BaF2 detector simulations, preliminary data analysis and fast DAQ studies

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- Geant4 simulation
- Data analysis
- Fast DAQ studies

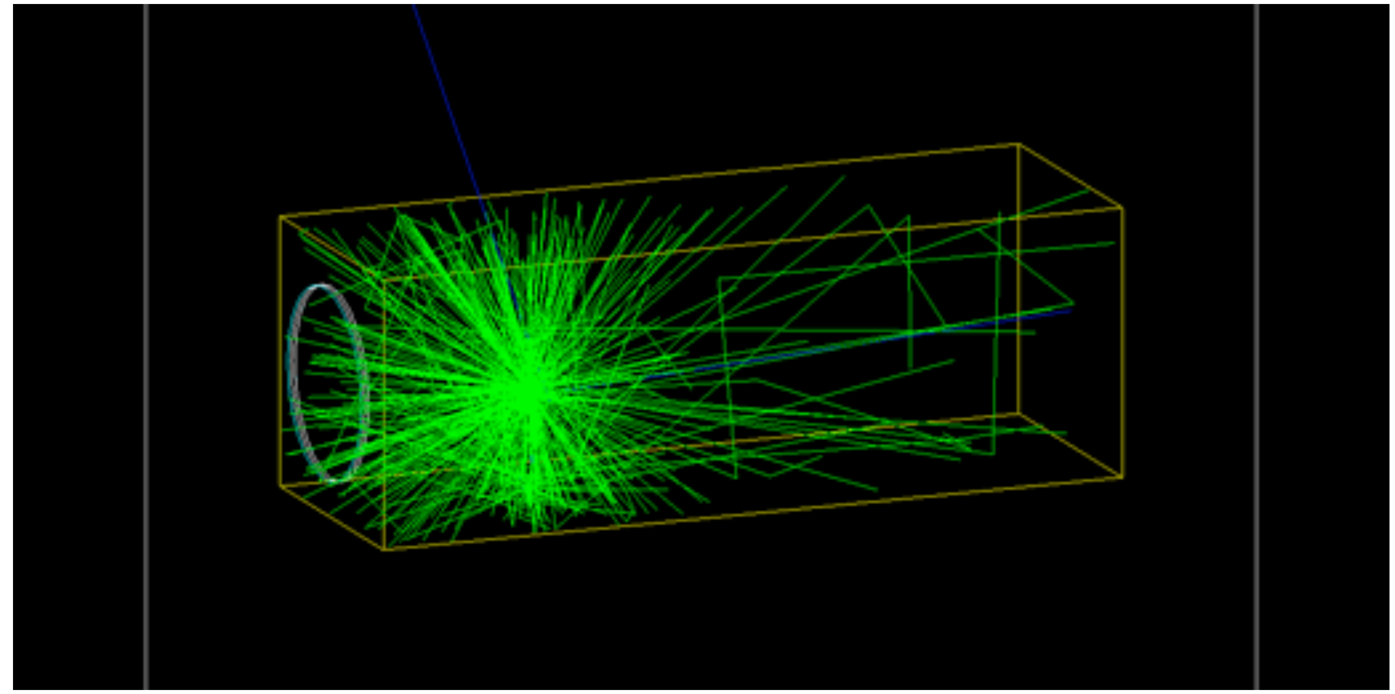
Motivation

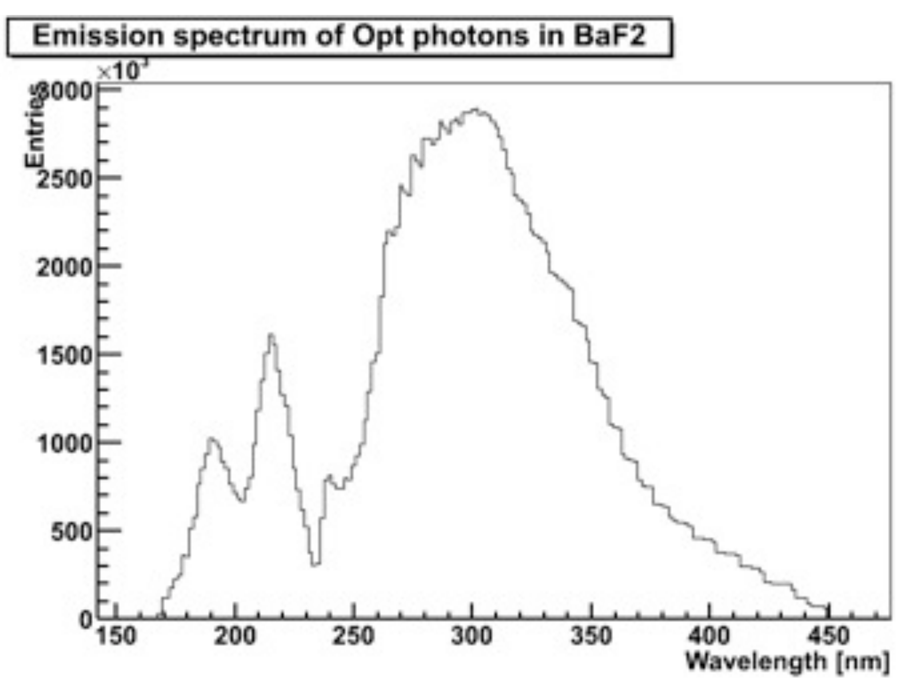
- Understand the physics, optical photons yield and timing of the calorimeter (Geant4)
- Preliminary analysis of the data collected recently
- Studies to specify the parameters of DAQ system to acquire the bunch per bunch Compton signal

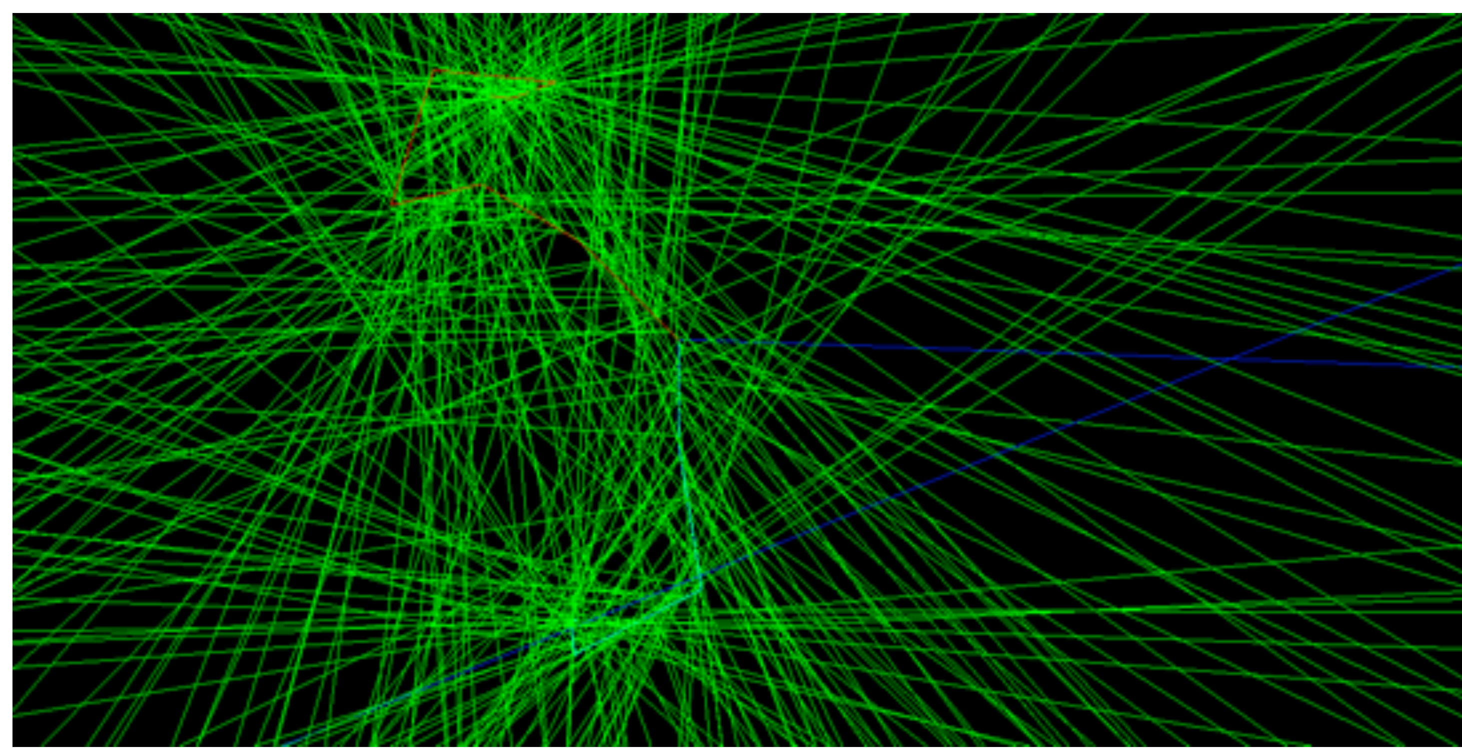
Detector's model

Geometry of BaF2 crystal:

- One piece of 200mm x 70mm x 70 mm (the optical surface between two pieces should be added)
- All surfaces are polished;
- Wrapping: absorbing material;







