Double Chooz Latest Results

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on behalf of the Double Chooz Collaboration

Applied Antineutrino Physics – Dec. 6th, 2019
Sun Yat-sen University, Guangzhou

HIGHLIGHTS

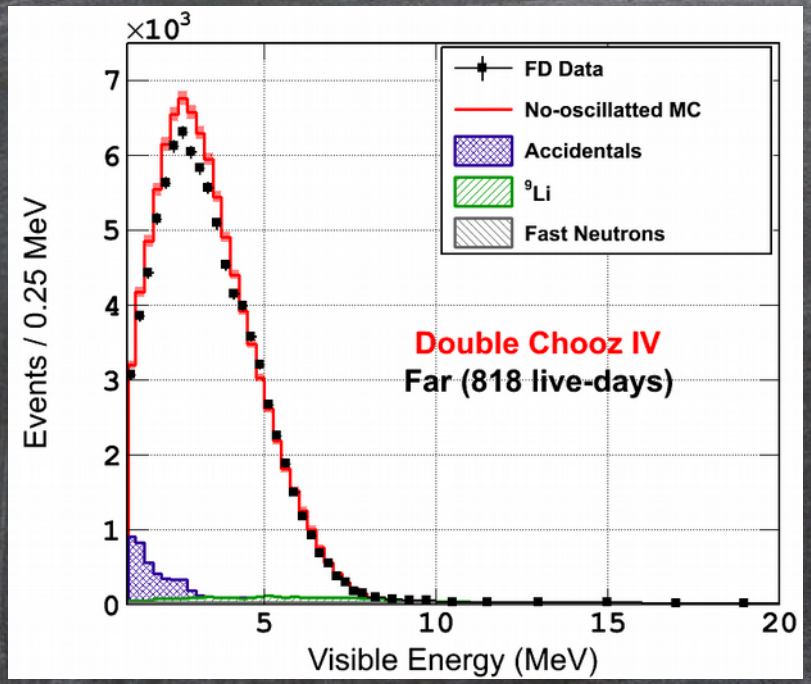
-> Double Chooz Near+Far results

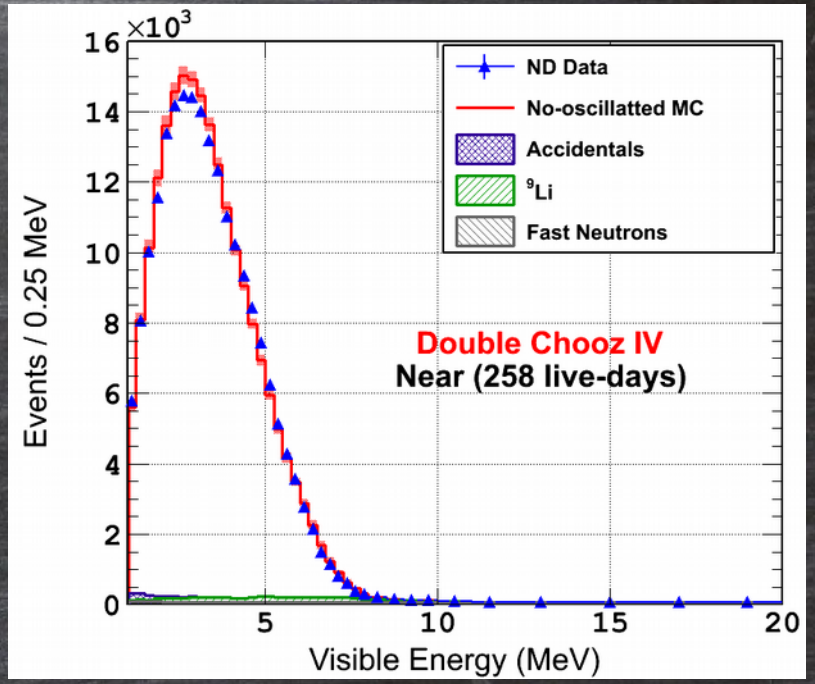
-> First ND measurement of MCSpF (world-best to date)

-> Spectral ~~bump~~ discussion
distortion

-> Reactor Monitoring

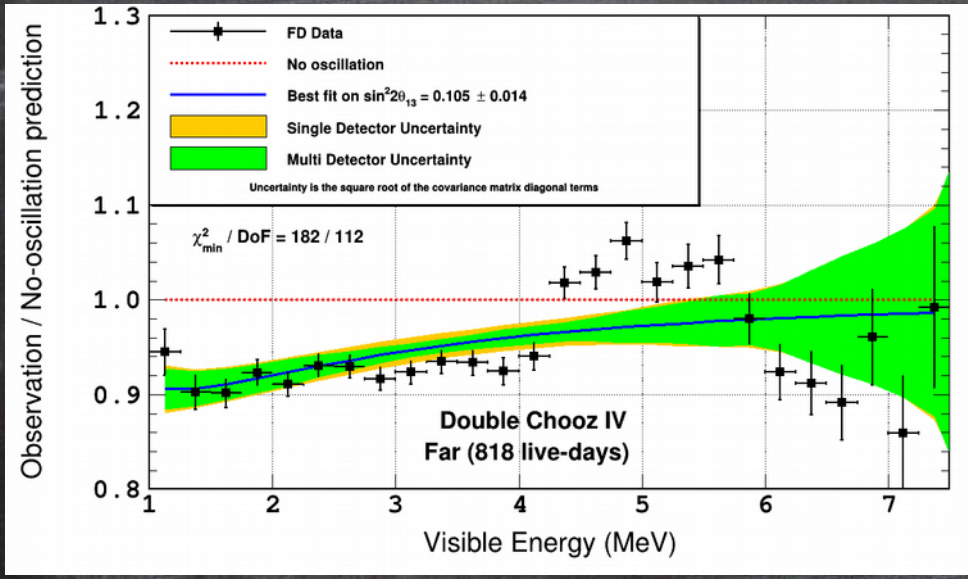
DC-IV Fit Results

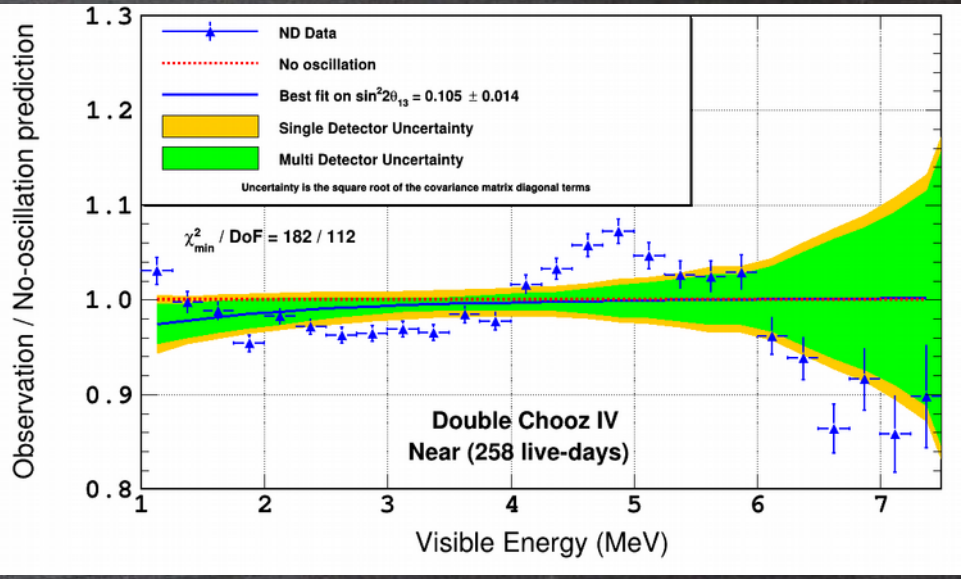




Data-MC fit including Bugey 4 normalization

DC-IV Fit Results



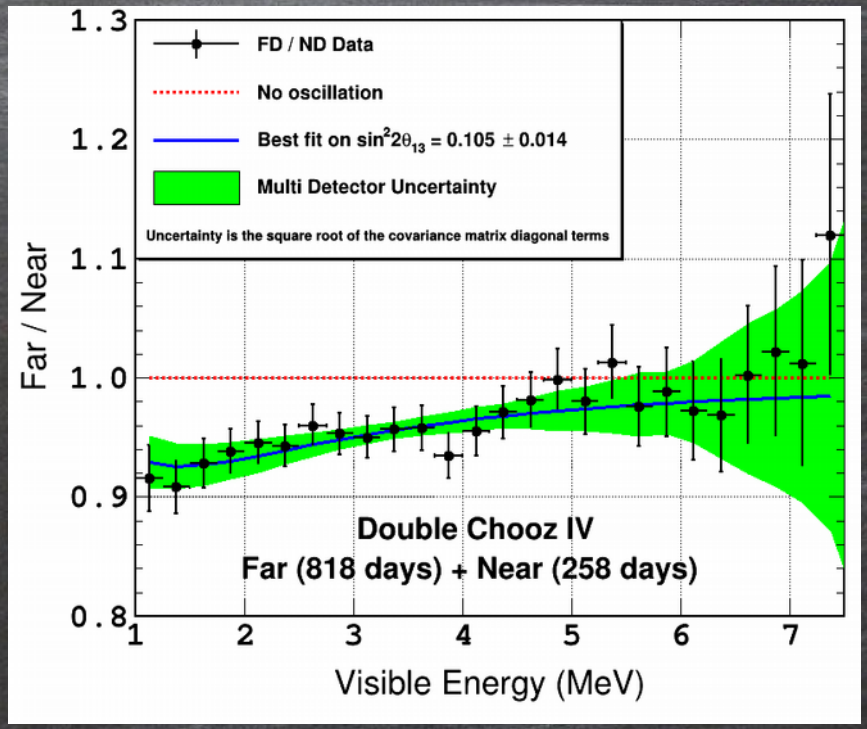


Data-MC fit including Bugey 4 normalization

$\sin^2 2\theta_{13} = 0.105 \pm 0.014$ (stat.+syst.)

arXiv : 1901.09445

DC-IV FIT RESULTS



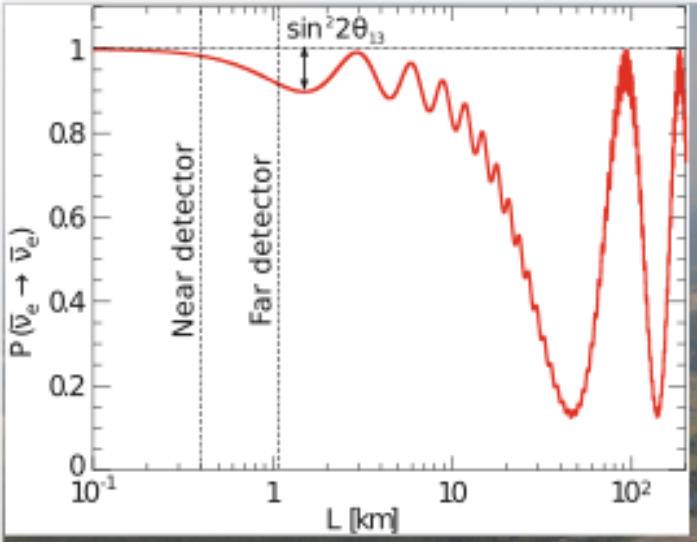
Data-MC fit including Bugey 4 normalization

$\sin^2 2\theta_{13} = 0.105 \pm 0.014$ (stat.+syst.)

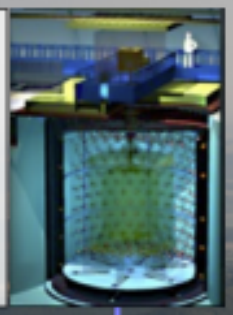
arXiv : 1901.09445

Multi detector fit robust against spectral distortion

„THE" SLIDE ON REACTOR NEUTRINOS



Far
< L > 1050m
~100 $\bar{\nu}_e$/ day
300 m.w.e.
2011



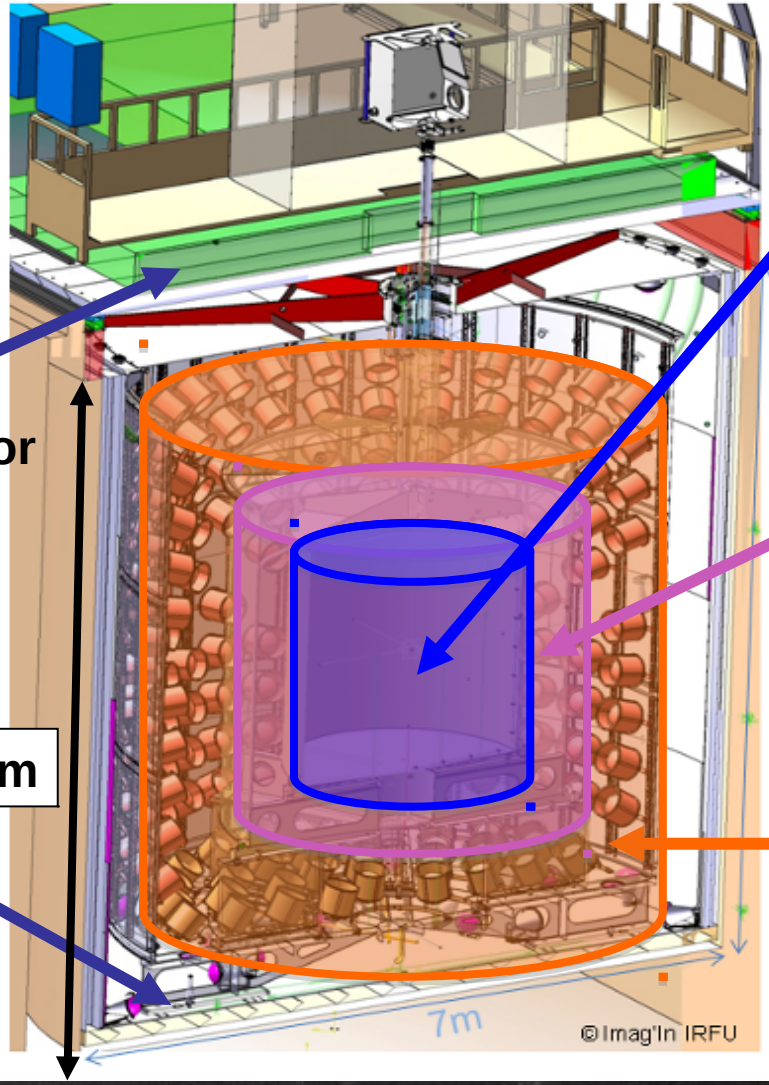
Near
< L > 400m
~800 $\bar{\nu}_e$/ day
120 m.w.e.
2015

2 reactors
2 × 4.25 GW_{th}
~ 10^{21} $\bar{\nu}_e$/ s

Near Detector: to suppress systematics

$\bar{\nu}_e$ Disappearance between Near and Far detectors → θ_{13}

DETECTOR DESIGN



Outer Veto:
Plastic scintillator

Inner Veto:
- **Steel**
- **70 t LS**
- **78 PMTs (8”)**

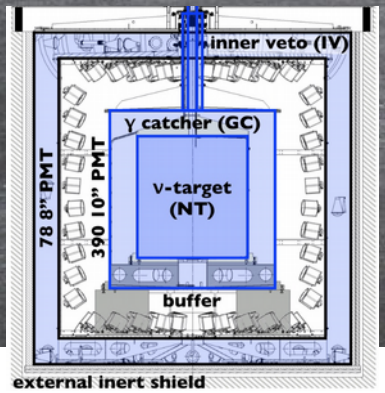
Inner detector:

Target (r = 1.2 m):
- Acrylic vessel
- 8.3 t Gd-scintillator (1 g/l Gd)

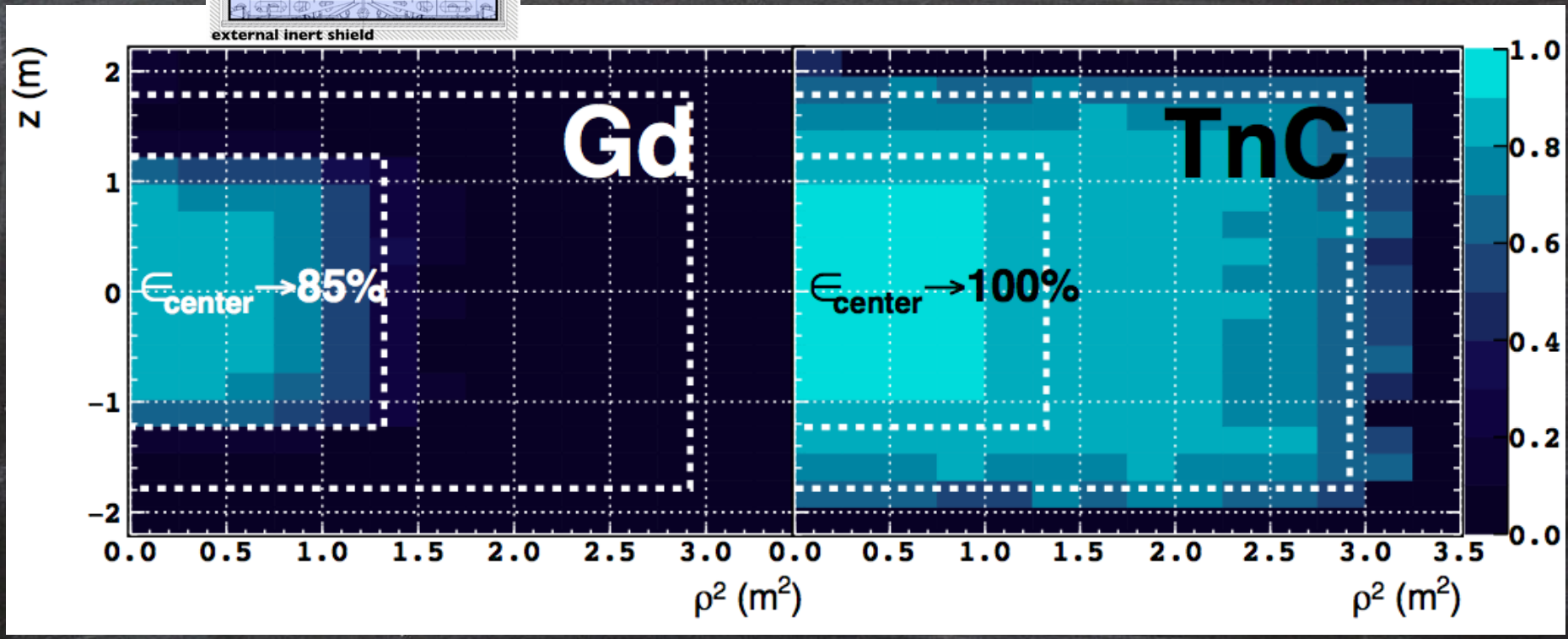
Gamma Catcher (0.55 m):
- Acrylic vessel
- 18 t liquid scintillator

Buffer (1.05 m):
- Steel vessel
- 80 t “oil”
- 390 PMTs (10”)

DC STATISTICS / EFFICIENCY

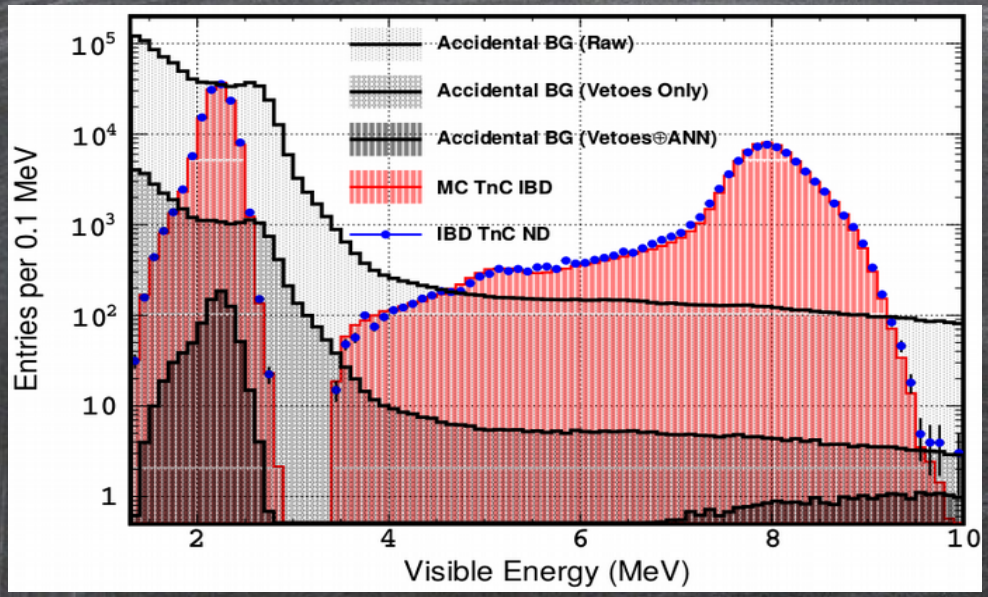


„Small" Gd-target (8.3 t)
and „only" two reactors



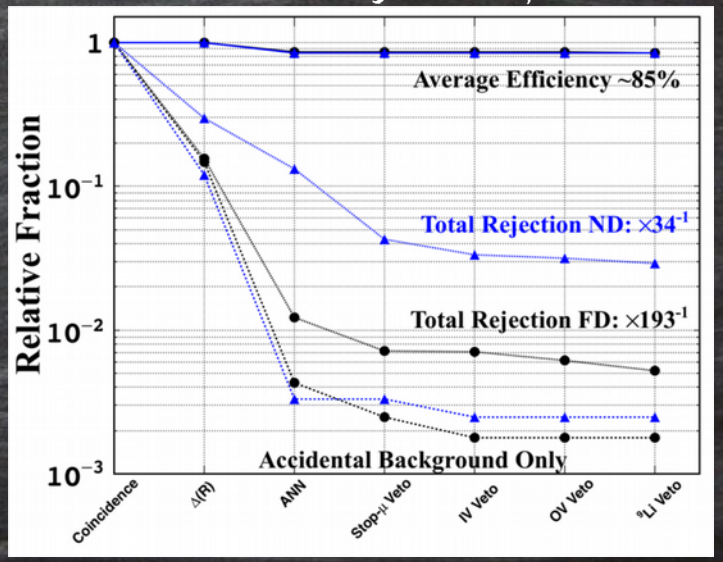
„Total n-Capture" (TnC) improves statistics factor 2.5!
(captures on Gd+H+C -> leak immune!)

BACKGROUND REDUCTION



Delayed E spectrum (data and MC) before and after cuts

Cumulative rejection per cut

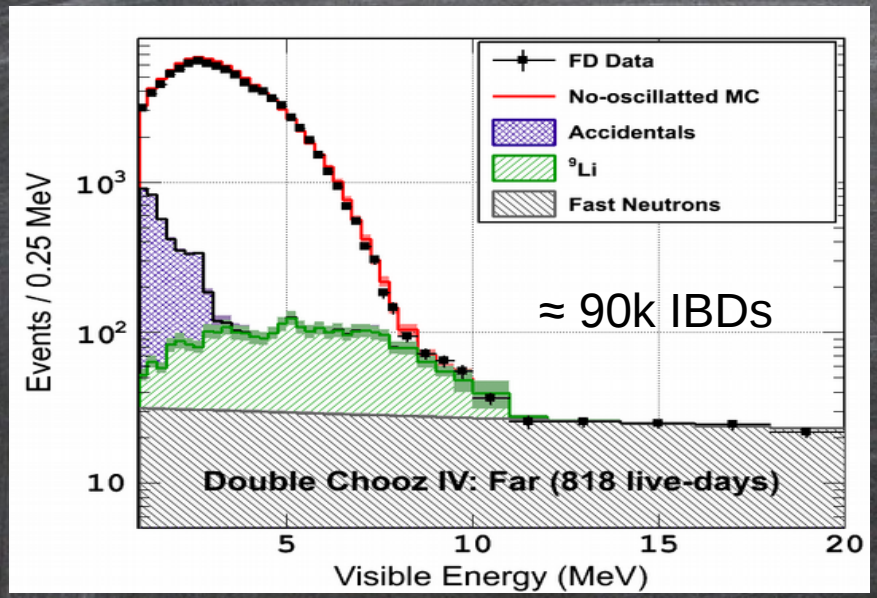


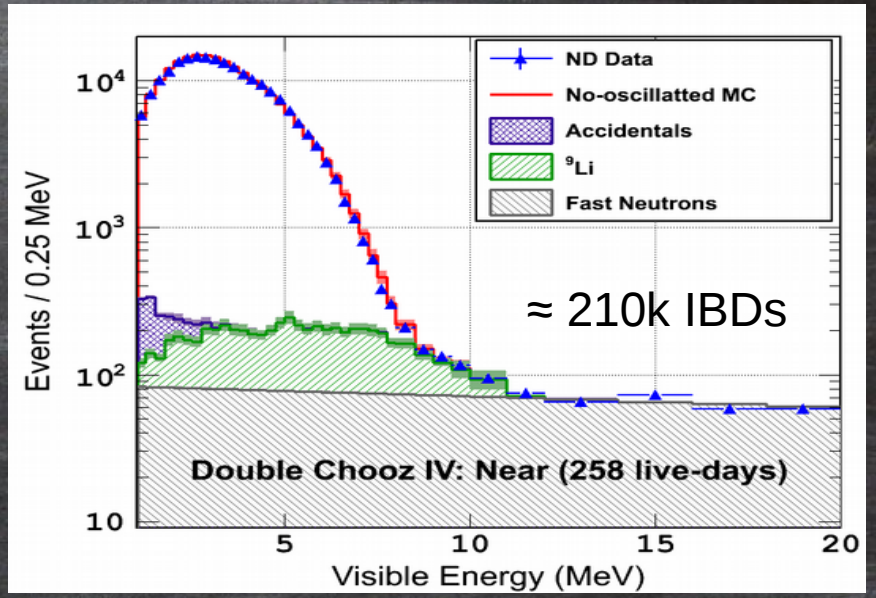
-> Good data/MC agreement for IBD candidates

-> Efficient background supression with cuts/vetoes

IBD efficiency and background rejection

SIGNAL AND BACKGROUNDS

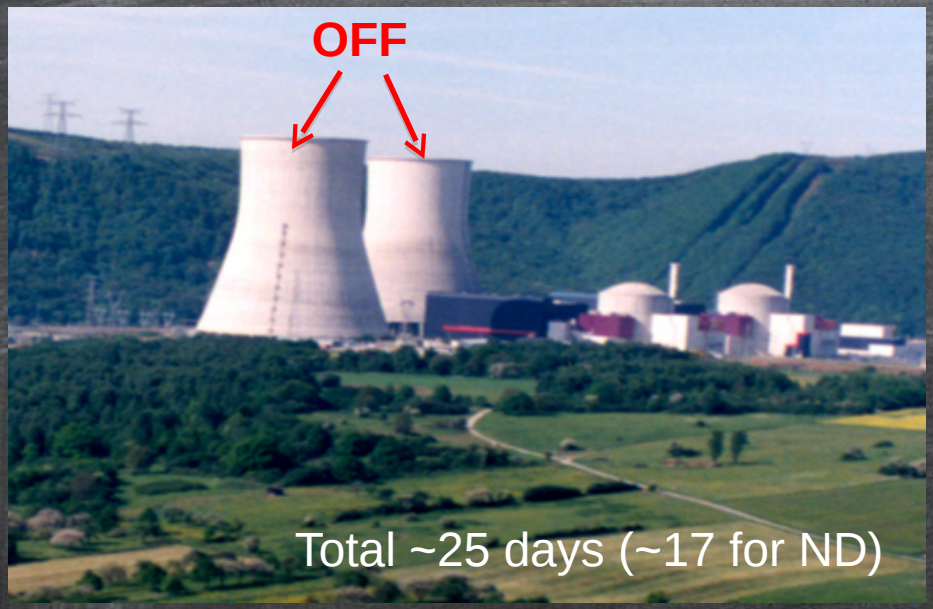


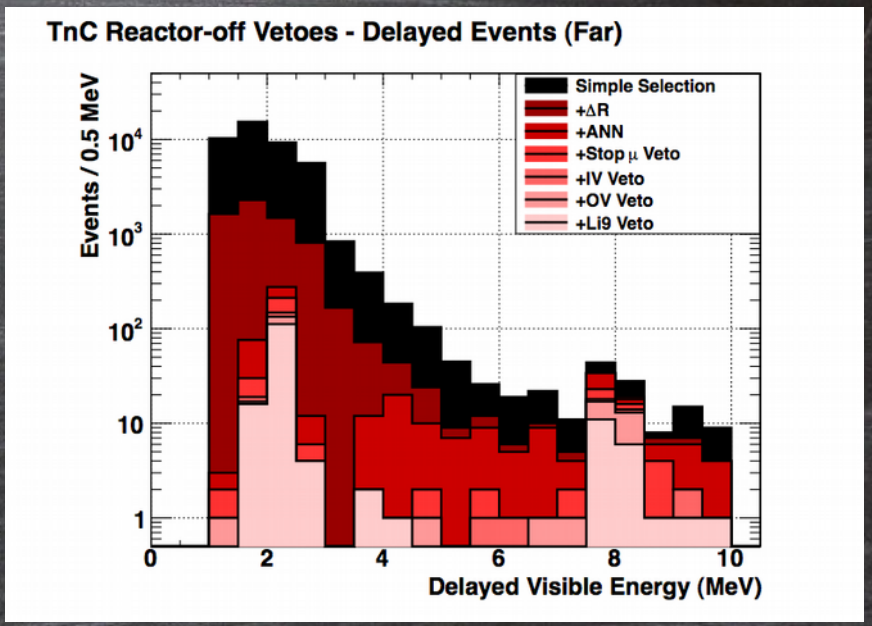


	Ev./day FD	Ev./day ND
IBD candidates	112	816
Cosmogenic BG (^{9}Li)	2.62 ± 0.27	14.52 ± 1.48
Fast n	2.50 ± 0.05	**20.85 ± 0.31**
Accidental BG	**4.13 ± 0.02**	3.11 ± 0.01

S/B>10!

