MEG実験2008

$\mu^+ \to e^+ \gamma$崩壊事象探索解析

日本物理学会第64回年次大会
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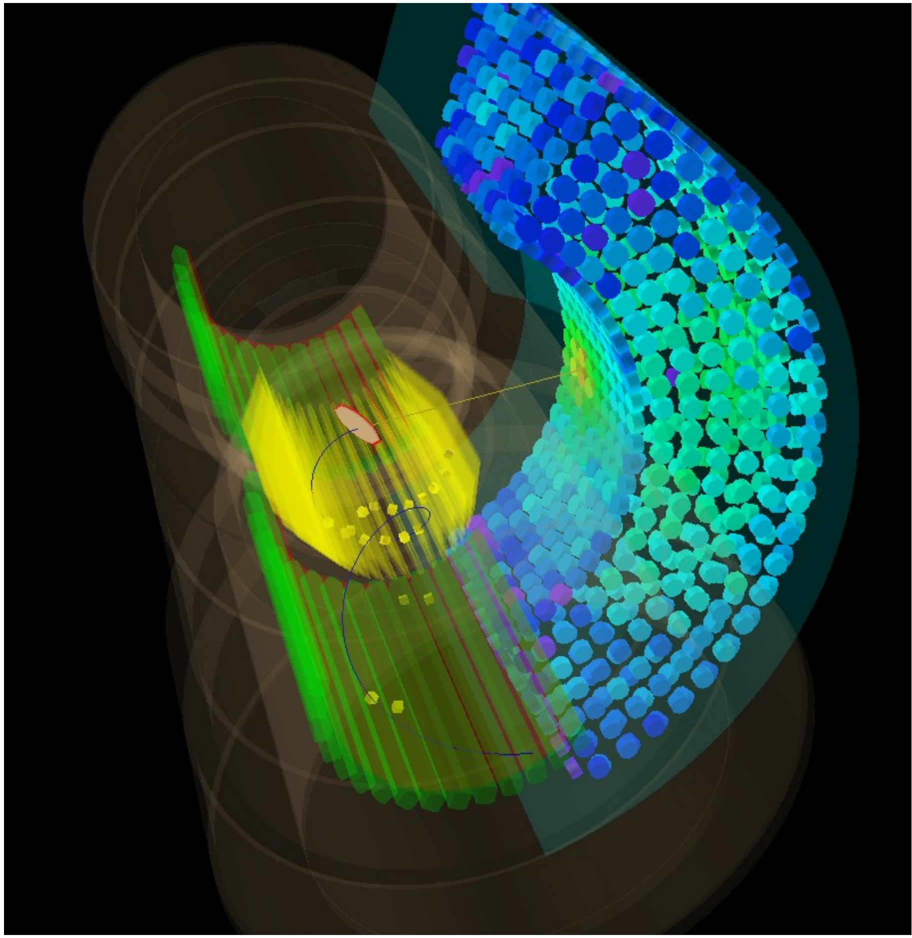

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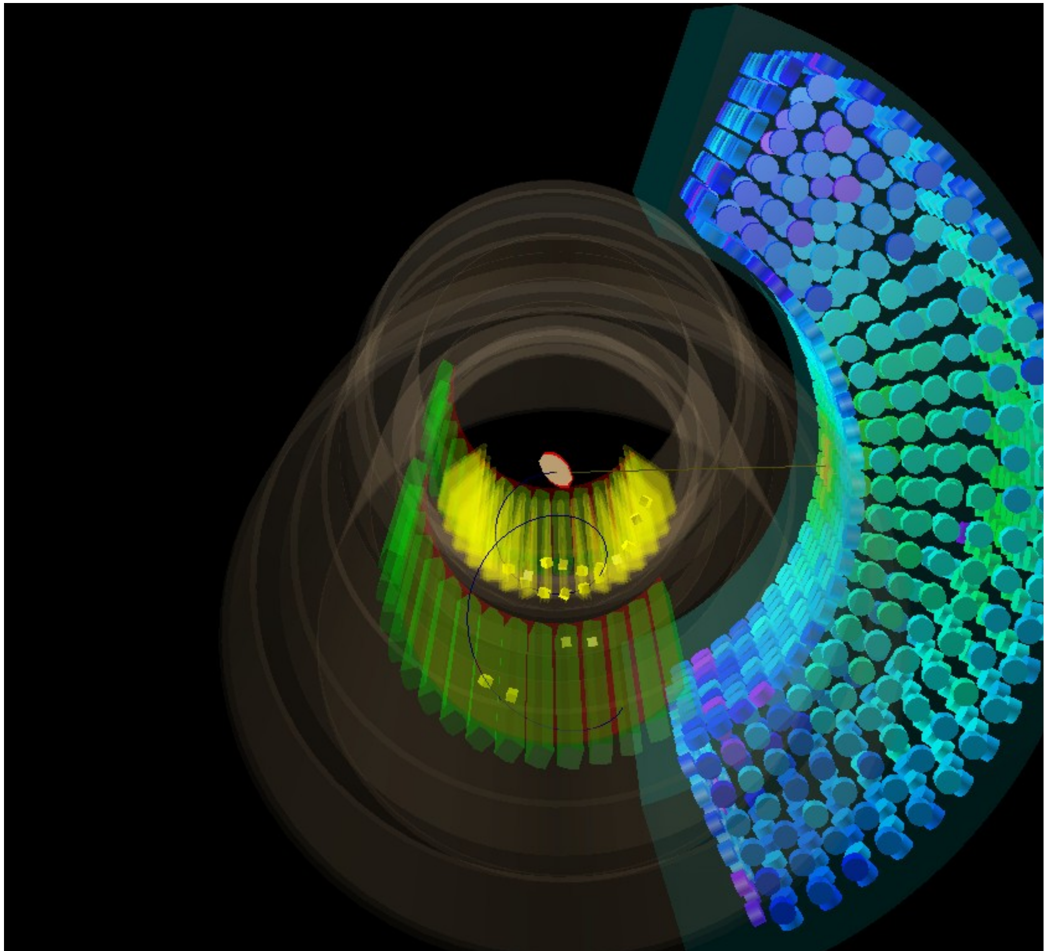
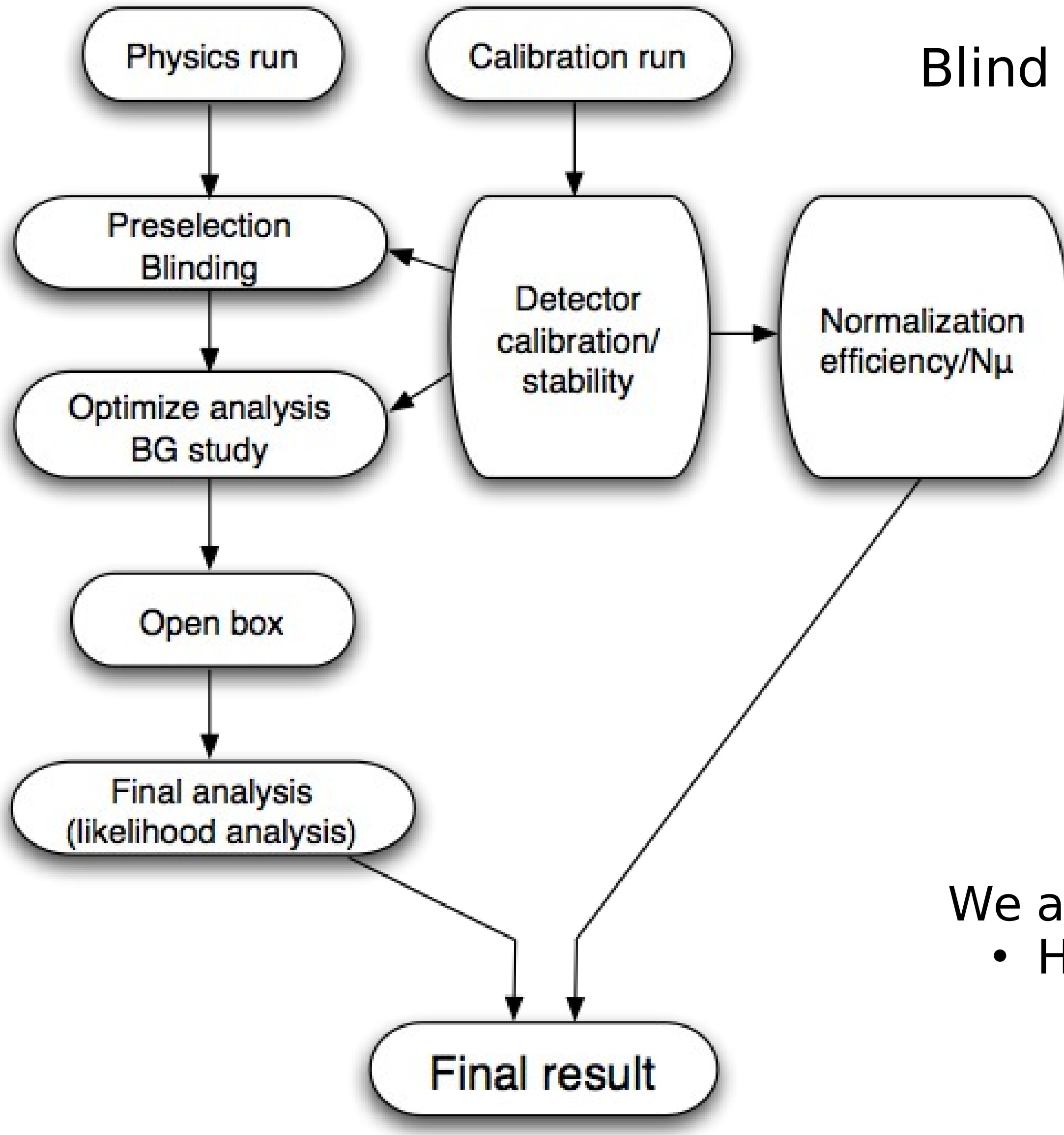
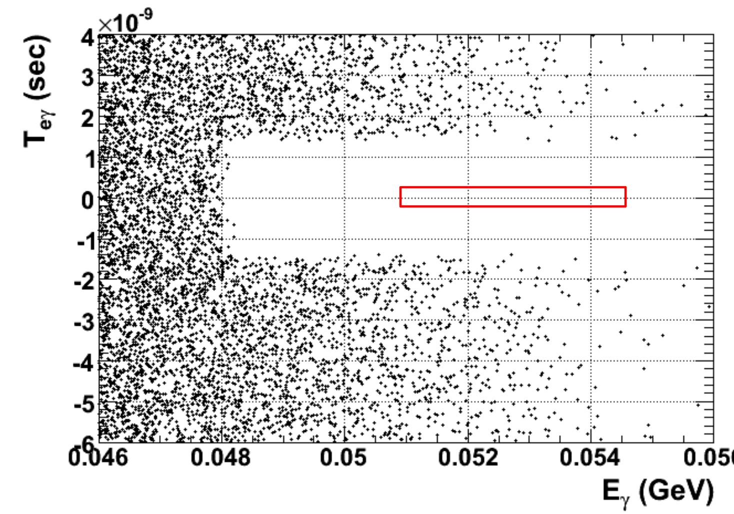


