Turbulence and Supernova Neutrinos

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SN Neutrinos

There has been rapid progress over the past few years in the understanding of how neutrinos propagate through a supernova.

- In 2003 Schirato & Fuller showed that the evolving density profile - aka the explosion - imprints itself on ν through the MSW effect.

Schirato & Fuller, arXiv:astro-ph/0205390

- In 2006 Duan *et al.* solved the multi-angle neutrino self-interaction problem in supernova.

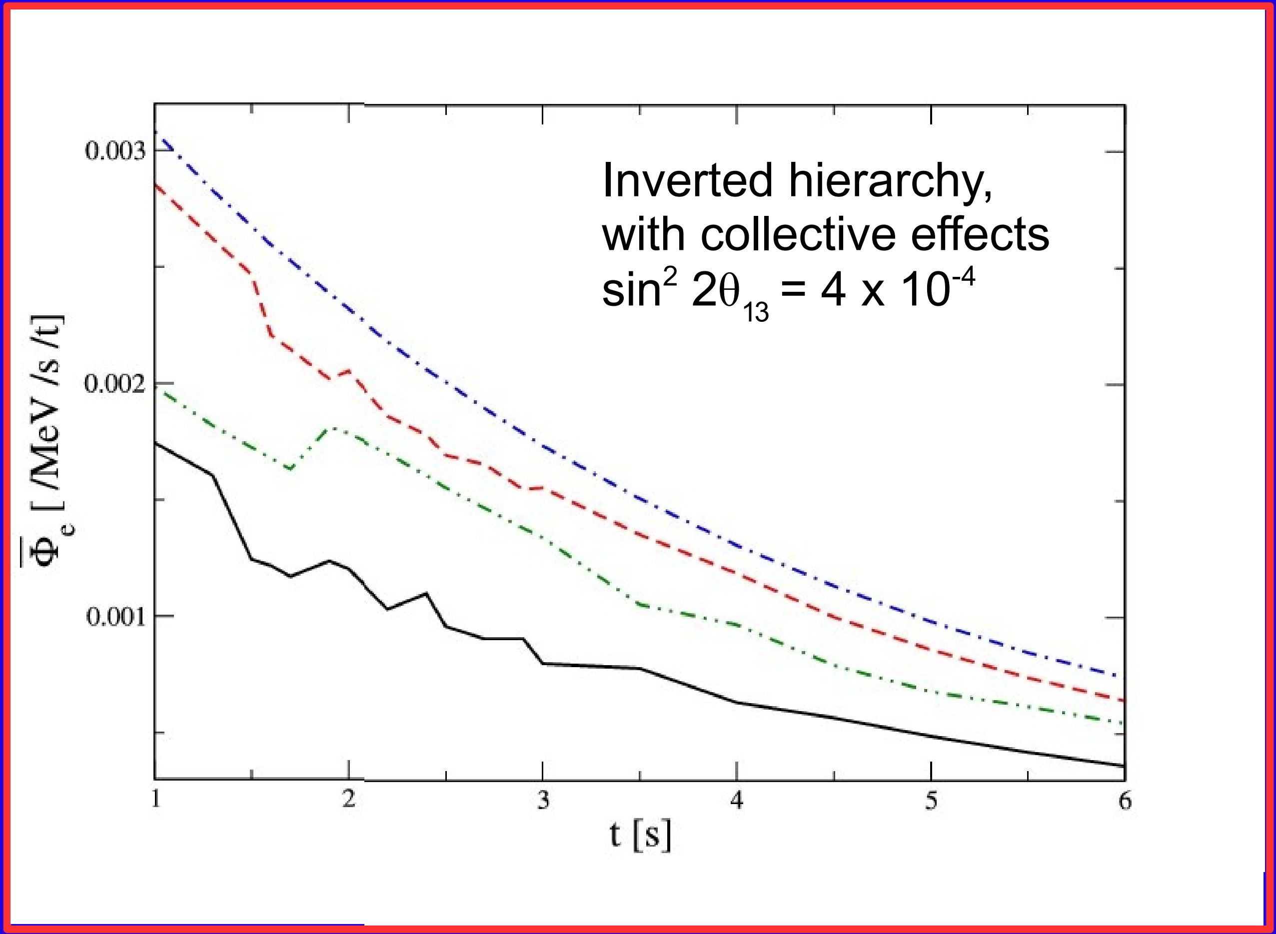
Duan, Fuller, Carlson & Qian, PRL, **97**, 241101 (2006)

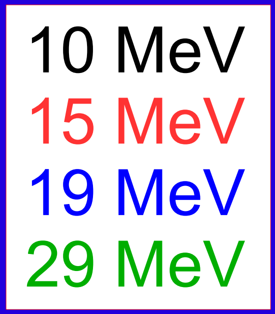
Duan, Fuller, Carlson & Qian, PRD, **74**, 105014 (2006)

For a review see Duan & Kneller, JPhG, **36**, 113201(2009).

The Signal from the next Galactic SN

We can construct expected signals in a water Cerenkov detector, such as SuperK, and look for signatures of the hierarchy, θ_{13} , θ_{23} , CP phase δ, etc. including SUSY signatures.



