Time Resolution Measurements with the SiPM-on-Tile Technology

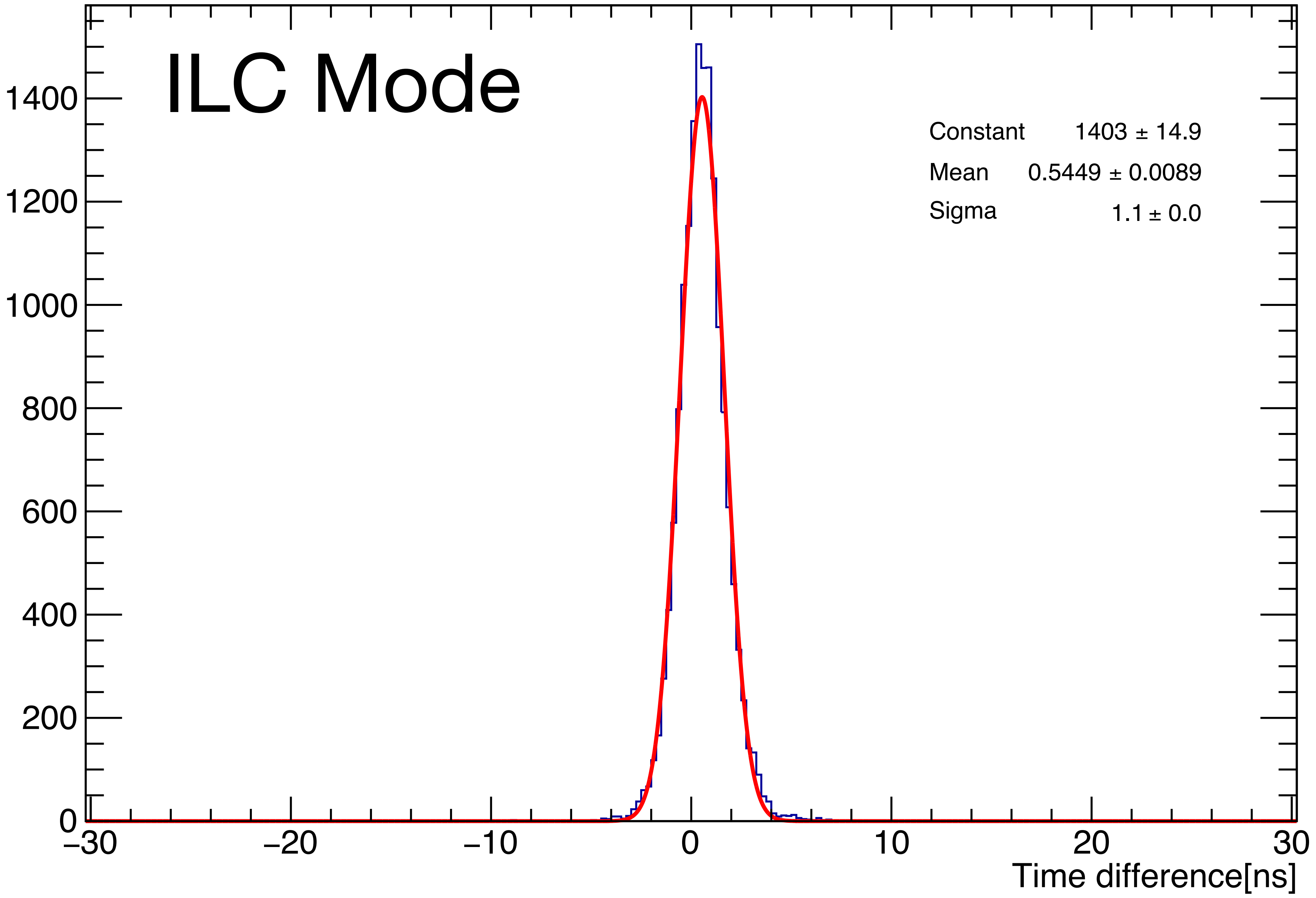
Test Beam 2021 - DESY

Lorenz Emberger, Fabian Hummer, Frank Simon

AHCAL Main Meeting - DESY 2021

Recap: The Test Beam in 2020

AHCAL



Single channel resolution: 1.1/√2 = 0.78ns

Key conclusion from 2020:

- AHCAL front-end contributes ~0.6ns
- Scintillator contributes ~0.505ns

Recap: The Test Beam in 2020

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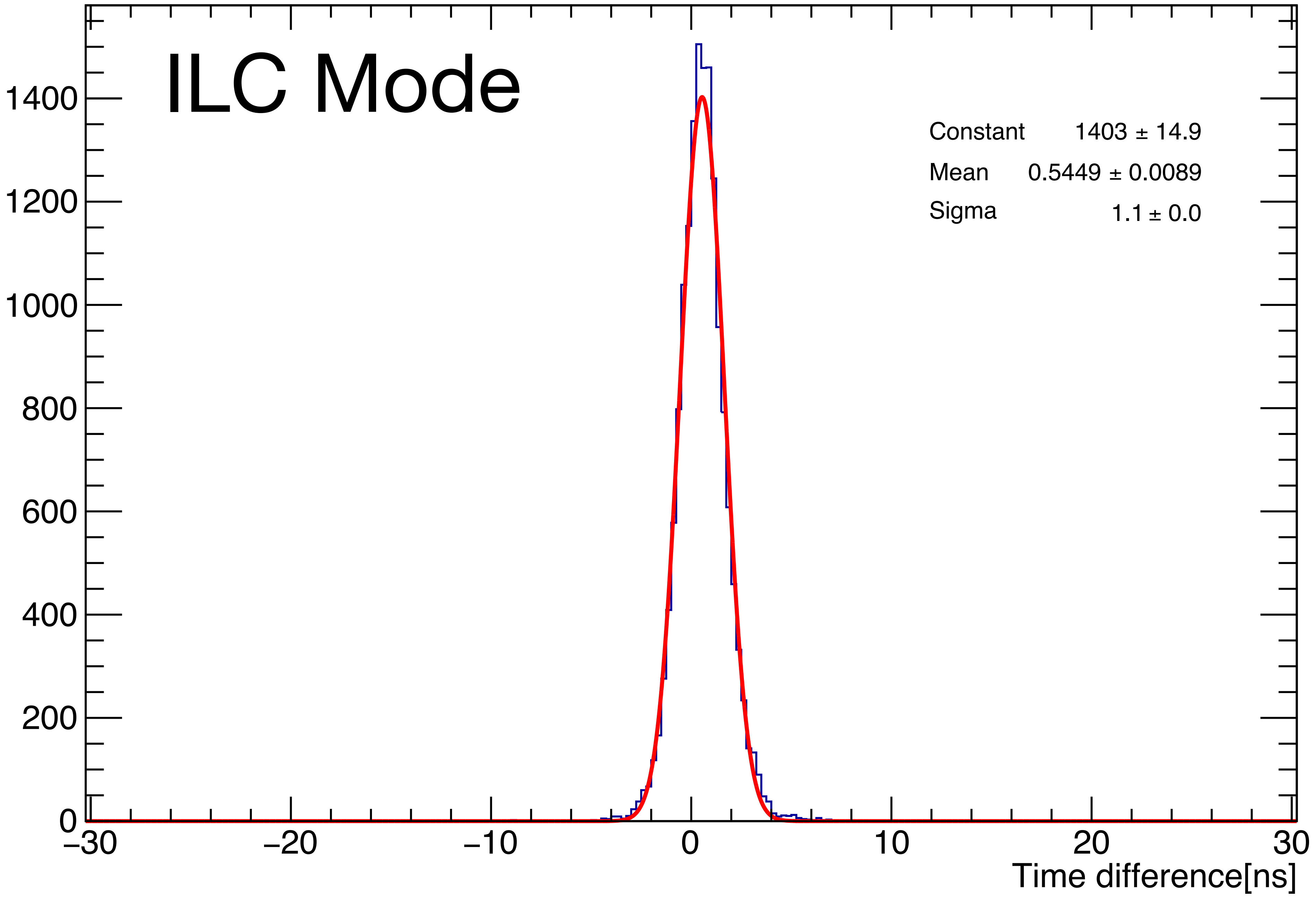

