Characteristics of SiPM and Signal in large scale scintillator detector

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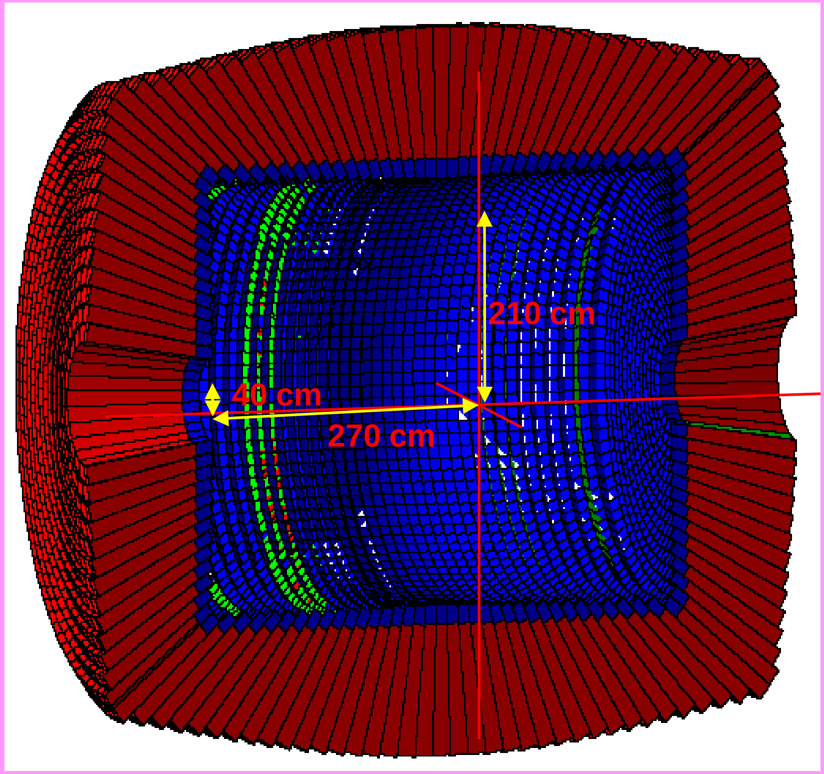
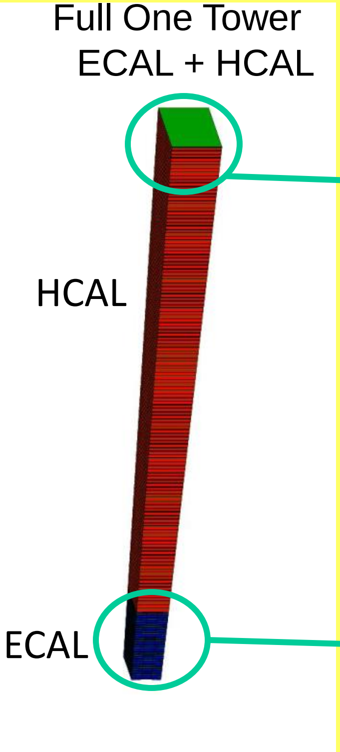
Introduction

- Side view



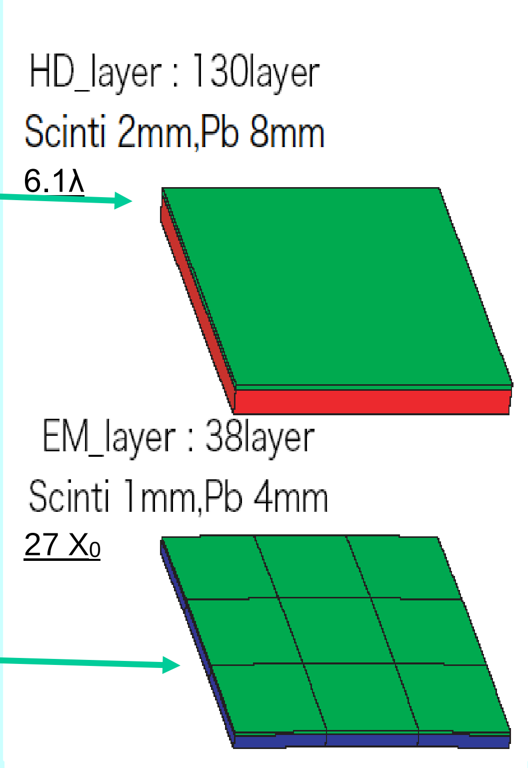
Barrel Tower Front : 210cm
Endcap Inner R : 40cm
Endcap Tower Front Z : 270cm

- Tower



- # of Layers
  ECAL : 38
  HCAL : 130

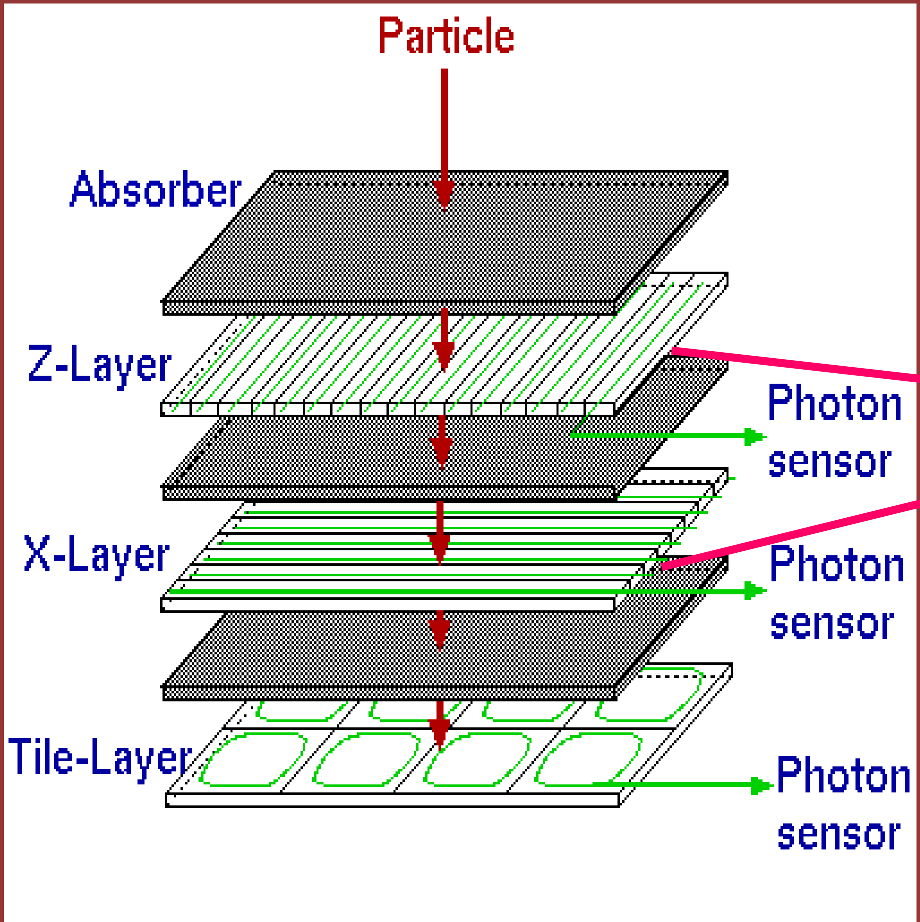
- Cell



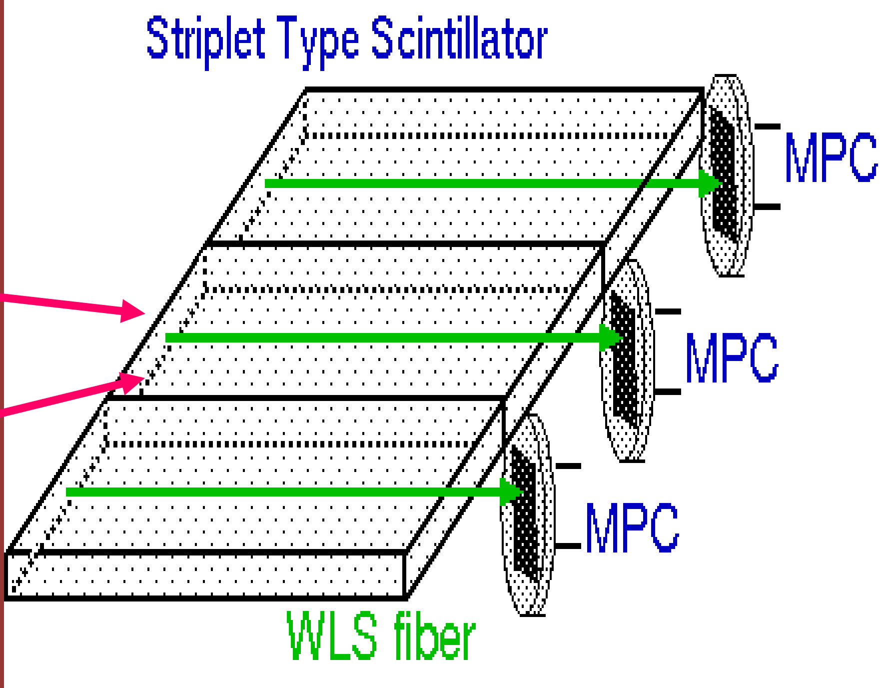
- Cell Size
  EM : 4cm x 4cm
  HD : 12cm x 12cm

Choice of cell size and material are under R&D.

Basic Configuration



-> Study of photon sensor



Fine segmentation scintillator
Read out by photon sensor

X, Z-layer strip scintillator : 10x200x2mm
Tile-layer : 40x40x1mm

Strip scint & SiPM(or MPC) R & D Studies important !

Geometry of SiPM

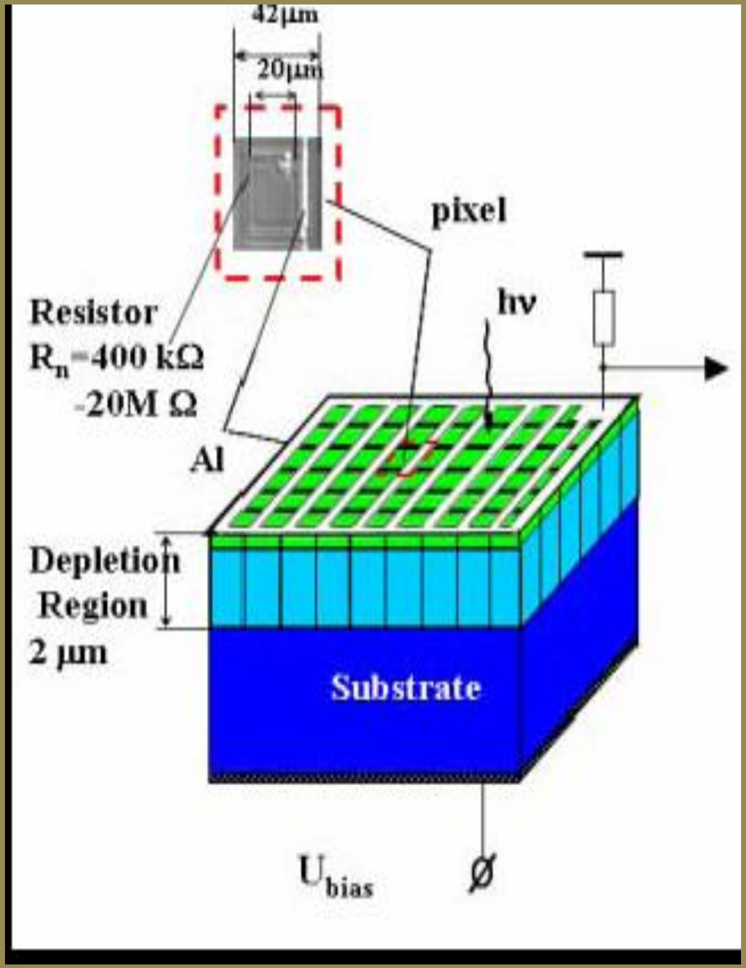
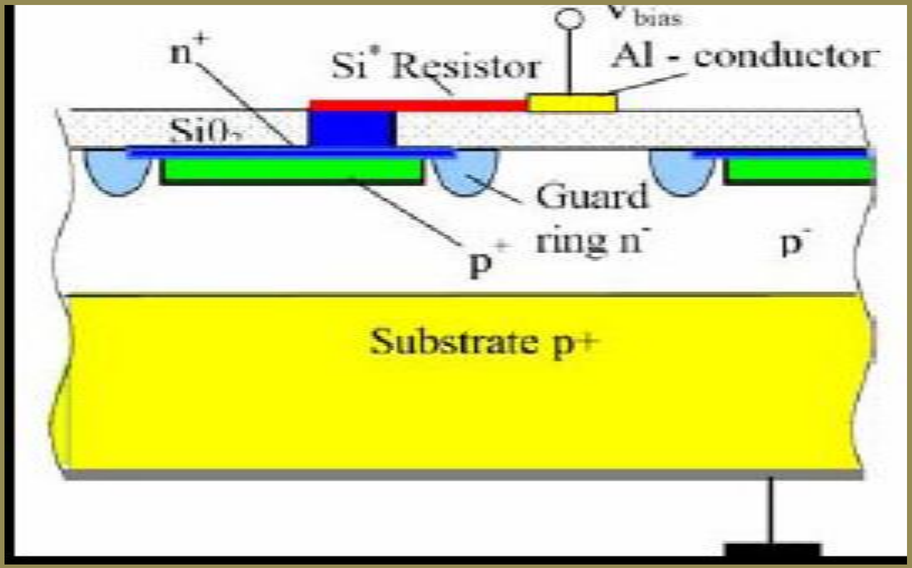


Figure 1: Schematic view of SiPM.

- Matrix of independent pixels arranged on a common substrate
- Each pixel has a size 25*25μm^2
- 1600 pixels/mm^2
- Pixels can be arranged in any shape to fit the shape of fiber



Operation of SiPM

- Each pixel operates in a self-quenching Geiger mode under bias voltage of 10-20% more than breakdown voltage, so each carrier generated by photons or thermally gives rise to a Geiger-type discharge($t_{discharge} < 1\ ns$).
- The strip resistor serves as a decoupling element between the individual pixels because $C_{pixel}\ R_{pixel}\ \sim 10^{-8} s >> t_{discharge}$
- Each pixel produces a standard response independent on number of incident photons (arrived within quenching time)
- Each pixel multiplies the carriers created by photon or thermally by a factor about 10^{6}, the value close to that of photomultiplier.
- Single pixel gain is determined by the charge accumulated in pixel capacity C_{pixel}: $Q_{pixel} = C_{pixel}\ (V_{bias} - V_{breakdown})$.

