New Results from the Double Chooz Experiment

Thiago Bezerra (SUBATECH Laboratory, Nantes, France)[1]
on behalf of the Double Chooz Collaboration

The XXIX International Conference on Neutrino Physics and Astrophysics (Neutrino2020)
June 25th, 2020

[1]now @ University of Sussex, Brighton, UK

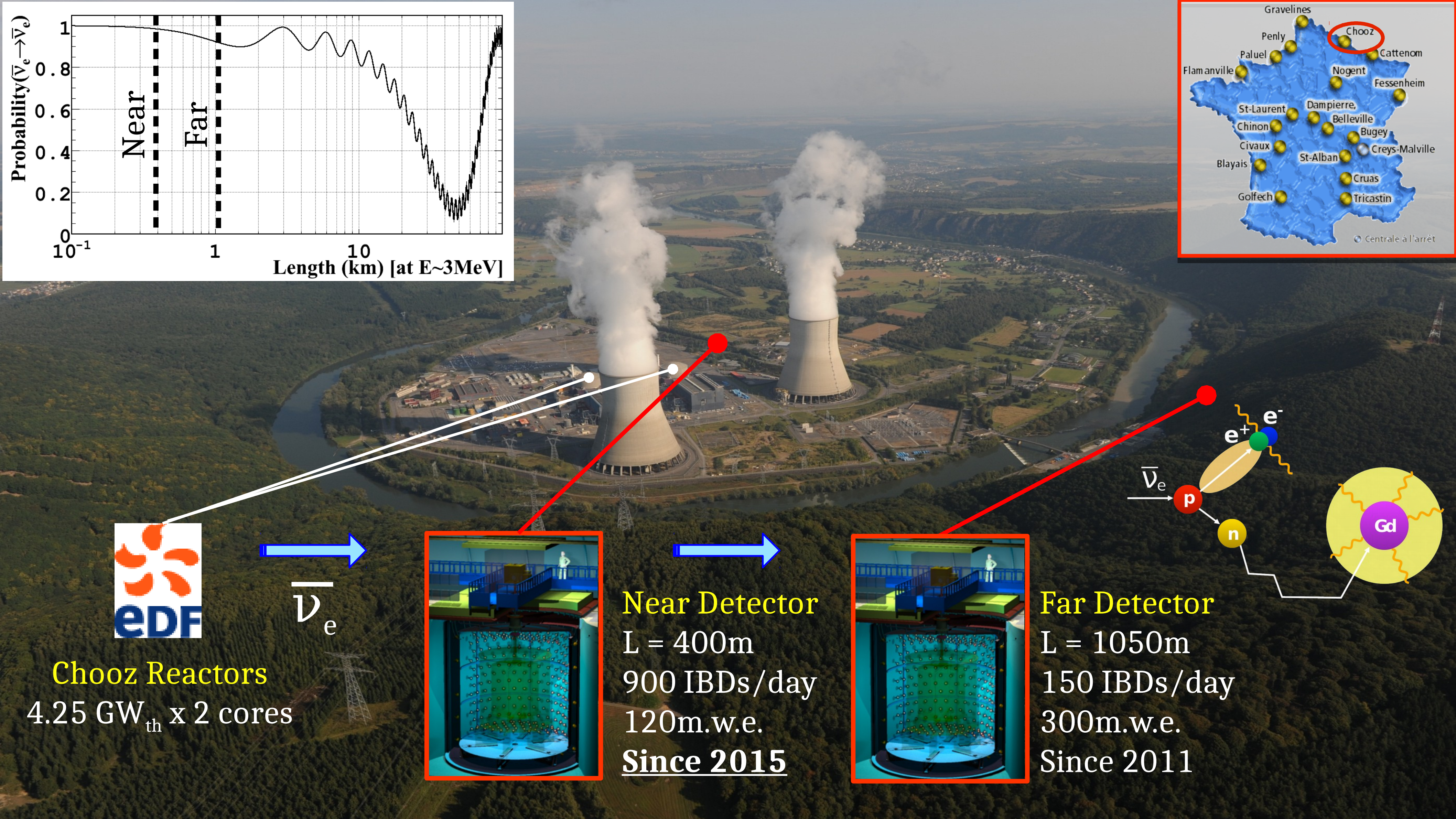
Outline

- What is Double Chooz and its milestones

- Where we were at Neutrino 2018

- Where we are now

- Prospects for the future

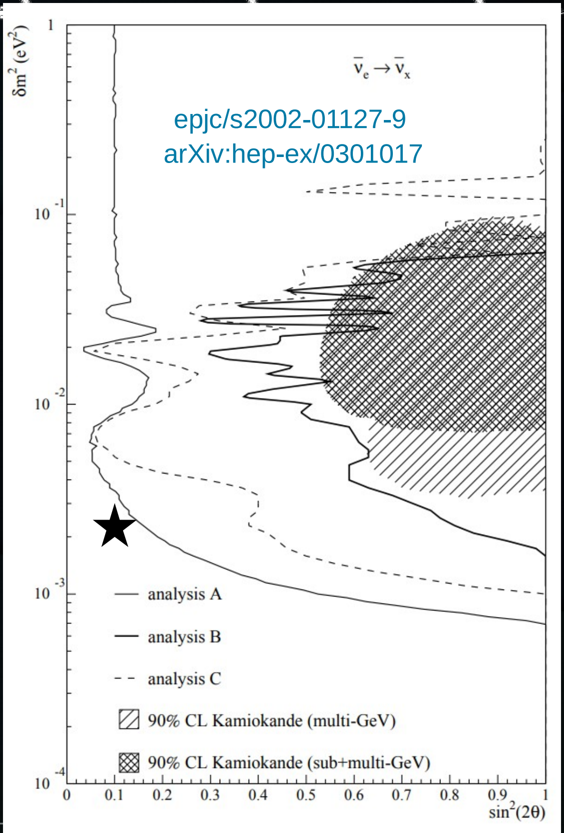


Probability($\bar{\nu}_e \rightarrow \bar{\nu}_e$)
1
0.8
0.6
0.4
0.2
0
10^{-1}
1
10
Length (km) [at E~3MeV]
Near
Far
Gravelines
Penly
Chooz
Paluel
Cattenom
Flamanville
Nogent
Fessenheim
St-Laurent
Dampierre,
Belleville
Chinon
Bugey
Civaux
Creys-Malville
St-Alban
Blayais
Cruas
Golfech
Tricastin
Centrale à l'arrêt
EDF
$\bar{\nu}_e$
e^-
e^+
p
n
Gd
Chooz Reactors
4.25 GW_{th} x 2 cores
Near Detector
L = 400m
900 IBDs/day
120m.w.e.
Since 2015
Far Detector
L = 1050m
150 IBDs/day
300m.w.e.
Since 2011

Timeline

2000 2010 2011 2012 2013 2014 2015 2018 2020

- Double Chooz is born (arXiv:hep-ex/0606025)
- Solutions to CHOOZ limitations

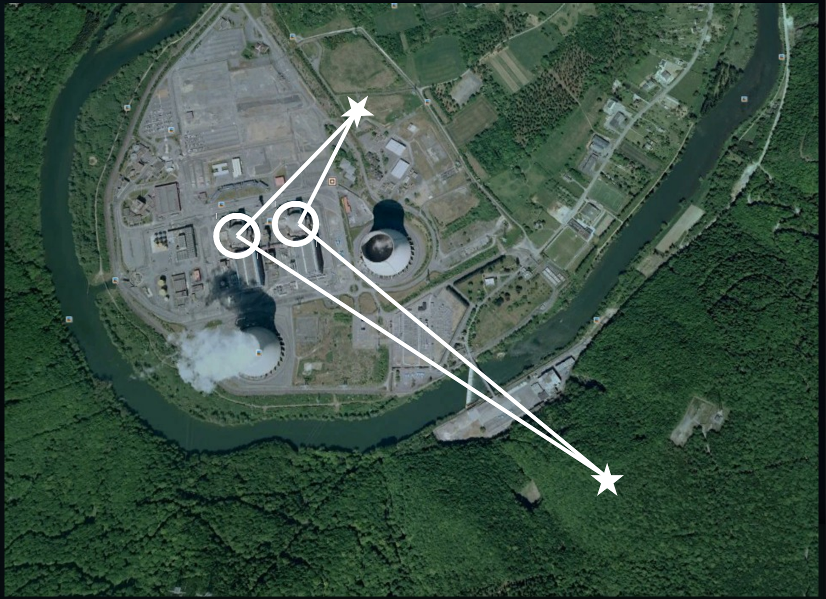


parameter	relative error (%)
reaction cross section	1.9%
number of protons	0.8%
detection efficiency	1.5%
reactor power	0.7%
energy released per fission	0.6%
combined	2.7%

Timeline

2000 ★ 2010 2011 2012 2013 2014 2015 2018 2020

- Double Chooz is born (arXiv:hep-ex/0606025)
- Solutions to CHOOZ limitations:
  - Near-Far approach (arXiv:hep-ex/9908047)
  - Close to Iso-flux

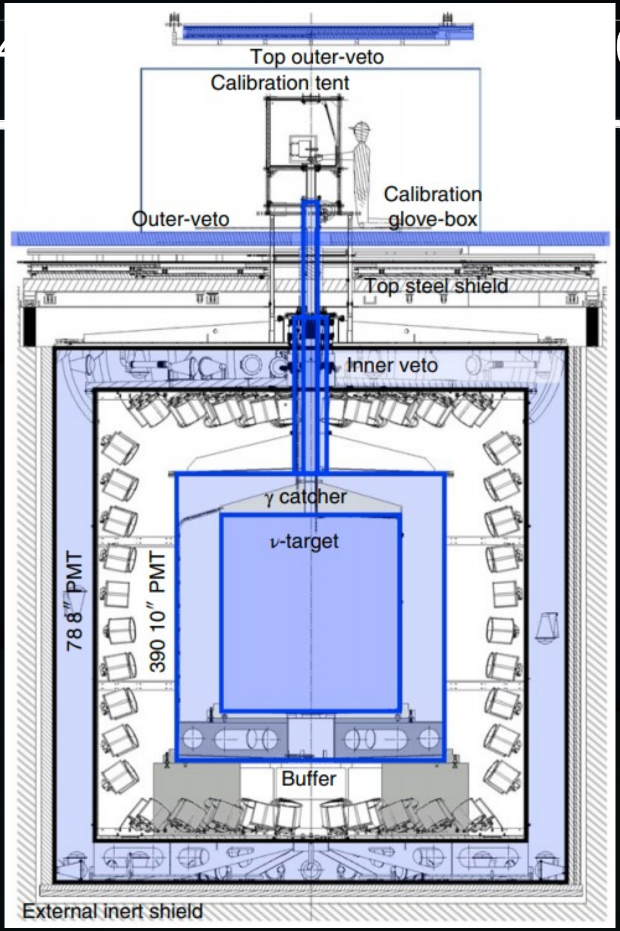


parameter	relative error (%)	
reaction cross section	1.9%	~0.1%
number of protons	0.8%	<0.5%
detection efficiency	1.5%	<0.5%
reactor power	0.7%	~0.1%
energy released per fission	0.6%	~0.0%
combined	2.7%	

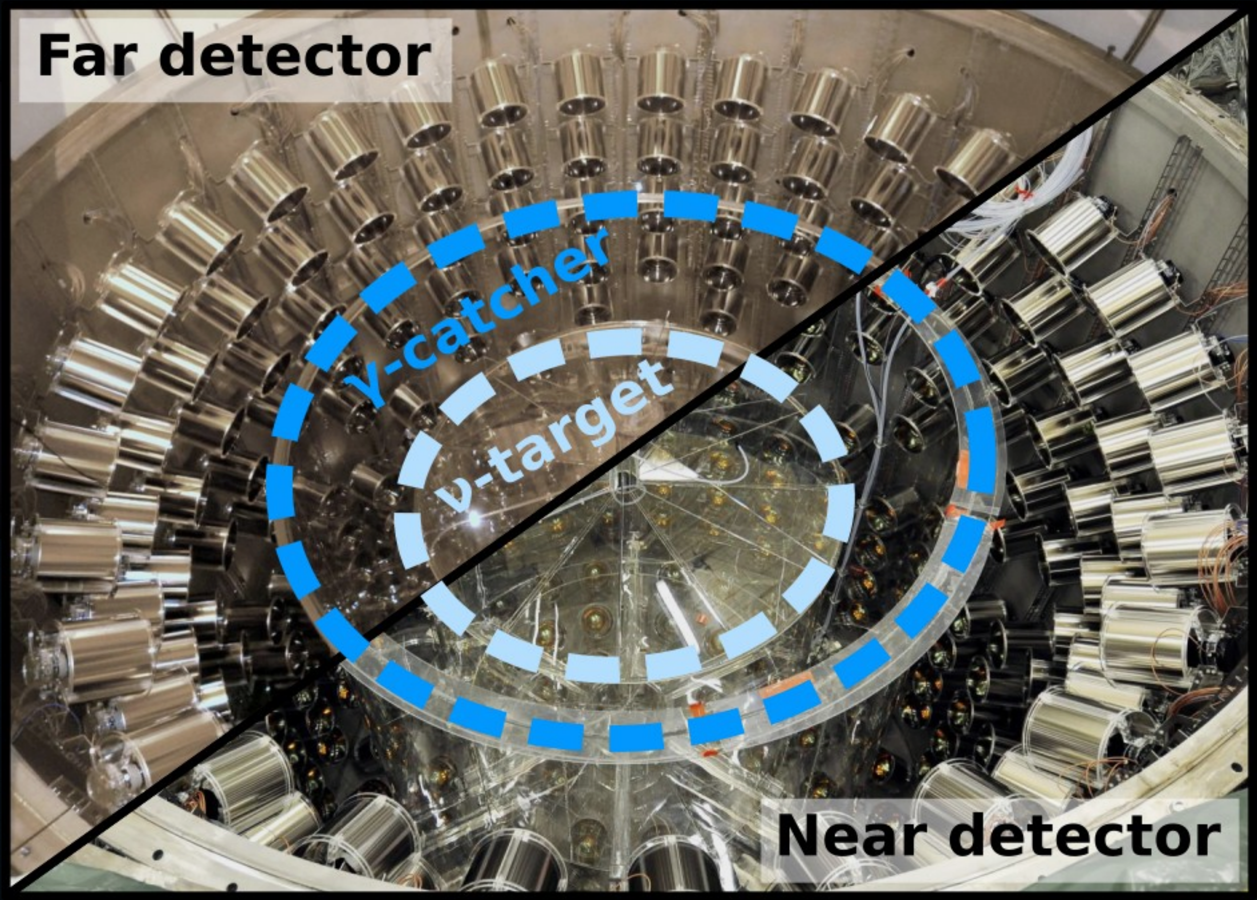
Timeline

2000 2010 2011 2012 2013 2014 … 2020

- Double Chooz is born (arXiv:hep-ex/0606025)
- Solutions to CHOOZ limitations:
  - Near-Far approach (arXiv:hep-ex/9908047)
  - Close to Iso-flux
  - 4 Layers detector
  - Stable Scintillator



