Precise Measurement of the $\pi^+ \rightarrow e^+\nu$ Branching Ratio

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One of the most important tasks of modern elementary particle physics is to determine the limits of the applicability of the Standard Model (SM) for electroweak interactions, to search for phenomena that go beyond it and thereby indicate the existence of a "new physics".

The ratio of the decay probabilities $R_{e/\mu} = \Gamma(\pi \rightarrow e\nu(\gamma)) / \Gamma(\pi \rightarrow \mu\nu(\gamma))$ is suppressed in the SM due to the V-A structure of the charged current constants, and is therefore sensitive to all CM extensions: pseudoscalar interaction, violation of lepton universality, contributions to semileptonic decays, appearing in the Minimal Supersymmetric Standard Model (MSSM). These effects are expected in the region of $\Delta R_{e/\mu}/R_{e/\mu} \leq 10^{-4} - 10^{-2}$ and there is a real chance to detect them.

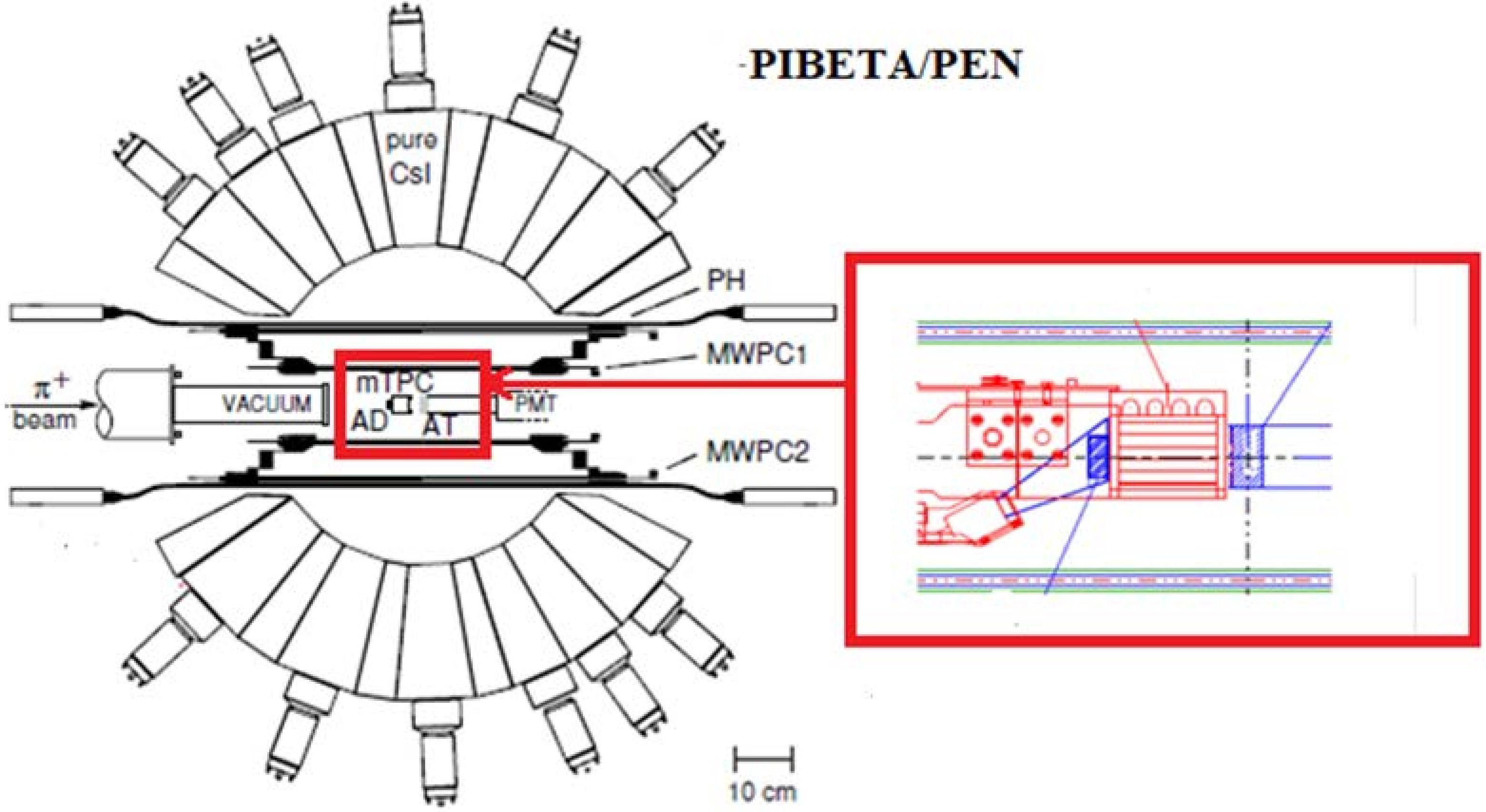
Well controlled theoretical uncertainties for the the $\pi^+\rightarrow e^+\nu$ decay render this process the most accurate experimental test of lepton universality available. At present, accuracy of the $\pi^+\rightarrow e^+\nu$ decay measurements lags behind the theoretical precision by an order of magnitude. A number of exotic physics scenarios outside the standard model may lead to a violation of lepton universality

