



African School of Fundamental
Physics and Applications

STUDY OF MUON INDUCED BACKGROUND IN DOUBLE CHOOZ NEUTRINO OSCILLATION EXPERIMENT

By
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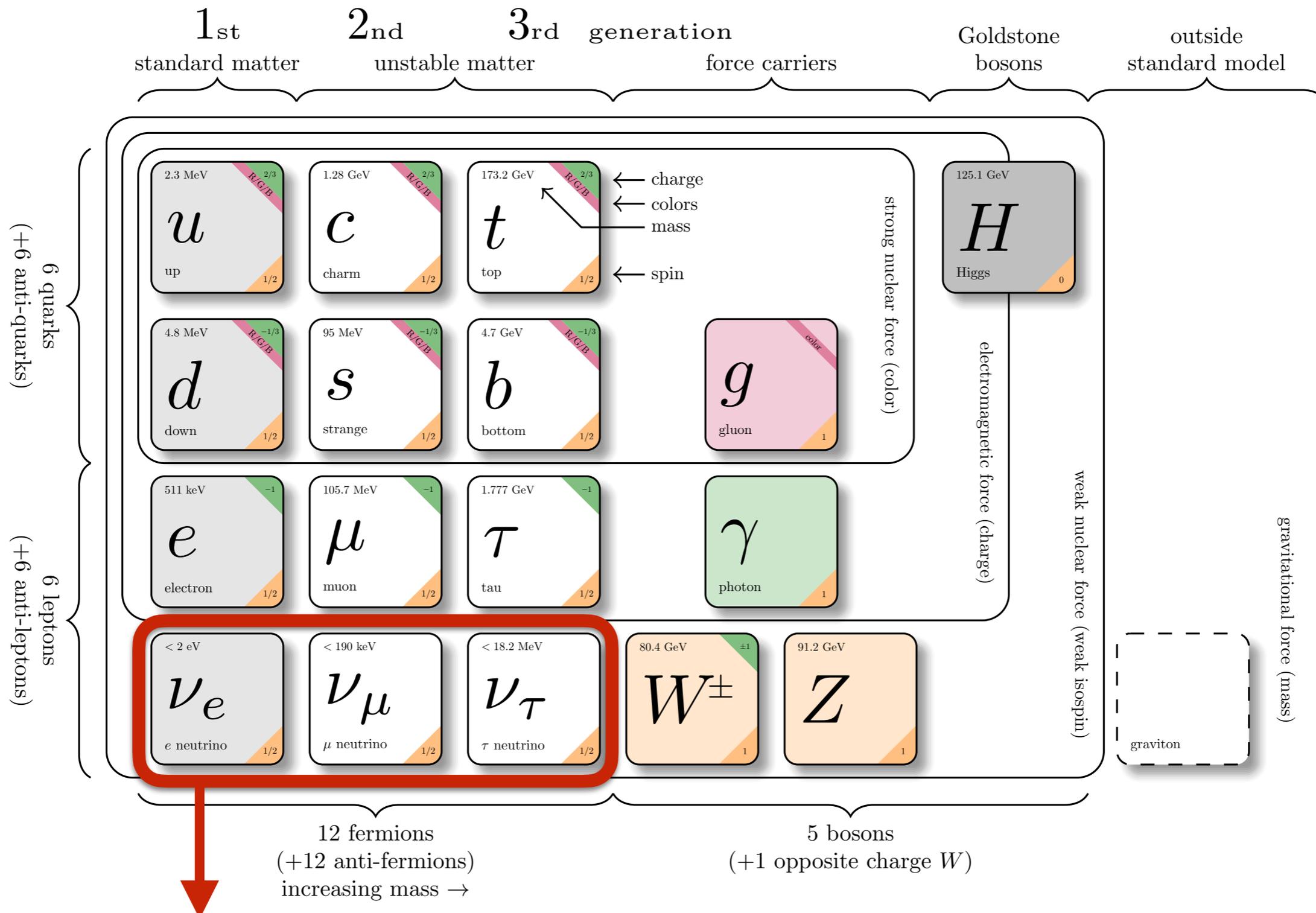
***2018 PhD in Particle Physics
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Particle physics research***

- Neutrinos in the Standard Model.
- Neutrino oscillations.
- Double Chooz experiment.
- Muon induced background.
- Conclusions.

NEUTRINOS IN THE STANDARD MODEL

NEUTRINOS IN THE STANDARD MODEL



3 NEUTRINO FLAVORS

Particular particles

- Neutral leptons.
- Most abundant in universe: **336 cosmic neutrinos/cm³**.
- Each second **10¹⁴ neutrinos** traverse your body.
- There exist only **left-handed neutrinos and right-handed antineutrinos**
- In the standard model neutrinos are massless but **we know now that they do have a mass !**
- As a consequence: **neutrinos oscillate.**

Neutrinos flux from the sun is lower than predictions of solar standard model (SSM).

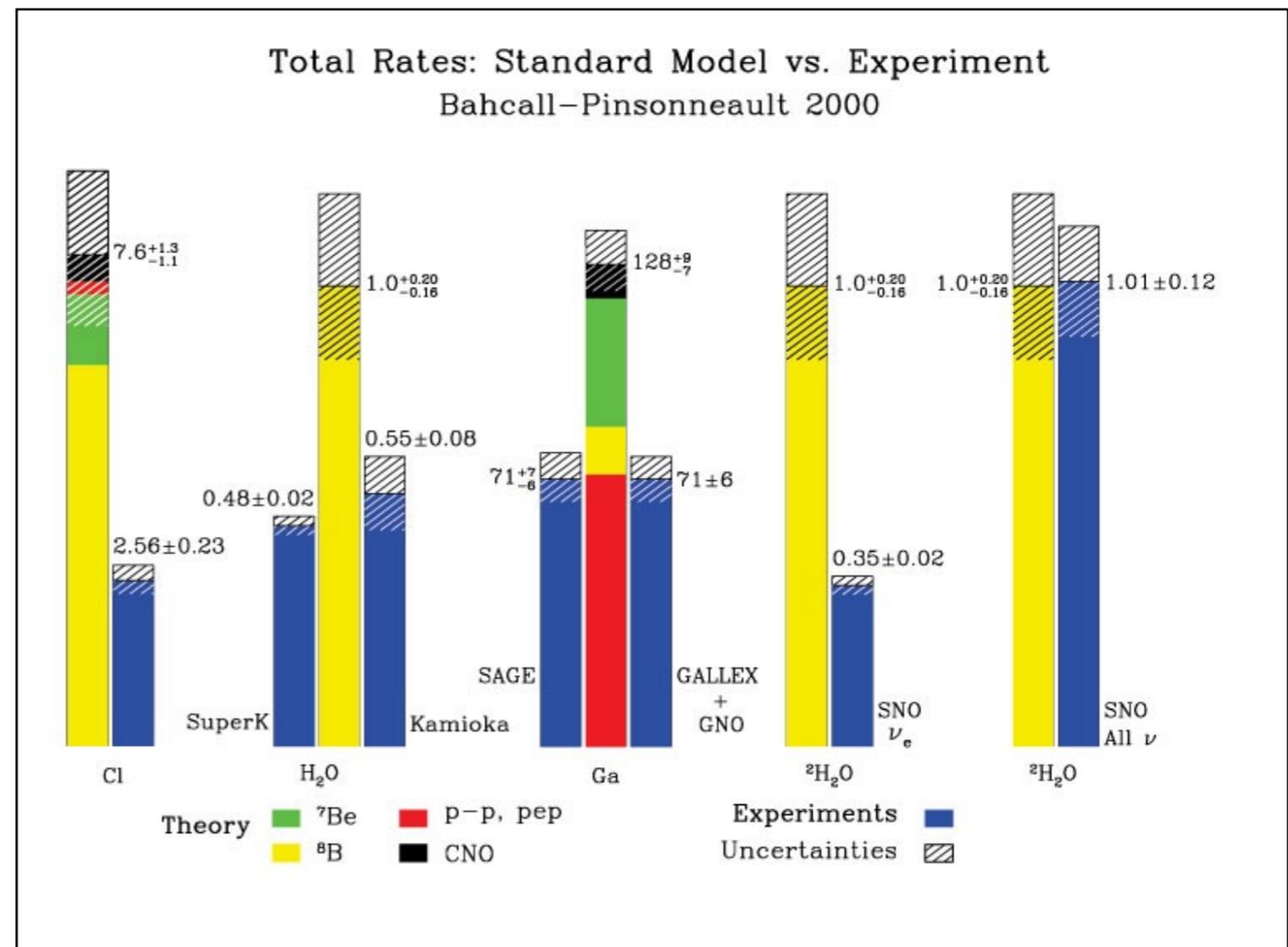
SNO EXPERIMENT

$$\Phi_e = 1.76_{\pm 0.48(stat)}^{\pm 0.45(syst)} \times 10^6 \text{ cm}^2 \text{ s}^{-1}$$

$$\Phi_{\mu,\tau} = 3.41_{\pm 0.45(stat)}^{\pm 0.48(syst)} \times 10^6 \text{ cm}^2 \text{ s}^{-1}$$

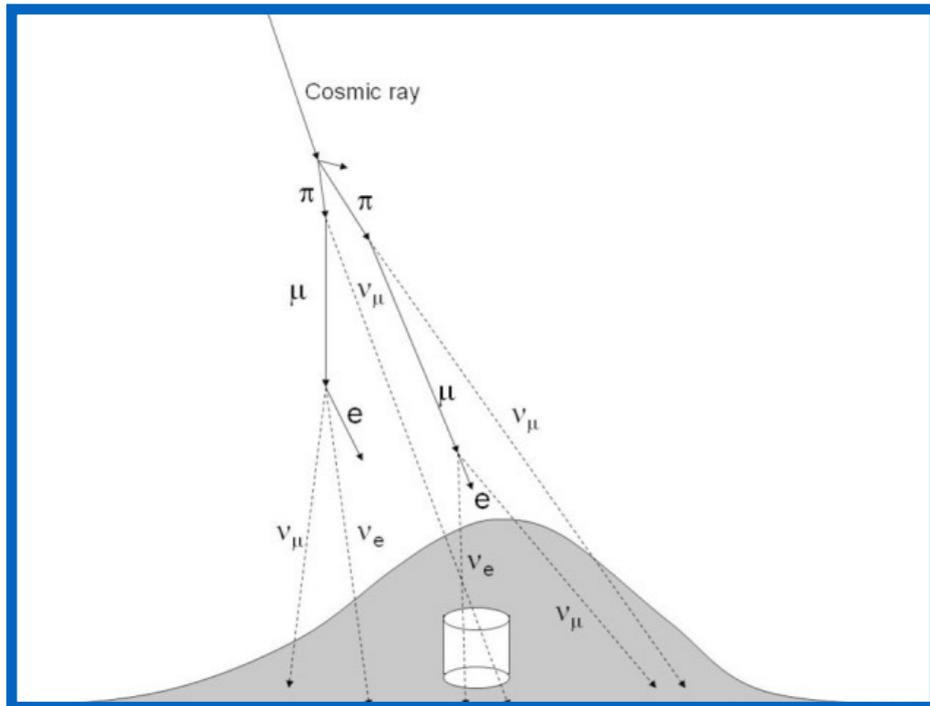
SSM PREDICTION

$$\Phi_{SSM} = 5.05_{-0.81}^{+1.01} \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$$



$\Phi_e + \Phi_{\mu,\tau} \simeq \Phi_{SSM} \rightarrow$ **neutrinos oscillate !**

Atmospheric neutrinos are produced when cosmic rays interact with nuclei in the air in the upper atmosphere.

