Detection of Electron-Antineutrinos in Double Chooz via the Inverse Beta Decay - Event Signatures, Backgrounds and Results

Martin Hofmann

Physik Department E15
TU Munich

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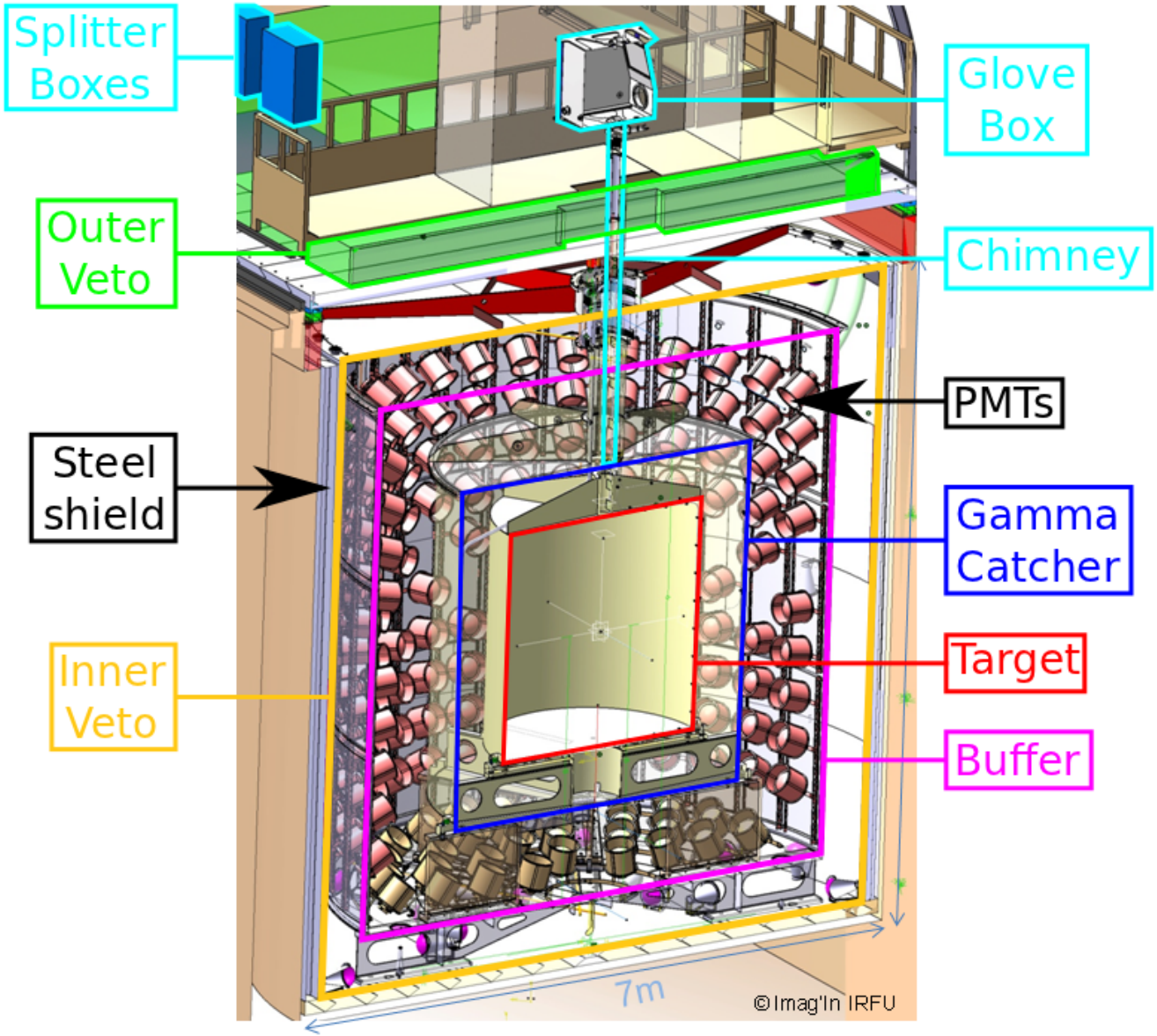
Double Chooz Detector Setup



