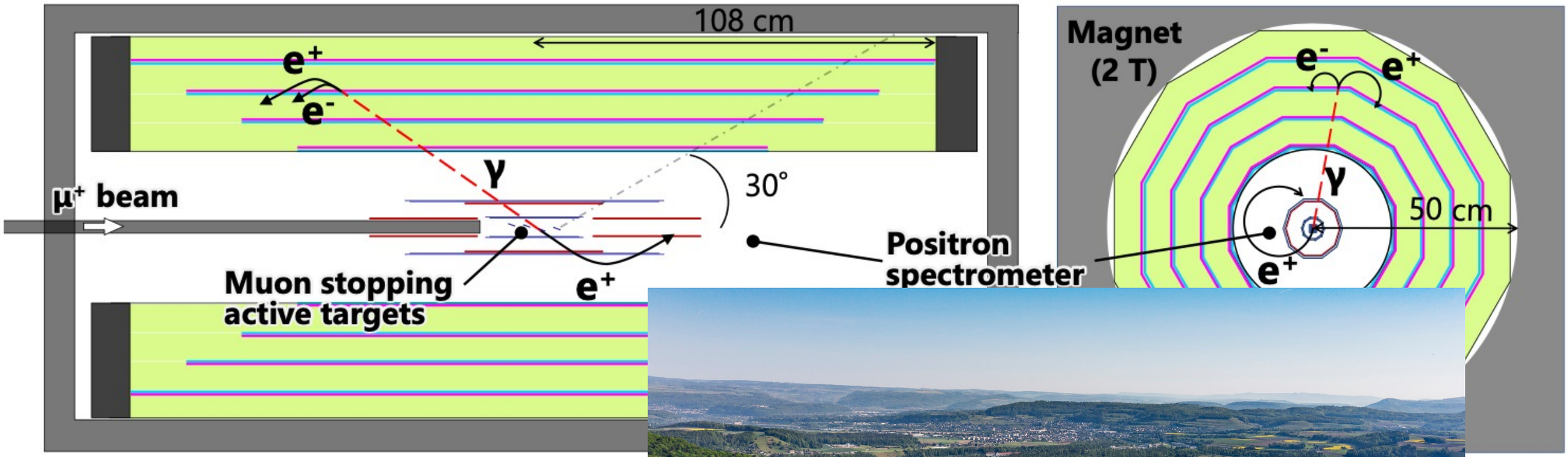






Toward a future μ⁺→e⁺ γ Experiment at PSI

DISCRETE 2026

Nov 13 – 17, 2026
Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava
Europe/Bratislava timezone

Paolo Walter Cattaneo
INFN Pavia

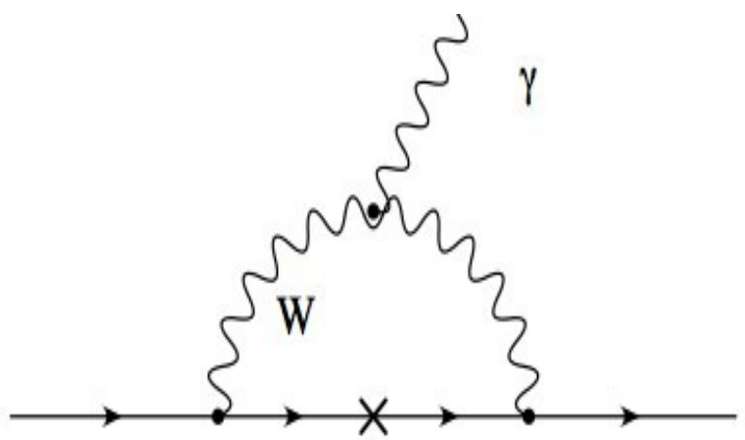
Istituto Nazionale di Fisica Nucleare

Charged lepton flavor violation (CLFV)

- One of the most powerful probes to search for New Physics (NP)
- The conservation of the lepton flavor is an accidental symmetry in SM
  - arising from the absence of right-handed neutrinos
- This symmetry is typically lost in NP models
  - CLFV is predicted at the level of the current experimental sensitivities
- Discovery of neutrino oscillations demonstrated this symmetry is not exact
  - Not sufficient to give observable cLFV effects
  - Their existence further stimulates the search for cLFV

Charged lepton flavor violation in Standard Model (with ν mass) vs new physics

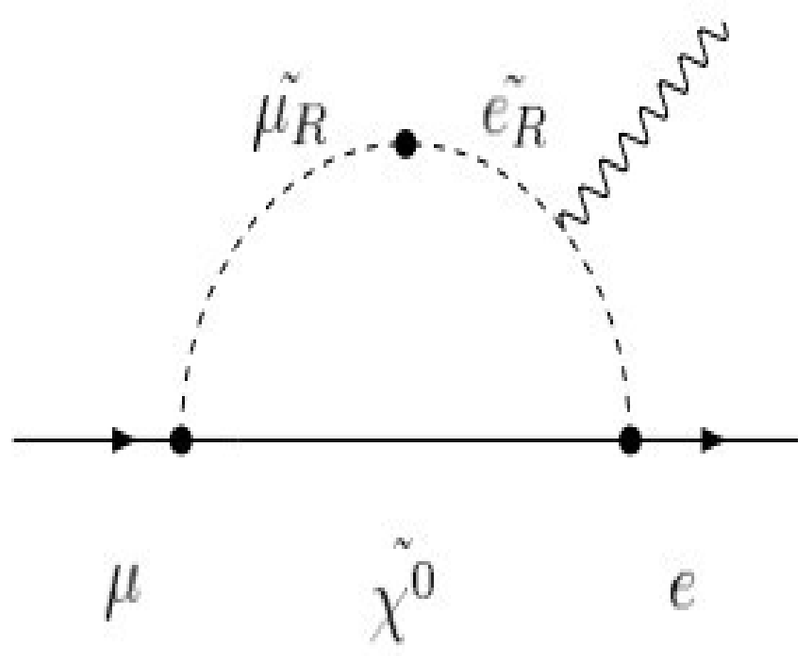
Charged lepton flavor transition has never been observed yet



$$\mathrm{BR}(\mu \to e\gamma) \simeq \frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu\bar{\nu})} = \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} \frac{U_{\mu k} U_{ek}^* m_{\nu_k}^2}{M_W^2} \right|^2$$

$\sim 10^{-54}$

Neutrino is too light

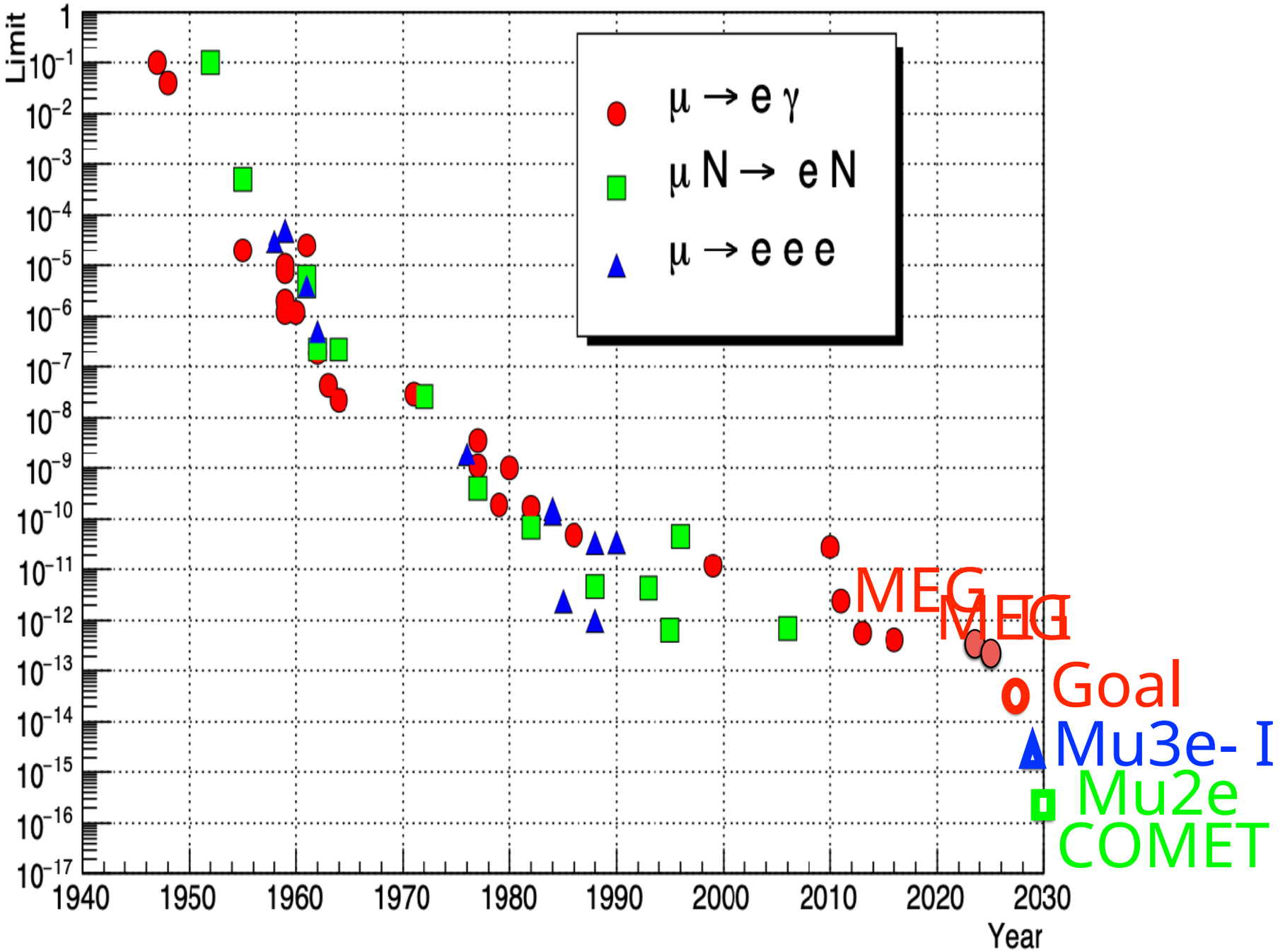


New particles from SUSY in the loop can enhance the branching ratio $10^{-(12\text{--}14)}$

SUSY-GUT / SUSY-seesaw

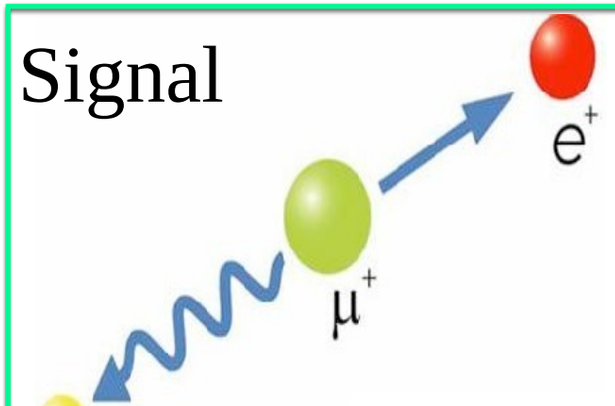
Evidence of $\mu^+ \to e^+\gamma$ = Evidence of new physics

$\mu^+ \to e^+\gamma$, $\mu^+ \to e^+e^-e^+$ $\mu^-\mathrm{N} \to e^-N$



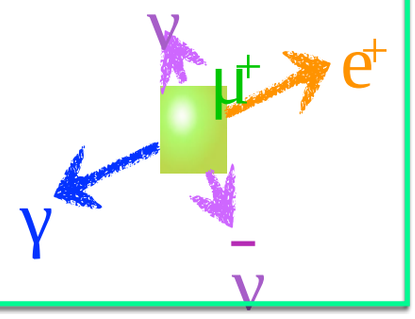
$\mu^+ \to e^+\gamma$ signal and backgrounds