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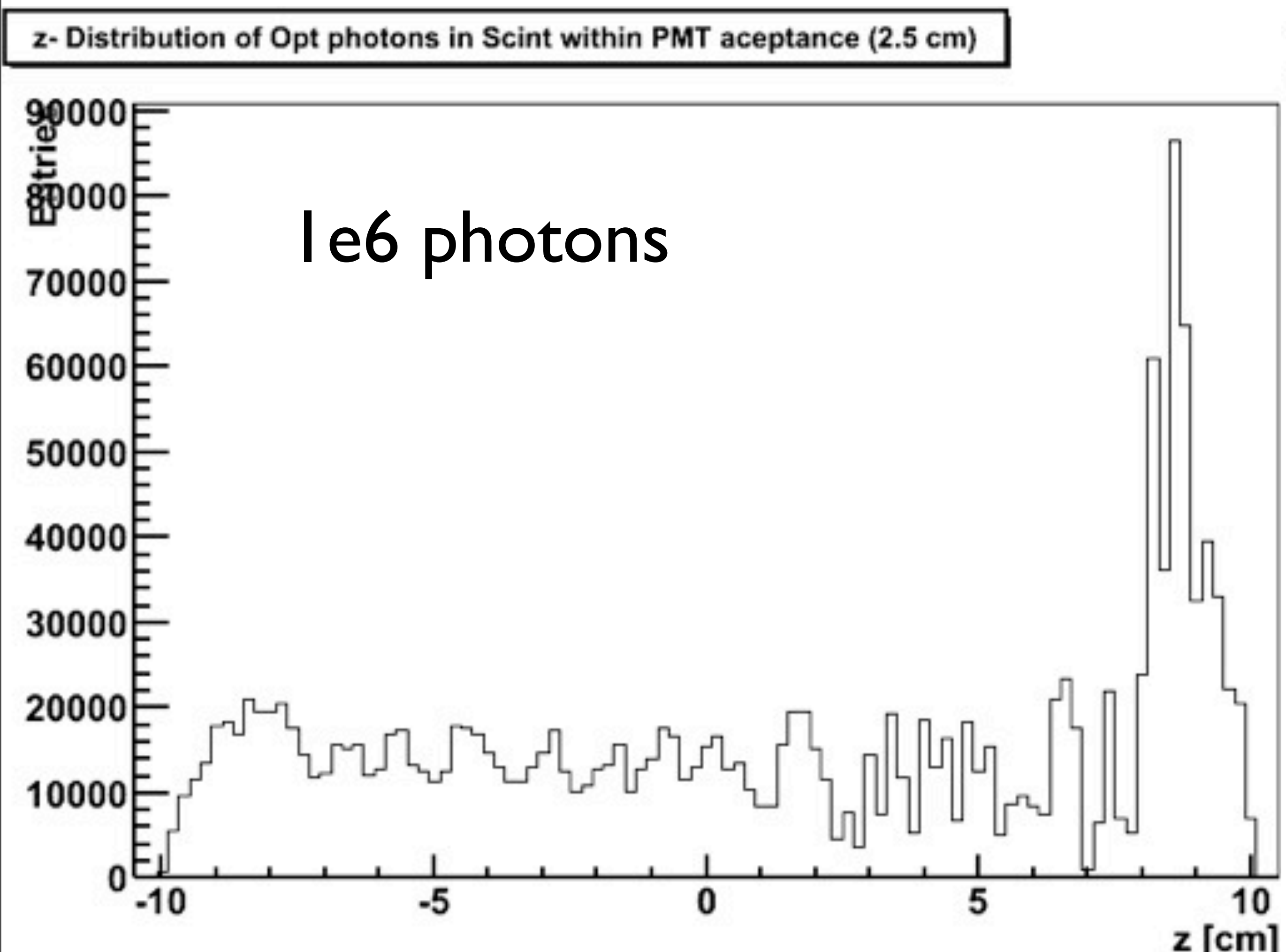
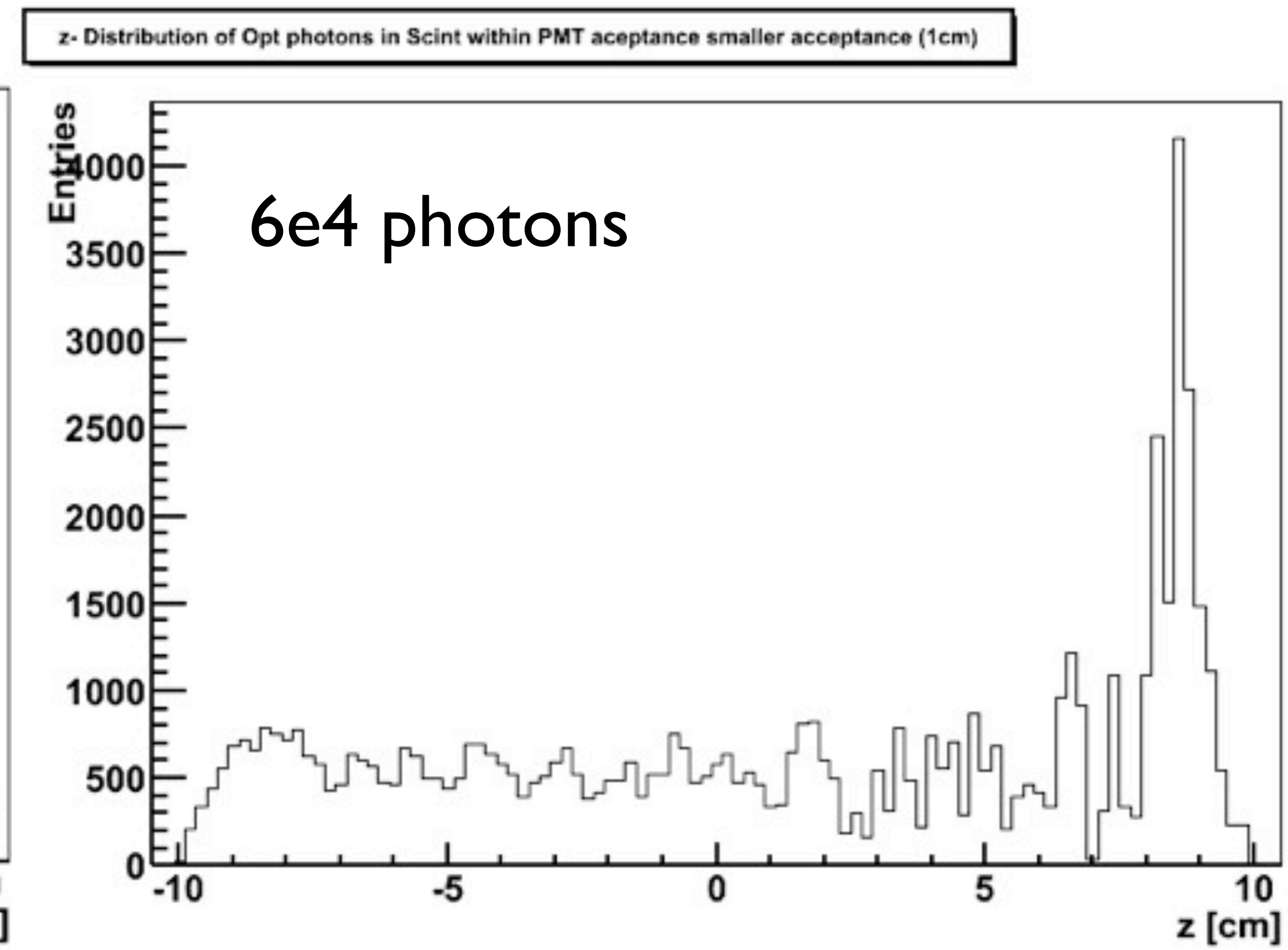
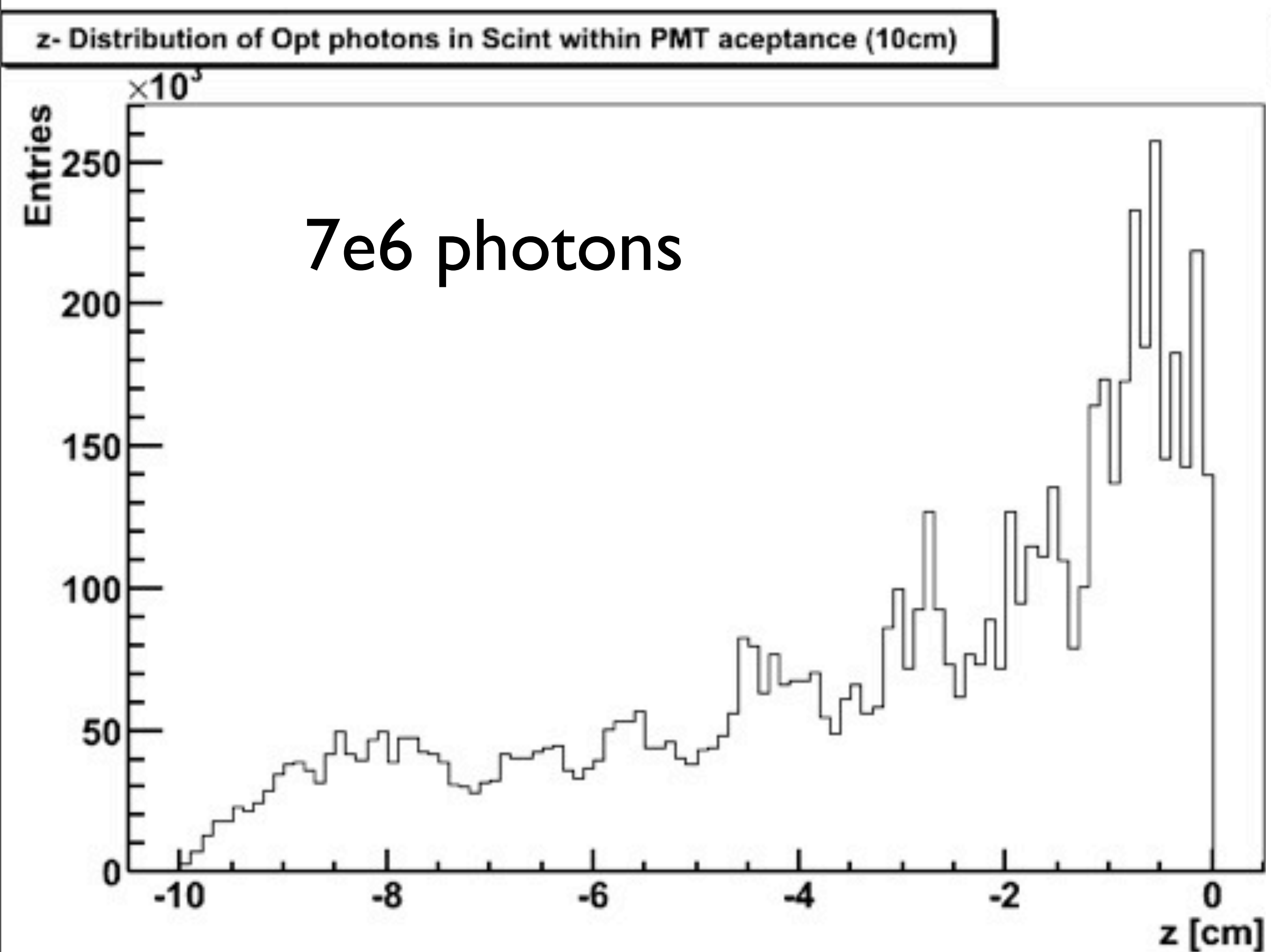
Location where the optical photons are produced inside the scintillator

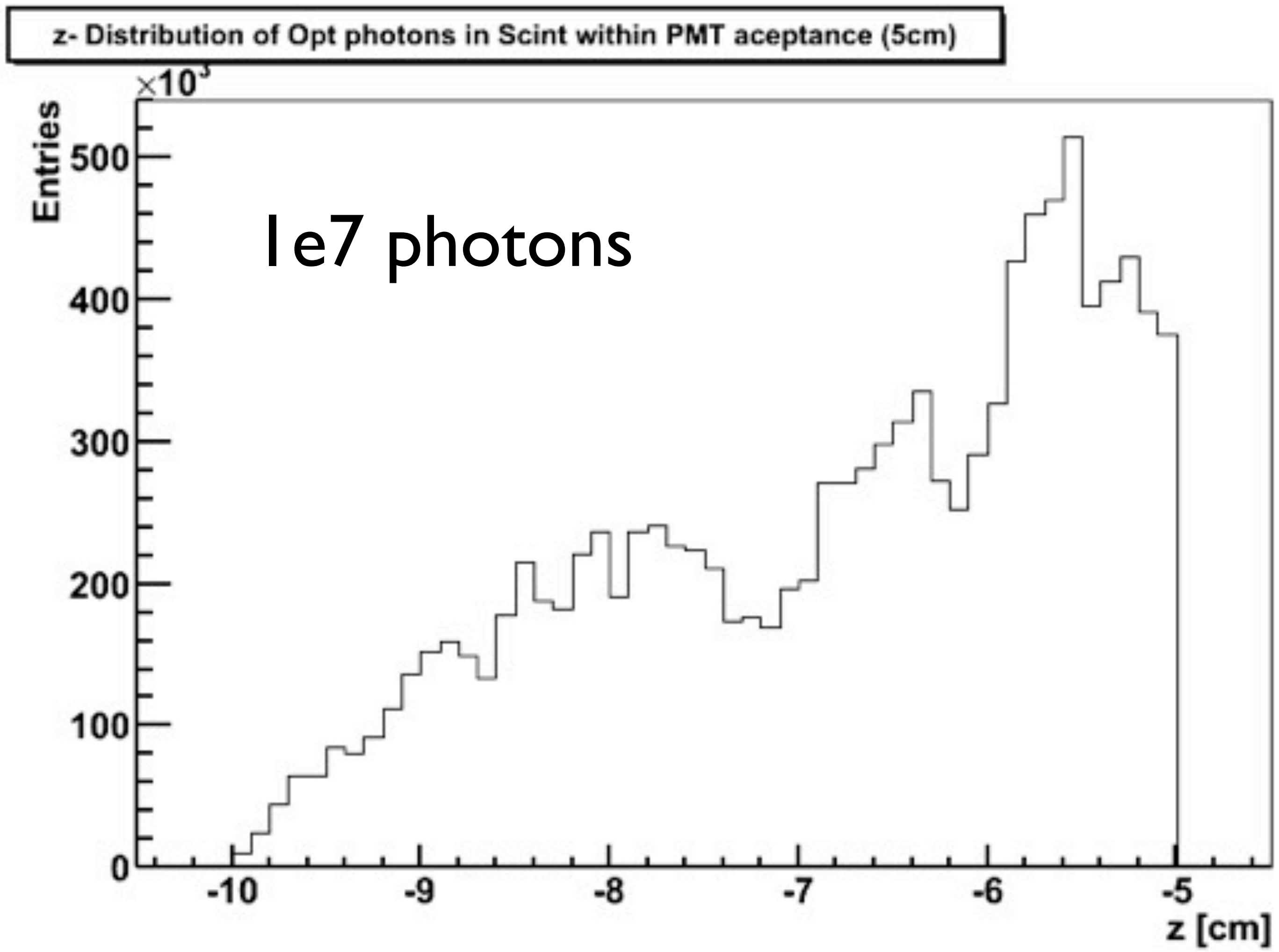




The number of optical photons accepted depends on the PMT acceptance. Reducing the PMT acceptance (e. g. adding the punched paper) leads to the reduction of accepted optical photons yield.

