Study of detection efficiency distribution and areal homogeneity of SiPMs

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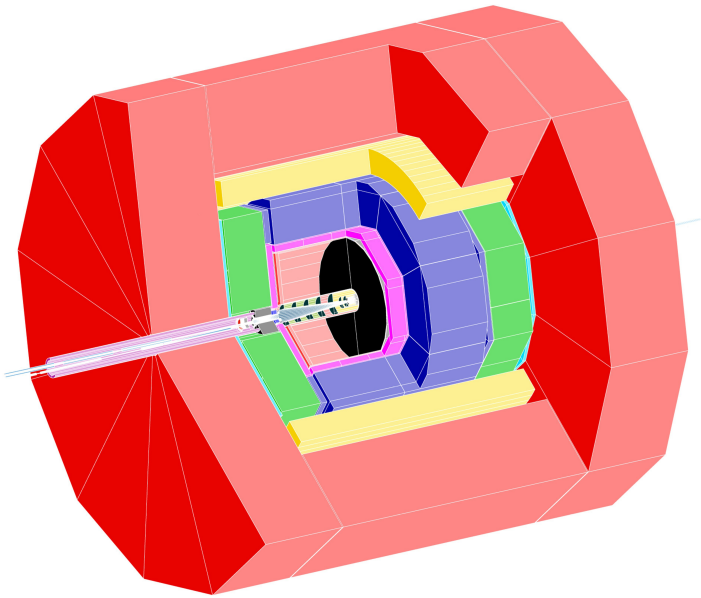
Outline

Future linear e^+e^- collider experiments

- two future machines are in development
  - ILC, up to $\sqrt{s} = 1$ TeV, (31 km length)
  - CLIC, up to $\sqrt{s} = 3$ TeV, (48 km length)
- physics program:
  - precision studies within standard model
  - search and study of physics beyond standard model

- these tasks require high jet energy resolution
- "particle flow" concept will be used to reconstruct the jets
- to meet these demands, highly granular ECAL and HCAL is needed

$\Rightarrow$ classical PMTs must be replaced by SiPMs



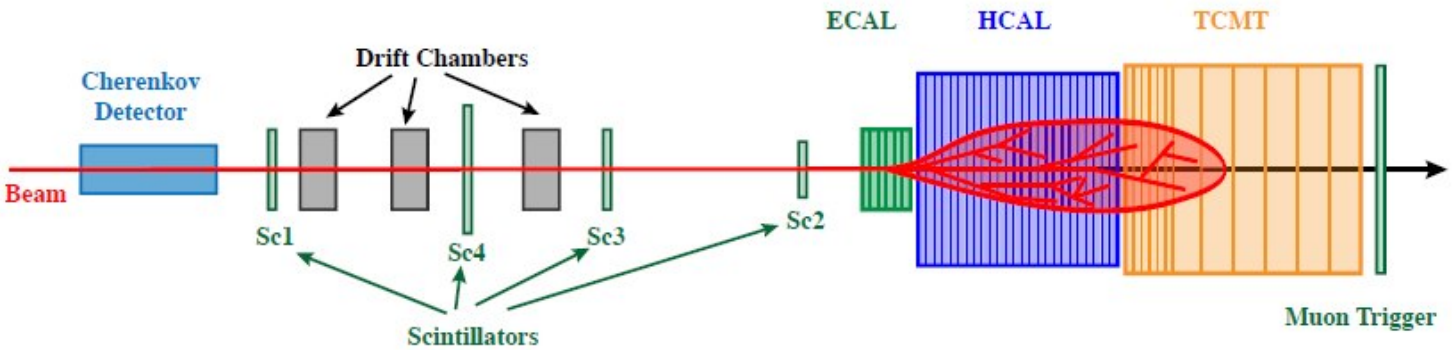
The International Large Detector (ILD)

