522. Wilhelm and Else Heraeus-Seminar

Detection of Electron-Antineutrinos in Liquid Scintillators via the Inverse Beta Decay - Event Signatures and Possible Backgrounds

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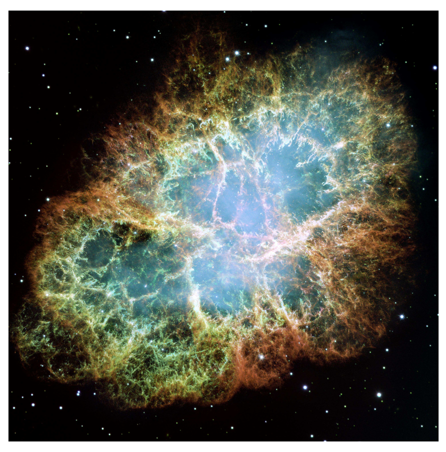
Physics Program: Natural and Anthropogenic Sources of Electron-Antineutrinos ($\bar{\nu}_e$)

Reactor Neutrinos

- From β^--decays of fission products in the reactor cores
- Energies up to ~12 MeV
- Total Flux: $2 \cdot 10^{20}\,s^{-1} \cdot GW_{th}^{-1}$
- Investigation of ν-oscillation parameters:
  - ϑ_{13} at short baselines (L ≈ 1 km)
  - Solar mixing parameters with LENA (L ≈ 120 km)
- Non-proliferation studies
- Tests of Lorentz violation [5]

Geoneutrinos

- From β^--decays of ^{40}K and isotopes from the U- and Th-chain in the earth's interior
- Maximum neutrino energies:
  - U-chain: 3.3 MeV
  - Th-chain: 2.25 MeV
  - ^{40}K: 1.3 MeV (below detection threshold)
- Connected to the heat production of the earth
- Information on the distribution of radioactive isotopes in the earth



Supernova Neutrinos and DSNB

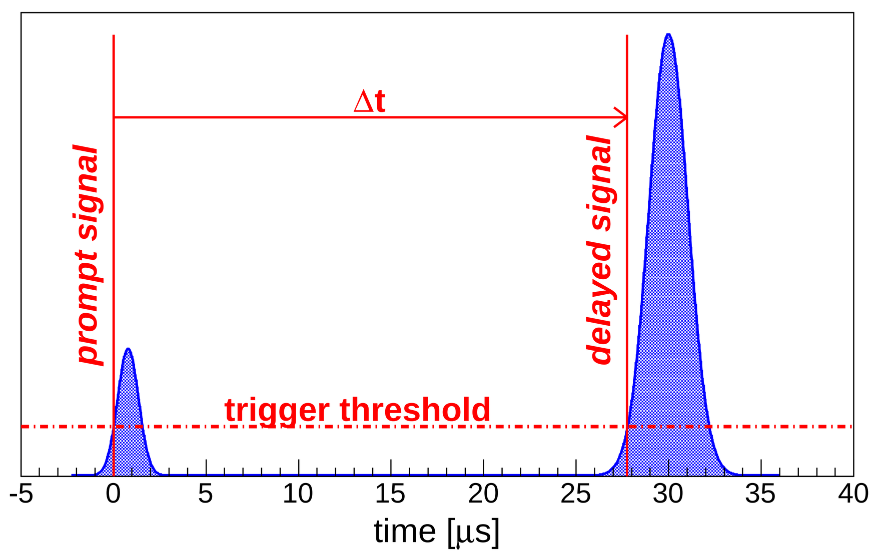
- Mainly thermal production in core-collapse SN
- Quasithermal spectrum with $T_{\bar{\nu}_e} \approx 5$ MeV
- DSNB redshifted with $E_\nu \lesssim 40$ MeV
- Investigation of supernova properties (explosion mechanism, rate)
- Information on neutrino mass m_ν

Inverse Beta Decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- High cross section: $\sigma_{IBD} \approx 9.30 \cdot 10^{-42} \left(\frac{E_\nu}{10\,MeV}\right)^2 cm^2$
- Energy threshold: 1.8 MeV
- Coincident signal between positron and neutron, in space (*few cm*) and time (*several μs*)

⇒ *Clear event signature*



Prompt Event (p^+)

- Energy deposition of the kinetic energy of the p^+ (+1.022 MeV by annihilation)
- Energy strongly correlated to the neutrino energy

