The silicon photomultiplier and its possible applications

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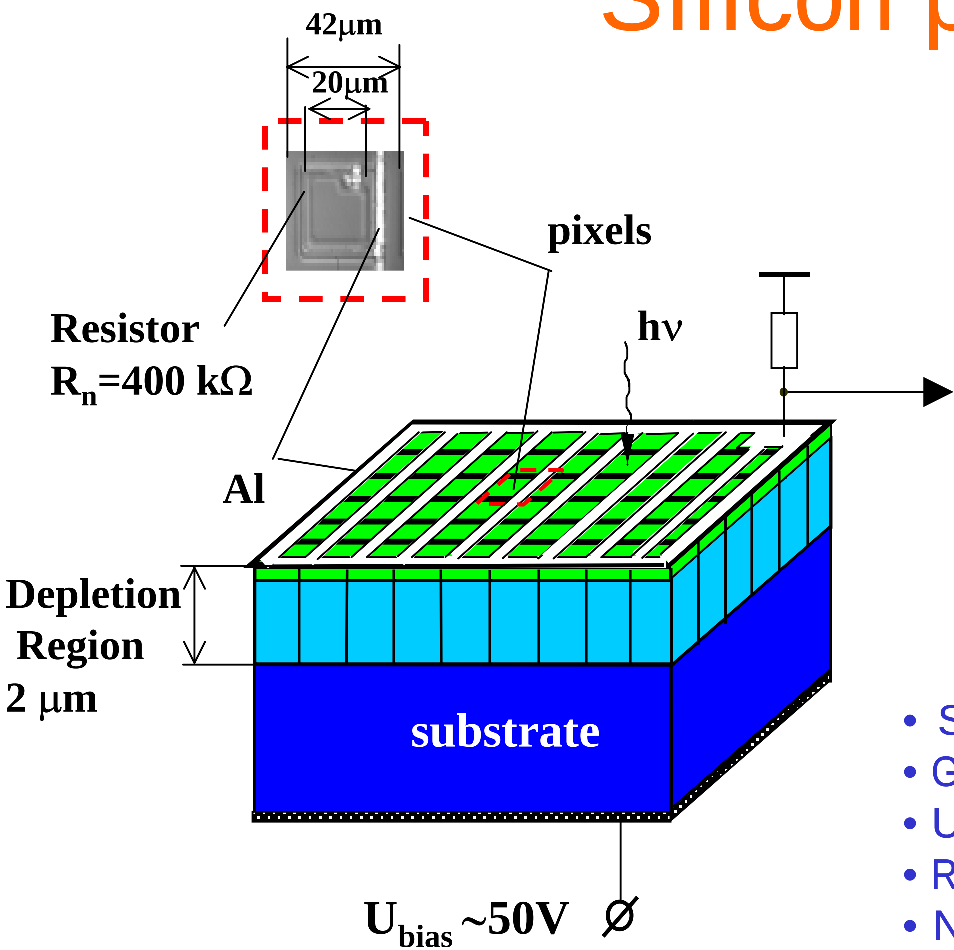
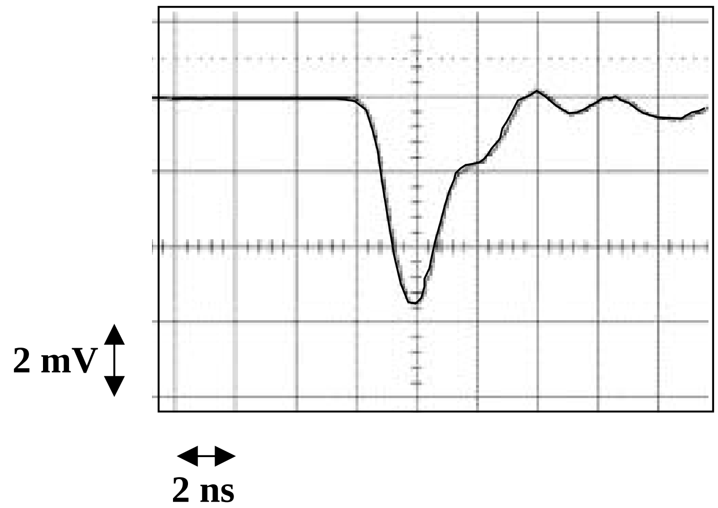
Silicon photomultiplier (SiPM)



