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MEG実験用液体キセノン検出器の波形解析による性能評価

東京大学 THE UNIVERSITY OF TOKYO

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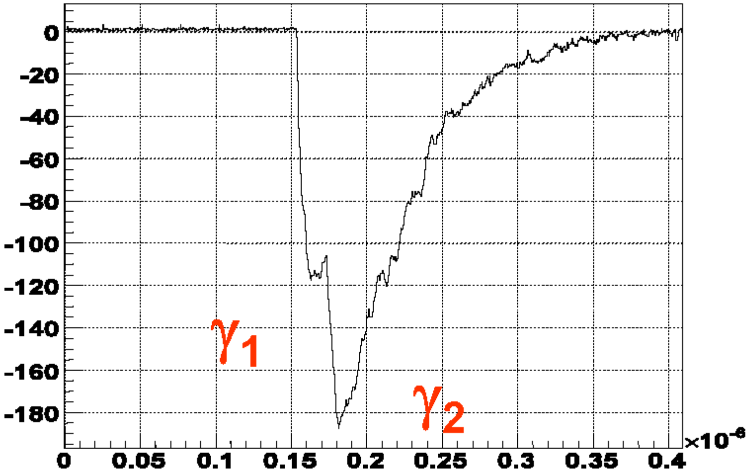
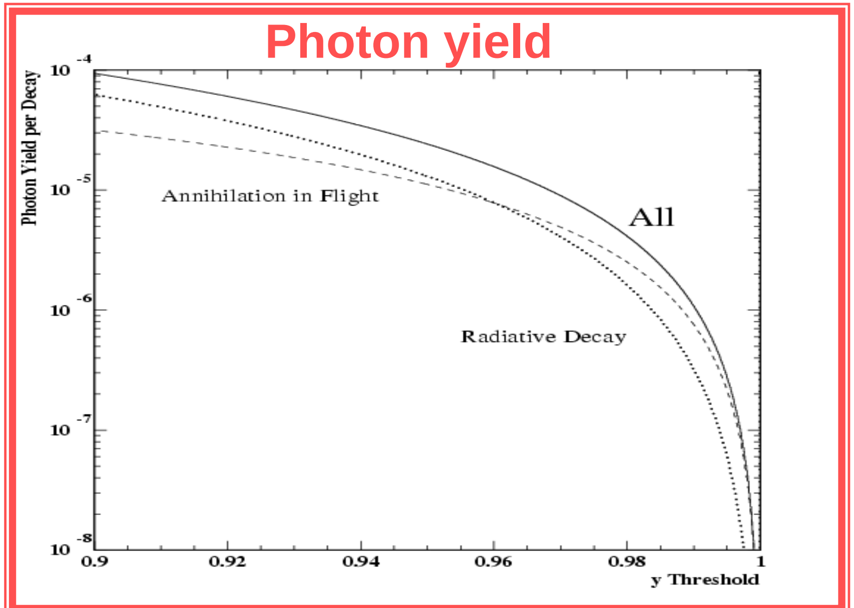
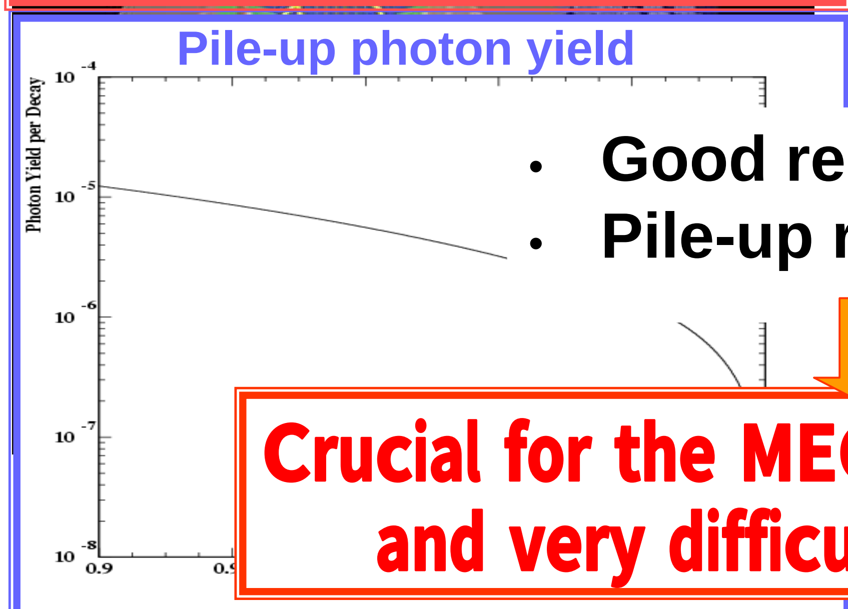
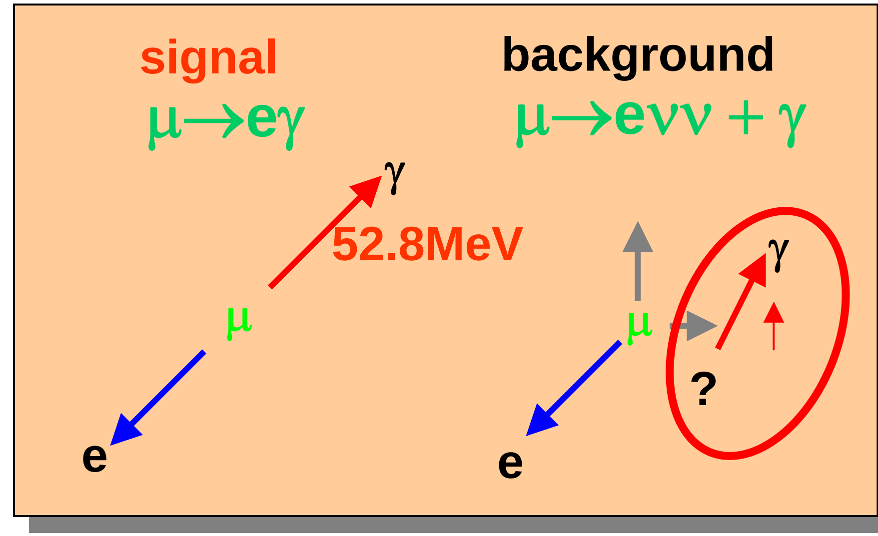


Background & waveform data







Major background

- Prompt background
- Accidental background

→ limit this experiment

- Good resolution
- Pile-up rejection

Unsegmented detector

Crucial for the MEG experiment and very difficult without waveform image

Waveform data

Domino Ring Sampler (DRS)

Developed by **Stefan Ritt**

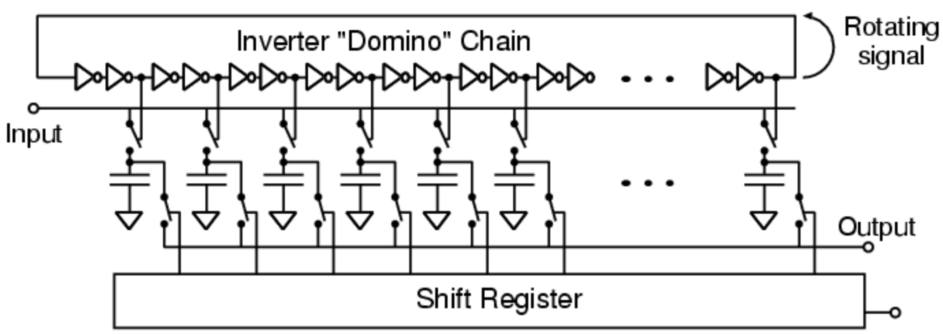
*NIM A **518**(2004) 470*

Analog sampling chip, switching capacitor circuits

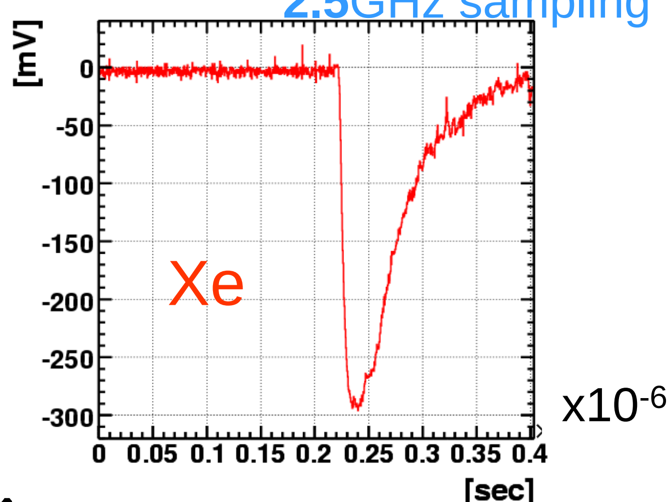
- Max sampling speed **4.5**GHz (required 2GHz)
- Sampling cells **1024**
- Read out speed ~**40**MHz, **12**bits
- Domino wave runs continuously, only stopped by
  the trigger (role of analog pipeline)

Xe waveform data were already taken successfully using prototype detector

We have also already developed waveform simulation successfully.



2.5GHz sampling

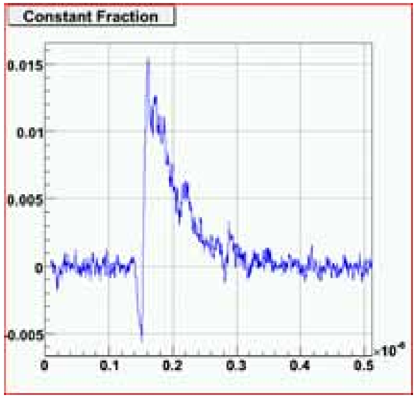


Xe scintillation pulse

Waveform analysis

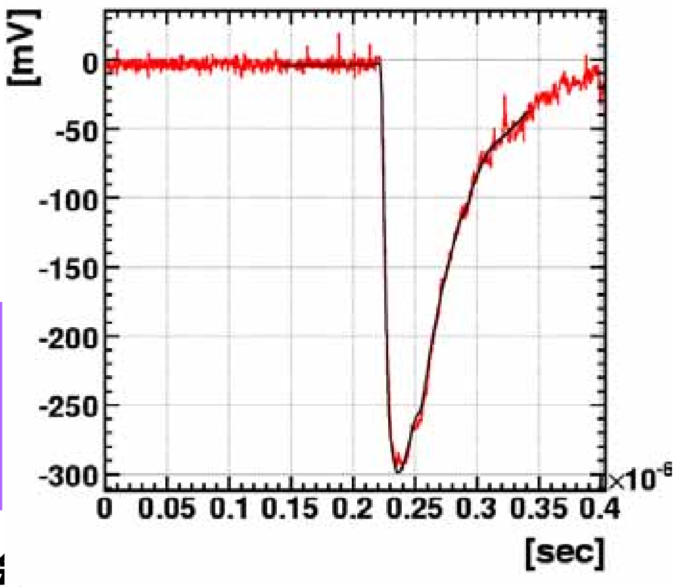
- Baseline
- Charge integration
- Constant fraction timing

Fast analysis



- Pulse fitting using template
  - Baseline, Charge, timing
  - Chi-square

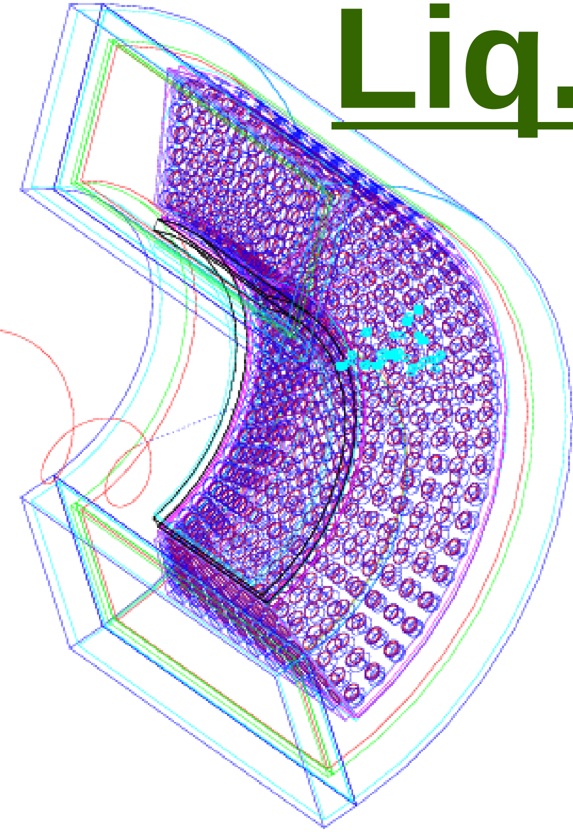
$$\chi^2 = \sum_{i=0}^{N} \left(\frac{y_i - y(x_i)}{\sigma_i} \right)$$



