Time Resolution Measurements with the SiPM-on-Tile Technology

Testbeam Results

MAX-PLANCK-INSTITUT
FÜR PHYSIK

Lorenz Emberger, Fabian Hummer, Frank Simon

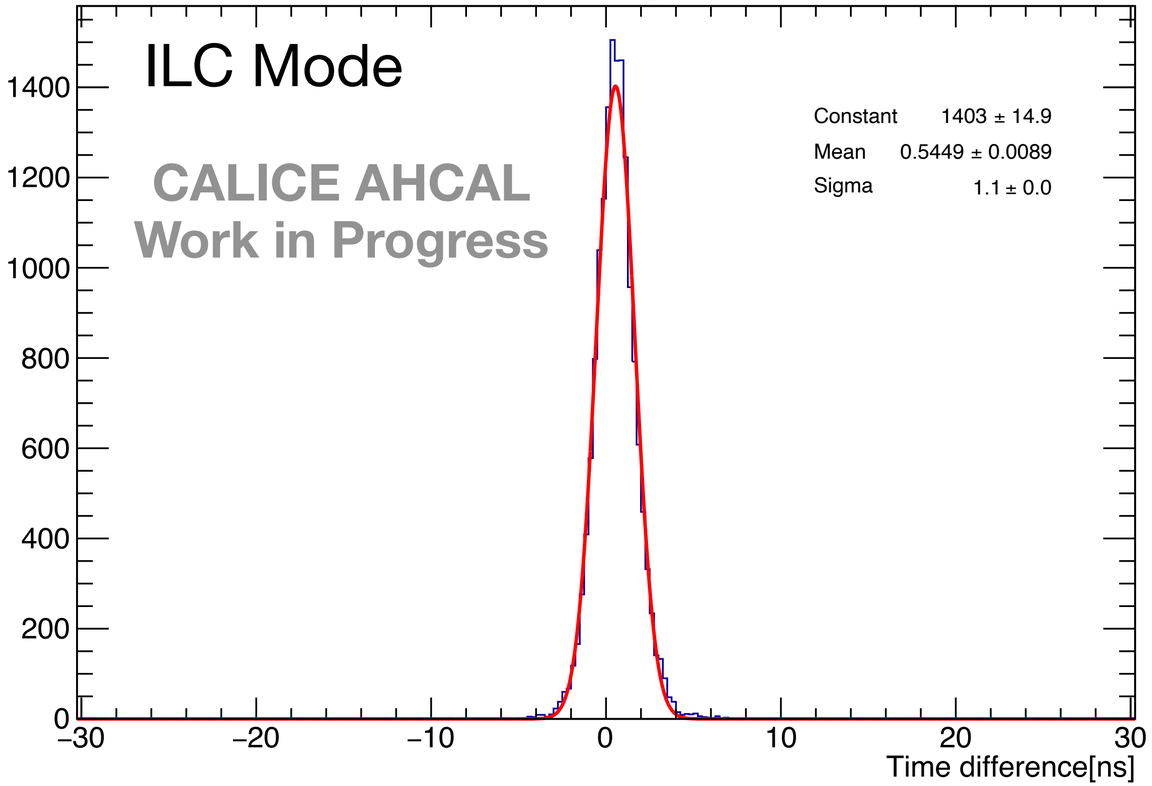
CALICE Collaboration Meeting - IJCLab 2021

Scintillator Timing Setup

MAX-PLANCK-INSTITUT FÜR PHYSIK

Motivation: Understand contribution of front end and SiPM-on-Tile to the time resolution of the AHCAL

AHCAL technological prototype

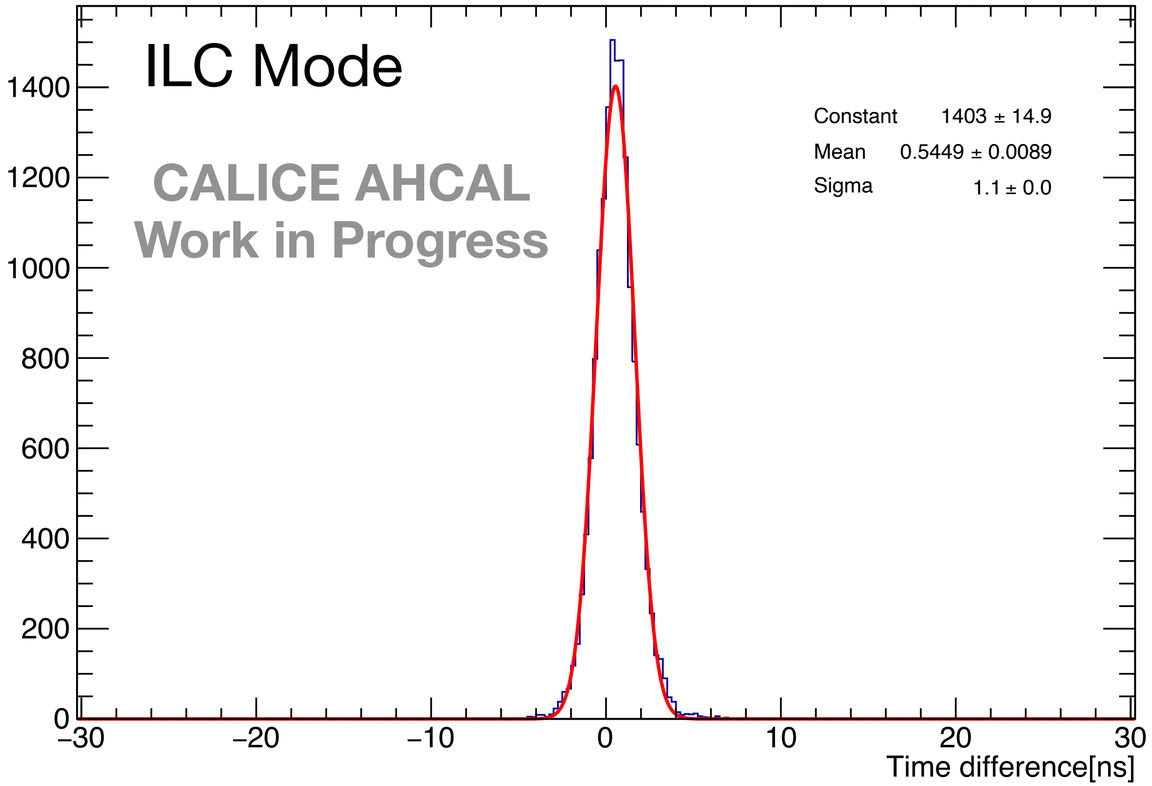


Single channel resolution: 1.1/√2 = 0.78ns

Scintillator Timing Setup

<u>Motivation</u>: Understand contribution of front end and SiPM-on-Tile to the time resolution of the AHCAL

AHCAL technological prototype

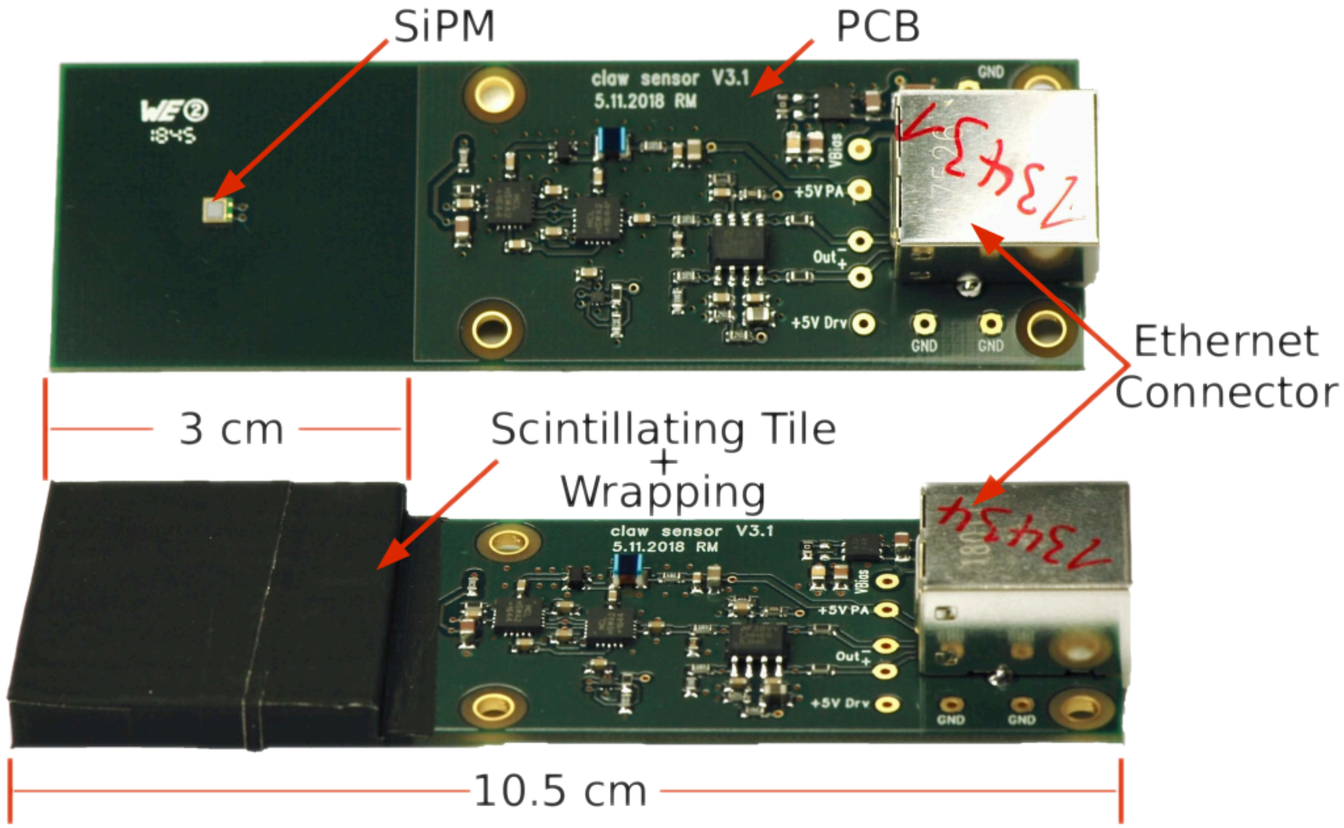


Single channel resolution: 1.1/√2 = 0.78ns

Strategy: 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 rate and controlled energies

