Investigation of a Transmission-Line Readout for Building PET Detector Modules

Contents

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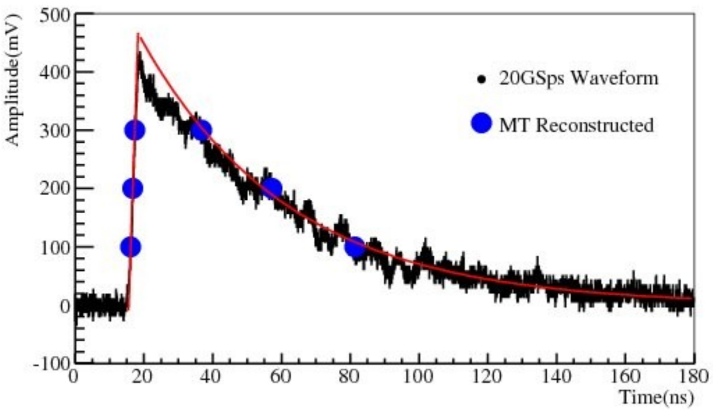
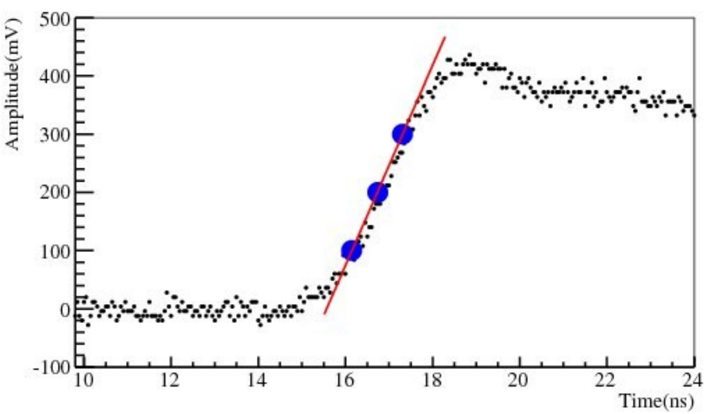
Idea of Multi-threshold sampling





Waveform from R9800PMT+LSO

•Conventional PET DAQ.
ADC for Energy
CFD Discriminator for Timing

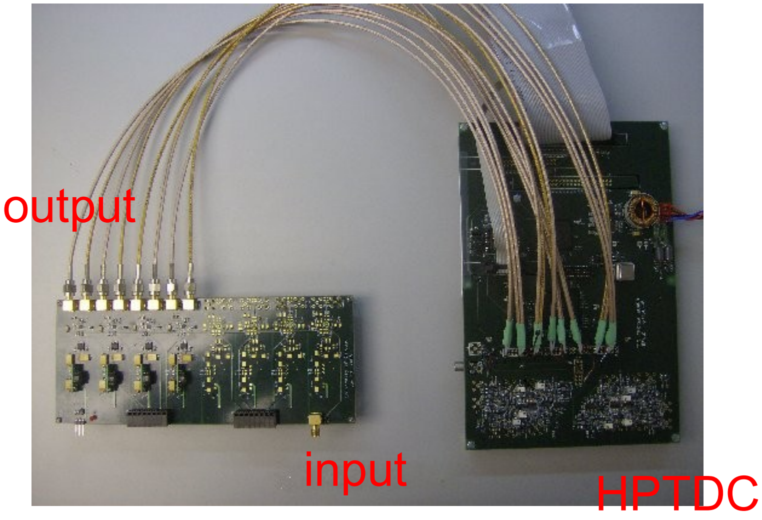
•Pulse sampling at the pre-defined Voltage.

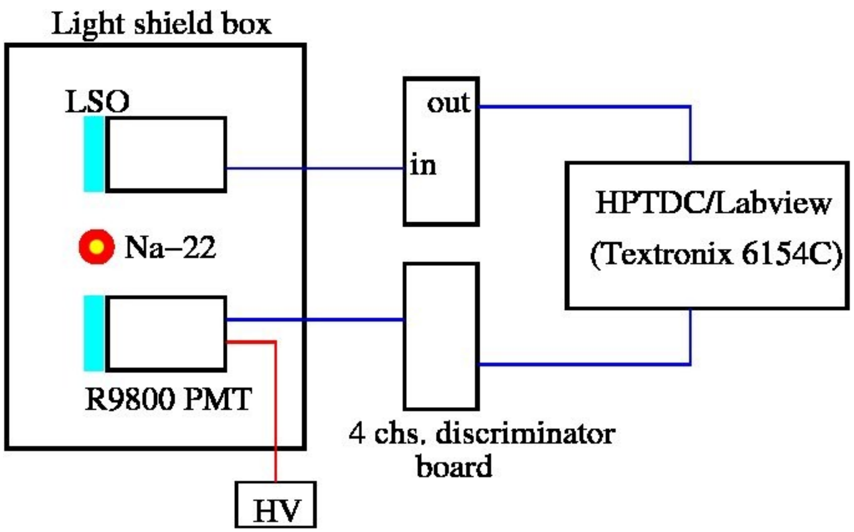
•Pulse reconstruction using timing readout
→Extract Energy.

