

# Double Chooz

## Reactor Rate Modulation $\theta_{13}$ Analysis

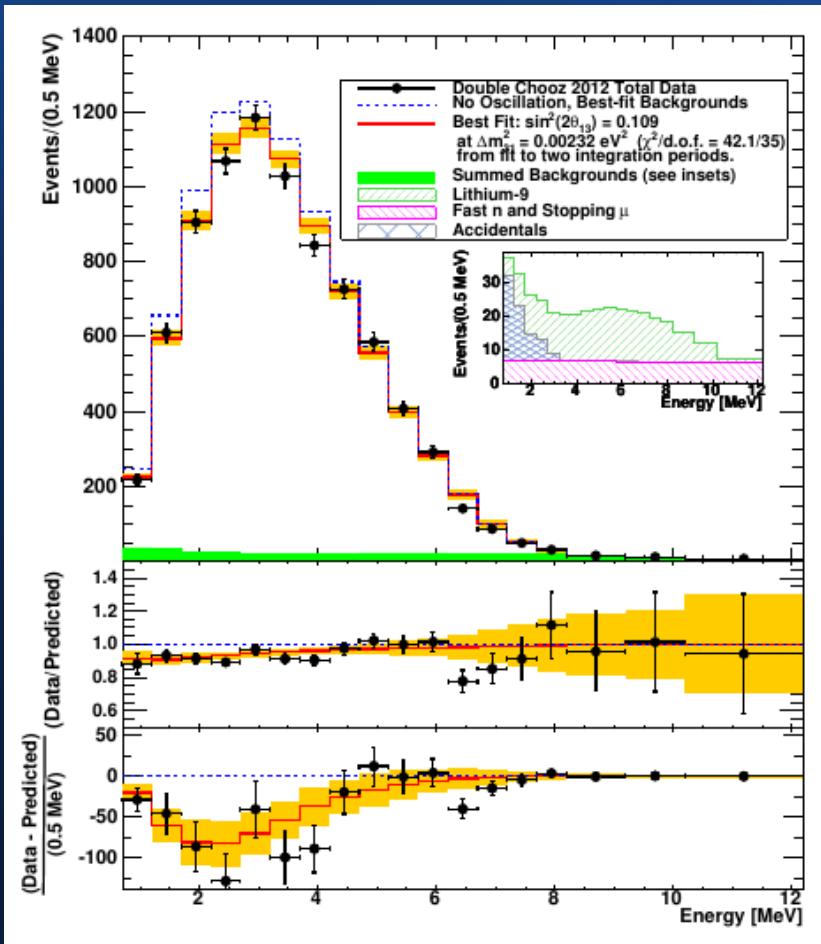
$\theta_{13}$  *Rate-Only Analysis with Reactor-off data*



