Test Beam Study for CALICE Scintillator Tiles

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Contribution to the
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Session T82.2
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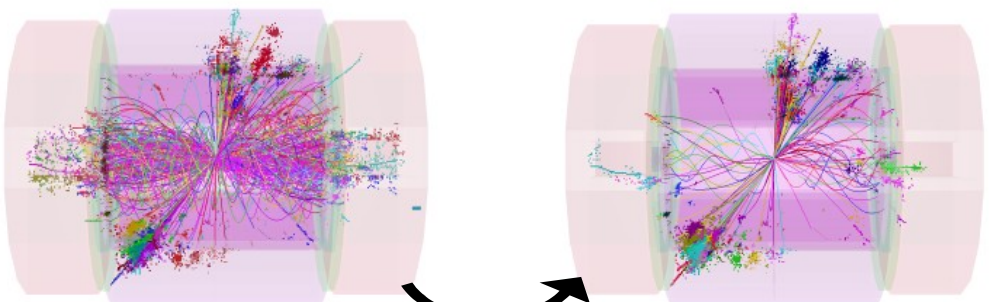
Motivation

Why do we need time information in calorimetry?

- Reject Background
- Improve Clustering
- Use in software compensation to identify components of hadronic showers



Time cut

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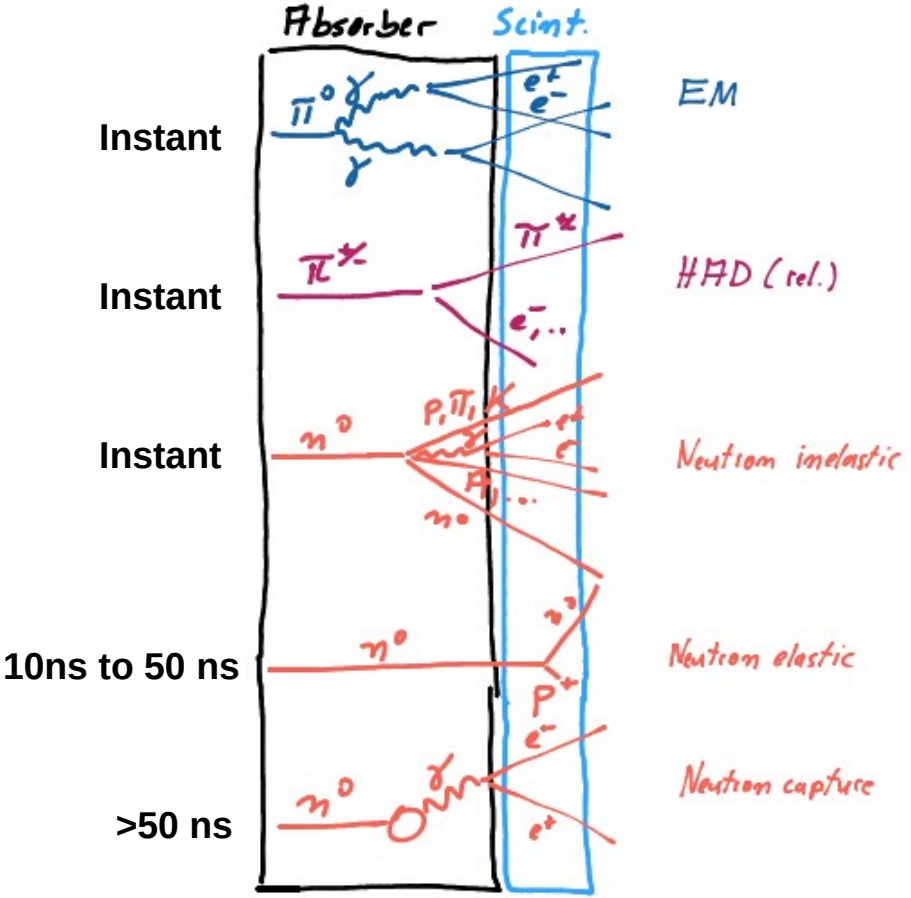


AHCAL Technological Prototype

Scintillator Tiles:

- 30x30 mm² injection moulded polystyrene
- Wrapped in reflective foil

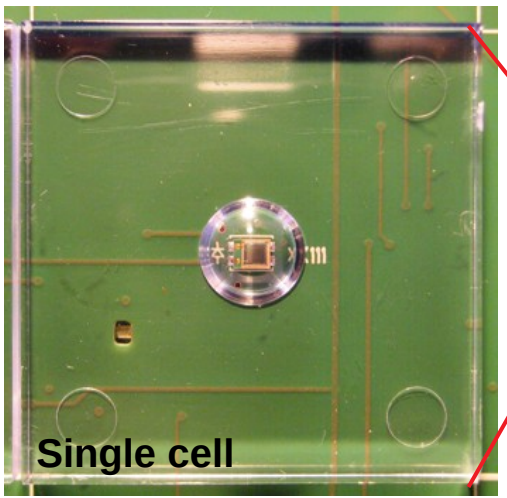
Active Layer:

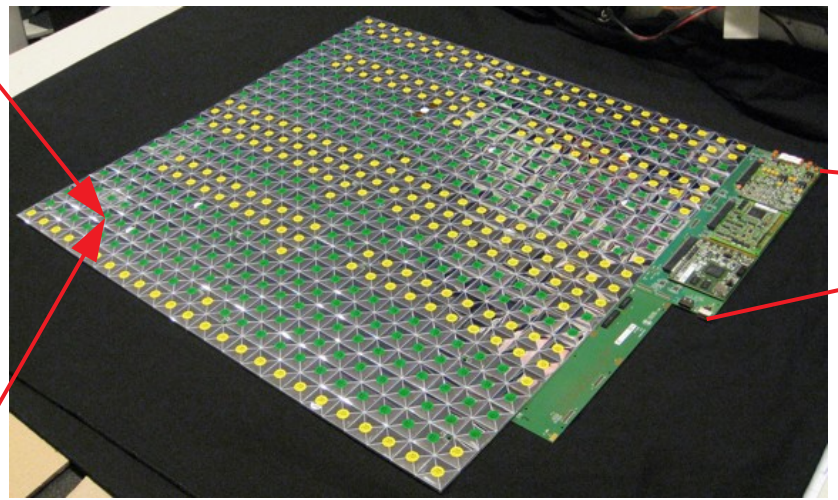
- Tiles placed directly on PCB
- Individual SiPM readout for each channel

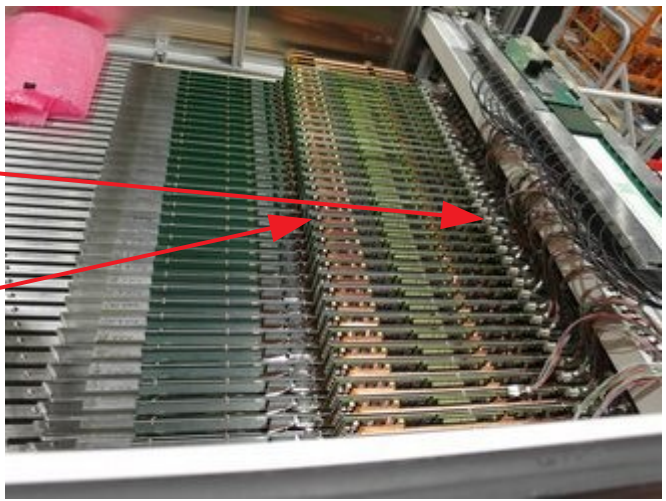
Large Technological Prototype:

40 fully assembled layers

- 17 mm steel absorbers
- 3 mm scintillator tiles







AHCAL Technological Prototype

40 fully assembled layers

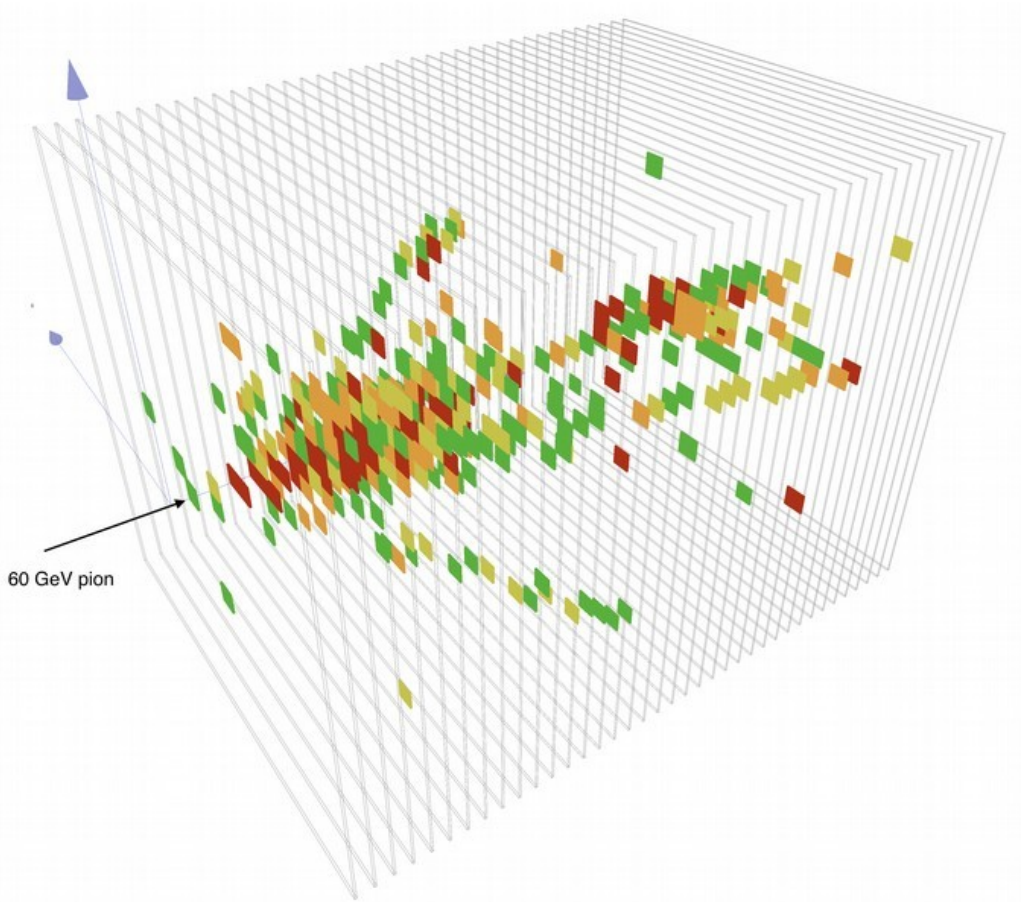
- ~ 4λ deep
- ~ 23000 channels

Dedicated test beam campaigns at SPS in 2018

- Stable data taking

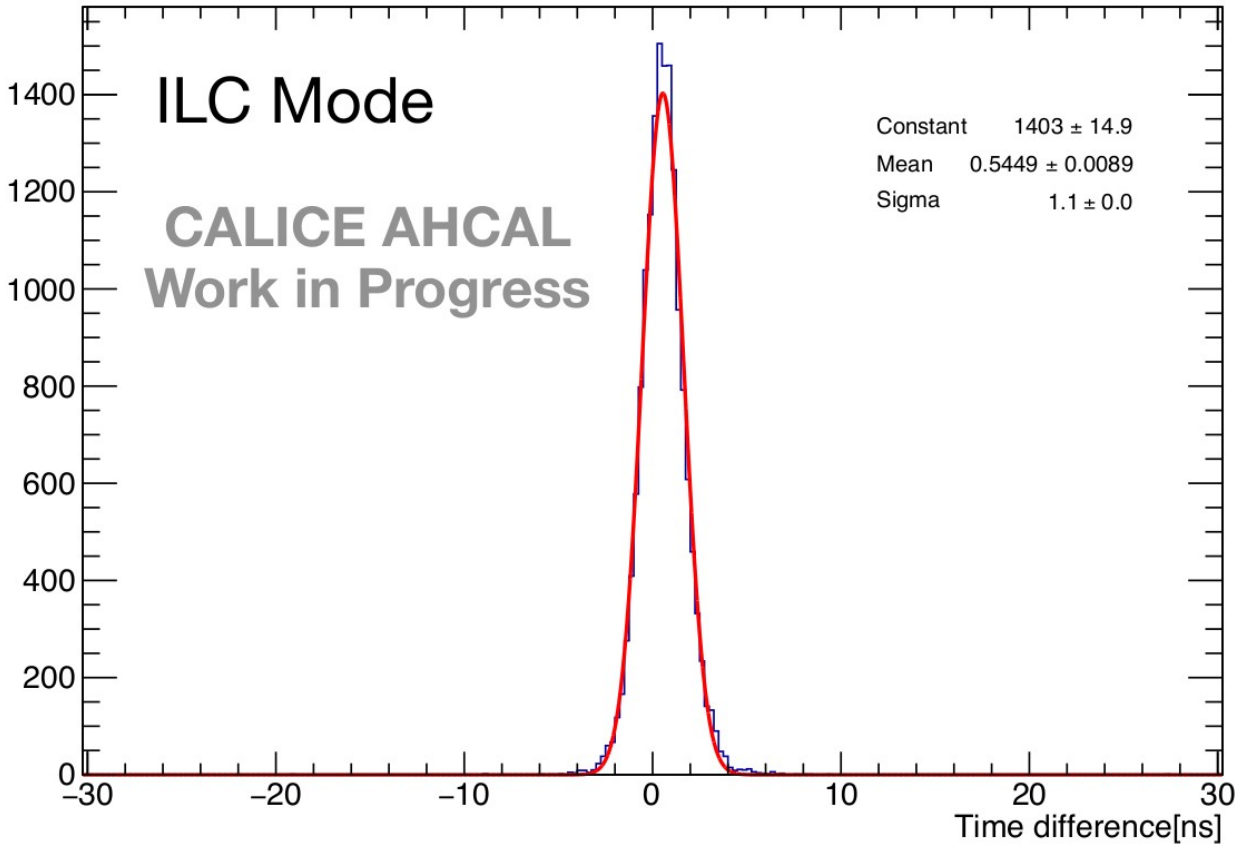
In total ~100 M recorded events of

- Muons (for energy and time calibration)
- Electrons
- Pions



AHCAL Timing Performance

- Design goal in ILC mode: ~1ns single channel
- Using the *time difference* between two tiles in adjacent layers
- Single channel time resolution achieved in current prototypes: $1.1/\sqrt{2} = 0.78$ ns
- Assumption: hit times uncorrelated random variables



Scintillator Timing Study (1)

Goal 1: Measure the time resolution of the SiPM-on-tile technology:

- Independent of the AHCAL electronics and DAQ
- In a simple but modular setup