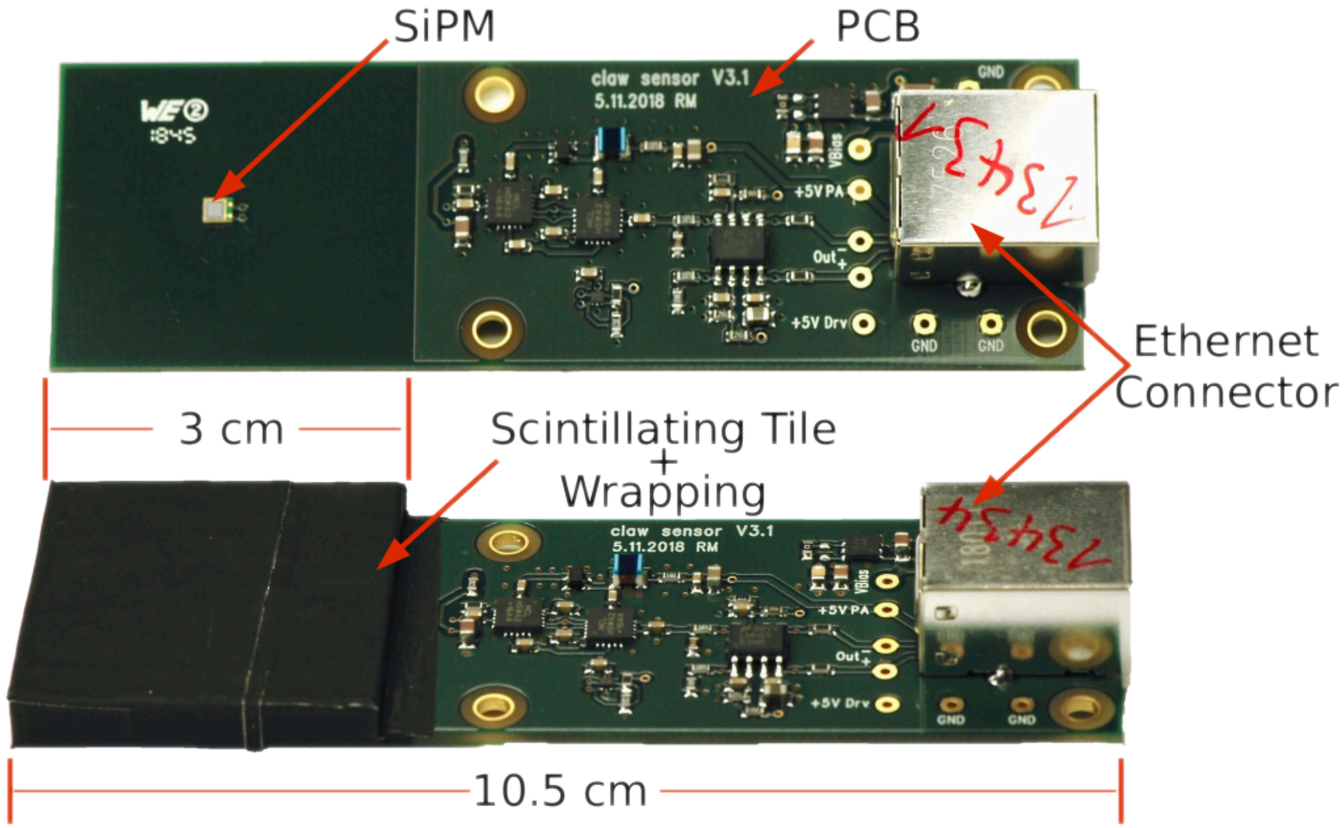
Beam Test Setup



Beam Test Setup

Stack of 4 Tiles:

- BC408 or AHCAL Scintillator
- Hamamatsu S13360-1325PE



Beam Test Setup

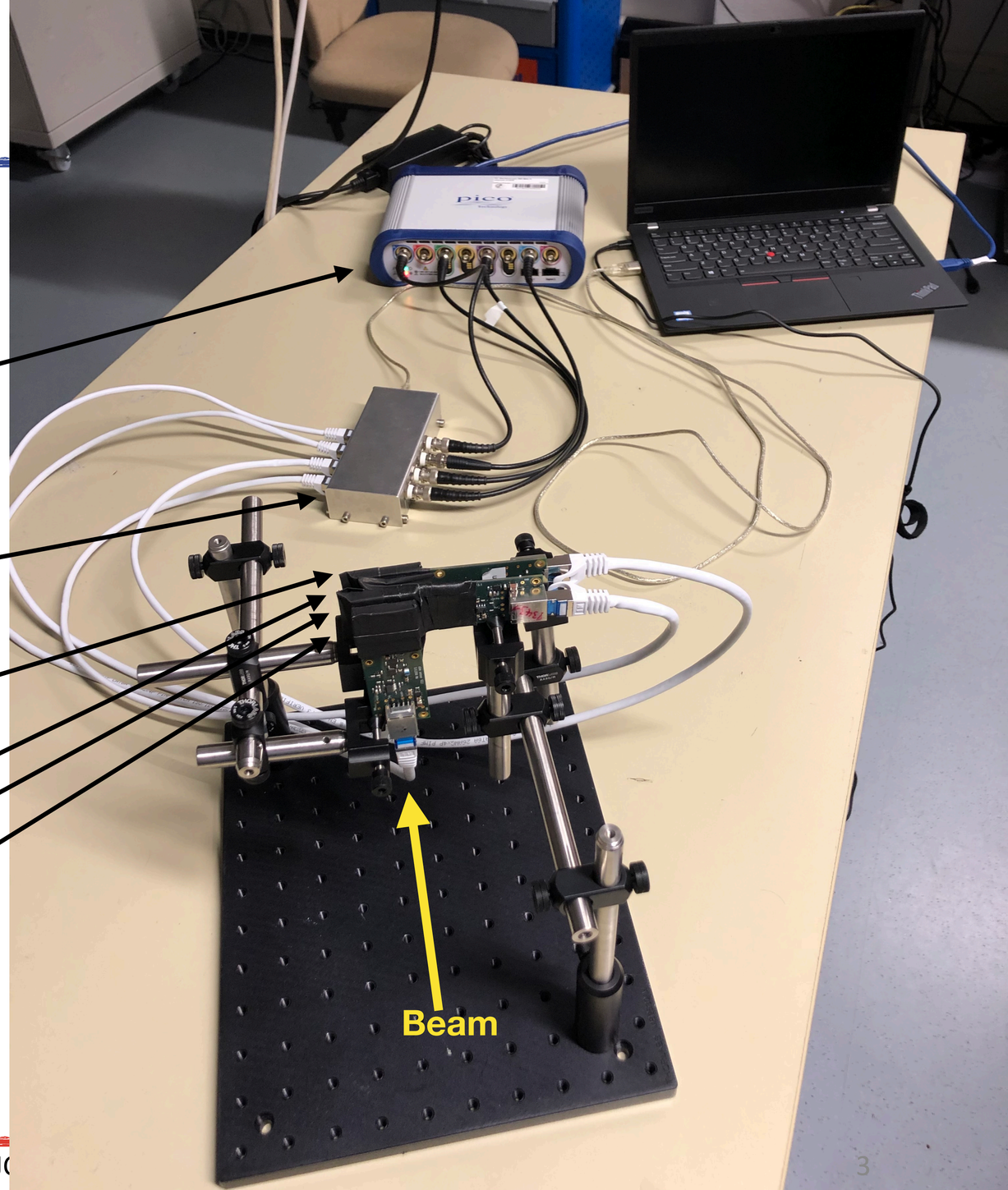
Stack of 4 Tiles:

- BC408 or AHCAL Scintillator
- Hamamatsu S13360-1325PE

Ethernet Cat 7

Receiver Box:

- USB controlled power supply
- Split signal and power lines



Beam Test Setup

Stack of 4 Tiles:

- BC408 or AHCAL Scintillator
- Hamamatsu S13360-1325PE

↓ **Ethernet Cat 7**

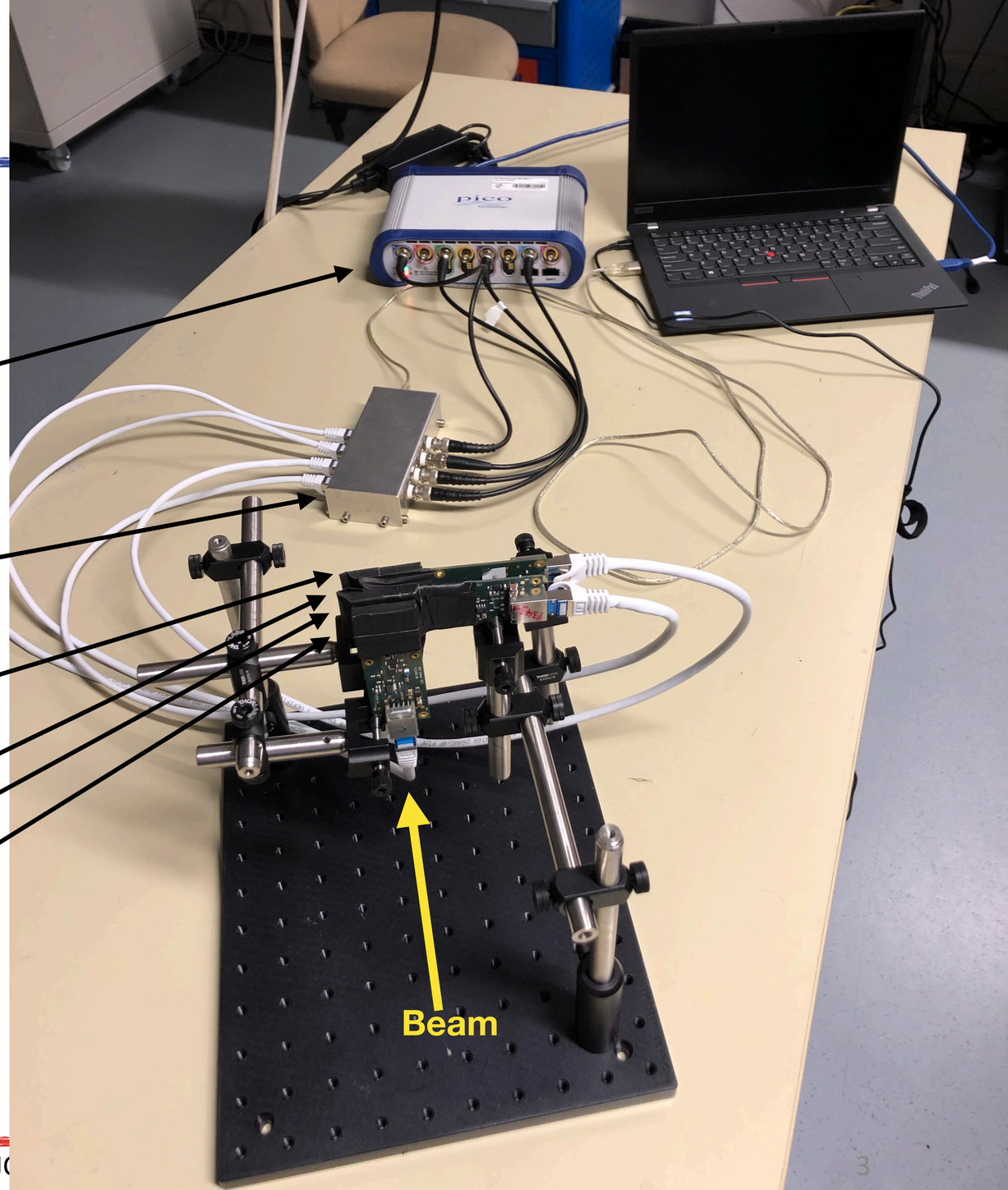
Receiver Box:

- USB controlled power supply
- Split signal and power lines

↓ **BNC**

Picoscope:

- Up to 2.5GHz sampling rate on 4 channels
- 300kHz peak trigger rate
- Save complete analog waveform



Data Taking and Processing

Binary files

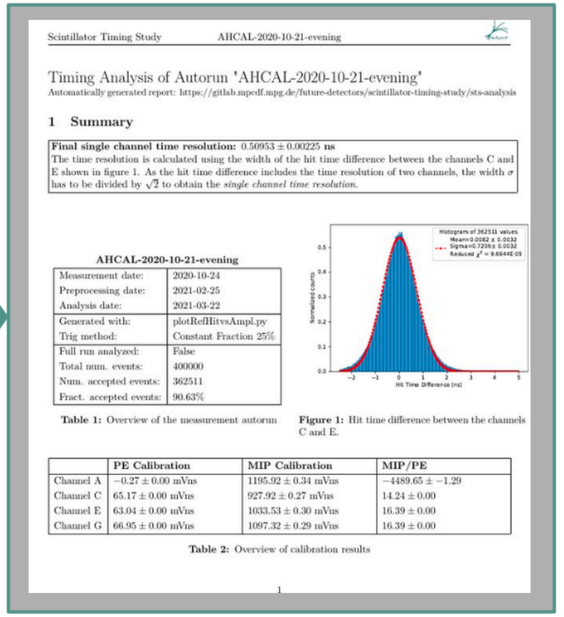
Waveforms

Preprocessing:
Event-based analysis,
MIP calibration

Event based data

.root

Timing Analysis:
Time resolution,
Light yield, ...



Scintillator Timing Study AHCAL-2020-10-21-evening

Timing Analysis of Autorun 'AHCAL-2020-10-21-evening'

Automatically generated report: https://gitlab.mpcdf.mpg.de/future-detectors/scintillator-timing-study/sts-analysis

1 Summary

Final single channel time resolution: 0.50953 ± 0.00225 **ns**
The time resolution is calculated using the width of the hit time difference between the channels C and E shown in figure 1. As the hit time difference includes the time resolution of two channels, the width σ has to be divided by $\sqrt{2}$ to obtain the *single channel time resolution*.

AHCAL-2020-10-21-evening

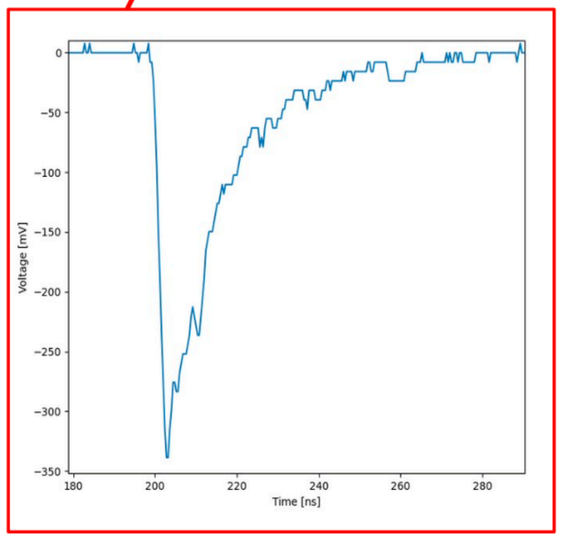
Measurement date:	2020-10-24
Preprocessing date:	2021-02-25
Analysis date:	2021-03-22
Generated with:	plotRelHitvsAmpl.py
Trig method:	Constant Fraction 25%
Full run analyzed:	False
Total num. events:	400000
Num. accepted events:	362511
Fract. accepted events:	90.63%

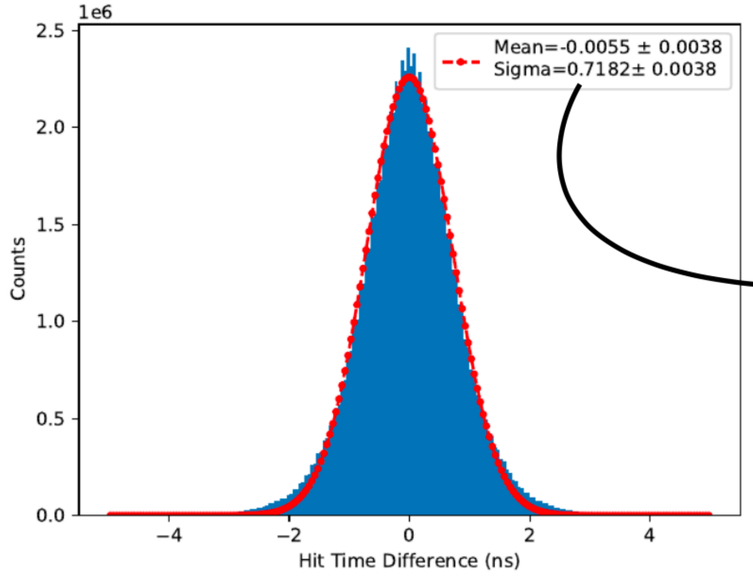
Table 1: Overview of the measurement autorun

Figure 1: Hit time difference between the channels C and E.

	PE Calibration	MIP Calibration	MIP/PE
Channel A	-0.27 ± 0.00 mVns	1195.92 ± 0.34 mVns	-4489.65 ± -1.29
Channel C	65.17 ± 0.00 mVns	927.92 ± 0.27 mVns	14.24 ± 0.00
Channel E	63.04 ± 0.00 mVns	1033.53 ± 0.30 mVns	16.39 ± 0.00
Channel G	66.95 ± 0.00 mVns	1097.32 ± 0.29 mVns	16.39 ± 0.00

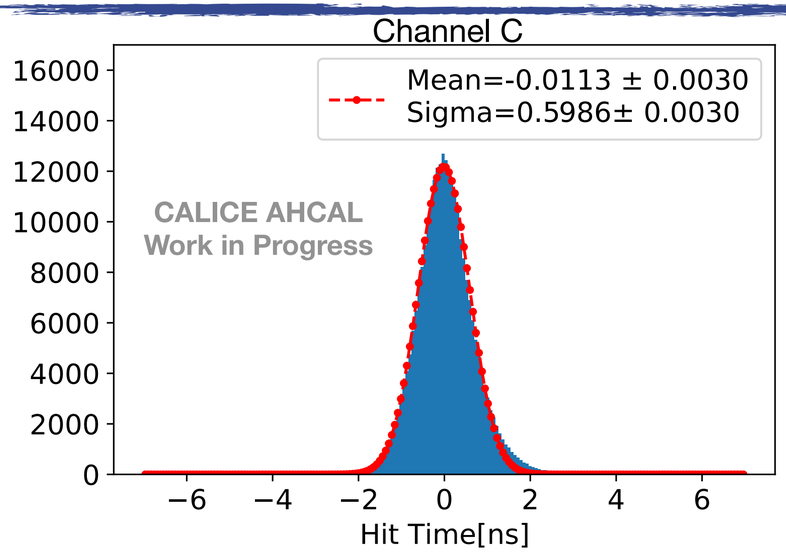
Table 2: Overview of calibration results

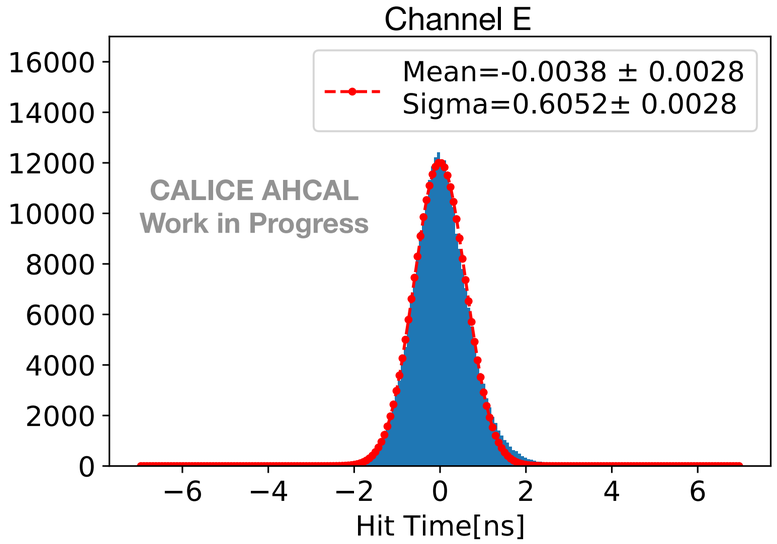




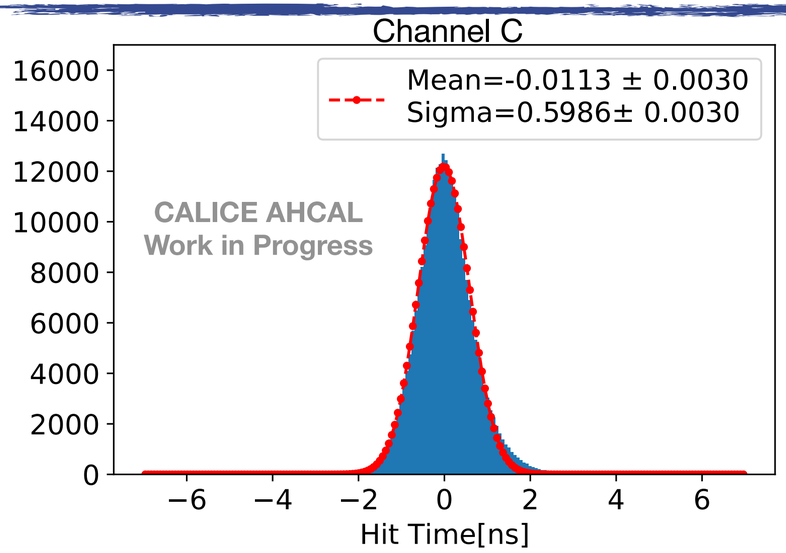
Hit time difference
→ time resolution

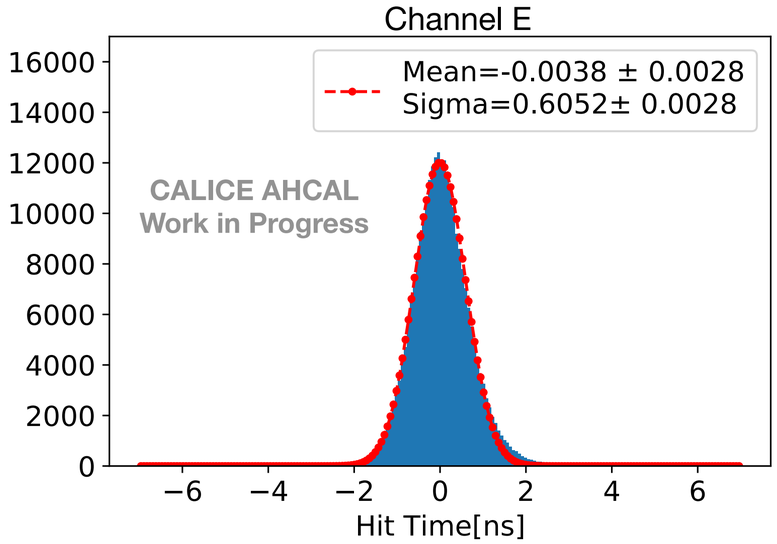
MIP Time Resolution - AHCAL Scintillator