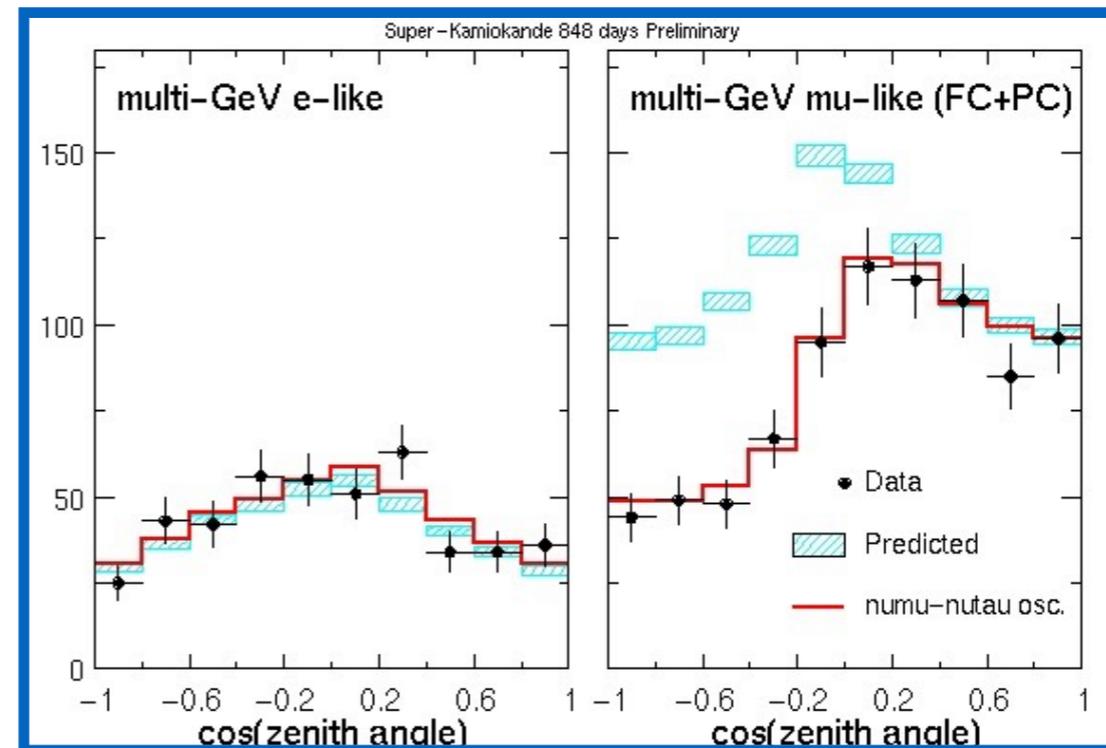
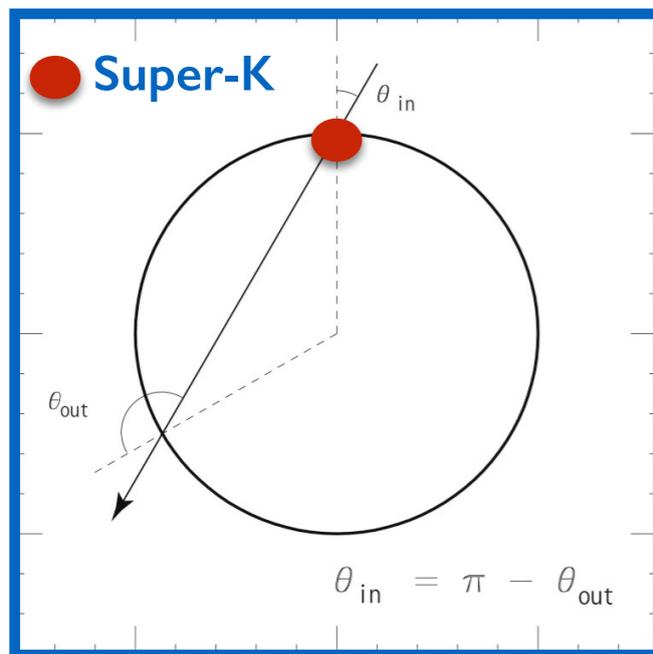


● **Ratio :**

$$R(\nu_{\mu}/\nu_e) = \frac{[(\nu_{\mu} + \bar{\nu}_{\mu})/(\nu_e + \bar{\nu}_e)]_{exp}}{[(\nu_{\mu} + \bar{\nu}_{\mu})/(\nu_e + \bar{\nu}_e)]_{th}}$$

is expected to be equal to 1.

● **Super-K :** $R = 0.68 \pm 0.02(stat) \pm 0.05(syst)$



The relative deficit of “up-going” muon neutrinos establishes the disappearance of these muon neutrinos via oscillation.

State of art of neutrinos parameters

Parameter	best-fit	3σ
Δm_{21}^2 [10^{-5} eV ²]	7.37	6.93 – 7.97
$ \Delta m^2 $ [10^{-3} eV ²]	2.50 (2.46)	2.37 – 2.63 (2.33 – 2.60)
$\sin^2 \theta_{12}$	0.297	0.250 – 0.354
$\sin^2 \theta_{23}, \Delta m^2 > 0$	0.437	0.379 – 0.616
$\sin^2 \theta_{23}, \Delta m^2 < 0$	0.569	0.383 – 0.637
$\sin^2 \theta_{13}, \Delta m^2 > 0$	0.0214	0.0185 – 0.0246
$\sin^2 \theta_{13}, \Delta m^2 < 0$	0.0218	0.0186 – 0.0248
δ/π	1.35 (1.32)	(0.92 – 1.99) ((0.83 – 1.99))

$$\Delta m^2 = m_3^2 - (m_1^2 + m_2^2)/2$$

Still open questions...

Are neutrinos their own antiparticles ?

What is neutrinos absolute masses ? ?

What is the mass hierarchy ?

Do neutrinos violate CP symmetry ?

What do neutrino tell us about universe ?

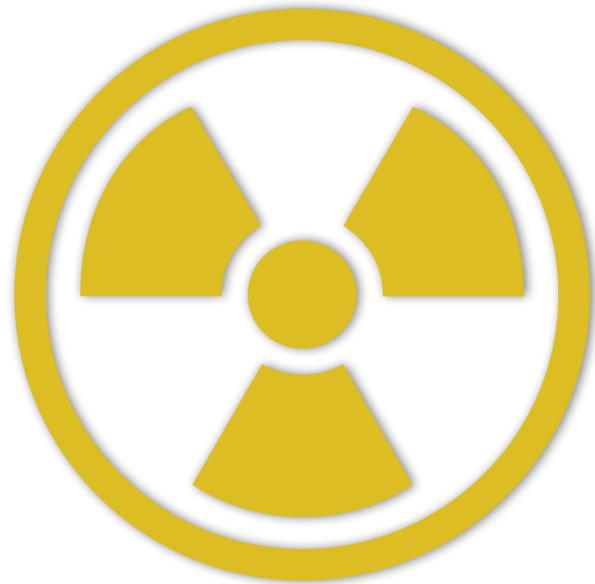
Are there more than 3 light neutrinos ?

Do neutrinos have non standard interactions ?

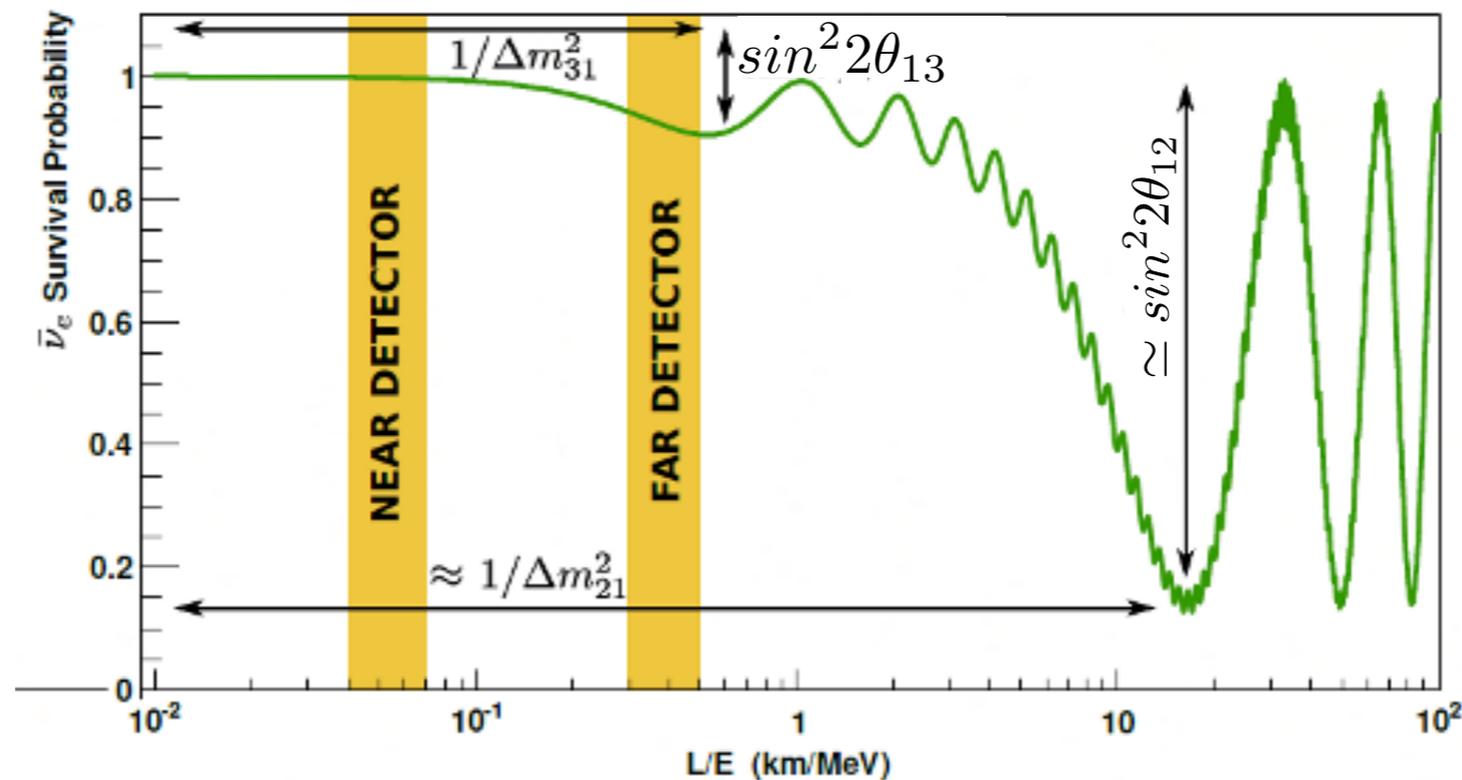
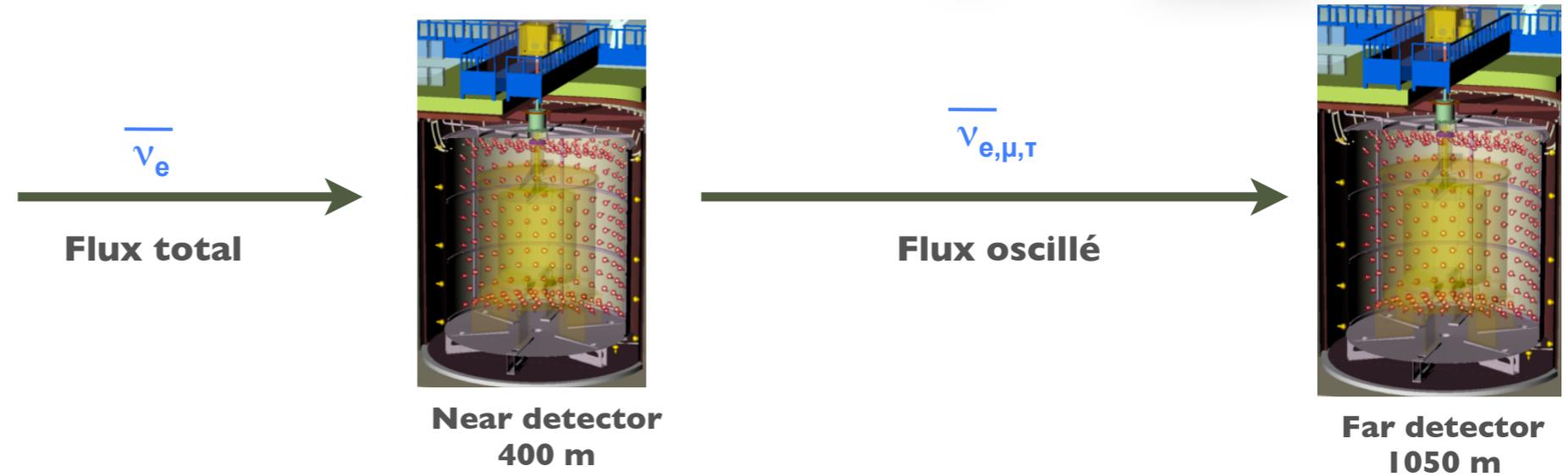
And more...

