Search for the forbidden decay μ→eγ: from MEG II to the High Intensity Muon Beam

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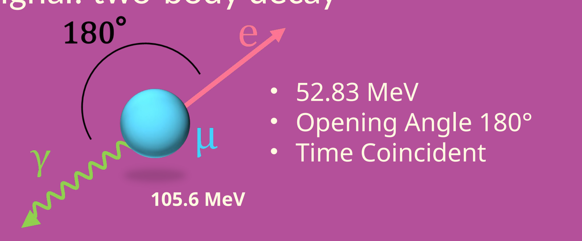
Abstract: The experiment MEG II located at PSI was designed to improve by an order of magnitude the sensitivity 4.2×10^{-13} reached by MEG on the search for $\mu^+ \to e^+\gamma$ decay.
The DC muon beam delivers up to $5 \times 10^7\ \mu^+$/s on a thin target where they stop and decay. The detector consists of a large LXe calorimeter for measuring the γ energy, timing and interaction point, complemented of a positron spectrometer built around the COBRA magnet, with the target at the centre, that delivers a solenoidal gradient field. The spectrometer consists of a drift chamber for measuring the positron momentum, direction and decay vertex complemented of pixelated Timing Counter based on plastic scintillators. Data taking started in 2021 and will continue till 2026.
Analysis of the 2021-2022 data resulted in $Br(\mu \to e\gamma) < 1.5\ 10^{-13}$. Analysis the data collected in the following years is ongoing and the expected sensitivity with the full sample is $6\ 10^{-14}$.
For the coming years, PSI plans to build a High Intensity Muon Beam facility delivering up to $10^{10}\ \mu^+$/s. The design of an experiment able to cope with this rate is ongoing.

Motivation

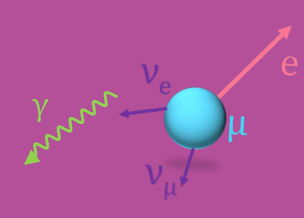
In MEG II experiment we search for the charged lepton flavor violation, $\mu^+ \to e^+\gamma$ decay, which would be evidence of BSM physics [1].

Precise measurement of emission angle, energy, and relative timing of positron and γ are essential.

