

Correlated Background measurement in Double Chooz experiment

Guillaume Pronost (Supervisor : Frederic Yermia)

SUBATECH

Journées de Rencontres des Jeunes Chercheurs 2013

OUTLINE

1 - Neutrino Physics

2 - Double Chooz

3 - Correlated Background Measurement

Neutrino Physics

Neutrino Physics (Reminder)

- ▶ 3 neutrinos flavor described in Standard Model.
- ▶ One major property : **Oscillations**.
- ▶ **A neutrino generated in a specific flavor can later be measured as another flavor.**
- ▶ Described by the PMNS matrix (Pontecorvo, Maki, Nakagawa & Sakata) :

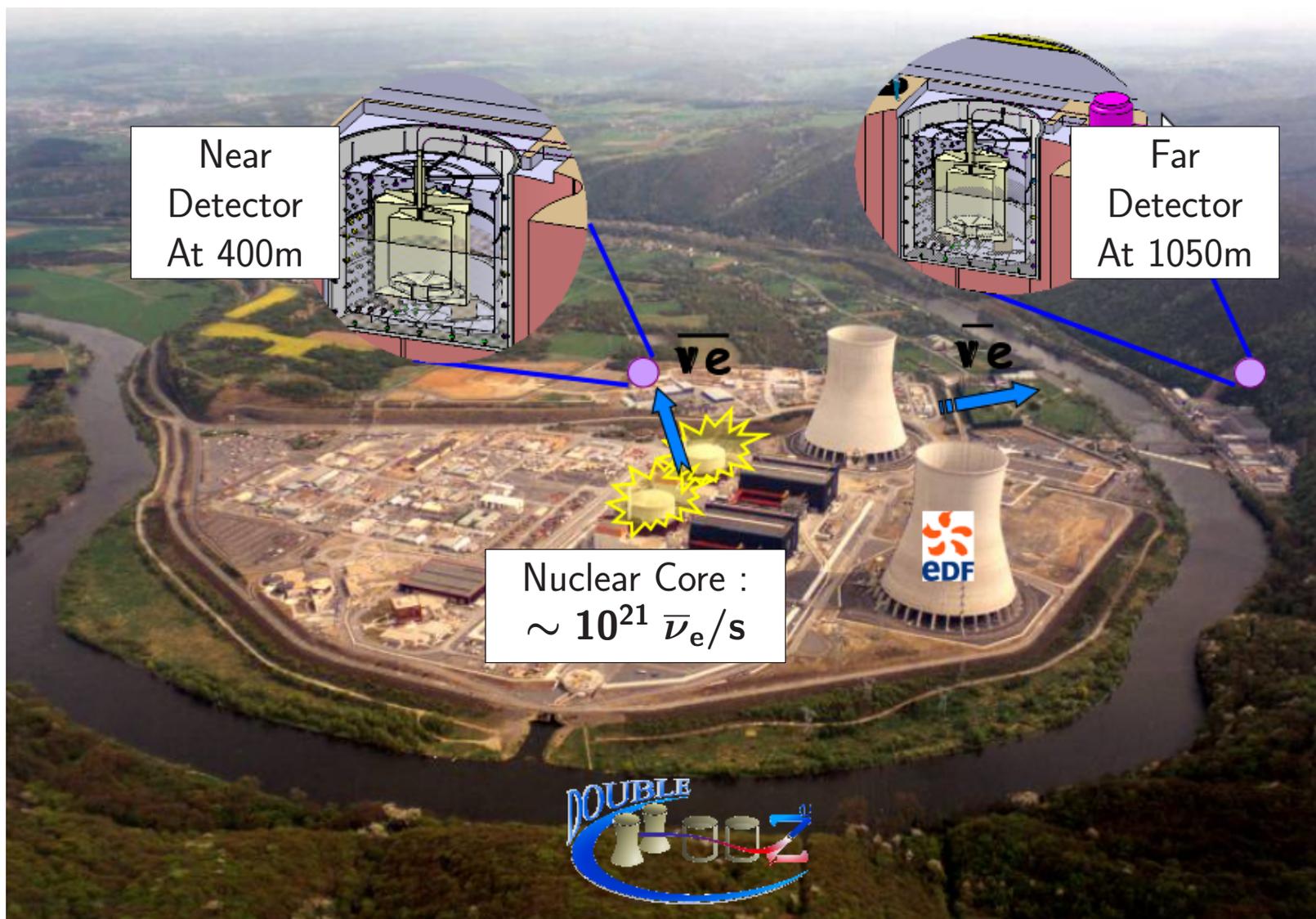
$$\mathbf{U} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_{23} & \sin \theta_{23} \\ 0 & -\sin \theta_{23} & \cos \theta_{23} \end{pmatrix} \cdot \begin{pmatrix} \cos \theta_{13} & 0 & \sin \theta_{13} \cdot e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin \theta_{13} \cdot e^{+i\delta} & 0 & \cos \theta_{13} \end{pmatrix} \cdot \begin{pmatrix} \cos \theta_{12} & \sin \theta_{12} & 0 \\ -\sin \theta_{12} & \cos \theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

θ_{23} : $\mathbf{P}(\nu_{\mu} \rightarrow \nu_{\mu})$ by Atoms. ν and ν beam
 θ_{13} : $\mathbf{P}(\nu_e \rightarrow \nu_e)$ by Reactor ν
 θ_{13} & δ : $\mathbf{P}(\nu_{\mu} \rightarrow \nu_e)$ by ν beam
 θ_{12} : $\mathbf{P}(\nu_e \rightarrow \nu_e)$ by Reactor ν and Solar ν

- ▶ 3 mixing angles : θ_{23} , θ_{13} & θ_{12} .
- ▶ 2 mass difference scales : Δm_{12}^2 & Δm_{23}^2
- ▶ 1 phase δ : CP violation in ν -sector
- ▶ Until November 2011 : **only one upper limit for θ_{13}**
- ▶ Goal of Double Chooz : **measure θ_{13}**

