Physics in the Double Chooz Experiment

Guang Yang
Argonne National Lab &
Illinois Institute of Technology

On behalf of Double Chooz collaboration

Neutrino Mixing

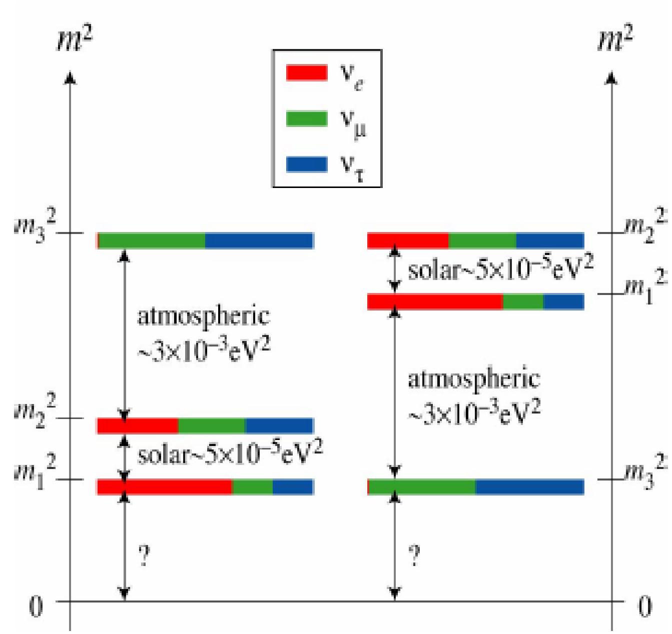
- PNMS matrix can be broken down into three 3*3 matrices:

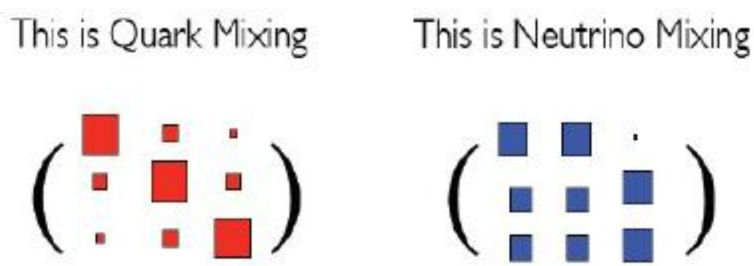
Current Measurements: $\Delta m^2_{21} \sim 8\times10^{-5}$ eV² $\Delta m^2_{31} \sim \Delta m^2_{32} \sim 0.0025$ eV²

$$U = \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{cp}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{cp}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}$$

"Solar" $\theta_{12} \sim 33°$ "Little mixing angle" $\theta_{13} < 11°$ (circa 2011) "Atmospheric" $\theta_{23} \sim 45°$

- Each mixing angle related to a mass splitting between the two mass states





Neutrino oscillation Experiments

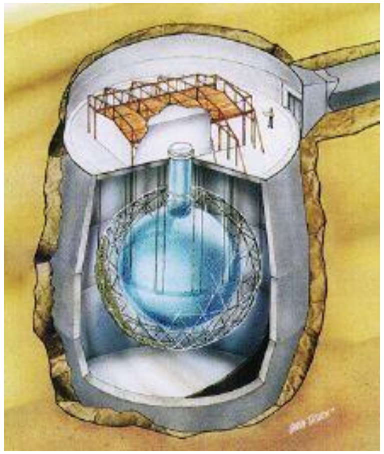
Solar: BOREXINO, SNO…

Atmospheric: Super-K…

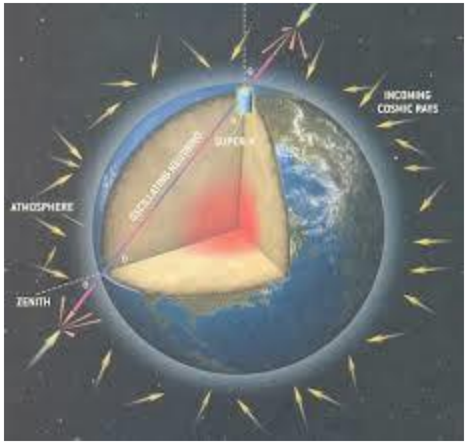
Accelerator: MINOS, NOvA, T2K...

Reactor: Daya Bay, Double Chooz, RENO, KamLAND...