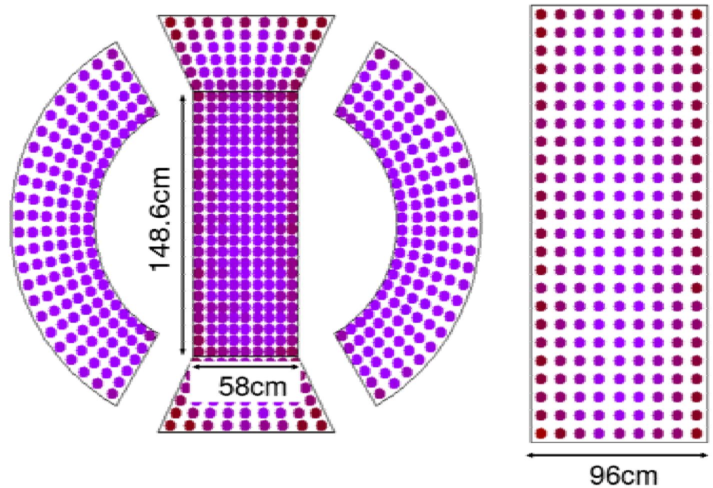
Performance Estimation of MEG γ-ray Detector using Waveform Simulation

- The first estimation
  - Full simulation of the final detector
  - Using waveform
  - Uniform injection for active volume

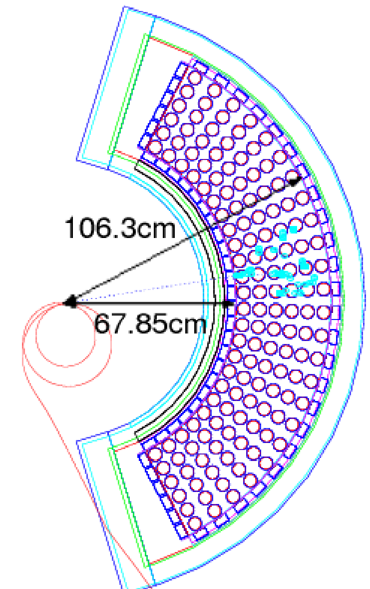
Liq. Xe γ-ray detector



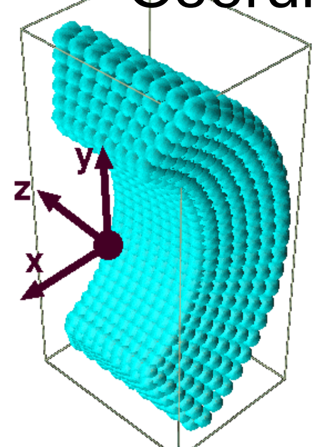
Development view

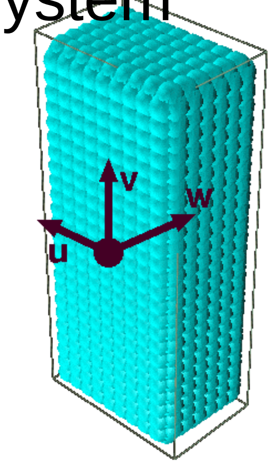


Cross section view



Coordinate system



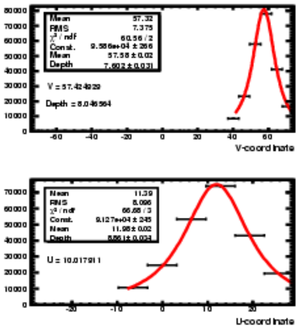


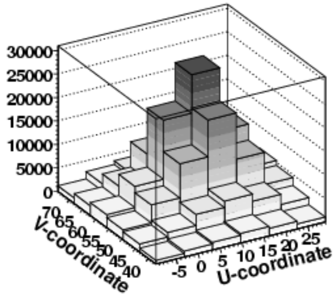
For signal γ-ray(52.8MeV)

- charge from integration
- timing from template fitting (χ^2–fitting)

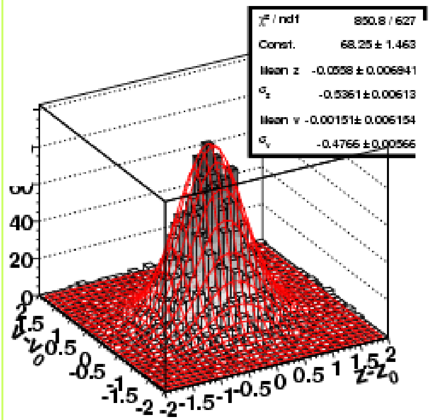
Position resolution

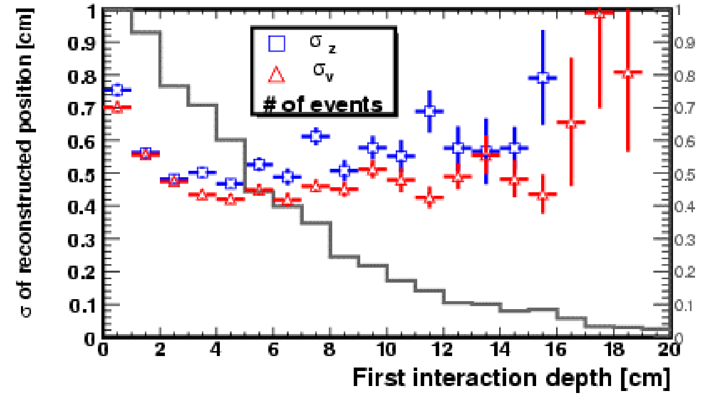
- Simple calculation of solid angle
- Fitting light distribution





$$\psi = \tan^{-1}\frac{x+R_{cath}}{d} - \tan^{-1}\frac{x-R_{cath}}{d}$$



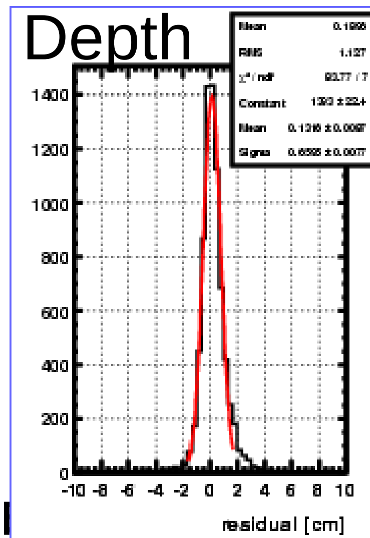


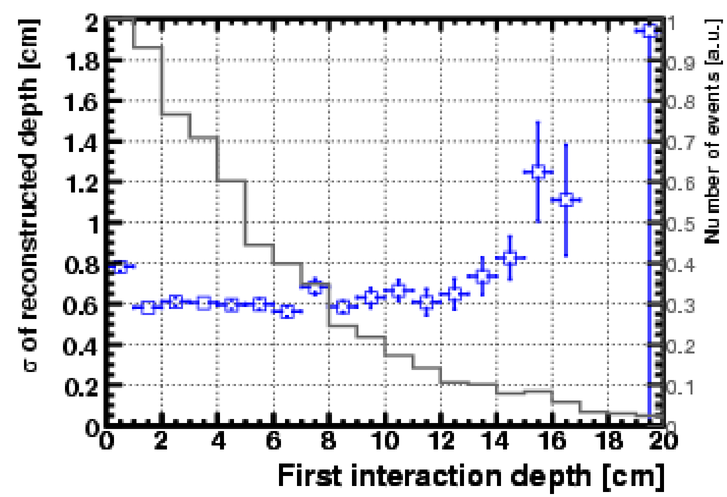
For energy deposit > 50MeV

σ_z=5.4mm
σ_v=4.8mm

σ_w=6.6mm

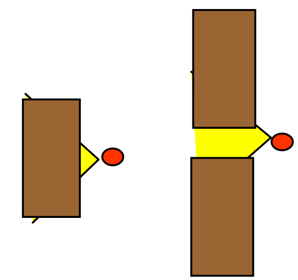
Depth



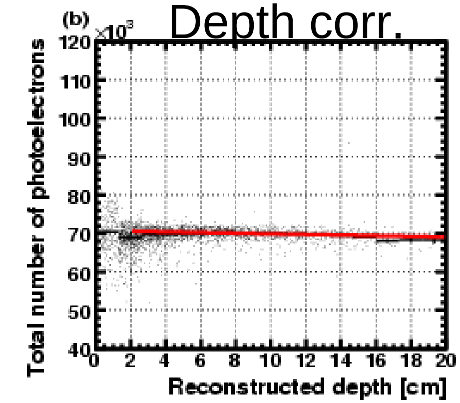


Energy reconstruction

- Sum of charge of all PMTs
- Weighted by density of PMT

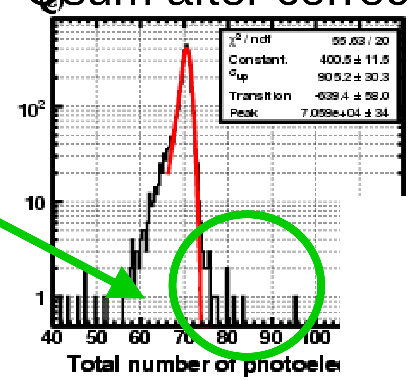


Depth corr.



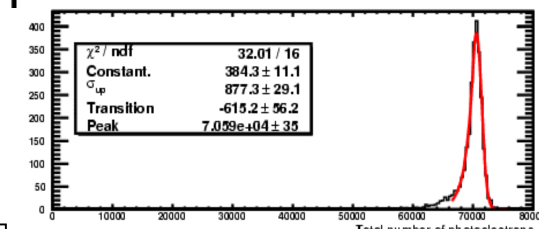
- correction by position
- cut if depth < 2cm (efficiency 81%)

Qsum after correction



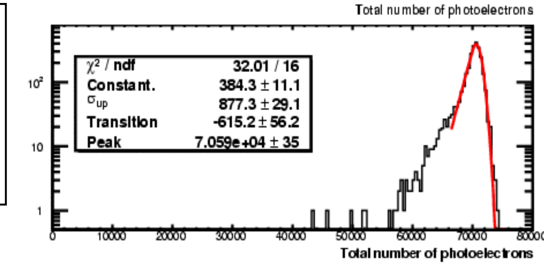
High energy tail is crucial

Light is concentrated on one PMT



Cut events if one PMT observe more than 9000p.e. (efficiency 91%)

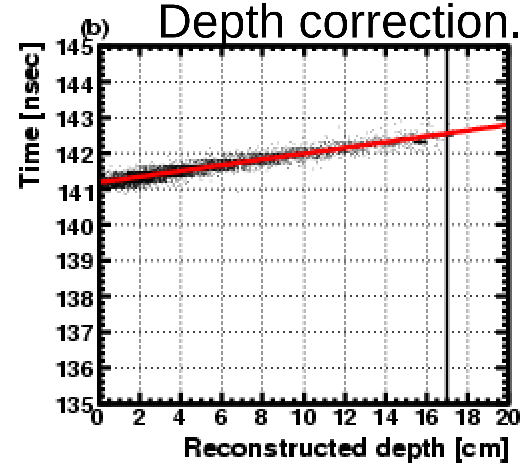
σ_{up}=1.2%
FWHM = 3.1%



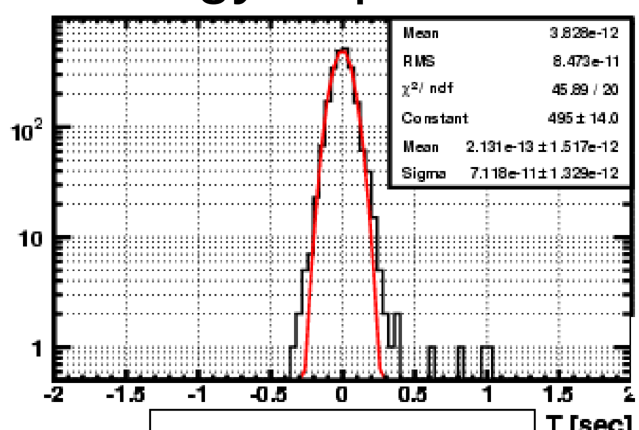
Time resolution

- Average of time of each PMT
- Weighted by square root of $N_{p.e.}$
- $N_{p.e.}$ threshold
- Correction by depth
- Correction by position

Depth correction.

