Latest nH analysis in the Double Chooz Experiment

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On behalf of Double Chooz collaboration

Neutrino Mixing

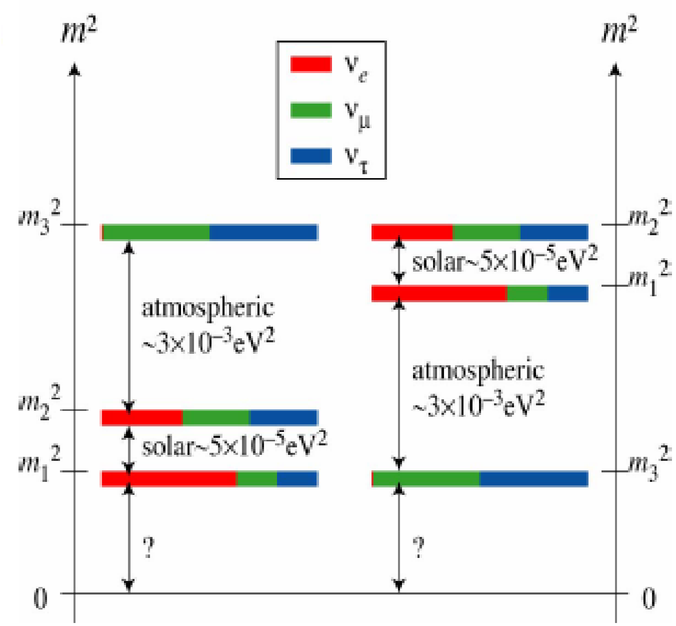
- PNMS matrix can be broken down into three 3*3 matrices:

Current Measurements: $\Delta m^2_{21} \sim 8\times10^{-5}\ eV^2$ $\Delta m^2_{31} \sim \Delta m^2_{32} \sim 0.0025 eV^2$

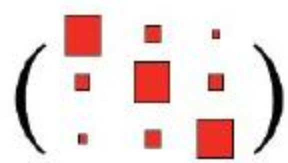
$$U = \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{cp}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{cp}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}$$

"Solar" $\theta_{12} \sim 33^\circ$ "Little mixing angle" $\theta_{13} < 11^\circ$ (circa 2011) "Atmospheric" $\theta_{23} \sim 45^\circ$

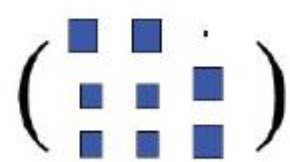
- Each mixing angle related to a mass splitting between the two mass states



This is Quark Mixing



This is Neutrino Mixing



Neutrino oscillation Experiments

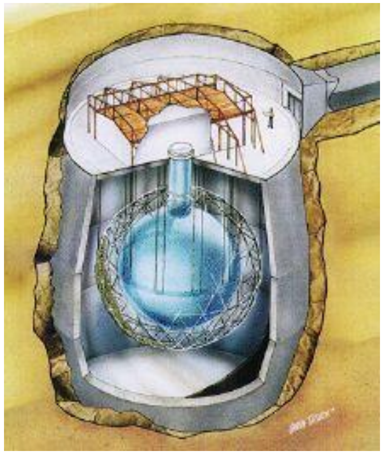
Solar: BOREXINO, SNO…

Atmospheric: Super-K…

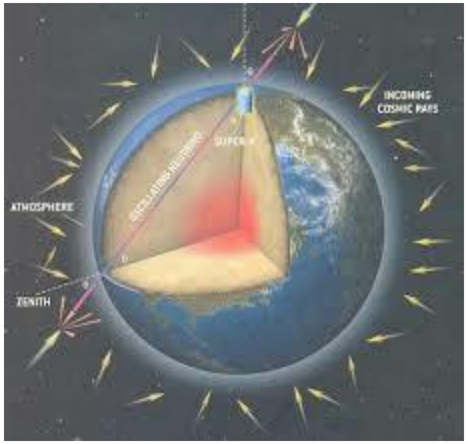
Accelerator: MINOS, NOvA, T2K...

Reactor: Daya Bay, Double Chooz, RENO, KamLAND...

Cosmic: IceCube…



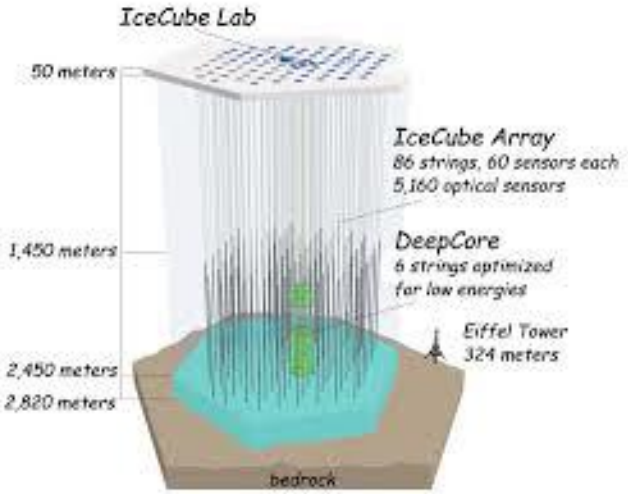
SNO ($\nu_e \to \nu_{\mu,\tau}$)



Super-K($\nu_\mu \to \nu_\tau$)

NOvA

Double Chooz ($\overline{\nu}_e \to \overline{\nu}_e$)



IceCube

Double Chooz Experiment

Brazil
- CBPF
- UNICAMP
- UFABC

France
- APC
- CEA/DSM/IRFU:
  - SPP
  - SPhN
  - SEDI
  - SIS
  - SENAC
- CNRS/IN2P3:
  - Subatech
  - IPHC

Germany
- EKU Tübingen
- MPIK Heidelberg
- RWTH Aachen
- TU München
- U. Hamburg

Japan
- Tohoku U.
- Tokyo Inst. Tech.
- Tokyo Metro. U.
- Niigata U.
- Kobe U.
- Tohoku Gakuin U.
- Hiroshima Inst. Tech.

