



Core-to-Core Program



MEG II 実験2021年データを用いた 液体キセノンガンマ線検出器の性能 および測定量の系統誤差の評価

山本 健介 (東大理)

他MEG IIコラボレーション

2023年9月16日(土)-19日(火)

日本物理学会第78回年次大会

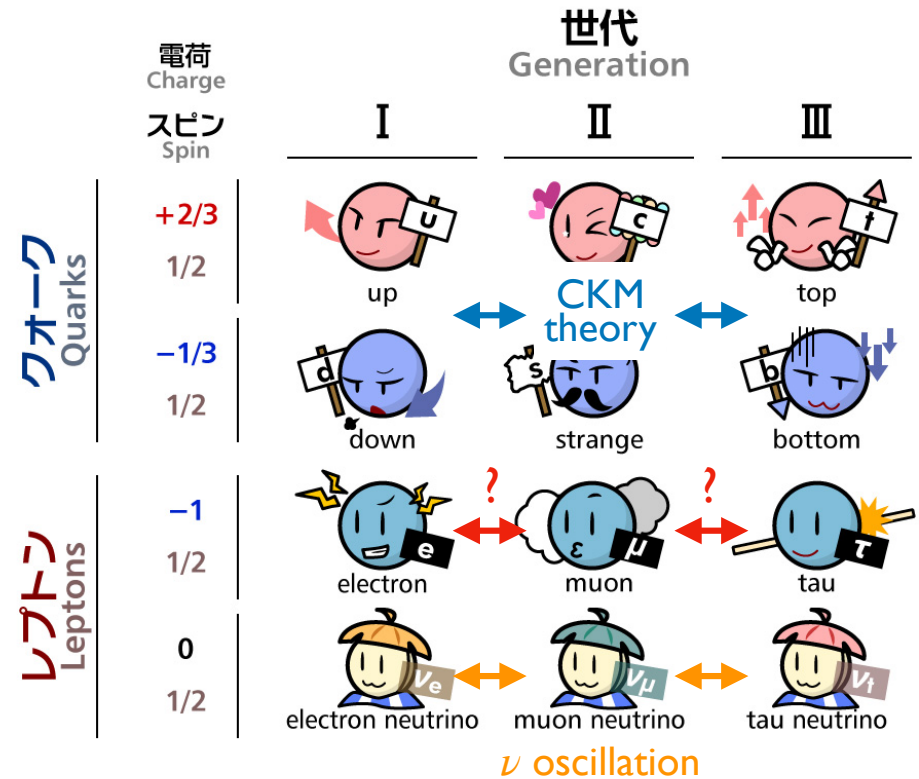
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Outline

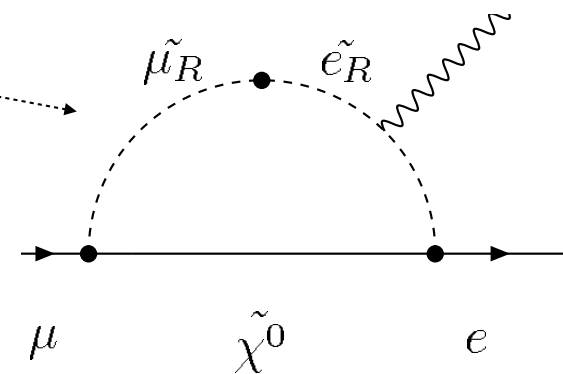
- Introduction
 - $\mu \rightarrow e\gamma$
 - MEG II experiment
- 2021 γ analysis
 - E_γ scale calibration
 - E_γ PDFs estimation for likelihood analysis
 - Systematic uncertainties
- Conclusion

Motivation of $\mu \rightarrow e\gamma$

- Charged Lepton Flavour Violation (cLFV)
 - Never observed
 - Strongly suppressed in SM + ν osc. ($\mathcal{B}(\mu \rightarrow e\gamma) \sim 10^{-54}$)
 - **Measurable branching ratio predicted by new physics** ($\mathcal{B}(\mu \rightarrow e\gamma) \sim 10^{-11} - 10^{-14}$)
 - SUSY-seesaw, SUSY-GUT, etc.

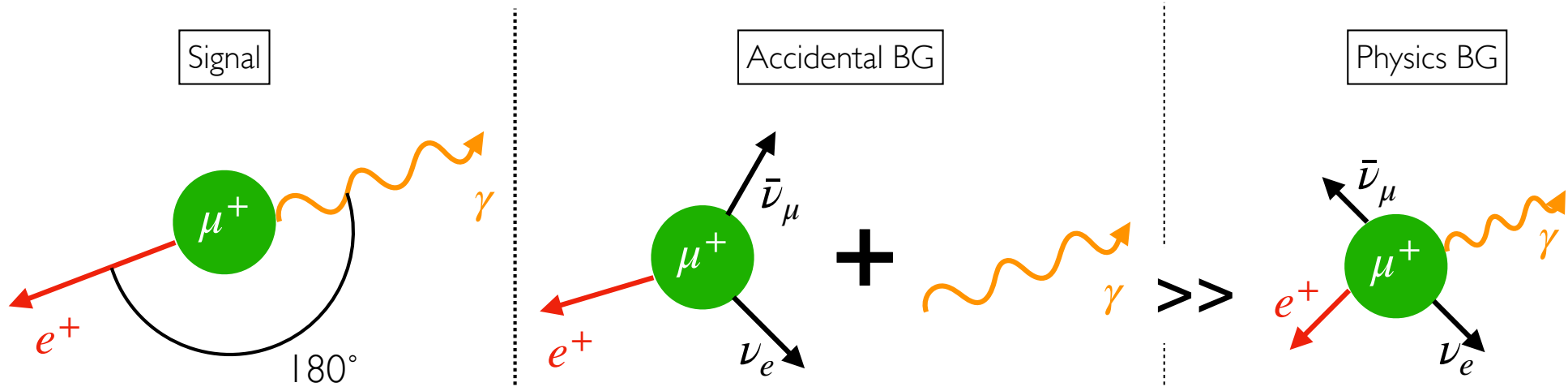


- $\mu \rightarrow e\gamma$: **Good probe of cLFV**
 - Current limit: 4.2×10^{-13} (90% C.L.) by MEG
 - Target sensitivity of MEG II: 6×10^{-14}



$\mu \rightarrow e\gamma$ signal and background

- Key: **Precise measurement of e^+ & γ** to discriminate signal & BG



- Same energy of 52.8 MeV
- Back-to-back
- The same timing

Signal-like accidental coincidence of e^+ and γ with ~ 52.8 MeV

$$N_{\text{sig}} \propto R_{\mu} \cdot T \cdot \mathcal{B}(\mu \rightarrow e\gamma) \cdot \epsilon$$

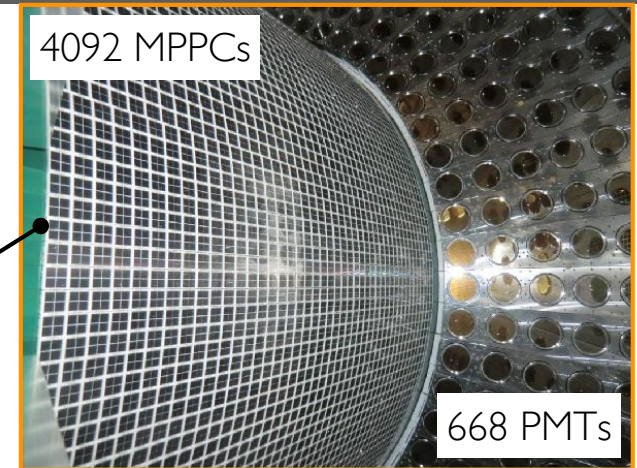
$$N_{\text{acc}} \propto R_{\mu}^2 \cdot T \cdot \Delta E_{\gamma}^2 \cdot \Delta E_e \cdot \Delta \Phi_{e\gamma}^2 \cdot \Delta T_{e\gamma}$$

