BaF2 detector simulations, preliminary data analysis and fast DAQ studies

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LAL, Orsay

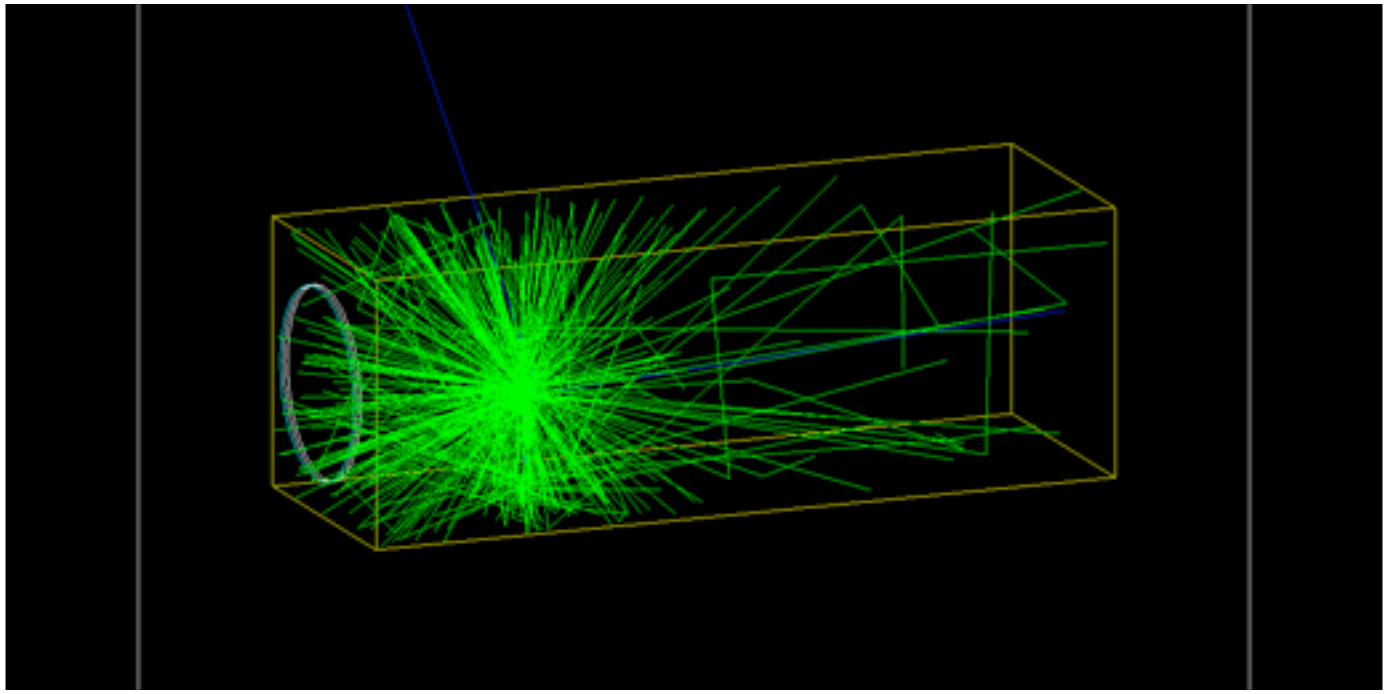
- Compton data acquisition status.

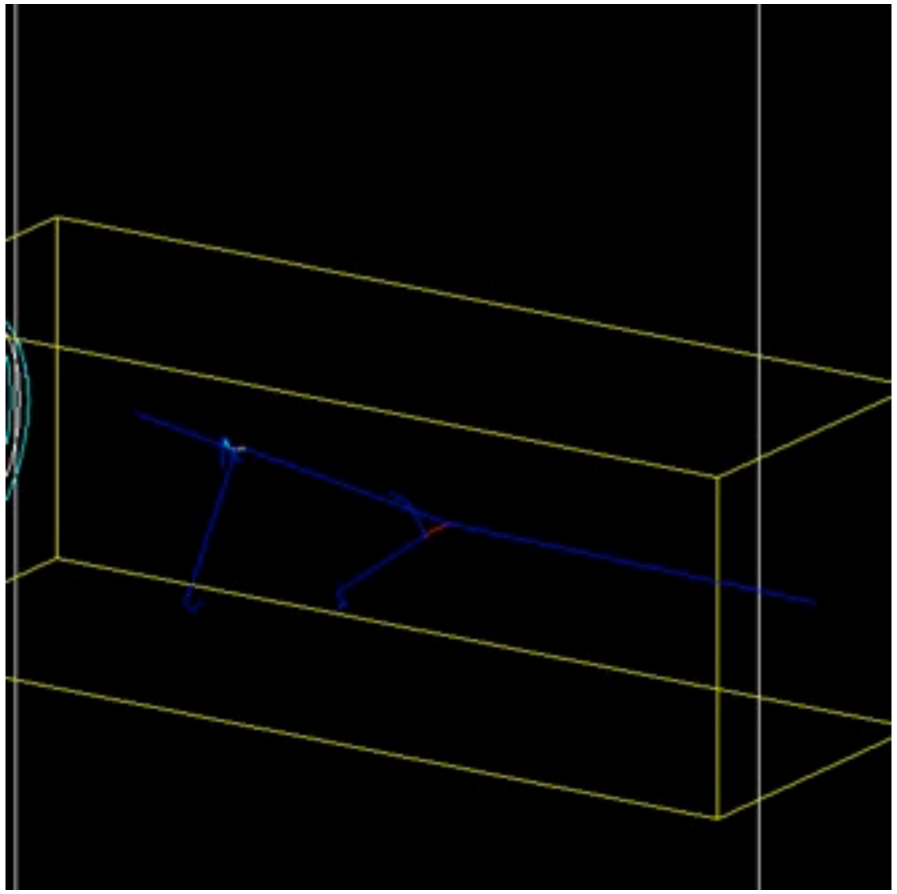
- Simulations, Data analysis and Compton data acquisition upgrade.

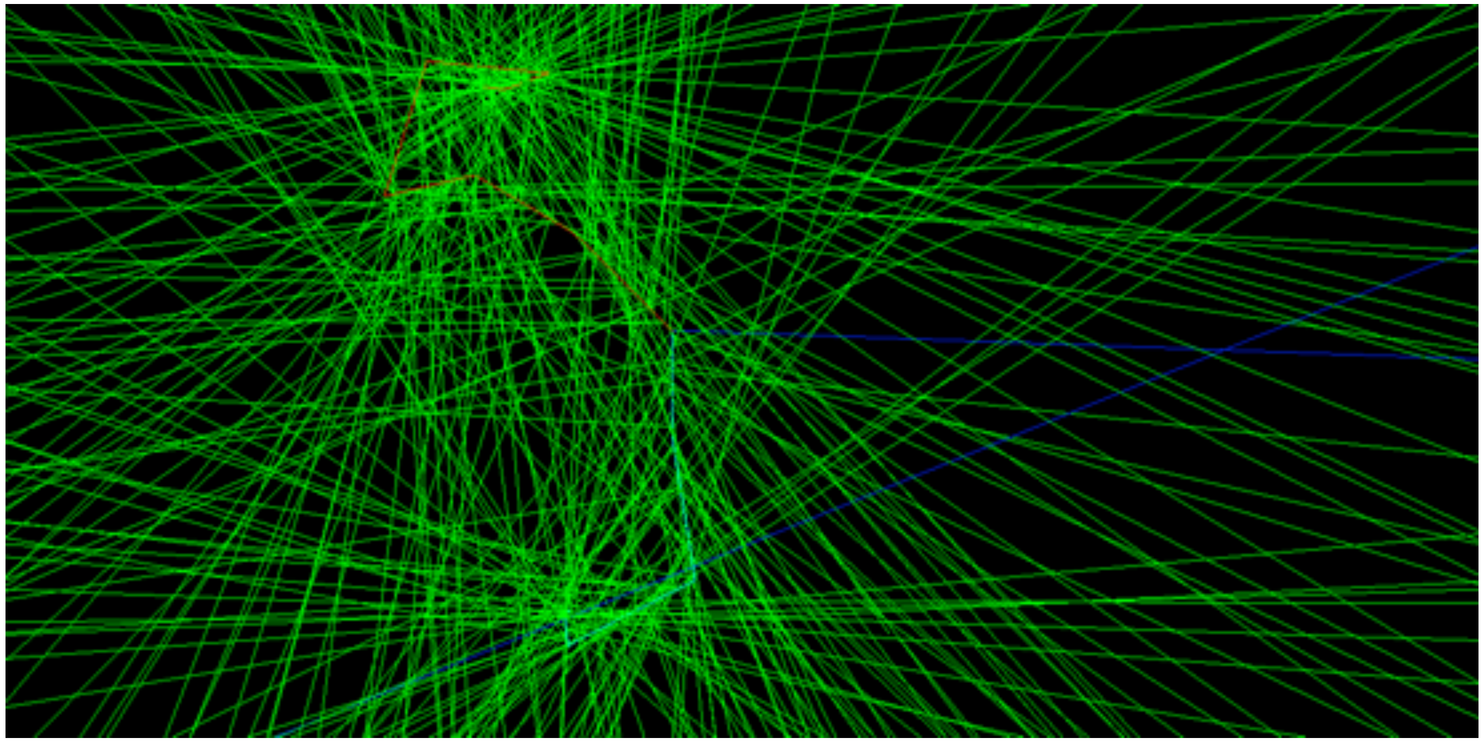
GEANT4 simulations

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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Scintillator crystal

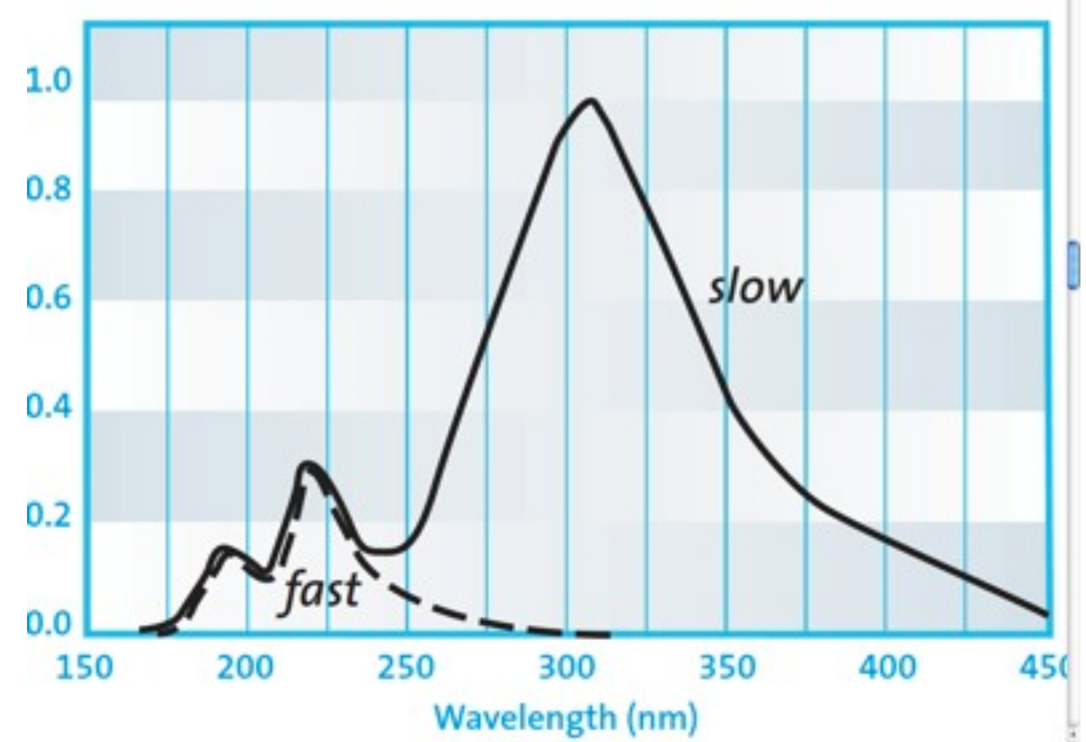
Material: BaF_2

Density [g cm^3]	4.89
Melting point [°C]	1280
Radiation length [cm]	2.06
Molière radius [cm]	3.39
Refractive index	1.5*
Luminescence [nm]	310s/220f
Decay time [ns]	630s/0.9f
Relative light yield	20s/4f**

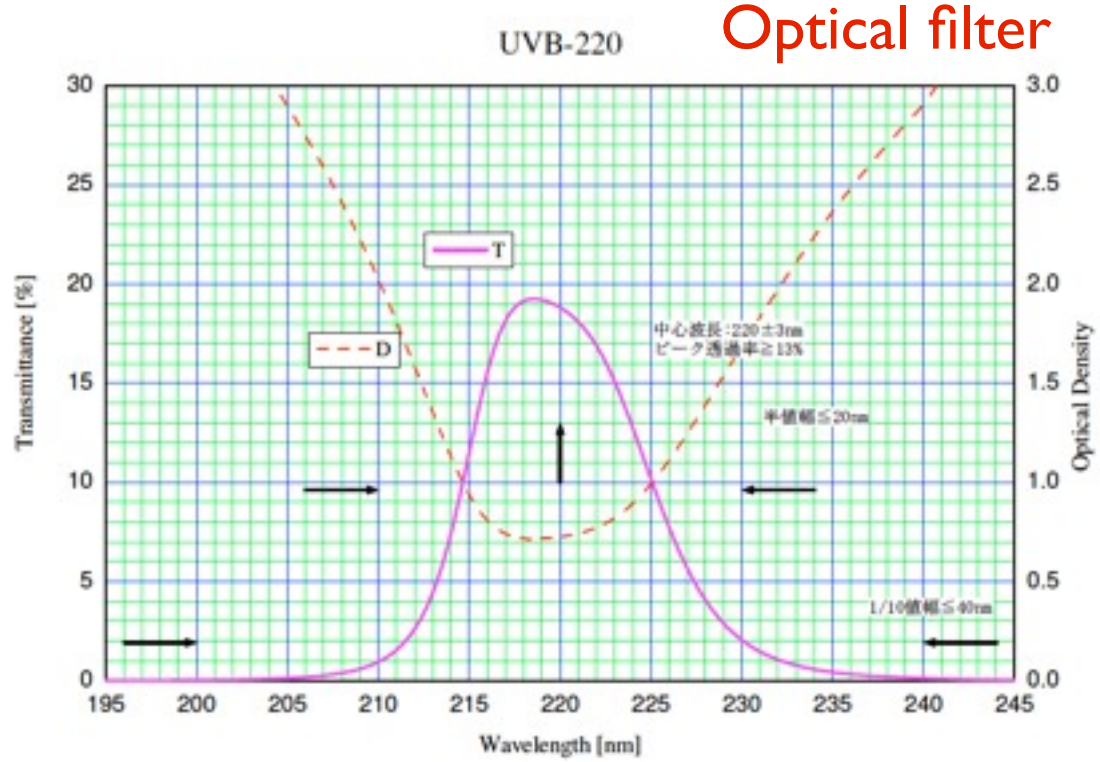
* At the wavelength of the emission maximum

