New results and future capabilities of the Double Chooz reactor antineutrino experiment

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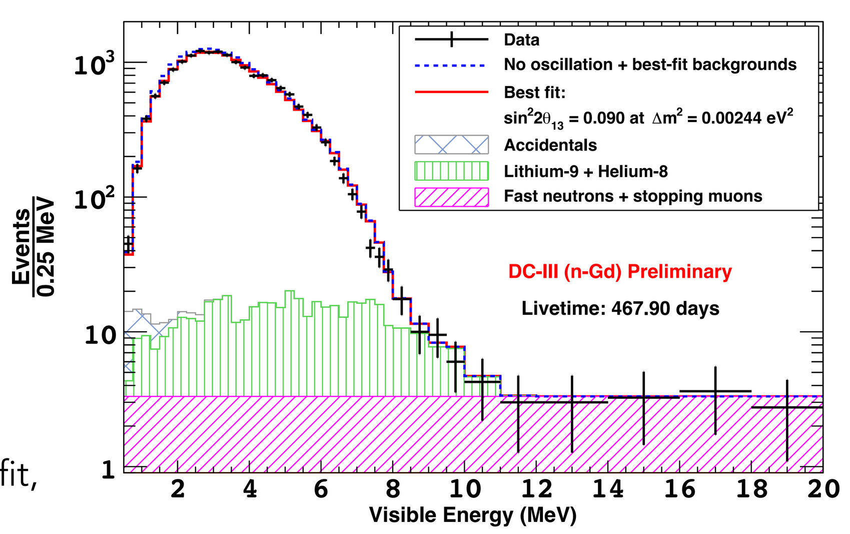
Energy spectrum fit

- Compares rate and prompt spectrum shape of data and prediction.
- Yields most precise measurement of θ_{13} from Double Chooz.

BACKGROUND MODEL

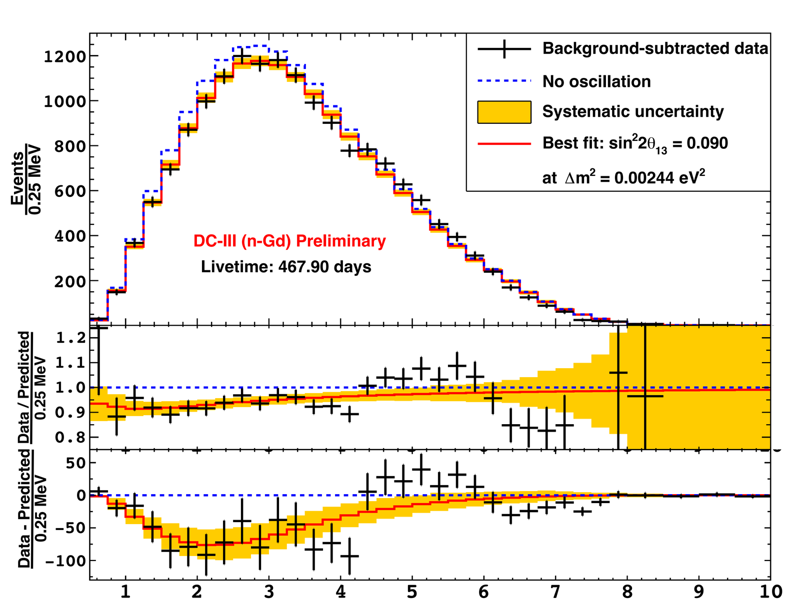
- **Accidental coincidences:** 0.070 ± 0.005 d^{-1}
- **Fast neutrons + stopping muons:** 0.67 ± 0.20 d^{-1}
- **Cosmogenic ^{9}Li + ^{8}He:** $0.97^{+0.41}_{-0.16}$ d^{-1}
- Background rates are constrained in fit, particularly for ^{9}Li + ^{8}He.
- Reactor-off measurement (see "Reactor-Off" section, bottom right) included as constraint on total background rates.



