Intrinsic Time Resolution of AHCAL SiPM-on-Tile Technology

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Contribution to the
CALICE Collaboration Meeting

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AHCAL Technological Prototype

Scintillator Tiles:

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

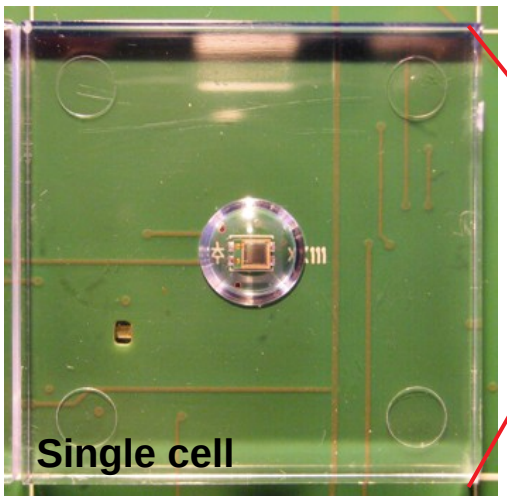
Active Layer:

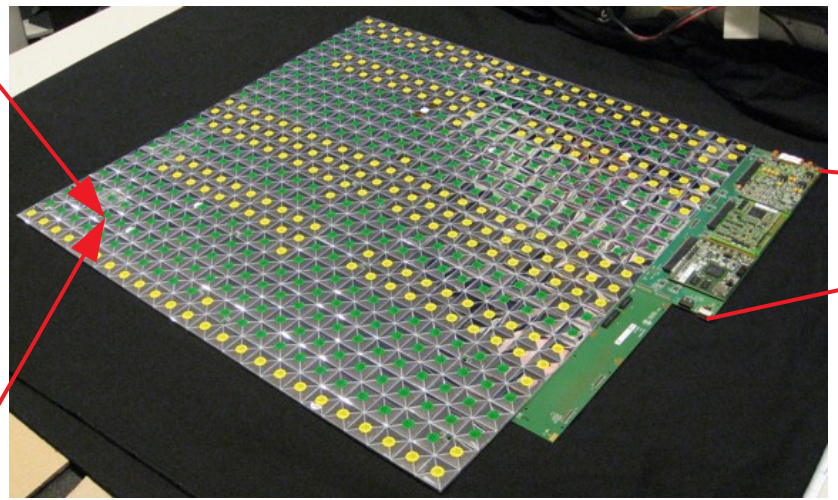
- Tiles placed directly on PCB
- Individual SiPM readout for each channel

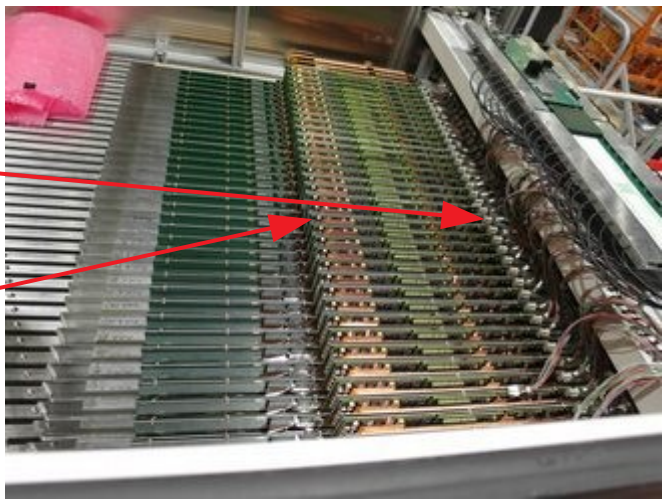
Large Technological Prototype:

40 fully assembled layers

- 17 mm steel absorbers
- 3 mm scintillator tiles

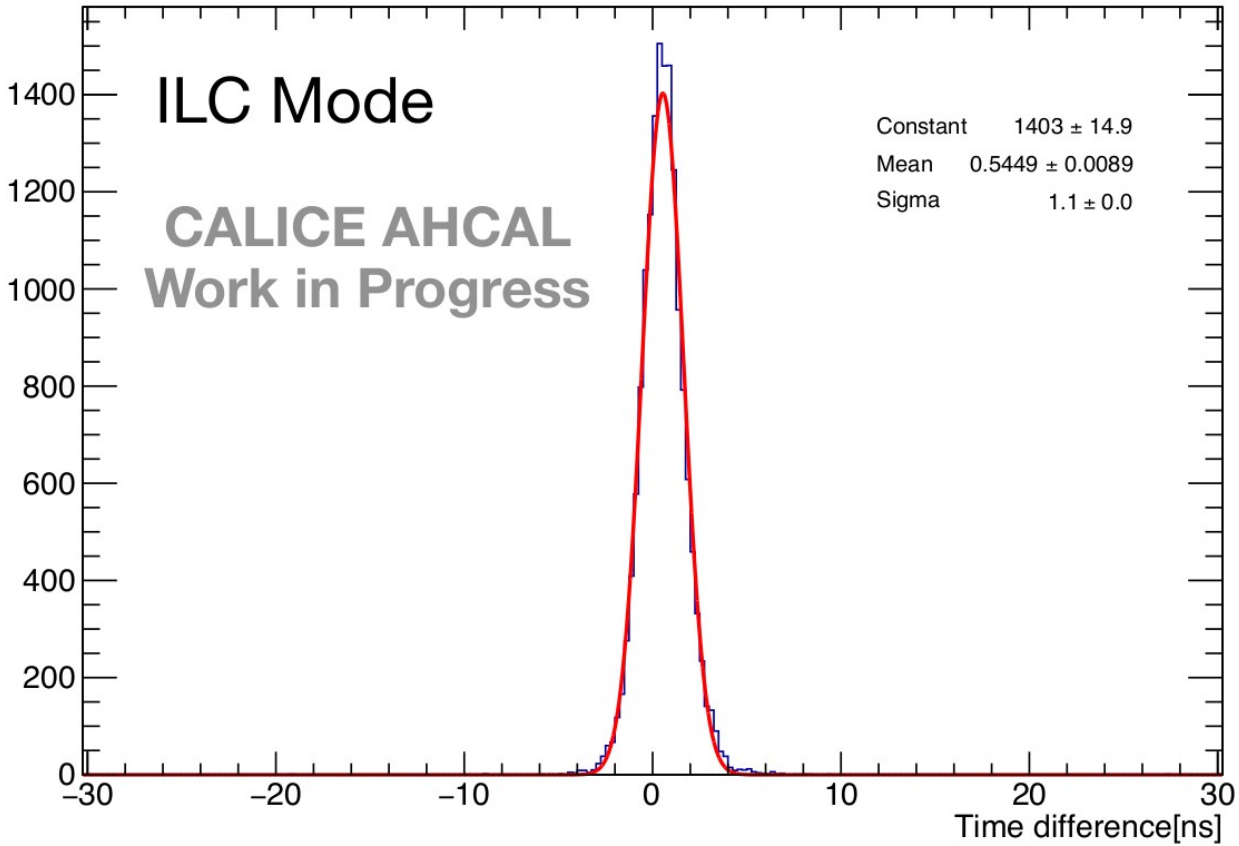






AHCAL Timing Performance

- 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:

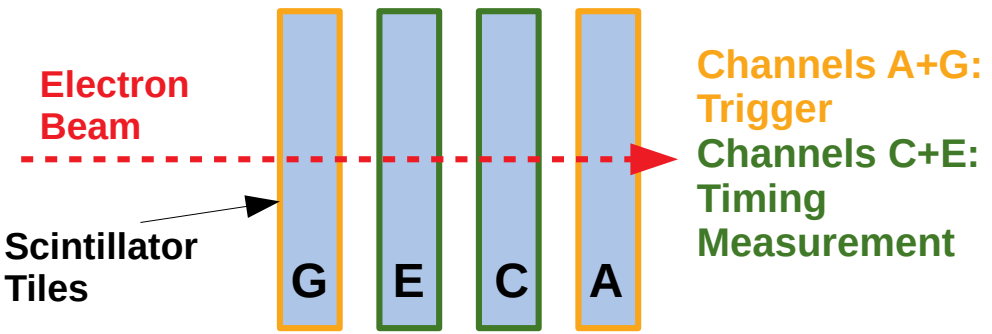
- Independent of the AHCAL electronics and DAQ
- In a simple but modular setup
- Without involved calibration and reconstruction procedures
- With high particle rates and controlled energies

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



Scintillator Timing Setup

Stack of 4 scintillator tiles:

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

↓ **Cat 7 Ethernet cable**

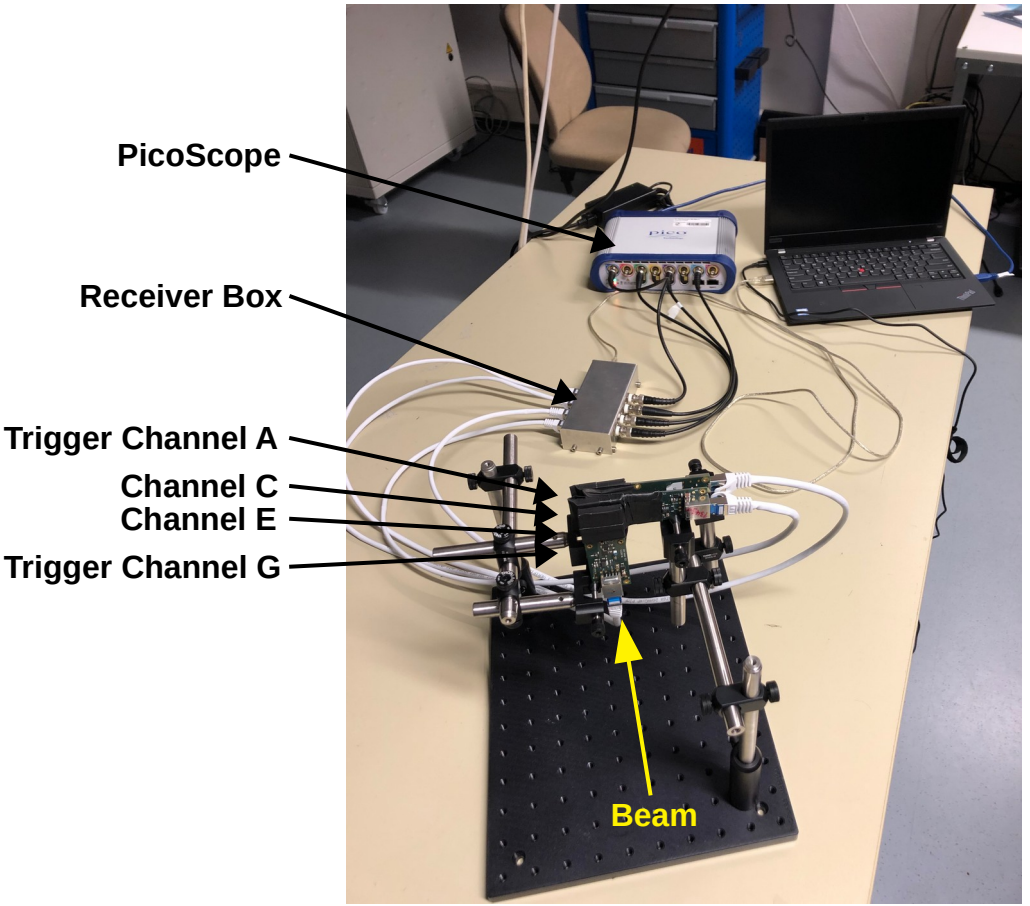
Receiver Box:

- 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



Scintillator Timing Study (3)

