Scintillators with SiPM Readout for Timing Measurements over long Time Windows

7th Belle II VXD Workshop

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Calorimeter for ILC

Excellence Cluster Universe

Outline

- The T3B detector
  - Active Elements
  - Data Acquisition
  - Analysis, calibration and performance

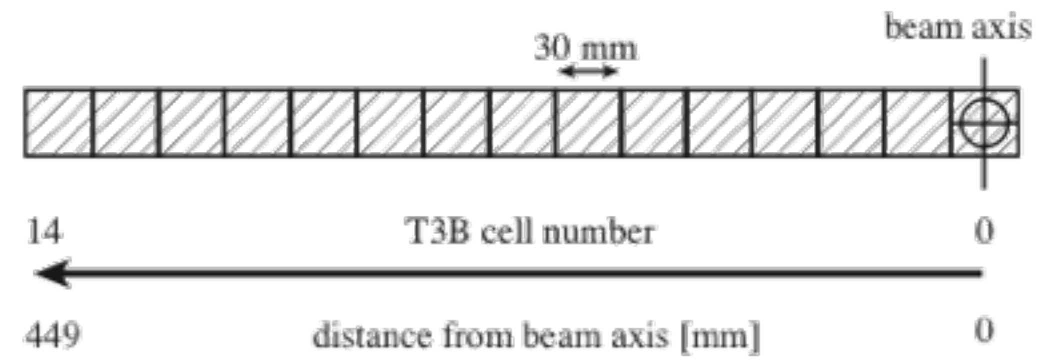
- A high time-resolution detector for Beast2: CLAWS
  - Detector design
  - Improvements and optimizations over T3B

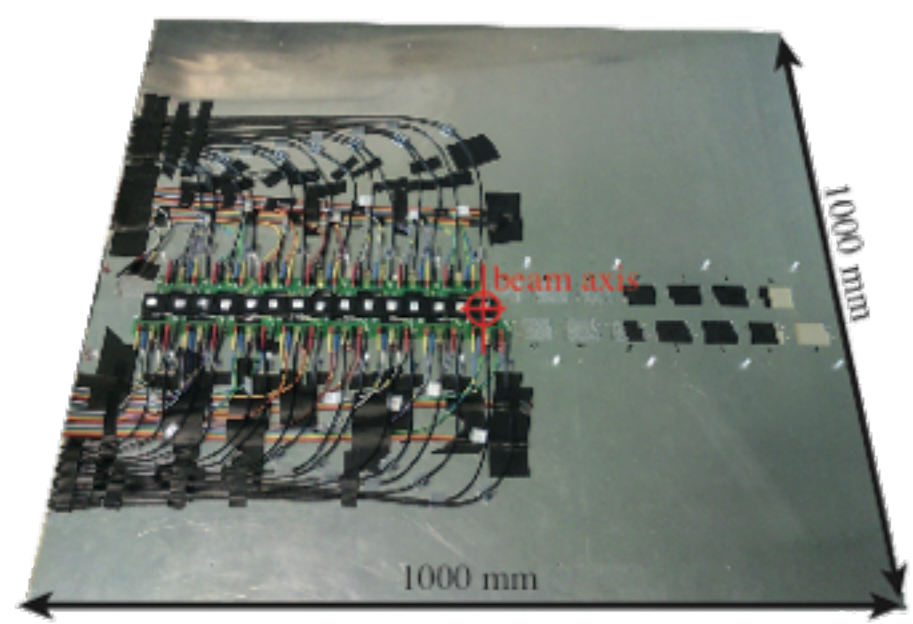
T3B Detector

Tungsten Timing T3B TestBeam

- 15 readout channel:
  - each consisting of 30x30x5 mm scintillating tiles coupled with a SiPM sensor
- Readout: 4 x USB picoscopes®: 1.25 GHz, 3000 sample (2.4 μs) per trigger
  - 15 channels + 1 sync channel

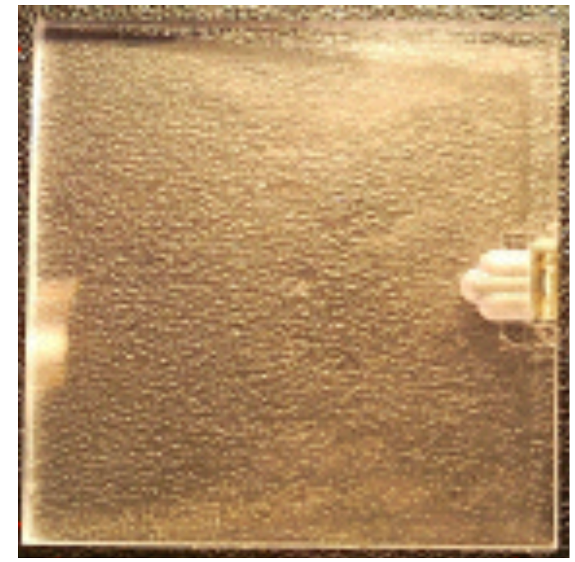
- Installed downstream of CALICE calorimeters: W-AHCAL (5 λ), SDHCAL (6 λ)
- With W-AHCAL: Synchronization of data streams possible (and demonstrated): Allows for event-by-event identification of shower start
- Optimized to study the time structure of hadronic showers with a small number of detector cells