** Relative signal measured with PMT with a bialkali cath

Emission spectrum



Optical filter



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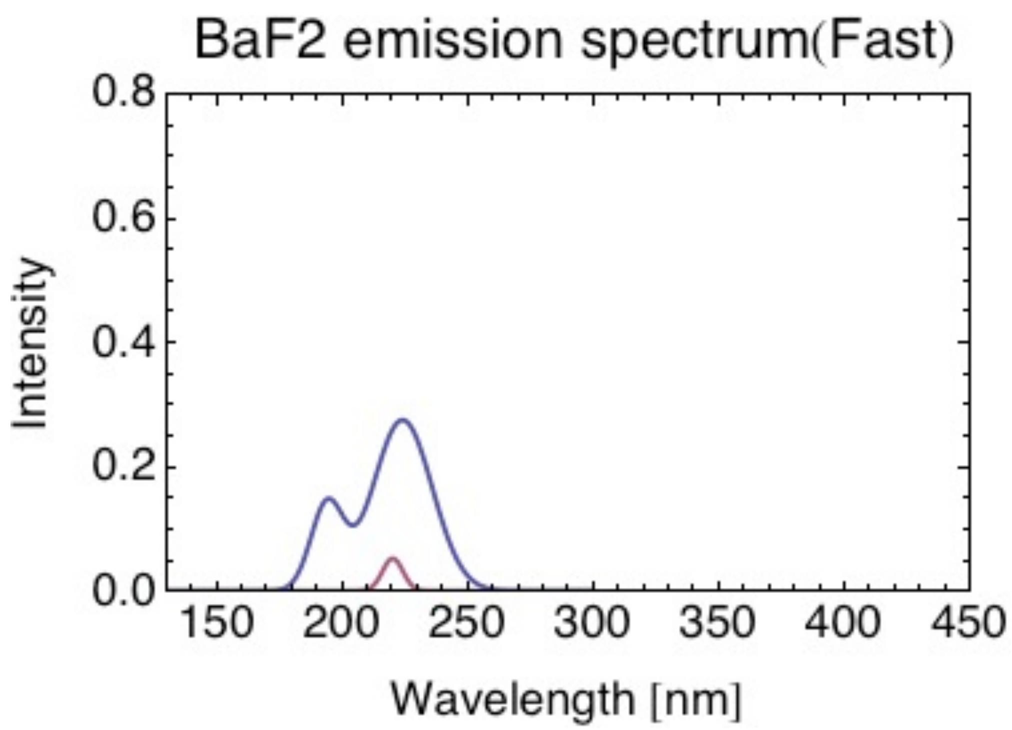
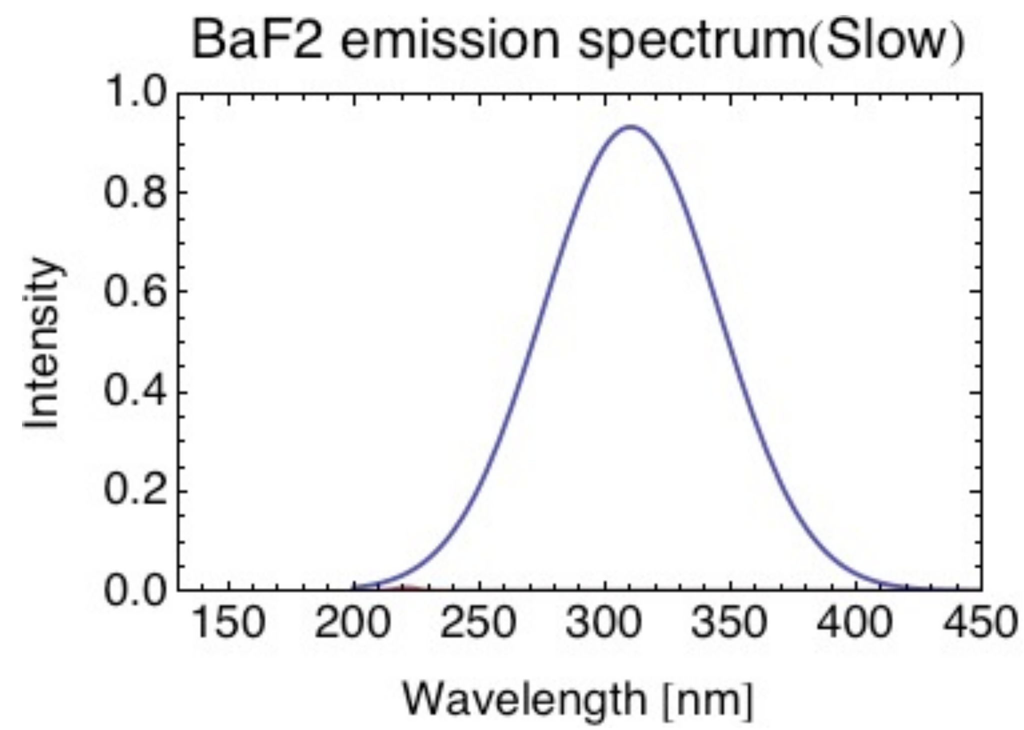
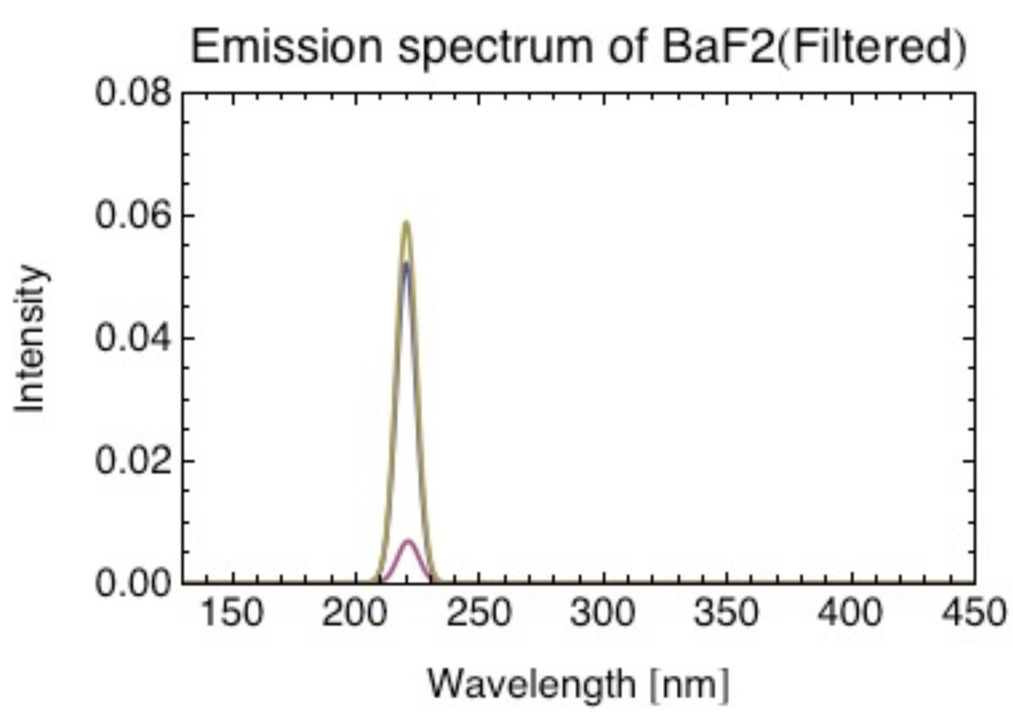
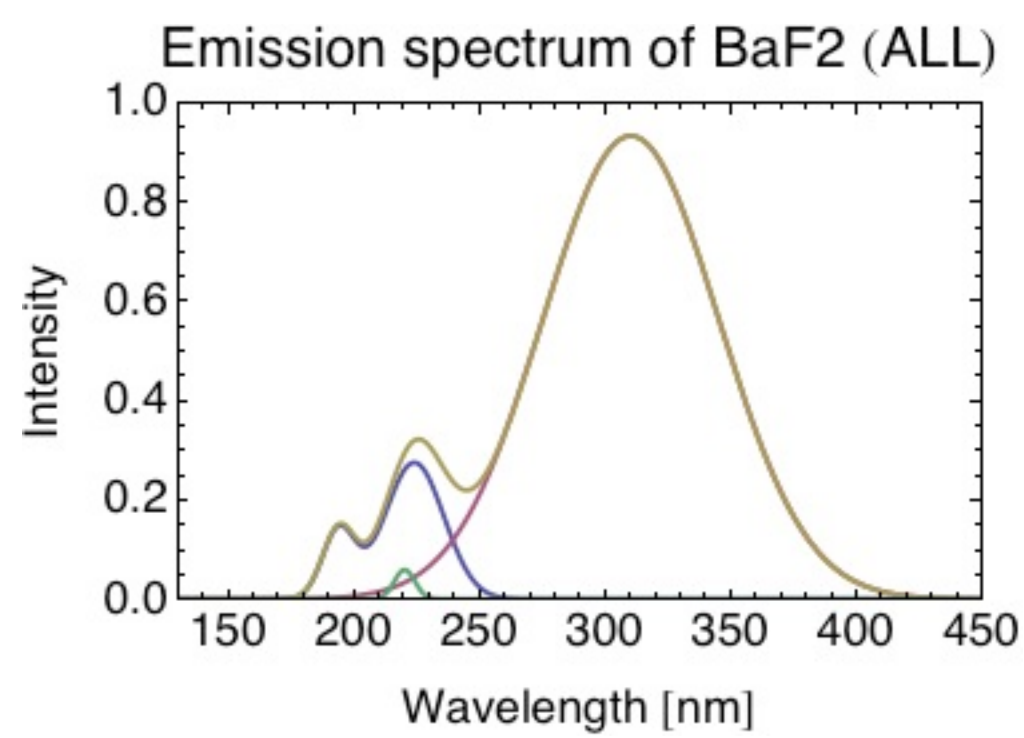
Emission spectrum of BaF2. Effect of the optical filter.









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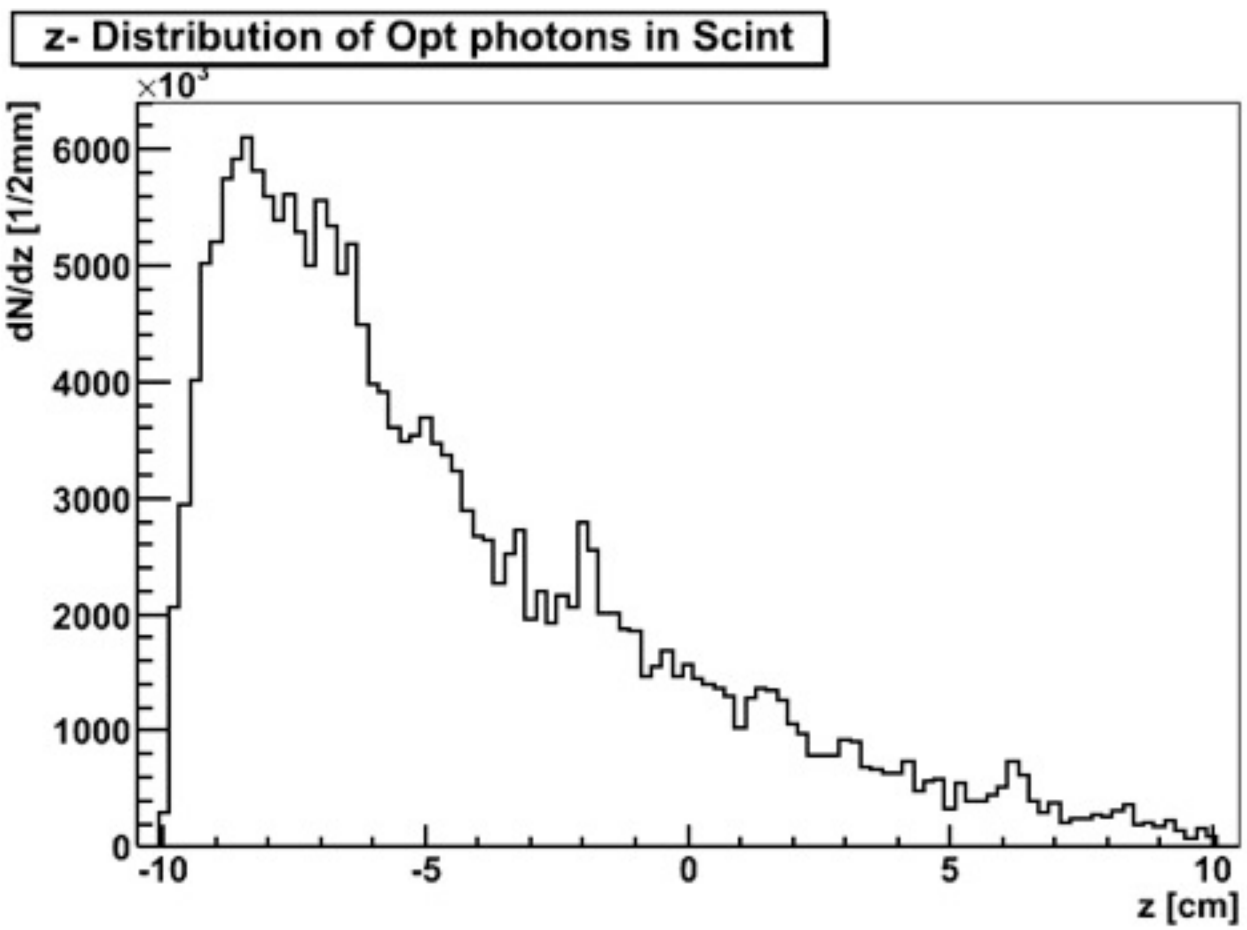
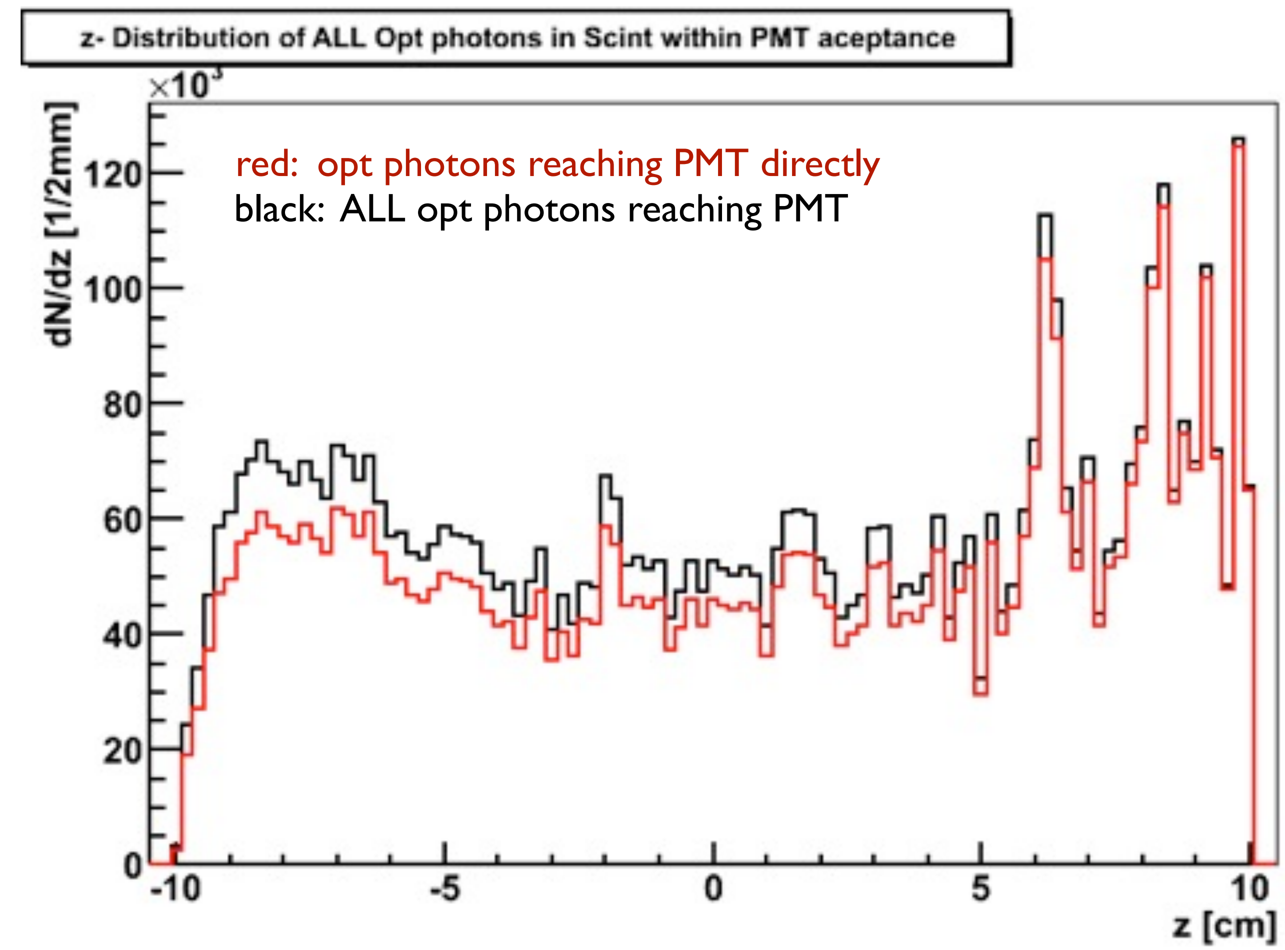
Location where the optical photons are produced inside the scintillator. Contribution of the reflections.





- Most of the optical photons are produced at the beginning of the scintillator.
- Photons generated at the beginning of the crystal have smaller acceptance to reach the PMT.
- 11% of the photons reaching the PMT undergo at least one reflection in the crystal.