Cosmic: IceCube…



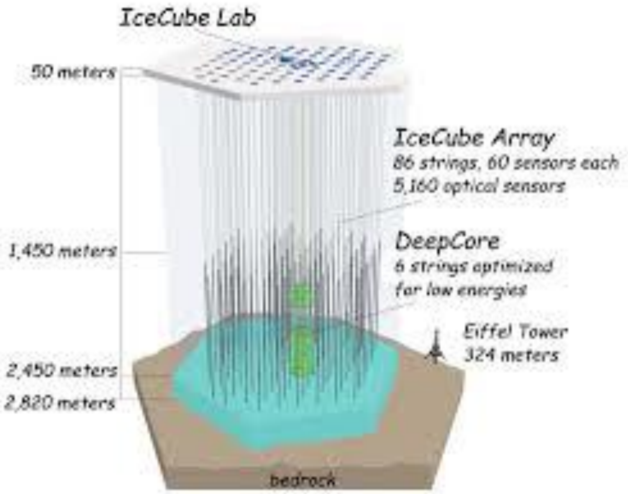
SNO ($\nu_e \rightarrow \nu_{\mu,\tau}$)



Super-K($\nu_\mu \rightarrow \nu_\tau$)

NOvA

Double Chooz ($\overline{\nu}_e \rightarrow \overline{\nu}_e$)



IceCube

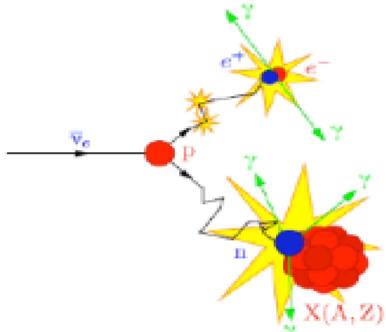
Double Chooz Experiment

Brazil	France	Germany	Japan	Russia	Spain	USA
CBPF UNICAMP UFABC	APC CEA/DSM/IRFU: SPP SPhN SEDI SIS SENAC CNRS/IN2P3: Subatech IPHC	EKU Tübingen MPIK Heidelberg RWTH Aachen TU München U. Hamburg	Tohoku U. Tokyo Inst. Tech. Tokyo Metro. U. Niigata U. Kobe U. Tohoku Gakuin U. Hiroshima Inst. Tech.	INR RAS IPC RAS RRC Kurchatov	CIEMAT-Madrid	U. Alabama ANL U. Chicago Columbia U. UCDavis Drexel U. IIT KSU LLNL MIT U. Notre Dame U. Tennessee

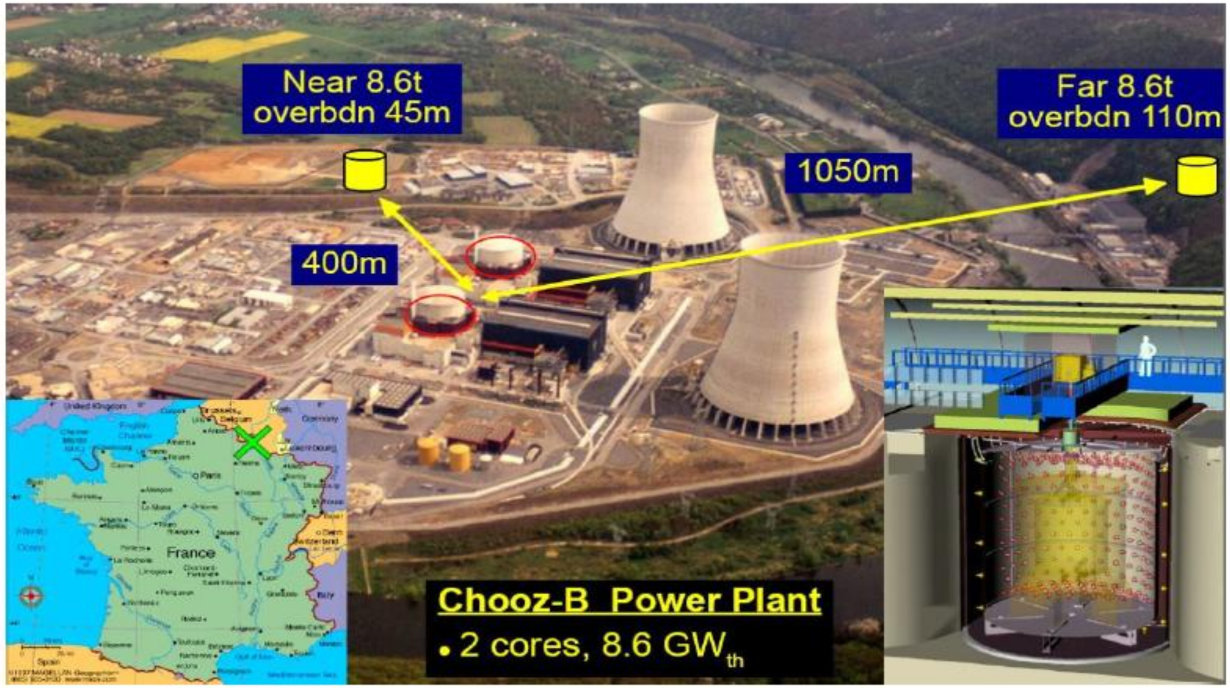
Spokesperson:
H. de Kerret (IN2P3)

