MEG2008 データ解析:

$\mu \to e\gamma$解析

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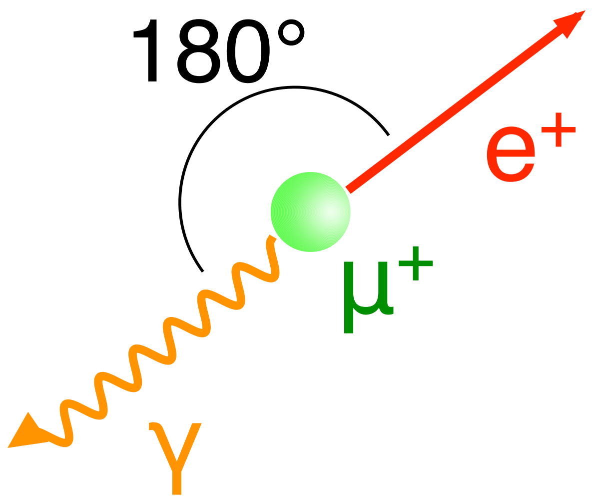
甲南大学

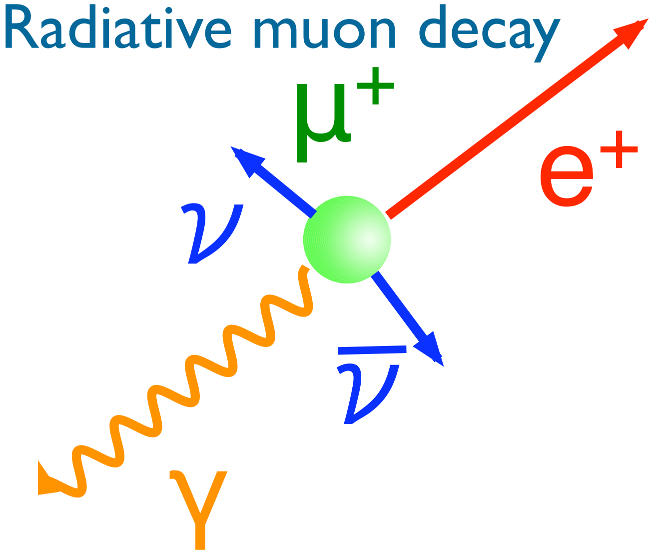
Signal and Background

Signal



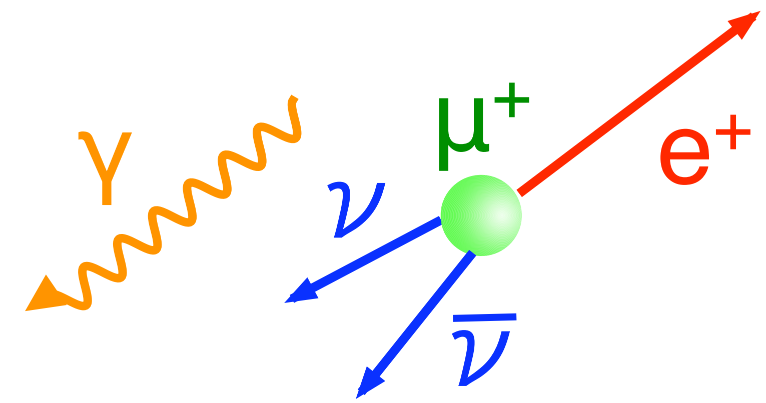
RMD

Radiative muon decay



BG

Accidental pileup

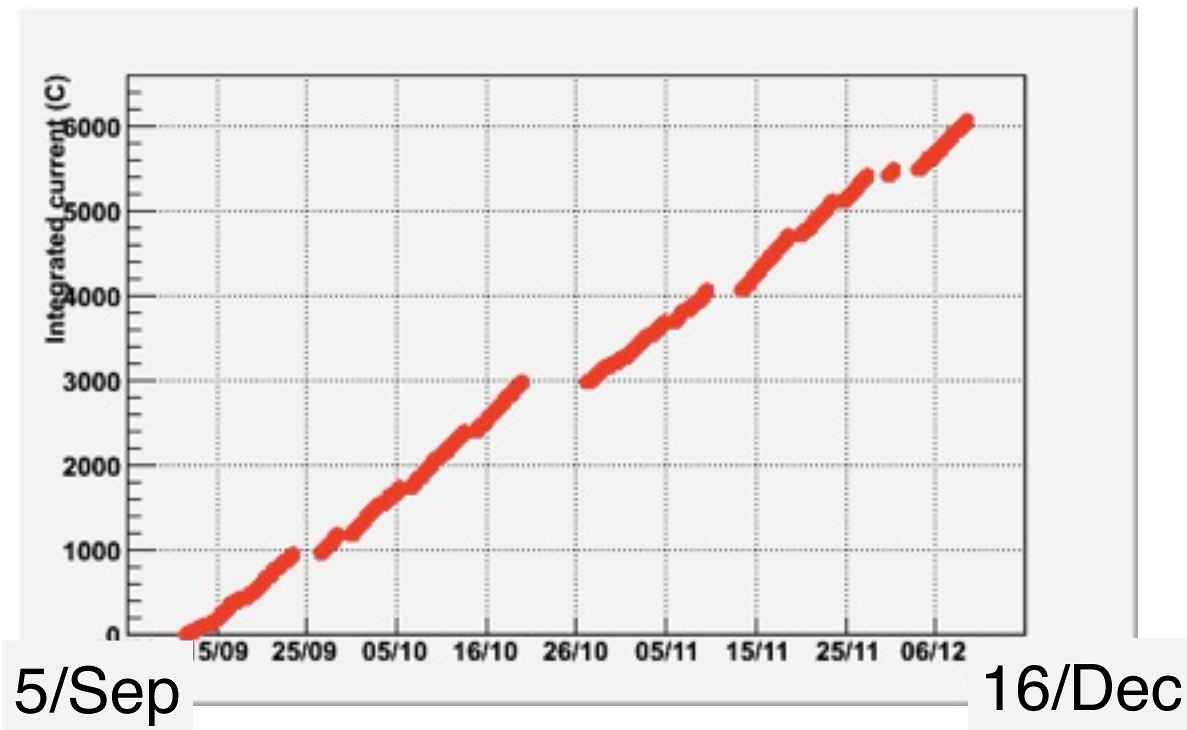


Back-to-Back	Any angle (Energy correlated)	Any angle
52.8 MeV	< 52.8 MeV	< 52.8 MeV *
Same time	Same time	Flat time difference

$E\gamma$ Ee^+ T ϕ θ

* Measured E_γ can be larger than signal in the case of pileup of two γs.

2008 data



- The first three months of MEG experiment
- 3×10^7 muons/sec rate, in total 9.5×10^{13} 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

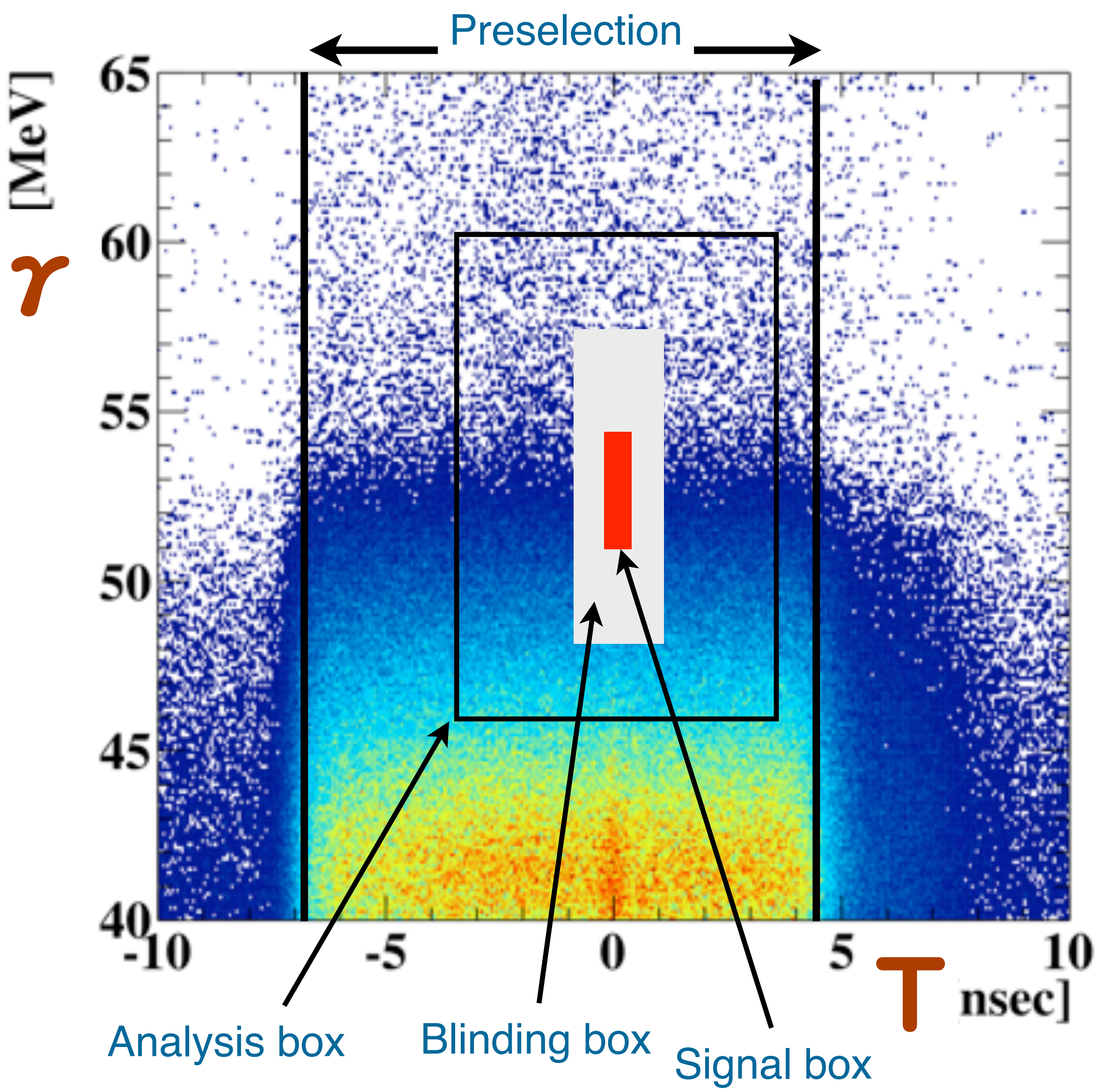
- Condition was not the best
  - DCH discharge (low efficiency and resolution.)
  - TC fiber not in operation. (lower trigger efficiency)

→ next talk

* including 15% of calibration events

Analysis procedure

All pre-selected events
(No selection by **Ee+, φ and θ**)



- Final analysis is done for pre-selected 3.7 M events (20% of recorded events).
- Blinding analysis (**T** and **Eγ**) 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 : **T** [-6.9, 4.4] nsec && at least one e+ track associated with trigger.
Blind box : **T** [-1, 1] nsec, **Eγ** [48, 57.6] MeV
Analysis box : **T** [-1, 1] nsec, **Eγ** [46, 60] MeV
(**T**[-3.5,3.5] nsec is used for sideband studies)

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 $E\gamma$, Ee^{+}, T, ϕ and θ.

