New results from Double Chooz

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for the Double Chooz Collaboration
ICFP 2012, 10 - 16 June 2012, Crete

The hunt for θ_{13}

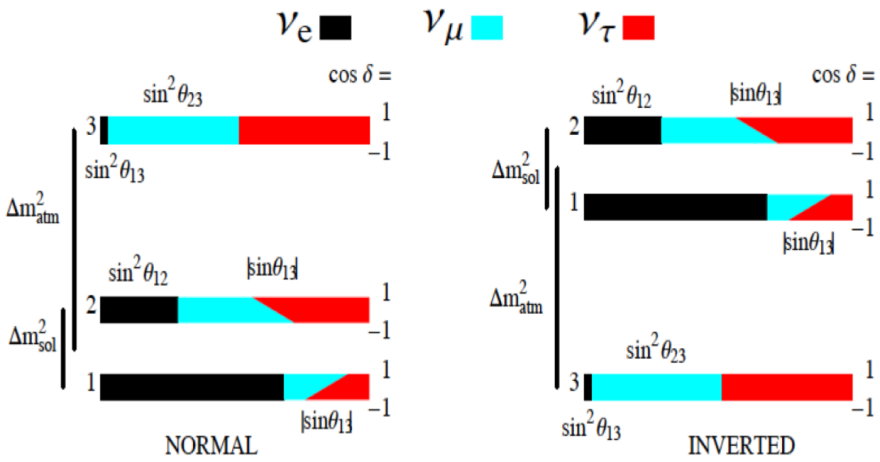
- Double Chooz is a two-detector short baseline experiment searching for the disappearance of reactor electron antineutrinos.
- Tight constrains from single reactor experiments performed in the 1990's (CHOOZ, Palo Verde).
- CHOOZ limit: $\sin^2(2\theta_{13}) < 0.20$ at 90% C.L. assuming $\Delta m^2_{atm} = 2.0\ 10^{-3}\ eV^2$.

<u>Predominant searches:</u>

- Disappearance mode: $\overline{\nu}_e \longrightarrow$?
  - (Reactor exp.) Double Chooz, RENO and Daya Bay
- Appearance channel: $\nu_\mu \longrightarrow \nu_e$ and $\overline{\nu}_\mu \longrightarrow \overline{\nu}_e$
  - (Accelerator exp.) MINOS, T2K and Nova
- Note though, that lower bounds (hints) can also be obtained through three flavour analyses to Solar and Atmospheric data.
- The value of on θ_{13} is important for the observation of genuine three flavour effects like CP violation in the lepton sector.

Neutrino mixing and oscillations

- The neutrino mass (energy) eigenstates ν_1, ν_2, ν_3, do not coincide with the flavor (interaction) eigenstates ν_e, ν_μ, ν_τ.
- Leptonic mixing matrix (in the minimal scenario):



O. Mena and S. Parke Phys. Rev. D 69, 117301 (2004)

$$|\nu_\alpha\rangle = \sum_{i=1}^{3} \mathcal{U}^*_{\alpha i}\ |\nu_i\rangle$$

$$\mathcal{U} = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\text{Atmospheric}} \times \underbrace{\begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix}}_{\text{1 - 3}} \times \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Solar}} \times \underbrace{diag\{e^{i\alpha_1/2}, e^{i\alpha_2/2}, 1\}}_{0\nu\beta\beta}$$

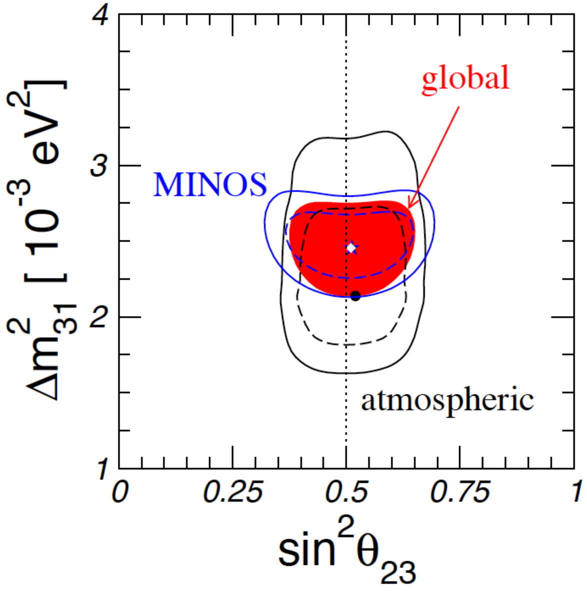
Lepton flavour violation through
the mechanism of neutrino oscillations

$$p(\ \nu_\alpha \rightarrow \nu_\beta\ ) = \sum_{i,j} \mathcal{U}^*_{\alpha i}\, \mathcal{U}_{\beta i}\, \mathcal{U}_{\alpha j}\, \mathcal{U}^*_{\beta j}\ e^{-i\left(\frac{\Delta m^2_{ij} L}{2E}\right)}$$

- The oscillation patterns are driven by the mass square differences, $\Delta m^2_{ij} = m^2_i - m^2_j$
- The oscillation formula is a function of L/E, (distance)/(energy).

Current Understanding

Atmospheric sector



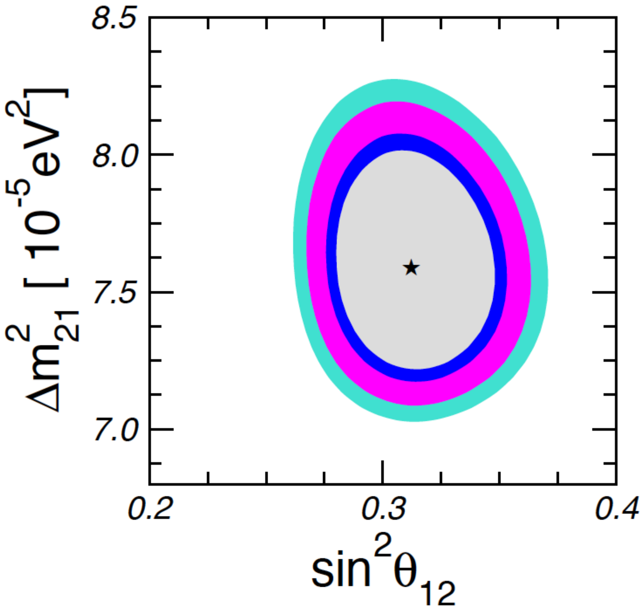
Super-K and MINOS

$|\Delta m^2_{31}| \approx 2.4\ 10^{-3}\ \mathrm{eV}^2$

$\sin(2\theta_{23}) \approx 1.0$

(almost maximal mixing)

Solar sector



Solar exp. and KamLAND

$\Delta m^2_{21} \approx 7.6\ 10^{-5}\ \mathrm{eV}^2$

$\sin(2\theta_{12}) \approx 0.85$

(large mixing angle)

1-3 sector

- Reactor experiments
  - CHOOZ
  - Palo Verde
- Solar exp. and KamLAND
- Atmospheric exp.
- K2K
- MINOS
- Results from global fits point towards a non-zero θ_{13} scenario.

No measurement before 2011

$\sin(2\theta_{13}) \approx 0.1$

θ_{13} is surprisingly small

Ref: T. Schwetz et al. arxiv.org/1103.0734

Oscillation search with reactor antineutrinos

- Reactors are copious sources of $\bar{\nu}_e$.
  - An 1 GW_{th} power reactor emits 2 10^{20} $\bar{\nu}_e$/sec.
- This intense flux permitted:
  - The observation of neutrino (Reines and Cowan)
  - Study of the electroweak sector of the SM.
- Flux characteristics:
  - Pure composition
  - Isotropic flux
  - Low energy antineutrinos, $\langle E_\nu \rangle$ = 3 - 4 MeV.
- $\bar{\nu}_e$ disappearance channel:

(L in km, E in GeV and Δm^2 in eV^2)

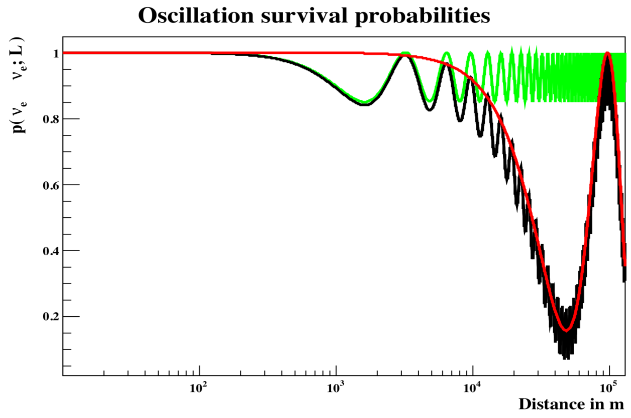
$$p(\ \nu_e \rightarrow \nu_e\ ) \ \simeq 1 - \sin^2(2\theta_{13}) \sin^2\left(1.27\Delta m^2_{13}\frac{L}{E}\right) - \cos^4\theta_{13} \sin^2(2\theta_{12}) \sin^2\left(1.27\Delta m^2_{12}\frac{L}{E}\right)$$

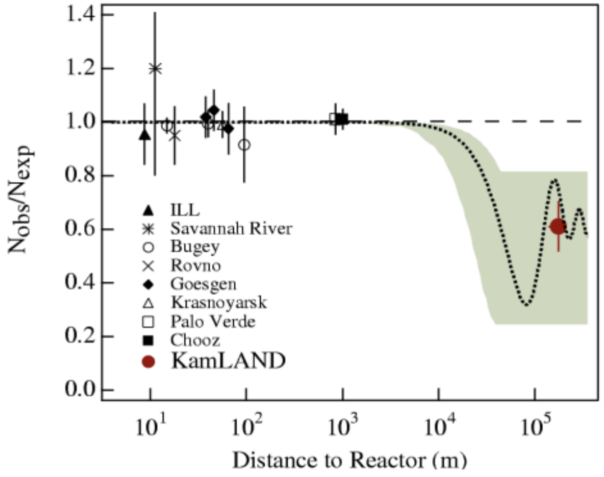
- No CP-violating terms,
- Negligible matter effects and small dependence on Δm^2_{12} at ≈ 1 km.

$\langle E_\nu \rangle$=3.0MeV

$\Delta m^2_{13}=2.30\ 10^{-3} eV^2$ and $\sin^2(2\theta_{13})=0.160$

$\Delta m^2_{12}=7.65\ 10^{-5} eV^2$ and $\sin^2(2\theta_{12})=0.304$





KamLAND Collaboration

Phys. Rev. Lett. 90, 021802 (2003)

Reactor systematics

NUMBER OF FISSIONS:

- Fissile isotopes contribution
  - ^{235}U, ^{239}P, ^{241}P and ^{238}U.
  - The uncertainty on these parameters is small.
- Thermal power
  - Monitored in the heat balance of the steam generator
  - The $\delta P_{th}/P_{th}$ is small.

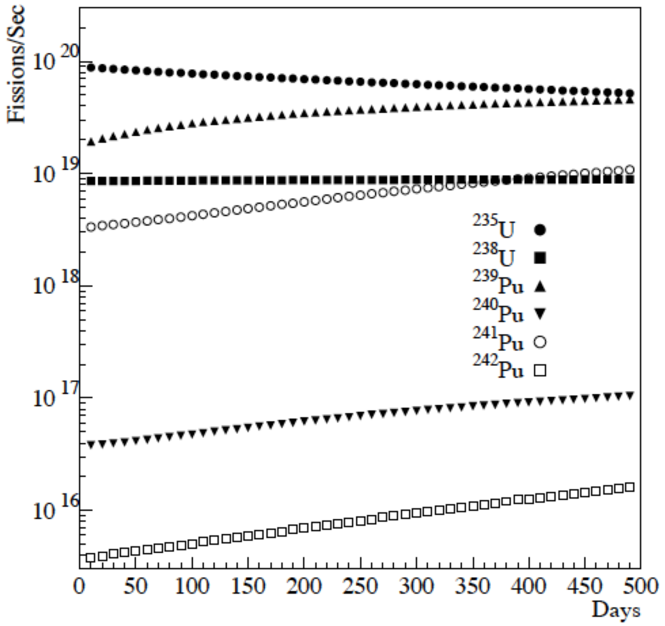
NEUTRINO YIELD:

- Electron antineutrino per MeV per fission
  - Conversion to the ILL reference spectrum
  - Drives the main uncertainty.
- Prediction: $\sigma_f = 5.824\ 10^{-19}$ b/fission ± 2.7 %
- Bugey-4: $\sigma_f = 5.752\ 10^{-19}$ b/fission ± 1.4 %

  (Phys. Lett. B338 (1994) 383-389)

C. Bemporad, G.Gratta and P. Vogel

Rev. Mod. Phys. 74 (2002) 297



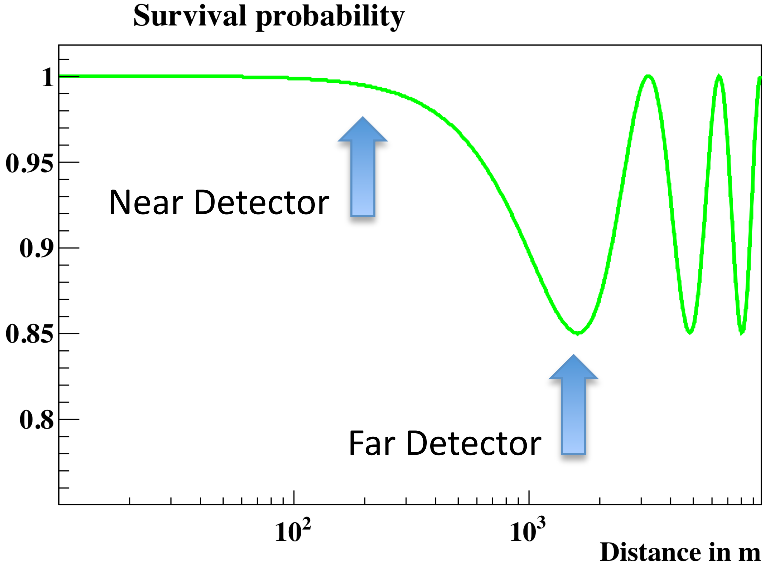
$$\sigma_f = \int_0^\infty S(E_\nu)\sigma_{V-A}(E_\nu)dE_\nu$$

$$n = \frac{1}{4\pi R^2}\,\frac{P_{th}}{< E_f >}\,N_p\,\sigma_f\,\epsilon$$

The novel two detector concept

$<E_\nu>=3.0\text{MeV}$

$\Delta m^2_{13}=2.30\ 10^{-3}\text{eV}^2$ and $\sin^2(2\theta_{13})=0.160$



$$p(\ \nu_e \to \nu_e;\ L\ ) \simeq 1 - \sin^2(2\theta_{13})\sin^2\left(1.27\Delta m^2_{atm}\frac{L}{E}\right)$$

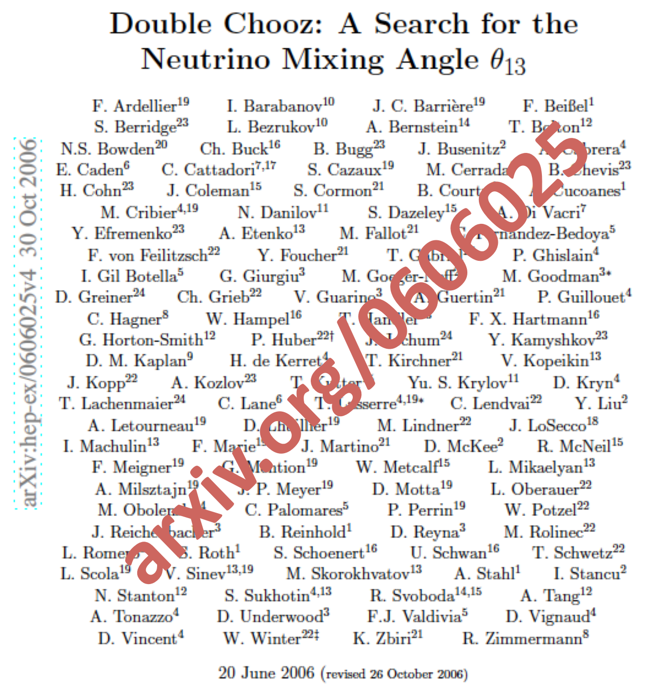
$$\frac{n_f}{n_n} = \left(\frac{L_n}{L_f}\right)^2 \left(\frac{N_{p,f}}{N_{p,n}}\right)\left(\frac{\epsilon_f}{\epsilon_n}\right)\left[\frac{p(E,L_f,\theta_{13})}{p(E,L_n,\theta_{13})}\right]$$

- In the 2000's it was realized that a two, or more, detector disappearance experiment can further improve the sensitivity on θ_{13} by an order of magnitude.
- Reduce the uncertainties in both the production and detection of electron antineutrinos.
- *"A new nuclear reactor experiment to measure ϑ_{13}", arxiv.org/0402041*.
- The near detector will monitor the reactor flux and spectrum.
- Identical detectors, as much as possible.

