The Double Chooz reactor neutrino experiment

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On behalf of
the Double Chooz collaboration

Neutrino Oscillation

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

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

Atmospheric

$\nu_\mu \to \nu_\mu$

Super-K+K2K+MINOS

$\sin^2 \vartheta_{23} = 0.50^{+0.08}_{-0.07}$

$\Delta m^2_{23} = \left(2.5^{+0.20}_{-0.25}\right) \times 10^{-3}\, eV^2$

Reactor etc.

CHOOZ
$\sin^2(2\theta_{13}) < 0.15$

+

Recent T2K, MINOS results

Solar

$\nu_e \to \nu_x$

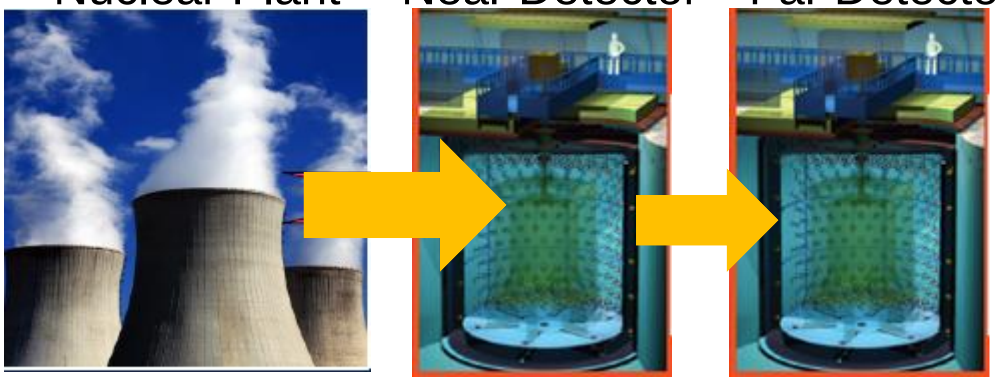
Solar+KamLAND

$\sin^2 \vartheta_{12} = 0.30^{+0.02}_{-0.03}$

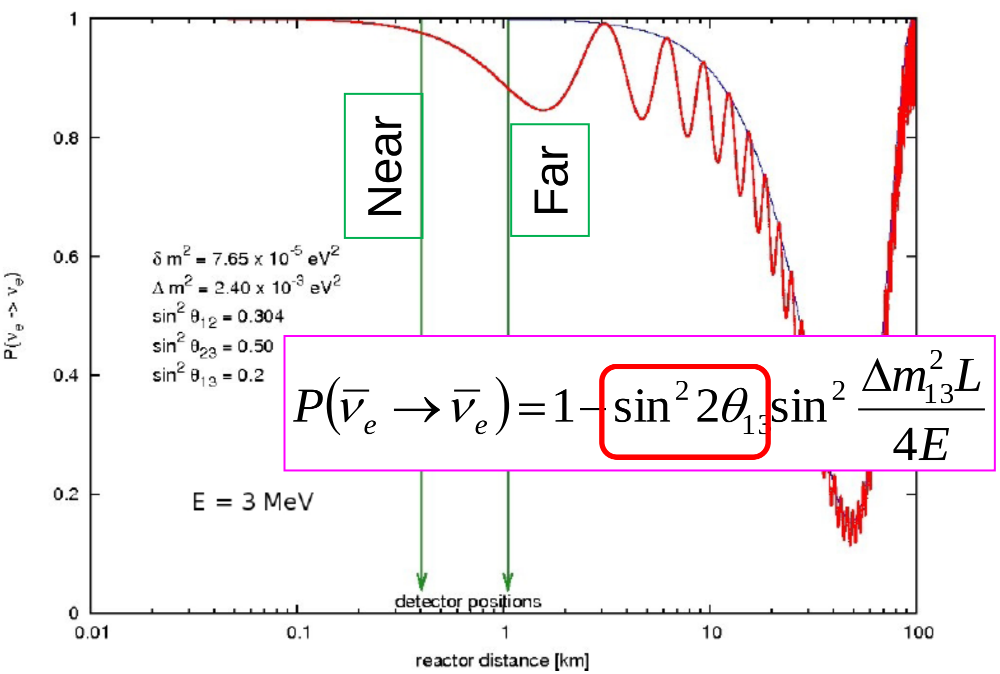
$\Delta m^2_{12} = (7.9 \pm 0.3) \times 10^{-5}\, eV^2$

- Remaining parameters ➔ θ_{13} , CP-violating phase δ, Mass hierarchy

Reactor Neutrino Experiment w/ multi detectors



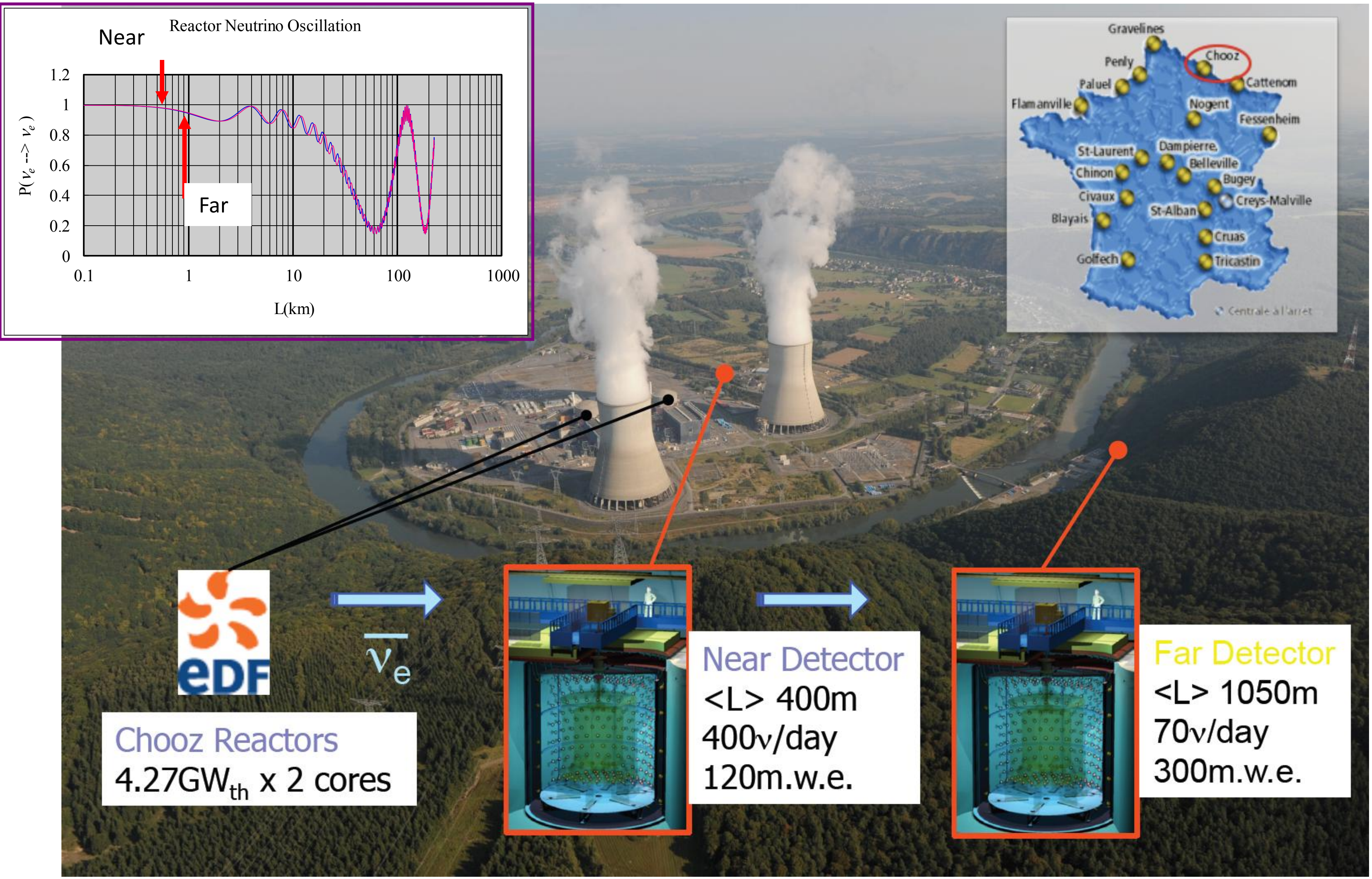
- Reactor ➔ Intense nu source
- Pure θ13 measurement
  - ✓Independent from CP-violating phase δ
  - ✓ Small matter effect
- Multi detector concept
  - ✓ Significant reduction of systematic errors



$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{13}^2 L}{4E}$$

	Uncertainty	Chooz	DC
	Statistical	**2.8%**	**0.4%**
Reactor	Flux, σ	1.9 %	<0.1 %
Reactor	E/fission	0.6 %	<0.1 %
Reactor	power	0.7 %	<0.1 %
Detector	# protons	0.8 %	0.2 %
Detector	Det.eff.	1.5 %	0.5 %
	Σ System.	**2.7 %**	**~ 0.6%**

