Development and Signal Analysis of Sandwich Veto Detector at COMPASS

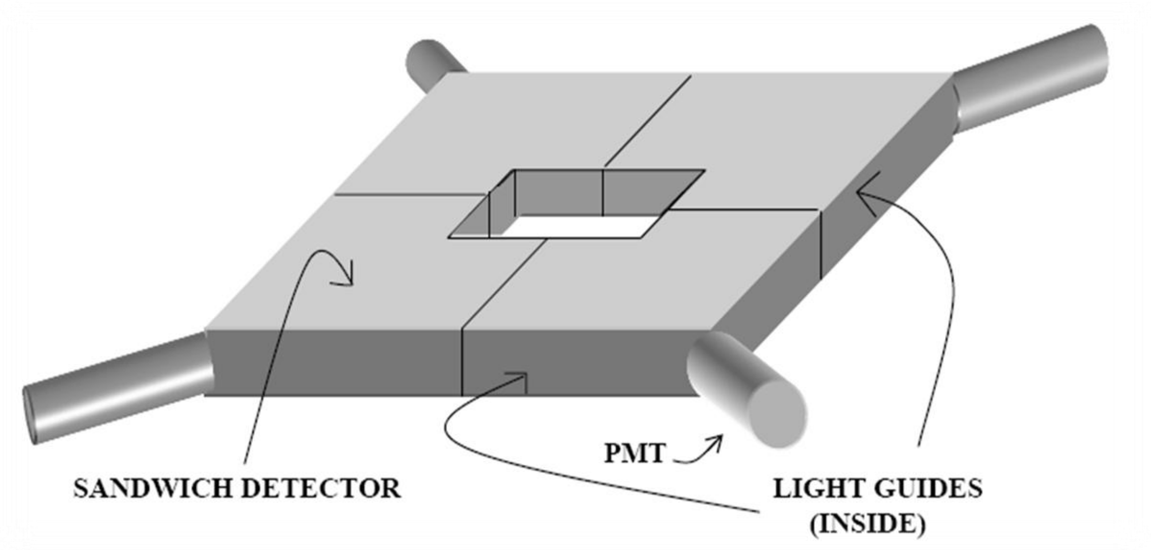
Sabyasachi Sarkar
(COMPASS Collaboration)

XIX DAE-BRNS High Energy Physics Symposium
13-18 December, 2010
Jaipur, India

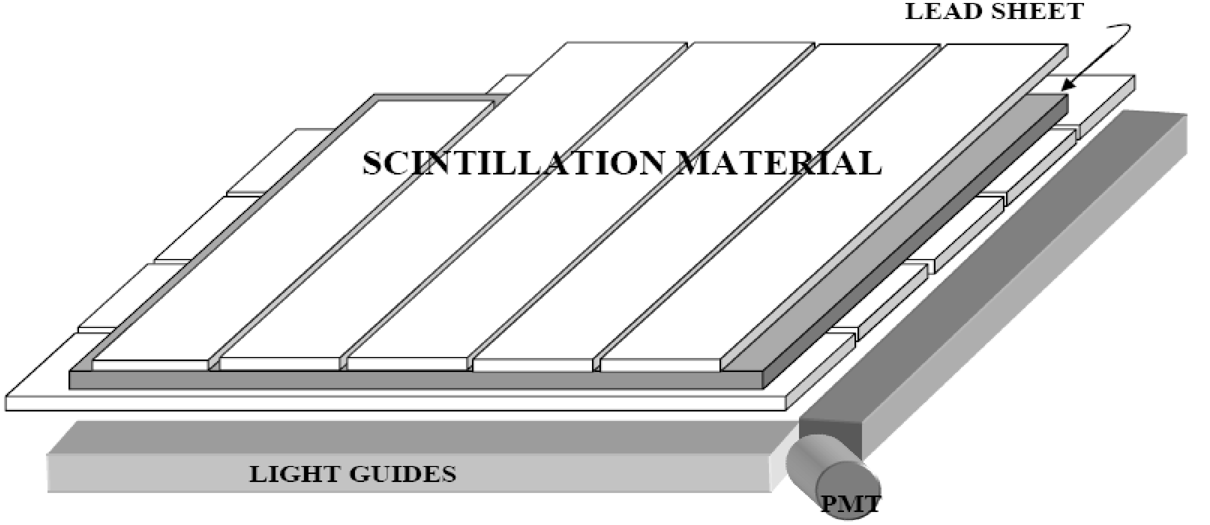
The Sandwich Veto detector is installed for COMPASS hadron run 2008-09. It is placed in front of RPD (Recoil Proton Detector) with an effective acceptance angle 11 degree. This is installed to detect the charged and neutral particles beyond the acceptance limit of the spectrometer.

As per COMPASS hadron program, 190 GeV pion beam (also proton or kaon beam) is bombarded over the liquid hydrogen target.

So this Sandwich Veto ensures the inert proton recoils.



The Sandwich Detector is of a square geometry and consists of four parts with a central hole for passing the beam.

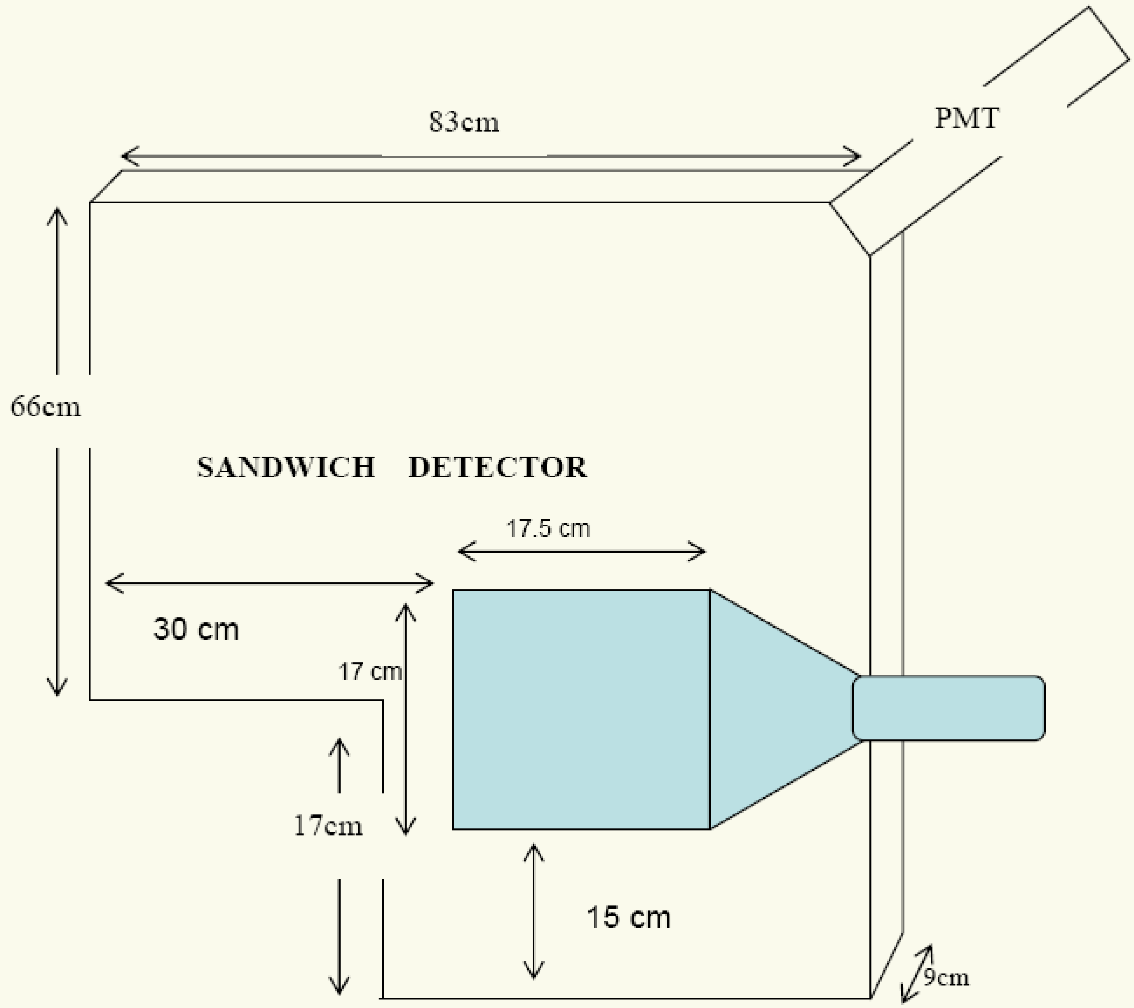


Two paddle type scintillation detectors are kept over and below the Sandwich Detector (SD), in a same vertical line.

Signals from paddle-1 and paddle-2 are in coincidence (logical AND). Trigger is on the paddles in the sense to get signals only for cosmic muons in the Sandwich Detector.

No trigger is applied on the Sandwich Detector.

Position of the paddle type scintillation detector



We are recording the pulse amplitude in *mV* with respect to time (ns) in *x*-axis in a DPO (Digital phosphor oscilloscope), with the three channels for the three output.

Actually in the *y*-axis of the oscilloscope we are recording the current *I* in amps, if we consider the oscilloscope resistance (about 50 ohms).

