Understanding solar ES signals and their backgrounds

Low Energy Physics Meeting - DUNE

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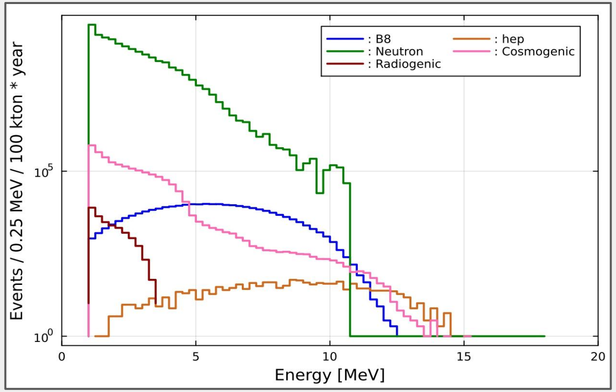
Low energy signals in DUNE

⇒ Estimation of the different signals : Solar neutrinos, neutron & cosmogenic backgrounds

Solar neutrino flux :
CC chanel events : B8 ⇒ 215 000 & Hep ⇒ 1 200 (for 100kton*year ≈ 10kton*10years)

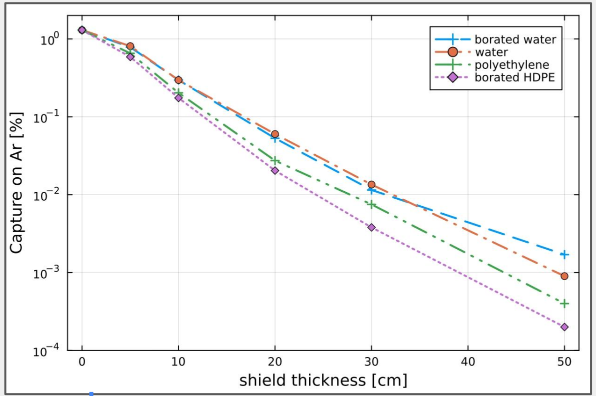
Background :
Neutron background : ≈ 2.13×10^9 neutron captures in LAr /100 kt *year
⇒ Much higher than the neutrino flux
Cosmogenic Background ⇒ Important below 5 MeV and equivalent to Hep above 12 MeV



Energy spectra of the different signals (former cluster method)

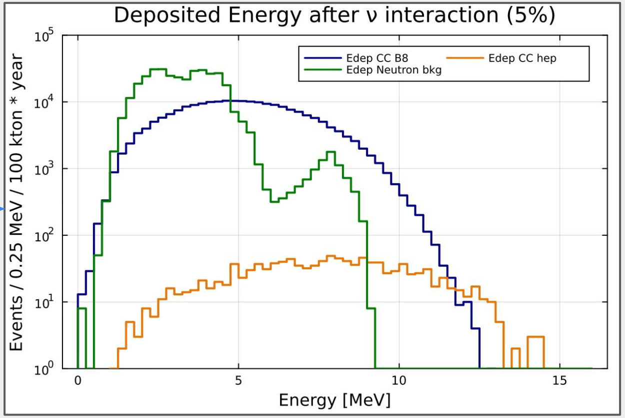
⇒ Reduction of the background by different methods

⇒ Implement a shielding around the detector
⇒ Apply a fiducialization on the active volume



Neutron capture as a function of shielding thickness (with a fiducialization of 1m for each axis)

⇒ Detection of Solar neutrino becomes possible



Energy spectra of the different signals, with 40cm Water shielding & 1m fiducialization (new cluster method)

