HRPPD AfterPulses

M.Osipenko, J.Agarwala et al.
INFN sez. di Genova

HRPPD meeting, 23 October 2025

AfterPulses: time of arrival from MCP1 face

- assuming uniform electric field E=200 V/1.1 mm, and zero initial velocity of ion at the entry MCP face we obtain:

$$t = \sqrt{\frac{2LM}{qE}} = \sqrt{\frac{2 \times 1.1mm \times 0.94AGeV/c^2}{Z_{eff} \times 200V/1.1mm}} = 11.23ns\sqrt{\frac{A}{Z_{eff}}}$$

- p.e. drift adds another 0.262 ns delay to the above estimate;
- thus, for major ions in the MCP (MgO layer, SiO_2,):

$$t_{H^+} = 11.49ns \quad t_{O^+} = 45.18ns \quad t_{Al^+} = 58.61ns$$

$$t_{Mg^+} = 55.28ns \quad t_{Mg^{2+}} = 39.16ns \quad t_{MgO^+} = 71.29ns$$

- no ion feedback at t<11 ns, having 200 eV kinetic energy we expect ion impact to produce signals with many photo-electrons.

AfterPulses: time of arrival from MCP1 bottom

- acceleration in the MCP1 (assuming free straight flight, no hits of the walls):

$$t_{MCP} = \sqrt{\frac{2M}{q\Delta V}}\frac{d_{MCP}}{c} = \sqrt{\frac{2\times 0.94AGeV}{Z_{eff}700V}}\frac{0.6mm}{30cm/ns} = 3.28ns\sqrt{\frac{A}{Z_{eff}}}$$

$$v_{MCP} = \sqrt{\frac{Z_{eff}\Delta V}{M}} = \sqrt{\frac{700V}{0.94GeV}}c\sqrt{\frac{Z_{eff}}{A}} = 8.63\times 10^{-4}c\sqrt{\frac{Z_{eff}}{A}}$$

- second acceleration in PC-MCP1 gap (missing drift of PE 0.262 ns + in MCP>0.23 ns):

$$t_{MCP+PC} = t_{MCP} + \frac{\sqrt{v_{MCP}^2 + 2Z_{eff}\Delta V_{PC}/M} - v_{MCP}}{Z_{eff}\Delta V_{PC}/ML} = t_{MCP} + \frac{L}{v_{MCP}}\frac{2}{1+\sqrt{1+\frac{2Z_{eff}\Delta V_{PC}}{Mv_{MCP}^2}}}$$

$$t_{MCP+PC} = 7.05ns\sqrt{\frac{A}{Z_{eff}}}$$

$t_{H^+} = 7.54ns$ $t_{Mg^+} = 35.0ns$ $t_{Mg^{2+}} = 24.9ns$

$t_{O^+} = 28.7ns$ $t_{MgO^+} = 45.1ns$ $t_{He^+} = 14.6ns$

Drift inside MCP

- drift time of the avalanche inside MCP, assuming electron mean kinetic energy =20 eV, with velocity of:

$$v_e = c\sqrt{\frac{2E_k}{m_e}} = 30\frac{cm}{ns}\sqrt{\frac{2 \times 20eV}{0.51MeV}} = 2.66\frac{mm}{ns}$$

- path length is difficult to estimate, but it is proportional to MCP thickness, thus drift time is:

$$t_e \sim \frac{t_{MCP}}{v_e} = \frac{0.6mm}{2.66\frac{mm}{ns}} = 0.23ns$$

AfterPulses: time of arrival from MCP1 bottom cont.

- for 200 V on PC we had:

$$t_{MCP+PC} = t_{MCP} + \frac{\sqrt{v_{MCP}^2 + 2Z_{eff}\Delta V_{PC}/M} - v_{MCP}}{Z_{eff}\Delta V_{PC}/ML} = t_{MCP} + \frac{L}{v_{MCP}} \frac{2}{1 + \sqrt{1 + \frac{2Z_{eff}\Delta V_{PC}}{Mv_{MCP}^2}}}$$

$$t_{MCP+PC} = 7.05ns\sqrt{\frac{A}{Z_{eff}}}$$

this is 0.8 ns larger than the observed peak position.

