Meeting for an Underground Facility in India
6-7 Aug 2022, TIFR Mumbai

# Deuterated Liquid Scintillator for Neutrino Detection

**based on the Science Case White Paper**
**+ JCAP 11 (2021) 005 by Bhavesh Chauhan, BD, Vivek Datar**
**+ ongoing work by the DLS study group at TIFR**
**+ ongoing work by DLS Task Force of DAE**

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# Deuterated Liquid Scintillator for Neutrino Detection

Or it could be
Scintillator + Gd dissolved in Heavy Water
[but we will not discuss this today]

# Remember SNO ?

- The solar neutrino problem was solved largely in part due to the Sudbury Neutrino Observatory (SNO) measurement of the Neutral Current neutrino-dissociation of deuteron:

$$\nu + d \rightarrow \nu + p + n$$

$$n + d \rightarrow {}^{3}\mathrm{H} + \gamma$$

- Challenges for SNO-like detector:
  - Heavy water is expensive and unavailable
  - Low neutron capture efficiency
  - Large Threshold
  - Proton is undetected
  - No spectral information

India can manufacture!

https://www.hwb.gov.in/

Just add Gd

Resolved if you have a scintillator!

50-100 more light compared to Cherenkov light
= lower threshold (<1 MeV)
+ better energy resolution (~3% at 10 MeV)

# Interactions and Detectables

Table : Neutrino deuteron interactions

| Interaction | Channel | -Q (MeV) |
|---|---|---|
| $\nu + d \rightarrow \nu + n + p$ | NC | 2.224 |
| $\overline{\nu} + d \rightarrow \overline{\nu} + n + p$ | NC | 2.224 |
| $\nu_e + d \rightarrow e^- + p + p$ | CC | 1.442 |
| $\overline{\nu}_e + d \rightarrow e^+ + n + n$ | CC | 4.028 |