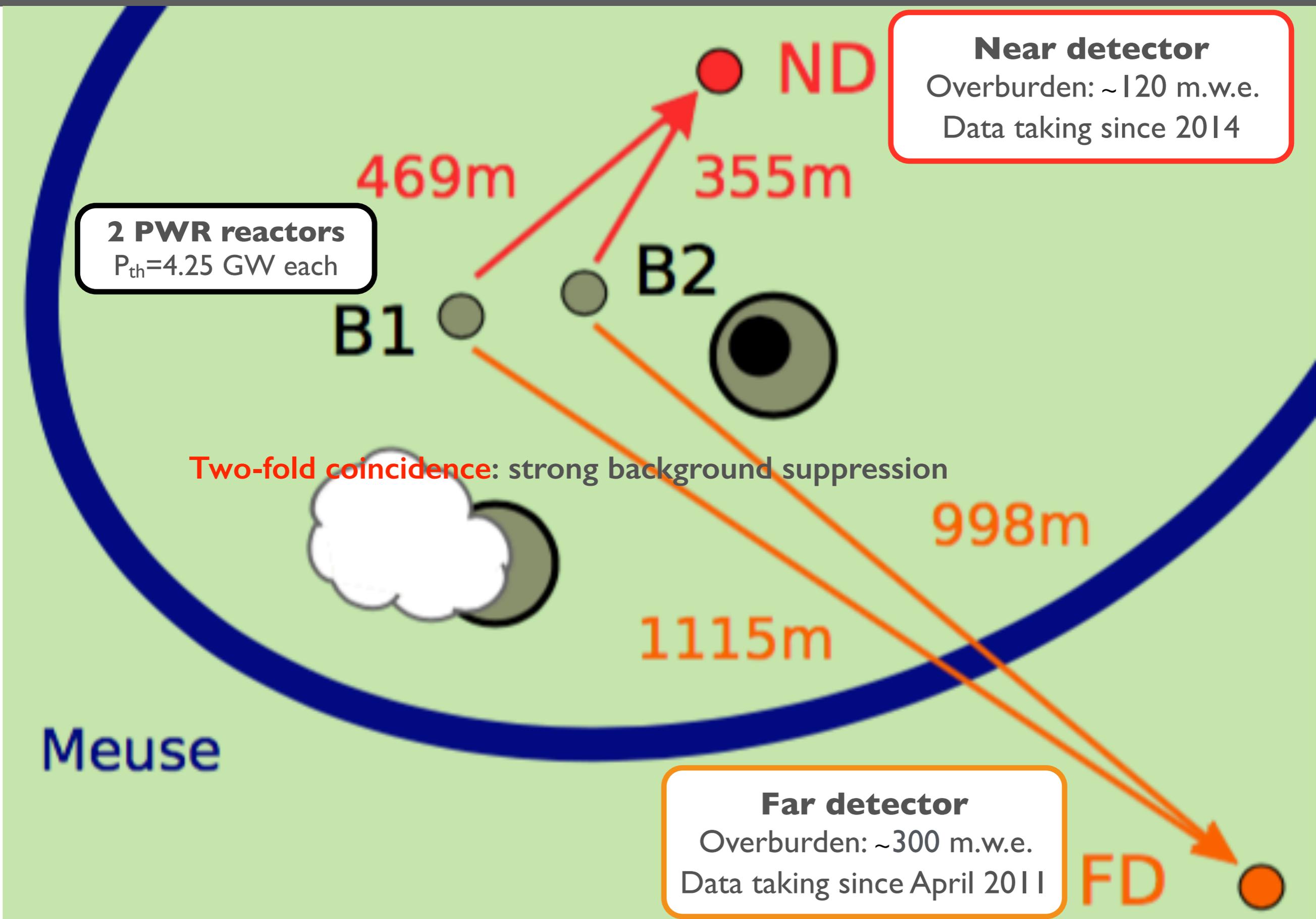
DOUBLE CHOOZ EXPERIMENT

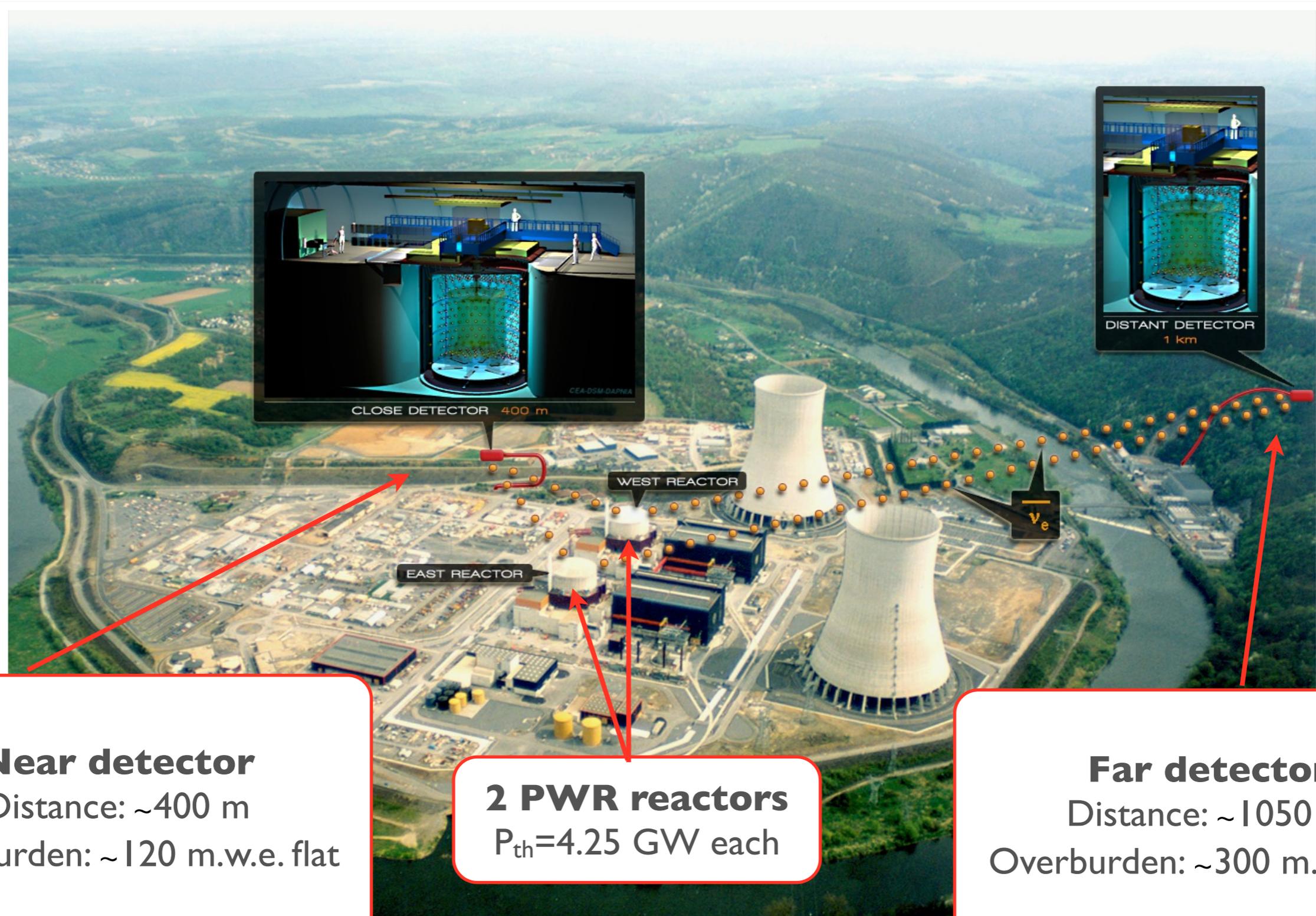
Probability of disappearance:
$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \simeq 1 - \sin^2(2\theta_{13}) \sin^2 \left(1.27 \frac{\Delta m_{32}^2 (\text{eV}^2) L(\text{m})}{E(\text{MeV})} \right)$$



Chooz Nuclear plant
2 réacteurs de 4.25 GW_{th} each





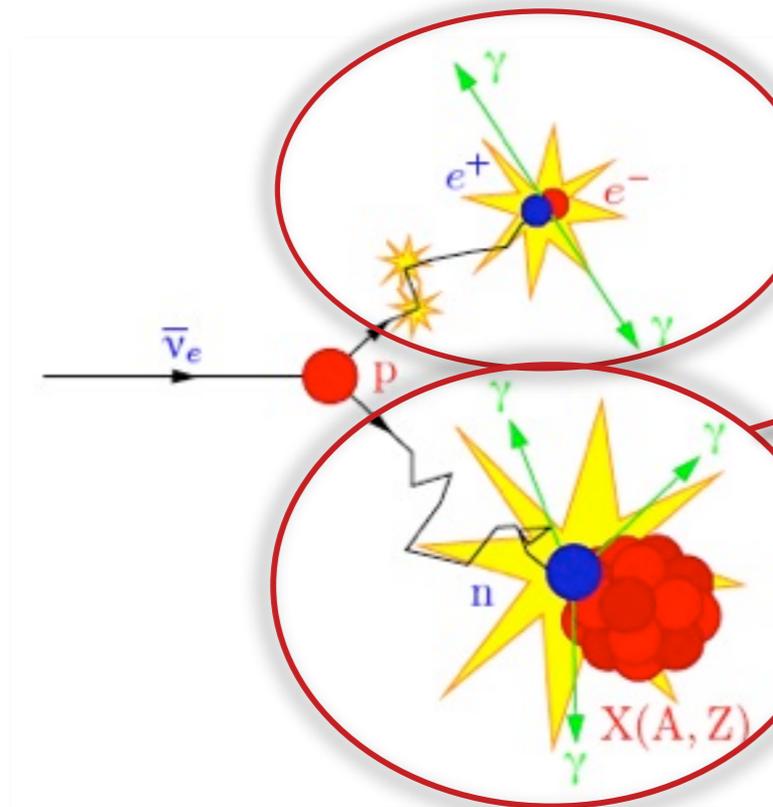


Near detector
 Distance: ~400 m
 Overburden: ~120 m.w.e. flat

2 PWR reactors
 $P_{th} = 4.25$ GW each

Far detector
 Distance: ~1050 m
 Overburden: ~300 m.w.e. hill

Inverse Beta Decay (IBD):
(Threshold à 1.8 MeV)