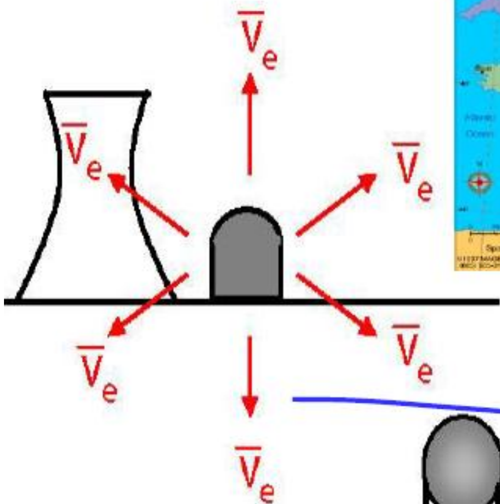
Project Manager:
Ch. Veyssière (CEA-Saclay)

Web Site:
www.doublechooz.org/

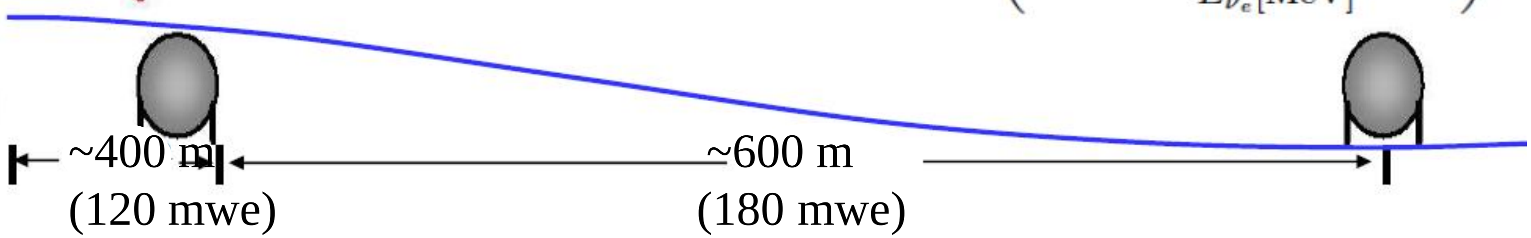


IBD: $\bar{\nu}_e$ +P -> e+ + n





$$P_{ee}(E_{\overline{\nu}_e}, L, \Delta m^2_{31}, \theta_{13}) = 1 - \sin^2(2\theta_{13}) \sin^2\left(1.27\frac{\Delta m^2_{31}[10^{-3}\ \mathrm{eV}^2] L[\mathrm{km}]}{E_{\overline{\nu}_e}[\mathrm{MeV}]}\right)$$



-Neutron created in IBD interaction may be captured by gadolinium (original analysis), or by hydrogen (extended analysis).

Double Chooz Detector

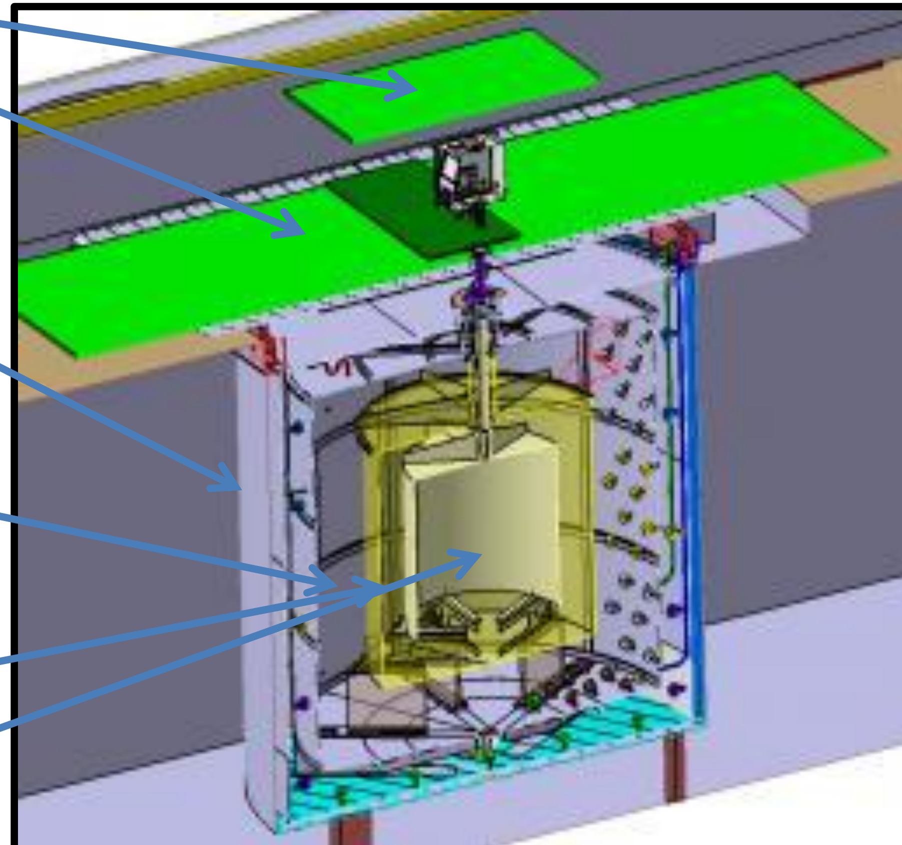
Outer Veto (OV)
Plastic scintillator strips

