Double Chooz

New results on θ_{13}

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On behalf of the Double Chooz Collaboration

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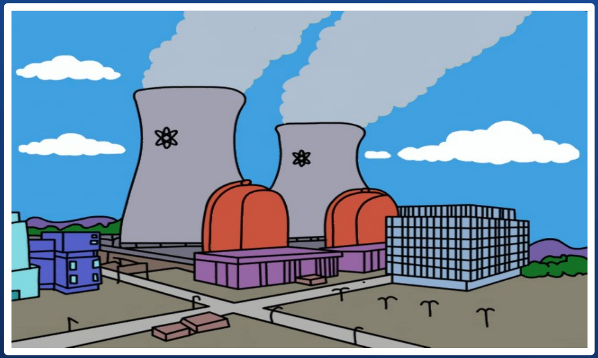
Overview

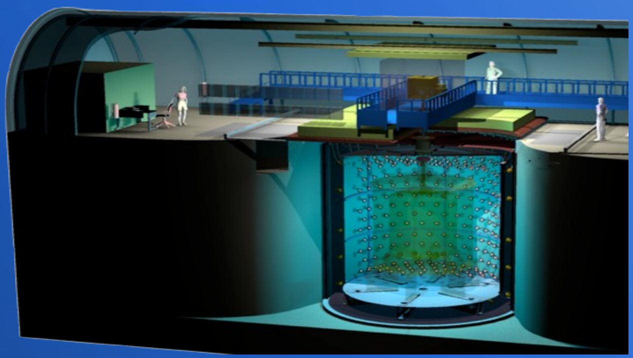
- Reactor neutrinos and θ_{13}
- The Double Chooz experiment
- New results on θ_{13}
- ND and Future projects
- Summary

Reactor neutrinos and θ_{13}



L ~ 1 km

$P(\bar{\nu}_e \rightarrow \bar{\nu}_x)$



- In contrast to accelerator experiments...

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

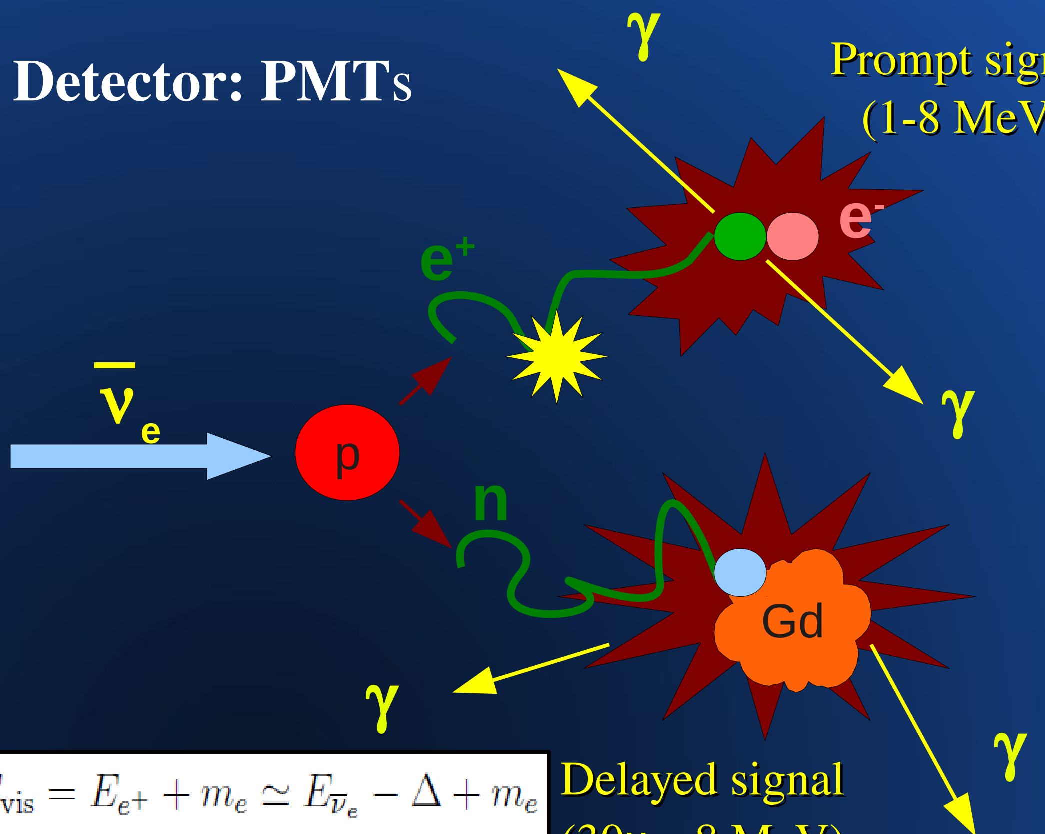
- No parameter correlations
- Pure $\bar{\nu}_e$ beam
- Low energy
- No matter effects
- Cheap, as source exists
- High flux and large x-section

Detecting reactor neutrinos

IBD: $\overline{\nu}_e + p \rightarrow e^+ + n$

- **Target: scintillator + n-catcher (Gd)**
- **Detector: PMTs**

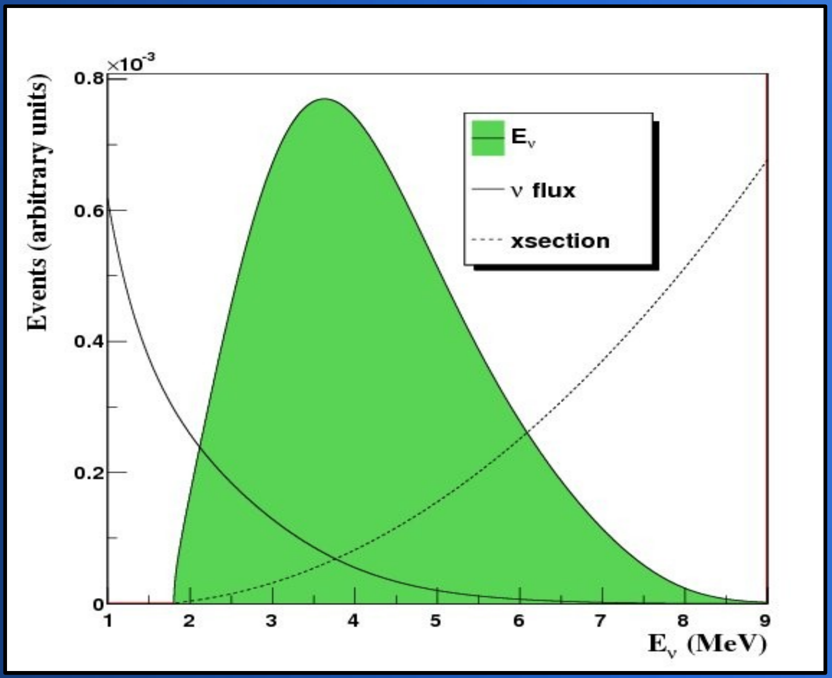
Th: 1.8 MeV. **Disappearance!**



$$E_{\text{vis}} = E_{e^+} + m_e \simeq E_{\overline{\nu}_e} - \Delta + m_e$$

Delayed signal
(30μs, 8 MeV)

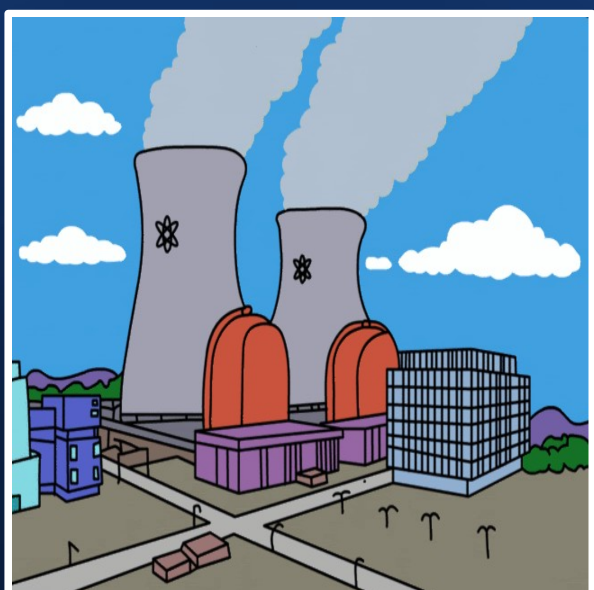
E_ν spectrum

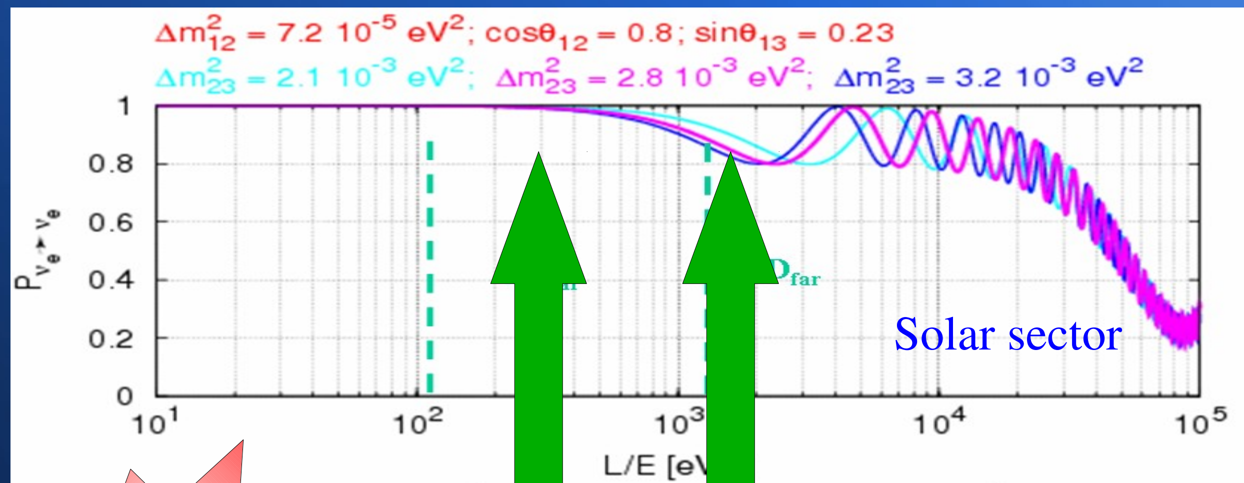


Setting up the experiment

Reactor neutrinos:

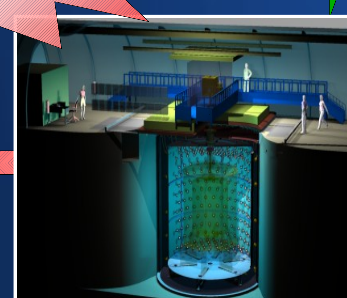
$\langle E_\nu \rangle \sim 4$ MeV

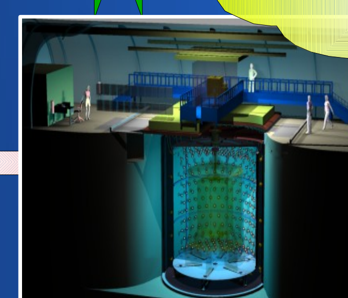




Systematics!