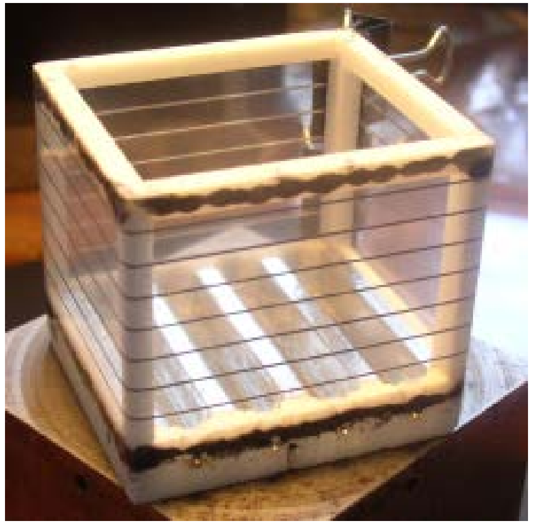
Calculations of the relative probability of the $\pi^+\rightarrow e^+\nu(\gamma)$ decay in the Standard Model reached a precision of 1×10^{-4}. Meanwhile, the experimental precision is more than one order of magnitude worse:

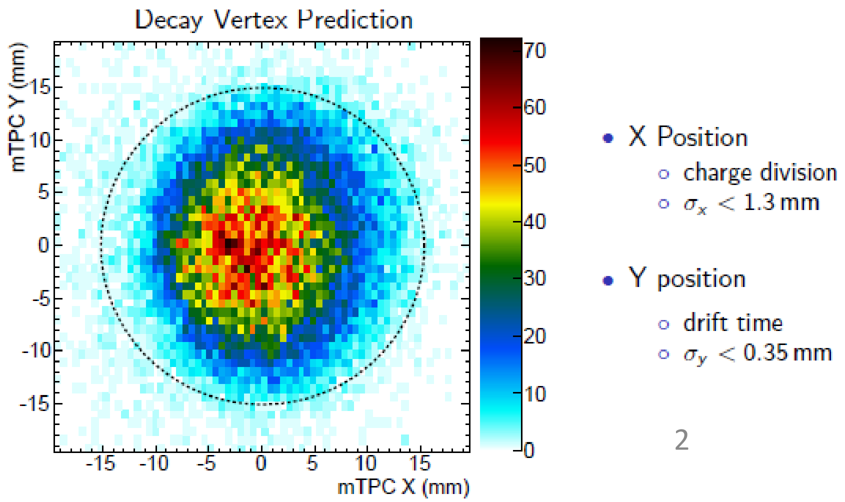
$$R_{e/\mu}^{exp} = [\Gamma(\pi^+\rightarrow e^+\nu(\gamma))/\Gamma(\pi^+\rightarrow \mu^+\nu(\gamma))]_{exp} = B(\pi^+\rightarrow e^+\nu(\gamma))_{exp} = (1.2327\pm0.0023)\times10^{-4}$$

