Background-independent measurement of θ_{13} with the Double Chooz experiment

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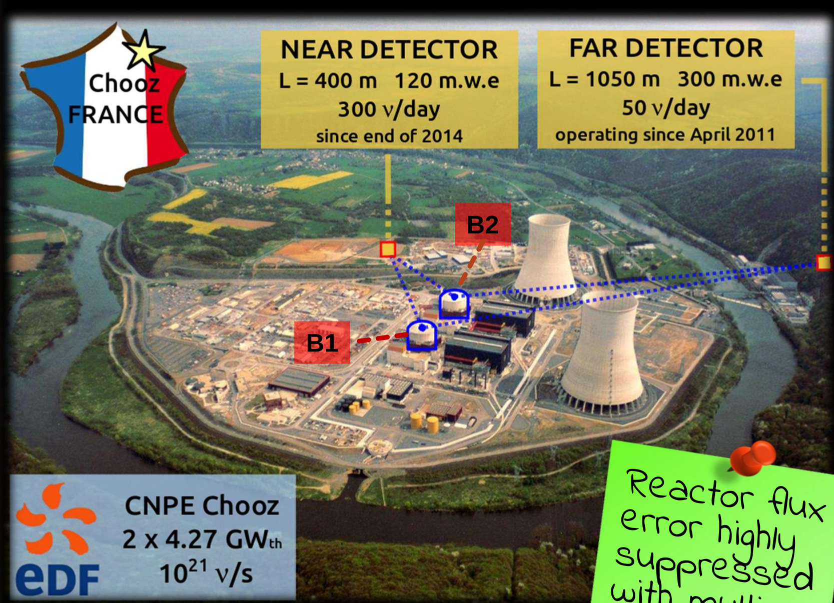
on behalf of the Double Chooz Collaboration