- for 50 V on PC we obtain: observed peak at 6.7+-0.015 ns moves to 7.2+-0.03 ns

$$t_{MCP+PC} = 7.38ns\sqrt{\frac{A}{Z_{eff}}}$$

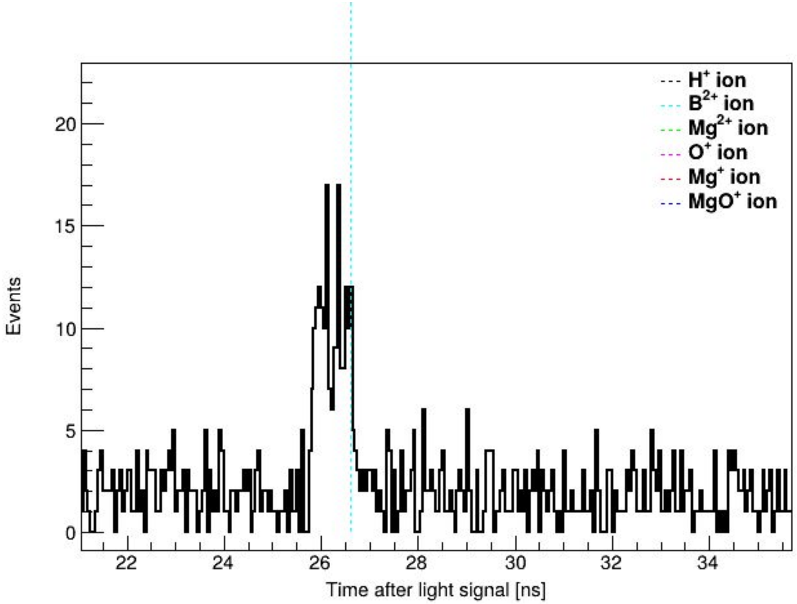
Thus, at V(PC)=50 V the H^+ peak delay must increase on 0.262(e)+0.335(H^+)=0.60 ns, observed 7 ns peak delay increase of 0.52+-0.03 ns.

AfterPulses: time of arrival from MCP1 bottom cont.

- observed peak at 26.2+-0.03 ns can be attributed to O^+ or Mg^{2+} ions coming from the bottom of entry MCP;
- varying PC voltage from 200 V to 50 V this peak delay increases on 1.26 ns, or 2.1 times more than for H^+ peak.

$$\sqrt{\frac{A}{Z_{eff}}(Mg^{2+})} = \sqrt{\frac{24}{2}} = 3.5$$

$$\sqrt{\frac{A}{Z_{eff}}(O^+)} = 4$$



Expected ions in HRPPD

- laser ablation data of MgO (secondary emission layer in HRPPD) show that at low energy most probable is emission of MgO^+, while at higher energy Mg^{++}, Mg^+ and O^+ become dominant.

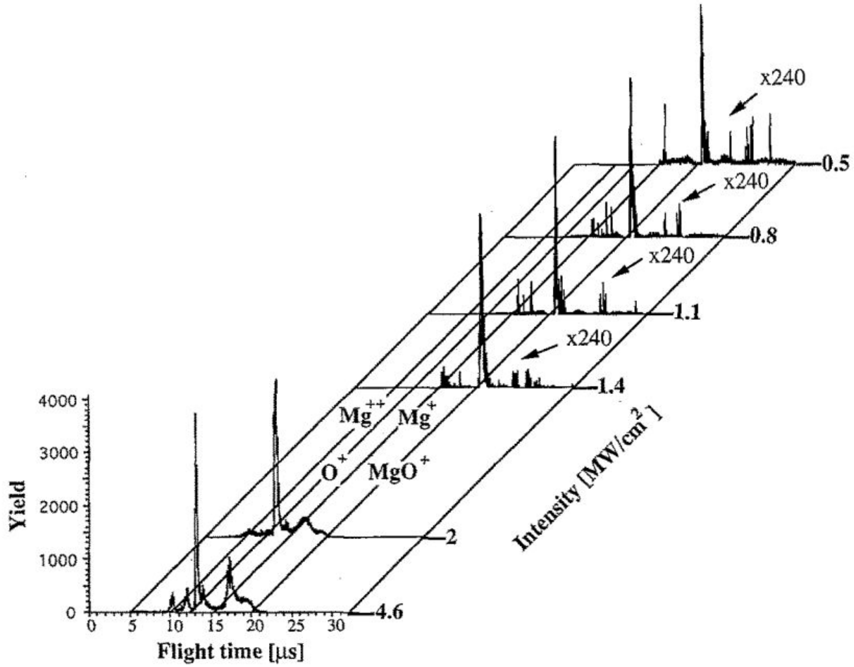
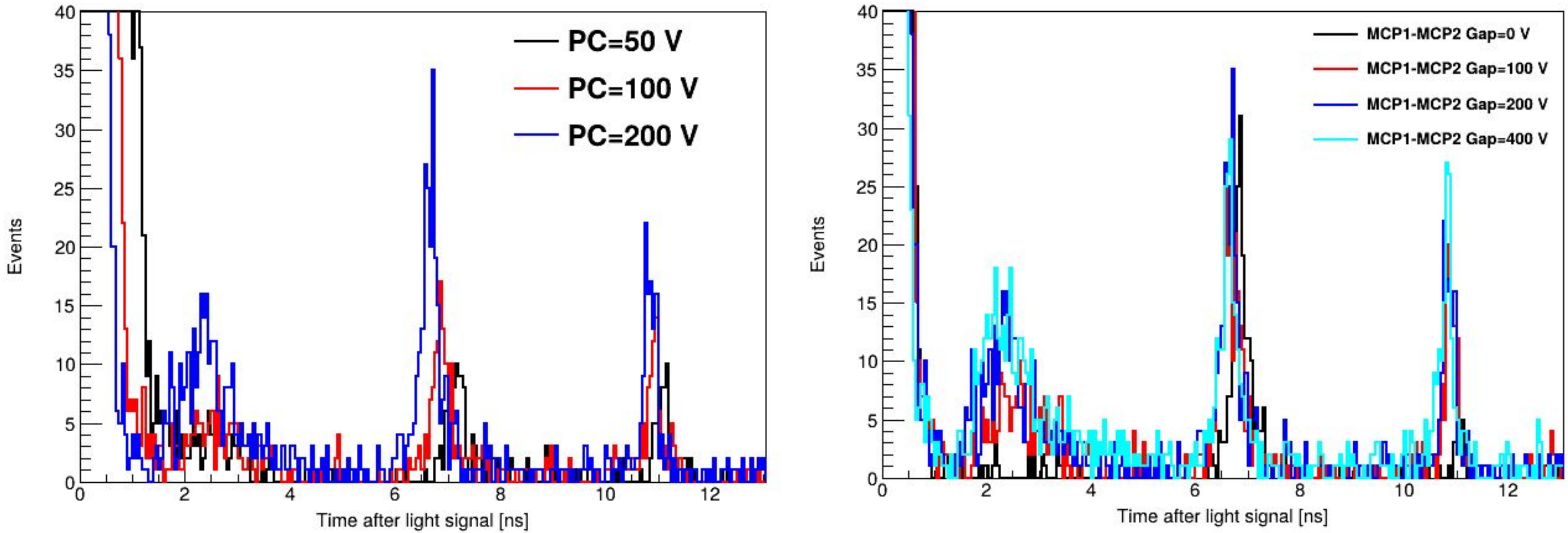


