MEG II実験2021・2022年データを用いた$\mu \to e\gamma$探索の物理解析

山本 健介 (東大理)

他MEG IIコラボレーション

日本物理学会第79回年次大会

2024年9月16日(月)-19日(木)

(17aWB106-2)

MEG II実験2021・2022年データを用いた$\mu \to e\gamma$探索の物理解析

に向けたガンマ線再構成

山本 健介 (東大理)

他MEG IIコラボレーション

日本物理学会第79回年次大会

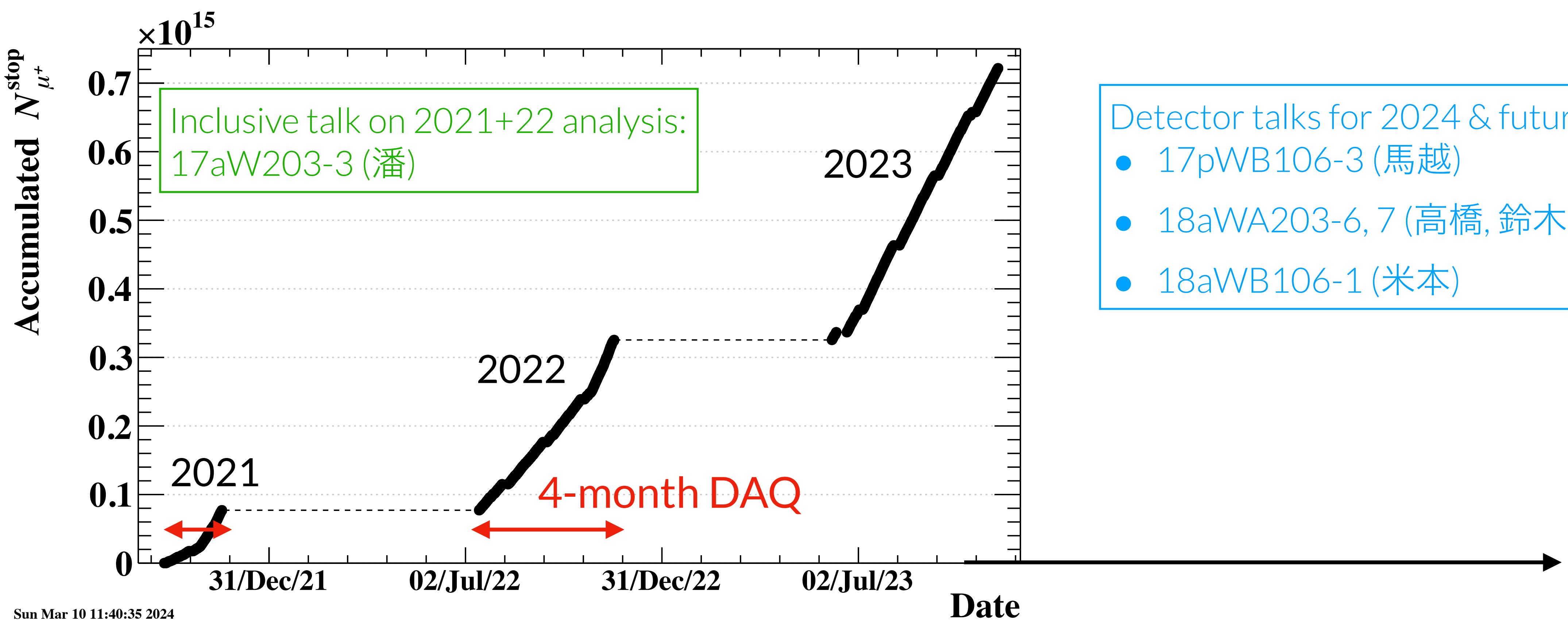
2024年9月16日(月)-19日(木)

(17aWB106-2)

$\mu \to e\gamma$ search in MEG II

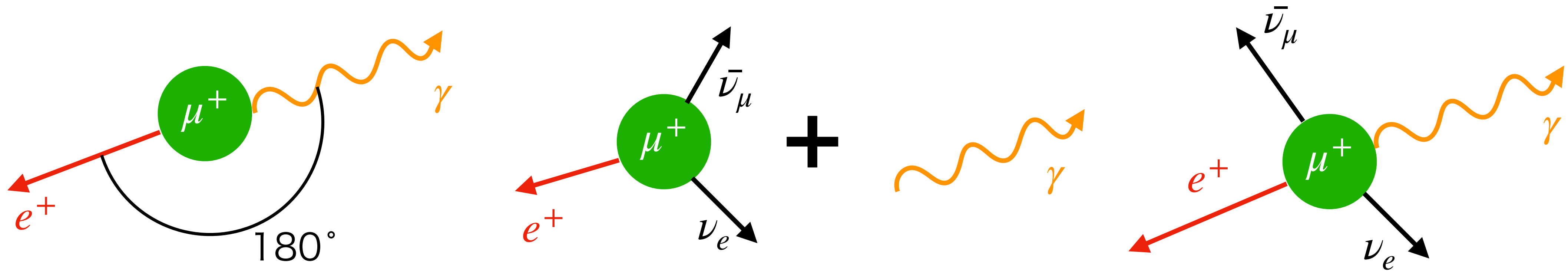
- MEG II experiment searches for $\mu \to e\gamma$ with target sensitivity of 6×10^{-14}
  - Strongly suppressed down to $\mathcal{O}(10^{-54})$ in SM + ν osc.
  - Predicted with $\mathcal{O}(10^{-12} - 10^{-14})$ in BSM, e.g. SUSY

- Physics run started in 2021
  - Sensitivity 8.8×10^{-13} for 2021 data *K. Afanaciev, et al., Eur. Phys. J. C 84 (2024), 214
  - Preliminary sensitivity 2.1×10^{-13} for 2021+2022 data



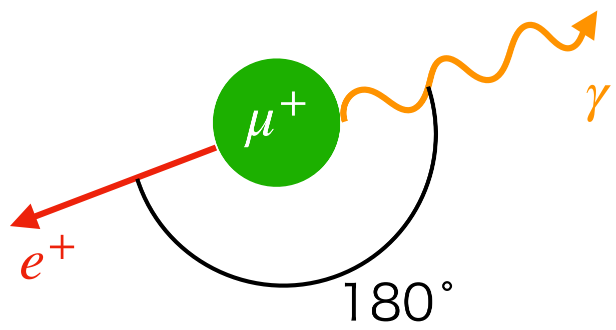
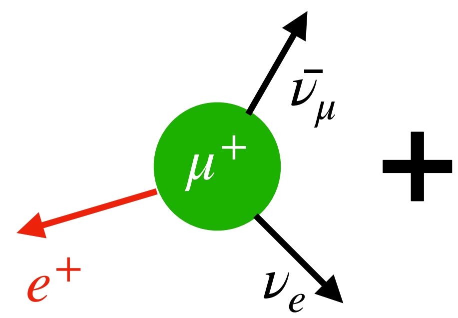
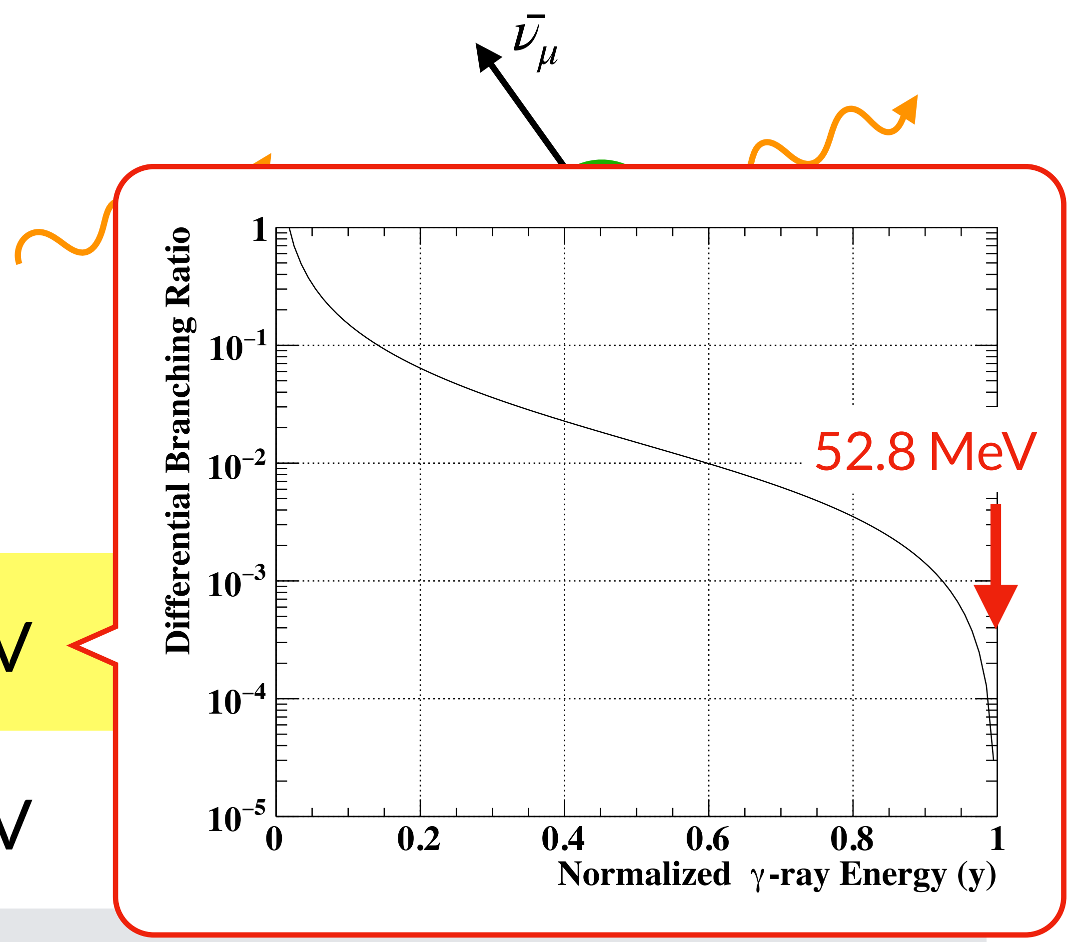
Detector talks for 2024 & future:
- 17pWB106-3 (馬越)
- 18aWA203-6, 7 (高橋, 鈴木)
- 18aWB106-1 (米本)

