Analysis of the MEG experiment to search for mu+ → e+ gamma decays

Ryu Sawada on behalf of the MEG collaboration

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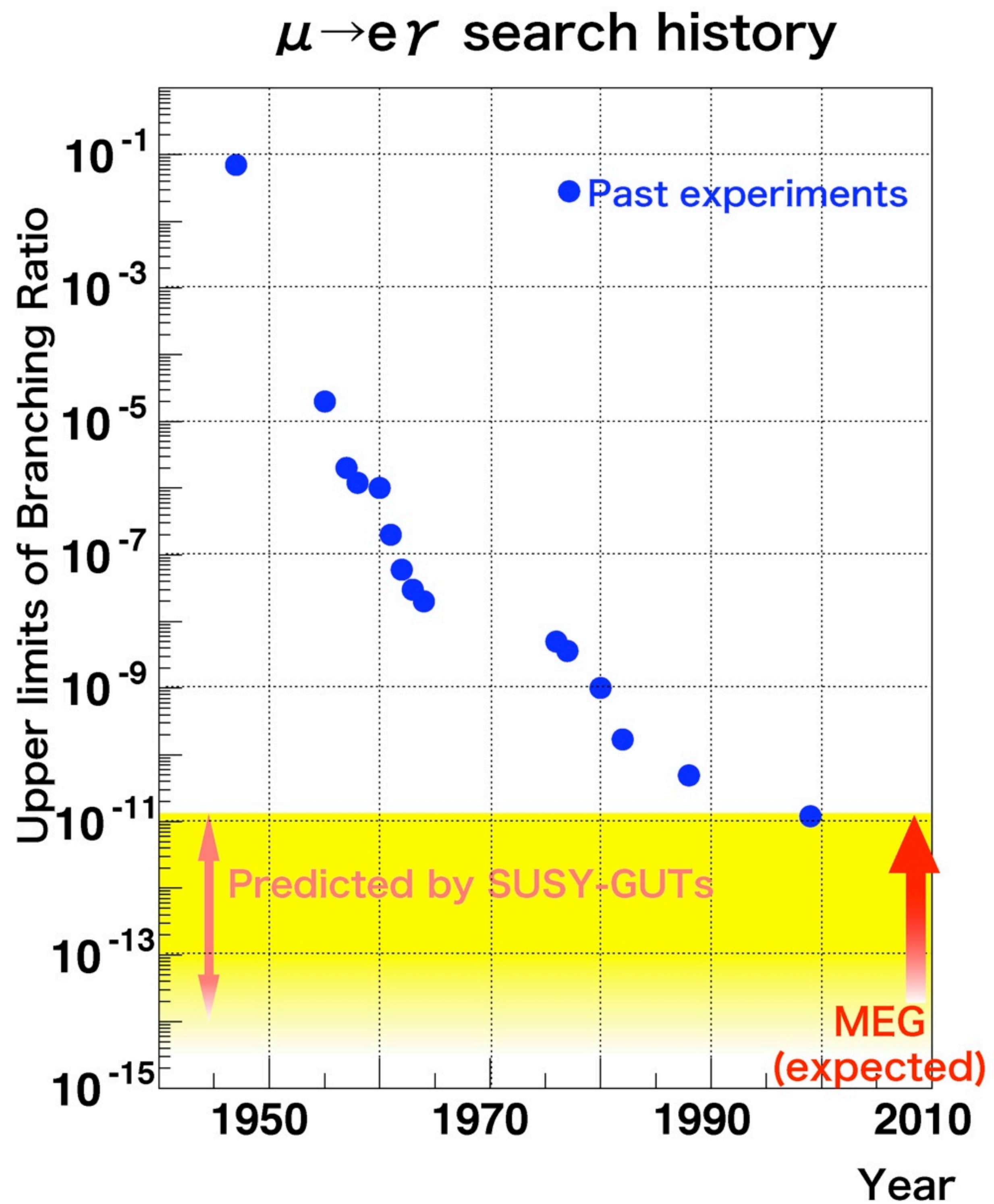
Palais des Congrès, Paris

MEG collaboration : ~60 physicists from 13 institutes

Japan : ICEPP U. of Tokyo, Waseda U., KEK
Italy : INFN&U.Genova, INFN&U.Lecce, INFN&U.Pavia INFN&U.Pisa, INFN&U.Roma
U.S. : UC Irvine
Switzerland : PSI, ETH
Russia : JINR Dubna, BINP Novosibirsk

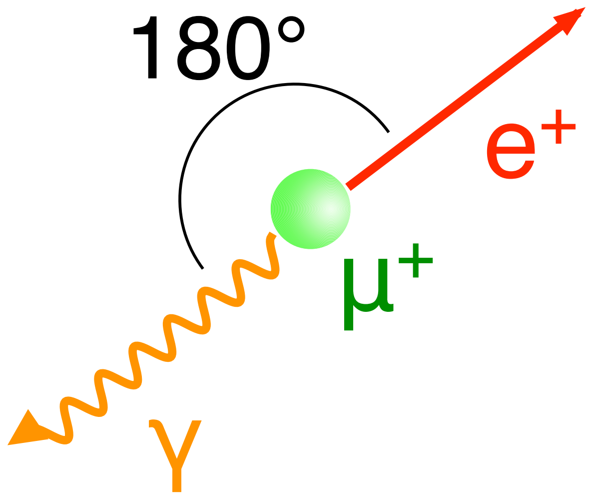
Physics Motivation

- LFV in the neutral sector was observed in solar, atmospheric and reactor neutrinos by several experiments.
- LFV in charged lepton sector has not been observed, but new physics, (e.g. SUSY-GUT), predict observable B.R. from 10^{-14} to 10^{-11}.
- Current upper limit of $\mu \to e\gamma$ (1.2×10^{-11}) is close to prediction.
- Discovery of LFV of charged lepton will be an evidence of a new physics beyond the standard model.
- MEG is designed to search with a sensitivity of 10^{-13} to cover most part of the predicted region.

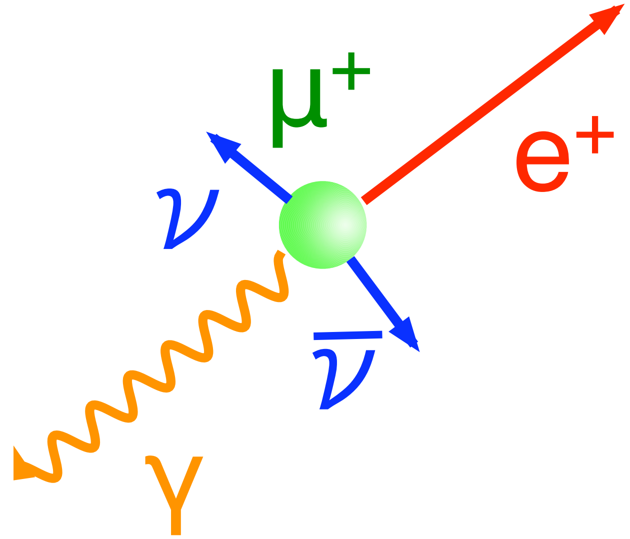


Signal and Background

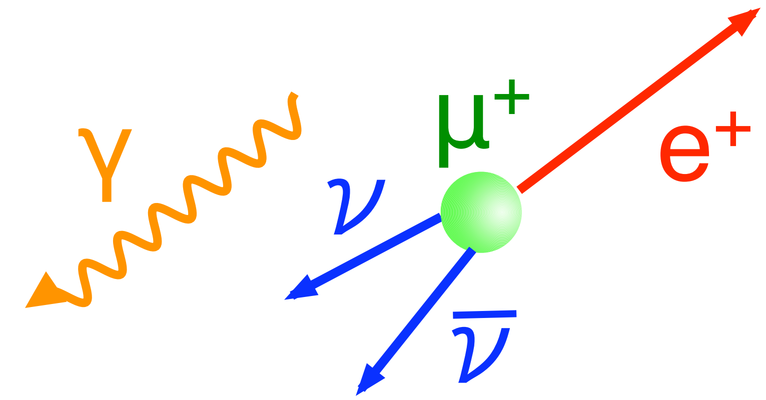
Signal



Prompt Background



Accidental Background

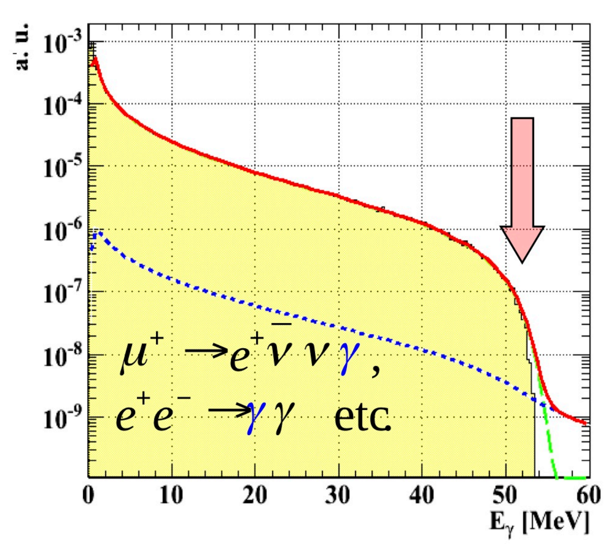


		Radiative muon decay	Accidental pileup
Angle	Back-to-Back	Any angle	Any angle
Energy	52.8 MeV/c	< 52.8 MeV/c	< 52.8 MeV/c
Time	Same time	Same time	Flat