Signal

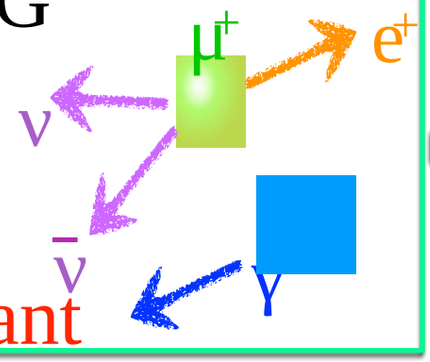


$E_\gamma, E_e = 52.8\text{MeV}$
$\Theta_{e\gamma} = 180, T_{e\gamma} = 0$

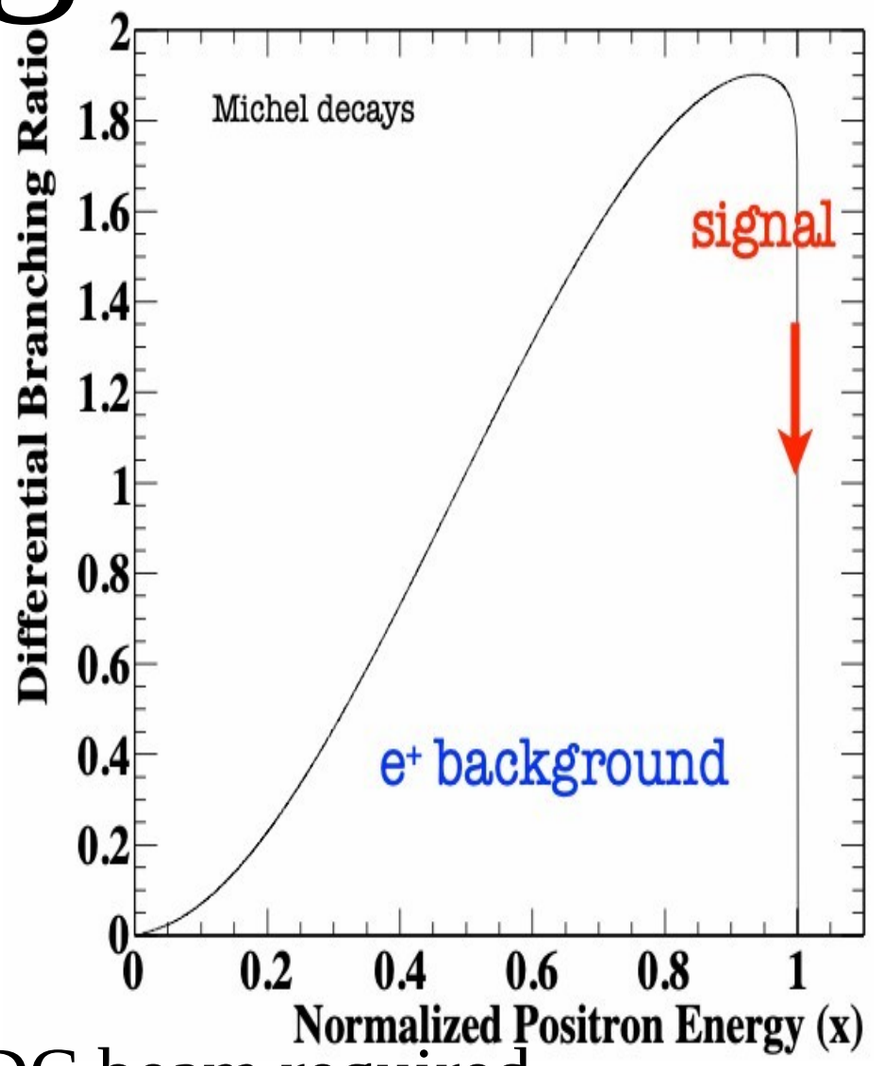
RMD BG

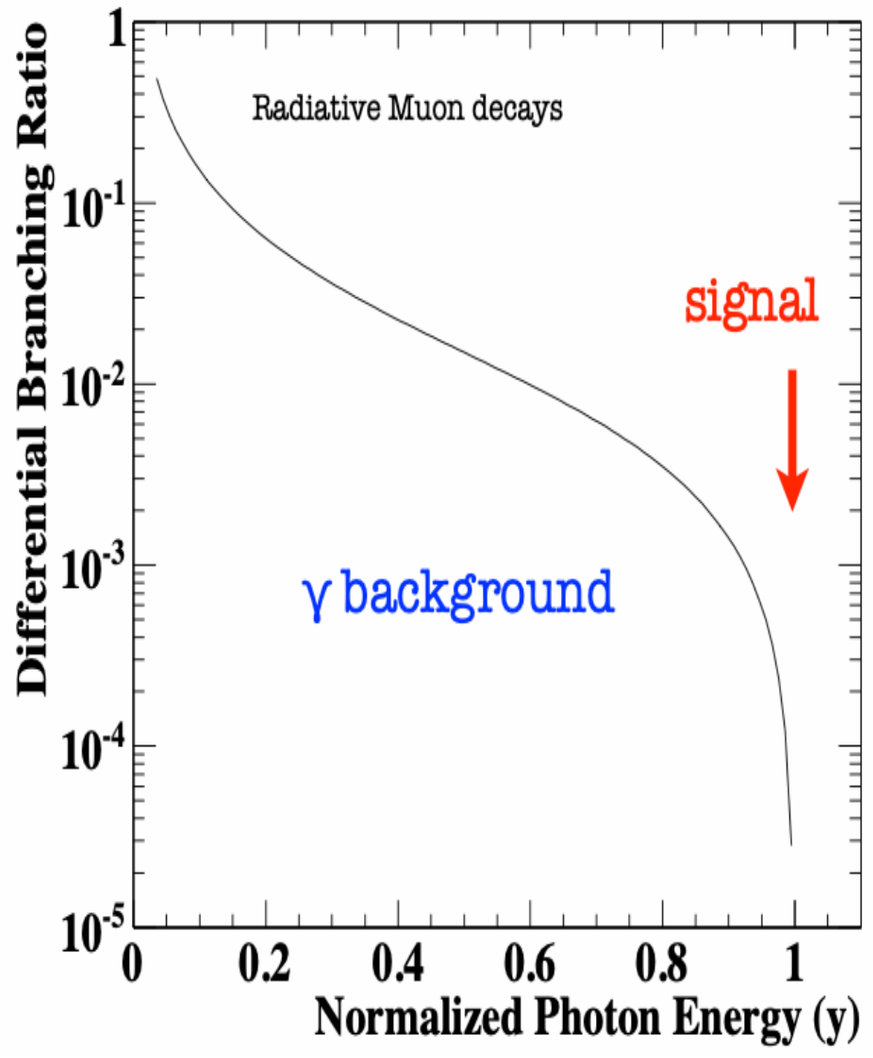


Acc BG



Dominant





DC beam required

$$N_{Sig} \propto R_\mu \times T \times Br(\mu \to e\gamma) \times \varepsilon$$

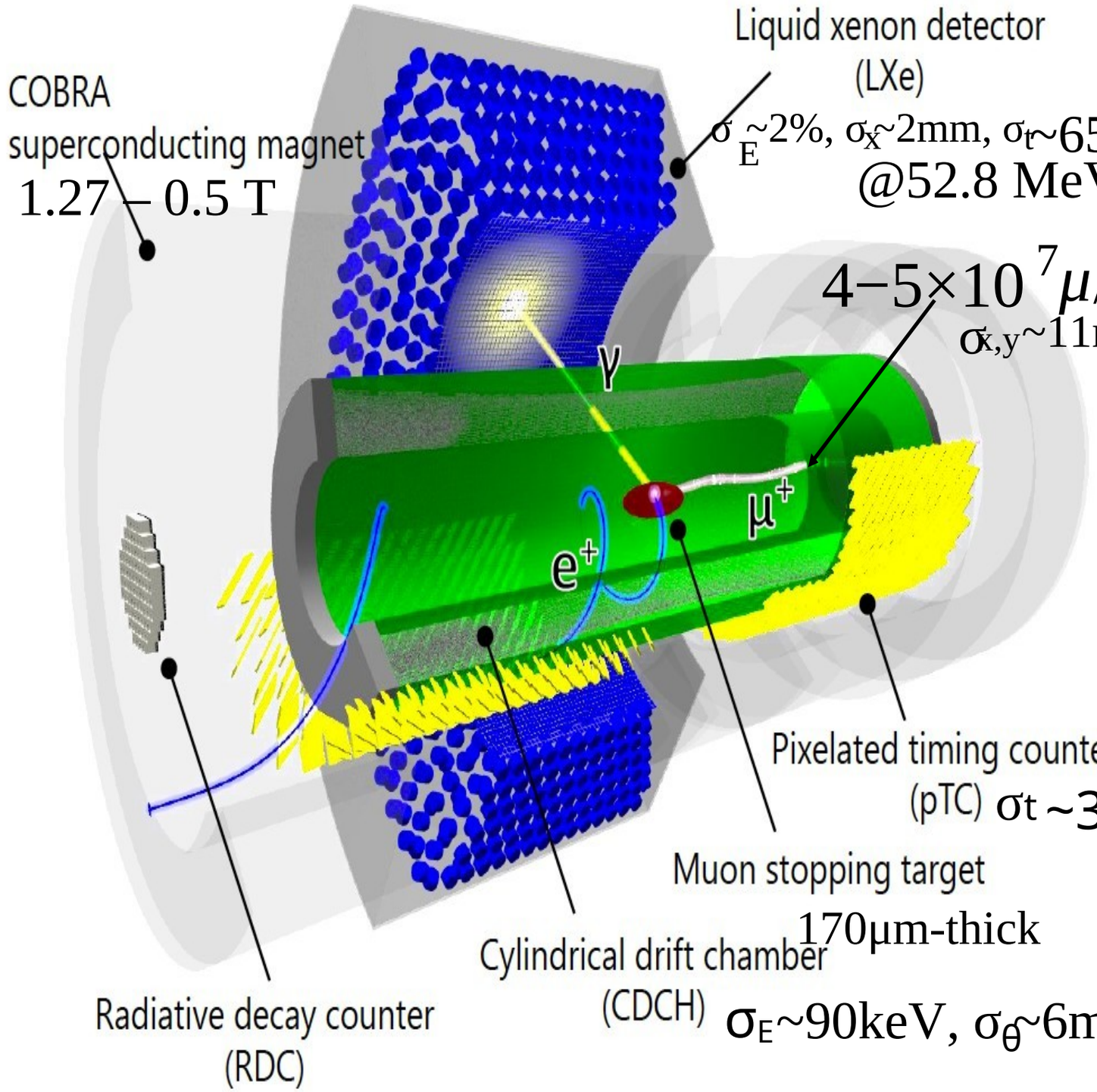
Effciency crucial for statistics

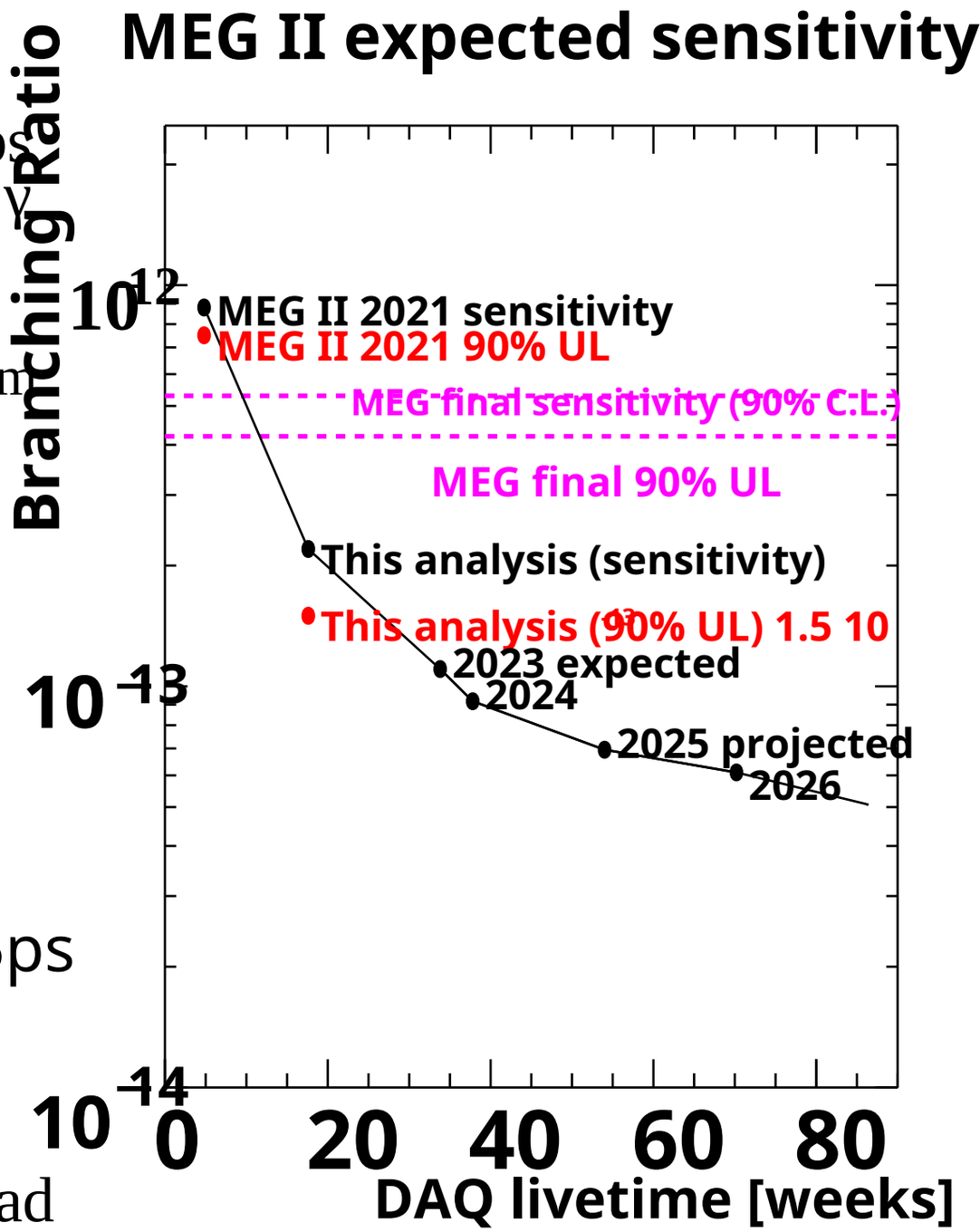
$$N_{BG} \propto R_\mu^2 \times \Delta E_\gamma^2 \times \Delta E_e \times \Delta \Theta_{e\gamma}^2 \times \Delta t_{e\gamma} \times T$$

