Neutrino physics with the XENONnT experiment

Federica Pompa

Supervisors:

Prof. Gabriella Sartorelli

Dr. Marco Selvi

Dr. Pietro Di Gangi

Alma Mater Studiorum – Università di Bologna

Dipartimento di Fisica e Astronomia

HIDDeν

Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

ESRs webinar - 14/12/2020

Outline

XENONnT

- What is it?
- Setup description
- Different kind of research

Supernova neutrino detection

- XENONnT detection efficiency (Inverse Beta Decay channel)

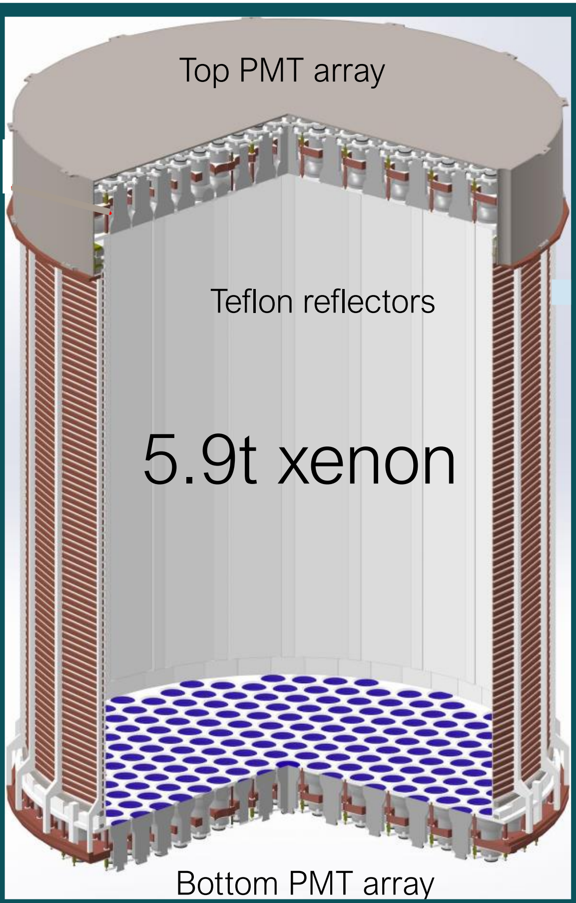
Neutrinoless double beta decay

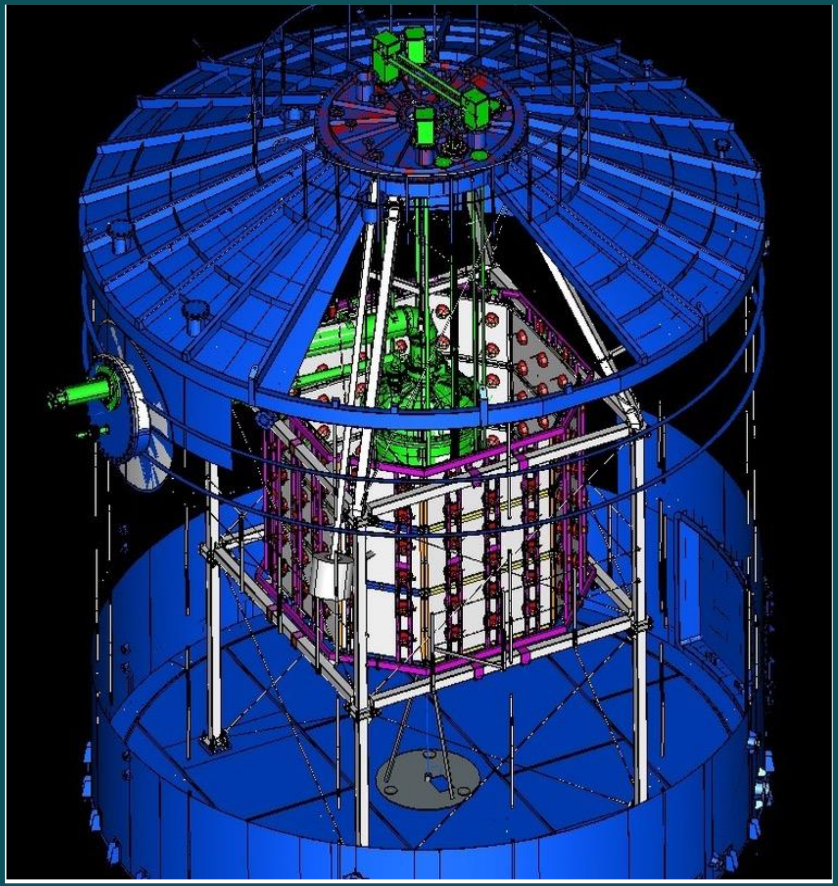
- Electronic recoil background
- XENONnT sensitivity

XENONnT

- Current state

XENONnT





8 t total Xe → 5.9 t in the TPC

- top array: 253 PMTs
- bottom array: 241 PMTs

- neutron Veto: 120 PMTs
- muon Veto: 84 PMTs

XENONnT: **not only** a Dark Matter detector

⬇

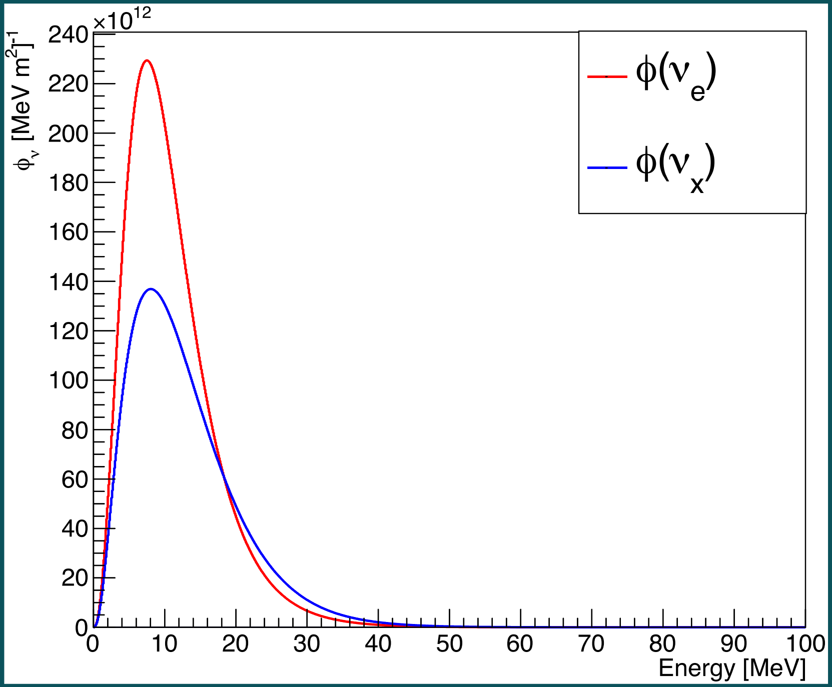
XENONnT **could be employed** to:

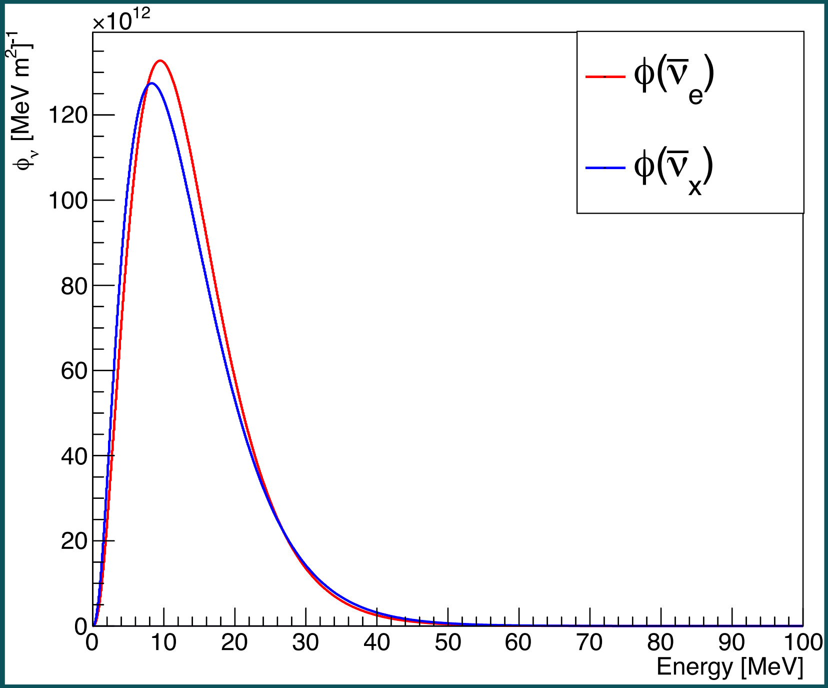
- detect Supernova neutrinos through interactions on protons in Gd-doped water of the Vetoes;
- search for the forbidden Standard Model neutrinoless double beta decay ($\beta\beta0\nu$) of ^{136}Xe isotope.

Supernova neutrino detection

- SN of mass $M = 27 M_\odot$ in LS220 Equation of State;
- distance from the Earth: 10 kpc.

https://wwwmpa.mpa-garching.mpg.de/ccsnarchive/.



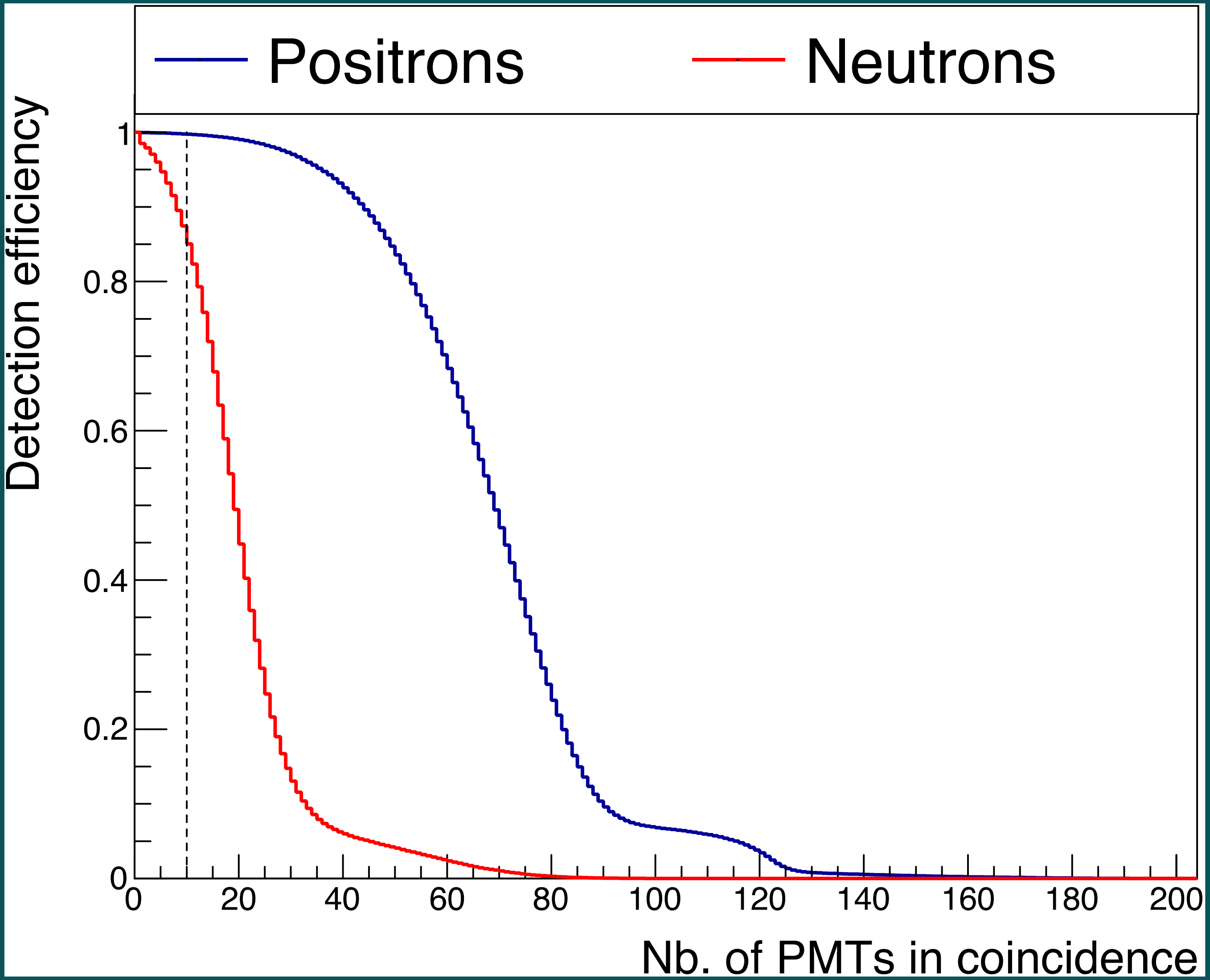


- IBD interactions in Gd-doped water at 0.2% mass concentration: $\overline{\nu}_e + p \longrightarrow n + e^+$;
- neutrons energy capture on Gd: γ cascade of $\simeq 8\,\mathrm{MeV}$.