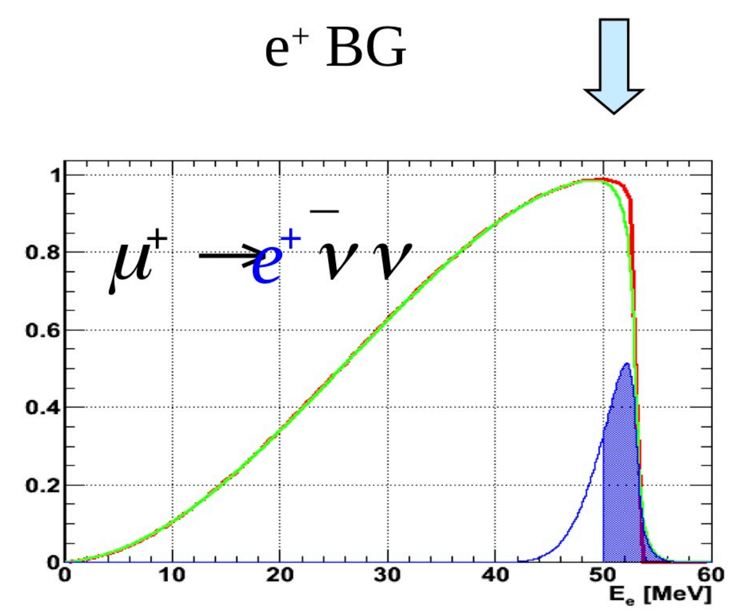
Dominant background is accidental.

Detector resolution is crucial.

γ BG



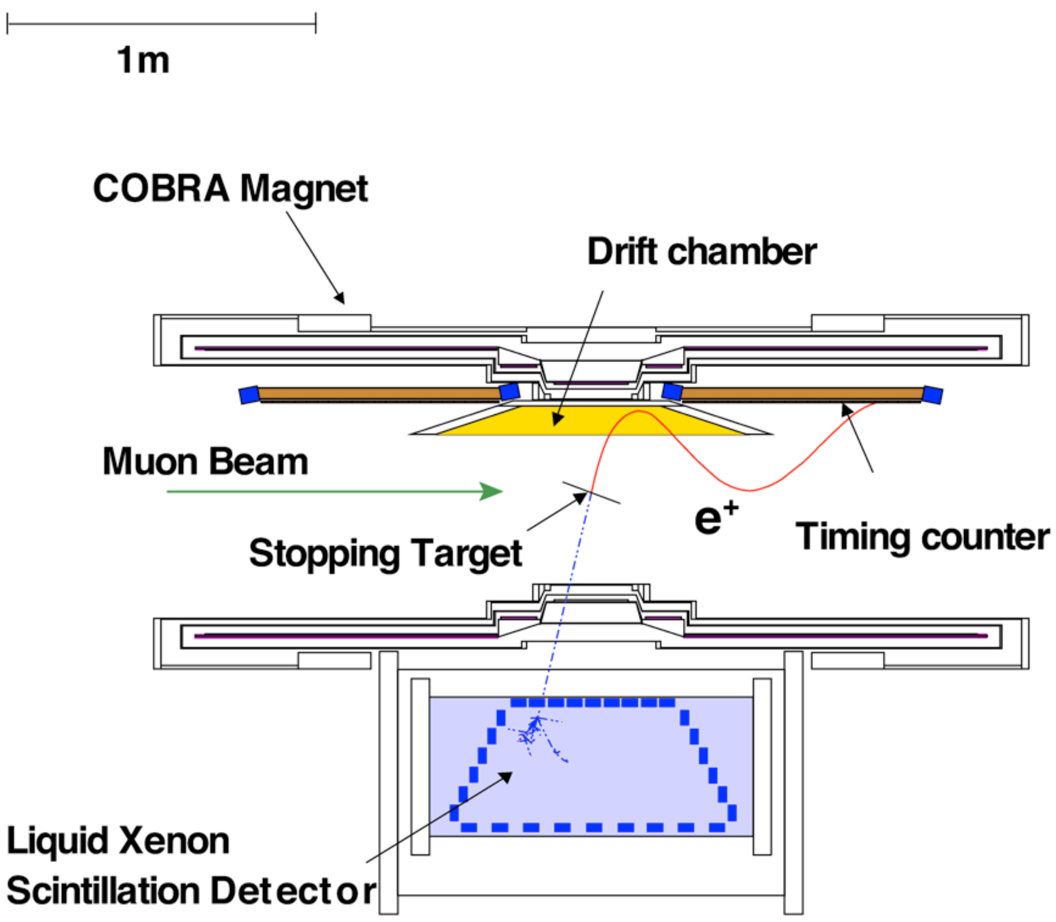
e^+ BG



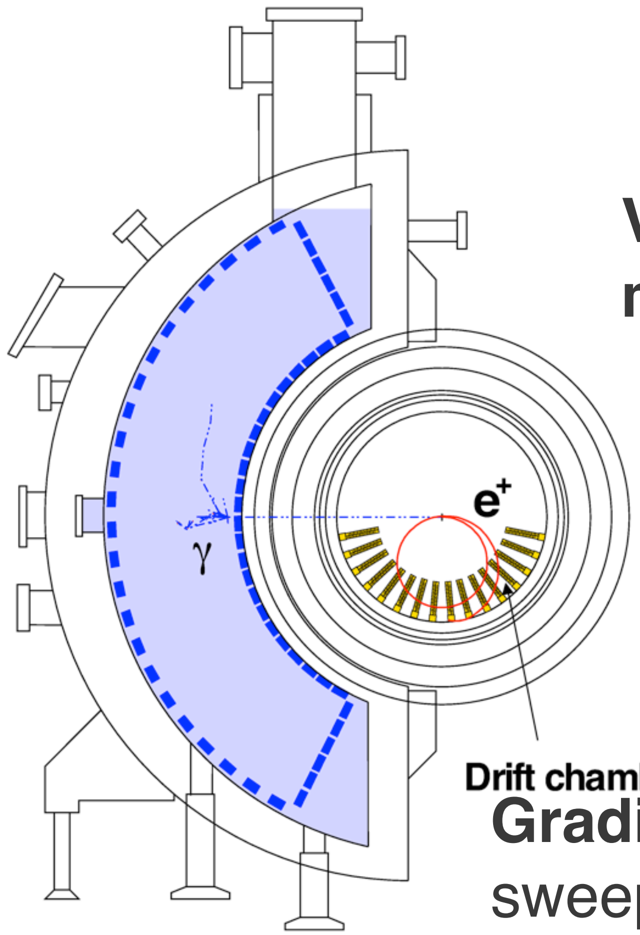
The Experiment

PSI : most intense DC muon

Beam transport system
stopping rate up to 10^8/sec on target



Various calibration and monitoring systems.