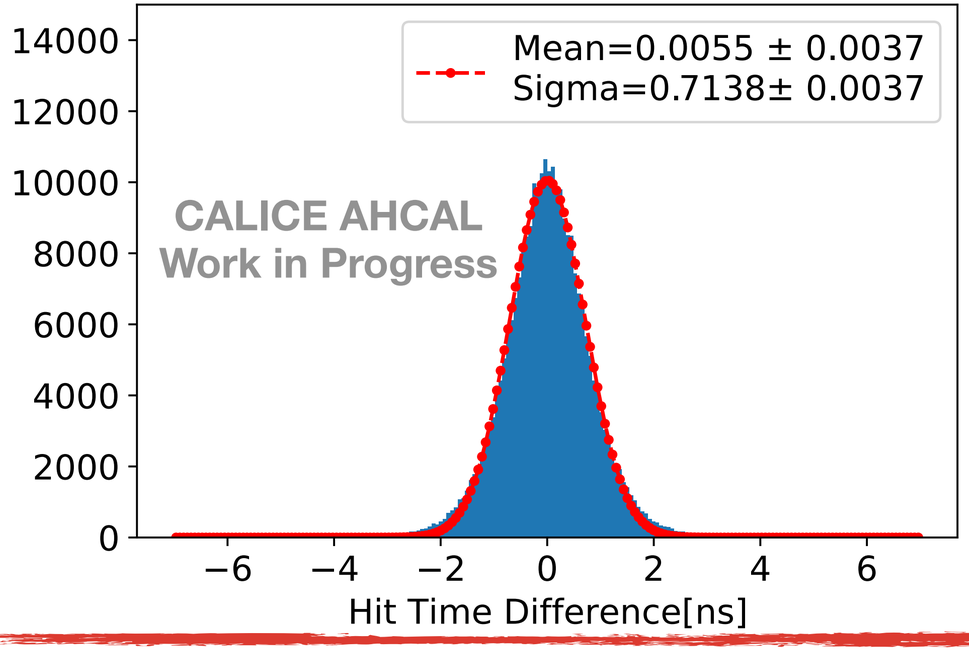




MIP Time Resolution - AHCAL Scintillator







Time resolution=0.714/sqrt(2)=0.505ns

- Interpret as intrinsic time resolution of SiPM-on-Tile

Compared to 0.780ns of the AHCAL:

- AHCAL front-end contributes ~0.6ns

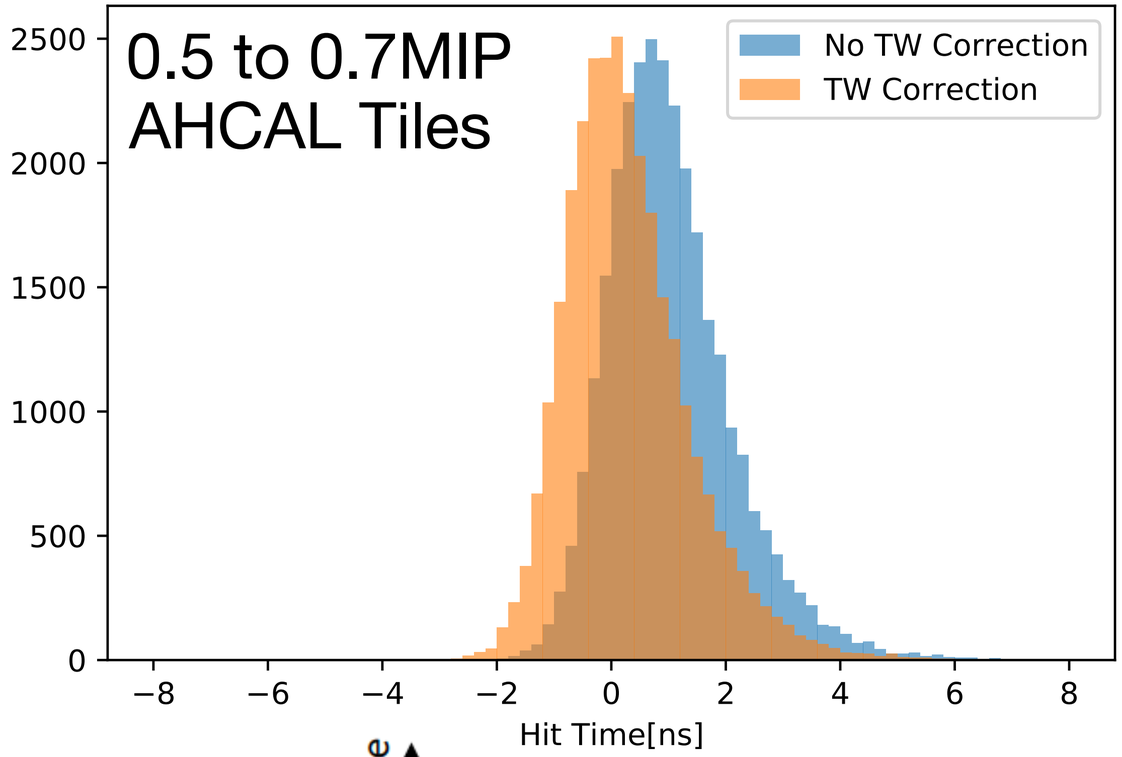
MIP Time Resolution - Comparison

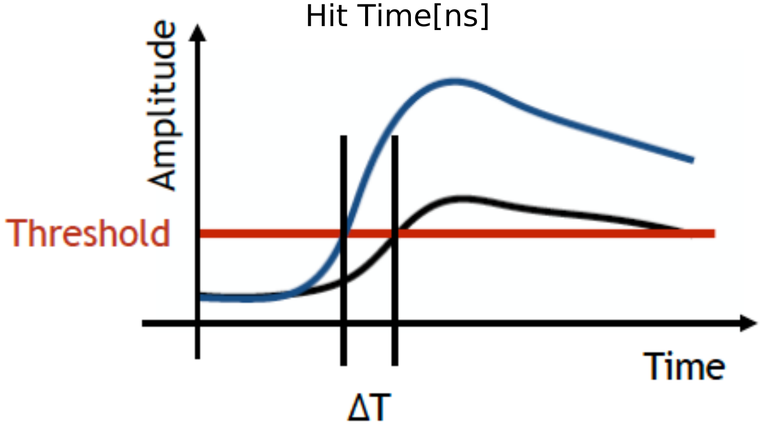
	AHCAL Scintillator 30x30x3mm³	BC408 30x30x3mm³	BC408 20x20x3mm³
MIP Time Resolution	0.505 ns	0.490 ns	0.371 ns

Next Studies:

- Energy binned time resolution (this Talk)
- Simulation of the experiment (next Talk by Fabian Hummer)
- Investigation of hardware time resolution (next Talk by Fabian Hummer)
- Participation in upcoming test beam at DESY

Asymmetric Hit Time Distribution





Hit time distribution of indiv. channel has tail to the right

Two (or more?) possible reasons:

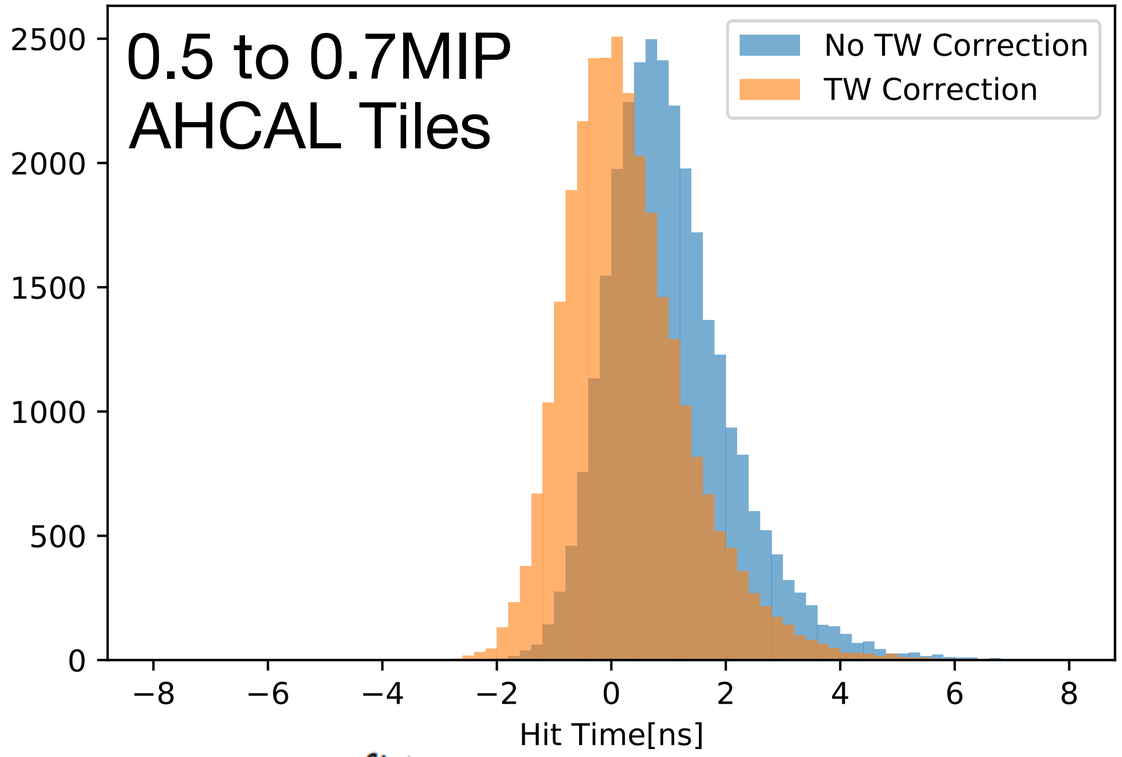
1. Timewalk

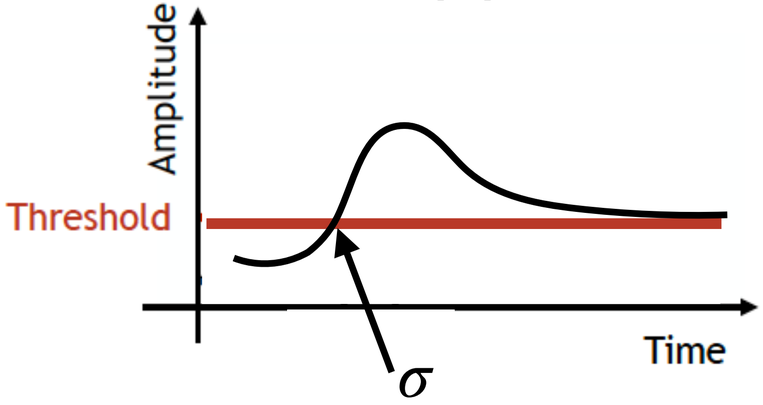
Higher amplitude —> faster rise time:

- Tail contains low energy events

But: Tail also present after time walk correction

Asymmetric Hit Time Distribution





Hit time distribution of indiv. channel has tail to the right

Two (or more?) possible reasons:

1. Timewalk
2. Photon emission and counting

Different times of threshold crossing of signals of the same amplitude due to:

- asymmetric emission time distribution of the scintillator
- detector noise
- poisson counting

Energy Binned Time Resolution

Binning of time walk corrected dataset:

- 0.2 MIP bins from 0.5 MIP to 5.1 MIP hit energy
- 0.4 MIP bins from 5.1 MIP to 7.5 MIP hit energy
- 1 MIP bins from 7.5 MIP to 15.5 MIP hit energy (mainly from absorber runs)

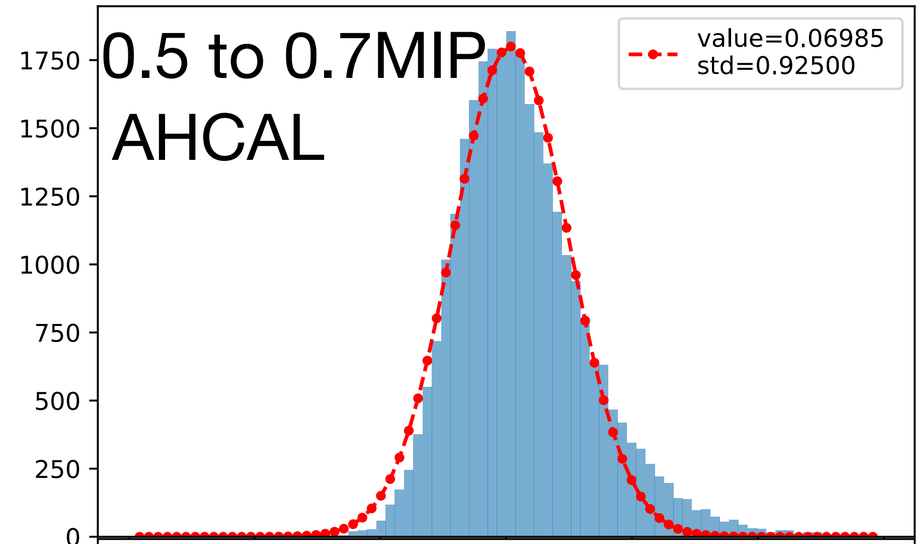
Only accept events with both hits within the same energy bin (only 10% of events)

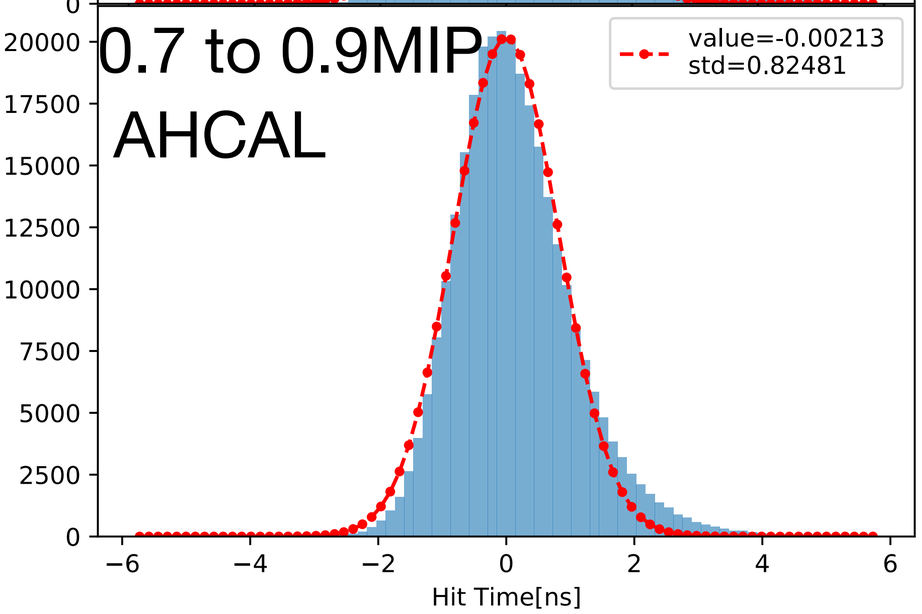
Trigger time obtained with constant fraction discrimination (elim. time walk in trigger)

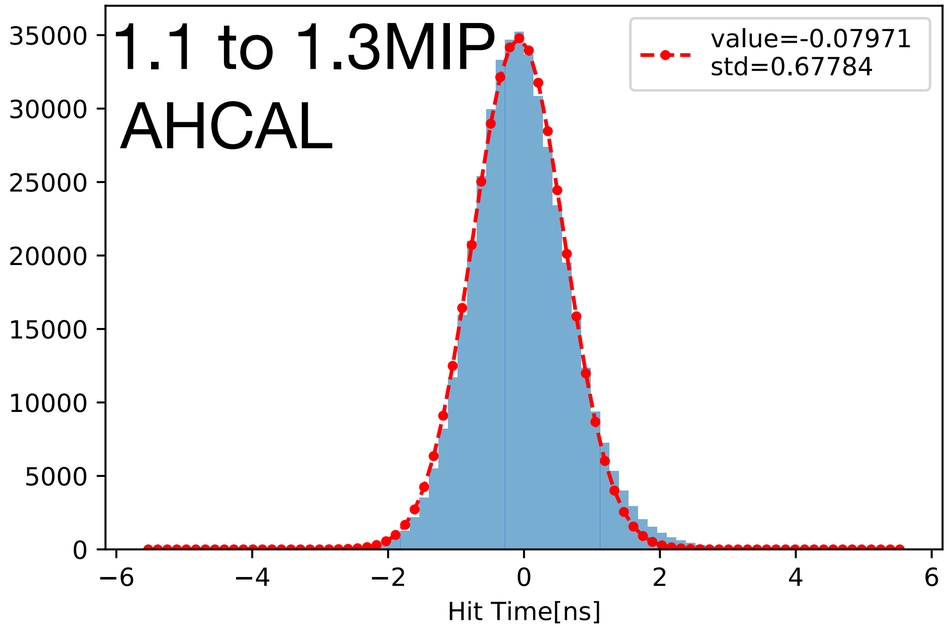
Signal times obtained with fixed amplitude threshold (25mV = ~3 pe) to :

- Disentangle effects from time walk and scintillator/photon counting
- Investigate different thresholds

Energy Binned Distributions







Distributions get narrow and approach a gaussian:

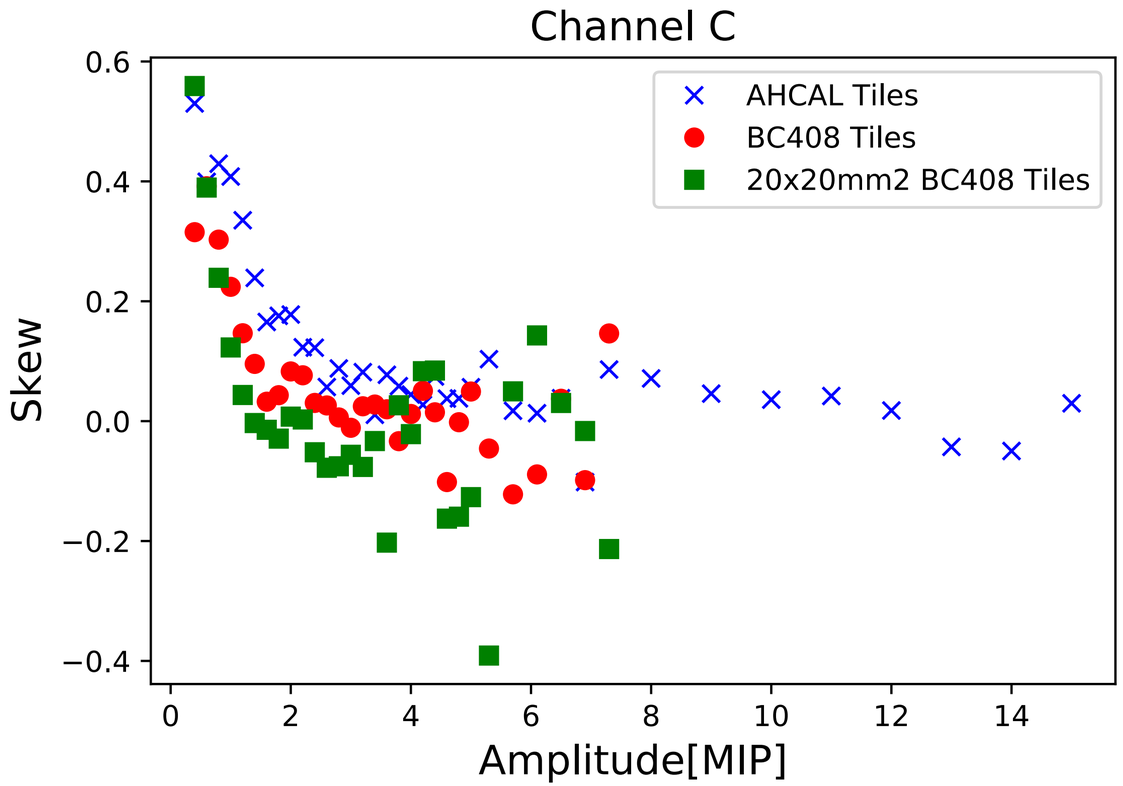
- Study evolution of skew with energy

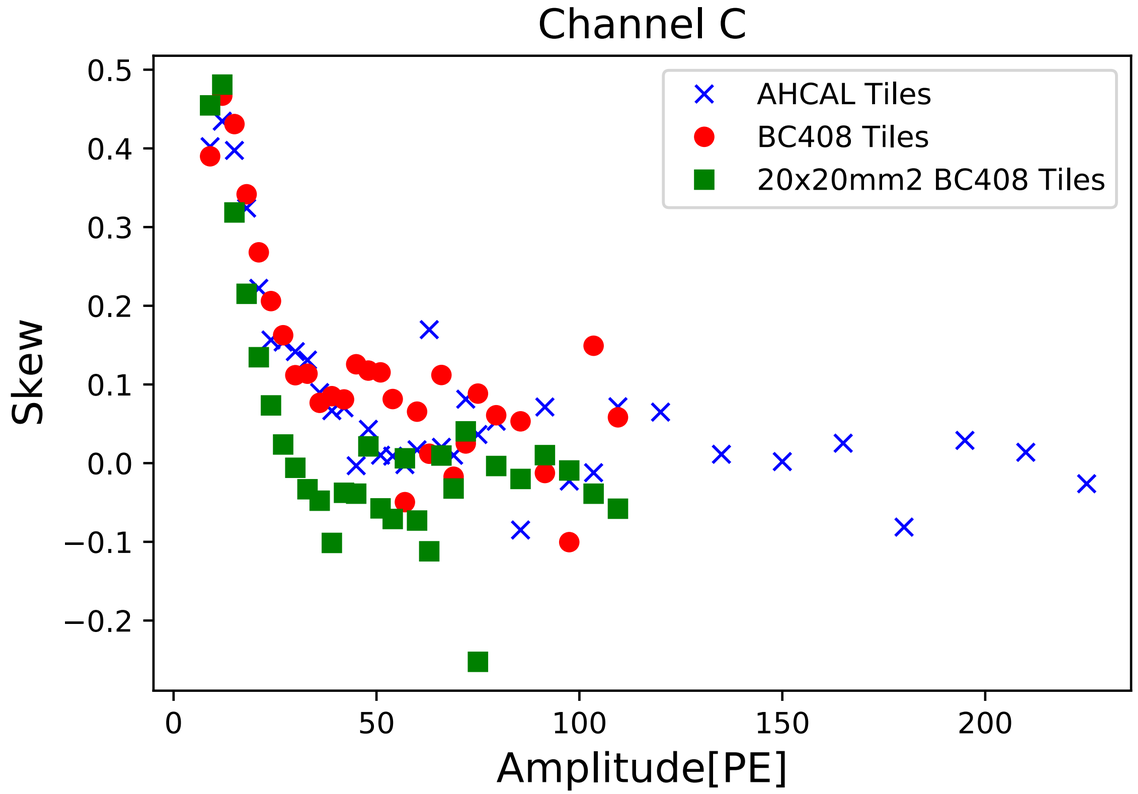
Asymmetric Hit Time Distribution

Studied Scenarios:

- AHCAL Scintillator 30 x 30 x 3 mm^3
- BC408 30 x 30 x 3 mm^3 and 20 x 20 x 3 mm^3

AHCAL:14.3 pe/MIP
BC408: 22.87 pe/MIP
20 x 20mm2 BC408: 21.85 pe/MIP

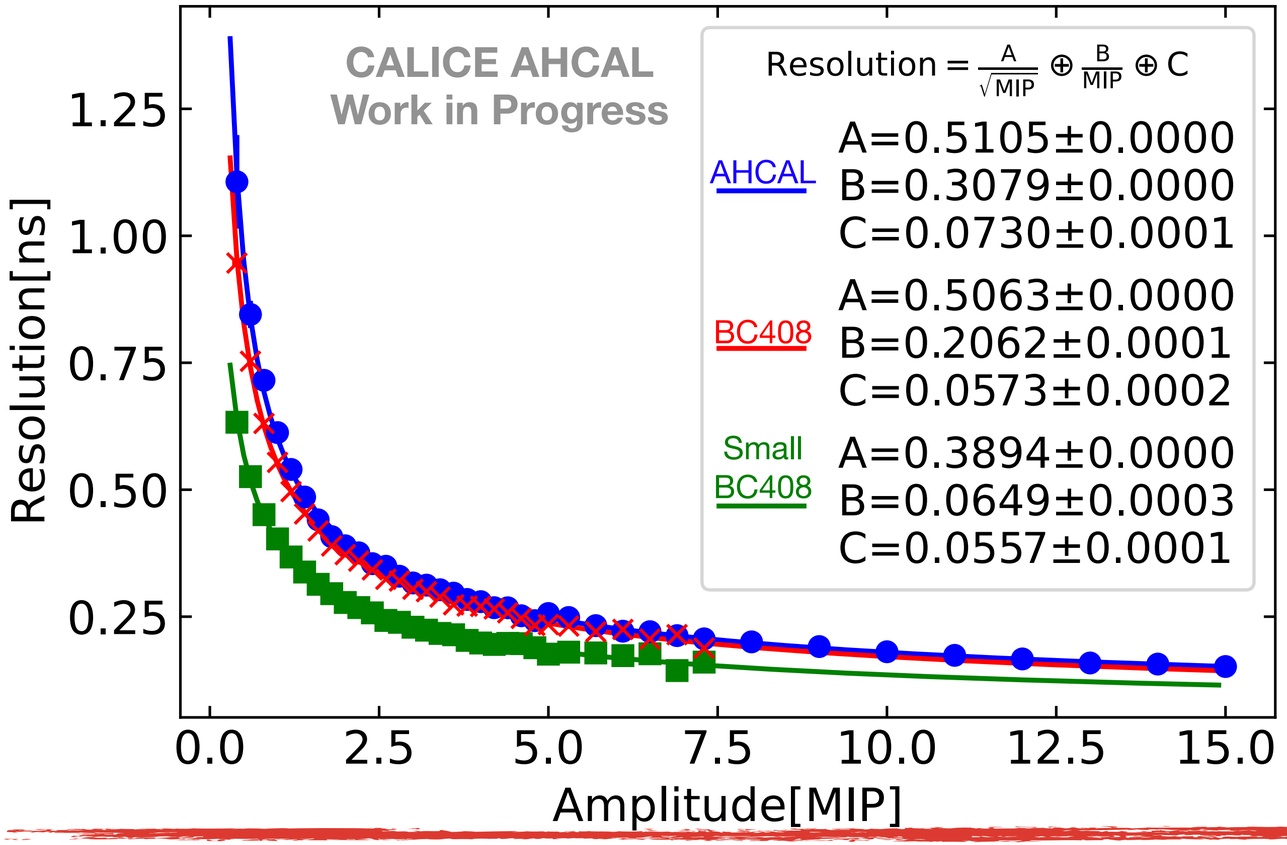




Energy Dependent Time Resolution

Studied Scenarios:

- AHCAL Scintillator 30 x 30 x 3 mm^3
- BC408 30 x 30 x 3 mm^3 and 20 x 20 x 3 mm^3



Poissonian statistics well reproduced:

- Material and size dependent

Noise (B) contribution to be understood

Sub 100ps for very high signals

Plans for Upcoming Test Beam

Impact of tile size on time resolution:

- 20mm x 20mm, 30mm x 30mm, 40mm x 40mm

Impact of scintillator properties on time resolution:

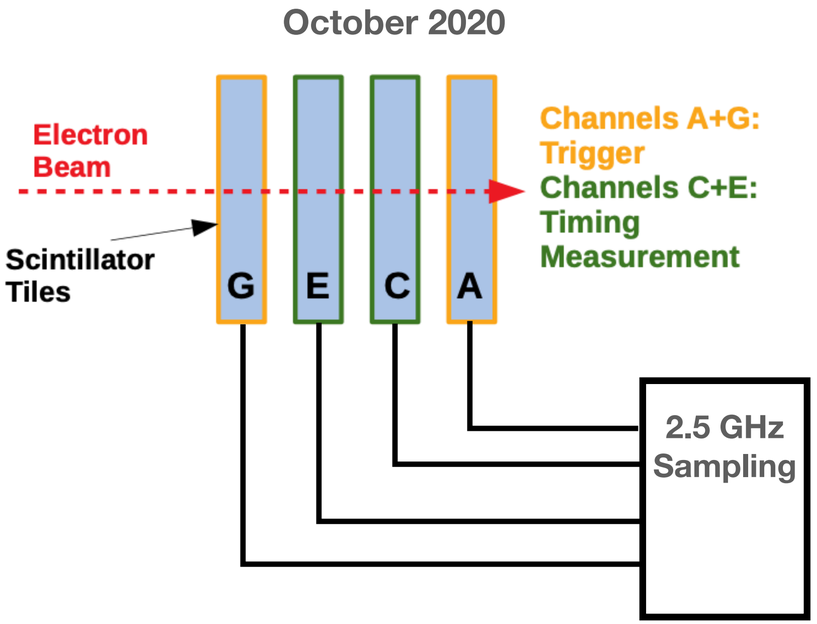
Properties	BC404	BC408	BC418	BC422Q
Light Output, %Anthracene	68	64	67	19
Rise Time (ns)	0.7	0.9	0.5	0.11
Decay Time (ns)	1.8	2.1	1.4	0.7
Pulse Width FWHM (ns)	2.2	2.5	1.2	0.36

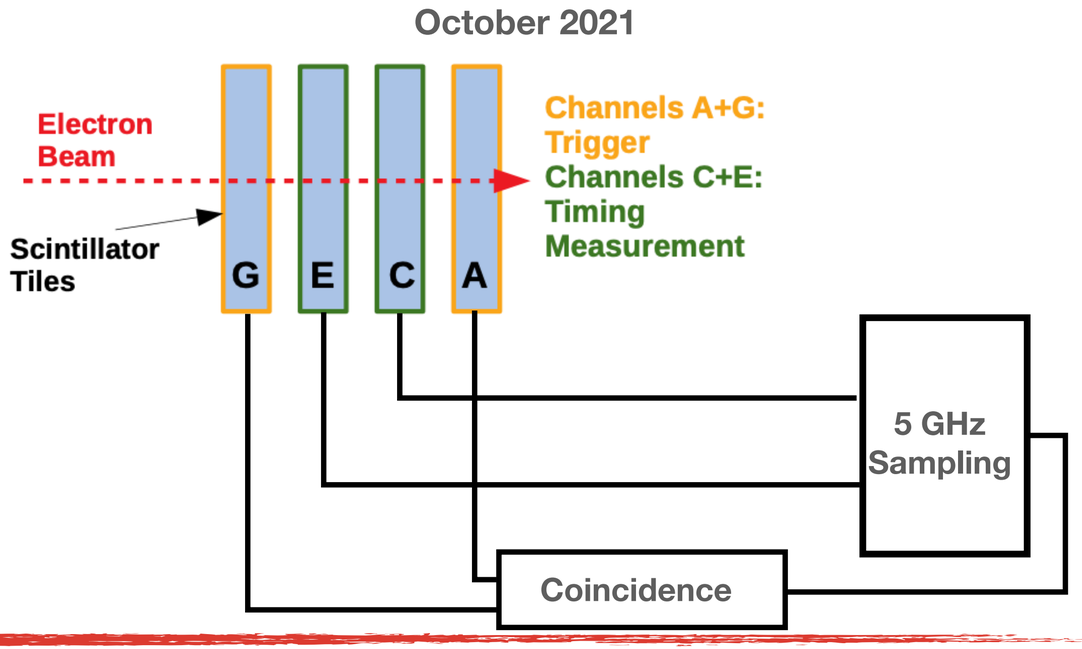
From crystals.saint-gobain.com

Plans for Upcoming Test Beam

Modifications to the setup:

- Improved mechanical stability
- Cooling plates for gain stability
- External trigger generation to enable 200ps sampling





