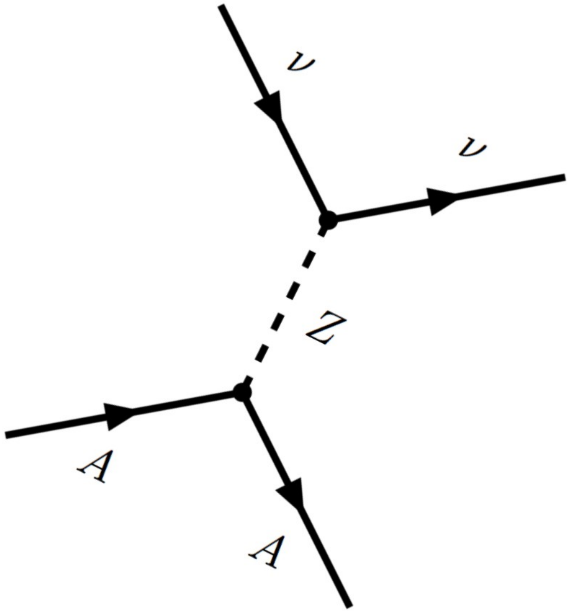
Neutrino Physics with the NEWSdm detector



Valerio Gentile

Antonia Di Crescenzo

LNGS, 2018 Feb 15th

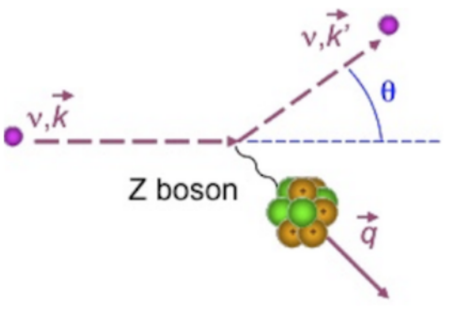
Outline

- Coherent elastic neutrino-nucleus scattering (CeνNS)
  1. Supernova neutrinos
  2. Neutrino floor
  3. Neutrinos from reactor
  4. Neutrinos from neutron spallation source (SNS)

CEνNS

Theory

A neutrino scatters off a nucleus elastically via Z-boson exchange
The nucleus recoils as a whole



RATE OF EXPECTED EVENTS

$$N(E) = \frac{dN}{dE} = \frac{M_{riv}}{Am_{uma}}\sigma(E)\mathcal{F}(E)$$

Detector mass (depending on the detector)

Neutrino cross-section

Neutrino flux (depending on the source)

Detector mass can be tuned to make an observation
The event rate depends on the neutrino flux } → $M \times T$ Key element

Maximization of the significance → $\frac{S}{\sqrt{S+B}}$

CEνNS

Cross-section

The neutrino-nucleon elastic cross-section for neutral current:

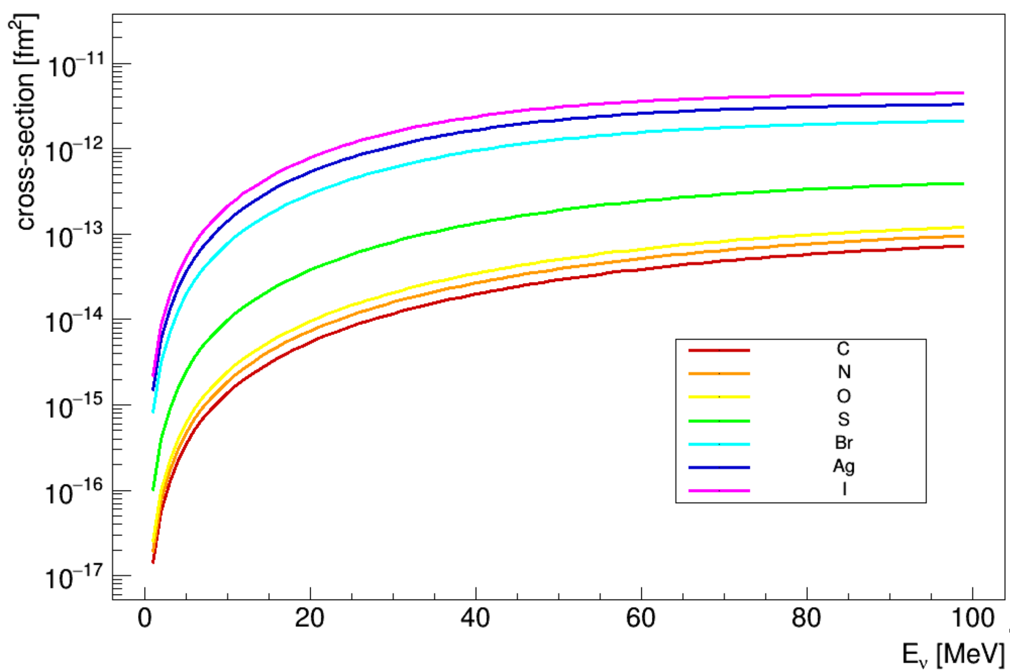
$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)$$

Cross-section vs incoming neutrino energy for NIT target elements

The cross-section enhances heavier targets more than lighter ones

But the kinematics makes lighter targets easier to detect

$$E_\nu^{\min} = \sqrt{\frac{m_N E_r}{2}}$$



1. Supernova neutrinos

Supernova Neutrinos

Source features

Differential fluence of incoming neutrinos:

$$\mathcal{F}(E) \equiv \frac{d\mathcal{F}}{dE} = \sum_{i=e,\bar{e},x} \frac{N_i}{4\pi D^2} f_i(E)$$

Neutrino flavors   Dispersion factor   Energy spectrum

Transient phenomenon, no dependence from time exposure

D is the distance from the Earth of the Supernova

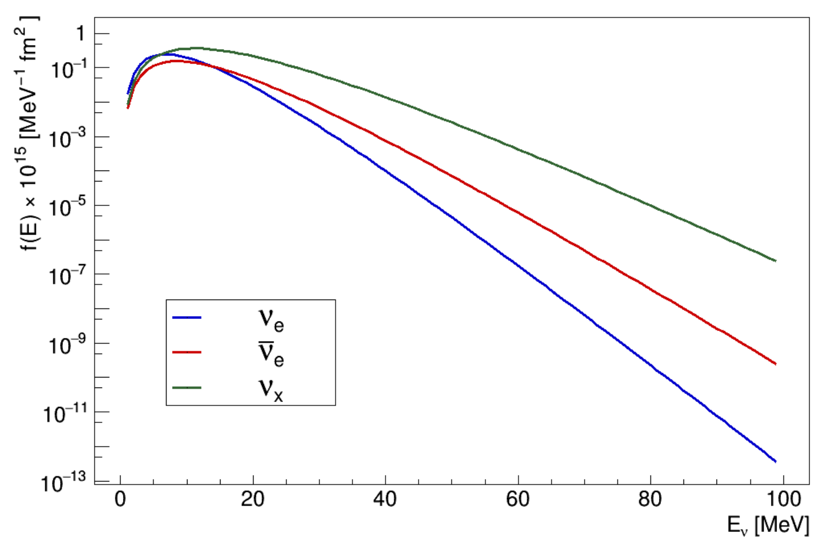
Generally is assumed $D = (10 \pm 5)$ kpc

The energy spectrum is parametrized with the alpha-fit distribution:

$$\alpha = 2.5$$
$$< E_e >= 9.5 \text{ MeV}$$
$$< E_{\bar{e}} >= 12 \text{ MeV}$$
$$< E_x >= 15.6 \text{ MeV}$$

$$f(E) = \frac{E^\alpha \beta^{\alpha+1}}{\Gamma(\alpha+1)} e^{-\beta E} \quad \text{con} \quad \beta = \frac{\alpha+1}{\langle E \rangle}$$

Fluences for the 3 neutrino species



Supernova Neutrinos

Event rate

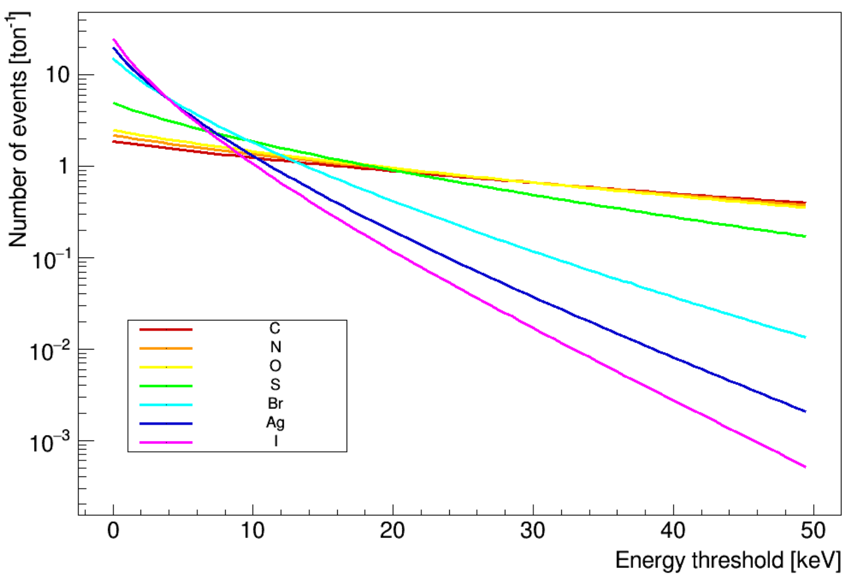
The event rate depends on the energy threshold of the detector