Gradient field SC magnet
sweeps out high rate e+ quickly
Constant bending radius of e+

Drift chamber
Made of light materials
Precise measurement of positron tracks

Timing counter
Good time resolution
Work in B-field

LXe gamma detector
2.7 tons of liquid xenon
Good time, position energy resolution
Fast signal : pileup identification

Time line and 2009 run

2008.sep-dec : **Physics data taking**
(lower efficiency and resolutions due to hardware problem)

2008 run result : Sensitivity = 1.3×10^{-11}
90% U.L. = 2.8×10^{-11}

2009 : Analysis of 2008 data
Hardware upgrades

2009.nov-dec : **Physics data taking**

2009.dec- : Analysis of
2009 data
Hardware upgrades

2010.jul- : Physics data taking

2009 run

stopping rate 2.9×10^{7} μ s^{-1}
93 TB data taken
22.3 M Triggers
43 days physics data taking

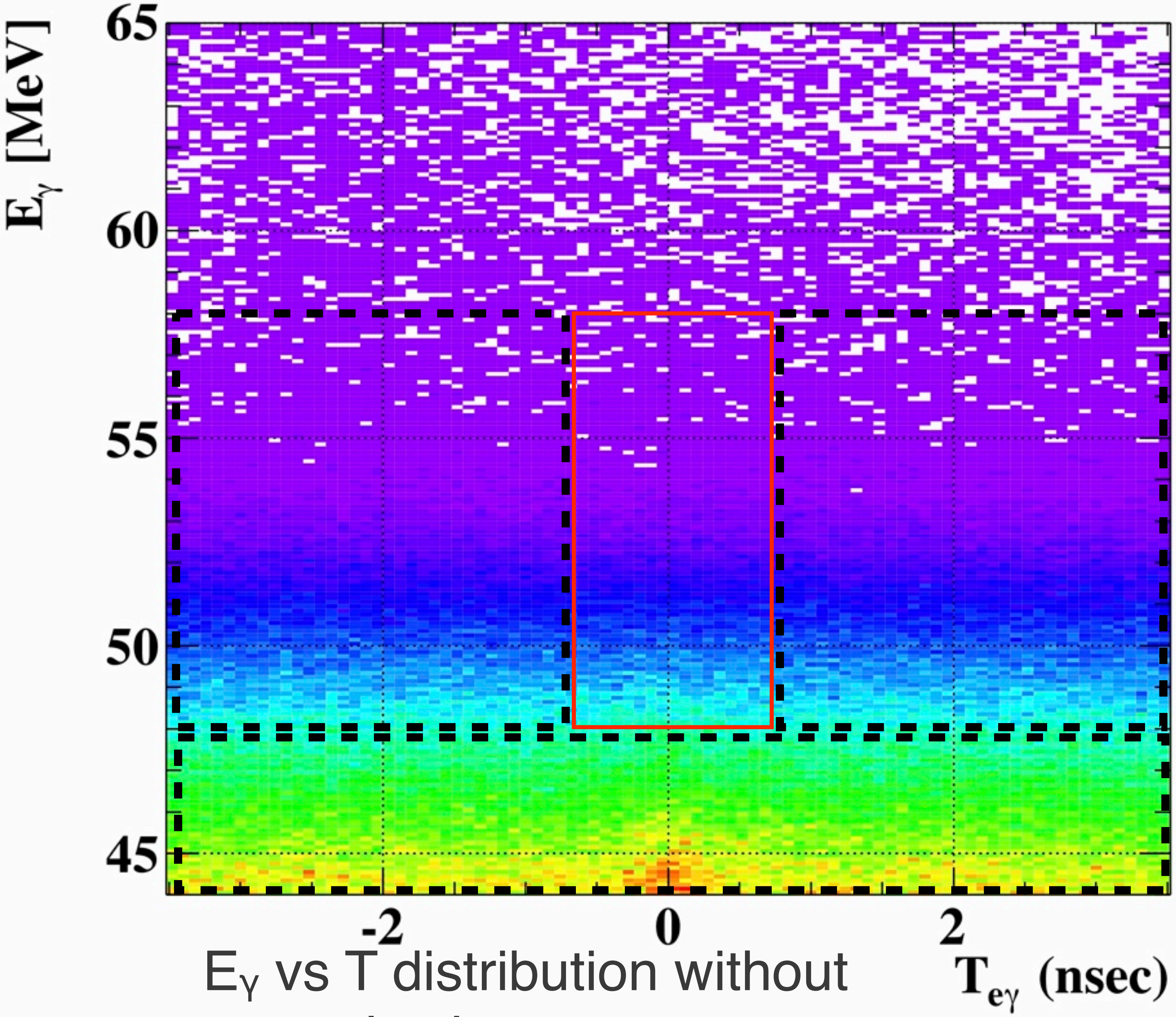
Performance in 2009

Stable detector operation in 2009

in sigma	
Gamma Energy (%)	2.1 (w>2cm)
Gamma Position (mm)	5(u,v) / 6(w)
e+ Momentum (%)	0.74 (core)
e+ Angle (mrad)	7.1(ϕ core),11.2(θ)
Vertex position (mm)	3.4 (Z), 3.3 (Y)
Gamma - e+ Timing (psec)	142 (core)
Gamma Efficiency (%)	58
Trigger Efficiency (%)	83.5

Details of detector ➔ T.Iwamoto 24th 9:00, Salle 252A

Data samples



E_γ vs T distribution without any selection.

Analysis box (~10σ width)

- $48 \le E_\gamma \le 58$ MeV
- $50 \le E_e \le 56$ MeV
- $|T_{e\gamma}| \le 0.7$ ns
- $|\phi_{e\gamma}|, |\theta_{e\gamma}| \le 50$ mrad*

Analysis box was blinded during calibration and optimization of physics analysis.

Time and E_γ sideband

- Accidental background PDF was made directly from sideband data. (Important because dominating background is accidentals)
- Positron detector response is studied by using Michel positrons.
- Time resolution is measured by using RMD peak in low gamma energy sideband.

* Angle is between gamma and flipped positron vectors.

Analysis Method

Extended unbinned maximum likelihood analysis on number of events

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

"BG" in this talk means accidental background.

Event types : Signal, RMD and Accidental background

Observables : E_γ, E_e, Relative time and Relative angle

- Fit is done for wide widow (about 10σ of each variable), and background events are fitted together.
- Fit is done by three independent likelihood analysis tools to check possible systematic effects.
- Event-by-event PDF
  - Position dependent PDF of gamma rays.
  - Two category PDF of positrons by reconstruction quality (fitting uncertainty etc.)
- Most of PDFs are made from data (next slide)
- RMD PDF is formed from theoretical shape and detecter response.

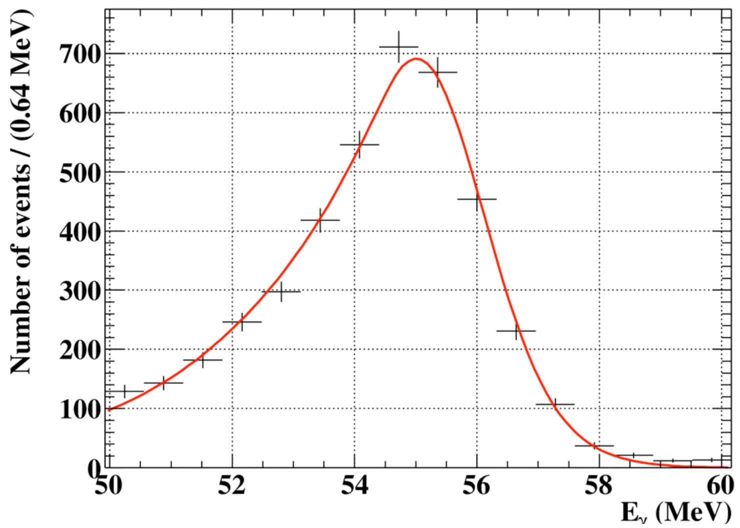
Normalization factor is obtained from number of observed Michel positrons taken simultaneously.

