Reactor Neutrinos Overview

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4th Conference on Science at the Sanford Underground Research Facility

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UNIVERSITY OF SUSSEX

Contents

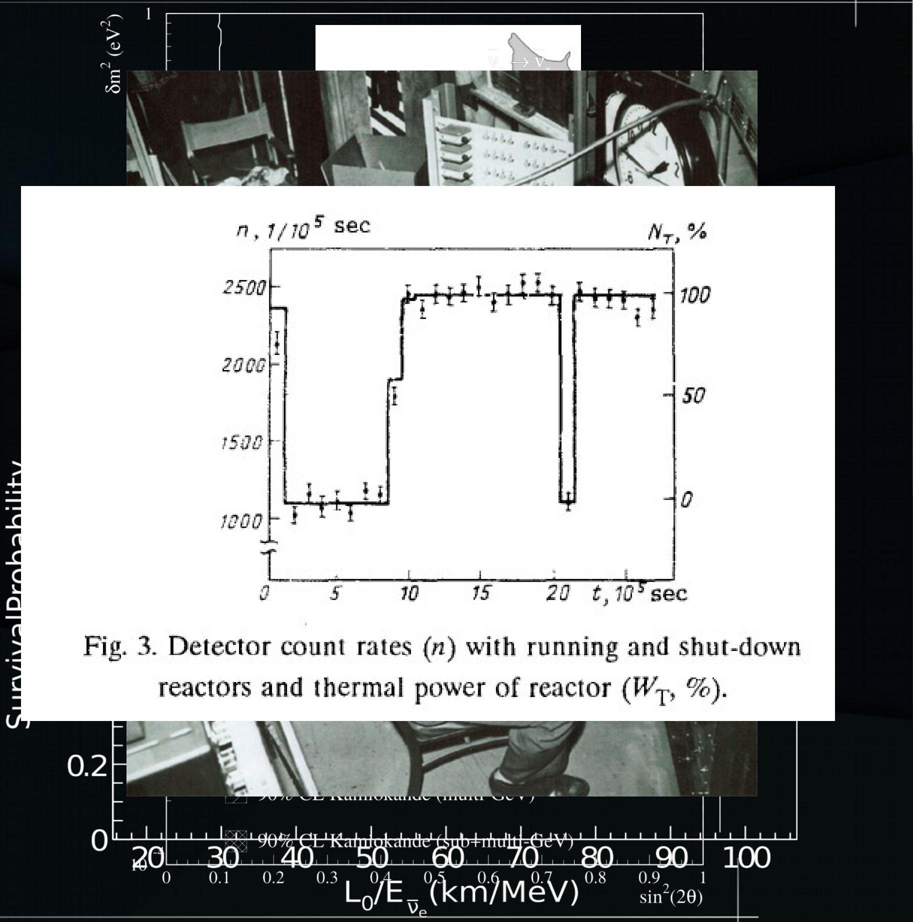
- Quick overview of the past

- Reactor neutrinos and 3 flavour oscillations status (IBD)
  - Other rich physics available: Sterile, CEνNS, E.S.

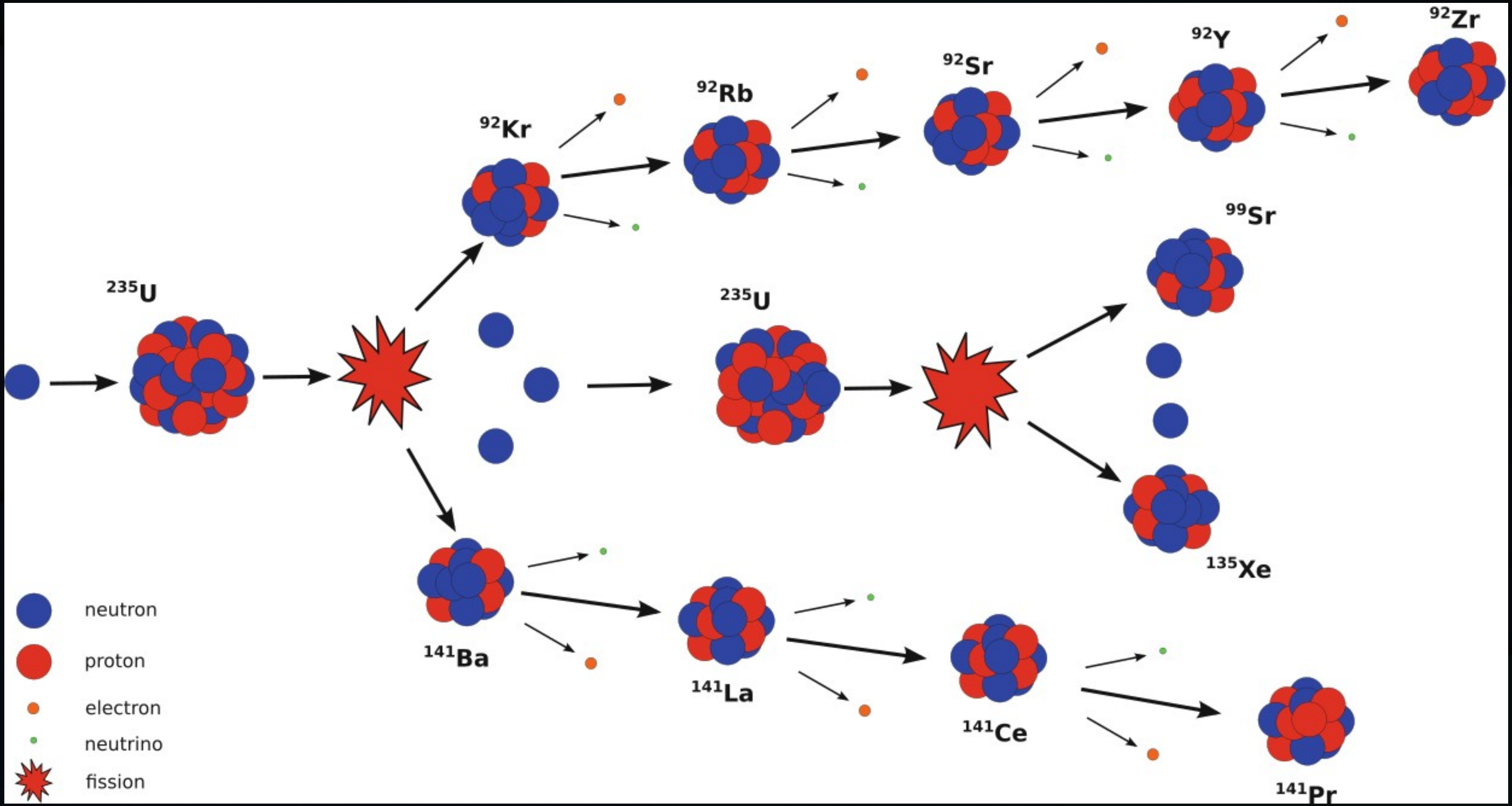
- Future: Positron tagging

Quick overview from the past

- 50's: ν discovery
- 80's: Reactor monitoring
- 90's: ν oscillations searches
  - Bugey4: Flux measurement (1.4%)
  - CHOOZ: Upper limit on θ_{13}
- 2000's: Settling ν oscillations
  - KamLAND (Δm^2_{21})



Nucl. reactors: “free” and copious ν source

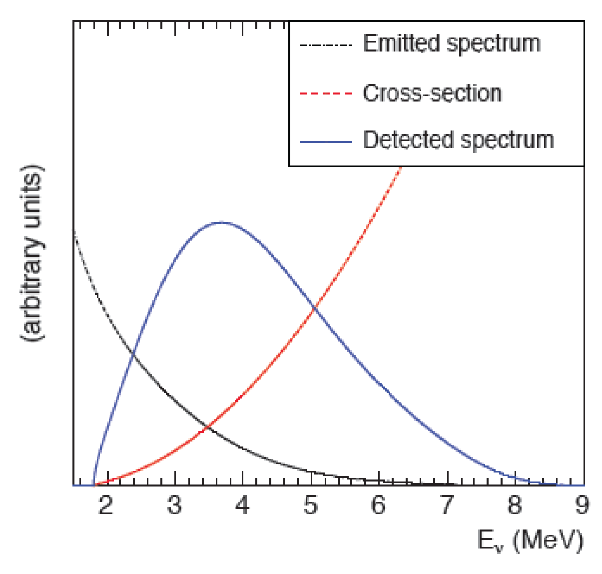


Commercial fission reactor produces ~10^{20} ν/sec

Reactor-ν detection via IBD

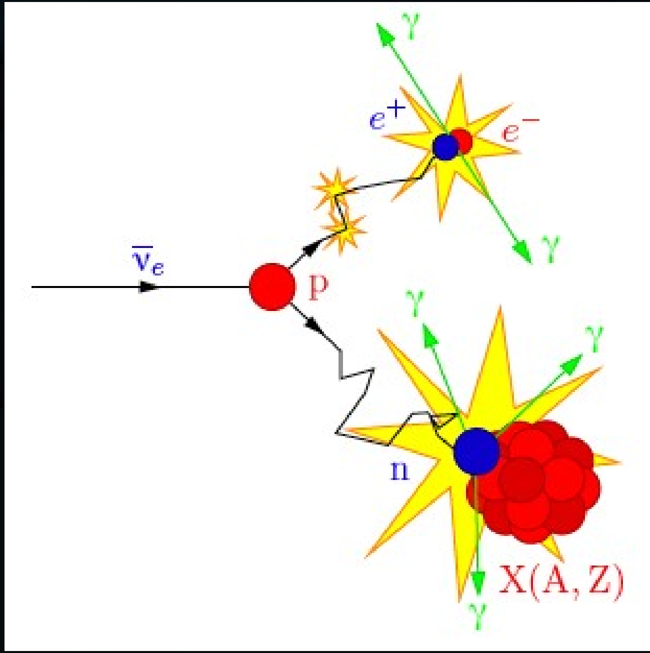
$$N_{\nu}^{\exp}(t) = \frac{\varepsilon N_p}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f \rangle} \times \langle \sigma_f \rangle$$