The CALICE prototype

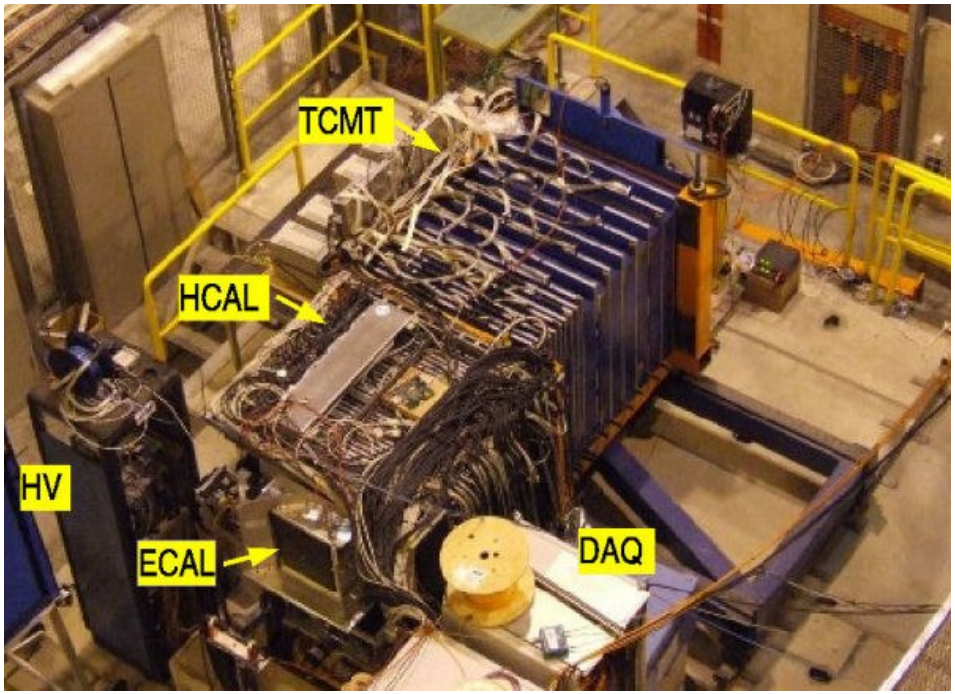
- the CALICE test detector was built to study performance of the new calorimeter concept

Focus: HCAL

- 38 active layers interleaved with 2 cm stainless steel (tungsten) plates
- each active layer is assembled of combination 3×3, 6×6 and 12×12 cm^2 0.5 cm thick scintillator tiles coupled with a SiPM
- total 7608 channels

