

MEG2008 データ解析: $\mu \rightarrow e \gamma$ 解析 _{東大素粒子物理国際研究センター}

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Signal and Background



Back-to-Back	Any angle (Energy correl	ated) Any angle
52.8 MeV	< 52.8 MeV	< 52.8 MeV *
Same time	Same time	Flat time difference
Eγ	Ee ⁺ T	φθ

* Measured E_{γ} can be larger than signal in the case of pileup of two γs .

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Z



2008 data



- Condition was not the best
 - DCH discharge (low efficiency and resolution.)
 - TC fiber not in operation. (lower trigger efficiency)

→ next talk

- The first three months of MEG experiment
- 3×10⁷ muons/sec rate, in total 9.5 × 10¹³ muons stopped on the tarted.
- Physics run

Event rate	4.6 event/sec
DAQ time	4.0 Msec
# triggered events	21.7 M *
Data size	1.5 MB/event
Total data size	31TB *

Several calibration trigger data were mixed in physics runs, with each pre-scaling factor

* including 15% of calibration events.

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Analysis procedure





- Final analysis is done for pre-selected
 3.7 M events (20% of recorded events).
- Blinding analysis (**T** and **Ε**γ) to avoid experimenter's bias.
- Analysis was tuned, and background spectrums were obtained from sideband data.
- Unblinded the box after fixing analysis and, selection criteria, chose of tools.

Pre-selection				
Blind box				
Analysis box				

- : T [-6.9, 4.4] nsec && at least one e+ track associated with trigger.
- : **T** [-1, 1] nsec, **Ε**γ [48, 57.6] MeV
- : **T** [-1, 1] nsec, **Ε**γ [46, 60] MeV (**T**[-3.5,3.5] nsec is used for sideband studies)

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Estimation of branching ratio

Number of signals (Numerator) -

Event quality cut for gamma(acceptance, partial pileup cut, CR cut) and positron(track fitting uncertainty, matching between DCH and TC...).

Selection of analysis event with $\mathbf{E}\gamma$, $\mathbf{Ee^{+}}$, \mathbf{T} , ϕ and θ .

Fitting distribution of $\mathbf{E}\gamma$, $\mathbf{Ee^{+}}$, \mathbf{T} , ϕ and θ , with **Signal** + **RMD** + **BG** probability density function(PDF).

- Number of observed muons [Denominator] -

Same event quality cut.

Counting number of muons by using Michel positrons, which was taken in parallel with physics data.

Scaling by difference of several efficiencies between Michel and Signal.

Branching Ratio

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Branching Ratio

Naximum LikelMaximum likelihood fitting

 $\mathcal{L}(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}})$ $= \frac{N^{N_{\rm obs}} \exp^{-N}}{N_{\rm obs}!} \prod_{i=1}^{N_{\rm obs}} \left[\frac{N_{\rm sig}}{N} S + \frac{N_{\rm RMD}}{N} R + \frac{N_{\rm BG}}{N} B \right]$

> study. The number of $\mu^+ \rightarrow e^+ \gamma$ events is determined by means of a maximum likelihood fit in the analysis window defined as $46 \text{ MeV} < E_{\gamma}$ 46 MeV, Fitting \mathcal{F}_{e} diposed in the standard likelihood function and $|\phi_{e\gamma}| < 100 \,\mathrm{mrad}$. An extended likelihood function

 \mathcal{L} is constructed as,

 $t_{\mathbf{e}\gamma}$

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Rev (accidental background)

 $=\frac{N^{N_{\rm obs}}\exp^{-N}}{\mathsf{RMD}}\prod_{i=1}^{N_{\rm obs}}\left[\frac{N_{\rm sig}}{N}S+\frac{N_{\rm RMD}}{N}R+\frac{N_{\rm BG}}{N}B\right],$

where $N_{\rm sig}$, $N_{\rm RMD}$ and $N_{\rm BG}$ are the numbers of $\mu \to e\gamma$, RMD and accidental background (BG) events, respectively, S, R and B are the probability density functions (PDFs) for $\mu \to e\gamma$, RMD and BG events, respectively, $N = N_{\rm sig} + N_{\rm RMD} + N_{\rm BG}$ and $N_{\rm obs}(= 1189)$ is the total