Multi timing hits on the rising edge
→ Event timing.

TOP : Waveform with 20Gsps sampling.
3 M-T sampled signal superimposed.
Bottom : Rising part only.

M-T board and Setup



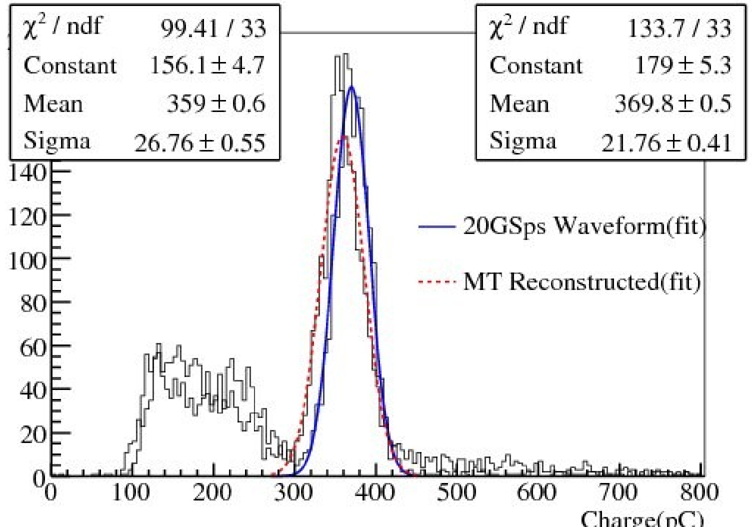


M-T Board(left)
  4 channels implemented.

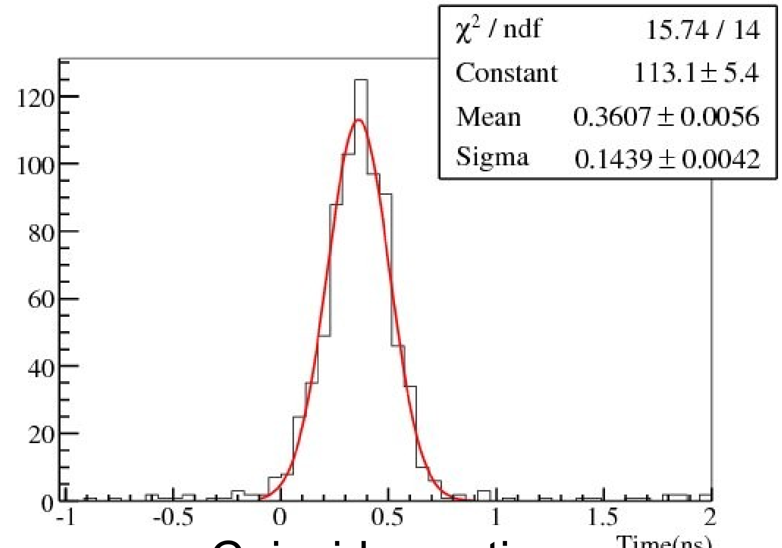
HPTDC(CERN)(right)
  readout timing from M-T board.
  8 channels with ~25ps resolution.

Na-22 for coincidence source.
Signal from R9800+LSO
Connected to M-T board
  with 4 different Threshold levels.
HPTDC readout through LabView.

Energy &Timing Resolution



Energy of 511keV gammma



Coincidence time

Pulse reconstruction using M-T sampling.
4~8 points from 2~4 thresholds.
Exponential fit to falling edge.
18% Energy resolution
(~14% using 20Gs sampling waveform)

Linear fit on the rising edges.
Coincidence timing resolution
~350ps
(~300ps using 20Gs sampling)

cf, "A multi-threshold sampling method for TOF-PET signal processing",
NIMA, In Press(doi:10.1016/j.nima.2009.01.100)

Introduction

- Micro-Channel Plate(MCP) PMT shows fast time response.
  (200~500ps anode rise time, 20~50ps TTS)

- Transmission Line(TL) Board can be a efficient way
  to readout multiple channels.

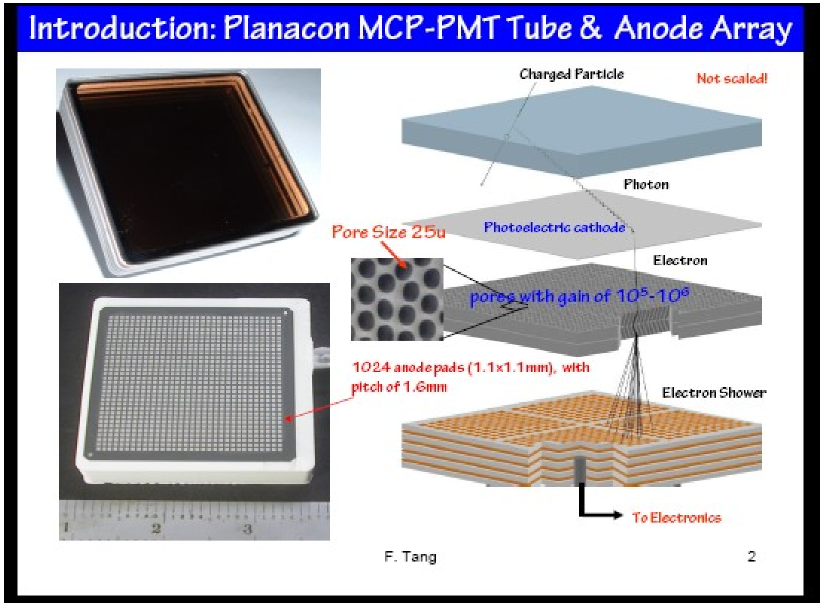
- MCP+TL Board can be an attracting option for PET detector design.