The Double Chooz collaboration

Brazil: CBPF, UNICAMP, UFABC
France: APC Paris, CEA/Irfu Saclay, Subatech Nantes, IPHC Strasbourg
Germany: EKU Tübingen, MPIK Heidelberg, RWTH Aachen TU München, U. Hamburg
Japan: Tohoku U., Tokyo Inst. Tech., Tokyo Metro. U., Niigata U., Kobe U., Tohoku Gakuin U., Hiroshima Inst Tech.
Russia: INR RAS, IPC RAS, RRC Kurchatov
Spain: CIEMAT - Madrid
USA: U. Alabama, ANL, U. Chicago, Columbia U., UC Davis, Drexel U., IIT, KSU, LLNL, MIT, U. Notre Dame, U. Tennessee

Spokesperson: H. de Kerret (CNRS/IN2P3 - APC)
Project manager: C. Veyssiere (CEA/Irfu - Saclay)



Double Chooz: A Search for the
Neutrino Mixing Angle θ_{13}

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20 June 2006 (revised 26 October 2006)

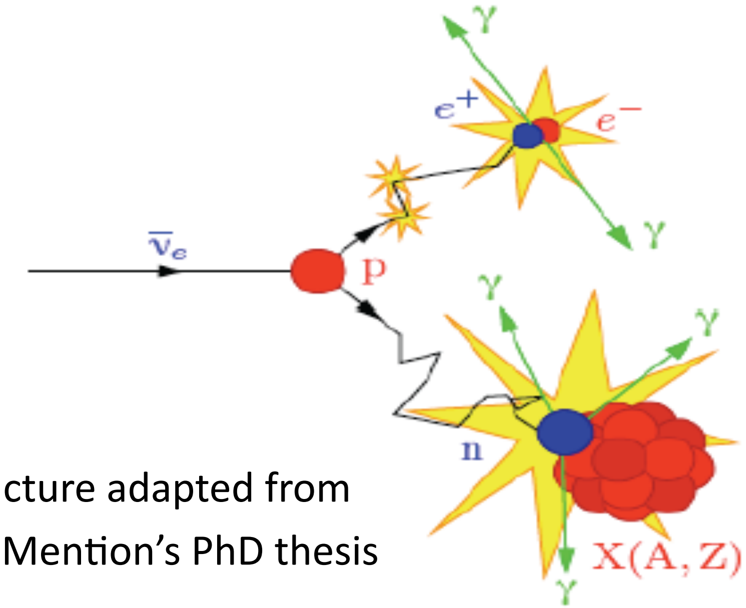
At the gardens of APC, May 2011

The site

- The Chooz Nuclear power plant is located at the North-East part of France, near the border with Belgium.
- Two nuclear reactors P_{th}=4.27 GW and P_e=1.5 GW each.
- The Chooz-far laboratory was constructed by the EDF during the 1990’s for the CHOOZ experiment.
- 300 mwe shielding from cosmics of 2.8 gr/cm^3 rock.
- The construction of near laboratory started at the 29th of April 2011.
- Artificial overburden of 120 mwe and flat topology.
- According to schedule the near detector would be ready to operate at 2013.
- Currently only one detector is taking data in stable conditions since April 2011.

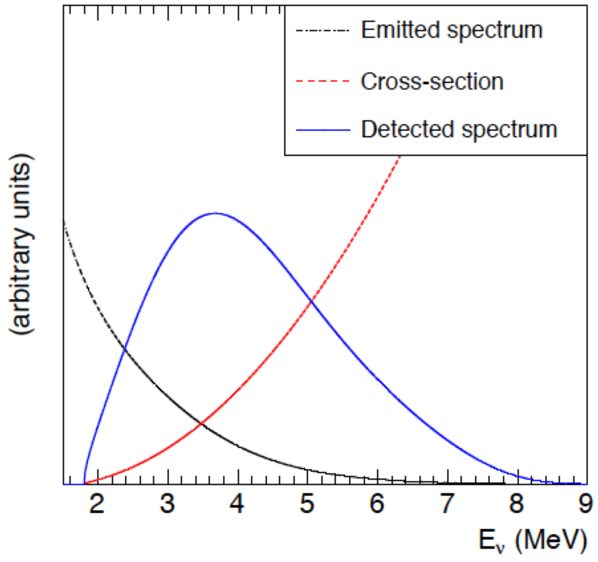
Neutrino detection

- Antineutrinos are detected through inverse beta decay (IBD) on the free protons of the scintillator, $\overline{\nu}_e + p \longrightarrow n + e^+$
- High cross section but threshold at 1.8 MeV.
- Prompt signal: e^+ thermalization and the subsequent annihilation.
- Delayed signal: n-capture on Gd; a number of gammas around 8 MeV.
- Time coincidence with $\tau_{mean} = 30\ \mu s$ and,
- Strong space correlation (< 1 m).



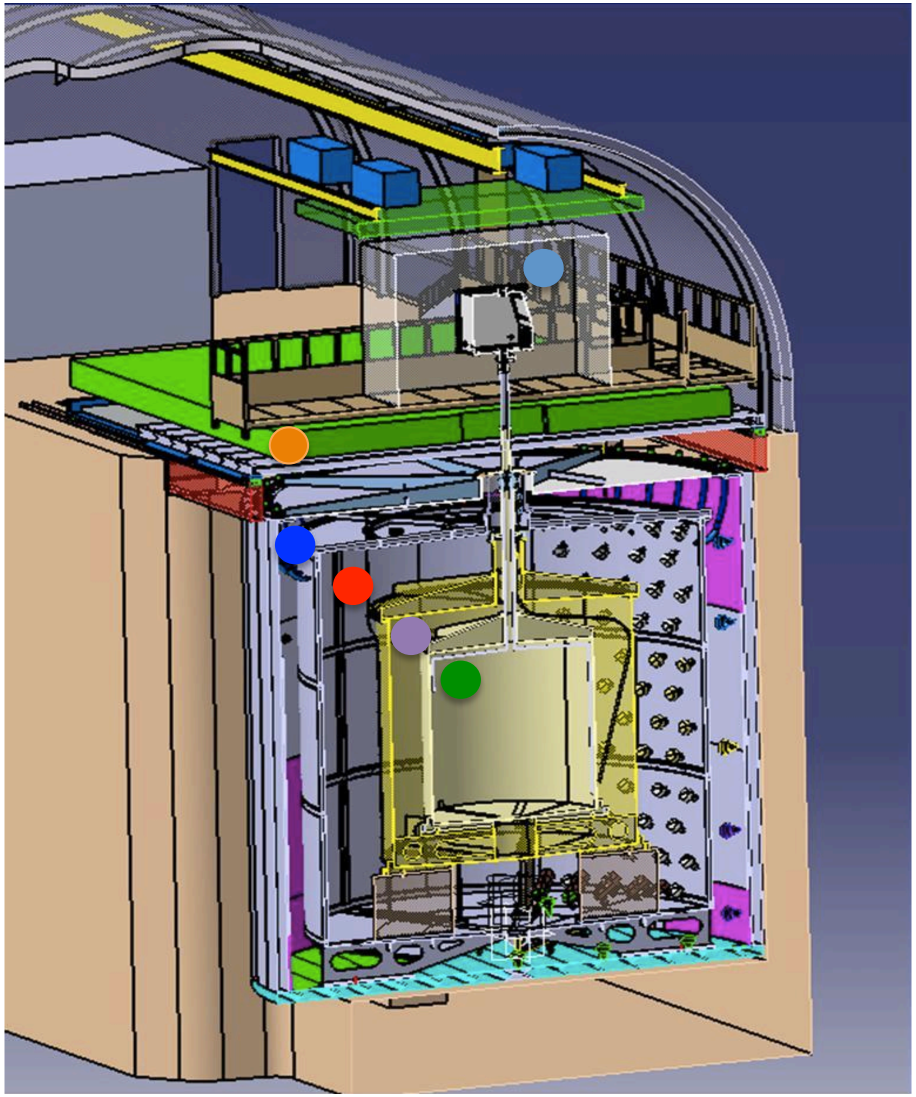
Picture adapted from
G. Mention's PhD thesis

T. Meuller et al.,
Phys. Rev. C 83, 054615 (2011)



The Double Chooz Detector

- Four concentric cylindrical detector volumes.
- A four-layer russian doll.
- Target volume : 10.3m^3 of liquid scintillator (PXE and dodecane, 20:80) doped with 0.1% Gd.
- Gamma catcher : 22.3m^3 of liquid scintillator.
- Buffer: 110 m^3 of mineral oil.
- 390 R7081 Hamamatsu PMT mounted in the Buffer vessel (10 inches diameter).
- Photocathode coverage ≈13%.
- Inner Veto : 90 m^3 of scintillator.
- 78 8-inched PMT in the Inner Veto (R1408 Hamamatsu)
- Steel shielding above the detector.
- Outer Veto : plastic scintillator strips.
- Calibration box.



February 2009

July 2009

December 2009

Neutrino selection cuts

Muon Veto:

- 1 ms away the muon signature.
- 0.5 s dead-time after a E_{ID}>600 MeV muon
- No OV coincidence in the prompt

Prompt signal:

- $0.7\ \text{MeV} < E_p < 12.2\ \text{MeV}$
- $Q_{max}/Q_{tot} < 0.09$ and $\text{RMS(Ts)} < 40$ ns

Delayed signal:

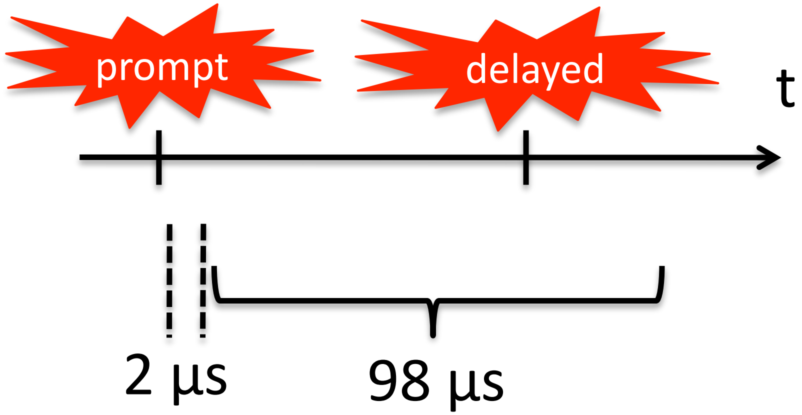
- $0.7\ \text{MeV} < E_d < 12.0\ \text{MeV}$
- $Q_{max}/Q_{tot} < 0.055$ and $\text{RMS(Ts)} < 40$ ns

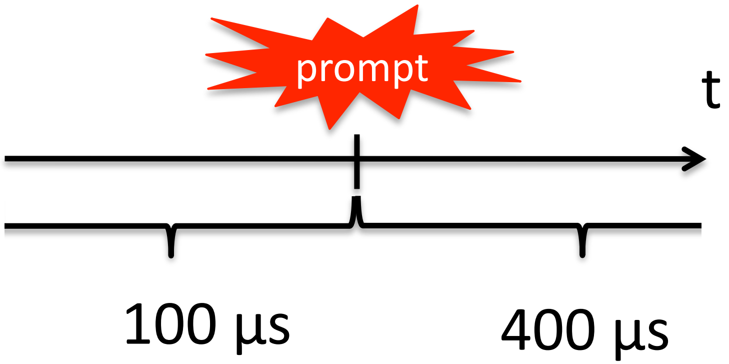
Coincidence window:

- [2, 100] μs

Multiplicity isolation cuts:

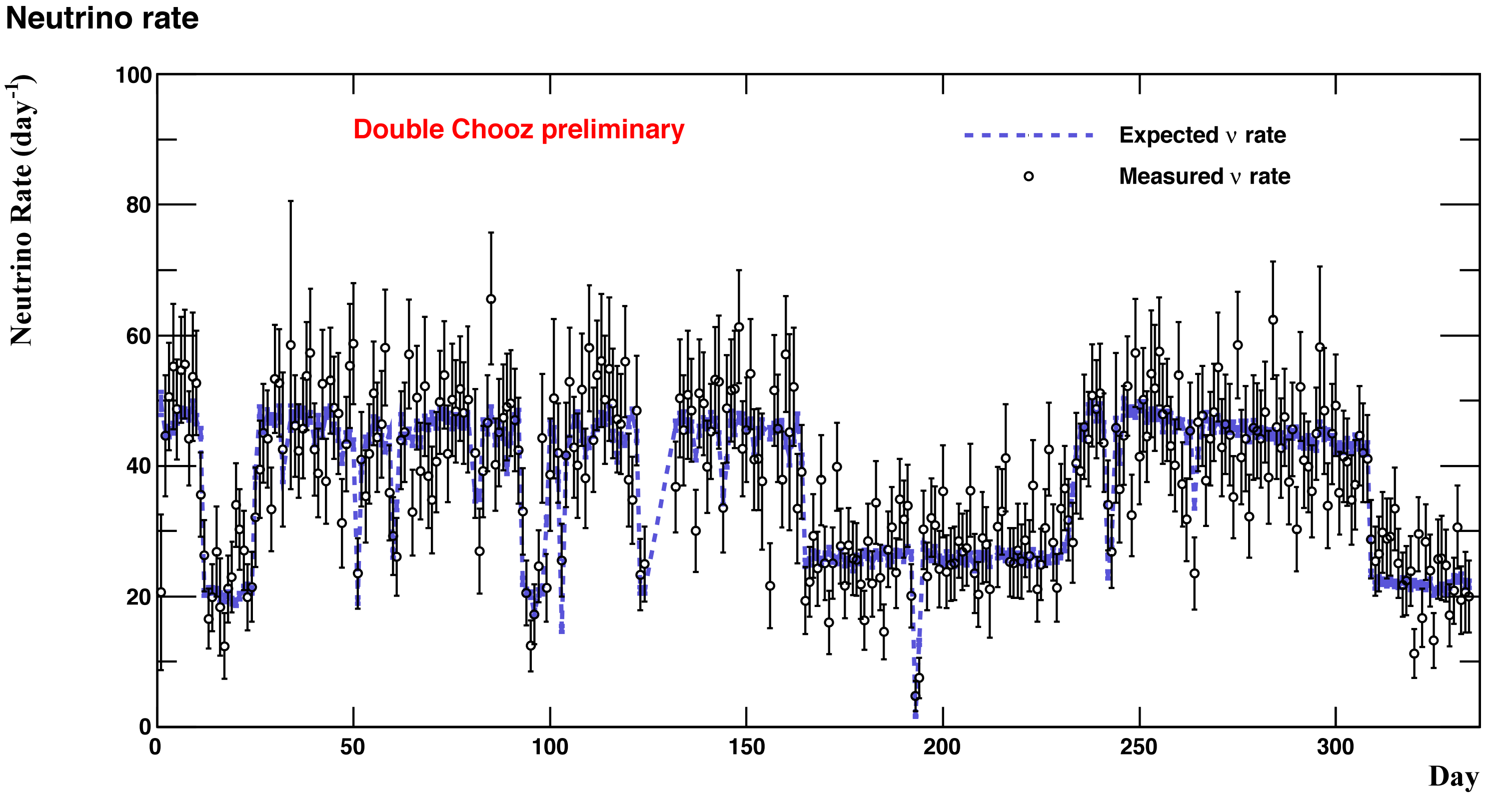
- Valid trigger: E > 0.5 MeV,
  $Q_{max}/Q_{tot} < 0.09$ and $\text{RMS(Ts)} < 40$ ns.
- No valid trigger 100 μs before the prompt
- No valid trigger 400 μs after the prompt