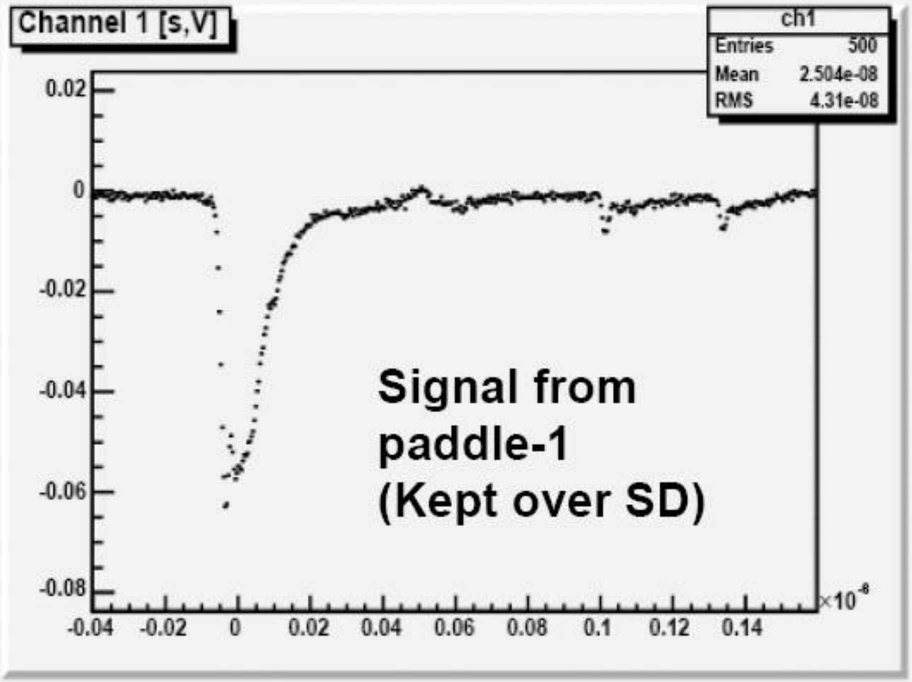
To know, how much charge (Q) is deposited in a single event, where

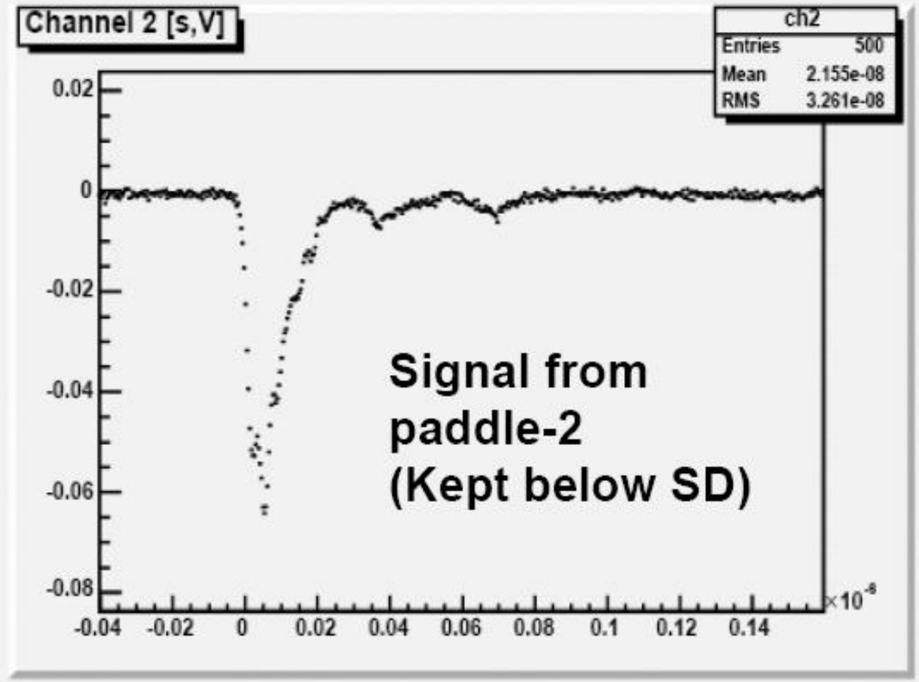
$$Q = \int \frac{V(t)}{R}\, dt,$$

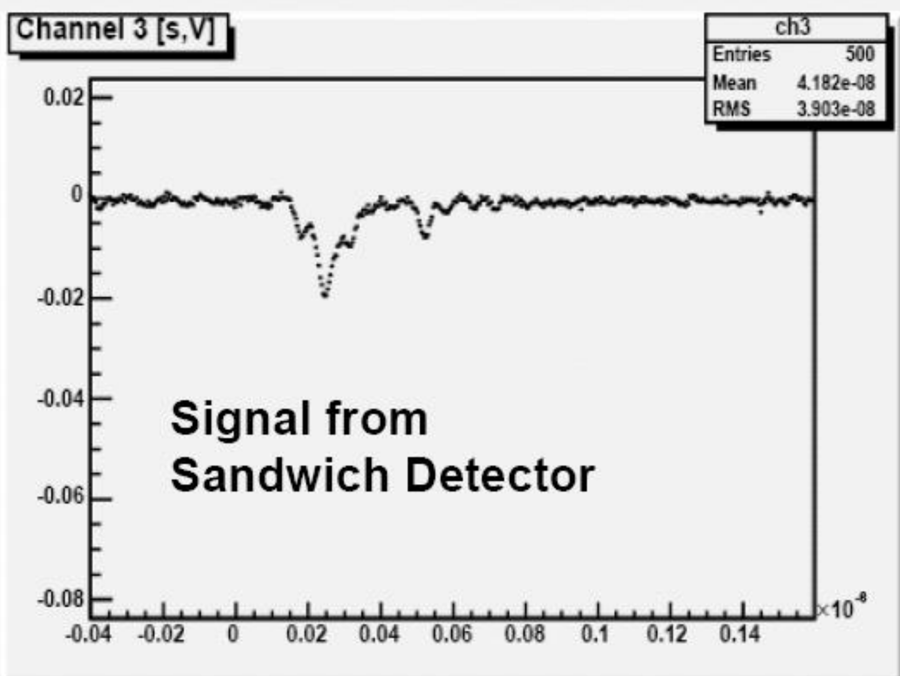
we integrate the histogram in time axis (*x*-axis) with a certain time interval, along with the background subtraction at that interval.

The resulting histogram peak will show the most probable value of charge deposition in nC (nano Coulomb) for a single event on that specific part of the Sandwich Detector.

To convert the charge deposition to the most probable number of electrons recorded per event we need to know the response of the detector for single electron.

