New results from the Double Chooz experiment

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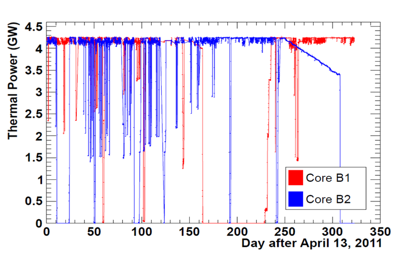
REACTOR FLUX PREDICTION

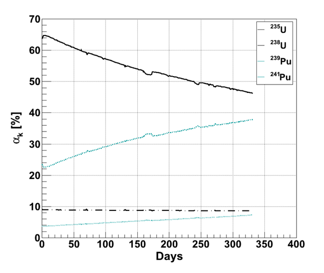
- P_{th} extracted from reactor data



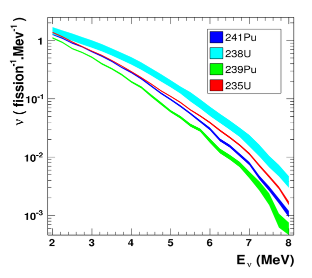
- Normalization from Bugey4 data

$$N_\nu^{exp}(E,t) = \frac{N_p \varepsilon}{4\pi L^2}\frac{P_{th}(t)}{\langle E_f\rangle}\langle\sigma_f\rangle$$

- Mean energy per fission from detailed simulation of core evolution



- Mean cross section per fission

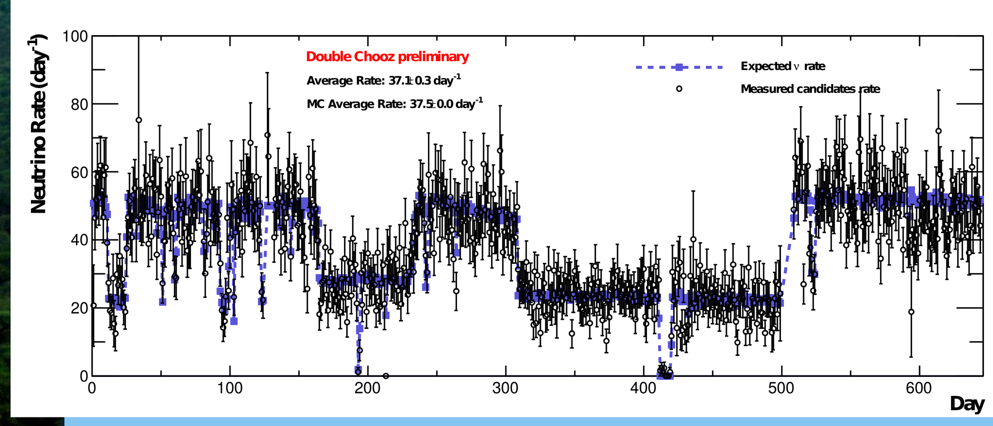


See [3] for more details.

DOUBLE CHOOZ SITE

CURRENT DATASET

- 650 days of data, roughly 2× previous analysis
- Total live-time: **467.9 days**
- **17358 inverse beta decay candidates,** with selection optimized for neutron capture on Gd