Russia
- INR RAS
- IPC RAS
- RRC Kurchatov

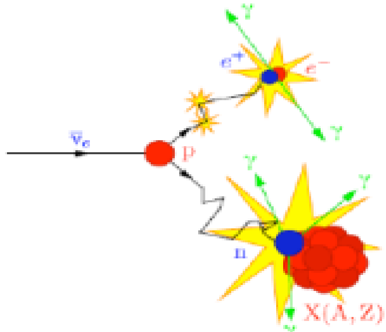
Spain
- CIEMAT-Madrid

USA
- U. Alabama
- ANL
- U. Chicago
- Columbia U.
- UCDavis
- Drexel U.
- IIT
- KSU
- LLNL
- MIT
- U. Notre Dame
- U. Tennessee

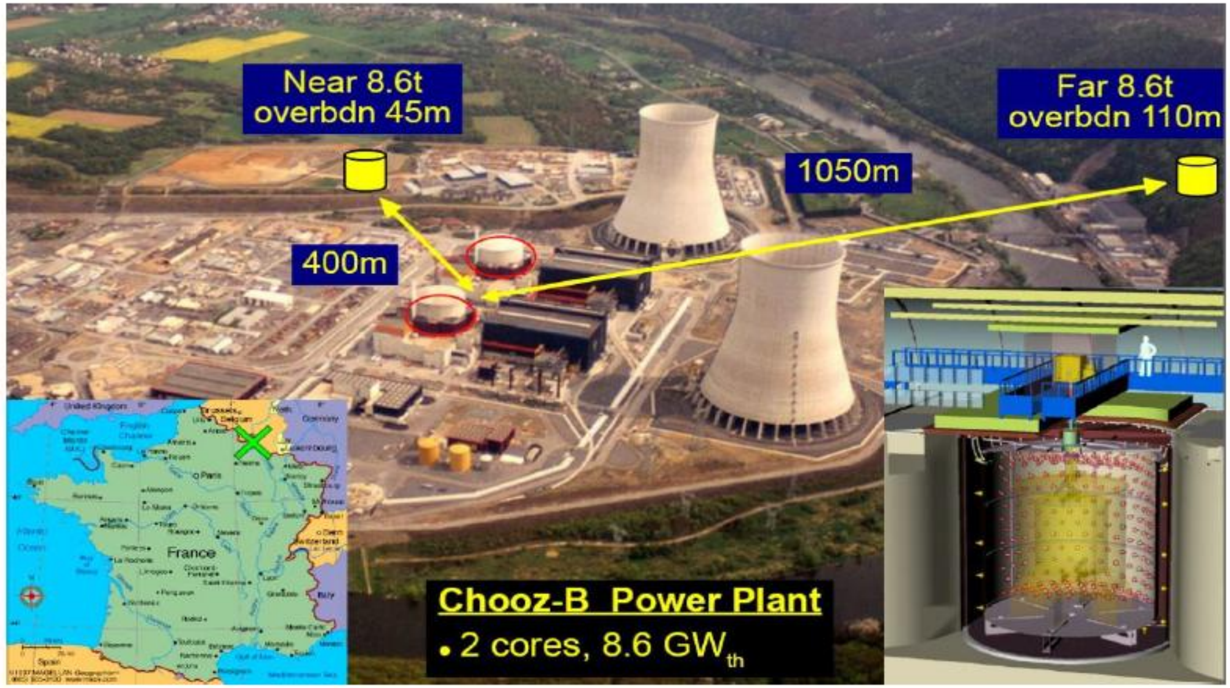
Spokesperson:
H. de Kerret (IN2P3)

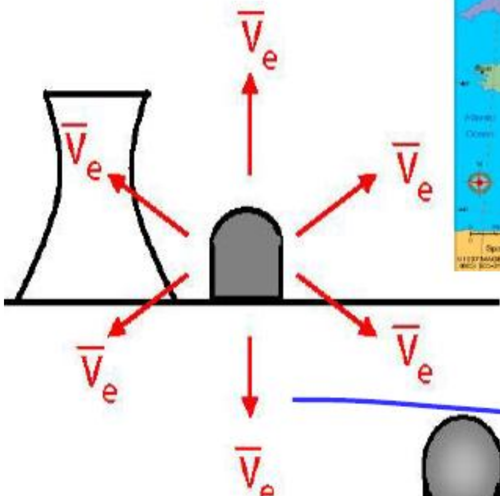
Project Manager:
Ch. Veyssière (CEA-Saclay)