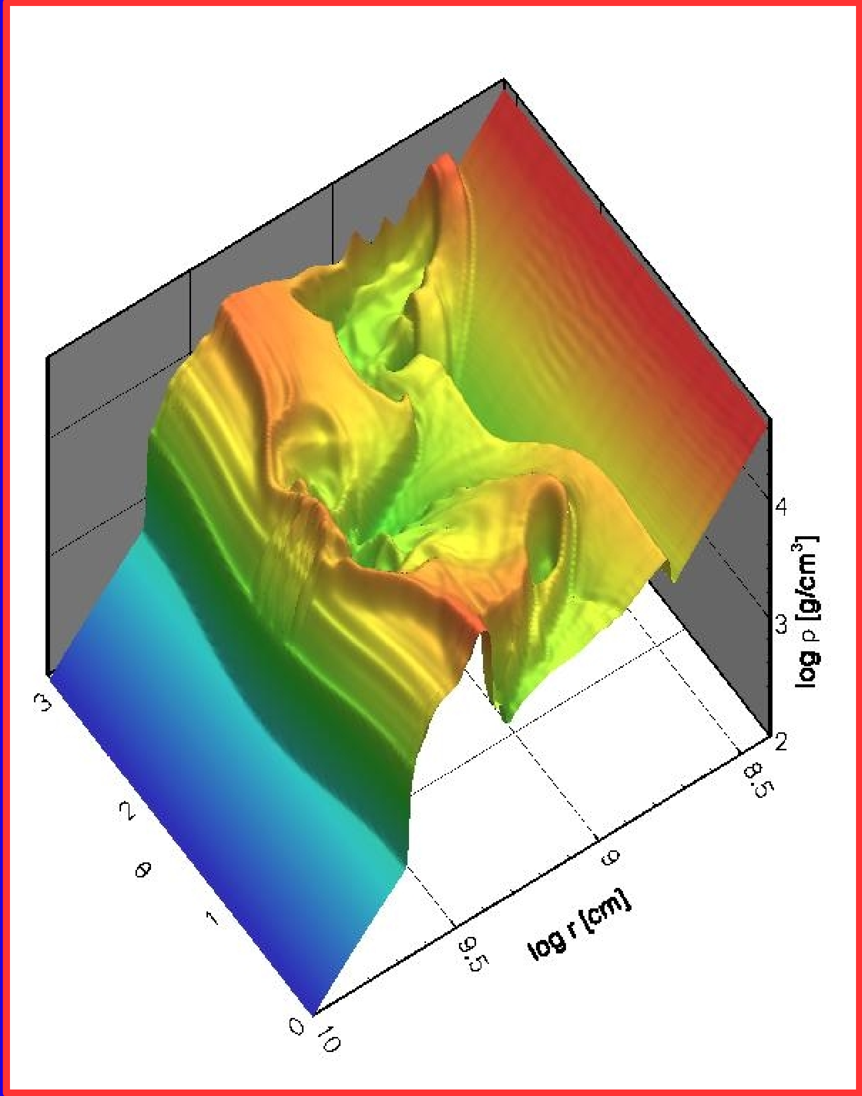


Gava, Kneller, Volpe & McLaughlin, PRL, **103**, 071101 (2009)

Turbulence

Multi dimensional supernova simulations are aspherical.

Turbulence is generated by non-radial flows through distorted shocks, etc...



Kneller, McLaughlin & Brockman, PRD, **77**, 045023 (2008)

Neutrinos and turbulence.

We want to determine the neutrino state at an earlier time from the signal we observe.

If the neutrino has passed through turbulence then its final state is exquisitely sensitive to the profile.

Two neutrinos with similar energies – separated by ~ 10keV or greater – end up in uncorrelated final states.

Two neutrinos with the same energy but emitted at different times (could) also end up in very different final states.

When we include inherent resolution of the detection process, the detector resolution and the necessity of binning in time and energy, the net result is that we expect equilibration of the fluxes for each flavour.

Equilibrated fluxes do not permit inversion of the signal.

The expectation is that turbulence ruins our neutrino vision.

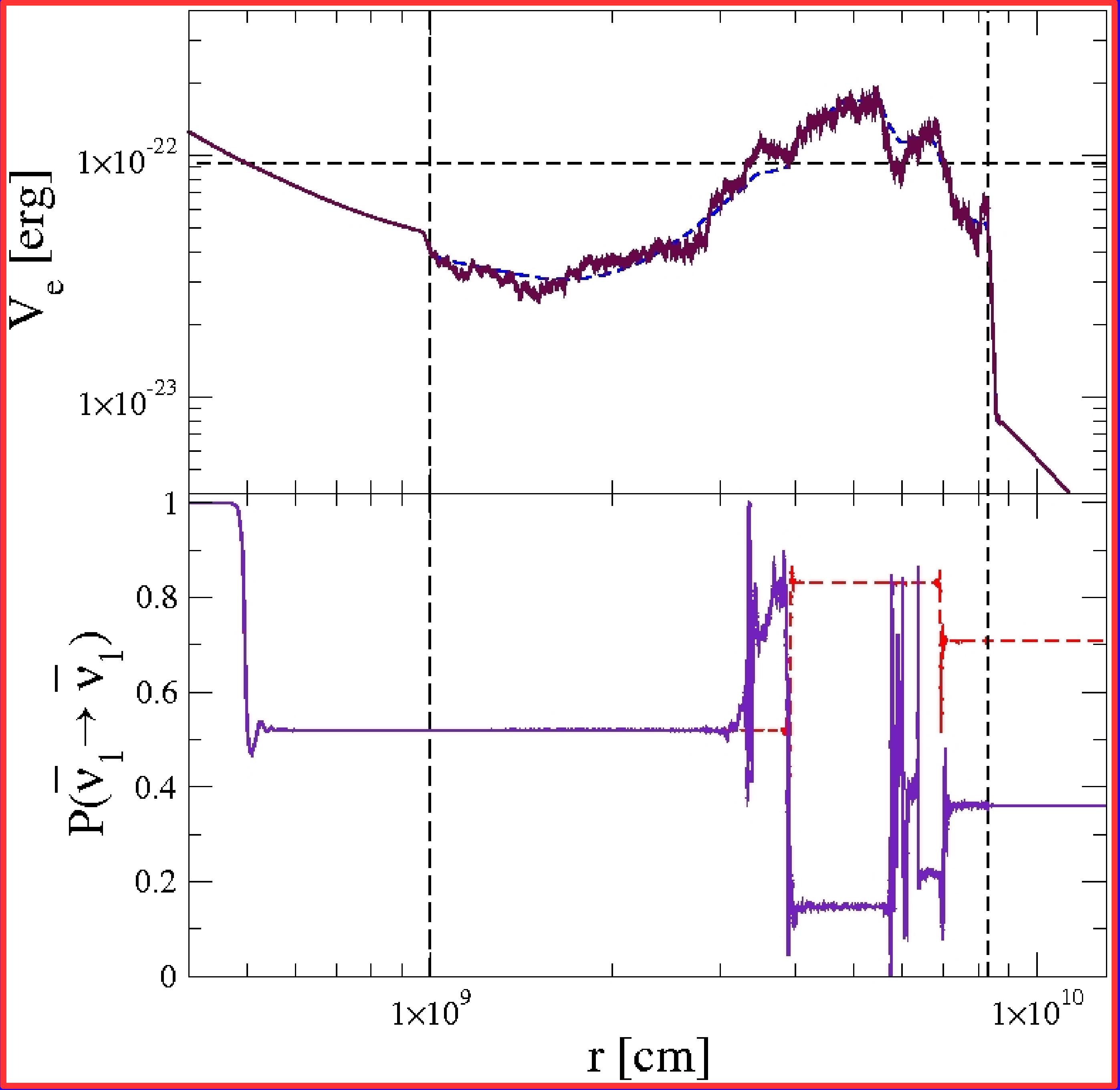
Adding turbulence

We can take a supernovae profile from a 1D hydrodynamical calculation and add turbulence to it.