Neutrino candidates

8249 neutrino candidates

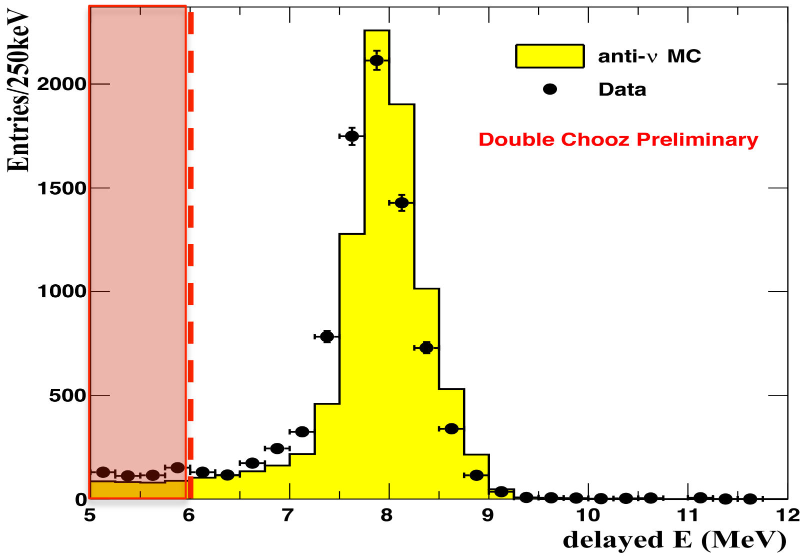


Attention, in this plot:

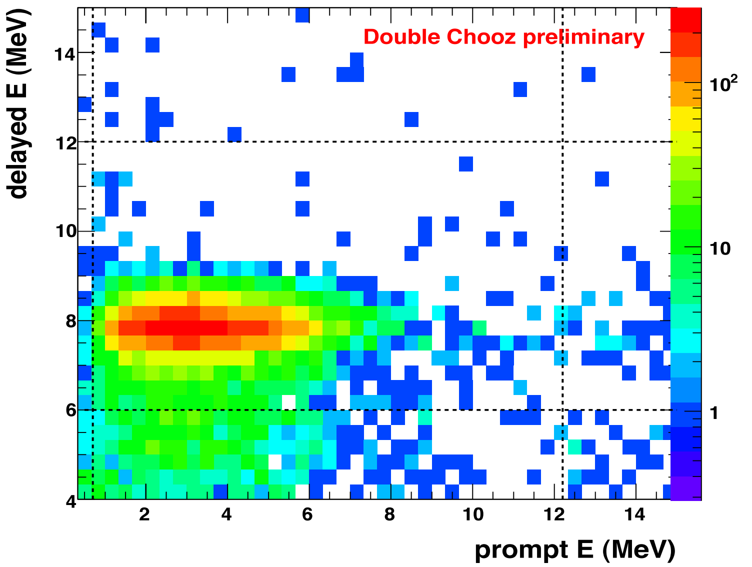
- No high energy muon veto
- No Outer Veto veto
- No background subtraction

Neutrino imprint

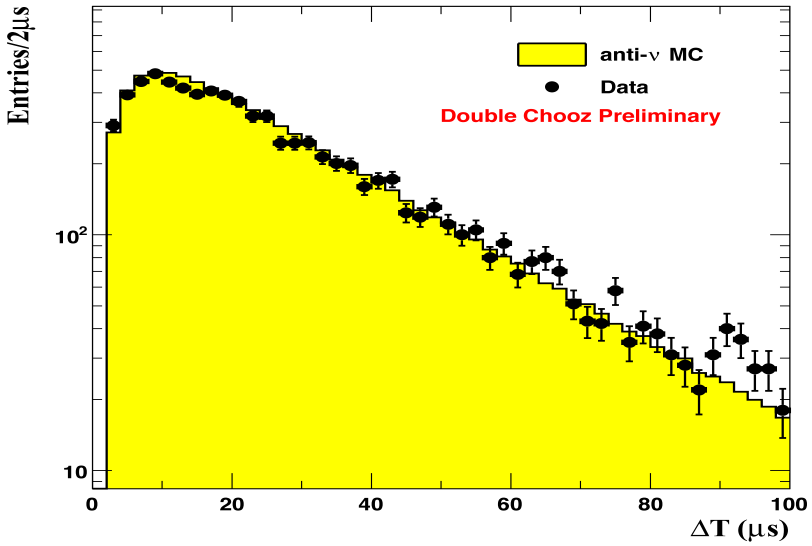
Delayed energy



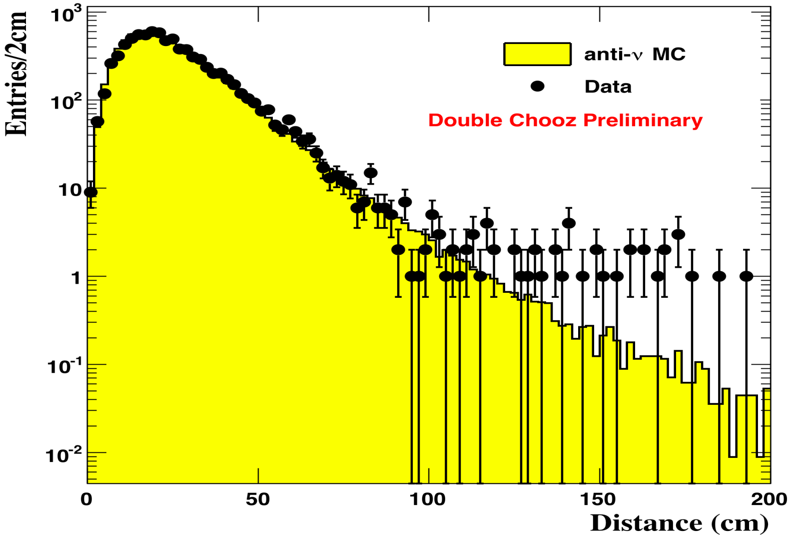
E_{prompt} vs $E_{delayed}$



Prompt-delay time difference

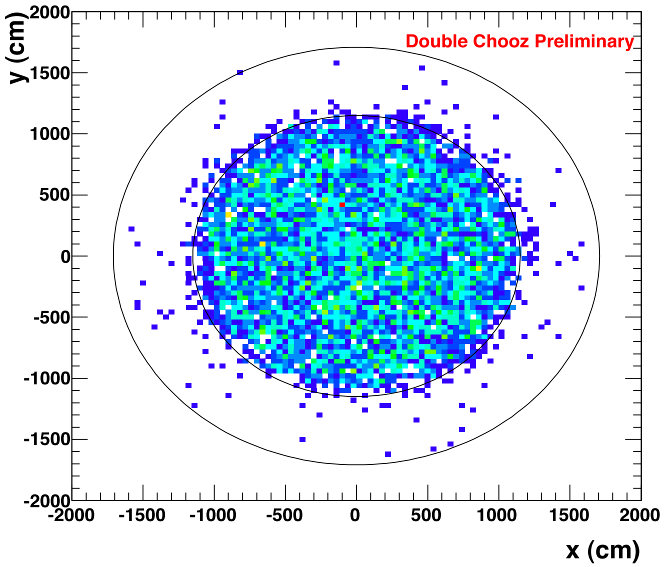


Distance

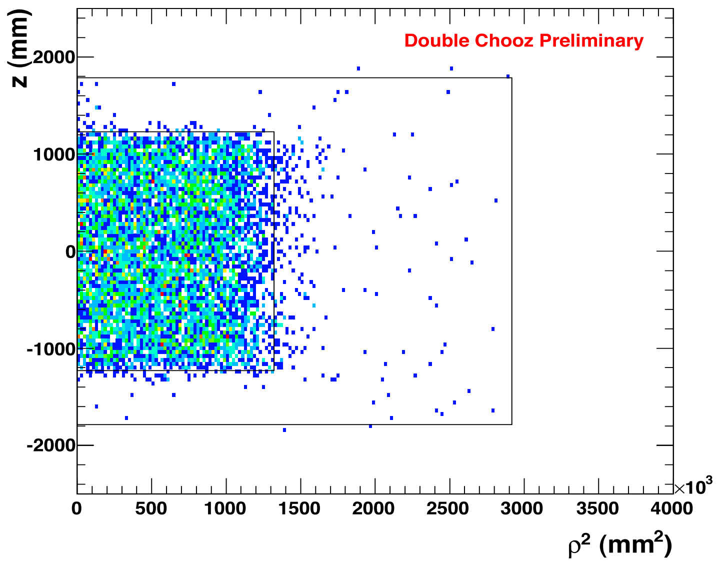


Reconstructed vertices

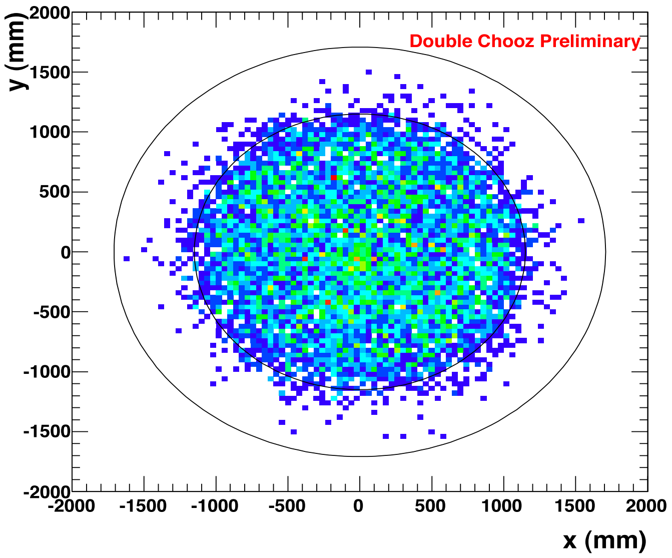
Prompt vertex XY position



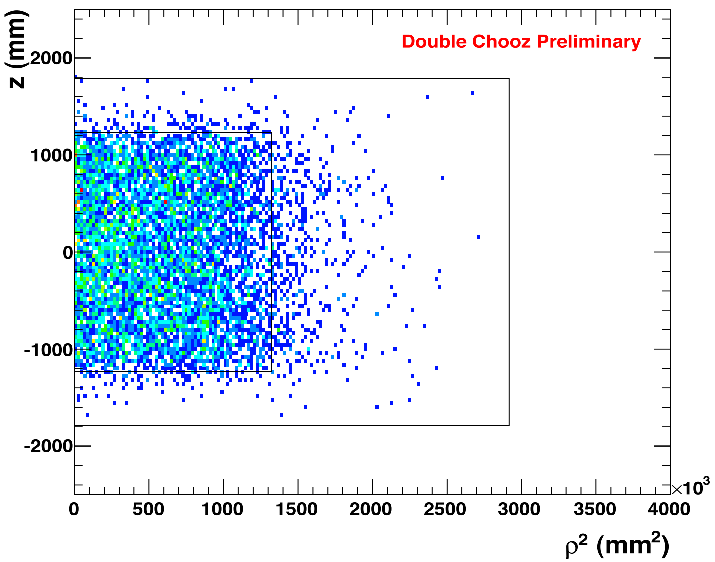
Prompt vertex Zρ^2 position



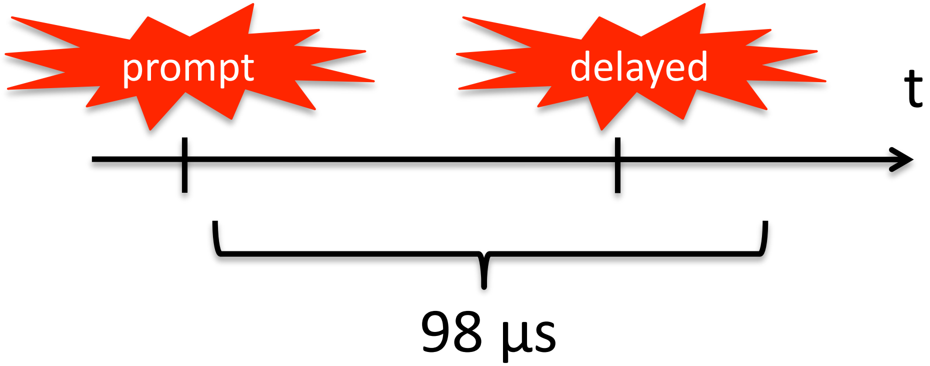
Delayed vertex XY position



Delayed vertex Zρ^2 position



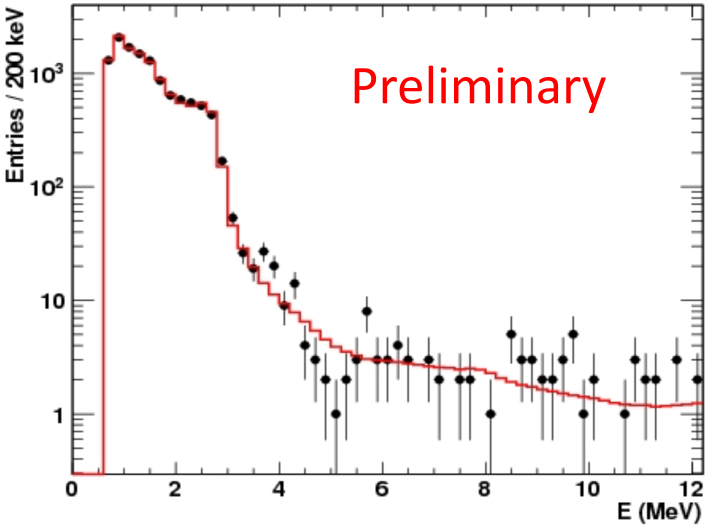
Accidentals

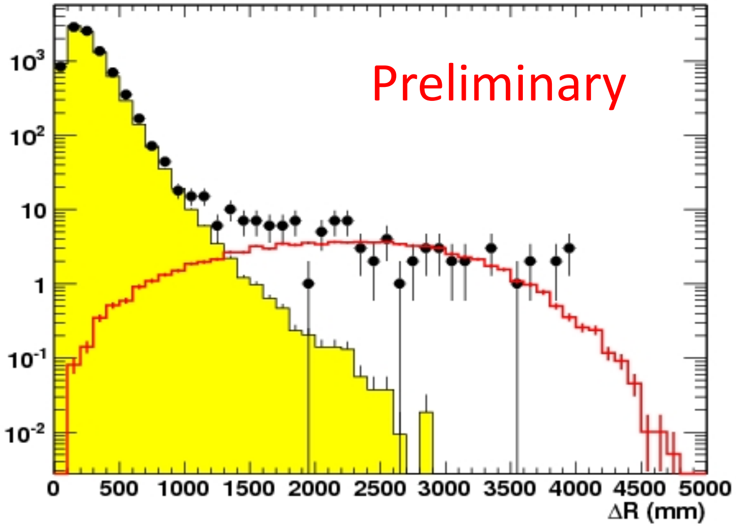


- Uncorrelated events.
- Prompt and delayed signals: natural radioactivity, mu-untagged spallation neutrons, etc …

Selection cuts:

- The same criteria used already for neutrino selection but,
- Altering the coincidence window: [1s+500*i+2μs, 1s+500*i+100μs], i = 0,…,197
- Rate: 0.261 ± 0.002 events per day (Stable).