Signal & BG kinematics



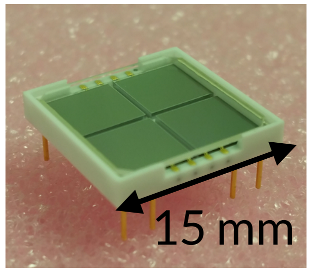
	Signal	Accidental BG ≫	Physics BG
E_γ	52.8 MeV	<52.8 MeV	<52.8 MeV
E_e	52.8 MeV	<52.8 MeV	<52.8 MeV
$t_{e\gamma}$	0 s	Flat	0 s
$\Theta_{e\gamma}$	180°	No correlation	<180°

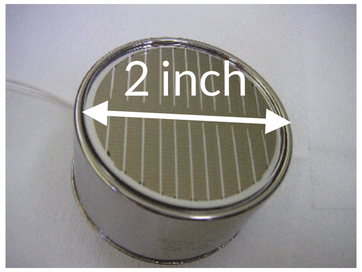
Signal & BG kinematics

	Signal	Accidental BG ≫	Physics BG
			
E_γ	52.8 MeV	<52.8 MeV	
E_e	52.8 MeV	<52.8 MeV	
$t_{e\gamma}$	0 s	Flat	0 s
$\Theta_{e\gamma}$	180˚	No correlation	<180˚

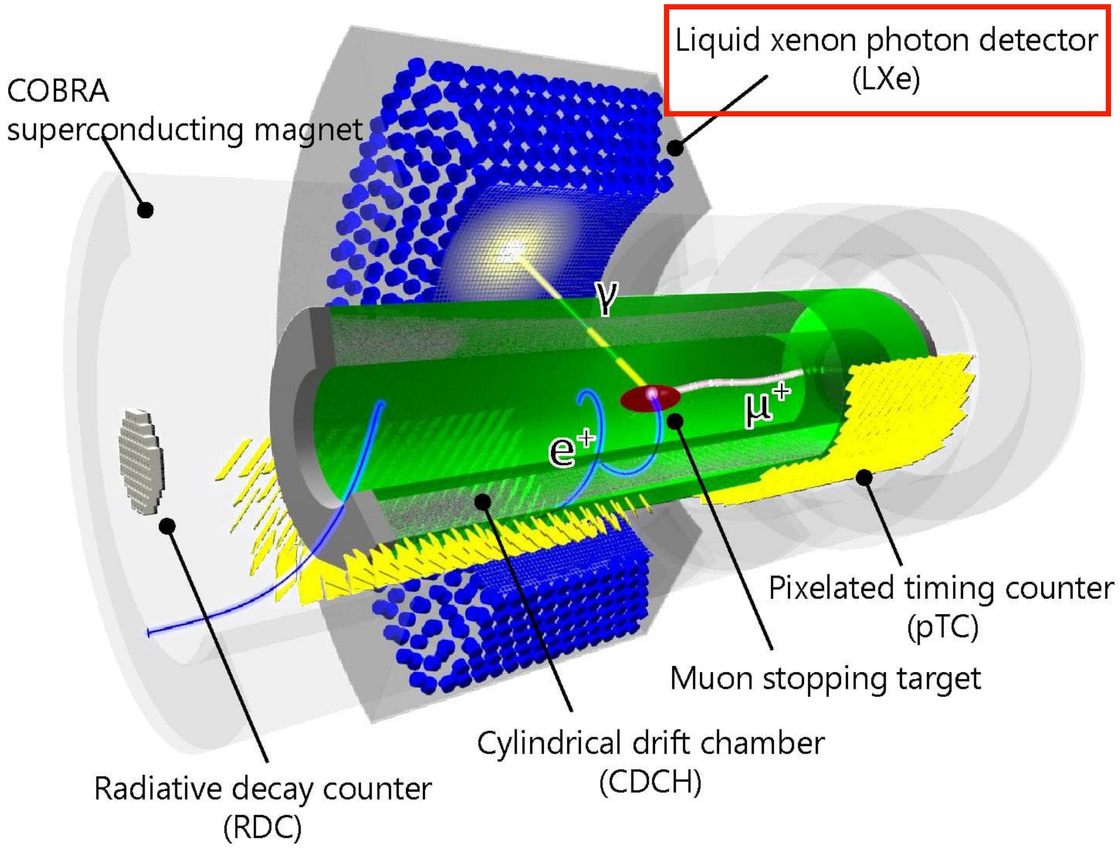
LXe photon detector

- **Scintillation light in LXe collected by VUV-sensitive photosensors**
  - 4,092 MPPCs on the γ entrance face
  - 668 PMTs on the other faces
  - Gain and PDE/QE calibrated