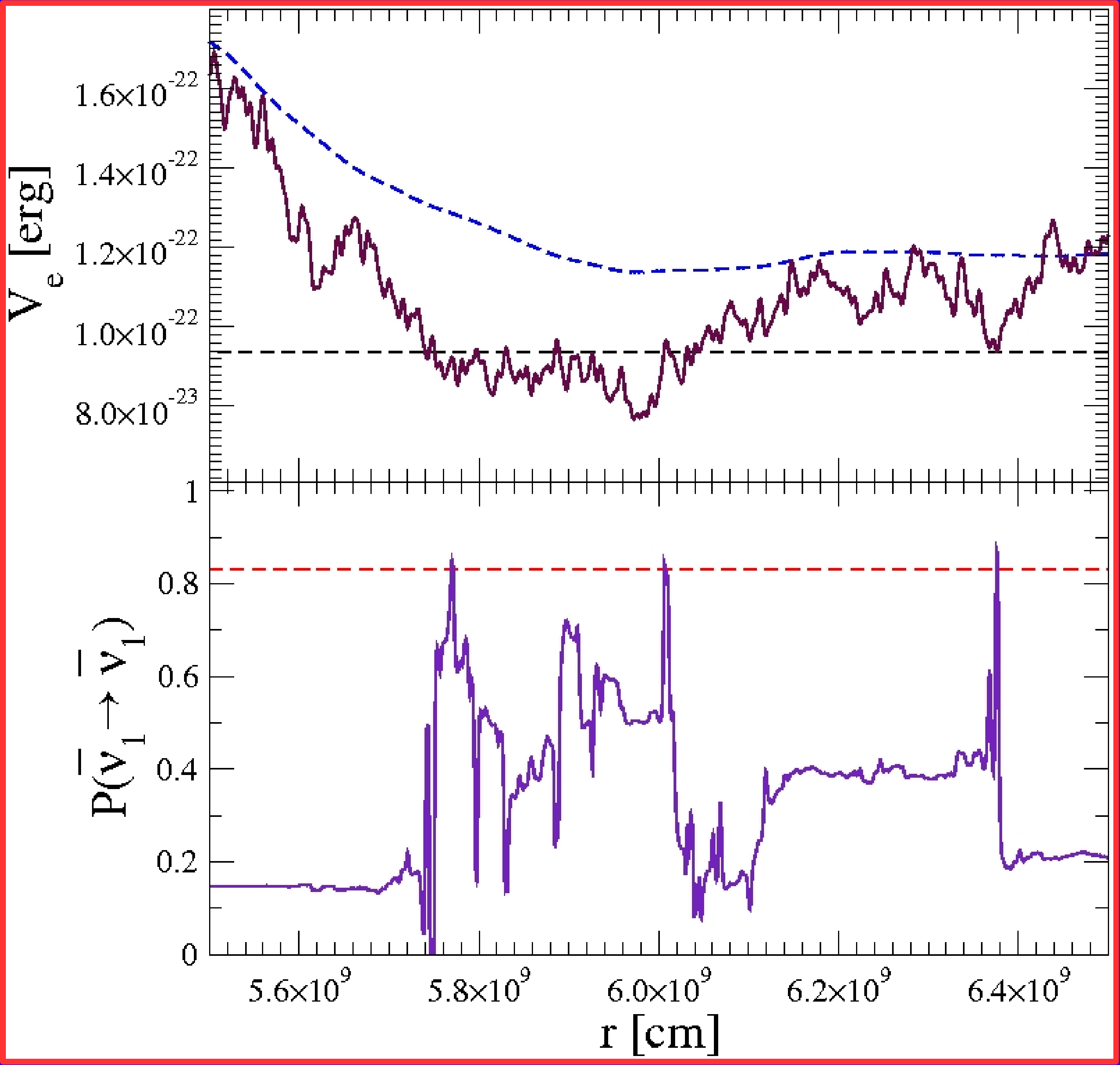
We then run neutrinos through the profile and determine the final states.

We do this many times and construct an ensemble of results.

From the ensemble we can determine the average final state, the variance etc.



Inverse Hierarchy, E = 25 MeV, $\sin^2 2\theta_{13} = 4 \times 10^{-4}$



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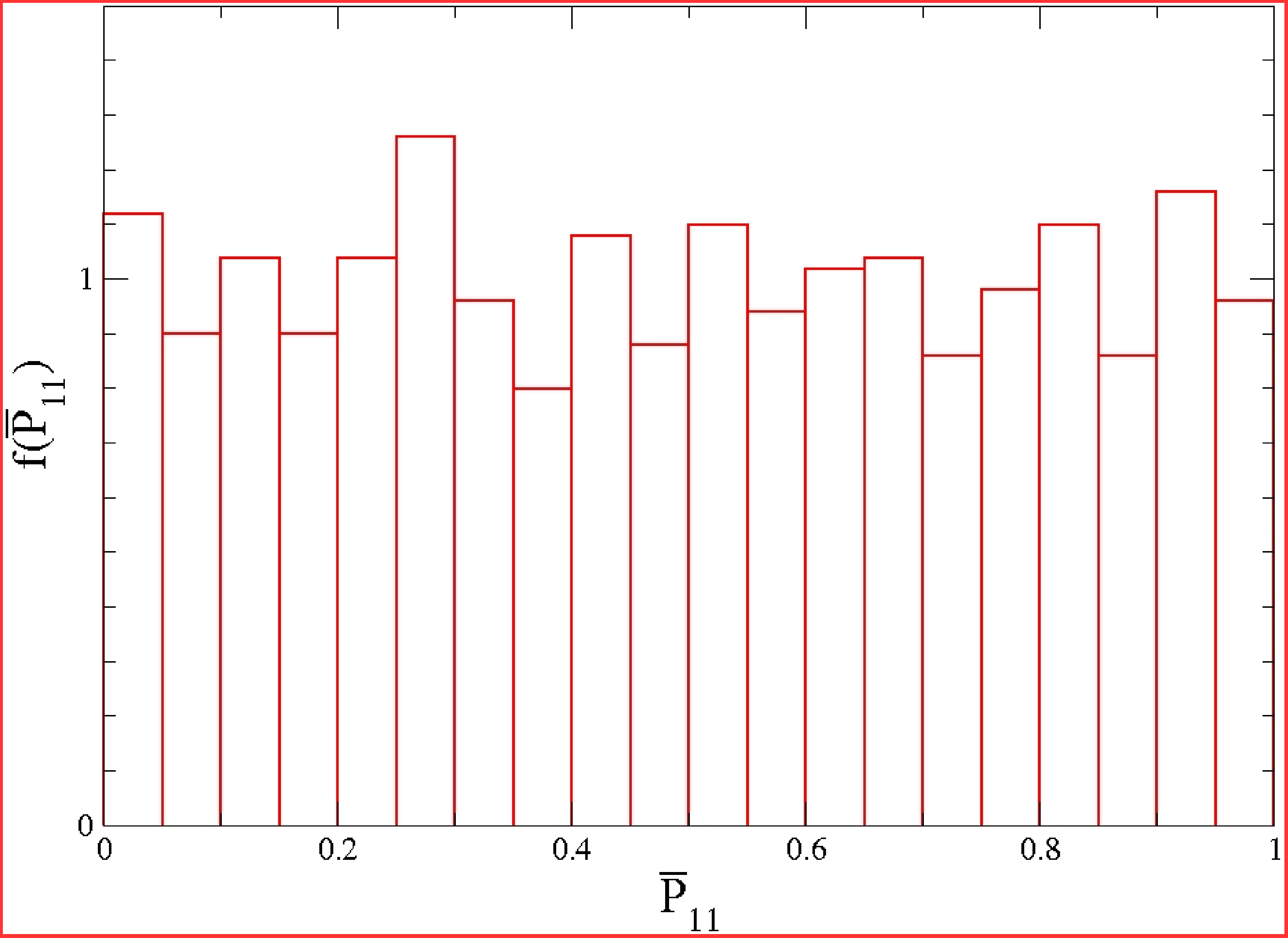