Double Chooz Experiment



Double Chooz Collaboration

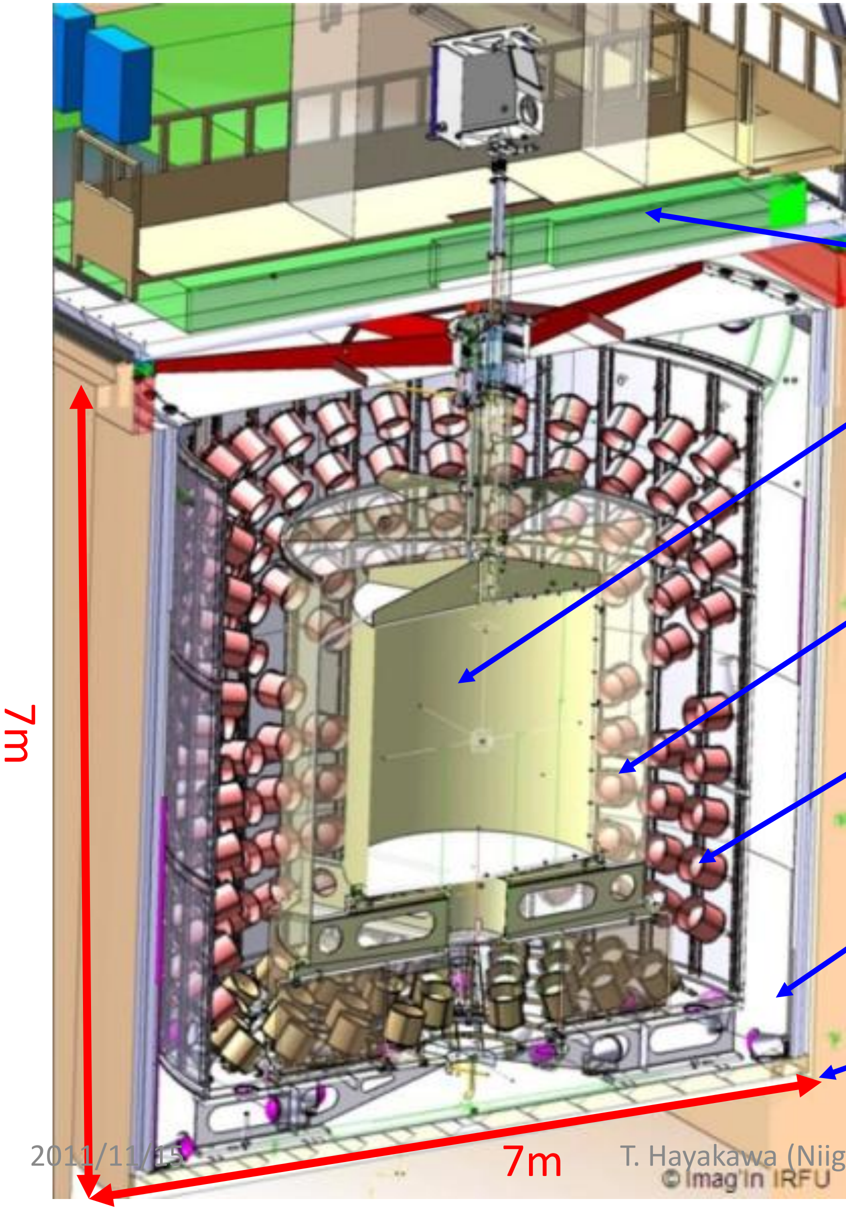
Brazil	France	Germany	Japan	Russia	Spain	UK	USA
CBPF UNICAMP UFABC	APC CEA/DSM/IRFU: SPP SPhN SEDI SIS SENAC CNRS/IN2P3: Subatech IPHC ULB	EKU Tübingen MPIK Heidelberg TU München U. Aachen U. Hamburg	Tohoku U. Tokyo Inst. Tech. Tokyo Metro. U. Niigata U. Kobe U. Tohoku Gakuin U. Hiroshima InstTech.	INR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

Spokesperson: H. de Kerret (CNRS/IN2P3-APC)

Project Manager: Ch. Veyssière (CEA-Saclay)

Web Site: www.doublechooz.in2p3.fr/

Double Chooz Detector



New 4-region large detector concept

Outer Veto: plastic scintillator strips (400 mm-t)

ν-Target: 10.3 m^3 scintillator doped with 0.1g/l of Gd in an acryclic vessel (8 mm-t)

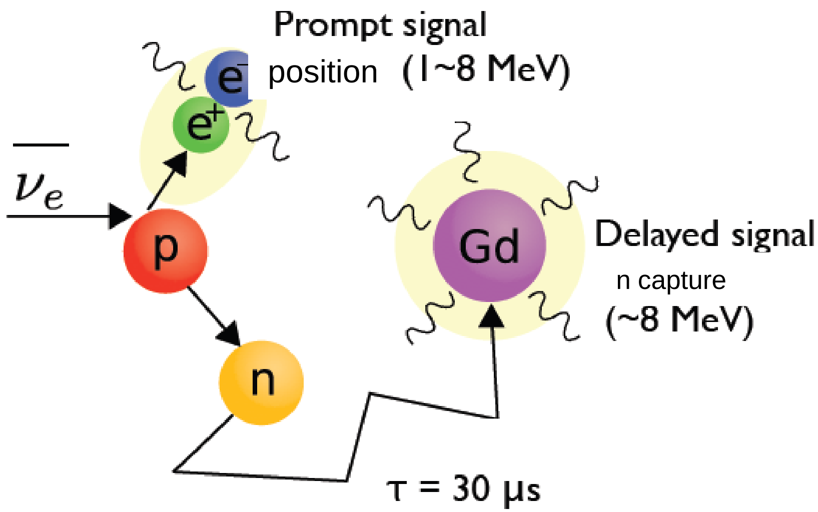
γ-Catcher: 22.3 m^3 scintillator in an acrylic vessel (12 mm-t)

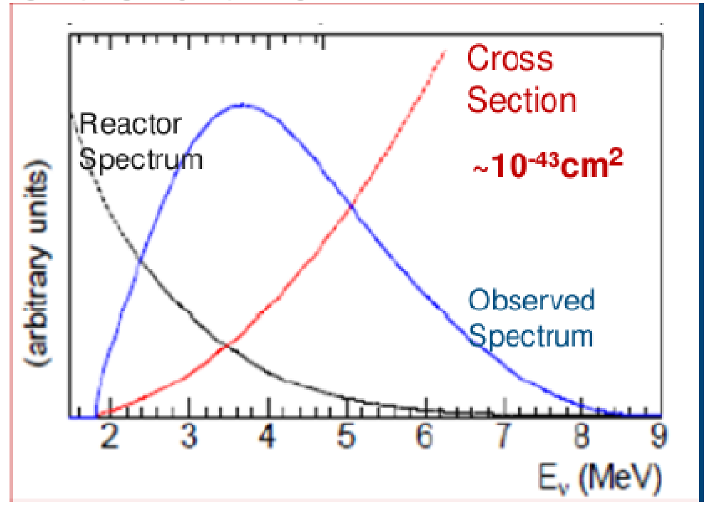
Buffer: 110 m^3 of mineral oil in a stainless steel vessel (3 mm) viewed by 390 PMTs

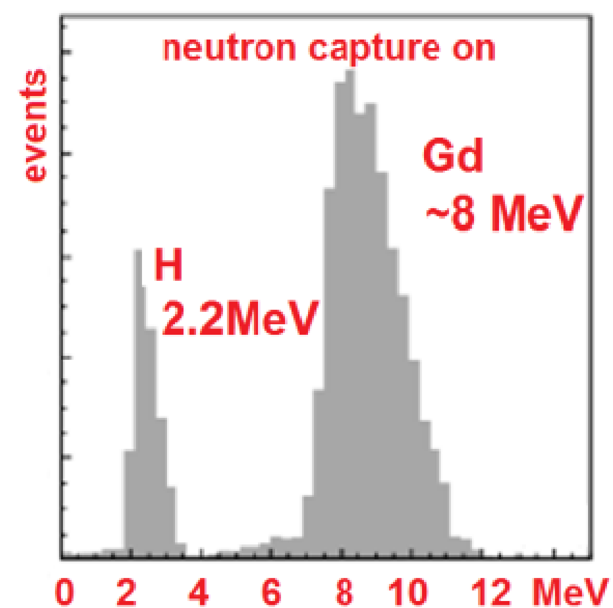
Inner Veto: 90m^3 of scintillator in a steel vessel equipped with 78 PMTs