Cluster algorithm for energy reconstruction

Former method :
Take energy deposit one-by-one

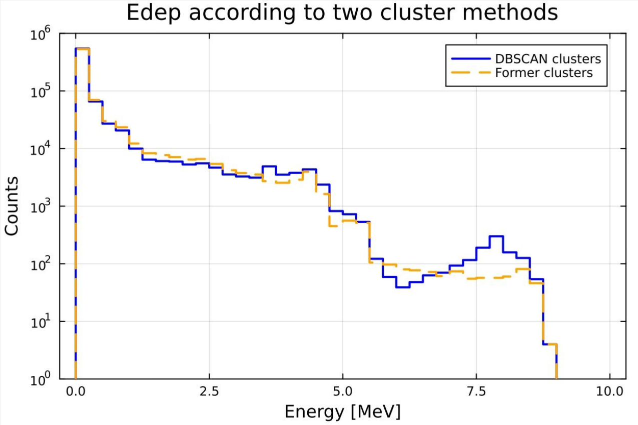
- If there is less than 1cm between the deposit and the next one ⇒ creation of a cluster and sum the deposited energy

Bug : Two clusters can be created next to each other if theirs deposits are not save one after another in the data file

New method : DBSCAN (Clustering.jl)

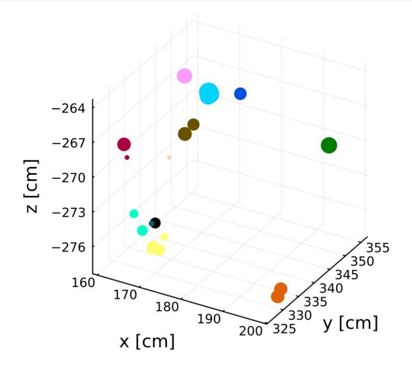
Take all energy deposits of an event with :
dbscan(spatial_coords, radius, min_neighbors=1, min_cluster_size=1)

- Clusters are created if there is less than X cm between at least two deposits, regardless the order in the data file

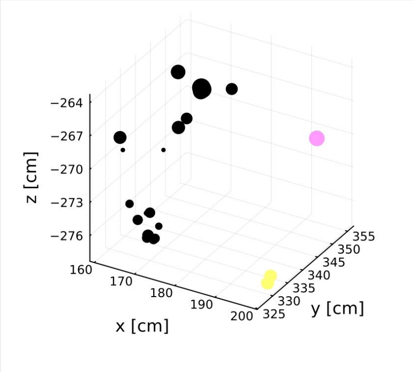


Difference of deposited energy according the two cluster methods

Deposits with the same color are in the same cluster



Energy deposits of gamma produced after Ncap, with an radius of 2.5cm

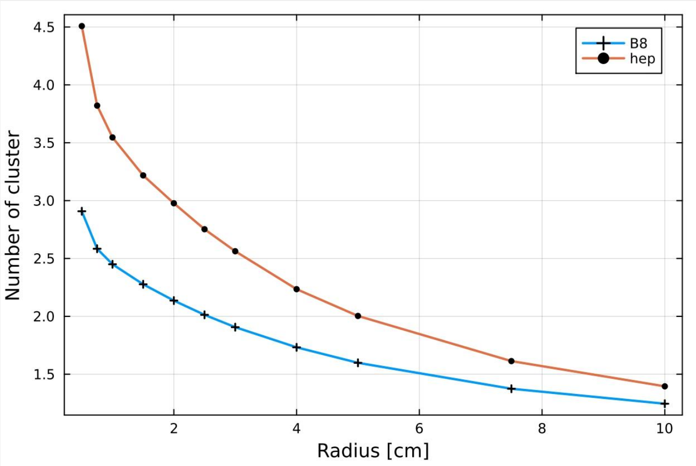


Energy deposits of gamma produced after Ncap, with an radius of 15cm

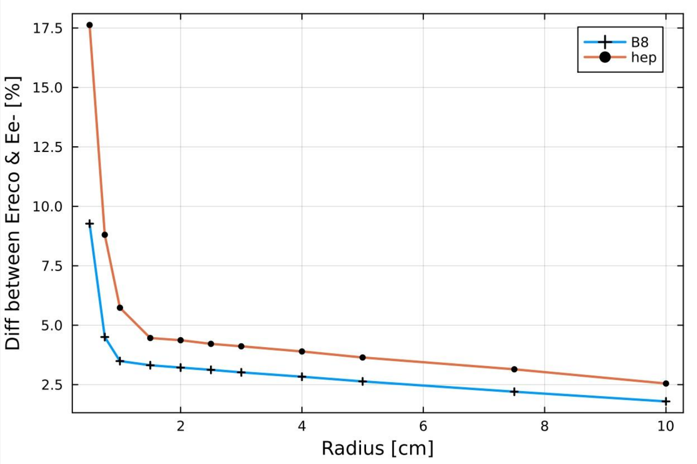
Cluster creation and neutrino energy reconstruction of ES signals

