Recent Results from Double Chooz

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On behalf of the DC collaboration

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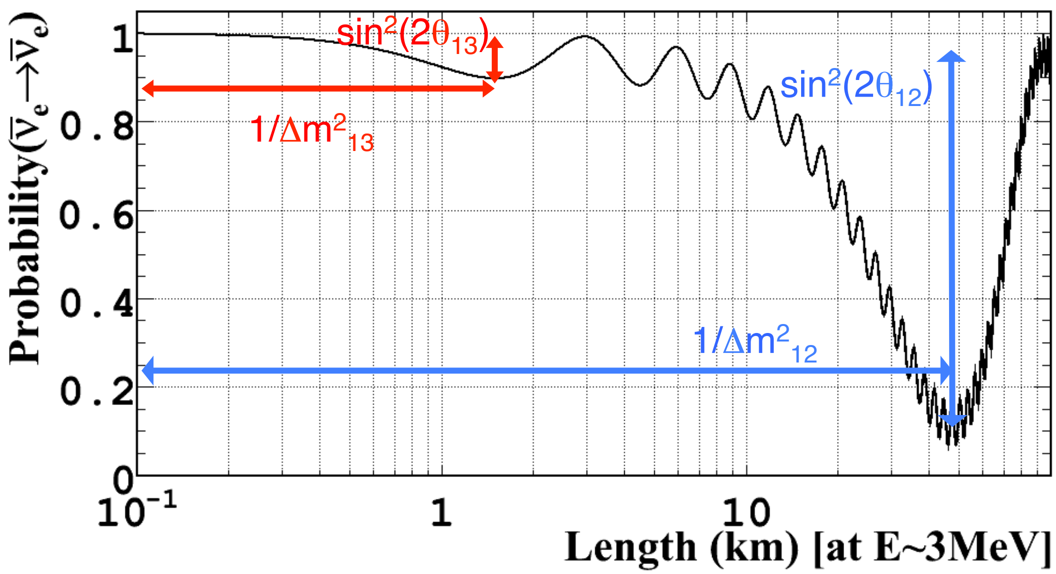
θ_{13} Measurement with Reactors

- Neutrino has still some mysteries.
- Mixing angles have been measured recently.
  - → θ_{13} was the remaining one until a few years ago.
  - → Precise measurement of θ_{13} is a key for neutrino problems.
- Reactor experiments are good for θ_{13} measurement by observing $\bar{\nu}_e$ disappearance:
  - → Reactor is a free and rich source of of $\bar{\nu}_e$.
  - → At ~1km(Δm^2~0.0025) from the reactor, pure θ_{13} measurement can be achieved.



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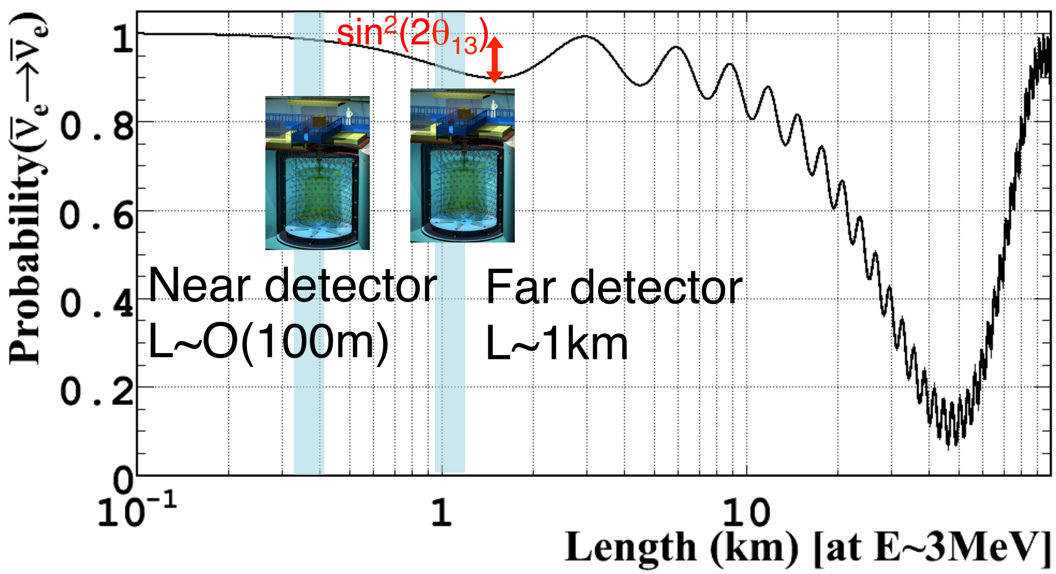
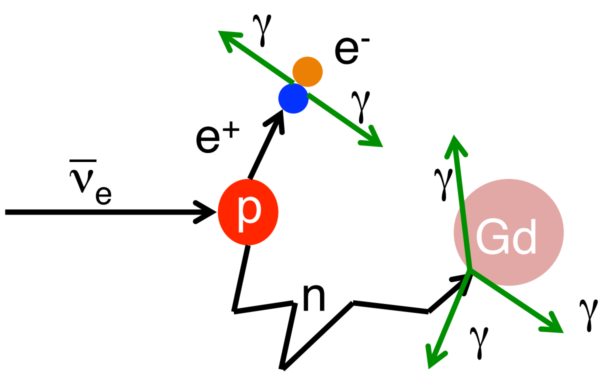


Antineutrino Detection

Inverse Beta Decay (IBD)