Web Site:
www.doublechooz.org/

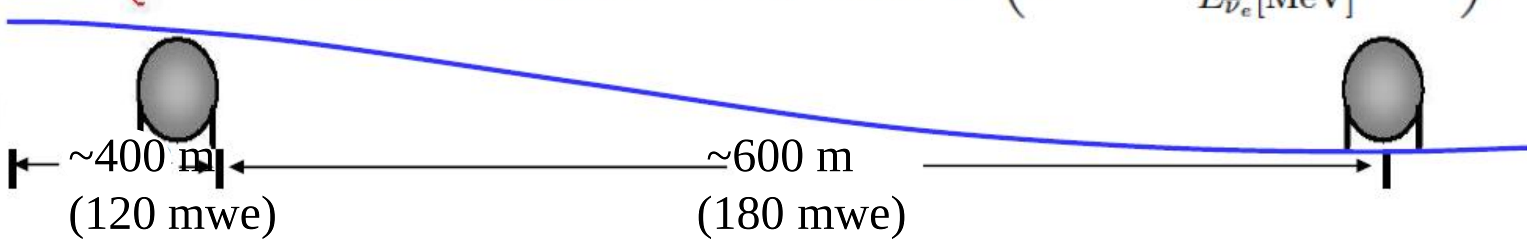


IBD: $\overline{\nu}_e$ +P -> e+ + n





$$P_{ee}(E_{\overline{\nu}_e}, L, \Delta m^2_{31}, \theta_{13}) = 1 - \sin^2(2\theta_{13}) \sin^2\left(1.27\frac{\Delta m^2_{31}[10^{-3}\ \mathrm{eV}^2] L[\mathrm{km}]}{E_{\overline{\nu}_e}[\mathrm{MeV}]}\right)$$

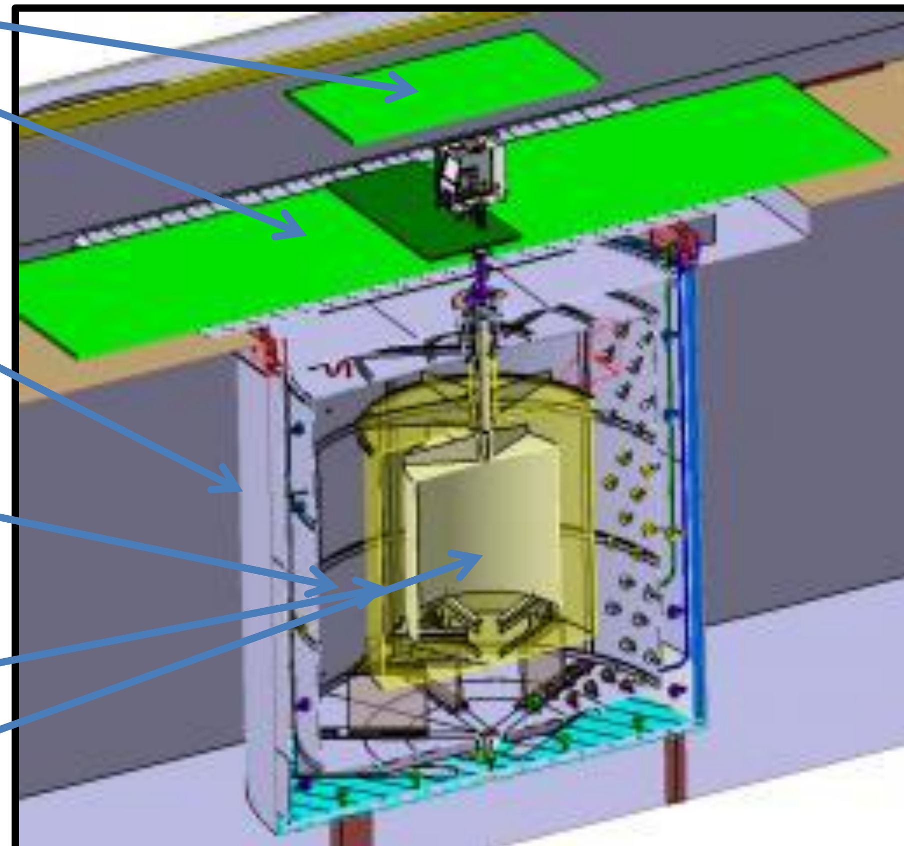


-Neutron created in IBD interaction may be captured by gadolinium (nGd analysis), or by hydrogen (nH analysis). This talk is dedicated to nH analysis.

Double Chooz Detector

Outer Veto (OV)
Plastic scintillator strips

Inner Veto (IV)
90 m^3 of scintillator in a steel Vessel (10 mm) equipped with 78 PMTs (8 inches)



Buffer
110 m^3 of mineral oil in a steel Vessel. (3mm) equipped with 390 low-background PMTs (10 in.)

Gamma Catcher (GC)
22.3 m^3 scintillator in an acrylic Vessel (12 mm)

Target
10.3 m^3 scintillator doped with 1 g/l of Gd in acrylic vessel (8 mm)

Key improvements in new DC H analysis

-Energy reconstruction
- improved PE, stability and uniformity calibrations for data and MC
- take account the light nonlinearity(LNL) and charge nonlinearity(QNL) for MC

-Background reduction
- Use functional value(FV) to reduce stopping muons and light noise
- Use ANN(neural network) to reject accidental background
- Use MPS(Pulse shape) to reject FN contamination

-Detection systematics
- Consider carefully the proton number uncertainty and spill in/out effect
- Use volume factorization method to calculate detection efficeincy