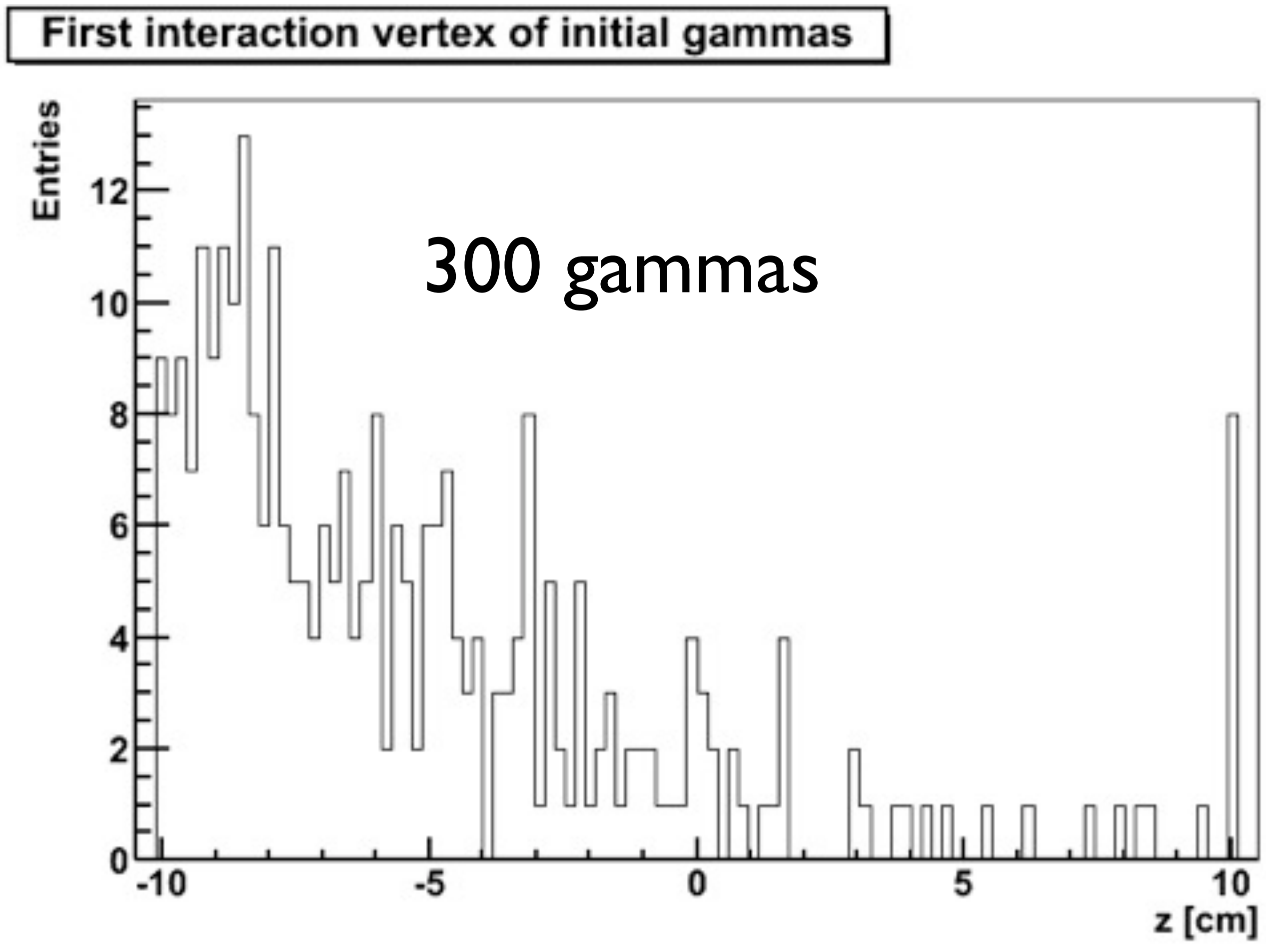
Location where the optical photons are produced inside the shorter scintillator

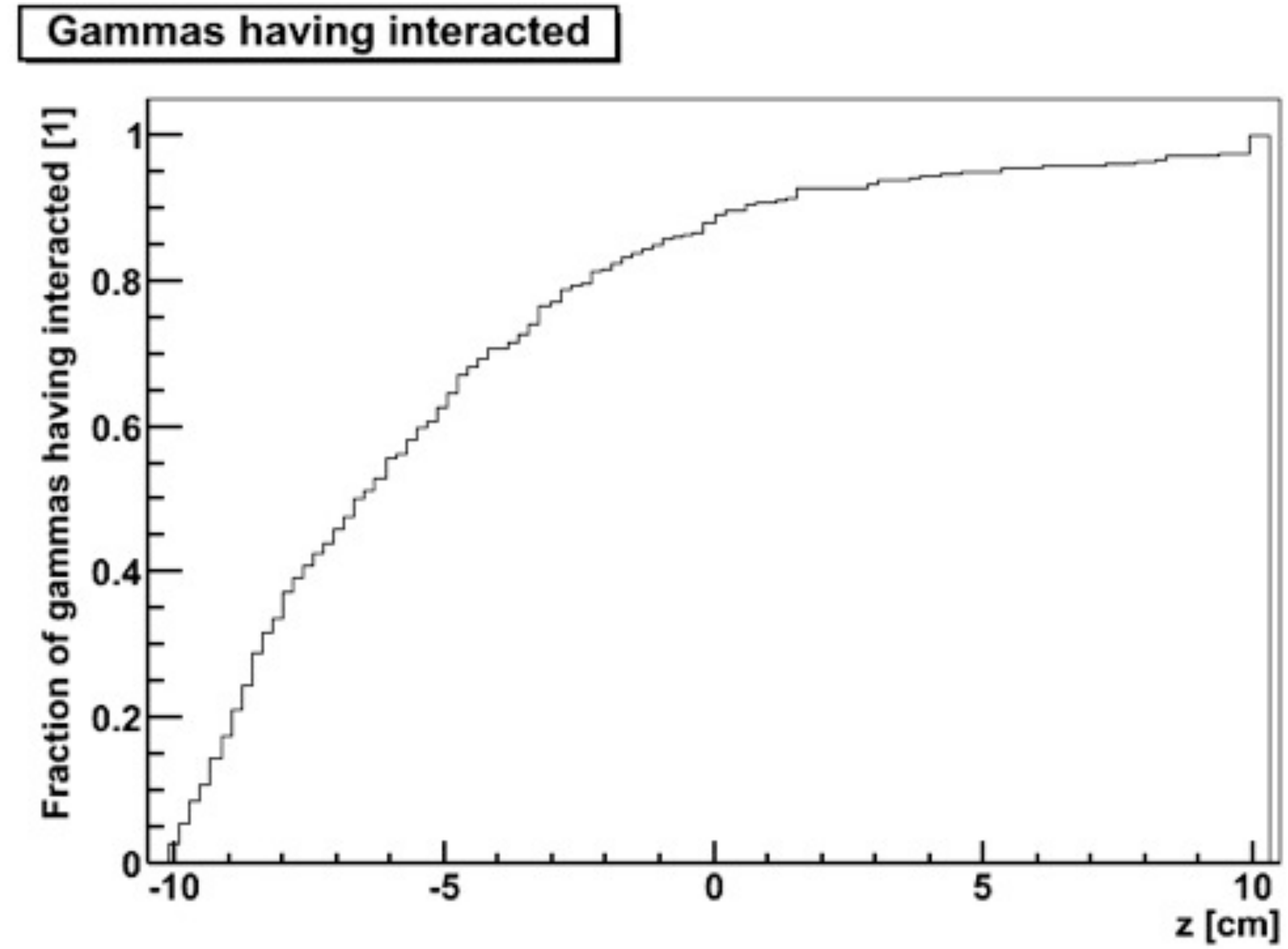




With a shorter crystal the optical photons yield remains good due to the enhancement of the crystal's acceptance.

First interaction of initial gammas inside the scintillator





The high energy Compton gammas interact along the crystal while the some of them pass the calorimeter without any interactions.
20 cm crystal = 0.97 of impinging gammas;
15 cm crystal = 0.95 of impinging gammas;
10 cm crystal = 0.86 of impinging gammas;
5 cm crystal = 0.58 of impinging gammas.
Shorter crystal reduces the linearity.

