

# Muon decays

**Francesco Renga**

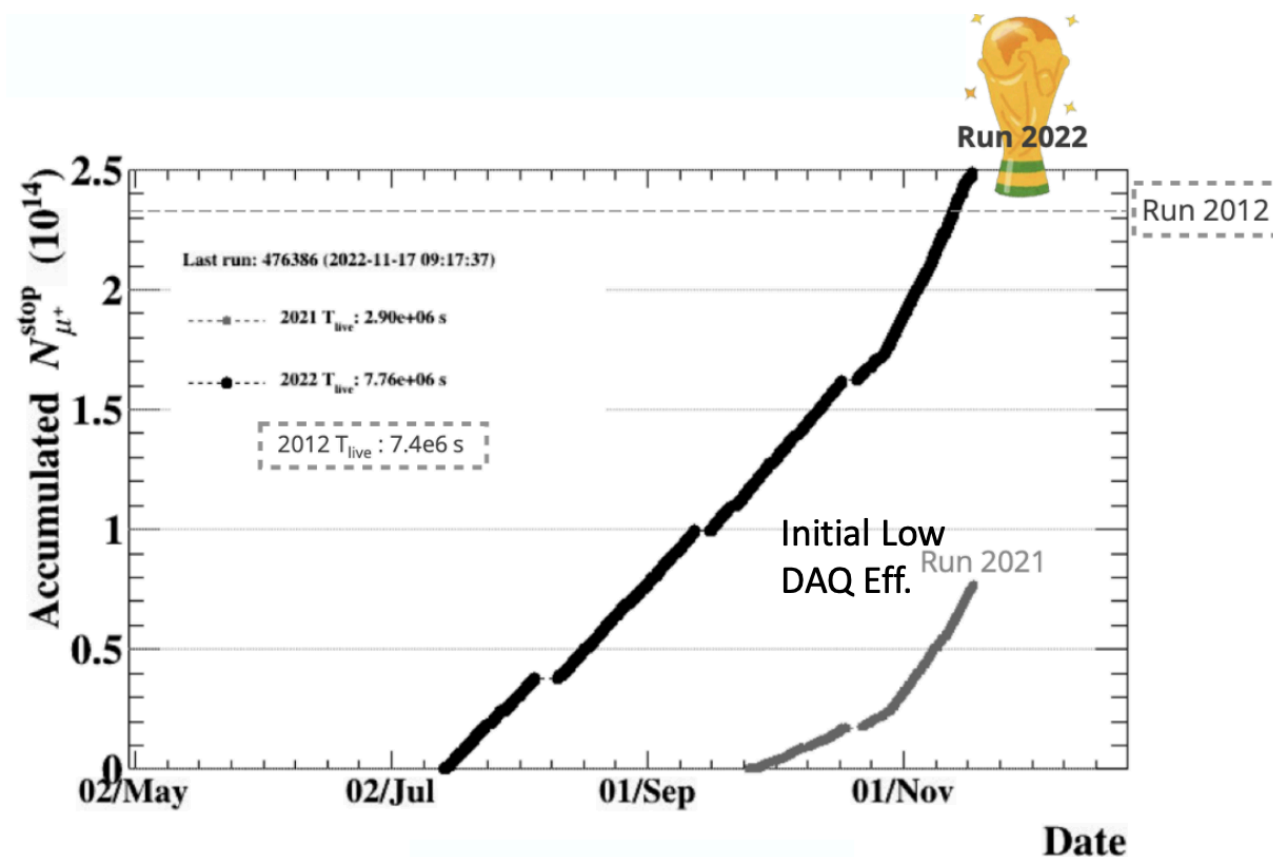
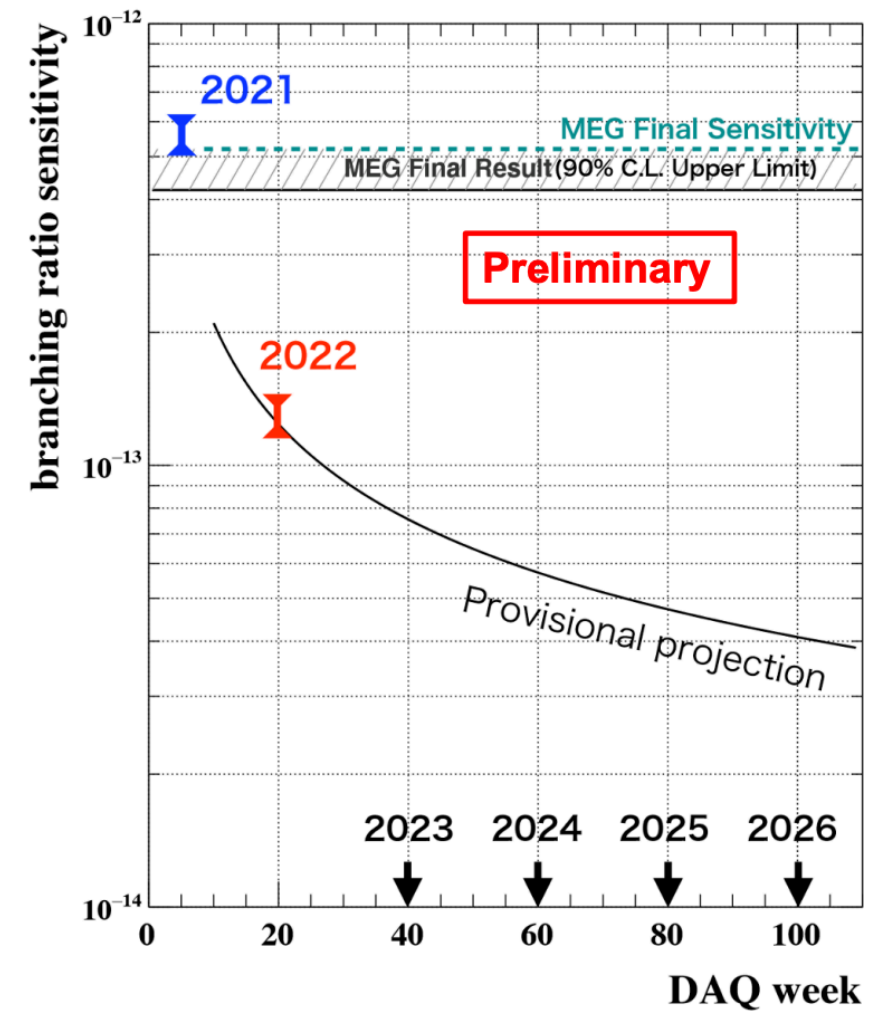
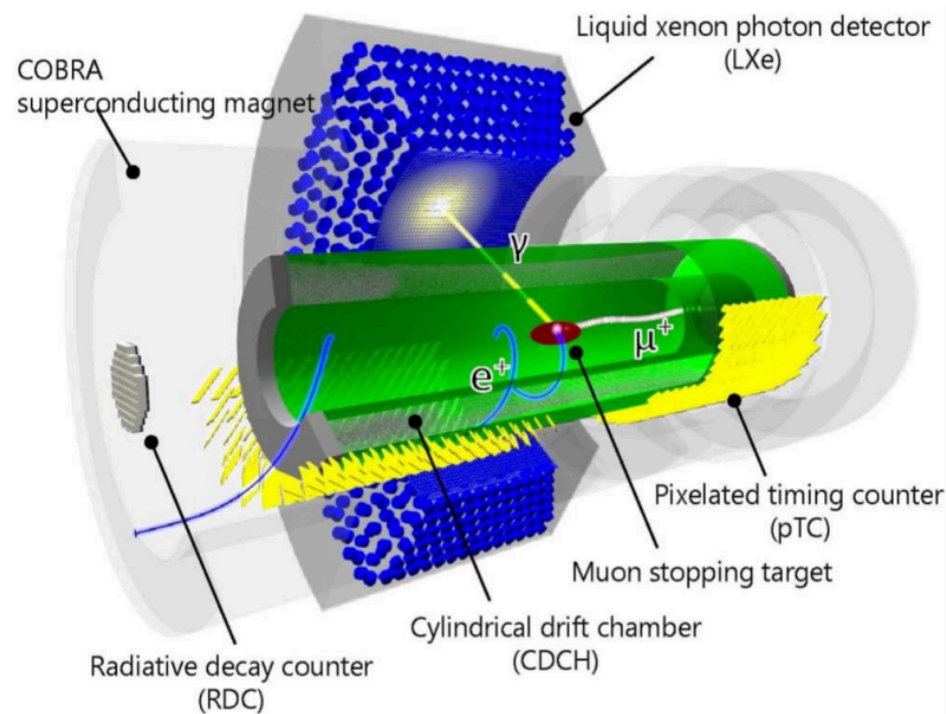
***INFN Roma***

# Golden channels and new opportunities

- MEG-II (D. Palo)
- Conceptual studies and R&Ds toward future  $\mu \rightarrow e \gamma$  searches (FR, W. Ootani)
- Mu3e and other programs with HiMB at PSI (A. Papa)
- Decays into exotic particle (D. Redigolo)