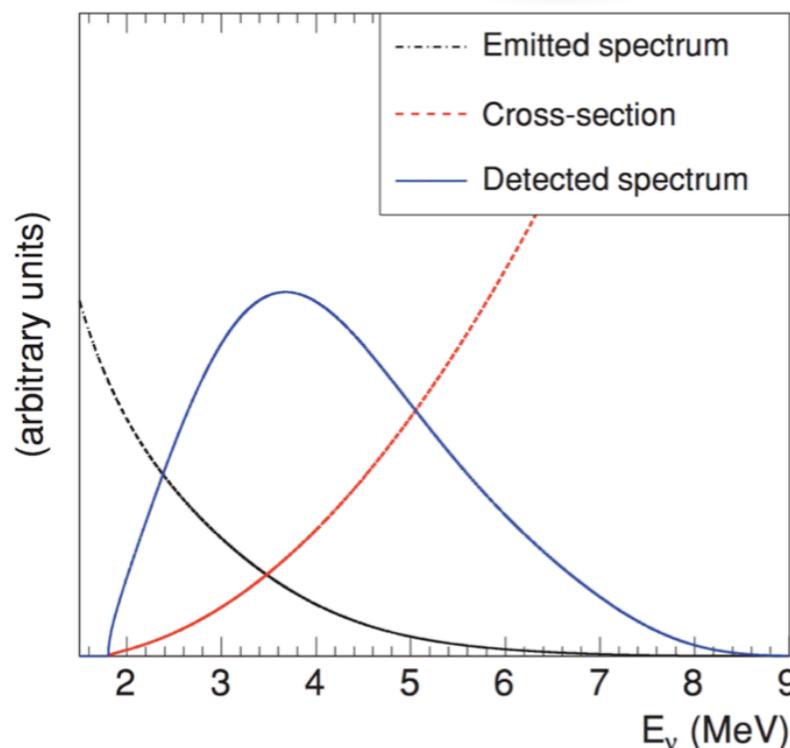


Prompt signal - Positron ionization+Annihilation

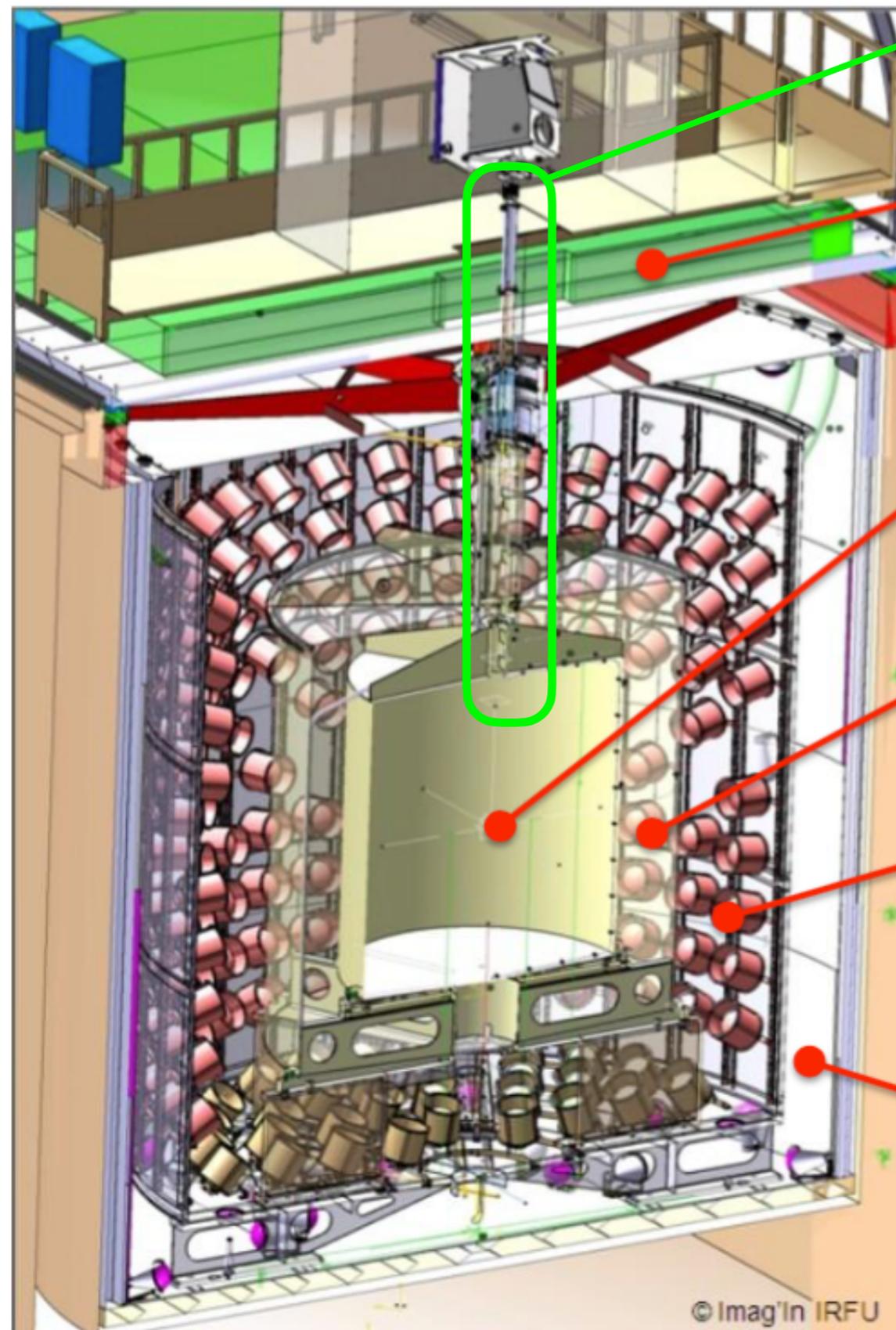
Delayed signal - capture of neutron by Gd (~ 8MeV)
Or H (2.2 MeV)

$\Delta t \sim 30 \mu s$ for neutron capture on Gd
 $\sim 200 \mu s$ for neutron capture on H

IBD selection



Delayed energy. : $1.3 < E_{vis} < 3 \text{ MeV (H)}$ or $4 < E_{vis} < 10 \text{ MeV (Gd)}$
Dist correlation. : $D_r < 1 \text{ m}$
Time correlation : $0.5 < D_t < 800 \mu s \text{ (H)}$ or $0.5 < D_t < 150 \mu s \text{ (Gd)}$



The Chimney

Outer Veto (OV):
Plastic scintillator strips

Inner Detector

ν -target (NT):

- Gd loaded liquid scintillator (10m^3)

γ -catcher (GC):

- Liquid scintillator (22m^3)

Buffer:

- Mineral oil (110m^3)
- 390 10-inch PMT

Inner Veto (IV):

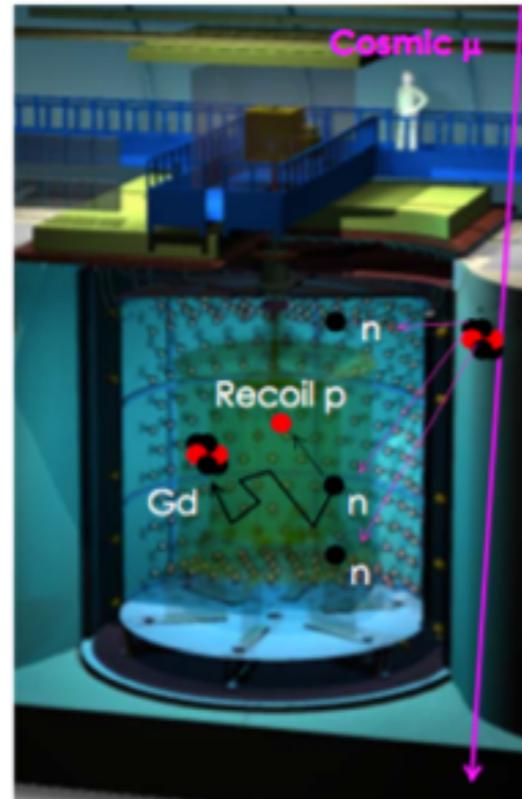
- Liquid scintillator (90m^3)
- 78 8-inch PMT

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Accidental BG

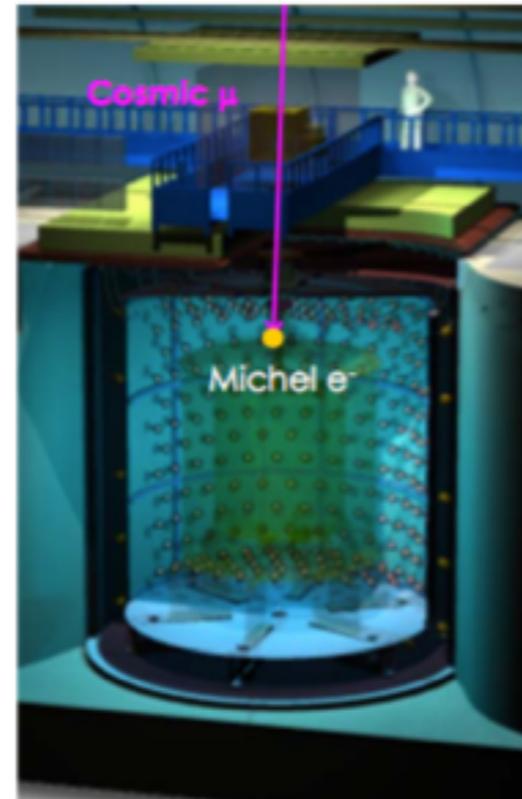


Fast neutrons

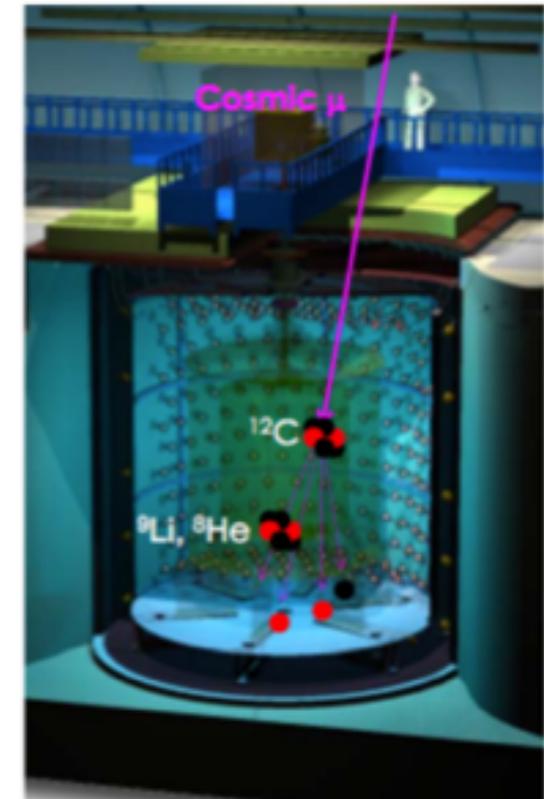


Correlated BG

Stopping μ



Cosmogenics



Prompt

Radioactivity from materials, PMTs, surrounding rock (²⁰⁸Tl).

Neutrons from cosmic μ spallation gives recoil protons (low energy).

Cosmic μ entering from the chimney.

Electrons from ⁹Li/⁸He β + n decays.

Delay

Neutrons from cosmic μ spallation captured on Gd/H, or γ like prompt fake signal in case of H analysis.

Neutrons from cosmic μ spallation captured on Gd/H, or γ like prompt fake signal in case of H analysis.

Michel electrons.

Neutrons from ⁹Li/⁸He β + n decays captured on Gd/H.

Double Chooz has developed dedicated techniques for identifying and studying these backgrounds.

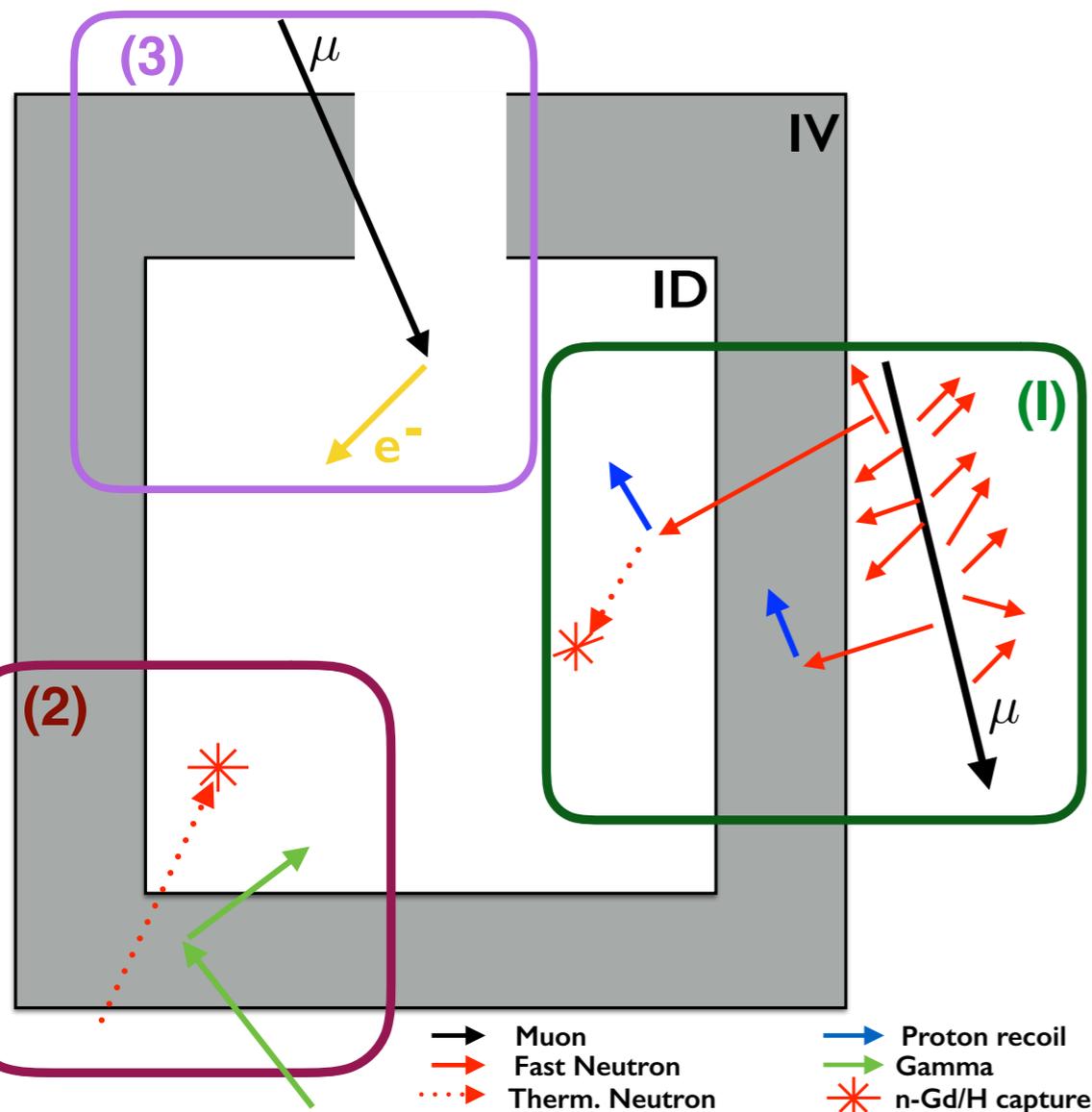
The identified background noise is removed from the final selection of IBDs for the final fit.