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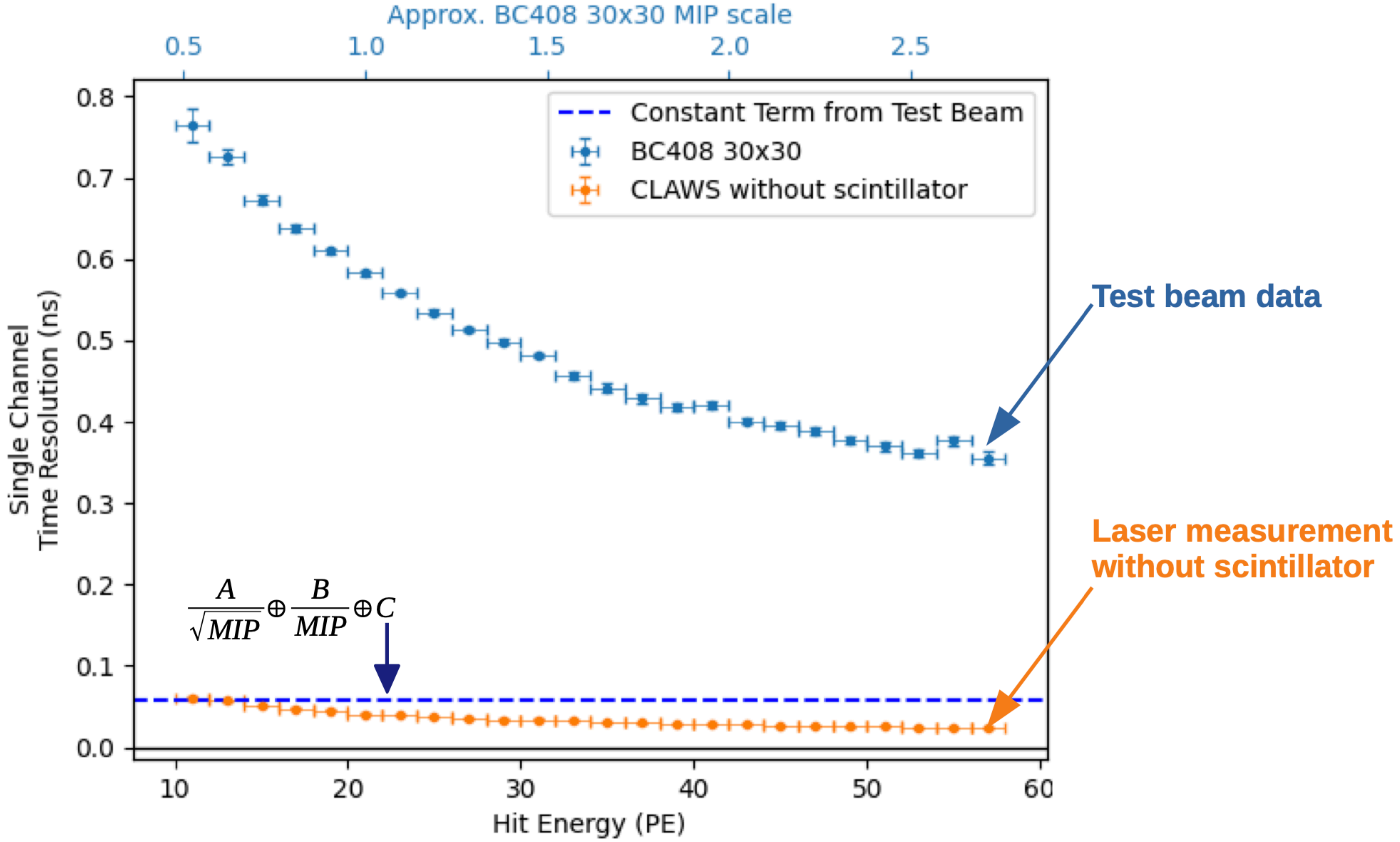
Test Beam Setup 2020