Double Chooz

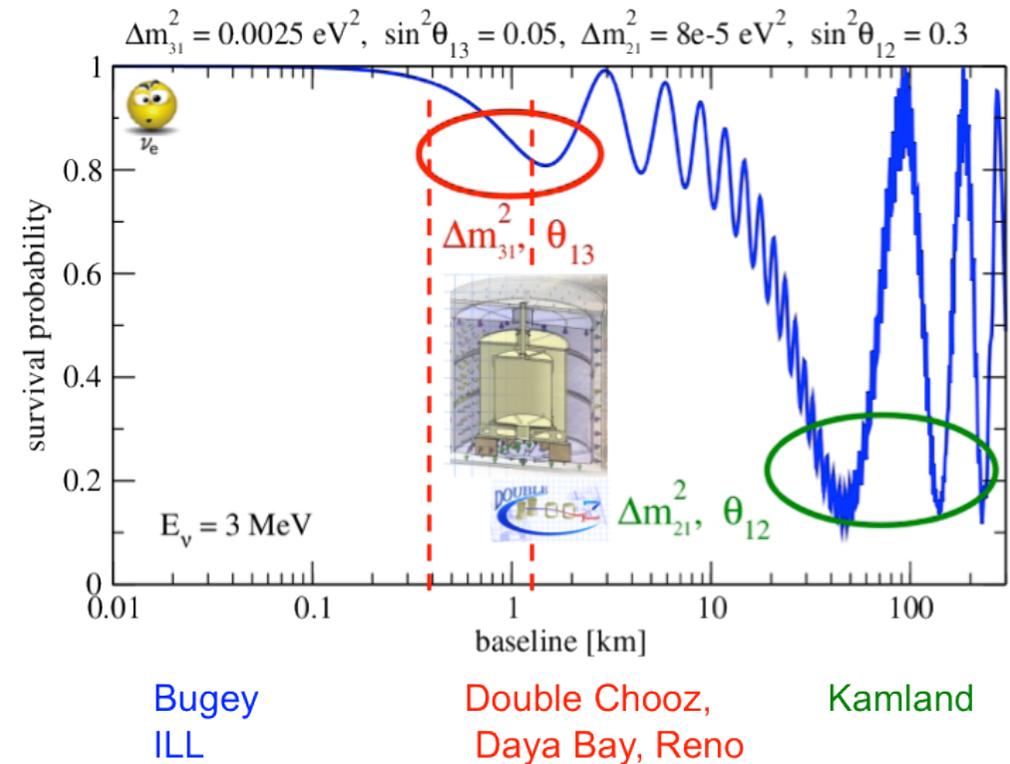
Double Chooz site



- ▶ International collaboration (Brazil, France, Germany, Japan, Russia, Spain, USA)
- ▶ Site at Chooz (Ardennes, France) near Chooz Nuclear Plant.

Double Chooz experiment

- ▶ Measure of an $\bar{\nu}_e$ **disappearance**.
- ▶ **Two** identical detectors of 8.3 t (\Rightarrow **Double Chooz**) :
 - ▷ **Near detector**. Measures the $\bar{\nu}_e$ flux **before** oscillations.
 - ▷ **Far detector**. Measures the $\bar{\nu}_e$ flux **after** oscillations.
- ▶ Comparisons between expected and observed $\bar{\nu}_e$ flux allow to access to θ_{13} measurement.
- ▶ **Two phases** in Double Chooz :
 - ▷ First phase : Only Far detector. Non-oscillated flux provided by **reactor core simulations**.
 - ▷ Second phase (half 2014) : Both detectors.



Double Chooz detection principle : Inverse Beta Decay

▶ Inverse Beta Decay (IBD) :



▷ e^+ (positron) quickly annihilates :

▶ Prompt Signal

▶ Visible energy = e^+ energy + annihilation γ 's
→ **1 ~ 12 MeV**

▷ n (neutron) captured on **Gd** or **H** :

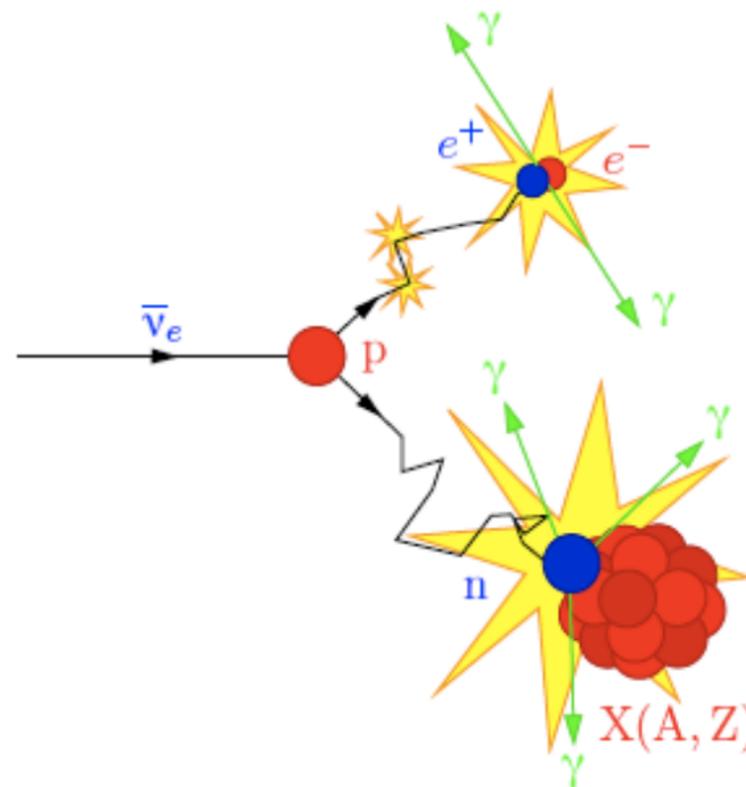
▶ Delayed Signal

▶ Visible energy = γ 's from neutron capture on
Gd / H → **~ 8 MeV** or **~ 2.2 MeV**.

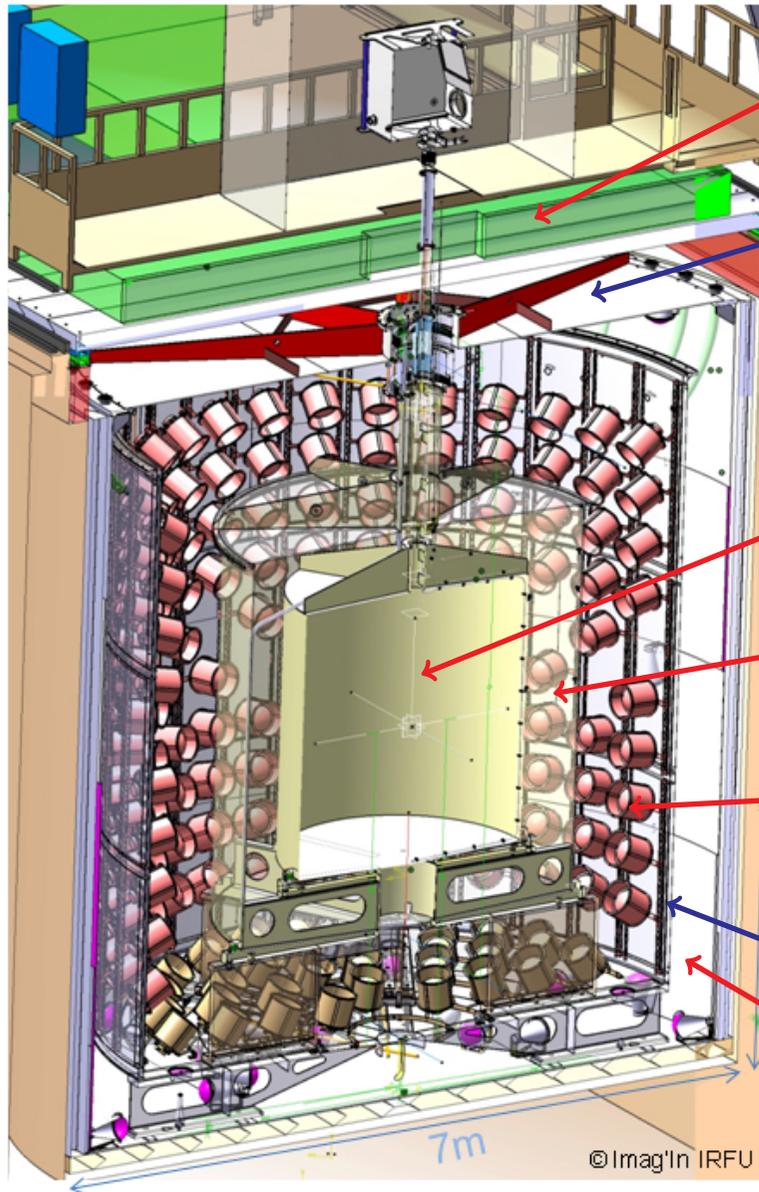
▷ Time interval :

▶ $\Delta t \sim 30\mu s$

▶ In this talk : Only Gd selection.



