Characterization of SiPM detector for the upgrade LHCb SciFi Tracker

CHIPP
30 June – 02 July 2014, University of Fribourg

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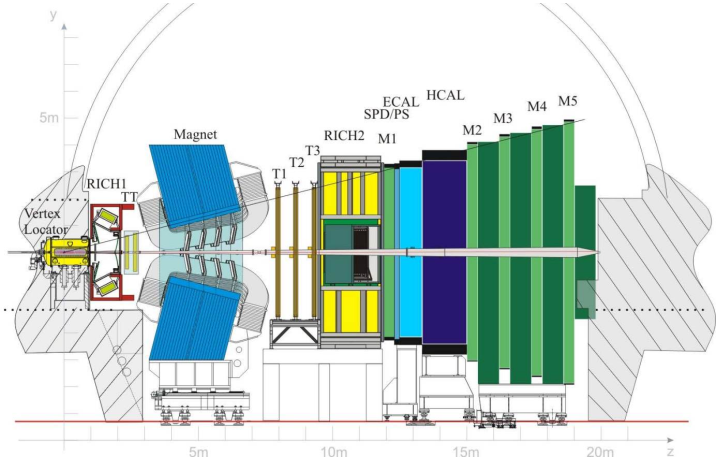
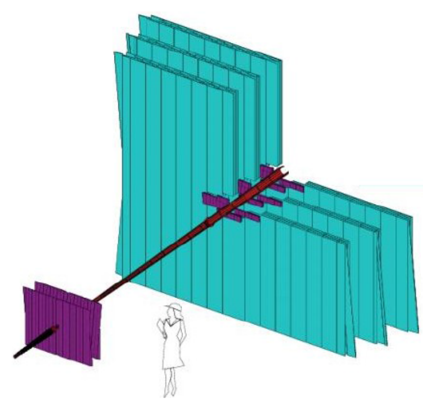
EPFL Lausanne, Switzerland

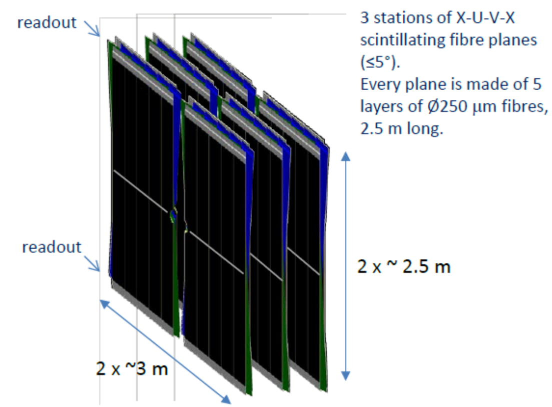
The upgrade LHCb SciFi Tracker

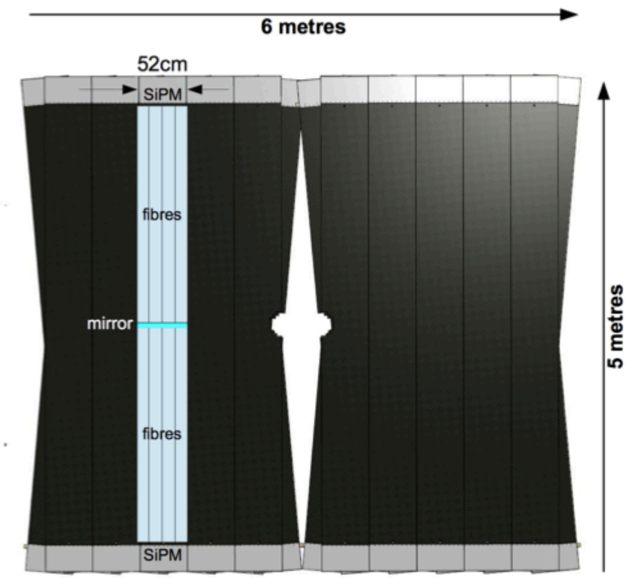


Today: OT+IT



SciFi 2019 (full tracker version)

