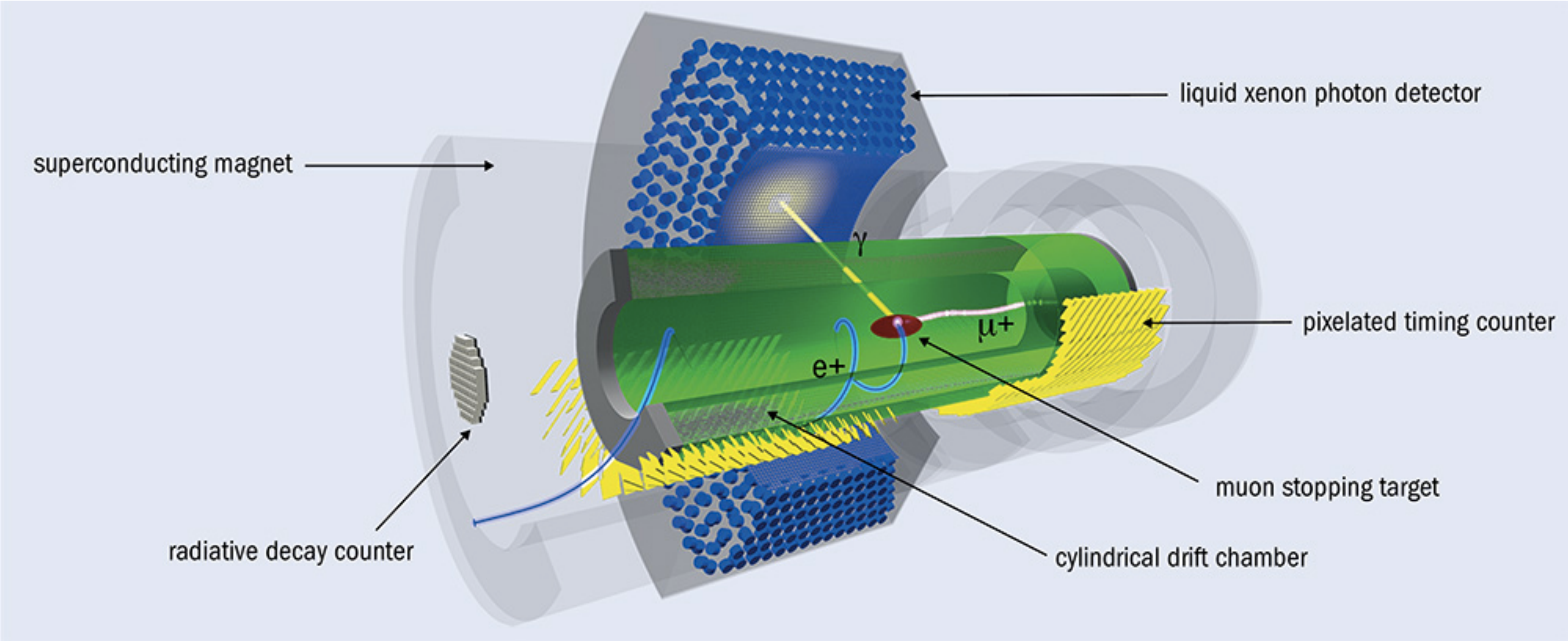


Lepton Flavour Violation Searches with the MEG-II Experiment

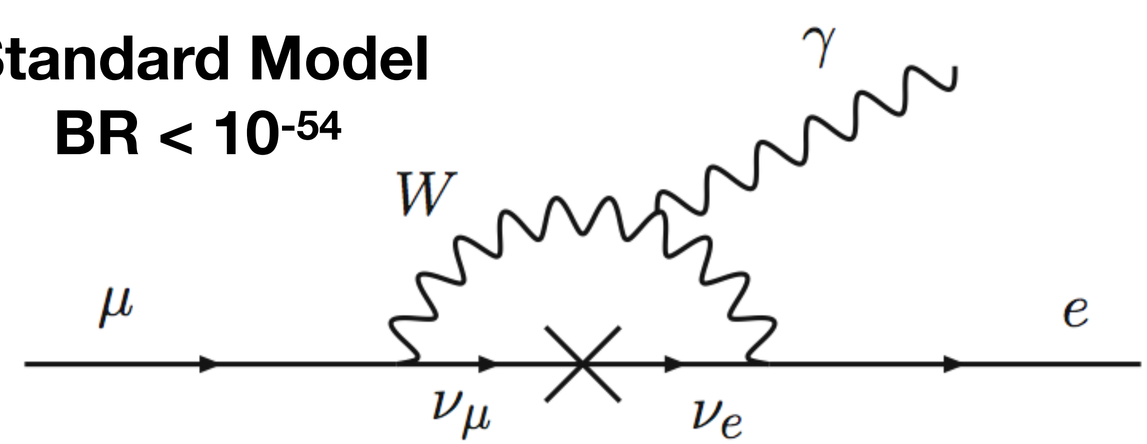
Francesco Renga
INFN Roma
for the MEG II Collaboration

Lepton Flavor Conservation in the Standard Model

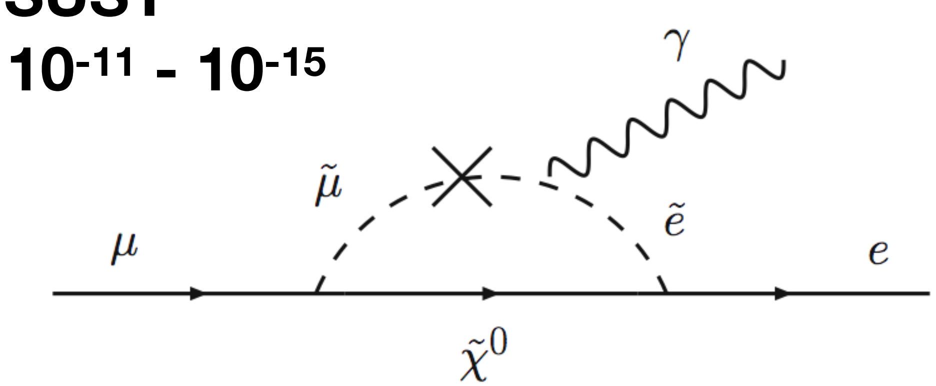
- Lepton Flavor conservation in the Standard Model is an *accidental symmetry*, arising from the particle content of the model

- Generally violated in most of New Physics models

Standard Model
BR < 10^{-54}



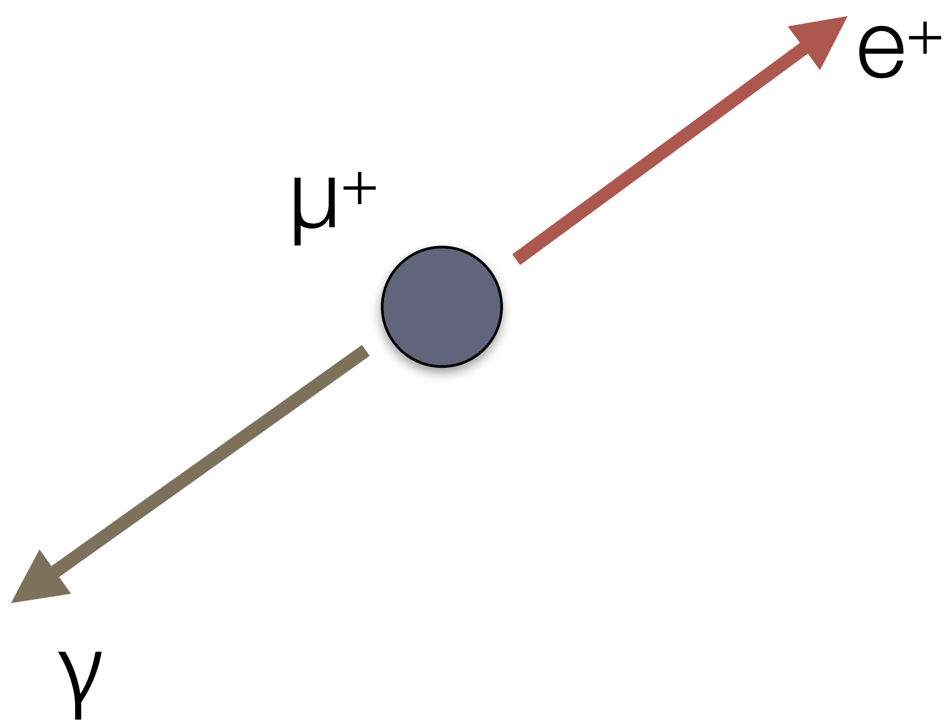
SUSY
BR ~ 10^{-11} - 10^{-15}



"Charged Lepton Flavor Violation (cLFV) is THE signature for New Physics"

— A. Schöning

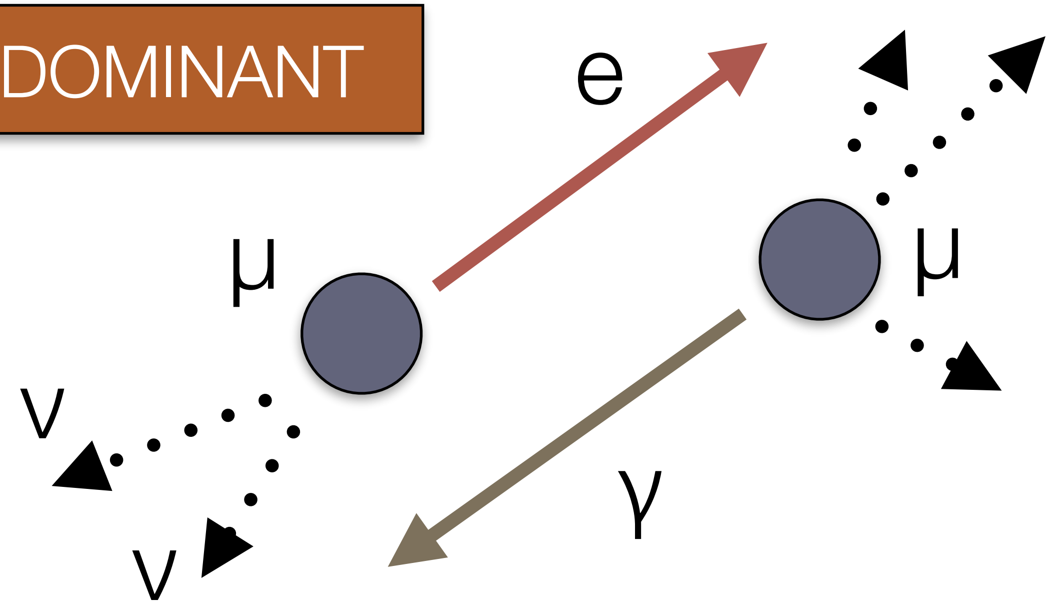
μ -> e γ searches



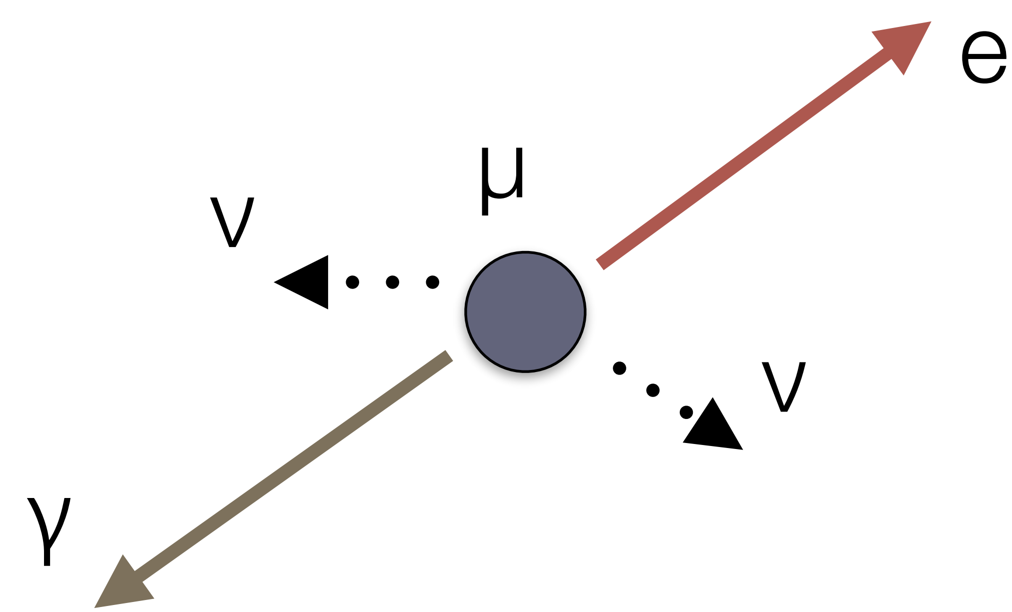
Positron and photon are **monochromatic** (52.8 MeV), **back-to-back** and produced at the **same time**;

