News from the Double Chooz experiment

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On behalf of DC Collaboration

16-th Lomonosov Conference MSU
22-28 August, 2013

Plan

- Neutrino oscillations
- Method of two identical detectors to minimize systematics
- Status of Double Chooz experiment
  - Experimental site
  - Detectors
  - Backgrounds
  - θ_{13} measurement results
- Conclusion and outlook

Neutrino oscillations

$$< \nu_\alpha | = \sum_i U_{i\alpha} | \nu_i > \qquad \alpha - e,\ \mu,\ \tau; \qquad i - 1,\ 2,\ 3$$

Atmospheric ν   Reactor ν   Solar ν

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \cdot \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{+i\delta} & 0 & c_{13} \end{bmatrix} \cdot \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$s_{\mathrm{ij}} = \sin\ \theta_{ij}\ , \quad c_{\mathrm{ij}} = \cos\ \theta_{ij}$$

Super-K, MINOS, T2K etc.

Double Chooz. Daya Bay, RENO

Homestake, KamLAND, SNO

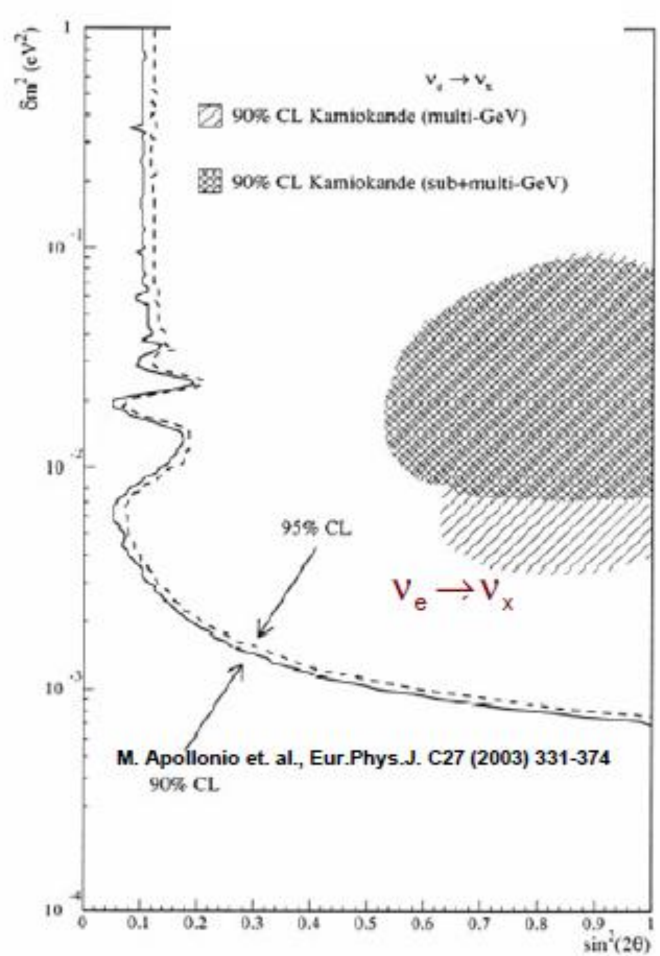
$$P_{\nu_l \to \nu_l} \approx 1 - \sin^2 2\theta_{lx} \sin^2\left(\frac{1.267 \cdot \Delta m^2 L}{E_{\nu_l}}\right)$$

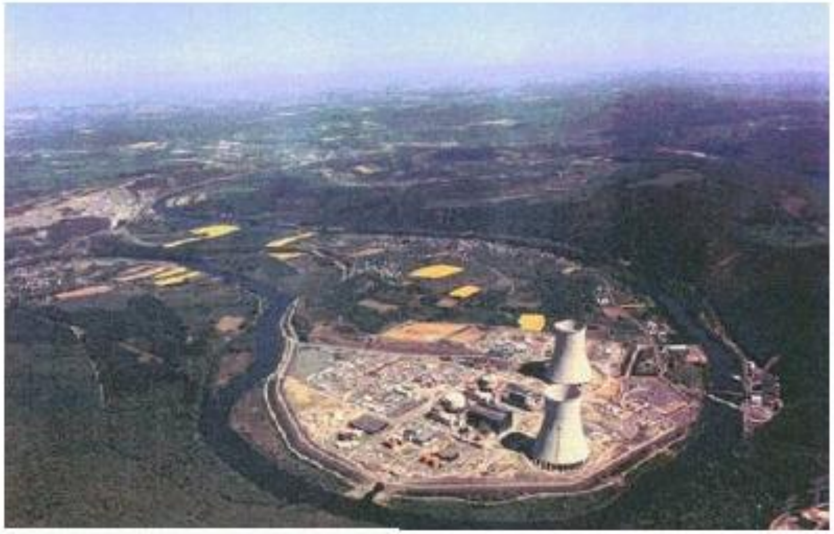
Chooz experiment (1995-1998)

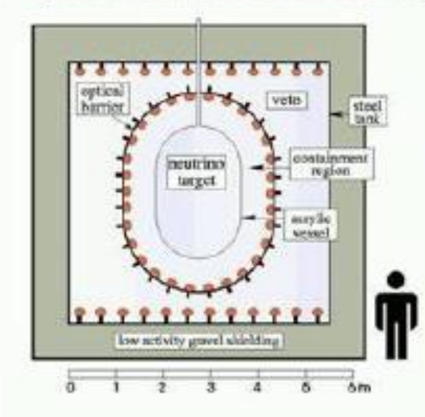
R = 1.01 ± 2.8% (stat) ± 2.7% (syst.)

Disappearance experiment
P=8.4GW. L=1.05 km. M=5 t @300 m.w.e.

$$\bar{\nu}_e \rightarrow \bar{\nu}_e$$







@Δm^2_{13} = 2*10^{-3} eV^2

$\sin^2(2\theta_{13}) < 0.2$

(90% C.L)

New concept of the reactor experiment:

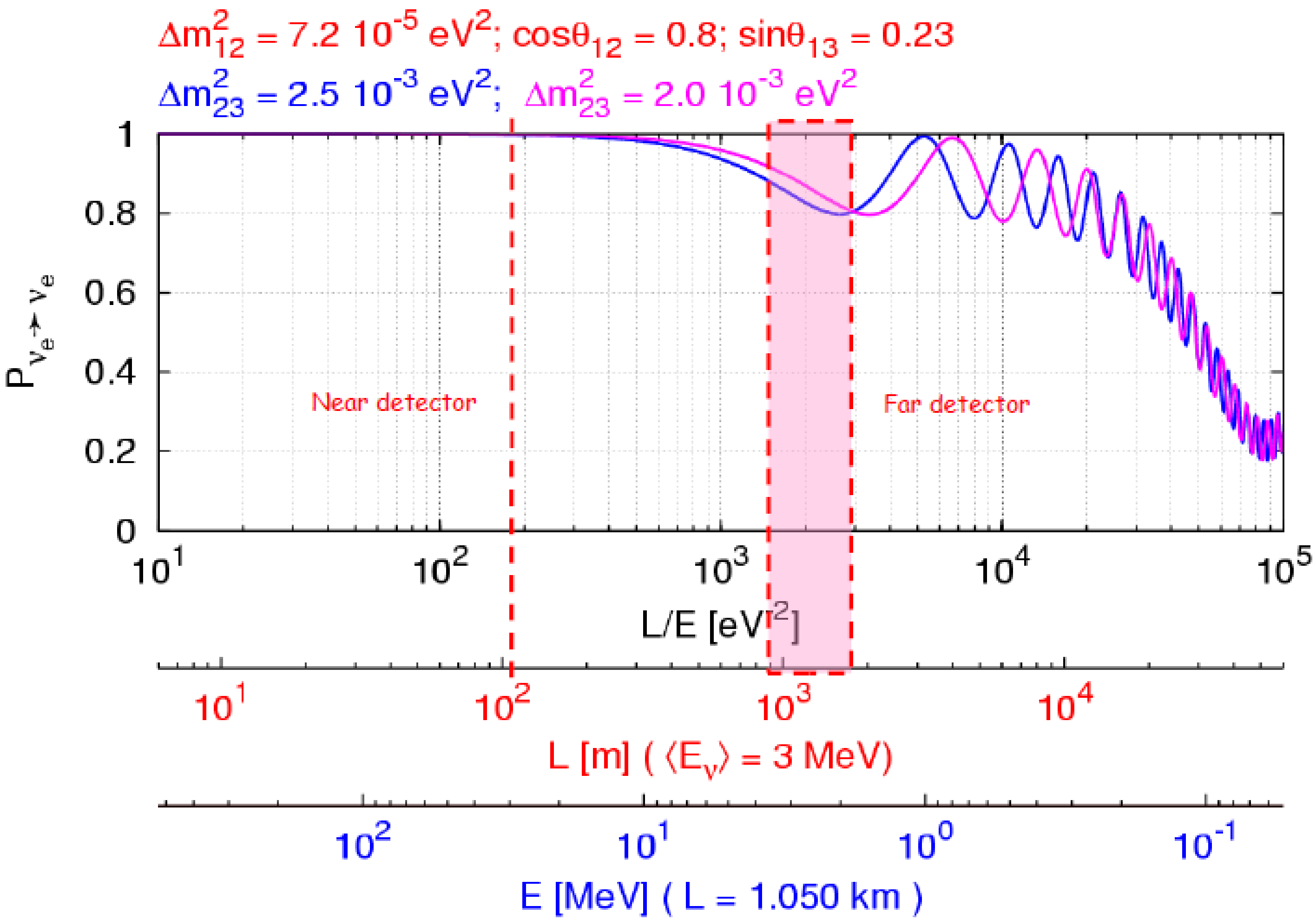
how to improve the results of CHOOZ

L.A.Mikaelyan and V.VSinev arXiv:hep-ex/9908047v1 11-Aug-1999
Talk given at the International Conference on Non-Accelerator New Physics, NANP-99, Dubna, (28/06-03/07)-1999.

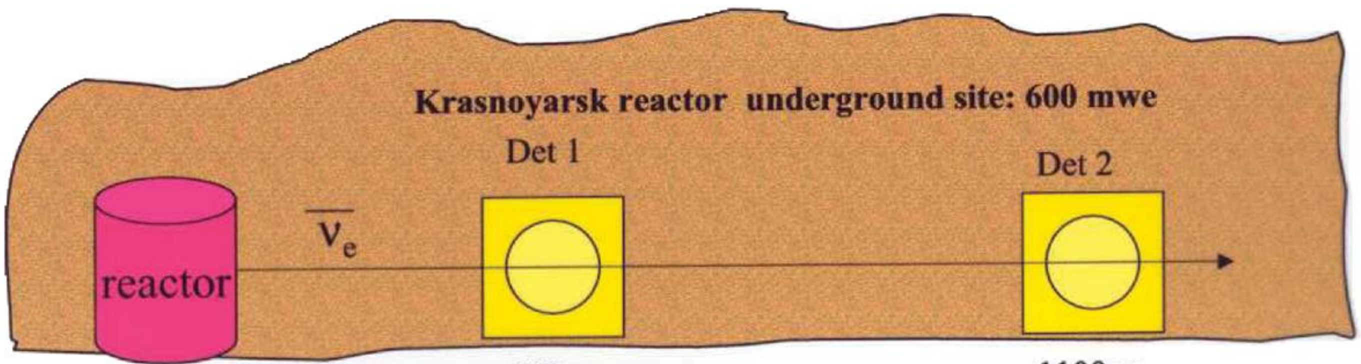
The White Paper «A new reactor neutrino experiment to measure θ_{13}»
hep-ex/0402041 (2002)

Double CHOOZ Proposal hep-ex/0606025 v2 20-June-2006

Probability of surviving



Kr2Det - probing U_{e3} with reactor ν_e



	100 m	1000 m
Target:	50 t	50 t
Rate:	$1.5 \cdot 10^6$ /year	$15 \cdot 10^3$ /year
S:B	>>1	~ 10:1

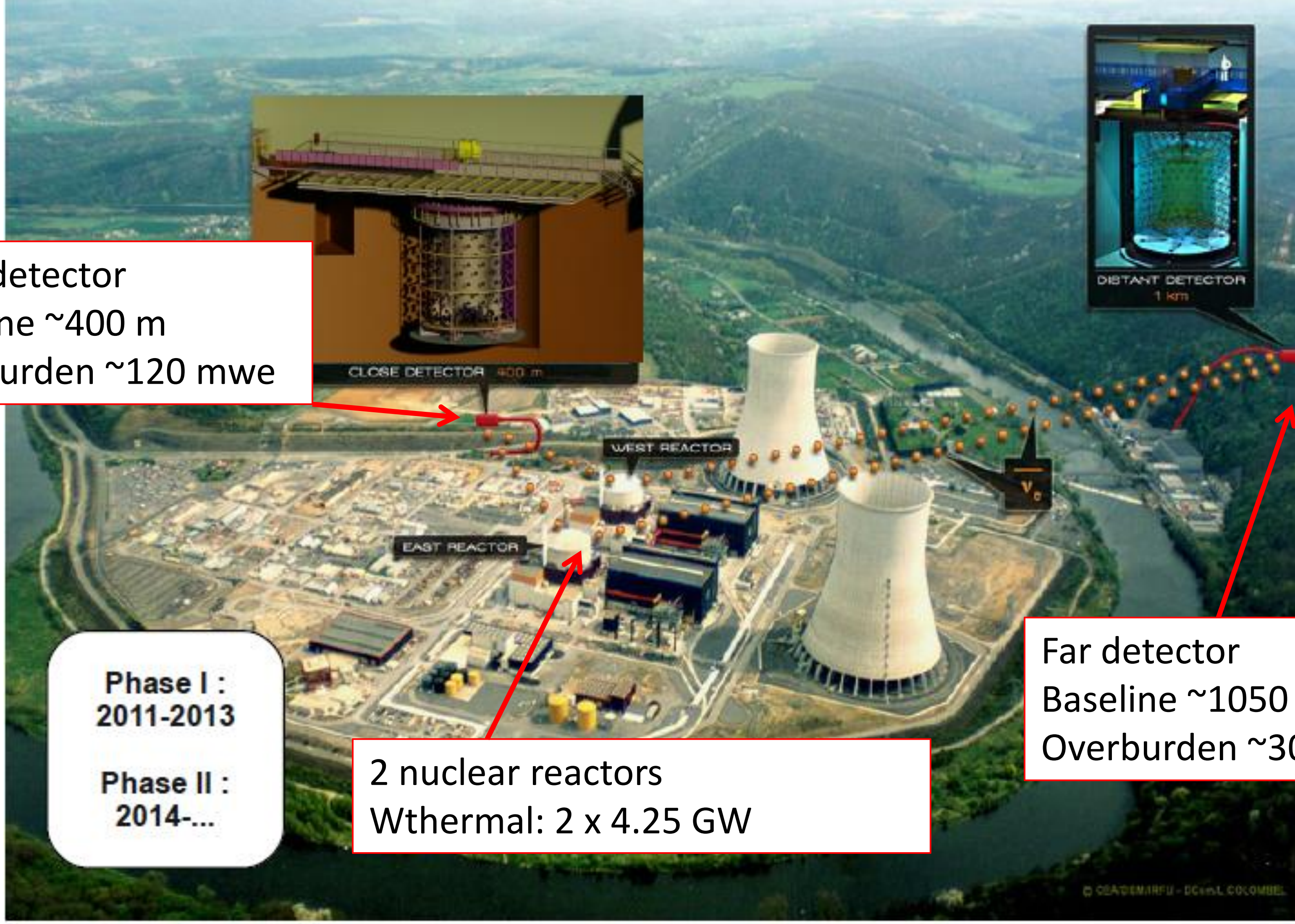
Collaboration Double Chooz

Brazil	France	Germany	Japan	Russia	Spain	USA
CBPF UNICAMP UFABC	APC CEA/DSM/IRFU: SPP SPhN SEDI SIS SENAC CNRS/IN2P3: Subatech IPHC ULB/VUB	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 Kansas State LLNL MIT U. Notre Dame Sandia National Laboratories U. Tennessee