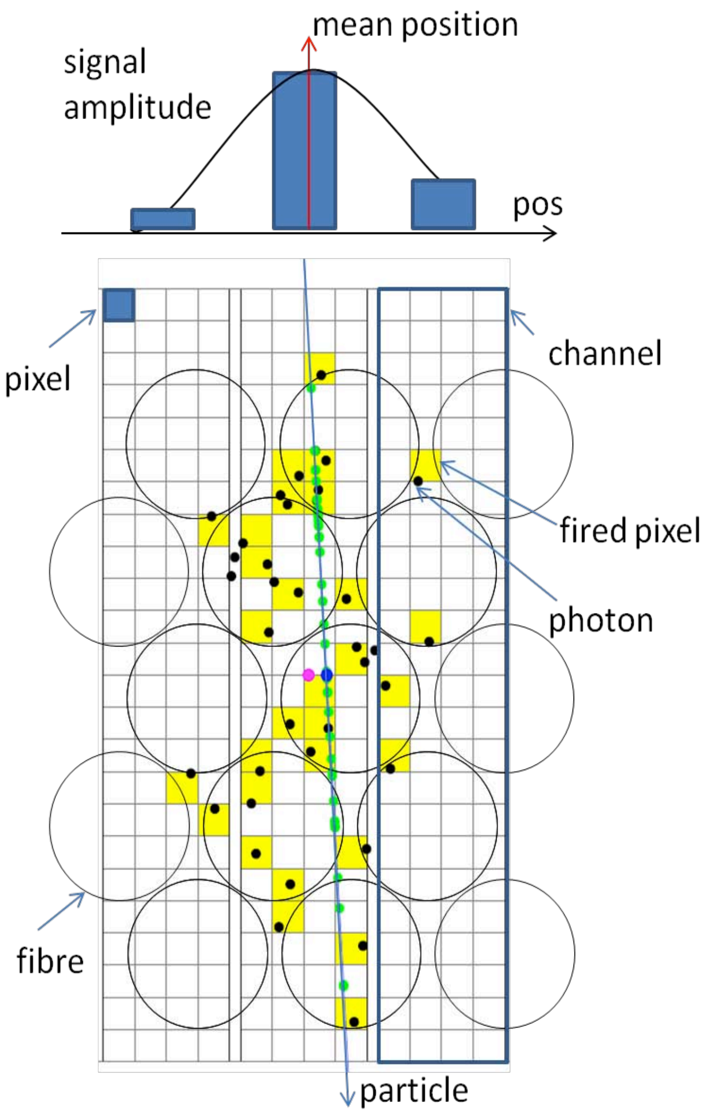


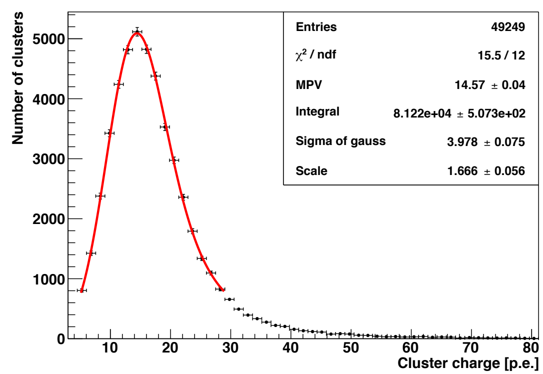


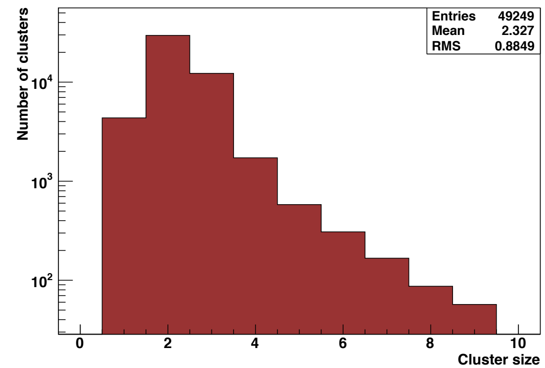
- Requirements on the detector performance:
  - **Radiation environment**, fibres up to 35 kGy, SiPMs $6\times10^{11} n_{eqv}/cm^2$ fluence (with neutron shield) + 100 Gy ionising dose
  - **Hit detection efficiency** greater than 98%, with **noise** less than 10% of signal
  - **Single hit spatial resolution** better than 100 µm
  - …

Detailed in “A SciFi Tracker for the LHCb Upgrade”, by Mark Tobin, 01 July 2014

SciFi Tracker working principle







Threshold based clustering algorithm is used to calculate the hit position
Typical signal produced by a traversing particle is larger than one channel

Scintillating fibres: 250μm diameter, 2.5m long, 6 layers near the beam-pipe and 5 every where else

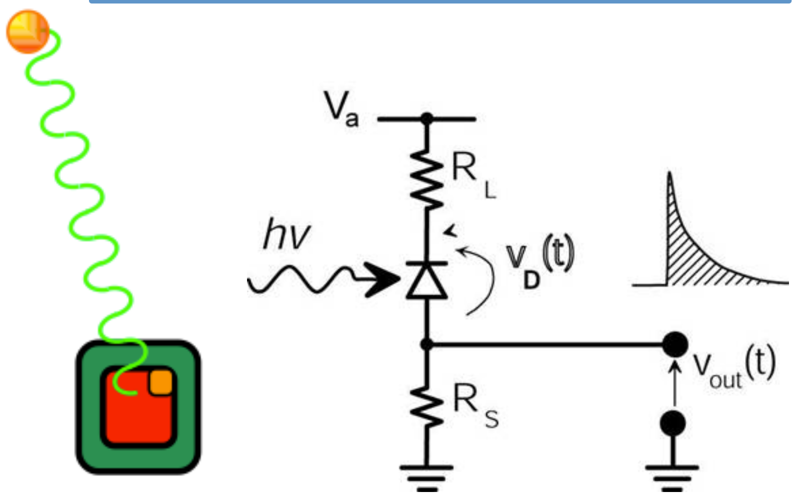
Multichannel array of SiPM 128 channels (Hamamatsu or KETEK devices under development)

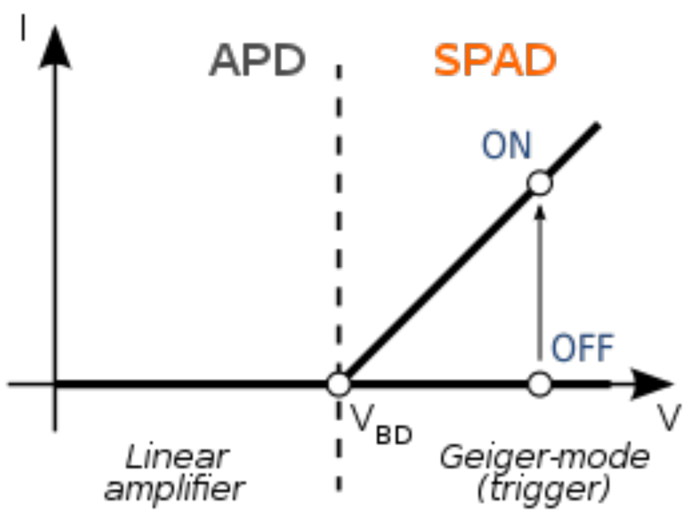
Channel: size 0.25×1.5mm^2, 96 pixels (57.5x62.5μm^2)

250μm channel width and 275μm fibre pitch

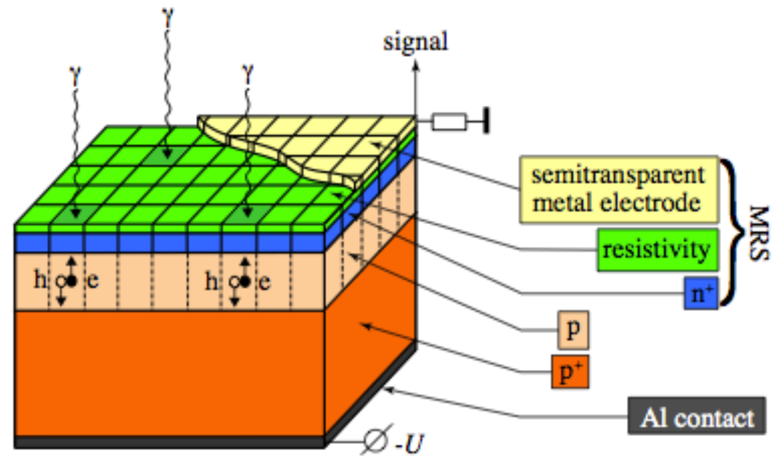
Silicon Photomultipliers

Single Photon Avalanche Diode





Silicon Photomultipliers (SiPM)