Mean cross section per fission



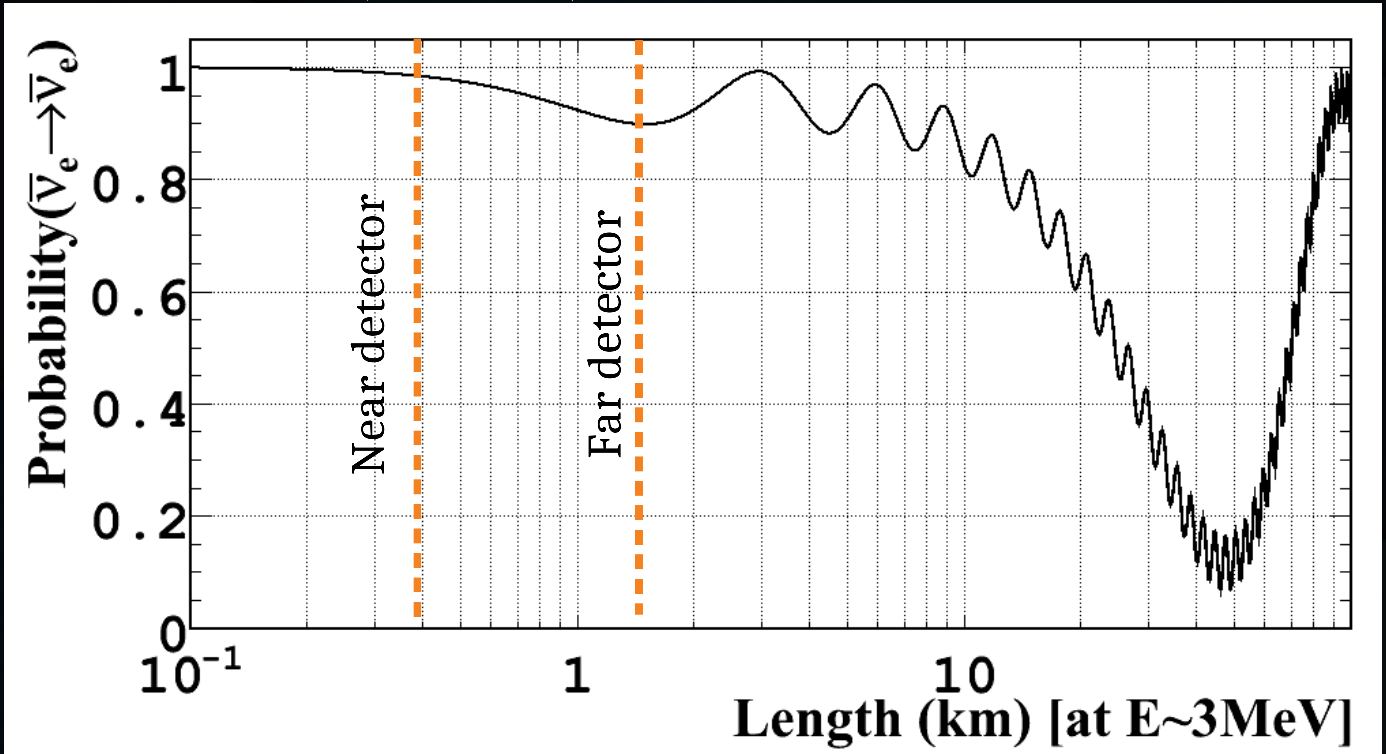
Inverse **B**eta **D**ecay

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

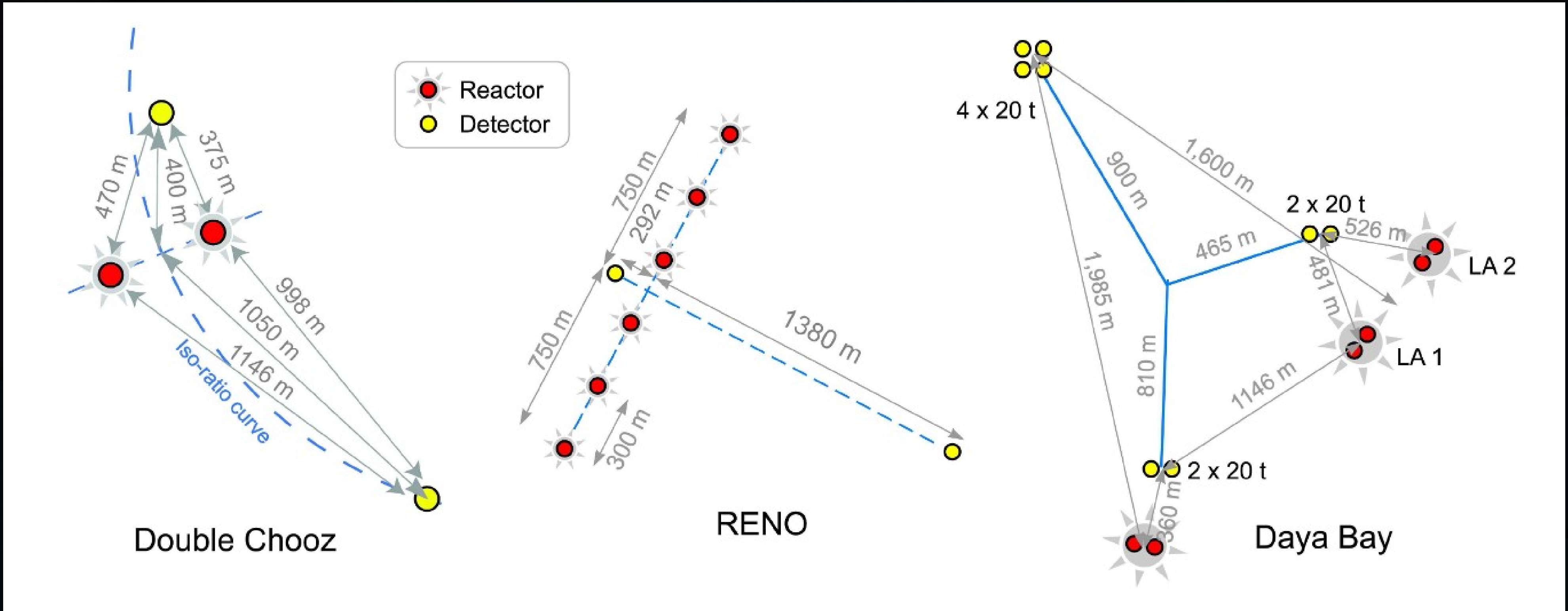


θ_{13} measurement with reactor ν's

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{ee} L}{4E}\right)$$



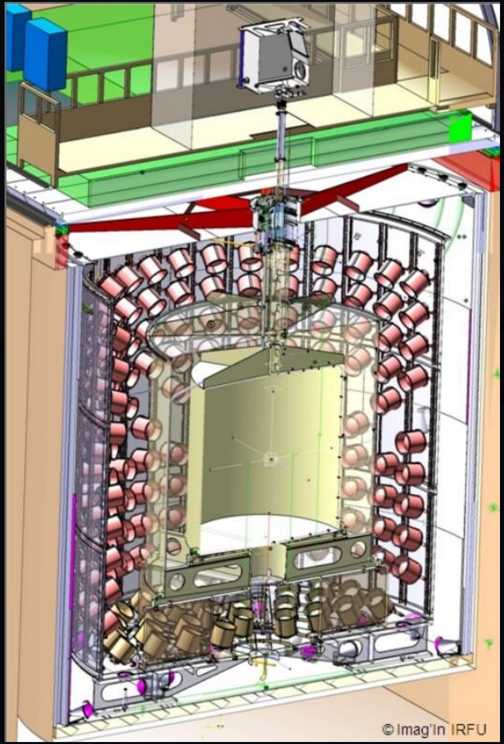
Reactor-θ_{13} experiments (2010 – present)



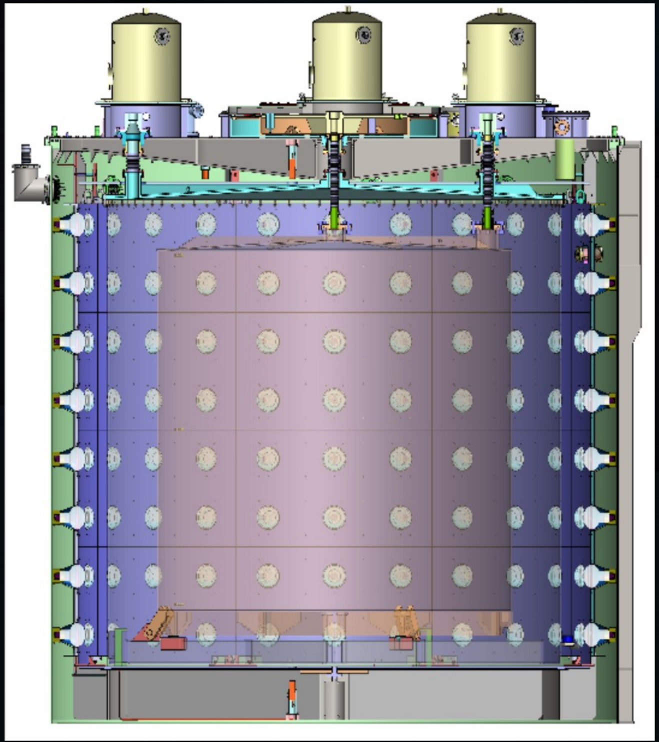
J.Phys.G37:103001,2010 (fig)