Neutrino energy : cluster with the higher energy

- Evolution of the difference between the most energetic cluster and the initial energy of the electron for the ES channel :
- Smaller and smaller when the radius increase
  - ⇒ electron track is complete and the gammas created by bremsstrahlung are added to the cluster energy



Average number of clusters as a function of the radius used in the DBSCAN algorithm



Difference between the most energetic cluster and the initial energy of the electron for ES interaction, as a function of the radius used in the DBSCAN algorithm

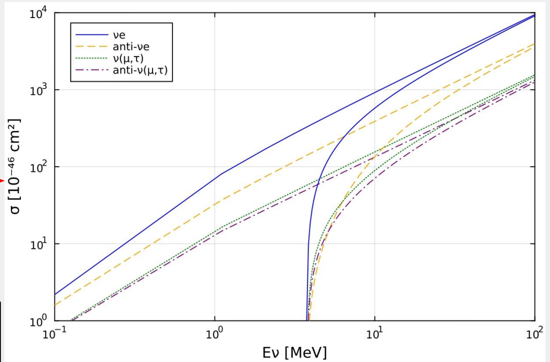
Number of ES events in DUNE

$N = \Sigma\, \phi_{\nu} * \sigma_{ES} * n_{e-}$

ϕ_{ν} ⇒ Predicted B8 flux : $5.25*10^{6}\ cm^{-2}.s^{-1}$
⇒ Measured B8 flux : $2.315*10^{6}\ cm^{-2}.s^{-1}$ (2312.12907)

σ_{ES} ⇒ Cross-section of Elastic Scattering (Fundamentals of Neutrino Physics and Astrophysics) :

$$\sigma(E_\nu, T_e^{\text{th}}) = \frac{\sigma_0}{m_e}\left[\left(g_1^2+g_2^2\right)\left(T_e^{\max}-T_e^{\text{th}}\right) - \left(g_2^2+g_1 g_2\,\frac{m_e}{2\,E_\nu}\right)\left(\frac{T_e^{\max 2}-T_e^{\text{th}2}}{E_\nu}\right)+\frac{1}{3}\,g_2^2\left(\frac{T_e^{\max 3}-T_e^{\text{th}3}}{E_\nu^2}\right)\right]$$



Cross-section of Elastic Scattering (ν + e- → ν + e-)

n_{e-} ⇒ Number of electron in the active volume

Verification of our calculation with the number of events in Super-Kamiokande :

⇒ 3.5 MeV Energy threshold cross section σ_{ES}

⇒ ≈ $1.1*10^{34}$ electrons in the water volume

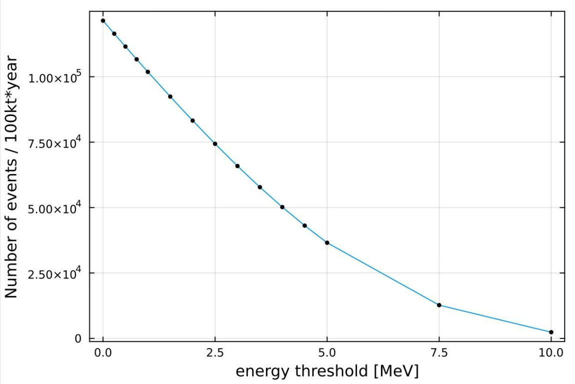
Number of B8 events in SK (per day) :

⇒ ≈ 65.443 in paper
⇒ ≈ 63.390 computed

Calculation of the number of events in DUNE

⇒ cross section σ_{ES} with no energy threshold
⇒ ≈ $2.7*10^{33}$ electrons in 10kton of LAr