# Current programs

MEG  
D. Palo



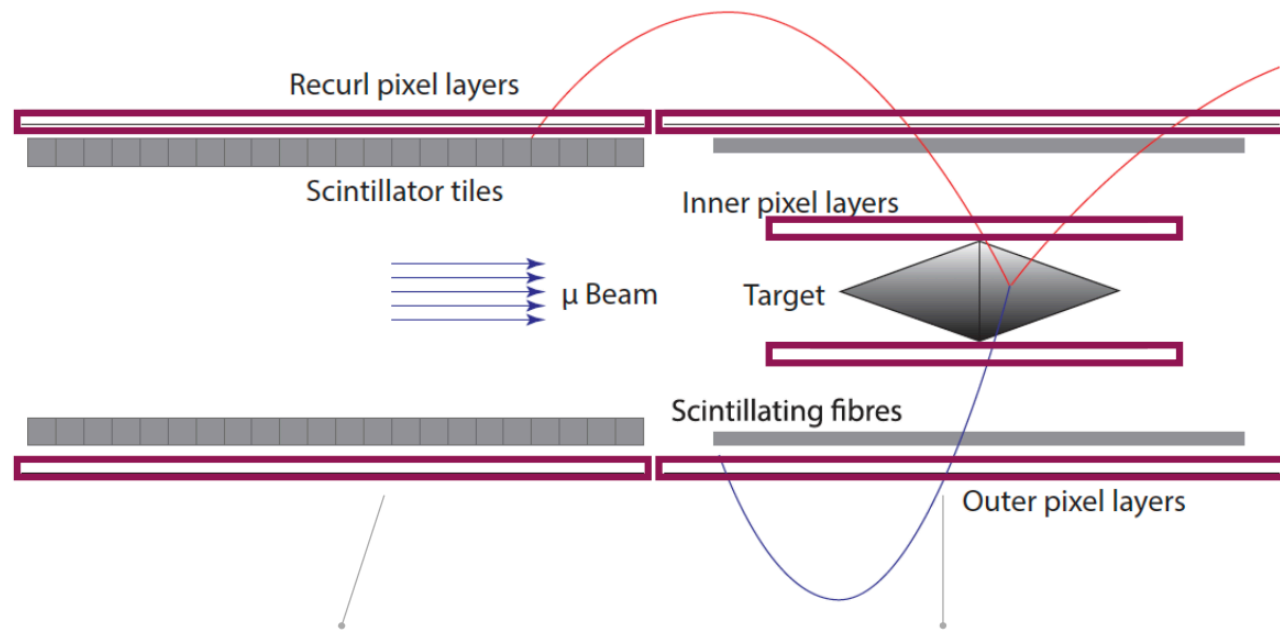
Kinematic Core $\sigma$	MEG I	MEG II Goal
$E_\gamma$ (%)	2.4	1.1
$u_\gamma(z_\gamma)$ (mm)	5	2.6
$v_\gamma(R\phi_\gamma)$ (mm)	5	2.2
$w_\gamma(R_\gamma)$ (mm)	6	5
$t_\gamma$ (ps)	60	60

Kinematic Core $\sigma$	MEG I	MEG II Goal
$p_{e^+}$ (keV)	380	130
$\theta_{e^+}/\phi_{e^+}$ (mrad)	9.4 / 8.7	5.3/3.7
$t_{e^+}$ (ps)	70	30
$z_{e^+}/y_{e^+}$ (mm)	2.4/1.2	1.6/0.7
e+ Efficiency	30	70

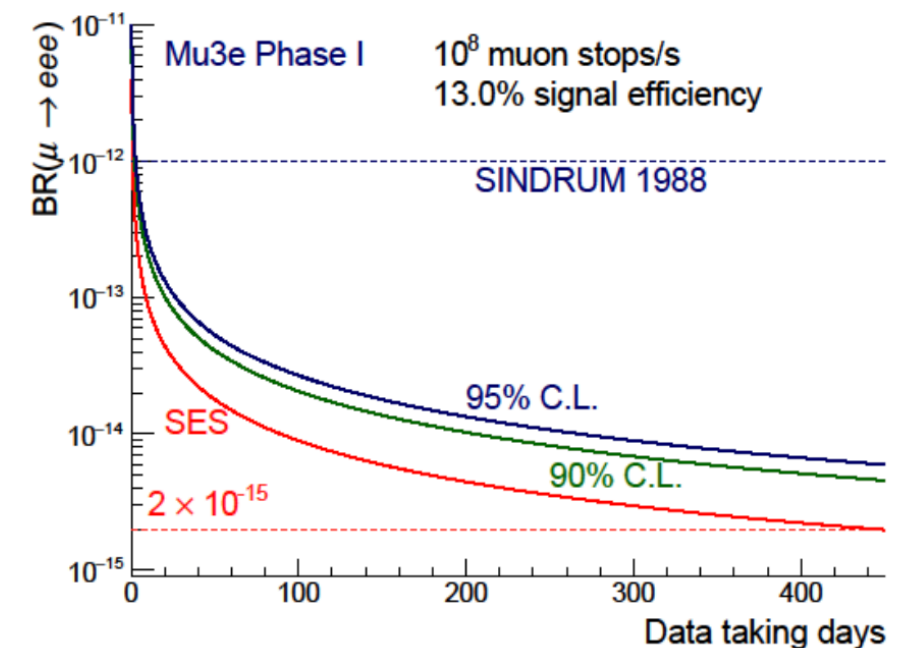
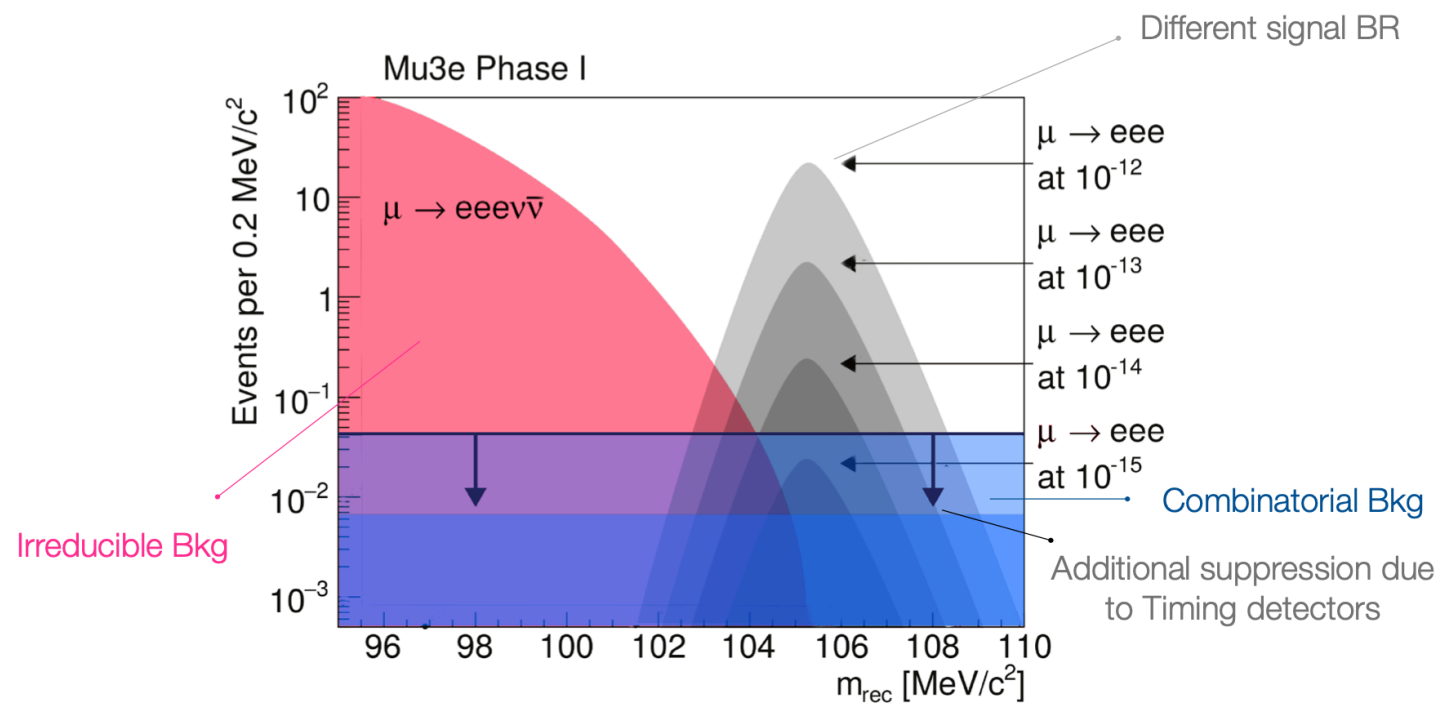
# Current programs