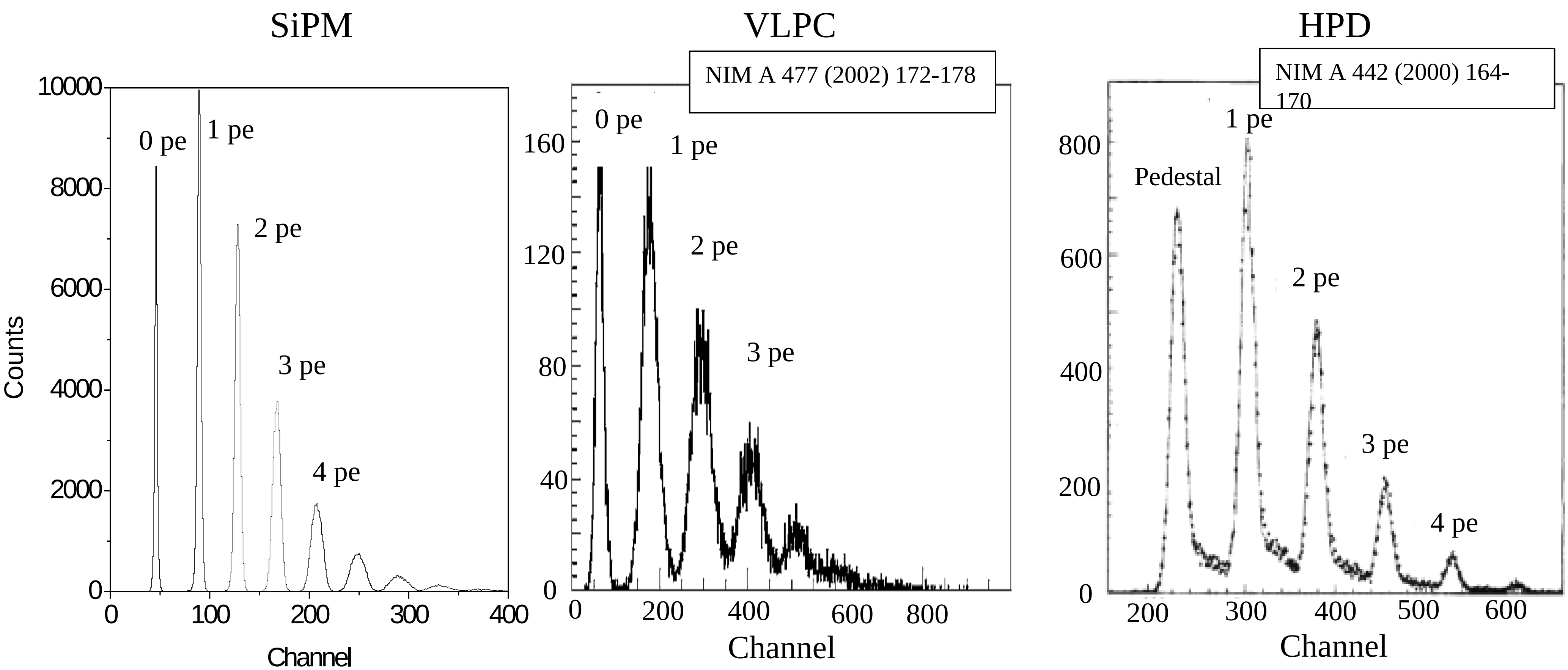


SiPM main features:

- Sensitive size 1x1mm^2 on chip 1.5x1.5 mm^2
- Gain $2{\cdot}10^6$
- U_{bias}~50V
- Recovery time ~ 100 ns/pixel
- Number of pixels: 576
- Nuclear counter effect: negligible (due to Geiger mode
- Insensitive to magnetic field
- Dynamic range ~10^3/mm^2

For further details see:
«Advanced study of SiPM»
http://www.slac.stanford.edu/pubs/icfa/fall01.html

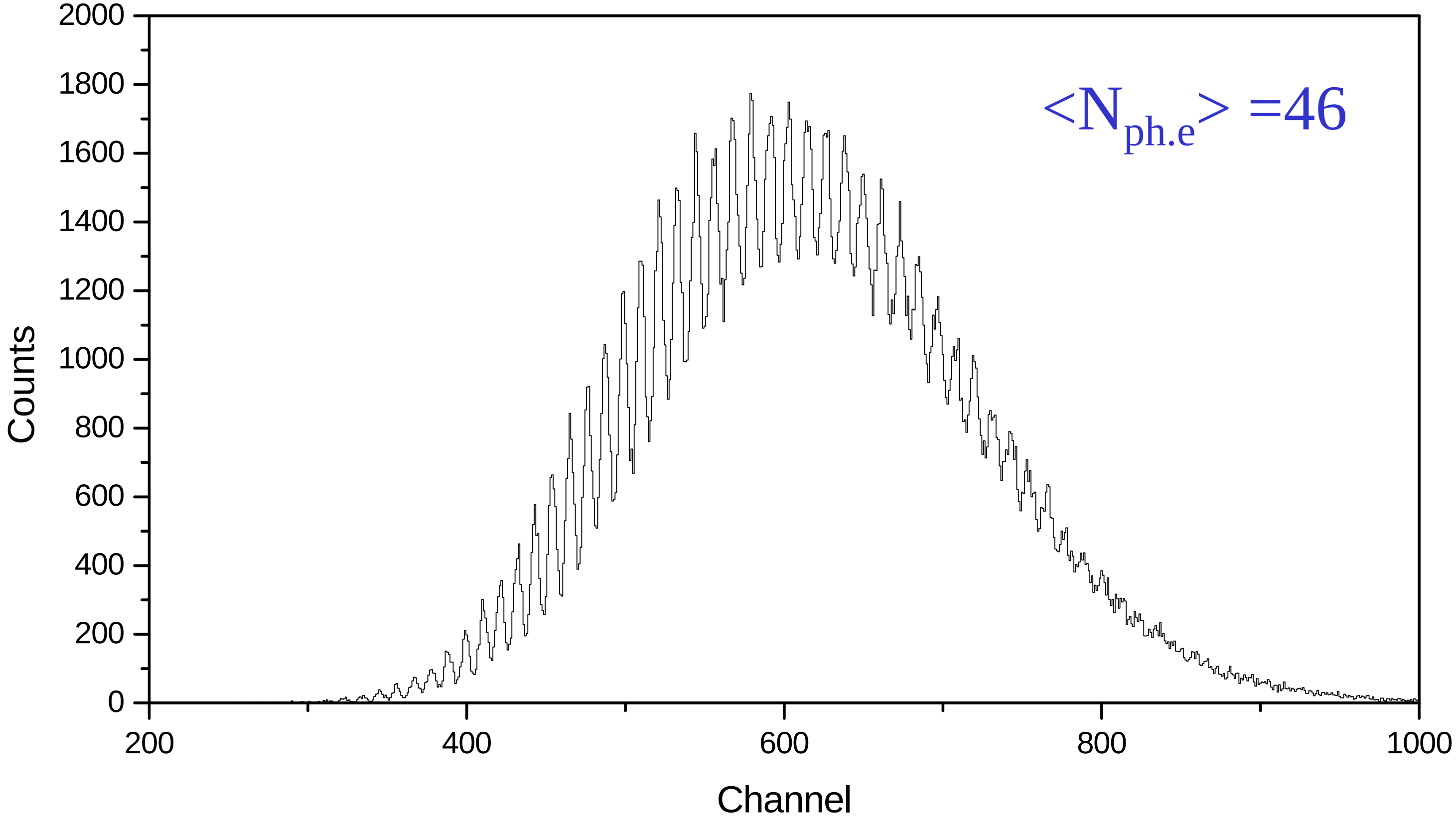
Single photoelectron (single pixel) spectra



