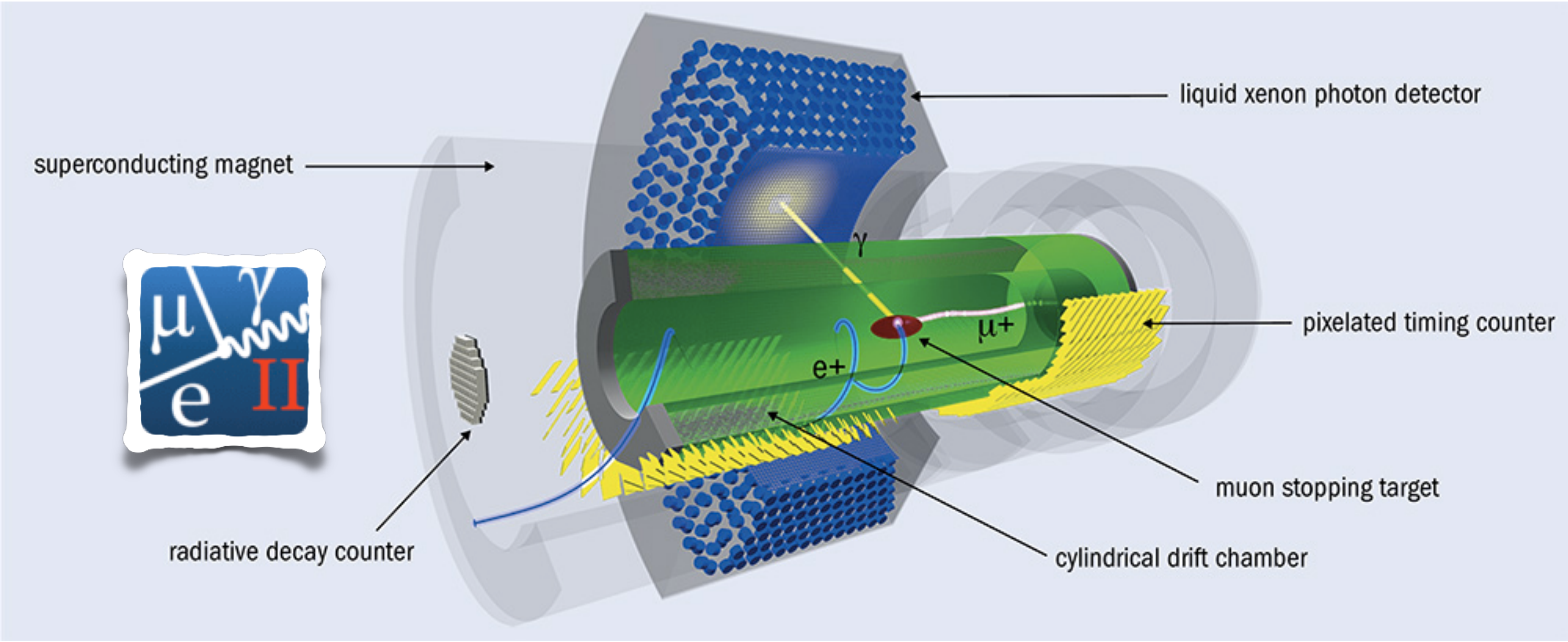


Lepton Flavour Violation Searches with the MEG-II experiment

Gianluca Cavoto - Sapienza Univ Roma and INFN Roma

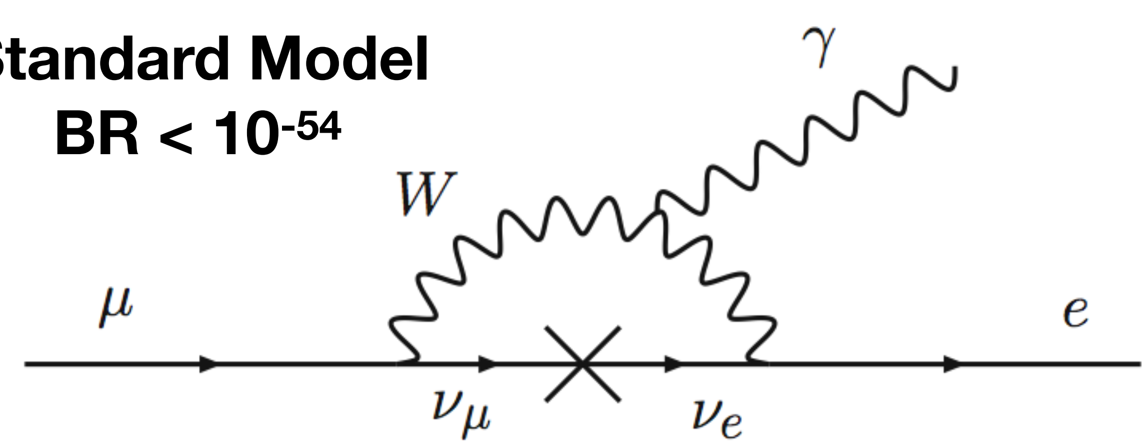
BLV 2022 - Bruxelles

Lepton flavour violation in the SM

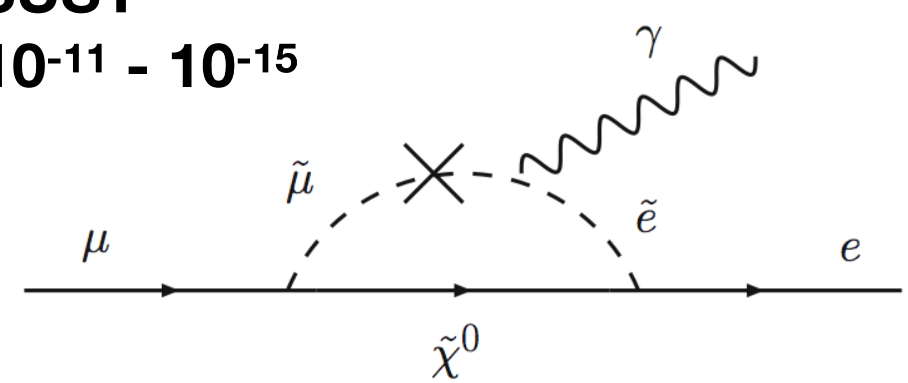
- SM prediction for LFV yields a more-than-tiny BF
  - Accidental symmetry of SM, neutrino mass is extremely small

- LFV easy to be implemented in New Physics
  - A striking signature of New Physics

Standard Model
BR < 10^{-54}



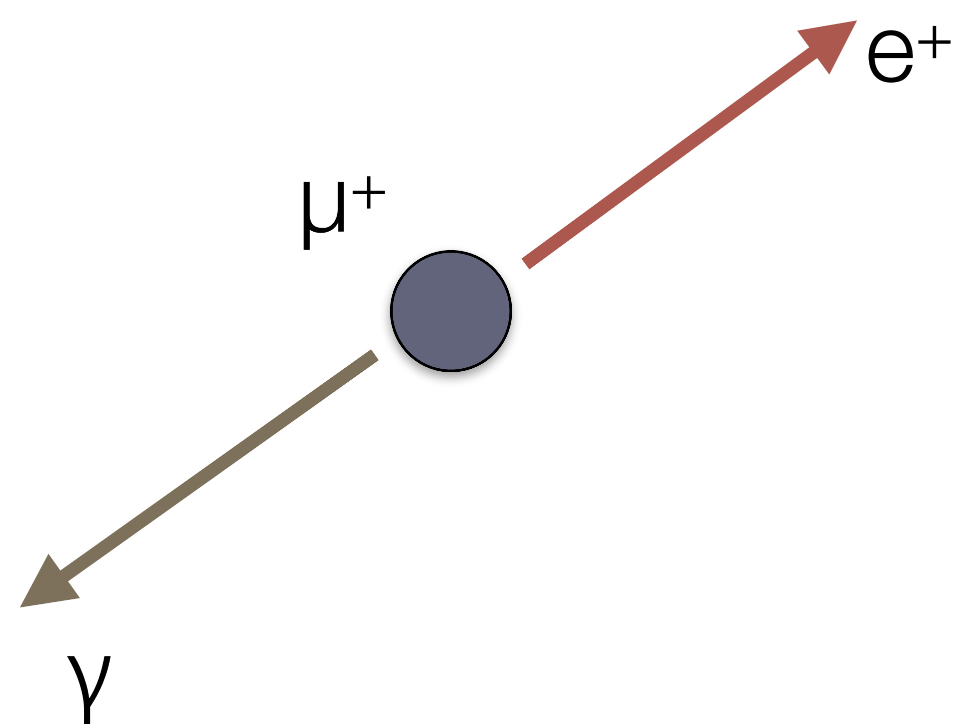
SUSY
BR ~ 10^{-11} - 10^{-15}



Not enough protons in the Universe to make so many muons to test SM

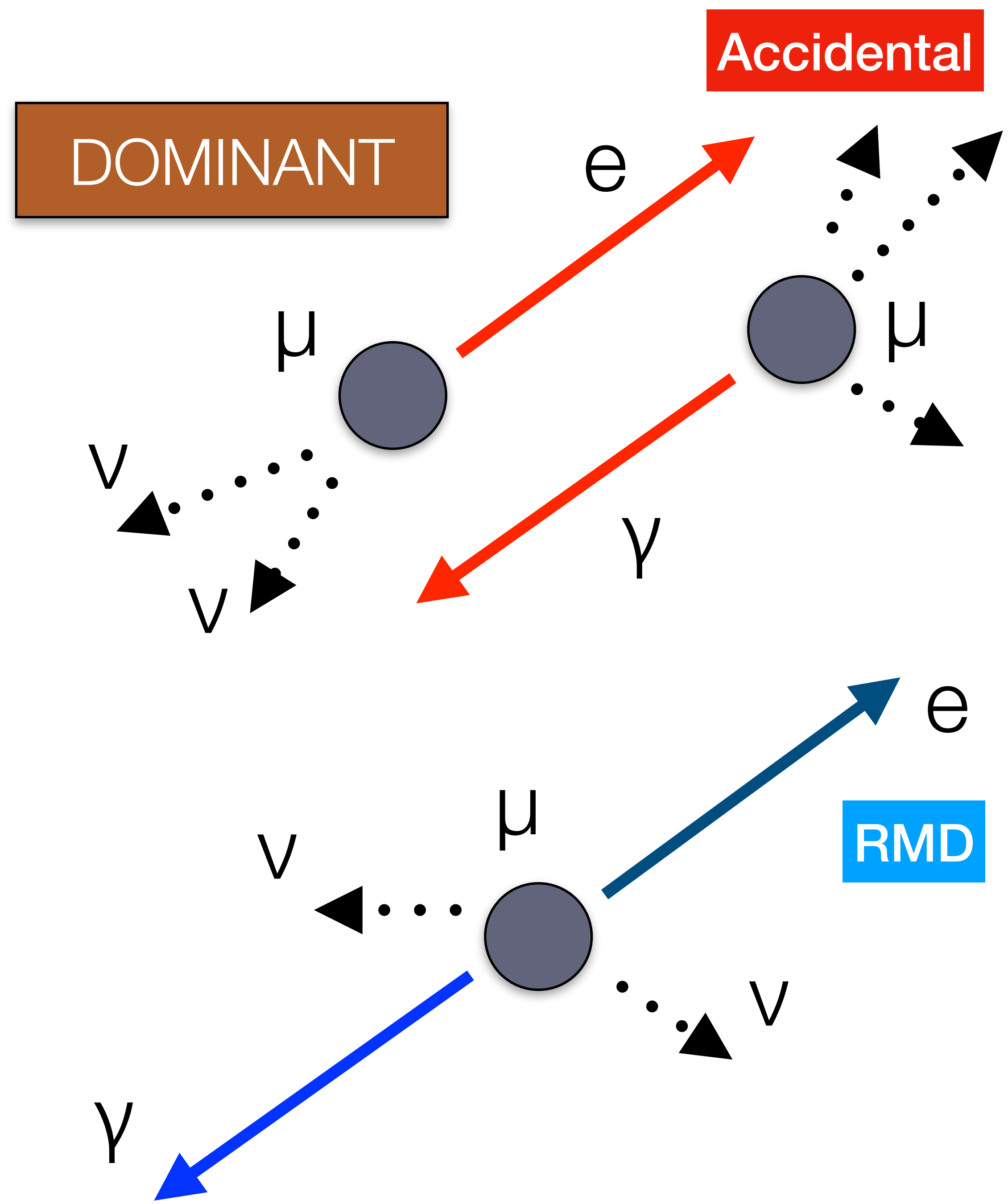
Searching for the $\mu \rightarrow e\gamma$ decay