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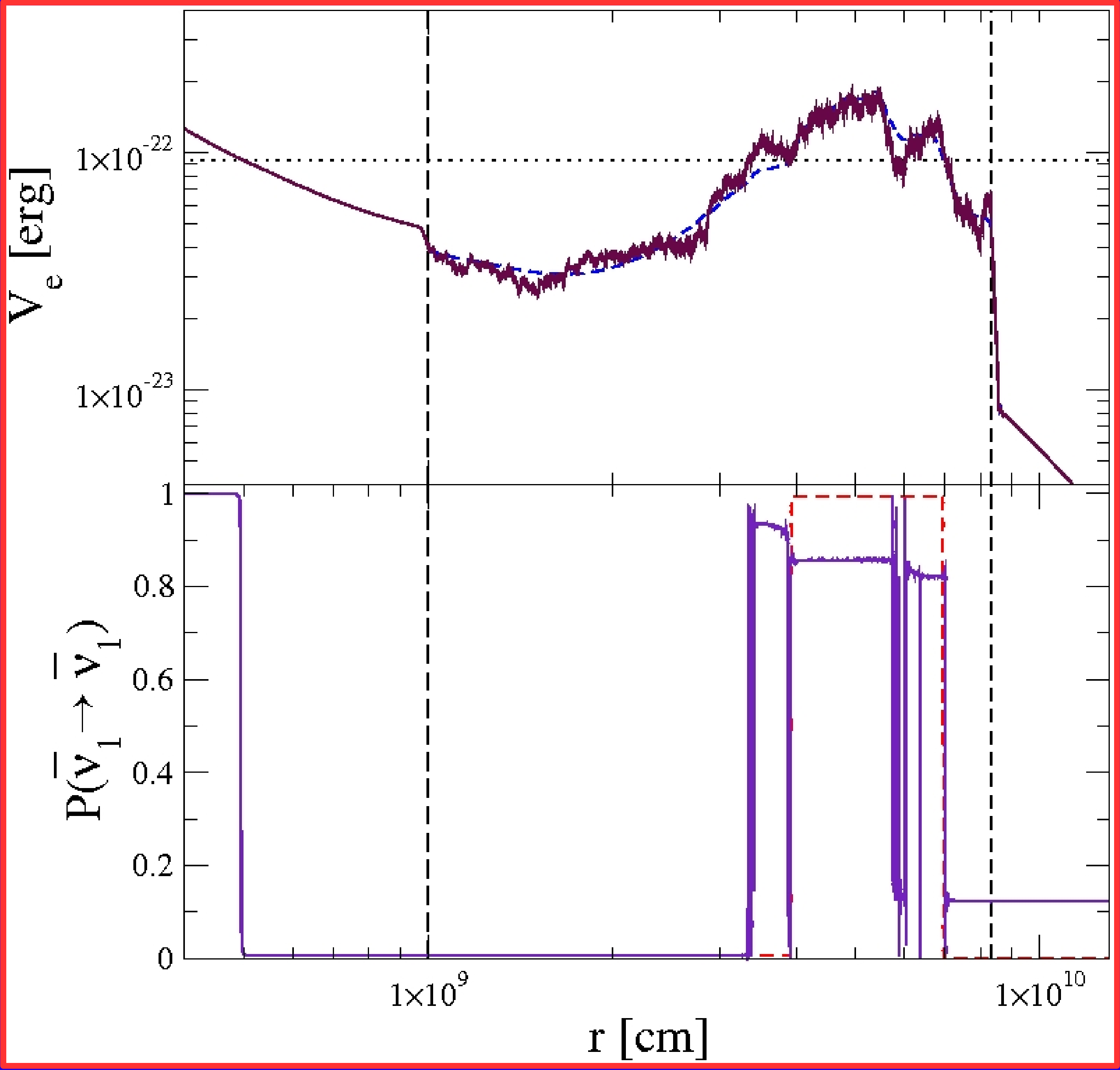

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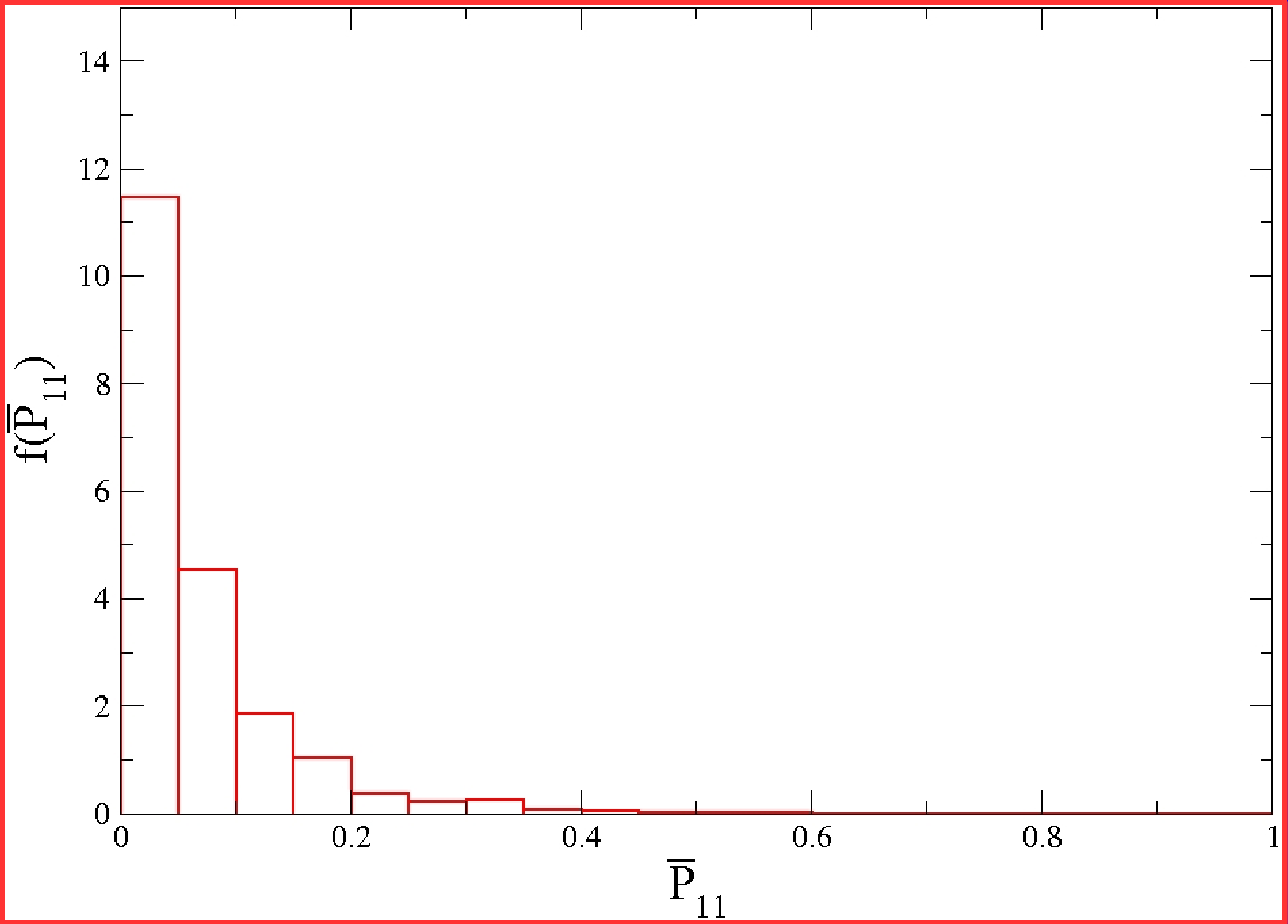