Inner Veto (IV)
90 m^3 of scintillator in a steel Vessel (10 mm) equipped with 78 PMTs (8 inches)

Buffer
110 m^3 of mineral oil in a steel Vessel. (3mm) equipped with 390 low-background PMTs (10 in.)

Gamma Catcher (GC)
22.3 m^3 scintillator in an acrylic Vessel (12 mm)

Target
10.3 m^3 scintillator doped with 1 g/l of Gd in acrylic vessel (8 mm)



physics goals in Double Chooz

Primary goal:

-precise measurement of neutrino mixing angle Θ_{13}, which is an important parameter for the neutrino mass hierarchy, CP violation phase, dirac vs. majorana particle etc.

Other goals:

-Test the Lorentz violation

-Neutrino directionality

-Muon-induced background studies

-Reactor flux distortion

-Light sterile neutrino search

Rate+Shape fit

-Our latest Gd-based analysis result.

-It is based on the prompt energy spectrum so that the energy scale is one of the most important things in Double Chooz.

$$\chi^2 = \sum_{i=1}^{40}\sum_{j=1}^{40}(N_i^{\rm obs} - N_i^{\rm exp})M_{ij}^{-1}(N_j^{\rm obs} - N_j^{\rm exp}) + \sum_{k=1}^{5}\frac{\epsilon_k^2}{\sigma_k^2}$$
$$+(\epsilon_a, \epsilon_b, \epsilon_c)\begin{pmatrix} \sigma_a^2 & \rho_{ab}\sigma_a\sigma_b & \rho_{ac}\sigma_a\sigma_c \\ \rho_{ab}\sigma_a\sigma_b & \sigma_b^2 & \rho_{bc}\sigma_b\sigma_c \\ \rho_{ac}\sigma_a\sigma_c & \rho_{bc}\sigma_b\sigma_c & \sigma_c^2 \end{pmatrix}^{-1}\begin{pmatrix}\epsilon_a \\ \epsilon_b \\ \epsilon_c\end{pmatrix}$$
$$+2\left[N_{\rm off}^{\rm obs}\cdot \ln\left(\frac{N_{\rm off}^{\rm obs}}{N_{\rm off}^{\rm exp}}\right) + N_{\rm off}^{\rm exp} - N_{\rm off}^{\rm obs}\right].$$

Fit Parameter	Input Value	Best-Fit Value
Li+He bkg. (d^{-1})	$0.97^{+0.41}_{-0.16}$	0.74 ± 0.13
Fast-n + stop-μ bkg. (d^{-1})	0.604 ± 0.051	$0.568^{+0.038}_{-0.037}$
Accidental bkg. (d^{-1})	0.0701 ± 0.0026	0.0703 ± 0.0026
Residual $\bar{\nu}_e$	1.57 ± 0.47	1.48 ± 0.47
Δm^2 (10^{-3} eV^2)	$2.44^{+0.09}_{-0.10}$	$2.44^{+0.09}_{-0.10}$
E-scale ϵ_a	0 ± 0.006	$0.001^{+0.006}_{-0.005}$
E-scale ϵ_b	0 ± 0.008	$-0.001^{+0.004}_{-0.006}$
E-scale ϵ_c	0 ± 0.0006	$-0.0005^{+0.0007}_{-0.0005}$