Spokesperson: H. de Kerret (IN2P3)
Project Manager: Ch. Veyssière (CEA-Saclay)

Web Site: www.doublechooz.org/

Double Chooz site

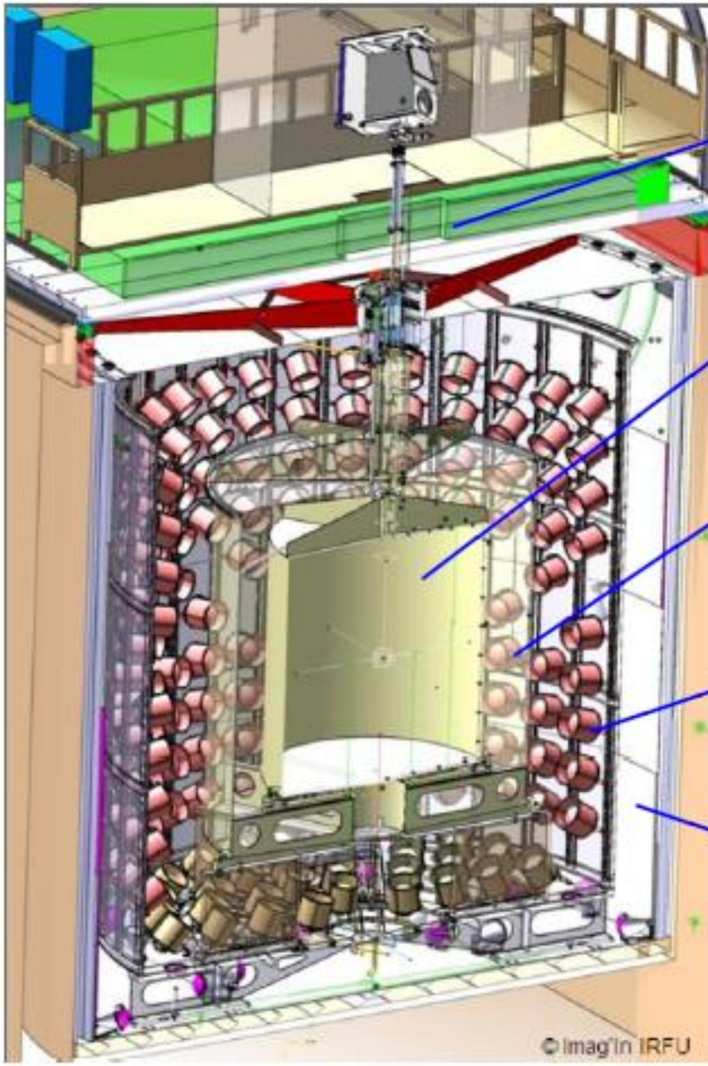


Near detector
Baseline ~400 m
Overburden ~120 mwe

Far detector
Baseline ~1050 m
Overburden ~300 mwe

2 nuclear reactors
Wthermal: 2 x 4.25 GW

Detector design



Outer Veto : plastic scintillator strips

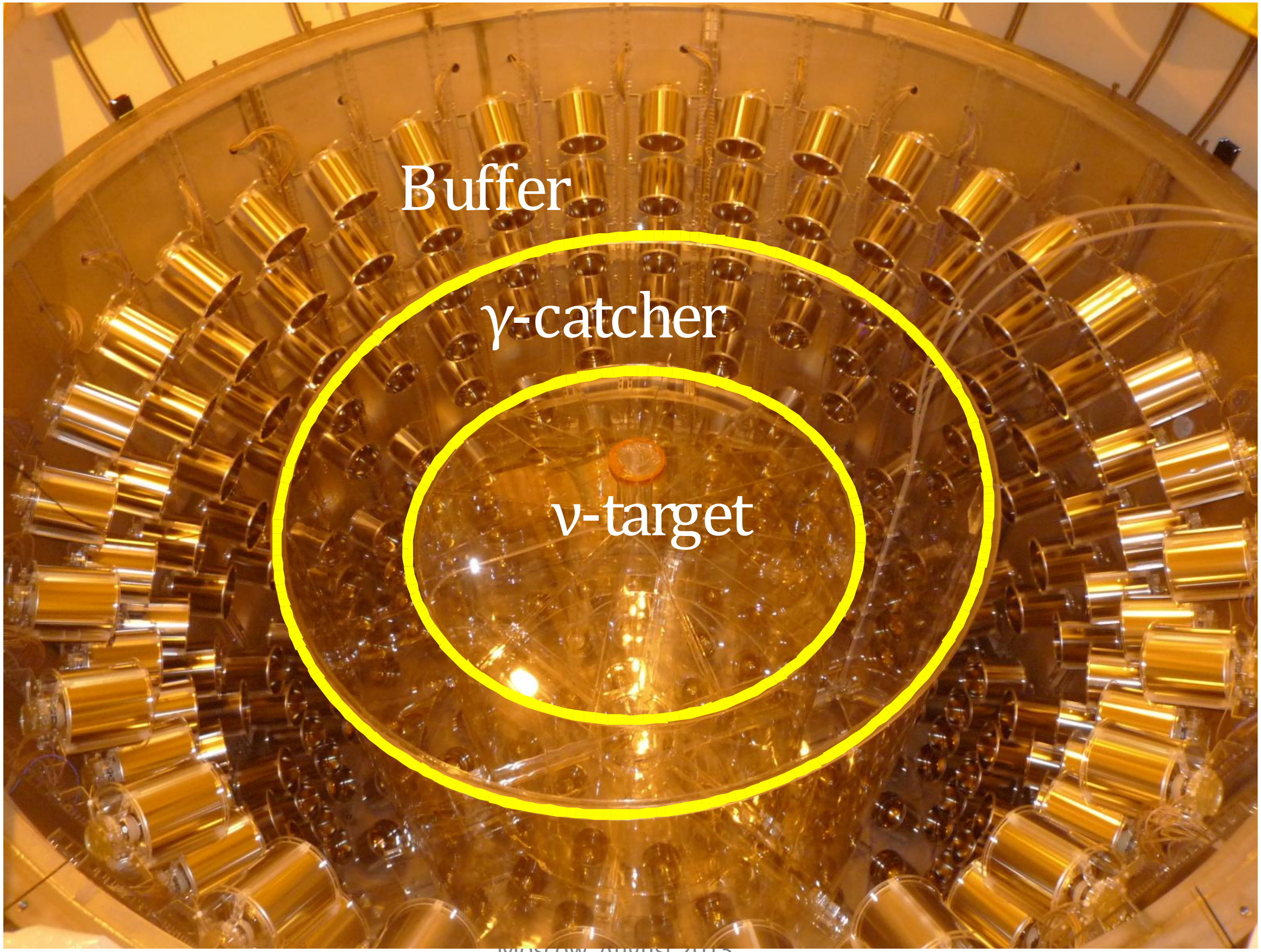
ν-Target: 10.3 m^3 liquid scintillator doped with 1g/l of Gd in an acrylic vessel (8 mm)