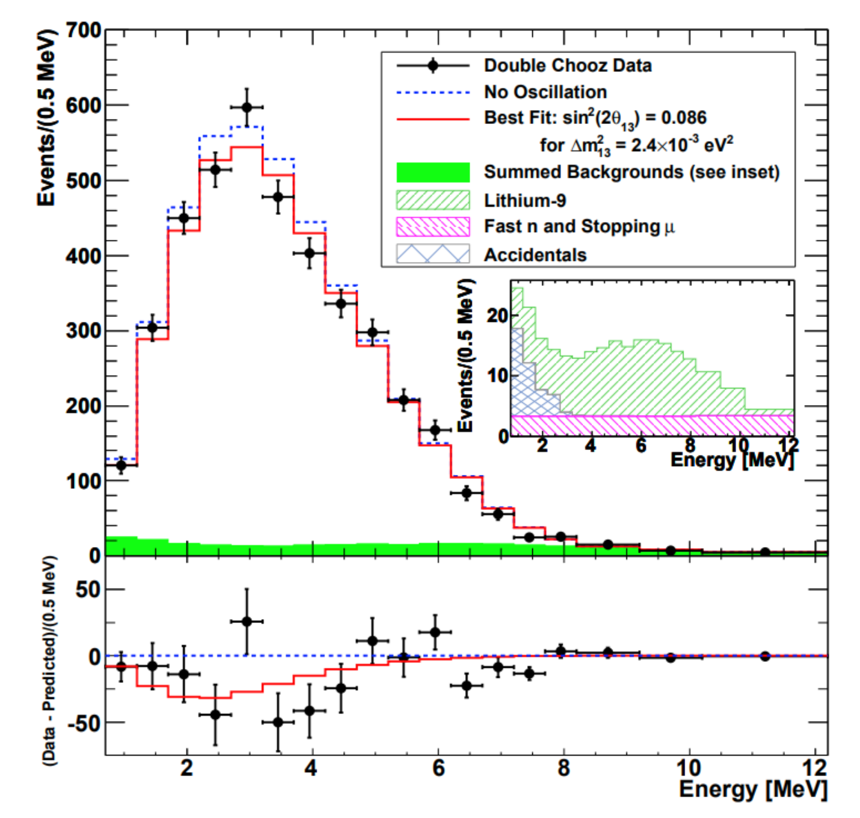
Identical Detectors



Timeline

2000 2010 2011 2012 2013

- First indication of Reactor $\theta_{13} > 0$ (@95% CL)
- 3σ in combination with T2K
- Start of the synergy Reactor + Accelerator

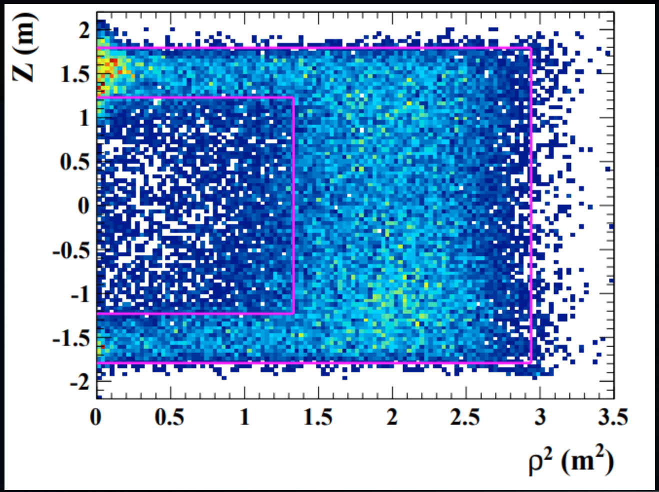


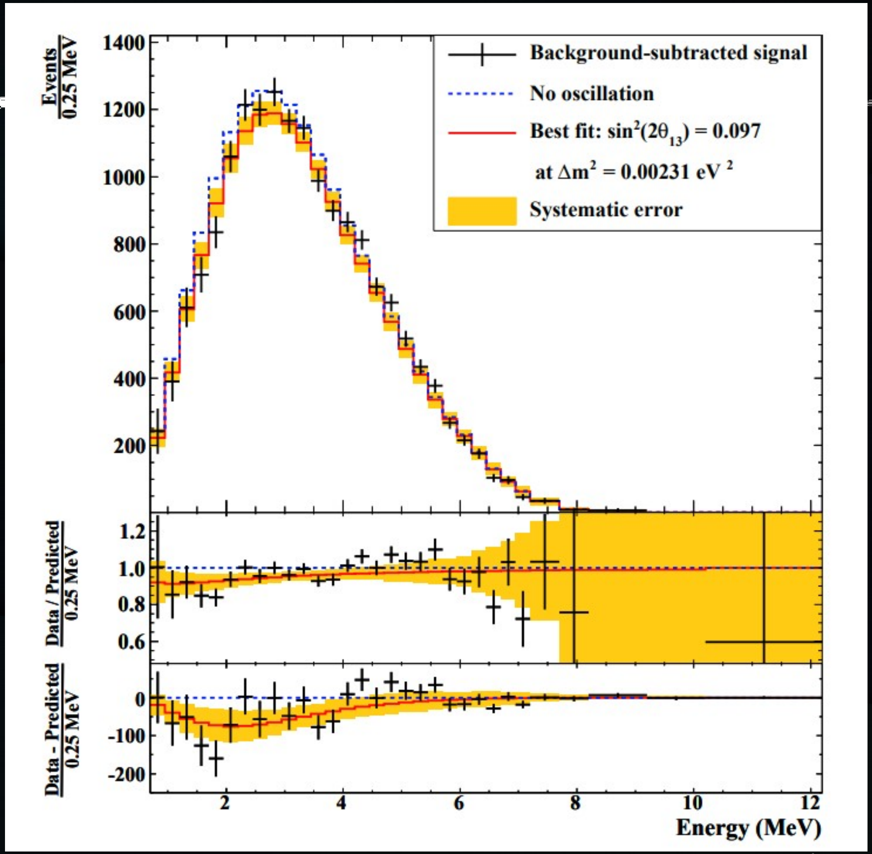
PhysRevLett.108.131801 arXiv:1112.6353

Timeline

2000 2010 2011 2012 2013

- First θ_{13} measurement with n-H captures
- Thought to be impractical, thus Gd loading
- Limitation: Proton number systematics
  (Gamma Catcher not meant as a Target)



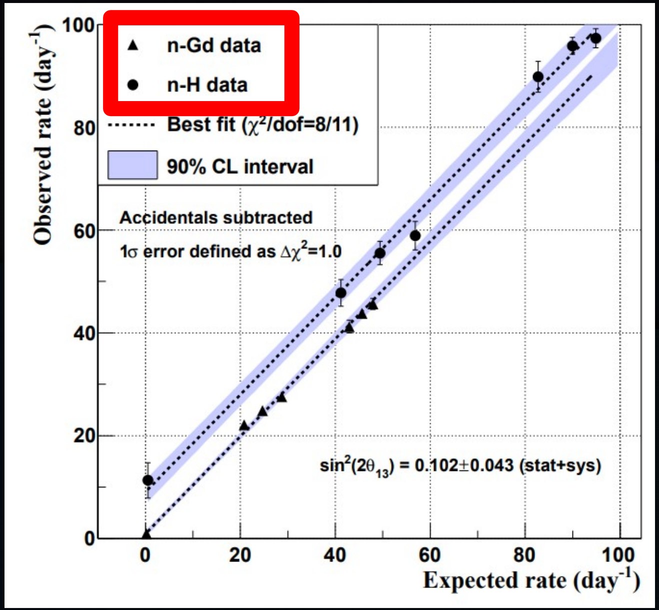


j.physletb.2013.04.050 arXiv:1301.2948

Timeline

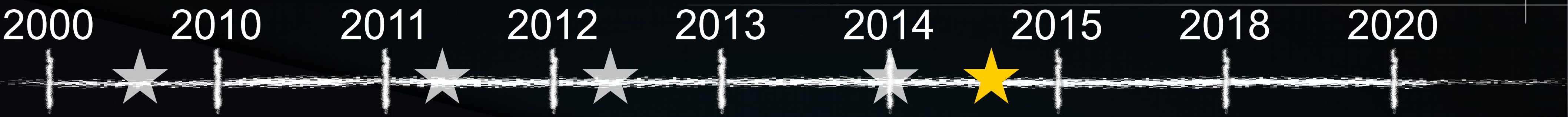
2000 2010 2011 2012 2013 2014 2015 2018 2020

- First θ_{13} via Reactor Rate Modulation with Reactor-off, n-Gd & n-H (as independent dataset)

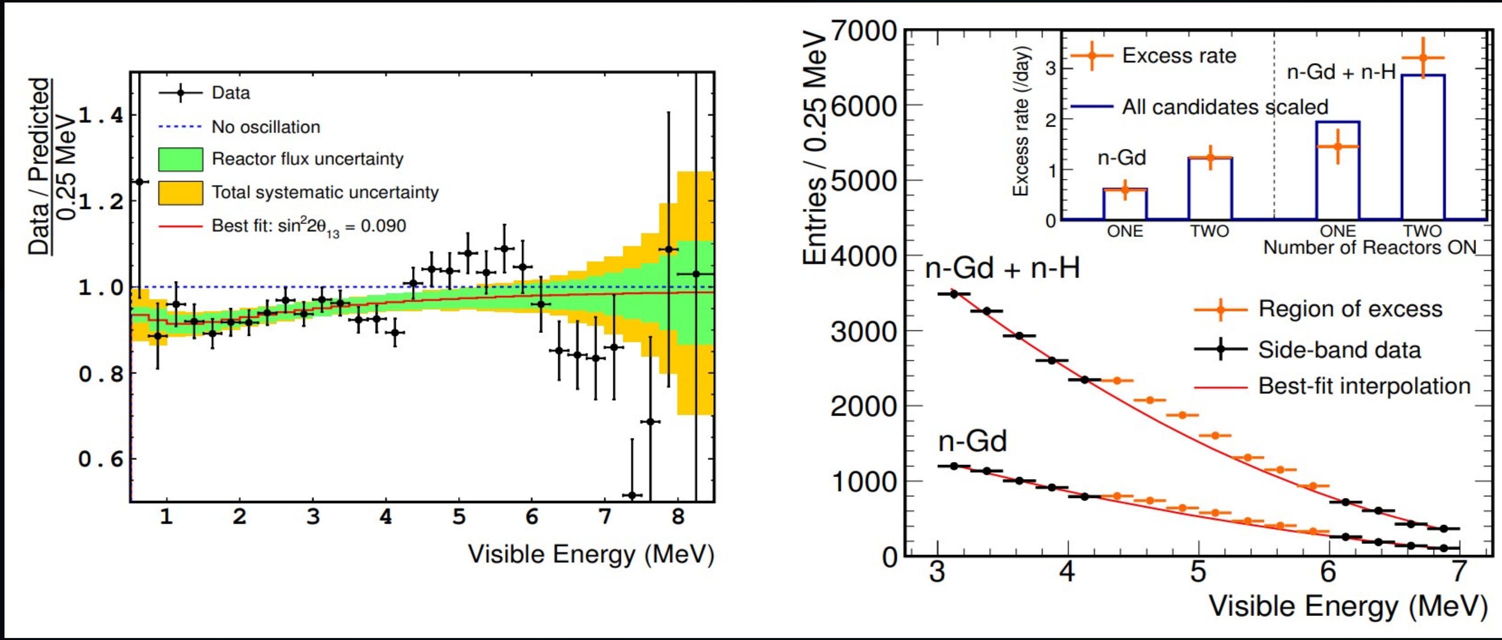


j.physletb.2014.04.045 arXiv:1401.5981

Timeline



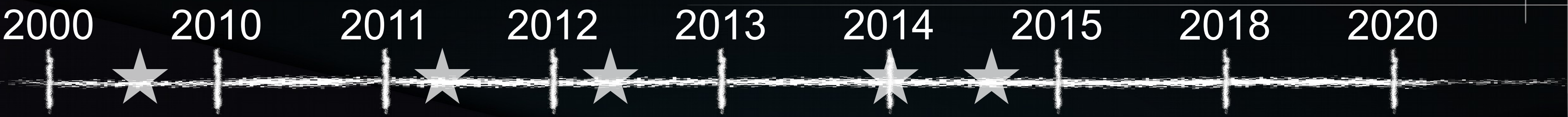
- First report on the reactor spectrum distortion (with 18k IBDs at Far Detector)



JHEP10(2014)086

arXiv:1406.7763

Timeline



- Double Chooz strategy:
  - Near-Far approach
  - Close to Iso-flux
  - ~~Proposed 4-Layers detector~~ - - - → 3 layers is enough (TnC)
  - Stable Scintillator

- First Indication of Reactor $\theta_{13} > 0$

- First θ_{13} measurement with n-H captures

- First θ_{13} measurement with Reactor Rate Modulation

- First report on the reactor spectrum distortion

Timeline

2000 2010 2011 2012 2013 2014 2015 2018 2020

- Near laboratory excavation, detector construction & commissioning

Construction Short Documentary
Click here to watch!
https://youtu.be/gXoKoVzIO74

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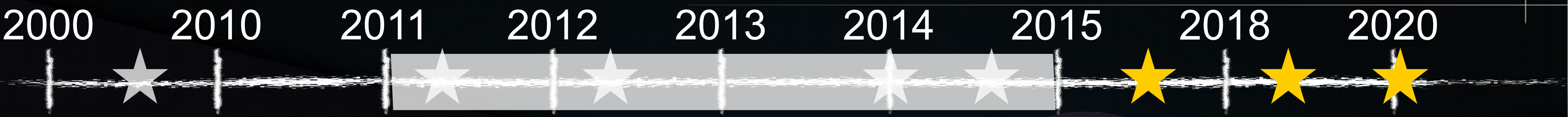


- First DC Near + Far Result Released
  - Preliminary @ CERN Seminar
  - Officially @ Neutrino 2018
  - Published @ Nature Physics