Preliminary

B.R. = Nsig / 1.0 ± 0.1 × 10^{12}

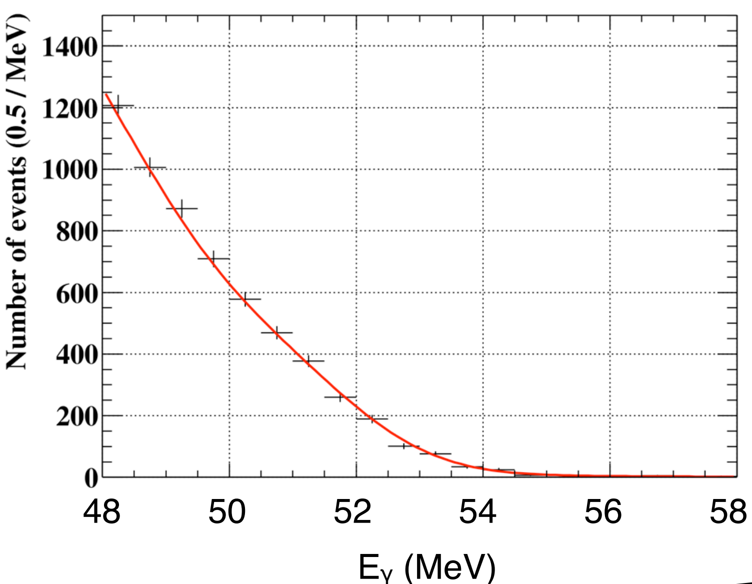
PDFs

55 MeV π^0 peak



Gamma

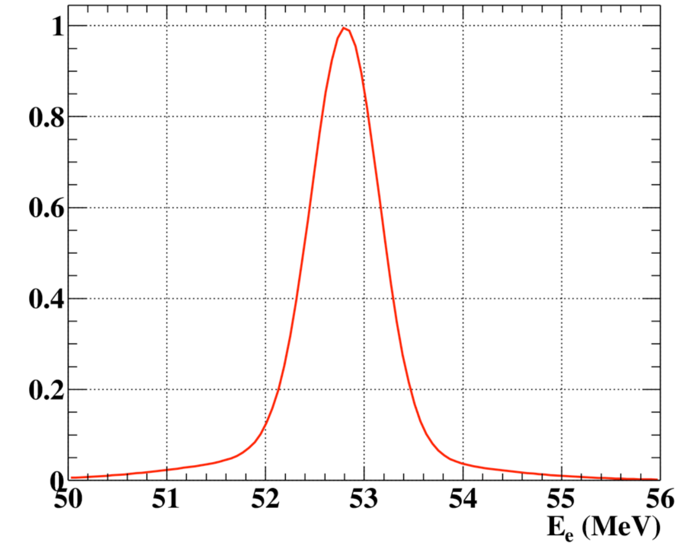
Signal PDF from 55MeV calibration gamma (π^0 decay)



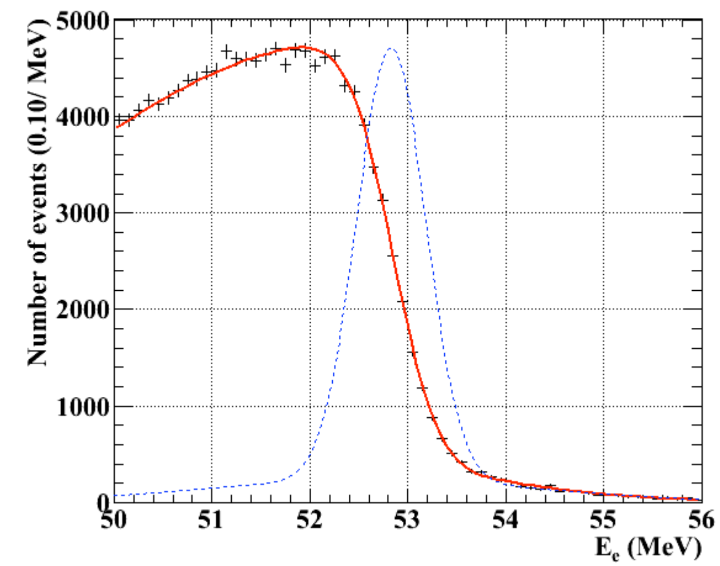
BG measured in sideband

Positron

Signal PDF from measured resolution



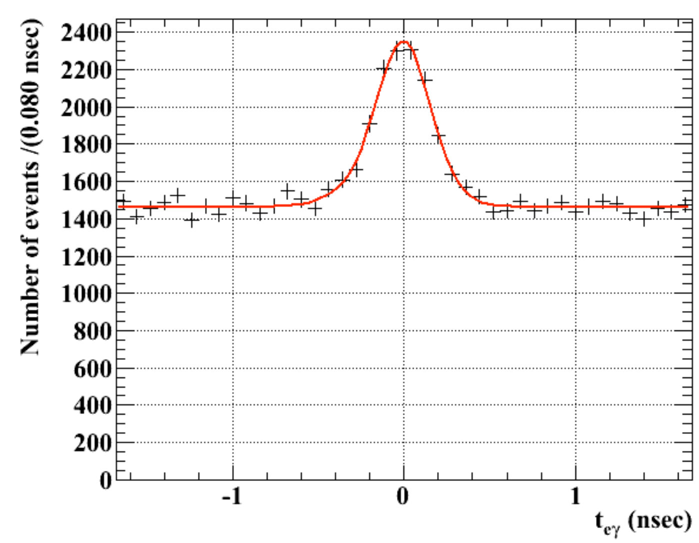
BG measured in sideband



Relative time

Signal PDF from measured RMD peak

RMD peak
mostly in low energy part



Relative angle

From measured resolutions and BG

Sensitivity

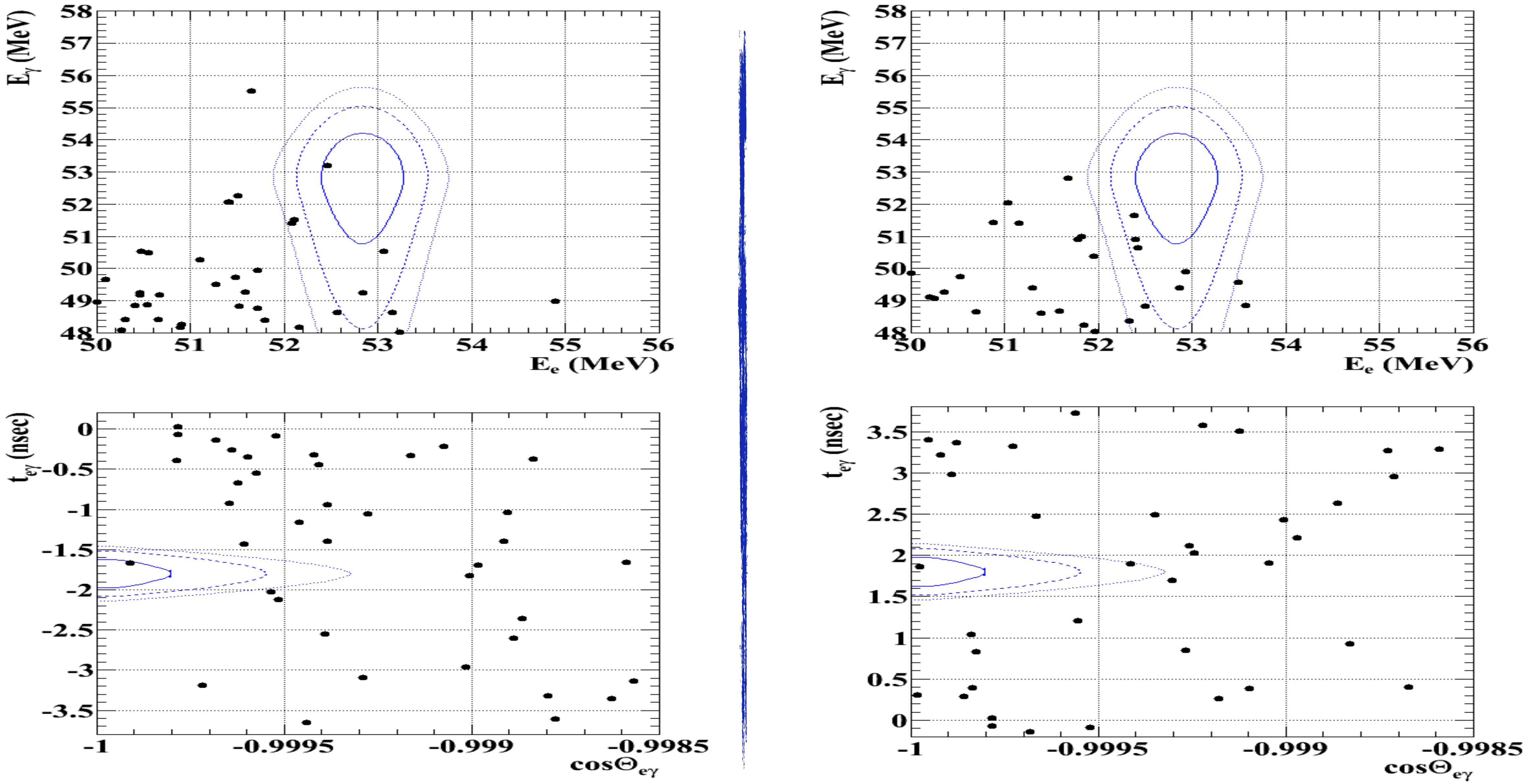
Average 90% C.L. upper limit of toy MC with null signal.

