Short-term effects in Vacuum Phototriods for the ECAL Endcaps

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Introduction

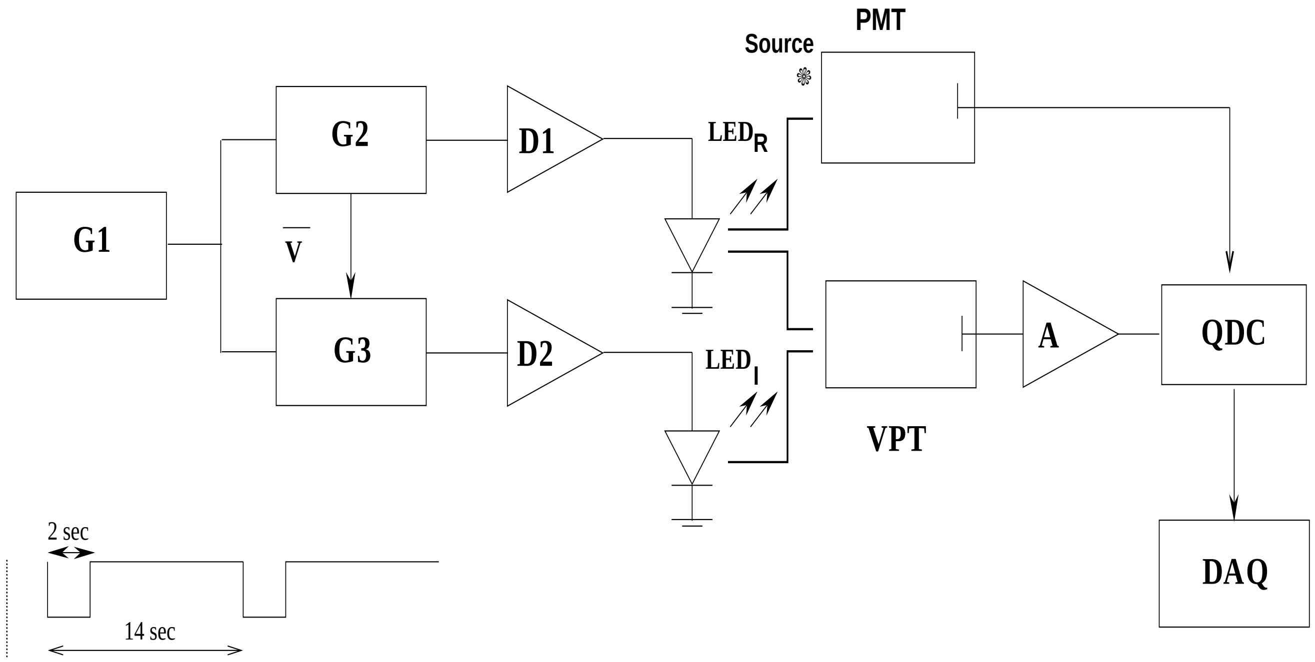
New generation of VPT relevant to our study fabricated by RIE (St.Petersburg)

- *PC/OD Diameters 13.5/20 mm*
- *bialkali semitransparent photocathode*
- *QE $\simeq$ 20 % at PWO $\lambda_{max} \simeq$ 420 nm*
- *fine mesh anode/single dynode; $V_D =$ 600 V, $V_A =$ 800 V; secondary emission up to $\simeq$20*
- *ability to operate in a strong magnetic field up to 4 T*
- *good long-term stability(PC aging)/linearity*

Rate effect

- *gain variation vs counting rate - well known effect, e.g. for photomultipliers*
- *origin of gain variation is notentirely clear.*
- *variation of counting rate - inevitable feature of ECAL operation at LHC,*
  the response of VPTs must be understood

Experimental Set-up



The main features of the VPT operation conditions were:

- *at initial state the reference LED was operating continuously, allowing also a check of stability of the system,* $I_R < 10^{-3} nA << I_I$
- *after measurements with illumination, system was operating in the initial state again till the stable condition. This allow the reproduceability of the data,* $I_A = I_R + I_I \approx I_I$

The gain variation measured at time moment t is defined as

$$\Delta G(t) = \frac{c(t)LED_R(t) - LED_R(0)}{LED_R(0)}$$

where $LED_R(t) = < QDC > - < PED >$ and QDC and PED are the output signal and QDC pedestal values of the LED_R at the moment t.
The initial reference state ($t < t_I$) $\rightarrow t = 0$.

The $c(t)$ is a monitor correction factor measured at t:

$$c(t) = \frac{LED_R^{PMT}(0)/S(0)}{LED_R^{PMT}(t)/S(t)}$$

Here $LED_R^{PMT}(t)$ and $S(t)$ are the reference LED$_R$ and radioactive source amplitude, respectively, measured with a reference PMT.