- A very simple signature: **two body** decay
- Muon decay at rest:
  - **52.8 MeV** photon and positron, at the **same** time.
  - Oppositely directed momenta (**back-to-back**)



Experimental background

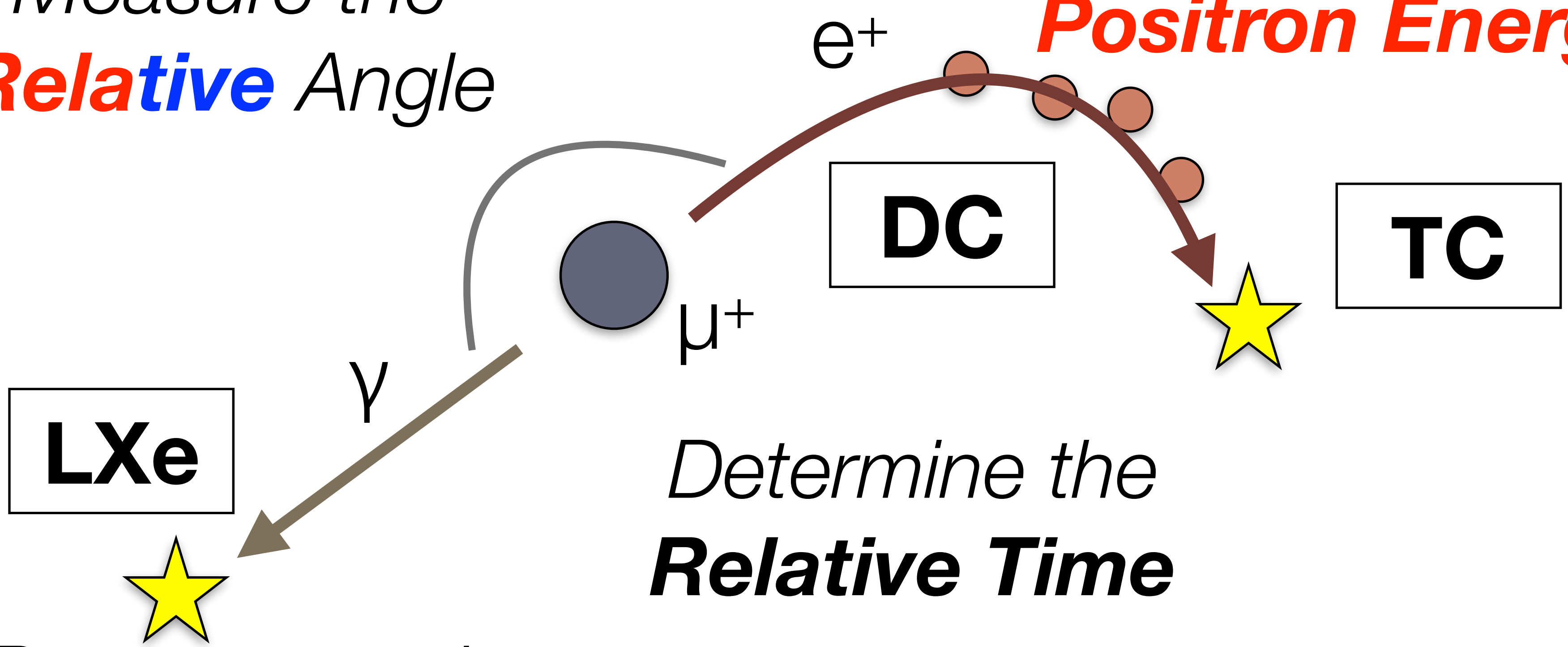
- To see a BF ~10^{-14} a lot of muons per seconds are needed
- Random superimposition of two standard (“Michel”) muon decays can be frequent (“**accidentals**”)
- Radiative decay (**RMD**) alone (corner of the phase space)



The experimental technique

Measure the ***Relative*** *Angle*

Reconstruct the
Positron Energy



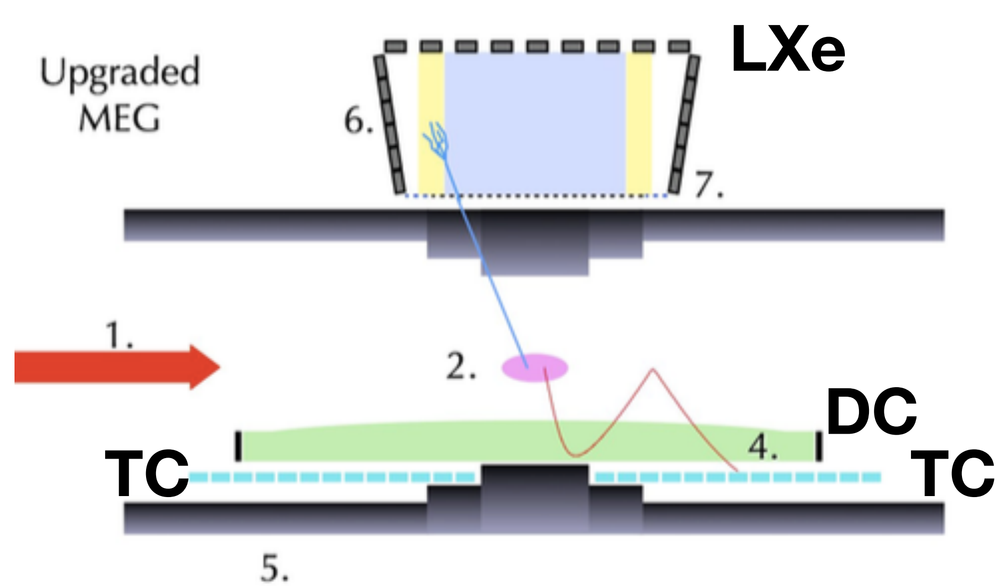
Determine the
Relative Time

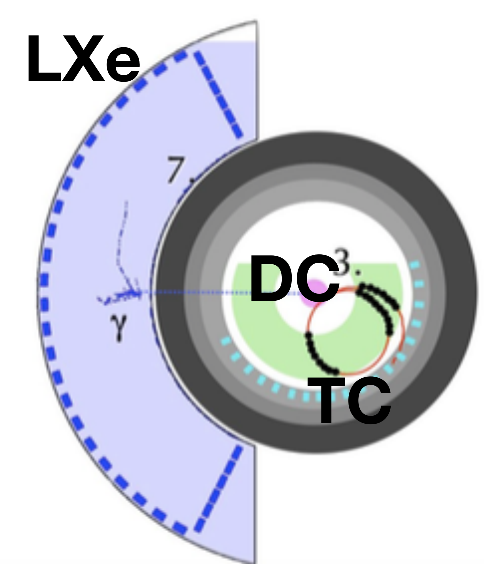
Reconstruct the
Photon Energy

LXe calorimeter

Magnetic spectrometer

Scintillators (e+ timing & trigger)





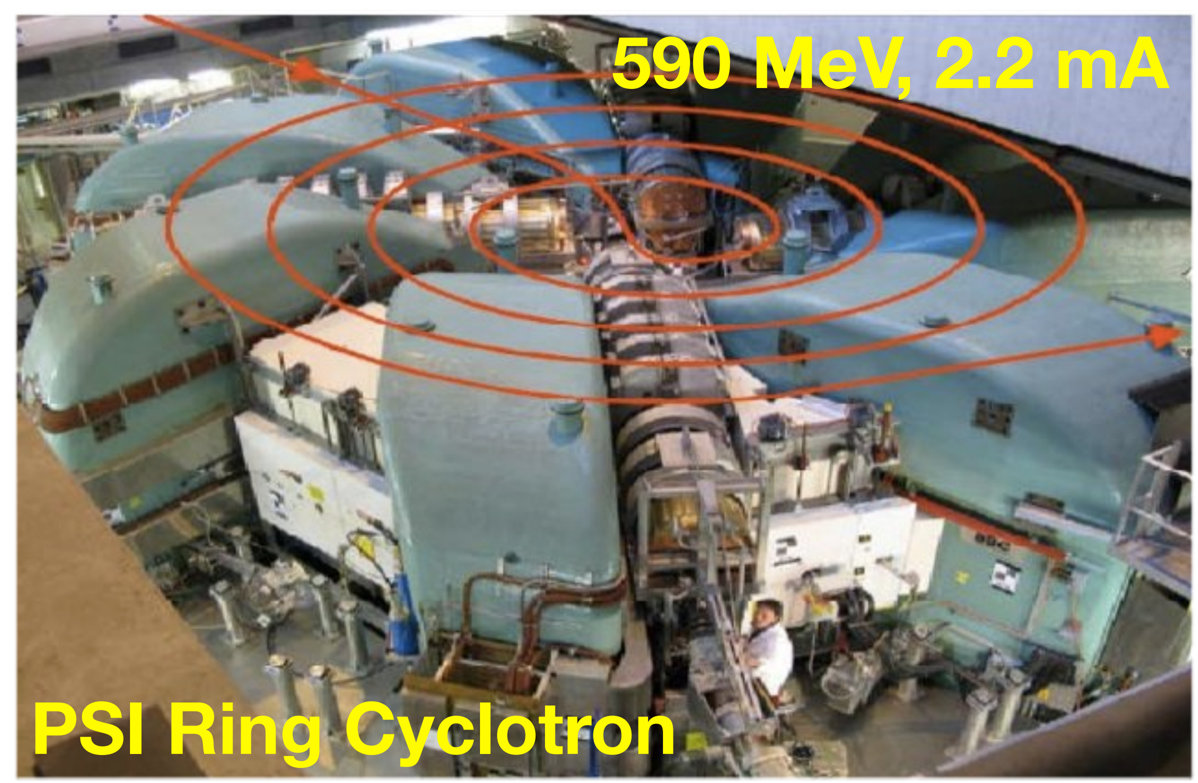
Background rejection

- Reducing acceptance to accidentals is the true challenge
  - Quadratic dependance from muon rate
- Better resolutions on the kinematic observables and relative timing

