



Latest results of $\mu \rightarrow e\gamma$ search with the MEG II experiment

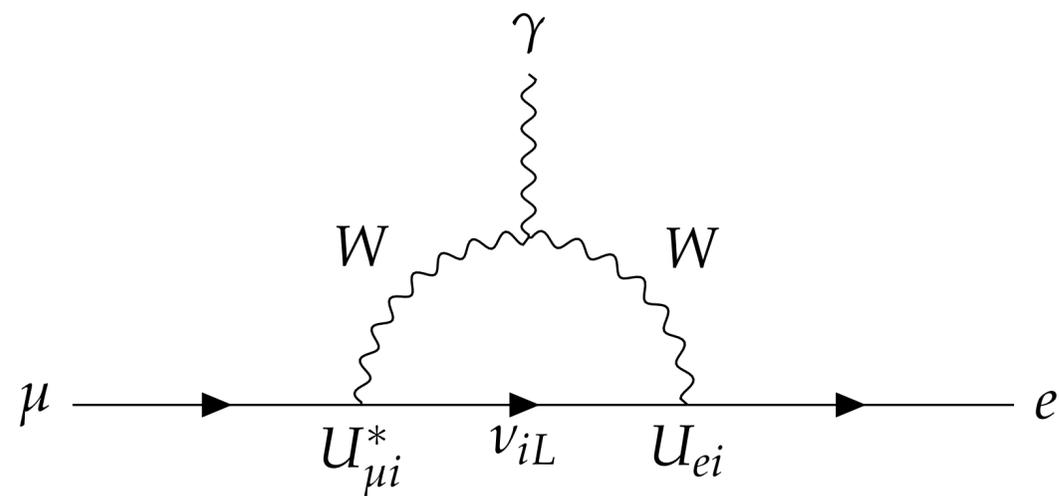
Kensuke Yamamoto (The University of Tokyo)
on behalf of the MEG II collaboration

32nd International Symposium on Lepton Photon Interactions at High Energies
August 25-29, 2025

Lepton-flavour-violating $\mu \rightarrow e\gamma$

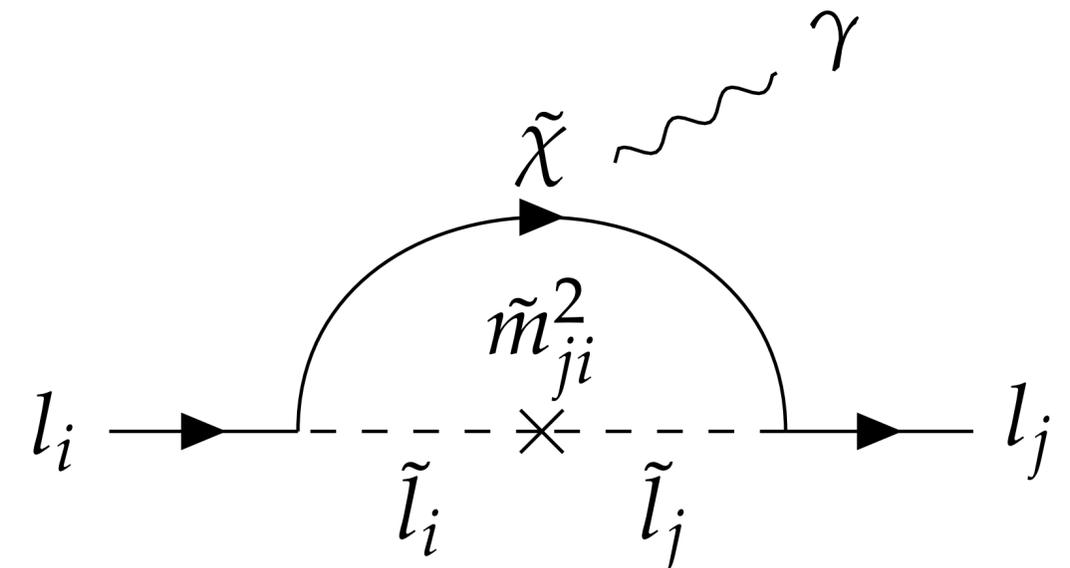
- Lepton flavour conservation is an accidental symmetry in the SM
- The charged-lepton-flavour-violating decay $\mu \rightarrow e\gamma$ is an interesting probe to search for new physics beyond the SM
 - Its discovery would be clear evidence of new physics

$$\mathcal{B}(\mu \rightarrow e\gamma) \sim 10^{-54} \quad \text{SM} + \nu \text{ oscillation}$$

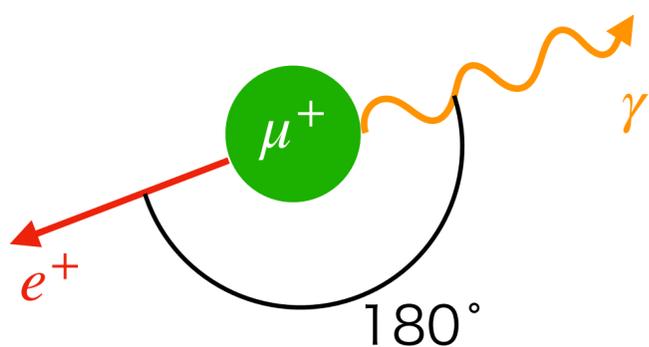
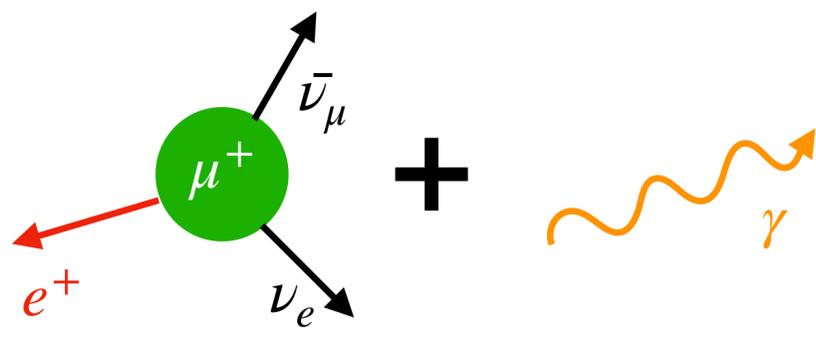
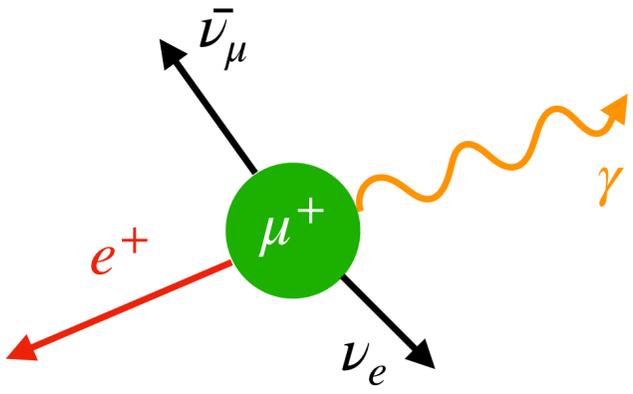


$$\text{BSM models (e.g. SUSY)}$$

$$\mathcal{B}(\mu \rightarrow e\gamma) \sim 10^{-14} - 10^{-12}$$

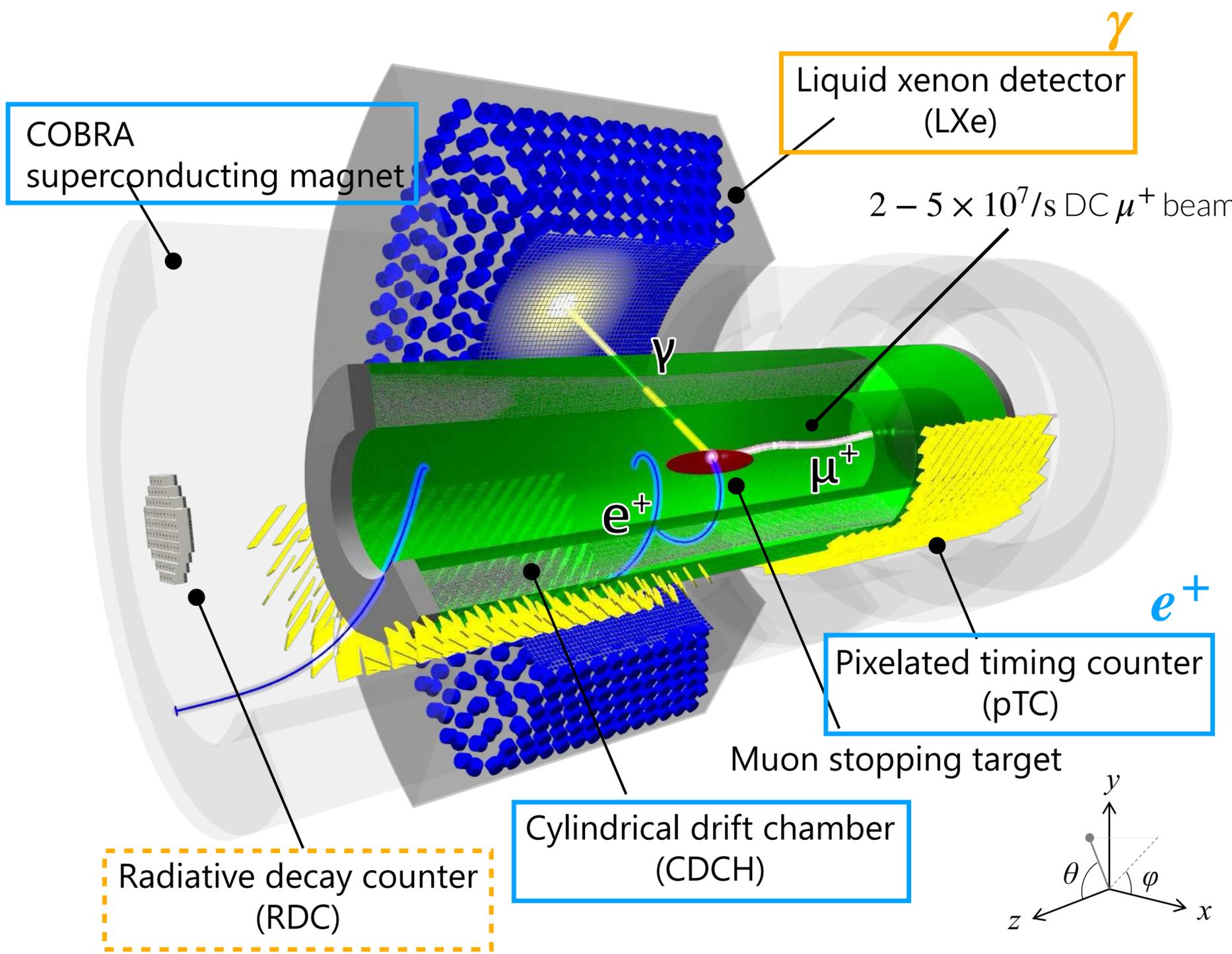


Event signature

	Signal	Accidental background \gg	RMD background
			
E_γ	52.8 MeV	<52.8 MeV	<52.8 MeV
E_e	52.8 MeV	<52.8 MeV	<52.8 MeV
$t_{e\gamma} = t_\gamma - t_e$	0 s	Flat	0 s
Opening angle	180°	<180°	<180°

Precise kinematics measurement required to distinguish signal from backgrounds

MEG II experiment in search of $\mu^+ \rightarrow e^+ \gamma$



World's most intense proton cyclotron (1.4 MW)
@Paul Scherrer Institut in Switzerland

High-intensity DC muon beam

×

Innovative high-resolution detector

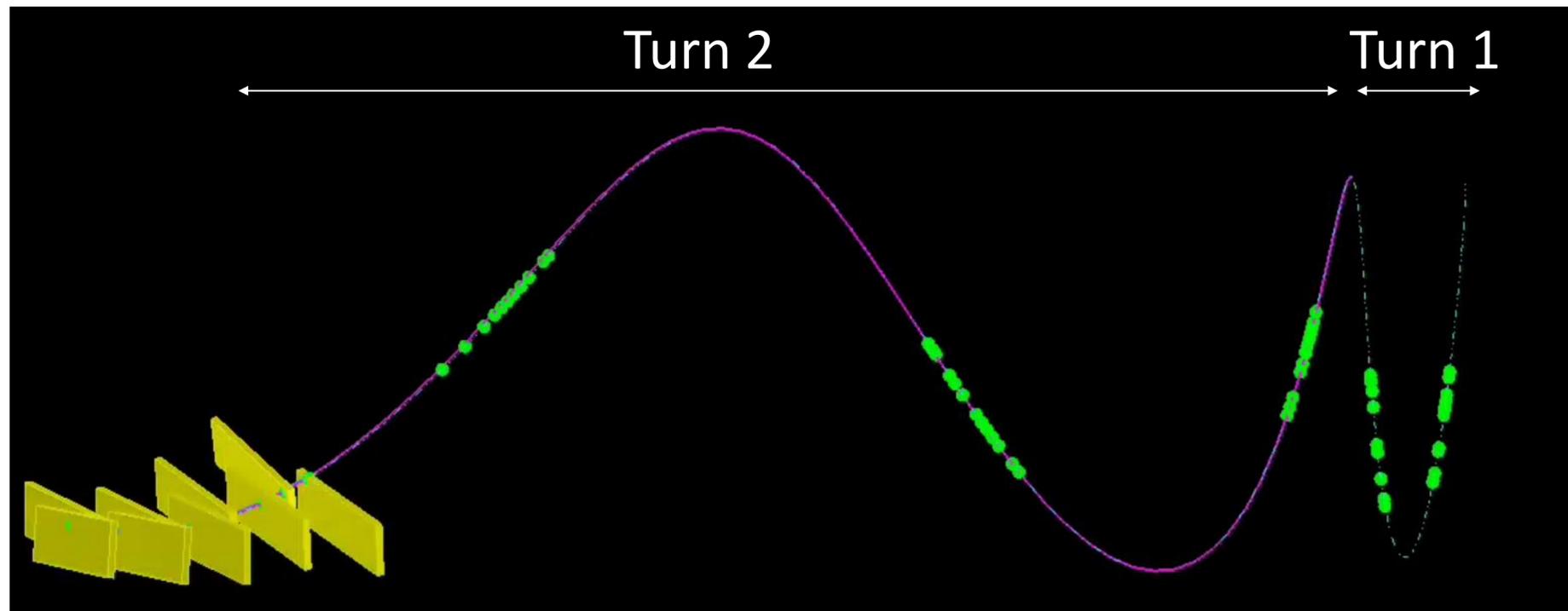
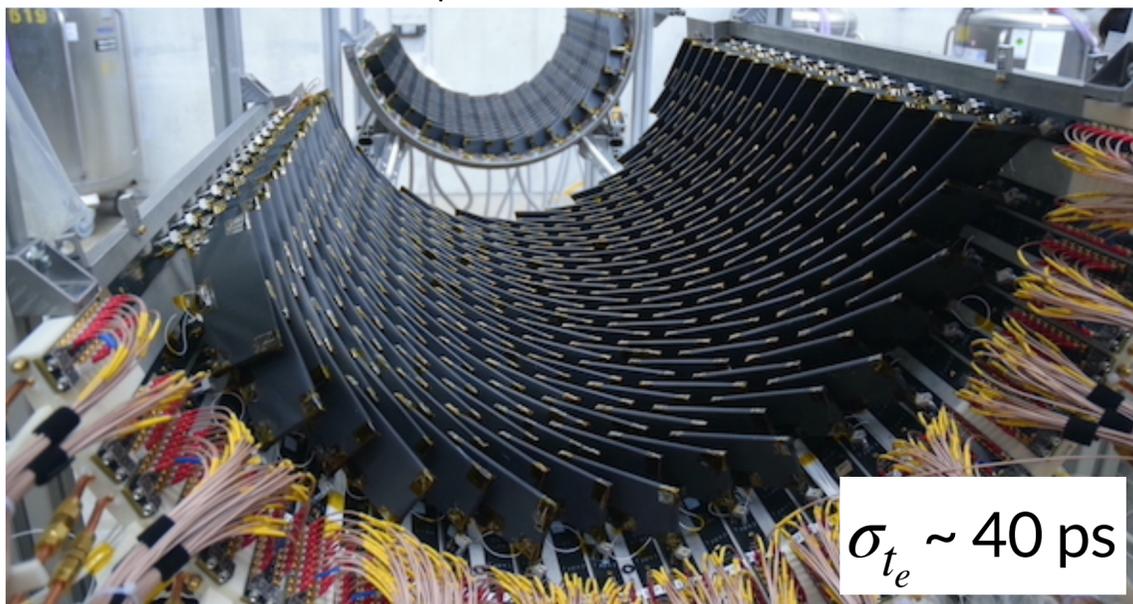
[Eur. Phys. J. C 84 \(2024\), 190](#)

→ **Target sensitivity of 6×10^{-14}**

Positron measurement with spectrometer

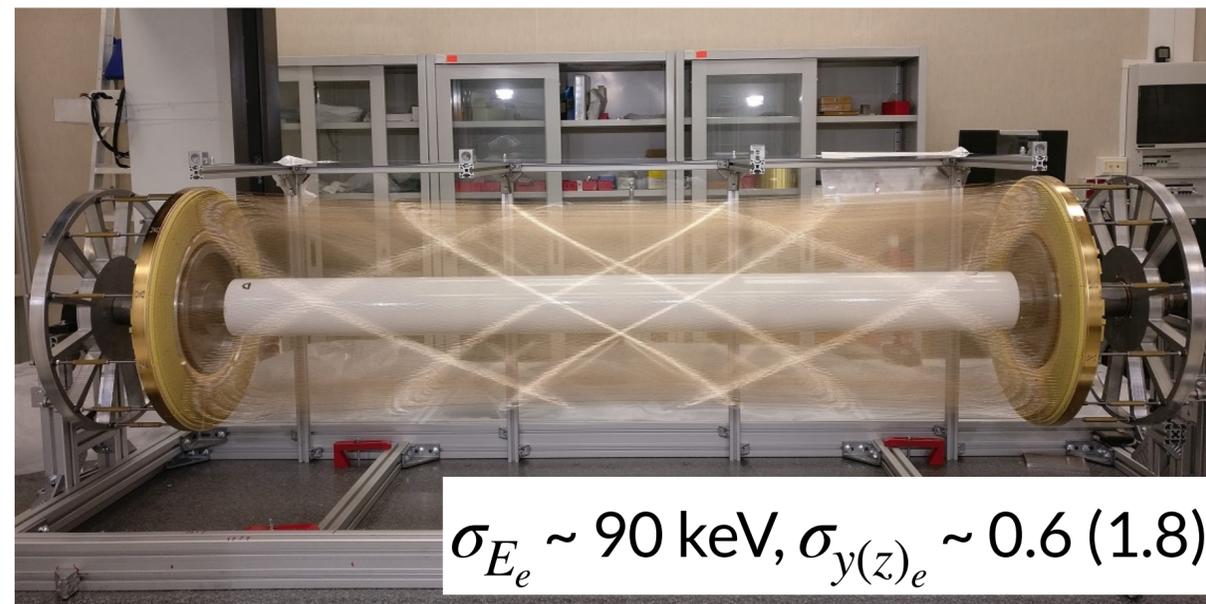
Pixelated timing counter

- 2 x 256 scintillation counters + SiPMs
- Multiple hits improve resolution by $\sqrt{N_{\text{hit}}}$



COBRA magnet

- Constant bending radius of positrons
- Gradient field (0.5-1.3 T)

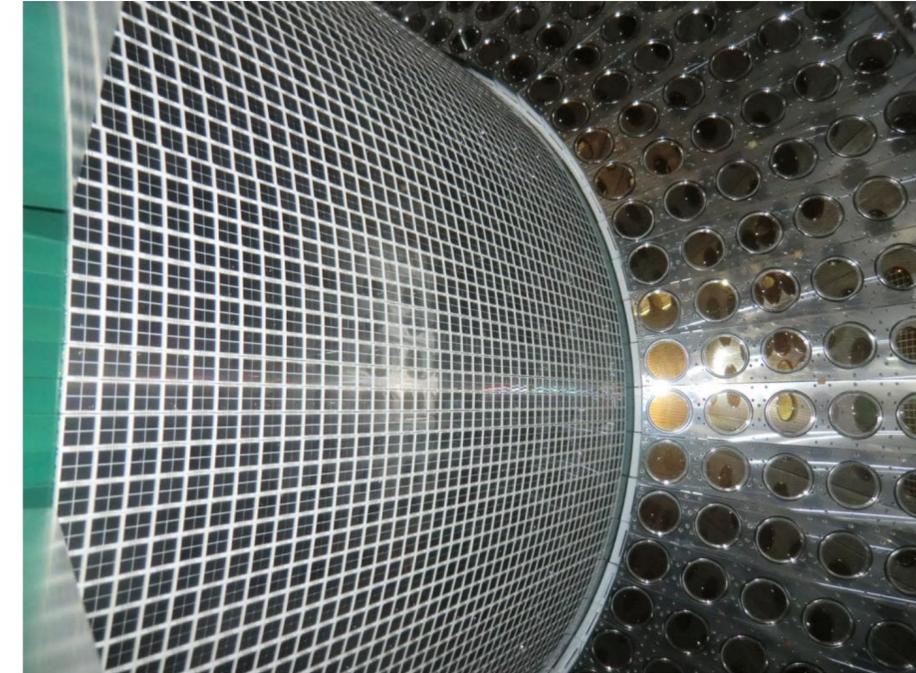
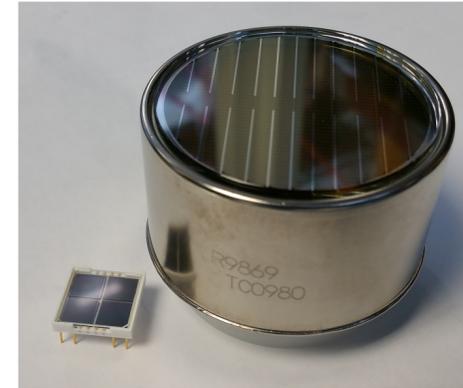