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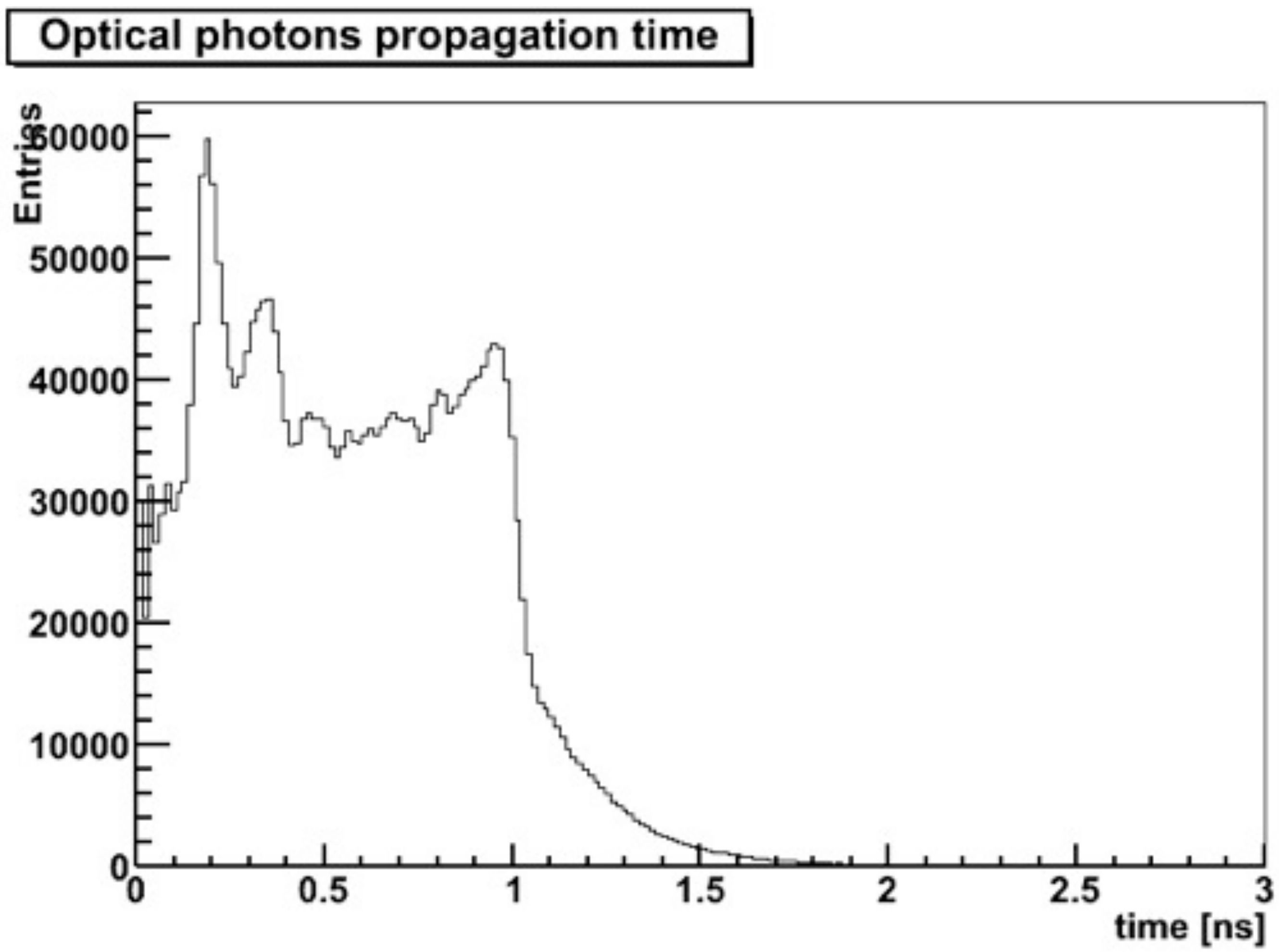
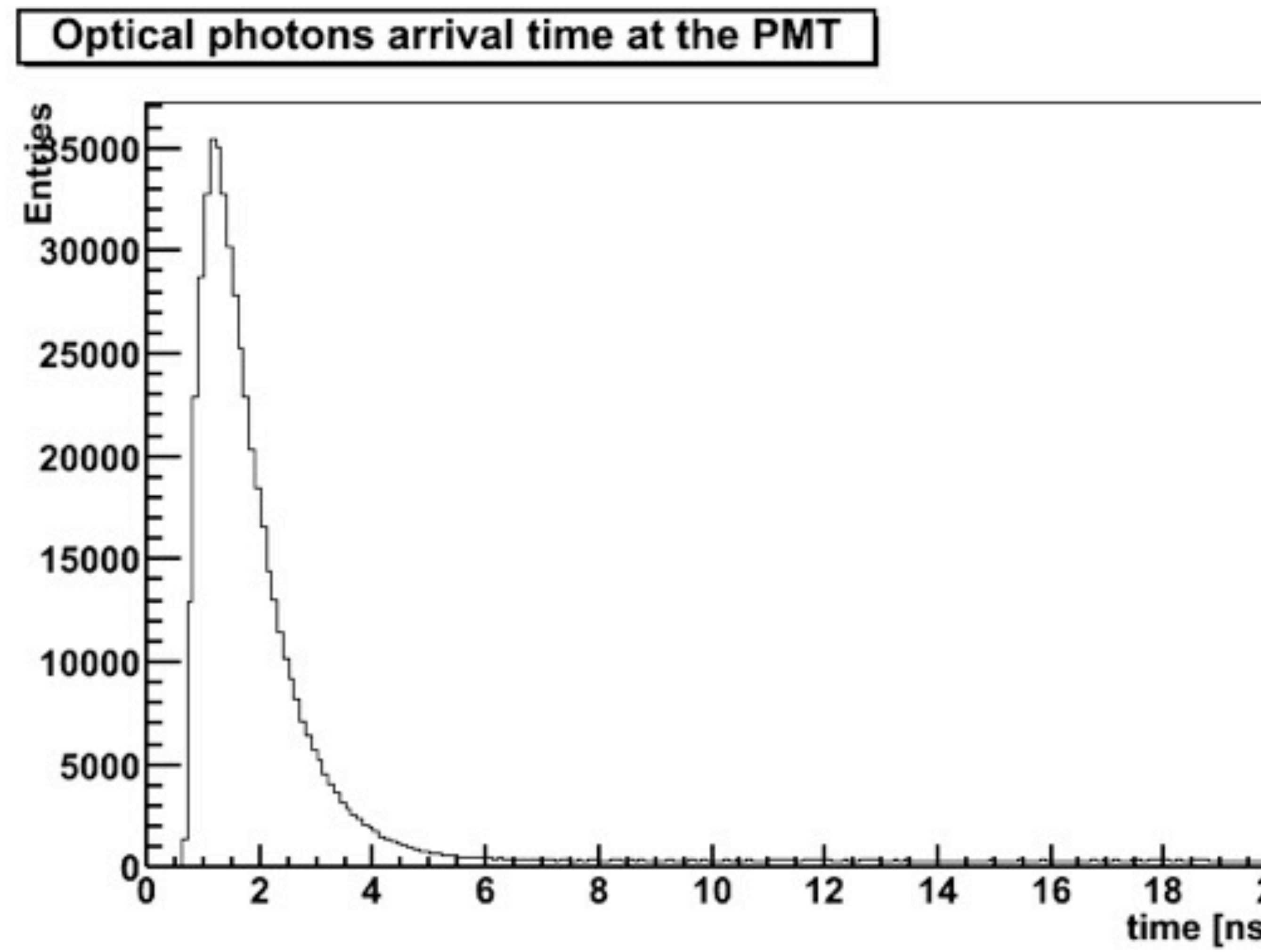
Timing of optical photons

Propagation time



Time of arrival at the PMT



The contribution of the propagation time to the signal duration is about 1 ns.
The total signal duration (including t_{prop} and t_{emit}) at the exit of the crystal is approximately 2 ns.

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Data analysis (preliminary)

- Data was acquired parasitically during ATF runs (1 train/1 bunch, 3 trains/1 bunch, 1 train/ 6 bunches)
- Data acquisition was performed using *LeCroy WS454* scope (1Gs/s, 500MHz bandwidth).
- Two locations for the scope (Nakanoshima and later DR)
- Peak values and integrals of the Compton signal have been calculated.

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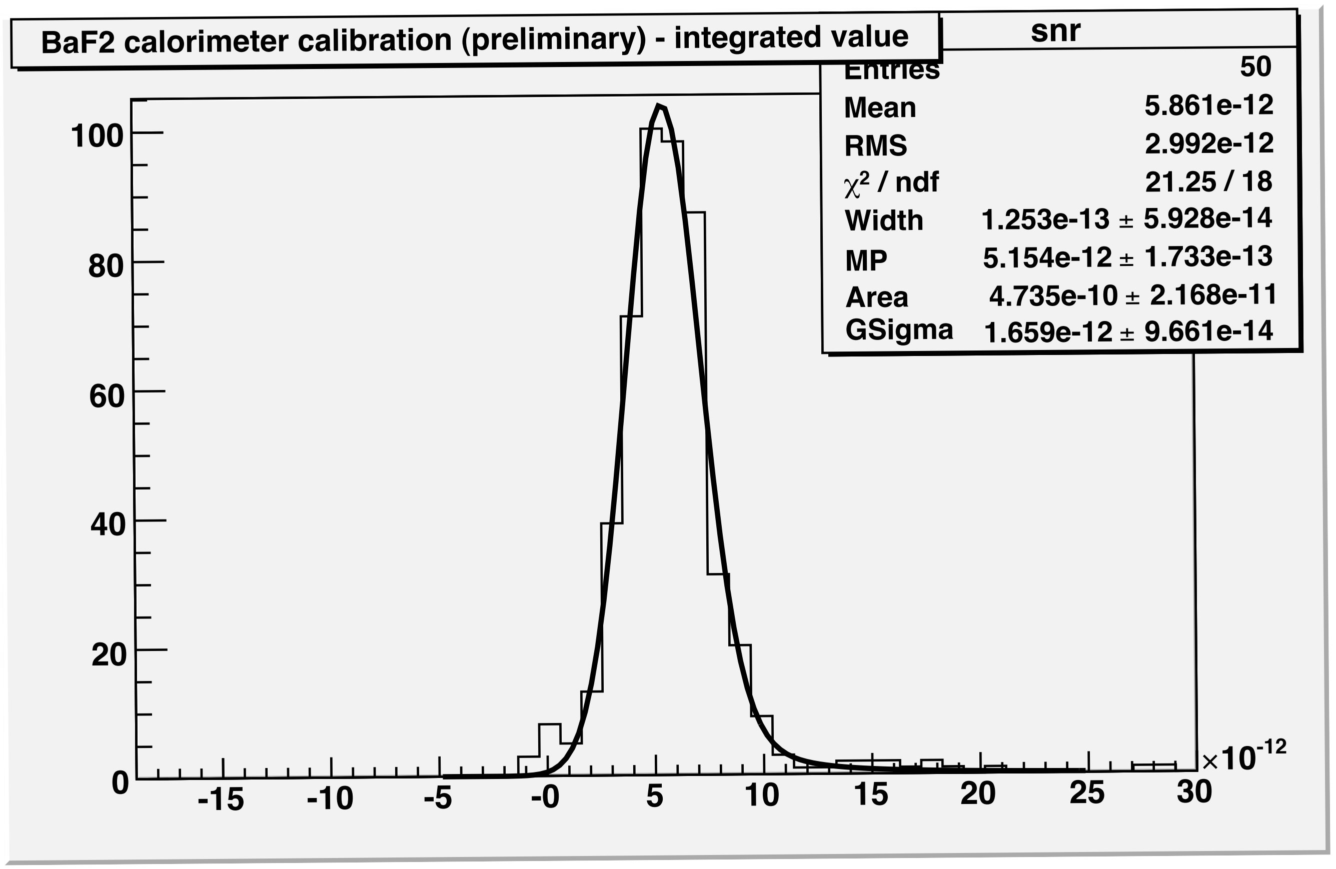
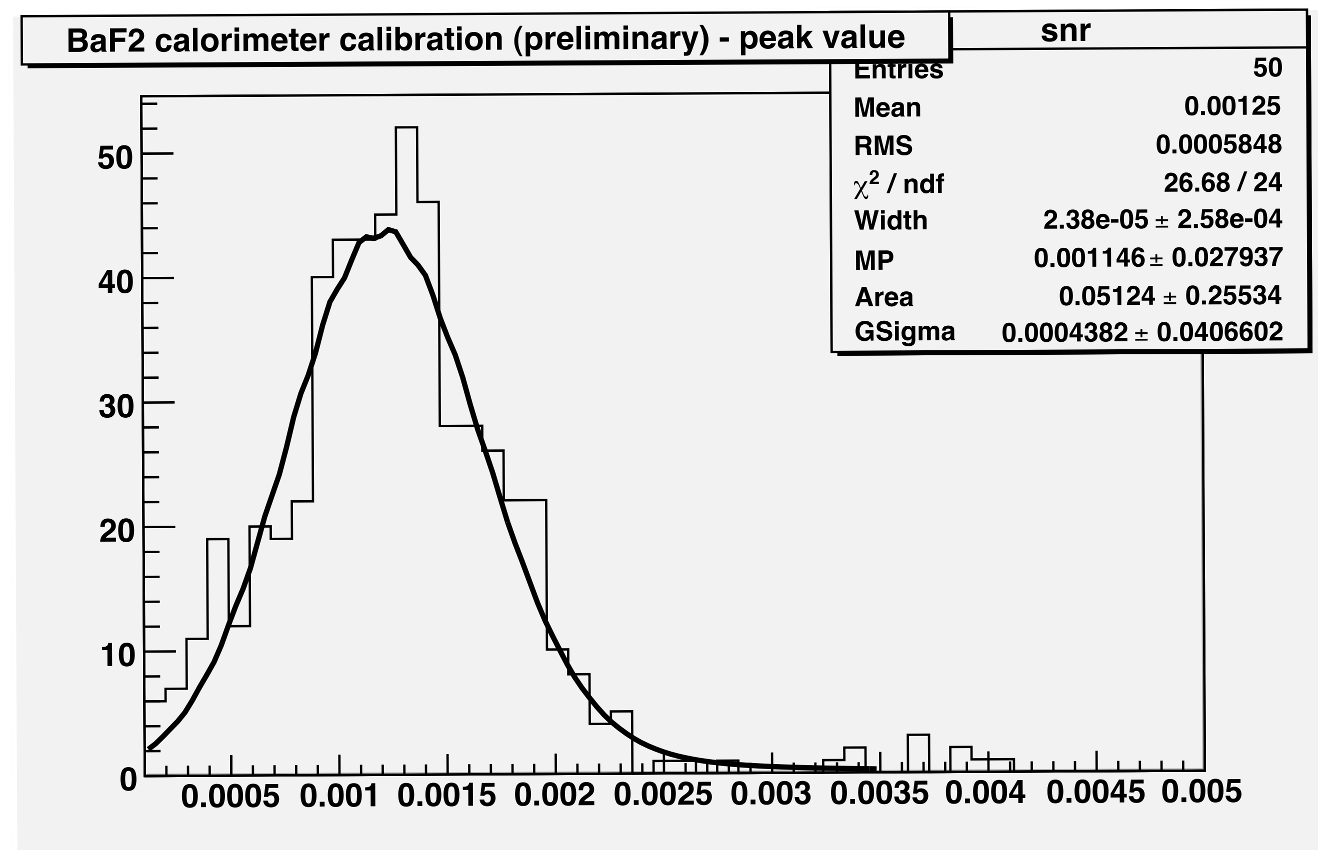
Calibration using cosmic rays