NEUTRINO 2018
4–9 June
Heidelberg

ARTICLES
https://doi.org/10.1038/s41567-020-0831-y

nature physics

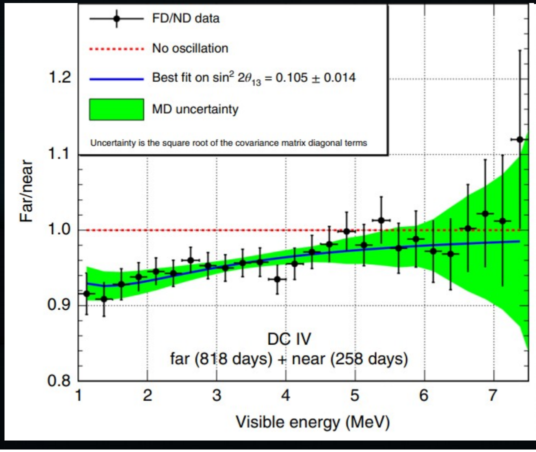
Double Chooz θ_{13} measurement via total neutron capture detection

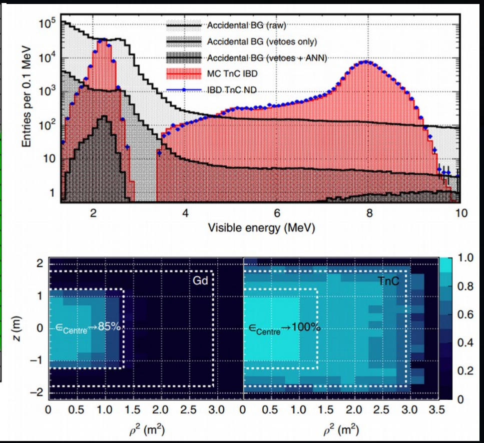
The Double Chooz Collaboration*

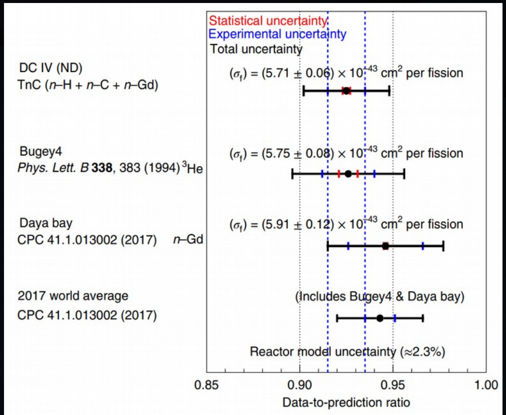
s41567-020-0831-y arXiv:1901.09445

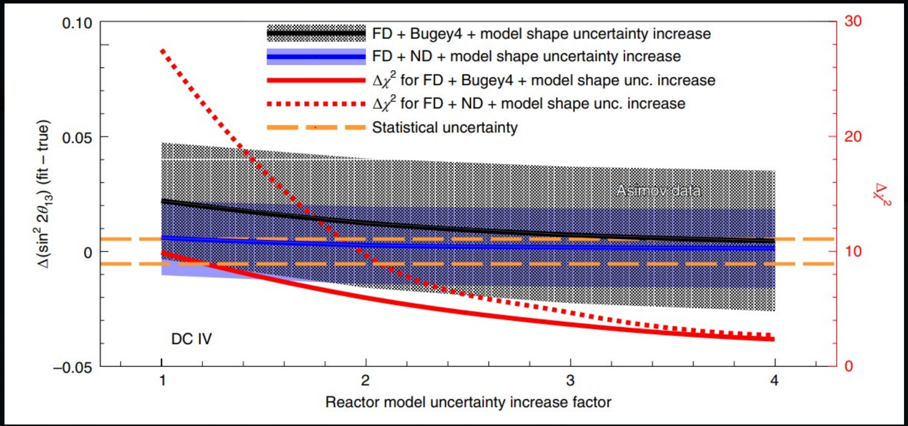
Highlights of Nature Physics

- Near and Far θ_{13}
  (almost full flux uncertainty cancellation)
- IBD with Total Neutron Capture (Gd + H + C)
  (3 volume-like, x2.5 statistics)
- Best Integral Flux Measurement to Date
- Spectra Distortion Bias on θ_{13}
  (no issue for Near-Far, big issue if Far only)









See more details
@ Poster#488
Session 4

Outline

- What is Double Chooz and its milestones

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- Where we are now

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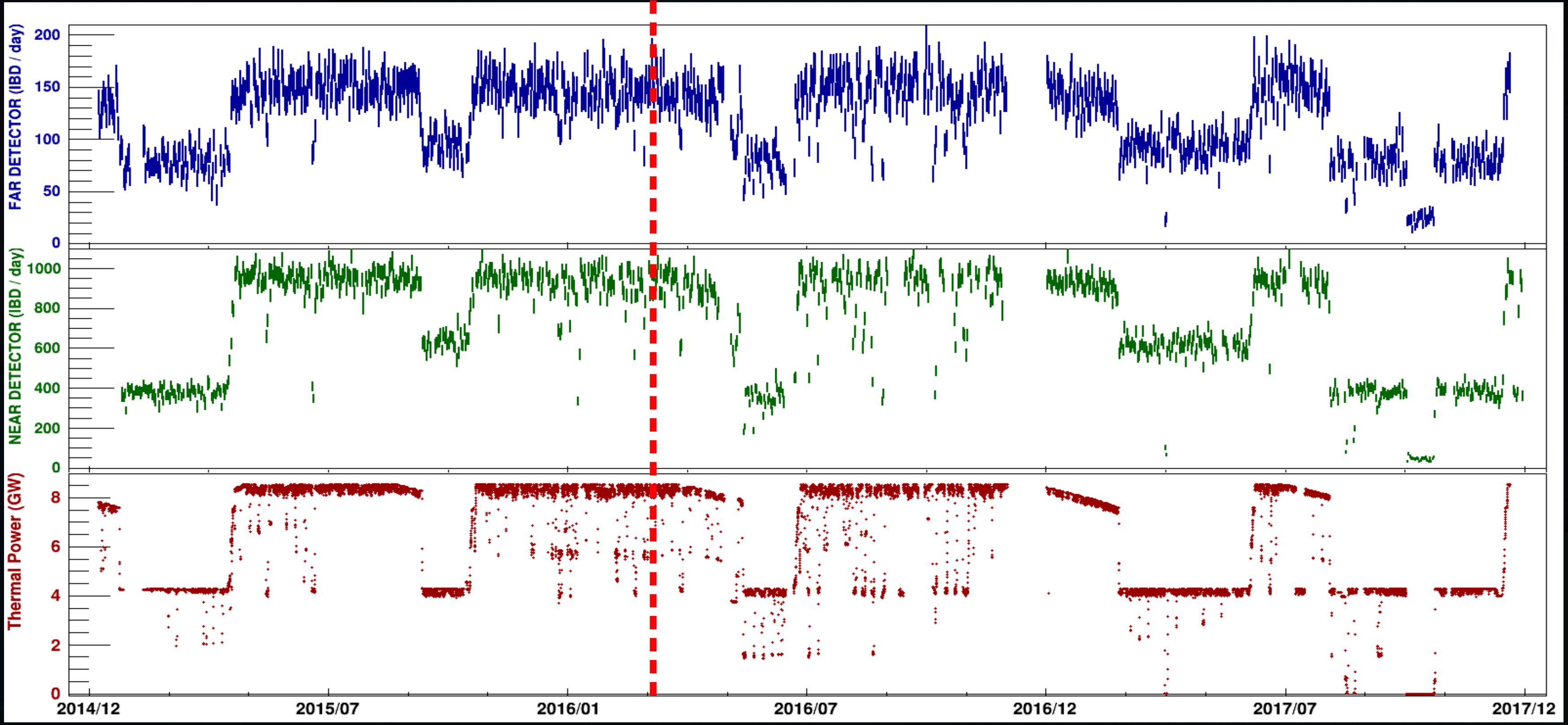
New Data

Nature Physics Data Set
(+1.5y of Far only data)

Extra Set of this release



Far Detector

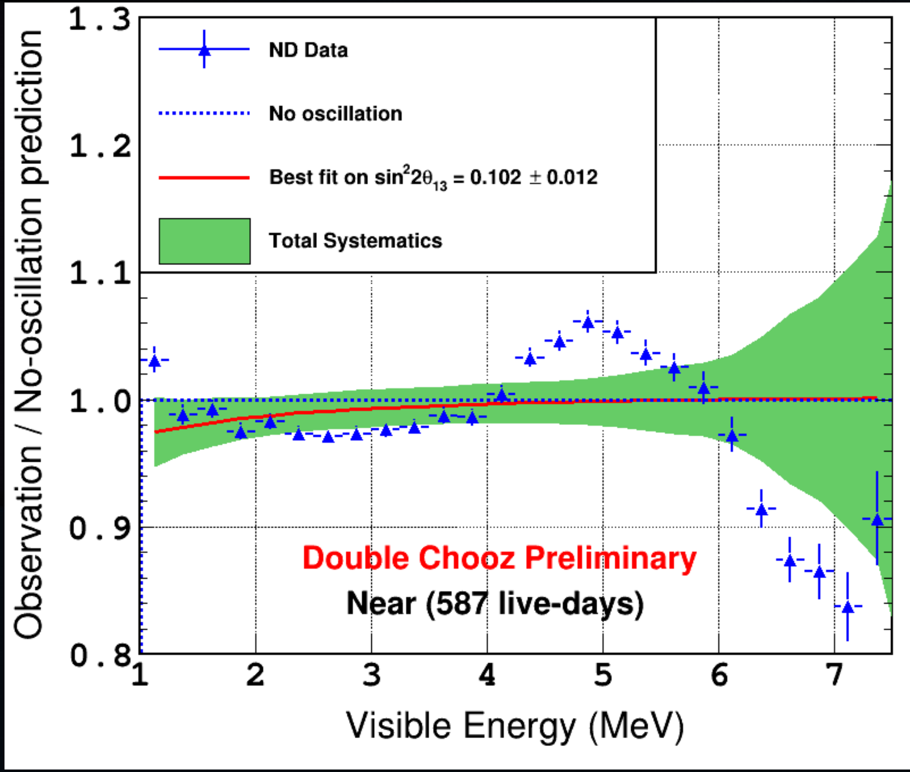
Near Detector

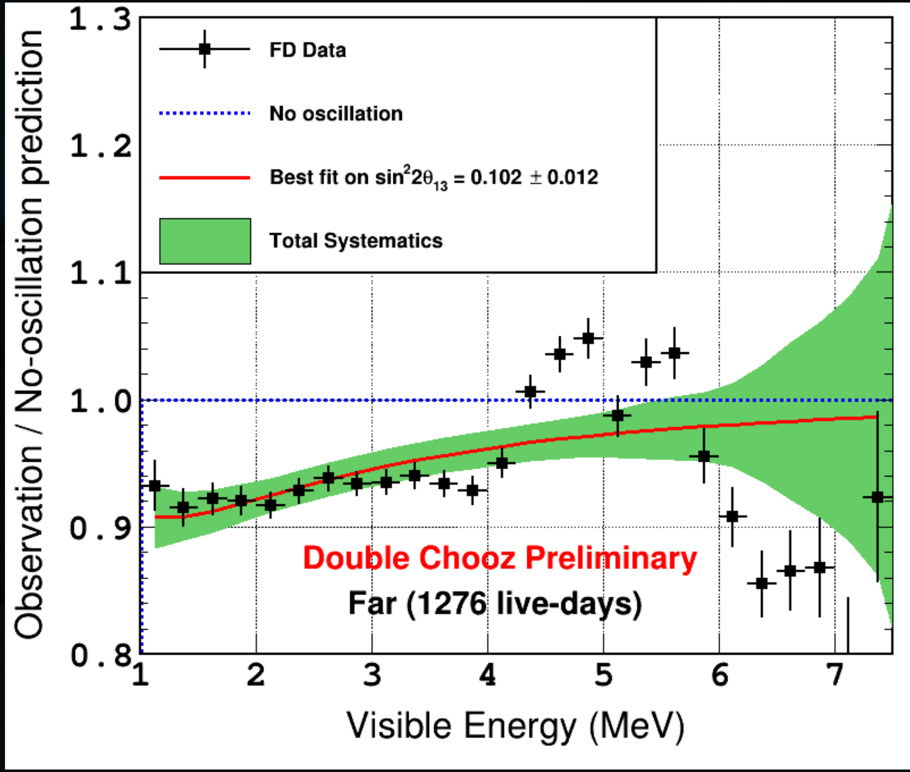
Reactor Thermal Power

New Data

Detector	Run Time (days)	Factor To Nature Physics Dataset
Far Alone (Reactor-ON)	481.12	1.00
Far Alone (Reactor-OFF)	7.57	1.00
Far (Reactor-ON)	868.11	**2.26**
Near (Reactor-ON)	788.73	**2.28**
Far (Reactor-OFF)	23.54	**NEW**
Near (Reactor-OFF)	23.12	**NEW**

Oscillation Analysis

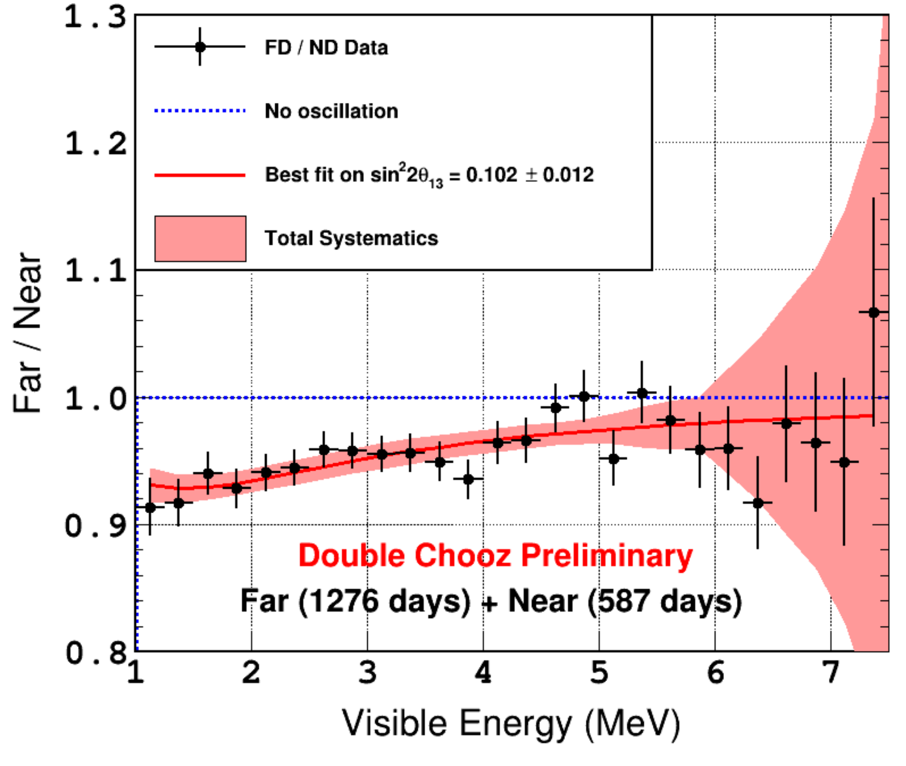




NEW! $\sin^2 2\theta_{13}$ = 0.102 ± 0.011 (syst.) ± 0.004 (stat.)