For NIT emulsion it means track length threshold

For carbon nucleus:

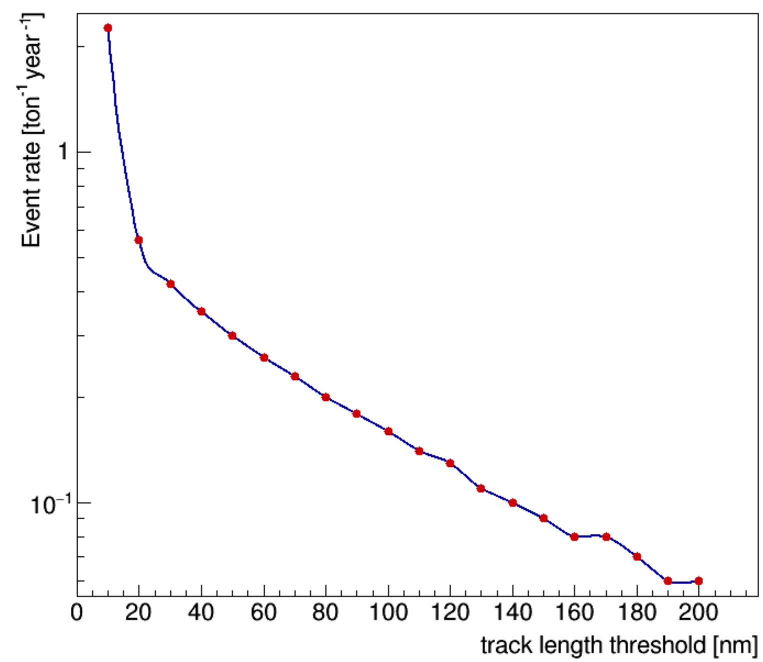
(~ 35 keV for 100 nm)

(~ 17 keV for 50 nm)



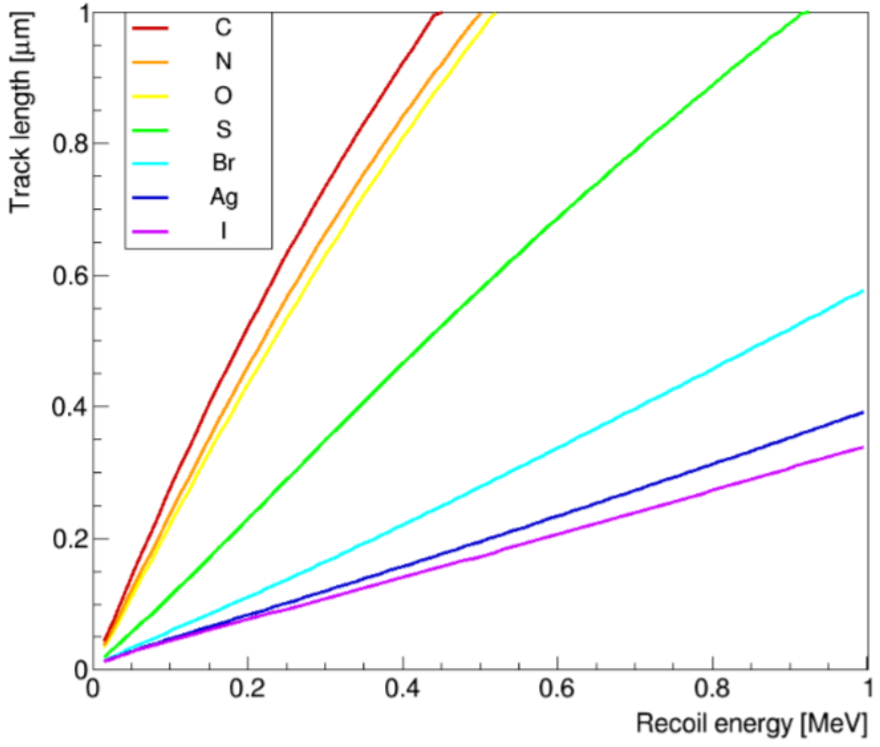
Total number of events of supernova neutrino induced recoils per ton of active mass, as a function of the energy threshold on the recoiling nucleus

Event rate of supernova neutrino induced recoils as a function of the track length threshold

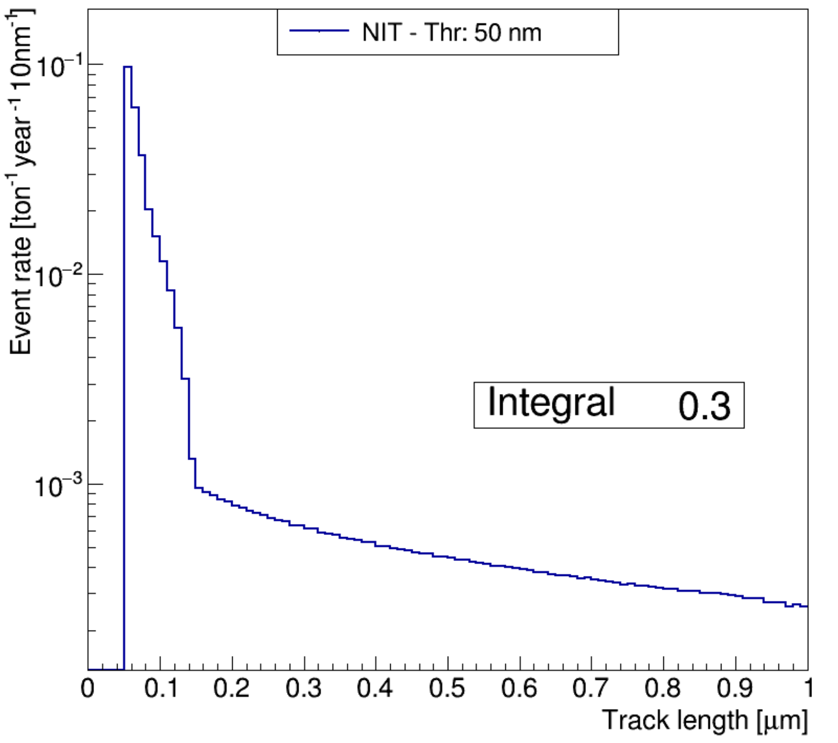


Supernova Neutrinos

Track length



Track length versus transferred energy for the target nuclei of NIT emulsions. Lighter nuclei can produce track lengths up to a few microns, while heavier ones only a few hundreds nanometers.



Track length distribution in NIT emulsions of supernova neutrino induced recoils in the range [0.05,1] um. The distribution is normalized to the number of expected events in one ton of active mass

Supernova Neutrinos

Number of expected events

SN induced recoil rate

$D = 8kpc$	
SR: [50 – 200]nm	
Element	Rate [ton^{-1} y^{-1}]
Ag	$\mathcal{O}(10^{-7})$
Br	$\mathcal{O}(10^{-4})$
I	$\mathcal{O}(10^{-9})$
C	0.12
N	0.03
O	0.09
S	$\mathcal{O}(10^{-3})$
TOT	0.24

Assumption:
Intrinsic neutron yield: 1 ton^{-1} y^{-1}
External neutron bkg: shielded
No intrinsic contamination from e^-
Signal region (SR): (50 – 200) nm

Background sources

- Expected events from intrinsic neutrons: ~ 0.13 ton^{-1} y^{-1}
- Expected events from ^{8}B neutrinos: ~ 0.18 ton^{-1} y^{-1}

