Double Chooz: first result on θ_{13}

Alberto Remoto

neutrino oscillation overview

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

atmospheric $\mathrm{P}(\nu_\mu \to \nu_\mu)$ | **reactor + accelerator** $\mathrm{P}(\nu_e \to \nu_e)$ & $\mathrm{P}(\nu_\mu \to \nu_e)$ | **solar** $\mathrm{P}(\nu_e \to \nu_x)$

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

$\sin^2\theta_{23} = 0.42^{+0.08}_{-0.03}$

$\Delta m^2_{23} = (2.35^{+0.12}_{-0.09}) \times 10^{-3} eV^2$

T2K & MINOS + Double Chooz

$\sin^2\theta_{12} = 0.306^{+0.018}_{-0.015}$

$\Delta m^2_{12} = (7.58^{+0.22}_{-0.26}) \times 10^{-5}$

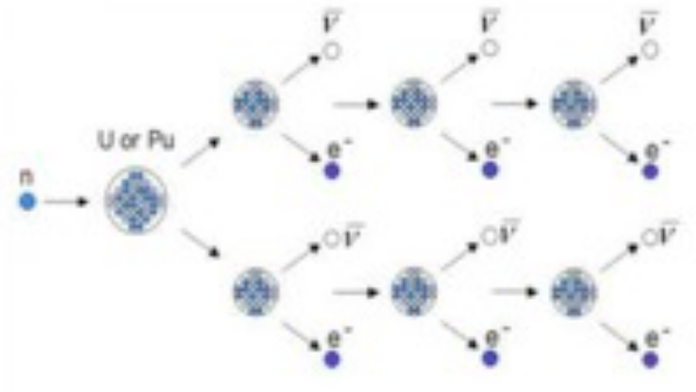
3 Flavour states

Mixing matrix
3 mixing angles, 1 complex phase

3 Mass states
$m_1 \neq m_2 \neq m_3$

- recent result from MINOS & T2K
- hint for $\theta_{13} > 0$ from global analysis (Fogli et al. arXiv:1106.6028v2)
- reactor experiments are complementary:
  - disappearance mode, δ-CP independent, short base line, negligible matter effect

experimental principe



- **use anti-ν_e from β decay from nuclear reactor**
- cheap, pure and isotropic antineutrino flux
- energy range < 10 MeV; mean energy @ 4 MeV
- ~2×10^{20} anti-ν_e s^{-1} per reactor (reactor power ~ 1 GW_{th})

anti-ν_e source

anti-ν_e

no oscillation

near detector

anti-$\nu_{e,\mu,\tau}$

oscillation

far detector

If we measure:

- anti-ν_e spectra @ **near detector**
- anti-ν_e spectra @ **far detector**

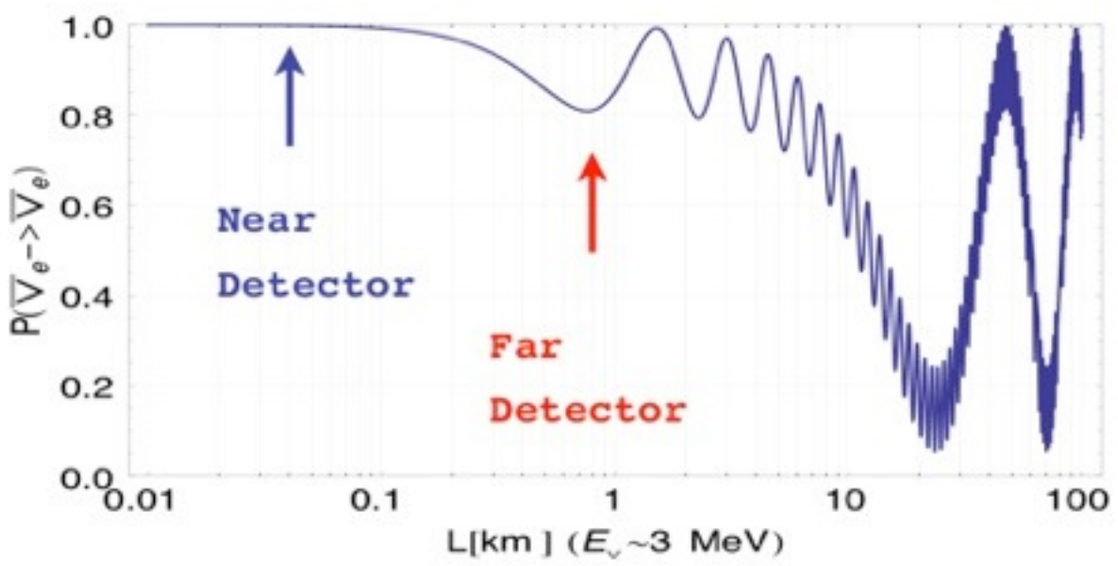
The comparison between them:

- precision measure of θ_{13}

Relative measurement:

- not driven by flux simulation
- improve systematic error (<1%)

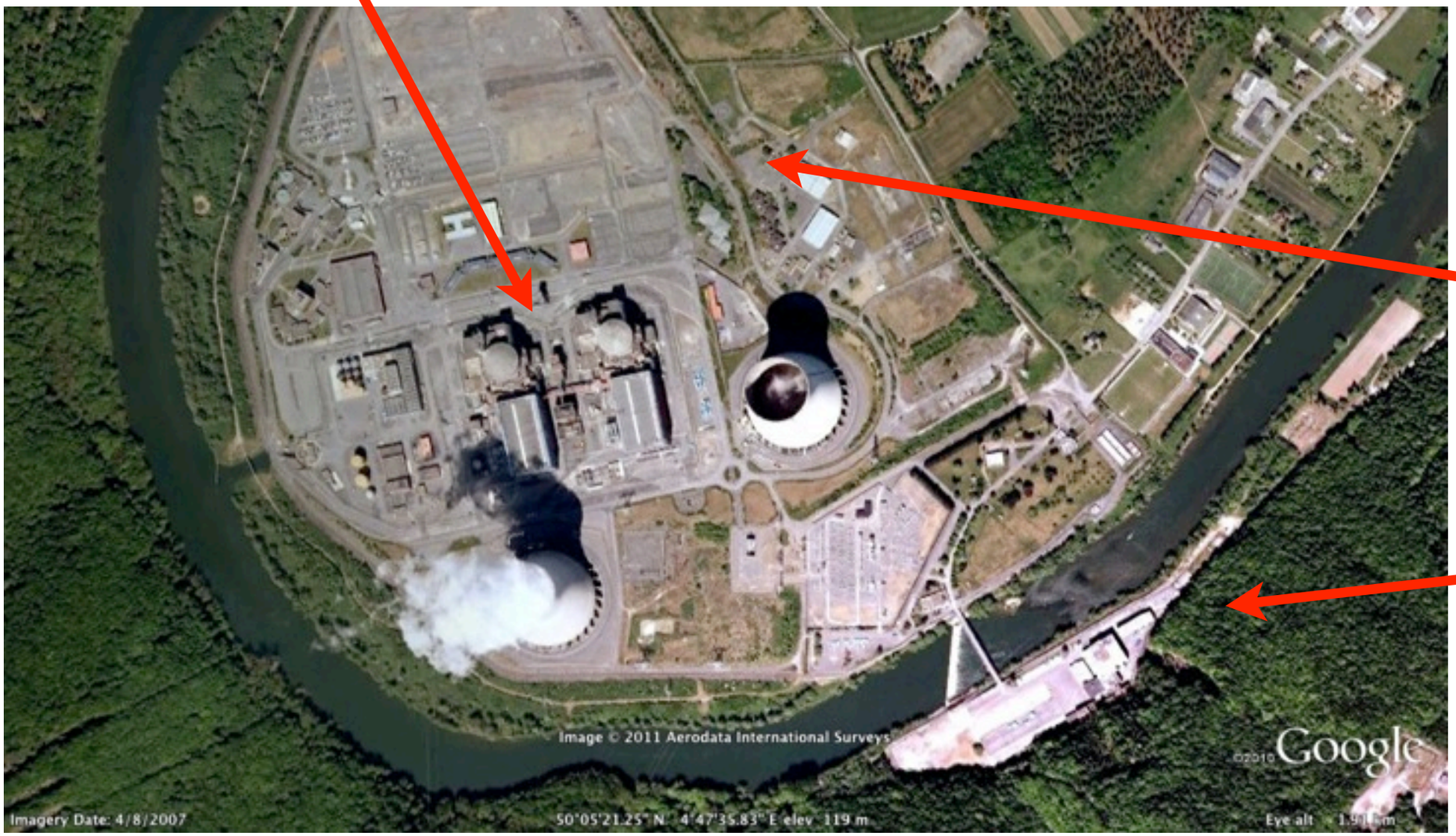
$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{13} L}{4E}\right) + O(\theta^2_{12})$$



experimental setup

Chooz reactors:

Power: 8.5 GW_{th}



Near detector:

distance: ~400 m

overbound: 120 mwe

target: 8.2 t

signal: ~400 ν/d

Far detector:

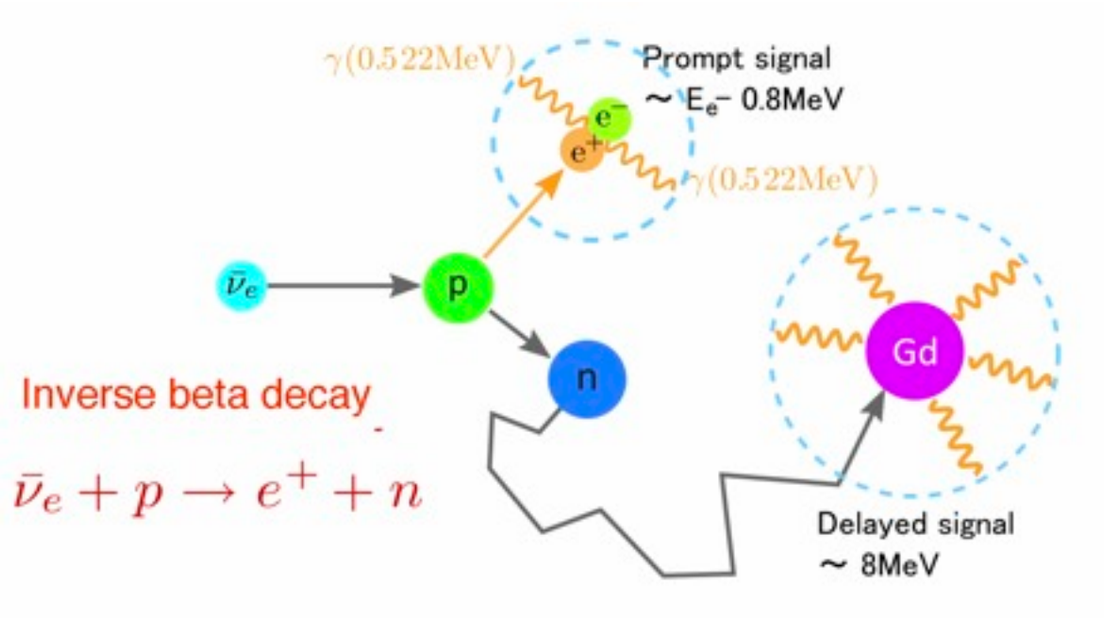
distance: ~1050 m

overbound: 300 mwe

target: 8.2 t

signal: ~50 ν/d

neutrino detection and background



signal: inverse beta decay

- prompt: positron annihilation (E > 1.8 MeV)
- delayed: thermal neutron captured on Gd (E ~ 8 MeV)
- time coincidence (τ~30 μs)

expected signal rate: ~ 50 d^{-1}

background: accidentals

- uncorrelated coincidence between two natural radioactivity events
- reduced by radiopurity of detector components & shielding against natural radioactivity
- rate: ~ 1 d^{-1} (near & far detector)

background: correlated

- fast neutrons induced by muons passing through the surrounding rock
- 9Li/8He isotopes produced by muons showering in the detector
- liquid-scintillator muon veto: tagging “muon” and physics associated to muon at very low threshold (even if muon does not hit detector)
- rate: ~2 d^{-1} (far detector) ~10 d^{-1} (near detector)

the detector

Calibration Glove-Box :