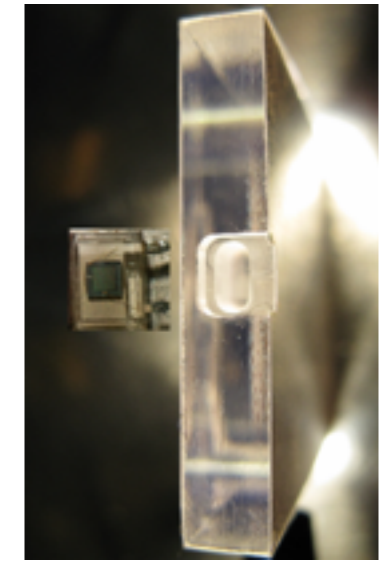


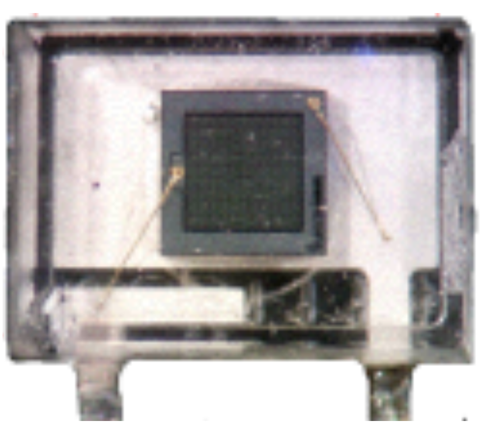


Active Elements

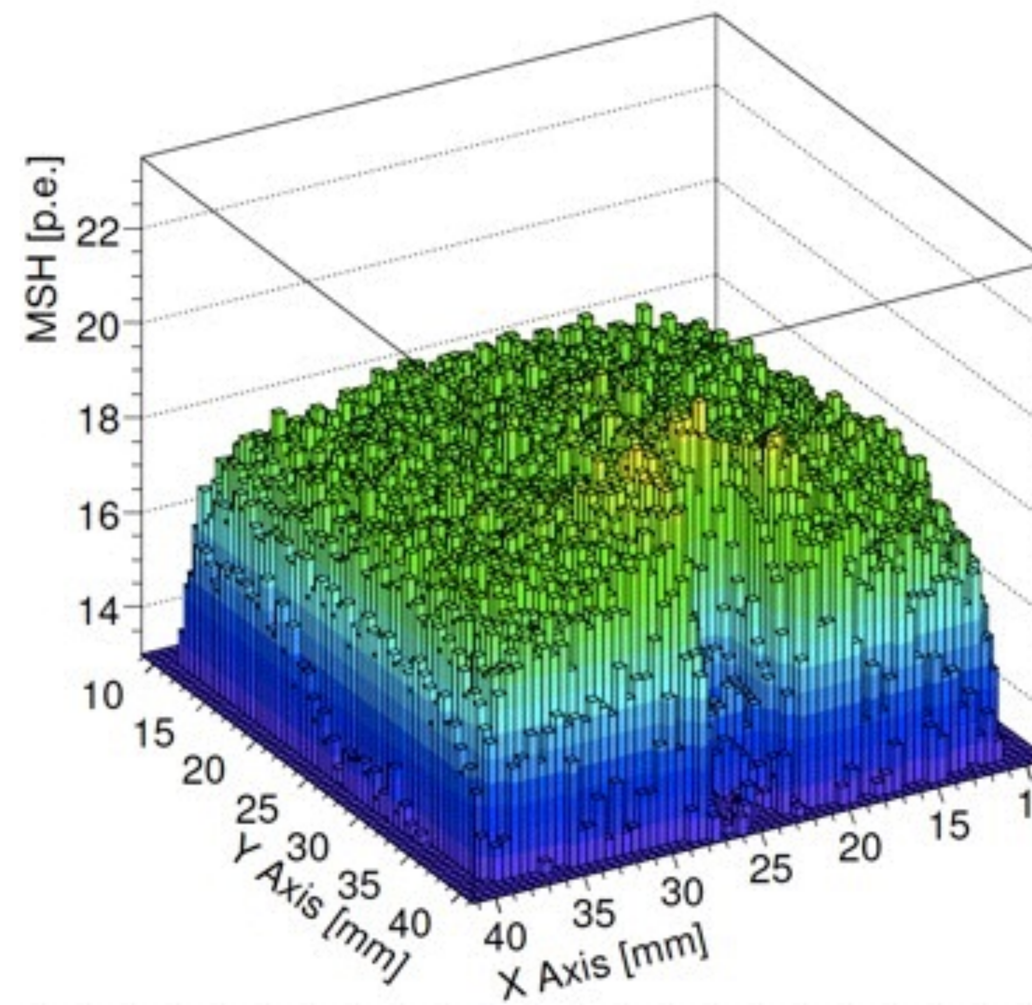
- Plastic scintillators (BC420) directly coupled to Hamamatsu MPPC50 SiPMs
  - fiberless coupling - improved time resolution, reduced mechanical complexity
  - scintillator geometry optimized for uniform response







- SiPM: Silicon Photomultiplier array of avalanche photodiodes operating in geiger mode
- Each pixel has a on/off response, the array output is a superposition of all pixels.



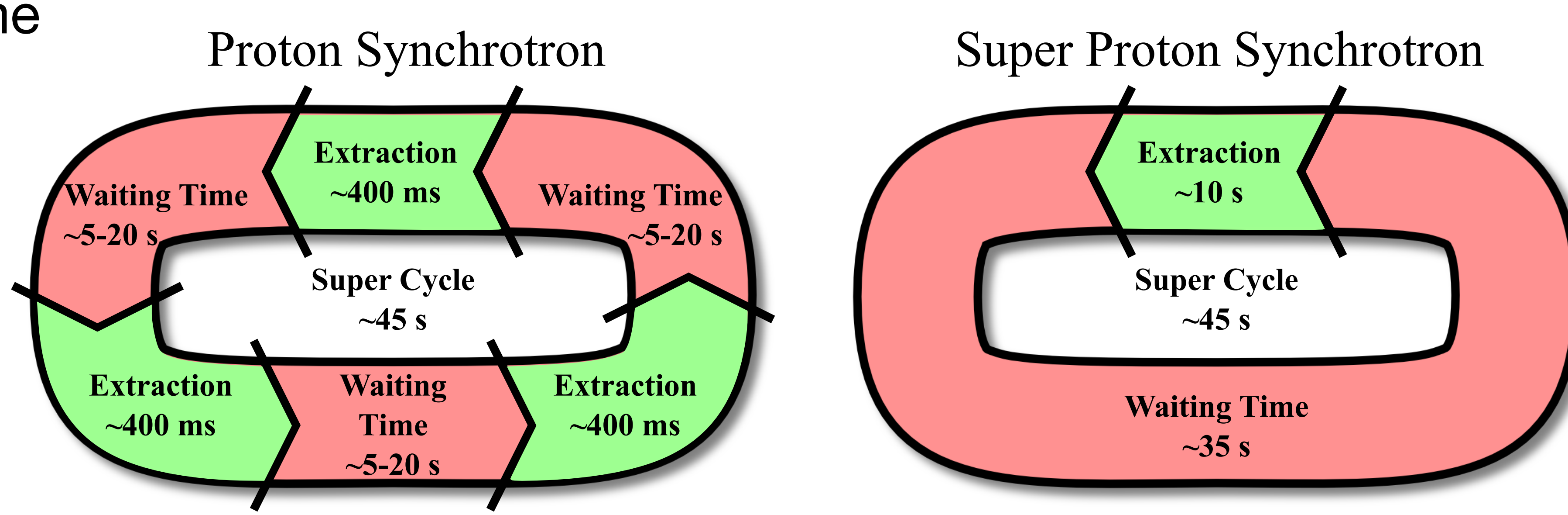
T3B Data Acquisition

- Key requirements:
  - Fast sampling to allow for single photon resolution → ≥ 1 GHz
  - Long acquisition window → ≥ 2 μs
  - Fast trigger rate: faster than the CALICE HCAL → ≥ a few kHz