Gamma-catcher: 22.6 m^3 liquid scintillator in an acrylic vessel (12 mm)

Buffer: 110 m^3 of mineral oil in a stainless steel vessel (3 mm)
viewed by 390 PMTs (10 inches)

Inner Veto: 90 m^3 liquid scintillator in a steel vessel (10 mm) equipped with 78 PMTs (8 inches) + steel shielding

View inside the detector with opened lid

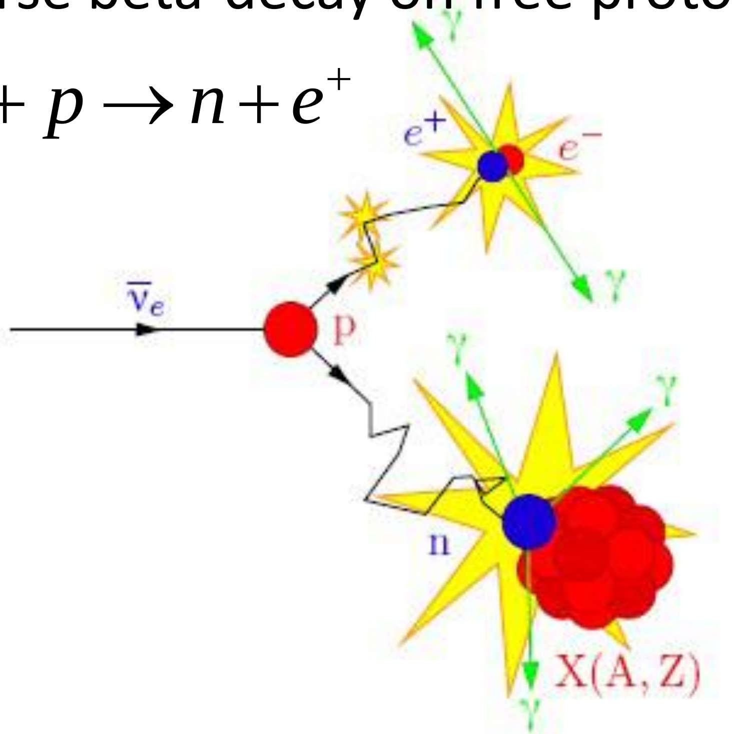


Far detector laboratory with outer veto carpet on the top

Neutrino signal

Inverse beta-decay on free proton

$$\overline{\nu_e} + p \rightarrow n + e^+$$



Delayed coincidence

Prompt: photons from ***e***$^+$ ionization and two annihilation gammas capture (2 * 511 keV) $E_{vis} = E_n - 0.78$ MeV + $O(E_e/m_n)$

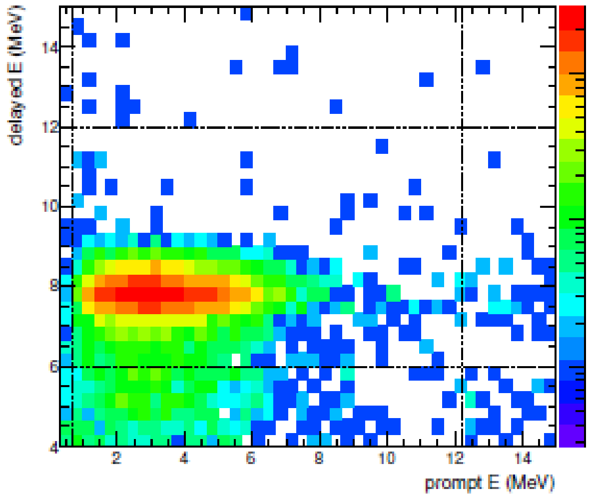
Delayed: photons from ***n*** capture on dedicated nuclei (Gd) Δt ~ 30 μs <E> ~ 8 MeV

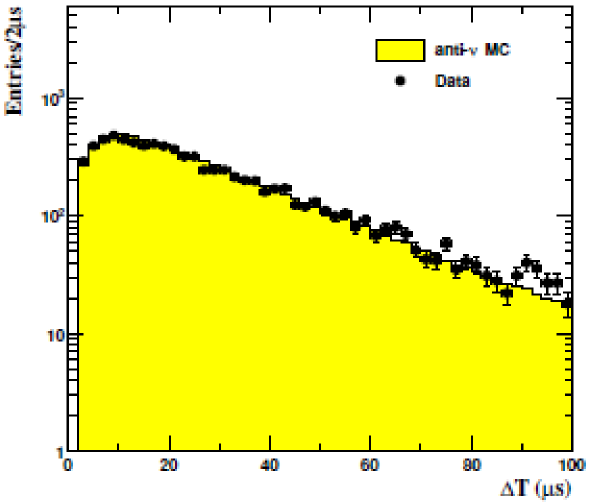
$$N_\nu^{exp}(E,t) = \frac{\varepsilon N_p}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f \rangle} \times \langle \sigma_f \rangle$$

Number of detected antineutrinos. Cross section anchored on Bugey measurement.

Selection of neutrino candidates

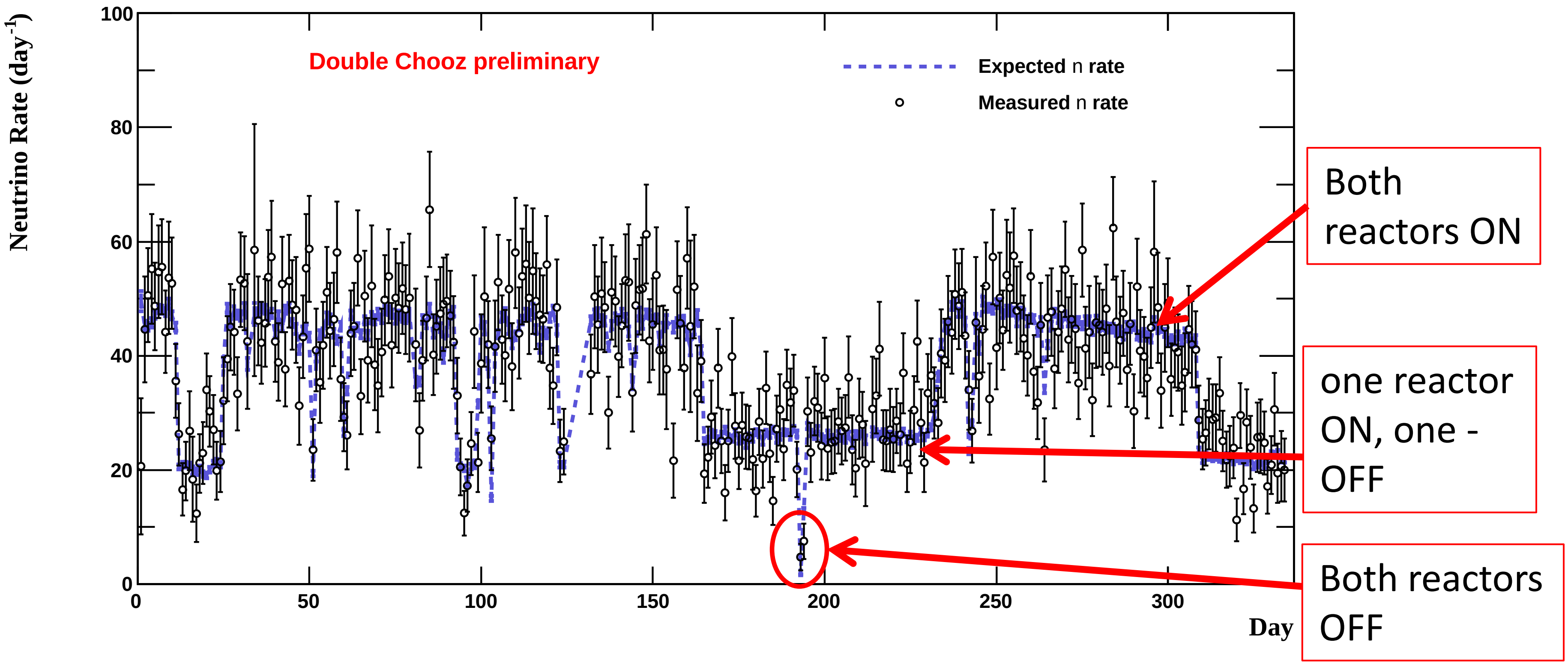
- Prompt signal Evis = [0.7, 12.2] MeV
- Delayed signal Evis = [6.0, 12.0] MeV
- Delayed Coincidence Δt = [2, 100] μsec
- Time to nearest muon before Δt_{μ} > 1 msec
- PMT light noise rejection cuts
    - PMT hits approx. homogeneous
    - PMT hits approx. coincident in time
- Multiplicity conditions:
    - No extra events around signal
- Background rejection:
    - No coincident signal in OV
    - Require Δt_{μ} > 500 msec if E_{μ} > 600 MeV