Accidental Background

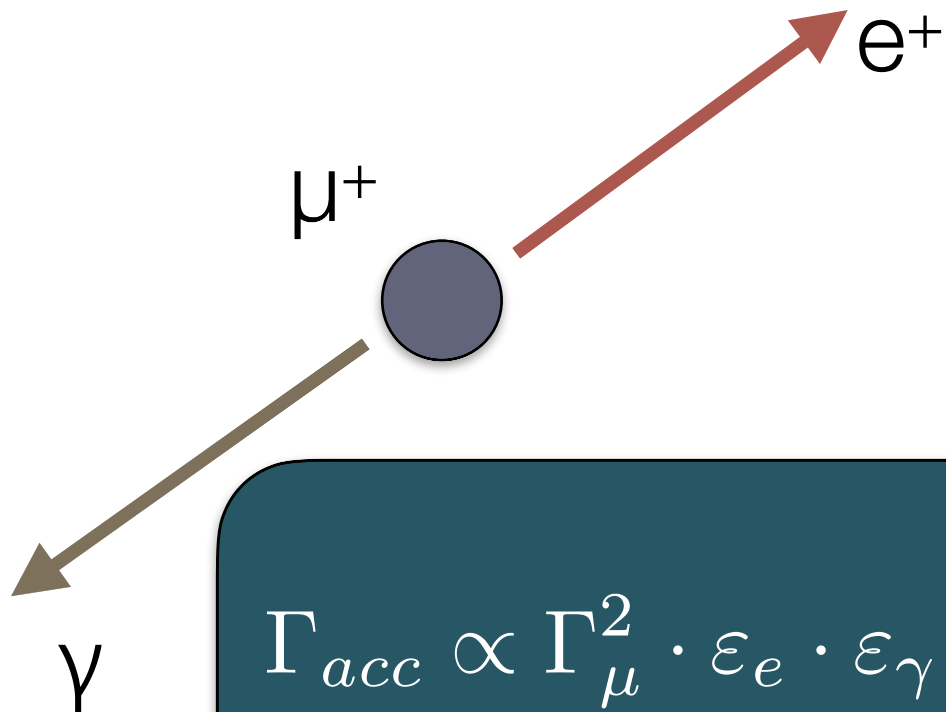
DOMINANT



Radiative Muon Decay (RMD)



μ -> e γ searches

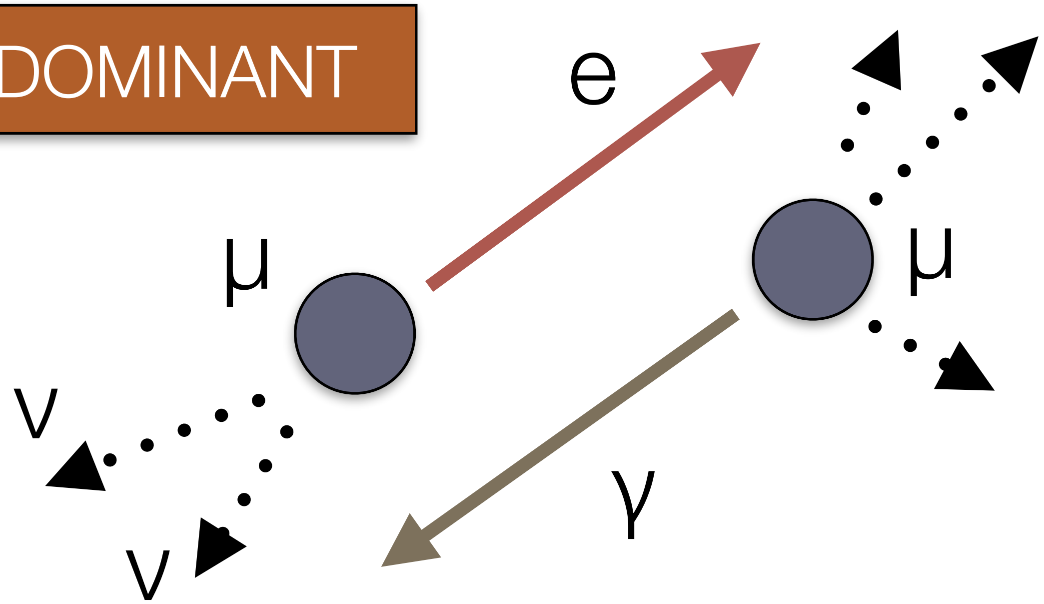


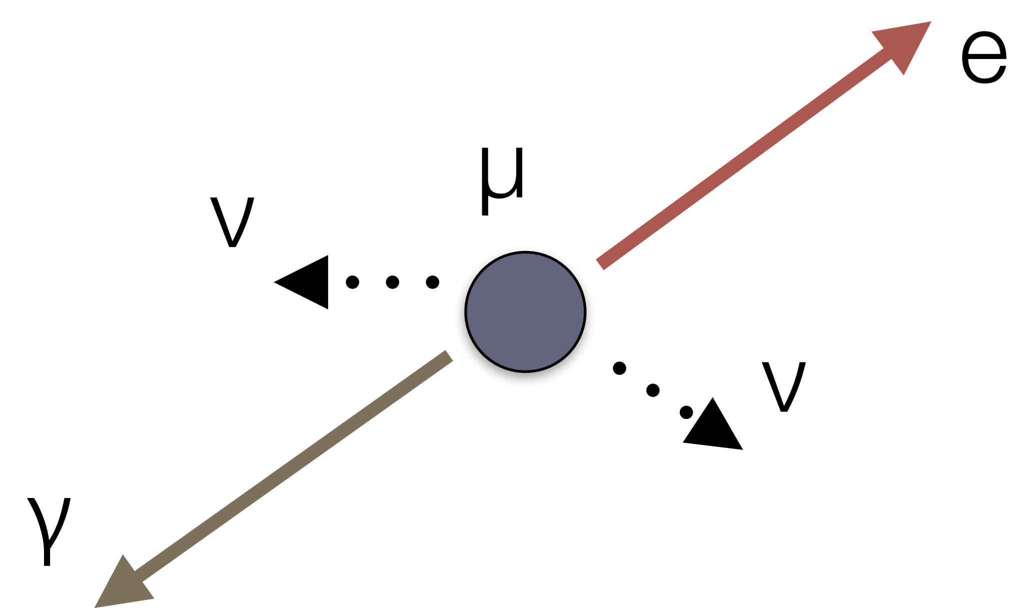
Positron and photon are **monochromatic** (52.8 MeV), **back-to-back** and produced at the **same time**;

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

Acci **ay (RMD)**

DOMINANT

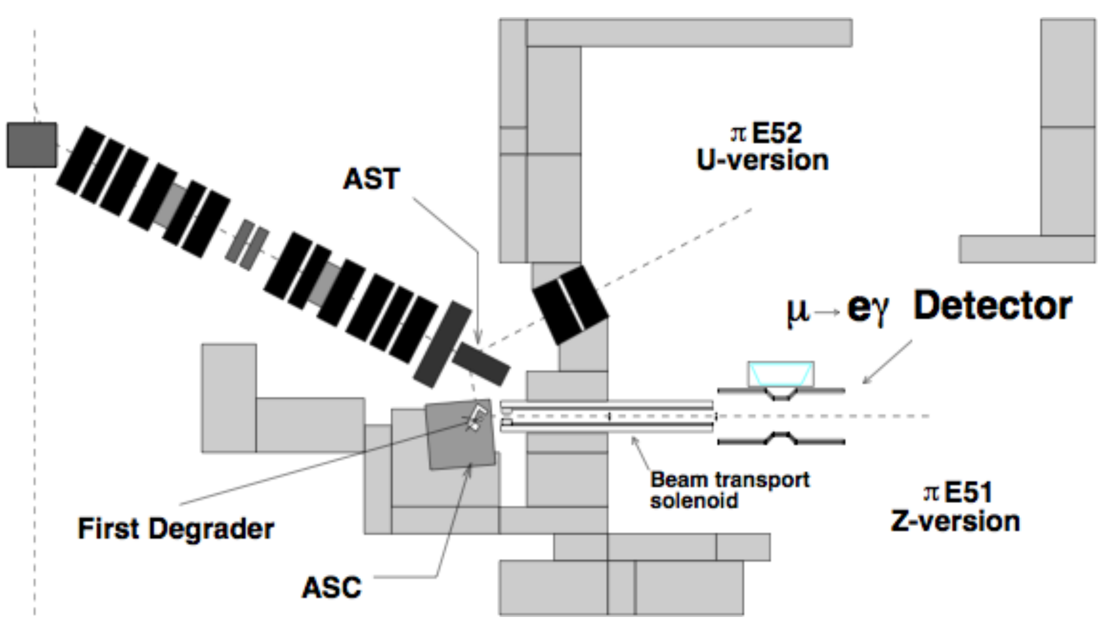




The most intense DC muon beam in the world

- The ring cyclotron at PSI (Villigen, CH) serves the most intense DC muon beam lines in the world