Sensitivity : 6.1×10^{-12}

Preliminary

Sideband fit result is consistent. Br < $4 \sim 6\times10^{-12}$

Negative $T_{e\gamma}$ sideband

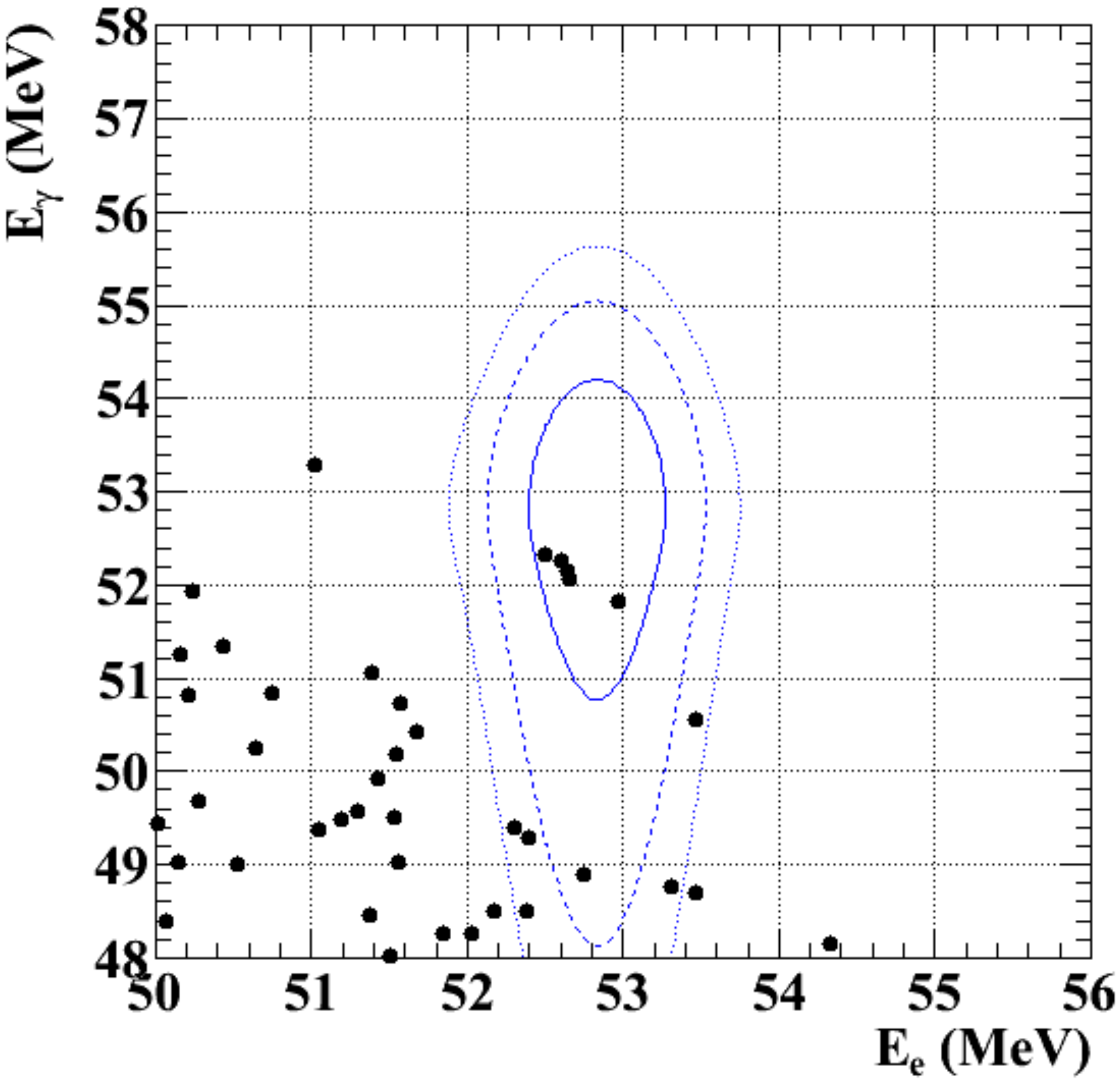


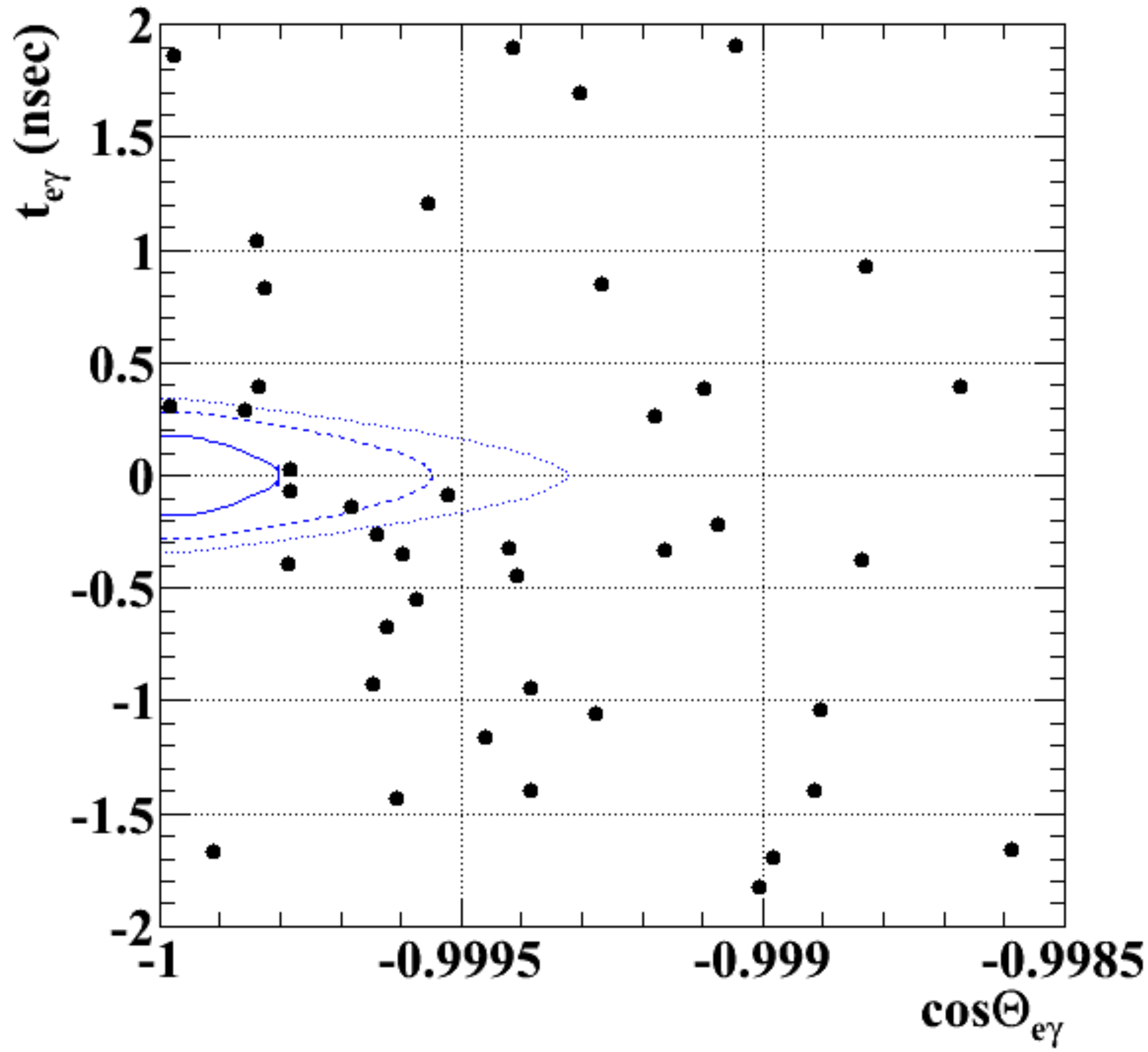
Positive $T_{e\gamma}$ sideband

Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.
For each plot, cut on other variables for roughly 90% window is applied.