- R_{μ} : μ stopping rate
- T : Experiment time
- ϵ : Efficiency
- Δ : Resolution

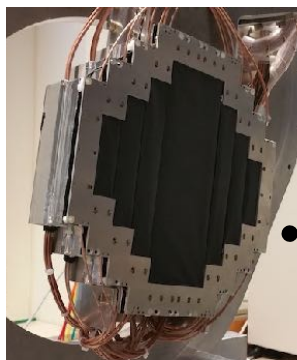
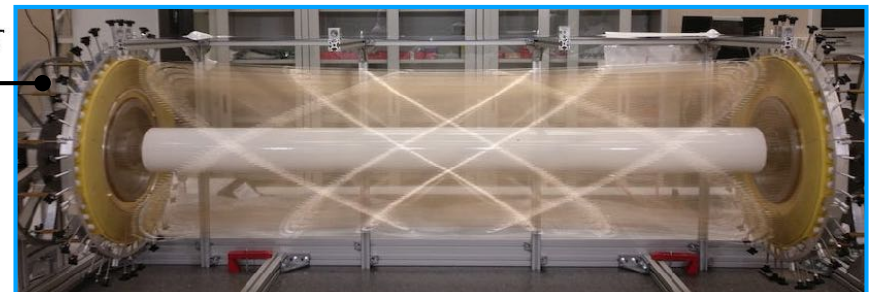
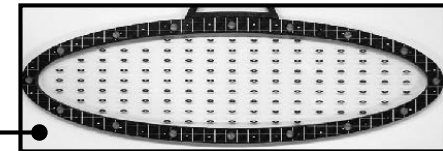
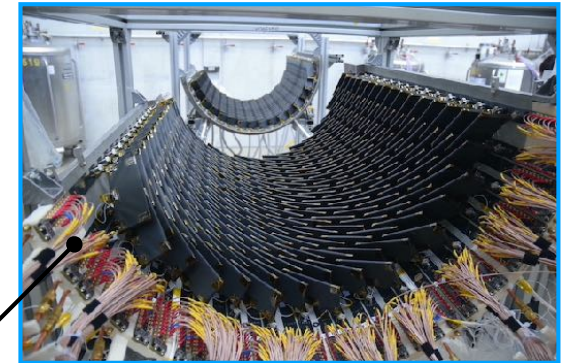
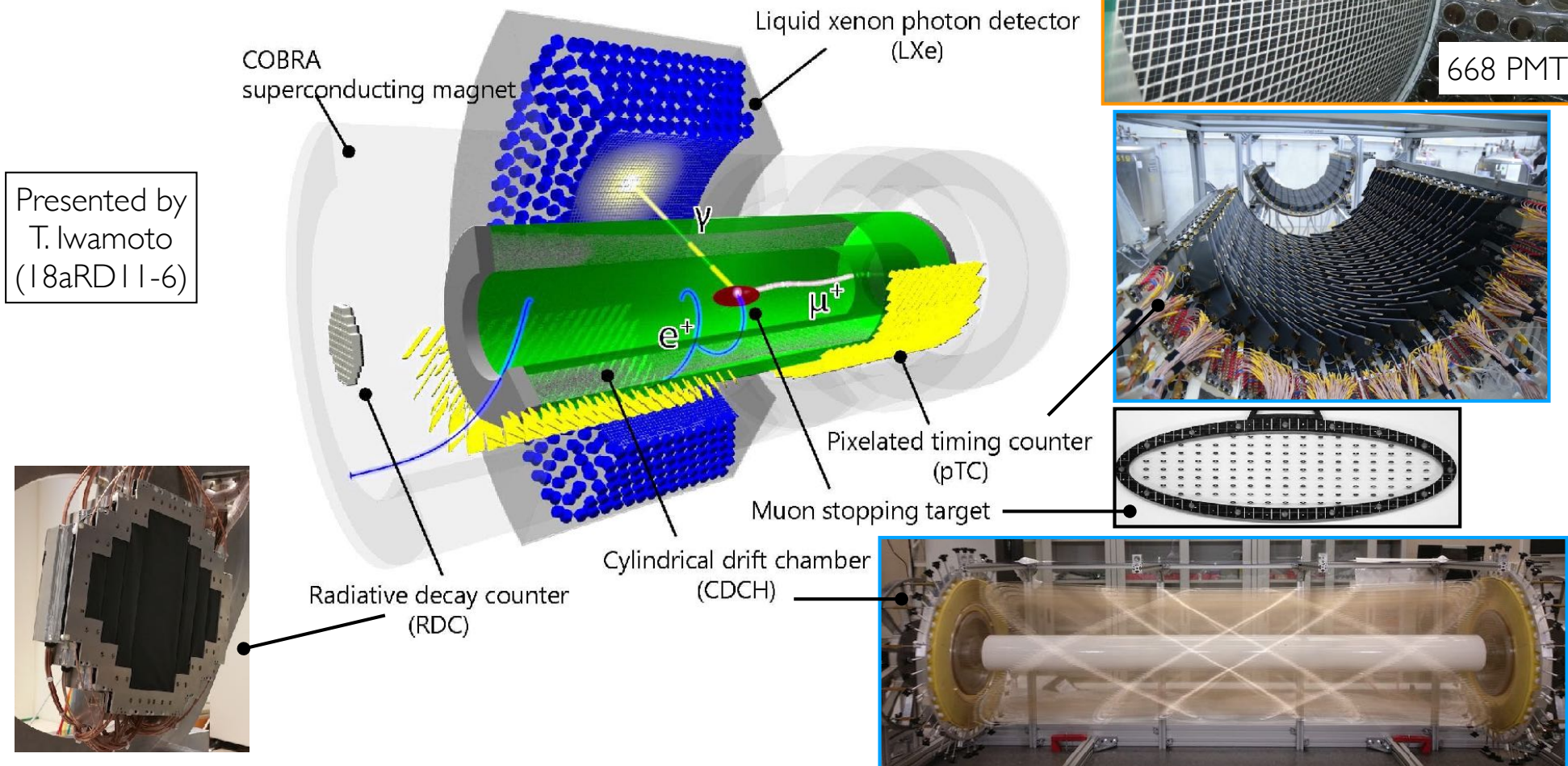
↑
DC μ^+ beam used at Paul Scherrer Institut

MEG II apparatus

- μ^+ stopped at target
- e^+ detected by COBRA+CDCH+pTC
- γ detected by LXe
 - BG- γ tagged by RDC