Number of B8 events in DUNE (per 10 years) : ≈ 121 000



- ≈ 66 000 with 3 MeV threshold
- ≈ 36 000 with 5 MeV

Number of B8 events as a function of the energy threshold

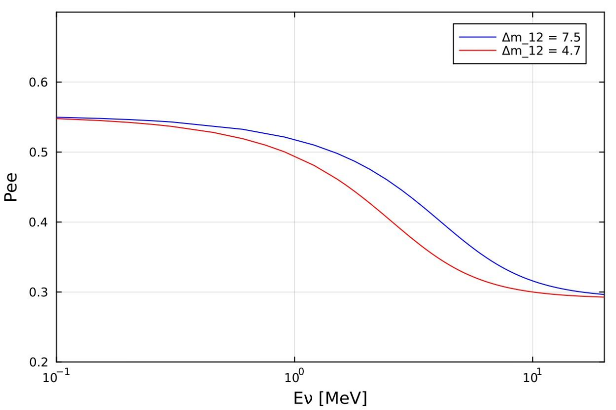
Number of ES events in DUNE with MSW effects

Probability used to calculate the number of ν_e, ν_μ and ν_τ (2401.12829) :

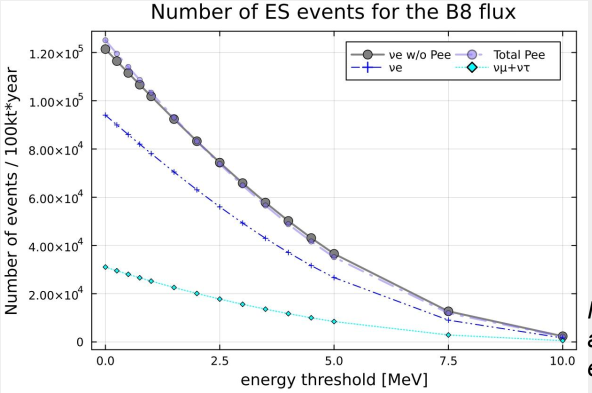
$$\beta = \frac{2\sqrt{2}\cos^2\theta_{13} n_e E}{\Delta m^2_{21}}$$

$$\cos 2\hat{\theta}_{12} = \frac{\cos 2\theta_{12} - \beta}{\sqrt{(\cos 2\theta_{12} - \beta)^2 + \sin^2(2\theta_{12})}}$$

$$P_{\nu_e \to \nu_e} = \frac{1}{2}\cos^4\theta_{13}[1 + \cos 2\hat{\theta}_{12}\cos 2\theta_{12}] + \sin^4\theta_{13}$$

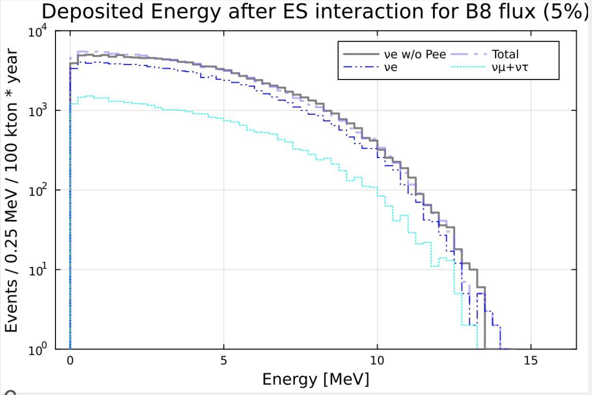


Survival probability of the electronic flavor as a function of the neutrino energy