Cylindrical drift chamber

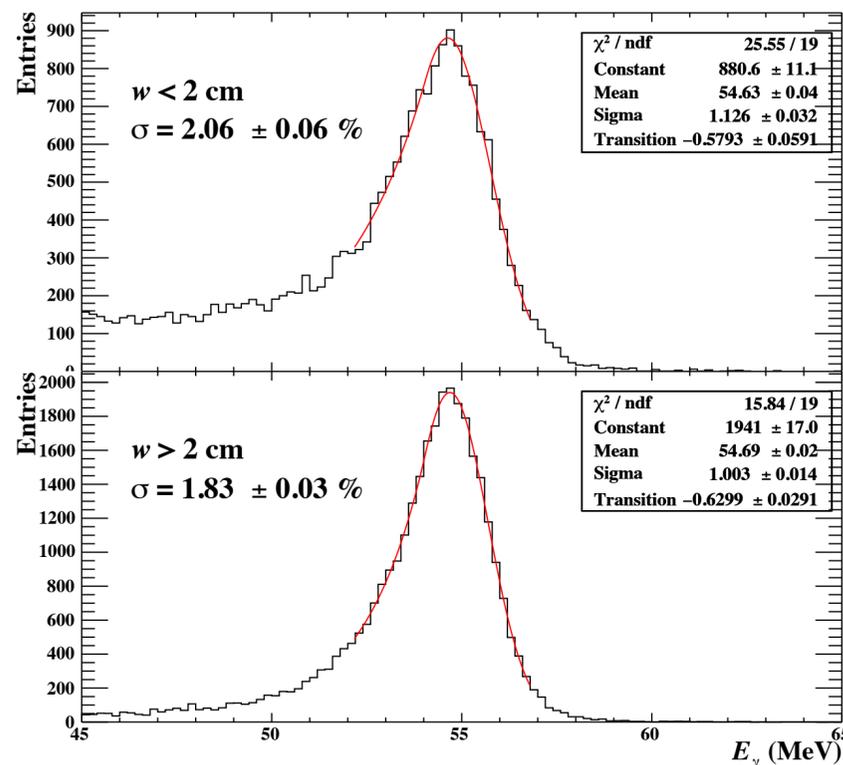
- Single-volume
- Low mass (0.16% X_0)
- Stereo wire geometry

Photon measurement with LXe detector

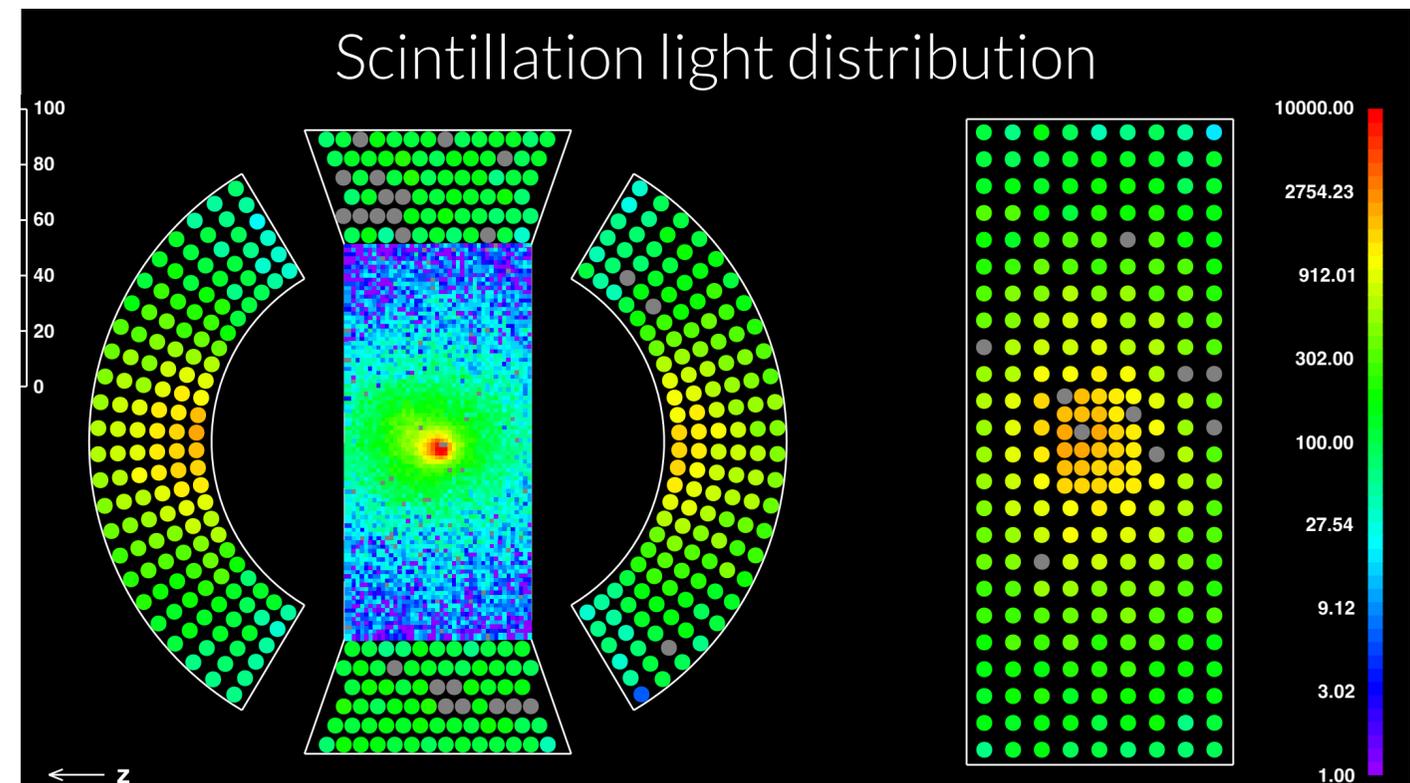
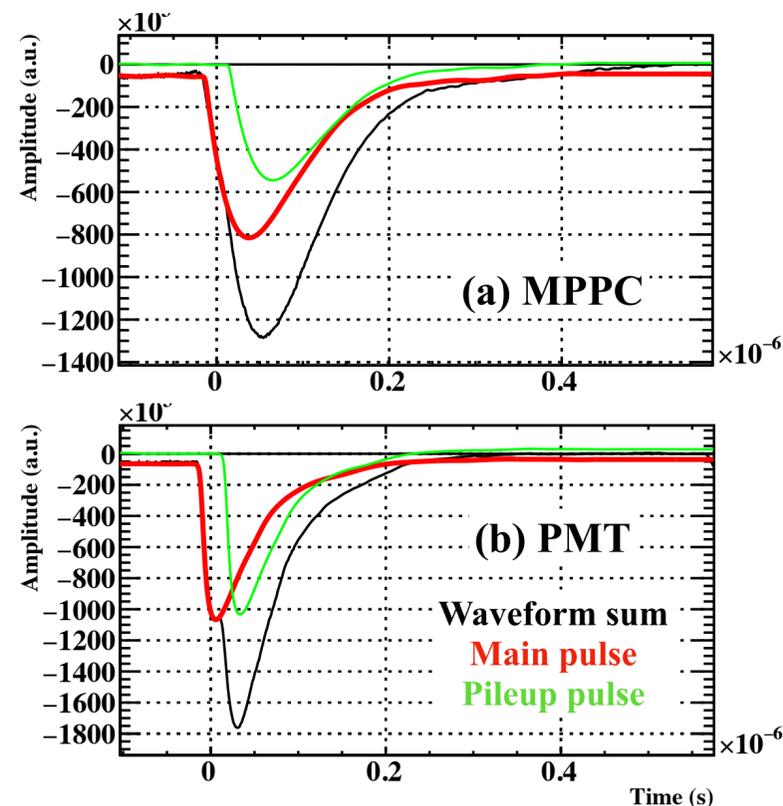
- 900 L of liquid xenon
- VUV-sensitive 4092 MPPCs + 668 PMTs
- $\sigma_{\vec{x}_\gamma} \sim 2.5$ mm, $\sigma_{t_\gamma} \sim 63$ ps, $\sigma_{E_\gamma} \sim 2.0$ %



Response to 55 MeV γ

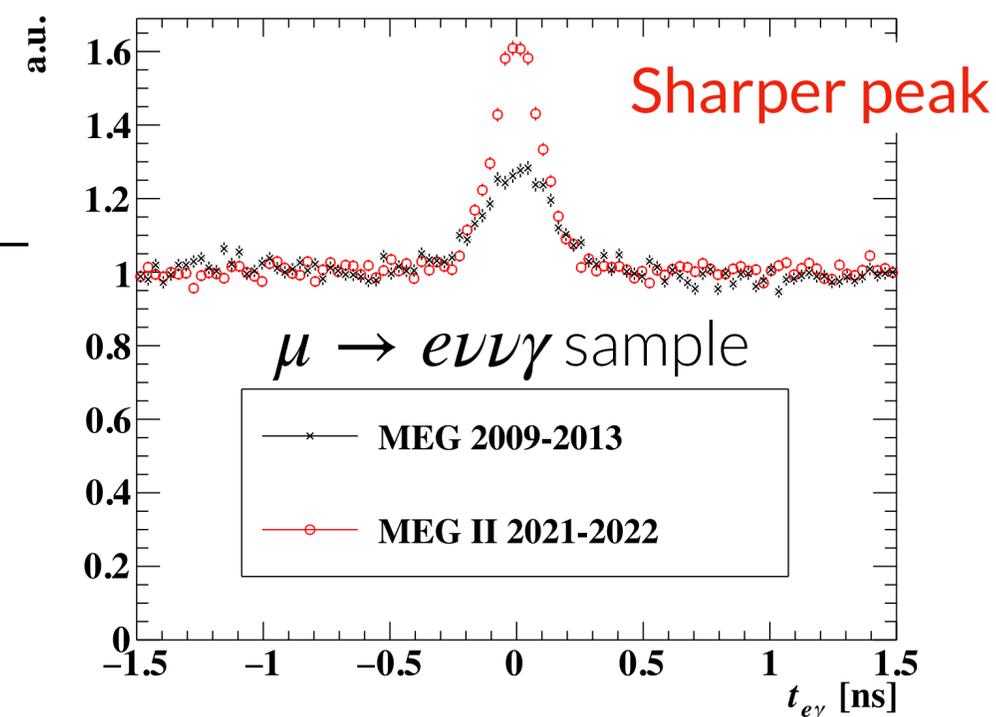
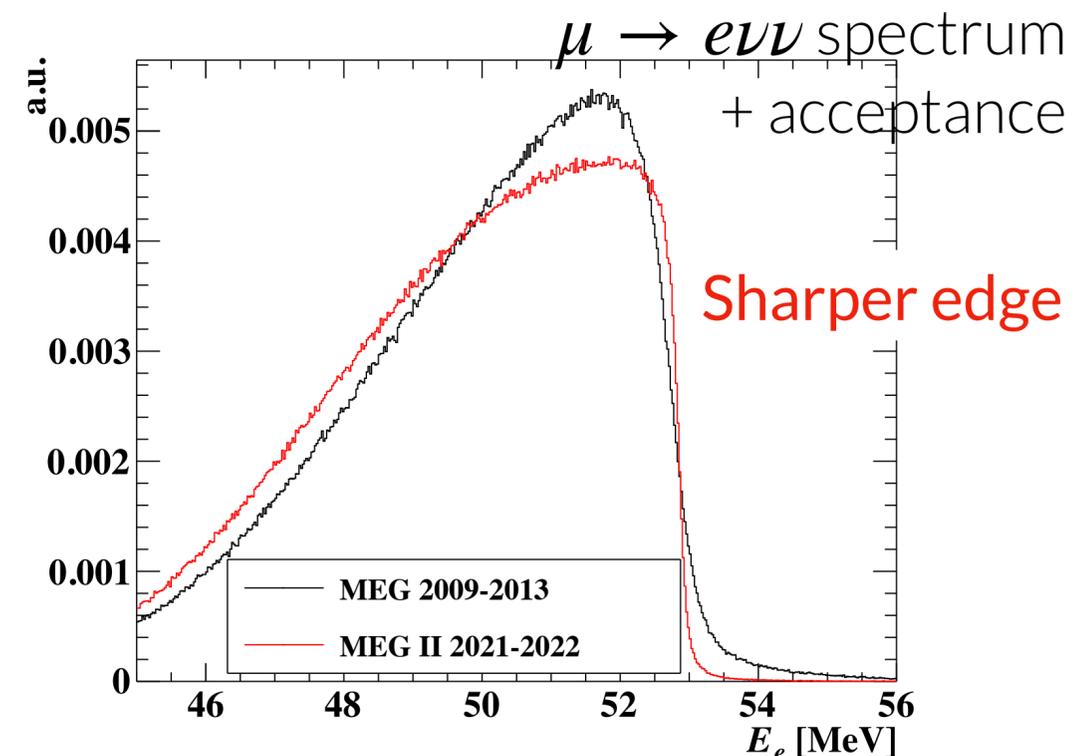


Pileup separation using waveform

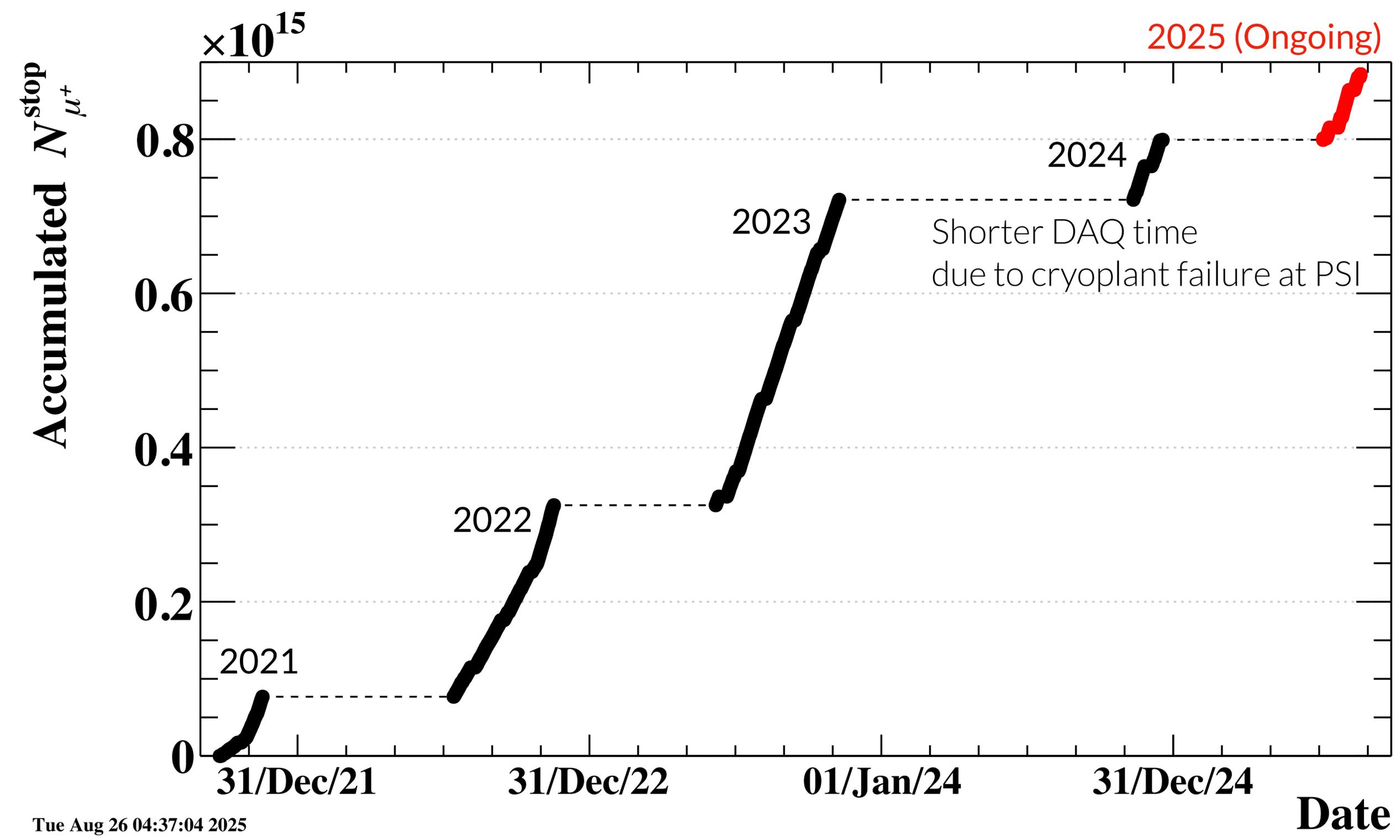


Highlights of performance improvement w.r.t. MEG

	MEG [44]	MEG II achieved in this work
Resolutions		
E_γ (%) ($w_\gamma < 2$ cm)/($w_\gamma > 2$ cm)	2.4/1.7	2.4/1.9
$u_\gamma, v_\gamma, w_\gamma$ (mm)	5, 5, 6 \longrightarrow	2.5, 2.5, 5
t_γ (ps)	67 [43]	63
E_e (keV)	380 \longrightarrow	89
θ_e, ϕ_e (mrad)	9.4, 8.7	6.2, 5.2
z_e, y_e (mm)	2.4, 1.2	1.76, 0.61
t_e (ps)	102 [43] \longrightarrow	~ 40
$t_{e\gamma}$ (ps)	122 \longrightarrow	78
Efficiencies		
ε_γ (%)	63	63
ε_e (%)	30 \longrightarrow	67
ε_{TRG} (%)	≈ 99	91

