Novel Total neutron-Capture (TnC) Detection Technique

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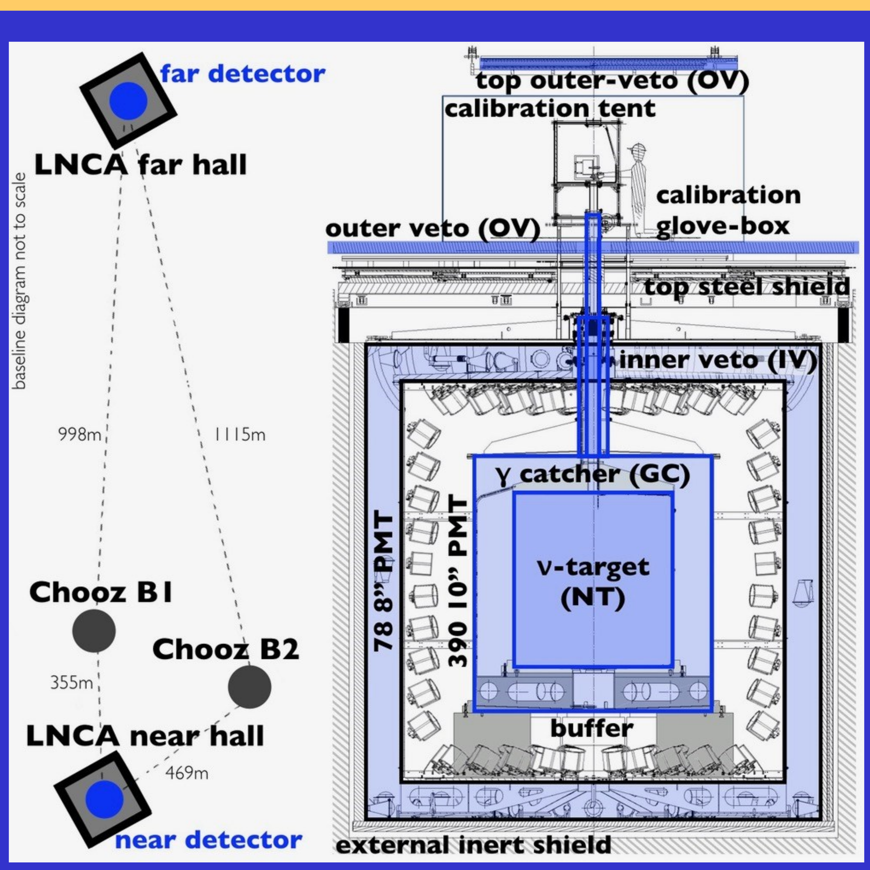
The Double Chooz experiment



The Double Chooz experiment goal is the precise measurement of the θ_{13} neutrino mixing angle. It measures $\bar{\nu}_e$ -flux from the two nuclear reactors of the Chooz NPP with total thermal power ~8.4 GW using two identical detectors. The near (ND) and far (FD) detectors are respectively at ~400 m and ~1050 m.