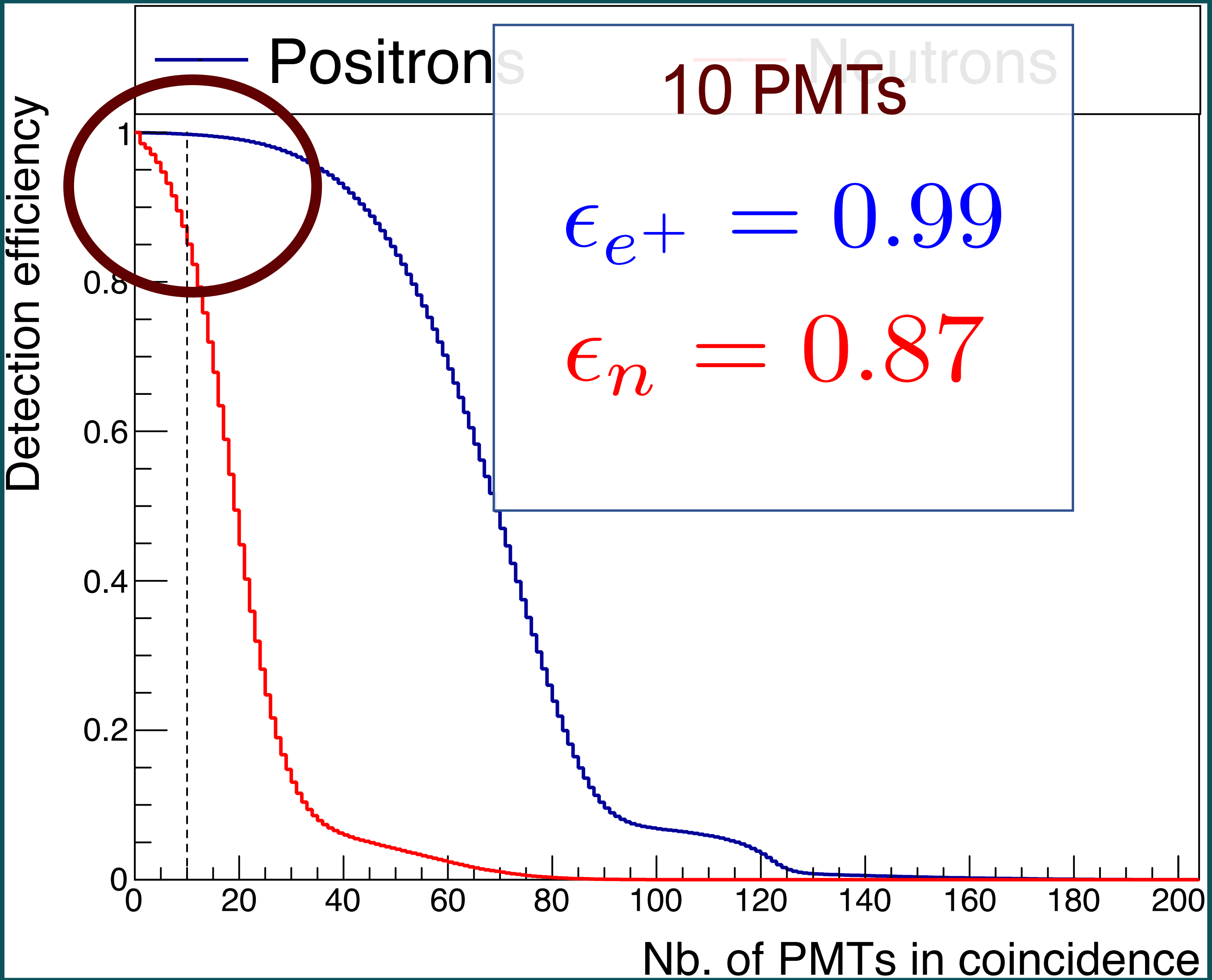
Monte Carlo simulation with XENONnT GEANT4 code:

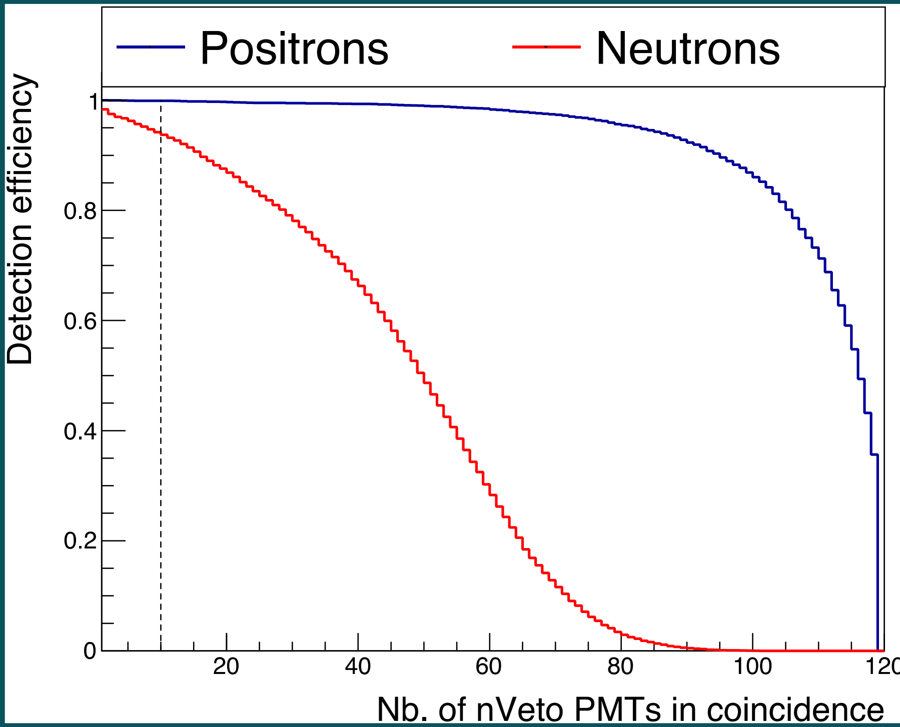
- 10^5 events generated uniformly in water:
  - muon Veto volume: 611 m^3;
  - neutron Veto volume: 53 m^3.
- primary particle and energy spectrum:
  - e^+ : $E_{e^+} = E_{\overline{\nu}_e} - 1.8\,\mathrm{MeV}$
  - n : $E_n = 1\,\mathrm{keV}$
- GEANT4 automatically generates the emission of Čerenkov photons, their transport in water and their detection on PMTs.

Total detection efficiency of neutron and muon Vetoes:



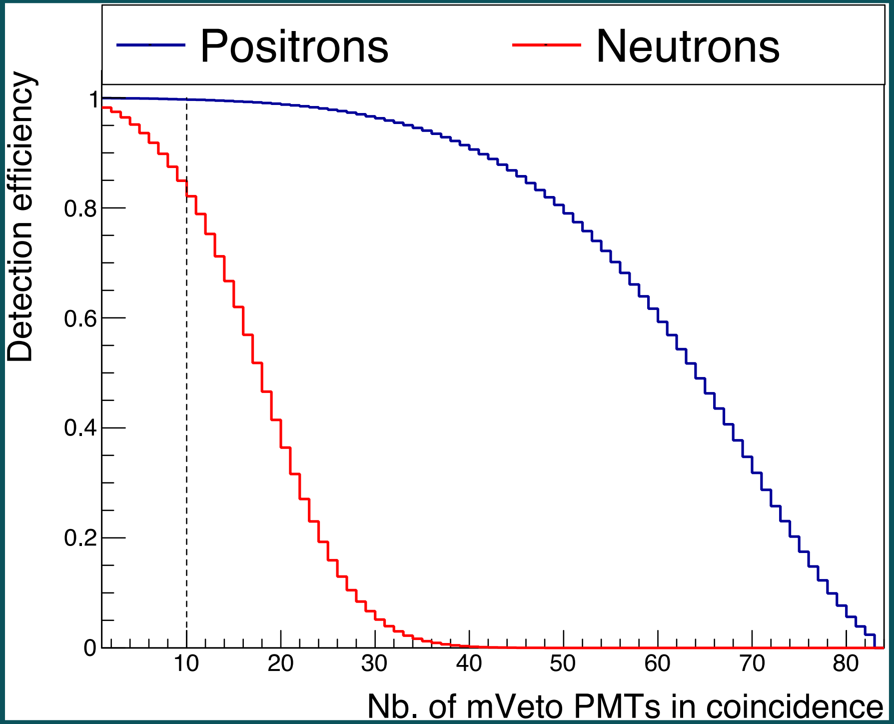
Total detection efficiency of neutron and muon Vetoes:

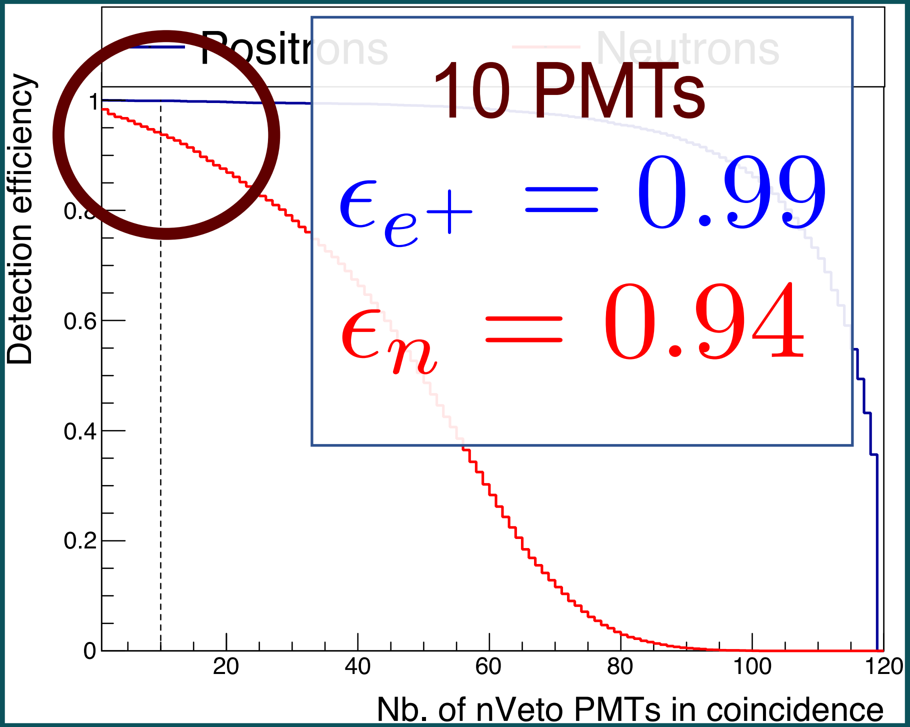




neutron Veto detection efficiency:

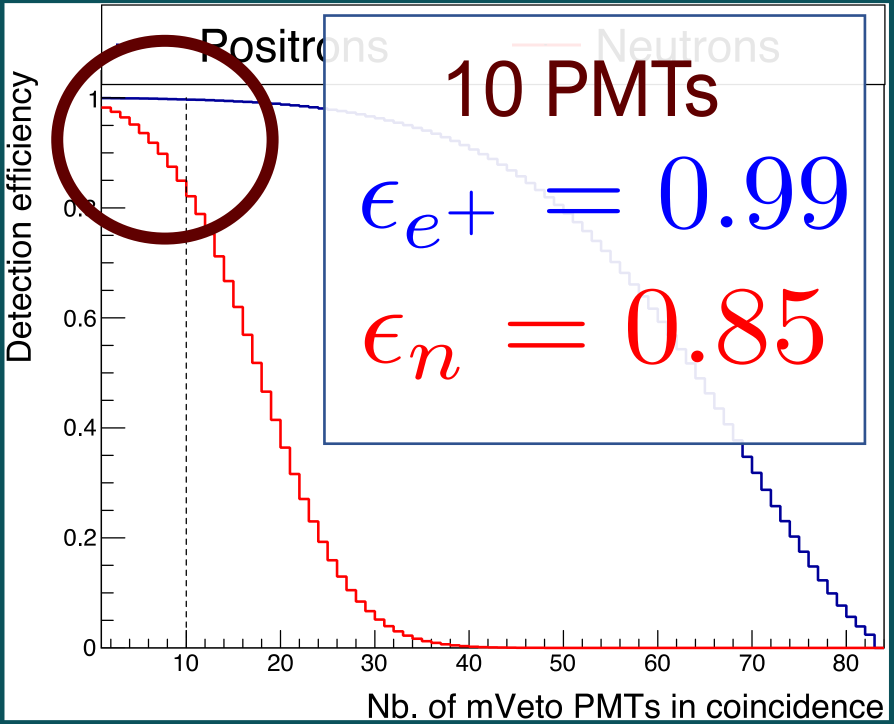
muon Veto detection efficiency:



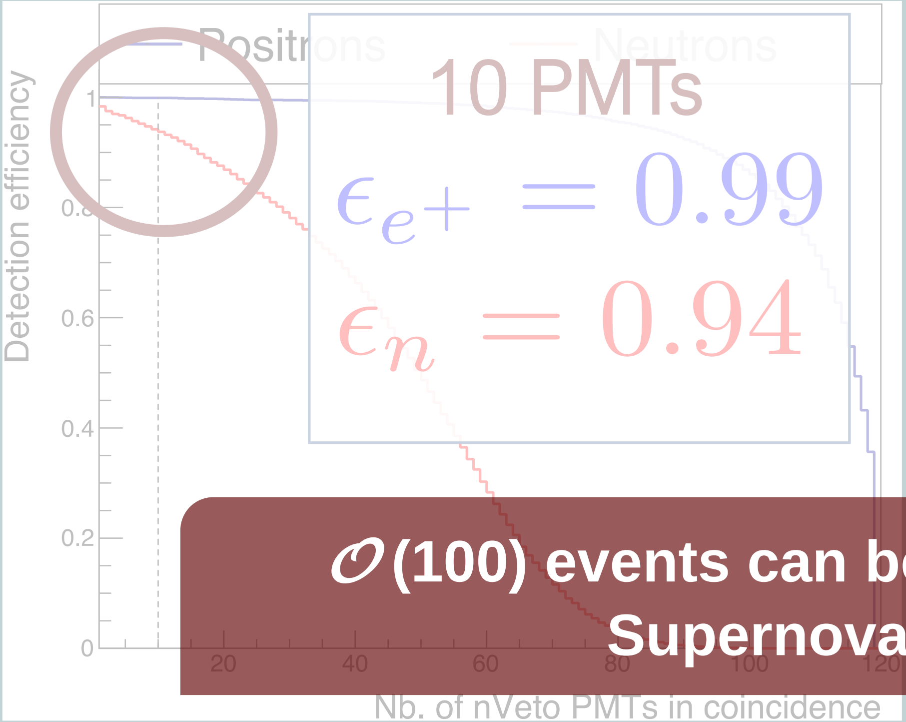


neutron Veto detection efficiency:

muon Veto detection efficiency:

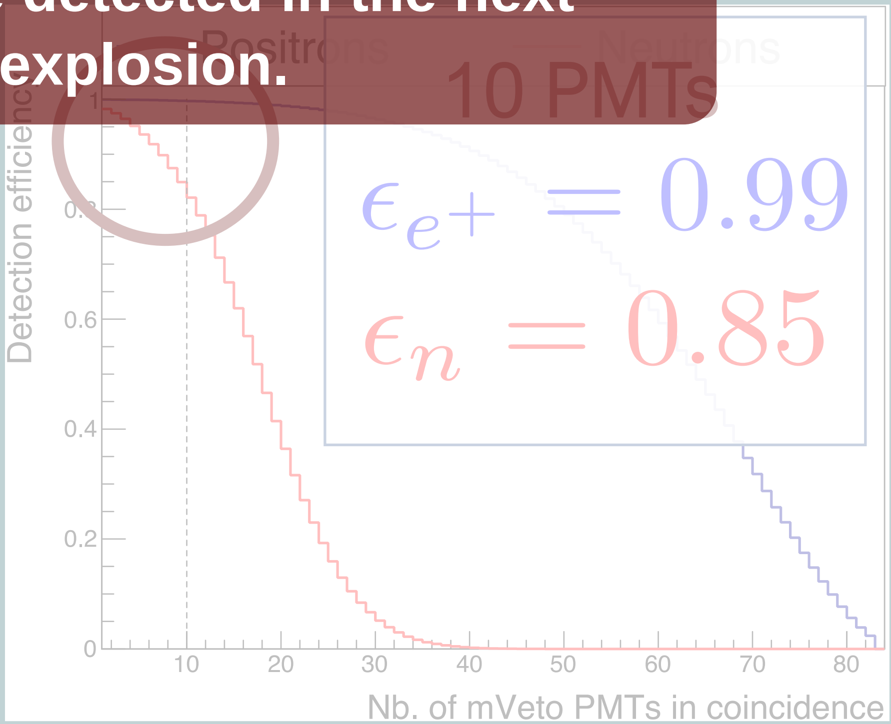


neutron Veto detection efficiency:



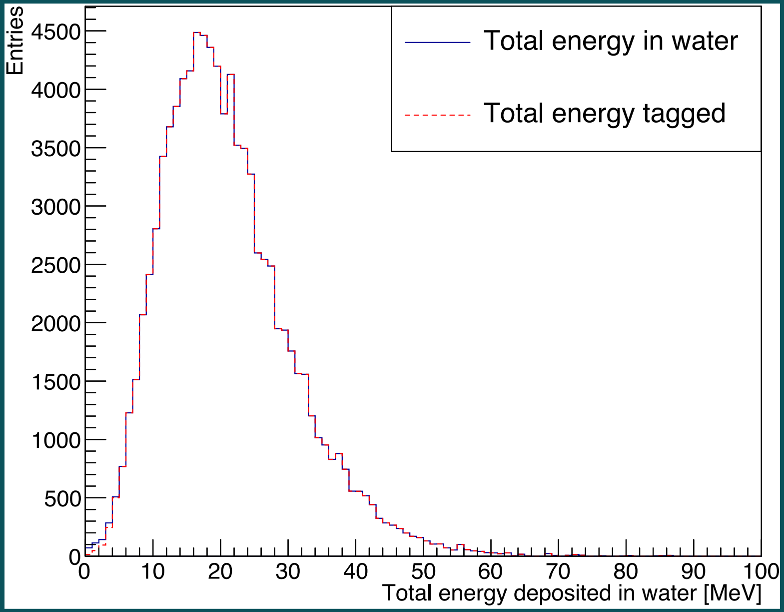
$\mathcal{O}(100)$ events can be detected in the next Supernova explosion.

muon Veto detection efficiency:

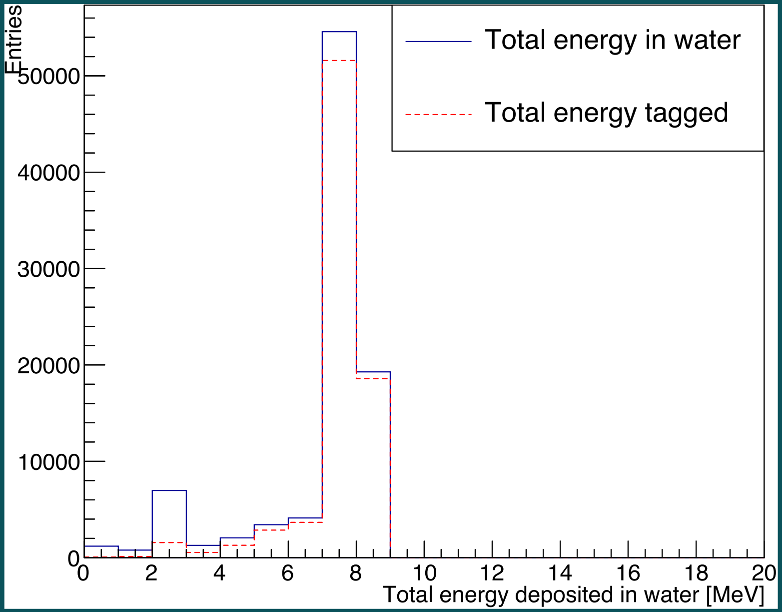


Total energy in water

Positrons

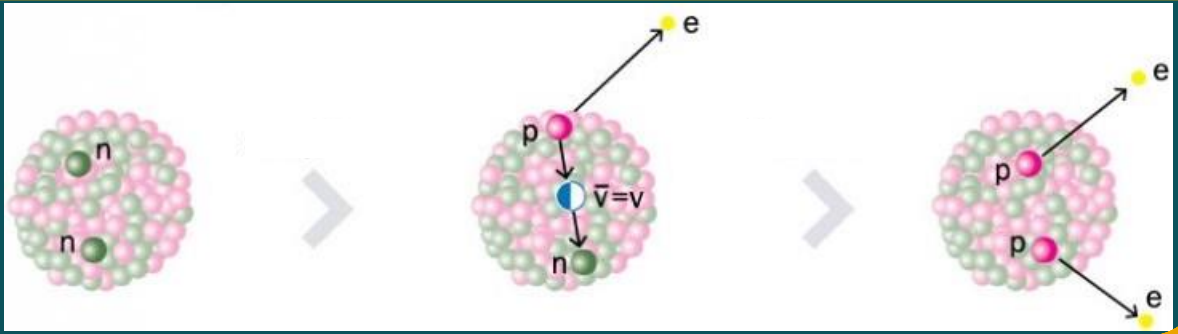


Neutrons



Neutrinoless double beta decay

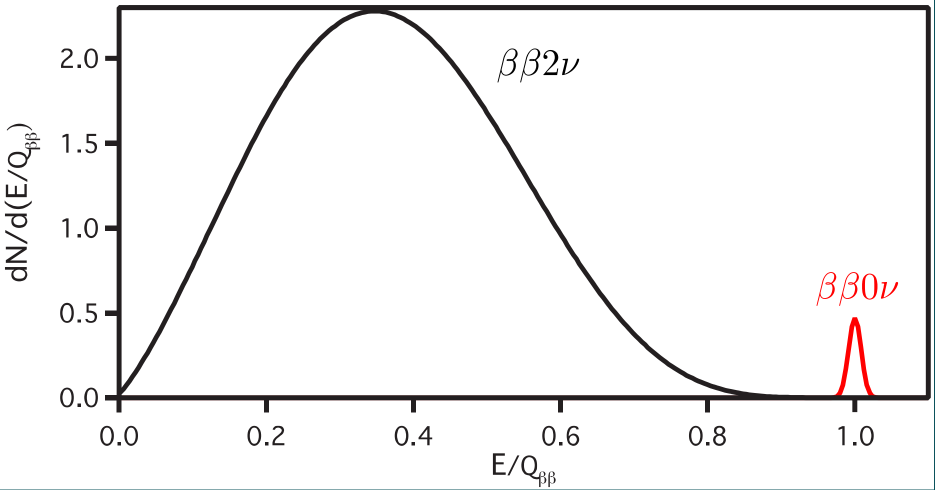
If $\nu = \overline{\nu}$



$$^{136}\mathrm{Xe} \longrightarrow {}^{136}\mathrm{Ba} + 2e^-$$

$$ia = 8.9\%$$

$$Q_{\beta\beta} = 2458\,keV$$



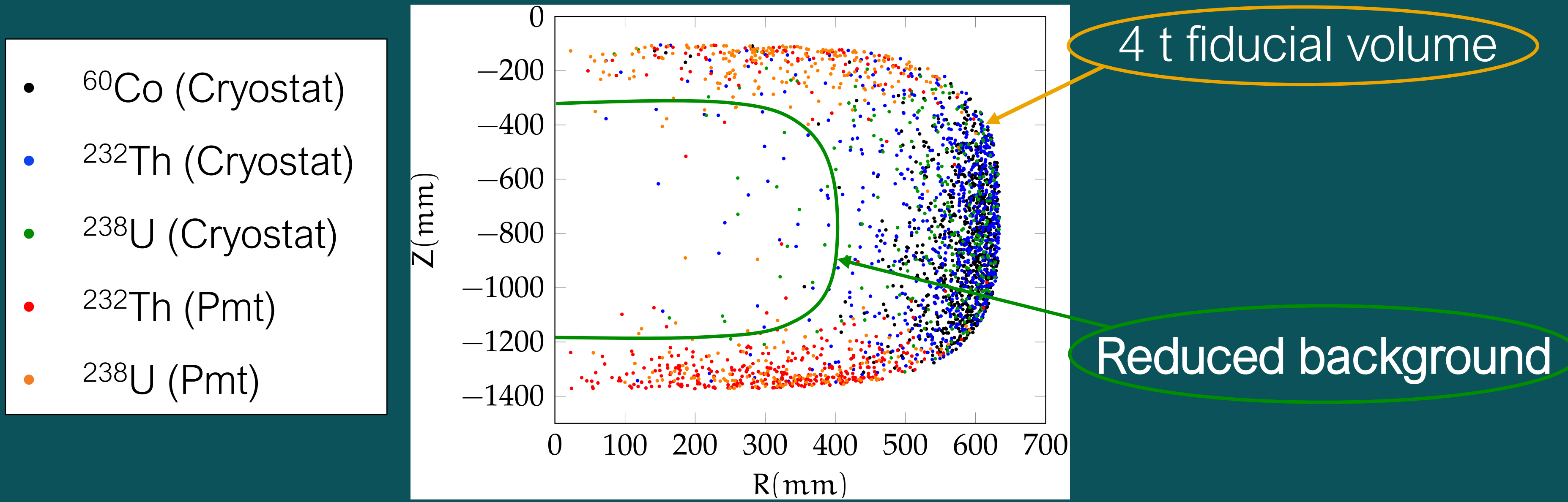
Energetic Region of interest (ROI): **[2.35, 2.55] MeV**

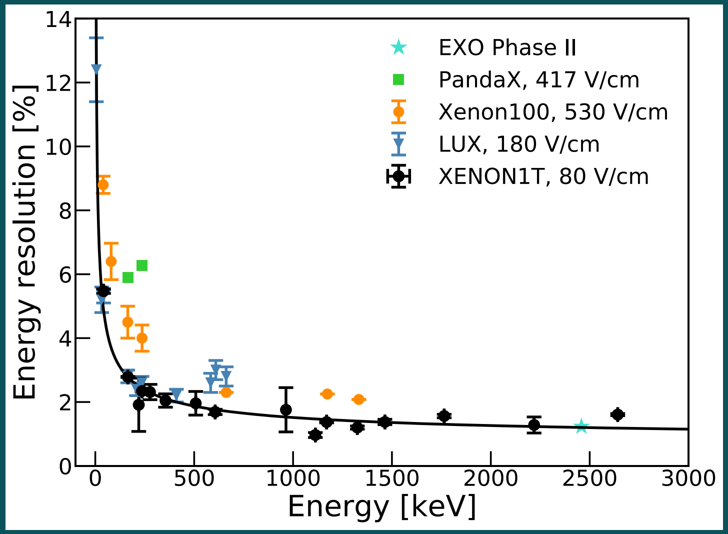
Electronic recoil (ER) background induced by the radioactive contaminations of materials around the TPC

γ rays producing a single scatter in the fiducial volume, releasing energy in ROI

Monte Carlo simulations of ^{60}Co, ^{238}U and ^{232}Th decays:

- $^{238}\mathrm{U} \longrightarrow {}^{230}\mathrm{Th} \quad , \quad {}^{226}\mathrm{Ra} \longrightarrow {}^{206}\mathrm{Pb}$
- $^{232}\mathrm{Th} \longrightarrow {}^{228}\mathrm{Ac} \quad , \quad {}^{228}\mathrm{Th} \longrightarrow {}^{208}\mathrm{Pb}$





$$\Delta E_{(FWHM)} = \sigma_E \cdot 2.355$$

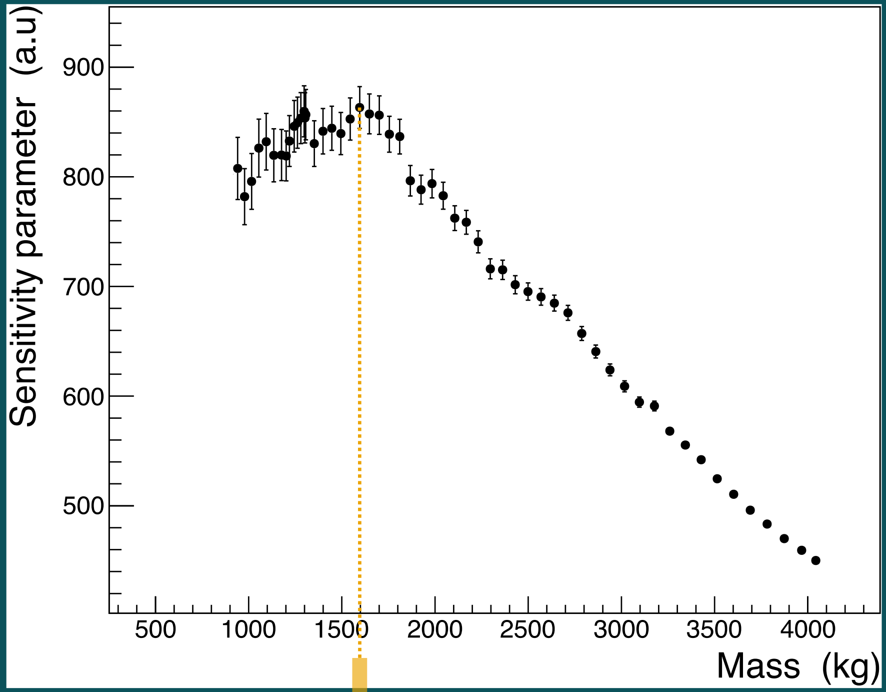
$$\sigma_E = E\left(\frac{a_1}{\sqrt{E}} + a_2\right)$$

$$\sigma_E = 1\% \text{ at } Q_{\beta\beta}$$

Sensitivity: $S^{0\nu} = \frac{\ln 2}{1.64}\epsilon\frac{ia}{A}\sqrt{\frac{M_{fv}\cdot t}{\Delta E \cdot b}}$

Sensitivity parameter: $\frac{M_{fv}}{\sqrt{B}}$

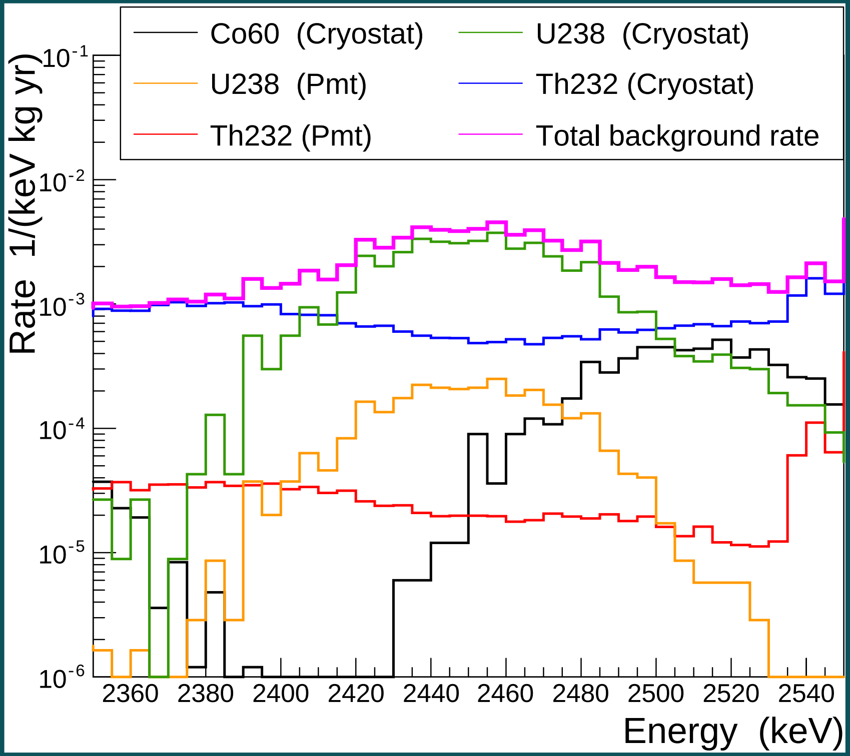
$$B = b \cdot M_{fv} \cdot \Delta E \cdot t$$