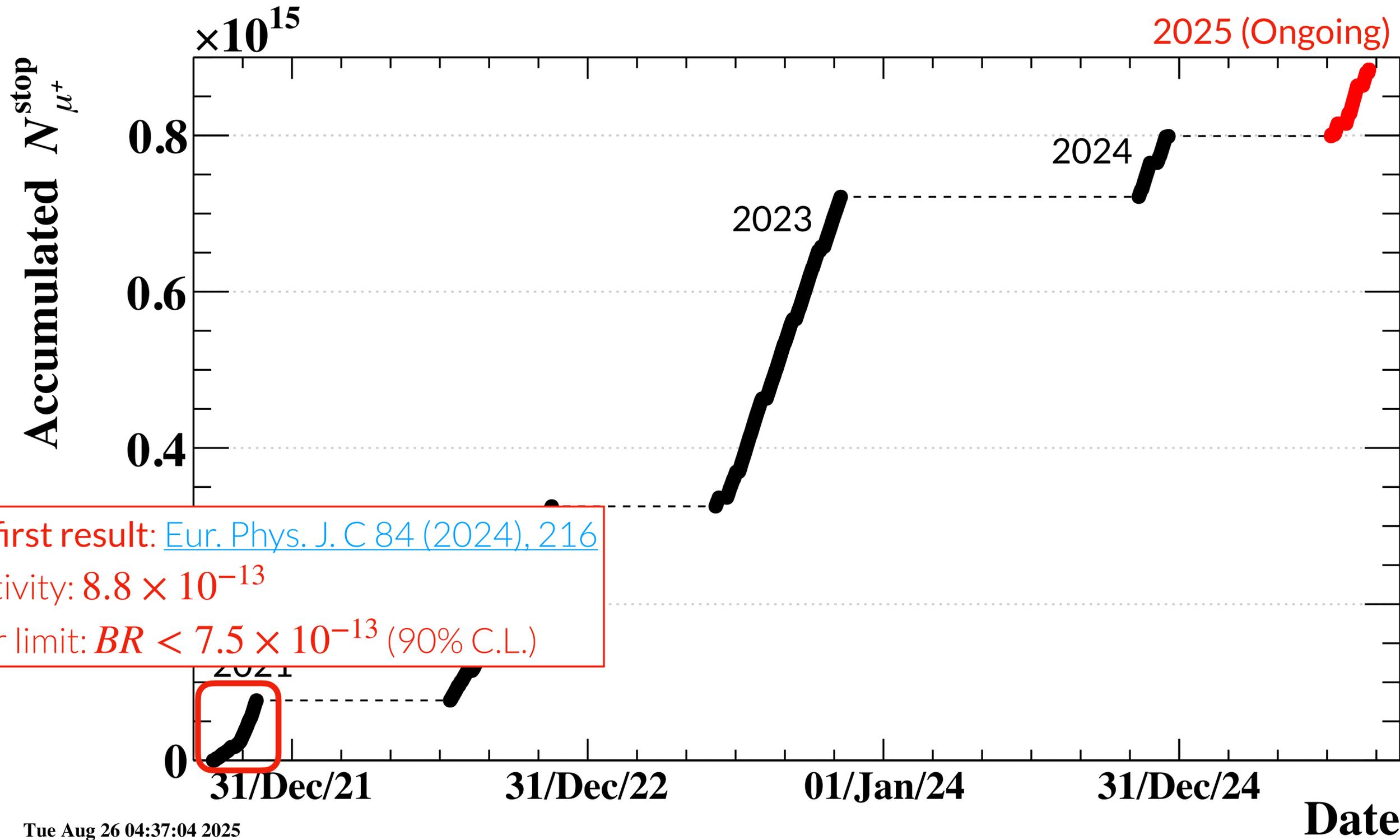


DAQ timeline



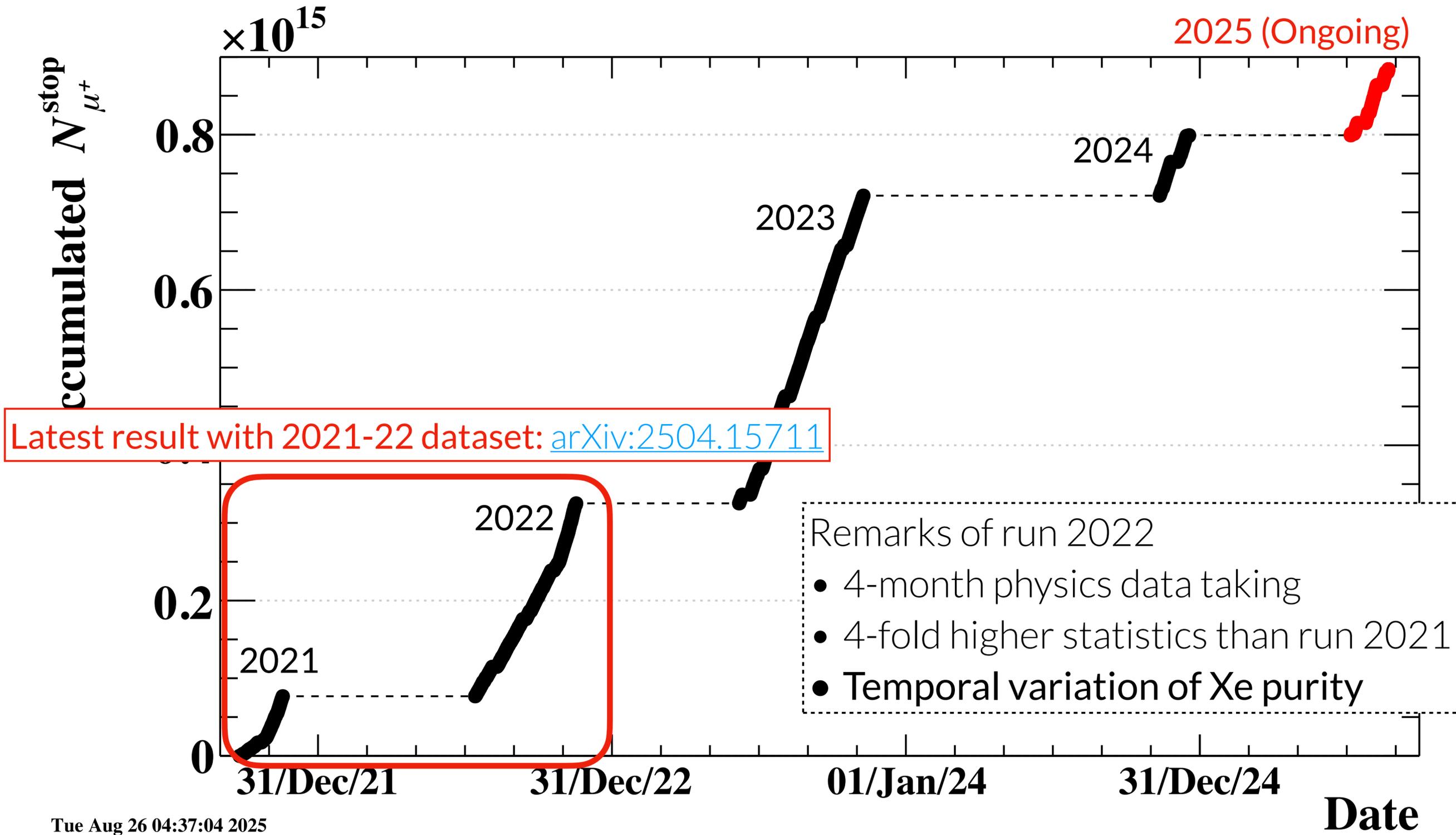
Tue Aug 26 04:37:04 2025

DAQ timeline



Tue Aug 26 04:37:04 2025

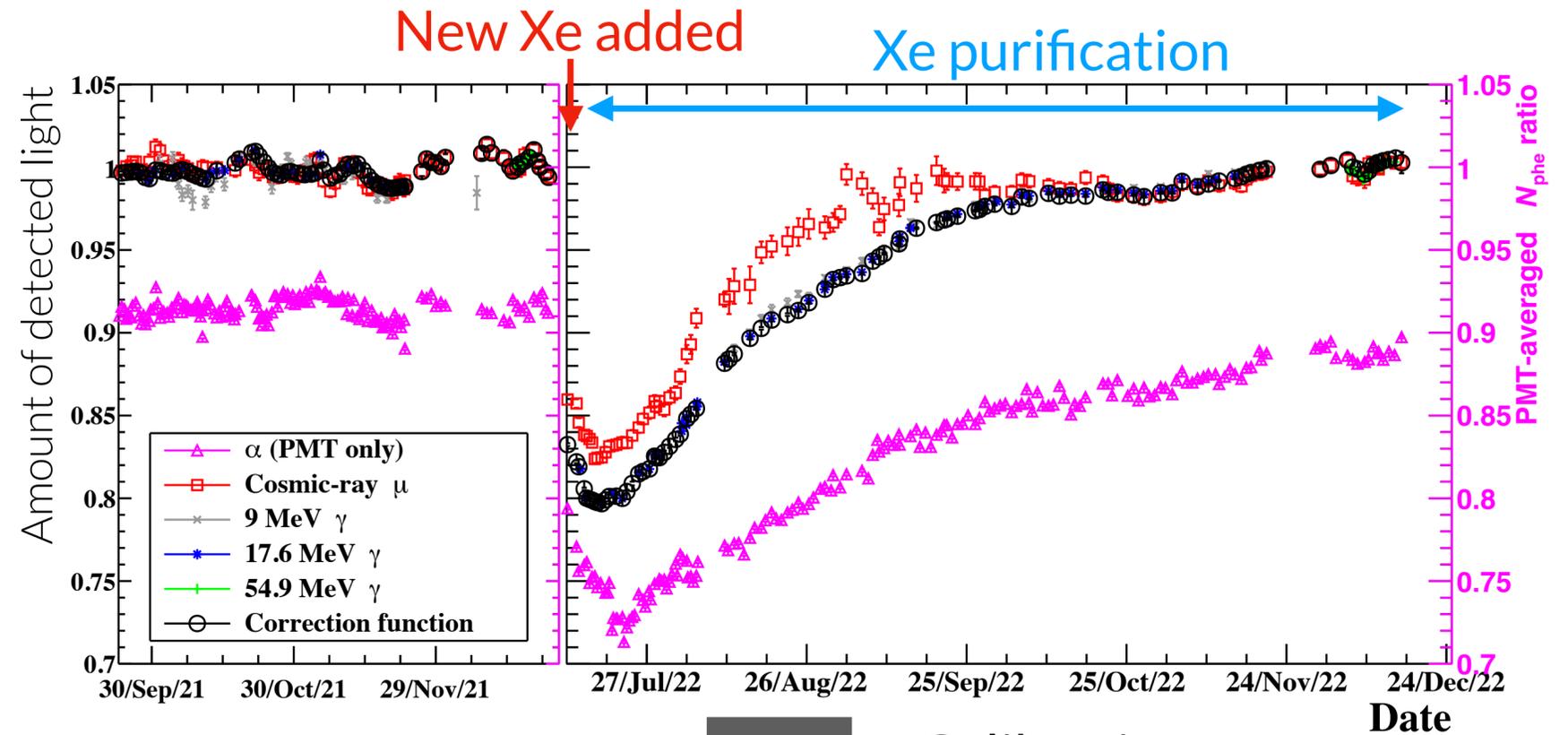
DAQ timeline



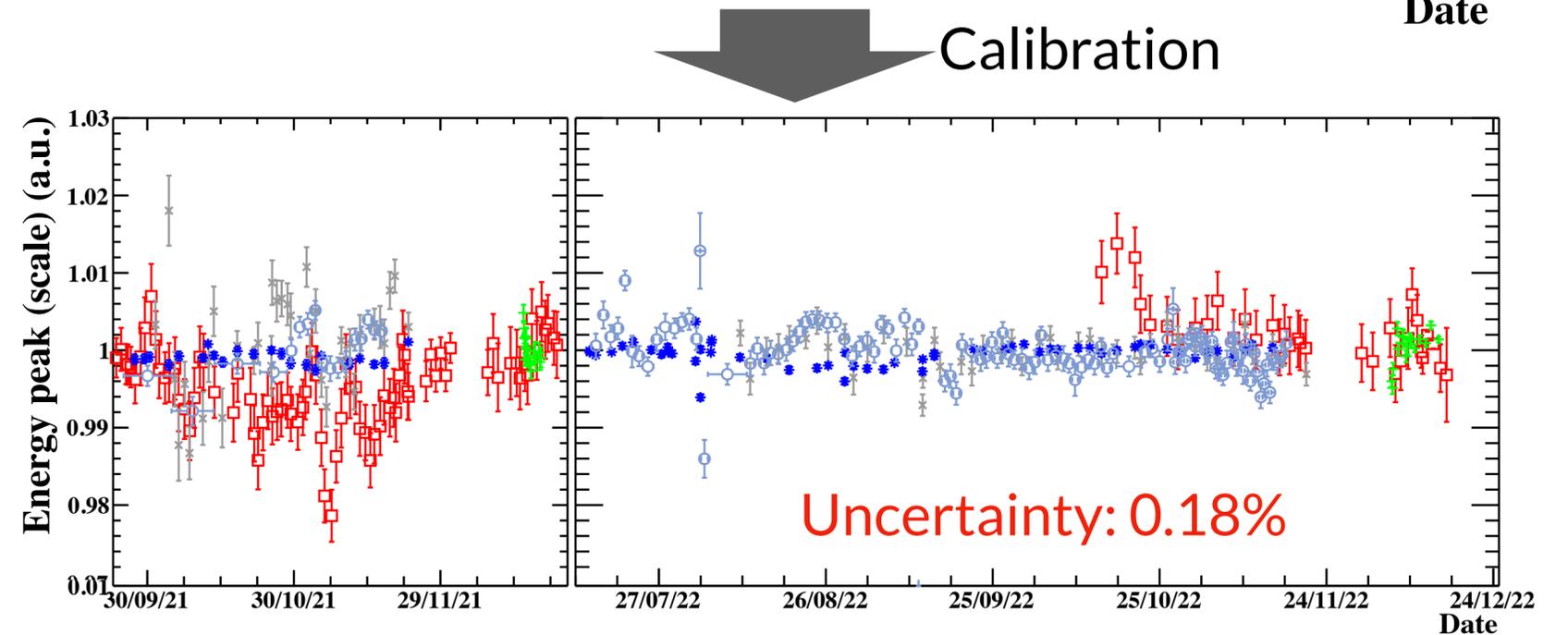
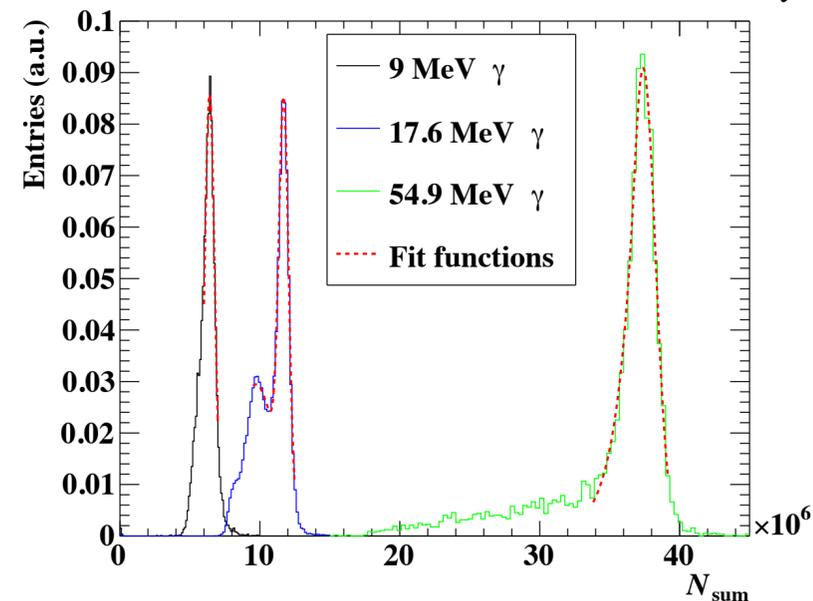
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High-quality data taken in the first long-term run

- Xe purity dropped at the beginning of run 2022
 - New Xe added to cover all photosensors
- **Data quality well controlled** thanks to careful detector calibration

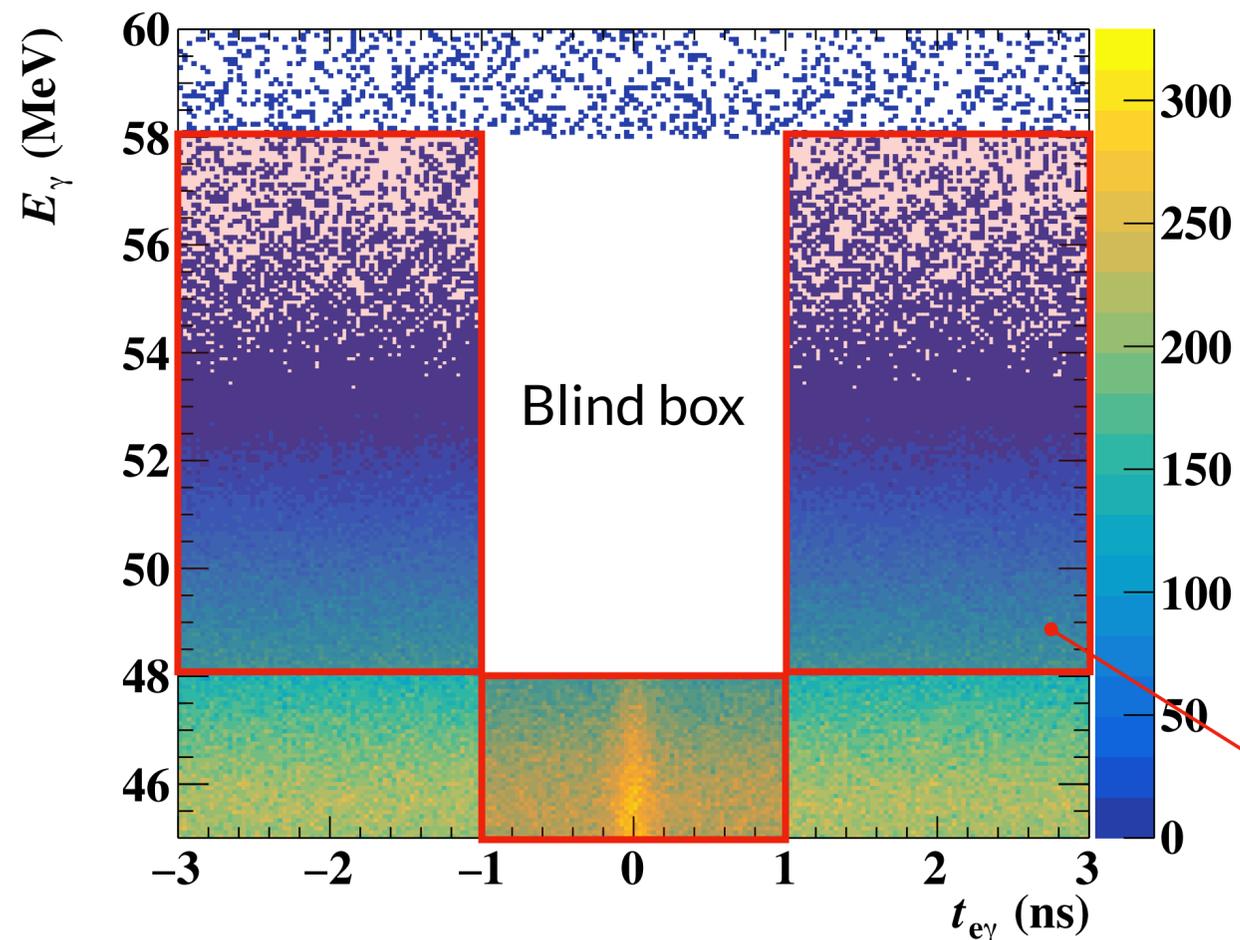


Response to monochromatic γ



Analysis strategy: Blind + likelihood analyses

- Maximum likelihood fit estimates the number of signal events N_{sig}
- N_{sig} converted to $BR(\mu \rightarrow e\gamma)$ by the number of effectively measured muons N_{μ}
 - $N_{\mu} = (1.34 \pm 0.07) \times 10^{14}$



$$\mathcal{L}(N_{\text{sig}}, N_{\text{ACC}}, N_{\text{RMD}}, X_{\text{T}})$$

$$= C(N_{\text{ACC}}, N_{\text{RMD}}, X_{\text{T}}) \quad \text{--- Constraint term}$$

$$\times \frac{e^{-N}}{N_{\text{obs}}!} \prod_{i=1}^{N_{\text{obs}}} \left[N_{\text{sig}} \underbrace{S(\vec{x}_i)}_{\text{signal}} + N_{\text{ACC}} \underbrace{A(\vec{x}_i)}_{\text{accidental BG}} + N_{\text{RMD}} \underbrace{R(\vec{x}_i)}_{\text{RMD BG}} \right]$$

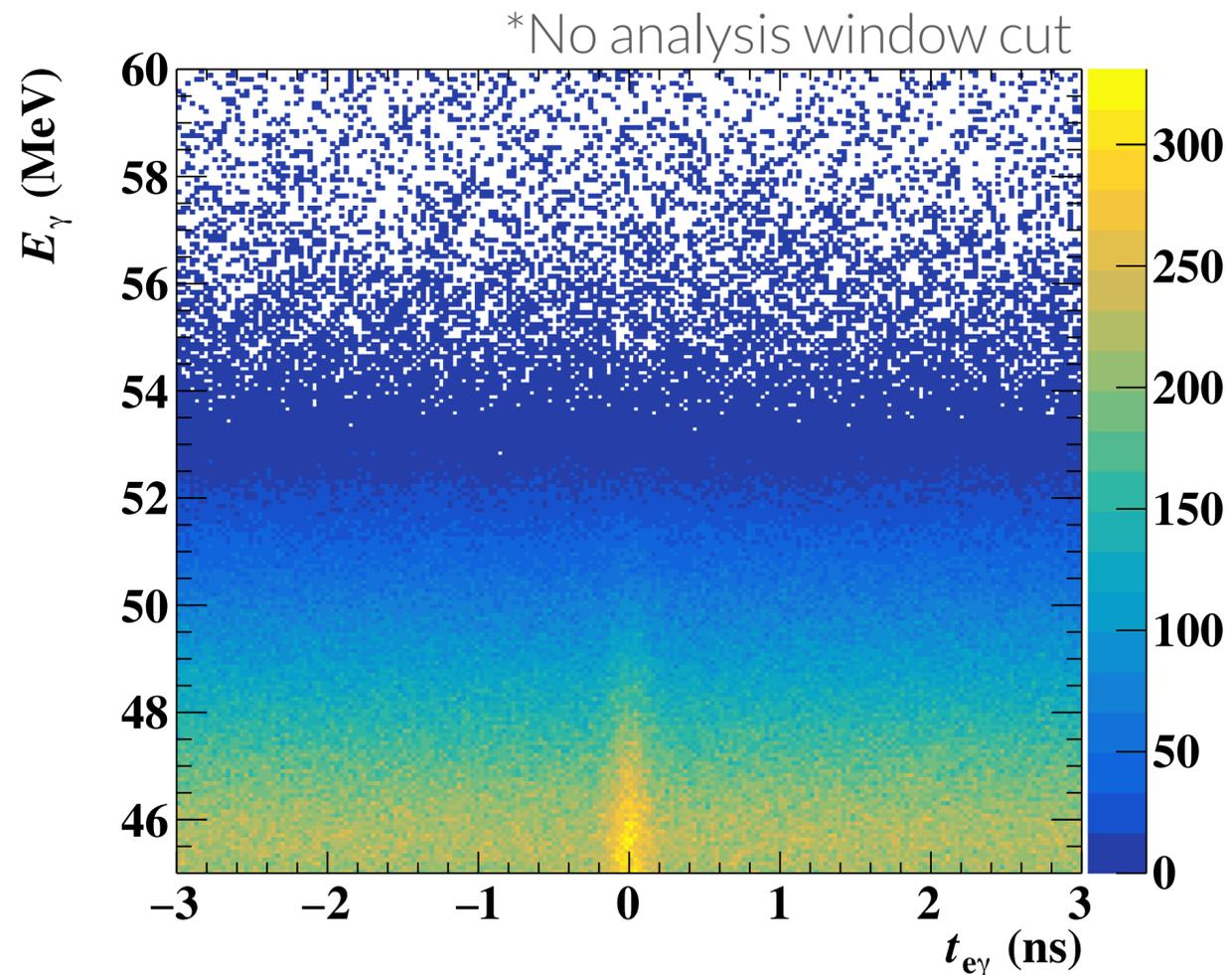
Probability density functions for **signal**, **accidental BG**, **RMD BG**

$$\text{Observables } \vec{x}_i = \{E_{\gamma}, E_e, t_{e\gamma}, n_{\text{pTC}}, \theta_{e\gamma}, \phi_{e\gamma}, t_{\text{RDC}}, E_{\text{RDC}}\}$$

