MEG II実験での$\mu \to e\gamma$探索解析の現状
－2021年解析の結果と2022年陽電子データの状況－

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2024年日本物理学会春季大会

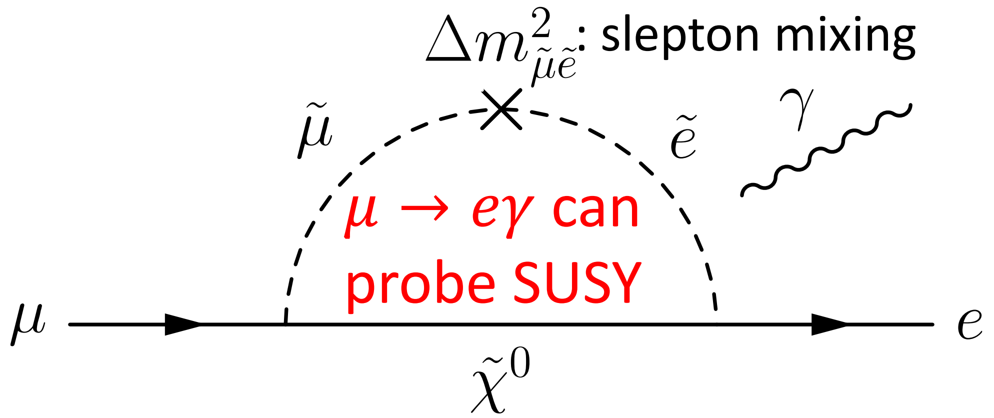
Outline

- Introduction
- Result of 2021 data analysis
- Ongoing analysis with 2022 data
- Summary and prospect

Introduction

$\mu \to e\gamma$ search: Motivation and Principle

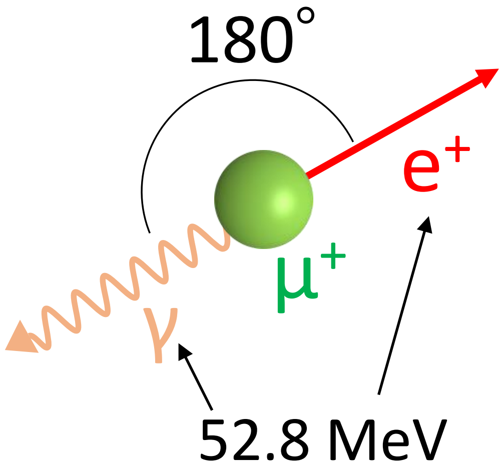
- $\mu \to e\gamma$ search by MEG II
  - $\mu \to e\gamma$: CLFV decay, forbidden in SM
  - Target sensitivity: Br($\mu \to e\gamma$) ~ $\mathbf{6 \times 10^{-14}}$
    → Can probe O(10 TeV) physics



- Search strategy

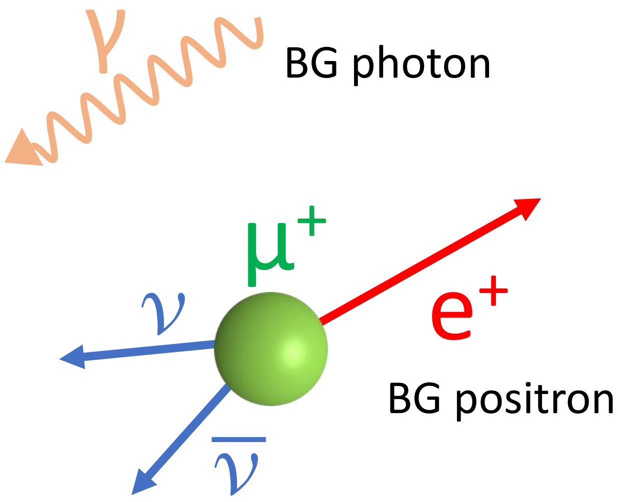
Signal

2-body kinematics



Background

Accidental coincidence



	Signal	Background
$\boldsymbol{E_e}$	52.8	< 52.8
$\boldsymbol{E_\gamma}$	52.8	< 52.8
$\boldsymbol{t_{e\gamma}}$	0	Flat distribution
$\boldsymbol{\Theta_{e\gamma}}$	180°	No correlation

Requirements to have high S/B

1. Continuous & High-rate muon beam
2. High resolution measurement

MEG II detector (muon & positron)

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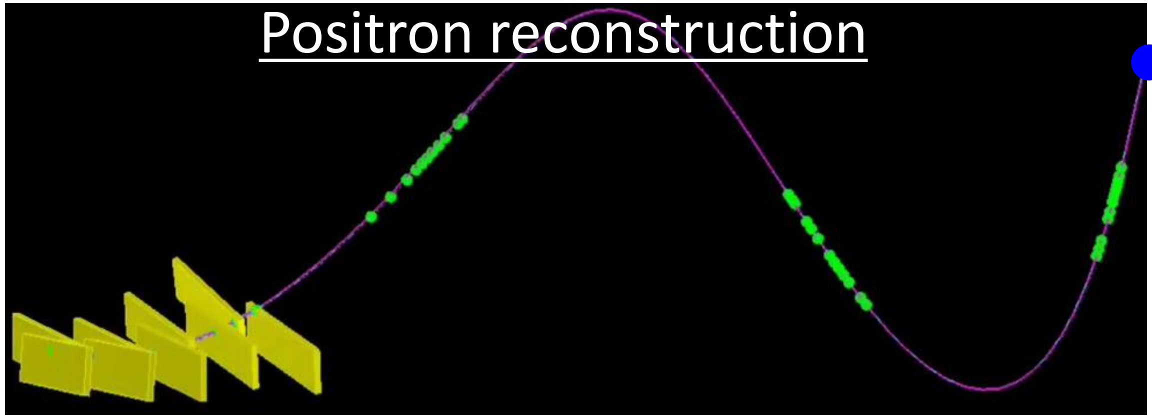
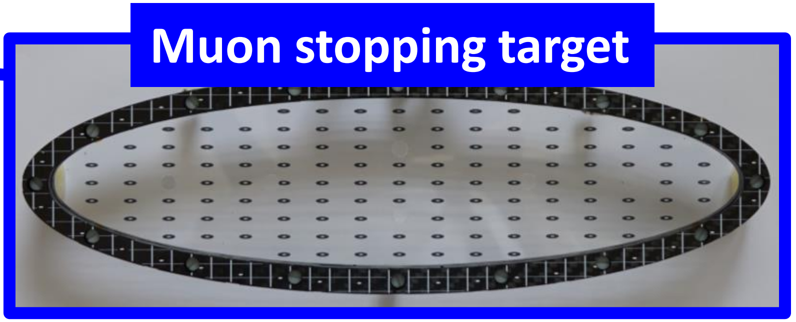
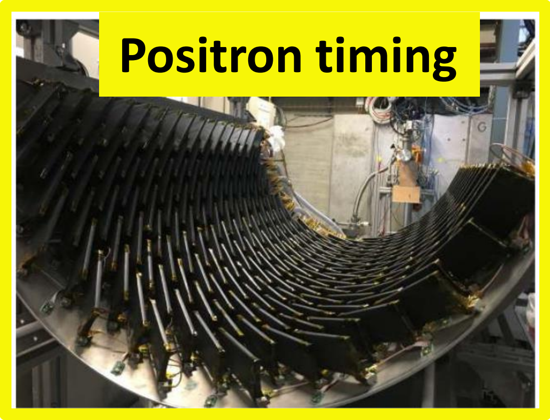