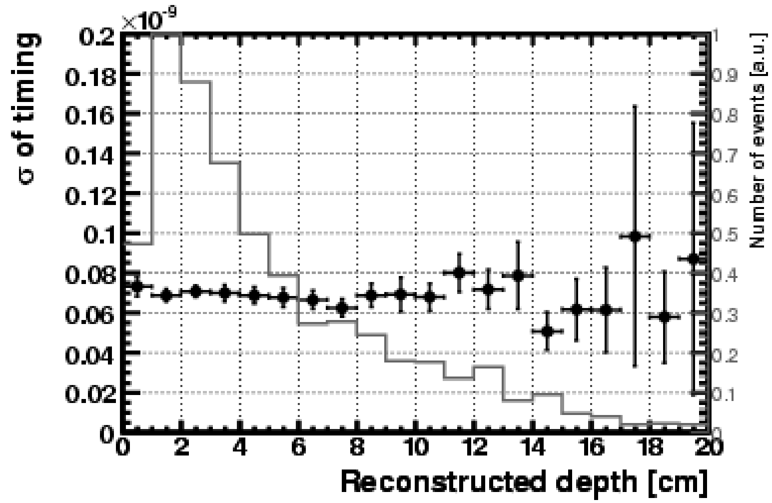


For energy deposit > 50MeV



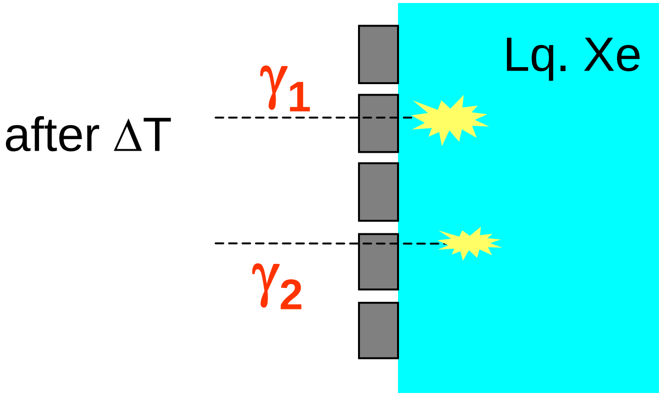
X10^{-9}

σ_t=71psec

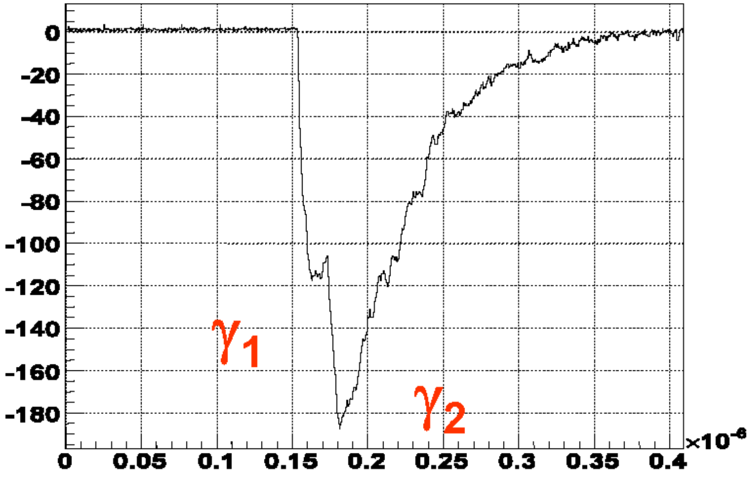


Pile-up rejection

Pile-up event

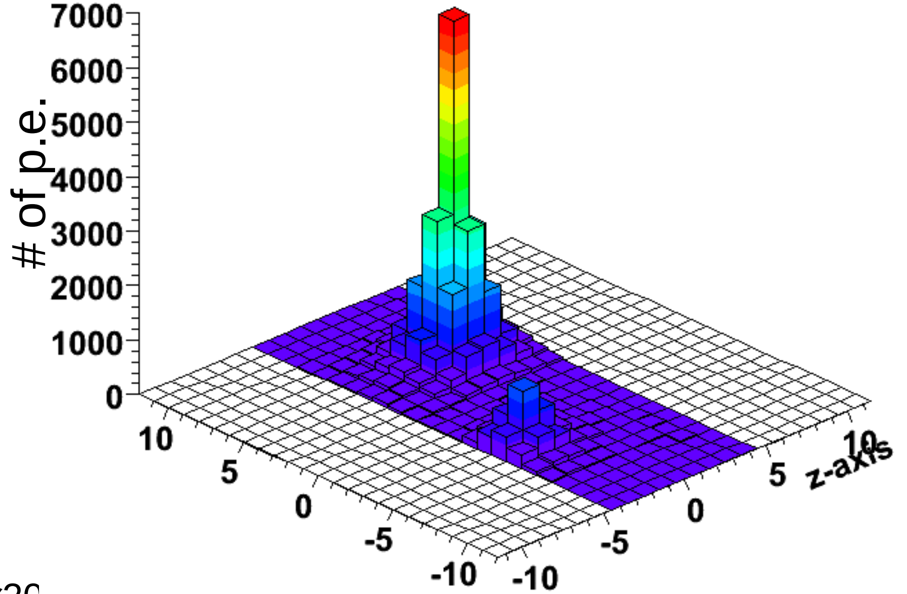


- $\Delta T = t_2 - t_1$
- $E_1 + E_2 = 1$ (signal energy)



1 PMT output

2000p.e. + 1600p.e., ΔT = 20nsec



deposit energy = 42.26MeV + 10.57MeV

0.8 + 0.2

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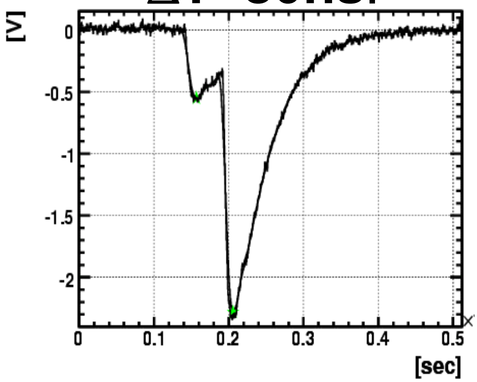
Pile-up Analysis

- Time separation
  - Use time distribution of each PMT
  - When gammas are away both in time & space.
- Waveform analysis
  - When gammas are close spatially.
- Pattern recognition
  - When gammas incident at the same time.
  - Two gammas from AIF

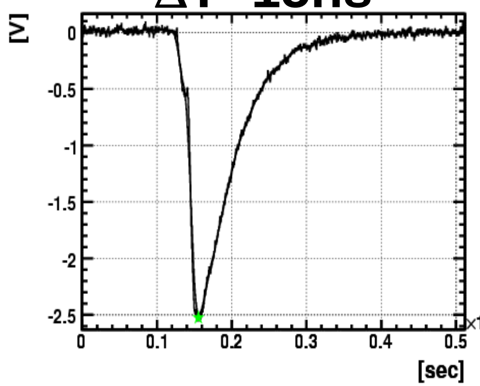
Pile-up rejection by waveform

Peak search method

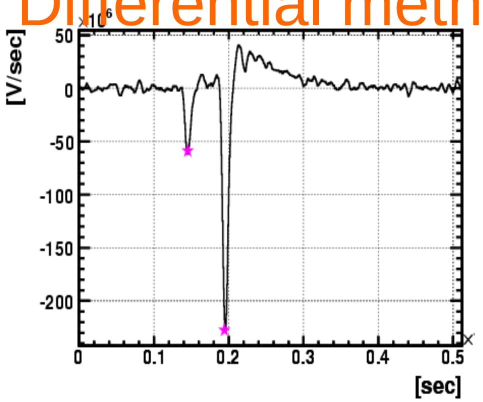
ΔT=50ns.