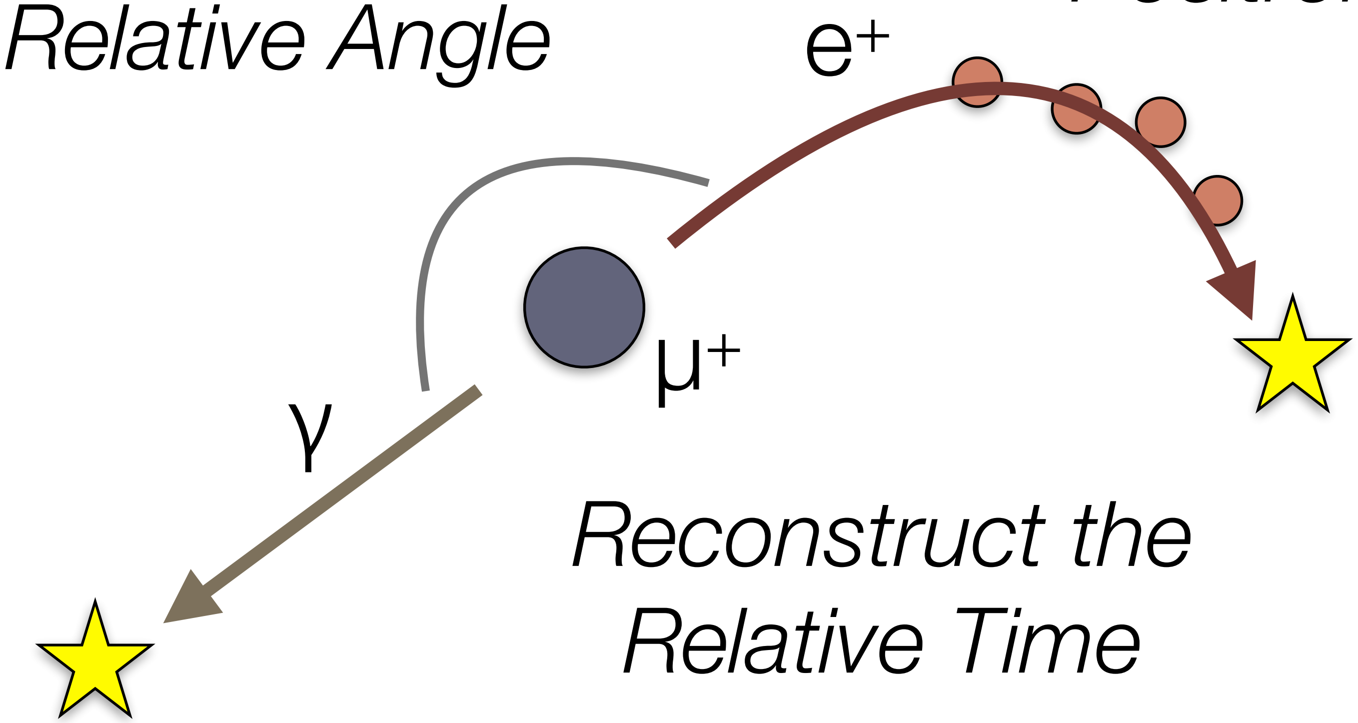
πE5 - up to 10^8 μ/s



Ingredients for a search of μ -> e γ

Reconstruct the Relative Angle

Reconstruct the Positron Energy



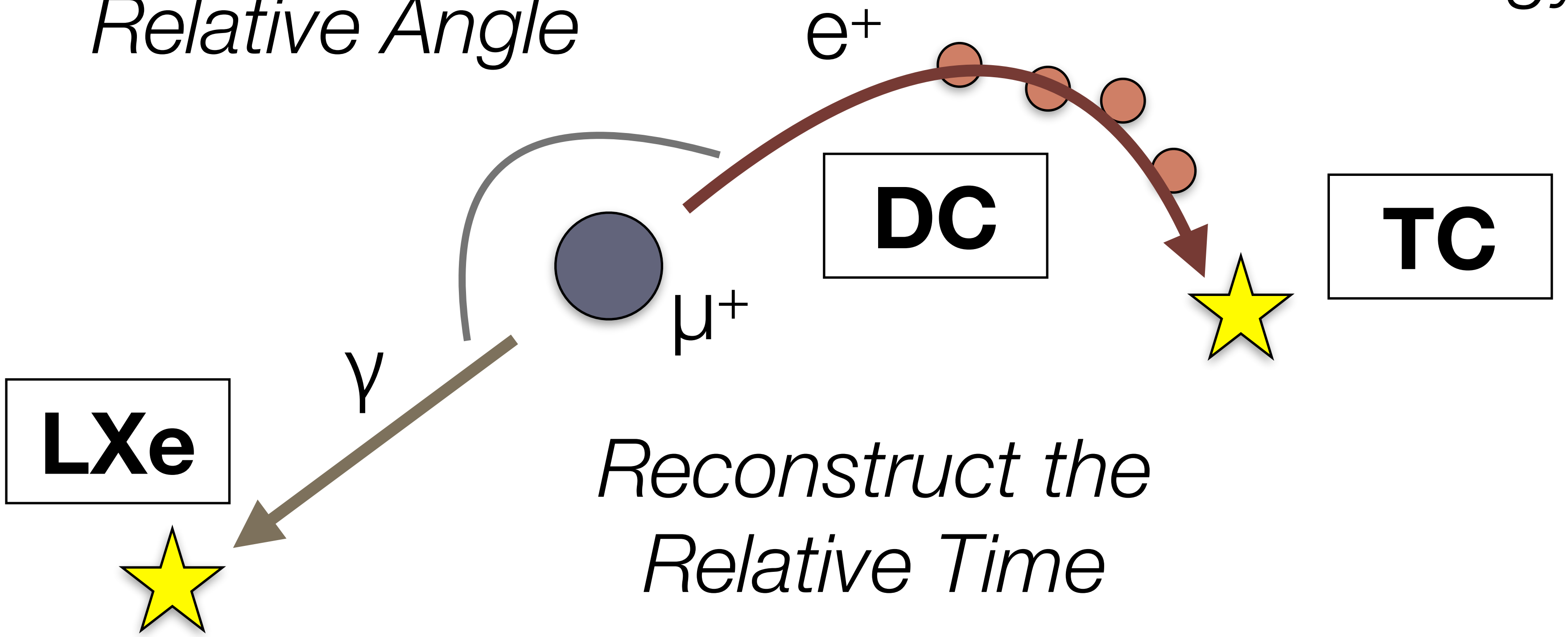
Reconstruct the Relative Time

Reconstruct the Photon Energy

The MEG and MEG II Experiments

Reconstruct the Relative Angle

Reconstruct the Positron Energy



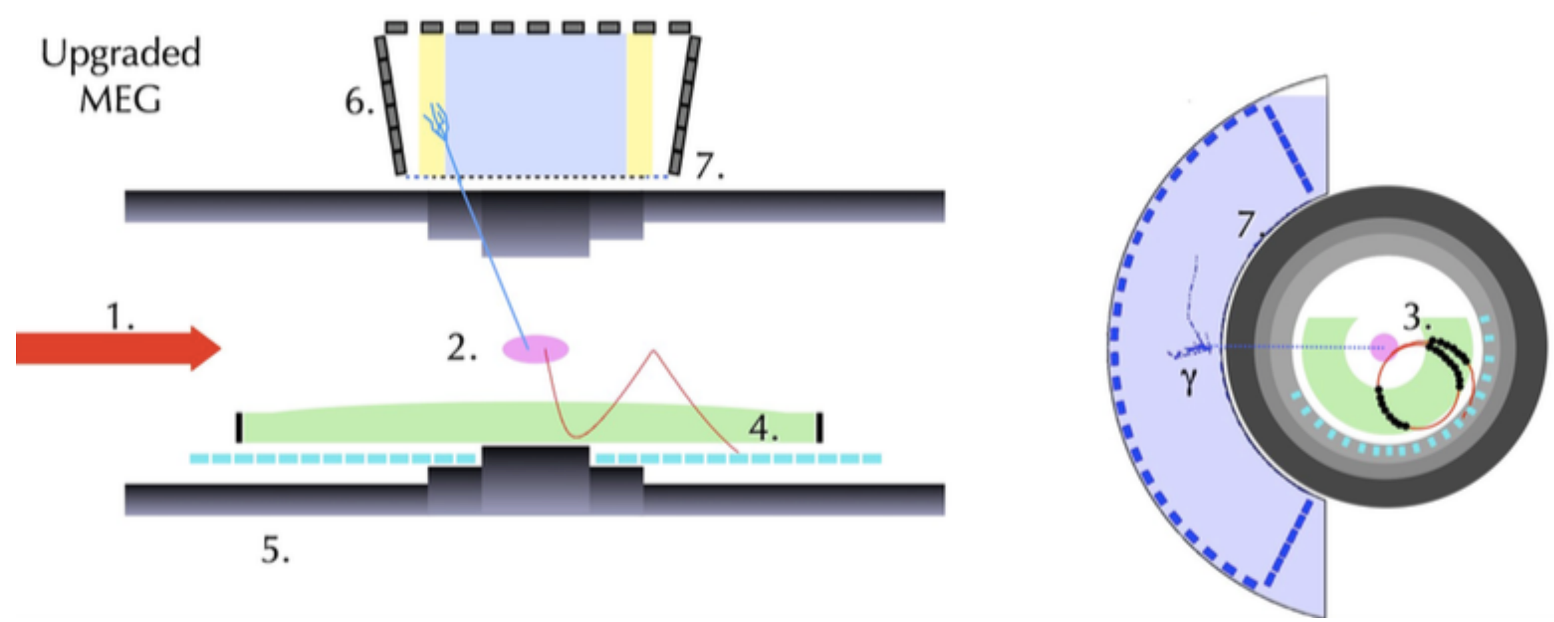
Reconstruct the Relative Time

Reconstruct the Photon Energy

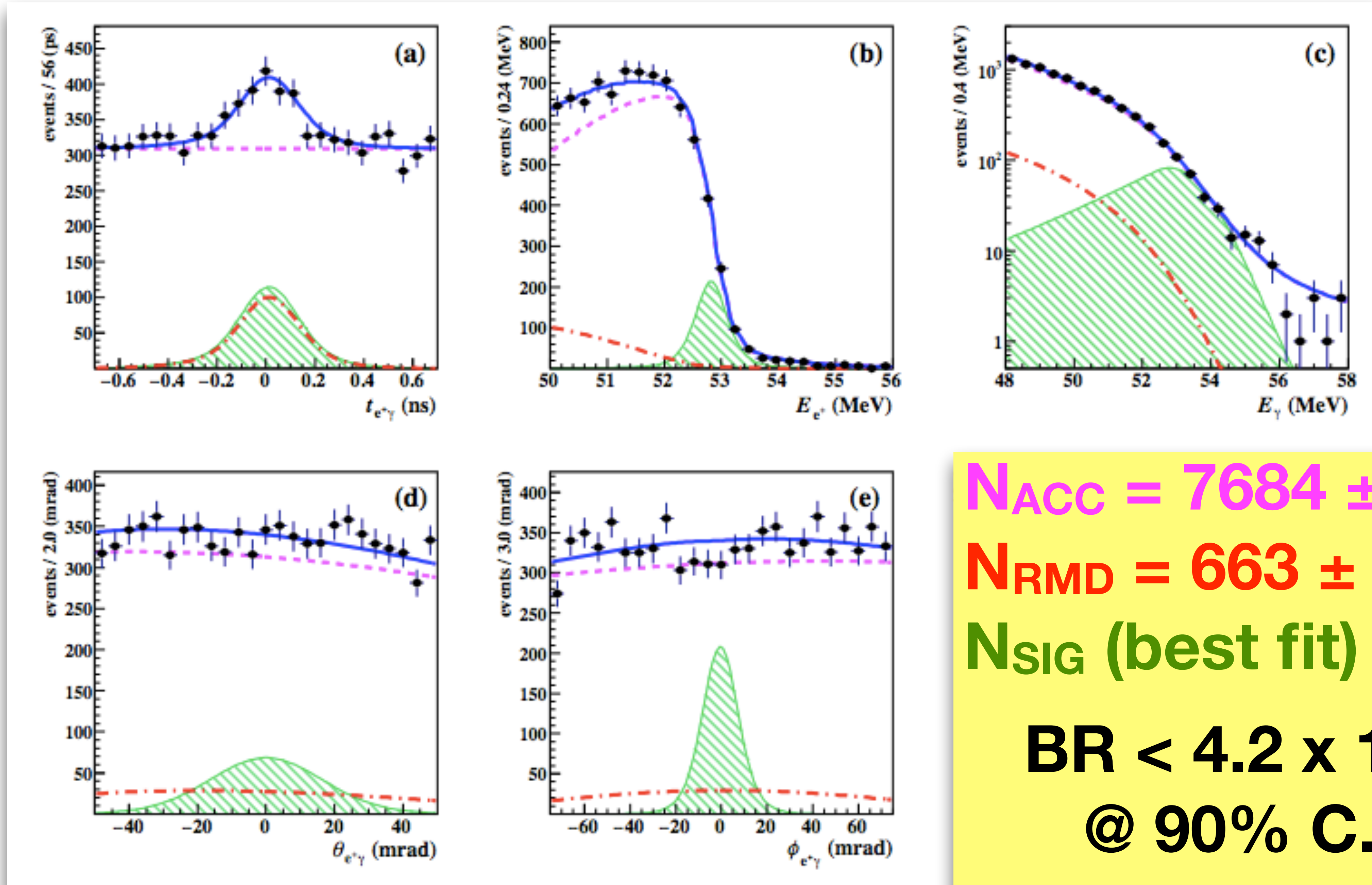
LXe calorimeter

Magnetic spectrometer

Scintillators (e+ timing & trigger)



The $\mu \rightarrow e\gamma$ limit from MEG



N_{ACC} = 7684 ± 103

N_{RMD} = 663 ± 59

N_{SIG} (best fit) = -2.2

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

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

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

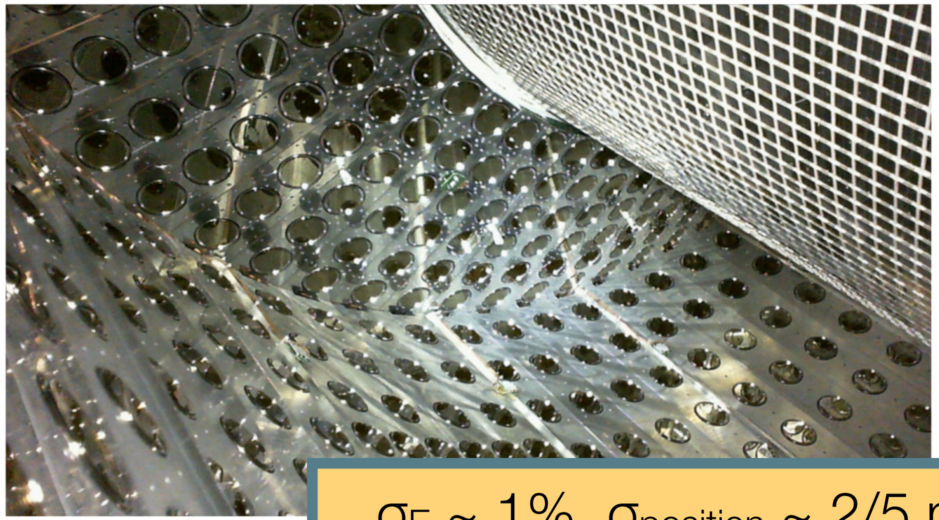
7.5 x 10^{14} μ on target

From MEG to MEG II

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

LXe calorimeter

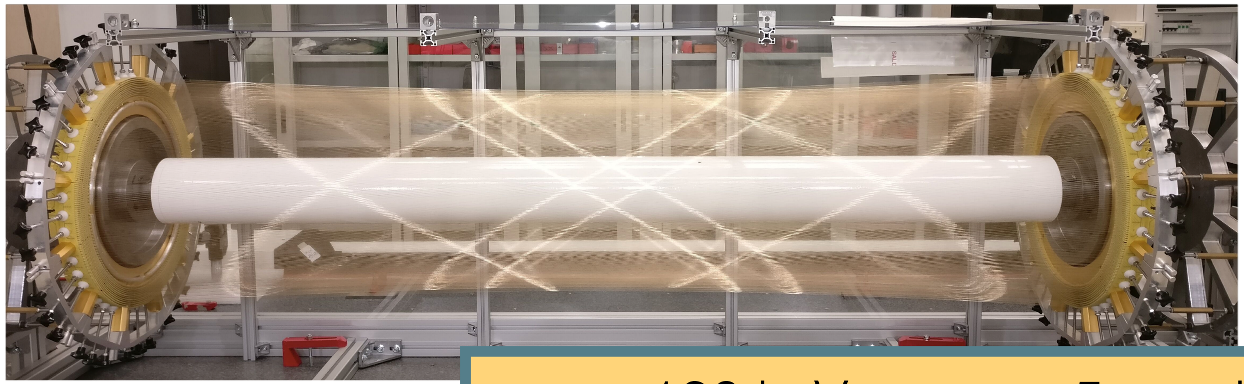
- Higher photon detector granularity in the inner face with custom VUV-sensitive MPPCs
- Larger sensitive volume



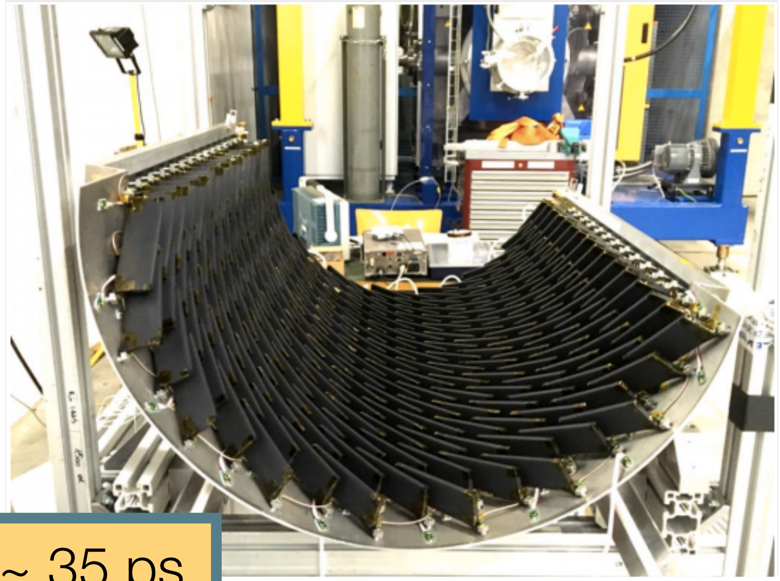
σ_E ~ 1%, $\sigma_{position}$ ~ 2/5 mm (x,y/z)