Veto Vessel (10mm) & Steel Shielding

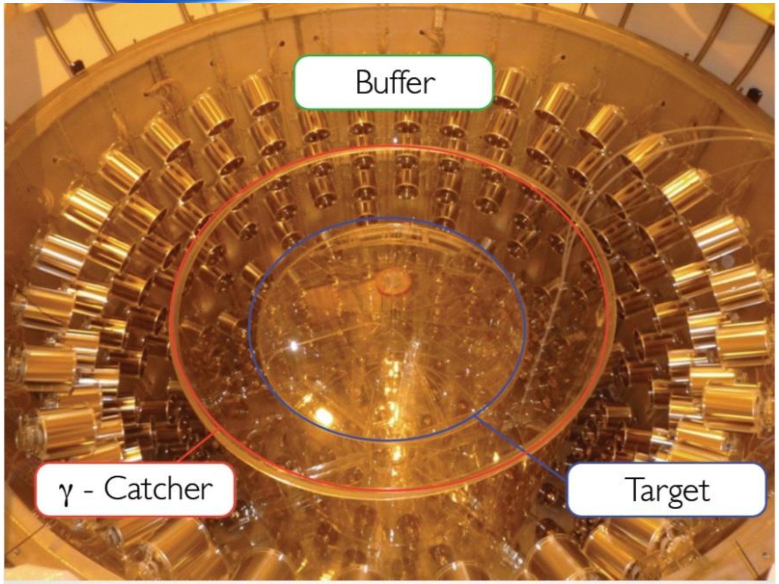
Neutrino Detection





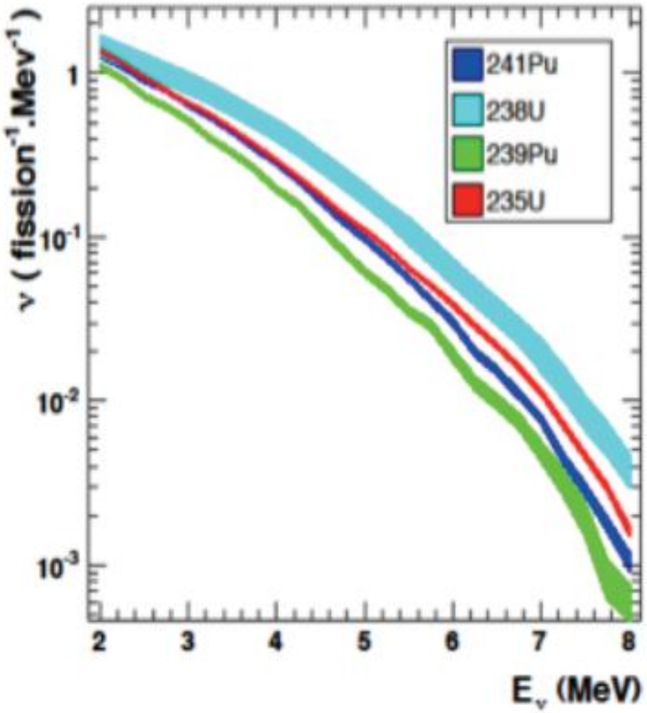


Milestones



- May 2008 - October 2010
  Far detector construction.
- December 2010
  Far detector filling completed.
- April 2011
  Far detector commissioned.
- April 2011
  - ✓ Start physics data taking with far detector.
  - ✓ Near laboratory construction started.
- July 2011
  Outer veto commissioned.
- November 2011
  FIRST DATA
- June 2012
  Near laboratory expected delivery.
- Beginning 2013
  - ➢ Near detector expected.
  - ➢ Data taking with two detectors.

Reactor Neutrino Flux



- Recent re-evaluations by
- Th.A. Mueller et al, Phys.Rev. C83 (2011) 054615.
- P. Huber, Phys.Rev. C84 (2011) 024617

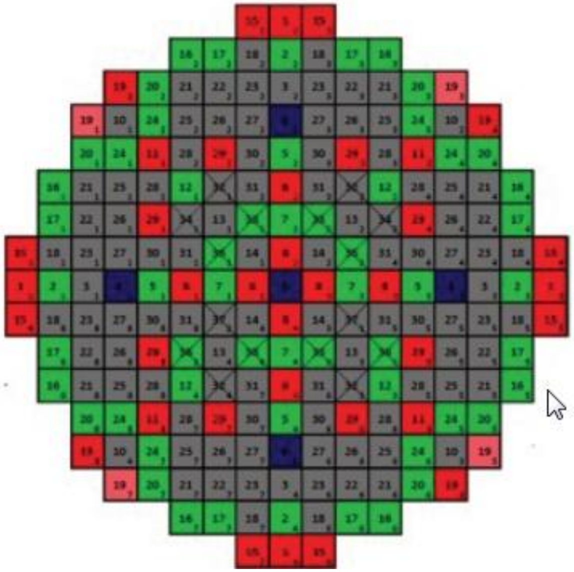
- Off-equilibrium corrections inclulded

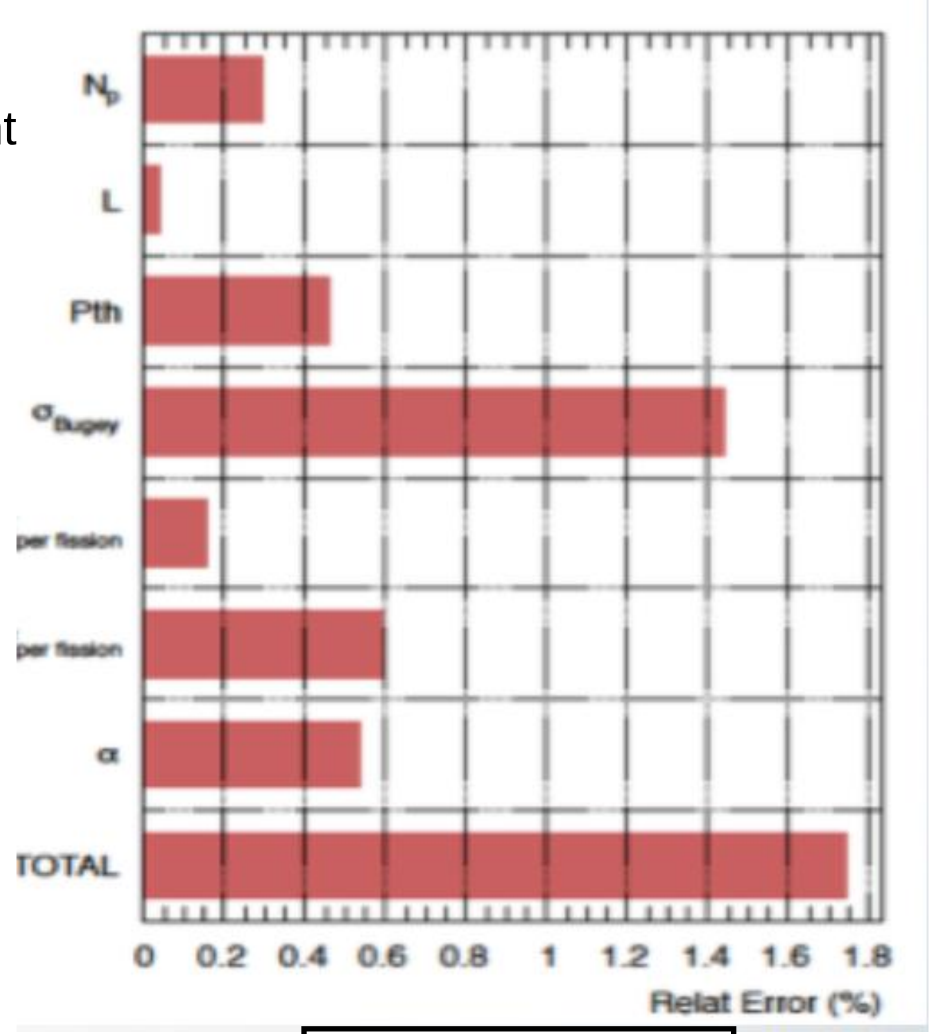
- Recent work defining new reference on the neutrino flux prediction
  - ➔ New flux calculation⟹ +6%
- All reactor neutrino experiment are below
  - ➔ use Bugey4 anchoring (as CHOOZ)⟹ Far phase
  - ➔ use 2 detectors⟹ Near & Far phase

Neutrino Flux Uncertainties

- Total flux uncertainty budget dominated by Bugey4 anchoring point (like in CHOOZ)

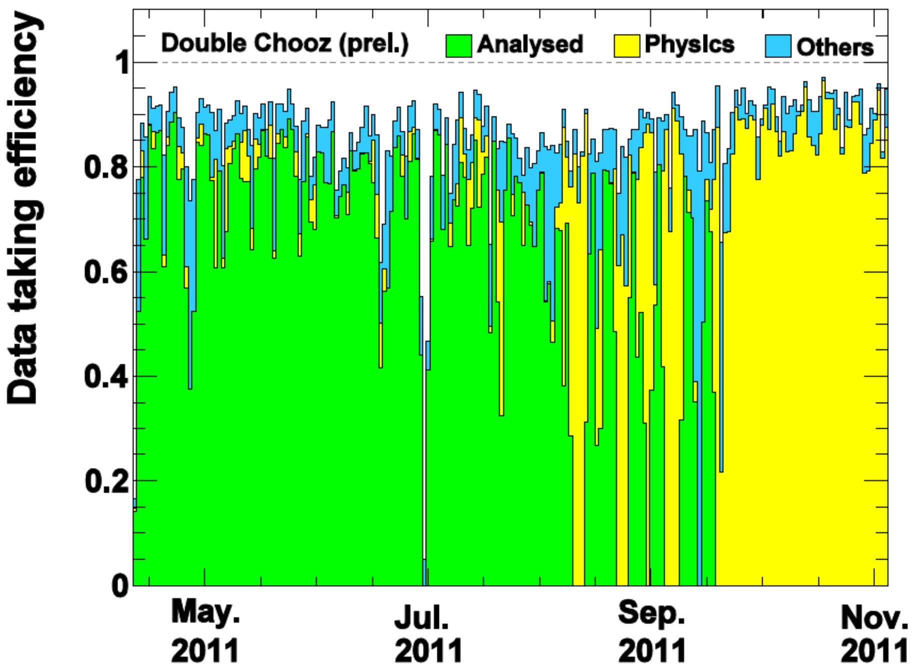
- Very detailed simulation of all reactor cycle (MURE) and fuel evolution [reactor data input]