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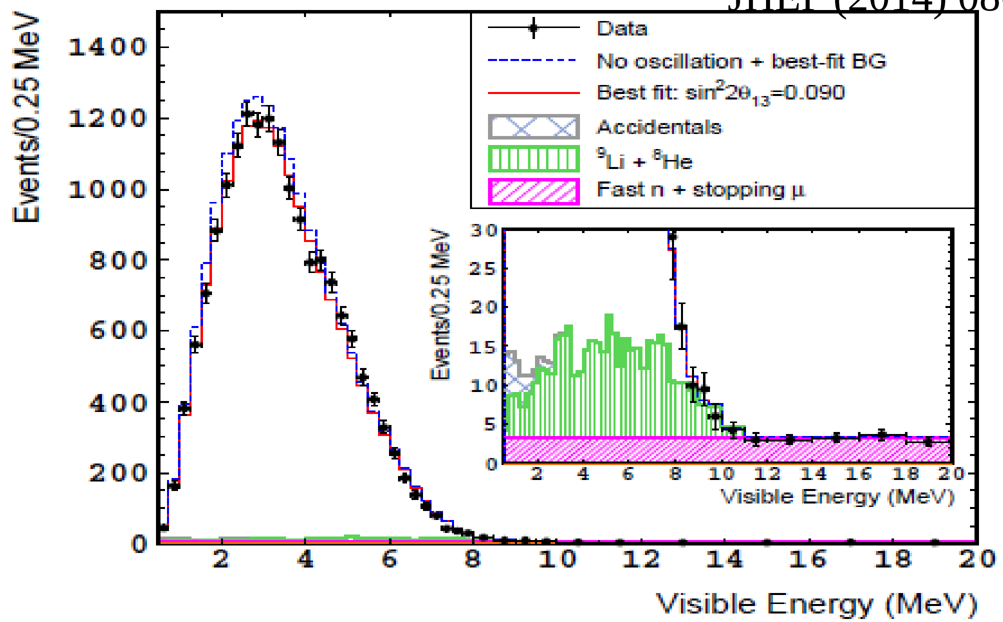


$$\chi^2_{\rm min}/d.o.f. = 52.2/40$$

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

Energy scale

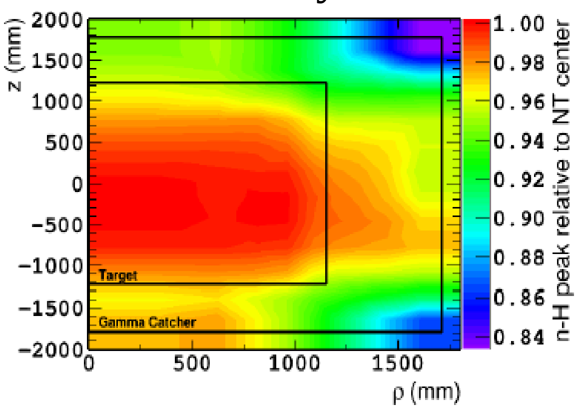
-Double Chooz uses unique energy calibration technique among reactor antineutrino experiments.

- We did the spatial uniformity and time stability calibrations first. The did a non-linearity correction for MC.

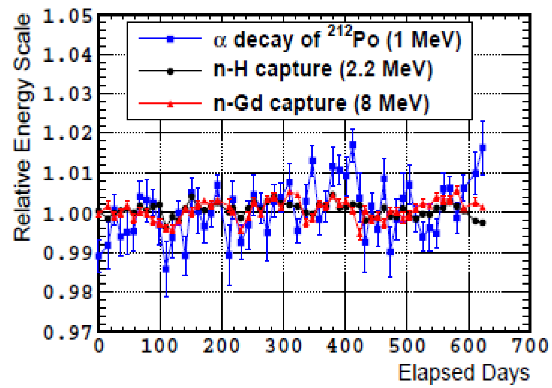
-After the light non-liearity correction, the MC energy scale agrees well with data.

-Even more spaces to improve.