Measured neutrino Rate

Neutrino rate



Backgrounds are not subtracted. Blue line – predicted rate in accordance with reactors power.

Detector Calibration

Energy Calibration

PMT and electronics gain non-linearity calibration

- LED light injection system

Correct for position dependence

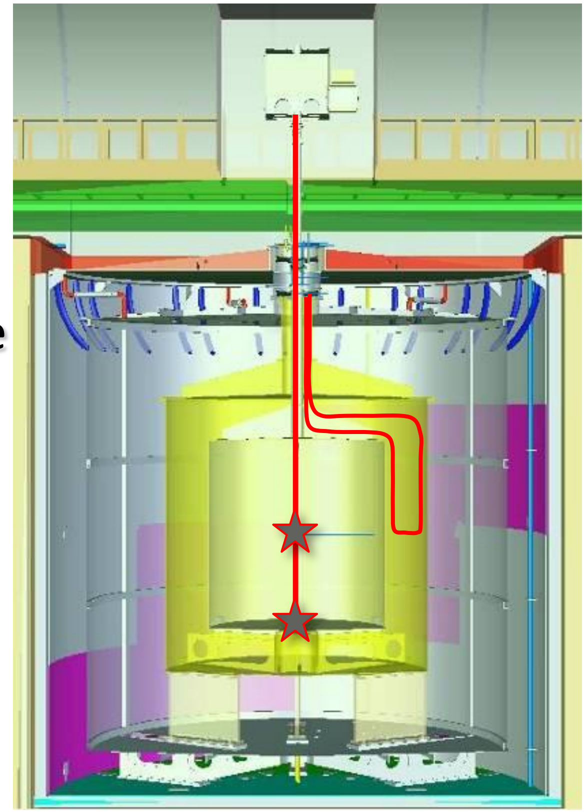
- Spallation neutron H captures

Correct for time stability

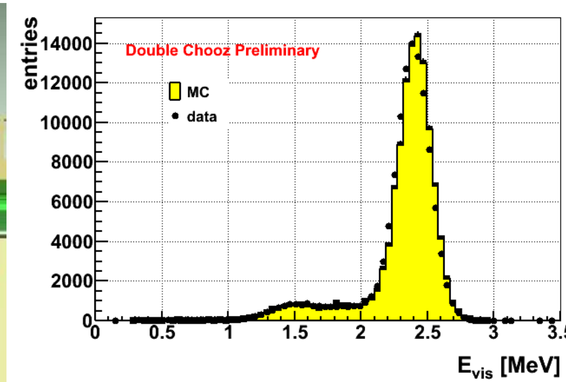
- Spallation neutron Gd captures

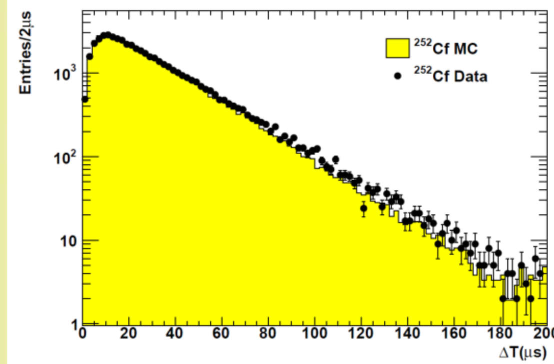
Energy scale

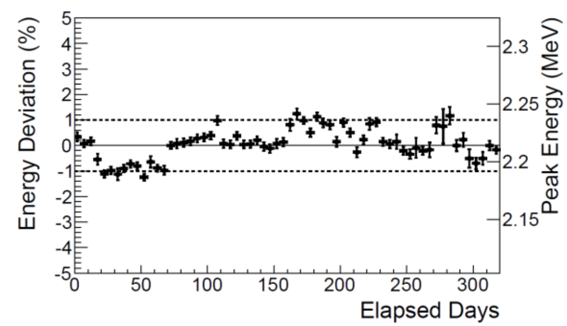
- Radioactive sources deployed into ν-target and γ-catcher



^{60}Co in center







Neutron Detection Efficiency

Energy & time window, Gd fraction, spill in/out effects

- ^{252}Cf source deployed into ν-target and γ-catcher

Backgrounds

Only 2 cores gave the possibility to explore in details detector backgrounds during periods when both reactors were OFF

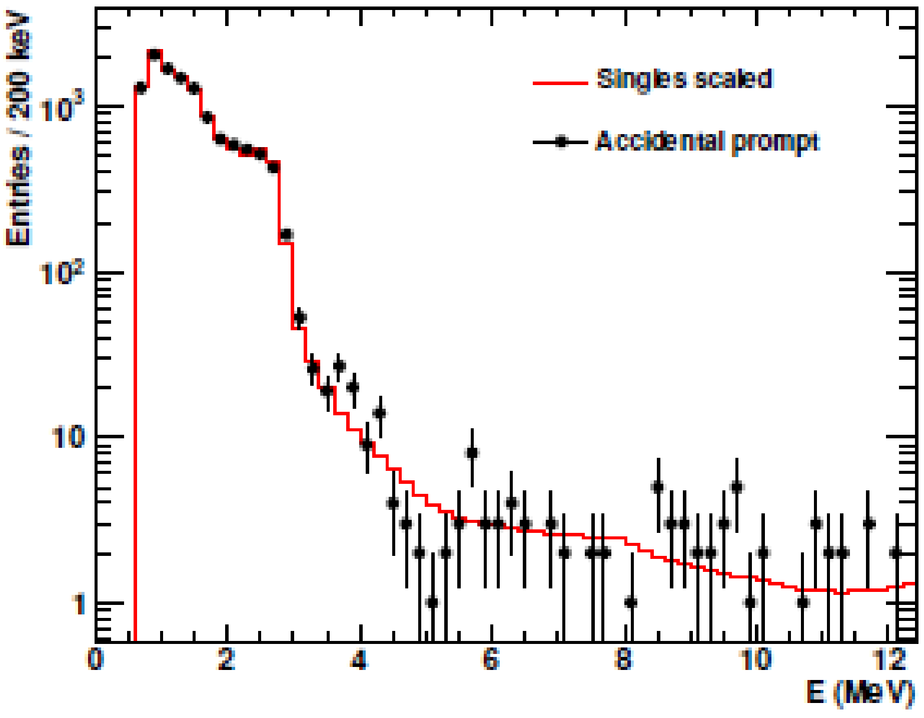
- Accidentals
- Cosmogenic isotopes $^{9}Li/^{8}He$
- Fast neutrons and stopped muons

Accidentals

Accidental coincidences of two uncorrelated single events.