BOTH REACTORS OFF DATA



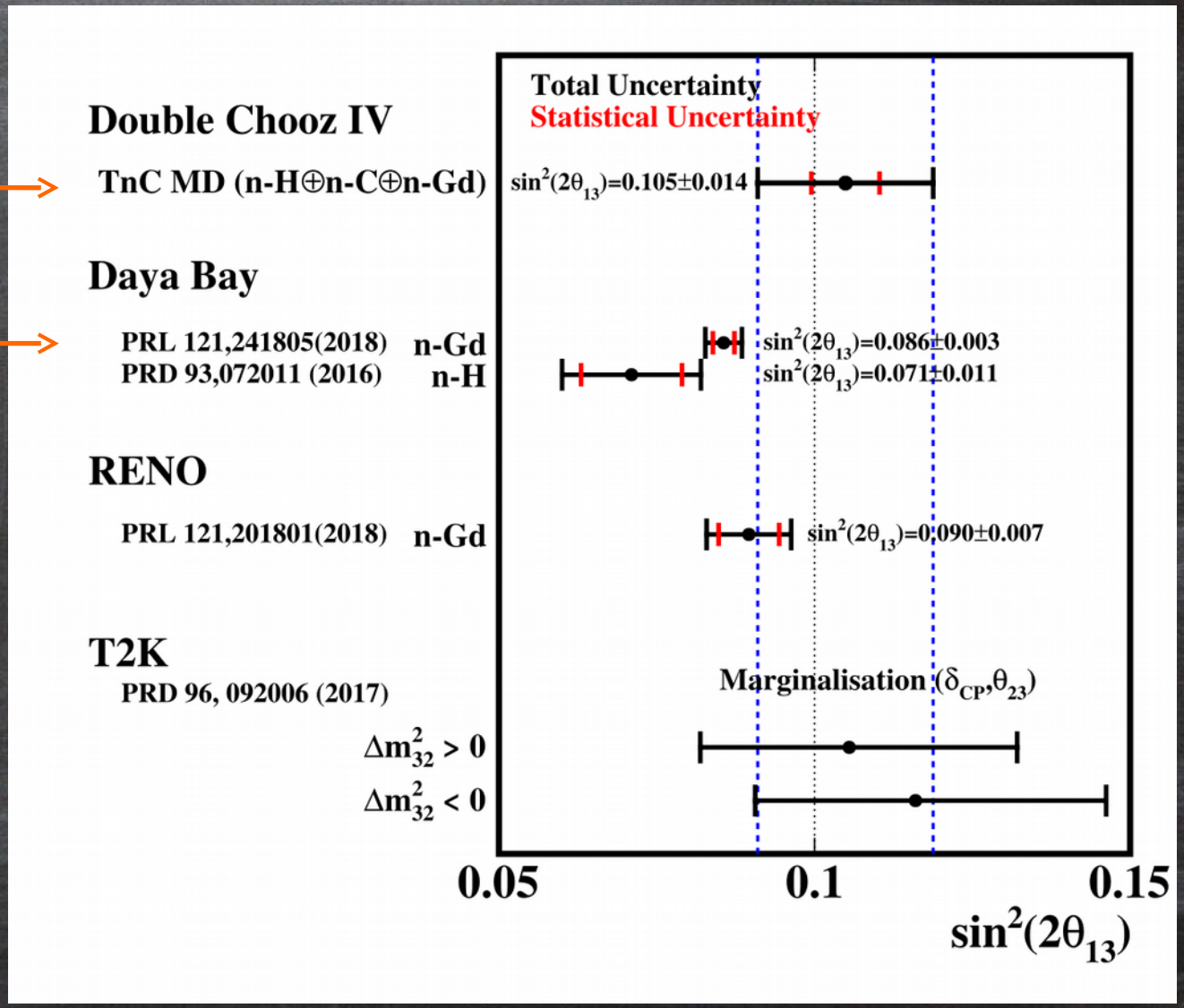


	ND (ev./day)	FD (ev./day)
OFF-OFF I (2012)	---	8.9 ± 1.2
OFF-OFF II (2017)	39.6 ± 2.5	9.8 ± 0.9
Rate+Shape values	38.5 ± 1.5	9.3 ± 0.3

Background understanding

All numbers within 1σ

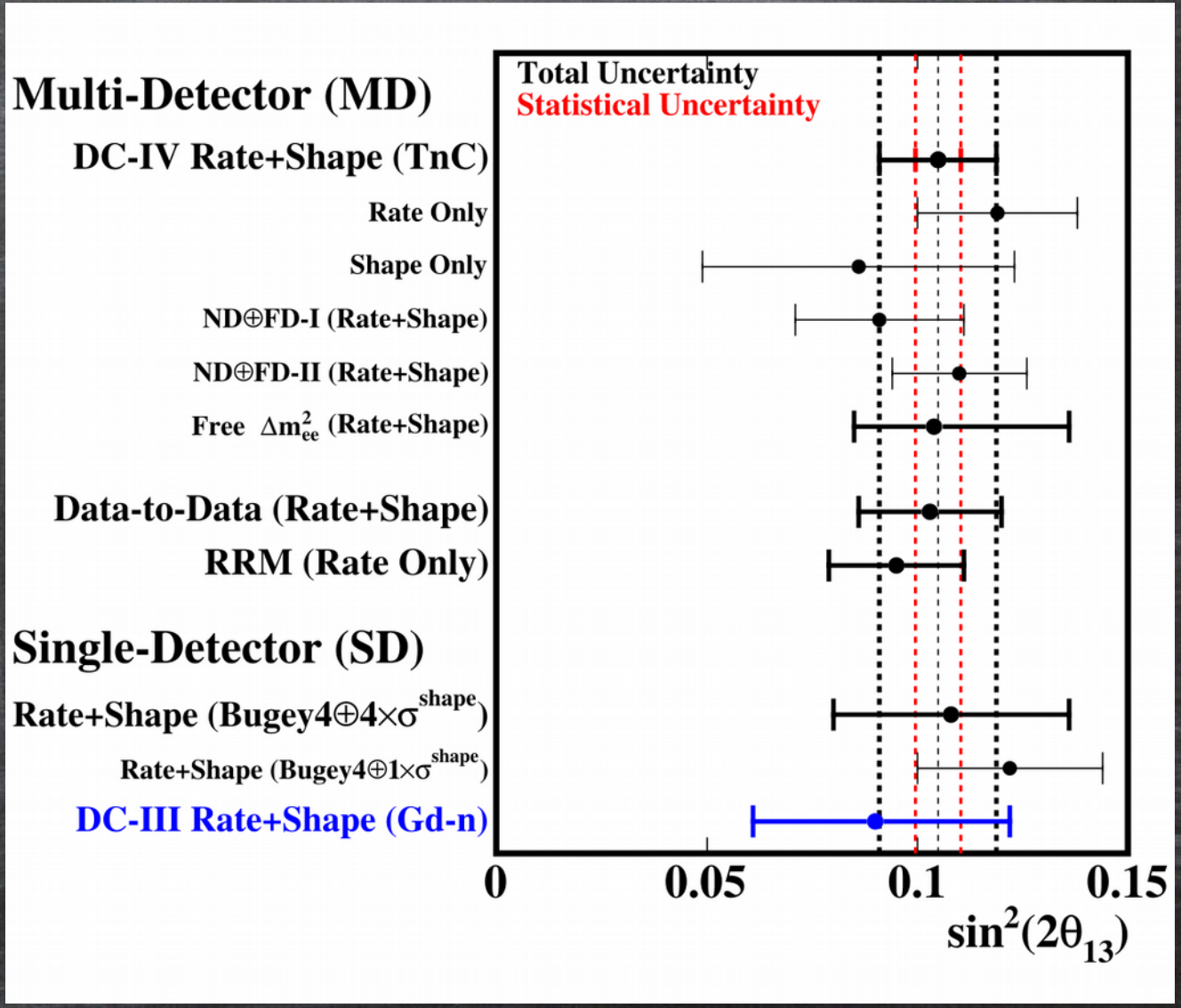
WORLDWIDE COMPARISON OF RESULTS



<~2σ difference (systematics!)

Intl. Reactor-θ_{13} Workshops: Combined (DC/DYB/RENO) effort to understand systematics

INTERNAL VALIDATION OF θ_{13}



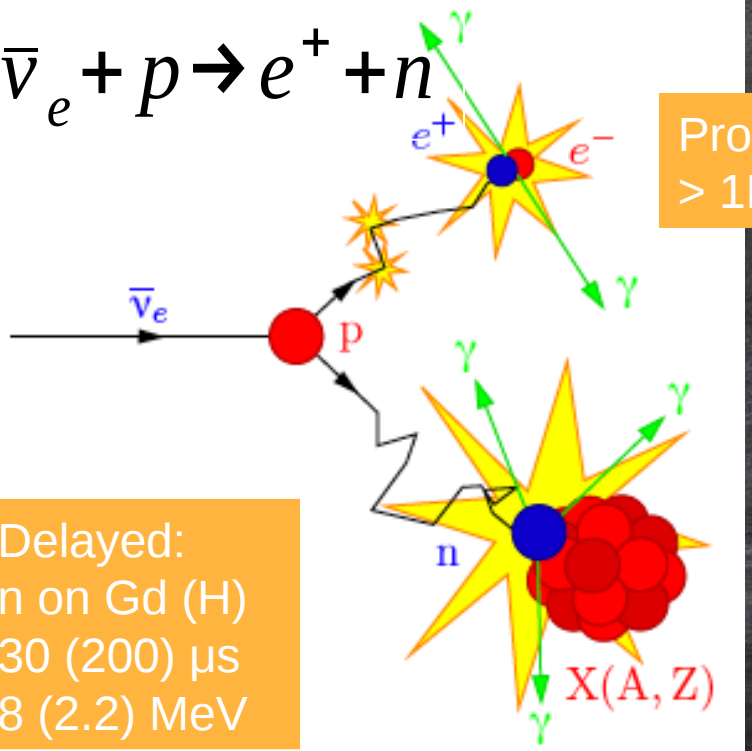

NORMALIZATION MEASUREMENT

NEUTRINO PRODUCTION / DETECTION

$$N_\nu^{\exp}(t) = \frac{\varepsilon N_p}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f \rangle} \times \langle \sigma_f \rangle$$

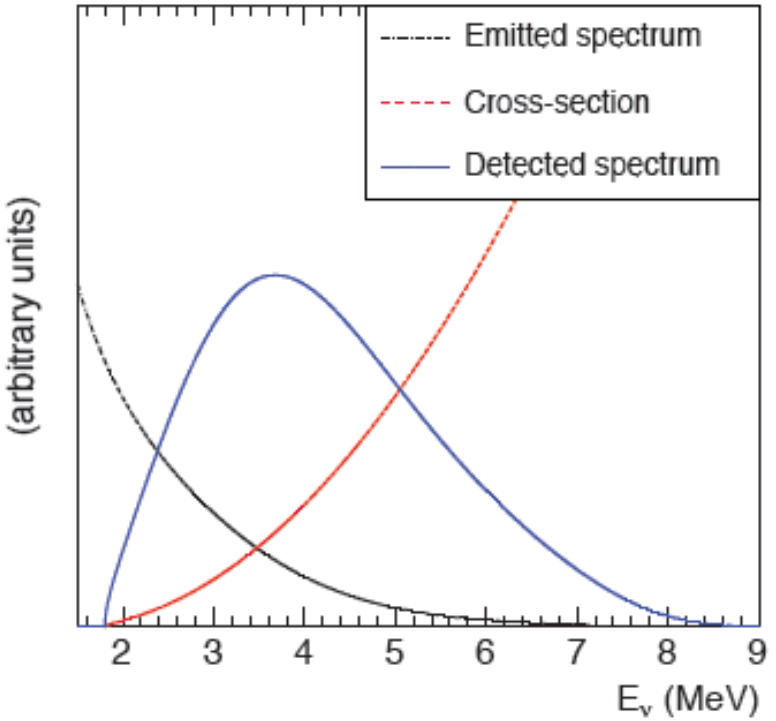
→ Mean cross section per fission (Near detector!)

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



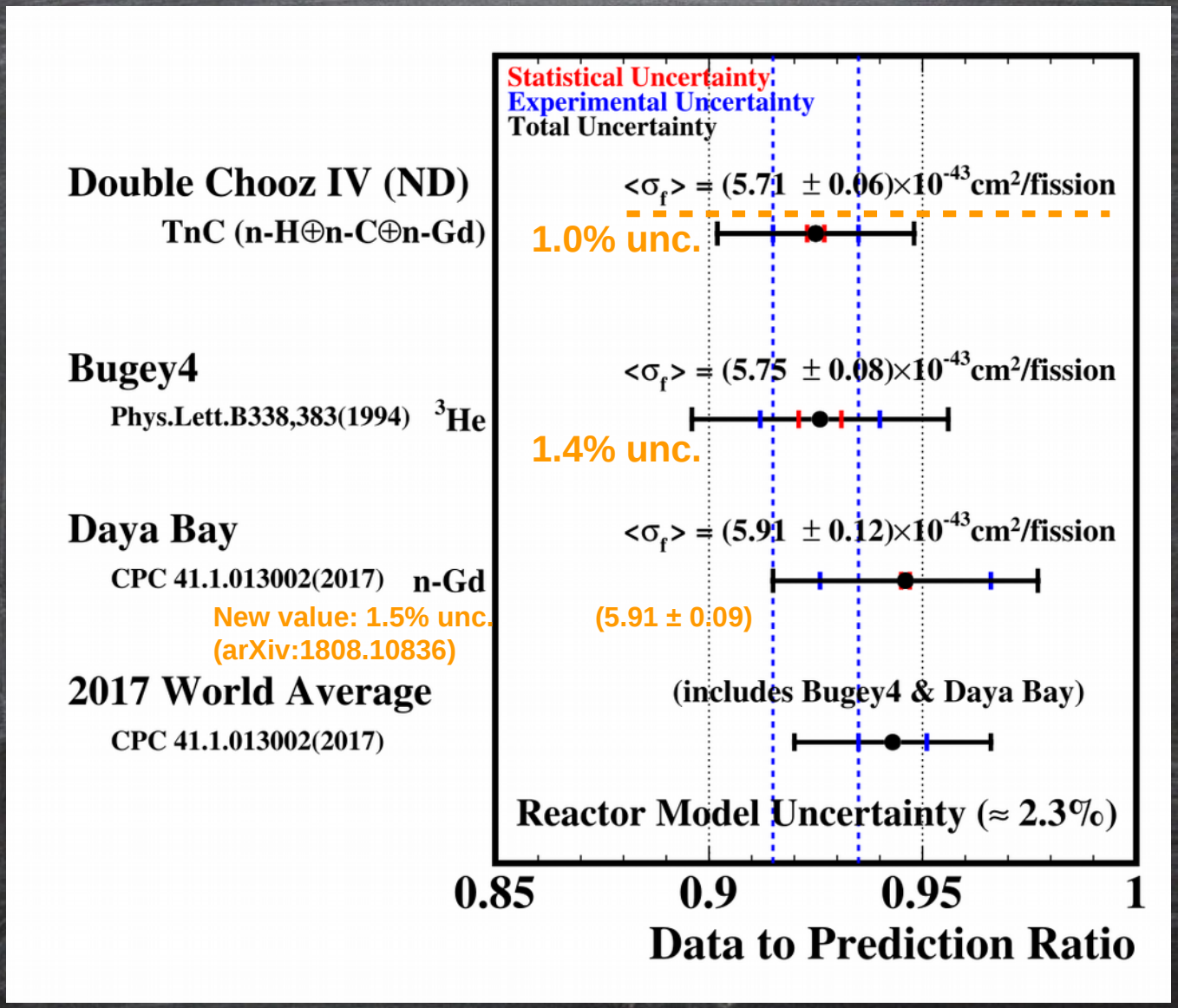
Prompt:
> 1MeV

Delayed:
n on Gd (H)
30 (200) μs
8 (2.2) MeV



$$E_{vis} = E_\nu - 0.8\,MeV$$

NORMALIZATION - ND VS BUGEY4



NEW!