Outer Veto :
Scintillator panels

Target : 10,3 m^3
LS; 80% $C_{12}H_{26}$ + 20% PXE +0,1% Gd
+ PPO + Bis-MSB

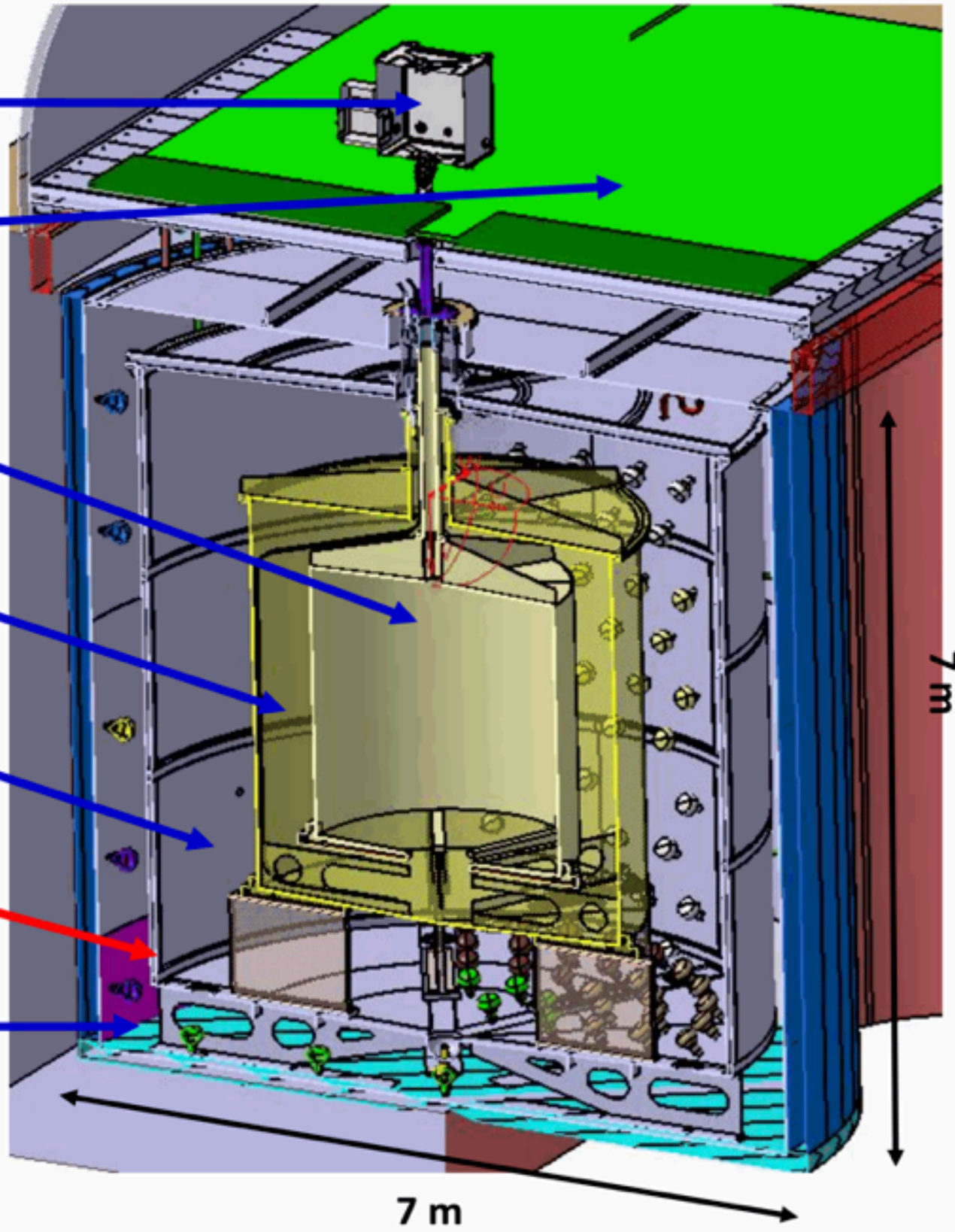
Catcher : 22,6 m^3
LS; 80% $C_{12}H_{26}$ + 20% PXE + PPO + Bis-MSB

Non scintillating Buffer : 114 m^3
mineral oil

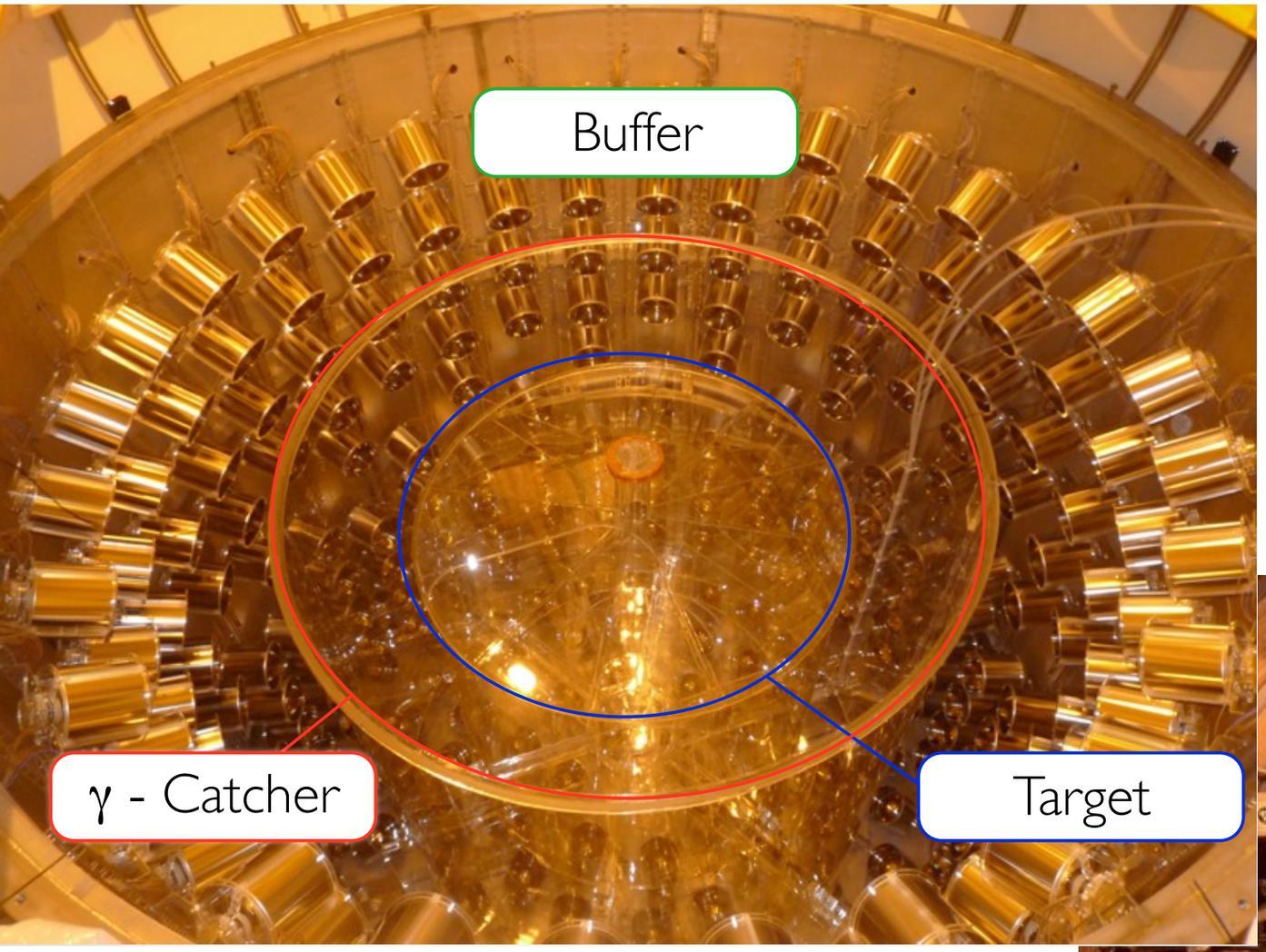
Buffer vessel & 390 10'' PMTs :
Stainless steel 3 mm

Inner Muon Veto : 90 m^3
mineral oil + 70 8'' PMTs

Steel Shielding :
17 cm steel, All around



the detector



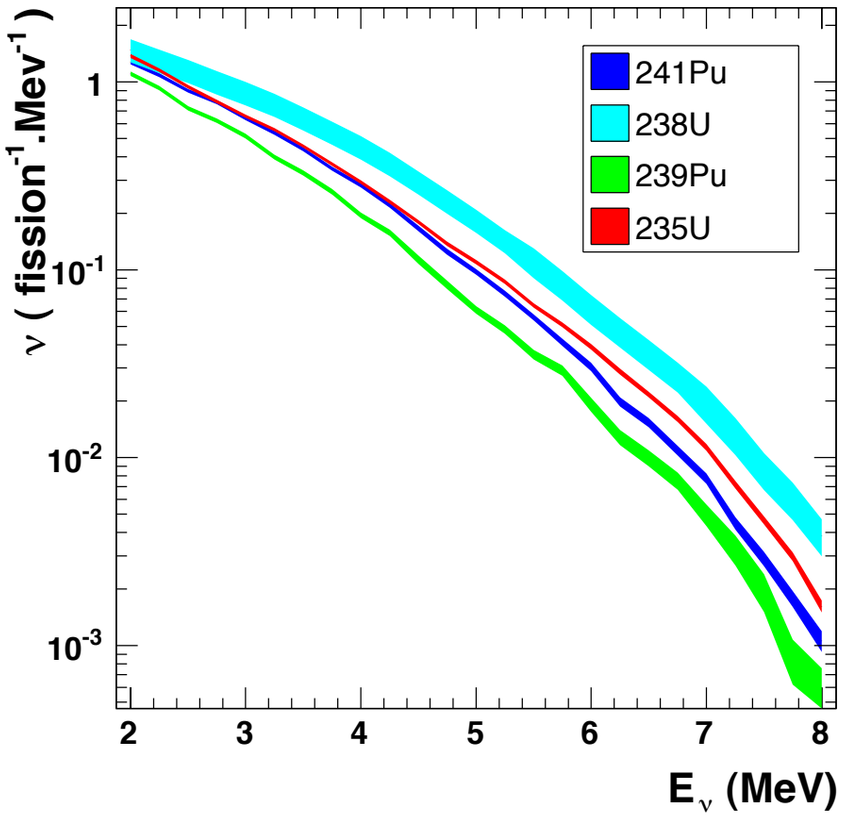
far detector:

- filled on december 2010
- commissioned on march 2011
- taking data from april 2011
- first data release on november 2011

near detector:

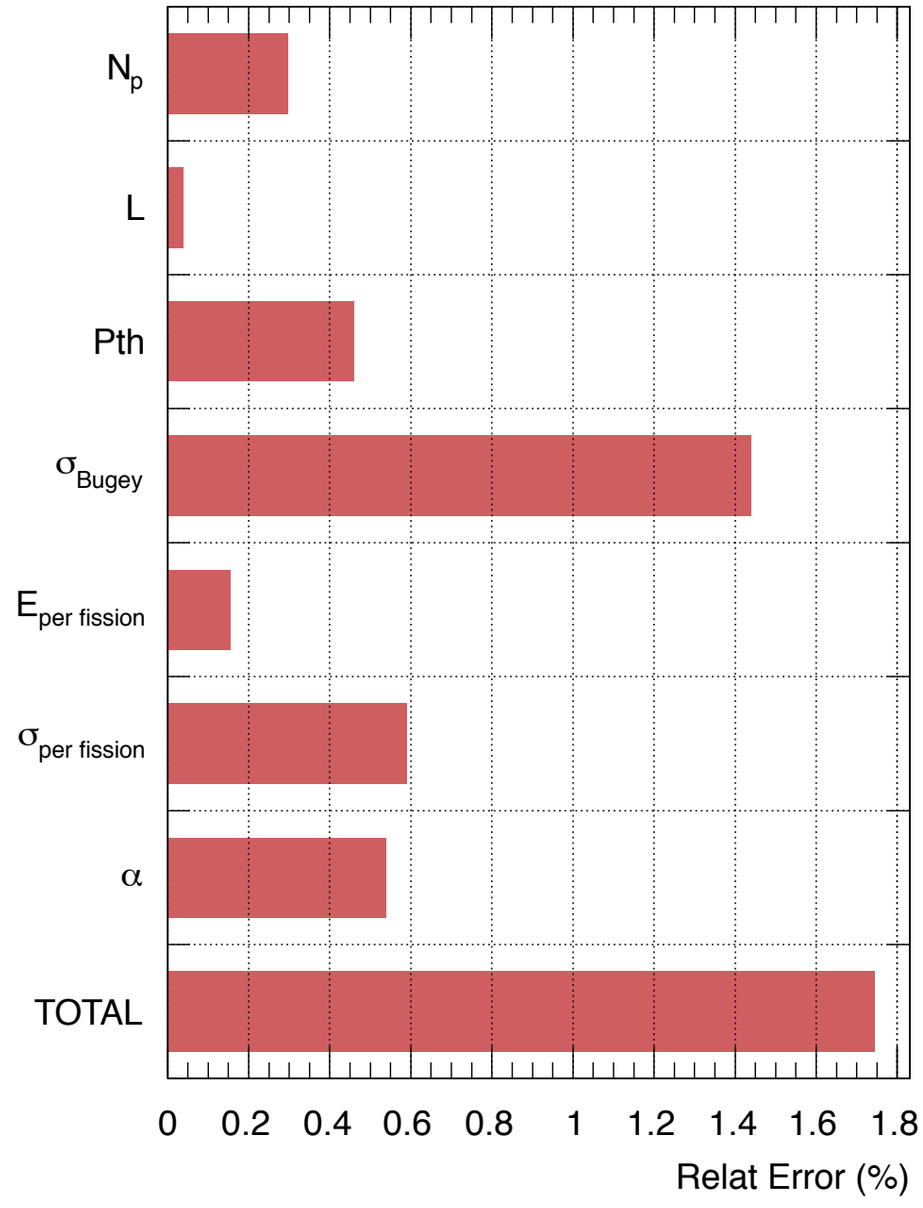
- lab. construction started in april 2011
- lab. deliver expected on june 2012
- near detector expected beginning 2013

reactor antineutrino flux



- Recent re-evaluation of antineutrino reference spectrum:
  - Th.A. Mueller et al. Pys.Rev. C83 (2011) 054615
  - P. Huber C84 (2011) 024617
- evolution of reactor core composition from accurate simulation
- Bugey-4 spectrum normalization
  - like a “cheap” ND (with ND: error <1%)
- 1.7% total systematic error

phase 1 Far detector only: antineutrino flux expectation form simulation is needed!



more details on reactor antineutrino flux this afternoon by Anthony Onillon

data taking statistics

Far detector taking regular data since 13th April 2011:

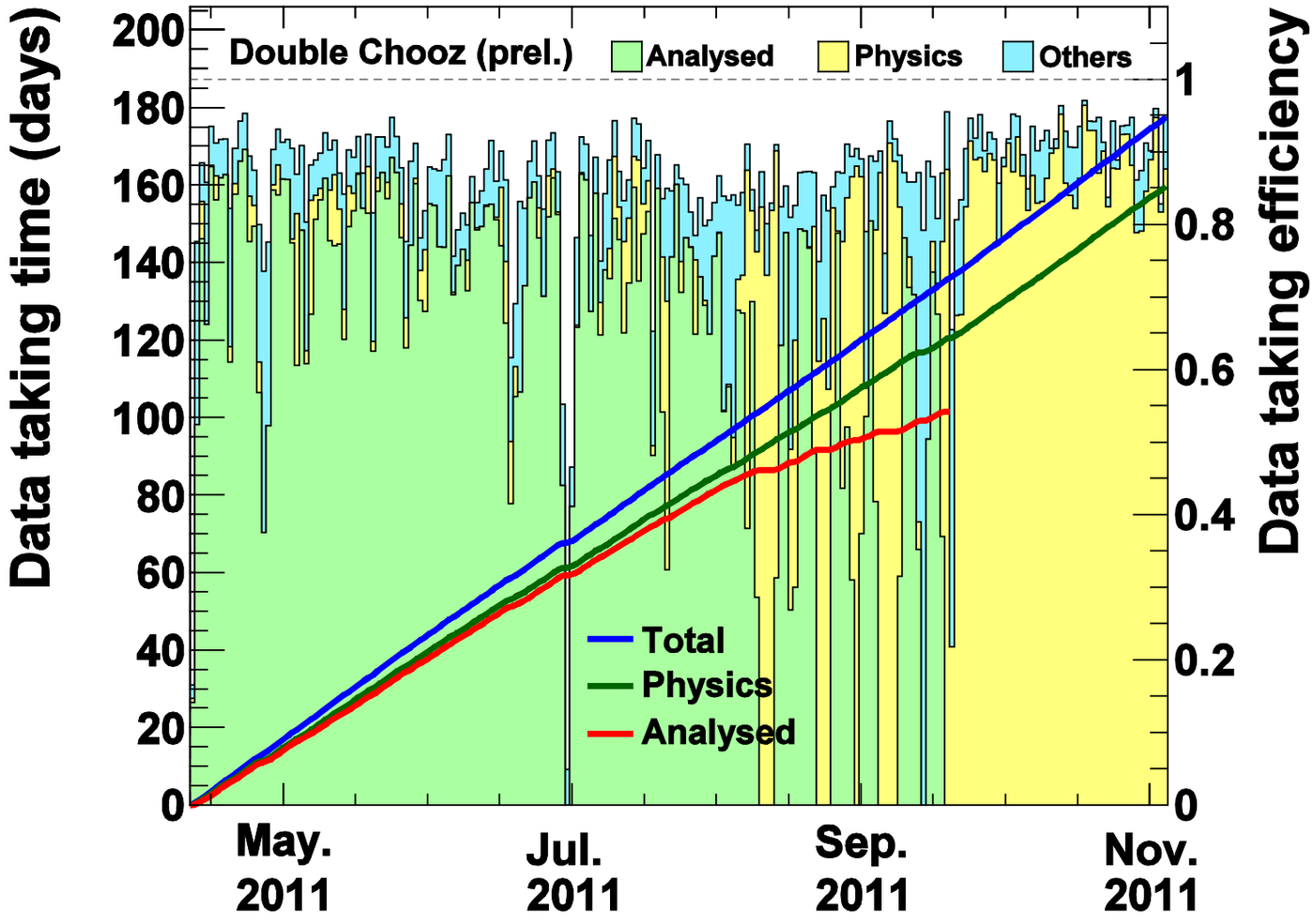
- Stable detector since data taking has started

From 13th April to 4th November:

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

Analysed data fraction:

- **101.5 days** from April 13th to September 18th



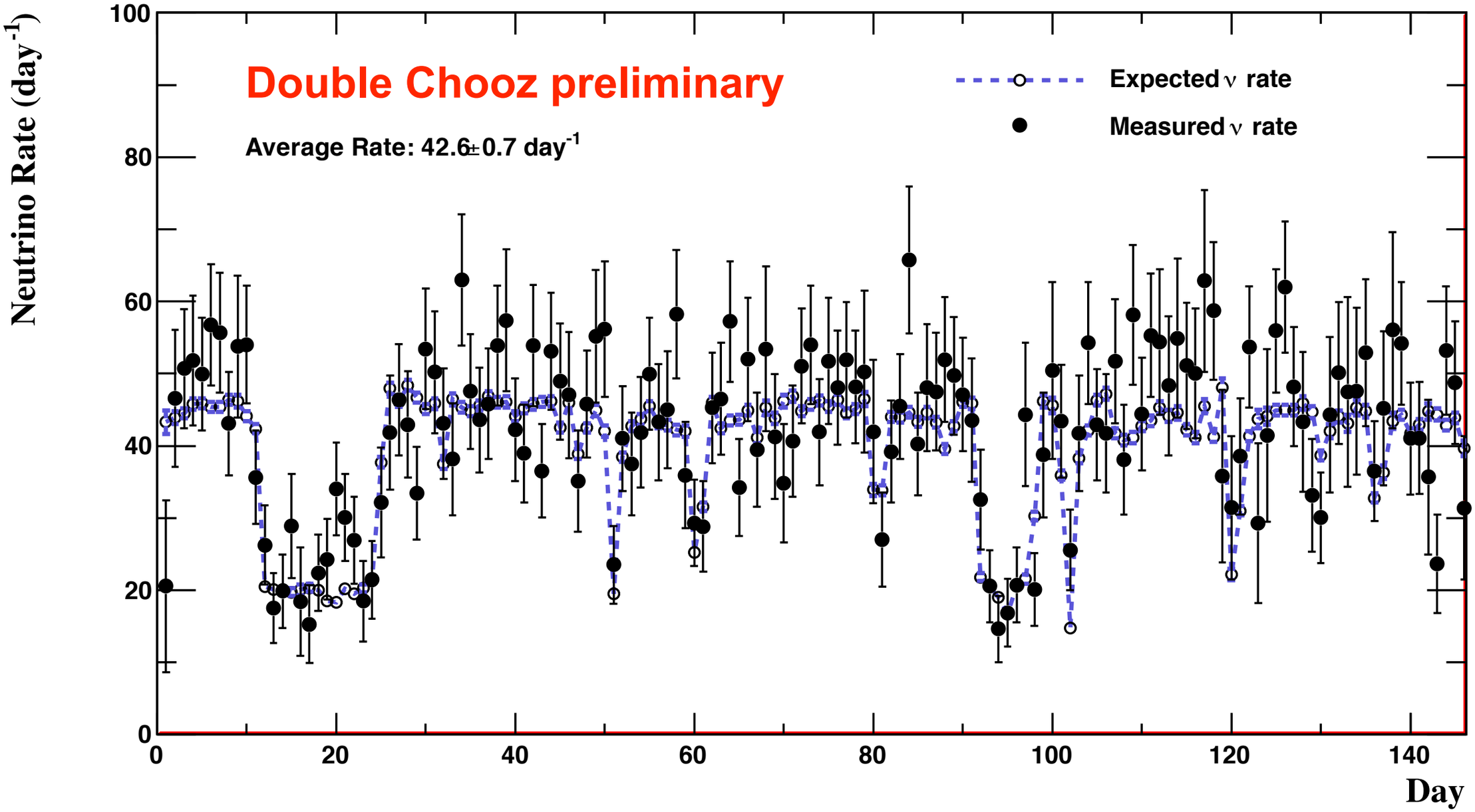
neutrino candidate selection

- Reject event in 1 ms after each muon (IV & ID based tagging muon)
- PMT spontaneous light emission rejection cuts:
  - Q_{max}/Q_{tot} : ensure light ~ homogeneously spread across the PMTs
  - RMS of hit-time per PMT: ensure light hit PMT ~ at the same time
- Prompt signal in [0.7,12] MeV
- Delayed signal in [6,12] MeV
- Coincidence window in [2,100] μs
- Multiplicity condition:
  - No trigger (E > 500 keV) 100 μs before the prompt
  - Only one trigger (E > 500 keV) 400 μs after the prompt
- No analysis fiducial volume cut (Target our physical fiducial volume)

Selection efficiency discussed in backup slide

neutrino candidate selection

Neutrino candidates rate (background not subtracted)



