A study of afterpulse effect due to Helium permeation in the H8500 MaPMT

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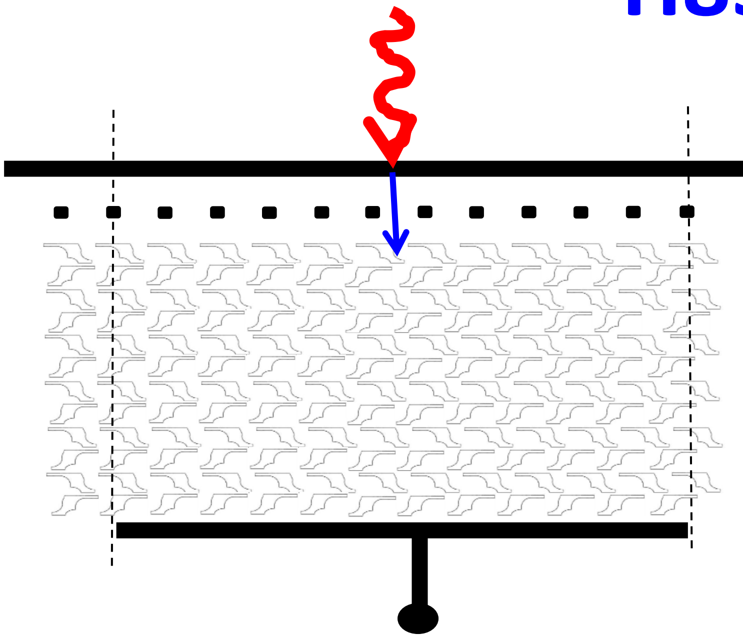
PID Barrel LNF Dec 13, 2011