- Adopted solution for T3B: Picoscope 6403
  - 1.25 GHz sampling for 4 channels per unit
  - 1GS buffer memory (shared between channels)
  - Burst trigger mode: maximum rate determined by window length → ≥ 100 kHz for 2.4 μs tested and used
  - 8 bit vertical resolution
  - Control & Readout via USB 2.0

T3B Readout Scheme

- Based on a test beam environment: Data taking during a “spill”, then readout during off-spill time



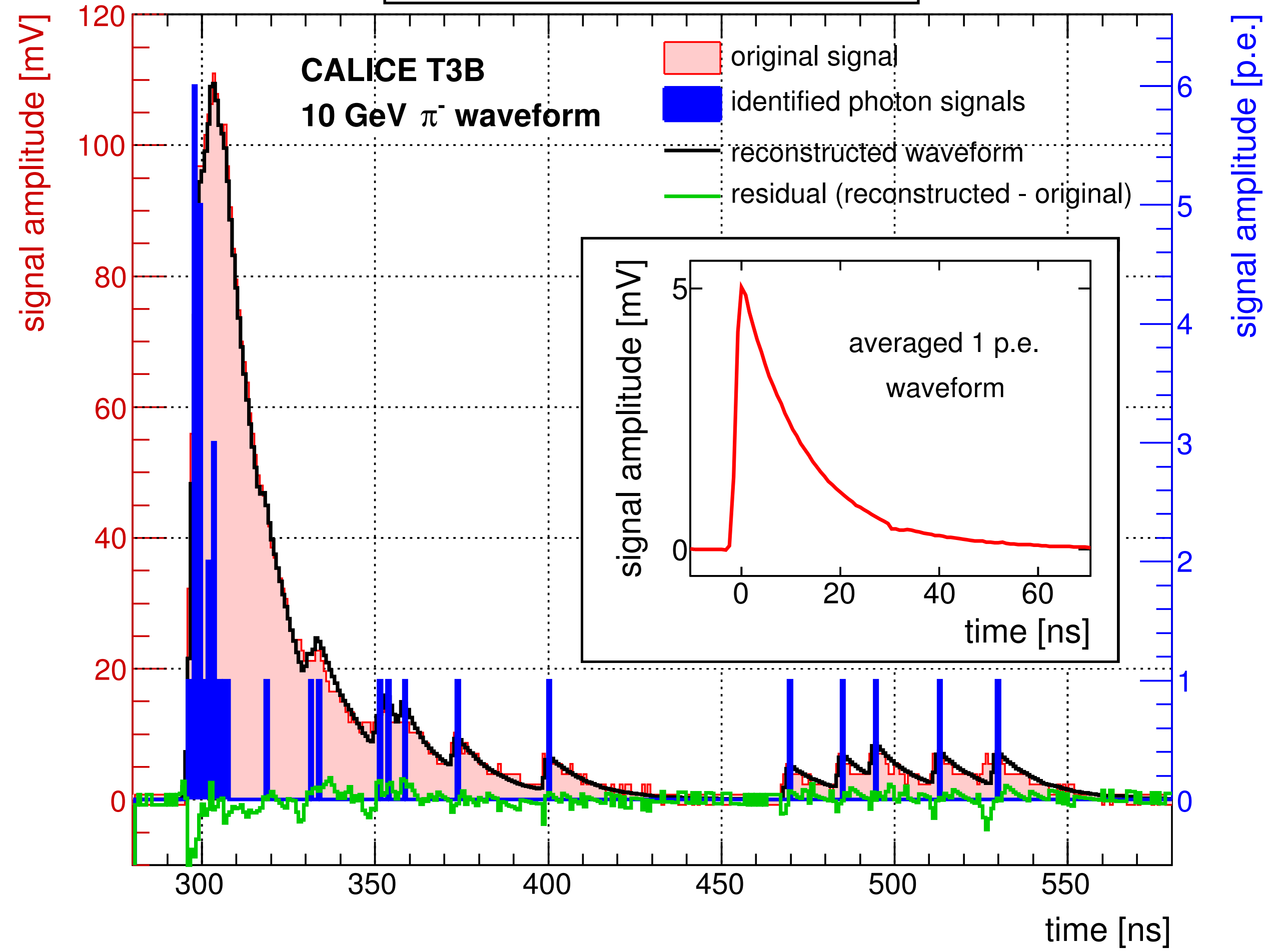
- Typical operation mode:
    - Up to 10k triggers per spill - data volume:
        - 3000 samples/ev, 8 bit per sample: 240 Mbit/ch/spill => ~ 1 Gbit / picoscope/spill
        - with four scopes: 500 MB/spill - read out over USB2
        - ▸ requires parallel readout over four controllers to read in less than 30s

▸ Summary: Record 10k events with high rate, then read out for ~ 30s, record again…
(NB: The number of recorded events before readout can be higher by x 5, then readout takes longer)

Data Analysis

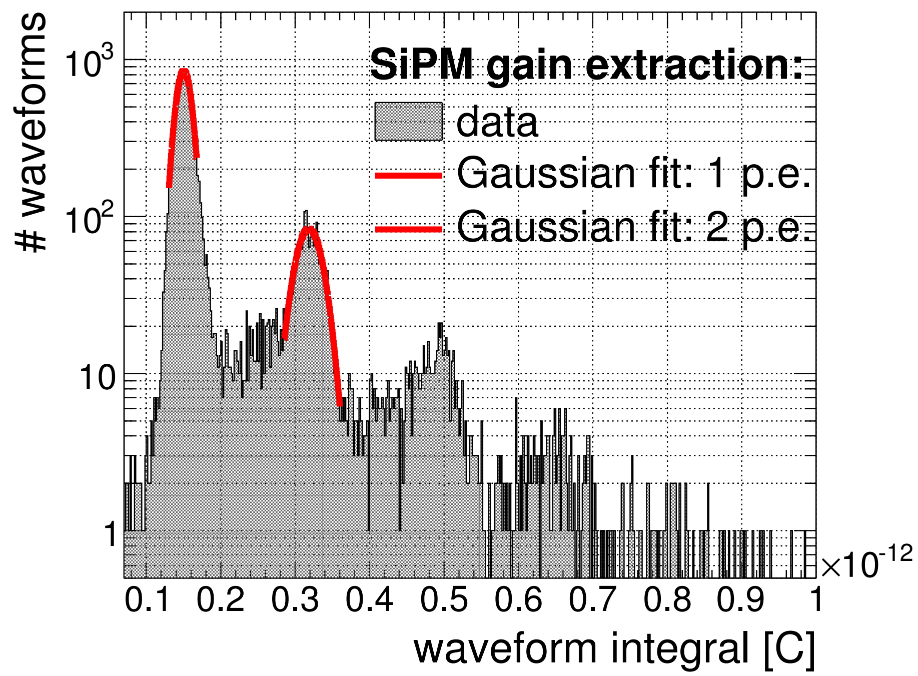
- Subtract the average response of a single SiPM pixel from the recorded signal, until no signal left:
  - Histogram with the time of arrival of each photon on the SiPM
- For this plastic/SiPM combination 1 MIP ~20 photons i.e. 820 keV in the scintillator