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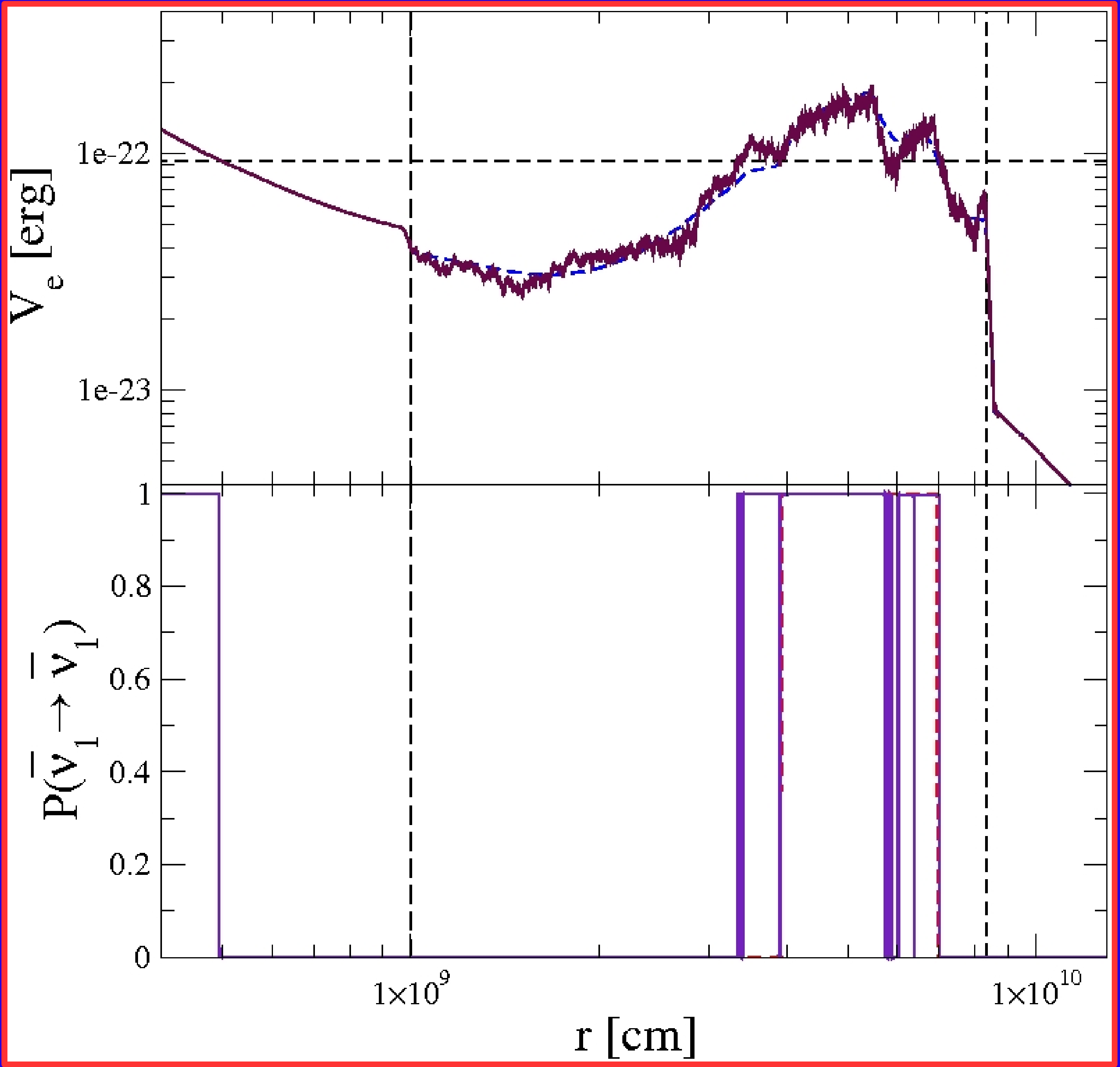
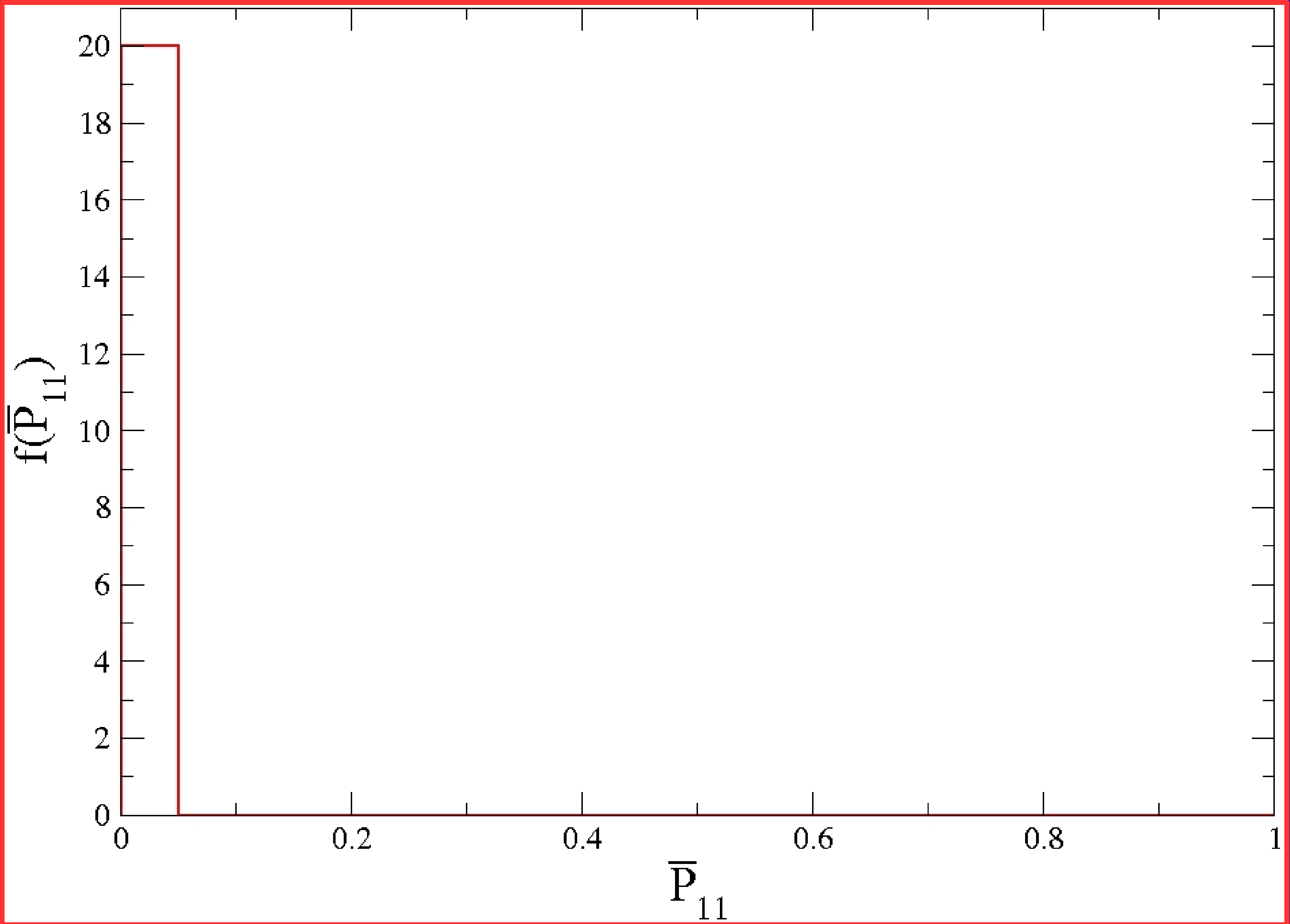