Fast Neutrons and Stopping Muons

Fast neutrons

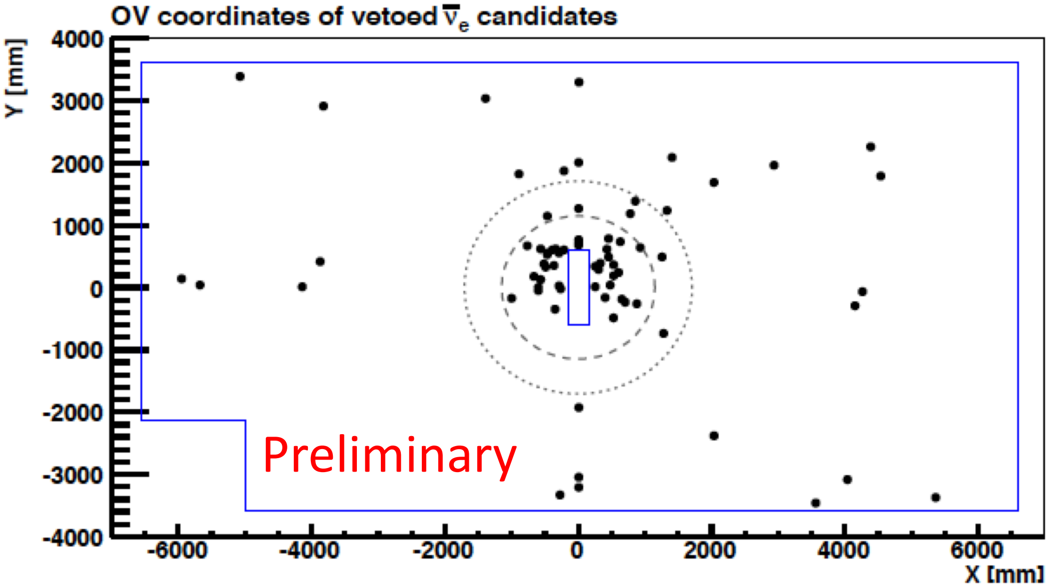
- Prompt signal: proton recoil, and delayed: normal neutron capture

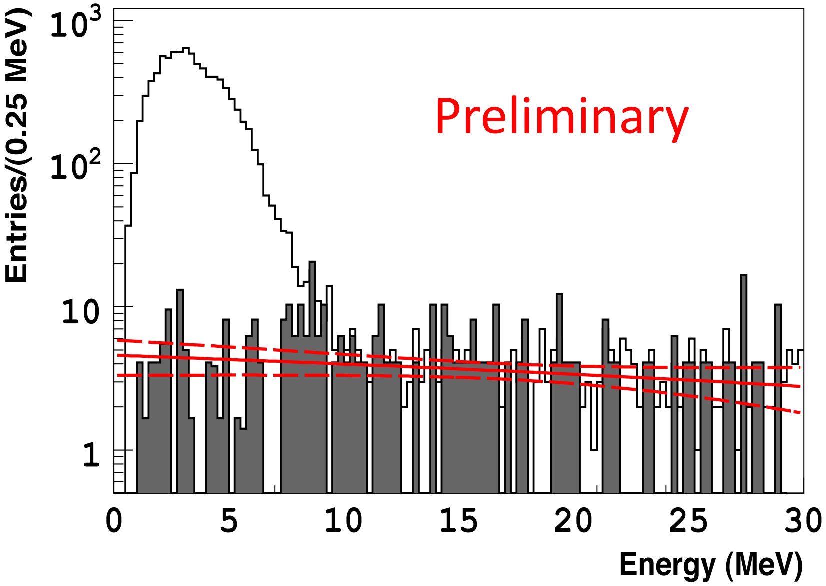
Stopping muons

- Muon michel decay: $\mu \longrightarrow e + \nu_{\mu} + \nu_{e,}$ $\tau \approx 2.2\ \mu s$

Selection cuts:

- The same criteria used already for neutrino selection but,
- Altering the prompt energy window to [0.7, 30.0] MeV.
- Rate: 0.67 ± 0.20 event/day



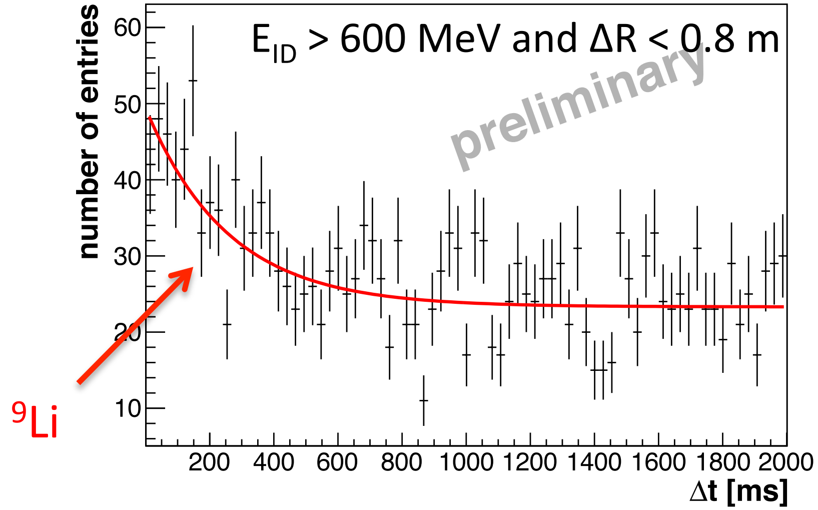


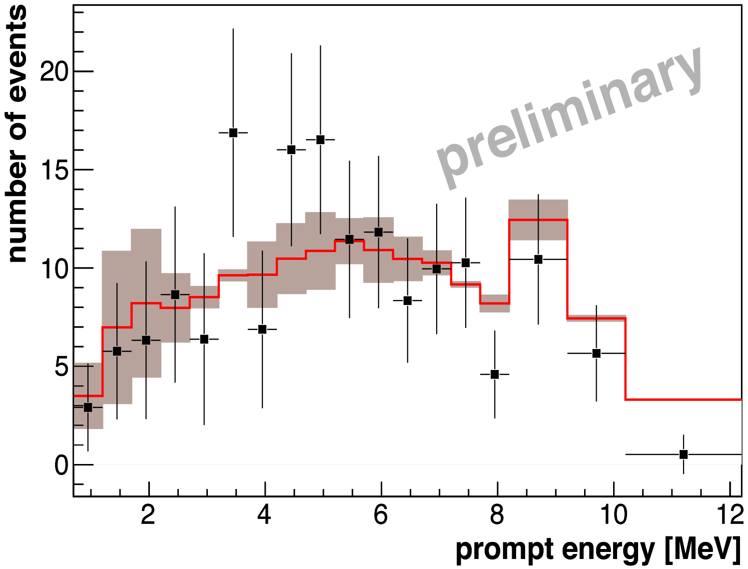
Cosmogenic isotopes

- High energy muons are able to create long-lived isotopes from spallation processes (arxiv.org/0907.0066).
- Large life-times; can not be tagged by the muon veto.
- ^{8}He and ^{9}Li have electron and neutron decay cascade modes that mimic the IBD signature.

Estimation:

- $E_{ID} > 600$ MeV rejected, estimate the residual ^{9}Li contribution.
- Separately in the 275 MeV $< E_{ID} <$ 600 MeV and $E_{ID} <$ 275 MeV regions
- Fits to the DT distributions
- Rate: 1.20+0.59/-0.48 évents per day

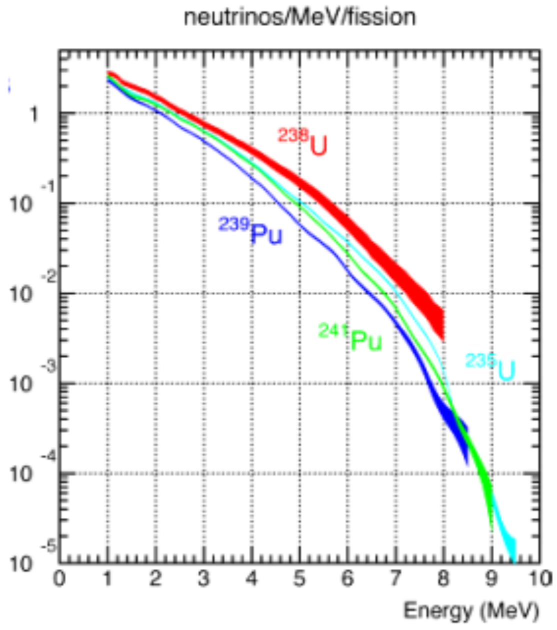




Reactor input

- Thermal power monitored by EDF from the balance at the steam generator.
- For the reactor evolution two simulation packages were used: the MURE simulation package and the DRAGON code, C. Jones et al. arxiv.org/1109.5379
- Lots of information from EDF:
  - Geometrical parameters
  - Fuel composition
  - Boron concentration, etc…
- JEFF3.1 nuclear database was used.
- Fissions per energy were taken from

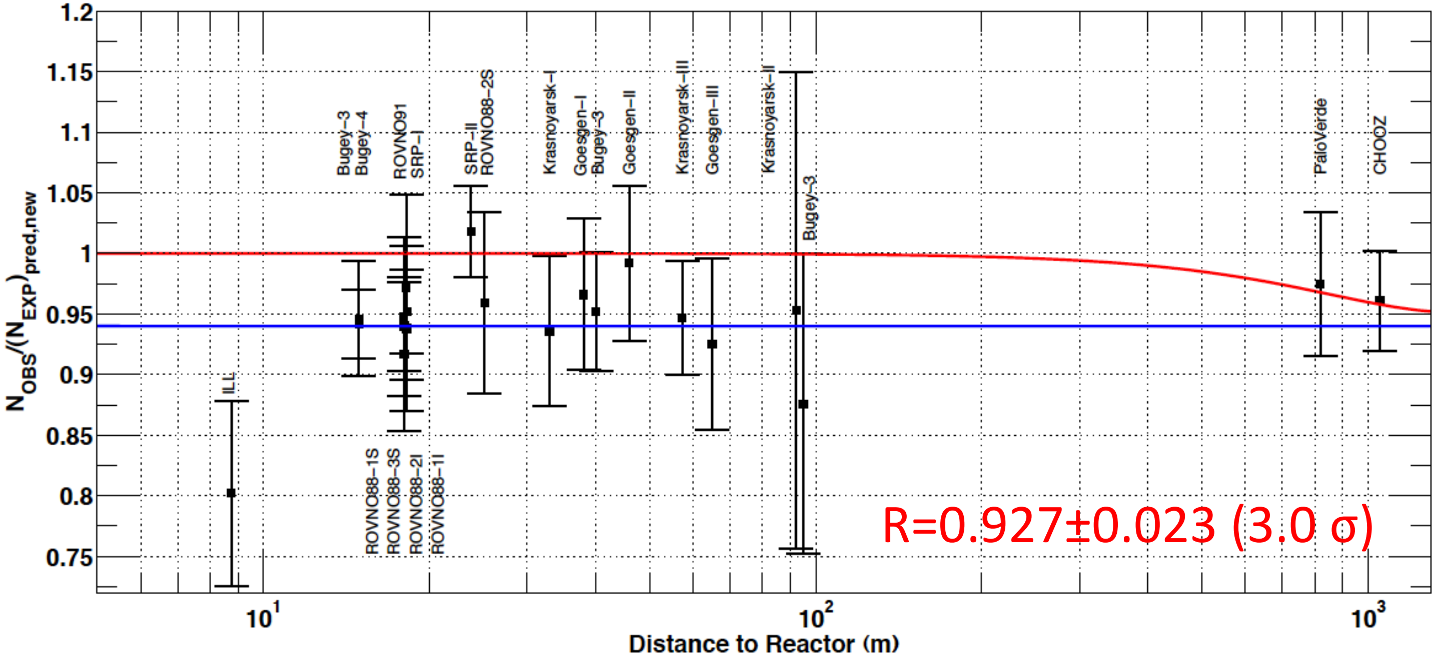
  V. Kopeikin et al., hep-ph/0410100v1.
- Neutrino yield: a new conversion method to the ILL reference spectrum developed by Saclay and Subatech.
- Net ≈ 3.0% upward shift in energy-averaged neutrino fluxes, Meuller et al., Phys. Rev. C 83, 054615 (2011)
- Confirmed by P. Huber, Phys. Rev. C 84, 024617 (2011).
- IBD cross-section also increased, neutron lifetime.



Additional information:
«Reactor Flux Calculations»
D. Lhuillier, Neutrino 2012

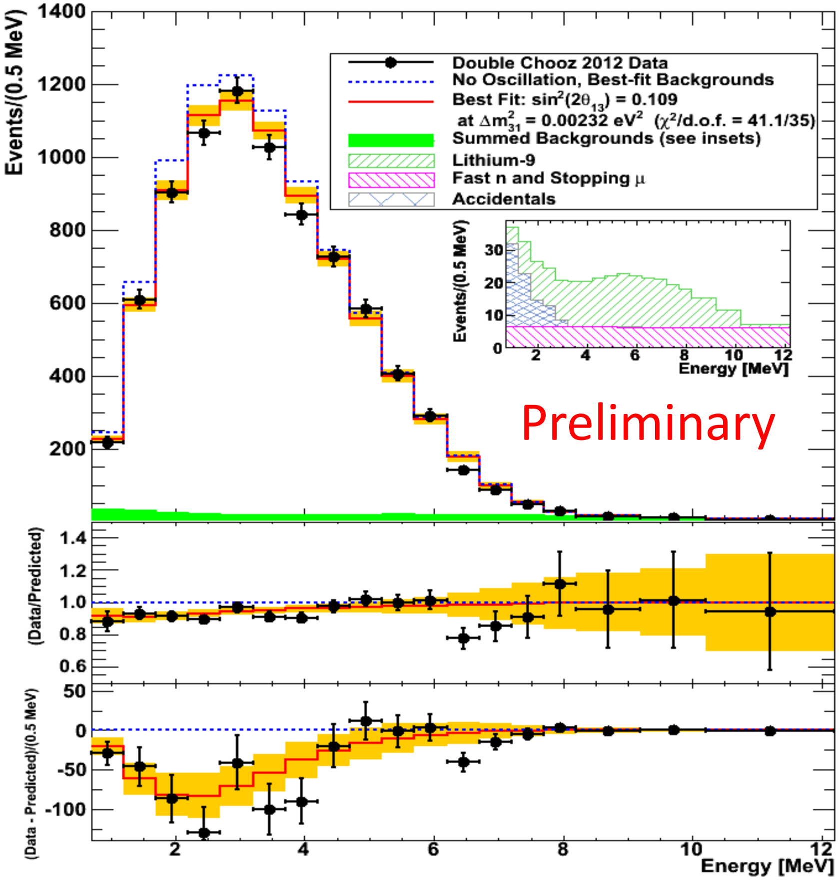
Reactor anomaly

(G. Mention et al. arxiv.org/1101.2755)



- A common shift to all exp. with baseline smaller than 100 m.
- Possible explanations:
  - Wrong estimation of the antineutrino spectrum
  - A common bias in all experiments!!!
  - Hint for new physics… a forth sterile oscillation mode?
- To avoid oscillations from possible sterile modes Double Chooz uses the absolute normalization of Bugey-4 correcting for the burn-up differences.
- Further info: P. Huber et al., arxiv.org/1204.5379 and Th. Lasserre's talk at Neutrino 2012

Oscillation analysis



NOTE:

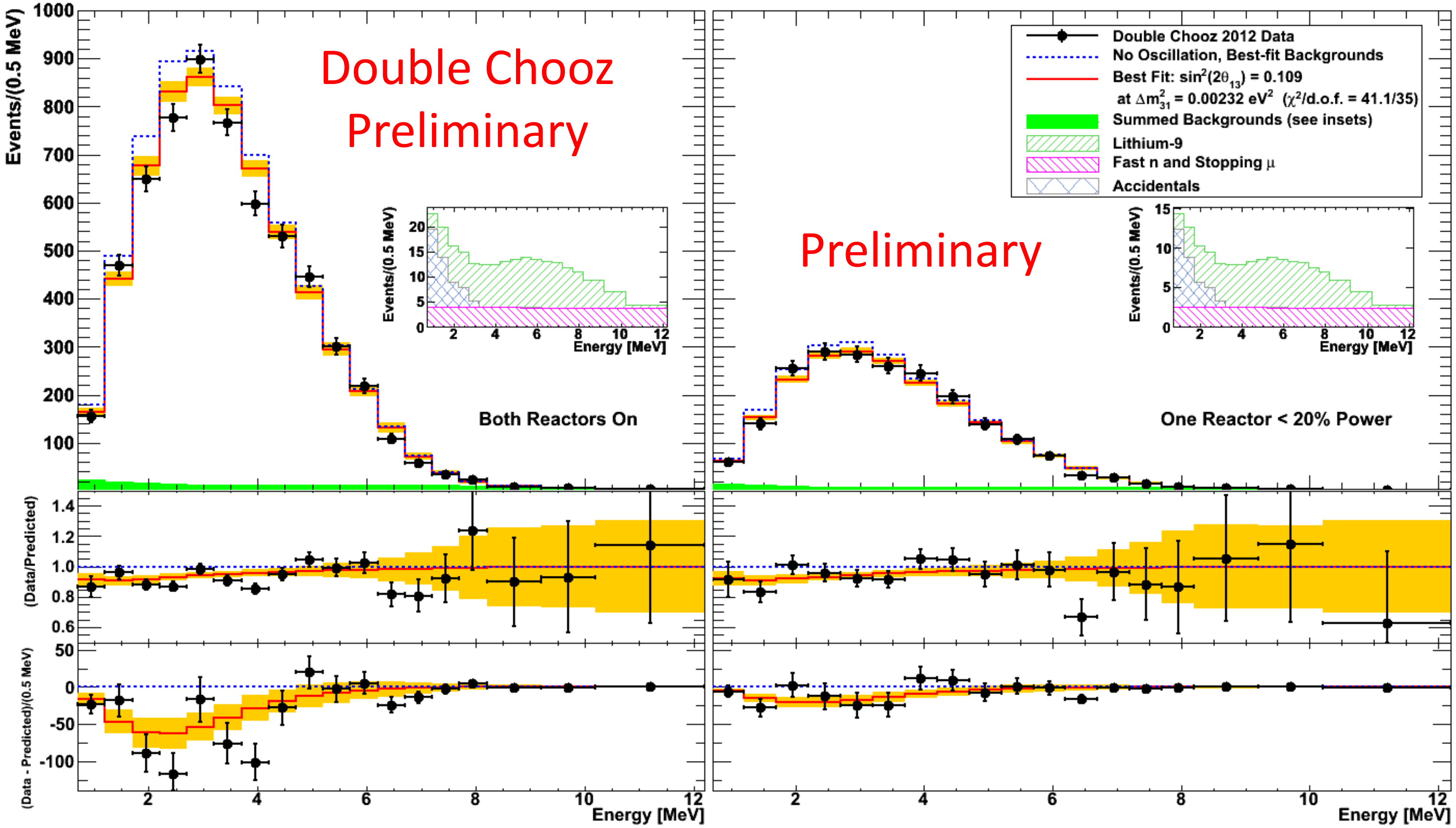
In a fit, dataset is divided into two periods based on reactor power (next slide)

Rate + Shape Fit: $\sin^2 2\theta_{13} = 0.109 \pm 0.030(stat.) \pm 0.025(syst.)$

Rate Only Fit: $\sin^2 2\theta_{13} = 0.170 \pm 0.035(stat.) \pm 0.040(syst.)$

Oscillation analysis (cont’d)

Two reactors on *One reactor on*



Rate + Shape Fit: $\sin^2 2\theta_{13} = 0.109 \pm 0.030(stat.) \pm 0.025(syst.)$

Rate Only Fit: $\sin^2 2\theta_{13} = 0.170 \pm 0.035(stat.) \pm 0.040(syst.)$

Summary

- Double Chooz has already delivered some very interesting physics:
  - A novel detector design
  - Hard radiopurity R&D and stable scintillator soluble
  - Improved reactor spectrum, “Reactor anomaly”.
  - Important oscillation analyses
- Double Chooz first result presented by H. de Kerret at LowNu 2011

  (Phys. Rev. Lett. 108 (2012) 131801)
- Updated result doubling the statistics and reducing systematics:

$$\sin^2 2\theta_{13} = 0.109 \pm 0.030(stat.) \pm 0.025(syst.)$$

Non-oscillation scenario excluded at a 99.9 C.L., 3.1σ

RENO, Neutrino 2012

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$$

Daya Bay, Neutrino 2012

$$\sin^2 2\theta_{13} = 0.089 \pm 0.010(stat.) \pm 0.005(syst.)$$

- Important news: almost a week of reactor OFF-OFF data!
- The near detector is expected to start data taking late 2013.

Thank you for your attention

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Additional plots and information

BACKUP SLIDES

Two flavour approximation

- Three flavour are highly suppressed since $|\Delta m^2_{31}| << \Delta m^2_{21}$ and $\cos^2(2\theta_{13}) \approx 1.0$
- Dominant oscillations are well described by effective two-flavour oscillations.
- One mixing angle no complex phase.

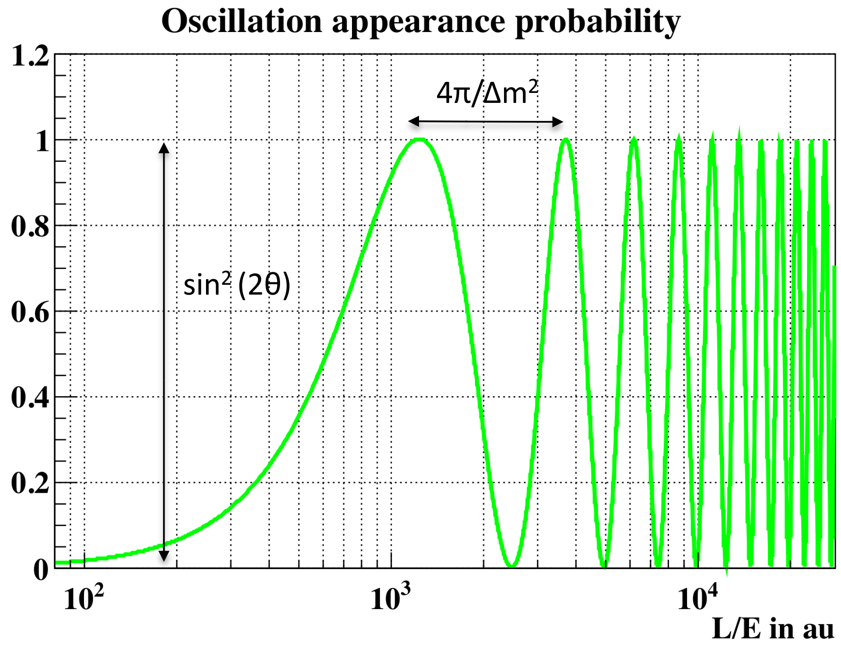
$$\mathcal{U} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

$$p(\ \nu_\alpha \rightarrow \nu_\beta\ ) = \sin^2 2\theta\ \sin^2 \frac{\Delta m^2 L}{4E}$$

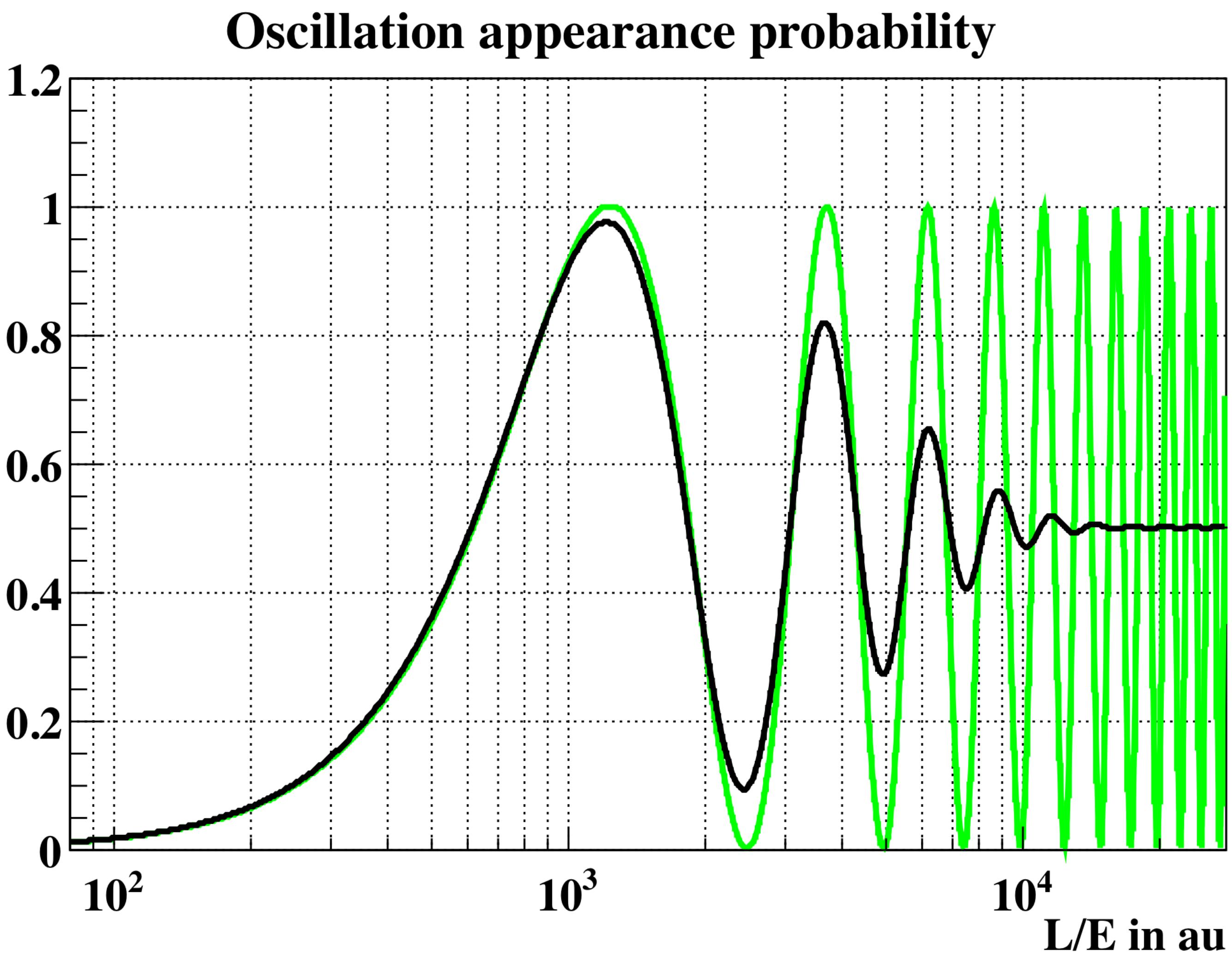
Appearance probability

Typical oscillatory behaviour

$\theta = \pi/4$, E = 1 GeV and $\Delta m^2 = 0.001$ eV^2



Oscillation appearance probability



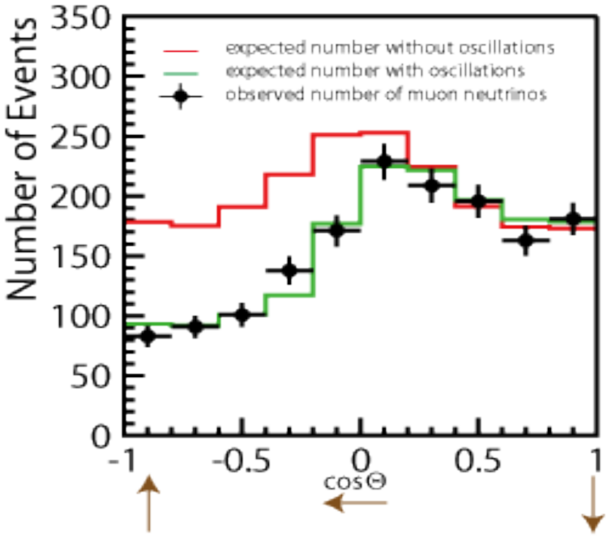
<E> = 1 GeV and ΔE = 0.1 GeV

Oscillation patterns

- Oscillation patterns driven by the mass square differences, $\Delta m^2_{ij} = m^2_i - m^2_j$
- The oscillation formula is a function of (distance)/(energy).
- Reduction in the neutrino flux and a combined energy spectrum distortion.

Super-Kamiokande

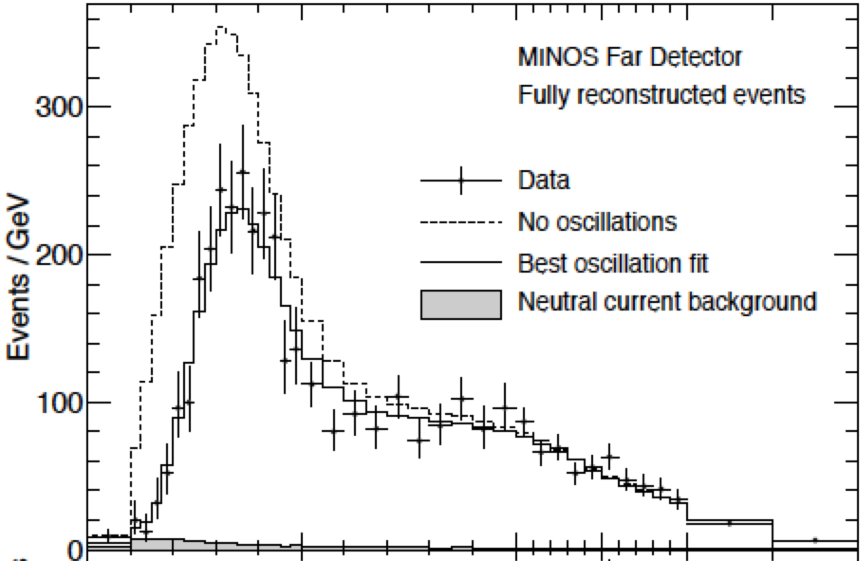
http://www-sk.icrr.u-tokyo.ac.jp/sk/physics/atmnu-e.html



130000 km

20 km

MINOS, Phys. Rev. Lett. 106, 181801 (2011)

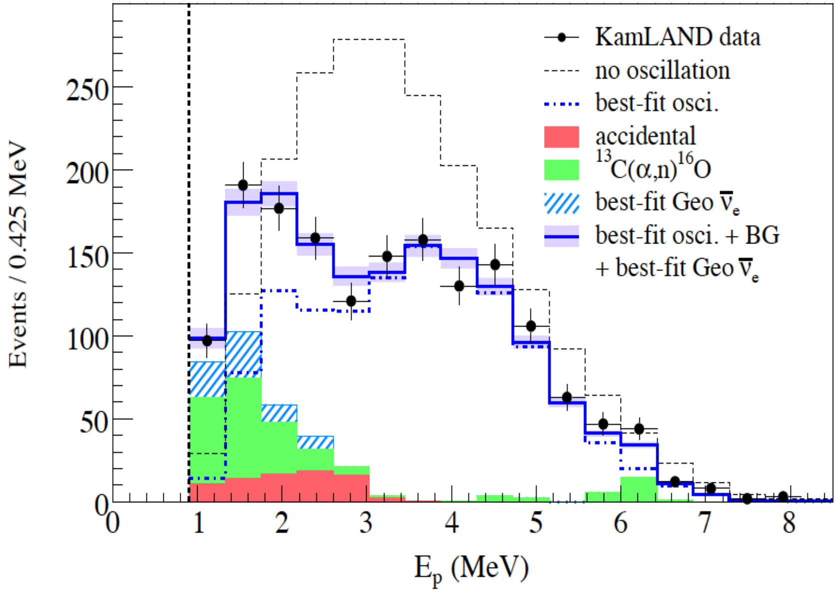


E (GeV)

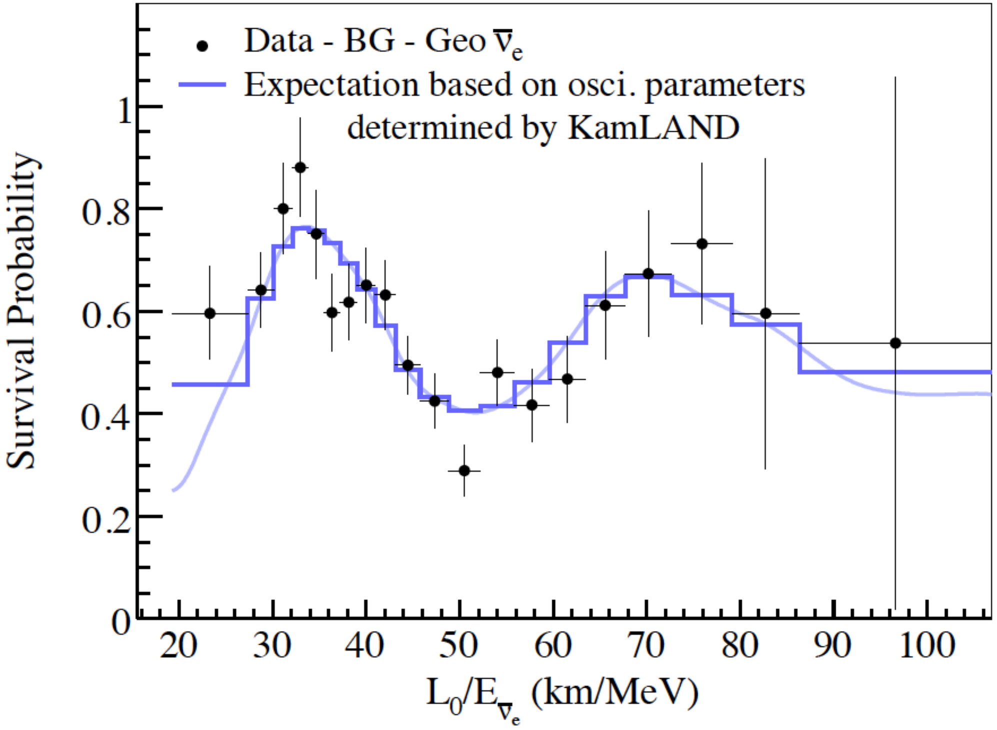
Precision measurements of solar oscillation parameters with KamLAND