Reactor-θ_{13} detectors

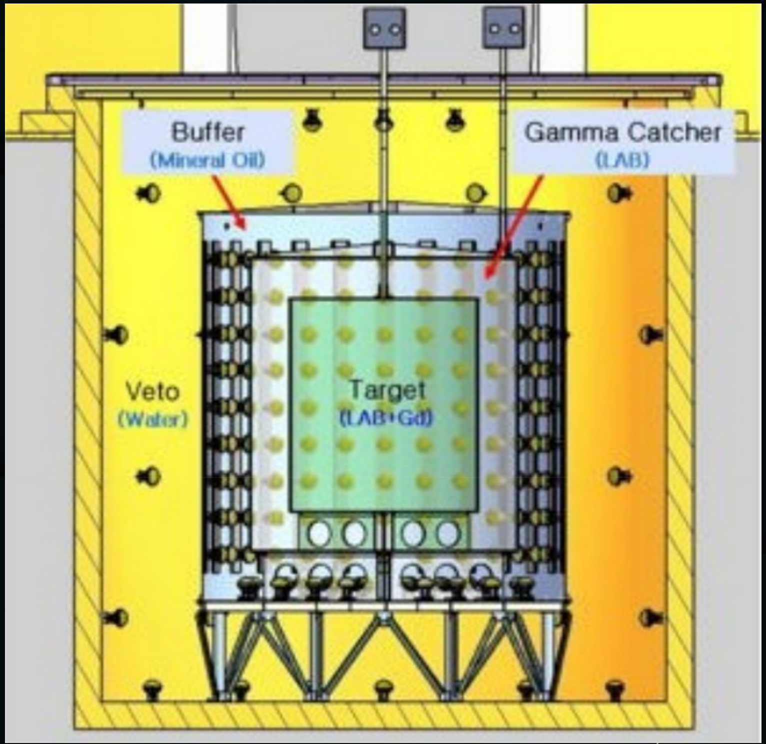
DC



DYB

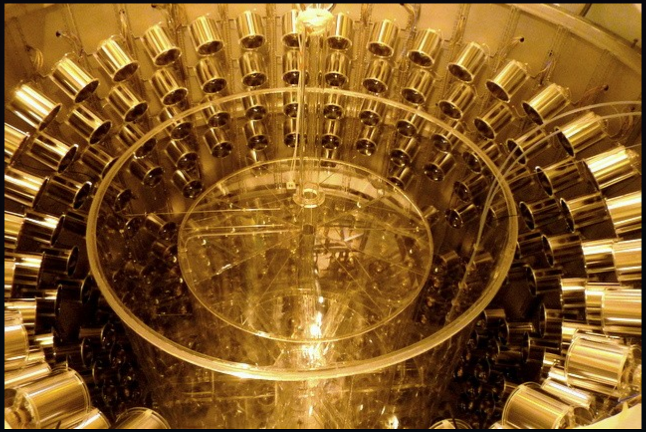


RENO



Reactor-θ_{13} detectors

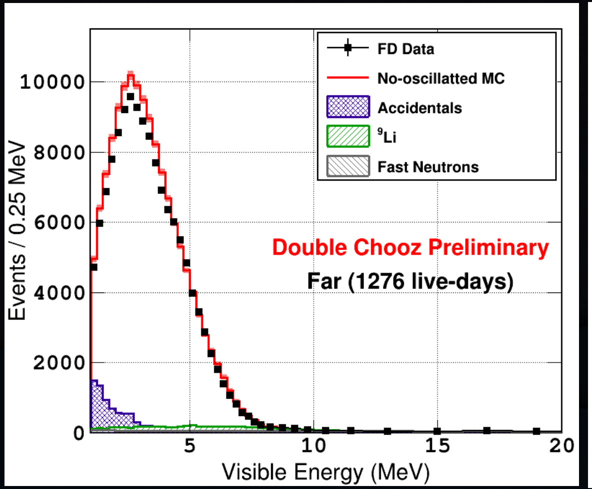
DC

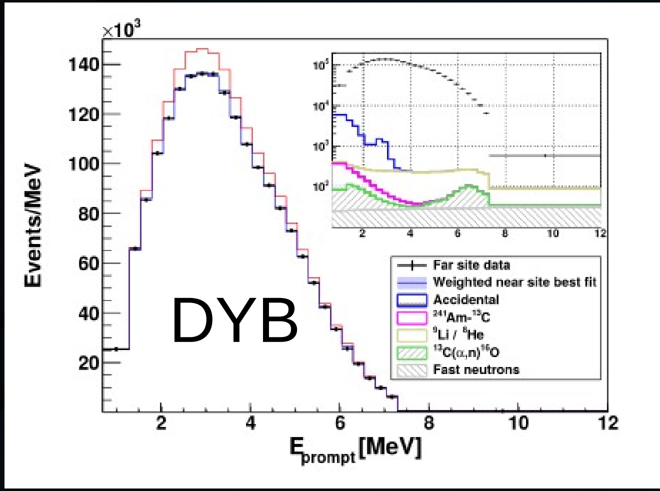


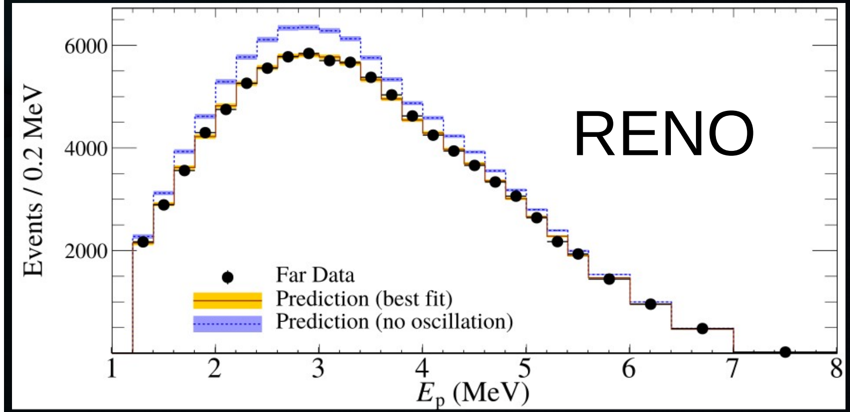
RENO

DYB

Reactor-θ_{13} spectra

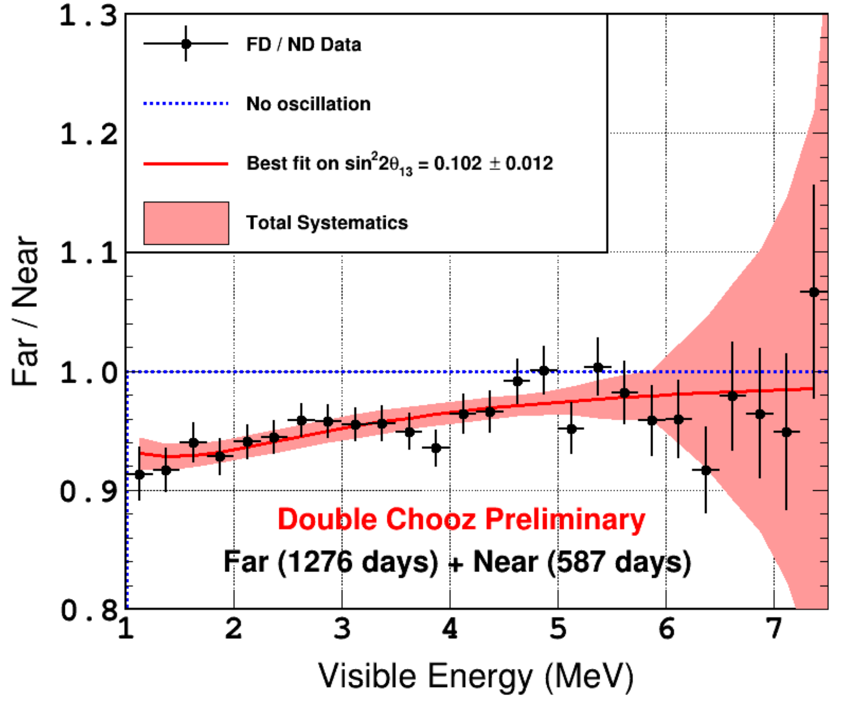




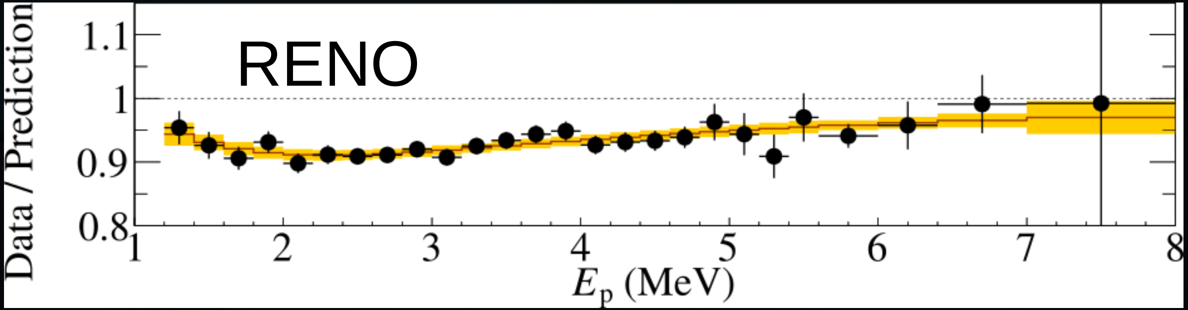


Reactor-θ_{13} far/near ratios

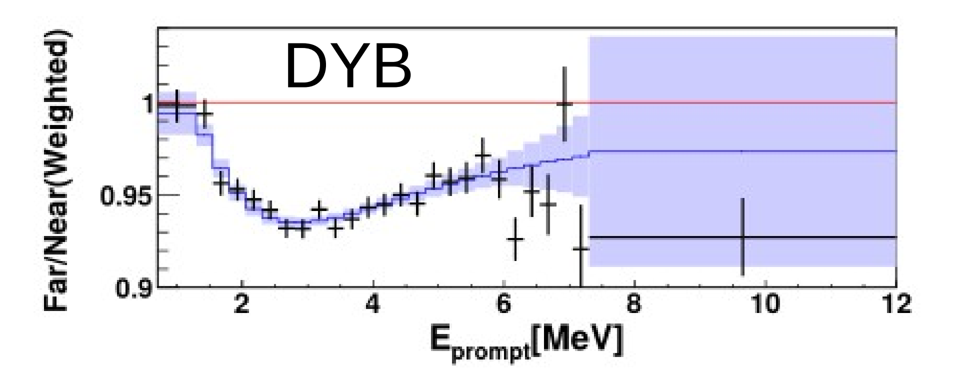
~1.0 km



~1.4 km

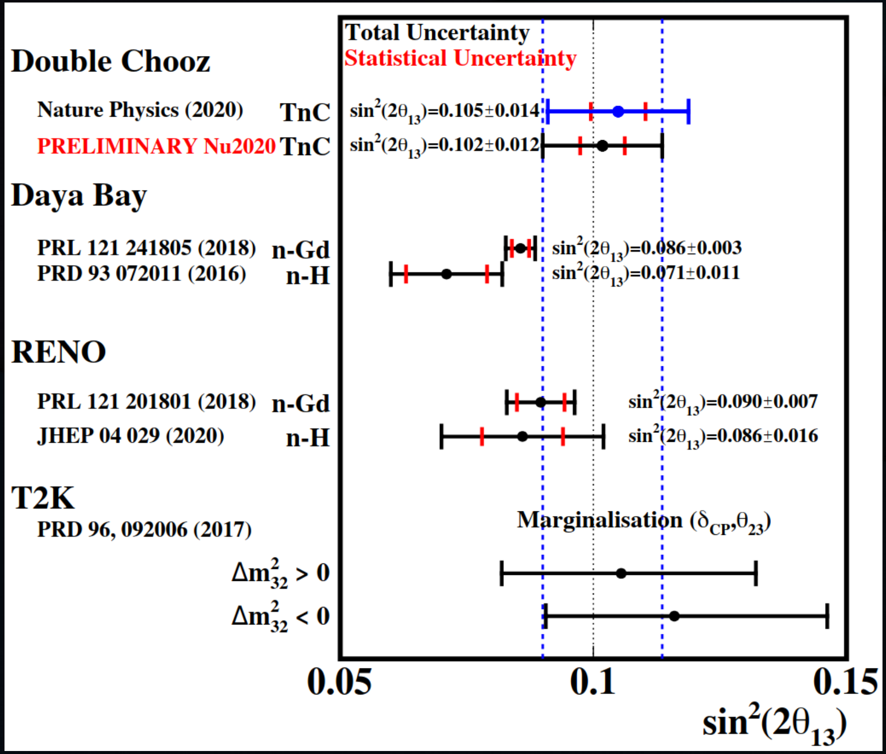


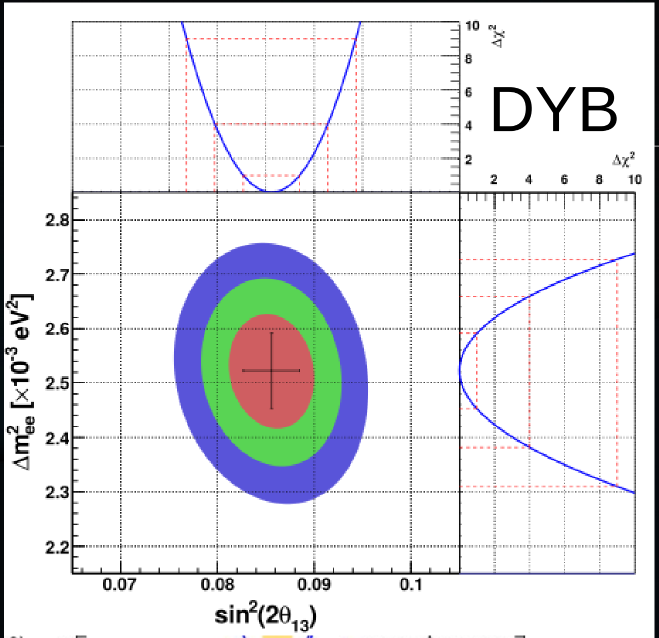
~1.7 km

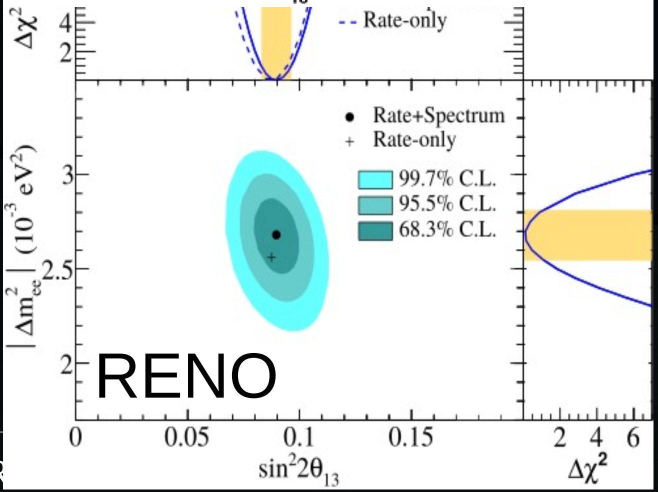


Reactor-θ_{13} summary