▲ *Prompt energy of inverse beta decay candidates (black points with statistical error bars), overlaid on stacked histograms of best-fit backgrounds plus no-oscillation signal (blue dashed line) and best-fit backgrounds plus best-fit signal (red line).*

SYSTEMATIC ERRORS

- **Reactor flux uncertainty:** 1.7% signal normalization and shape
- **Detection efficiency uncertainty:** 0.63% signal normalization
- **MC energy scale,** *modeled as $E_{corrected} = a + bE_{MC} + cE_{MC}^2$, covering uncertainties in energy scale nonlinearity, instability over time, and non-uniformity over detector volume. Coefficients a,b, and c are nuisance parameters in fit.*



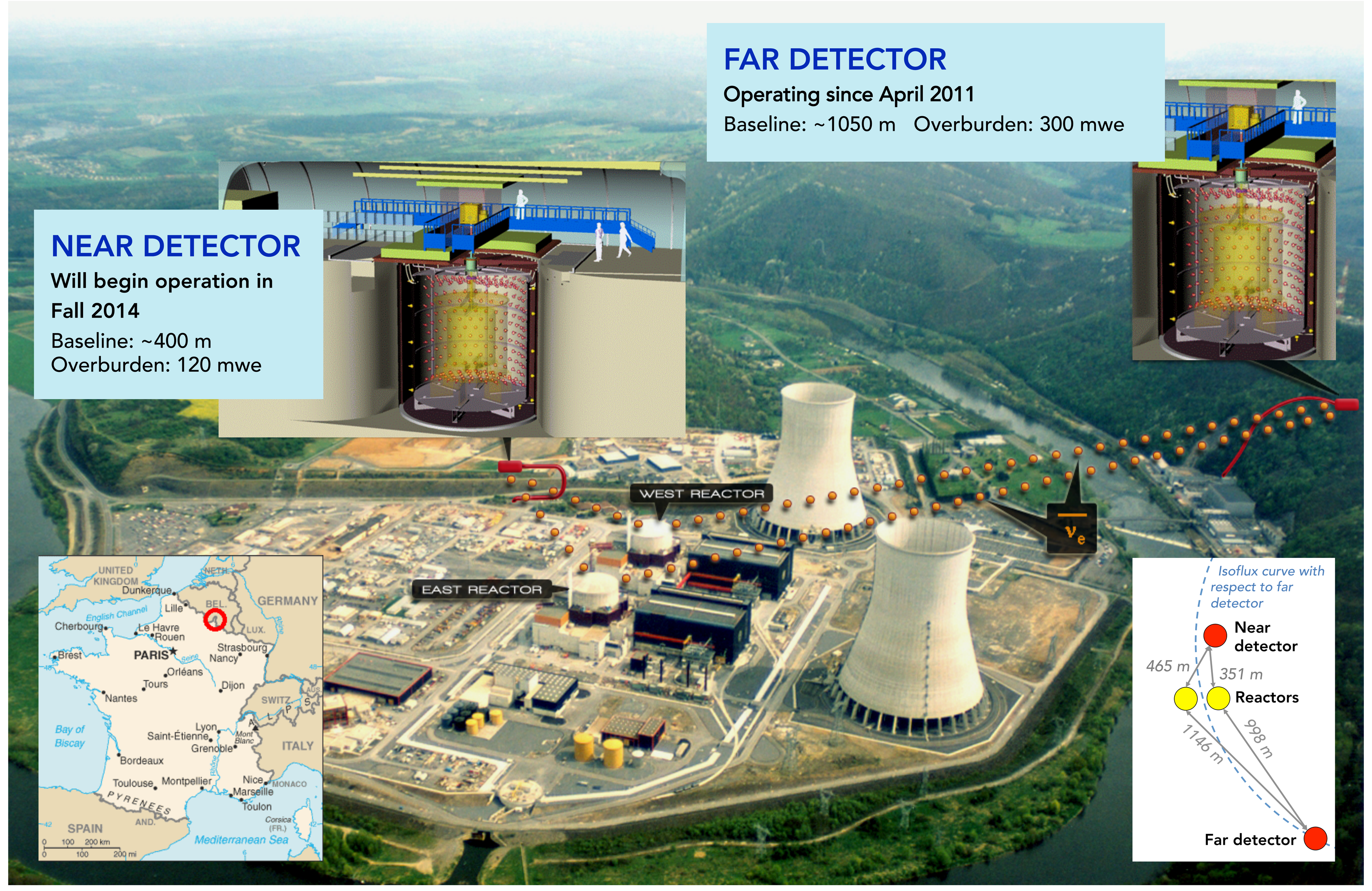
RESULTS

$\sin^2 2\theta_{13} = 0.090^{+0.033}_{-0.028}$

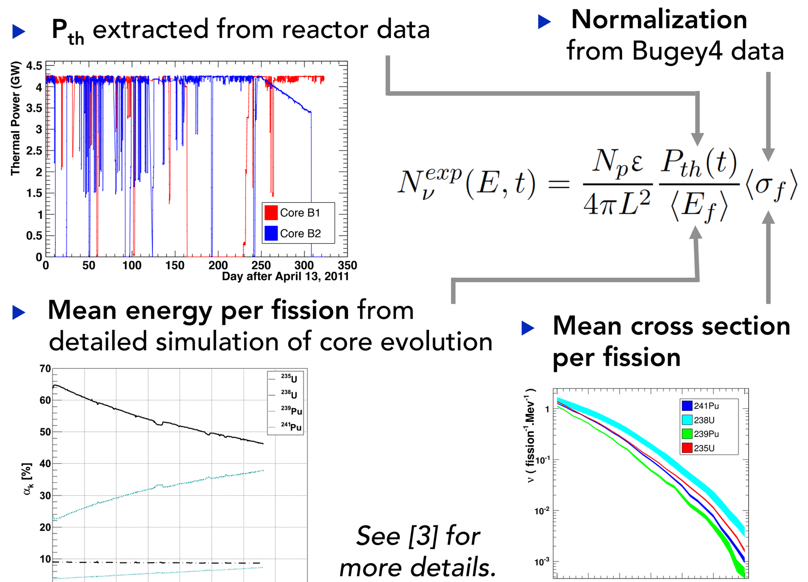
Fast n + stopping μ: 0.56 ± 0.04 d^{-1}
^{9}Li + ^{8}He: $0.80^{+0.15}_{-0.13}$ d^{-1}
χ^2/d.o.f = 51.4/40