Pau Novella (CNRS/APC)  
*On behalf of the DC Collaboration*

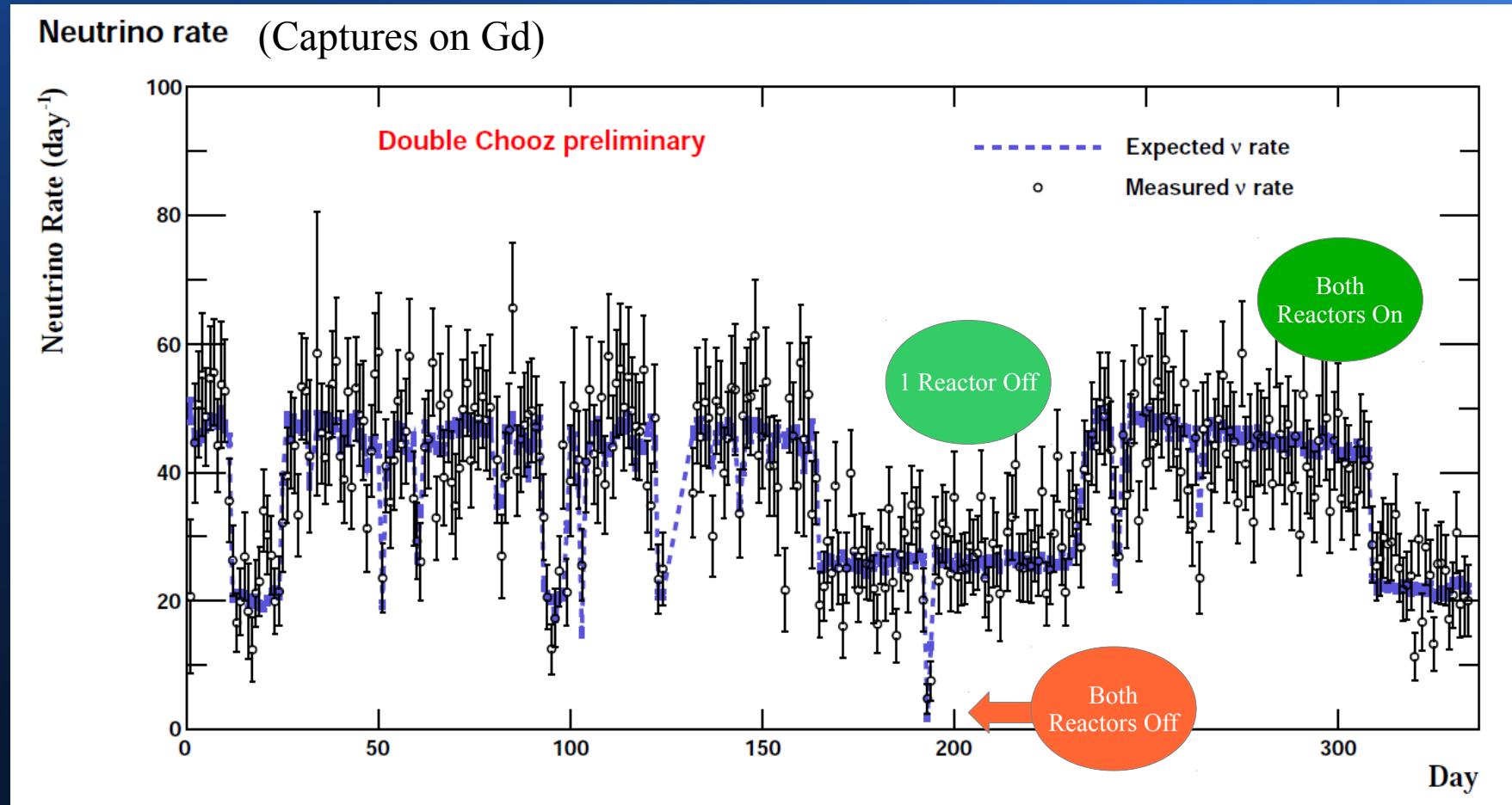
# Overview

Phys.Rev. D86 (2012) 052008



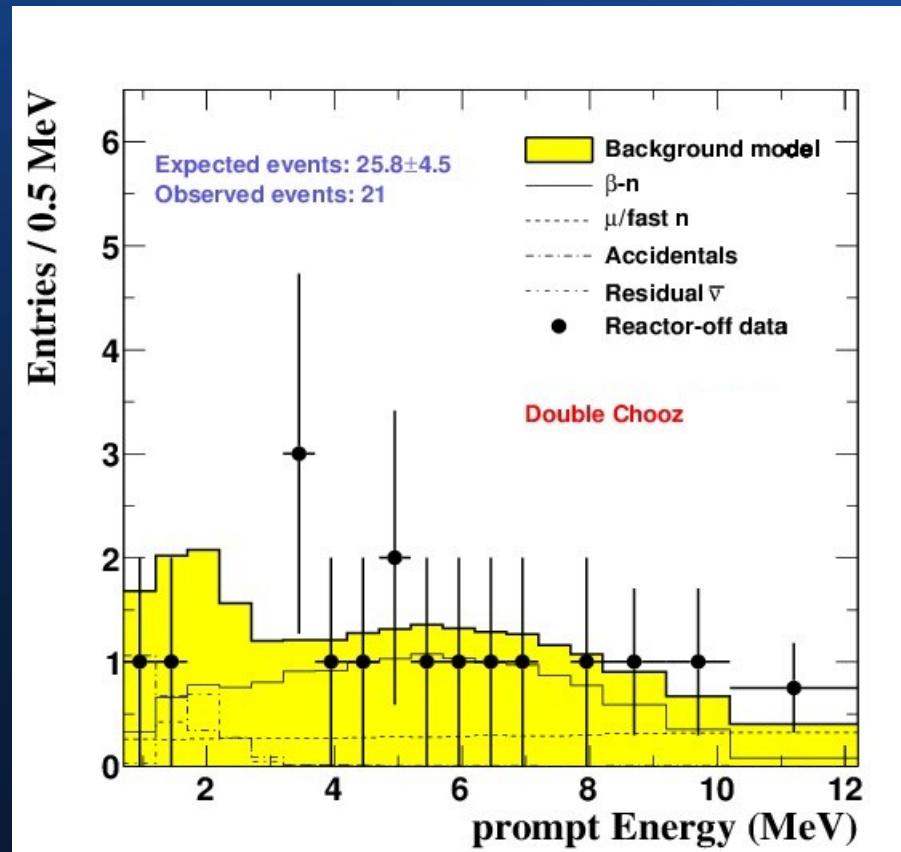
- DC published results rely on background (B) models from reactor-on data
- New independent analysis:  $(\theta_{13}, B)$  fit
  - Obs. vs Exp.  $\nu$ -candidates rate
    - different reactor powers
  - Extra handle: Reactor-Off data
  - No background model