Oscillation!





~100 m

~1 km

The Double Chooz Experiment

Near Detector
L = 400m
$10m^3$ target
120 m.w.e.
2013

Far Detector
L = 1050m
$10m^3$ target
300m.w.e.
April 2011 ~

Chooz Reactors
$4.27GW_{th}$ x 2 cores

- Pioneered reactor experiments after CHOOZ:
  - Experimental concept of using two detectors
  - New detector structure: 4 layers detector
  - Low background (S/N ~ 20, proven by reactor OFF)
  - Stable Gd loaded LS developed

The Double Chooz Collaboration

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

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Columbia U.
UCDavis
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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/

Double Chooz Detectors

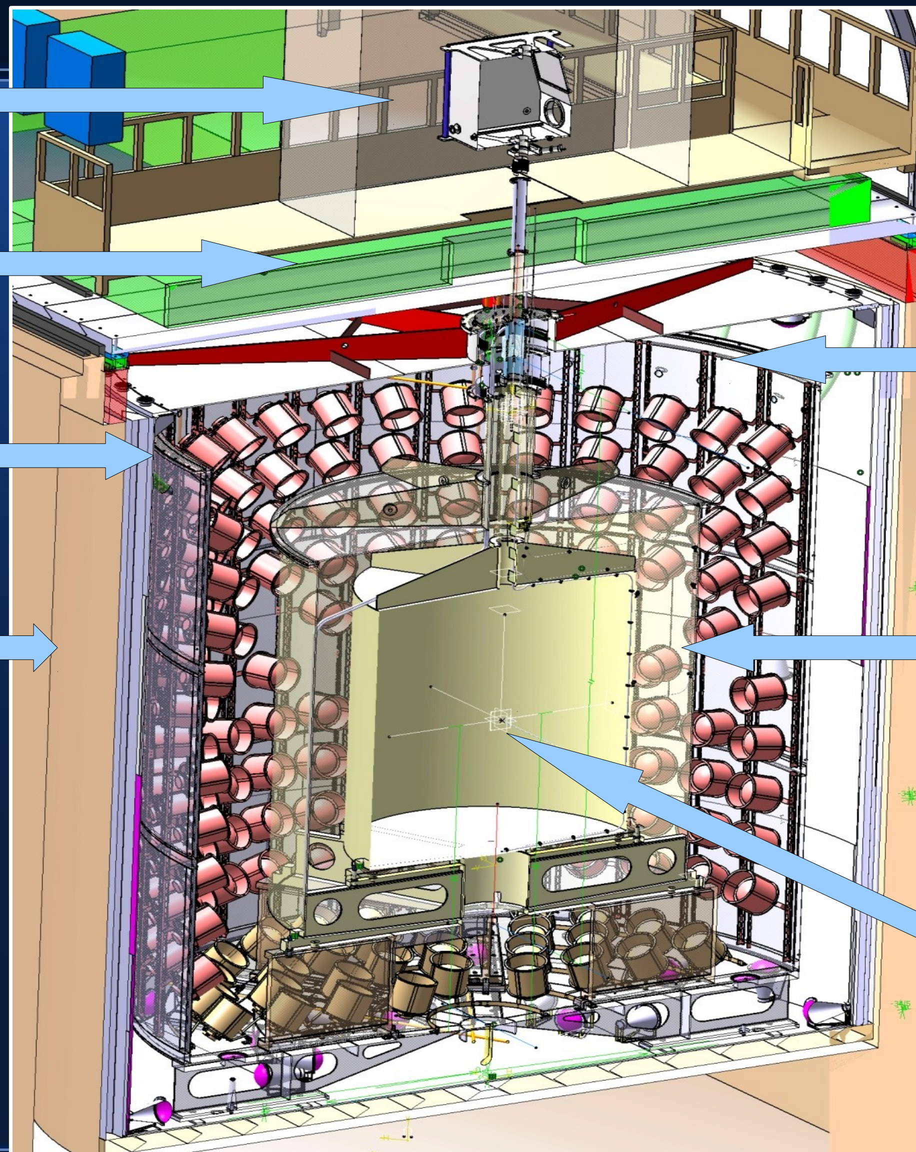
Glove box

μ Outer Veto

Inner Veto

Iron Shield

Inner
ND and FD
are identical



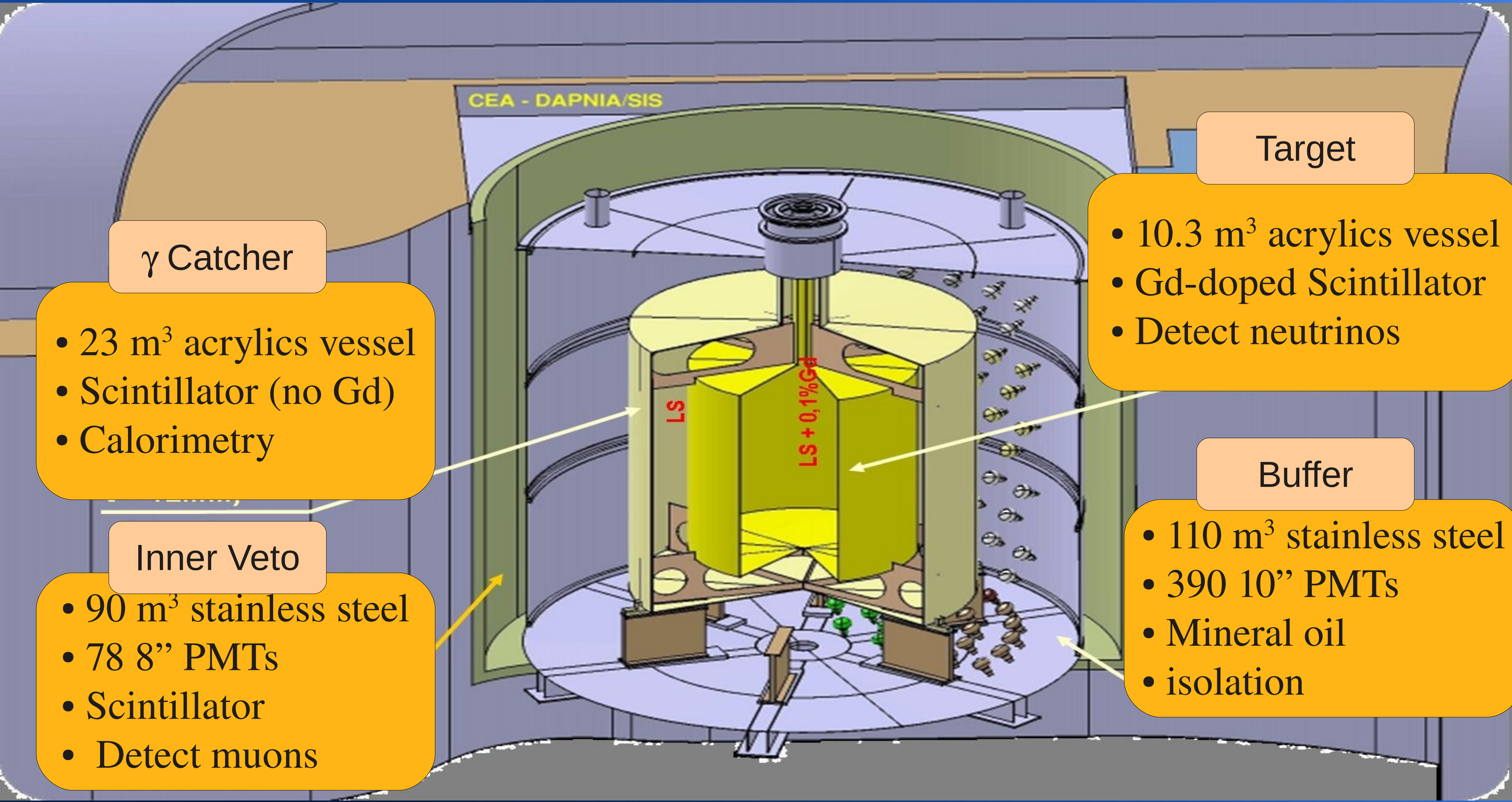
Inner Detector

Buffer

Gamma Catcher

Target

Double Chooz Detectors



γ Catcher

- 23 m³ acrylics vessel
- Scintillator (no Gd)
- Calorimetry

Inner Veto

- 90 m³ stainless steel
- 78 8” PMTs
- Scintillator
- Detect muons

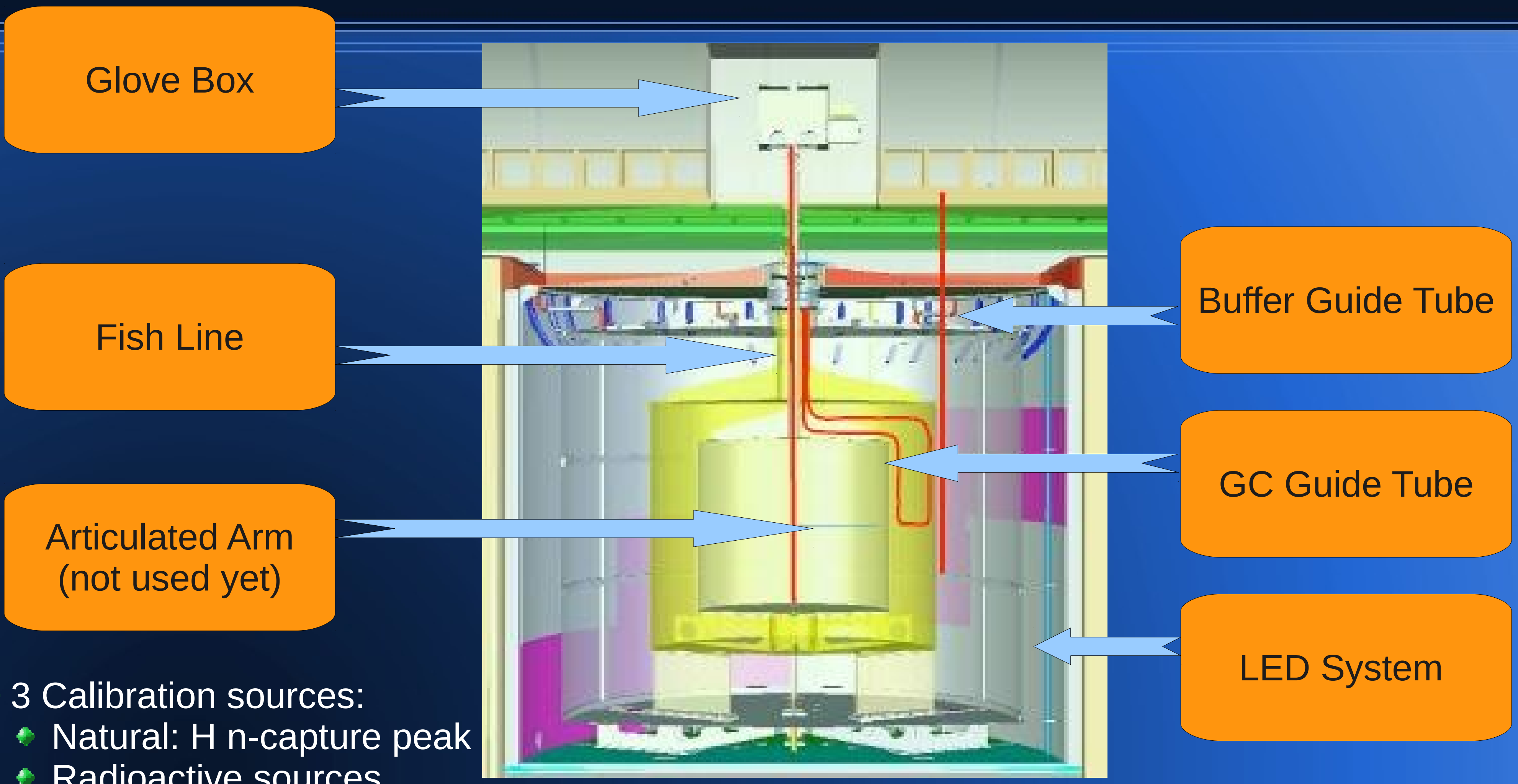
Target

- 10.3 m³ acrylics vessel
- Gd-doped Scintillator