- Without involved calibration and reconstruction procedures
- With high particle rates and controlled energies

Goal 2: Identification of limiting factors of the time resolution of the AHCAL

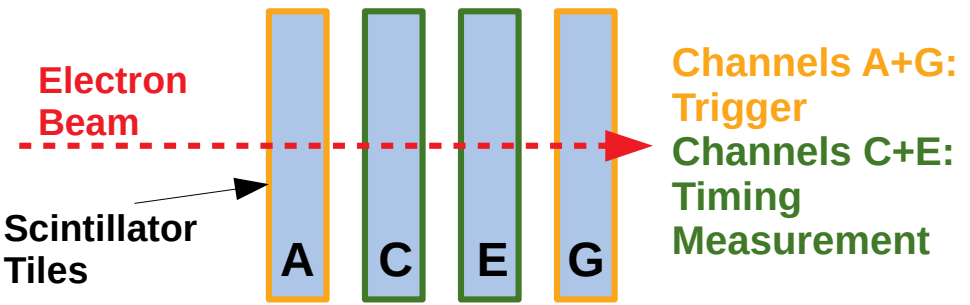
Scintillator Timing Study (2)

Concept of the Measurement:

- Scintillator telescope with two coincidence triggers (**Ch A+G**)
- Use a fast digitizer to (2.5GHz) to measure the hit time directly from the raw SiPM waveform
- Two additional scintillator tiles (**Ch C+E**) to determine the time resolution as hit time difference of the channels

Objectives of the First Test Beam (October 2020, DESY):

- Investigation of AHCAL tiles
- Investigation of material dependence (injection moulded polystyrene vs. cast BC408)
- Effect of tile size on time resolution (30x30 mm² vs. 20x20 mm²)



Scintillator Timing Setup

Stack of 4 scintillator tiles:

- BC408 or Polystyrene (AHCAL)
- Hamamatsu S13360-1325PE

↓ **Cat 7 Ethernet cable**

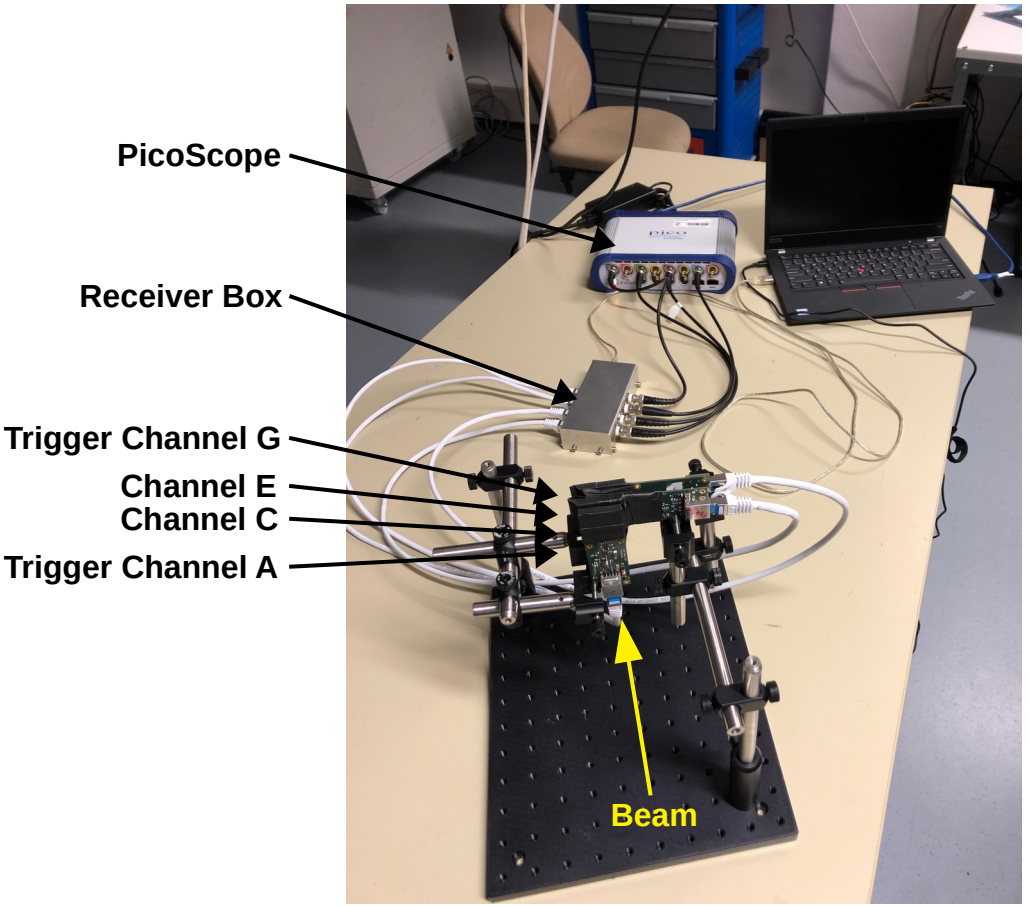
Receiver Box:

- USB controlled power supply
- Split signal and power lines

↓ **BNC**

Picoscope:

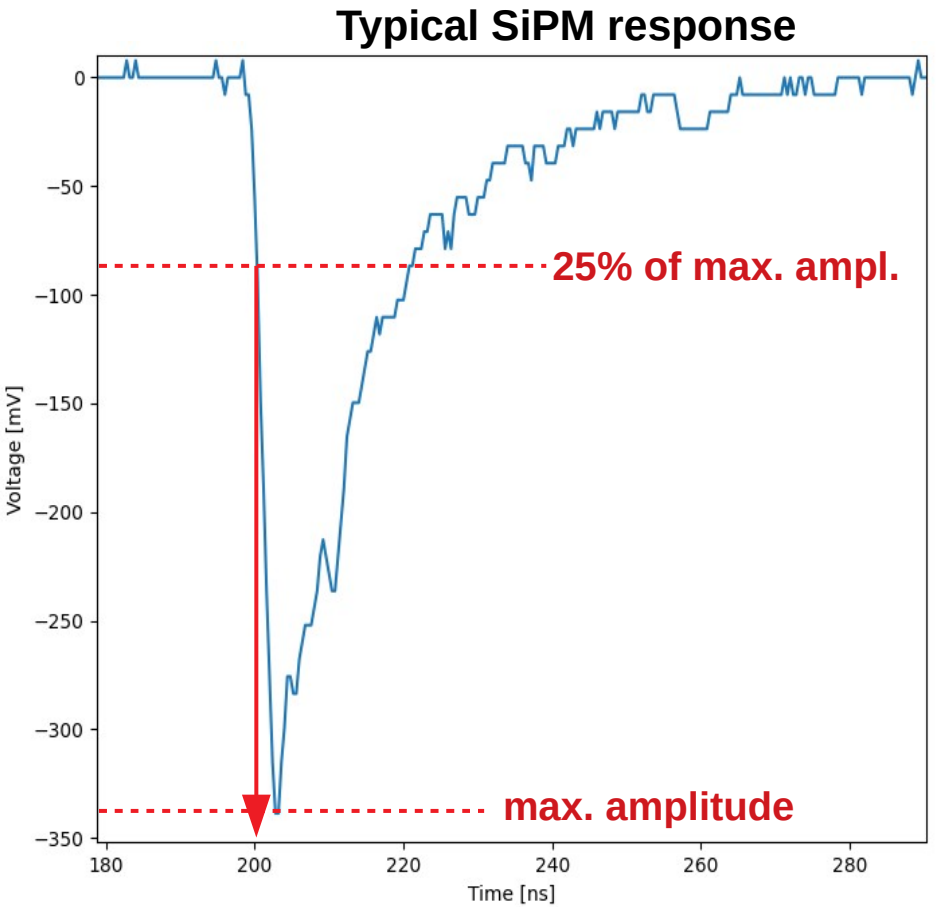
- Up to 2.5 GHz sampling rate on 4 channels
- 300 kHz peak trigger rate
- Save complete analog waveform
- Coincidence Trigger on Channels A and G