Detection Reaction: Inverse Beta Decay

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

$\Rightarrow$ $E_\nu \approx E_{vis} + 0.8\,MeV$

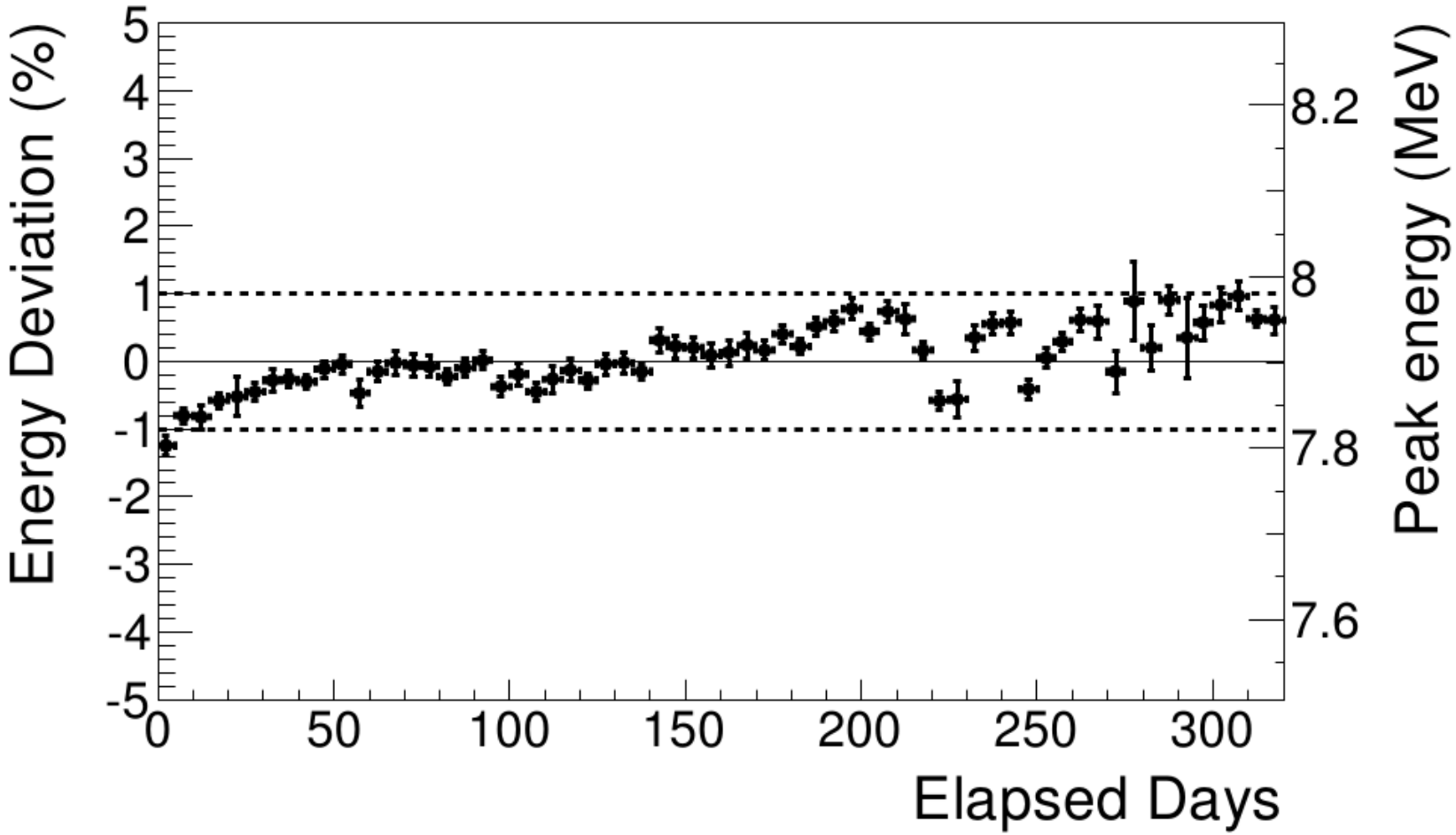
- Subsequent thermalization and capture of the neutron