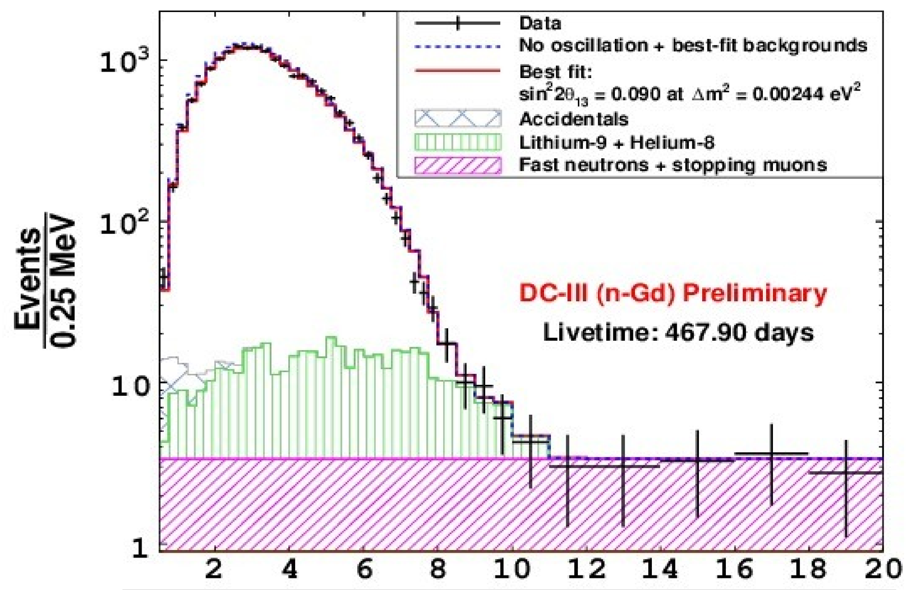
Energy spectrum fit

- Compares rate and positron 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 and stopping muons:** 0.67 ± 0.20 d^{-1}
- **Cosmogenic ^{9}Li and ^{8}He:** $0.97^{+0.41}_{-0.16}$ d^{-1}

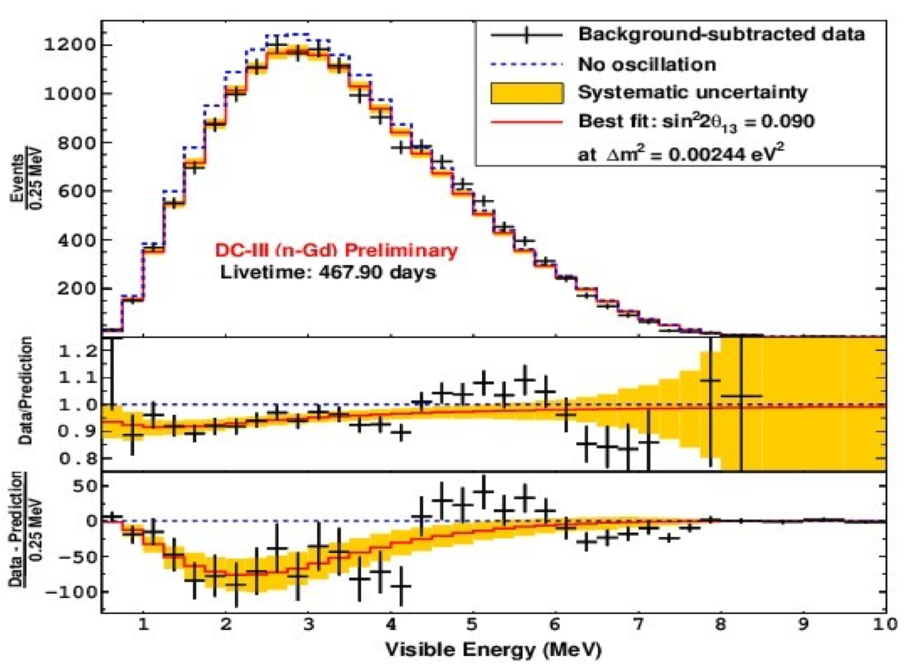
- Background rates are constrained in fit, particularly for ^{9}Li+^{8}He.
- Reactor-Off measurement included as constraint on the background total rate.