- Detect neutrinos

Buffer

- 110 m³ stainless steel
- 390 10” PMTs
- Mineral oil
- isolation

Calibration Systems



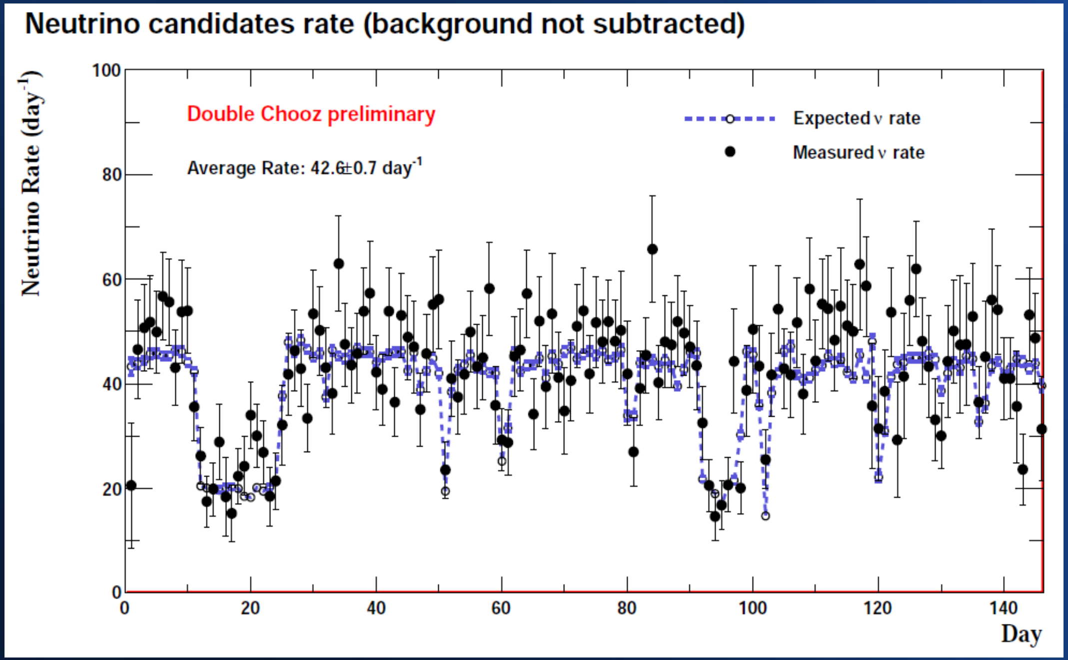
- 3 Calibration sources:
  - Natural: H n-capture peak
  - Radioactive sources
  - Laser and LED system

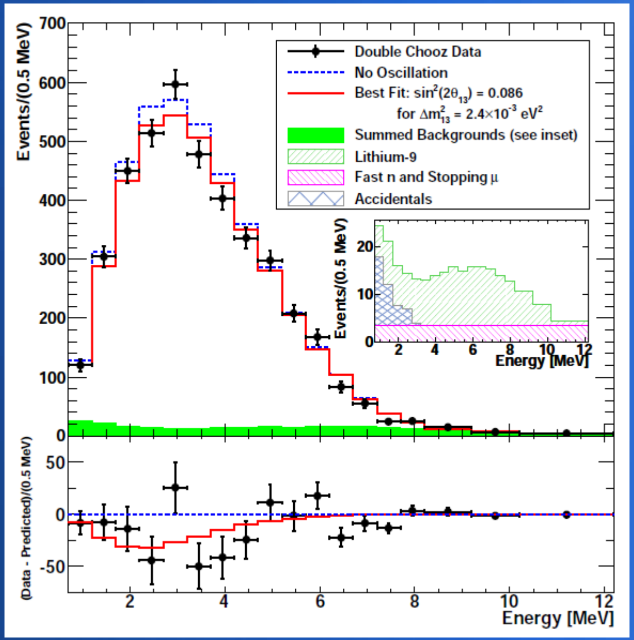
The Far Detector

Taking data since April of 2011

DC First Analysis

- Announced first results in November 2011:
  - First θ_{13} measurement by reactor experiment (firs result from CHOOZ)
  - Indication of non-zero θ_{13} at 94% C.L. and hint for a large value of θ_{13}
    - Evidence at 3σ by combination with LBL experiments (MINOS & T2K)

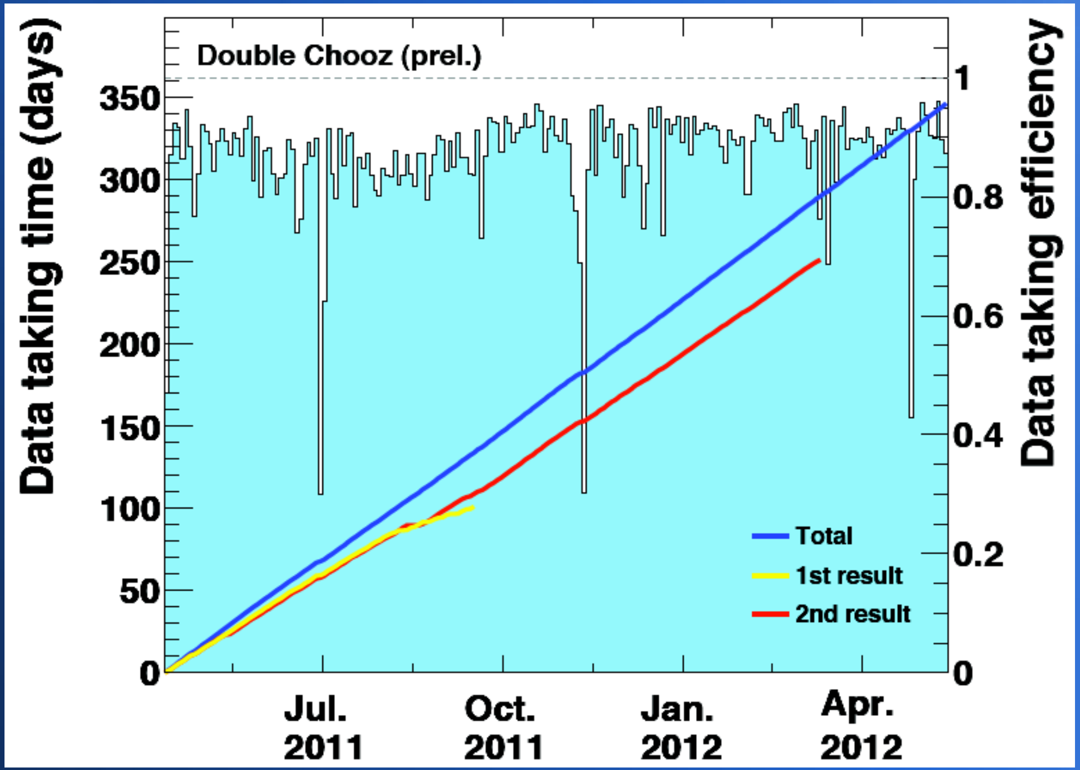




Phys.Rev.Lett. 108 (2012) 131801

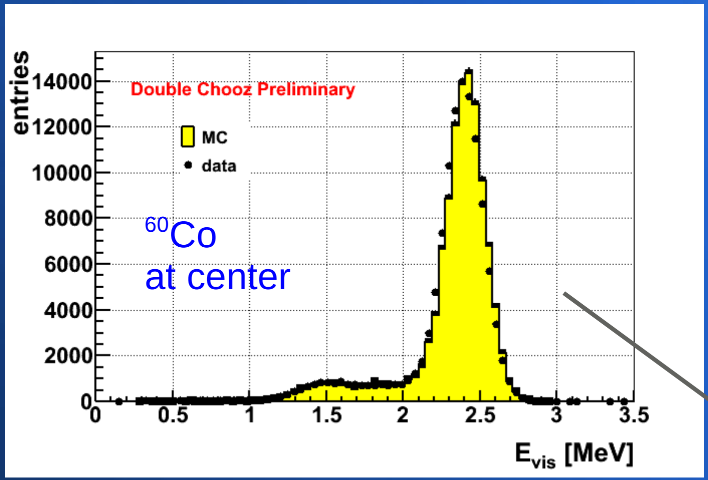
DC Second Analysis

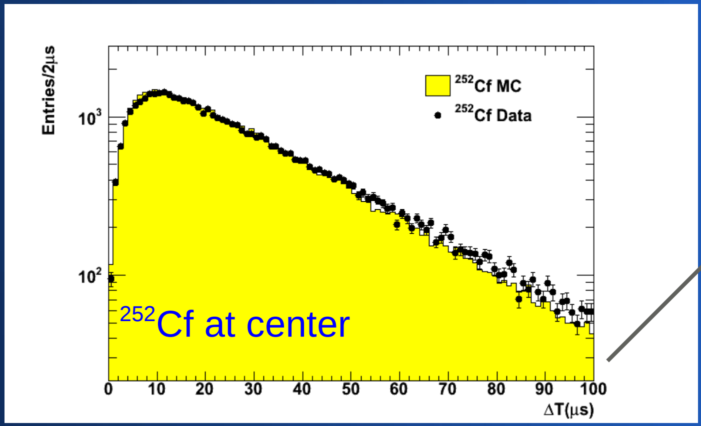
- **Doubled statistics**
  - 96.8 → 227.9 days live time
  - 4121 → 8249 ν candidates
- **Improved analysis**
  - Energy calibration improved
    - Readout MC tuning
    - Corrections for non-linear gain, position dependence, stability
  - Additional μ veto implemented (^{9}Li)
  - OV veto implemented
  - Data divided into two periods:
    - Both reactors on: 139.3 days
    - One reactor off: 88.7 days