Fig. 1. Time-of-flight spectra of MgO are shown as a function of laser intensity at 193 nm.

[O. Kreitschitz, W. Husinsky, G. Betz, N.H. Tolk, "Laser induced desorption of ions from insulators near the ablation threshold", NIM B78, (1993) 327-332]

AfterPulses with >=1 p.e. amplitude

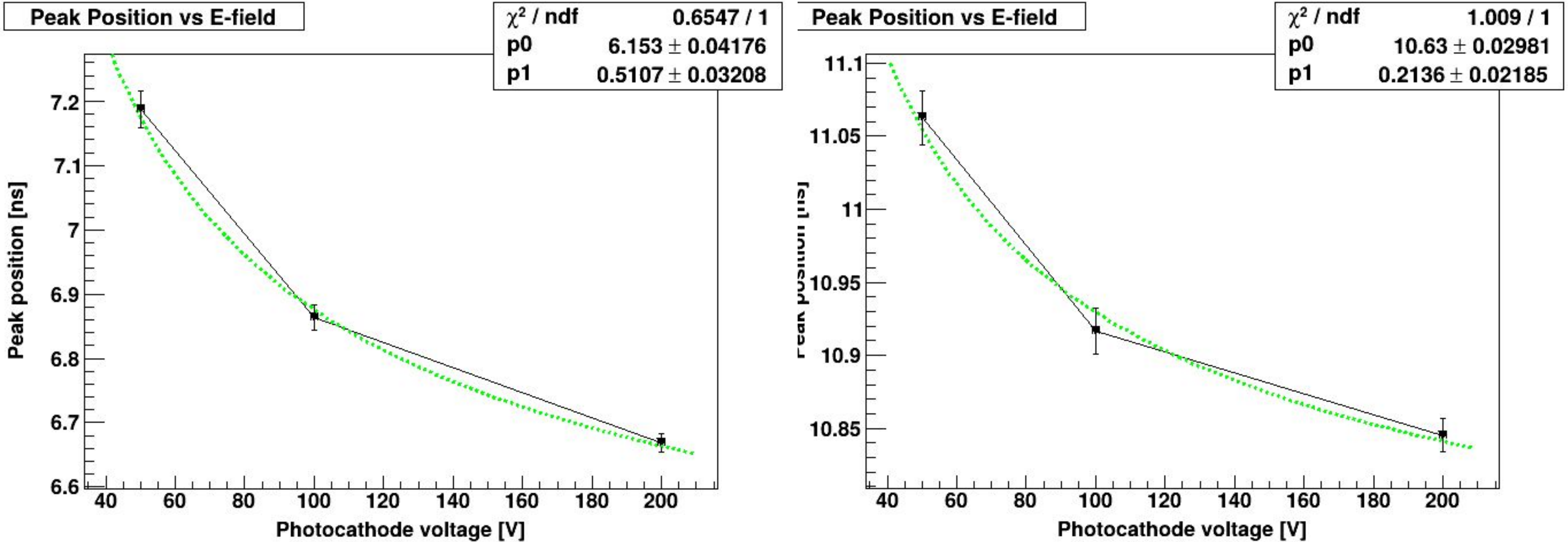
- PC bias increase by factor 2 gives peak time reduction on 0.1-0.3 ns - expected factor 1.4 reduction, or for H^+ ions -5 ns, while for p.e. it should be -0.1 ns;
- peak at 2.5 ns almost disappears at PC<200 V;
- at zero voltage in MCP1-MCP2 gap peaks at 2.5 and 11 ns almost disappear.