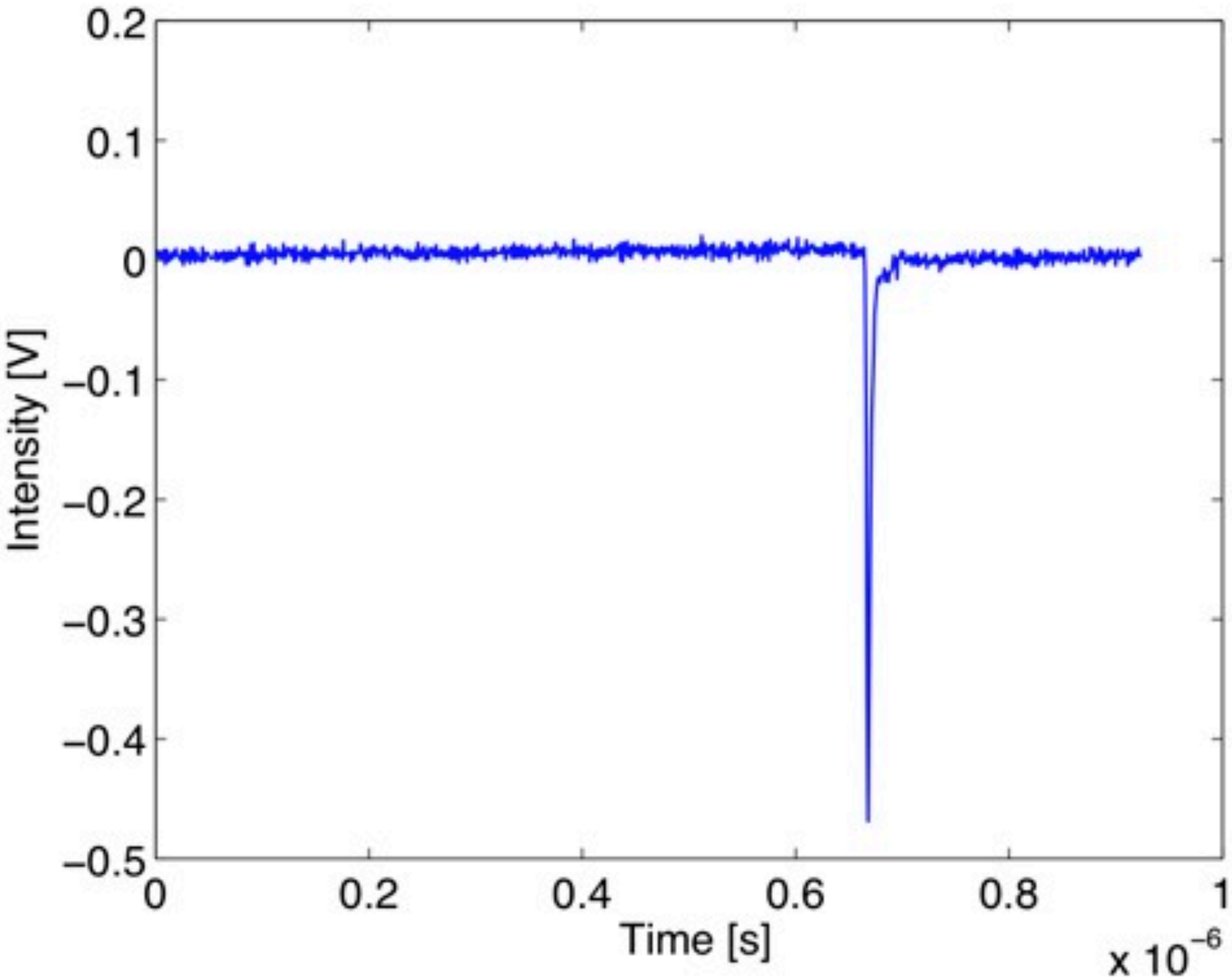


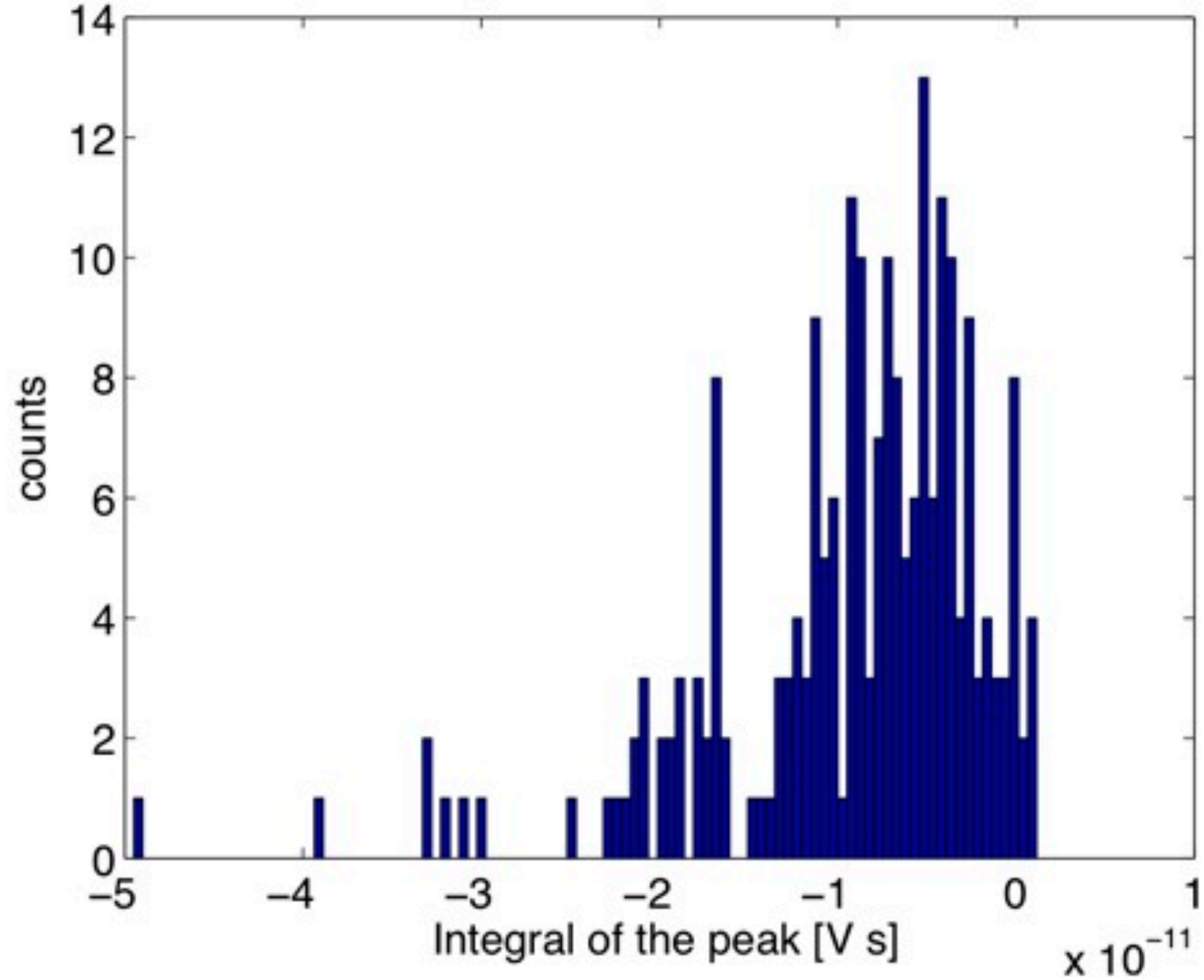


The most probable value for the integrated signal is 5.2 mV.ns and most probable value for the peak is 1.1 mV

Assuming minimum ionization, the energy deposition in BaF2 is 6.374 MeV/cm. So, the values above correspond to approximately 45 MeV of energy deposited.

Data analysis. 1 bunch/train





Waveforms were analyzed using a stochastic stacking technique. The 357 MHz clock has been used to define the Compton integration gate .

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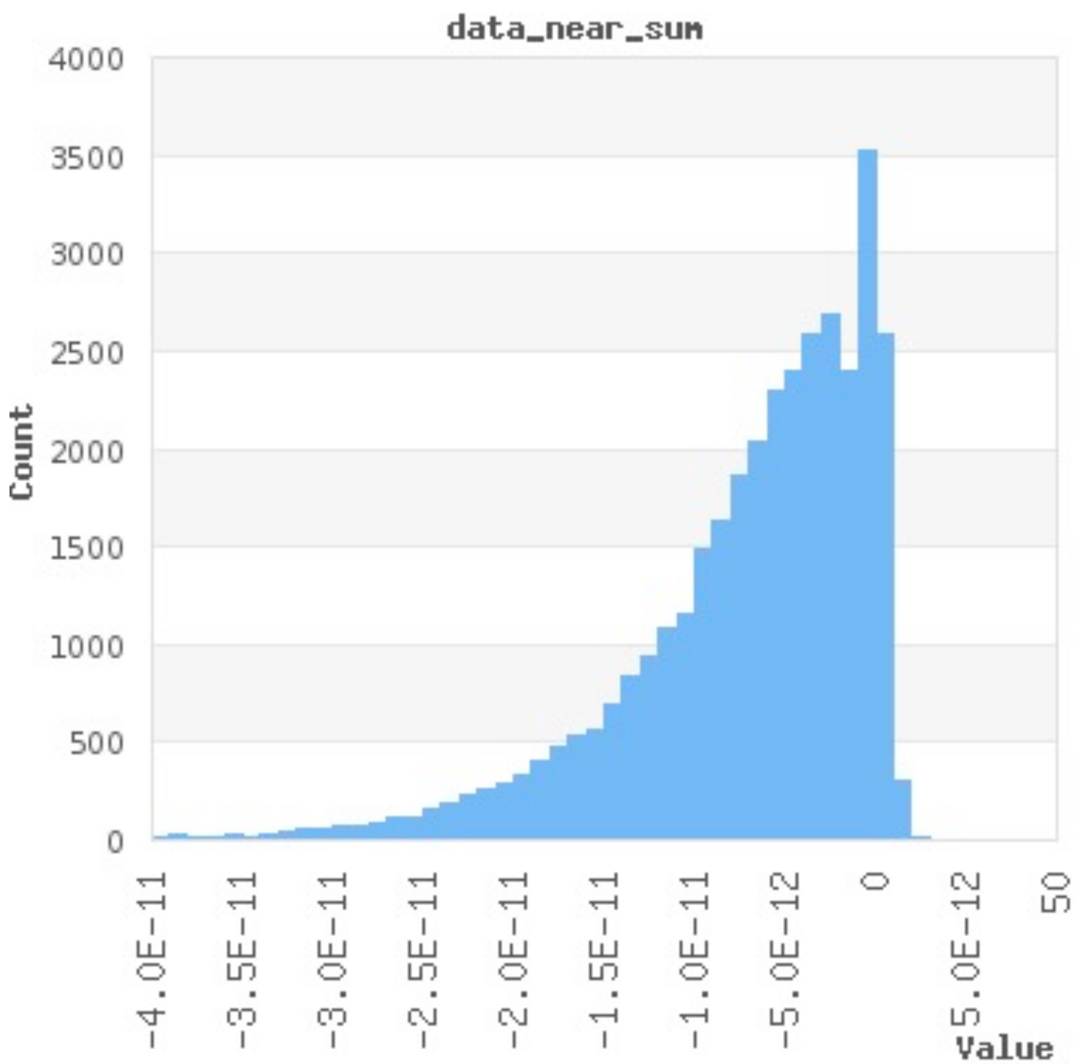
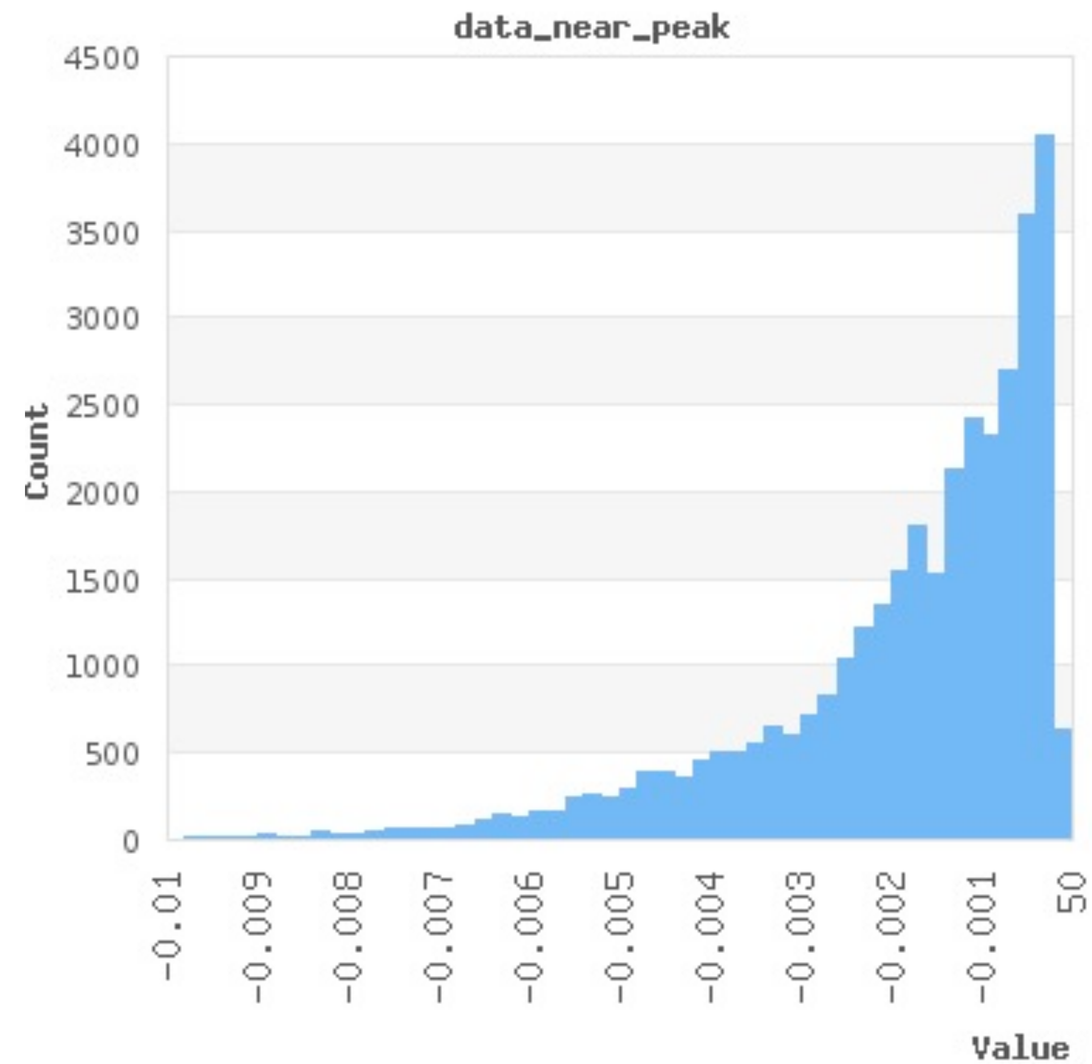
Energy spectrum of the gammas (preliminary)