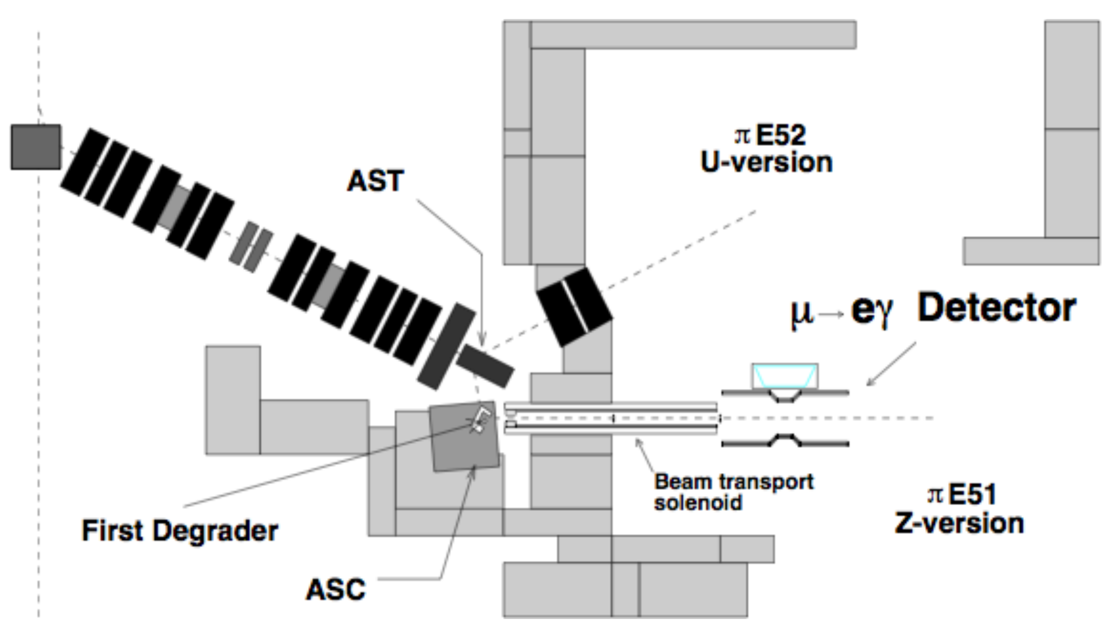
$$\Gamma_{acc} \propto \Gamma_{\mu}^{2} \cdot \varepsilon_{e} \cdot \varepsilon_{\gamma} \cdot \delta E_{e} \cdot (\delta E_{\gamma})^{2} \cdot (\delta \Theta_{e\gamma})^{2} \cdot \delta T_{e\gamma}$$

Intense muon beam at PSI

- A MW class proton **cyclotron** at the Paul Scherrer Institut (Villigen, CH)
- Several DC muon beam lines (the most **intense** in the world)



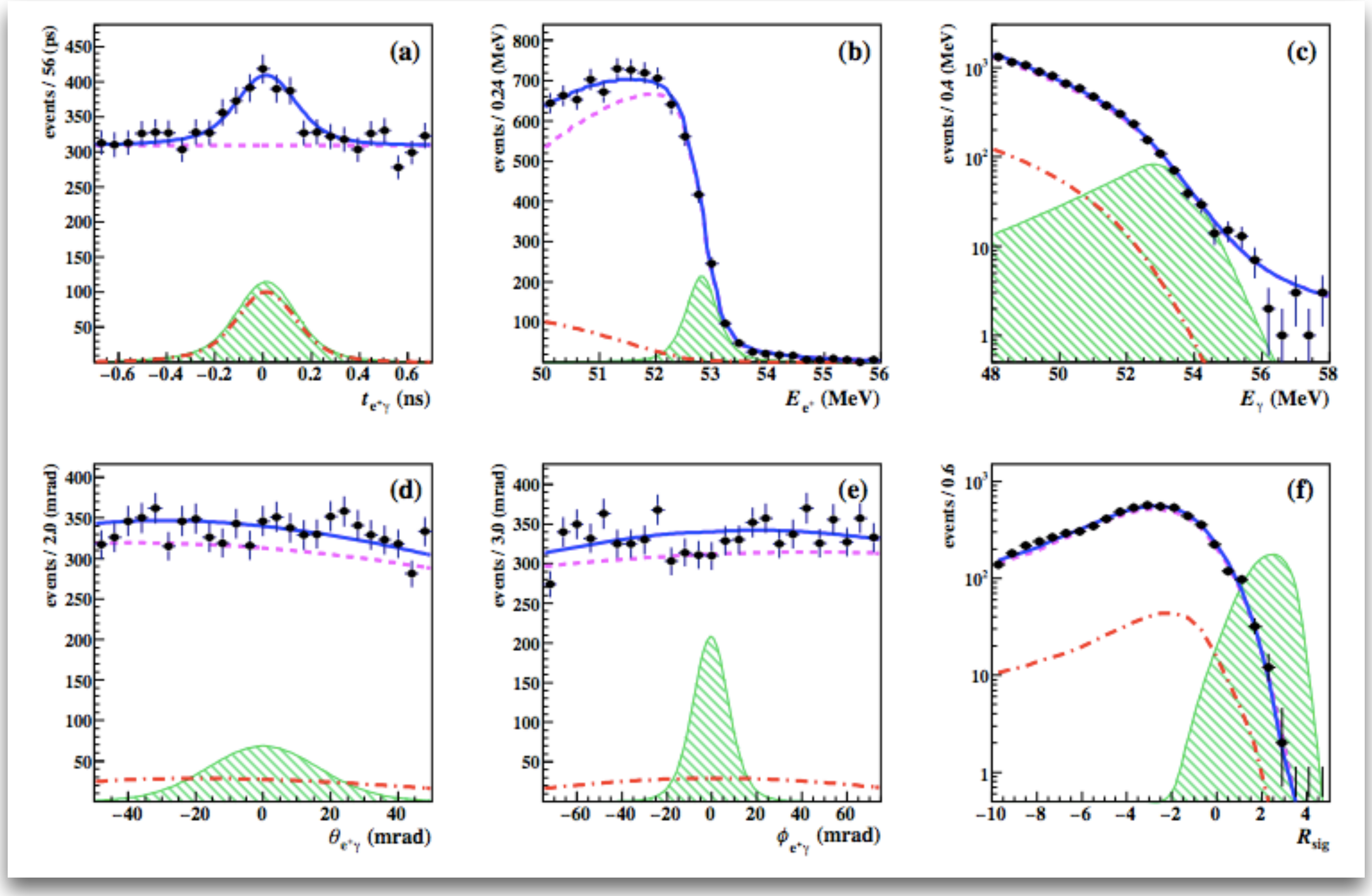
πE5 beam line- up to 10^8 μ/s



The best $\mu \to e\gamma$ limit (from MEG)

Magnified signal (BR = 4 x 10^{-11})

7.5 x 10^{14} μ on target



No evidence of signal

N_{ACC} = 7684 ± 103

N_{RMD} = 663 ± 59

BR < 4.2 x 10^{-13} @ 90% C.L.

Eur. Phys. J. C76, 434 (2016)

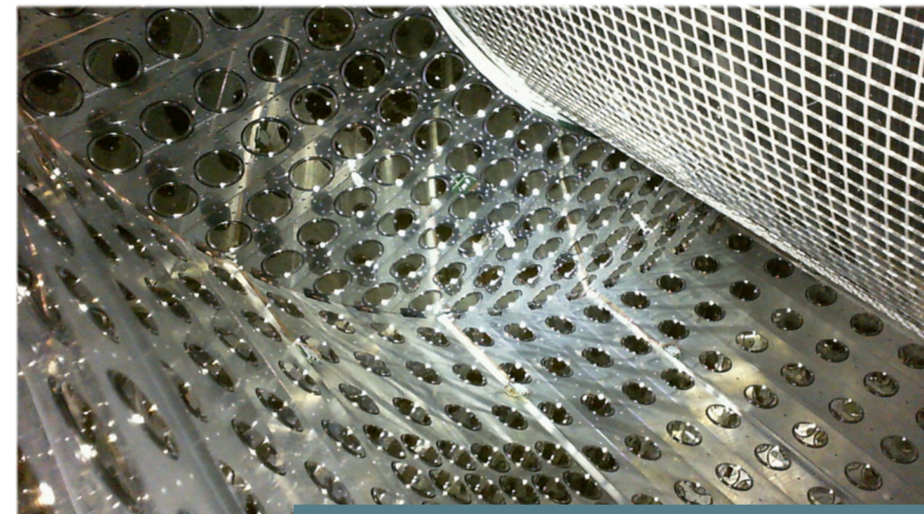
Call for a better detector (better resolution) and larger muon rate

Eur. Phys. J. C78 (2018) no.5, 380

An upgraded detector: MEG-II

LXe calorimeter

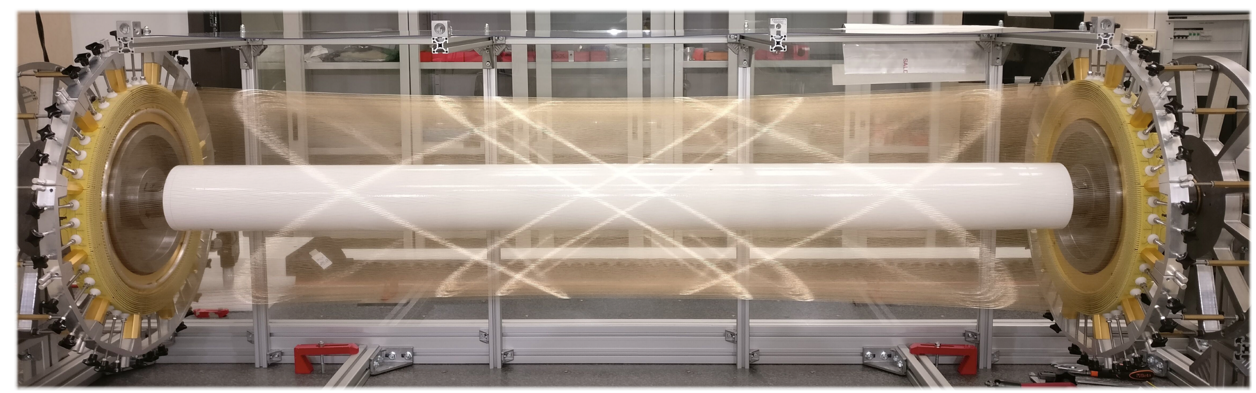
- Higher photon detector granularity in the inner face with **custom VUV-sensitive MPPCs**
- Larger sensitive volume



$\sigma_E \sim 1\%$, $\sigma_{position} \sim 2/5$ mm (x,y/z)