Determining the Time Resolution (1)

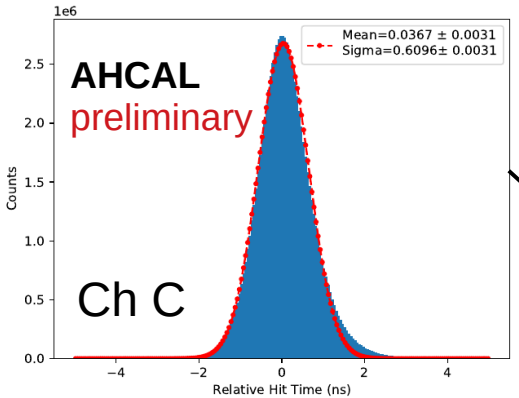
Constant Fraction Discrimination:

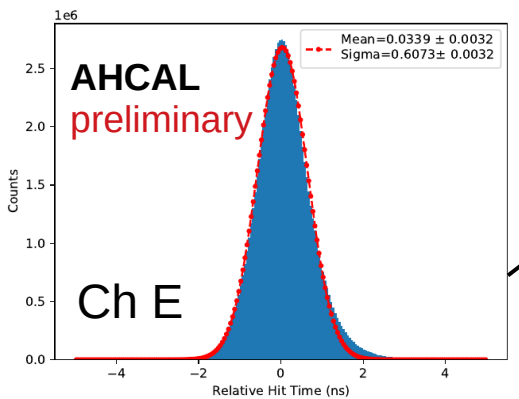
- Get maximum amplitude of the event
- Search for the first time that the signal crosses 25%
- If the crossing is between two bins, interpolate linearly



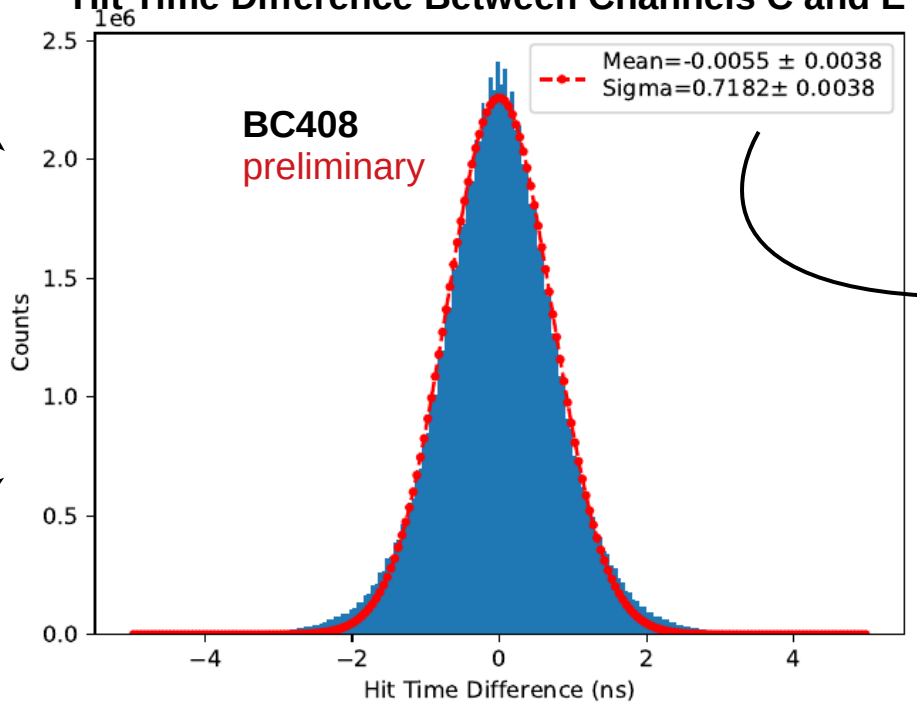
Determining the Time Resolution (2)