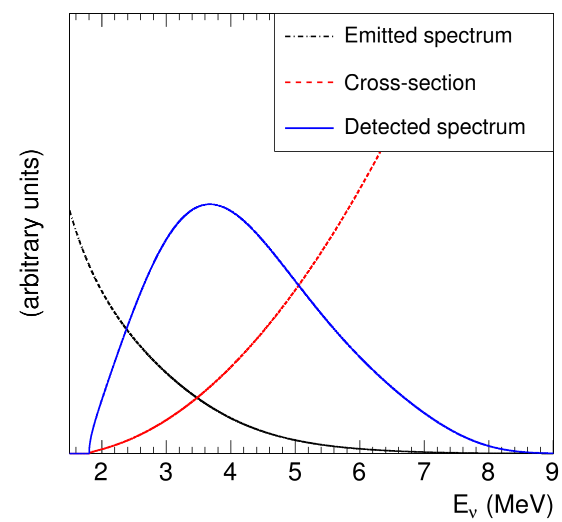
$\bar{\nu}_e + p \rightarrow e^+ + n$



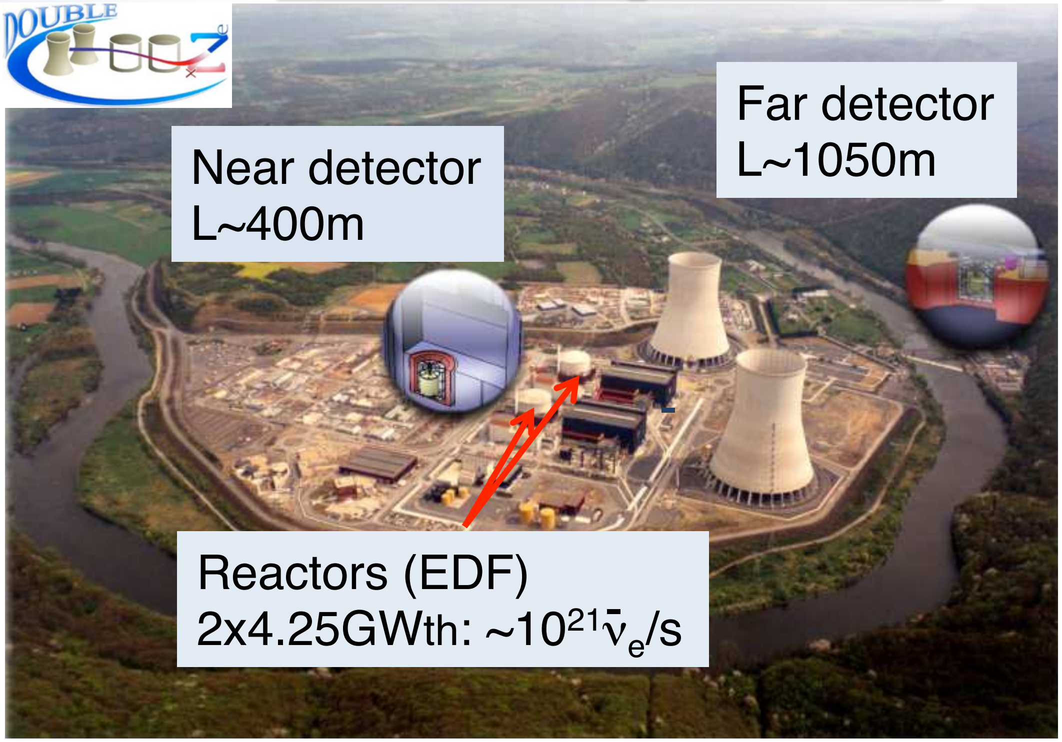
- Two different timing signals are generated at IBD event.
- Prompt signal:
  - → e^+ ionization and e^+e^- annihilation.
  - → 1-8 MeV.
- Delayed signal:
  - → Neutron capture on Gd.
  - → ~8MeV, ~30μs delayed from prompt signal.
  - → Signals of neutron capture on H also can be used independently.
    - → ~2.2MeV, 200μs delay.

- Prompt signal energy (visible energy) is related to initial neutrino energy:

$$
\begin{aligned}
E_{vis} &= E_{e^+} + 2m_e \\
&\approx E_{\bar{\nu}_e} - (m_n - m_p) + m_e \\
&\approx E_{\bar{\nu}_e} - 0.78\text{MeV}
\end{aligned}
$$

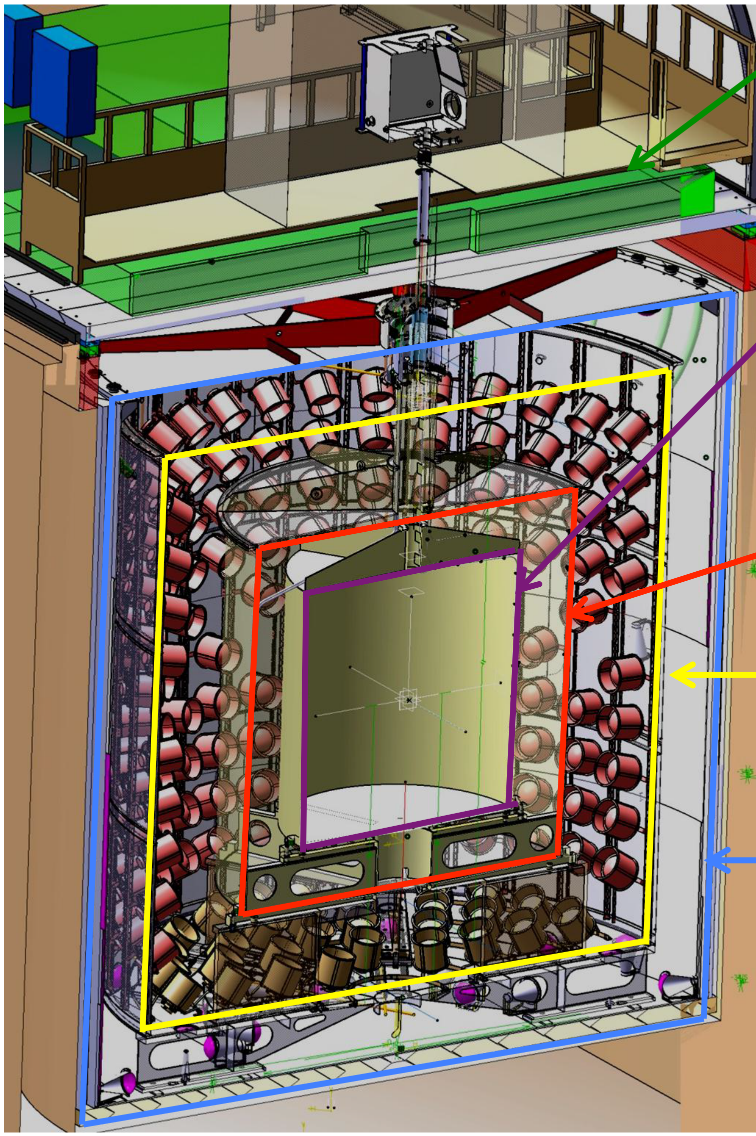


Double Chooz



- The reactor neutrino experiment at Chooz, France.
- Collaboration:
  - →~150 people from 7 countries.
  - →Brazil, France, Germany, Japan, Russia, Spain and USA.
- Far detector is running since Apr/2011.
- Near detector is just starting to take data.

The Double Chooz Detector



Outer veto (OV)

- Plastic scintillator strip.
- Identify cosmic μ.