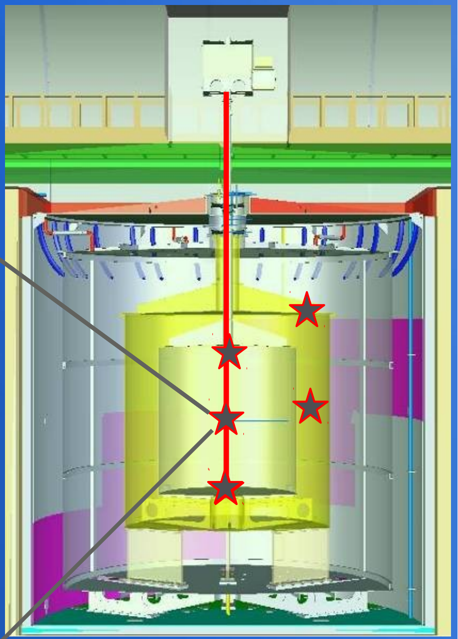


Calibration

- **Energy calibration:**
  - PMT and electronics gain non-linearity calibration
    - LED light injection system
  - Correction for position dependence & stability
    - Spallation neutron captures on H and Gd
  - Energy scale
    - Radioactive sources deployed into ν-target and γ-catcher
- **Neutron detection efficiency:**
  - Energy & time window, Gd fraction, spill in/out effects
    - ^{252}Cf source deployed into ν-target and γ-catcher

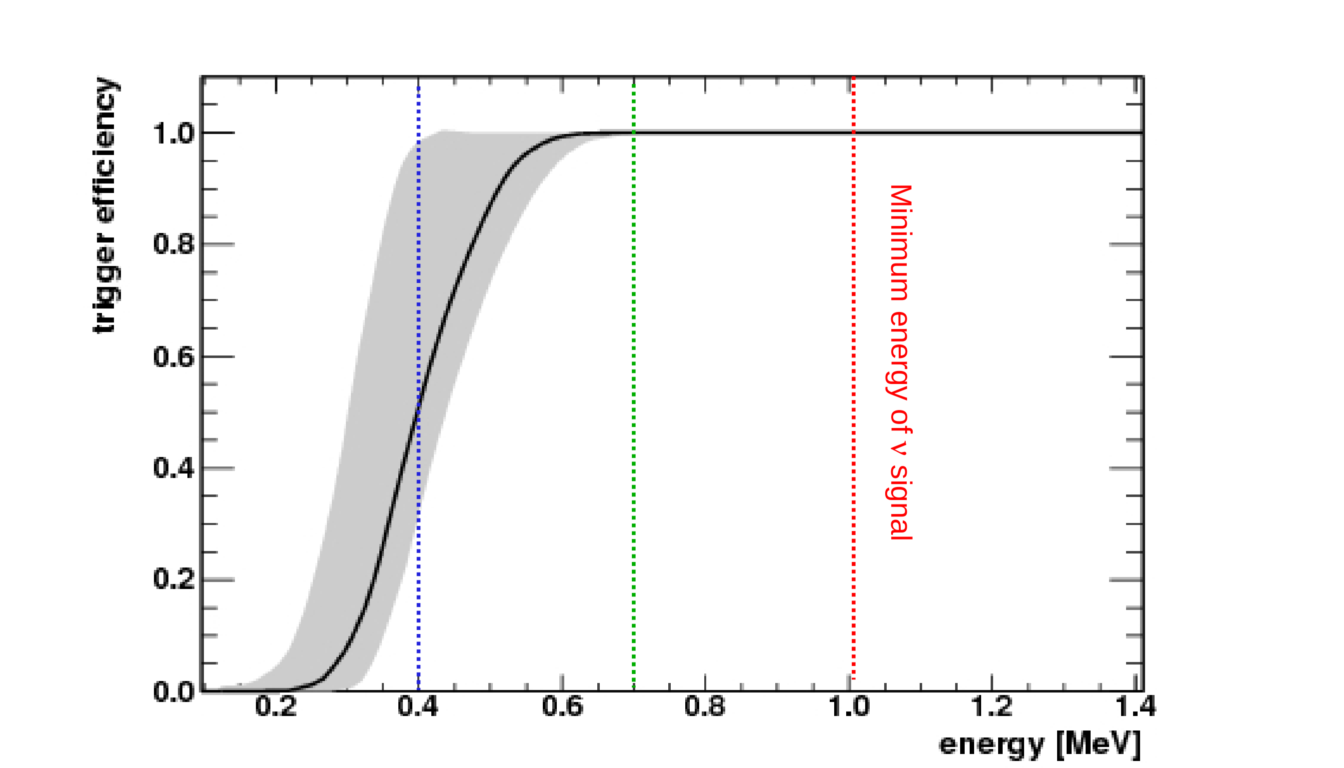






Neutron detection efViciency

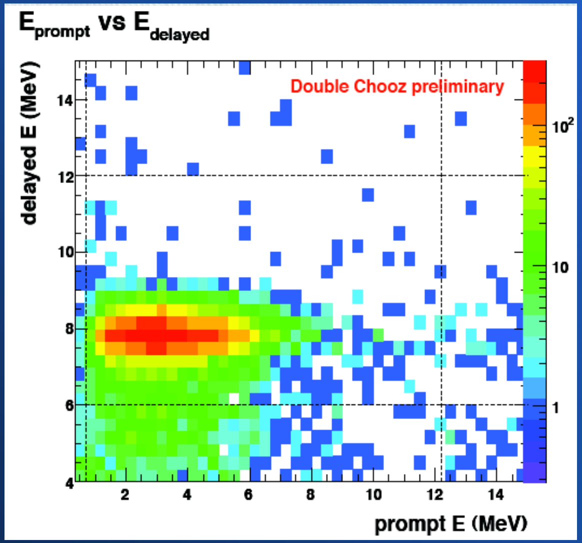
Trigger Efficiency

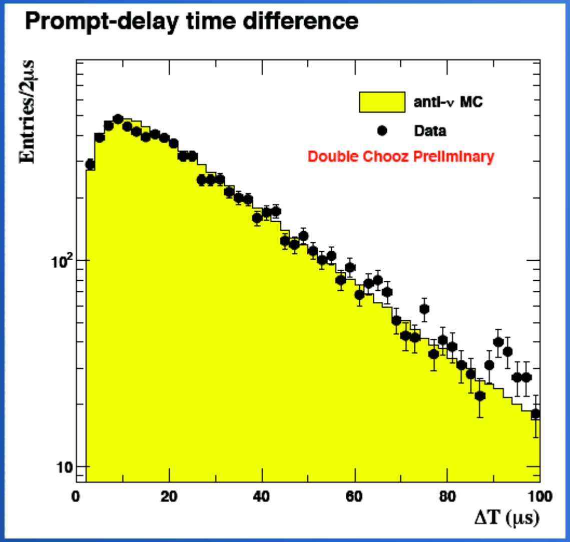


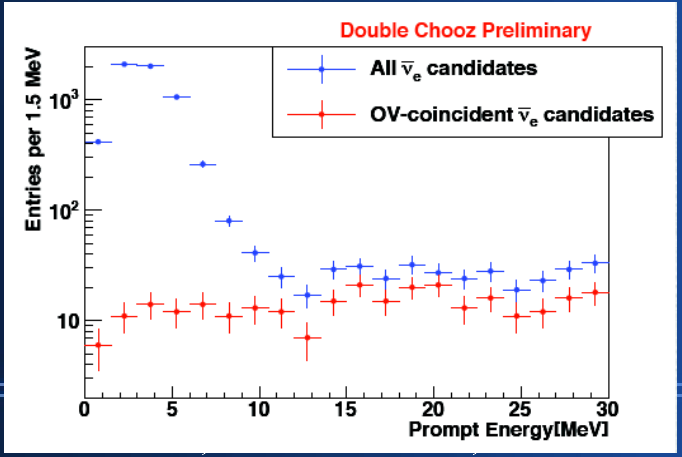
- Threshold at 400keV (ε=50%)
- ε =100% above 700keV

Neutrino Selection

- **Muon veto**
  - No coincidence signal in IV
  - $\Delta t_{\mu} > 1$ msec
- **Prompt event**
  - 0.7 < Evis < 12.2 MeV
  - PMT Light noise cuts
- **Delayed event**
  - 6 < Evis < 12 MeV
  - PMT Light noise cuts
- **Delayed coincidence**
  - 2 < Δt < 100 μsec
- **Multiplicity**
  - No extra events around signal







- **Further BG reduction:**
  - $\Delta t_{\mu} > 500$ msec
    - Eμ > 600MeV
  - No coincidence signal in OV

Reactor Neutrino Simulation

- Reactor ν flux — MURE (DRAGON, ...)
- IBD Process — Custom made
- Detector — Geant4
- Readout/trigger — Custom made

Data → Reconstruction → Selection

Neutrino yield per fission

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

$$\langle \sigma_f \rangle = \langle \sigma_f \rangle^{Bugey} + \sum_k \left(\alpha_k^{DC}(t) - \alpha_k^{Bugey} \right) \langle \sigma_f \rangle_k$$