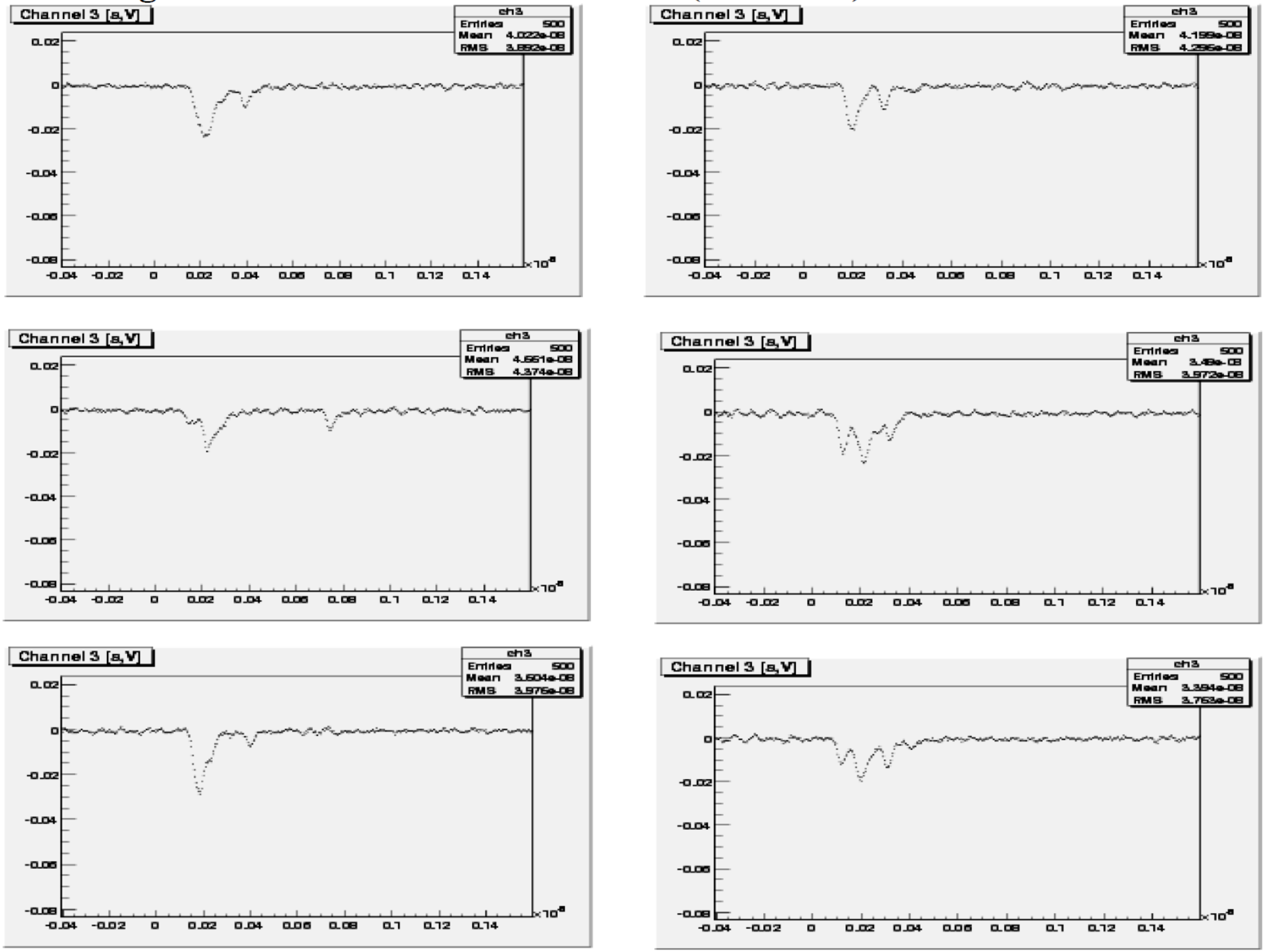


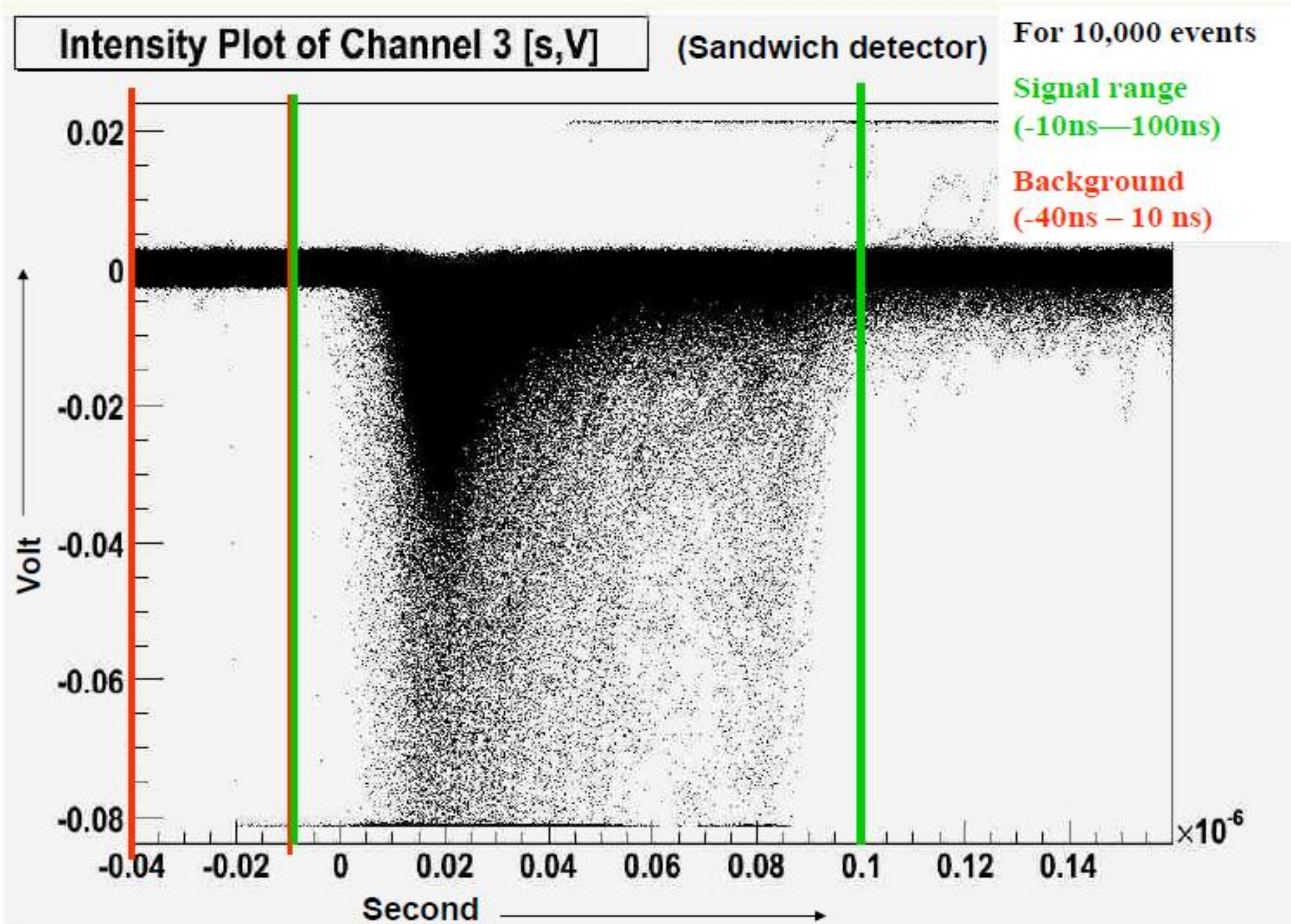




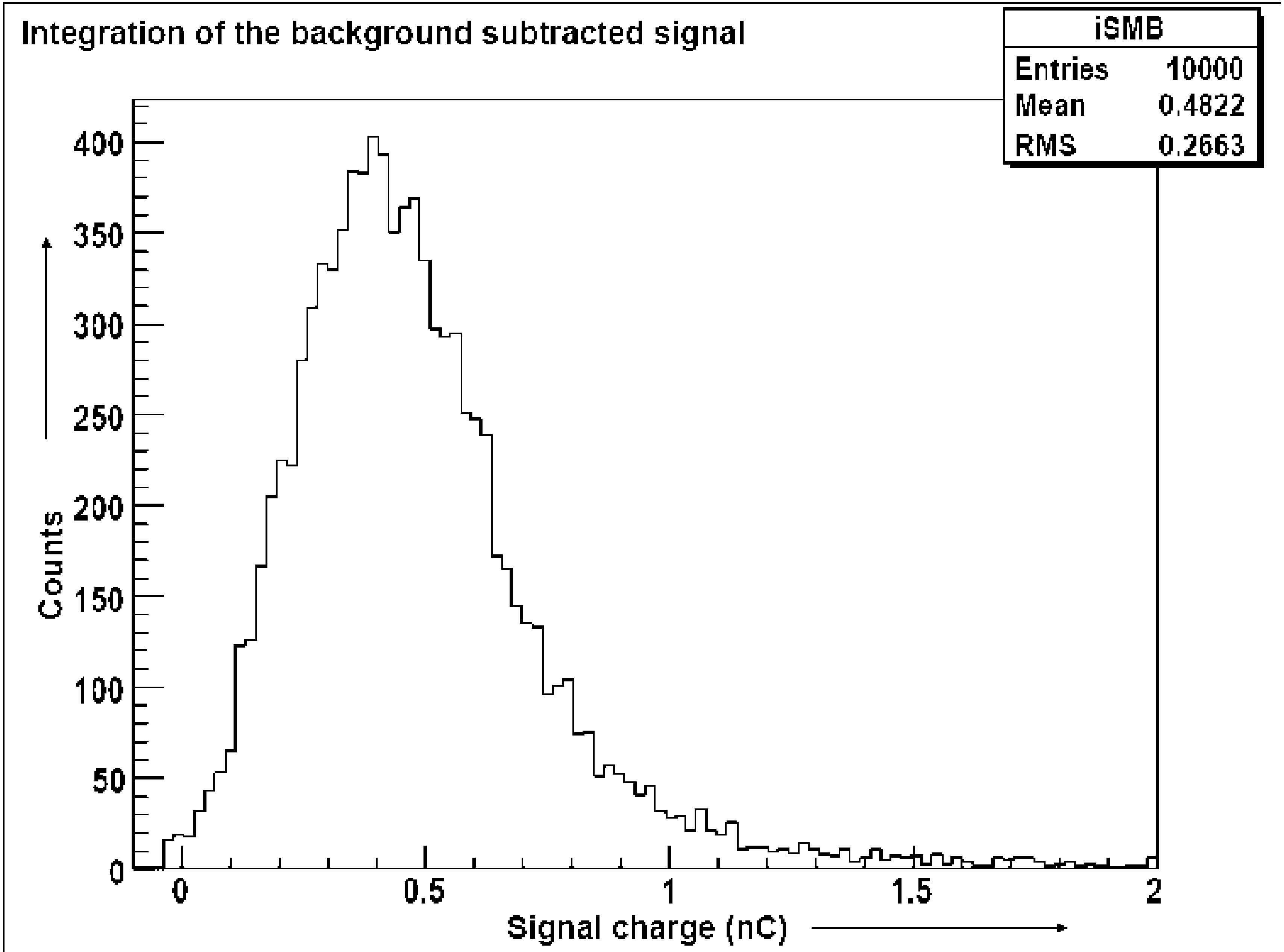
- **Channel 1 & 2 of the oscilloscope are in coincidence.**
- **Responses shown here for single event.**