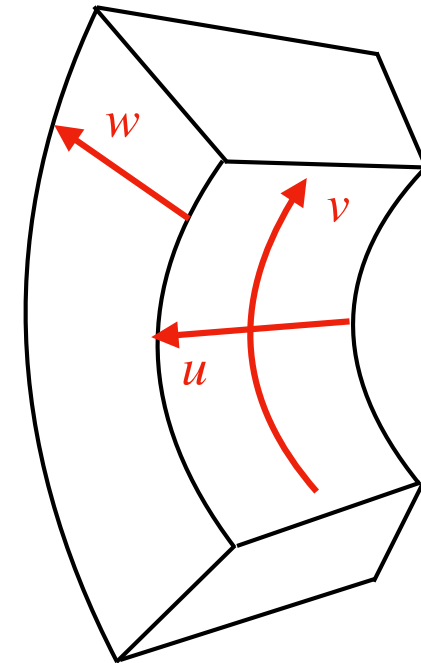
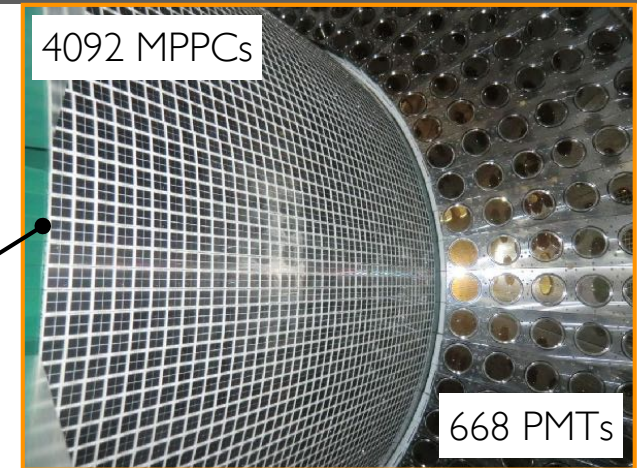
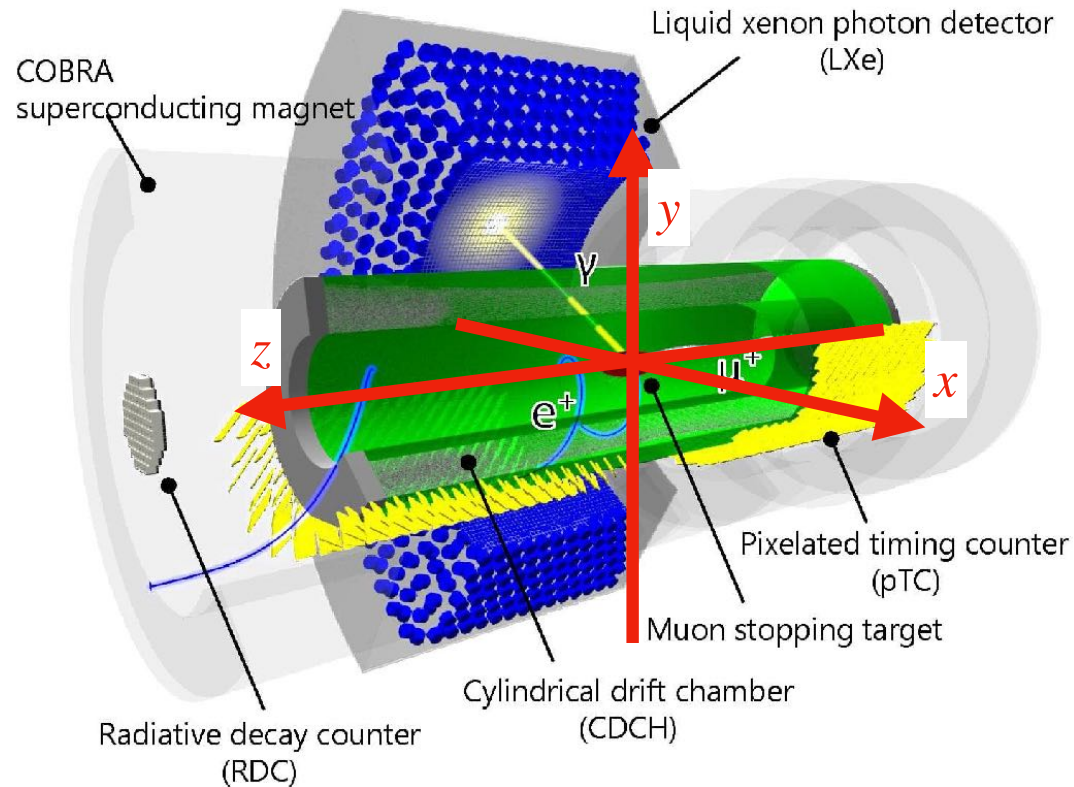


Presented by
T. Iwamoto
(18aRD11-6)



Coordinate systems

- μ^+ stopped at target
- e^+ detected by COBRA+CDCH+pTC
- γ detected by LXe
 - BG- γ tagged by RDC



Today's topics: 2021 γ analysis finalisation

- The first physics dataset collected for 1.5 months in 2021

- Beam rate: $2,3,4,5 \times 10^7 \mu/s$
- Calibration datasets also collected
 - 55 MeV γ from $\pi^0 \rightarrow \gamma\gamma$
 - 17.6 MeV γ from ${}^7\text{Li}(p, \gamma){}^8\text{Be}$ reaction

σ_{x_γ} [mm]	2.5
σ_{t_γ} [ps]	61
σ_{E_γ} [%]	2.0/1.8
ϵ_γ	0.67×0.92

- LXe performance evaluated so far

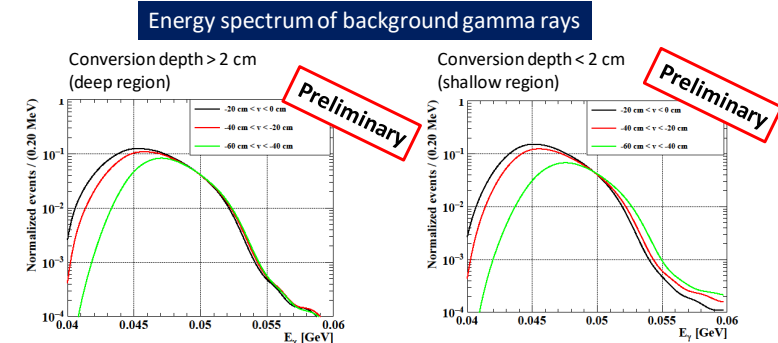
- E_γ scale non-uniformity found

- **Today's topics: γ analysis finalisation**

- E_γ calibration update
- E_γ PDFs for likelihood analysis
- Systematic uncertainties

S. Kobayashi (23pTI-1)
in JPS 2023 spring

Uniformity



- Non-uniformity of the energy scale is corrected based on the energy peak of 55 MeV gamma ray.
- A large non-uniformity for shallow gamma-ray energy spectrum is found.
- We are checking the non-uniformity carefully.

E_γ PDFs & uncertainties

- Likelihood function to estimate N_{sig}

$$\mathcal{L}(N_{\text{sig}}, N_{\text{acc}}, N_{\text{RMD}}) = (\text{external constraint terms}) \times \frac{e^{-(N_{\text{sig}}+N_{\text{acc}}+N_{\text{RMD}})}}{N_{\text{obs}}!} \prod_{\text{dataset}} (N_{\text{sig}} \cdot S(x) + N_{\text{acc}} \cdot A(x) + N_{\text{RMD}} \cdot R(x))$$

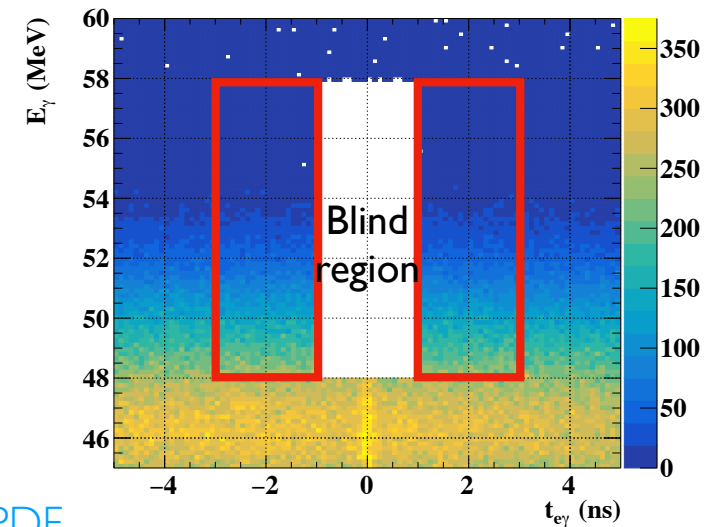
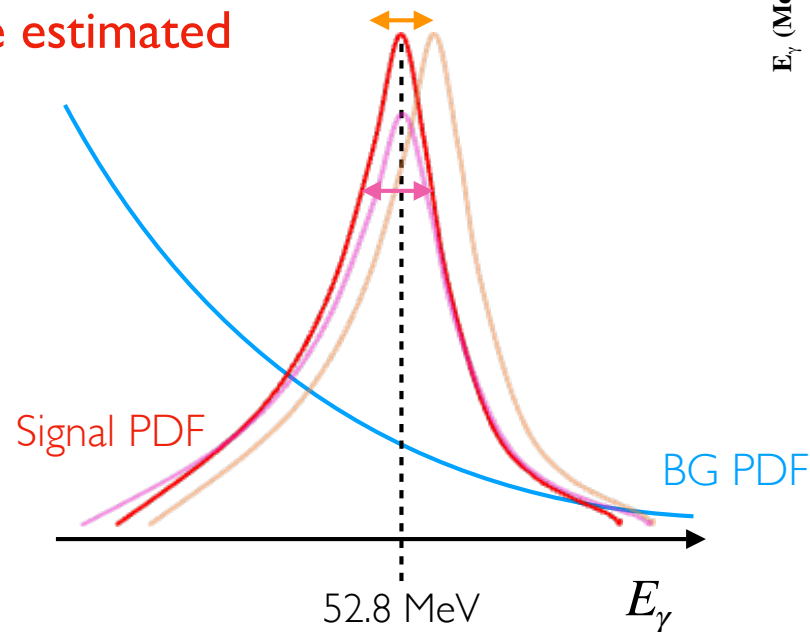
- Fiducial volume segmented by v, w to incorporate E_γ response difference
 - Physics model-independent search for $\mu \rightarrow e\gamma$
 - Polarisation $\rightarrow z(u)$ independent