# Neutrinos vs Reactor Power

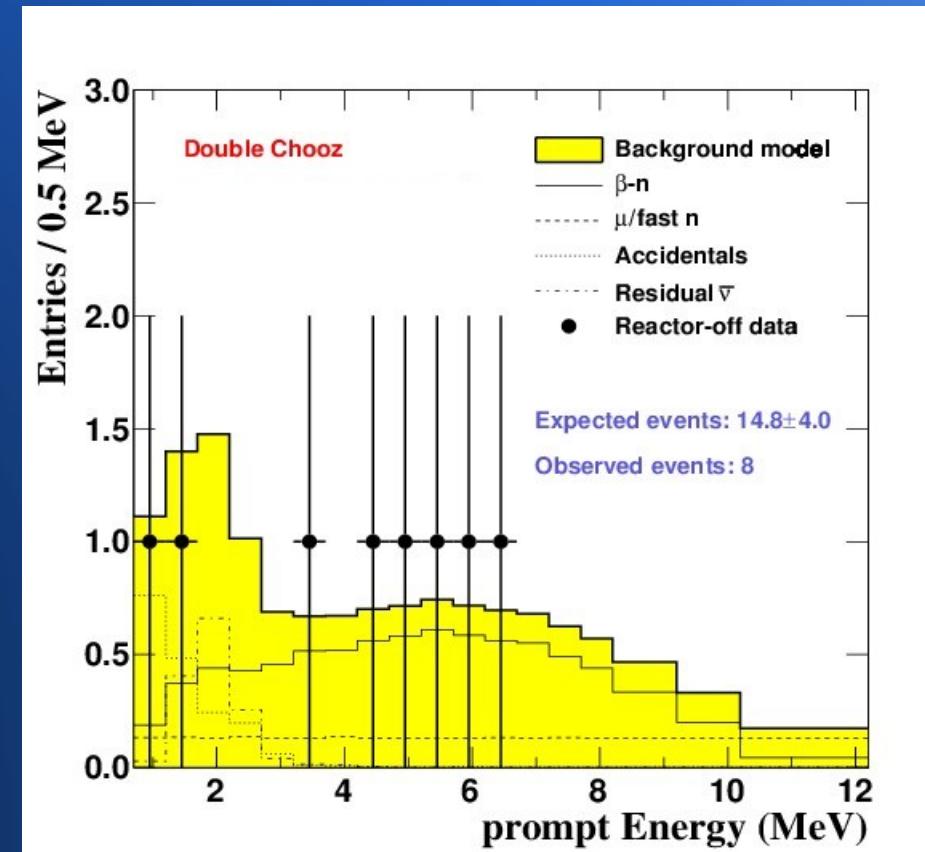


# Reactor-Off data

2011 and 2012 reactor-off data samples: 7.53 days



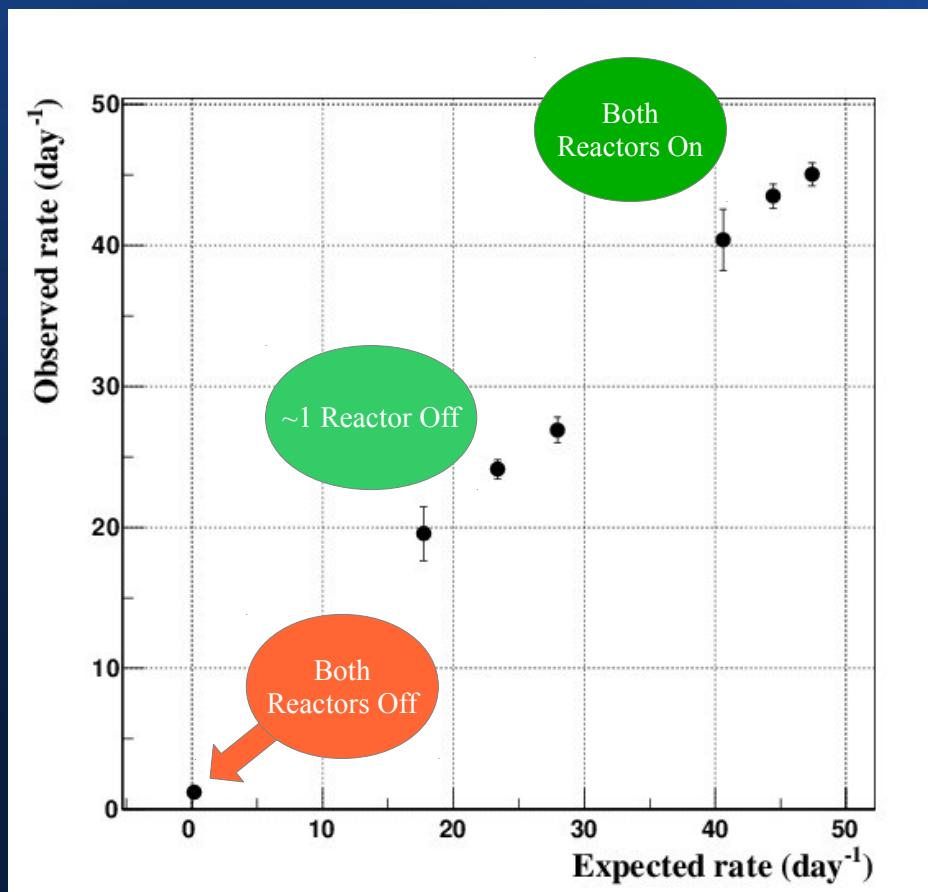
IBD selection in first DC publication



IBD selection in second DC publication

# Observed vs Expected Rate

Grouping the obs.  $\nu$  in bins of expected rate...



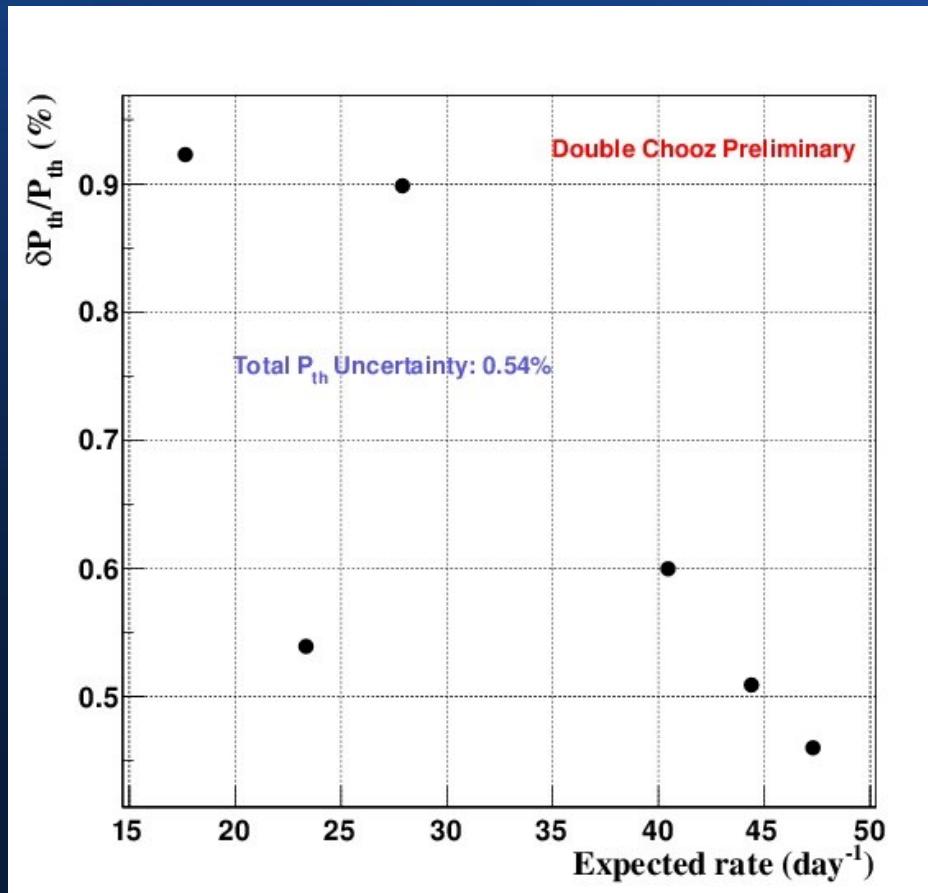
- Fit to a straight line model:

$$f(R^{exp}) = B + \left(1 - \sin^2(2\theta_{13}) \cdot \alpha_{osc}\right) \cdot R^{exp}$$

- $\theta_{13}$ : fit slope ( $\alpha$  from MC)
- B: extrapolation to zero power
- $\chi^2$  minimization:  
$$\chi^2 = \chi^2_{on} + \chi^2_{off}$$
- Reactor-Off : poisson stats.
- Different systematics

# Expected Rate Uncertainty

Reactor power ( $P_{th}$ ) uncertainty:

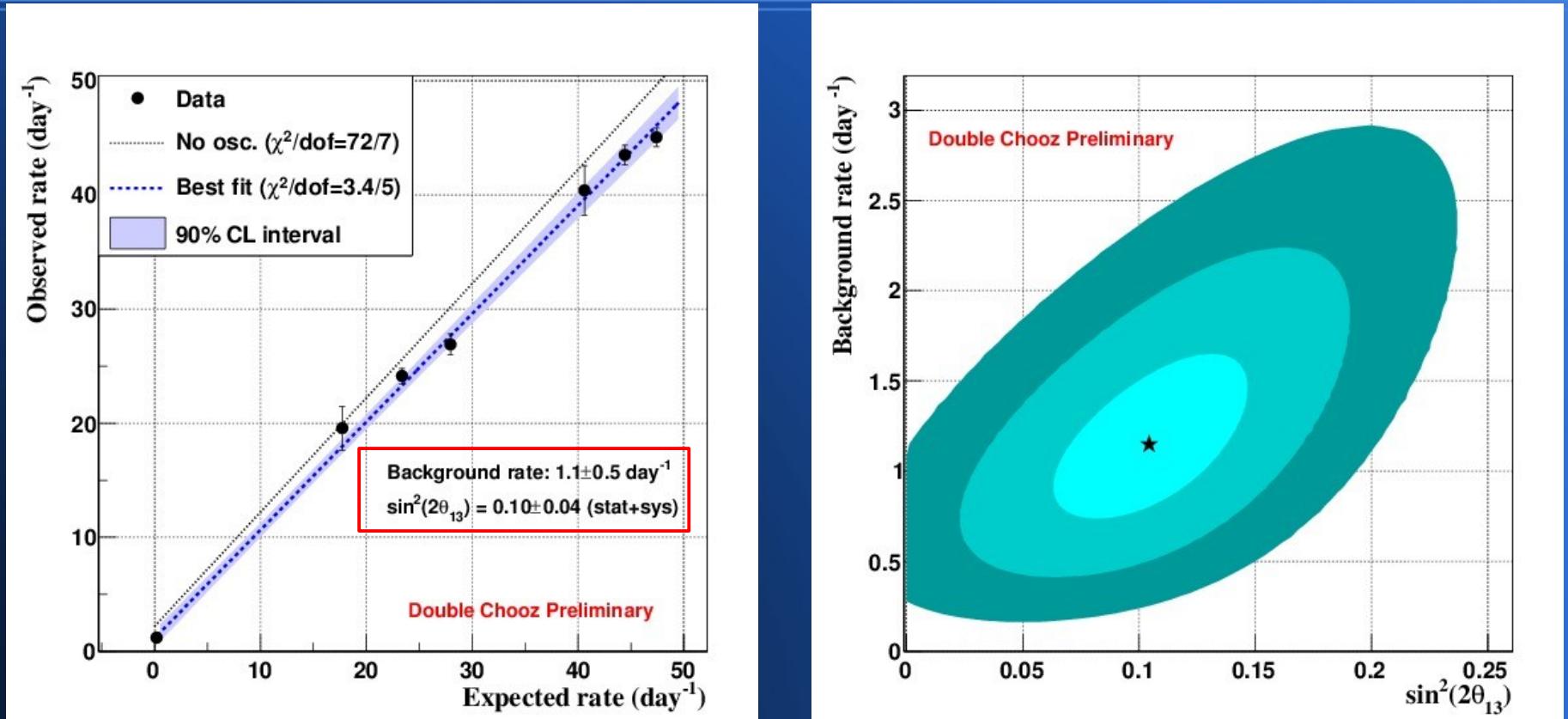


- Three sources of systematics:
  - Detection efficiency
  - Reactor-on  $\nu$  prediction ( $R^\nu$ )
  - Reactor-off residual  $\nu$  ( $R^{r-\nu}$ )
- Error on  $P_{th}$  depends on  $P_{th}$ :
  - Variable error

Sys. source	Error (%)	$R^\nu$	$R^{r-\nu}$
det. efficiency ( $\sigma_d$ )	1.005	yes	yes
Reactor-on pred. ( $\sigma_r^i$ )	1.75-1.92	yes	no
Reactor-off pred. ( $\sigma_\nu$ )	30	no	yes