- Sandwich configuration: MCP + LSO + MCP
  - High Sensitivity (~80% detection efficiency)
  - 3D positioning with resolution < ~4mm.
  - <~500ps coincidence timing resolution.

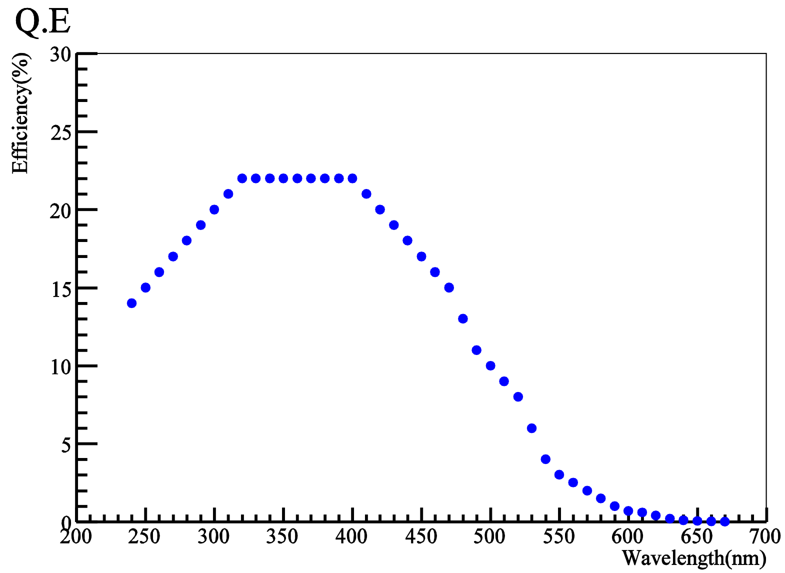
- Need optimization before building proto type detector module.

- Preliminary study was done using Geant4 simulation.

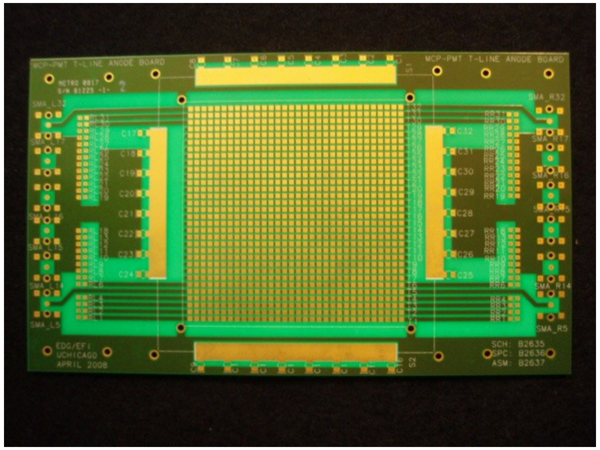
MCP & Transmission line Board



(From Fukun's slides)