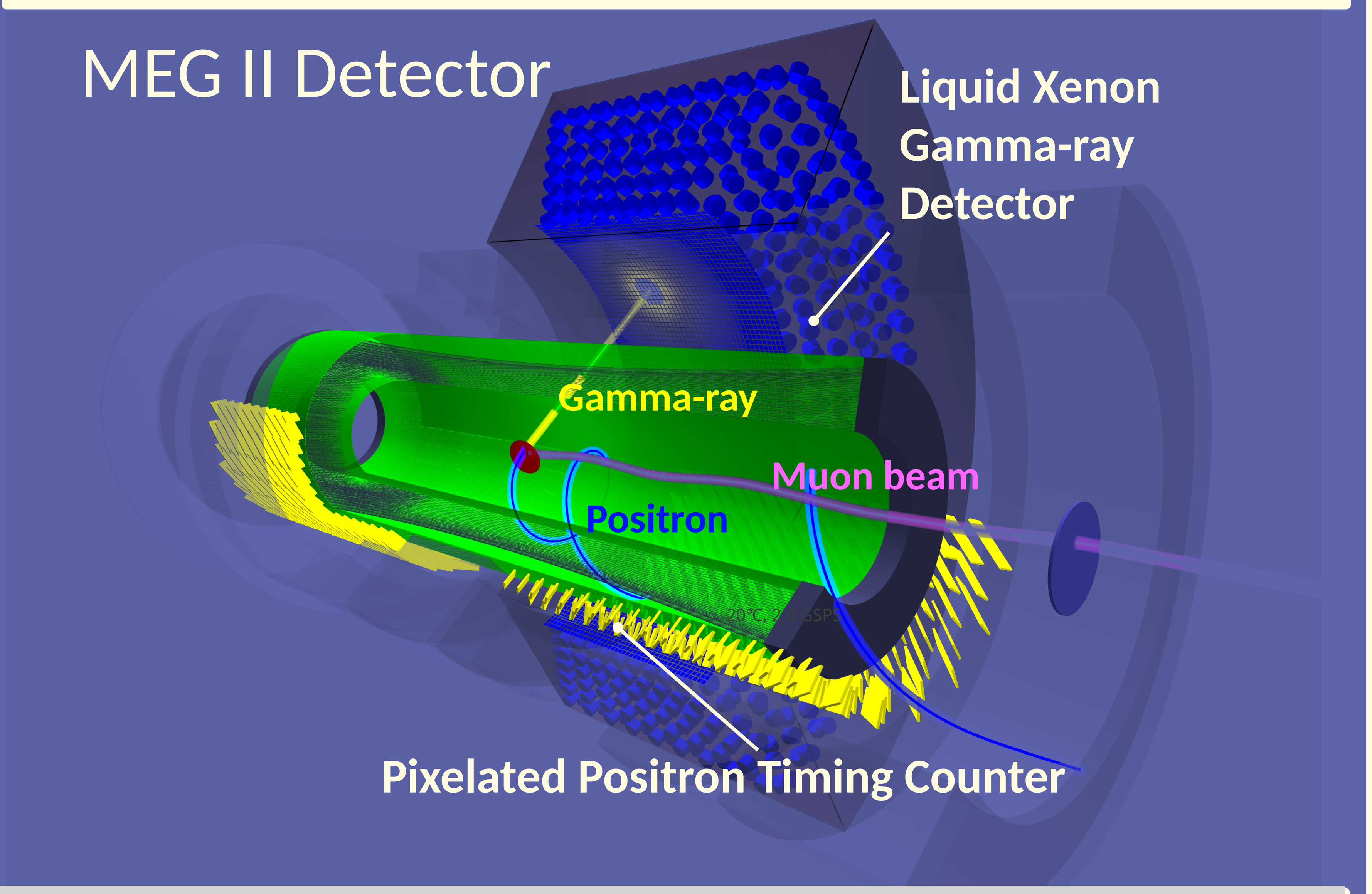
Signal: two-body decay

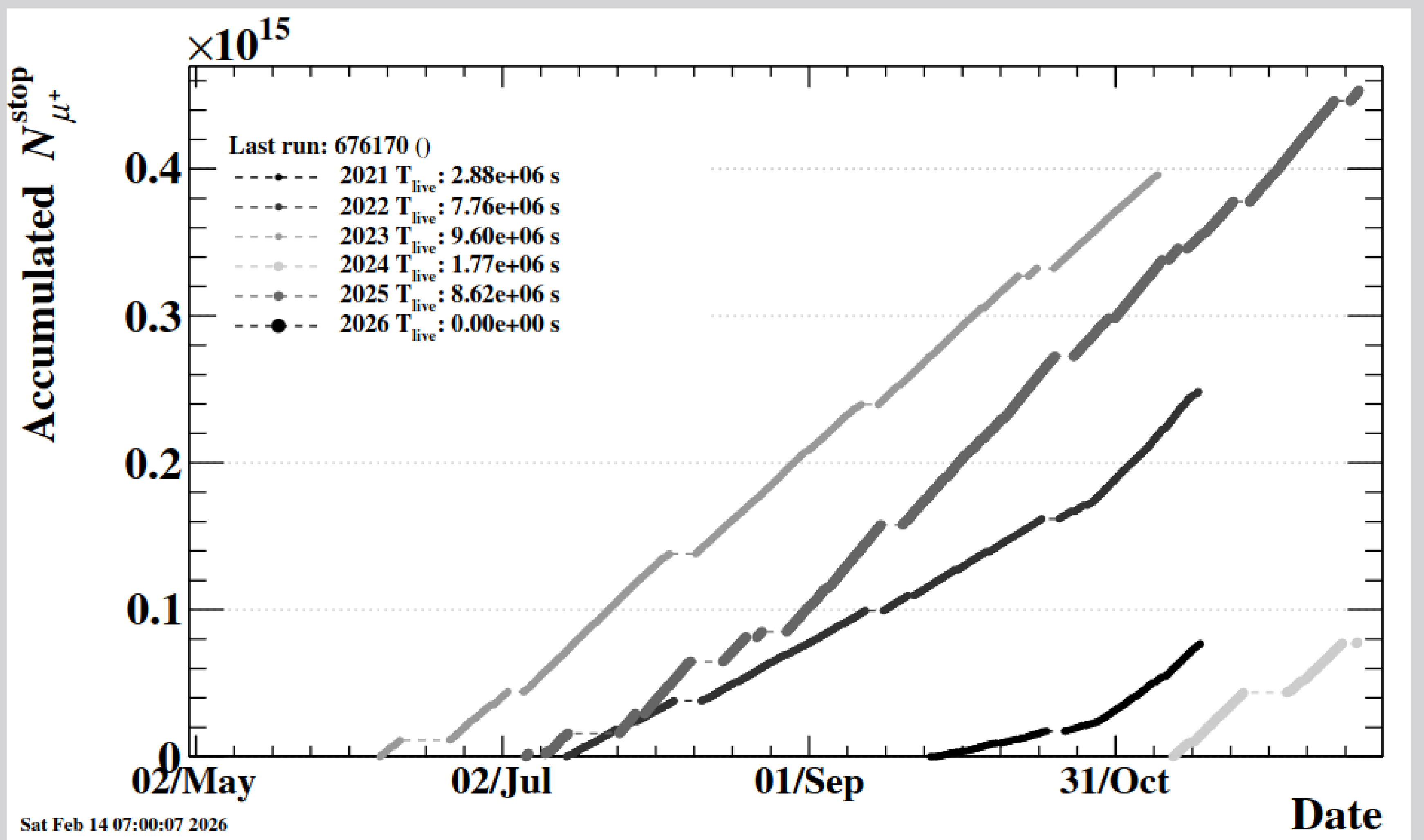


Dominant BG: accidental



MEG II Detector





Expected total muons delivered in target including 2026: ~1.5 10^{15}