- 175 μm-thick plastic scintillator
- Stops muons at $3 - 5 \times 10^7$ /s rate
- Placed with 15° slant angle w.r.t beam



Positron spectrometer
- **Gradient B-field**
- **Drift chamber for tracking**
- **Scintillation timing counter**

→ See also 21aT1-1

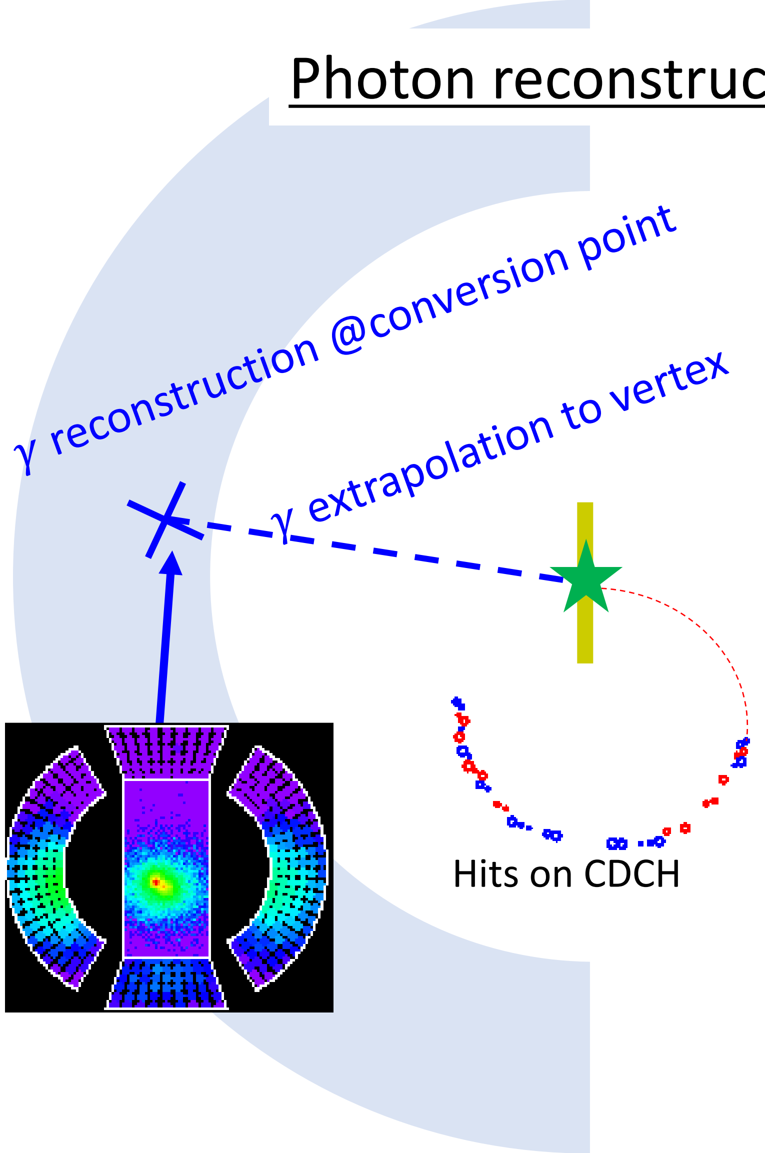
- 512 plastic counters in total
- 110 ps resolution / hit
- 9 hits (average) / 52.8 MeV track

- Wire chamber with stereo geometry
- High-density readout (2 – 3 cells / cm^2)
- Reduced material ($1.6 \times 10^{-3}\ X_0$)

MEG II detector (γ-ray)