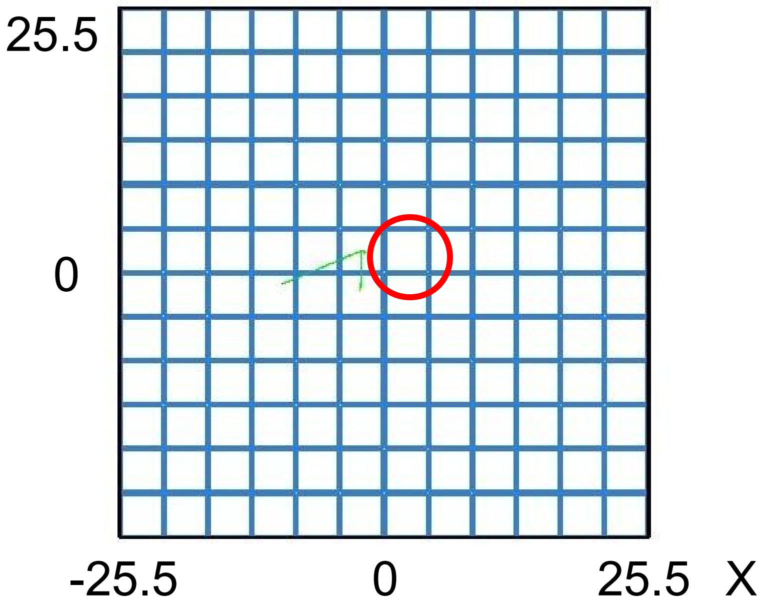
Q.E of Planacon(Burle) MCP

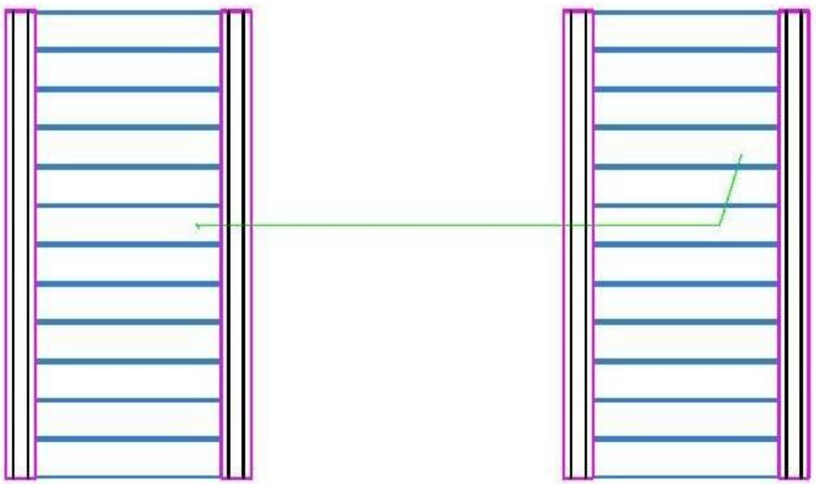


2inch square head-on MCP(Burle/Photonis).
10um, 25um pore size.
Anode #: 32x32 (1.6mm pitch)
7.5x10e5 gain at 2,600V(85011-spec)

TL Board : readout MCP anodes with 32x2.
→Modified to 12x12 anodes for this simulation.

Simulation Setup(Geant4)

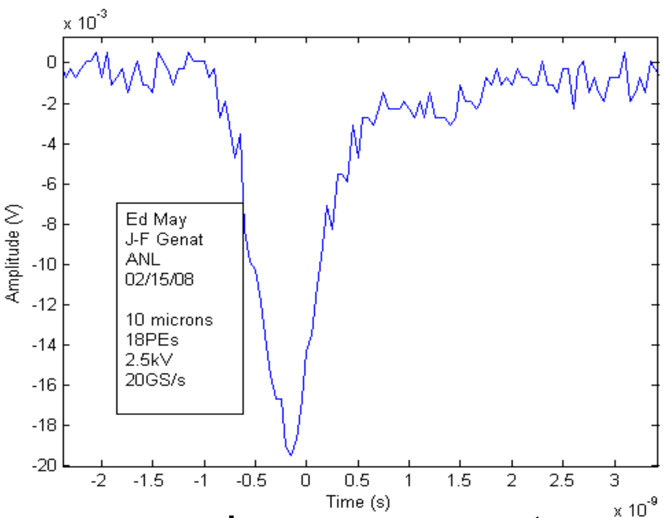




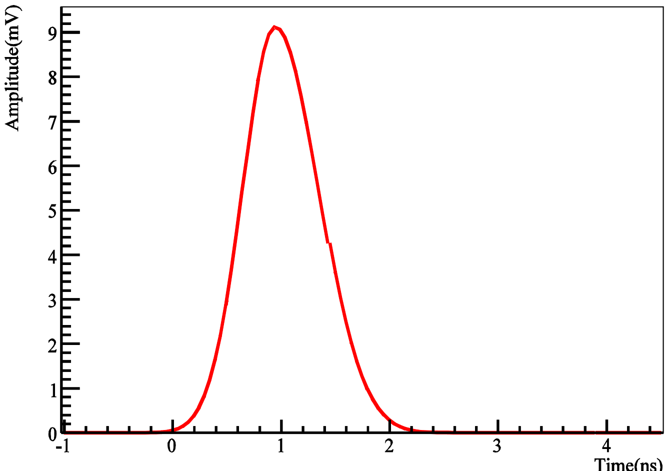
- Dimension : 51x51x33mm3
- LSO(1 pixel => 4x4x25mm3)
  pixelated into 12x12(left)
  Crystal pitch : 4.25mm
- MCP(51x51x4mm3)
- Photocathode embedded in MCP.
- Module = LSOs between 2MCPs.

LSO : Decay time 40ns
Lightout : 30,000/MeV
511keV two gammas at the center.
180 deg angle between two gammas.
50mm separation between two modules.
Surface: "groundbackpainted"
(Unified model)