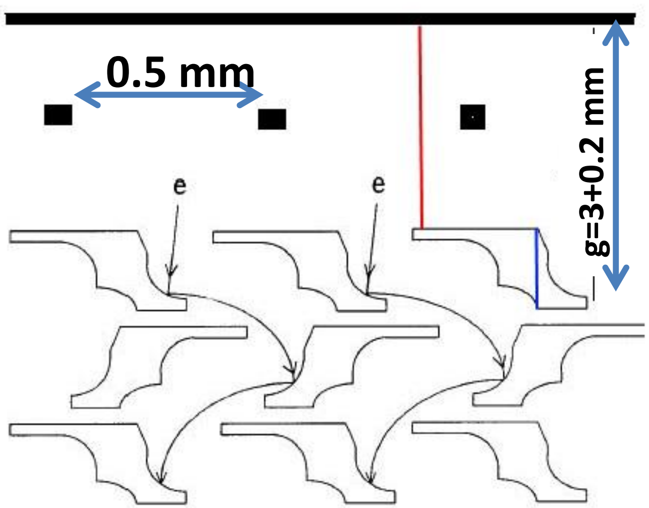
Afterpulses

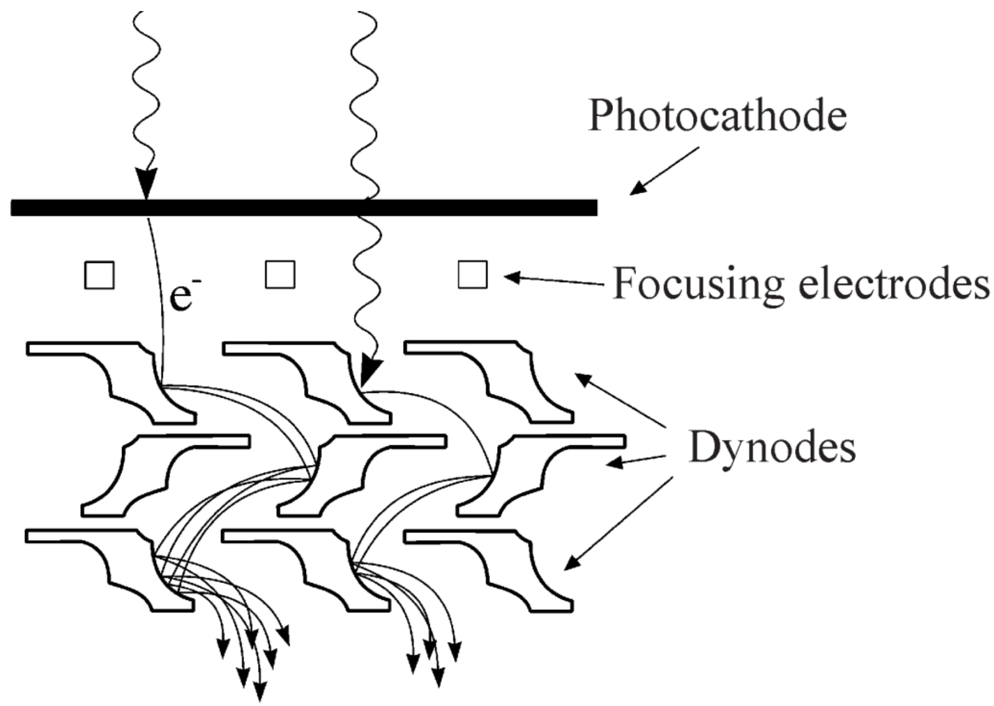
- When a PMT is operating in pulse mode, spurios pulses after the signal output may occur (“afterpulses").
- Afterpulses generated after a long delay may be caused by positive ions, which are generated by the ionization of residual gases in the PMT.
- These positive ions return to the photocathode (ion feedback) and produce photolectrons, which result in afterpulses.
  – The amplitude of afterpulses depends on the type of ions and on the position where they are generated.
- Helium gas is known to produce afterpulses because it may easily penetrate through the PMT bulb
  – some caution should be adopted when PMTs are operating in a Helium rich environment.

H8500 structure



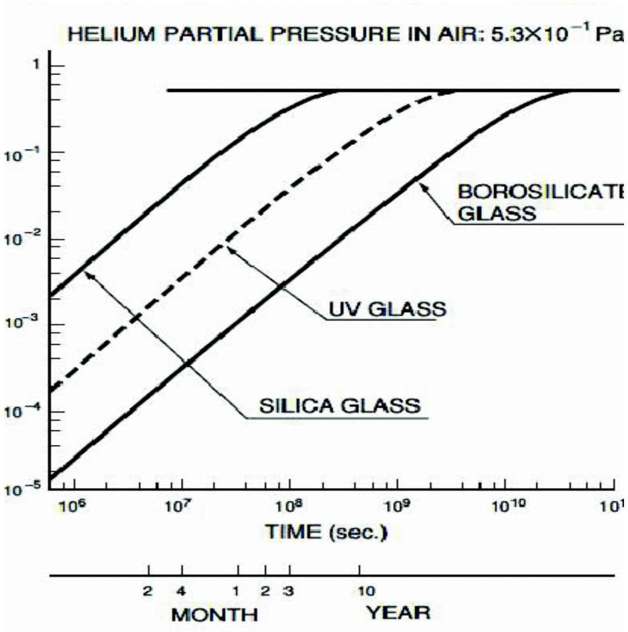
- 11 dynode chains/pixel
- Photocathode-first dynode gap is about 3.2 mm (Hamamatsu private communication)
- Borosilicate window 1.5 mm thick





Helium accumulation in the PMT

- Helium gas exists on the Earth at a partial pressure of about 0.5 Pa (i.e. about 5 ppm).
- Due to the permeability of Helium through the window glass of the PMT, the Helium pressure inside the PMT will increase up to the external pressure (p_{ext}).



Helium partial pressure inside a 28 mm diameter PMT, window 0.6 mm thick (Hamamatsu Photomultipliers tubes: Basic and applications,

- The equation that describes the time dependence of the Helium pressure in the PMT is:

$$p(t) = p_{ext} - (p_{ext} - p_0)e^{-\frac{t-t_C}{\tau}}$$

where p_0 is the Helium pressure in the PMT volume at the beginning of its life ($p_0 \approx 10^{-4}$ Pa), and t_c is a characteristic time required for steady flow of a gas through glass (few days).

- The pollution time τ for the H8500 is about 1.0×10^{10} sec.