Good resolution crucial to lower the accidental Background (BG)

Beam rate Resolutions Elapsed time

Current running experiment





https://arxiv.org/abs/2504.15711

Physics motivation

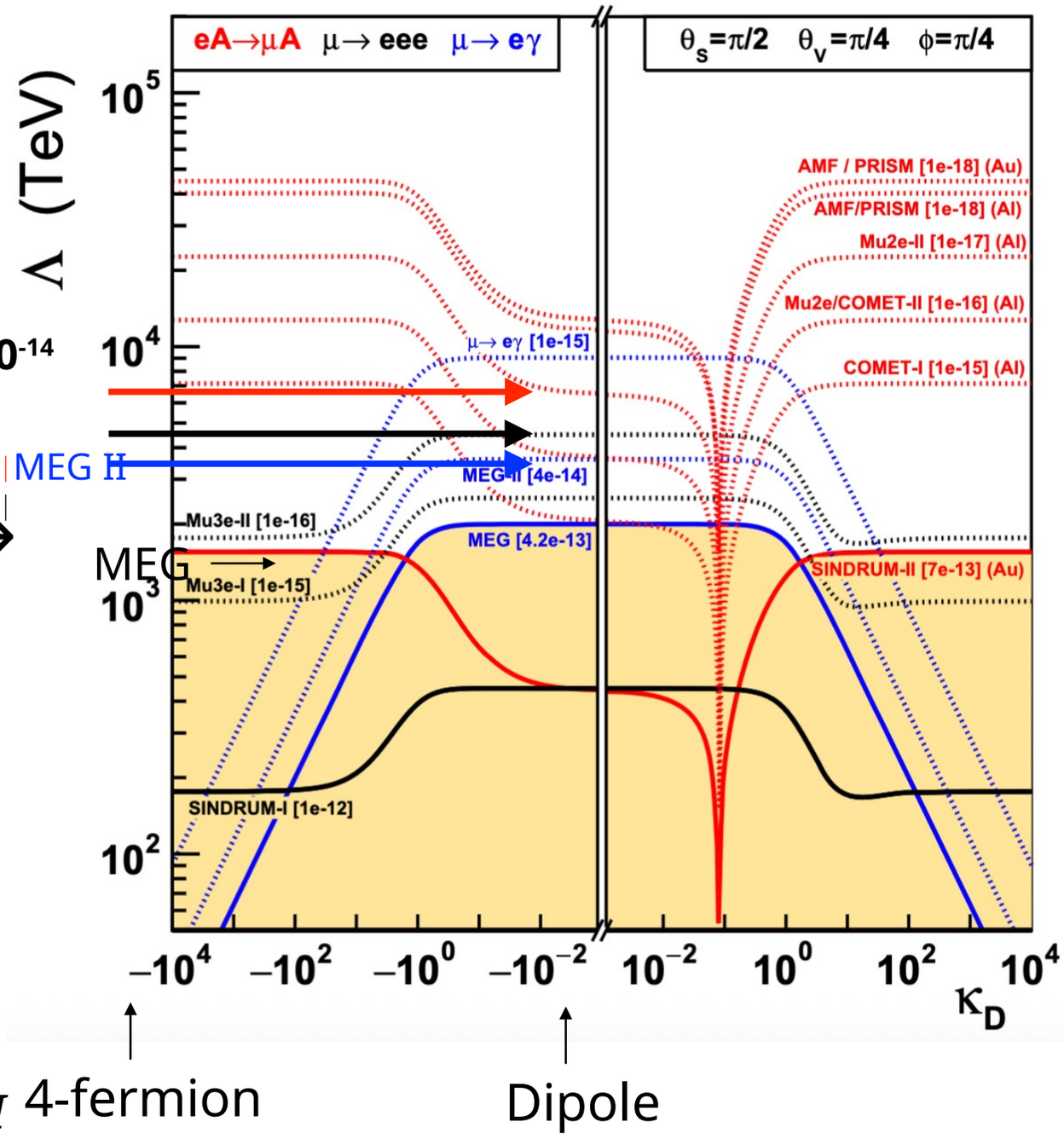
- 3 cLFV golden channels in the muon sector
  - μ e γ (**MEG II**), μ -> 3e (**Mu3e**), and μ -> e conversion in nuclear fields (**Mu2e/COMET**)

Current limit from **MEGII** on **Br(μ →e γ) < 1.5 x 10^{-13}**
Final expected sensitivity (end data taking 2026) **~5-6 x10^{-14}**

- In EFT, muon cLFV takes contributions from several different operators
  - complementarity of all channels
  - making progress in each one, and with comparable sensitivities, is critical to **increase the discovery potential and allow model discrimination** if a signal is observed

- *Building on MEGII expertise we have a unique know-how to be exploited to target*

BR(μ→e γ)~O(10^{-15}) > *x20 better than MEG II*



https://arxiv.org/abs/2504.18831

HiMB @ PSI and the future of μ → e γ

The PSI muon beam lines will be upgraded during the 2028-2029 long Shutdown up to 10^{10} μ^+/s (100x increase)

A μ→e γ experiment at 10^9 -10^{10} μ^+/s requires a drastic redesign of the apparatus.

Sensitivity in μ→e γ searches saturates at increasing beam intensity, due to the accidental background (MEG II optimal beam rate ~ 5 x 10^7 μ^+/s)

- $$B_{acc} = R_\mu \cdot \delta t_{e\gamma} \cdot \delta x \cdot (\frac{\delta y}{15})^2 \cdot (\frac{\delta \theta_{e\gamma}}{2})^2 \cdot f(\theta_\gamma)$$

  ➡️ **Improve the resolutions, to stay in a almost zero-background status!**

- A **Letter of Intent** was submitted to the PSI scientific committee for a new experiment aiming at **x20 better sensitivity than MEG II**
  - keep outstanding positron resolutions in a x 20-100 higher rate environment
  - strongly improve photon resolutions with alternative detection technique

2504.18831 [hep-ex]

Mostly from MEGII and Mu3e, open to additional groups

LETTER OF INTENT
for a future $\mu^+ \to e^+\gamma$ experiment
at the High Intensity Muon Beam facility at PSI

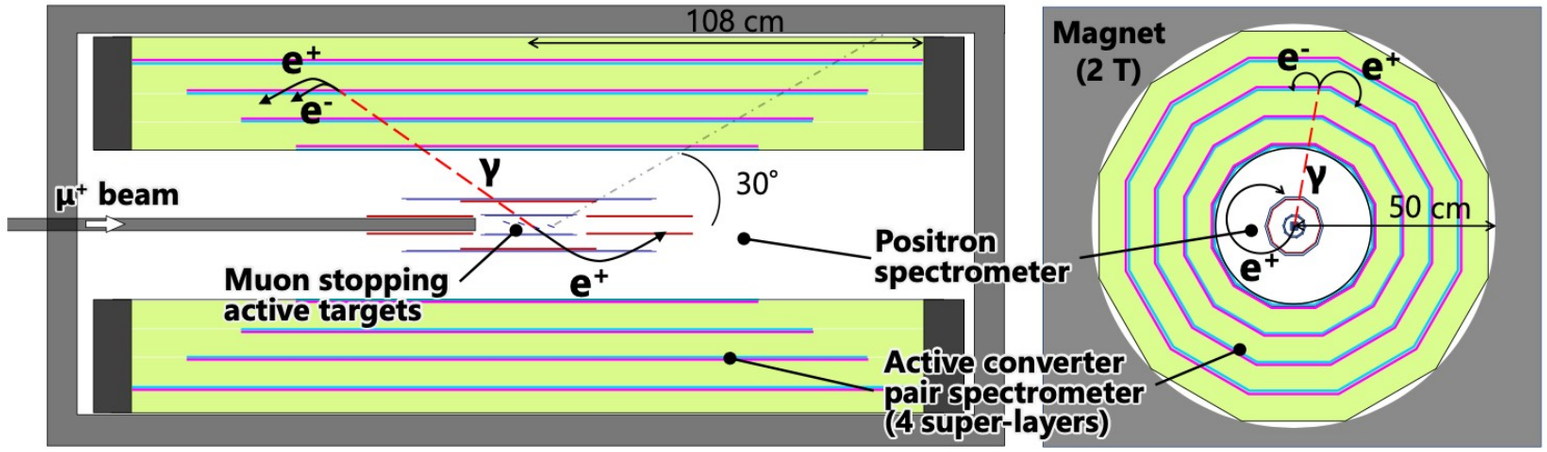
THE STUDY GROUP FOR FUTURE $\mu^+ \to e^+\gamma$ EXPERIMENTS

Paolo Walter Cattaneo,[1*] Wataru Ootani,[2*] Francesco Renga,[3a*] André Schöning,[4*] Heiko Augustin,[4] Haris Avudaiyappan,[5] Sei Ban,[2] Paolo Beltrame,[6] Hicham Benmansour,[7ab] Daniela Bortoletto,[8] Alessandro Bravar,[9] Gianluca Cavoto,[3ab] Marco Chiappini,[7a] Alessandro Corvaglia,[18a] Giovanni Dal Maso,[10] Sacha Davidson,[11] Matteo De Gerone,[12] Lorenzo Ferrari Barusso,[12] Marco Francesconi,[13] Luca Galli,[7a] Giovanni Gallucci,[7] Flavio Gatti,[12] Helen Hayward,[6] Gavin Hesketh,[14] Malte Hildebrandt,[15] Fumihito Ikeda,[2] Fedor Ignatov,[6] Toshiyuki Iwamoto,[2] Tamasi Kar,[4] Marius Köppel,[16] Francesco Leonetti,[7ab] Weiyuan Li,[2] Ashley McDougall,[8] Satoshi Mihara,[17] Toshinori Mori,[2] Ljiljana Morvaj,[15] Donato Nicolò,[7ab] Hajime Nishiguchi,[17] Hiroyasu Ogawa,[2] Atsushi Oya,[2] Angela Papa,[7ab,15] Marco Panareo,[18ab] Daniele Pasciuto,[3a] Davide Pinci,[3a] Richard Plackett,[8] Nikolaos Rompotis,[6] Massimo Rossella,[1] Thomas Rudzki,[4] Rei Sakakibara,[2] Susanna Scarpellini,[3ab] Taikan Suehara,[2] Hiromu Suzuki,[19] Masato Takahashi,[19] Michele Tammaro,[20] Gianfranco Tassielli,[18ac] Yusuke Uchiyama,[17] Ryusei Umakoshi,[2] Antoine Venturini,[7ab] Luigi Vigani,[4] Cecilia Voena,[3ab] Joost Vossebeld,[6] Rainer Wallny,[16] Kensuke Yamamoto,[2] Yuji Yamazaki[19]

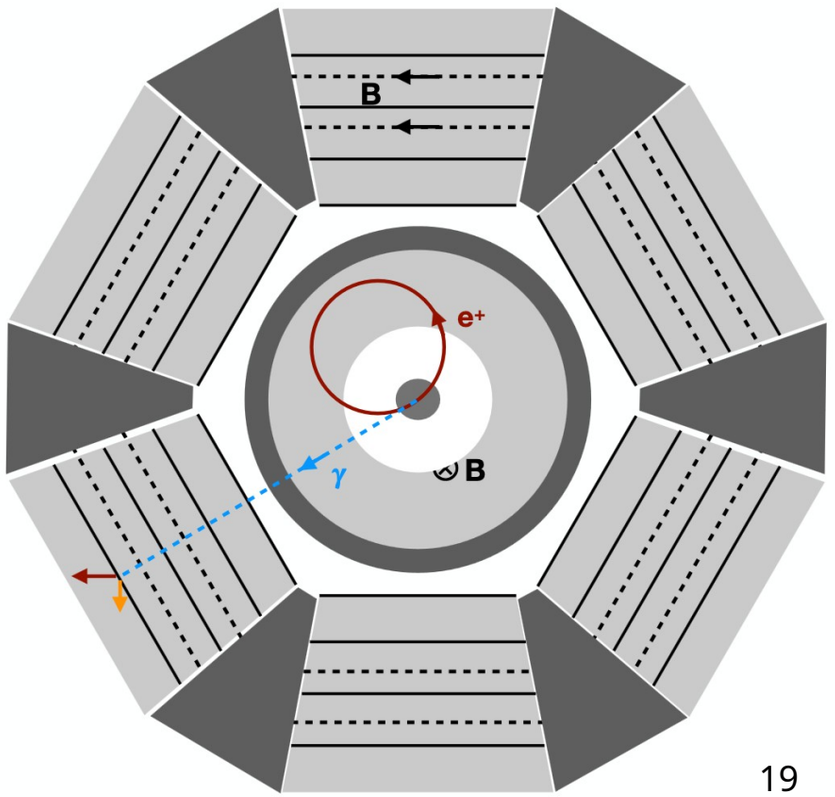
31v3 [hep-ex] 24 Feb 2026

Possible magnetic configuration

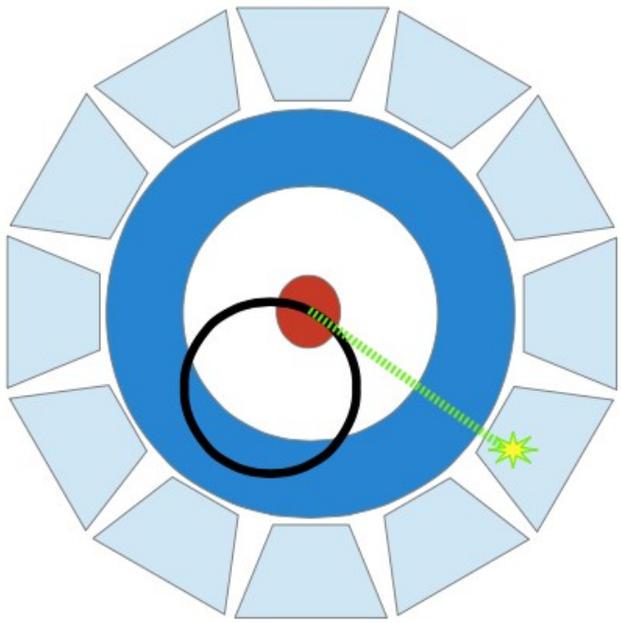
- Everything in a single solenoid
  - standard and well understood configuration
  - low material budget in front of the photon detector ⟶ maximum efficiency and acceptance