Double Chooz detector



Outer Veto (OV) : Plastic Scintillator
Used to cosmic μ detection

Steel shield (15cm thick)

Inner Detector (ID)

ν -target : Gd loaded Liquid Scintillator
Target of neutrino interaction (IBD)

γ -catcher : Liquid Scintillator
Measure γ escaped from ν -target

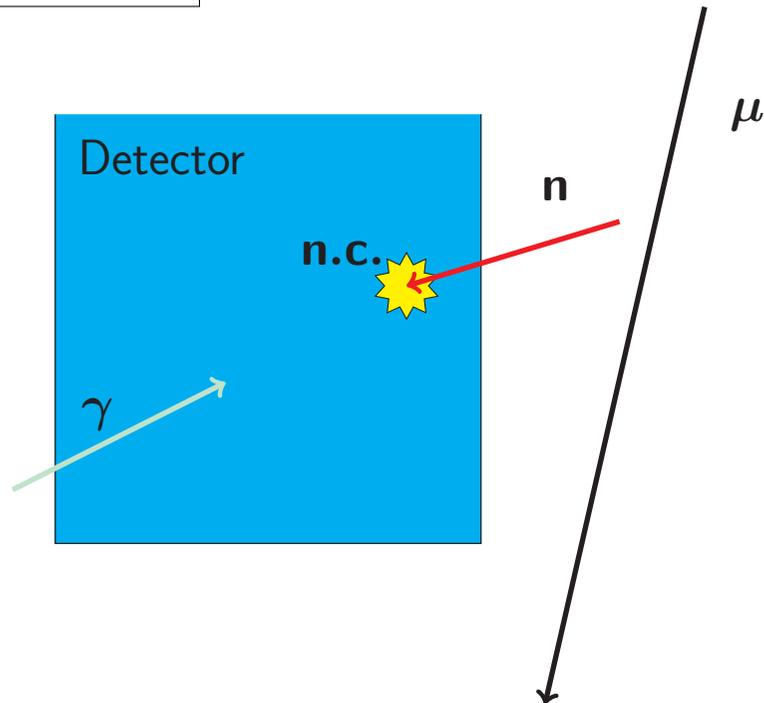
Buffer : Mineral oil & 390 PMTs
Reduction of γ from PMTs and from radioactivity.

Steel tank (3mm)

Inner Veto (IV) : Liquid Scintillator & 78 PMTs
Used to cosmic μ and fast neutron detection

Double Chooz detection : Backgrounds (Gd selection)

Accidentals



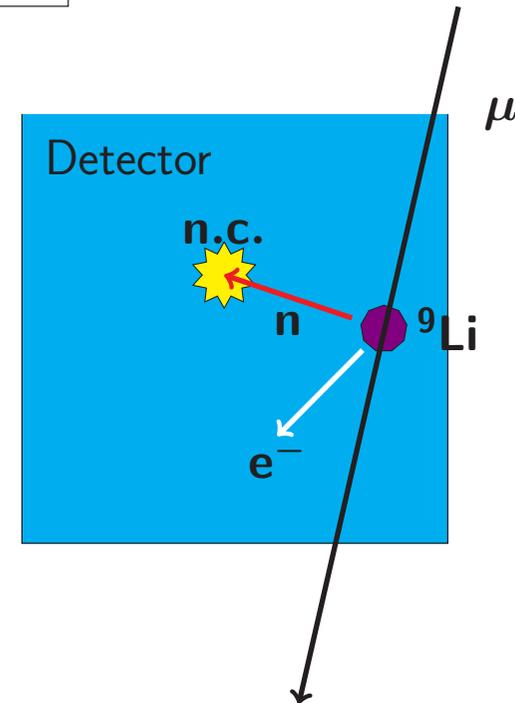
n.c. : neutron capture

Prompt signal : γ from radioactivity.

Delayed signal : Fast Neutron from muon spallation in rock.

Rate : 0.261 ± 0.002 events/day^[1].

⁹Li



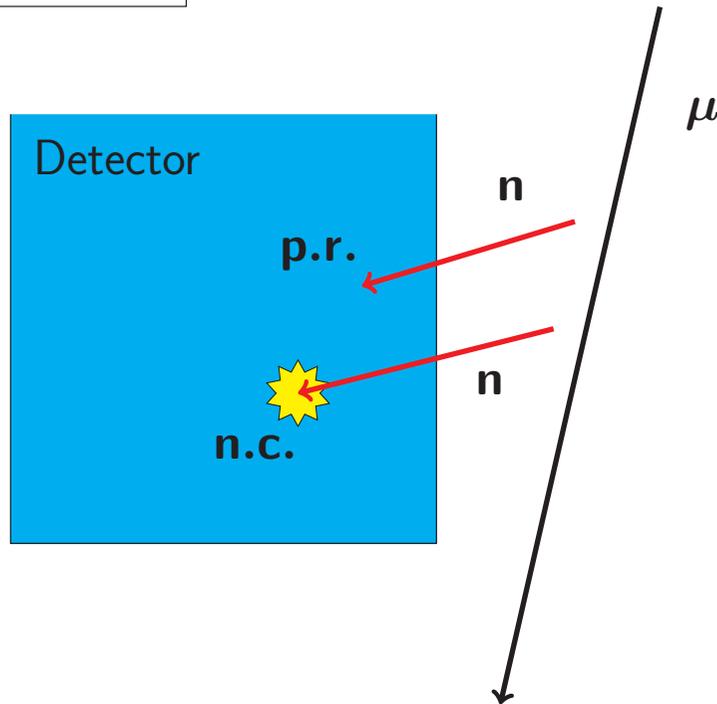
Prompt signal : e^- .

Delayed signal : neutron.

Residual rate : 1.25 ± 0.54 events/day^[1].

Double Chooz detection : Correlated Background (Gd selection)

Fast Neutrons



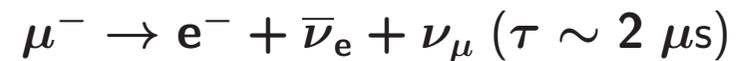
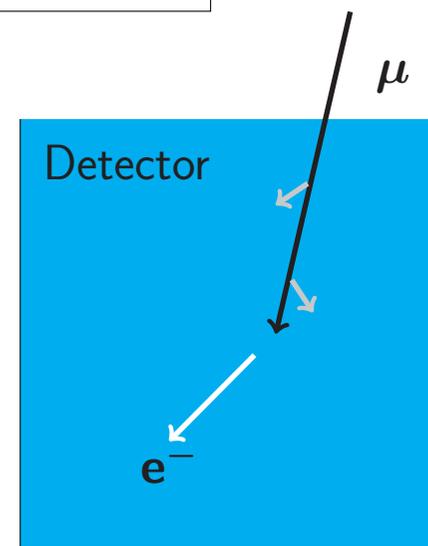
p.r. : proton recoil **n.c.** : neutron capture

Prompt signal : γ from radioactivity.