Relation between average VPT photocurrent and Dose rate

- *Luminosity* $L = 10^{34} cm^{-2} sec^{-1}$;
- $\sigma_{ine} \sim 100mb$ $\rightarrow$*rate* $R \sim 10^9 inelastic\ pp/sec$;
- *40 MHz* $\longrightarrow$ *25 events (ine)/crossing;*
- *Total dose D for 10 years(3*$\times 10^8$*sec) D= 1-200 kGy depending on* η *(ECAL TDR and More detailed Calculations with MARS-96)*
  the integral dose at shower maximum in PWO crystals from about 4 kGy at $\eta \sim 1.5$ *to about 90-100 kGy at* $|\eta| \sim 2.6$.
- *1 Gy = 100 Rad = 1 joule/kg = 6.24* $\times 10^{12}$ *MeV/kg;*
  D=2.5$\times 10^{16}$ *- 1.2*$\times 10^{18}$ *MeV/kg*
- *1 EE PWO* $\sim$ *1 kg;*
- *Finally: Dose/sec = 3*$\times 10^8$ *- 10*^{10} *MeV/PWO/sec vs* η
- *1 MeV = 2 ph.e.* $\longrightarrow$ *6*$\times 10^8$ *- 6*$\times 10^{10}$*phe/sec vs* η*, 20 mV* $\simeq$ *2000 ph.e.*
- *Finally:*

$$D[kGy] = 0.15 \times A[V] \times \nu[kHz] \qquad (1)$$

where D- dose rate in kGy per 10 years, A - amplitude in V of the VPT amplifier, ν *- frequency in kHz.*

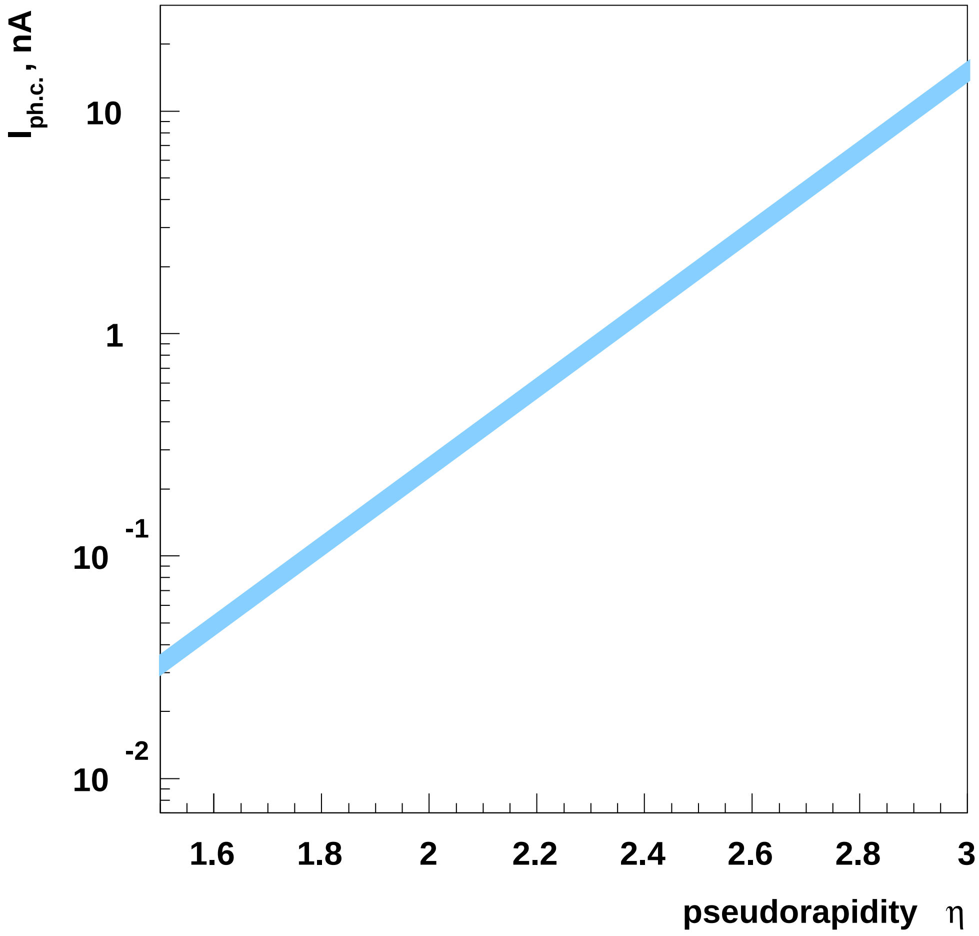


Figure 1: Average end-cap VPT photocathode current $I_{ph.c.}$ as a function of pseudorapidity η. The average VPT anode current $I_A = g \times I_{ph.c.}$, where $g \simeq 10$. The width of the curve roughly represents uncertainties in the VPT photocathode estimations.

Gain stability during end-cap calibration.