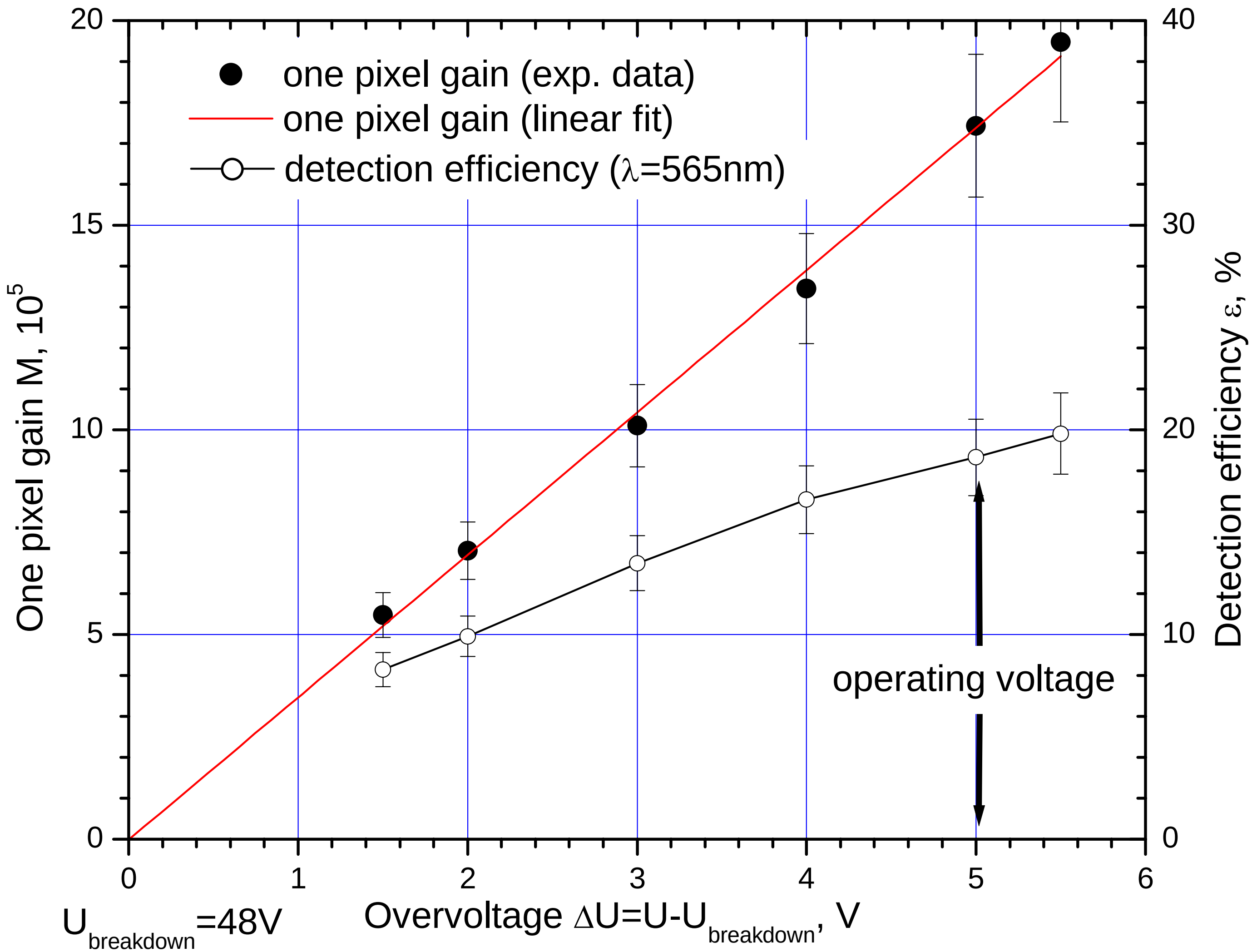
SiPM:

- excellent single photoelectron resolution
- low ENF expected

More about pixel signal resolution: tens of photoelectrons



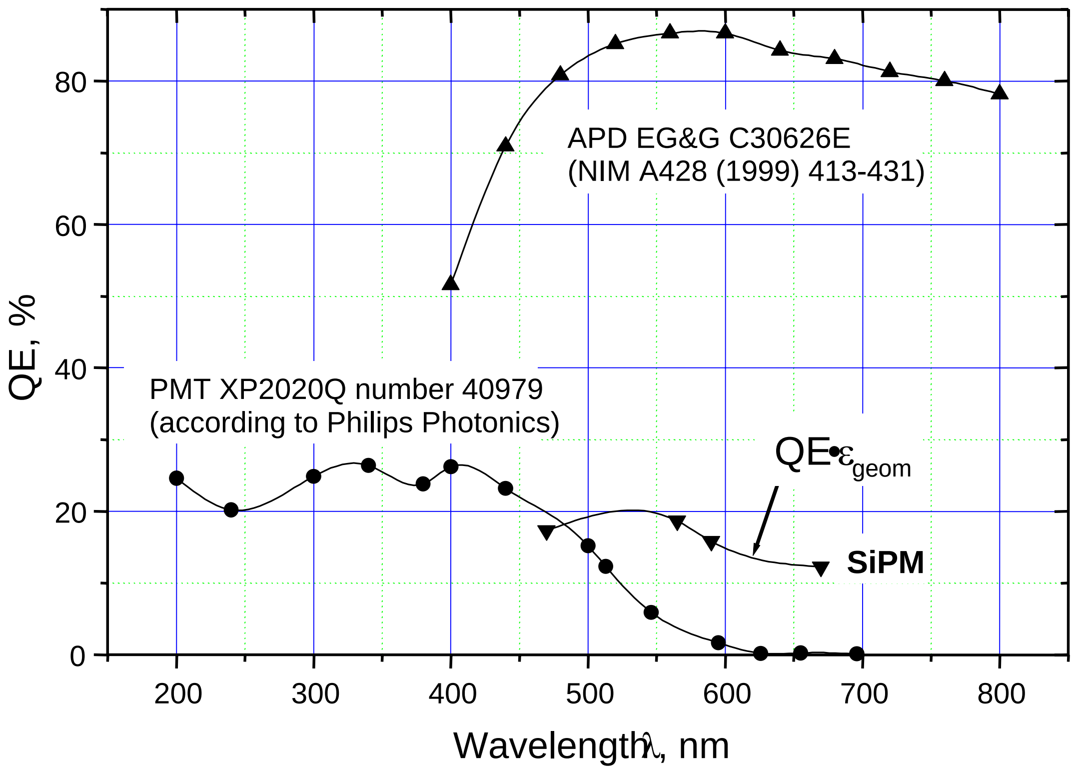
- SiPM consists of a large number of pixel photoelectron counters with binary readout for each pixel, working as analogue device
- signal uniformity from pixel to pixel is quite good



Photon detection efficiency $\varepsilon = QE \cdot \varepsilon_{geom}$

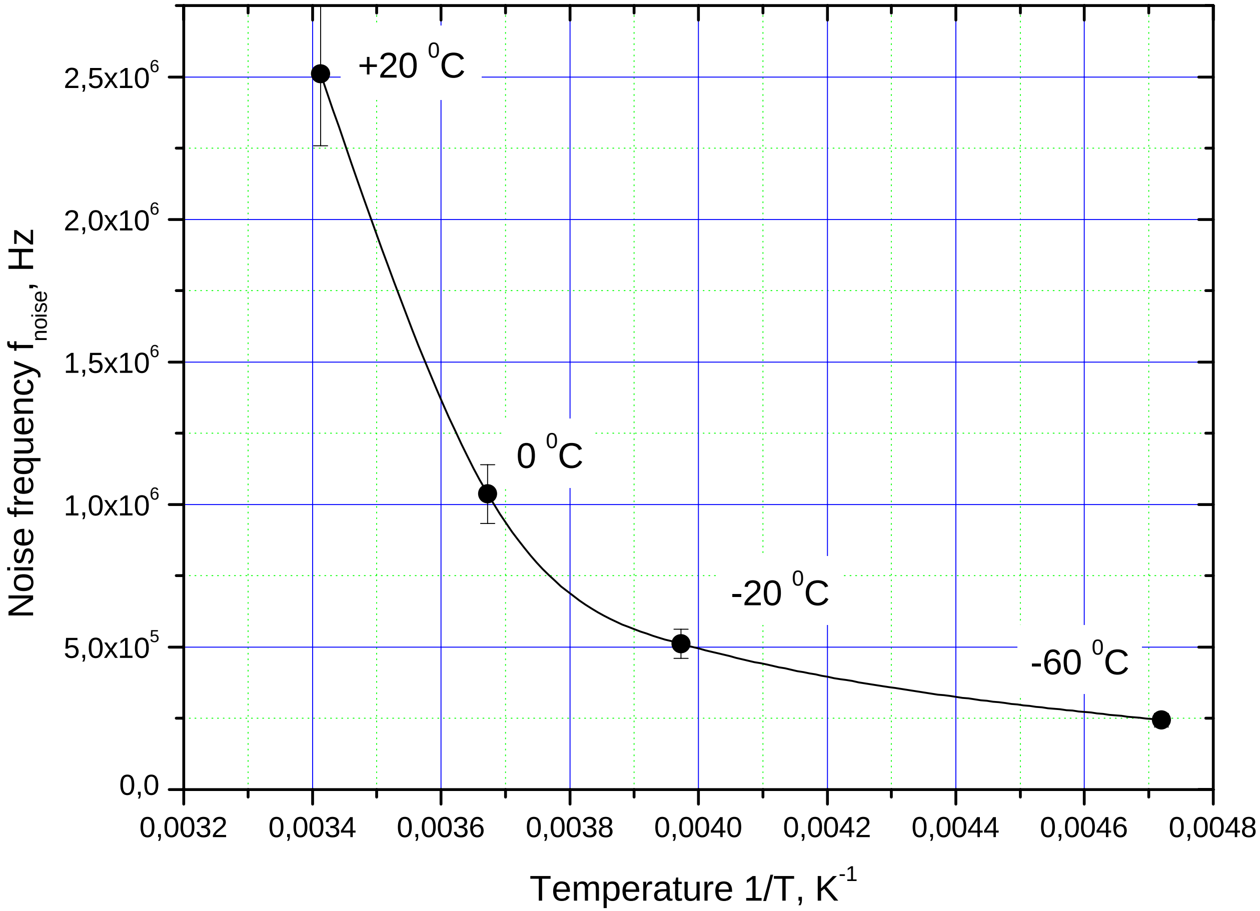
Photon detection efficiency

Spectral dependence of quantum efficiency for different photodetectors
(room temperature)



SiPM: ε = QE$\cdot\varepsilon_{geom}$, ε_{geom}~0.3 (possible improvement up to ~ 0.5)

SiPM noise



- Electronics noise - negligible (less than 0.1e - because the SiPM gain ~10^6)
- dark rate noise

Even for room temperature the contribution of the dark rate is rather low (less than 1 ph.e. for a gate of 50 ns)