Bugey4 measurement as anchor point

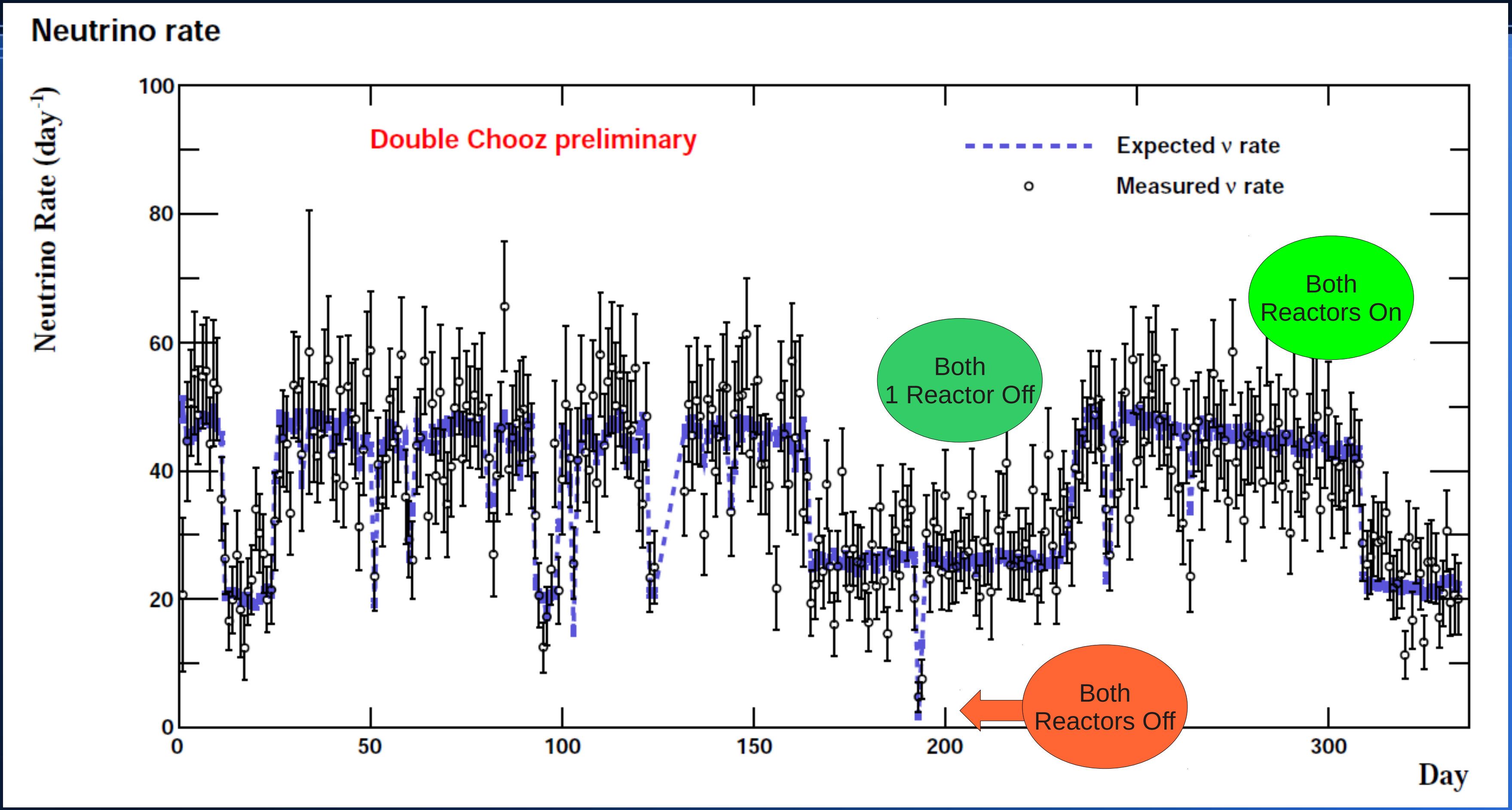
Fission fraction in CHOOZ core

New ν flux reference

Phys.Rev. C83(2011) 054615, Phys.Rev. C84 (2011) 024617

Uncertainty on ν flux using Bugey4: 2.7% → 1.8%

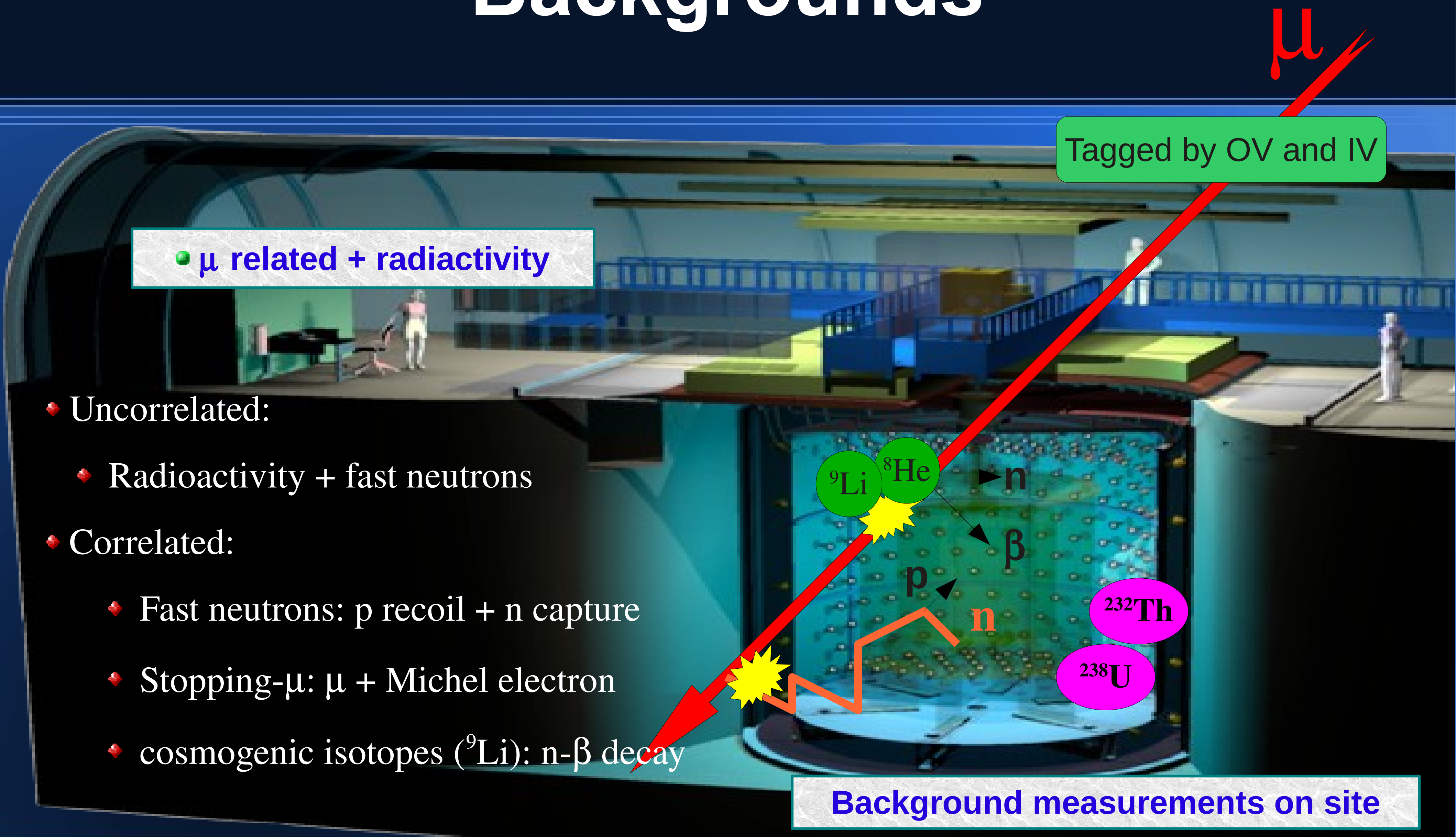
Neutrino Candidates



- No 9Li reduction and OV veto
- Background not subtracted

- Rate evolution consistent with expectation

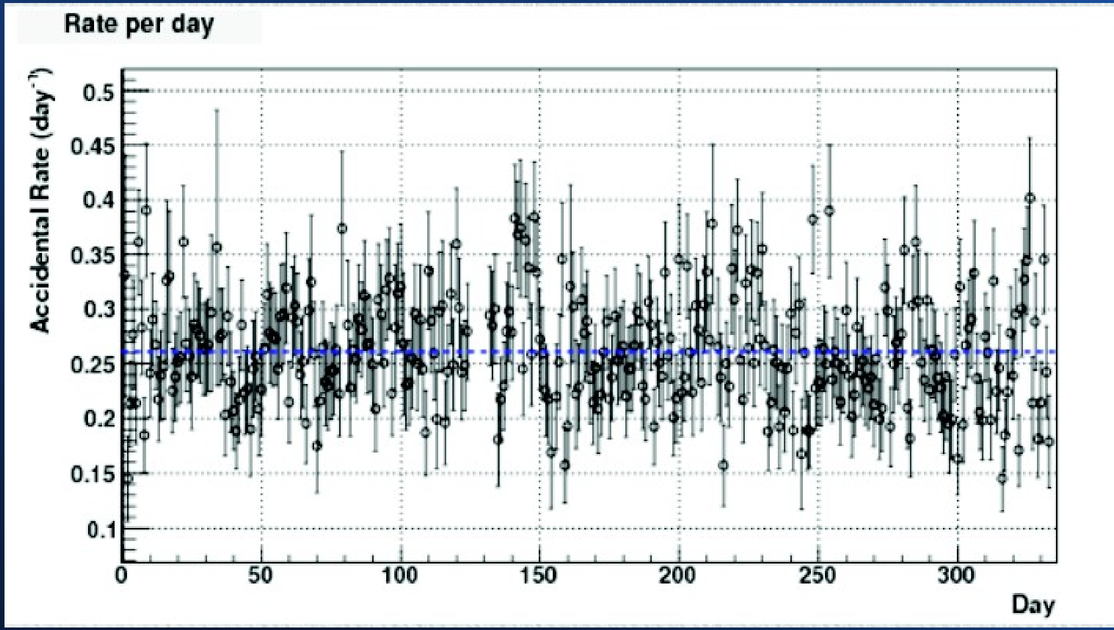
Backgrounds

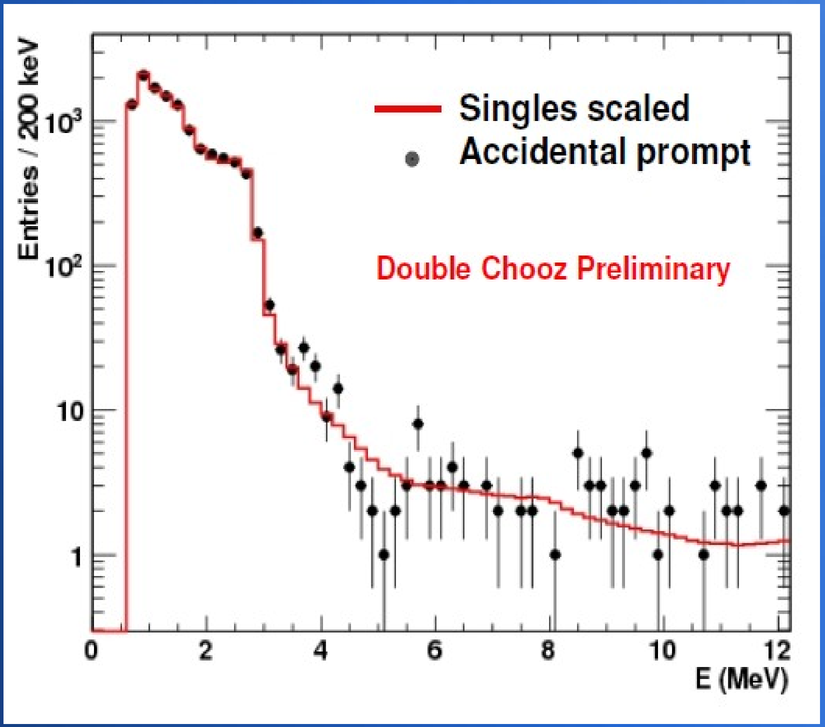


- Uncorrelated:
  - Radioactivity + fast neutrons
- Correlated:
  - Fast neutrons: p recoil + n capture
  - Stopping-μ: μ + Michel electron
  - cosmogenic isotopes (^{9}Li): n-β decay