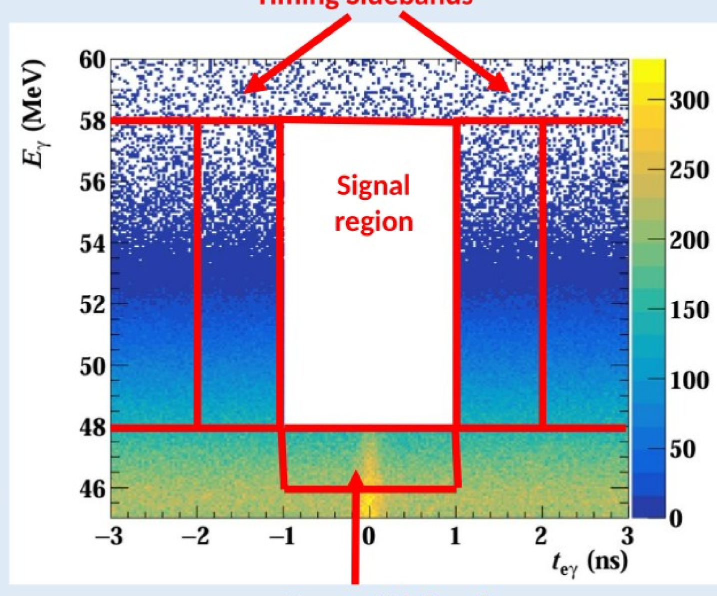
Analysis Strategy

We blind events in the signal region and use the other events (SideBands), plus Simulation and Calibrations, to evaluate Probability Distribution Functions to be used in a likelihood fit.