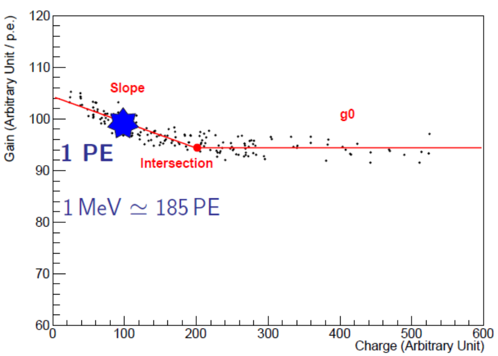
-Final Fit
- RRM fit performed, which is model independent
- New features added to Rate+Shape fit

Energy reconstruction

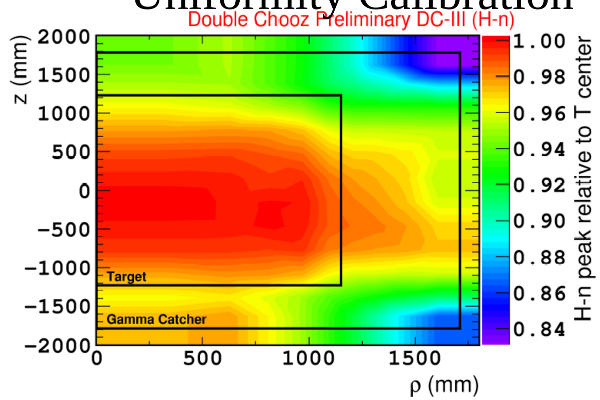
$$E_{vis} = N_{pe} \times f_u(\rho, z) \times f_{PE/MeV} \times f_s^{data}(E_{vis}^0, t) \times f_{nl}^{MC}$$

-Use spallation neutron capture in H for spatial uniformity calibration
-Use Cf252 H capture for PE/MeV calibration
-Done for data and MC seperately

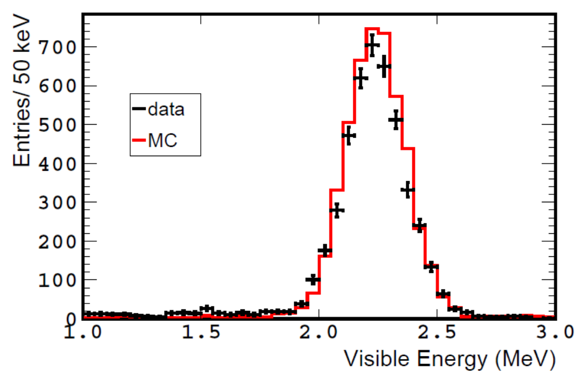
PE calibration



Uniformity Calibration



PE/MeV Calibration

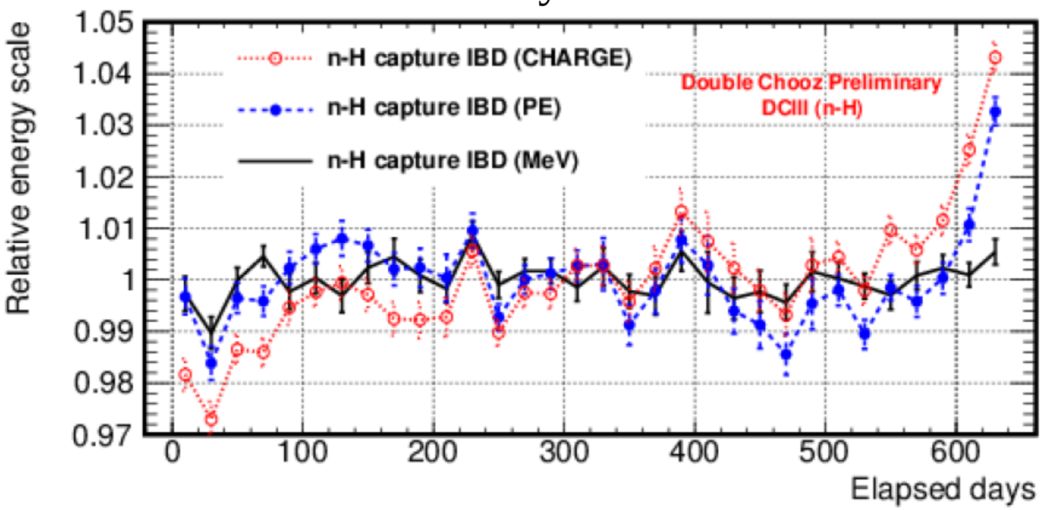


Energy reconstruction

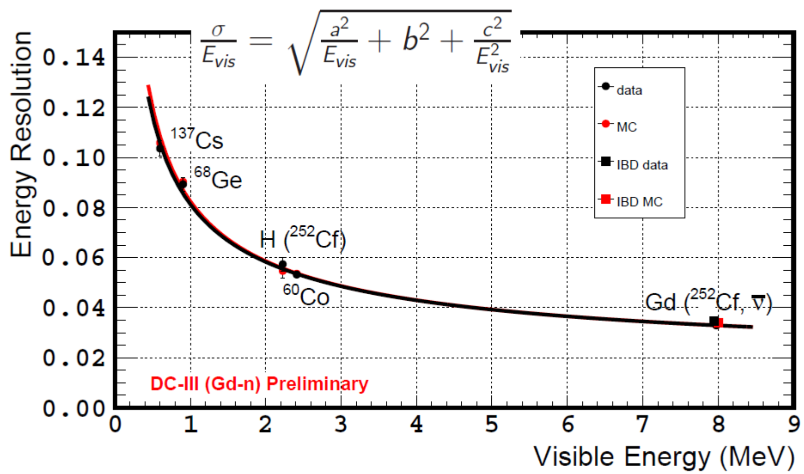
$$E_{vis} = N_{pe} \times f_u(\rho, z) \times f_{PE/MeV} \times f_s^{data}(E_{vis}^0, t) \times f_{nl}^{MC}$$