⇒ *Neutrino spectroscopy possible*

Delayed Event (n)

- Capture of the thermalized neutron on a nucleus A:

$$n + A \rightarrow (A+1)^* \rightarrow (A+1) + \gamma$$

- Subsequent γ-emission:

Hydrogen:	$E_\gamma \approx 2.2$ MeV
Carbon:	$E_\gamma \approx 4.9$ MeV
Gadolinium:	$E_\gamma \approx 8$ MeV

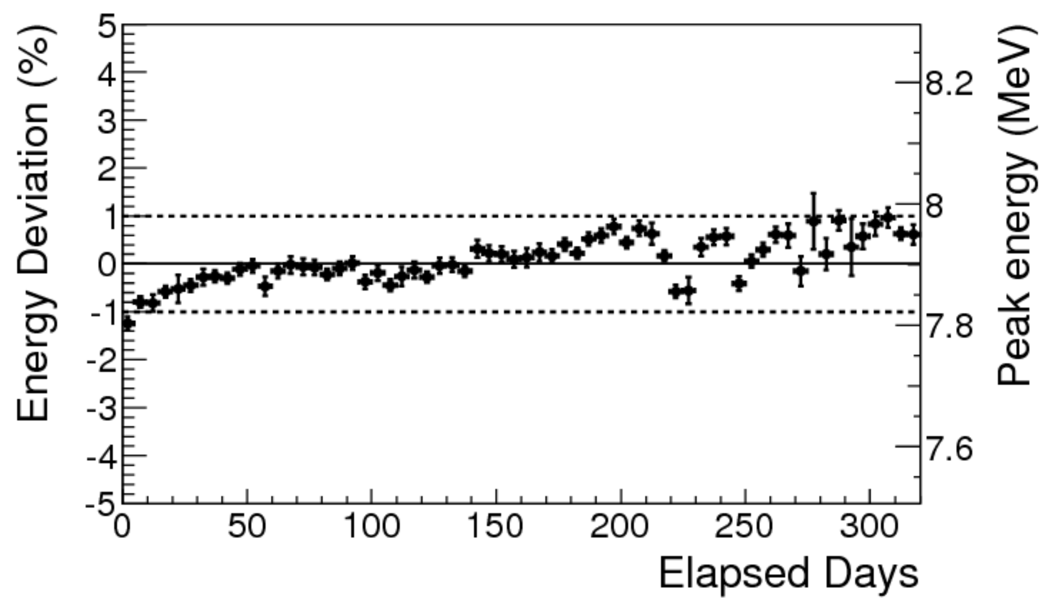
Radioactivity-Induced Background

Accidental coincidences

- Random coincidences between positron-like and neutron-like event
- Mainly radioactivity-induced

⇒ *Background at small energies ($\lesssim$ 3 MeV)*

- Greatly reduced by Gd doping:
  - $E_{delayed} \gg E_{vis}(\alpha, \beta, \gamma)$
  - Δt shortened to ≈ 30 μs
  - → Stability of Gd-doped liquid scintillator proven at Double Chooz



Mean energy of the Gd-neutron capture peak in the Double Chooz Target liquid as function of elapsed days [2]

(α,n)-Reactions

- Fast neutrons created directly in the scintillator
- KamLAND: dominant reaction: ^{13}C $(\alpha, n)^{16}$O with α-particle from ^{210}Po [4]
  - → One (α,n)-event per $3.1 \cdot 10^7$ α-decays of ^{210}Po
- Neutron energies up to 7.3 MeV, but visible energy quenched