Scintillator Timing Study Test Beam (October 2020, DESY):
~ *estimated event numbers* in units of 10^8 events

• Investigation of AHCAL tiles 30x30 mm²:	~ *2.19*	**Primary objective**
• Investigation of BC408 tiles 30x30 mm²:	~ *1.62*	**Secondary objectives:** • Material dependence • Tile size dependence
• Investigation of BC408 tiles 20x20 mm²:	~ *1.39*	
• Mix AHCAL and BC408 tiles:	~ *0.27*	
• EM Shower, AHCAL tiles 30x30 mm², different numbers of absorbers:	~1.41	**Further investigations:** Showers, signal delays, impact position dependence
• Impact position dependence, AHCAL tiles:	~ 0.36	
• BC408 tiles 30x30 mm², delayed signal:	~ 0.10	

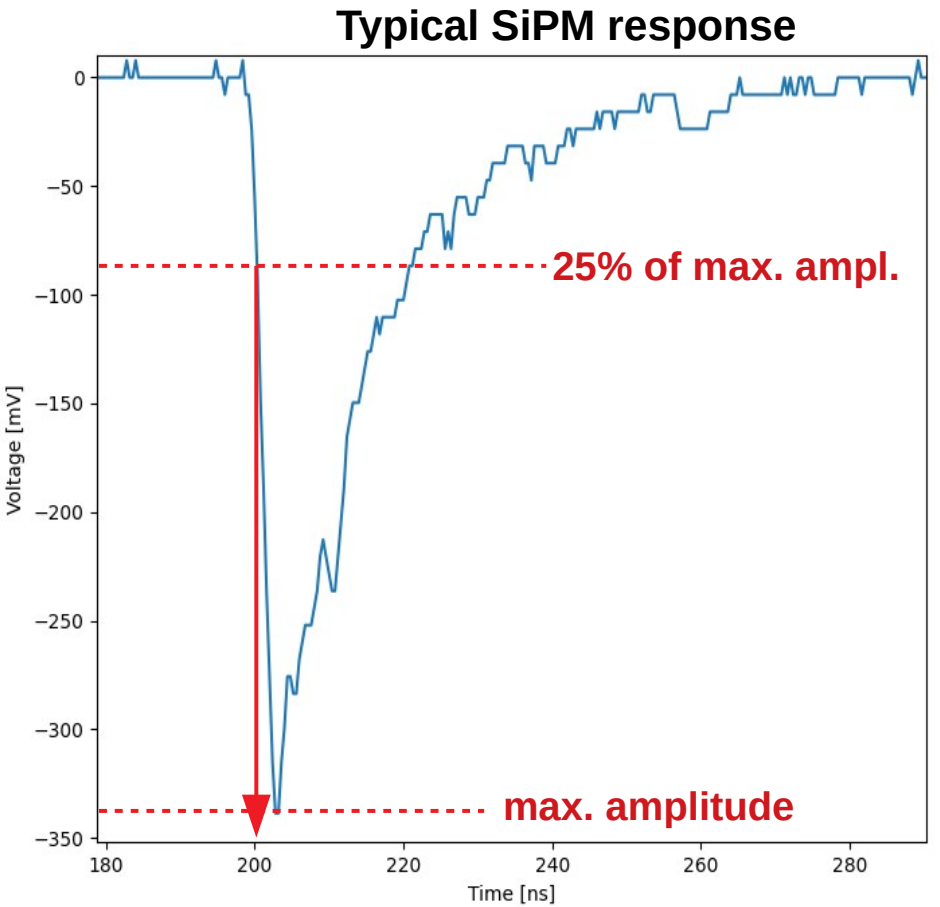
Determining the Time Resolution (1)

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

Leading Edge Method:

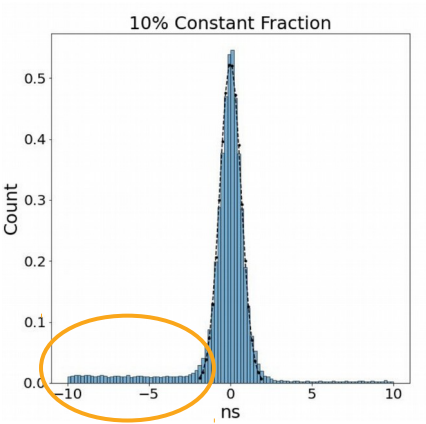
- Set threshold to fixed voltage



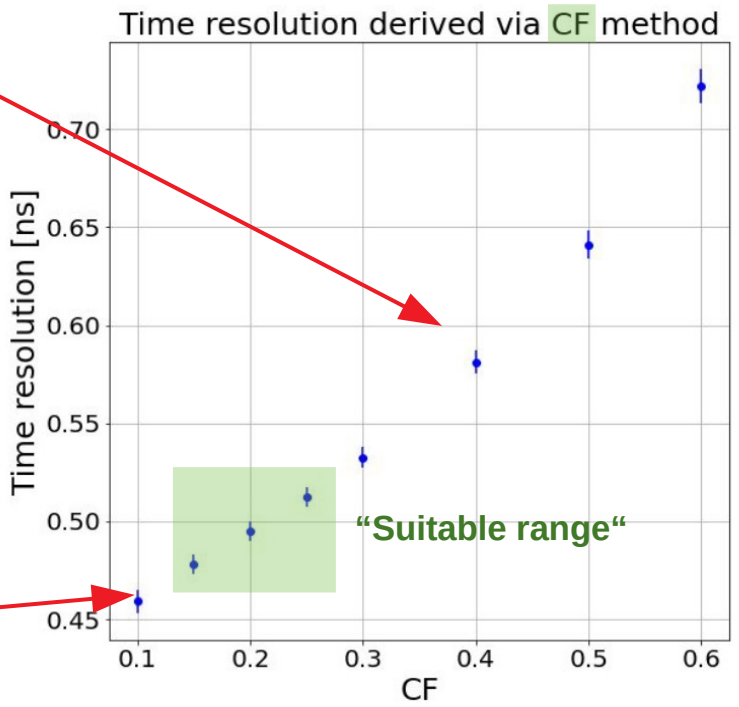
Determining the Time Resolution (2)