SiPM gain: temperature and voltage dependence

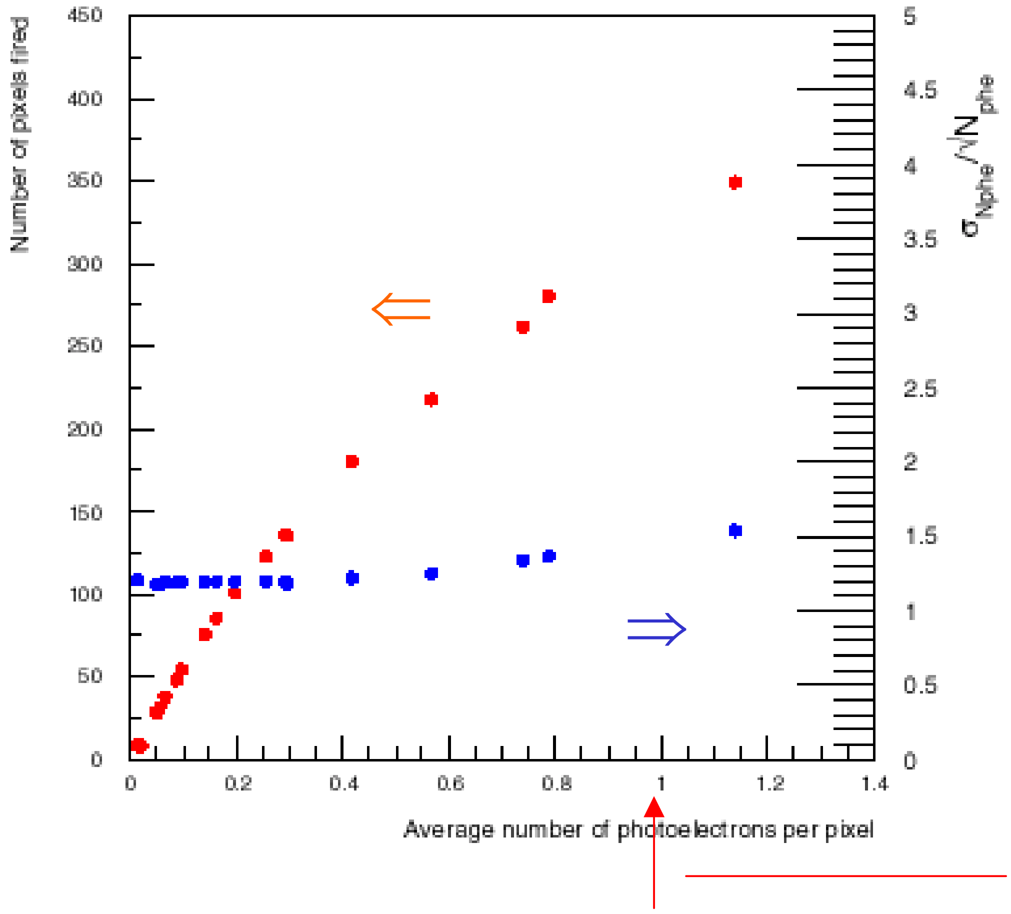
Photodetector	ΔT for $\Delta M/M=1\%$	$\Delta V/V_0$ for $\Delta M/M=1\%$
PMT	~10^o	$0.5V/1500V = 3\cdot10^{-4}$
APD EG&G C30626E*	0.15^o	$0.4V/400V = 10^{-3}$
APD Hamamatsu S5345 (high capacitance)*	0.3^o	$0.04V/300V = 1.5\cdot10^{-4}$
SiPM $M=2\cdot10^6$	2.5^o	$0.05V/50V = 10^{-3}$