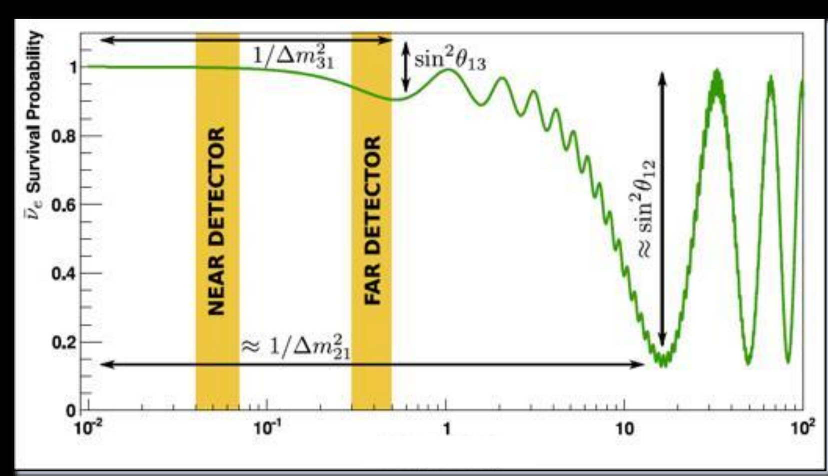
The Double Chooz Experiment



Reactor flux error highly suppressed with multi-detectors

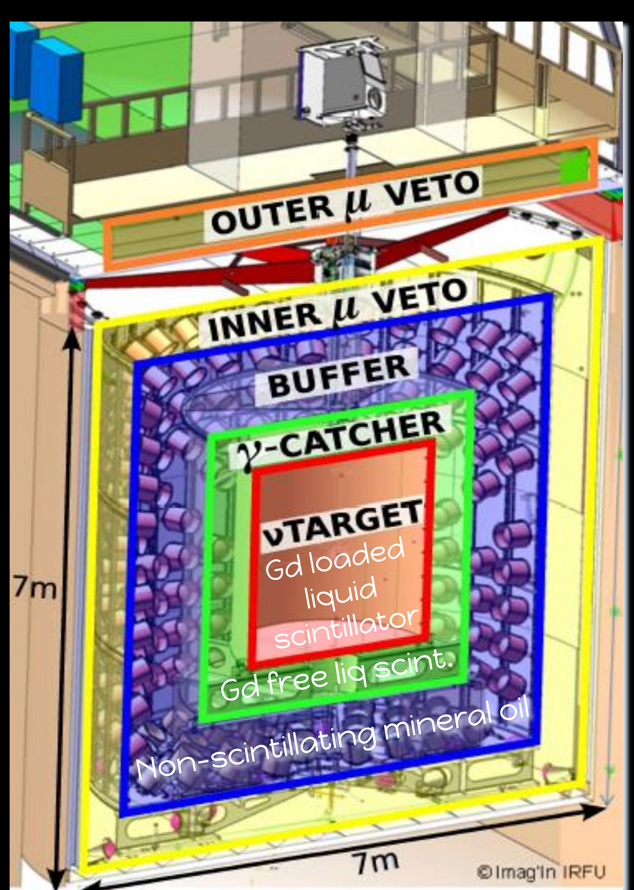
In reactor experiments, the determination of the θ_{13} mixing angle is extracted via the survival probability of $\bar{\nu}_e$:

$$P_{\bar{\nu}_e\to\bar{\nu}_e}(L,E) \simeq 1-\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{31}L}{4E_\nu}\right)$$



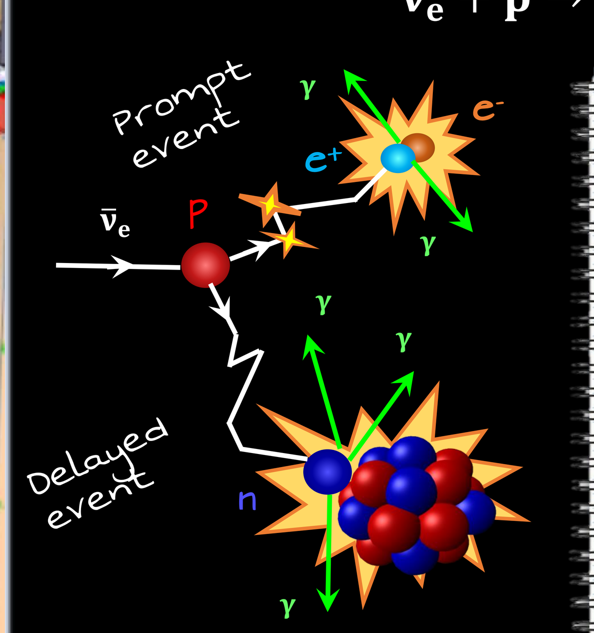
Multi-detector analysis

- 455 days FD-I (single detector)
- 363 days FD-II (multi-detectors)
- 258 days ND (multi-detectors)



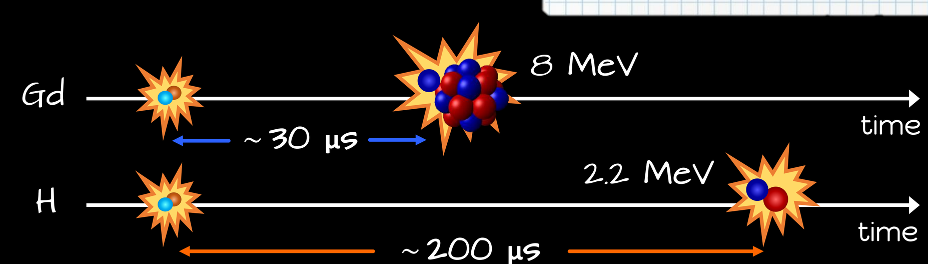
$\bar{\nu}_e$ are detected via the inverse β decay (IBD)

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



- $\bar{\nu}_e$ interact with p of the organic scintillation target
- Prompt signal: Energy losses + e^+ annihilation