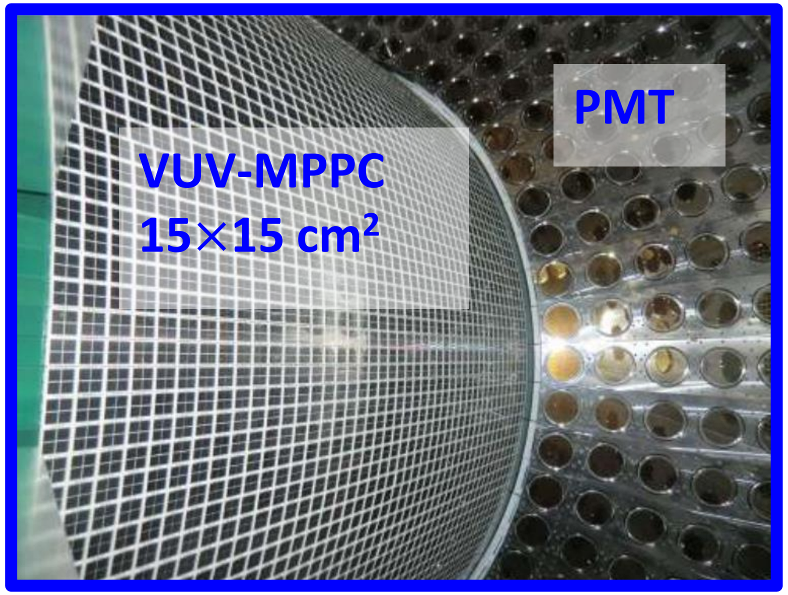
epjc/s10052-024-12415-3

Photon reconstruction



γ-ray detector
- **LXe scintillator (900 L)**
- **VUV-sensitive sensors**

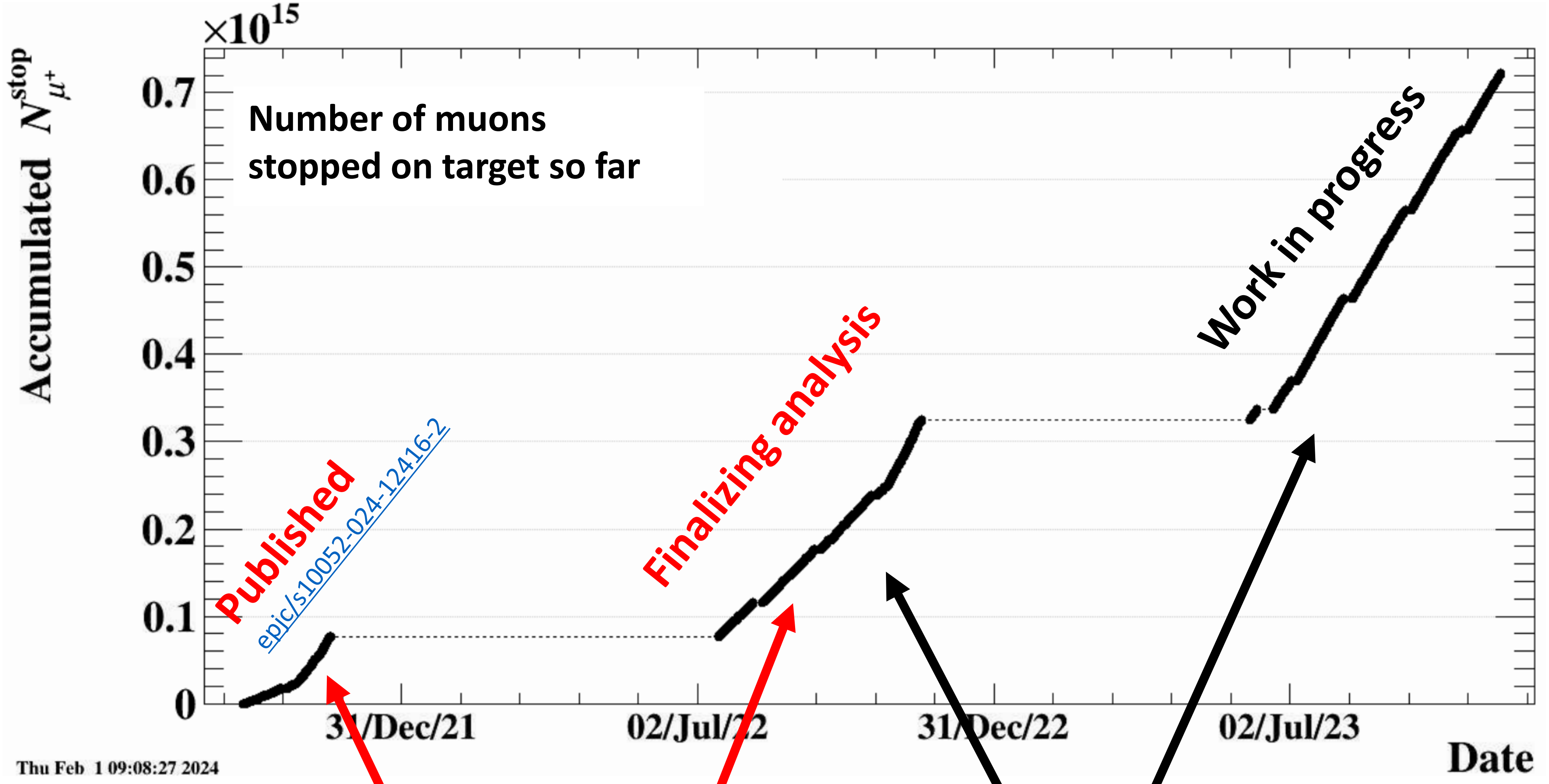
LXe properties
- High stopping power (X_0 =2.8 cm)
- High light yield (46000 photon/MeV)
- Fast response (45 ns decay time)



- 4092 MPPC (inner face)
  → Granular & uniform
- 668 PMT (other face)

→ See also 18pT3-6, 18pT3-7

MEG II DAQ so far



This talk
(covers positron for 2022)

Next talk
(covers γ-ray for 2022)

Outline

Result of 2021 data analysis

Published in epjc/s10052-024-12416-2

Muon statistics

- Normalization factor: k
  - Number of effectively measured muon decay

$$Br(\mu \to e\gamma) = \frac{N_{sig}}{k}$$

- $k_{2021} = (2.64 \pm 0.12) \times 10^{12}$
  1. Evaluation by background positron counting in dedicated dataset
  2. Evaluation by counting $\mu \to e\nu\nu\gamma$ events