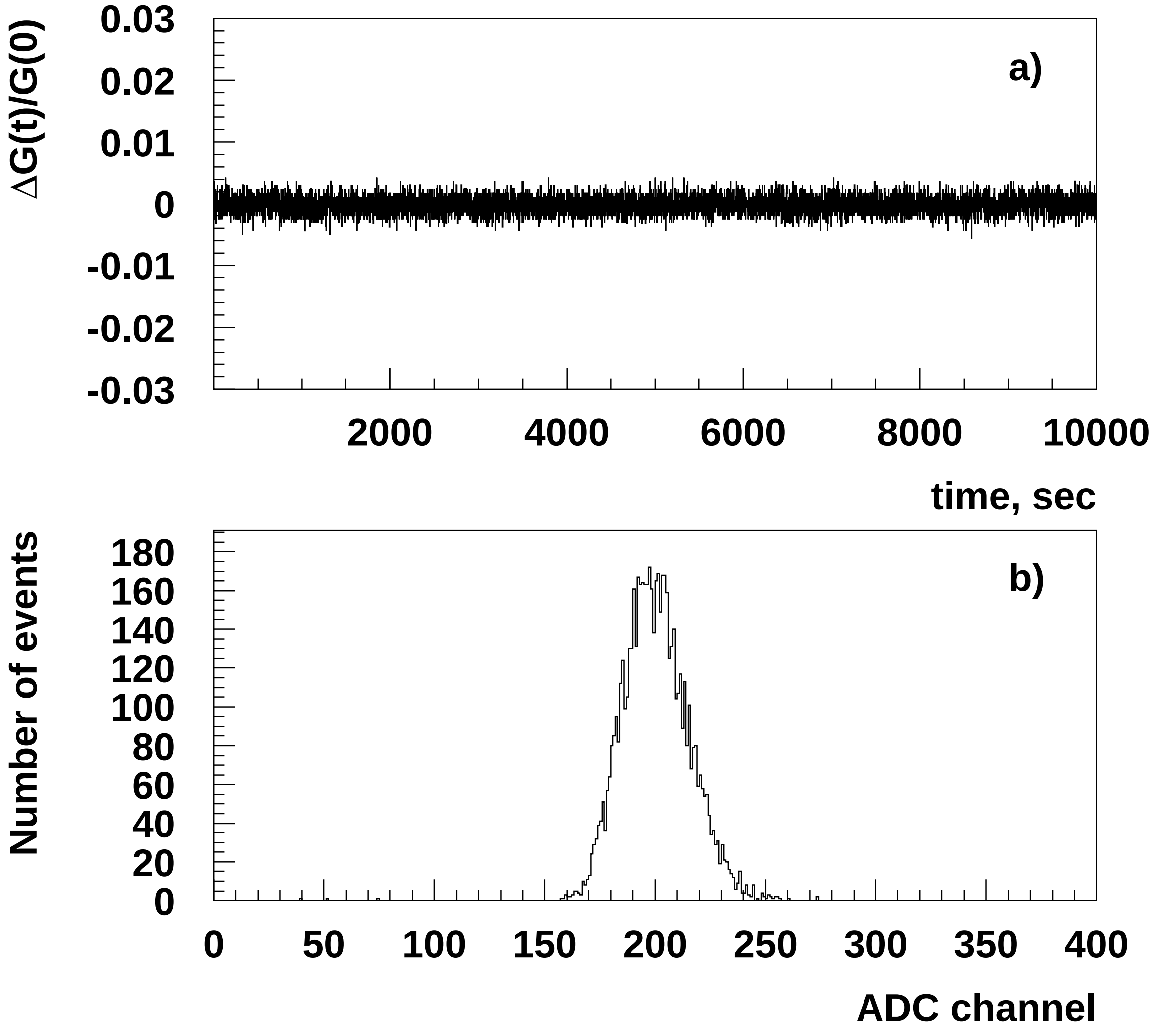


Figure 2: An example of a) the reference LED signal behavior as a function of time, and b) the amplutude spectrum from the monitor radioactive source.