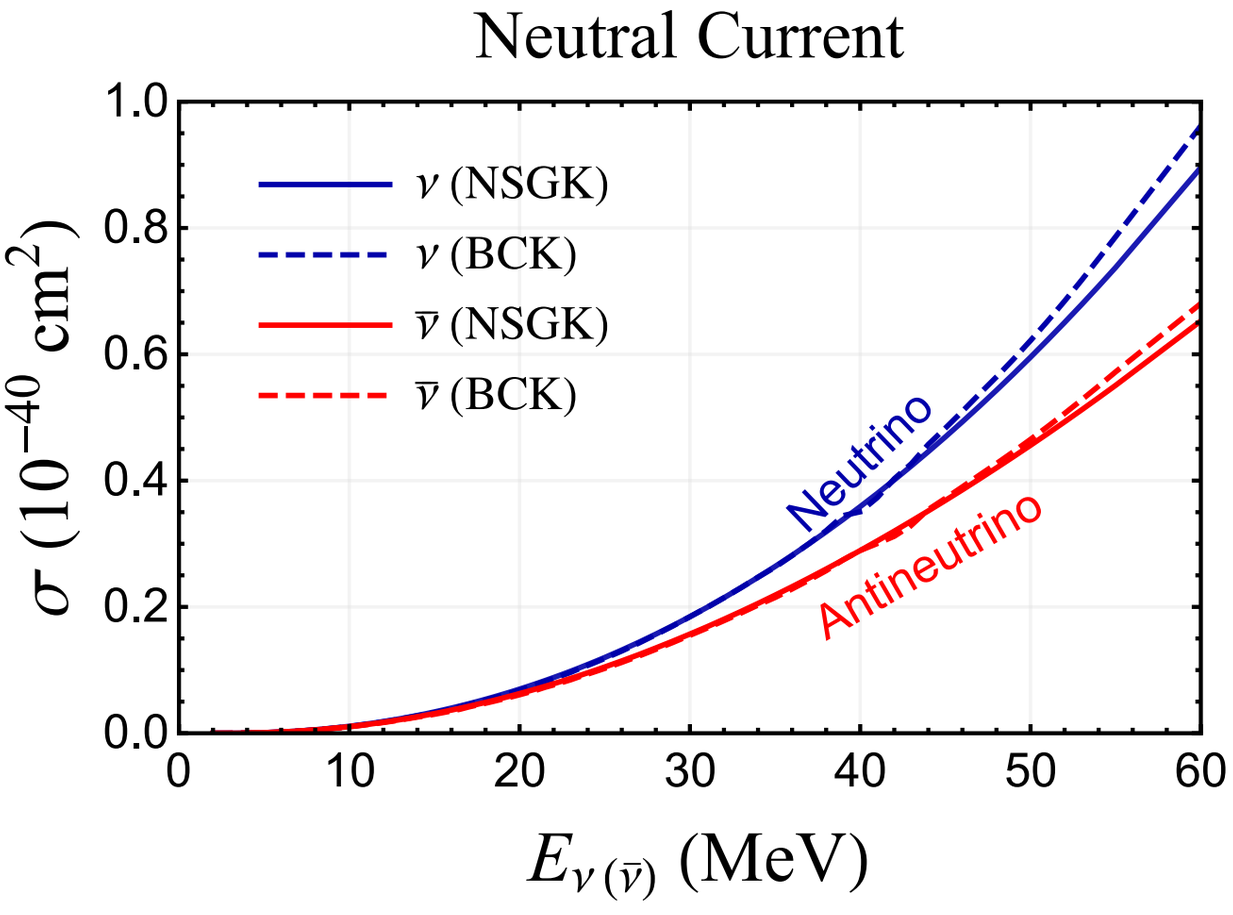
$\nu$, $e^{\pm}$, $p$, $n$

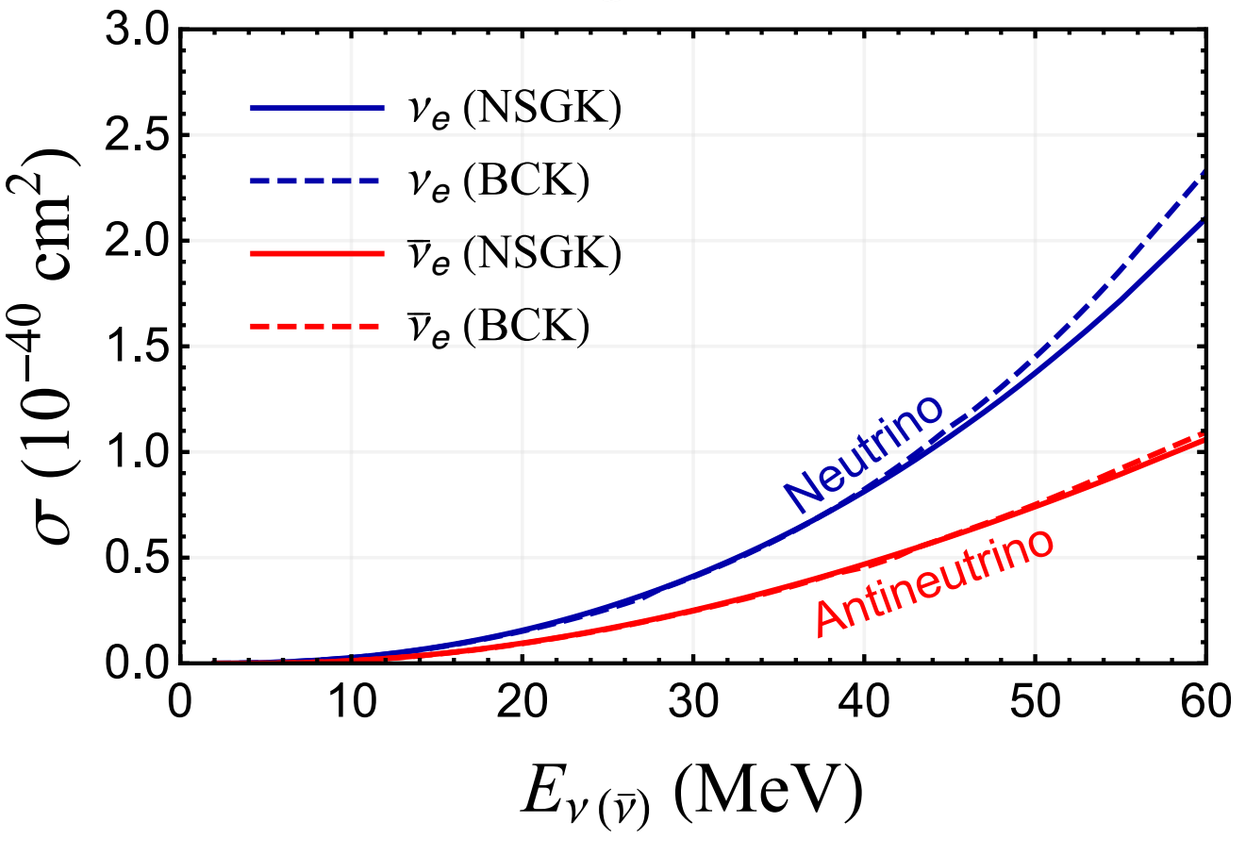
Cannot be detected

Scintillator = low threshold

Thermalises and Captured! Can be used as a “tag”

# Cross Sections




Cross sections and differential cross sections obtained using Pionless EFT [nucl-th/0008032] are available at:
https://github.com/bhvzchhn/NeutrinoDeuteron

# Deuterated Liquid Scintillator Detector for Solar Neutrinos: A Brief Overview of Experimental Issues and the Science Case