(stable result also for Rate or Shape only analysis)

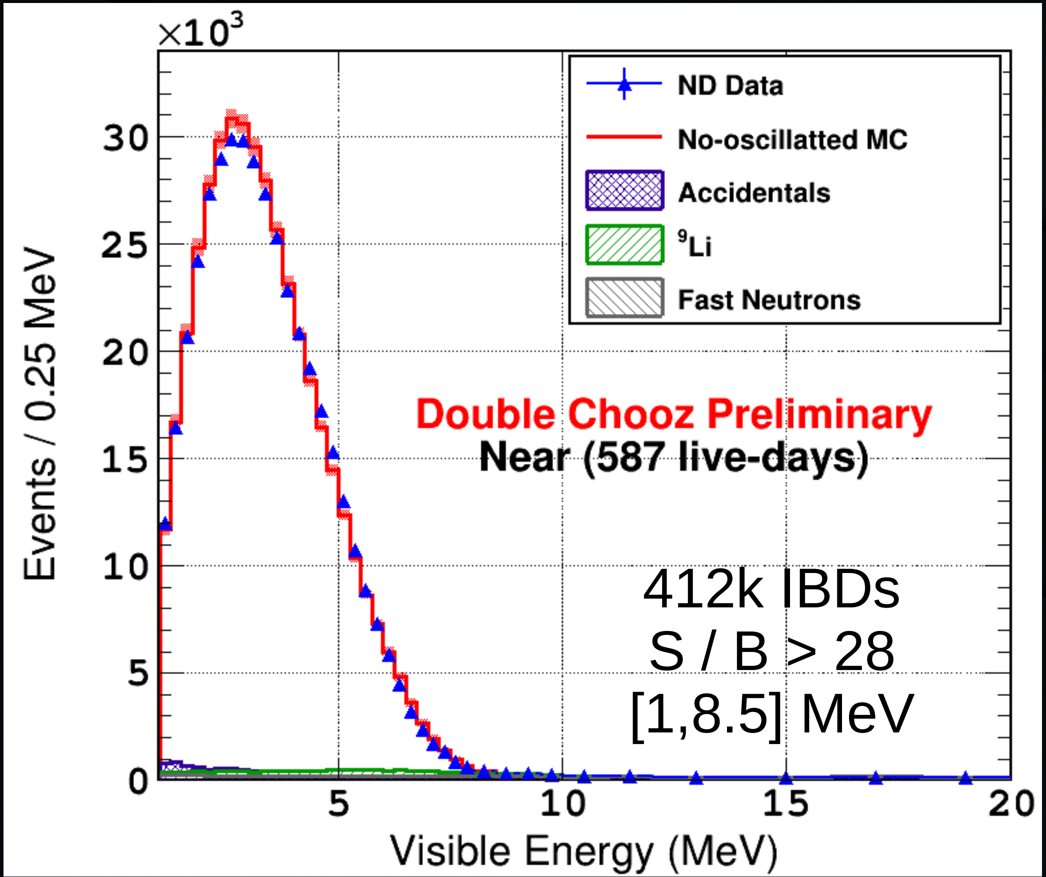
Oscillation Analysis

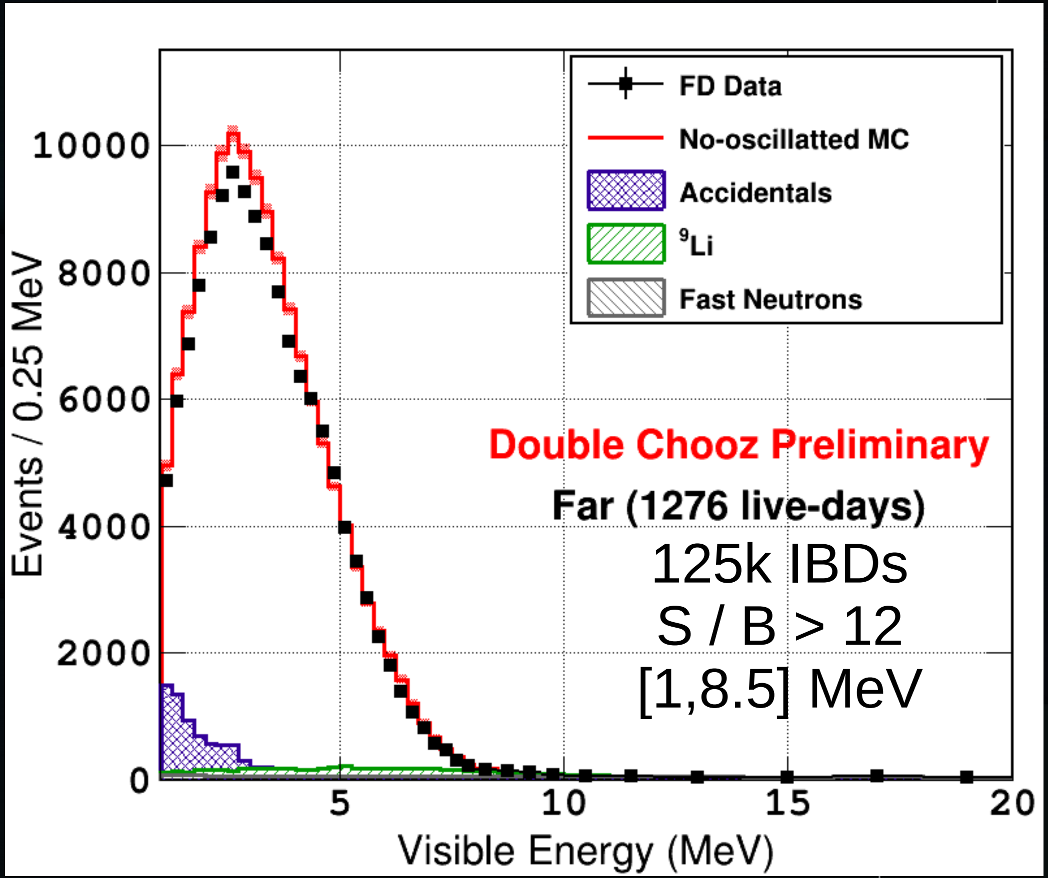


NEW! $\sin^2 2\theta_{13}$ = 0.102 ± 0.011 (syst.) ± 0.004 (stat.)

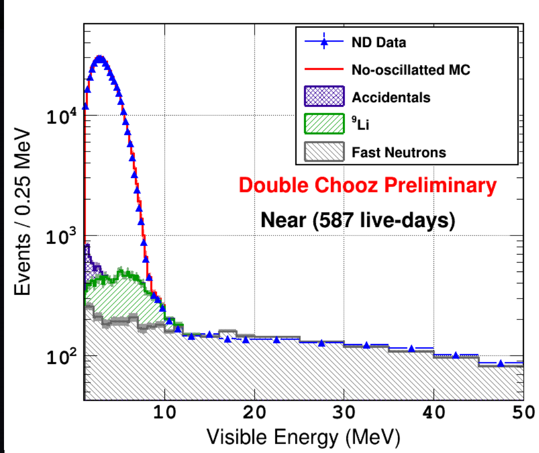
(spectral distortions cancelled in Near-Far approach)

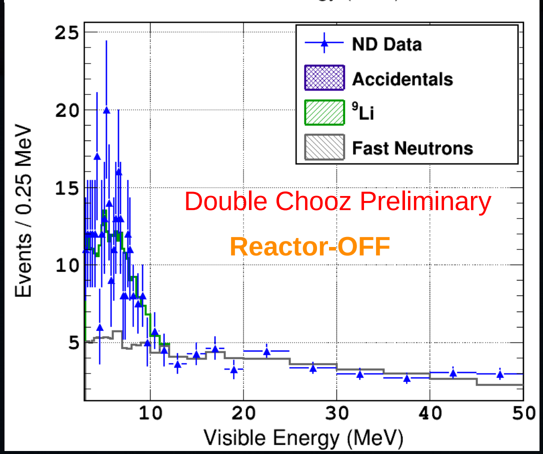
Data, Signal & Backgrounds



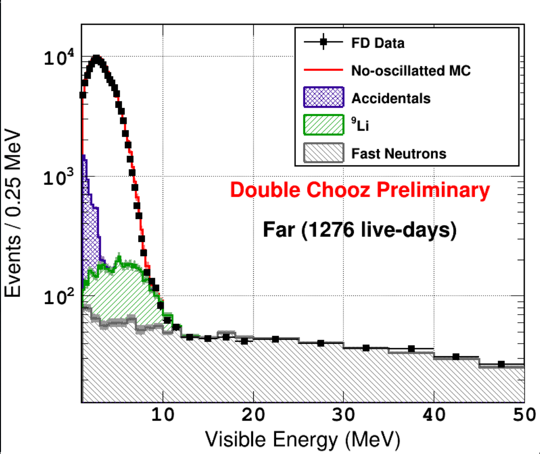


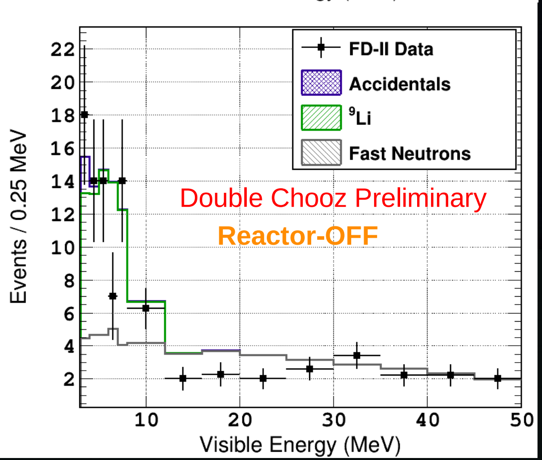
Data, Signal & Backgrounds



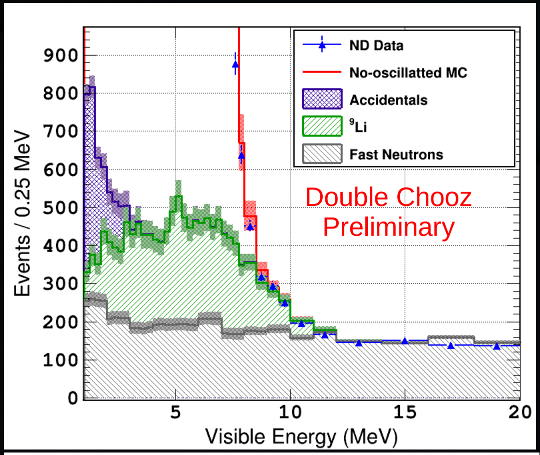


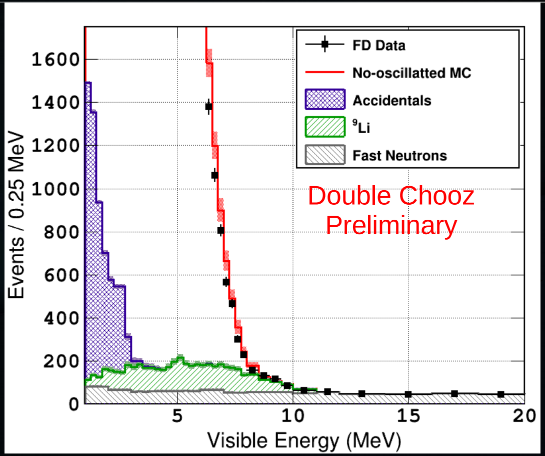
^{9}Li Rate unc. 7%
Fast-n Rate unc. 1%
Accidental Rate unc. < 1%





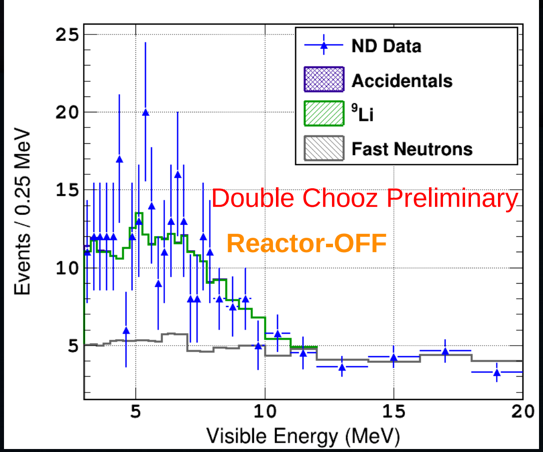
Data, Signal & Backgrounds

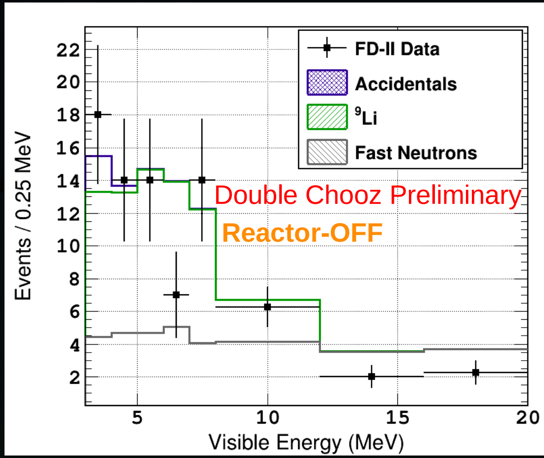




^{9}Li Rate unc. 7%
Fast-n Rate unc. 1%
Accidental Rate unc. < 1%

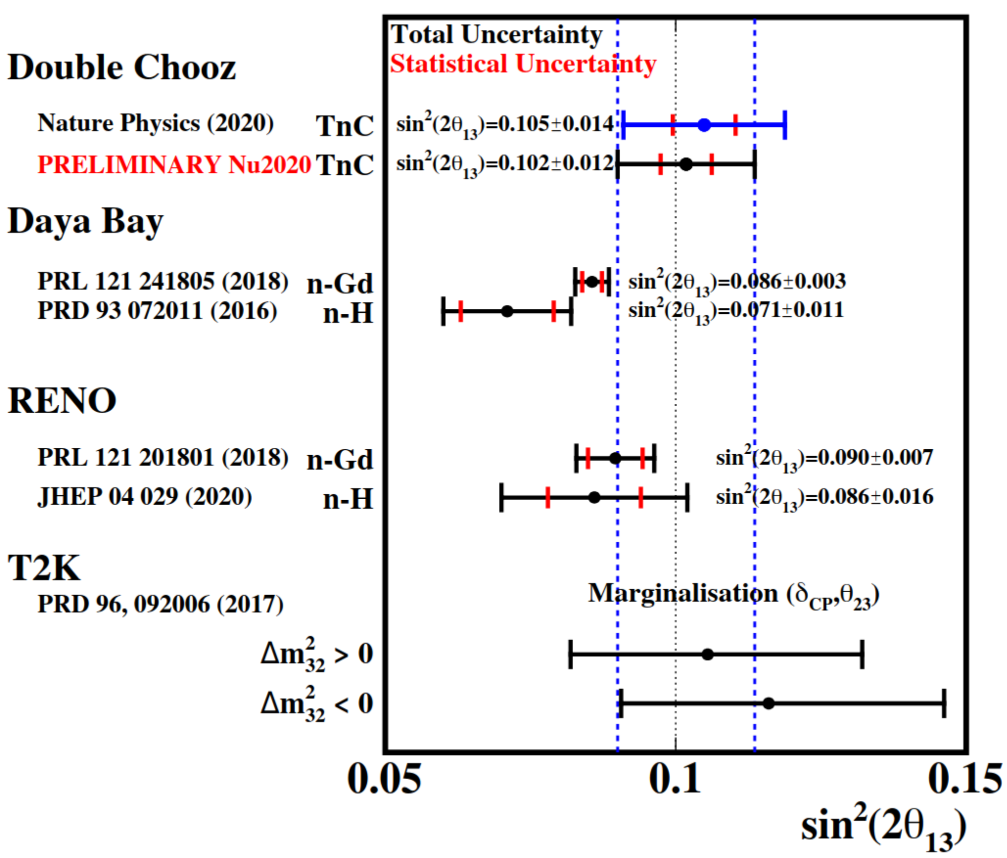
Reactor-off Data
Gives Extra Constrains on
BG above 3 MeV