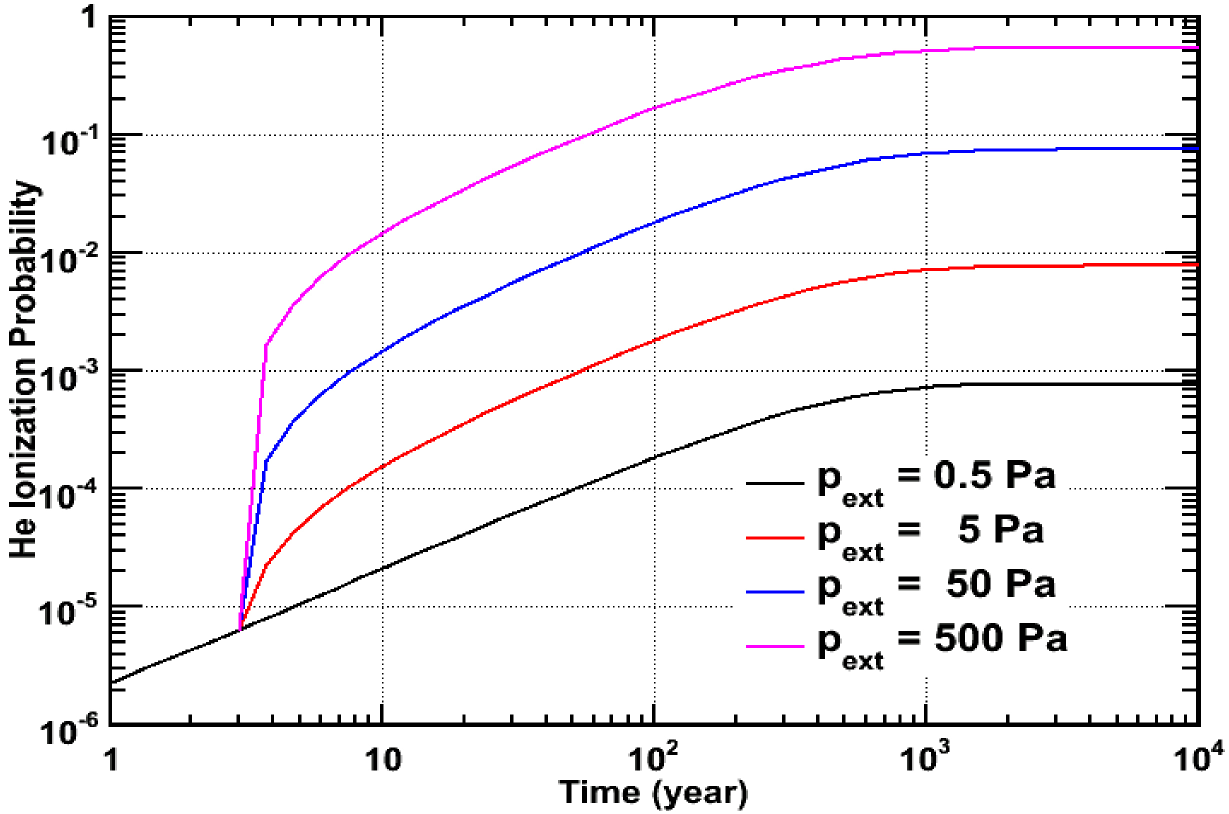
Afterpulses rate

- To evaluate the fraction of afterpulses per photoelectron due to He ions in the PMT volume, we assume that the helium ionization cross section for the electron energy accelerated in the PMT is about $\sigma_{ion} = 20\ Mbarn$
- Then concentration of He atoms in this volume is given by using the ideal gas law: $n_{He} = \frac{p}{kT}$
- The probability of occurrence of the afterpulses is the same as the He ionization probability $P(l) = 1 - e^{-\frac{l}{\lambda_{ion}}}$, where l is the distance travelled by the photoelectron before the ionization of the Helium atom, and λ_{ion} is the ionization interaction length $\lambda_{ion} = \frac{1}{\sigma_{ion} n_{He}} = \frac{kT}{p\sigma_{ion}}$

Afterpulses rate (cont'd)