$$B(\pi^+\rightarrow e^+\nu(\gamma))_{calc} = 1.2352(1) \times 10^{-4}$$

The measurements in PSI were carried out using the PEN detector. JINR has made a major contribution to this experimental setup: cylindrical proportional chambers with electronics, pure CsI crystals for the calorimeter and DAQ system. Also an original mini-TPC chamber has been developed and implemented for the PEN experiment by the JINR physicists. Data taking had been finished in 2010, and JINR participates in the analysis of data. There were detected about 23 million of $\pi \to e\nu$ decays, more than $1.5 \cdot 10^8$ of $\pi \to \mu \to e$ decays as well as a great amount of radiative muon and pion decays. The expected total error including both statistics and systematics for $\pi \to e\nu$, will be $\Delta R/R < 5 \cdot 10^{-4}$ as originally planned.







PEN Collaboration Plans

A comprehensive blinded analysis is under way to extract a new experimental value of $R_{\pi,e/\mu}$.
There appear no obstacles that would prevent the PEN collaboration to reach a precision of $\Delta R/R < 10^{-3}$.

A first publication based on 2009/2010 data is expected before the end of 2017.

New results also will be obtained soon from the analysis of radiative pion and muon decay events.

Search for the Lepton Flavor Violating $\mu^+ \rightarrow e^+\gamma$ decay in the MEG experiment