Signals from the Sandwich Detector (channel 3) for different events





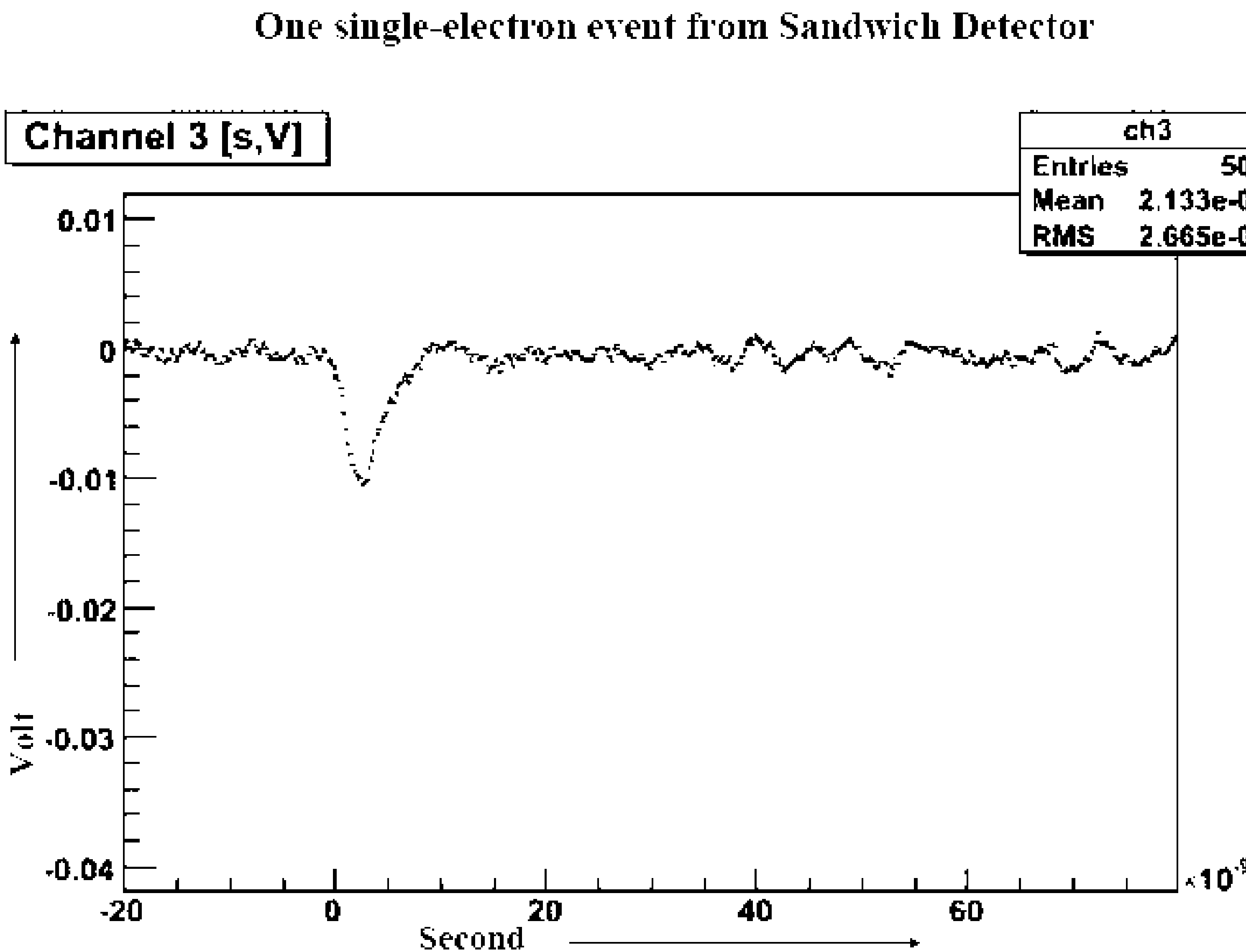
Intensity Plot of Channel 3 [s,V]
(Sandwich detector)
For 10,000 events
Signal range
(-10ns—100ns)
Background
(-40ns – 10 ns)
Volt
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
×10^-6
Second

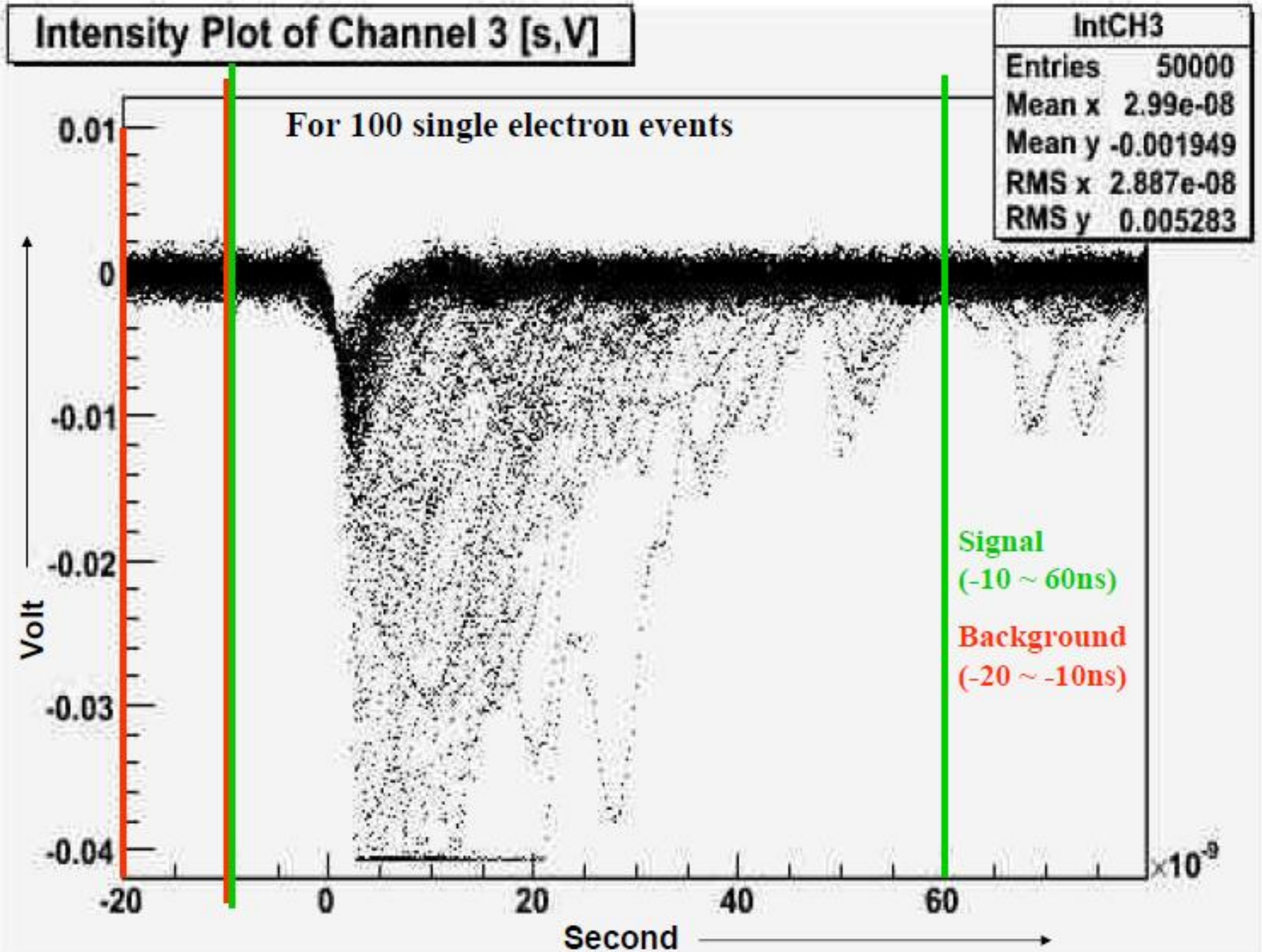

Integration of the background subtracted signal
iSMB
Entries 10000
Mean 0.4822
RMS 0.2663
Counts
0
50
100
150
200
250
300
350
400
0
0.5
1
1.5
2
Signal charge (nC)