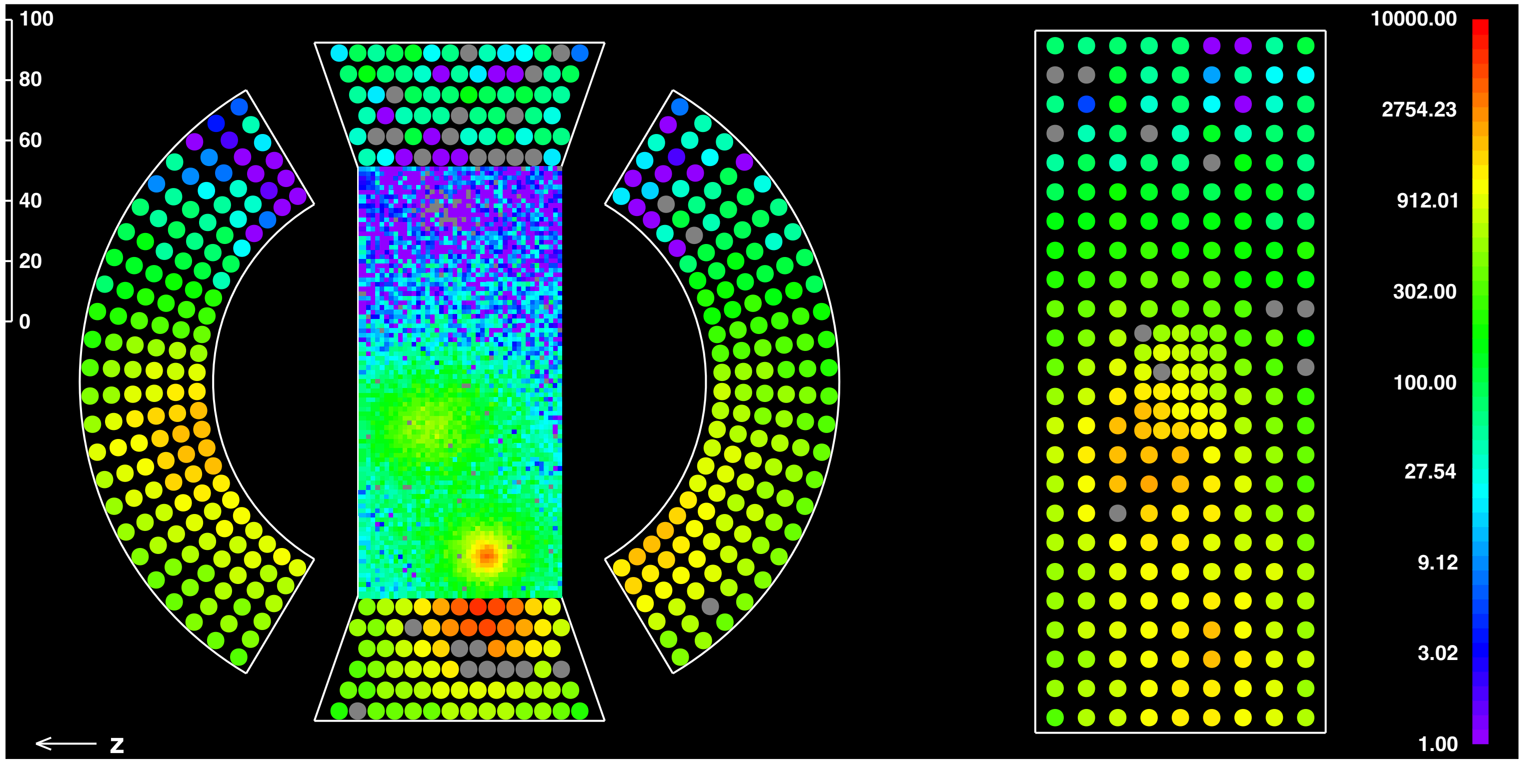


- **Measure γ position, timing, and energy**
  - Energy reconstructed by collecting all scintillation photons and converting it



*K. Afanaciev, et al., Eur. Phys. J. C 84 (2024), 190

Detected scintillation photon distribution of a multi-γ event

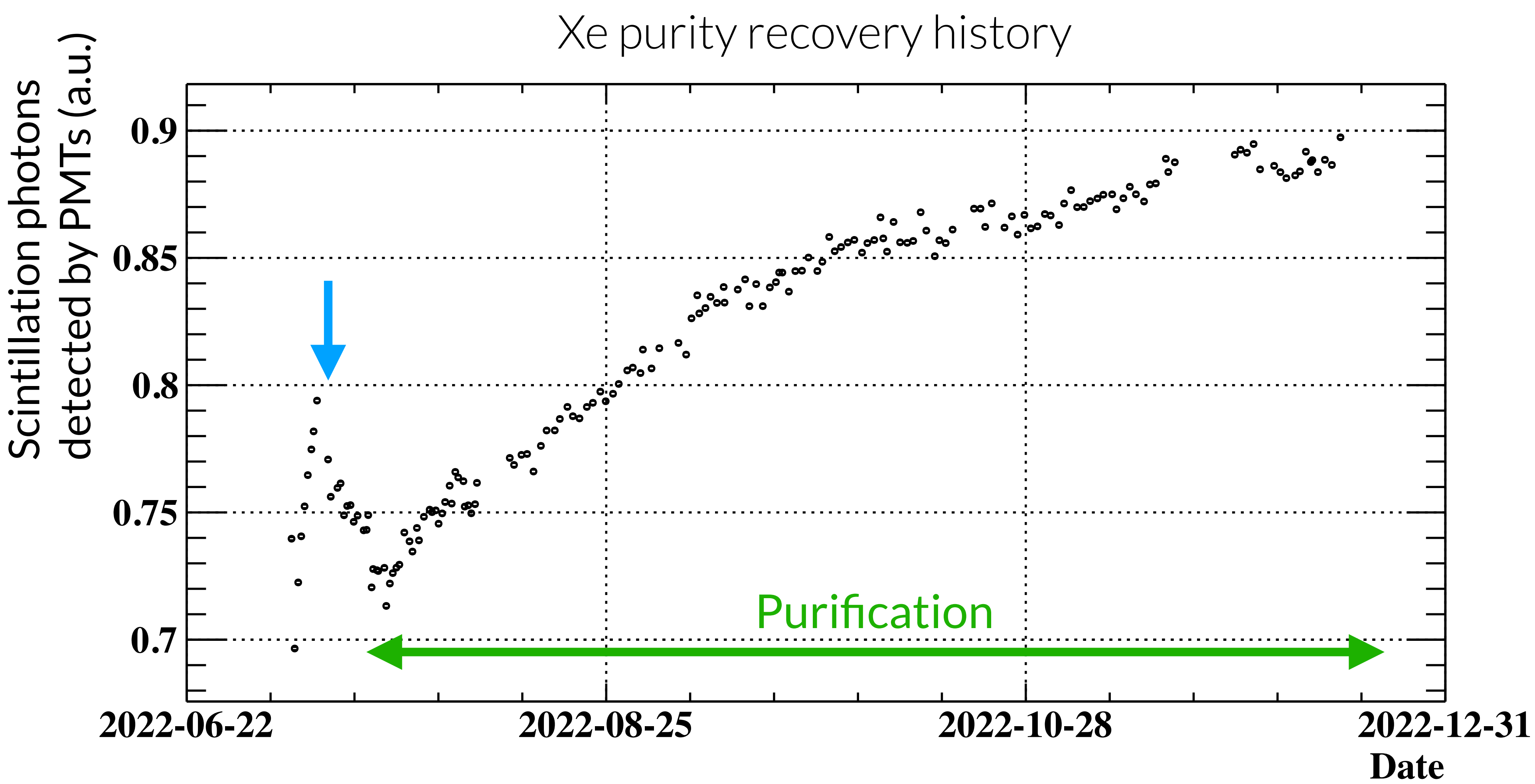


Light absorption due to impurity

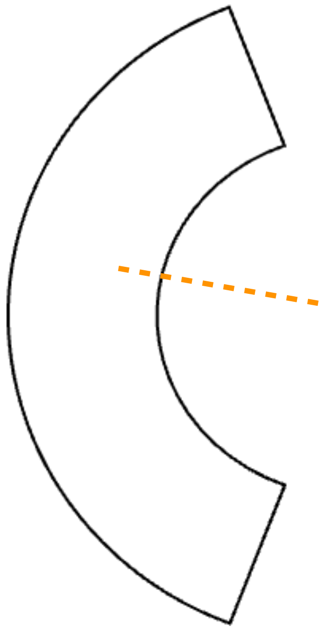
- Impure Xe added at the beginning of the 2022 run
  - Water contaminated

➡ Shorter light absorption length at the beginning

- Purification in parallel with DAQ



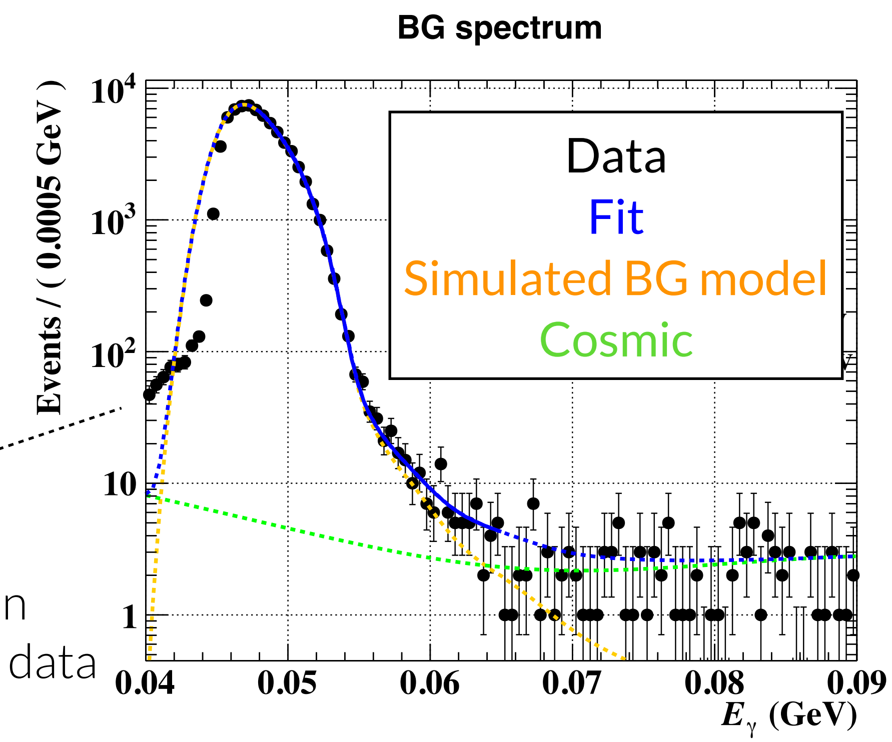
Calibration datasets



γ rays

- 18 MeV γ from $^{7}\text{Li}(\text{p},\gamma)^{8}\text{Be}$
- 9 MeV γ from $^{58}\text{Ni}(\text{n},\gamma)^{59}\text{Ni}$
- <52.8 MeV γ from μ decays (BG)