## Mu3e

A. Papa

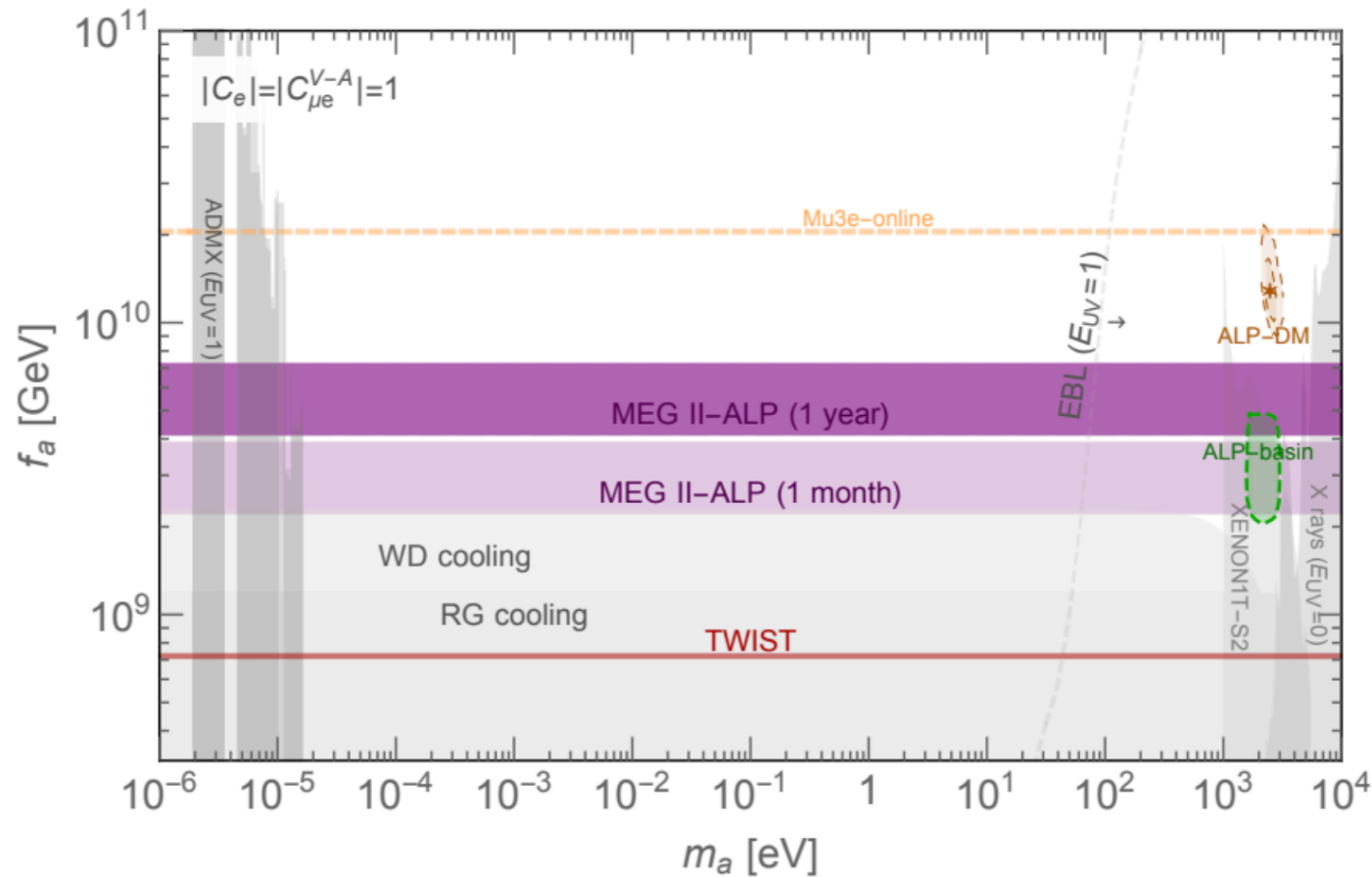


- MuPix mass production: ongoing
- Complete integration run: 2023
- Engineering run: 2024
- First physics run: 2025

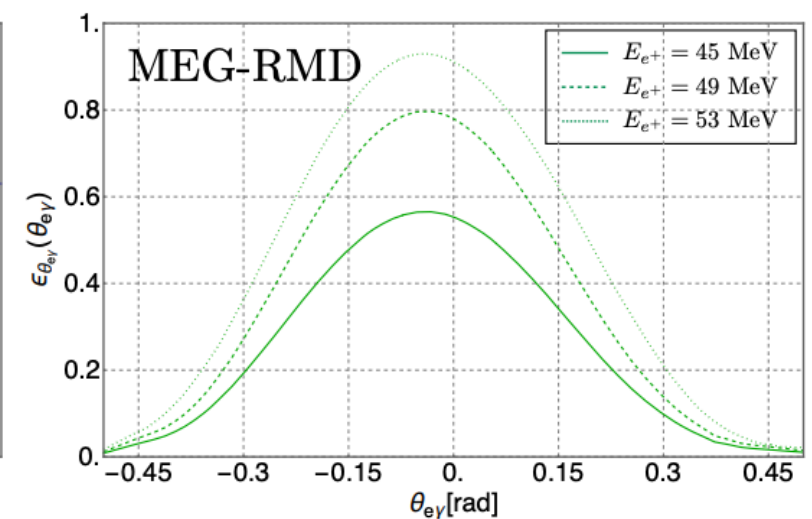
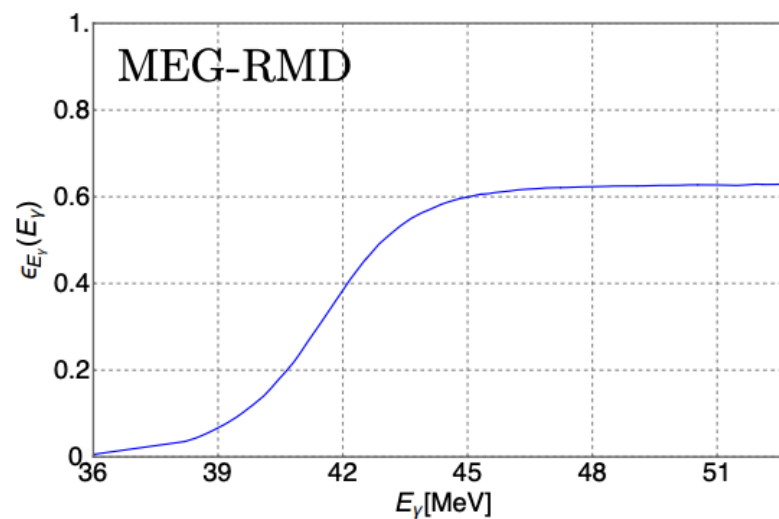
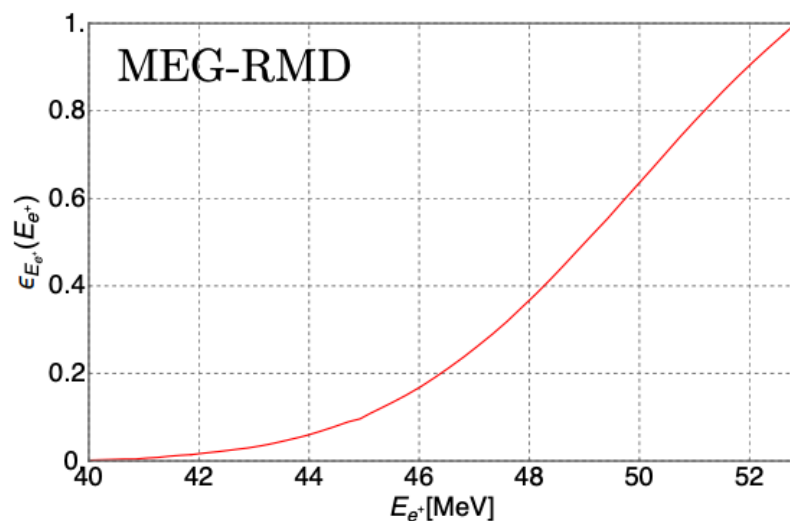