Neutron Capture

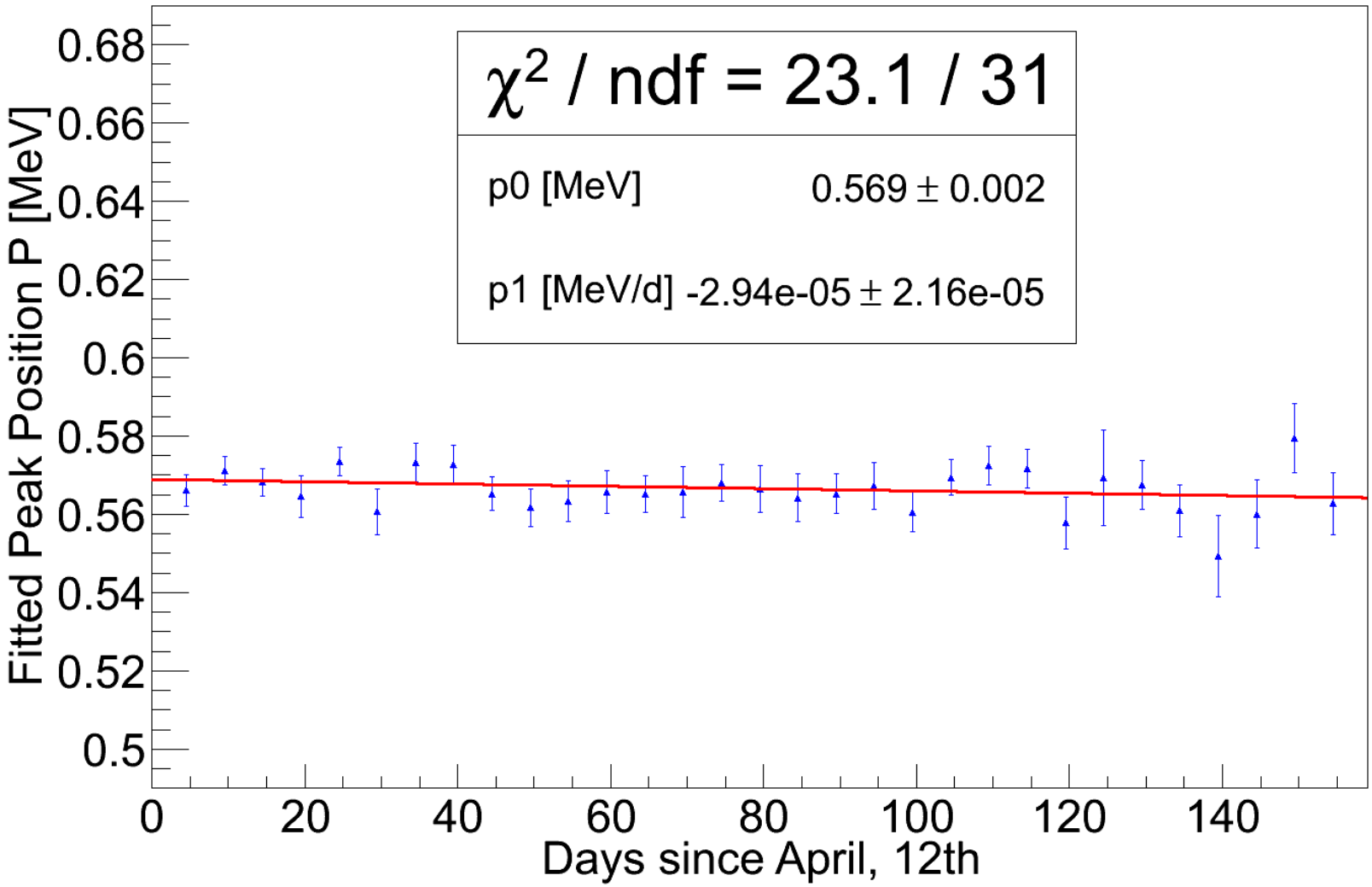
$$\begin{aligned} n + Gd &\rightarrow Gd^* \rightarrow Gd + \sum_i \gamma_i \ (\sim 8\,MeV) \\ n + H &\rightarrow d + \gamma \ (2.2\,MeV) \end{aligned}$$

$\Rightarrow$ Clear event signature (Coincidence in space and time)

Stability of the Gd-loaded scintillator



Detector Stability (Po-214)



Possible backgrounds to the IBD

Correlated background

- β-n-emitting cosmogenic isotopes like ^{9}Li or ^{8}He produced by muons in the scintillator
- Fast neutrons, especially after spallation reactions of untagged muons
- Stopping muons entering the detector through the chimney
- (α,n)-reactions in the liquid scintillator

Accidental background

- Accidental coincidences between a positron-like prompt event and a neutron-like delayed event, which are correlated in space and time