Sidebands defined for calibration, PDF extraction, analysis check

Analysis strategy: Blind + likelihood analyses

- Maximum likelihood fit estimates the number of signal events N_{sig}
- N_{sig} converted to $BR(\mu \rightarrow e\gamma)$ by the number of effectively measured muons N_{μ}
 - $N_{\mu} = (1.34 \pm 0.07) \times 10^{14}$



All studies and checks done

	MEG 2009-2013	MEG II 2021-2022
N_{μ}	1.71×10^{14}	1.34×10^{14}
Sensitivity	5.3×10^{-13}	2.2×10^{-13}

Unblind

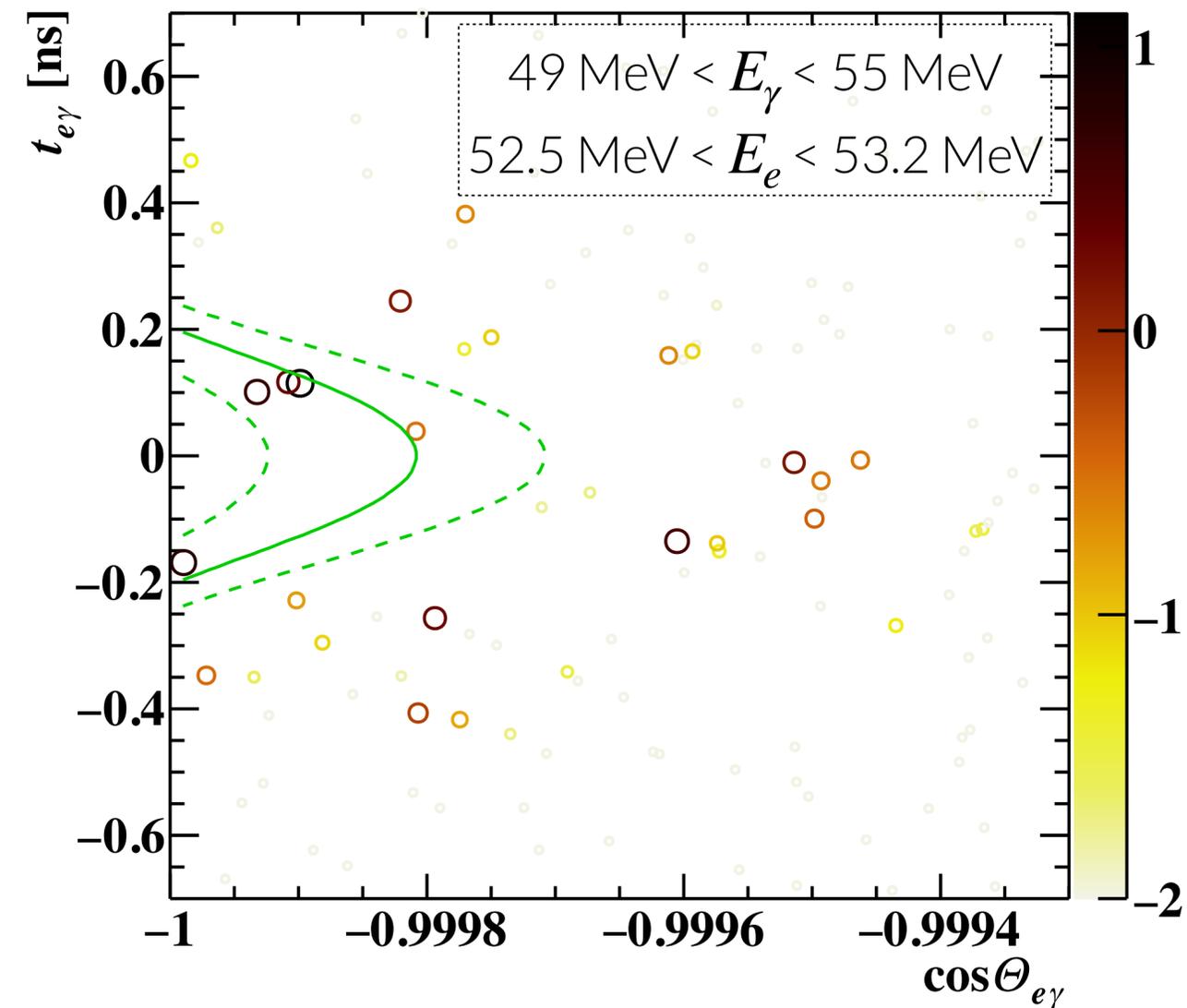
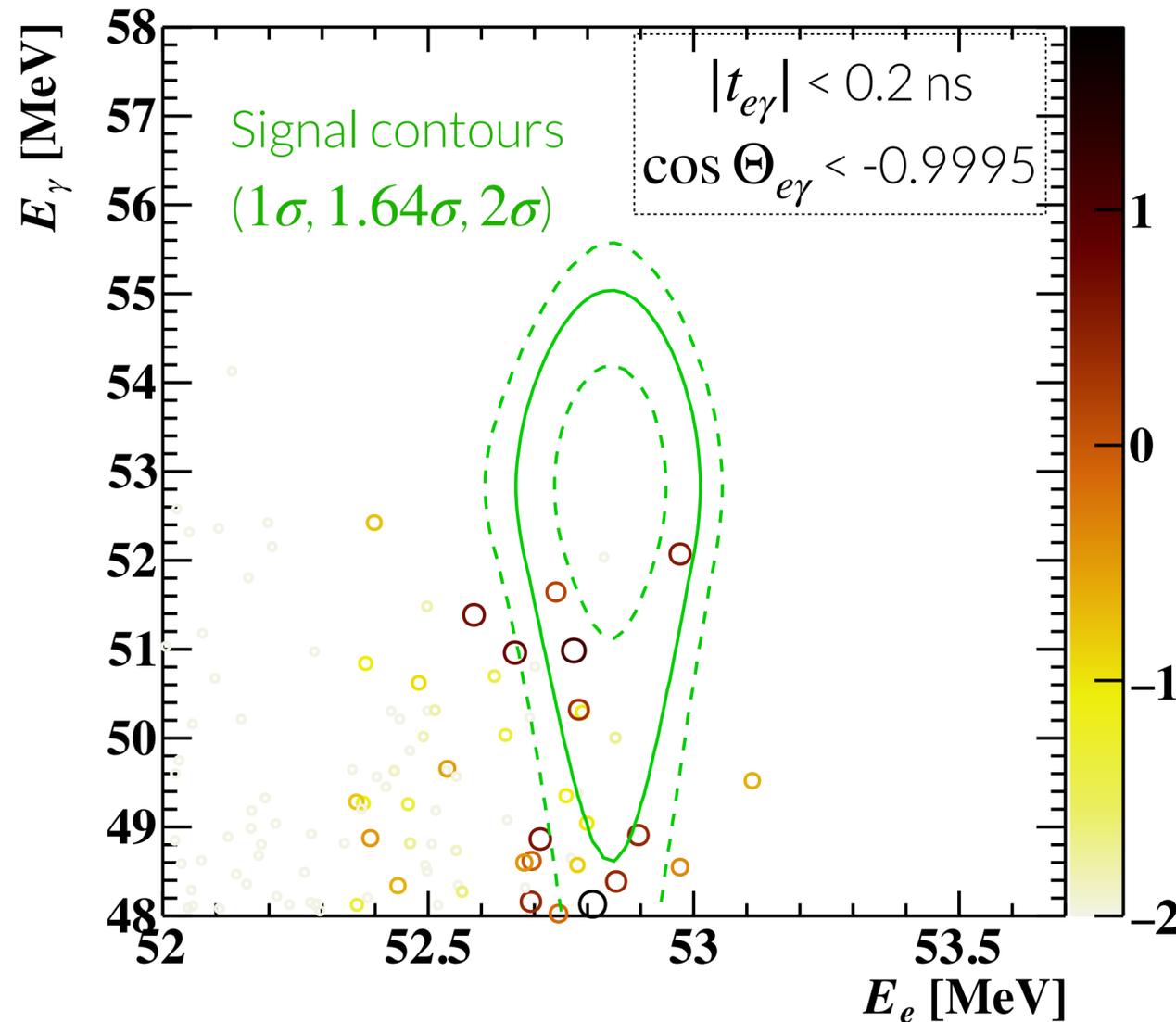
Unblind results: Event distribution

- No event excess observed in signal region

Colour bar: Relative signal likelihood

$$R_{\text{sig}}(\vec{x}_i) = \log_{10} \left(\frac{S(\vec{x}_i)}{(1-r) \cdot A(\vec{x}_i) + r \cdot R(\vec{x}_i)} \right)$$

$$r = \frac{N_{\text{RMD}}}{N_{\text{ACC}} + N_{\text{RMD}}}$$



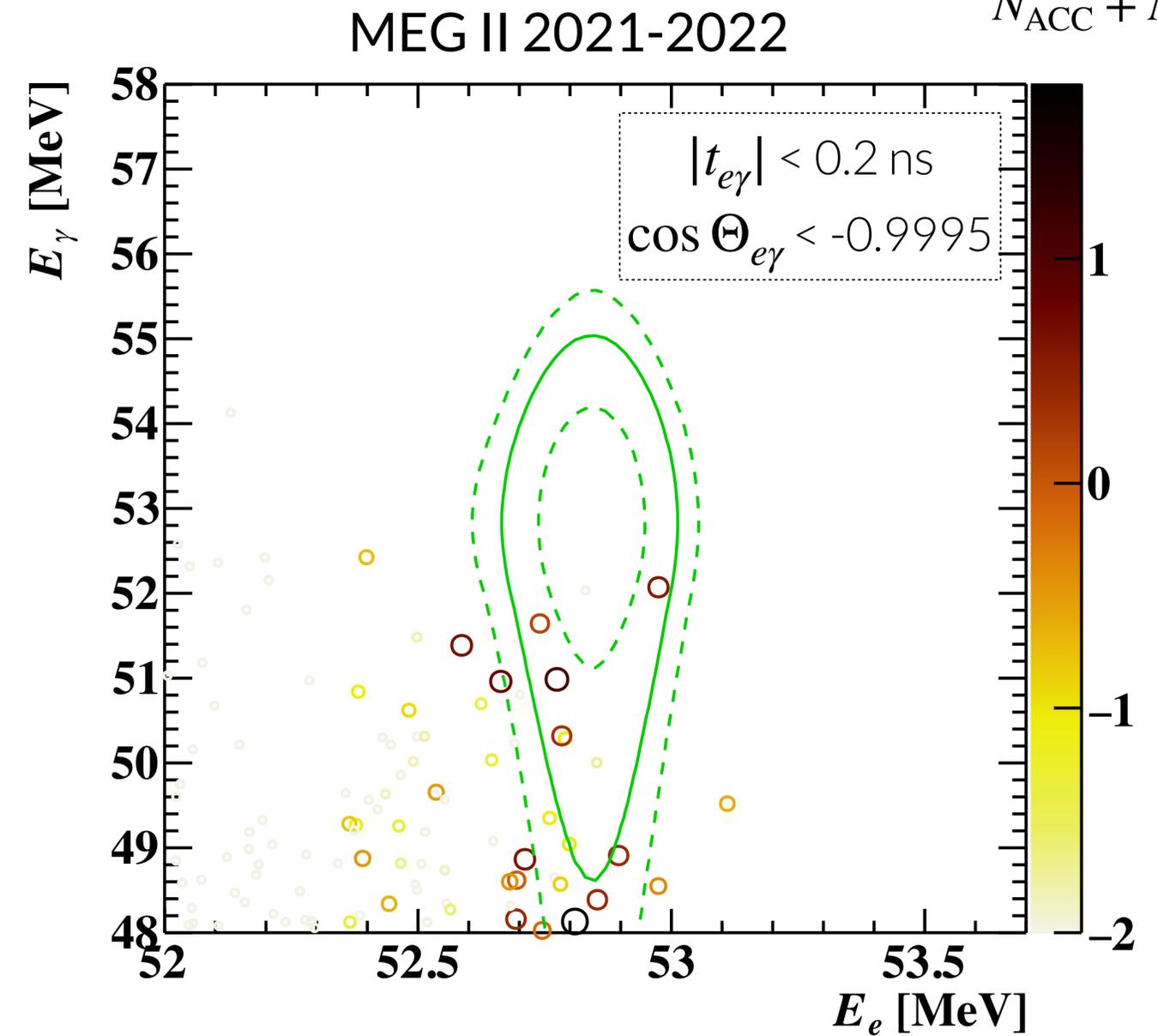
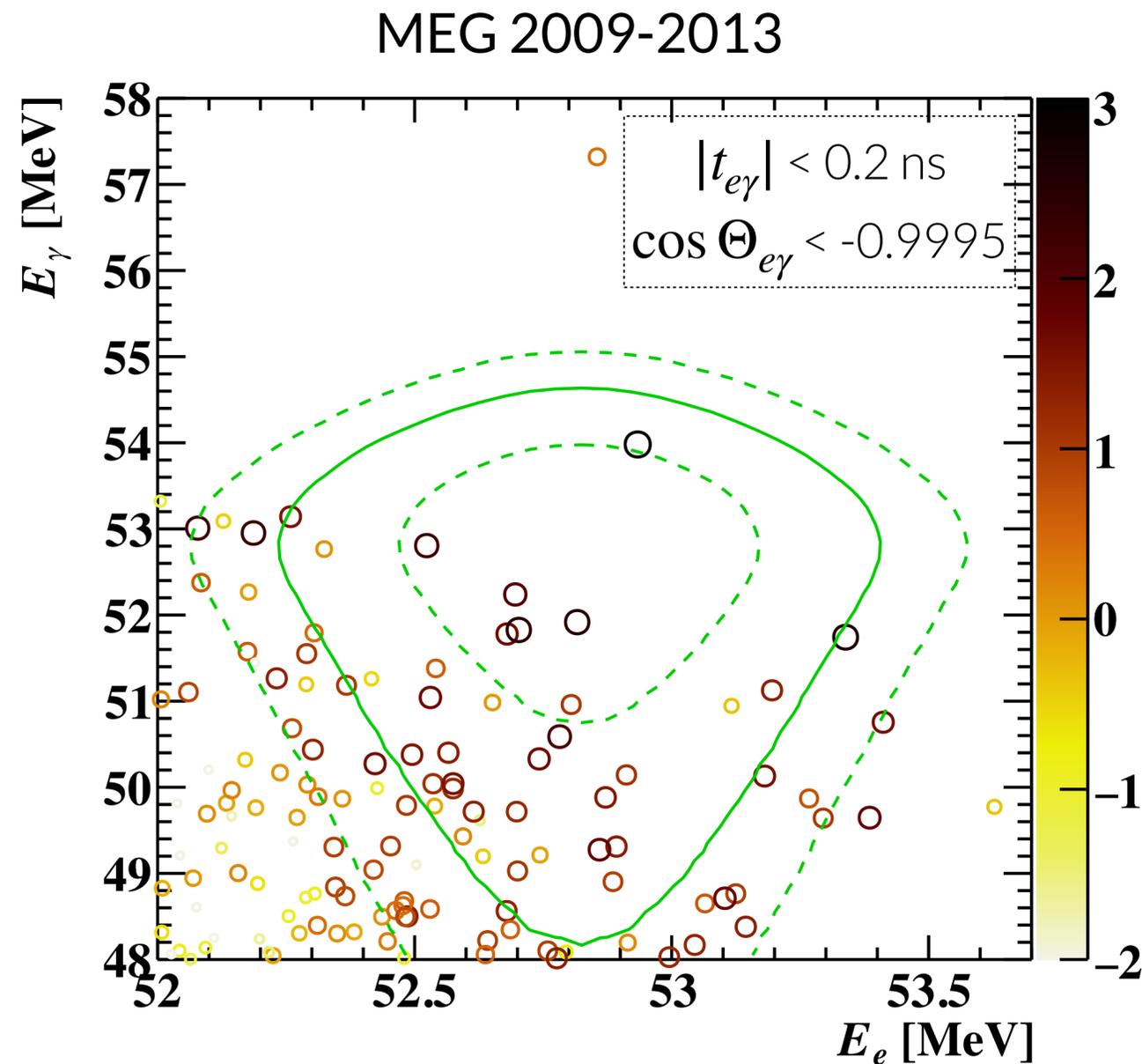
Unblind results: Event distribution