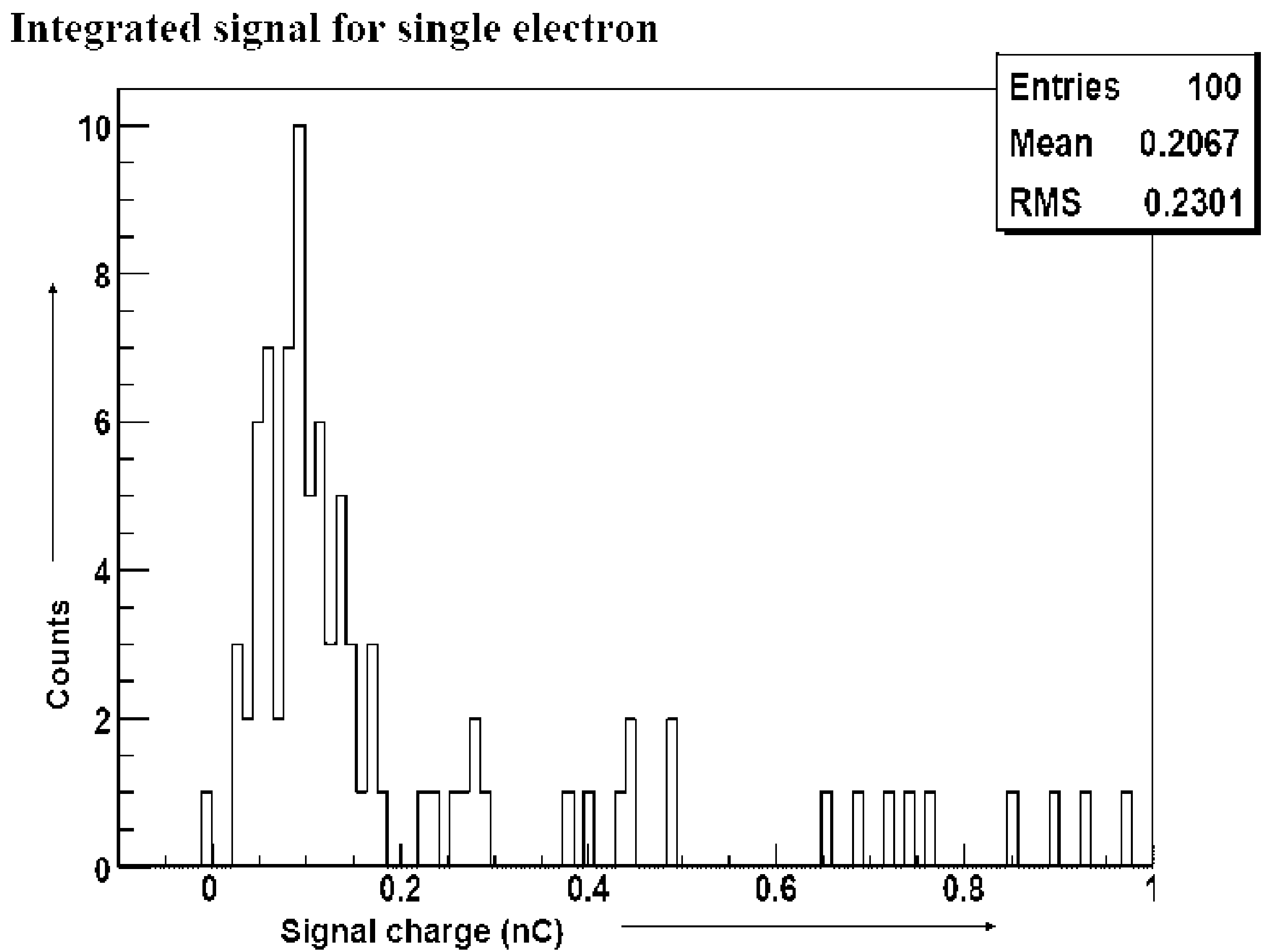
The task is:

To know how many electrons are recorded in the detector for a single event, we have to divide the total signal charge by the single electron charge deposition.

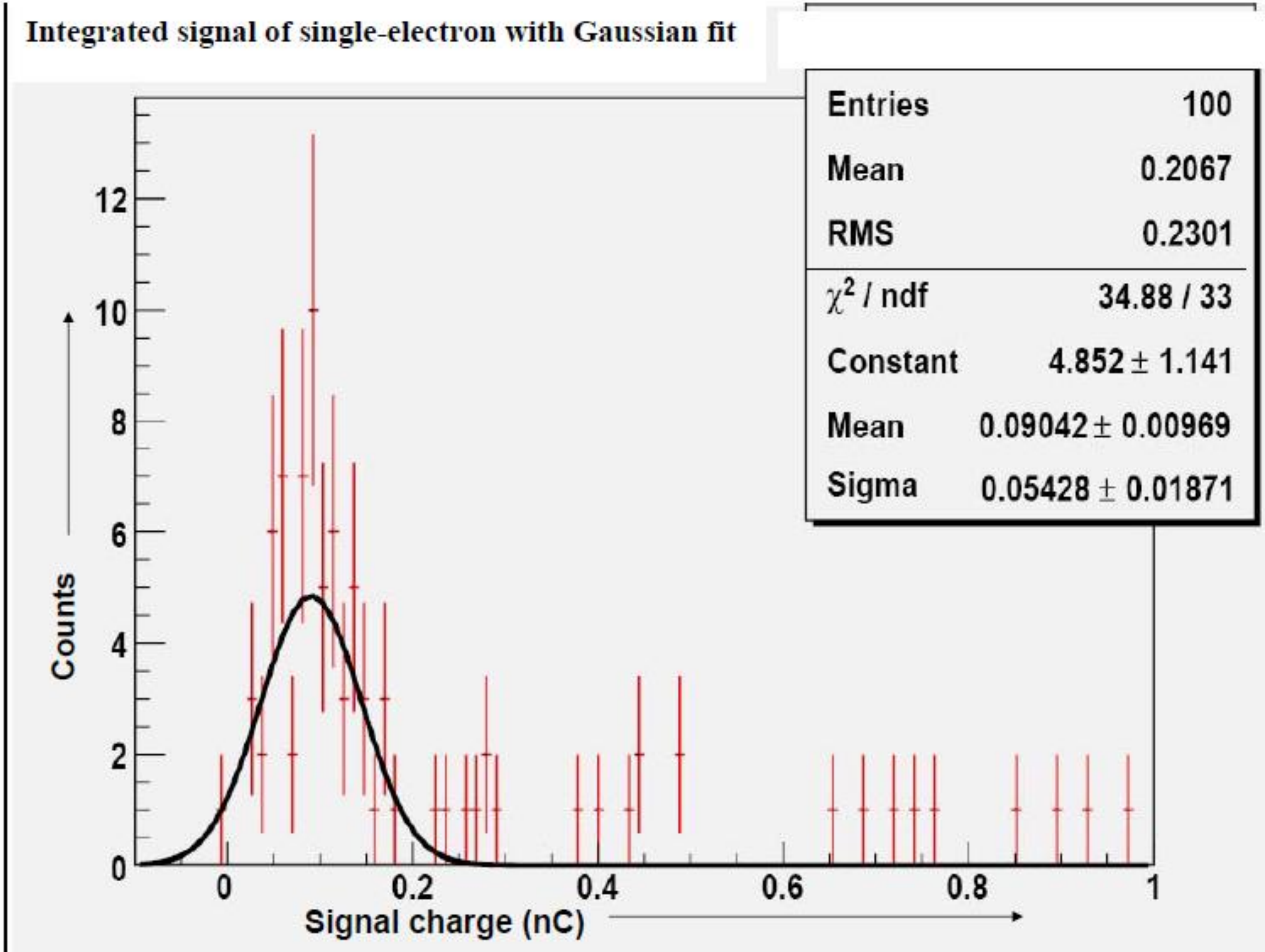
To estimate how much charge a single electron can deposit, we trigger on the Sandwich Detector with a low threshold.


One single-electron event from Sandwich Detector
Channel 3 [s,V]
ch3
Entries 500
Mean 2.133e-08
RMS 2.665e-08
0.01
0
-0.01
-0.02
-0.03
-0.04
Volt
-20
0
20
40
60
x10^-9
Second