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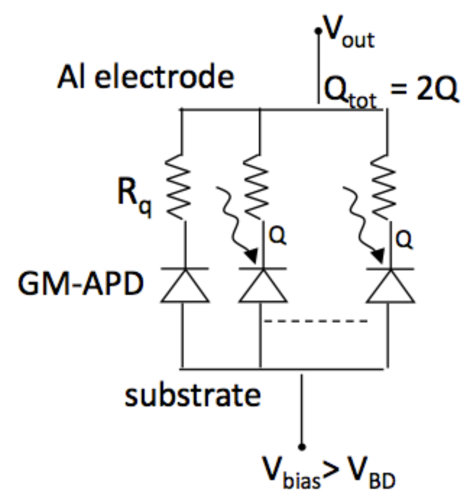
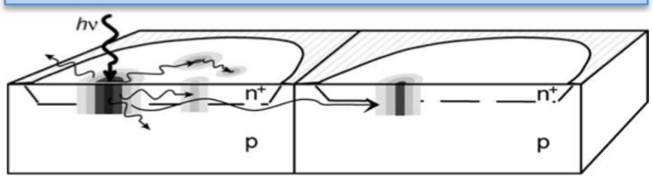
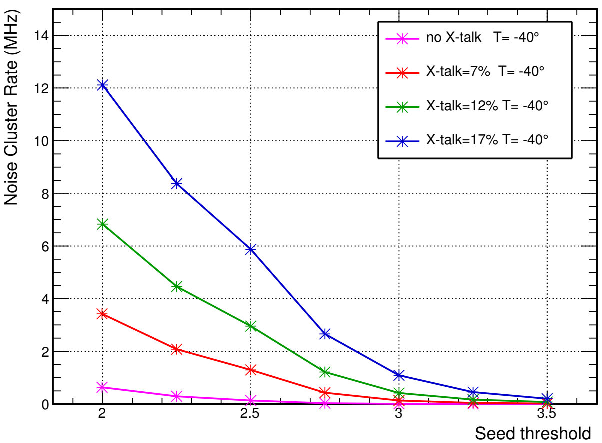


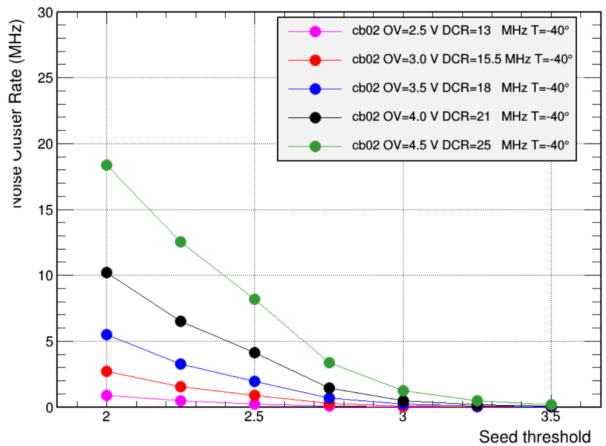
Noise cluster rate (NCR)

Cross-talk: photons absorbed in the adjacent cell and triggered an avalanche





Dark count rate: pulses triggered by thermal/ tunneling generated carriers



After-pulsing: carriers trapped during an avalanche to be released and triggered another avalanche.
Small effect due to fast shaping.

Clustering algorithm: threshold-based algorithm.
DCR of 10MHz per channel ➔ NCR of 5MHz per 128 channel

Electronics shaping: LHC bunch spacing 25 ns and signal propagation time in the fibre (~15 ns for 2.5 m direct signal)

Photon detection efficiency:

PDE= QE*PT*FF

- QE=quantum efficiency
- PT=avalanche triggering probability
- FF= fill factor

Cosmic ray test: SciFi Tracker modules

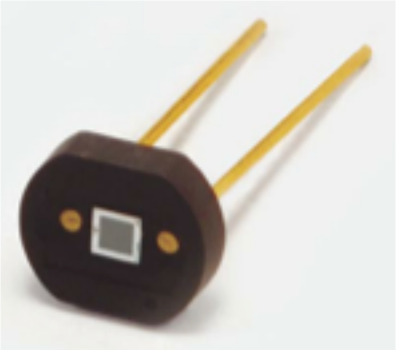
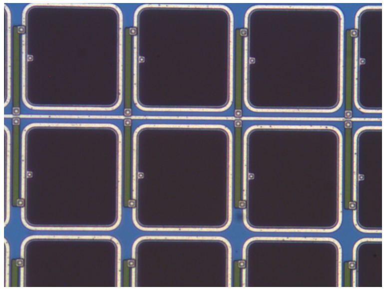
Single hit detection efficiency

Single hit spactial resolution

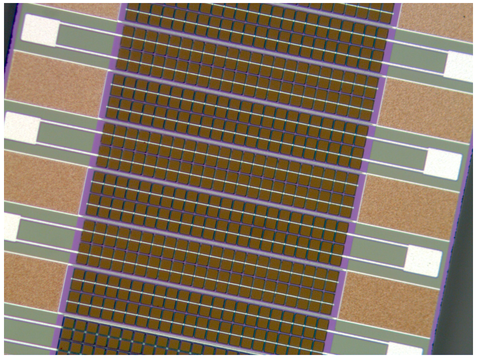
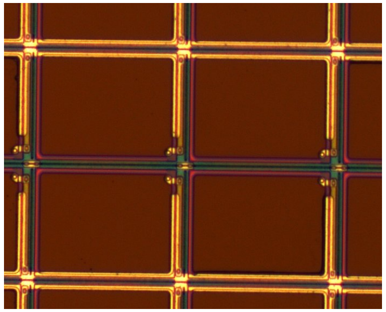
Characterization of SiPMs

Detector type	Pixel size [μm²]	T_C[mV/K]	V_{BD} [V]	Over-voltage [V]*	Gain [e/PE]
Ham. S10262-11-050C	50×50	56	69	1.3	$0.75*10^6$
Ham., with trench (2013)	50×50	43	55	3.5	$2.0*10^6$
KETEK, W1C2, with trench	60×62.5	15	23.5	3.5	$8.5*10^6$
KETEK, W1C3, with trench	82.5×62.5	15	23.5	3.5	$12.0*10^6$
KETEK, W7C3, double trench	82.5×62.5	22	32.4	3.5	$9.5*10^6$

* Possible operation point for SciFi application (note that the DCR increases with over-voltage)