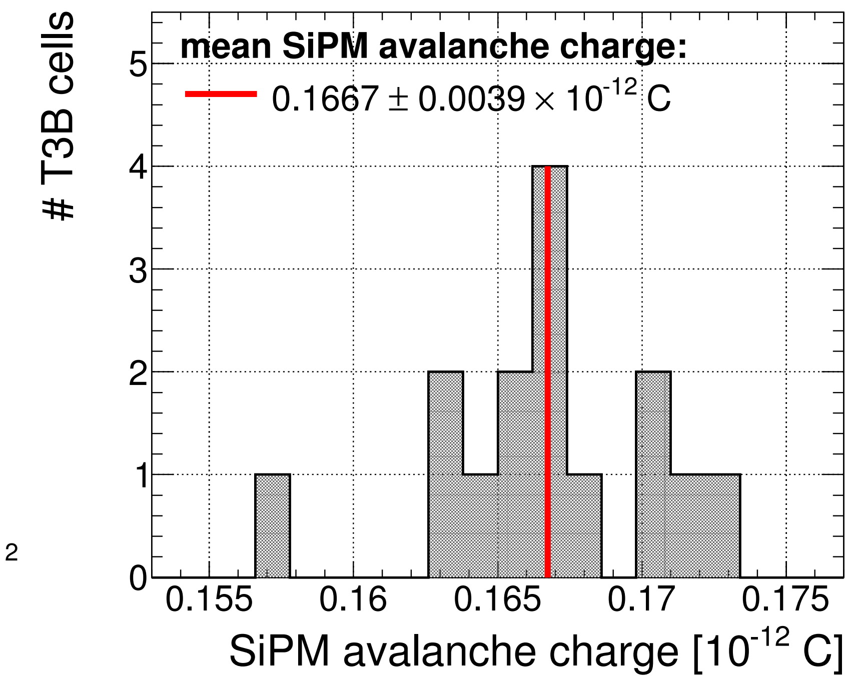
JINST 8 P12001 (2013)



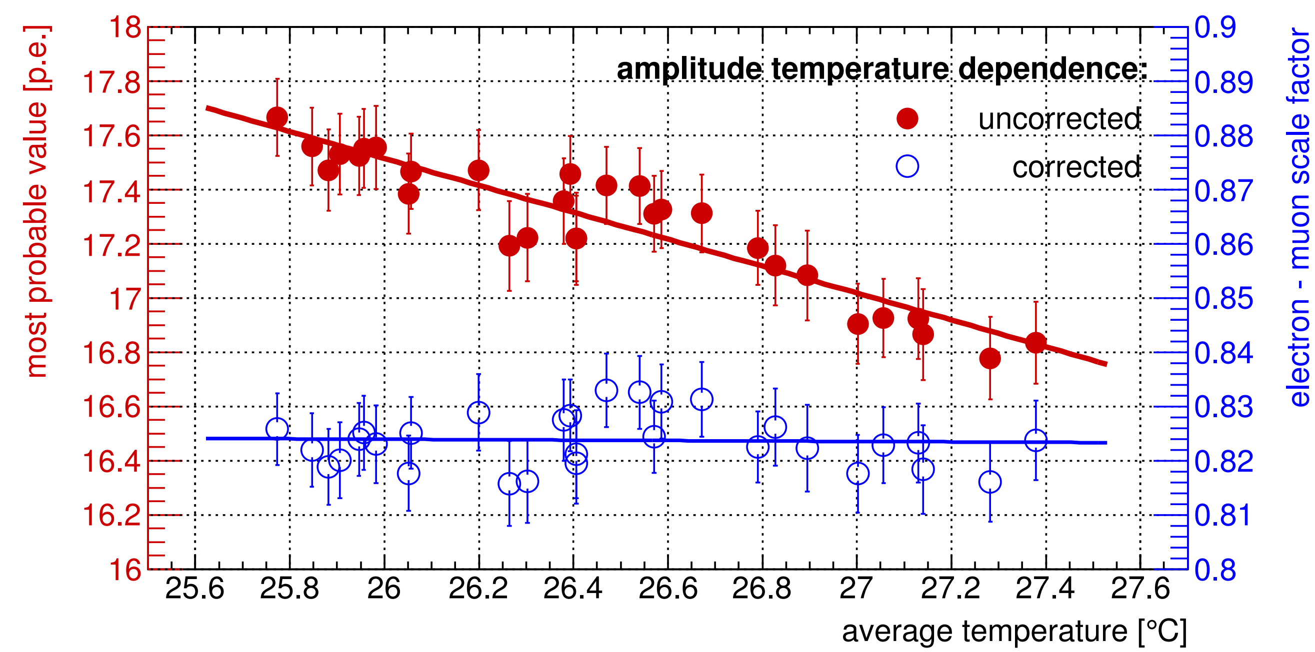
- For robustness: Use only the first hit in each cell in an event - avoids uncertainties from hit separation, afterpulsing, … High granularity ensures multiple real hits are rare (at the %-level)
- Main observable: “Time of first hit” - Timing given by the second reconstructed photon (SiPM)