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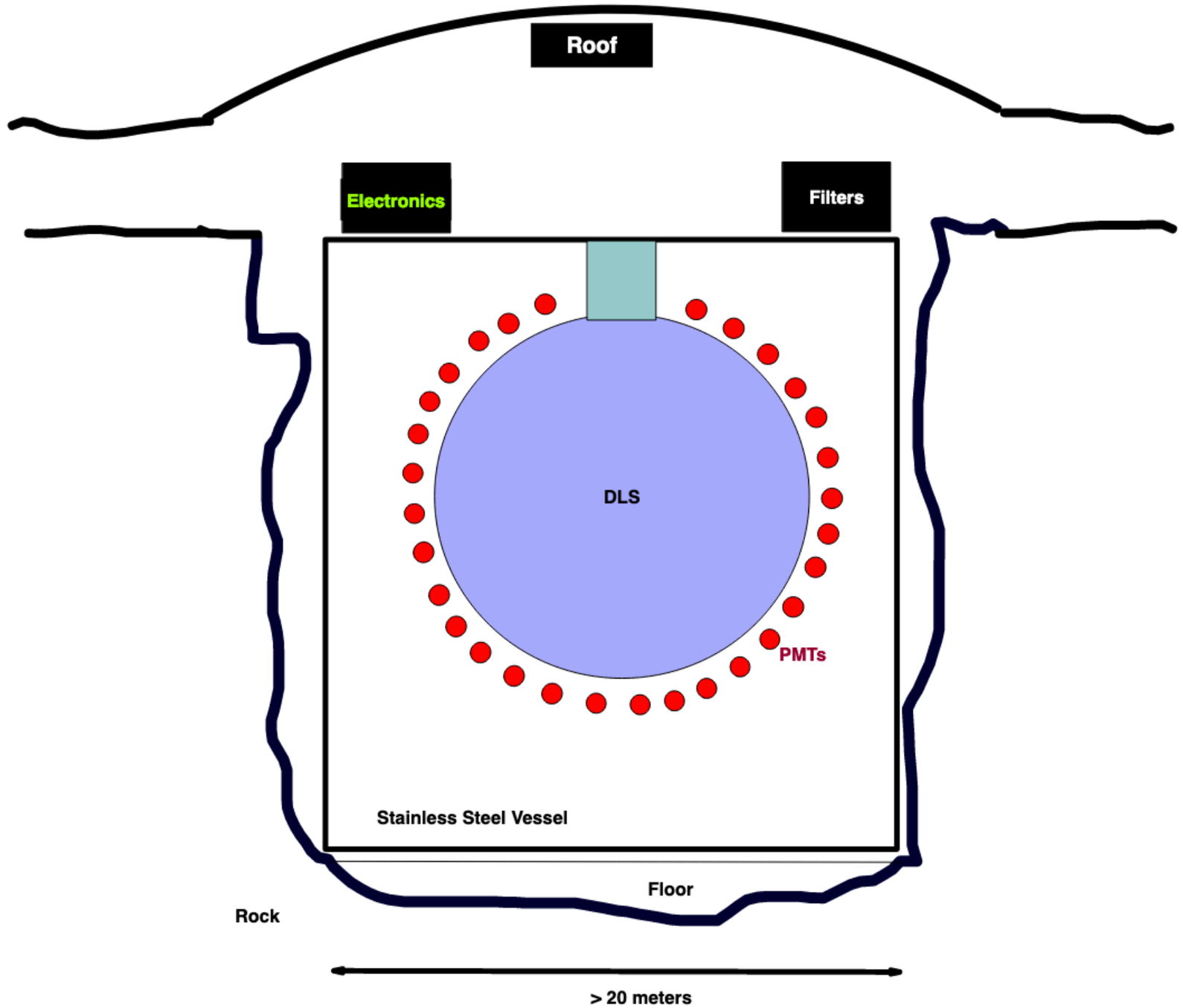
# Concept Drawing