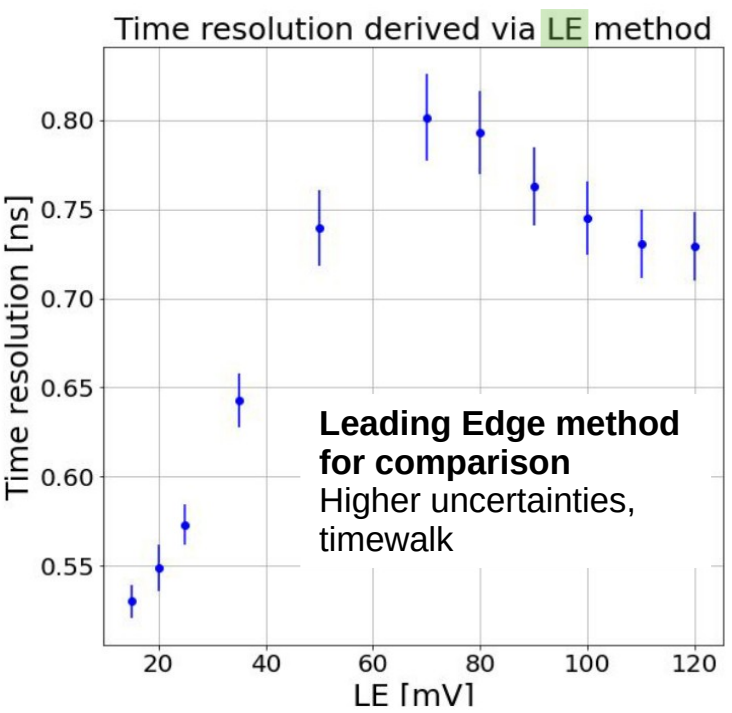
- How was the constant fraction method (and value) chosen?
  - Considered time walk and uncertainties

Too high CF value:
Tendency to greater uncertainties



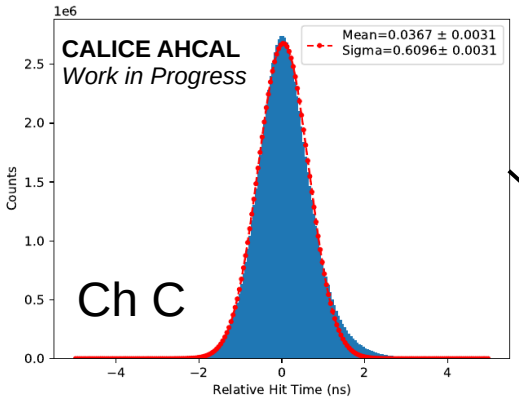
Too low CF value:
Early hits

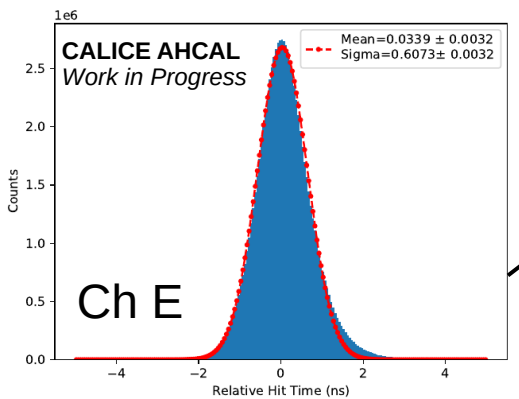




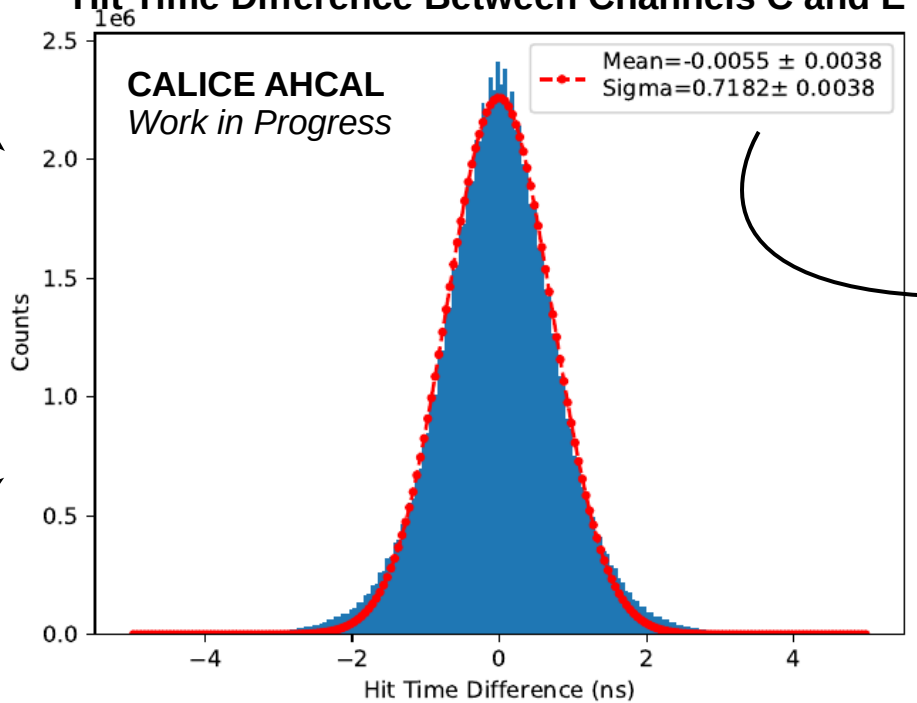
Determining the Time Resolution (3)