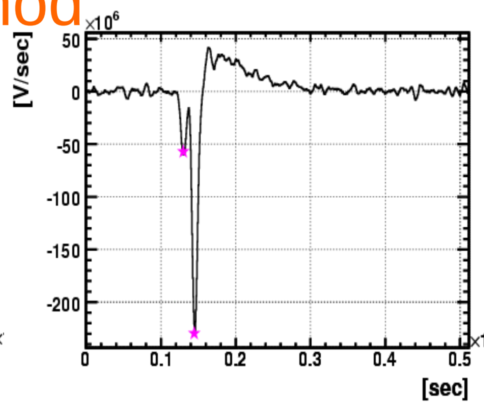


ΔT=15ns

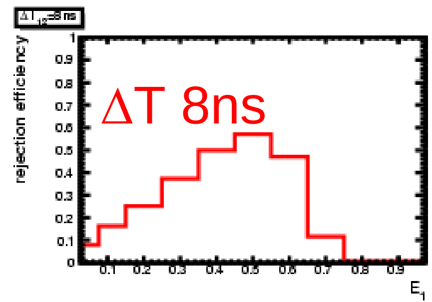


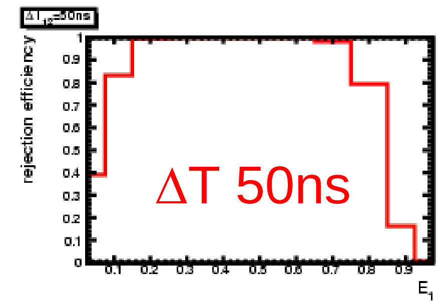
Differential method

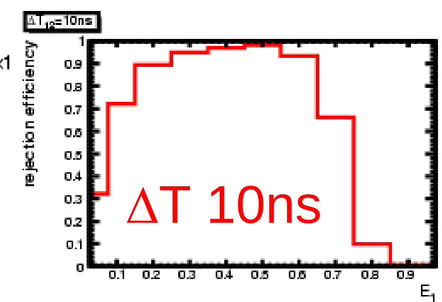


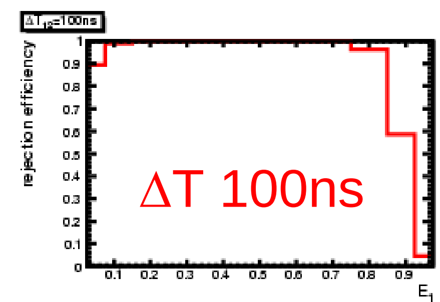


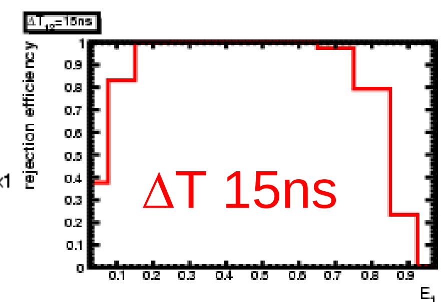
11MeV + 42MeV









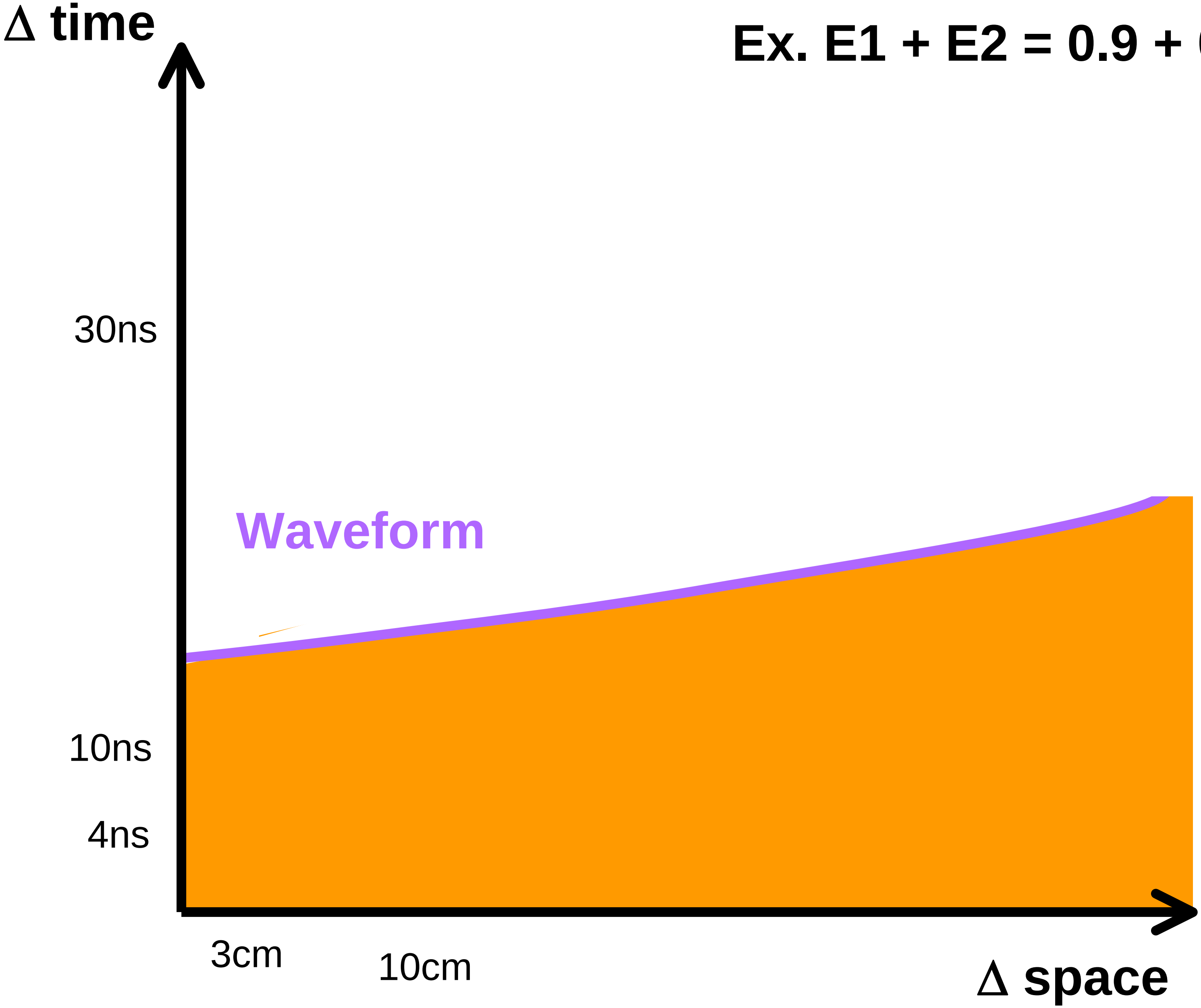


Weak point
- ΔT less than 10nsec
- Small pulse after large one

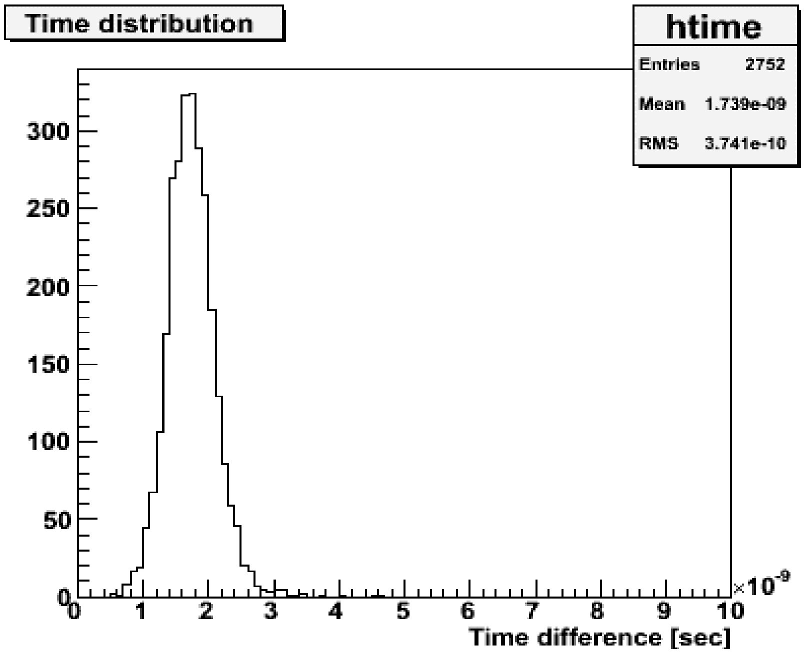
Misidentification probability

< 0.05%

Ex. E1 + E2 = 0.9 + 0.1



Pile-up rejection by timing



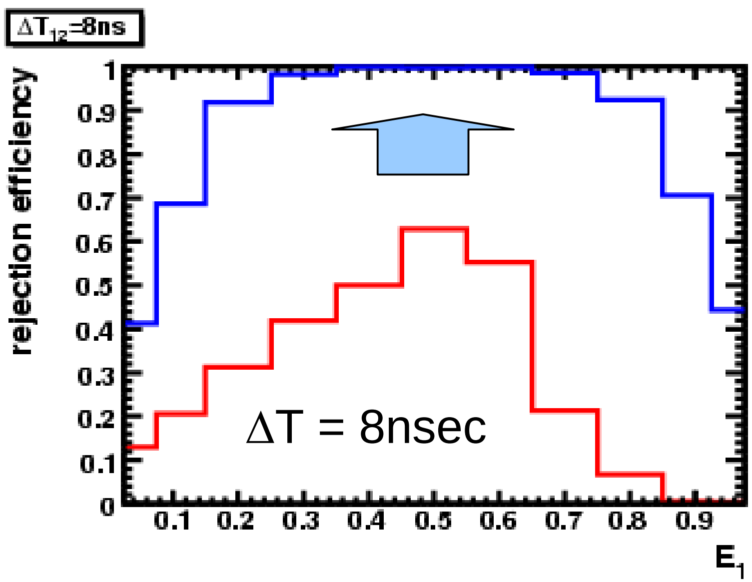
Maximum time difference between PMTs

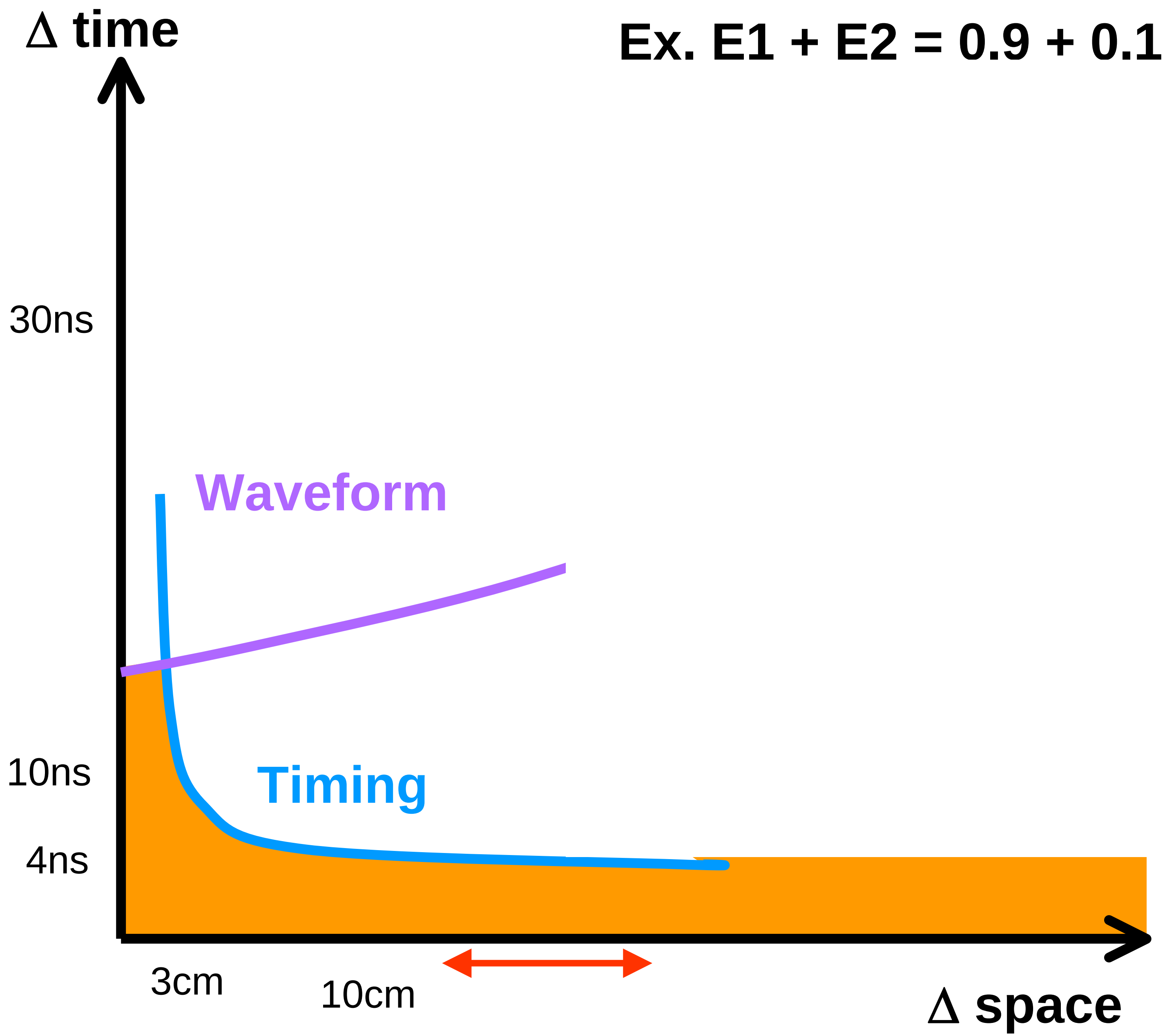
Can close up to 3~4 nsec

Assume,

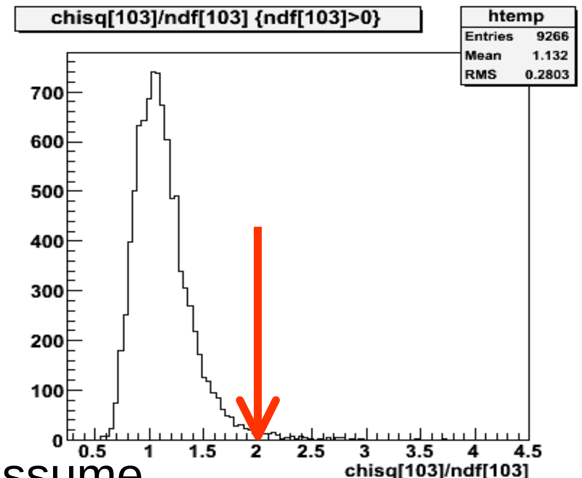
If time difference > 4nsec, then that event is pile-up event.

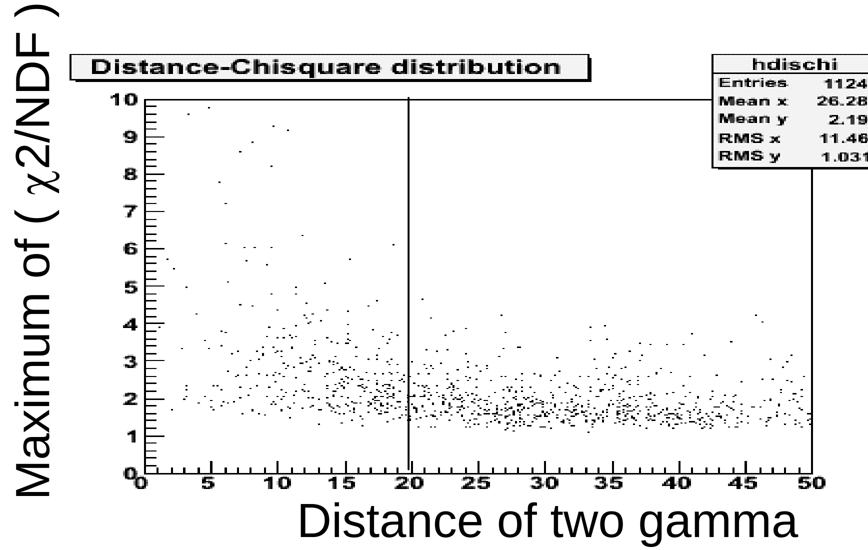
Miss ID probability : 1.0%




Δ time
Ex. E1 + E2 = 0.9 + 0.1
30ns
Waveform
10ns
Timing
4ns
3cm
10cm
Δ space

Pile-up rejection using $\chi2$





Assume,

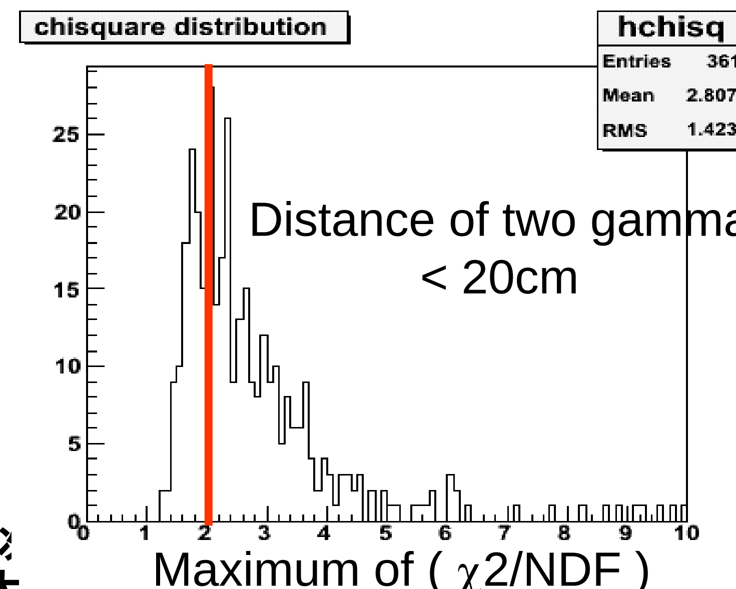
If $\chi2$/NDF > 2,
then that event is pile-up event.