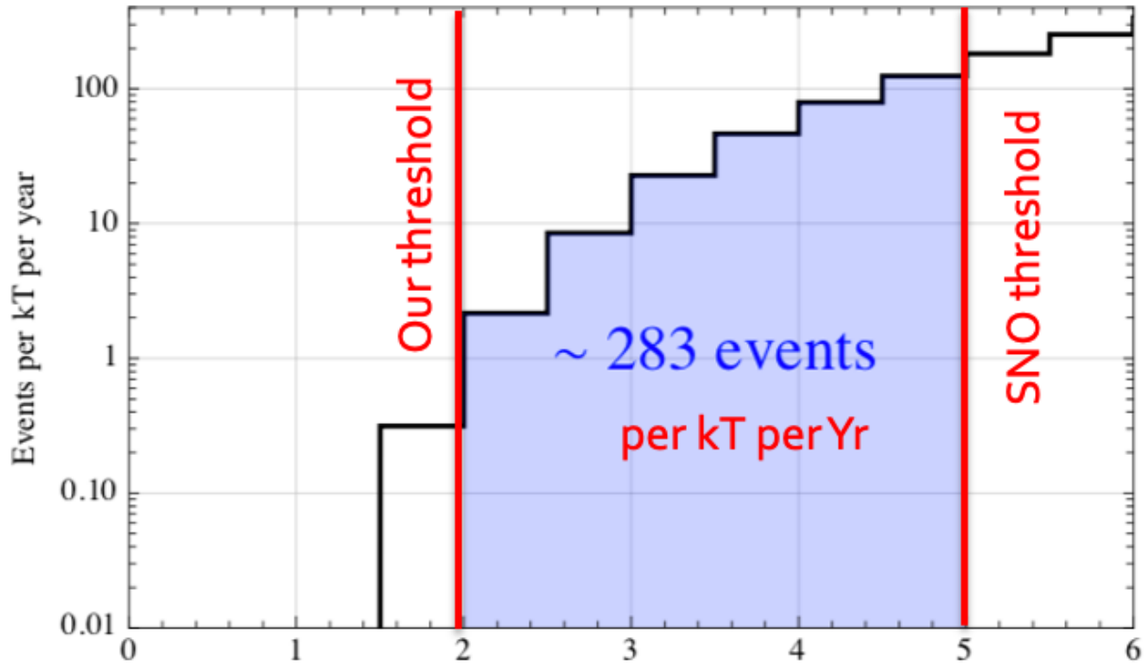
# Potential Science Case

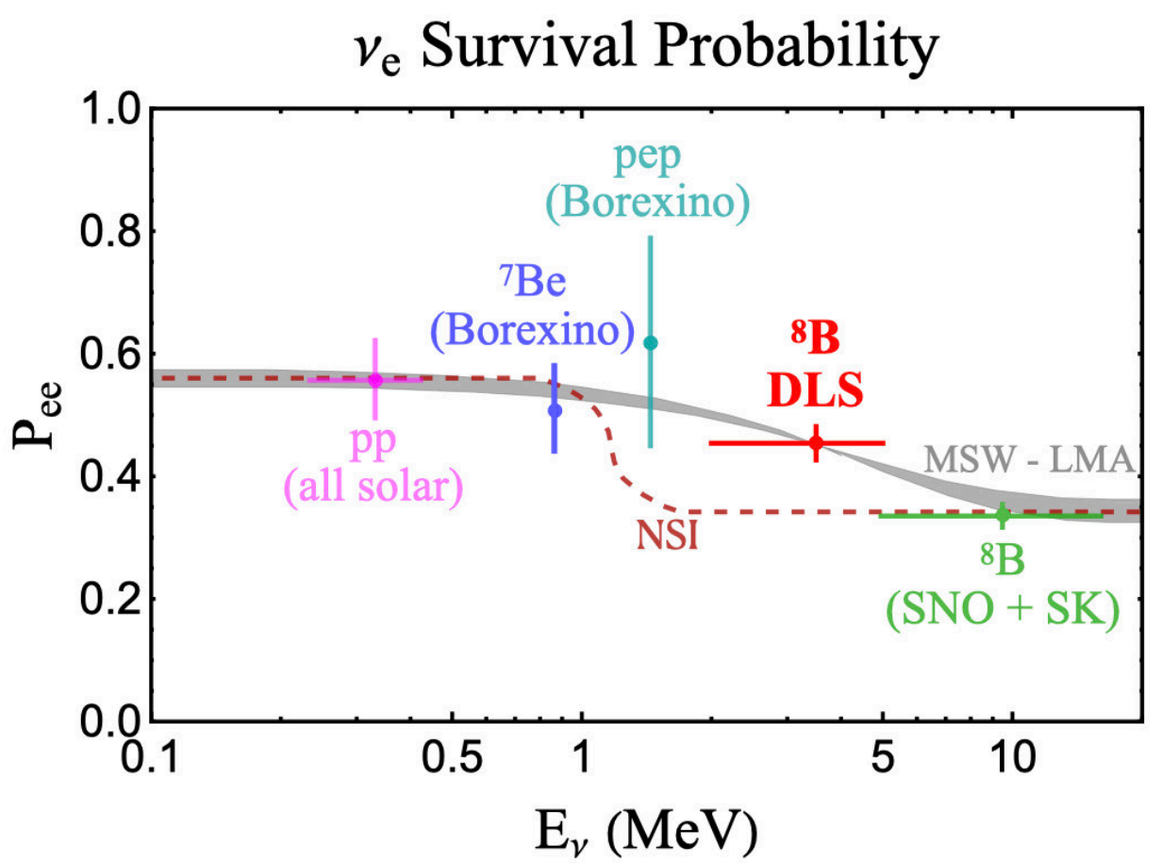
- Solar Neutrinos in the 2-5 MeV range
- Day-Night Asymmetry of Solar Neutrinos
- Unique Opportunities with Supernova Neutrinos
- Other things that other scintillator detectors do ...
- Reactor anti-nu, Sterile searches, ...
- New Ideas ???
- Possible Issues ???

# AIM 1: Solar Neutrinos at DLS

- DLS will detect electron neutrinos (+ all other flavors)
- Approximately 6% precision in survival probability with 1 kton-yr
- Can be a stringent test of the LMA-MSW solution
- May be a way to discover non-standard interactions and other exotic effects

Unique opportunity



# AIM 2: Day-Night Asymmetry

- At night neutrinos can cross the core
- Many Indian locations see substantial day-night effect
- The effect reverses sign at lower energies