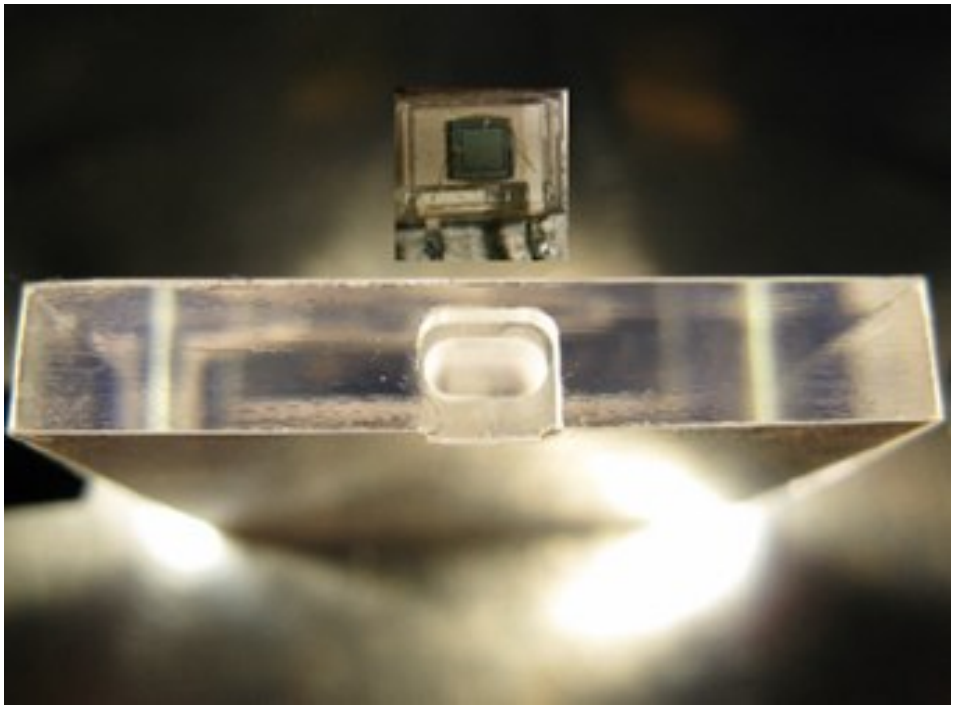


The CALICE prototype



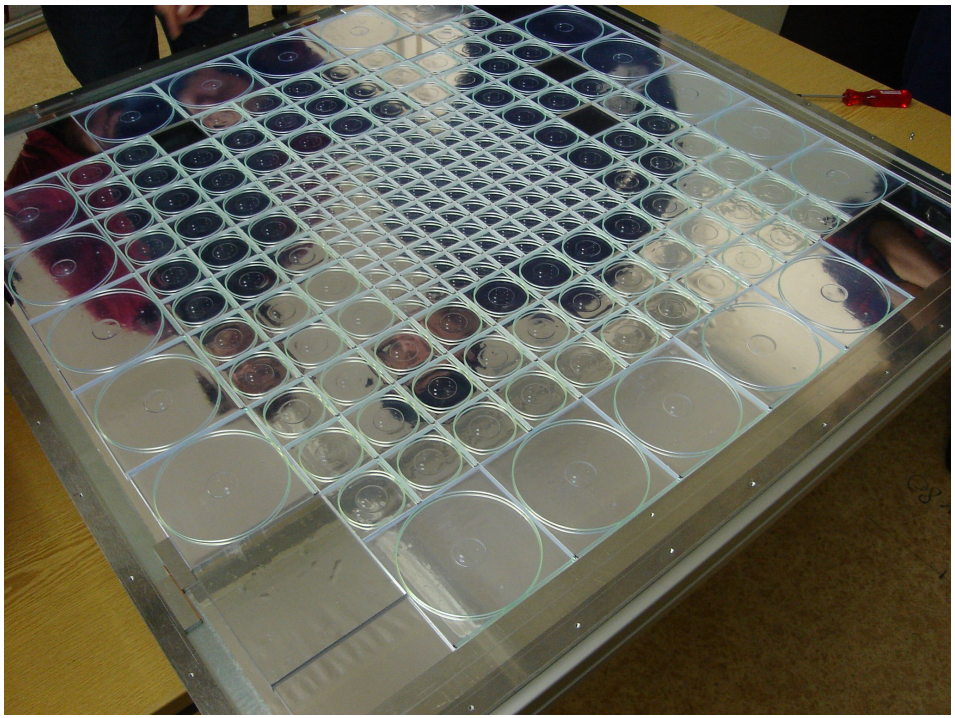
1 m^3 HCAL prototype

new scintillator concept



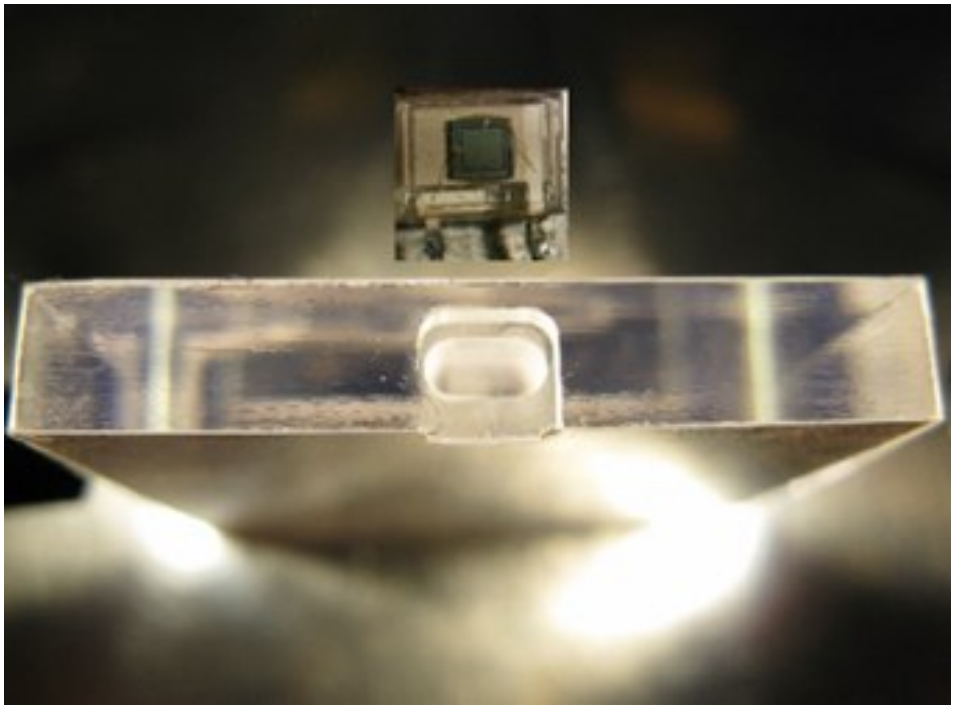
SiPM and scintillator size comparison

The CALICE prototype



one scintillator layer of the CALICE

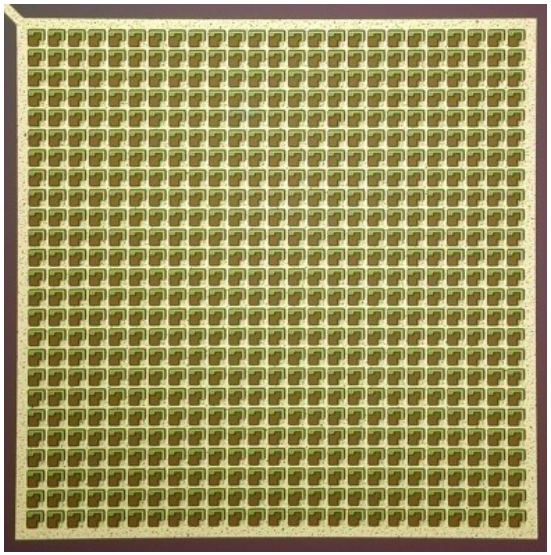
new scintillator concept

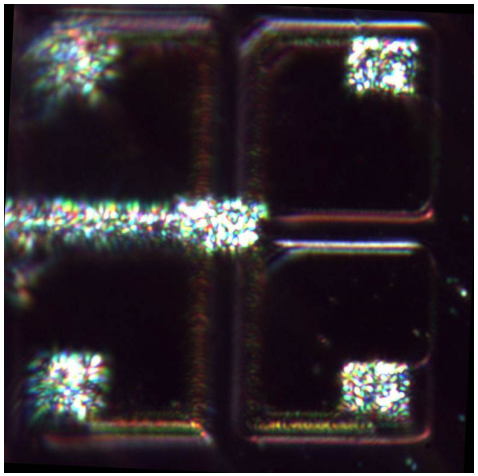


SiPM and scintillator size comparison

Silicon Photomultipliers (SiPM, MPPC, GAPD, ...)

- silicon photon detectors made of an array of avalanche photodiodes (APD)
- APDs are operated in Geiger mode (slightly above breakdown voltage)
- incident photon induces an avalanche
