# Comments on the Use of Avalanche Photodiodes in the Electromagnetic Calorimeter of a Tau-Charm Factory

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*Introduction*

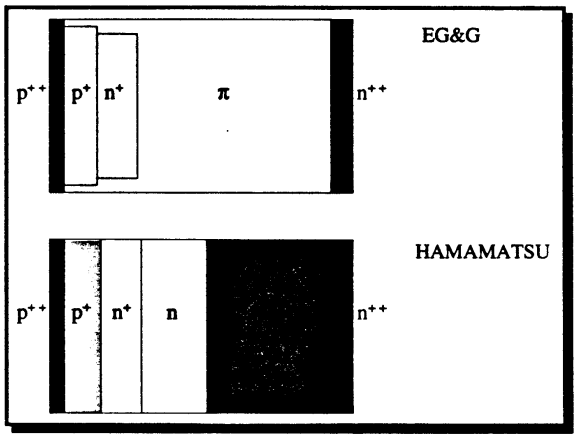
**Avalanche photodiodes are relatively new devices, about to be used in a large-scale experiment (CMS) for the first time: 61,200 $PbWO_4$ crystals to read out (earlier proposed for TEXAS and SDC fibre trackers).**

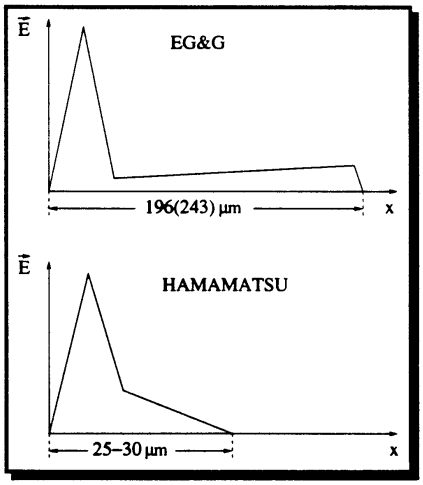
**High electric field leads to avalanche multiplication following electron-hole pair creation due to absorbed photons.**

- **Advantages:**
  - **Much recent R&D**
  - **Several manufacturers (EG&G, Hamamatsu, RMD)**
  - **(can be) Radiation hard and able to work in large $\vec{B}$ fields**
  - **Provide gain of $\sim$ 100 easily with bias $\sim 400$ V**
  - **Very high QE ($\sim 80$ %)**
  - **Small and mechanically robust**
  - **Fast (low capacitance); Gain $\times$ BW = 100 GHz easy**

- **Drawbacks:**
  - **Gain is voltage-sensitive (1/M dM/dV $\sim$ a few %/V typical)**
  - **Gain is temperature-sensitive (1/M dM/dT $\sim$ 3%/°C typical)**
  - **Noisier than PMT's (at least at normal temperatures); fluctations; excess noise factor**
  - **Maximum size $\sim$ 5 mm$\times$ 5 mm (but can use pairs)**
  - **Care needed with "Nuclear counter effect"**

## Device Structures



## Device Characteristics

| Diode | Area [$mm^2$] | Bias at Gain 50 [V] | $I_{bulk}$ [nA] | C [pF] | Q.E. at 480 nm [%] |
|---|---|---|---|---|---|
| BC-16 | 19.6 | 183.5 | 6 | 140 | 63 |
| EG&G-15 | 25 | 365 | 9.2 | 25 | 78 |
| EG&G-3 | 25 | 420 | 16.2 | 20 | 83 |
| S3590-01 | 100 | $40(M=1)$ | 0.6 | 69 | 65 |

Table 1: Parameters of APD's and PIN photodiode measured at 20 C before irradiation.