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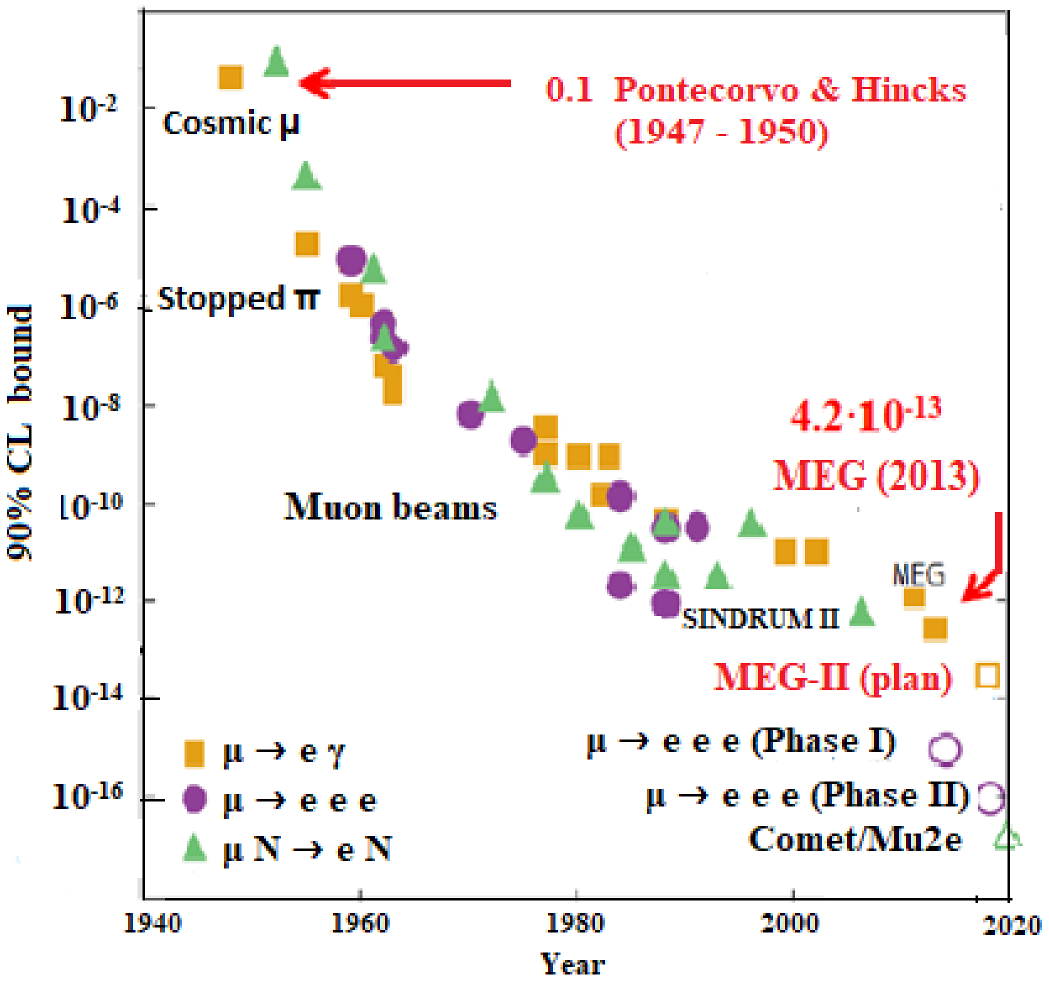
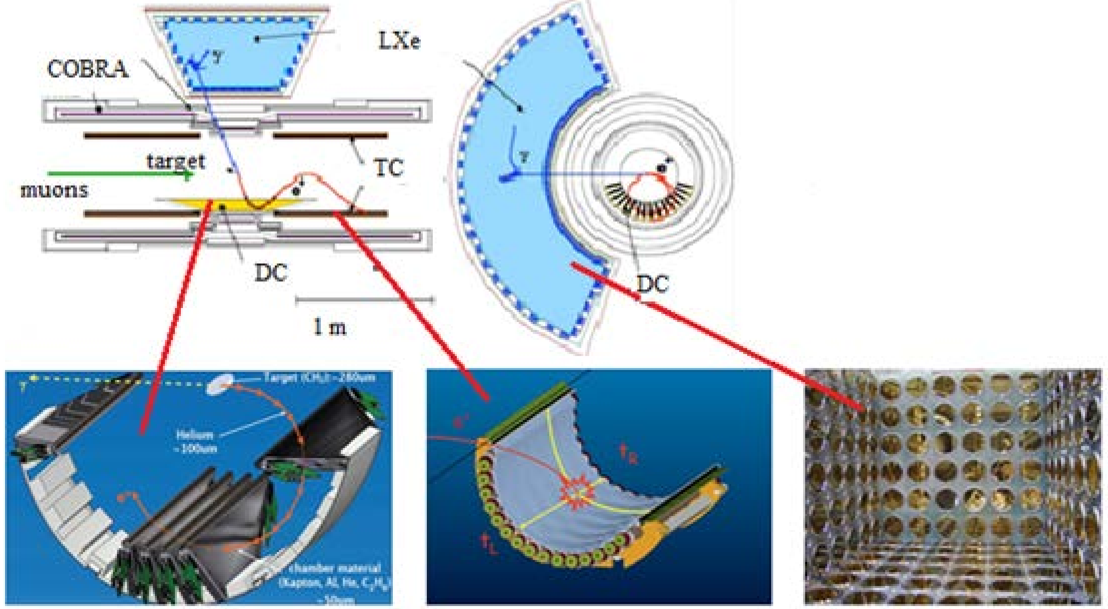
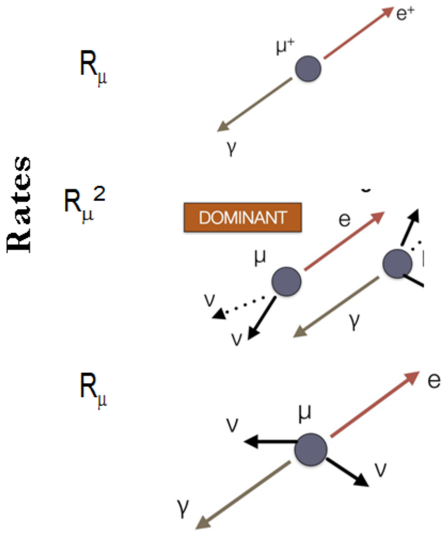