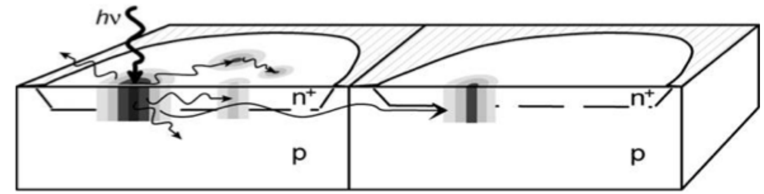



Hamamatsu 1mm² single channel devices

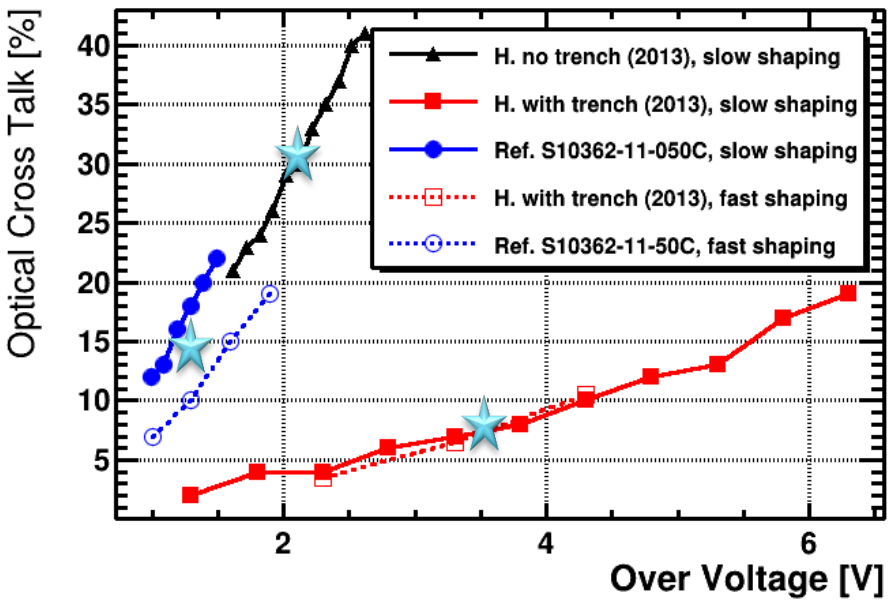



KETEK multichannel devices

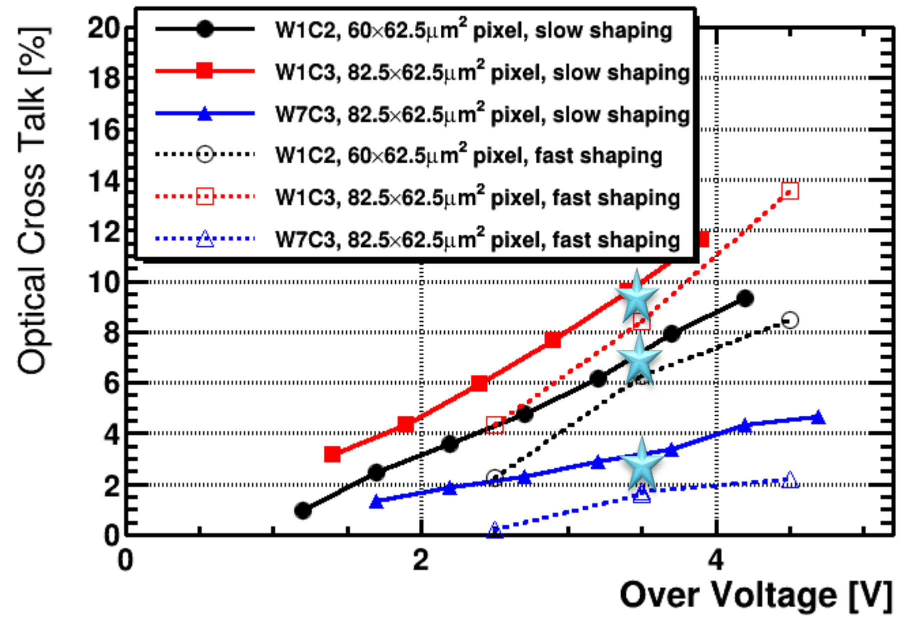
X-talk measument



Comparison of different Hamamatsu 50um pixel devices.



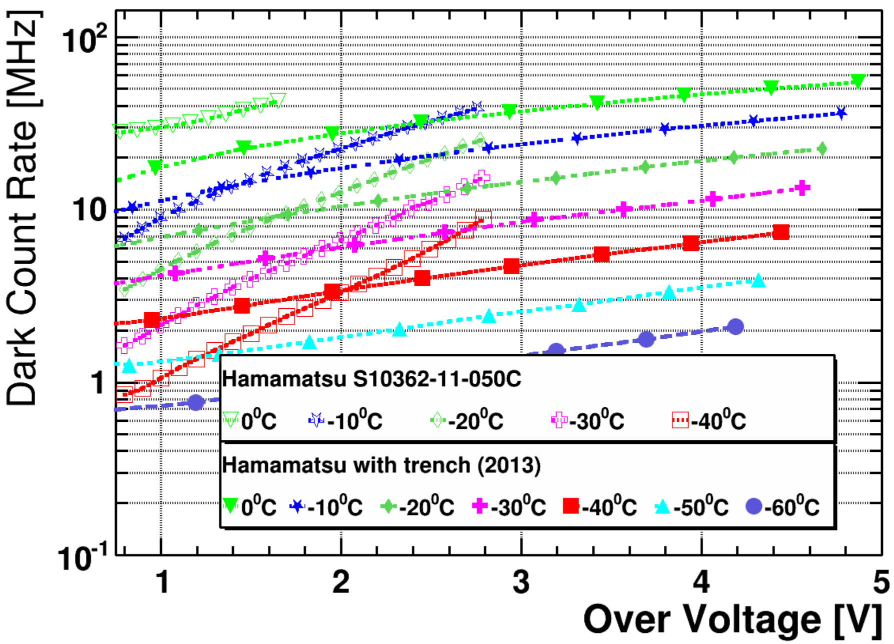
Comparison of different KETEK devices with different pixel sizes.



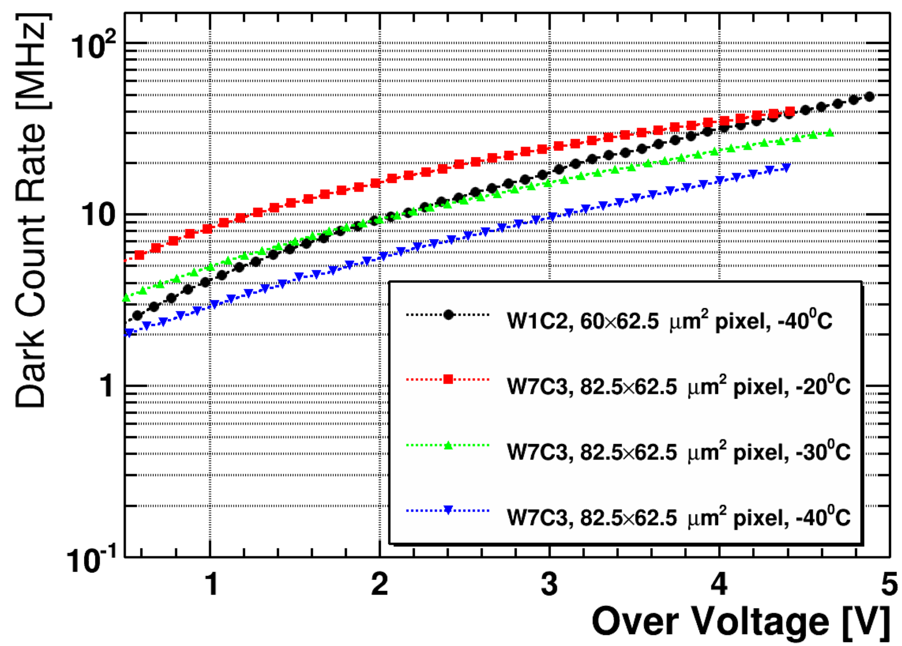
- Difference between dotted line (open markers) and full line (full markers) is due to the after-pulses.
- Detectors with (double) trenches can hugely reduce the x-talk.