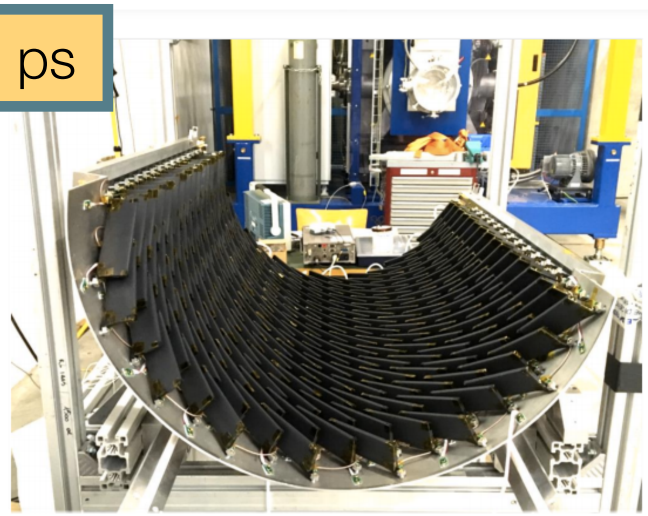
Magnetic spectrometer

- From 16 planar drift chambers to a **unique-volume** cylindrical drift chamber
  - Larger efficiency, improved resolutions



$\sigma_E \sim 130$ keV, $\sigma_{angles} \sim 5$ mrad

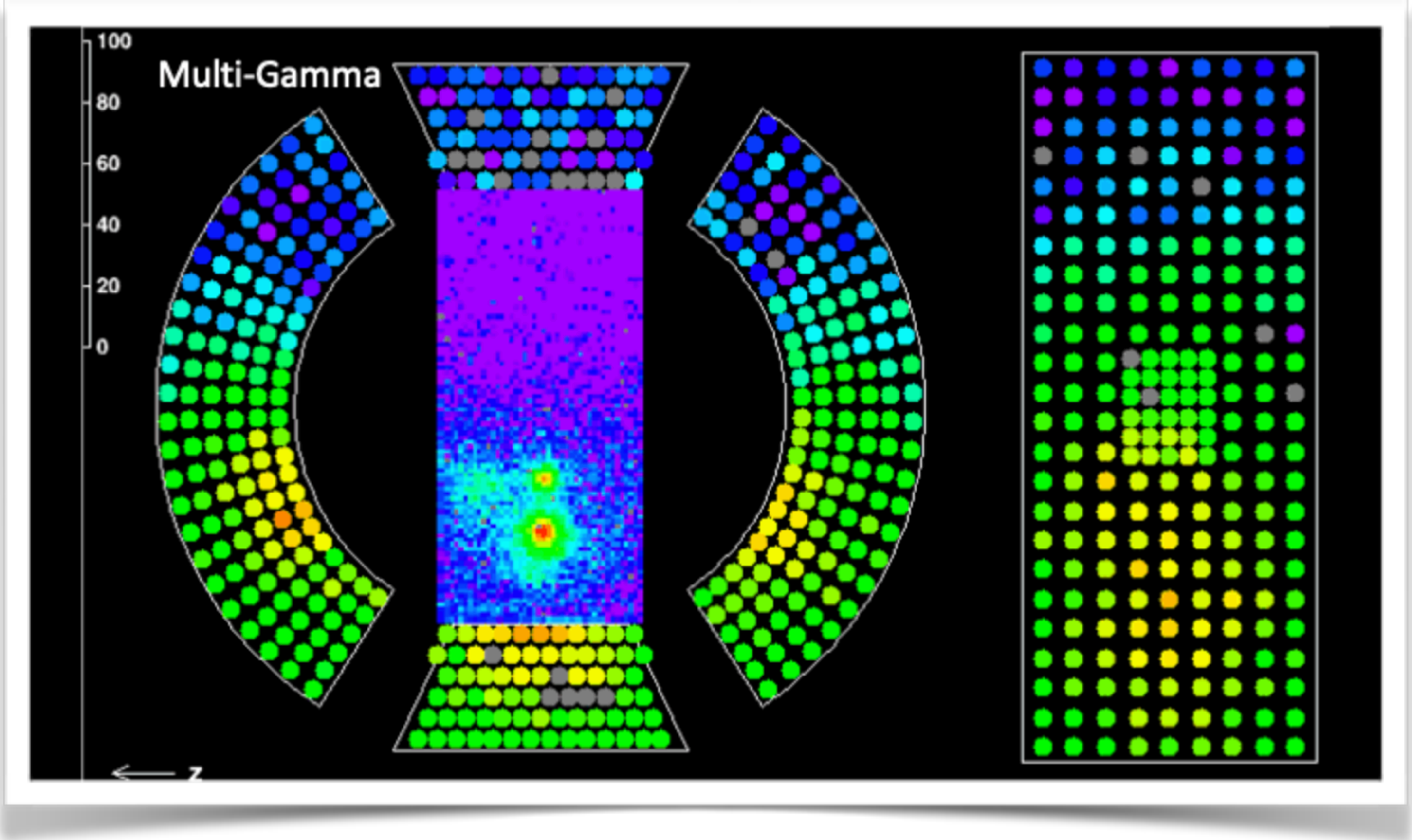
$\sigma_T \sim 35$ ps



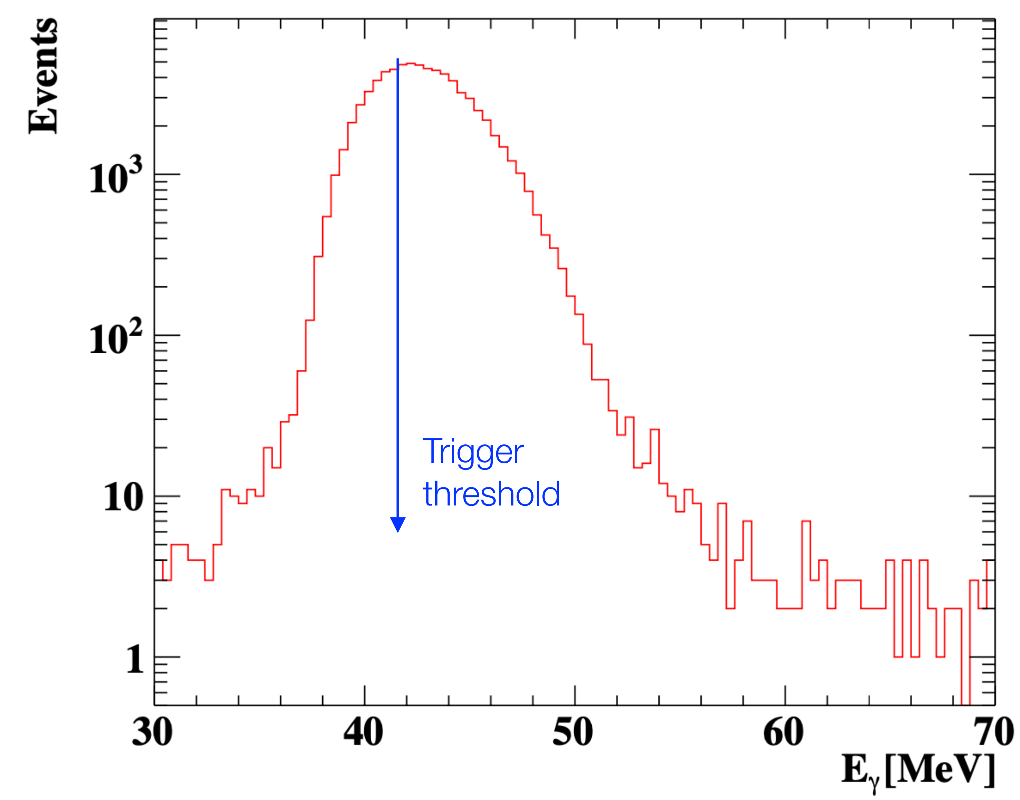
Timing counter

- **Higher granularity** with 2 x 256 small scintillating tiles readout by SiPMs

The MEG-II LXe calorimeter



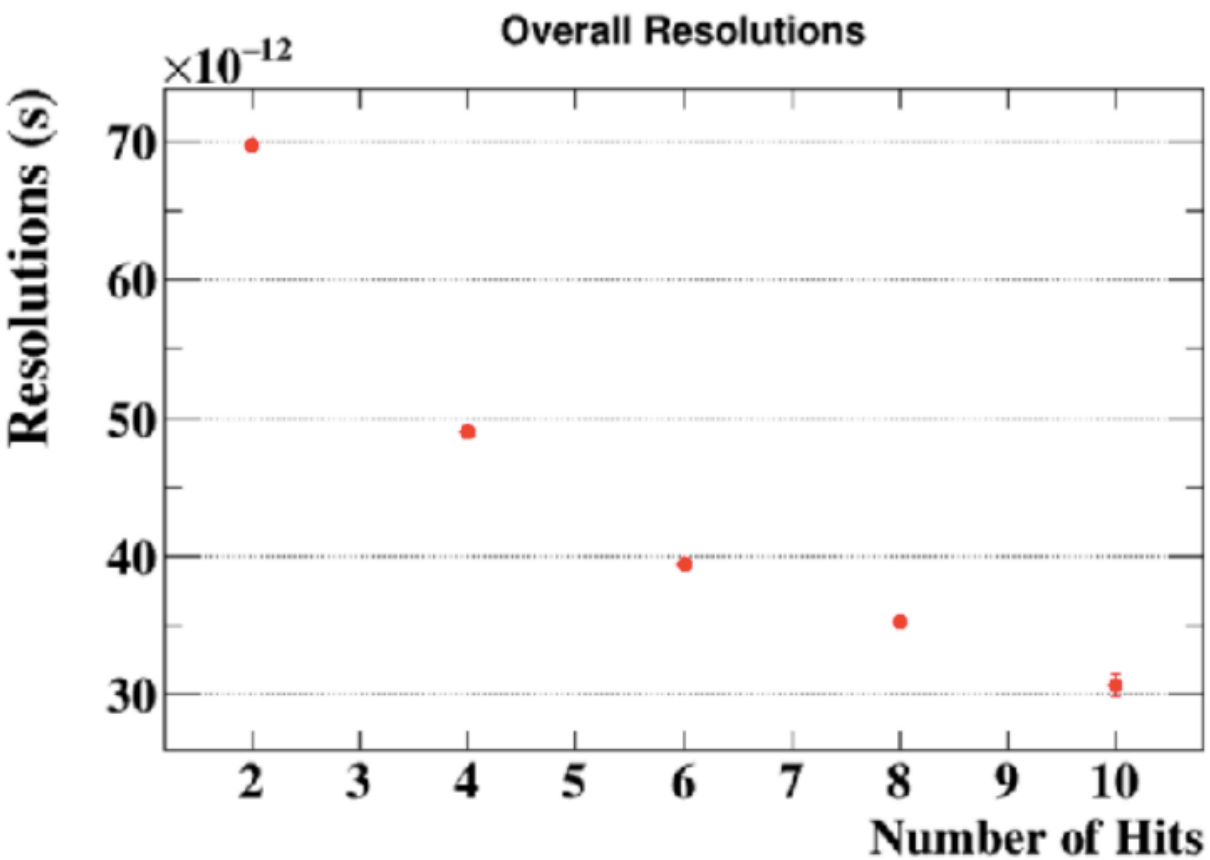
In 2021, first data collected with full readout