- **Signal PDF needs to be estimated**

- Based on 55 MeV γ

- Calibration

- Resolution evaluation



BG PDF parametrised
measured spectrum in $t_{e\gamma}$ sideband

BG γ further study

Previous study

This work

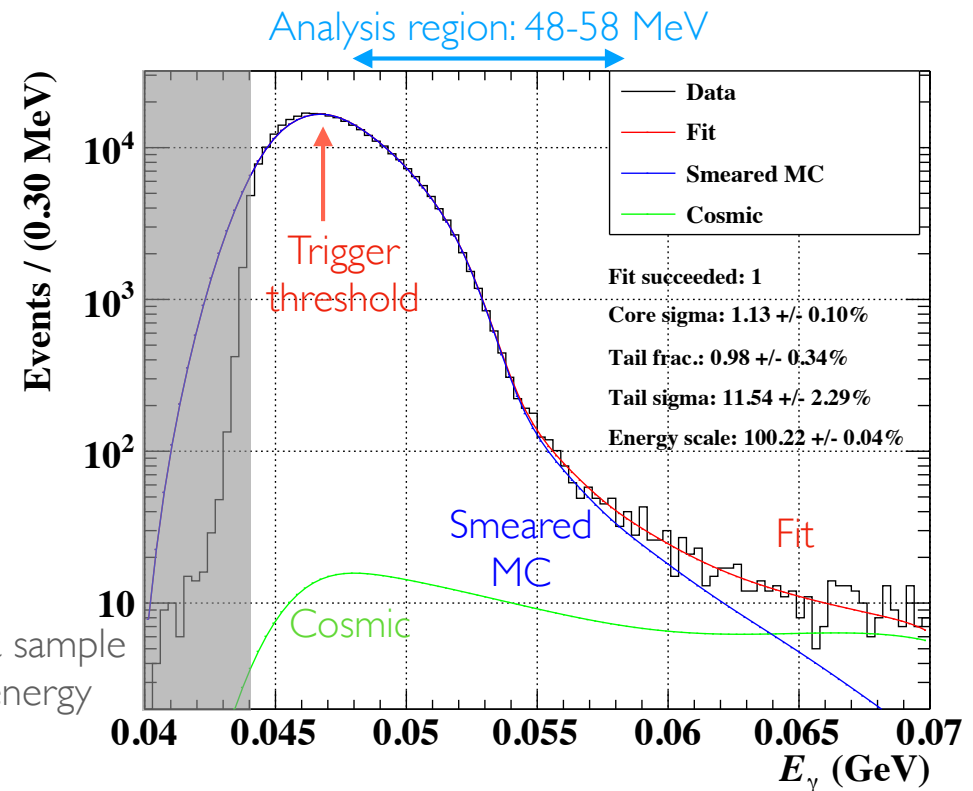
Calibration
dataset

55 MeV γ

55 MeV γ + 17.6 MeV γ + **BG γ**

BG spectrum further studied and fit improved
→ **Trigger threshold not fully covers analysis region in some segments**

Cut as unused data sample
due to too low energy



BG γ further study

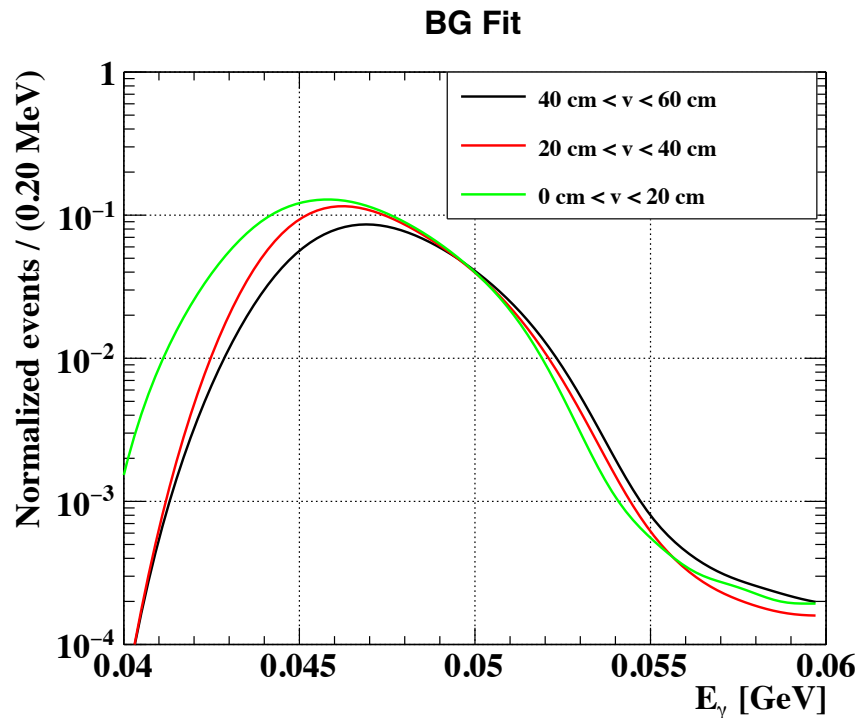
Previous study

This work

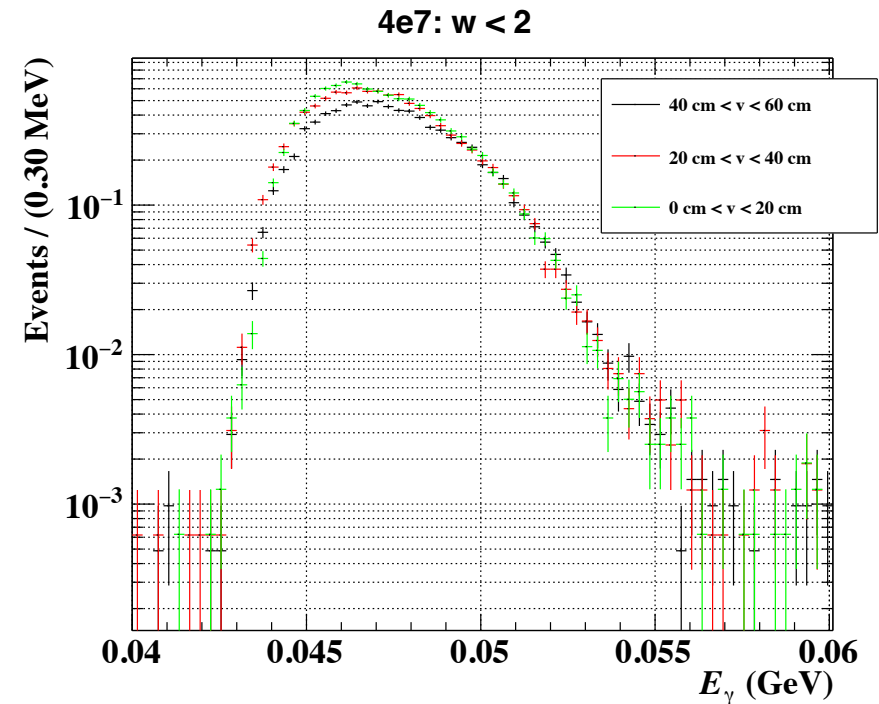
Calibration
dataset

55 MeV γ

55 MeV γ + 17.6 MeV γ + **BG γ**



Normalised in [48 MeV, 58 MeV]