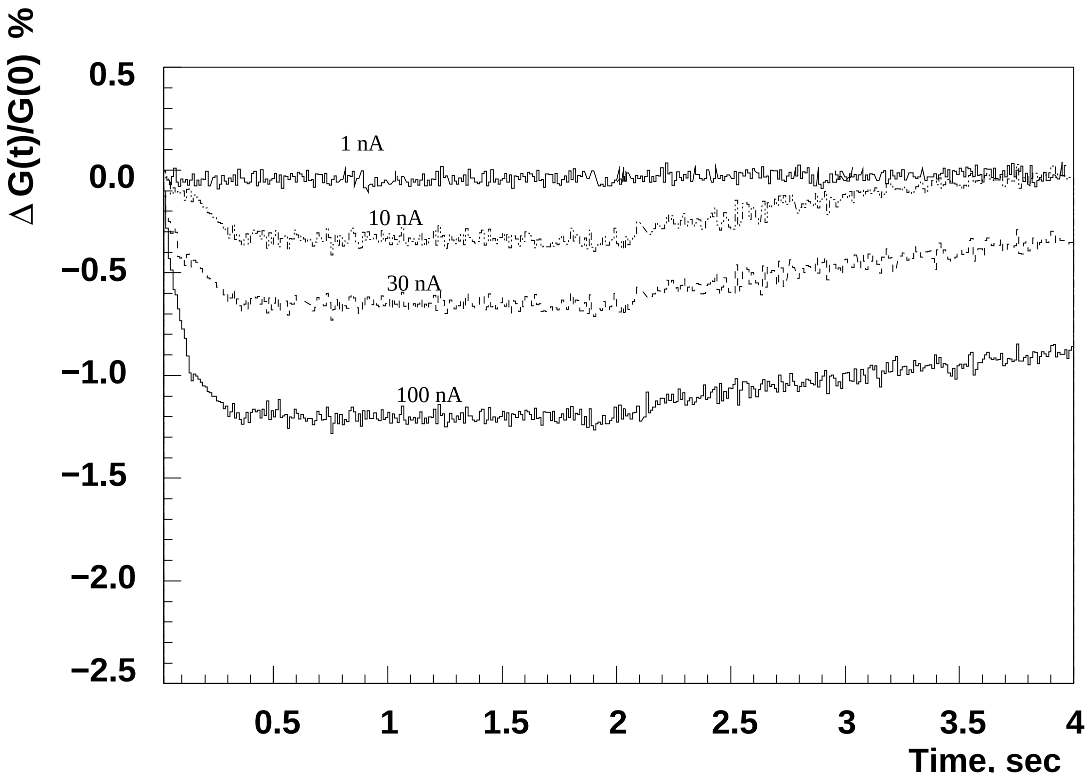


Figure 3: Relative variation of the VPT gain averaged over 20 spills as a function of time for different average VPT anode currents. The gain is normalized to its maximum value.

No effect for EE calibration since $I_A < 1$ nA

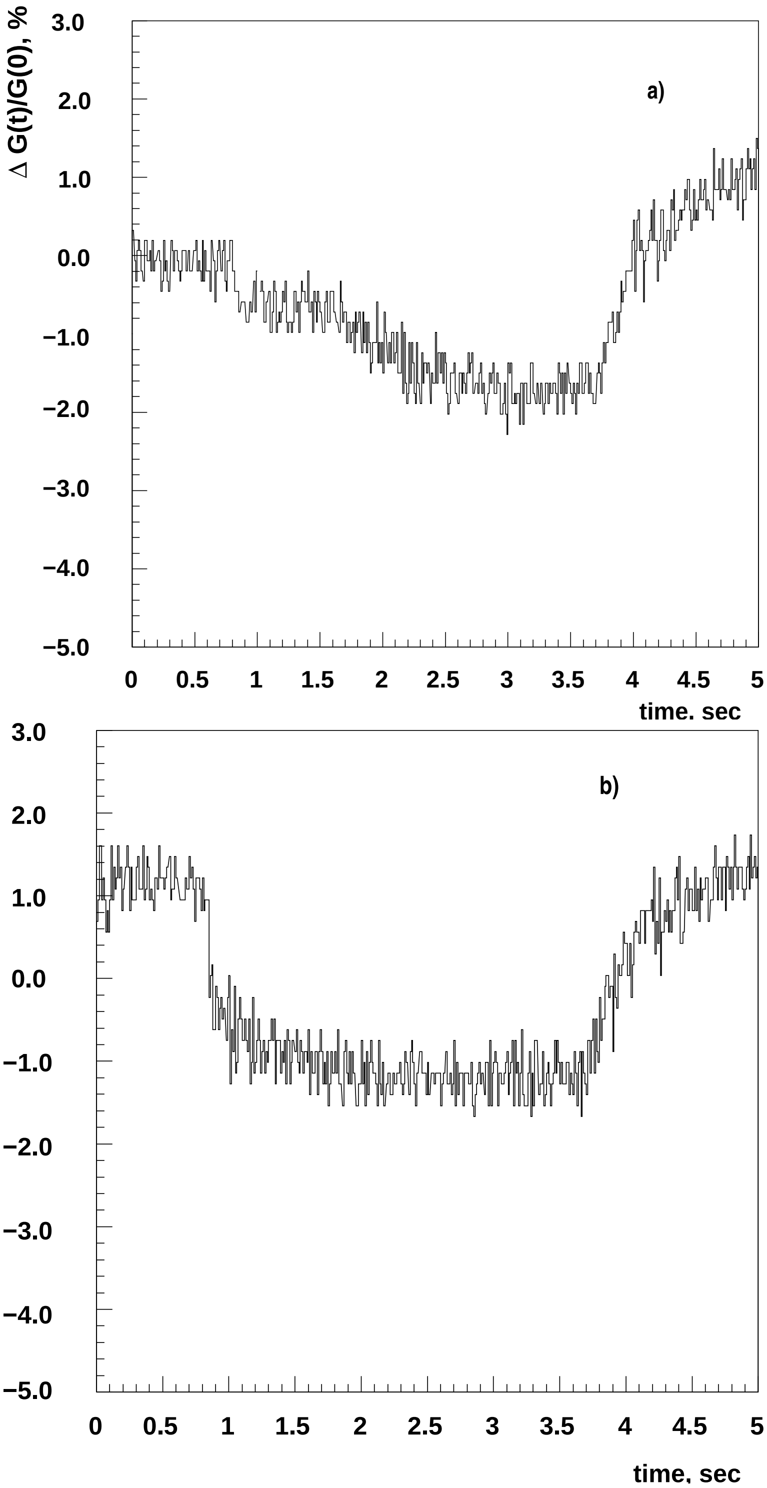


Figure 4: Relative variation of the VPT gain after the first SPS spill. Relative variation of the same VPT gain averaged over 20 SPS spills.

Gain instability during end-cap operation at LHC.