# Muon decays to axions D. Redigolo



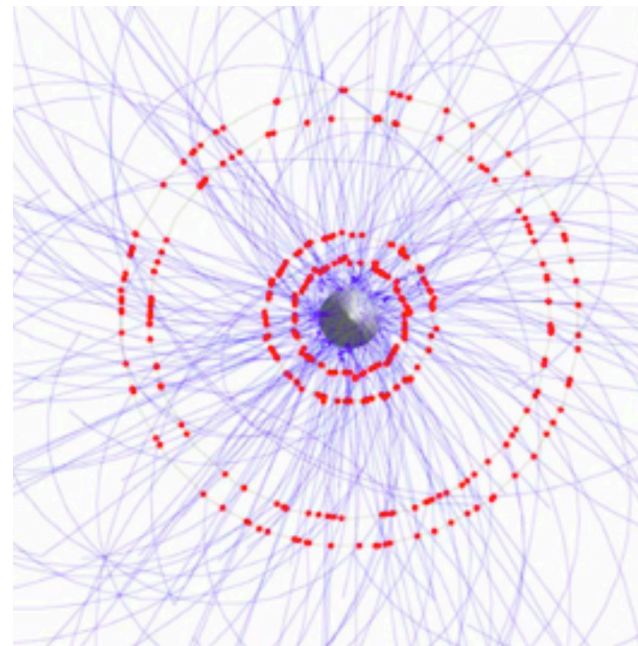
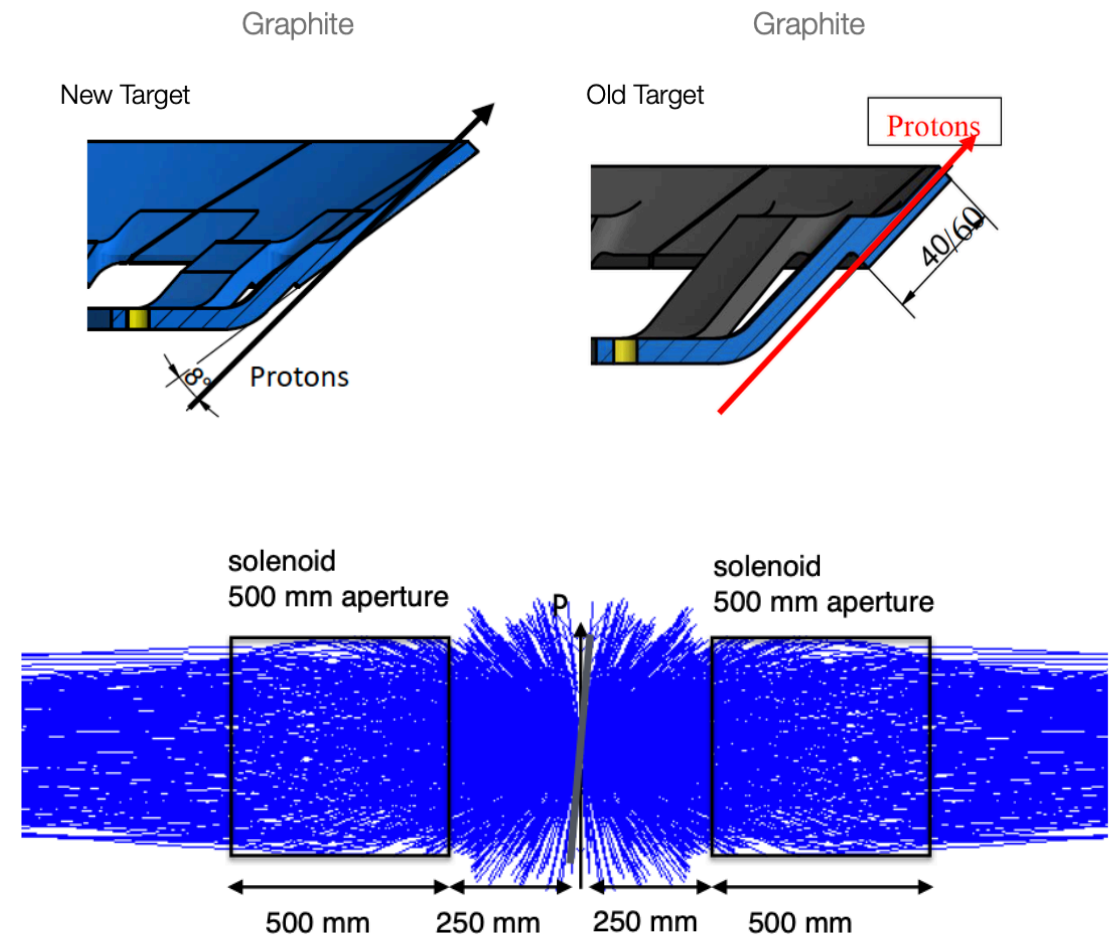
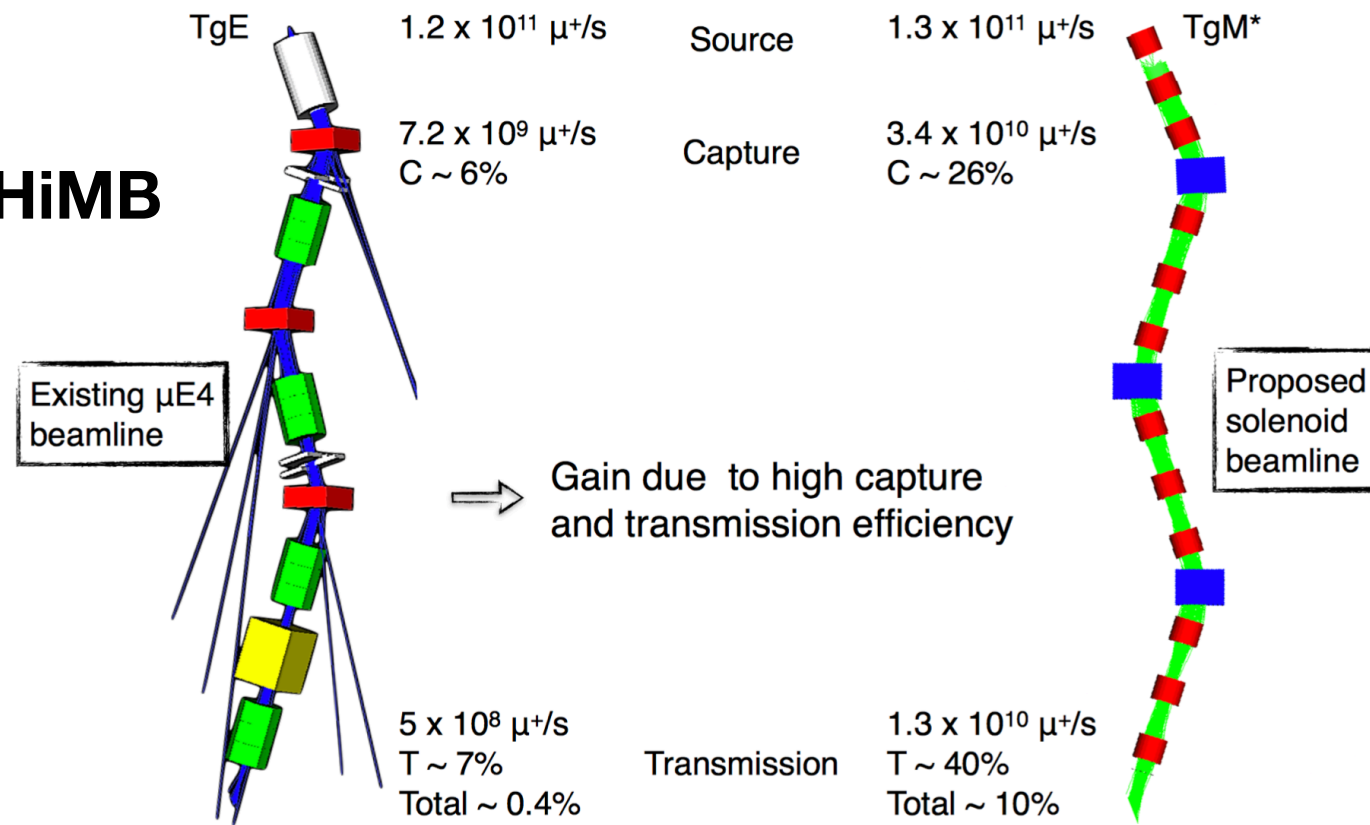
$$\mathcal{L}_{\text{eff}}^{\text{LFV}} \supset \frac{\partial_\mu a}{2f_a} \bar{\mu} \gamma^\mu (C_{\mu e}^V + C_{\mu e}^A \gamma_5) e + \text{h.c.}$$