| Diode | Bias at Gain 50 [V] | $I_{bulk}$ [$\mu$A] | $L_{eff}$ [$\mu$m] | Q.E. at 480 nm [%] | neutron fluence [$n/cm^2$] |
|---|---|---|---|---|---|
| BC-16 | 183.5 | 13 | $4.5 \pm 0.5$ | 51 | $2.33 \times 10^{13}$ |
| EG&G-15 | 374 | 30 | $9 \pm 1$ | 78 | $2.33 \times 10^{13}$ |
| EG&G-3 | 450 | 39 | $11 \pm 1$ | 83 | $2.33 \times 10^{13}$ |
| S3590-01 | $5(M=1)$ | 13 | $170 \pm 10$ | 63 | $2.17 \times 10^{13}$ |

Table 2: Parameters of APD's and p-i-n photodiode (last line) measured at 20 C after irradiation.

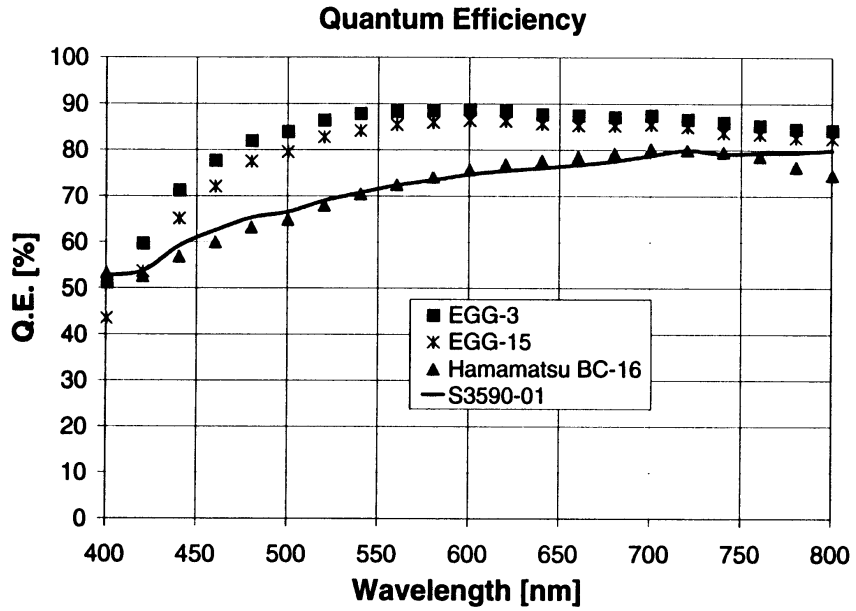



Figure 1: Measured quantum efficiency versus wavelength for APD's and S3590-01 photodiode.