AfterPulses peak position drift

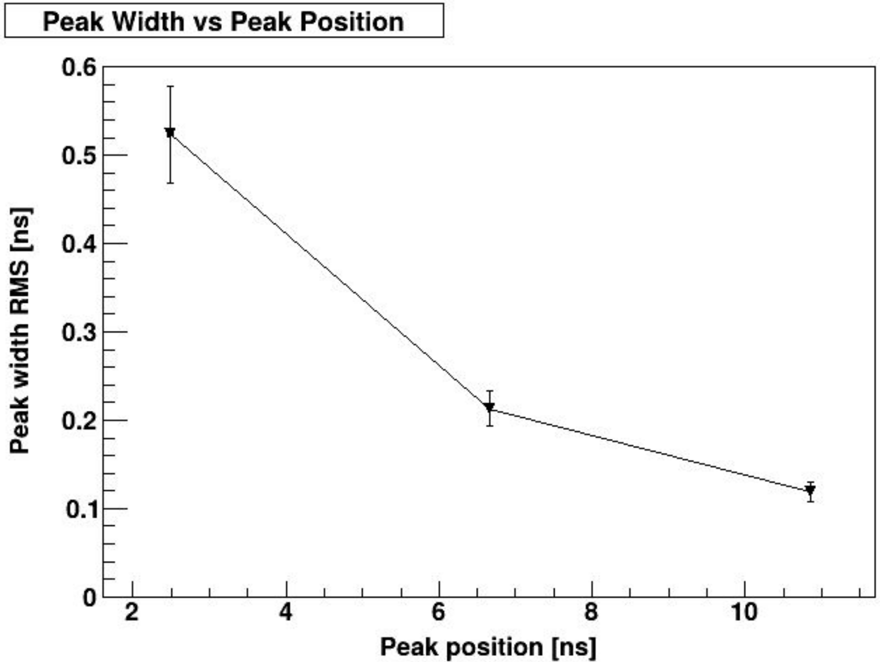
- PC-MCP1 electric field dependence suggests only p.e. contribution to delay time, since at 200 V p.e. drift =0.262 ns and fit gives:

$$t(V_{PC}) = p_0 + \frac{p_1}{\sqrt{V_{PC}/200V}}$$



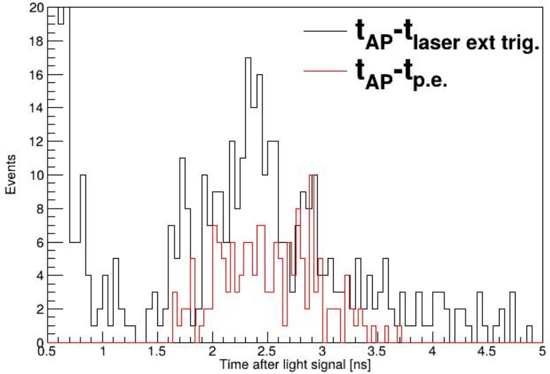
AfterPulses peak width

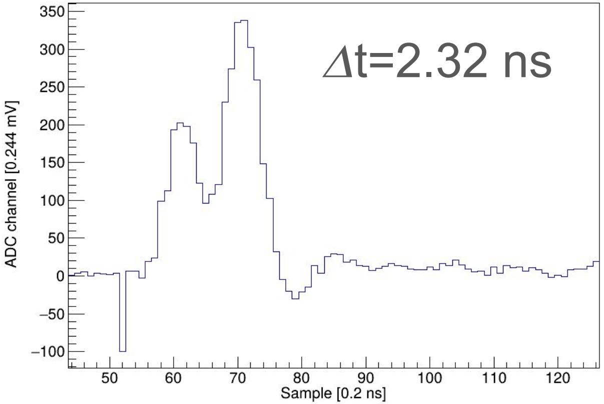
- strange trend of peak width reduction is observed for the first three peaks:

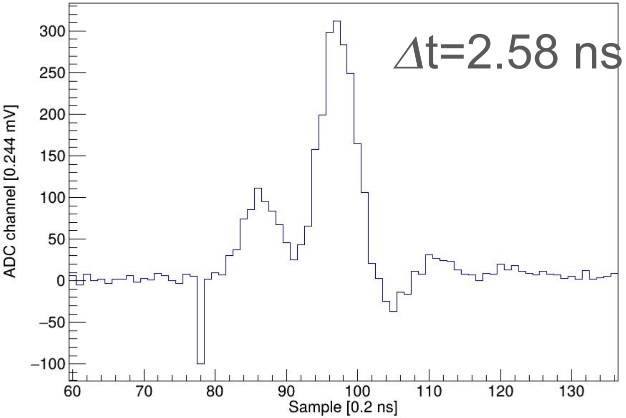


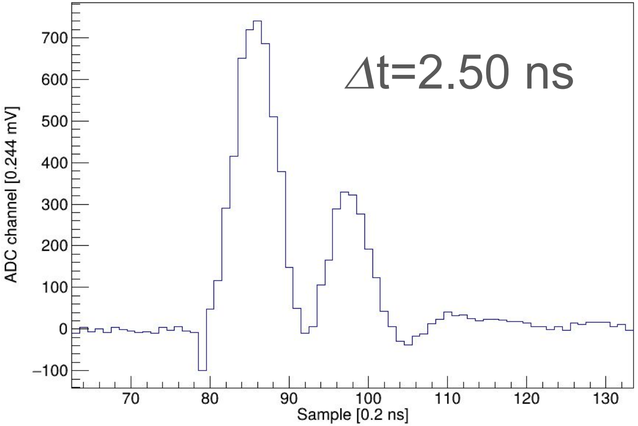
Examples AfterPulses at 2.5 ns

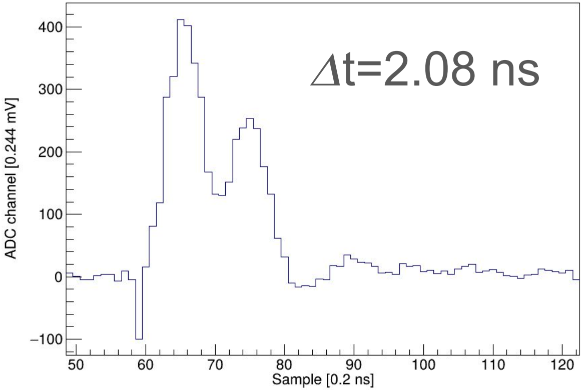
- delay time is measured w.r.t. the laser ext. trigger signal;
- laser trigger is calibrated w.r.t. p.e. signal (RMS<0.2 ns);
- 50% CFD is used to determine the AfterPulse time (same for p.e. and laser trigger signals).





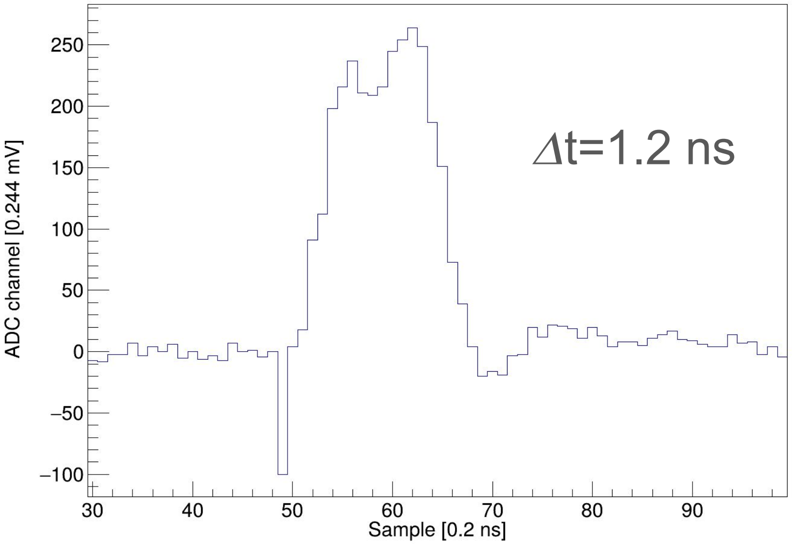


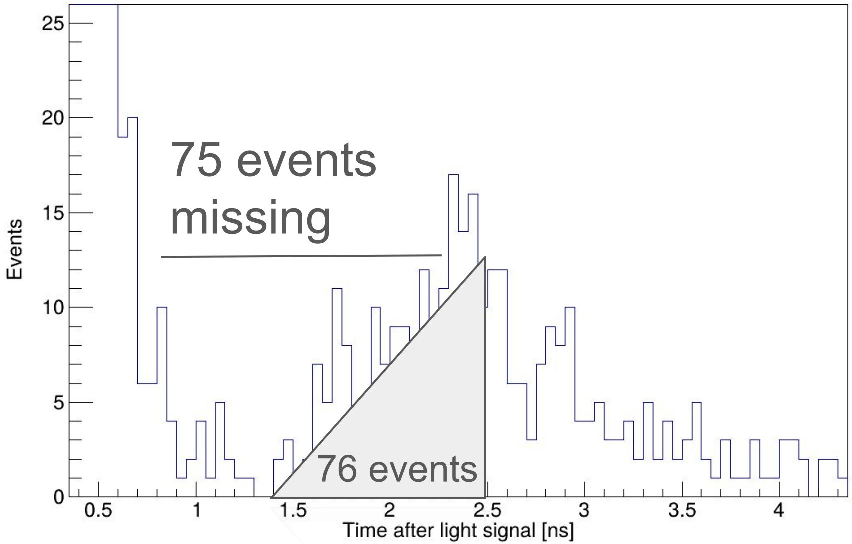




AfterPulses below 2.5 ns

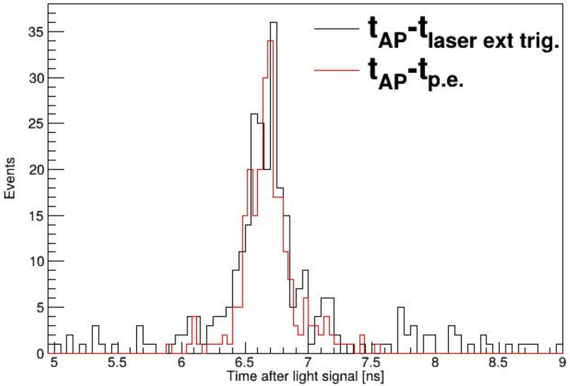
- for delays <2 ns the two signals (1.5 ns wide) cannot be distinguished;
- there are 75 events with almost twice larger signal FWHM>10 samples (mean =6.6 samples);
- this number is comparable with the value necessary to fill the dip between the main peak and 2.5 ns peak ⇒ this peak is actually a shoulder, seen also here.