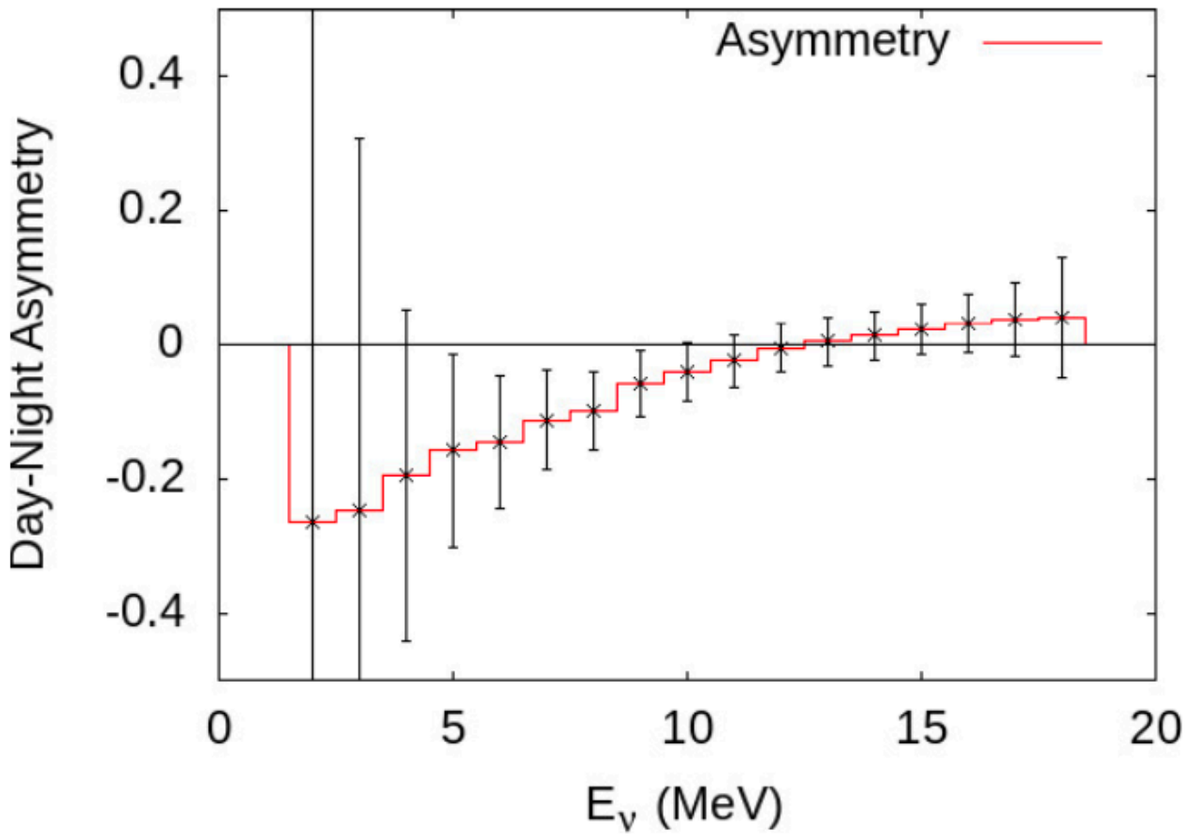
We have geographical advantage + low threshold

*2.1 Solar neutrino physics*

The current and planned solar neutrino detectors are all at latitudes above 35 degrees. These detectors have very small exposure times to neutrinos traveling through the core of the earth, about ten days in a year. The MSW phenomenon can play an important role in the regeneration of neutrinos in earth's core. To study this, it is important to build a solar neutrino detector as close to the equator as possible. India offers a possibility geographically, as well as in terms of scientific expertise, engineering expertise, manufacturing, and tall mountains which provide good shielding.

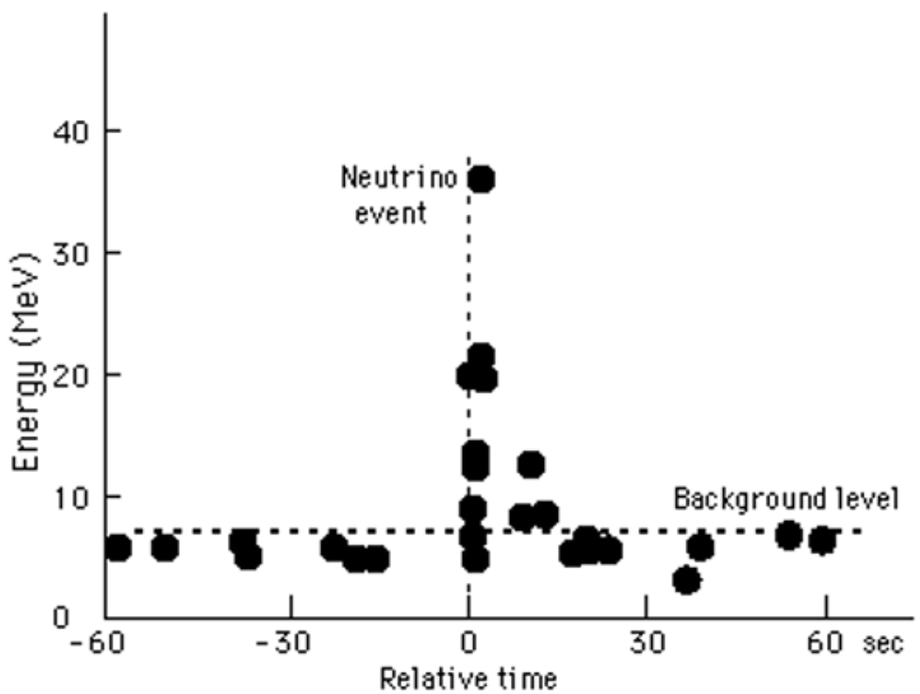
Such a detector will allow one to check the parameter range for time-of-night variation. Some effort is needed to examine the theoretical issues involved more closely. For example, there is a need to do a detailed calculation of rates, for a hypothetical detector located close to the equator, taking into account the constraints on the neutrino parameters already in existence. This effort is needed to examine the basis of justification of such a large endeavour, but preliminary indications at this workshop make it appear promising.