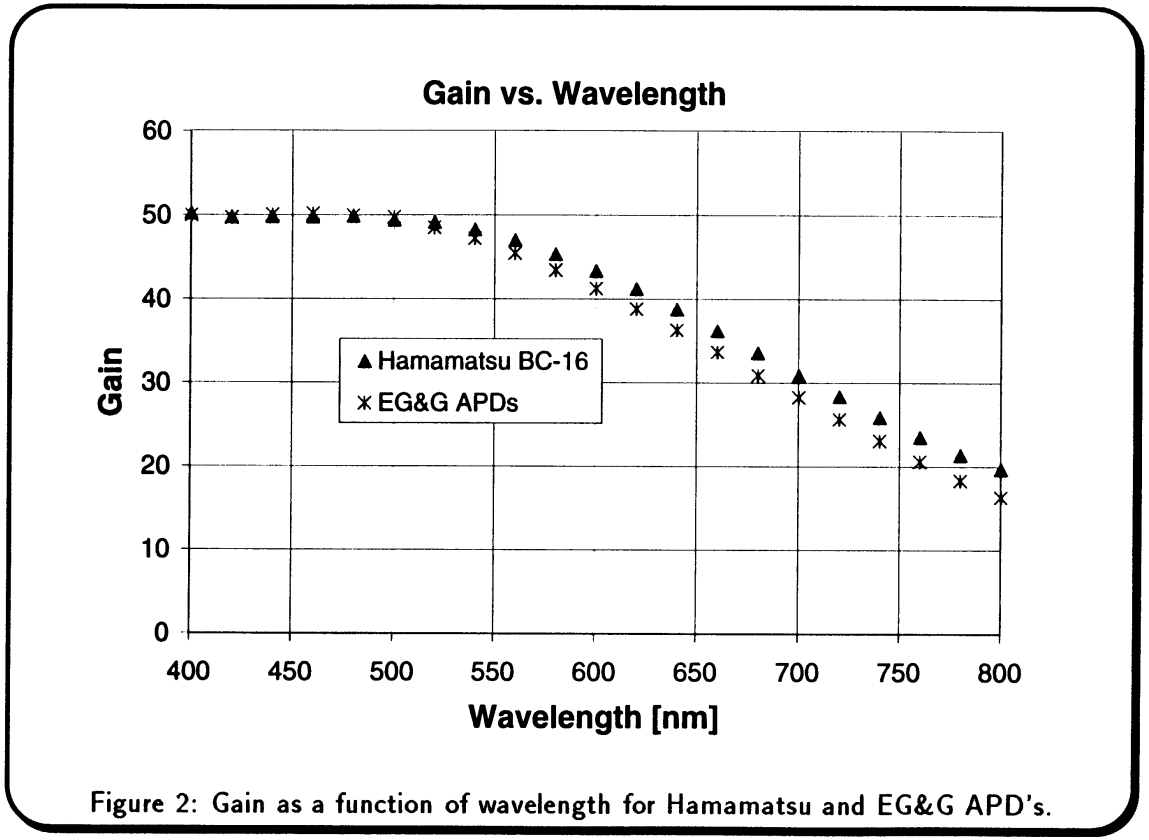



Figure 2: Gain as a function of wavelength for Hamamatsu and EG&G APD's.

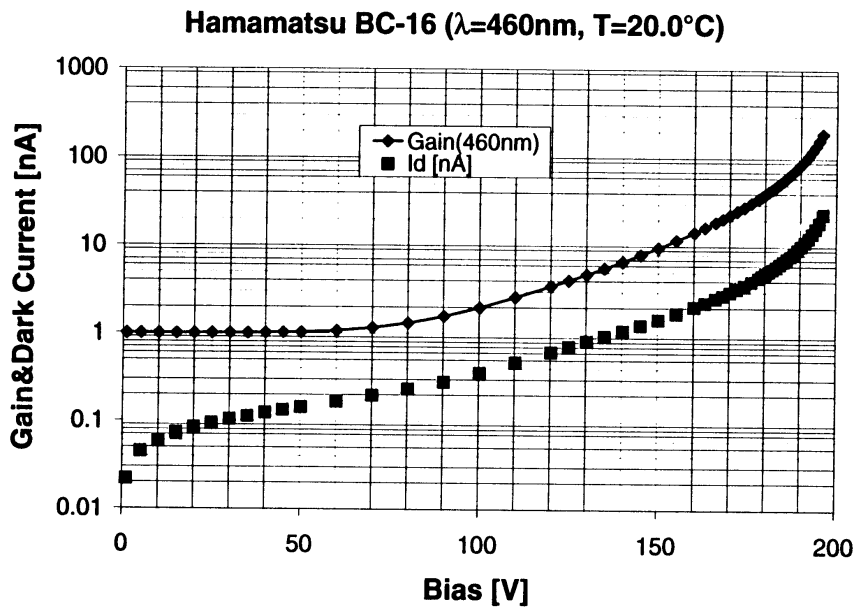



Figure 3: Gain and dark current as functions of bias voltage for Hamamatsu BC-16 APD measured before irradiation.