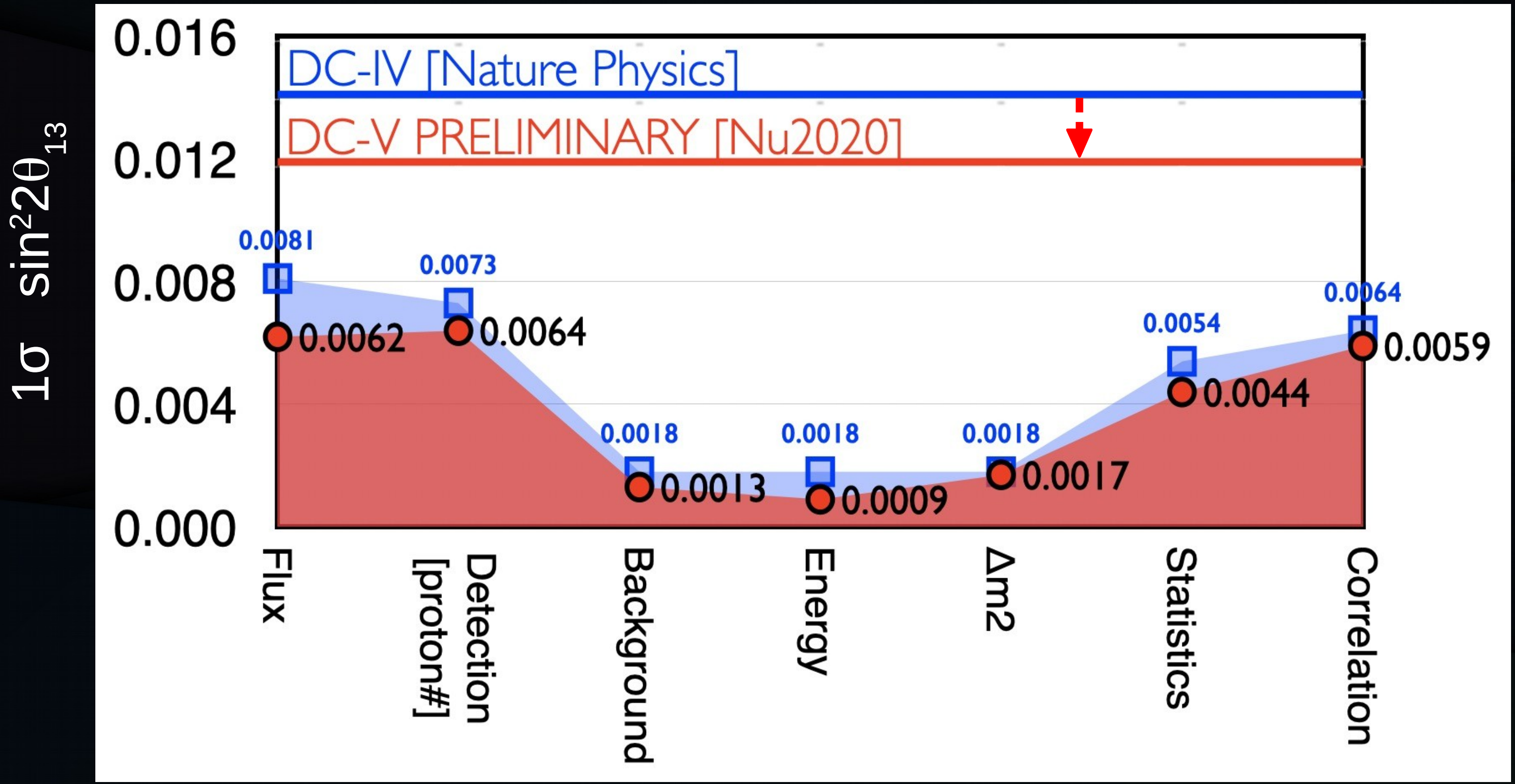


What happens < 3 MeV?
Details @ Poster#390
Session 4

Our Result in Perspective

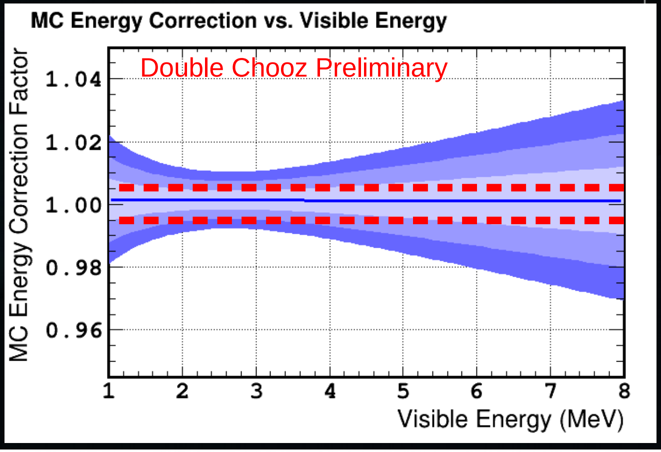


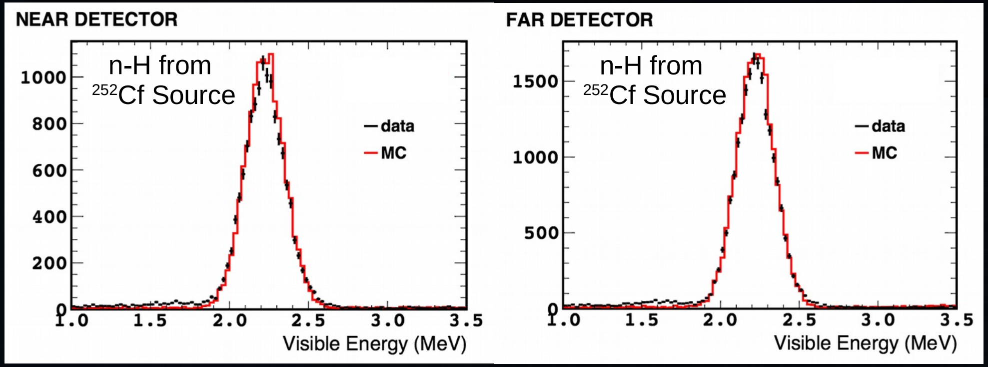
Systematics Breakdown

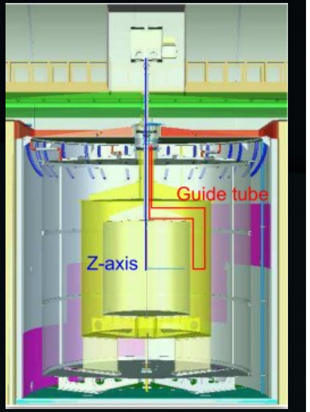


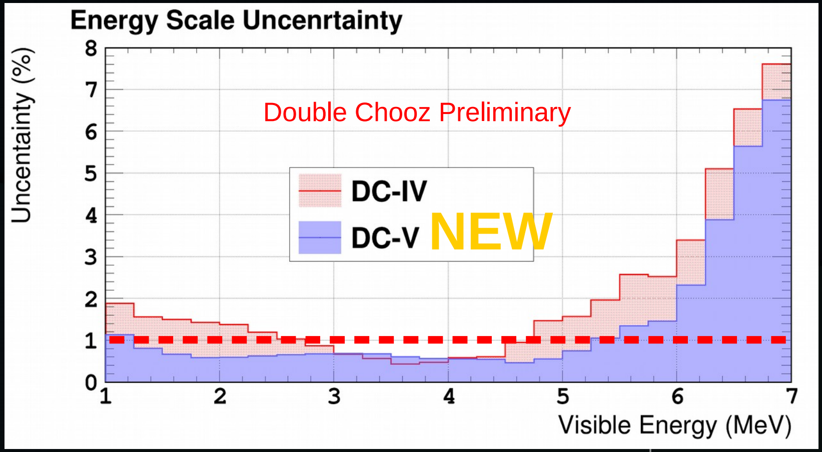
Positron Energy Model

- More Data allowed:
  - Better understanding of detector stability & uniformity
- Deticated calibration campaigns allowed:
  - Extra constrain of light & charge non-linearities
- Energy controlled ~0.5% in θ_{13} region



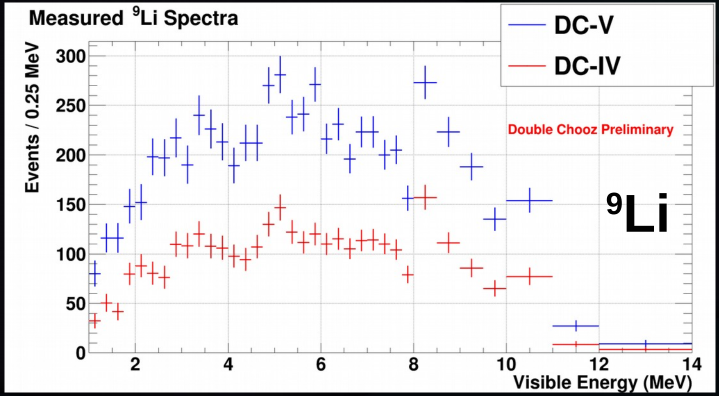


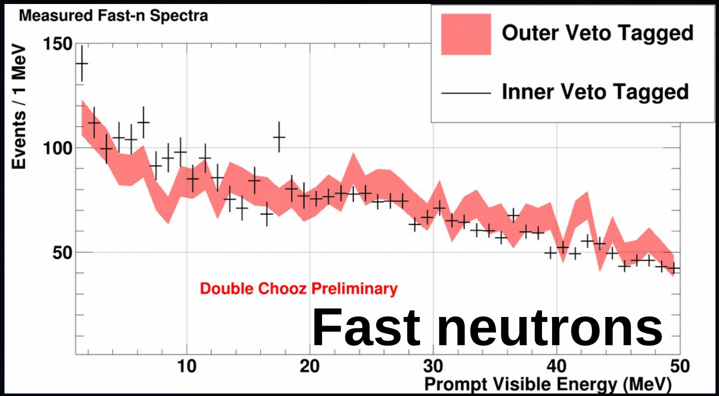




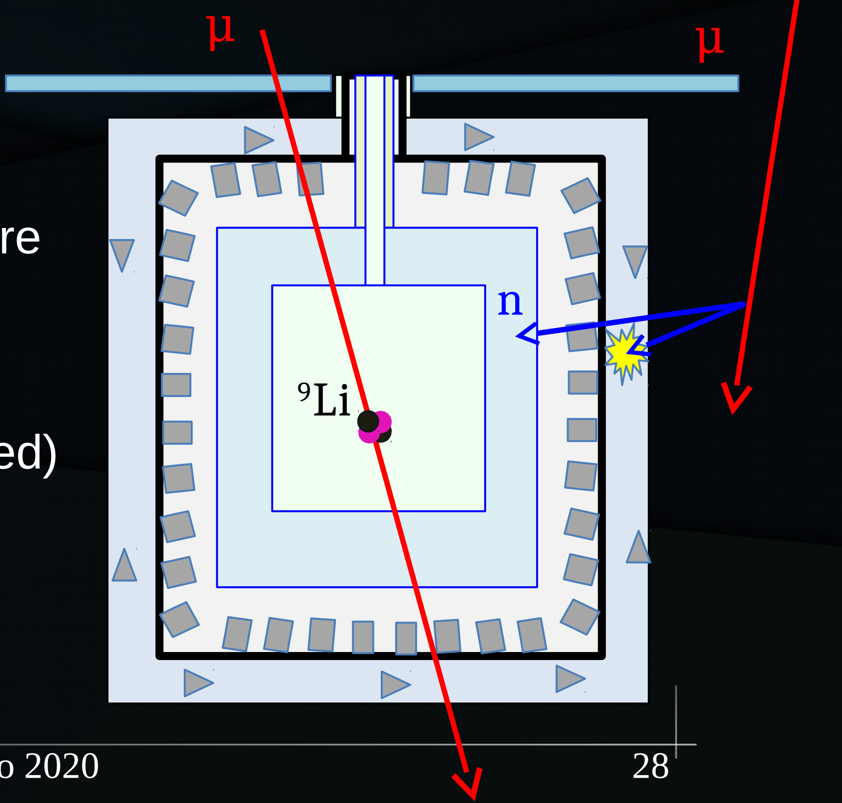
Backgrounds Measurement

- Lithium-9 Measurement (Time & Space conicidence with muon track)
- Fast-neutrons Measurement (Time & Space conicidence with Inner Veto activity)





All Backgrounds are Measured Independently (no MC nor parametrization used)



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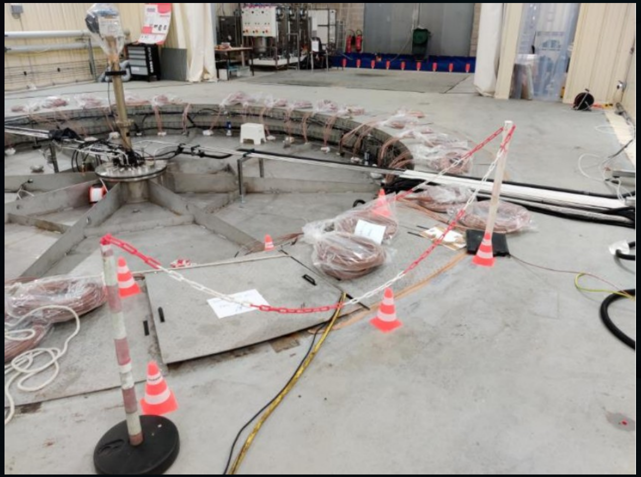
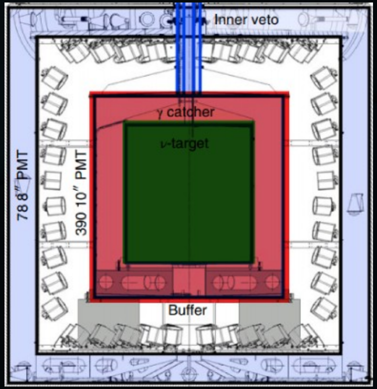
Prospects for Improvement

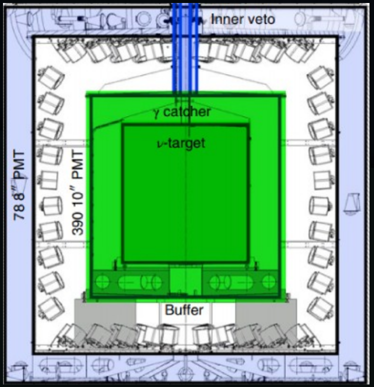
Detector dismantling underway. Goal: a better proton number measurement.