-Use natural radioactive sources to do the time stability calibration
-Last terms applied to MC in Final Fit. It comes from the light nonlinearity and charge nonlinearity

Time stability calibration



nGd resolution



Backgrounds

Tree kinds of backgrounds considered in the oscillation analysis:

Accidental Background
- rejected by ANN and inner veto to reject compton gamma from outside

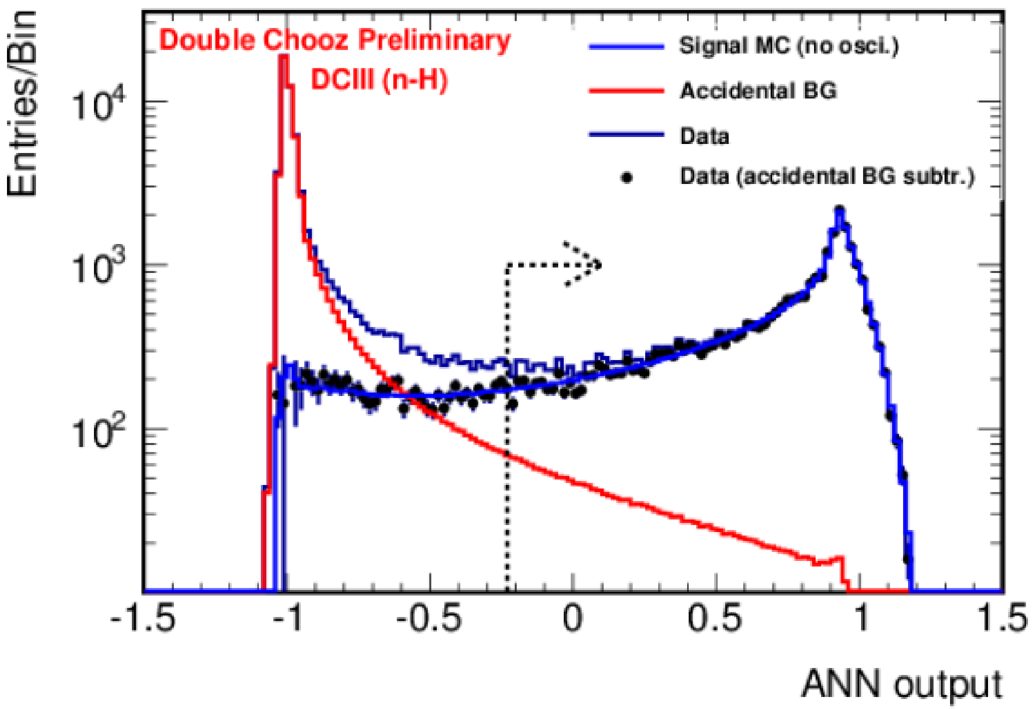
Fast Neutron
- rejected by IV, OV tagging and MPS

Stopping muons
- rejected by IV, OV tagging and FV

Li-9/He-8
- rejected by the time and space correlation to the progenitor muon

Backgrounds

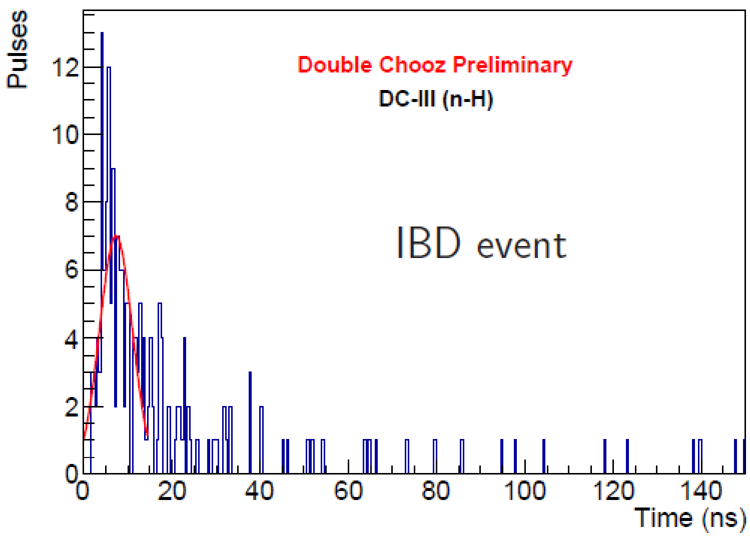
-With dT, dE and dR information, we can employ the neural network to get an ANN value.
-The output value can be used to identify the Accidental background.
- Put a cut around 0 and make the signal/background ratio to be ~12.