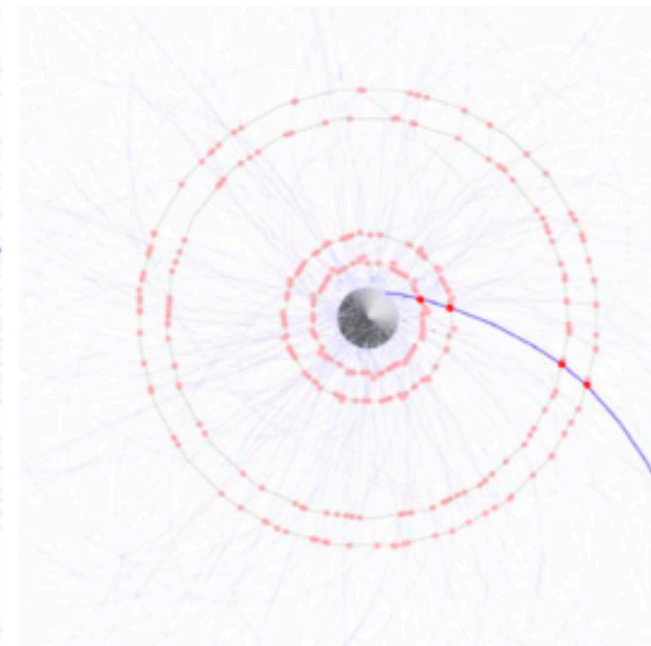
# Mu3e phase-II

A. Papa

HiMB



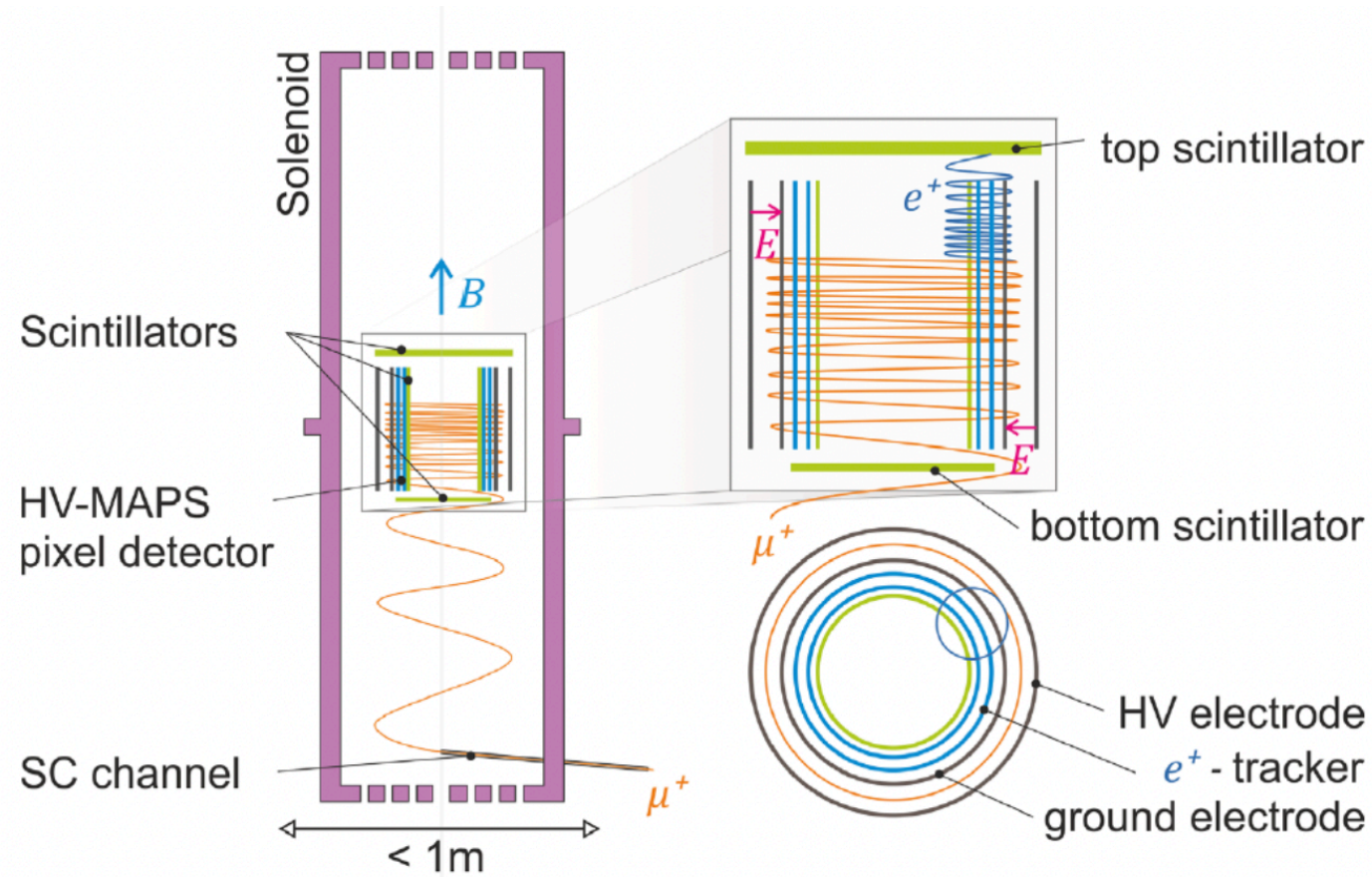
Pixels:  $O(50 \text{ ns})$



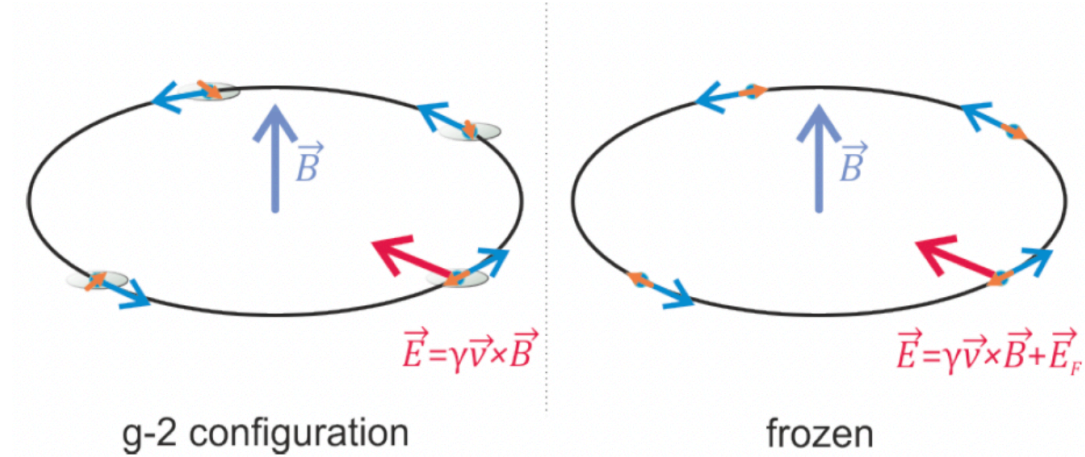
Scintillating fibres  $O(1 \text{ ns})$ ;  
Scintillating tiles  $O(100 \text{ ps})$



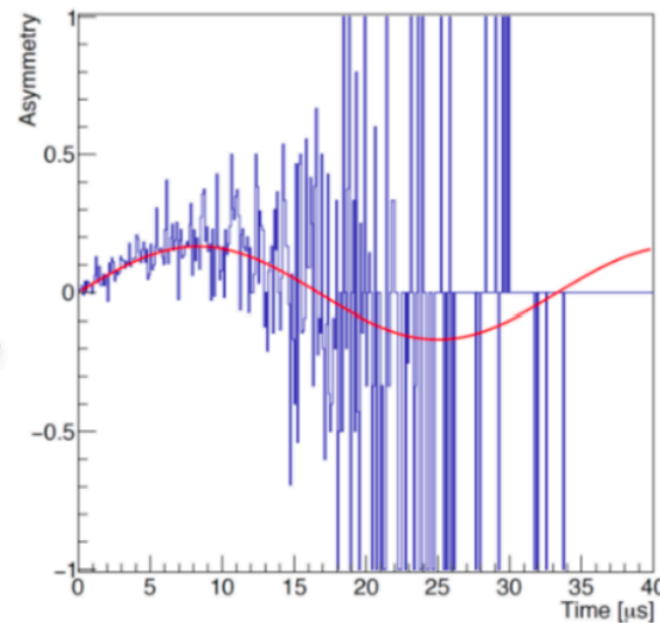
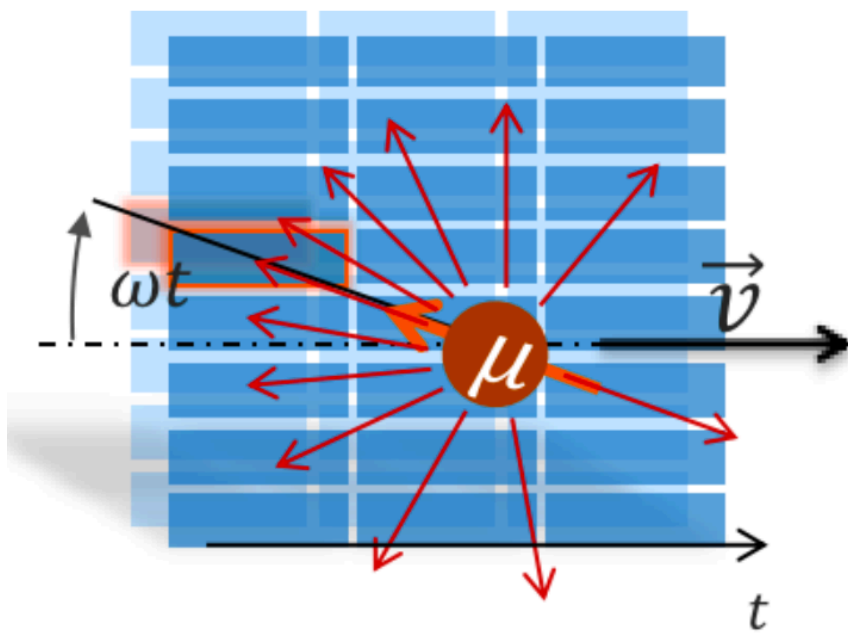
# muonEDM A.Papa