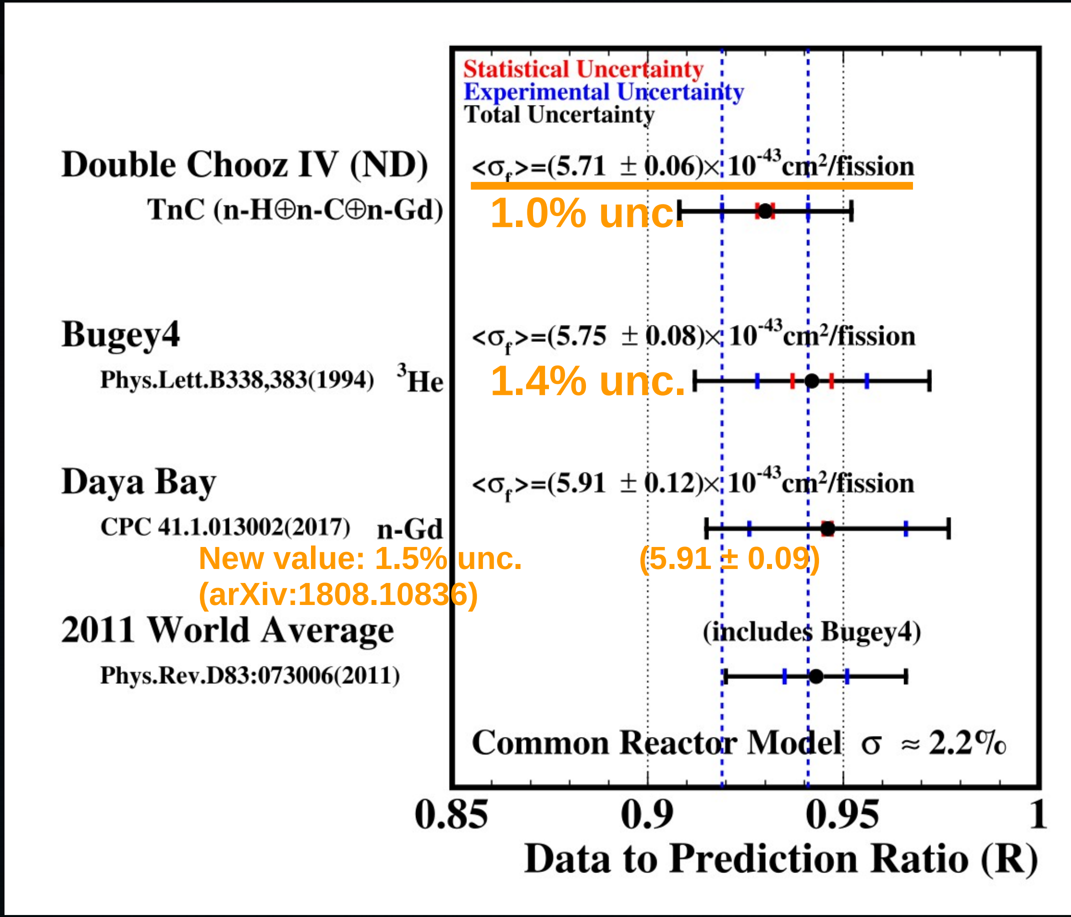
$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{ee} L}{4E}\right)$$





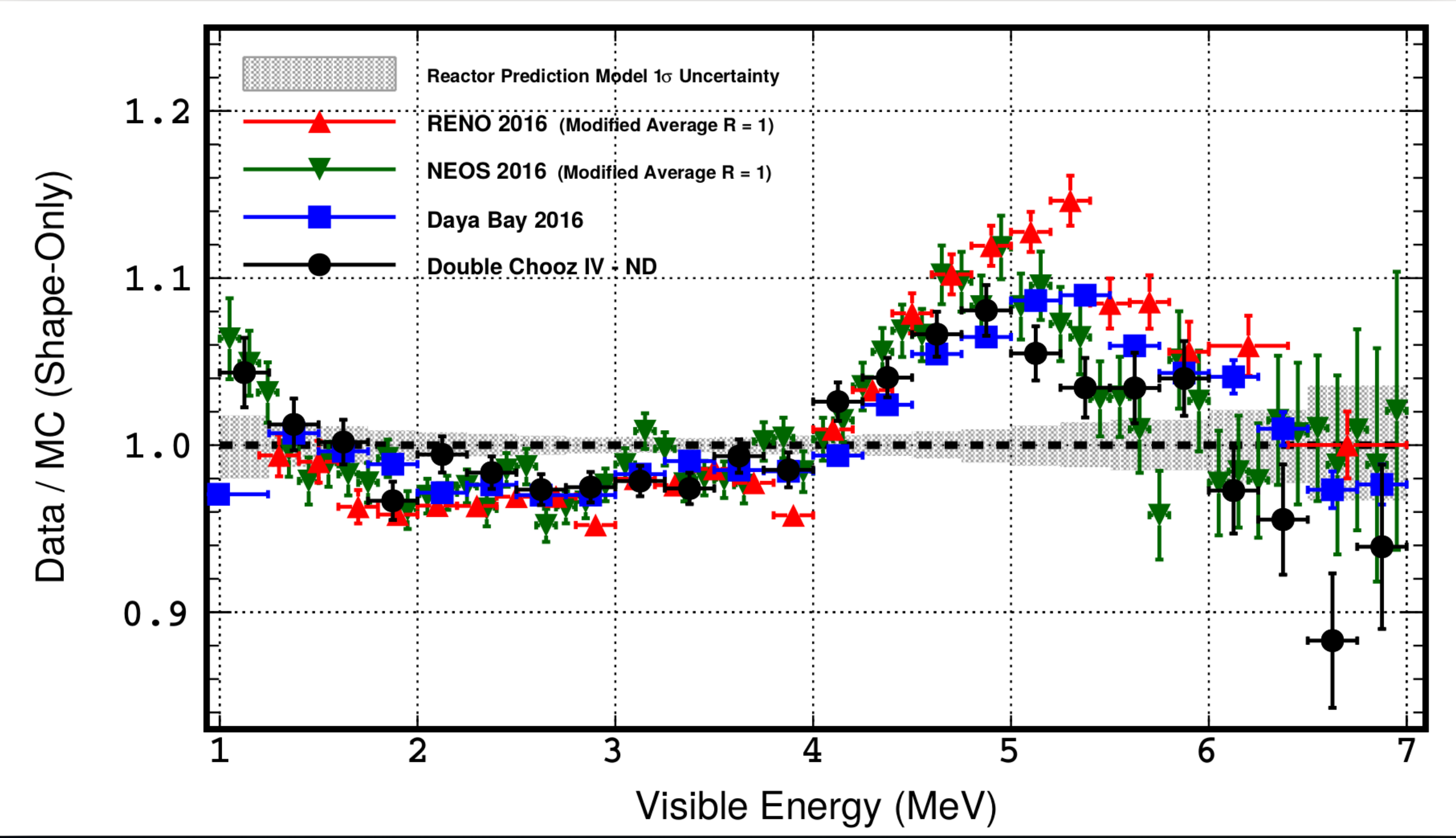


Reactor-θ_{13} : flux normalization



Many experiments exploring this effect (VSBL)

Reactor-θ_{13} : spectral shape distortion



Nature Physics, volume 16, pages 558–564 (2020)

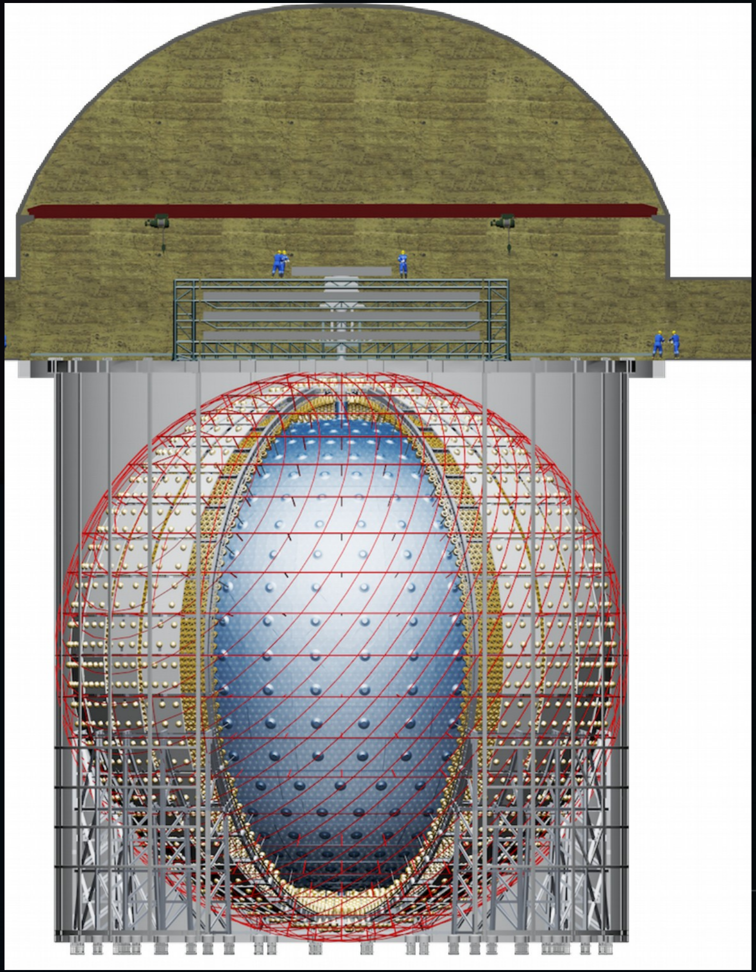
C.Giunti *et al.*, Flux prediction review: arXiv:2110.06820

Reactor IBD Future

JUNO

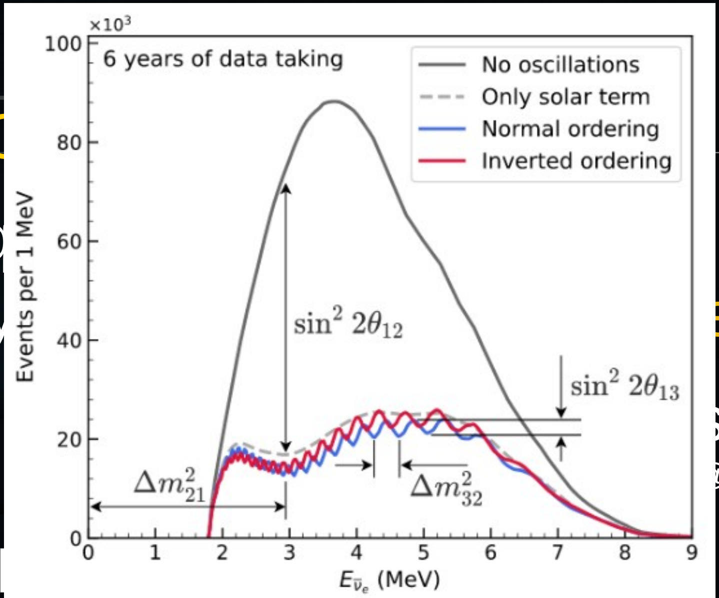
JUNO

The Jiangmen Underground Neutrino O



-> Huge liq

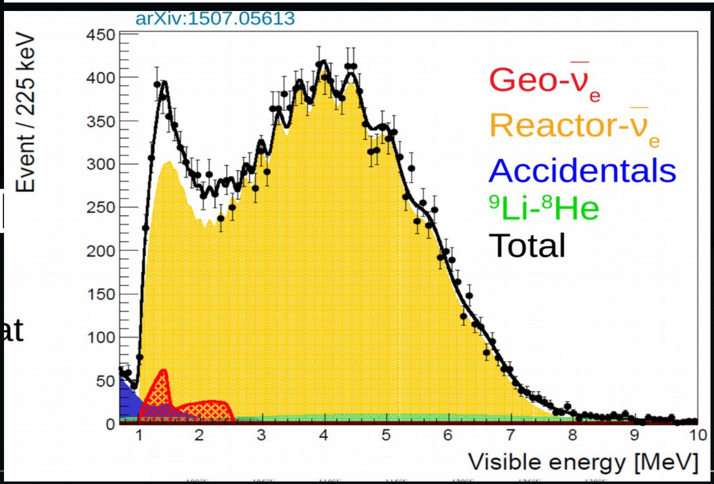
-> Two key



ecise

solution

@ 1 MeV)

