Advancing front-end readout ASICs with BiCMOS SiGe technology for ultra-fast sensors

PhD Thesis Proposal

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November 25, 2021

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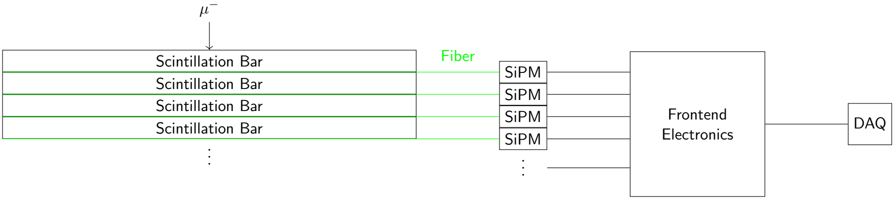
Muon Detection

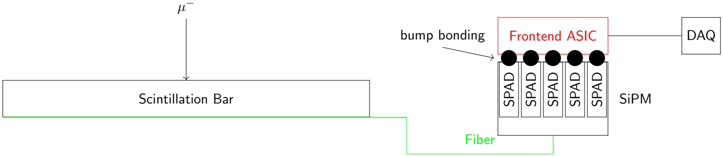
- Aim: Improve muon detection in AMIGA [1] and ANDES [2] experiments



Schematic of Current AMIGA Muon Detection Setup [3], [4]

- One SiPM per scintillation bar
  - connected to one readout channel in frontend
- Time resolution only by counting incoming photons in a certain time interval

Proposed Muon Detection Setup



Proposed Detector for one Scintillation Bar in ANDES

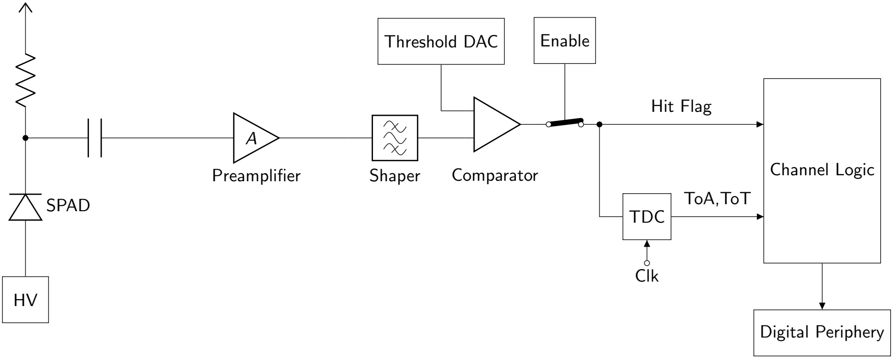
- High-granularity SiPM[1] of FBK[5] using 2D integration technology
  - reduced optical cross-talk due to trench isolation
  - pile-up mitigation
- SiPM bump-bonded to frontend ASIC
- Readout with high time resolution and high granularity
  - detection of angle of incoming photon and fiber delay
  - → improved muon hit position resolution

[1] joint development between KIT-IPE and FBK

Activities

- Design frontend readout ASIC for advanced SiPM technology
  - with high-granularity
  - each SPAD cell is readout individually
  - photon counting with very high time resolution
- Characterization of designed ASIC
  - testing general functionality
  - timing characterization
  - testing under bad environmental conditions
- High-density integration by bump bonding of SiPM to ASIC
  - using gold-stud bumping at KIT-IPE [6]
- Testing of hardware with muon counter at ITeDA

SPAD Readout



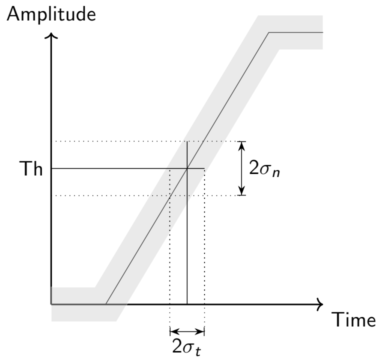
Proposed Readout Chain for one Pixel/SPAD

Time Resolution

Time jitter [1]

$$\sigma_t = \frac{\sigma_n}{\frac{dV}{dt}|_{V_T}} \approx \frac{t_r}{S/N}$$

- High time resolution requires
  - Fast rise time
  - High signal to noise ratio

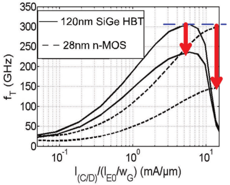


Threshold Crossing [7]

[1] $\sigma_n = \frac{S}{N}$, S: Signal amplitude, N: RMS-noise voltage

The solution: Heterojunction Bipolar Transistors (HBT)

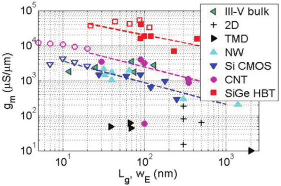
- High time resolution requires
  - Fast Amplifiers = high f_T



Transit frequency f_T
HBT vs. MOSFET [8]

  - low noise

- Pixelated design requires
  - low area consumption



g_m vs. area of different technologies [8]

  - low power consumption

→ HBT offers better performance in analog circuits than CMOS

SiGe BiCMOS

- SiGe HBT performance very good for analog design
- CMOS has advantages for
  - low-power digital design
  - bias circuits, because PMOS available

→ SiGe BiCMOS

- Our process: IHP SG13G2 130 nm SiGe BiCMOS with $f_T = 300\,\mathrm{GHz}$ [9]
  - IHP is a research institute working closely together with KIT
  - IHP offers the HBTs with highest f_T
  - PDK for Cadence Virtuoso design environment
  - already used for pixel sensors with high time resolution[10]

Summary

- New generation of SiPM for muon counters in AMIGA and ANDES experiments
- SiGe BiCMOS technology allows SiPM readout with
  - high granularity
  - high time resolution

→ ASIC development for measurements with high spatial and time resolution

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