The results were obtained for the following single cycle time structure:

- *initial state* $I_A = I_R + I_I$ *during of* $\simeq$ *100 sec;*
- *illumination is increased by a factor* $f \simeq 2 - 3$, $I_A = I_R + I_I \times f$, *and is stable during next 1000 sec;*
- *then initial condition* $I_A = I_R + I_I$ *is restored again.*

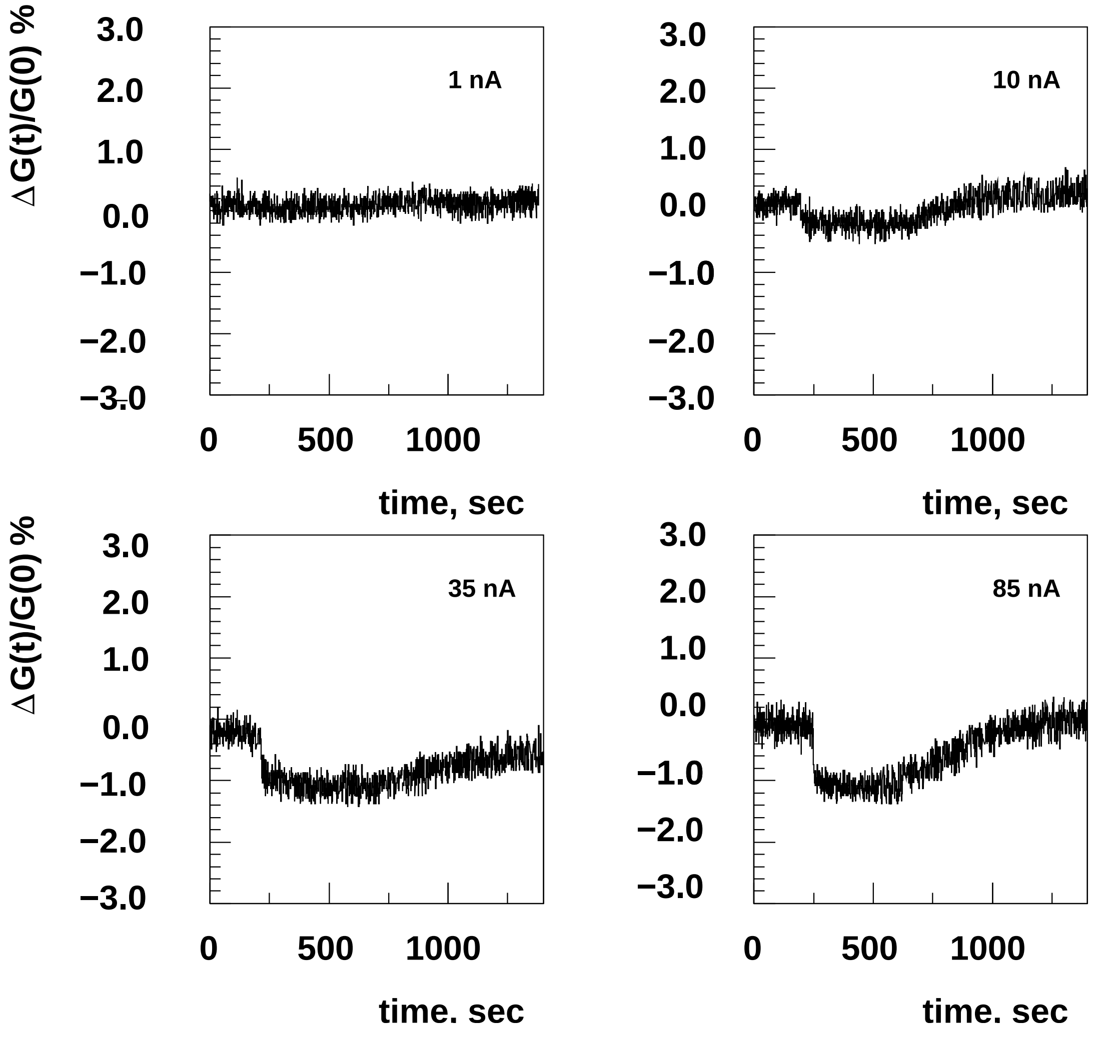


Figure 5: Typical variation of the VPTs gain after rapid changes of LHC luminosity. The numbers showes increases of the VPT anode currents.