Fitting distribution of $E\gamma$, 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

Number of signals (Numerator)

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Branching Ratio

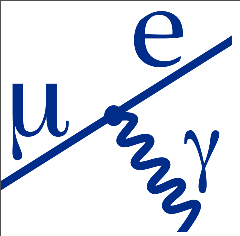
Maximum likelihood fitting

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

- Fitting 5 dimensional event distribution with three PDFs
  - **BG** (accidental background)
  - **RMD** (radiative muon decay)
  - **Signal**
- PDFs are obtained mostly from data.
- Event-by-event PDF to take into account position or time dependent change of response.
- **RMD** PDF is made from theoritical **RMD** shape ⊗ detector response function.

E_{e^+} E_γ

T ϕ θ

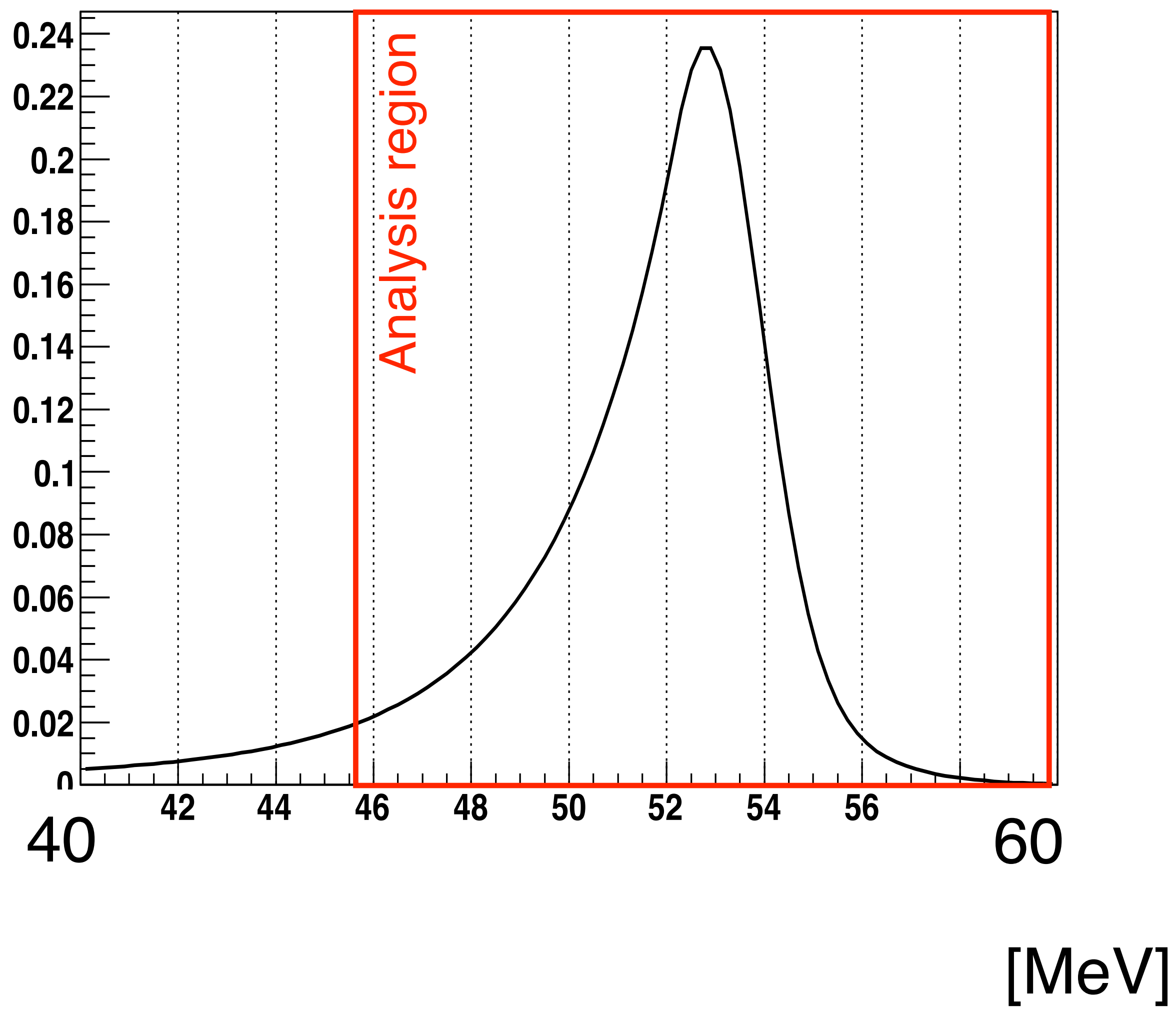


PDF - Gamma energy

Eγ

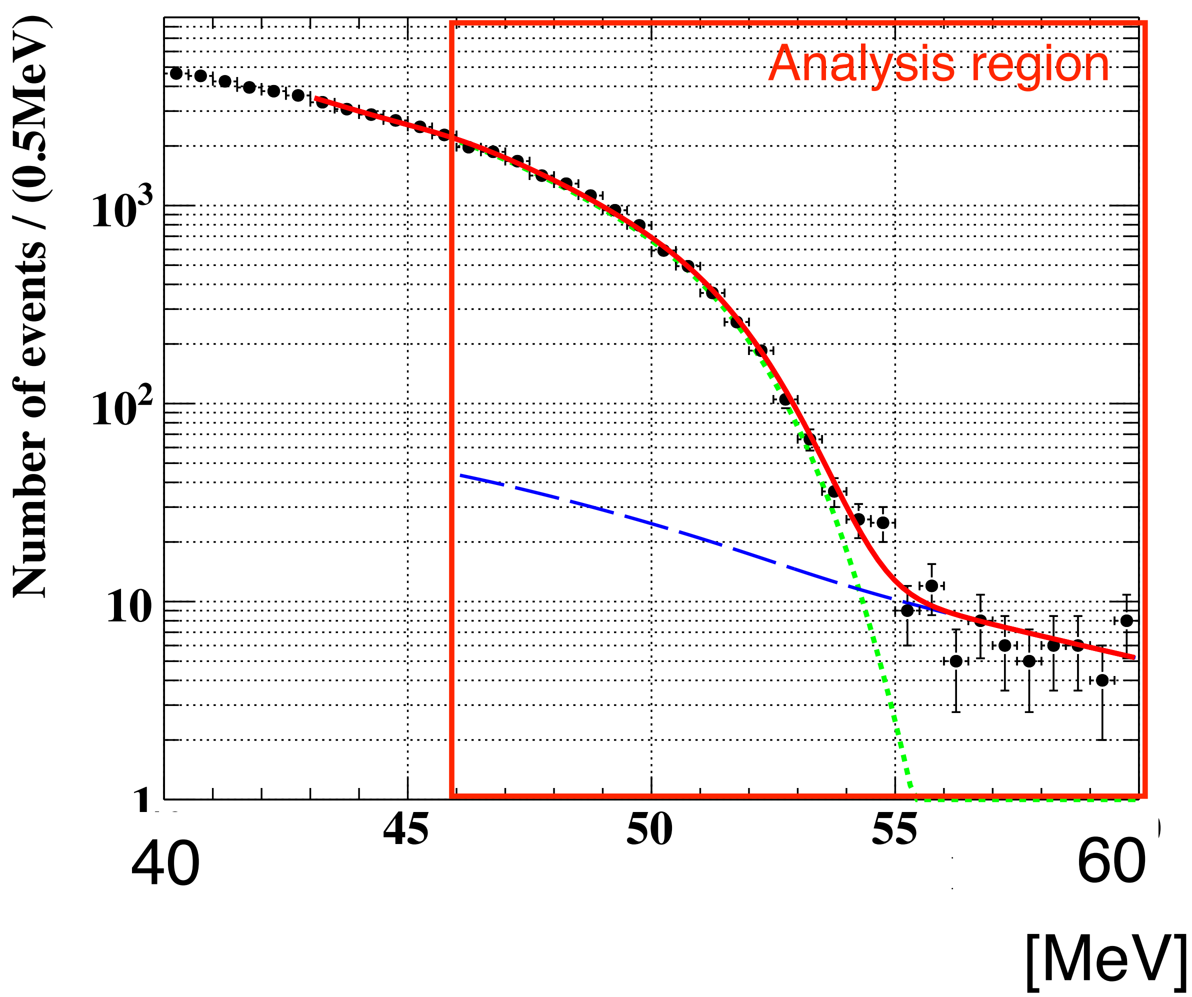
Signal

Response from π beam test *



BG

Fitting muon sideband data



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

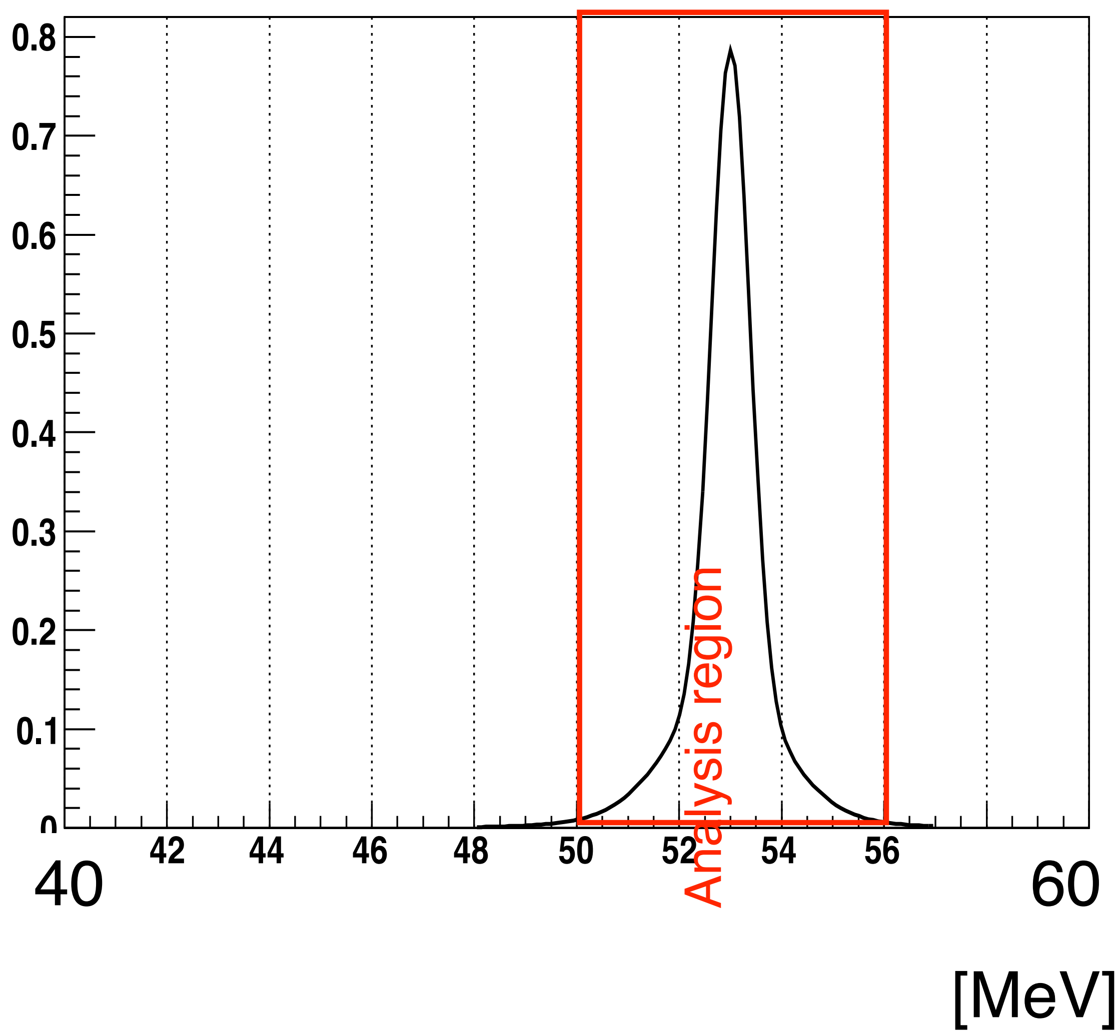
PDF - Positron energy

Ee+

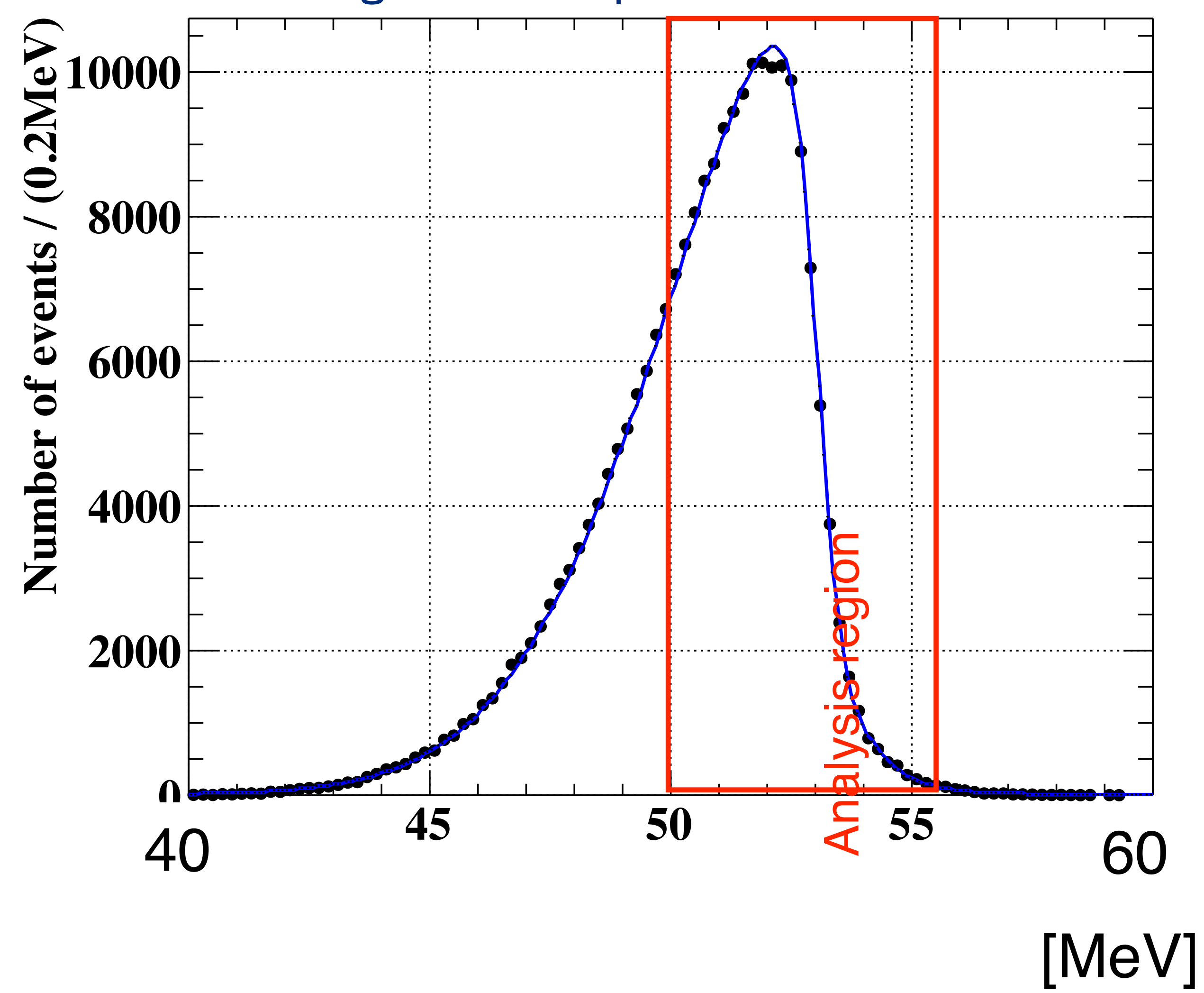
Signal

BG

Response function with Michel fit parameters



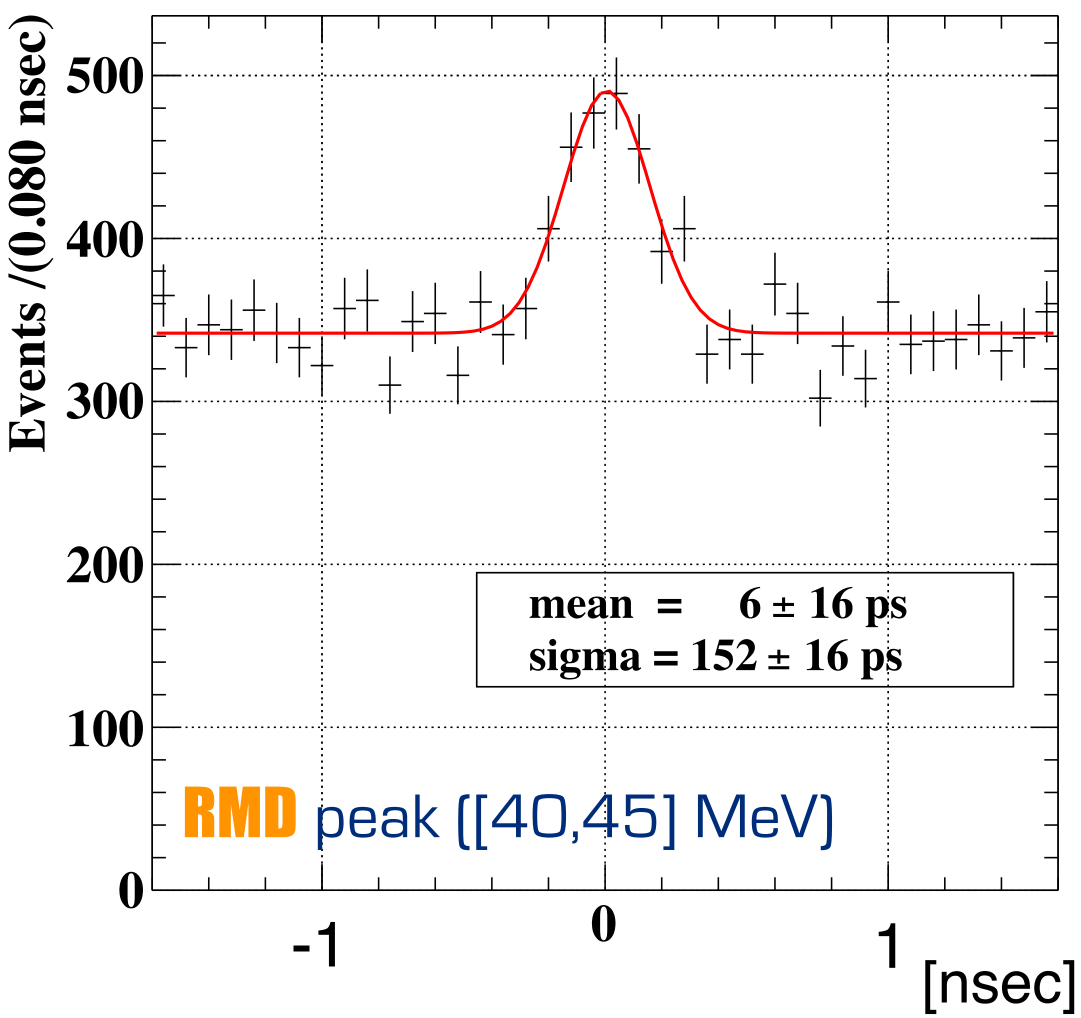
Fitting Michel spectrum

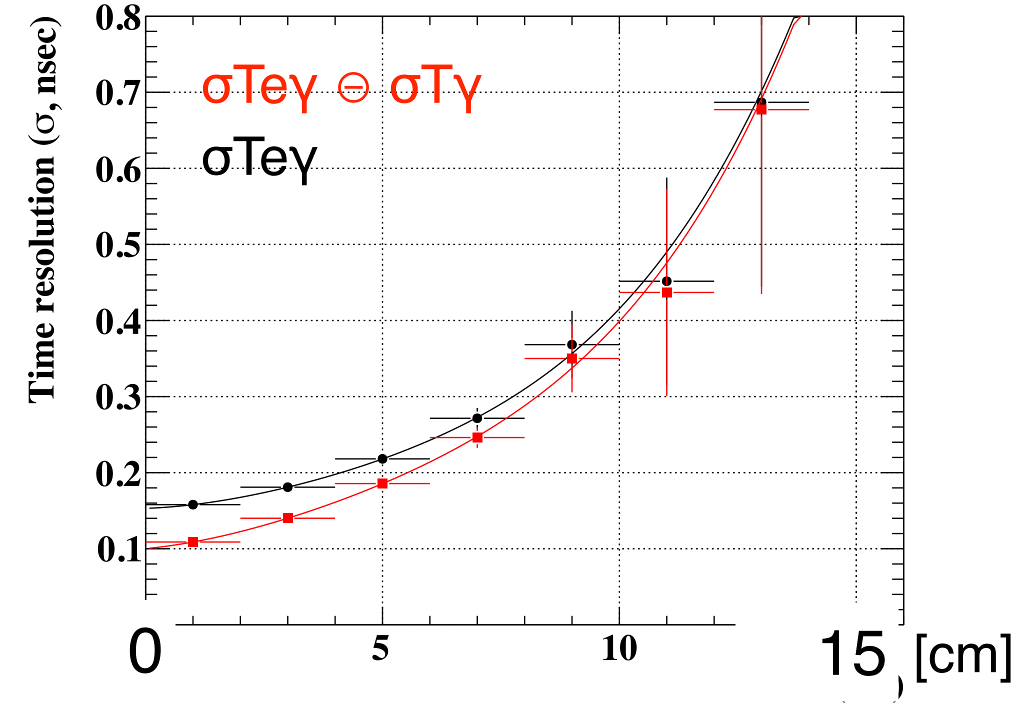


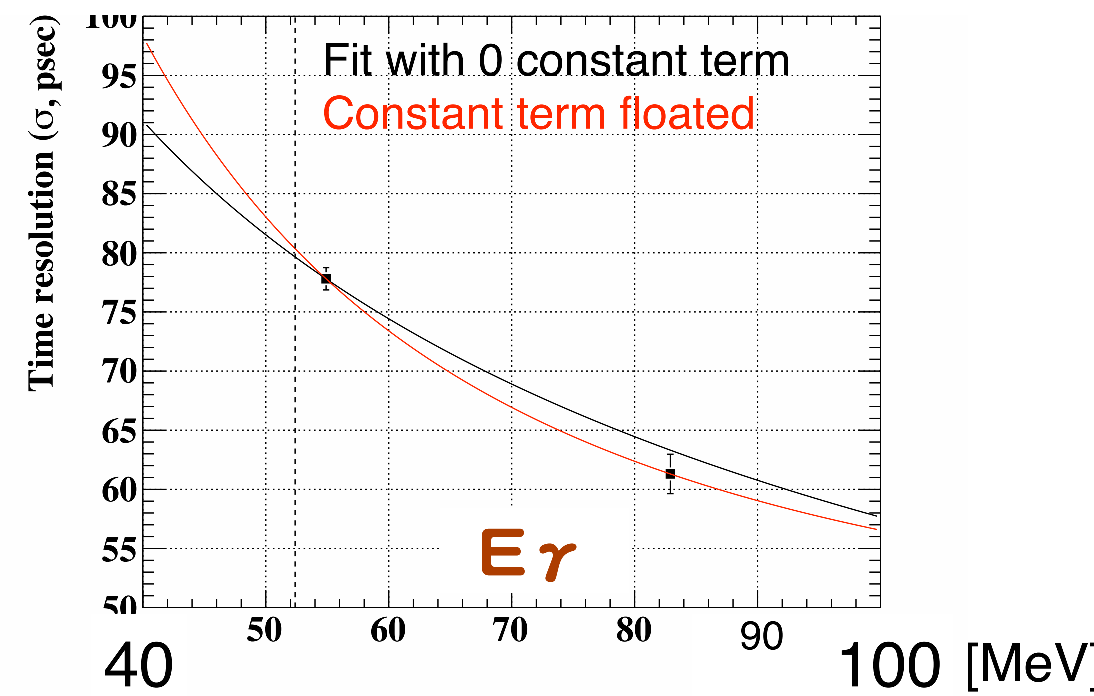
PDF - Time difference

T Signal

- 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.*







BG : flat