- Alternative design, with inner solenoid (for e+) + external toroid (for e^+-e^-)
  - relax geometrical constraints (e.g. planar TPCs), to optimize the separate fields for different tasks and simplify the technical design
  - achievable inner solenoid transparency to photons under investigation



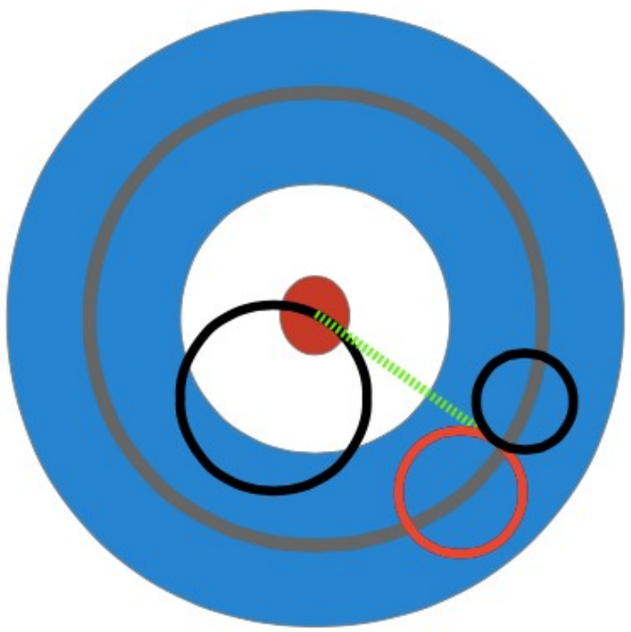
Toward the next generation of μ → e γ searches: Photon Reconstruction



Calorimetry

High efficiency
Good resolutions

MEG II:
LXe calorimeter
10% acceptance



Photon Conversion

Low efficiency (~ %)
Extreme resolutions
+ eγ Vertex

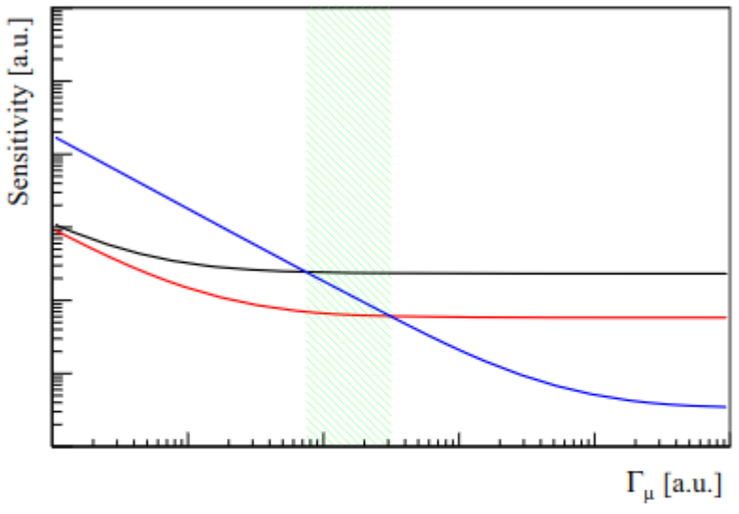
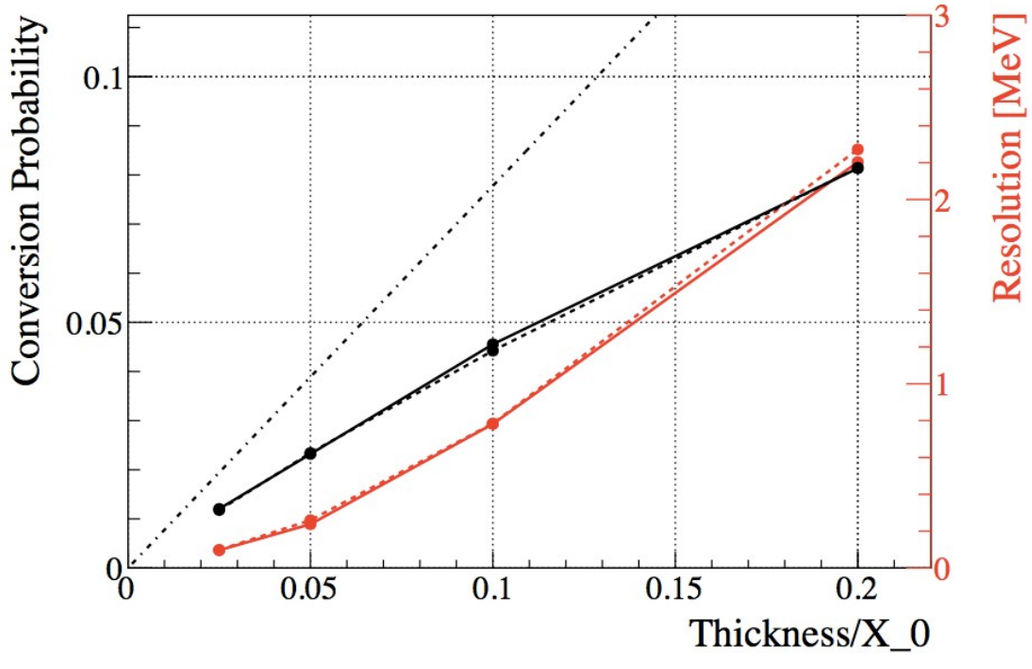


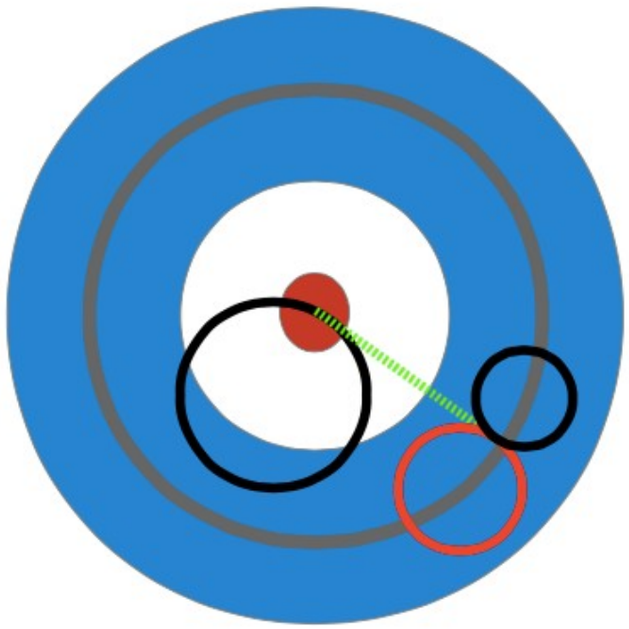
Fig. 2 Sensitivity trends as a function of the beam intensity, for a calorimetry-based design (black), a photon-conversion-based design with unchanged positron resolutions (blue) and a calorimetry-based design with a factor two improvement in resolutions (red). See the text for a detailed description

With passive converter +e^+e^- tracker, resolution is dominated by energy loss fluctuations in the converter.



G. Cavoto et al., EPJ C 78 (2018) 1, 37

Toward the next generation of μ → e γ searches: Photon Reconstruction

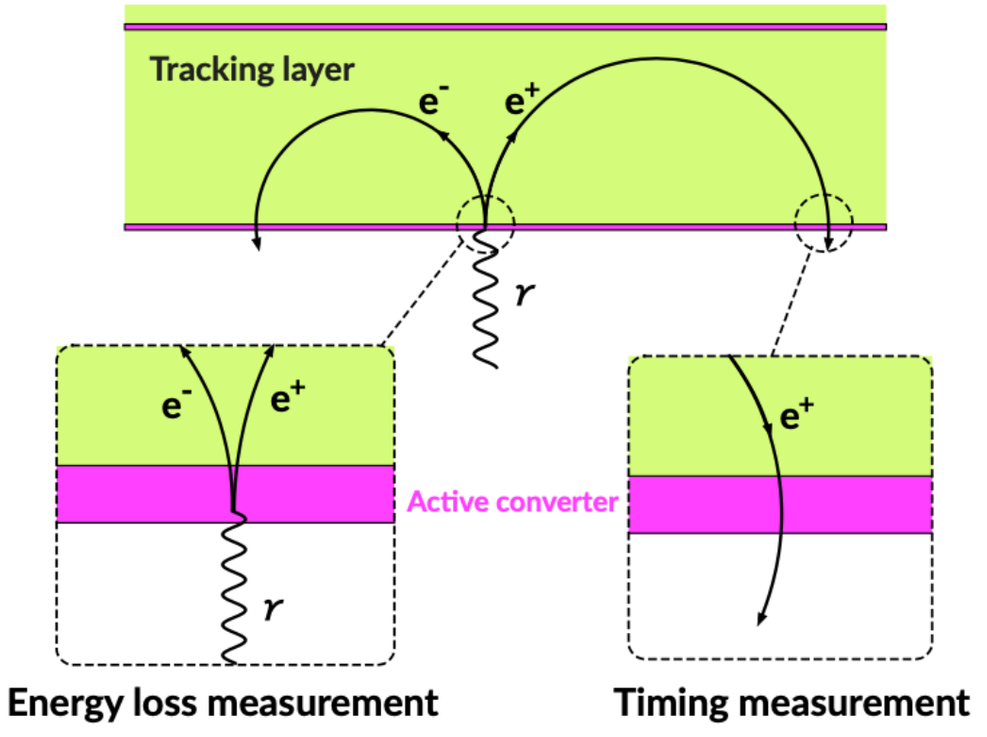


Photon Conversion

Low efficiency increased with multiple layers (3 → ~ 20%)

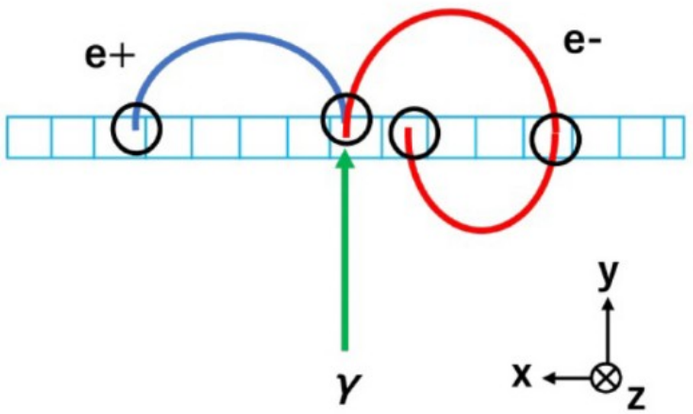
- Active converter (LYSO) to recov the energy loss