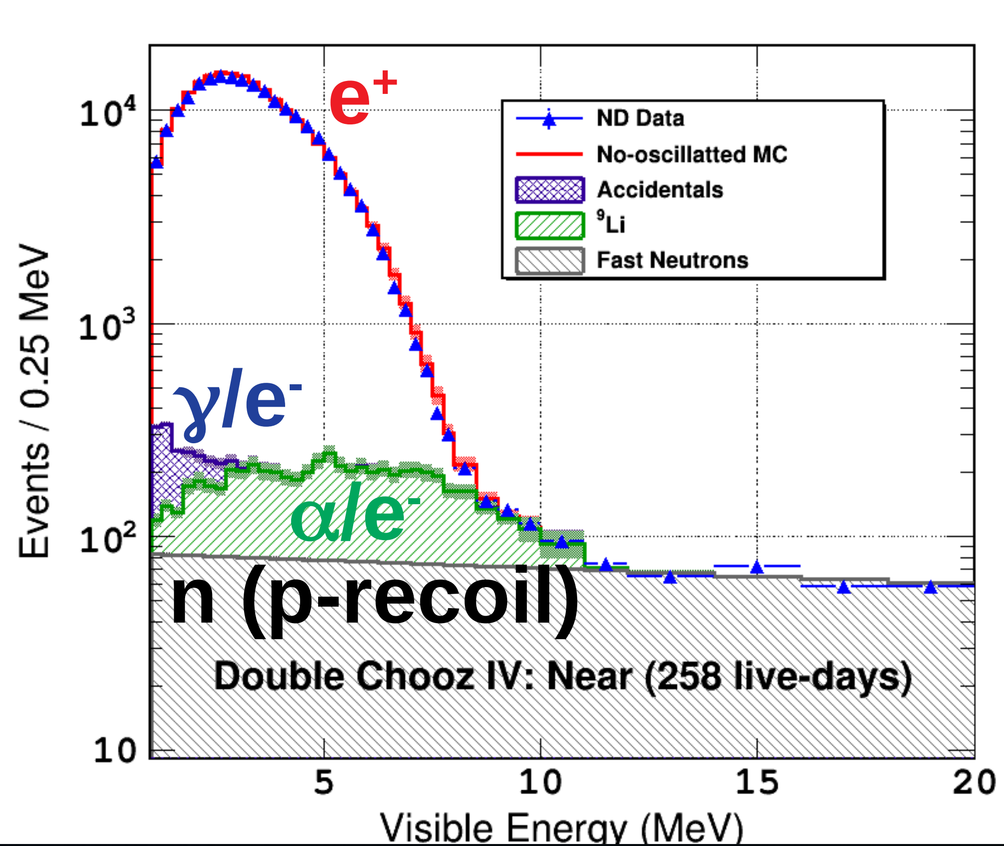


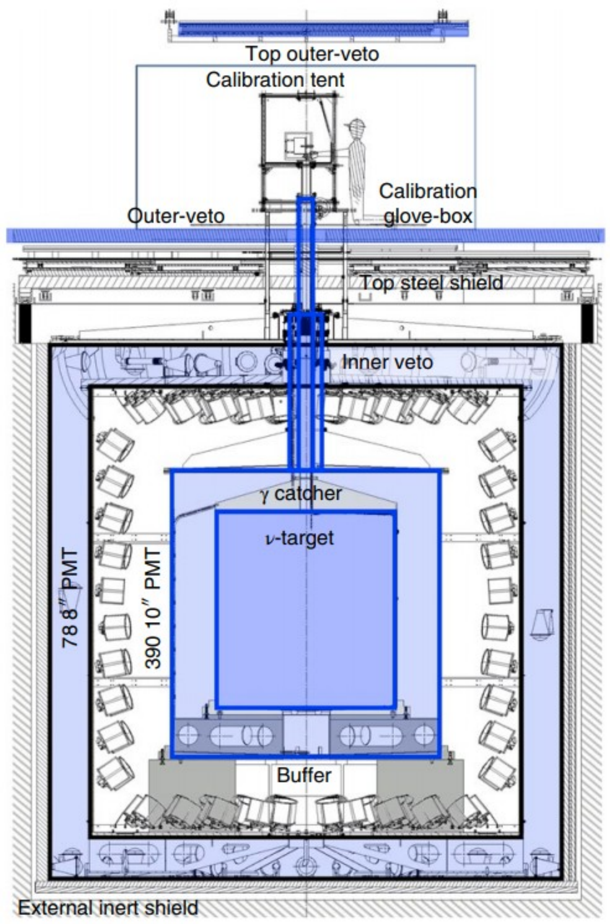
DC/DYB/I	8%
Borexino	5%
KamLANI	6%
JUNO at	3%

Reactor IBD Future (beyond JUNO)

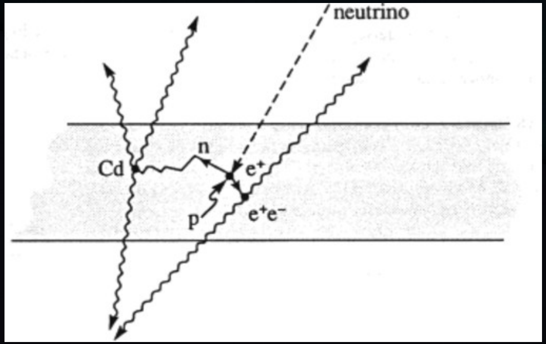
Positron Tagging

Expensive way to remove backgrounds

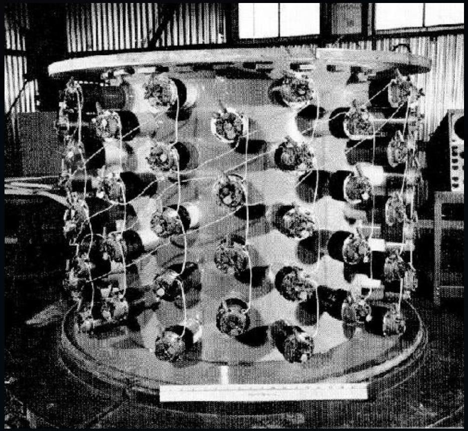


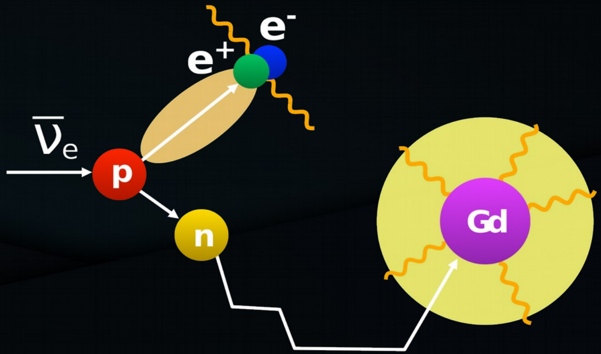


60 years old strategy!