Normalised in [50 MeV, 58 MeV]

E_γ scale uniformity calibration

Previous study

This work

Calibration dataset

55 MeV γ

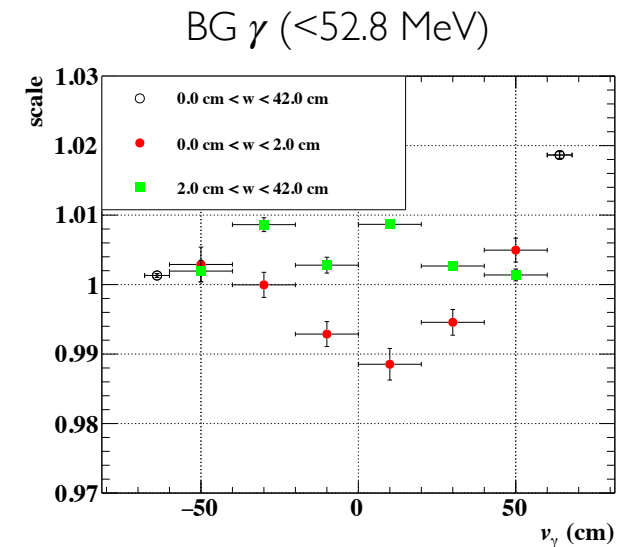
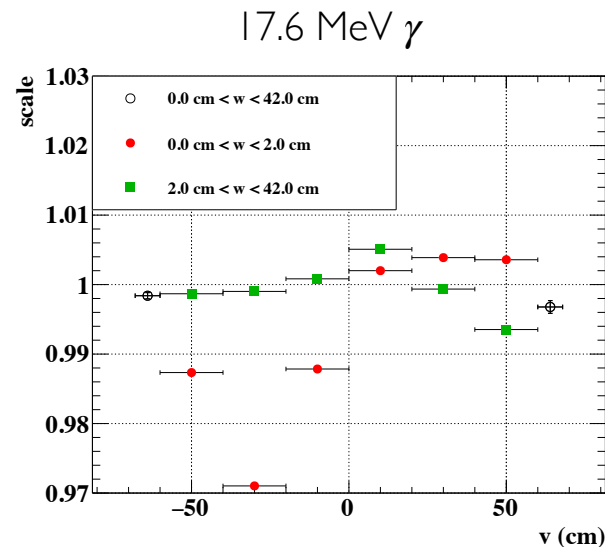
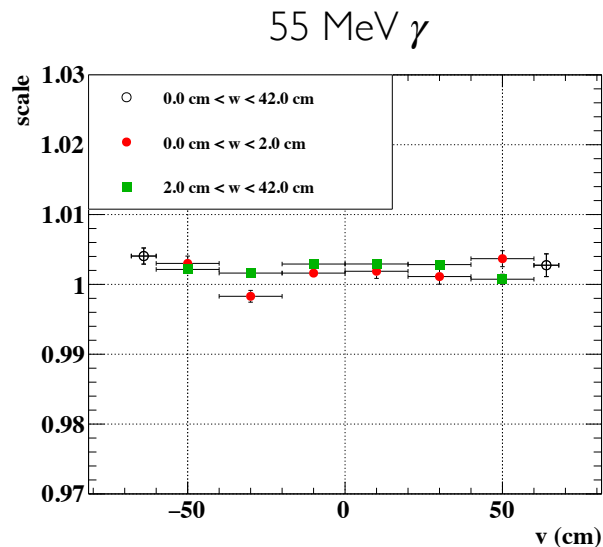
55 MeV γ + 17.6 MeV γ + BG γ

Uncertainty from non-uniformity

0.4% on average

0.2% on average

Different non-uniformity trends observed
→ Treat it as uncertainty



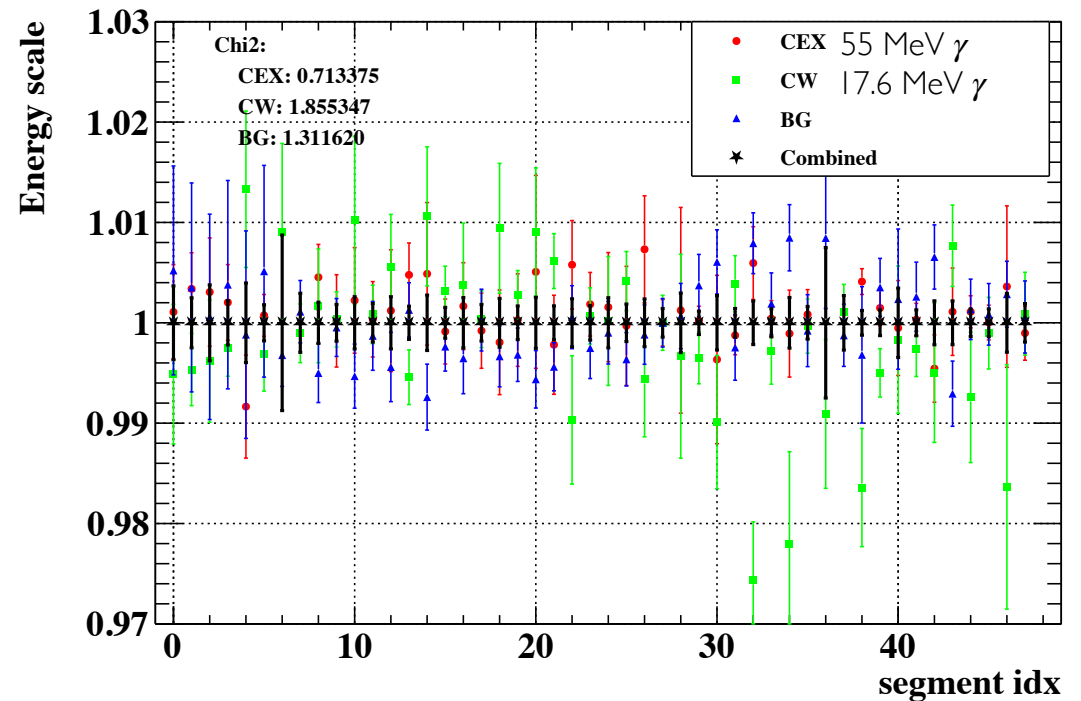
Calibrated by 55 MeV γ

E_γ scale uncertainty

- E_γ scale uncertainty estimated to be 0.4%
- Uncertainty from
 - History: 55 MeV γ peak vs BG γ scale
 - Uniformity: Errors of weighted average in every segment