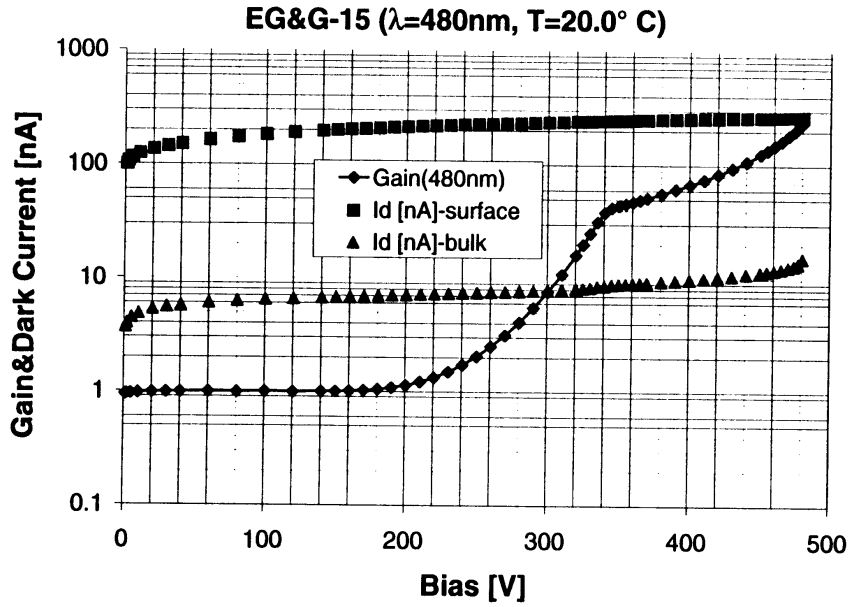



Figure 4: Gain and dark current as function of bias voltage for EG&G-15 APD measured before irradiation.

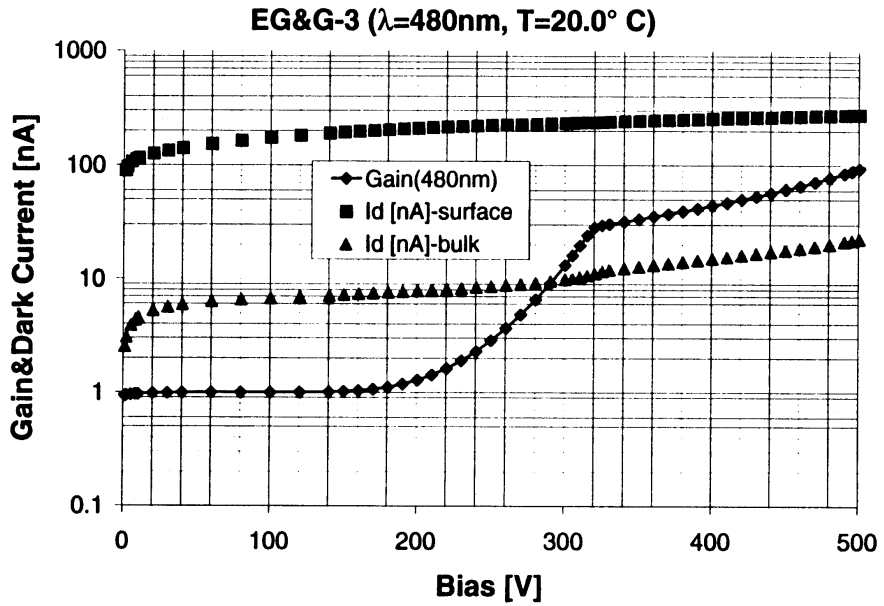



Figure 5: Gain and dark current as function of bias voltage for EG&G-3 APD measured before irradiation.

## *Conclusions*

- **Avalanche photodiodes are potentially attractive readout devices for next generation experiments**
- **They are no longer "exotic" (use in CMS as well as in telecommunications and PET scanners – expect prices to drop)**
- **Detailed studies may be needed, but manufacturers are used to dealing with HEP customers and eager to be involved in R&D**