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

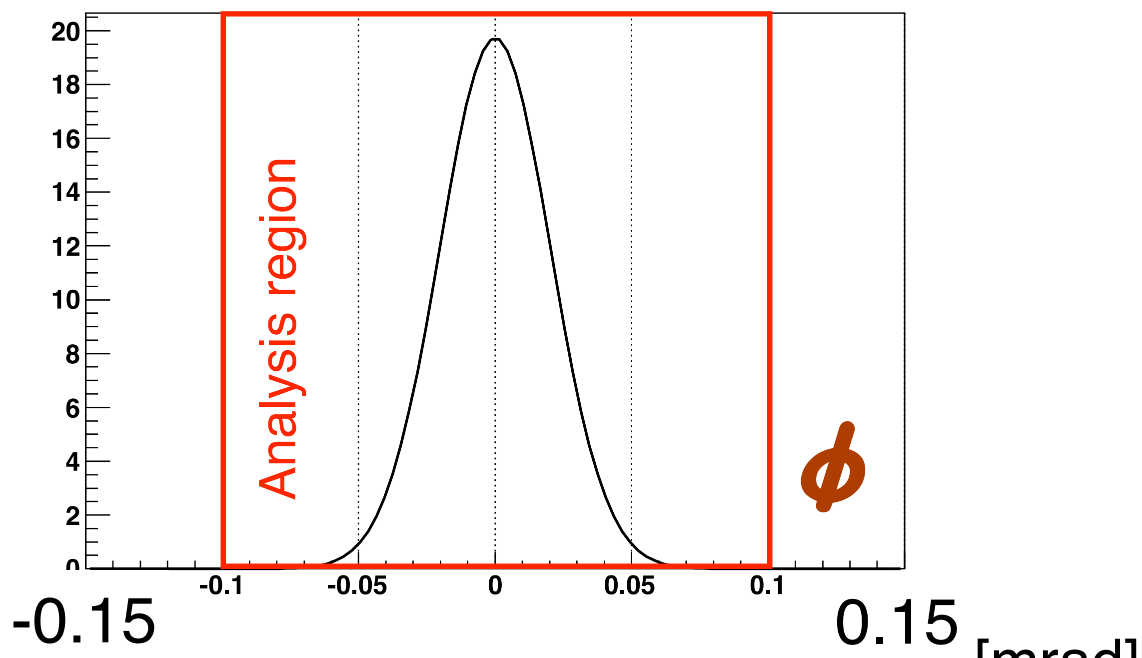
PDF - Opening angle

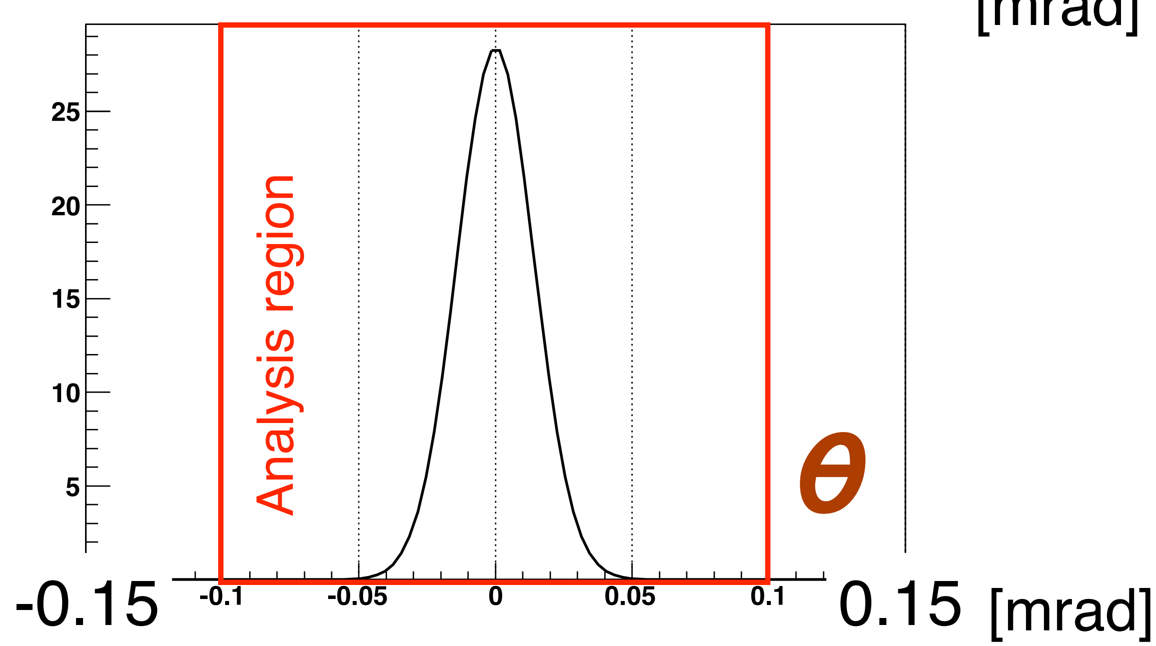
ϕ θ

Signal

e+ resolution : from double turn events

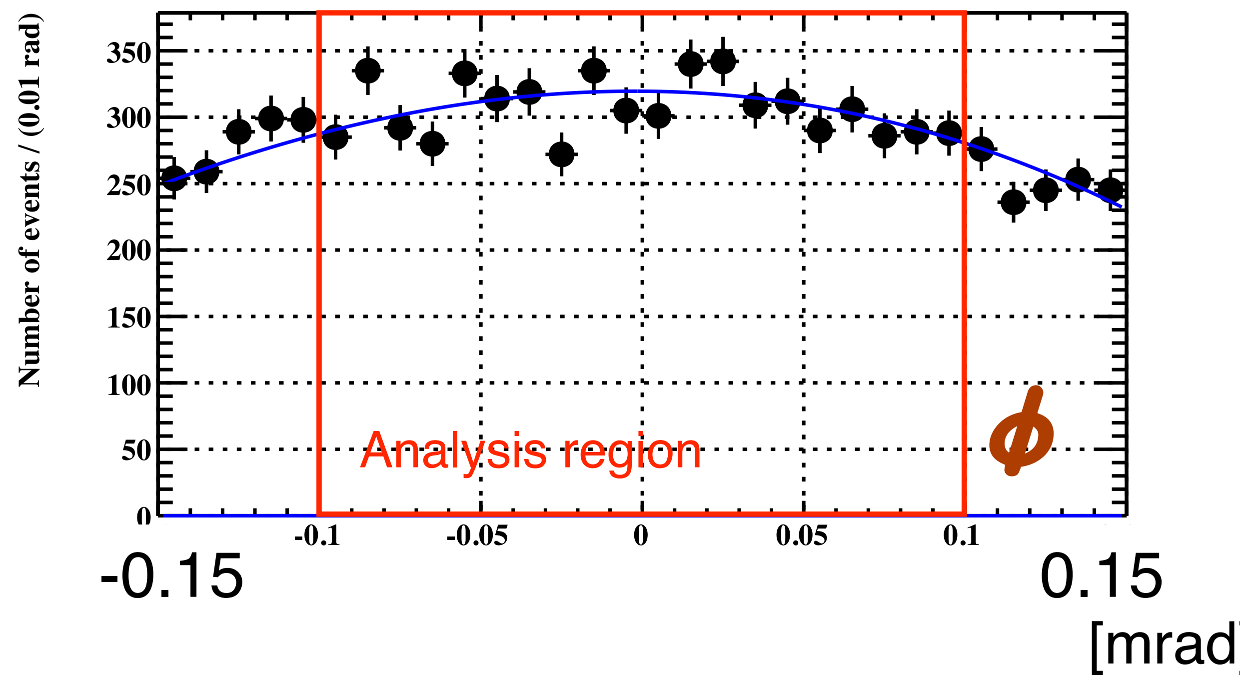
γ resolution : π beam test, collimator run

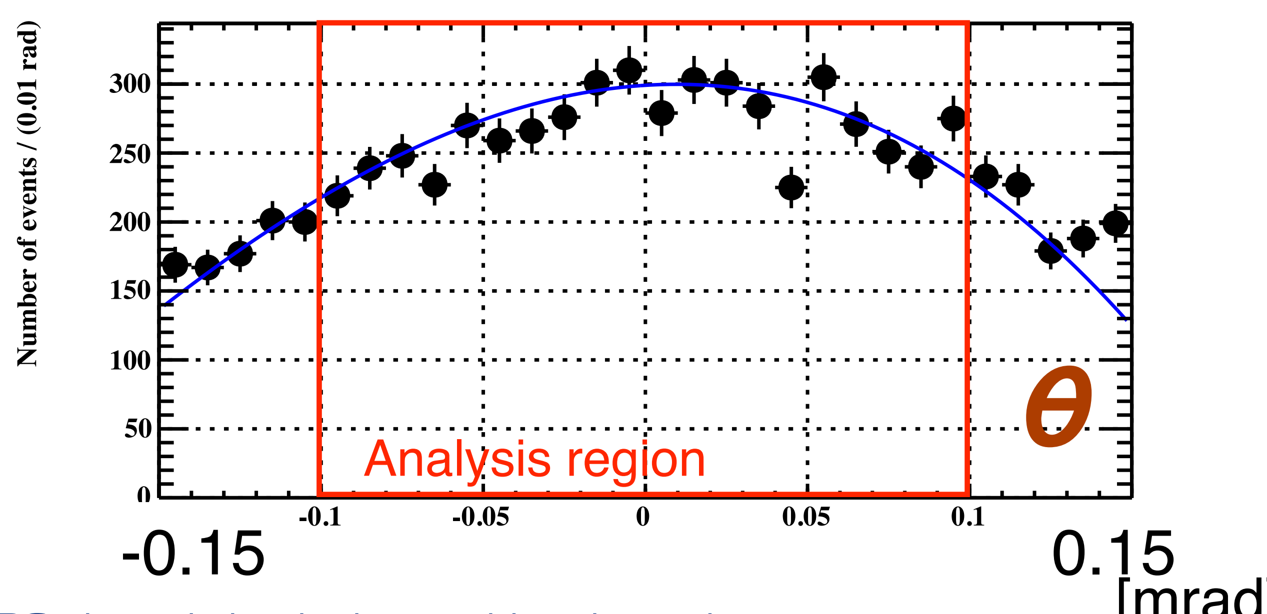




BG

Measured distribution of sideband





* Average response is shown. Actual fitting is done PDF for each position. BG shape is impinging position dependent.

Sensitivity

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}**.

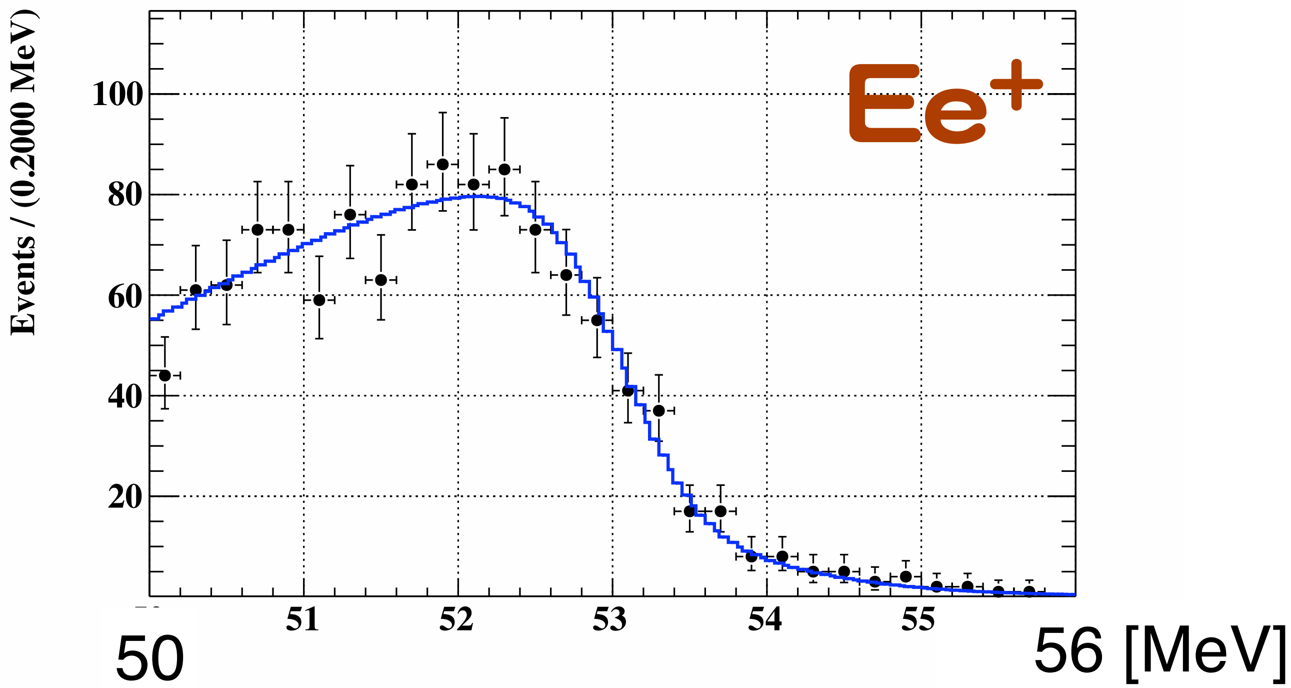
(Current upper limit given by MEGA in 1999 is $1.2\text{x}10^{-11}$)