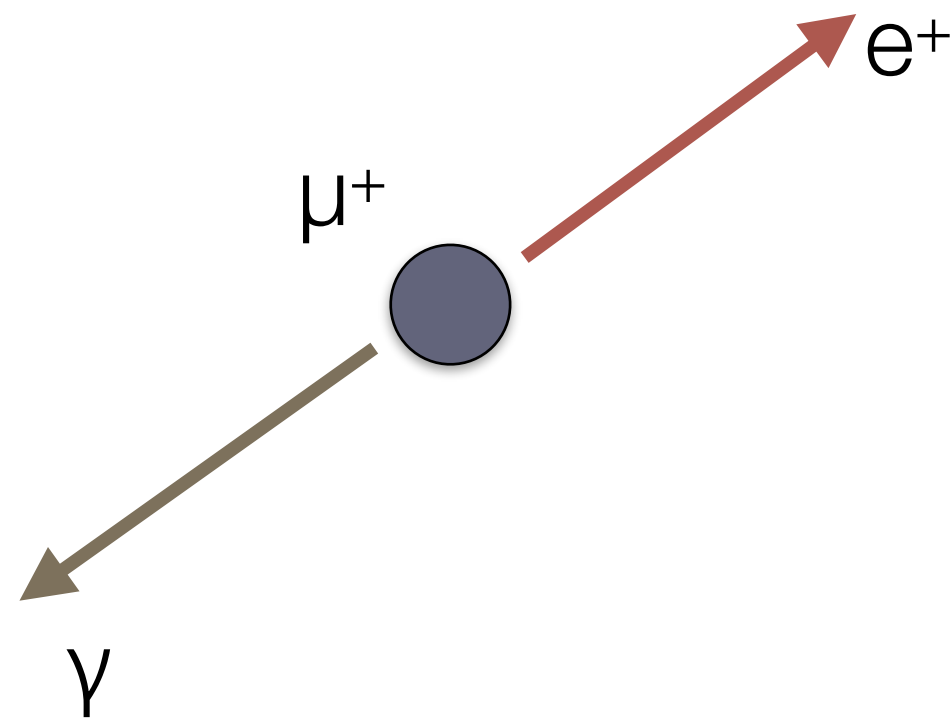
$p=125 \text{ MeV/c}$  [muE1]



	$\pi\text{E1}$	$\mu\text{E1}$
Muon flux ( $\mu^+/s$ )	$4 \times 10^6$	$1.2 \times 10^8$
Channel transmission	0.03	0.005
Injection efficiency	0.017	0.60
Muon storage rate (1/s)	$2 \times 10^3$	$360 \times 10^3$
Gamma factor $\gamma$	1.04	1.56
$e^+$ detection rate (1/s)	500	$90 \times 10^3$
<b>Detections per 200 days</b>	$8.64 \times 10^9$	$1.5 \times 10^{12}$
Mean decay asymmetry $A$	0.3	0.3
Initial polarization $P_0$	0.95	0.95
<b>Sensitivity in one year (<math>e \cdot \text{cm}</math>)</b>	$< 3 \times 10^{-21}$	$< 6 \times 10^{-23}$