  → Can automatically include efficiency factors

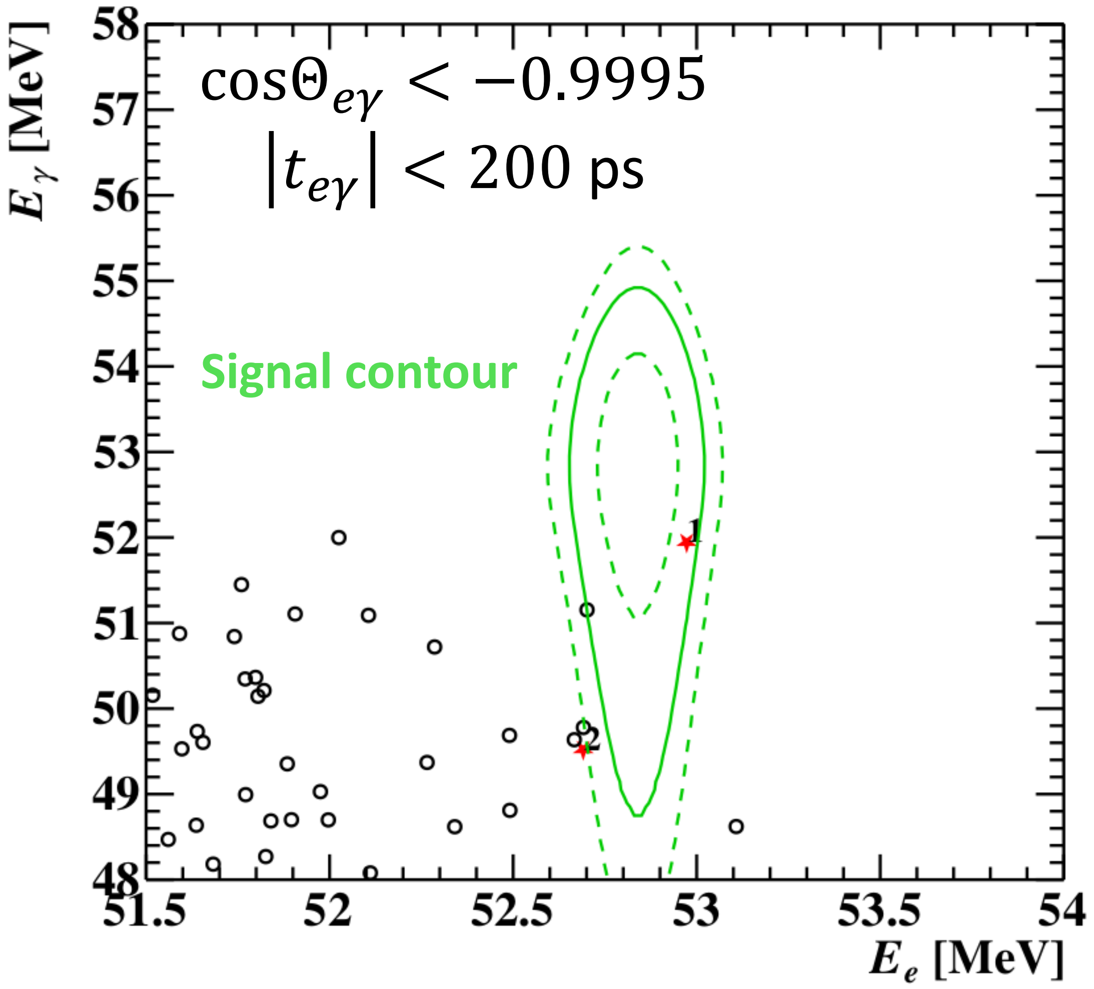
Breakdown

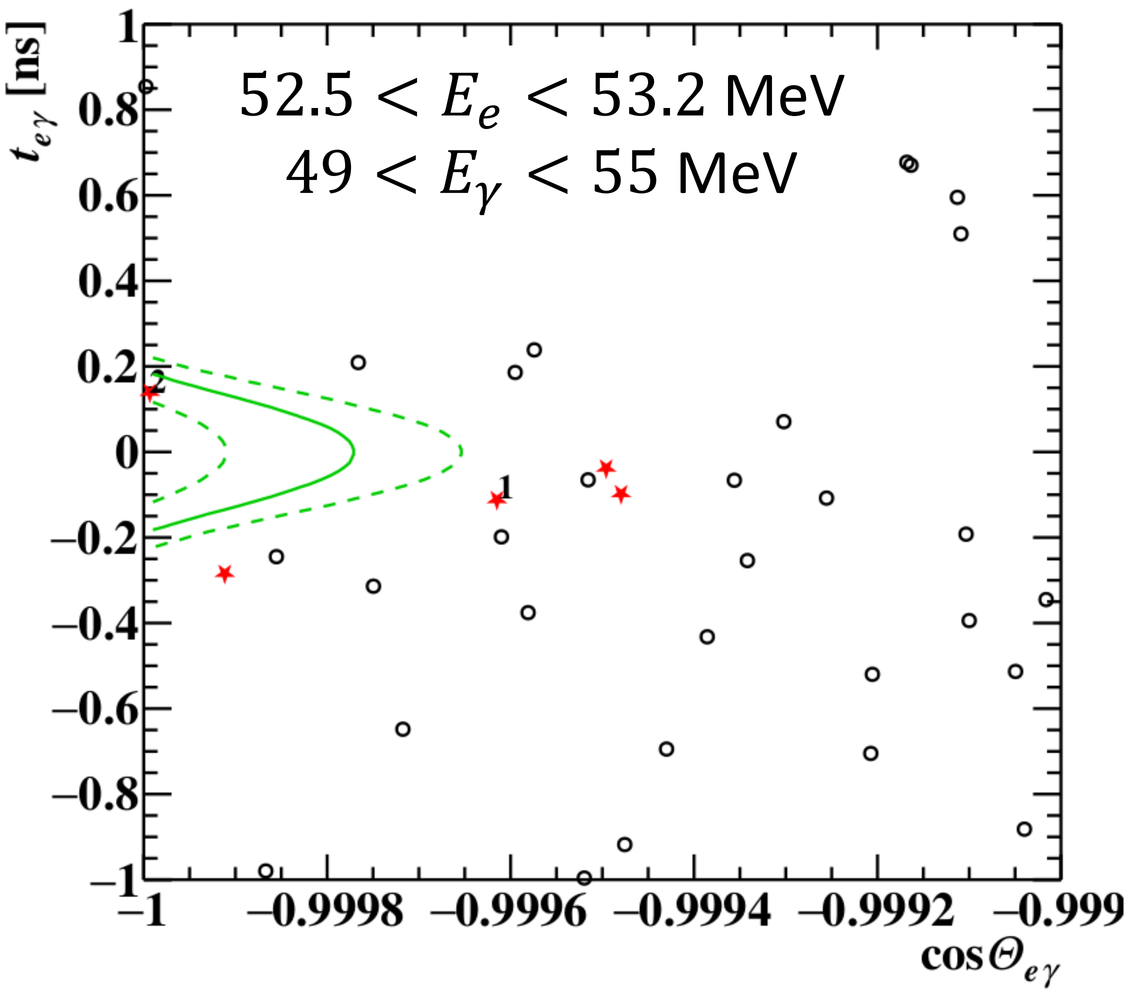
	Value	Inclusion in counted number
Stopped muons	7.7×10^{13}	Included in both count
Geometrical acceptance	11%	Included in both count
$\epsilon_{positron}$ (average)	67%	Included in both count
ϵ_{photon}	62%	Included in $\mu \to e\nu\nu\gamma$ count
$\epsilon_{trigger}$	80%	Partly included in $\mu \to e\nu\nu\gamma$ count
ϵ_{DAQ}	85%	Included in both count

← Limited only in 7 weeks engineering (Stopped muons)

← Not fully optimized in 2021 ($\epsilon_{trigger}$, ϵ_{DAQ})