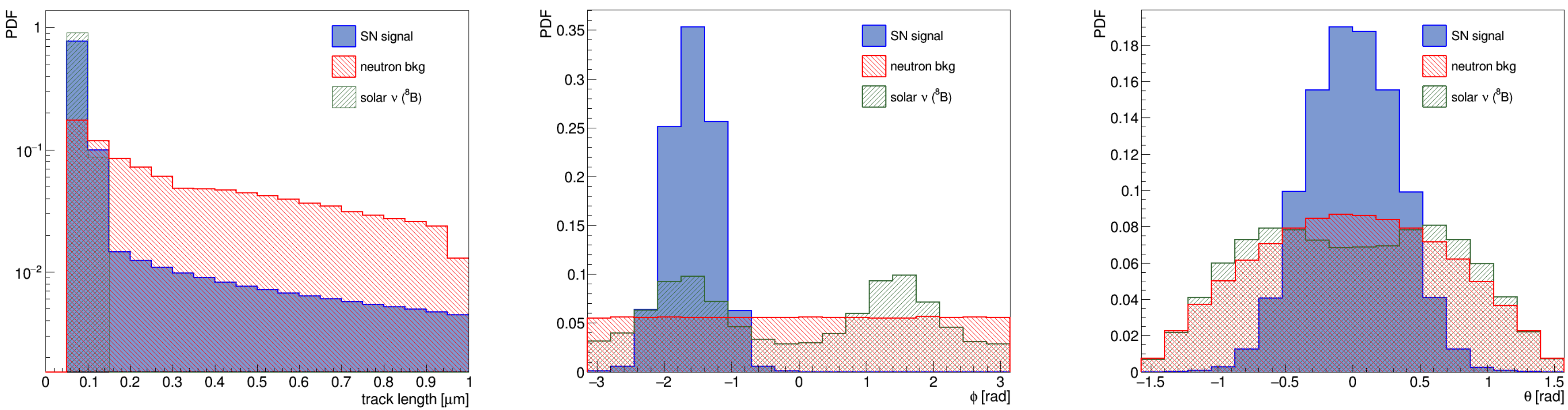
EXPECTED EVENTS FOR 30T DETECTOR

- SN: 7.2
- BKG: 9.3 y^{-1}

Supernova Neutrinos

Probability density function

PDFs of the induced recoils for each source



A Profile Likelihood Ratio Test has been performed to evaluate the capability of NEWSdm detector to distinguish the SN neutrino induced recoil from background events

$$\mathcal{L} = \frac{(\mu_s + \mu_b)^N}{N!} e^{-(\mu_s+\mu_b)} \times \prod_{i=1}^{N} \left(\frac{\mu_s}{\mu_s + \mu_b} \prod_j S(x_{ij}) + \frac{\mu_b}{\mu_s + \mu_b} \prod_j B(x_{ij}) \right),$$

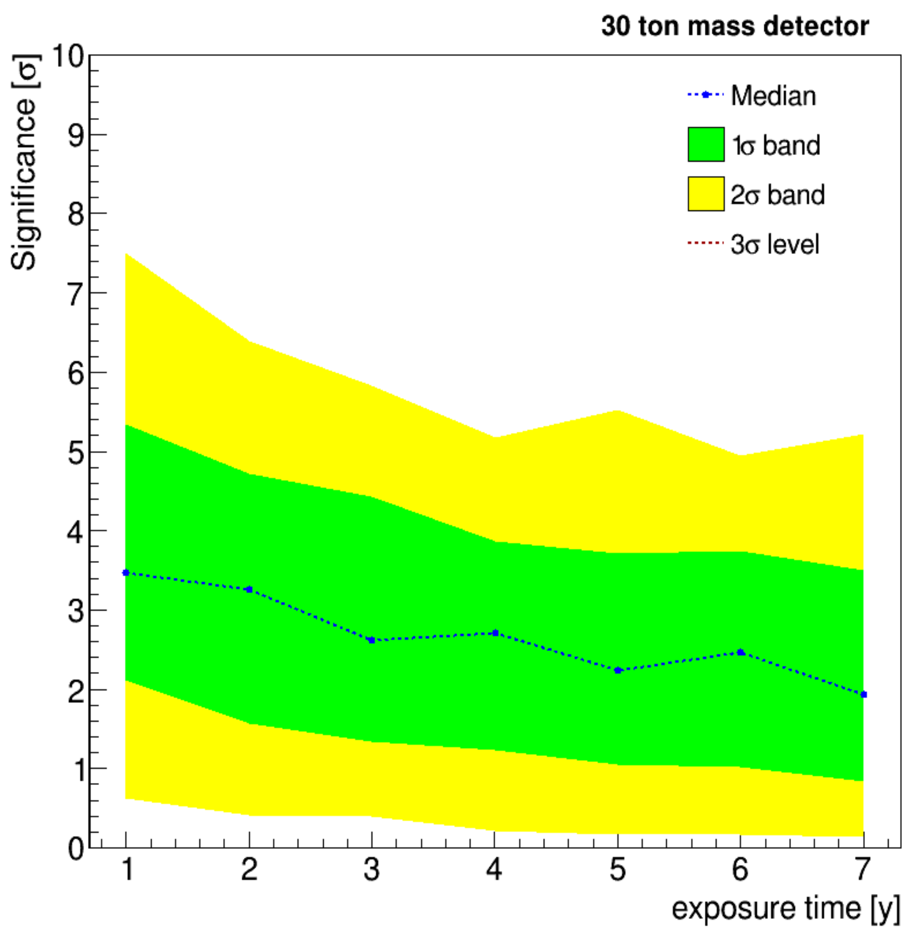
H_0 : only background

H_1 : signal plus background

Supernova Neutrinos

Significance of the observation

The significance of the test statistics has been studied using the `ROOFIT` toolkit



The shorter the exposure time the larger the significance of the signal, since the number of background events increase with the time while the supernova explosions are a transient phenomena

The median expectation is larger than 3σ for exposures shorter than 2 years and larger than 2σ up to 7 years

Solar Neutrinos from ^{8}B

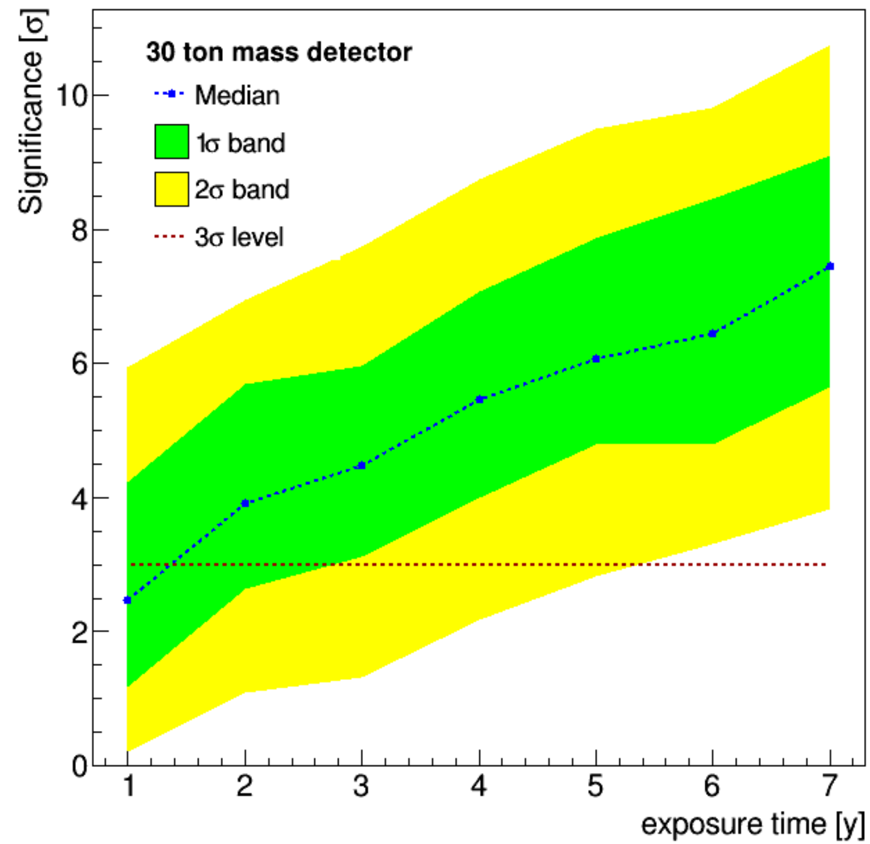
Significance of the observation

A Profile Likelihood Ratio Test has been performed also to evaluate the capability of NEWSdm detector to distinguish the solar neutrino from 8B induced recoil from neutron induced recoils

SIGNAL: Solar neutrinos from 8B

BACKGROUND: Intrinsic neutrons

The larger the exposure time the larger the significance of the signal, since the signal to noise ratio increase with the time



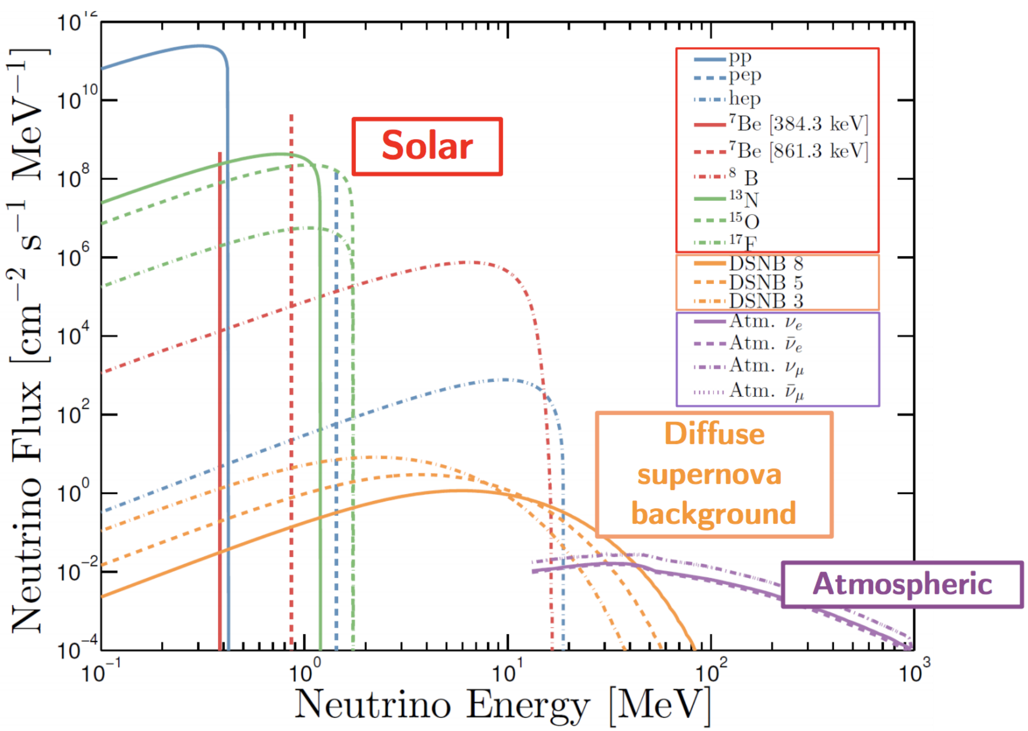
The median expectation is larger than 3σ for exposures longer than 2 years