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



RESULTS

$\sin^2 2\theta_{13} = 0.090^{+0.032}_{-0.029}$

Fast-n/Stopping-μ: 0.56±0.04 d^{-1}

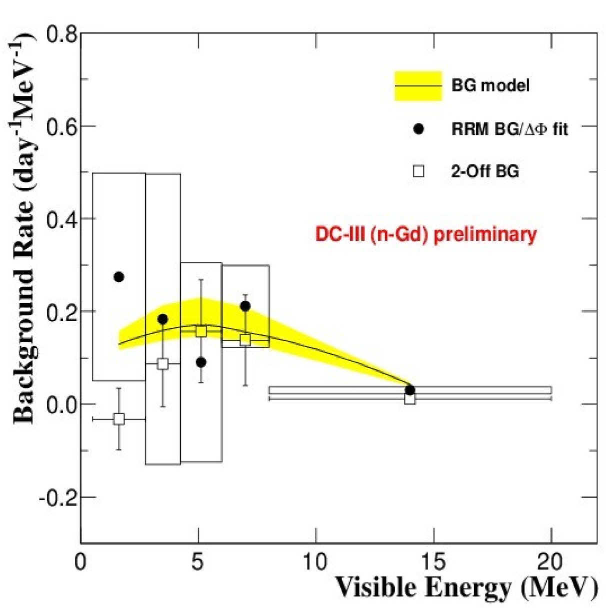
^{9}Li+^{8}He: $0.80^{+0.15}_{-0.13}$ d^{-1}

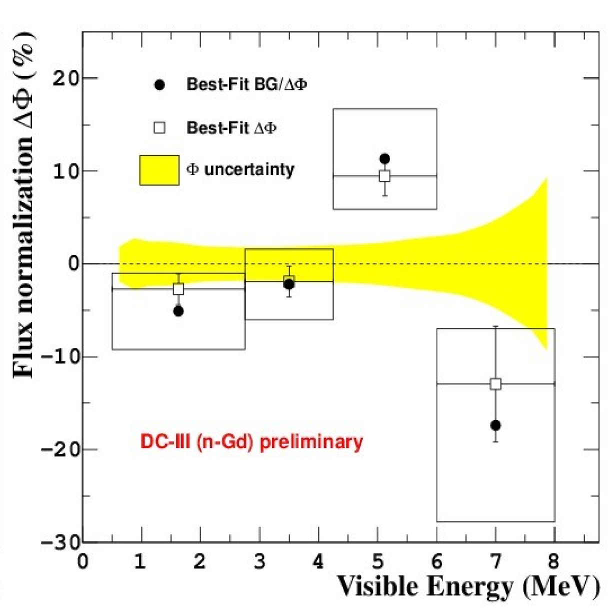
χ^2/d.o.f = 51.6/40

*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:** positron energy spectrum. **Center:** ratio of data to prediction. **Bottom:** difference between data and prediction.*

ν SPECTRUM >4MeV

Reactor power fits to the background (BG) rate and the $\bar{\nu}$ flux normalization (ΔΦ), while constraining θ_{13}. 5 energy ranges are considered. A bias in the flux prediction if favored as the cause of the structures above 4 MeV. A 2σ tension is observed with respect to the flux prediction in the 4.25-6.0 MeV range. The tension is increased to 3σ if the background is constrained to the estimates when performing the fit.

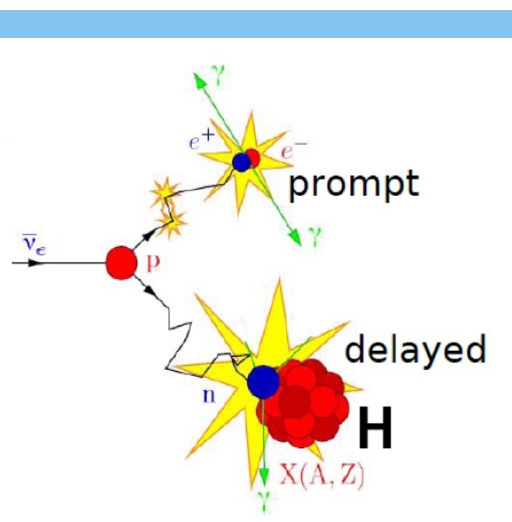




Hydrogen capture analysis

MOTIVATION

- Higher signal statistics (≈2×)
- 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.