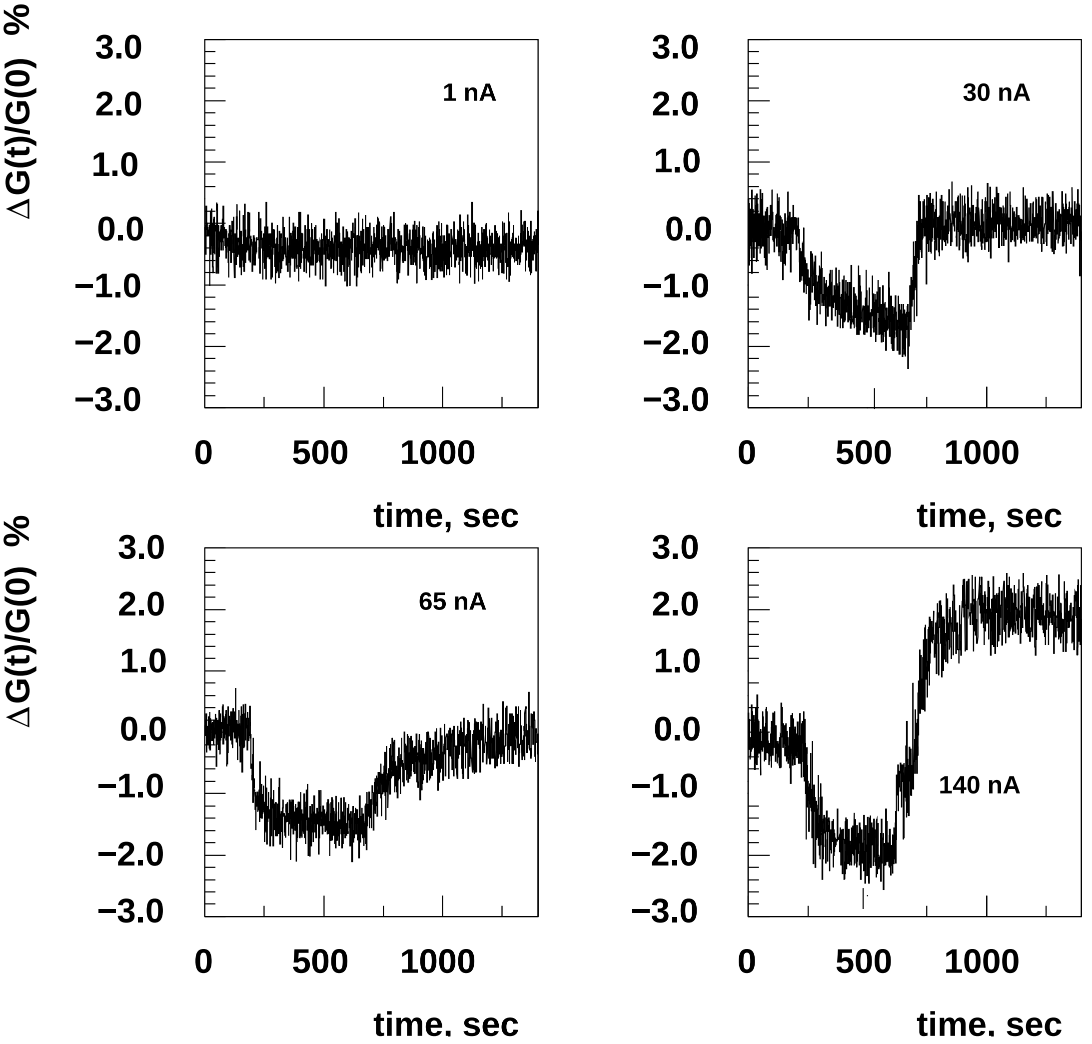


Figure 6: An example of a VPT gain variation after rapid changes of LHC luminosity. The numbers showes increases of the VPT anode currents.