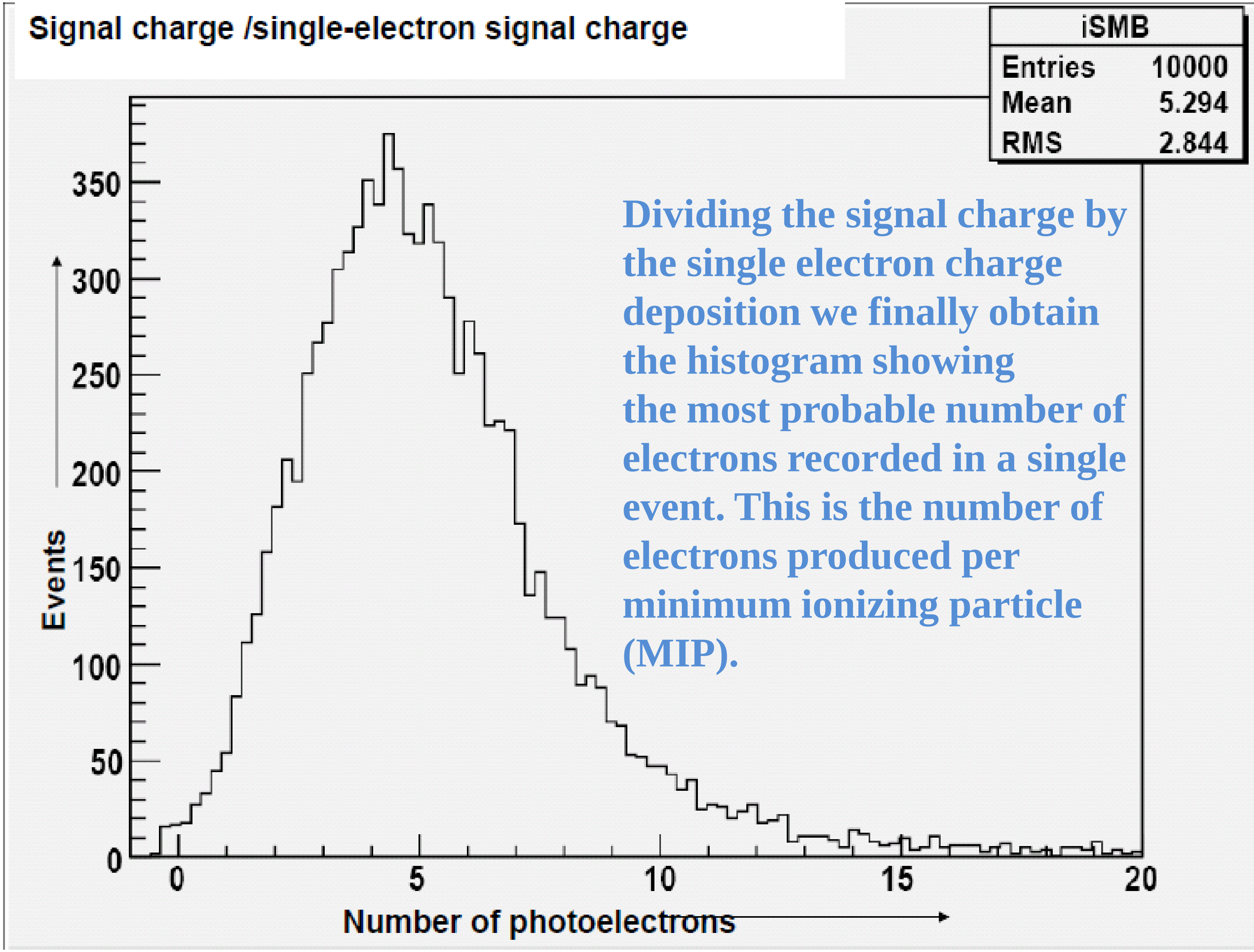

Intensity Plot of Channel 3 [s,V]
IntCH3
Entries 50000
Mean x 2.99e-08
Mean y -0.001949
RMS x 2.887e-08
RMS y 0.005283
For 100 single electron events
0.01
0
-0.01
-0.02
-0.03
-0.04
Volt
-20
0
20
40
60
×10⁻⁹
Second
Signal
(-10 ~ 60ns)
Background
(-20 ~ -10ns)



Integrated signal for single electron
Entries 100
Mean 0.2067
RMS 0.2301
Counts
0
2
4
6
8
10
0
0.2
0.4
0.6
0.8
1
Signal charge (nC)



Integrated signal of single-electron with Gaussian fit
Entries 100
Mean 0.2067
RMS 0.2301
χ² / ndf 34.88 / 33
Constant 4.852 ± 1.141
Mean 0.09042 ± 0.00969
Sigma 0.05428 ± 0.01871
Counts
Signal charge (nC)
0
2
4
6
8
10
12
0
0.2
0.4
0.6
0.8
1



Dividing the signal charge by the single electron charge deposition we finally obtain the histogram showing the most probable number of electrons recorded in a single event. This is the number of electrons produced per minimum ionizing particle (MIP).

To get the mean number of electrons produced in the PMT we did a simulation in an independent approach.

When the non stopping cosmic muons are passing through the scintillation material, they excite scintillator molecules causing fluorescence along the path.

The energy deposition by the muon on the scintillator cause the excitation of the electrons and when the electrons drop back to there ground state, emit photons isotropically.

Simulations have been done as follows:

As the cosmic muons passes through the scintillation material (polystyrene), it loose energy according to Landau distribution:

$$f(\Delta, x) = \frac{1}{\pi}\frac{1}{\xi}\int_0^\infty \exp\left(-t\ln t - \frac{\Delta - \Delta_{MPV}}{\xi}\right)\sin \pi t \, dt,$$

Where the most probable value of energy loss:

$$\Delta_{MPV} = \xi\left(\ln\frac{2m_e c^2\gamma^2\beta^2 T_{max}}{I^2} - \beta^2 + 1 - \gamma_E\right).$$

The parameters are $\xi = \frac{2\pi N_A e^4 Z}{m_e \beta^2 c^2 A}\rho x$

x = path length through absorber,

γ_E = Euler's constant *0.577*.

The *mean energy loss* can be obtained by the ***Bathe-Block formula***,

$$\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left(\frac{1}{2} \ln \frac{2m_e c^2 \gamma^2 \beta^2 T_{max}}{I^2} - \beta^2 - \frac{\delta}{2} \right)$$

Now for the Polystyrene as a scintillation material of 2.5 cm thickness, we obtain Δ_{MPV} as 5.27 MeV, and the spread parameter ξ = 0.216 MeV (considering mean energy of the muons at sea level ≈ 4 GeV).

The number of photoelectrons produced by the PMT was taken from the Poisson distribution

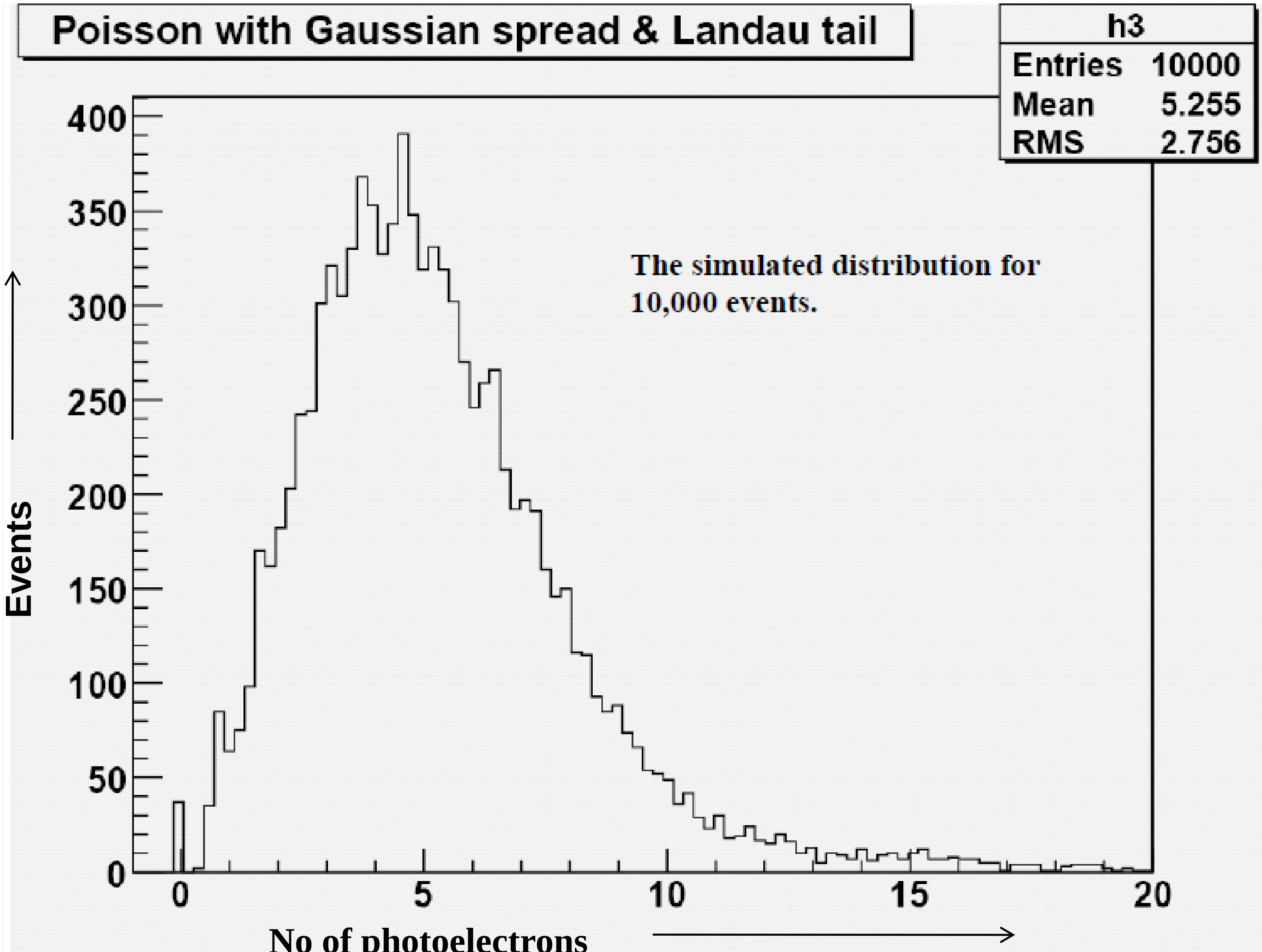
$$f(\lambda,k) = e^{-\lambda} \lambda^k / k! ,$$

where λ is the most probable number of photoelectrons produced, which is in fact, proportional to the actual energy deposited by the muon in the detector.