$$\mathcal{L}(N_{sig}, N_{RMD}, N_{ACC}, x_T) = \frac{e^{-(N_{sig}+N_{RMD}+N_{ACC})}}{N_{obs}!} C(N_{RMD}, N_{ACC}, x_T) \times \prod_{i=1}^{N_{obs}} (N_{sig}S(\vec{x}_i) + N_{RMD}R(\vec{x}_i) + N_{ACC}A(\vec{x}_i))$$

PDFs

$$x_i = \{E_\gamma, E_{e^+}, t_{e^+\gamma}, \theta_{e^+\gamma}, \phi_{e^+\gamma}\}$$

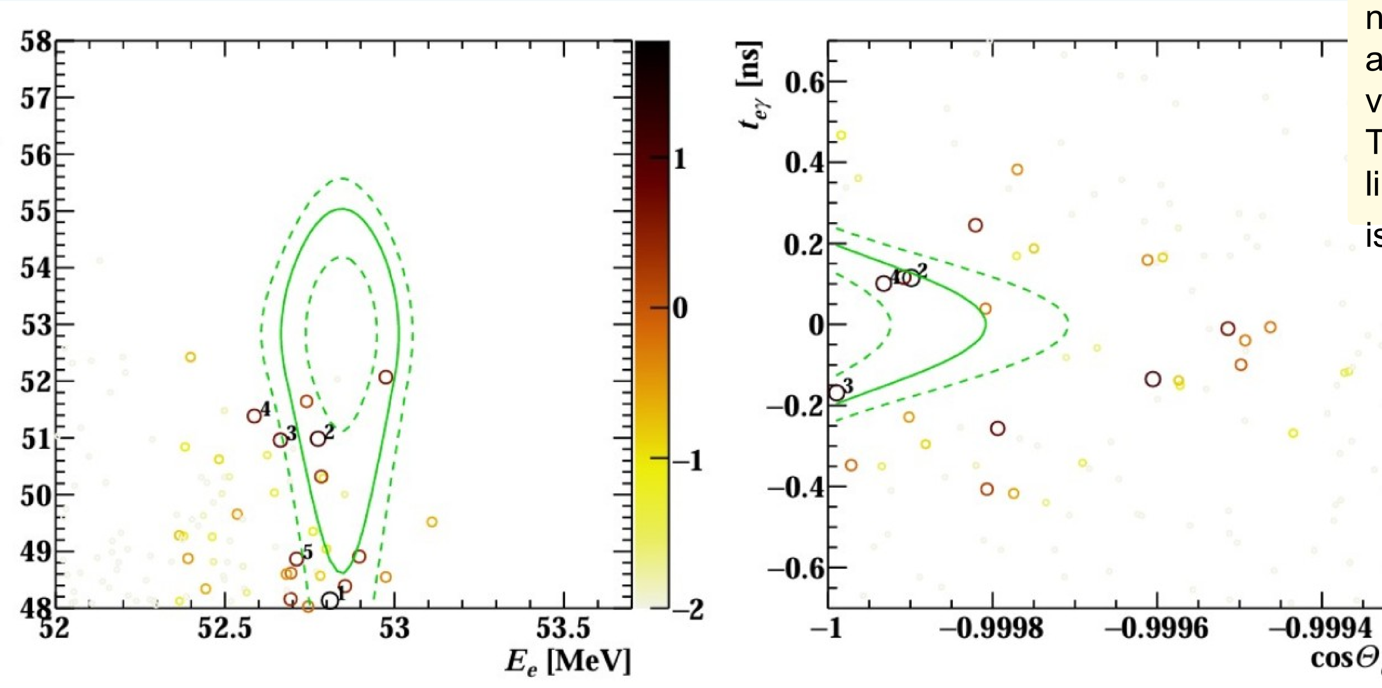


NRMD and NACC are in the signal region are constrained by the events measured in the sidebands