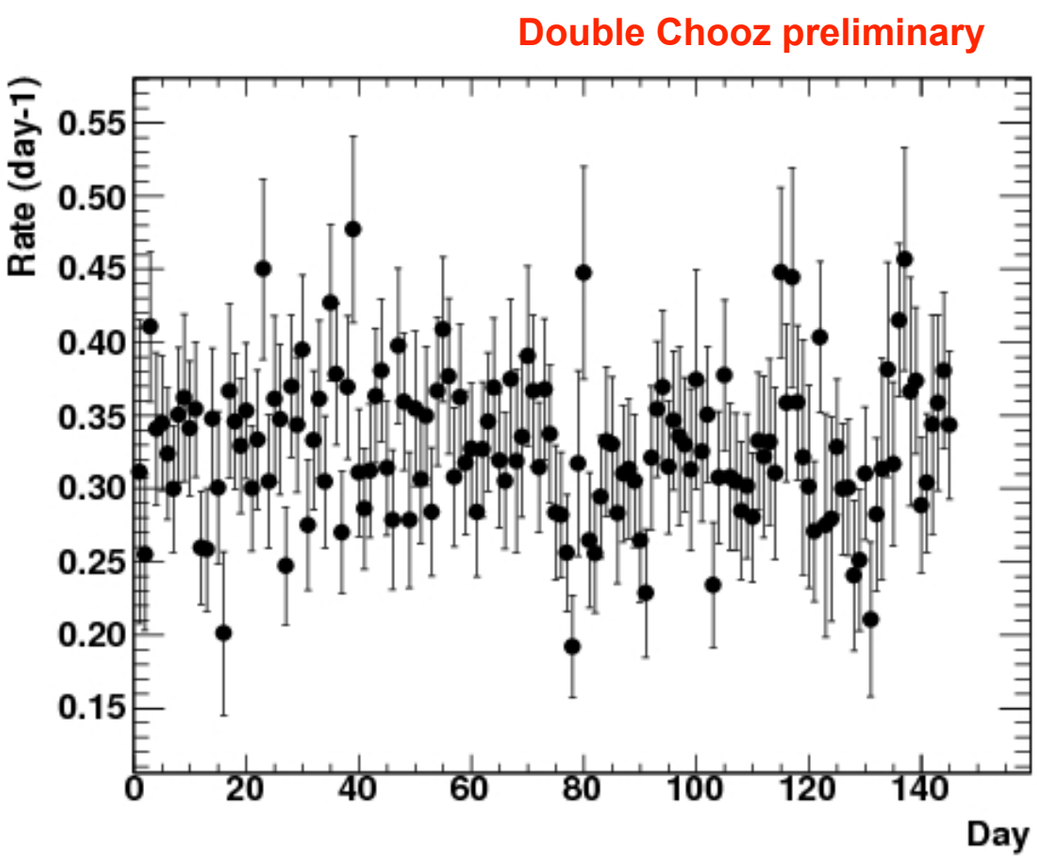
Average rate = 42.6 +/- 0.7 anti-ν/day

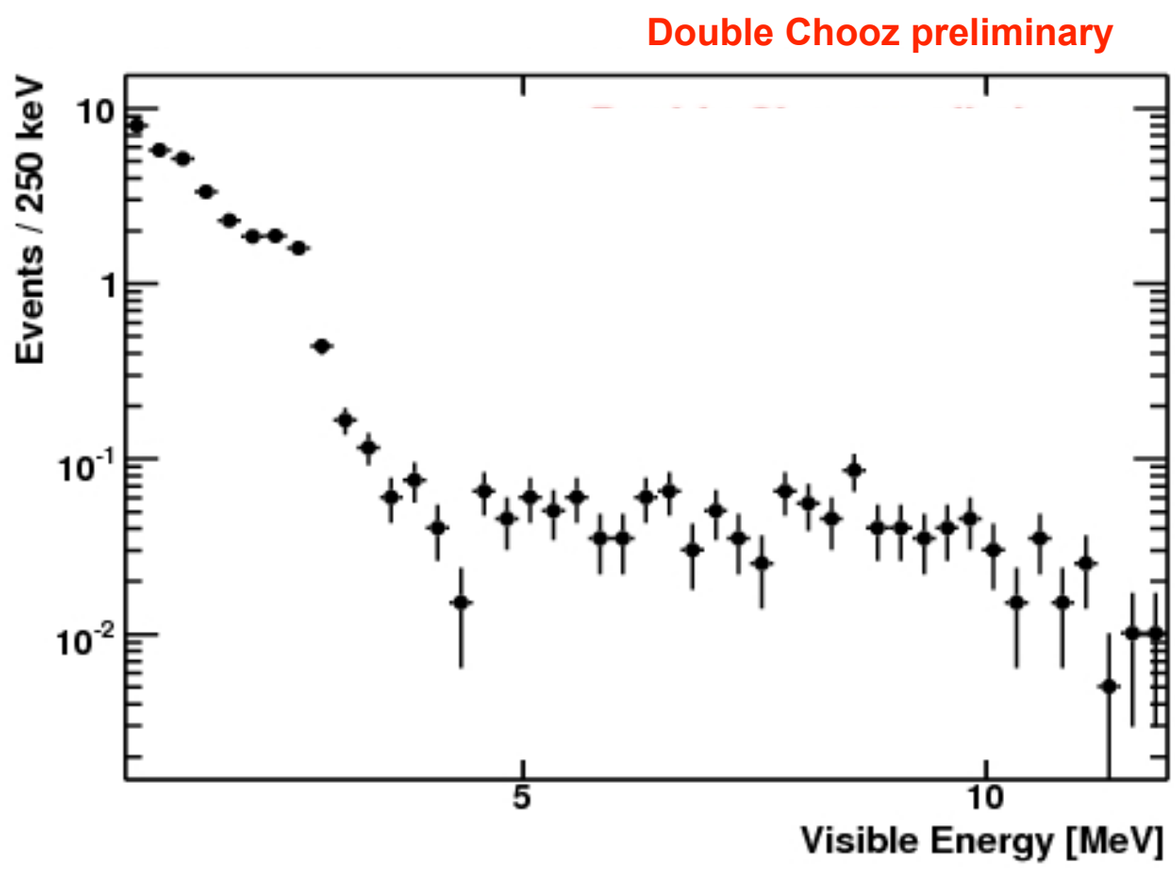
accidental background

uncorrelated coincidence between two natural radioactivity events

natural radioactivity gamma + capture of thermic neutron

analysis method: off time window from [1,100] ms





rate: 0.332 +/- 0.004 day^{-1}

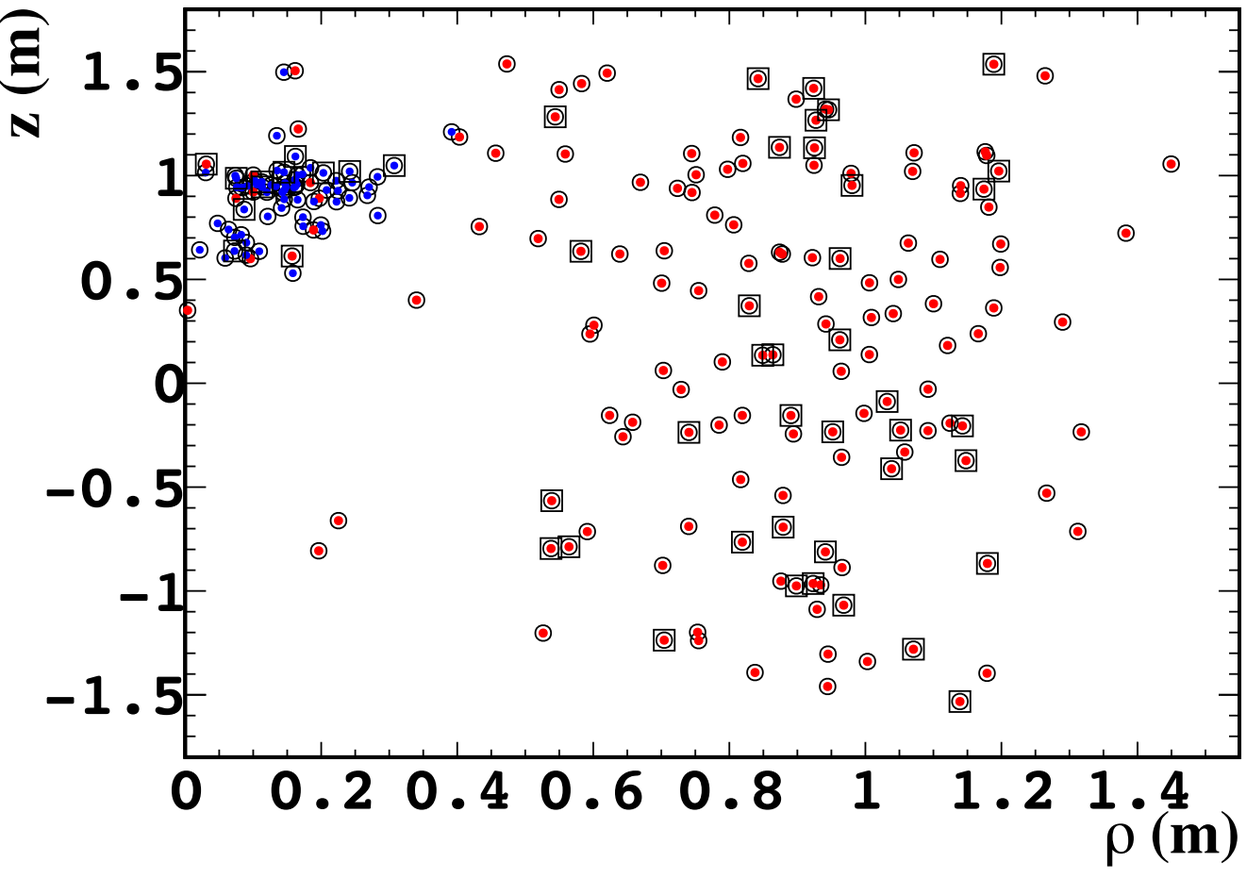
spallation neutron background

fast neutrons induced by muons passing through the surrounding rock

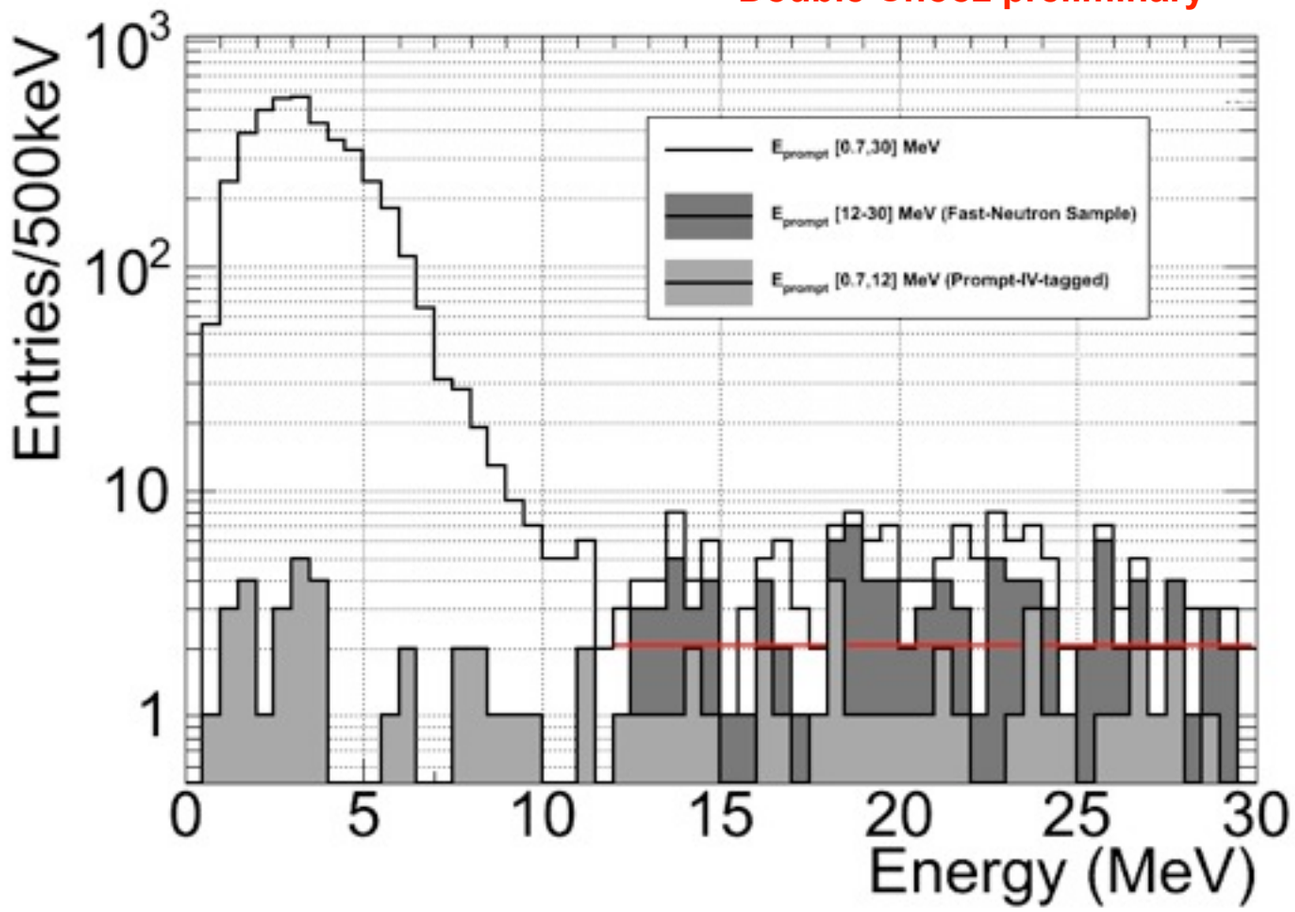
proton recoil + neutron capture

analysis method: spectrum extrapolation from high-energy to low-energy region

Double Chooz preliminary



Double Chooz preliminary



a flat energy spectrum was assumed and deviations from flatness is taken as spectrum systematic uncertainties

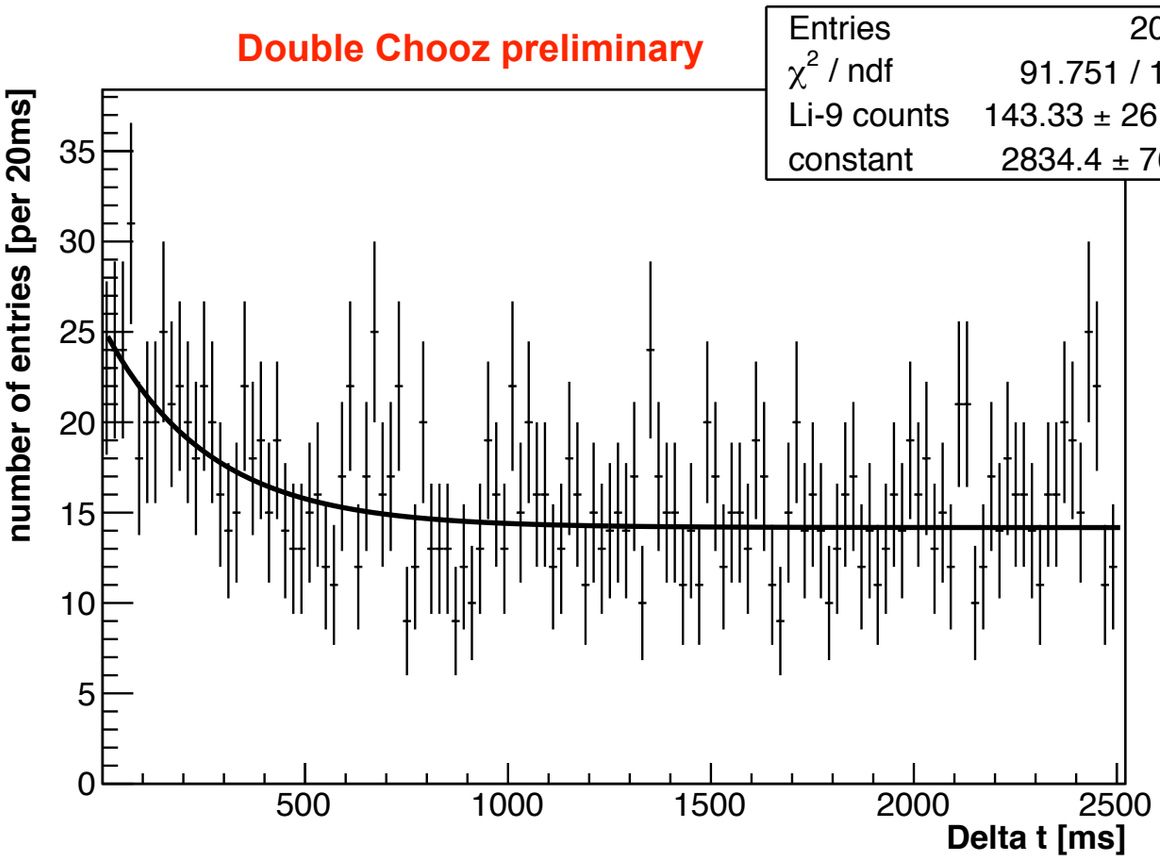
rate: 0.7 +/- 0.5 day^{-1}

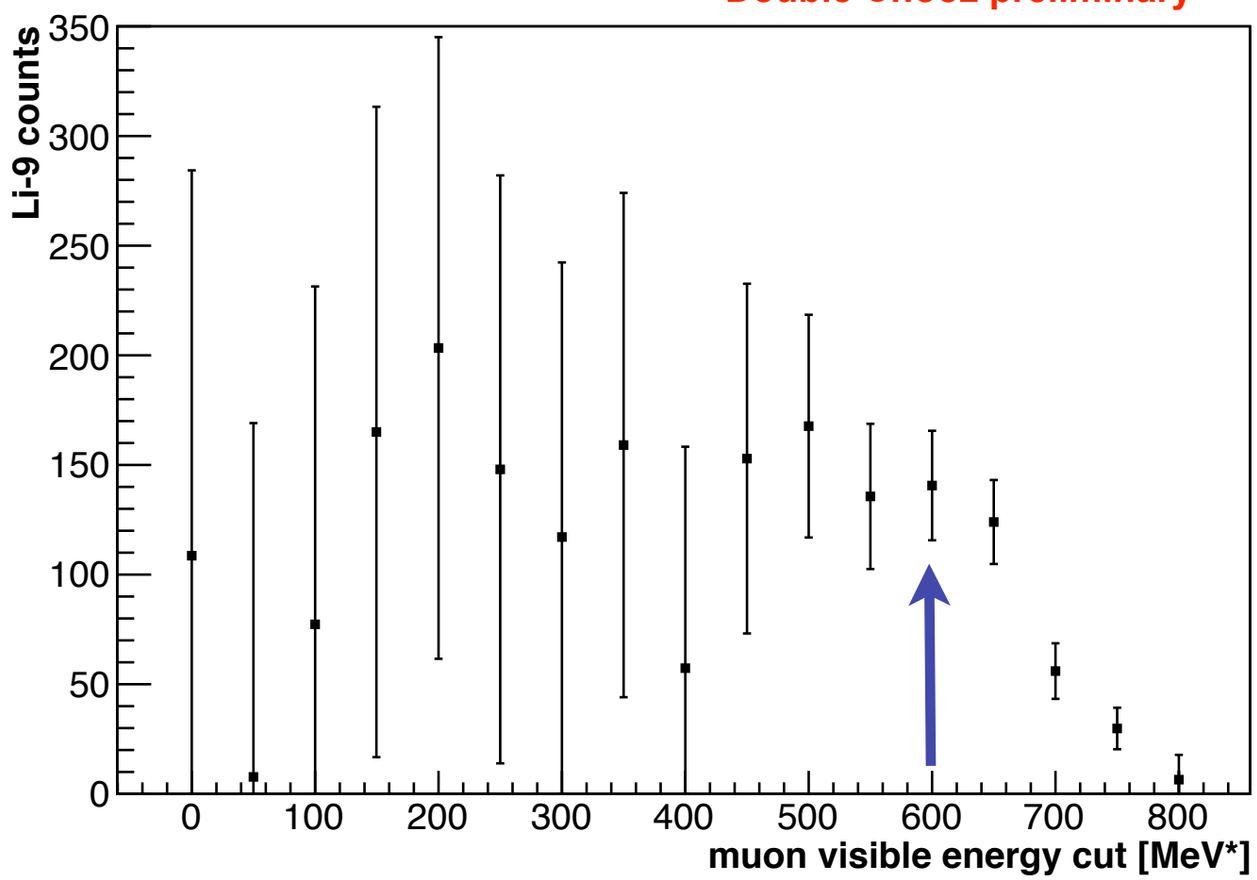
^{9}Li/^{8}He background

9Li/8He isotopes produced by muons showering in the detector

beta + n emission from cosmogenic isotopes decay (long live time)

analysis method: statistical search for triple fold coincidence between showering muon and neutrino like-event





showering muon: E_{dep} > 600 MeV

rate: 2.3 +/- 1.2 day^{-1}

observed vs expected rate

Background summary:

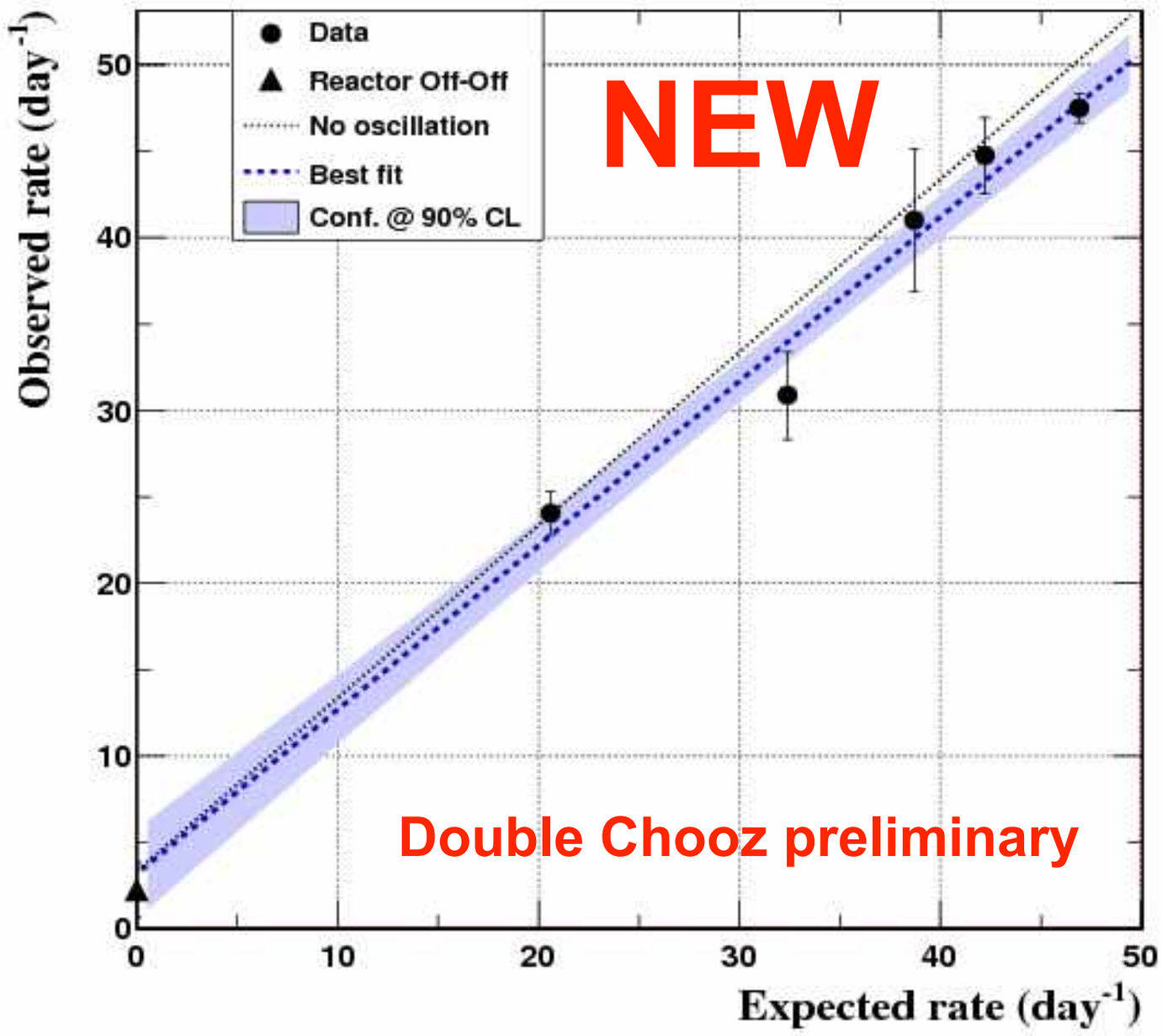
- Accidentals: 0.332 +/- 0.004 day^{-1}
- Fast Neutrons: 0.7 +/- 0.5 day^{-1}
- Li9: 2.3 +/- 1.2 day^{-1}
- **Total: 3.33 +/- 1.32 day^{-1}**

Rector OFF-OFF:

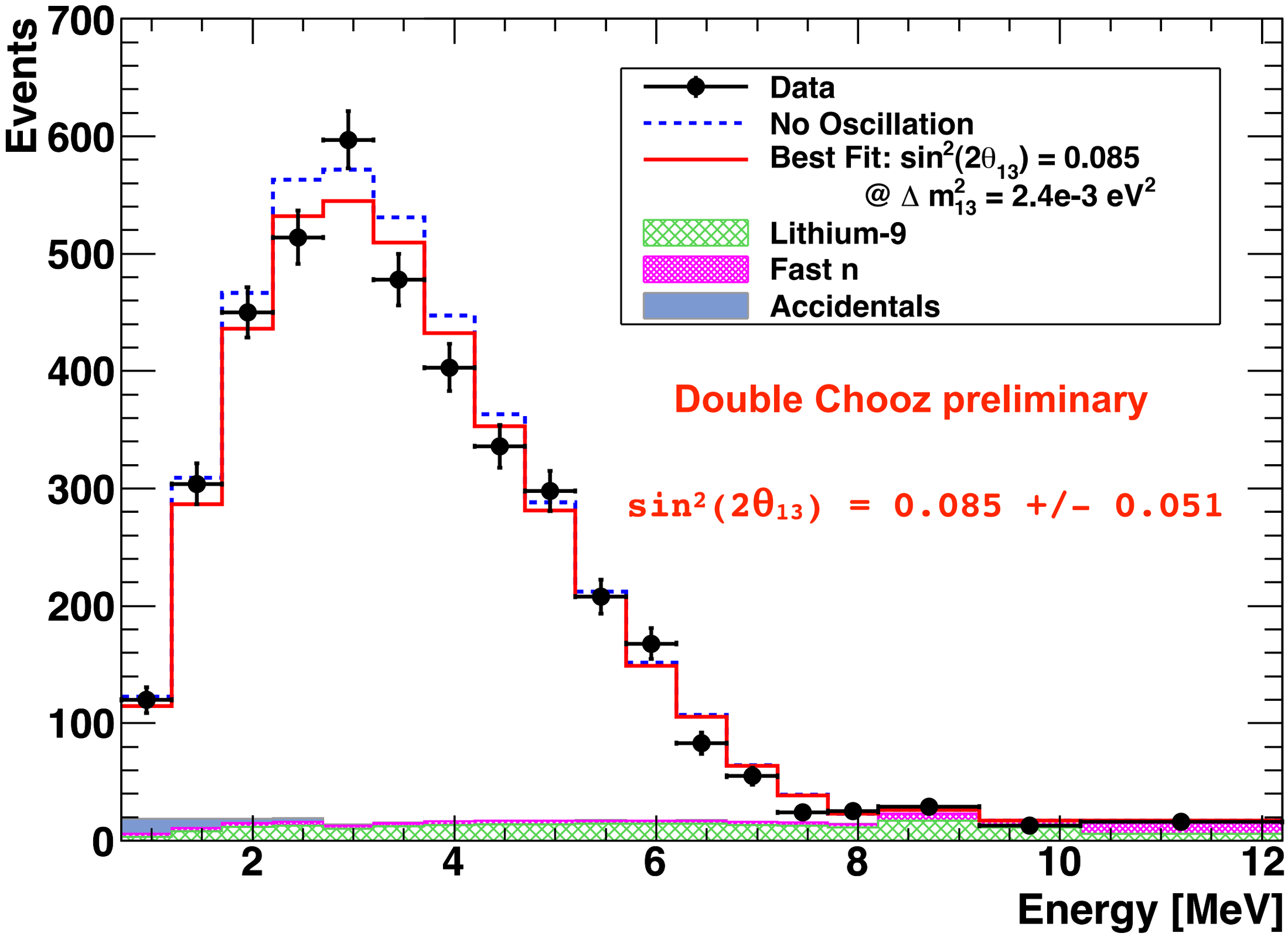
- **2 candidates** in 22h reactor OFF-OFF
- direct measure of background rate

Expected vs Observed rate analysis:

- measured background: 5.0 +/- 2.3 day^{-1} (no background informations)
- measured background: 3.2 +/- 1.3 day^{-1} (reactor OFF-OFF informations)
- disappearance fraction: 1 - 0.95
- **$\sin^2(2\theta_{13}) = 0.093 +/- 0.065$**



θ_{13} rate+shape analysis: preliminary result



conclusion

Far detector:

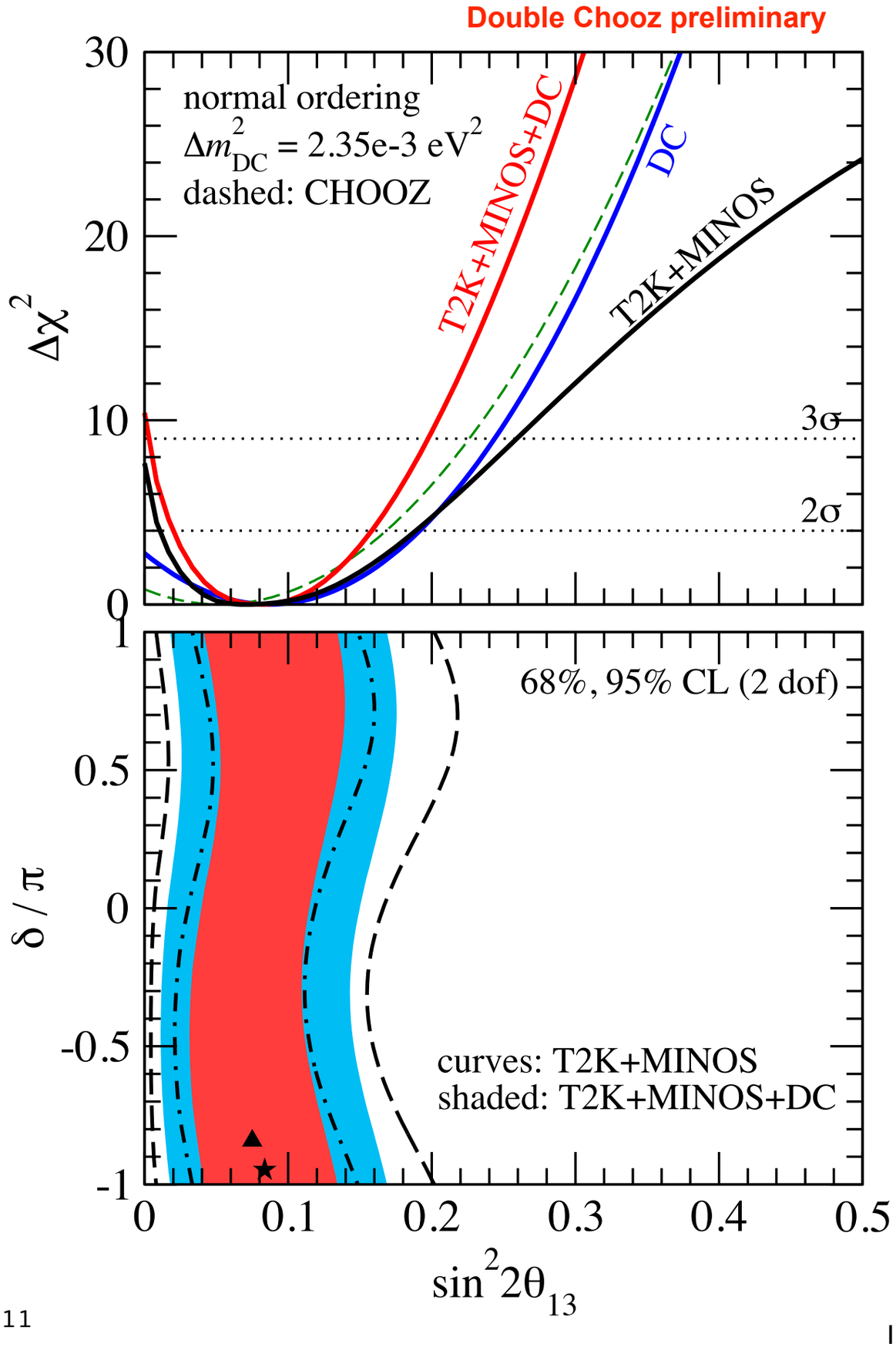
- stable running since April 2011
- 206 total days of data taking till 4th November

Near detector:

- laboratory digging on going
- near+far detector combined running expected beginning 2013

100 days data analysis:

- first release on Nov. 9. @LowNu Conf., Seoul, by H. de Kerret
- observed / simulated flux comparison
- hint for positive value of θ_{13}
- **$\sin^2(2\theta_{13}) = 0.085 +/- 0.051$**
- DC+MINOS+T2K combined analysis: $\sin^2(2\theta_{13}) > 0$ @ 3σ



backups

the Double Chooz collaborations

Brazil
CBPF
UNICAMP
UFABC

France
APC
CEA/DSM/IRFU:
SPP
SPhN
SEDI
SIS
SENAC
CNRS/IN2P3:
Subatech
IPHC
ULB/VUB