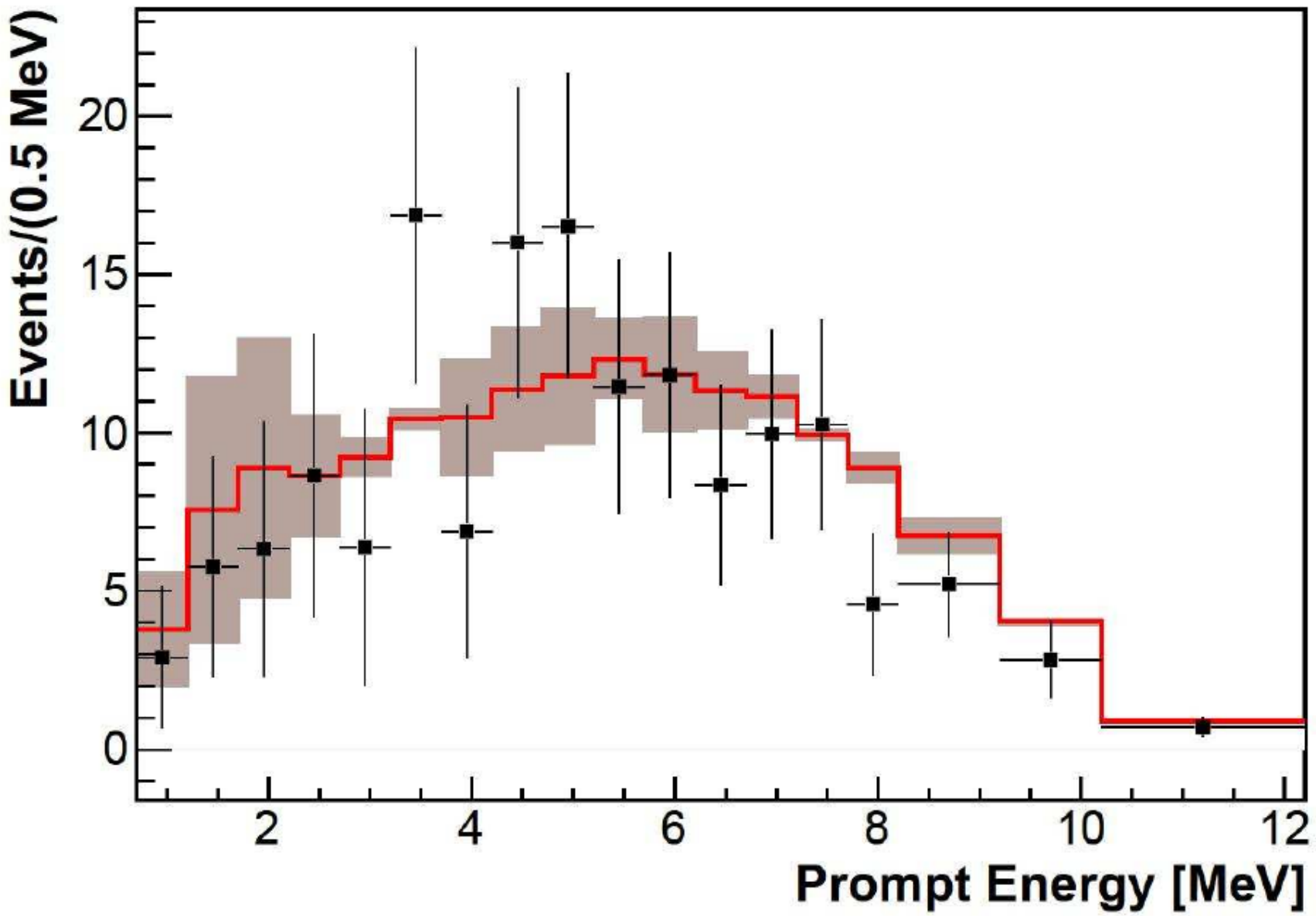
Muon-induced Background

Double Chooz: **46 Hz** muon rate in InnerVeto

- Cosmogenic Isotopes (^{9}Li and ^{8}He)
  - Produced in spallation reactions on ^{12}C
  - Long half-lives (178.3 ms and 119 ms)
  - Prompt energies up to $\sim$10 MeV
  - Determined with a fit to the $\Delta t_{\mu IDB}$-distribution of muon-IBD candidate-pairs