Calibration



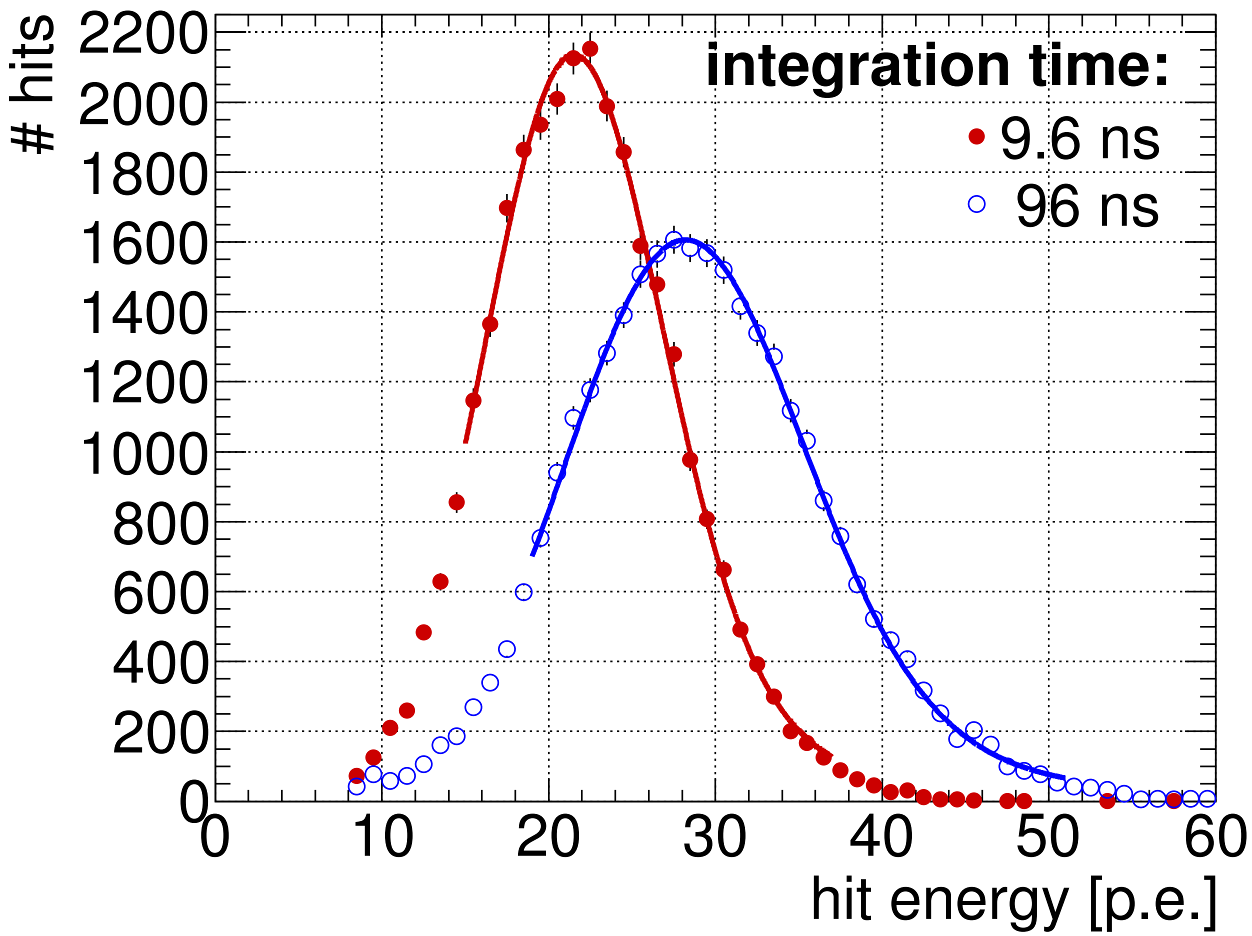


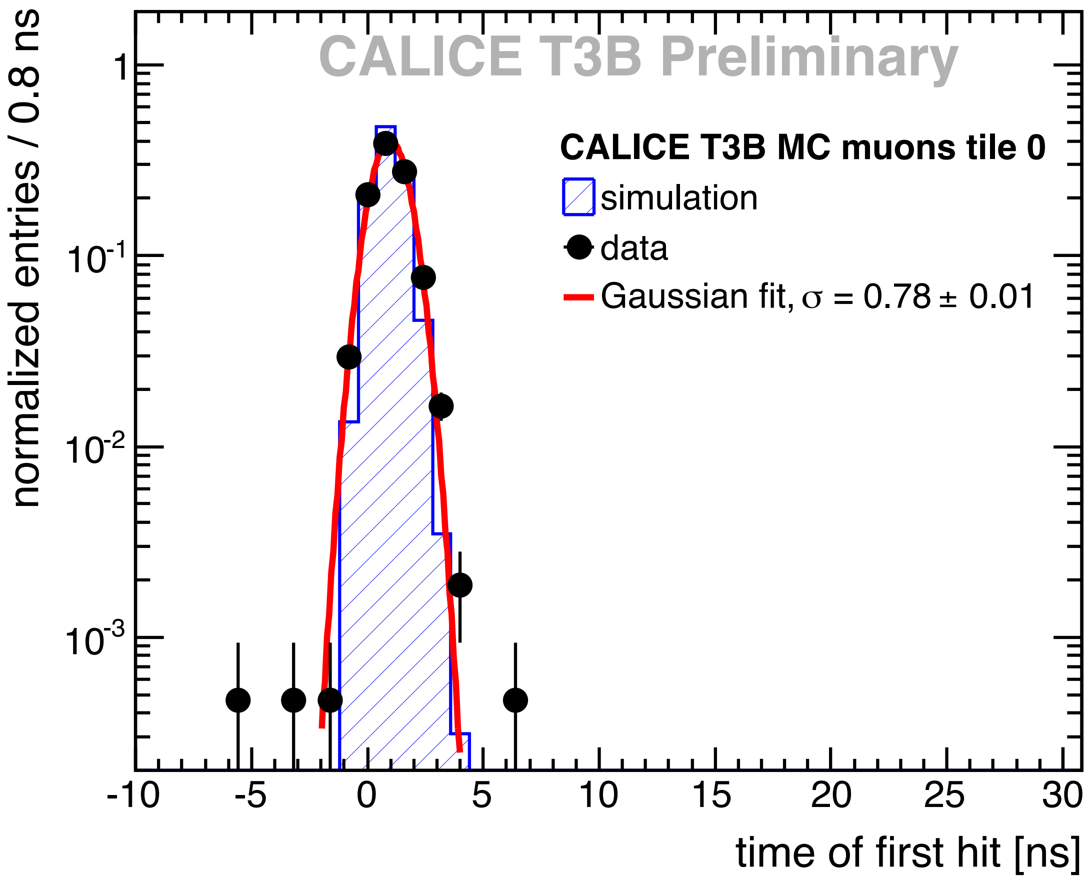
- Real-time gain calibration, using dark noise taken between physics spills
- Temperature monitoring to correct for temperature effects



Performance

Reconstructed amplitude for particle signals depends on integration time (afterpulsing of photon sensor)