DC ND Fission Fraction
(2 reactors weighted)

235U -> 0.520

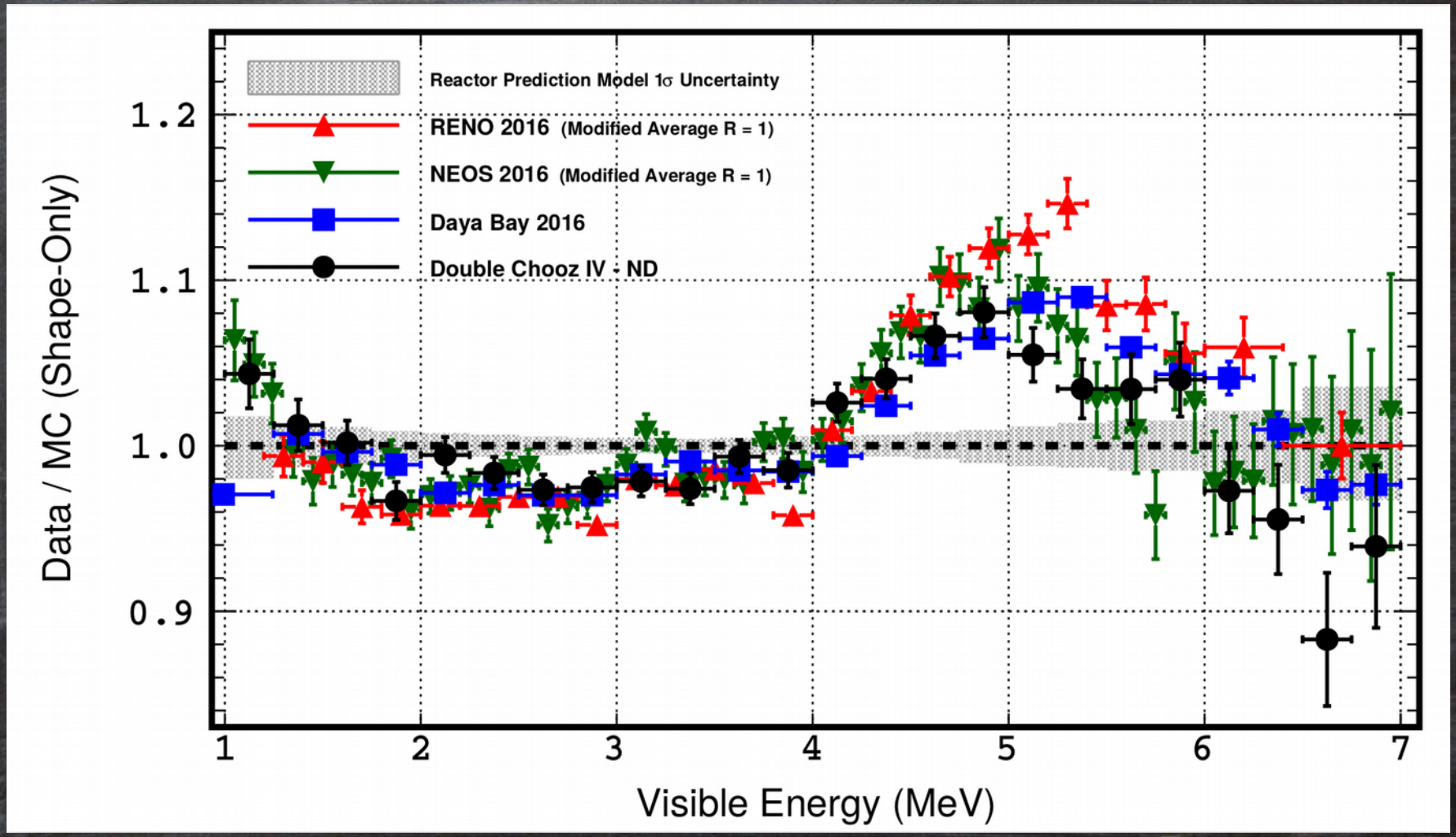
238U -> 0.087

239Pu -> 0.333

241Pu -> 0.060

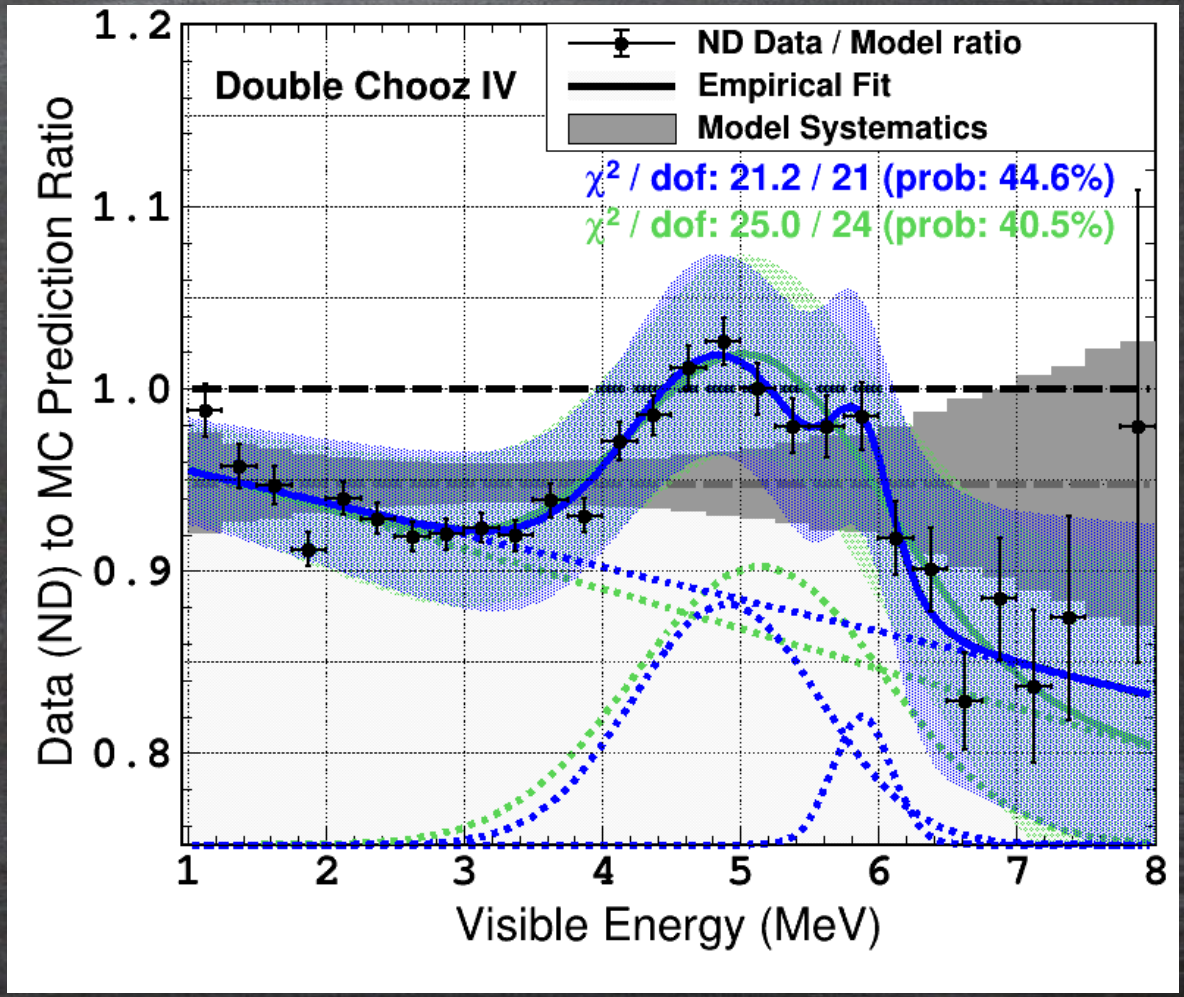
SPECTRAL DISTORTION

SPECTRAL DISTORTION COMPARISON (SHAPE ONLY)



Good agreement to first order

SPECTRAL DISTORTION COMPARISON (SHAPE & RATE)

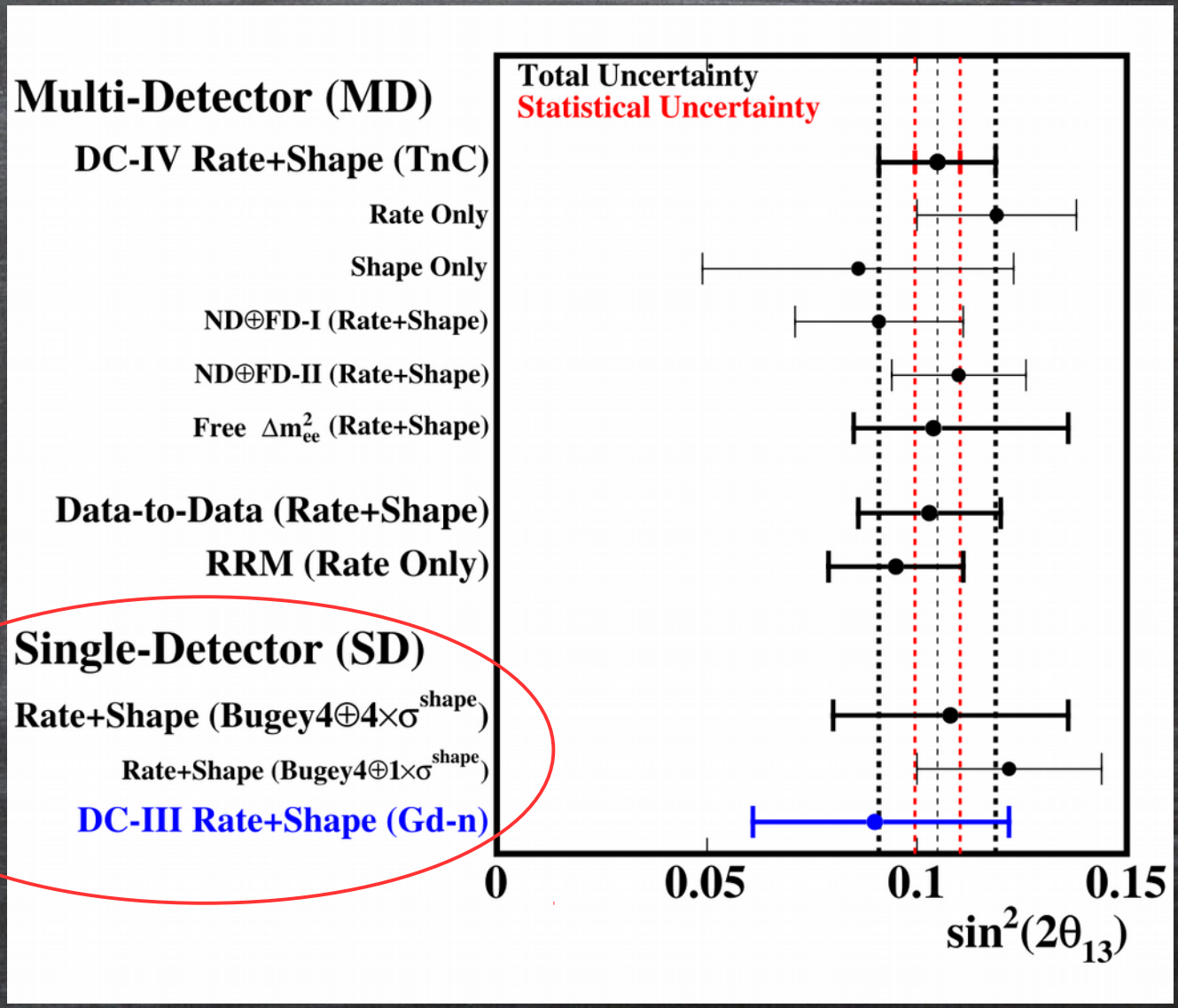


-> "Excess" in agreement with Flux model

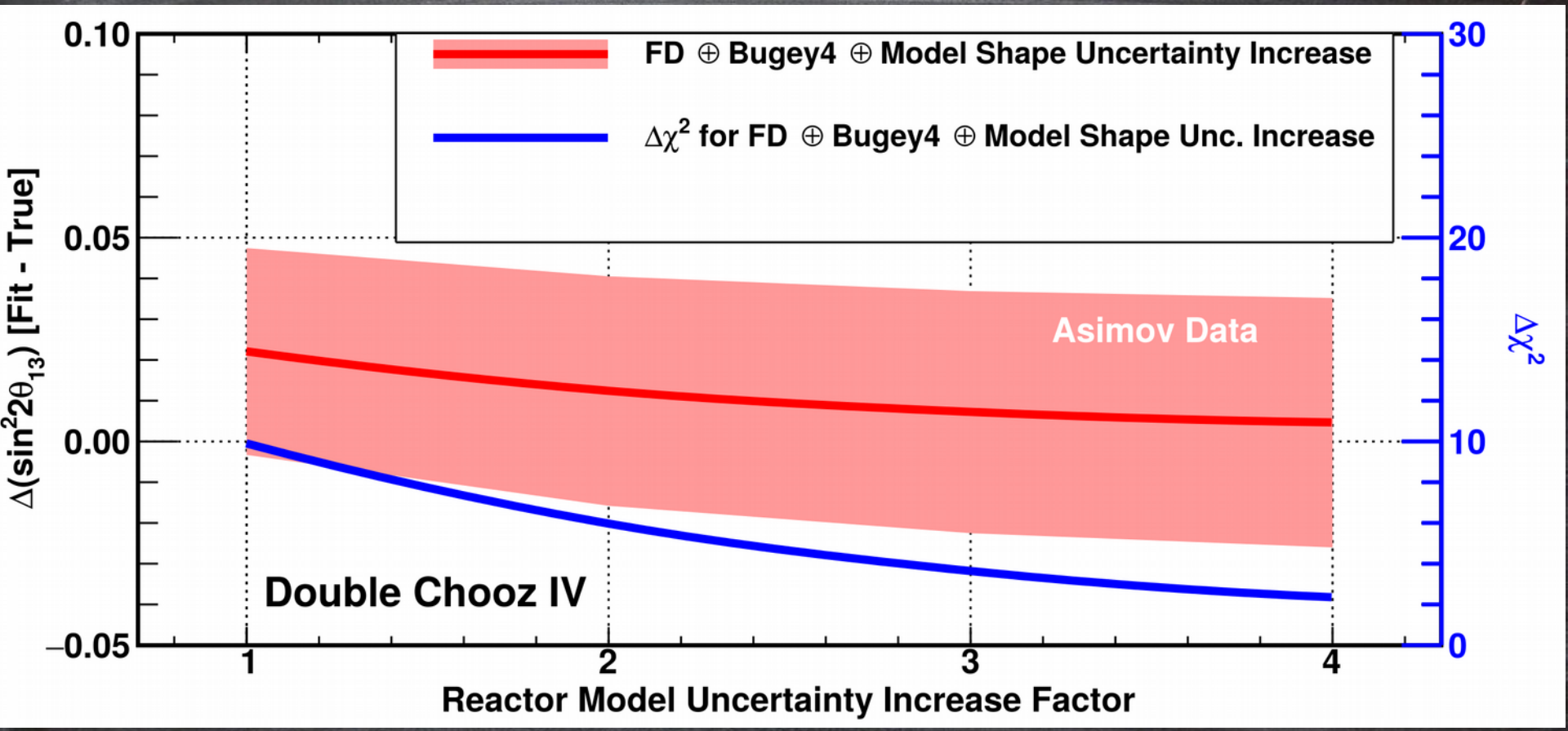
-> **Empirical** fit: negative slope and double peak