Miss ID probability ： 3.7%

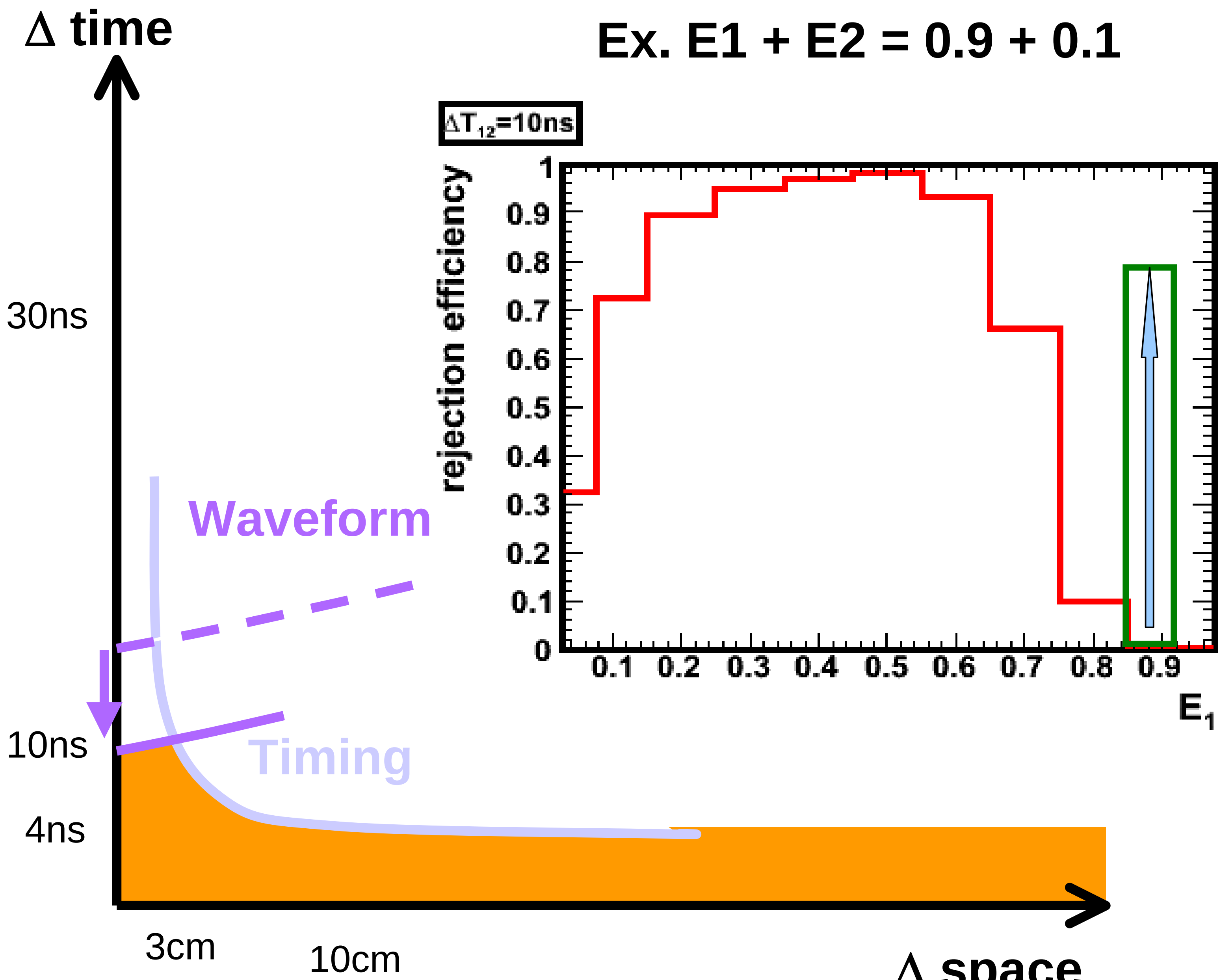
0.9 + 0.1 = 1 (E1 + E2 = Esignal)

Δt = 10nsec

Rejection efficiency ： 72.3%

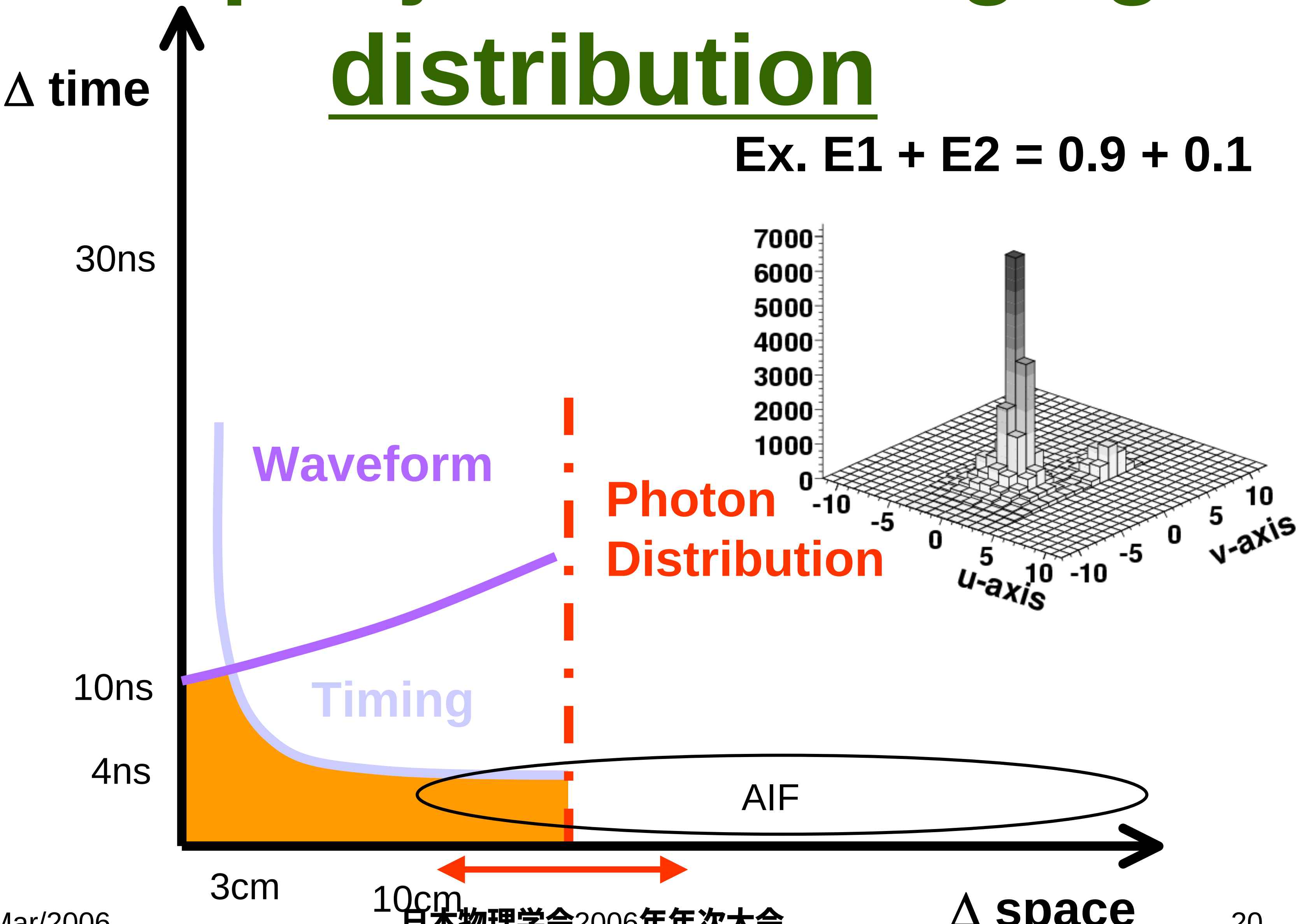


Ex. E1 + E2 = 0.9 + 0.1



Δ time
30ns
10ns
4ns
3cm
10cm
Δ space
Waveform
Timing
ΔT12=10ns
rejection efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
E1

Pile-up rejection using light distribution

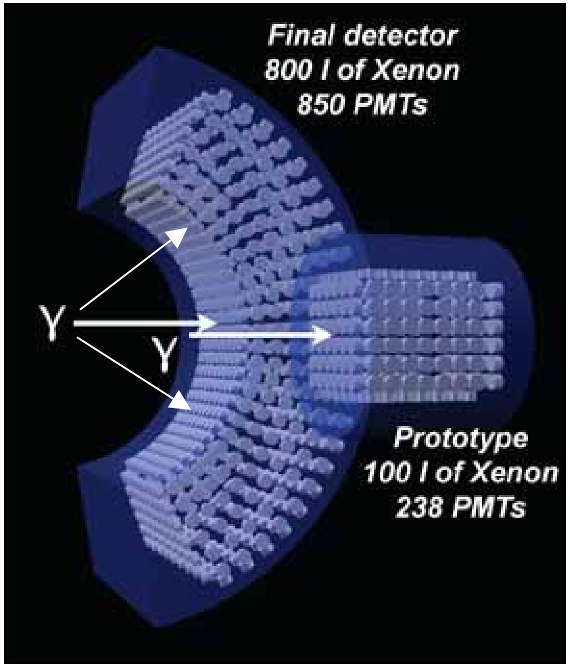


Summary

- Performance estimation was done using simulated waveform
- Able to get performance estimated from prototype detector (a bit worse)

• new geometry (C-shape)
• waveform data
• randomly injection

- Large improvement in pile-up rejection



	Prototype beam test	Simulation
position	4mm	5mm
energy	1.3%	1.2%
timing	65psec	71psec

(sigma)

Summary

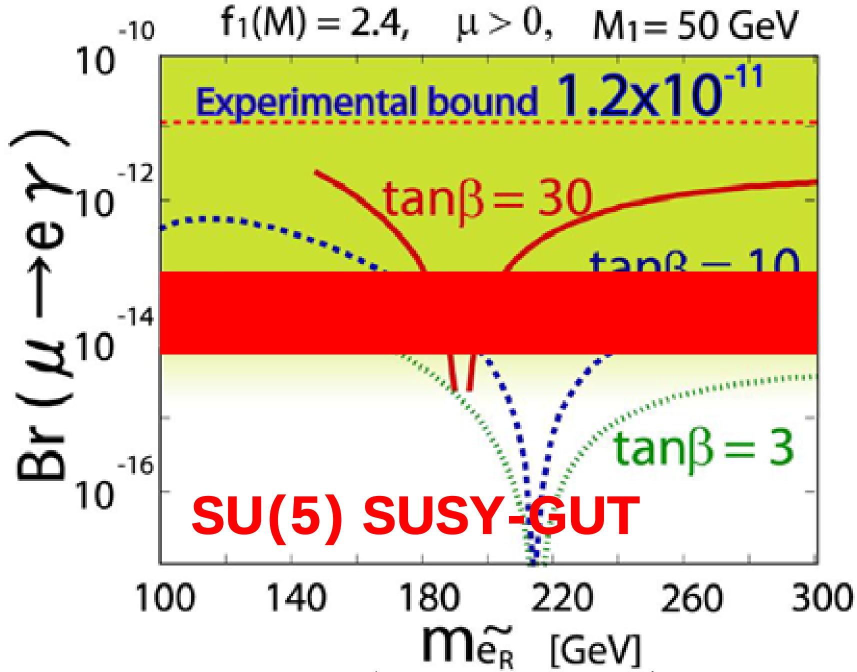
- It is important to develop the algorithm appropriate for the design of final detector
- Pile-up rejection by light distribution
- Preparation to analyze real data