Phys. Rev. Lett. 100, 221803 (2008)

Spectral distortion

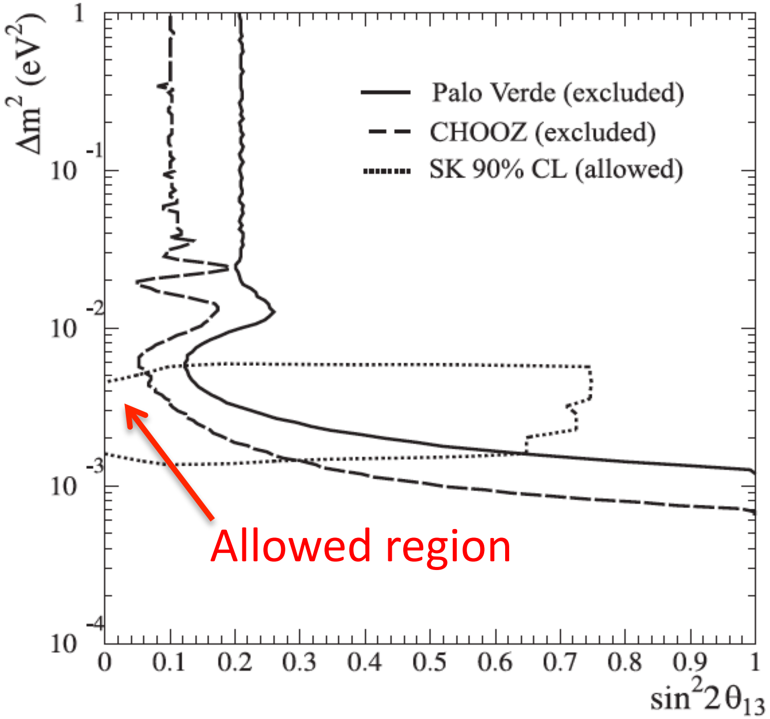


L/E dependence



Prehistory of θ_{13}

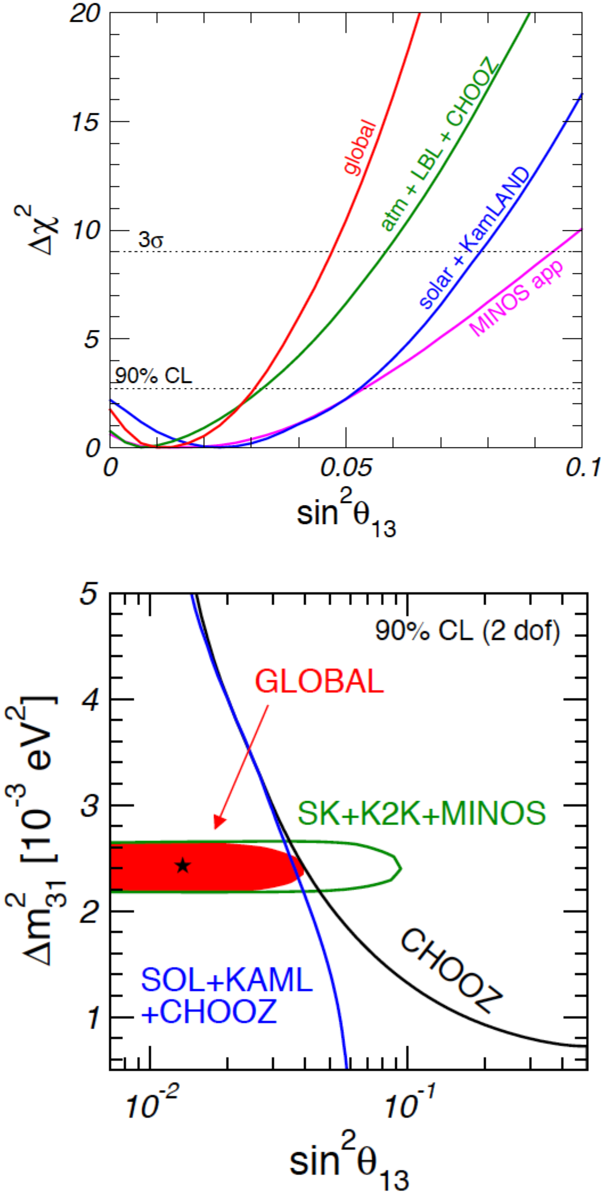
Palo Verde, Phys. Rev. D 64, 112001 (2001)



Allowed region

Results from CHOOZ, Palo Verde and Super-K suggest that θ_{13} is surprisingly small!

Old CHOOZ limit, Eur. Phys. J. C27 (2003) 331



Global fits with the inclusion of Solar, Atmospheric exp., K2K and MINOS results suggest $\theta_{13} \neq 0$

MINOS fisrt appearance result:

Phys. Rev. Lett. 103, 261802 (2009)

Ref: M. Mezzeto and T. Schwetz. arxiv.org/1003.5800

ν_e appearance

- Complicated formula:

$$p(\ \nu_\mu \to \nu_e\ )\ \simeq\ \sin^2(2\theta_{13})\sin^2(\theta_{23})\frac{\sin^2(A-1)\Delta}{(1-A)^2}$$

$$+\alpha\sin^2(2\theta_{13})\sin^2(2\theta_{12})\sin^2(2\theta_{13})\cos(\Delta+\delta)\frac{\sin(A\Delta)}{A}\frac{\sin^2(A-1)\Delta}{(1-A)}$$

$$+\alpha^2\sin^2(2\theta_{12})\cos^2(\theta_{23})\frac{\sin^2(A\Delta)}{A^2}$$

$$\alpha=\frac{\Delta m^2_{21}}{\Delta m^2_{31}}$$

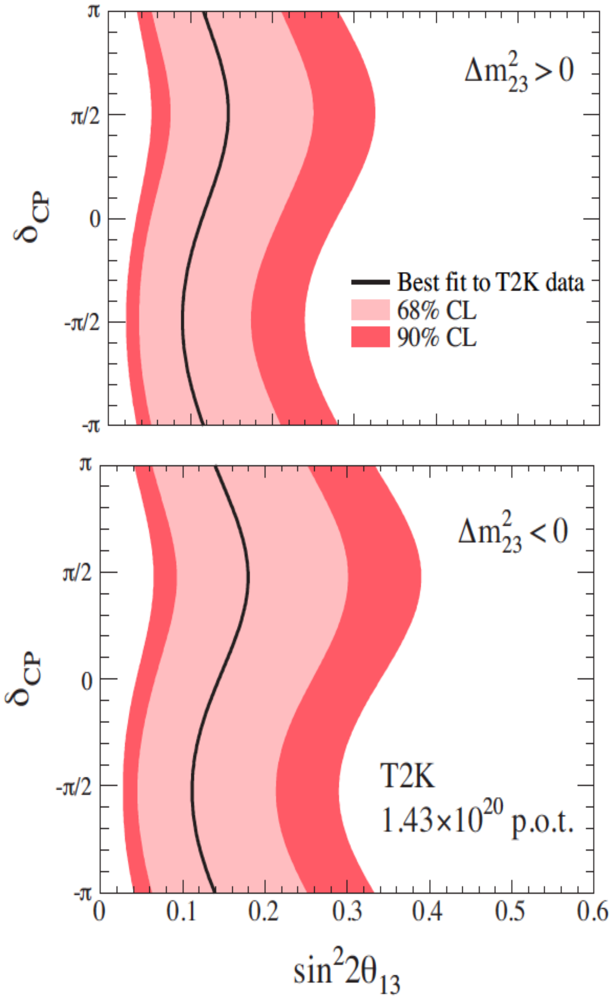
$$A=\frac{2EV}{\Delta m^2_{31}}$$

$$\Delta=\frac{\Delta m^2_{31}L}{4E}$$

- Dependence on CP-violating terms, mass hierarchy.
- An overall eight-fold correlation (θ_{13} , δ_{CP} , $|\Delta m^2_{31}|$, θ_{23}, $\pi/2 - \theta_{23}$)
- The bibliography is very rich:
  - *G.L. Fogli, E. Lisi, Phys. Rev. D54 (1996) 3667*
  - *J. Burguet-Castell et al., Nucl. Phys. B608 (2001) 301*
  - *H. Minakata, H. Nunokawa, JHEP 10 (2001) 001*
  - *V. Barger, D .Marfatia, K .Whisnant, Phys. Rev. D65 (2002) 073023*
  - *P .Huber, M. Lindner, W. Winter, Nucl. Phys. B645 (2002) 3*
  - *And many more…*

T2K and MINOS

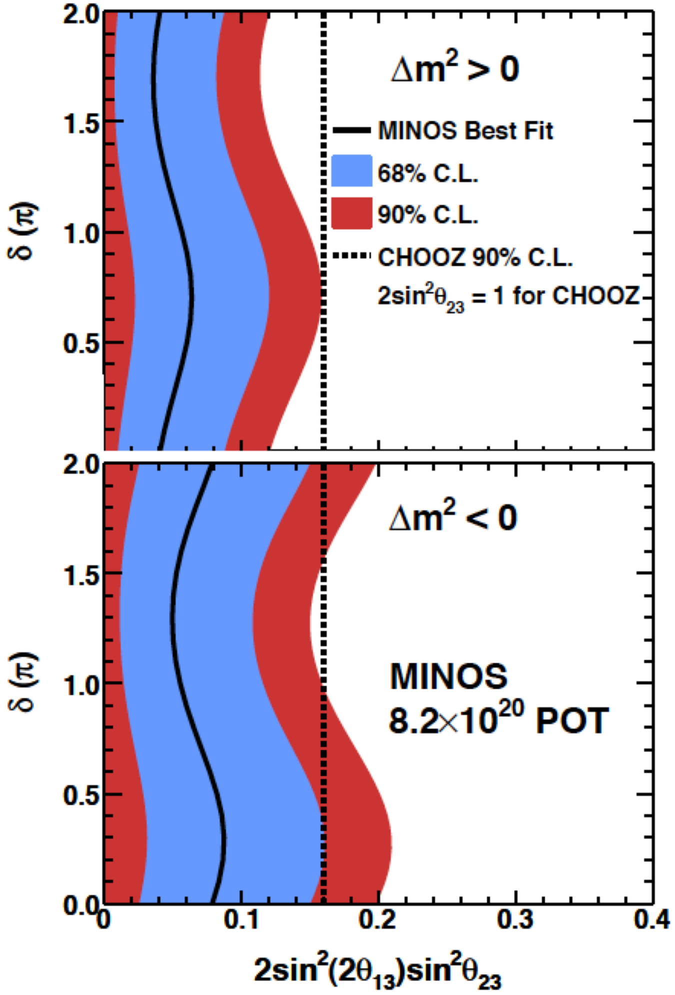
T2K, Phys. Rev. Lett. 107, 041801 (2011)



NH: $0.03 < \sin^2(2\theta_{13}) < 0.28$

IH: $0.04 < \sin^2(2\theta_{13}) < 0.28$ at 90% CL

MINOS, Phys. Rev. Lett. 107, 181802 (2011)



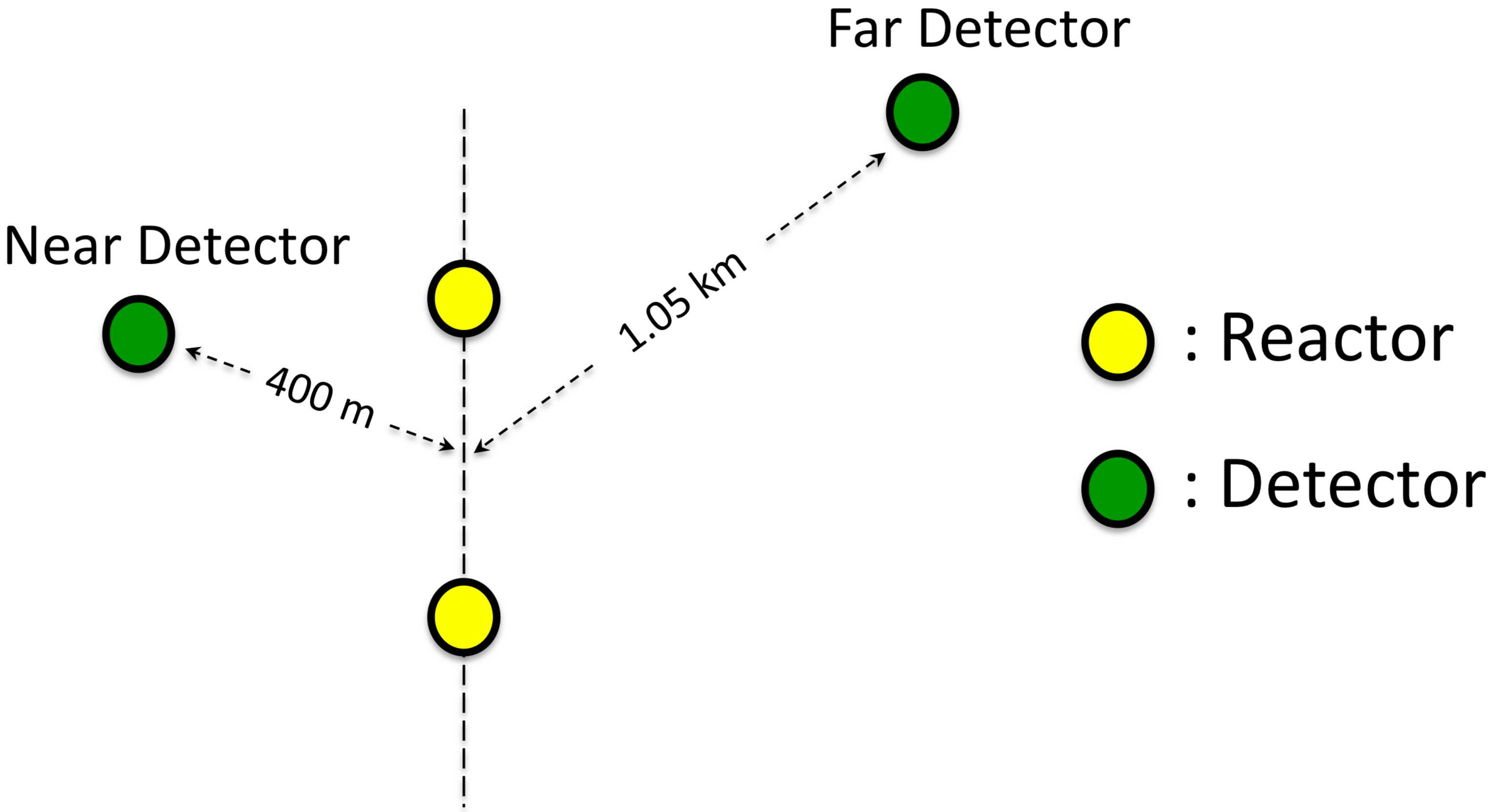
NH: $0.0 < \sin^2(2\theta_{13}) < 0.12$

IH: $0.0 < \sin^2(2\theta_{13}) < 0.19$ at 90% CL

Improving CHOOZ

- Statistics:
  - Larger detector volume
  - Longer exposure
- Antineutrino flux and cross-section:
  - Detectors at different distances from the reactors
  - Identical detectors to face possible inter-detector systematics
- Detector associated errors:
  - Improve detector design
  - Better detector understanding
  - More careful calibration campaign
- Backgrounds:
  - Reduce the accidental rate: detector design and shielding
  - Aggressive radiopurity efforts
  - Improve background knowledge