2. Neutrino floor

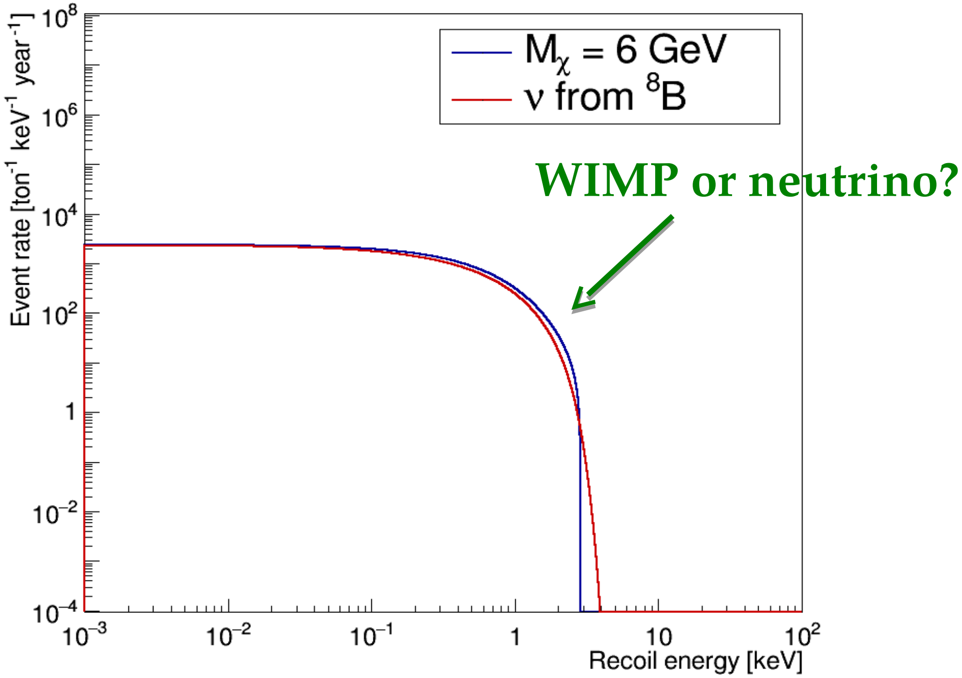
Neutrino Floor

Neutrino flux at Earth based detector

Neutrino energy spectra that are backgrounds to direct detection experiments: solar, atmospheric, and the diffuse supernova background



Neutrino scattering off nuclei can mimic WIMP scattering



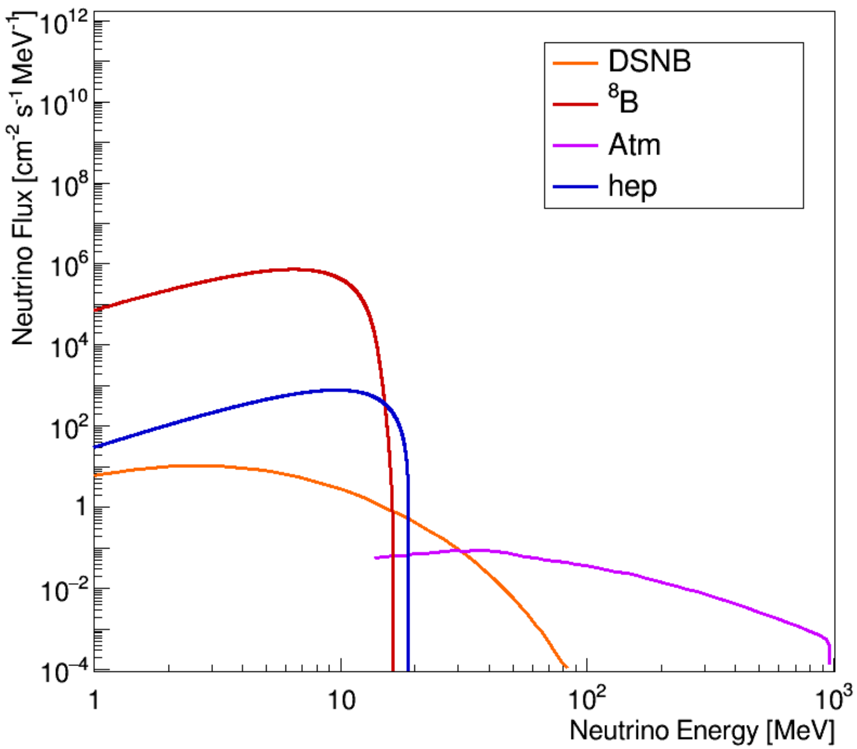
For a Xe target

(cfr. PRD 94 (2016) 063527)

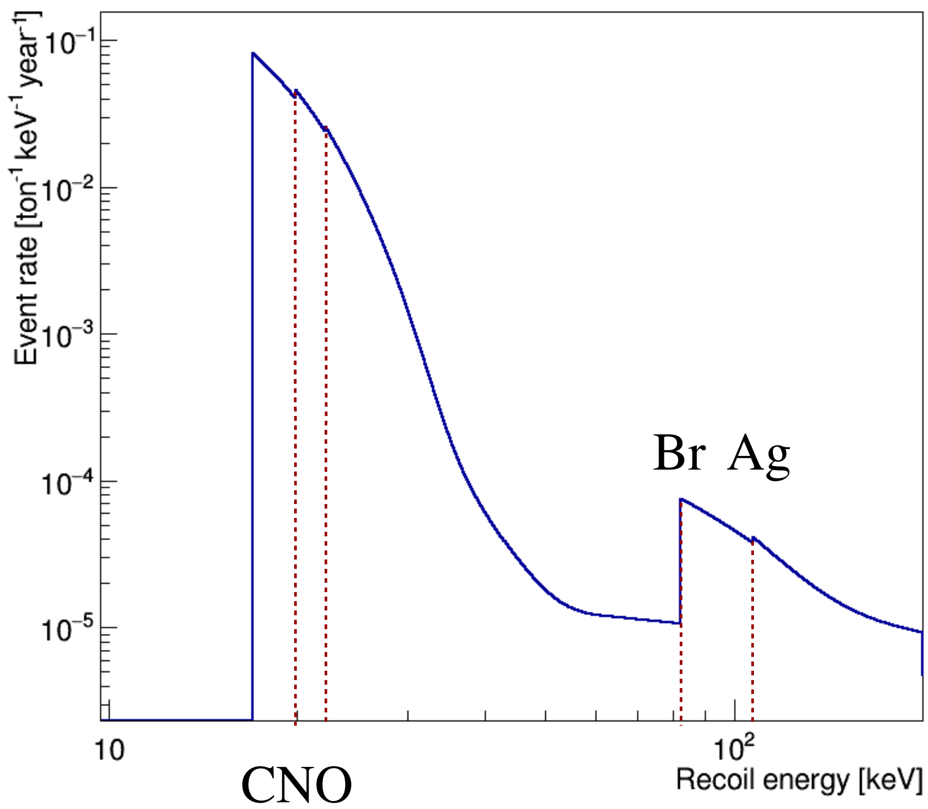
Neutrino Floor

Case study: NEWSdm detector

Components of the neutrino spectrum relevant for the NEWSdm detector (track lengths > 30 nm)



Number of neutrino-induced nuclear recoils in NIT emulsions
Threshold: 50 nm



Neutrino Floor

Case study: NEWSdm detector

How to build the neutrino floor:

1. For a given threshold, evaluate the number of neutrino-induced recoils above the threshold
2. Adjust the exposure in such a way that the number of expected neutrino events is one for a give threshold