Number of B8 events as a function of the energy threshold

The probability used for these plots is with a Δm_{12} value of 7.5



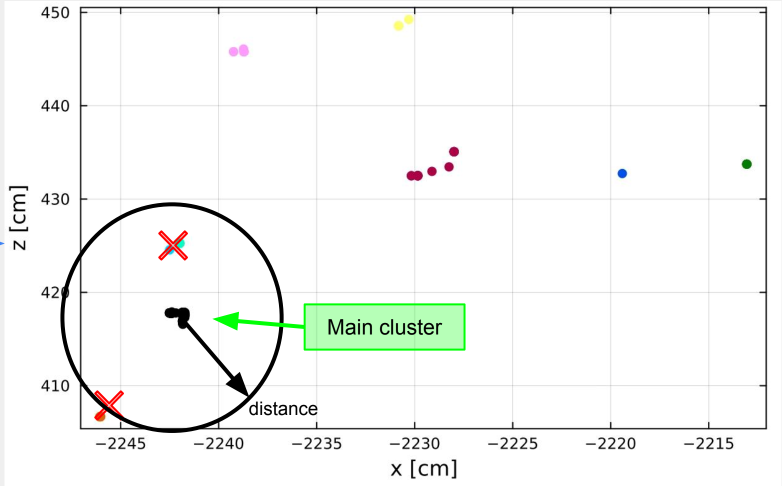
energy spectra of each flavors neutrino fluxes

Cluster discrimination for ES events

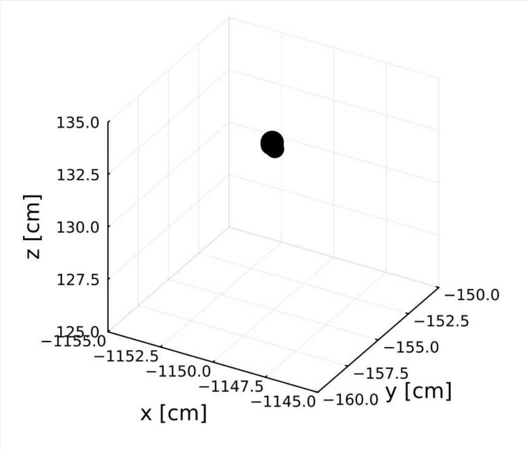
Apply condition on event selection :

- Most of electron tracks of ES event are continuous and without any deposit around