- Detector improvements reduced BG

Colour bar: Relative signal likelihood

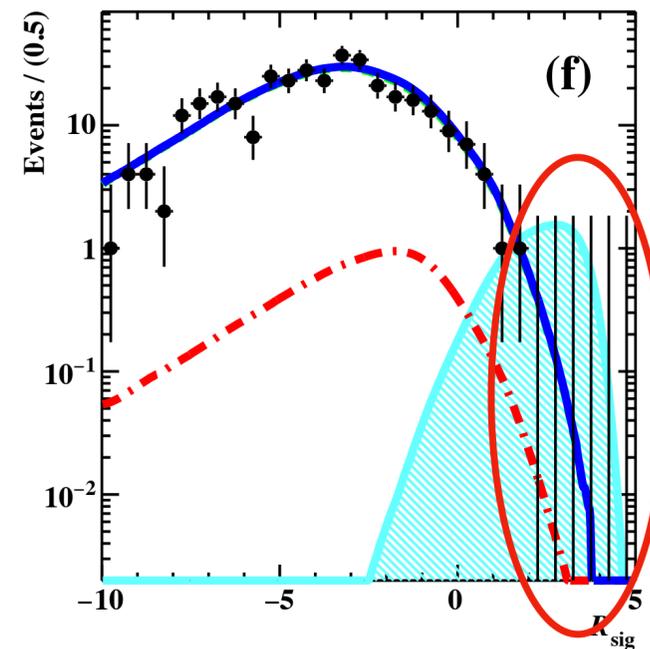
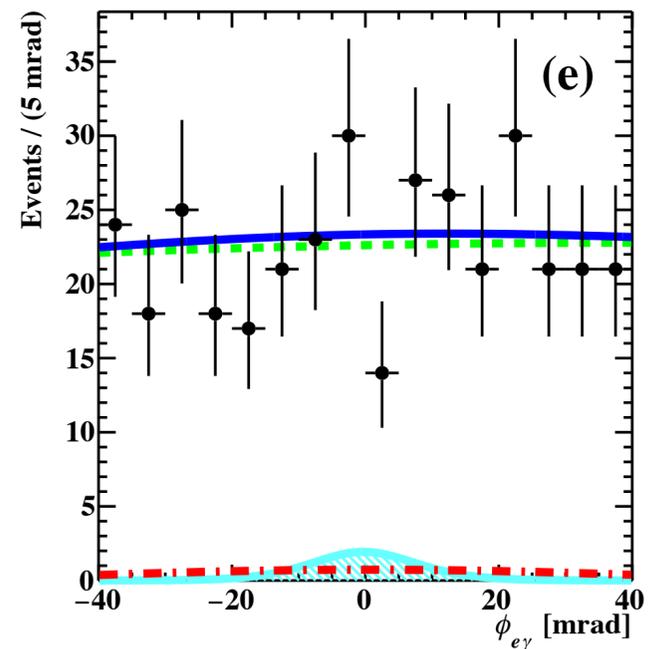
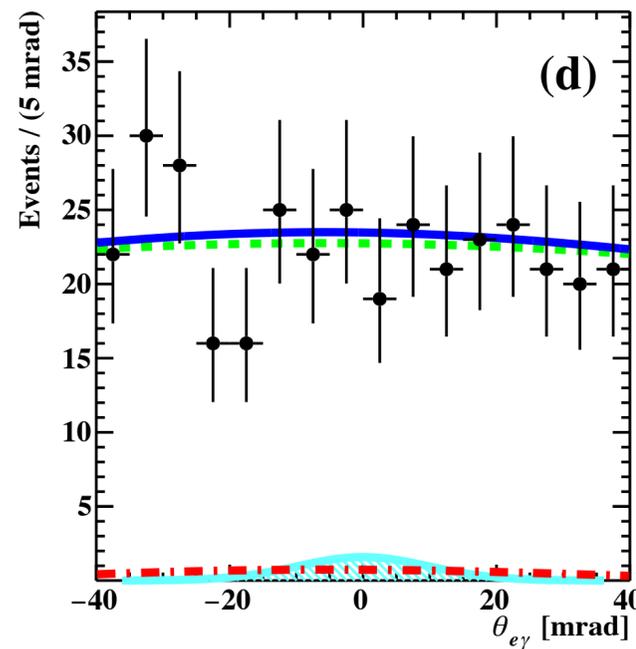
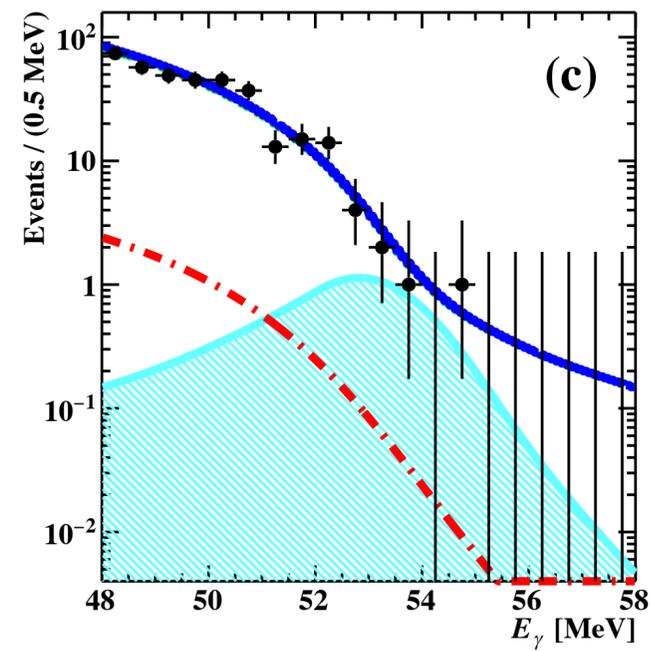
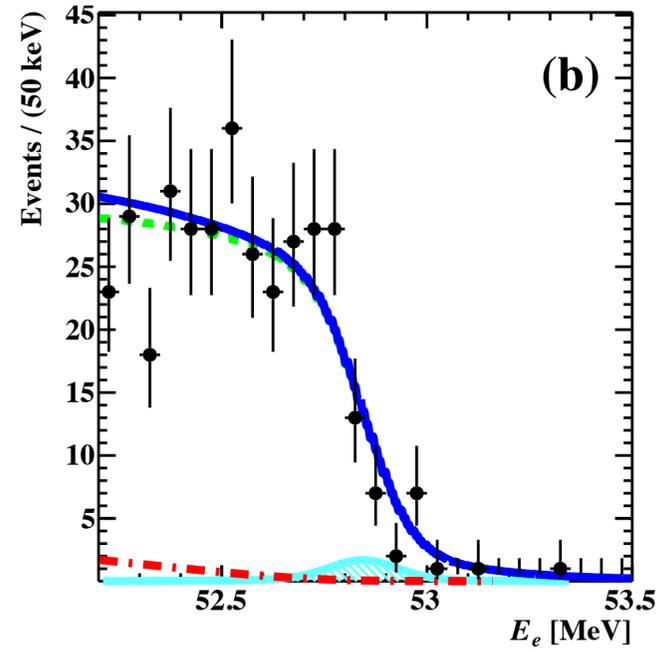
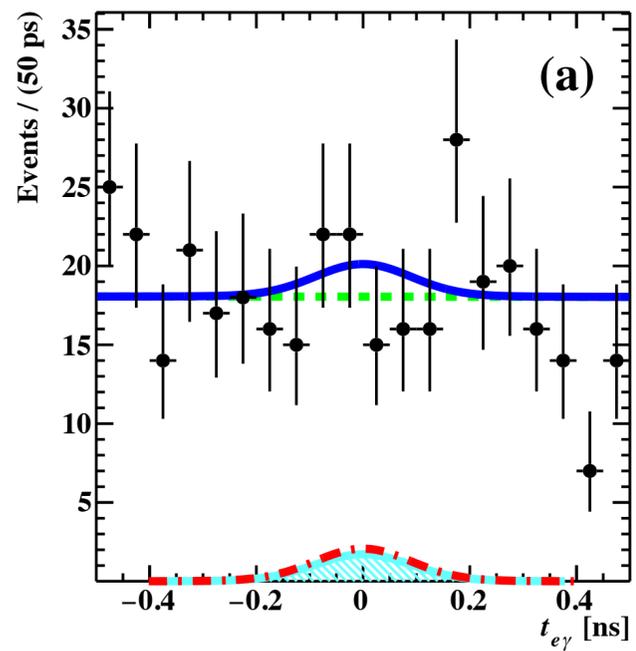
$$R_{\text{sig}}(\vec{x}_i) = \log_{10} \left(\frac{S(\vec{x}_i)}{(1-r) \cdot A(\vec{x}_i) + r \cdot R(\vec{x}_i)} \right)$$

$$r = \frac{N_{\text{RMD}}}{N_{\text{ACC}} + N_{\text{RMD}}}$$

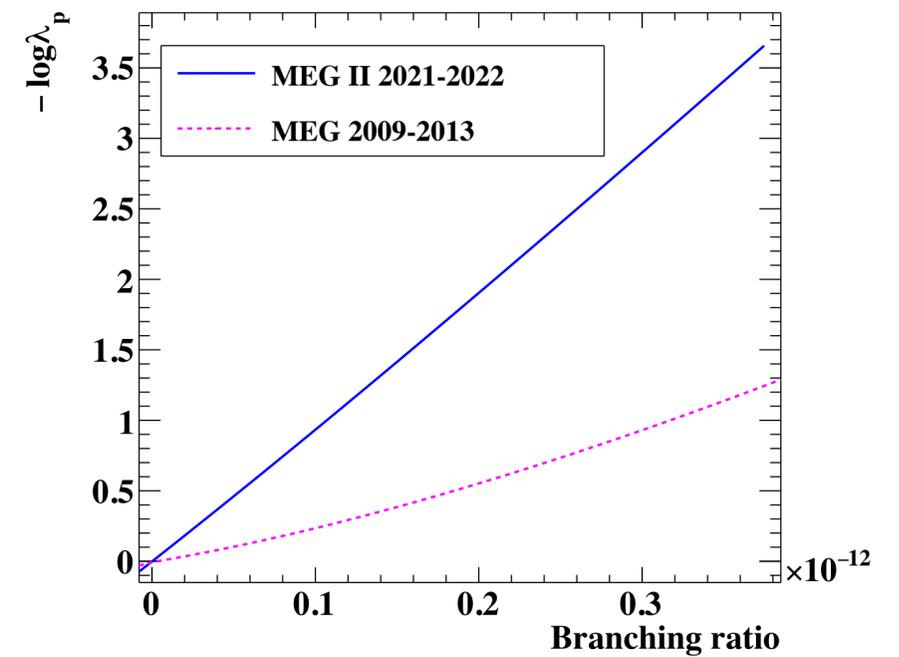


Unblind results: Fit results & confidence interval

Data (357 events), N_{sig} upper limit (2) x 4, N_{ACC} (360.9), N_{RMD} (9.7)

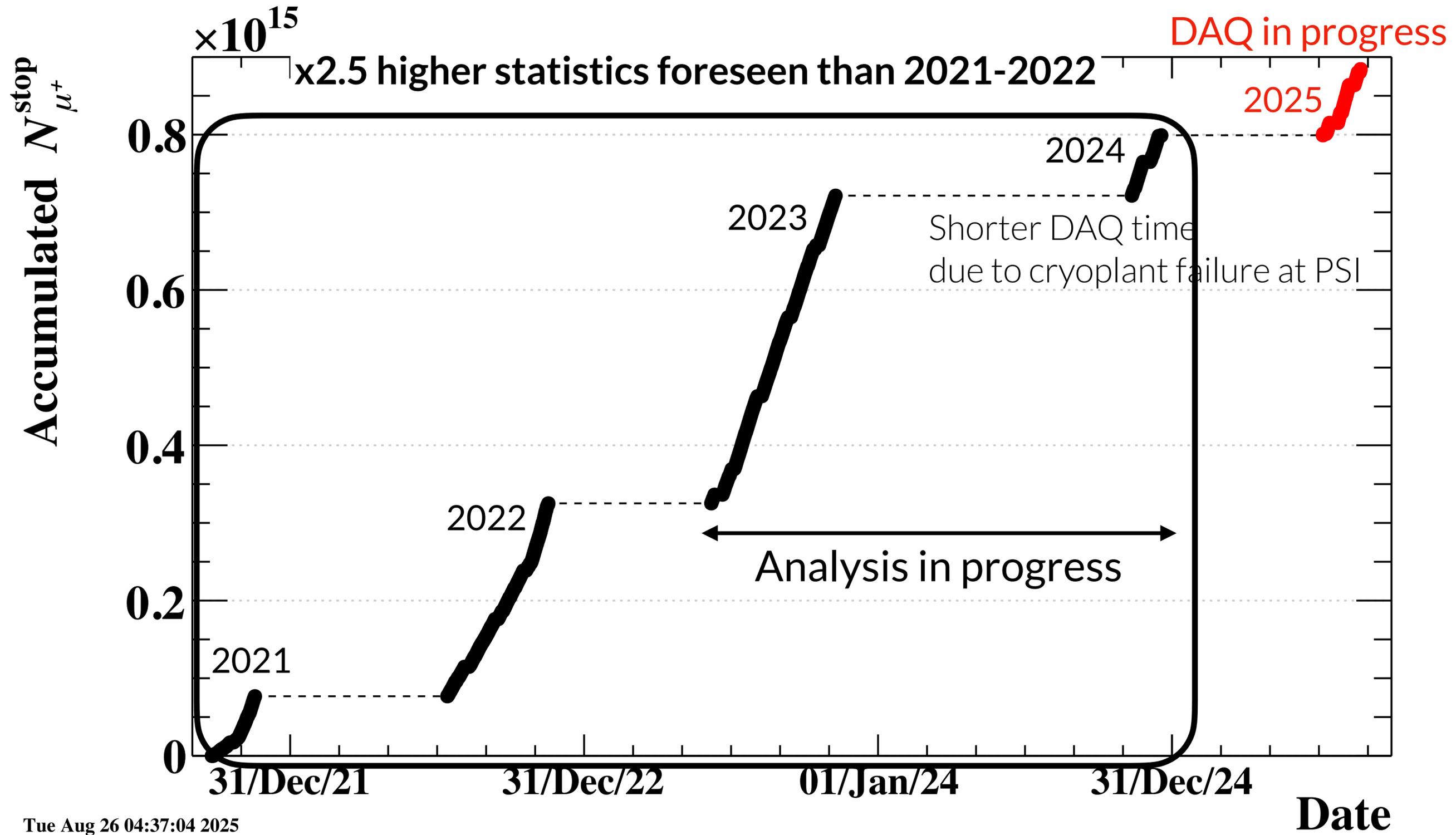


- $BR(\mu \rightarrow e\gamma) < 1.5 \times 10^{-13}$ (90% C.L.)
- Most stringent to date
- MEG: 4.2×10^{-13}



No event excess observed

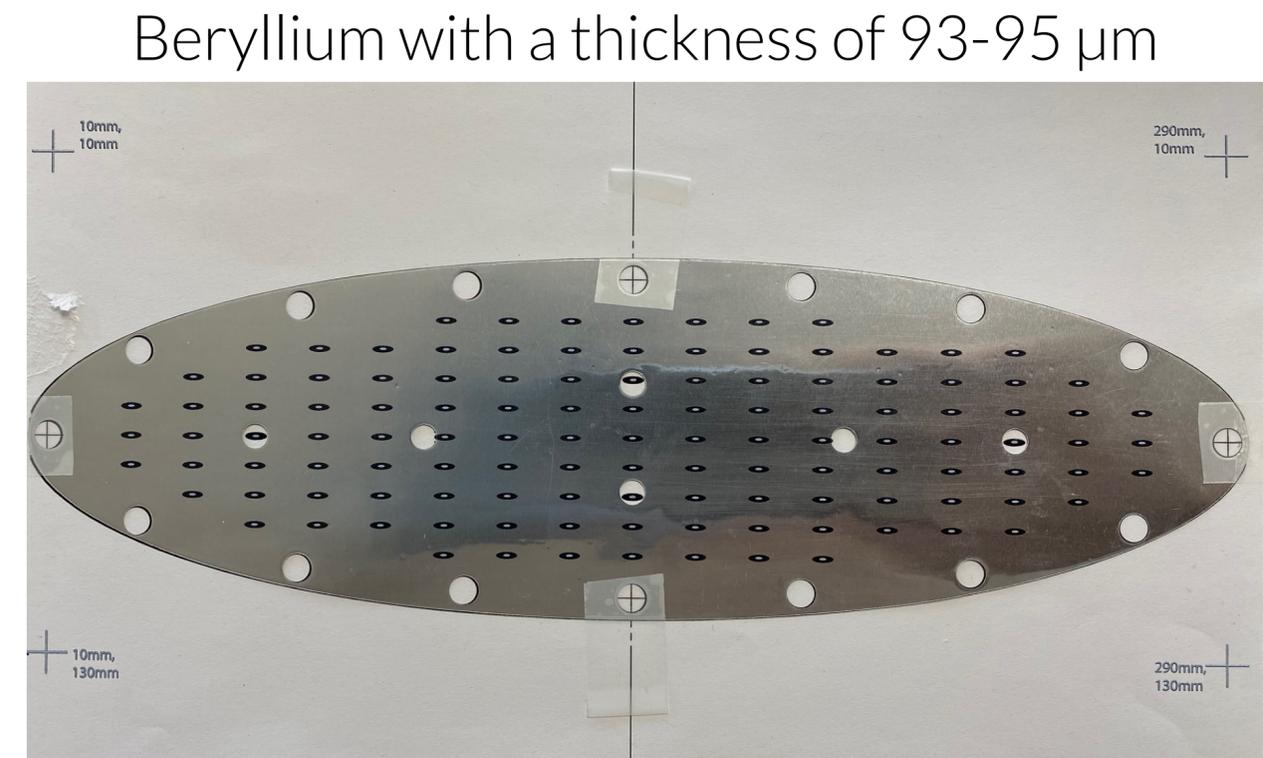
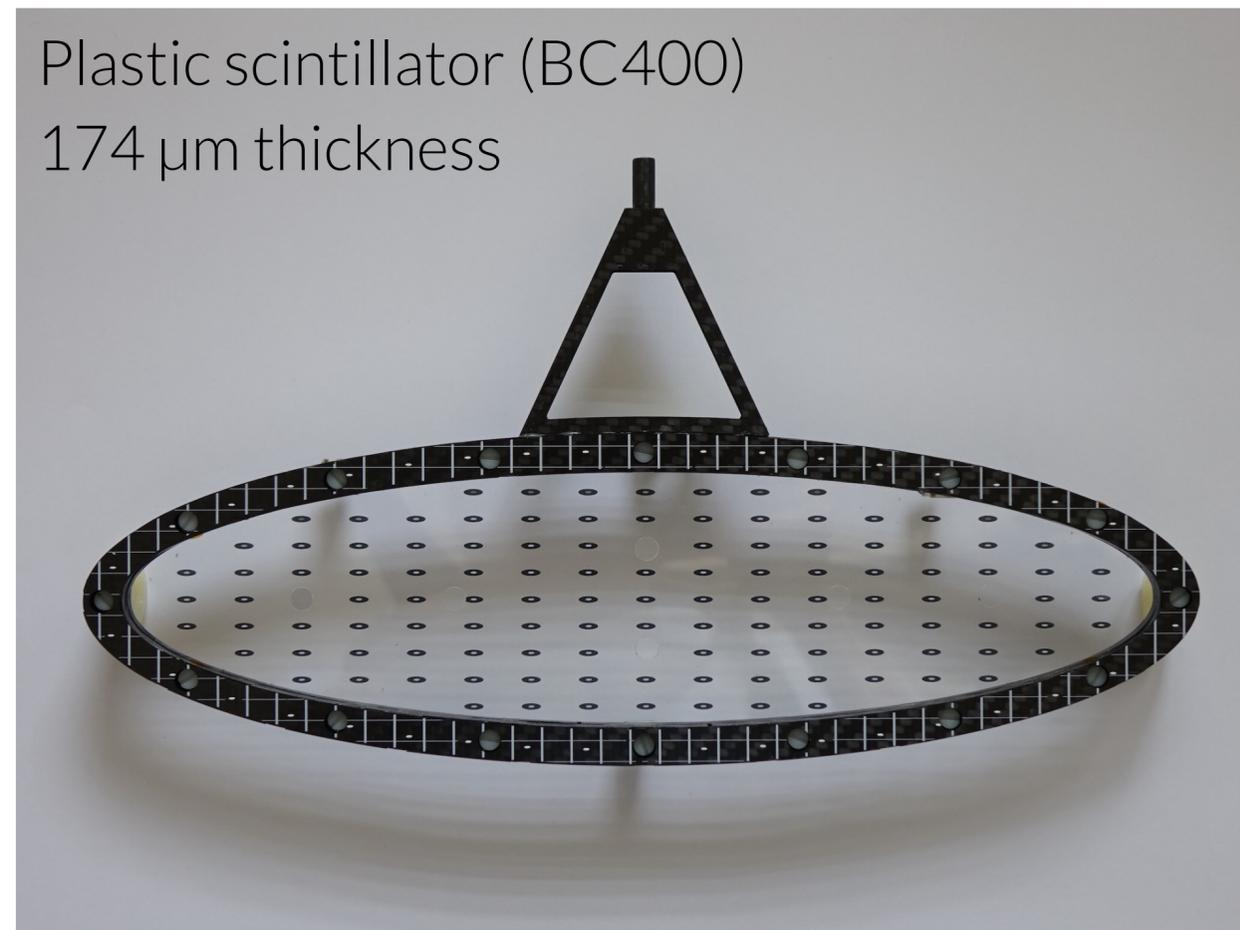
DAQ timeline



Tue Aug 26 04:37:04 2025

Exchange muon stopping target in 2025

- A source of systematic uncertainty: **Temporal variation of target deformation**
 - Another observation: Degree of deformation increased over the years
- **More rigid Beryllium target installed since run 2025**