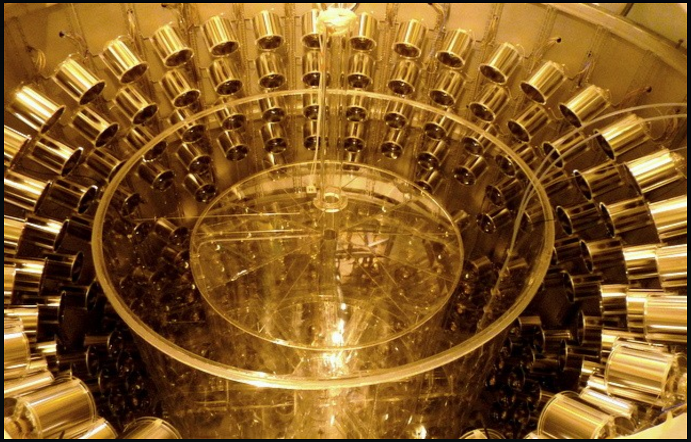


1950's



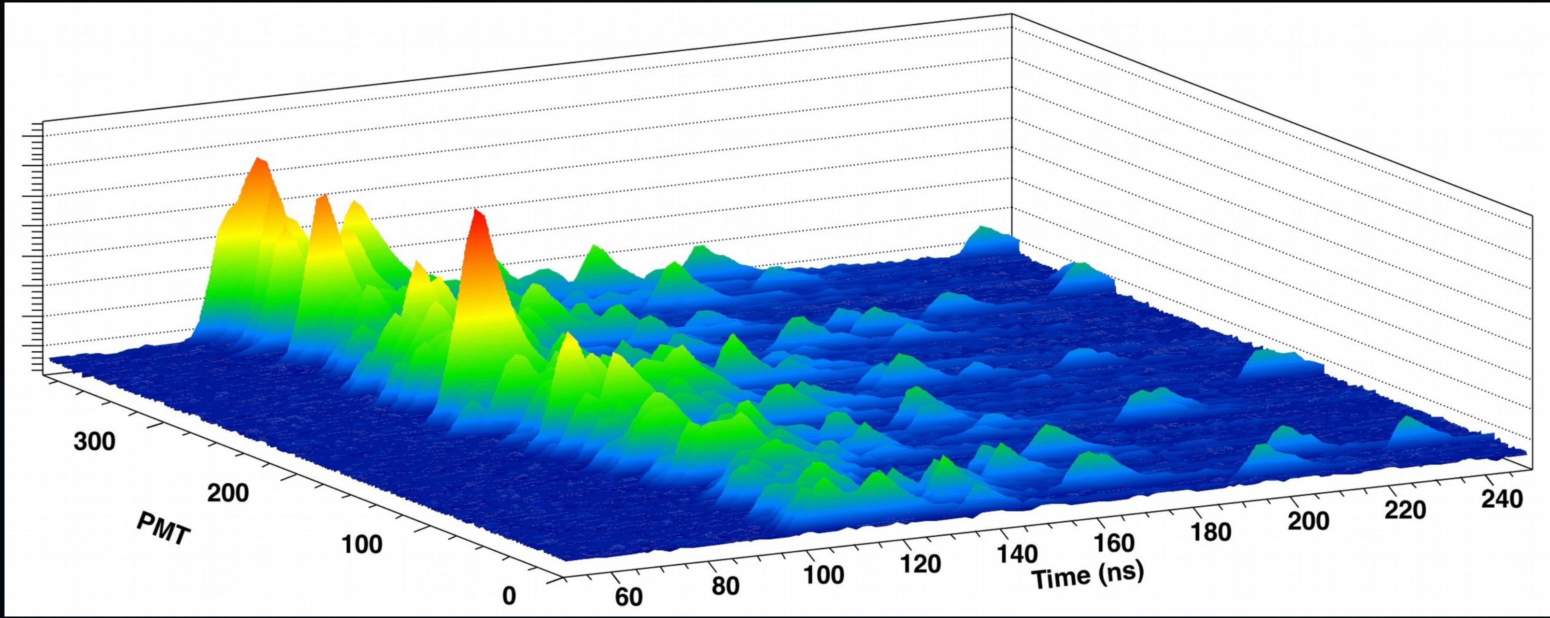


2010's

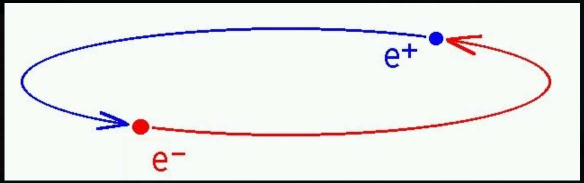


Efforts on e^+ identification

Double Chooz case: FADC, a powerful tool

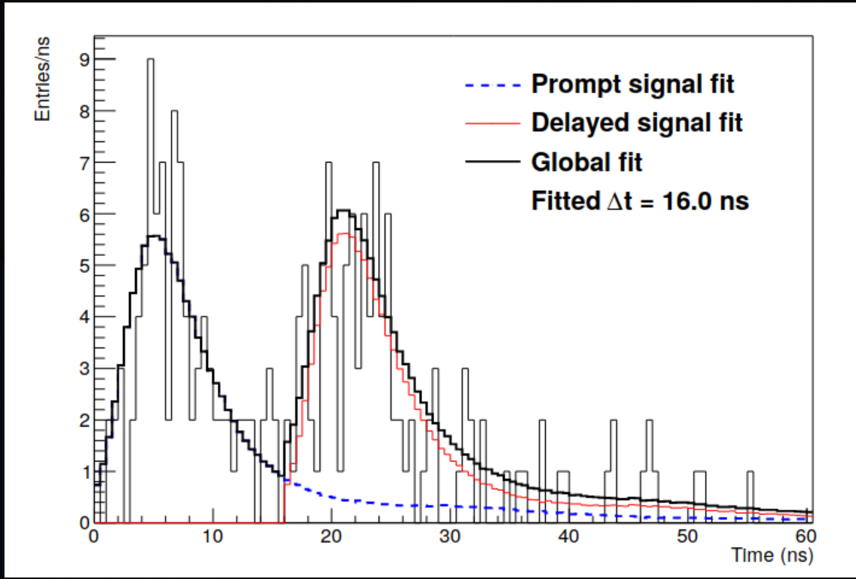


Efforts on e^+ identification



ε < 50%

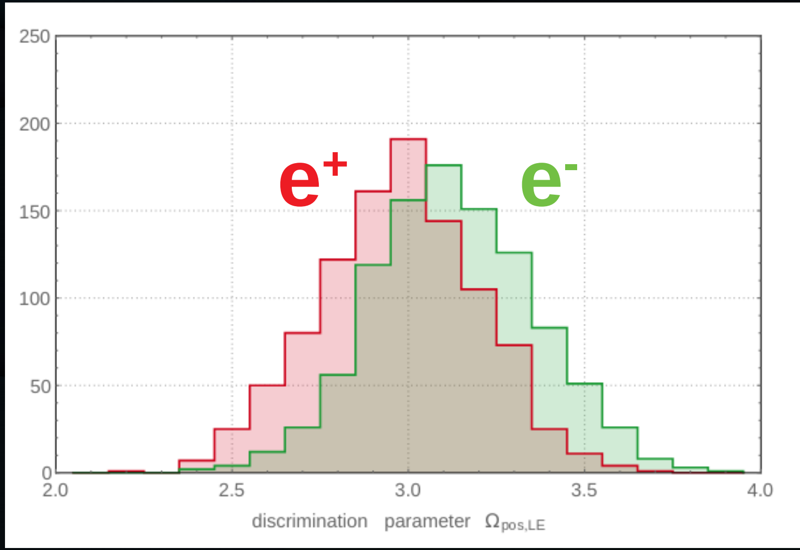
Ortho-positronium observation



JHEP 1410 (2014) 032

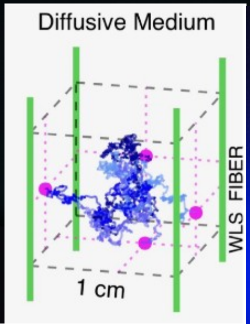
Pulse shape discrimination

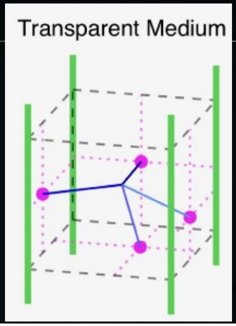
Fourier power spectra of scintillator pulses

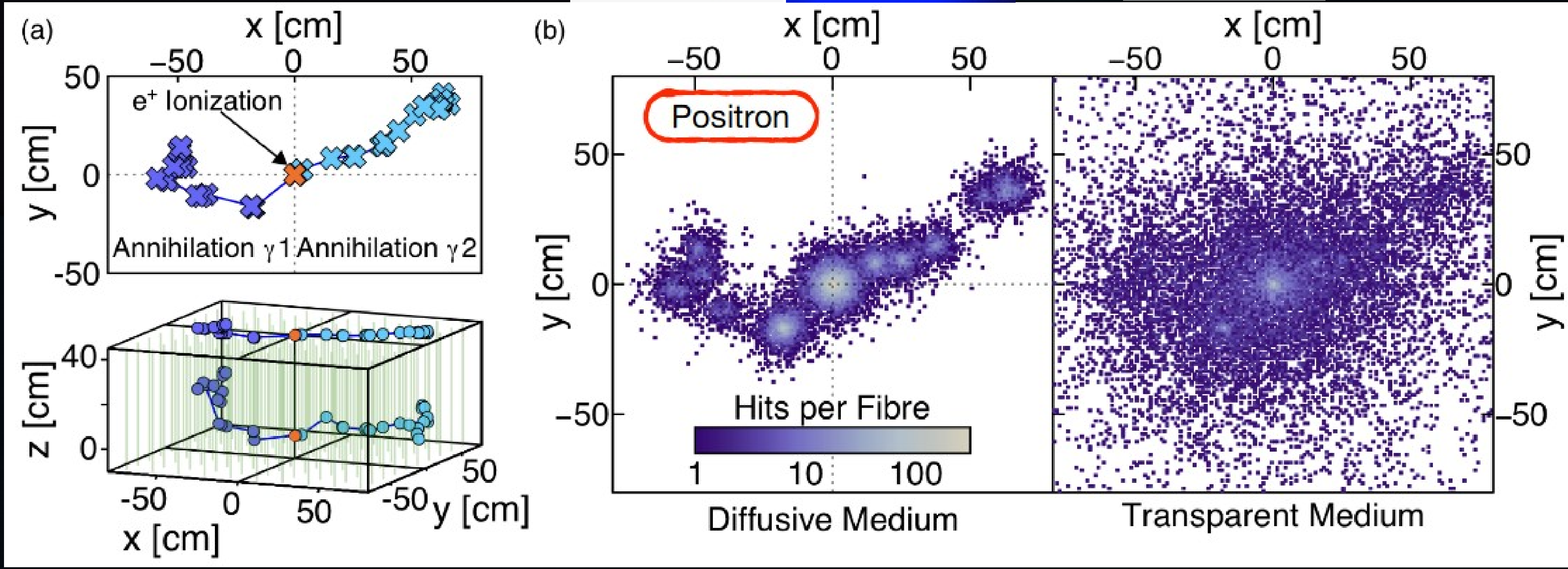


2018 JINST 13 P01031

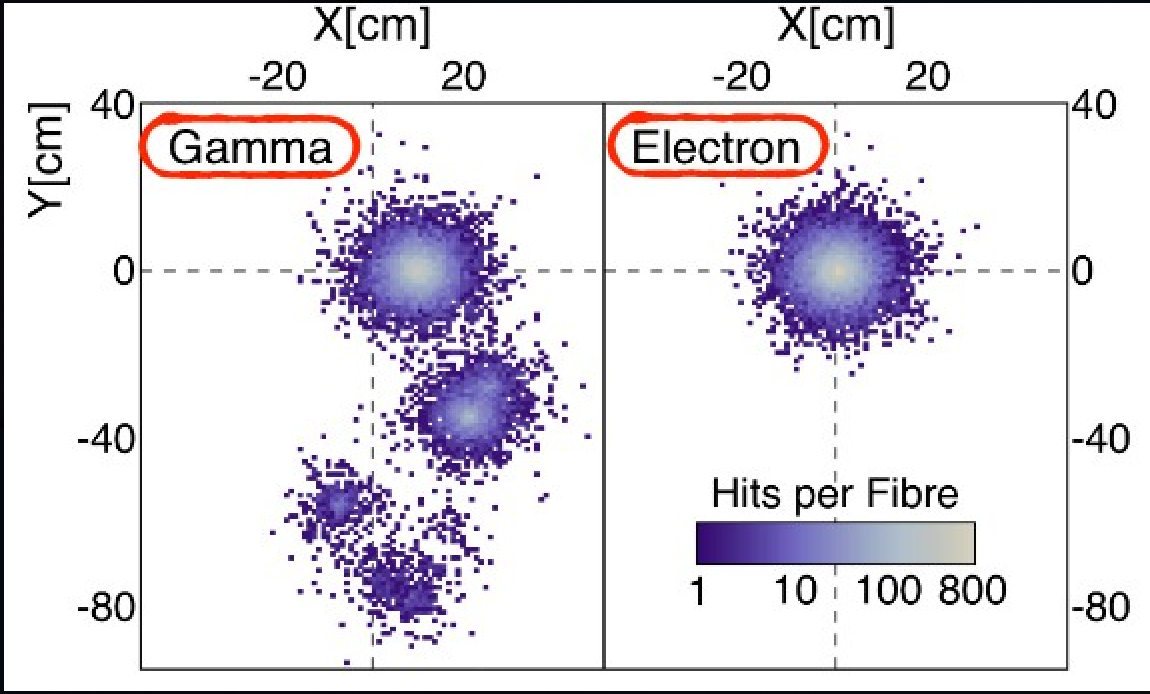
A new approach!

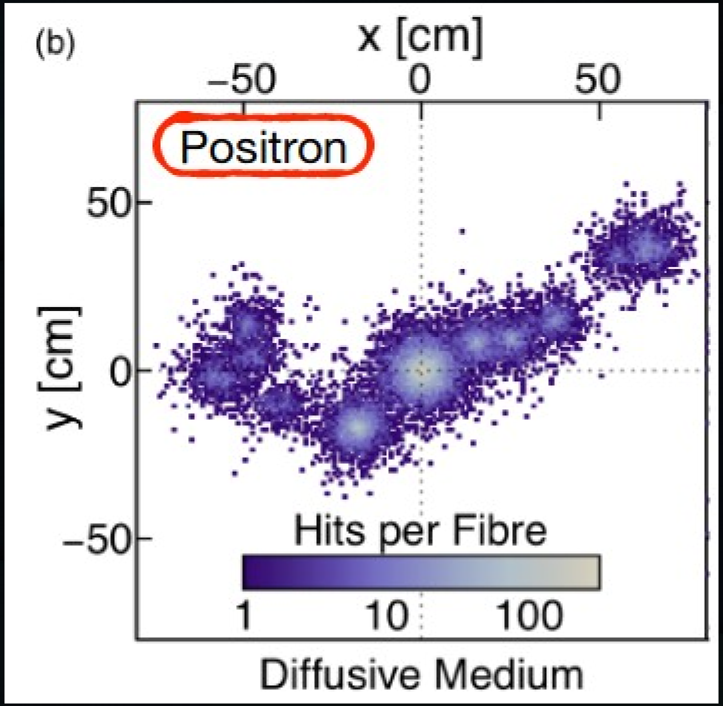






Powerful particle identification!





Cannot separate these 3 on an event-by-event basis with conventional LS detectors!

First papers

arXiv:1908.02859

communications
physics

ARTICLE

https://doi.org/10.1038/s42005-021-00763-5 OPEN

Neutrino physics with an opaque detector

LiquidO Consortium*

In 1956 Reines & Cowan discovered the neutrino using a liquid scintillator detector. The neutrinos interacted with the scintillator, producing light that propagated across transparent volumes to surrounding photo-sensors. This approach has remained one of the most widespread and successful neutrino detection technologies used since. This article introduces a concept that breaks with the conventional paradigm of transparency by confining and collecting light near its creation point with an opaque scintillator and a dense array of optical fibres. This technique, called LiquidO, can provide high-resolution imaging to enable efficient identification of individual particles event-by-event. A natural affinity for adding dopants at high concentrations is provided by the use of an opaque medium. With these and other capabilities, the potential of our detector concept to unlock opportunities in neutrino physics is presented here, alongside the results of the first experimental validation.

arXiv:1908.03334

Jinst

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Revised: *September 30, 2019*
Accepted: *October 21, 2019*
Published: *November 5, 2019*

Novel opaque scintillator for neutrino detection

C. Buck,[1] B. Gramlich and S. Schoppmann

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Saupfercheckweg 1, 69117 Heidelberg, Germany

E-mail: christian.buck@mpi-hd.mpg.de

Abstract: There is rising interest in organic scintillators with low scattering length for future neutrino detectors. Therefore, a new scintillator system was developed based on admixtures of paraffin wax in linear alkyl benzene. The transparency and viscosity of this gel-like material can be tuned by temperature adjustment. Whereas it is a colorless transparent liquid at temperatures around 40°C, it has a milky wax structure below 20°C. The production and properties of such a scintillator as well as its advantages compared to transparent liquids are described.