For 70 years of the history of research of rare processes, the experimental accuracy has improved by 12 orders of magnitude. This is achieved both by improving the measurement technique, and the progress in building new high intensity accelerators.





Signal

Muon at rest:

$E_\gamma = E_e$=52.8 MeV

Back-to-back

e - γ coincidence ($t_{e\gamma}$=0)

ACCidental coincidence

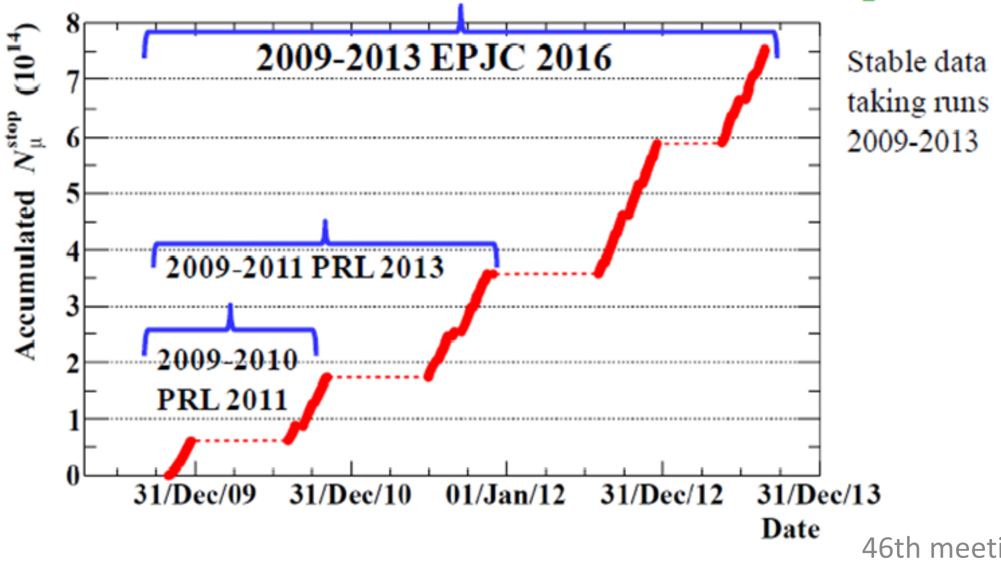
Michel e^+ & γ

γ from either RMD, e^+annihilation, or e^+Bremsstrahlung

Radiative Michel Decay (RMD)

$t_{e\gamma}$=0 but x20 less than accidental

Amount of data **almost doubled wrt 2009-2011 sample**



The goal of the MEG experiment is to detect the lepton flavour violating decay $\mu^+ \to e^+\gamma$ or put an upper limit on its branching ratio. The final result obtained in 2016 is based on the analysis of 7.5 × 10^{14} muons stopped in the target. No significant excess of events is observed in the dataset with respect to the expected background and a new upper limit on the branching ratio of this decay of $B(\mu^+ \to e^+\gamma) < 4.2\times10^{-13}$ (90% confidence level) is established, which represents the most stringent limit on the existence of this decay to date.

The key features of new MEG upgrade, aimed at significantly improving the experimental sensitivity, are to increase the rate capability of all detectors to enable running at the intensity frontier, while also improving the energy and angular and timing resolutions, for both the positron and photon arms of the detector.