  $\Rightarrow$ Rate: $(1.25 \pm 0.54) \cdot d^{-1}$

Energy Spectrum of Cosmogenics



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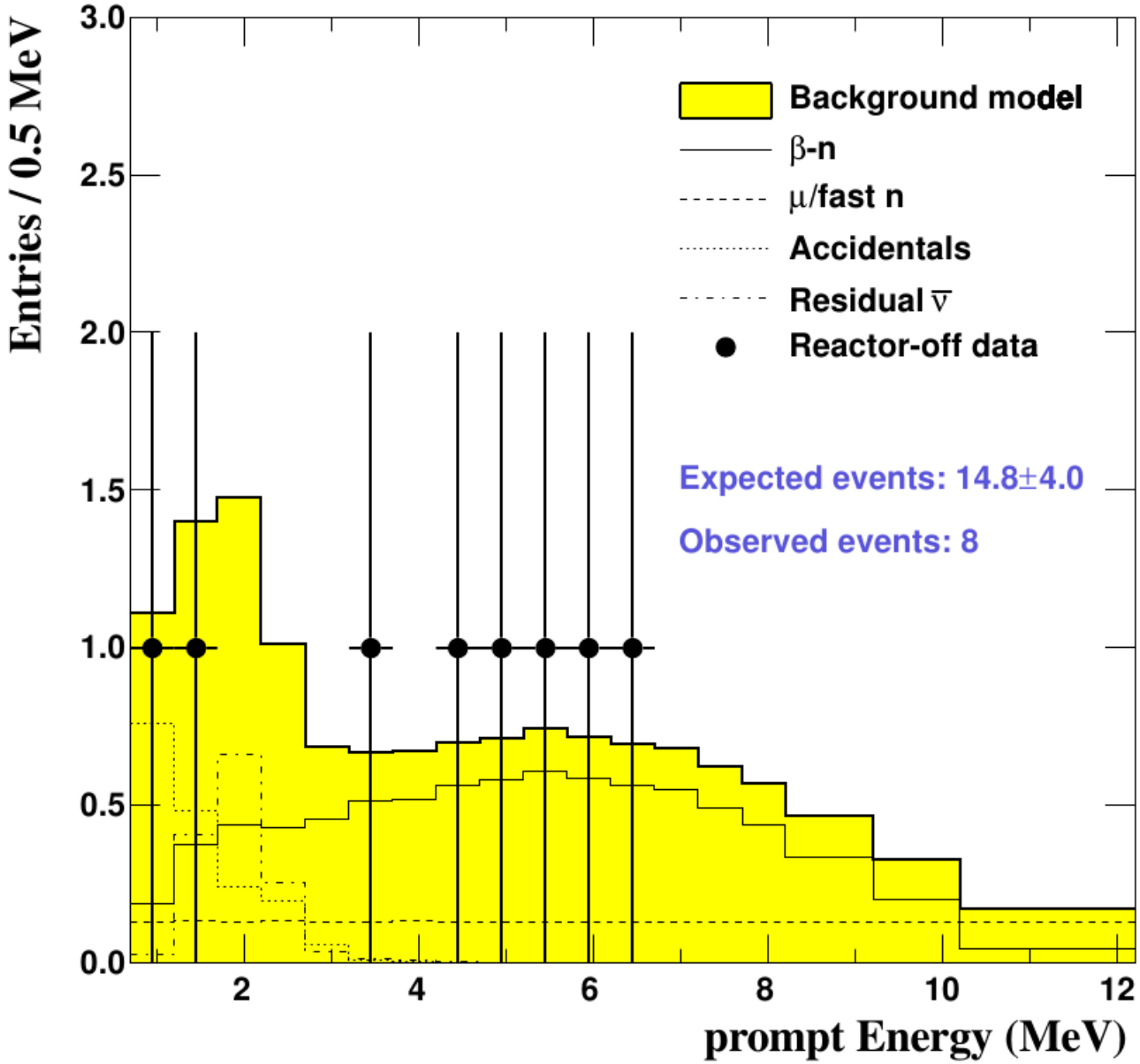
- Fast Neutrons and Stopping Muons
  - Produced by untagged muons
  - Statistically separable by Δt between prompt and delayed event
  - Flat energy spectrum up to tens of MeV

  $\Rightarrow$ Rate (FN): $(0.30 \pm 0.14) \cdot d^{-1}$

  $\Rightarrow$ Rate (SM): $(0.34 \pm 0.18) \cdot d^{-1}$

- Rates confirmed during reactor off period

Energy Spectrum of Background (Reactor off period)



Radioactivity-induced Background (BiPo analysis)

	U-chain	Th-chain
mass concentration	$(1.71 \pm 0.08) \cdot 10^{-14} \frac{g}{g}$	$(8.16 \pm 0.49) \cdot 10^{-14} \frac{g}{g}$

- DC design goal (in sum $< 4 \cdot 10^{-13} \frac{g}{g}$) matched very well!
- Internal prompt trigger rate $\sim$ **0.4 Hz·m^{-3}**

