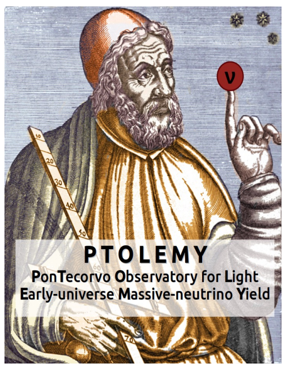


# The PTOLEMY Project:

## How to Make a Screenshot of the very Early-Universe

INFN
Open Day
2025

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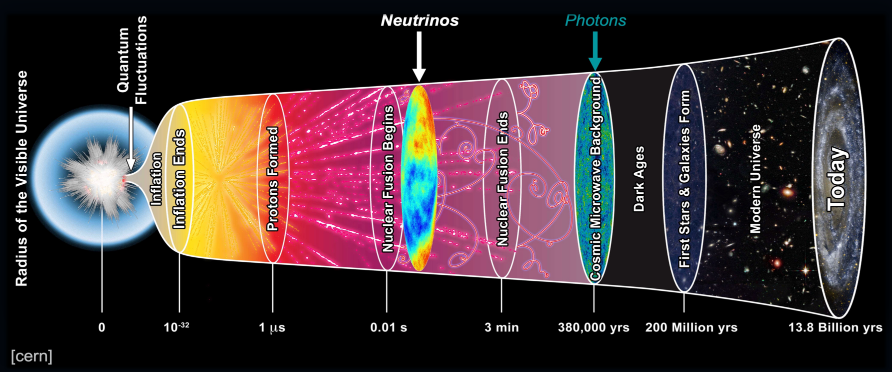
## Introduction

The Cosmic Neutrino Background (**CνB**) decoupled from matter **1 second after the Big Bang**. Its direct observation would be a rich glimpse of the Universe just after its creation.

**PTOLEMY** (*PonTecorvo Observatory for Light, Early-universe, Massive-neutrino Yield*) brings together the cutting-edge in graphene technology, radio-frequency, microcalorimetry, and a new concept, the transverse drift filter, to measure the **absolute neutrino mass** and make direct detection of the **CνB for the first time**.



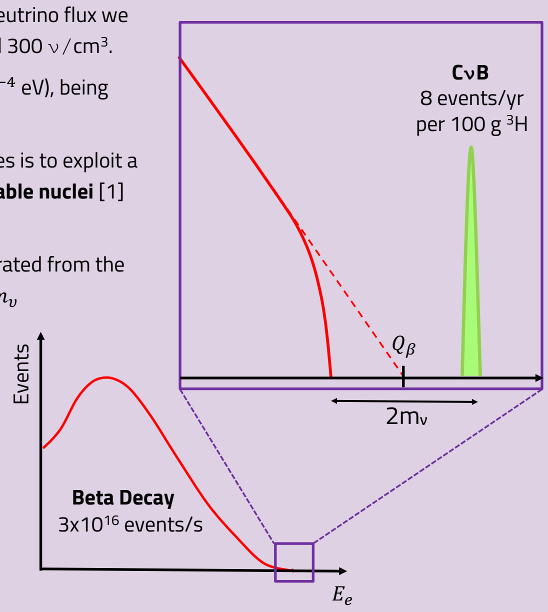

[cern]

## Signature

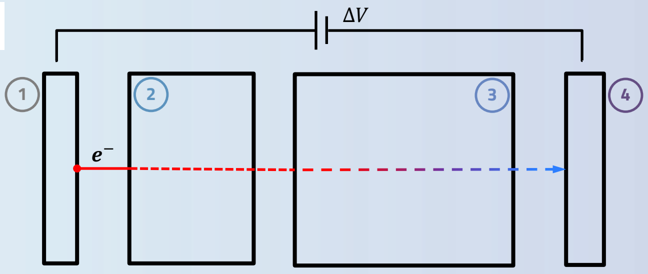
- Neutrinos from CνB constitute the **most abundant** neutrino flux we have on Earth. Their density is expected to be around 300 ν/cm$^3$.
- At the same time they have a very **low energy** ($\sim 10^{-4}$ eV), being their temperature today roughly 1,95 K.
- A smart solution to detect such low-energetic particles is to exploit a threshold-less reaction, like the **ν-capture on β-unstable nuclei** [1]

$$\nu_e + (A, Z) \rightarrow (A, Z+1) + e^-$$

- The result is a **monocromatic peak** at $Q_\beta + m_\nu$, separated from the spectrum end-point of the analougous β-decay by $2m_\nu$
  - ❑ High energy-resolution electron detector needed
- Being the cross section for this reaction extremely small, the following requirements must be met:
  - ❑ β-unstable isotope with reasonable half-life & relatively high cross-section: tritium $^3H$
  - ❑ Large target: 100 grams to get 4/8 events/yr (Dirac/Majorana)
  - ❑ Efficient, high-rate handling filter



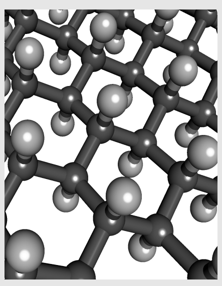

## Ingredients

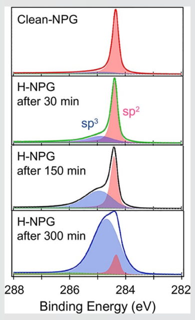



**Final Energy:** $E_e = q\Delta V + E_{TES} + E_{RFcorr}$

### ① TRITIUM TARGET

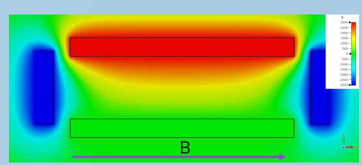
- Experiment on neutrinos commonly use tritium in gaseous molecular form. The idea of PTOLEMY is to use loading of **atomic tritium** onto **free-standing graphene** (*tritiated graphene*) to **reduce smearing** due to the source itself and the scattering of emitted electrons.
- Carbon-based supports have the unique feature of enabling a **high-density source of tritium**. A 90% loading of nanoporous graphene (NPG) has been recently achieved [2].