Inverse Hierarchy, E = 25 MeV, $\sin^2 2\theta_{13} = 4 \times 10^{-8}$



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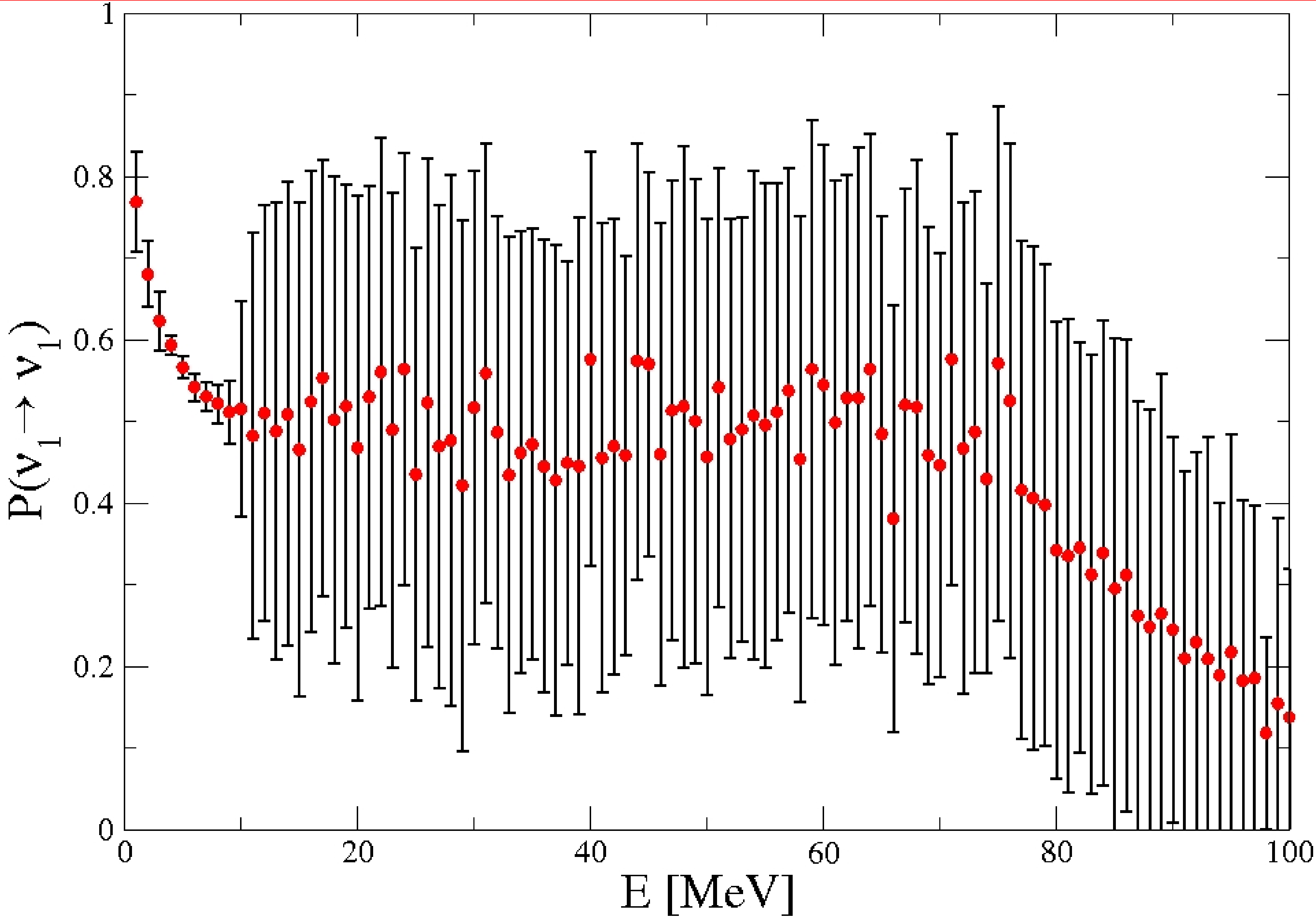

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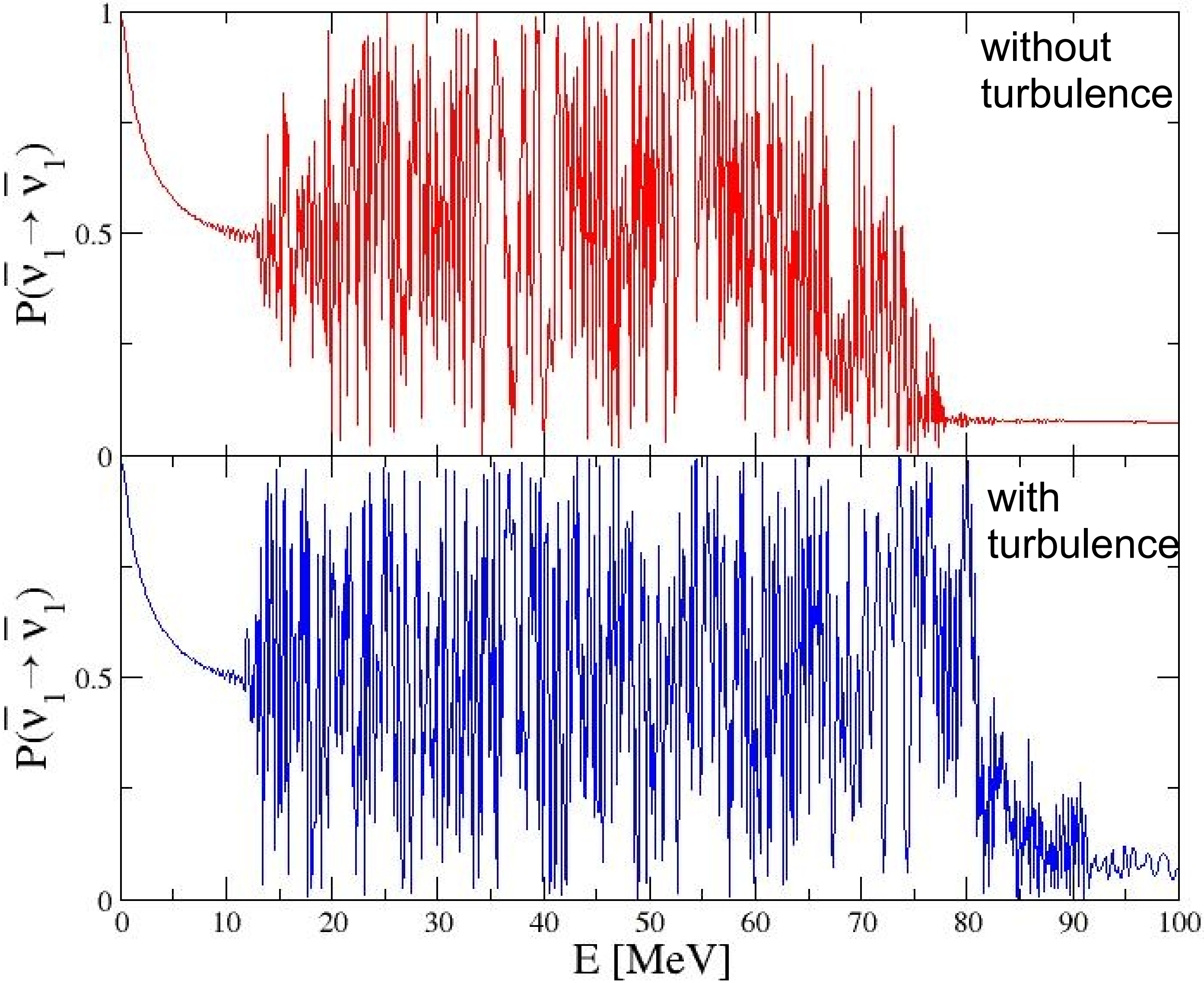