However, since the cuts are never 100% efficient, we must estimate the level of background remaining in the final sample of IBDs to constrain the final fit and therefore improve the precision of the measurement of θ_{13}

The first background I study are fast neutrons (FN).

FAST NEUTRONS

IVT: Identification des bruits de fond grâce à l'Inner Veto



1. NEUTRONS RAPIDES (FN)

- Crées par les interactions des muons avec la roche environnante.
- Entre dans l'IV and diffuse sur les protons
- Le recul du proton et la capture du neutron imitent le signal

2. EVENEMENTS - GAMMA GAMMA (γ - γ)

- Coincidence fortuite entre un gamma de la radioactivité naturelle et une capture neutronique.

3. STOPPING MUONS (SM)

- Peut déposer de l'énergie dans l'IV
- S'arrêter puis désintégrer dans le détecteur
- L'énergie d'arrêt puis les électrons michel imitent les signaux IBD.

What we want to do

- ⇒ Select efficiently correlated background : **FAST NEUTRONS**.
- ⇒ Determine corresponding **spectral shape**.
- ⇒ Calculate remaining rate ⇒ **inputs pour the final fit**.

For that purpose

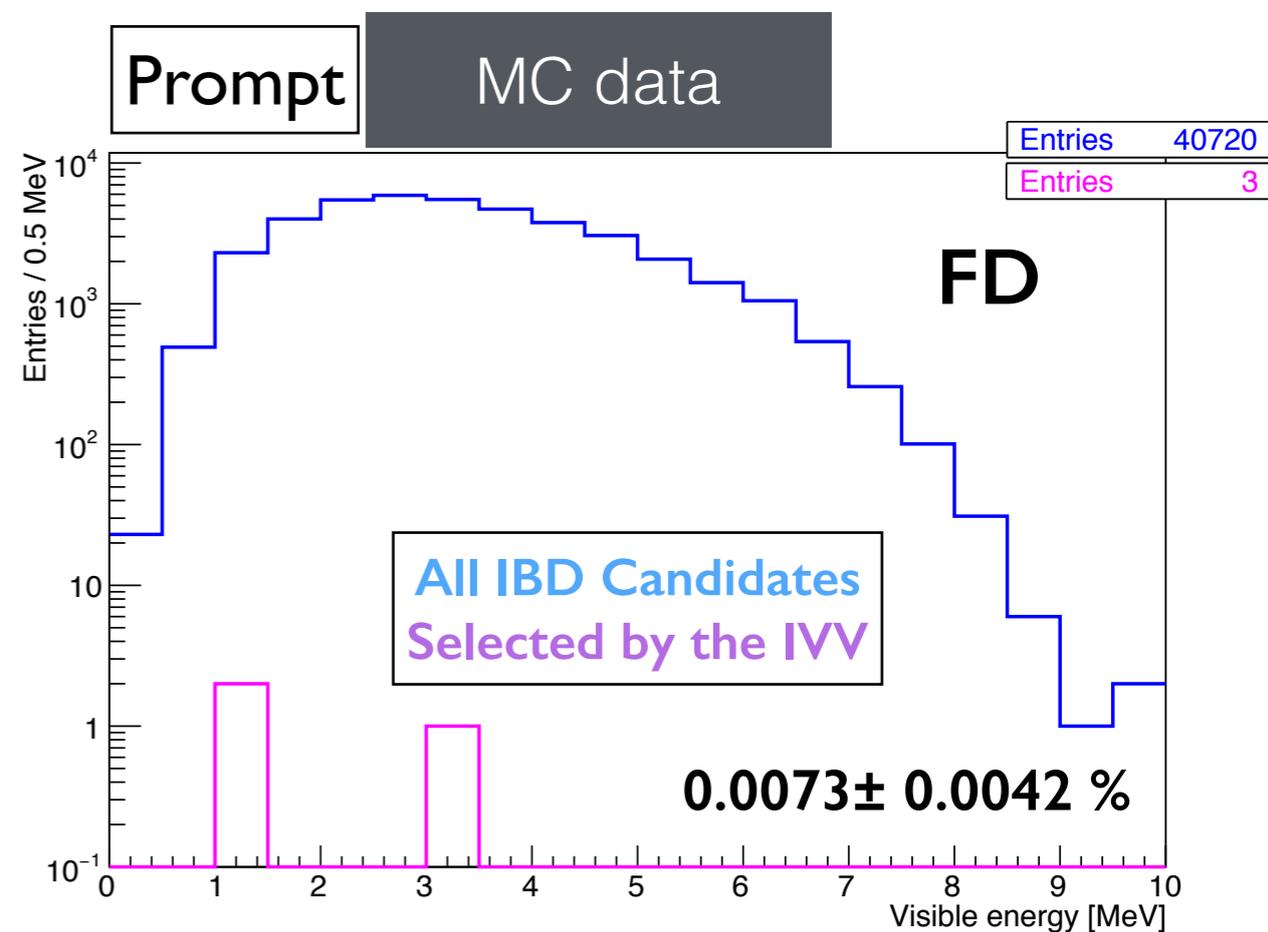
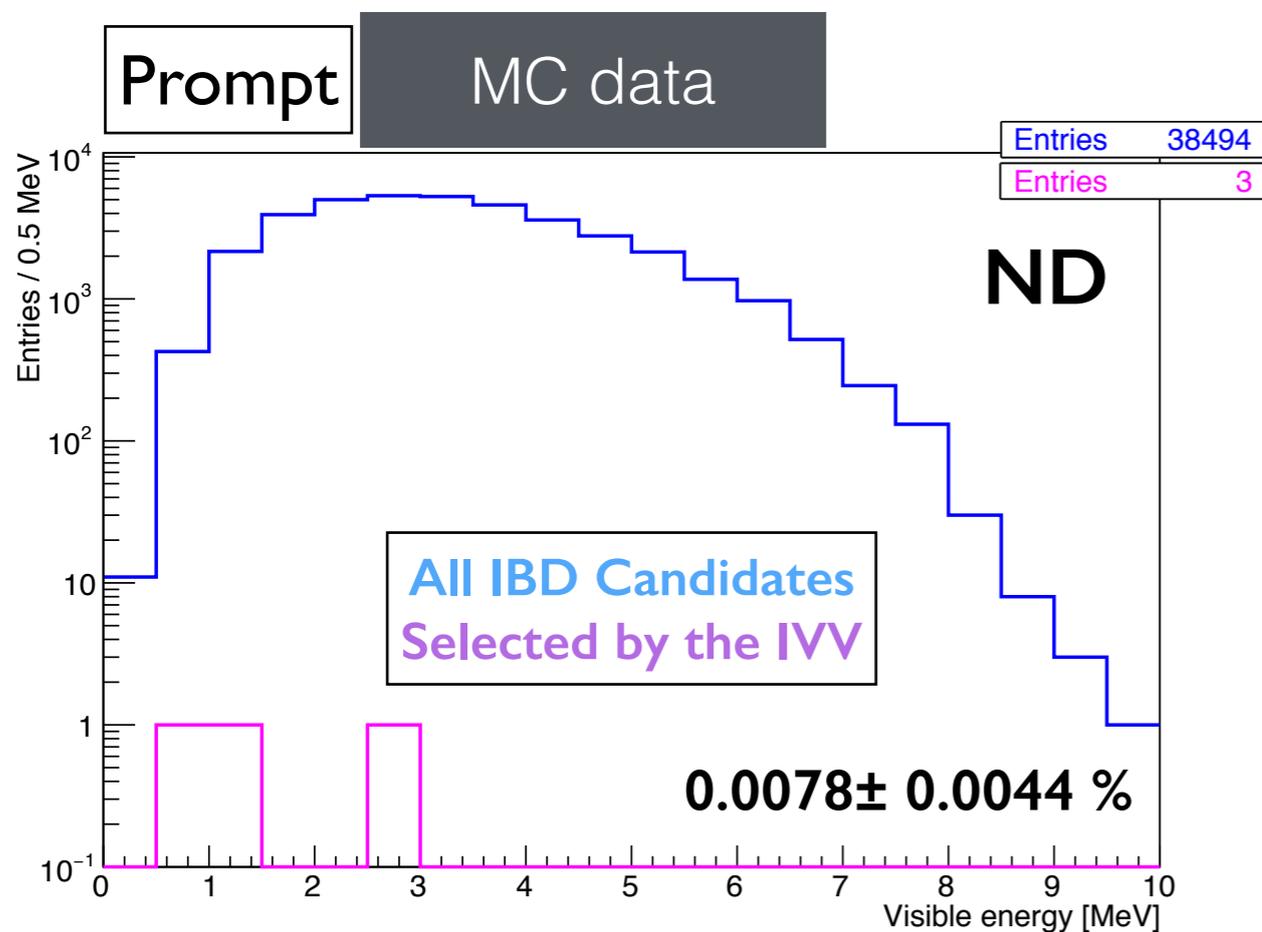
- ⇒ 23 Months IBD **candidates** IBD sample is studied
- ⇒ 2 selections are used : **Gd** and **Gd+H**.
- ⇒ Analysis performed for 2 detectors (**ND & FD**).

First step

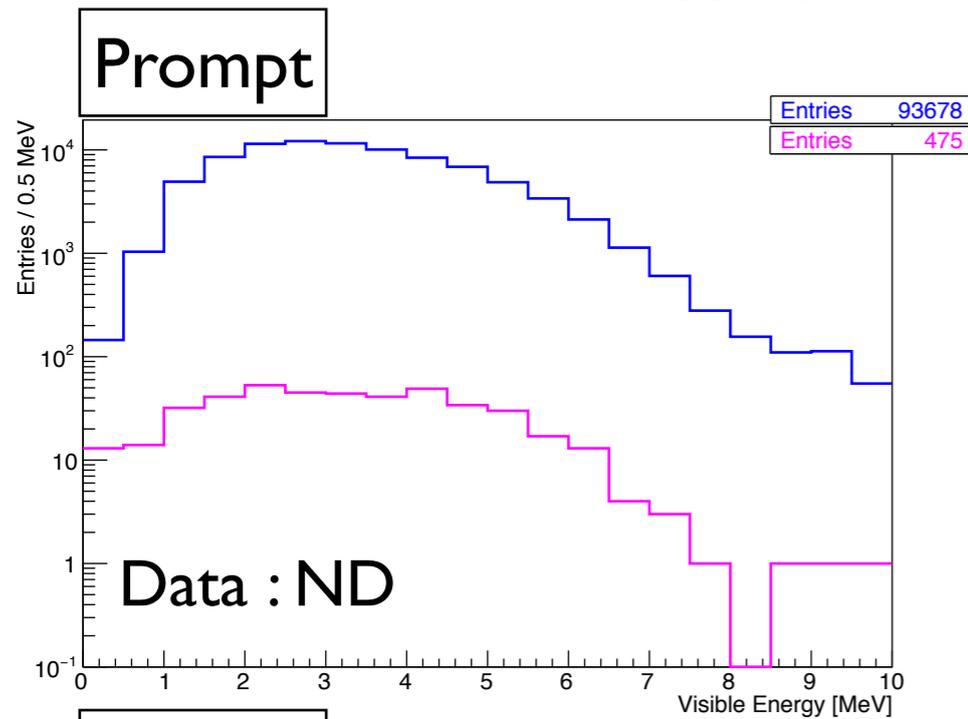
⇒ Set the **OPTIMAL CUTS THAT SELECTS EFFICIENTLY THIS BACKGROUND**.