Inner Detector

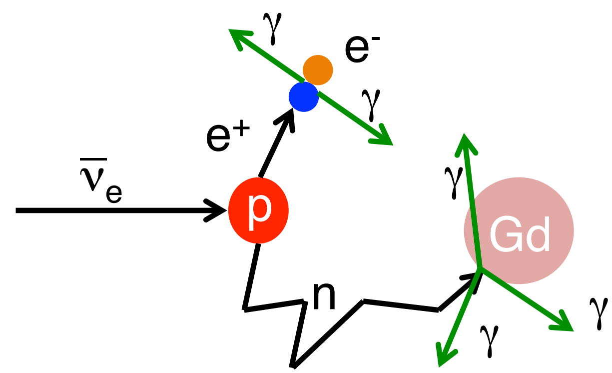
- ν-target:
  - → Gd-loaded (1 g/l) liquid scintillator (10.3m^3) in acrylic vessel.
  - → Neutrino interaction point.
- γ-catcher:
  - → Liquid scintillator (22.3m^3) in acrylic vessel.
- Buffer region:
  - → Mineral oil (110m^3) in stainless steel vessel.
  - → 390 PMTs (10”) are set in this region.

Inner veto (IV)

- Liquid scintillator (90m^3) with 78 PMTs (8”) in stainless steel vessel.
- Identify cosmic μ, reduce environmental γ

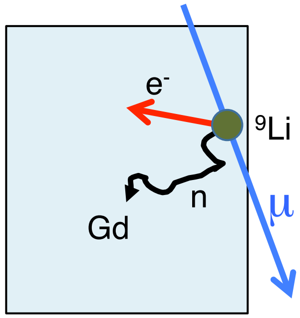
Neutrino Candidate Selection

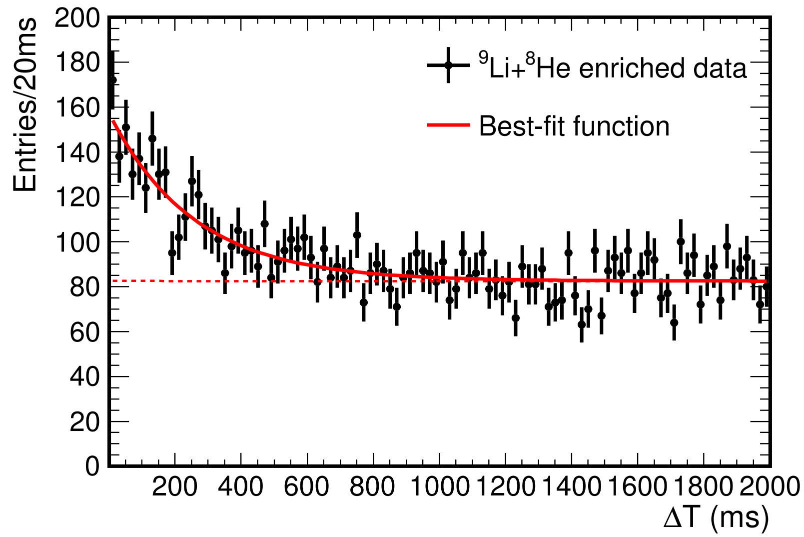
- Single event selection
  - → Veto 1ms after μ event (high energy event).
  - → Light noise event rejection.
- IBD selection
  - → $0.5 < E_{prompt} < 20$ MeV
  - → $4 < E_{delayed} < 10$ MeV
  - → $0.5 < \Delta T < 150$ μs
  - → $\Delta R < 100$ cm
  - → No events within 200 μs before and 600 μs after prompt event

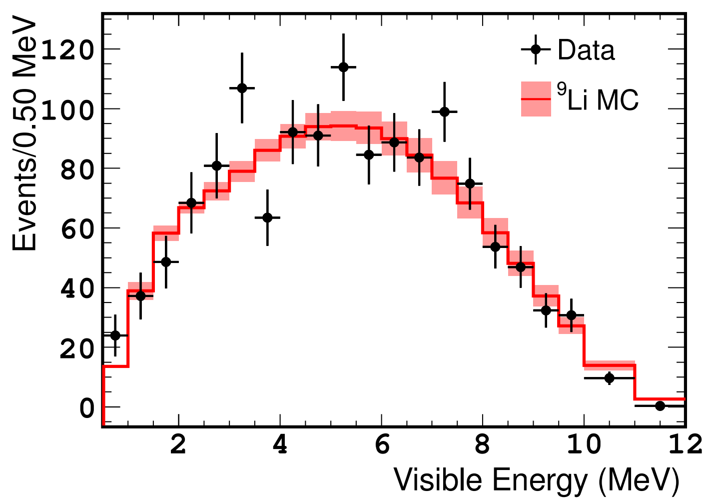


- Improvements from DC-II (PRD86(2012)052008) to DC-III(JHEP10(2014)086)
  - → Doubled events: 227.9 live days -> 467.9 live days.
  - → Improved energy measurement: The energy uncertainty 1.1%->0.74%.
  - → Better background rejection (next slides).
  - → Increased signal efficiency: S/B 15.6 -> 22.0.