  Typically, C_{pixel} '100 fF, *and* V_{bias}-$V_{breakdown}$ ' *a few volts, so* Q_{pixel} ' *few times 100 pC and the* single pixel "gain" is about 10^6
- One pixel – logical signal: 0 or 1
- SiPM at whole integrates over all pixels: SiPM response = number of fired pixels

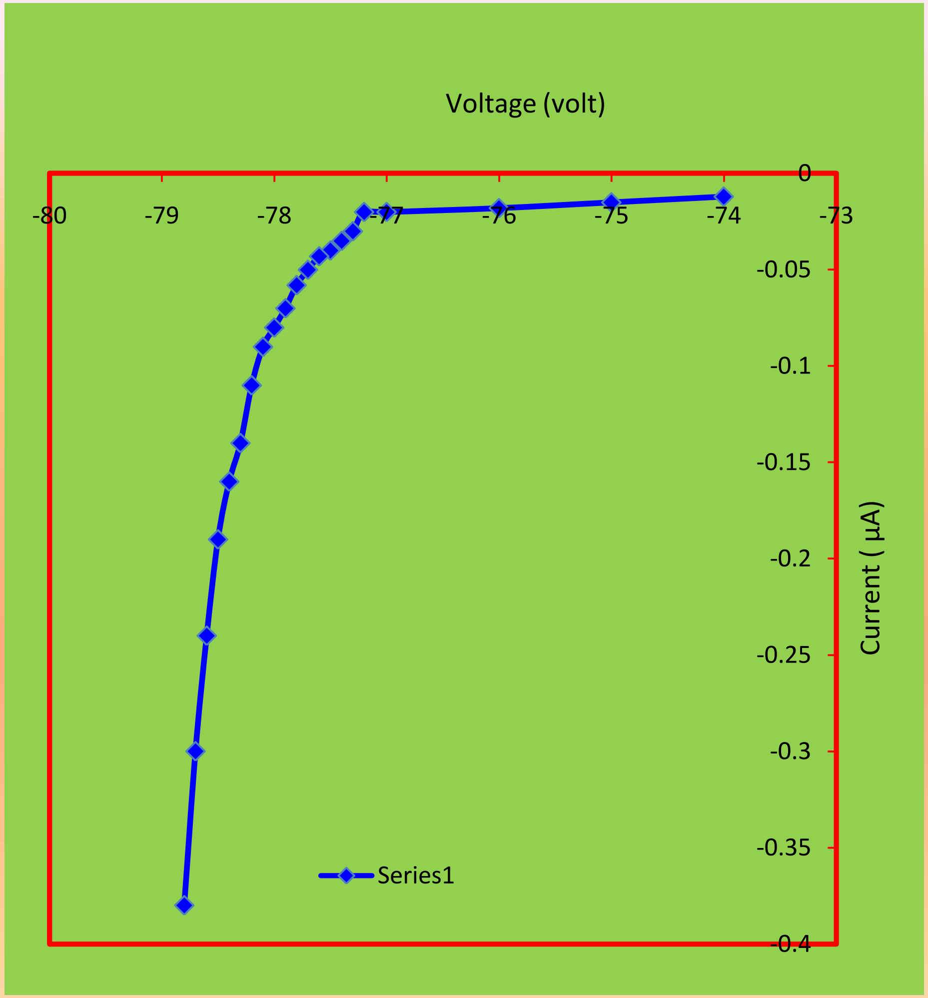
ADVANTAGES

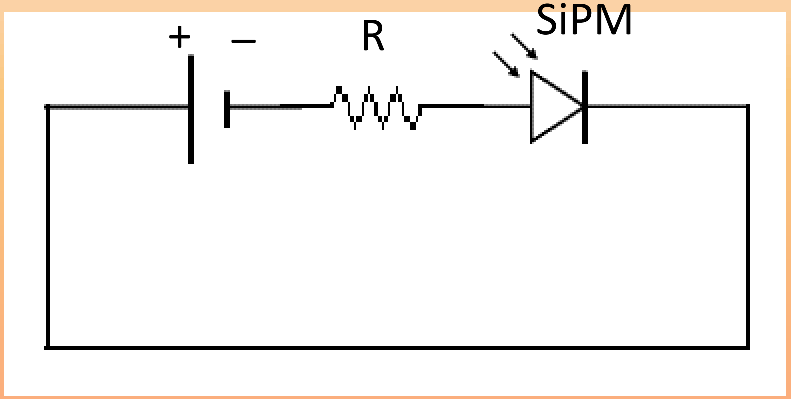
1. High quantum efficiency,
2. Photon counting capability
3. Low electronic noise(<0.1 electrons)
4. Fast response,
5. Short signal rise time (~1ns)
6. Short recovery time (<100ns)
7. Very low power consumption,(~7 W)
8. Low bias voltage (30-80V) (comparable to PMT's ~1kV)
9. Good temperature and voltage stability (much better than for APD)
10. Insensitive to magnetic fields
11. Compactness and robustness
12. Low cost and simplicity of measurement system.

DRAWBACKS

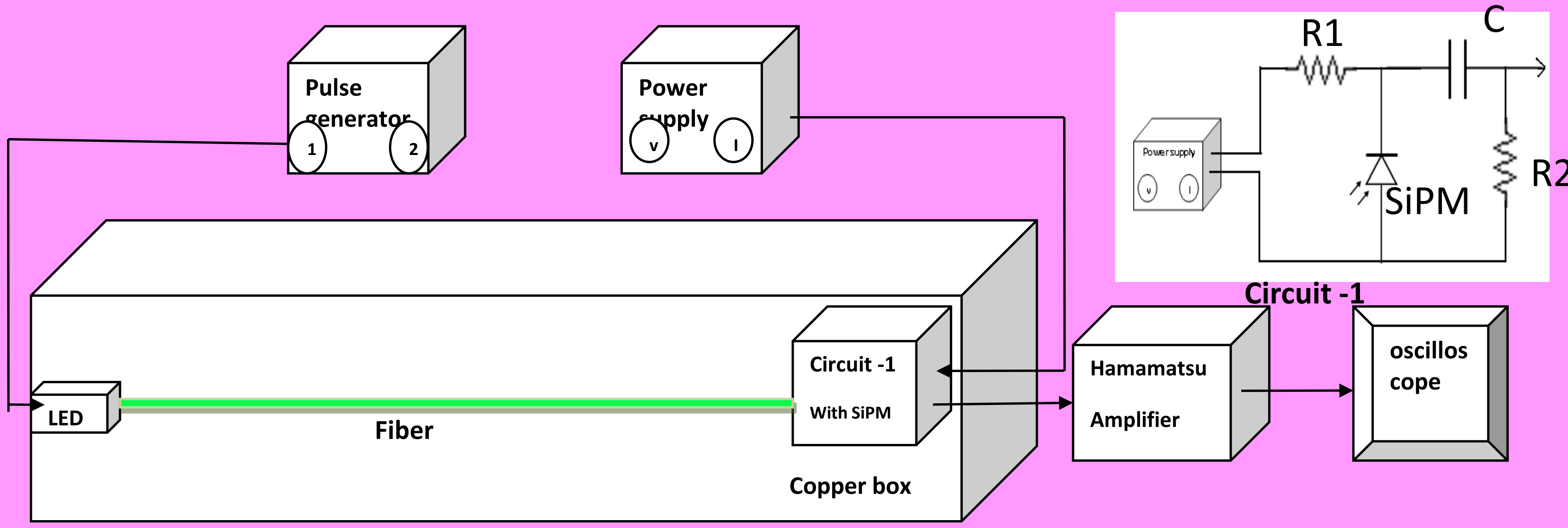
1. A large dark urrent, (1-2MHz/mm^2)
2. Crosstalk between micropixels (< 0.2%)
3. Relatively low sensitivity to UV and blue light.
4. Nonlinear response
5. Temperature dependent