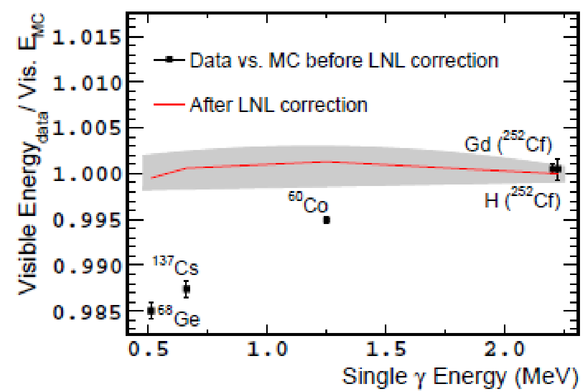
Uniformity



Stability



LNL correction



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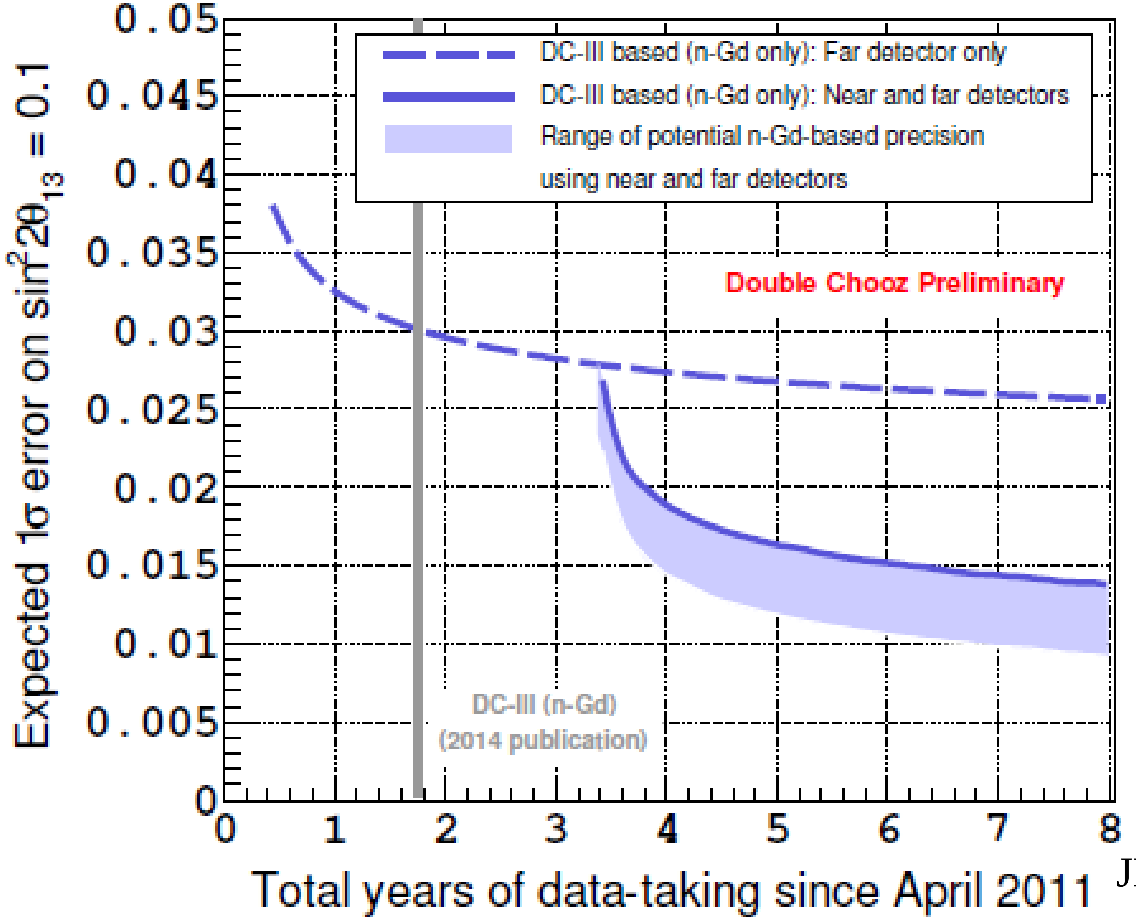
Double Chooz Θ_{13} sensitivity two-detector projection