Single Electron Responses



real measurement



Simulated pulse shape

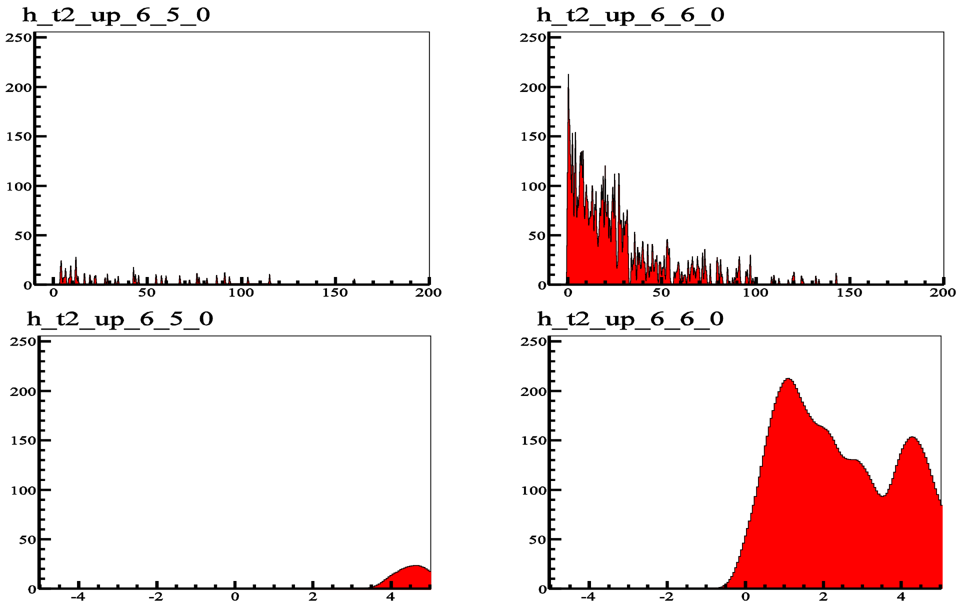
1. Pulse Shape
   ~500ps rise time(top)
   (real measurement by J-F)
   similar value for falling time
   assume asymmetric gausian shape

2. Average gain factor : 10e6
   Single electron gain
   ~70% in FWHM.

3. Transit Time Spread
   sigma = 50ps(real measurement by J-F).

cf.
Seng's slides at Picosecond workshop at Lyon08

Signals at anodes



Simulated signal shape at anodes
Beam was on the right anode.
Signal is localized.

Top : Time(-10 ~ 200ns)
Bottom : Time(-5 ~ 5ns)

Example : maximum signal anode and neighbor

<u>Pulse formation procedure</u>

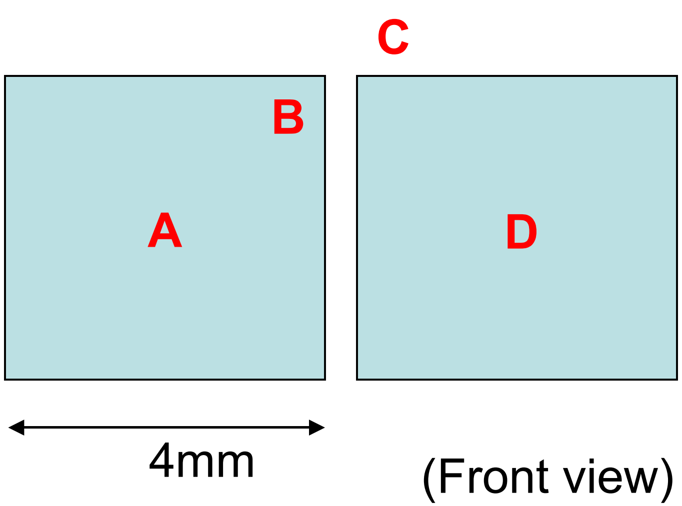
1. Detect photons at photocathode.
2. Apply Q.E of MCP
3. Apply single electron response to photoelectron.
4. Sum up pulse at each anode.

Data Set

5,000 events generated for each set.

1) Two gamma (along Z direction)

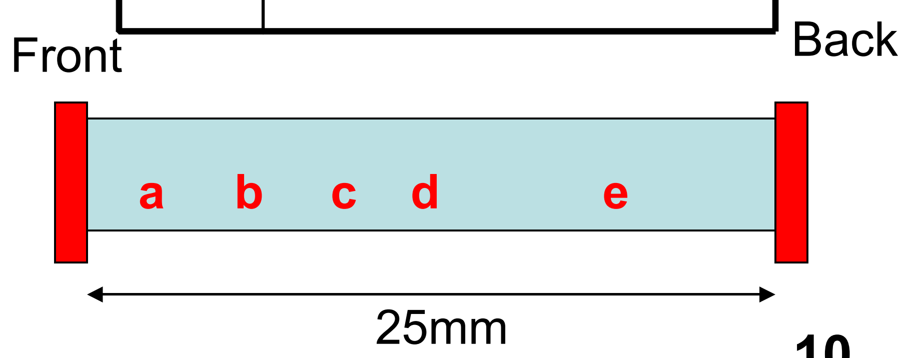
	x	y
A	2.125	2.125
B	4.0	4.0
C	4.5	4.5
D	6.375	2.125



(Front view)

2) DOI measurement(varying Z)