(Current B.R. upper limit is 1.2×10^{-11} by MEGA)

Event distribution after unblinding



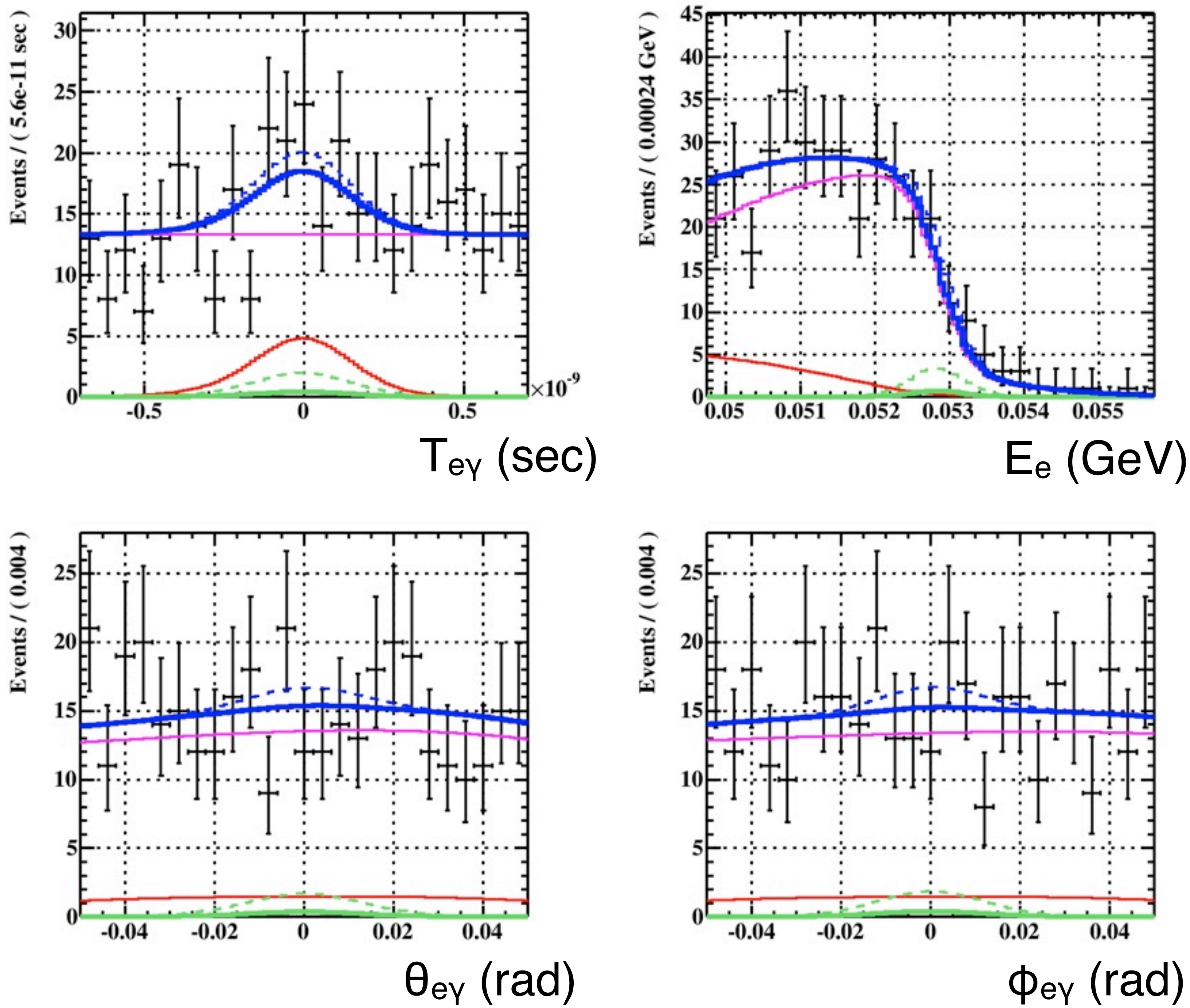


Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.

For each plot, cut on other variables for roughly 90% window is applied.

Fit Result

Preliminary



Accidental BG

RMD

Signal

Total

$N_{RMD}=35^{+24}_{-22}$
(Expectation from sideband = 32±2)

Dashed lines : 90% C.L. UL of Nsig

Nsig < 14.5 @ 90% C.L

Nsig=0 is in 90% confidence region

Nsig best fit = 3.0

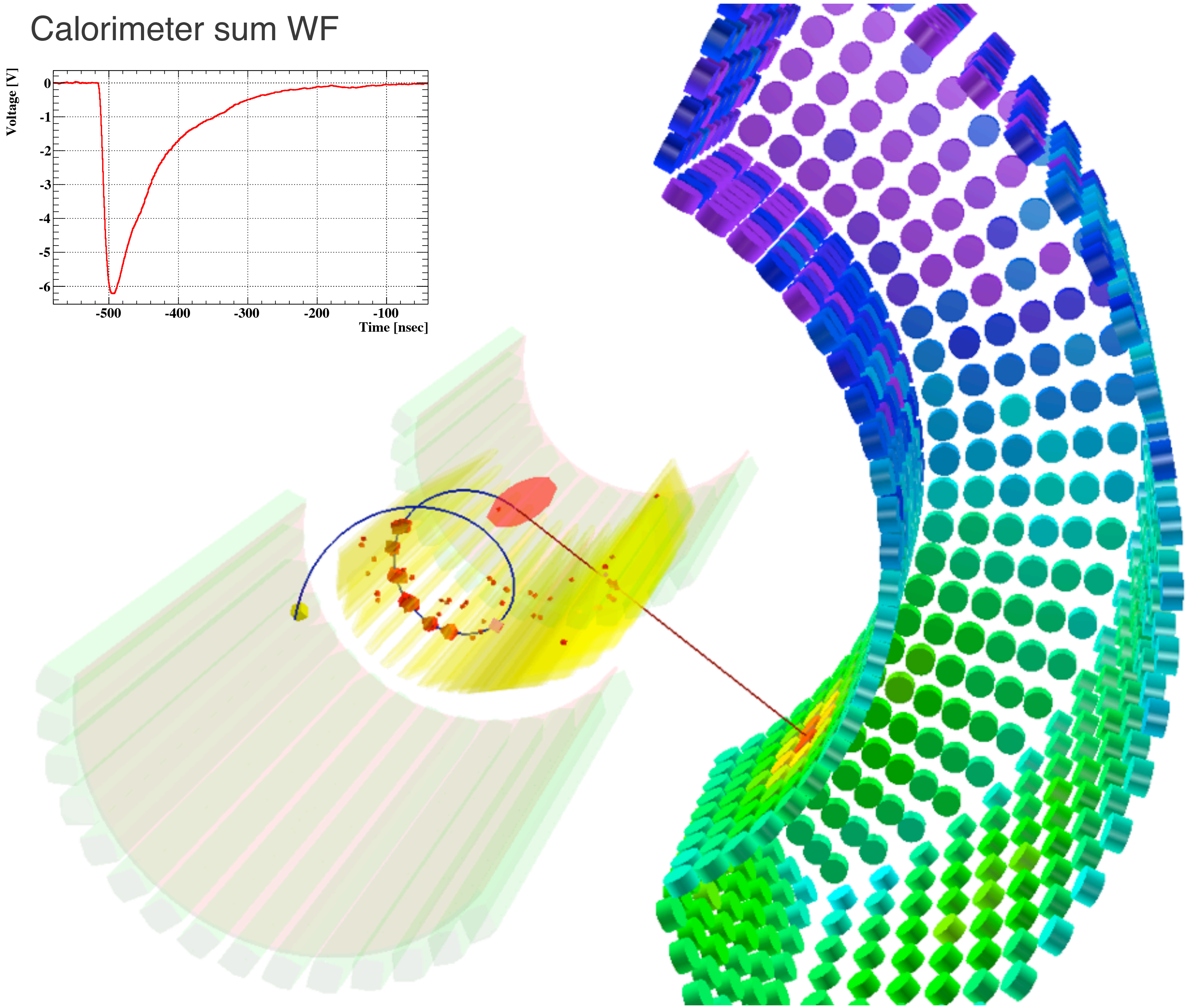
Fitting was done by three groups with different parametrization, analysis window and statistical approaches, and confirmed to be consistent (Nsig best fit = 3.0-4.5, UL = $1.2\text{-}1.5\times10^{-11}$)