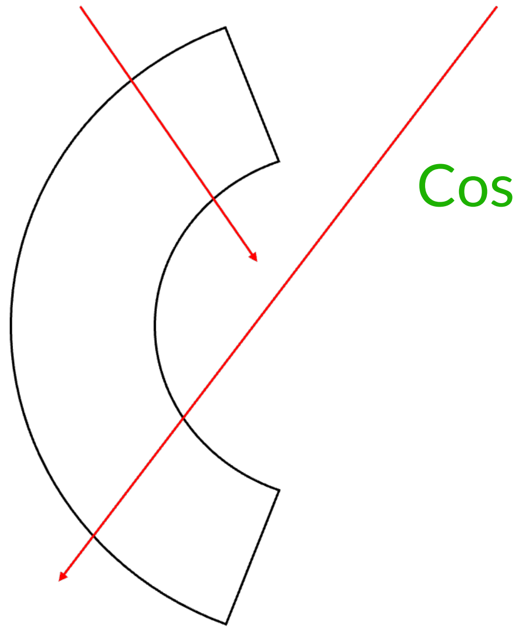
Spectra comparison in MC and data



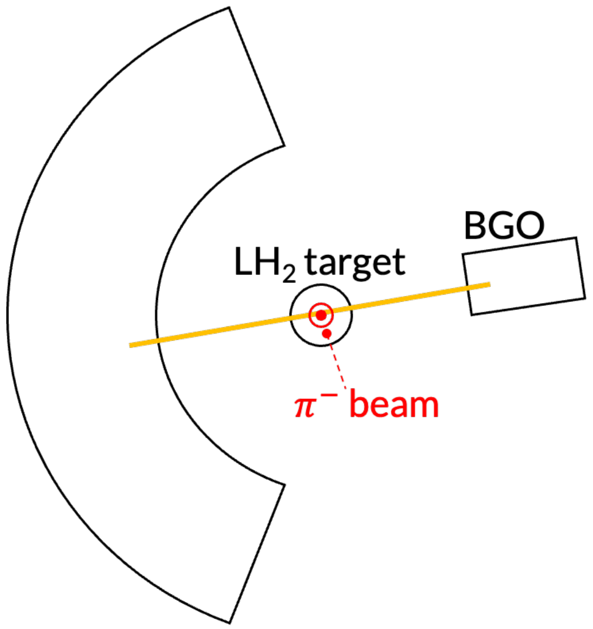
Physics run period

Date

Calibration run period



Cosmic rays

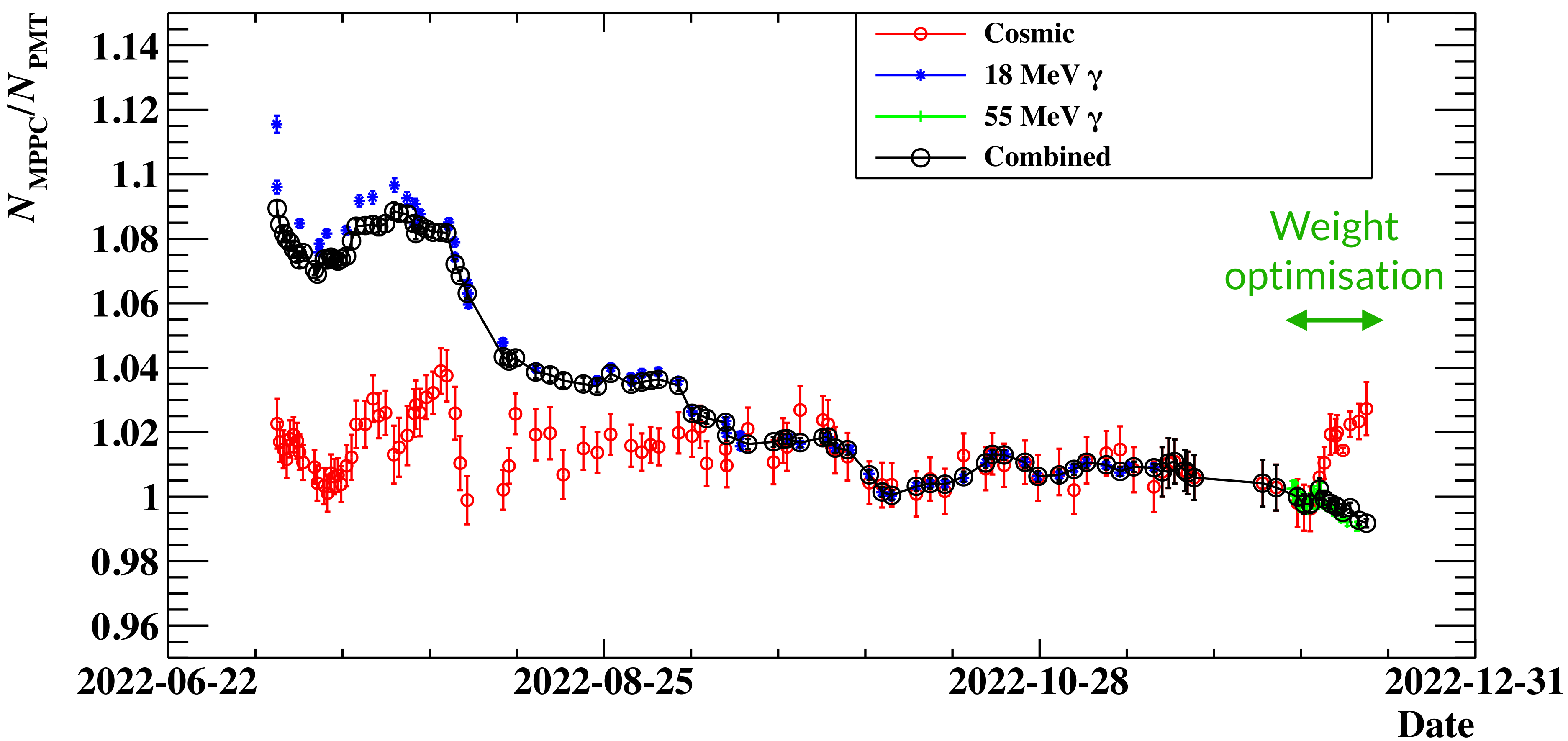


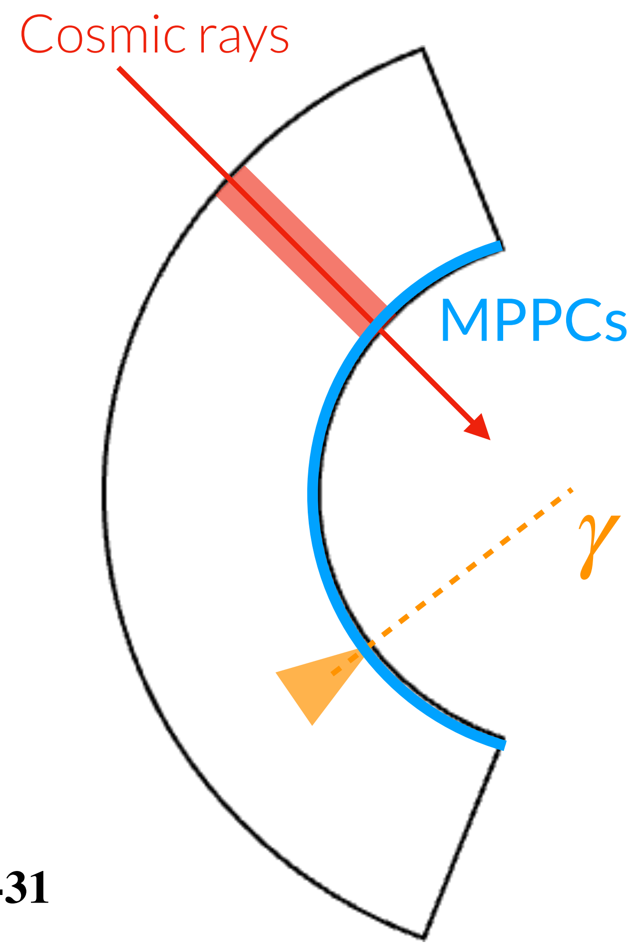
55 MeV γ rays from

- $\pi^- \text{p} \to \pi^0 \text{n}$
- $\pi^0 \to \gamma\gamma$

Temporal variation in light collection

- Optimise weight for MPPCs to sum up scintillation photons with 55 MeV photons
- **Weight depends on absorption length**