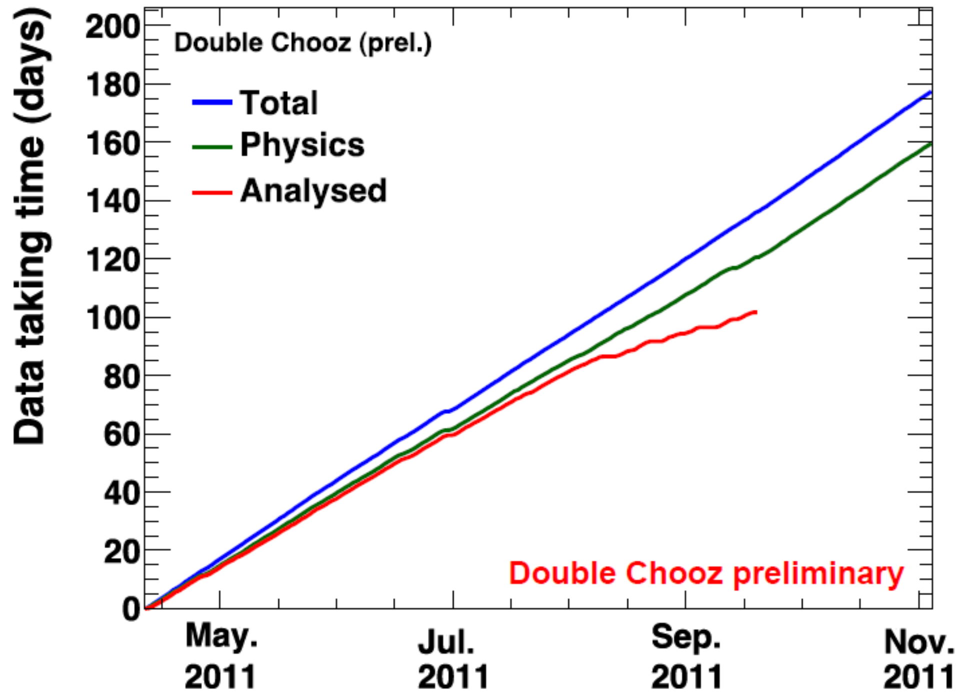




Total error =1.7%

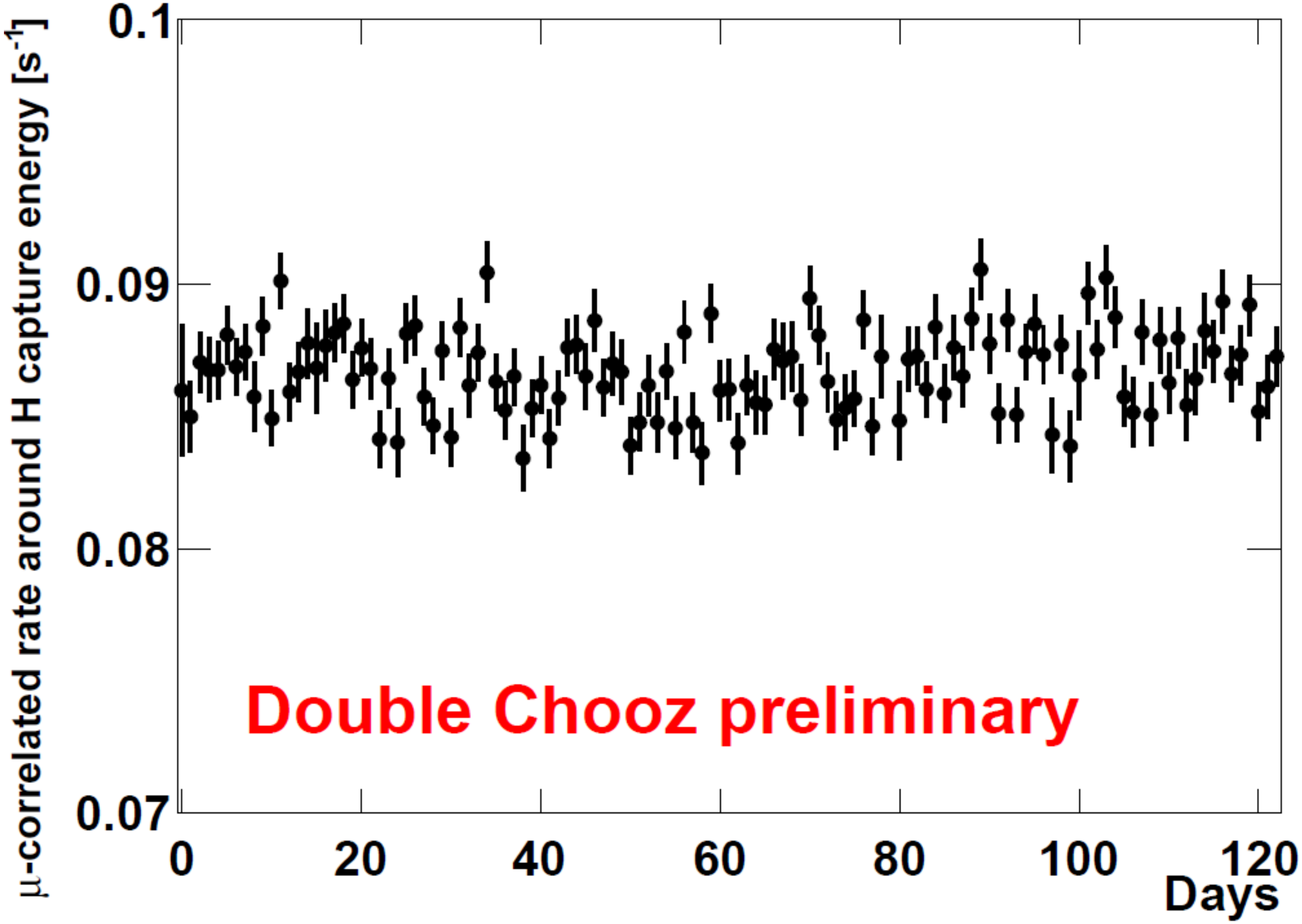
Data taking





- ✓ Number of data taking days : **206 days**
- ✓ Integrated data taking time in total : **177.4 days**
- ✓ Integrated data taking time for physics : **159.6 days**
- ✓ Data taking efficiency in total : **86.2 %**
- ✓ Data taking efficiency for physics : **77.5 %**

Detector Stability



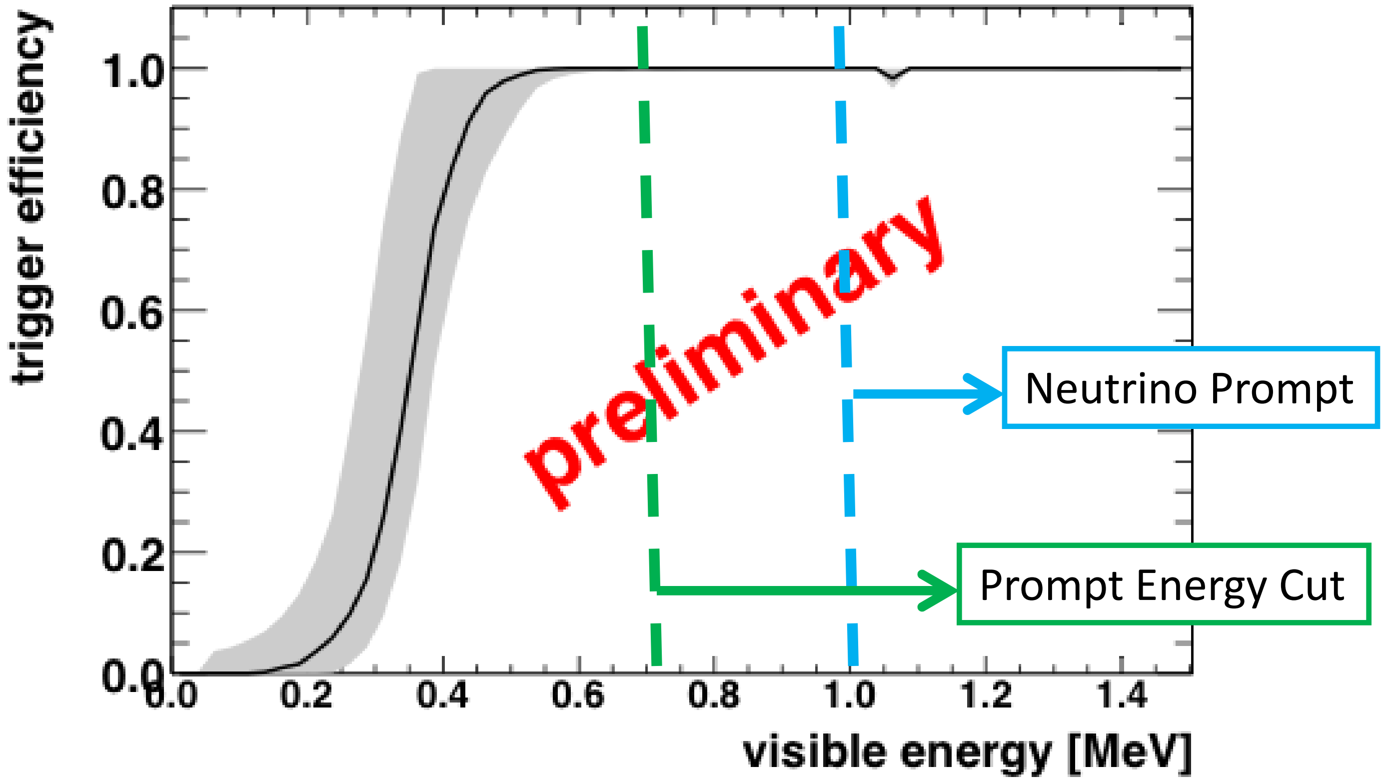
- neutron capture on proton after muon

Neutrino Selection

- Discard all triggers in 1ms after each muon
- PMT spontaneous light emission rejection cuts
  (using ratio Qmax/Qtotal, RMS of hit-time per PMT)

- Prompt signal within [0.7,12]MeV
- Delayed signal within [6,12]MeV
- Coincidence window between [2, 100]μs
- Multiplicity condition
  - E>500keV
  - -100μs < dTime < 400μs