An example of MEG trigger event

Physics Analysis



Blind analysis & Likelihood analysis



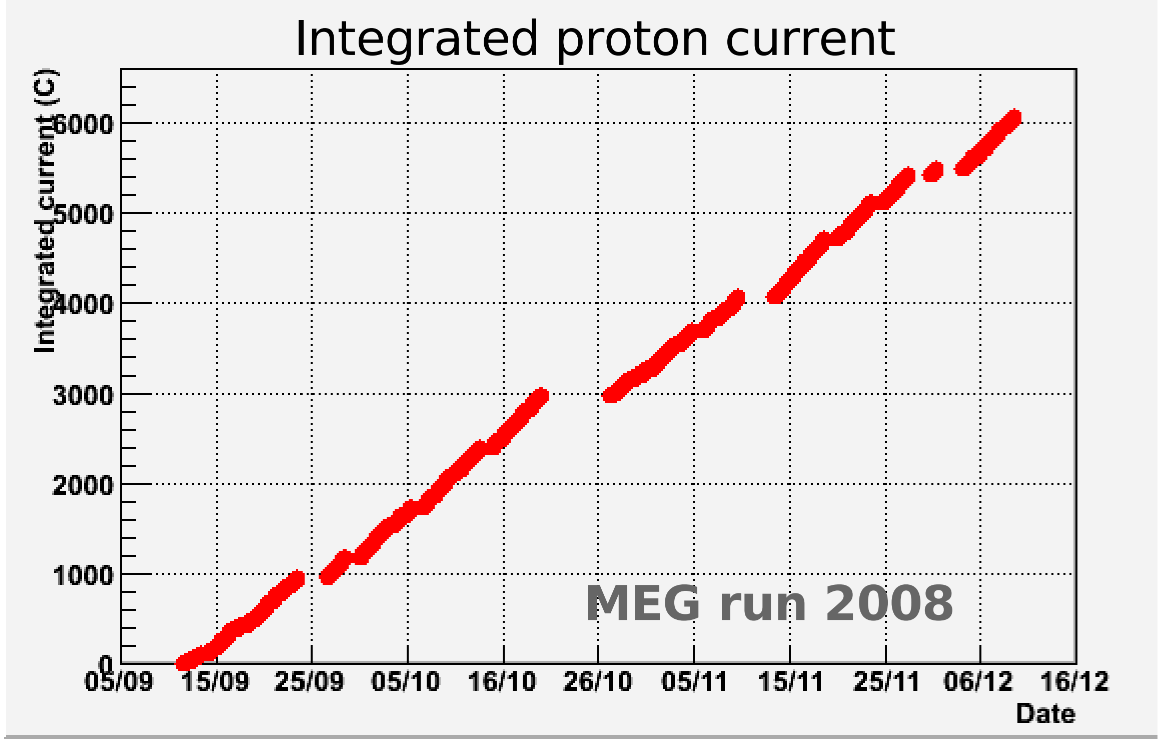
We are now blind to the signal events

- Hidden parameters
  - ✔ (Eγ, Teγ)

Data & Run

Normal physics data taking :

- **MEG run** w/ 11 mixed trigger : Normal beam, 6.5Hz trig. rate, ~83% livetime
- Daily **LED calibration** w/ beam ON
- 3/week **Full calibration** sets
- 1/week 24H **RD run**



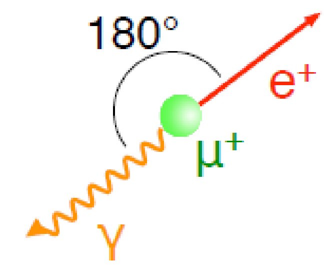
Live time : 3.4×10^{6} sec

Total 9.1×10^{13} muons

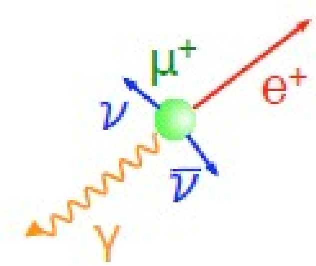
Beam Mode	R_μ Measured Rate COBRA at 2mA	R_{stop} Stopping Rate at 2mA (ε_{STOP}= 0.794)
"High"	$8.4 \cdot 10^{7}\ \mu^{+}s^{-1}$	$6.7 \cdot 10^{7}\ \mu^{+}s^{-1}$
"Normal"	$3.5 \cdot 10^{7}\ \mu^{+}s^{-1}$	**$\sim 2.8 \cdot 10^{7}\ \mu^{+}s^{-1}$**
"Ultra-low"	$1.5 \cdot 10^{6}\ \mu + s^{-1}$	$\sim 1.2 \cdot 10^{6}\ \mu^{+}s^{-1}$

Signal & Background

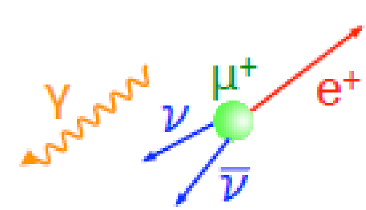
- **signal**
  - Back to back
  - Mono energetic : Ee=52.8MeV, Eγ=52.8MeV
  - Coincidence in time