*) for APDs M=100 /Karar et al NIM A428(1999) 413/

SiPM dynamic range

Dynamic range is limited due to finite total number of pixels *m*

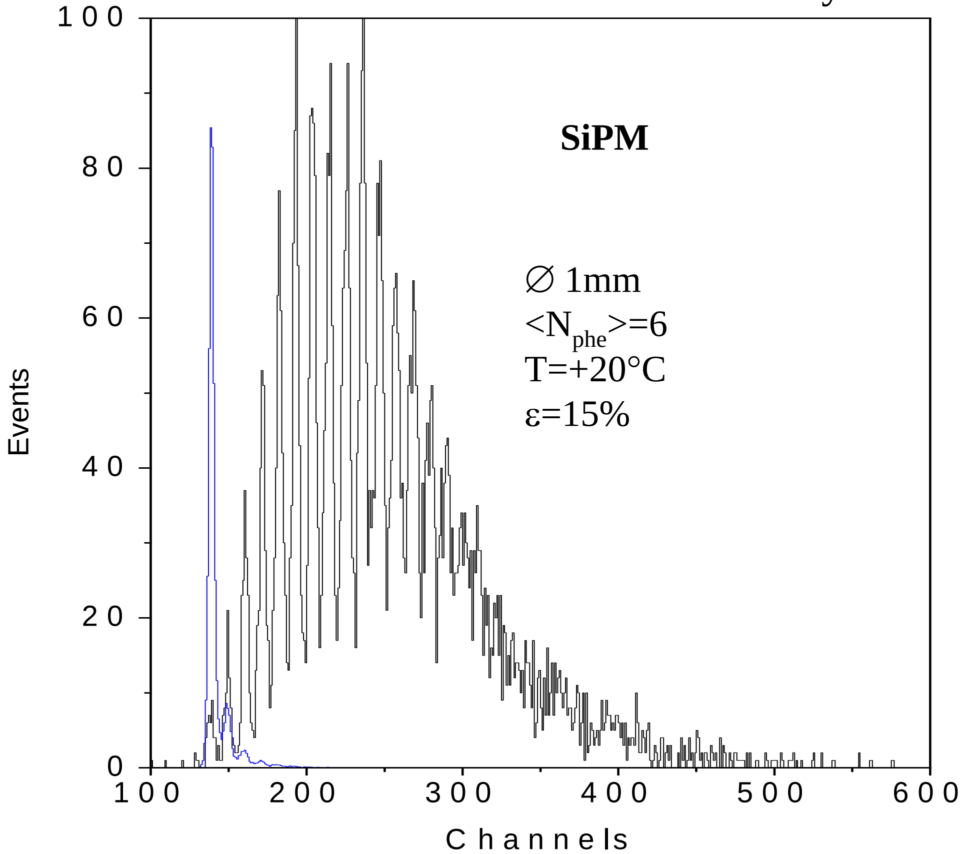
$Signal \sim m(1-exp(-N_{ph.e}/m))$

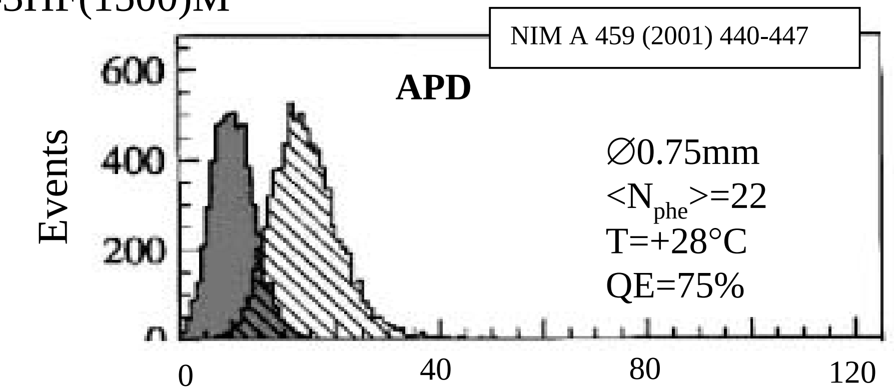


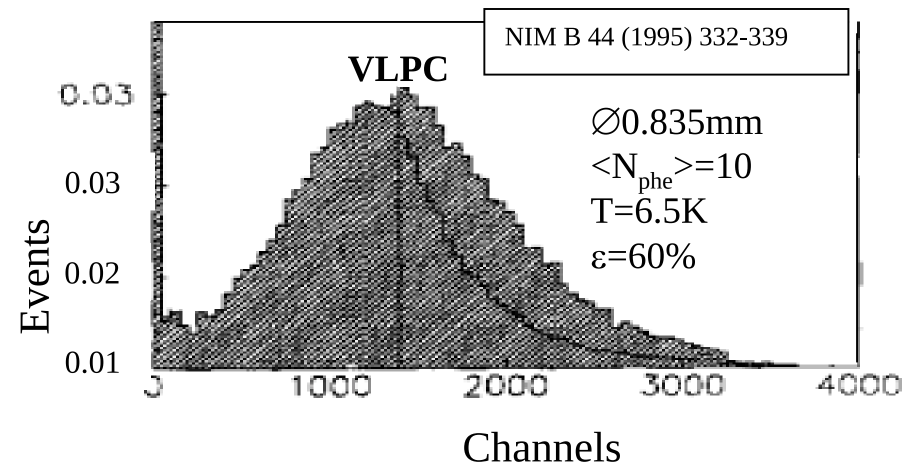
"Dispersion limit" of dynamic range: $N_{ph.e}/m < 1$