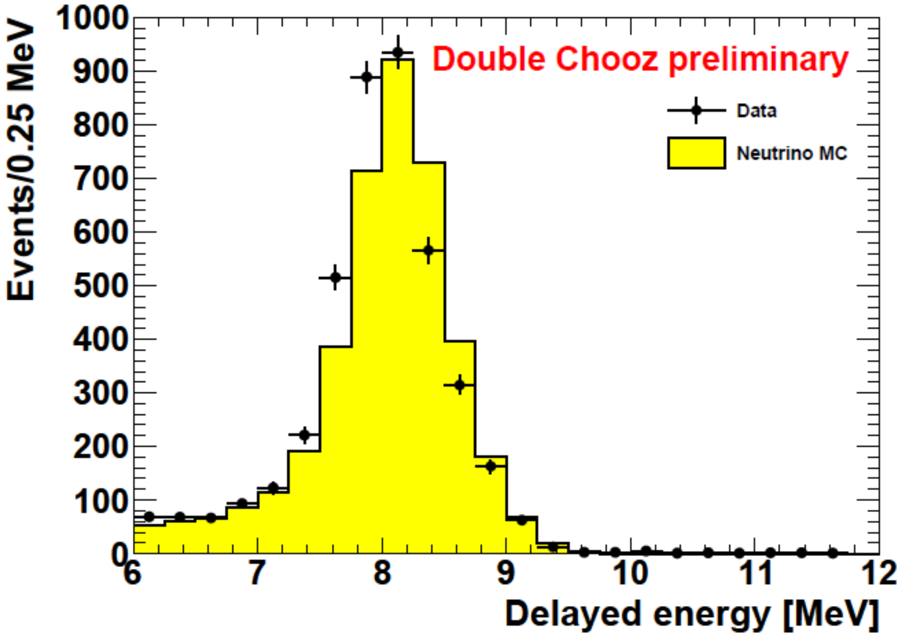
Neutrino Prompt Signal & Trigger Efficiency

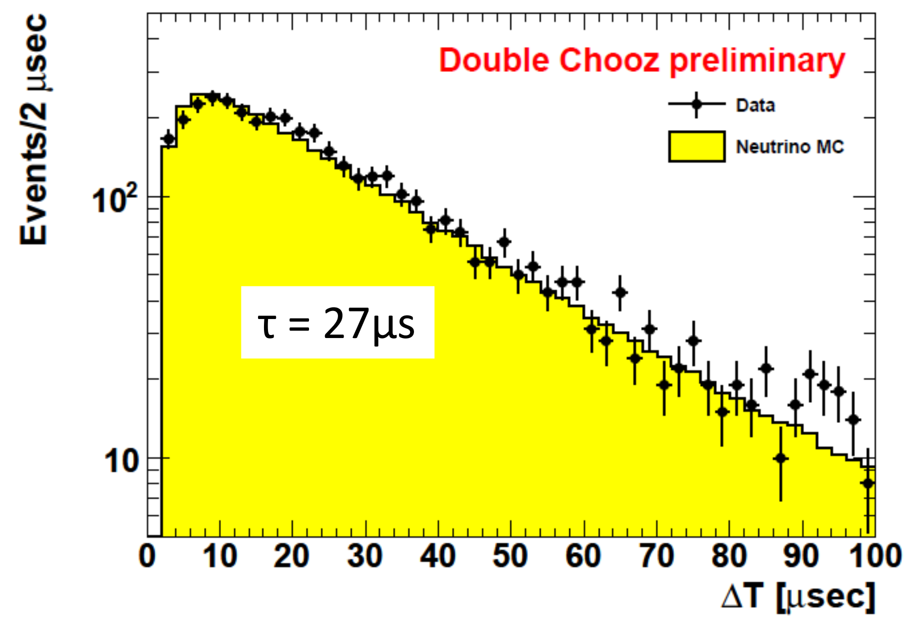


- Trigger threshold (defined as 50% efficiency) is 0.350MeV
- Trigger efficiency is 100% +0/-0.4% above 0.7MeV

➔ No Prompt Energy Cut Inefficiency

Delayed Energy Spectrum & Prompt-Delayed ΔT





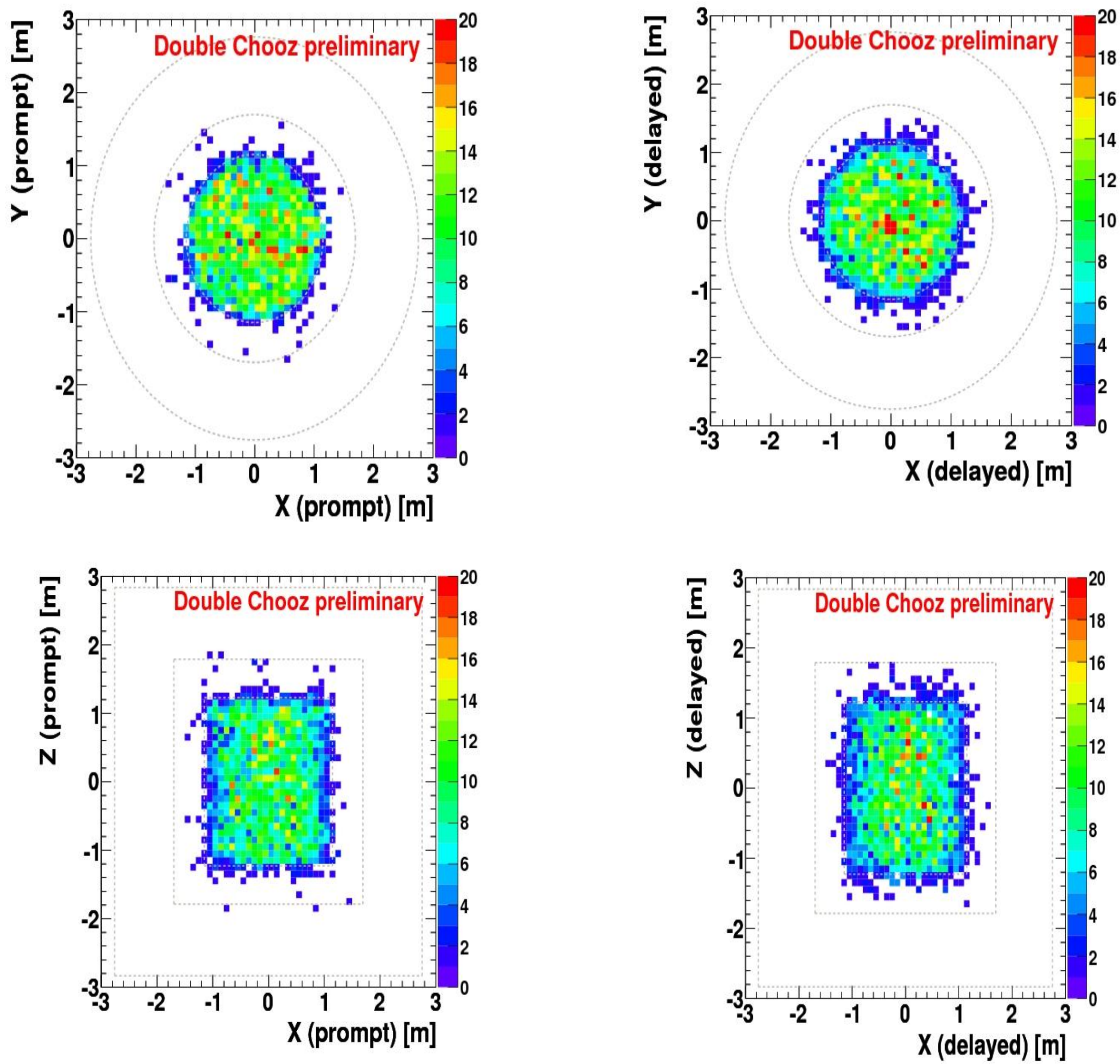
✓Selection of Neutron Capture on Gd only

➔ Allow to define the fiducial volume by the mass of Gd-loaded LS

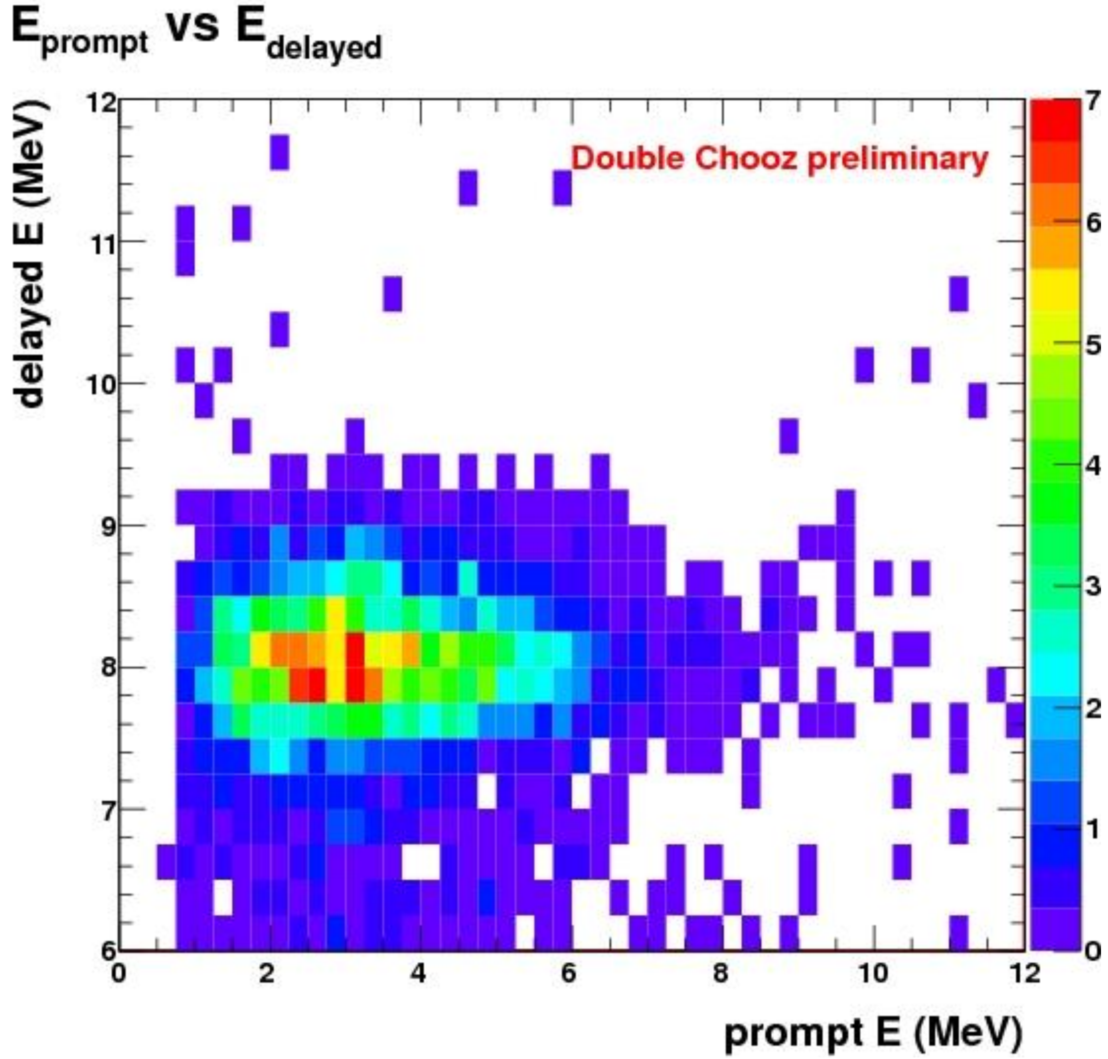
➔ Delayed Energy Cut Efficiency : 0.86 +/- 0.6%.