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





Hit Time Difference Between Channels C and E

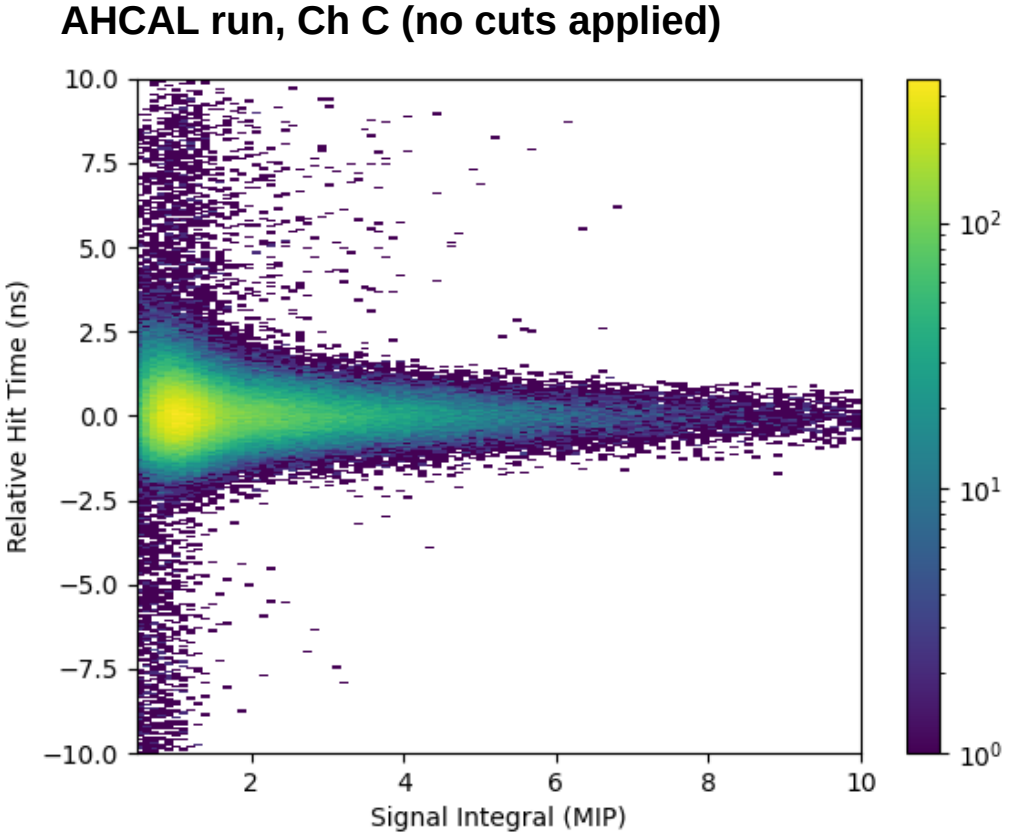


Single Channel Time Resolution:

0.718/√2 = 0.507 ns for AHCAL tiles (30x30 mm²)

Timewalk Correction (1)

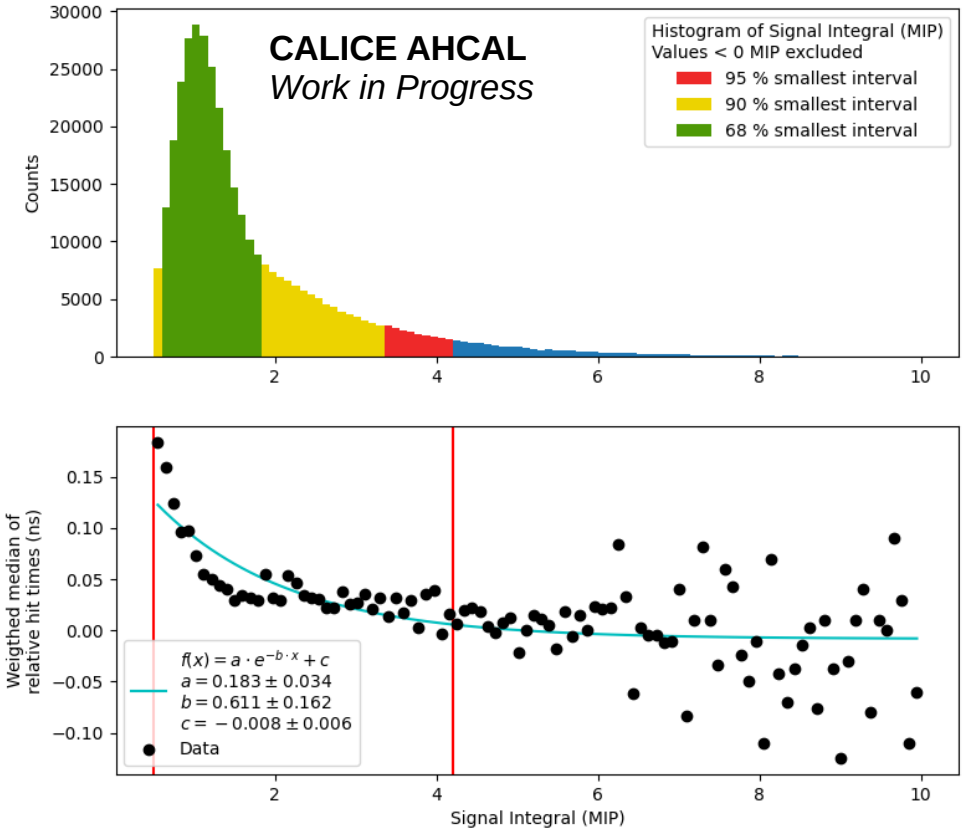
- No significant impact of timewalk expected (because of CF)
- Observed: Slight asymmetry in relative hit time vs. signal integral
- Variation of hit times high compared to timewalk



Timewalk Correction (2)