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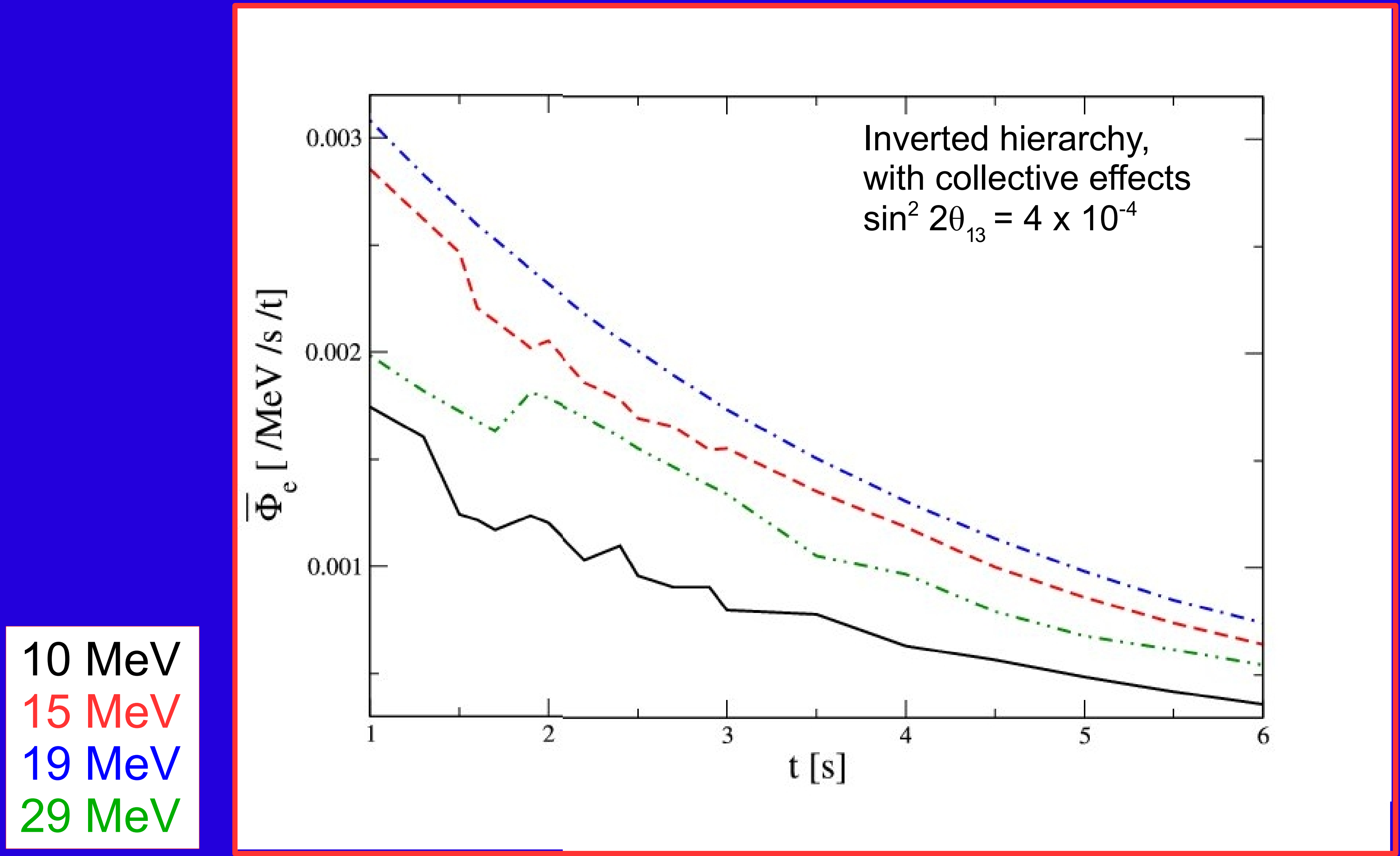
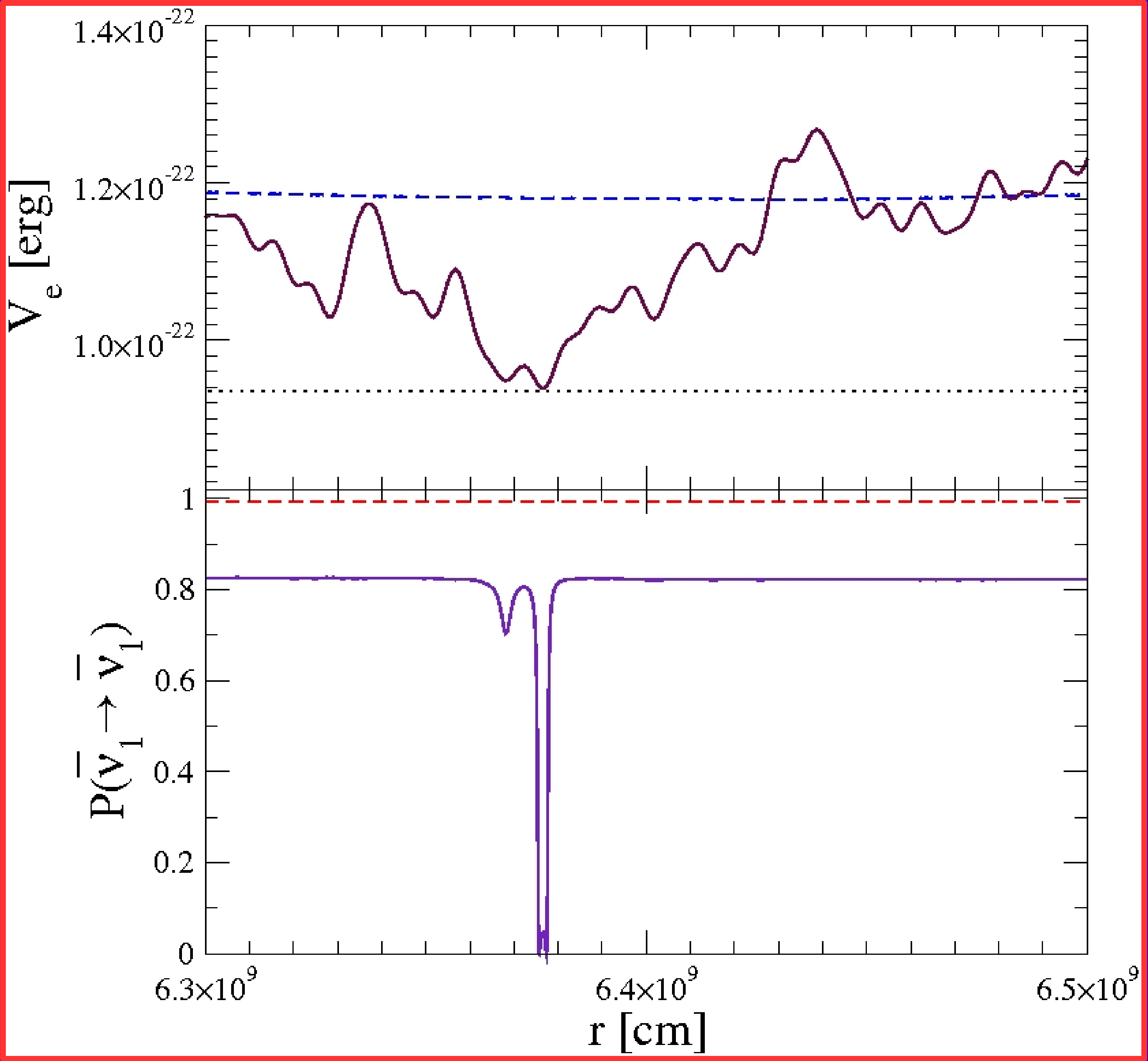