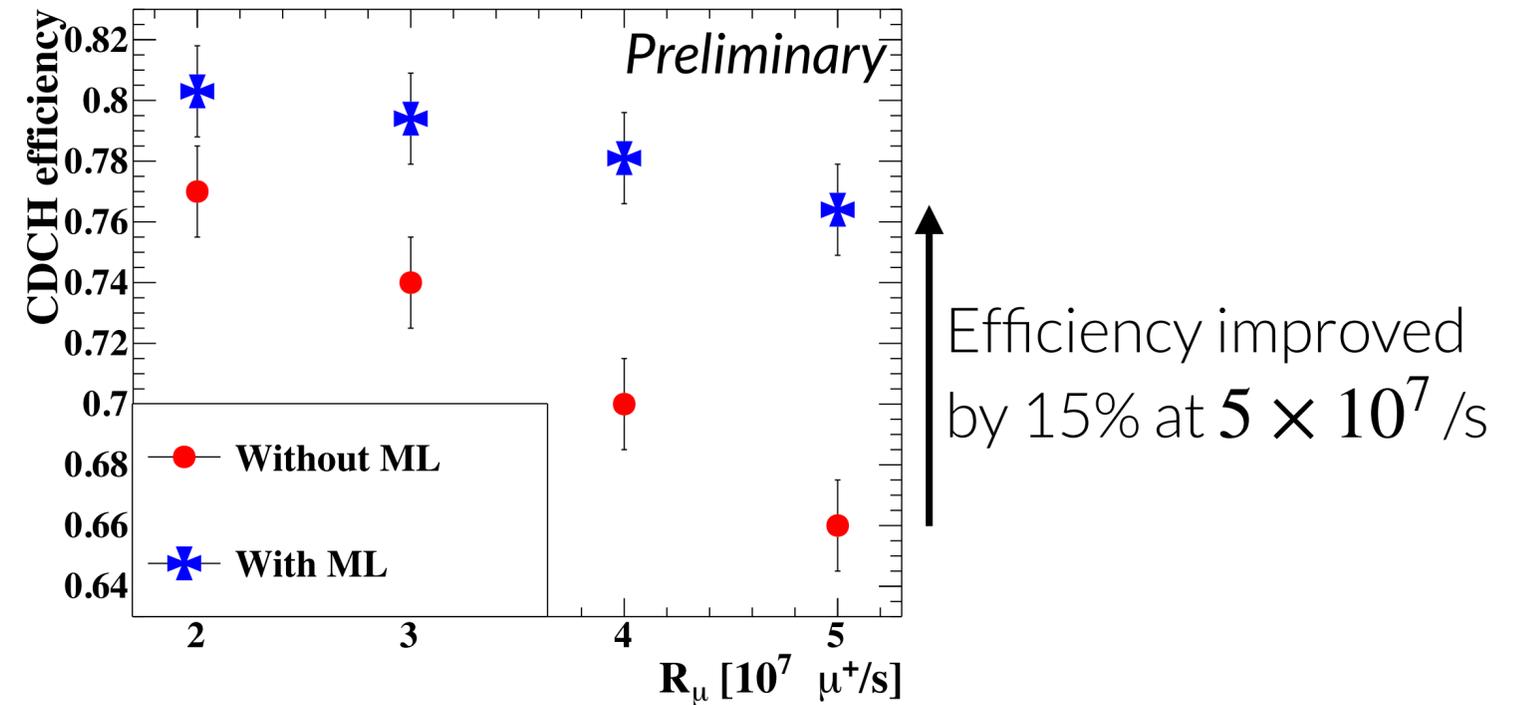


Foreseen analysis improvements

- Developing machine learning-based positron tracking

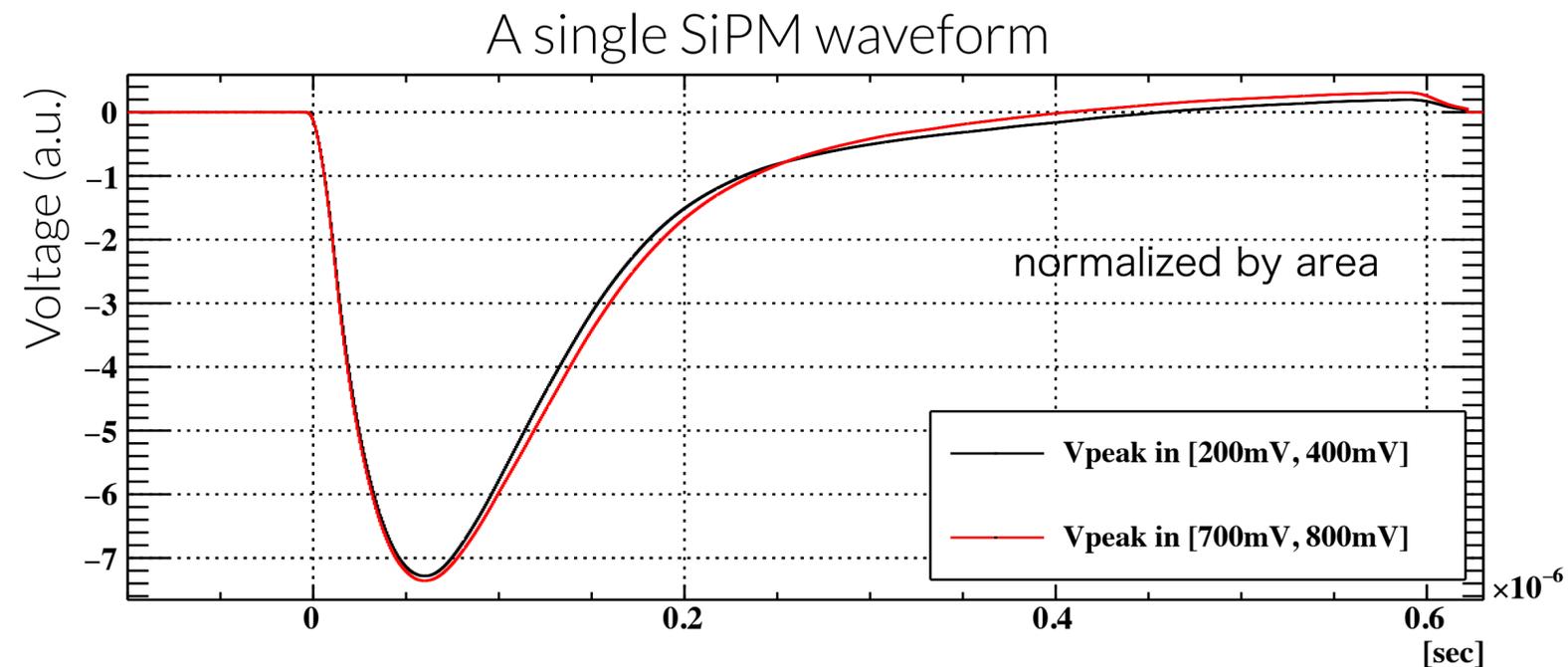
- Filter out pileup hits → Better track finding

→ Higher beam intensity: $4 \rightarrow 5 \times 10^7 \mu/s$ since this year



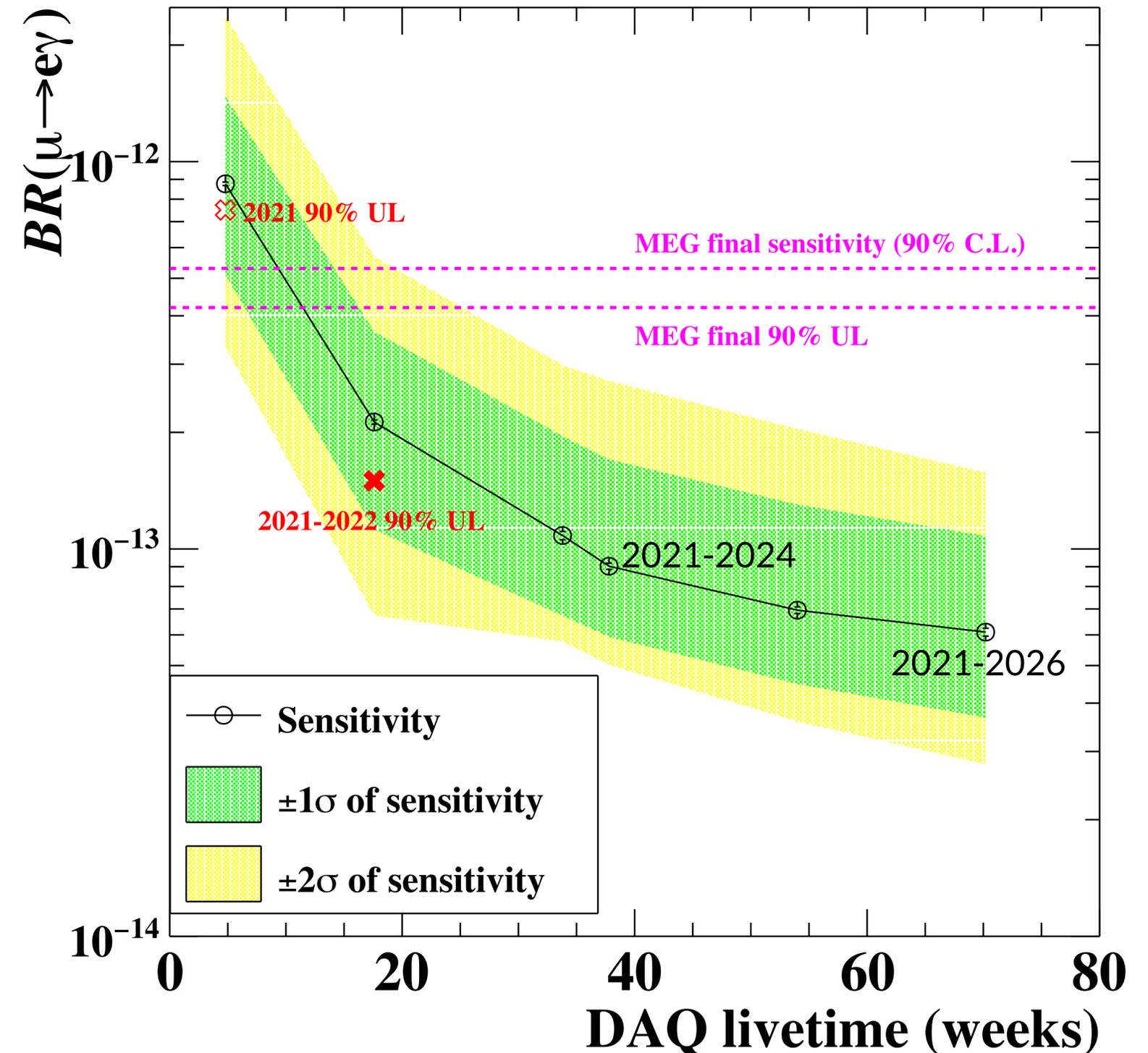
- Calibrating the non-linearity of SiPMs in the LXe detector

- Given LXe scintillation light emission time of 45 ns
- Expect energy resolution improvement for shallow events



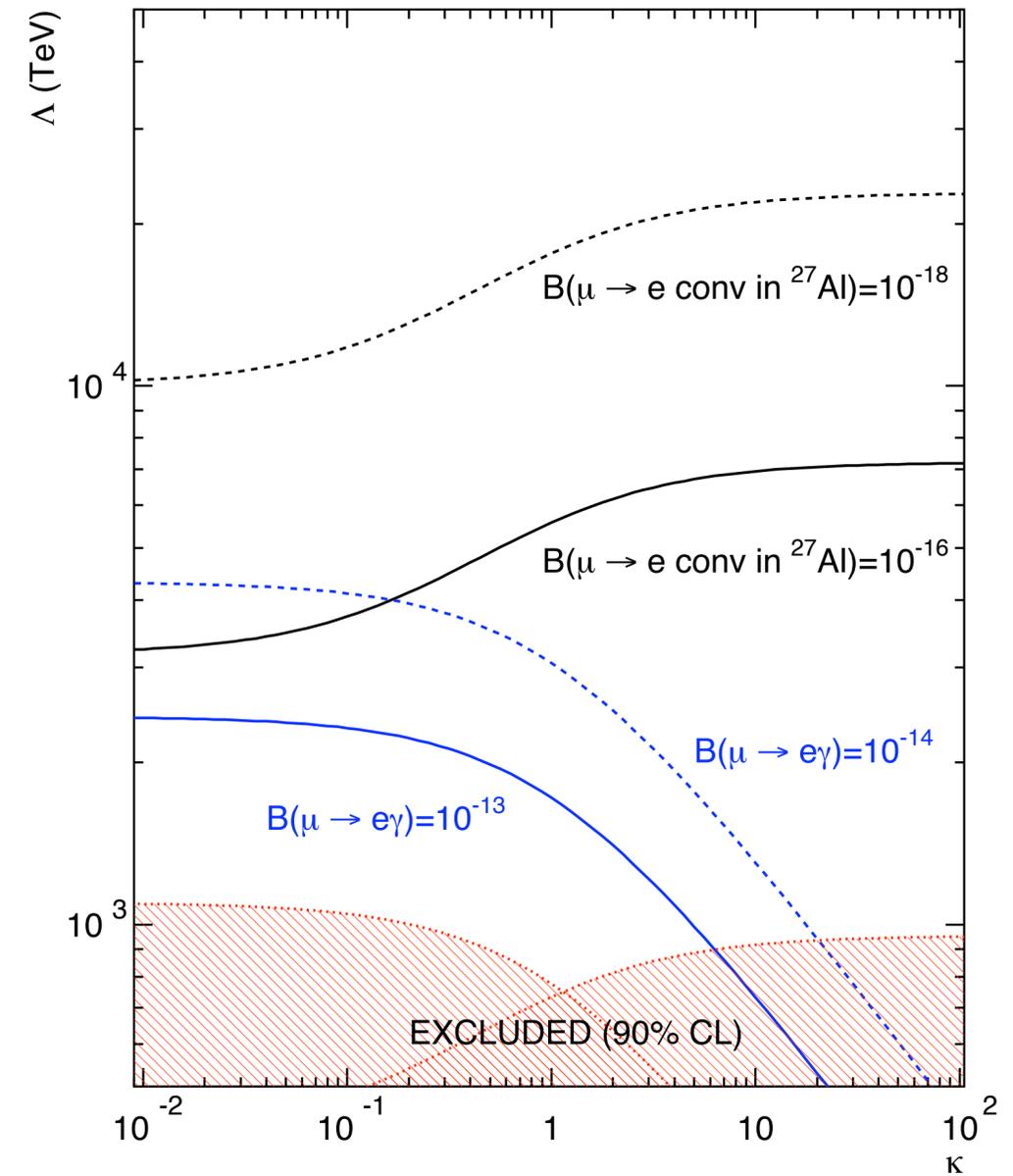
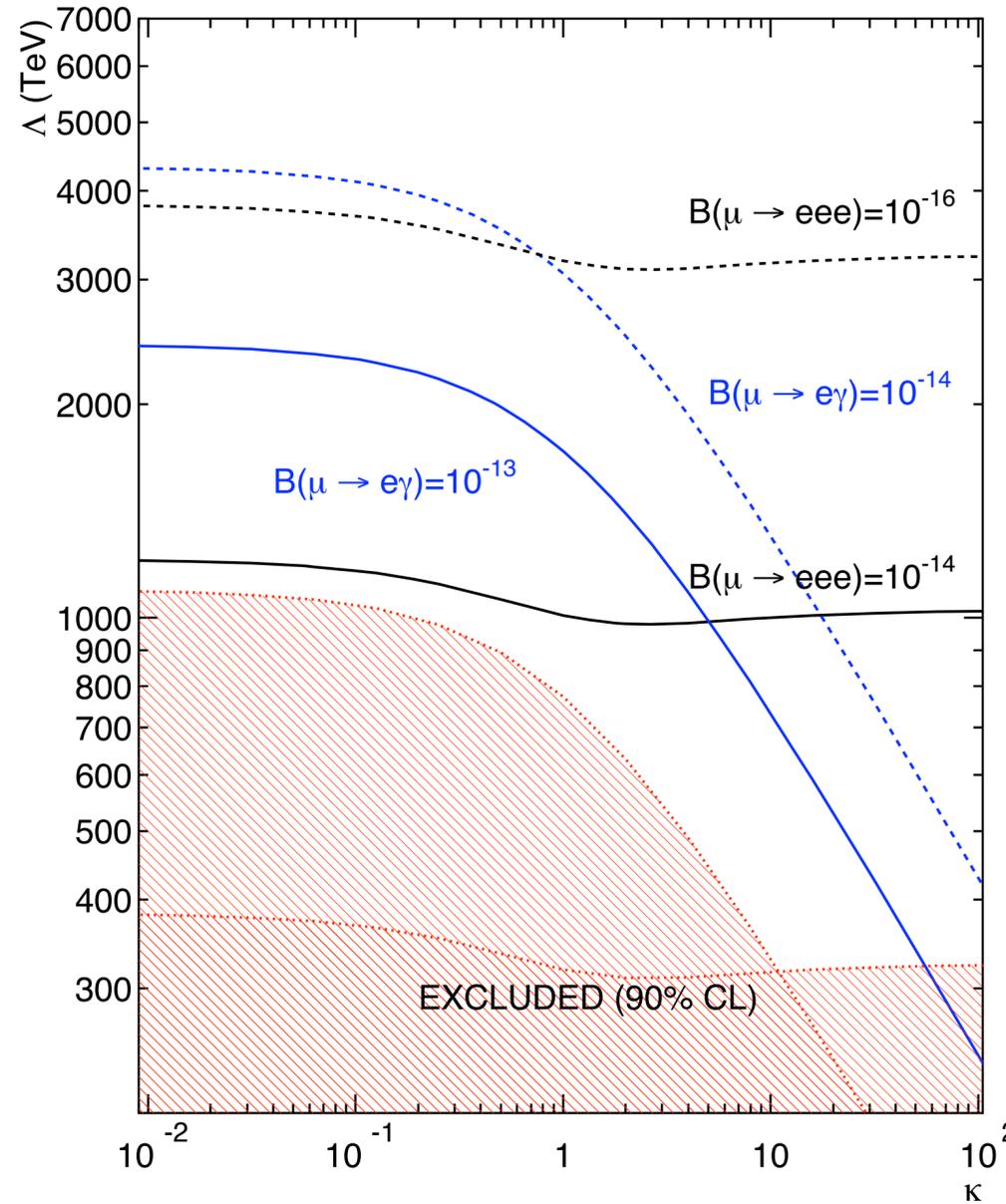
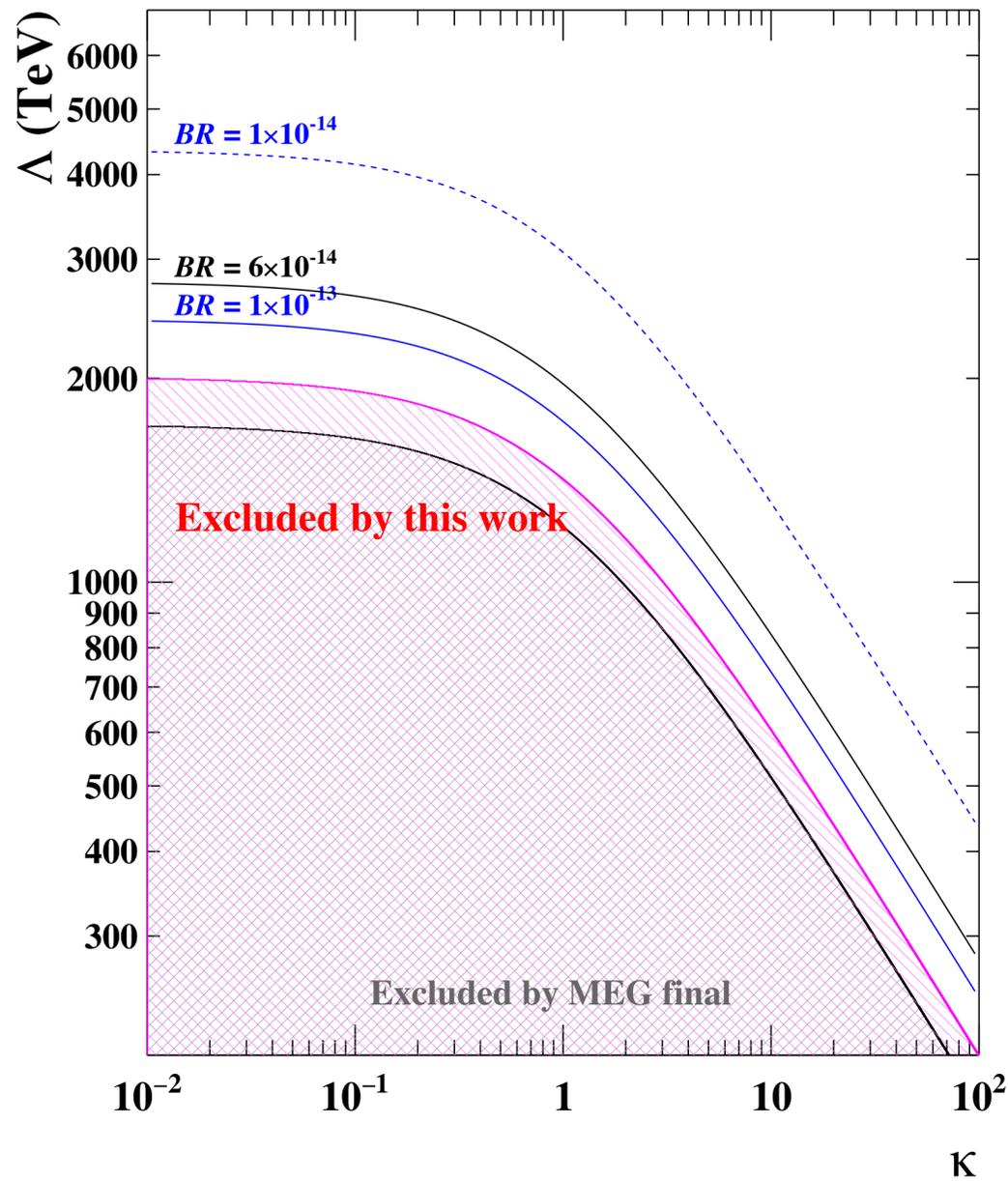
Conclusion and prospects

- The MEG II experiment has been taking physics data since 2021
- The latest result based on 2021-2022 dataset:
 - $BR(\mu \rightarrow e\gamma) < 1.5 \times 10^{-13}$ (90% C.L.)
 - Most stringent upper limit to date
- DAQ will continue until 2026, reaching a target sensitivity of 6×10^{-14}
 - Not only taking data, but also further improving analysis methods for better sensitivity than 6×10^{-14}