- the avalanche is quenched by a decrease of bias voltage over a quenching resistor
- all cells are connected in parallel
- different implementations of the quenching resistor are being used





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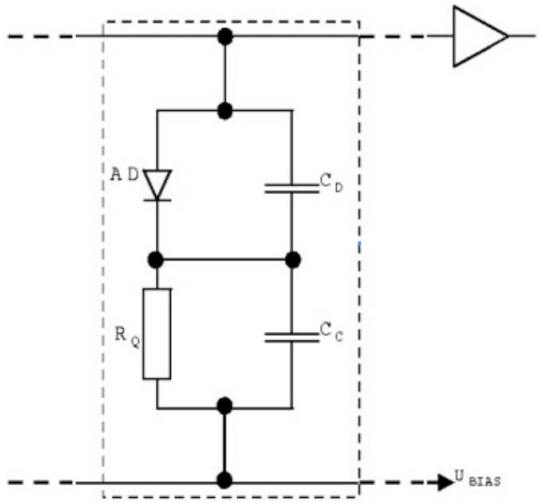
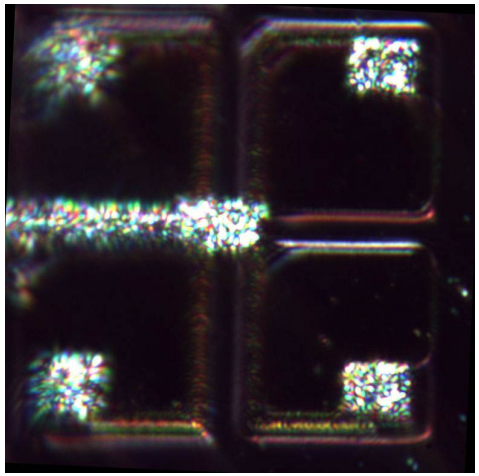




Silicon PM properties overview

Advantages

- small dimensions (usually $\sim 1{\times}1$ mm^2)
- insensitivity to magnetic field
- low supply voltage (tens of volts)
- single photon counting capability
- high gain

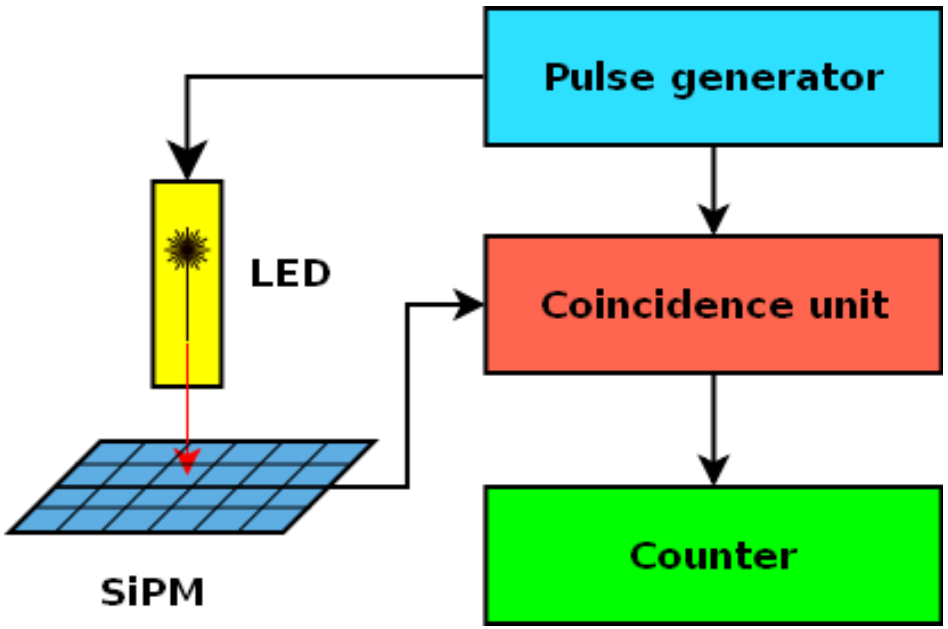
Drawbacks

- low radiation tolerance
- high thermal noise rate (dark count)
- optical crosstalk
- afterpulsing