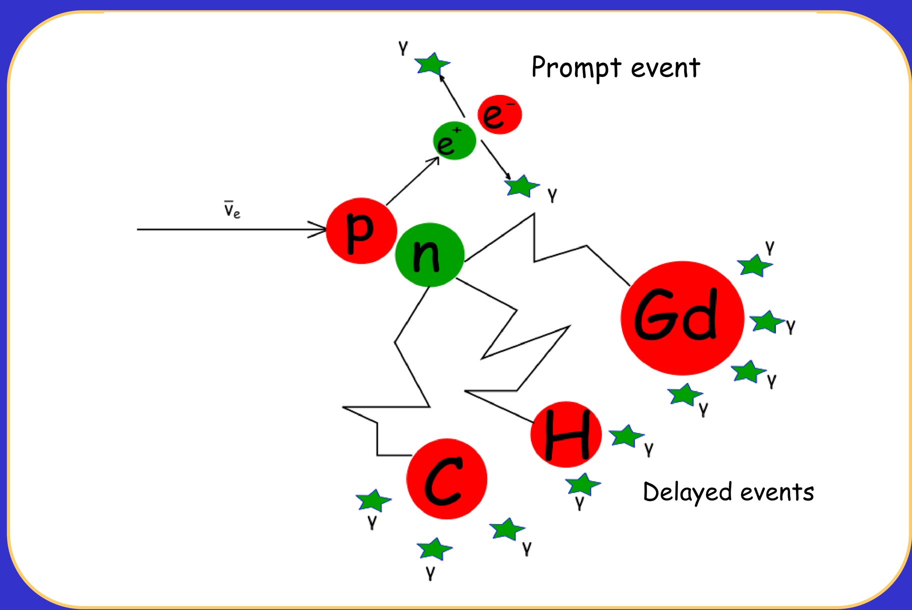
To estimate θ_{13} the survival probability is used:

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2(2\theta_{13})\sin^3(\frac{\Delta m^2_{31} L}{4E})$$

The detection technique:

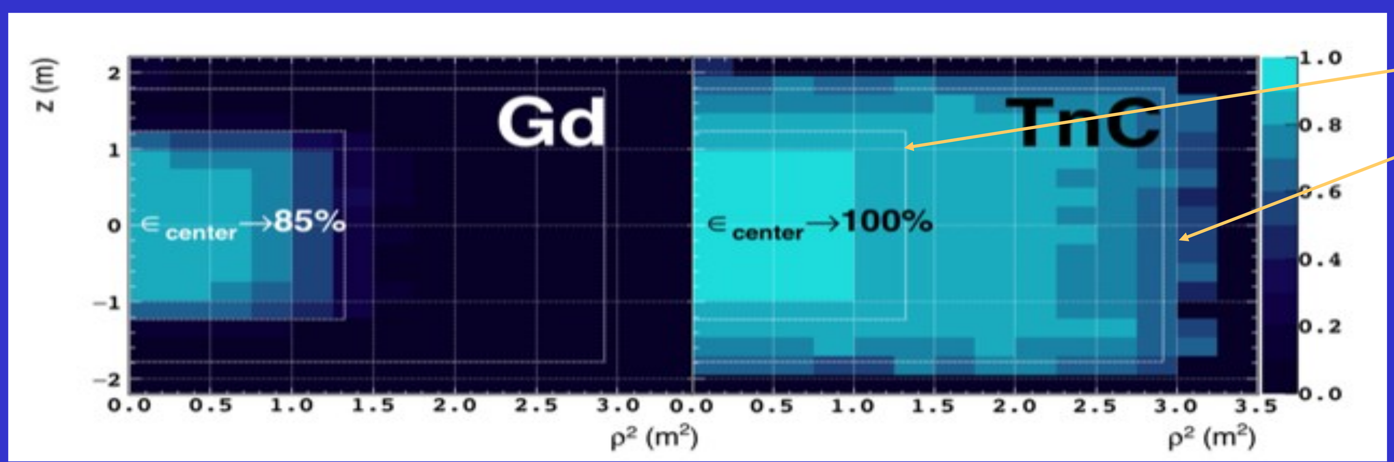
The cornerstone of the $\bar{\nu}_e$ detection is the inverse beta decay (IBD) reaction:

$$\bar{\nu}_e + p \to e^+ + n$$



Prompt signal:
e^+ annihilation resulting in an emission of two γs (E_γ ~ 0.511 keV each).