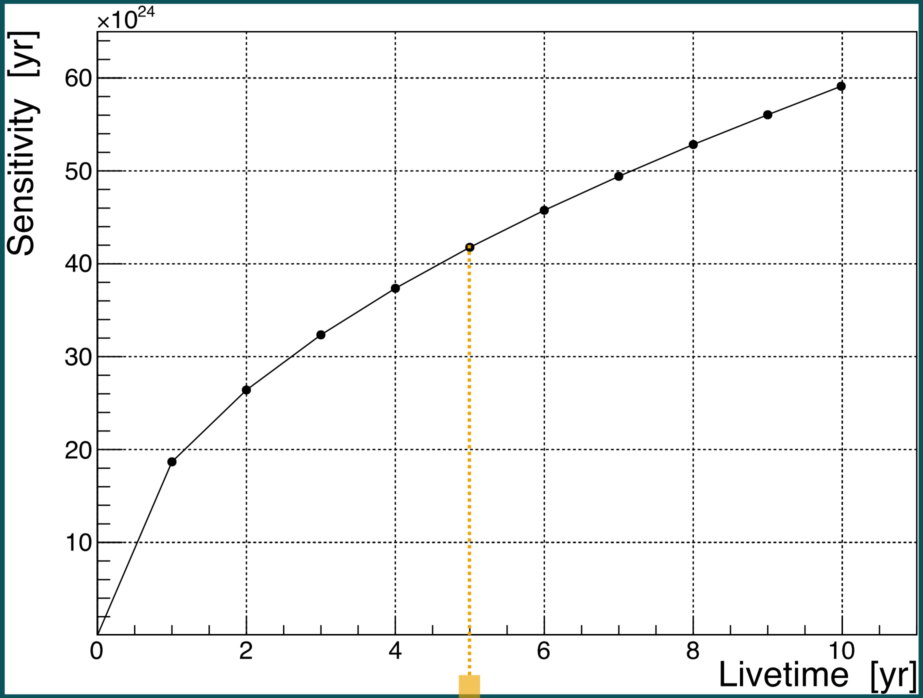


Maximizing the sensitivity parameter:

M_{fv} = 1.6 t

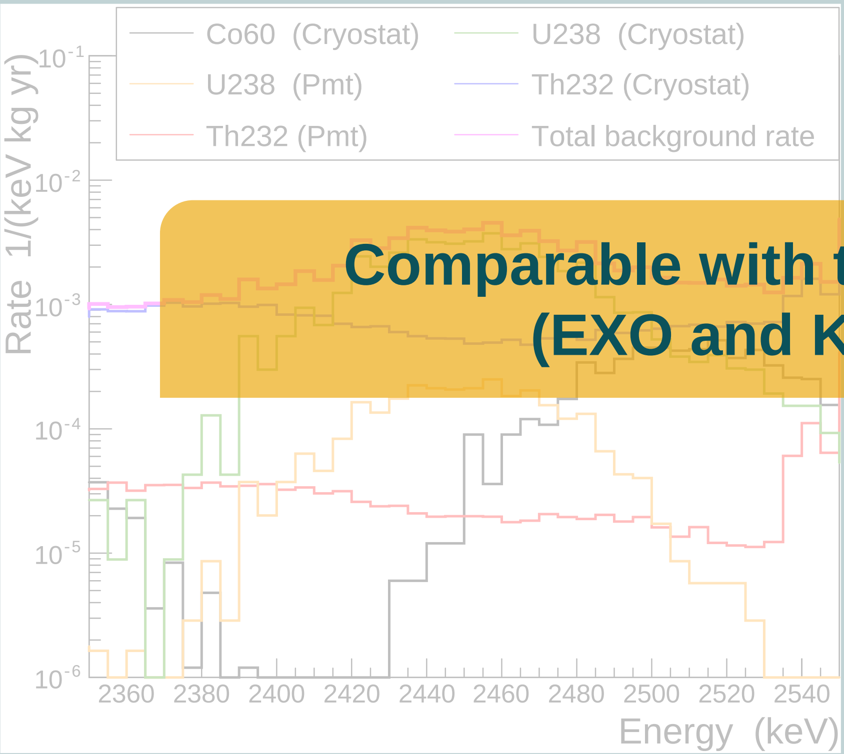
- M_{fv} = 1.6 t super-ellipsoid volume;
- b = 2.1 × 10^{-3} (kg keV yr)$^{-1}$ in ROI.

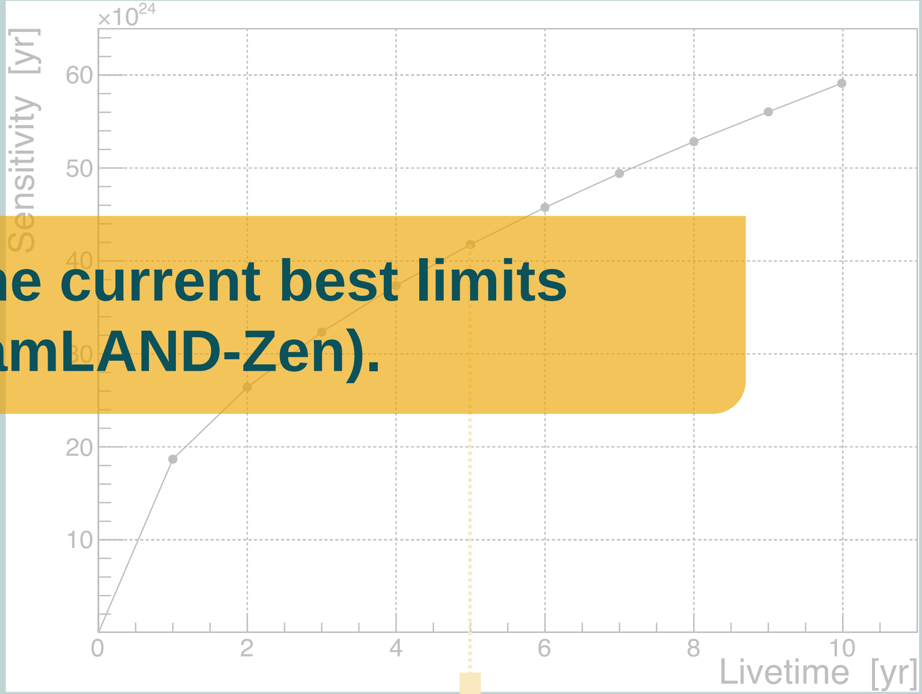




- After 5 yr: $S^{0\nu}$ = 4.2 × 10^{25} yr

- M_{fv} = 1.6 t super-ellipsoid volume;
- b = 2.1 × 10^{-3} (kg keV yr)$^{-1}$ in ROI.