Magnetic spectrometer

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



σ_E ~ 130 keV, σ_{angles} ~ 5 mrad



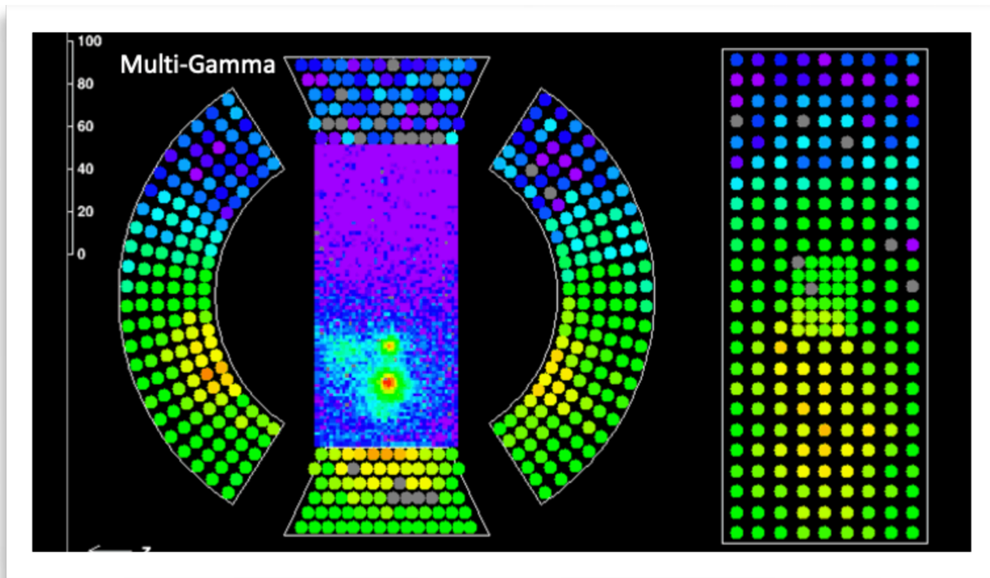
σ_T ~ 35 ps

Timing counter

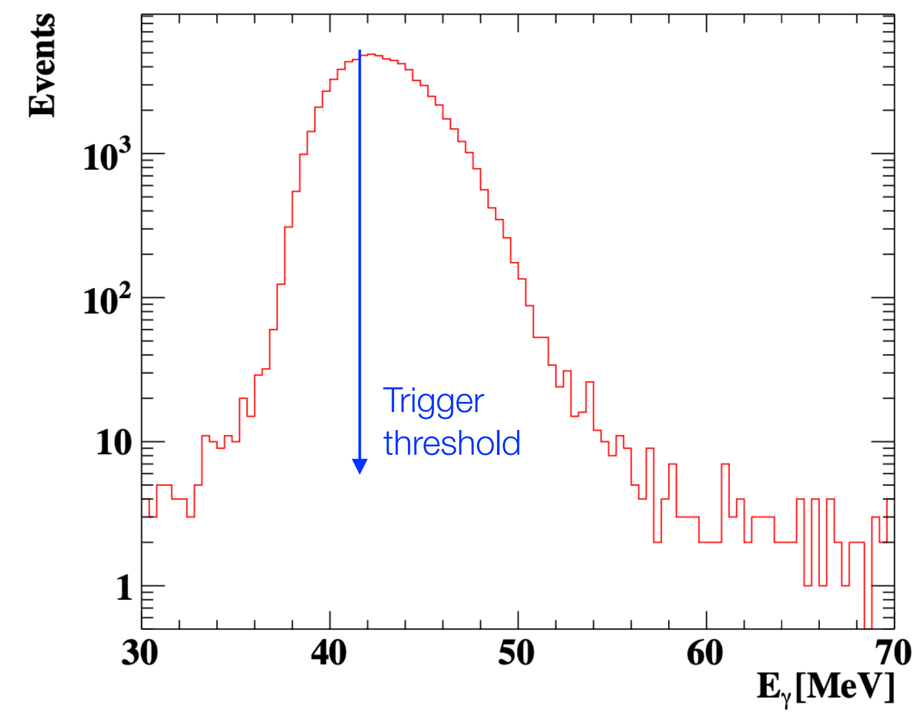
- Higher granularity with 2 x 256 small scintillating tiles readout by SiPMs

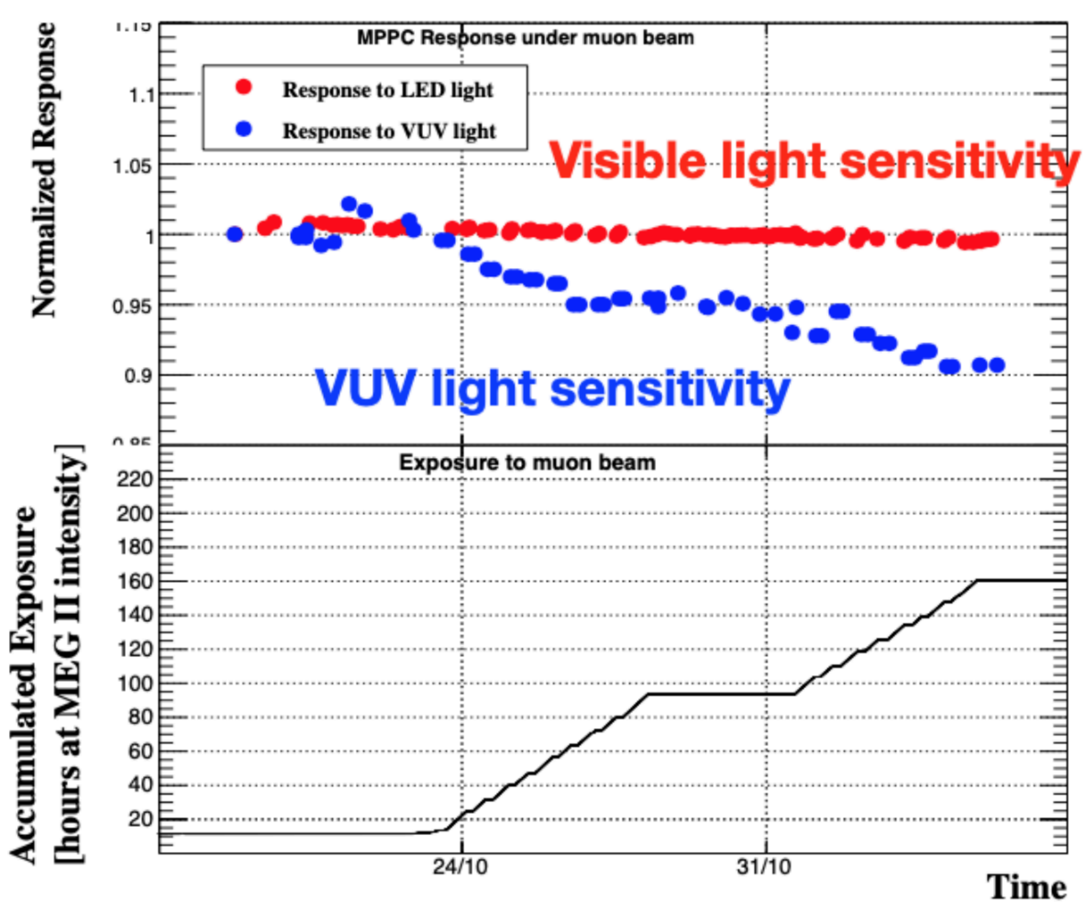
UL ~ 6 x 10^{-14} in a 3-year run

MEG-II Highlights - The LXe Calorimeter



In 2021, first data collected with full readout





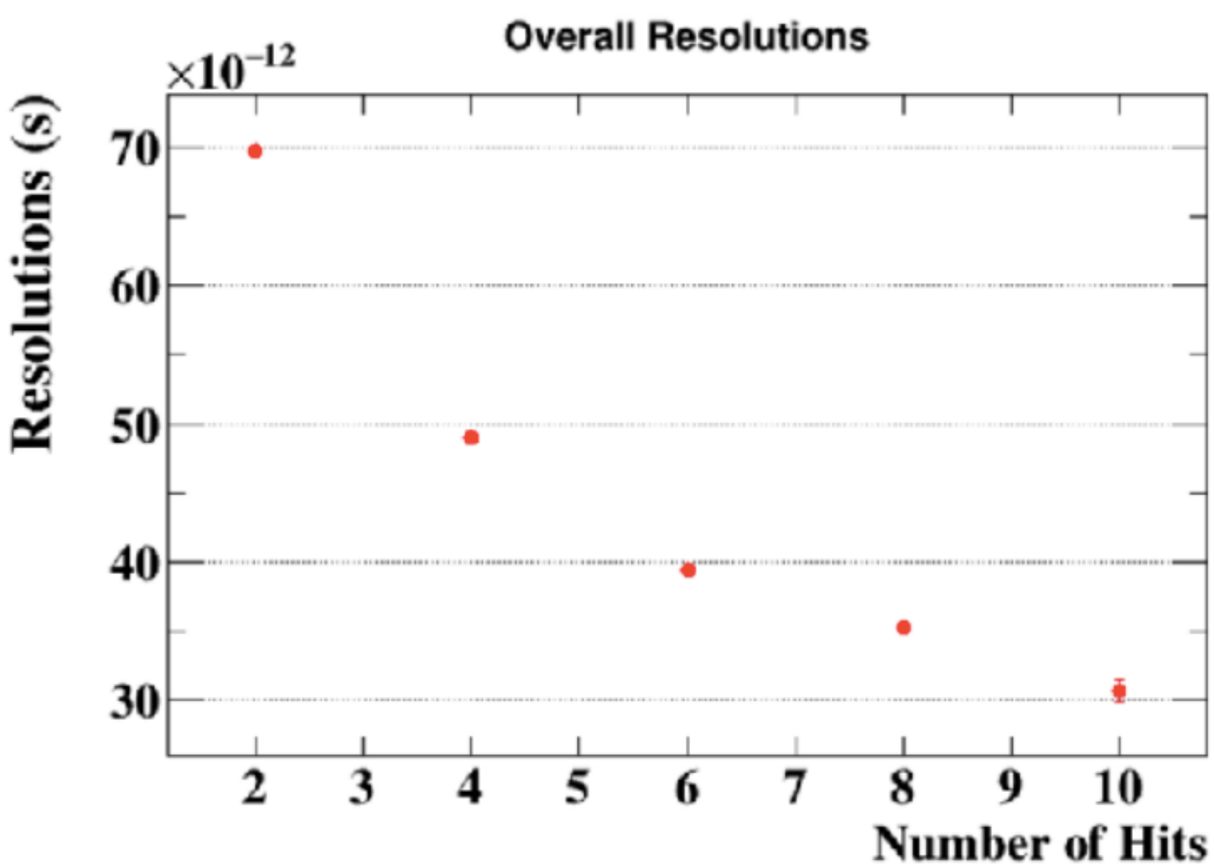
Degradation speed ~0.08%/hour

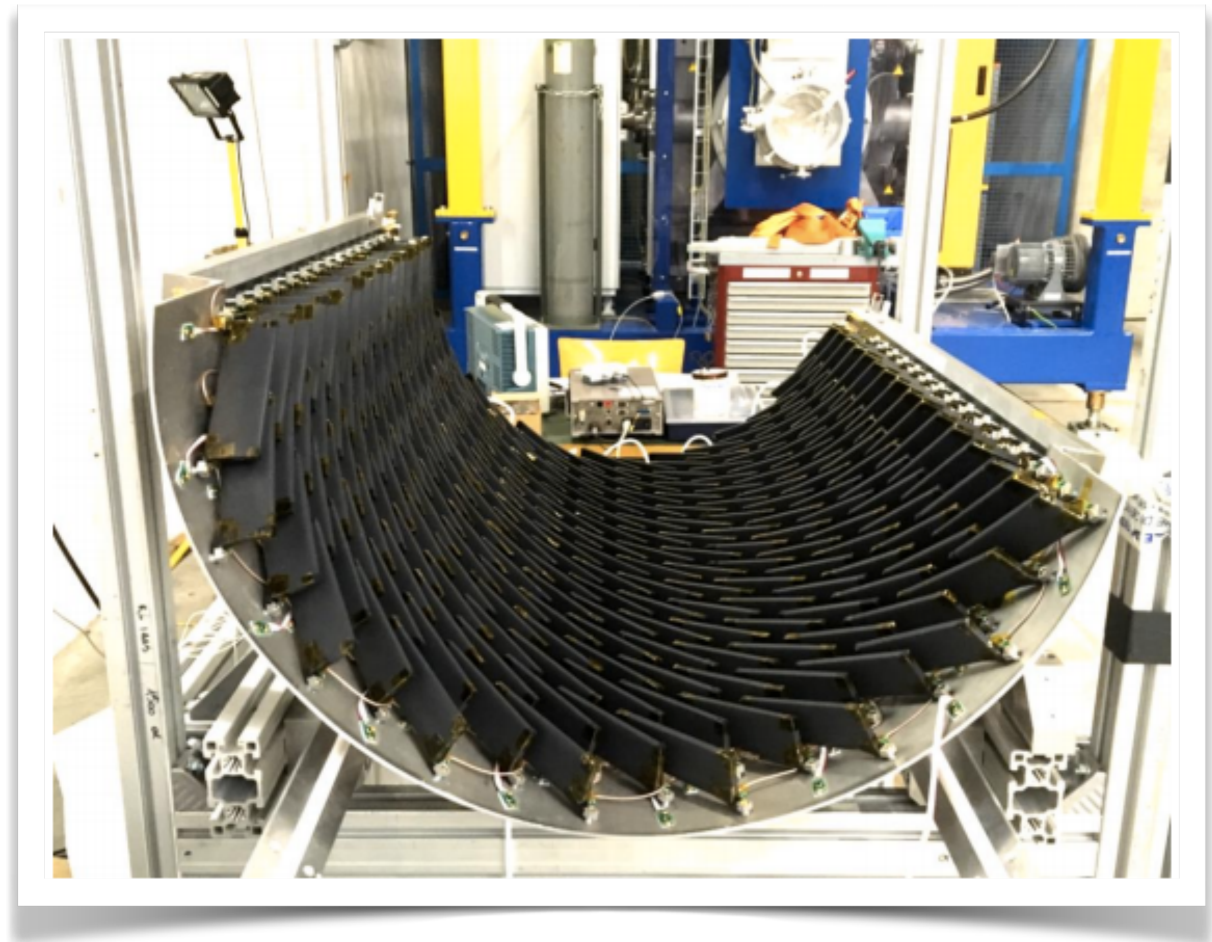
We observe a degradation of the PDE of MPPCs under beam

We successfully experimented a recovery procedure, to be repeated periodically
(annealing by heat: we let the MPPCs drawing a large current when illuminated by LEDs, so to heat them by Joule effect up to 70 °C for several hours)