- For each energy bin, compute the weighted median of the hit times (lower plot)
- Fit exponential function
- For each event, subtract the function's value at the event's energy
- Does not change time resolution significantly

AHCAL run, Ch C (no cuts applied)



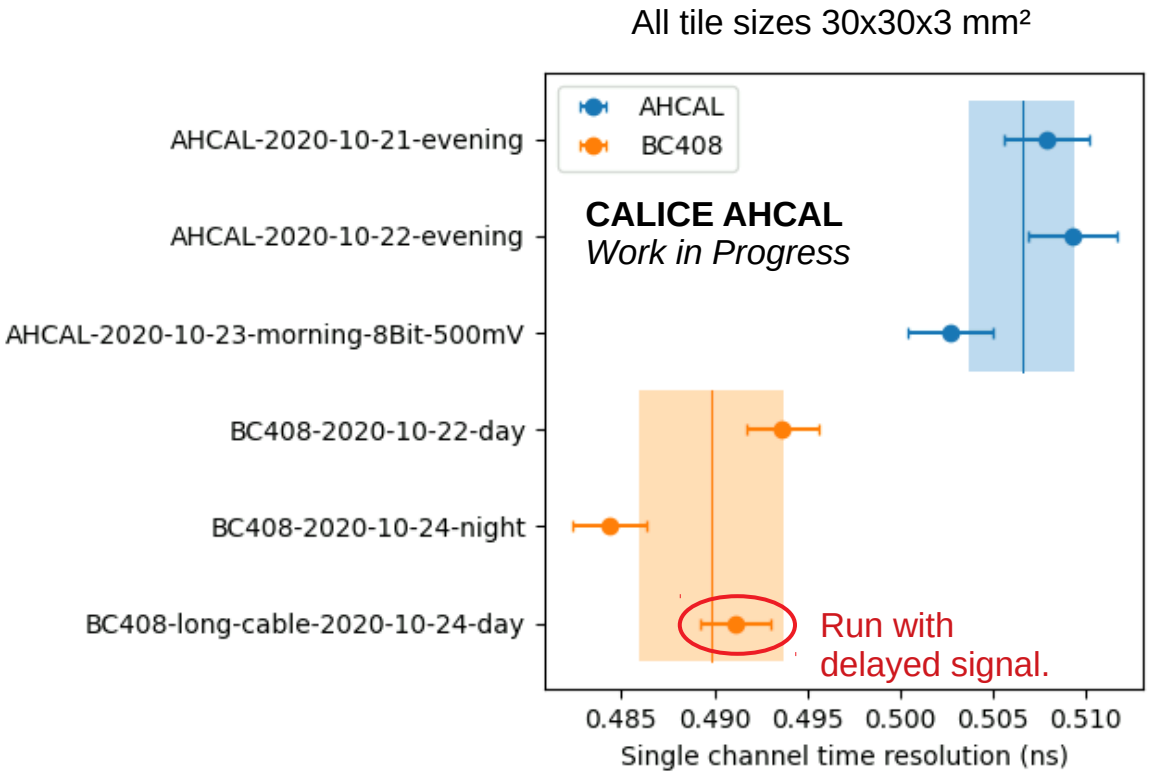
Findings: AHCAL Time Resolution

Single Channel Time Resolutions:

AHCAL tiles 30x30x3 mm³
(506.5 ± 2.5) ps

- AHCAL *tiles*: single channel time resolution of **0.507 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: Material Dependence



- BC408 tiles have slightly better time resolution than AHCAL tiles
- BC408 has higher light yield than PS used in AHCAL
- Higher light yield → shorter rise time

$$\sigma_t \propto \frac{1}{dV/dt}$$

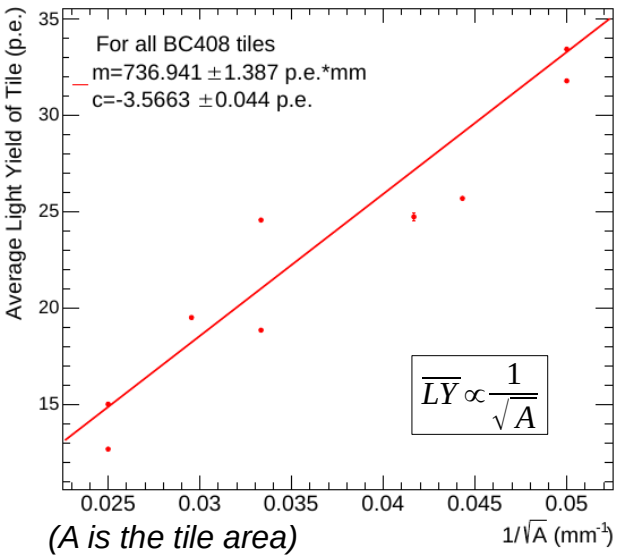
AHCAL (PS) 30x30x3 mm³	**BC408** 30x30x3 mm³
(506.5 ± 2.8) ps	(489.9 ± 3.9) ps

Findings: Tile Size

Single Channel Time Resolutions:

BC408 30x30x3 mm³	**BC408** 20x20x3 mm³
(489.9 ± 3.9) ps	(370.9 ± 1.2) ps

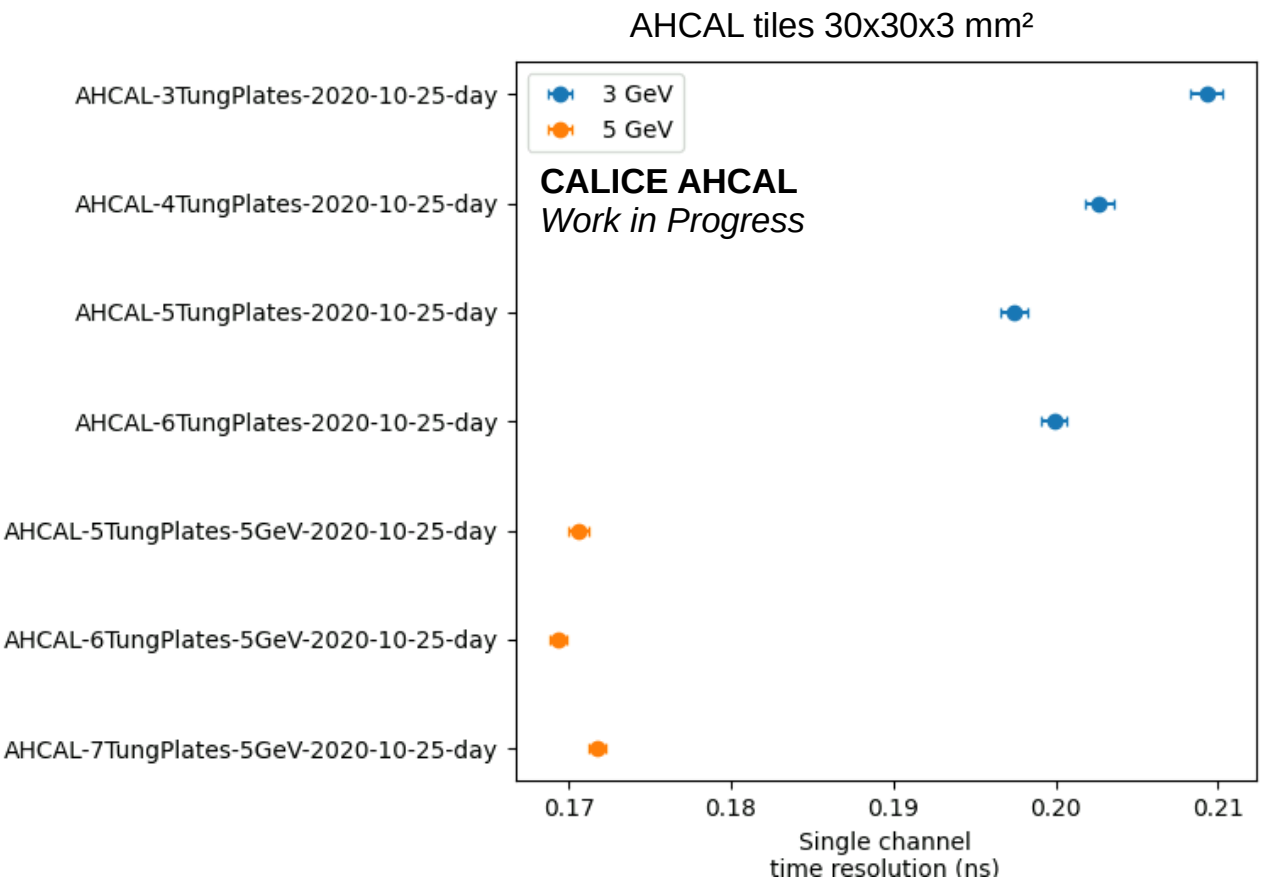
- Tile size has huge impact on time resolution
  - Area or volume dependent?
- We expect that higher light yield results in better time resolution
- Previous work has shown that smaller tiles have a higher light yield
- Further studies required

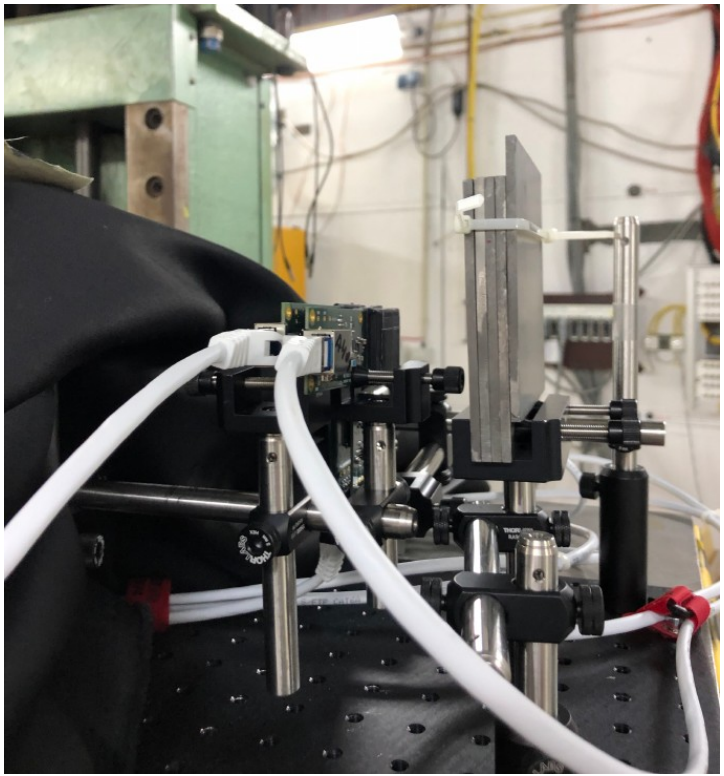


(A is the tile area)