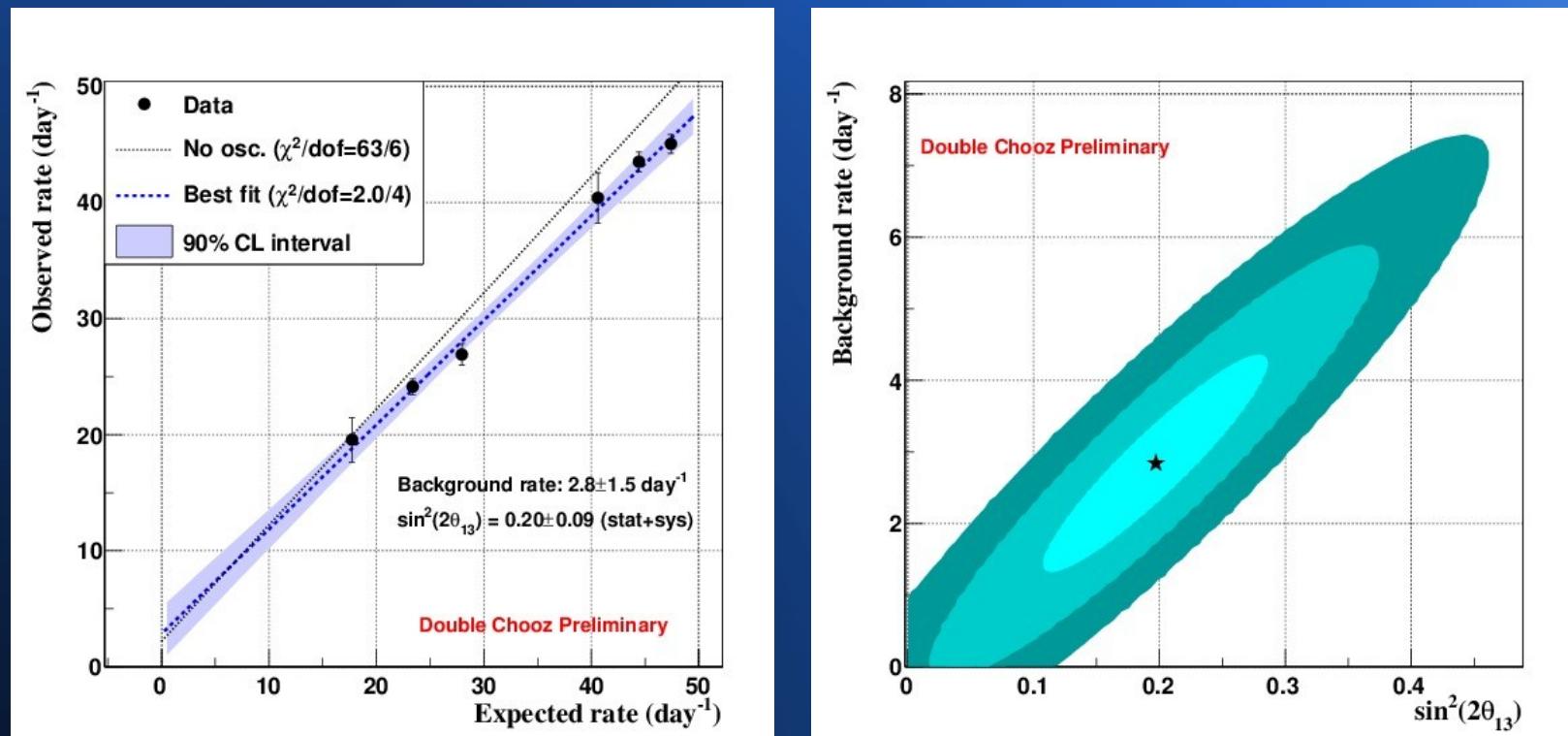
Introduced in the fit as pulls

# $\theta_{13}$ -Background Results



- In agreement (~same precision) with DC Rate+Shape results
- $\sin^2(2\theta_{13})=0.10\pm0.04$  ( Phys.Rev. D86 (2012):  $\sin^2(2\theta_{13})=0.109\pm0.039$  )