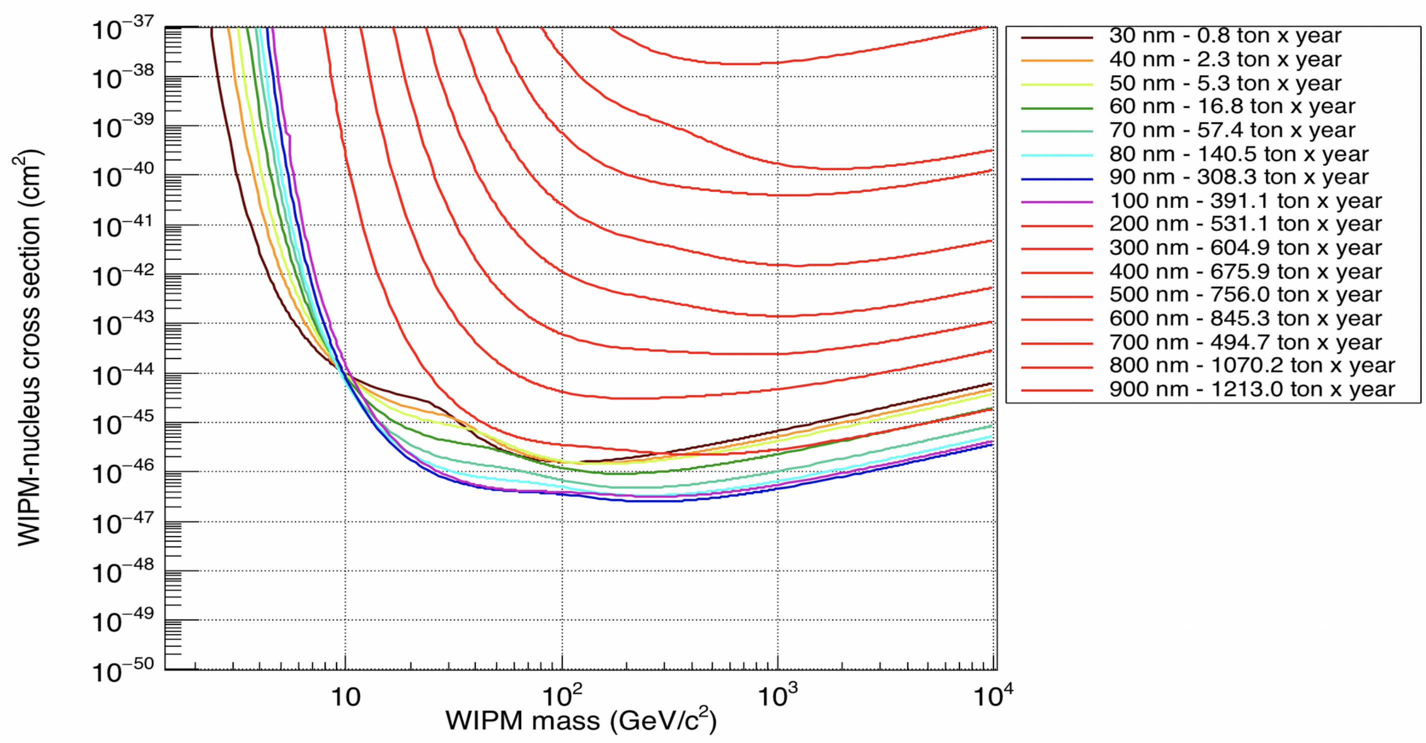
Threshold (nm)	Exposure (ton x year)
30	0.8
40	2.3
50	5.3
60	16.8
70	57.4
80	140.5
90	308.3
100	391.1
200	531.1
300	604.9
400	675.9
500	756.0
600	845.3
700	494.7
800	1070.2
900	1213.0

Neutrino Floor

Case study: NEWSdm detector

How to build the neutrino floor:

1. For a given threshold, evaluate the number of neutrino-induced recoils above the threshold
2. Adjust the exposure in such a way that the number of expected neutrino events is one for a give threshold
3. For that exposure, evaluate the upper limit on the WIMP-nucleus scattering cross-section as a function of the WIMP mass

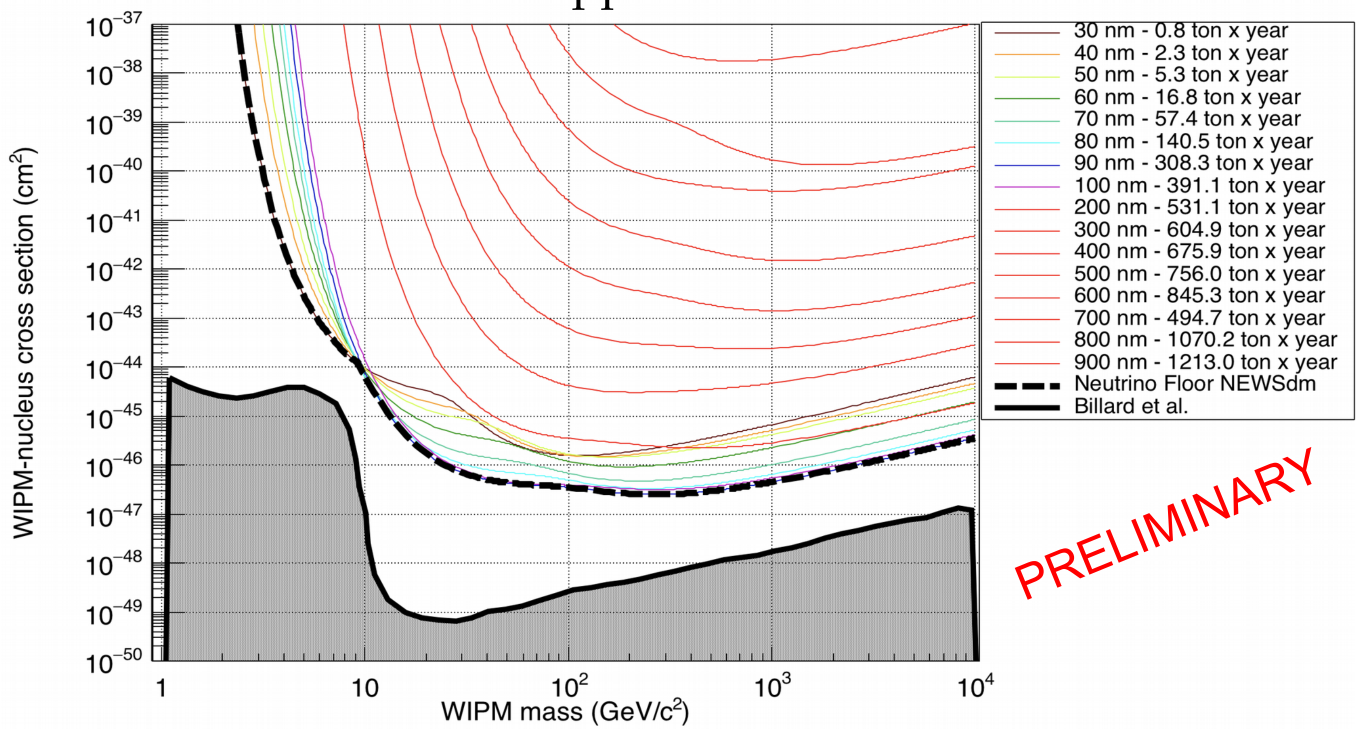


Neutrino Floor

Case study: NEWSdm detector

How to build the neutrino floor:

1. For a given threshold, evaluate the number of neutrino-induced recoils above the threshold
2. Adjust the exposure in such a way that the number of expected neutrino events is one for a give threshold
3. For that exposure, evaluate the upper limit on the WIMP-nucleus scattering cross-section as a function of the WIMP mass
4. Neutrino floor: minimum of the upper limits of all thresholds