	Z(mm)
a	3.125
b	6.25
c	9.375
d	12.5
e	18.75

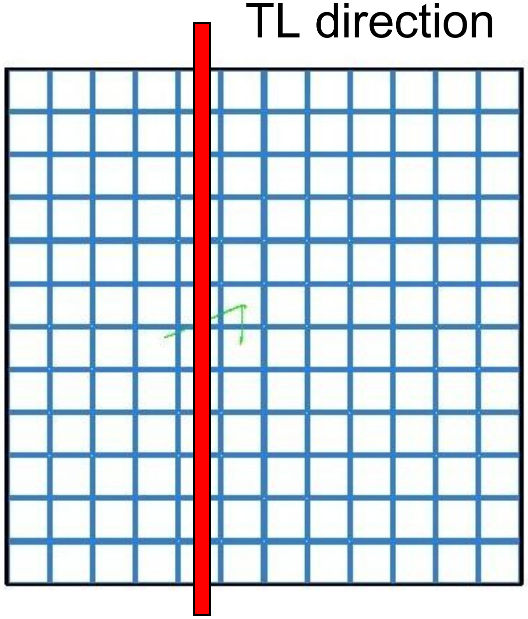


(Side View)

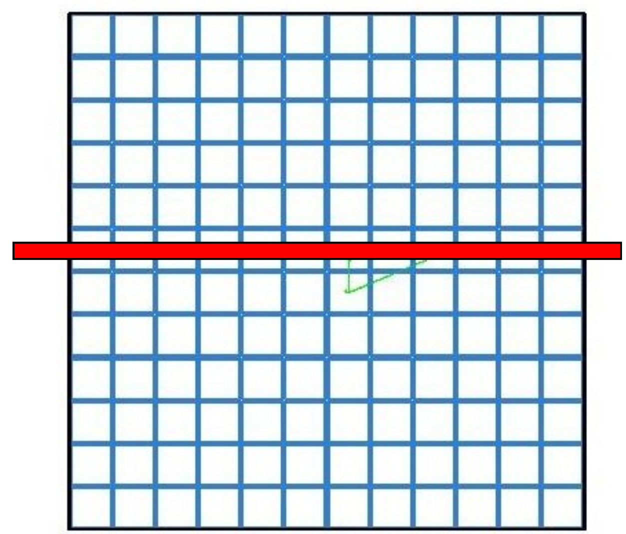
Readout Scheme

- Readout signals from 12 horizontally (vertically) running TLs.
- Total 12x2 channels for a module.
- Position : Maximum signal TL coordinate.
- Energy : Sum of two sides(e.g, 3 TL sum w.r.t the maximum for each side)
- Timing : Average of maximum TL from each side.
- DOI : Ratio of energies from two side(or timing)