0.261 ± 0.002 ev/day

It was measured through multiple off-time windows

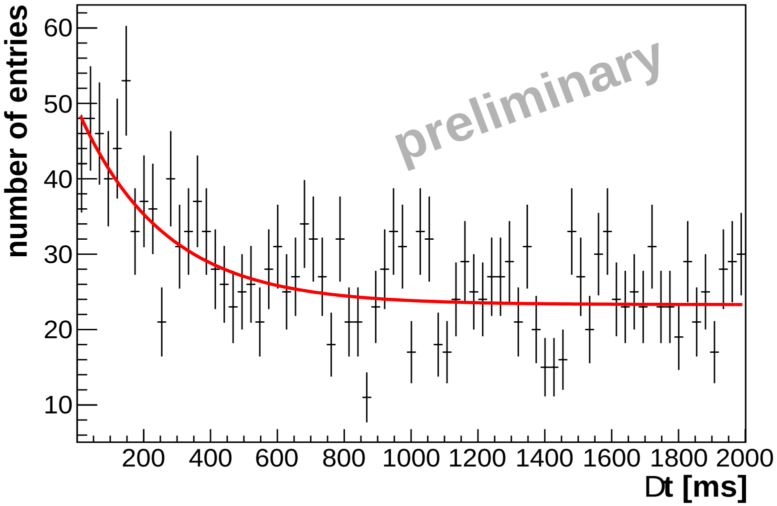


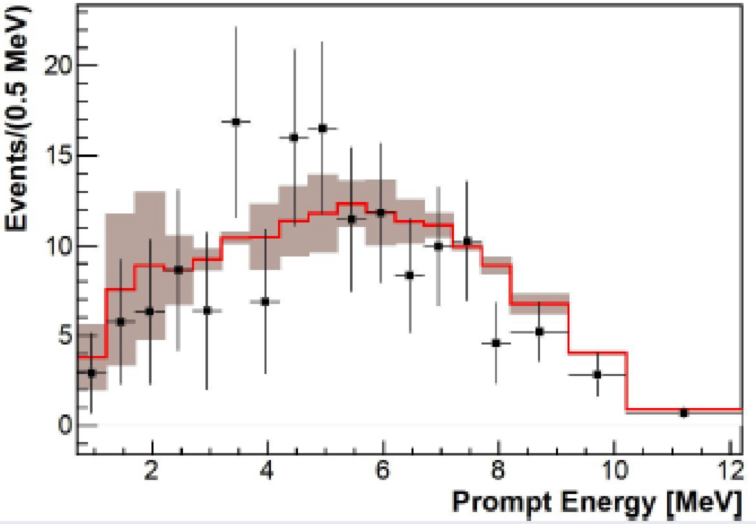
Cosmogenic isotopes $^{9}Li/^{8}He$

Correlated background due to spallation reactions on ^{12}C caused by muon passing through the target. As a result isotopes of $^{9}Li/^{8}He$ produced which are β-n emitters.

1.25 ± 0.54 ev/day

It was measured by tagging to muons through going the target. They looked for IBD pair after muon.



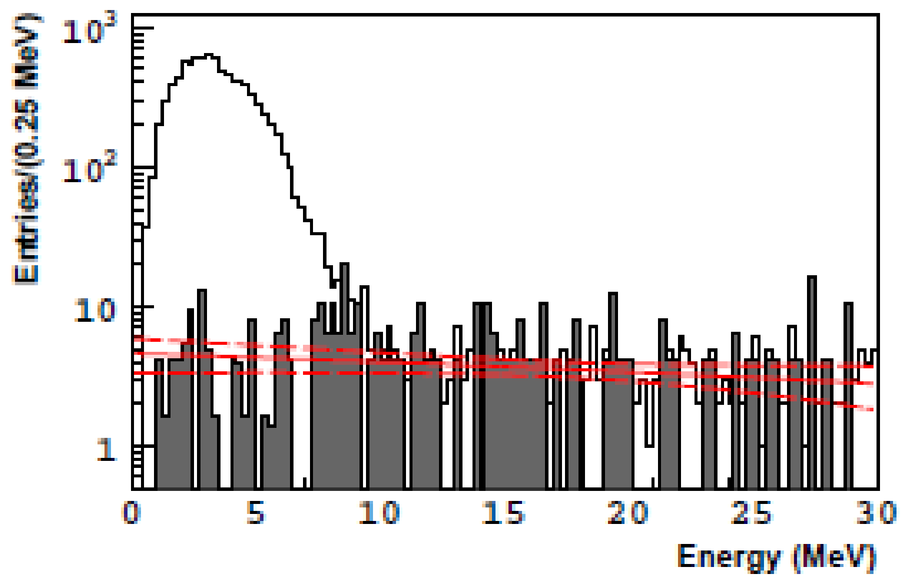


Fast neutrons and stopped muons

Correlated background fast neutrons produced by muon passing out of the target or muons stopped in the target and after giving Michel electrons.

0.67 ± 0.20 ev/day

It was measured by tagging to muons bypassing the target.



2 Analyses

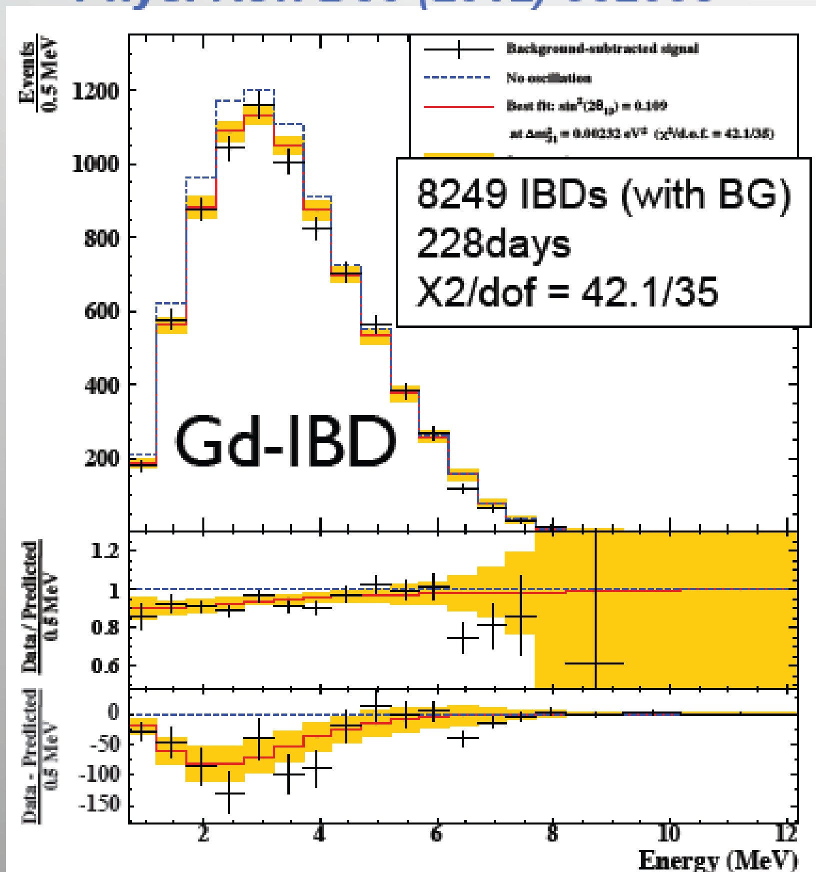
n-Gd capture	n-H capture
• High efficiency of neutron detecting • Well known volume and proton number in the target • Neutron capture time ~30 μs • Delayed signal energy ~8 MeV • Low statistics (8249)	• Low efficiency of neutron detecting • 3 times larger volume but not so well known • Neutron capture time ~180 μs • Delayed signal energy ~2 MeV • High statistics (36284)