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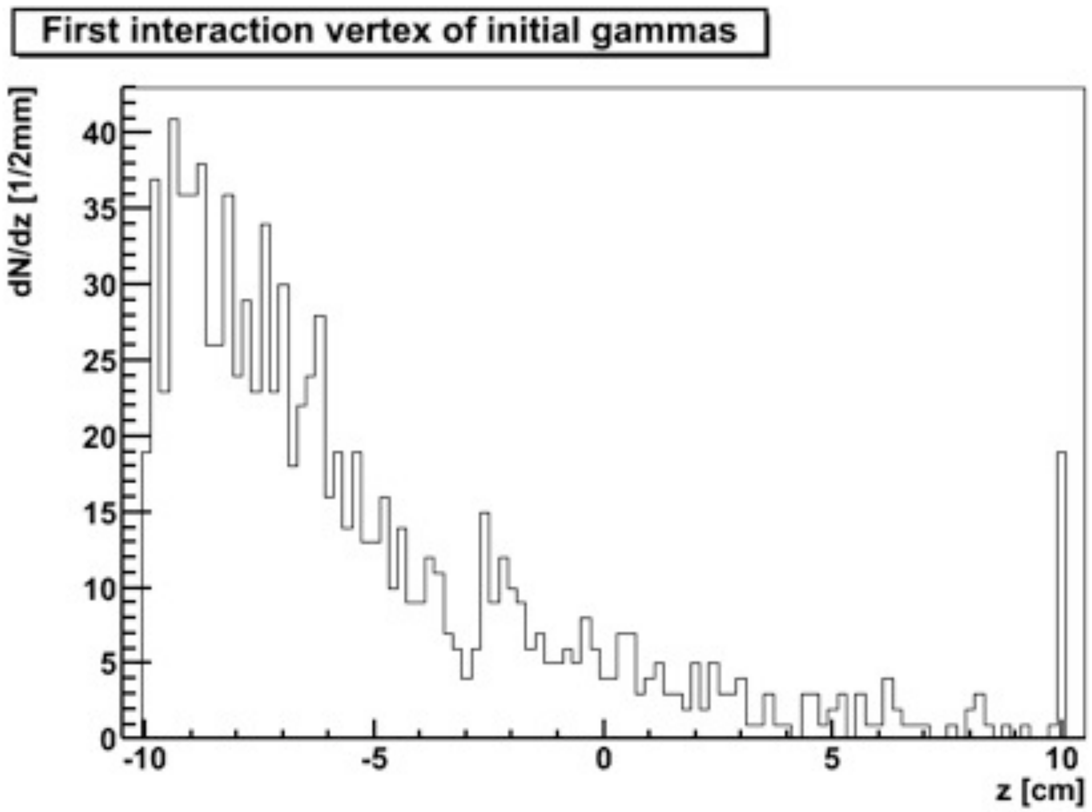
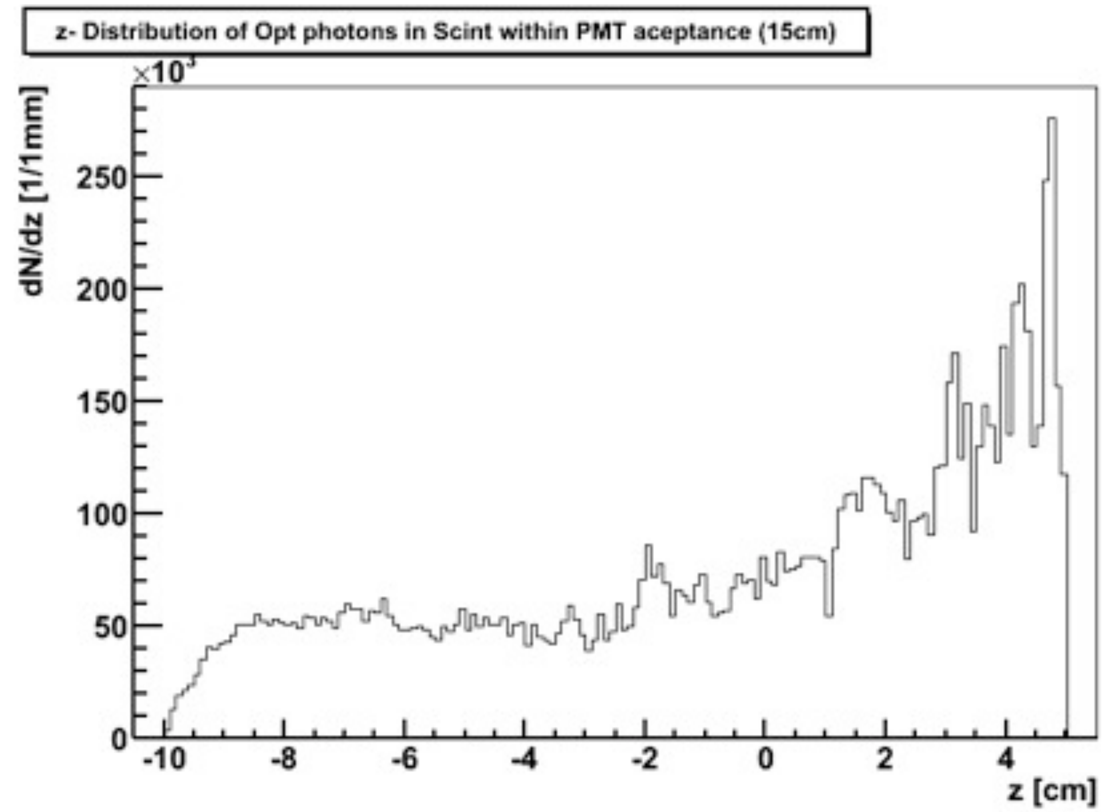
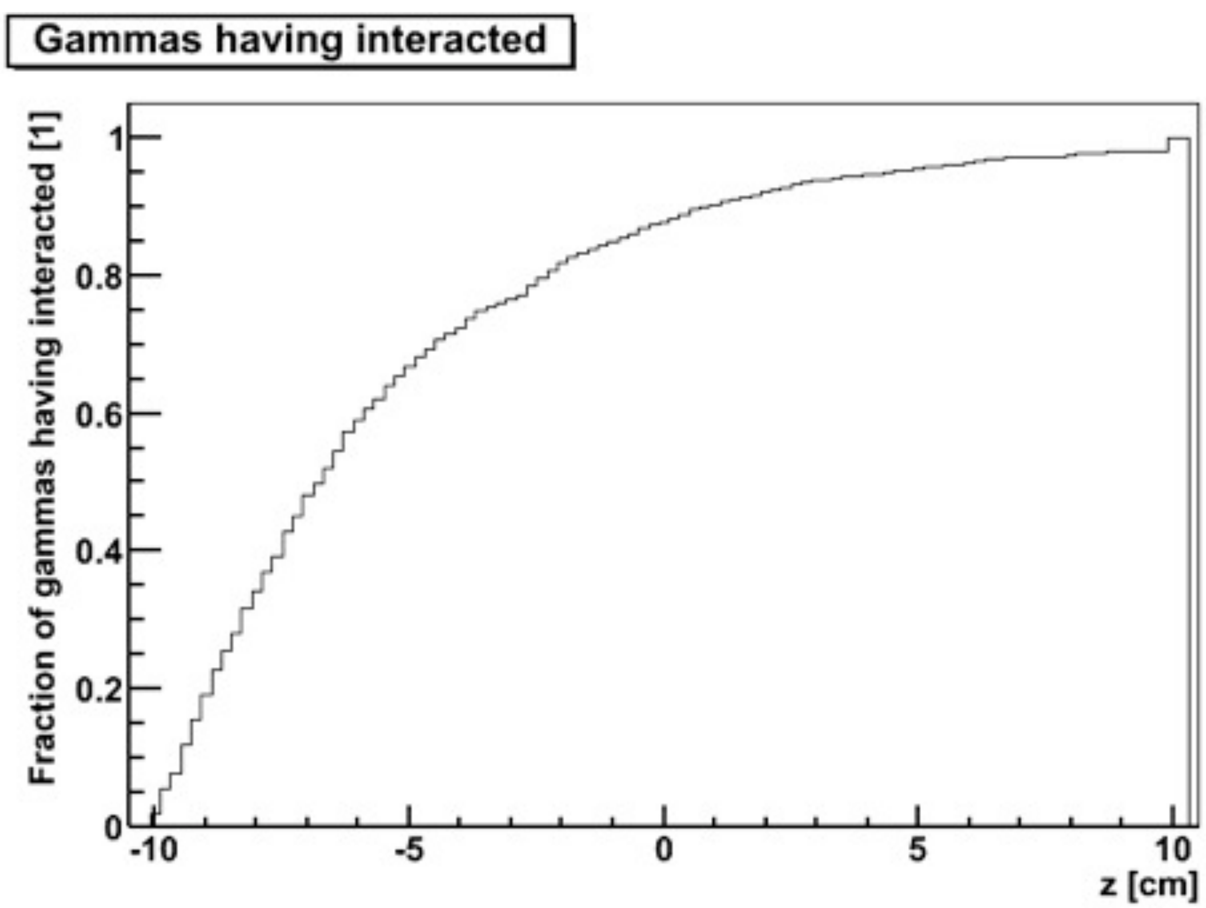
Location where the optical photons are produced inside the shorter scintillator







The high energy Compton gammas interact along the crystal while some of them pass the calorimeter without interacting.

20 cm crystal = 0.98 of impinging gammas;
15 cm crystal = 0.95 of impinging gammas;
10 cm crystal = 0.87 of impinging gammas;
5 cm crystal = 0.64 of impinging gammas.

Shorter crystal reduces the linearity.

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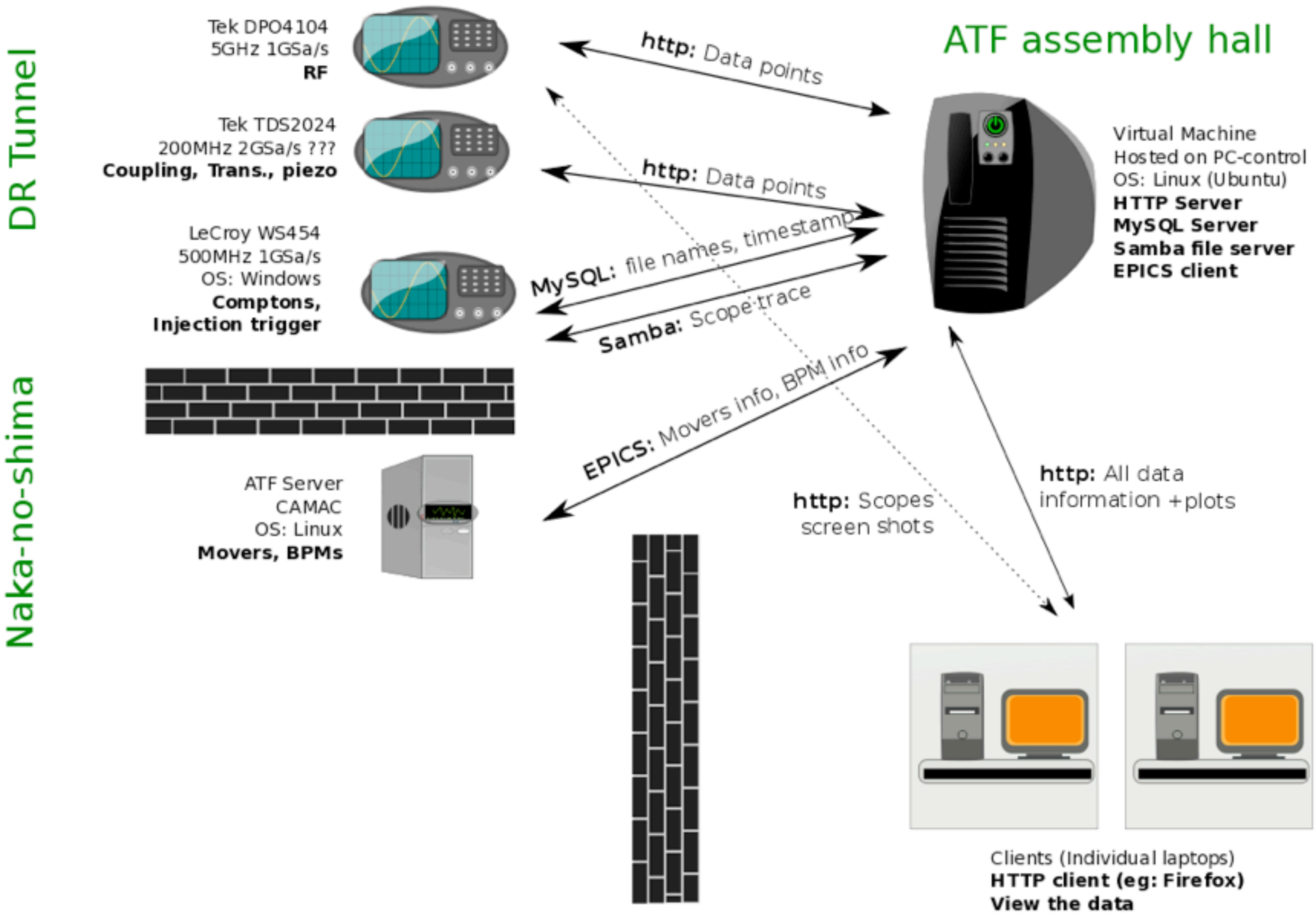
Data aquisition. Data flow.



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Data taking and analyzing

• During the data taking we usually save on the server the waveforms of the Compton signal, the transmitted power from the LASER cavity, 357 MHz clock and BPMs data.

• All information such as the type of the data, names of the files, the date and time are sent to a DataBase.

• MatLab/Octave framework is used to process the data.

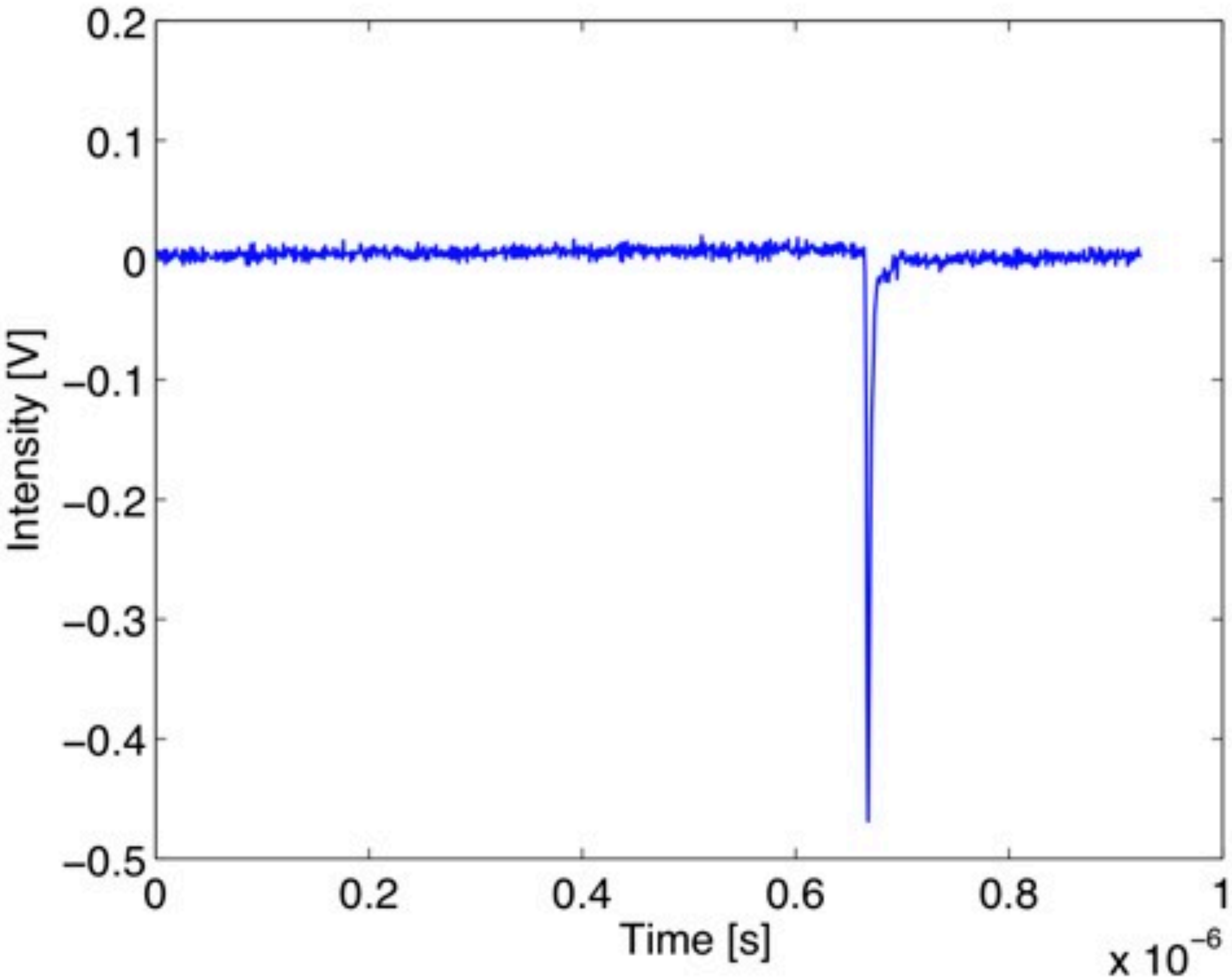
• After processing, the results are saved in the Data Base for further usage.

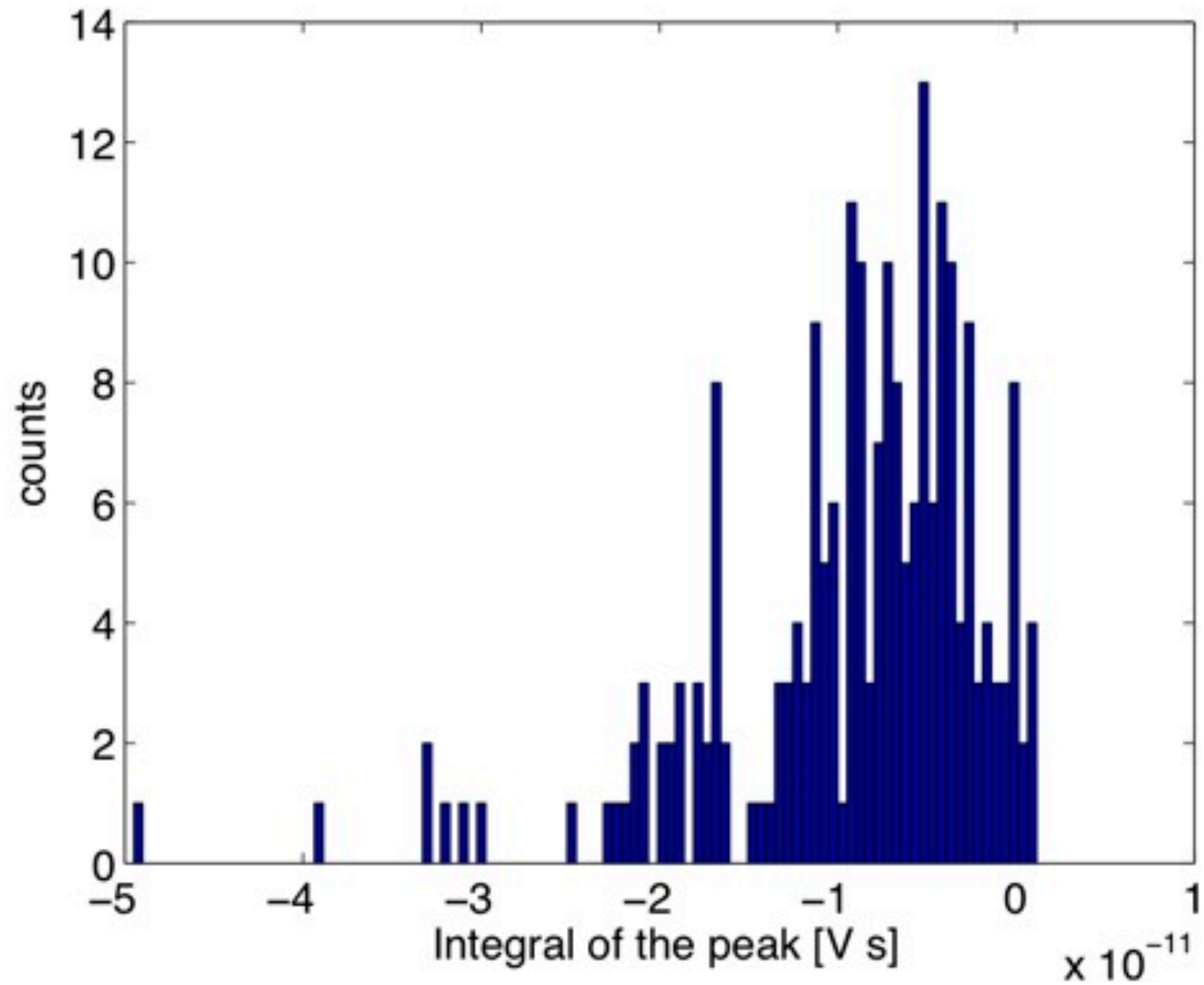
• Data was acquired parasitically during ATF runs (1 train/1 bunch, 3 trains/1 bunch, 1 train/ 6 bunches)

• Data acquisition was performed using *LeCroy WS454* scope (1Gs/s, 500MHz bandwidth).

• Peak values and integrals of the Compton signal have been calculated.