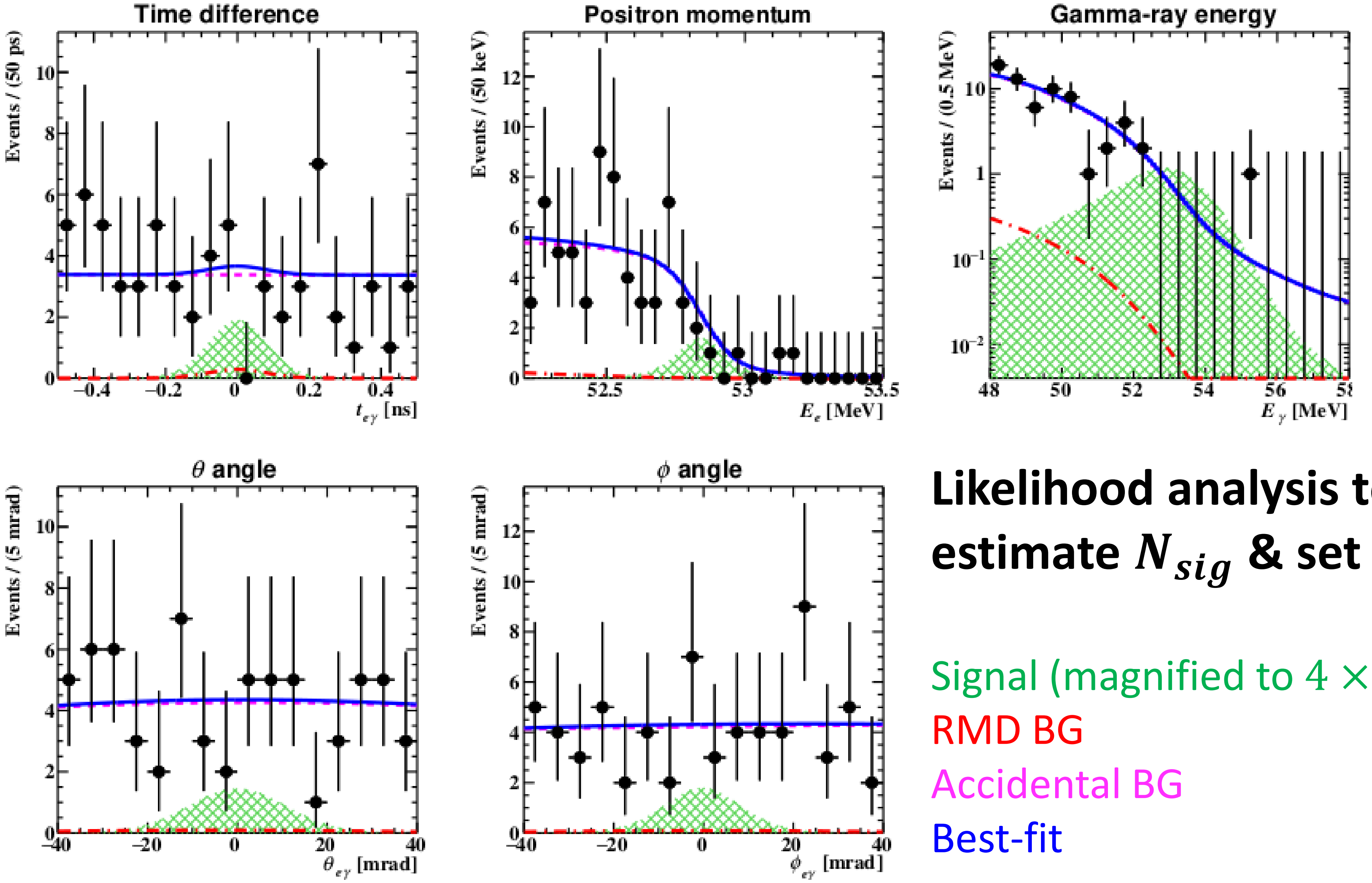
Event distribution





No signal excess observed

Fitting

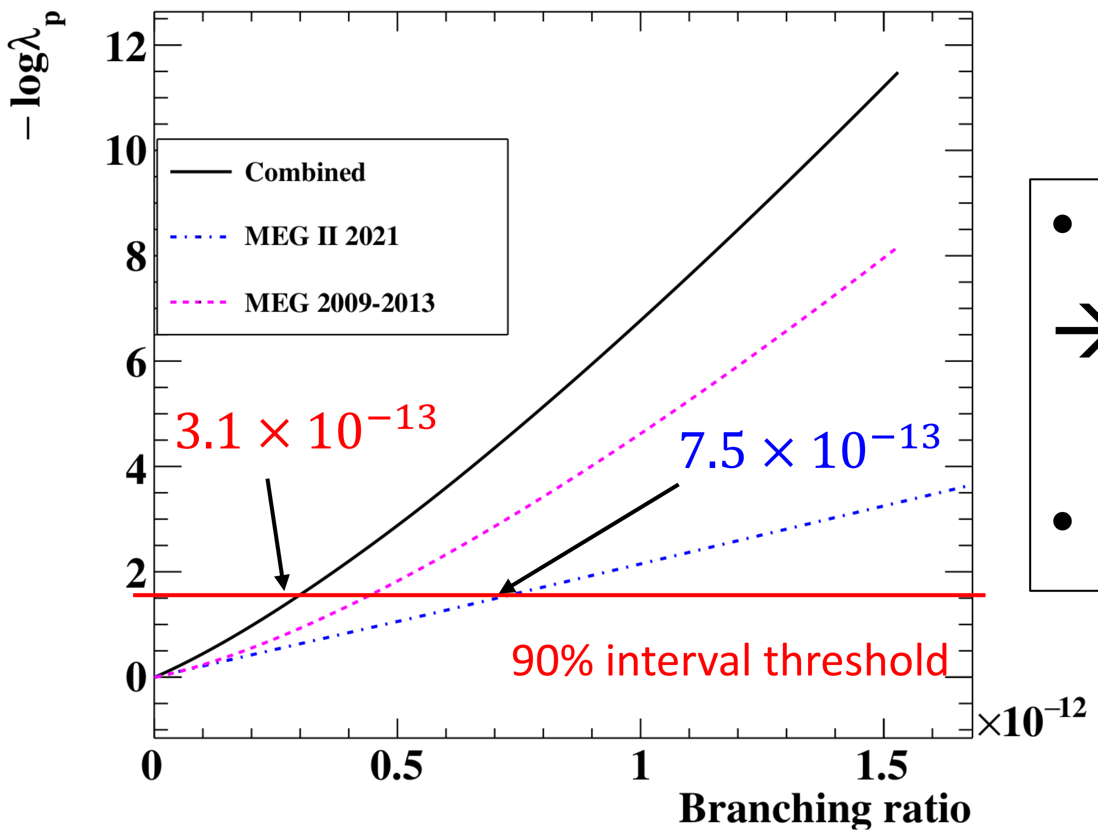


Likelihood analysis to estimate N_{sig} & set interval

Signal (magnified to 4 × upper limit)
RMD BG
Accidental BG
Best-fit

Result with 2021 data

	Sensitivity	Limit from data
MEG final (2016)	5.3×10^{-13}	$Br(\mu \to e\gamma) < 4.2 \times 10^{-13}$
MEG II 2021	8.8×10^{-13}	$Br(\mu \to e\gamma) < 7.5 \times 10^{-13}$
Combined	4.3×10^{-13}	$Br(\mu \to e\gamma) < 3.1 \times 10^{-13}$