TL direction

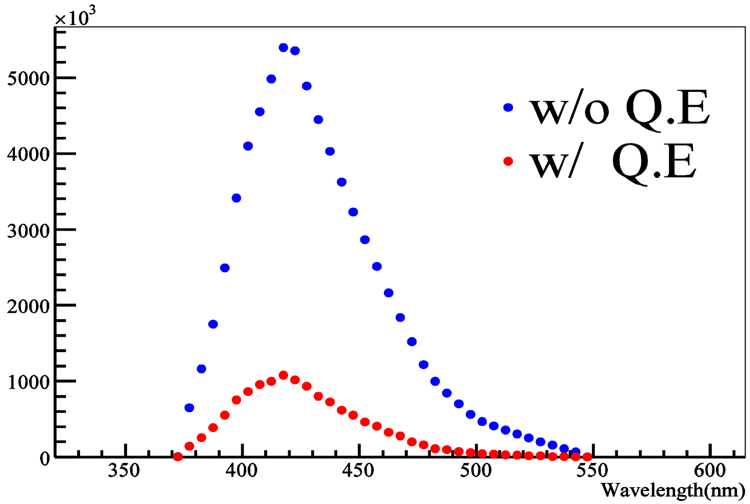


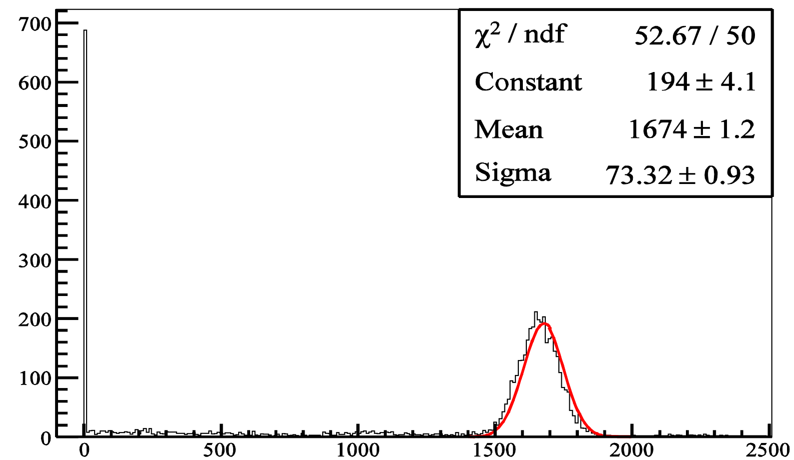
Front Side



Back Side

Detection Efficiency





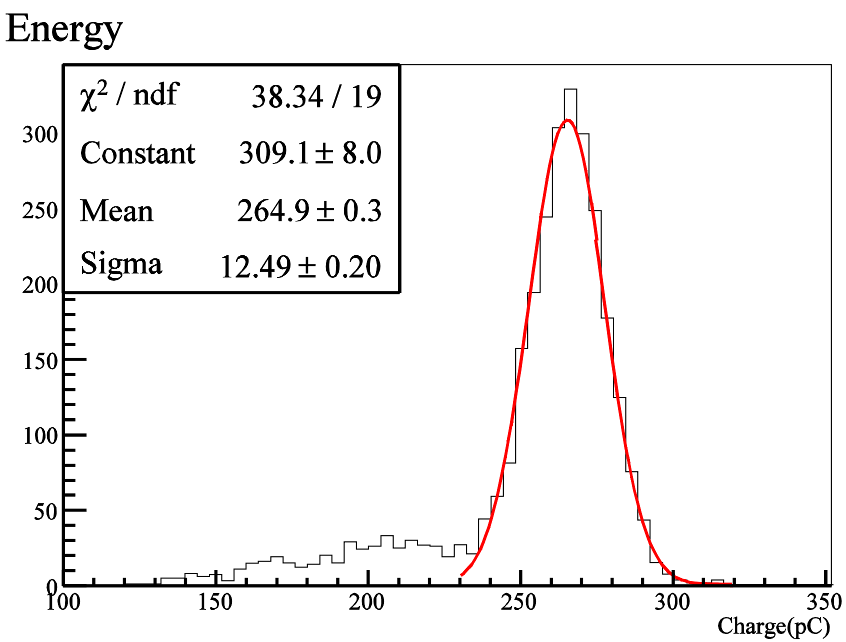
TOP L: Photon Emission Spectrum
detected at photo-cathode

TOP R: # of photon per event.
After Q.E applied.

'# of photon > 1000' required for efficiency.

Beam position	Efficiency(%)
A	76
B	75
C	74
D	77

Energy Resolution



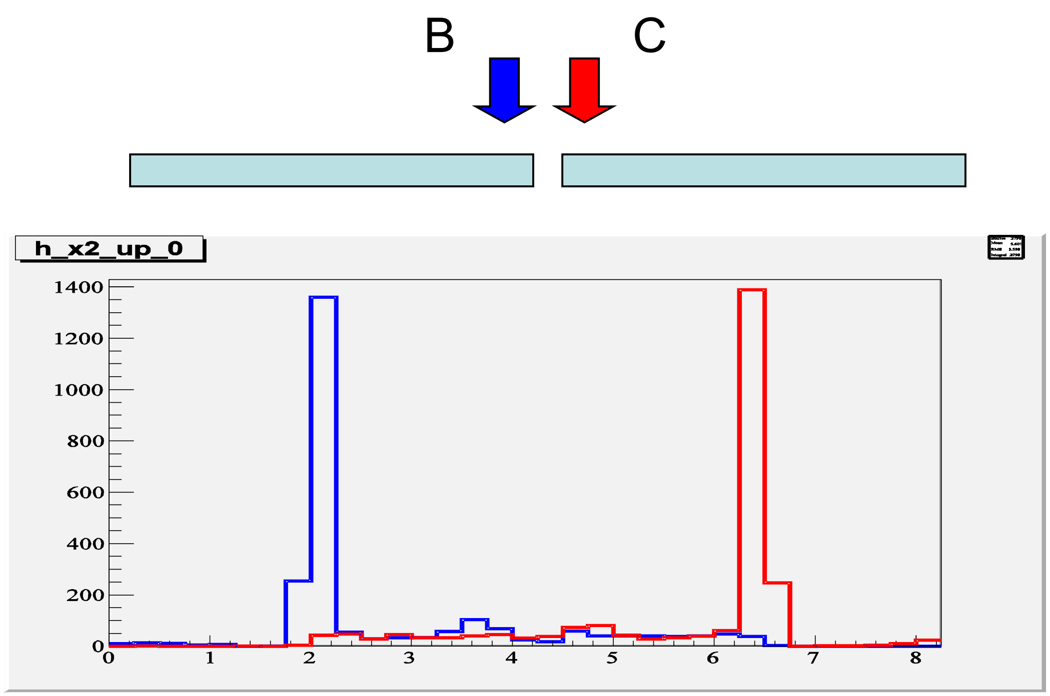
Energy distrubution of 511keV

Beam position	FWHM(%)
A	11.1
B	11.2
C	11.3
D	11.1

Sum of 3 TLs signal w.r. t the maximum TL.
Sum of two sides for a module.

Position Measurement

- Use Anger logic with 3 highest TL's signal.
  X_{det} = Sum(Xi*Ei) / Sum(Ei) (for Vertically running TL in Front)
  Y_{det} = Sum(Yi*Ei)/ Sum(Ei) (for Horizontally running TL in Back)