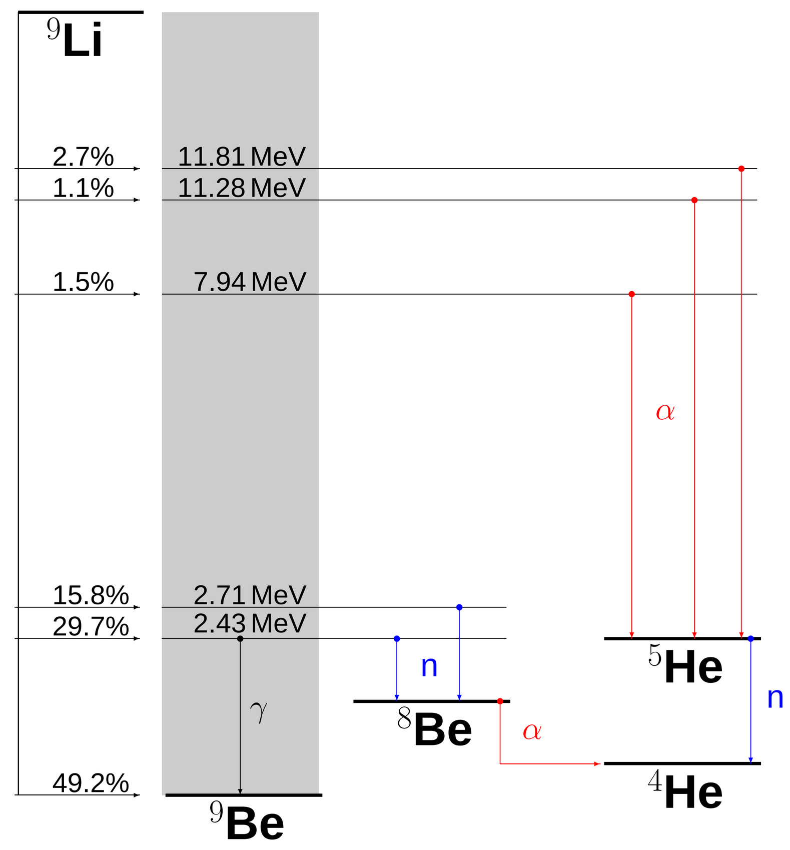
⇒ *Background at small energies ($\lesssim$ 3 MeV)*

⇒ *Discrimination by Pulse Shape Analysis*

Muon-Induced Background

β-n-emitters (^{9}Li and ^{8}He)

- Produced in spallation reactions on ^{12}C: ^{12}C $(\mu, 3p)^9$ Li and ^{12}C $(\mu, 4p)^8$ He
- Electron from β^--decay mimics prompt event, emitted neutron delayed event



Simplified decay scheme of the β-n-emitter ^{9}Li

- Long half-lives (178.3 ms and 119 ms)
- Continuous energy distribution up to ~10 MeV