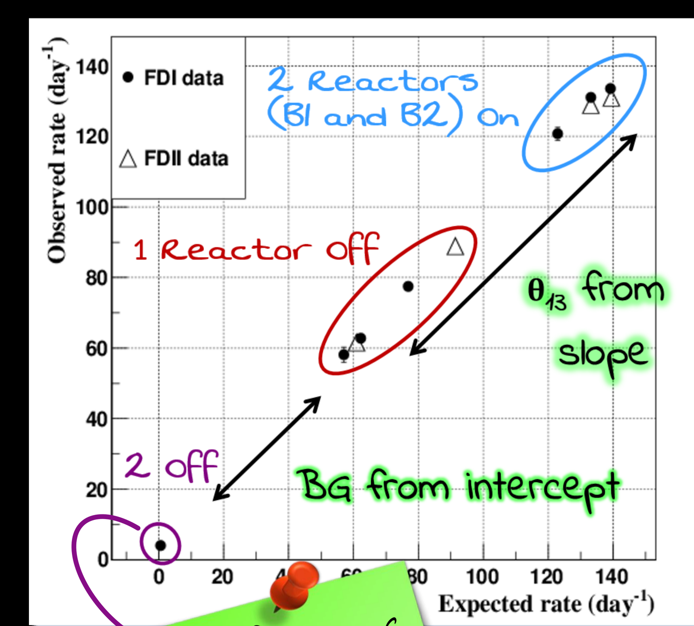
  $E_{vis} \simeq E(\bar{\nu}_e) - 0.8$ MeV
- Delayed signal: Neutron capture over all available isotopes in the liquid scintillator volumes: Gadolinium (Gd) (8 MeV γ rays), Hydrogen (H) (~2.2 MeV) or Carbon (C) (~5 MeV)



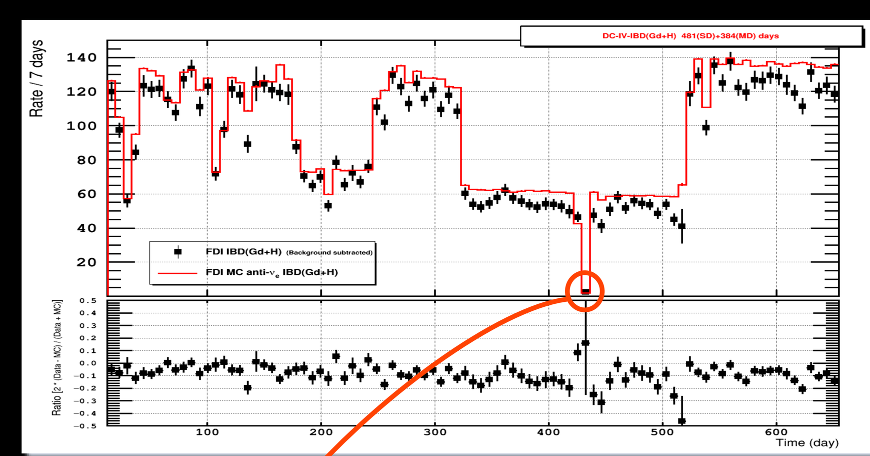
The Reactor Rate Modulation (RRM) Approach

θ_{13} and cosmogenic BG rates (BG) are determined simultaneously by comparing the observed $\bar{\nu}_e$ candidates rate (R^{obs}) with the expected one (R^{exp}) for different reactor power conditions:

$$R^{obs} = BG + R^{exp} = BG + (1-\sin^2(2\theta_{13})\eta_{osc})R^{\nu}$$



Unique feature in DC that allows a direct measurement of the BG



During 2-Off period, a few β-decays in the reactor core: Residual ν emitted

Systematics Uncertainties

	Detector	Parameter	Uncertainty	Correlated
Detection efficiency	FD	ϵ^{FD}	σ^{FD}_{det} = 0.39%	No
	ND	ϵ^{ND}	σ^{ND}_{det} = 0.22%	No
Reactor flux	FDI	$\alpha^{FDI}_{B1}\omega^{FDI}_{B1}, \alpha^{FDI}_{B2}\omega^{FDI}_{B2}$	σ^{FDI}_R = 0.91%	No
	FDII	$\alpha_{B1}\omega^{FDII}_{B1}, \alpha_{B2}\omega^{FDII}_{B2}$	σ_R = 0.91%	No
	ND	$\alpha_{B1}\omega^{ND}_{B1}, \alpha_{B2}\omega^{ND}_{B2}$	σ_R = 0.91%	No