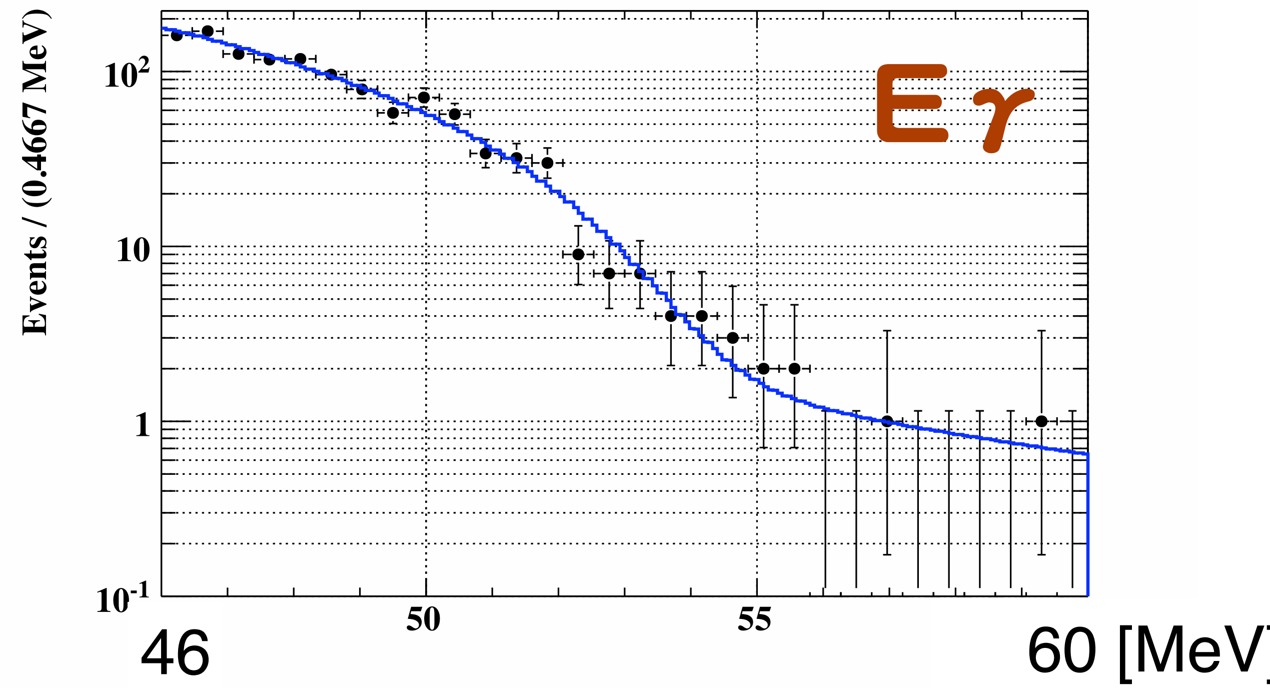
Preliminary

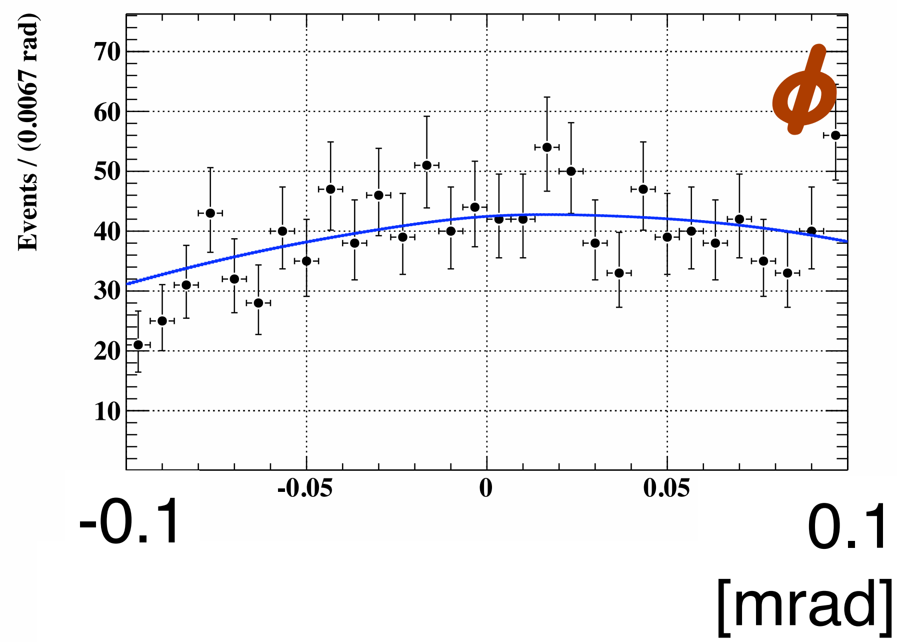
Normalization used for this calculation will be discussed later.