Backgrounds: $^9Li/^8He$



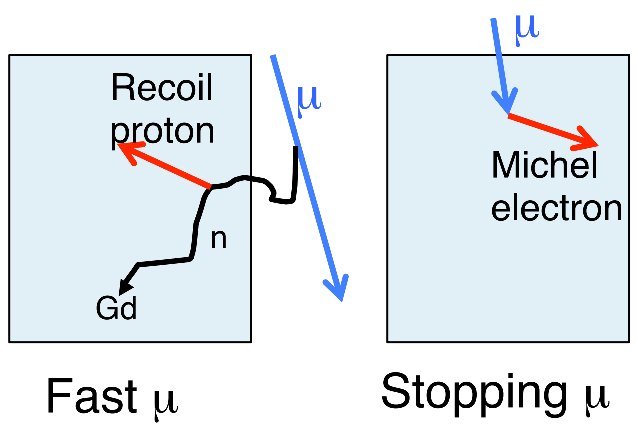


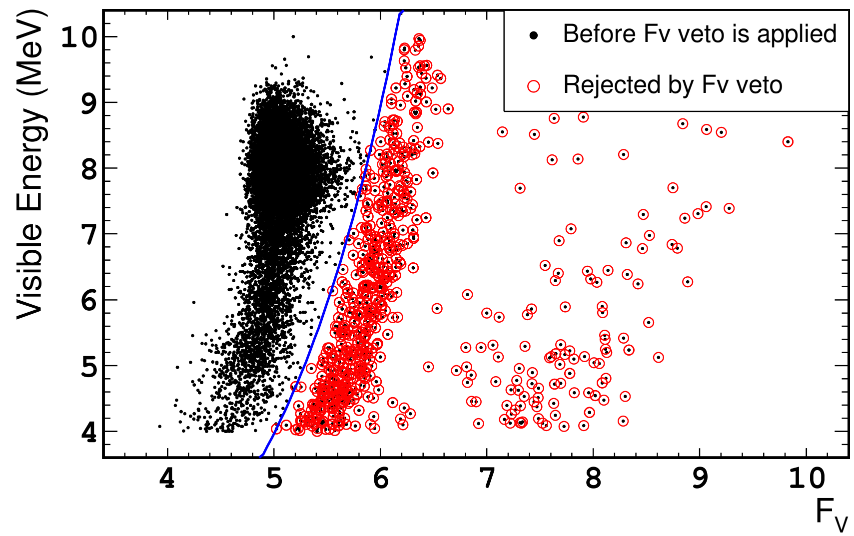


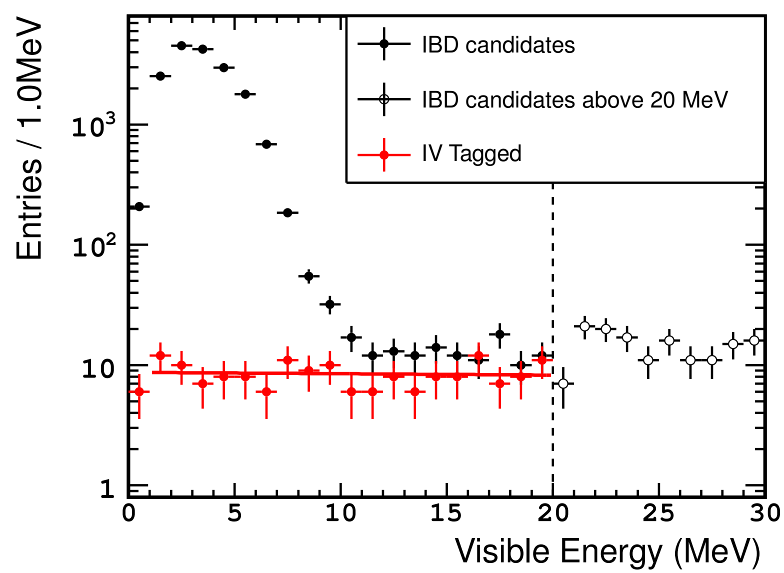
- Rejected by:
  - → Likelihood veto (new).
- Measured by ^{9}Li enriched data.
  - → ΔT for rate.
  - → Visible energy for shape.

- Rate: $0.97^{+0.41}_{-0.16}$ (day^{-1})
  - → DC-III/DC-II = 0.78

Backgrounds: Correlated Backgrounds



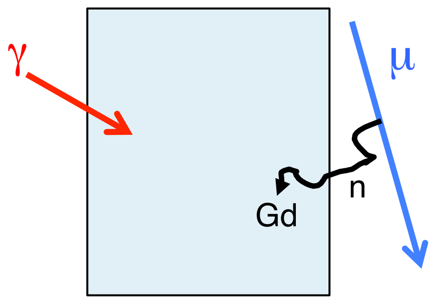


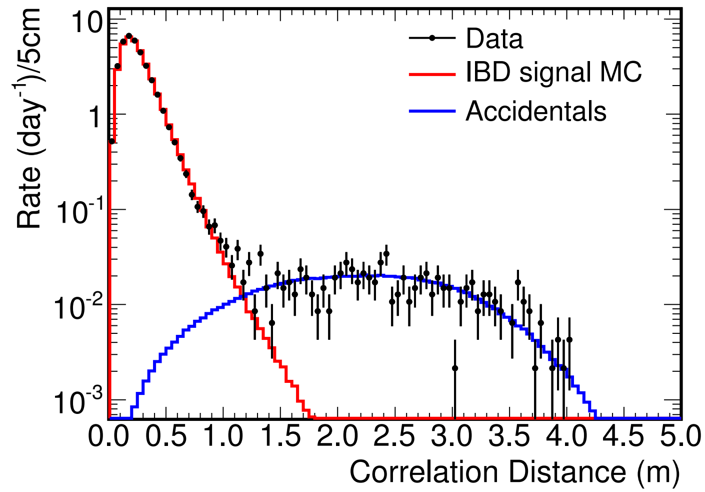


- Rejected by:
  - → Vertex reconstruction goodness(F_v) (new).
  - → OV cut, IV vetos.
- Measured by IV-tagged events.

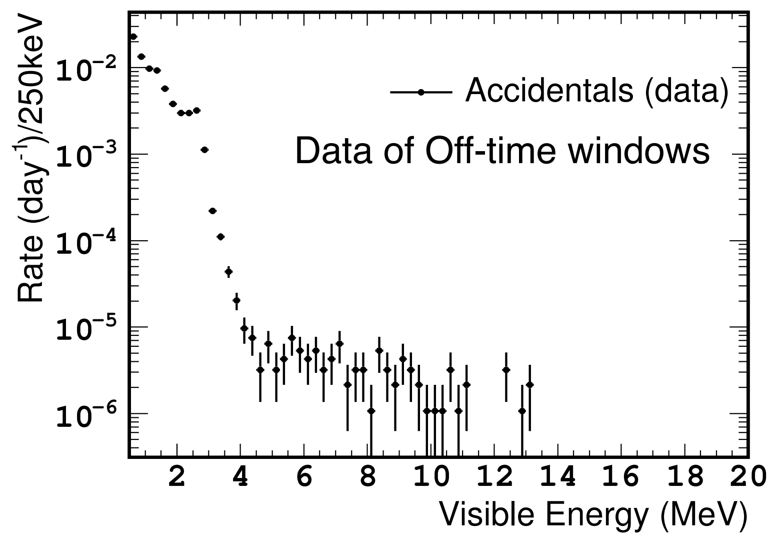
- Rate: 0.604±0.051(day^{-1})
  - → DC-III/DC-II = 0.52