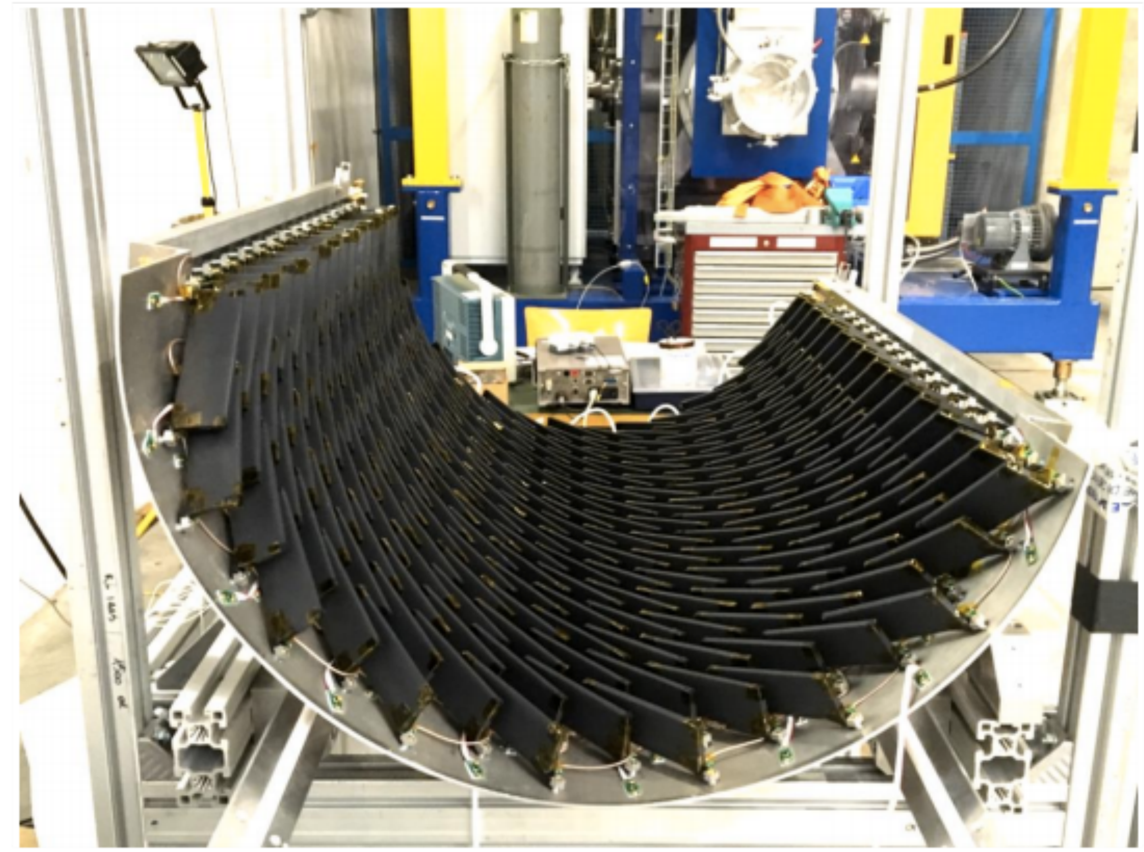


- Continuously calibrated to get the desired energy resolution and uniformity response.
- MPCC sensors **VUV** photon **efficiency** need periodic recovery procedure (time consuming)

The timing counters

- Very stable operation since 2017





$\sigma_T \sim 35$ ps

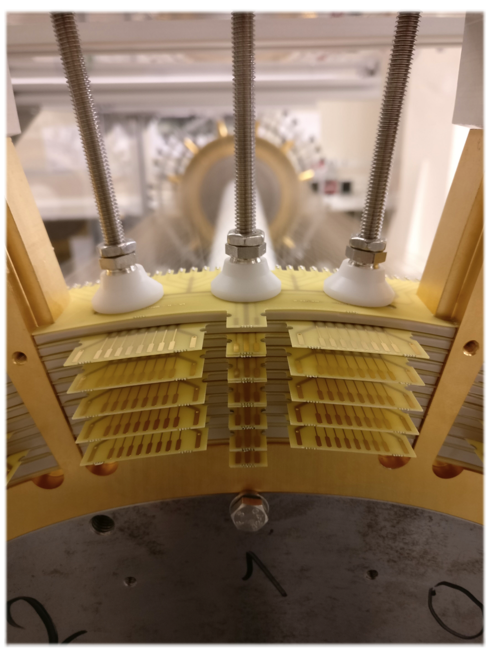
Already reached the design resolution

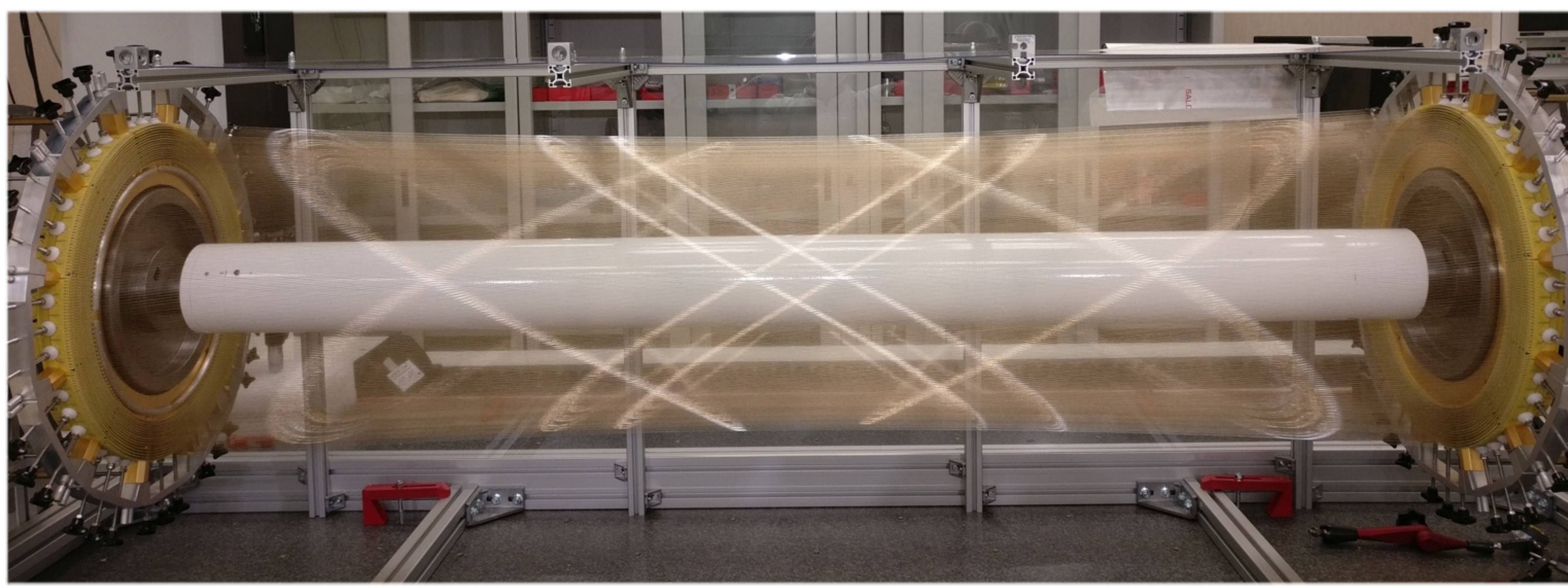
An ultimate drift chamber

- **A <u>challenge</u>**: minimal material budget (reduce multiple Coulomb scattering) and very high granularity (to deal with the high rate)
- Small square cells (6 mm), very thin wires (20 μm W(Au) + 40-50 μm Al(Ag))

<u>Innovative wire techniques</u> (no feedthrus)

Very <u>fragile</u>, sensitive to humidity and contaminants





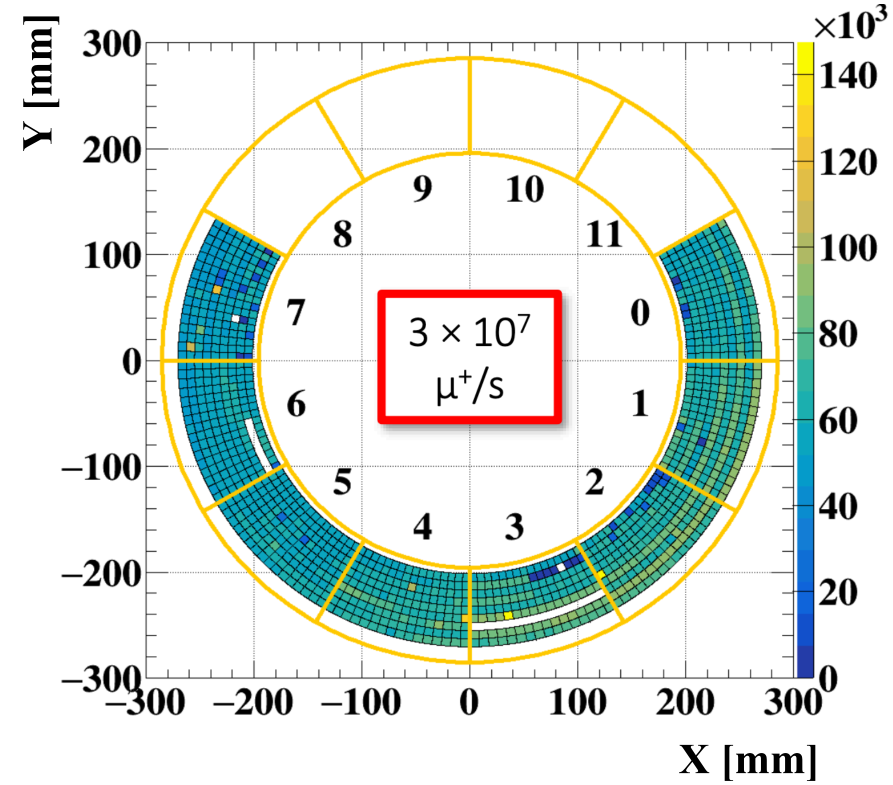
A second more robust version being constructed

Drift chambers performances

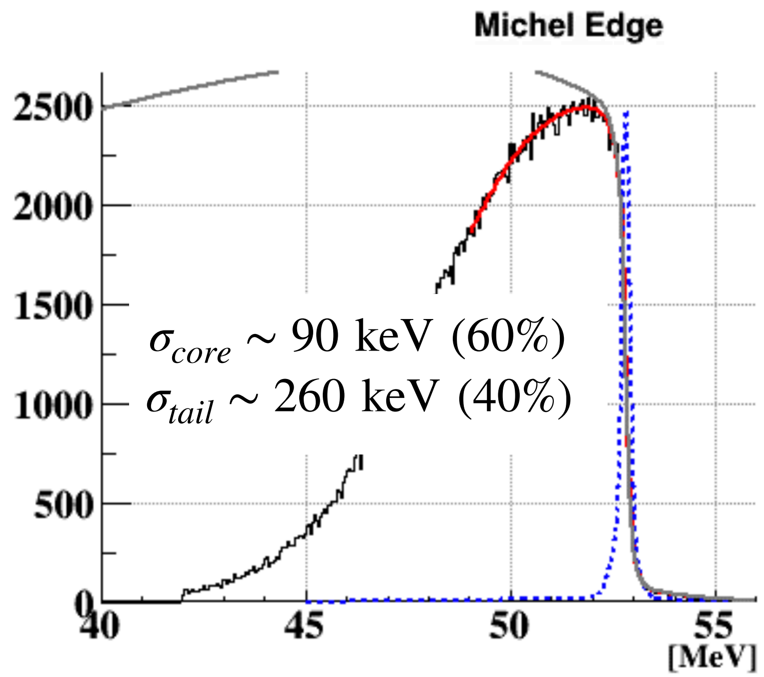
- In **2020** first **stable operation** with special gas mixture

