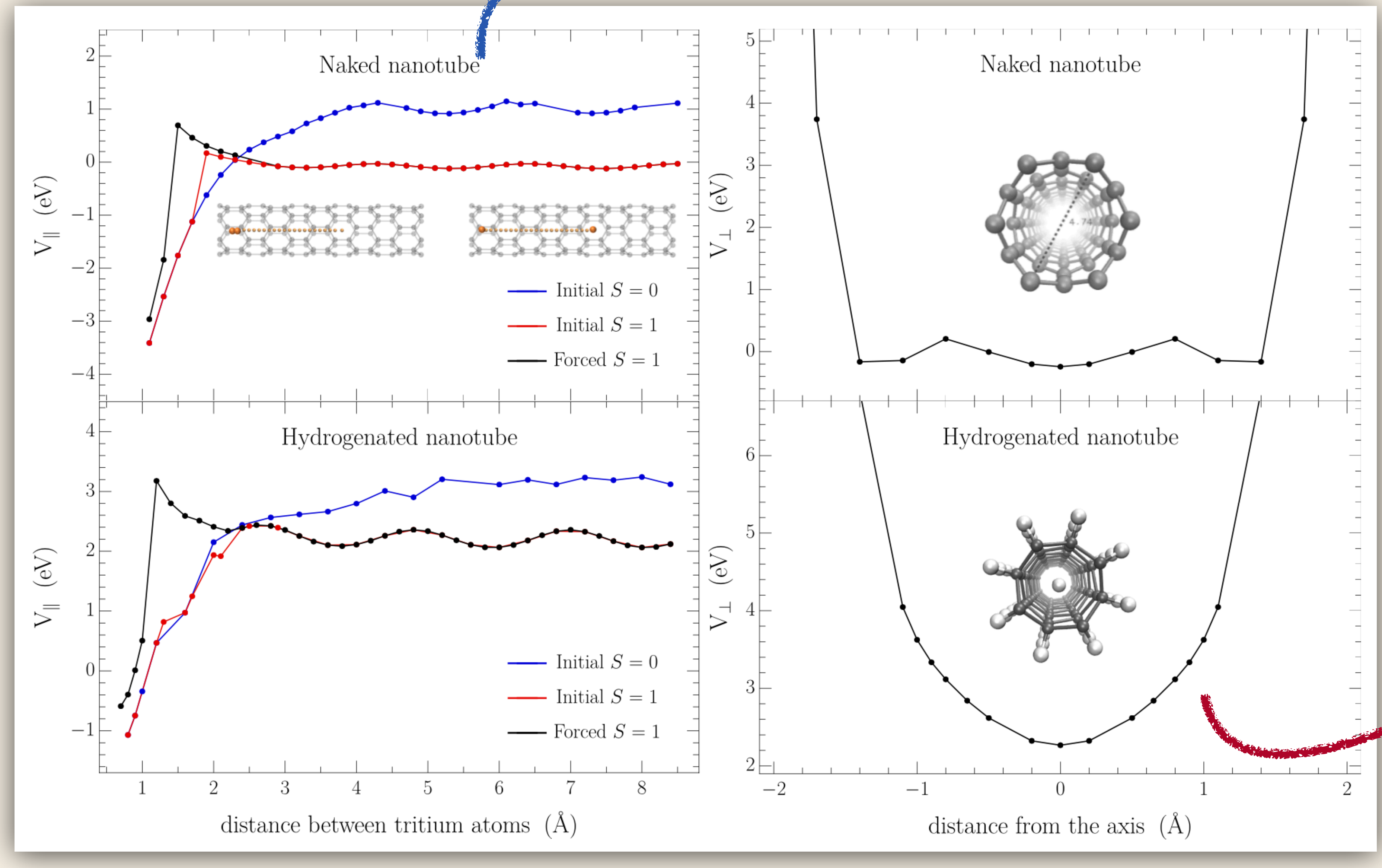
Only partially visible ✘

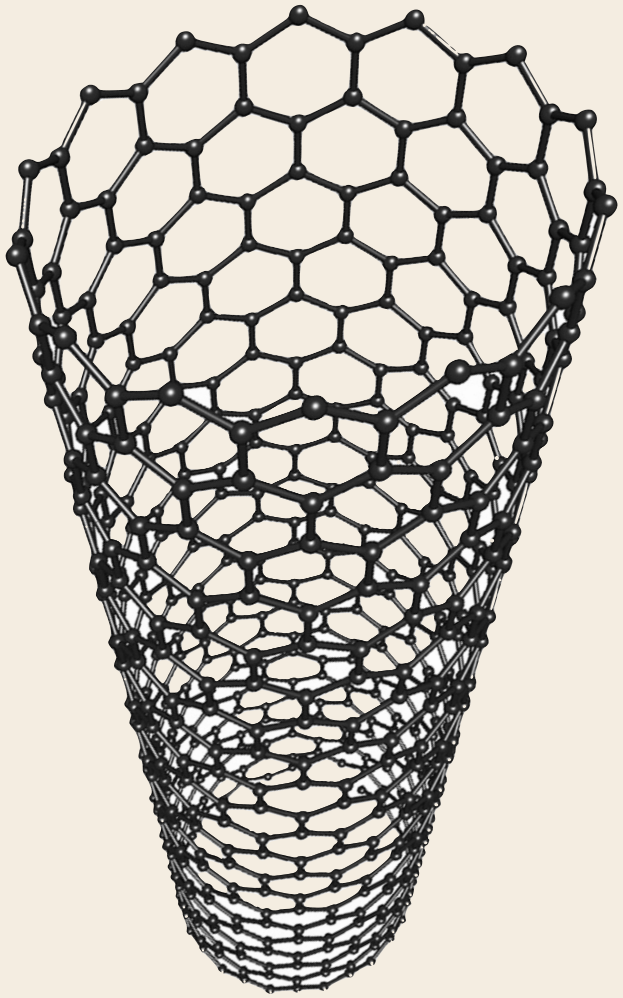
Other ideas?

- **Carbon nanotubes**

Free along axis



[PTOLEMY — PRD 2022, 2203.11228]



Bound in the other directions

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