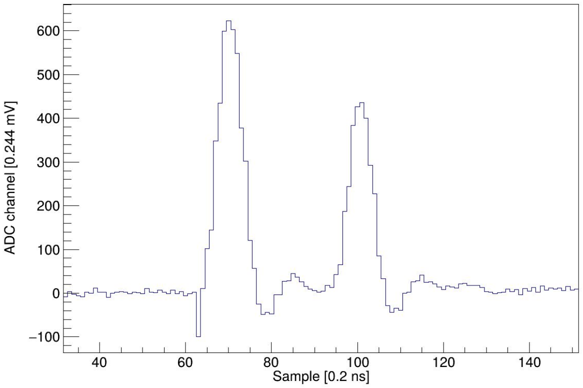


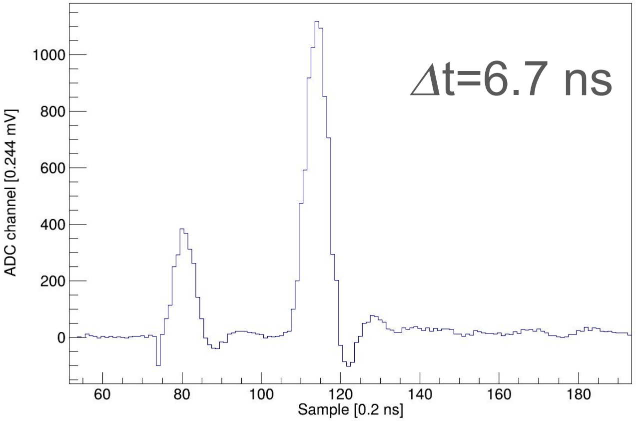


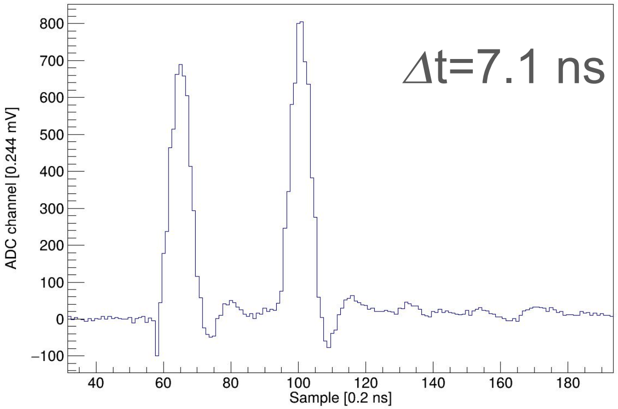
Examples AfterPulses at 6.7 ns

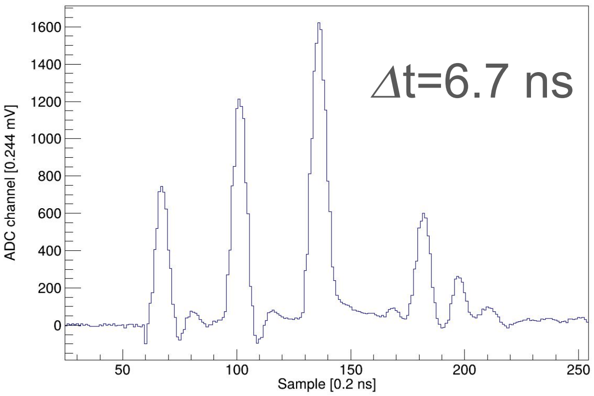
- calibration w.r.t. laser trigger is very precise;
- most AfterPulses here are larger than main signal;
- many waveforms have triple signals.