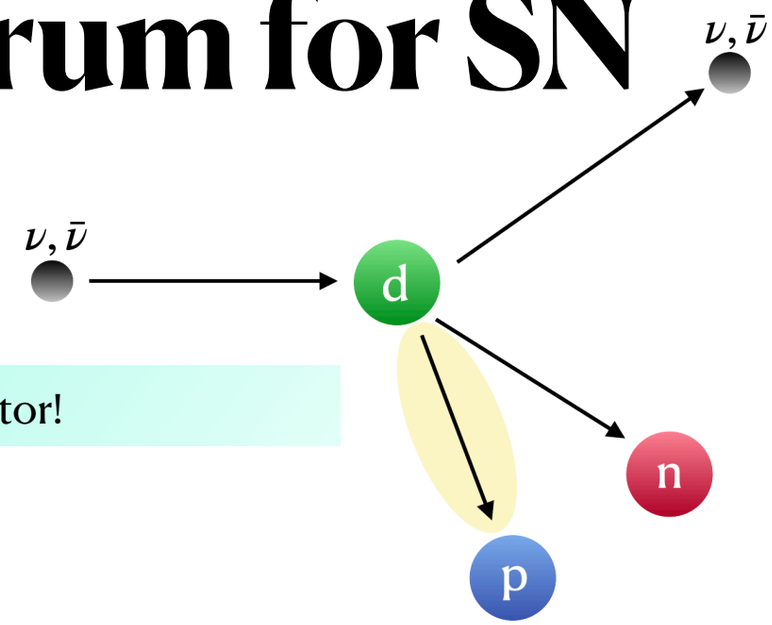


# Supernova Neutrinos

- Stars with mass > 8-10 x Sun explode as a supernova
- ~99% of the energy released is through neutrinos in ~ 10secs
- In our galaxy 1-3 / 100 yr. The last one was ~ 1900 but not seen due to dust. In 1987 a SN seen optically in nearby galaxy and also through neutrinos.