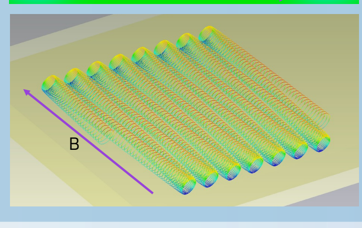





### ② PRESELECTOR

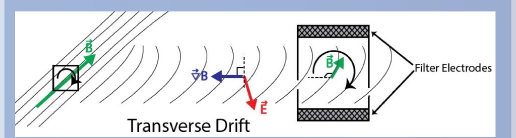
- A **radio-frequency (RF) antenna** detects the electromagnetic emission of an electron spinning in a constant magnetic field and bouncing between two electrodes.
- This allows to determine the electron **energy and transverse momentum** in order **to select** only events very close to the tritium $\beta$-spectrum end-point.

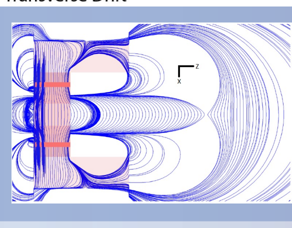



### ③ DYNAMIC FILTER

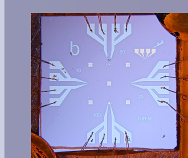
- The **transverse drift filter** [3] exploits the gradient-B drift of a charged particle in the presence of statically decaying electric and magnetic fields to **reduce its transverse momentum** till few eV.
- The main advantages are in the **compactness** of the filter dimensions (less than 1 $m^3$) and the direct transition to a **zero magnetic field** region at the end of the filter.

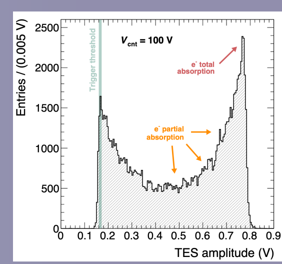


### ④ ELECTRON DETECTOR

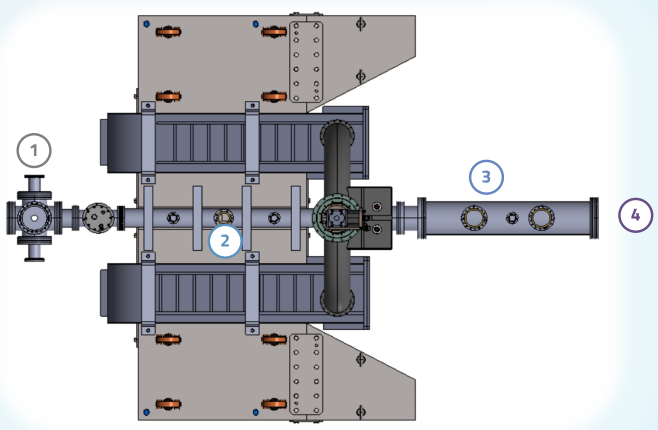
- A key point for the project is the development of a device capable to detect electrons with an energy resolution lower than 50 meV.
- **Microcalorimeters based on transition-edge sensors** (TES) are among the best candidates since they already reach single-photon Gaussian energy resolutions below 50 meV for 0.8 eV photons.
- For the **first time fully-absorbed electrons** in the (95 – 105) eV energy range has been recently detected using TES with a resolution between 0.8 and 1.8 eV [4].






## Demonstrator @ LNGS

- The PTOLEMY Demonstrator is being **built and operated at LNGS** in its first stage. It acts as a **proof-of-principle** set-up with the first goal of **testing** the full electron transportation from the source to the micro-calorimeters, determining filter efficiency, and aiding in its possible **optimization**.
- The demonstrator consists of a **superconductive magnet** (here at LNGS in early 2026!) shaped to allow a constant B field region and a varying B field with an exponential fall along the filter axis.
  - ❑ The source and RF antenna (1, 2) will be located in the constant B region
  - ❑ Beyond this region, where the B field drops with the desired shape, electrons close to the tritium $\beta$-spectrum end-point are pre-selected and slowed down by the dynamic filter powered by appropriate electrodes (3)
  - ❑ At the bottom of the filter, an array of TES microcalorimeters or an hemispherical electron energy analyzer (4) detect the chosen electron and precisely measure its energy
- An $^{83m}$Kr standard source and a specialized electron gun will be used to **calibrate the filter**.




- After the test and optimization stages, a second phase with the first sizable prototype source will exploit the filter performances for the **first physics goal** of the **neutrino mass measurement** from the **distortion of the $\beta$-spectrum end-point.** It is expected that only **1 µg** of tritium is sufficient to be competitive with KATRIN.

## Have a Look


[1] Probing low energy neutrino backgrounds with neutrino capture on beta decaying nuclei, A.G. Cocco et al., JCAP 06 (2007) 015

[2] Gap Opening in Double-Sided Highly Hydrogenated Free-Standing Graphene MG, Betti et al., Nano Letters (2022), 22, 7, 2971–2977

[3] Implementation and optimization of the PTOLEMY transverse drift electromagnetic filter, A. Apponi et al., JINST 17 (2022) 05, P05021

[4] Detection of Low-Energy Electrons with Transition-Edge Sensors, C.Pepe et al., eprint arXiv:2405.19475


➢ PTOLEMY website:



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