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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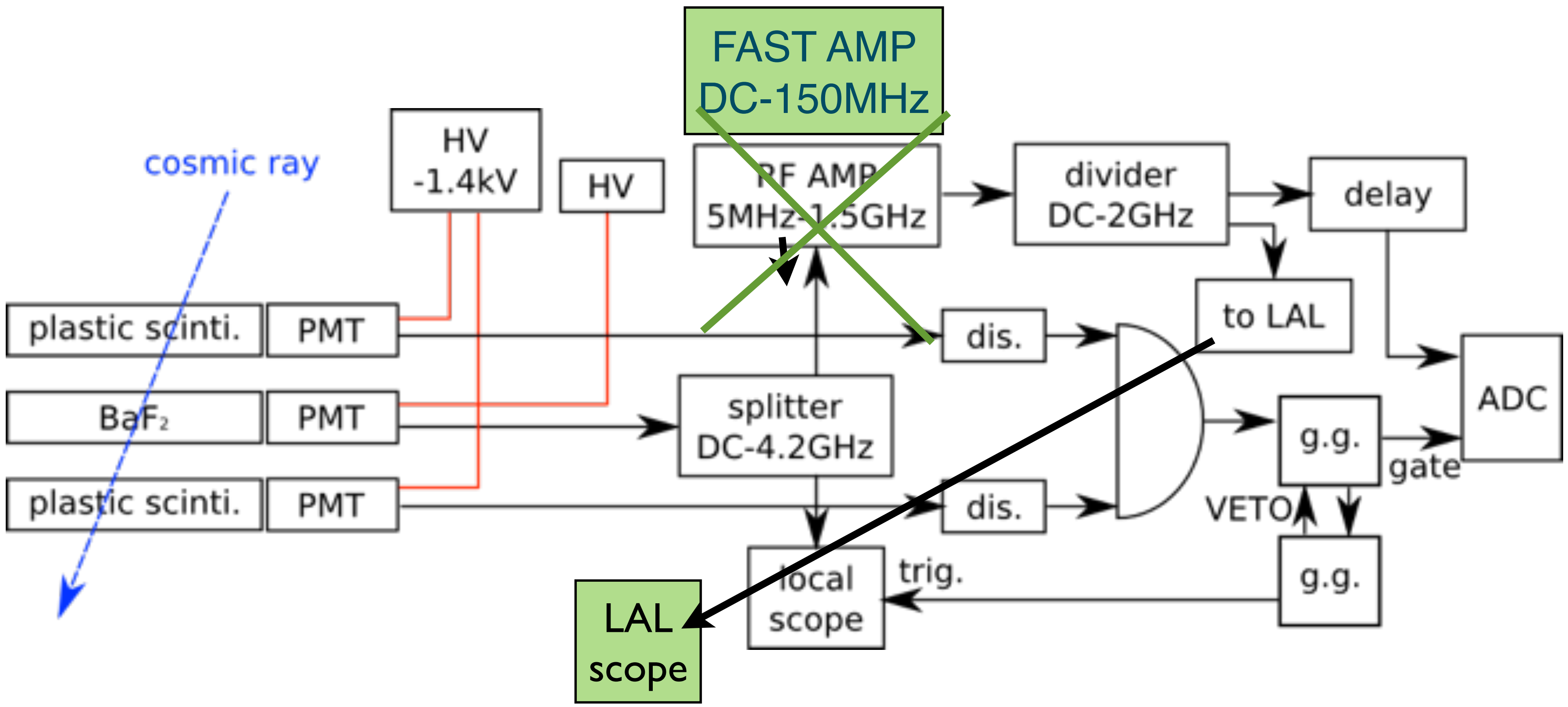
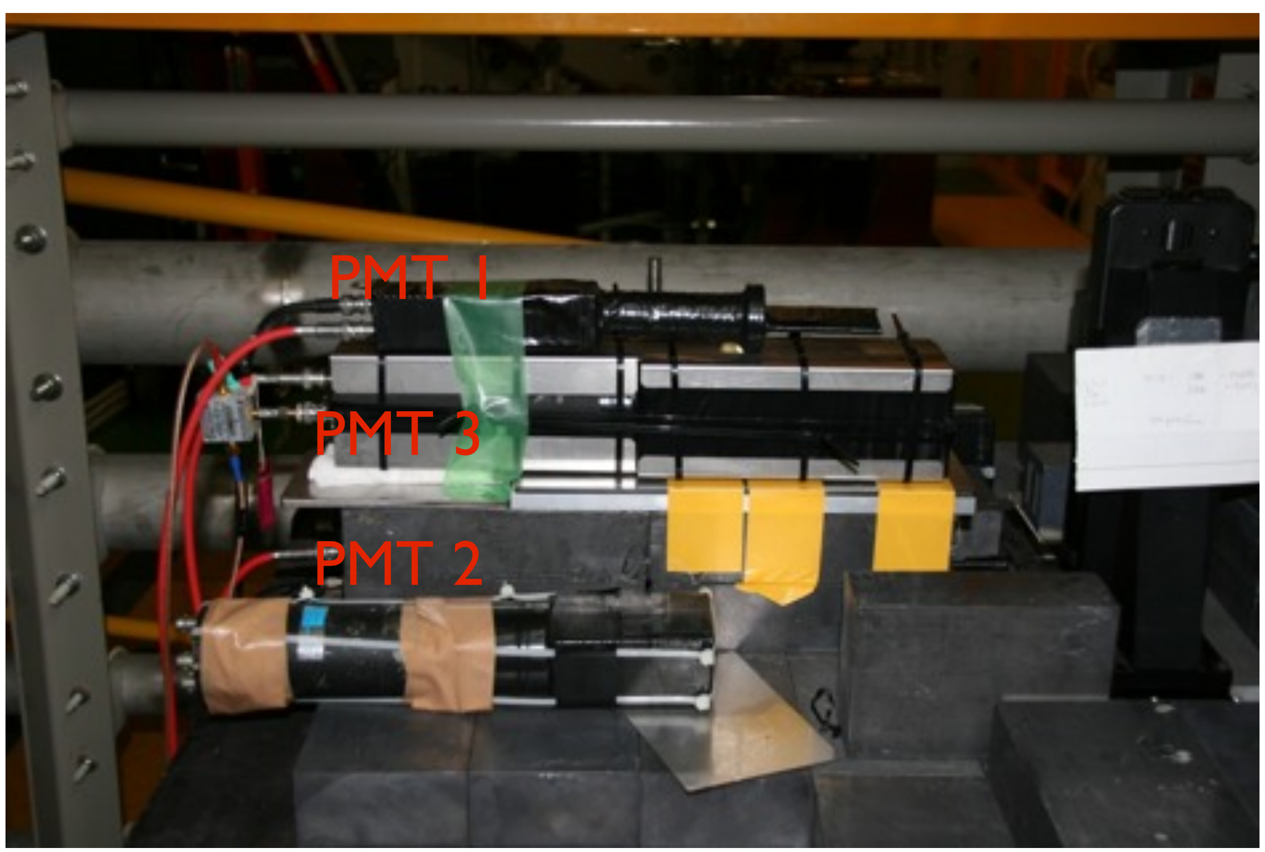
Calibration layout





- The RF Amplifier (5MHz - 1.5GHz) was changed for Fast Amplifier (DC - 150MHz).
- Scope was moved to the Damping Ring

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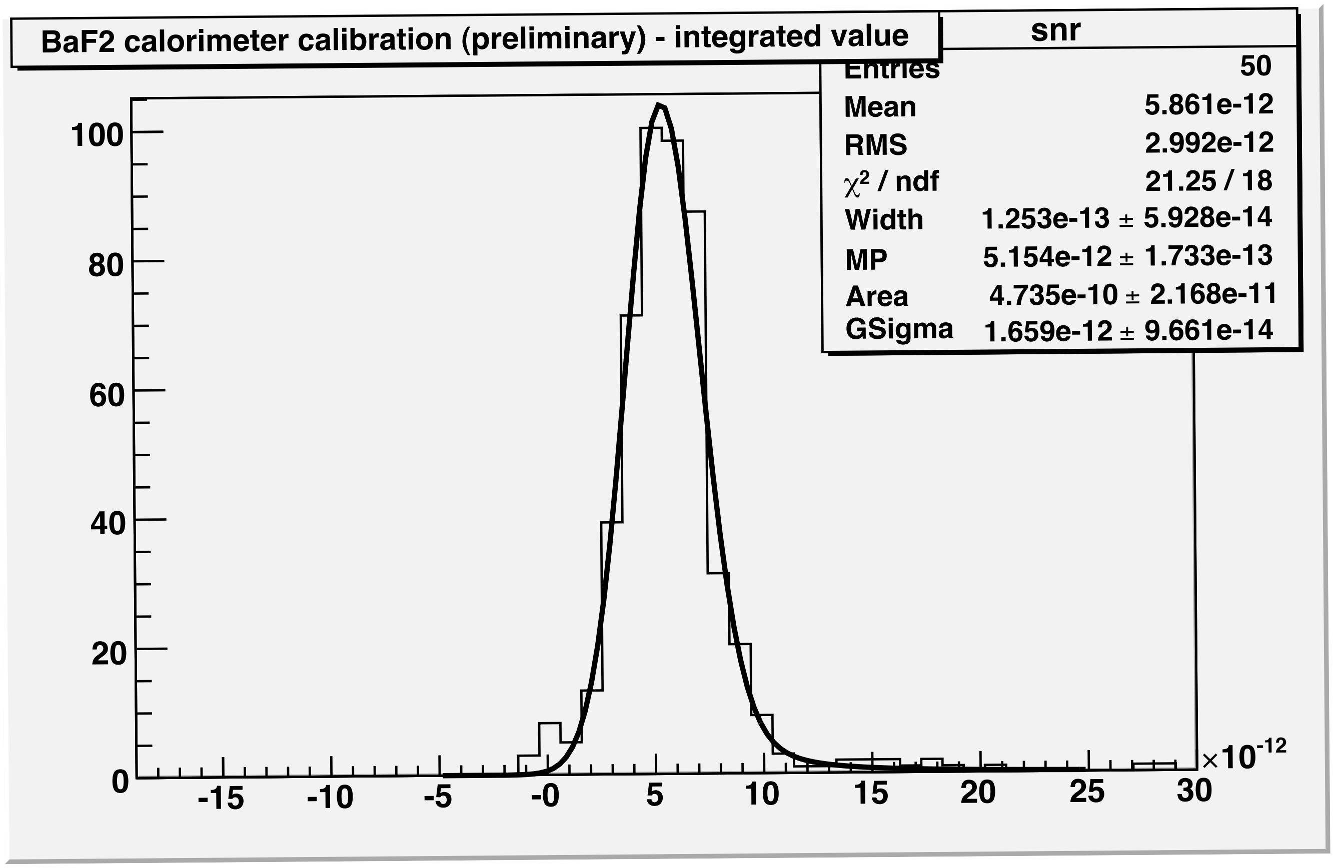
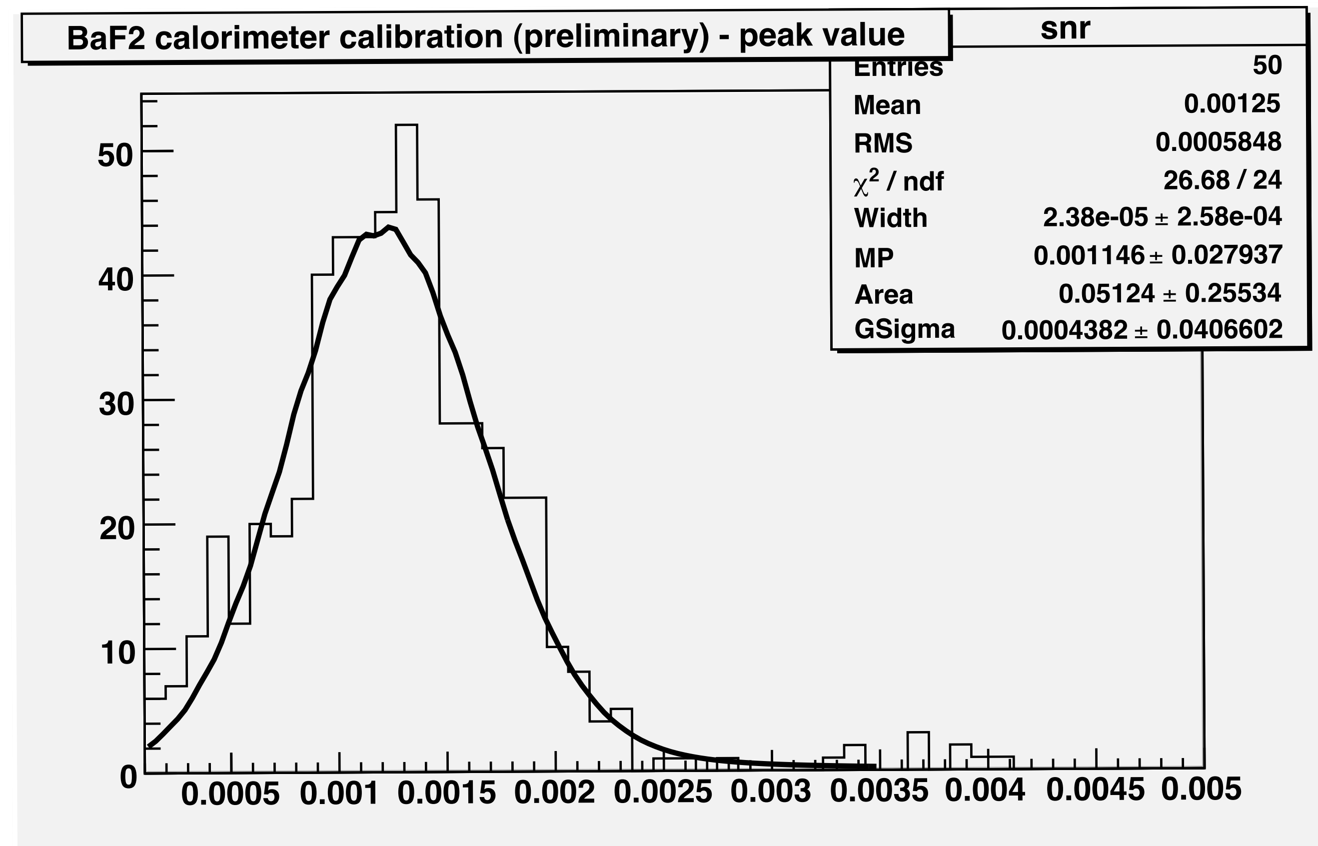
Calibration using cosmic rays





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.

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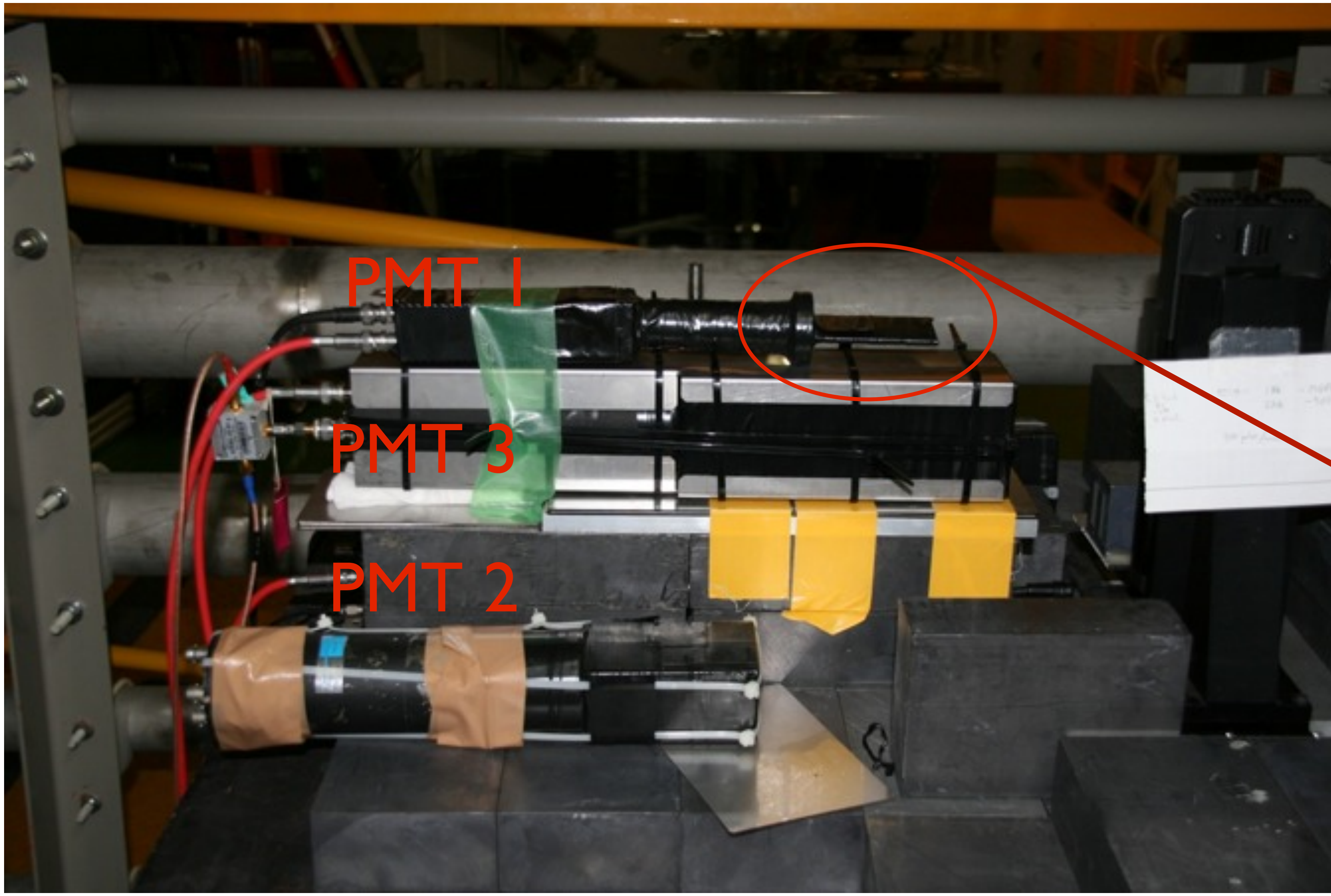
Calibration factors



Factor 1

A = all opt photons in BaF2
B = opt photons within PMT acceptance

$\boxed{F1 = A/B = 39}$

Factor 2

C = all opt photons in BaF2 within calibration acceptance
D = opt photons within calibration acceptance & PMT acceptance

$\boxed{F2 = C/D = 47}$

$$\boxed{E_{gamma}\ [MeV] = V_{gamma}[mV]\ E_{cosm}[MeV]\ / V_{cosmic}[mV])(F1/F2)}$$

According to calibration, 1 mV peak value on the scope equals to 34 MeV of energy deposited and 1mV.ns integrated value corresponds to 7 MeV.