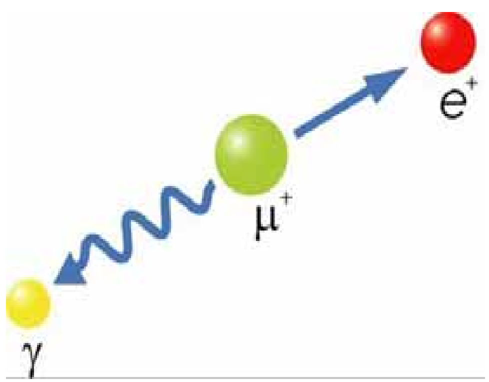
Data taking will start in this year

<u>End of slides</u>

Physics motivation

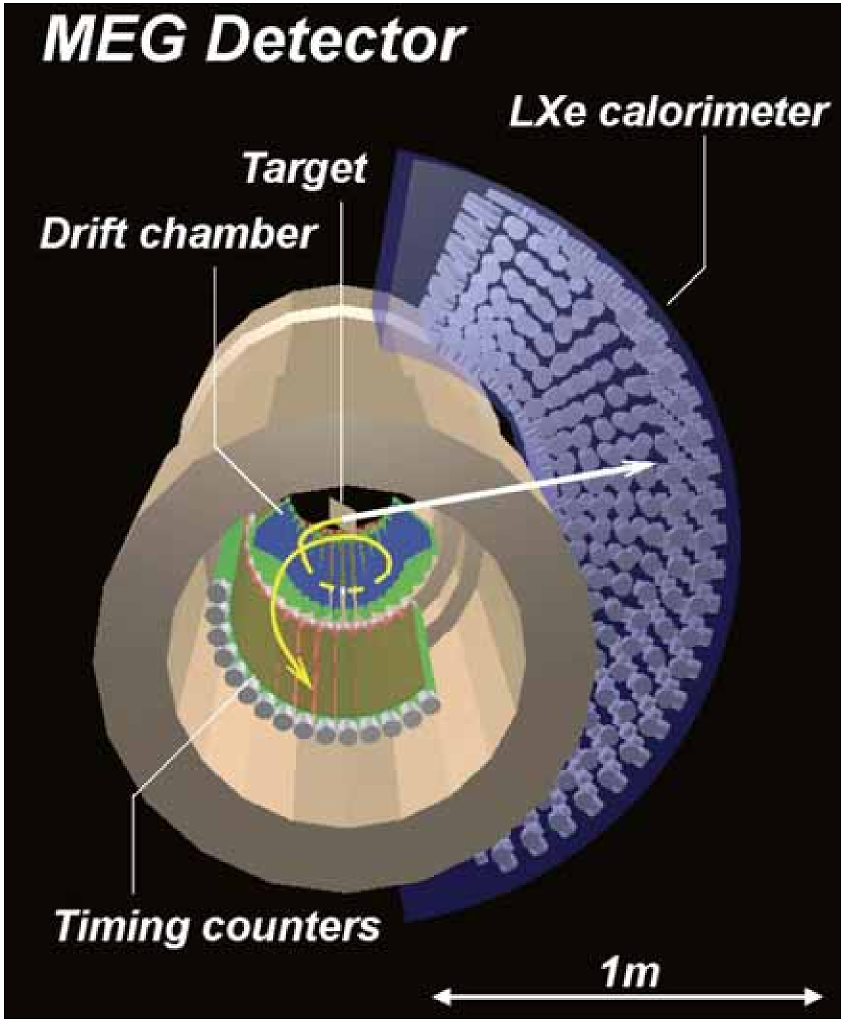
- Lepton Flavor Violation **過程**
- minimal SM**では禁止されている**
- Sensitive to the new physics
  - SUSY GUT
  - SUSY seesaw, etc





- SM**によるバックグラウンドがない**
- Clear 2-body kinematics
  - Ee = Eγ = 52.8 MeV
  - Back to back
  - Time coincidence

MEG experiment



Approved in 1999,
at Paul Scherrer Institut
Physics run in **2006**
Initial goal at 10^{-13},
finally to 10^{-14}

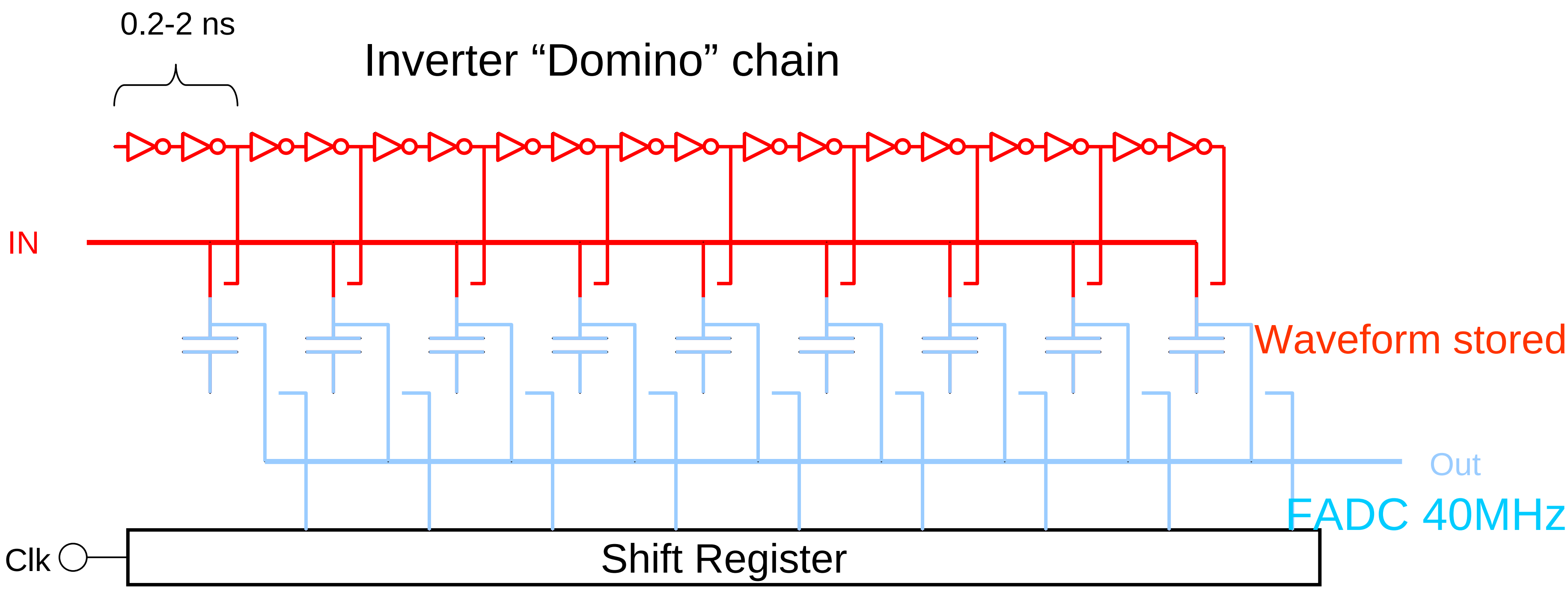
μ^+ beam :
世界最大強度 DC Beam $10^8\ \mu^+$ /s

γ detector :
800liter **液体キセノン**
シンチレーションン検出器
850 PMTs

→ 波形データ

e^+ detector :
勾配磁場をつくる超伝導
ソレノイドマグネット (COBRA)
Drift chamber system
Timing counter

DRS principle



“Time stretcher” GHz → MHz

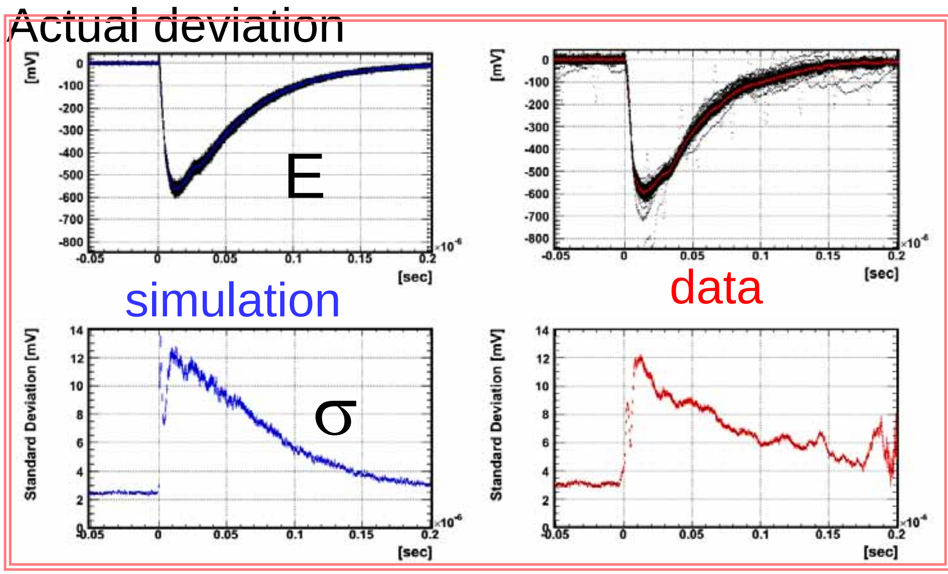
Error of pulse shape

- Basically consider the statistical error of photoelectrons.

  → $\propto \sqrt{E}$

- Have to take care of the correlation between point and point.

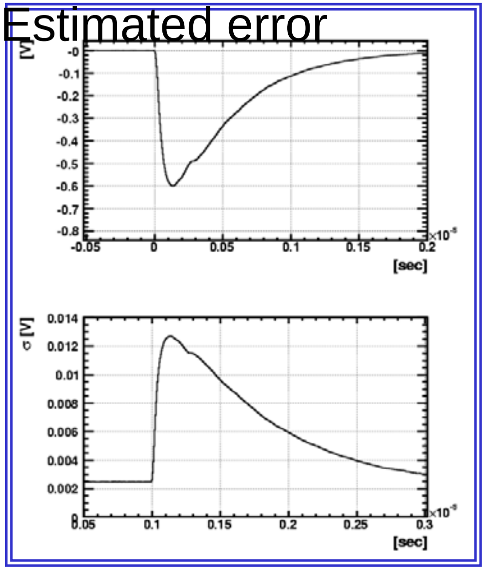
  → **Some kind of scale factor**(like fano factor)



- Choose this factor from the effect of shaping of the system

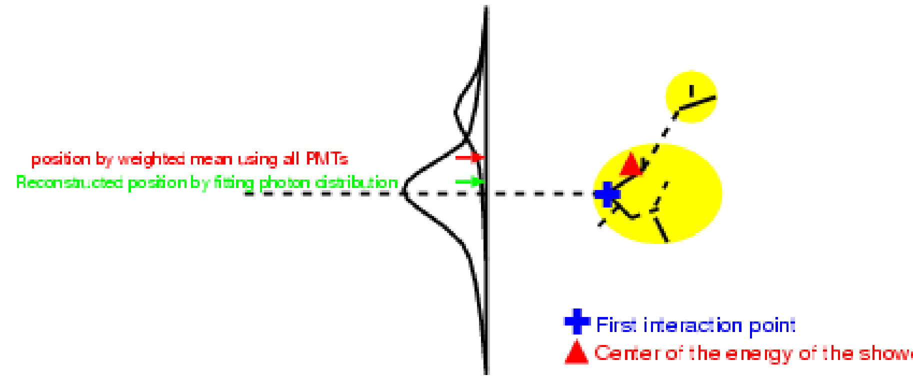
$$\sigma_i = \sqrt{(\sigma_{stat})_i^{\ 2} + (\sigma_{noise})_i^{\ 2}}$$

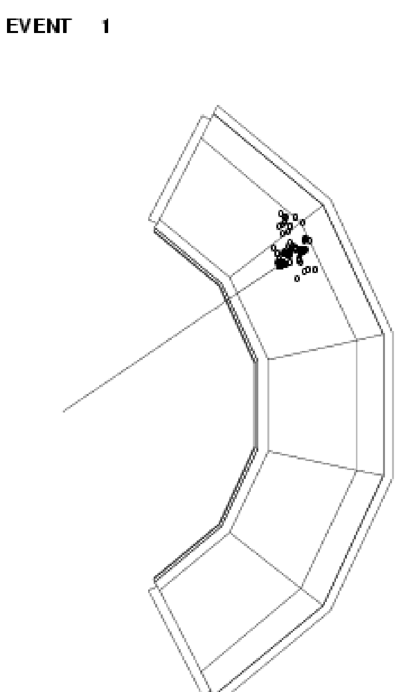
$$(\sigma_{stat})_i = \frac{R*e*G}{\Delta t} \times \sqrt{(N_{p.e.})_i} * \frac{1}{\sqrt{M}} = \boxed{A\sqrt{E_i}}$$