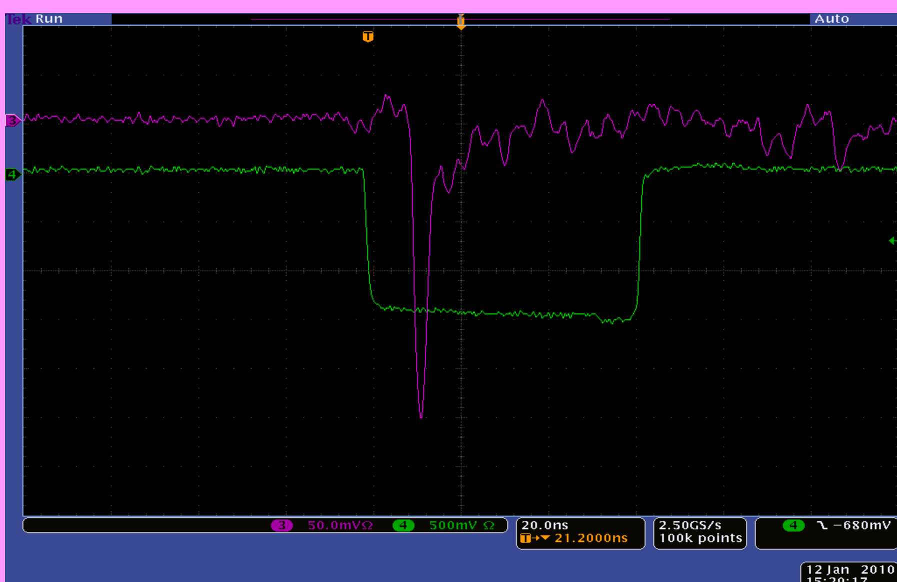
I-V Characteristics of SiPM

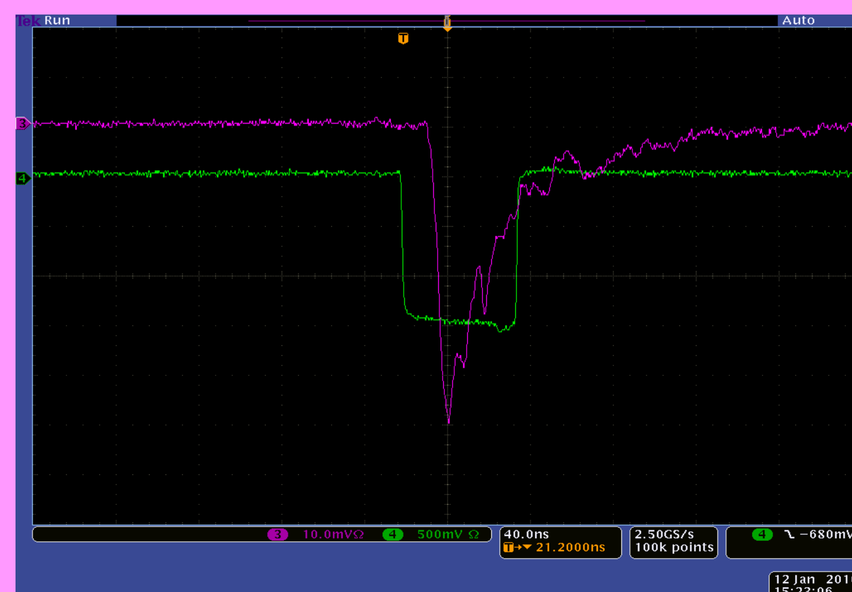




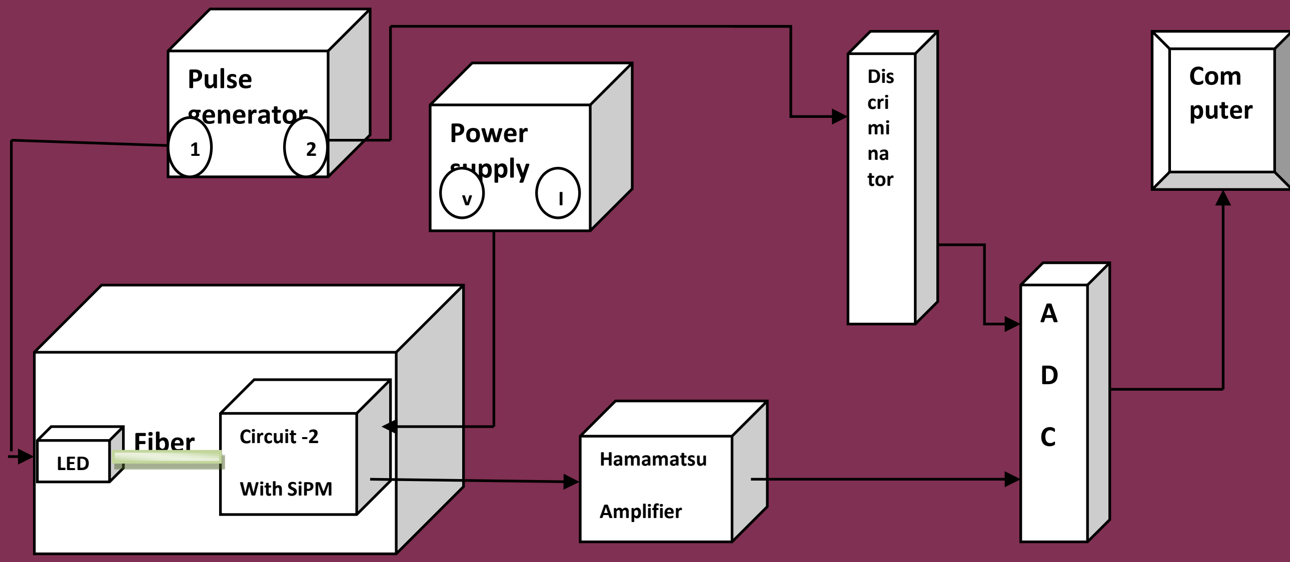
TESTING LAYOUT AND MEASUREMENT PROCESS







MEASUREMENT RESULTS



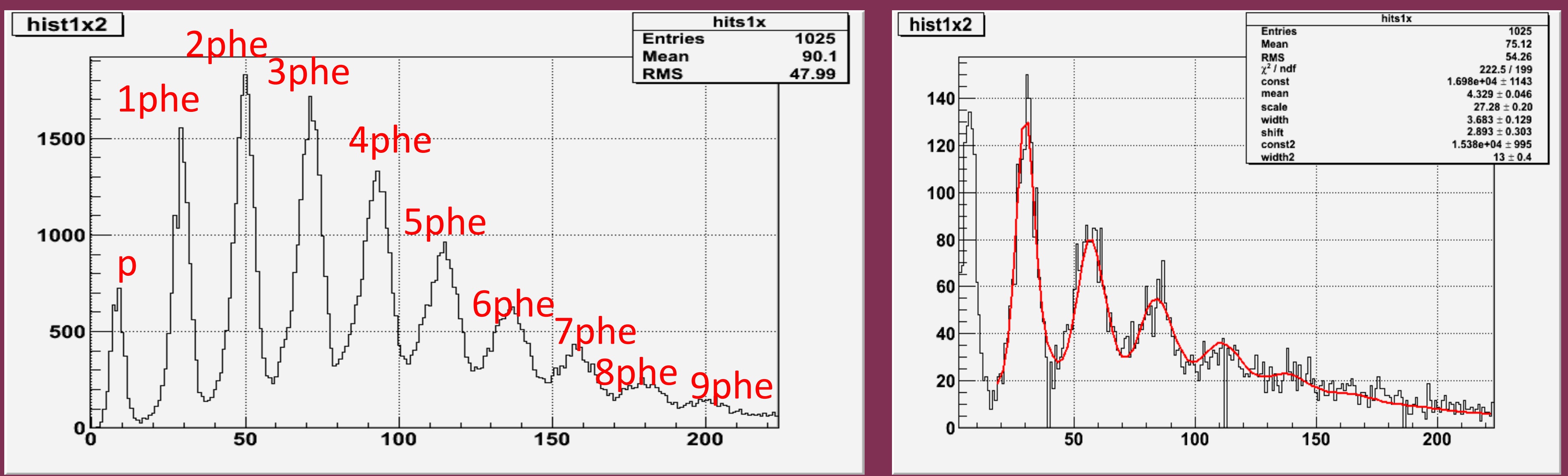
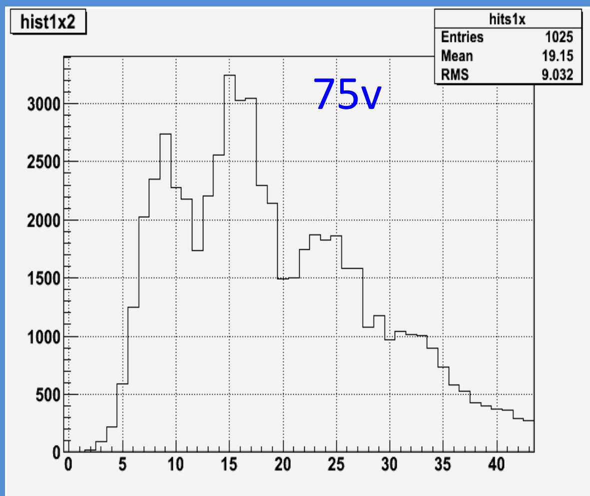
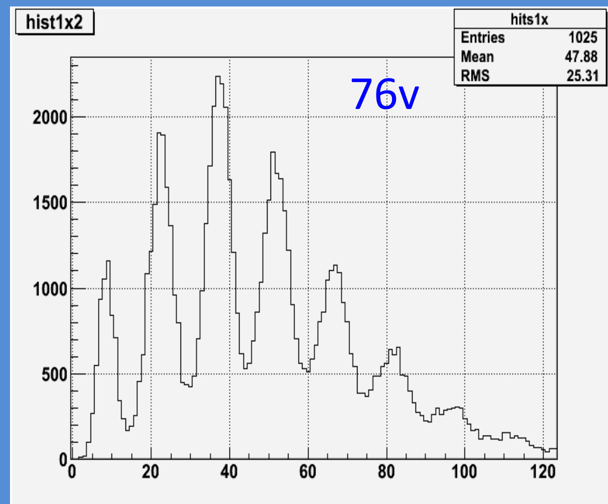
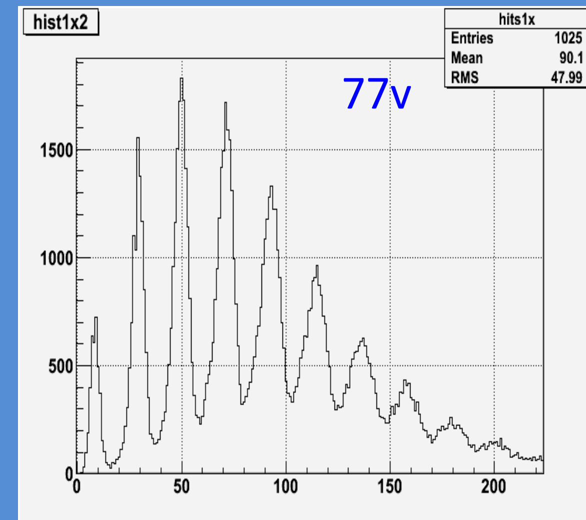


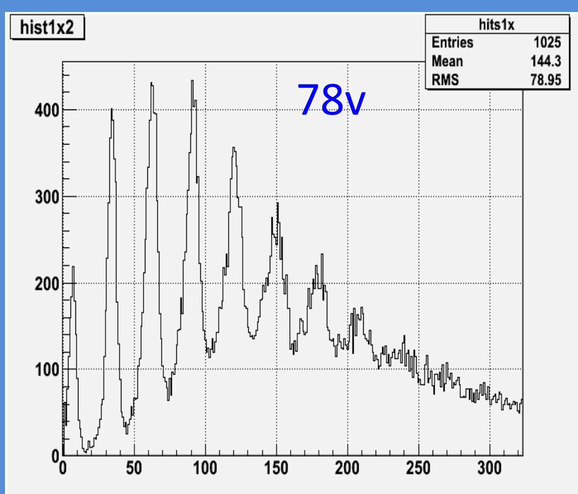
Figure : Amplitude spectrum and pixel impulse

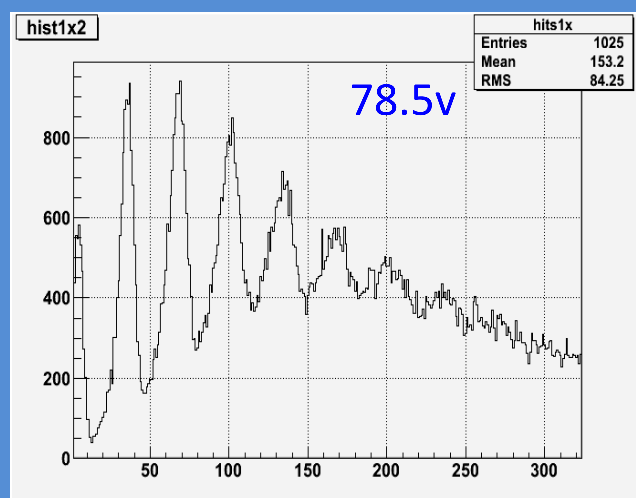
Measurement results for different bias voltage

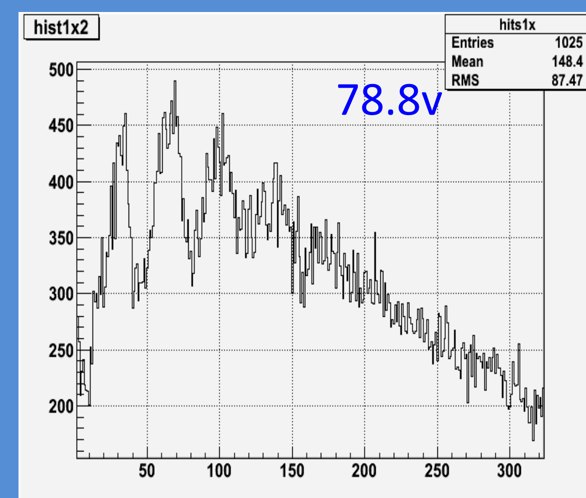






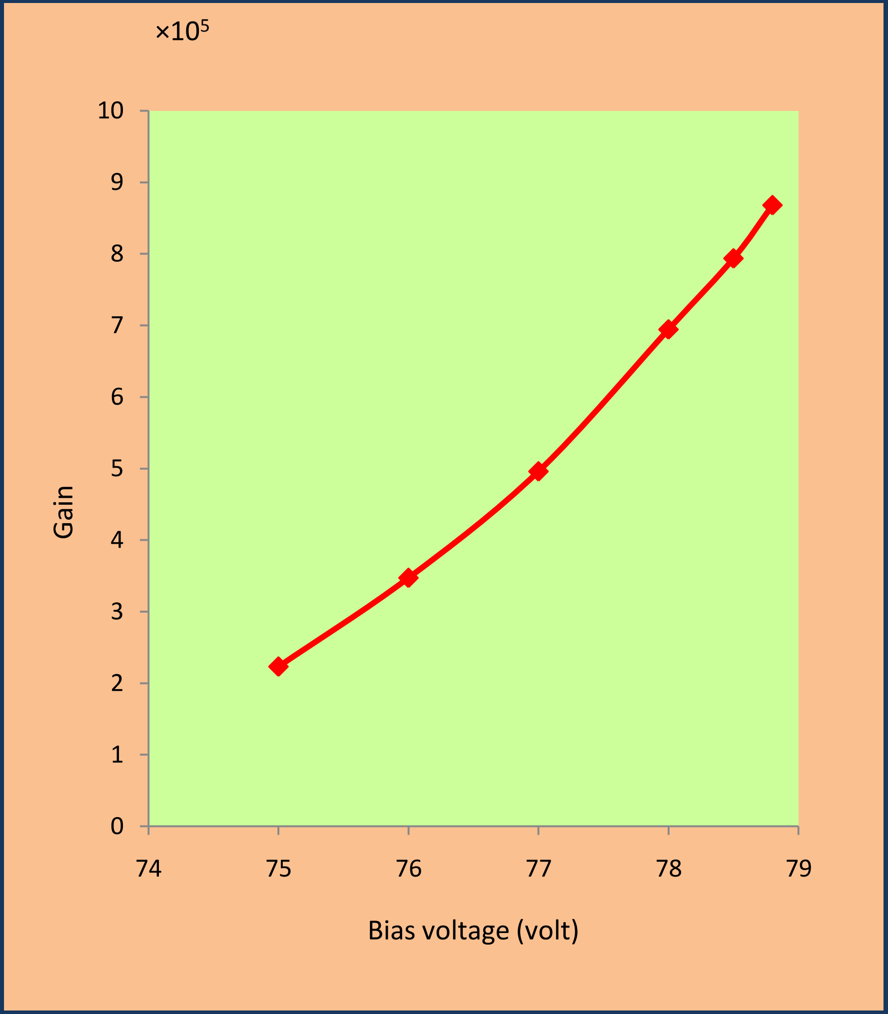




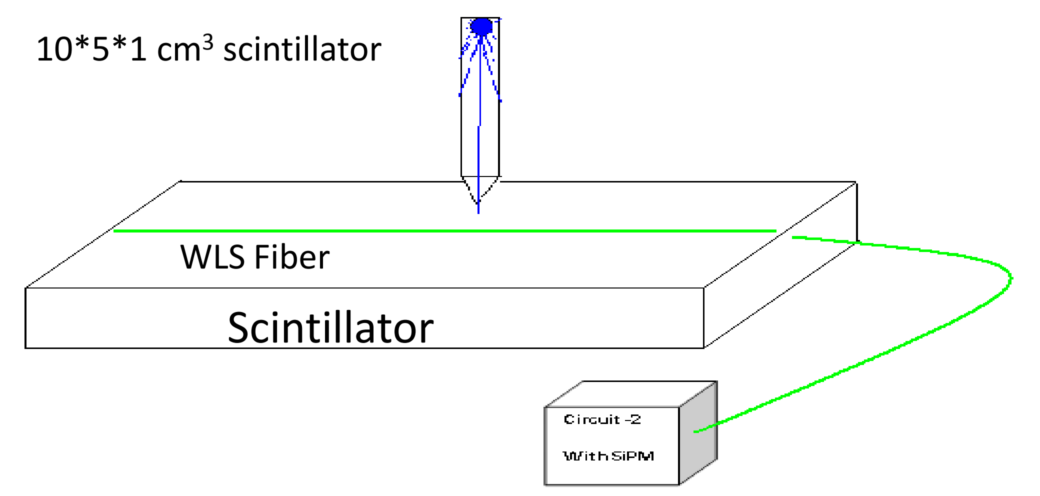


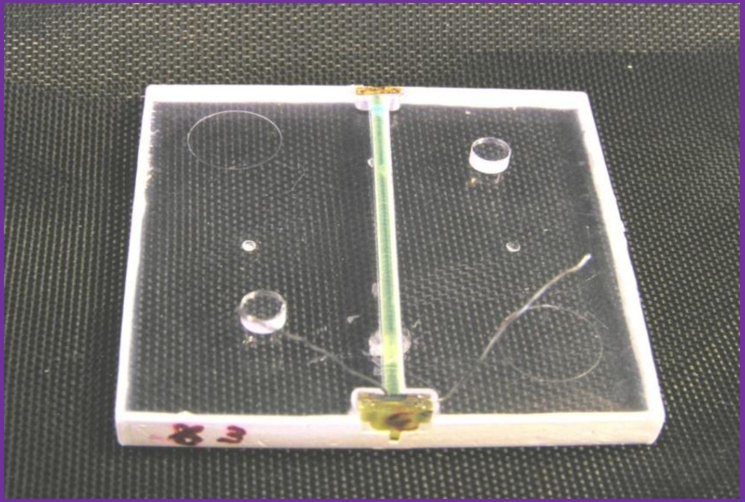
Gain measurement of SiPM

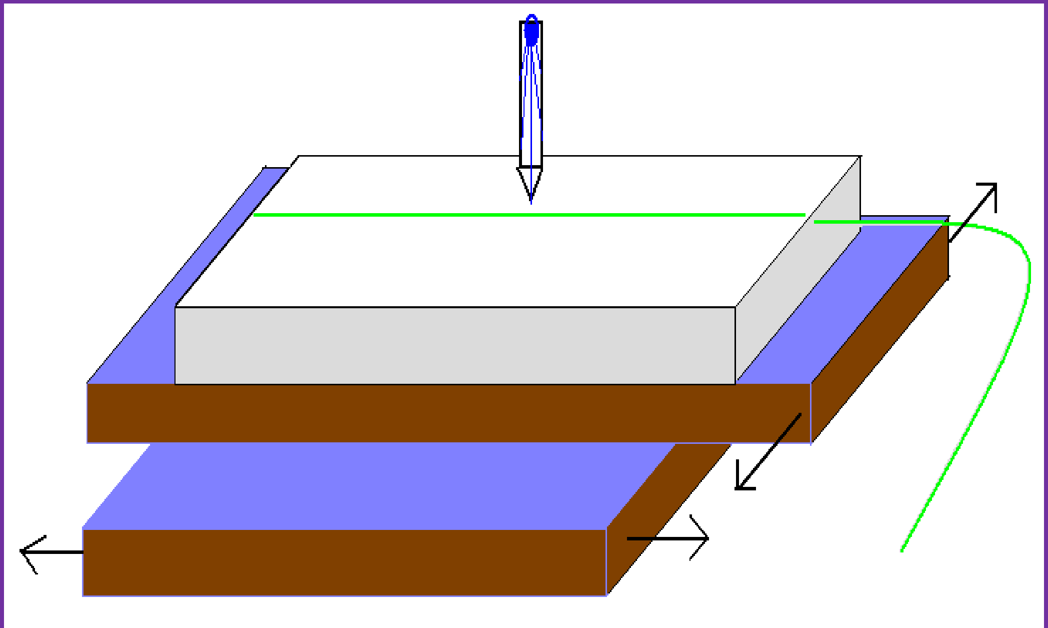
- 1st peak corresponds to fire of one pixel and
- 2nd peak corresponds to fire of two pixels
- The difference between two simultaneous peaks gives the gain of one pixel.
- so number of channels between two simultaneous peaks times least count of our ADC (0.25 pc) gives total charge created in one pixel i.e., the gain of one pixel.