Reactor-Off data

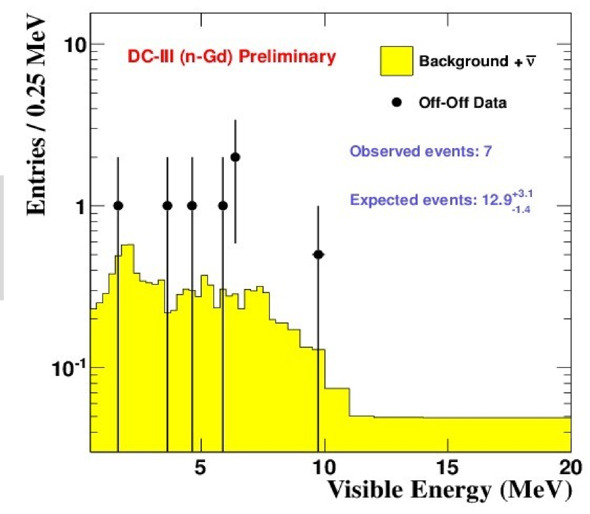
UNIQUE OPPORTUNITY

- Only reactor $\bar{\nu}$ experiment with opportunities to take data with all reactors off.
- Serves as background constraint in oscillation fits.

DATA COLLECTED

Reactor-off data (black points with statistical errors) overlaid upon background and residual reactor neutrino prediction.

- 7.24 live days of reactor-off data
- 7 candidates passing signal selection cuts
- After subtracting residual reactor neutrinos, yields total background rate of 0.76 ± 0.37 d^{-1}, consistent within background model.



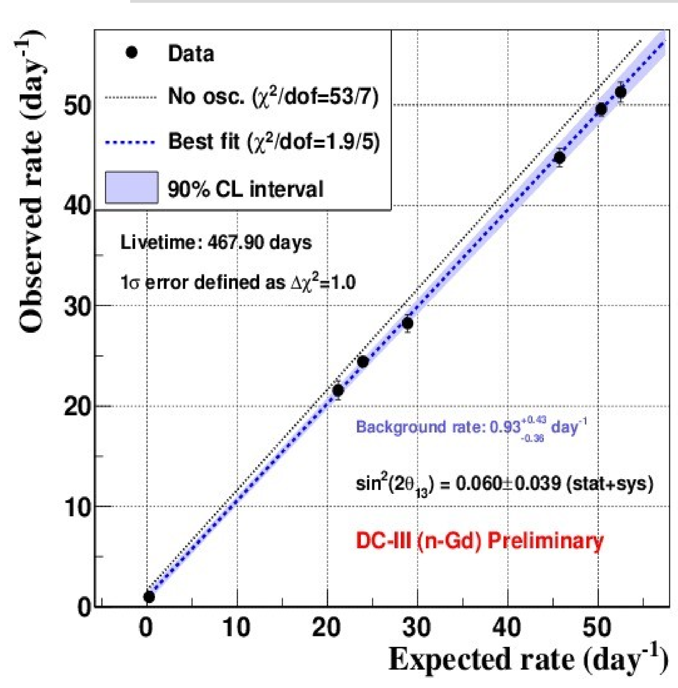
Reactor power fit

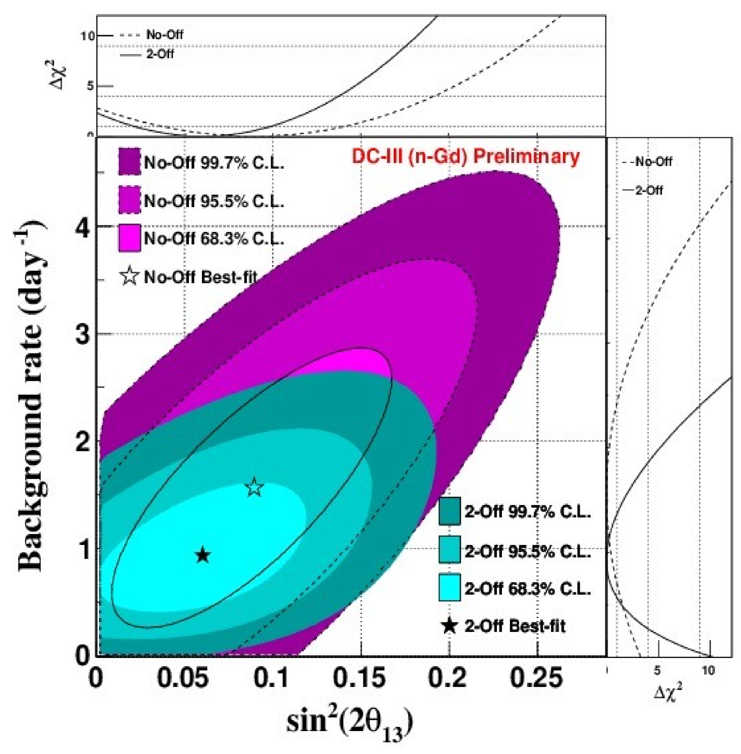
- Compares observed and predicted rate at different reactor powers.
- Provides a background-model-independent measurement of θ_{13}.