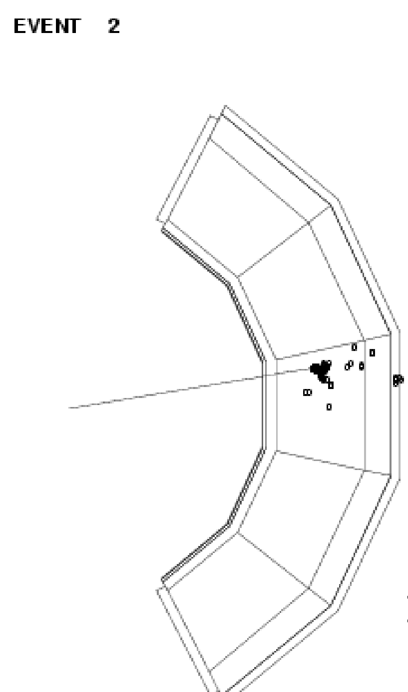


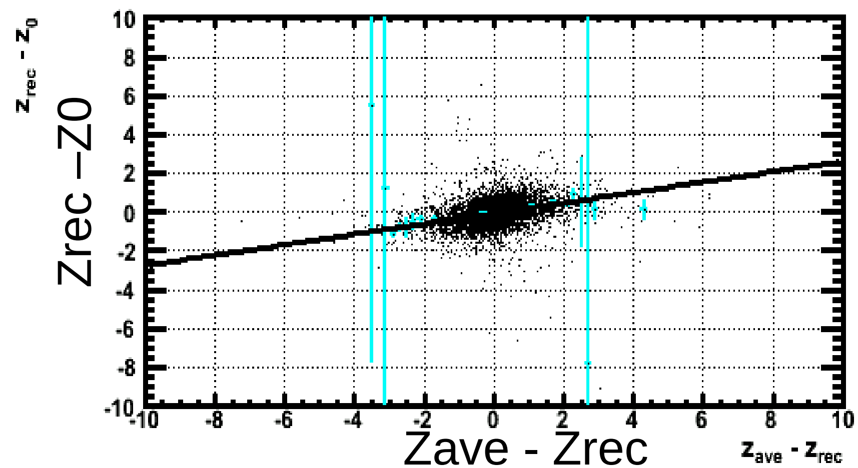
Shower estimation

- Reconstruction of 1st interaction point is affected by spread of shower
- Center of light would reflect the effect





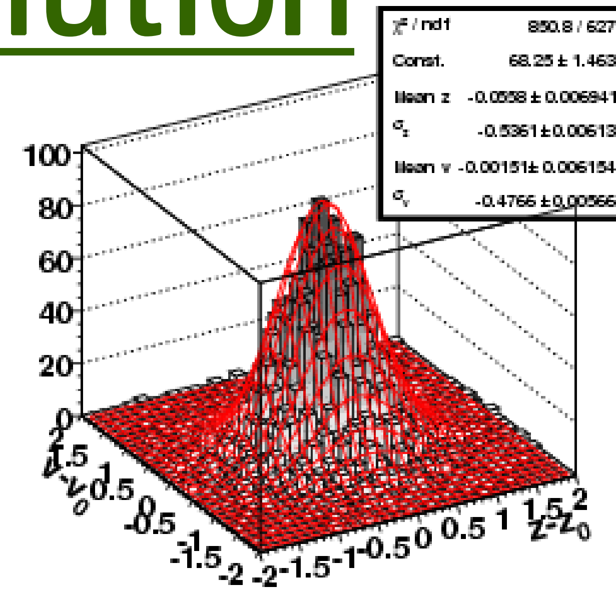




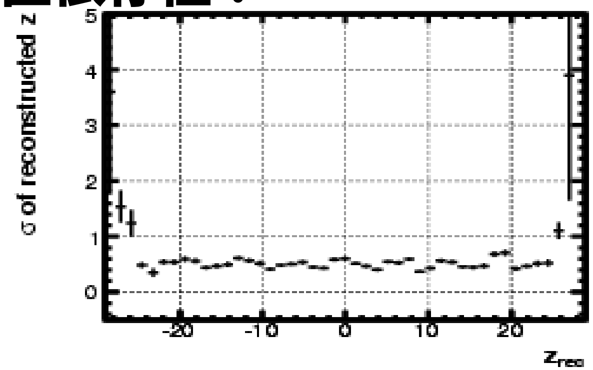
Position resolution

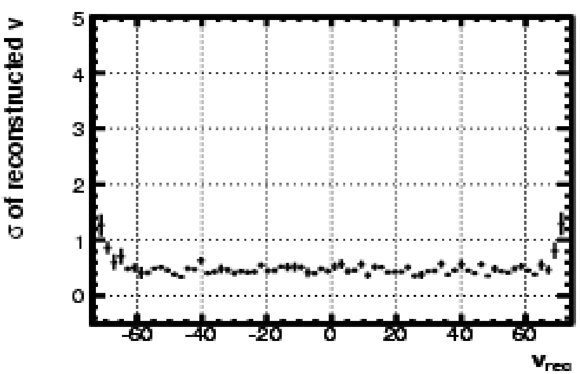
Energy deposit > 50MeVに対して

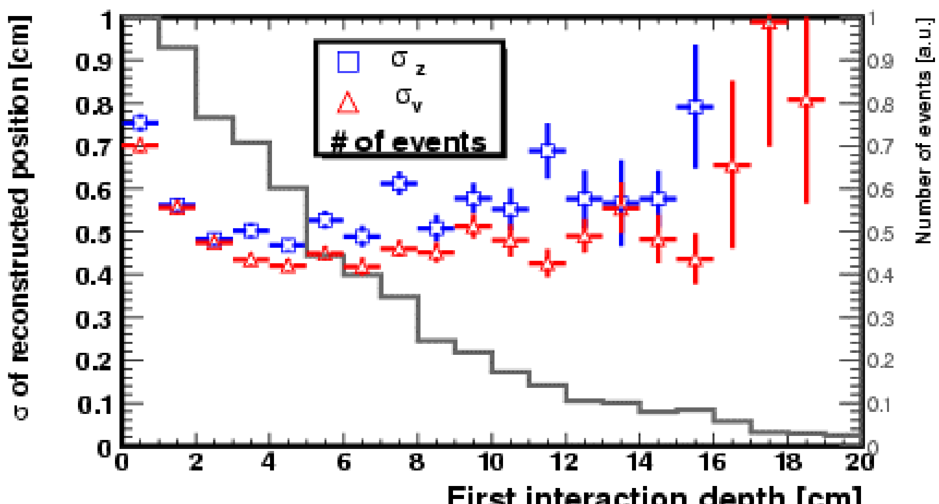
σ_z=5.4mm
σ_v=4.8mm



位置依存性？

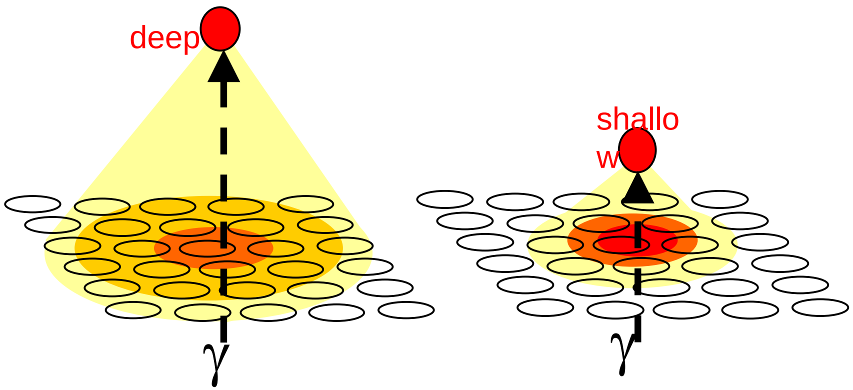




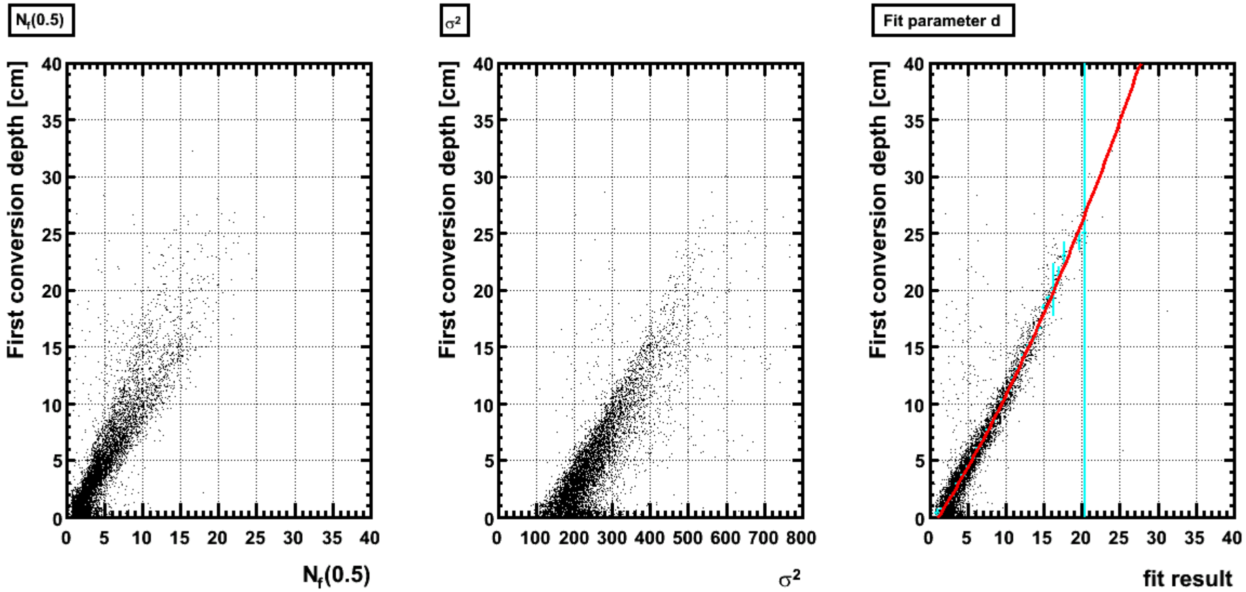


Depth reconstruction

- Depth parameter
  - σ^2
  - Nf(0.5)
  - Fit parameter d

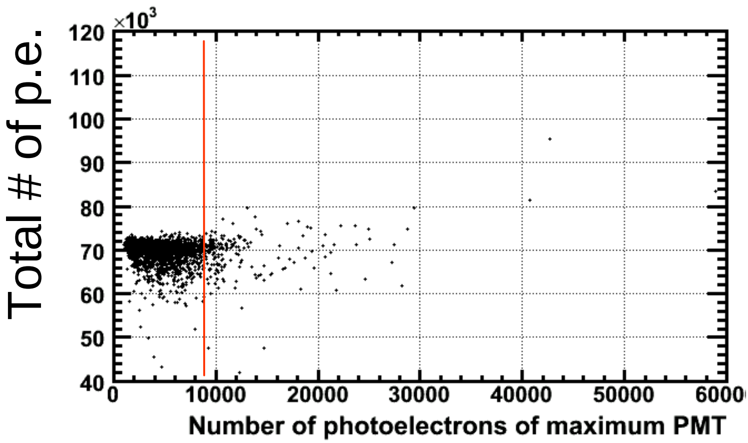


$$\psi = \tan^{-1}\frac{x+R_{cath}}{d} - \tan^{-1}\frac{x-R_{cath}}{d}$$



Fitting light distribution is suitable for the final detector

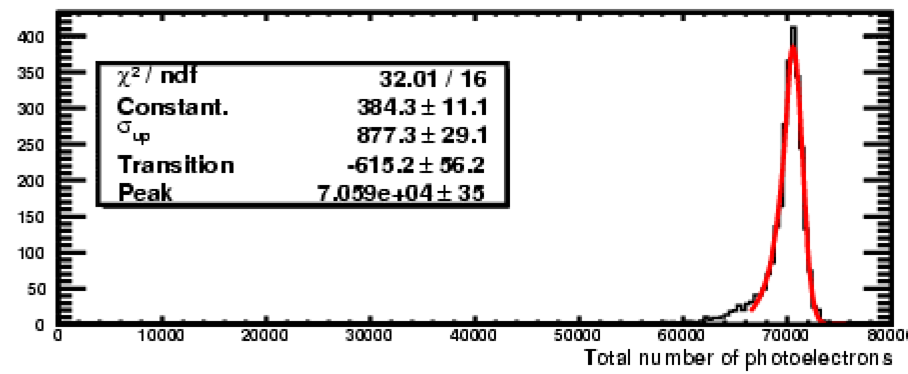
Energy resolution

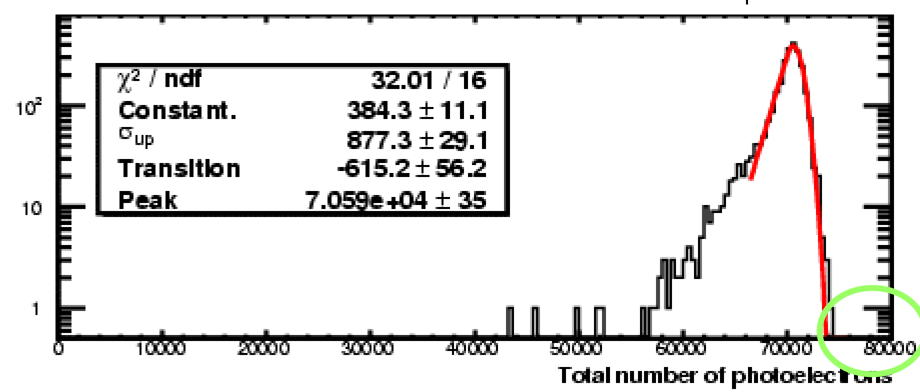


Event in high energy tail are seen when light is concentrated on one PMT

Cut events if one PMT observe more than 9000p.e. (efficiency 91%)