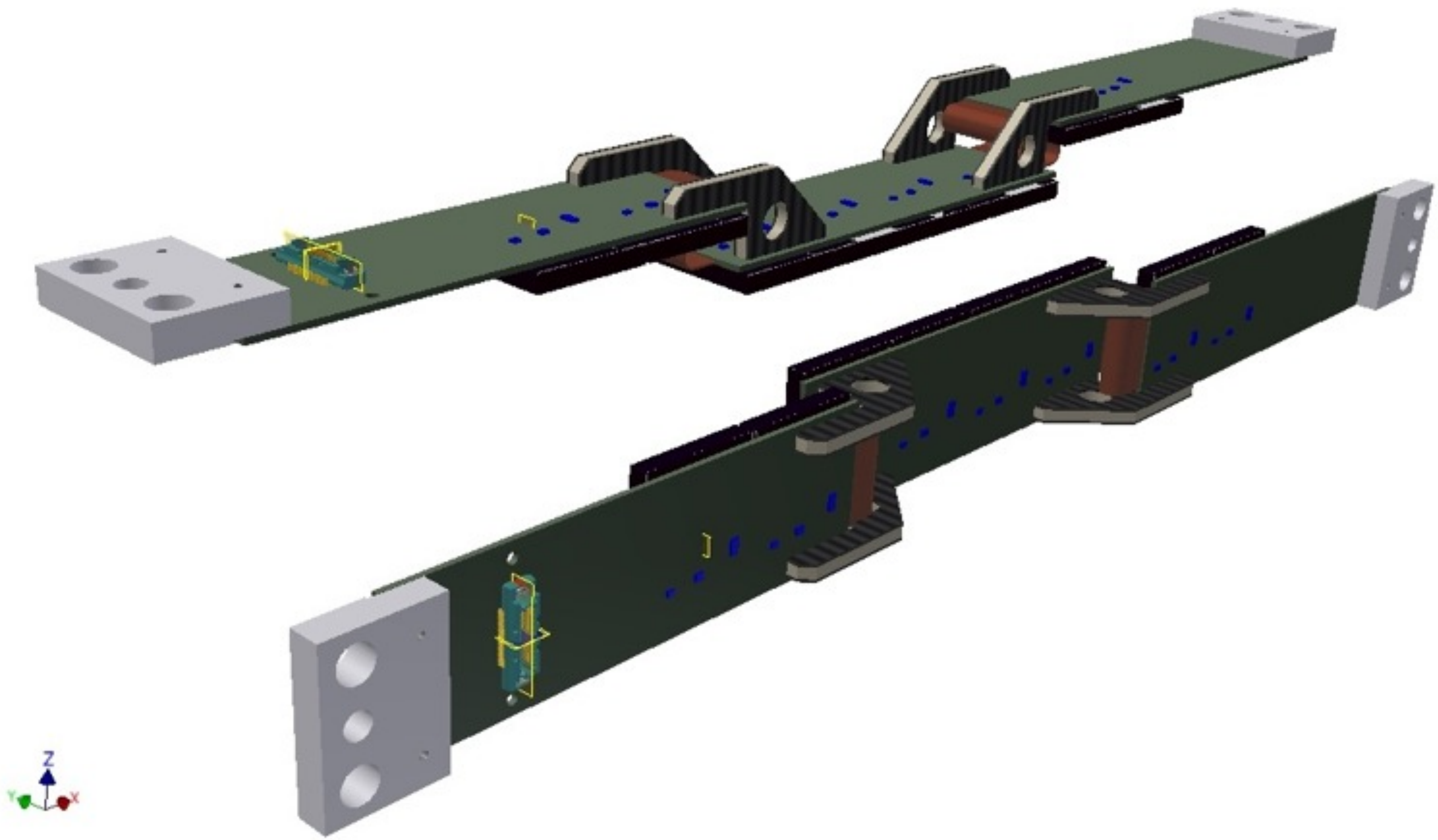




Time resolution of complete system (including CALICE trigger) < 800 ps

CLAWS

(sCintillation Light And Waveform Sensors)

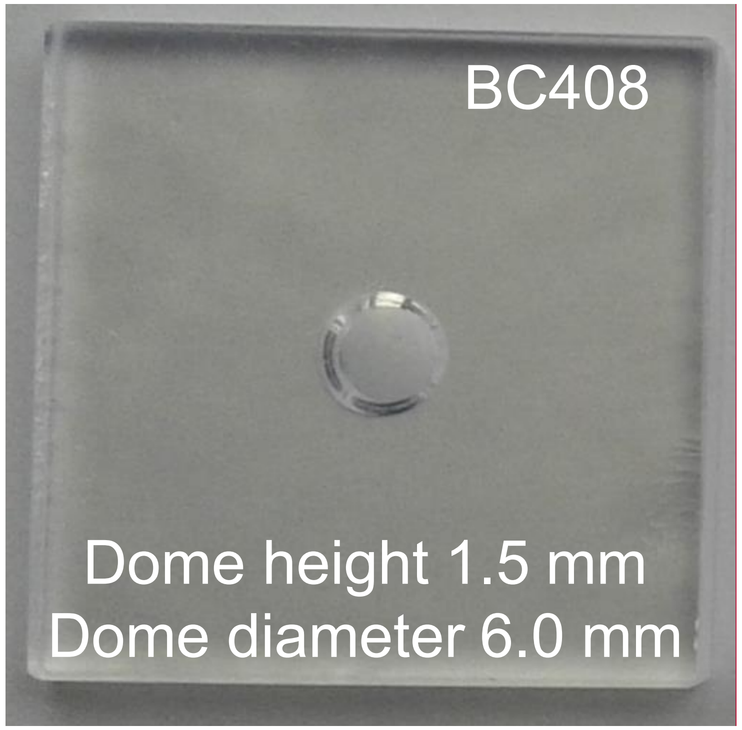


Use the experience accumulated with T3B and the developments in scintillator design and SiPMs to build a sub-ns long time-baseline detector for BEAST2

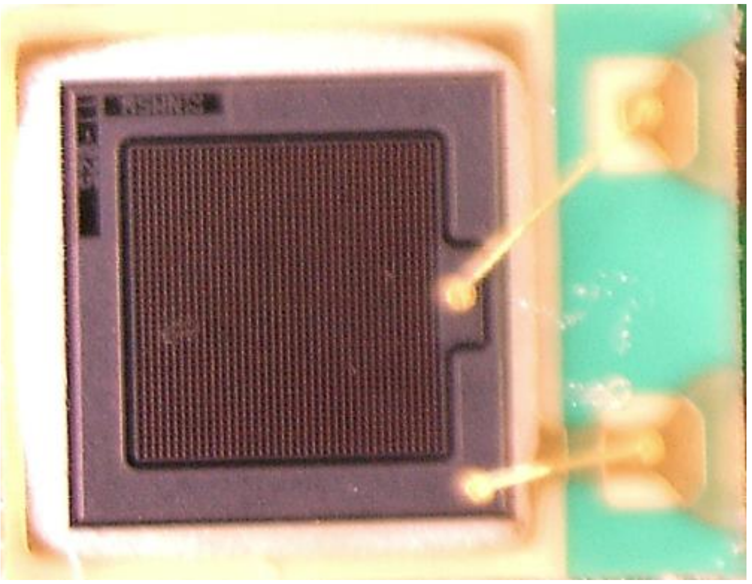
CLAWS

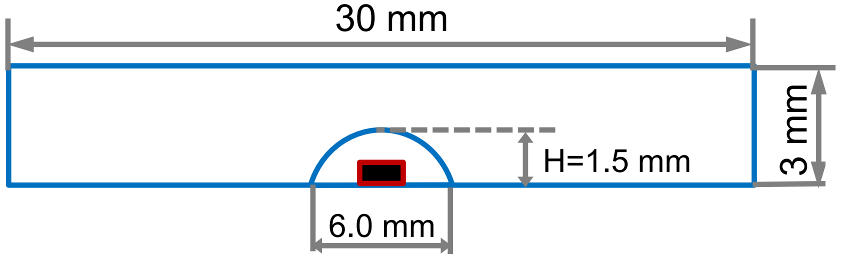
(sCintillation Light And Waveform Sensors)