Dark count rate

Hamamatsu 1mm single channel devices



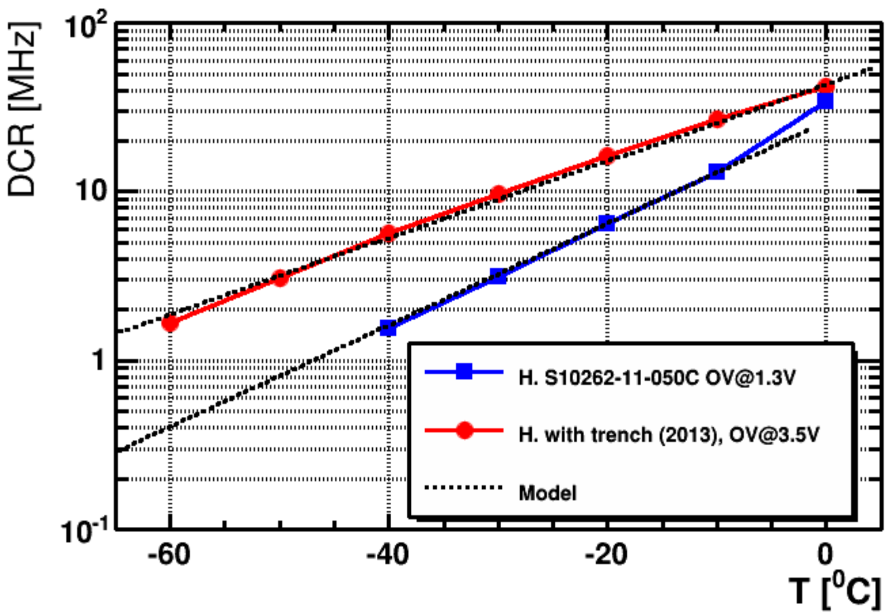
KETEK multichannel devices



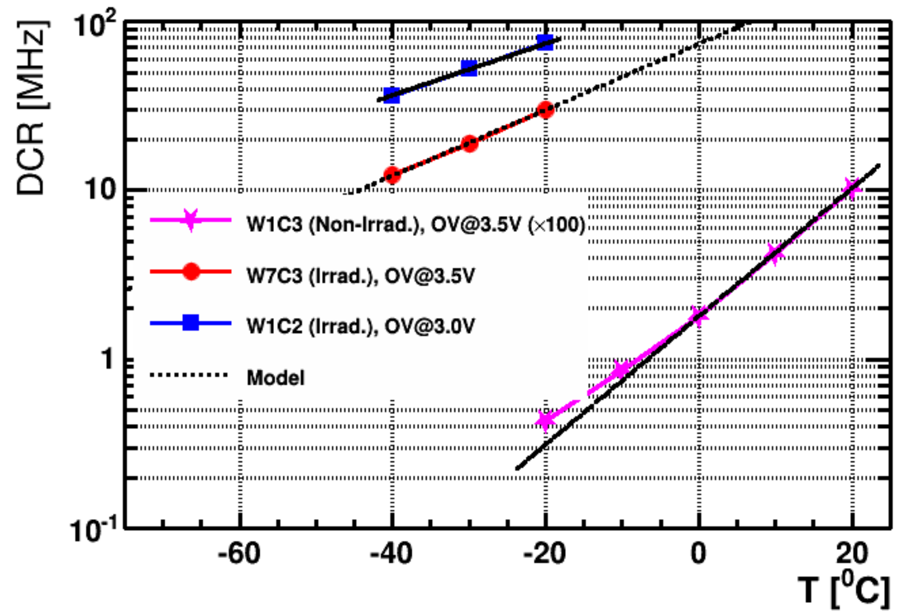
- **The detector with trenches** can work at a higher over-voltage (to increase the PDE) but this increases the DCR!
- The DCR for **the double trench KETEK** device is a factor **2-3 higher** than Hamamatsu with trench, at 3.5V over-voltage and -40°C.

DCR vs Temperature

Hamamatsu 1mm single channel devices



KETEK multichannel devices



- ❑ The DCR dependence on temperature is different with **different SiPM technologies**.
- ❑ DCR dependence on temperature also changes between, **before and after irradiation**.

Photon detection efficiency

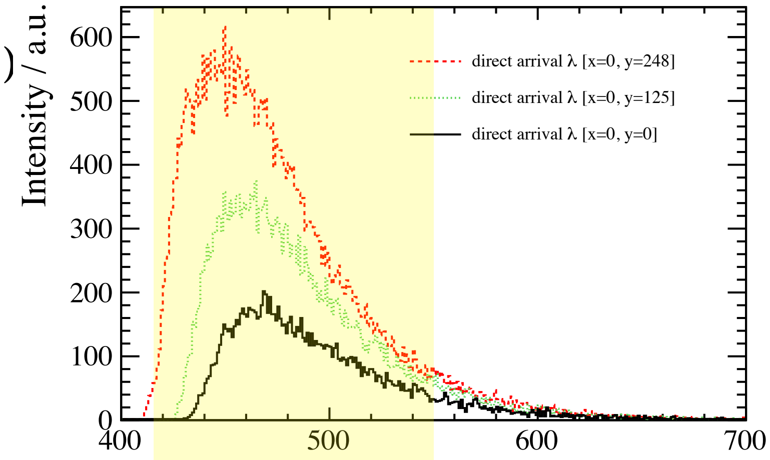
$$\mathbf{PDE_{rel,SiPM}(\lambda) \propto (I_{SiPM}(\lambda)-I_{Dark})/(1+P_{x\text{-}talk}) / G * QE_{PD}/I_{PD}(\lambda)}$$