Basic idea of the measurement

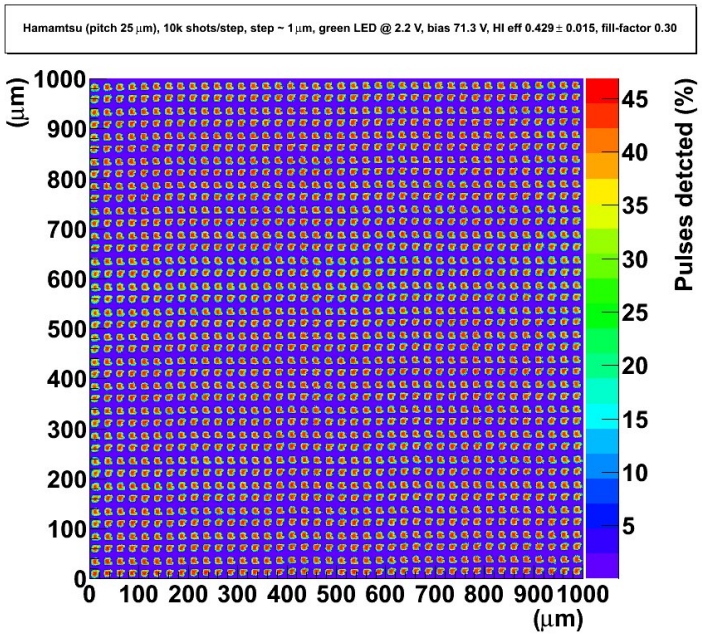
Ultimate goal of our study

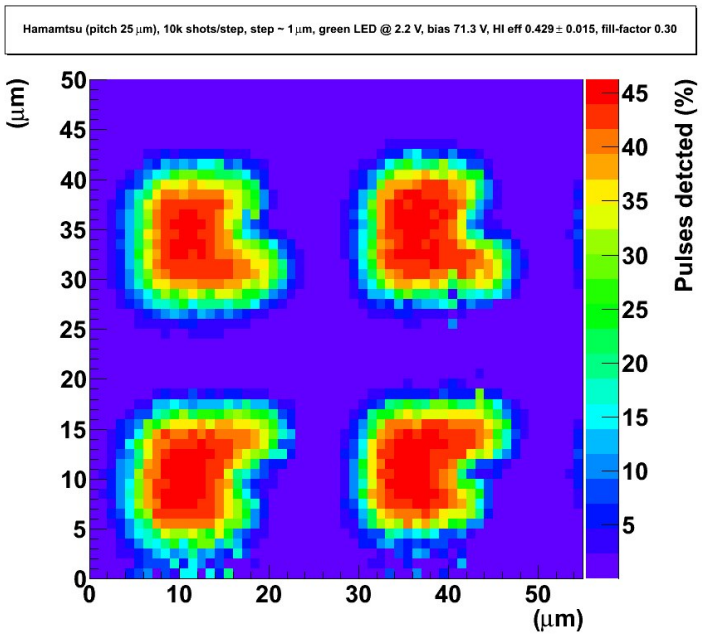
Discovering of sensitivity distribution of a SiPM over its area and calculating further characteristics out of this data



- light from an LED is focused to a small point
- the LED is pulsed
- SiPM response is measured in coincidence with LED pulses
- the light beam is driven through pixel matrix in discrete steps
- a sensitivity scan of a 1×1 mm^2 device with 1 μm step size can be completed in $\sim$ 40 hours