Backgrounds: Accidentals

- Accidental coincidence:
  - E.g. Environmental γ + Fast-n



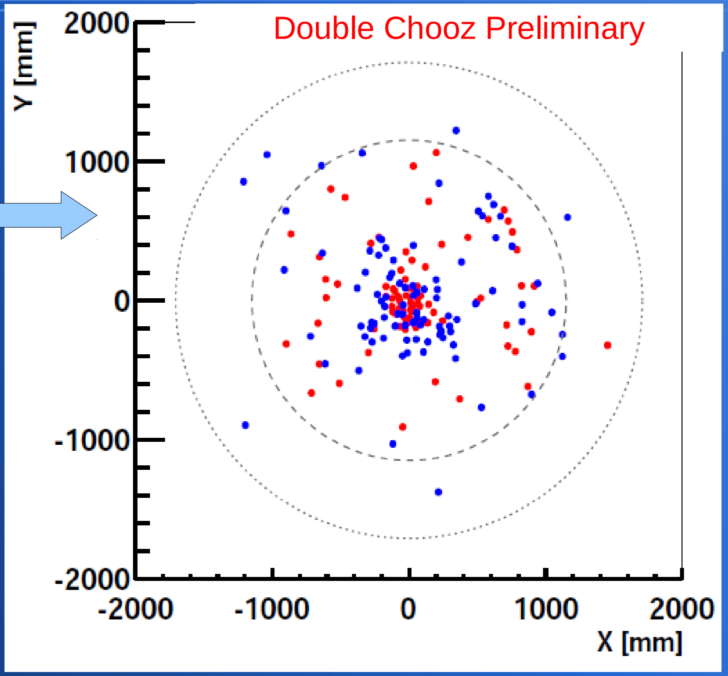


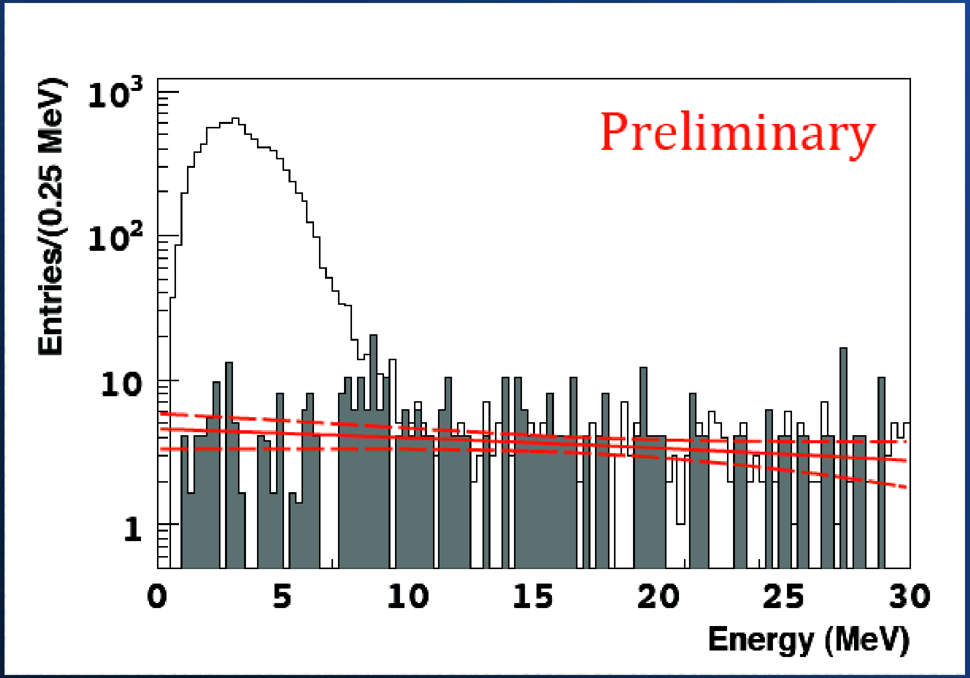
BG estimated from coincidence in off-time window

R = 0.261±0.002 event/day

Backgrounds: Fast-n + Stop-μ

- Fast-n: proton recoil+ capture on Gd
- Stop-μ: μ + Michel e (mostly tagged by OV)



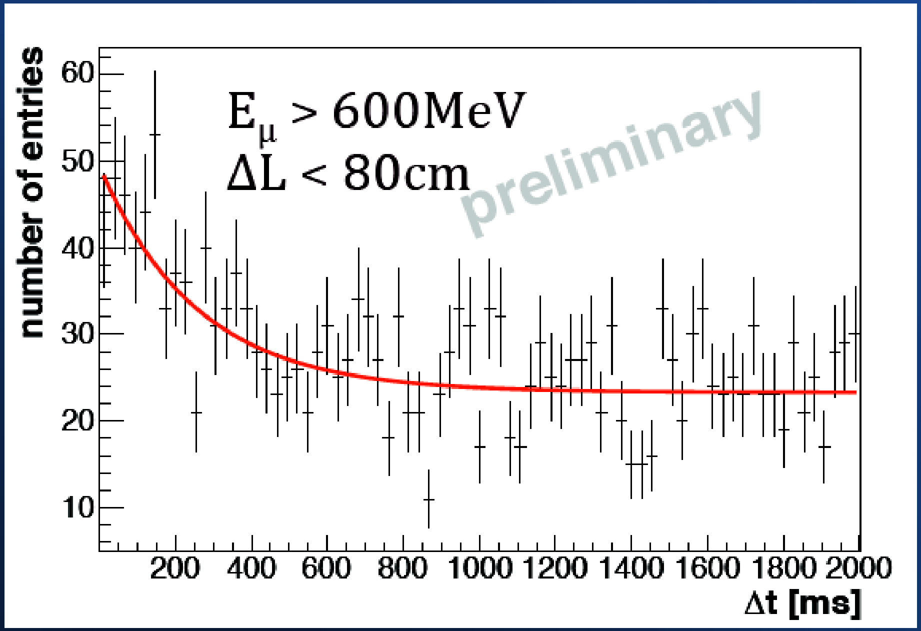


Estimated from IV and OV coincident events:

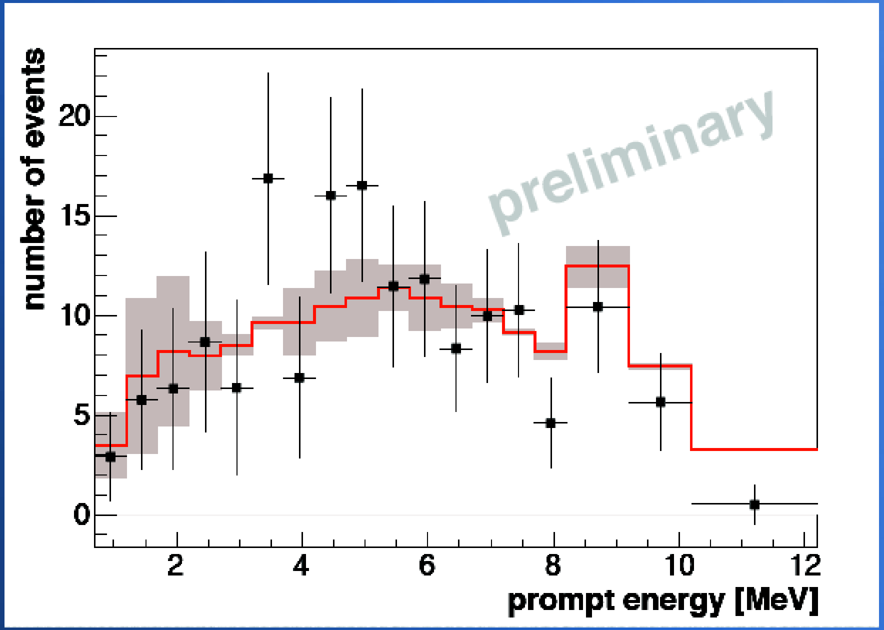
R = 0.67 ± 0.20 event/day

Backgrounds: ^{9}Li

- Spallation product from μ:
  - $^{9}Li \rightarrow e^- + n + {}^{8}Be$ (τ ~ 200 ms)