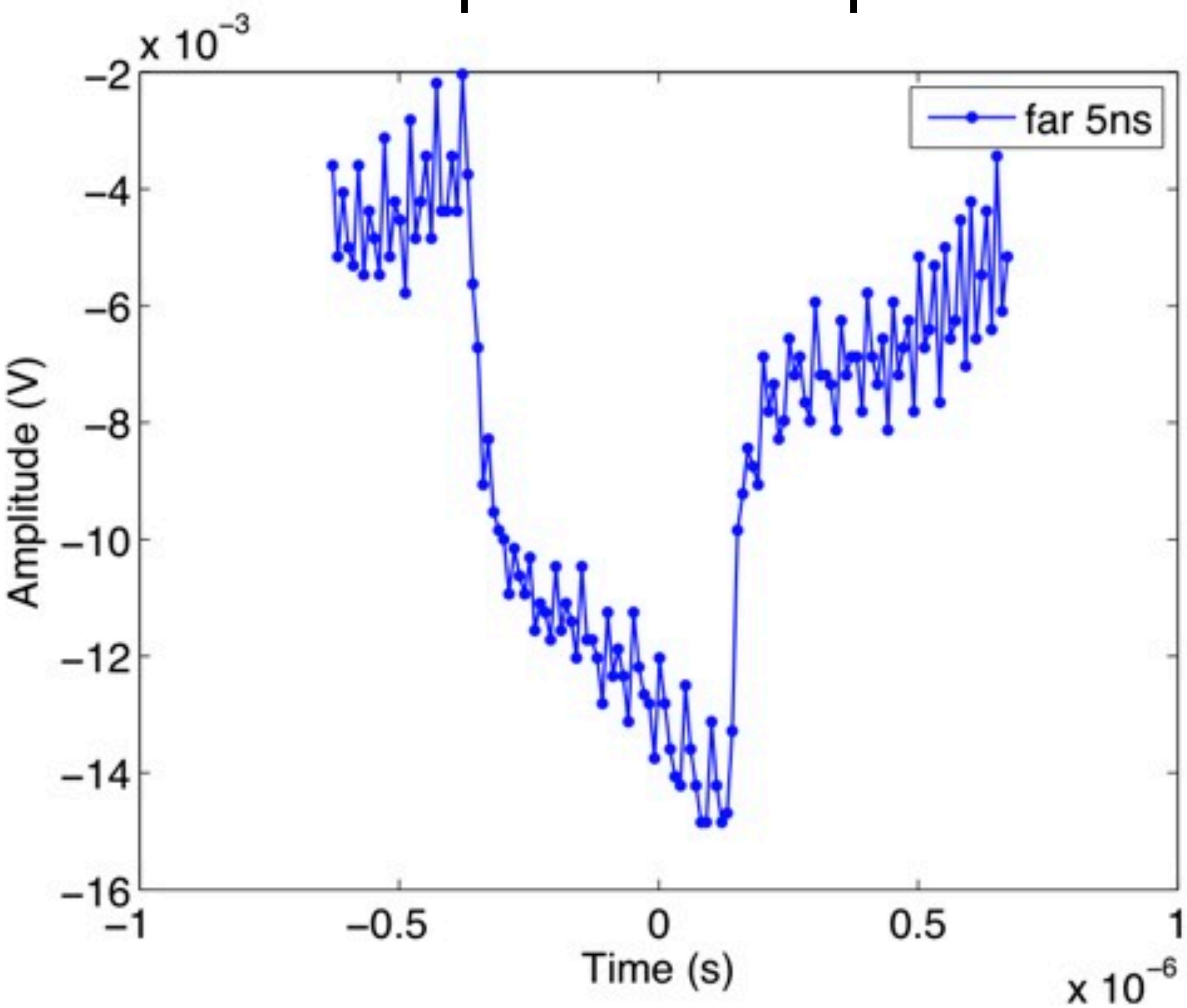


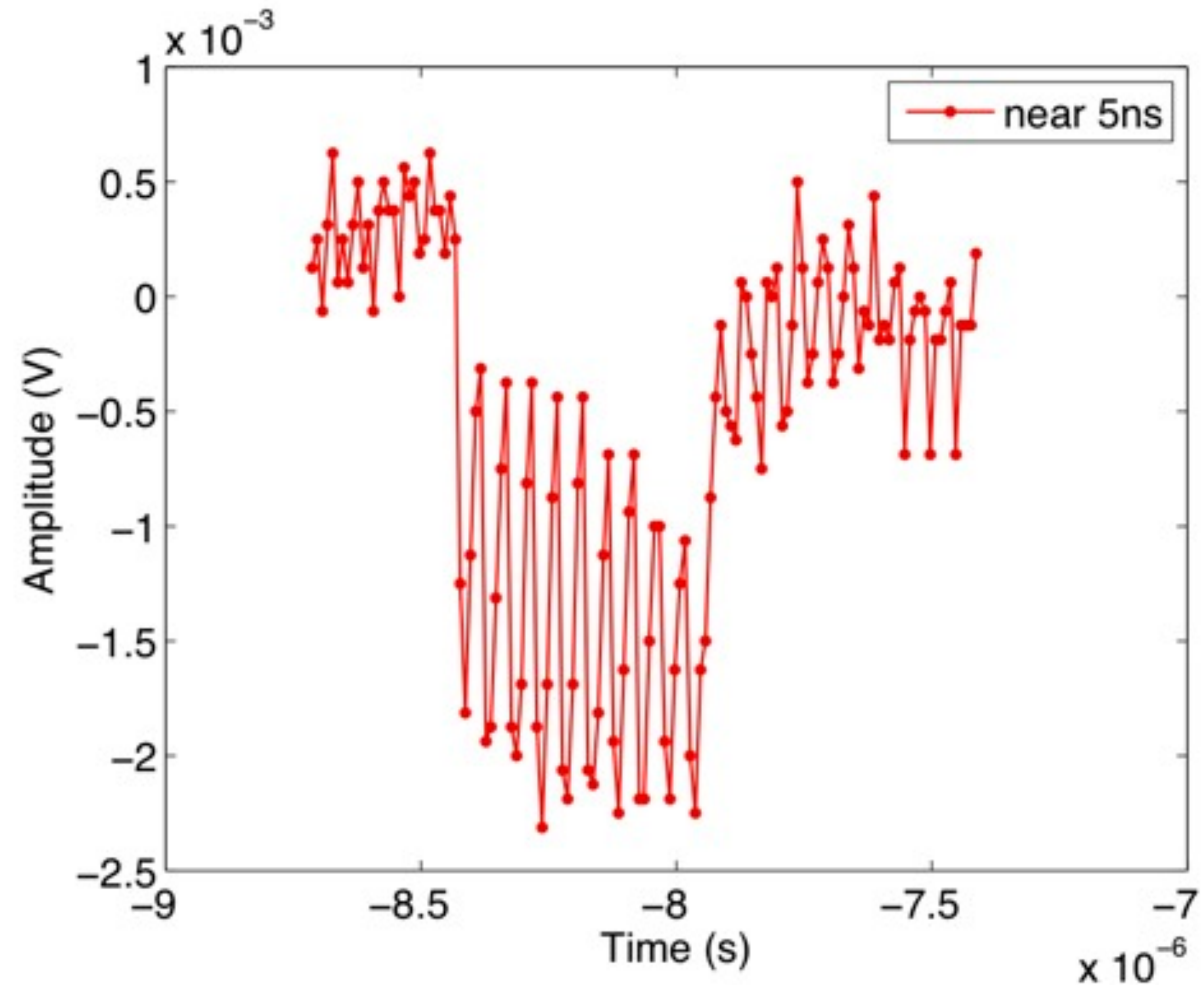
According to the calibration, 20 MeV gammas deposit 2.3 mV.ns with a peak of 0.49 mV.

Between 1 and 4 gammas are produced per bunch crossing.

Data analysis. Multibunch simulations with calibration data

The peaks correspond to the energy deposited by the cosmic rays.