MEG-II Highlights - The Timing Counters

Stable operations since 2017

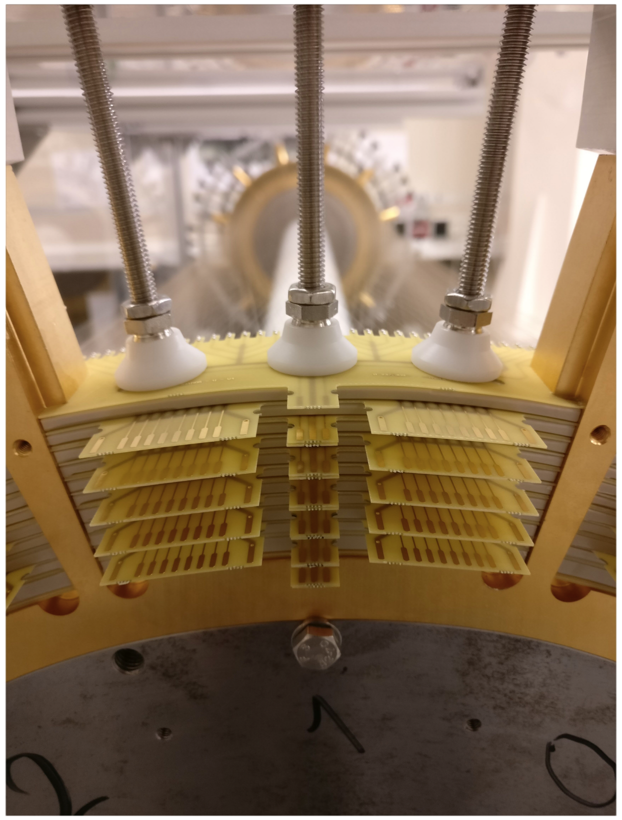




$\sigma_T \sim 35$ ps

Already reached the design resolution

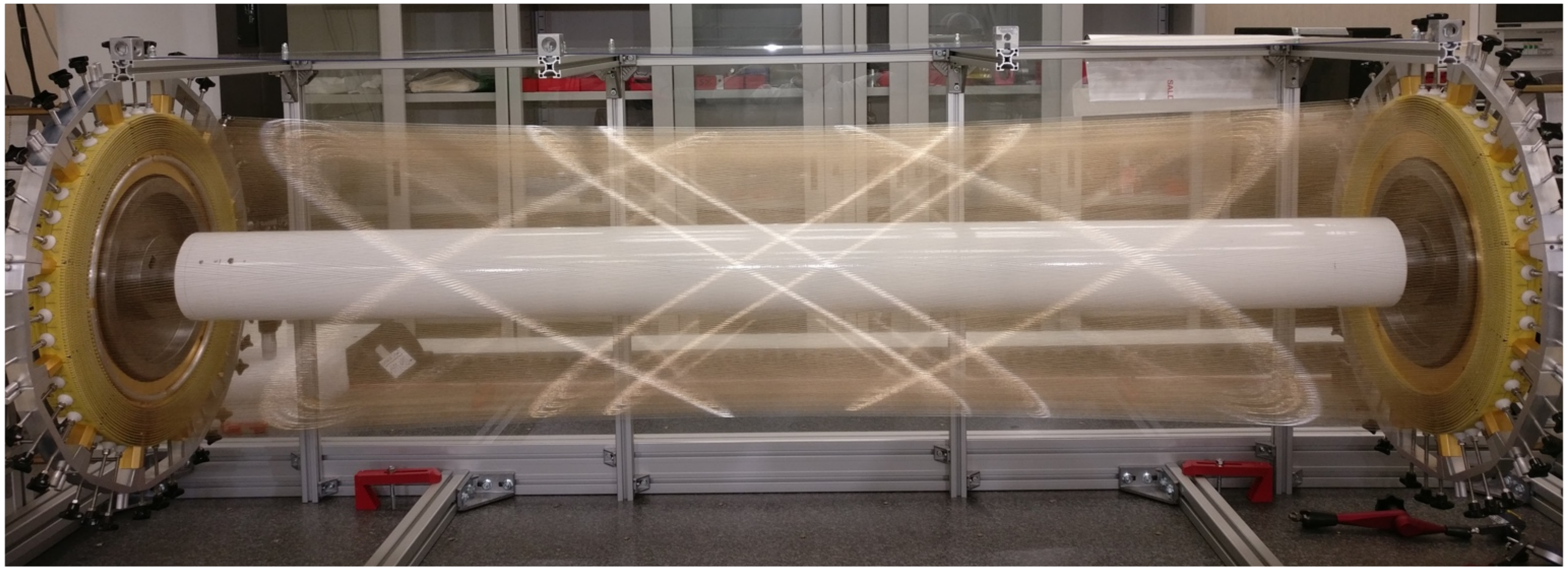
MEG-II Highlights - The Drift Chamber



The challenge: minimal material budget (to reduce MS of 50 MeV e^+) and **very high granularity** (to cope with the high rate) —> small cells (down to < 6 mm) + extremely thin wires (20 μm W(Au) + 40-50 μm Al(Ag))

Innovative wiring technique (no feedthroughs)

Severe problems of wire fragility in presence of contaminants + humidity



A second version of the chamber is under construction (installation foreseen in 2024) to fix some limitations of the old construction (more robust wires, reduced exposure to humidity, improved electrostatic stability, one additional layer)

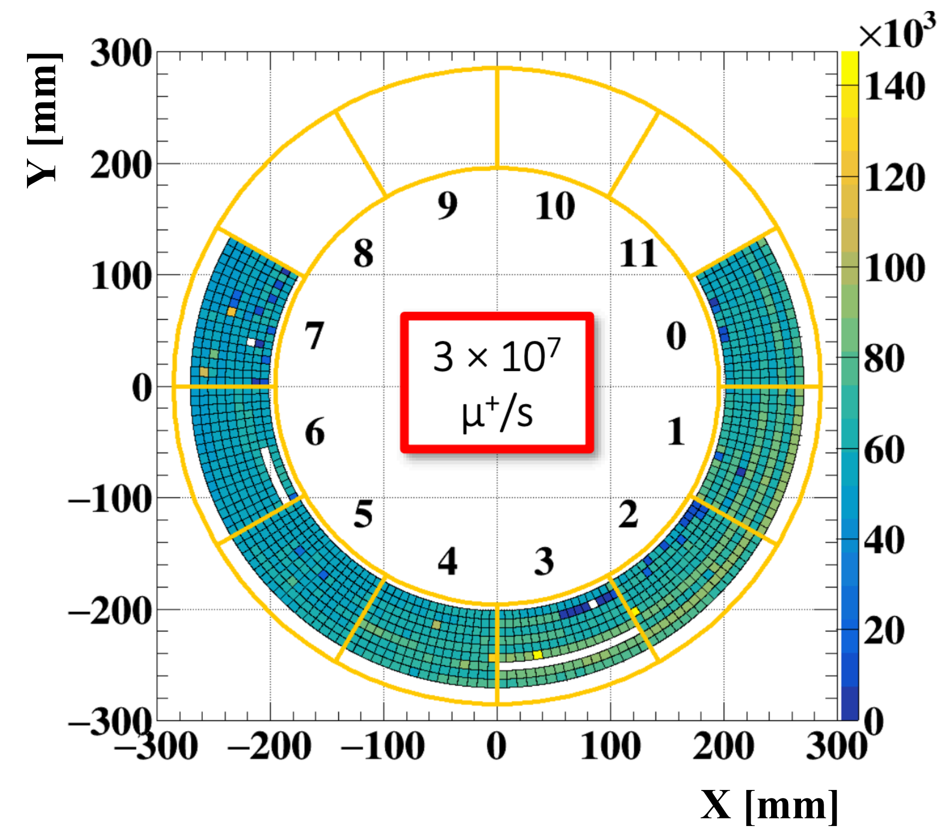
MEG-II Highlights - The Drift Chamber

In 2020 the drift chamber could be operated stably under beam with a 4-component gas mixture

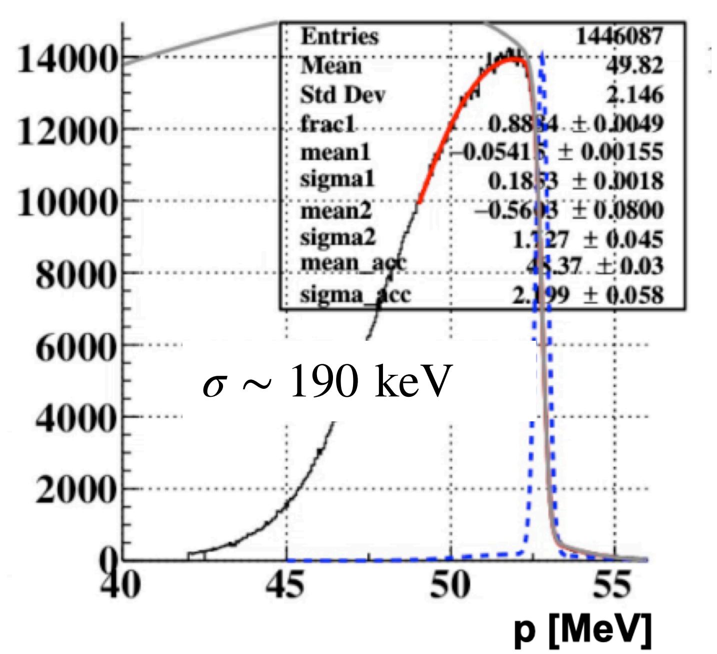
He : C_4H_{10} : isopropyl alcohol : O_2
(88.2 : 9.8 : 1.5 : 0.5)

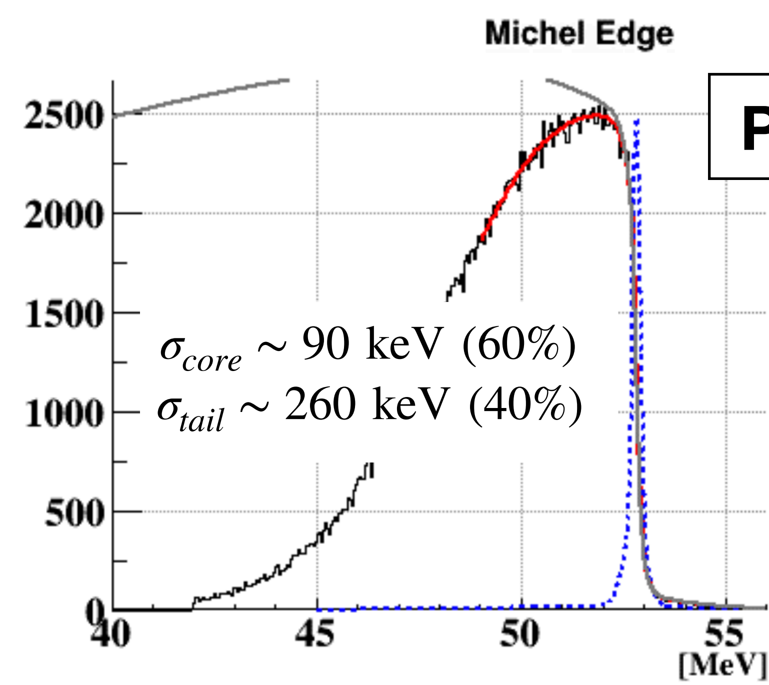
In 2021, first data collected with full readout of the $\mu \rightarrow e\gamma$ acceptance region

-> calibrations, alignment and optimization of the reconstruction algorithms are ongoing



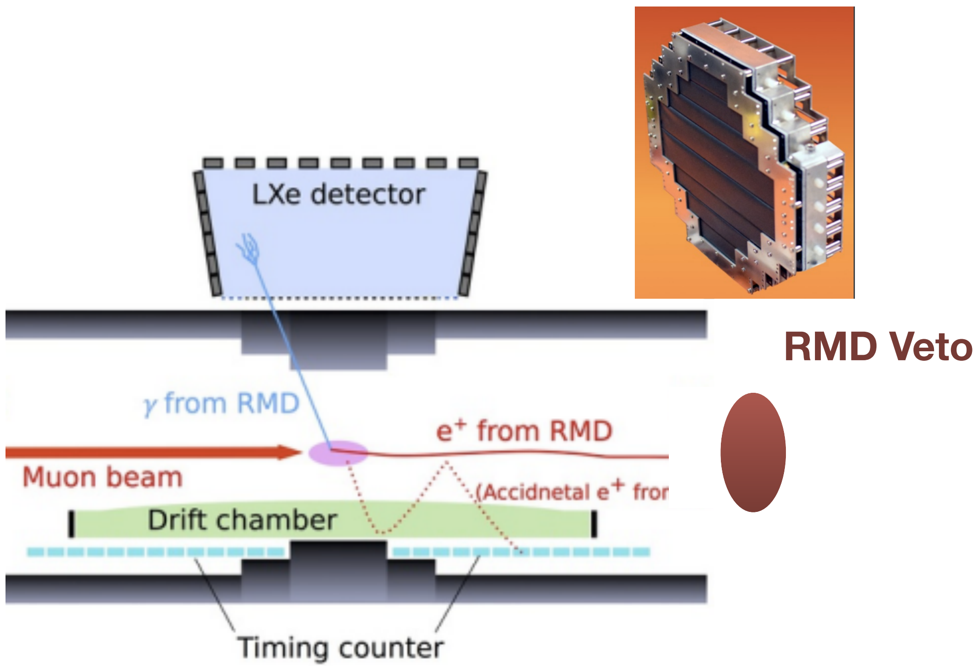
before alignment





after alignment and optimised reconstruction

RDC & Target monitoring



50% of acc. background photons come from RMD w/ positron along the beam line

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

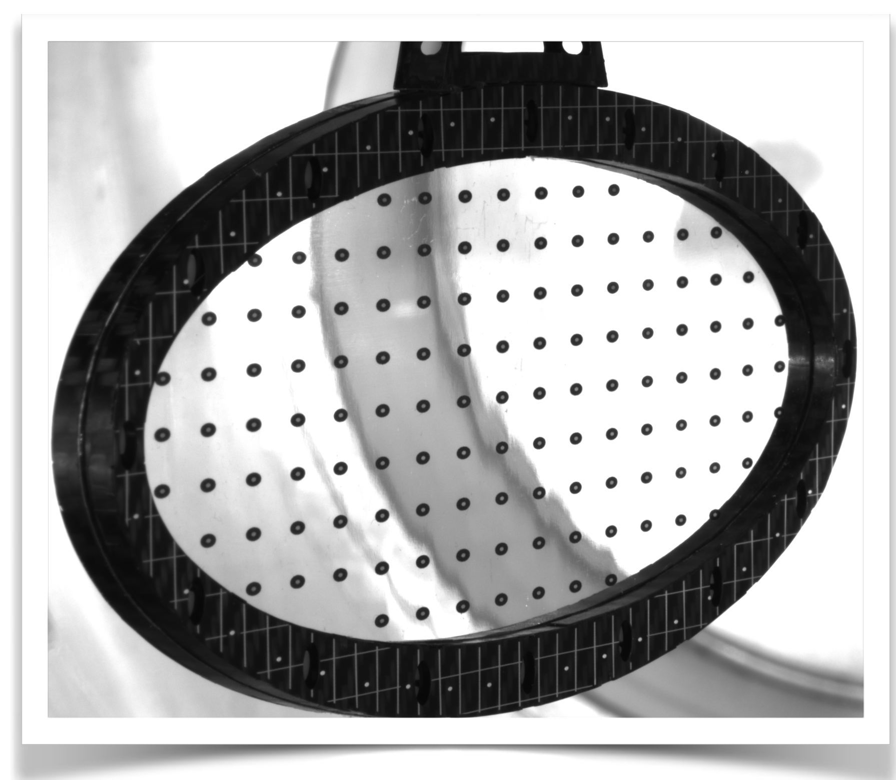
A new detector (LYSO + plastic scint.) built and tested in 2017 -> 16% better sensitivity