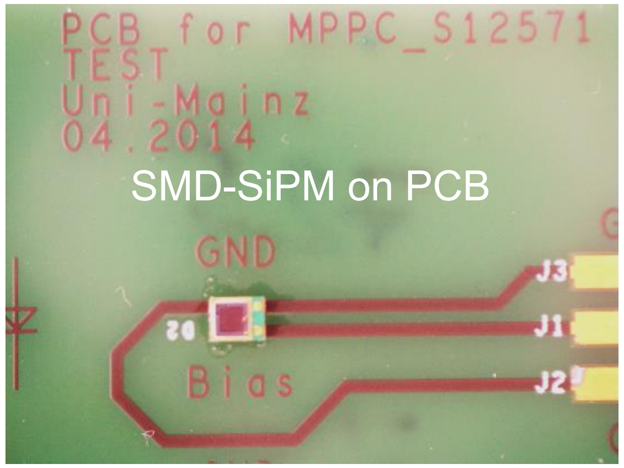
- Scintillator tiles optimised for SMD SiPMs, directly mounted on a PCB
  - Designed at Mainz, inspired by MPP studies
- New generation of SMD SiPMs with better noise levels, lower afterpulsing and crosstalk

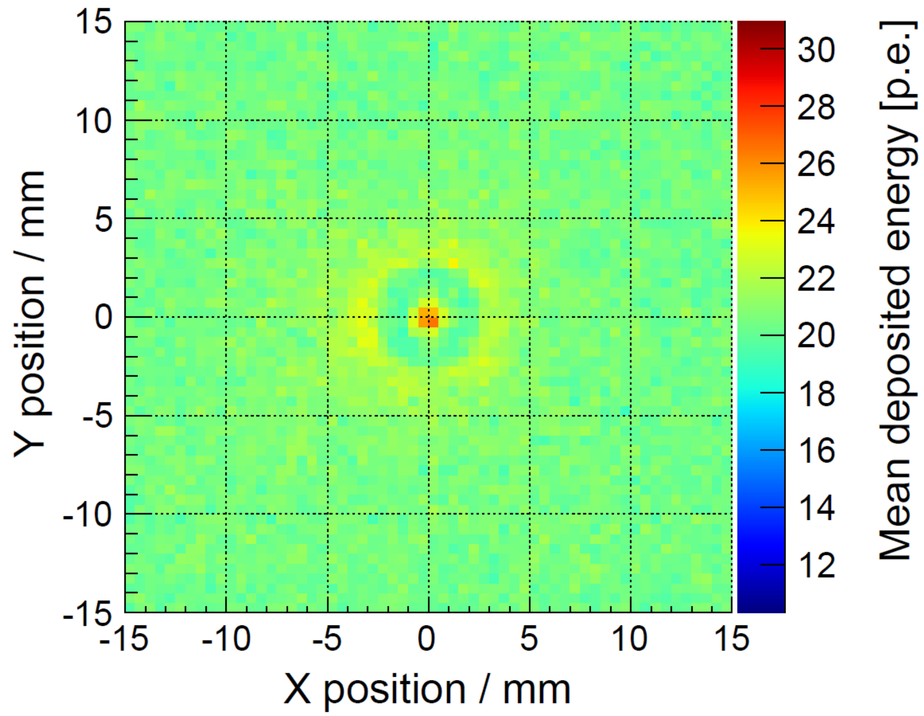


MPPC S12571-025P
1×1mm², 25µm (1600 pixels)