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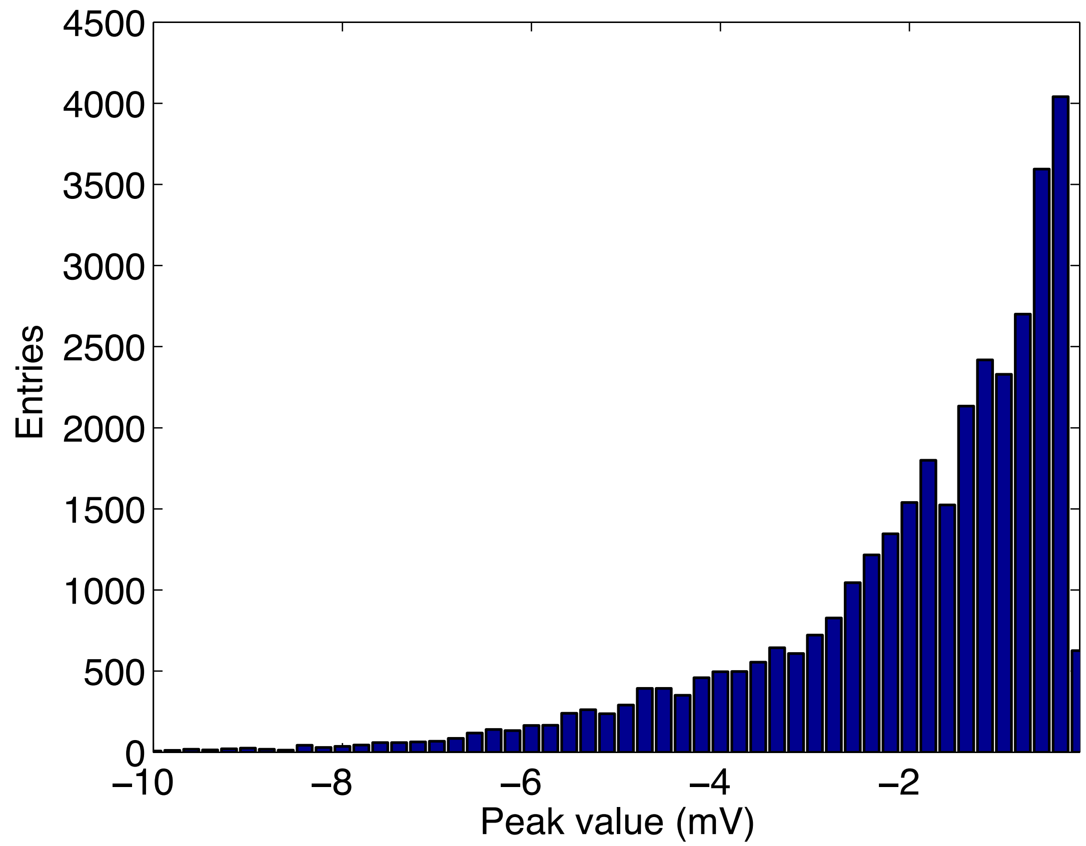
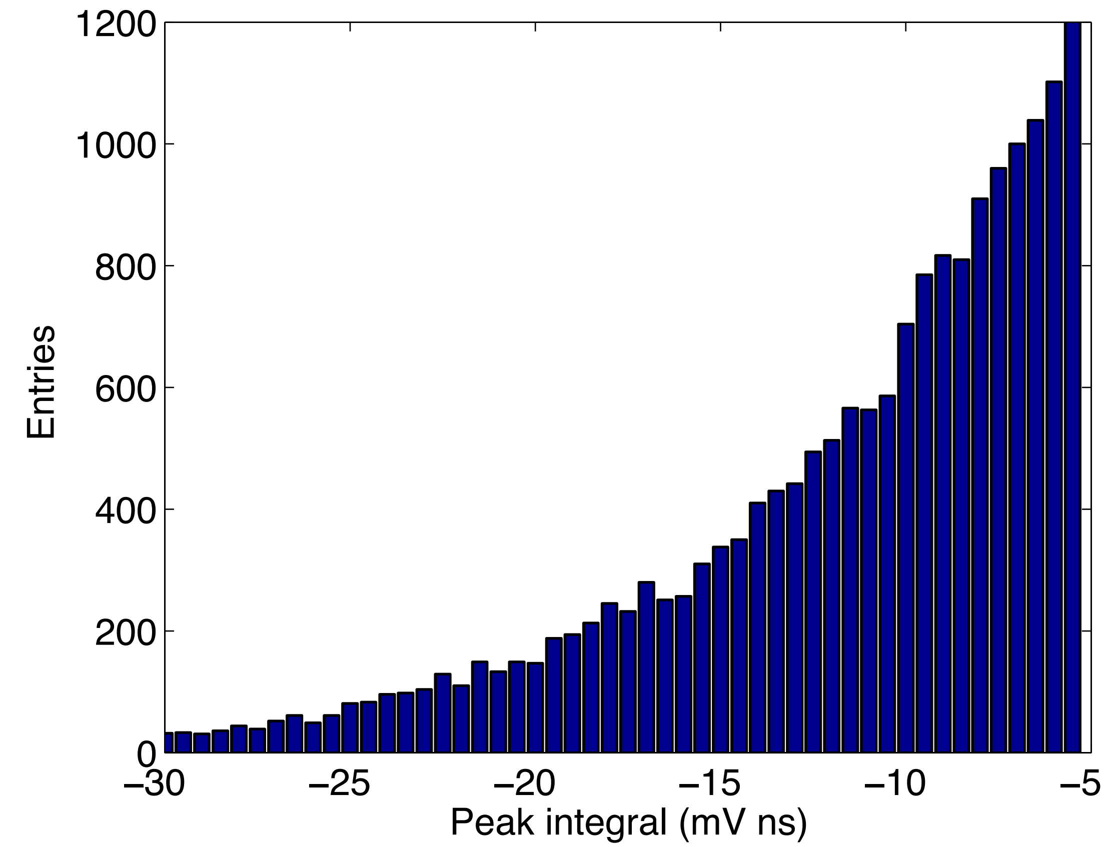
Energy spectrum of the gammas (preliminary)



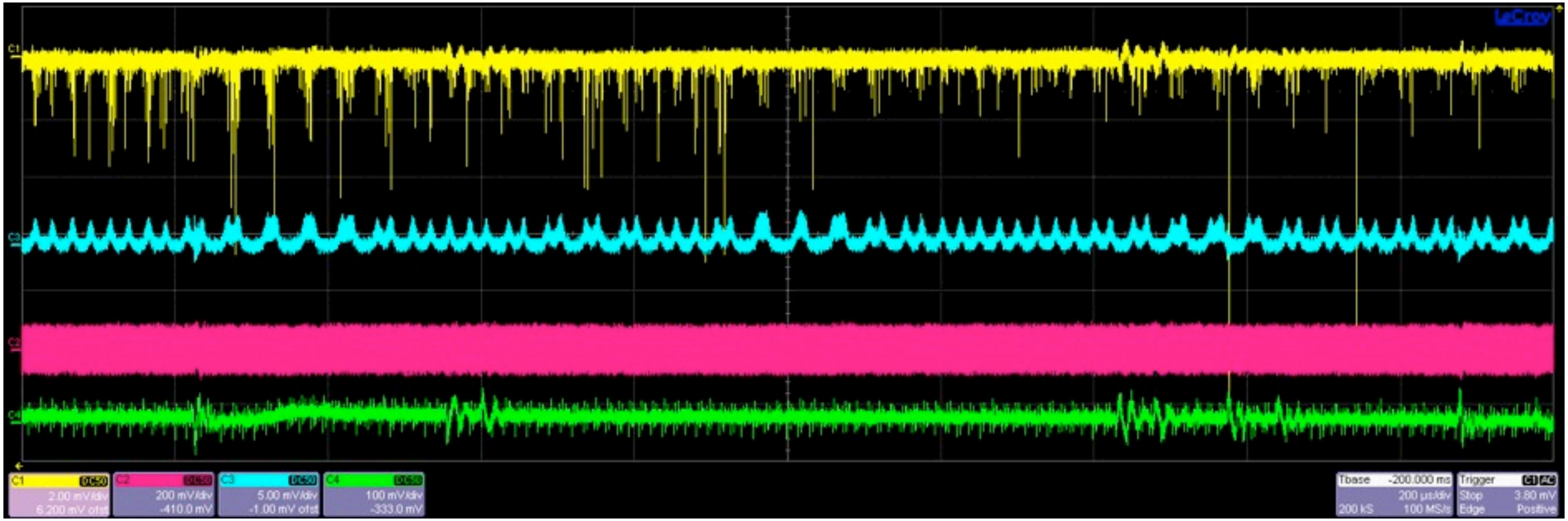


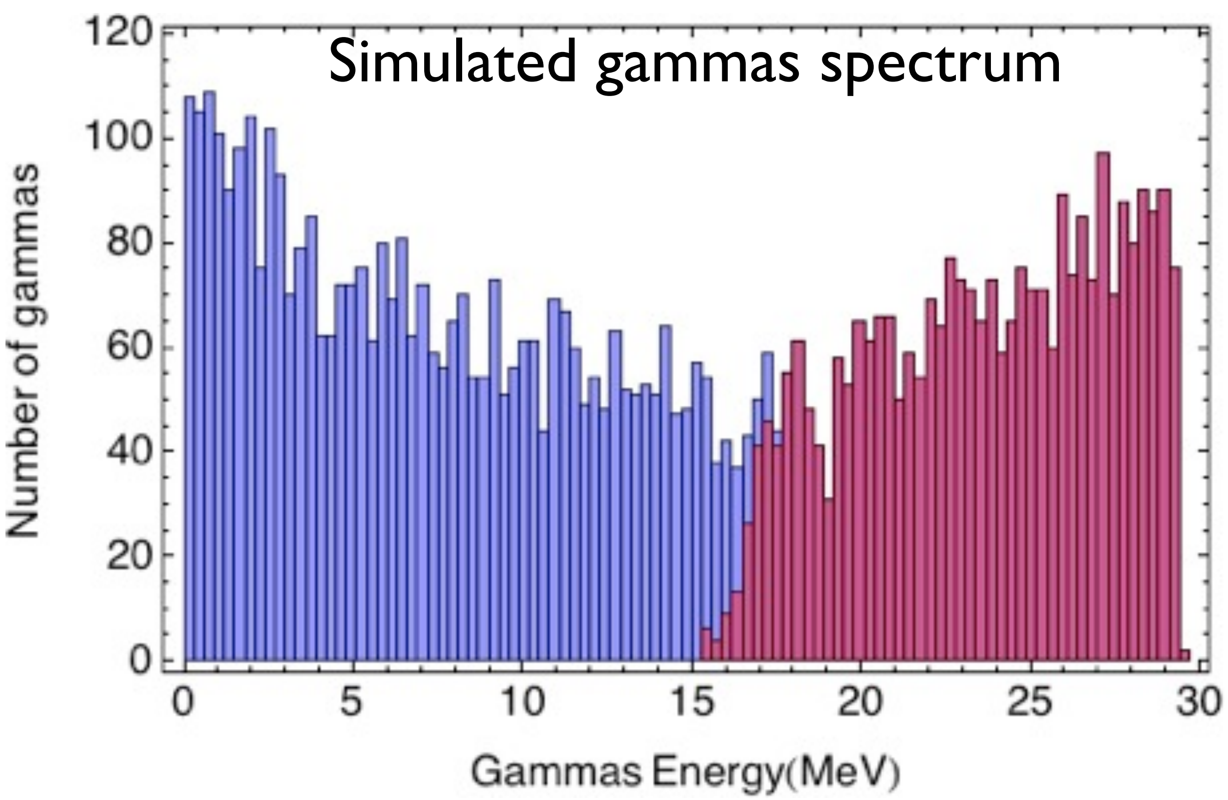
According to the calibration, 24 MeV gammas deposit 3.4 mV.ns with a peak of 0.7 mV.

Between 1 and 2 gammas are produced per bunch crossing. If we had 2 gammas per crossing over 500 ms(one injection-extraction cycle), the flux would be be 1.5 million gammas per second.

Additional work is needed to reject the background from low intensity events.

Additional considerations





Above:

- The FP cavity is locked to the ATF clock.
- Fluctuations of the LASER power (blue) affect the Compton signal (yellow) despite a constant electrons intensity (BPM in green).

Left:

- The collimators only accept photons with an energy above ~15 MeV

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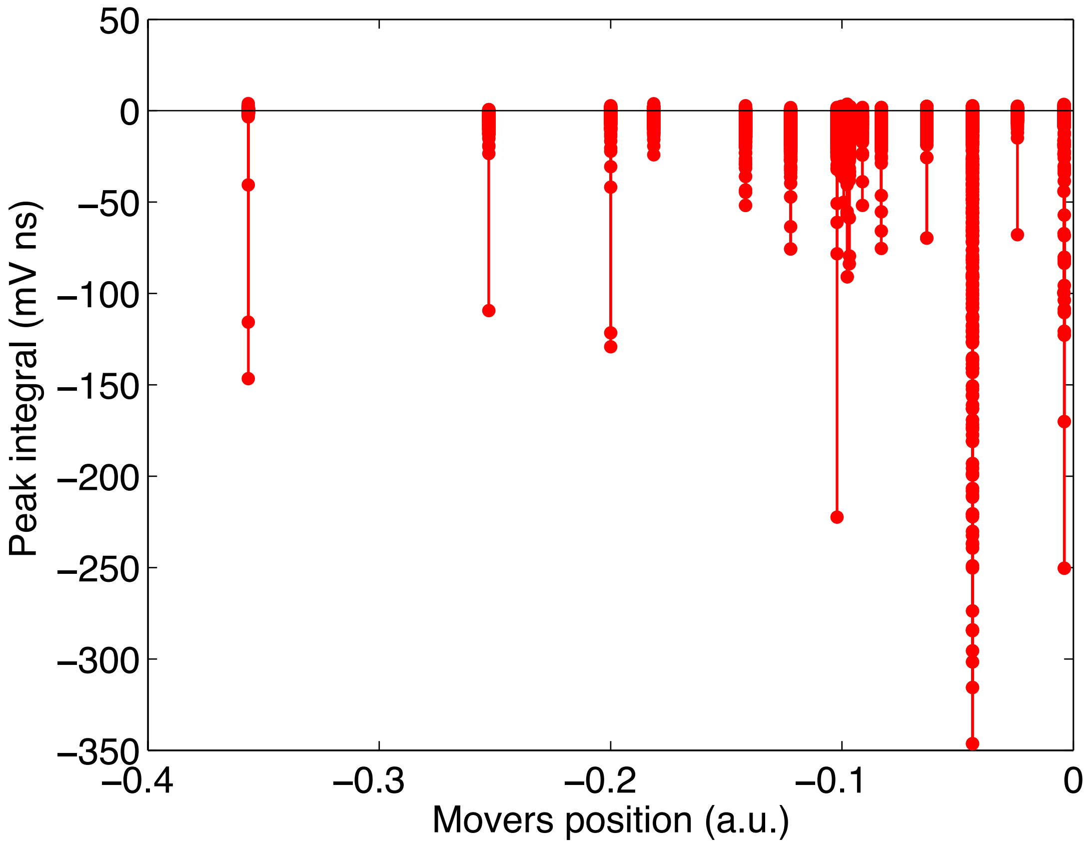
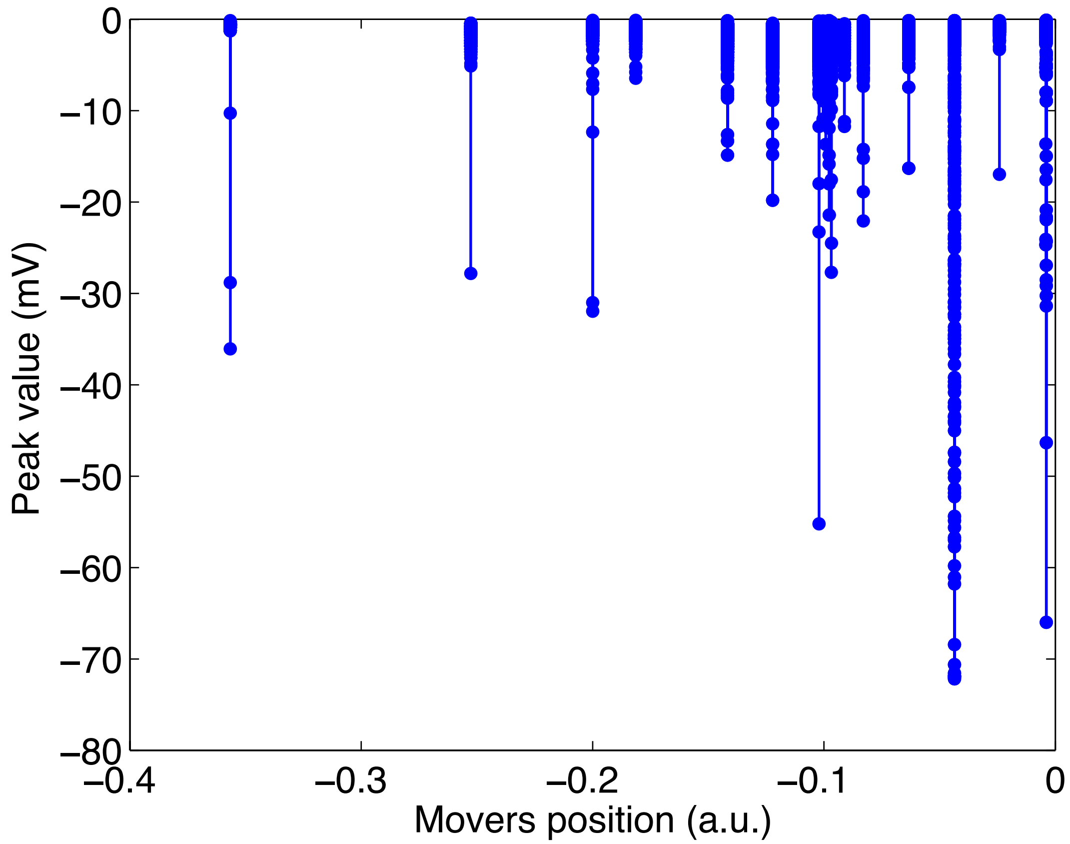
Position scan (very preliminary)





- We started to study the correlations between the position of the LASER and that of electrons.
- This will allow us to optimize the luminosity.
- More work is needed: clean the data, remove the background, fast acquisition, online processing.
- The large line around -0.05 is not understood but seems to be real signal.