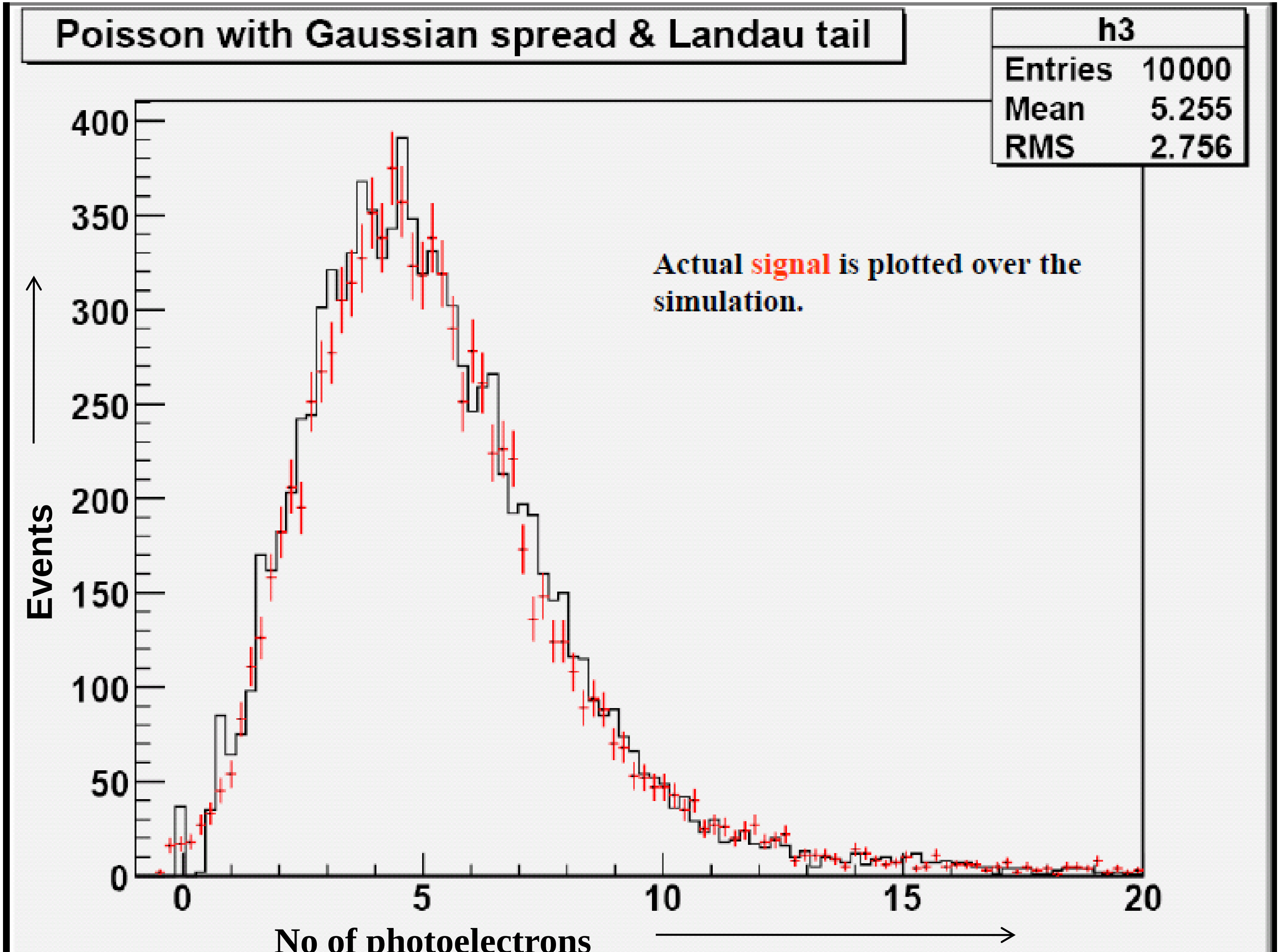
This proportionality factor was chosen (0.85) to match the actual signal with the simulation

So we convolute the Landau distribution with the Poisson distribution. Assuming the number of electrons produced by per minimum ionizing particle we get the mean electrons from Poisson distribution.

In practice the electron peak is not sharp but have a Gaussian spread due to PM response. The spread is proportional to the square-root of the number of electrons produced. The proportionality factor is here *0.25*.

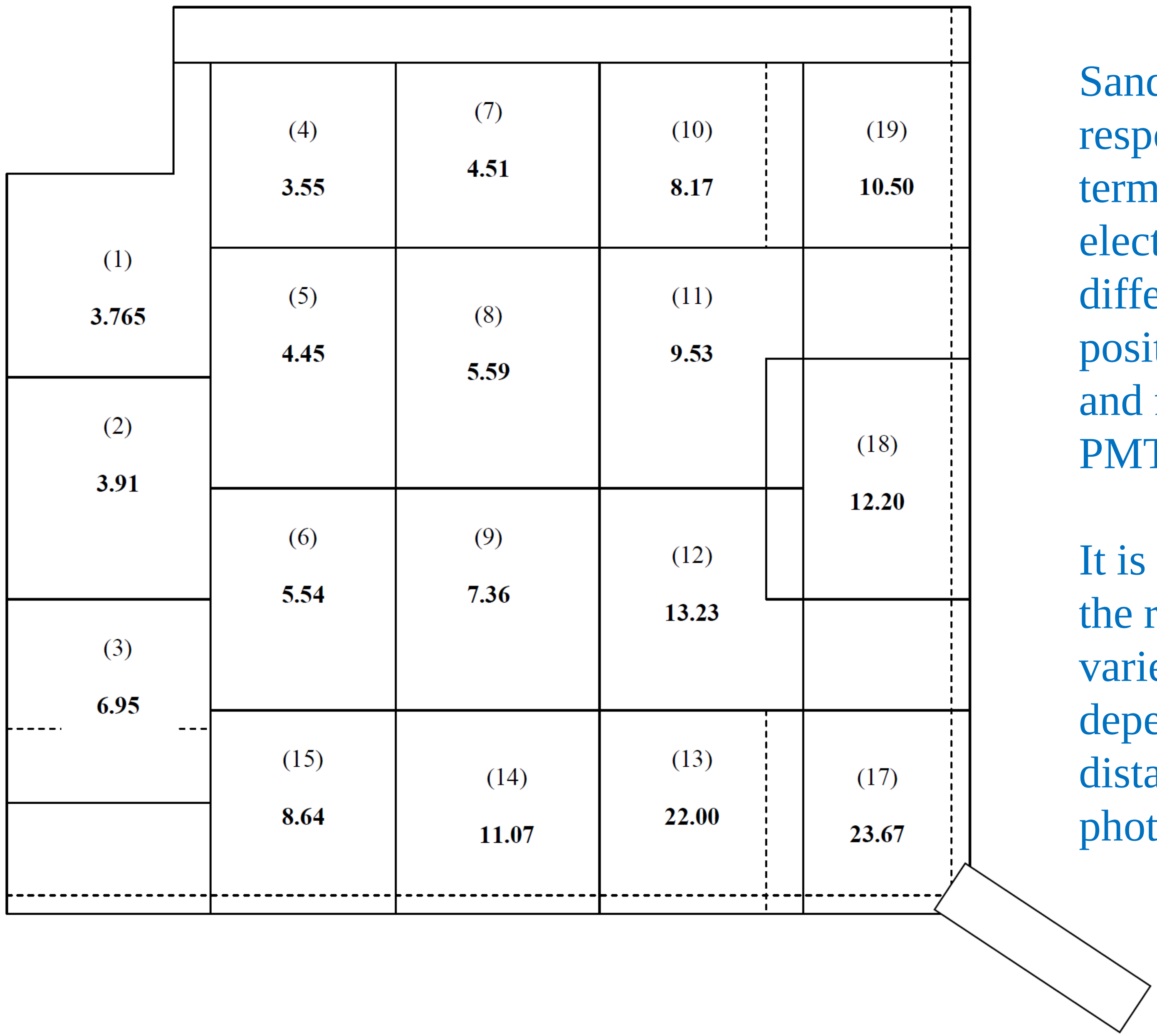


Poisson with Gaussian spread & Landau tail
h3
Entries 10000
Mean 5.255
RMS 2.756
The simulated distribution for
10,000 events.
400
350
300
250
200
150
100
50
0
0
5
10
15
20
Events
No of photoelectrons


Poisson with Gaussian spread & Landau tail
h3
Entries 10000
Mean 5.255
RMS 2.756
Actual signal is plotted over the simulation.
Events
No of photoelectrons
0
50
100
150
200
250
300
350
400
0
5
10
15
20