Delayed signal : Fast Neutron from muon spallation in rock.

Rate : 0.30 ± 0.14 events/day^[1].

Stopping Muon



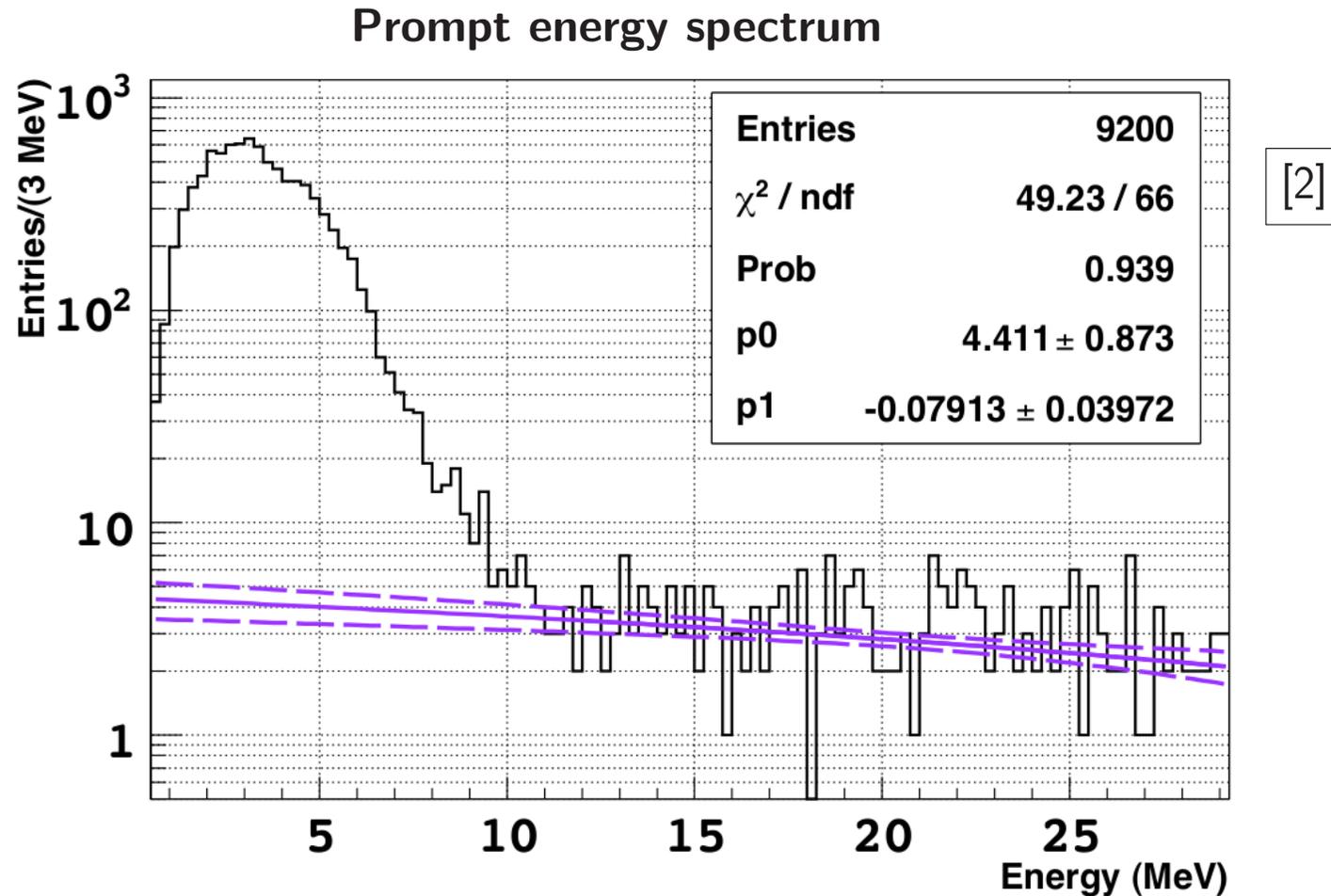
Prompt signal : short μ track.

Delayed signal : “Michel” e^- (from μ decay)

Rate : 0.34 ± 0.18 events/day^[1].