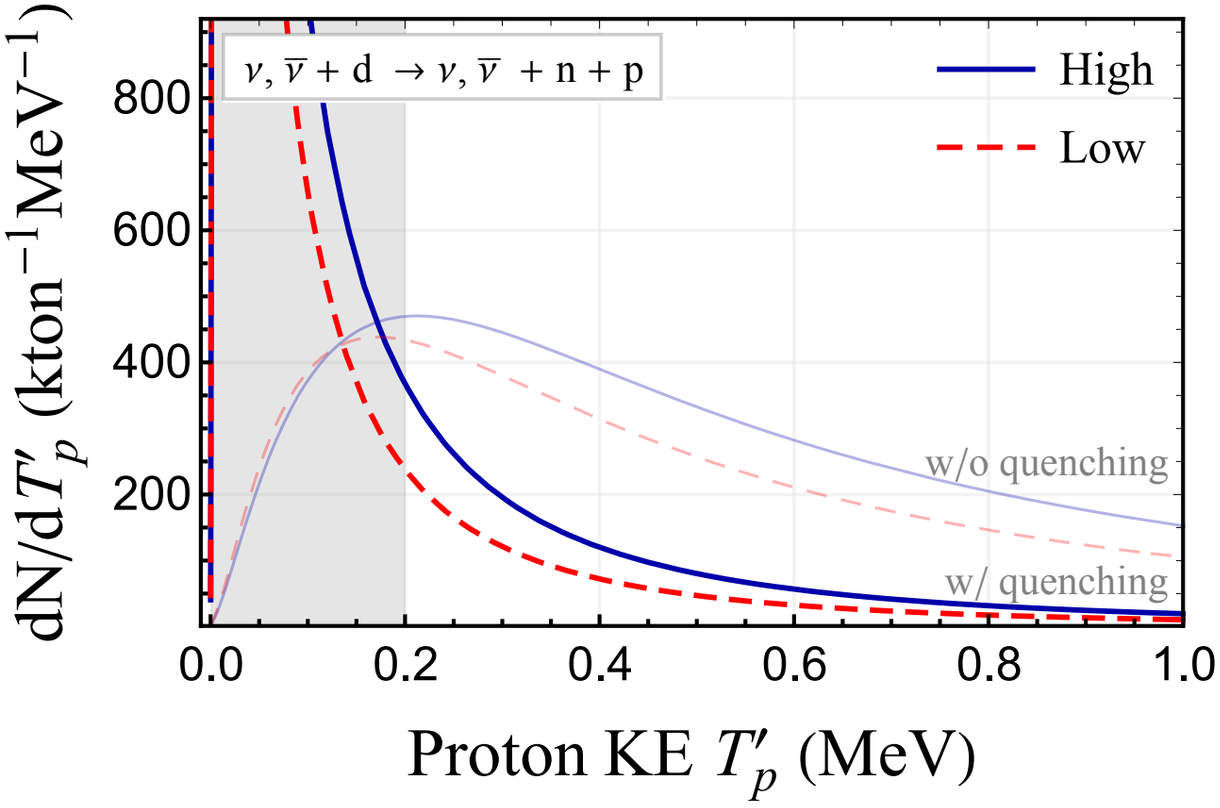
# AIM 3: All Flavor Spectrum for SN



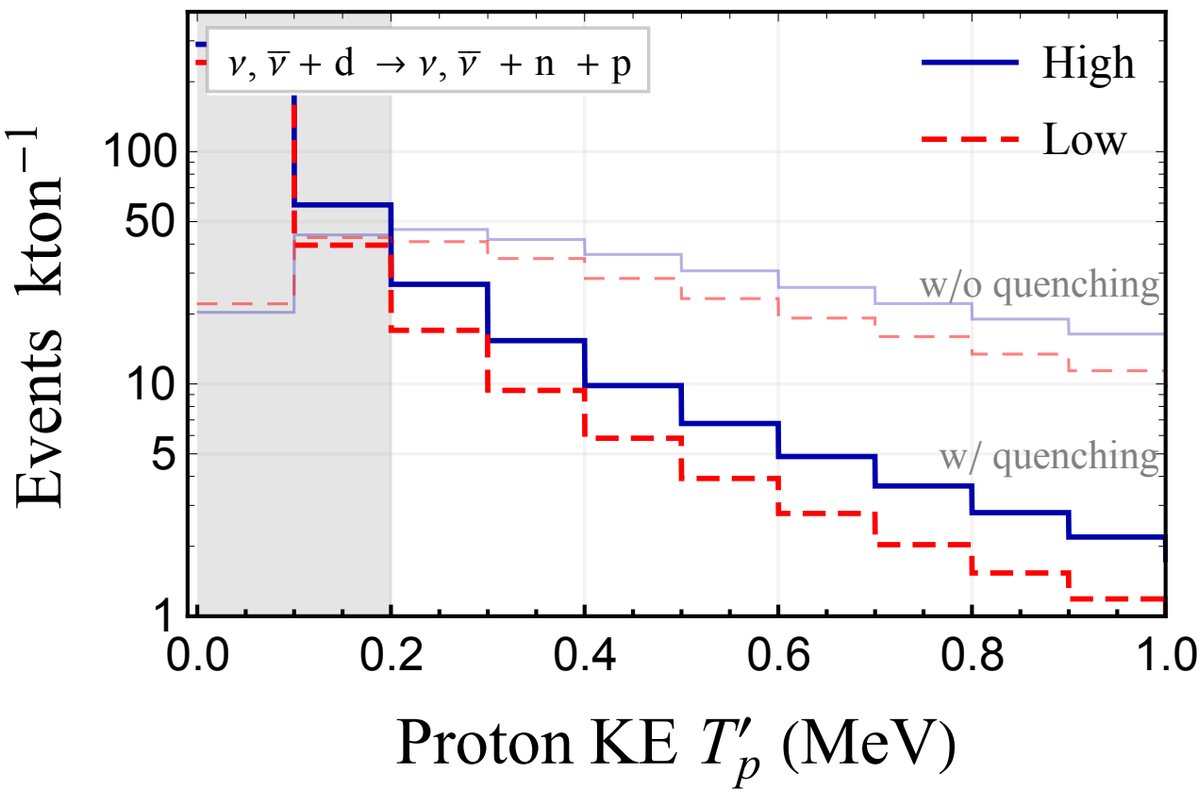

## Neutral Current

Neutron tag is possible unlike in usual scintillator!