Channels C and E give two independent hit times
→ subtract to eliminate trigger resolution effects





Hit Time Difference Between Channels C and E



Single Channel Time Resolution:

0.718/√2 = 0.508 ns for AHCAL tiles (30x30 mm²)

Findings (1)

Single Channel Time Resolutions:

AHCAL tiles 30x30x3 mm³
(507.9 ± 2.7) ps

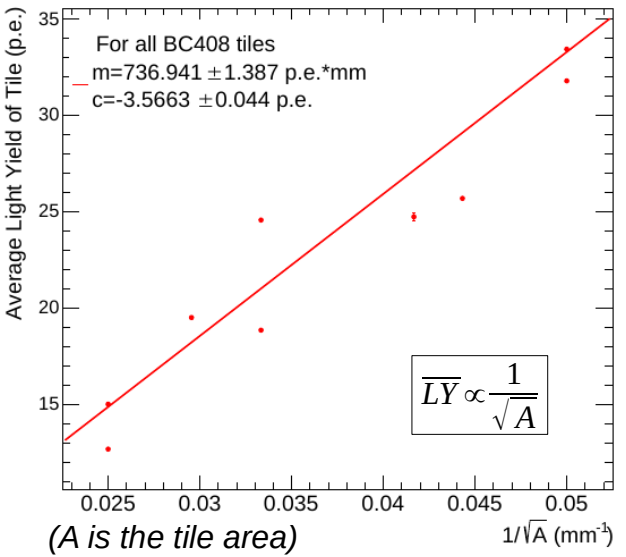
- AHCAL *tiles*: single channel time resolution of **0.508 ns**
  - Interpret as intrinsic time resolution of the SiPM-on-tile - scintillator
- AHCAL time resolution (technical prototype) of **0.780 ns**
  - AHCAL front-end electronics contribute ~0.6 ns
    (has to be added in quadrature)
- Improve front-end *and* SiPM-on-tile to significantly improve AHCAL time resolution

Findings (2)

Single Channel Time Resolutions:

AHCAL tiles 30x30x3 mm³	**BC408** 30x30x3 mm³	**BC408** 20x20x3 mm³
(507.9 ± 2.7) ps	(496.9 ± 2.0) ps	(370.1 ± 1.3) ps

- Tile size has huge impact on time resolution
  - Area or volume dependent?
- We expect that higher light yield results in better time resolution
- Previous work has shown that smaller tiles have a higher light yield
- Further studies required



(A is the tile area)

Figure from Malinda De Silva‘s Master Thesis

Outlook

- Analysis of full dataset ongoing:
  - Different cable lengths on channels C and E
  - Runs with tungsten absorbers (EM showers)
  - Impact position dependent measurements
  - Energy binned timing analysis
- Goals for next (second) test beam:
  - Measure time resolution for more different tile sizes and thicknesses