$1\sigma \sin^2 2\theta_{13}$

0.012



0.0105

Summary

- Double Chooz reaching its life-cycle end...
- Smallest detectors, flux & overburden -> **Pushes for Innovation!**
- **New** result: $\sin^2 2\theta_{13}$ = **0.102 ± 0.012** (w/ full two detectors data)
- Still room for $\sin^2 2\theta_{13}$ improvement (**$1\sigma \lesssim 0.01$**)
- Other results update from Nature Physics (best flux measurement, distortion, etc) underway
- Publications in preparation

  Sterile search, Rate Modulation update, Detector, Reactor-off & Residual flux

In Memory of

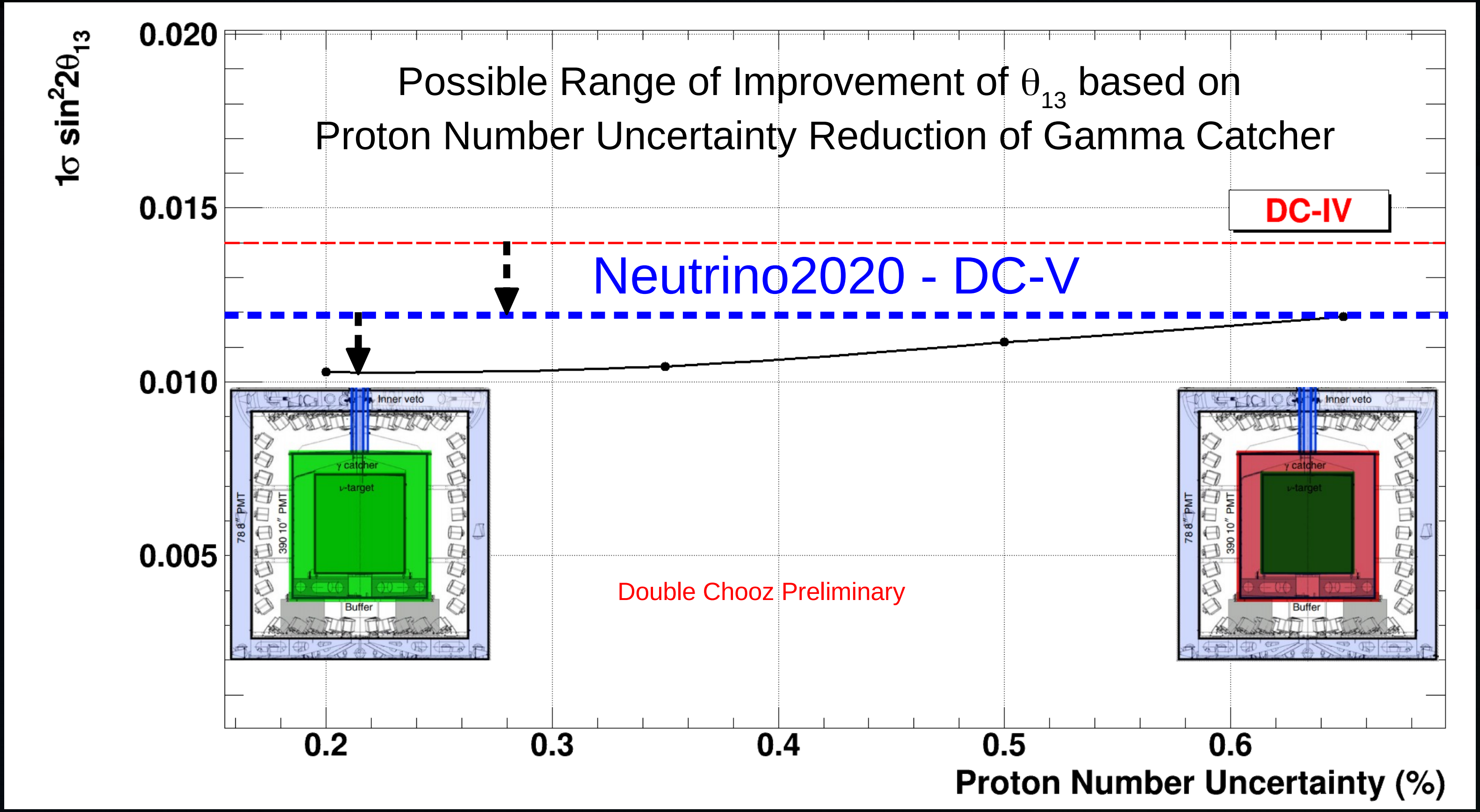
Herve de Kerret
(Spokesperson 2004 – 2017)

DOUBLE CHOOZ COLLABORATION

THANK YOU !

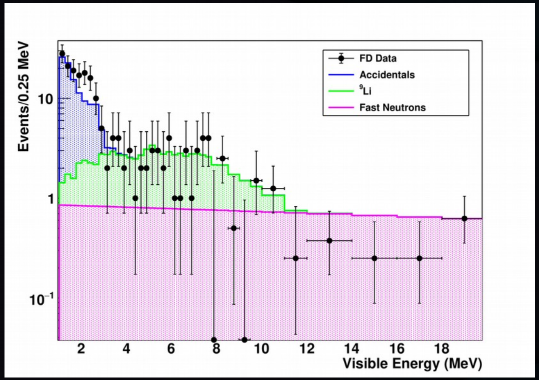
Backup Slides

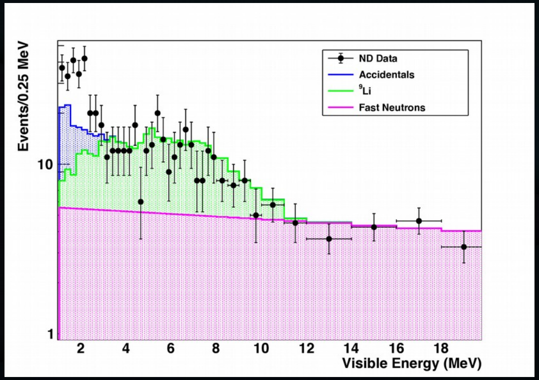
Prospects For Improvement



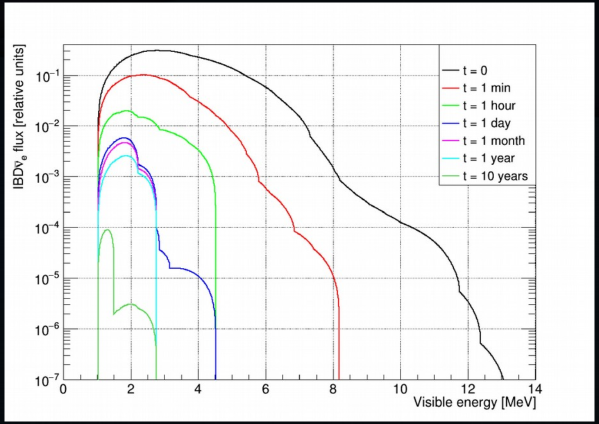
Reactor-off Data

- Validation of Background model





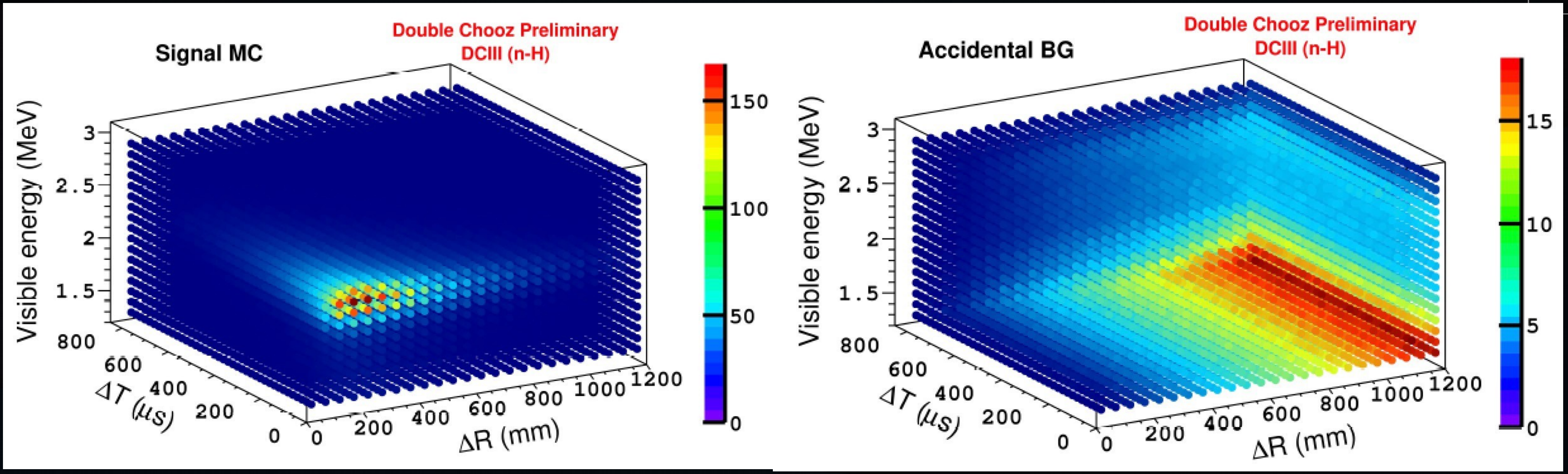
-> Data and Background model



-> Measurement of Residual Flux (Reactor Radiative Cooling)

Details @ Poster#390

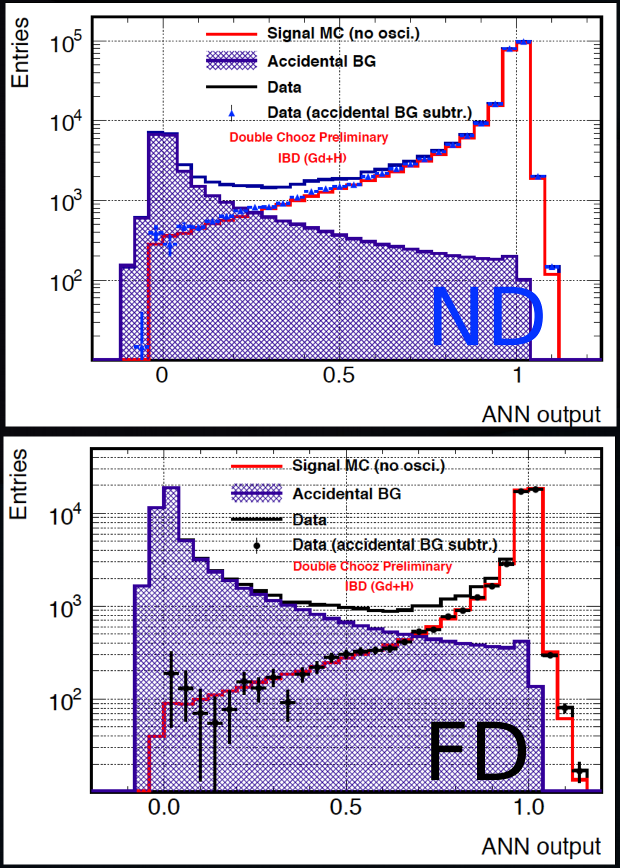
ANN Training for Acc. Rejection



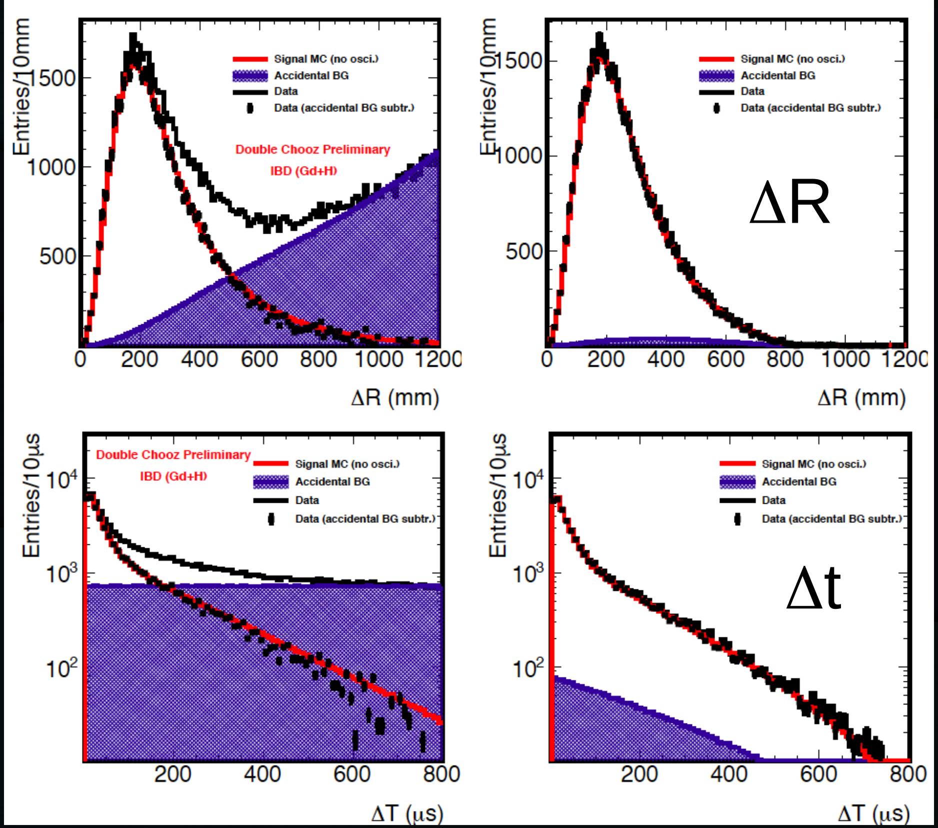
IBD (signal)
(correlated)