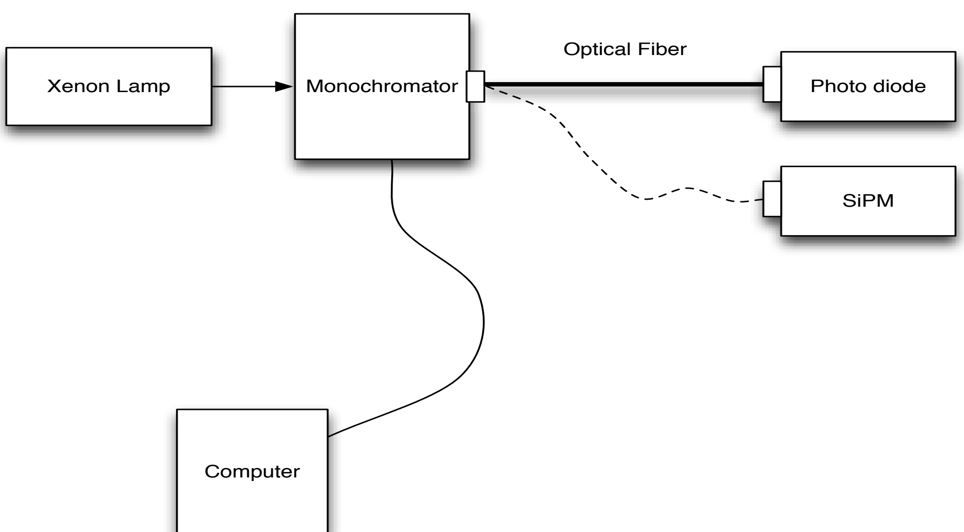
Corrections for: Dark current (I_{dark}),

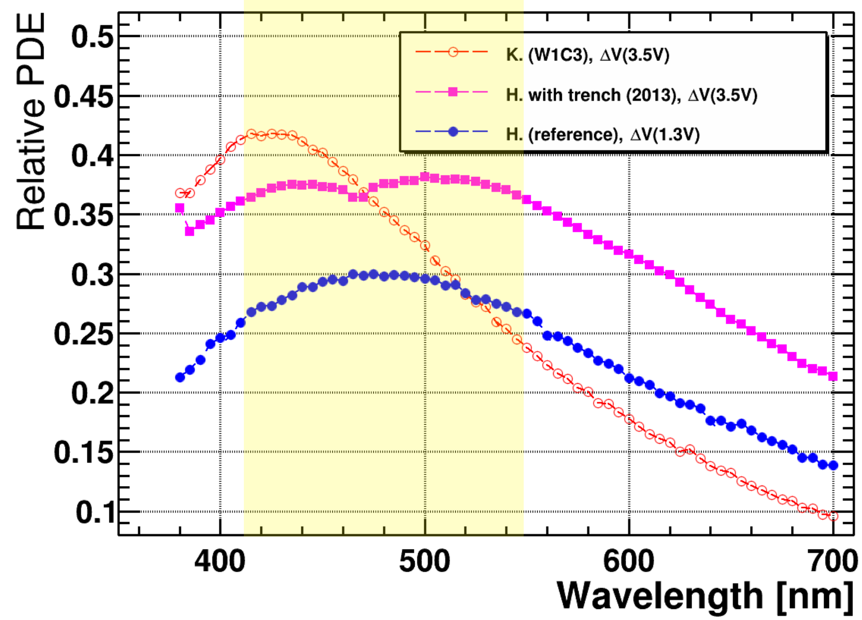
x-talk (+after pulse) ($P_{x\text{-}talk}$),

lamp emission ($I_{PD}(\lambda)$)

The 128ch SiPM array from Hamamatsu (based on the technology of the S10262-11-050C with adapted pixel size) is used as the reference and its peak PDE is set to 30% (after corrections).