Backgrounds: Accidental Coincidences



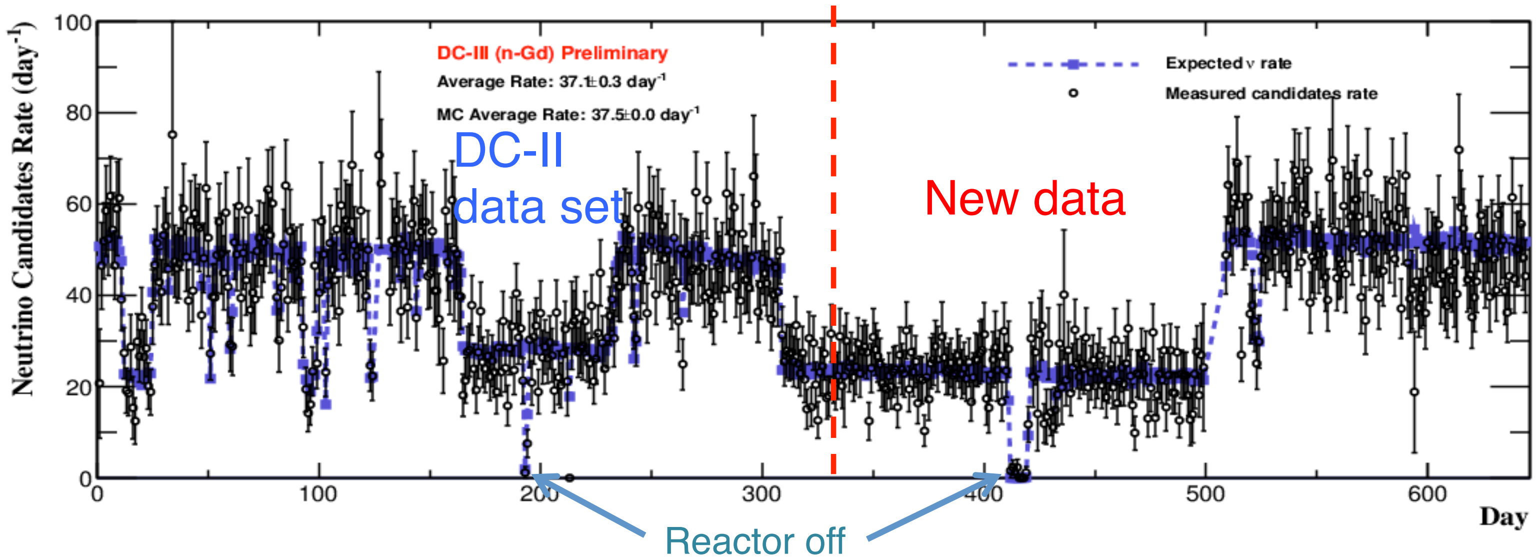


- Rejected by:
  - →Correlation distance cut (new).
  - →Timing cut.
- Measured by the data in off-time windows.



- Rate: 0.070±0.003 (day^{-1})
  - →DC-III/DC-II = 0.27

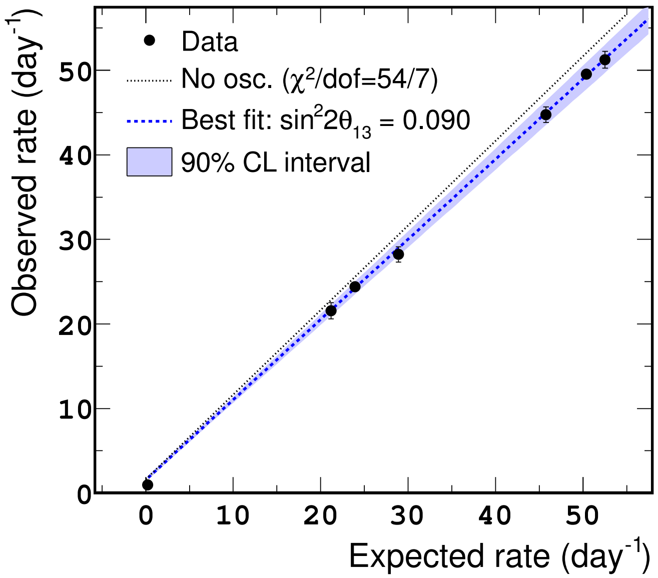
Data and Uncertainties

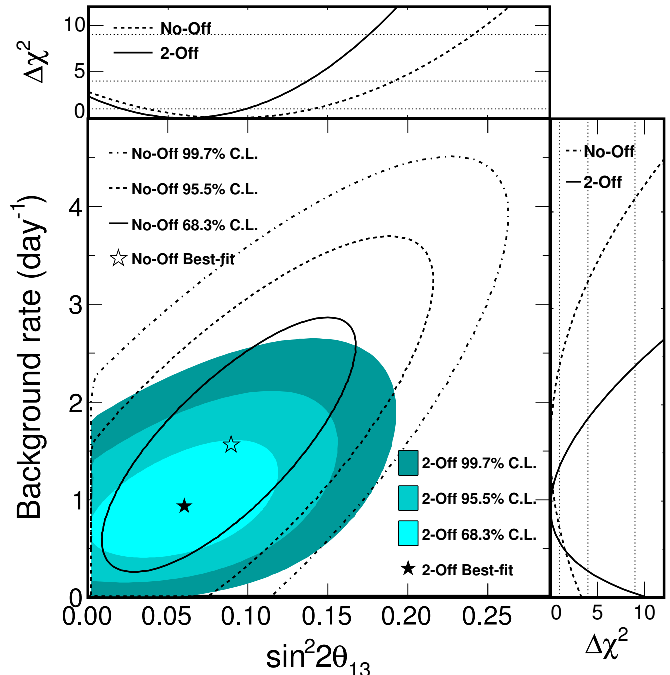


	Uncertainty(%)	DC-III/DC-II
Reactor flux	1.7	1.0
Detection efficiency	0.6	0.6
$^{9}Li/^{8}He$	+1.1/-0.4	0.5
Correlated background	0.1	0.2
Statistics	0.8	0.7
Total	+2.3/-2.0	0.8

- 460.67 live days data with reactors.
  → 17351 IBD candidates.
- 20% reduction of the total uncertainty.
- 7.24 live days data of reactor off.
- Δm^2 input from MNOS.
  → $2.44^{+0.09}_{-0.10} \times 10^{-3}eV^2$

Reactor Rate Modulation Analysis





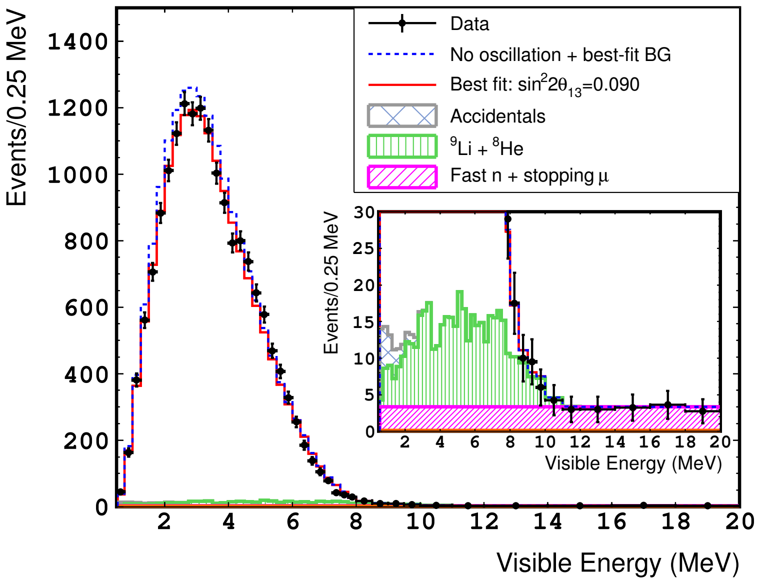
- Fit the IBD rate of different reactor power data (2-on, 1-off, 2-off)