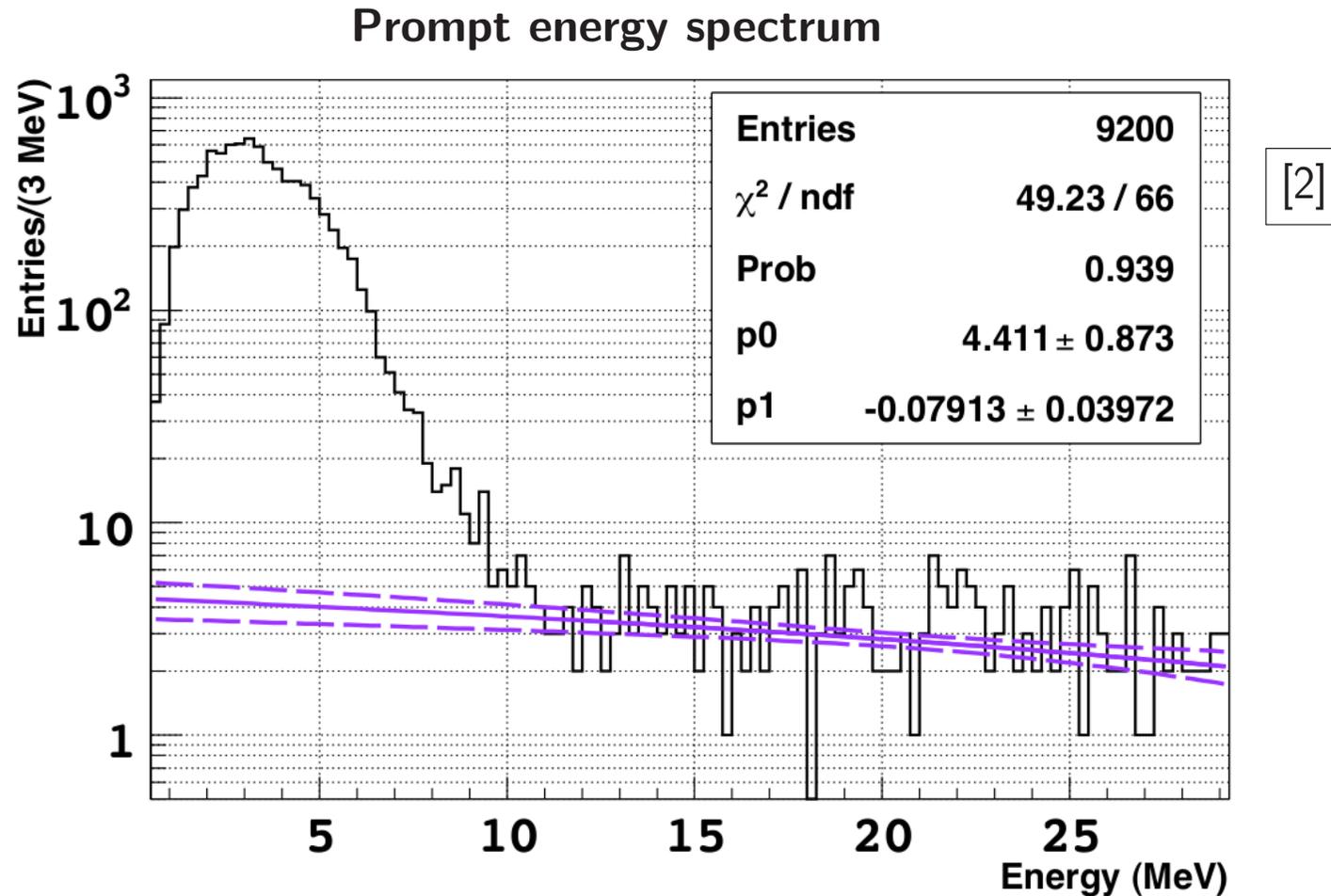
Correlated Background Measurement

Problematic of a Correlated Background Measurement



- ▶ Estimation of Correlated Background :
 - ▷ Extend E_{prompt} cut up to 30 MeV.
 - ▷ Between $12 \text{ MeV} < E_{\text{prompt}} < 30 \text{ MeV}$, no IBD expected \rightarrow Correlated Background.

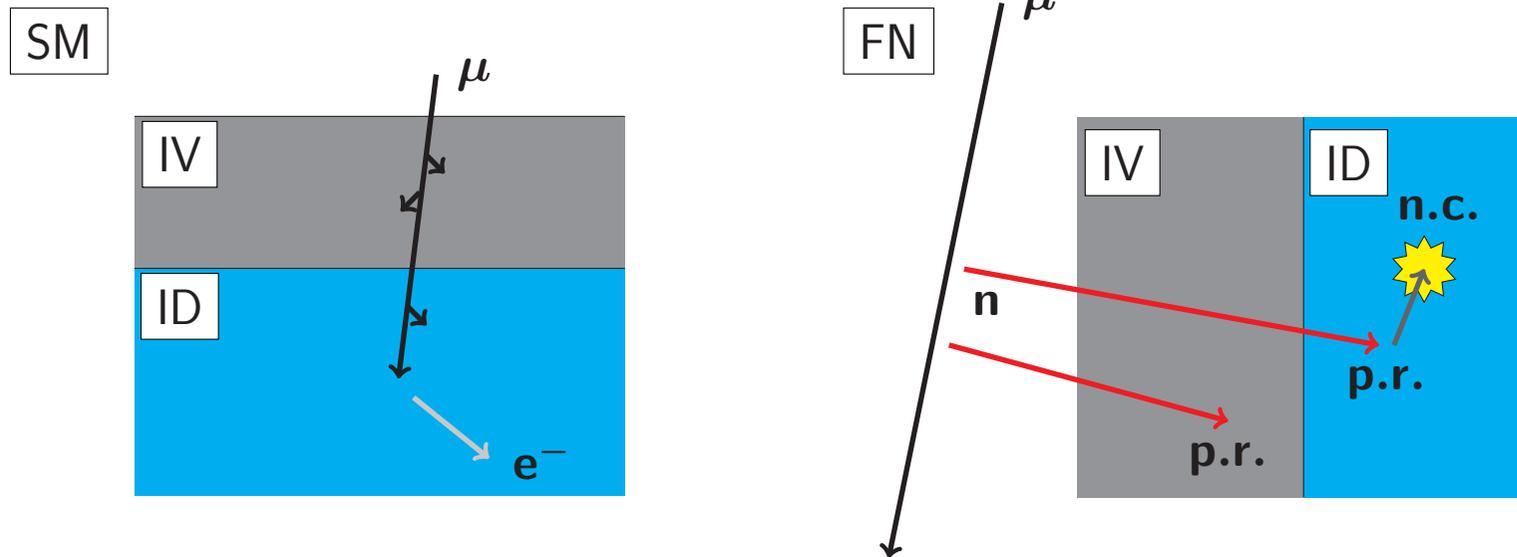
Problematic of a Correlated Background Measurement



- ▶ Estimation of Correlated Background at **Low Energy** :
 - ▷ **Daya Bay, RENO** : Flat shape assumption.
 - ▷ **Double Chooz** : Direct measurement (in this talk : “Inner Veto Tagging” method)

Why Inner Veto Tagging ?

- ▶ Correlated Background : Events from **outside detector**.
- ▶ **Fast Neutron (FN)** : Lot of **FN** generated by $\mu \rightarrow$ **some** expected to hit Inner Veto (**IVTagged**).
- ▶ **Stopping Muon (SM)** : from chimney \rightarrow **few** expected to hit Inner Veto.
- ▶ Select a **pur** sample of “**IVTagged**” **Fast Neutron** should give the **shape** of FN at low energy.