  He : C_4H_{10} : isopropyl alcohol : O_2 (88.2 : 9.8 : 1.5 : 0.5)

- In **2021** first **data collected** with full readout



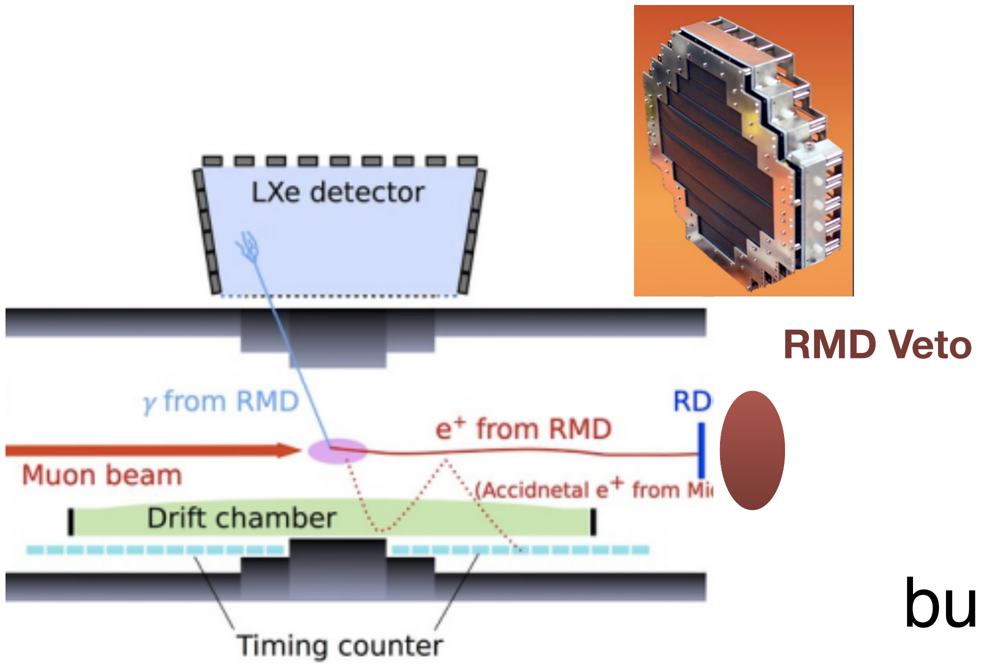
Calibrations, alignment and optimization of the reconstruction algorithms are ongoing



PRELIMINARY

after alignment and optimised reconstruction

The RMD counter and the muon target



50% ACCIDENTAL photons come from **RMD** with positron along the beam line

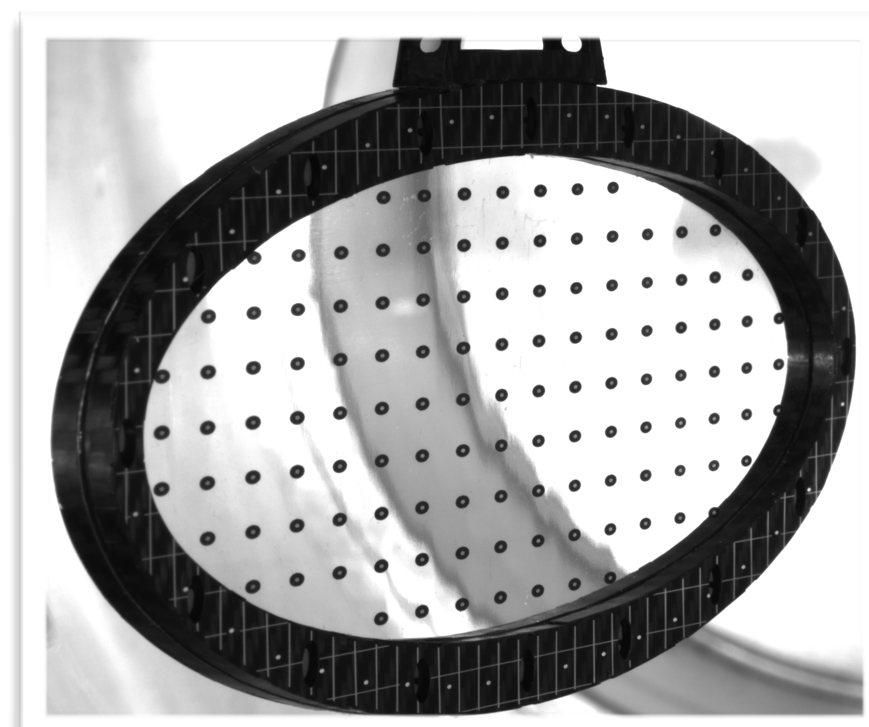
Can be **vetoed** by detecting the positron in coincidence with the photon

A new detector (LYSO + plastic scint.) built and tested in 2017 **(16% better sensitivity on BF)**

The **muon target** position has to be known with an accuracy ~ 100 μm not to compromise the angular resolution