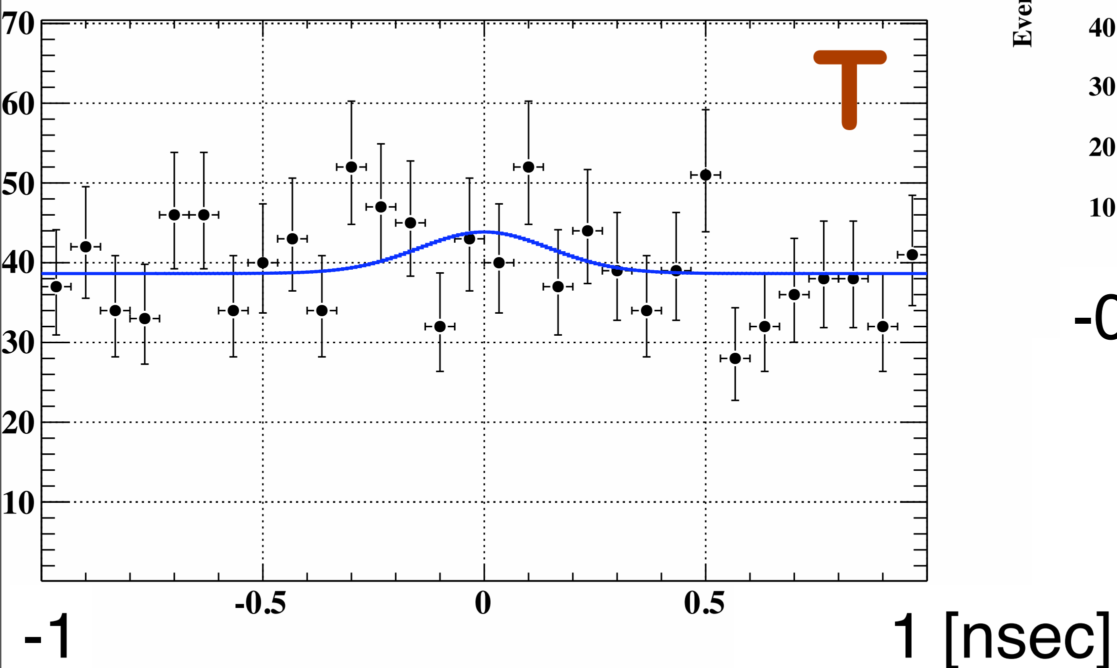
2008 data fit result

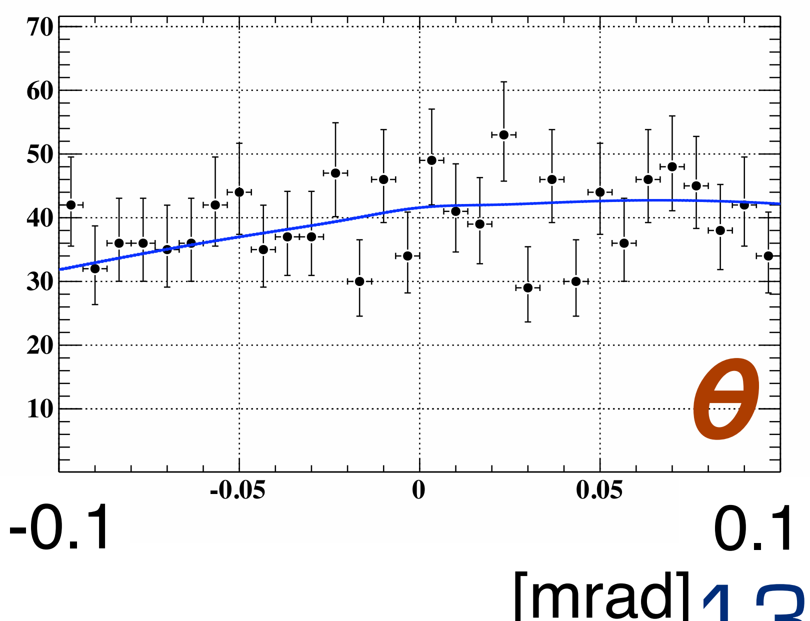
1189 analysis events





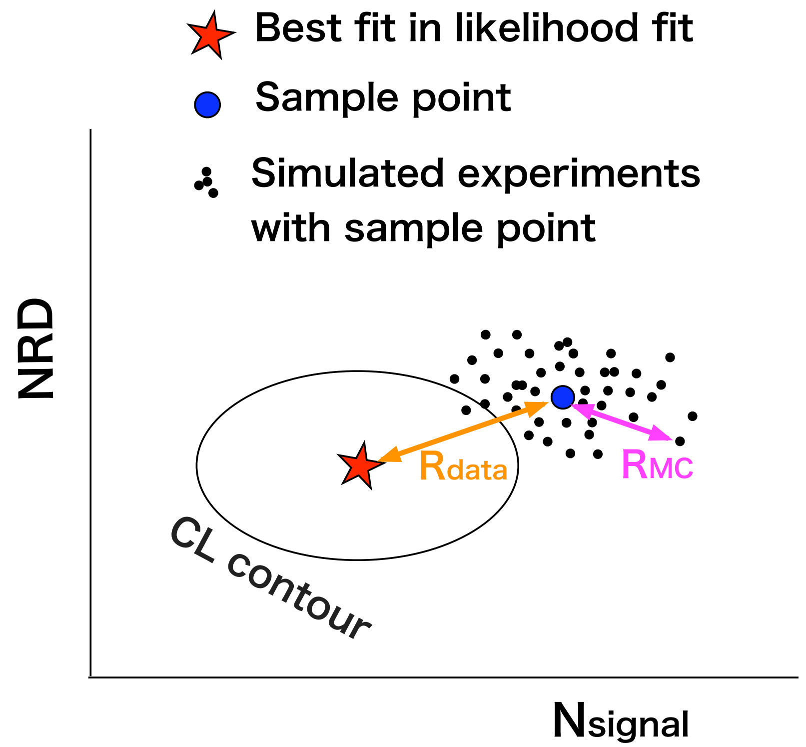


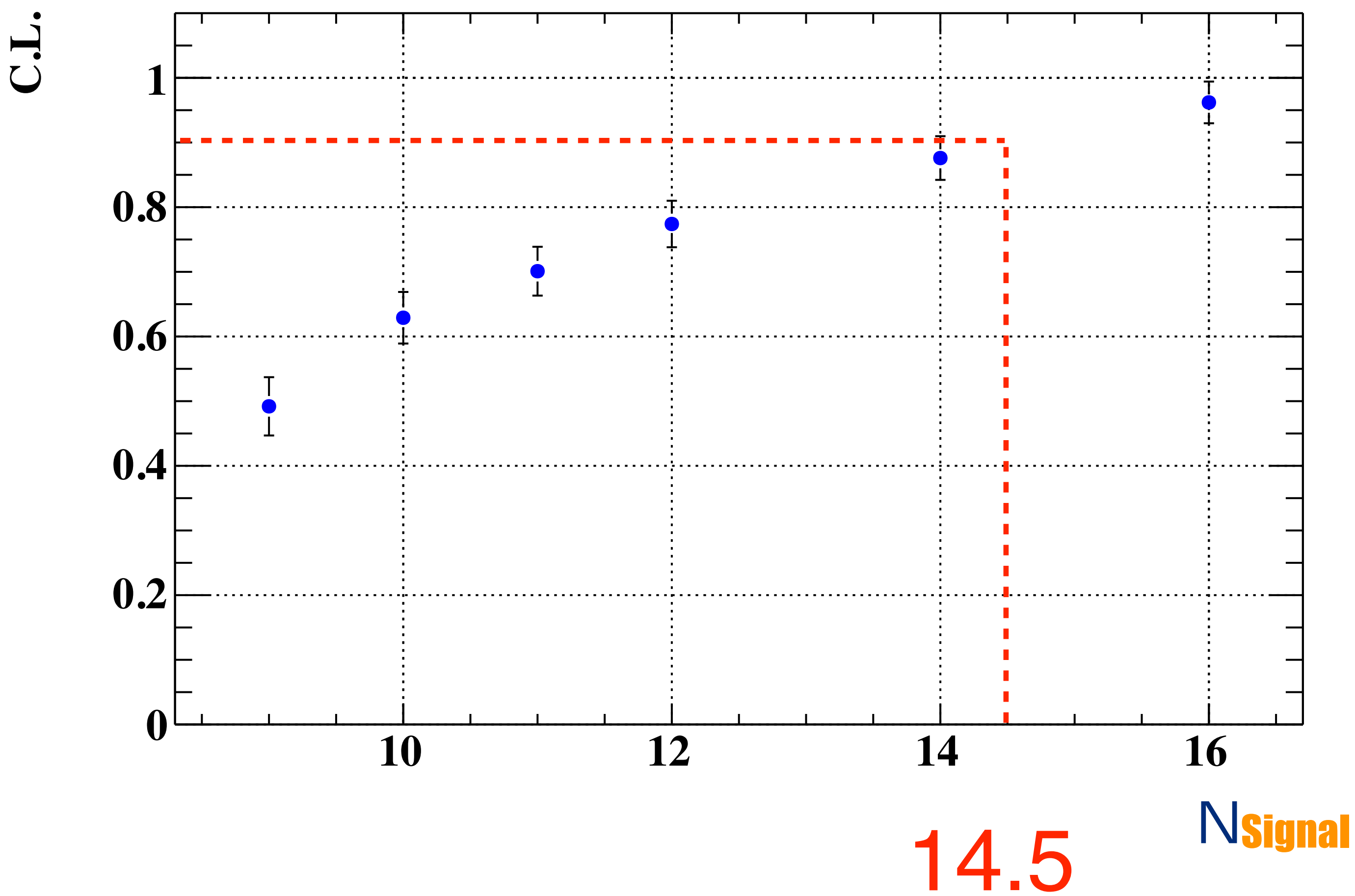




Upper limit

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



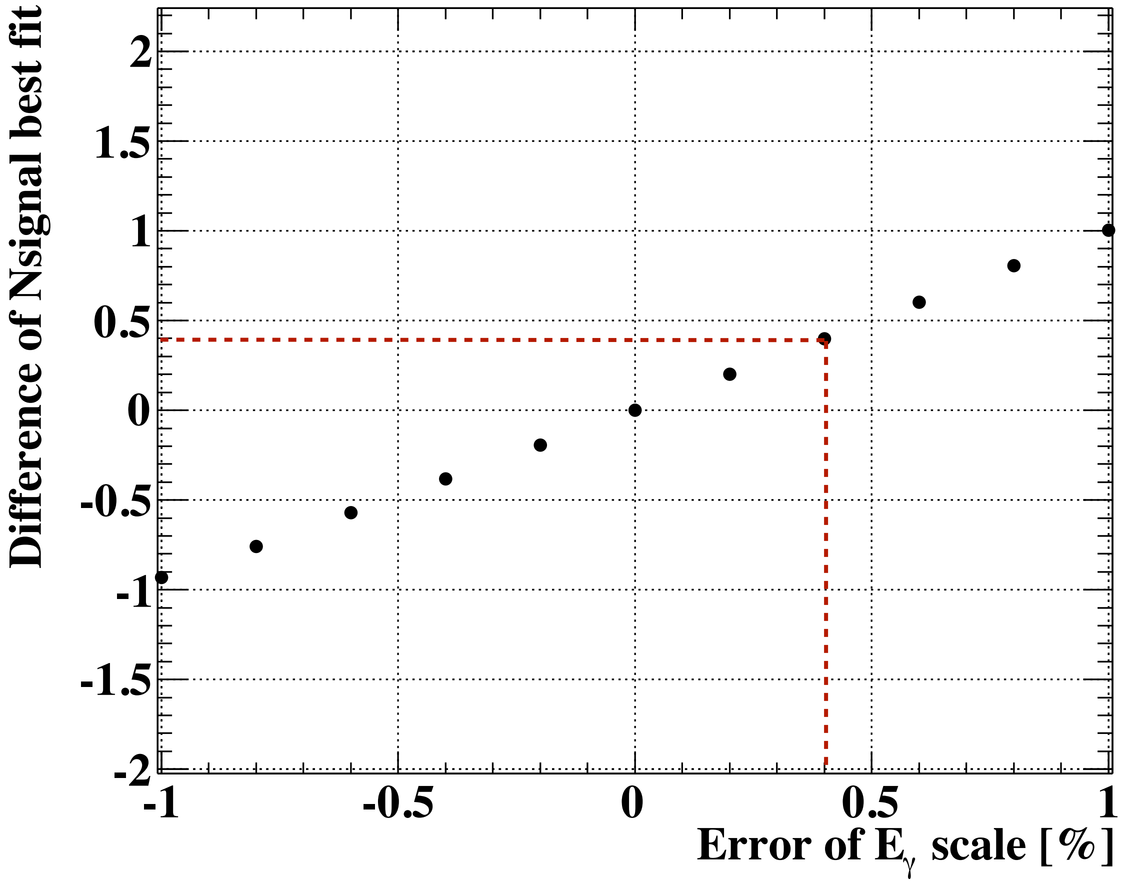


- Perform many toy-MC experiments at several (N_{Signal}, N_{RMD}) sampling points by means of PDF.
- Compare $R_{data}=L_{data,max}/L_{data}(N_{Signal},N_{RMD})$ and $R_{MC}=L_{MC,max}/L_{MC}(N_{Signal},N_{RMD})$ for each simulated experiment.
- If the probability of $R_{data}<R_{MC}$ is less than 90%, the sampling point is outside of 90% C.L. contour.

Systematic errors

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

For example, on **Eγ**



Dominant errors

Eγ scale : 0.4 events

Ee^+ spectrum parameters : 1.1 events

Total : **1.3** events

Upper limit including systematic error = **14.7**

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 **$E\gamma$, Ee^{+}, T, ϕ** and **θ.**

Fitting distribution of **$E\gamma$, 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

Normalization

Signal

trigger | positron | gamma