Detectors configuration



Far Detector

Near Detector

400 m

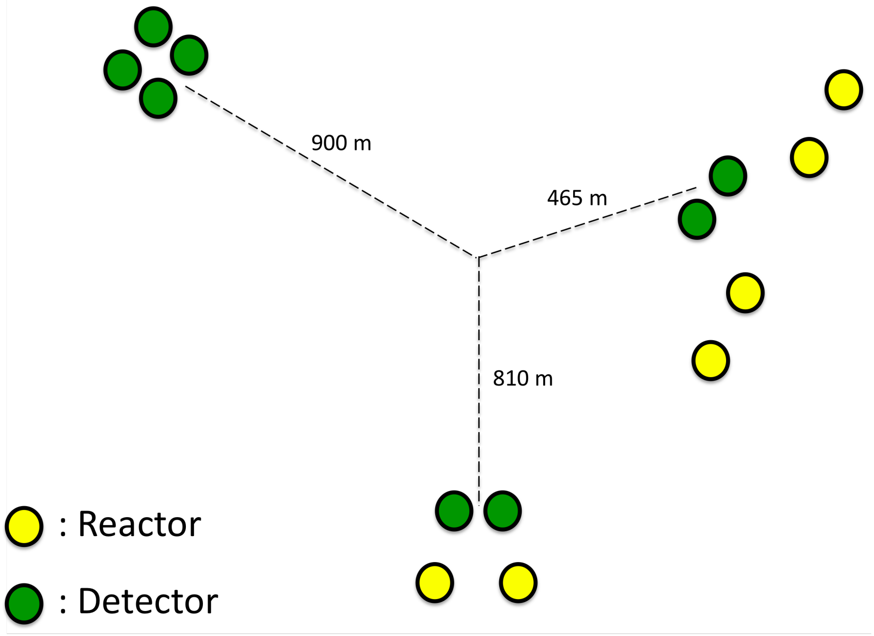
1.05 km

🟡 : Reactor

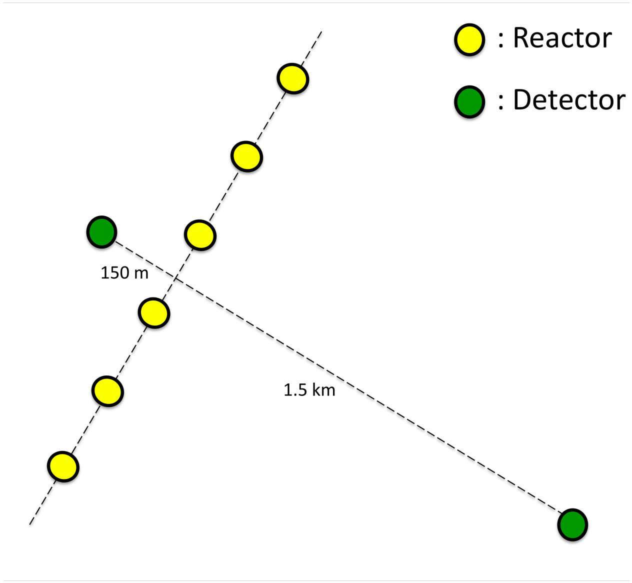
🟢 : Detector

Daya Bay and RENO

Daya Bay (China)



RENO (Korea)

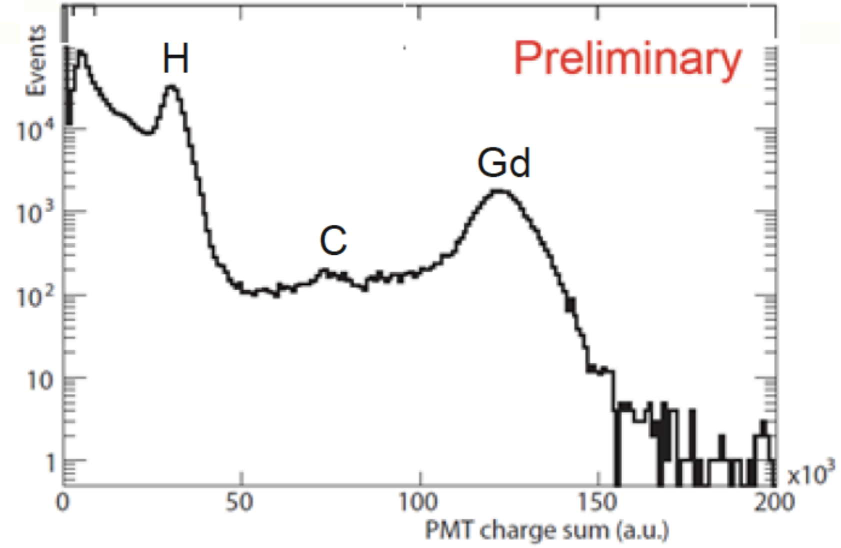


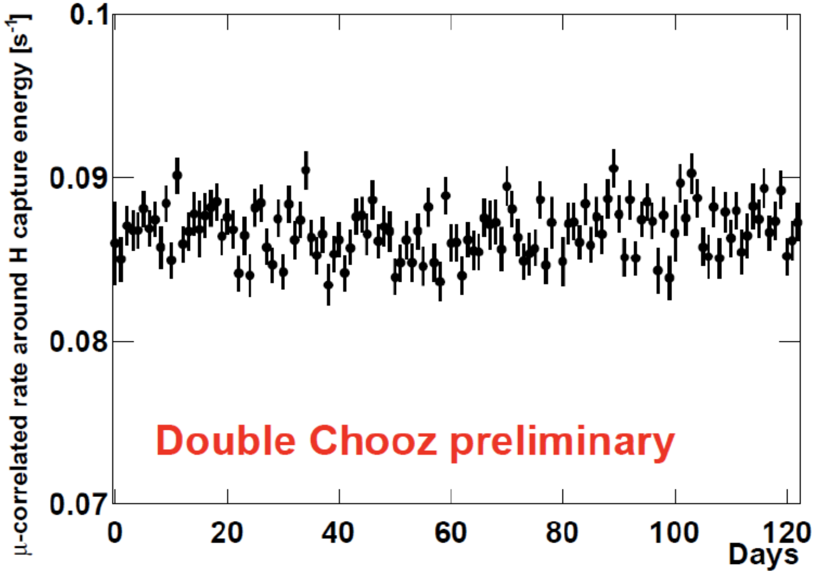
<u>See this in connection with:</u>

“A unified analysis of the reactor neutrino program towards the measurement of the ϑ_{13} mixing angle”, G. Mention *et al., arxiv.org/0704.0498*

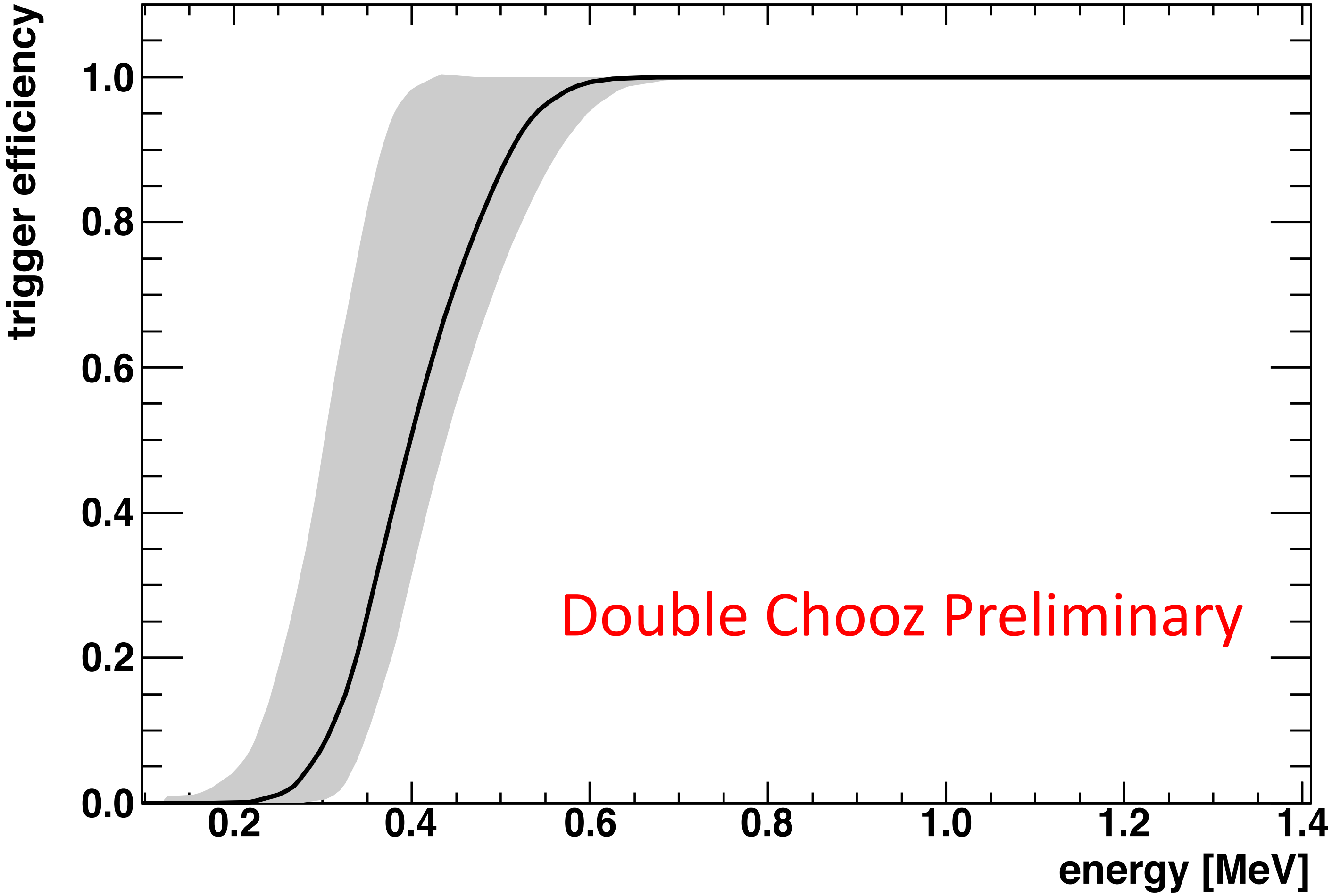
Spallation neutrons

- Muons create copiously spallation products.
- Among them neutrons can be absorbed in hydrogen and gadolinium several μs after the prompt muon signal.
- Neutron capture peaks are very pronounced and can be used to calibrate the detector (set the energy scale) and,
- Monitor its stability.