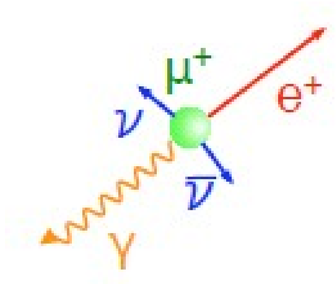
- **Background**
  - Prompt background
    - Radiative muon decay (RD)
      - Small branching ratio
      - Able to suppress with current resolution



  - Accidental overlap
    - Will be dominant in our experiment



Radiative Decay Analysis



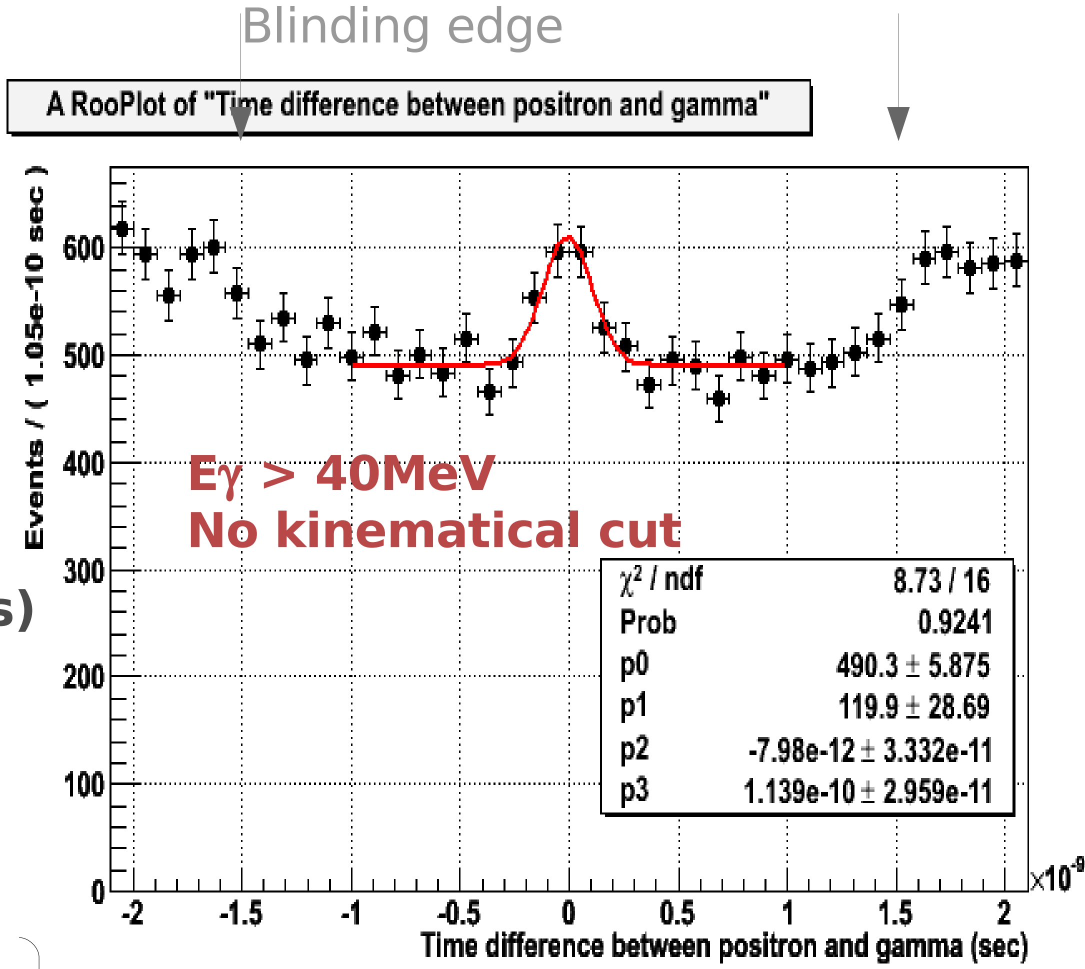
RD events is our 2nd signal

- **Quite important** to identify RD events in order to demonstrate the quality of our experiment
- Time calibration with real coincident events

- Two type of data samples
  - Dedicated RD runs
    - “Ultra low” beam intensity (1.2×10^{6} /s)
    - Low accidental BG
    - Low energy threshold, no back-to-back requirement
  - MEG runs
    - “Normal” beam intensity (2.8×10^{7}/s)

RD Search in MEG Runs

- We observed RD peak !
  - Even on higher floor of acci.BG
  - Another & powerful time calibration source



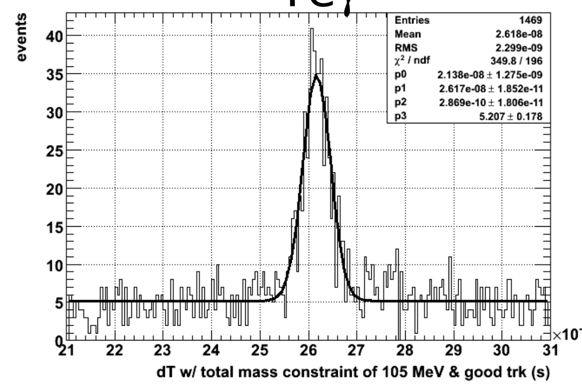
- **T0 is well centered**
  - T0 is calibrated using different calibration source
    - Dalitz decay of $\pi 0$
    - Taken in summer $\pi 0$ run
- **Peak width = 114 ± 30 ps (s)**
  - Show the improvement of time resolution as increase of γ energy
  - Close to combined resolution of each detector

$$\underset{Xe}{100} \oplus \underset{TC}{70} \oplus \underset{Track}{50} = 132\text{ps}$$

We are really sensitive to the $\mu \to e\gamma$ signal !