Residual ν rate in FDI in the 2-Off period α_ν = 0.584 ± 0.175 day^{-1}

Overall normalization and correlated errors included in η_{norm} (σ_{norm}=1.4%), dominated by the constraint imposed by Bugey4 data

Oscillation and Cosmogenic BG Fit

Rate-only fit that relies on a χ^2 minimization:

$$\chi^2 = \sum_i \chi^2_i + \chi^2_{FD-off} + \chi^2_{BG} + \chi^2_{pen} + \chi^2_{norm} \qquad \sum_i \chi^2_i = \chi^2_{FDI} + \chi^2_{FDII} + \chi^2_{ND}$$

$$\chi^2_i = \left(\frac{1}{\sigma^i_{stat}}\right)^2\left[R^i_{obs} - R^i_{exp}\left(1+\eta_{norm}+\sum_{r=B1,B2}(\omega^i_r\alpha^i_r)+\epsilon^i\right) - BG^i\right]$$

$$\chi^2_{FD-off} = 2\left(N^{obs}\ln\frac{N^{obs}}{BG_{FD}+N^{exp}[1+\epsilon^{FD}+\alpha^\nu]} + BG_{FD} + N^{exp}[1+\epsilon^{FD}+\alpha^\nu] - N^{obs}\right)$$

2 ways of performing RRM fit:

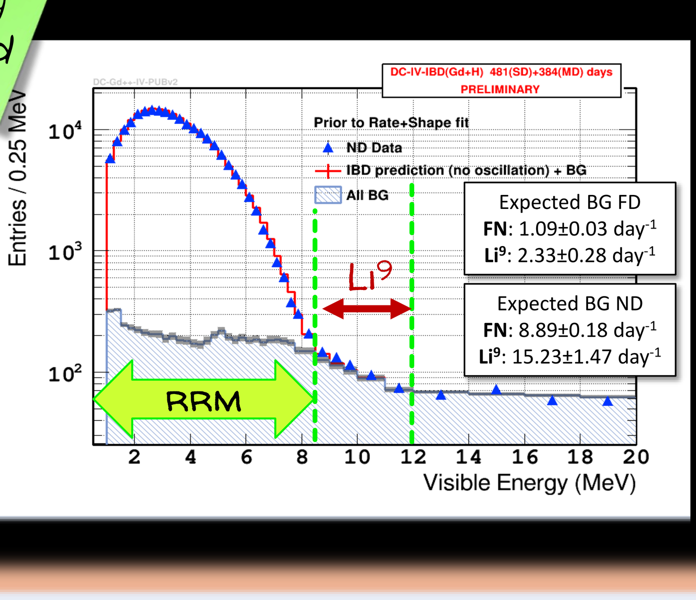
1. Constrained background: priori knowledge of BG is required, θ_{13} determined with high precision
2. Unconstrained background: measurement of θ_{13} independent of the BG model and best fit values of the BG can be confronted to the BG model

Background sources:

Cosmogenic background: Fast neutrons + Cosmogenic Isotopes (Li^9)

$$\chi^2_{BG} = \sum_{i=FD,ND}\left(\frac{BG_i - BG^{exp}_i}{\sigma^{exp}_{BG_i}}\right)^2$$