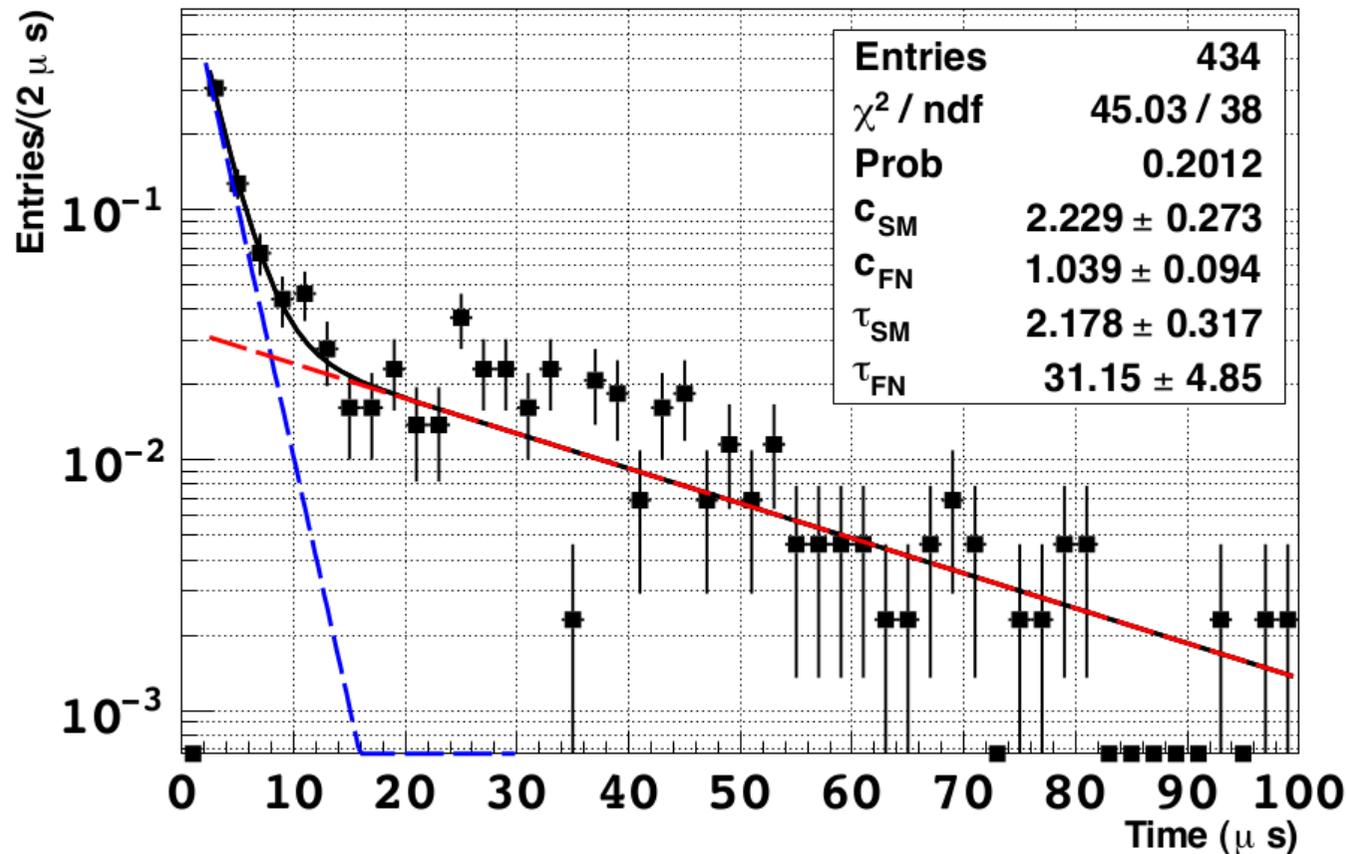


p.r. : proton recoil
n.c. : neutron capture

- ▶ However : **Other** kind of events can be “IVTagged”.

Fast Neutron / Stopping Muon separation

Time correlation between prompt and delayed events



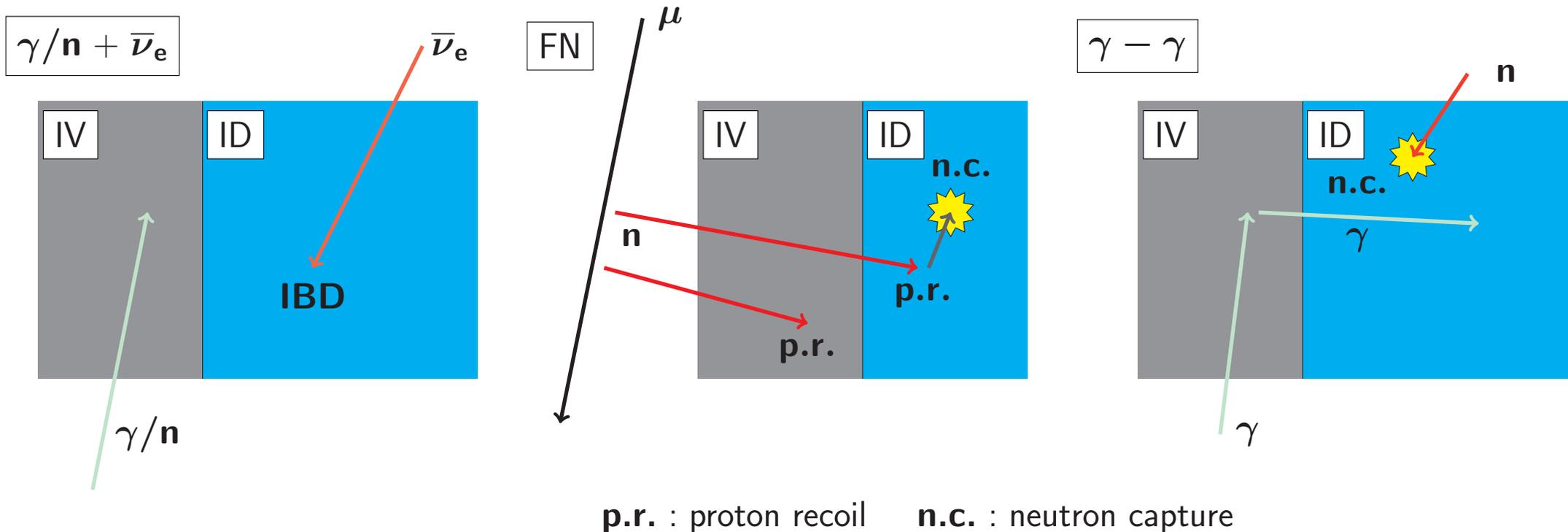
[2]

► $\tau(\mu) \sim 2\mu\text{s}$:

- Separation between Fast Neutron and Stopping Muon done by using $\Delta t[\text{Prompt} - \text{Delayed}]$
- In this talk : Only Fast Neutron shape estimation.

IVTagged events

► IVTagged events :

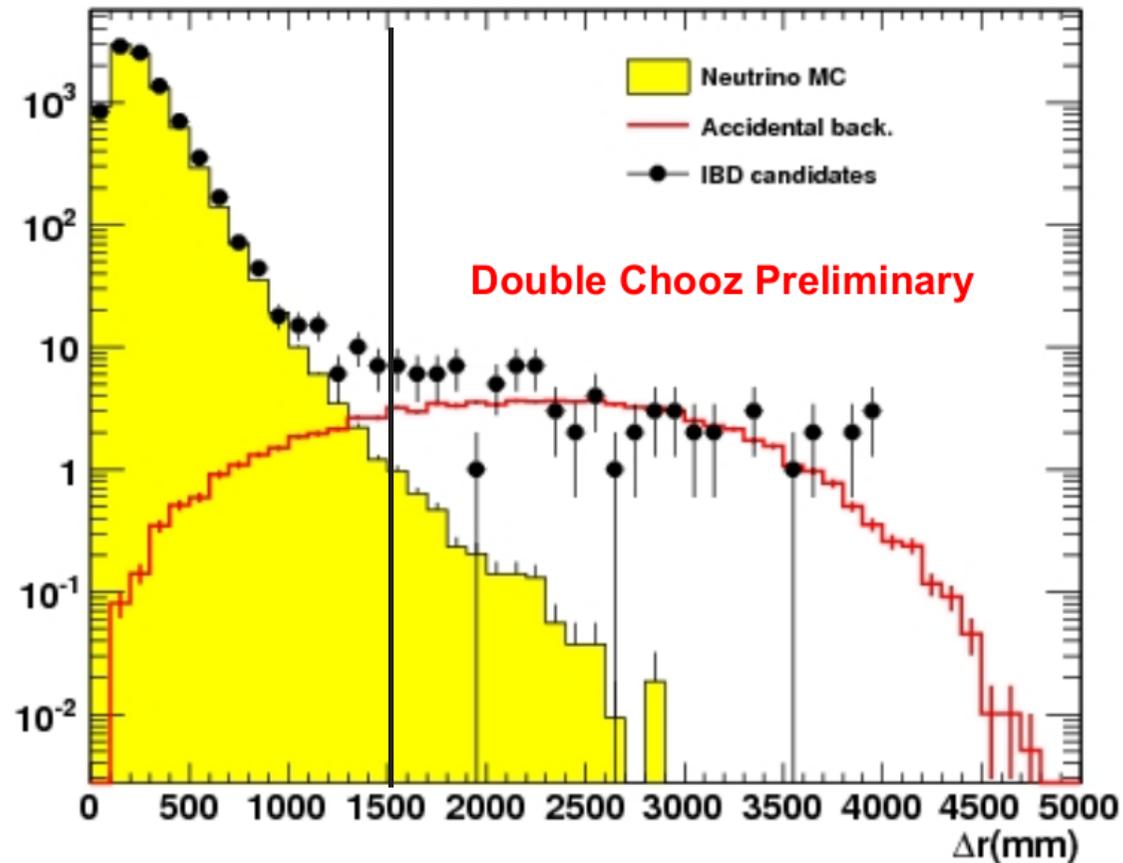


► How to separate these events? → Use correlations :