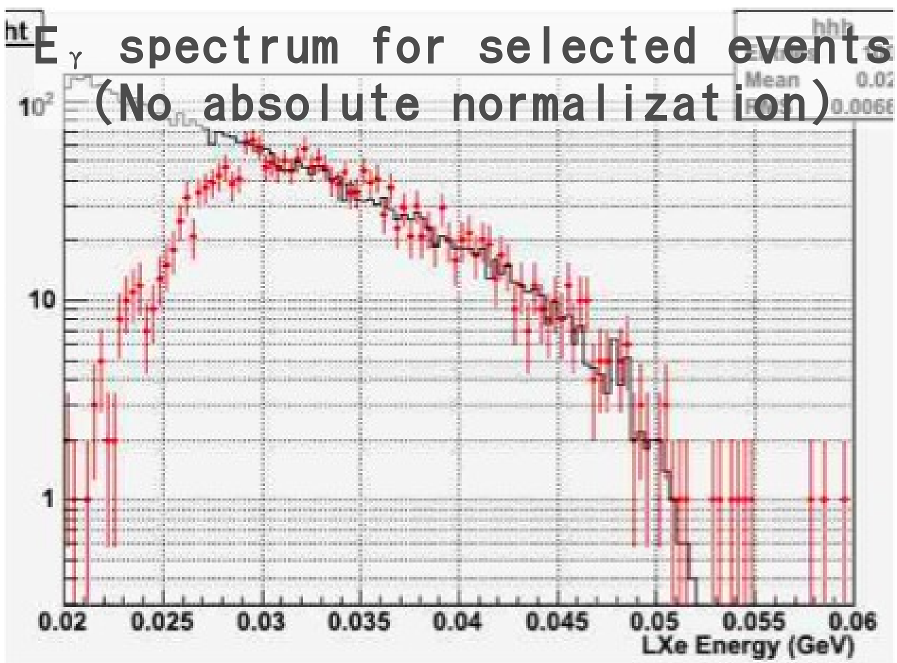
RD Events in Dedicated Run

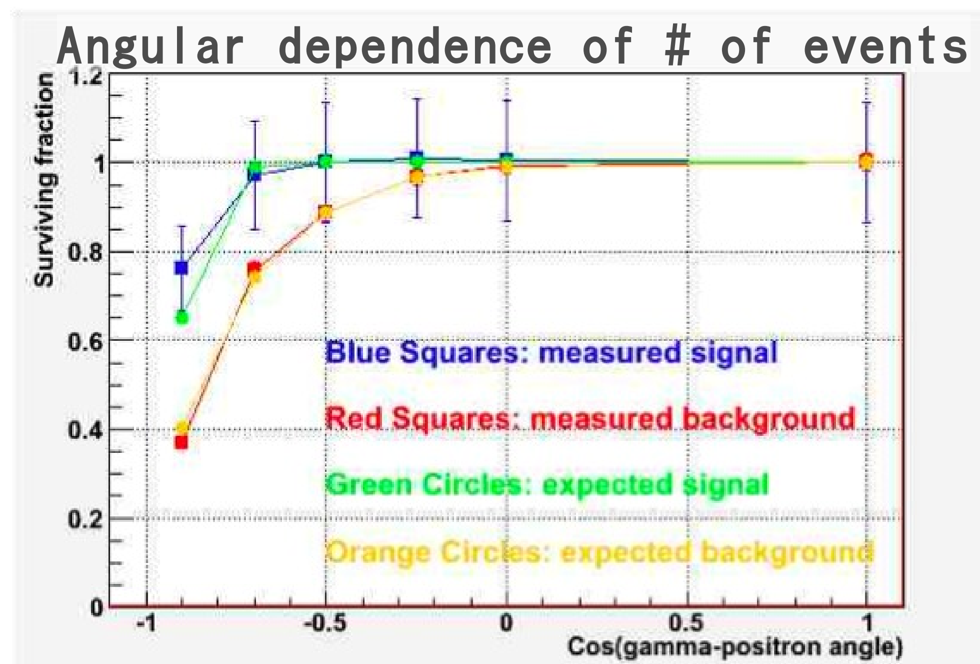
Teγ



Comparison with expectation

- Use dedicated run (low intensity (factor 25))
- Cleaner sample (better S/N~2.8)



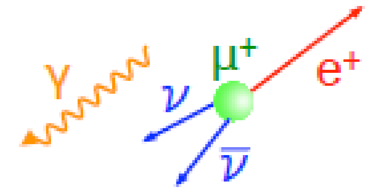


- Eγ spectrum shape is well reproduced by MC
- Angular dependence is in agreement with the expectation