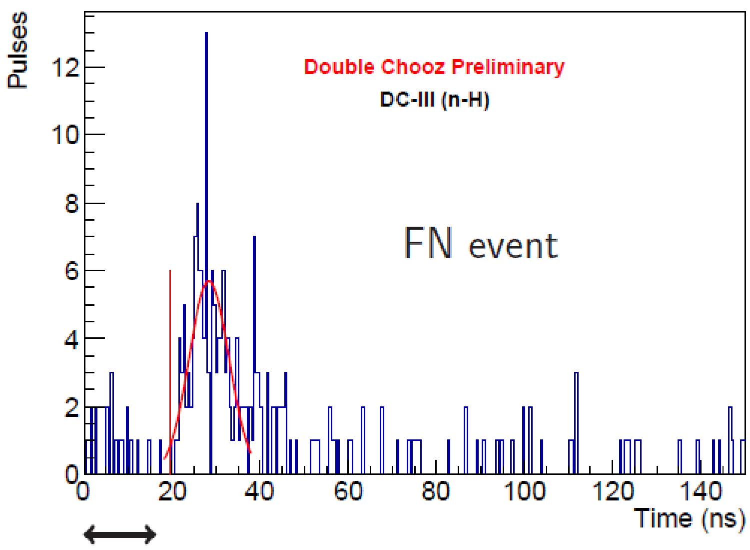


Backgrounds

-Low energy proton recoil will not be tagged as fast neutron (FN).
-MPS deals with those FN backgrounds.

-Pulse time distribution comes from the summation of all PMT times.
-Good pulse has a distribution shown at the left plot.
-The low energy proton recoil caused by FN may result in a delayed time window.



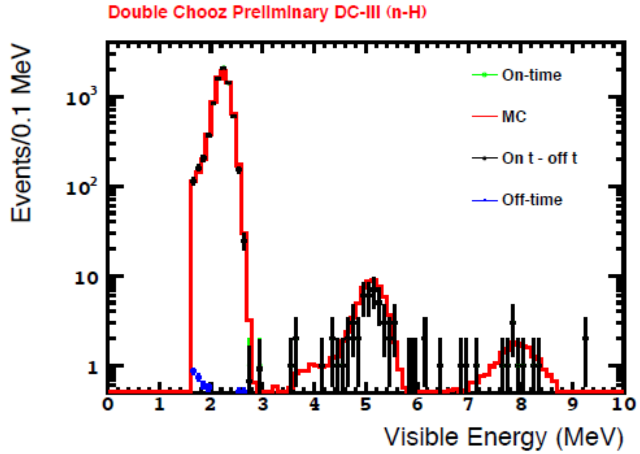


Detection systematics

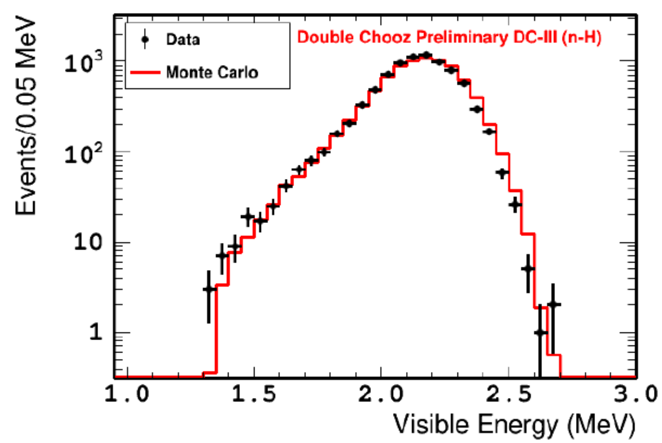
-Three factors taken into account:

- Hydrogen fraction: the fraction neutron captured by H
  - two methods used: IBD and Cf252, they agree very well.
- Spill in/out: Use discrepancy between different simulation tools to set systematics
- proton number uncertainty