- Approached MEG2016 sensitivity in 7 weeks

→ Demonstration of MEG II capability

- We just need more statistics

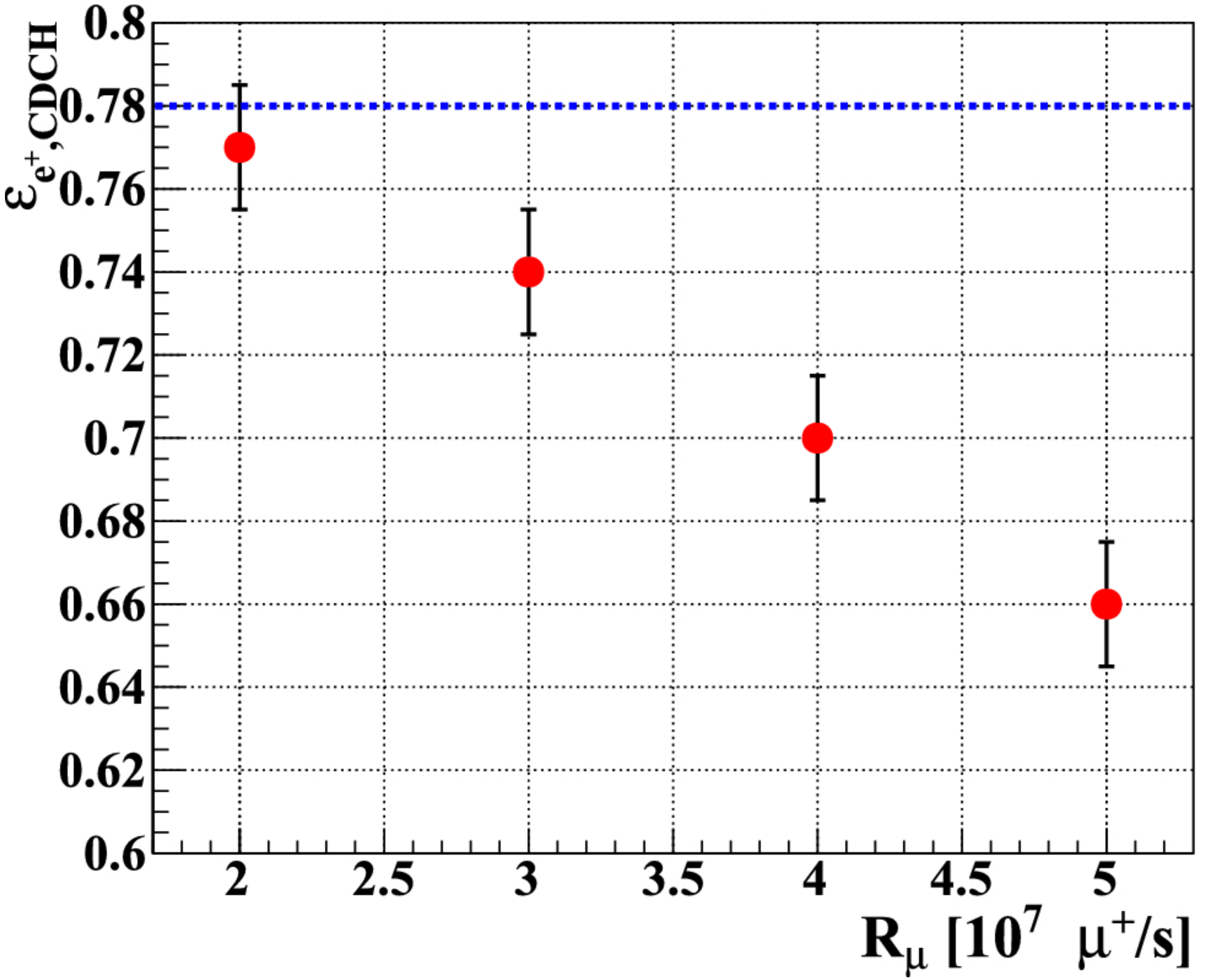
Other lesson from this analysis

- Which muon rate is optimal?
  - More muons at higher rate: $N_\mu \propto R_\mu$
  - More BG at higher rate: $N_{BG} \propto R_\mu^2$
  - Positron efficiency depends on R_μ

→ Highest sensitivity at 4×10^7 rate with current performance

→ Feedbacked to DAQ in 2023

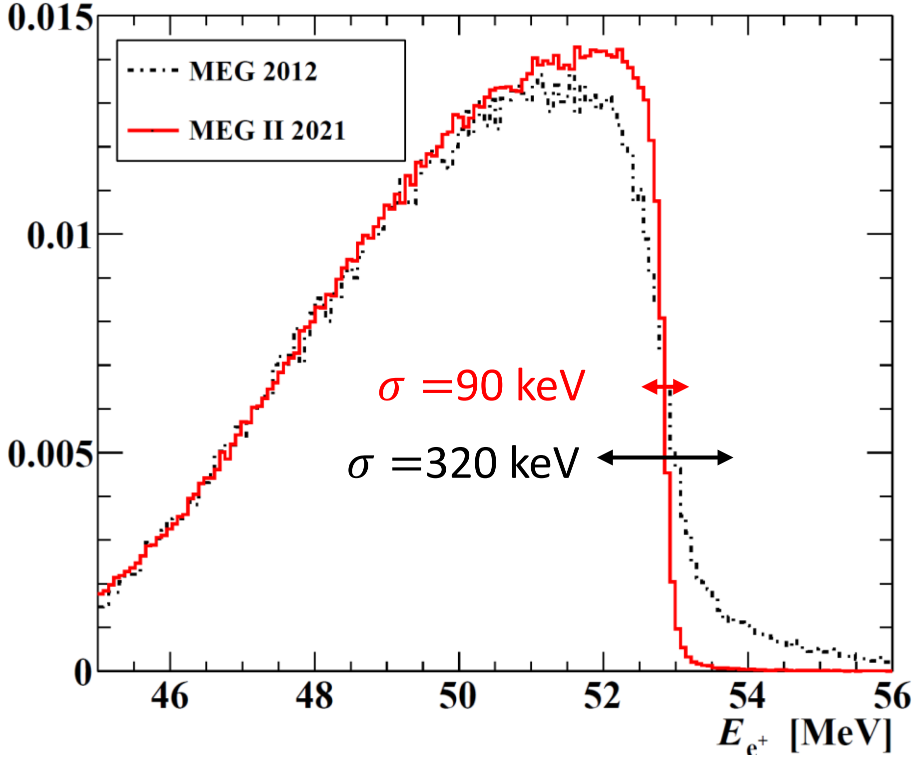
Drift chamber efficiency vs muon rate



Important improvement from MEG

- Positron improvement highly contributed to sensitivity
  - $\times$ 3.5 improvement in momentum resolution
  - $\times$ 2 improvement in efficiency
  - $\times$ 2 improvement in angle resolution