Rate uncertainties

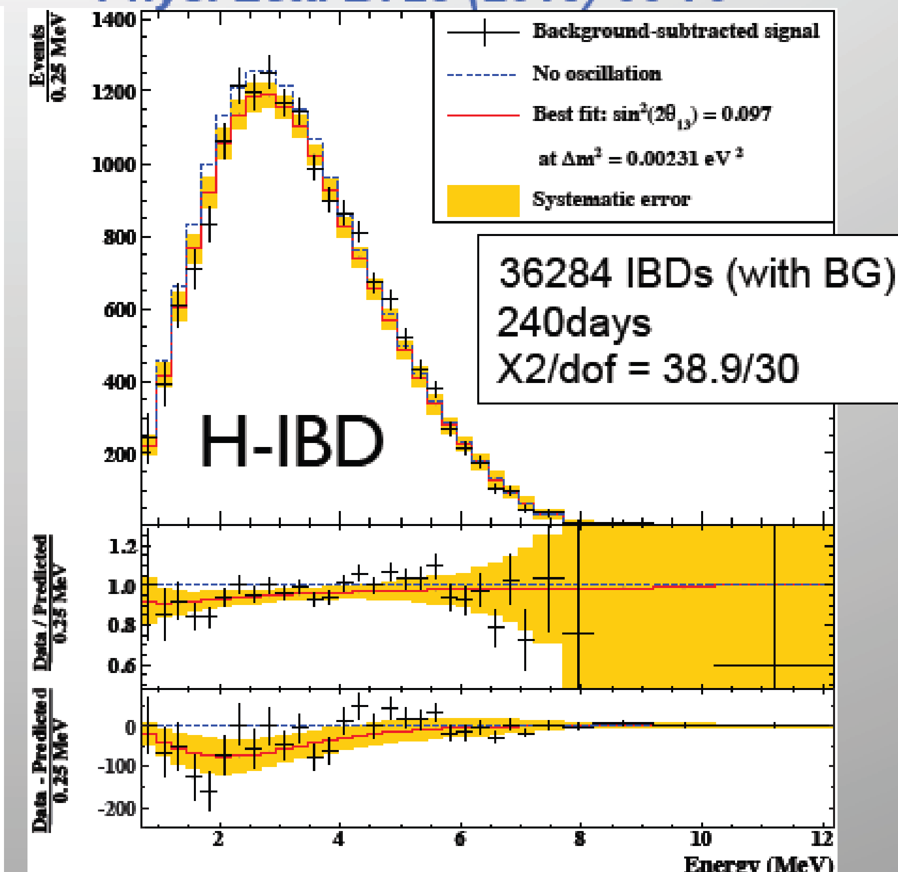
	n-Gd	n-H
Statistics Flux Efficiency Background	1.06% 1.7% 1.0% 1.6%	1.1% 1.7% 1.6% 1.7%
Total	2.7%	3.1%

Measured neutrino spectra

Phys. Rev. D86 (2012) 052008



Phys. Lett. B723 (2013) 66-70



DC-II(Gd): $\sin^2 2\theta_{13} = 0.109 \pm 0.039$ $[0.030^{stat} \pm 0.025^{syst}]$

DC-II(H): $\sin^2 2\theta_{13} = 0.097 \pm 0.048$ $[0.034^{stat} \pm 0.034^{syst}]$

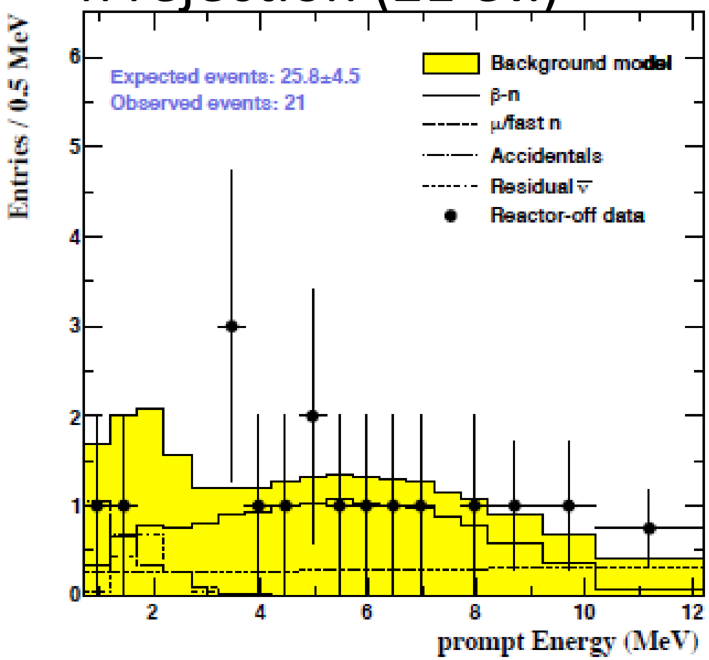
Off-Off data

There were two periods “off-off”
0.84 d (Oct., 2011) and 6 d (June, 2012)

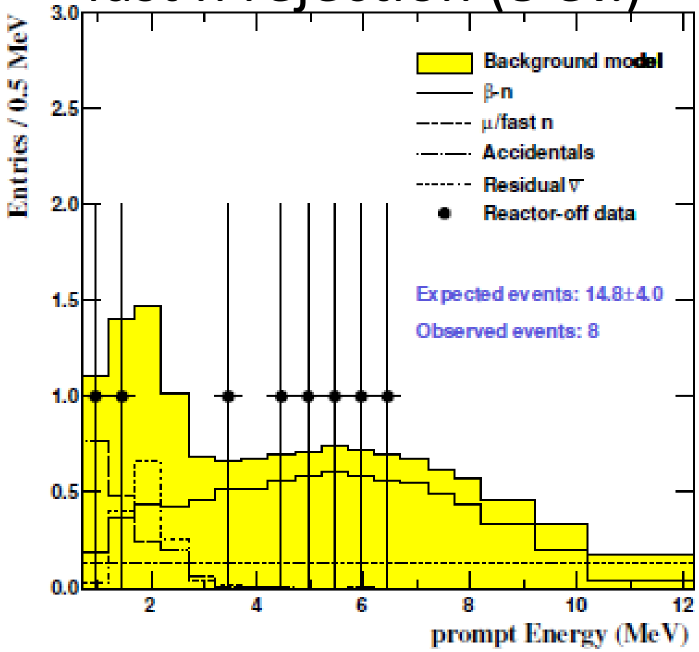
Totally 8 events (1.2 ± 0.4 ev./d),
expected 2.2 ± 0.6 ev./d

Spectra measured at off-off

DC-I cuts w/o Li and fast n rejection (21 ev.)