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

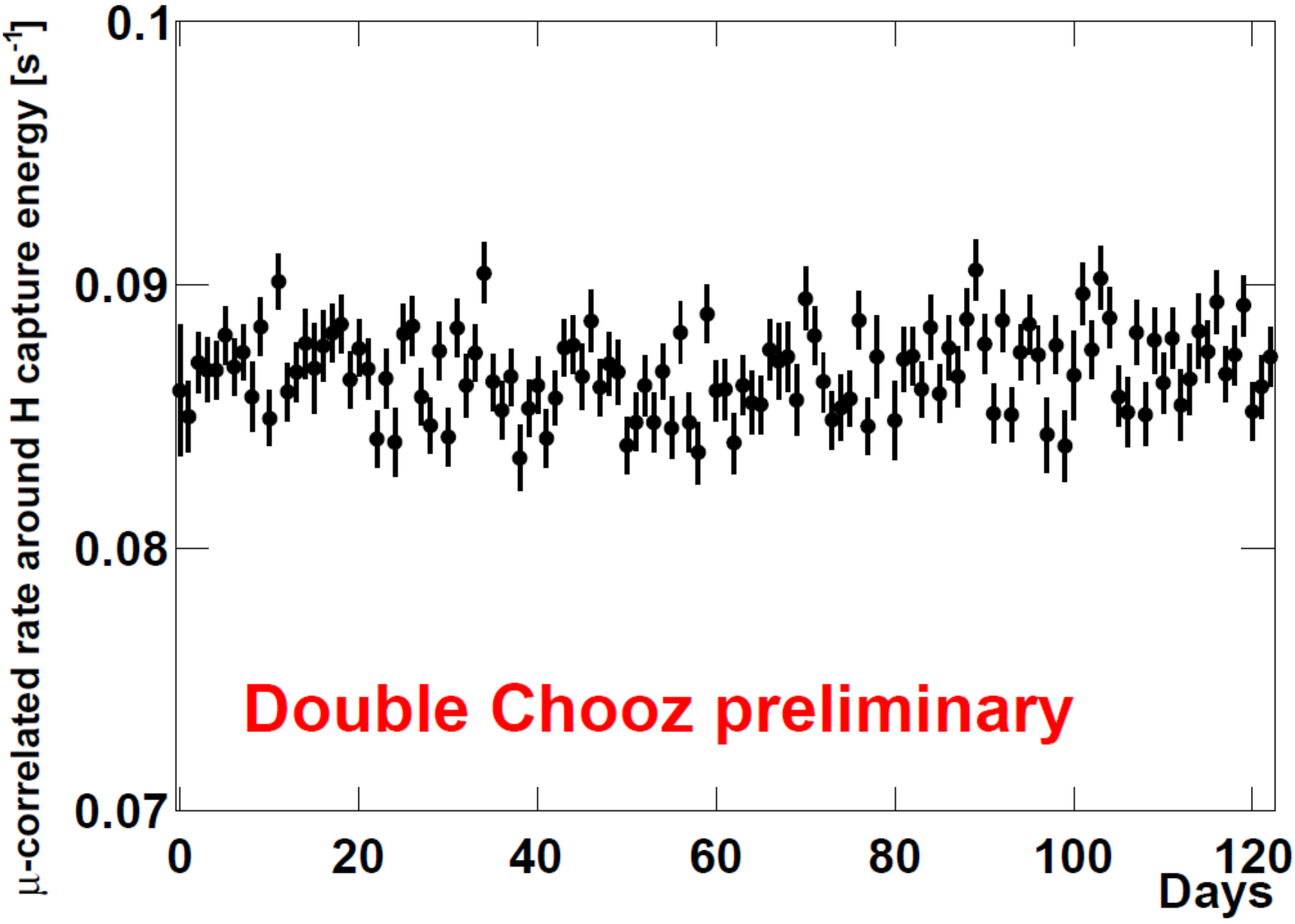
UK
Sussex

USA
U. Alabama
ANL
U. Chicago
Columbia U.
UCDavis
Drexel U.
IIT
KSU
LLNL
MIT
U. Notre Dame
Sandia National Laboratories
U. Tennessee

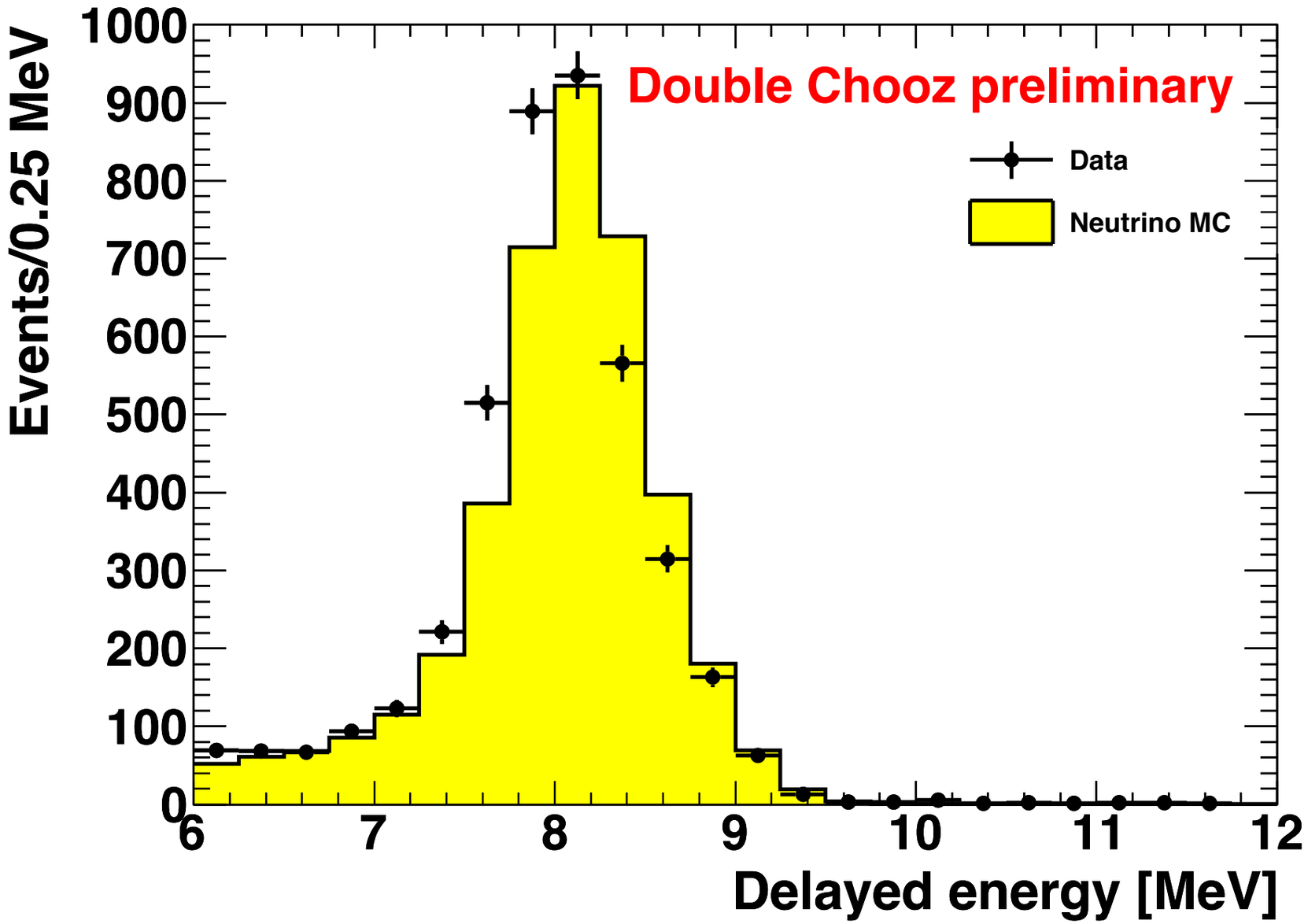
Spokesperson: H. de Kerret (IN2P3)
Project Manager: Ch. Veyssière (CEA-Saclay)

Web Site: www.doublechooz.org/

detector stability



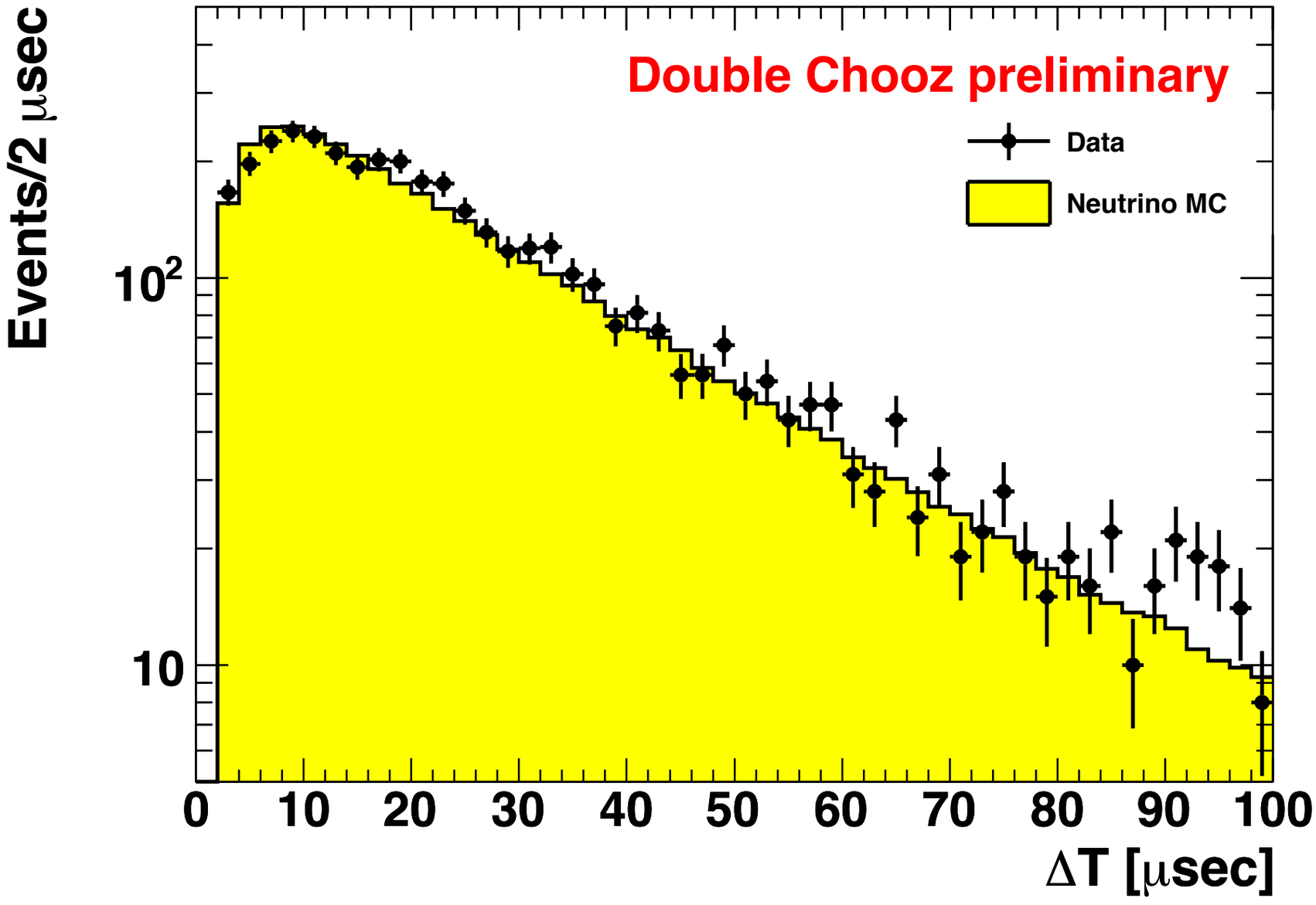
selection efficiency: delayed energy cut