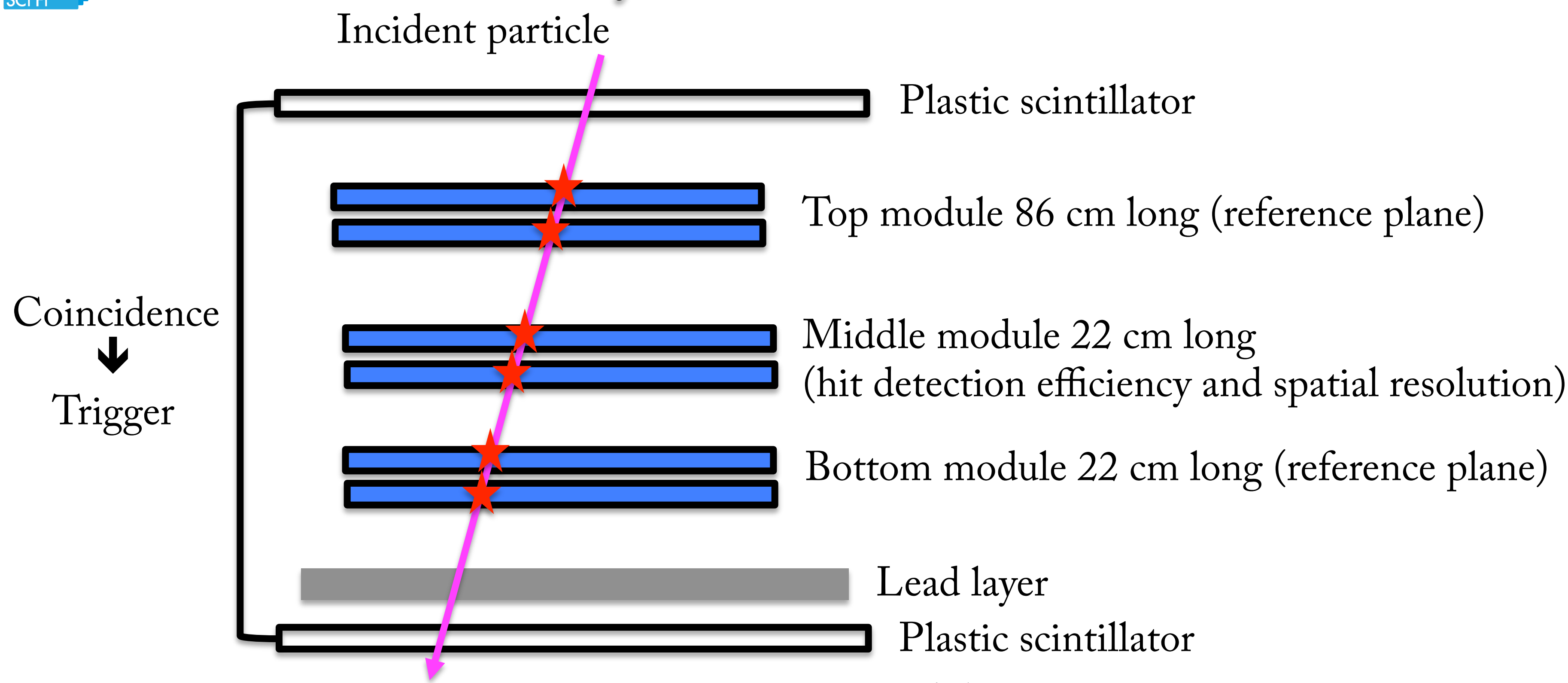


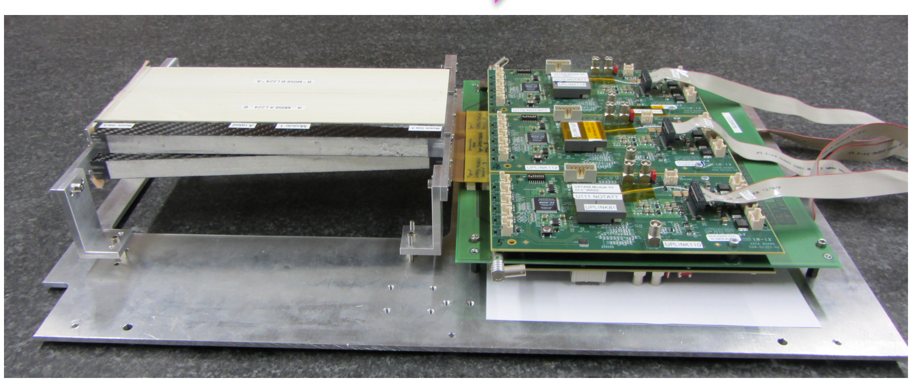
A short summary

Detector type	H. S10262-11-050C	H. with trench (2013)	K. W7C3, double trench
Surface [mm^2]	1	1	1/3
Pixel size [μm^2]	50×50	50×50	82.5×62.5
T_C [mV/K]	56	43	22
Over-voltage [V]	1.3	3.5	3.5
X-talk + After-pulsing	17%	7%	3%
V_{BD} [V]	69	55	32.4
Gain [e/PE]	0.75×10^6	2.0×10^6	9.5×10^6
PDE @peak	30%	37%	40%
Weighted PDE integral	1.26	1.61	1.47
DCR (annealed[1]), -40°C [MHz]	~1.5	~5.5	~12

[1] Annealed and also scaled to 1 mm^2 surface and $2\text{x}10^{11}$ n_{eqv}/cm^2

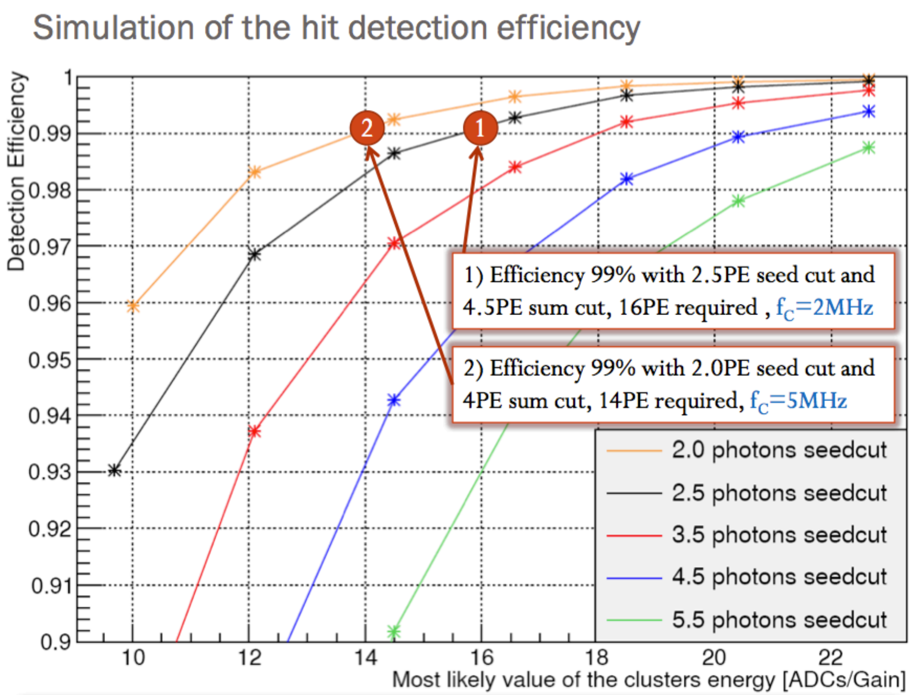
A cosmic ray test stand

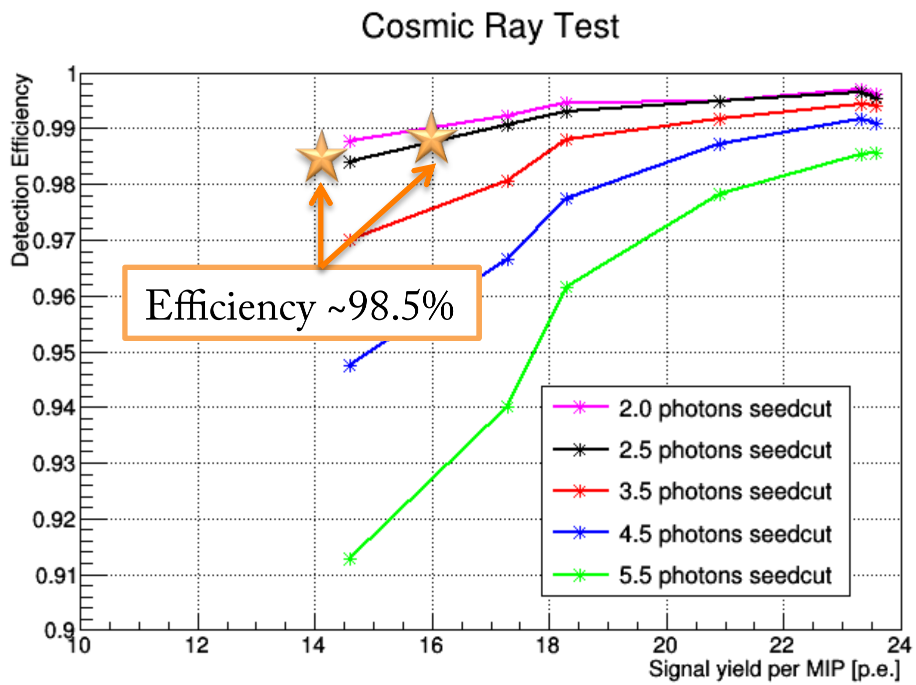




- Module construction:
  - Fibre modules: 5 layers of fibres
  - SiPMs: 128ch Hamamatsu detector and 2 SiPMs per layer
  - Readout: VATA64
- Stereo angle: ±5 (±1) for short (long) module
- Stabilized at 15 ^{0}C for SiPMs