---

The target position in MEG-II has to be known with an accuracy ~ 100 μm to not compromise the angular resolution

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

<< 100 μm resolution reached

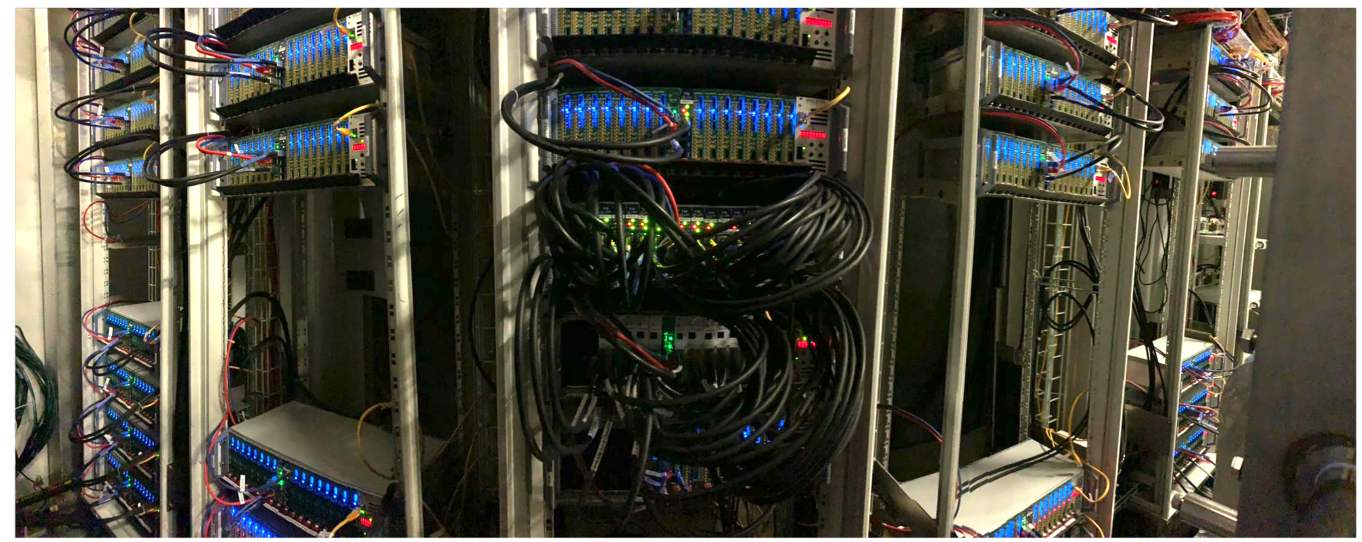


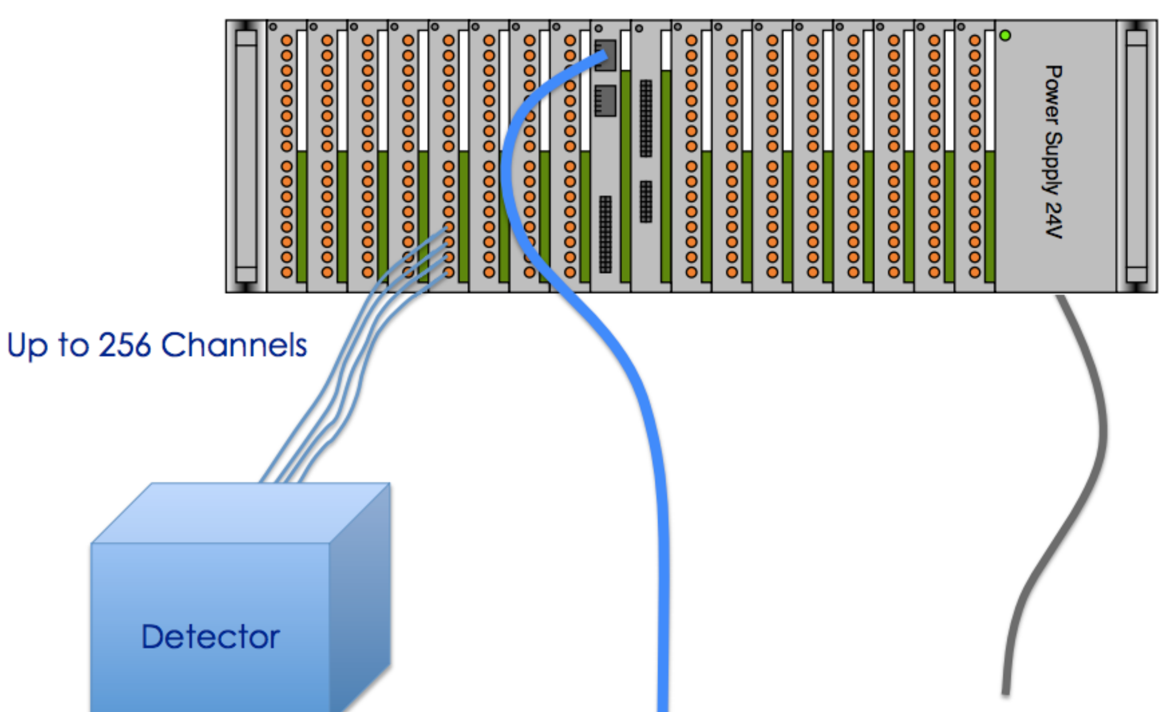
MEG-II Highlights - DAQ, Trigger

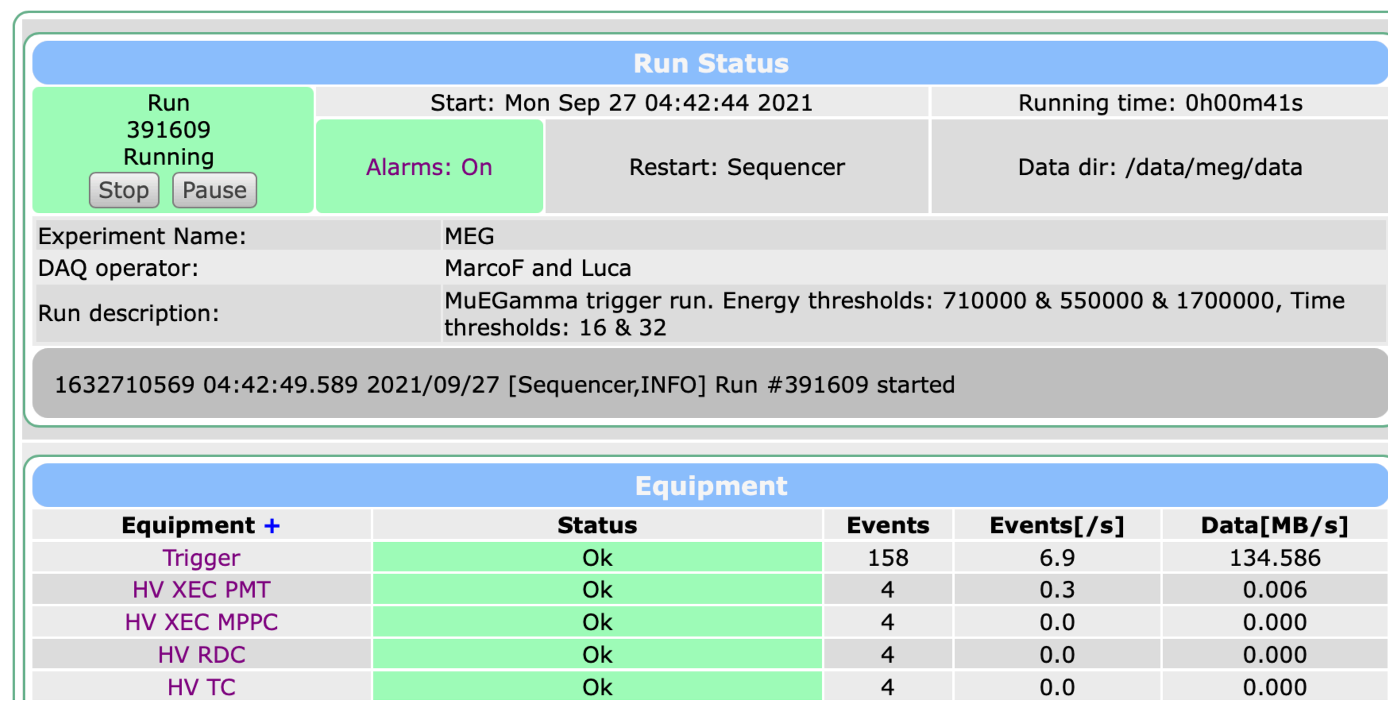
Trigger and DAQ integrated in a single, compact system (WaveDAQ)

Also provides power and amplification for SiPM/MPPC

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

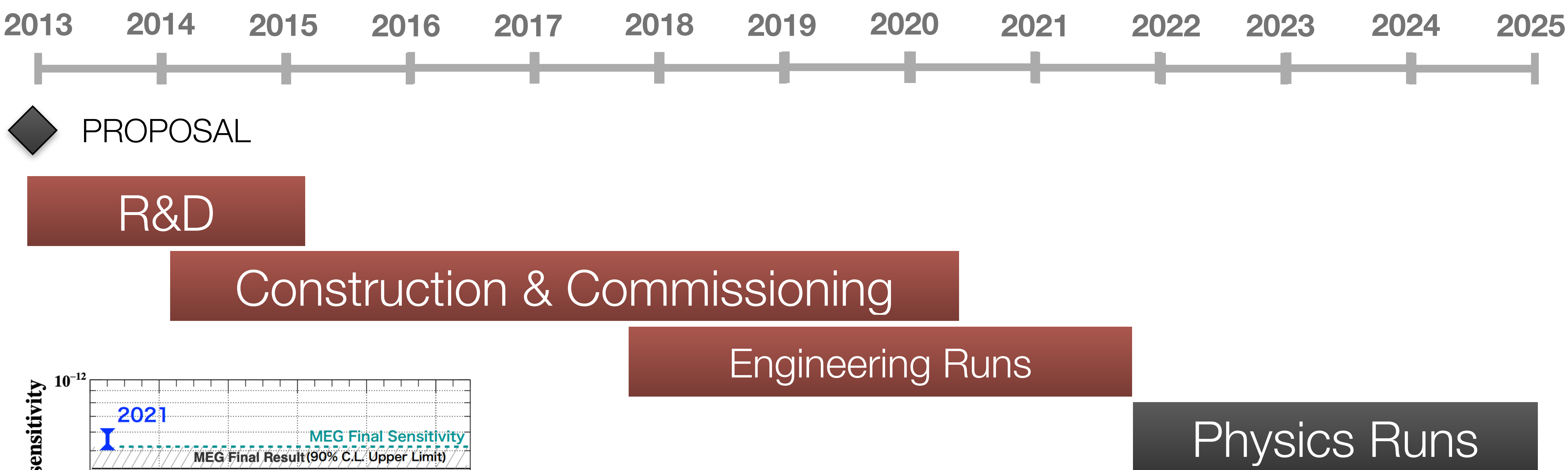
Experiment Name:	MEG
DAQ operator:	MarcoF and Luca
Run description:	MuEGamma trigger run. Energy thresholds: 710000 & 550000 & 1700000, Time thresholds: 16 & 32