- Pippes of vento biserver in the analysis for the five $r_{\rm H}$ signal PDF S is the product of the PDFs for the five $r_{\rm H}$ observables $(E_{\gamma}, E_{\rm e}, t_{\rm e\gamma}, \theta_{e\gamma} \text{ and } \phi_{e\gamma})$, each defined by
- the detector response function with the measured resolu-Livens, as previously described. The Range of the count position or time dependent change of **Product of the** PDF for $t_{e\gamma}$, which is the same as that for the signal and the PDF for the other correlated observables $(E_{\gamma}, E_{\rm e}, \theta_{e\gamma} \text{ and } \phi_{e\gamma})$. The latter is formed by

folding the theoretical RMD spectrum [6] with the detec-tor response functions and BCODF DISTREPACE of the background spectra for the five observables, which are precisely measured in the data sample in the sidebands outside the blinding- box. The position dependefice of Bereson Done of Act throw the effects between the signal and the normaliza-into account in the PDFs, together with all their proper into account in the PDFs, together with all their proper



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FIG. 3: Distribution of E_{γ} for all the events in the analysis window. A solid line shows the projection of the fitted likelihood function.

normalizing the upper limit on $N_{\rm sig}$ to Michel positrons counted simultaneously with the signal, with the same analysis cuts, assuming $BR(\mu \to e\nu\bar{\nu}) \approx 1$. This techniqueshape a a detectors respects function. positron acceptance and efficiency factors associated with the DCH and TC, which differ only for small momentum



PDF - Gamma energy

Signal



Response from π beam test *

Fitting muon sideband data



В

^{*} Average response is shown (including shallow events). Actual fitting is done PDF for each position.



PDF - Positron energy

Signal





PDF - Time difference

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•Resolution of low γ energy **RMD** peak •Extrapolation to signal energy by known relation from π beam test.

•Event-by-event PDF as a function of ΔZ .*





*Difference of z hit position between TC reconstruction, and extrapolation of DC tracking. **R.Sawada**







Sensitivity can be estimated by using MC based on PDF

- Sensitivity (average 90% C.L. upper limit with null signal hypothesis) is estimated by repeating the fitting for many toy-MC to be 1.3×10⁻¹¹.
- 90% C.L. upper of two sidebands (negative/positive T) are **0.9**. and **2.1×10**⁻¹¹.

(Current upper limit given by MEGA in 1999 is 1.2x10-11)

Preliminary

Normalization used for this calculation will be discussed later.

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2008 data fit result 1189 analysis events





Upper limit

90% C.L contour set by means of Feldman-Cousins approach.



- Best fit in likelihood fit
 Sample point
 Simulated experiments with sample point
- Perform many toy-MC experiments at several (Nsignal, NRMD) sampling points by means of PDF.
 - Compare R_{data}=L_{data,max}/L_{data}(Nsignal,N RMD) and R_{MC} =L_{MC,max}/L_{MC}(Nsignal,N RMD) for each simulated experiment.
- If the probability of R_{data}<R_{MC} is less than 90%, the sampling point is outside of 90% C.L. contour.

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Systematic errors

Systematic error is estimated by repeating fitting with using alternative parameters.

For example, on $\mathbf{E}\gamma$



Dominant errors **E** γ scale : 0.4 events **Ee^+** spectrum parameters : 1.1 events

Total : 1.3 events

Upper limit including systematic error = 14.7

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Number of signals (Numerator) -

Event quality cut for gamma(acceptance, partial pileup cut, CR cut) and positron(track fitting uncertainty, matching between DCH and TC...).

Selection of analysis event with E7, Ee^{+,} T, Ø and Ø.

Fitting distribution of **E**γ, **Ee^{+,} T**, **φ** and **θ**, with **Signal** + **RMD** + **BG** probability density function(PDF).

-Number of observed muons [Denominator] -

Same event quality cut.

Counting number of muons by using Michel positrons, which was taken in parallel with physics data.

Scaling by difference of several efficiencies between Michel and Signal.

Branching Ratio

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Normalization

Signal		trigger		positr	ron	,	gamm	a		
$N_{sig} = N_{\mu}$	$ imes Br_{e\gamma}$	$\times \tau_{e\gamma} \times$	$\epsilon_{e\gamma}^{trig} \times$	$G_{e\gamma}^{DC}$	$\times A_{e\gamma}^{TC} \ \times$	$ < \epsilon^{DC}_{e\gamma} \times $	$A_{e\gamma}^{LXe}$ ×	$\epsilon_{e\gamma}^{LXe}$		
$N_{e\nu\bar{\nu}} = N_{\mu} >$	$\times Br_{e\nu\bar{\nu}}$:	$\times \tau_{e \nu \bar{\nu}} \times$	$\epsilon^{trig}_{e\nu\bar\nu}\times$	$G^{DC}_{e\nu\bar{\nu}}$	$\times A_{e\nu\bar{\nu}}^{TC} \times$	$\epsilon^{DC}_{e\nu\bar\nu}$			$\times f^E_{e\nu\bar{\nu}} \times$	P
Nichel trigger e	events (>5	OMeV)								
#of observation #of stopped mu	Branching ratio	Live time	Trigger efficiency	Geometrical acceptance of DCH	Conditional [*] probability of TC detection	DC efficiency	Conditional geometrical acceptance of LXe	LXe efficiency	Fraction of >50MeV of Michel spectrum	Trigger pre-scaling

 $^{\star}\ensuremath{\mathsf{given}}$ an accepted positron by DC

By using using Michel positrons, normalization is independent of beam rate, and insensitive to absolute positron detection efficiency.