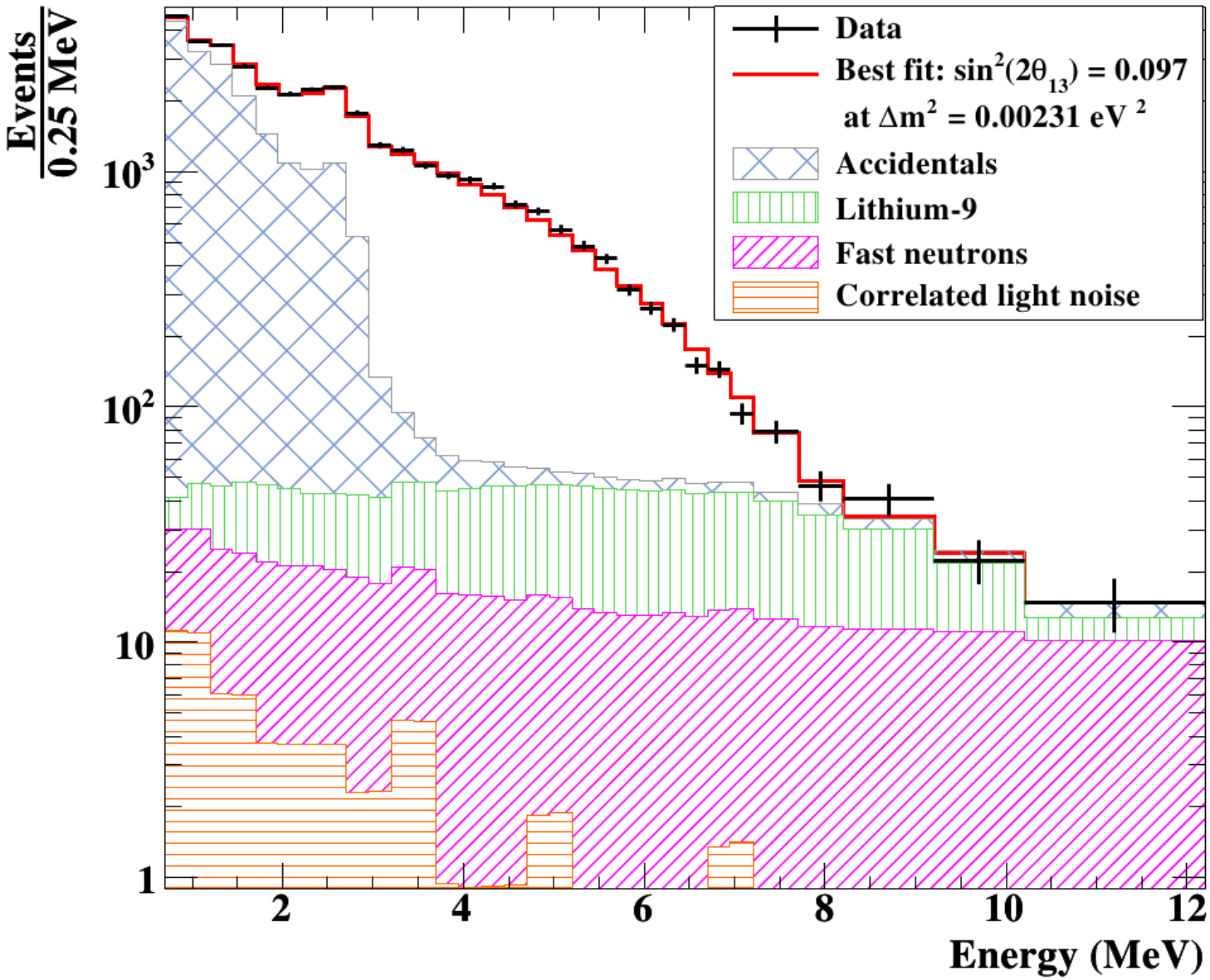
$\Rightarrow$ Accidental Coincidences:

$(0.261 \pm 0.002) \cdot d^{-1}$ Gd-analysis ($\Delta t < 100\,\mu s$)
$(73.45 \pm 0.16) \cdot d^{-1}$ H-analysis ($\Delta t < 600\,\mu s$)