◀ *Background-subtracted data (black points, with statistical error bars) superimposed upon best-fit (red line) and no-oscillation (blue dashed line) signal, with systematic errors in each bin (gold bands). Top: prompt energy spectrum. Center: ratio of data to prediction. Bottom: difference between data and prediction.*

The Double Chooz Experiment

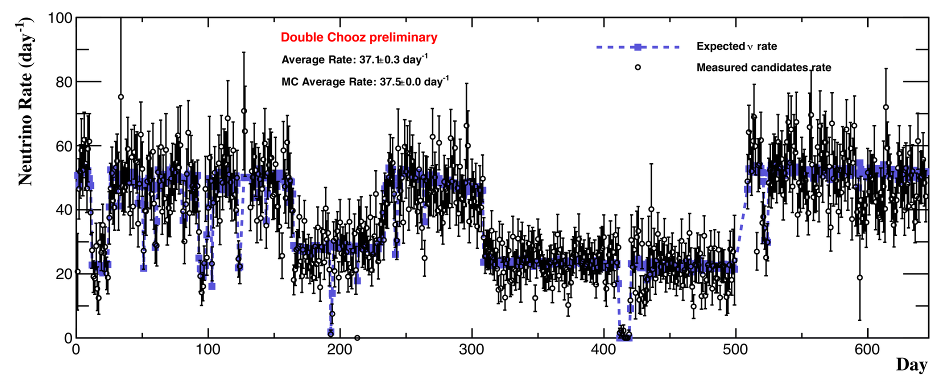


REACTOR FLUX PREDICTION



CURRENT DATASET

- 650 days of data, roughly 2× previous analysis
- Total live-time: **467.90 days**
- **17358 inverse beta decay candidates,** with selection optimized for neutron capture on Gd

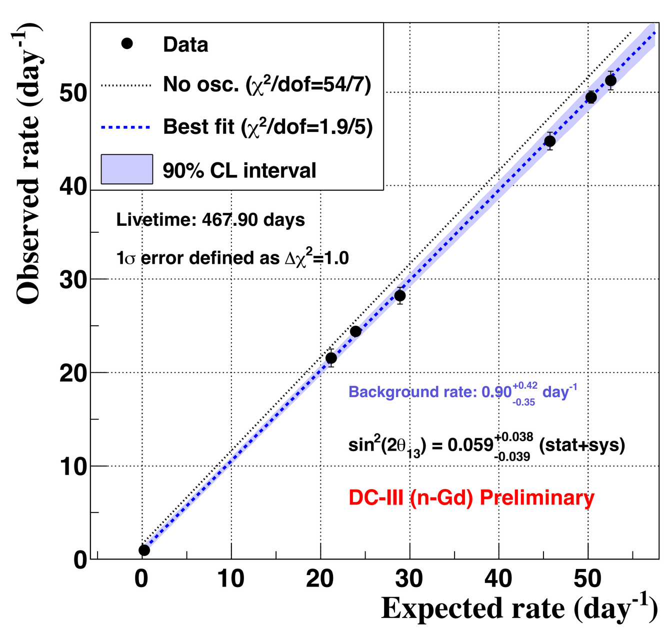


Further information on dedicated posters:

- *Determination of the detection systematics in the Double Chooz experiment*
- *Reactor antineutrino detection in Double Chooz: New techniques for backgrounds*
- *The visible energy of Double Chooz*
- *Neutrino directionality measurement with Double Chooz*
- *Observation of ortho-positronium formation in Double Chooz*
- *Status of the Double Chooz detectors*

Reactor power fit

- Compares observed and predicted rate at different reactor powers.
- Provides a background-model-independent measurement of θ_{13}.