Summary of the main improvements of the MEG-II upgrade:

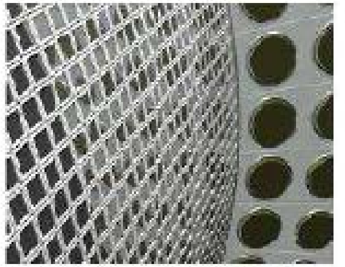
1. **Increased statistics of muons stopped in the target.**
2. **A thinner but more solid target and smaller amount of matter on the path of muons and positrons.**
3. **New positron tracker with reduced radiation length, better granularity and position resolution.**
4. **Improved characteristics of the positron tracker by measuring the e^+ trajectory in the timing counter.**
5. **Improved granularity and characteristics of the timing counter.**
6. **Larger detector acceptance for gamma by more than a factor 2.**
7. **Improved energy, spatial and timing resolution for surface gamma.**
8. **New DAQ system.**

MEG | MEG - II

- single volume drift chamber with stereo angle wire configuration

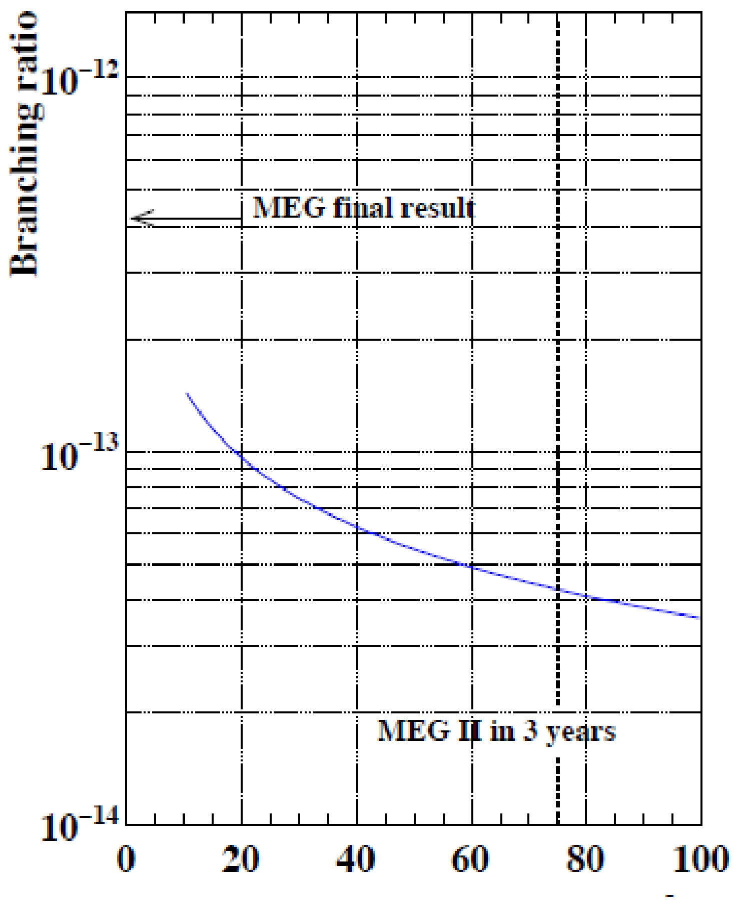
- scintillator tiles timing counter with SiPM readout

- SiPM readout of LXe front face



Resolution (Gaussian) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
E_{e^+} (keV)	306 (core)	130
θ_{e^+} (mrad)	9.4	5.3
ϕ_{e^+} (mrad)	8.7	3.7
e^+ vertex (mm)	2.4 / 1.2	1.6 / 0.7
E_γ (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
position (mm) u/v/w	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	99	99
γ	63	69
e^+	40	88



Thus, as a result of the MEG (MEG-II) experiment in 2018-2020, a new upper limit on the branching ratio of the $\mu^+ \to e^+\gamma$ decay of **$(4\text{-}5) \times 10^{-14}$** will be reached.