Keywords: Detector design and construction technologies and materials; Neutrino detectors; Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators)

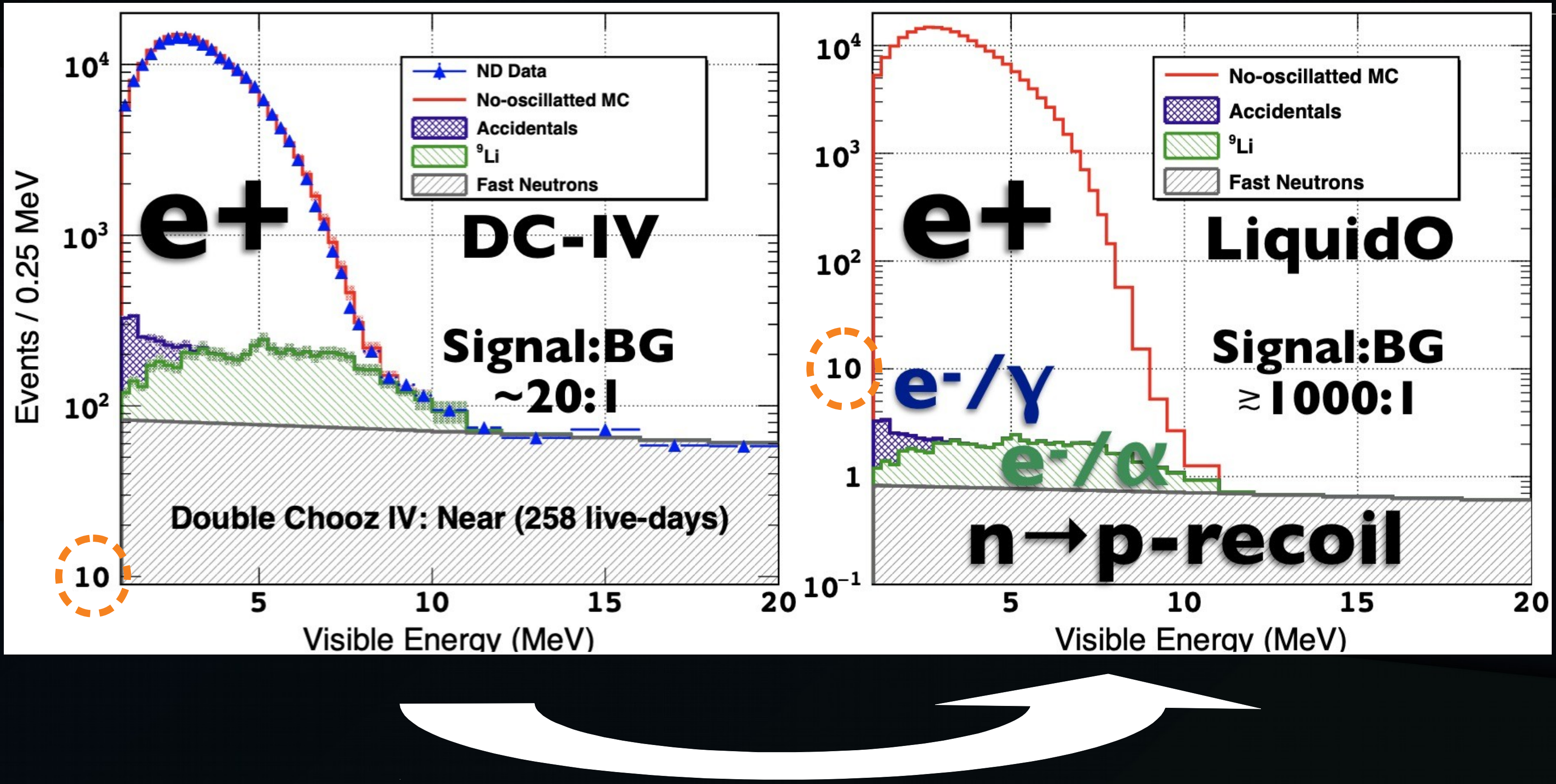
ArXiv ePrint: 1908.03334

[1]Corresponding author.