$\mu \rightarrow e\nu\nu$ measured spectrum



To keep the performance,

- Need careful calibration
- Need long-term stability of detector

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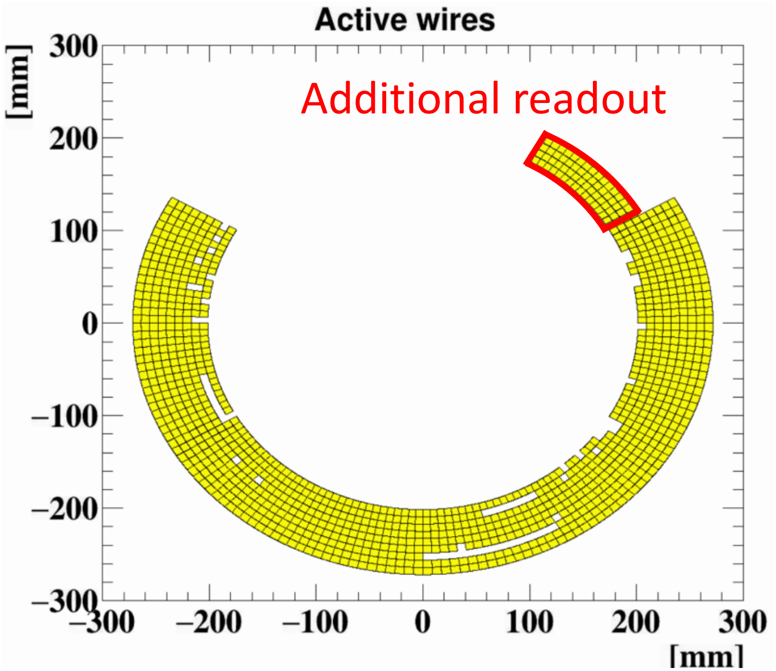
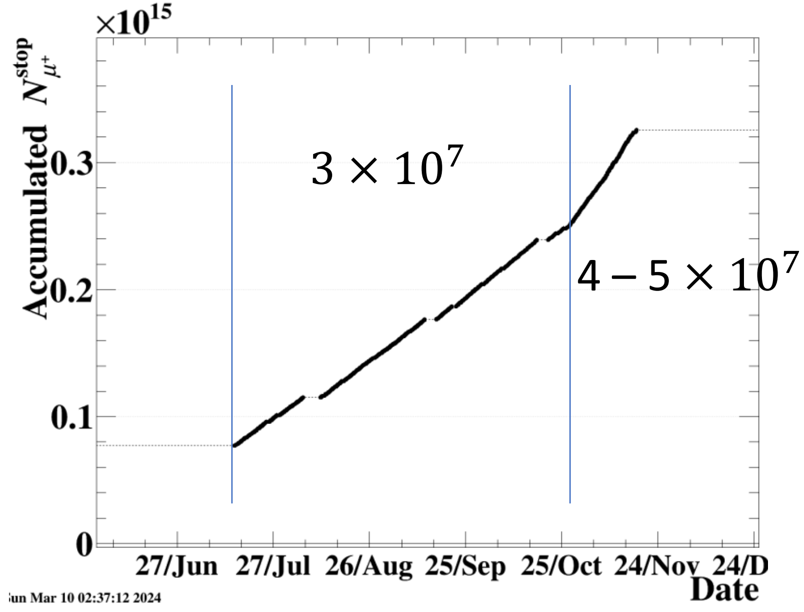
Ongoing analysis with 2022 data

DAQ in 2022

- Hardware improvements
  - Additional readout in CDCH
    - Signal positrons may leave hits on these wires
    - Though small opportunity, they were missed in 2021 DAQ
  - DAQ hardware
    - Better trigger calibration
      → Higher DAQ-related efficiency ($\times$ 1.15, preliminary)



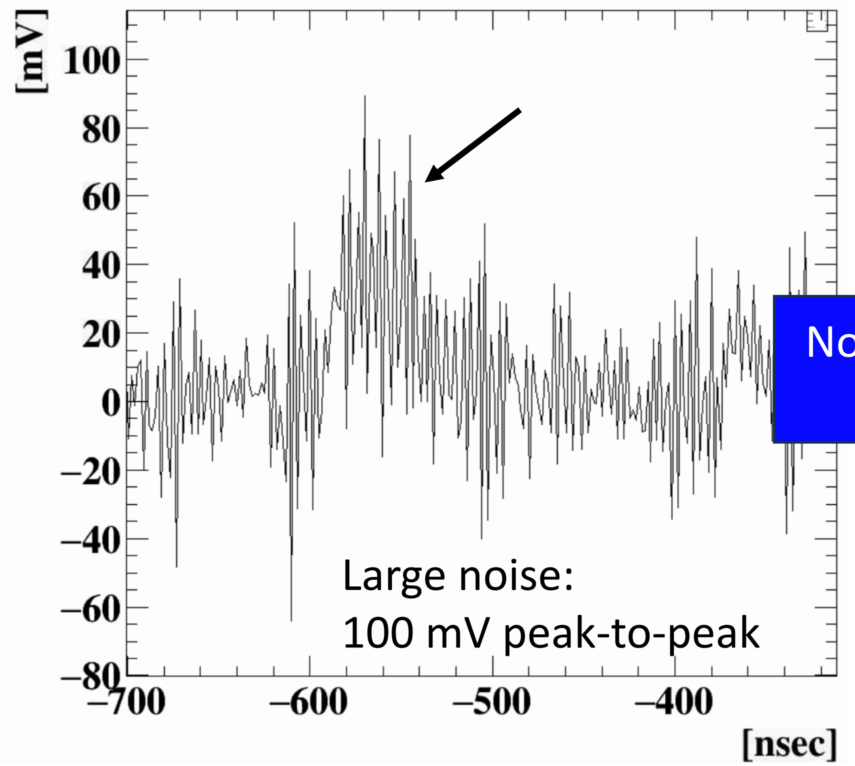
- Beam rate was not optimized yet
  - Concerned PDE decrease of MPPCs in γ-ray detector
    - Only once/year chance of annealing to recover PDE
    - Decrease speed was not precisely estimated
  - DAQ hardware capability at higher pileup environment
  - Sensitivity at different beam rates was not yet known