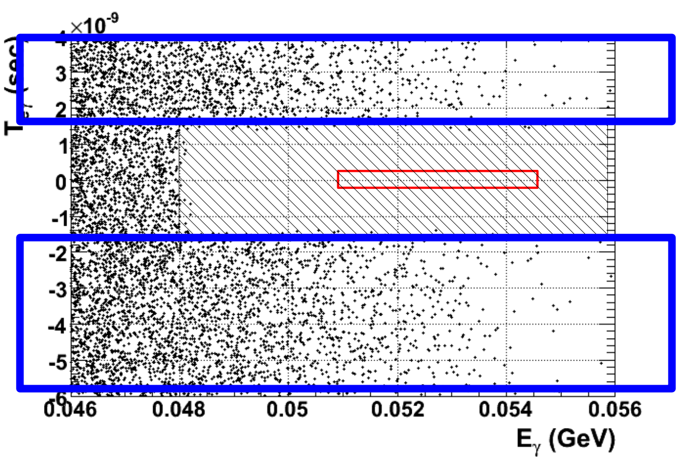
Background Study

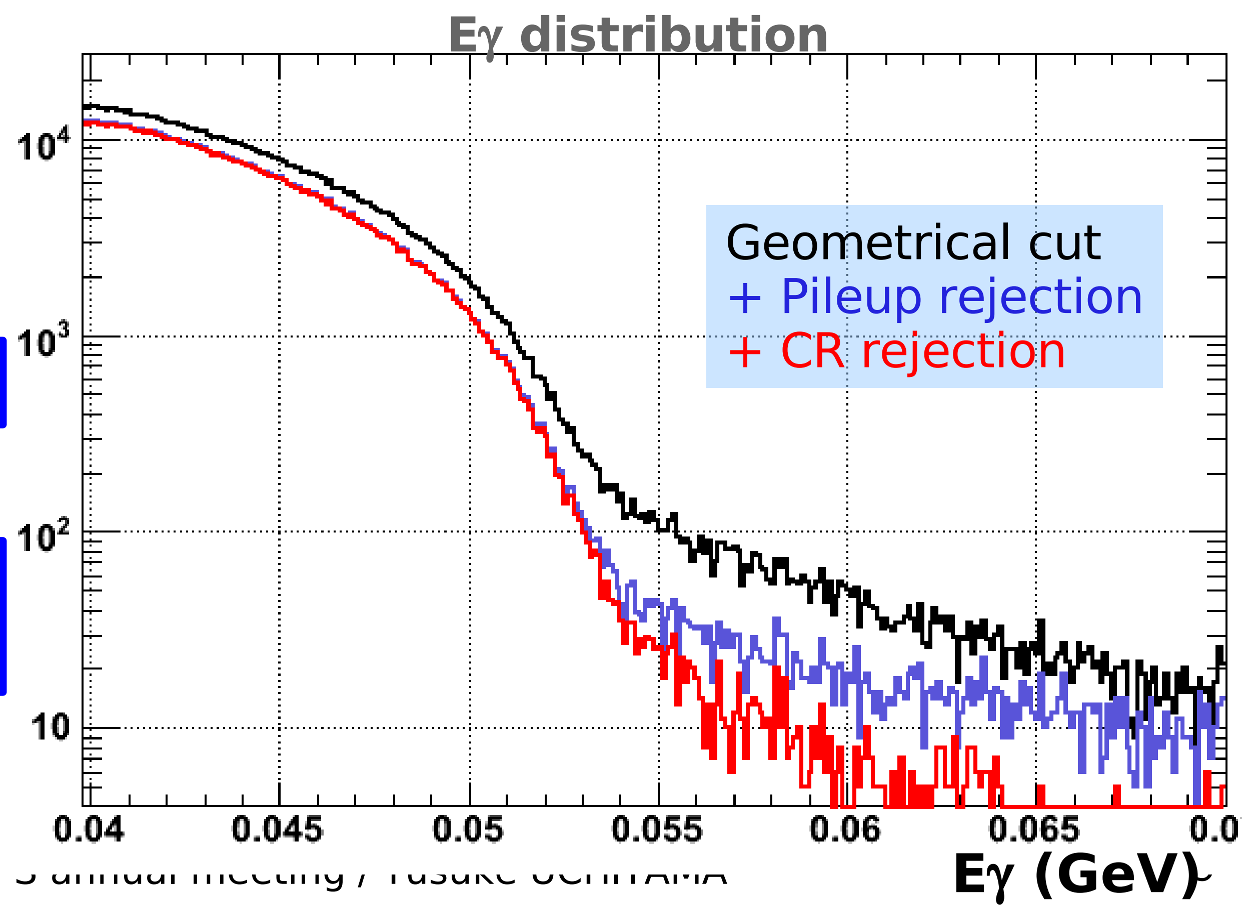
We can study accidental background with

- Single trigger events (mixed in MEG data)
- Side-band data

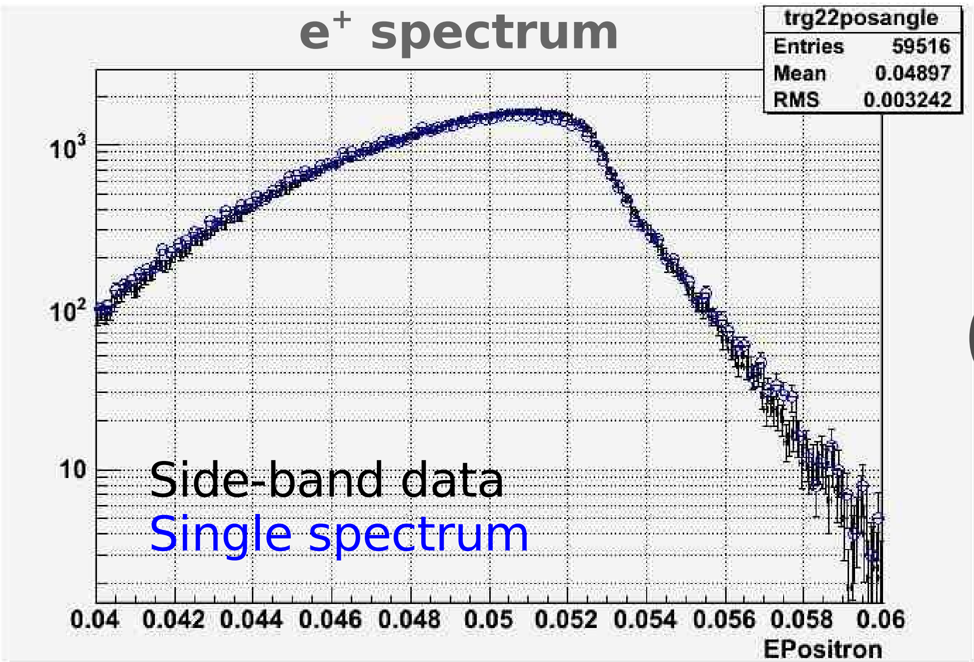


- – Obtain distributions for accidental background → for likelihood fit
- – Estimate number of background in signal region





BG Study with Single Spectra



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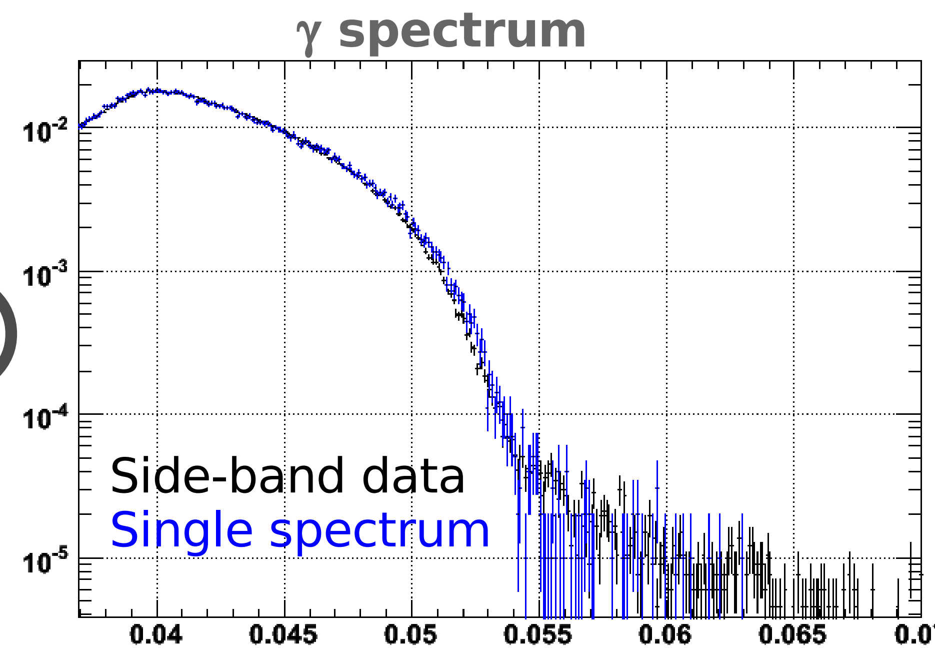
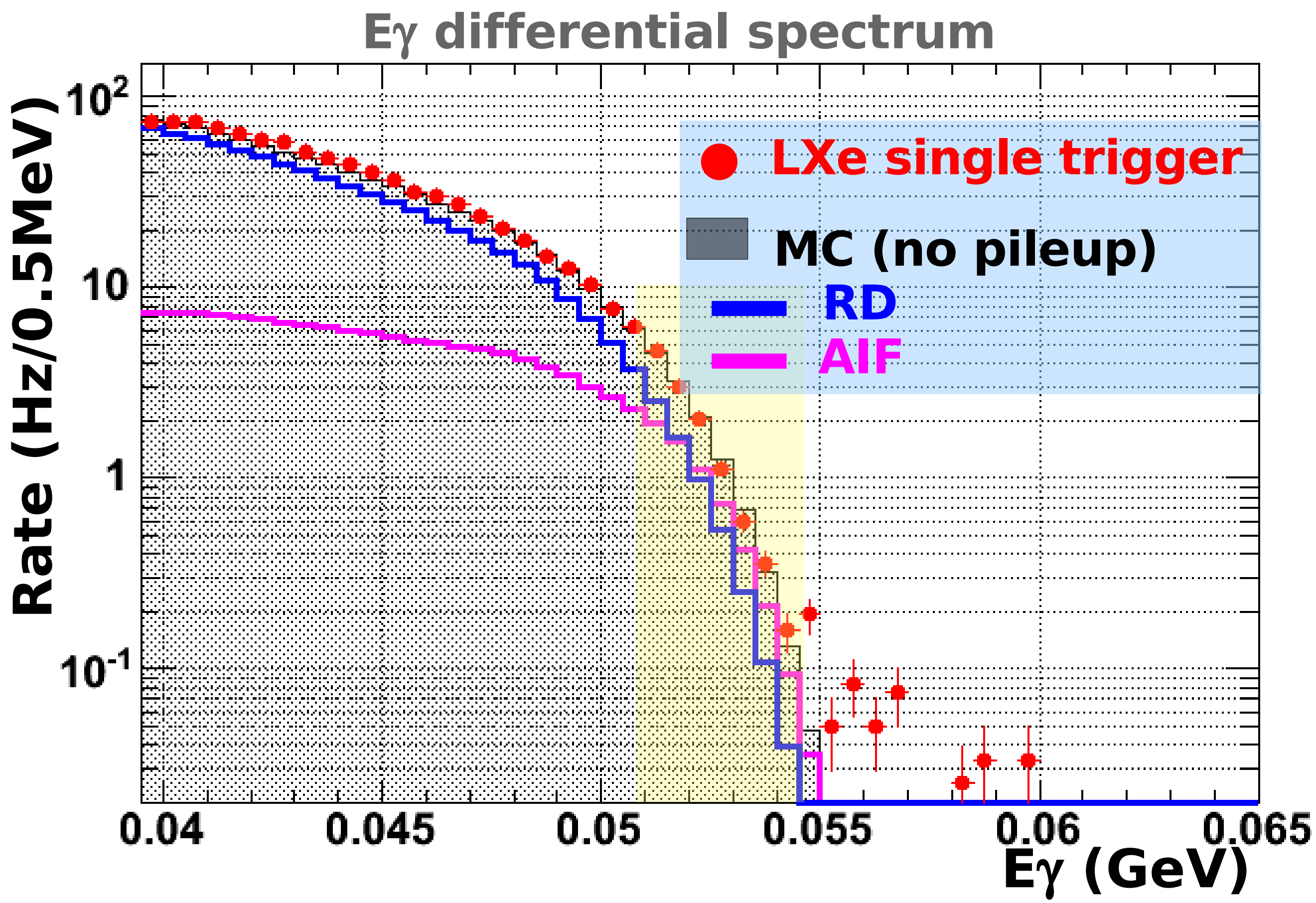


- Consistency check between side-band and single data
- Background is dominant with accidental overlap

BG Study with Single Spectra



- Spectrum fit MC
  - No unexpected background
    - Pileup effect to be investigated
  - Absolute rate within ~20%
    - Uncertainty from Eγ efficiency & energy scale