✓The efficiency within [2,100] μs is 0.965 ± 0.5%

Vertex Reconstruction



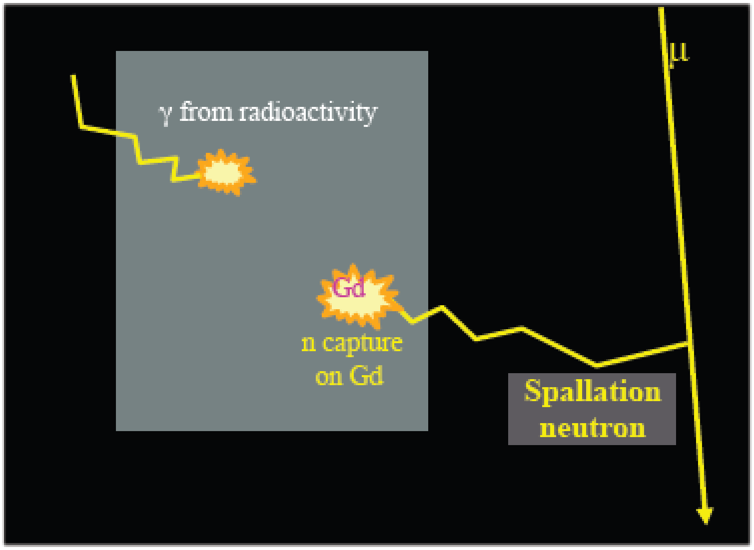
Prompt energy vs Delayed energy

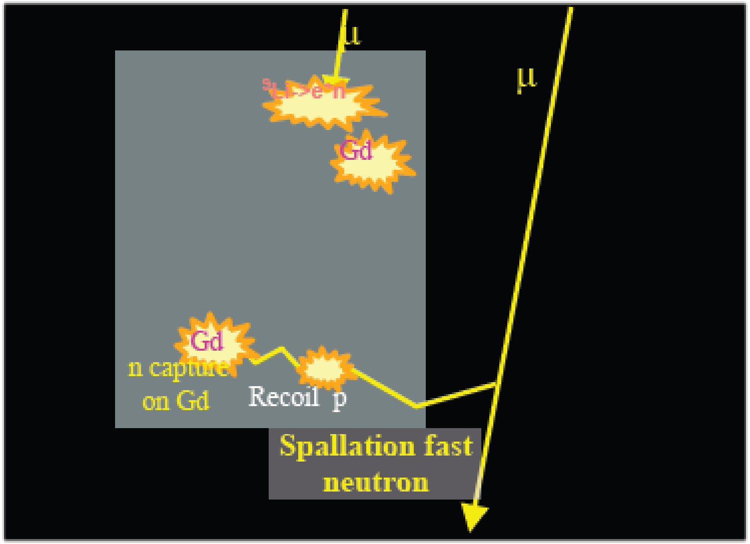


Background

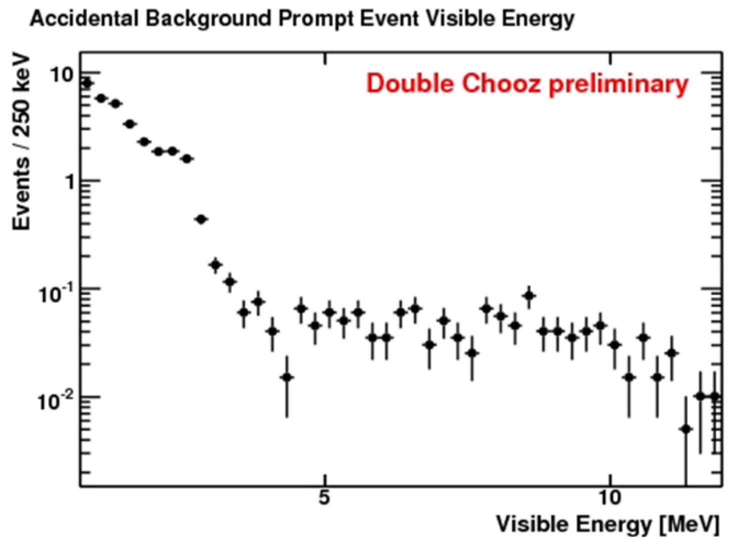
- ☐ Accidental Backgroud
  - ✓ prompt-like signal: radioactivity from materials, PMTs, surrounding rock
  - ✓ n signal: n from cosmic μ spallation,

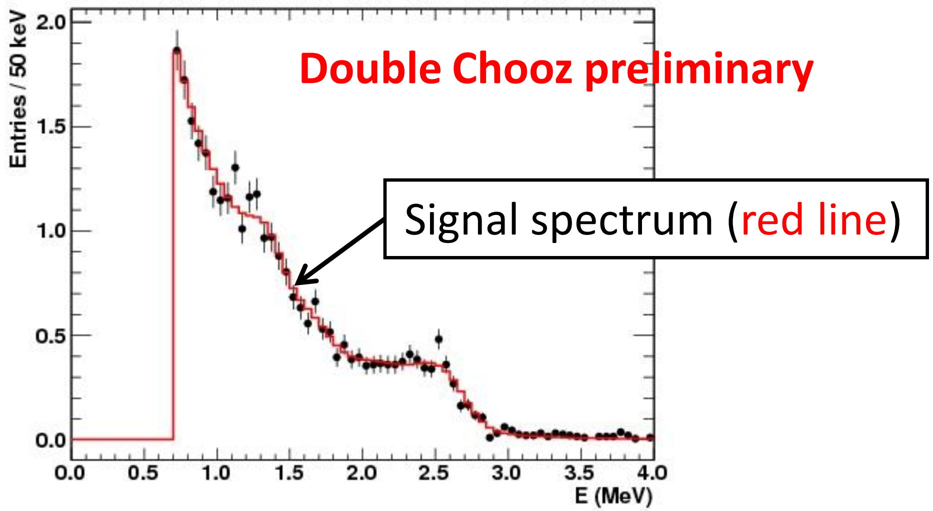
- ☐ Correlated BG
  - ✓ Fast neutrons (by cosmic μ) gives recoil protons and are captured on Gd.
  - ✓ Stopping-muons followed by muon-decay (Michel electron)
  - ✓ Long-lived (9Li, 8He) β+n-decaying isotopes induced by μ.