A system of **photo cameras** has been installed to monitor the target position

<< 100 μm resolution reached

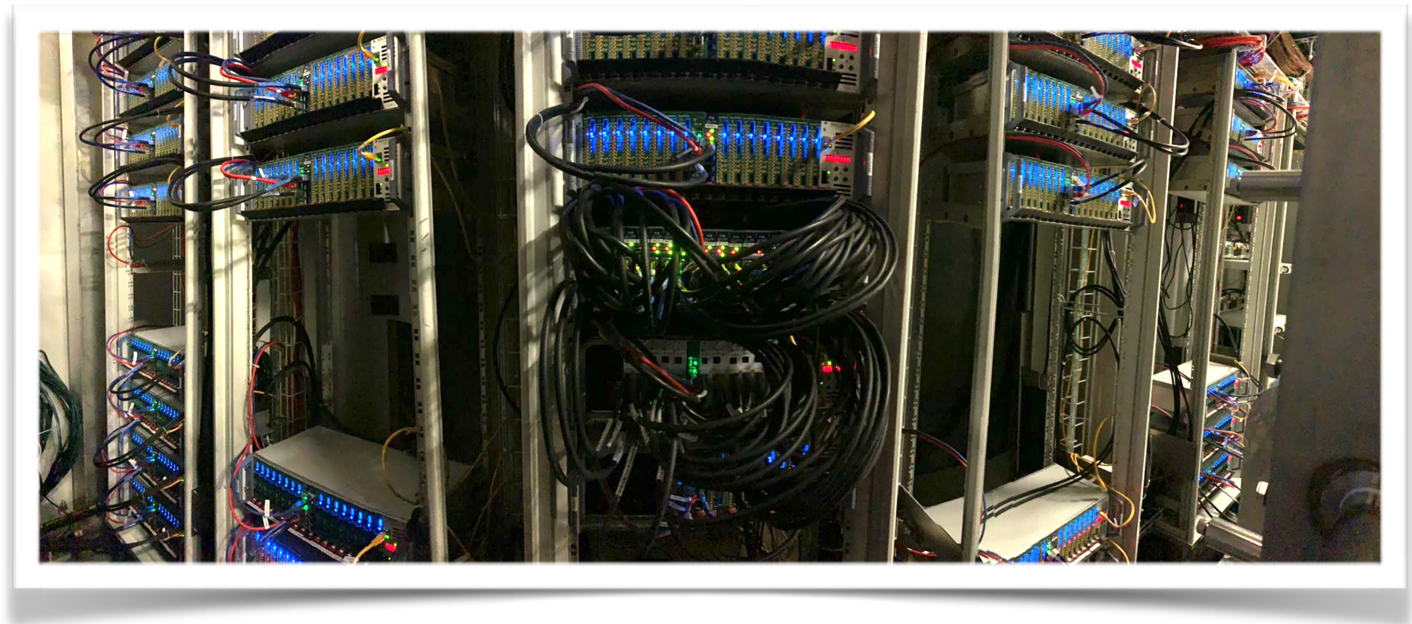


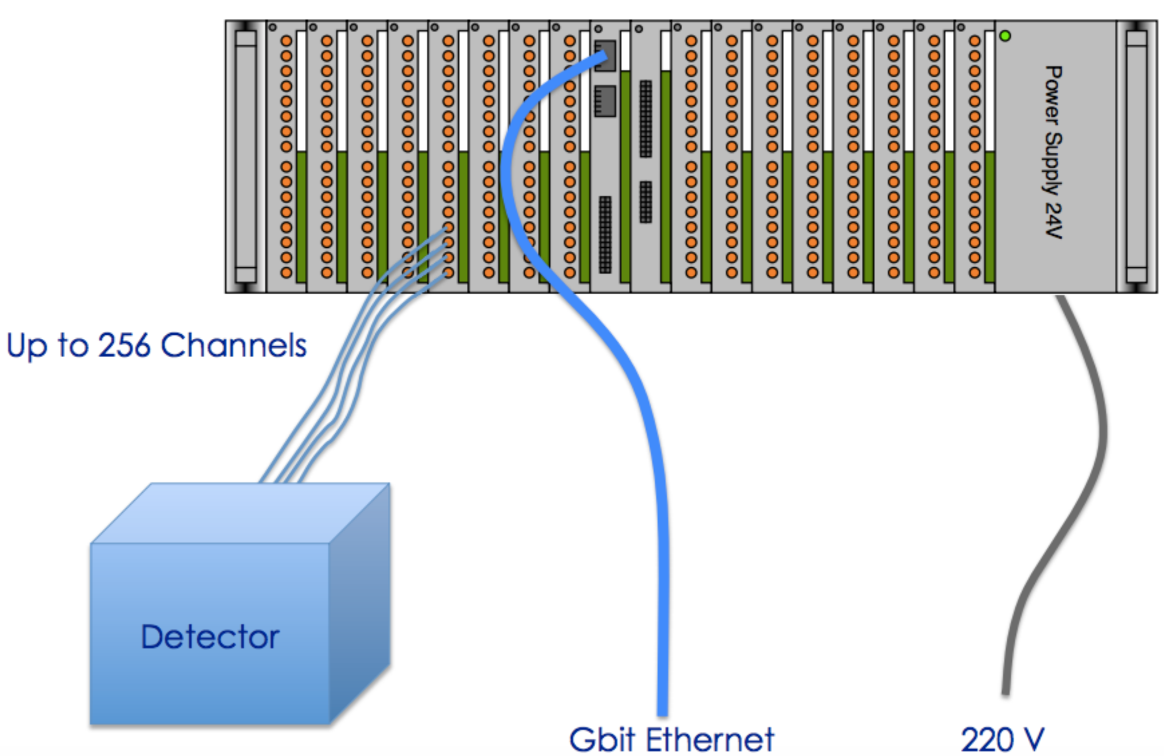
A renovated DAQ and trigger

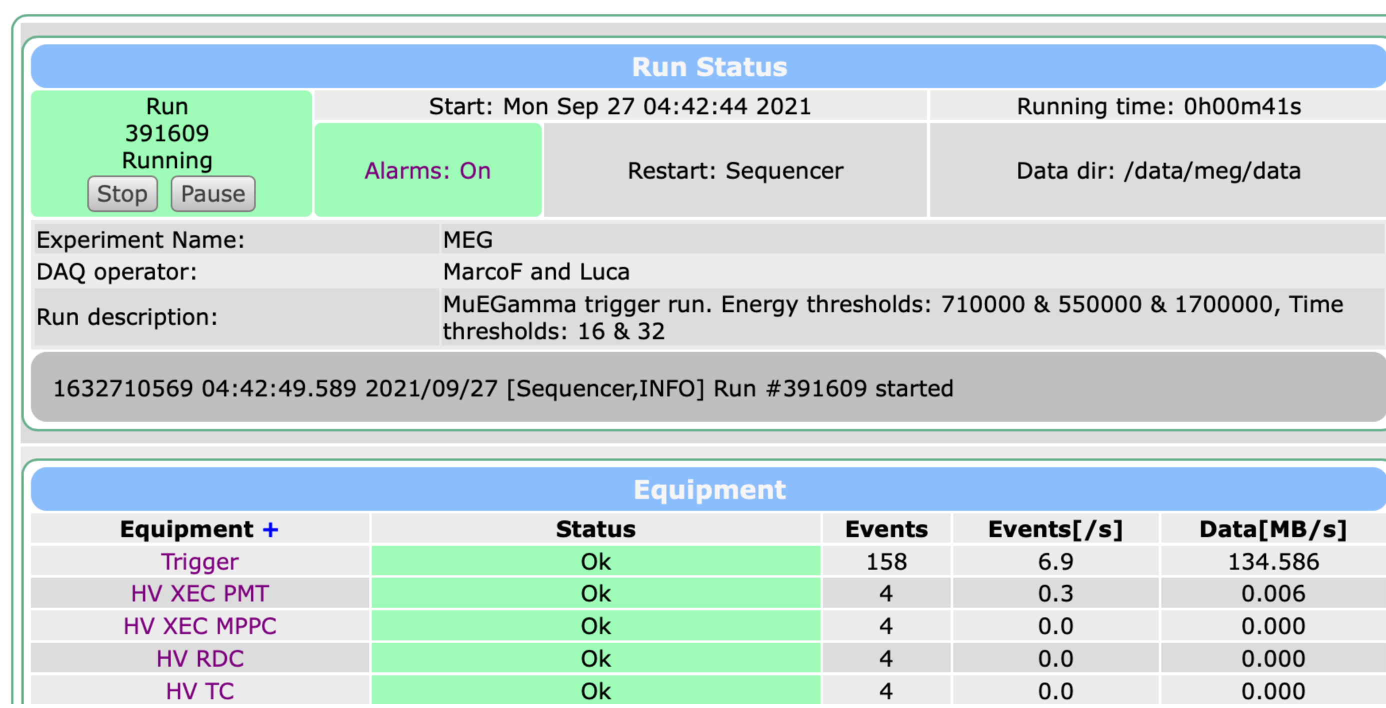
Trigger and DAQ integrated in a **single, compact system** (WaveDAQ)

Also provides power and amplification for SiPM/MPPC

In 2021, first data collected with full readout of all detectors + $\mu \to e\gamma$ trigger







Run Status

Run 391609 Running (Stop) (Pause)	Start: Mon Sep 27 04:42:44 2021		Running time: 0h00m41s
	Alarms: On	Restart: Sequencer	Data dir: /data/meg/data

Experiment Name:	MEG
DAQ operator:	MarcoF and Luca
Run description:	MuEGamma trigger run. Energy thresholds: 710000 & 550000 & 1700000, Time thresholds: 16 & 32

1632710569 04:42:49.589 2021/09/27 [Sequencer,INFO] Run #391609 started

Equipment

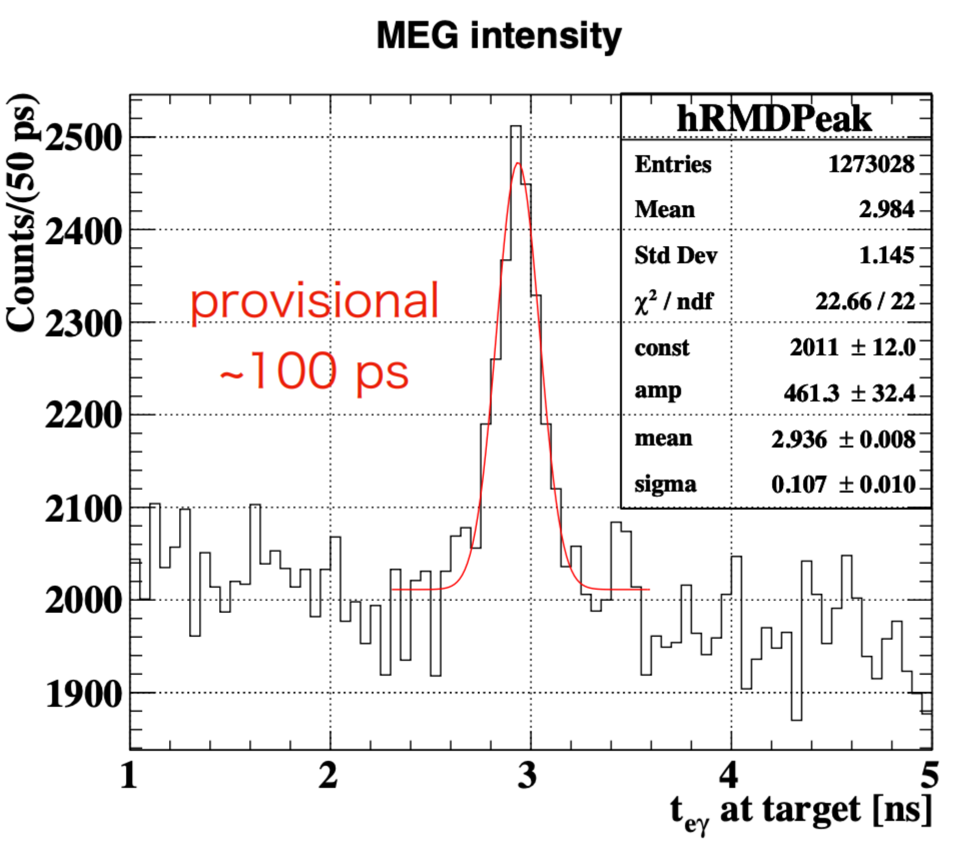
Equipment +	Status	Events	Events[/s]	Data[MB/s]
Trigger	Ok	158	6.9	134.586
HV XEC PMT	Ok	4	0.3	0.006
HV XEC MPPC	Ok	4	0.0	0.000
HV RDC	Ok	4	0.0	0.000
HV TC	Ok	4	0.0	0.000

MEG-II (long) journey

- Long R&D and then (since 2018) engineering runs phase
- In 2021 data-taken with the full detector