IVT CUTS: Events whose prompt signal satisfy these conditions are tagged as background.

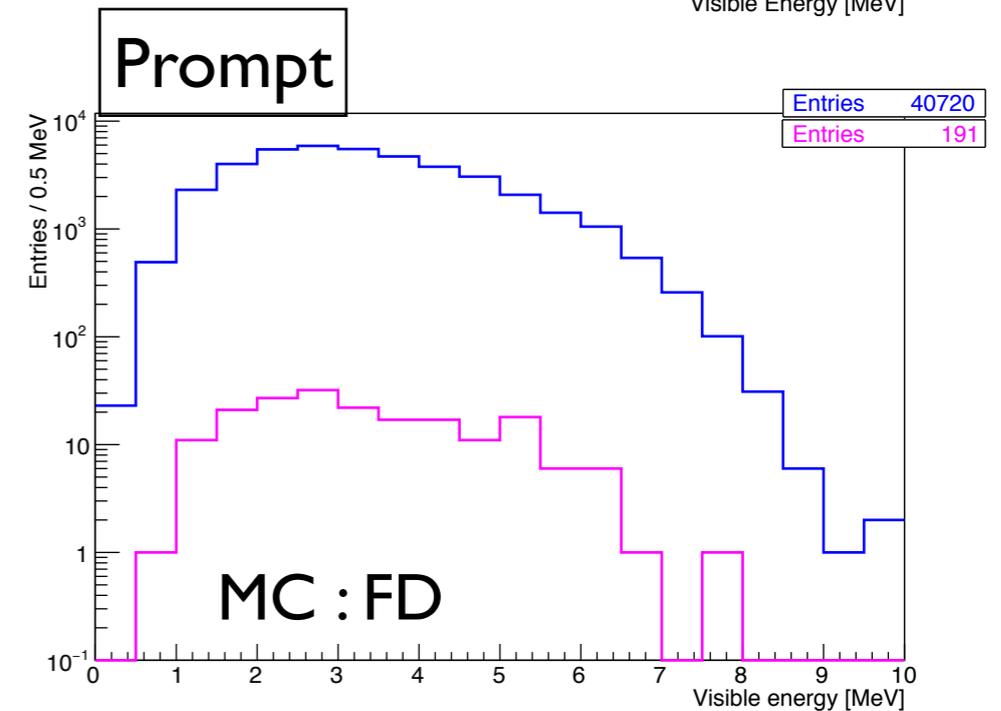
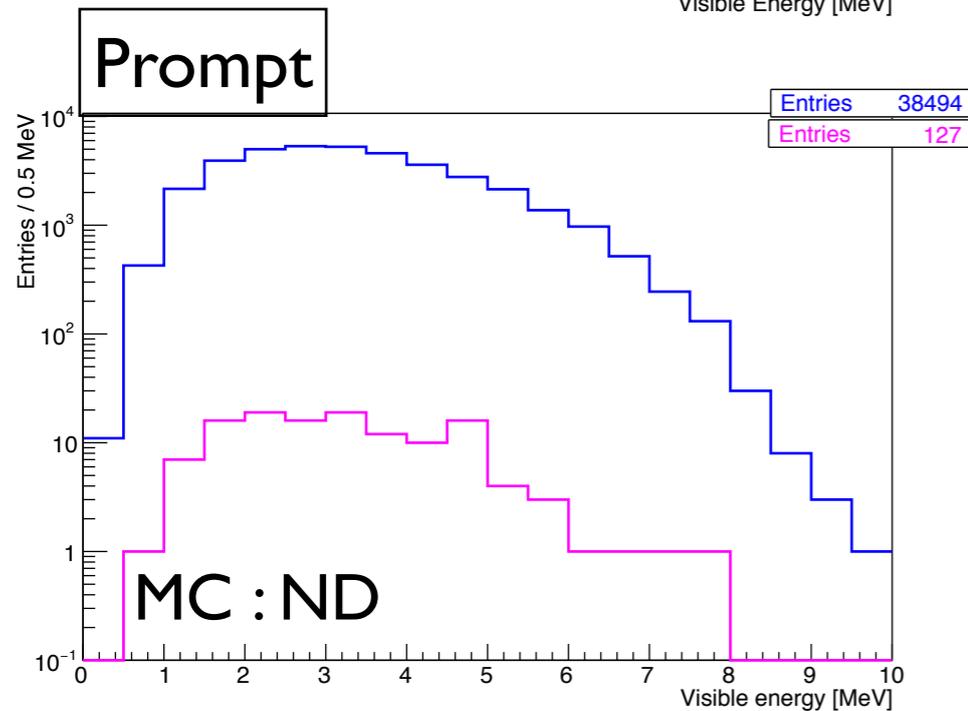
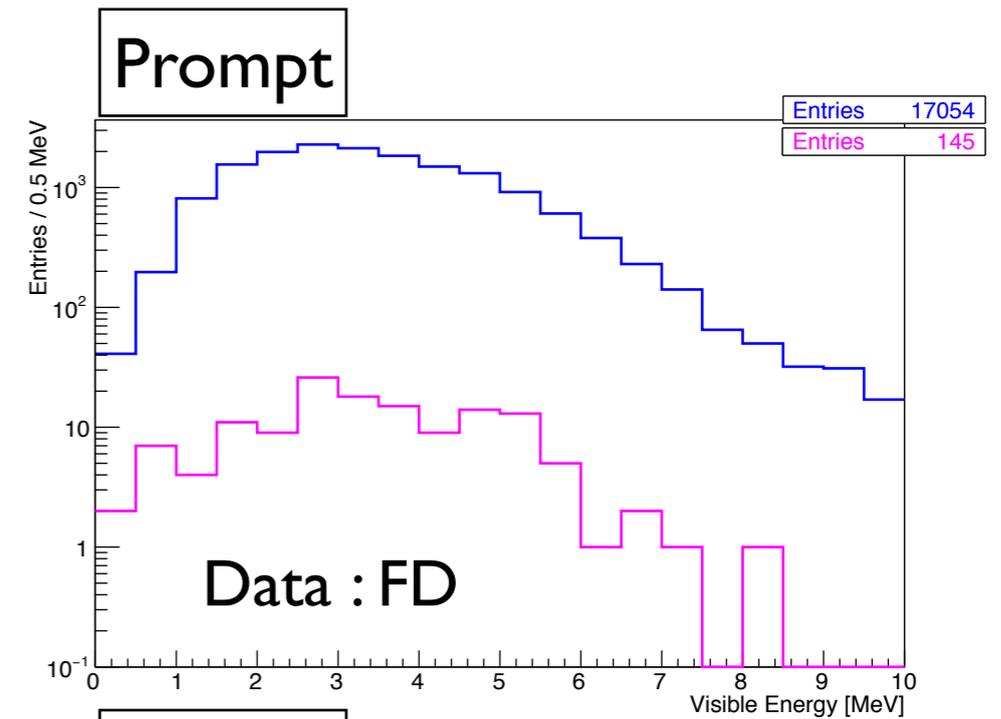
Cuts	ND & FD-II
#PMT IV	nPMT > 1
DR (ID-IV)	< 3.7 m
Dt (ID-IV)	[-40;70] ns
Charge	> 300 DUQ