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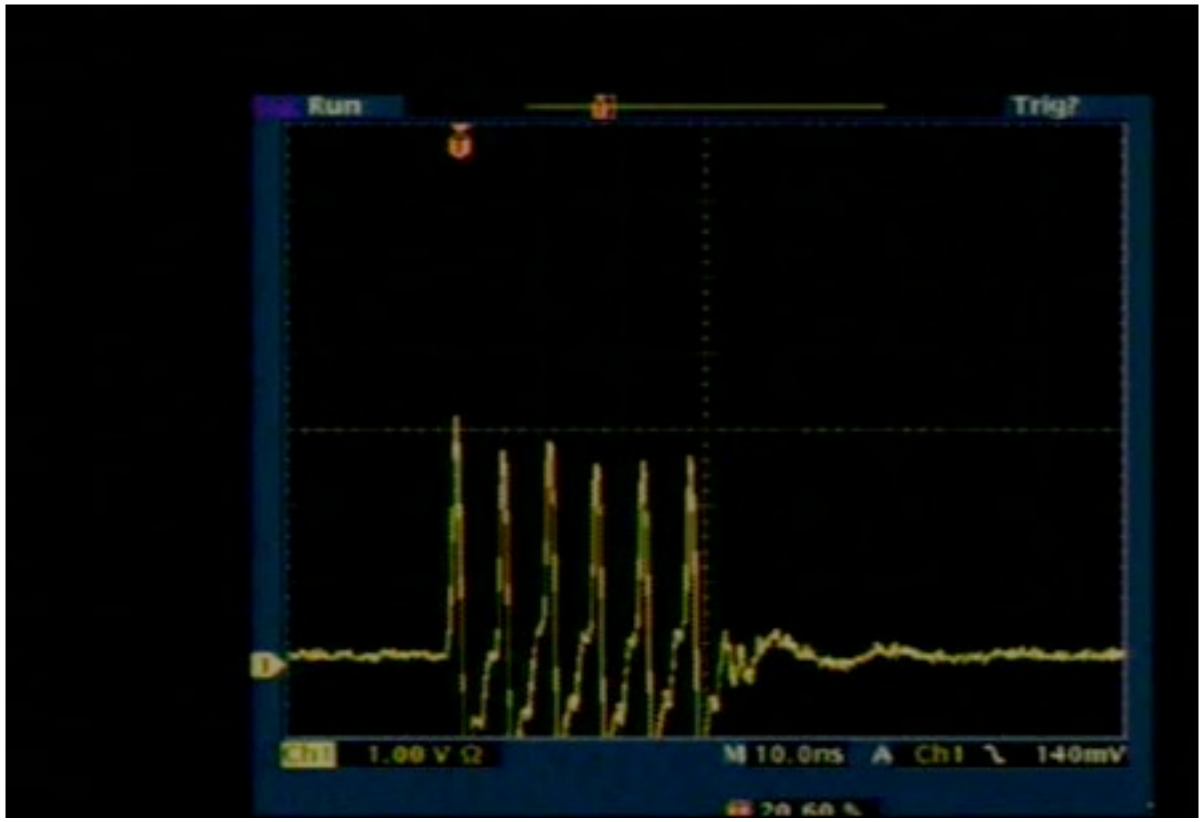
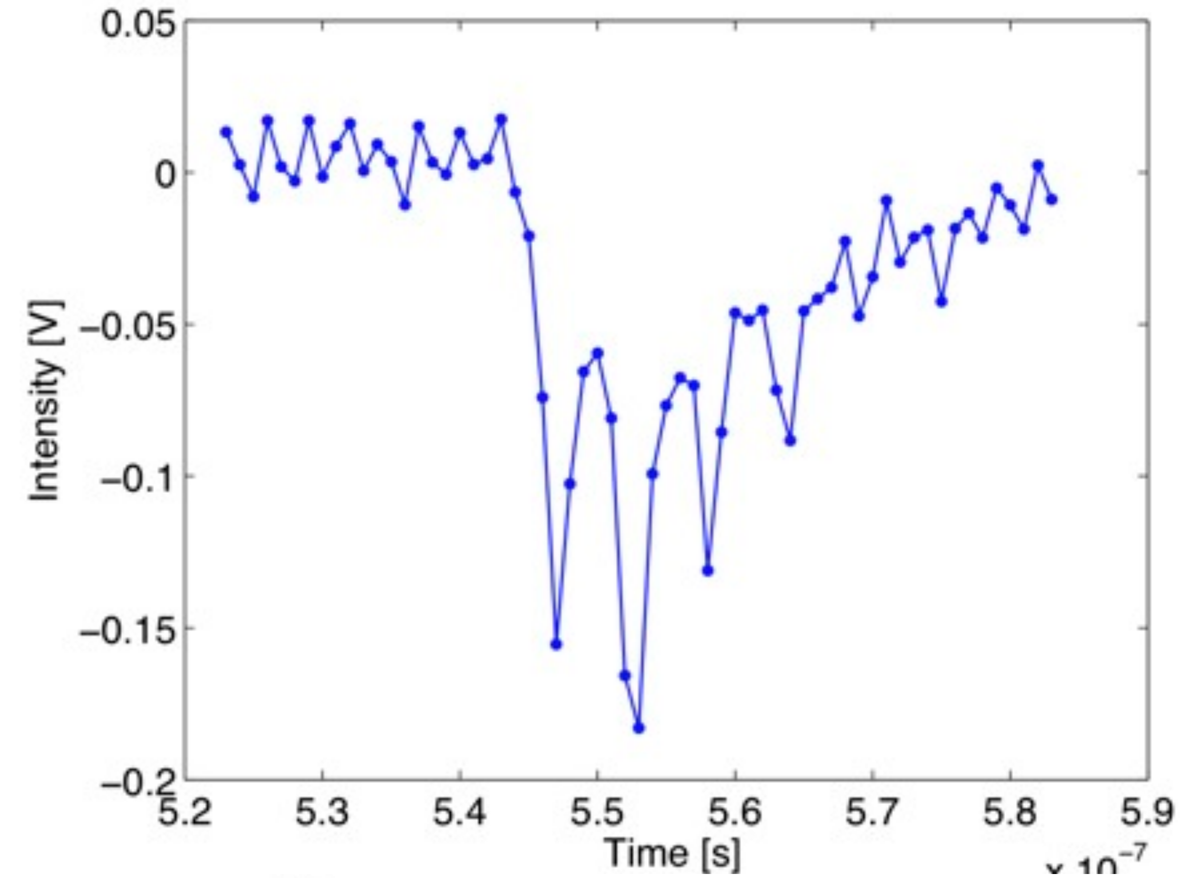
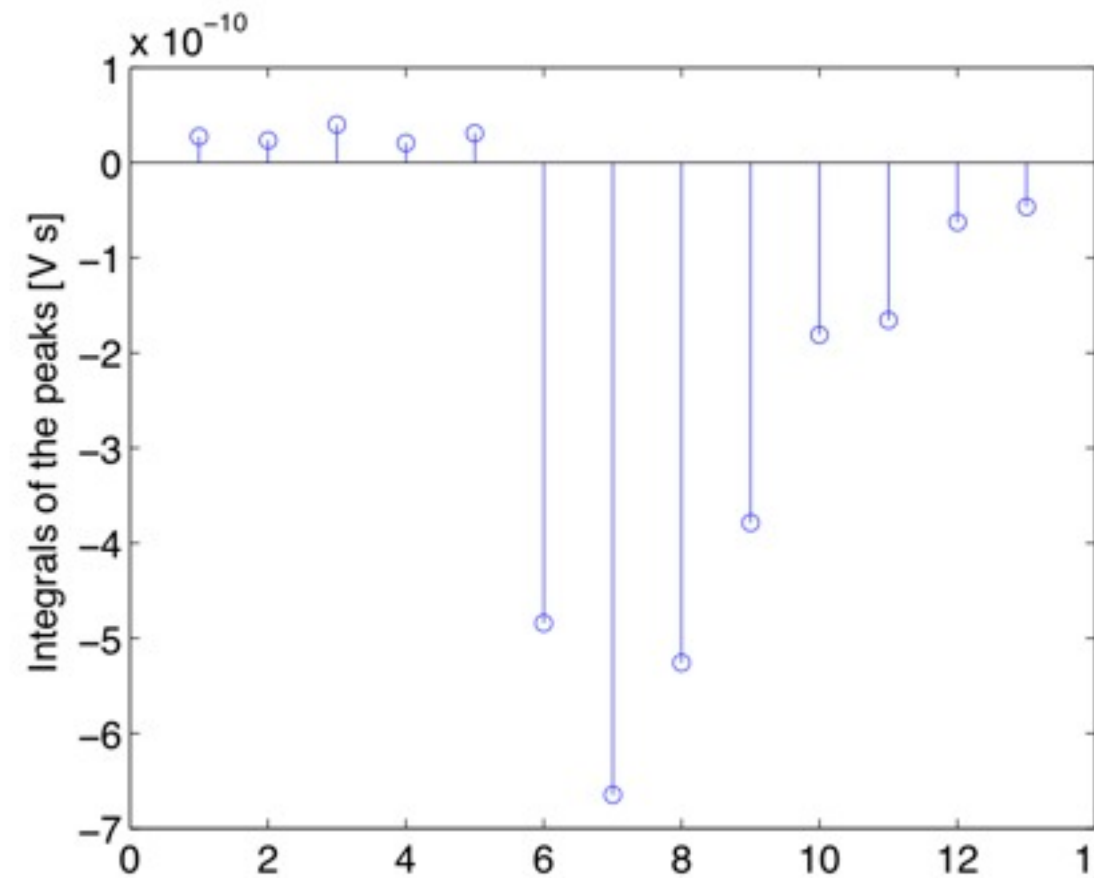
Data analysis. Multibunch data.







- 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)

- Hamamatsu to be contacted about possible changes to the PMT electronics.

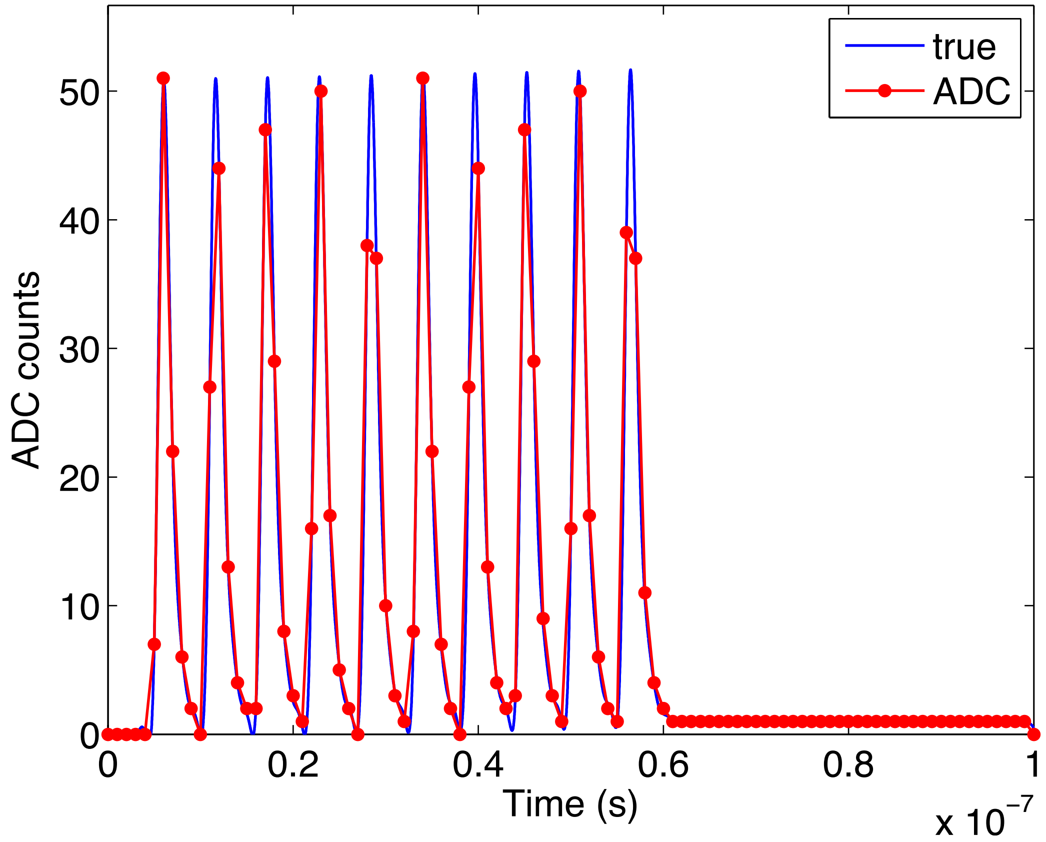
Fast DAQ studies

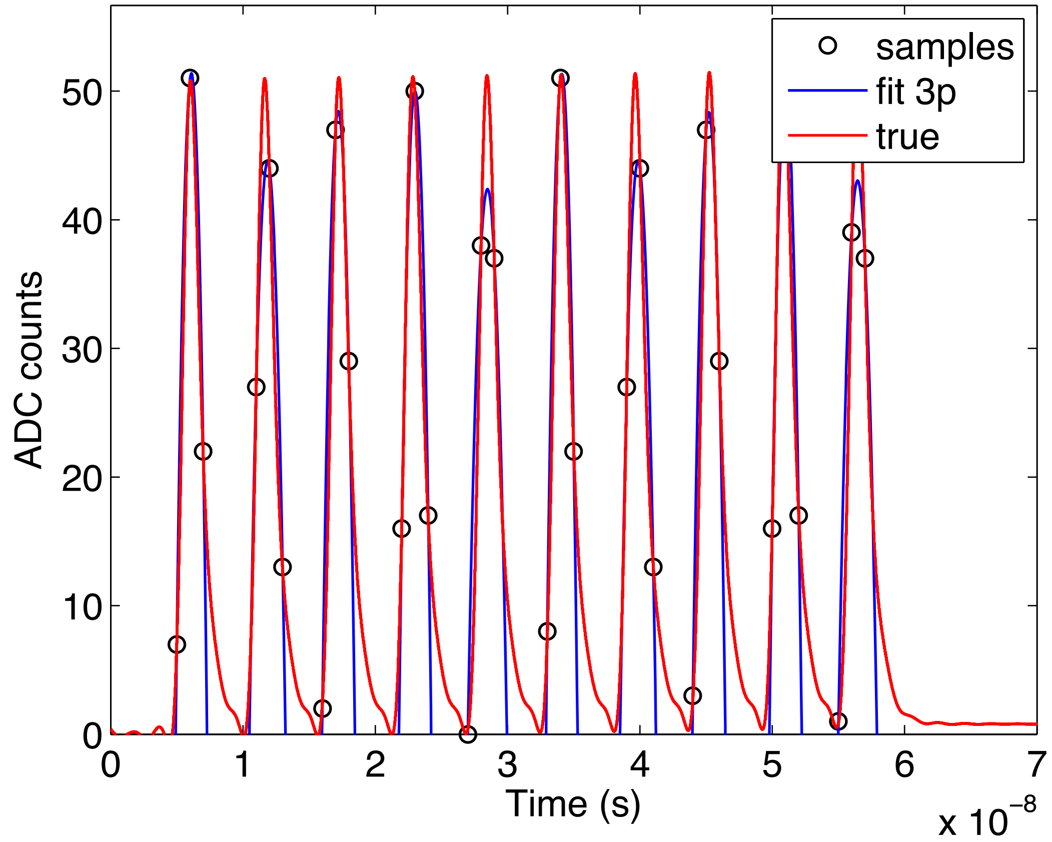
- We perform studies of a faster and more accurate DAQ system .

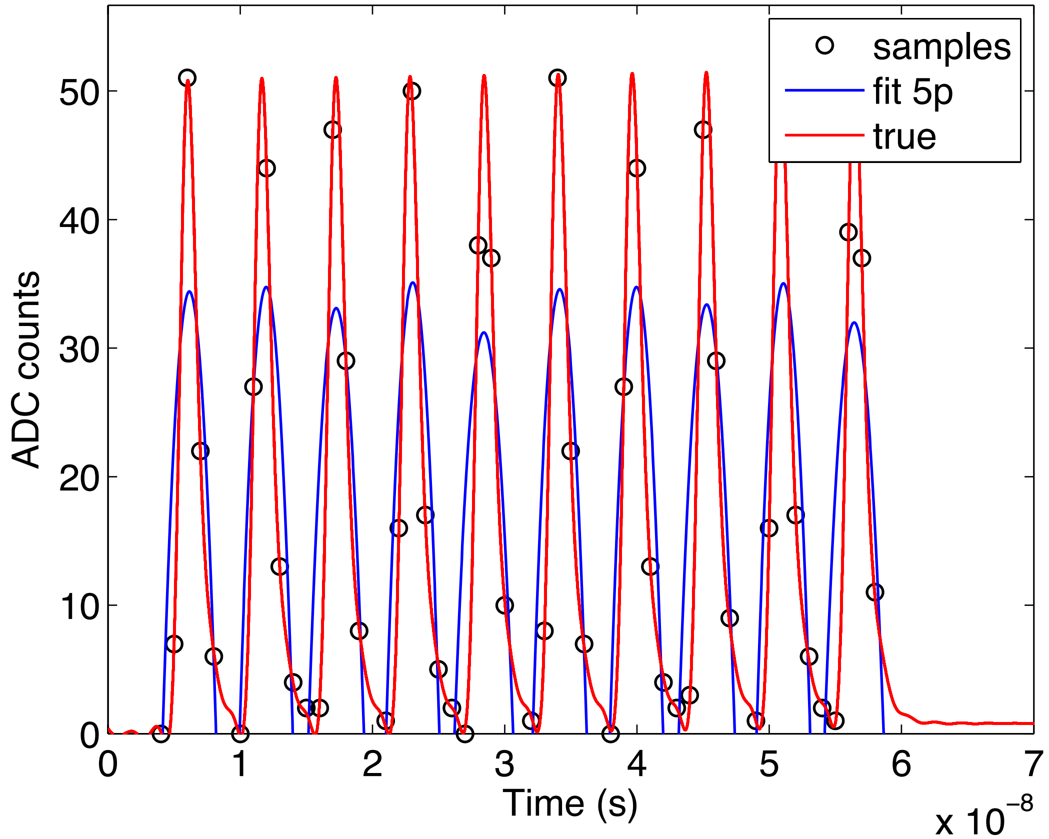
- We have studied the effect of limited bandwidth, sampling rate and ADC resolution.