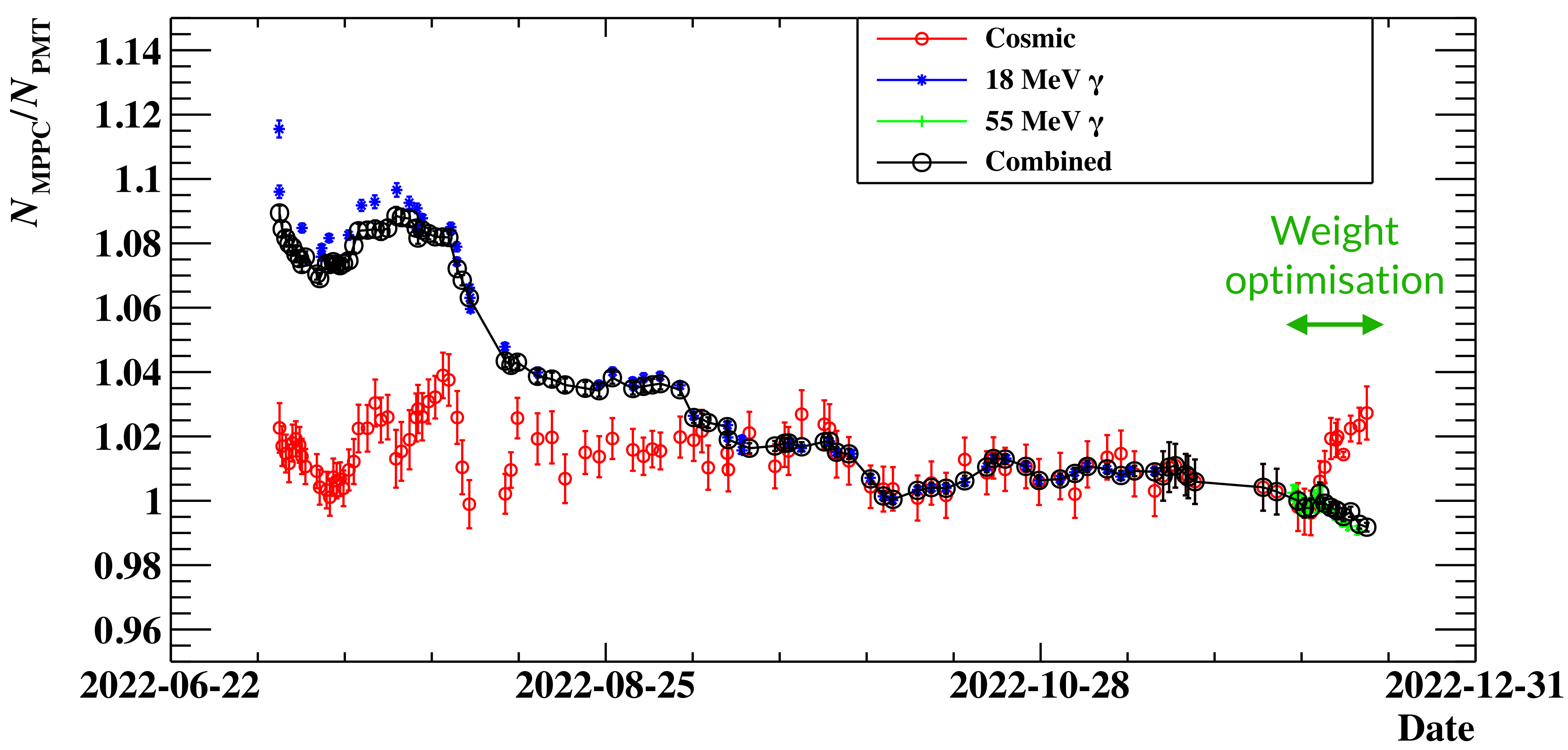


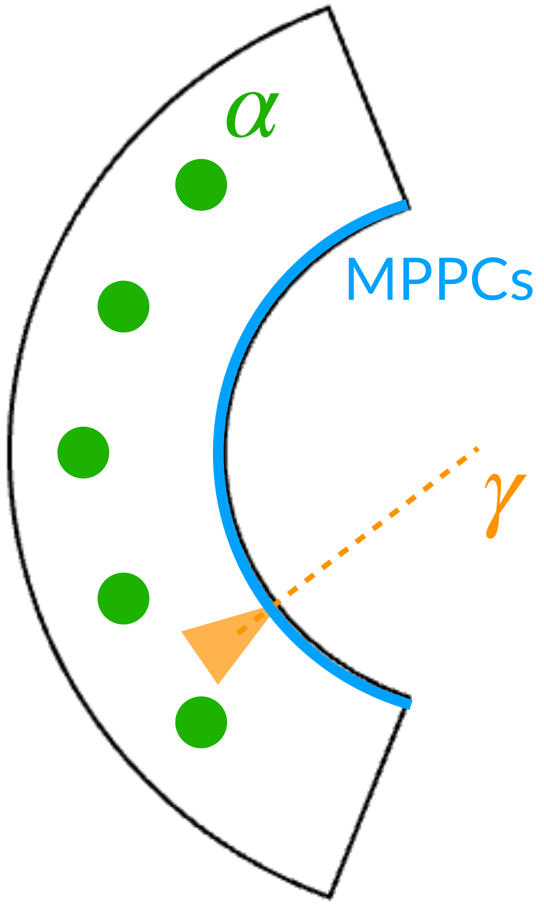


MPPC and PMT response difference

- Difference of response to γ between MPPCs and PMTs
  - α used to calibrate photon detection efficiency for MPPCs and quantum efficiency for PMTs

- **Correct weight and response difference as a function of time**

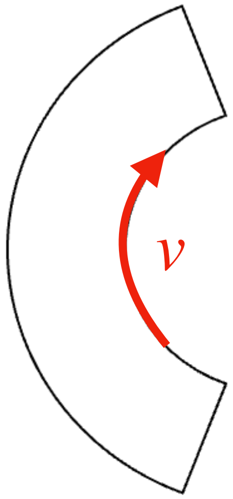




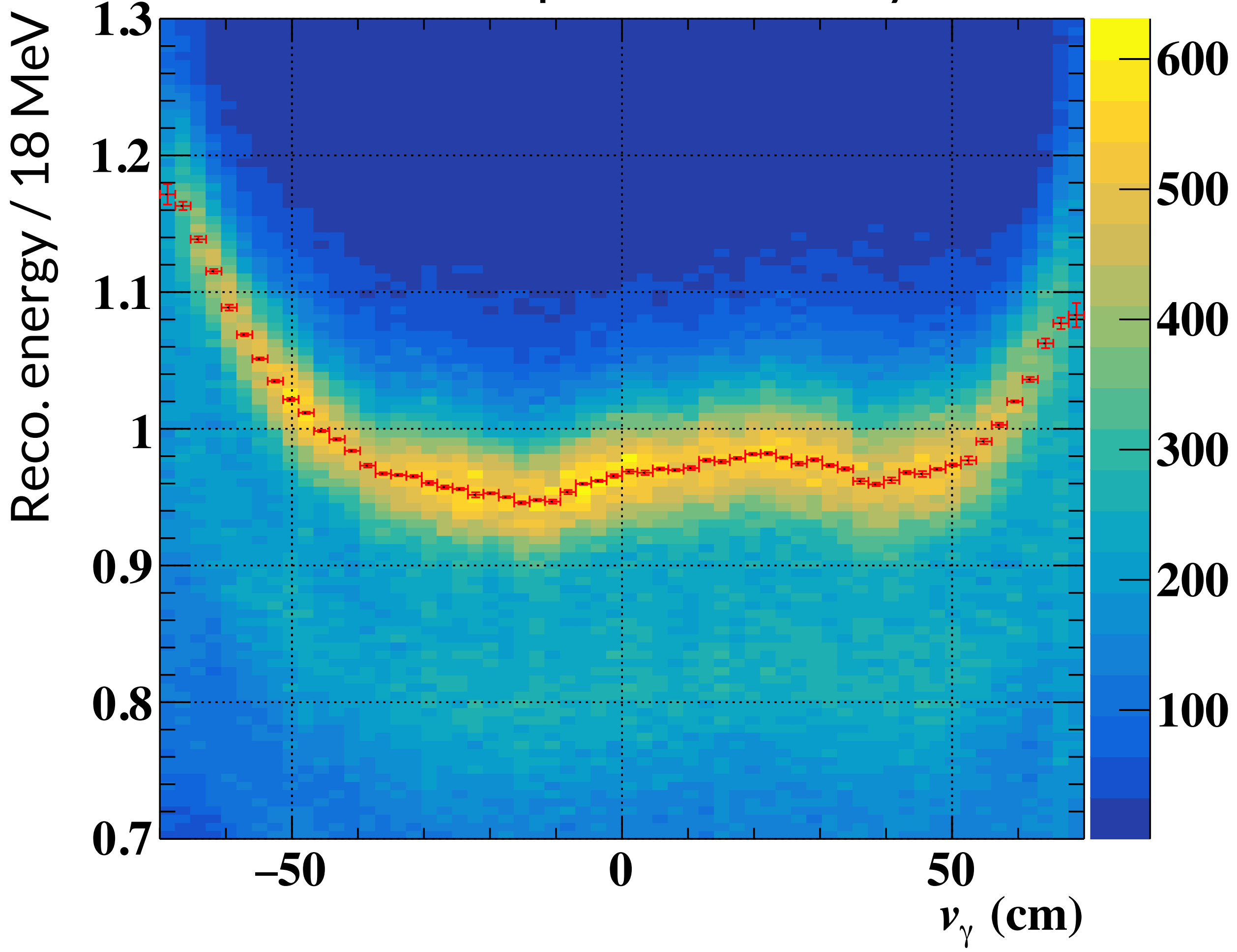
Temporal variation in position dependence