⇒ Select only most energetic cluster without other cluster in a distance of x cm

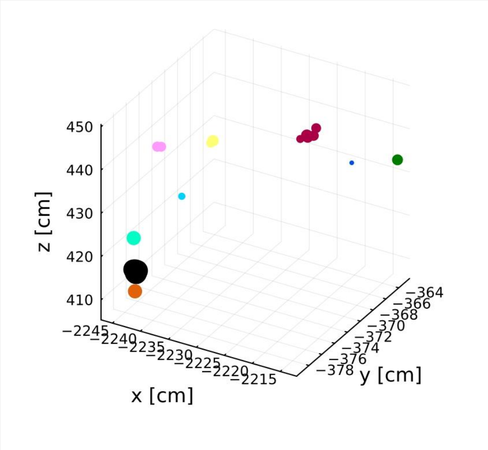


Energy deposits after ES interaction



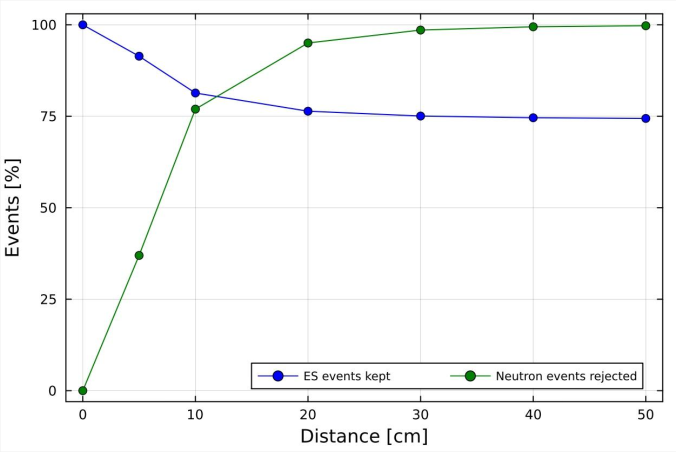
Energy deposits after ES interaction

Event kept



Event that can be rejected

Cluster discrimination for ES events



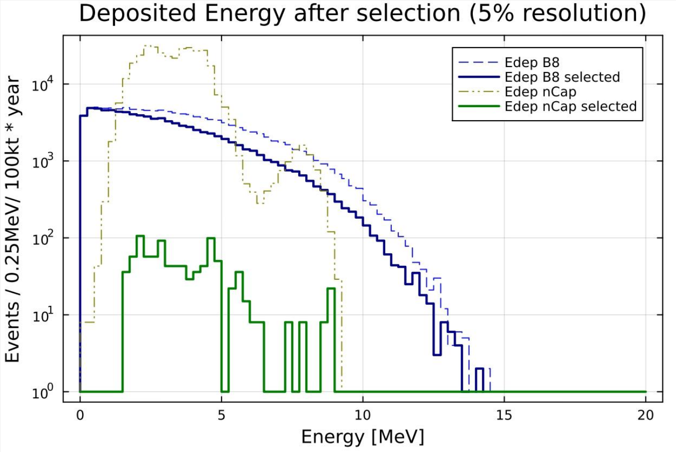
Rates of ES B8 events saved (blue) or Neutron background rejected (green)

Few ES events are deleted **BUT** almost all Neutron events are rejected !!

⇒ For a 50 cm distance : **74.4 %** of ES events are kept and **99.7 %** of background events are removed

⇒ Important reduction of the background with this method

⇒ Possibility to **observe** the ES B8 flux because the neutron background becomes smaller



Energy spectra after selection, with a 40cm water shielding and a fiducialization of 1m and a discrimination distance of 50cm

⇒ The signature of ES event is a continuous track for most of the cases

- In around 29.0 % bremsstrahlung gammas produce other energy deposits
- With a radius of 2.5 cm used in the DBSCAN algorithm, most of the electron energy deposits are in the same cluster

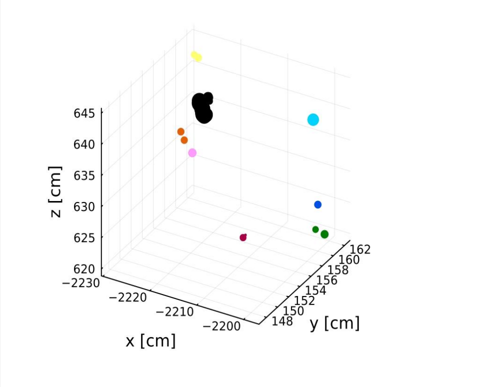
⇒ Most events have only one cluster thus the condition is respected

Reconstruction of CC events

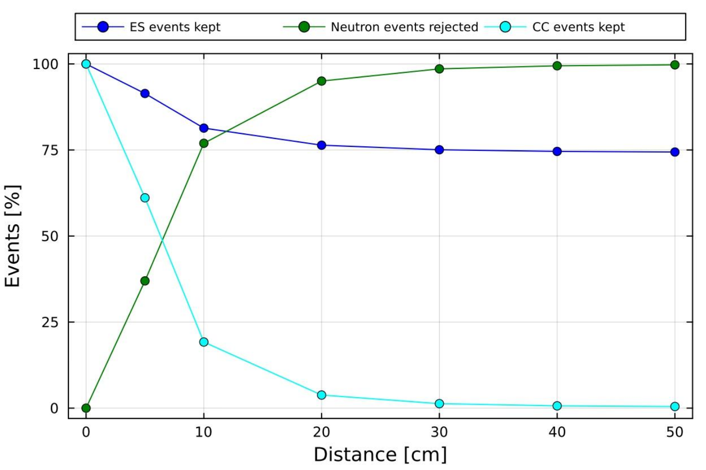
⇒ The signature of CC event is a continuous track for the electron and several energy deposits for the gammas