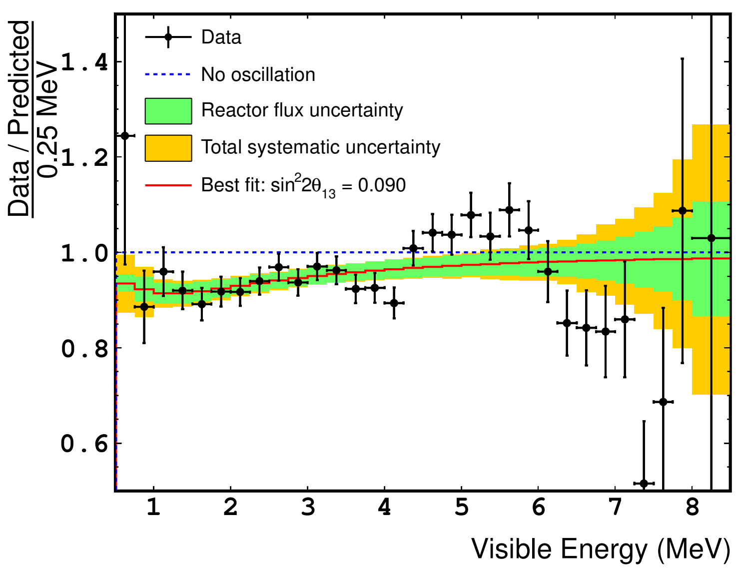
$$R^{obs} = \left(1 - \sin^2(2\theta_{13})\sin^2\left(\frac{\Delta m_{13}^2 L}{4E}\right)\right) R^{IBD} + B$$

- w/ background constraint with 2-off data:
  - $\sin^2(2\theta_{13})=0.090^{+0.034}_{-0.035}$, $B=1.56^{+0.18}_{-0.16}$ (day^{-1})
- Background model independent fit (no constraint on B, unique of DC):

→ $\sin^2(2\theta_{13})=0.060\pm0.039$, $B=0.93^{+0.43}_{-0.36}$ (day^{-1})

Rate + Shape Analysis

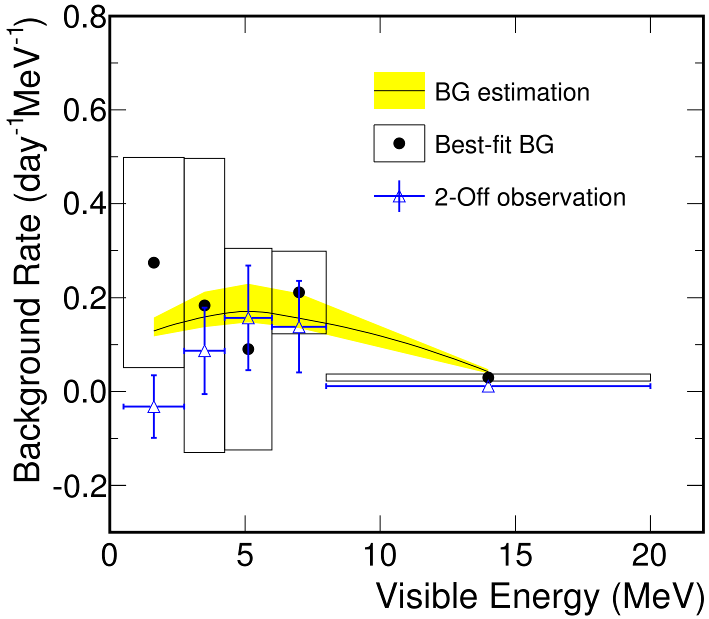


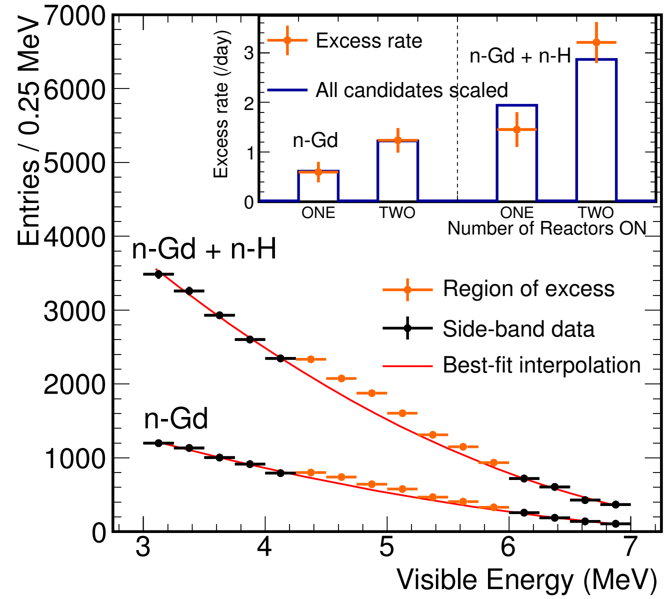


- Compare energy spectrums of observed IBD and prediction.
- Improvements from Gd-II.
  - → Improvement of energy reconstruction.
  - → Data-driven background shape estimation.
  - → Finer binning (with more statistics).
  - → Reactor off data.

- $\sin^2(2\theta_{13})=0.090^{+0.032}_{-0.029}$
  - → χ^2/ndf = 52.2/40
  - → Background rate = 1.38±0.14 (day^{-1})
  - → 5.3% improvement of precision from Gd-II.