IBD delayed energy in GC

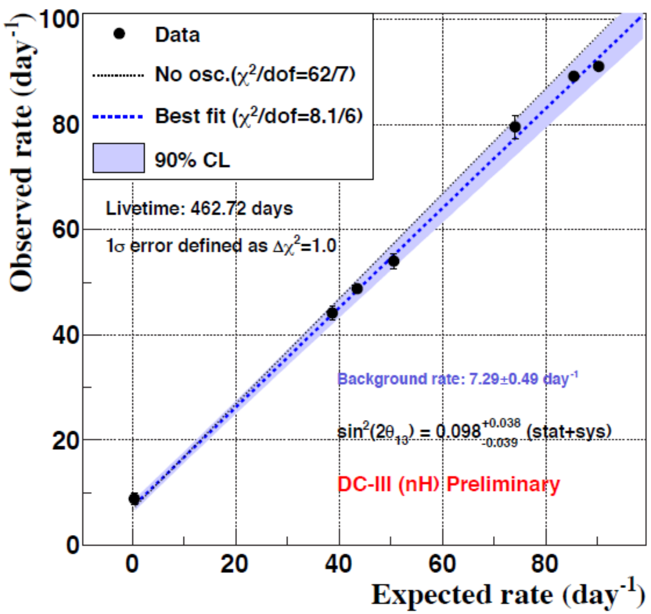


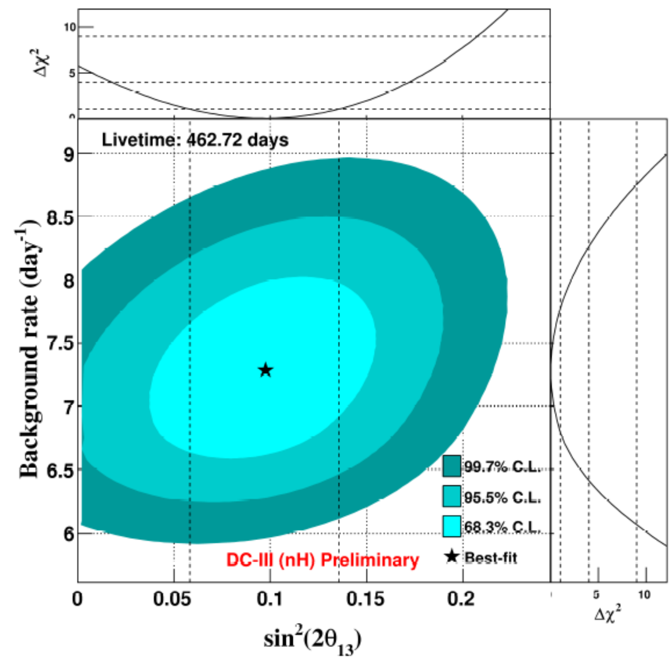
Cf252 delayed energy in GC



RRM fit

$$R^{obs} = B + \left(1 - \sin^2 2\theta_{13} \left\langle \sin^2 \frac{1.27\Delta m^2 L}{E_\nu} \right\rangle \right) R^{exp,\, no\ osc}$$

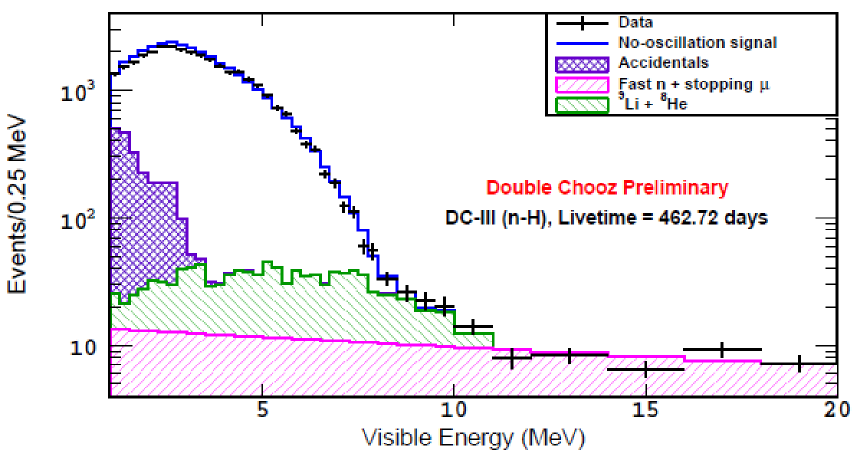




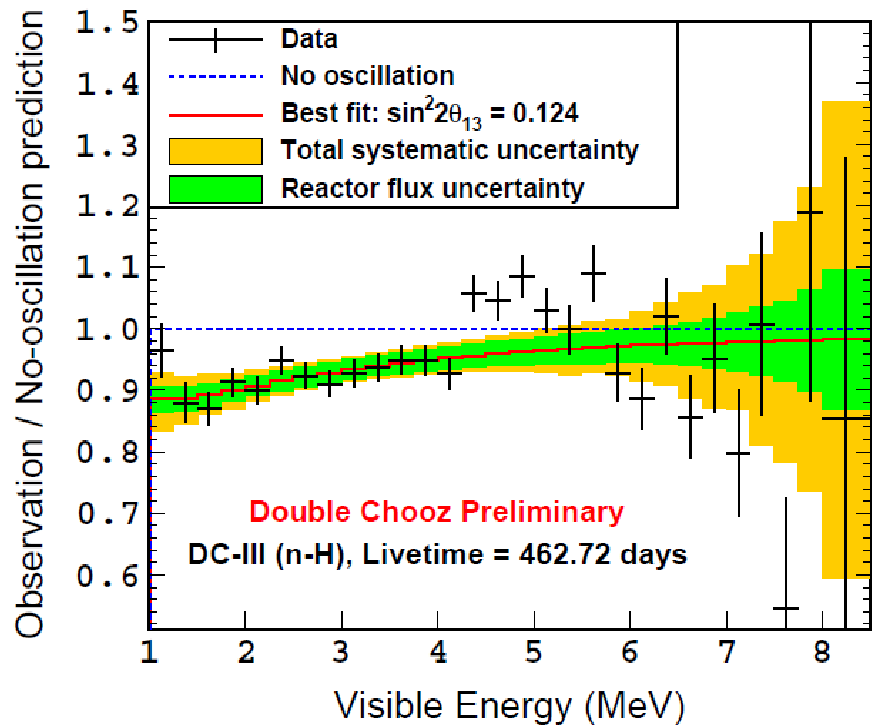
$$\sin^2 2\theta_{13} = \mathbf{0.098^{+0.038}_{-0.039}}$$

Rate+Shape fit

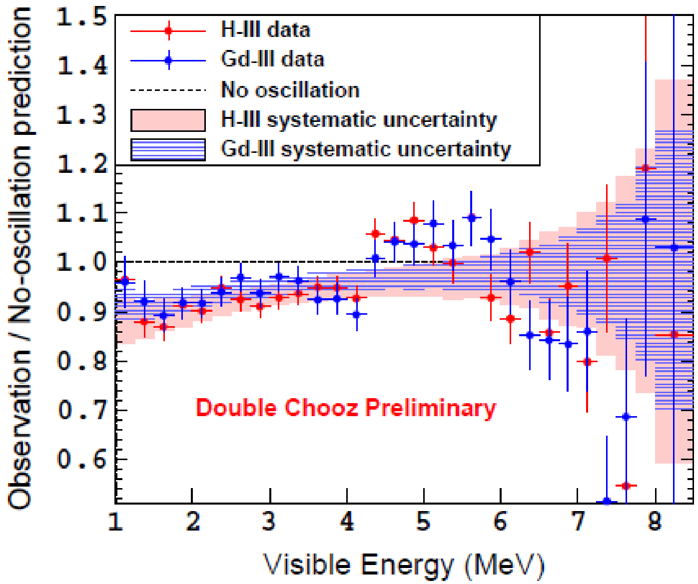
-Apply different detection efficiency correction to different volumes
-Apply new FN model
- 5MeV distortion still there