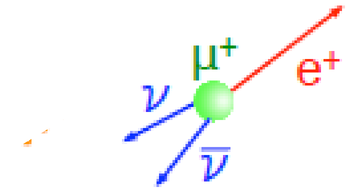
Normalization

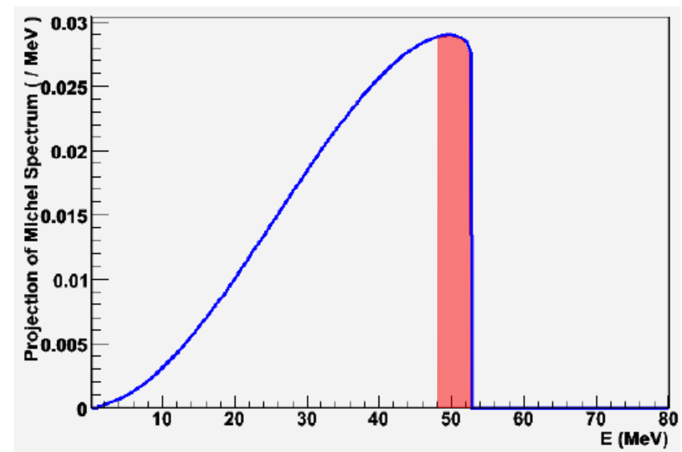
$$Br(\mu \to e\gamma) = \frac{N_{sig}}{N_\mu (\Omega/4\pi) \epsilon_\gamma \epsilon_e \epsilon_{trigger} \epsilon_{sel}}$$

- Use **Michel decay** as normalization channel
  - Michel samples mixed in normal data taking
  - Count reconstructed *high momentum Michel* positrons

$$N_\mu = \frac{N^{Michel} P^{Michel}}{B^{Michel} \epsilon_e^{Michel}}$$

  - In the branching ratio calculation, Positron efficiency is canceled out to the first order.





N^{Michel}: # of observed Michel events
P^{Michel}: Prescale factor of Michel tirgger
B^{Michel}: Fraction of Michel decay used to count

$$Br(\mu \to e\gamma) = \frac{N^{sig}}{N_\mu \epsilon_e \epsilon_\gamma \epsilon_{trigger} \epsilon_{sel}}$$

Other methods are available. Cross check.
Preliminary analyses indicate reasonable agreements

Single Event Sensitivity

MEG
Mu-E-Gamma Collaboration

- Roughly estimate sensitivity of 2008 data
  - Large uncertainty of normalization
  - Analyses are not finalized yet

Efficiencies

	2008 provisional
Gamma	0.28
e+	0.12−0.23
Trigger	~0.8
Selection	0.9^3x0.95=0.69

Expected S.E.S (for box analysis)

$(30\sim 50) \times 10^{-13}$

- Worse than expectation
  - (for example 4times from the previous JPS meeting)

!! All numbers are provisional !!

Possible Improvements (2008 Data)

- All numbers in this study are very preliminary ones.
  - Using currently obtained performance.
  - Large uncertainty in many parts
- There is some room to improve

To achieve good sensitivity with 2008 data, it is very important to recover efficiencies

- Efficiencies
  - Gamma :
    - Recover fiducial volume (now discard shallow events (35%))
    - Unfold and reconstruct pile-up events
  - Positron :
    - Optimize selection criteria for tracking
- Resolutions
  - We are quoting here rather conservative resolutions
    - ex) Resolution of $T\gamma$ include clock synchronizing error which is not same as that for TC.
    - Gamma position resolution includes the spread due to the collimator edge and target spread
    - $E\gamma$ resolution includes larger pedestal distribution from high rate pi beam
  - Further study of reconstruction algorithms and calibrations

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	2008 provisional
Gamma	> 0.5 x 0.65x0.85
e+	(0.3−0.57) x 0.4
Trigger	1 x0.99 x 0.8
Selection	0.9^3x0.95=0.69

Possible Improvements (2008 Data)

Mu-E-Gamma Collaboration

- All numbers in this study are very
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  - Large uncertainty in many parts
- There is some room to improve

(σ)	2008 provisional
Eγ (%)	<2.3
Tγ (ps)	<100
g position (mm)	<5
Pe^+ (%)	1.5–2.0
Te^+ (ps)	<60–90
e^+ angle (mrad)	9 – 18
μ decay vertex (mm)	3 – 4
Teγ (ps)	< 150

- Efficiencies
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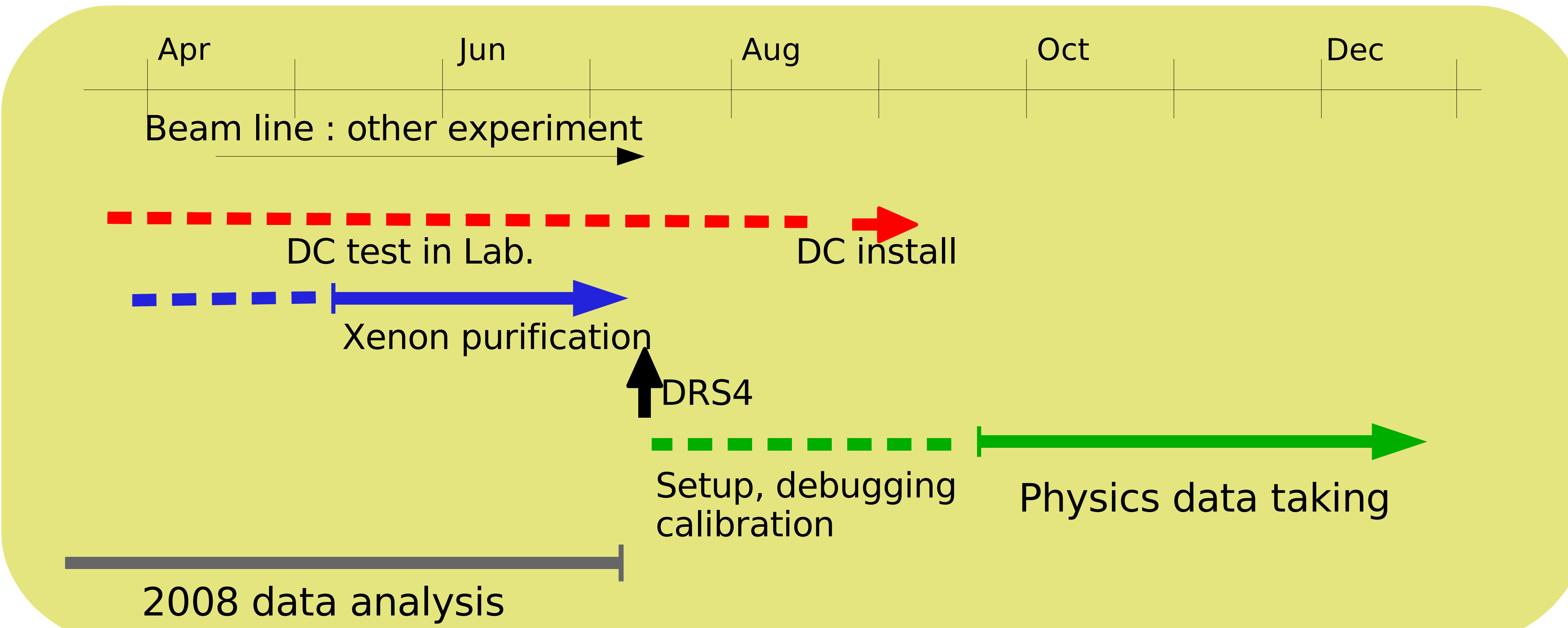
Future Prospect

- Run **2009** will start in September
  - Fix DC problem
  - Optimize run coordination
  - Optimize trigger & DAQ system
  - Introduce new waveform digitizer
  - Perform further LXe purification before the physics run starts

Recover efficiency (applies to the first four items above)



Efficiencies

	2008 provisional	2009 provisional prospect
Gamma	>0.5 x 0.65x0.85	>0.5 x 0.9
e+	(0.3-0.57) x 0.4	0.85 x 0.5
Trigger	1 x0.99 x 0.8	>0.99
Selection	0.9^3x0.95=0.69	0.69
DAQ	0.8 x 0.93	> 0.9 x 0.99
Calibration etc.	~0.7	0.9
Running time (week)	11.5	11.5
S.E.S (10^{-13})	30-50	< 3-5

Our "Goal" of S.E.S ~ 0.5 x 10^{-13}

Resolutions

(σ)	2008 provisional	2009 provisional prospect
Eγ (%)	<2.3	< 1.7
Tγ (ps)	<100	< 80
γ position (mm)	<5	< 5
Pe^+ (%)	1.5–2.0	0.7 – 0.8
Te^+ (ps)	<60–90	60
e^+ angle (mrad)	9 – 18	11
μ decay vertex (mm)	3 – 4	2
$Te^+\gamma$ (ps)	150	100
Background (10-13)		< 0.6 – 3

Uncertainty coming from γ energy scale

Our "Goal" of BG ~ 0.1-0.3

Summary

- In 2008 run, we successfully took various data samples sufficient to evaluate
  - the detector performance
  - the background level
- Clear observation of the radiative decay events in our physics data
  - Important to demonstrates well that we are really sensitive to the $\mu \to e\gamma$ events
- We are still blind to the signal events
  - Analyses are progressing intensively in daily base
  - Analysis result should be ready before this year run starts
- This year's run will start in **September**
  - The year 2009 will mark a significant step forward to the goal of the MEG experiment.
- We need **3 years** to achieve the target sensitivity
  - Continue to run the experiment until the end of 2011

Efficiencies

!! All numbers are provisional !!