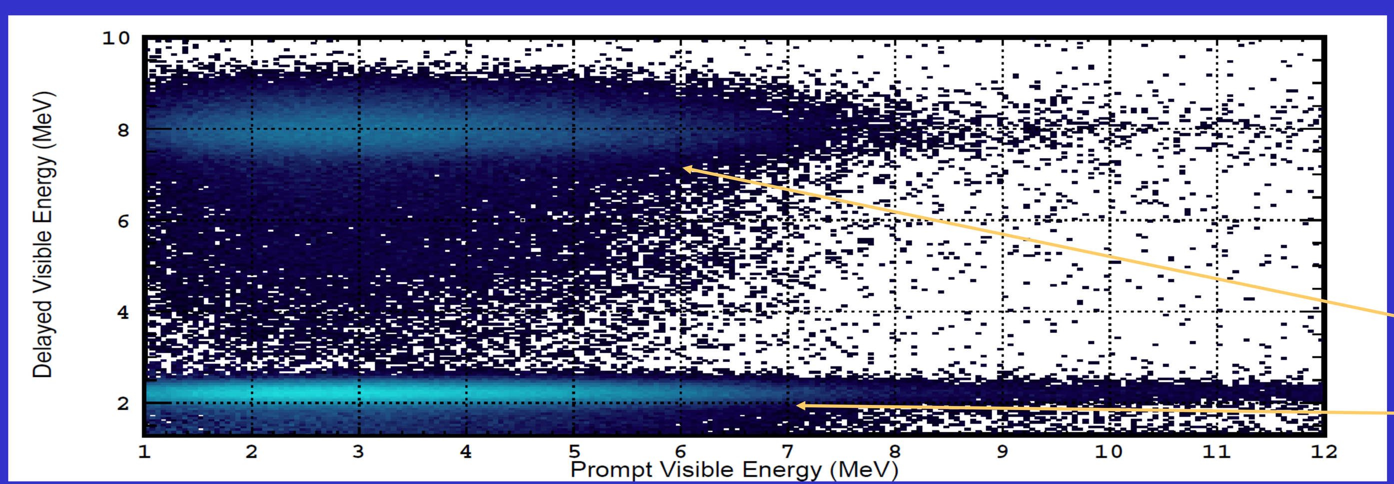
Delayed signal:
Neutron capture over all possible isotopes in the liquid scintillator volumes resulting in an emission of multiple γs with E_{total} ~ 2.2MeV, ~ 8MeV, ~ 5MeV respectively for H, Gd, C nuclei.



Target volume boarder

γ-catcher volume boarder

Due to **Isotope independence** (inclusive integration over all selection, energy scale and captures) of TnC technique, the effective detection volume has increased up to a factor of ~3.