Rate estimated from spatial and time coincidence with muons



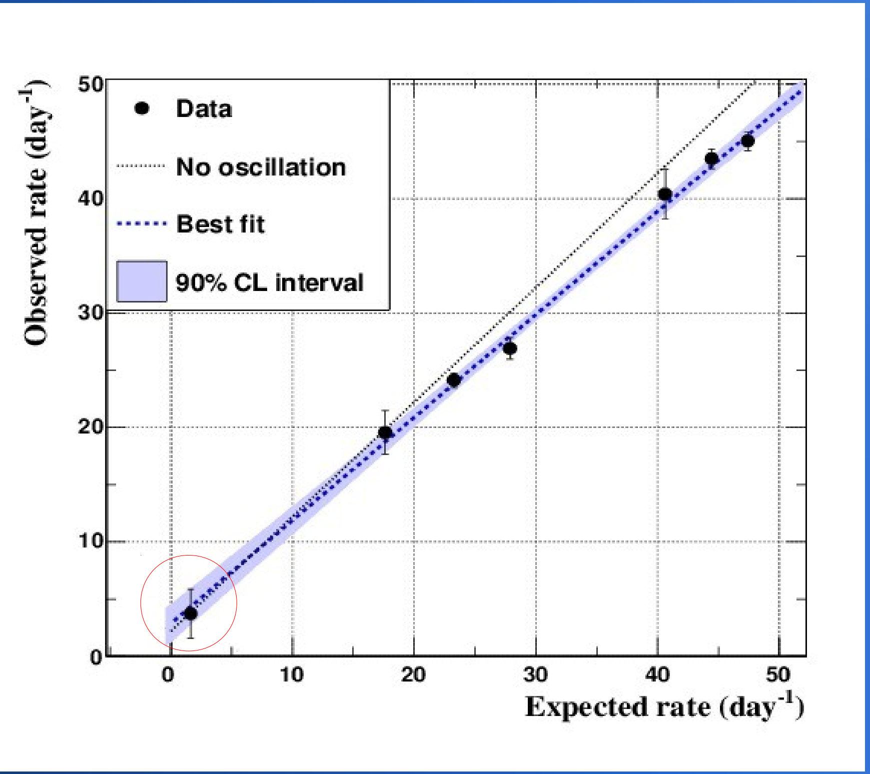
R = 1.20 +0.59/–0.48 event/day

R = 2.05 +0.62/-0.52 event/day

without ^{9}Li reduction

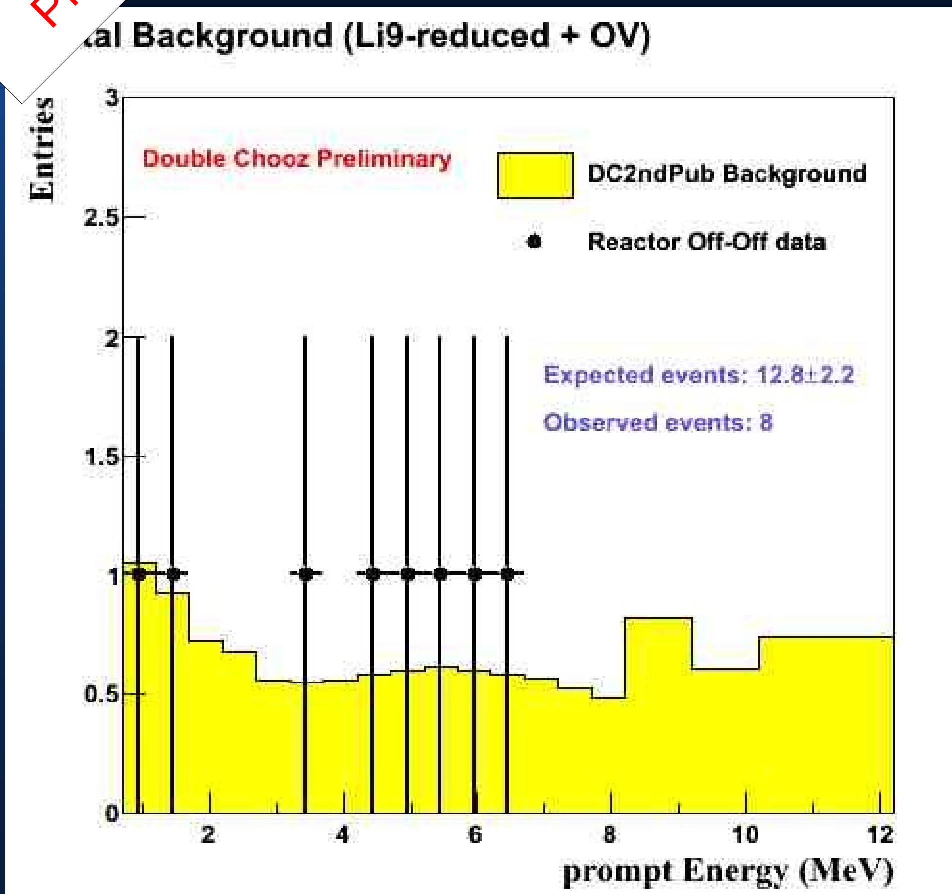
Total Background: Reactor Off-Off

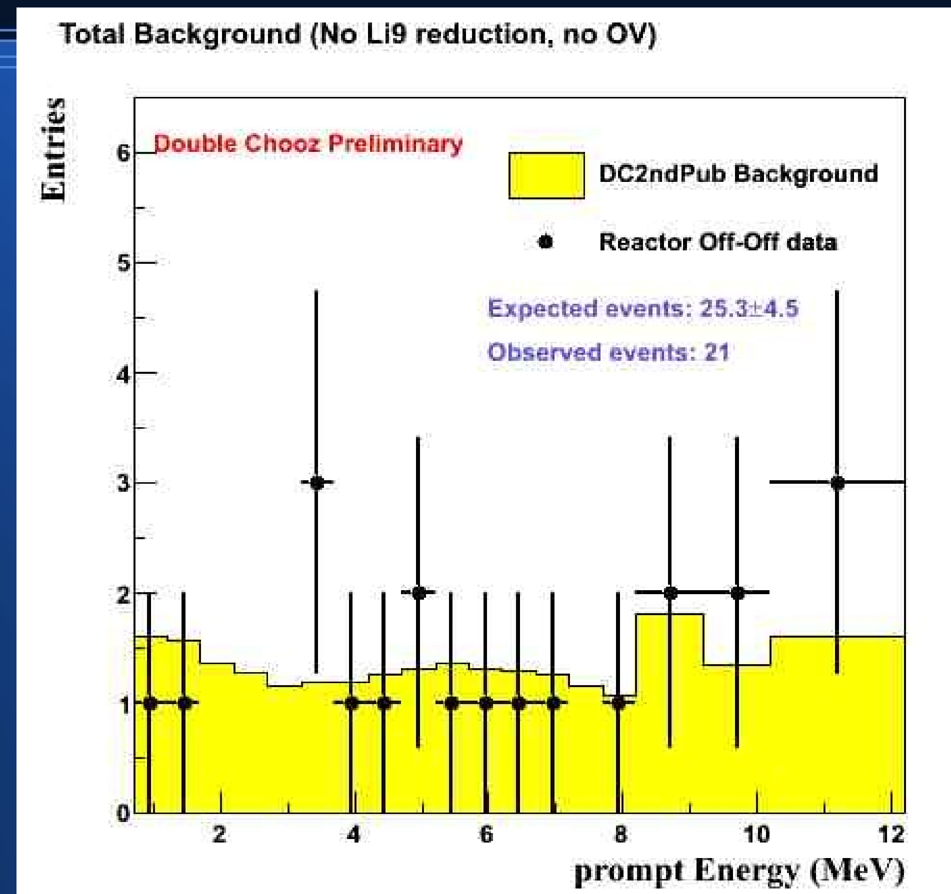
- live-time with both reactors off: 0.84 day
  - Total background rate = 2.2 event/day (two events)
- Consistent with estimation:
  - 2.2 ±0.6 event/day
- Best fit to expected rate:
  - 2.9 ± 1.1 event/day
- 7.53 more days with off-off data:
  - Analysis ongoing...



Preliminary

New Off-Off Data





- Background rate: 1.0 ± 0.4 events/day
  - Expected: 1.7 ± 0.3 events/day

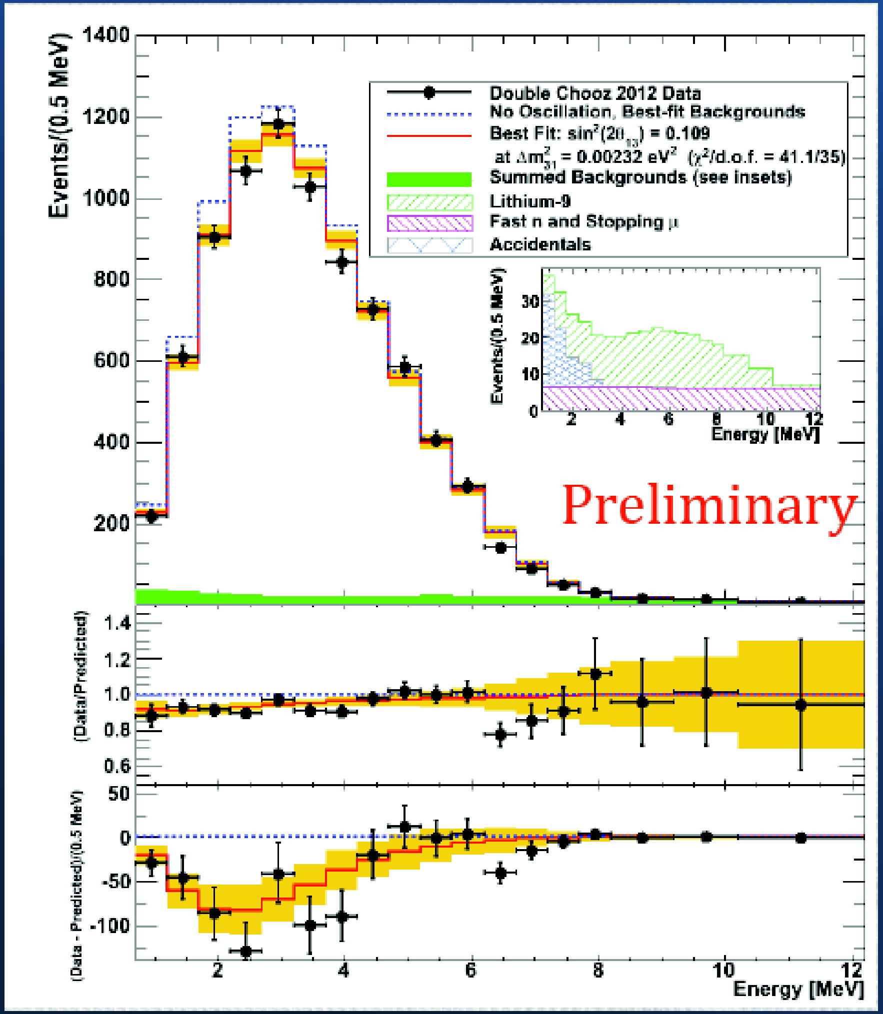
- Background rate: 2.7 ± 0.6 events/day
  - Expected: 3.4 ± 0.6 events/day

Rate Systematic Uncertainties

Preliminary

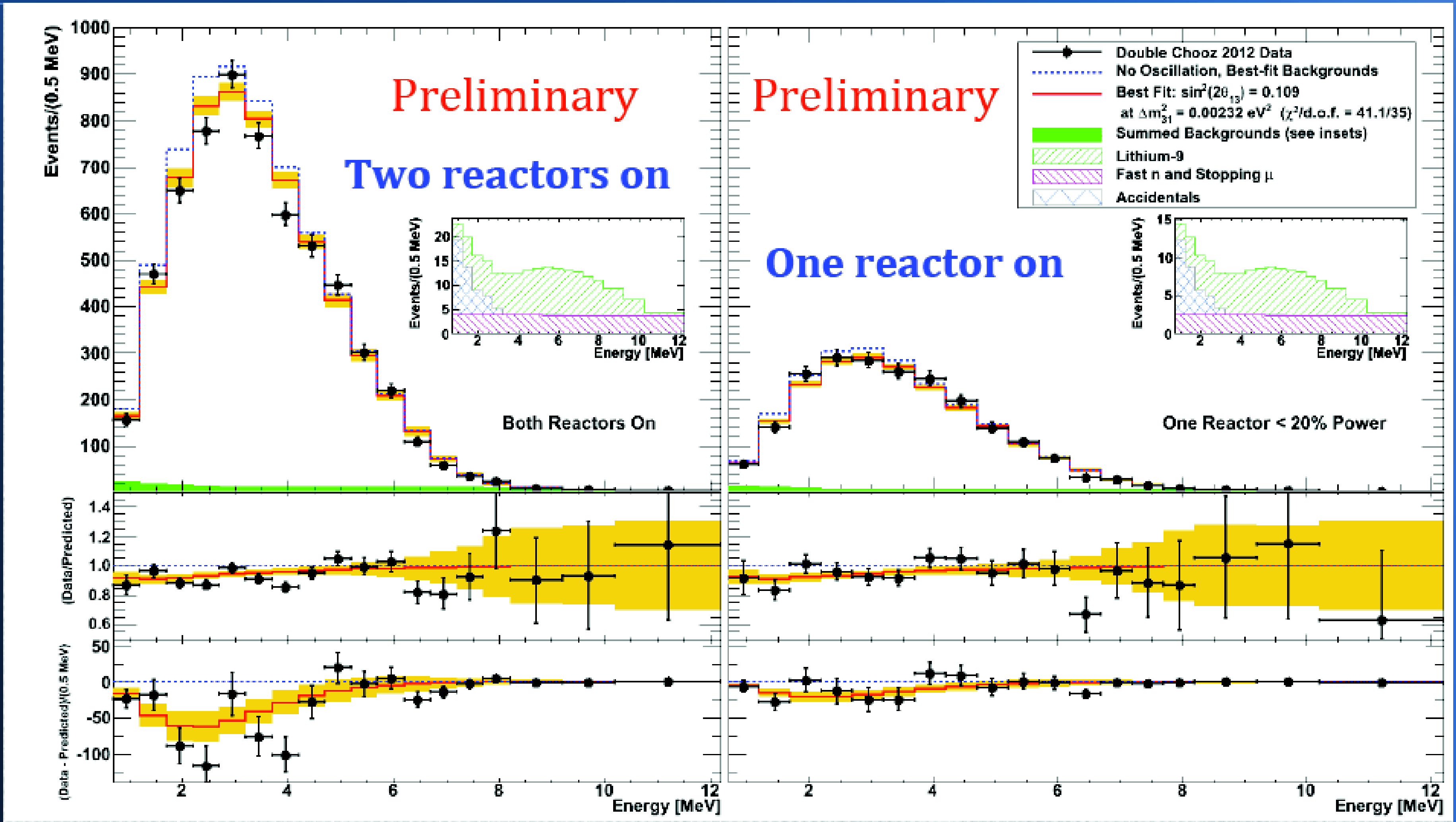
Source		Uncertainty w.r.t. signal (previous analysis)	
Statistics		1.1% (1.6%)	
Flux		1.7%	
Detector	Energy response	0.3% (1.7%)	1.0% (2.1%)
	E_{delay} containment	0.7%	
	Gd fraction	0.3%	
	Δt cut	0.5%	
	Spill in/out	0.3%	
	Trigger efficiency	<0.1%	
	Target H	0.3%	
Background	Accidental	<0.1%	1.6% (3.0%)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