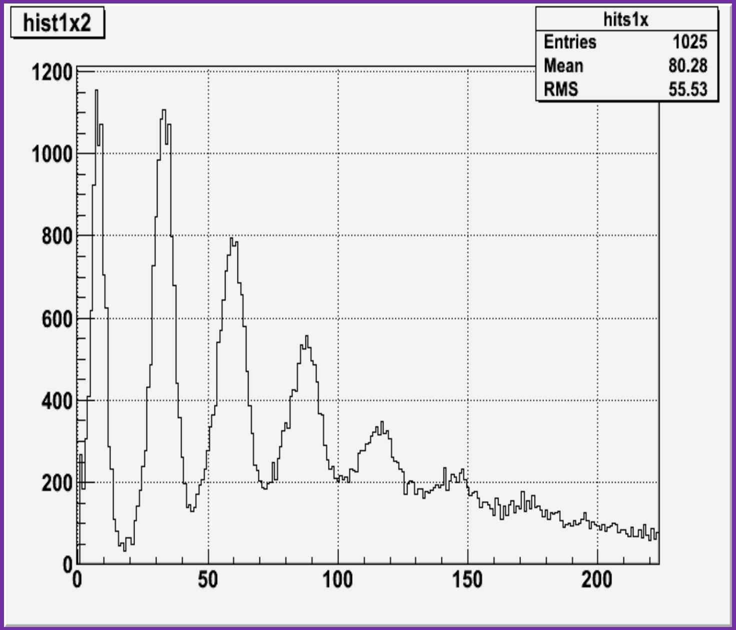


Scintillator + Wavelength shifter + SiPM

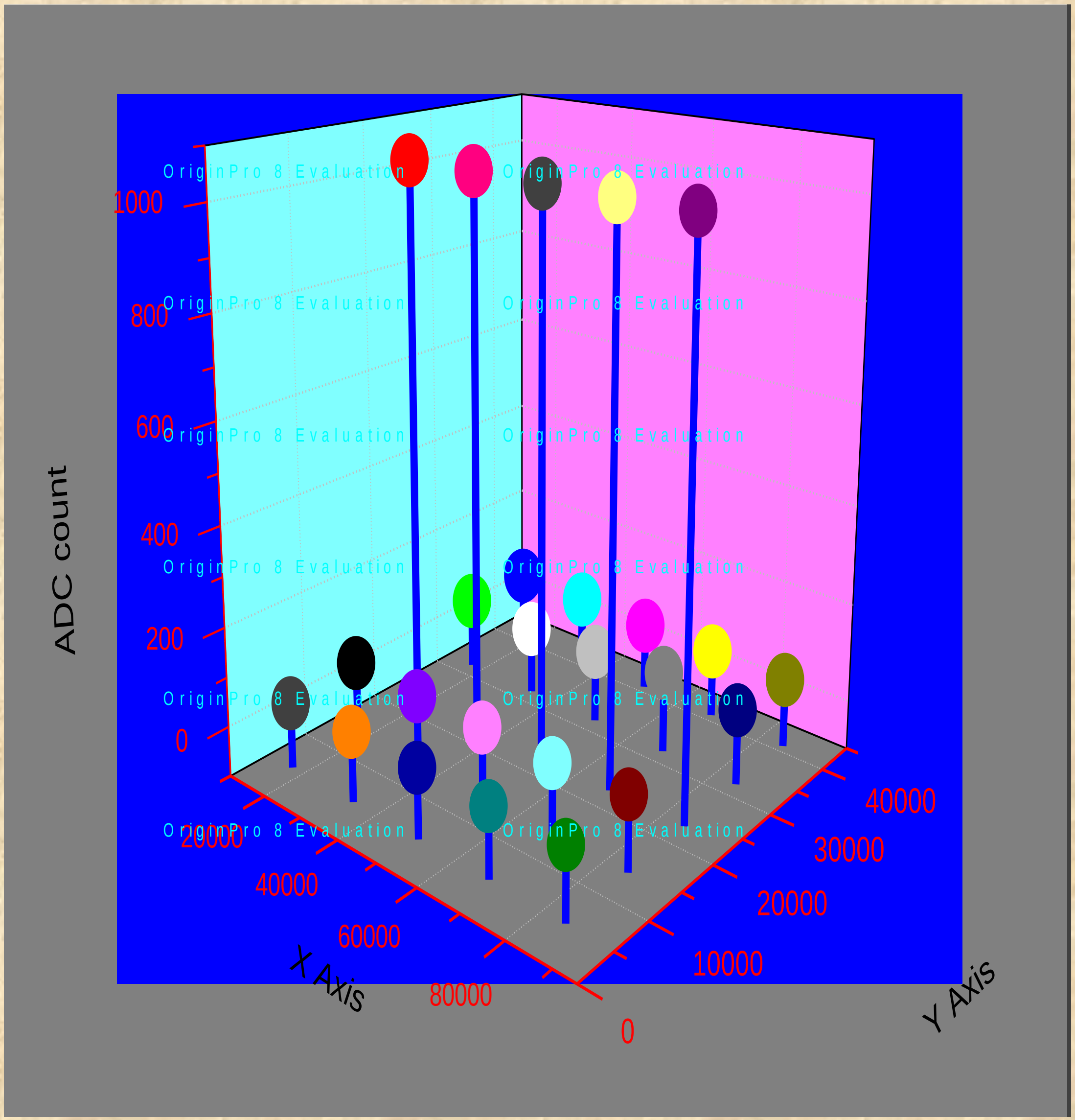


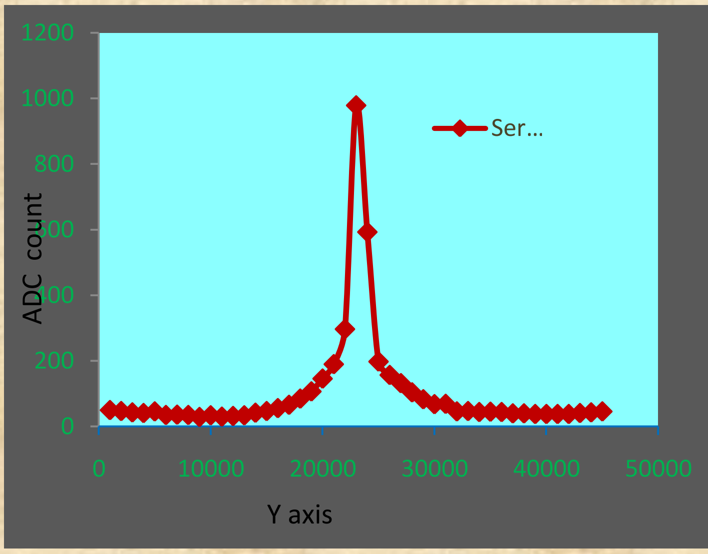


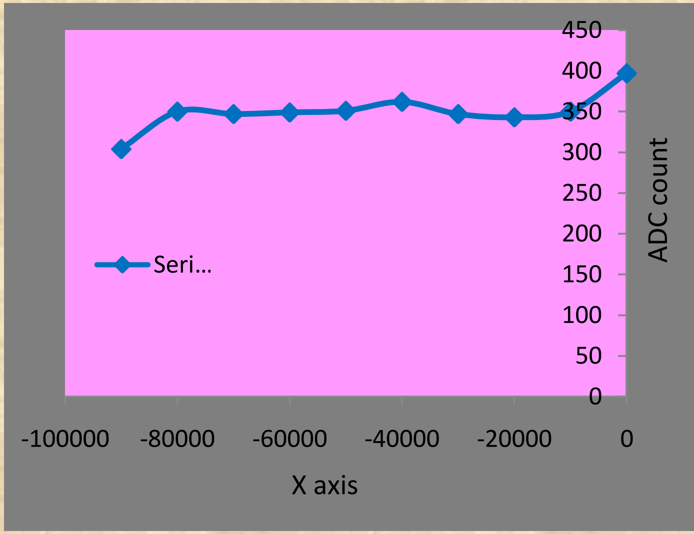




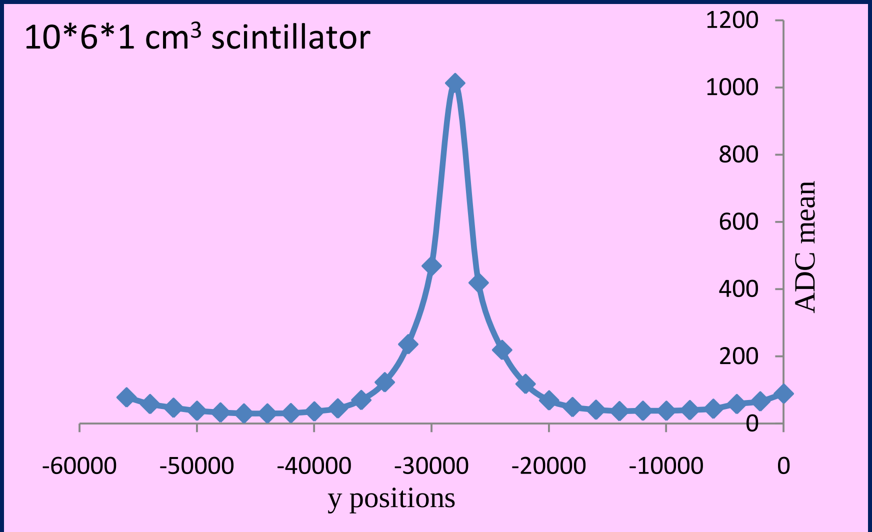
Response with varying position of light source