MEG
Mu-E-Gamma Collaboration

- Individual components of efficiencies are (being) estimated
  - Large uncertainty. Some of them are likely to be changed
  - Most of them are evaluated with real data

Ω/4π	0.09 (depending on cuts)		
γ	0.28	Detection	0.5
		Analysis	0.65 x 0.85 (Depth cut x pileup)
e^+	0.12-0.23	Reconstruction	0.3 – 0.57 (Selection criteria)
		DC-TC match	0.4
trigger	0.8*	Eγ	>0.99
		Timing	0.99
		Direction match	~0.8*
selection	0.69 (=0.93x0.95, only for box analysis)		
N_μ	9.13×10^{13} μstops		

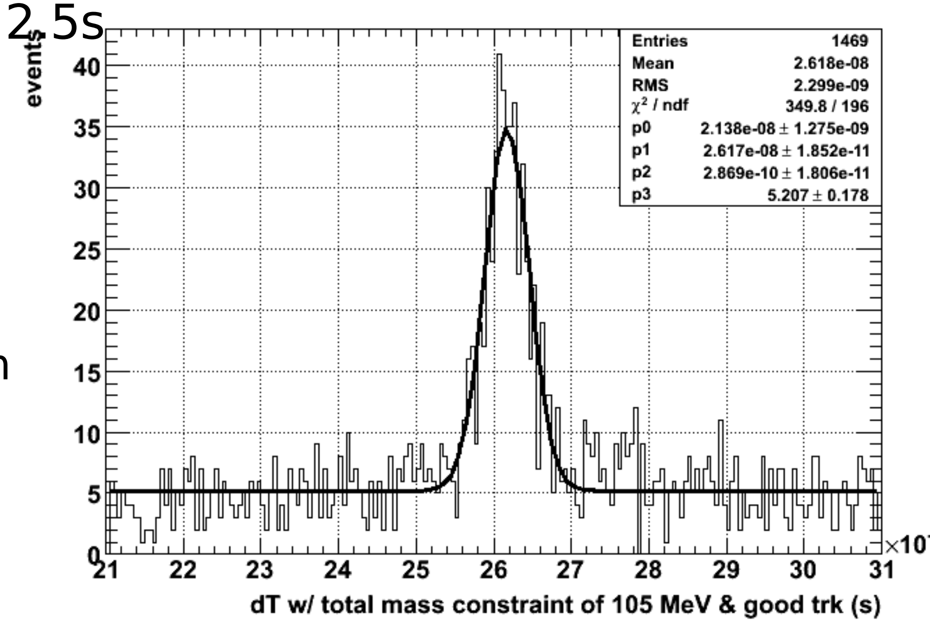
* Recent study indicates this value is overestimate

RD Dedicated Run Analysis

- Dedicated run with lower intensity beam (factor 25)
  - 24H / week
  - Total livetime : 4.88×10^5s
  - Eγ threshold ~25MeV
- Selection criteria
  - Geometrical cuts, track quality cuts, time and energy cuts
  - Kinematical constraint greatly improve S/N (0.83→2.8)

➔ Clear peak !
  - Found 428 RD events on 152 BG in 2.5s

➔ Peak width : 287 ± 18ps (σ)
  - worse resolution
    - Lower γ energy
    - Suffered from time drift over time
      - Change of light yield, waveform
      - Can be corrected



Teγ

Likelihood Analysis

Mu-E-Gamma Collaboration

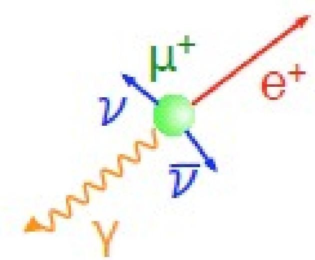
- Final analysis will be done with maximum likelihood fitting

- Maximum likelihood analysis
  - P(xi) = (NsigS(xi) + NRDS'(xi) + NBGB(xi)) / N
  - N = Nsig + NRD + NBG
  - L(Nsig, NRD) = Π(P(xi))
  - Describe detector non-uniformity (position, angle dependence)
    - PDFs for different region
  - Analysis region : +-5σ

Prompt Background Estimation

- Prompt background (radiative muon decay)
- Branching ratio (B_{RD}) can be calculated from theoretical formula
- Rough estimation of B_{RD} with current resolutions
  - $B_{RD} \sim 5.8\times10^{-4}\,(\delta x)^2(\delta y)[\delta x/3+\delta y](\delta z)^2$