Comparable with the current best limits (EXO and KamLAND-Zen).

- After 5 yr: $S^{0\nu}$ = 4.2 × 10^{25} yr

XENONnT: current state

XENONnT is almost ready!

✓ Neutron Veto (entirely designed and built by the Bologna group);

✓ TPC and Cryostat;

○ Water tank: work in progress…

XENONnT will start taking data soon!

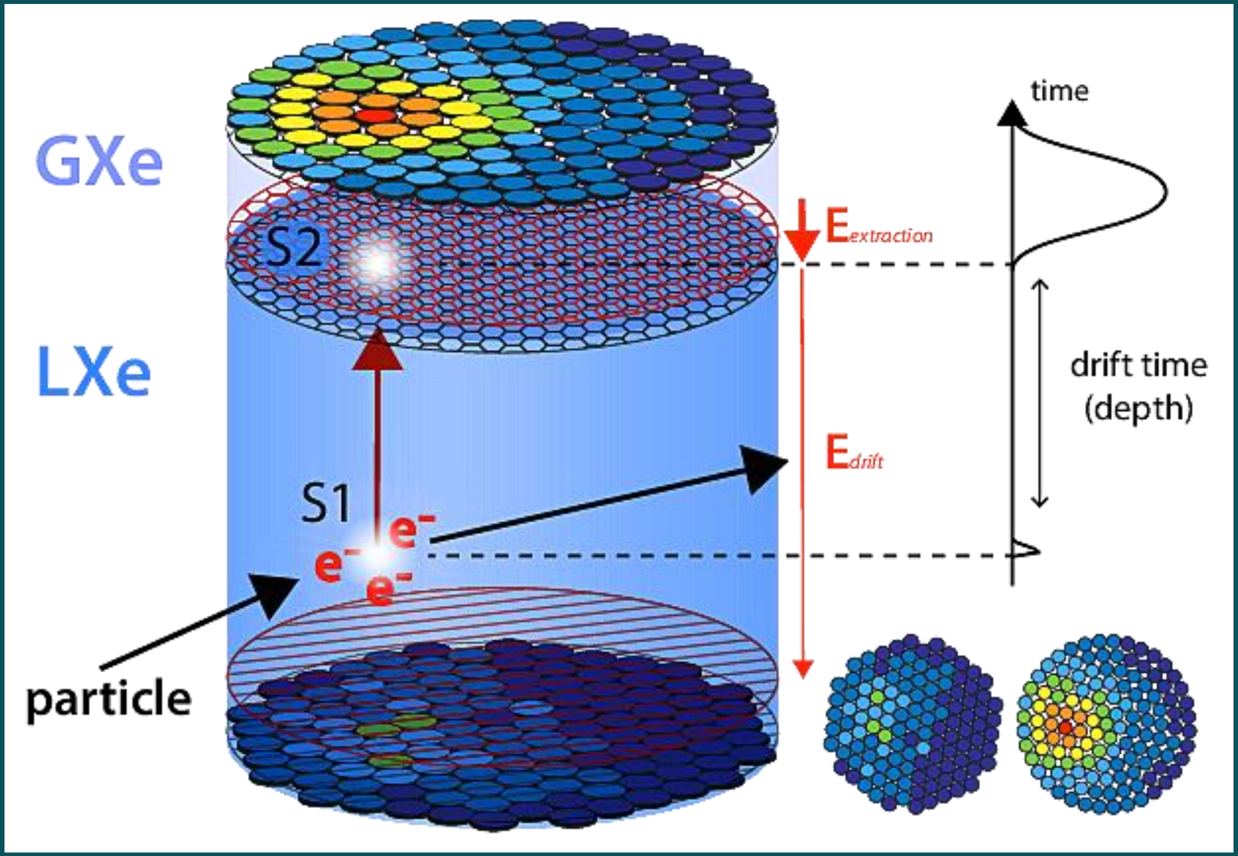
Conclusions

- ✓ High detection efficiency from muon and neutron Vetoes can be obtained for both the products of IBD interactions of Supernova electron antineutrinos. **$\mathcal{O}$(100) events can be detected with the next Supernova explosion.**
- ✓ After five years of livetime, **XENONnT will achieve a sensitivity for neutrinoless double beta decay comparable with the best current limits.** We need to wait for next generation experiments to explore region of parameters not yet observed.

"This project has received funding/support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860881-HIDDeN"

Backup slides

Dual-phase TPC working principle



Dark Matter search VS **Neutrino search**

Dark Matter search VS **Neutrino search**

Dark Matter search

WIMPs

- LXe of the TPC: TPC PMTs

≠

Neutrino search

Supernova neutrinos

- Water tank: nVeto and mVeto PMTs

Dark Matter search

VS

Neutrino search

WIMPs

- LXe of the TPC: TPC PMTs

≠

Supernova neutrinos

- Water tank: nVeto and mVeto PMTs

This study can be performed simultaneously!

Dark Matter search	VS	Neutrino search
↓		↓
WIMPs		$\beta\beta0\nu$
▪ LXe of the TPC: TPC PMTs	=	▪ LXe of the TPC: TPC PMTs
▪ NR background ▪ ROI ≈ [1, 12] keV ▪ M_{fv} = 4 t of LXe	≠	▪ ER background ▪ ROI ≈ 2.5 MeV ▪ M_{fv} = 1.6 t of LXe

Dark Matter search VS Neutrino search

WIMPs | $\beta\beta0\nu$

- LXe of the TPC: TPC PMTs | =
- LXe of the TPC: TPC PMTs

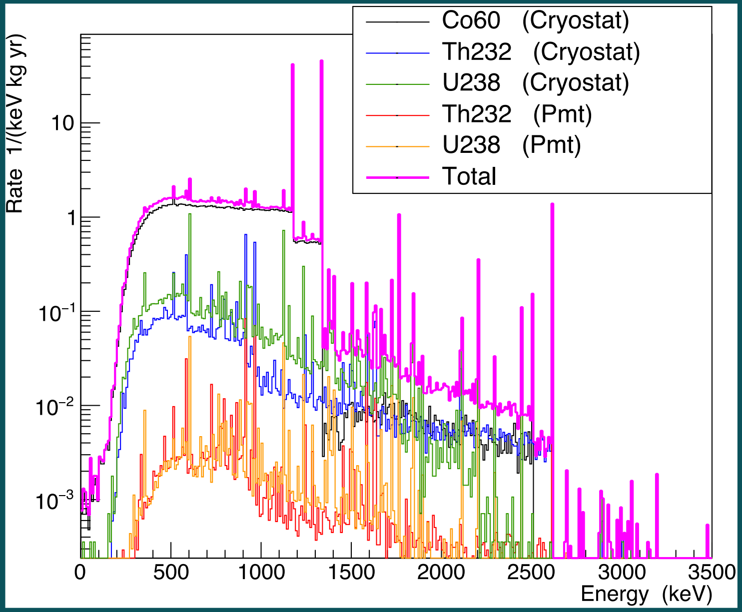
This study can be performed simultaneously!

- NR background
- ROI ≈ [1, 12] keV
- M_{fv} = 4 t of LXe

≠

- ER background
- ROI ≈ 2.5 MeV
- M_{fv} = 1.6 t of LXe

ER background spectra



$$\sigma_E = E\left(\frac{a_1}{\sqrt{E}} + a_2\right)$$

$$a_1 = 30.98\sqrt{keV}$$

$$a_2 = 0.37$$