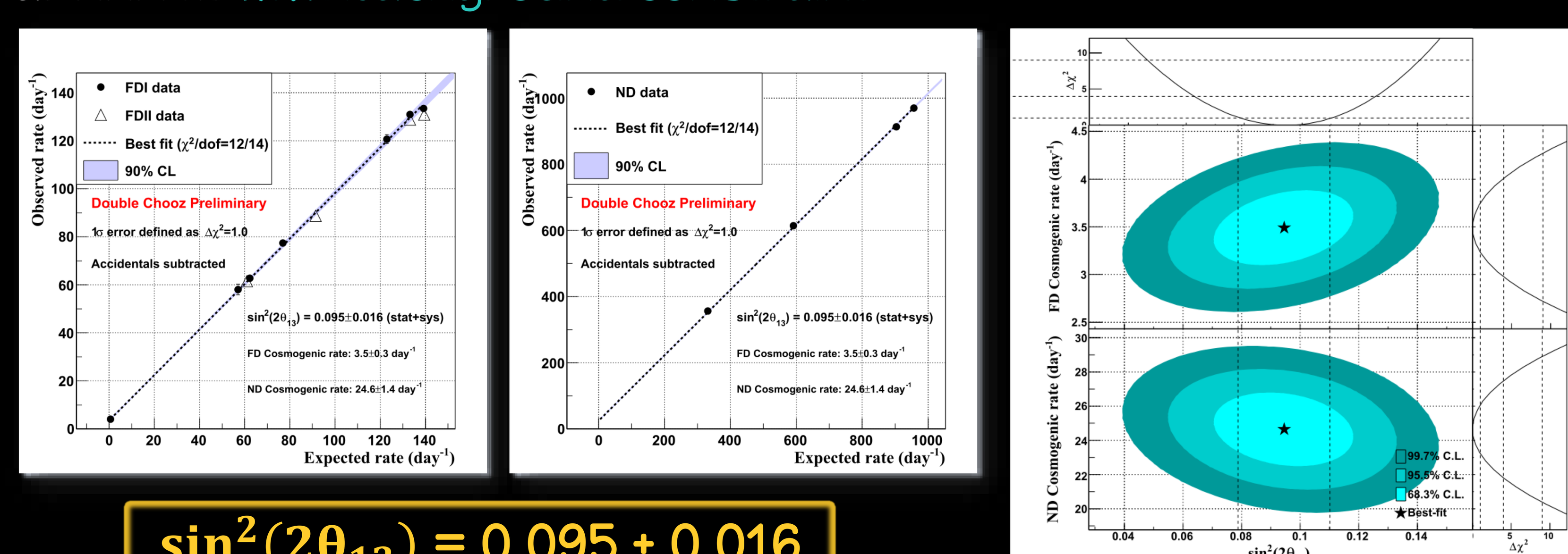
Accidental coincidences subtracted from DATA (not included in the fit)



- RRM fit: 1.0-8.5 MeV energy window
- Li^9 extracted from candidates in the 8.5-12.0 MeV window:
  - Subtract FN estimation in the 8.5-20.0 MeV range
  - Remaining candidates in the 8.5-12 MeV provide the Li^9 rate
  - Extrapolate rate to 1.0-8.5 MeV according to shape spectrum

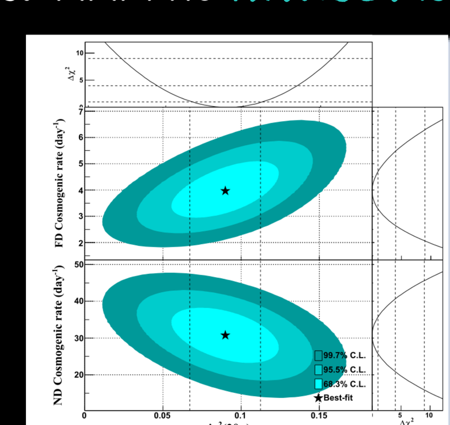
RRM Oscillation Fit Results

a. RRM fit with background constraint



$\sin^2(2\theta_{13})$ = 0.095 ± 0.016

b. RRM fit without background constraint



- BG treated as free parameter in the fit
- $\sin^2(2\theta_{13})$ = 0.090 ± 0.023
- θ_{13} independent of the BG model
- BG_{FD} = 4.0 ± 0.7, BG_{ND} = 30.7 ± 5.0 events/day (FN+Li^9) consistent within 1σ with the BG model
- The constraint on the total BG rate given by the 2-Off data improves precision of θ_{13}

c. Crosscheck of the Rate+Shape fit

- Same energy window (1.0-20.0 MeV) assumed
- $\sin^2(2\theta_{13})$ = 0.110 ± 0.018
- R+S fit: $\sin^2(2\theta_{13})$ = 0.105 ± 0.014

RRM fit yields almost same precision as R+S fit

d. Flux normalization consistent with expectation: η_{norm} = -0.1 ± 0.7 %

- Fit compatible with flux reactor model
- σ_{norm} is reduced from 1.4 % to 0.7 % thanks to relative comparison FD to ND

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