Summary

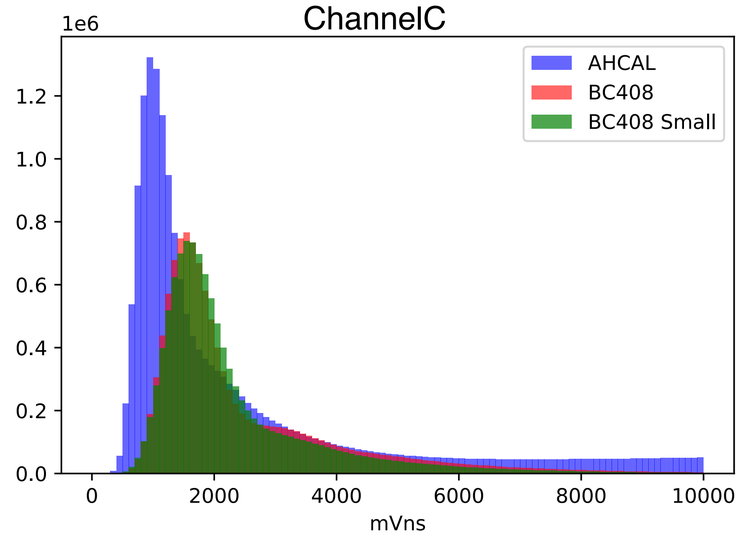
Testbeam in October 2020 at DESY was successful:

- Test of SiPM-on-Tile technology with AHCAL scintillator and BC408
- Investigation of MIP time resolution
- Energy binned time resolution up to 15 MIP thanks to 10^8 recorded events

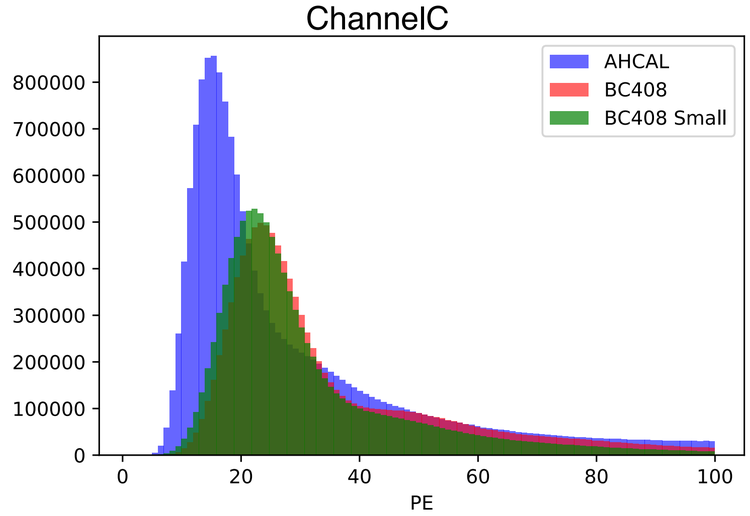
Upcoming testbed in October 2021 at DESY:

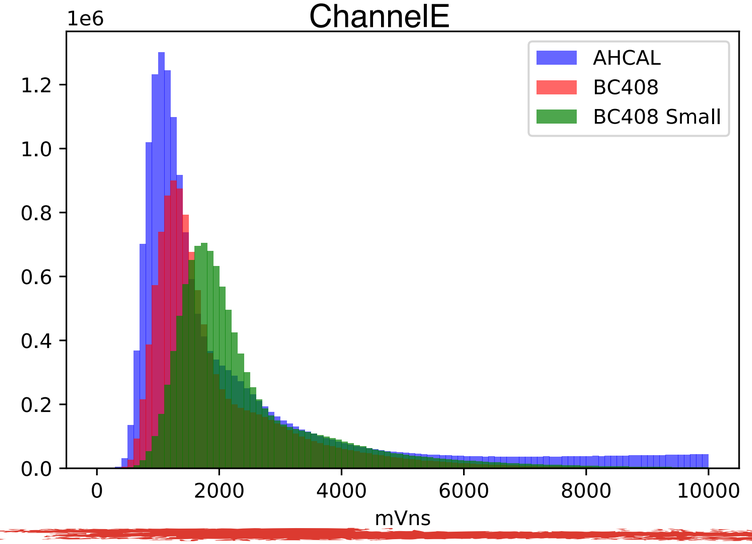
- Test scintillators with different timing properties
- Modifications to the setup for better stability, increased sampling resolution, …

Comparison of PE Calibration

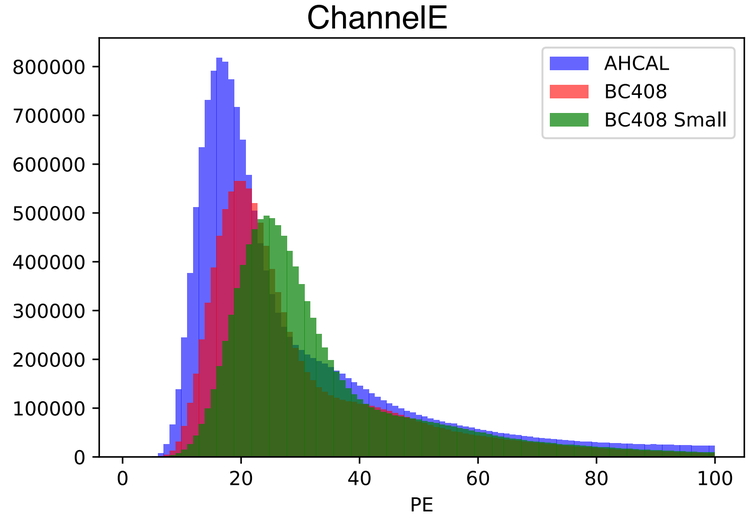


ChannelC:
AHCAL: 65.370mVns = 1PE
BC408: 65.680mVns = 1PE
BC408small: 71.930mVns = 1PE

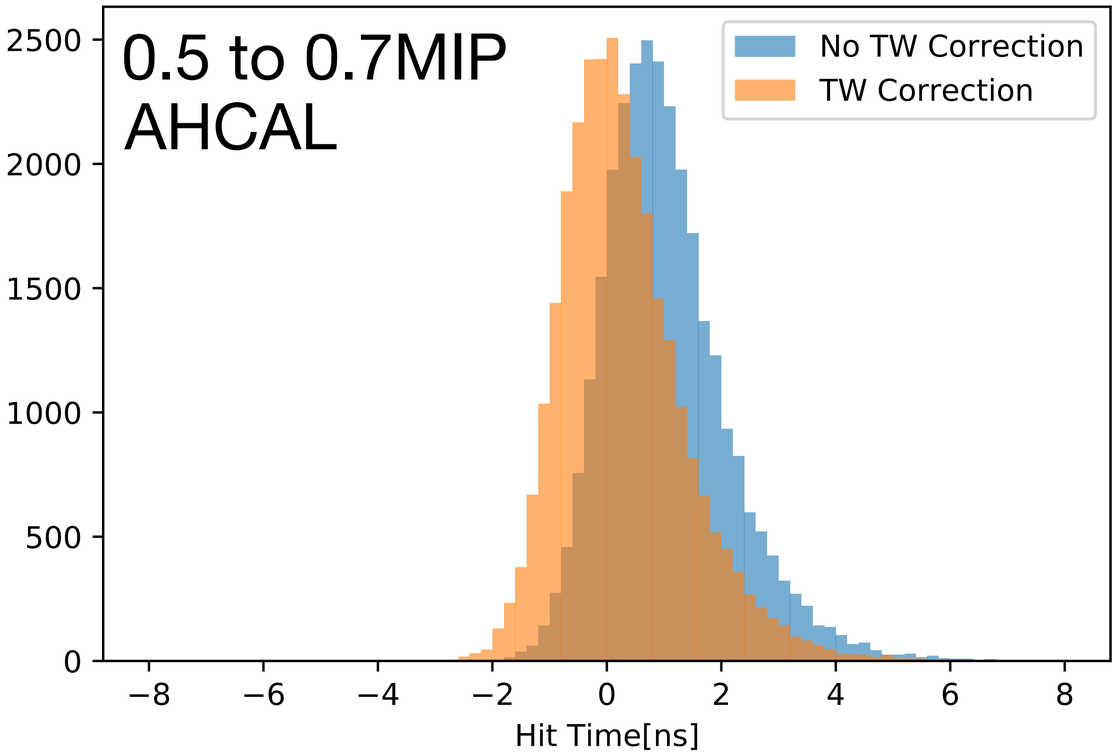


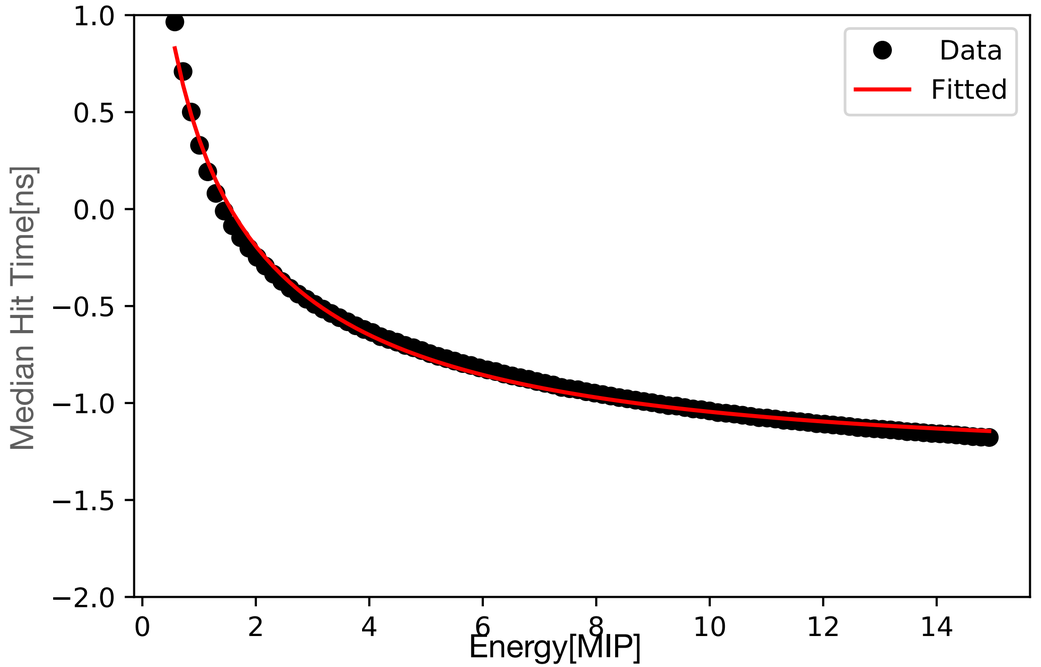


ChannelE:
AHCAL: 63.656mVns = 1PE
BC408: 63.534mVns = 1PE
BC408small: 70.717mVns = 1PE