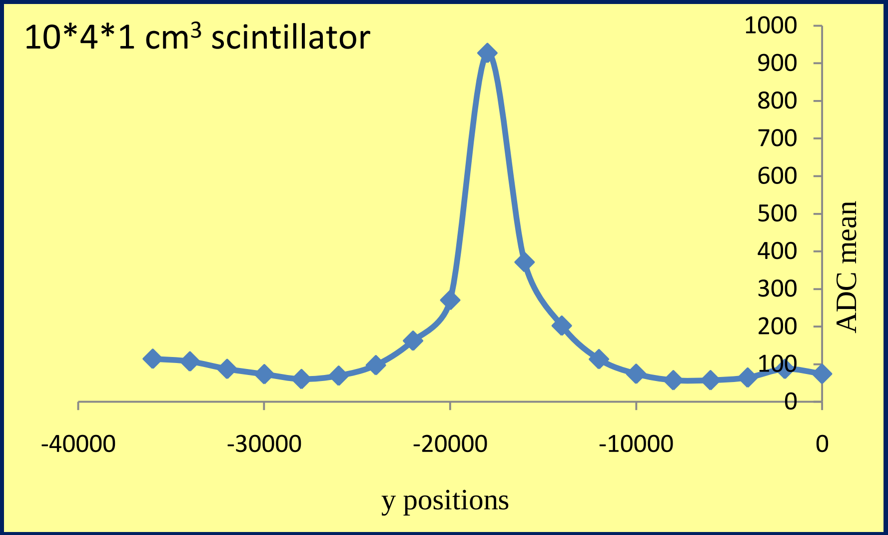


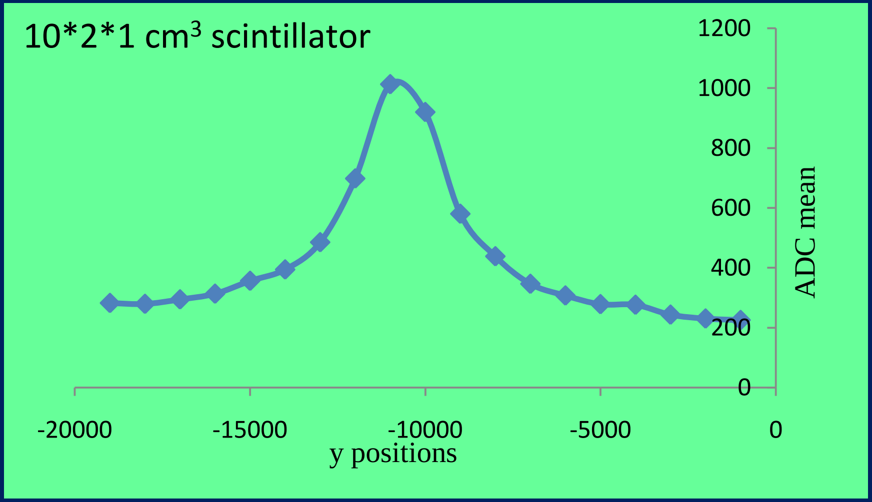




For different size of scintillators

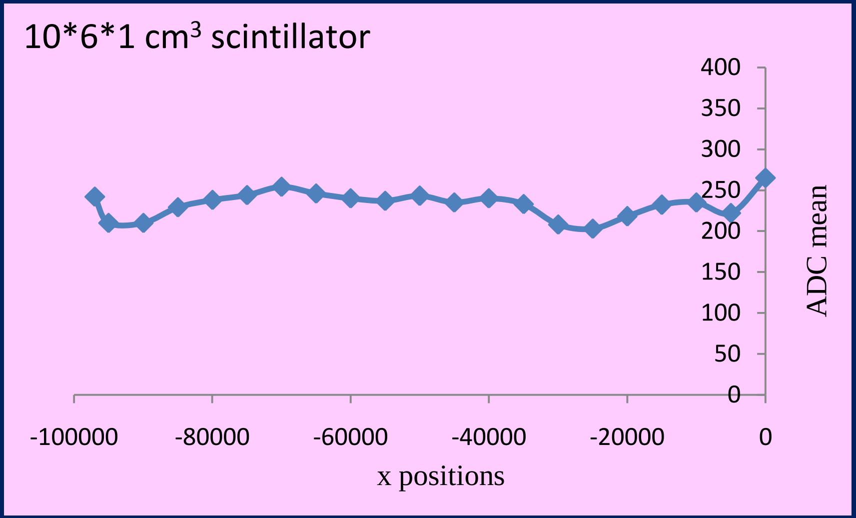


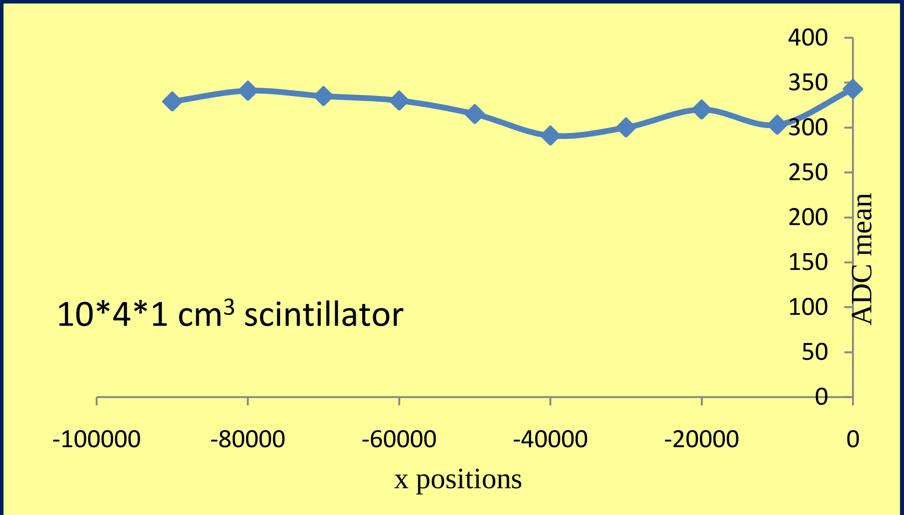


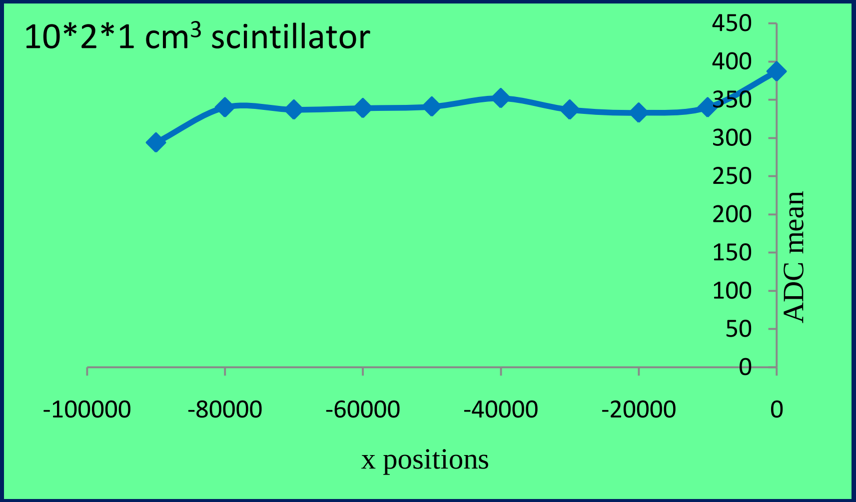


- Responses are nearly equals in a plot except at the middle.
- Amplitudes are increasing with decreasing the width of the scintillator.

For different size of scintillators

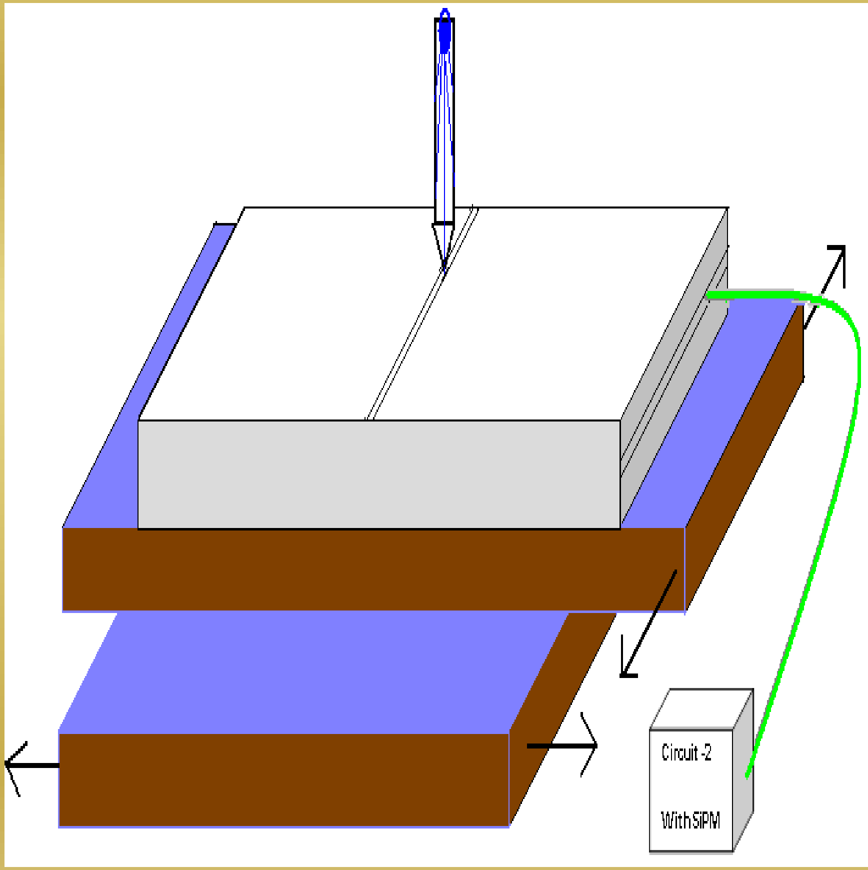


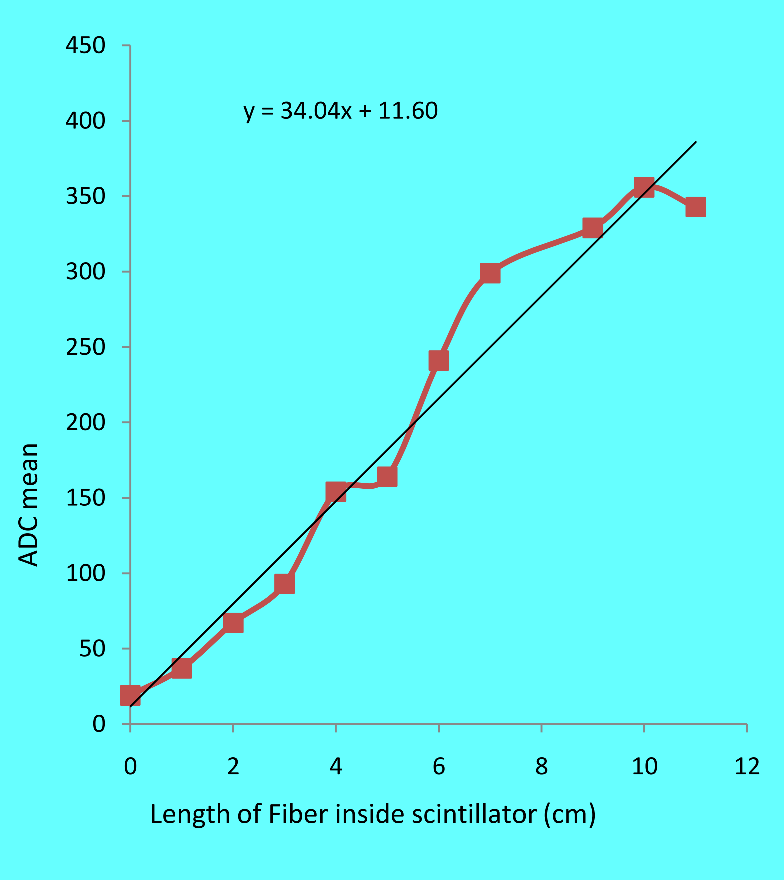




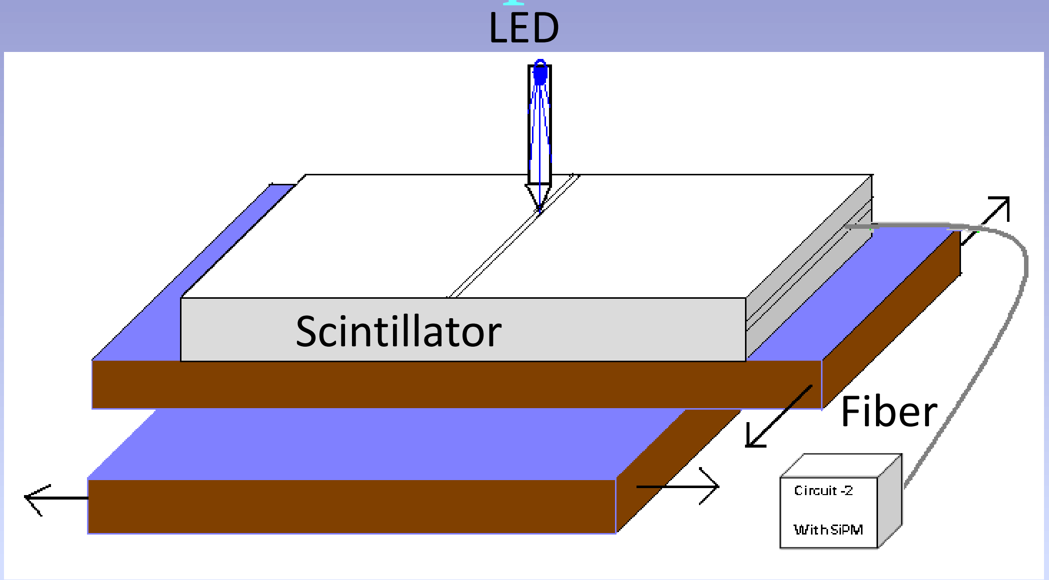
- Responses are nearly equals in a plot .
- Amplitudes are increasing with decreasing the width of the scintillator.

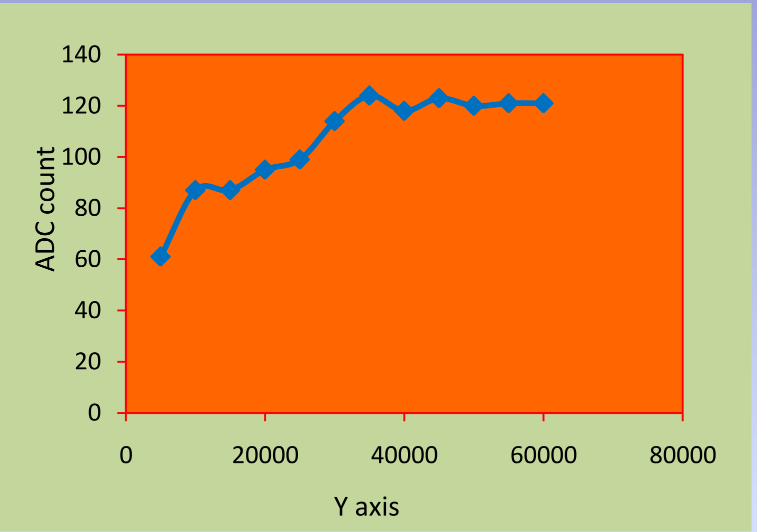
Response with varying the length of WLS fiber inside the Scintillator