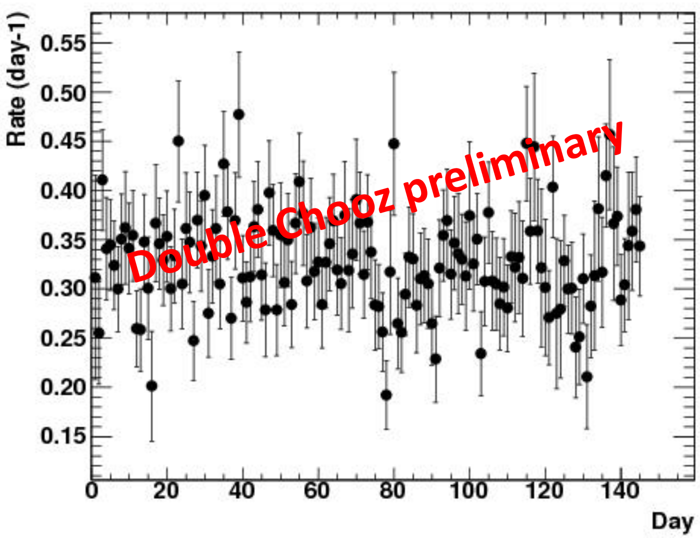




Accidental Background



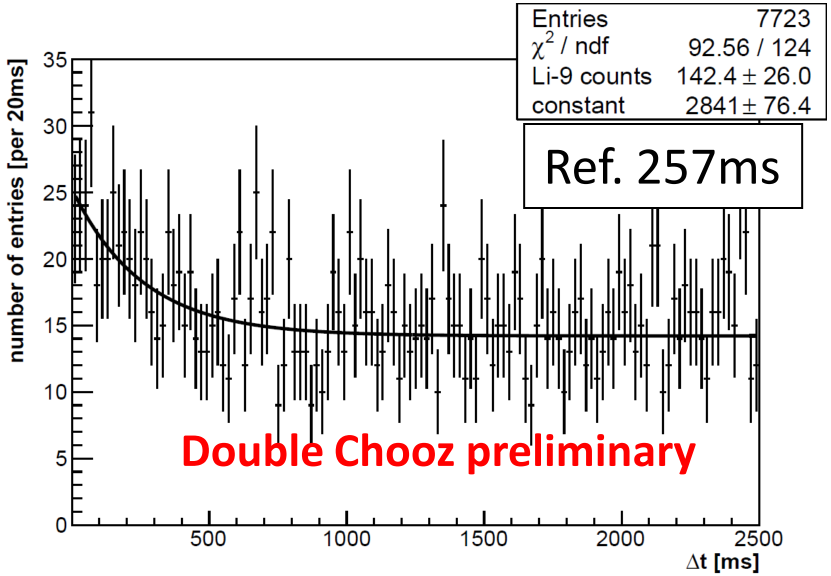


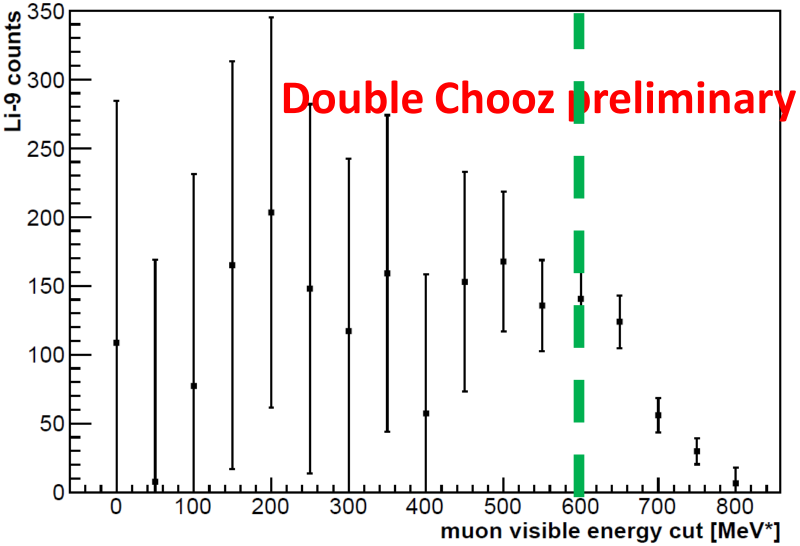


- on time window: [2,100]μsec
- off time window: [1002,1100]μsec

Rate=(0.332±0.004)day-1

9Li/8He Background

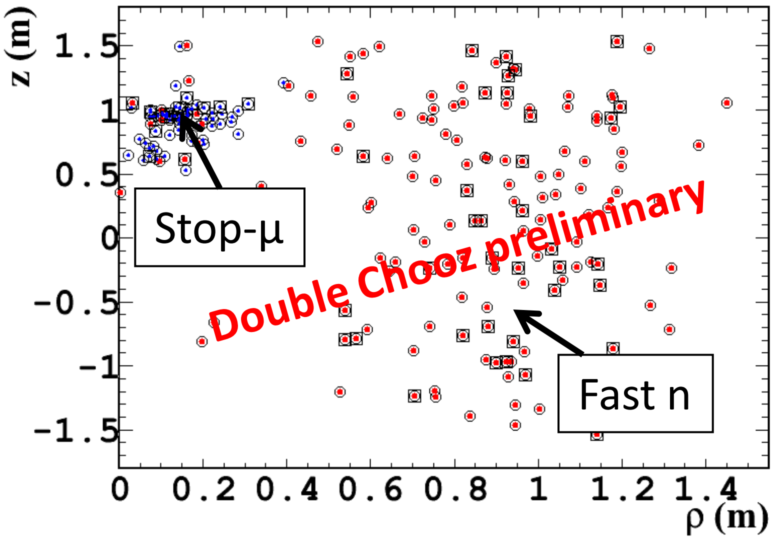


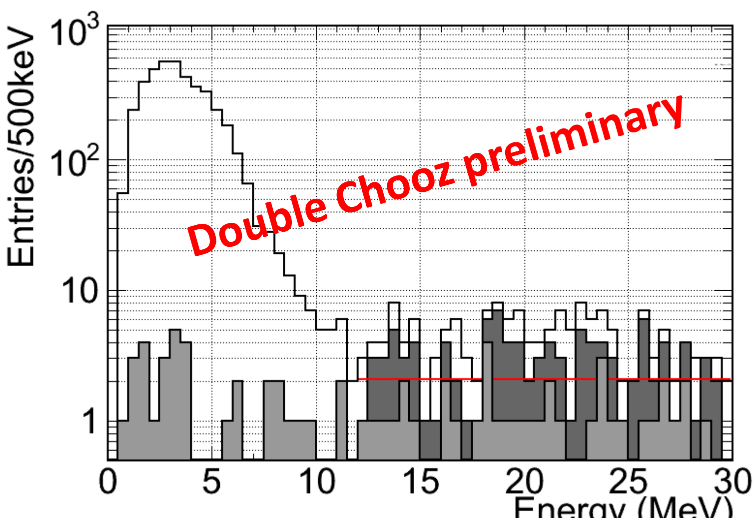


- 9Li events selection:
  - ✓Statistical
  - ✓Search for a triple delayed coincidence between showering muon and neutrino-like coincidence
- Showering muon : E>600 MeV
- Δt between showering muon and prompt event is given by the ^{9}Lilike life time (257ms).

Rate: 2.3 -1.2 +1.2 per Day

Fast Neutron Background

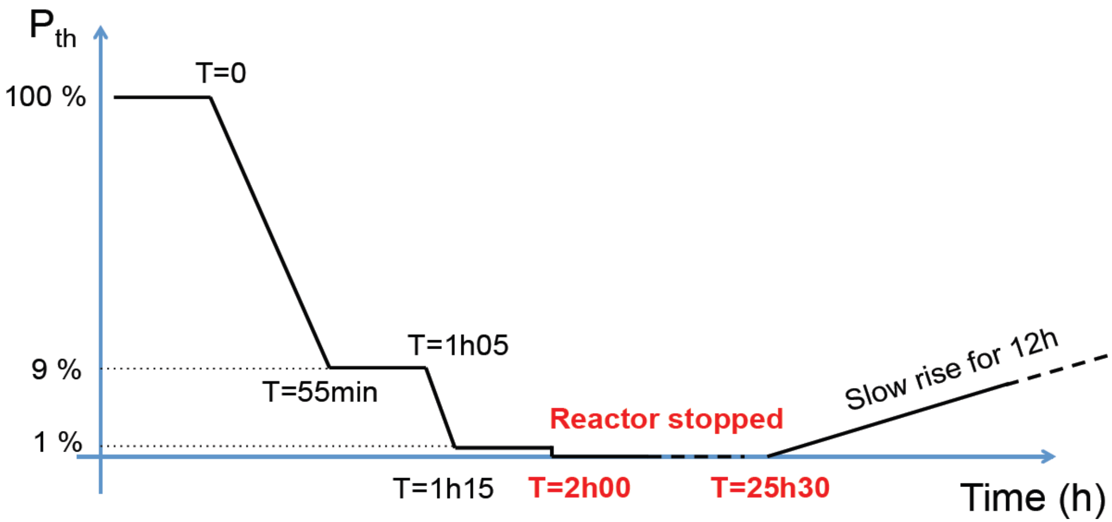


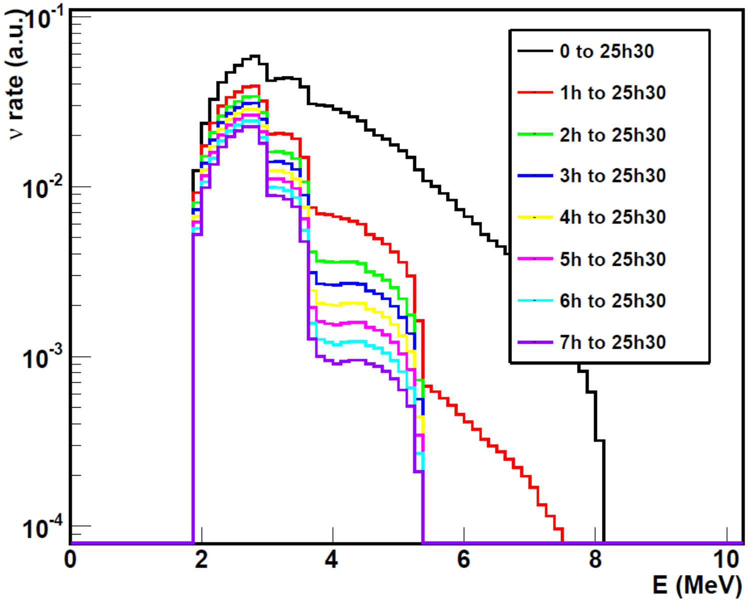


- Neutrino Analysis with prompt energy extended to 30 MeV
- Two populations:
  - ✓ Fast-n
  - ✓ Stopping-muon
- Rate:
  - ✓ Extrapolation from high Energies to lower ones
  - ✓ **0.7 -0.5 +0.5 per Day**
- Spectrum:
  - ✓ Flat
  - ✓+ Stopped Mu Shape Unc.