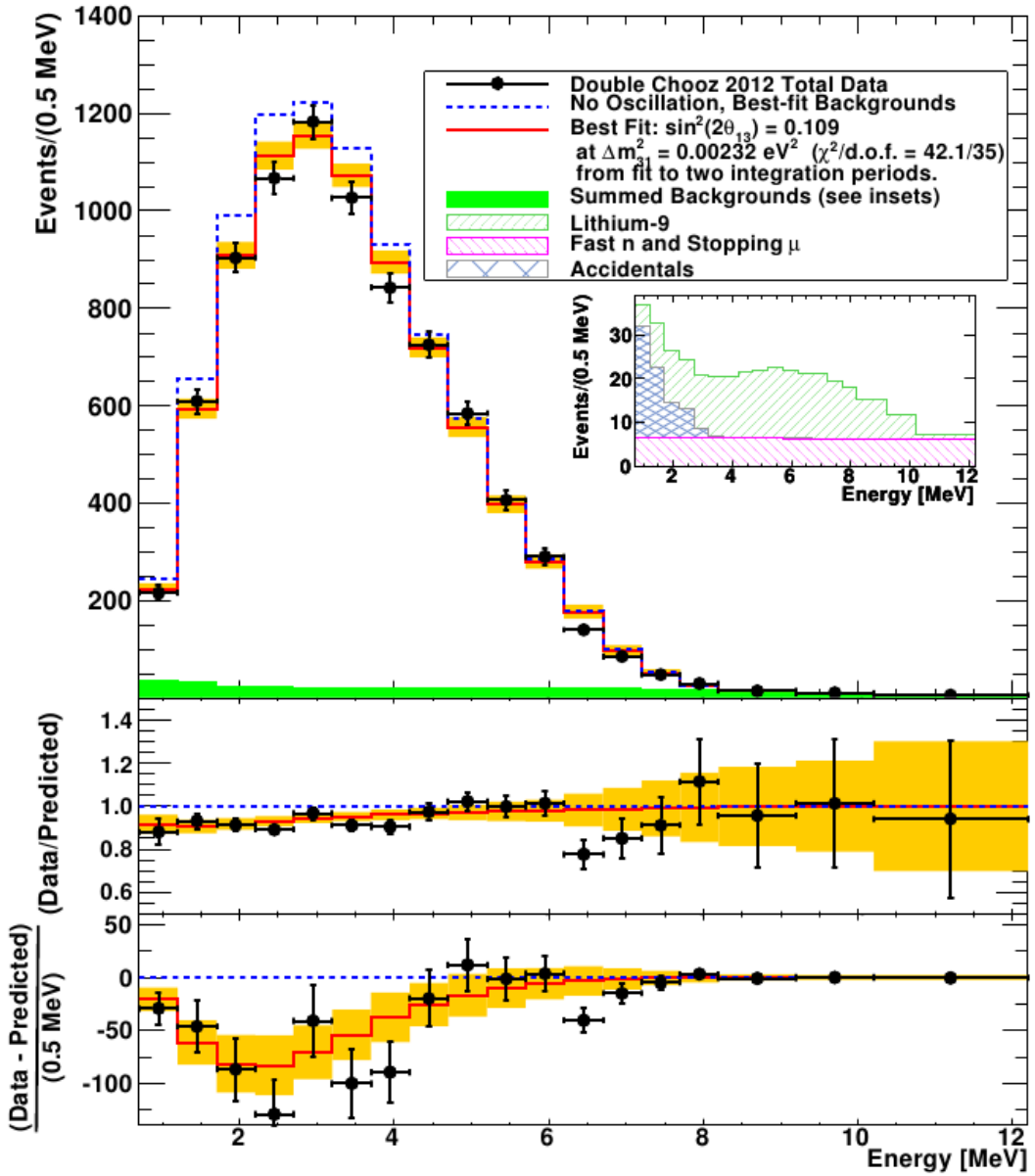
$\Rightarrow$ (α,n)-reactions: $< 1.72 \cdot 10^{-2} \cdot d^{-1}$

- Background below ~ 3 MeV

Backgrounds (H-analysis)