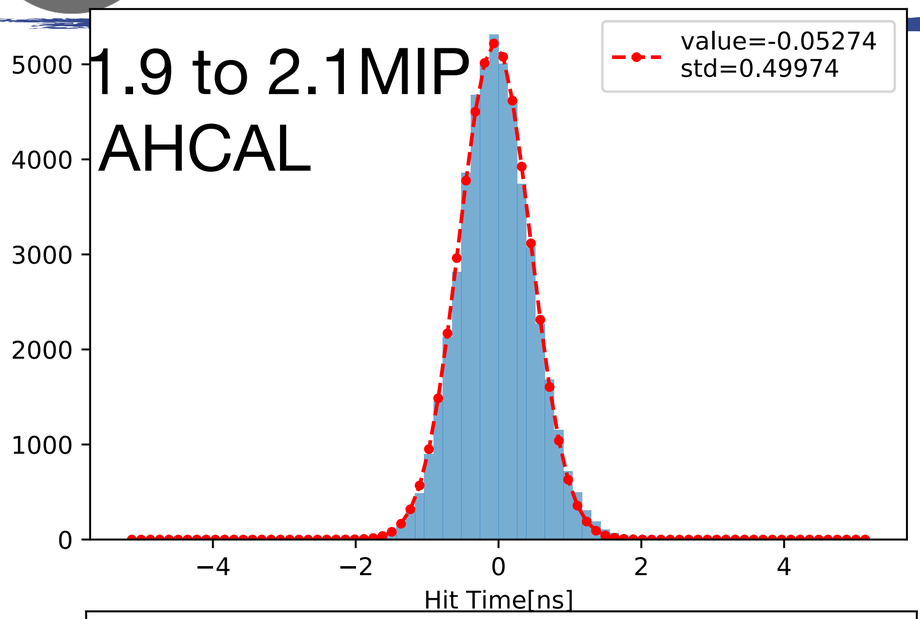
AHCAL Dataset - Time Walk

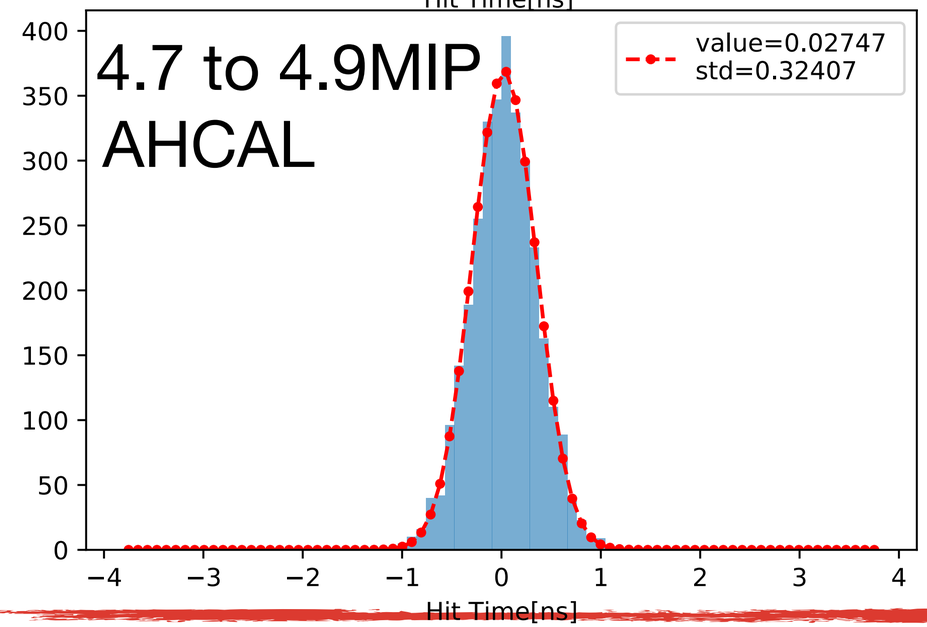




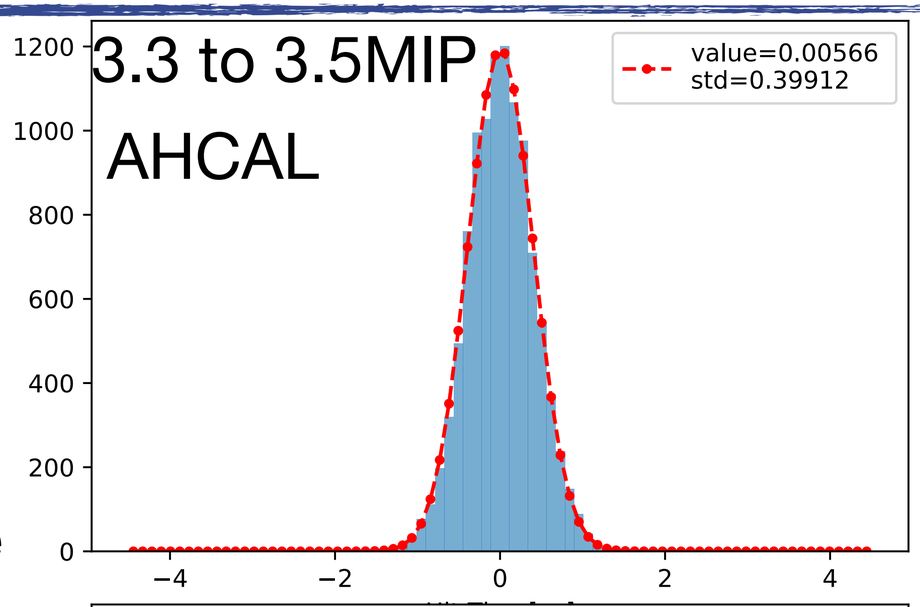
Time walk correction reduces width of distribution, but tail remains

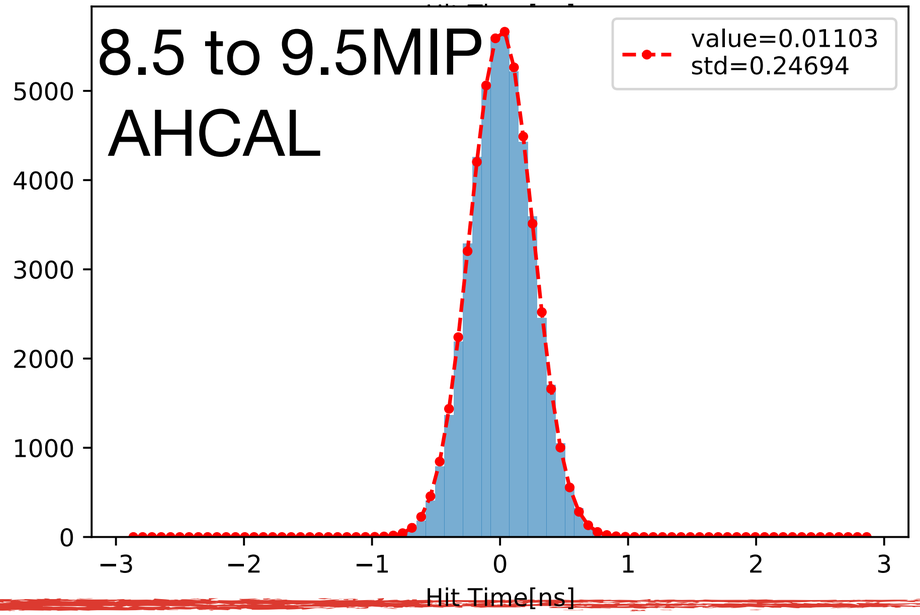
Energy Binned - Distributions

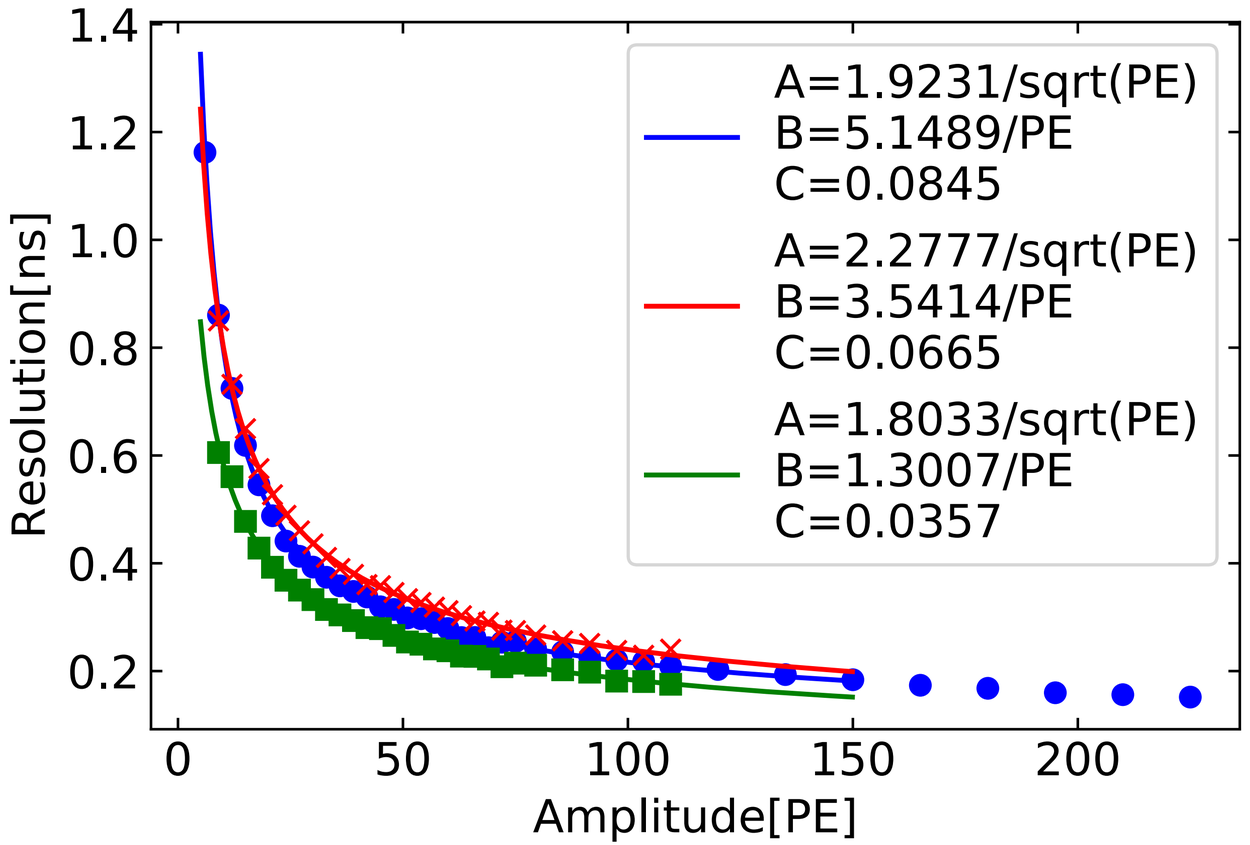




Distributions get narrow and more gaussian like






Resolution[ns]
Amplitude[PE]
A=1.9231/sqrt(PE)
B=5.1489/PE
C=0.0845
A=2.2777/sqrt(PE)
B=3.5414/PE
C=0.0665
A=1.8033/sqrt(PE)
B=1.3007/PE
C=0.0357