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Backup Slides

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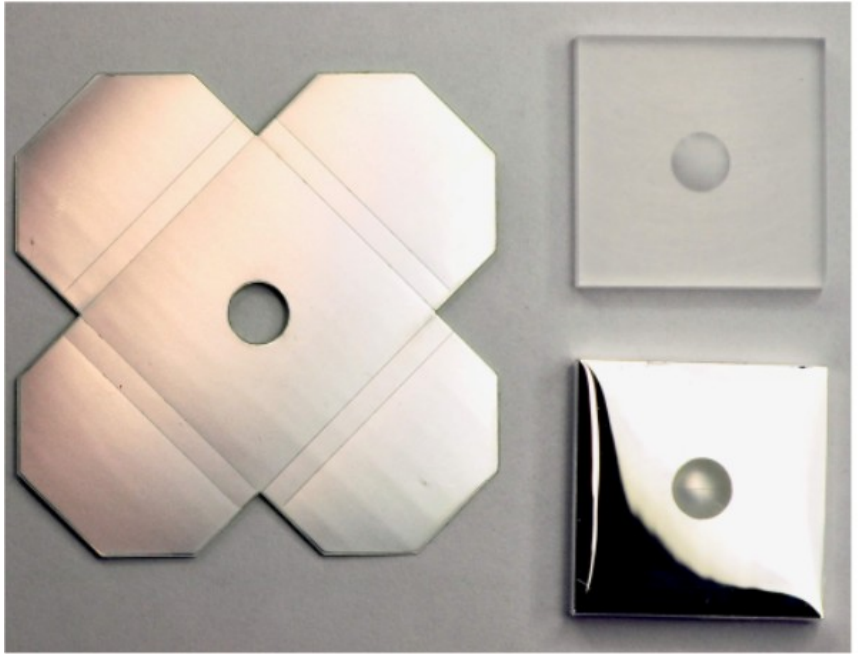
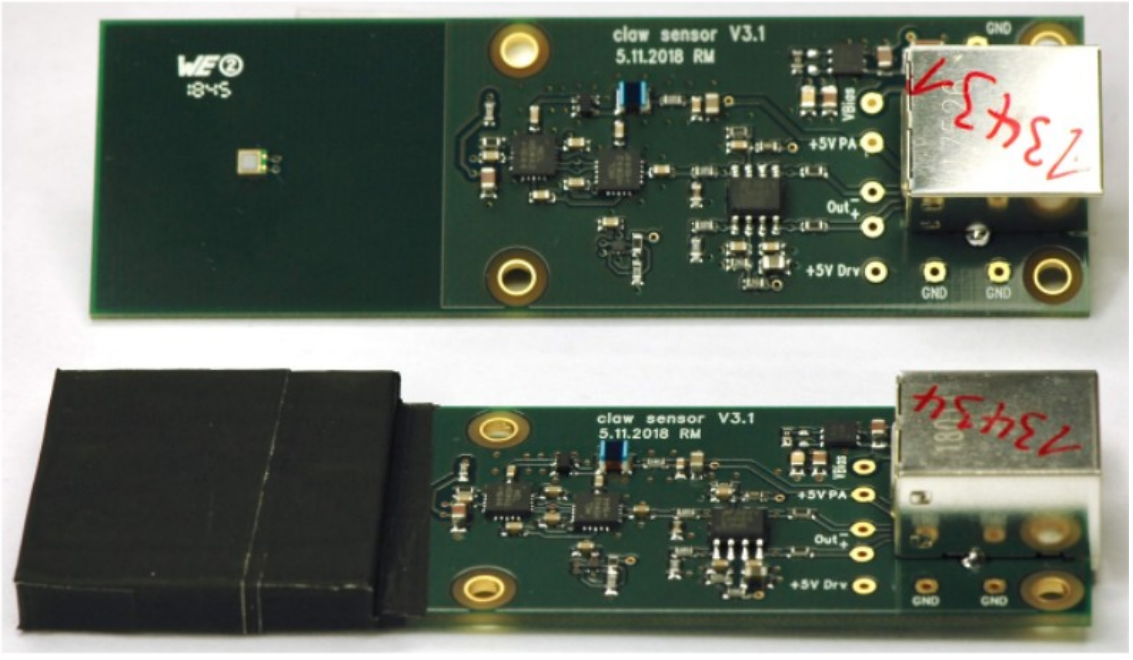
Sensors for the Scintillator Timing Study





SiPM: Hamamatsu S13360-1325PE

Number of channels	1 channel
Effective photosensitive area	1.3 x 1.3 mm^2
Number of pixels per channel	2668
Pixel size	25 µm
Spectral response range	320 … 900 nm
Gain (typical)	$7.0 \cdot 10^5$

Information taken from: https://www.hamamatsu.com/eu/en/product/type/S13360-1325PE/index.html

System Stability

- Use 1 p.e. calibration values to assess system stability over the measurement period
- The calibration factor gives the integrated signal area that corresponds to one photoelectron