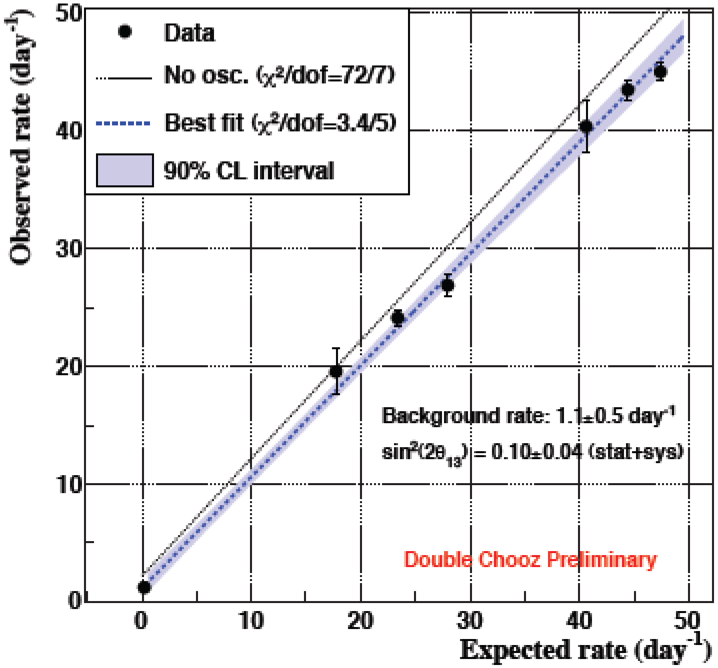


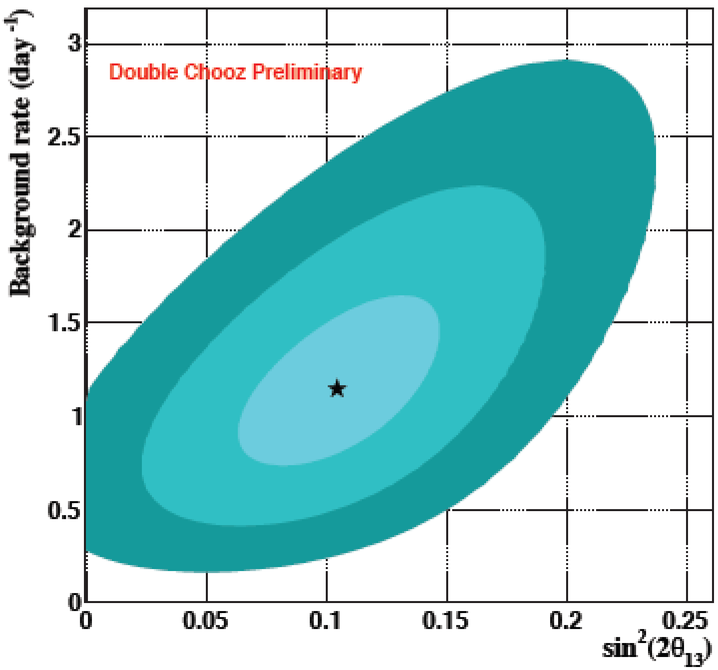
DC-II cuts with Li and fast n rejection (8 ev.)



Phys. Rev. D 87, 011102 (2013)

Reactor rate modulation





Gd-Analysis 8249 neutrino events. 227.93 days.

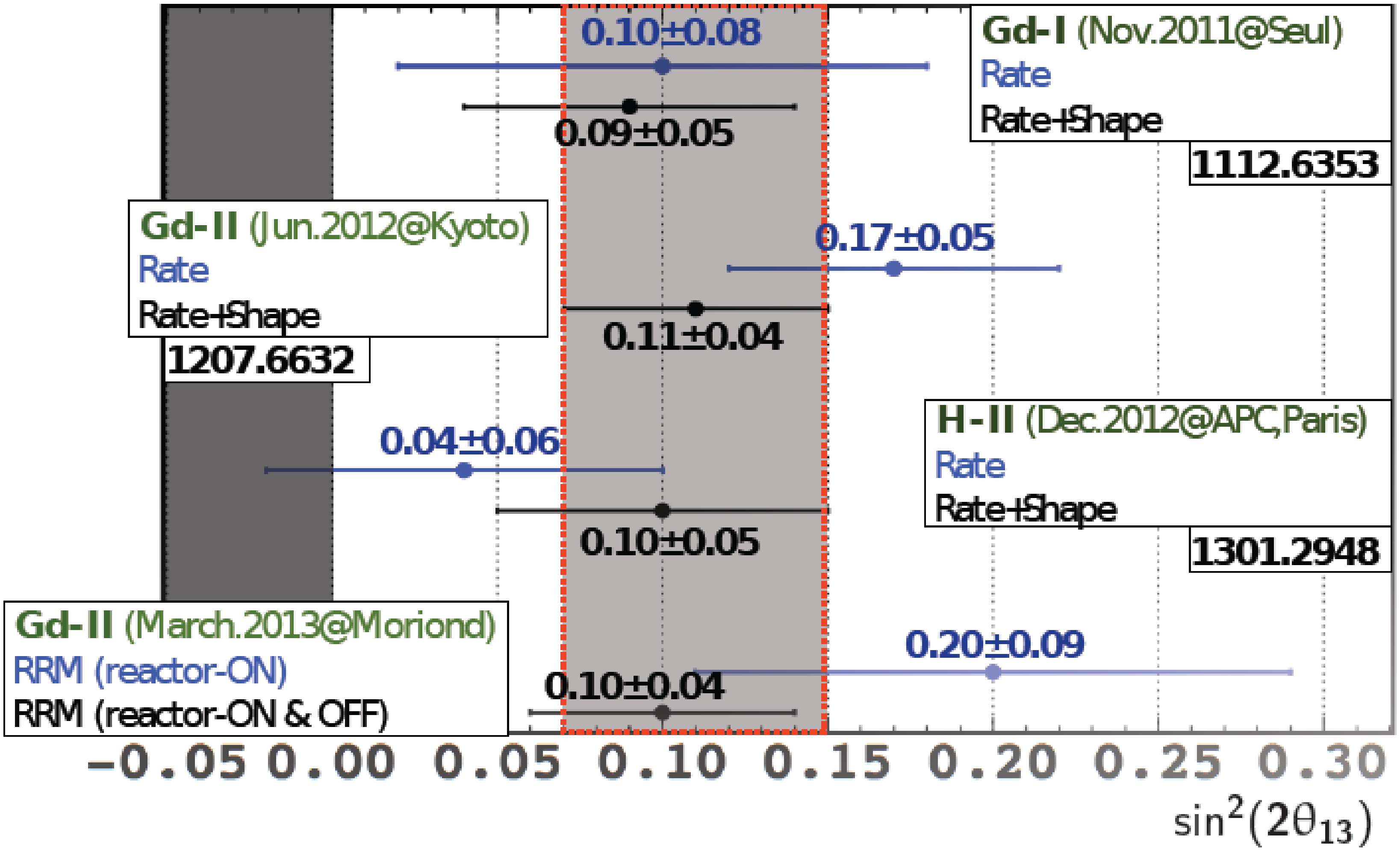
$\sin^2 2\theta_{13} = 0.10 \pm 0.04$

H-Analysis 36284 neutrino events. 240.06 days

$\sin^2 2\theta_{13} = 0.13 \pm 0.07$

Same results as Rate + Shape

Progress in measurement θ_{13} by DC



Near detector laboratory start data taking at 2014

Distance 415 m, overburden 115 m.w.e.

Conclusion and outlook

- Till 2014 Double Chooz woks in phase I (only far detector)
- First observation of effect from θ_{13}

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

$\sin^2 2\theta_{13}$ = 0.097 ± 0.034 (stat.) ± 0.034 (syst.)

- Careful measurement of backgrounds due to the periods when both reactors were OFF
- From 2014 – phase II (far + near detectors). Decrease of uncertainty at least factor 3.