- Temporal dependence on MPPC weight caused temporal variation in position dependence
  - Higher energy reconstructed in regions close to edge

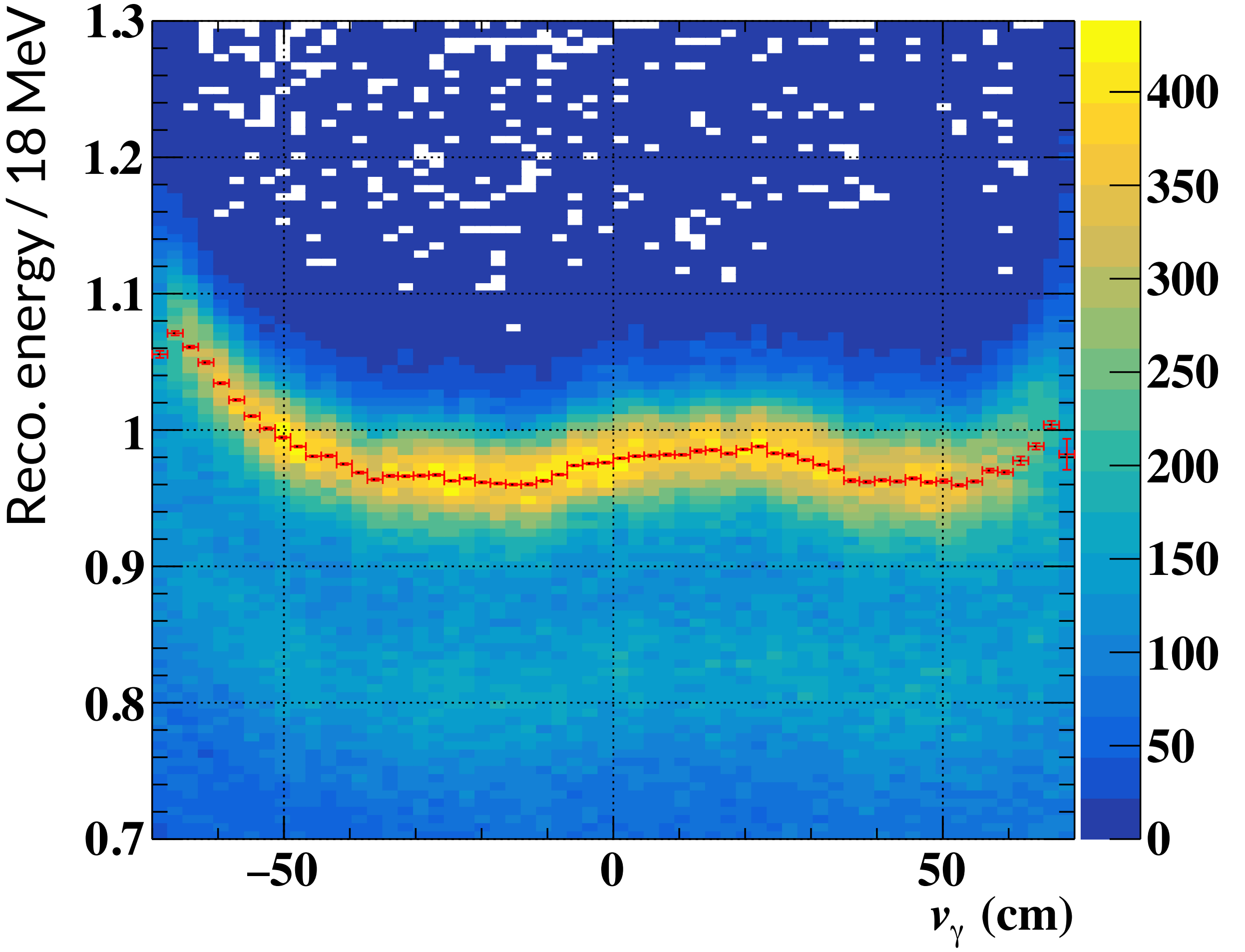
➡ Correct it to achieve uniform response and high resolution for whole 2022 run



18 MeV photons in July



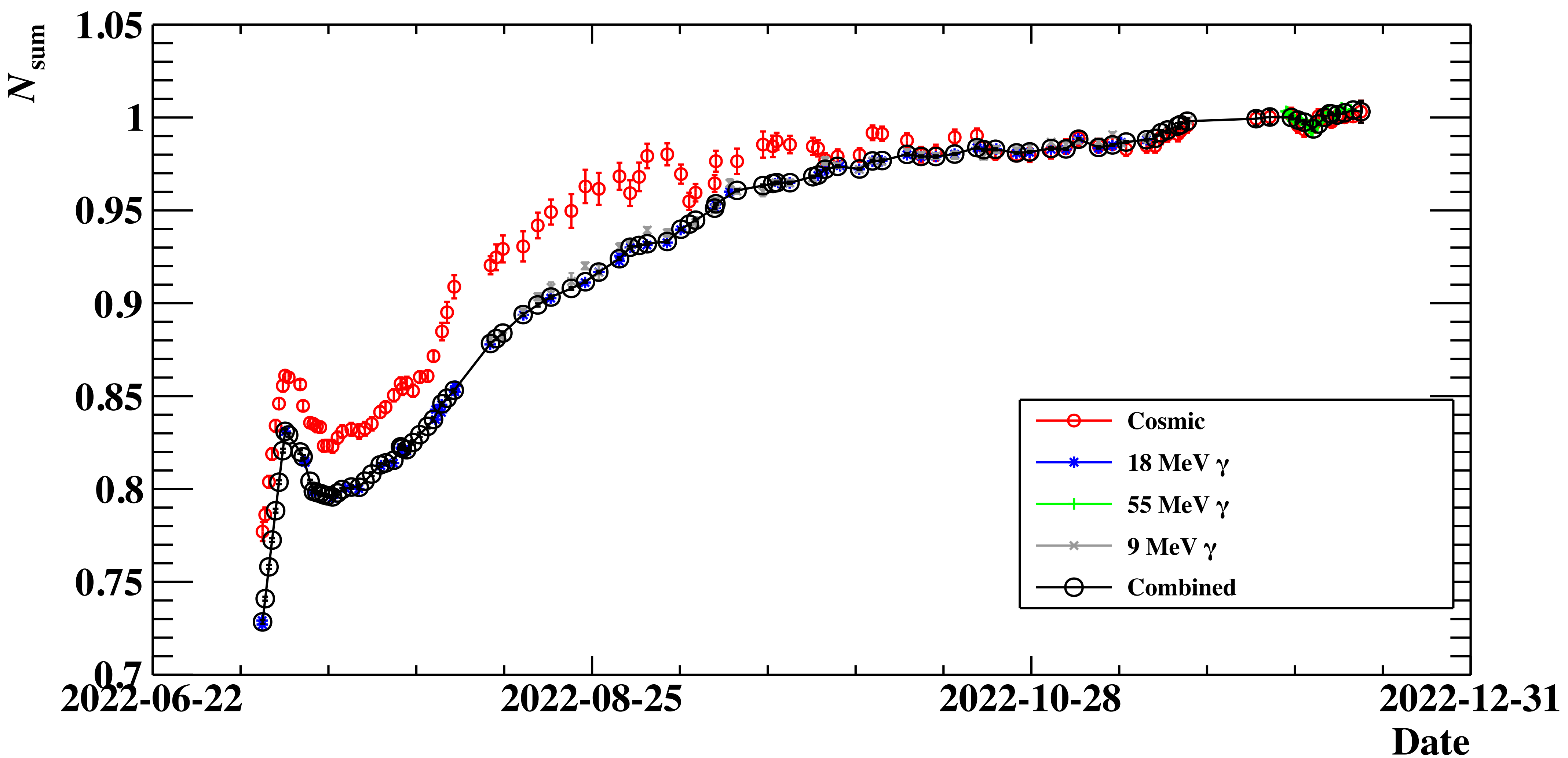
18 MeV photons in October



Temporal evolution of energy scale

- The number of detected scintillation photons increased as a function of time
  - Due to Xe purity recovery