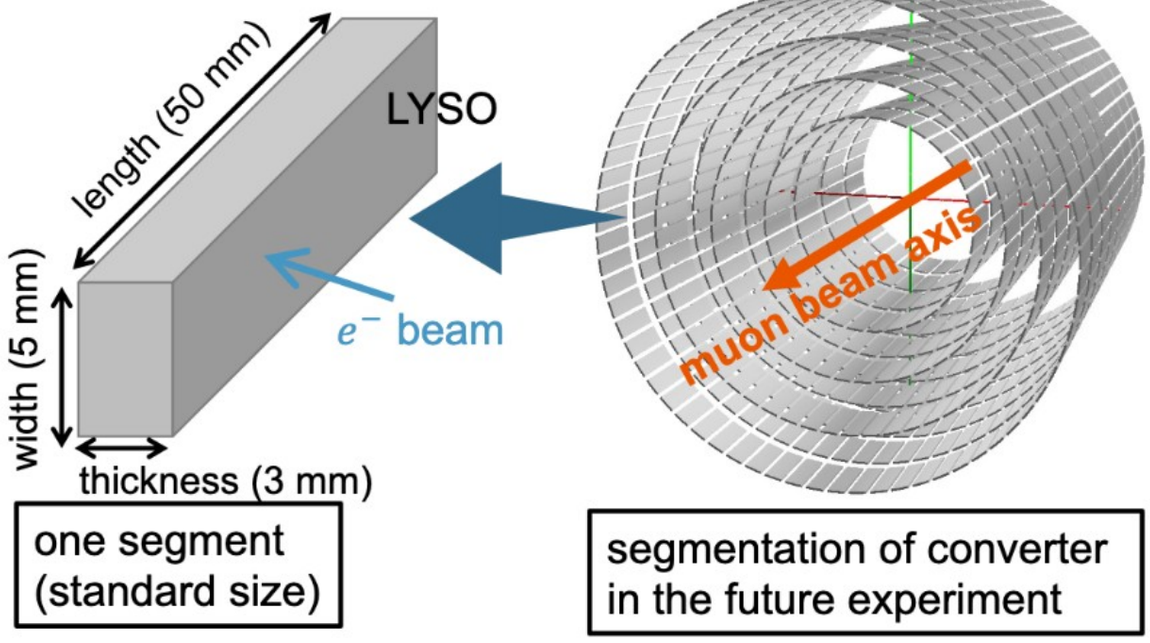
  ➡️ photon timing with the required resolution (< 40 ps)



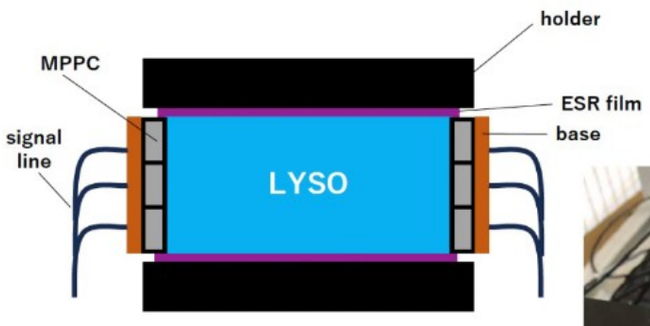
S. Ban et al., arxiv:2512.24209

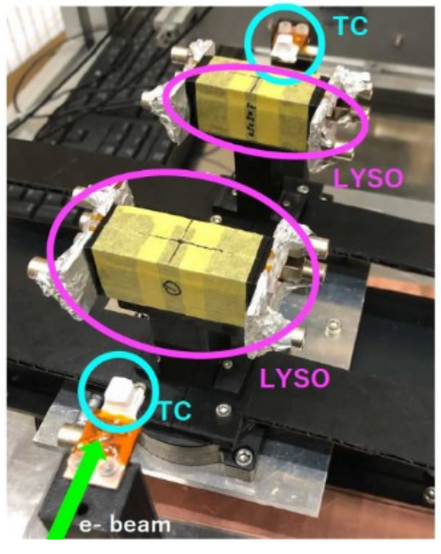
The LYSO crystal active converter: first beam test

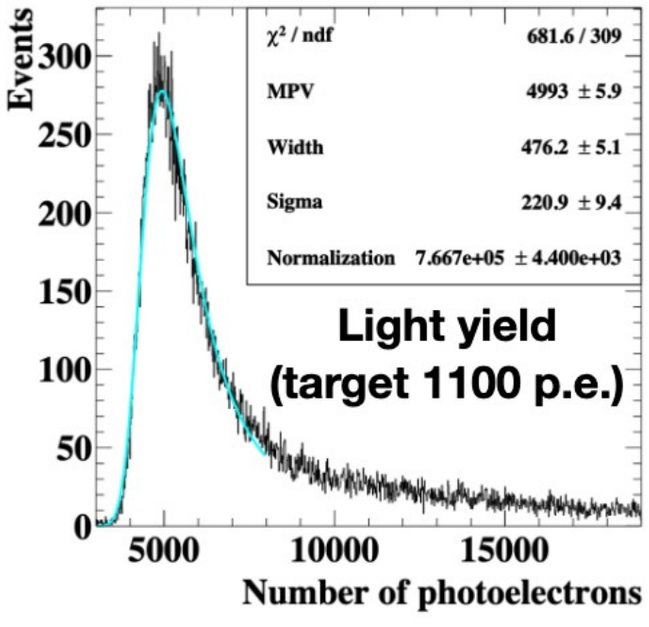


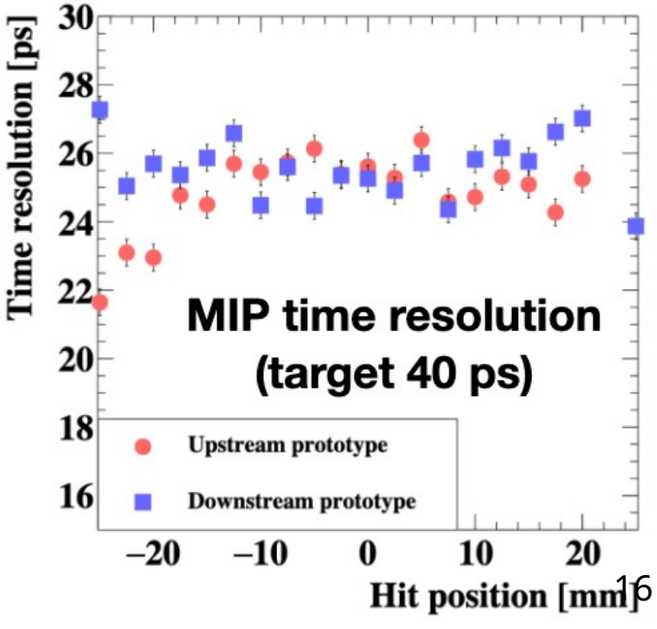


CONVERTER PROTOTYPE







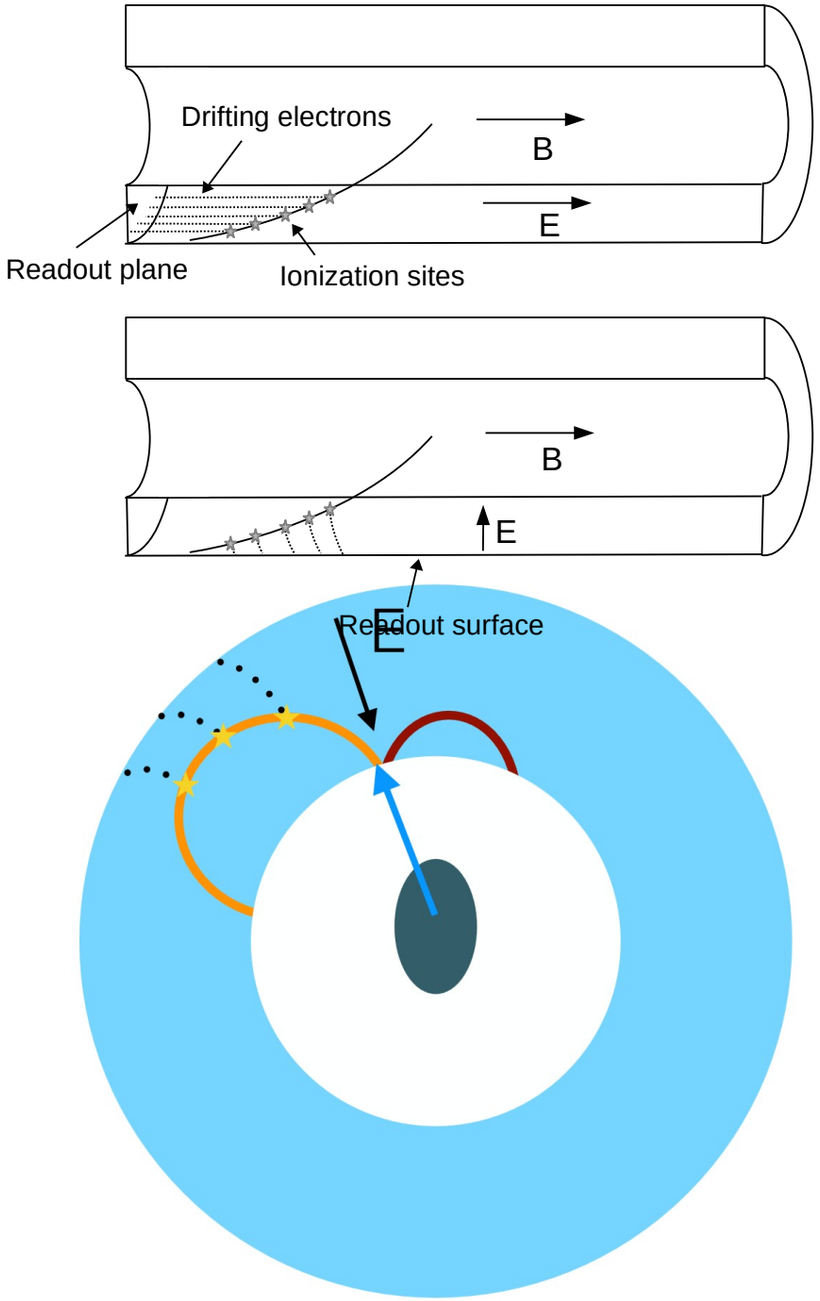


The e^+e^- tracker

- Pairs can be highly asymmetric in momentum

  ➡️ tracking momenta down to a few MeV with high efficiency and resolution

  ➡️ extremely light detector (avoid MS) with extreme granularity and resolution (reconstruct very low bending radii)



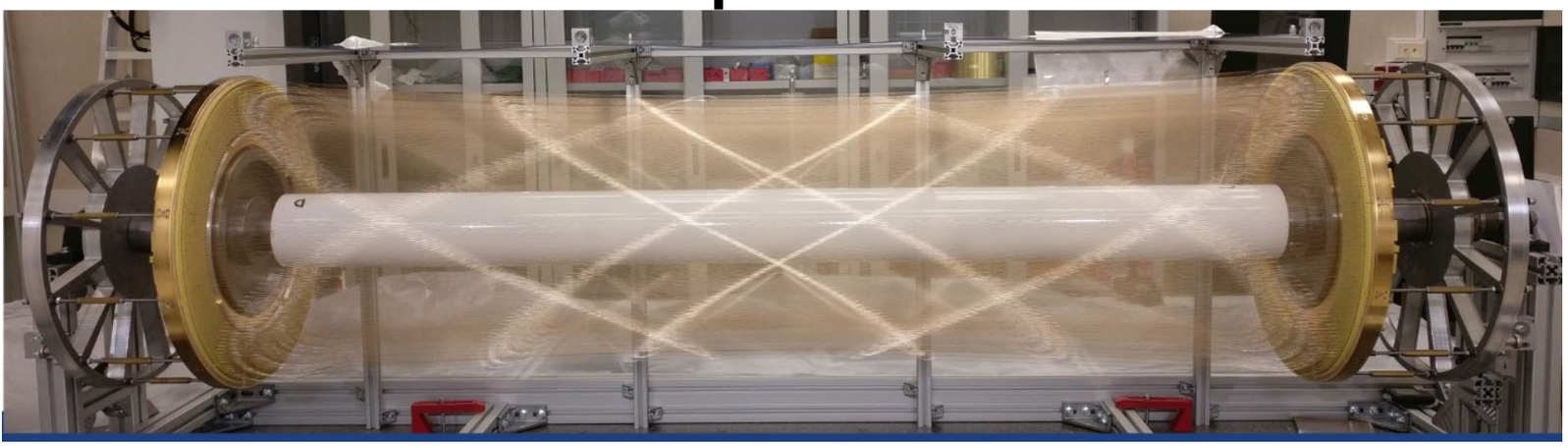
- Proposed solution:

  - Time Projection Chamber (TPC) possibly with **radial drift**

  ➡️ short drift, O(10 cm), can provide good resolution (i.e. low diffusion) also with very light, He-based gas mixtures

Toward the next generation of μ -> e γ searches: Tracking positrons at few 10^8 and $10^{9\text{-}10}$ μ^+/s

At ~ few $10^8 \mu^+/s$

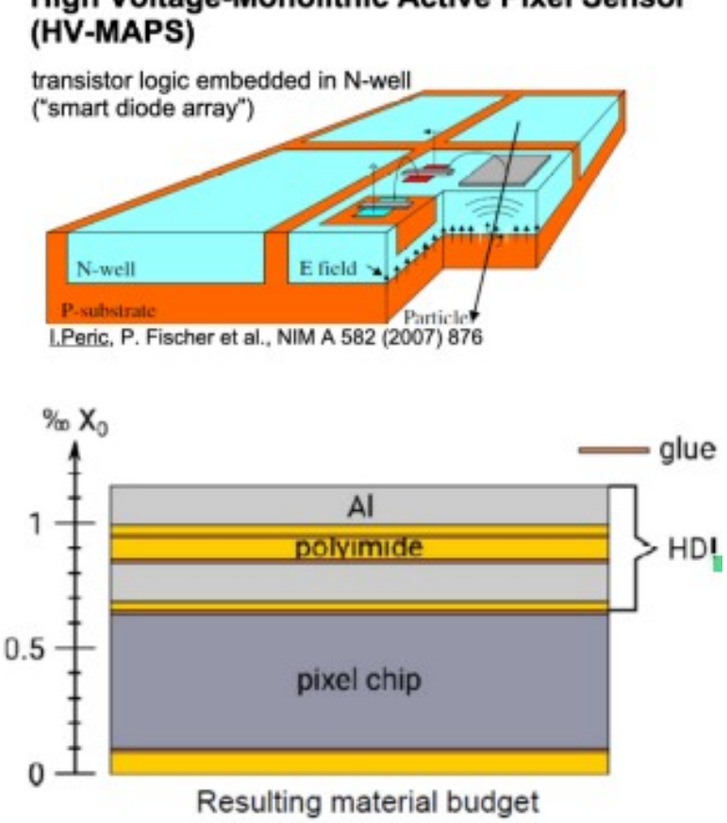


Reuse of the MEGII CDCH.
High rate test done in October.