⇒ *Dangerous Background at low energies*

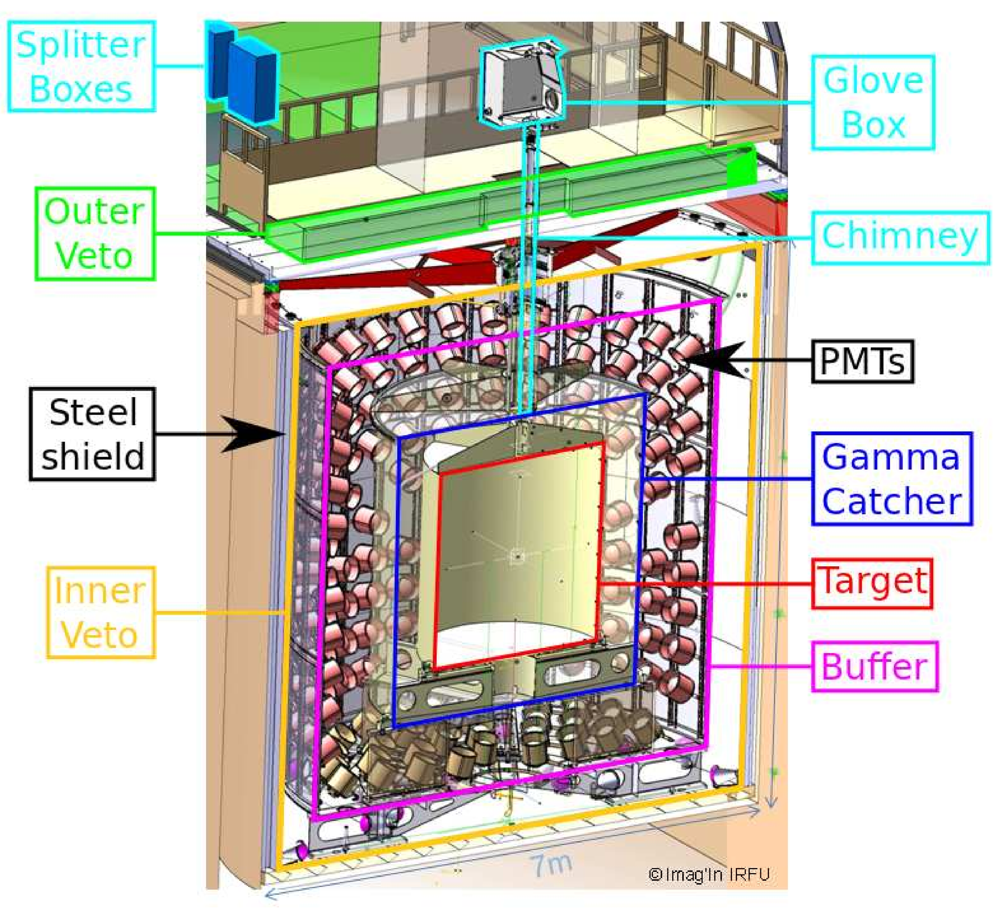
Fast neutrons & Stopping muons

- Prompt event: Proton recoiling off neutron // Energy deposition by μ
- Delayed event: Subsequent capture of thermalized neutron // μ-decay
  - → Statistically separable by Δt
- DC: Flat energy spectrum up to tens of MeV [1,2,3]

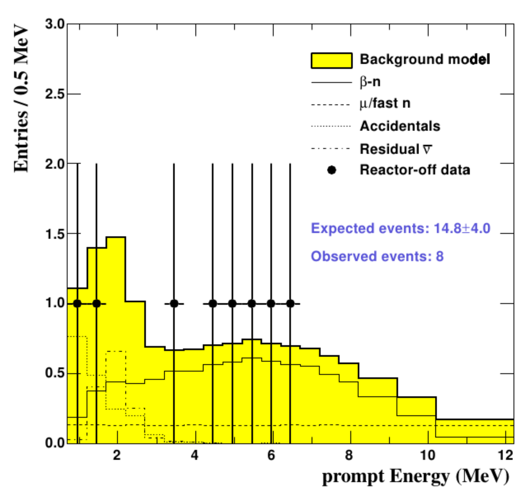
⇒ *Dangerous Background at all energies*

⇒ *Discrimination by Pulse Shape Analysis*

Double Chooz: Detector Design and Results



- Target: 10.3 m^3 Gd-loaded unpurified scintillator
  - → Measured concentration of U and Th (BiPo analysis [6]):
    - U: $(5.2 \pm 0.4) \cdot 10^{-15}$ g/g
    - Th: $(2.1 \pm 0.1) \cdot 10^{-13}$ g/g
  - ⇒ Internal prompt trigger rate ~**0.4 Hz·m^{-3}**
  - ⇒ *Accidental coincidences: $(0.261 \pm 0.002) \cdot d^{-1}$ (Measured with offtime window [2])*
  - ⇒ *(α,n)-reactions: $< 1.72 \cdot 10^{-2} \cdot d^{-1}$ [6]*
- 300 m.w.e. overburden in hill topology
  - → Measured μ-rate: **46 Hz** in InnerVeto
  - ⇒ *Cosmogenic isotopes: $(1.25 \pm 0.54) \cdot d^{-1}$ (Fit to Δt distribution μ↔IBD [2])*
  - ⇒ *Fast neutrons: $(0.30 \pm 0.14) \cdot d^{-1}$ ($E_{prompt} > 12.2$ MeV and Δt > 10 μs [2])*
  - ⇒ *Stopping muons: $(0.34 \pm 0.18) \cdot d^{-1}$ ($E_{prompt} > 12.2$ MeV and Δt < 10 μs [2])*
- Rates confirmed during reactor off period



Energy spectra of the various background contributions measured during 7.5 days reactor off, confirming the predicted rates

References

[1] Y. Abe et al., Double Chooz collaboration, PRL **108**, 131801 (2012)

[2] Y. Abe et al., Double Chooz collaboration, Phys. Rev. D**86**, 052008 (2012)

[3] Y. Abe et al., Double Chooz collaboration, Phys. Rev. D**87**, 011102 (2013)

[4] S. Abe et al., KamLAND collaboration, PRL **100**, 221803 (2008)

[5] Y. Abe et al., Double Chooz collaboration, Phys. Rev. D**86**, 112009 (2012)

[6] M. Hofmann, Ph.D. thesis, TU München (2012)