E_γ γ energy
E_{e+} positron energy
$t_{e+\gamma}$ relative timing
$\theta_{e+\gamma}\phi_{e+\gamma}$ relative angles

Opening the box

Opening the Signal Region



cosΘeγ < −0.9995 and |teγ| < 0.2 ns

49.0 < Eγ < 55.0 MeV and 52.5 < Ee < 53.2 MeV

In the signal region no excess of event above background is visible.
The result of the maximum likelihood fit is $Br(\mu \to e\gamma) < 1.5\ 10^{-13}$

Future μ→e γ experiment

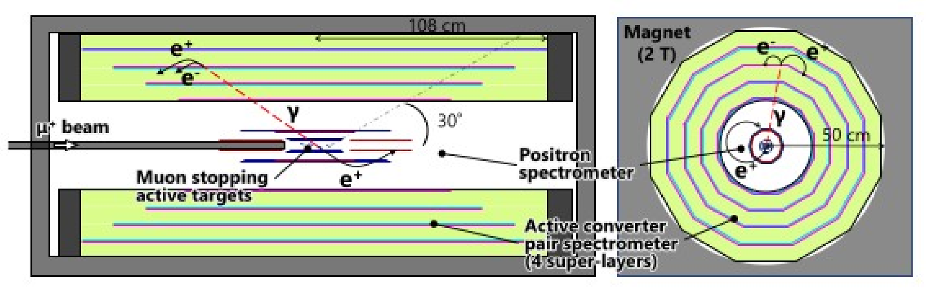


Figure 4: A sketch of a detector for $\mu^+ \to e^+\gamma$ decays with a silicon pixel tracker for positrons, and active conversion layers with e^+e^- trackers for photons, within a single, long solenoid.

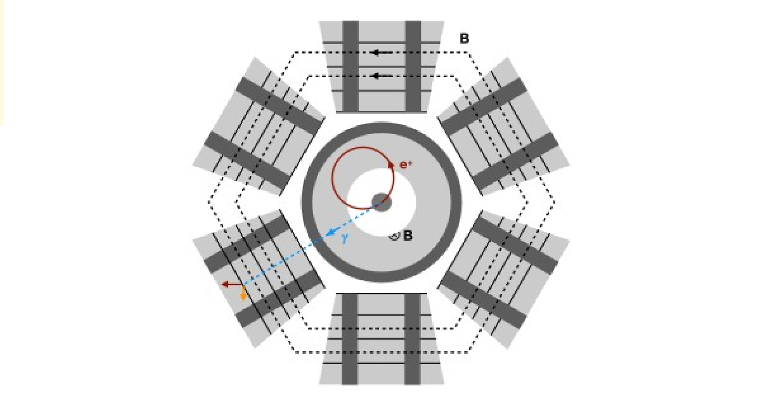


Figure 5: A sketch of a detector for $\mu^+ \to e^+\gamma$ decays with a central tracker for positrons within a solenoid, and active conversion layers with e^+e^- trackers for photons in an external toroidal field. The hexagonal configuration is only indicative, it could be as well octagonal.

Letter Of Intent presented at PSI for a future μ→e γ experiment.
Two options of magnetic field structure: only solenoidal or toroidal-solenoidal. The γ detector is a pair converter of active high-Z material followed by TPC. Two stage experiment: first at 2×10^8 μ/s with Drift Chamber as positron tracker, second above 10^9 μ/s with silicon tracker.

