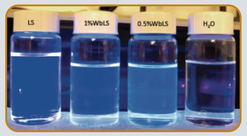
Sensitivity to Nucleon Decay in Theia

Morgan Askins[1,2] for the Theia Collaboration

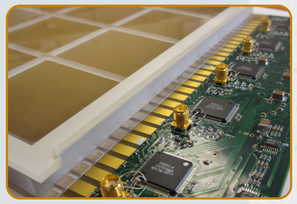
Detection Medium

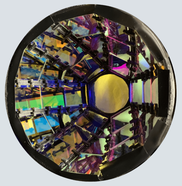
Theia takes advantage of new developments in liquid scintillators, fast photon detectors, and chromatic sorting to discriminate between Cherenkov and Scintillation signals [1].



Water-based liquid scintillator (WbLS) emits both Cherenkov and scintillation light in similar quantities [2].

Fast photodetectors can separate the prompt Cherenkov from the delayed scintillation light [3-4].





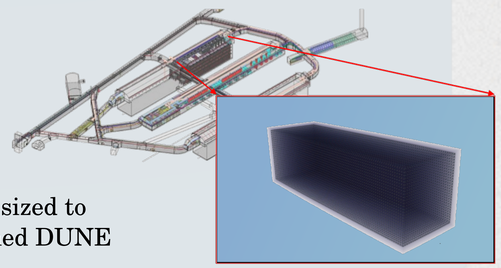
Chromatic separation further separates the light into long wavelength Cherenkov and shorter wavelength scintillation [5].

Depth, Geometry, and Mass

Two geometries explored, each with 90% PMT coverage and a 5% WbLS target medium.

Theia 100

100-kt total mass right circular cylinder.



Theia 25

25-kt total mass, sized to fit within a planned DUNE cavern.

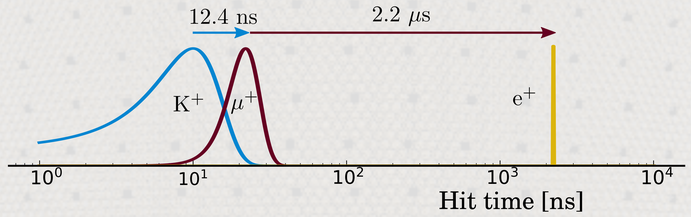
Proton Decay

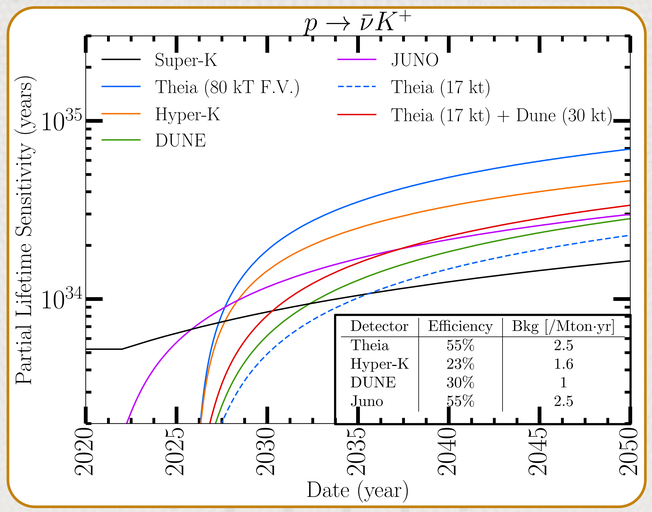
The two highest priority modes to search for proton decay are $\mathrm{p} \to \mathrm{e}^+\pi^0$ *and* $\mathrm{p} \to \bar{\nu}\mathrm{K}^+$ *. Of the two, Theia provides improved sensitivity to* $\mathrm{p} \to \bar{\nu}\mathrm{K}^+$

$$\mathrm{p} \to \bar{\nu}\mathrm{K}^+$$

Triple coincidence signal surpresses most backgrounds

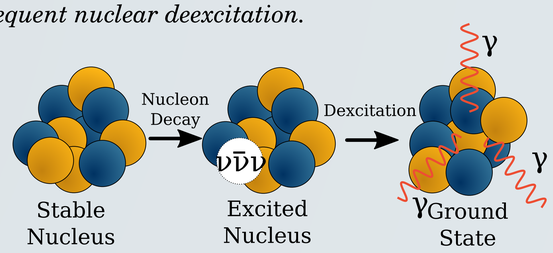
Decay Mode $\tau = 12.4$ ns	Branching Ratio
$\mathrm{K}^+ \to \mu^+\nu_\mu$	63.32%
$\mathrm{K}^+ \to \pi^+\pi^0$	21.13%
$\mathrm{K}^+ \to \pi^+\pi^+\pi^-$	5.58%
$\mathrm{K}^+ \to \pi^0 e^+\nu_e$	4.87%
$\mathrm{K}^+ \to \pi^+\pi^0\pi^0$	1.73%





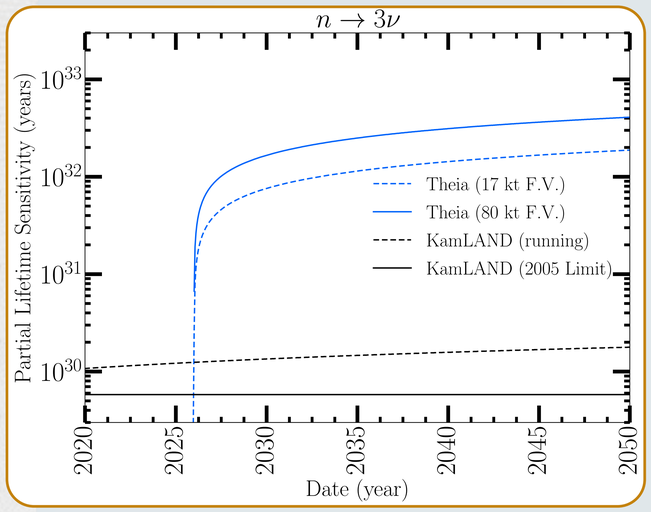
"Invisible" Neutron Decay
(e.g.) $\mathrm{n} \to 3\nu$

The so-called "invisible" modes do not directly deposit energy in the detector, but can be observed through their subsequent nuclear deexcitation.



$$^{16}\mathrm{O} \to {}^{15}\mathrm{O}^* \to {}^{15}\mathrm{O} + \gamma(6.18\ \mathrm{MeV})$$

Water provides a better signal compared with scintillator because the branching ratio in Oxygen (44%) is much higher than in Carbon (5.8%). Theia's target medium and depth provide sensitivity that no other experiment can match.



References

[1] M. Askins *et al.,* "Theia: An advanced optical neutrino detector," *Eur. Phys. J. C,* **80** (2020).
[2] M. Yeh *et al.*, "A New Water-based Liquid Scintillator and Potential Applications," *Nucl. Inst. Meth. A* **660** (2011).
[3] A. Lyashenko *et al.*, "Performance of Large Area Picosecond Photo-Detectors (LAPPD)," *Nucl. Inst. Meth. A* **958** (2020).
[4] J. Caravaca *et al.*, "Experiment to Demonstrate Separation of Cherenkov and Scintillation Signals," *Phys. Rev. C* **95** (2017).
[5] T. Kaptanoglu *et al.* "Spectral Photon Sorting for Large-Scale Cherenkov and Scintillation Detectors," *Phys. Rev. D*, **101** (2020).

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