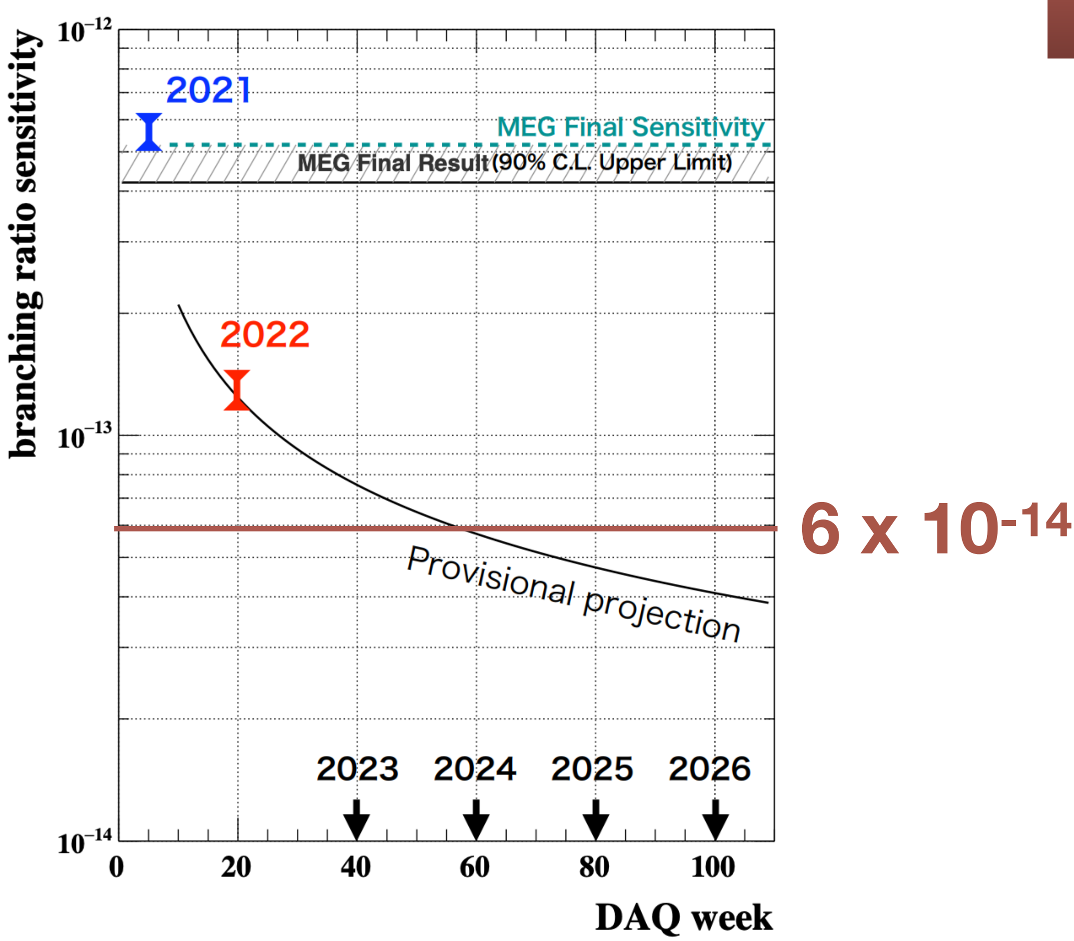
1632710569 04:42:49.589 2021/09/27 [Sequencer,INFO] Run #391609 started

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 schedule & sensitivity

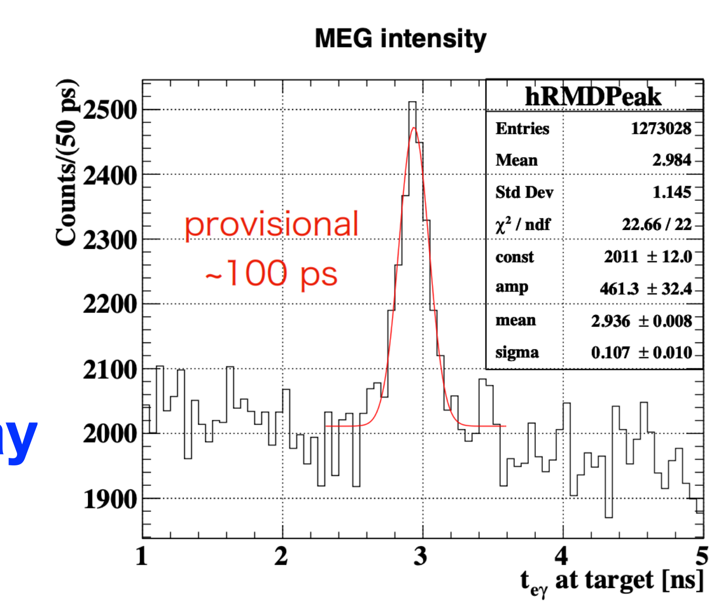




6 x 10^{-14}

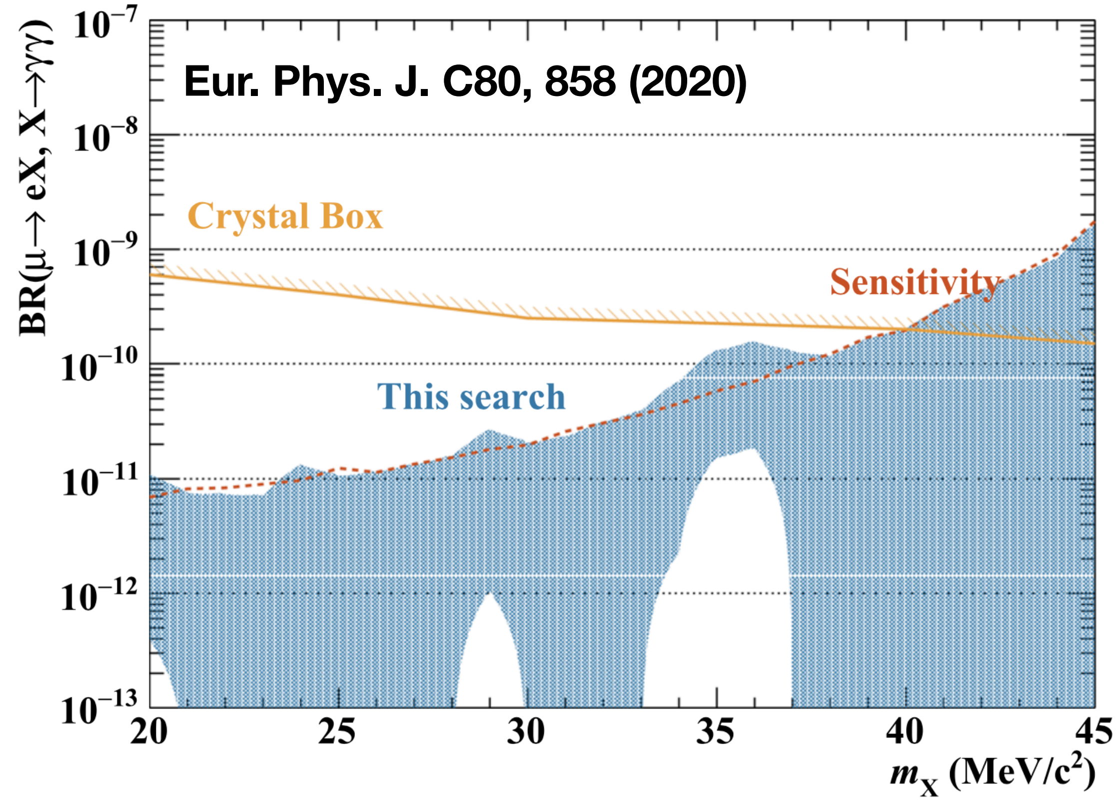
First physics data collected in 2021, analysis ongoing

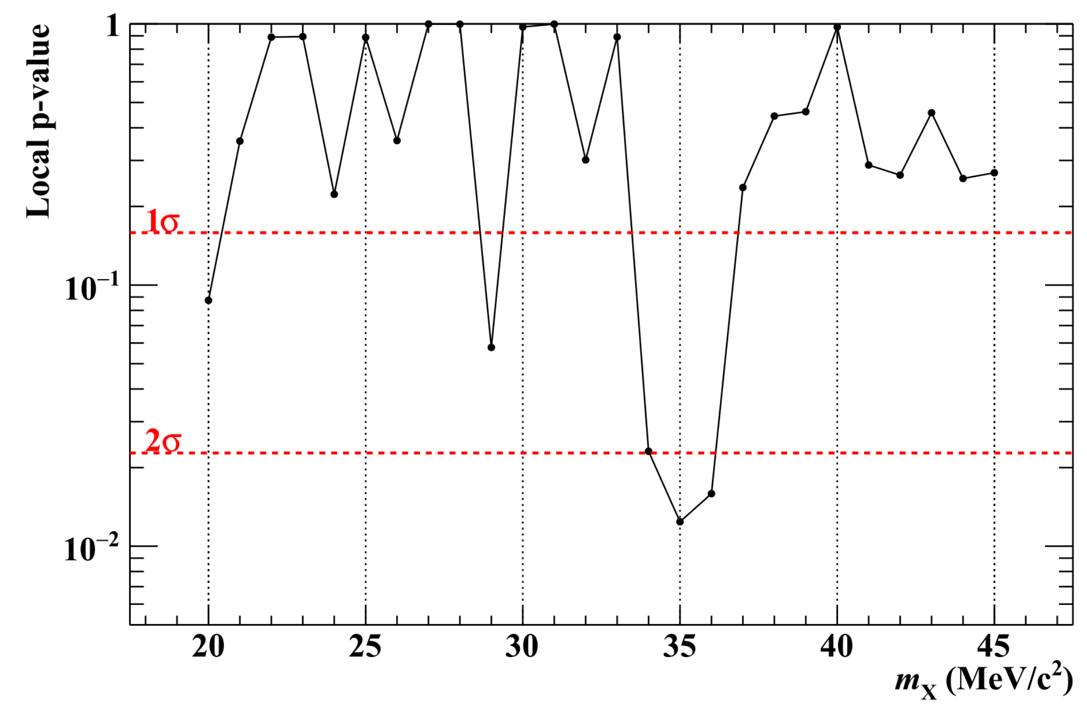
Radiative muon decay peak observed



Going beyond $\mu \to e\gamma$ with MEG (II) data

- The MEG detector collects a huge amount of normal and radiative muon decays, though in a quite limited phase space region, tailored for the $\mu \to e\gamma$ search
  - 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
- Feasibility studies for $\mu \to e + invisible$ and $\mu \to e\,\gamma + invisible$ at MEG II are also foreseen



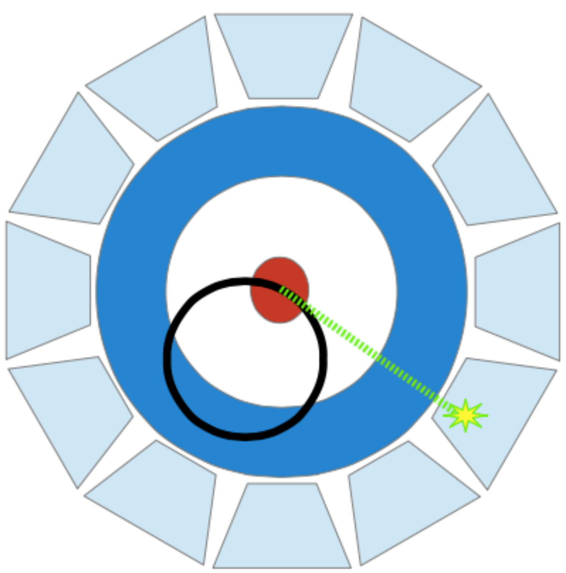


Conclusions

- cLFV in muon decays is a **golden probe** for NP beyond the SM
- MEG currently gives the **best limits** on muon cLFV
- **MEG-II** will improve the sensitivity by a factor ~ 10
    - Engineering run in 2021 with the full detector under running conditions and first MEG trigger data already collected!!!

Going beyond MEG II

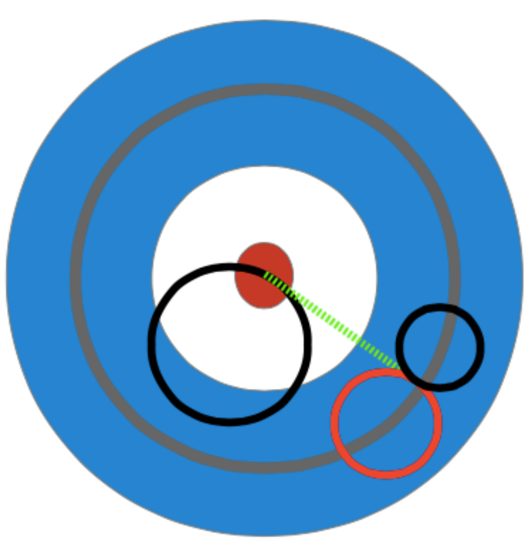
- What about $\mu \to e\gamma$ at proposed, future high-intensity muon beam facilities at PSI and/or FNAL?