▲ *Observed rate of inverse beta decay candidates as a function of rate expected with no oscillation (black points, with statistical errors) superimposed on best fit (dashed blue line, with systematic error band). Fit includes reactor-off data. Also shown: the null hypothesis of observed rate equal to expected rate (black dotted line).*

FIT PROCEDURE

- θ_{13} and total background rate are determined simultaneously by comparing expected and observed rates for **different reactor power conditions.**
- **Does not use *a priori* background model.**
- Performed using only reactor-on data or also **including reactor-off data** for improved background constraint (see "Reactor-Off" section below).

SYSTEMATIC ERRORS

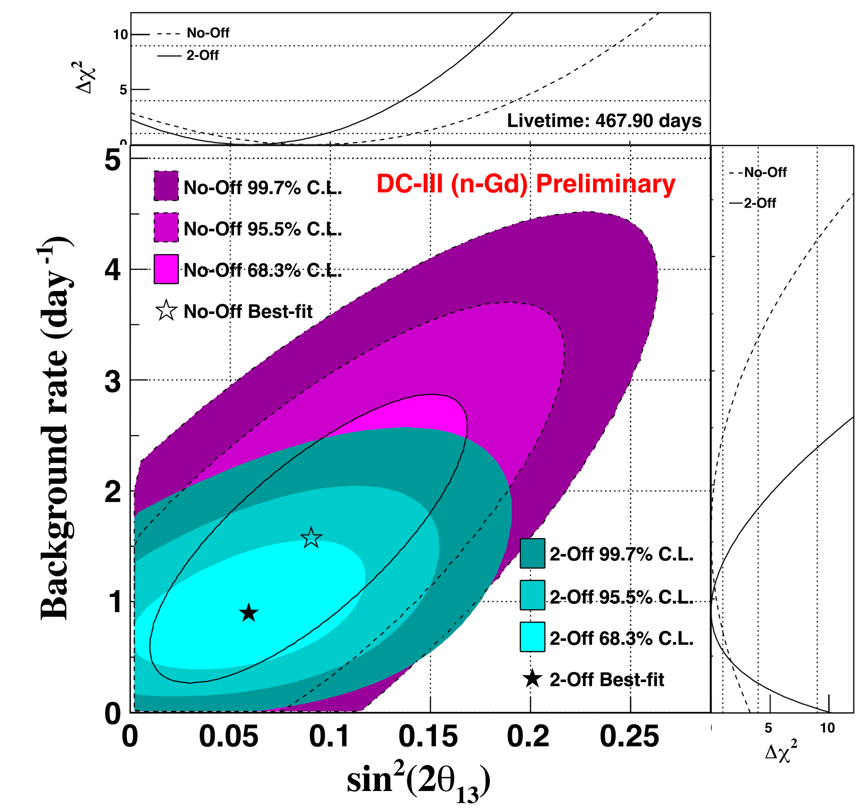
Involves only **normalization uncertainties:**

- Reactor flux uncertainty (~1.7%)
- Detection efficiency uncertainty (0.63%)
- Uncertainty on rate of reactor-off residual neutrinos (30% of predicted rate)

RESULTS

Using only reactor-on data:
$\sin^2 2\theta_{13} = 0.090 \pm 0.052$
Background rate = 1.57 ± 0.86 d^{-1}

Also including reactor-off data:
$\sin^2 2\theta_{13} = 0.059^{+0.038}_{-0.039}$
Background rate = $0.90^{+0.42}_{-0.35}$ d^{-1}

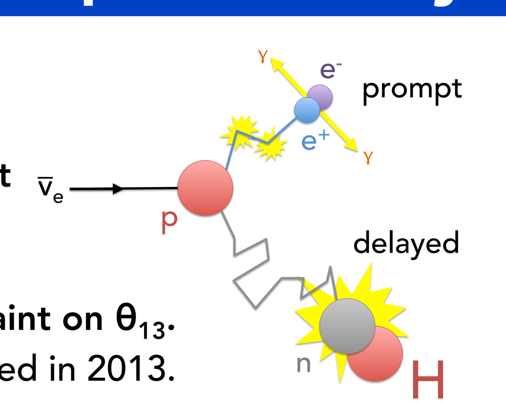


▶ *The best fit to $\sin^2 2\theta_{13}$ and total background rate using reactor-on data only (open star) and also including reactor-off data (filled star) with 68.3%, 95.5%, and 99.7% CL contours for each.*