-> Widths significant larger than energy resolution

DISTORTION IMPACT ON θ_{13}



FLUX ERROR BUDGET & SINGLE DETECTOR θ_{13}



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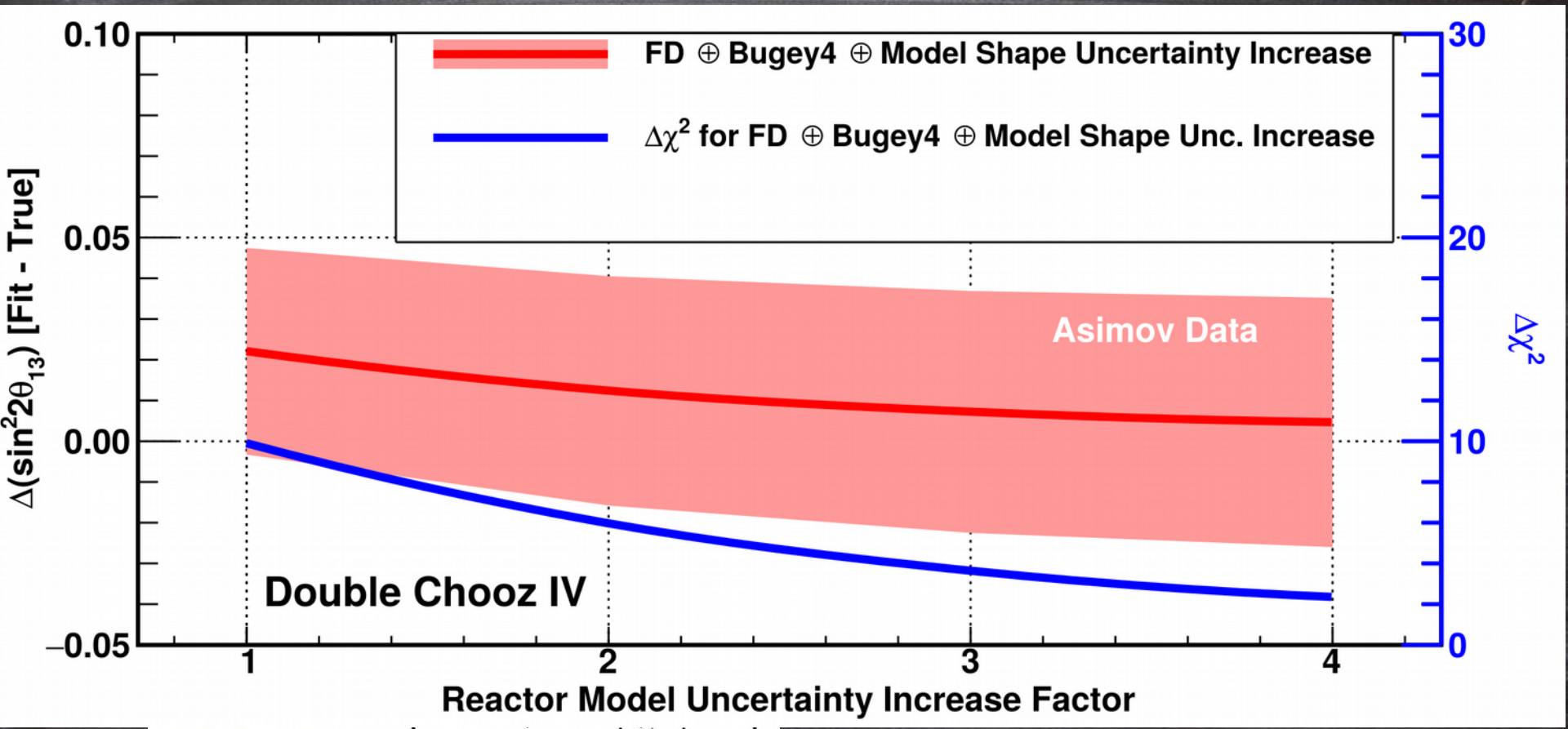
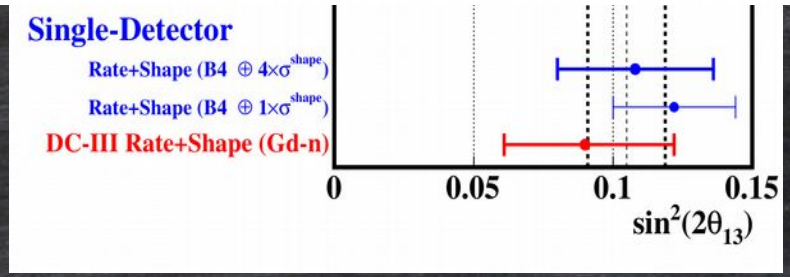
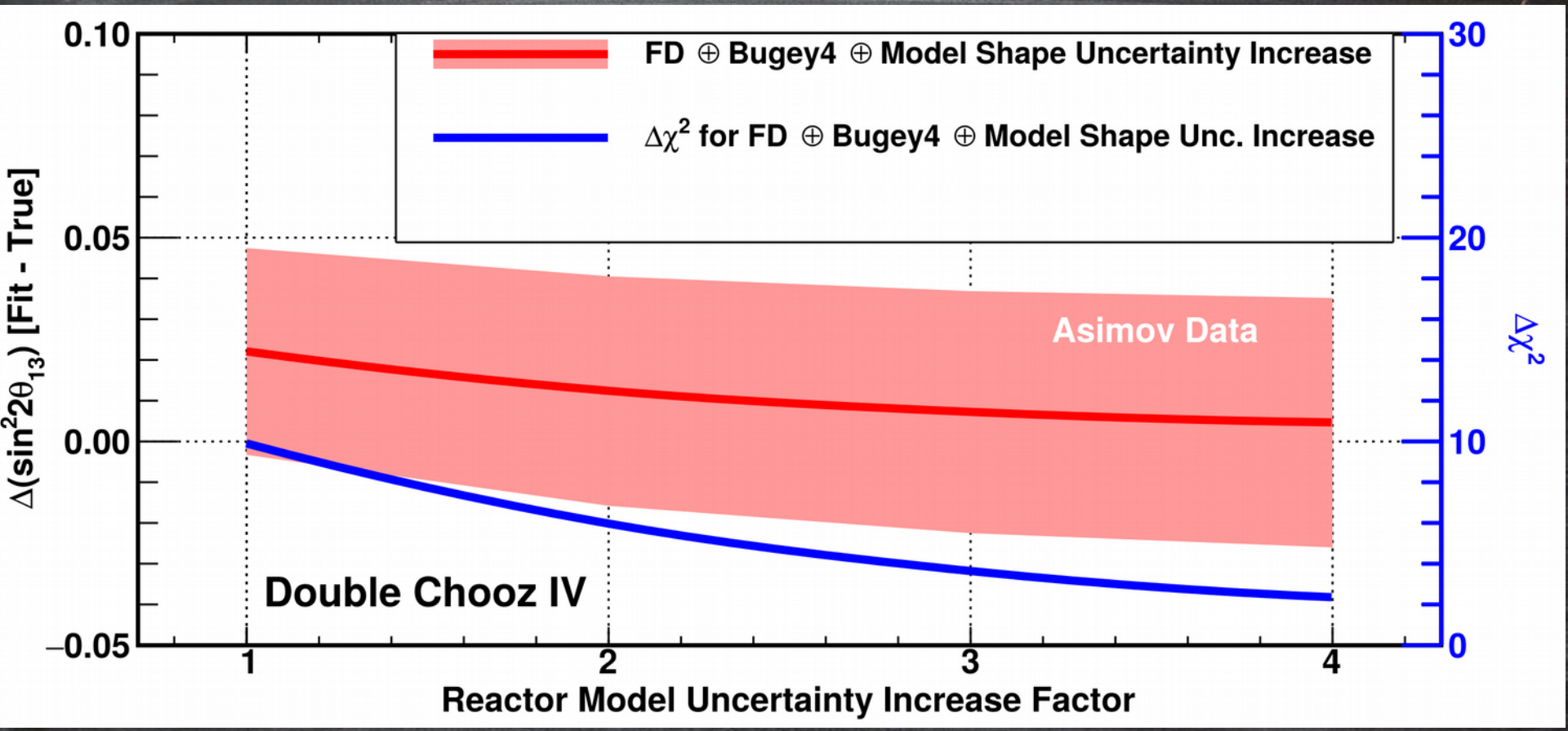




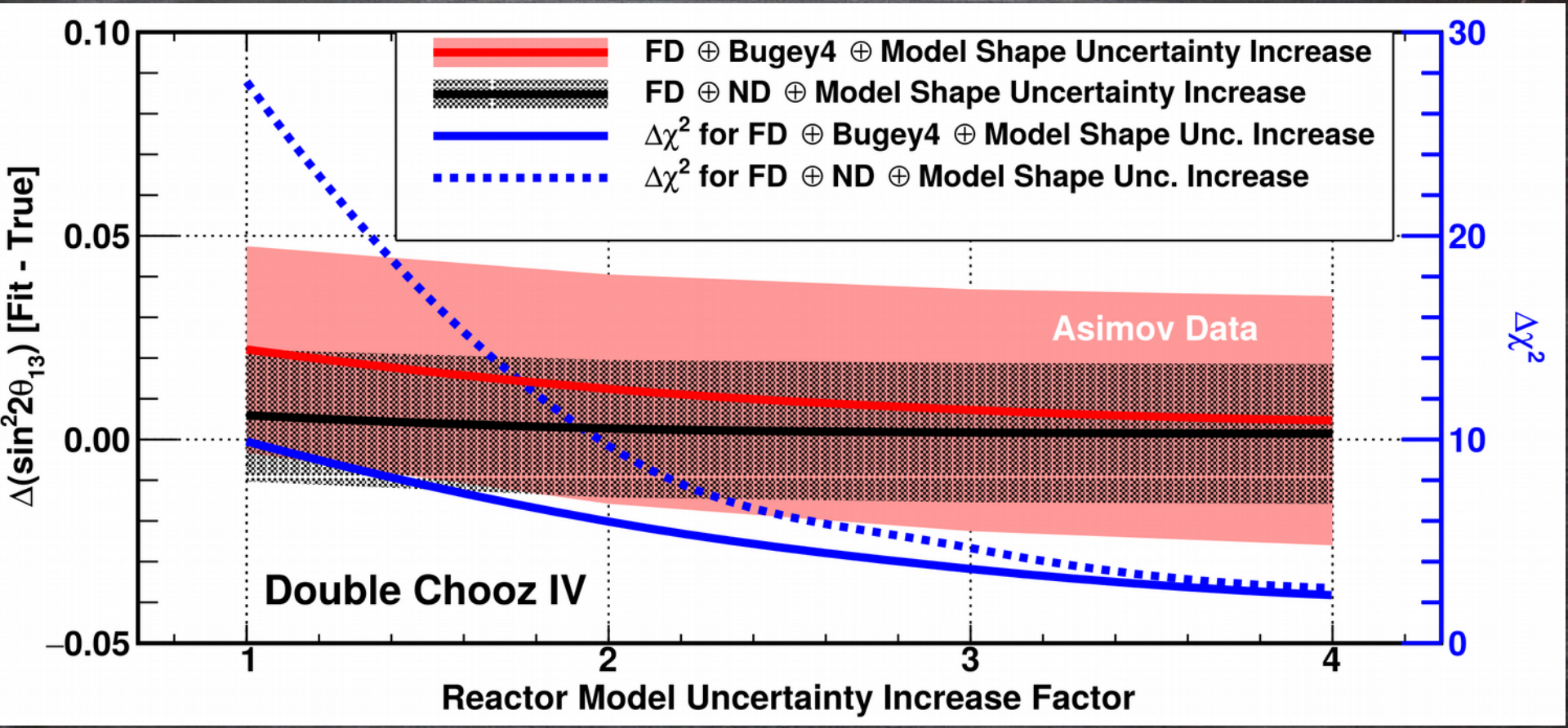
FLUX ERROR BUDGET & SINGLE DETECTOR θ_{13}



-> Distortion causes χ^2 to blow up

χ^2 (x1 -> x4 error) w/ Data:
FD+B4 = 105 -> 53 (74 DoF)

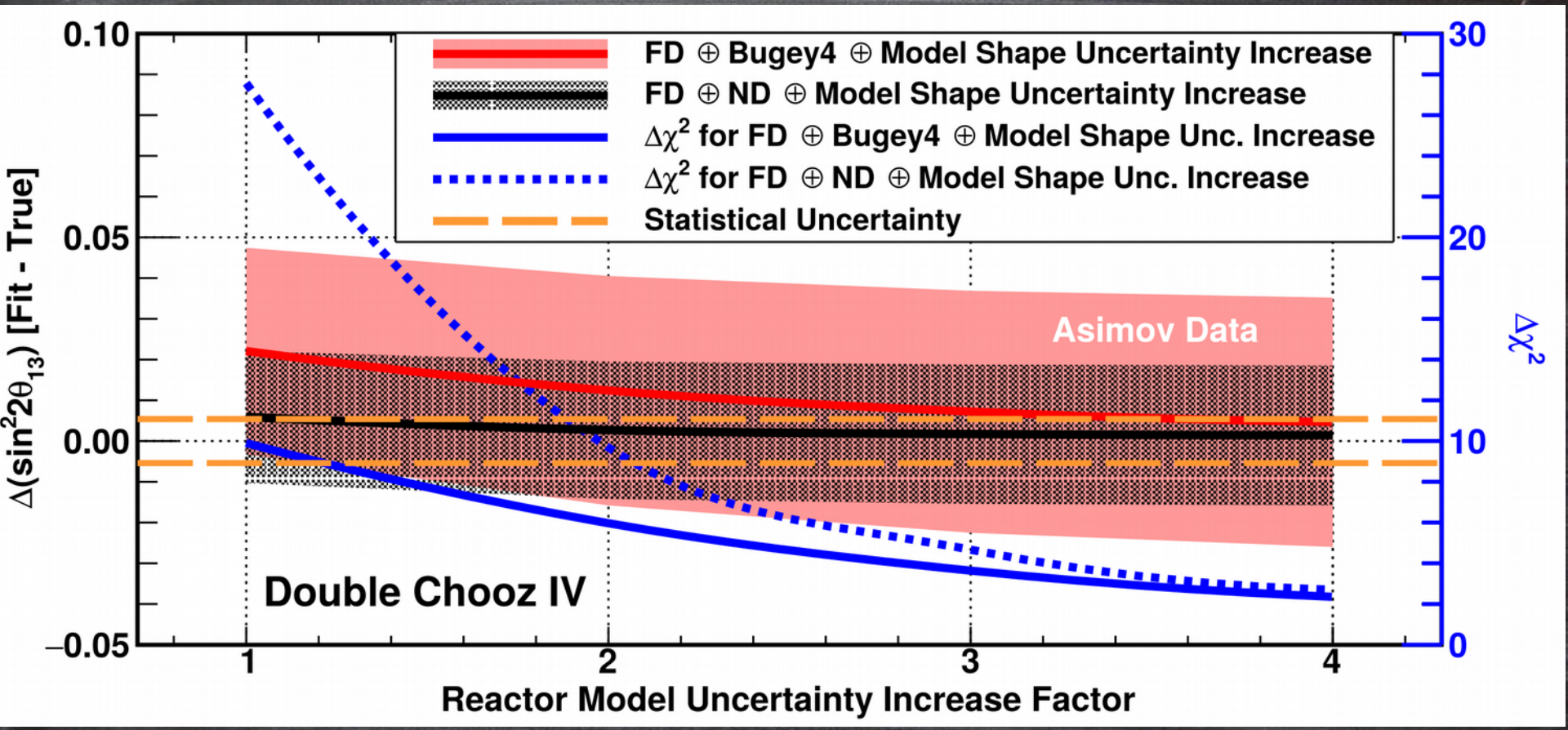
FLUX ERROR BUDGET & SINGLE DETECTOR θ_{13}