Accidental BG
(Random)
(i.e. longer Δt, ΔR)

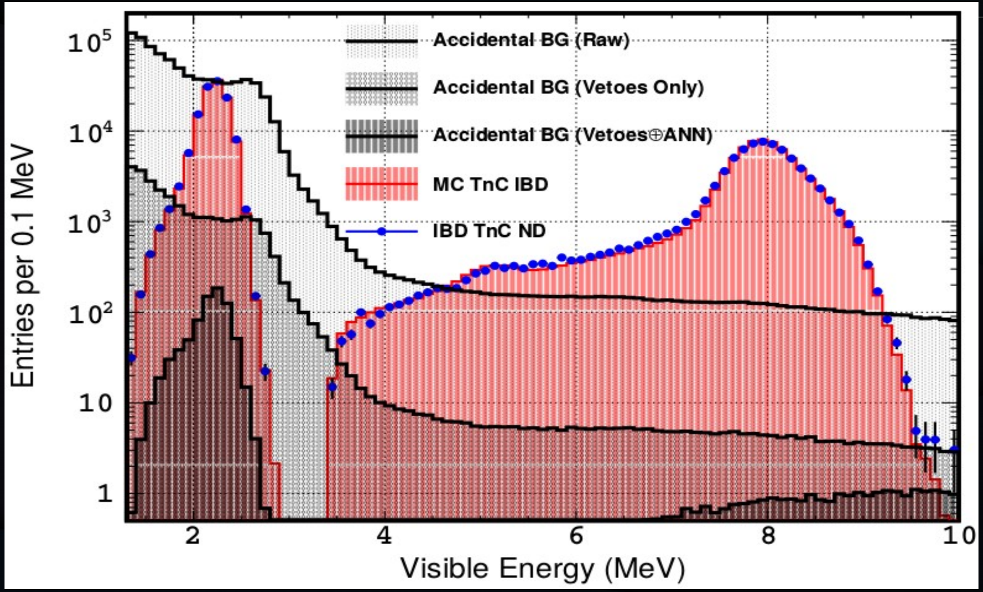
ANN Training for Acc. Rejection



Before **After**

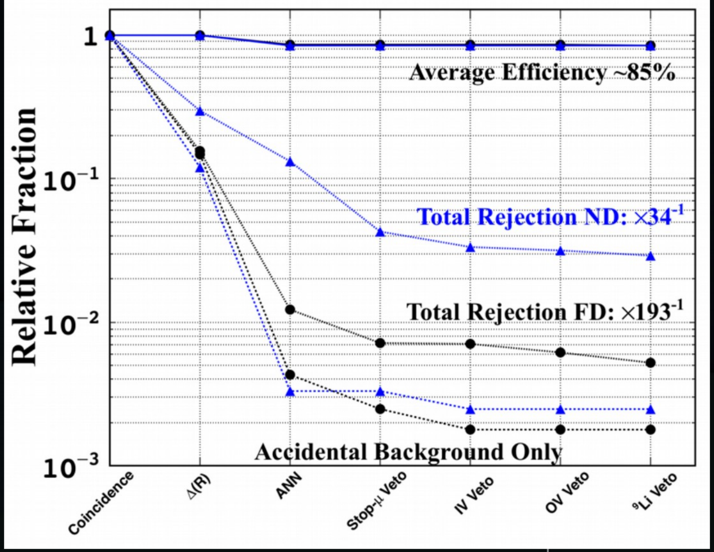


Background Rejection



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

Cumulative rejection per cut

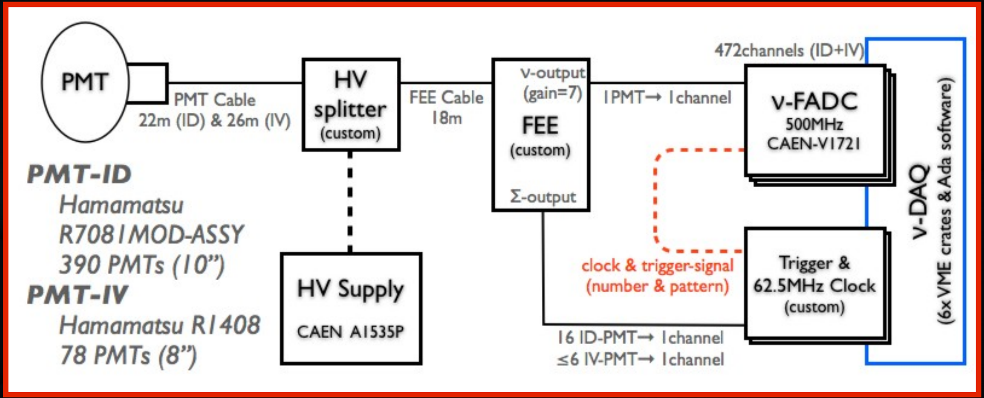


-> Good data/MC agreement for IBD candidates

-> Efficient background supression with cuts/vetoes

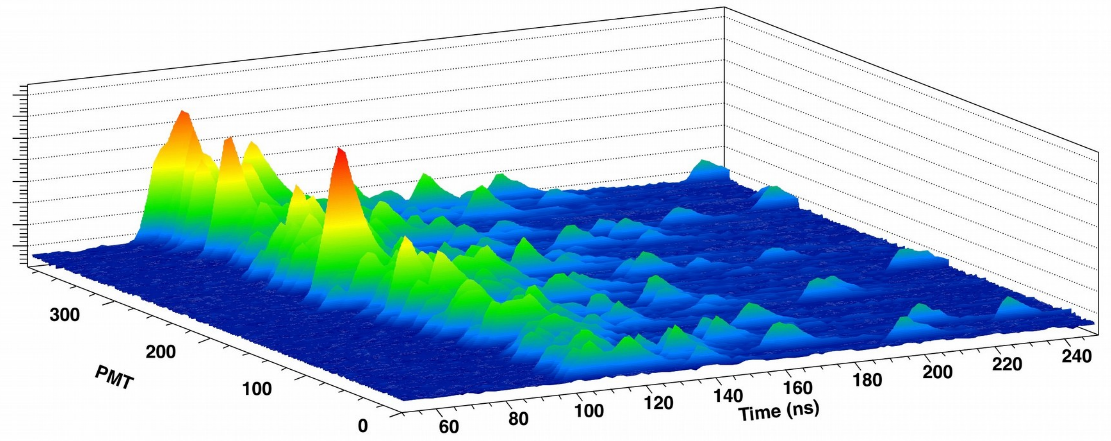
Readout Liquid Scint. Light

Liquid Scintillator
+
10” PMTs
+
analogue electronics
(clean & μ-handling)
+
500MHz FADC readout



Rich off-line reconstruction: energy & BG reduction

- time,charge
  - Control of linearity
- position (x,y,z,t)
  - Uniformity & BG vetoes
- multiplicity & inter-detector-layer correlation
  - BG vetoes



Near Detector Construction

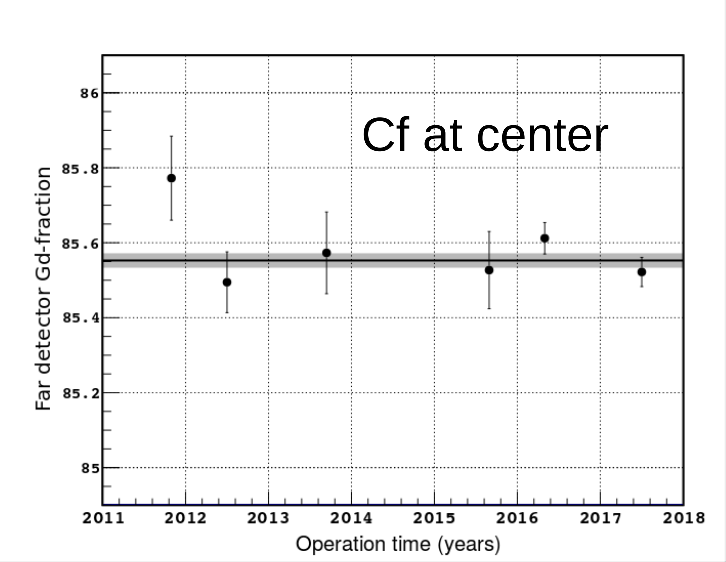
- 2011 : Tunnel and Cave Digging
- 2012 : Detector pit and lab construction
- 2013 : Water shield, Inner Veto, Buffer, wall and bottom PMTs
- 2014 : Acrylics, lids, filling, commissioning, Outter Veto
- 2015 : Official data-taking started (January)

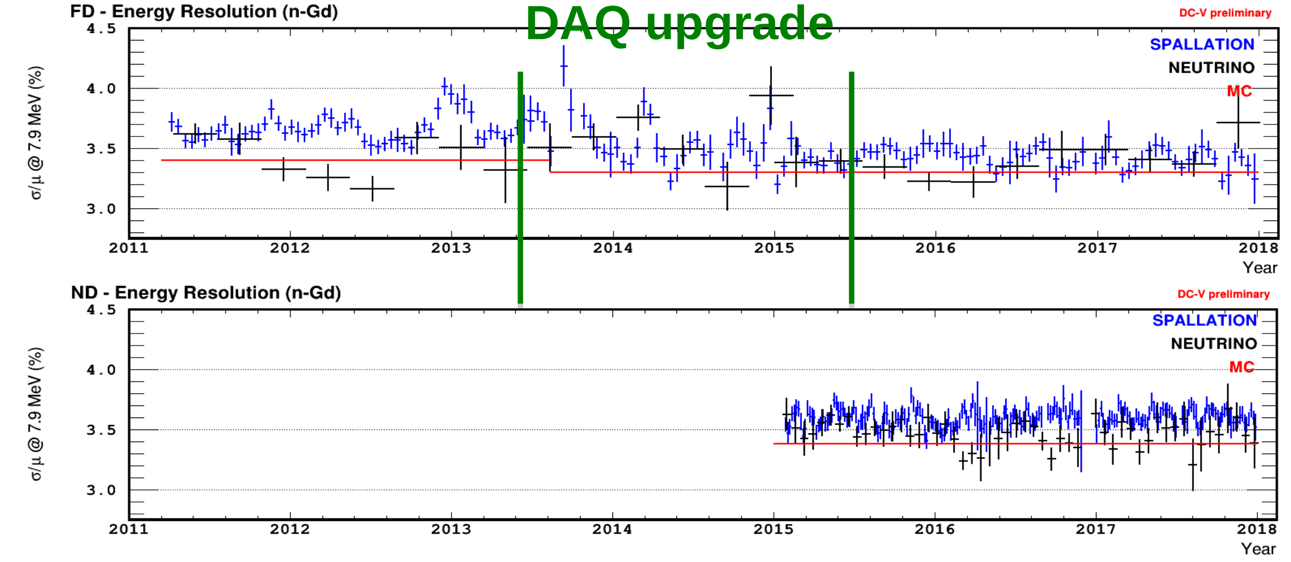
Construction Short Documentary
Click here to watch!
https://youtu.be/gXoKoVzIO74

Scintillator Stability

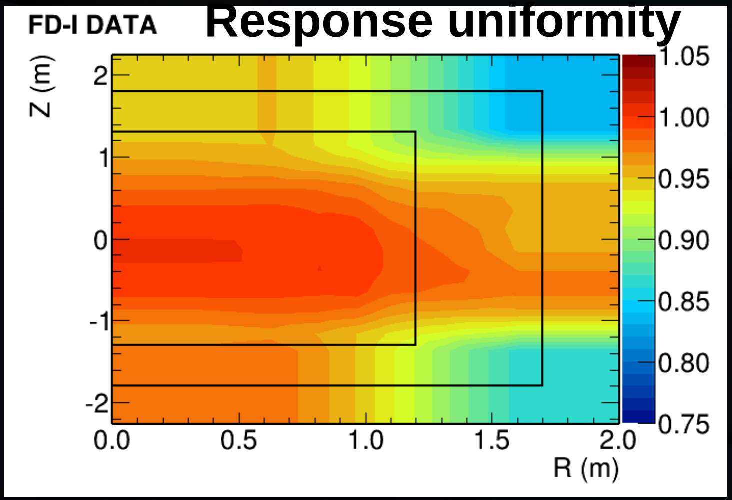
- Optical and chemical stability of Gd loaded scintillator (7 years)

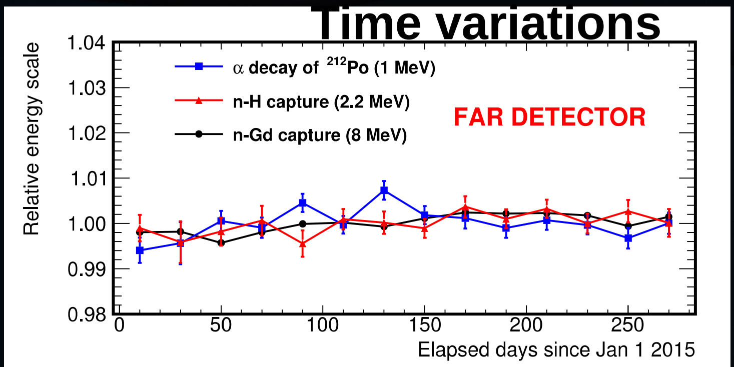
- Gd fraction (center) stable on < 0.1% level