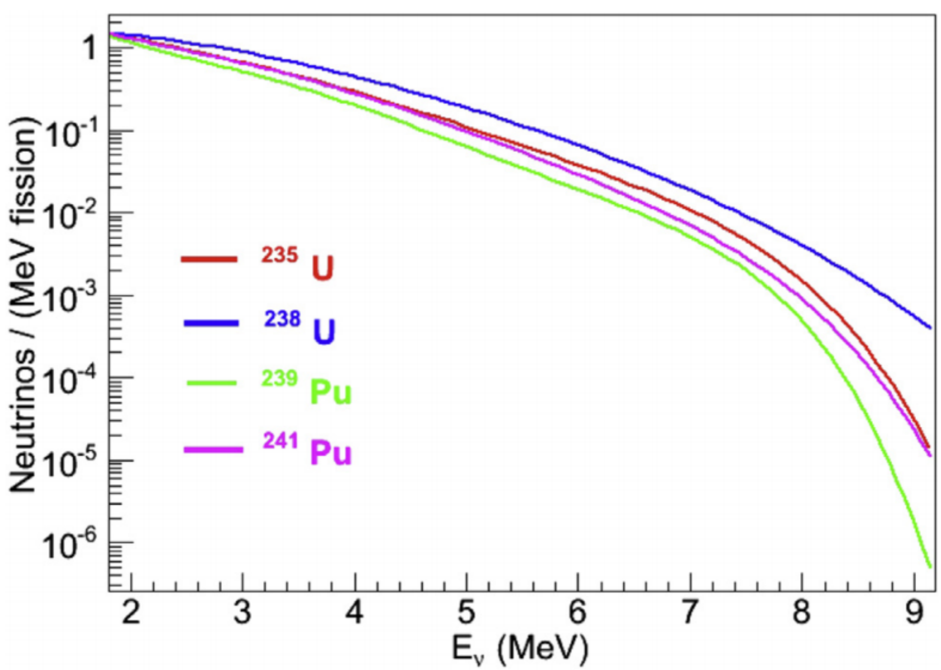
3. Neutrino from reactor

Neutrinos from reactor

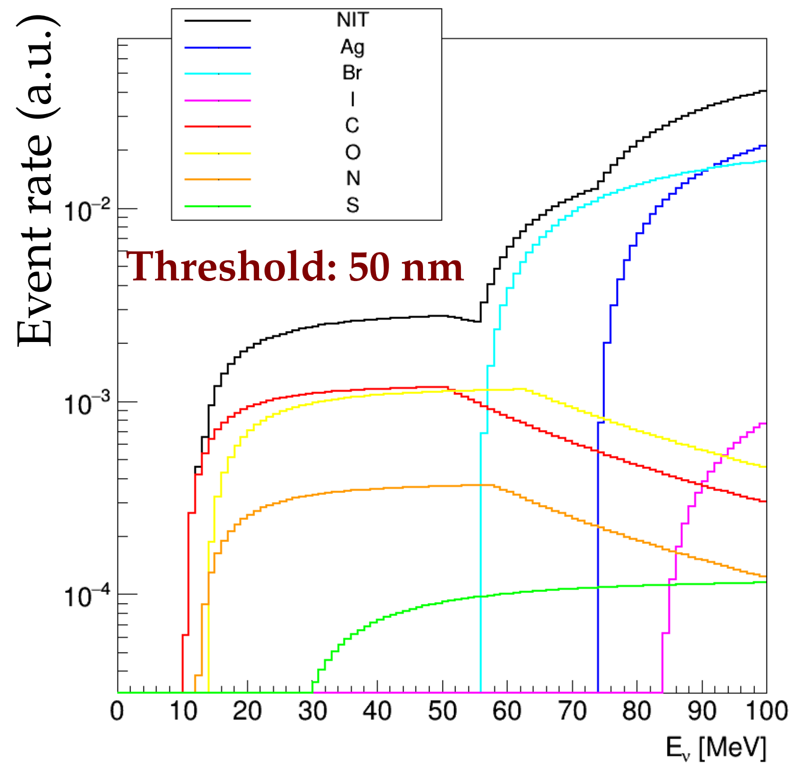
Energy spectrum and facility

Investigation of the possibility to observe CEνNS using reactors as neutrino source

Neutrino energy spectra at reactors
End-point at around 9 MeV



Event rate of neutrino-induced recoils
as a function of neutrino energy



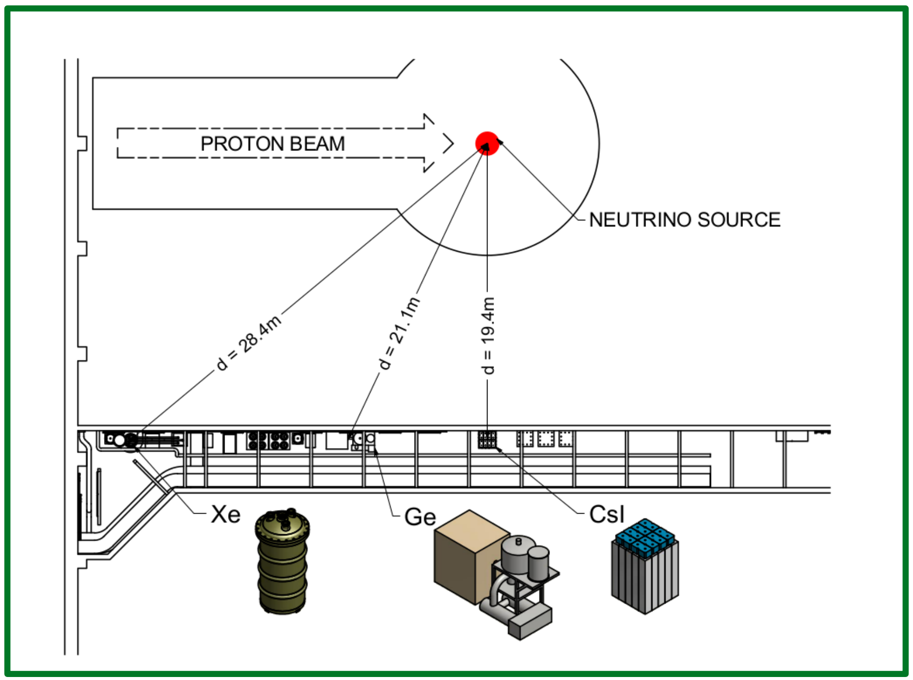
Recoils visible in NIT (L>50 nm) for neutrino energies higher than 10 MeV
No chance to observe CEνNS from reactors

4. Neutrinos from neutron spallation source

Neutrinos from SNS

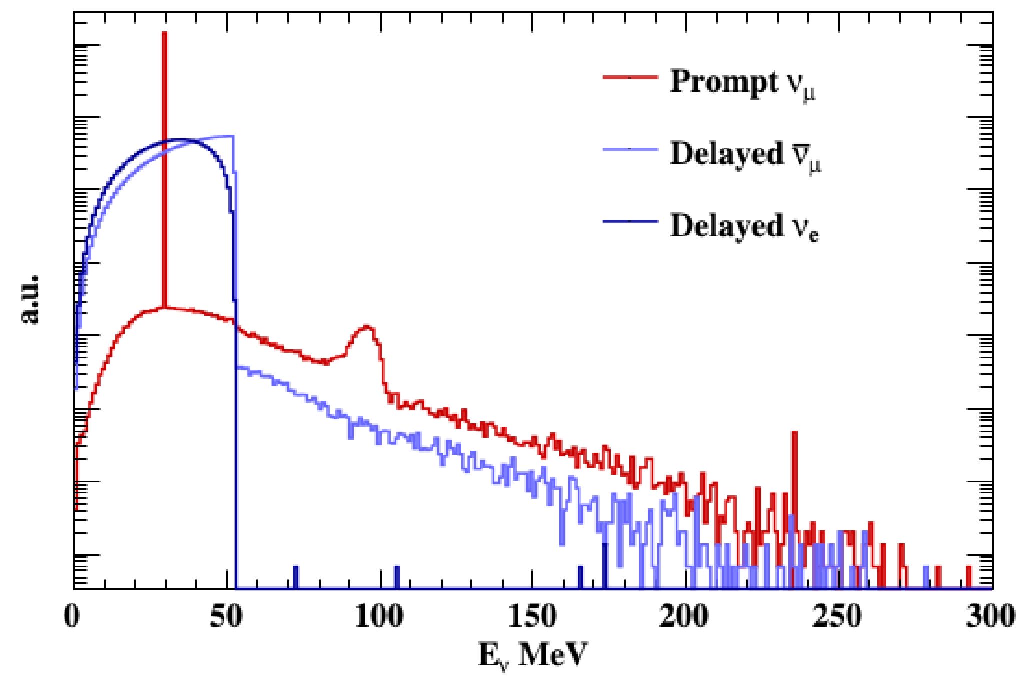
Oak Ridge facility and energy spectrum

Study of CEνNS using neutrinos provided by spallation neutron source at Oak Ridge National Laboratory