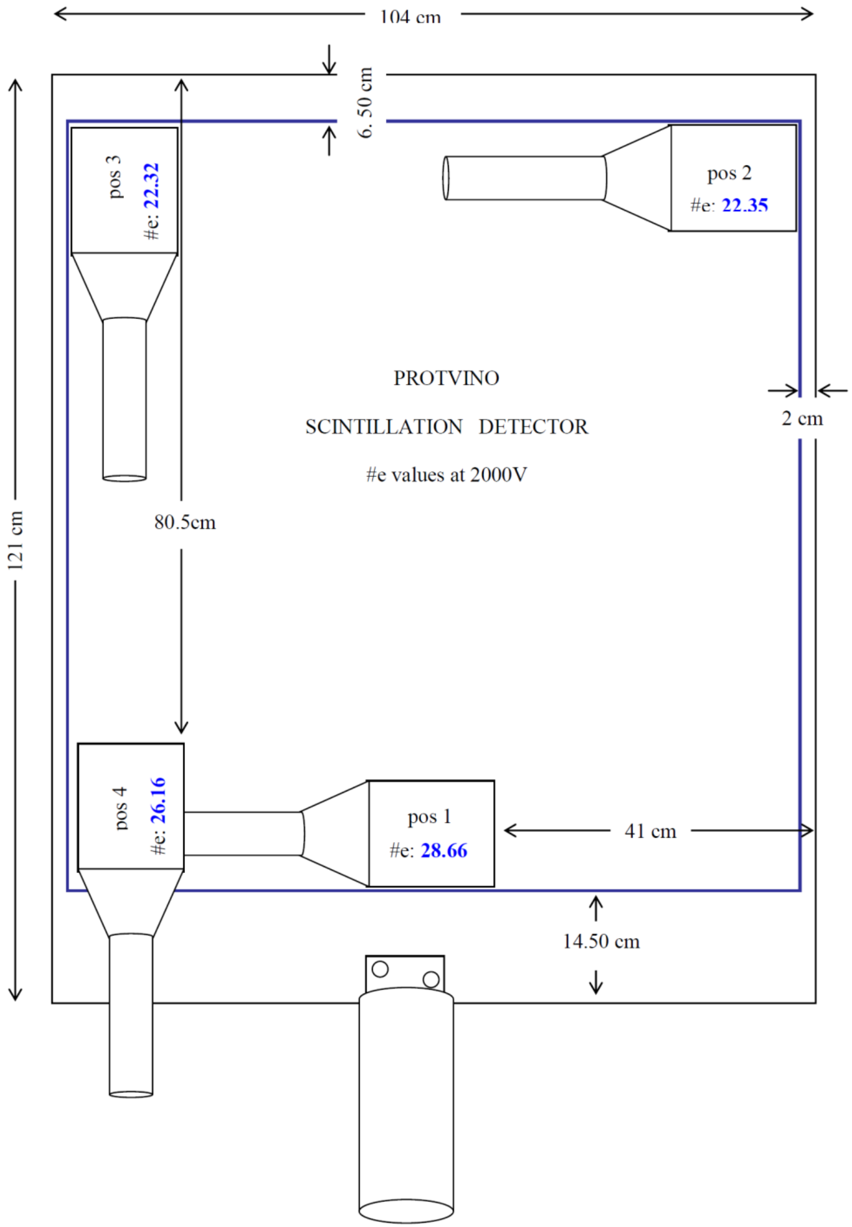
It is found that the simulation matches well with the data. This indicates the accuracy of the simulation and ability to found the single electron pulses with a good accuracy.

The most important thing is by this method one can test the efficiency of a sandwich type detector in terms of single electron response without any test beam. It just require cosmic muons and very easy and nominal arrangements.



Sandwich Veto response in terms of single electrons for different positions (near and far end of PMT).

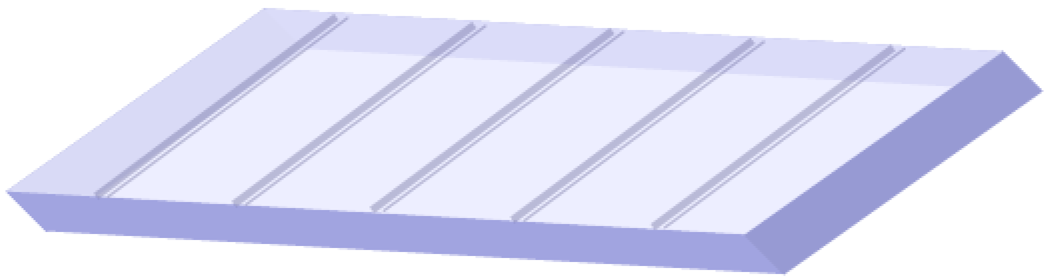
It is found that the response varies much depending on the distance from photo-multiplier.



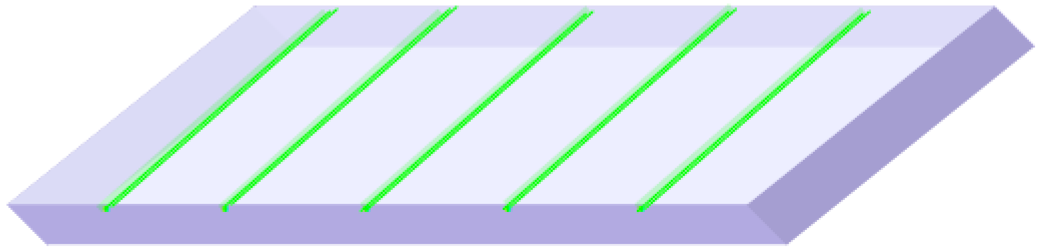
For the poor response the previous detector is discarded and a new detector with little different construction is introduced. (only one module is shown here)

There are fiber optics in the grooves of the scintillator material which ensures a fast response.

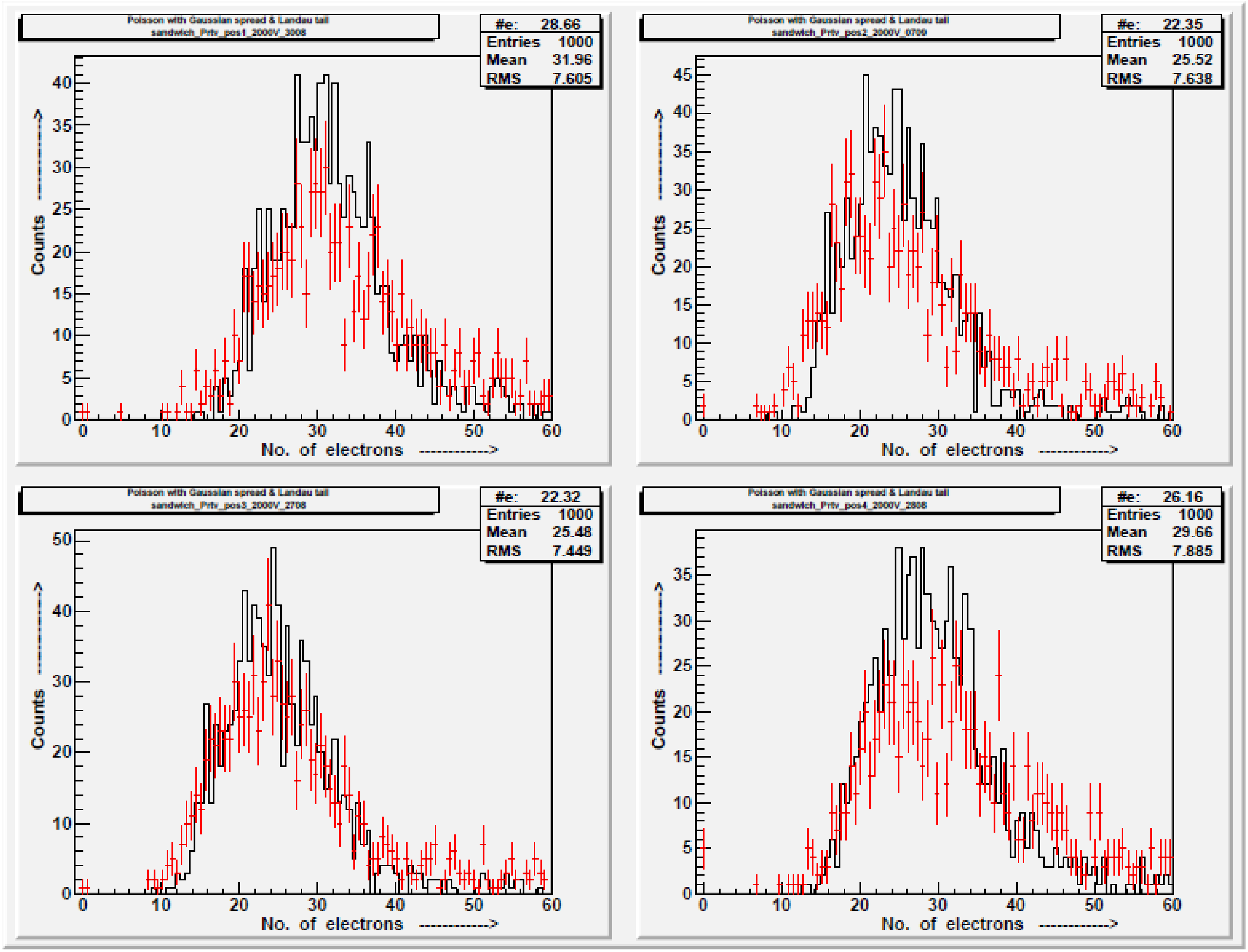
The near and far end response are quite comparable.



Scintillator slabs from Protvino with grooves on its surface to place scintillating fiber.



Scintillating fibers (green) molded in the groove



Four position response of the new sandwich detector (signal in red) and the simulation. The match is quite prefect. One only need the data of most probable number of electrons produced in that position.

Conclusions

New technicalities have been developed to test the Sandwich Veto counter, and the testing is very successful. It is found that the counter is quite efficient and sensitive to a single electron charge.

As basically the detector is an electromagnetic calorimeter, there are huge scopes to analyze its data from different perspectives and develop new kind of particle detectors.