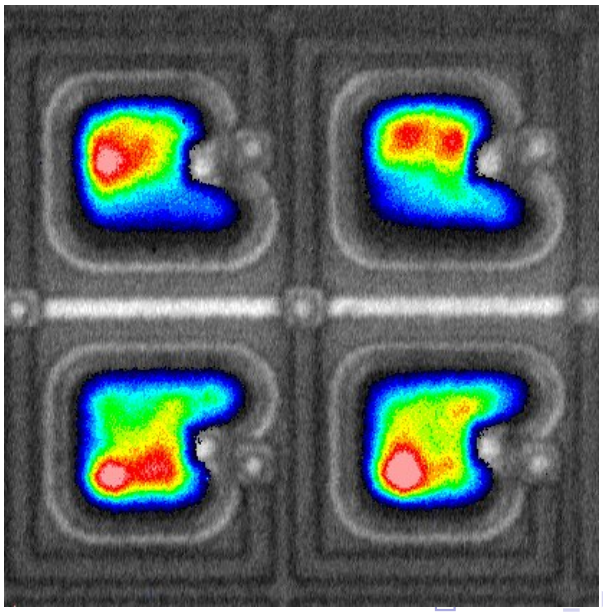
Results: Hamamatsu (MPPC) (25 μm pitch)



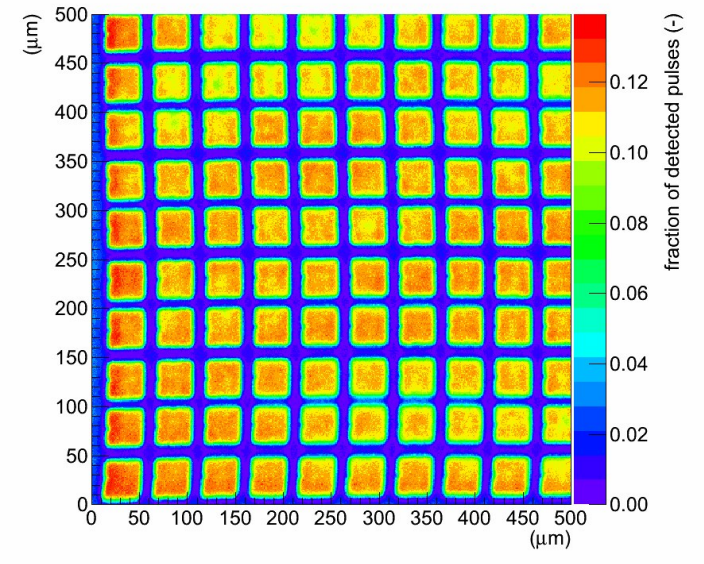


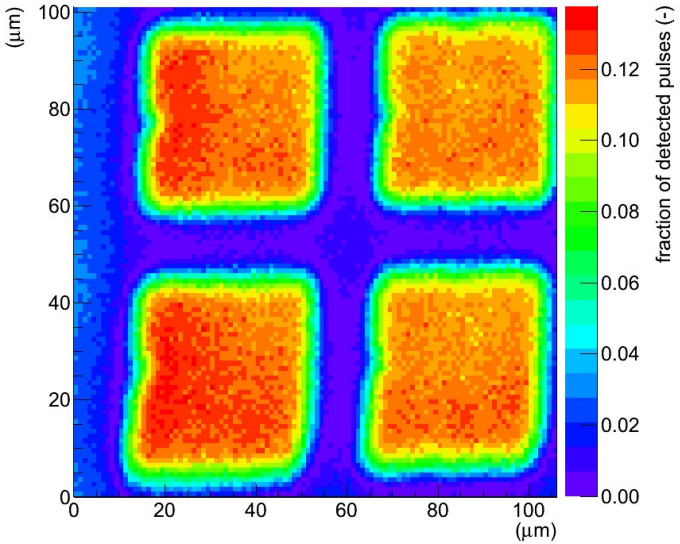
sensitive area is obviously significantly reduced by the quenching resistor placed on surface of the device

Photo + photoemission image



Results: Hamamatsu (MPPC) (50 μm pitch)