	ID Time	ID Space	ID-IV Time	ID-IV Space
Fast Neutron	Some	Some	Some	Some
γ/n (IV) + $\bar{\nu}_e$ (ID)	Some	Some	None	None
$\gamma - \gamma$ + n/γ	None	None	Strong	Strong

Space Correlation between Prompt and Delayed : $\gamma - \gamma$ rejection

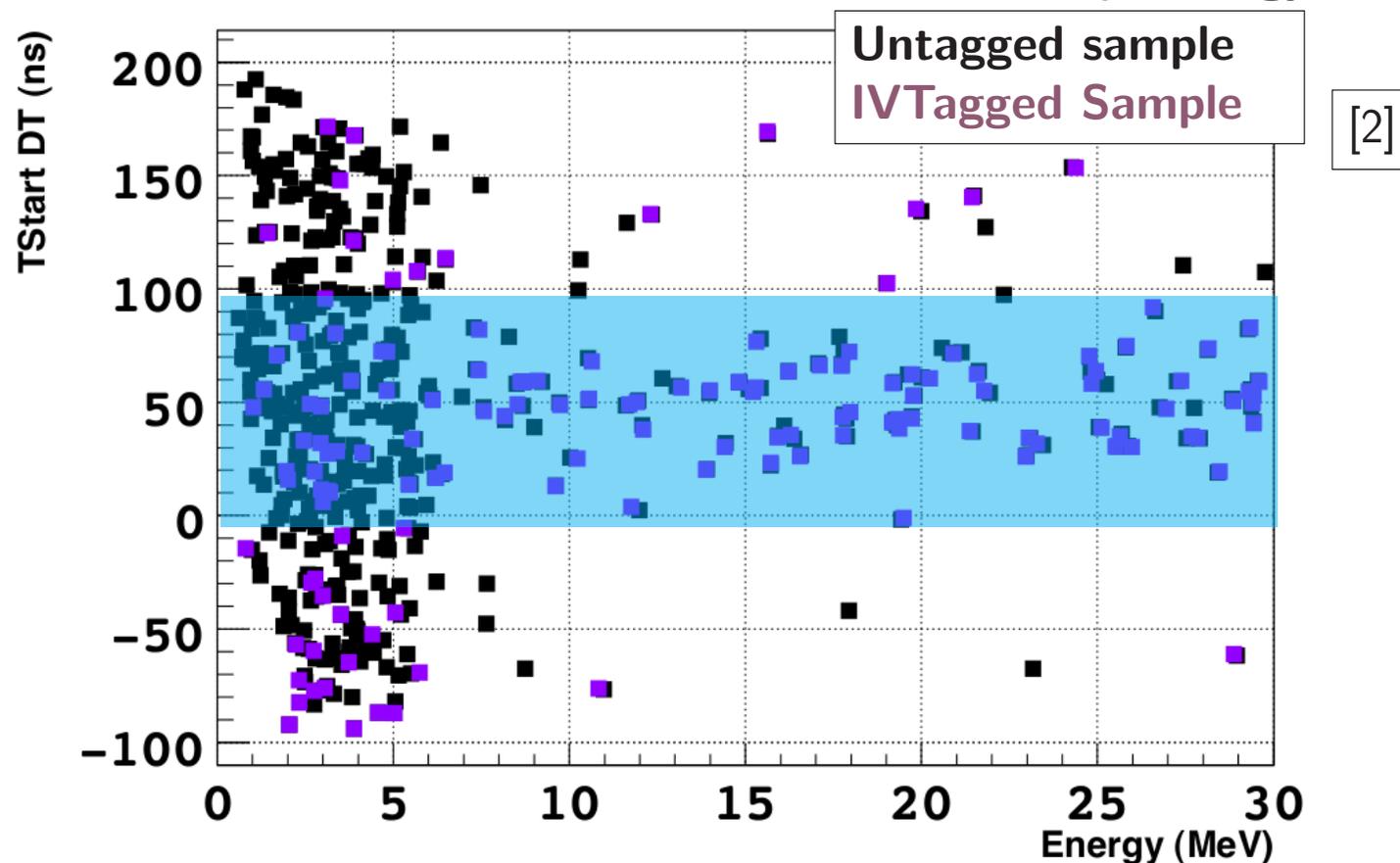
Space correlation between Prompt and Delayed



- ▶ $\gamma - \gamma$: Come from accidental background.
- ▶ Prompt-Delayed space correlation up to ~ 1500 mm.
- ▶ Cut on $\Delta R(\text{Prompt} - \text{Delayed}) < 1500$ mm \rightarrow Reduction to $\sim 2\%$ of remaining IVT sample.

Time Correlation between ID and IV : $\bar{\nu}_e$ rejection

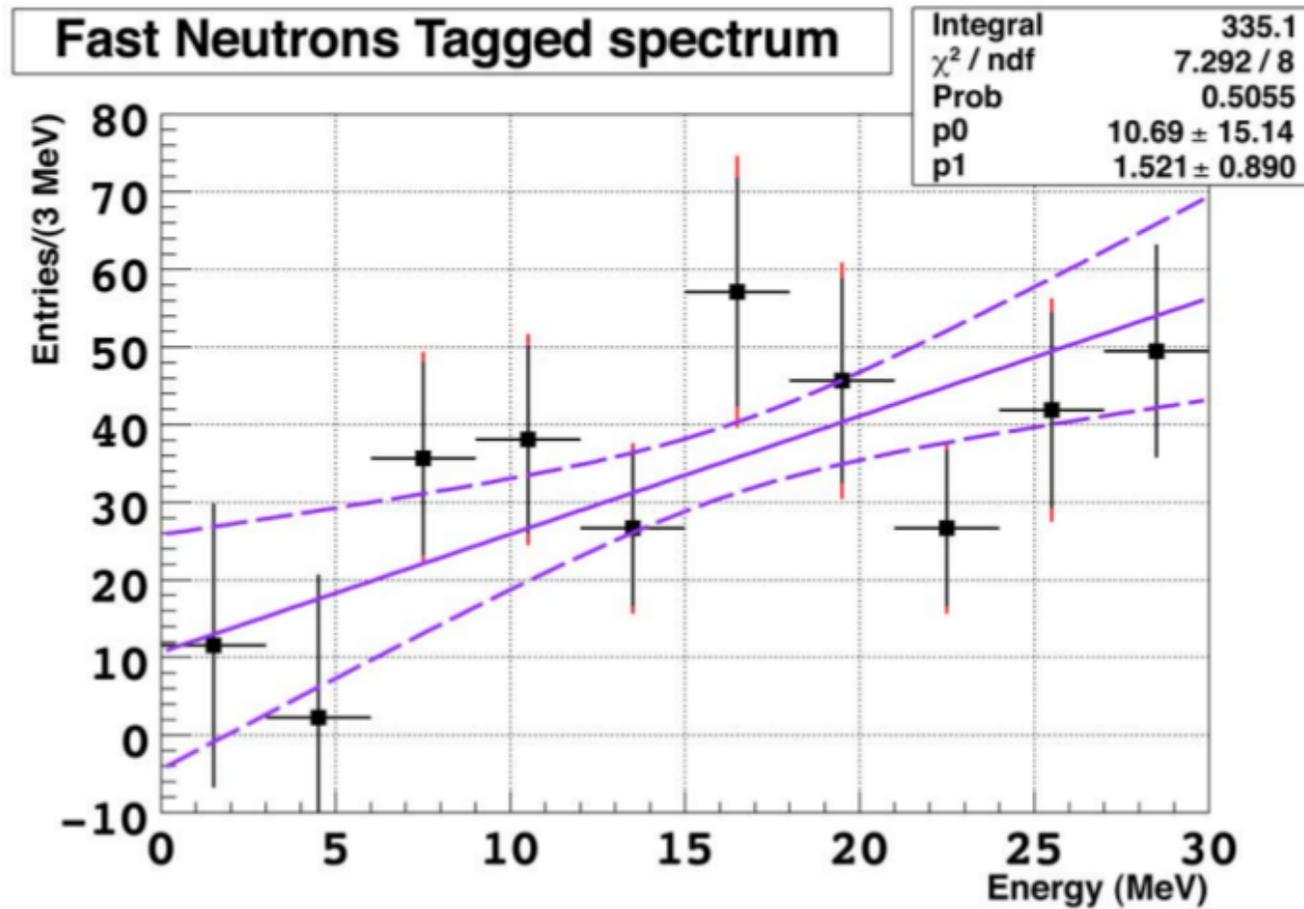
Time correlation between ID and IV versus Prompt energy