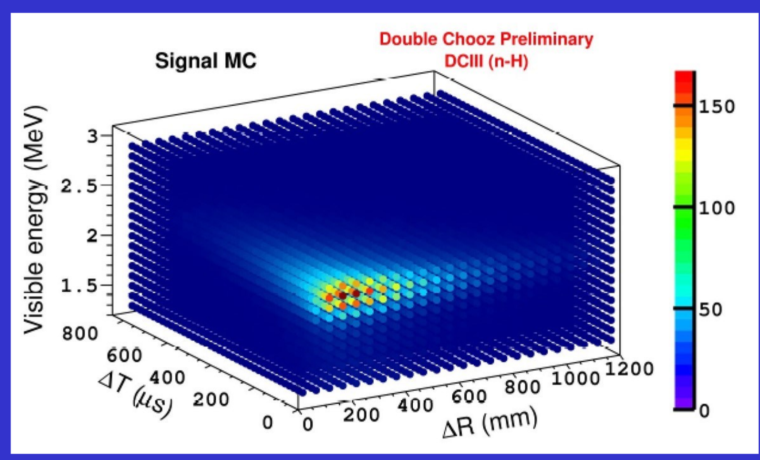
Gadolinium captures

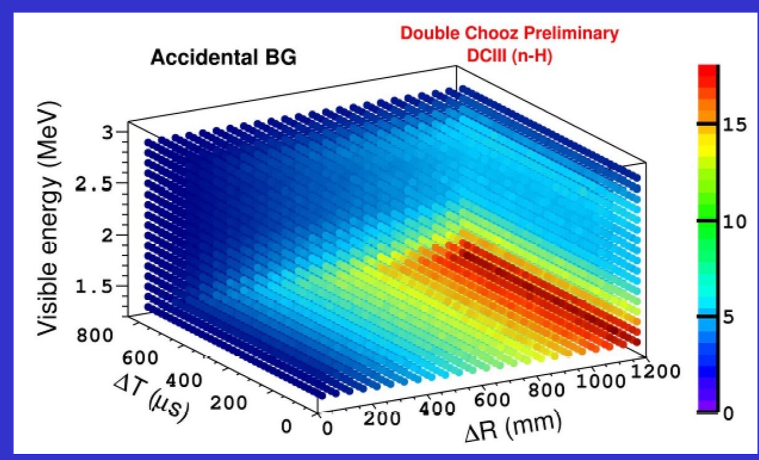
Hydrogen captures

Selection and Background

1. Selection criteria and accidental BG subtraction (ANN)

E^{prompt} : [1.0, 20.0] MeV,
ANN coincidence : >0.85 (FD), >0.86 (ND)
Δt^{prompt} (unicity) : [-800, 900] μs