Effect of a high integrated dose to be considered

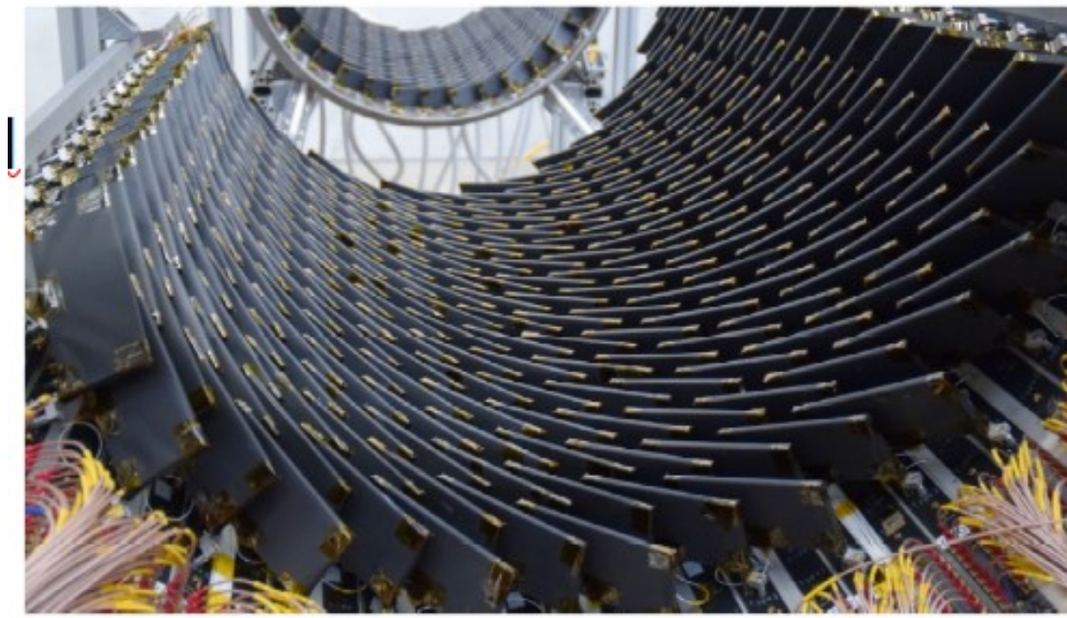
Above $10^9 \mu^+/s$

- Monolithic silicon pixels (HV-MAPS) guarantee the necessary granularity and high-rate tolerance, keeping the material budget very low
- Progress in this directions by Mu3e
  - production chips with ~0.1% X_0 now available

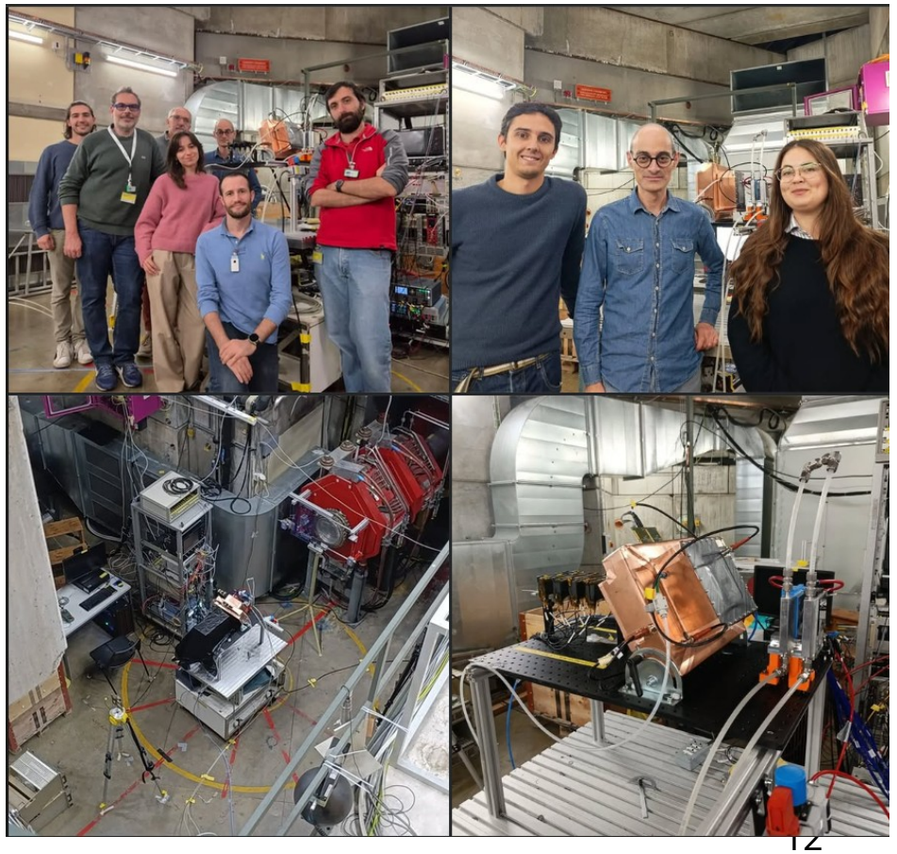


Toward the next generation of μ → e γ searches: Positron Timing

- Scintillating tiles readout by SIPMs as in MEGII guarantee the required timing performances
- Tiles with reduced size to handle higher occupancies
- Larger area SiPMs and smaller tiles to improve light collection
- Radiation hardness could be a challenge



In October several configurations of tiles readout by SiPMs were tested at PSI with radioactive sources and with e^+ and μ^+ beams.
Analysis is ongoing and will be released soon.



Simulation and Performance

	Resolutions/efficiencies
Photon energy	200 keV
Photon position	200 μm
Photon timing	30 ps
Photon angle	150 mrad
Photon detection efficiency (4 layers)	10 %
Positron energy	100 keV
Positron angle	6 mrad
Positron timing	30 ps
Positron detection efficiency	70 %
Geometrical acceptance	85 % (36 %)

MEG II

Resolutions	
E_{e+} (keV)	89
ϕ_{e+}, θ_{e+} (mrad)	5.2/6.2
y_{e+}, z_{e+} (mm)	0.61/1.76
E_γ(%) (w_γ<2 cm)/(w_γ>2 cm)	2.4(2.1)/1.9(1.8)
$u_\gamma, v_\gamma, w_\gamma$ (mm)	2.5/2.5/5.0
$t_{e+\gamma}$ (ps)	78
Efficiencies (%)	
ε_γ	63
ε_{e+}	67
ε_{TRG}	91(88)

→ ~ 1 MeV

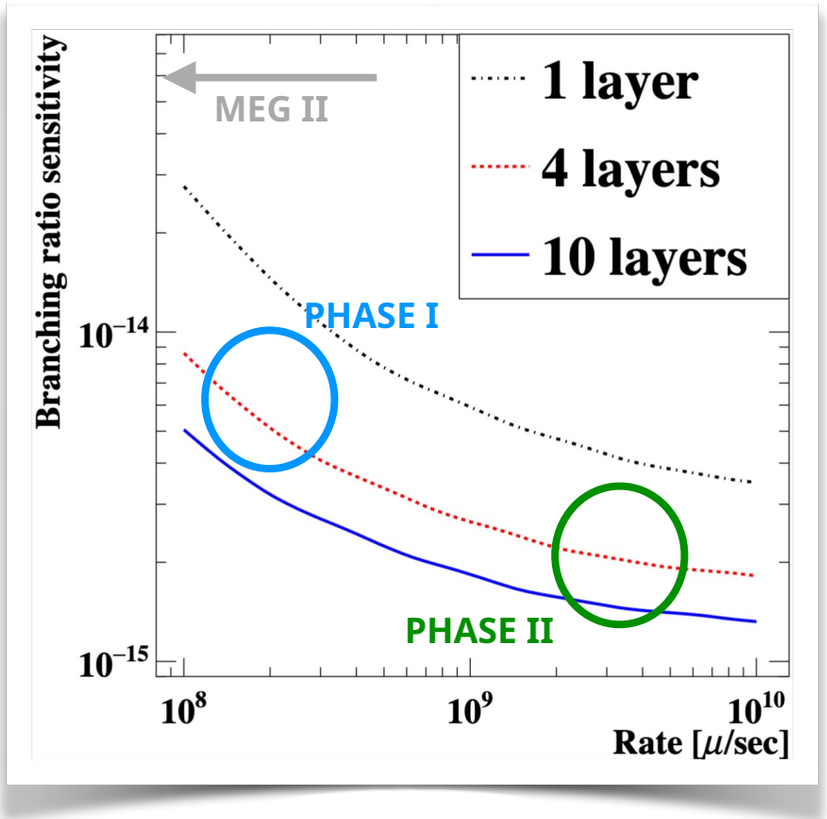
Tentative schedule

2016 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039

R&D and Design

Proof-of-Concept phase

Technology demonstration with small prototypes



Construction

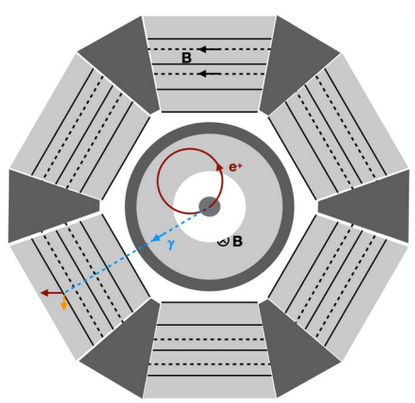
Run

Phase I Experiment

Low intensity (~ 2×10^{8} μ/s)

Reuse of MEG II Drift Chamber and Magnet for positron tracking

2-3 conversion layers



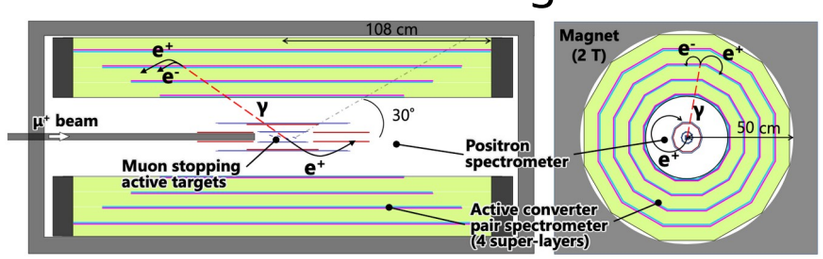
Construction

Run

Phase II Experiment

High intensity (10^{9} μ/s)