Oscillation Results



- Rate only:
- $\sin^2(2\theta_{13})$ = 0.170 ±0.035(stat) ±0.040(syst)
- Rate+Shape:
- $\sin^2(2\theta_{13})$= 0.109 ±0.030(stat) ±0.025(syst)
- χ^2/dof = 41/35
- $\sin^2(2\theta_{13})$ = 0 excluded at 99.9% (3.1σ) (frequentist study)

Oscillation Results (II)



ND and Future Projects

- Near detector:
- ND laboratory excavation completed
- Start data taking by end of 2013

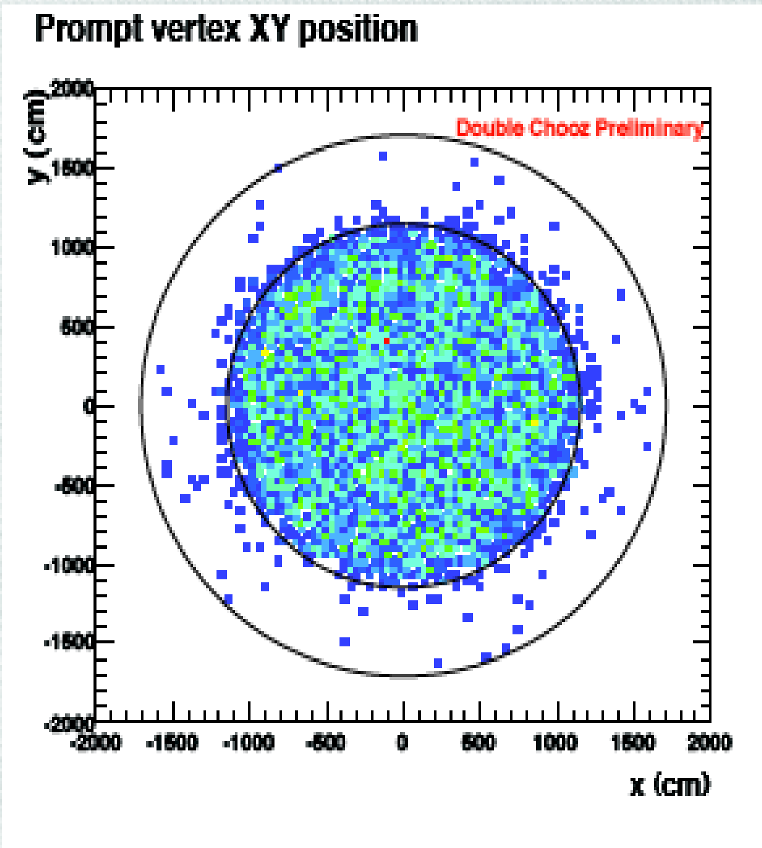
- Increase statistics
- Precise measurement of θ_{13}
  - CP violation, mass hierarchy
- Test unitarity of mixing matrix – sterile neutrino admixture ?
- Other physics possibilities
  - n-H capture event analysis
  - Neutrino directionality study
  - ^{9}Li from muon capture
  - Constraint to $|\Delta m_{31}^2|$
  - Lorentz violation

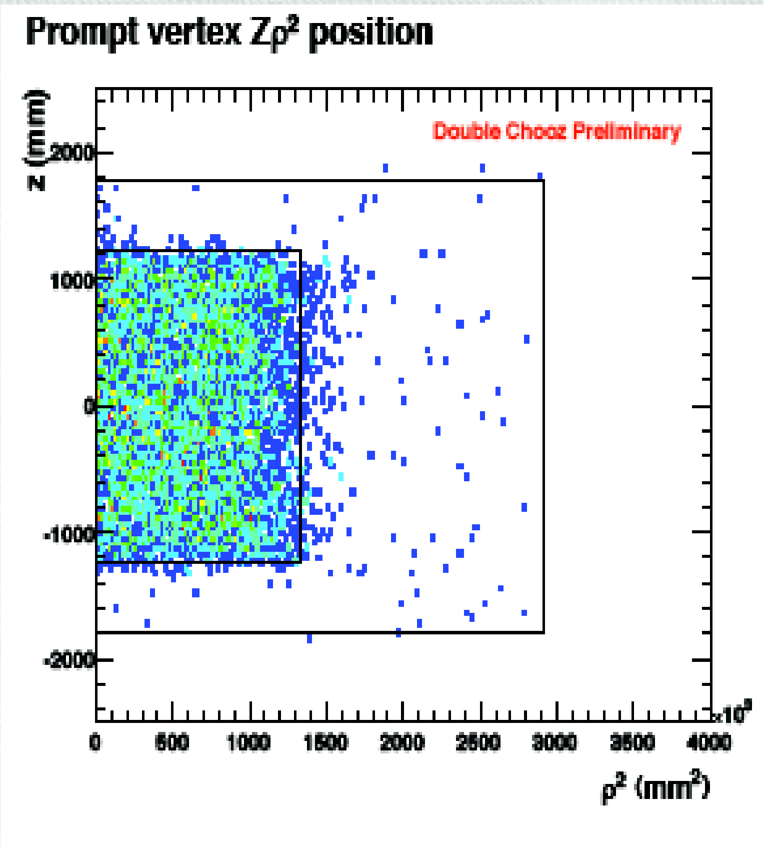
Summary

- Double Chooz new results on θ_{13}
- Doubled statistics: 4121 $\rightarrow$ 8249 ν candidates
- Improved analysis:
  - Background reduction
  - Systematics reduction
- $\sin^2(2\theta_{13}) = 0.109 \pm 0.030$ (stat) ± 0.025 (syst)
- Null oscillation excluded at 99.9% (3.1σ)

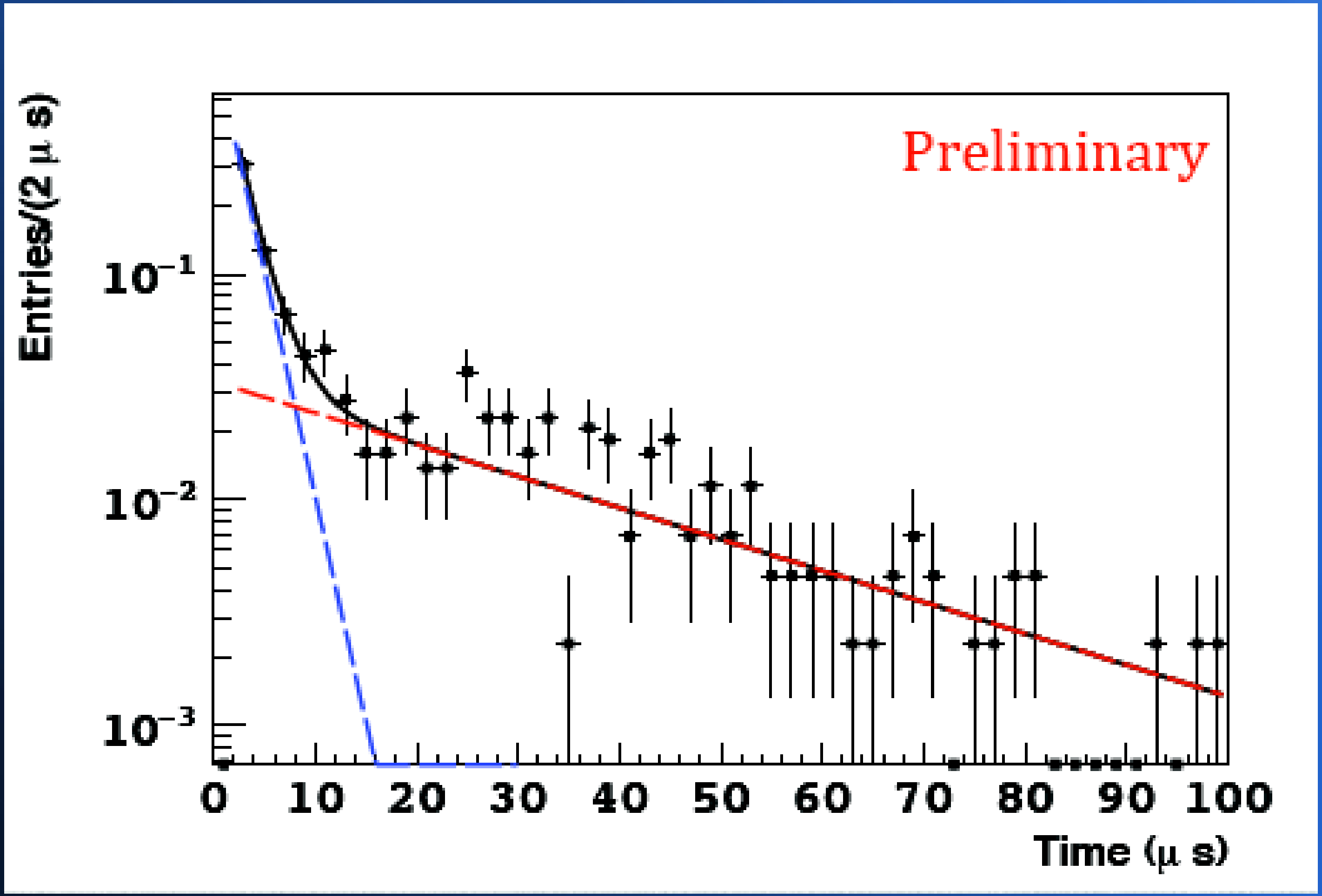
Tank you!

Neutrino Vertex





Stop-μ vs Fast-n



Pull terms

Source		Input	Output
Background	Fast neutron + stop μ	0.67±0.20 cpd	0.64±0.13 cpd
	^{9}Li	1.20±0.52 cpd	0.96±0.27 cpd
Energy scale		±1.1%	−1.4±0.7%
Δm^2		$(2.32\pm0.12)\times10^{-3}$eV^2	$(2.32\pm0.12)\times10^{-3}$eV^2