Differential event spectrum



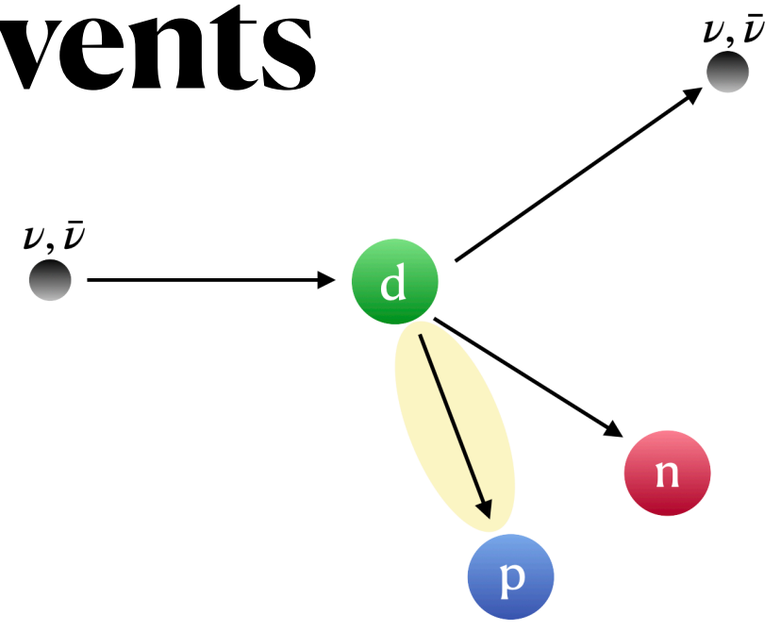

Binned events




High (Low) Fluence: 84 (50) proton above 200 keV

# Spectrum of NC events

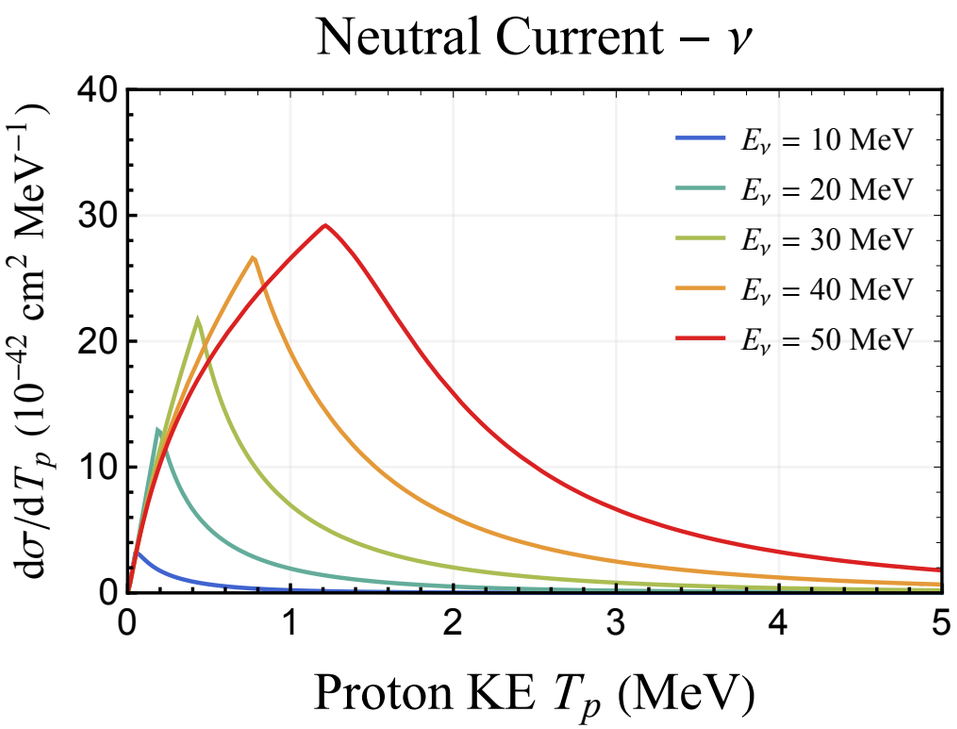
Neutral Current

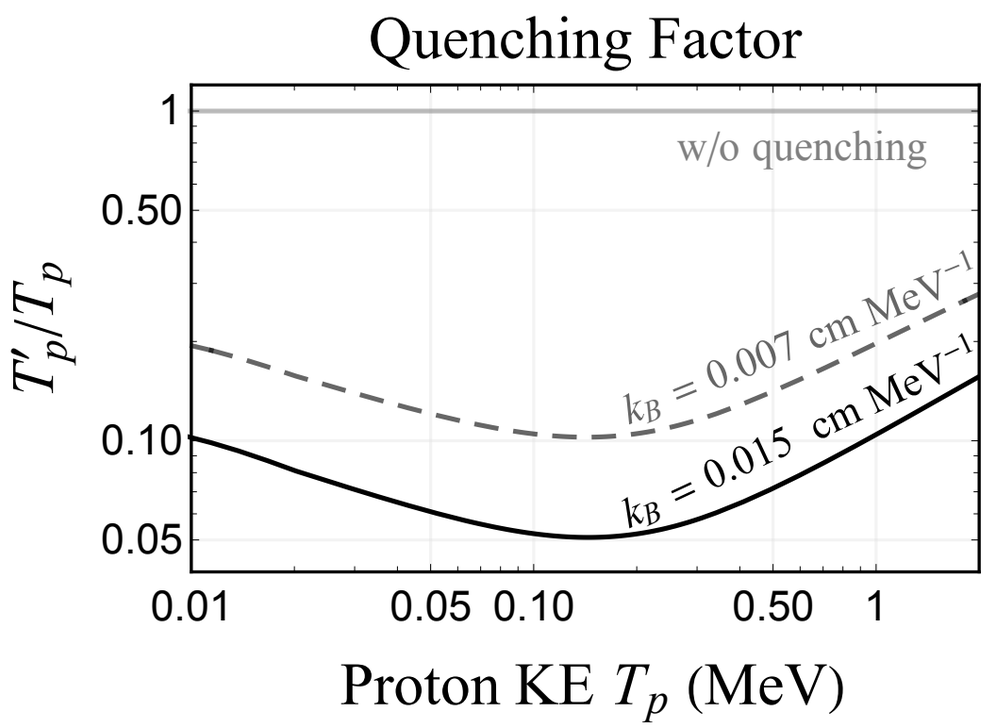



Detecting scintillation from NC channel has two issues :

1. Small momentum transfer to proton
2. Photosaturation losses / Quenching

$$E_{vis} = T'_p = Q(T_p) = \int_0^{T_p} \frac{dT}{1 + k_B \langle dT/dx \rangle}$$



# Progress Report

- Synthesis and testing of LAB scintillator + fluors, Interfacing with Detectors (Prakash Rout, Dibakar Goswami)
- Studies of DLS synthesis (LAB, DBenzene, DXylene) (Dibakar Goswami, Sandip Das)
- Low Background Setup + U/Th testing of D2O (Vandana Nanal)
- Close-loop, PMT setup WBLS (Milind Diwan)
- Detector simulation in GEANT (Deepak Samuel)
- Physics studies (BD, Vivek Datar, Indumathi, Murthy,...)
- ...

# Neutrinos, DLS, Underground Lab

- Neutrino measurements (reactor, solar, atmospheric, supernova, ...) are challenging but open a new window to the universe
- A deuterated scintillator with chemical composition ~ [$CD_2$]n offers novel scientific opportunities
  - ability to detect all flavors
  - at MeV-scale energies
  - with “tags”
  - with spectral info
- Useful for a variety of standard measurements and new physics searches
- Significant scientific and technical challenges
- ... that will certainly benefit from an underground lab