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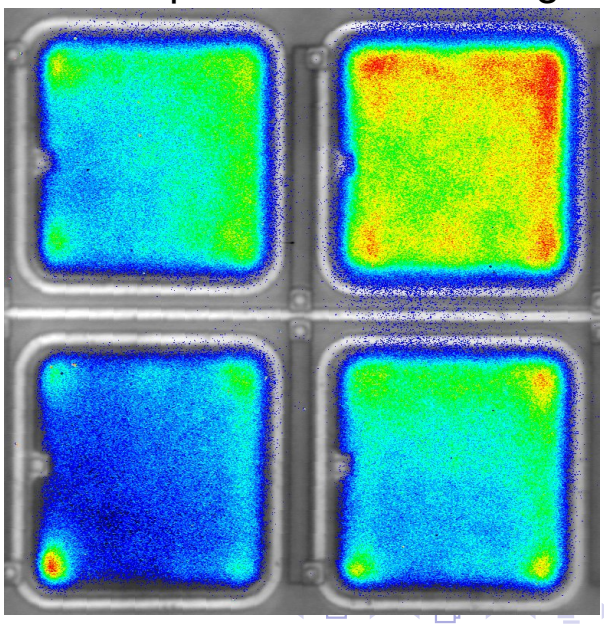
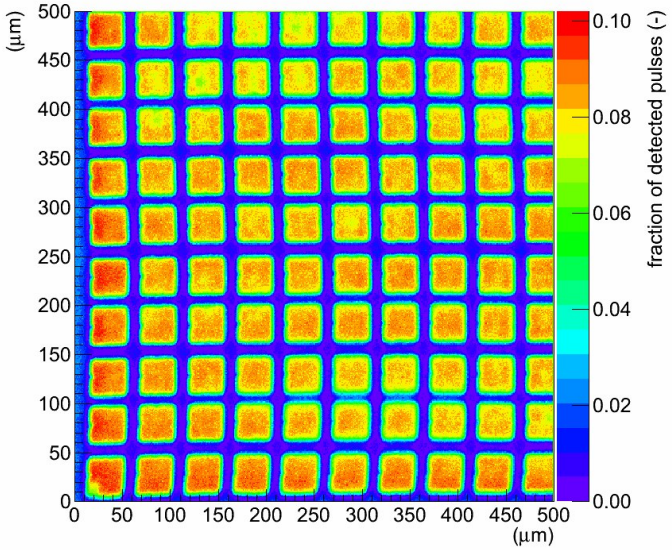
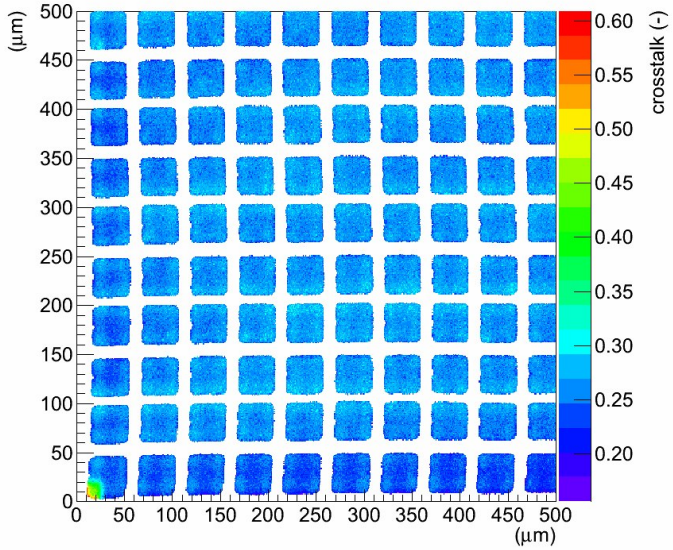


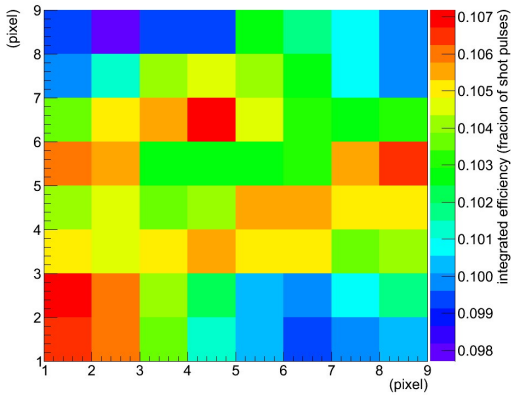
Results: Hamamatsu MPPC (50 μm pixel pitch)



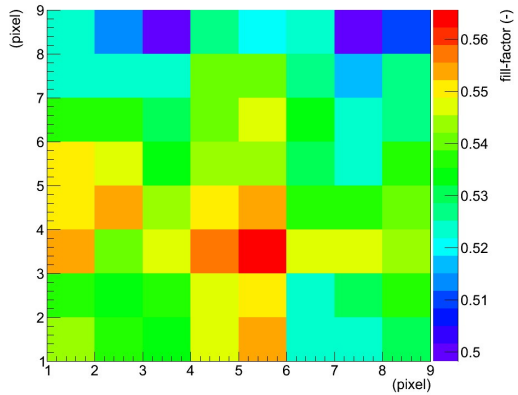
pure 1 p.e. map



crosstalk probability map



integrated efficiency map



fill-factor map

Hamamatsu MPPC 50 μm pitch (CALICE type)