$$N_{sig} = N_\mu \times \boxed{Br_{e\gamma}} \times \tau_{e\gamma} \times \epsilon^{trig}_{e\gamma} \times G^{DC}_{e\gamma} \times A^{TC}_{e\gamma} \times \epsilon^{DC}_{e\gamma} \times A^{LXe}_{e\gamma} \times \epsilon^{LXe}_{e\gamma}$$

$$N_{e\nu\bar{\nu}} = N_\mu \times Br_{e\nu\bar{\nu}} \times \tau_{e\nu\bar{\nu}} \times \epsilon^{trig}_{e\nu\bar{\nu}} \times G^{DC}_{e\nu\bar{\nu}} \times A^{TC}_{e\nu\bar{\nu}} \times \epsilon^{DC}_{e\nu\bar{\nu}} \times f^{E}_{e\nu\bar{\nu}} \times P$$

Michel trigger events (>50MeV)

- #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

*given an accepted positron by DC

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

Normalization

$$N_{sig} = N_\mu \times Br_{e\gamma} \times \tau_{e\gamma} \times \epsilon^{trig}_{e\gamma} \times G^{DC}_{e\gamma} \times A^{TC}_{e\gamma} \times \epsilon^{DC}_{e\gamma} \times A^{LXe}_{e\gamma} \times \epsilon^{LXe}_{e\gamma}$$

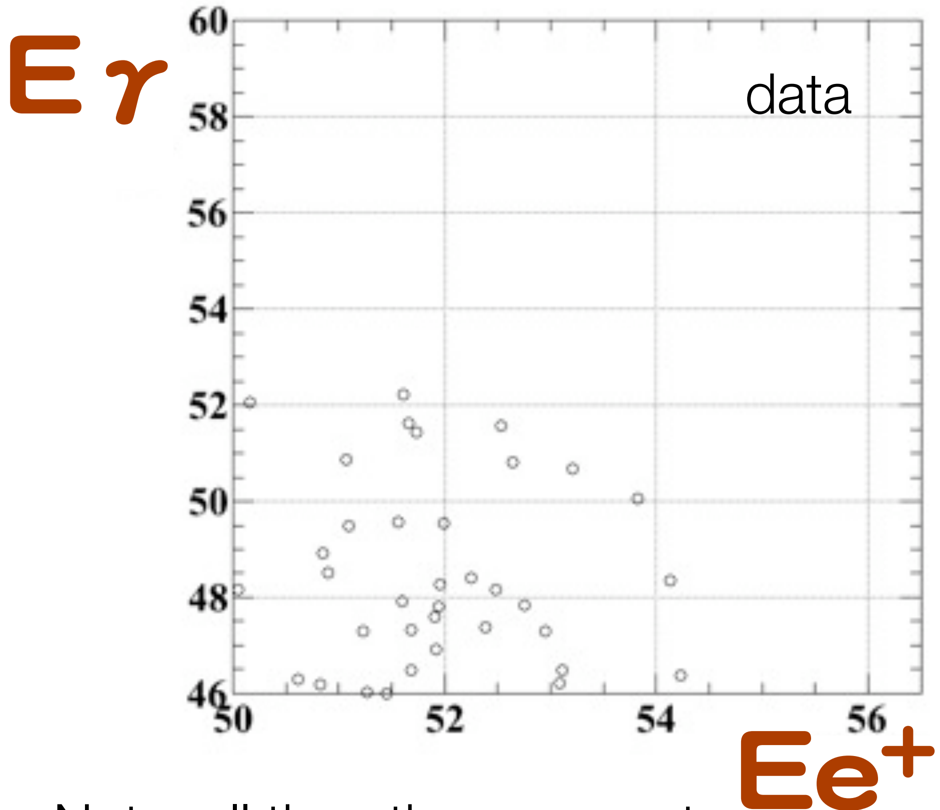
$$N_{e\nu\bar{\nu}} = N_\mu \times \underset{1}{Br_{e\nu\bar{\nu}}} \times \tau_{e\nu\bar{\nu}} \times \epsilon^{trig}_{e\nu\bar{\nu}} \times G^{DC}_{e\nu\bar{\nu}} \times A^{TC}_{e\nu\bar{\nu}} \times \epsilon^{DC}_{e\nu\bar{\nu}} \times f^{E}_{e\nu\bar{\nu}} \times P$$