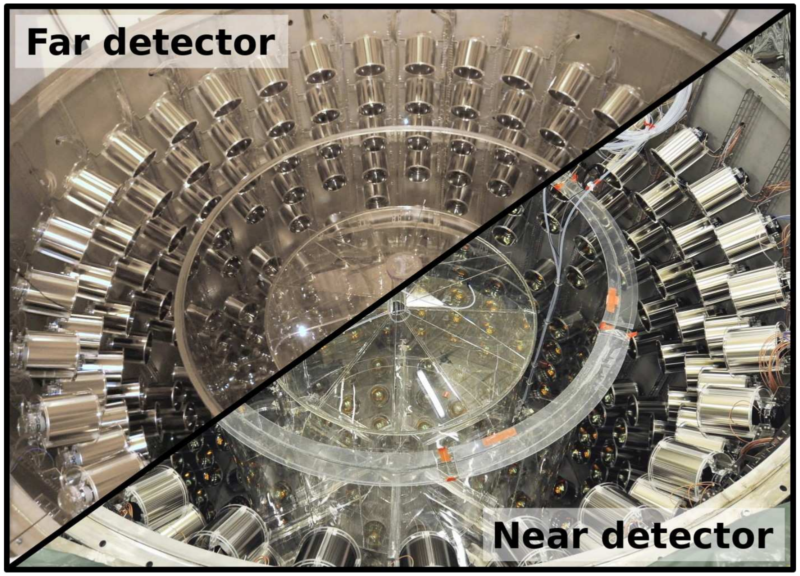
Unexpected Spectrum Distortion





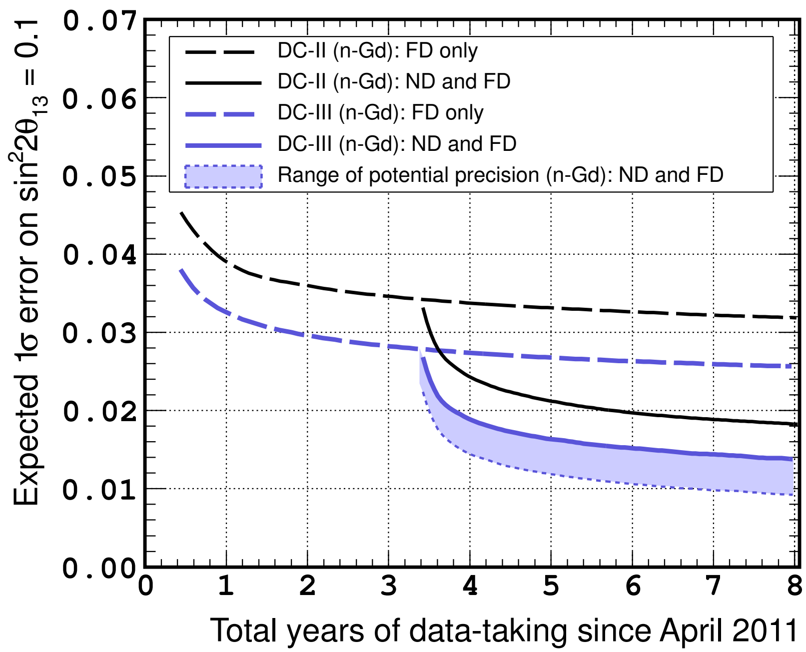
- Unexpected spectrum distortion is found above 4 MeV of the prompt energy.
- Energy scale around 5 MeV is confirmed by Carbon capture events.
- No correlation with any backgrounds is found.
- Strong correlation with the reactor power is confirmed.
- The effect on θ_{13} measurement is insignificant compared to the uncertainty.

Near Detector Prospect



- Construction (w/o OV) was finished in the last Autumn.
- Commissioning was done and now it is starting data taking.
- New results with ND are coming soon.

- ND flux information can suppress current largest uncertainty of the reactor flux.
- 0.01~0.015 uncertainty of $\sin^2(2\theta_{13})$ is expected in 3 years.
- In addition, new analyses such sterile neutrino search can be studied.



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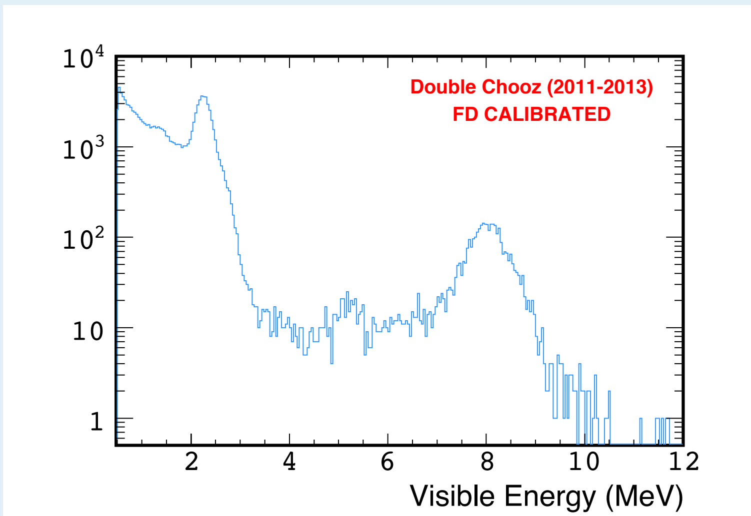

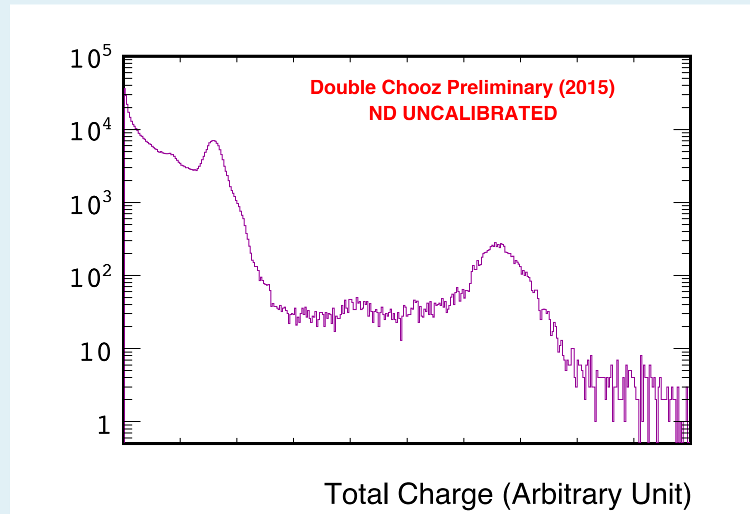

- Spallation neutron capture spectrum of early ND data compared to FD data.
- Similar spectrums can be seen:
  - Indicate feasibility of IBD measurement.
  - Radiopurity is well controlled.
  - Shielding works as expected.

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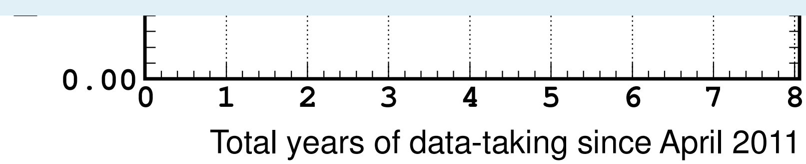


