SiPMs with plastic scintillators

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Introduction

• SiPMs were invented in the late 90s by Golovin and Sadygov, as single photon detectors
• In the last 10 years the performance in terms of efficiency and noise improved significantly
• Many experiment in different areas now use or plan to use SiPMs

• Aim of this laboratory is the sharing of our experience on a specific application: *photodetection of light produced in plastic scintillator by minimum ionizing particles*
SiPM architecture

• A silicon photodiode with high gain

• p-n junction engineered to provide high field
  o Photon produces e-h pair
  o Avalanche multiplication
  o Cell (pixel) discharges
  o Avalanche is stopped by passive quenching

• Matrix of Geiger-mode pixels
  o Each pixels fires when hit by one photon (or by noise)
  o Signals from all pixels are summed

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SiPM characteristics

- High Quantum Efficiency
- Insensitive to magnetic field
- Small, cheap, robust

But

- Sensitive to temperature
- Suffers from radiation damage
- High Dark Count Rate
Performance improvements

Photon Detection Efficiency

Dark Count Rate

Crosstalk

Afterpulse
Recent SiPM trends

• Smaller microcells
  - More dynamic range
  - Better timing
  - Lower fill factor but improving

• Improved UV/IR sensitivity
  - For LXe/LAr scintillation light
  - For IR laser detection (LIDAR)

• Digital circuit integration
  - CMOS gates for active quenching, amplifiers, …

• Noise reduction
  - Trenches, guard rings around cells
Goals - 1

• For those of you who did not have the chance to work with SiPMs yet, we will show some examples
  o Samples of different area, pixel size, packages..
  o Measurement of the IV curve and choose working point
  o Looking at signals on the scope, with high band preamplifier
  o Shape of signal by illuminating with laser and LED
  o Integrated charge spectrum for calibration with charge amplifier
Goals - 2

• Coupling SiPM to plastic scintillator
  o light collection with WLS fiber or direct coupling?

• Different types of scintillator wrapping/coating:
  o Aluminized mylar, tyvek, teflon, white painting, black painting
  o What’s best for mip detection, calorimetry, timing?
  o optical coupling of SiPM to scintillator or WLS…very critical!
Goals - 3

• Optimize plastic scintillator tile for timing (SHiP r&d)
  o target resolution < 600 ps
  o maximum size of tile
  o SiPM direct coupling
  o optimal SiPM size and number of SiPMs/tile
  o FE electronics (amplifier + digitizer SAMPIC)

• Optimize plastic scintillator tile for calorimetry (ENUBET r&d)
  o WLS light collection
  o high efficiency
  o best achievable timing
Setup 1

- Measure breakdown voltage with I-V curve
- Illuminate with Laser or LED: look at signal on scope
Setup 2

- Integrated charge spectrum

Scintillator+WLS+SiPM

VERSABOARD
custom multipurpose board

PC

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Setup 3

• Test time resolution on different tiles:
  o two sizes
  o different coatings or dressing
  o Readout and trigger by SAMPIC digitizer

• Time reference provided by Cherenkov detector
  o quartz crystal readout by two 6x6 mm2 SiPM
Setup 4

- Test time resolution and efficiency of a tile with 2 WLS shifter fibers readout by SiPM

Diagram:
- PMT 1
- PMT 2
- SiPM
- amplifier
- CRATE VME:
  - discriminator
  - trigger pm1 && pm2
  - digitizer
  - controller
- PC

-800 V
Setup 4

- Acquire cosmic ray muons triggering with two PMT
- Analog signals (Slow and Fast) from SiPM acquired by means of a waveform digitizer controlled via VME
- Data file processed offline to reconstruct the pulse amplitude of the analog signal

- Analysis to test time resolution and efficiency of a tile with 2 WLS shifter fibers readout by SiPM
Setup 4

- Timing measurement

Timing PMT - Fast

\[ \chi^2 / \text{ndf} = 811.9 / 68 \]

- \[ \sigma_{\text{PMT}} \sim 240 \text{ ps} \]
- \[ \sigma_{\text{SIPM}} \sim 440 \text{ ps} \]

- Constant: 9996 ± 48.3
- Mean: 8.474e−009 ± 1.952e−012
- Sigma: 5.079e−010 ± 1.541e−012
SiPM readout electronics

• For typical scintillator light pulses, SiPMs require further signal amplification before digitization.
  
  o $O(100)$ photons, $O(10^6)$ Gain => ~few pC signals

• Different circuit architectures are in use, both discrete and in ASIC form
  
  o Voltage Amplifiers
  o Transimpedance Amplifiers
  o Current mirrors

  o ASICs are superior for dense detectors, but large experiments with sparse channels can benefit from discrete amplifiers mounted close to SiPMs
Common SiPM amplifier types

- **V/V**
  - Simplest type
  - Timing limited by SiPM capacitance

- **Charge sensitive**
  - Faster
  - Provides charge integration

- **Current buffer**
  - Highest speed
  - Best dynamic range
Our implementation

- Common base transistors offers low input impedance
  - Limits the effect of large SiPM capacitance
  - But... Chance of ringing

- Low overall gain
  - Second stage with OpAmp THS4303, G=10
  - Power consumption significant but not problematic, thanks to “low density” of frontend channels

- Very fast
The SAMPIC digitizer

- ASIC develop by LAL – Orsay:
  - 16 channels (each equipped with programmable threshold
  - 64 analog switched capacitor sampling cells per channel
  - 11 bit Wilkinson ADC per cell
  - time window at 3.2 GS/s = 20 ns

- Capable of <10 ps resolution thanks to waveform interpolation
Simulation

• Light emission and propagation + SiPM response is simulated by Fluka

• Comparison with real tiles/SiPM, allows to tune MC free parameters

• After tuning with data, MC can be use to simulate different tile configurations/geometries

• Code almost ready for the comparison with real data