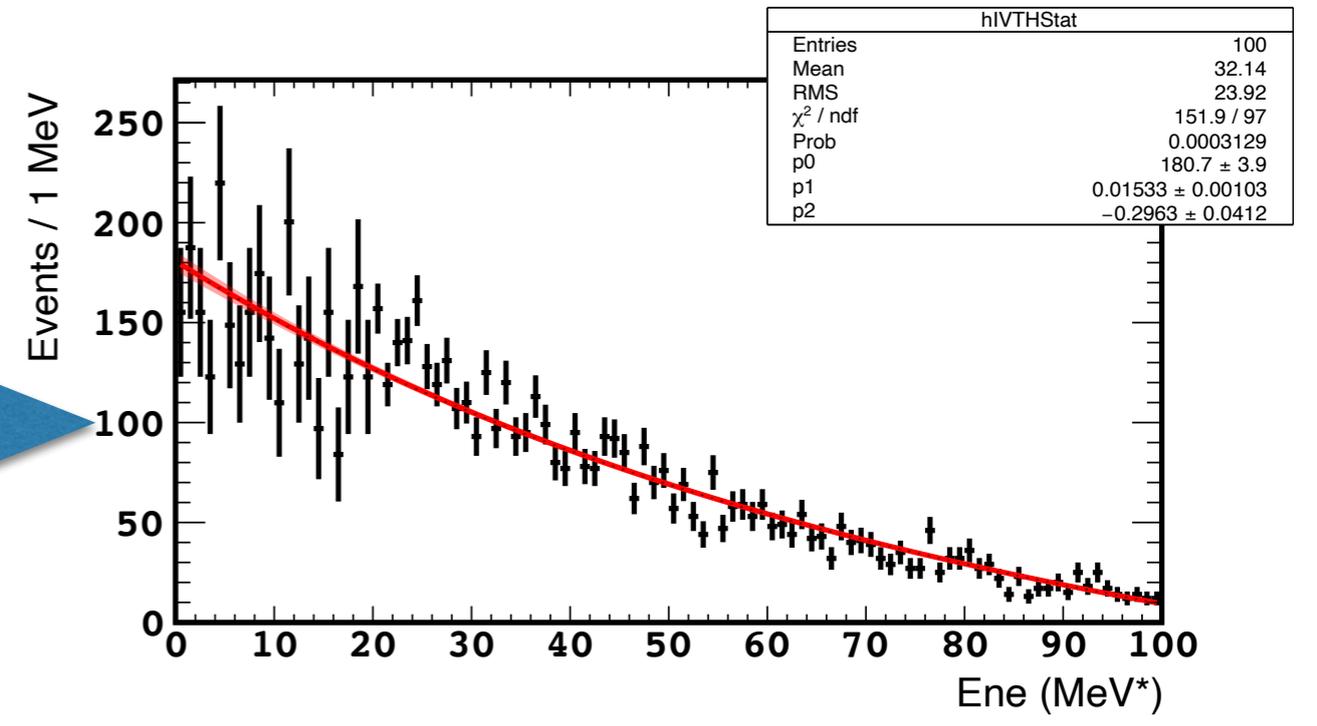
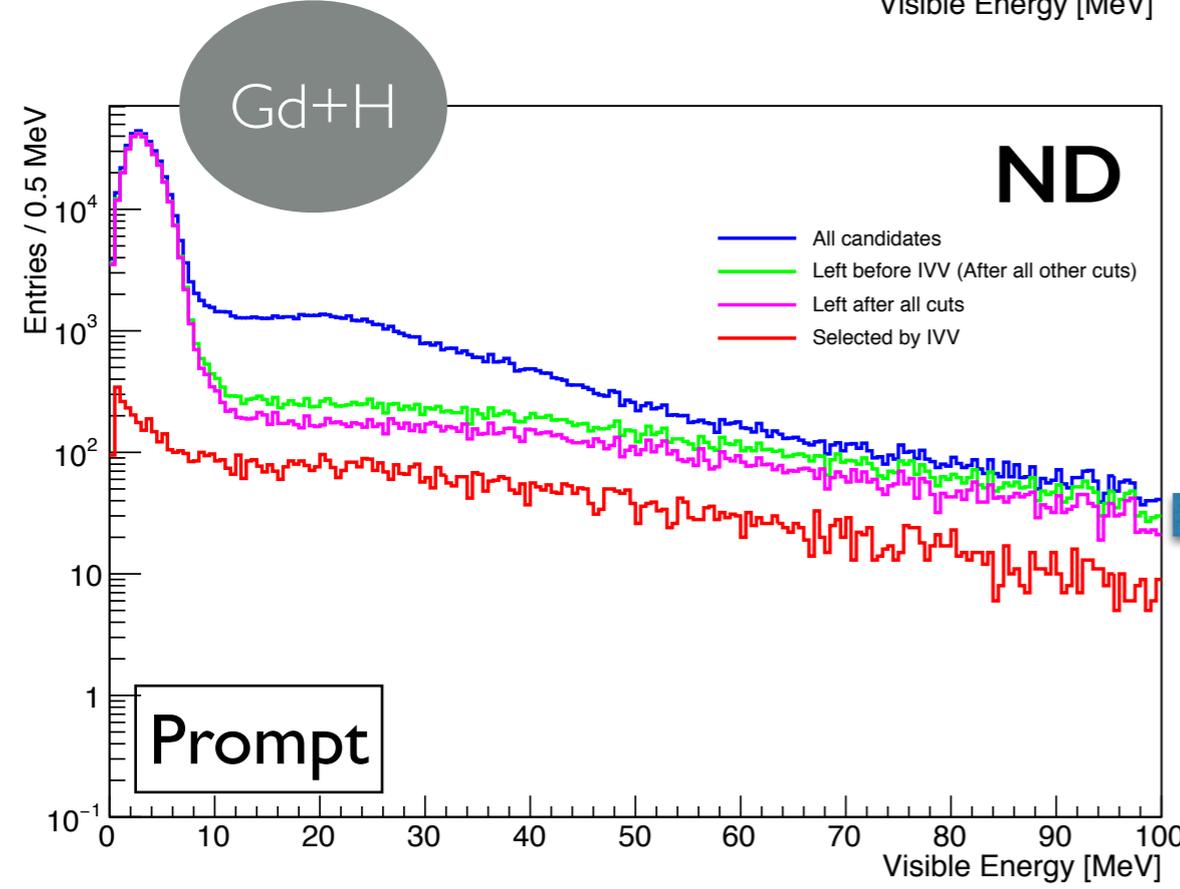
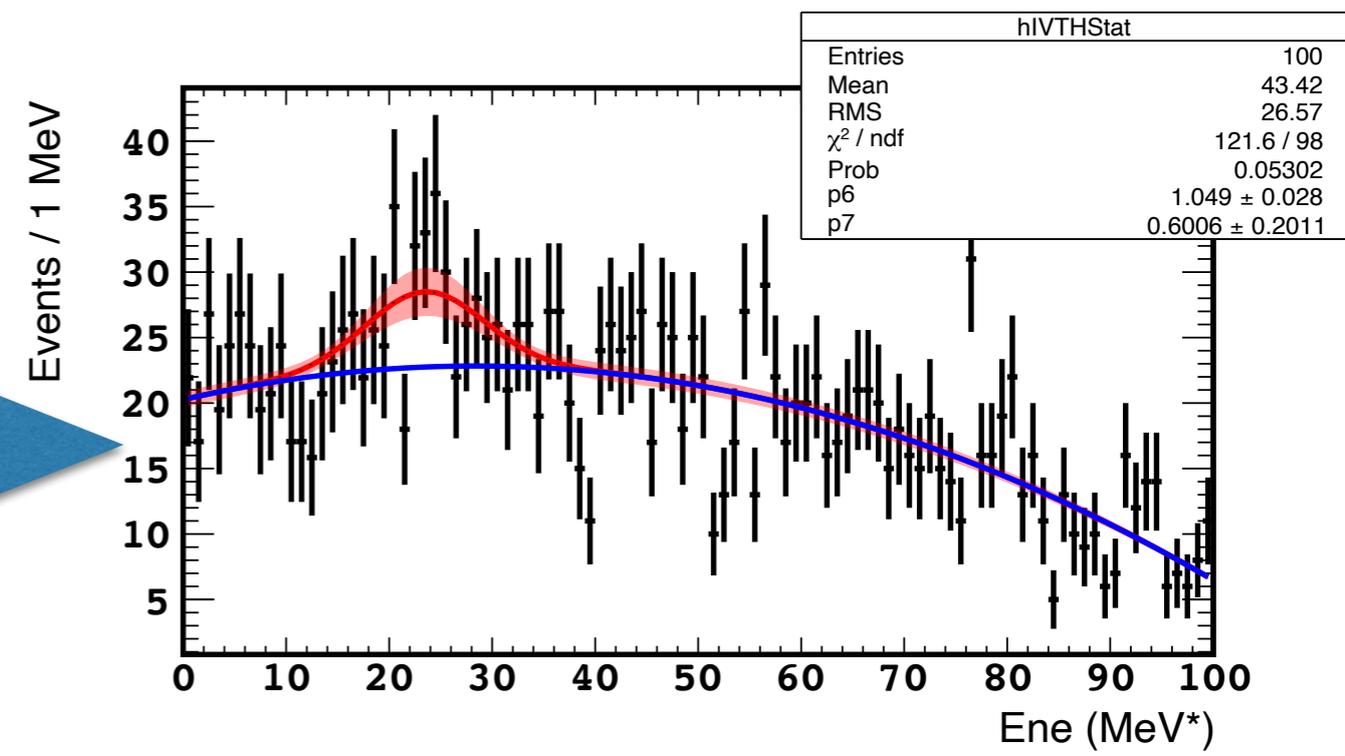
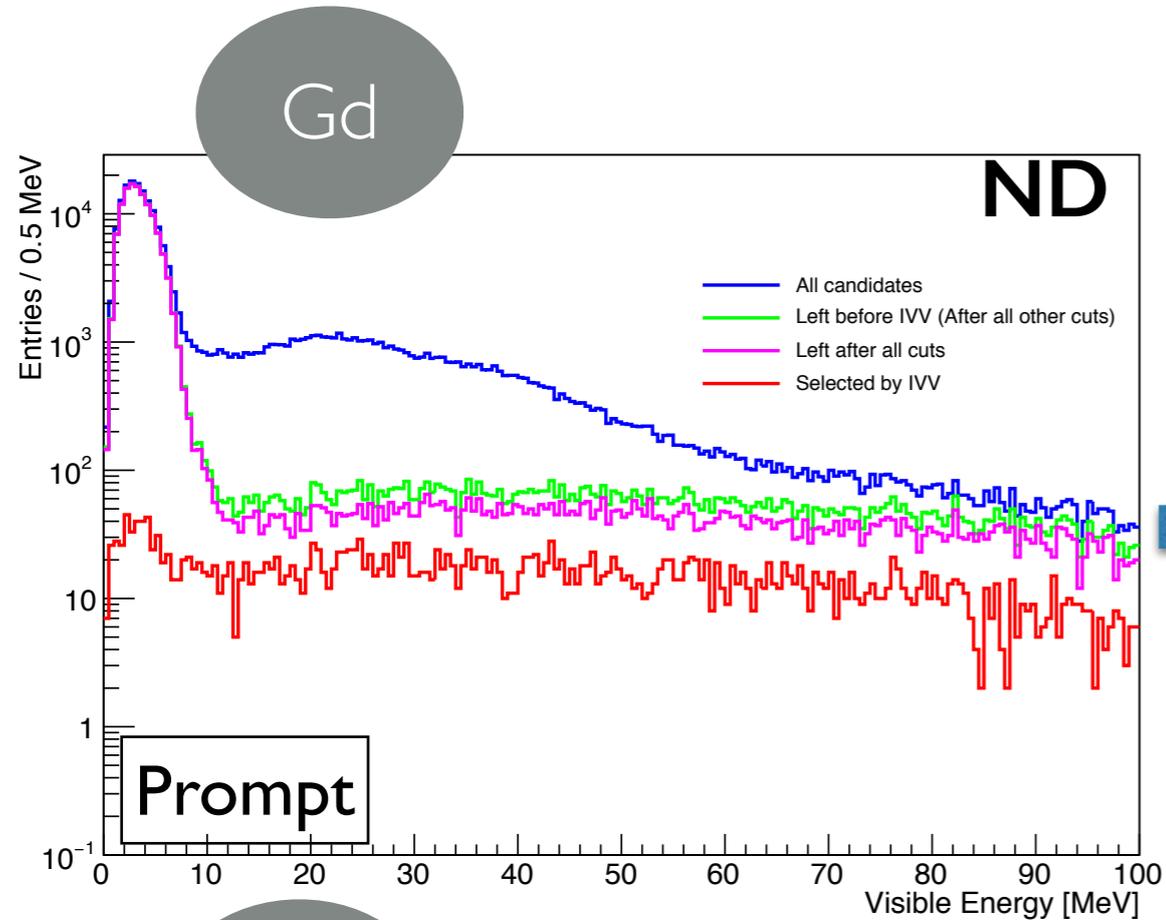
IVT retardé appliqué sur la sélection Gd a servi à valider le MC utilisé



All IBD candidates
Selected by IVV

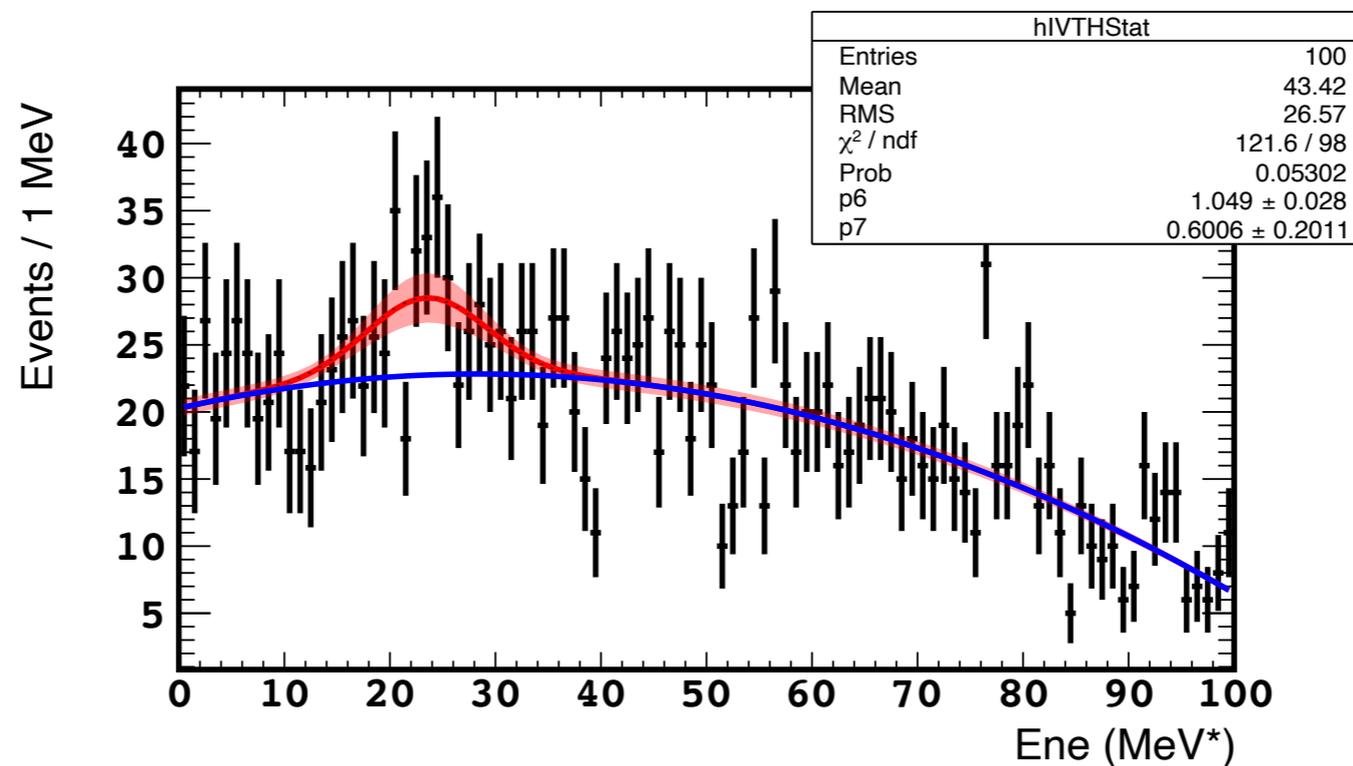


Detector	\bar{e}_{D-IVV} (Monte Carlo)	\bar{e}_{D-IVV} (Data)
ND	$0.33 \pm 0.03 \%$	$0.50 \pm 0.02 \%$
FD	$0.47 \pm 0.03 \%$	$0.85 \pm 0.07 \%$