⇒ With a maximum distance of 2.5cm, all deposits cannot be in the same cluster

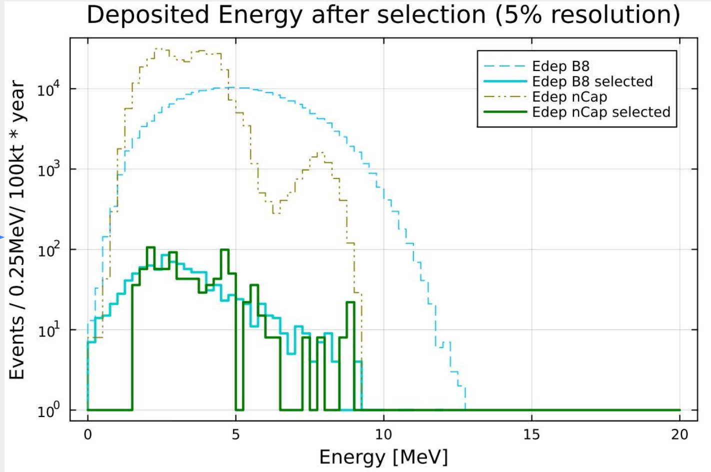
⇒ With the same condition of discrimination, numerous CC events are deleted



Energy deposits after CC interaction



Rates of events saved (blue and cyan) or rejected (green)



Energy spectra after selection, with a 40cm water shielding and a fiducialization of 1m and a discrimination distance of 50cm

⇒ Possibility to **differentiate** the CC and ES events

Conclusion

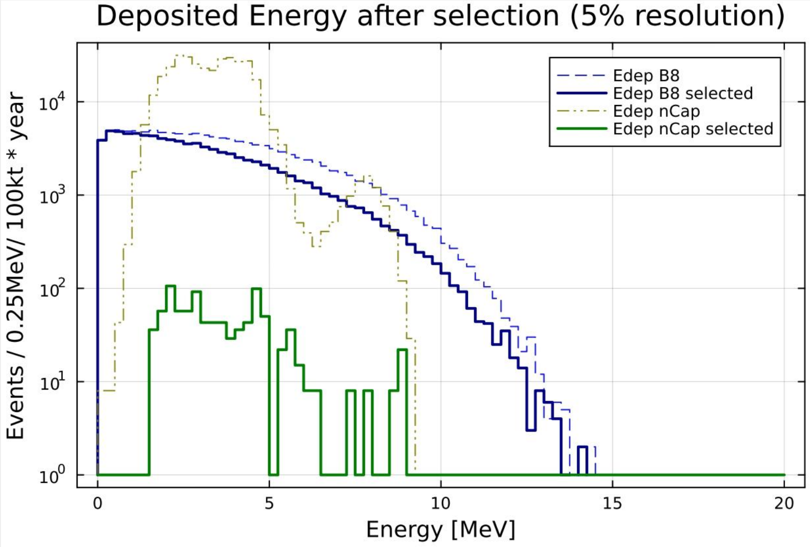
⇒ DBSCAN clustering algorithm seems to be an efficient and realistic approach for solar neutrino reconstruction

⇒ Estimation of number of ES events in 100kt*year to simulate the signal of this interaction

⇒ Apply discrimination conditions to select only ES events :

- By using signals isolated within a sphere of 50 cm :
  - The neutron background is significantly reduced by **99.7 %**
  - Only **25.6 %** of ES events are lost
  - Detecting CC events under the same conditions is not possible