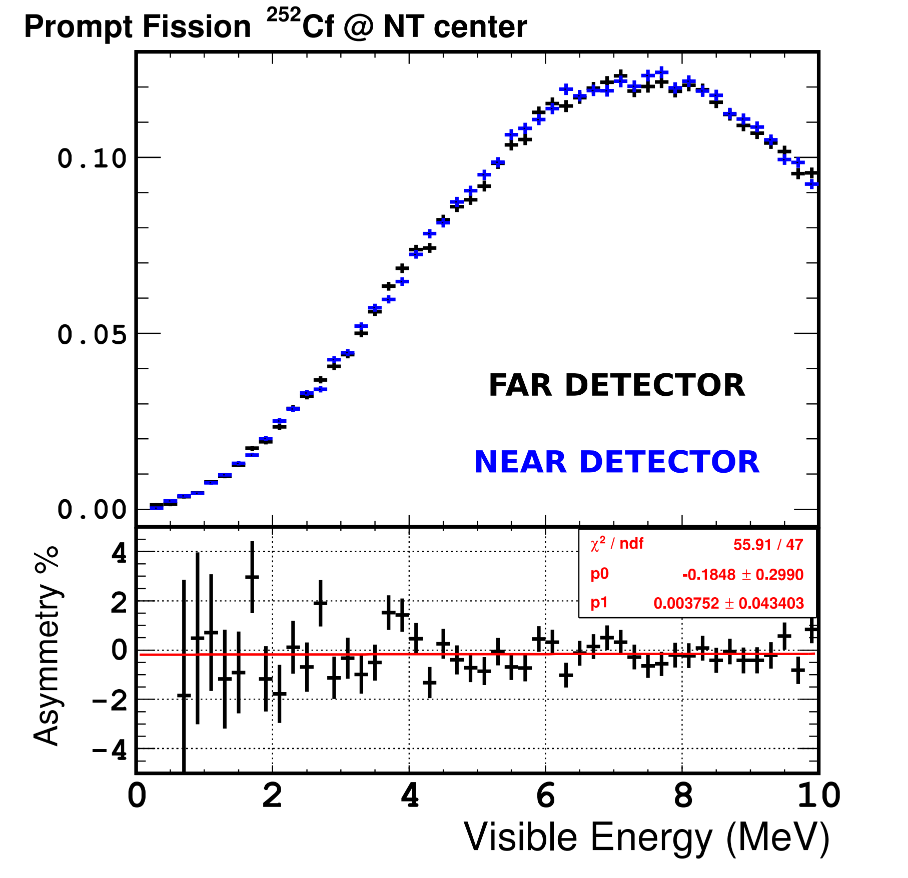




Energy Reconstruction





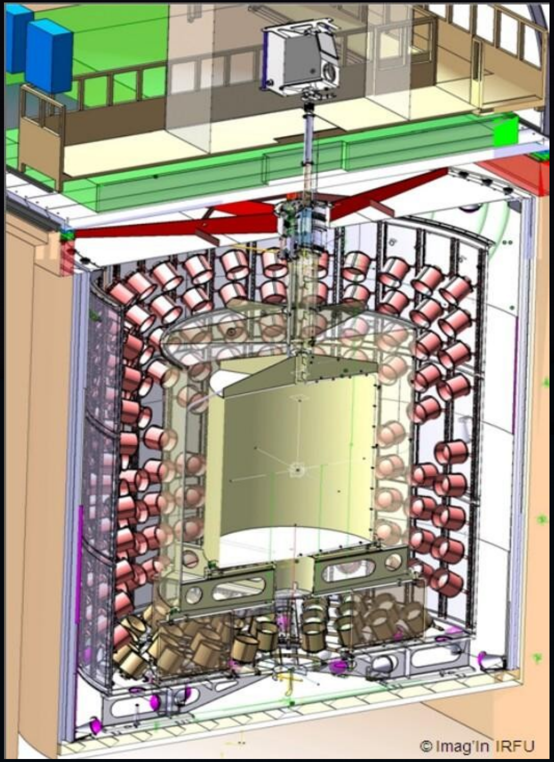


Very Good Near – Far Agreement

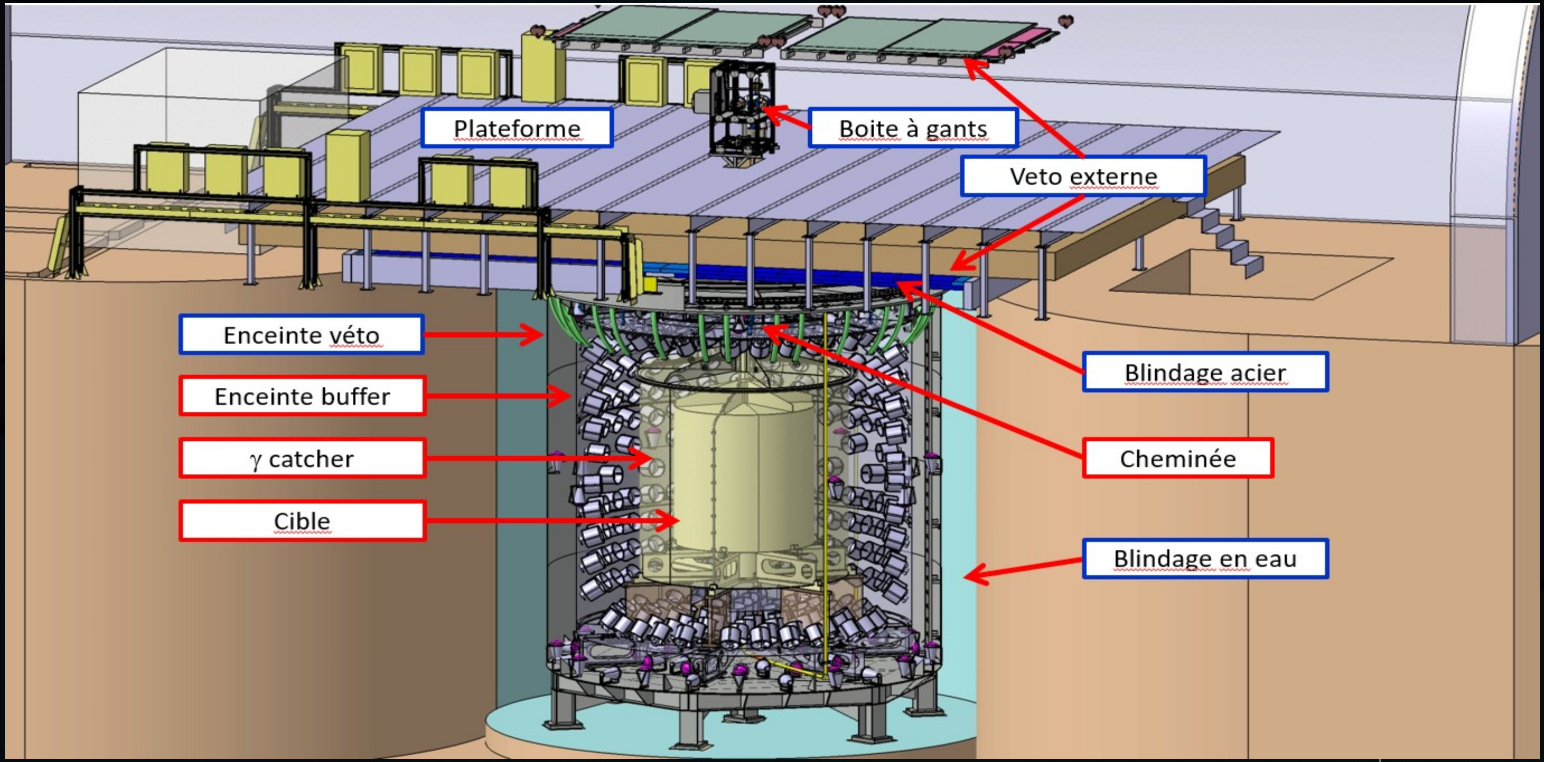
No Near-to-Far slope!
$\sigma = 0.04$

Detectors Components

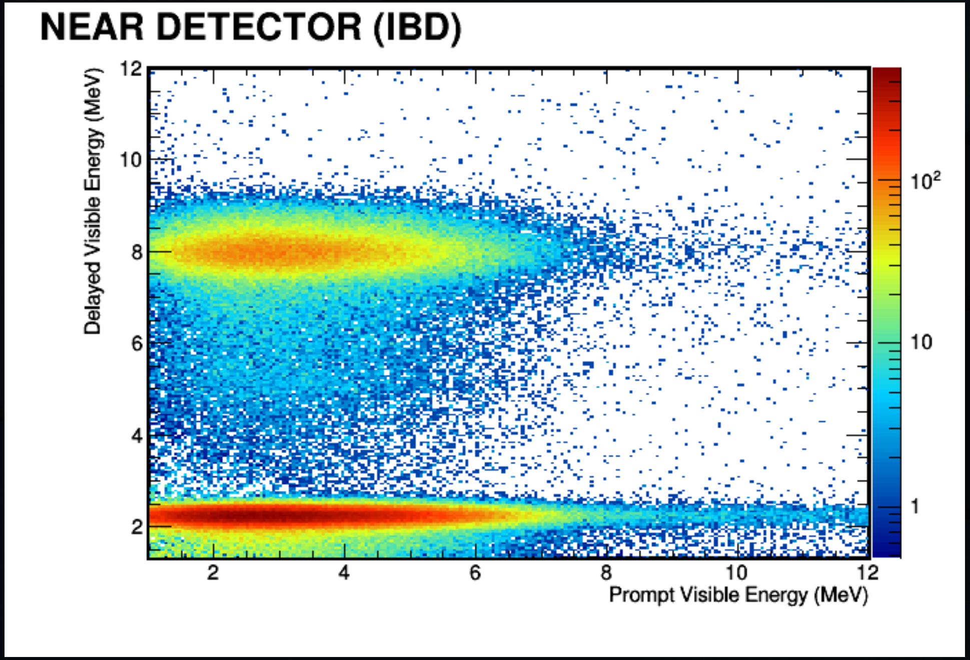
Far



Near



The Largest Single θ_{13} Target



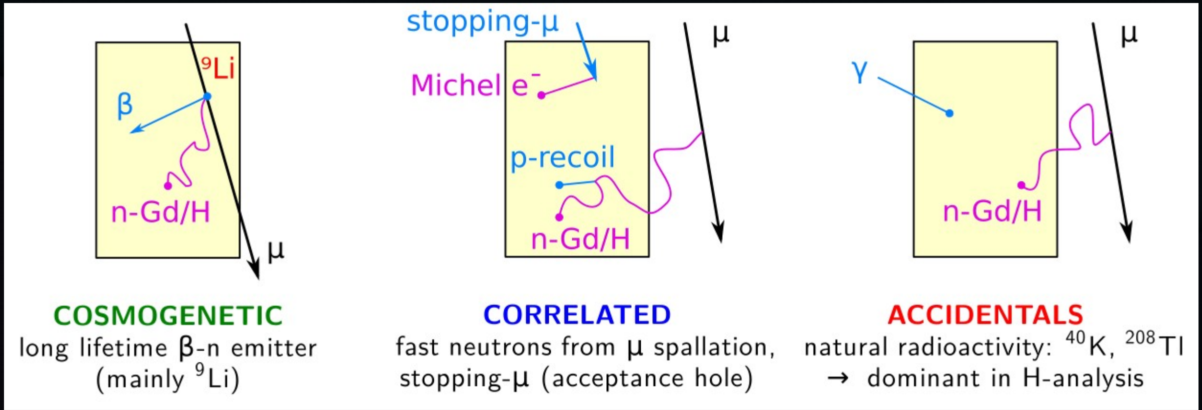
IBD (Gd)

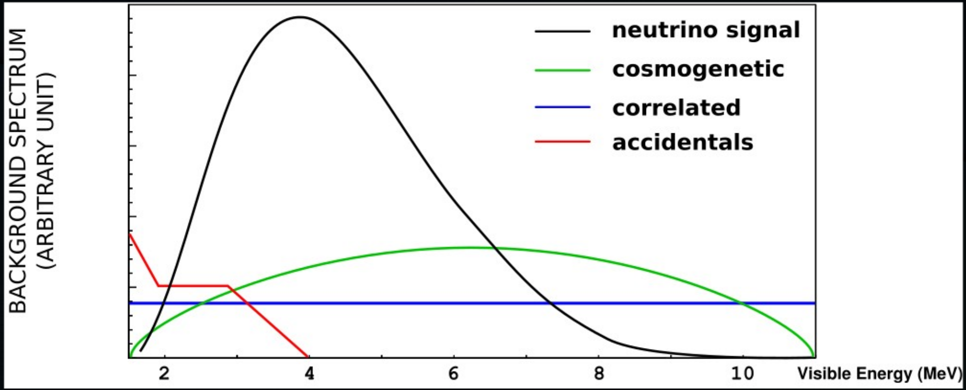
Target: ~8t (smallest θ_{13} target)

IBD (Gd+H+C)

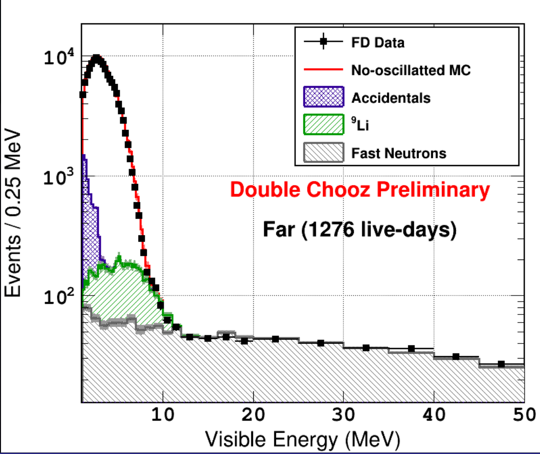
Target: ~27t (largest θ_{13} single detector target)

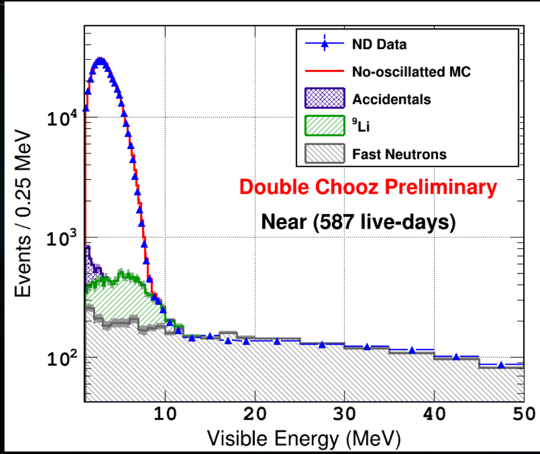
Background Mechanisms





Signal & Backgrounds





[1, 50] MeV	Ev./day FD	Ev./day ND
IBD candidates	112	765
^{9}Li	2.74 ± 0.22	12.97 ± 0.97
Fast n	5.85 ± 0.08	45.49 ± 0.36
Accidental	4.36 ± 0.01	3.07 ± 0.01

Spectrum ~~Bump~~ Distortion

Shape **and** Rate inspection of the Reactor Spectrum