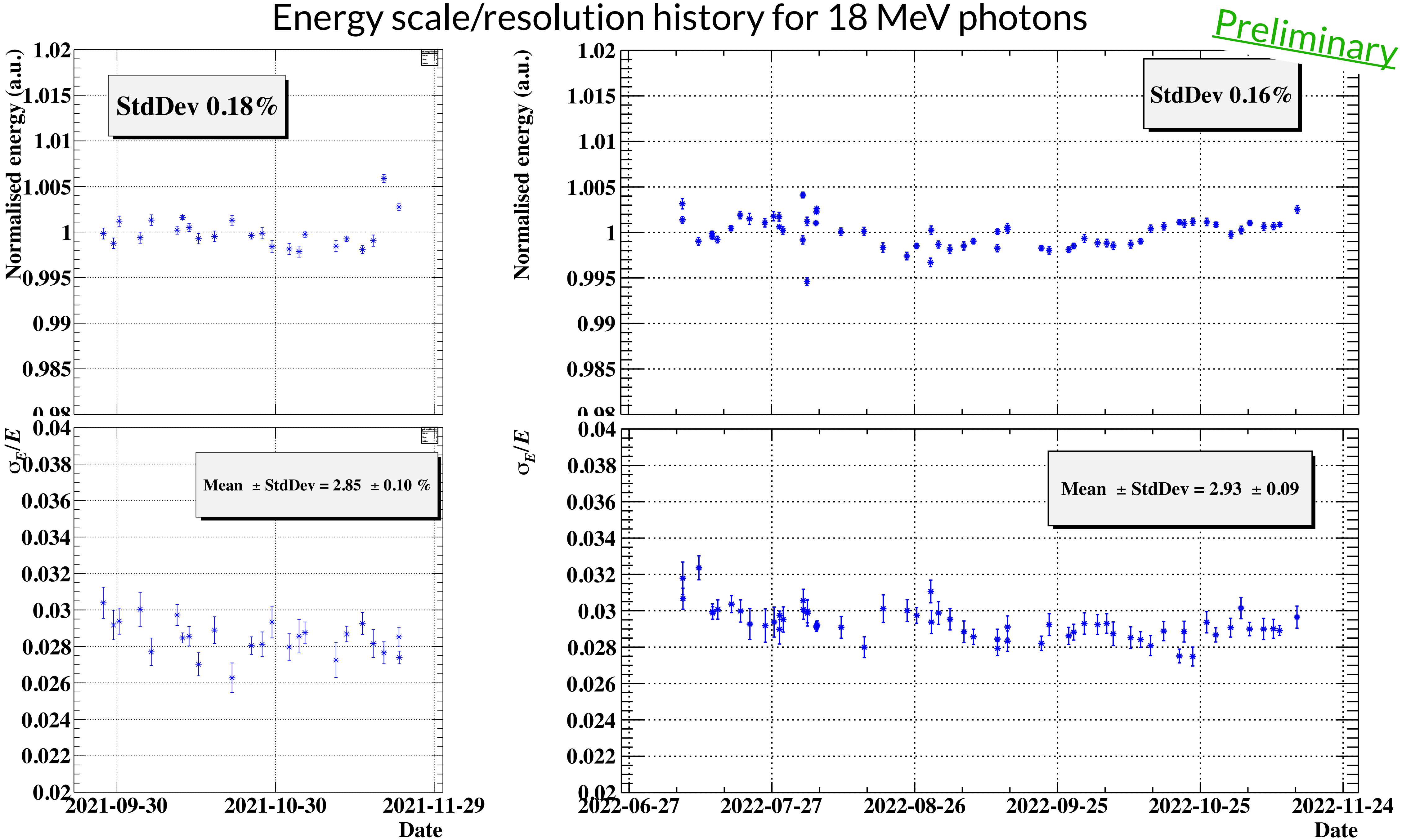
➡ Correct the temporal evolution of energy scale



Energy scale and resolution stabilities

- **Stable energy scale and resolution achieved by calibrations**
  - Temporal variation of energy scale ≪ Resolution

Energy scale/resolution history for 18 MeV photons



Conclusion

- 2021+22 MEG II data analysis ongoing in search of $\mu \to e\gamma$ with the highest sensitivity
  - Preliminary sensitivity 2.1×10^{-13}
- Discuss photon energy reconstruction
  - Calibrate energy scale of LXe detector
  - A challenge in 2022: Large variation in Xe purity
- Aim to publish the result this autumn

Stay tuned!

*ひっぐすたん

Backup

2021+2022 combined sensitivity

- Branching ratio $BR = N_{\text{sig}}/k$
  - # effectively measured μ decays: $k_{2021+22} = 1.28 \times 10^{13}$
- Sensitivity S: Median 90% C.L. upper limits on BR for BG-only hypothesis
  - Median 90% C.L. upper limit on N_{sig}: 2.7

➡ $S_{2021+22} = 2.1 \times 10^{-13}$

  - c.f. $S_{2021} = 8.8 \times 10^{-13}$
  - c.f. $S_{\text{MEG}} = 5.3 \times 10^{-13}$
- Assume 2021 detector performance
  - Photon eeconstruction updates not included
  - **Further sensitivity improvement expected**