SiPM application for sci fiber MIP detection

Kuraray SCSF-3HF(1500)M

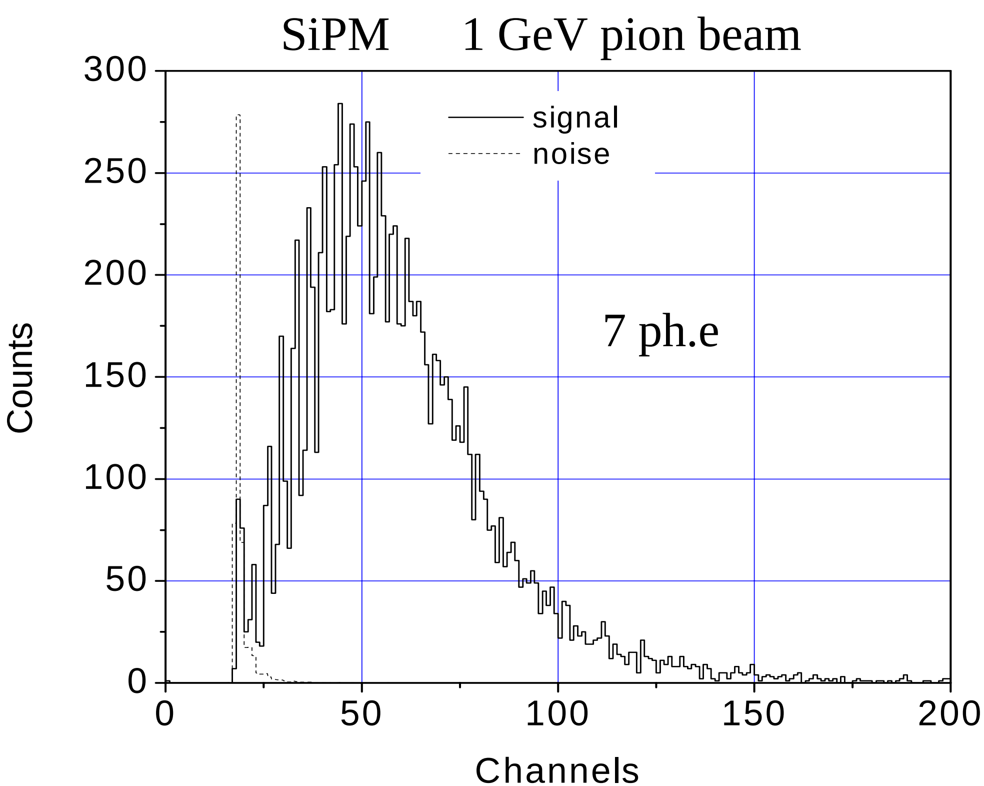


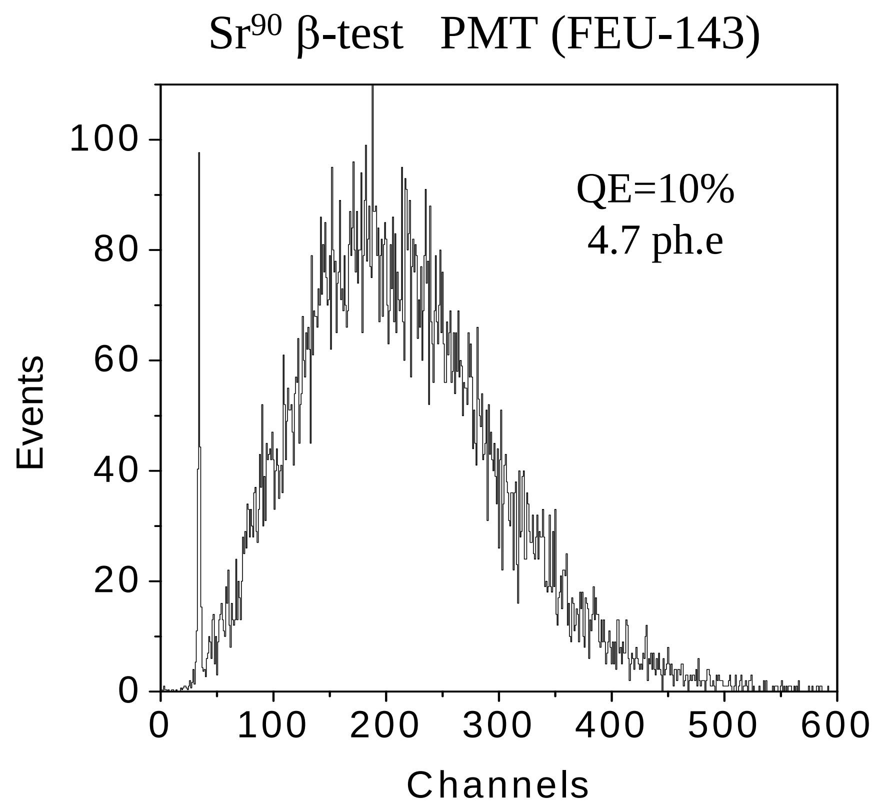




- SiPM is better than APD for room temperature
- SiPM at room temperature is good enough even compared to VLPC at 6.5°K

SiPM application for scintillator + wavelength shifter (WLS) readout





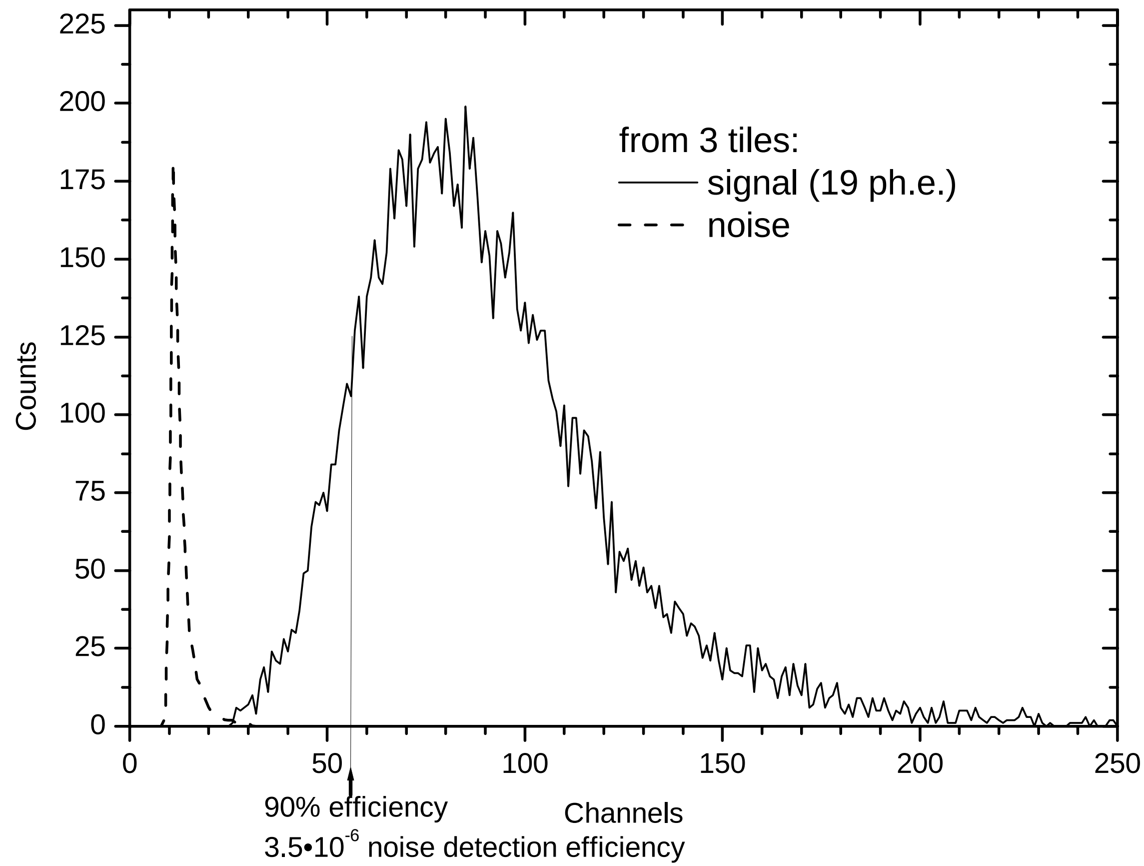
SiPM: ε=15%, M=2·10^6, N_{pixel}=576, U_{bias}=53V