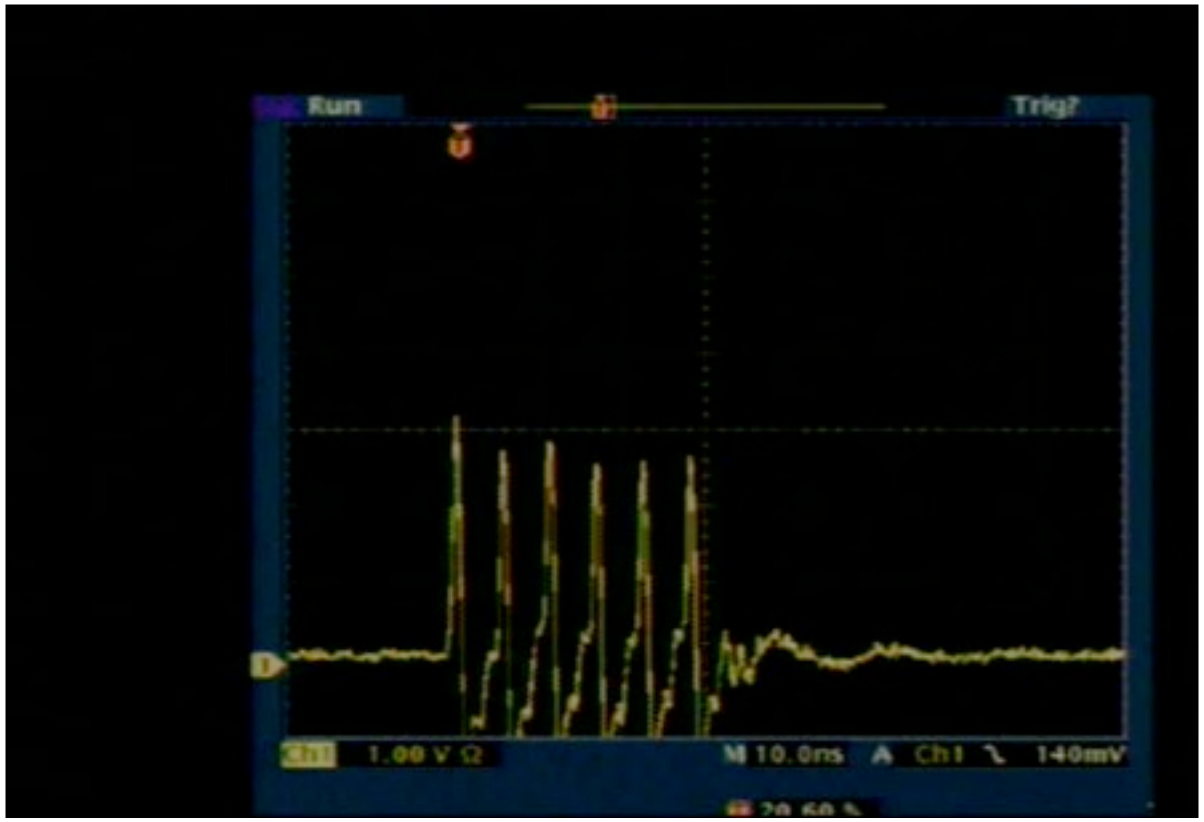


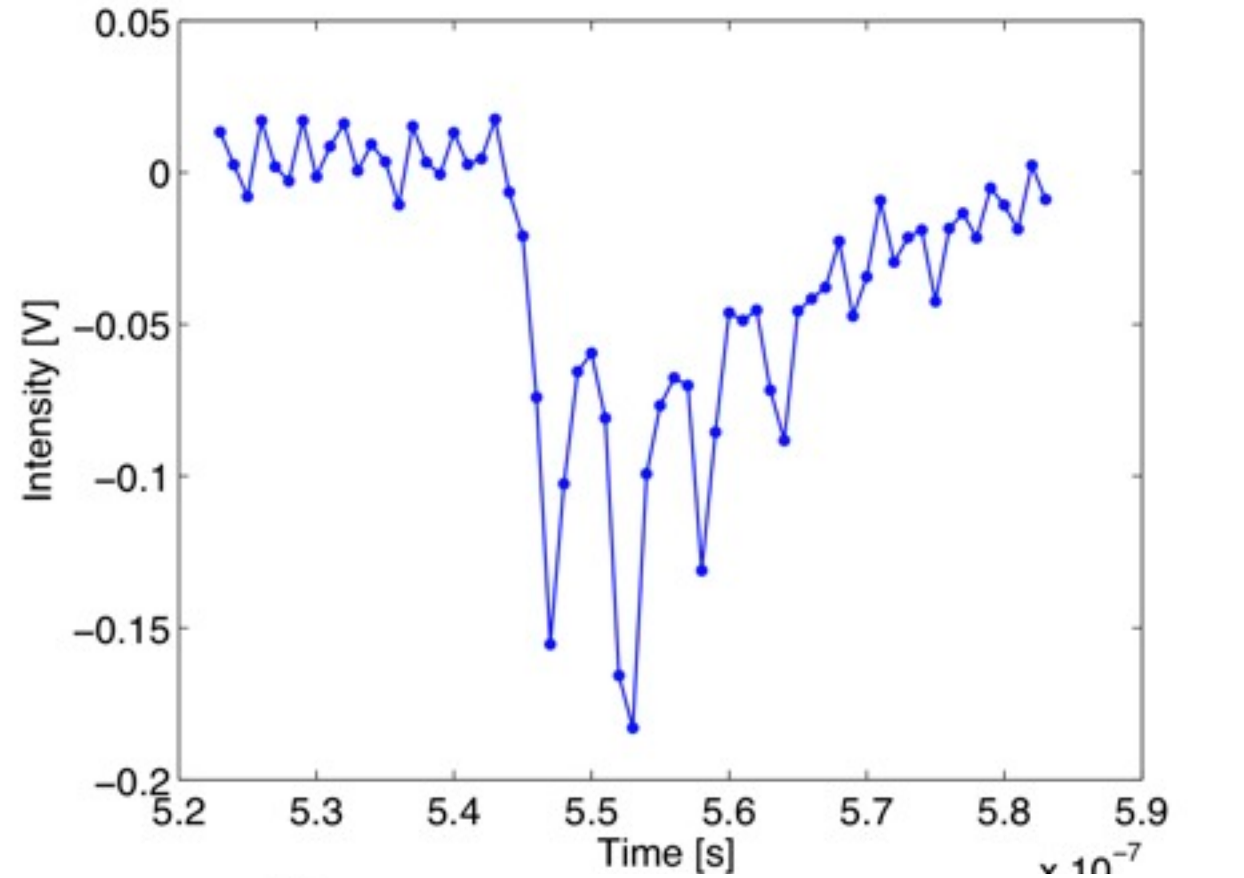


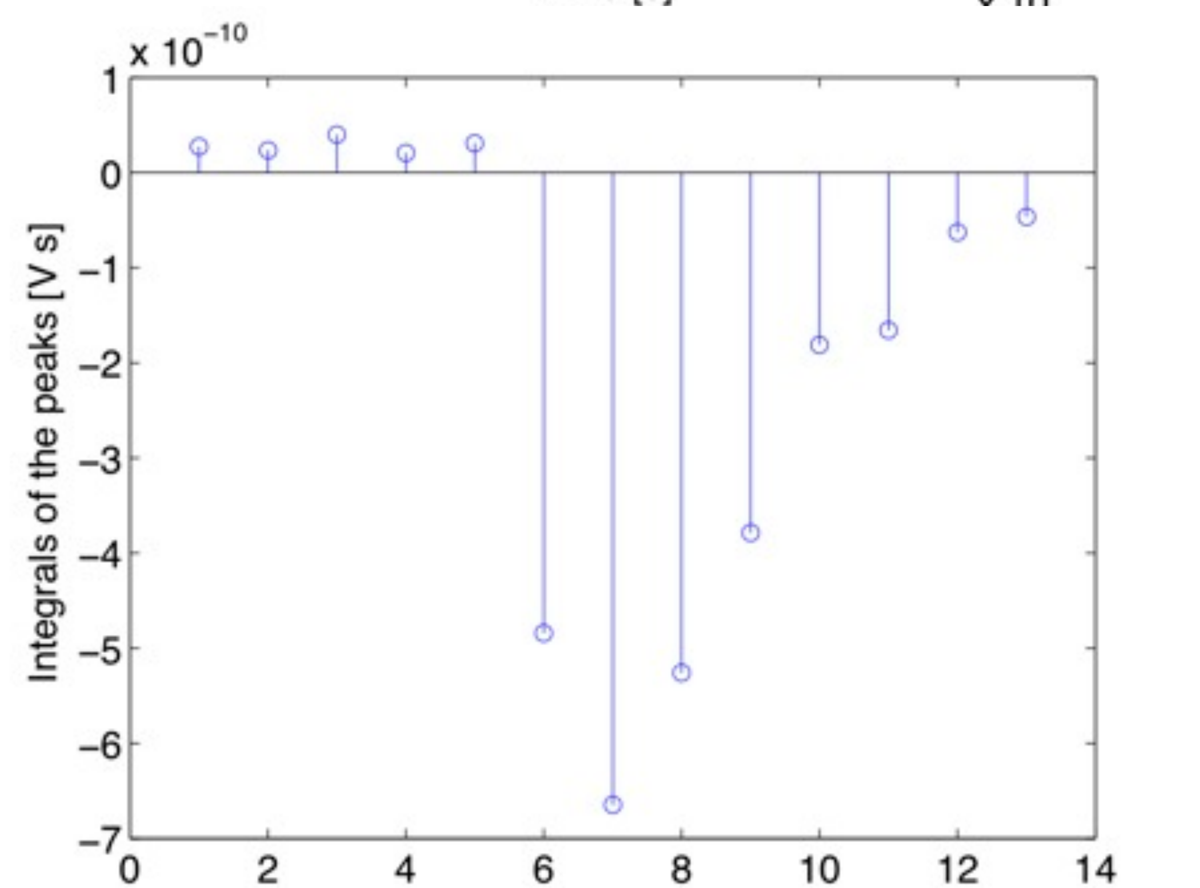
The width of the peaks are different. The amplitude of the peak is different for these two cases because when we moved the scope into the DR, the signal is not anymore amplified by the amplifier.

It is clear that the resolution in the "near" configuration is better.

Data analysis. Multibunch data.

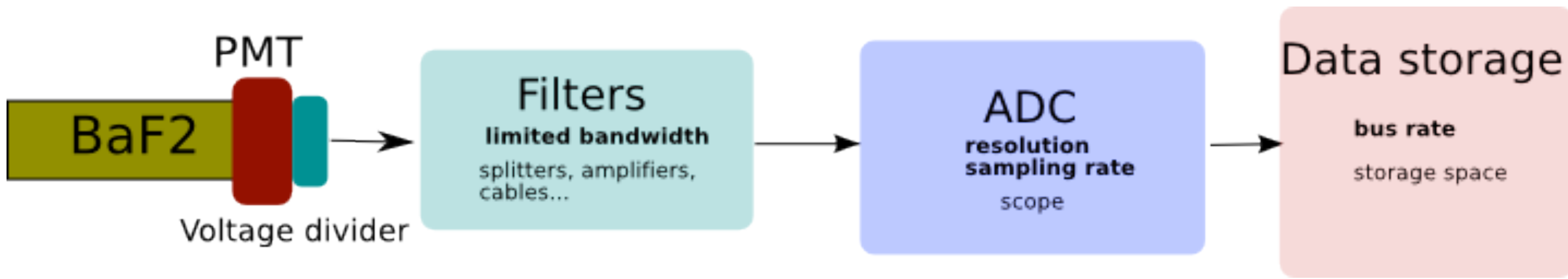






The multibunch data shows the presence of pile-up between the bunches in the train as well as a contribution from the decay components (electronics response)

Fast DAQ studies



- We intend to build a fast data acquisition system to resolve the gamma production on a bunch per bunch basis.

- We have simulated the components of the data acquisition chain to understand their limitations.

- This new fast data acquisition system should be installed in the middle of next year. Final parameters to be decided soon.