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Normalization

 $N_{sig} = N_{\mu} \times Br_{e\gamma} \times \tau_{e\gamma} \times \epsilon_{e\gamma}^{trig} \times G_{e\gamma}^{DC} \times A_{e\gamma}^{TC} \times \epsilon_{e\gamma}^{DC} \times A_{e\gamma}^{LXe} \times \epsilon_{e\gamma}^{LXe}$ $N \text{Normalization} \epsilon_{\nu} \text{to} \epsilon \text{Costruct}^{F} \text{to} \text{for all } \text{fo$ $BR(\mu^{+} \to e^{+}\gamma) = \frac{N_{sig}}{N_{e\nu\bar{\nu}}} \times \frac{f_{e\nu\bar{\nu}}^{E}}{P} \times \frac{\epsilon_{e\nu\bar{\nu}}^{trig}}{\epsilon_{e\gamma}^{trig}} \times \frac{A_{e\nu\bar{\nu}}^{TC}}{A_{e\gamma}^{TC}} \times \frac{\epsilon_{e\nu\bar{\nu}}^{DC}}{\epsilon_{e\gamma}^{DC}} \times \frac{1}{A_{e\gamma}^{LXe}} \times \frac{1}{\epsilon_{e\gamma}^{LXe}} \times$ (1)# of Michel trigger events Nsig normalized to 404 Michel 2 Fraction of Michel > 50 MeV positrons counted ± 0.006 3 simultaheously 9,66ht 103 trigger efficiency ratio 4 1.11 ±0.02 DC-TC matching efficiency ratio cianal (5) 1.02 ± 0.005 DCH reconstruction and acceptance ratio 6 0.98 ± 0.005 Geometrical acceptance of LXe Independent of .61 ± 0.03 $\overline{(7)}$ LXe efficiency instantaneous bears fote Normalization factor and insensitive to positron

(effect of radiative decay is negligible.) R.Sawada 10/Se

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ethe Preliminary 2008 Data Result

$BR(\mu^+ \to e^+ \gamma) < 3.0 \times 10^{-11}$



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Summary

- Physics data of the first 3 months of MEG was analyzed. Because of hardware problems, statistics is much lower than expected.
- B.R. upper limit was estimated to be 3.0×10^{-11} .
 - Normalization was obtained with a method insensitive to DCH efficiency.
 - Maximum likelihood fitting by means of PDF based on measured response.
 - Upper limit by Feldman-Cousins approach.
- 5 times improvement of sensitivity is expected in 2009. => Next talk.

http://arxiv.org/abs/0908.2594.

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Backup

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Cross check of efficiency

Ω/4π	0.09			
γ	0.66 x 0.91 (Eγ>46MeV)x(pileup, CR)	4.6x10 ⁻³	280/250 (RD sideband	
e⁺	0.15 (DCH x DC-TC match)	(from BG rate, E _γ >45MeV, E ₂ >50MeV)		
Trigger	0.66 (DM)		E _e <48MeV, #expected / #observed)	
Selection	0.99 x 0.98 (DCH x γ			
Nμ	9.4x10¹³ μ stops (3.0x10 ⁷ μ/s			
SES	2.0x10 ⁻¹²	2.2x10 ⁻¹²	2.2x10 ⁻¹²	

Normalization

Z Normalization to beam rate, and insensitive to positron detection efficiency.

$$BR(\mu^+ \to e^+ \gamma) = \frac{N_{sig}}{N_{e\nu\bar{\nu}}} \times \frac{f_{e\nu\bar{\nu}}^E}{P} \times \frac{\epsilon_{e\nu\bar{\nu}}^{trig}}{\epsilon_{e\gamma}^{trig}} \times \frac{A_{e\nu\bar{\nu}}^{TC}}{A_{e\gamma}^{TC}} \times \frac{\epsilon_{e\nu\bar{\nu}}^{DC}}{\epsilon_{e\gamma}^{DC}} \times \frac{1}{A_{e\gamma}^{LXe}} \times \frac{1}{\epsilon_{e\gamma}^{LXe}} \times \frac{1}{\epsilon_{e\gamma}^{LXe}}$$



- Nsig normalized to Michel positrons counted simultaneously with the signal.
- Independent of instantaneous beam rate and insensitive to positron acceptance and efficiency

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NRD fit result

- data 25 +17 -16
- Expected 40± 8

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