# Future $\mu \rightarrow e \gamma$ searches FR, W. Ootani

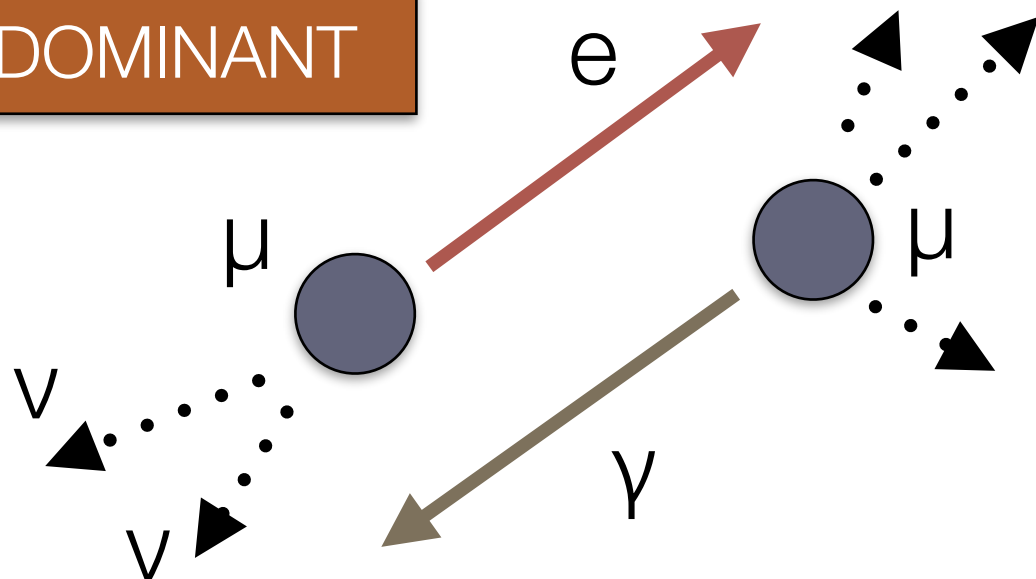


2-body decay of muons are stopped on a thin target

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

## Accidental Background

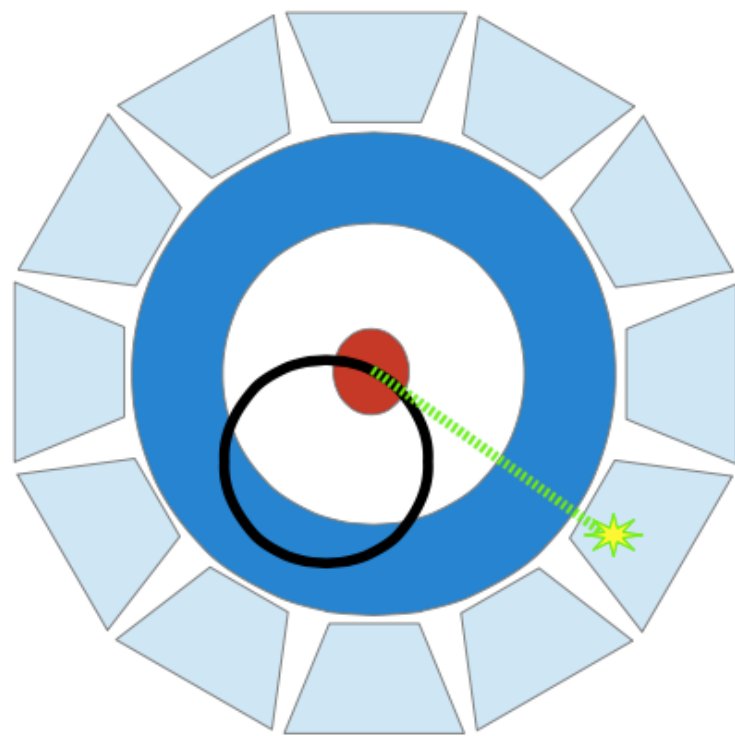
DOMINANT



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

# Future $\mu \rightarrow e \gamma$ searches

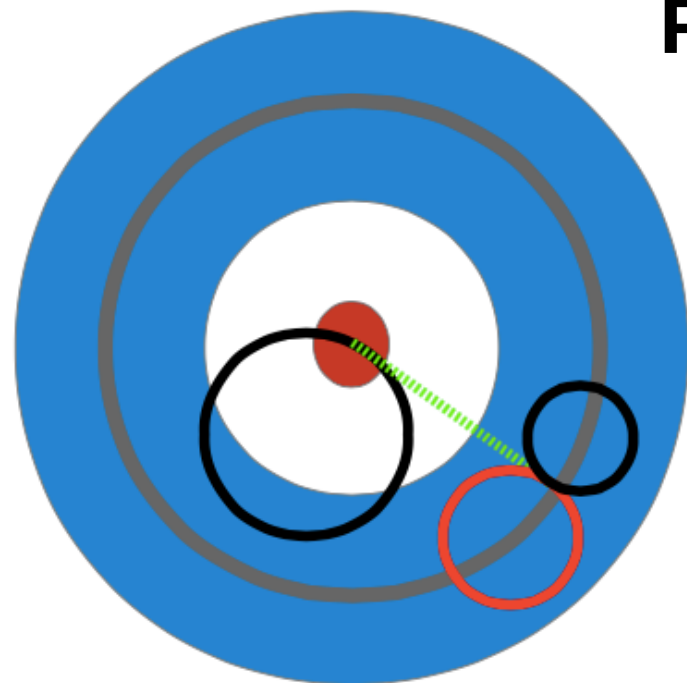
FR, W. Ootani



## Calorimetry

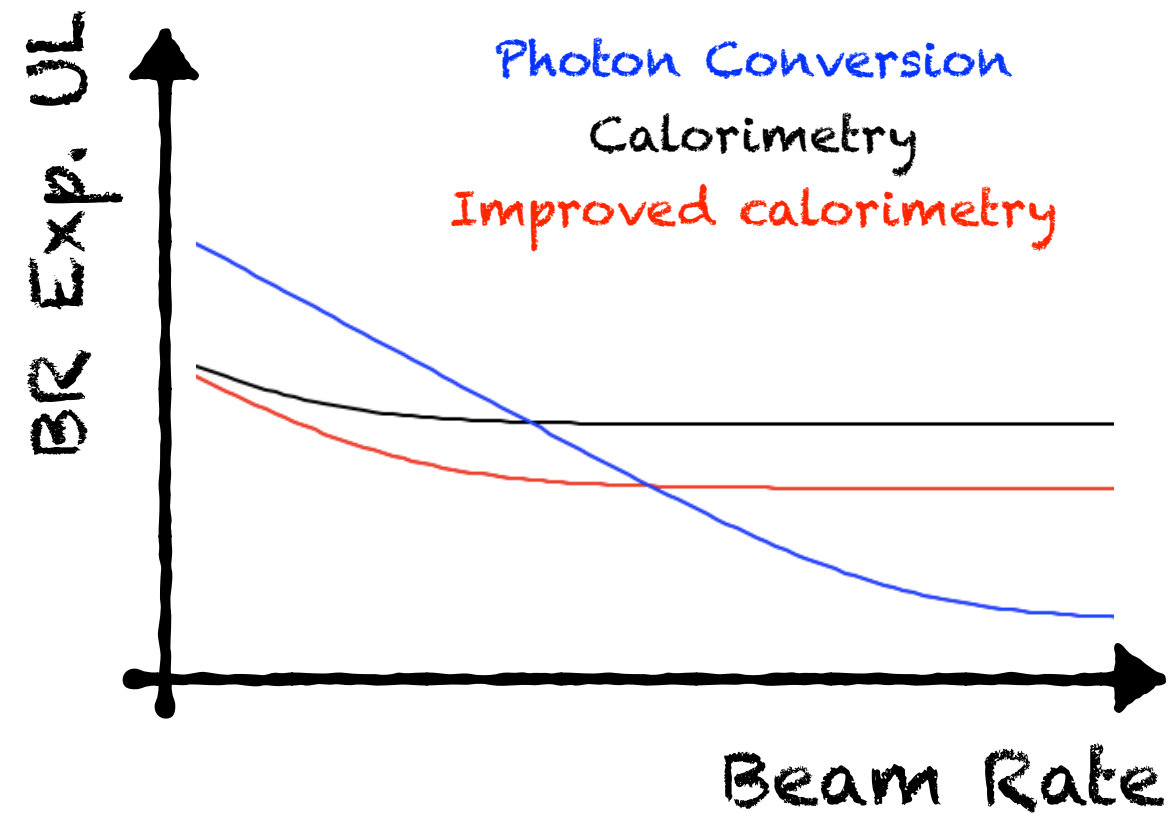
High efficiency  
Good resolutions

*MEG:*  
*LXe calorimeter*  
*10% acceptance*

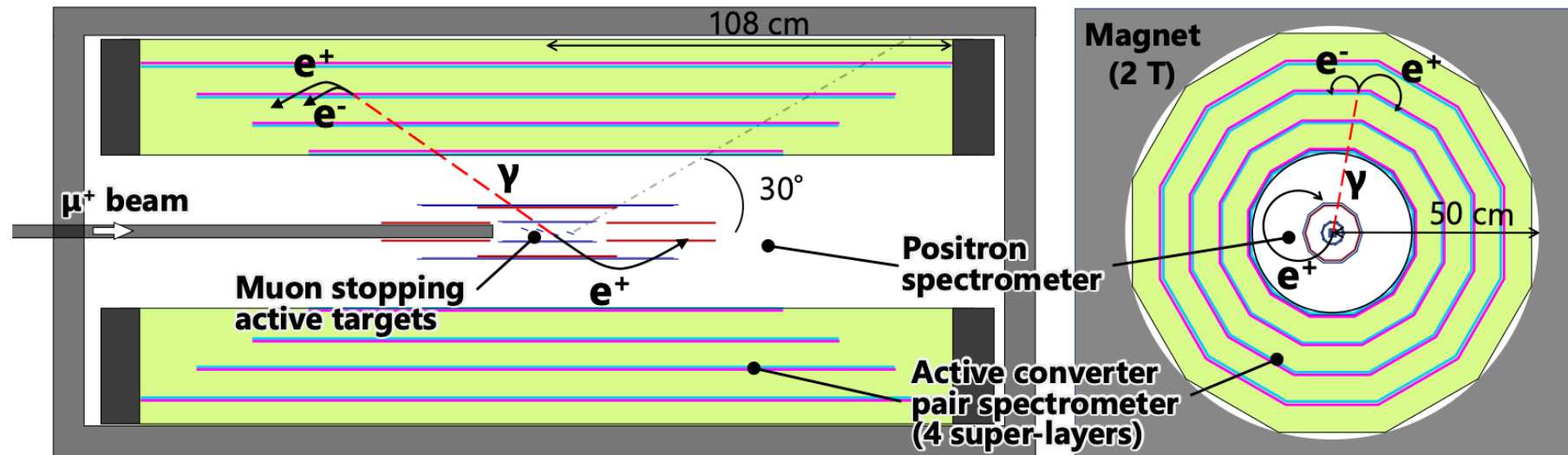


## Photon Conversion

Low efficiency ( $\sim \%$ )  
Extreme resolutions  
+  $e\gamma$  Vertex

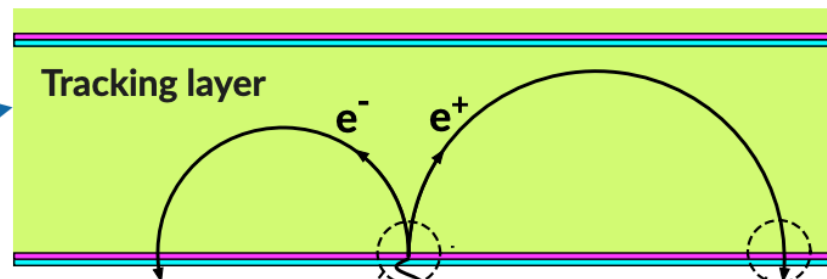


# Future $\mu \rightarrow e \gamma$ searches FR, W. Ootani



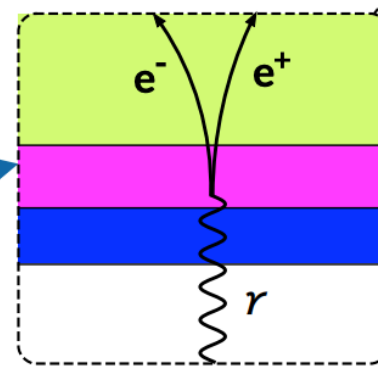
## Tracking layer

- Measure momentum of conversion pair
- Possible technologies
  - Drift chamber (a la MEG II CDCH)
  - Radial-TPC
  - Silicon detector



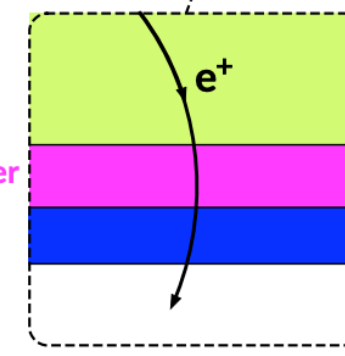
## Active conversion layer

- Thin active material to measure energy loss of conversion pair
- Possible technologies
  - Scintillator + photo-detector
  - Silicon detector