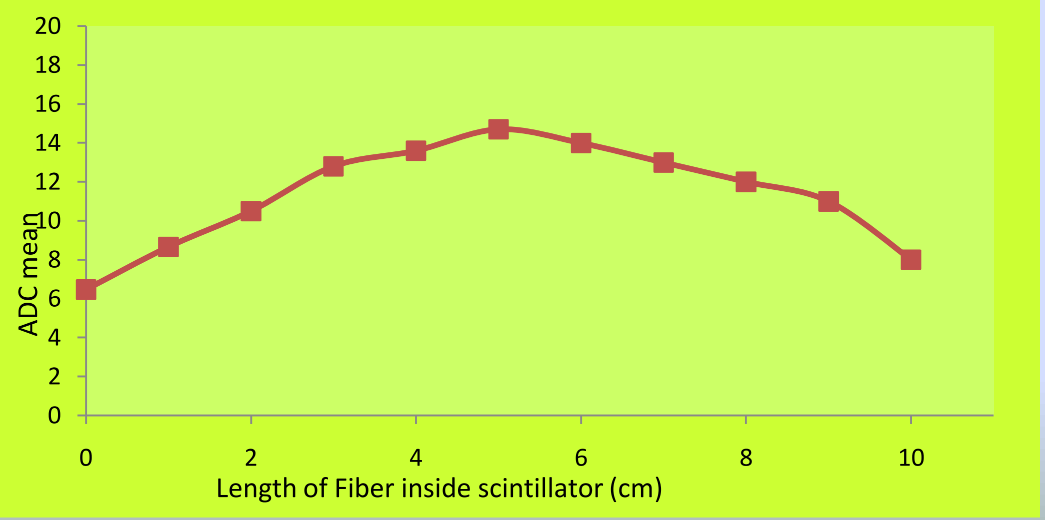


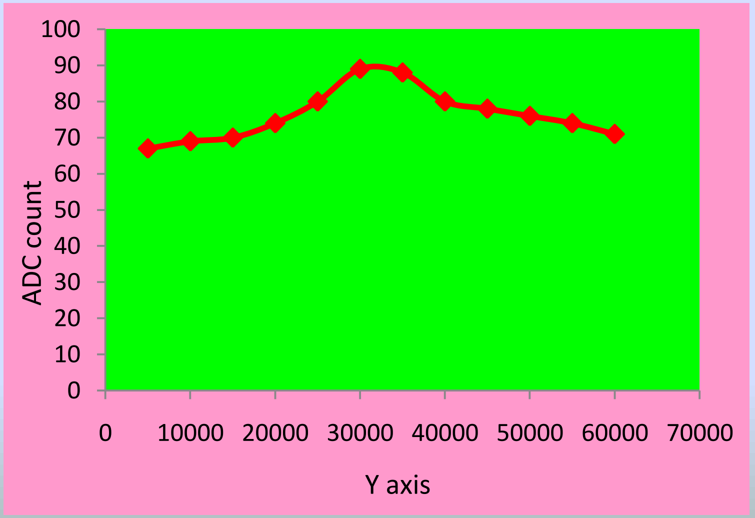


Response with varying the length & position of clear fiber

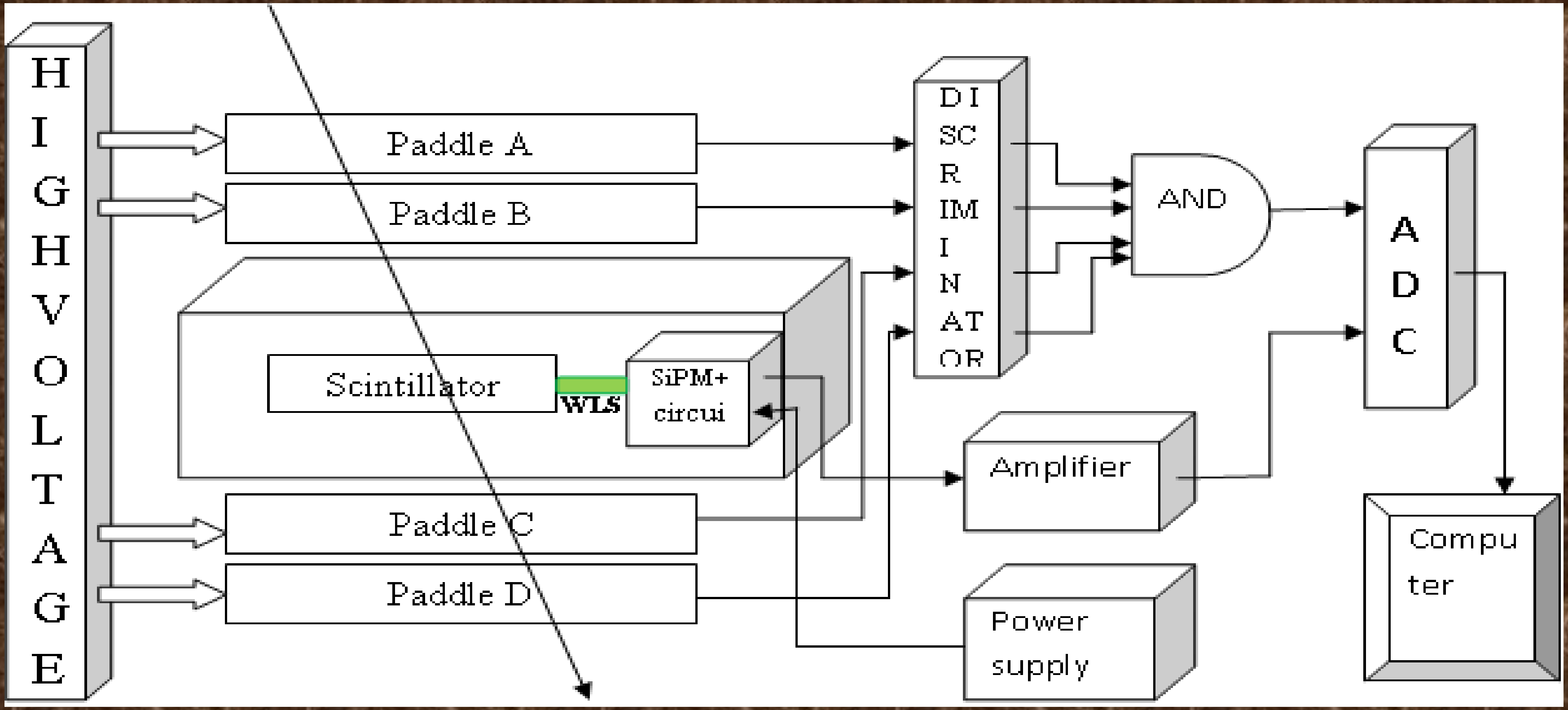


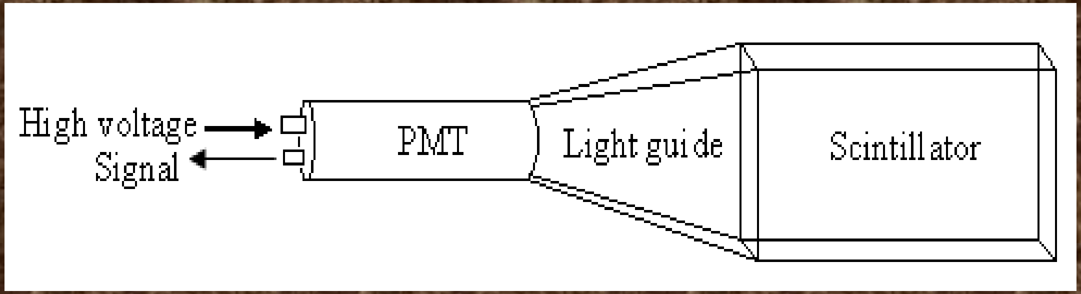




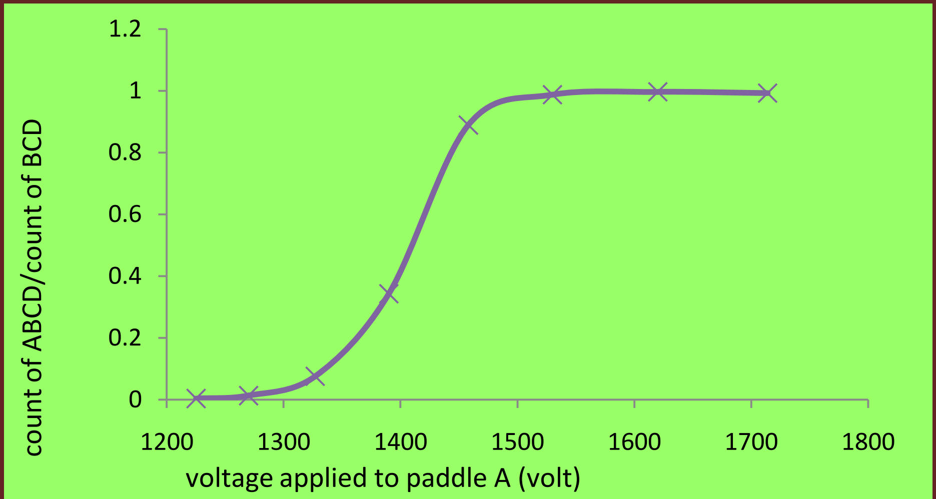


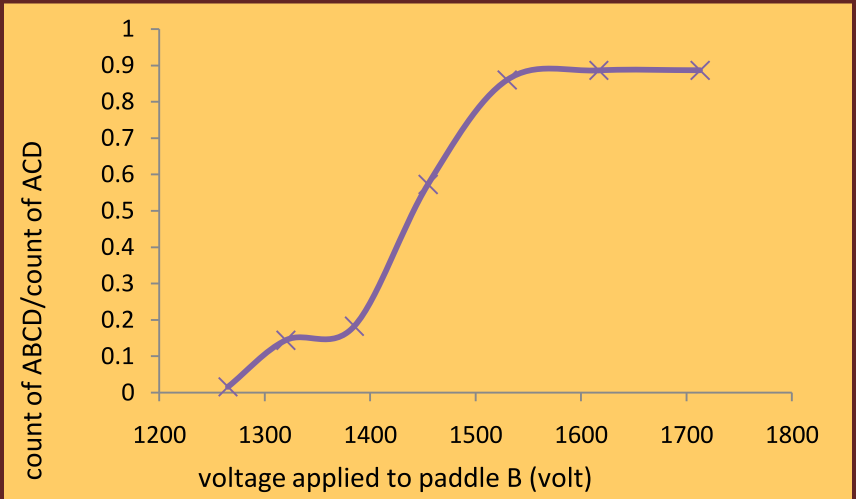
Study of Scintillator detector using cosmic particles