neutron capture efficiency: 86.0 +/- 0.6 %

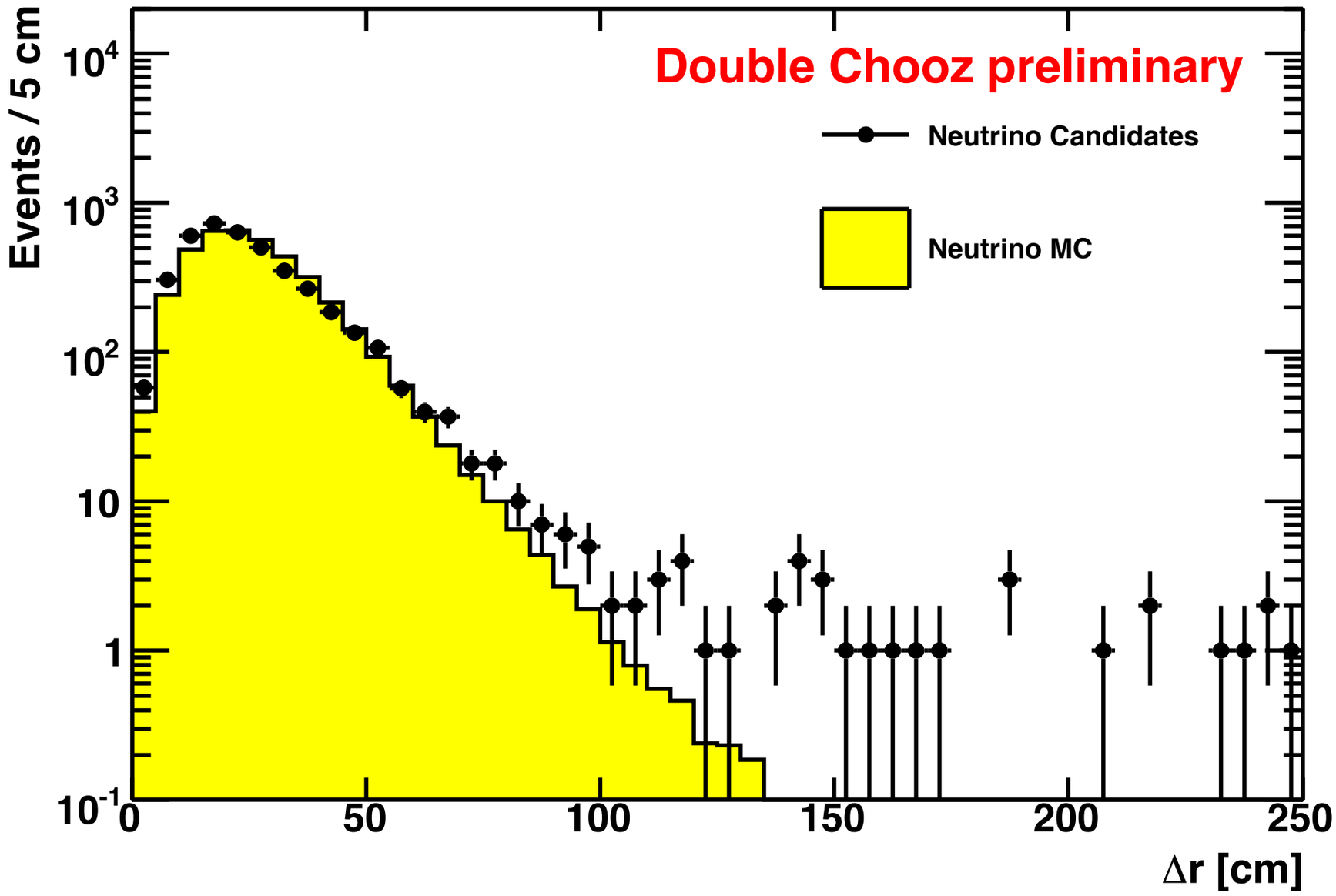
delayed energy cut efficiency: 94.5 +/- 0.6 %

selection efficiency: time correlation



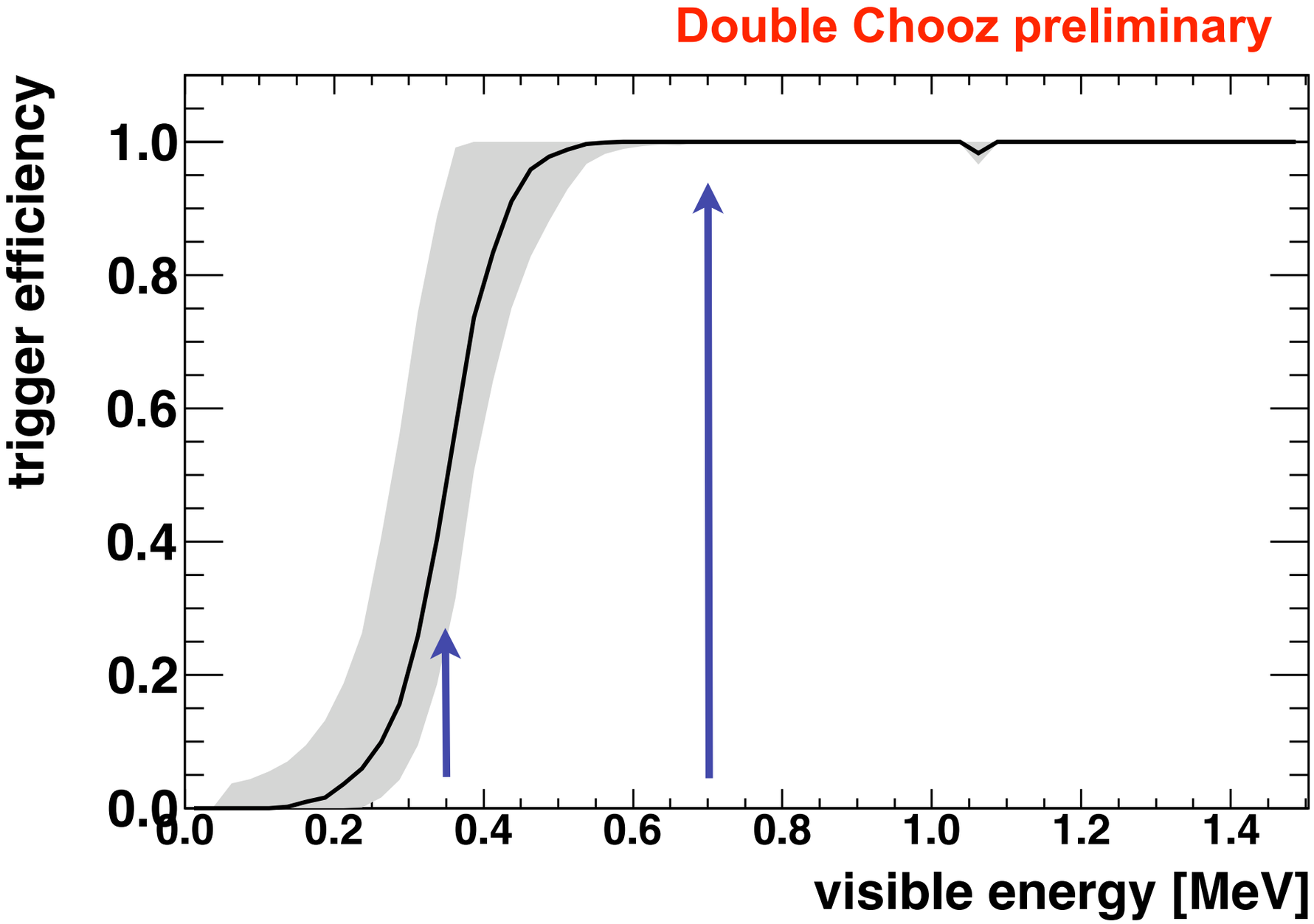
prompt delayed time window efficiency: 96.5 +/- 0.4 %

selection efficiency: distance correlation



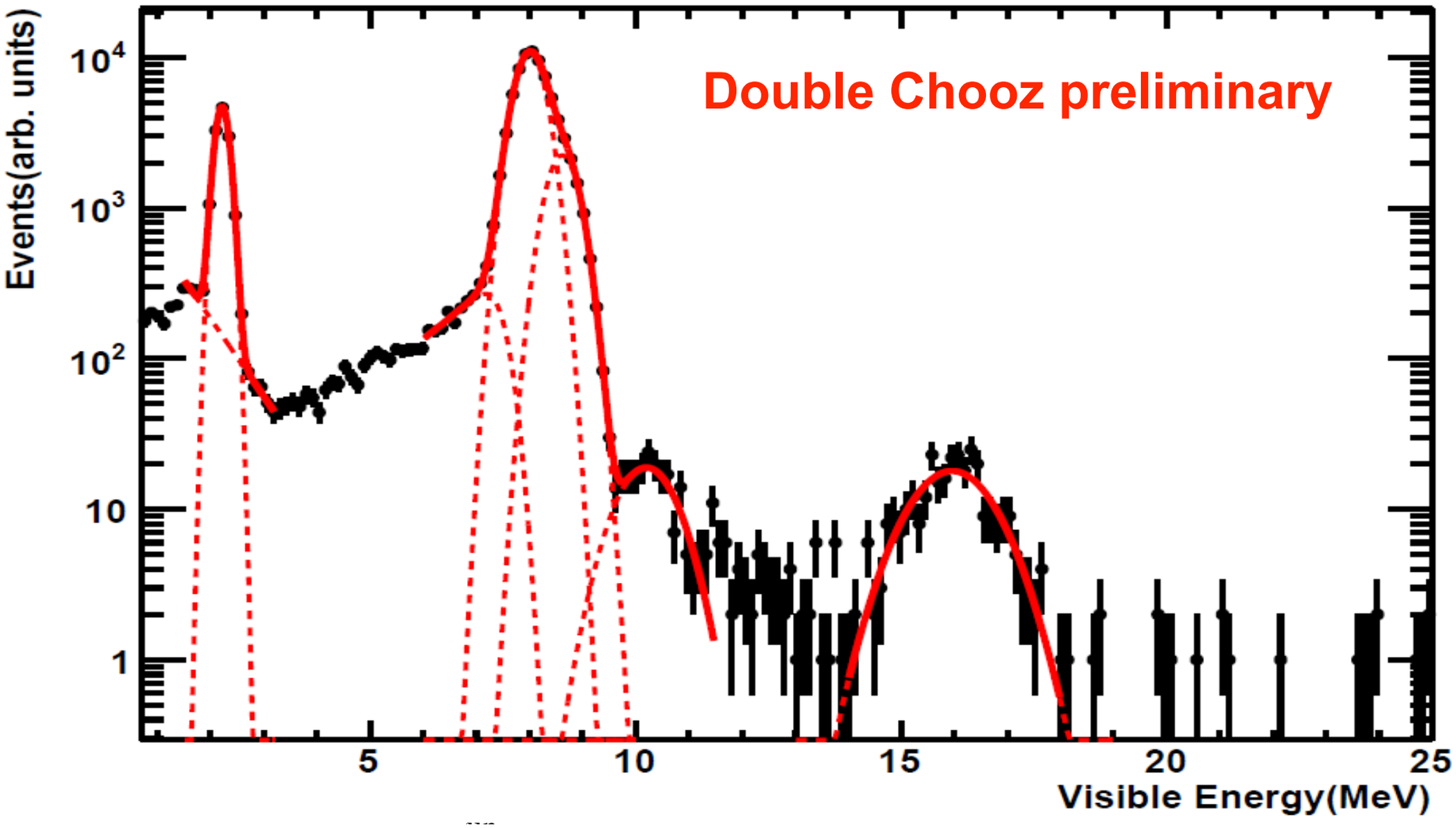
no analysis fiducial volume cut

trigger efficiency



- 50% efficiency @ 0.350 MeV: defined as trigger threshold
- 100% efficiency @ 0.700 MeV: prompt energy threshold
- **no prompt energy cut inefficiency**

Gd fraction and efficiency

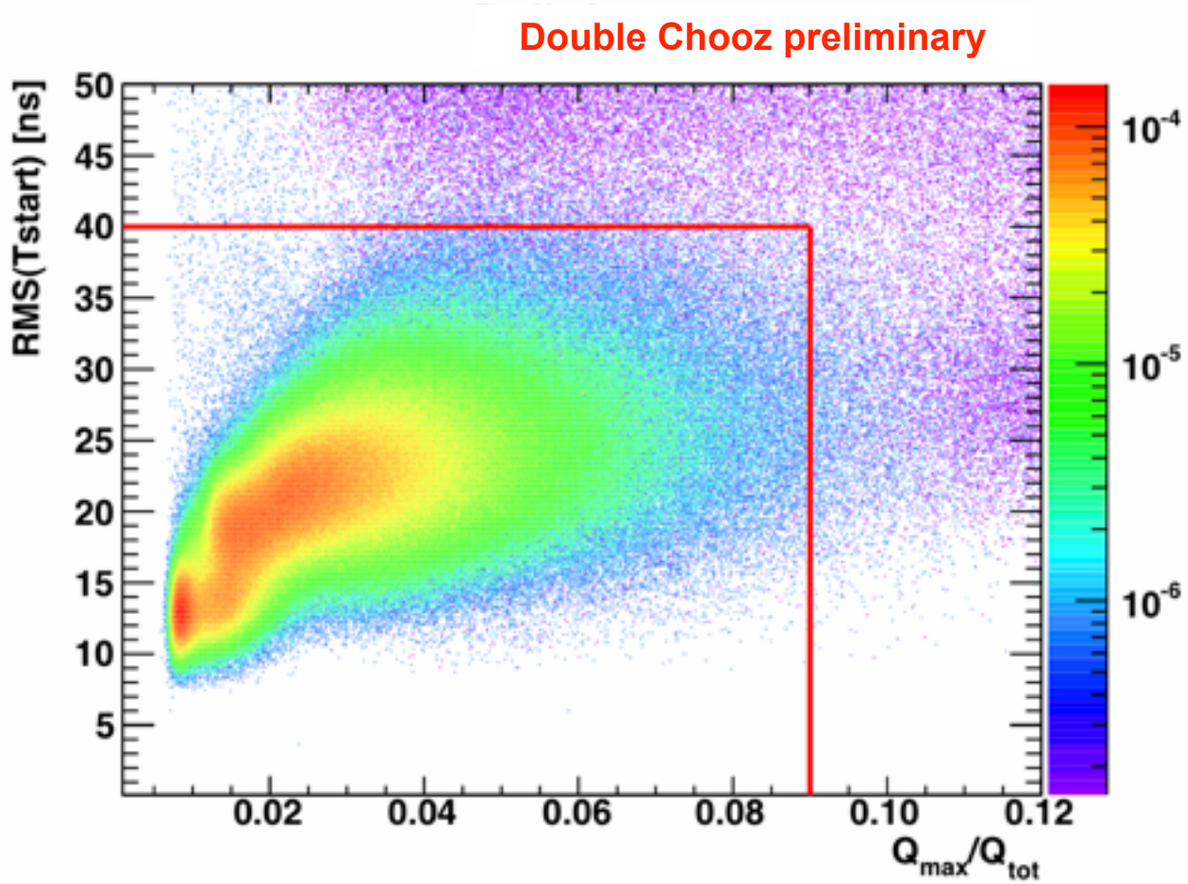


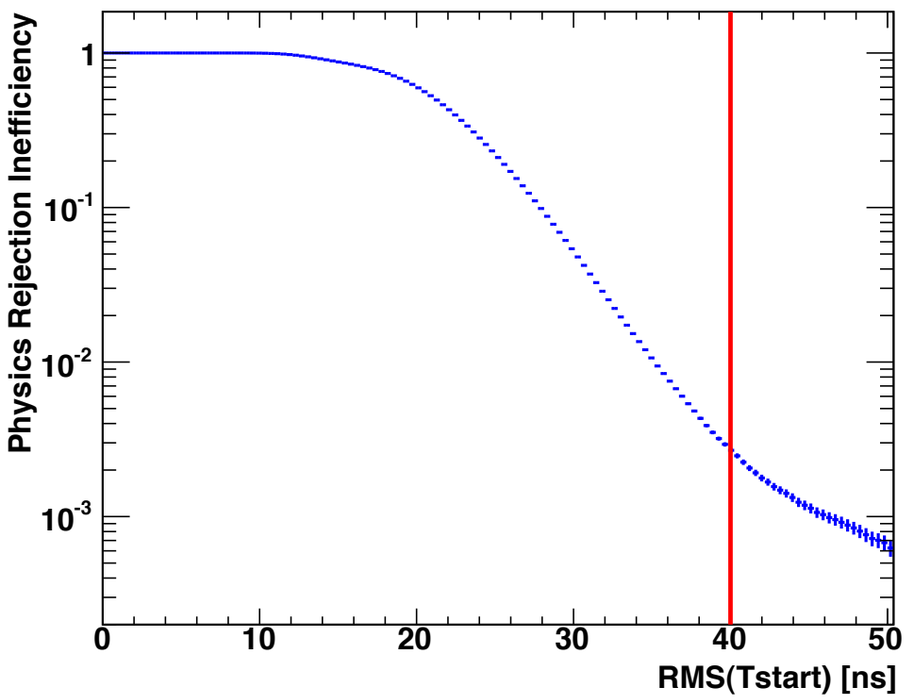
- ^{252}Cf source scan along z-axis
- Gd fraction defined as Gd/(Gd+H): 0.860 +/- 0.005
- Δt and ΔE efficiency systematics from ^{252}Cf MC/DATA comparison +/- 0.5% and +/- 0.6%, respectively