Ratio of observed rate to rate expected with no oscillation (black dots) superimposed on best fit (dashed blue line). Fit includes reactor-off data. Black dotted line shows the null hypothesis of observed rate equal to expected rate.

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.





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.

SYSTEMATIC ERRORS

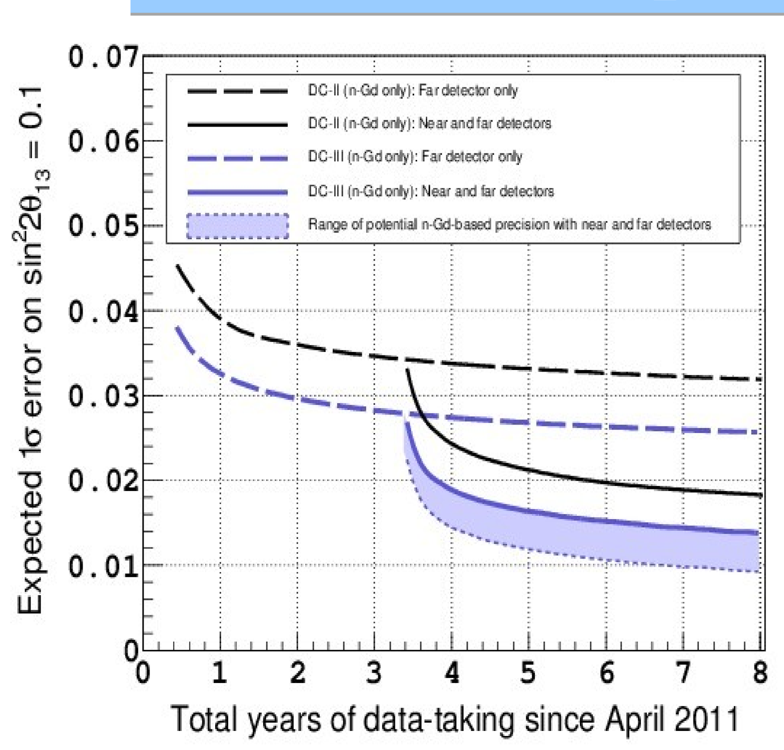
Involves only normalization uncertainties:

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

RESULTS

Using only reactor-on data:	Also including reactor-off data:
$\sin^2 2\theta_{13} = 0.089 \pm 0.052$	$\sin^2 2\theta_{13} = 0.060 \pm 0.039$
Background rate = 1.57 ± 0.86 d^{-1}	Background rate = $0.90^{+0.43}_{-0.36}$ d^{-1}

Future precision



- Now significantly more sensitive than in previous Gd-based analysis [2]
- Near detector will sharply increase the 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 same systematics, live-to-calendar time ratio, and far detector backgrounds as the present analysis (previous Gd-based analysis [2]); near detector backgrounds are estimated from measured muon flux. We assume 0.2% of detection efficiency uncertainty and 0.1% of reactor flux uncertainty is uncorrelated between detectors. Shaded blue region represents potential future precision, depending on reduction of systematic errors

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)