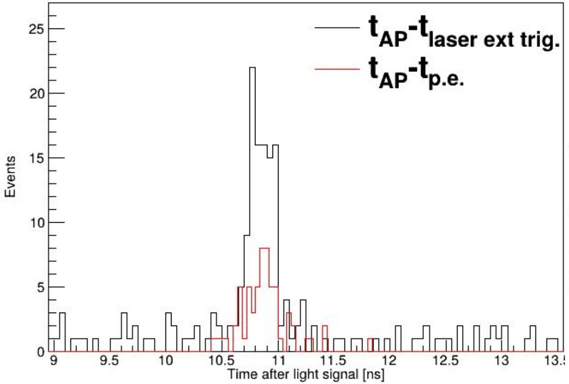


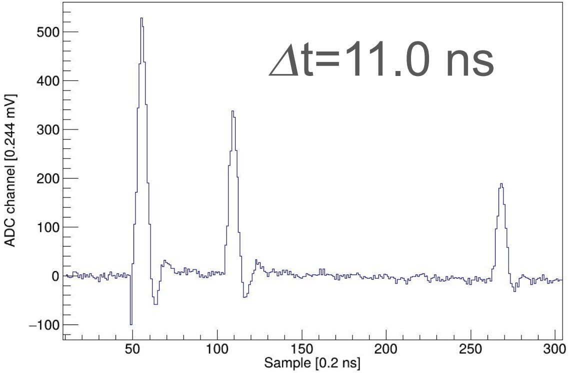


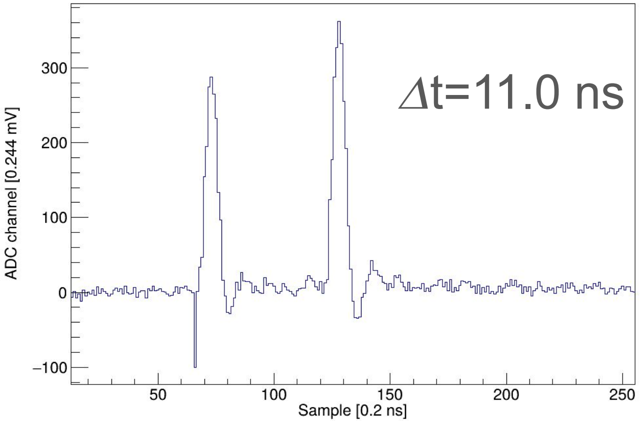


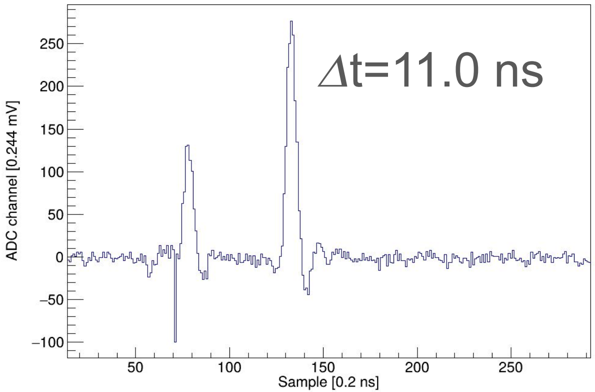
Examples AfterPulses at 11 ns

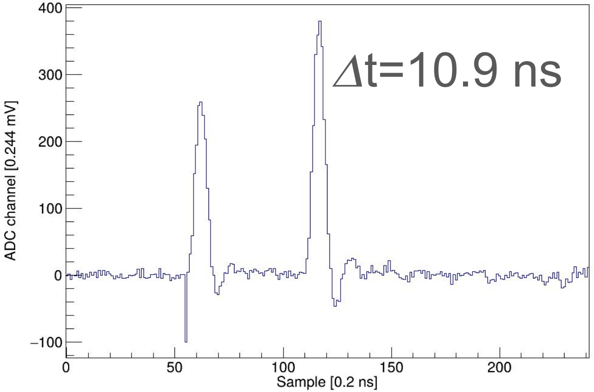
- calibration w.r.t. laser trigger is reasonable;
- afterpulses are similar to p.e. signals.