Event display

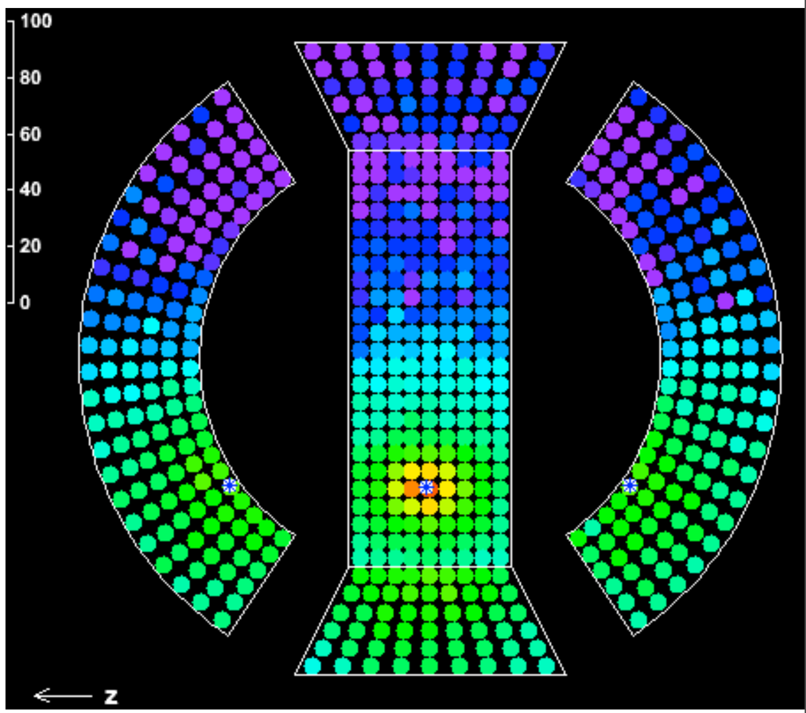
One of the most signal-like events.

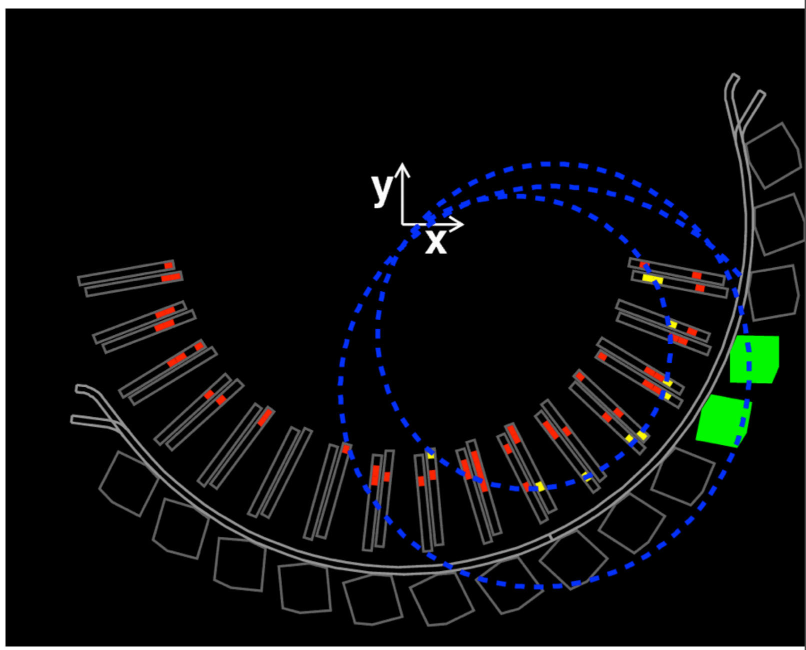
E_γ = 52.25 MeV
E_{e+} = 52.84 MeV
$\Delta\theta$ = 178.8 degrees
ΔT = 2.68×10^{-11} s

Calorimeter sum WF



Calorimeter PMT hit map





Spectrometer hits and a track

Each highly ranked event is checked carefully.