Backup

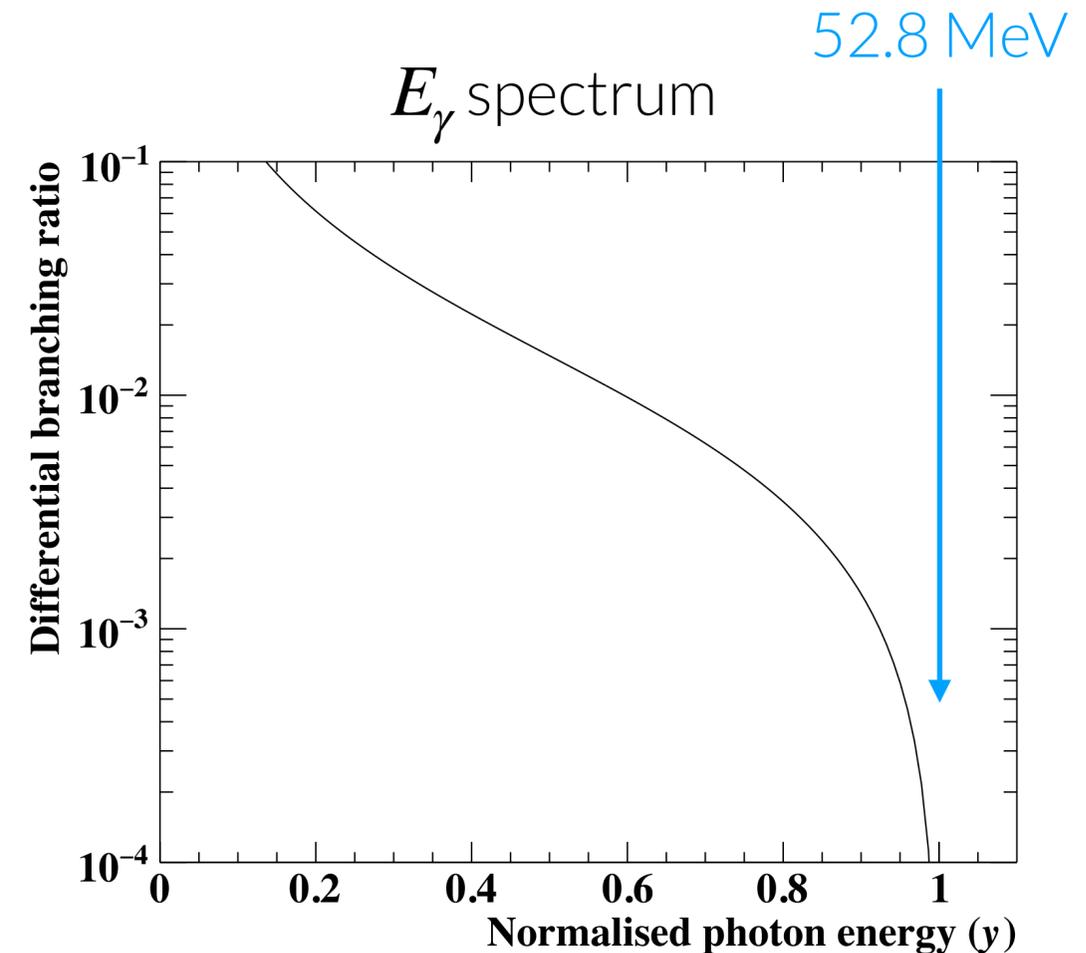
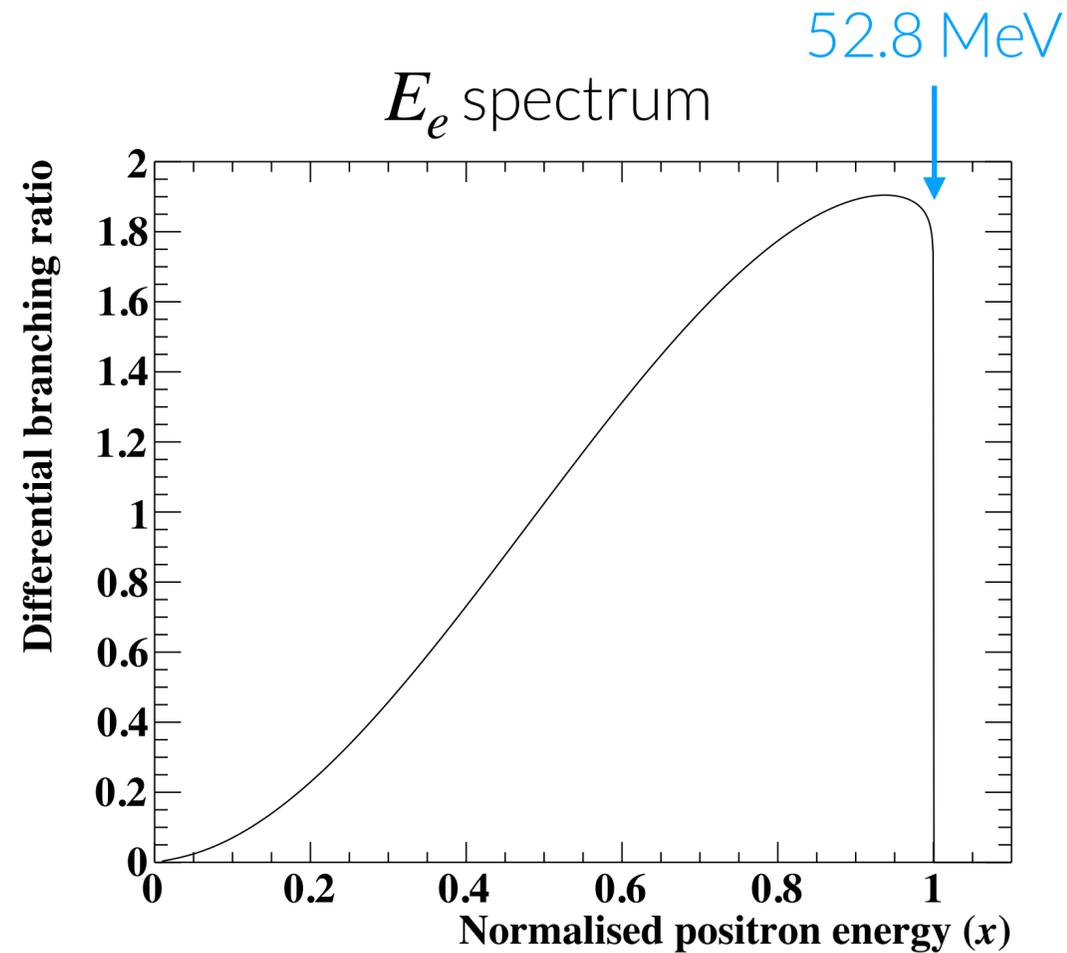
NP scale reached by cLFV searches



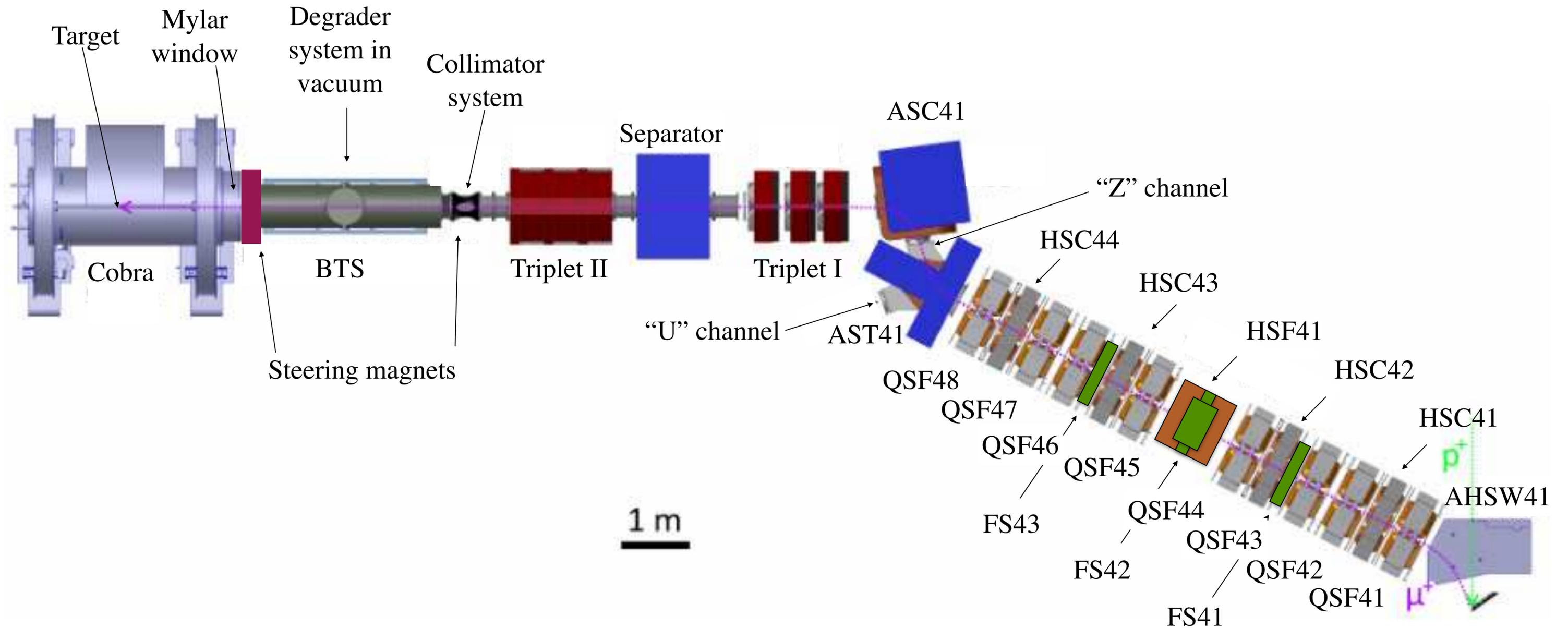
[A. De Gouvea, P. Vogel, Prog. Part. Nucl. Phys. 71 \(2013\) 75-92](#)

Signal and background

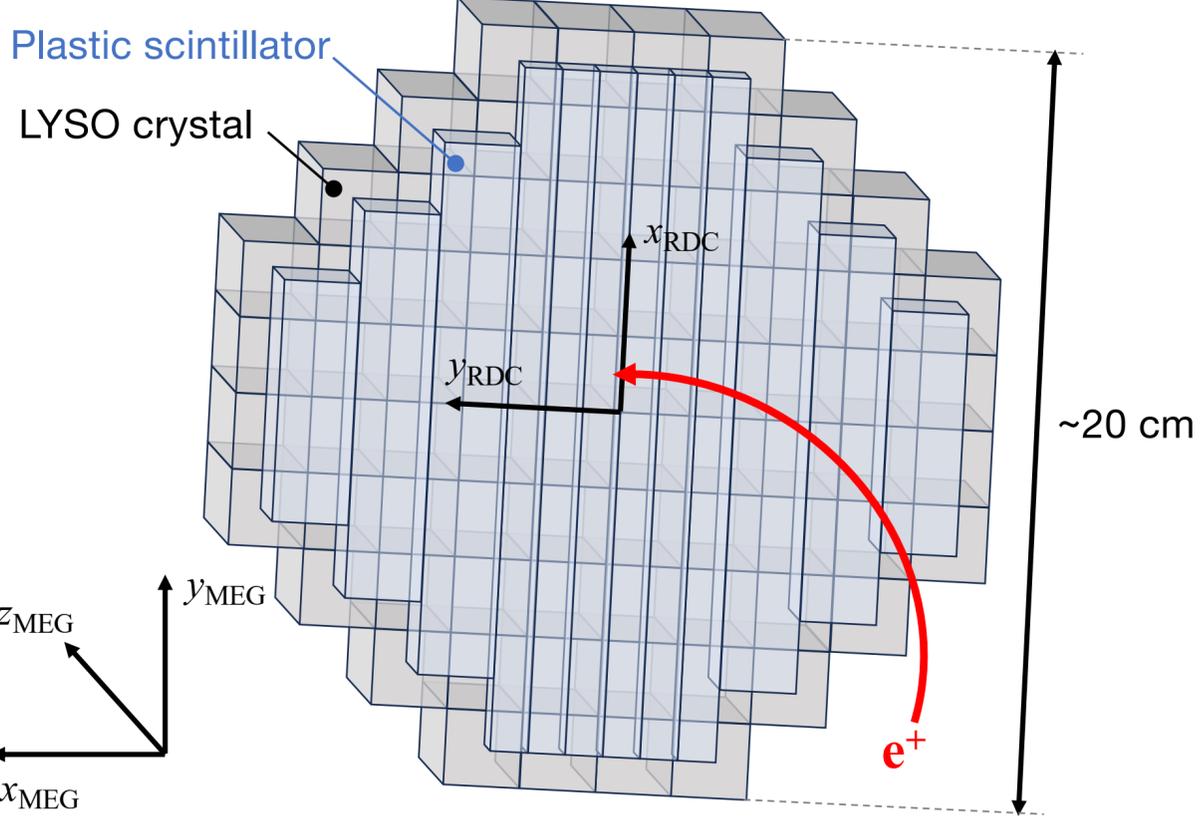
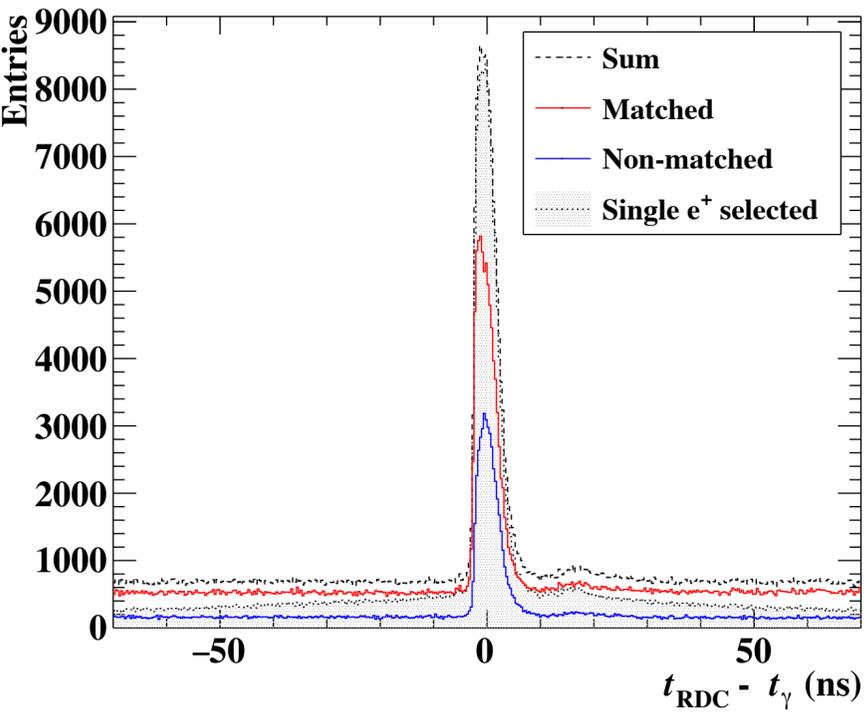
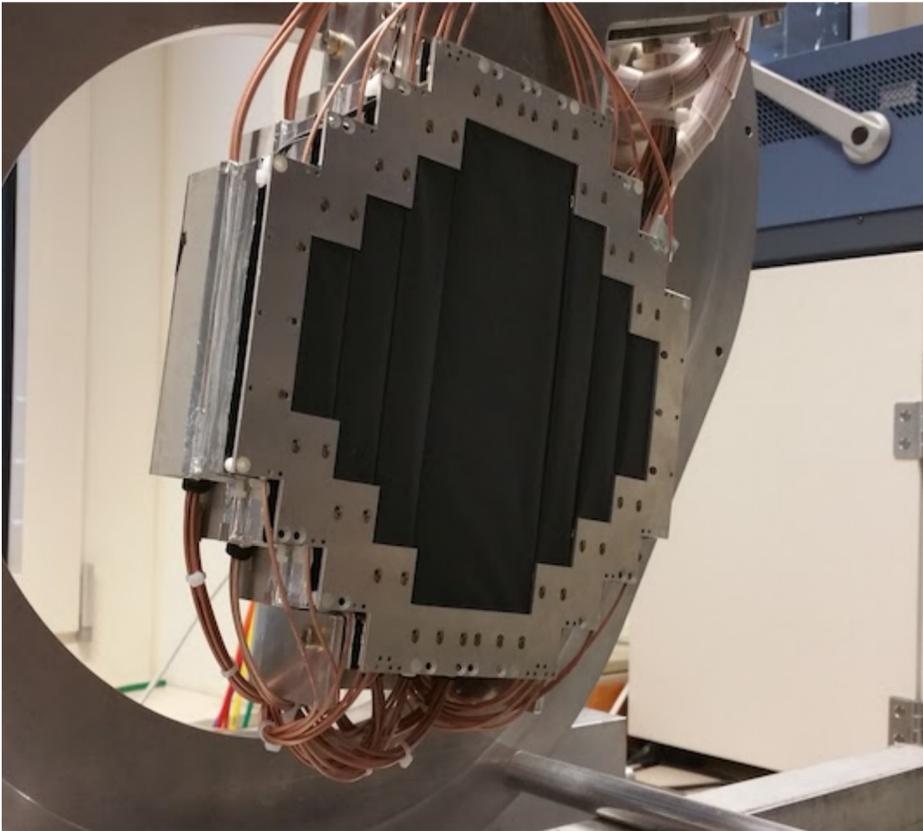
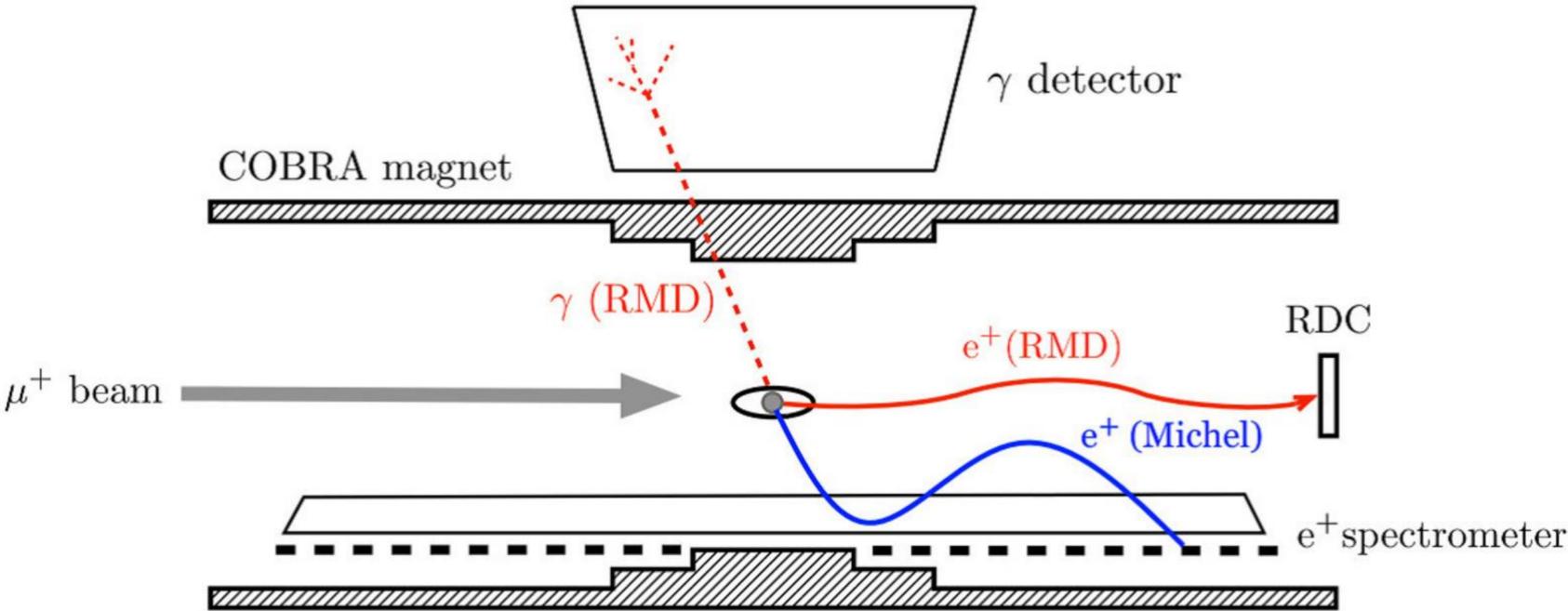
- $N_{\text{sig}} = R_{\mu} \cdot T \cdot \Omega \cdot \varepsilon \cdot BR(\mu \rightarrow e\gamma)$
- $N_{\text{ACC}} \propto R_{\mu}^2 \cdot T \cdot \sigma_{E_e} \cdot \sigma_{E_{\gamma}}^2 \cdot \sigma_{t_{e\gamma}} \cdot \sigma_{\Theta_{e\gamma}}^2$