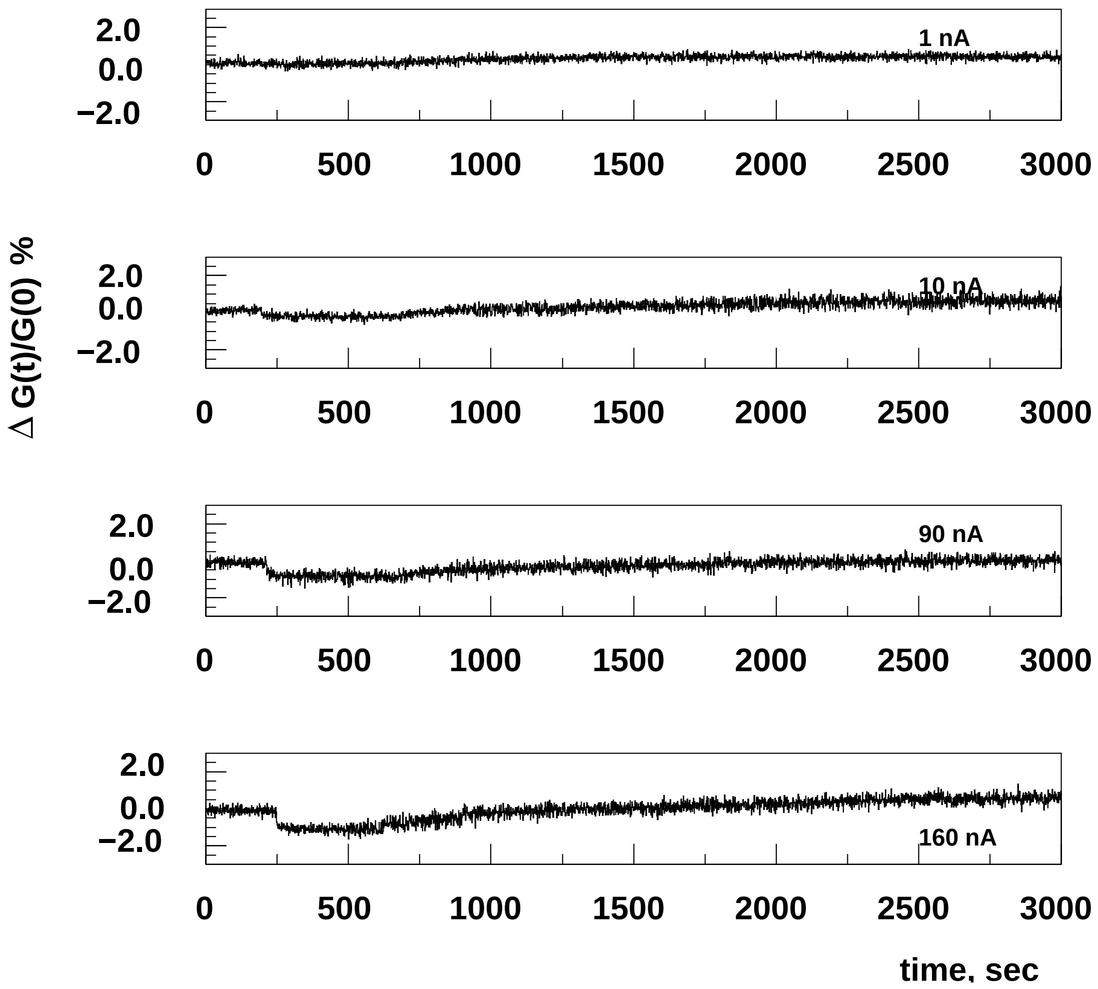


Figure 7: Typical variation of the VPTs gain after rapid changes of LHC luminosity traced during an hour. The numbers showes increases of the VPT anode currents.

Sample to sample variation of the VPT response

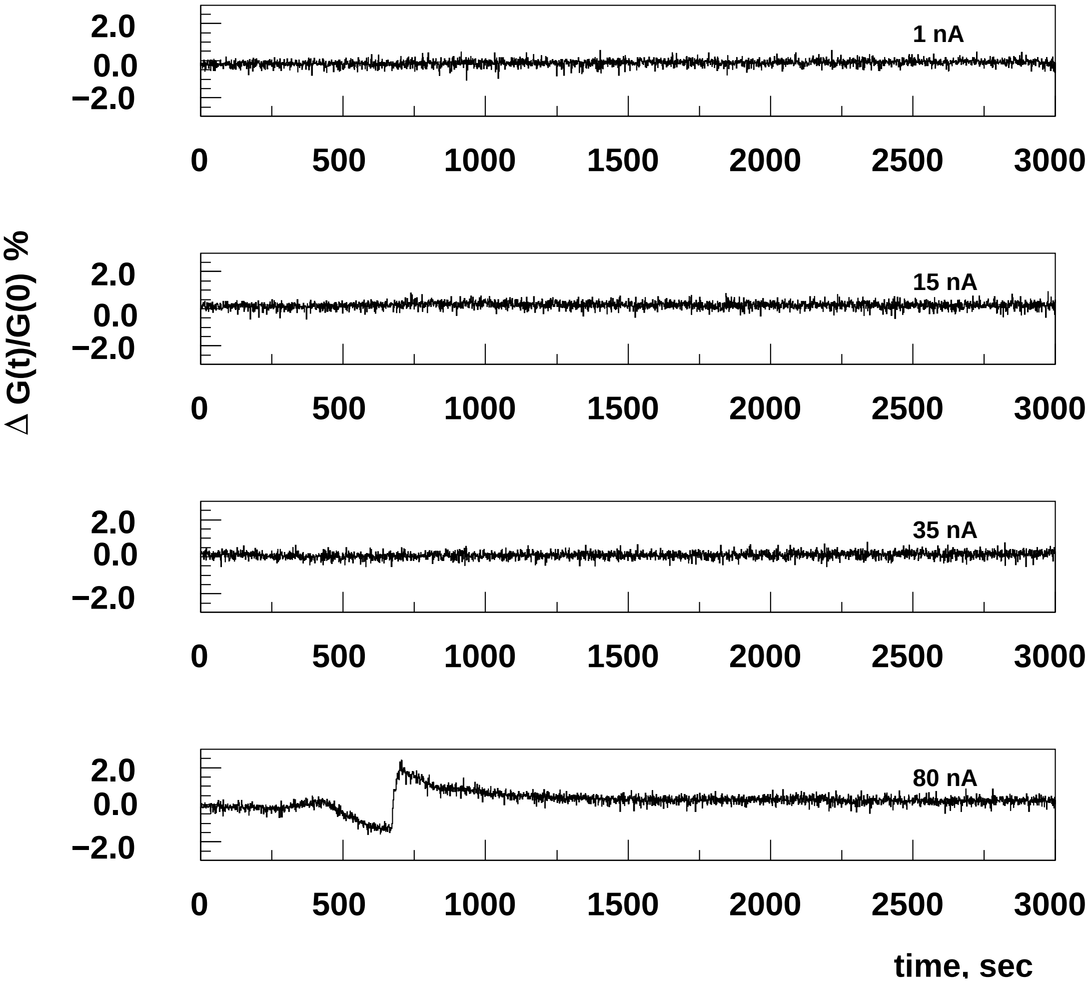


Figure 8: An example of a VPT gain variation after rapid changes of LHC luminosity traced during an hour. The numbers showes increases of the VPT anode currents.