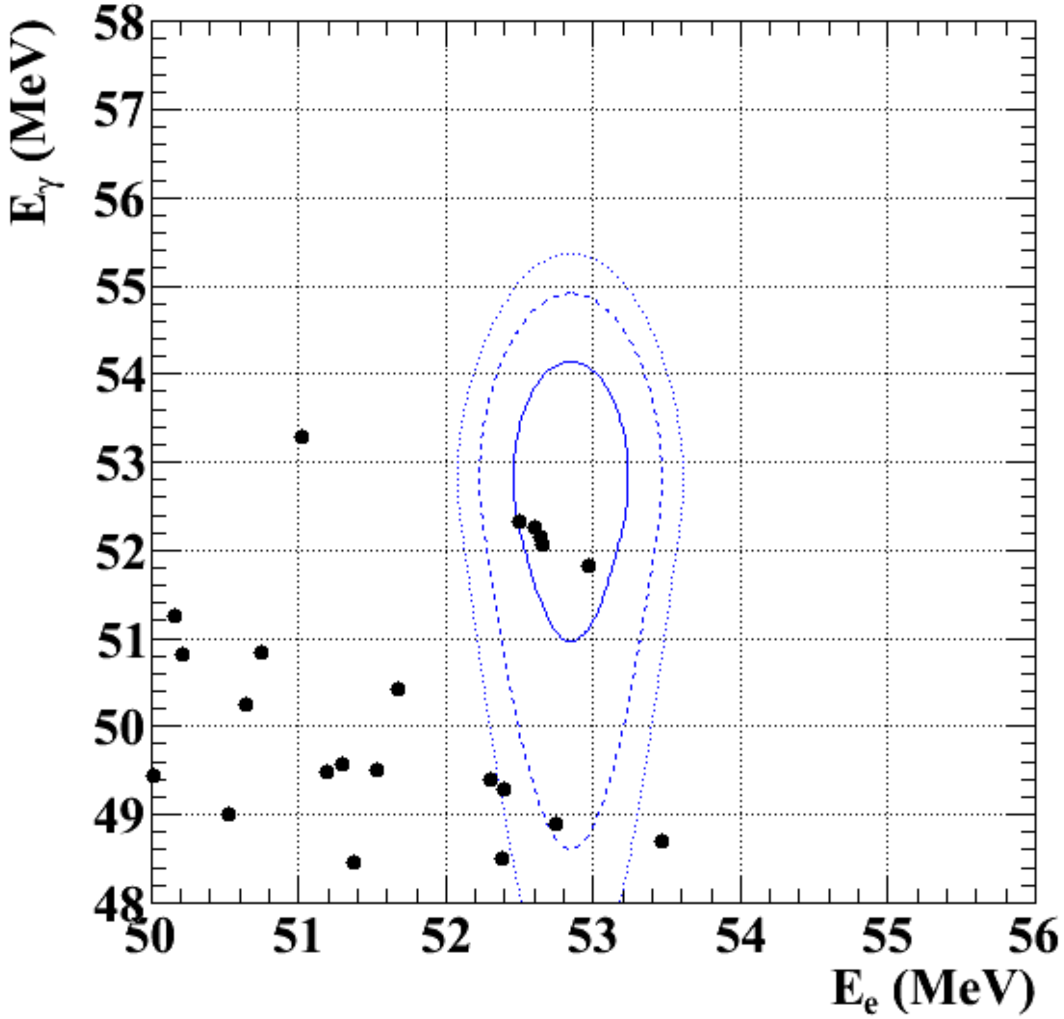
Check of events

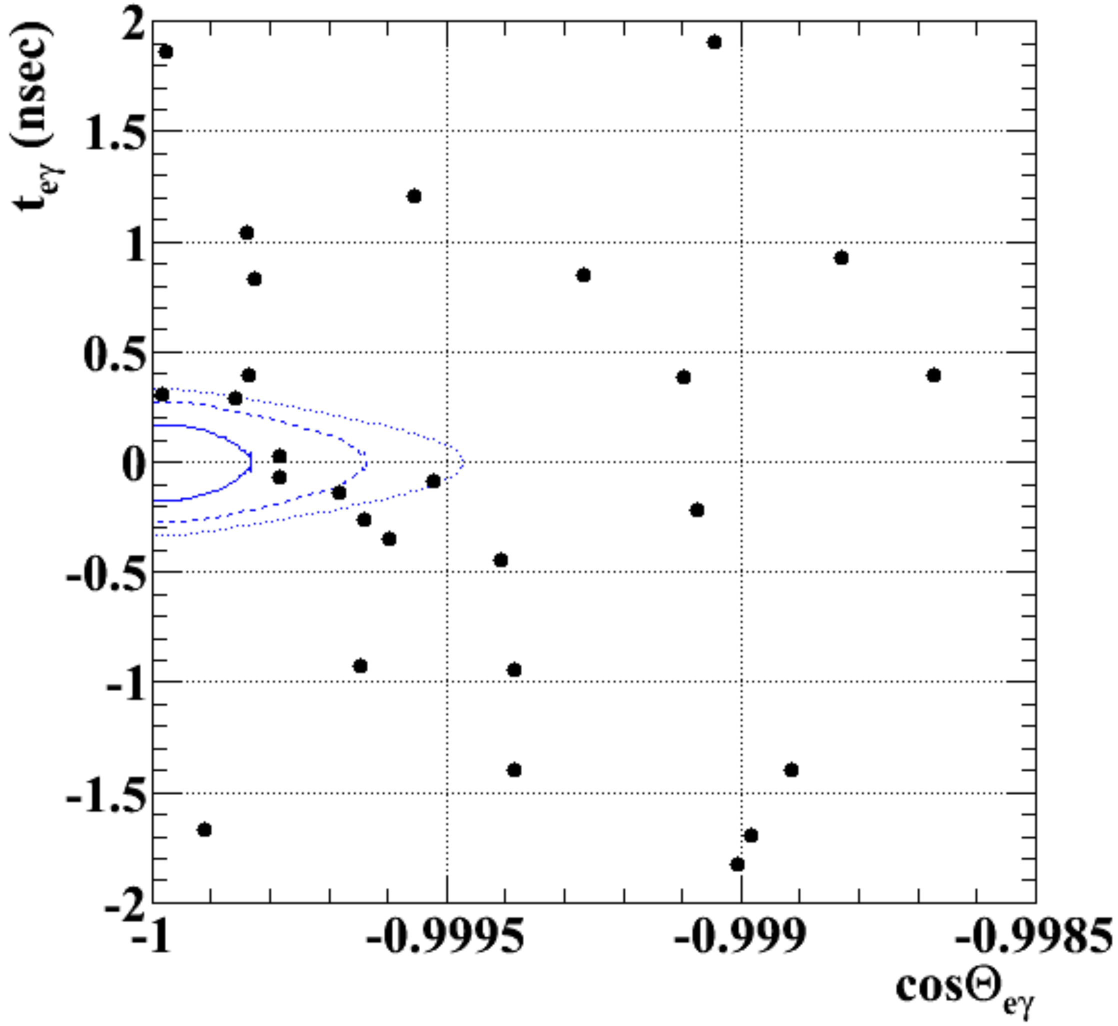
High quality e^+ track category events

Selected by number of drift chamber(DC) hits, E_e, θ_e, ϕ_e fitting uncertainties, track fitting χ^2, r and z difference between timing counter hit and extrapolation of a track.

Events around signal region do not disappear by selecting high quality track events.

High quality fraction = 59%





Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.

For each plot, cut on other variables for roughly 90% window is applied.

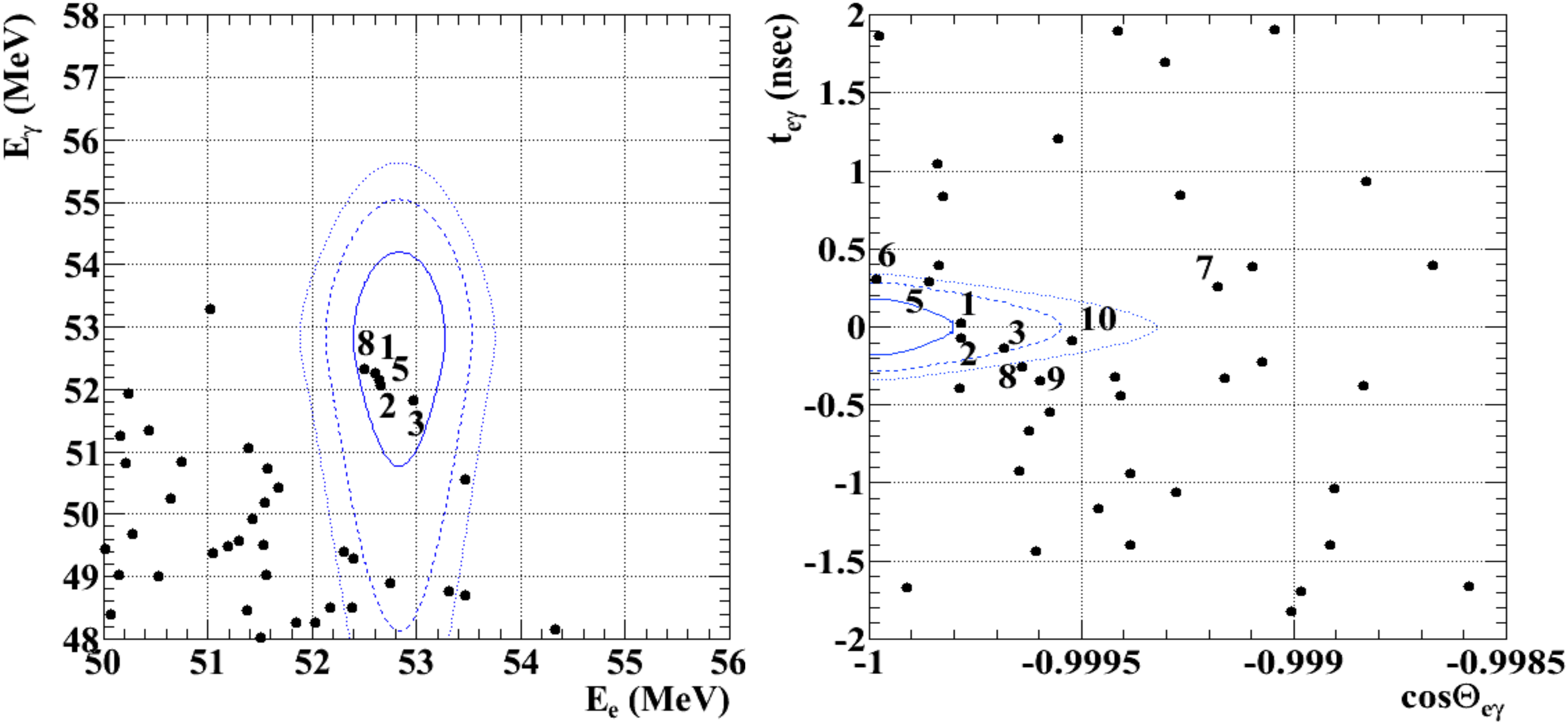
Summary

- MEG started to take data for 2 months in 2009, with a stable detector condition.
- Preliminary results from 2009 data,
  - Sensitivity : 6.1×10^{-12}.
  - 90 % C.L. upper limit : 1.5×10^{-11}
  - Nsig=0 is in 90% C.L. region.
- 2010 run is going to start soon. And we would have another 3 years to reach a few$\times10^{-13}$ sensitivity. We can clarify the result without statistical error.

Rare lepton and K-meson decays ➔ A. Baldini 27th 15:30, Plenary

Back up

Event distribution after unblinding



Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.

For each plot, cut on other variables for roughly 90% window is applied.

Numbers in figures are ranking by $L_{sig}/(L_{RMD}+L_{BG})$. Same numbered dots in the right and the left figure are an identical event.

Normalization

Conversion factor from Nsig to B.R.

$$N(\mu \to e\gamma) = \boxed{N_\mu} \cdot Br(\mu \to e\gamma) \cdot (\Omega/4\pi) \cdot \epsilon_\gamma \cdot \boxed{\epsilon_e} \cdot \epsilon_{\rm trig} \cdot \epsilon_{\rm sel}$$

$$N(Michel) = \boxed{N_\mu} \cdot (\Omega/4\pi) \cdot \boxed{\epsilon'_e} \cdot \epsilon'_{\rm trig} \cdot P(Michel)$$

Efficiency for Michel   Trigger preselection

- Use Michel decay as normalization channel
  - Michel samples mixed in normal data taking
  - Count reconstructed high momentum Michel positrons
  - In the branching ratio calculation, the positron efficiency is cancelled out in the first order. Rather precise evaluation should be possible in spite of the varying positron efficiency during the run.

Perspective

- Data taking will be **restarted at end of July**;
- Strategies to **combine 2008 and 2009 data** under discussion;
- We would have **3 years of stable data taking** from now until end of 2012 (large fluctuations expected to disappear);
- **Expected improvements:**
  - a factor 2 on electronic contribution to timing (hardware fine tuning);
  - possible better positron calibration (monochromatic beam) + DCH noise reduction ⇒

    $\sigma_{\theta,\phi}$: → 8 mrad; σ_p: → 0.7%;
  - relative timing resolution: → 120 ps (timing + track length evaluation);
  - possible refinement in calorimeter analysis (σ_E/E = → 1.5%).
- **Continue running for the final goal (sensitivity ~ a few x 10^{-13})**