study results

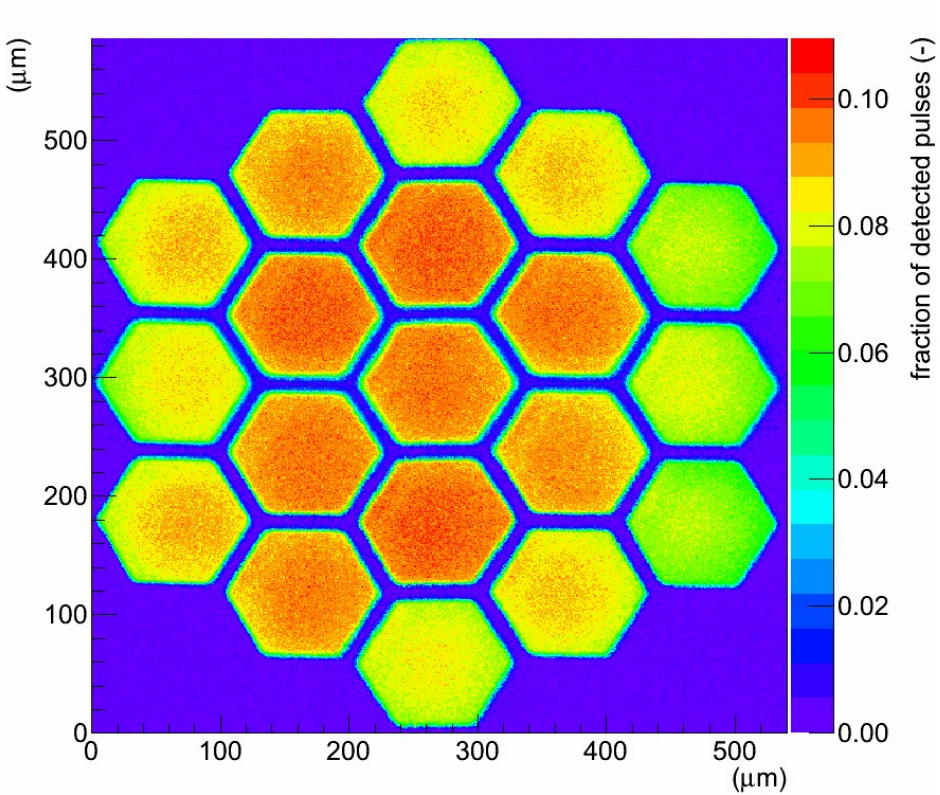
- detection efficiency patterns change with over-bias voltage negligibly
- geometrical fill-factor does not change with over-bias voltage
- edge breakdown observed, disappears with increasing over-bias voltage
- much better performance in comparison with SensL SPMs and MPPC 25 μm pitch

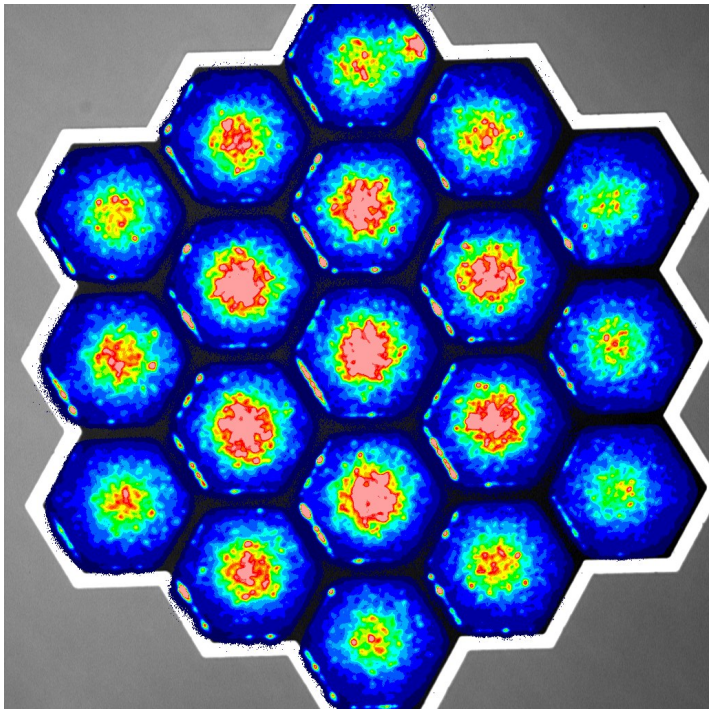
quantity	value
PDE spread	8 %
fill-factor spread	11 %
crosstalk probability	18 %
geometrical fill-factor	55 %

Table: Hamamatsu 50 μm pitch (CALICE type) measured characteristics

Results: SiMPl (130 μm pitch)

no surface structures inside of a pixel $\Rightarrow$ higher possible geometrical fill-factor





Measurements done at room temperature. Due to high dark count of 2^{nd} iteration series, it would be better to cool the devices down.

Summary

Summary:

- detector systems for future linear e^+e^- colliders are in development
- future calorimeters will use scintillators coupled with SiPMs
- the SiPMs must be evaluated, understood and improved
- the sensitivity scan is a good tool for that

Achievements:

- setup for uniformity characterization of SiPMs has been developed
- measurement provides relative sensitivity and crosstalk probability map
- fill factor and other homogeneity measures can be determined
- successful tests of different devices have been done