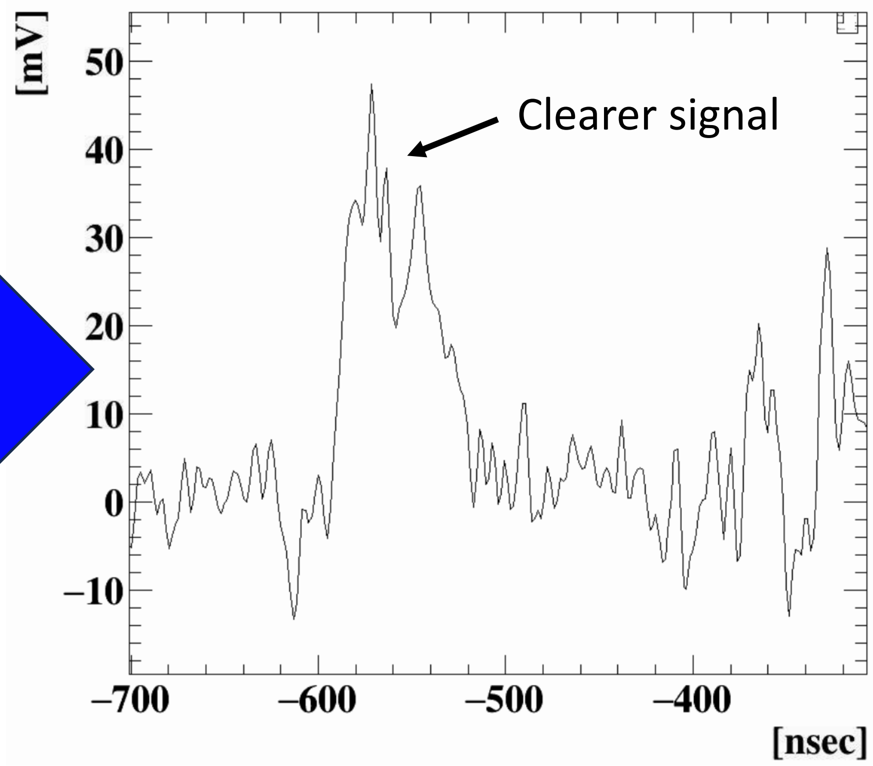
Chamber hardware problem in 2022

- Sudden damage to electronics of drift chamber
  - Damaged in the middle of DAQ
  - Not realized for two weeks
  - Impact: Increase of high-frequency noise
    → Successful reduction in analysis

Improved real-time monitoring.
Efficiency monitoring introduced in 2023



Noise reduction
in analysis



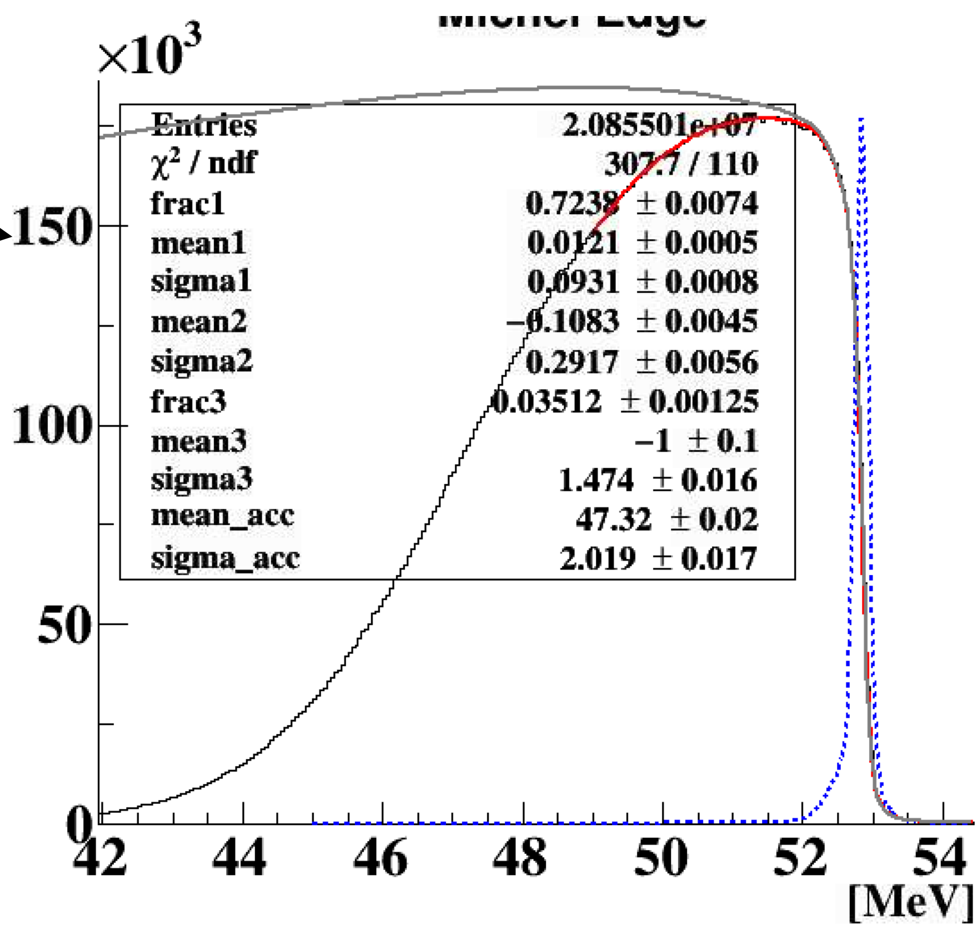
Positron analysis for 2022

- Calibration in long-term DAQ
  - ✓ Found small variations from 2021 in alignment & electronics calibration
  - ✓ But they were stable during 2022 DAQ

- Computing is becoming severe
  - Expected to take 3 months to reconstruct all positron tracks
    - Started in Feb → Expected to finish in May
  - Bottleneck: Pattern recognition to find tracks
    → Positron inefficiency at higher rate is also from pattern recognition
  - Need to explore possible improvements of the situation for the coming years

Positron performance for 2022

- Comparable performance as 2021
  - E.g. 93 keV momentum resolution
  → Validated quality of reconstruction



- Estimated statistics (preliminary)
  - $k_{2022} = 1.06 \times 10^{13}$
  - $k_{2021+22} = 1.32 \times 10^{13}$
  - $\times$ 5 larger statistics than 2021
  - Currently, 10% uncertainty before finalization
  - Expect 1.9×10^{-13} sensitivity in the next publication
    (To be detailed in the next talk considering γ-ray reconstruction)

Summary

- Presented results with 2021 dataset
  - Measured 2.64×10^{12} muon decays in 7 weeks
  - Searched with 8.8×10^{-13} sensitivity
    → Approached MEG2016 only in 7 weeks. Demonstration of MEG II capability
  - Combination with MEG2016 gave $Br(\mu \rightarrow e\gamma) < 3.1 \times 10^{-13}$ limit
    → Most stringent limit ever

- Status of 2022 data analysis
  - Positron calibration finished & Validated reconstruction quality
  - Processing positron reconstruction, expected to finish in May
  - Can measure additional 1.06×10^{13} muon decays
  - Discussions about γ-ray analysis in the next talk