Tile: Bicron BC-404, 50x50x5 mm^3

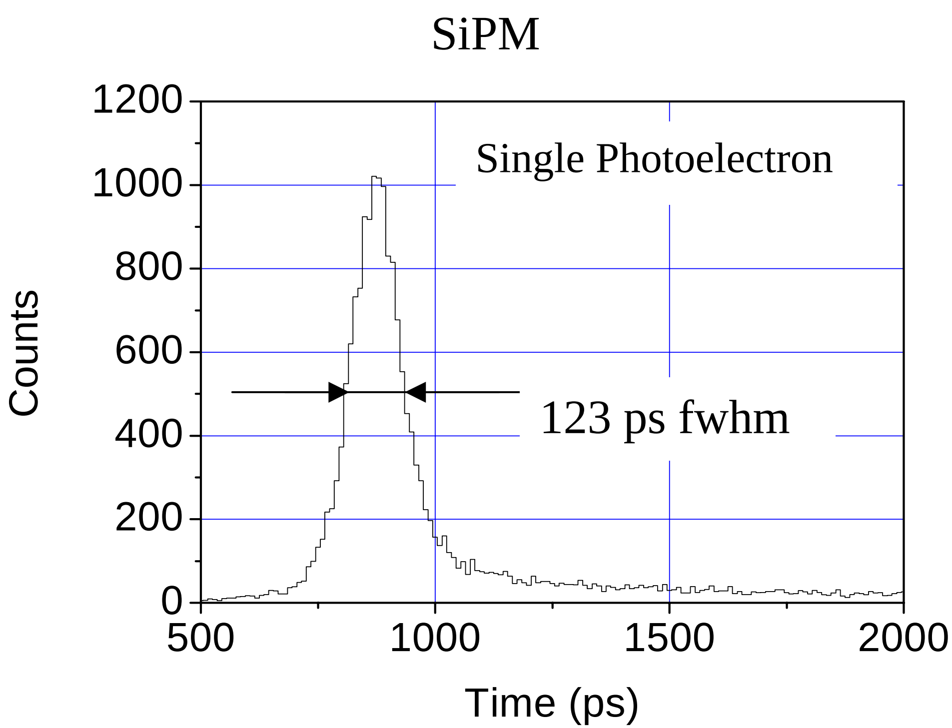
WLS: Kuraray Y11 ∅1mm x 34 cm

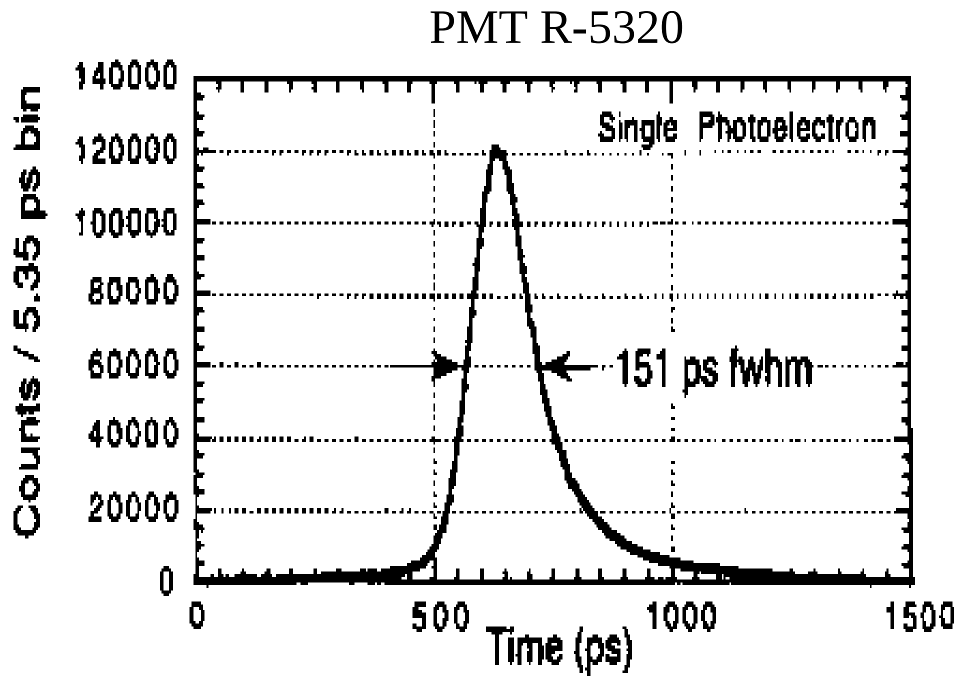
More about Sci+WLS readout: TESLA Hadron Tile calorimeter beam test of 3tile+WLS cell

1 GeV π detection with 3 tiles of Bicron BC-404 and 1 mm diameter 34 cm long WLS Kuraray Y11 (with aluminized mylar mirror) coupled to 3 SiPMs



Timing by SiPM: possible application for Cherenkov Imaging Counters





SiPM:

- position sensitive (~1 mm^2)
- a single photon detection capability with background hits density : $2 \cdot 10^{-3}$ 1/ns·mm^2 (room temperature)
  $3 \cdot 10^{-4}$ 1/ns·mm^2 (-50°C)
- insensitive to magnetic field
- good time resolution (~50 ns rms)

FWHM: Laser (40 ps) + electronics (60 ps) => SiPM (100 ps)

Conclusion

The R&D developments of SiPM show that after tuning of some parameters (photon detection efficiency, gain, timing, dynamic range etc.) one can consider the SiPM as a suitable photodetector for a number of applications