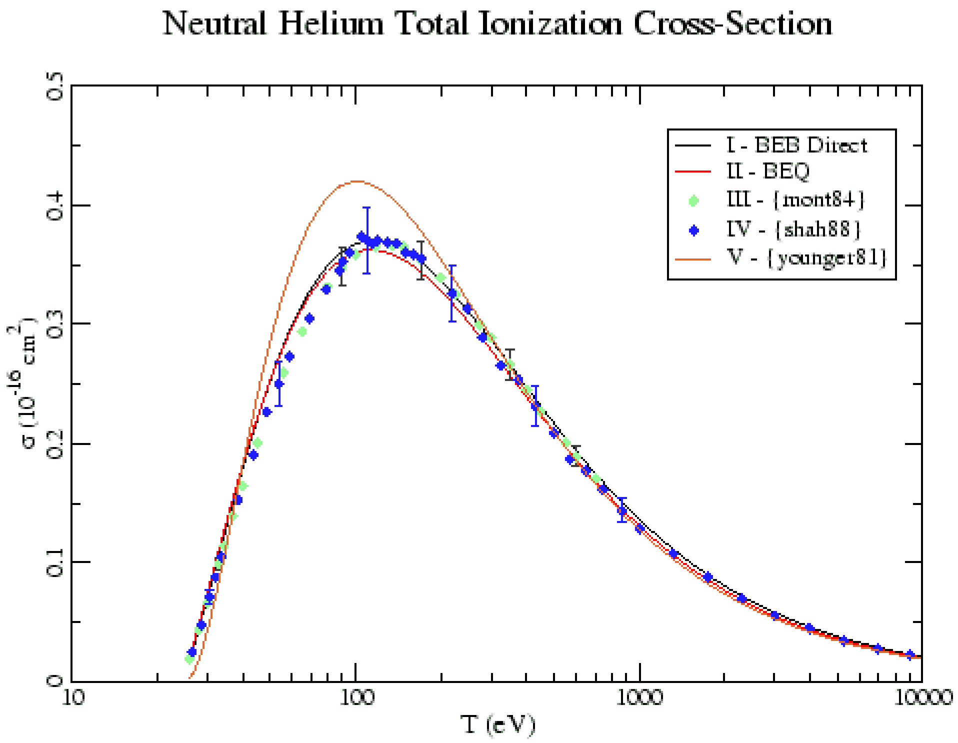
- We can assume the electric eld intensity E between the photocathode and the first dynode for the H8500 is constant, and it is given by E = $\Delta V/g$
  - ΔV is about 80 V when the H8500 operates at 1 kV
- The ionized Helium atoms He^+ will strike the photocathode after a time: $t_{aft} = \sqrt{\frac{2lM_{He}}{eE}}$
  - The ionization interaction length at low pressure is much higher than the distance between the photocathode and the first dynode, thus the pulses initiated by the photoelectron in these collisions will not necessarily occur at a constant delay relative to the primary pulse
- However, the ionization probability is maximum for $l = g$, so the delay relative to the primary photoelectron is about 100 ns or less (more later)
  - We assume that the ionization occurs only between the photocathode and first dynode
  - The ionization between other dynodes is neglected, even though there are many electrons in the avalanche
    - In this case the amplitude of the afterpulse is lower and it depend where it occurs

Afterpulses rate (cont'd)



- He ionization probability per photoelectron as function of time (in years), for the standard He partial pressure in the atmosphere
- Starting from the third year of the beginning of life of the H8500, an increases of a factor ×10, ×100 and ×1000 with respect to the standard value in the atmosphere have been assumed

Some remarks



http://physics.nist.gov/cgi-bin/Ionization/ion_data.php?id=HeI&ision=I&initial=&total=Y

- The He ionization cross section is a function of the electron energy, with a threshold of about 25 eV
- The He could be ionized after a minimum distance, since the electron should have enough energy
  - In the H8500 the He can be ionized after about g/3 at 80 V ddp
  - The minimum delay of the afterpulse is about 30 ns

Conclusion

- It seems that the He ionization probability is less than few % in 10 years of operation, even in some extreme scenario.
- However, the Helium may enter into the PMT through other side and radiation damage may increase the He permeability through to the materials.
- Some caution should be adopted to avoid an accumulation of He near the detector
  - A minimum air flow should be planned