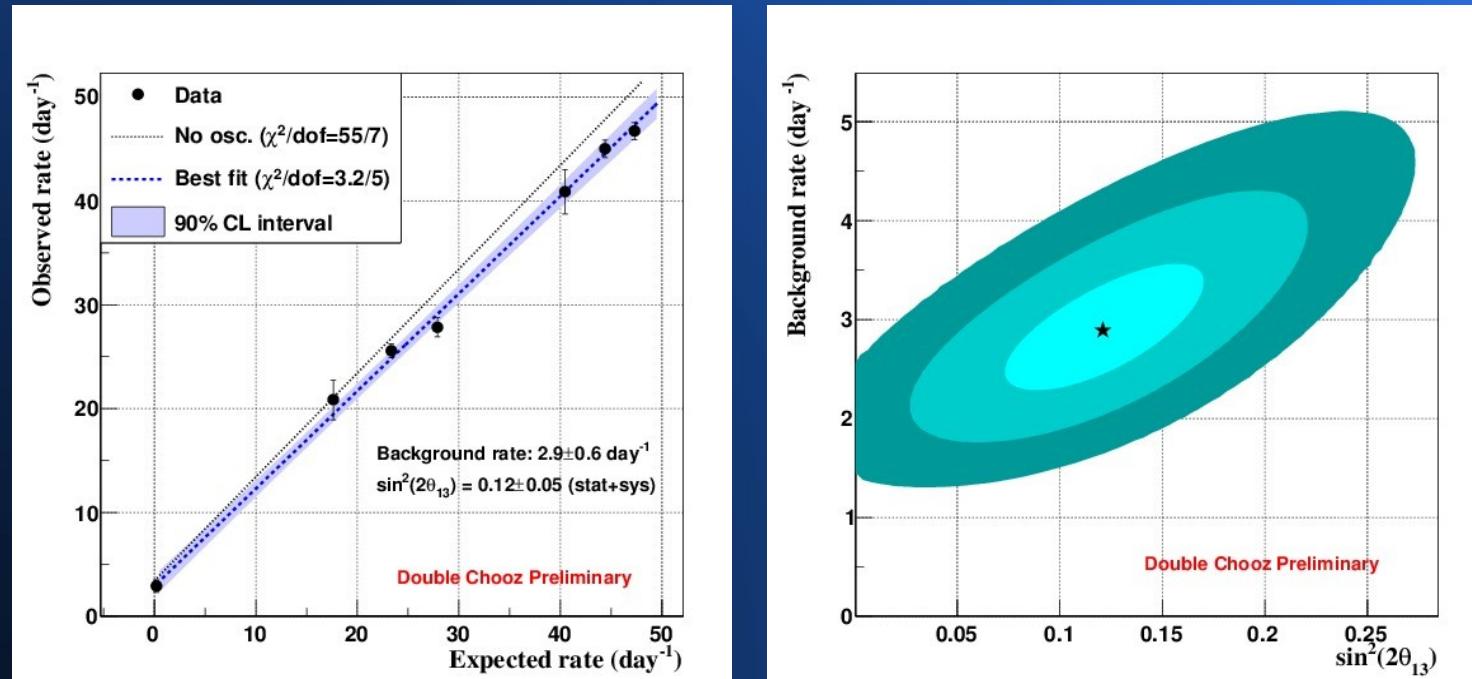
# Results w/o Reactor-Off data



- In agreement with DC Rate-Only results:
  - Phys.Rev. D86 (2012):  $\sin^2(2\theta_{13})=0.170\pm0.052$

# Impact of Neutrino Selection

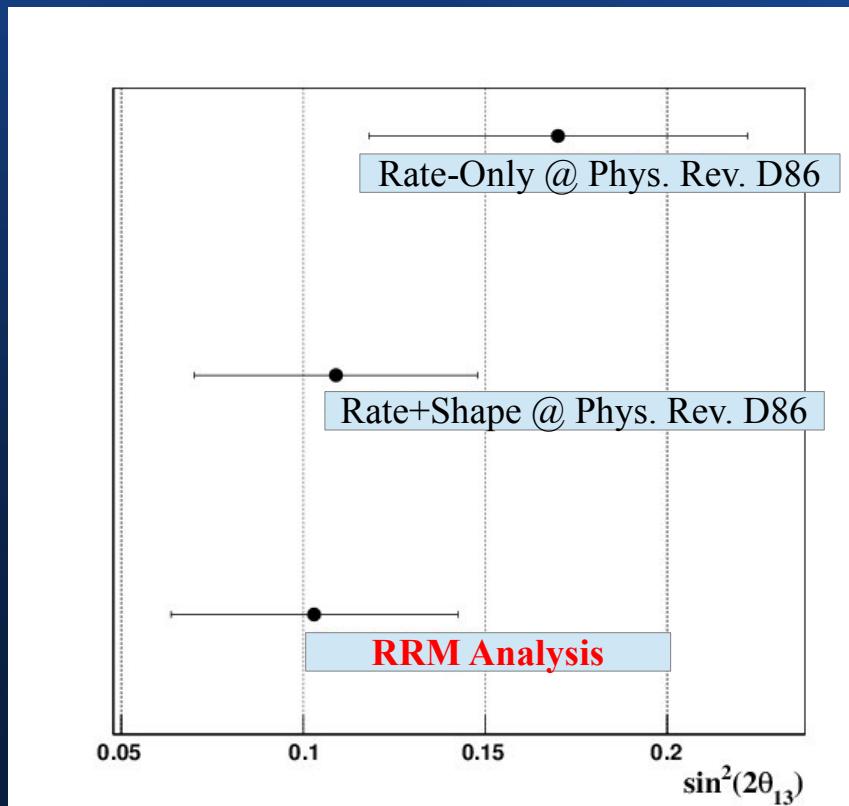
- Although  $B$  depends on  $\nu$  selection,  $\theta_{13}$  must be independent
- Applying a looser set of cuts (DC @ Phys.Rev.Lett. 108):