- ▶ ID-IV Time correlation between $[-2, 95]$ ns.
- ▶ Cut on $\Delta t(\text{ID} - \text{IV}) \in [-2, 95]$ ns \rightarrow Reduction to $\sim 12\%$ of remaining IVT sample.

Fast Neutron shape with IVT method

- ▶ In last DC publication : Purity of Fast Neutron sample : $\sim 86\%$
- ▶ Non-flat shape for Fast Neutron. Yet, big uncertainties.

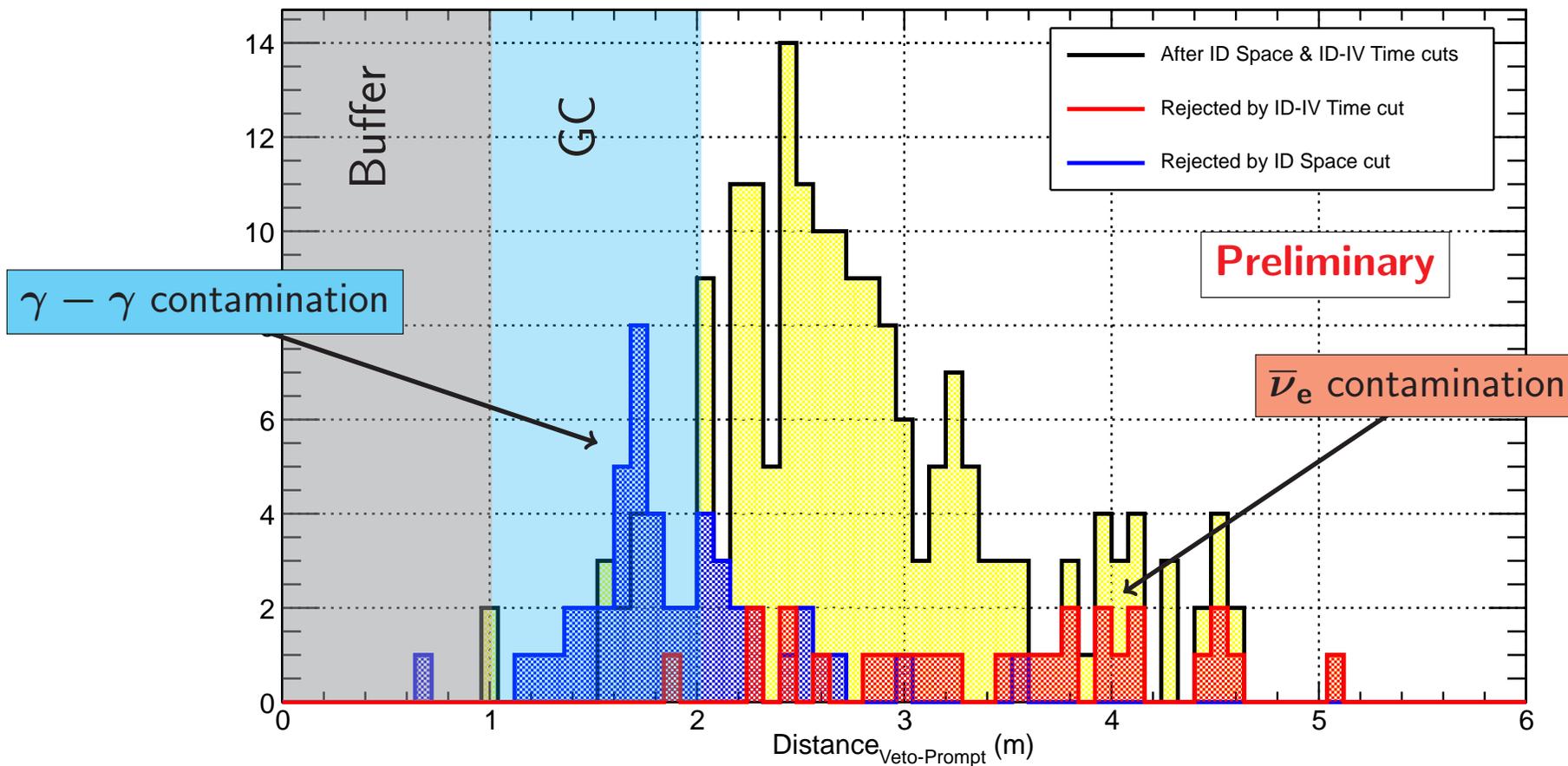


[2]

(Preliminary) Space correlation between ID and IV

- ▶ Since last publication : development of an algorithm to reconstruct position in IV.
- ▶ We can use space correlation between IV and ID to improve Fast Neutron sample purity.

Space Correlation between ID and IV



Summary

- ▶ Double Chooz :
 - ▷ Experiment to measure θ_{13} value.
 - ▷ Detection of Inverse Beta Decay in detectors.
 - ▷ Three main background : Accidentals, ^9Li and Correlated.
- ▶ Correlated background :
 - ▷ Fast Neutron from cosmic muon spallation in rocks.
 - ▷ Stopping Muon decay in detector Target.
- ▶ Shape at Low Energy :
 - ▷ Flat assumption is most part of other reactor experiment.
 - ▷ Direct measure in Double Chooz.
- ▶ Inner Veto Tagging :
 - ▷ Method to measure the low energy shape for Fast Neutron.
 - ▷ Different kind of events tagged.
 - ▷ Separation with correlation in ID or between ID and IV.
 - ▷ [Preliminary] Space correlation add in the method to improve purity.

References

[1] : K. Abe et al. (Double Chooz Collaboration), “Reactor $\bar{\nu}_e$ disappearance in the Double Chooz experiment”, Phys. Rev. D 86, 052008 (2012)

[2] : A. Remoto thesis

Correlated Background Energy spectrum

Correlated Background Energy spectrum