Summary

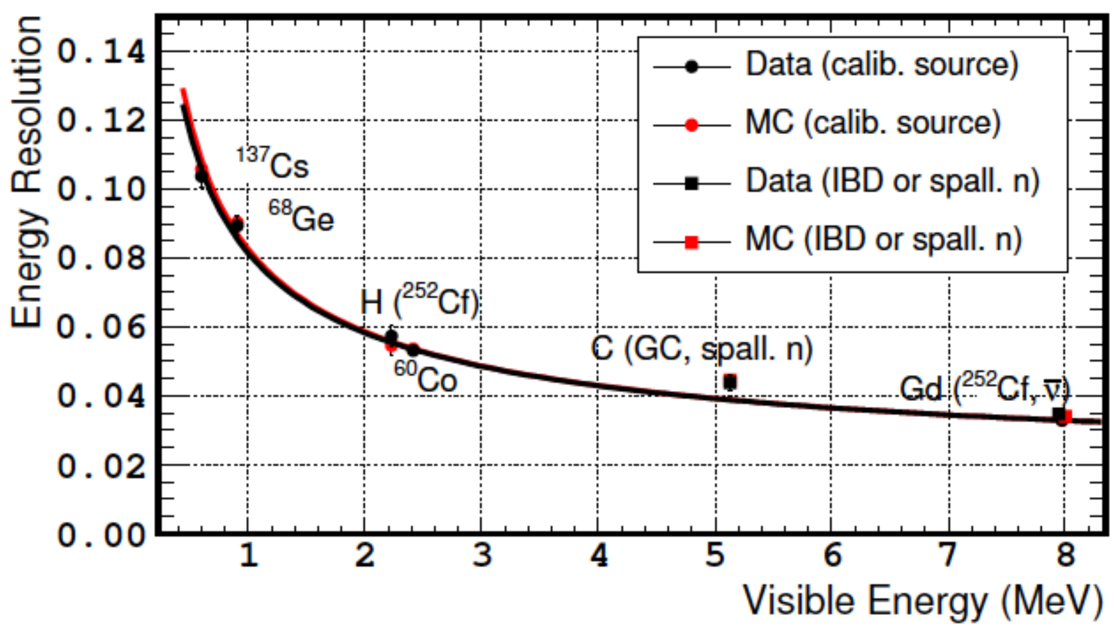
- Double Chooz' latest results (from JHEP 1410 (2014) 86) were shown.
  - → New n-Gd analysis (DC-III) has a lot of improvements.
    - → Improved energy reconstruction.
    - → Better background rejection.
    - → Higher signal efficiency.
    - → Doubled statistics.
  - → Results
    - → Reactor Rate Modulation: $\sin^2(2\theta_{13})=0.090^{+0.034}_{-0.035}$
    - → Rate+Shape: $\sin^2(2\theta_{13})=0.090^{+0.032}_{-0.029}$
  - → Although spectrum distortion above 4MeV is still under investigation, it has strong correlation with the reactor flux.
  - → The Near Detector just starts data taking.
- Other recent results from Double Chooz:
  - → Ortho-positronium observation in the Double Chooz Experiment (JHEP 1410 (2014) 32)
  - → Background-independent measurement of θ_{13} in Double Chooz (Phys. Lett. B735 (2014) 51-56)
  - → First Measurement of θ13 from Delayed Neutron Capture on Hydrogen in the Double Chooz Experiment (Phys. Lett. B723 (2013))

Backup

Energy calibration improvement

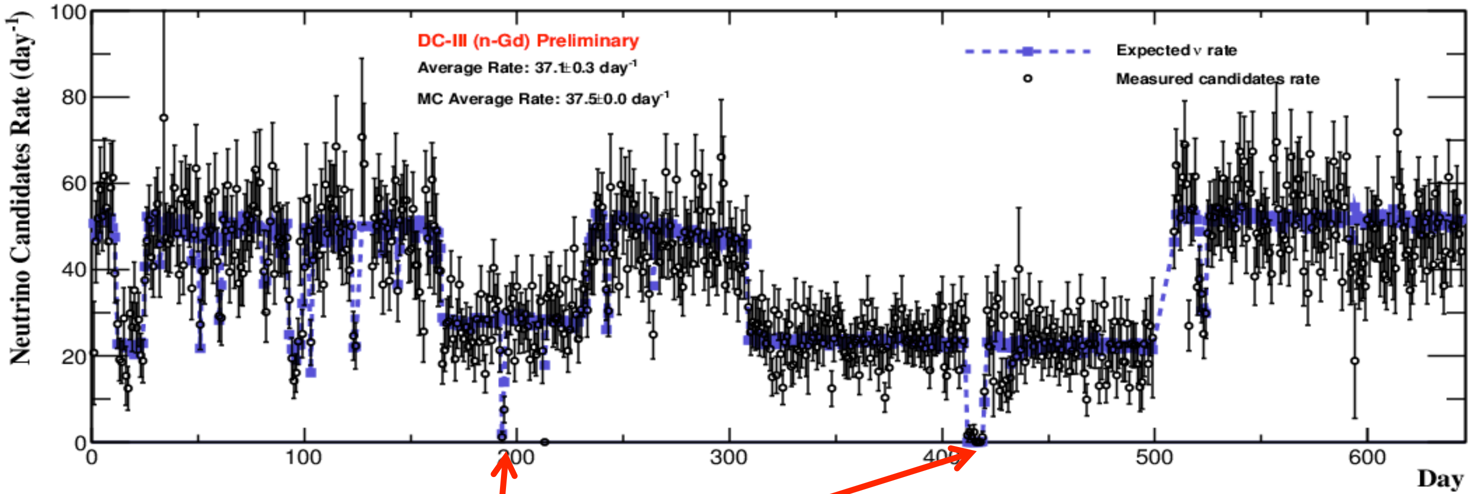
Systematic uncertainties on energy scale

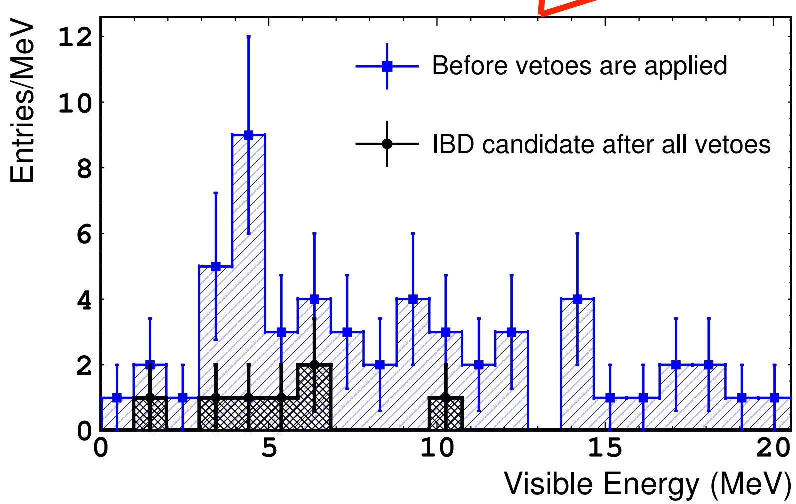
Source	Uncertainty (%)	Gd-III/Gd-II
Non-uniformity	0.36	0.84
Instability	0.50	0.82
Non-linearity	0.35	0.41
Total	0.74	0.65



Data-MC energy comparison

Reactor Off Data





- 7.24 days data with both two reactors off.
- 7 events after all selections.
  → Expected: $12.9^{+3.1}_{-1.4}$
- Reactor off data are used to constrain the total background rate.