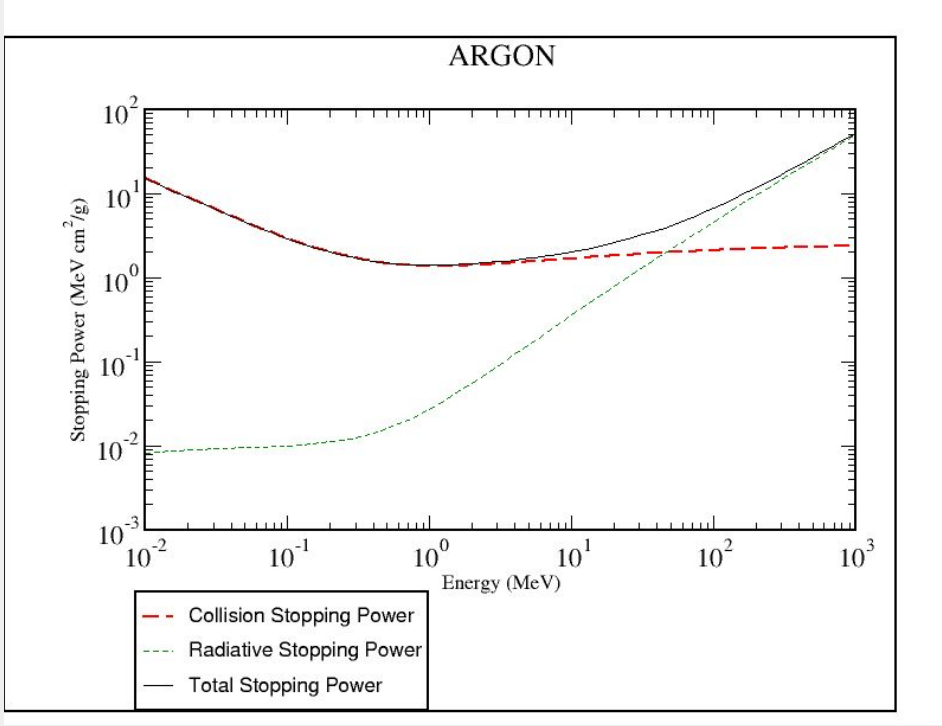
- **However**, the same method can be used to effectively separate ES from CC signals



Energy spectra after selection, with a 40cm water shielding and a fiducialization of 1m and a discrimination distance of 50cm

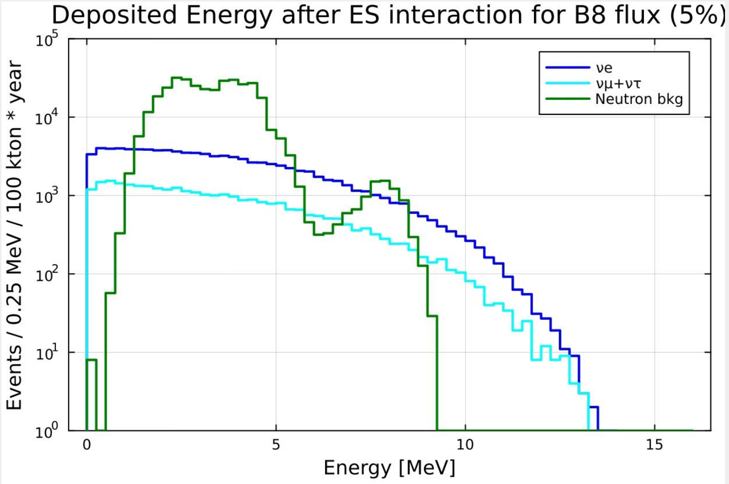
Thank you for listening

Backup

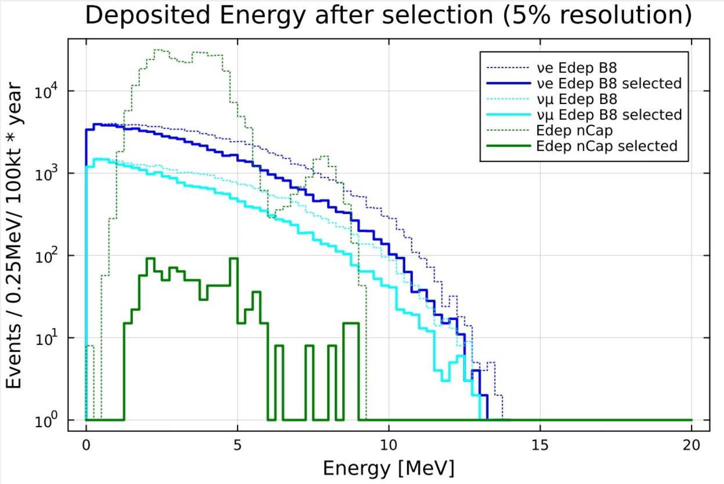


Stopping power of Argon for electrons

Backup



Energy spectra of the B8 flux oscillated, with 40cm Water shielding & 1m fiducialization



Energy spectra after selection, with a 40cm water shielding and a fiducialization of 1m and a discrimination distance of 50cm. The B8 flux used is oscillated.