-> Distortion causes χ^2 to blow up

χ^2 (x1 -> x4 error) w/ Data:
FD+B4 = 105 -> 53 (74 DoF)
FD+ND = 182 -> 93 (112 DoF)

FLUX ERROR BUDGET & SINGLE DETECTOR θ_{13}



-> Distortion causes χ^2 to blow up

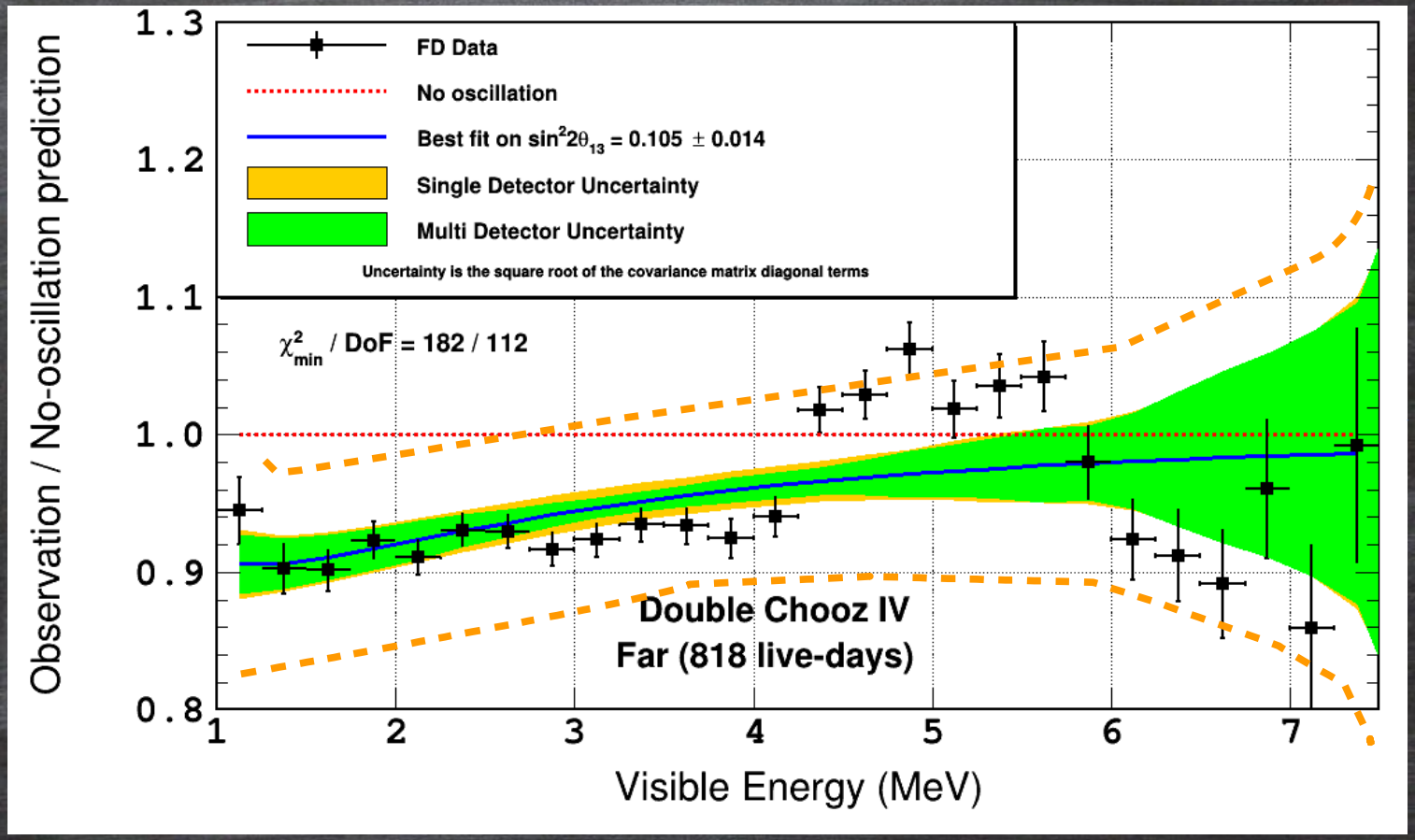
-> Corroborated with Data

χ^2 (x1 -> x4 error) w/ Data:

FD+B4 = 105 -> 53 (74 DoF)

FD+ND = 182 -> 93 (112 DoF)

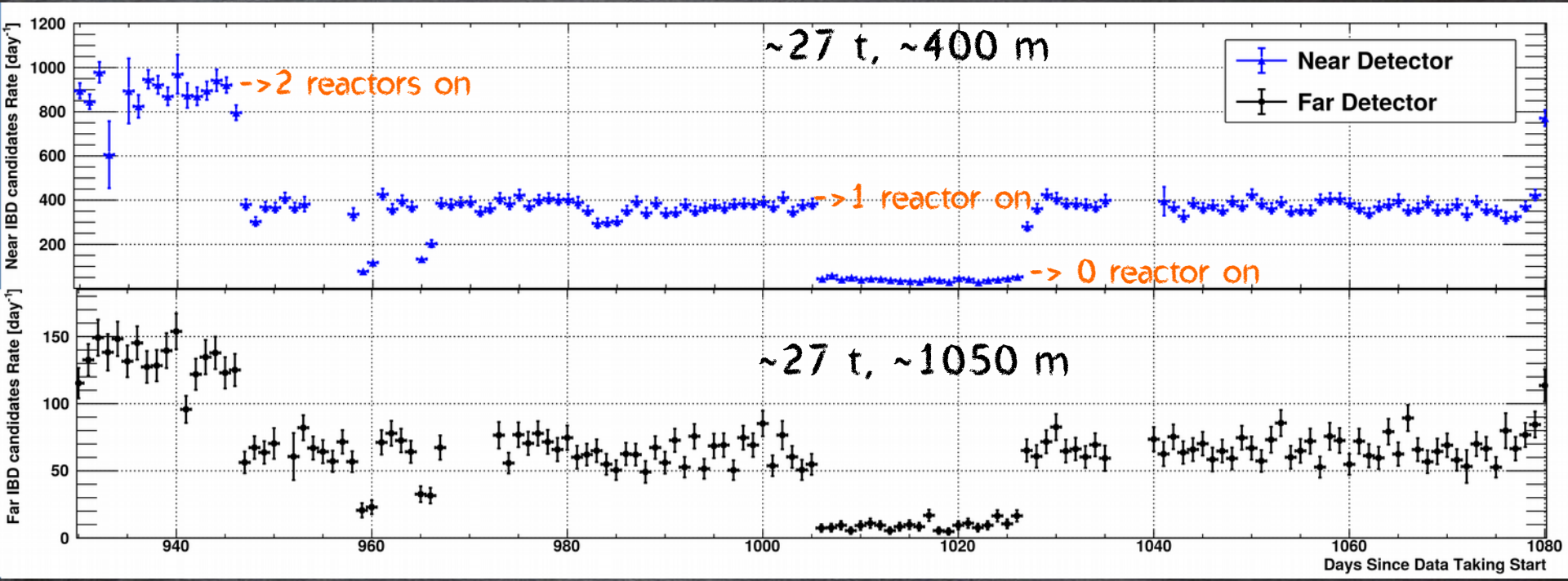
IN SHORT...



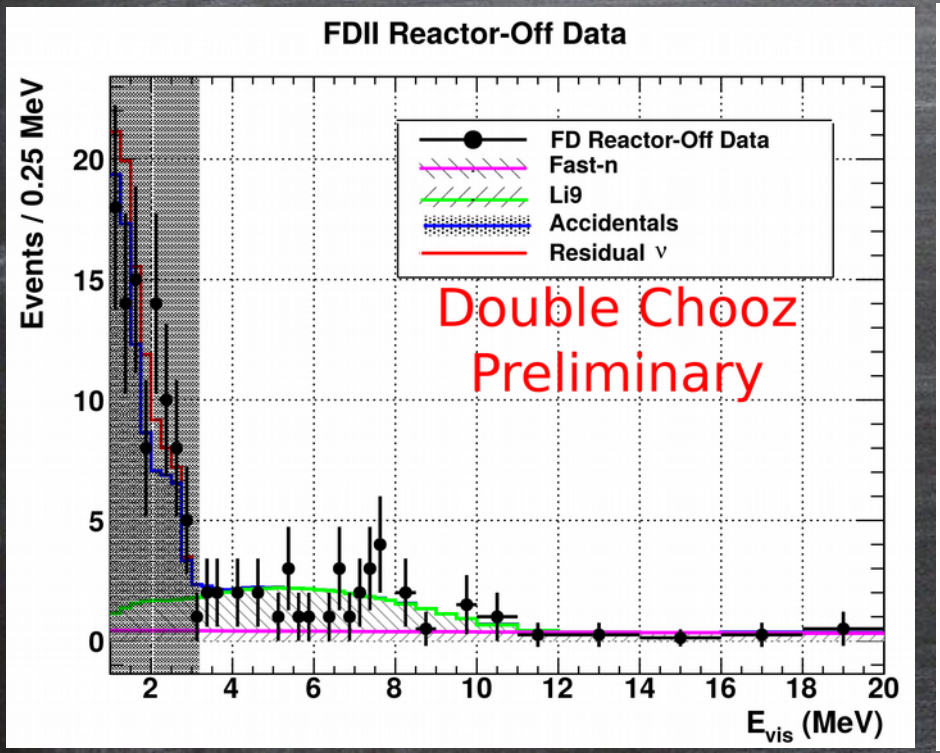
-> Prediction uncertainty should be increased if Near Detector not available