Phase Effects were included.

Summary

- Turbulence does not destroy our neutrino vision.
  - The underlying profile already produces phase effects in the probabilities.
  - Like turbulence, phase effects cause rapid oscillations of the probabilities with energy.
- The resolution of the detection process, the detector resolution and the necessity of binning in time and energy, all lead to flux equilibration for the neutrinos experiencing phase effects.
- Turbulence affects the neutrino energies which are experiencing phase effects.
- Both turbulence and phase effects are not everywhere at all times.

- Turbulence actually introduces new things to observe in places where nothing was visible previously:
  - it extends the range of sensitivity to θ_{13} by roughly an order of magnitude,
  - and it leads to time-dependent signals in the 'wrong' channel (unshown).



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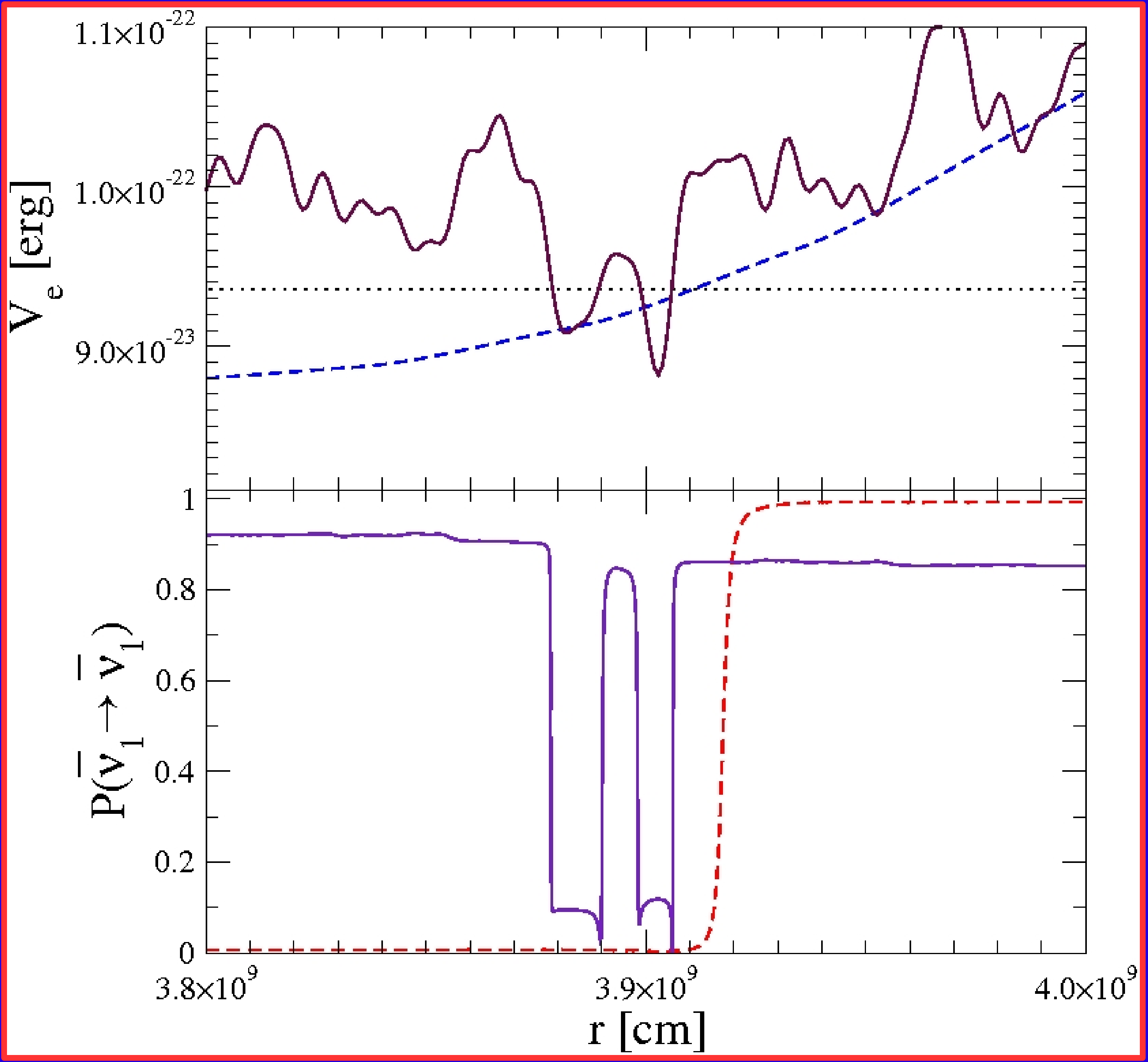

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