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-Reactor flux distortion

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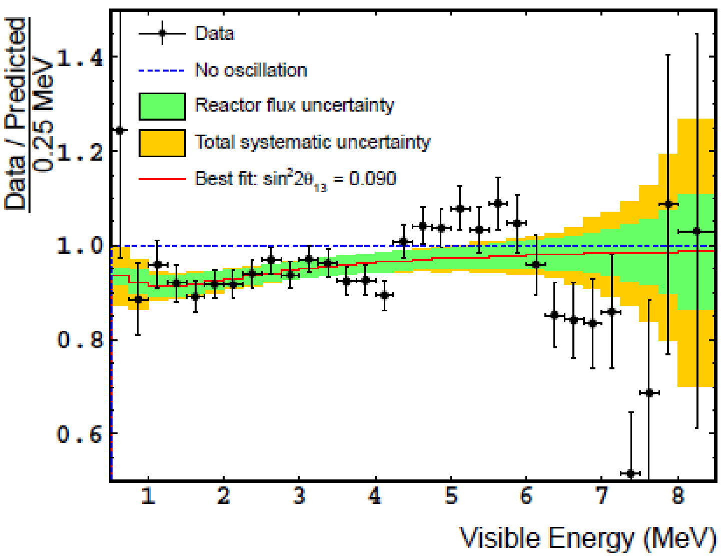
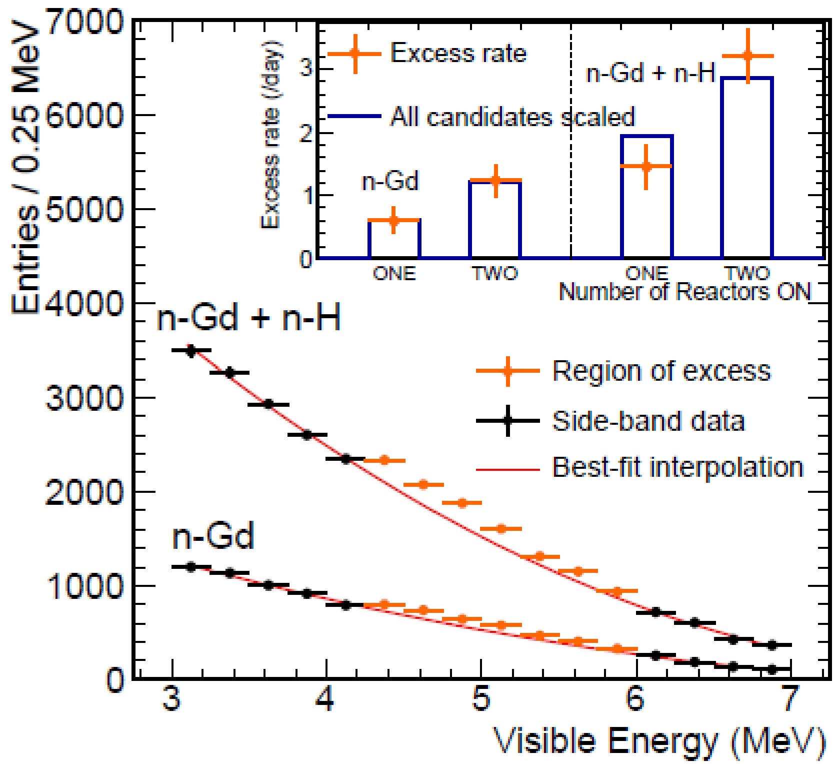
Reactor flux distortion

-Double Chooz is the first to report the 4-6MeV distortion.
-Confirmed by Daya Bay and RENO.
-More precise reactor antineutrino spectra needed.





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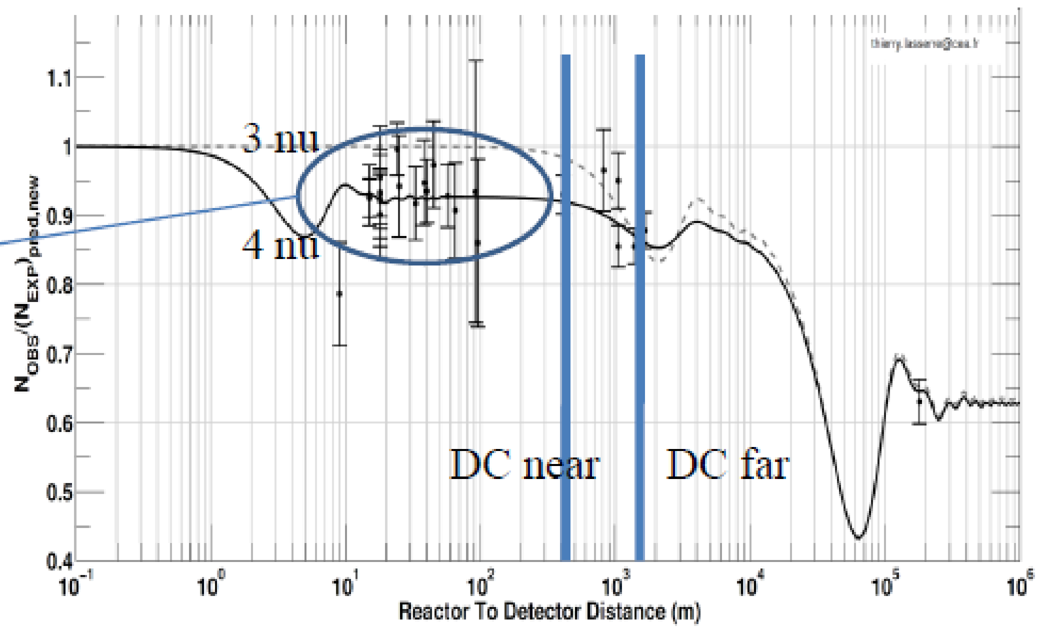
3+1 neutrino model

$$P_{ee} = 1 - \cos^4\theta_{\rm new}\sin^2(2\theta_{13})\sin^2\left(\frac{\Delta m^2_{31}L}{4E_{\bar{\nu}_e}}\right) - \sin^2(2\theta_{\rm new})\sin^2\left(\frac{\Delta m^2_{\rm new}L}{4E_{\bar{\nu}_e}}\right).$$