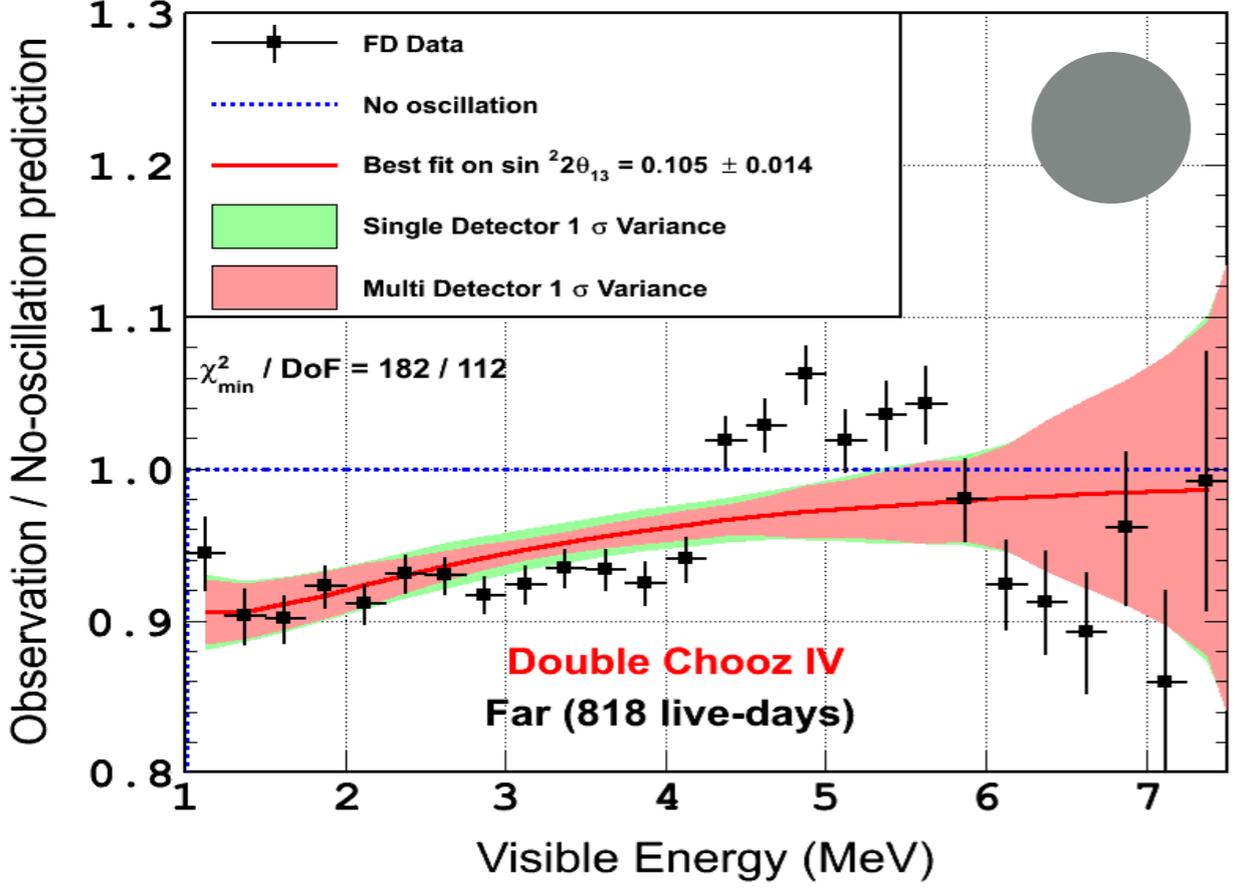
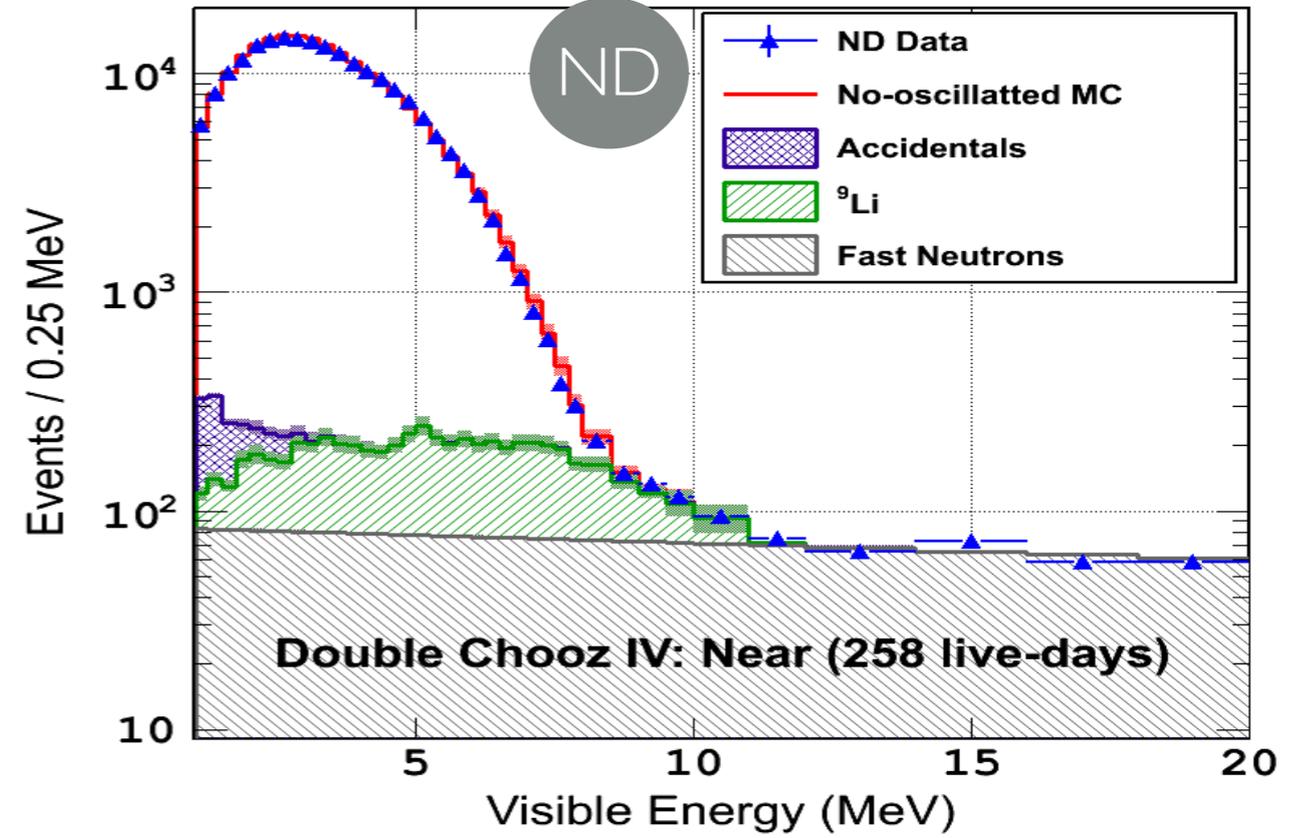
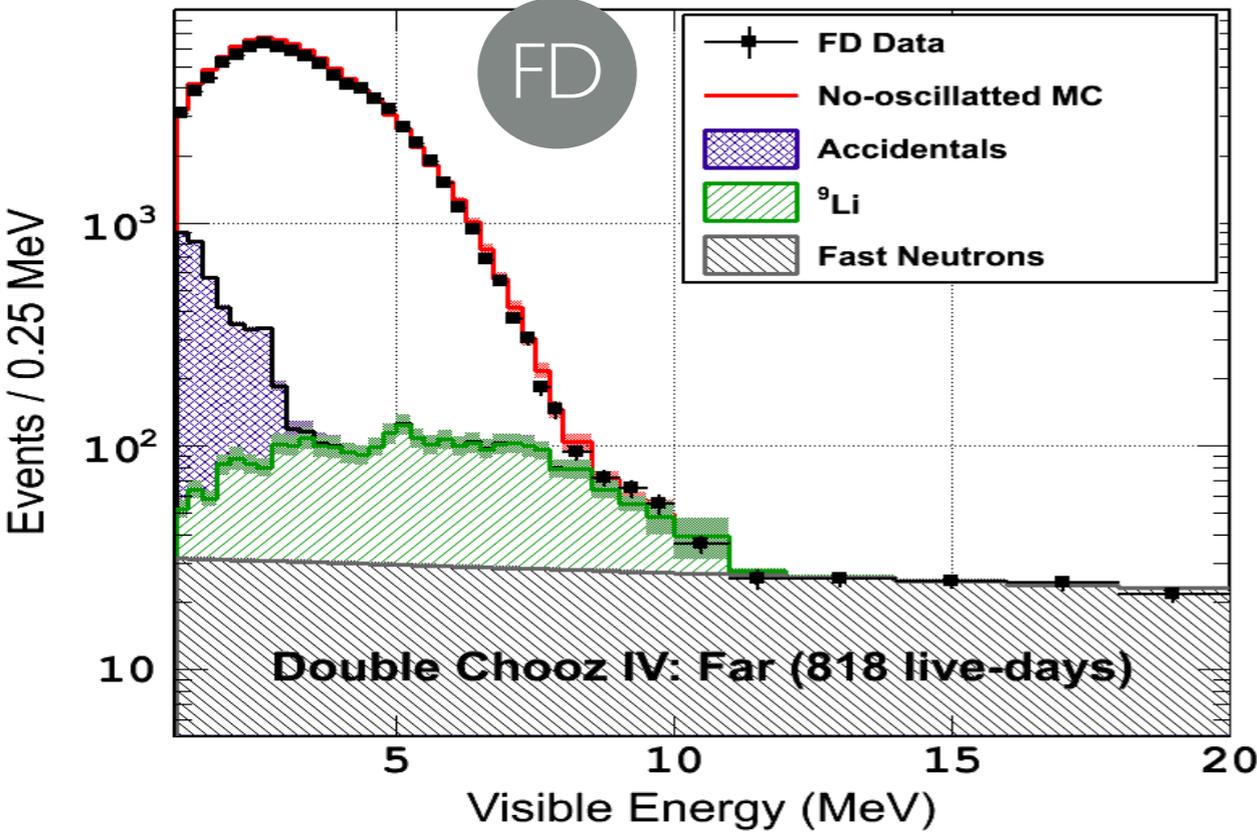
To measure the rates

- We consider there are only fast neutrons beyond 20 MeV.
- We calculate our cut efficiency IVV in this region [20;100] MeV



- This allows an estimation of the remaining rate (**per day**) in the final fit region i.e [0;20] MeV

Detector	Gd selection	Gd+H selection
ND	3.42 ± 0.23	20.77 ± 0.43
FD	0.586 ± 0.06	2.54 ± 0.10



$\sin^2(2\theta_{13}) = 0.105 \pm 0.014$



Rate / day of fast neutrons

Output	2.50 ± 0.05	20.85 ± 0.31
Input	2.54 ± 0.10	20.77 ± 0.43



SUMMARY

- ☑ (IVV) tagging of fast neutrons set by me is the **official** Double Chooz .
- ☑ **Spectrum** of events selected by **I'IVV** allowed fast neutrons remaining rate, which serves as **input** to the final fit.
- ☑ Analysis updated for each data release and still valid..

CONCLUSIONS

What I do and have done

- ☑ A full analysis of correlated background.
 - ☑ IVV cuts set with inefficiency < 0.1 %
 - ☑ Spectral shapes defined
 - ☑ Daily rate calculated

- ☑ A full analysis of Double neutron captures
 - ☑ Cuts defined and fine tuned basée
 - ☑ Rate measured
 - ☑ Impact on θ_{13}

*“Pure logical thinking cannot
yield us any knowledge of
the empirical world; all
knowledge of reality starts
from experience and ends in
it.”*

A. EINSTEIN

THANKS FOR YOUR ATTENTION