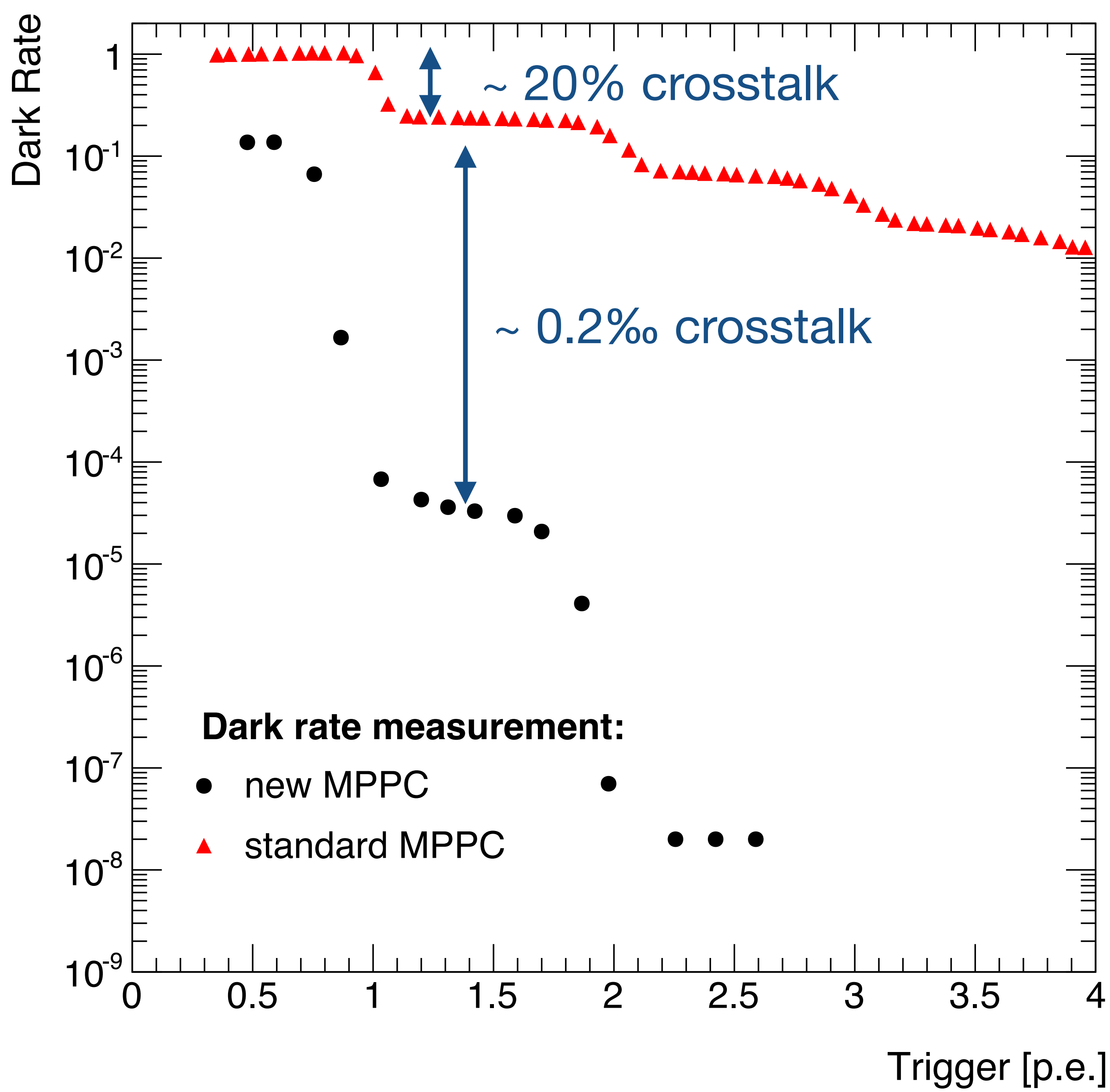






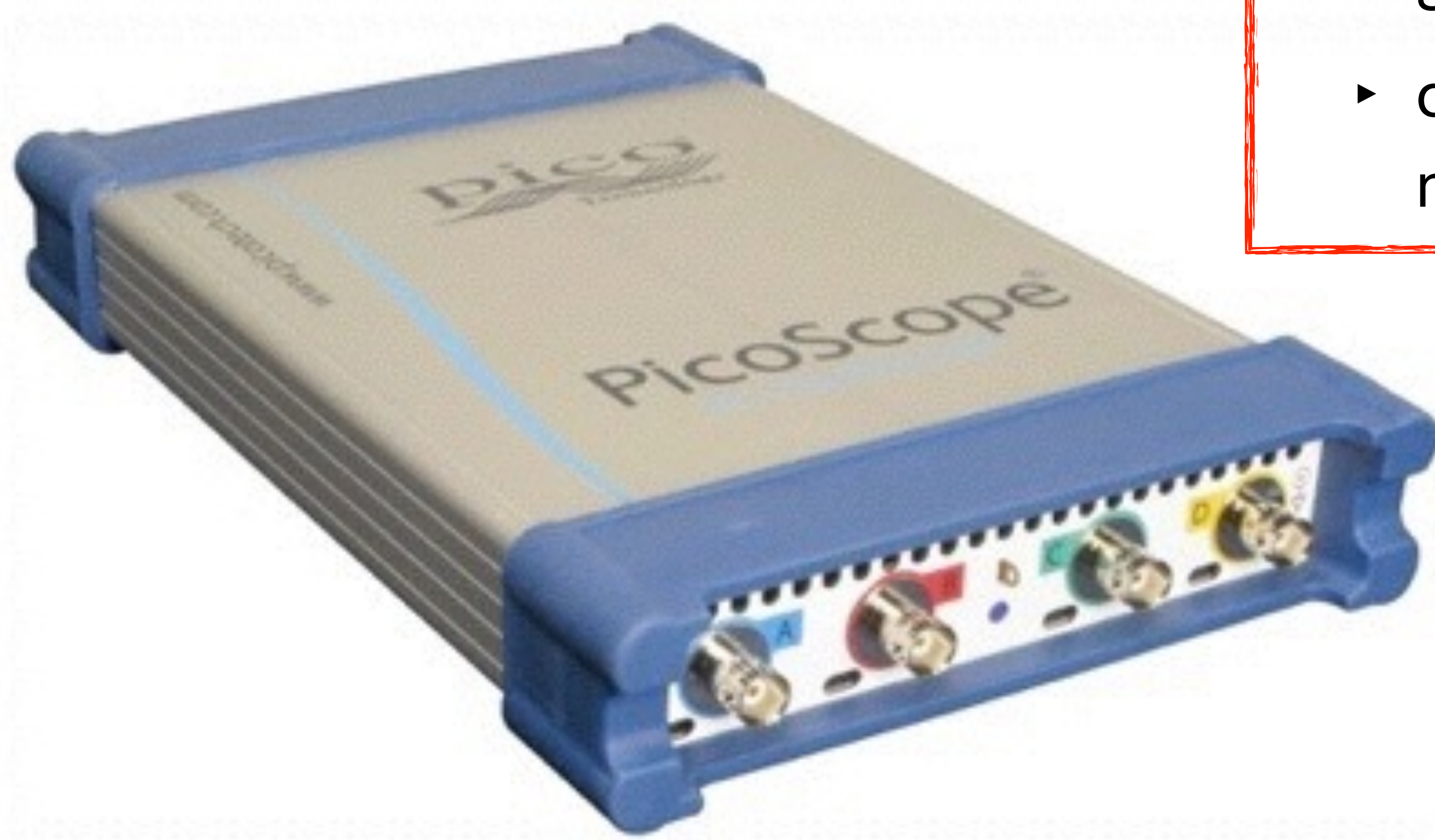


Improvements - SiPMs



- Current SiPMs: 12571 series from Hamamatsu - still with high noise rates due to interpixel cross talk
- New generation (not yet officially available) eliminates this problem - plan to use for CLAWS
  - The challenge: Also eliminates our calibration strategy - need to find a new solution, for example based on LEDs

Improvements - DAQ



- New generation of oscilloscopes from Picotech (6404D)
  - 2GS buffer
  - USB3.0
  - continuos data taking until full buffer i.e. ≥ 100 milliseconds windows sampled at 1.25GHz (800 ps resolution)
  - or continuos 150 MS/s until computer memory full

Optimizations

- There is a set of tunable parameters that depend greatly on the goals of the measurement:
  - SiPM pixel density
  - SiPM active area (up to 3x3 mm^2)
  - Scintillator material and thickness

that will impact on the resolution, range and material budget of the device

We need a clear set of requirements regarding what CLAWS should measure in BEAST2:

- what is the energy range it should be able to detect?
- what time resolution is needed?
- what energy resolution is needed?

Conclusions

- We propose a high time resolution detector:
  - Can reach sub-nanosecond precision
  - capable of continuously recording for very long time windows
- Detector and DAQ are well tested and have withstand hundreds of hours of runs in our lab as well as several testbeam data taking campaigns at CERN PS and SPS
- New developments in SiPM noise rate and oscilloscope readout can push the boundaries even further

- Need to know:
  - What exactly we want measure with this system?
  - What are the expected energies?
  - What are the expected rates?
- We need input from your side to optimize the detector and customize it to your needs