- We used a quadratic fitting algorithm to estimate the different ways of data treatment.

Current configuration (LeCroy scope). Fitting.







- Effect on a true signal of the LeCroy scope: 500 MHz, 1 Gs/s, 8 bits.

- The quadratic fit for each pulse of the Compton multibunch signal is shown.

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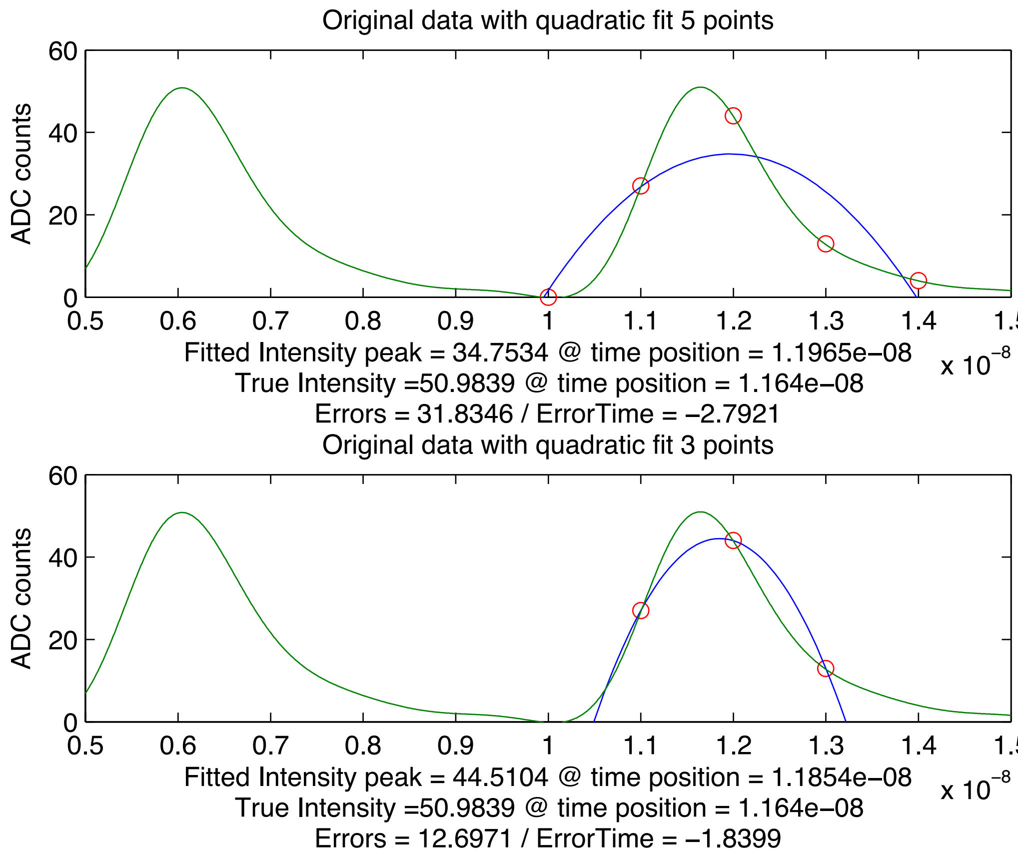
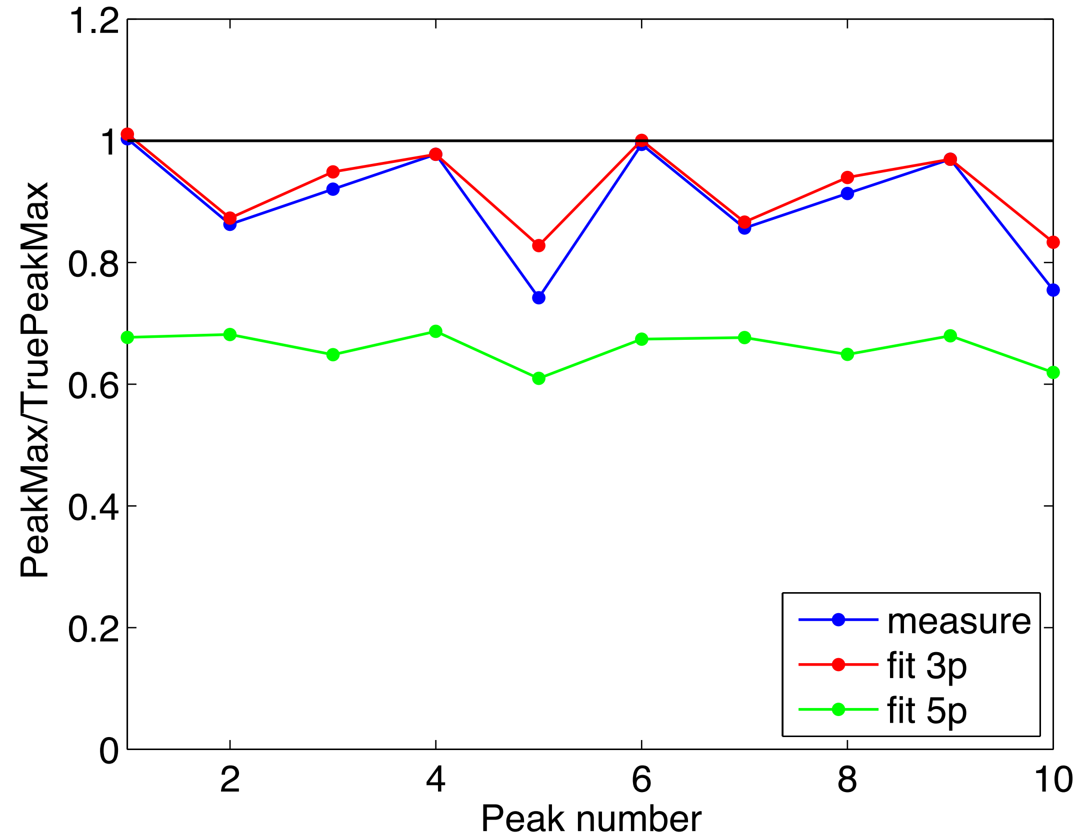
Quality of the fit





- The fit using 3 points is better with relative error of 13% for the intensity maximum than the fit for which five data points have been used (relative error of the intensity maximum is 32%). This is due to the time over which five samples are spread.

- The fit does not significantly improve the peak value.

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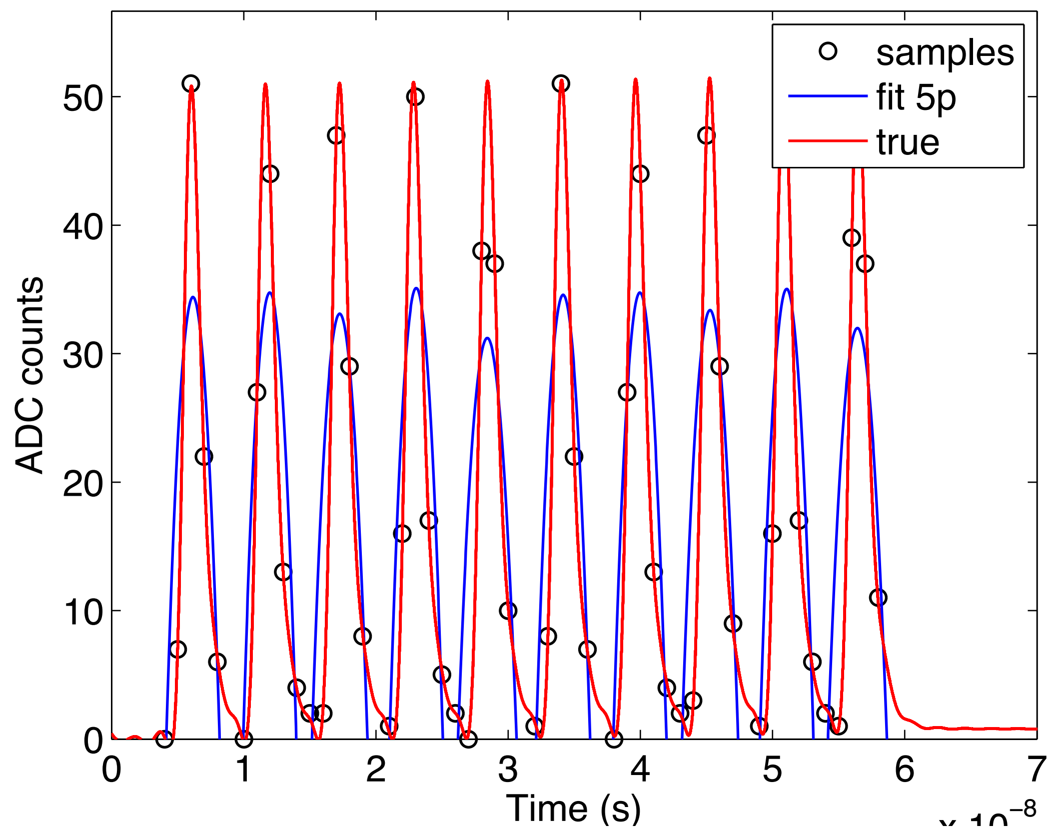
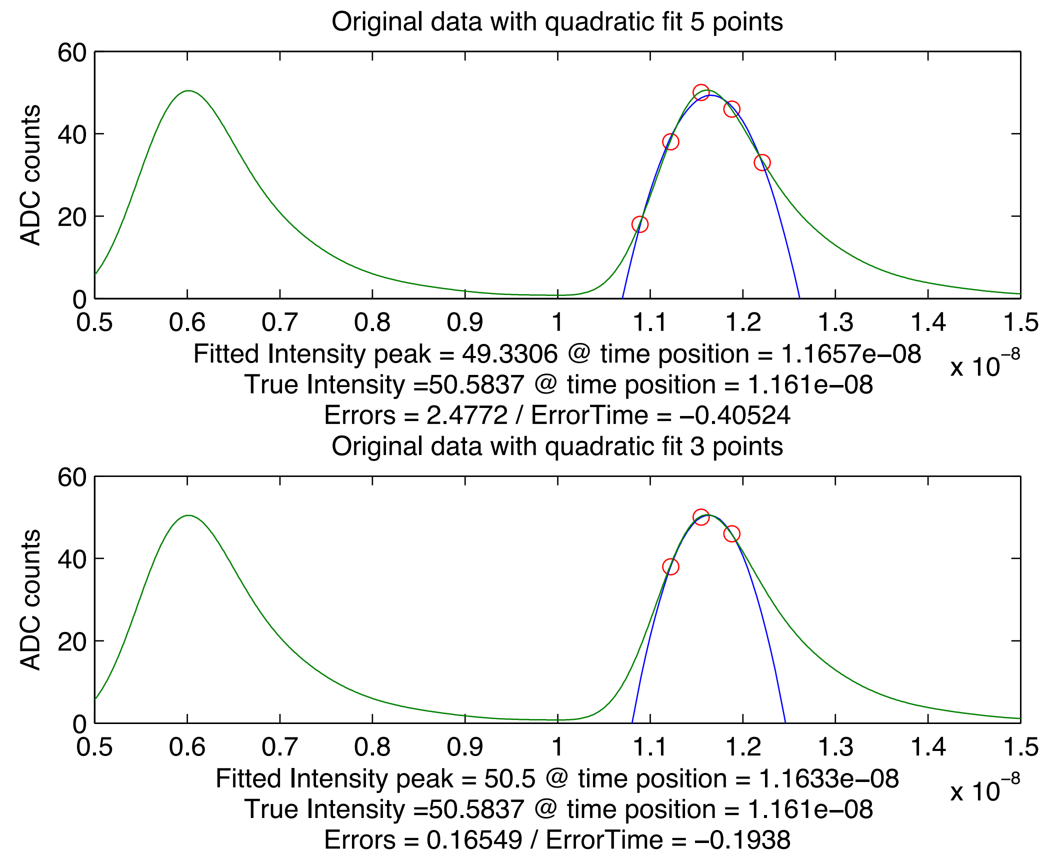
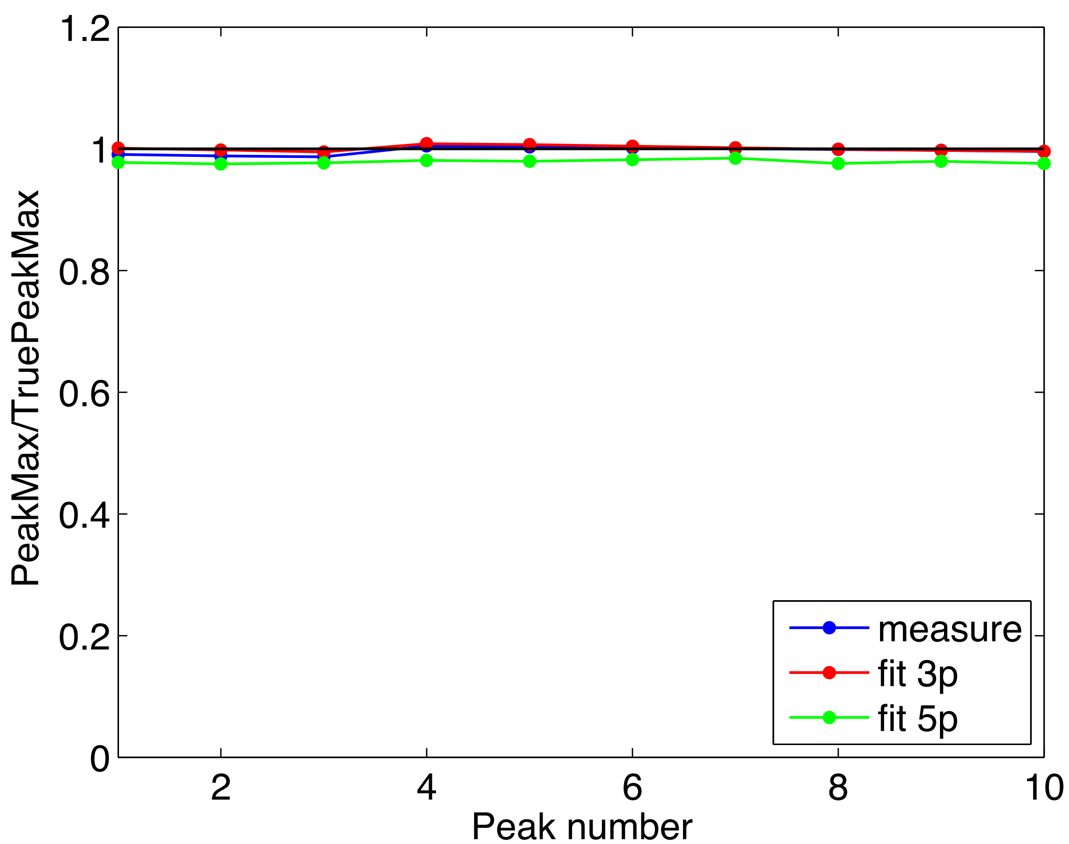
DAQ configuration (800 MHz, 3GS/z). Fitting







The results of the fitting are better, but the results for the directly measured value of the intensity maximum are already very accurate.

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Proposed DAQ upgrade

Channels needed:

- Compton signal ~GS/s
- BPMs (2 or 4 channels) ~GS/s
- Transmitter power from LASER cavity ~MS/s

- Clock (synchronization)
- Injection trigger
- Turn by turn trigger
- Scalers

Available DAQ cards:

-vendor1-

Sampling rate 3.6 GS/s
ADC resolution 12-Bits
Bandwidth 2GHz
2- 4 channels

-vendor 2-

Sampling rate 1.5-3 GS/s
ADC resolution 8-Bits
Bandwidth 800 MHz
2 channels

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BACKUP

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;

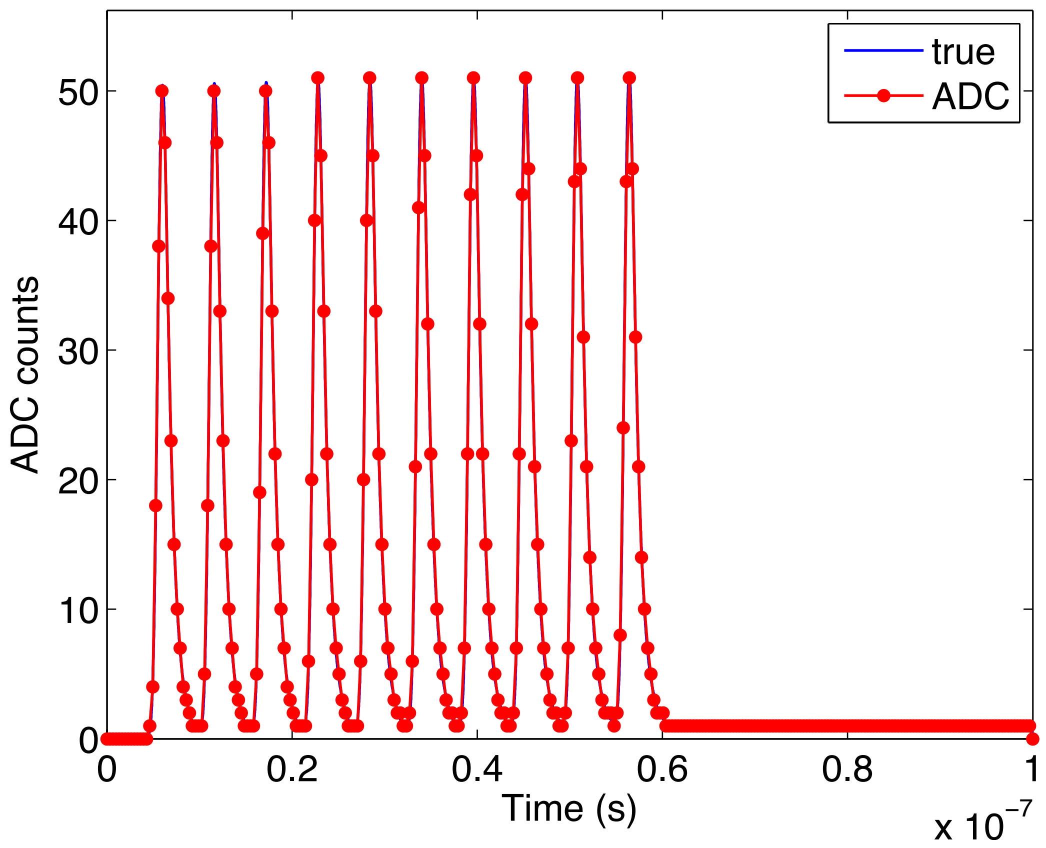
t_0 - starting point of the time interval;