Silicon tracker and multiple conversion layers
Dedicated magnet



Conclusions

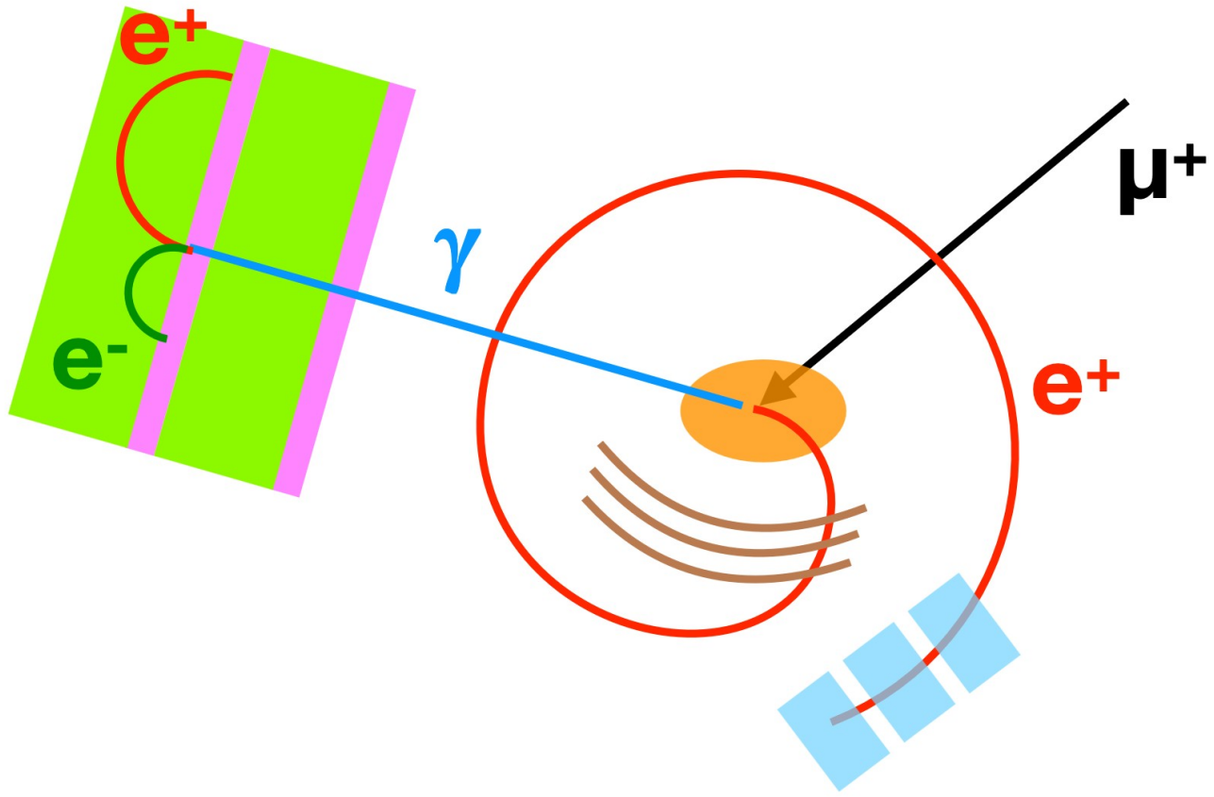
- HIMB at PSI, with **x100 higher muon beam intensity** available by the end of 2029, opens new perspectives for cLFV searches in muon decays

- A detector design with tracking for a high occupancy environment and photon detection with pair conversion could allow to fully exploit the highest available intensities for μ -> e γ searches

- We have the possibility of improving the MEG II limit in the early 2030s, and start exploring **BR(μ -> e γ) ~ O(10^{-15})** within the next 10 years.

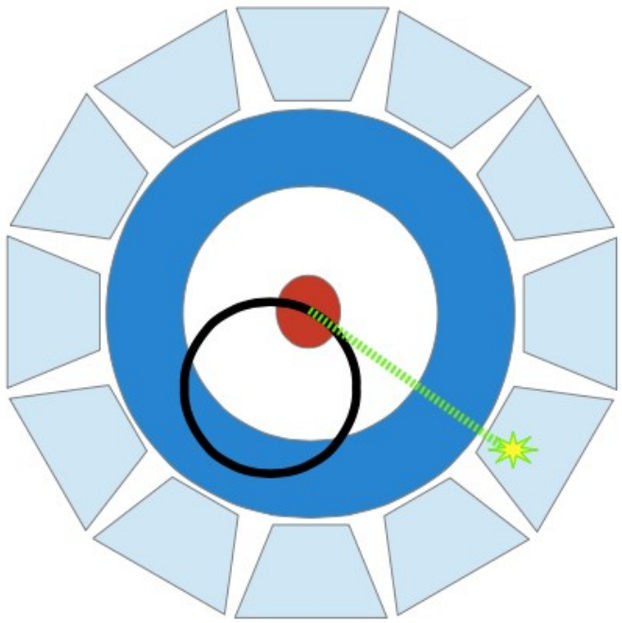
Backup

Concept for a future μ -> e γ experiment



- **Inner silicon tracker** + **timing** for positrons
- A few layers of **active converter** + **gaseous tracker**
  - target photon energy resolution ~ 200 keV

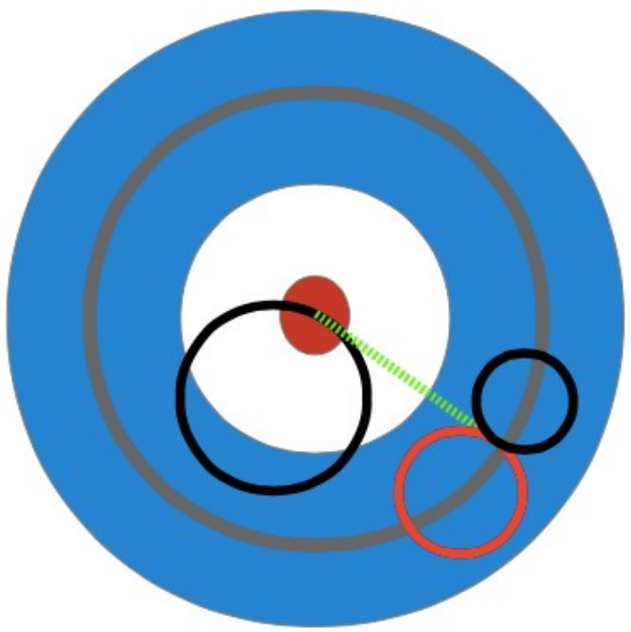
Toward the next generation of μ -> e γ searches: Photon Reconstruction



Calorimetry

High efficiency
Good resolutions

MEG:
LXe calorimeter
10% acceptance

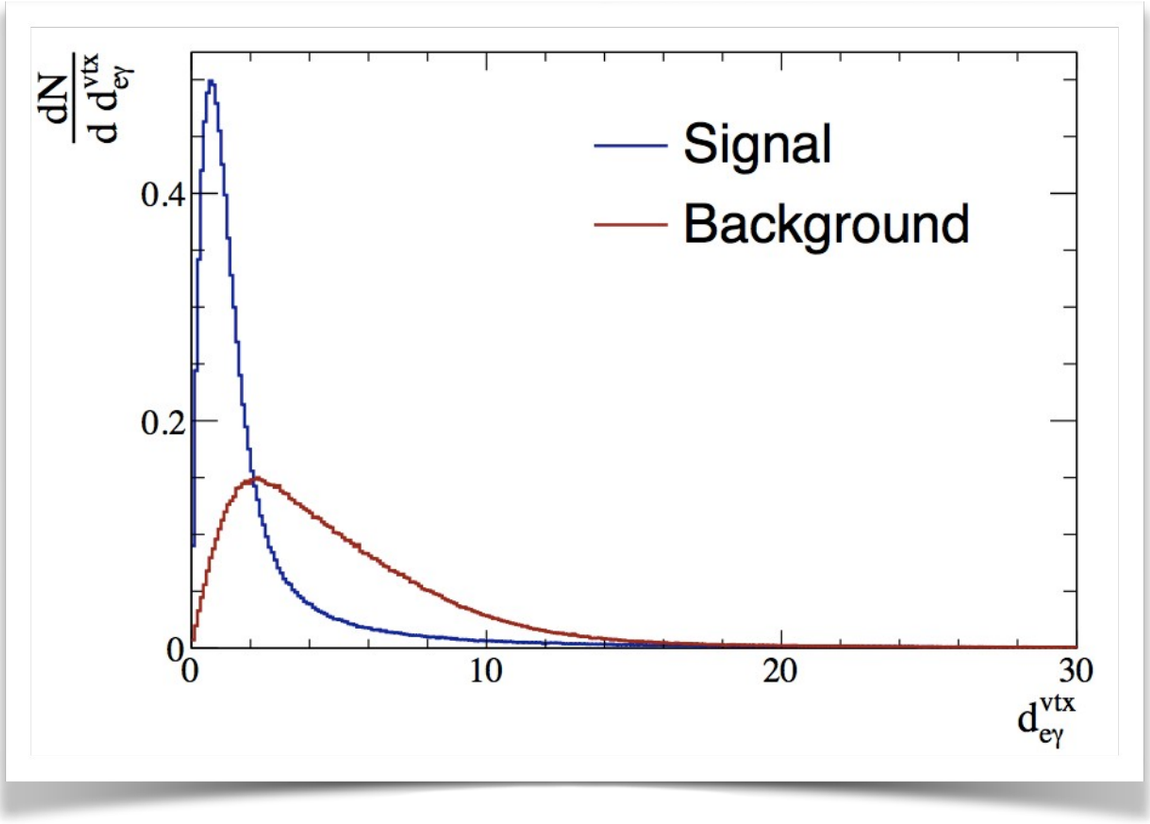


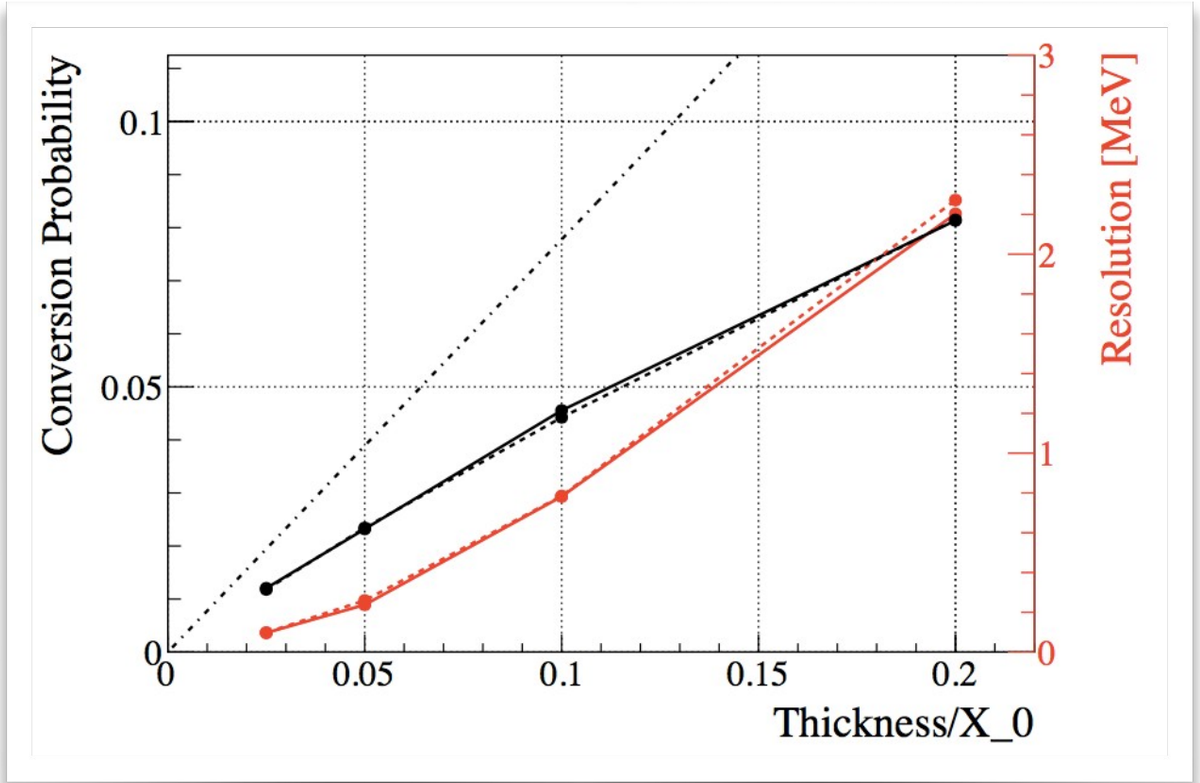
Photon Conversion

Low efficiency (~ %)
Extreme resolutions
+ eγ Vertex

Limiting factors — Photon conversion

- Interactions in the converter (conversion probability e^+e^- energy loss and MS)
- Possible improvement with active converter





- Can take advantage of the photon direction determination form the e^+e^- reconstruction

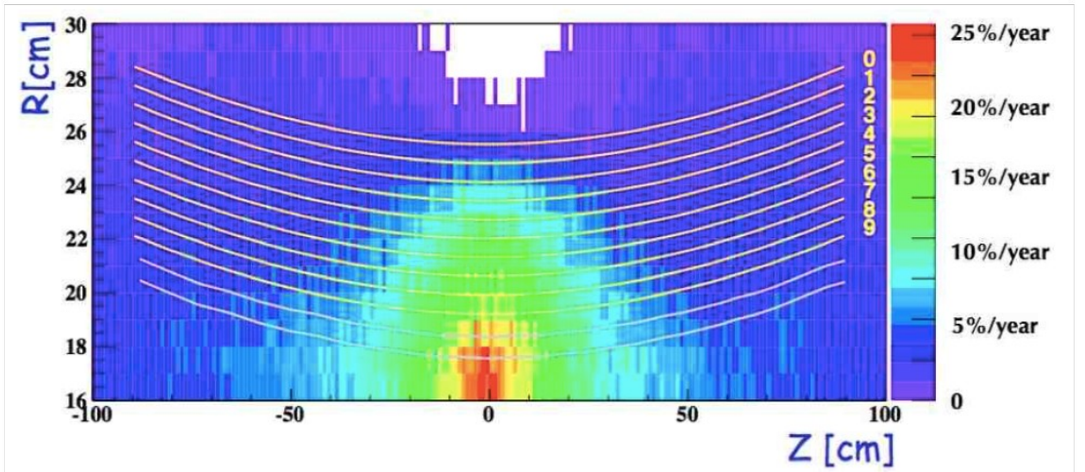
$$d_e^{vtx} = \sqrt{\left(\frac{X_e - X}{\sigma_X}\right)^2 + \left(\frac{Y_e - Y}{\sigma_Y}\right)^2}$$