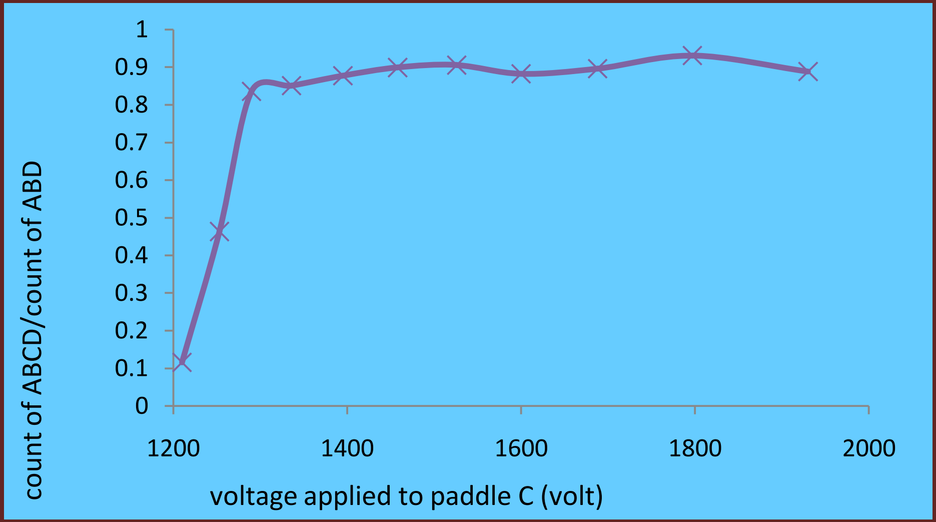


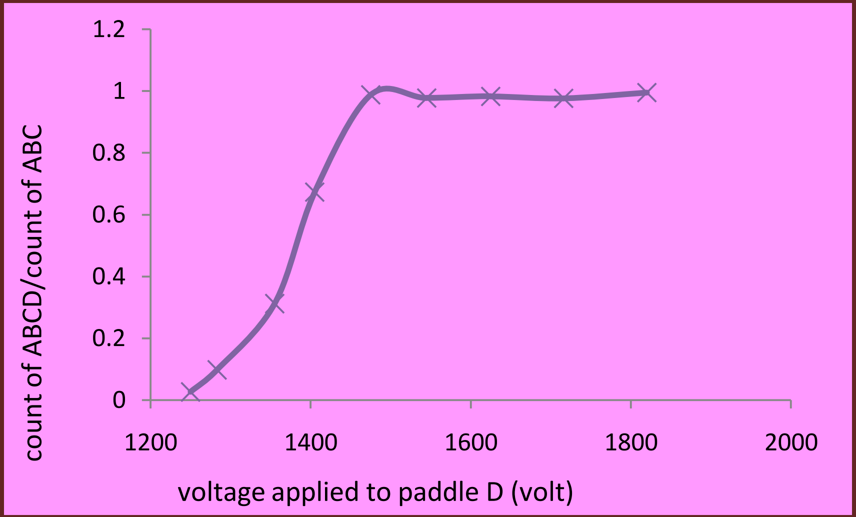


Determination of operating voltage

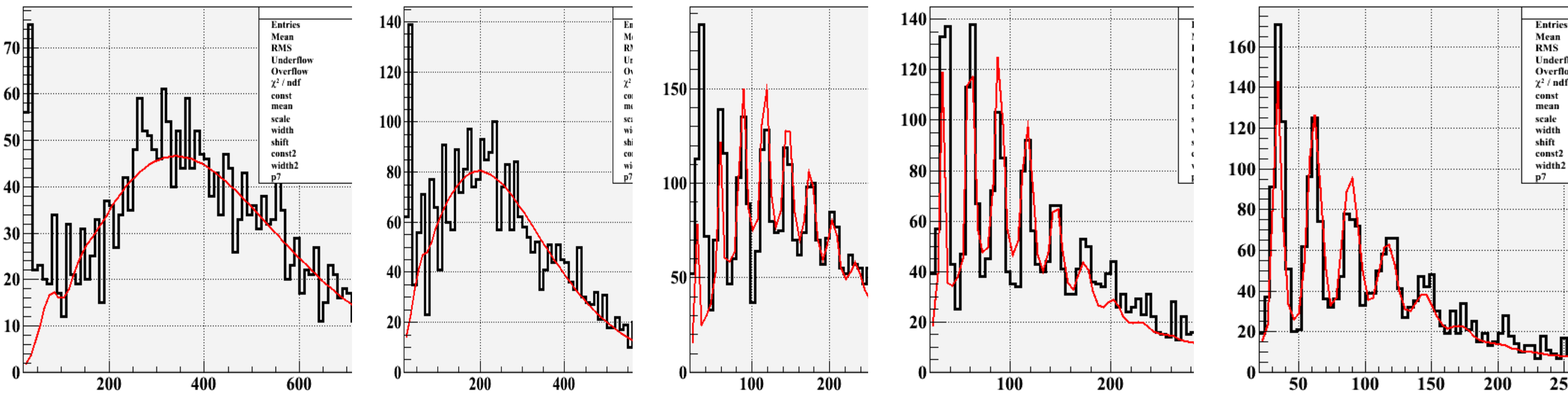




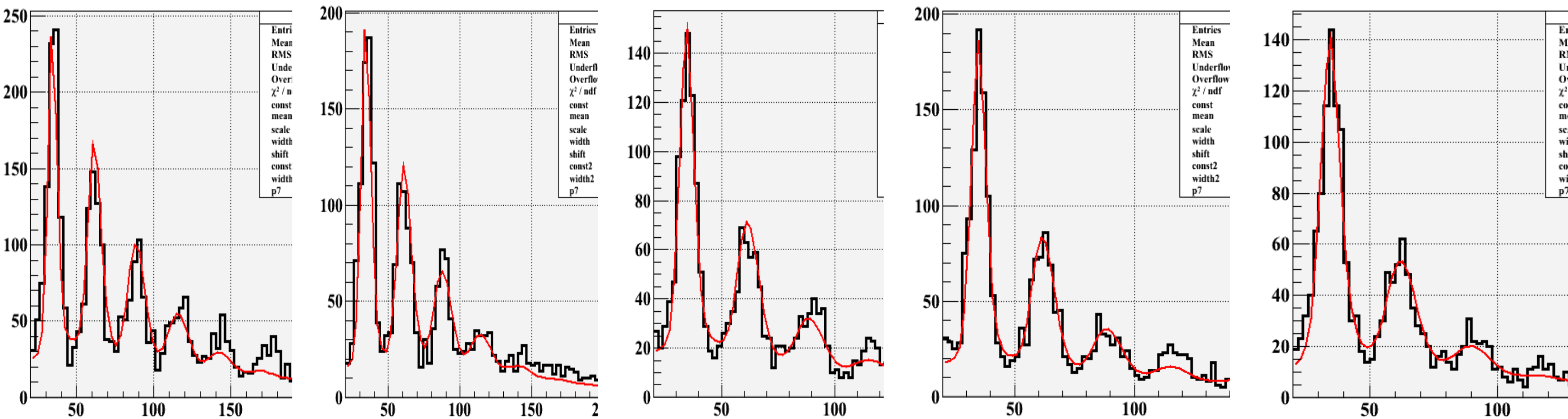




Responses with varying the length of WLS fiber



20cm 1m 2m 3m 4m

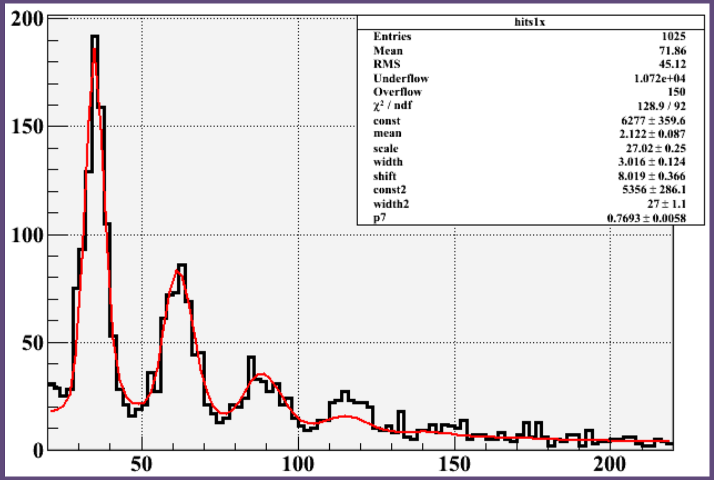


5m 6m 7m 8m 9m

Inefficiency calculation

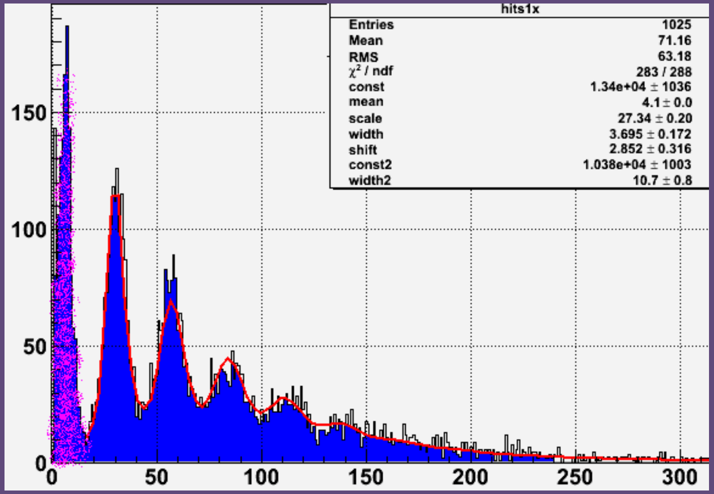
Using mean(μ) of the fit

- According to the Poisson Distribution, the probability of observing r events $P(r)=\mu^r e^{-\mu}/r!$
- $P(0)=e^{-\mu}$

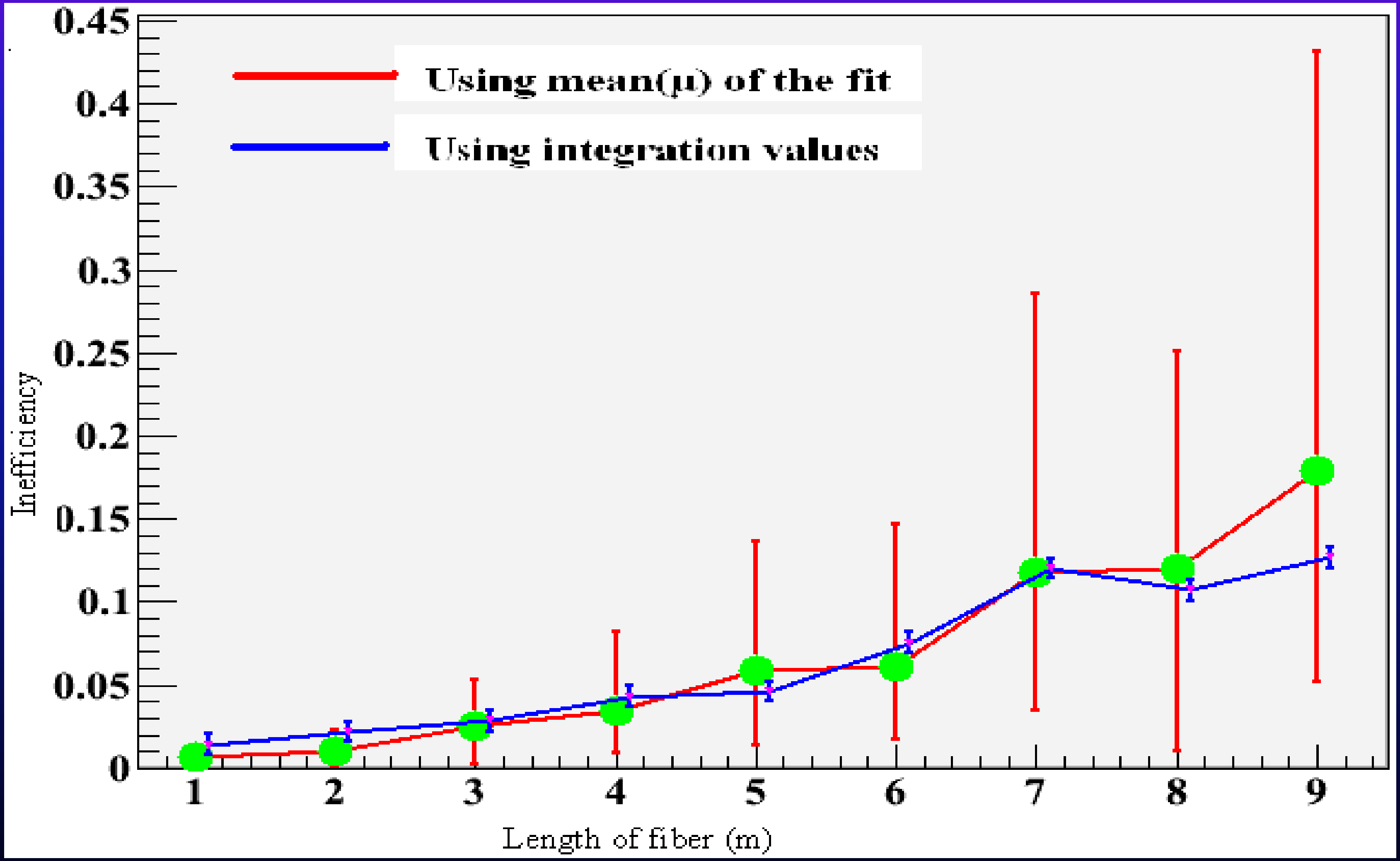


Using integration values

- N=Int. of pedestal
- N_0=Int. of total plot.
- $f = N/N_0$
- $f_0 = N/N_0$ for zero (20cm) length fiber.
- Inefficiency = $f-f_0$



Inefficiency variations with the length of WLS fiber



Conclusions

- We have successfully studied some characteristics of SiPM.
- We made an good arrangement for photon counting system.
- Getting good response from the scintillator + SiPM detector and there is a great chance to use it for ILC (Inter national collider) calorimeter.
- This detector is good enough to measure the cosmic muon.
- Plot of inefficiency variation with length of WLS fiber will help to choose the length of future detector for the INO (India-based Neutrino Observatory).

Producers

- JINR Dubna, Russia
- HAMAMATSU Hamamatsu City, Japan
- PULSAR Moscow, Russia
- CMTA Moscow, Russia

- Similar performance has been reached.
- No real mass production yet, each of the producers is has built ~10000 pieces so far
- Many R&D for future detectors including LHC and ILC use SiPM from all three producers.

References

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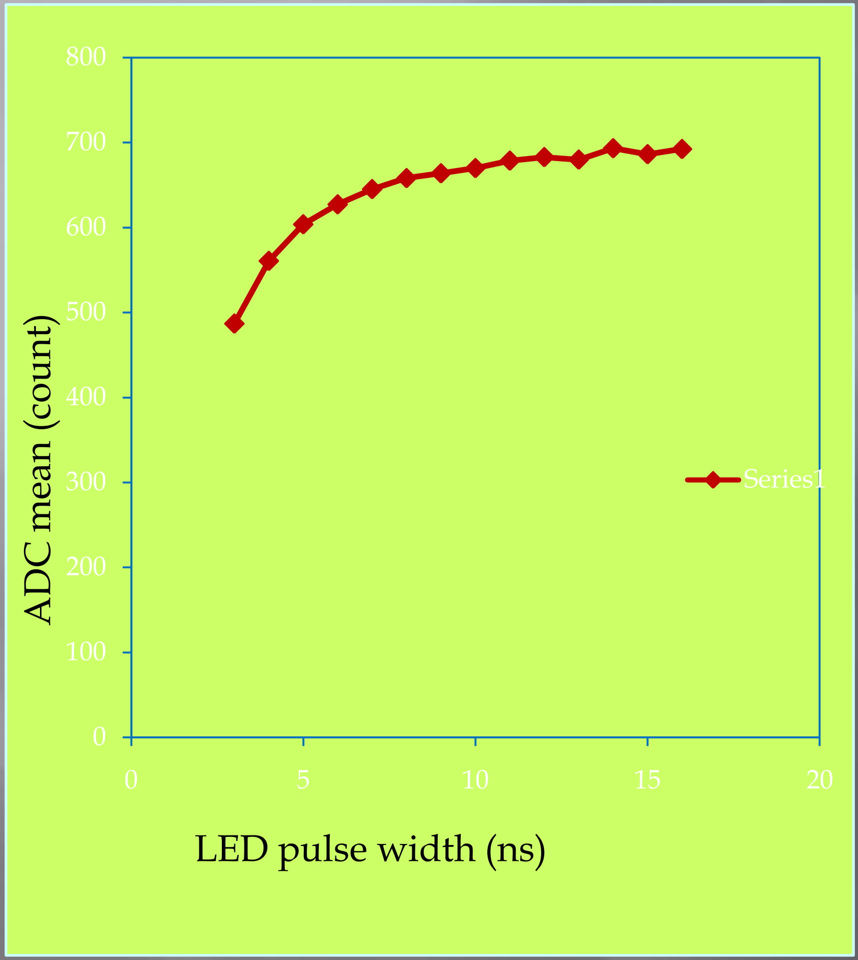
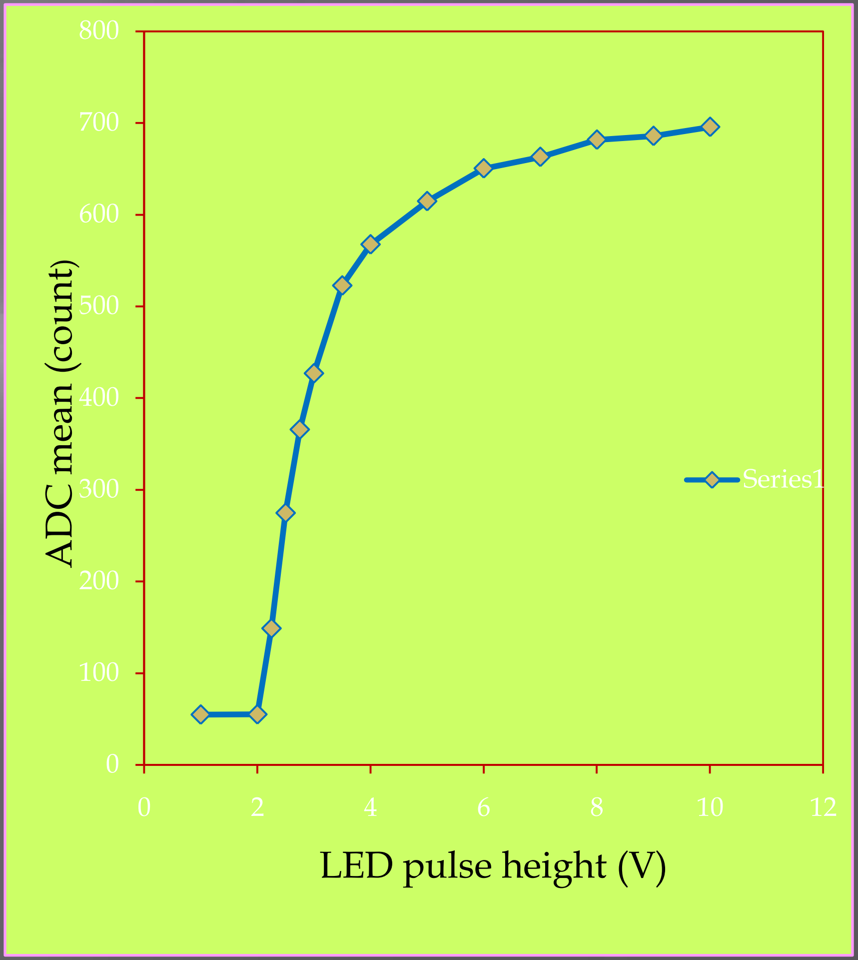
- FLC–*SIPM: Front-End Chip for SIPM Readout for ILC Analog HCAL***,** C. de La Taille, G. Martin-Chassard, L. Raux *IN2P3/ LAL, Orsay, 91898, FRANCE*

Thank you very much for listening!