- In agreement with previous and DC Rate+Shape results

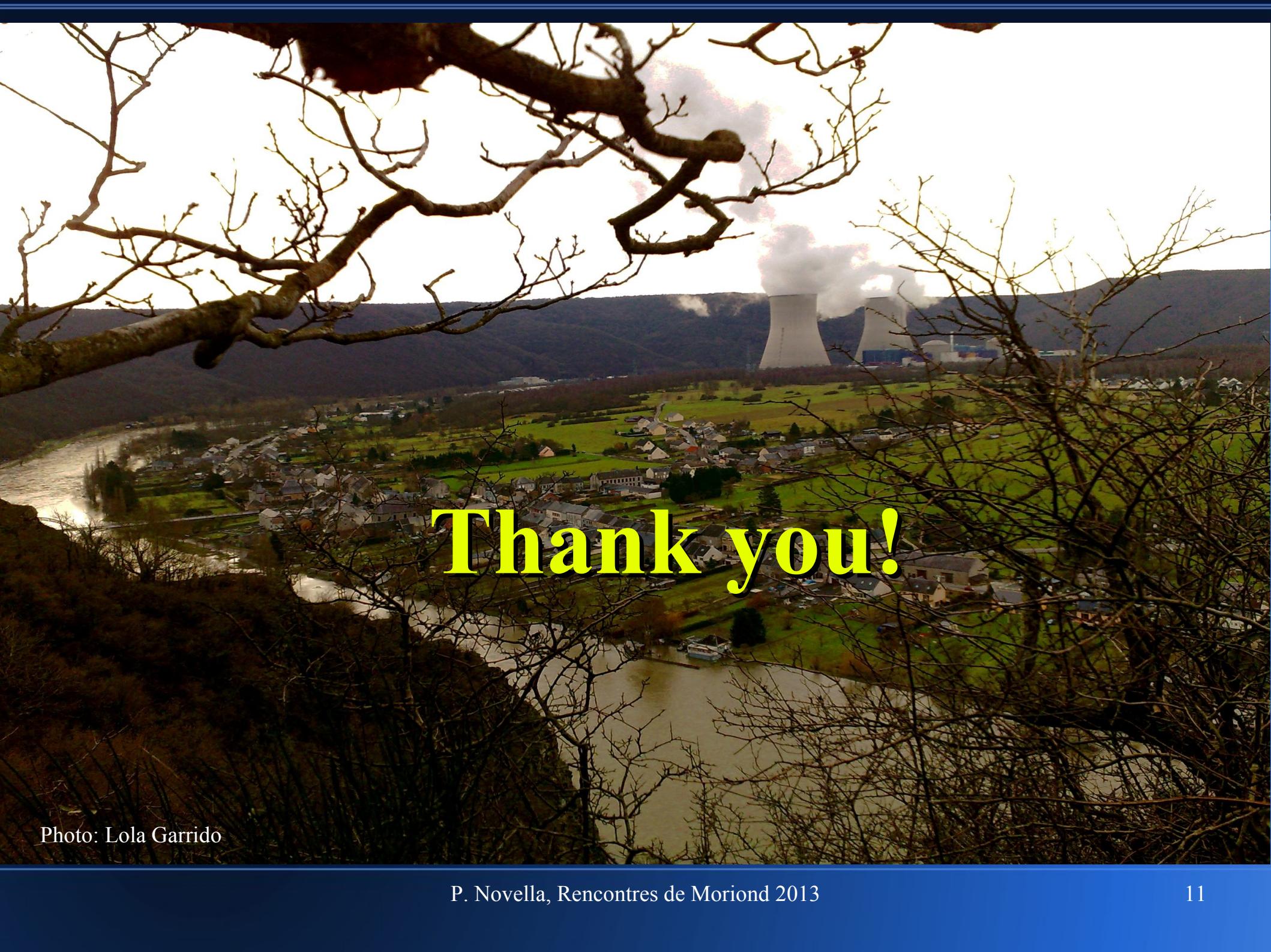
# Summary

Available DC (Gd) results:



## Reactor Rate Modulation $\theta_{13}$ /B Analysis

- New/independent rate-only  $\theta_{13}$  analysis:
  - Different  $P_{th}$  conditions
  - Reactor-off data
  - No a priori B assumptions
- Consistent with DC published results:
  - Almost same precision
  - $\theta_{13}$  value and B model confirmed



# Thank you!

Photo: Lola Garrido

# $\chi^2$ definition

$$f(R^{exp}) = B + \left(1 - \sin^2(2\theta_{13}) \cdot \alpha_{osc}\right) \cdot R^{exp} \quad \chi^2 = \chi_{on}^2 + \chi_{off}^2$$

$$\chi_{on}^2 = \sum_i^N \frac{\left(R_i^{obs} - f(R_i^{exp}) \cdot [1 + \alpha^d + \alpha_i^r + w_i \cdot \alpha_i^\nu]\right)^2}{\sigma_{stat}^2} + \frac{\alpha^d}{\sigma_d} + \sum_i (\frac{\alpha_i^r}{\sigma_i^r}) + \frac{\alpha^\nu}{\sigma_\nu}$$

$$w_i = \frac{R_i^{r-\nu}}{R_i^{exp} + B}$$

$$\chi_{off}^2 = 2 \left( R^{obs} \cdot T_{off} \cdot \ln \frac{R^{obs} \cdot T_{off}}{K \cdot [1 + \alpha^d + w_i \cdot \alpha^\nu]} + K \cdot [1 + \alpha^d + w_i \cdot \alpha^\nu] - R^{obs} \cdot T_{off} \right) \quad K = B + \left(1 - \sin^2(2\theta_{13}) \cdot \alpha_{osc}\right) \cdot \frac{N_{res-\nu}}{T_{off}}$$