Proposed siting in the SNS basement hallway by the Coherent experiment

D. Akimov et al 2017 J. Phys.: Conf. Ser. 798 012213



Expected ν spectrum at the SNS

Total flux: 4.3×10^7 ν /cm^2 /s at 20 m

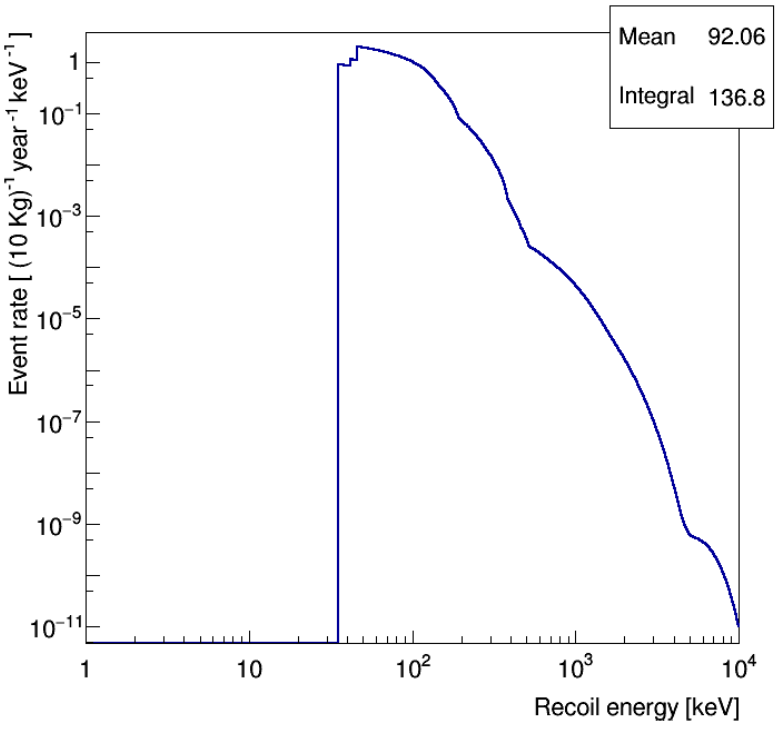
Neutrinos from SNS

Preliminary results

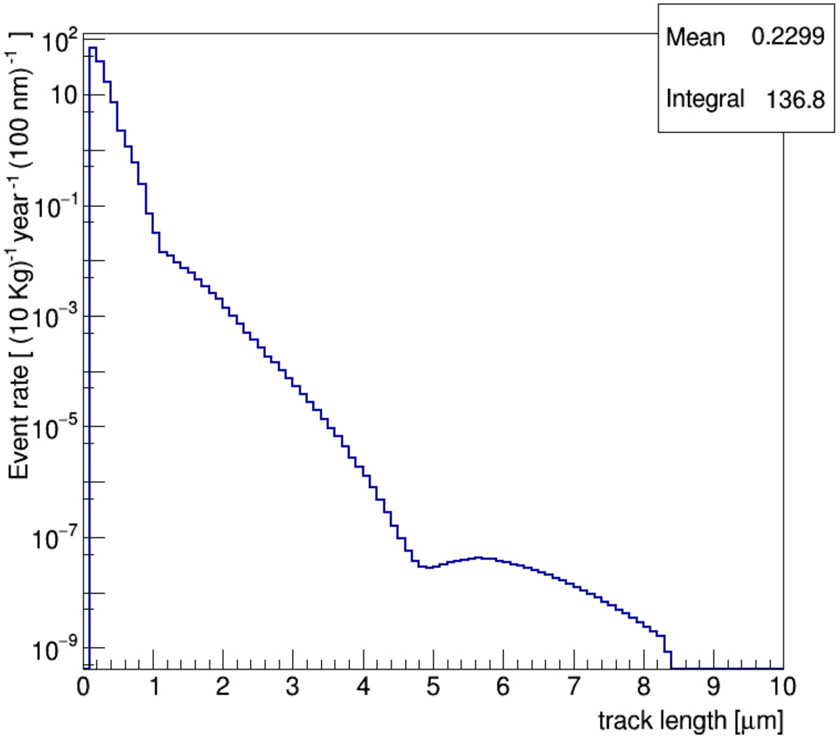
Event Rate

Mass exposure: 10 Kg x year	
Threshold: $L \geq 100$nm	
Ag	$\mathcal{O}(10^{-4})$
Br	$\mathcal{O}(10^{-3})$
I	$\mathcal{O}(10^{-6})$
C	70.8
N	18.2
O	47.6
S	0.1
TOT	136.7

Event rate vs recoil energy



Event rate vs track length



The number of expected events is about 136 per 10 Kg per year

CEνNS

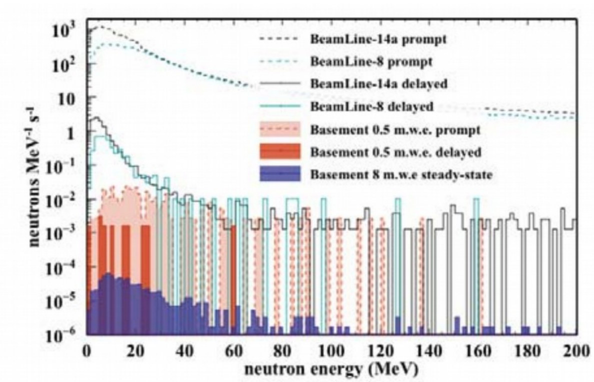
Conclusions and perspectives

- Study of NEWSdm capability to detect coherent elastic neutrino-nucleus scattering (CeνNS)

  1. Supernova neutrinos can be observed with >3 sigma with a 30T mass detector and an exposure shorter than 2 years
  2. Preliminary evaluation of neutrino floor for an emulsion detector
  3. Neutrinos from reactor cannot be observed in NEWSdm due to low energy spectrum
  4. Neutrinos from neutron spallation source (SNS):

     About 136 events expected for 10 kg*year exposure

     Next step: evaluation of neutron background →



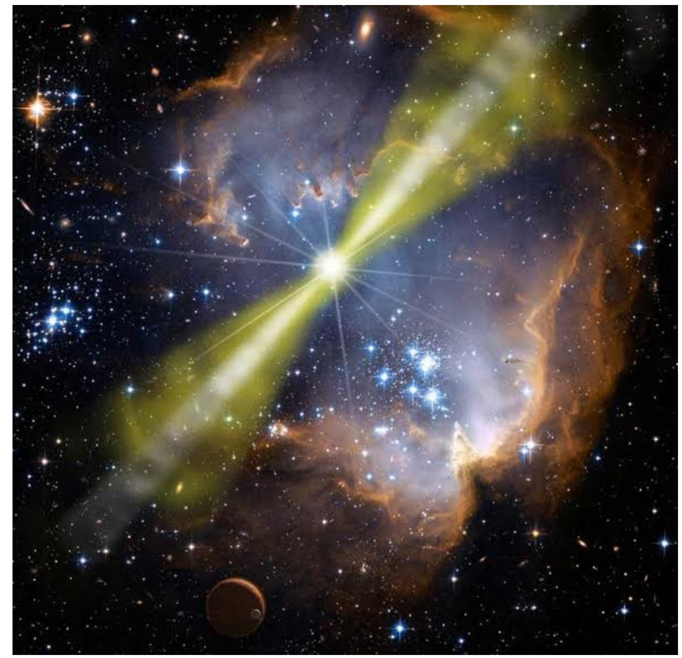
J. Phys. Conf. Ser. 888 (2017) 012152

Thank you

Backup slides

Supernova Neutrinos

Motivation



The explosion of a Supernova is one of the most energetic phenomenon observable in the Universe.

Neutrinos coming from supernovae are largely investigated since they carry almost the total energy emitted by the source and are weakly interacting.

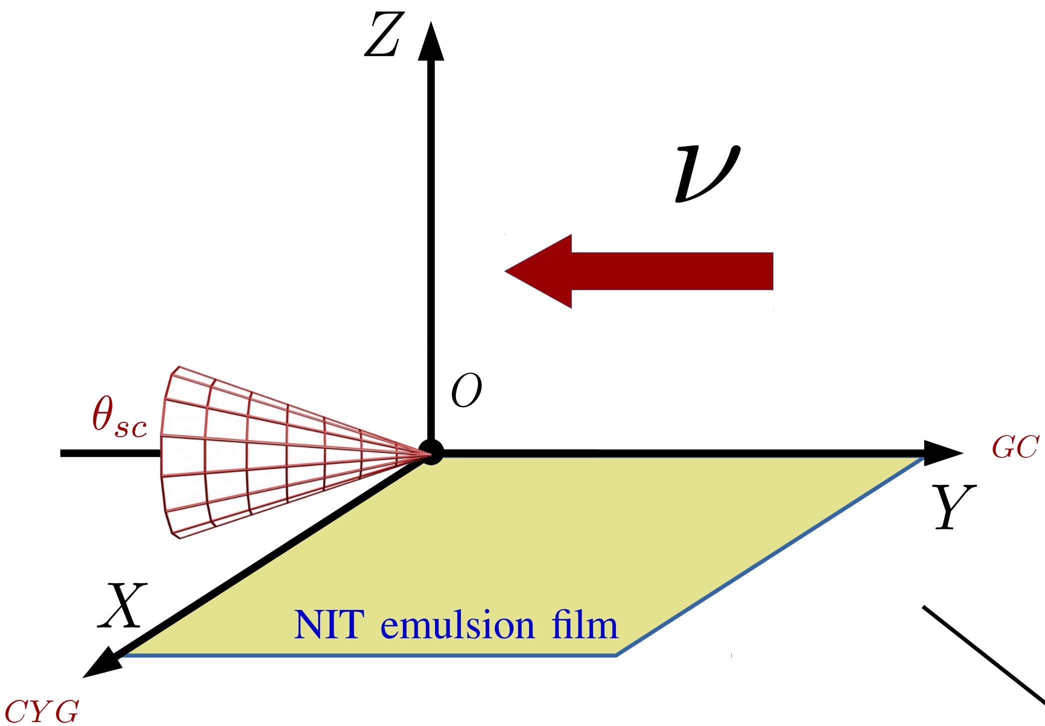
They could directly explain the underlying processes inside a star leading to the supernova explosion.

A directional detector like NEWSdm could detect supernova neutrinos taking advantage of the angular distribution of the induced recoils.