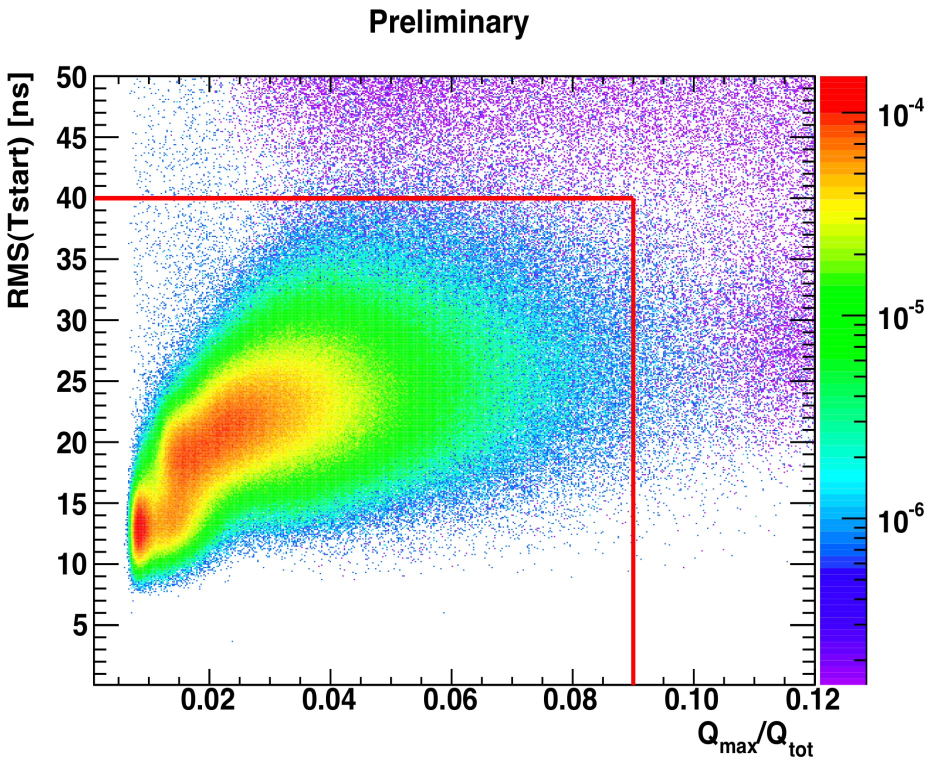


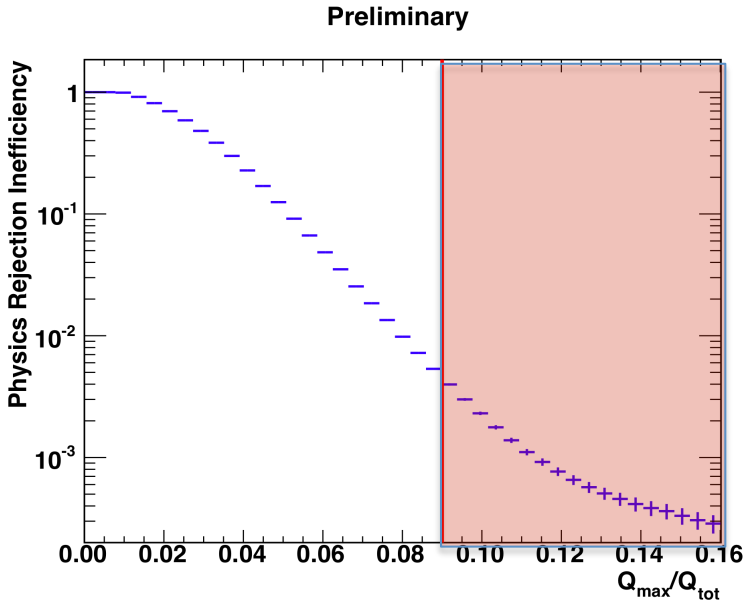
Trigger efficiency

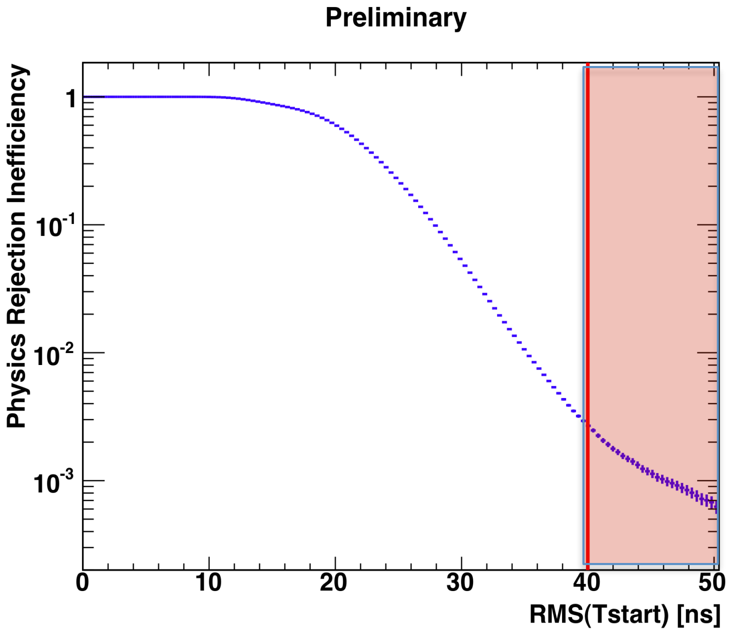


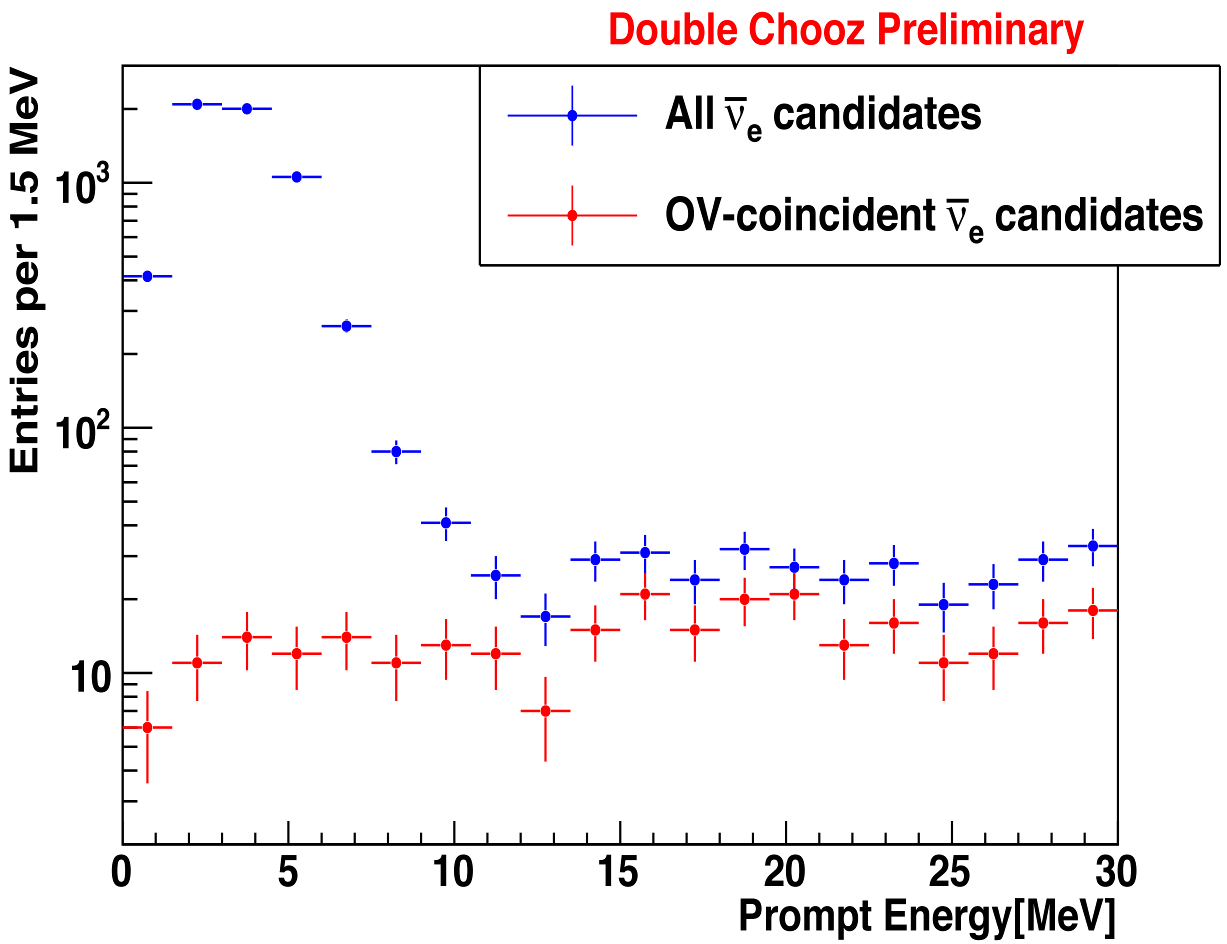
Spontaneous light emission

- Parasitic light emitted by some photomultiplier bases.
- 14 phototubes switched off.
- Software cuts:
  - Q_{max}/Q_{tot}<0.09(prompt), 0.055 (delayed)
  - RMS(Ts)<40.0 ns
- This issue is well under control.

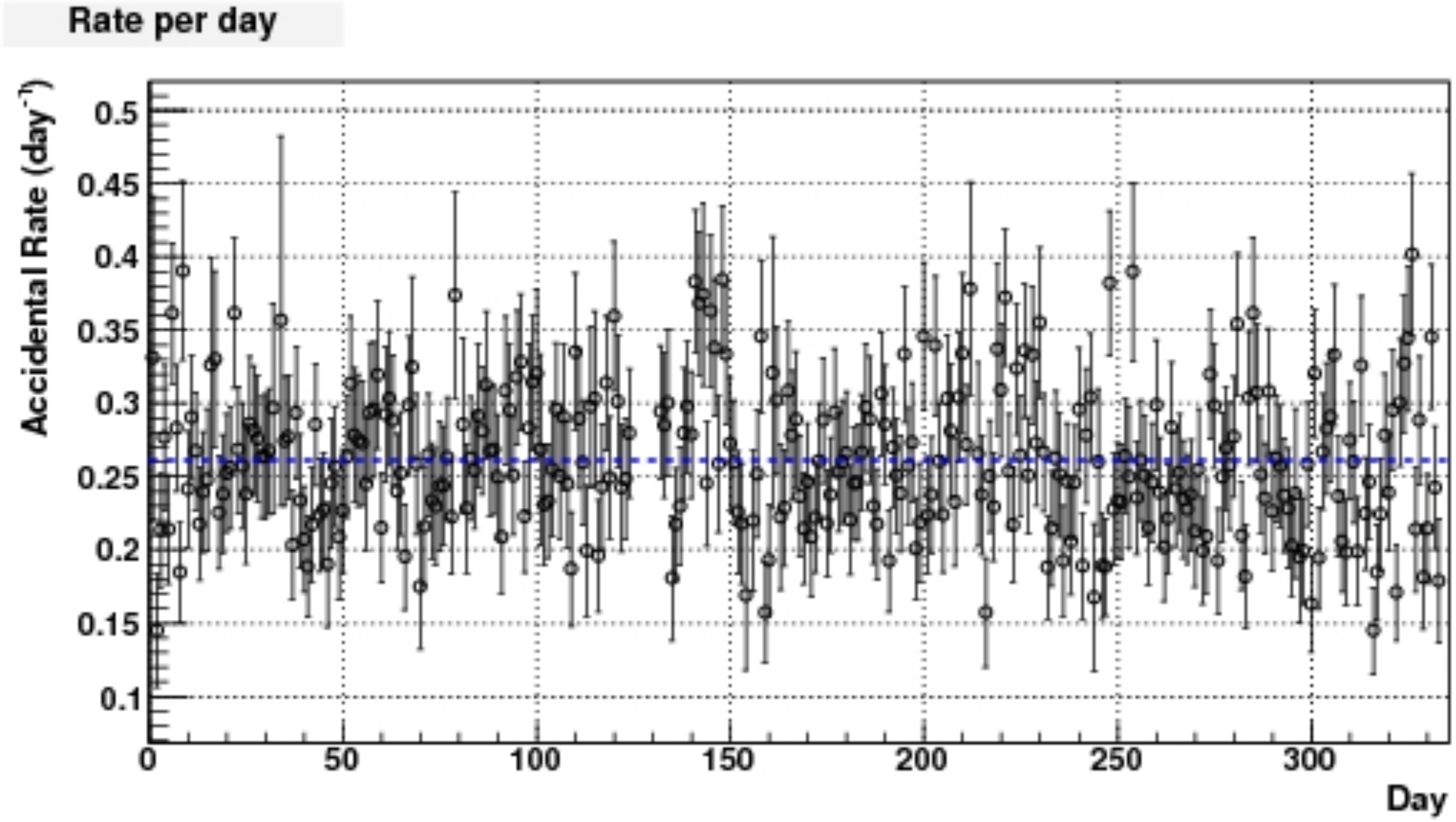






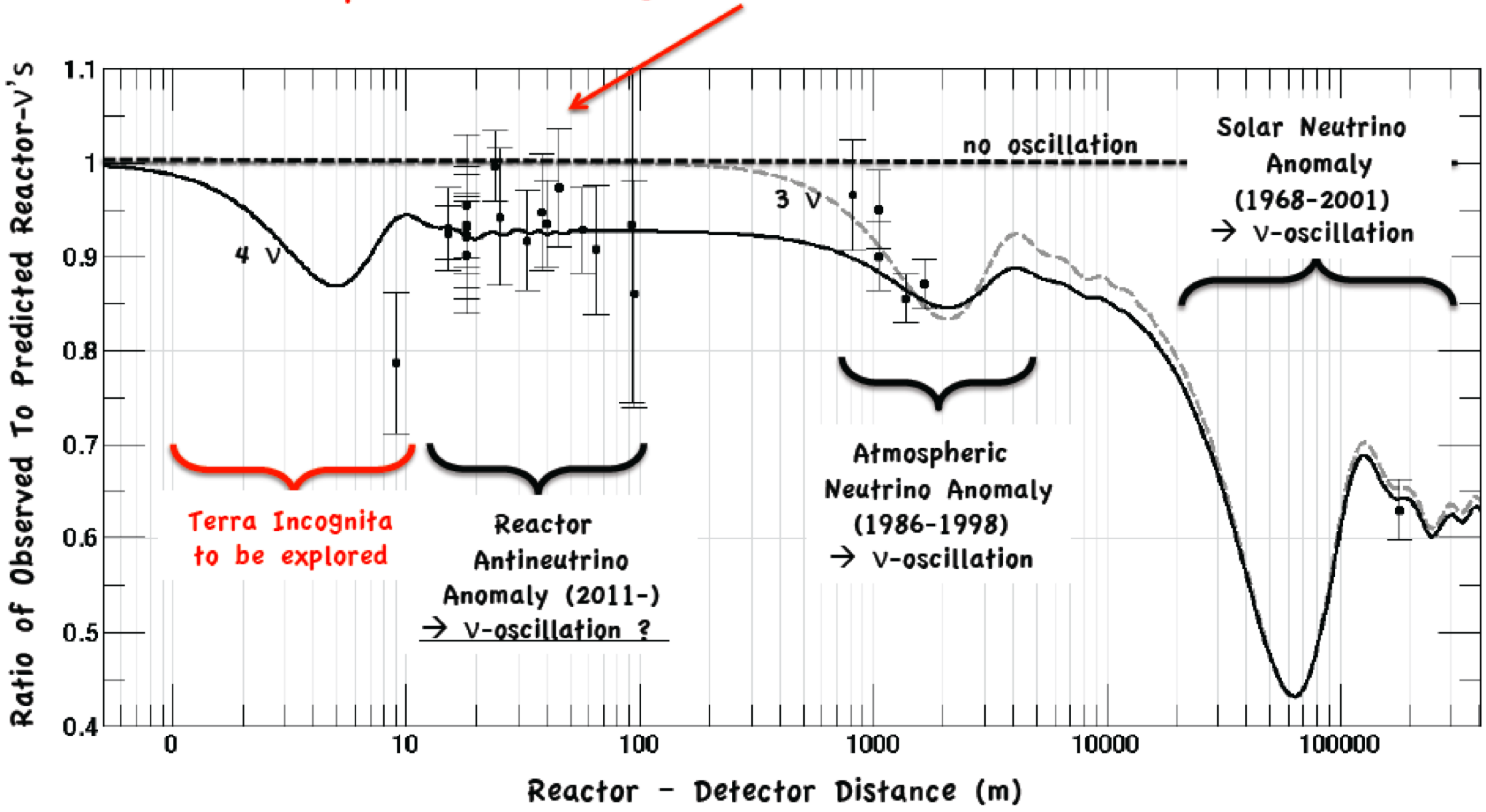

Double Chooz Preliminary
All $\bar{\nu}_e$ candidates
OV-coincident $\bar{\nu}_e$ candidates
Entries per 1.5 MeV
10^3
10^2
10
0
5
10
15
20
25
30
Prompt Energy[MeV]

Accidental rate



Terra incognita

- Observed/predicted averaged event ratio: R=0.927±0.023 (3.0 σ)



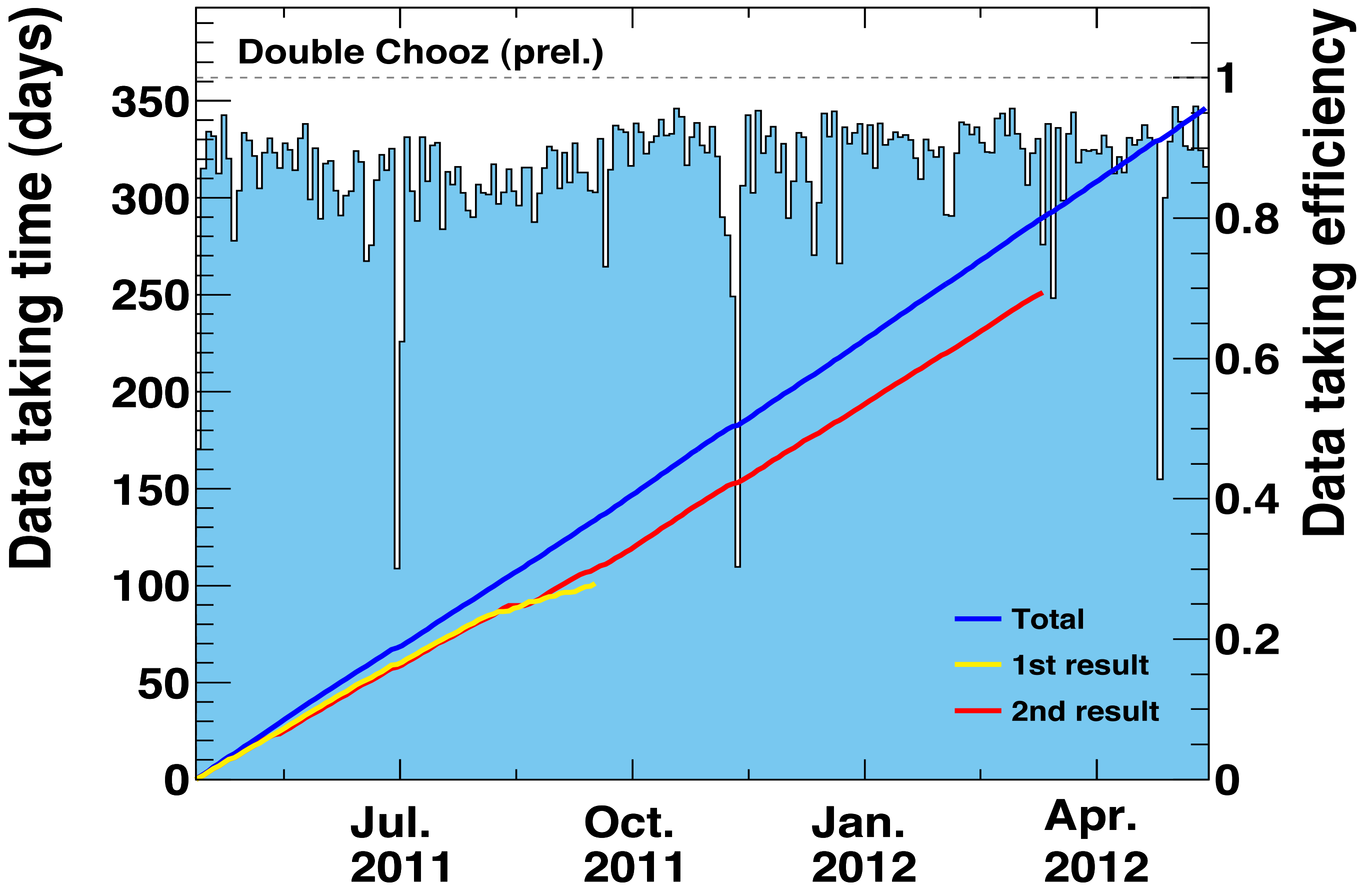
Th. Lasserre Neutrino 2012

Error budget

(M. Ishitsuka, Neutrino 2012)

Source		**Uncertainty w.r.t. signal** (previous analysis)	
Statistics		**1.1%** (1.6%)	
Flux		**1.7%**	
Detector	Energy response	**0.3%** (1.7%)	**1.0%** (2.1%)
	E_{delay} containment	0.7%	
	Gd fraction	0.3%	
	Δt cut	0.5%	
	Spill in/out	0.3%	
	Trigger efficiency	<0.1%	
	Target H	0.3%	
Background	Accidental	<0.1%	**1.6%** (3.0%)
	Fast neutron + stop μ	**0.5%** (0.9%)	
	^{9}Li	**1.4%** (2.8%)	

Data taking summary



- Run-time: **251.3 days** (13 April 2011 - 15 March 2012)
- Data taking efficiency in total: **87.0 %**
- Data taking efficiency for physics: **79.8 %**