Figure from Malinda De Silva‘s Master Thesis

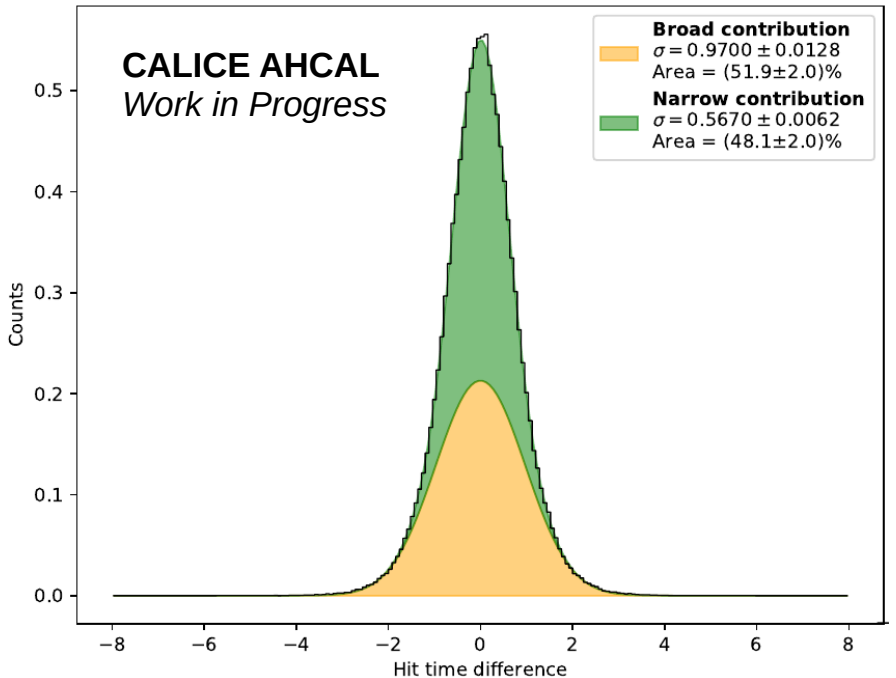
Outlook: EM Showers





Summary & Next Steps

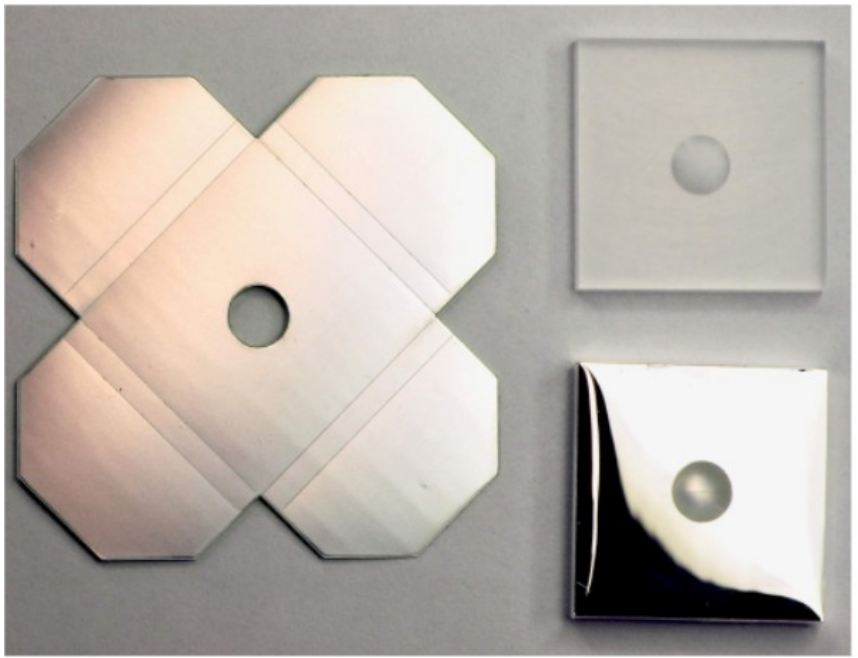
- Analysis of full dataset ongoing
  - Investigate hit time distribution
  - Energy dependent timing analysis
- Geant4 simulation: Gain a better understanding of the observed results
- Goals for next timing study test beam: Measure time resolution for more different tile sizes and thicknesses
- Measurements with muons (at least for bigger tiles)

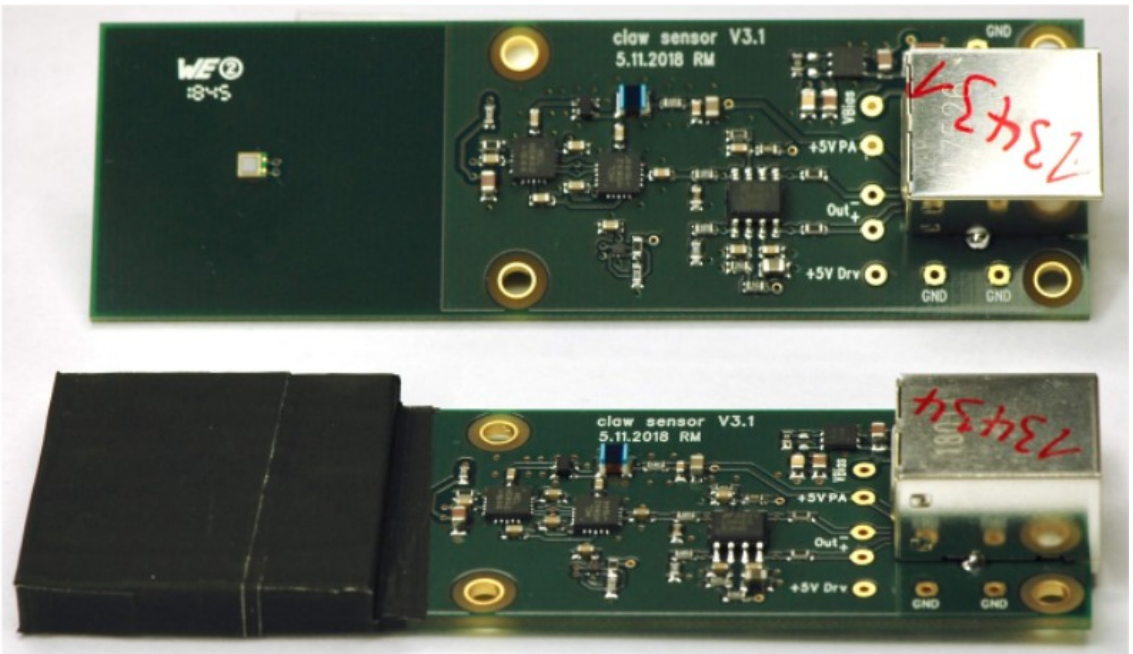


The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Backup Slides

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