Limiting factors — Positron

- Gaseous tracking detectors currently provide the best resolutions
  - very light gas mixtures
  - 100 keV energy resolution in MEG II
  - aging and pattern recognition are a severe issue at large rates
- Silicon detectors are becoming competitive with expected developments
  - if 25 μm HV-MAPS will be available

Expected aging (gain loss) in MEG II

A. Baldini et al., arXiv:1301:7225

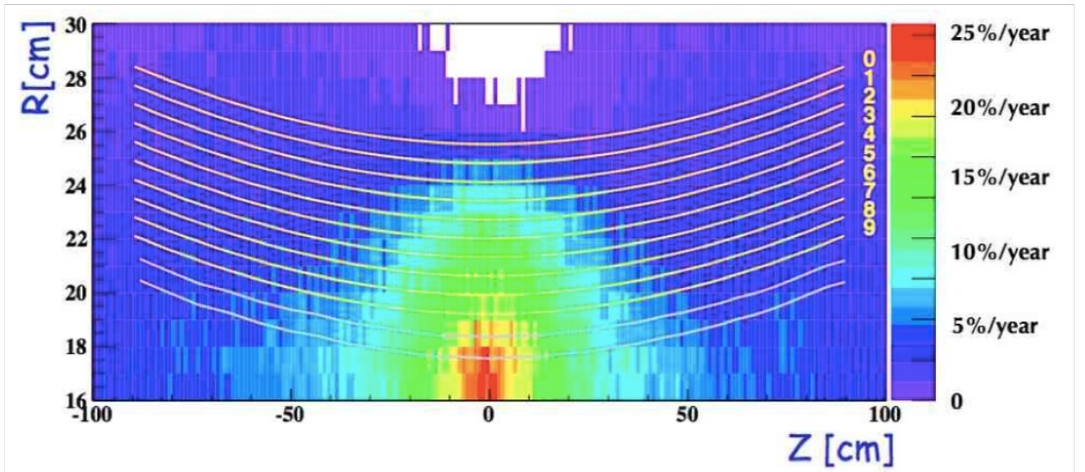


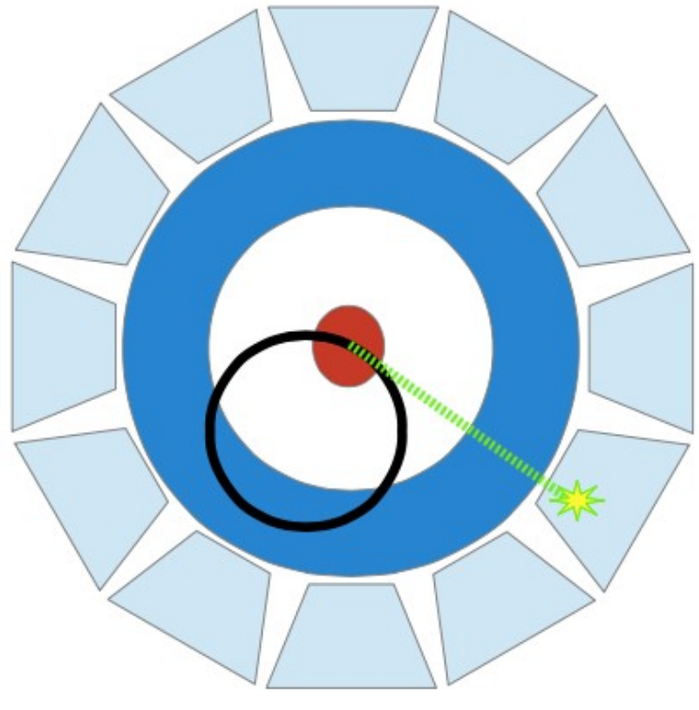
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- Silicon detectors are becoming competitive with expected developments
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- Multiple scattering before the detector (target + gas + detector walls)
  - ~ 4 mrad contribution to the angular resolutions

Expected aging (gain loss) in MEG II

A. Baldini et al., arXiv:1301:7225





Gaseous positron trackers toward 10^9-10^{10} μ/s

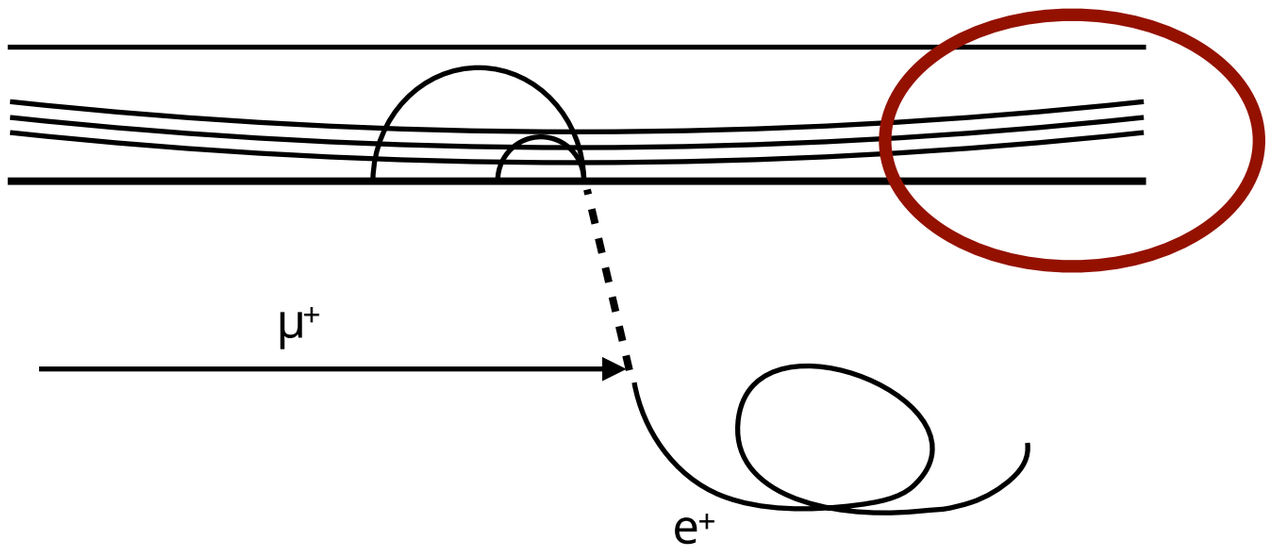
- Some improvement in resolution could come from the cluster counting technique (not large), then the ultimate performances for drift chambers are achieved.

- Future R&D should aim to:
  - preserve such good resolutions
  - keep the same (or reduce the) material budget
  - **operate at extremely high rates**

Gaseous tracker for photon reconstruction

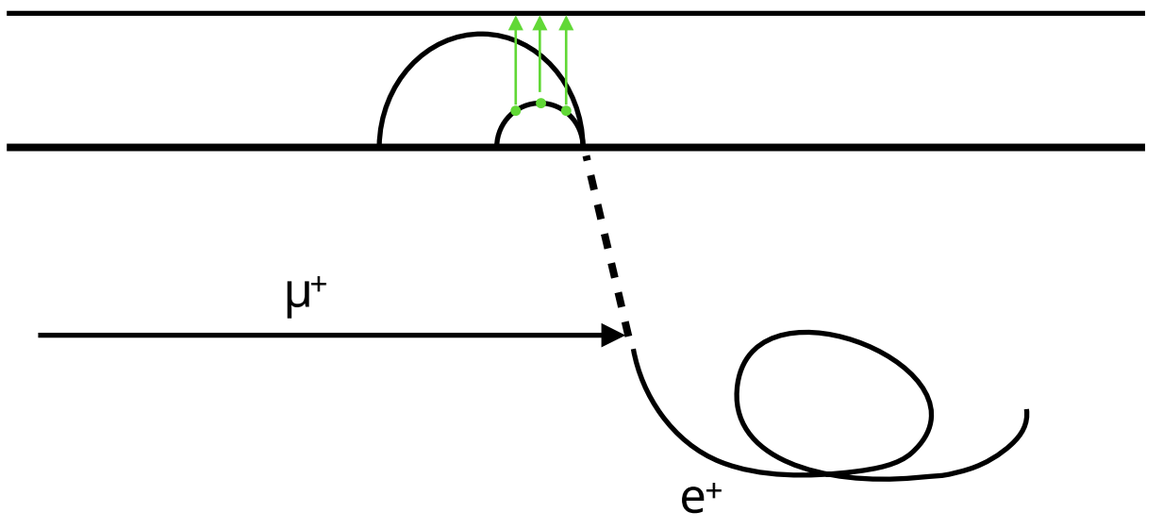
- Low rate —> much less demanding w.r.t. positron trackers

Wire chamber



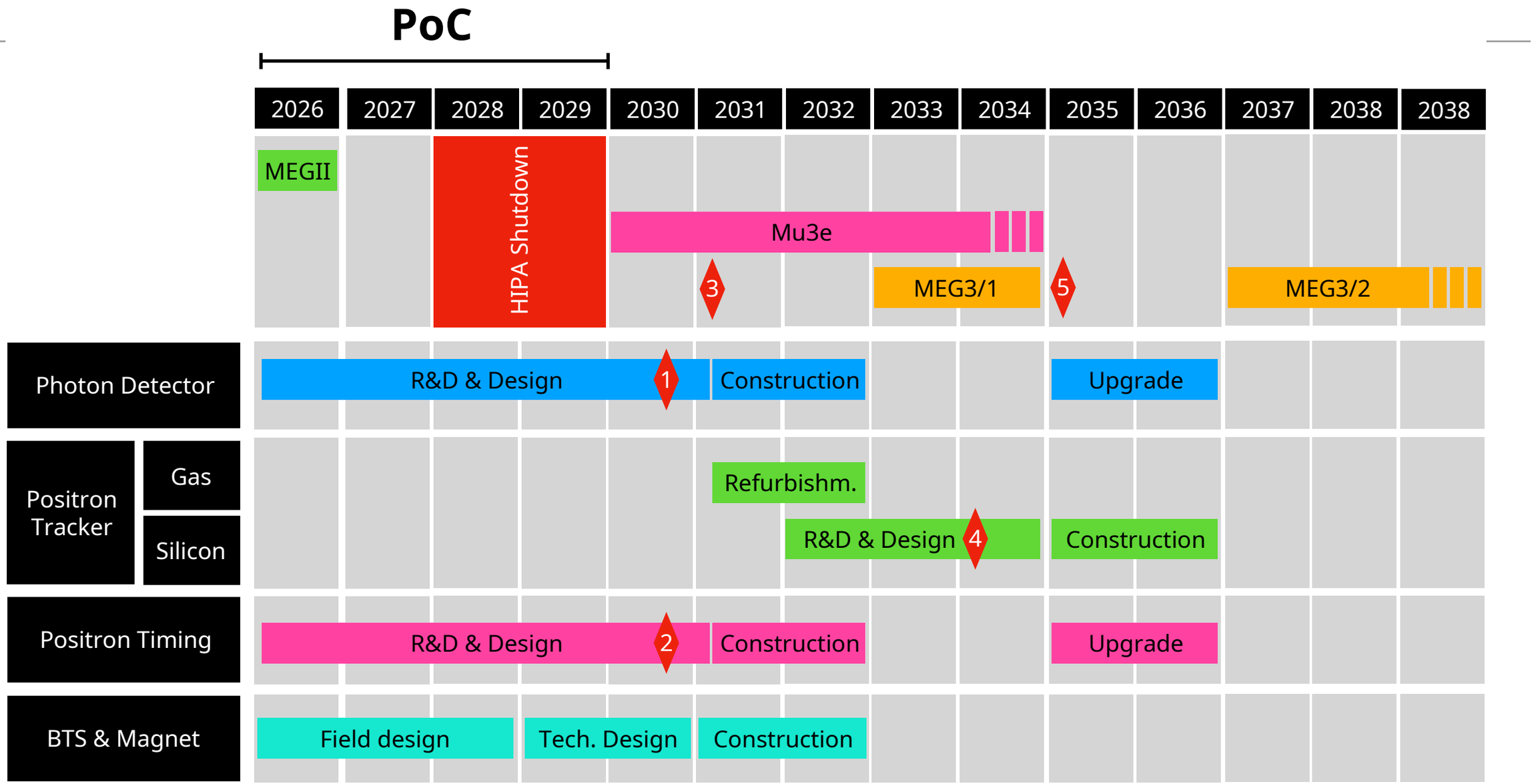
Low efficiency at low momentum in this region (even for a graded B field)

Radial TPC



Cylindrical MPGD
(e.g. cylindrical GEM,
cfr. BES-III and KLOE)

Schedule



- 1: Photon converter proof of principle (CEX with converter + tracker in the MEG COBRA magnet)
- 2: Decision about positron timing technology
- 3: phase-I approval by PSI and funding agencies
- 4: Decision about positron tracker technology for phase-II
- 5: phase-II approval by PSI and funding agencies