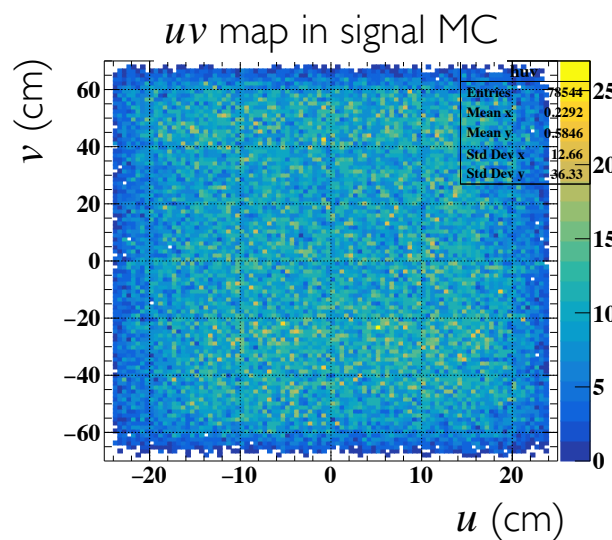
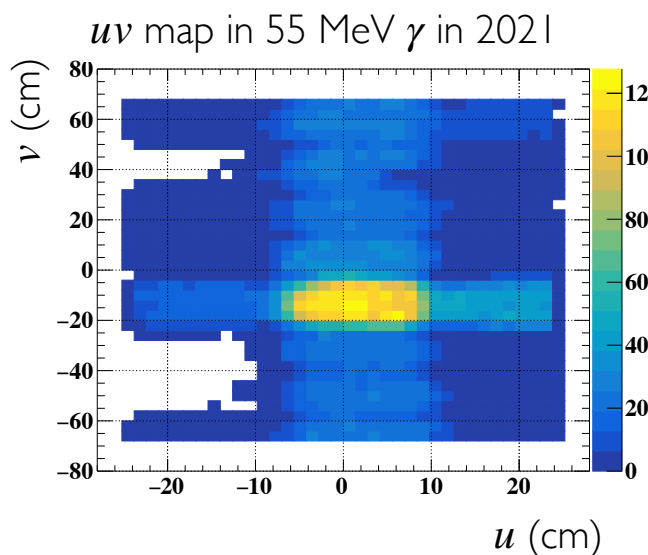
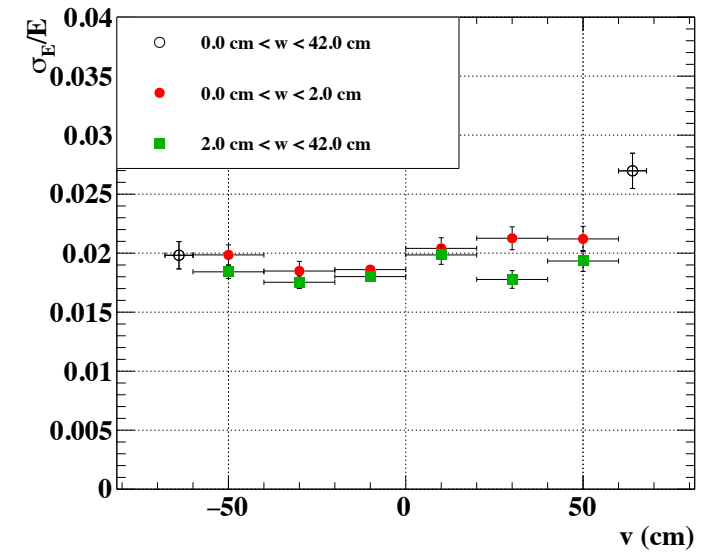
Segment indices					
$w < 2$			$w > 2$		
0	2	4	1	3	5
6	8	10	7	9	11
12	14	16	13	15	17
18	20	22	19	21	23
24	26	28	25	27	29
30	32	34	31	33	35
36	38	40	37	39	41
42	44	46	43	45	47

	Uncertainty
History	0.3%
Uniformity	0.2% on average
Linearity	0.1%
Total	0.4%

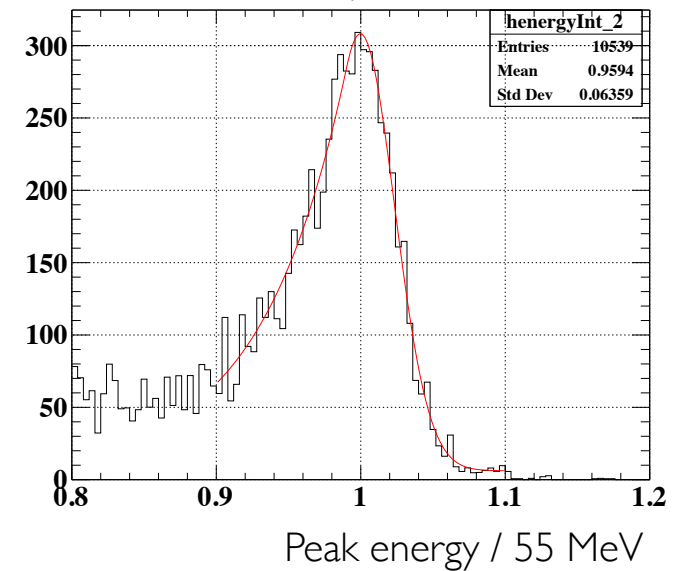


Resolution estimation

- Resolution in signal PDF consists
 - Resolution for 55 MeV γ
 - Smearing by non-uniformity for u
 - Integrated out for u
 - 0.1-0.7% smearing

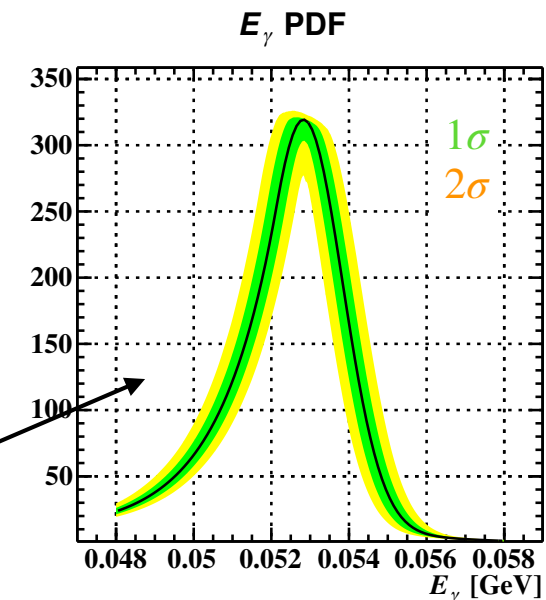


Integrated E_γ spectrum



Conclusion

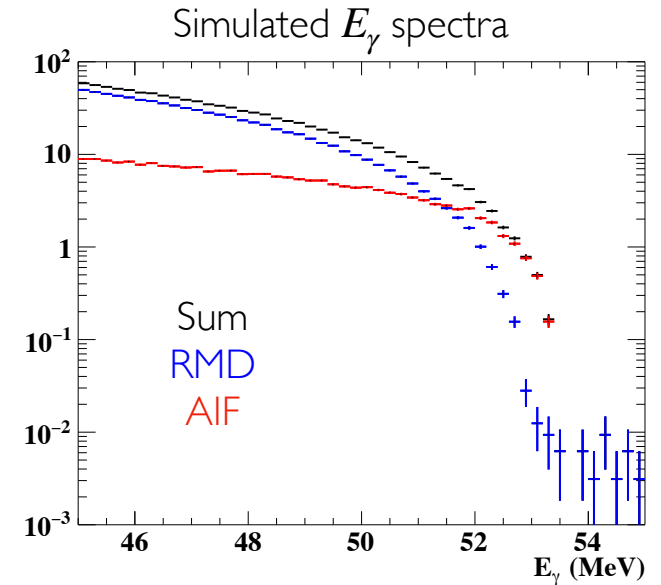
- MEG II searches for $\mu \rightarrow e\gamma$ with target sensitivity of 6×10^{-14}
 - Physics data taking started in 2021
- 2021 γ analysis finalised
 - E_γ uniformity calibrated
 - Scale uncertainty: 0.4%
 - BG PDF parametrised with fitting
 - Signal PDF extracted based on 55 MeV γ
 - Aim at narrower band in 2022 analysis
- $\mu \rightarrow e\gamma$ search analysis reported in next talk