First physics data collected in 2021, analysis ongoing

Radiative muon decay peak observed

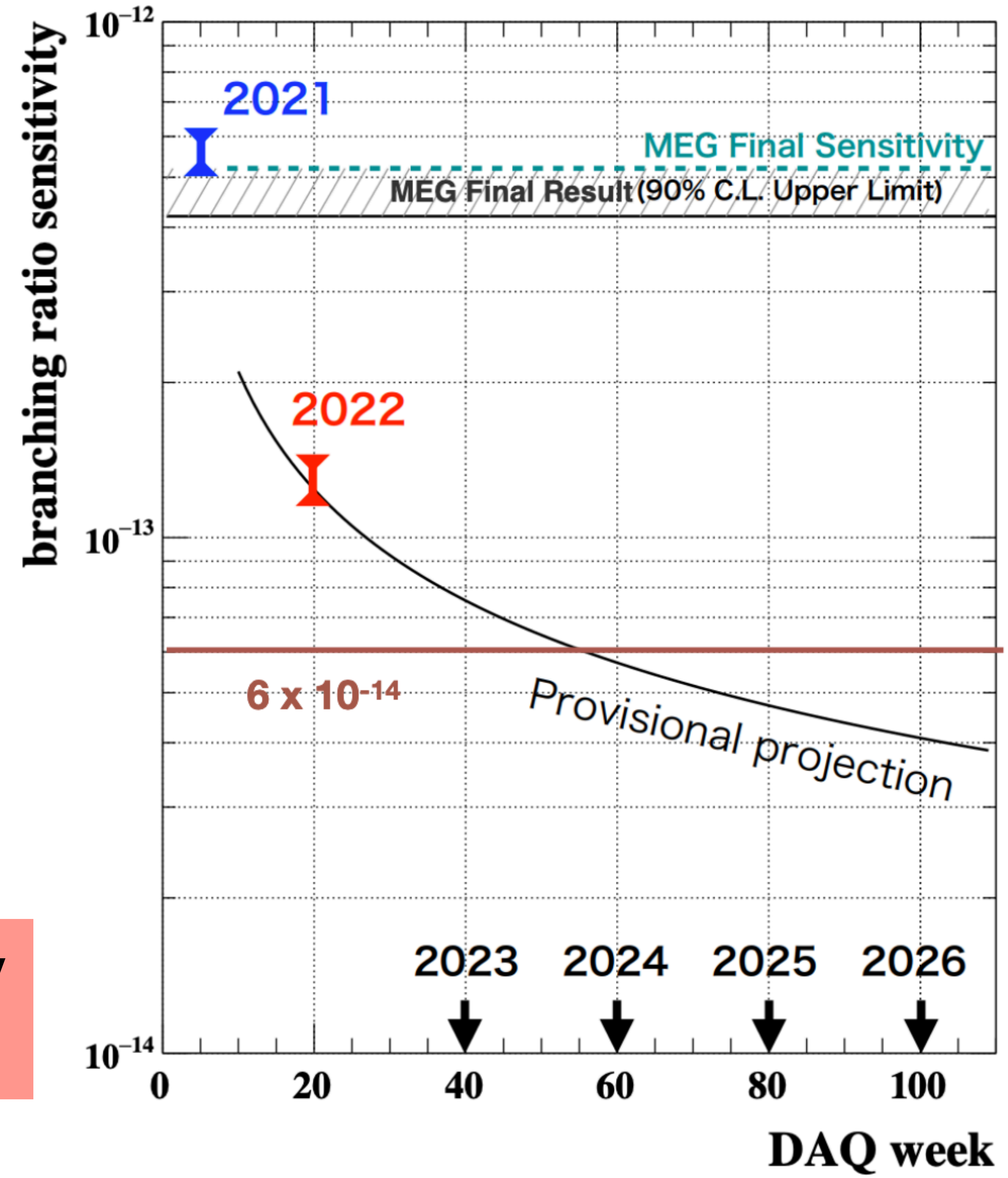


MEG-II perspective

Symmetry 2021, 13(9), 1591

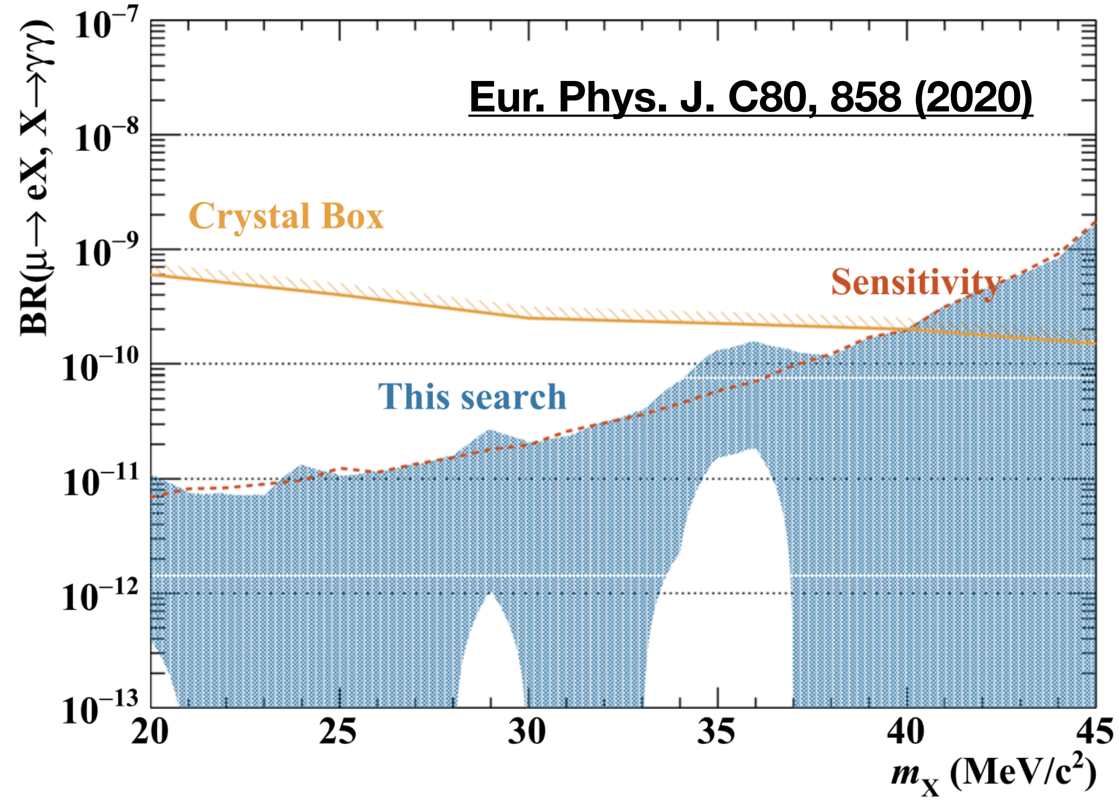
- Since **early July 2022** again in **Physics** Run!
- **Stable** run condition to go well beyond MEG
- Eventually, still statistics-dominated

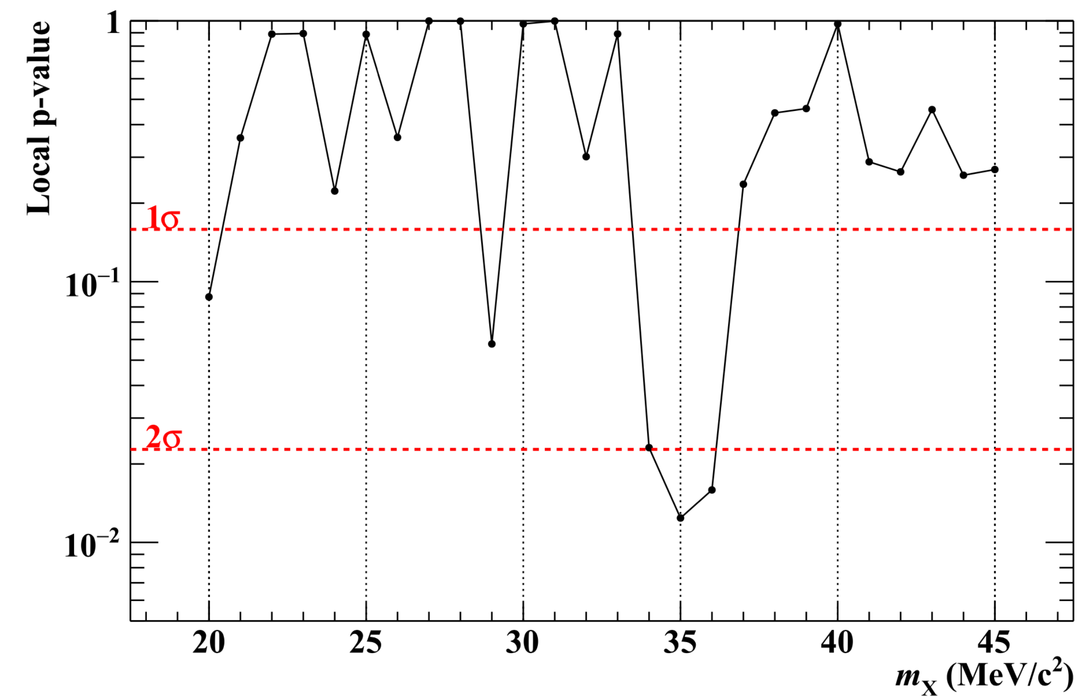
Goal is to reach a BF sensitivity $6\ 10^{-14}$



More than $\mu \to e\gamma$

- With MEG detector a lot of standard Michel decays and RMD collected , (though in a quite limited phase space region)
  - some room for searches of even more **exotic muon decays**
- A search for $\mu \to e\,X$ with $X \to \gamma\,\gamma$ was performed on MEG data
- Currently, feasibility studies for $\mu \to e + invisible$ and $\mu \to e\,\gamma + invisible$ at MEG II





Outlook

- **Charged Lepton Flavour violation** is definitively a key element in the search of New Physics
  - Next decade will see several experiment taking data.

- The MEG experimental concept is currently **leading** this search.

  - **MEG-II aims to improve by x10 the MEG limit**

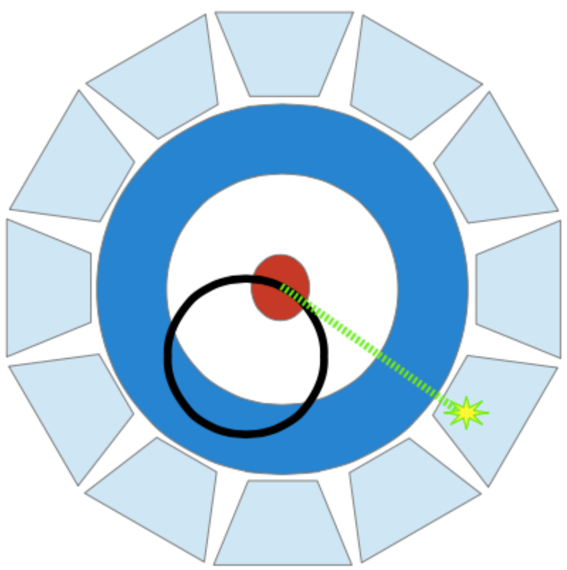
  - Now MEG-II in full data-taking run and data analysis is on-going

- If more intense beams available in the future, $\mu \to e\gamma$ will still be a highlight of cLFV - possibly with new detector concepts.

Backup

Beyond MEG-II

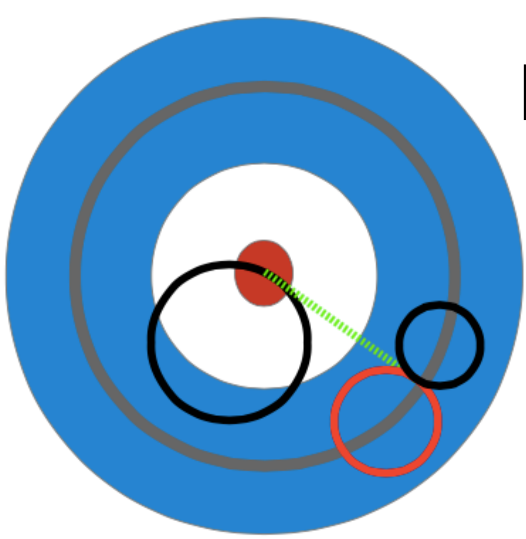
- More intense beam (up to 10^{10} muon per second) being investigate at PSI and FNAL



Calorimetry

High efficiency
Good resolutions

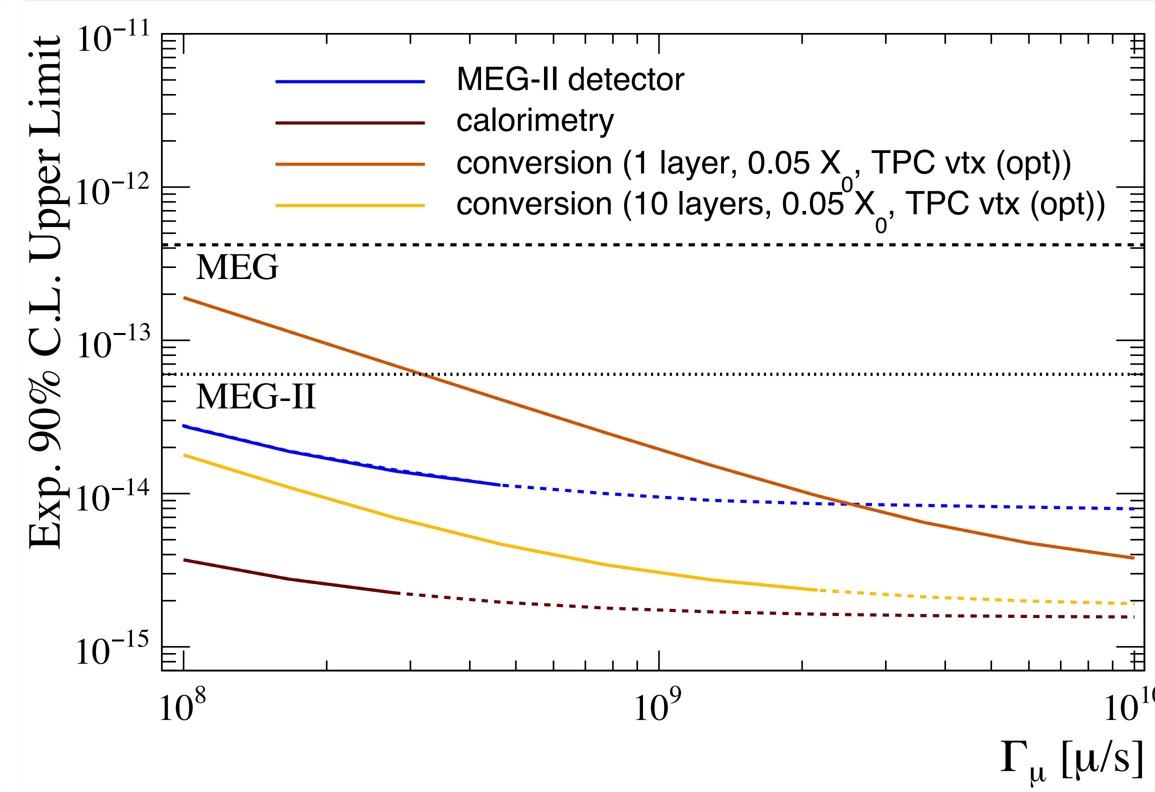
MEG:
LXe calorimeter
10% acceptance



Photon Conversion

Low efficiency (~ %)
Extreme resolutions
+ eγ Vertex

MEGA/Mu3e



G. Cavoto, A. Papa, FR, E. Ripiccini and C. Voena
Eur. Phys. J. C78, 37 (2018)

M. Aiba et al.
arXiv:2111.05788