https://doi.org/10.1088/1748-0221/14/11/P11007

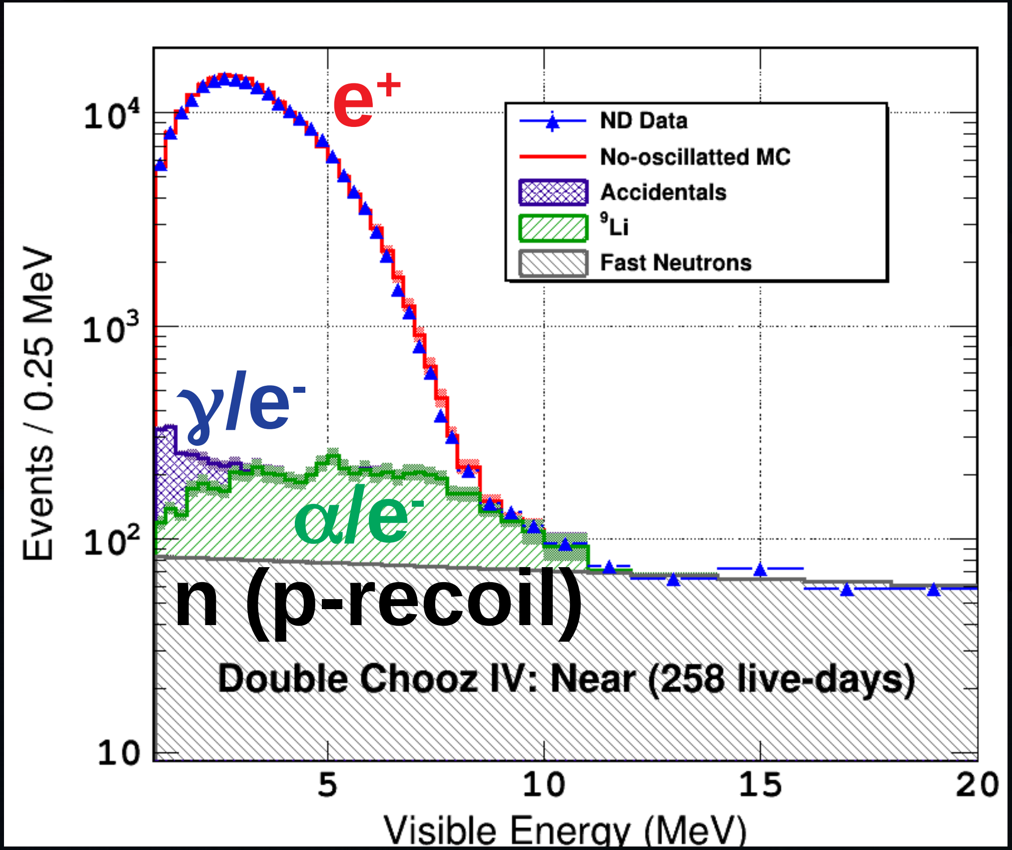
2019 JINST 14 P11007

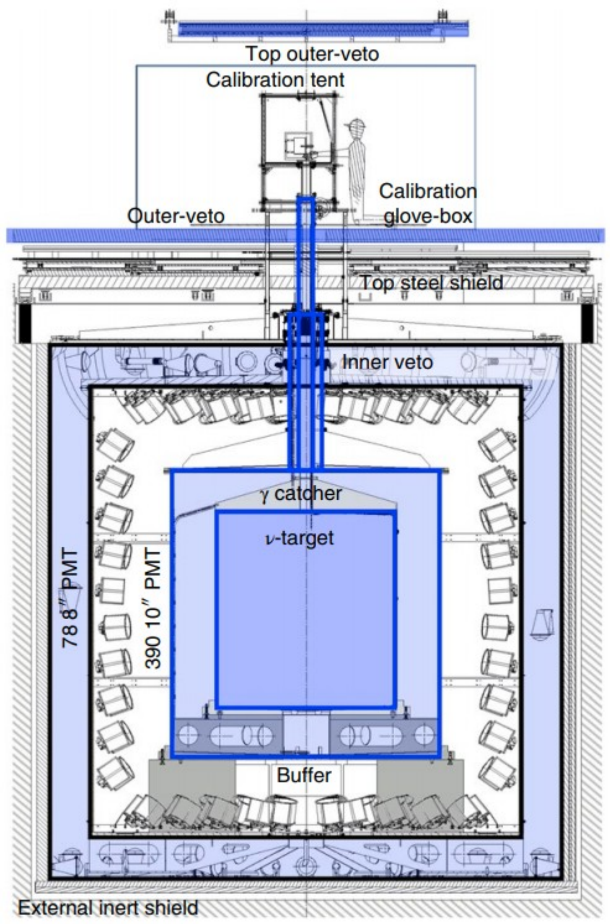
Impact on IBD detection



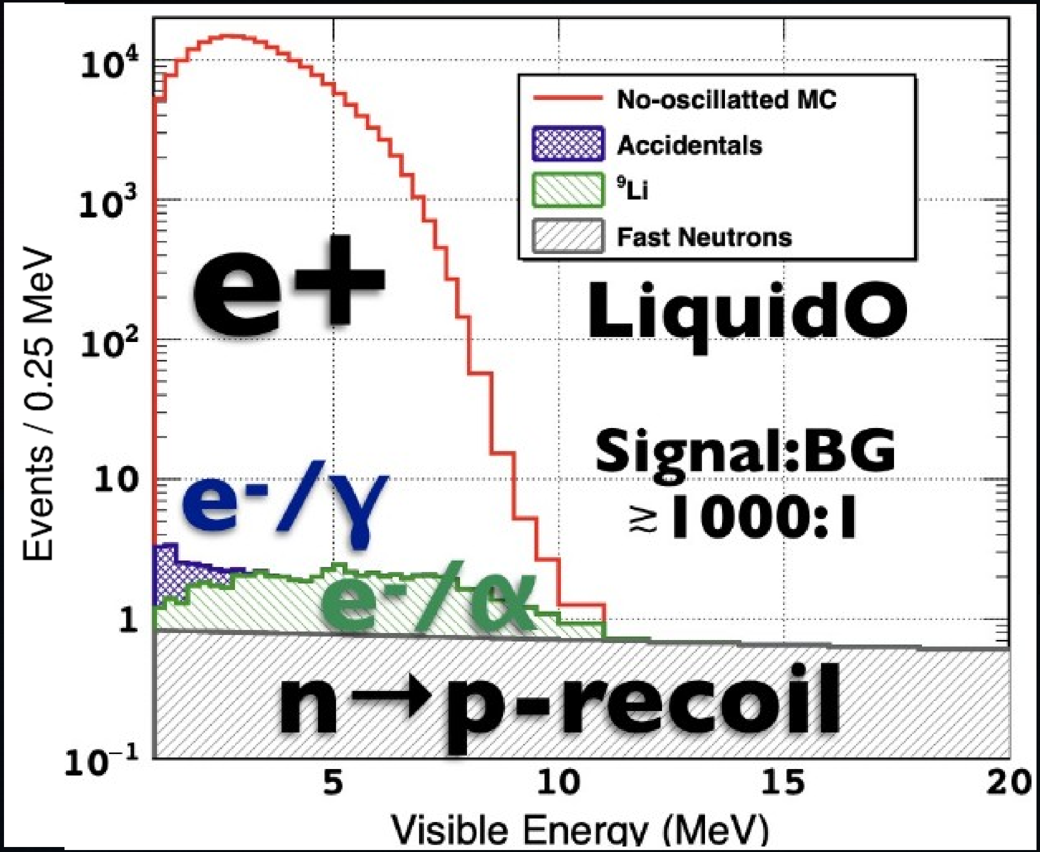
Applying expected PID and BG rejection

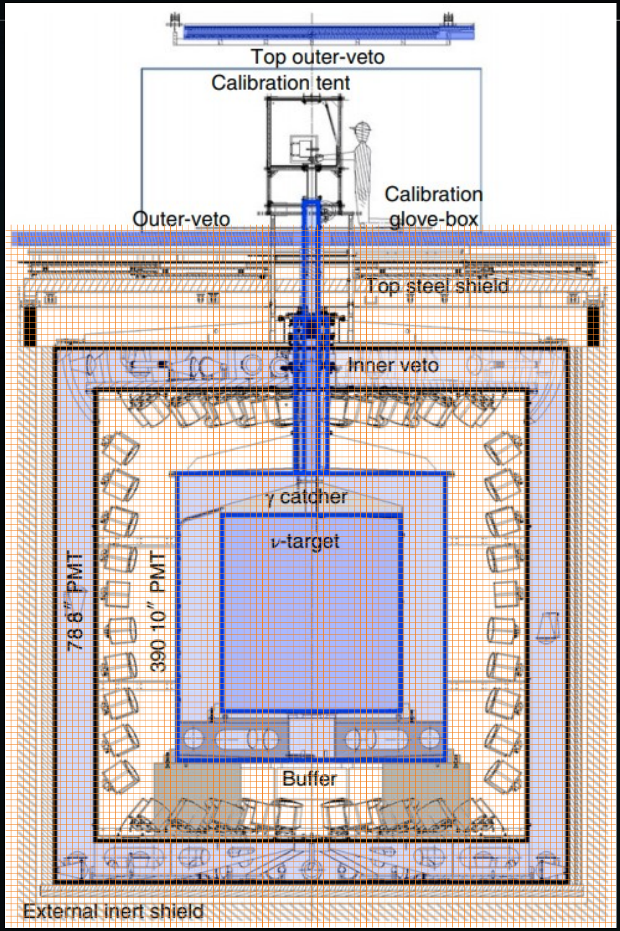
Expensive way to remove backgrounds





Smart way to remove backgrounds



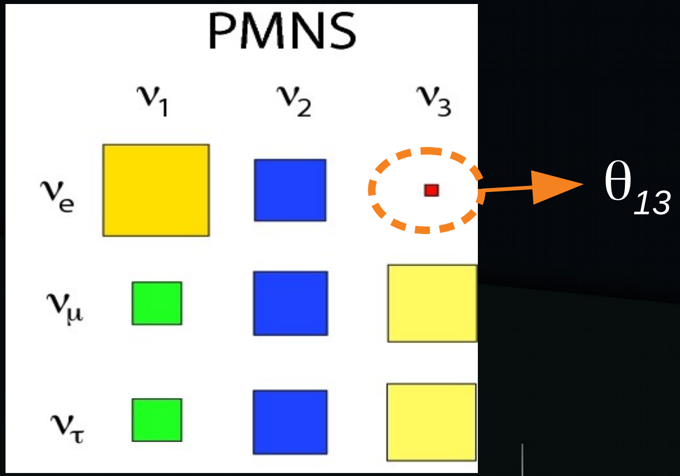


10 fold increase!

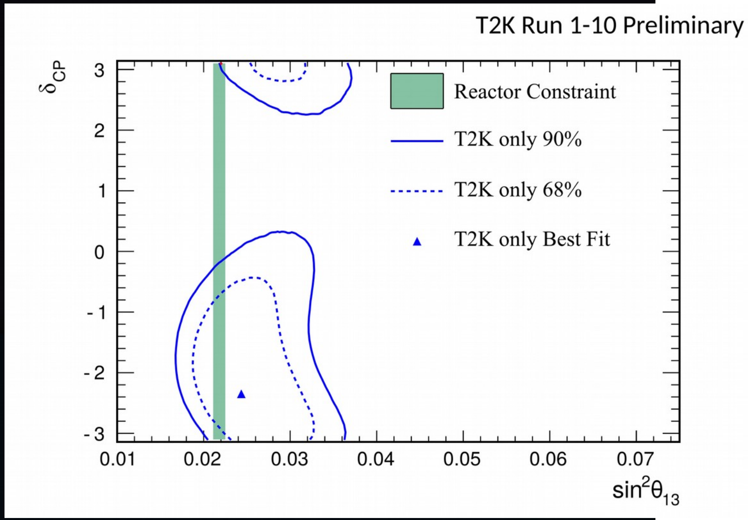
Impact on θ_{13}

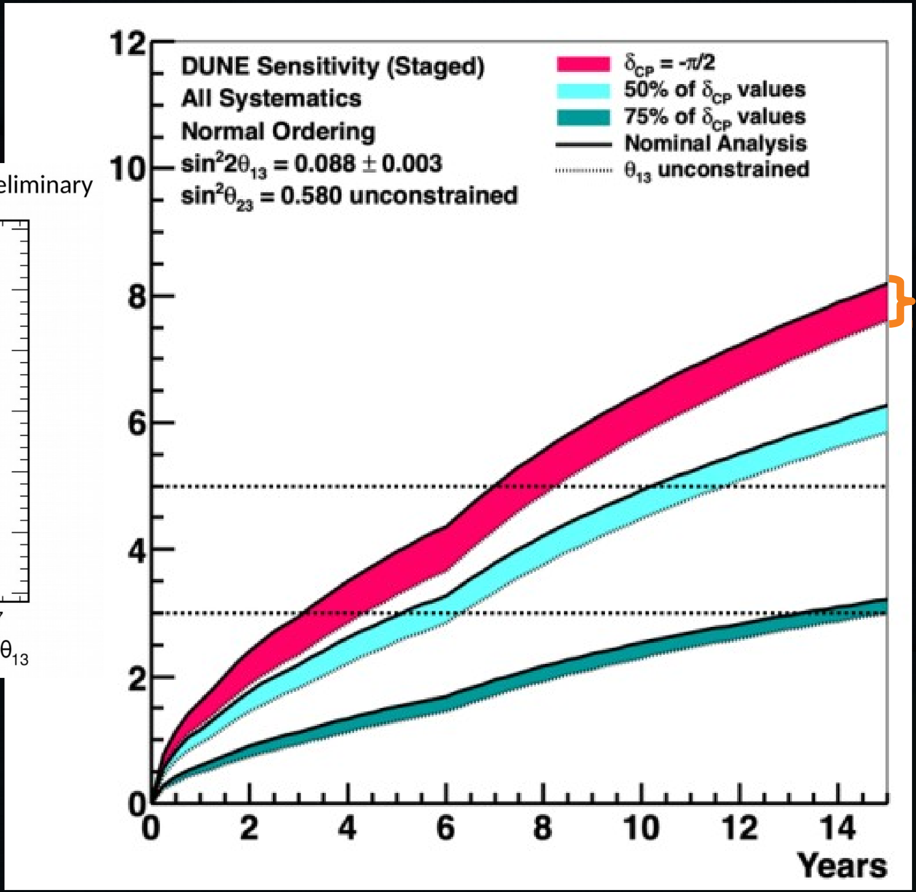
- Not “doomed” to 2~3% unc. any more
- Possible to get sub-percent unc. with current technology (preliminary, energy scale main syst.)

$$J_r = \sin\theta_{12}\cos\theta_{12}\sin\theta_{23}\cos\theta_{23}\sin\theta_{13}\cos^2\theta_{13}\sin\delta_{CP}$$



Impact of sub-percent θ_{13}





Impact of constraining $\sin^2 2\theta_{13}$ within 3.4%

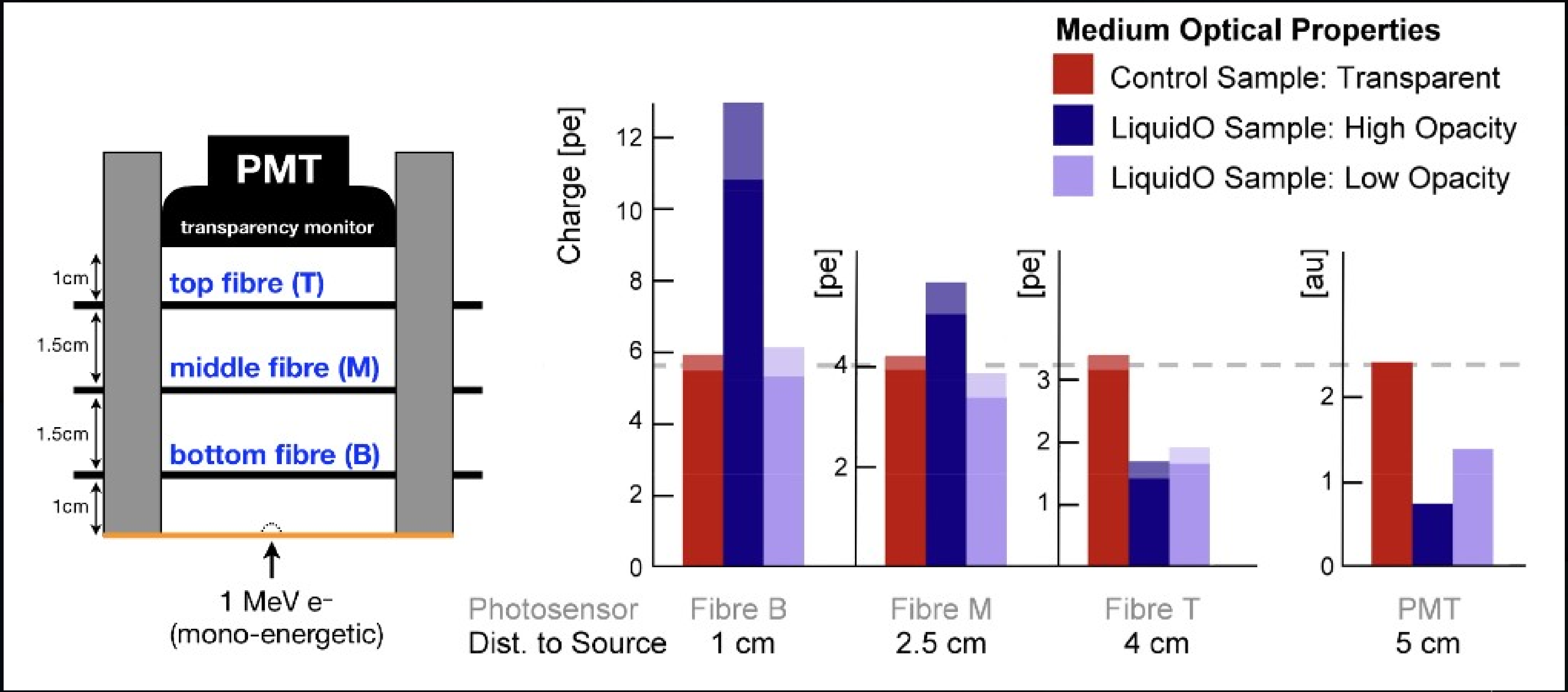
How many years we gain if < 1%?

Summary

- Nuclear reactors are a key source for neutrino physics (no doubt!);
- IBD channel driving θ_{13}
  - Best known oscillation parameter (others soon too, with JUNO)
- Positron tagging with opaque scintillator has a promising future
  - Counter intuitive technique
  - Proof-of-principle already obtained. Working towards multi-ton demonstrator
  - Possible way to do a sub-% measurement of θ_{13}

Back up slides

Does it work?



Medium Optical Properties
Control Sample: Transparent
LiquidO Sample: High Opacity
LiquidO Sample: Low Opacity
PMT
transparency monitor
1cm
top fibre (T)
1.5cm
middle fibre (M)
1.5cm
bottom fibre (B)
1cm
1 MeV e-
(mono-energetic)
Charge [pe]
0
2
4
6
8
10
12
[pe]
2
4
[pe]
1
2
3
[au]
0
1
2
Photosensor
Dist. to Source
Fibre B
1 cm
Fibre M
2.5 cm
Fibre T
4 cm
PMT
5 cm

Commission a 7.5 litre prototype called “Mini-LiquidO”