BACK UP

SIPM responses with LED light





Inefficiency calculation

fiber length	file name	Int(0-1025) (N0)	Int(0-20) (N)	mean(μ)	del(μ)
20cm	29061001	9245	6456	6.5426	0.686
1m	30061001	11228	7999	5.05281	0.301
2m	01071001	15911	11457	4.53355	0.126
3m	01071002	10807	7852	3.66461	0.083
4m	02071001	10290	7628	3.37437	0.321
5m	02071002	14459	10763	2.8353	0.279
6m	03071001	11328	8767	2.78811	0.331
7m	04071001	13194	10799	2.13522	0.347
8m	05071001	13310	10718	2.1218	0.087
9m	06071001	11329	9346	1.72155	0.347
10m	06071002	14130	11786	1.58061	0.089

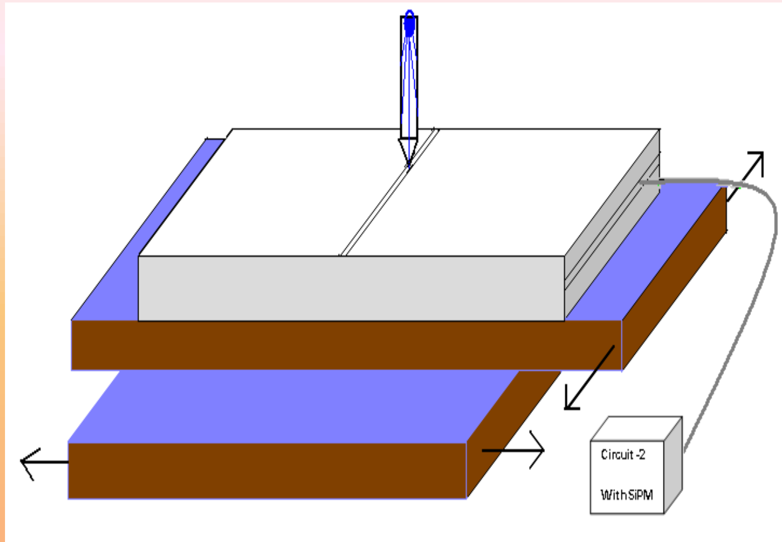
leng	f(i)=N/N0	del(N/N0)	f(i)-f(0)	exp(-μ)	expo(-μ-dμ)	expo(-μ+dμ)
20cm	0.698323	0.0047736	4.18064e-07	0.00144074	0.000725536	0.00286095
1m	0.712415	0.00427168	0.0140924	0.00639135	0.00473009	0.00863605
2m	0.720068	0.0035593	0.0217449	0.0107425	0.00947072	0.012185
3m	0.726566	0.00428757	0.0282431	0.0256142	0.023574	0.0278309
4m	0.741302	0.00431704	0.0429792	0.0342397	0.0248383	0.0471996
5m	0.744381	0.00362765	0.0460577	0.0587009	0.0444096	0.0775913
6m	0.773923	0.00393007	0.0756	0.0615374	0.0441965	0.0856822
7m	0.818478	0.00335567	0.120155	0.118219	0.0835575	0.167258
8m	0.805259	0.00343247	0.106936	0.119816	0.109832	0.130707
9m	0.824962	0.00357015	0.126639	0.178789	0.126369	0.252953
10m	0.834112	0.00312931	0.135789	0.205849	0.18832	0.22501

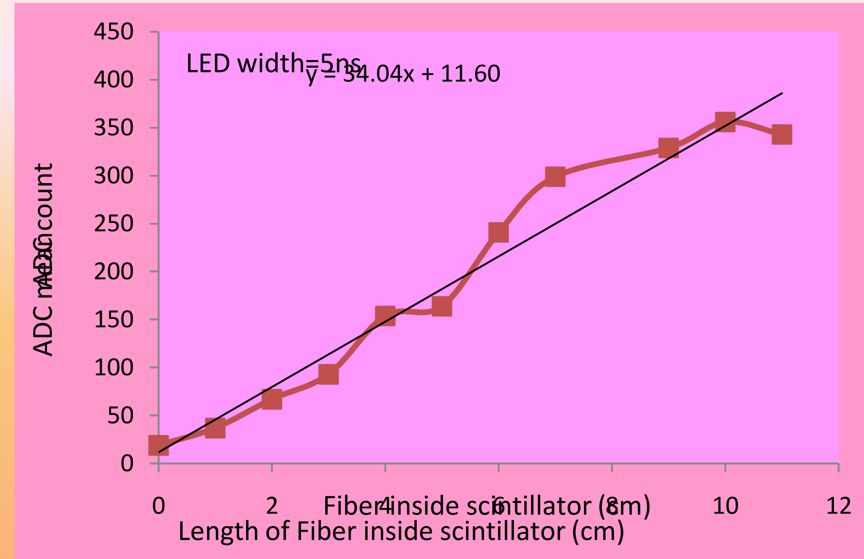
```
awk '{print $1," ",$4/$3," "sqrt($4*($3-$4)/($3*$3*$3))," ",($4/$3-0.698323),
" "exp(-$5)," ",exp(-$5-$6)," ",exp(-$5+$6)," ",-log($4/$3-0.698323)}' test.txt
```

Fit function

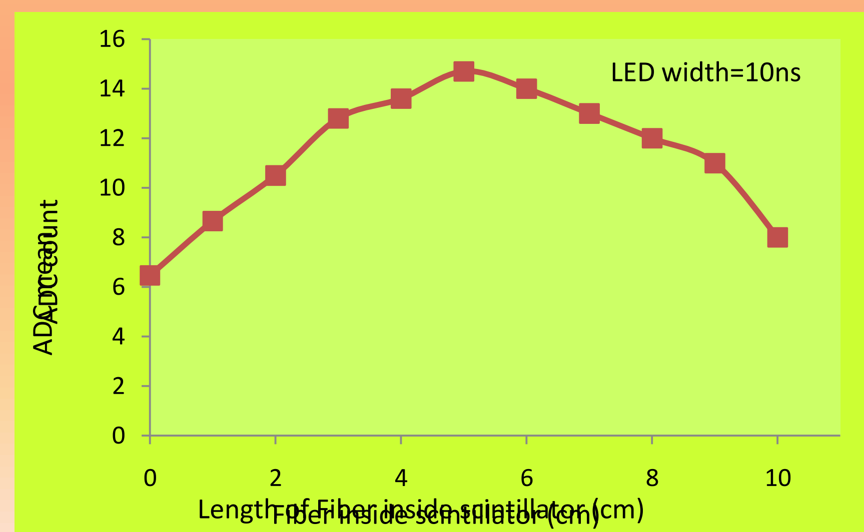
```
Double_t poisgaufun(Double_t *x, Double_t *par)
{
  Double_t invsq2pi = 0.3989422804014;   // (2 pi)^(-1/2)
  Double_t sc =   5.0; // convolution extends to +-sc Gaussian sigmas
  Double_t xx;
  Double_t fland;
  Double_t sum = 0.0, sum1=0.0;
  double invscl = 1./max(1., par[2]);
  double xval = x[0] - par[4];
  double scale=pow(max(xval*invscl,1.), 0.6);
  int xlow = max(1.,((xval - sc * scale*par[3])*invscl+0.5));
  int xupp = ((xval + sc * scale*par[3])*invscl+0.5);
  for(int i=xlow; i<=xupp; i++)
  {
    xx = float(i)/invscl;
    fland = (TMath::Poisson(i,par[1]))*pow(par[7], double(i));
    sum += fland * TMath::Gaus(xval,xx,scale*par[3]);
  }
  scale=pow(max(xval*invscl,1.), 1.0);
  xlow = max(1.,((xval - sc * scale*par[6])*invscl+0.5));
  xupp = ((xval + sc * scale*par[6])*invscl+0.5);
  for(int i=xlow; i<=xupp; i++)
  {
    xx = float(i)/invscl;
    fland = (TMath::Poisson(i,par[1]))*pow(par[7], double(i));
    sum1 += fland * TMath::Gaus(xval,xx,scale*par[6]);
  }
  return (par[0] * sum * invsq2pi / (scale*par[3]) +
        par[5] * sum1 * invsq2pi / (scale*par[6]));
}
```

Comparison between WLS & clear Fiber





- When both of them are attached at the edge give same result
- With increasing amount inside the scintillator of WLS, count increases significantly and linearly but in the case of white fiber change is very small.
- So for the same configurations when white fiber gives count 36 at the edge, WLS gives count 471 keeping 10 cm inside the scintillator.

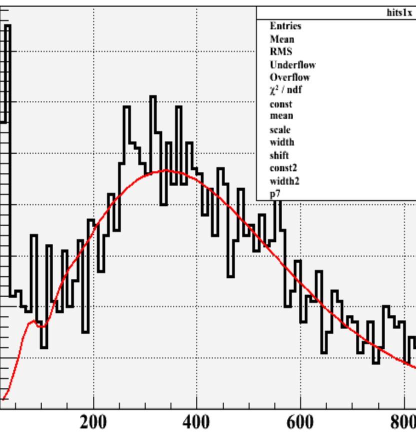


Comparisons of typical present photo-detectors

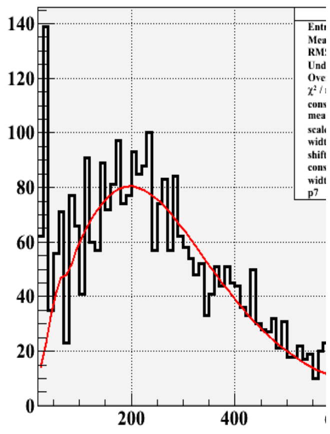
Table 1:

	PMT	APD	HPD	SiPM
Photon detection efficiency:				
blue	20%	50%	20%	12%
green - yellow	a few %	60-70%	a few %	15%
red	<1%	80%	<1%	15%
Gain	10^6-10^7	100-200	10^3	10^6
High voltage	1-2 kV	100-500 V	20 kV	25 V
Operation in the magnetic field	problematic	OK	OK	OK
Threshold sensitivity S/N$\gg$1	1 ph.e.	$\sim$10 ph.e.	1 ph.e.	1 ph.e.
Timing /10 ph.e.	$\sim$100 ps	a few ns	$\sim$100 ps	30 ps
Dynamic range	$\sim 10^6$	large	large	$\sim 10^3/\text{mm}^2$
Complexity	high (vacuum, HV)	medium (low noise electronics)	very high (hybrid technology, very HV)	relatively low

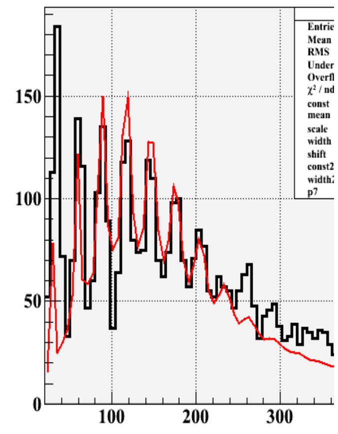
Responses with varying the length of WLS fiber



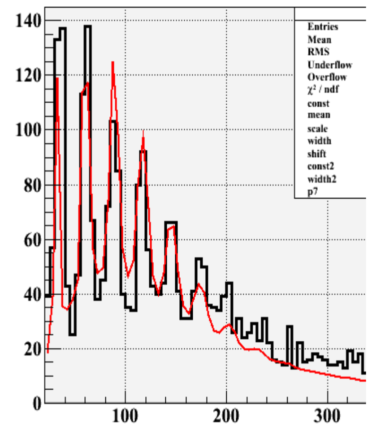
20cm



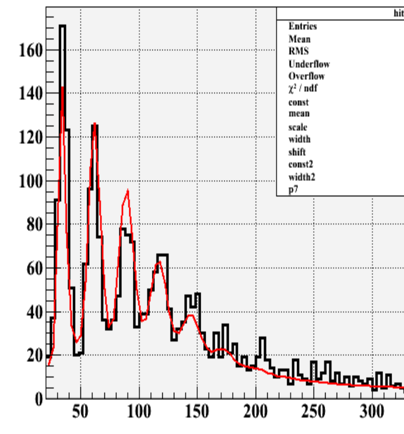
1m



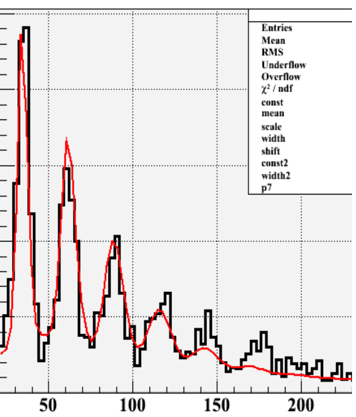
2m



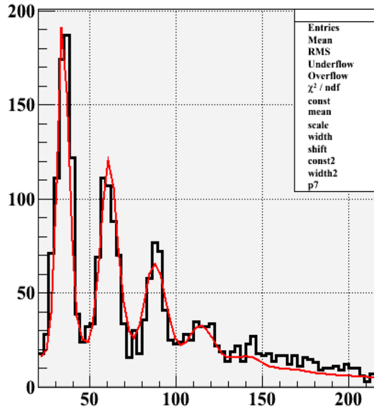
3m



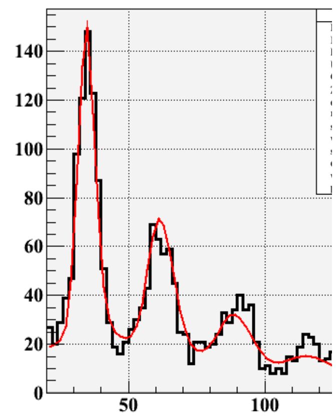
4m



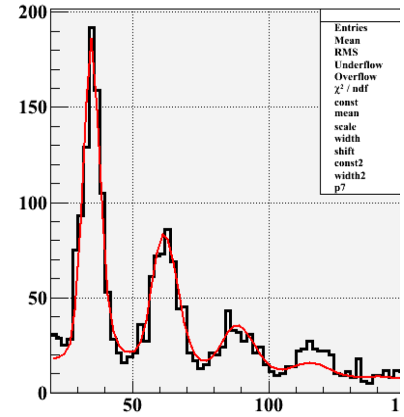
5m



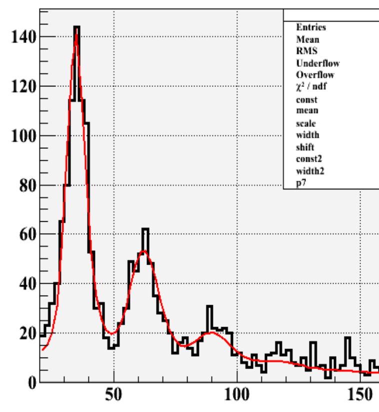
6m



7m



8m



9m