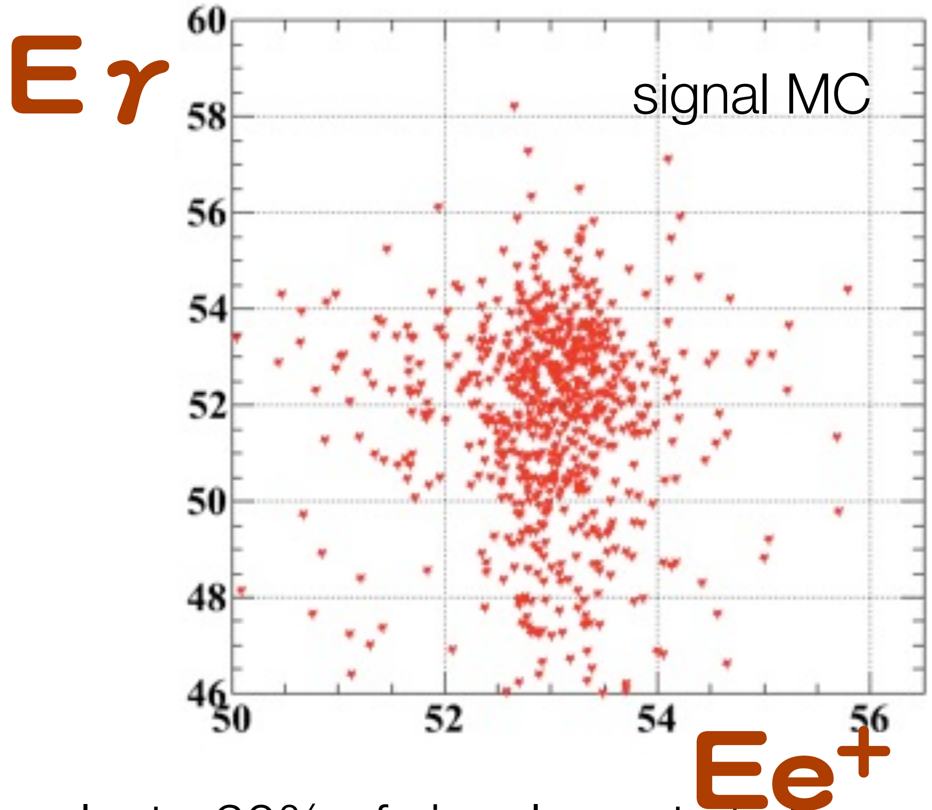
$$\mathrm{BR}(\mu^+ \to \mathrm{e}^+\gamma) = \underbrace{\frac{N_{\mathrm{sig}}}{N_{e\nu\bar{\nu}}}}_{①} \times \underbrace{\frac{f^E_{e\nu\bar{\nu}}}{P}}_{②} \times \underbrace{\frac{\epsilon^{trig}_{e\nu\bar{\nu}}}{\epsilon^{trig}_{e\gamma}}}_{③} \times \underbrace{\underbrace{\frac{A^{TC}_{e\nu\bar{\nu}}}{A^{TC}_{e\gamma}}}_{④} \times \underbrace{\frac{\epsilon^{DC}_{e\nu\bar{\nu}}}{\epsilon^{DC}_{e\gamma}}}_{⑤}}_{=\sim 1} \times \underbrace{\frac{1}{A^{LXe}_{e\gamma}}}_{⑥} \times \underbrace{\frac{1}{\epsilon^{LXe}_{e\gamma}}}_{⑦}$$

①	# of Michel trigger events	11414
②	Fraction of Michel > 50 MeV	0.101 ± 0.006
③	trigger efficiency ratio	0.66 ± 0.03
④	DC-TC matching efficiency ratio	1.11 ±0.02
⑤	DCH reconstruction and acceptance ratio	1.02 ± 0.005
⑥	Geometrical acceptance of LXe	0.98 ± 0.005
⑦	LXe efficiency	0.61 ± 0.03
	Normalization factor	**2 ± 0.2×10^{-12}**

(effect of radiative decay is negligible.)

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





Note: all the other parameters are cut to select ~90% of signal events in these plots

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.

Backup

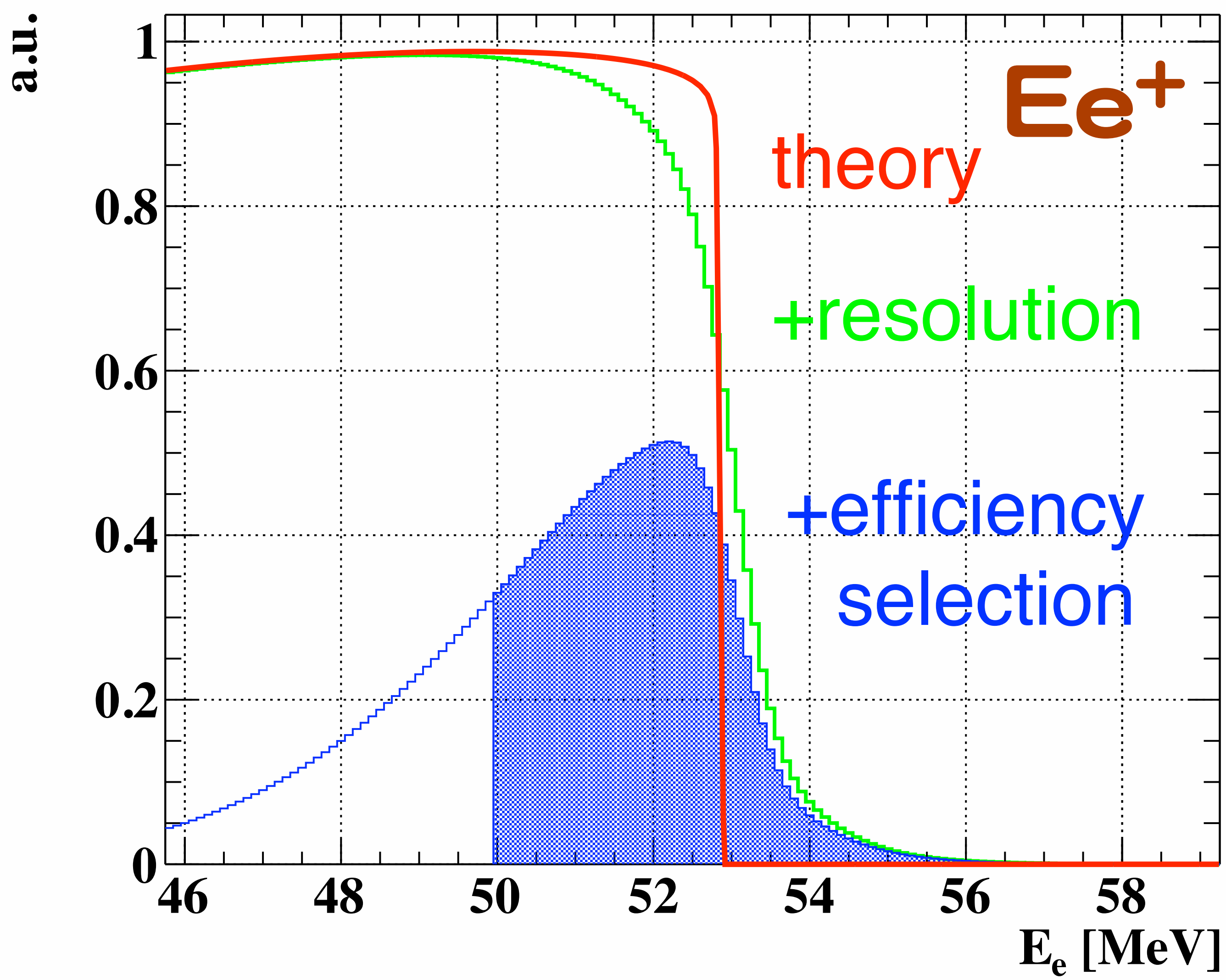
Cross check of efficiency

<table>
<tr><td>$\Omega/4\pi$</td><td>0.09</td><td rowspan="4">4.6×10^{-3}
(from BG rate,
$E_\gamma>45$MeV,
$E_e>50$MeV)</td><td rowspan="6">280/250
(RD
sideband
data,
$E_e<48$MeV,
#expected /
#observed)</td></tr>
<tr><td>γ</td><td>0.66 x 0.91
($E\gamma>46$MeV)x(pileup, CR)</td></tr>
<tr><td>e^+</td><td>0.15
(DCH x DC-TC match)</td></tr>
<tr><td>Trigger</td><td>0.66
(DM)</td></tr>
<tr><td>Selection</td><td colspan="2">0.99 x 0.98 (DCH x γ acc.)</td></tr>
<tr><td>$N\mu$</td><td colspan="2">9.4×10^{13} μ stops (3.0×10^{7} μ/s/2mA·6290C)</td></tr>
<tr><td>SES</td><td>2.0×10^{-12}</td><td>2.2×10^{-12}</td><td>2.2×10^{-12}</td></tr>
</table>

Normalization

Normalization by using Michel positrons.
Independent of beam rate, and insensitive to positron detection efficiency.

$$\mathrm{BR}(\mu^+ \to \mathrm{e}^+\gamma) = \frac{N_{\mathrm{sig}}}{N_{e\nu\bar{\nu}}} \times \frac{f^{E}_{e\nu\bar{\nu}}}{P} \times \frac{\epsilon^{trig}_{e\nu\bar{\nu}}}{\epsilon^{trig}_{e\gamma}} \times \underbrace{\frac{A^{TC}_{e\nu\bar{\nu}}}{A^{TC}_{e\gamma}} \times \frac{\epsilon^{DC}_{e\nu\bar{\nu}}}{\epsilon^{DC}_{e\gamma}}}_{=\,\sim 1} \times \frac{1}{A^{LXe}_{e\gamma}} \times \frac{1}{\epsilon^{LXe}_{e\gamma}}$$



NRD fit result

- data 25 +17 -16
- Expected 40± 8