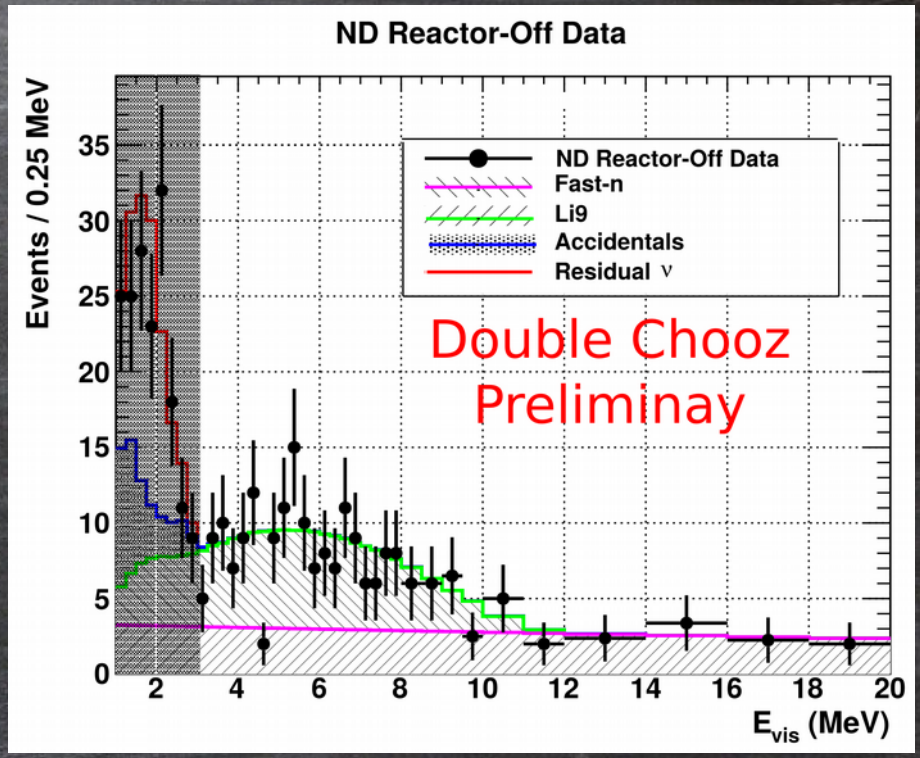
REACTOR MONITORING WITH NEAR DETECTOR

IBD-LIKE INTERACTIONS VS TIME



VALIDATION OF BACKGROUND MODEL



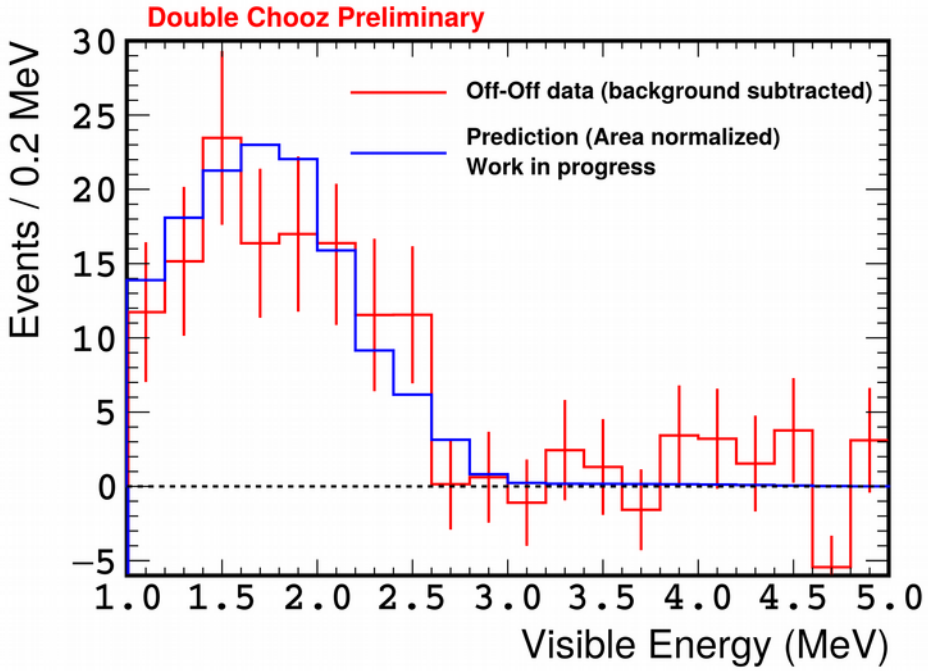


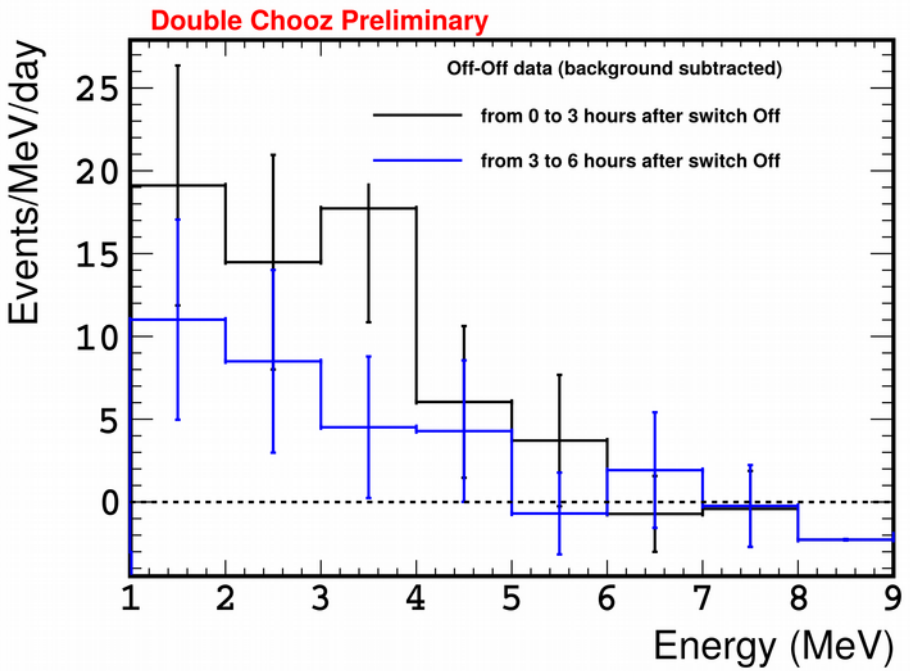
Rate (day^{-1})	FD	ND
IBD Candidates	112	816
Breakdown		
Accidental	4.13 ± 0.02	3.110 ± 0.004
Fast-Neutron	2.50 ± 0.05	20.85 ± 0.31
^{9}Li Isotope	2.62 ± 0.27	14.52 ± 1.48
[μ-tag]	3.01 ± 0.60	12.32 ± 2.01
Stopped-μ	<0.19 @ 98%CL	<0.21 @ 98%CL
Others (^{12}B, BiPo)	<0.01	0.04 ± 0.01
Total		
Σ-Exclusive	9.3 ± 0.3	38.5 ± 1.5
Inclusive (17 days)	9.8 ± 0.9	39.6 ± 2.5
Signal to BG	11.0	20.2

-> Validation of BKGs rates & shapes

-> October 2017 data

RESIDUAL NEUTRINOS





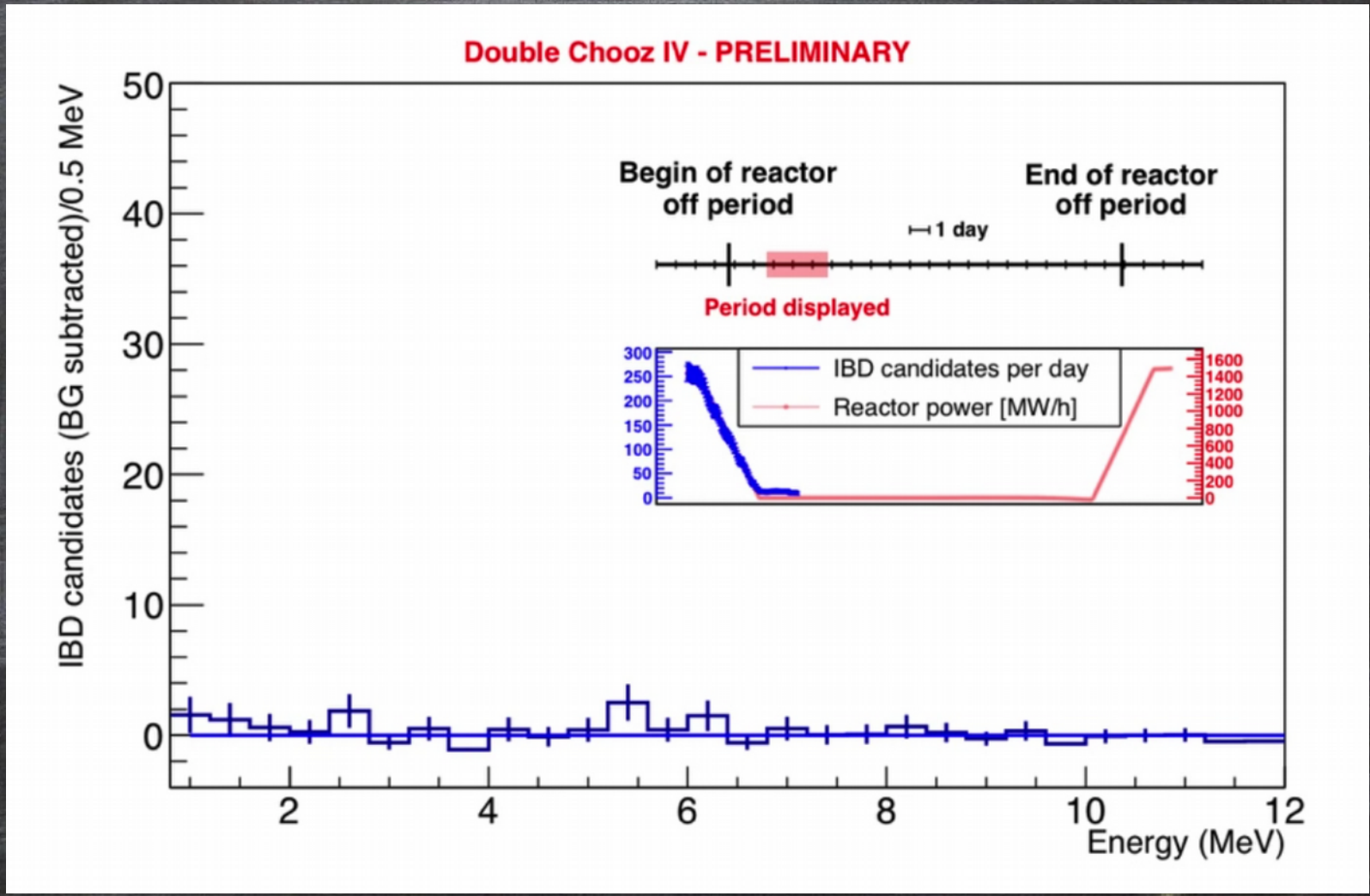
-> Remaining IBD spectrum & preliminary simulation

-> Simulation: FISPACT code and BESTIOLE database

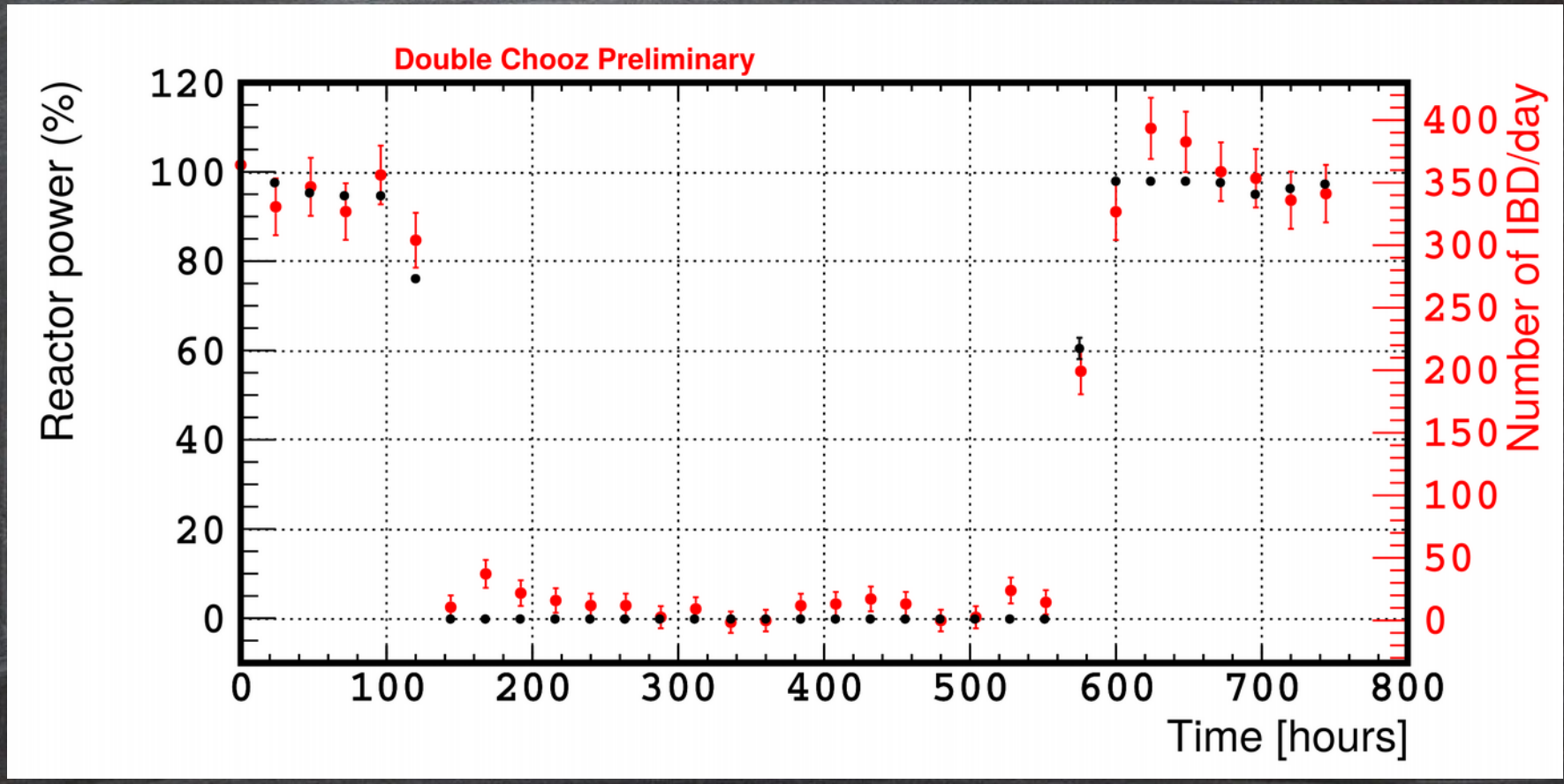
-> New simulation under development

-> Remaining IBD, after reactor-off, time evolution

VALIDATION OF BACKGROUND MODEL

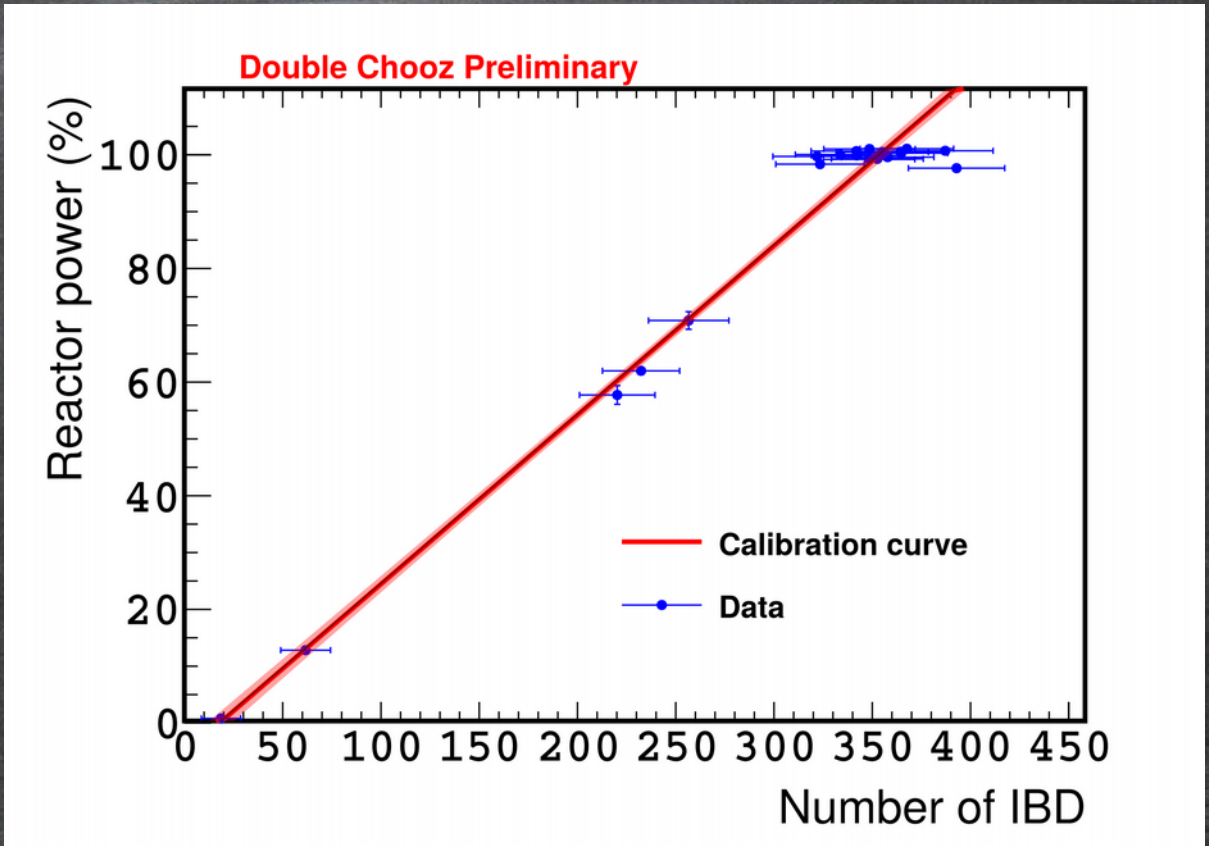


IBD CANDIDATES & THERMAL POWER



-> Each point: 24 hours mean value
-> Background subtracted IBD sample
-> October 2017 data

IBD CANDIDATES VS THERMAL POWER



-> At what resolution can we measure the reactor thermal power with IBDs?
-> August 2017 data
-> Analysis under review

SUMMARY

-> Three Years of Double Chooz 2 detectors data: 2015 - 2017

-> Novel IBD detection : Total Neutron Capture

- Improved statistics & systematics

-> Good background control (S/B > 10) -> Confirmed background model with Reactor-off Data!