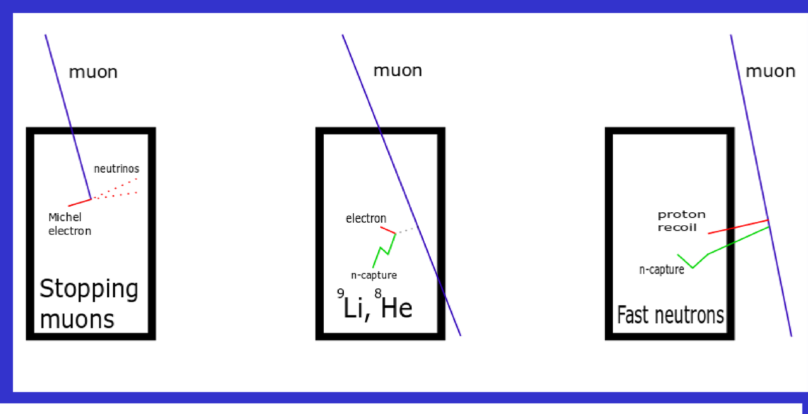
2. Background

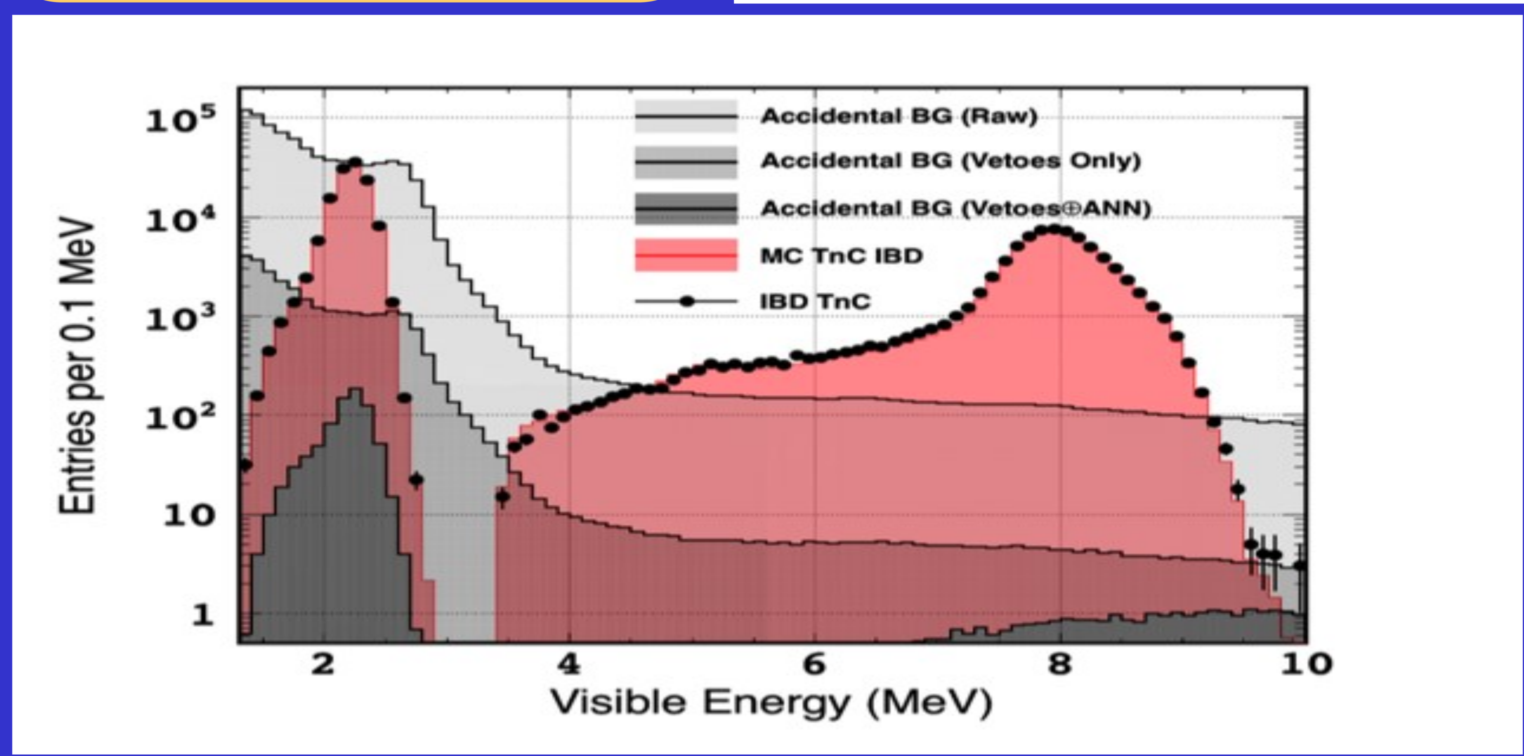
Accidental BG : a random coincidence of two triggers which mimic the IBD event.

Artificial Neural Network (ANN)

Limits of utilized variables:
$E^{delayed}$: [1.3, 10.0] MeV;
$\Delta t^{prompt-delay}$: [0.5, 800] μs;
$\Delta R^{prompt-delay}$: ≤1.2m.

Correlated BG : two physically correlated events which mimic the IBD event.





	FD-I (day^{-1})	FD-II (day^{-1})	ND (day^{-1})
Life-time (days)	455.207	362.974	257.959
IBD candidates	105.77	117.53	815.94
IBD^{MC} candidates	112.03	128.84	1118.88
Accidental BG	3.93±0.01	4.32±0.02	3.110±0.004
Fast n + Stop μs	2.54±0.07		20.77±0.43
Cosmogenic BG (^{9}Li)	3.01±0.60		12.32±2.01
Total BG	9.48±0.6	9.87±0.6	36.20±2.06

Detection Systematics Uncertainties

Observed neutrino candidates:

$$N(E)^{observed} = \varepsilon \times N(E)^{expected} + N(E)^{Background}$$

where: $N(E)^{expected}$ - expected neutrino flux;
$N(E)^{background}$ - background;

Detection efficiency ε can be factorized like following:

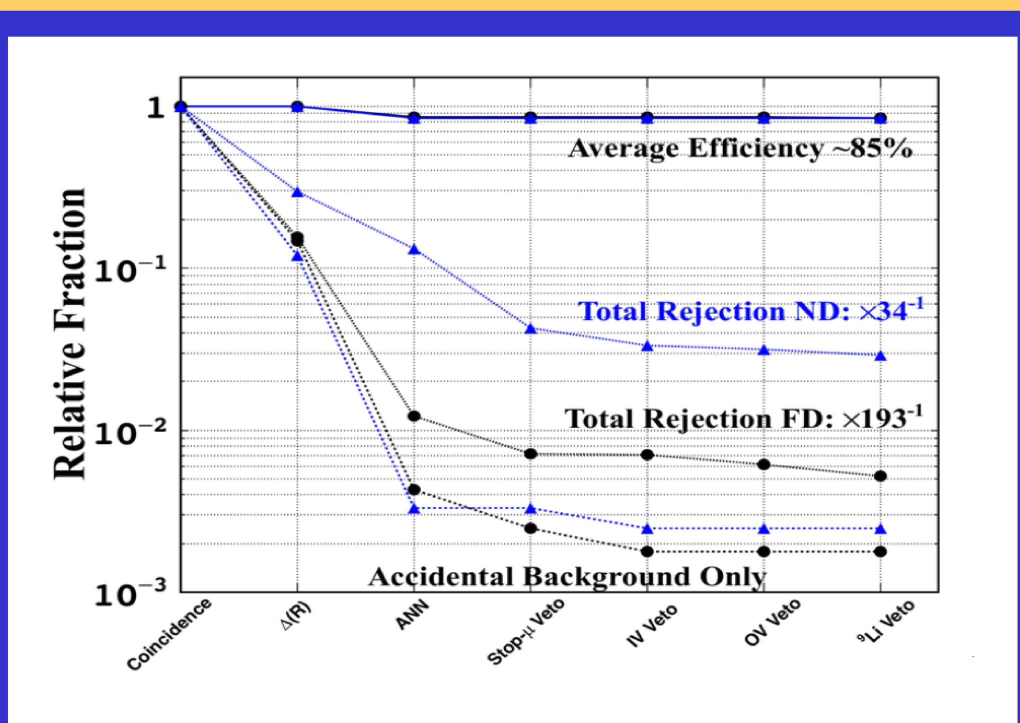
$$\varepsilon = \varepsilon_{proton} \times \varepsilon_{boundary} \times \varepsilon_{vetoes} \times \varepsilon_{IBD}$$

IBD neutron selection efficiency:

$$\varepsilon_{IBD} = \frac{N(Selection)}{N(Selection\ open\ cuts)} \qquad c_v = \frac{\varepsilon^{DATA\ FD}_{IBD}}{\varepsilon^{DATA\ ND}_{IBD}} \text{ or } \frac{\varepsilon^{DATA}_{IBD}}{\varepsilon^{MC}_{IBD}}$$

IBD neutrons which are homogeneously distributed have been used to estimate neutron detection efficiency in the whole detector volume.

Boundary effect: Due to TnC technique, there is no spill in/out effects. The boundary effect is caused by the Buffer-Gamma Catcher boarder. Systematic uncertainty computed via MC simulation.



Proton number: the number of targets for IBD interaction in the detection volume.
It is the main contribution to the detection systematics due to the lack of the precision knowledge of the γ-catcher composition (~1%) compared to the one of the neutrino target (~0.3%). It is planned to be re-measured during dismantling.

Vetoes efficiency: Inefficiency in the neutrino selection due to the background rejection cuts which are only relevant for the DATA.

IBD selection efficiency (%)	$\varepsilon^{FD\ DATA}_{IBD} = 86.78 \pm 0.21$		$\varepsilon^{FD\ MC}_{IBD} = 86.75 \pm 0.01$
	$\varepsilon^{ND\ DATA}_{IBD} = 85.47 \pm 0.08$		$\varepsilon^{ND\ MC}_{IBD} = 85.54 \pm 0.02$
Uncertainty (%)	**SD**	**MD**	**MD** projection
Proton number	0.65	0.38	~0.1?
IBD Selection	0.33^{FD} / 0.12ND	0.27	~0.2 (stat.)
Boundary	0.20	-	-
Vetoes Efficiency	≤0.05	≤0.05	≤0.05

Summary: The TnC yields major systematics reduction, as compared to any isotope dependent detection. IBD selection deviation was up to <0.1%. The best is yet to come after the re-estimation of the γ-catcher proton number.

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