Experiment results

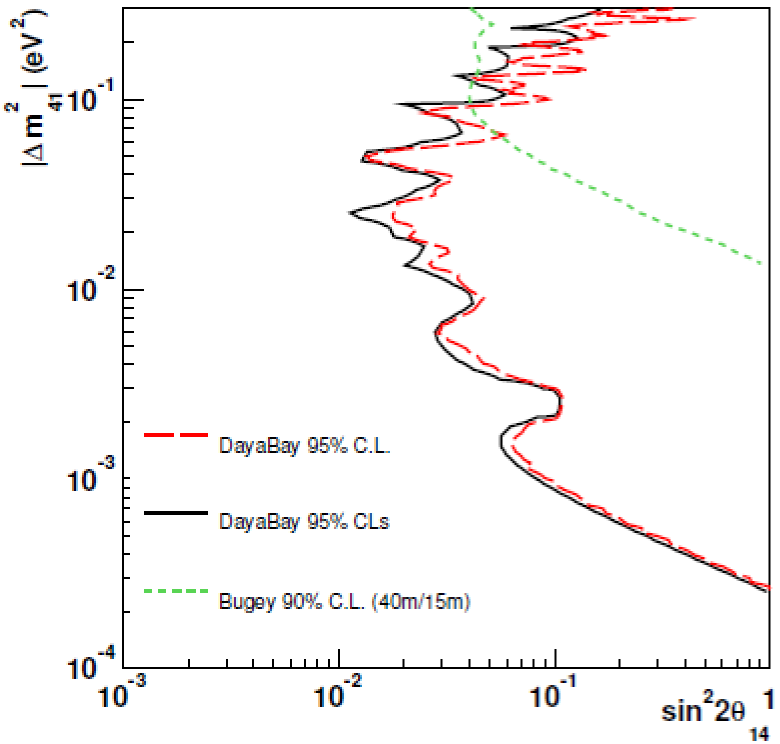


-4 nu model is possible to explain the reactor anomaly.

-DC(and other short baseline reactor antineutrino experiments) is sensitive to certain 4 nu model parameter region but cannot exclude all the parameter region of reactor anomaly.

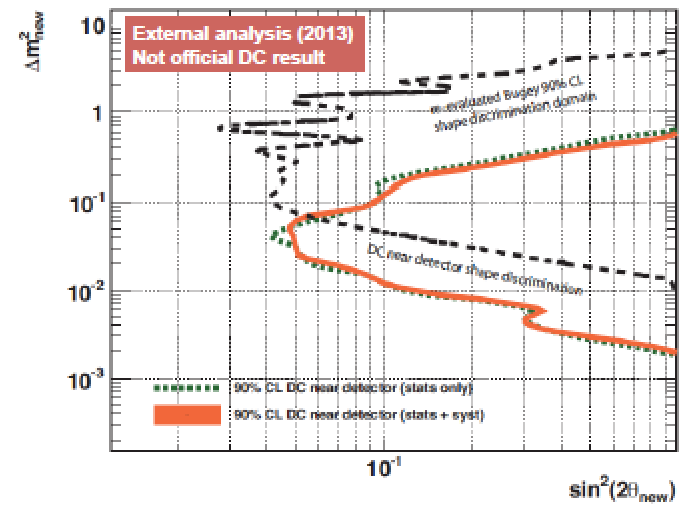
Sterile neutrino search

Daya Bay results



Phys. Rev. Lett. 113, 141802 (2014)

Double Chooz 2012 shape-only results



arXiv: 1303.0310

- Our sensitivity of the light sterile neutrino is comparable to the Daya Bay study.

Conclusion

-Latest Gd analysis best fit gives $\sin^2 2\Theta_{13}$ = 0.090 + 0.032 -0.029.

-Reactor rate module fit, which is independent of energy scale, gives consistent results.

-Near detector has started the data taking. We are preparing for the Near+Far analysis. Precision of $\sin^2 2\Theta_{13}$ will be improved significantly.

-Beyond Θ_{13}, Double Chooz is able to do some other kinds of researches, like sterile neutrino search, reactor flux anomaly, etc.