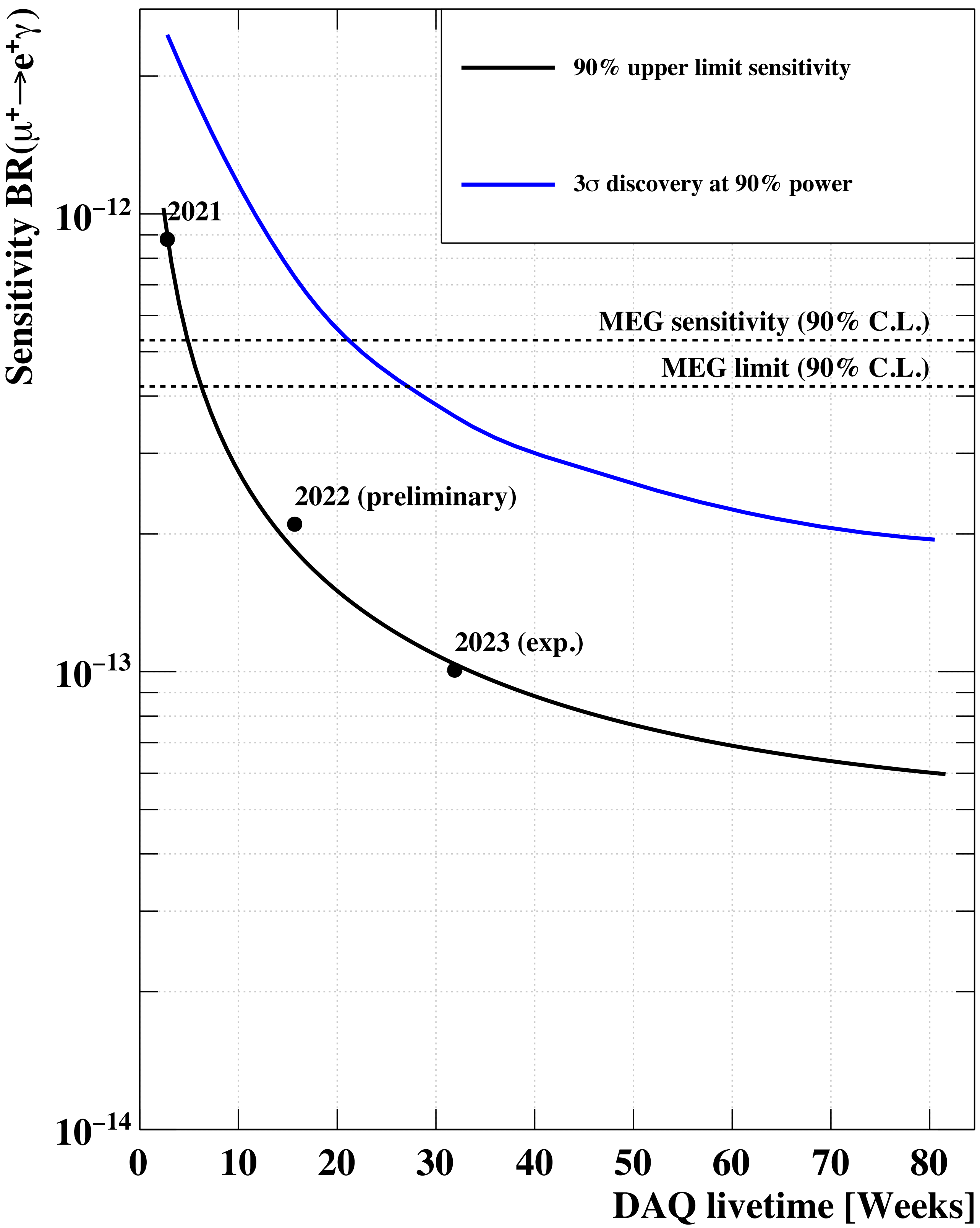
Prospects

- **Aim to publish 2021+22 combined result this summer**

- MEG II prospects
  - Long shutdown at PSI πE5 beamline planned in 2027-28
  - Beamtime to be shared with Mu3e experiment in 2025,26?

➡ Maximise DAQ time and efficiency

➡ **$(5-6)\times 10^{-14}$ sensitivity will be reached**



PMT gain calibration

A. Matsushita,
78th annual meeting (17aRA81-1)

PMT gain calculation

PMT gain can be calculated from LED intensity scan data.

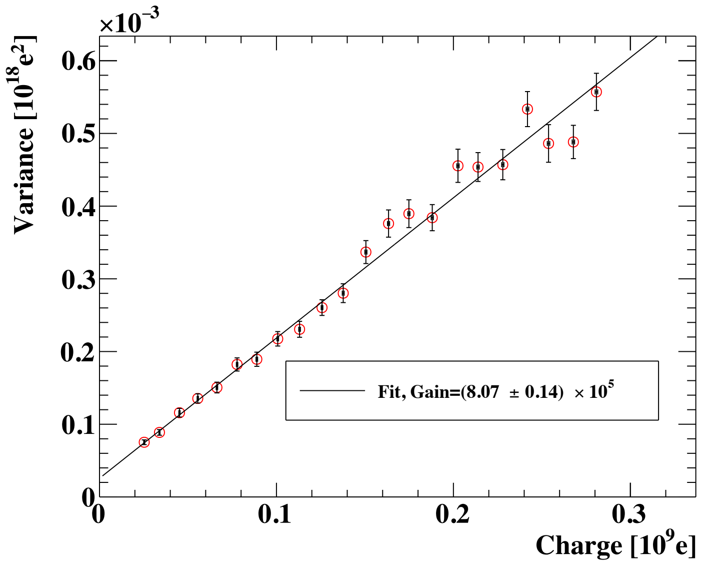
$$\boldsymbol{\sigma_q^2 = G \times e \times \bar{q} + \sigma_0^2}$$

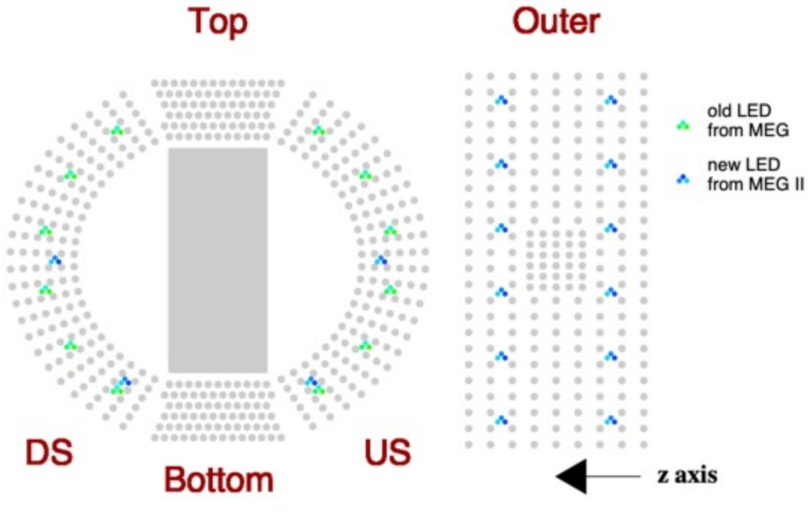
σ_q: spread of integrated charge distribution

G: gain

e: elementary charge

$\bar{q}$: mean of integrated charge





positions of LEDs inside LXe detector

6

MPPC gain calibration

A. Matsushita,
78th annual meeting (17aRA81-1)

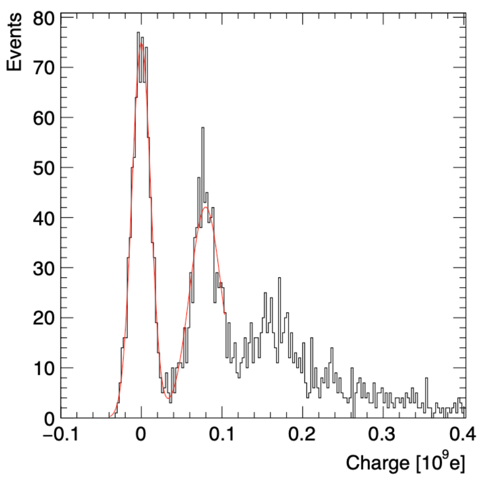
MPPC Gain and ECF calibration

- MPPC gain is calculated from 0 p.e. and 1 p.e. peak using LED data.

  Charge is calculated in multiple integration ranges

$$G(t) = G \times \left(1 - \exp\left(-\frac{t - t_0}{\tau_{\mathrm{fall}}}\right)\right)$$

τ_{fall}: time constant



example of charge distribution
(integration range 70 ns)

- Excess Charge Factor (ECF)

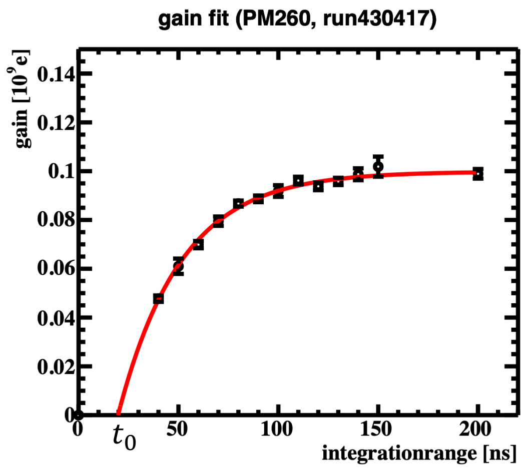
  Charge increase due to cross-talk or after-pulse.

  Calculated assuming the LED light is Poisson light.

$$\mathrm{ECF} = \frac{\mu}{\lambda}$$

$\mu = \frac{\bar{Q}_{measured}}{G}$: Net average number of photoelectrons

$\lambda = -\log \frac{N_{pedestal}}{N_{total}}$: mean of Poisson distribution



10

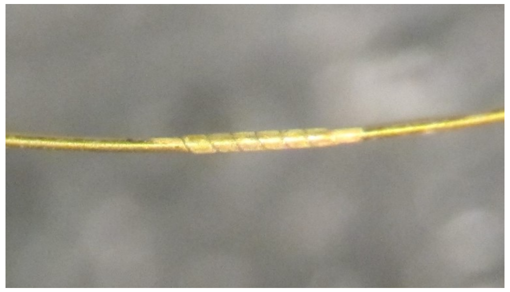
MPPC PDE/PMT QE calibration

- Definition of PDE/QE

$$\epsilon_i = \epsilon_i^{\mathrm{MC}} \times \frac{\bar{N}_{\mathrm{phe},i}}{\bar{N}_{\mathrm{phe},i}^{\mathrm{MC}}} \times F_{\mathrm{LY}}$$

- ϵ_i: PDE/QE of i-th sensor
  - ϵ_i^{MC}: 12% PDE, 16% QE
- $\bar{N}_{\mathrm{phe},i}$: mean of the number of photoelectrons
- F_{LY}: Light yield correction

- Calibration source: α-ray from ^{241}Am
  - Comparison b/w MC and data needed
  - Reflectivity of PMT holder in MC is 50% based on absorption curve



- Averaged PMT QE fixed at 16%
  - Supplied from Hamamatsu
  - ➡ N_{PMT} history interpreted as relative light yield history F_{LY}