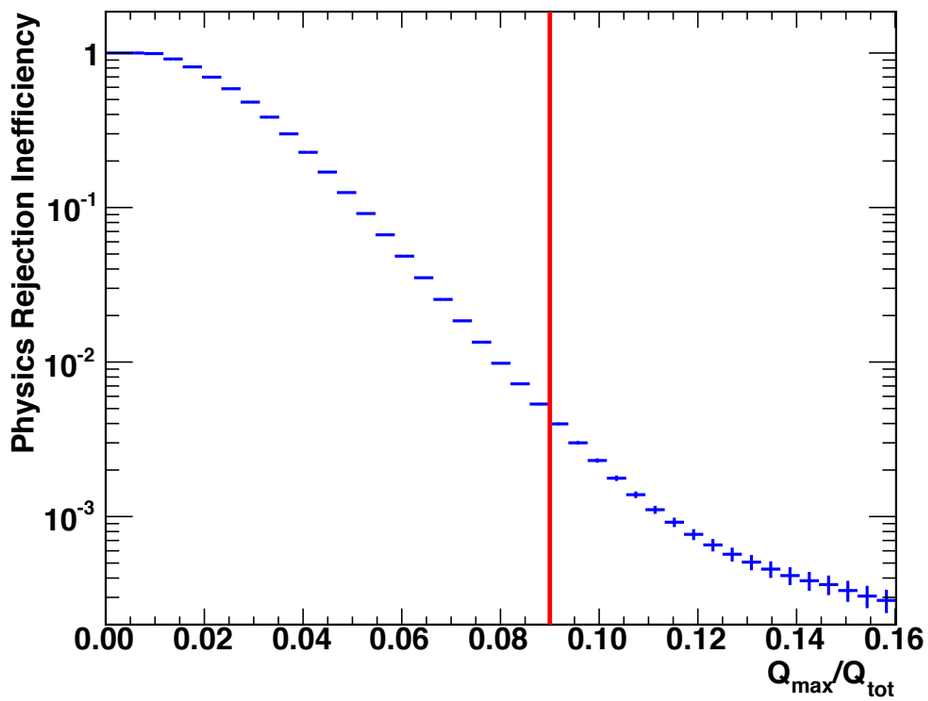
light noise

- unexpected light emission from PMT's was found
- the rate has the same order of magnitude as the singles rate which is in line with the proposal
- the signal is rather different from single events and can be distinguished
- noise is under control
- analysis work in ongoing to asses the systematics

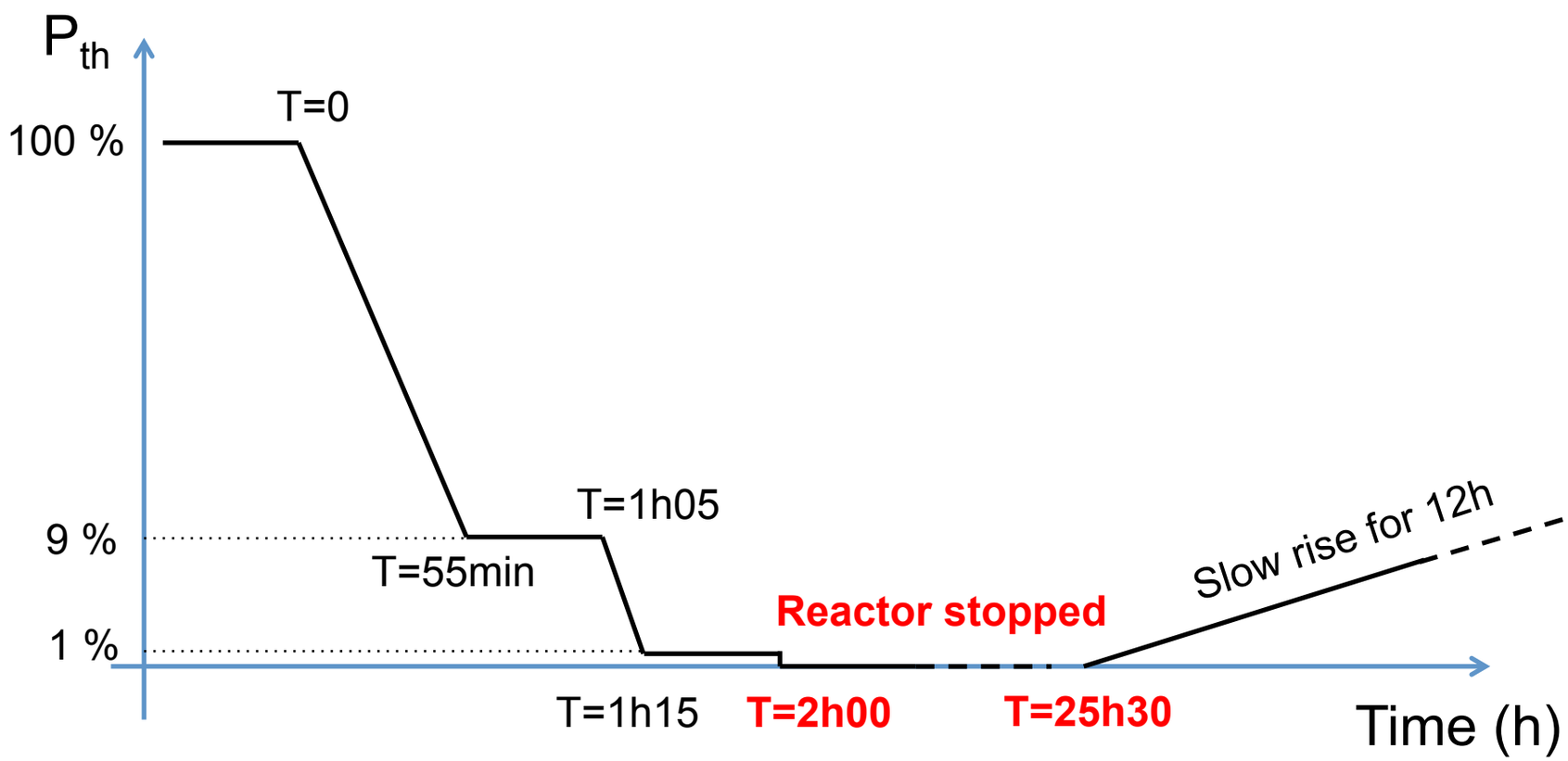
light noise


Double Chooz preliminary
RMS(Tstart) [ns]
50
45
40
35
30
25
20
15
10
5
0.02
0.04
0.06
0.08
0.10
0.12
Q_{max}/Q_{tot}
10^{-4}
10^{-5}
10^{-6}


Double Chooz preliminary
Physics Rejection Inefficiency
1
10^{-1}
10^{-2}
10^{-3}
0
10
20
30
40
50
RMS(Tstart) [ns]


Double Chooz preliminary
Physics Rejection Inefficiency
1
10^{-1}
10^{-2}
10^{-3}
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Q_{max}/Q_{tot}

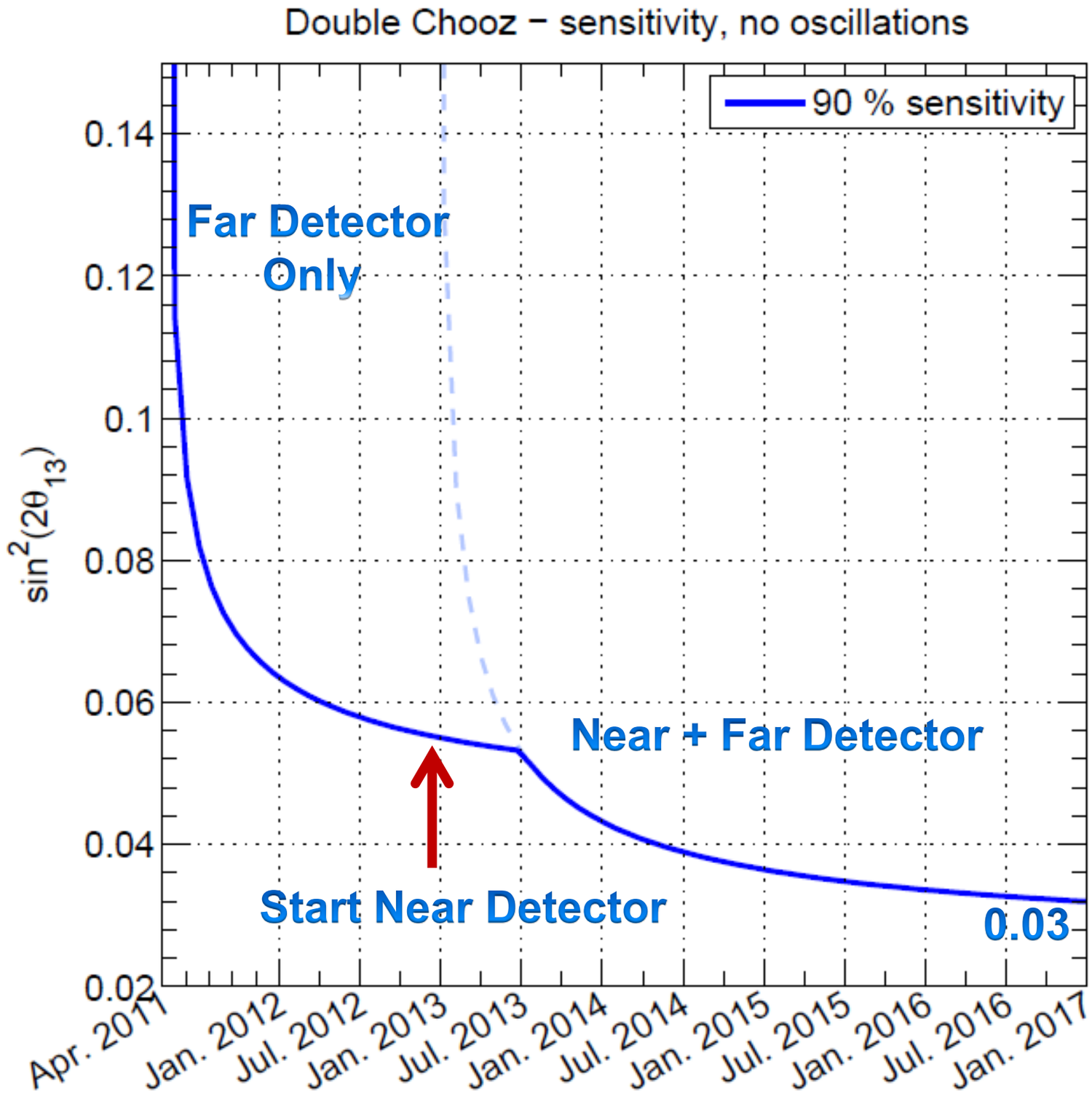
24h reactor off-off



- One reactor OFF for ~2 months (reactor re-fueling)
- Two reactor OFF for ~24h
- 3 events below 30 MeV
  - two possible Li/He candidates
  - one possible stopping-muon candidate

data analysis summary

# anti-ν of candidates	4121	
accidentals		-31.6 +/- 5.9
fast neutrons		-92.9 +/- 54.4
lithium		-227.3 +/- 118.6
muon dead time	/.952 (negligible sys.)	
spill in	/1.0177 +/- 0.5 %	
multiplicity	/.995 (negligible sys.)	
neutron capture eff.	/.86 +/- 0.6 %	
delayed energy cut eff.	/.945 +/- 1 %	
time corr. cut eff.	/.965 +/- 0.4 %	
corrected # of anti-ν candidates	**4952.5 +/- 202.2**	


Double Chooz − sensitivity, no oscillations
90 % sensitivity
Far Detector Only
Near + Far Detector
Start Near Detector
0.03
$\sin^2(2\theta_{13})$
0.14
0.12
0.1
0.08
0.06
0.04
0.02
Apr. 2011
Jan. 2012
Jul. 2012
Jan. 2013
Jul. 2013
Jan. 2014
Jul. 2014
Jan. 2015
Jul. 2015
Jan. 2016
Jul. 2016
Jan. 2017