Beamline

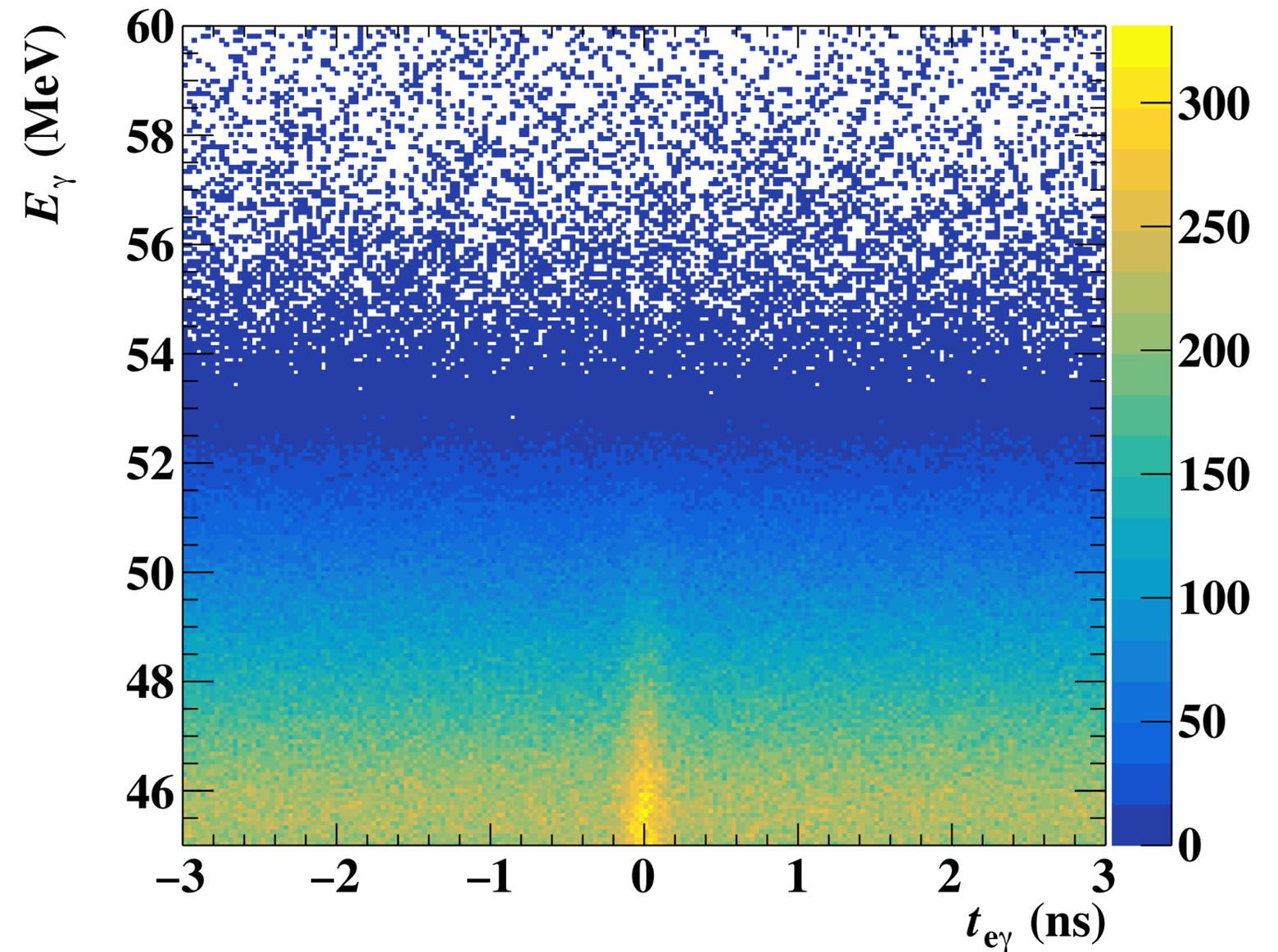


Radiative decay counter

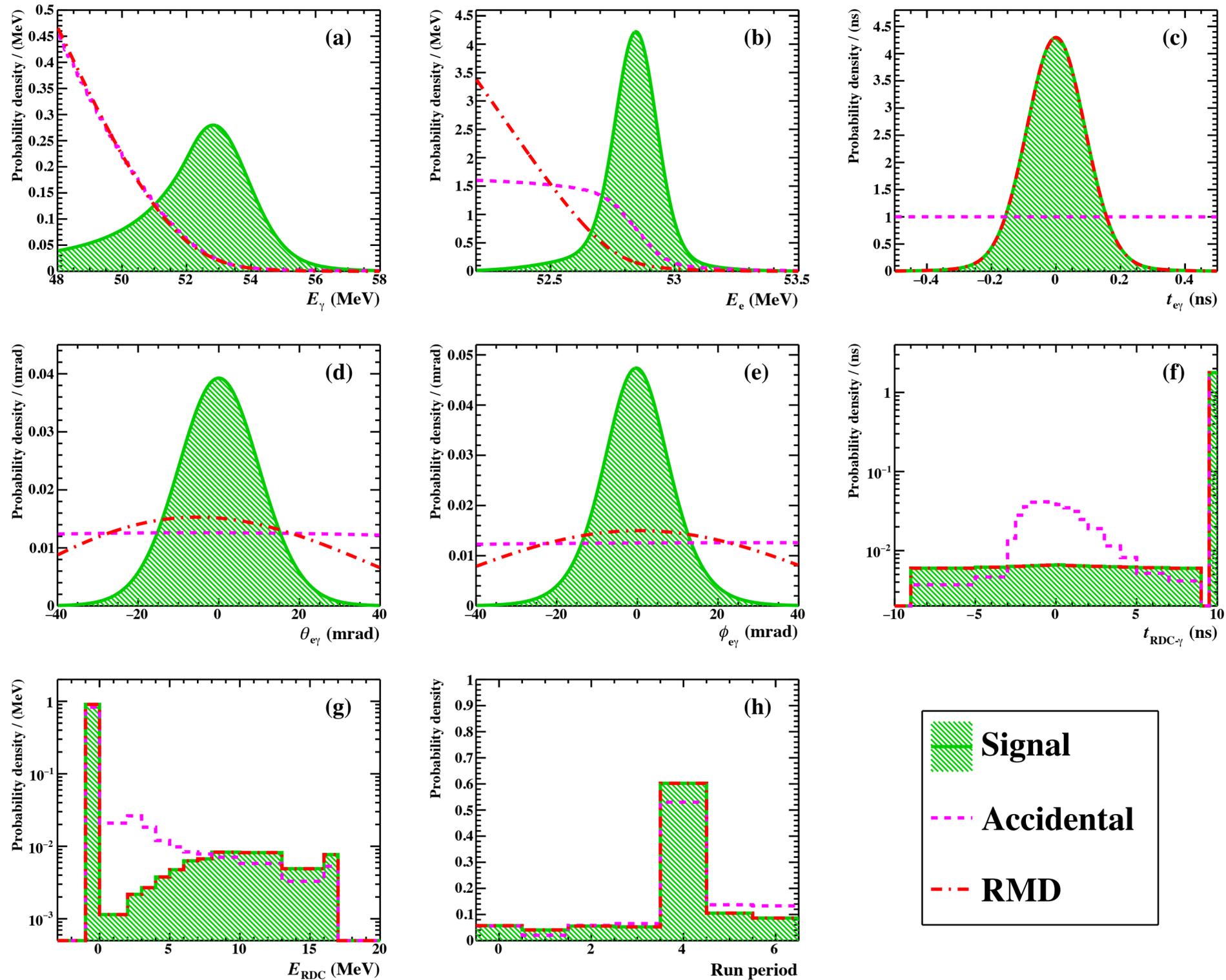


Analysis window

- $48 \text{ MeV} < E_\gamma < 58 \text{ MeV}$
- $52.2 \text{ MeV} < E_e < 53.5 \text{ MeV}$
- $|t_{e\gamma}| < 0.5 \text{ ns}$
- $|\theta_{e\gamma}| < 40 \text{ mrad}$
- $|\phi_{e\gamma}| < 40 \text{ mrad}$



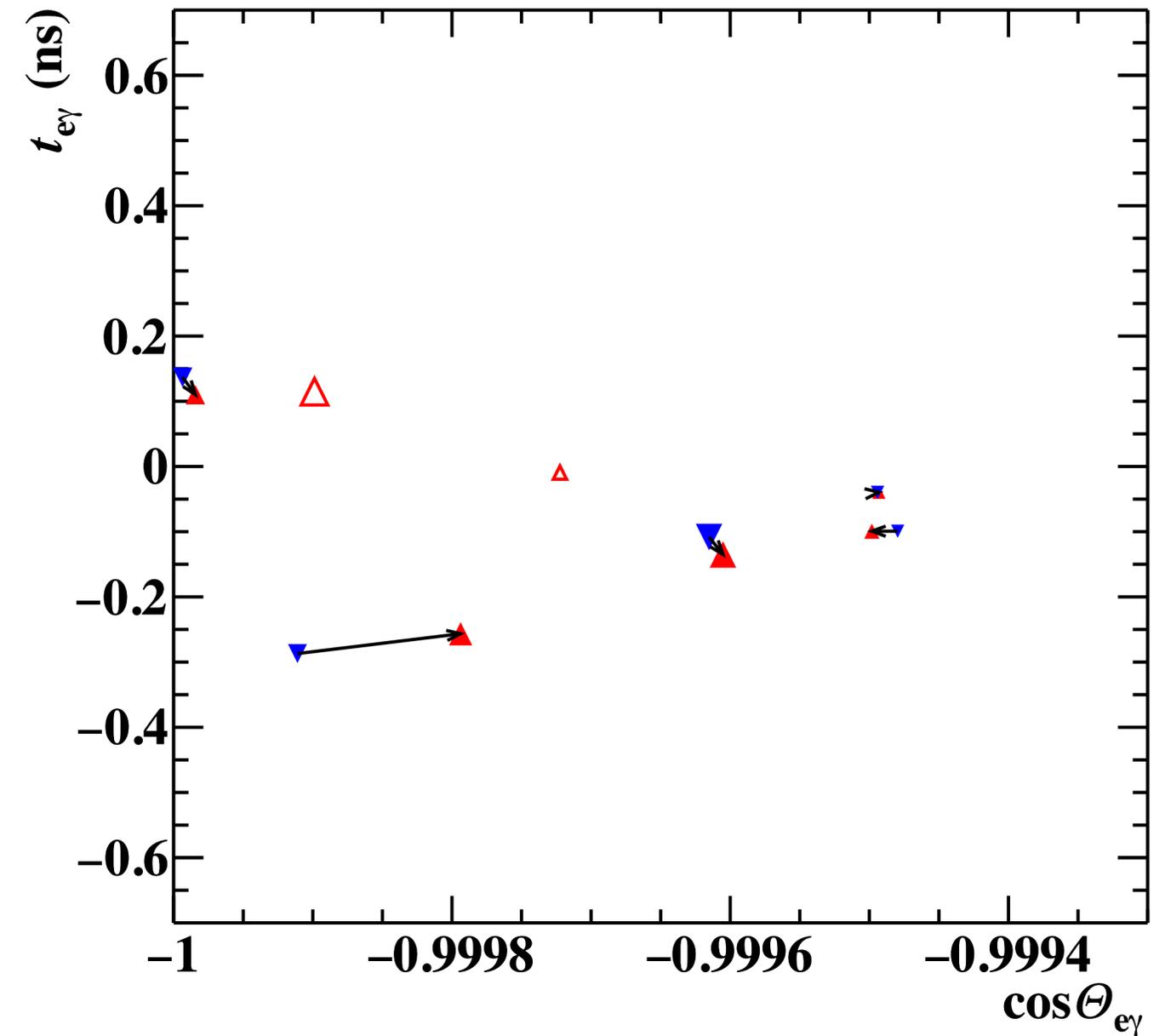
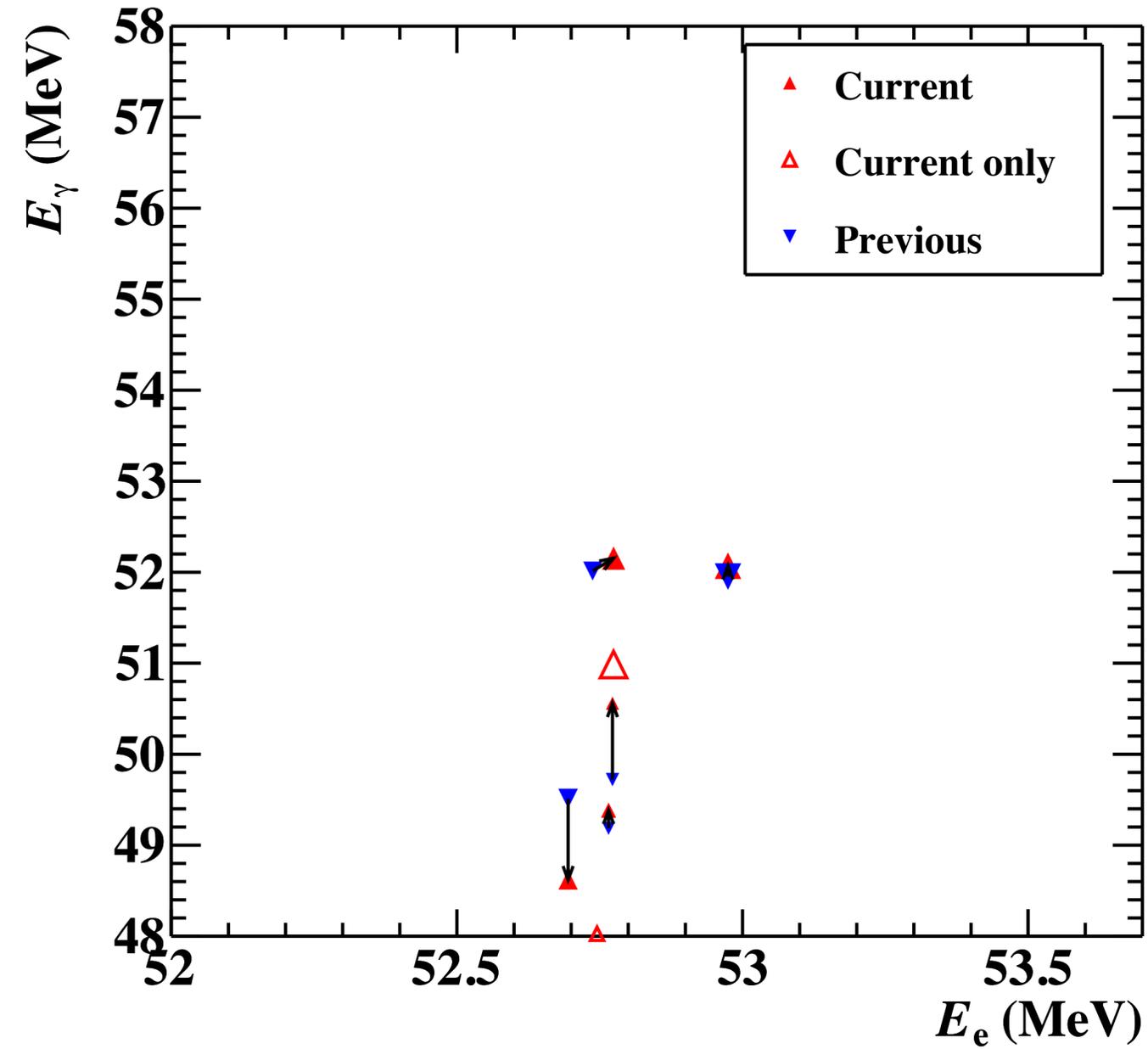
PDF projection



Systematic uncertainty

Source	Impact on sensitivity
Angle (including both $\theta_{e\gamma}$ and $\phi_{e\gamma}$) uncertainty	1.4 ‰
E_γ uncertainty	1.0 ‰
Normalisation uncertainty	0.4 ‰
E_e uncertainty	0.1 ‰
$t_{e\gamma}$ uncertainty	< 0.1 ‰
RDC uncertainty	< 0.1 ‰
Total	3 ‰

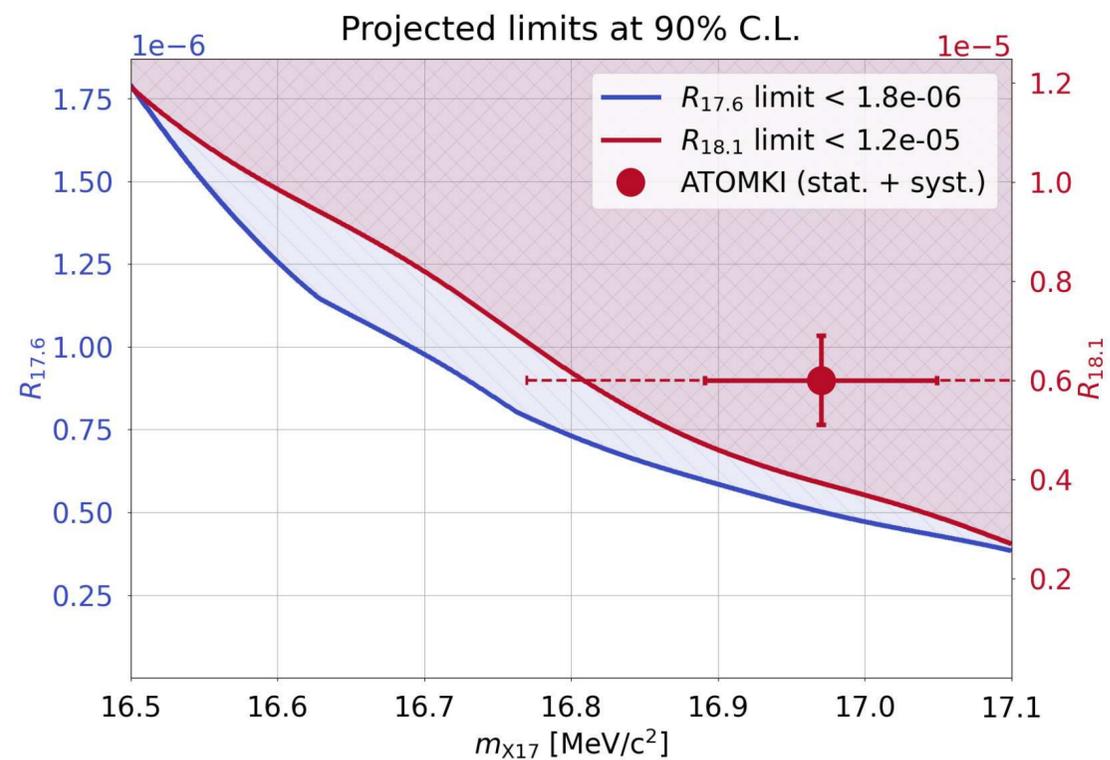
2021 data



Other physics opportunities in MEG II

X17 boson search

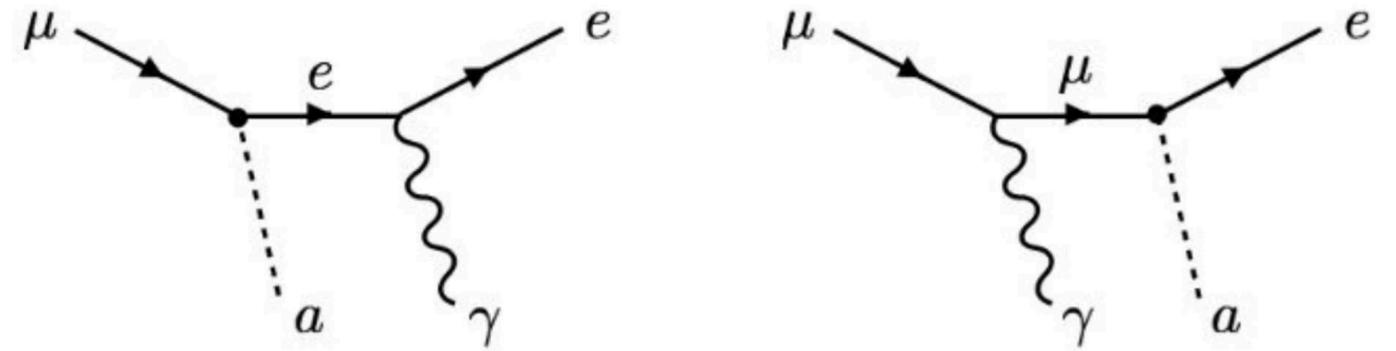
- Hypothetical X17 boson reported by ATOMKI to be checked/excluded
- No significant excess observed
- Compatibility with ATOMKI result $\sim 6.2\%$ (1.5σ)



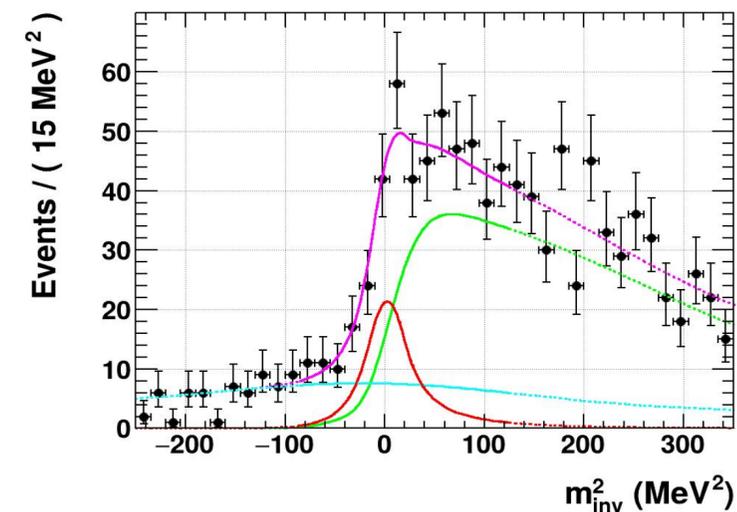
[Eur. Phys. J. C 85 \(2025\), 763](#)

ALP search via $\mu^+ \rightarrow e^+ a \gamma$

- Search for a peak in missing mass distribution
- Dedicated data acquisition with relaxed trigger conditions



toy with 100 **signal** events



toy with no **signal** events