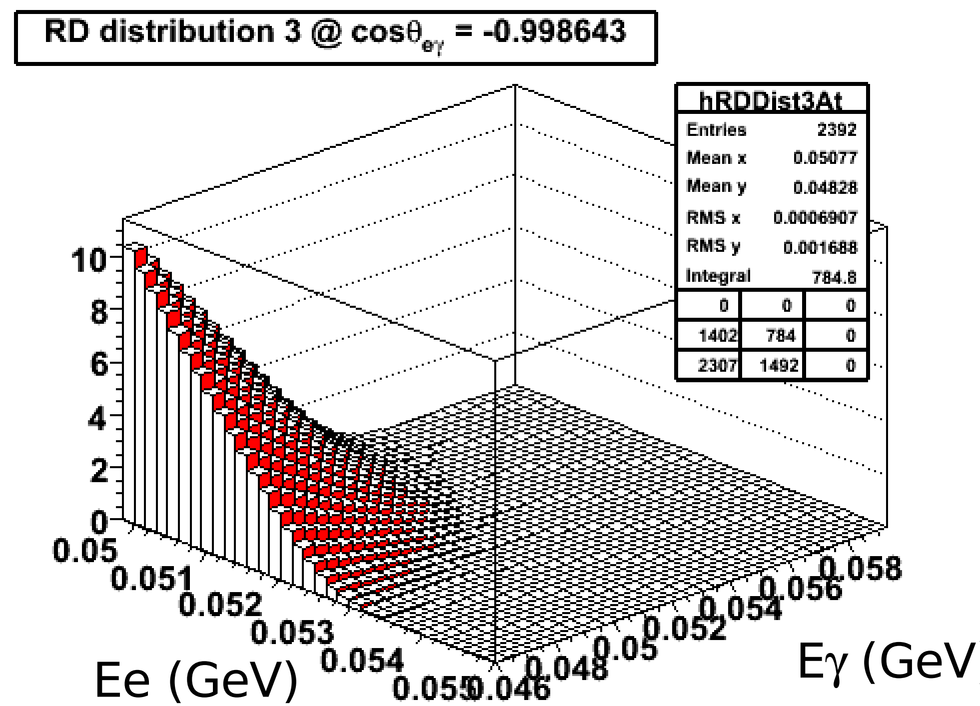
    $= 2.4 \times 10^{-14}$



$x : 2E_e/M_\mu$

$y : 2E_\gamma/M_\mu$

$Z : \pi - \theta_{e\gamma}$

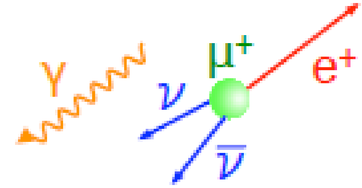


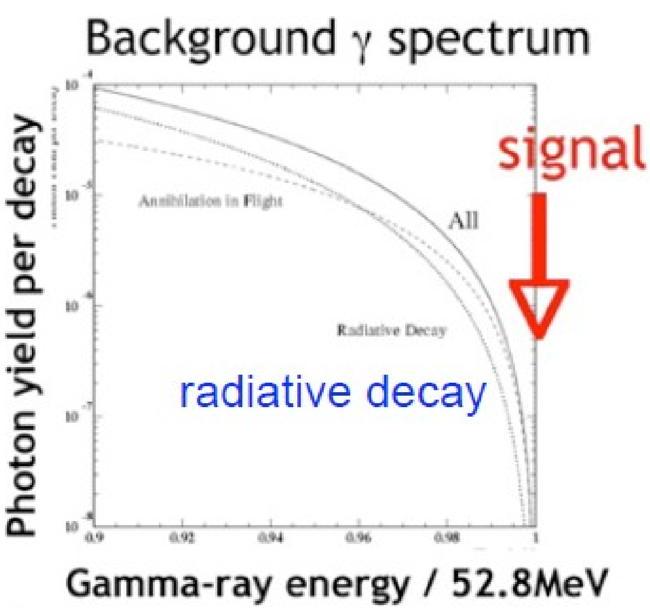
Accidental Background

- Background
  - Can estimate with

$$B_{acc} = R_{\mu} \cdot f_e^{\,0} \cdot f_\gamma^{\,0} \cdot (\delta\omega / 4\pi) \cdot (2\delta t)$$

$= N_\mu$ (DC beam) — Back to back — Time overlap





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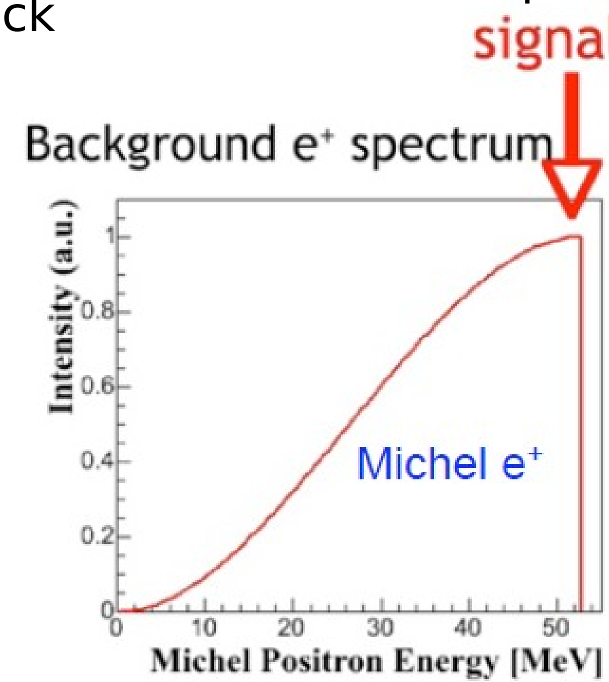
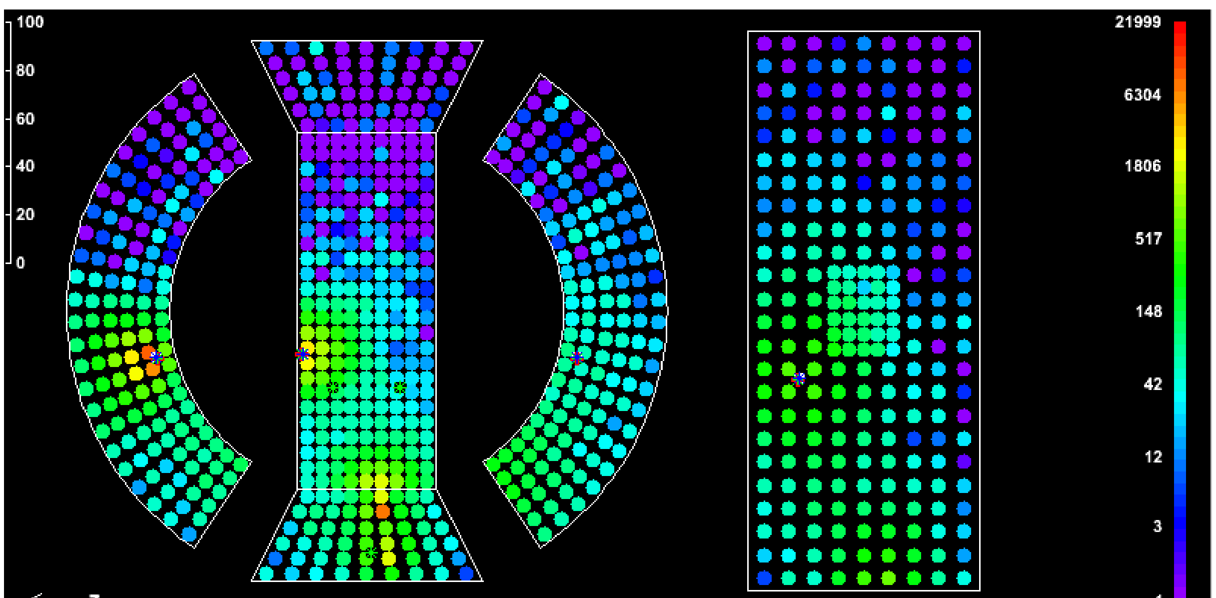


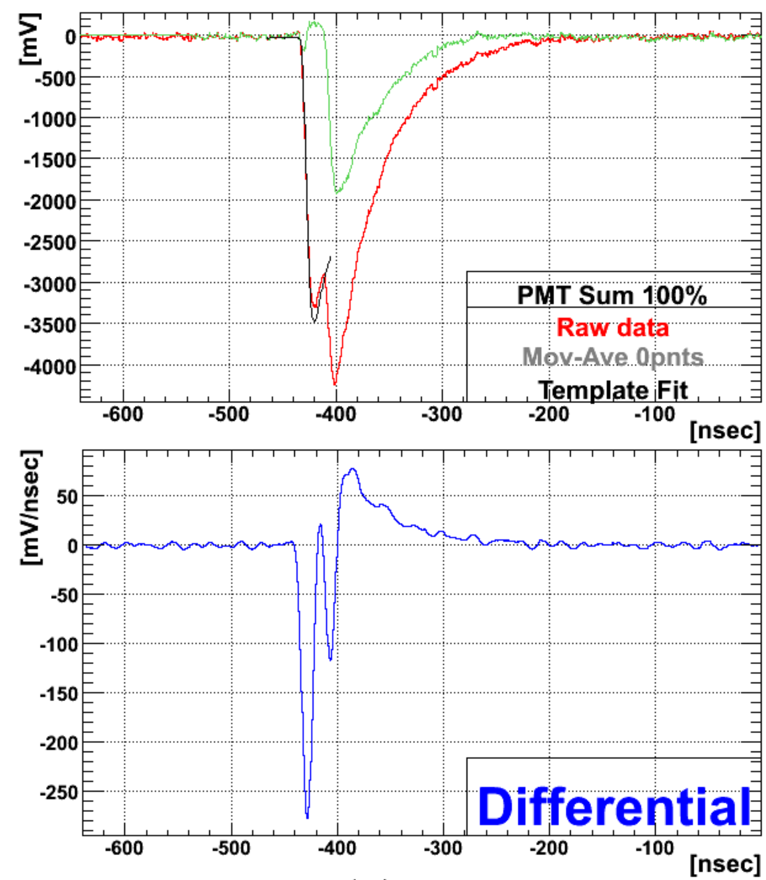
- Accidental background is dominant background source
  - γ ray measurement is most important

Pileup Identification

- Pileup events become dominant background source as increasing beam intensity

- The detector can identify pileup events by
  - Pattern of the light distribution
  - Time difference of every PMT
  - Waveform





MEG : μ → e γ Search Experiment

- Search for Lepton-flavor violating muon decay : $\mu \rightarrow e + \gamma$
  - Clear evidence of new physics beyond the SM
- Expected sensitivity : B.R. ~ 10^{-13}
  - Can improve the present limit two orders of magnitude