Rate=0.7 -0.5 +0.5 per Day

Reactor off-off data

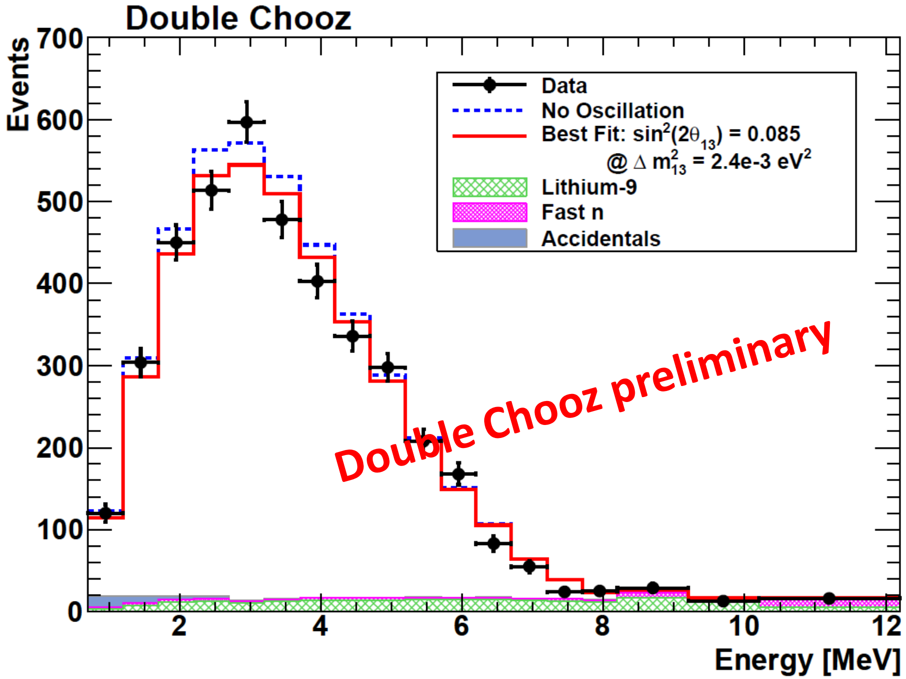


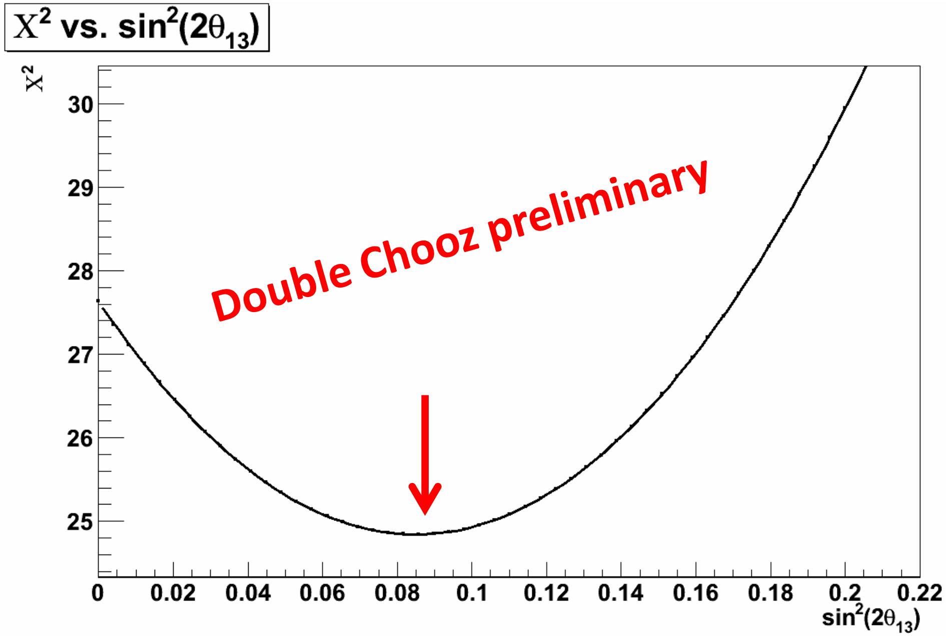


- Second reactor OFF for one day

➔ **3 events <30MeV**
- ✓ two possible Li/He candidates
- ✓ one consistent with stopping-muon candidate

Oscillation Analysis





θ_{13} Preliminary Results

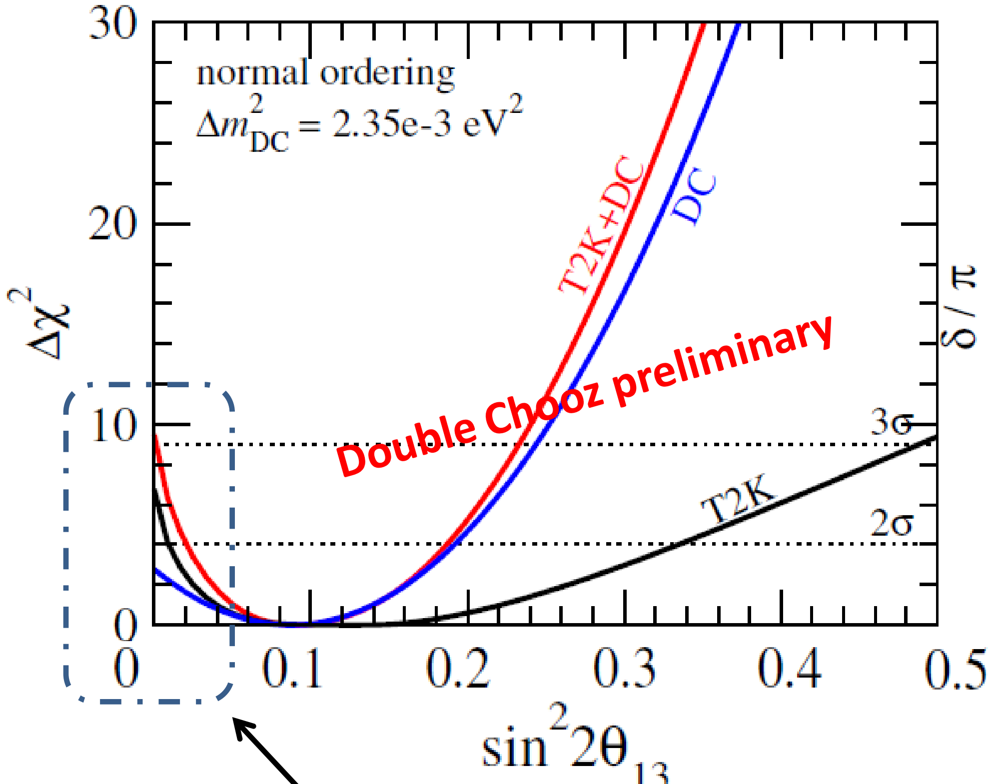
- **Rate + Shape Analysis:**

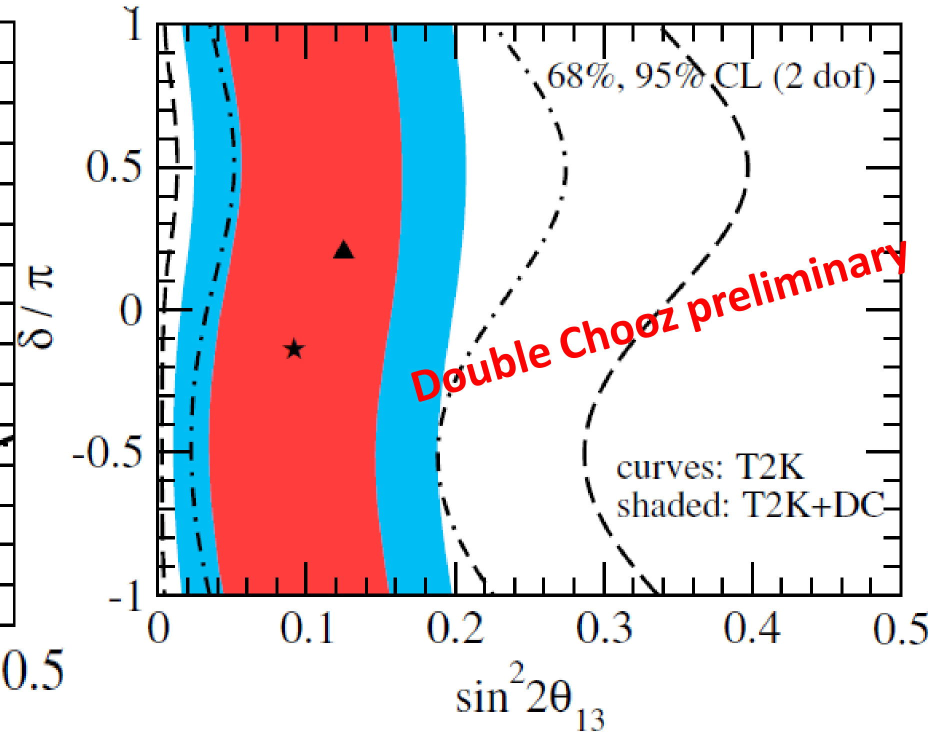
  sin2(2θ13) = 0.085±0.029(stat)±0.042(syst)

- **Rate Only:**

  sin2(2θ13) = 0.093±0.029(stat)±0.073(syst)

DC-T2K combination





Combined best fit point is at 0.092
θ13 = 0 is excluded at 3 sigma from T2K+DC

Conclusions

- Far Detector
  - Data taking since April 2011
  - Report of Analysis of 100 days of data.
  - Hint for positive value of θ13
    - ✓ **$\sin 2(2\theta_{13}) = 0.085 \pm 0.029(stat) \pm 0.042(syst)$**
    - ✓ **No-Oscillation excluded at 92.1% CL**

- Near Detector
  - Detector completed until end of 2012
  - Far + Near detector data taking:
    Beginning of 2013