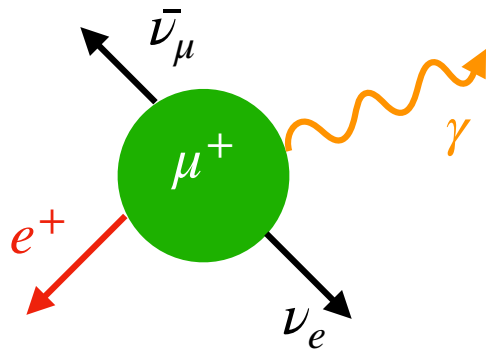
Backup

Background γ

- Background γ source: RMD & AIF
 - RMD/AIF = 65/35 for γ with >48 MeV
- **<65% of BG- γ can be suppressed by RDC**
 - Depending on detection efficiency

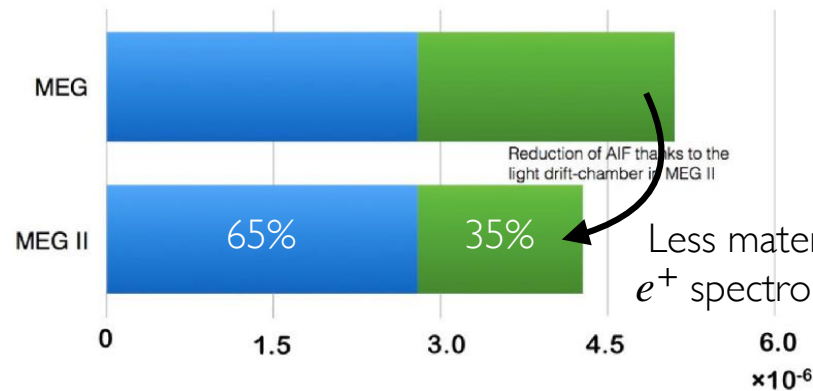


Radiative Muon Decay

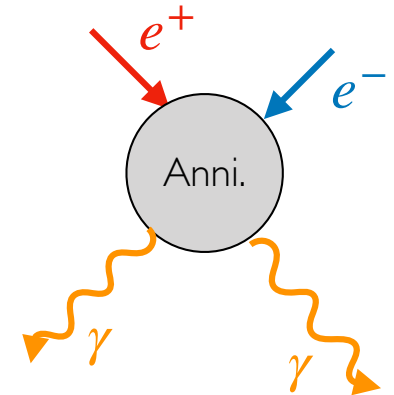


■ RMD ■ AIF

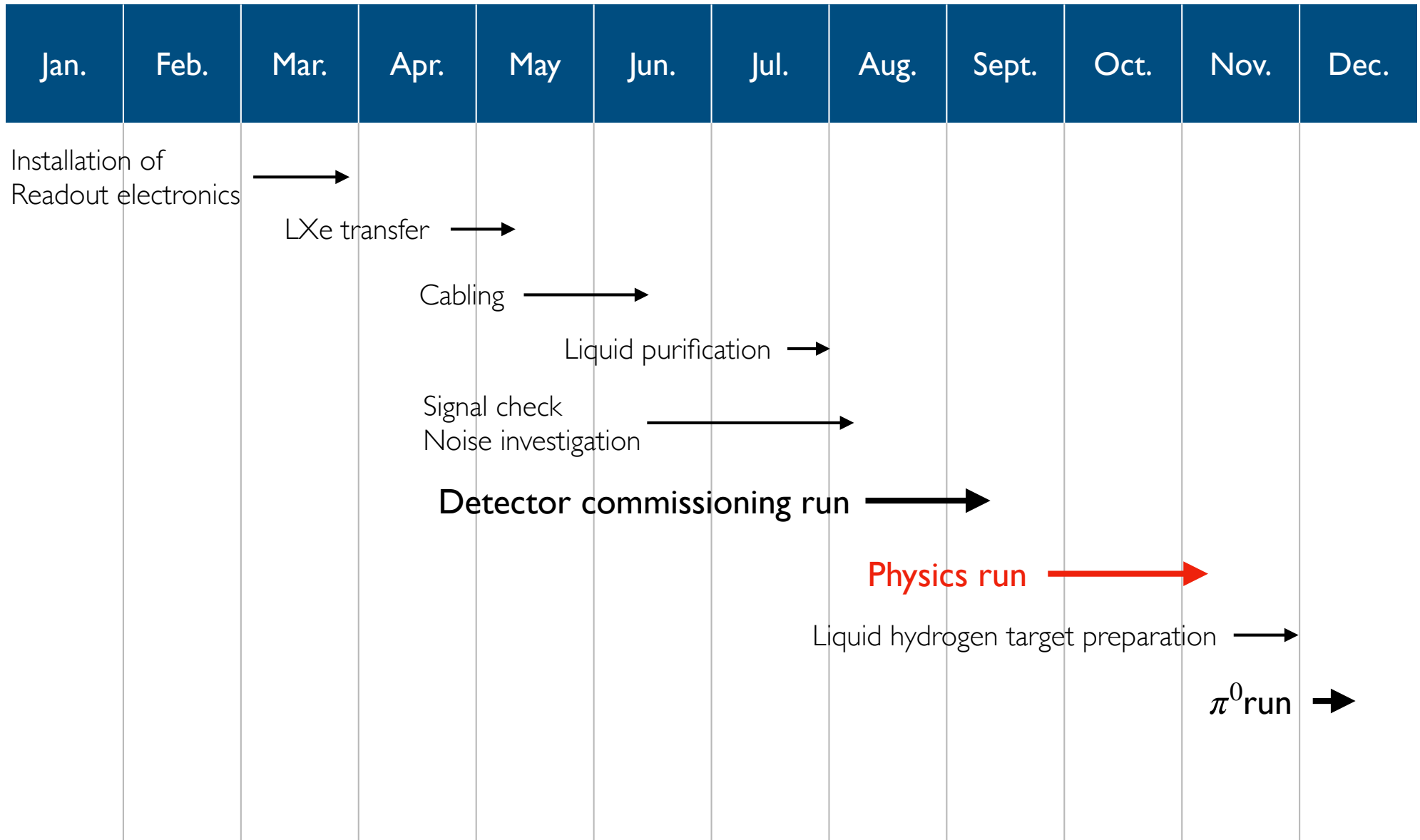
Simulated >48 MeV photon yield per muon decay



Annihilation In Flight

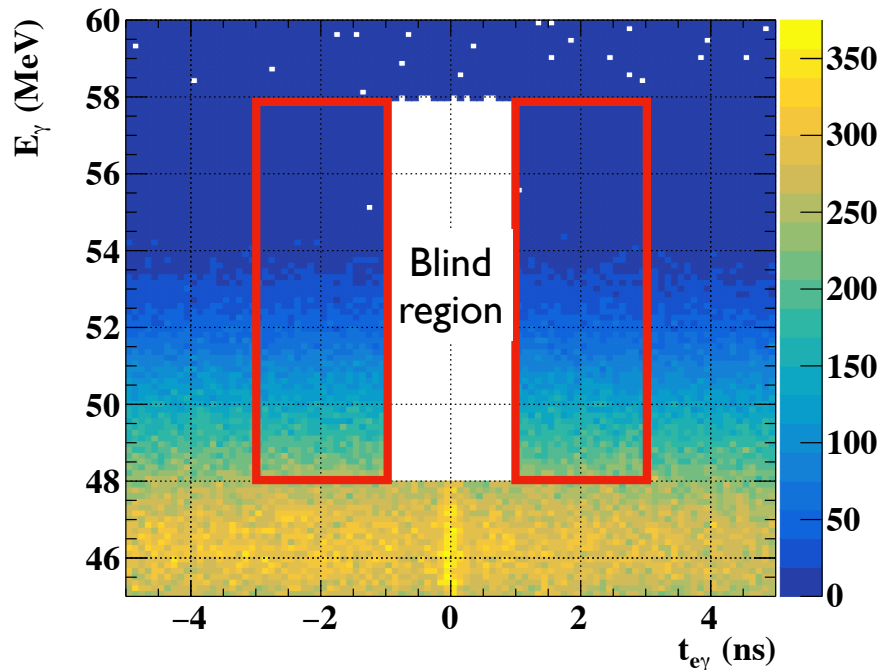
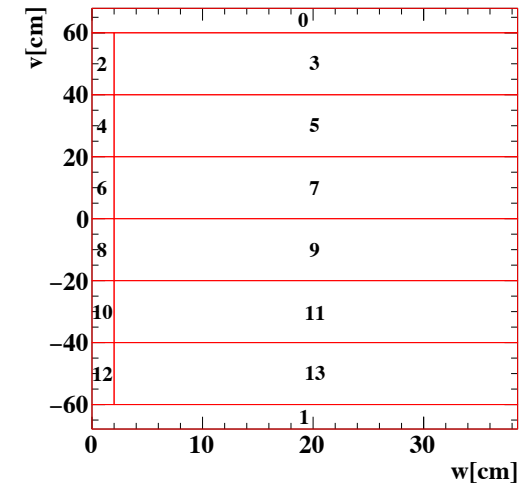