Summary

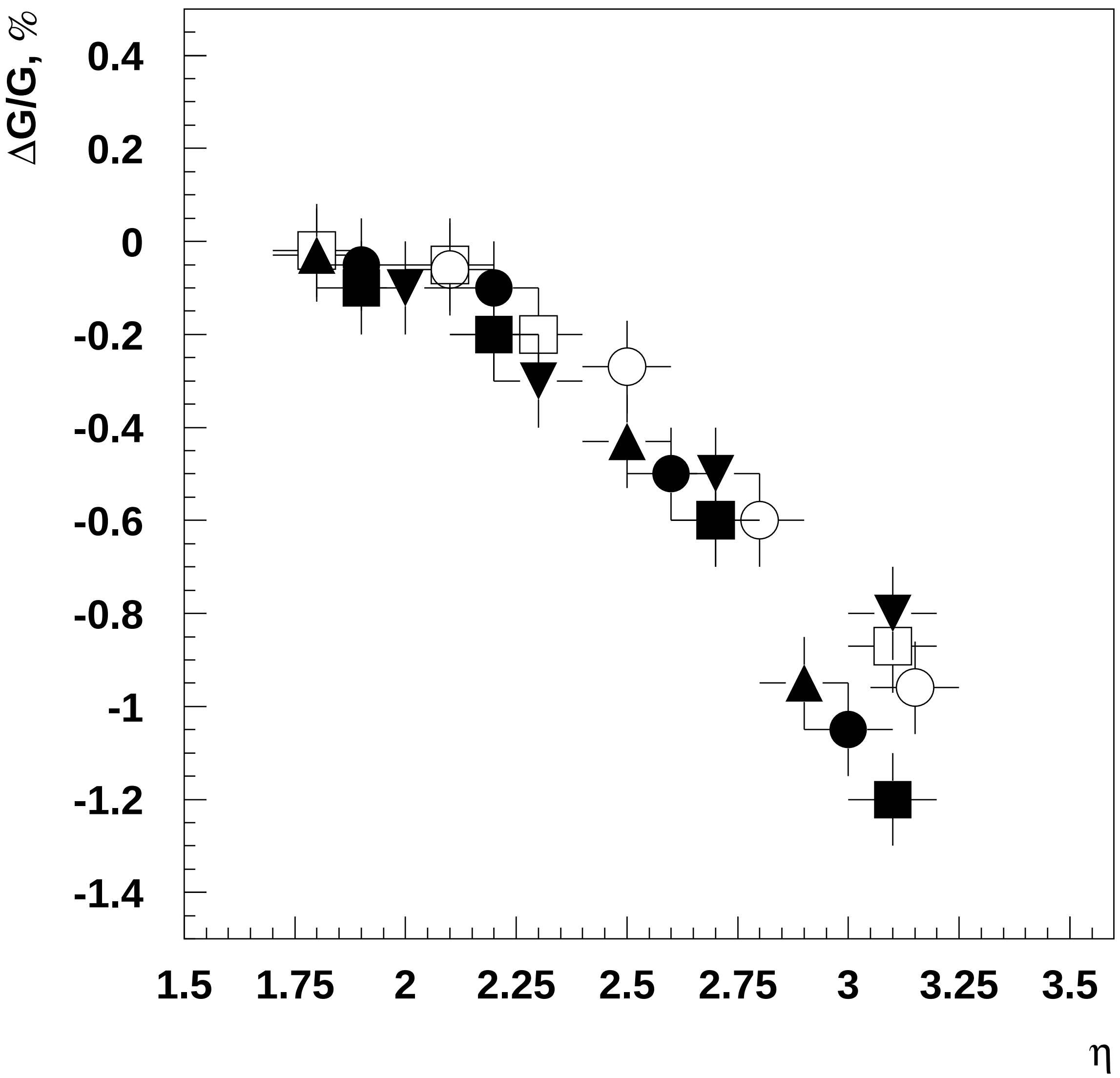


Figure 9: Relative VPT gain variations as a function of η when end-cap illumination increase twice.

Summary

The VPTs of RIE Company show good short-term stability under counting rate variations expected at LHC.

Some qualitivly conclusions:

- *illumination being increase, for the most VPTs the gain drops and reach the plateau. A fit to the single exponential results in gain fall time constant dependence on the illumination intensity and on individual VPT, varying from 0.1 to 0.5 sec;*
- *illumination being decrease, the VPT gain increase with the rise time, estimated in a simple exponential model, varies from a few sec up to tens of minutes.*
- *in the region of pseudorapidity* $\eta < 2.5$ *the VPT gain variation, assuming end-cap operation at the full LHC luminosity and its instability within a factor 2 results in less than 0.5 % gain drops, which seems does not affect the end-cap performance;*
- *for the region* $\eta > 2.5$ *the VPT gain variation under above condition results in more than 0.5 % gain variation. This might require additional effort for VPT gain stabilisation, such as higher monitoring frequency or additional VPT illumination.*
- *for the region* $\eta > 2.5$ *the frequency of monitoring the VPT gain variations with the ECAL monitoring system might depends on stability of the LHC beam luminosity and on VPT recovery or fall time constants.*

???:

- *effect of the magnetic field*
- *effect of radiation damages*
- *methods of VPT gain stabilisation/monitoring in the forward region*