Double Chooz Final Results on ϑ_{13}



Double Chooz Final Results on ϑ_{13}

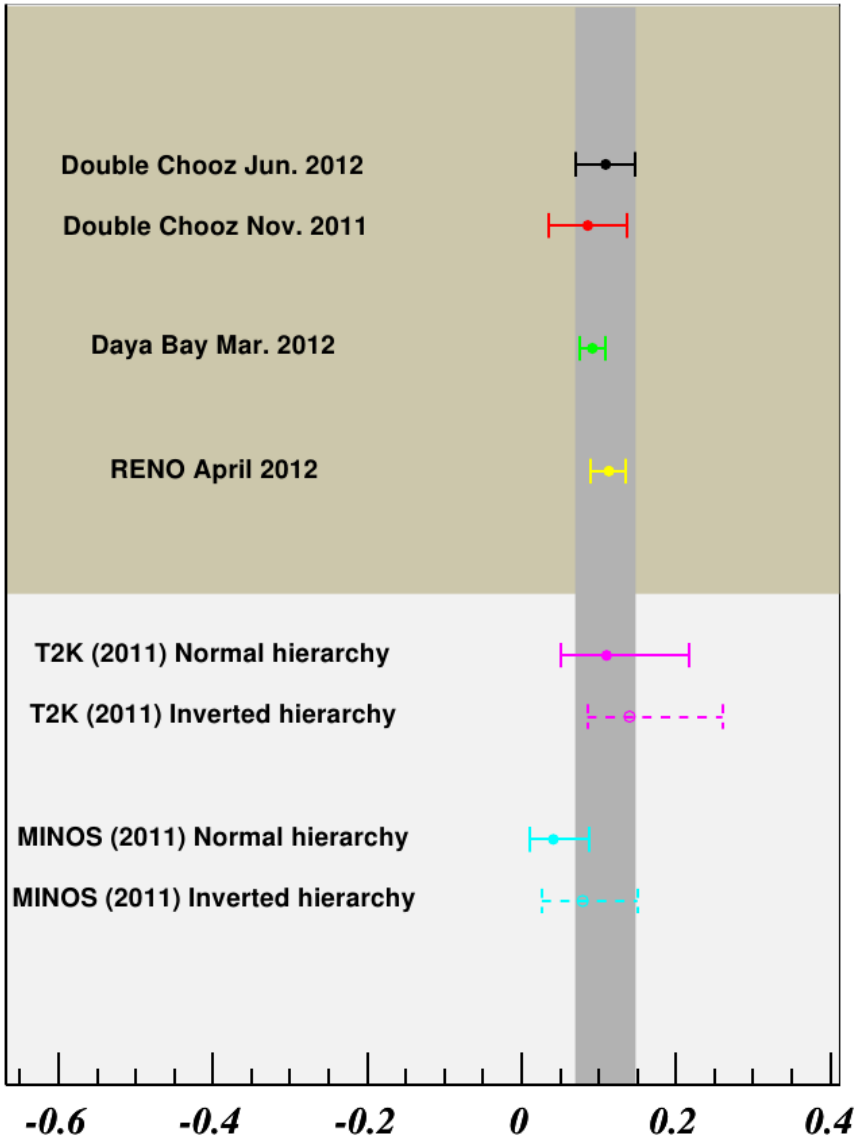
Double Chooz Result

$$\begin{aligned} \sin^2(2\vartheta_{13}) &= 0.109 \pm 0.030(stat) \pm 0.025(syst) \quad (Gd) \\ \sin^2(2\vartheta_{13}) &= 0.097 \pm 0.034(stat) \pm 0.034(syst) \quad (H) \end{aligned}$$

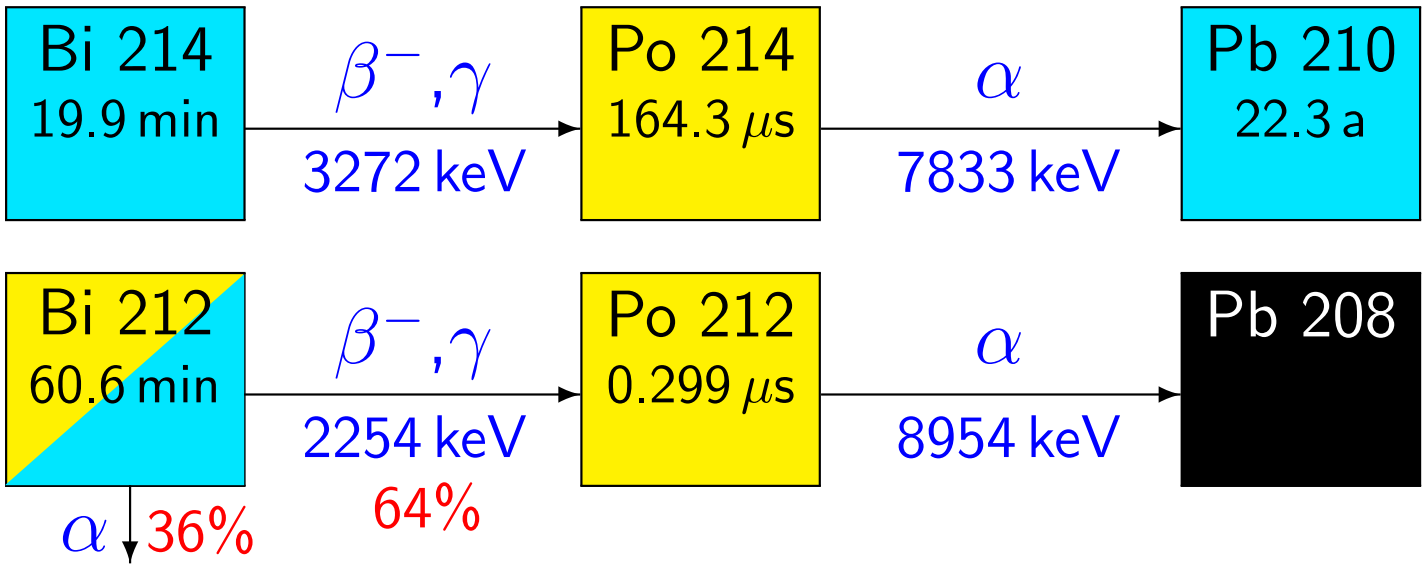
- Rate+Shape Analyses, Far Detector only
- Two independant analyses of ϑ_{13}

Backup Slides

Measurements of ϑ_{13}



Decay scheme of the BiPo coincidences



- Fast coincidence signal between β^- and α signal, spatially correlated

$\Rightarrow$ Clear signal and easily distinguishable from background

$\Rightarrow$ Tagging of the number of decays within the U decay chain and the Th decay chain (assuming radioactive equilibrium)