-> New result: $\sin^2 2\theta_{13}$ = 0.105 ± 0.014 (w/ 15 months of data)

-> Single Detector Fit protected with a new Flux error budget

-> Spectral ~~bump~~ distortion: A rate+shape inspection

-> Best MCSpF measurement to date: $(5.71 \pm 0.06) \times 10^{-43}$ cm²/fission

-> $\sin^2 2\theta_{13}$ sensitivity improvement: extra data and better proton number measurement under consideration -> ~< 0.01

THANK YOU !

DOUBLE CHOOZ COLLABORATION

Brazil

CBPF
UNICAMP

France

APC (IN2P3)
CEA/IRFU:
- SPP
- SPhN
- SEDI
- SIS
- SENAC

CENBG (IN2P3)
LNCA (IN2P3/CEA)
Subatech (IN2P3)

Germany

EKU Tübingen
MPIK Heidelberg
RWTH Aachen
TU München

Japan

Tohoku U.
Tokyo Inst. Tech.
Tokyo Metro. U.
Tokyo U. Science
Kitasato U.
Kobe U.

Russia

INR RAS
RRC Kurchatov

Spain

CIEMAT-Madrid

USA

Alabama U.
ANL
Chicago U.
Drexel U.
Hawaii U.
Notre Dame U.
Virginia Tech.

Spokesperson:
A. Cabrera (IN2P3/CNRS)

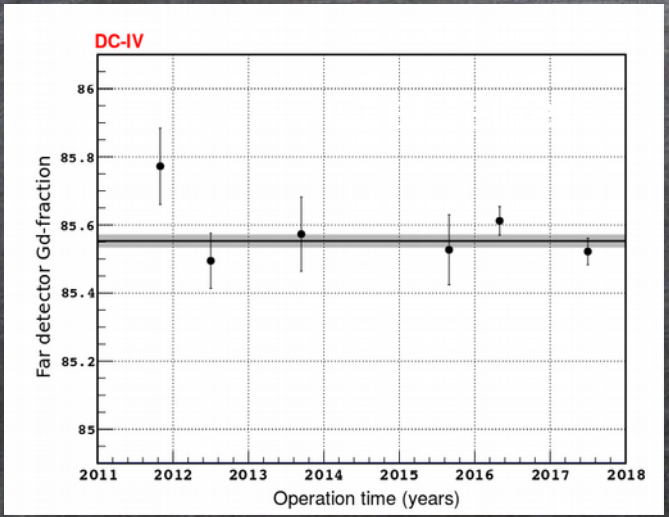
Project Manager:
Ch. Veyssière (CEA)

97 scientists 25 institutions (Americas, Asia, Europe)

doublechooz.in2p3.fr

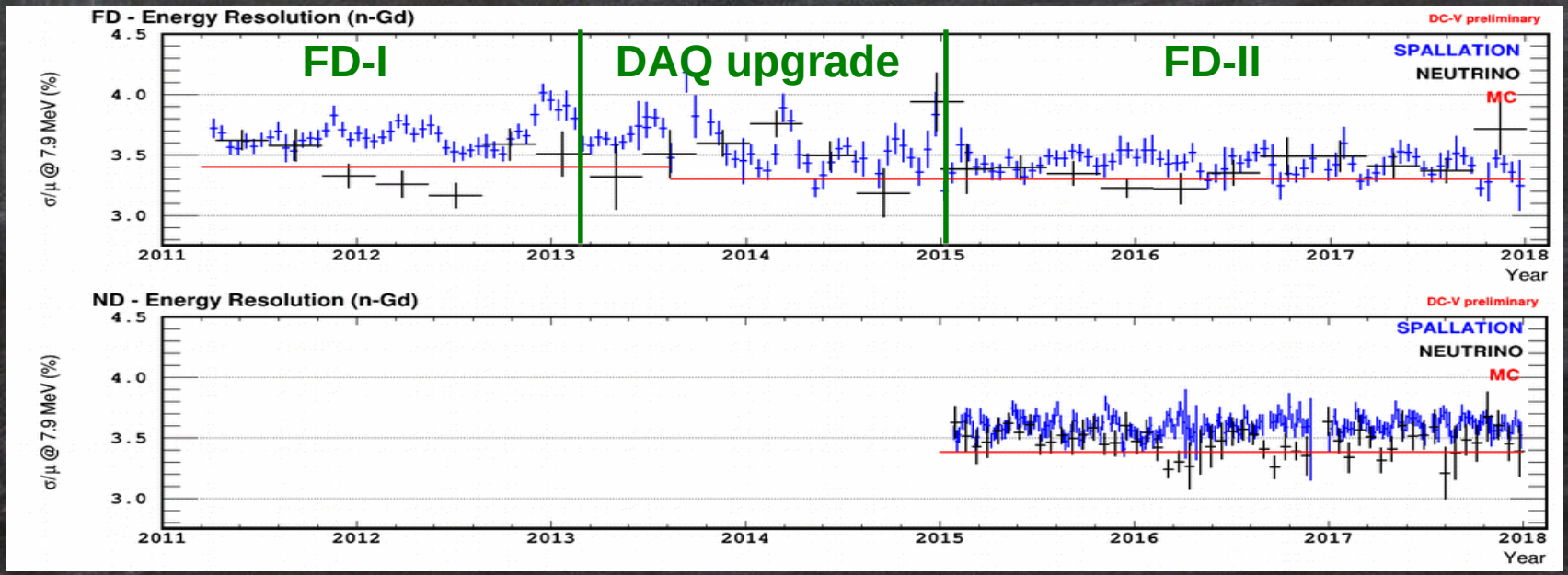

BACKUPS

SCINTILLATOR STABILITY

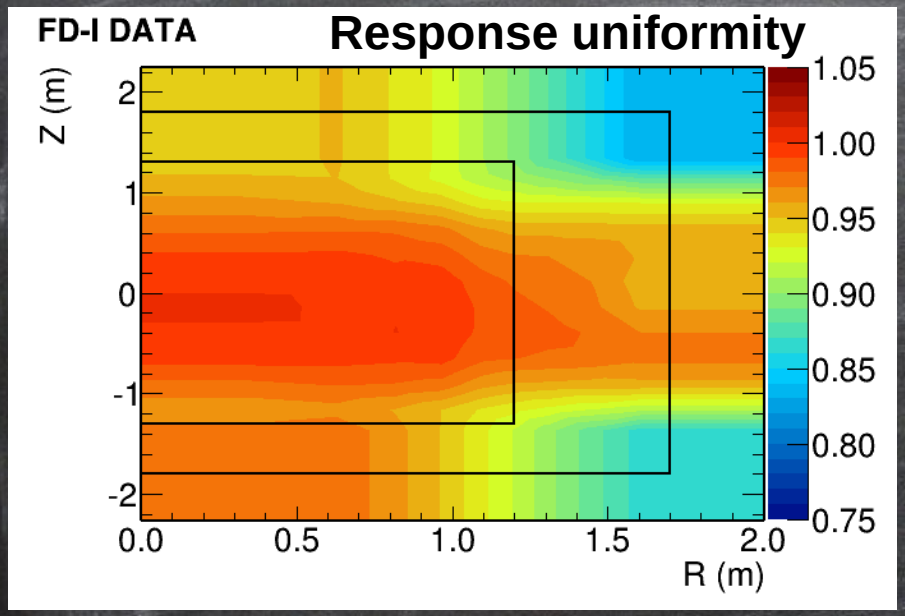


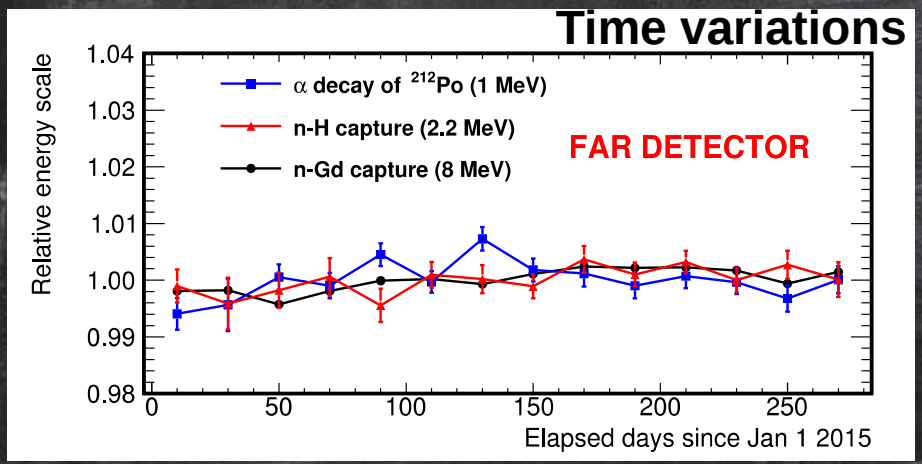
-> Optical and chemical stability of Gd-scintillator (7 years)

-> Gd fraction (center) stable on < 0.1% level

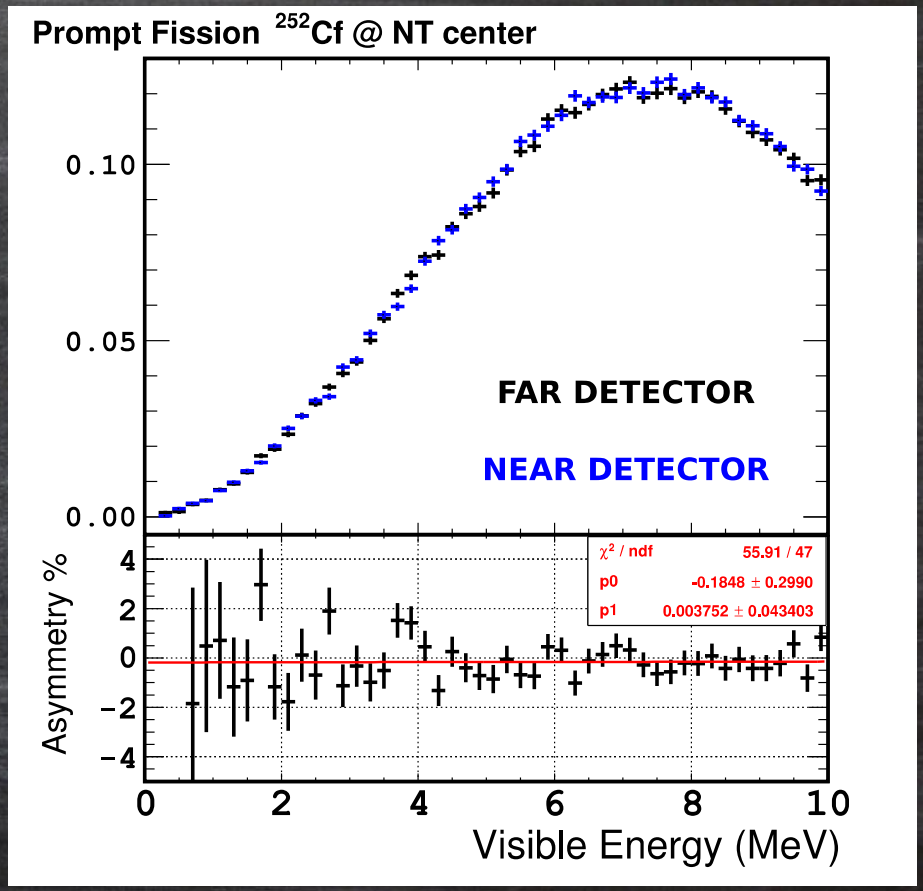


ENERGY RECONSTRUCTION





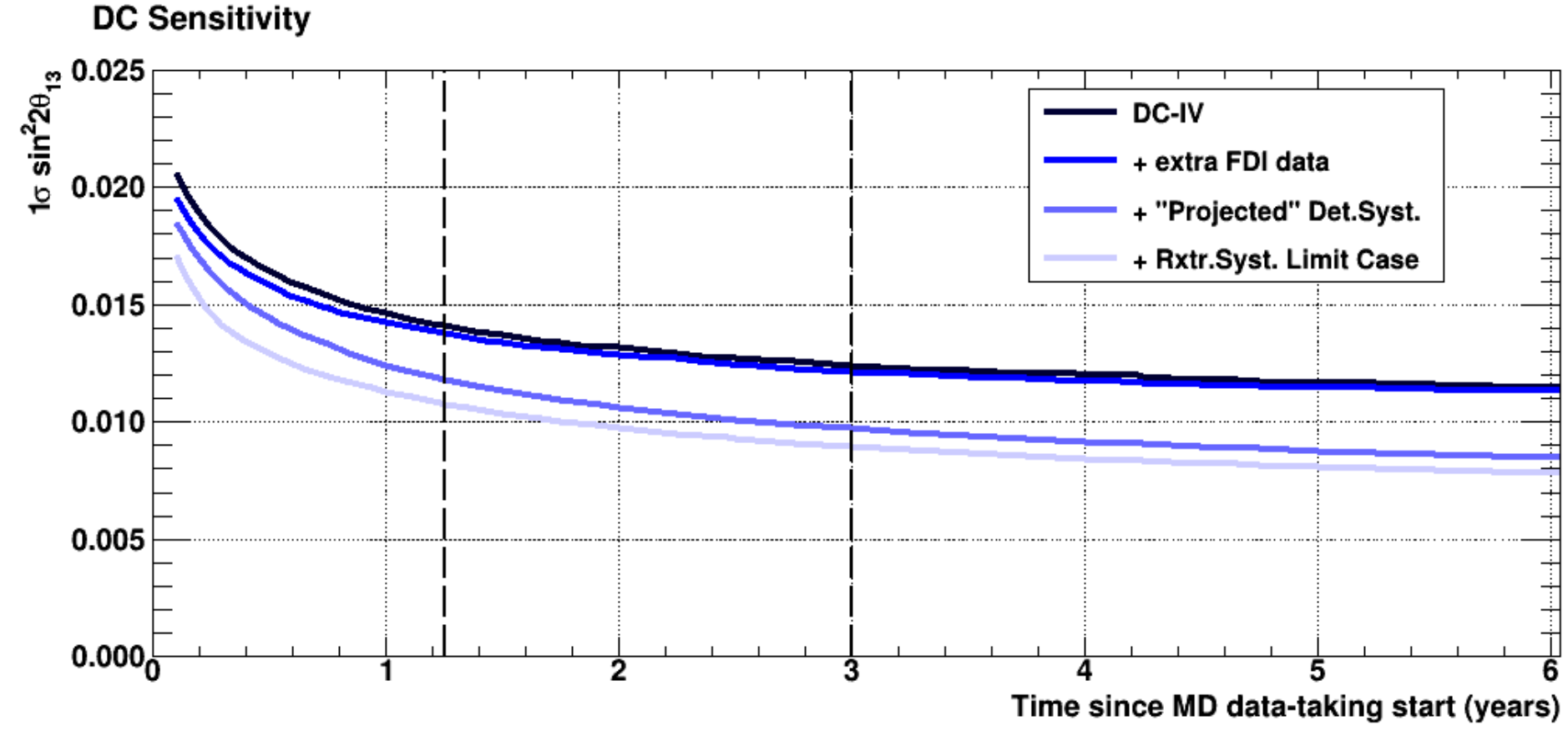
VERY GOOD NEAR - FAR AGREEMENT



No Near-to-Far slope!

σ = 0.04

SENSITIVITY PROJECTION



-> Double Chooz final sensitivity: 0.009~0.010 !