Single hit detection efficiency

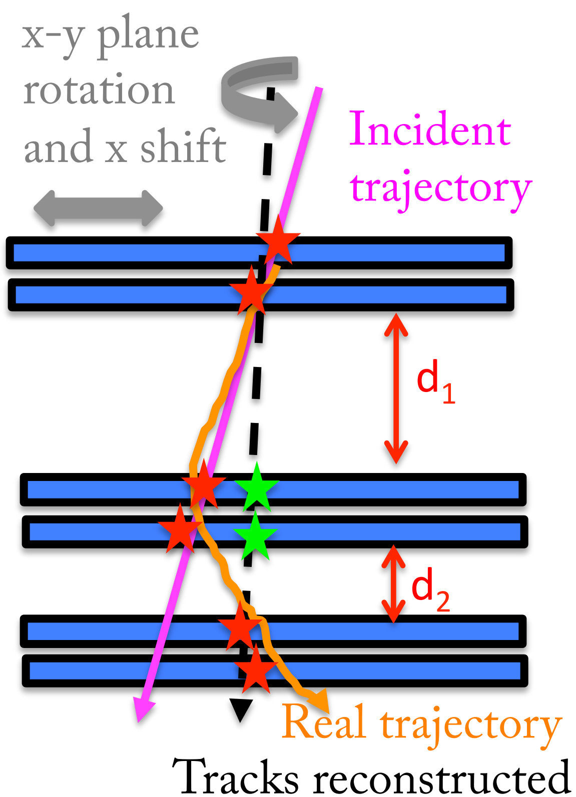




- The simulation results is confirmed by the cosmic ray test.
- The single hit detection efficiency is greater than 98% which fulfills the requirement of the SciFi Tracker requirement.

Spatial resolution

- **Multiple scattering effect** could be crucial in spatial resolution study with this cosmic ray test stand.
- Single hit resolution given by simulation: σ_{single}**~56μm**
- The expected measurement on the spatial resolution: $\sigma \sim \sqrt{(2\,\sigma^2_{single} + \sigma^2_{scattering})}$



- By minimizing the distance d_2, the multiple scattering effect can be largely reduced.
- Simulation predict O(100 μm) and the measurement 104 μm
- Single hit spatial resolution upper limit (without considering multiple scattering effect) **75μm**

The preliminary results from the cosmic ray test stand demonstrated **the sufficient hit detection efficiency** and **spatial resolution** of the SciFi Tracker design.

Conclusion

Radiation environment

- The high neutron flux in the LHCb Upgrade will lead to a dramatic increase of the DCR.
- Lowering the temperature to -40 ^{0}C and low x-talk devices can reduce the noise cluster rate to an acceptable level.

Hit detection efficiency

- The hit detection effiecency was simulated and measured with a cosmic ray test stand. To obtain a values above 98%, a signal of 15 photons is required. (this value is 14 photons for 6 layer modules)
- Devices with high PDE is very important.

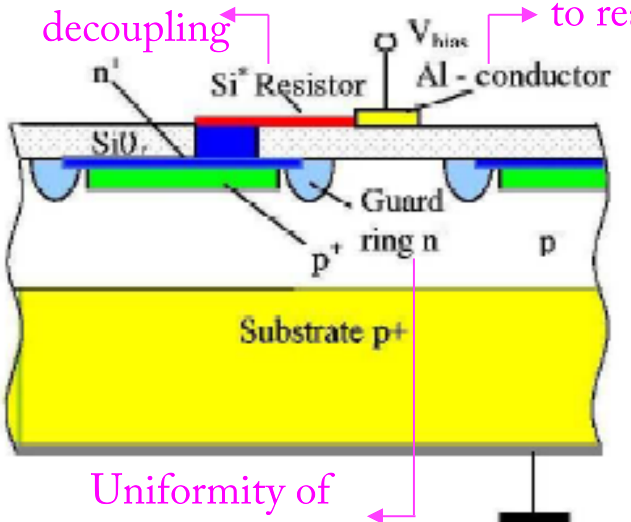
Hit spatial resolution

- The hit spatial resolution is not a critical requirement as long as the signal is above 12 photons.

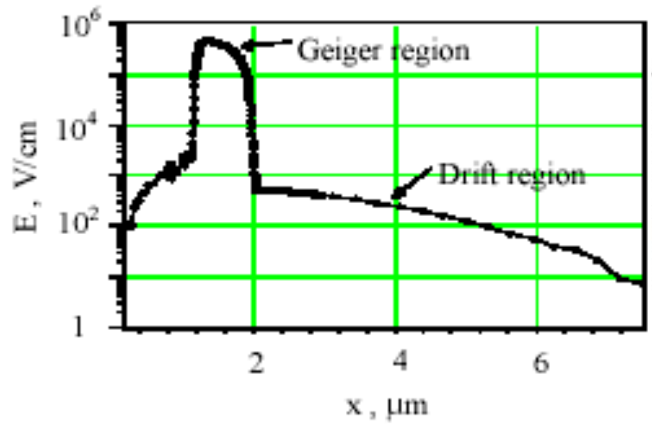
Silicon Photomultipliers

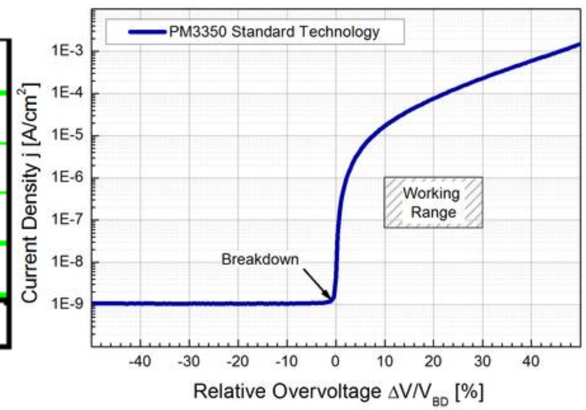
Electrical decoupling

to readout the signal

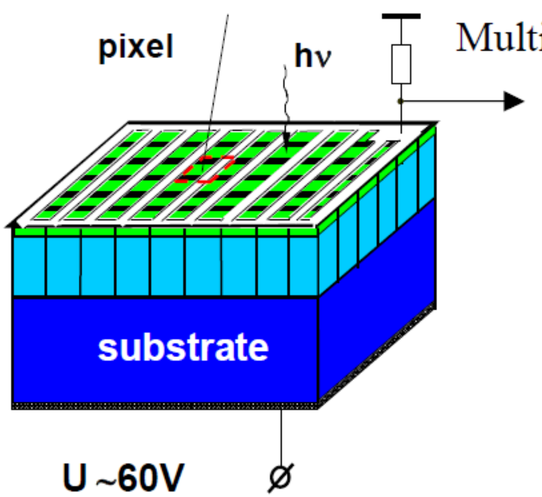


Uniformity of the electric field

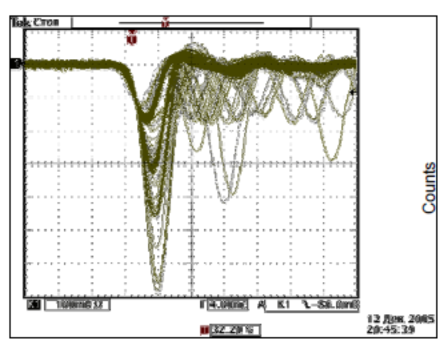




Multipixel device with common readout



Scope signal



Amplitude spectrum