Converter with active crystals

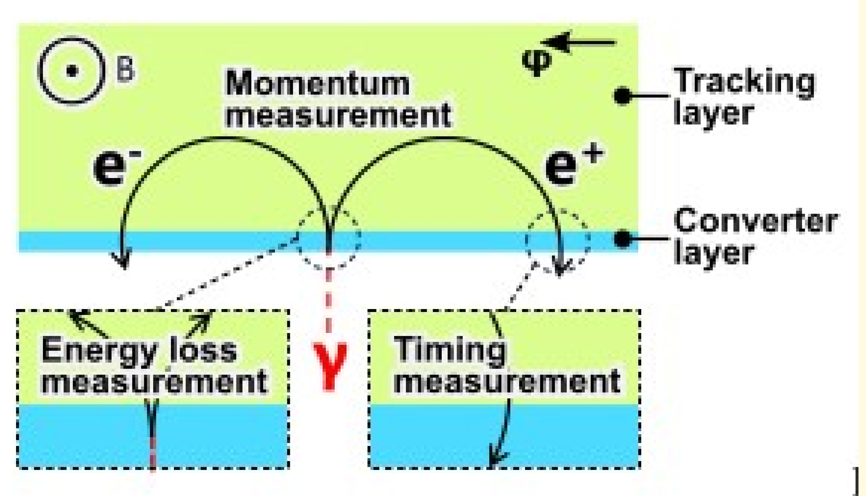


Figure 6: Concept of the active converter.

Converter measures energy loss of the pair in the crystal and the momenta of the pair in the TPC. The crystal measures also the g timing.

Sensitivity

The sensitivity depends on the number of converter layers that are limited by geometry cost and magnetic field intensity.