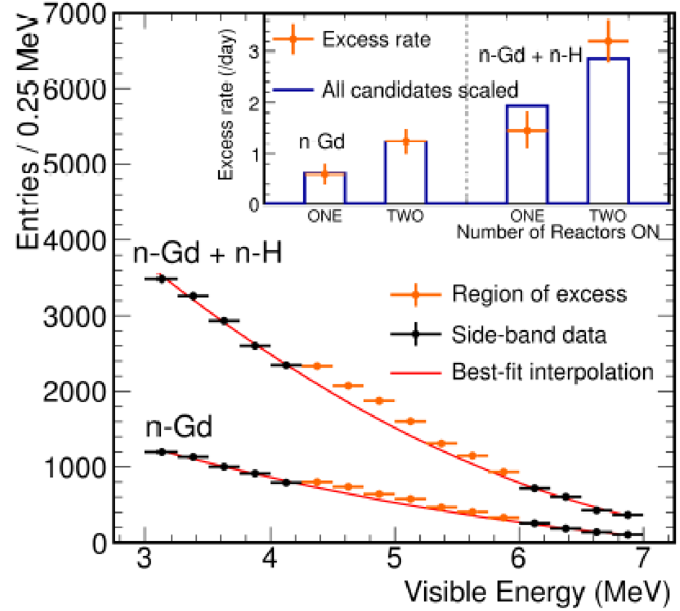


$$\sin^2 2\theta_{13} = 0.124^{+0.030}_{-0.039}$$



5MeV distortion

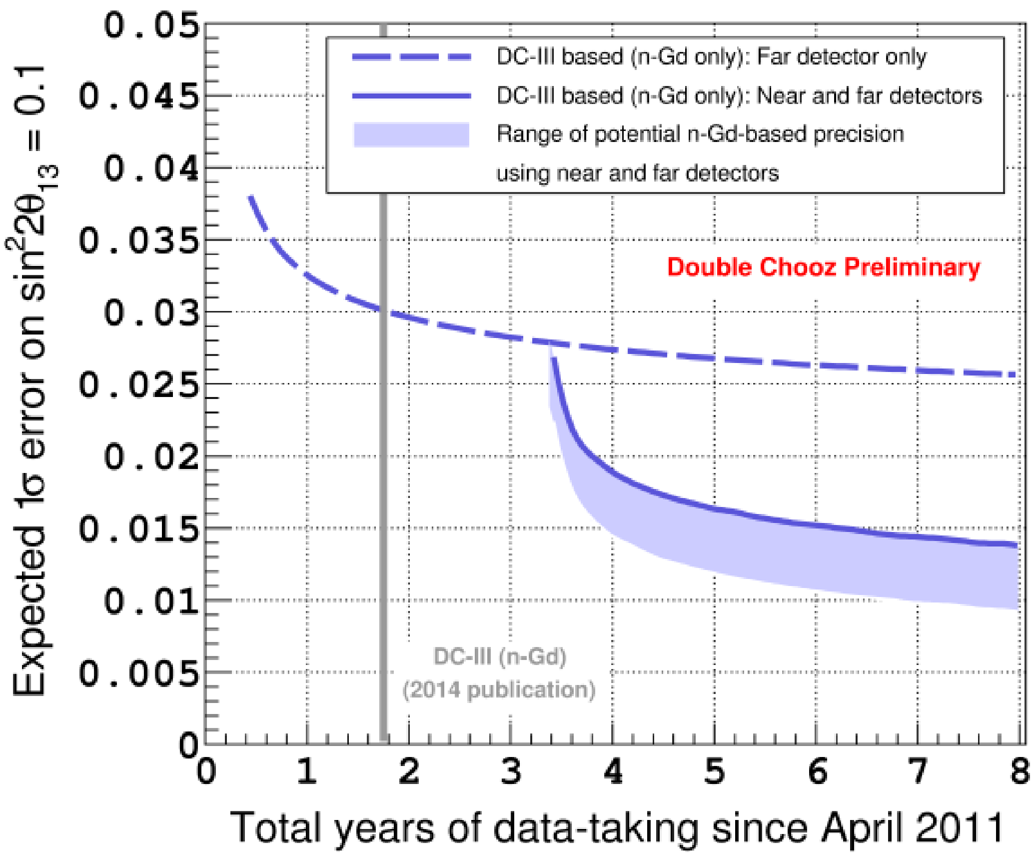




-nGd and nH analyses give similar feature.

-Might come from mismodelling of the reactor flux. Need to be updated.

Future sensitivity



Conclusion

-Latest nH RRM analysis best fit gives $\sin^2 2\Theta_{13}$ = 0.098 + 0.038 -0.039 and nH R+S analysis gives $\sin^2 2\Theta_{13}$ = 0.124 + 0.030 -0.039.

-Near detector has started the data taking. We are preparing for the Near+Far analysis. Precision of $\sin^2 2\Theta_{13}$ will be improved significantly.

-Beyond Θ_{13}, Double Chooz is able to do some other kinds of researches, like sterile neutrino search, reactor flux anomaly, etc. Results will be reported in the future.