Calorimetry

High efficiency
Good resolutions

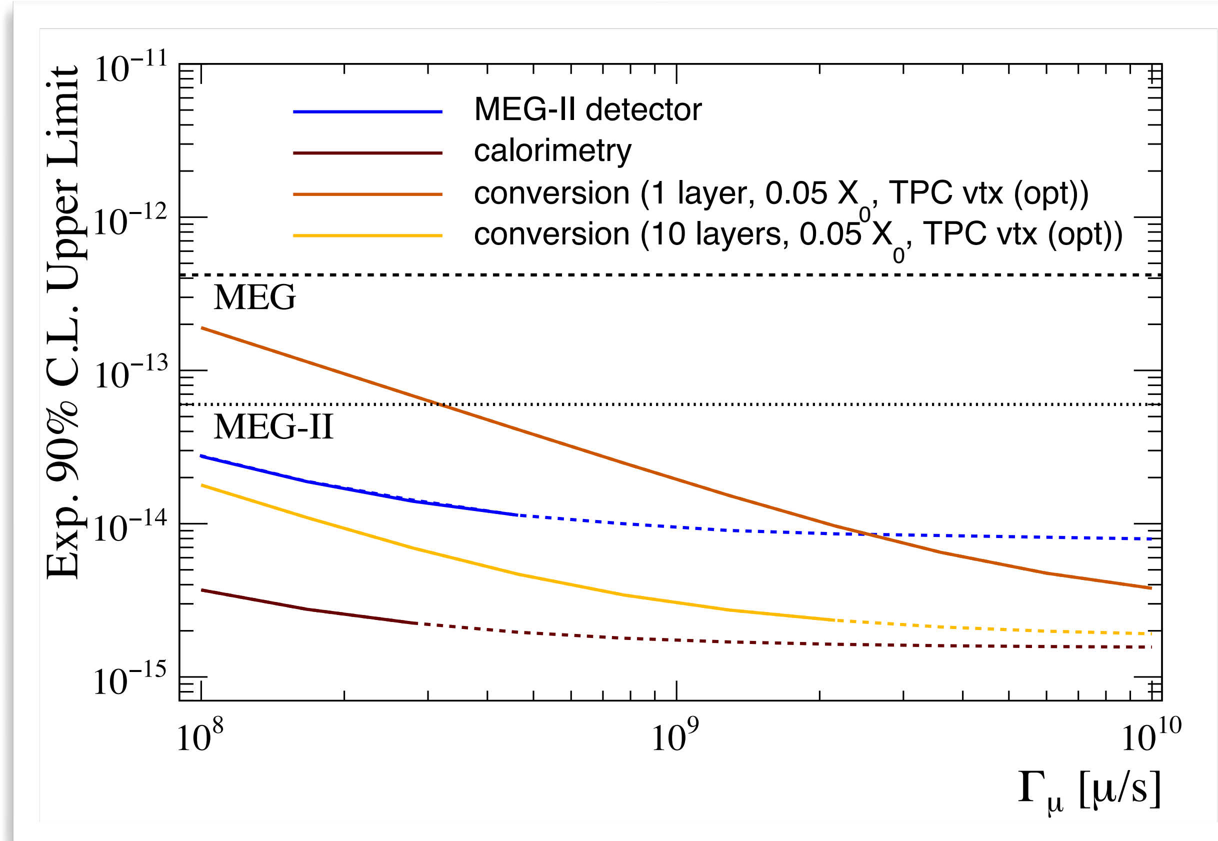
MEG:
LXe calorimeter
10% acceptance



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

Backup

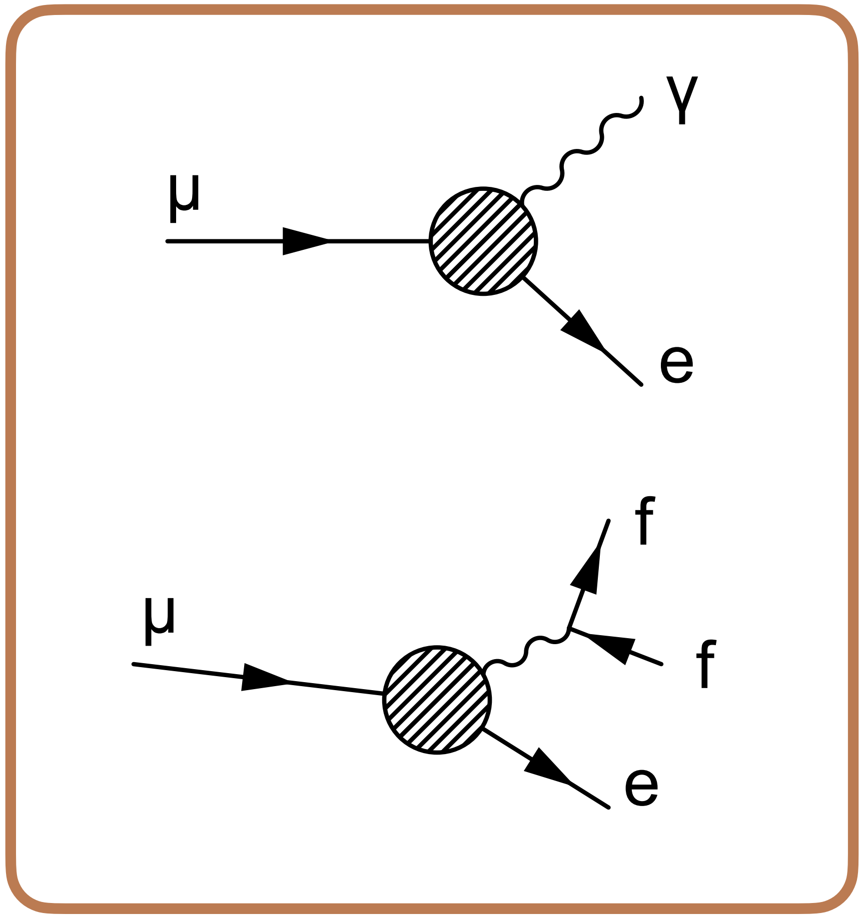
cLFV searches in the muon sector - the naive view

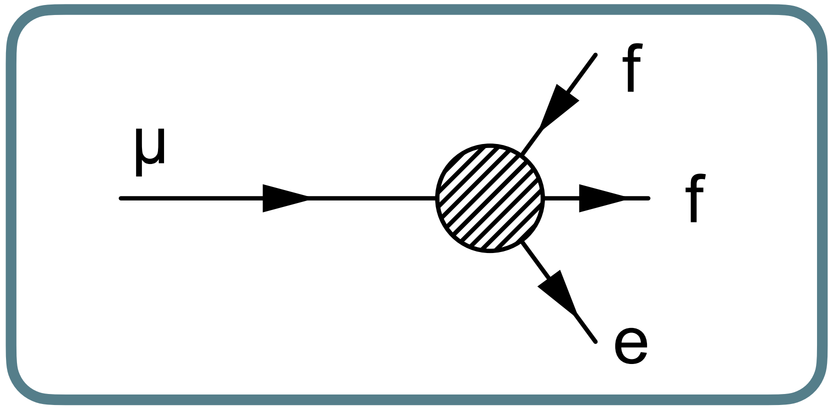
- cLFV in the muon sector searched for decays (**μ -> e γ**, **μ -> e e e**) and **μ -> e conversion** in nuclei

- Effective Field Theory (EFT) approach:

  - **μ -> e γ** sensitive to **dipole operators**

  - **μ -> e e e** and **μ N -> e N** sensitive to both **dipole** and **4-fermion operators**



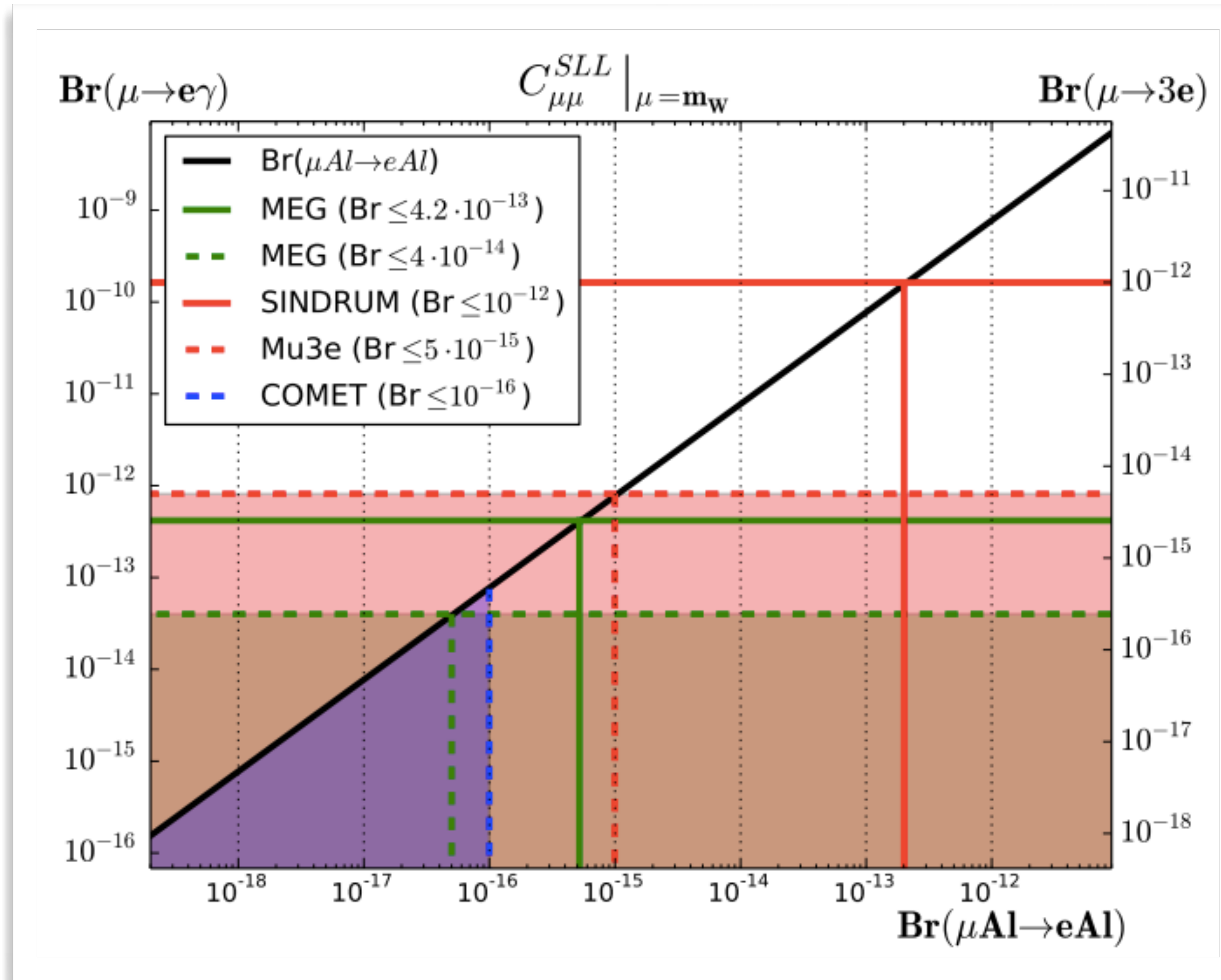


Naive conclusion: the upcoming μ -> e conversion experiments will overcome the muon decay experiments

cLFV searches in the muon sector - the full view

- Operators mix at the loop level:
  - **μ -> e γ** also sensitive to 4-fermion operators
  - **μ -> e γ** can give the strongest bound in some scenarios

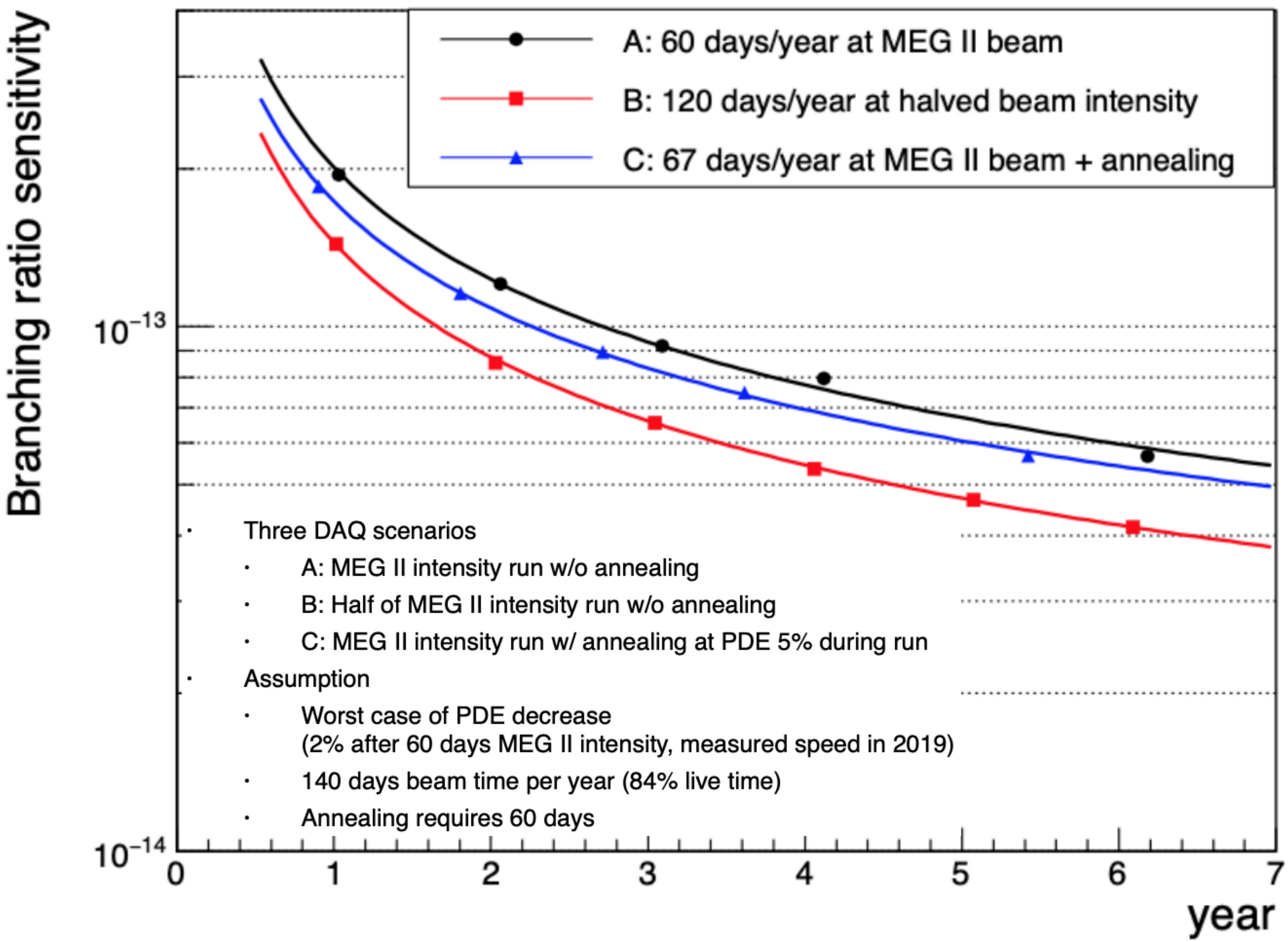
STRONG COMPLEMENTARITY



A. Crivellin et al., JHEP 1705 (2017) 117

Even in the era of the upcoming μ -> e conversion experiments, μ -> e γ (and μ -> e e e) will continue to play a crucial role

Possible operation scenarios for physics run



- Three DAQ scenarios
  - A: MEG II intensity run w/o annealing
  - B: Half of MEG II intensity run w/o annealing
  - C: MEG II intensity run w/ annealing at PDE 5% during run
- Assumption
  - Worst case of PDE decrease (2% after 60 days MEG II intensity, measured speed in 2019)
  - 140 days beam time per year (84% live time)
  - Annealing requires 60 days