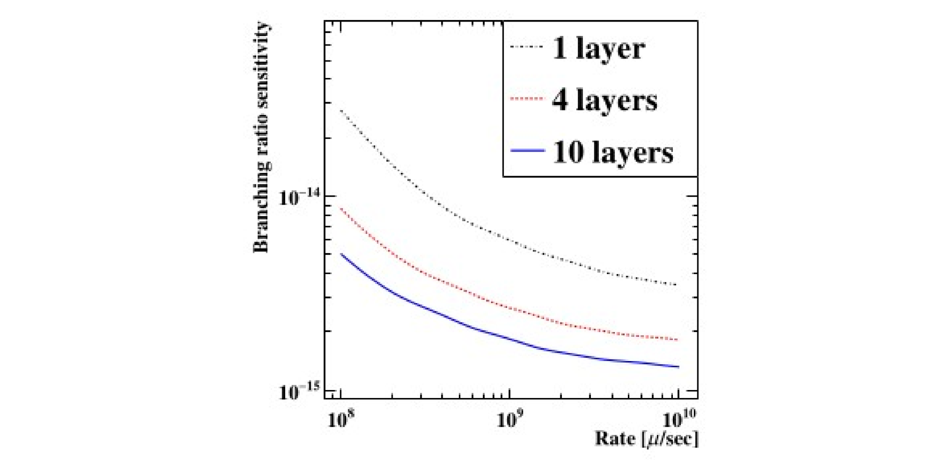
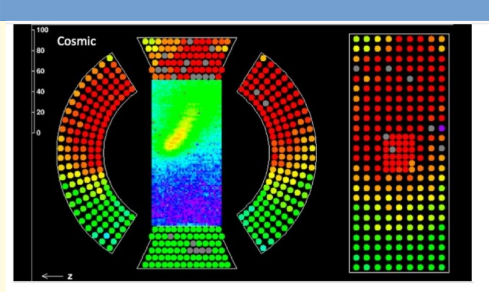
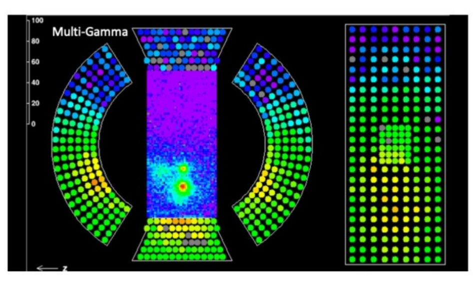
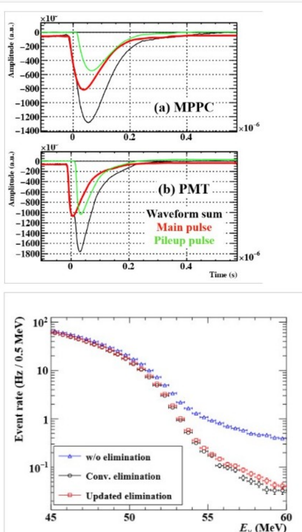
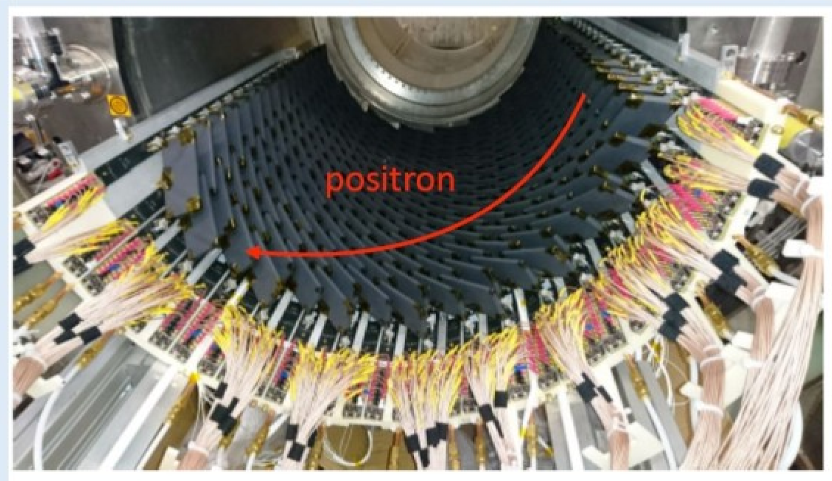
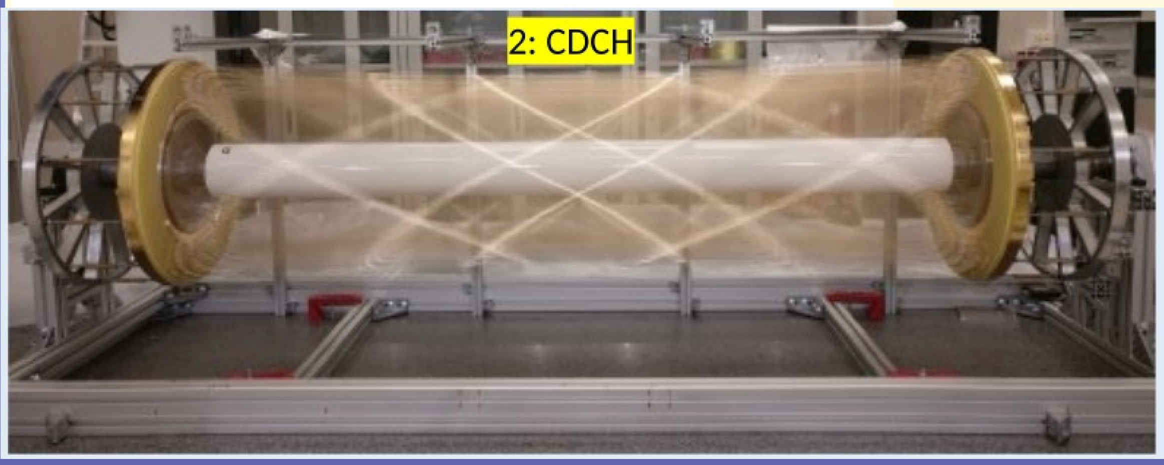


Figure 12: The projection of the branching ratio sensitivity (90% C.L. upper limit) for a 3-year run as a function of the beam rate for the experiment with the conversion pair spectrometer. Three scenarios for the number of conversion layers are compared.

The detectors: LXe, CDCH, pTC



1.9 m x .5 m Φ