Energy loss measurement

Active converter  
Timing layer



Timing measurement

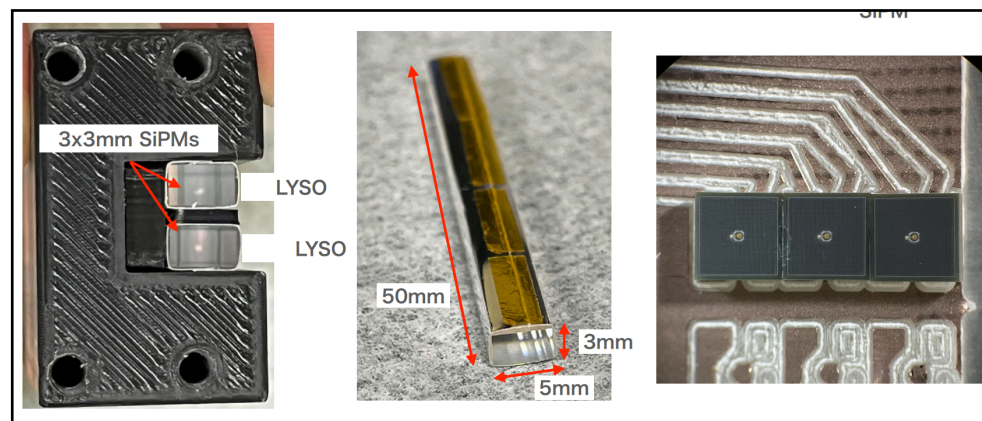
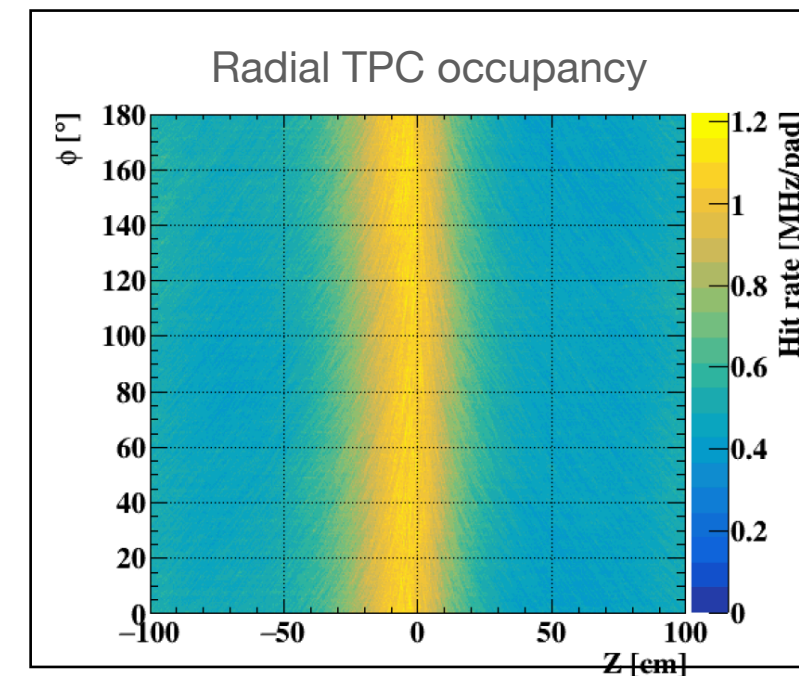
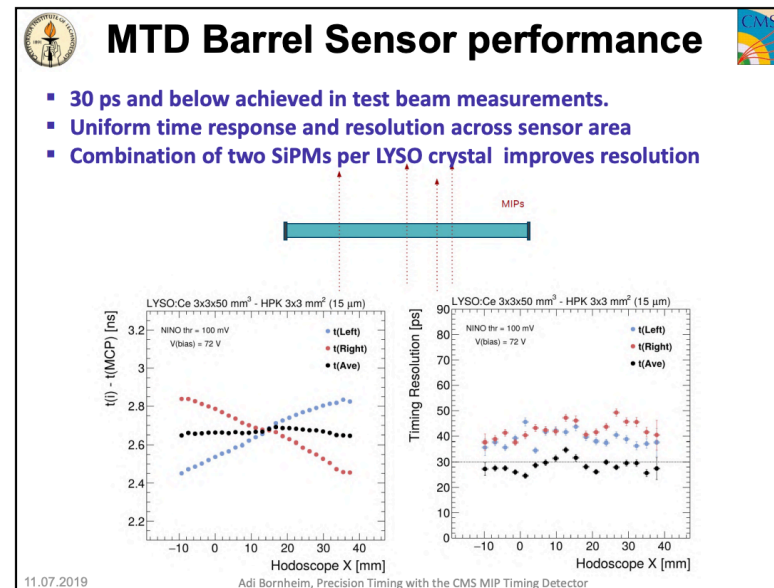
## Timing layer

- Measure timing of returning conversion pair
- in front of active converter
- Possible technologies
  - Multi-layer RPC (mRPC)
  - Active converter = timing detector

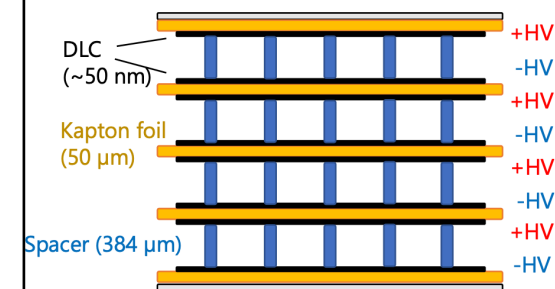


# Future $\mu \rightarrow e \gamma$ searches FR, W. Ootani

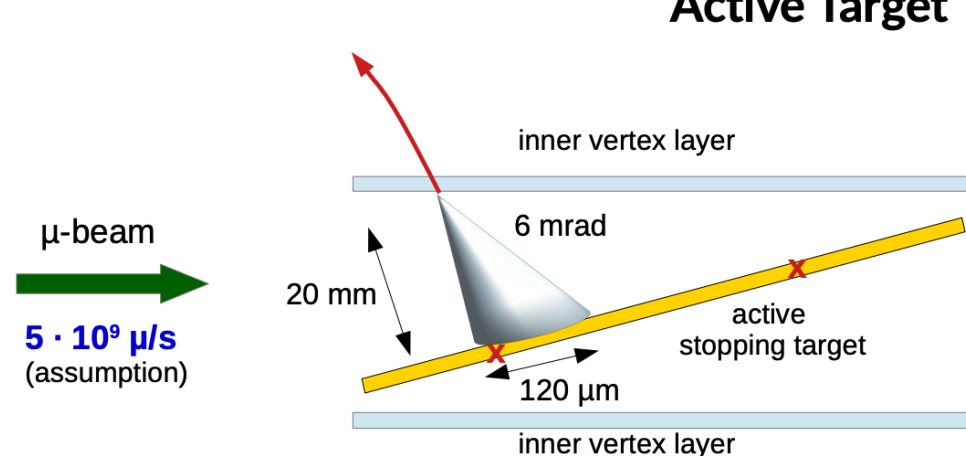
Crystal	NaI	LYSO(Ce)	LaBr <sub>3</sub> (Ce)	YAP(Ce)	Plastic scintillator	Silicon
Density [g/cm <sup>3</sup> ]	3.7	7.4	5.1	5.4	1.0	2.3
Light yield (relative to NaI)	100%	75%	160%	70%	30%	-
Peak Emission [nm]	415	420	380	370	400	-
Decay time [ns]	230	40	16	27	2-4	-
Radiation length [cm]	2.6	1.1	1.9	2.7	43	9.4
Critical energy* [MeV]	13	12	12	23	93	39
Hygroscopicity	Yes	No	Yes	No	No	-



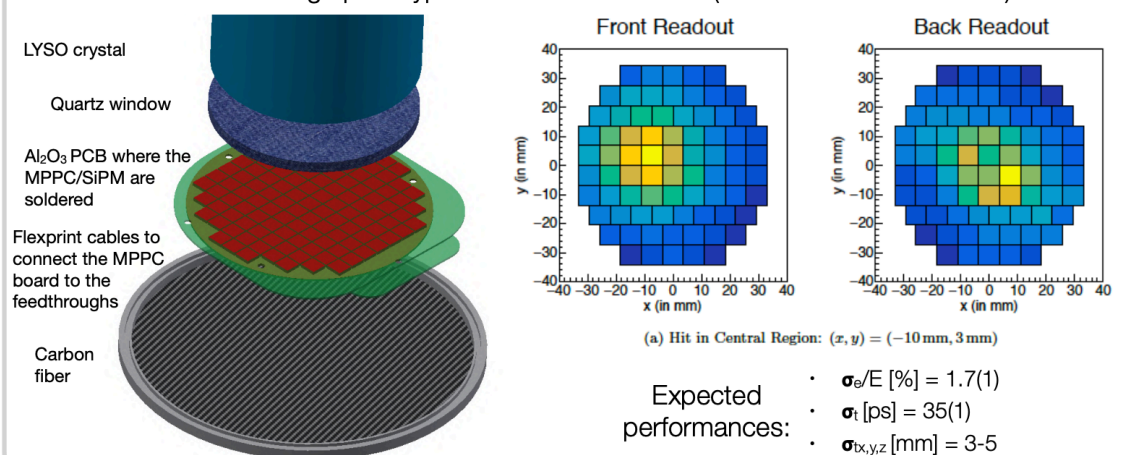
## Multi-layer DLC-RPC (MEG II)



## Active Target



The first large prototype is under construction (D = 7 cm and L = 16 cm)



# Take-home messages

- Within the next couple of decades we'll have a lot of muons and we'll have a lot of muon decay studies to do with them
- Effort needed to have the best detectors for this kind of physics
  - $\mu \rightarrow e \gamma$  detector concept to be redesigned, some ideas but nothing written in stone
  - merging multiple channels into the same detector concept would be beneficial under many points of view
- A lot of room for new ideas, new detector R&Ds, new collaborations