Hydrogen capture analysis

MOTIVATION

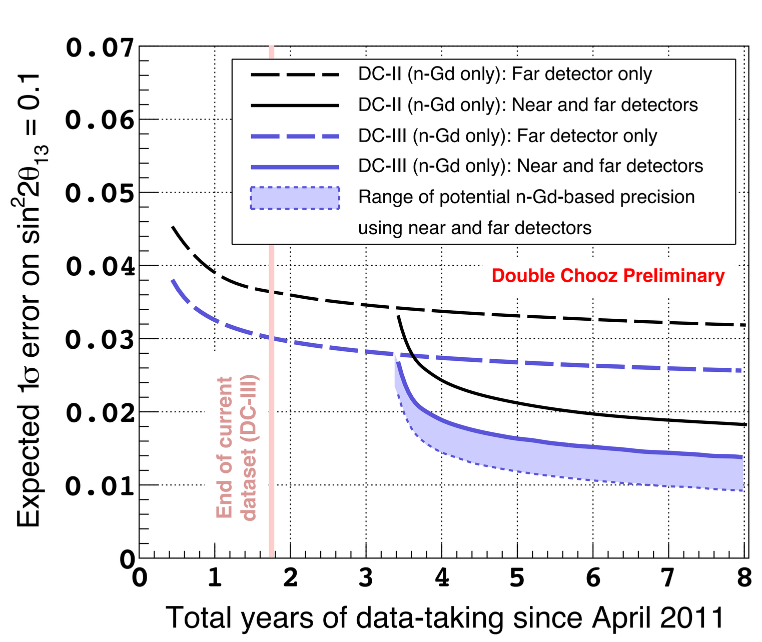
- **Higher signal statistics** (≈2×) and largely **independent** systematics with respect to Gd capture analysis.
- Important **cross check** of Gd capture analysis.
- Combination of Gd and H analyses yields **best constraint on θ_{13}.**
- First H results published [1] and Gd+H results presented in 2013.



OUTLOOK

- **H capture analysis of current dataset in progress** (≈2× statistics of published analysis).
- Developing **powerful new background rejection methods,** especially for accidentals.

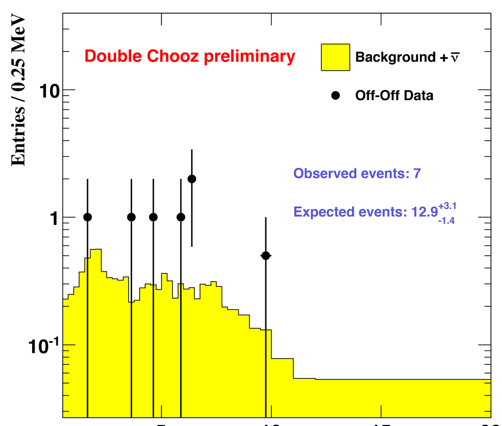
Future precision



- Now significantly **more sensitive than in previous Gd-based analysis** [2].
- **Near detector will sharply increase precision.**
- Potential Gd-based precision reaches **0.01.**
- **Including H capture data will increase precision** beyond levels shown in plot.

◀ *Projected Double Chooz precision from the energy spectrum fit. Blue (black) curves use systematics, live-to-calendar time ratio, and far detector backgrounds from present analysis (previous Gd-based analysis [2]); near detector backgrounds are estimated from measured muon flux. We assume 0.2% detection efficiency uncertainty and 0.1% reactor flux uncertainty is uncorrelated between detectors. Shaded blue region represents potential future precision, depending on reduction of systematic errors.*

Reactor-off measurement



▲ *Reactor-off data (black points with statistical errors) overlaid on background and residual reactor antineutrino prediction.*

UNIQUE OPPORTUNITY

- **Only reactor antineutrino experiment** with opportunities to take data when all reactors are off.
- Serves as background constraint in oscillation fits.

DATA COLLECTED

- **7.23 live days** of reactor-off data
- **7 candidates** passing signal selection cuts
- After subtracting residual reactor antineutrinos, yields total background rate of **0.76 ± 0.37 d^{-1}**, consistent within 2σ with background model ($1.57^{+0.42}_{-0.18}$ d^{-1}).

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References: [1] Y. Abe *et al.* (Double Chooz Collaboration), Phys. Lett. B **723** (2013). [2] Y. Abe *et al.* (Double Chooz Collaboration), Phys. Rev. D **86**, 052008 (2012). [3] T. Mueller *et al.*, Phys. Rev. C 83, 054615 (2011).