σ_{up}=1.2%
FWHM = 3.1%



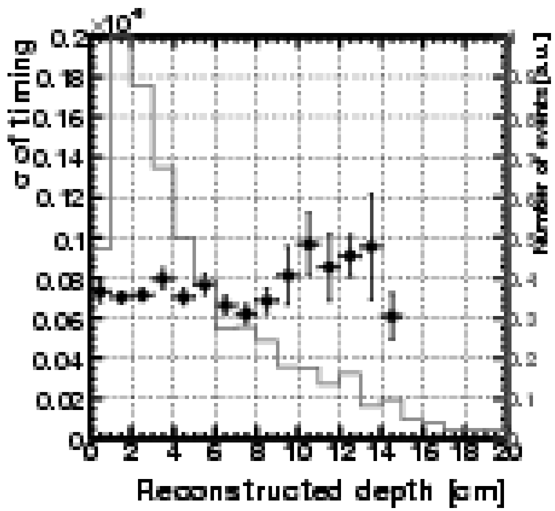


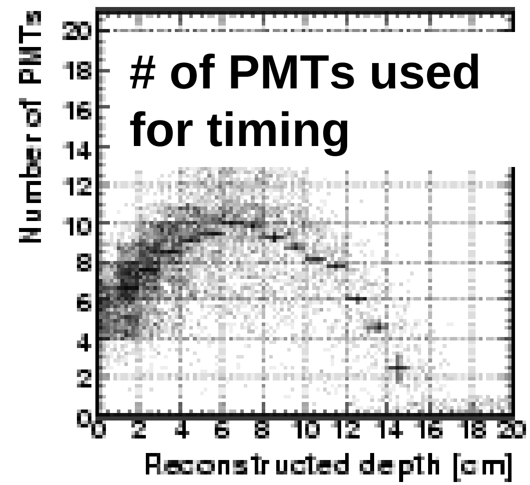
No events

Time resolution

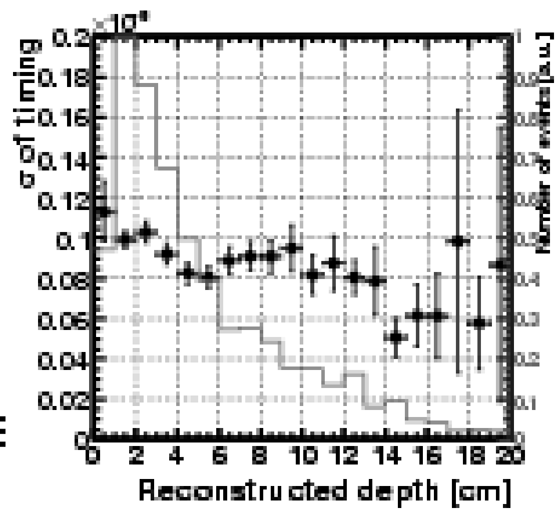
- Shallow event
  - High threshold for Np.e.
  - Inner face only
- Deep event
  - Low threshold
  - Use all faces

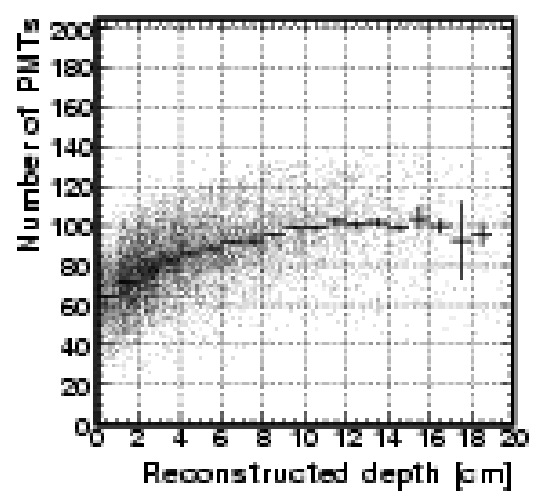
• p.e. > 1100 PMT (inner face)



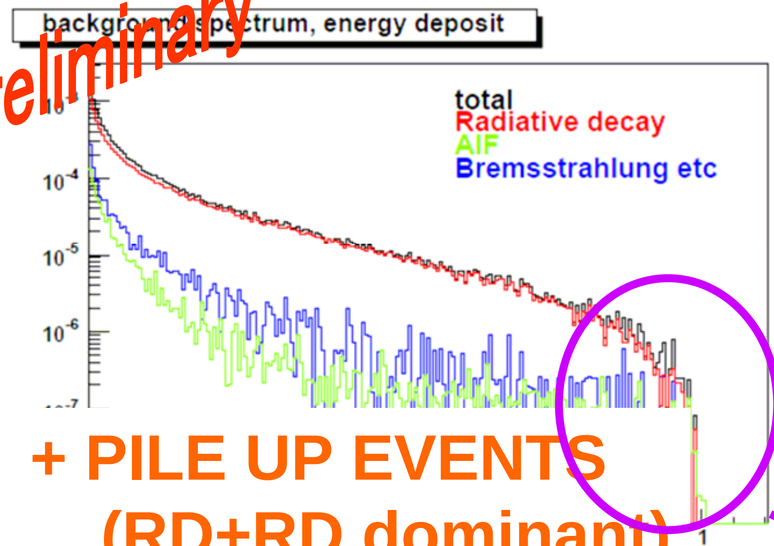


• p.e. > 100 PMT (all faces)



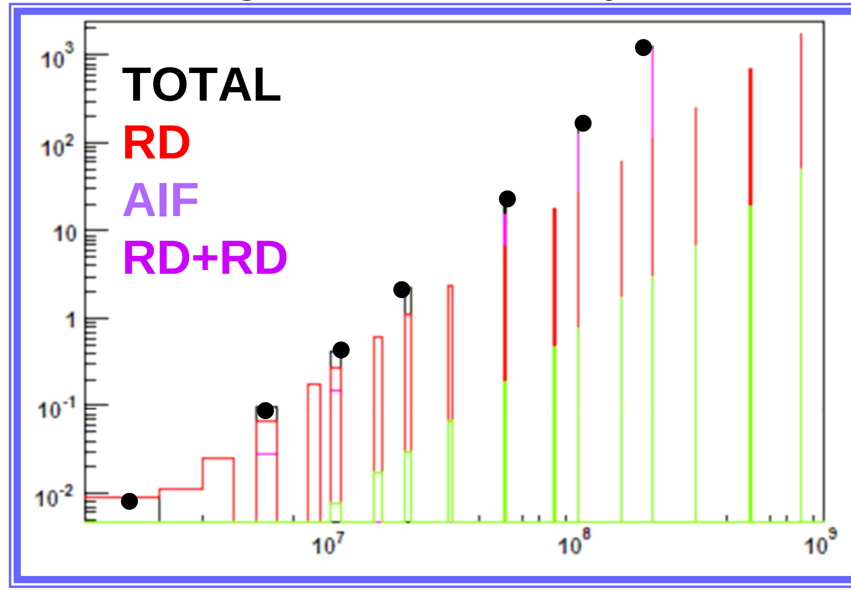


Background

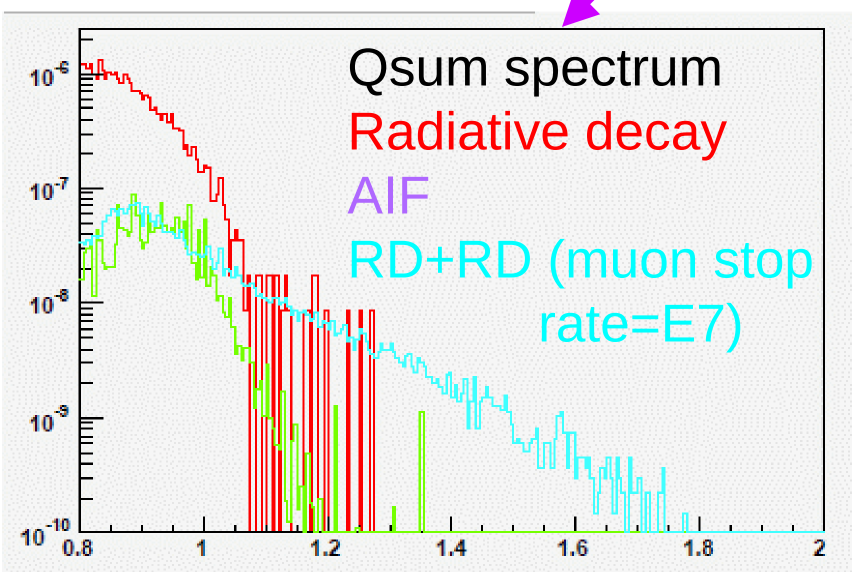


+ PILE UP EVENTS
(RD+RD dominant)

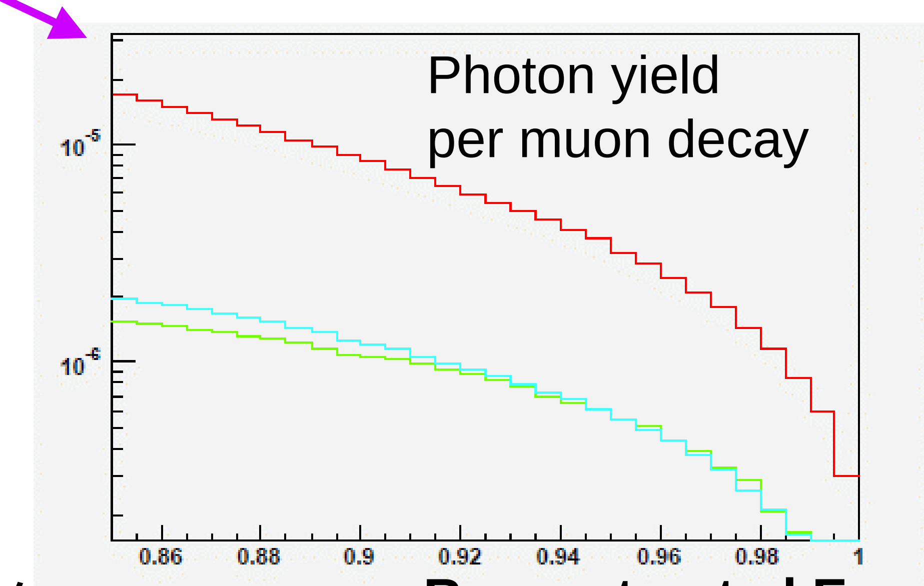
# of Background events, 2 years RUN



Muon stopping rate [/sec]



Reconstructed E

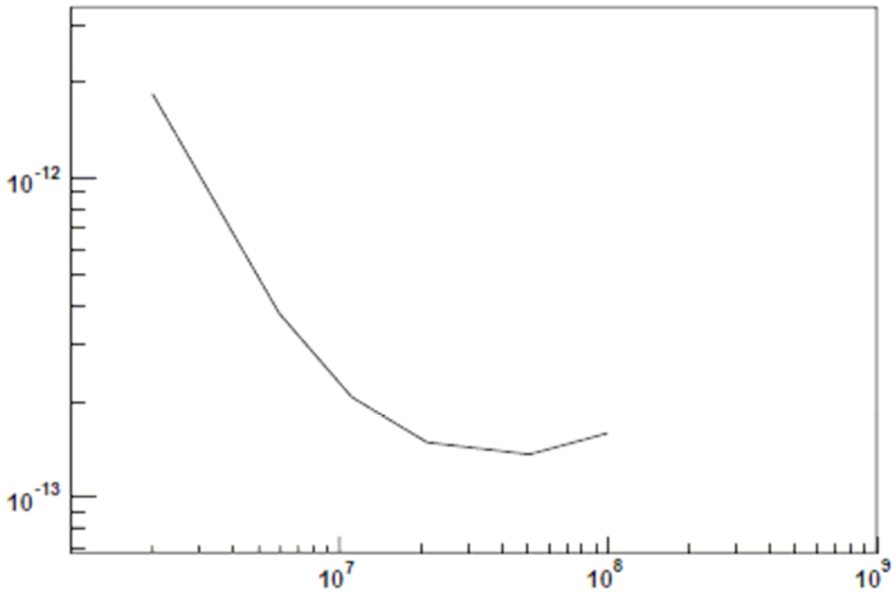


Reconstructed E

preliminary

CL 90% Sensitivity

BEAMTIME=4E7 sec
2 year



YEAR 2006
1 MONTH BEAMTIME