The capability to observe supernova neutrino events for a ton-scale detector based on NIT emulsion is described.

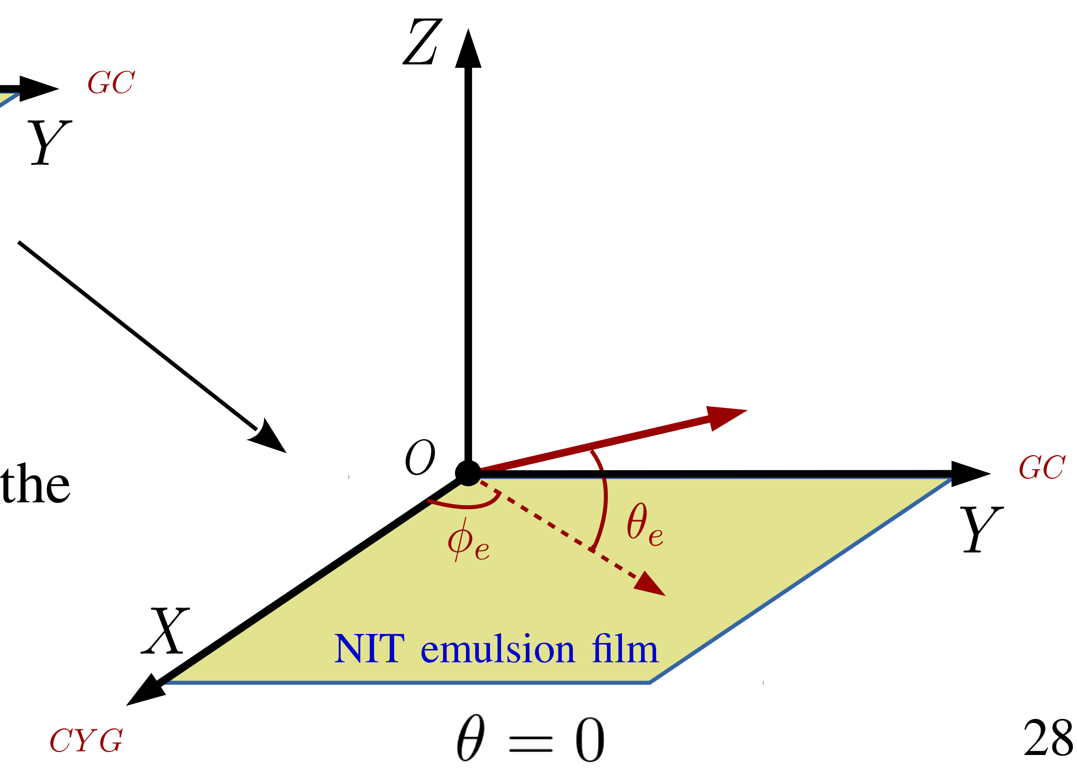
Supernova Neutrinos

Reference frame and angles



Recoils are scattered in a cone of aperture θ_{sc}

$$\cos\theta_{sc} = \frac{E_\nu + M}{E_\nu}\sqrt{\frac{K}{2M}},$$

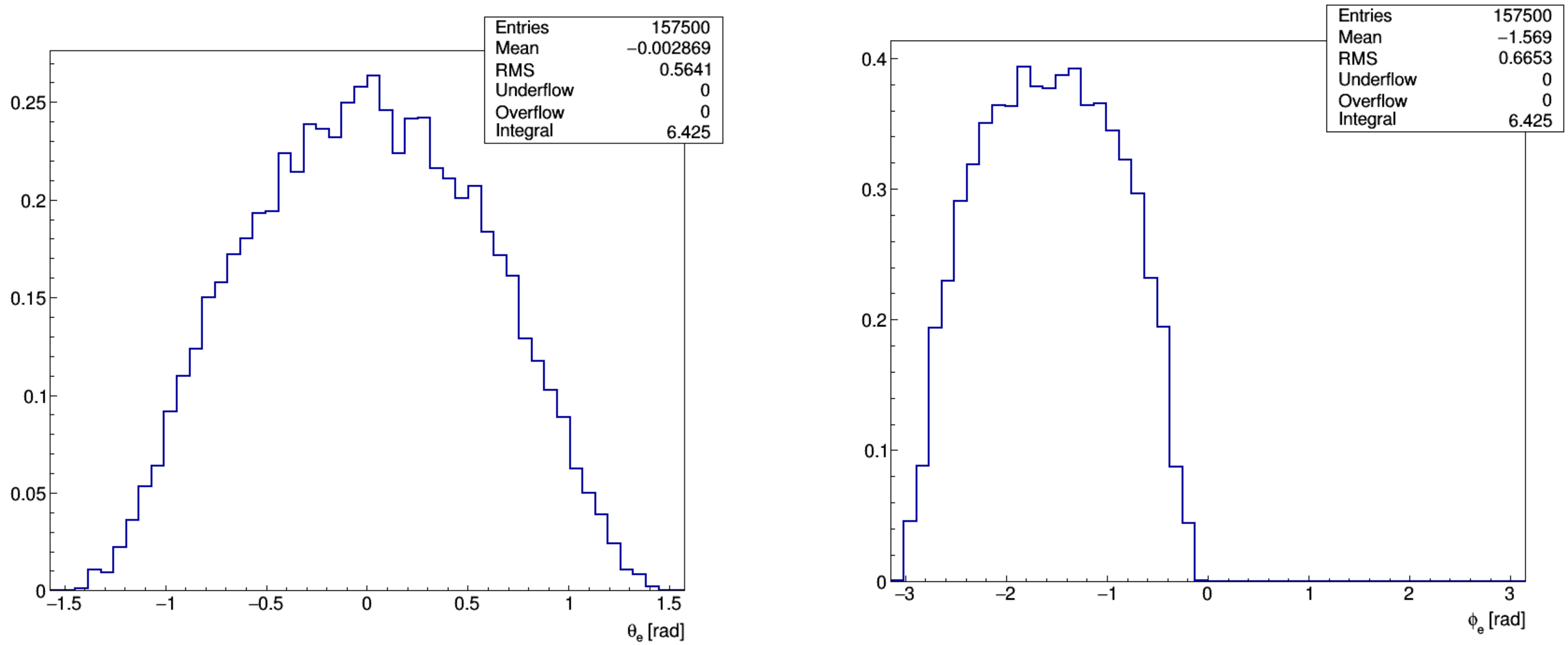


θ_e Inclination angle with respect to the xy plane (galactic plane)

ϕ_e Rotation angle in the xy plane

Supernova Neutrinos

Angular distributions



Theta and phi angle distributions of supernova neutrino induced recoils in the NEWSdm detector. The induced recoils are scattered mainly in the direction ($\theta_e = 0$) and opposite to the incoming supernova neutrino direction

Supernova Neutrinos

Background sources

Assumption:
Intrinsic neutron yield: 1 ton^{-1} y^{-1}
External neutron bkg: shielded
No intrinsic contamination from e^-
Signal region (SR): (50 – 200) nm

Recoils induced by intrinsic neutrons:

- Isotropic angular distribution
- Track length threshold at 50 um
- Expected events from simulation: ~ 0.13 ton^{-1} y^{-1}

Recoils induced by solar neutrinos from 8B:

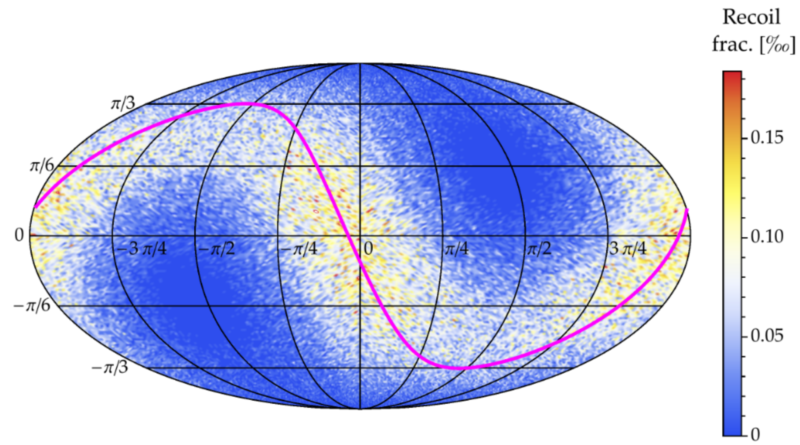
- Complex angular distribution

- and the Earth's orbital velocity relative to the Sun:

Lewin-Smith

$$u_{E_x} = u_E(\lambda) \cos\beta_x \sin(\lambda - \lambda_x),$$
$$u_{E_y} = u_E(\lambda) \cos\beta_y \sin(\lambda - \lambda_y),$$
$$u_{E_z} = u_E(\lambda) \cos\beta_z \sin(\lambda - \lambda_z)$$

- Track length less at 50 um
- Expected events from simulation: ~ 0.18 ton^{-1} y^{-1}



Mollweide projection in a Galactic-like coordinate system of the induced recoils from 8B solar neutrinos