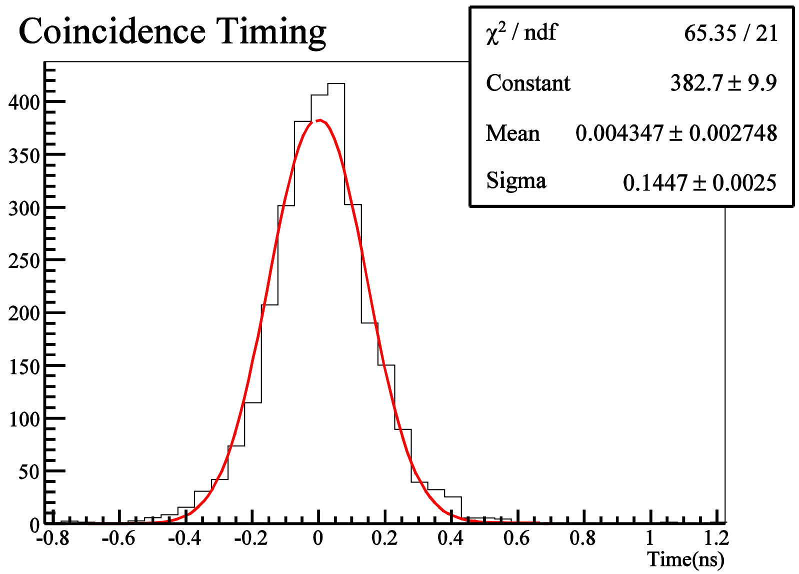
Reconstructed X coordinate.

Beam Entering Position(X cor)
B : 4.0mm
C : 4.5mm

Photon(Signal) is highly localized within crystal pitchs(4.25mm).

Position resol. for coincidence event ~ 2mm

Timing

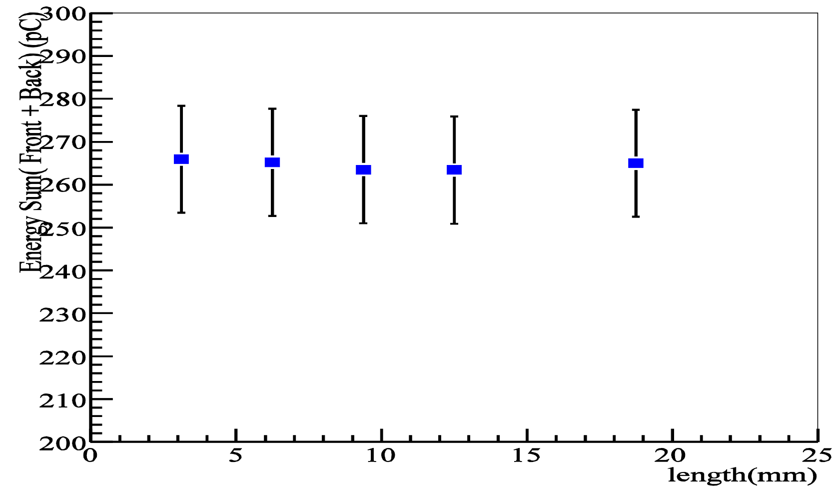


Beam position	δ (T) (FWHM)
A	340ps
B	358ps
C	367ps
D	350ps

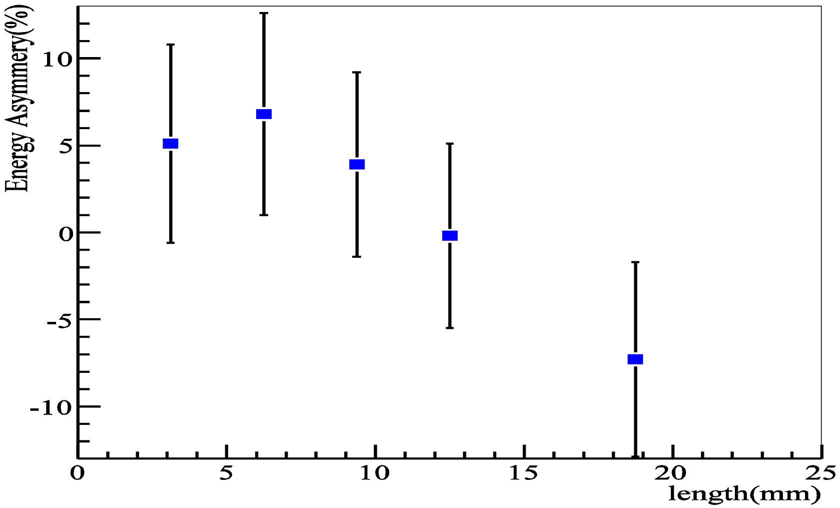
Timing of the maximum signal TL.
Apply leading edge for timing pick-up(Threshold: 20mV)
Transmission time was corrected depending on position.
T0: Average of two maximum TL for a module.

Time difference between T0s from two modules.

DOI measurement



Distance from front side(mm)



- (Ef+Eb) is not dependent on DOI.
  Ef = Energy of Front side
  Eb = Energy of Back side

- Separate readout of front/back enable to use energy asymmetry.

- Energy Asymmetry :
  (Ef – Eb)/(Ef + Eb)*2*100(%)

- E Asymmetry vs Beam position
  Error bar is the spread the distribution.

Summary and Plans

- A Geant4 study for PET detector design.
  LSO+MCP+TL Board.

- Preliminary results obtained.
  E resolution : ~12%
  Timing resolution : ~350ps
  Position resolution : ~4mm
  DOI : found tendency

- Need more data and investigations for optimization.
  Crystal(LaBr), dimension, # of readout channel.
- Try another readout scheme.
- Validation with real tests.