Run 2021

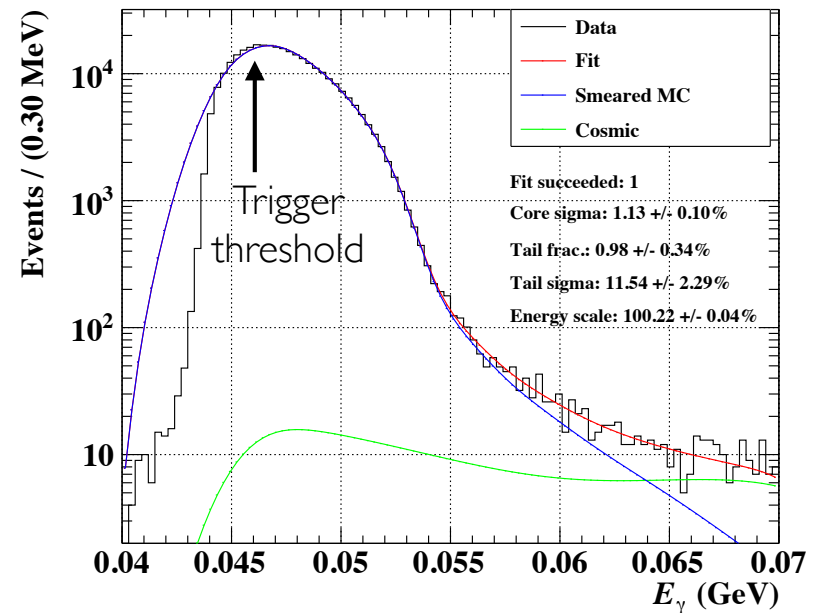


BG E_γ PDF

- BG PDF
 - Parametrised E_γ spectrum in $t_{e\gamma}$ sideband
 - Segmented by v, w
 - For each μ beam intensity
- PDF uncertainty comes from fit error

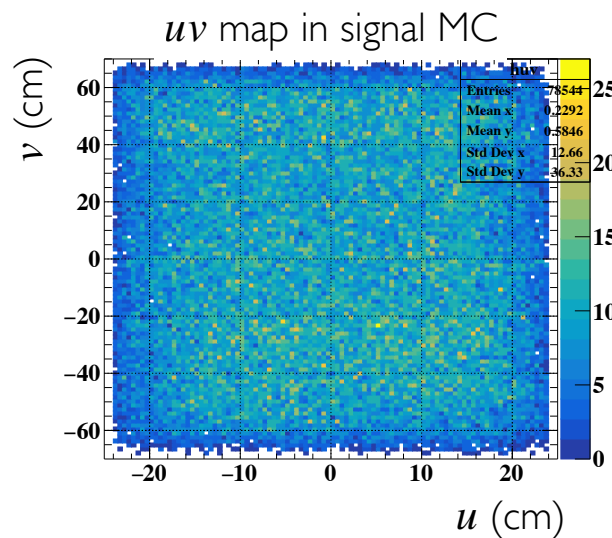
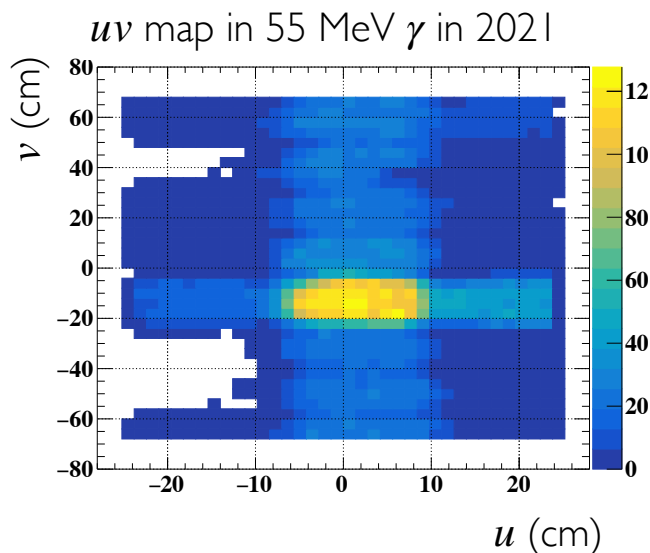
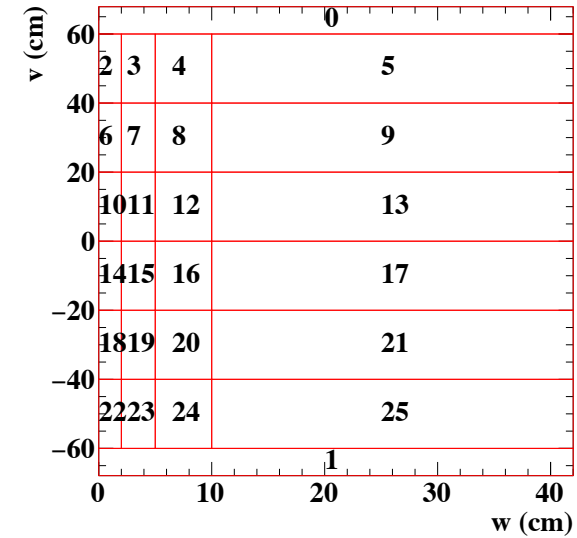


BG γ spectrum at $4 \times 10^7 \mu/s$

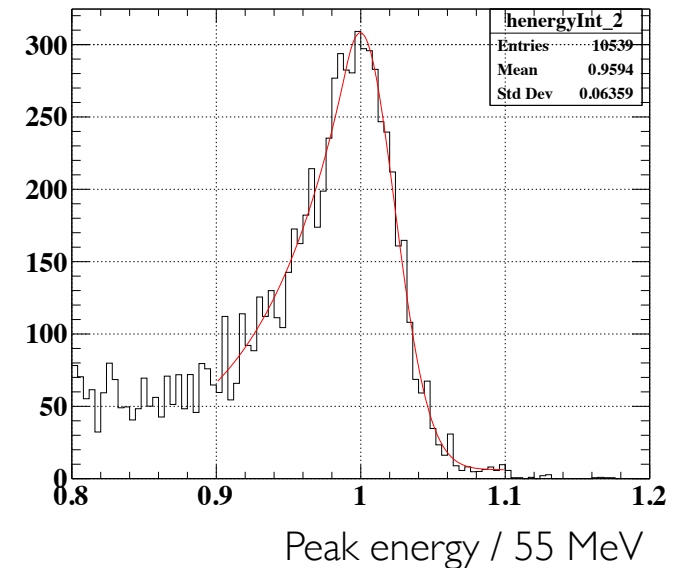


Signal E_γ PDF

- Signal PDF: based on 55 MeV γ
 - **Double exponential+Gaussian function**
 - Take into account
 - **Difference in event distribution**
 - **Integration for u**
- ➔ Normalised E_γ spectra extracted with u, v, w segmentation
- ➔ Integrate out for u with randomised energy scale



Integrated E_γ spectrum



Signal E_γ PDF

- The procedure repeated 1000 times
- PDF parameters and uncertainty estimated
 - Worse resolution due to non-uniformity can be incorporated