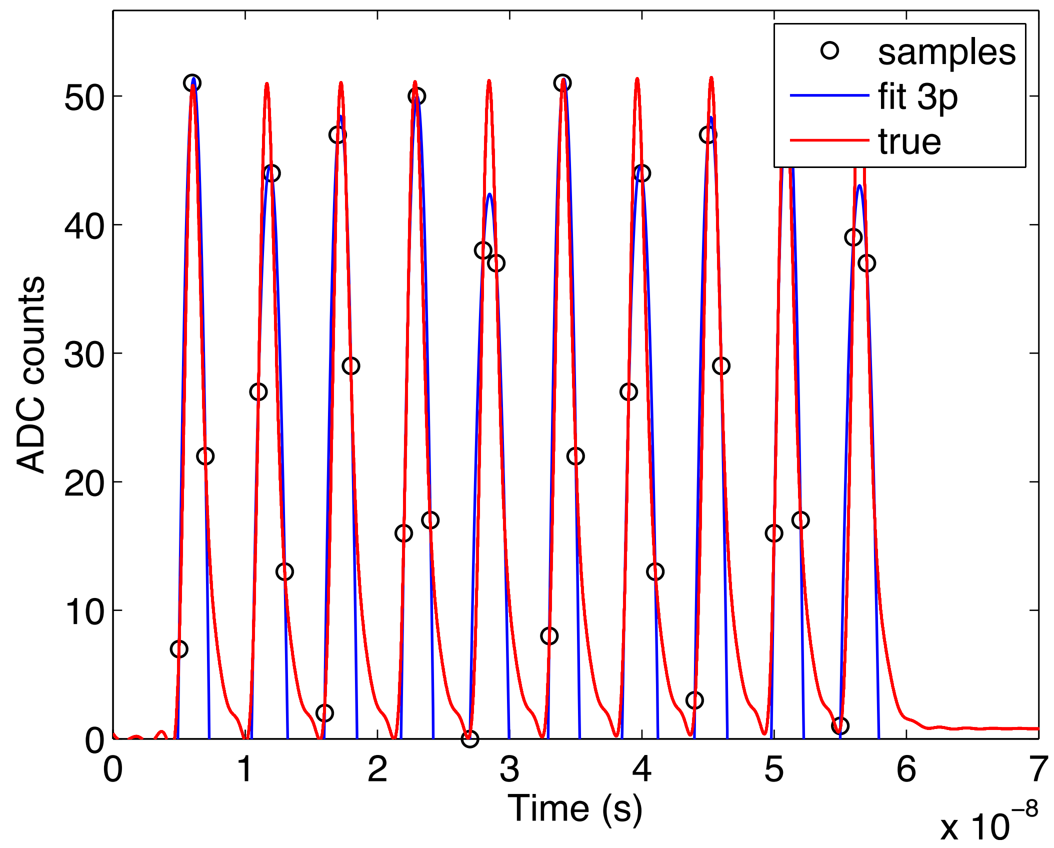
$$S_{RC} = \frac{A_r}{\theta} e^{-\frac{t-\mathrm{t}0}{\theta}} \operatorname{erfc}\left(\frac{\sigma}{\sqrt{2}\theta} - \frac{t-\mathrm{t}0}{\sqrt{2}\sigma} \right) \longrightarrow$$

response of RC (voltage divider) circuit should be understood

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

DAQ configuration. Fitting





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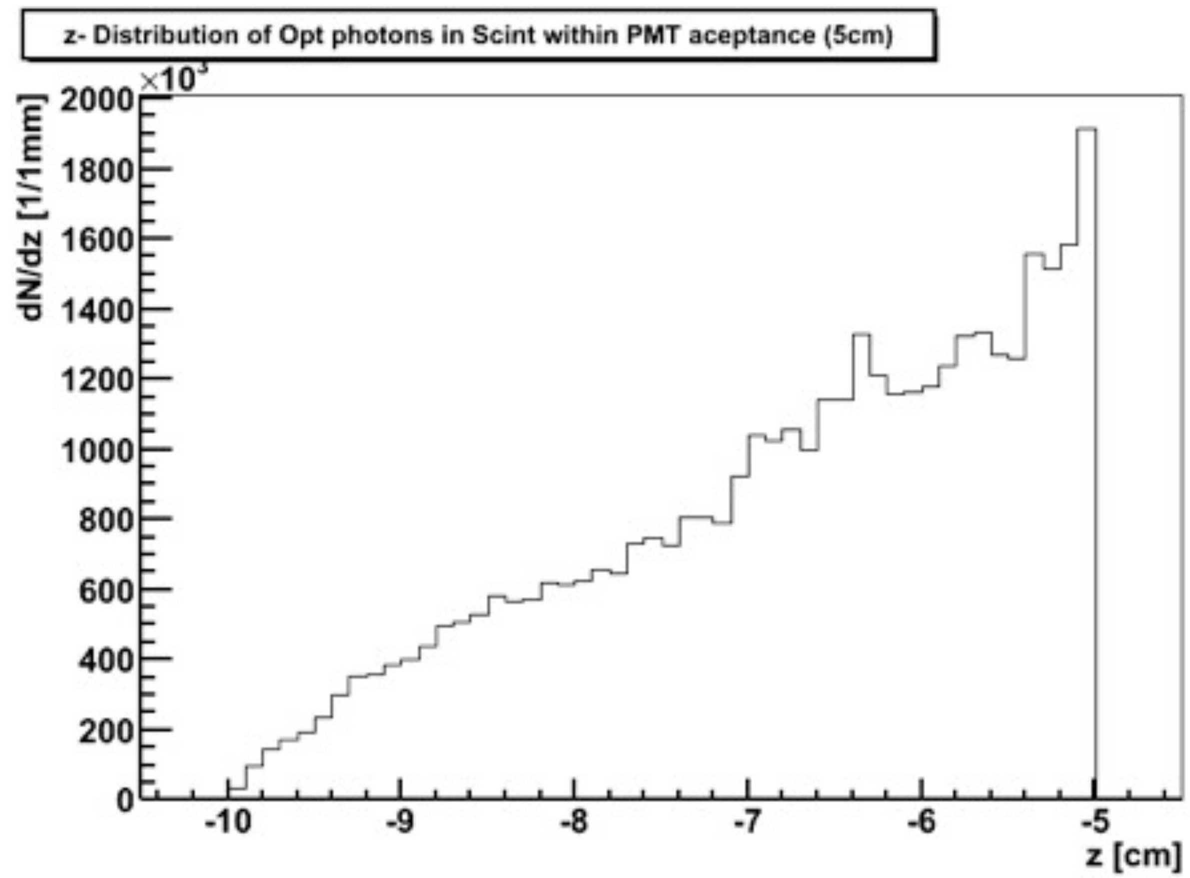
Location where the optical photons are produced inside the scintillator.



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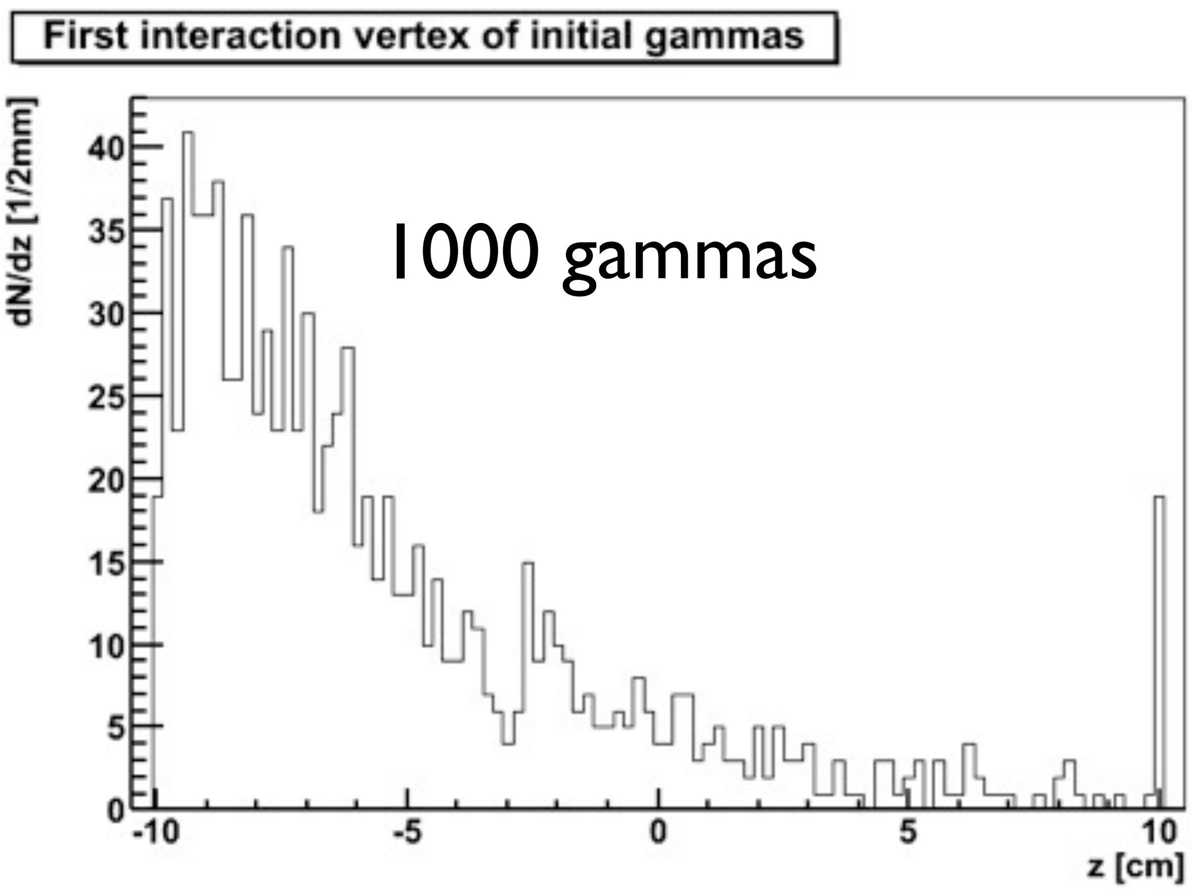
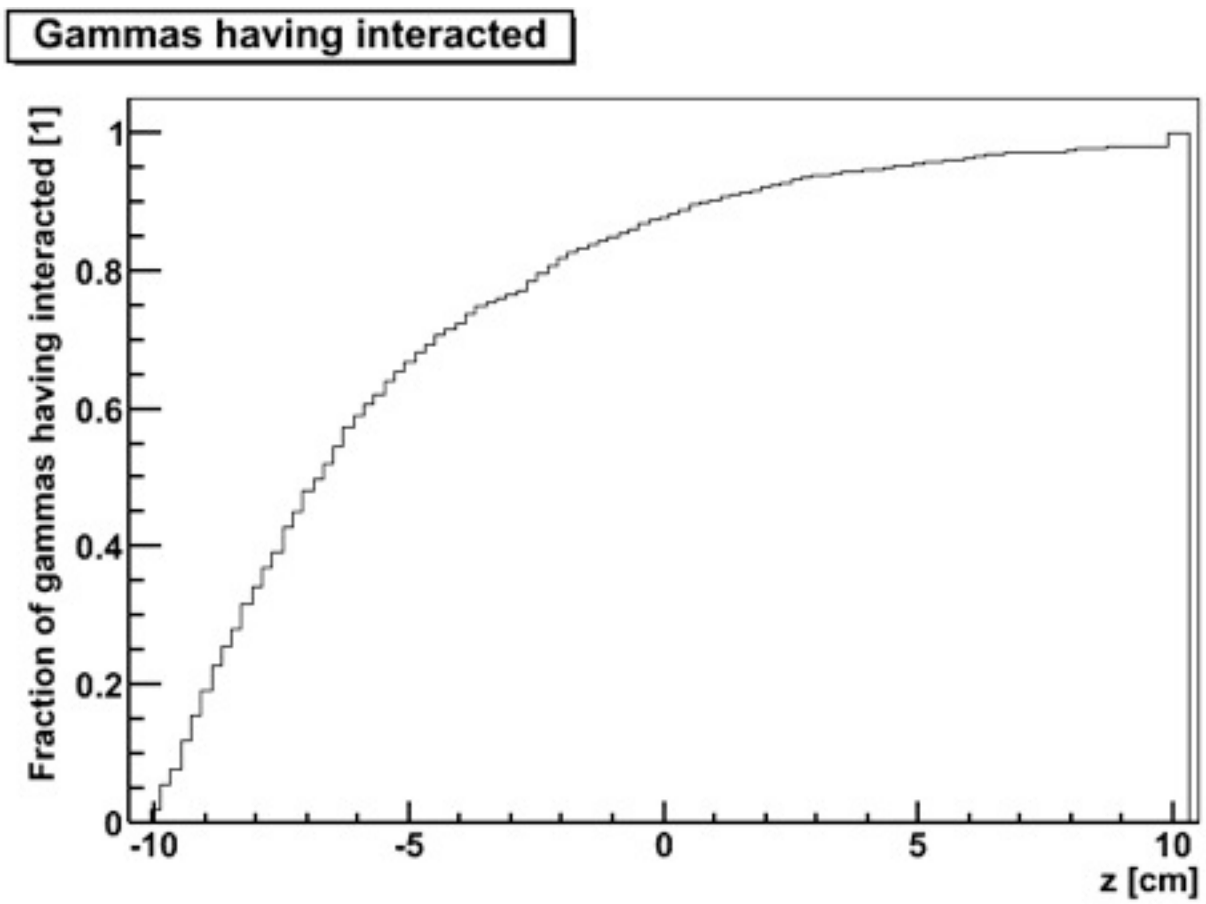
First interaction of initial gammas inside the scintillator





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Shorter crystal reduces the linearity.

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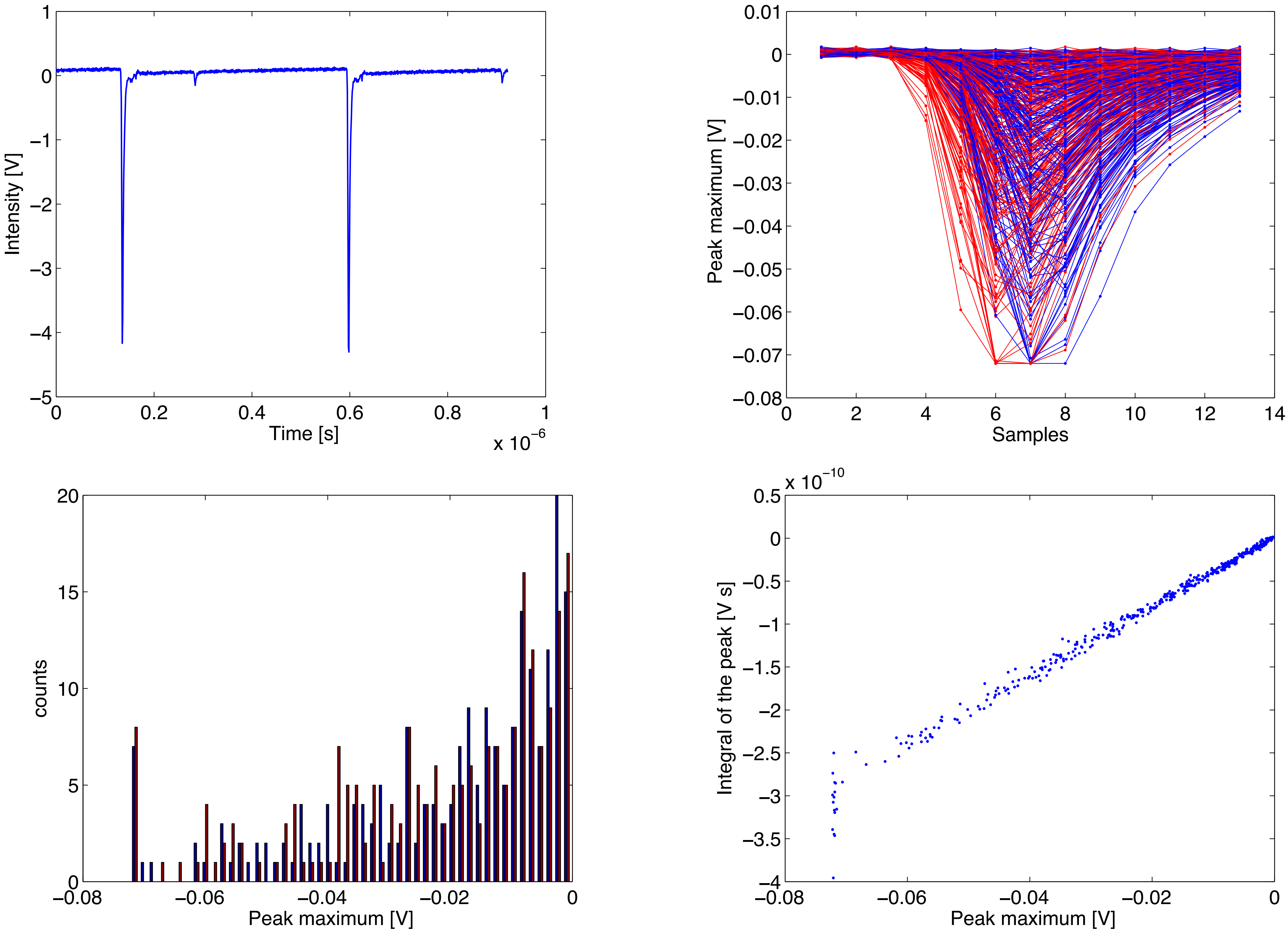
Position scan (the biggest peak)



Orsay