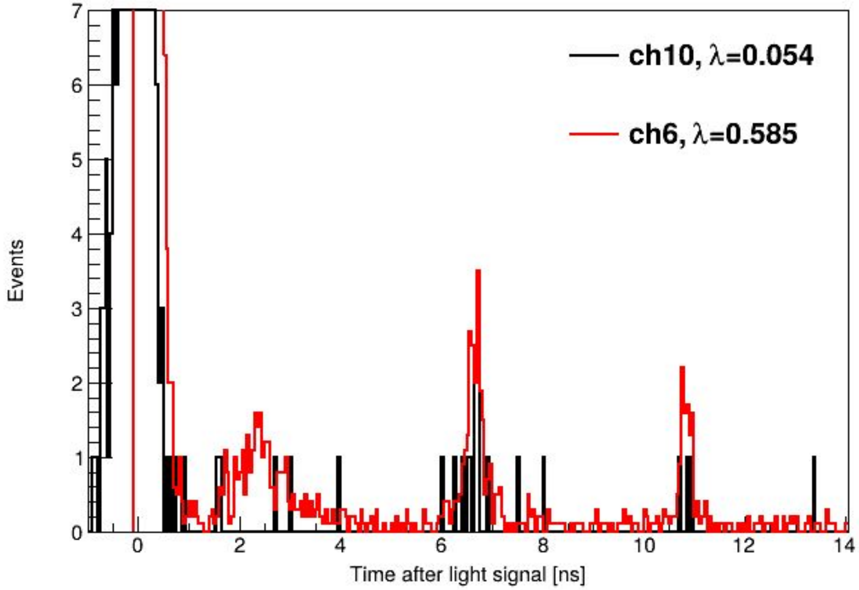






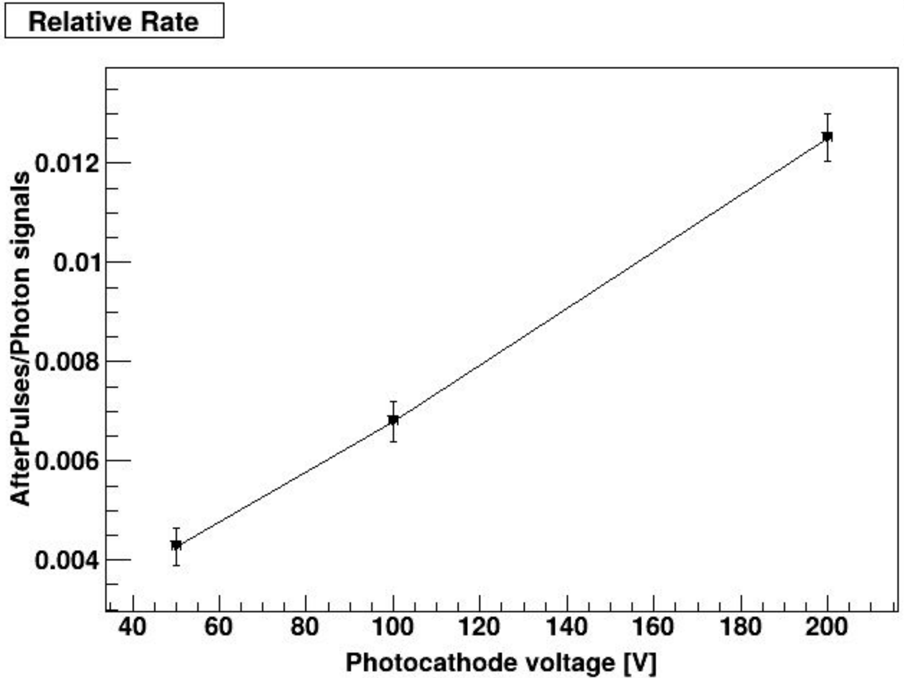
AfterPulses at different λ

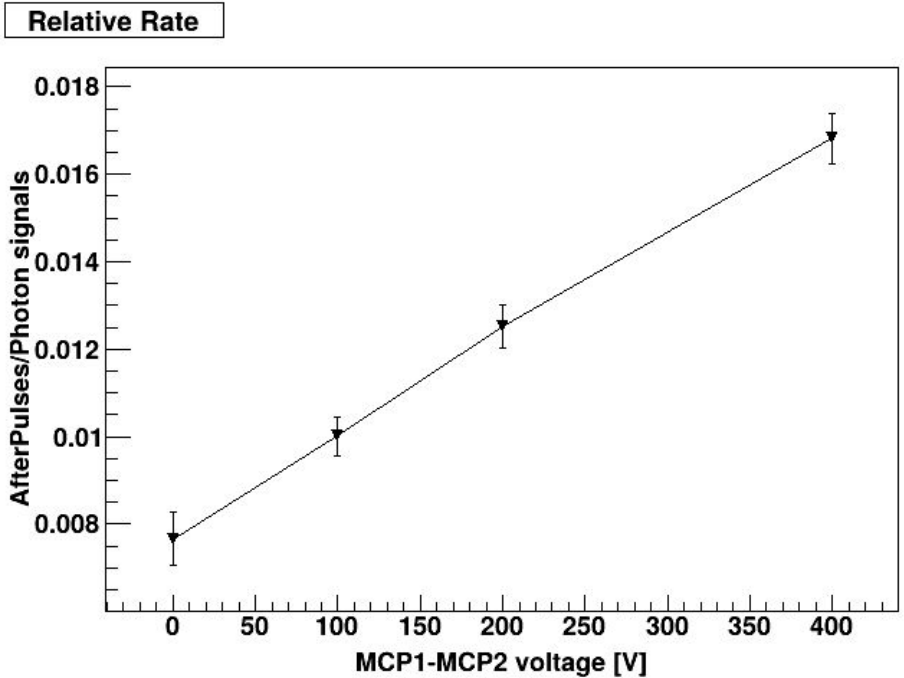
- at different mean number of photons the afterpulse peaks look similar, except 2.5 ns peak.



Relative rate of AfterPulses with t>10 ns

- rate of AfterPulses increases linearly with PC and MCP1-MCP2 gap voltages;
- we reached integrated precision of 0.05%, but still don’t see ion feedback peaks;
- each run of 10^5 pulses had about $5*10^4$ PE signals - still insufficient?

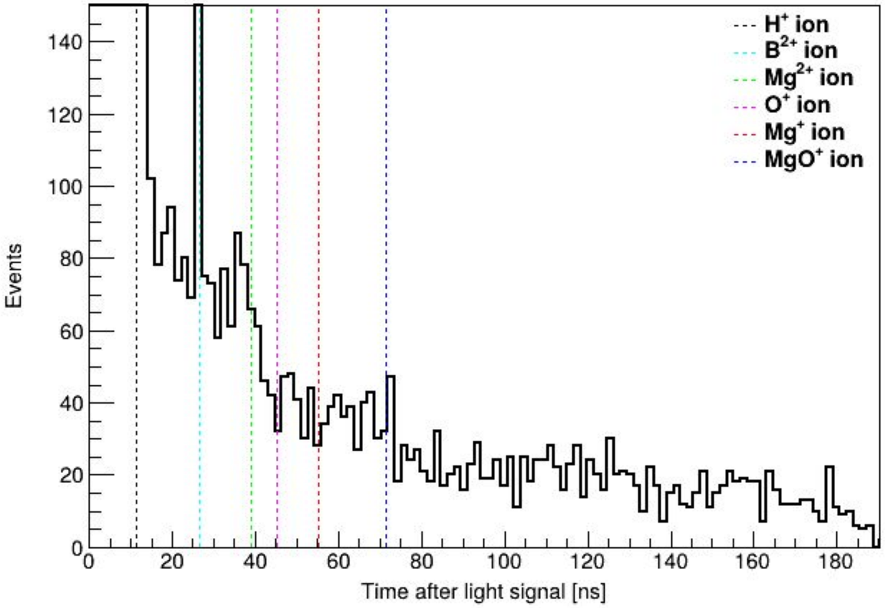




AfterPulses combined data at PC=200 V

- summed up 9 runs for about $4*10^5$ signals;
- limits: $Mg^{2+}<10^{-4}$, $O+<10^{-5}$, $Mg+<10^{-5}$, $MgO+<4*10^{-5}$;
- datasheets quote AfterPulse contribution <4%.

threshold >=1 p.e.



threshold>=2 p.e.