Signal Model

$$S_s(t) = \frac{A_s}{2\tau_s} e^{\frac{\sigma^2}{2\tau_s^2} - \frac{t-t_0}{\tau_s}} \operatorname{erfc}\left(\frac{\sigma}{\sqrt{2}\tau_s} - \frac{t-t_0}{\sqrt{2}\sigma}\right)$$

$$S_f(t) = \frac{A_f}{2\tau_f} e^{\frac{\sigma^2}{2\tau_f^2} - \frac{t-t_0}{\tau_f}} \operatorname{erfc}\left(\frac{\sigma}{\sqrt{2}\tau_f} - \frac{t-t_0}{\sqrt{2}\sigma}\right)$$

$$S(t) = S_f(t) + S_s(t)$$

A_f	0.18
A_s	0.82
τ_f	0.8 ns
τ_s	630 ns
σ	0.4 ns
t_0	5 ns

$A_f, A_s,$ - relative light yields ;

τ_s, τ_f - the decay constants of the light;

σ - variance of the Gaussian response of the PMT to a light pulse;

t_0 - starting point of the time interval;

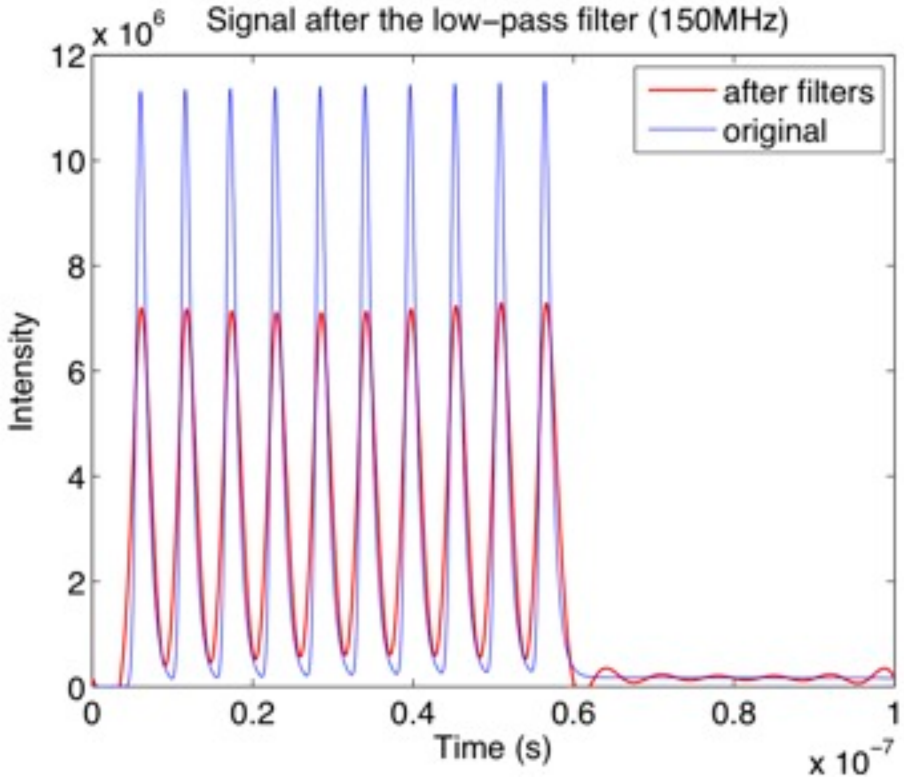
$$S_{RC} = \frac{A_r}{\theta} e^{-\frac{t-\mathrm{t}0}{\theta}} \operatorname{erfc}\left(\frac{\sigma}{\sqrt{2}\theta} - \frac{t-\mathrm{t}0}{\sqrt{2}\sigma}\right) \longrightarrow$$

response of RC (voltage divider) circuit should be understood

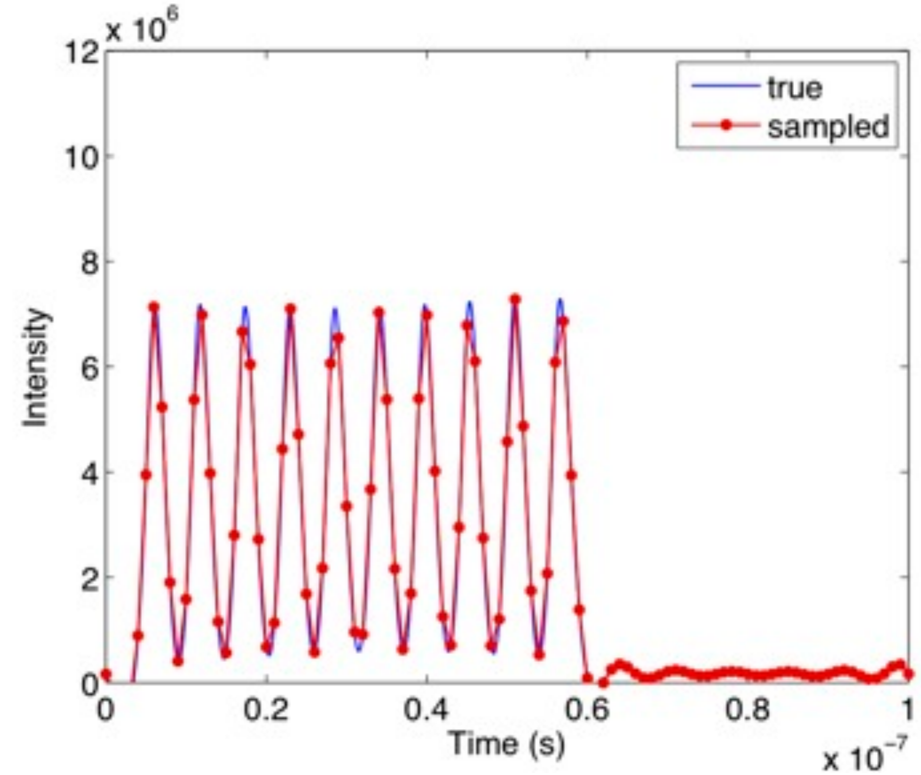
S. Marrone et al. NIM A 568 (2006) 904–911

DAQ simulations. Examples of limitations.

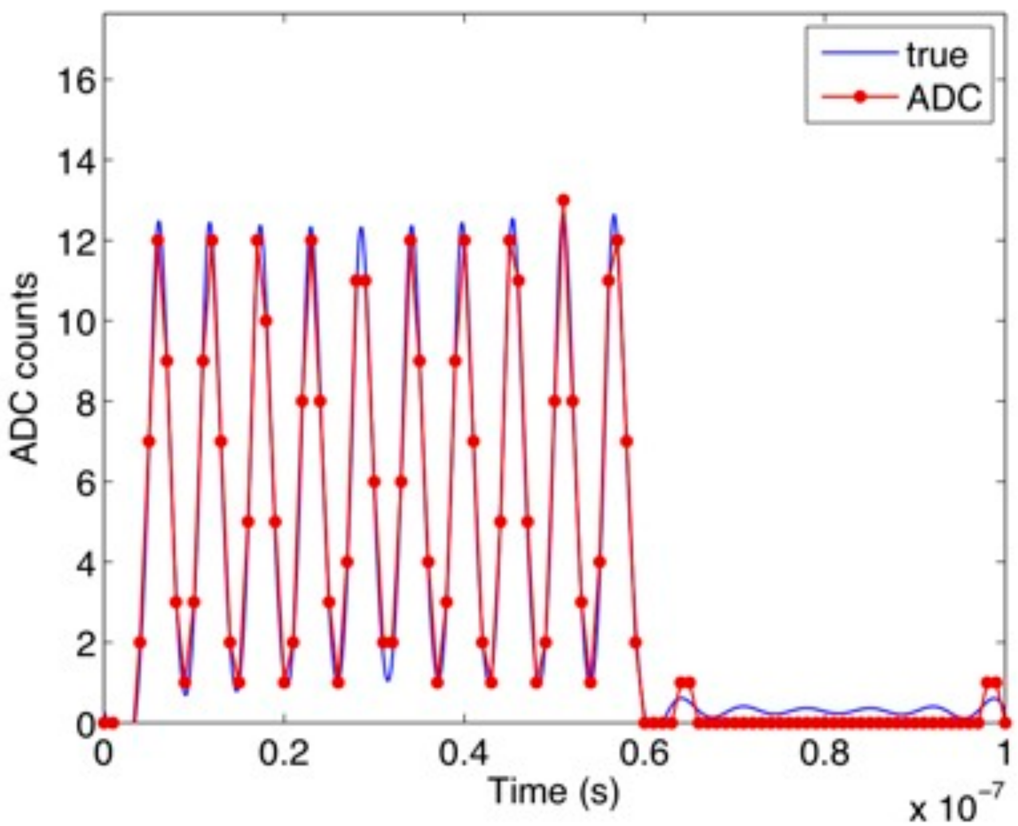
Limited bandwidth



Limited sampling rate (1GS/s)



Limited ADC resolution (6bits)



We have simulated some effects which affect the signal shape and limit the performance of the data acquisition system

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Fast DAQ specifications

Channels needed:

- Compton signal
- Transmitter power from LASER cavity
- Clock
- Injection trigger
- Turn by turn trigger
- BPMs (2 or 4 channels)
- Scalers

Fast DAQ specifications

- Compton signal
  - Limited by response time of the calorimeter (fast component = 0.6 ns)
  - Limited by PMT + Voltage divider (rise time = 0.8 ns)

Bandwidth > 2 GHz
Sampling rate = 3-4 GS/s
ADC resolution = 12 bits or more

- Transmitted power from LASER cavity
  - Limited by fast photodiode (rise time ~ 1 ns)
  - Located 20m from the calorimeter -> reasonable cables quality

Bandwidth >= 1 GHz
Sampling rate >= 1 GS/s
ADC resolution = 8 bits

- 357 MHz clock

Bandwidth = 500 MHz
Sampling rate = 1 GS/s
ADC resolution = 6 bits

Fast DAQ specifications

- Injection trigger
  - Used as a trigger

Bandwidth = few MHz

Sampling rate = few samples/s

ADC resolution = 6 bits or less

- Turn by turn trigger
  - Used as a trigger

Bandwidth = few MHz

Sampling rate = few samples/us

ADC resolution = 6 bits

- BPMs
  - Located 20m from the calorimeter -> good quality cables
  - Measure the passage and positions of the electrons

Bandwidth > 1 GHz

Sampling rate > 1 GS/s

ADC resolution = 8 bits

- Scaler
  - Data synchronization

Fast DAQ specifications. Data rate.

- Compton signal
  - 100 - 300 ns / us over one injection (500 ms)
  - Using given sampling rate = 4 GS/s -> 400 S/us during 500 ms
  - One train: 400 S/ us x 500000 us = 200e6 Samples
  - 12 bits ADC -> 1 Sample = 2 bytes-> 400 Mb/injection
  - Overall 3 x 400 Mb/injection = 1.2 Gb/injection !!!

- Transmitted power from LASER cavity
  - Same as above except Sampling rate = 1GS/s and ADC resolution = 8 bits
  - 100 S/us x 500000 us = 50e6 S
  - 1 Sample = 1 byte -> 50 Mb/injection
  - Overall: 3 x 50 Mb/injection = 150 Mb/injection

- 357 MHz clock
  - Overall: 150 Mb/injection

- BPMs
  - We want to store 60 ns every 3 times /us
  - Overall: 100 Mb/injection per BPM

Fast DAQ specifications. Data rate.

Data rate of the order of 2 Gb/ injection !!!

There are different scenarios of data reduction:

1. Fast Online Processing (reducing the volume of data).
Use the dedicated memory integrated on the FPGA board to perform preliminary data analysis.

2. Reduce data rate by not saving all turns. Good statistical accuracy can be achieved without saving all turns.

Channel	Number of channels	Bandwidth	Sampling rate	ADC resolution	Data rate/ injection
Compton signal	1	> 2 GHz	3-4 Gs/s	12 bits or more	~1 Gb
Transmitted power	1	> 1 GHz	> 1 Gs/s	8 bits	~150 Mb
357 MHz clock	1	500 MHz	> 1 Gs/s	6 bits	~150 Mb
Injection trigger	1	few MHz	few S/s	6 bits	few kb
Turn by turn trigger	1	few MHz	few S/us	6 bits	few kb
BPM	2(4)	> 1 GHz	> 1 Gs/s	8 bits	~100 Mb/ BPM
Scalers	1	few MHz	few kS/s	8 bits	few kb

Summary

- We have developed a Geant4 simulation to be able to study the calorimeter's response. We are looking at the alternative calorimeter length.

- The first data have been taken and a preliminary analysis has been done. Further understanding of background source, calibration and pile-up effects is needed.

- Preliminary parameters of the fast data acquisition system have been specified and final parameters will be decided shortly.