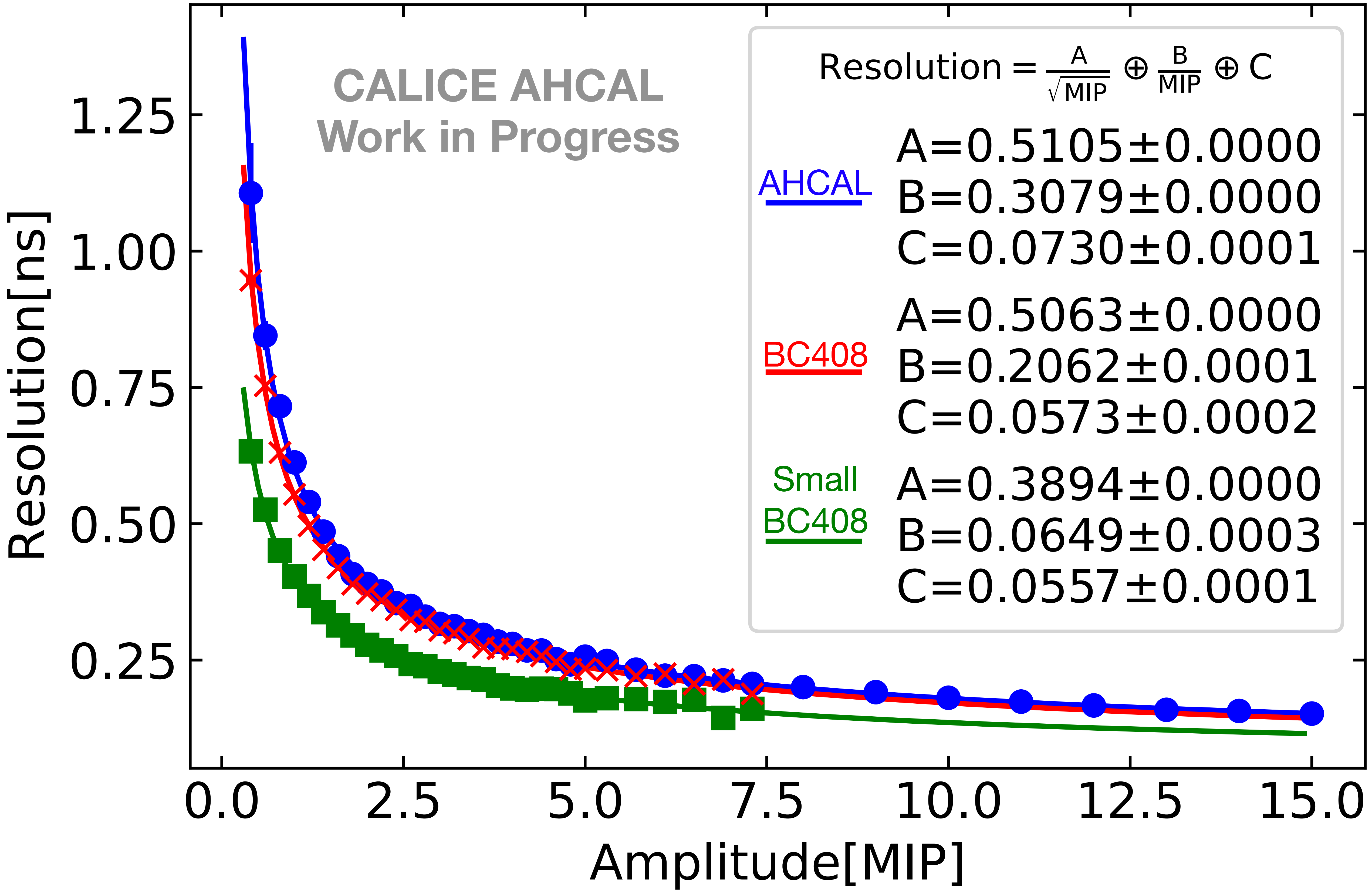
Key conclusion from 2020:

- AHCAL front-end contributes ~0.6ns
- Scintillator contributes ~0.505ns

Time resolution is determined by scintillator and tile properties

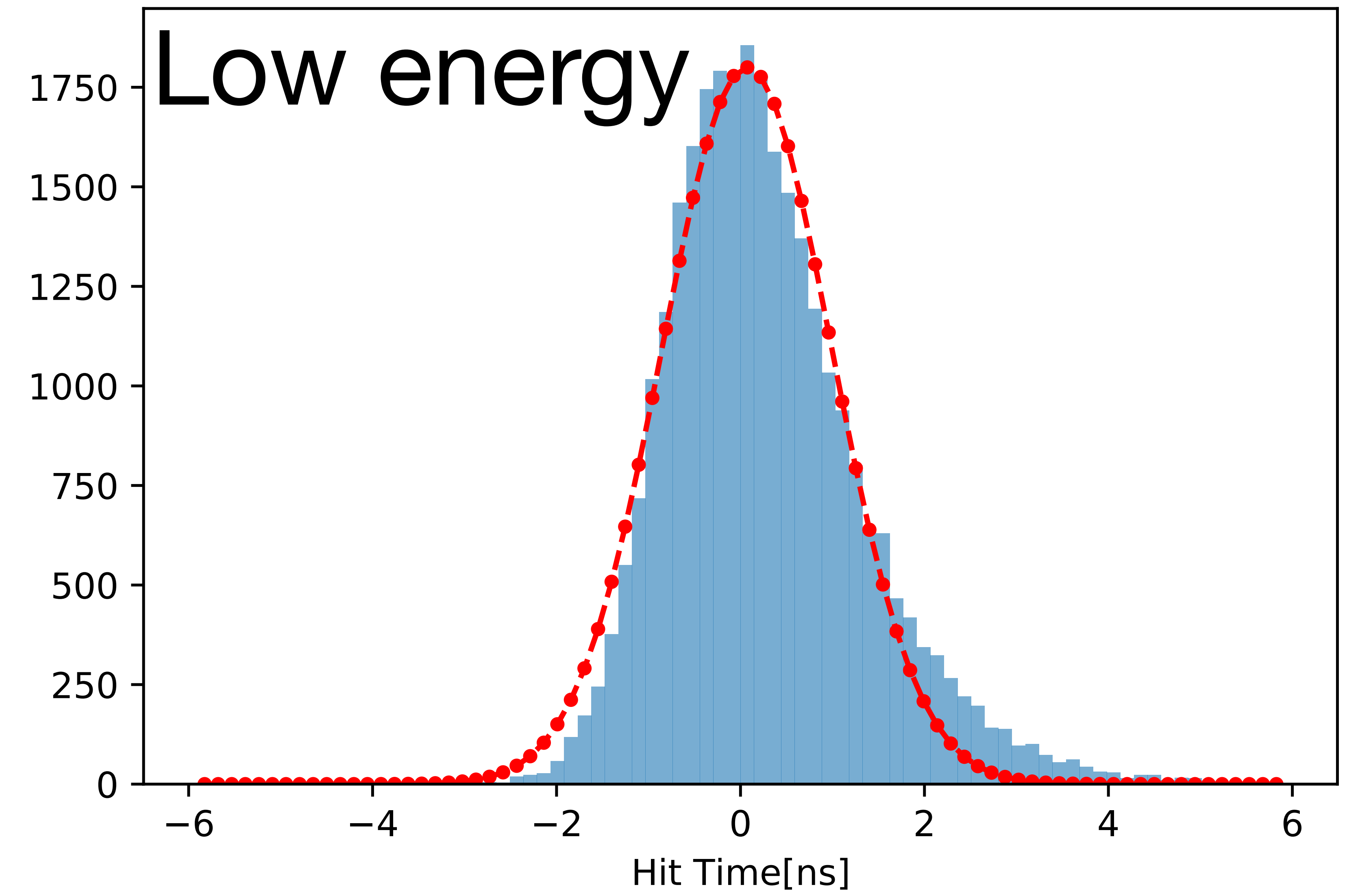
Motivation for the Test Beam 2021

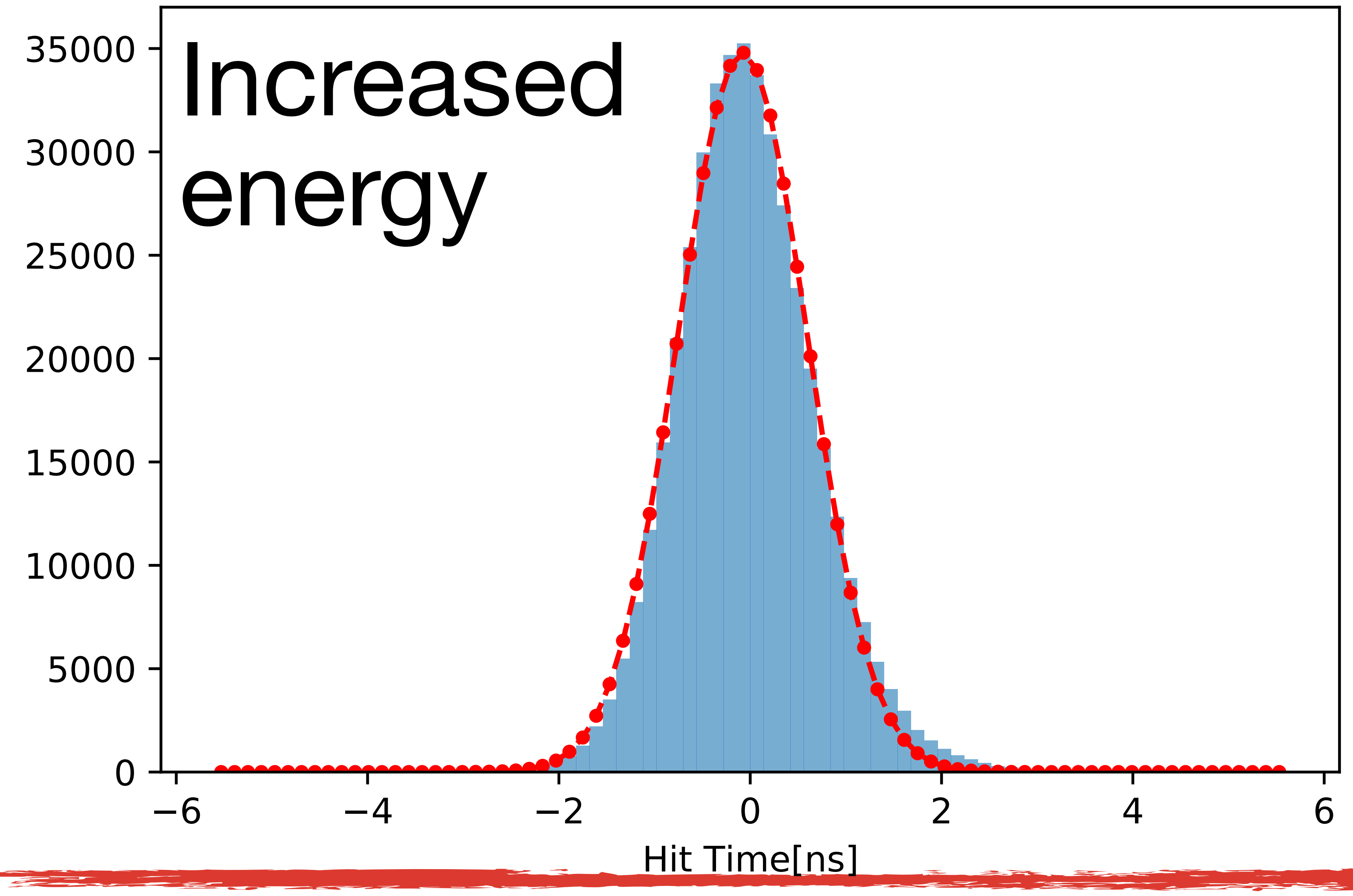
Observations from the 2020 TB:



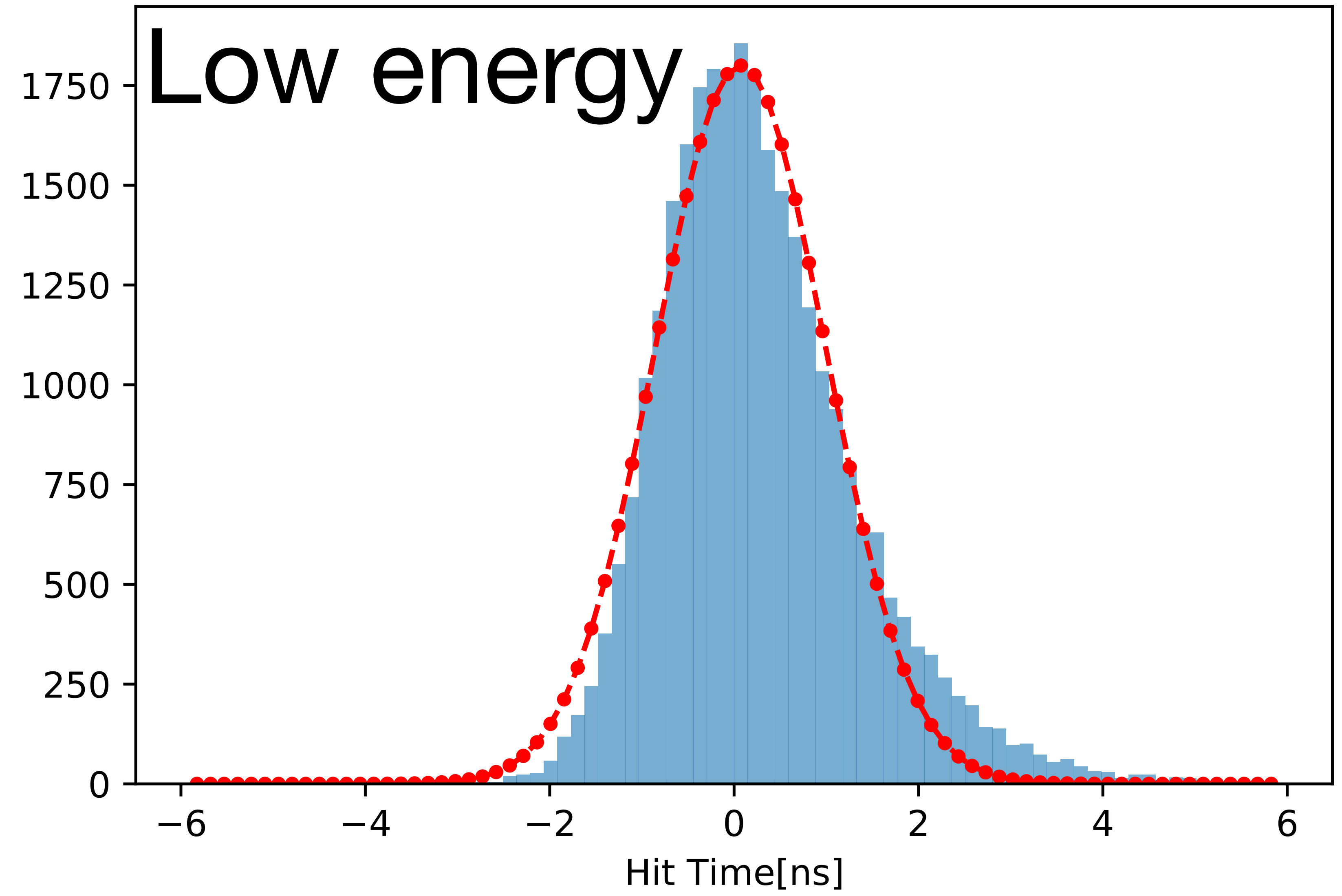
Extend this data set to more sizes and materials

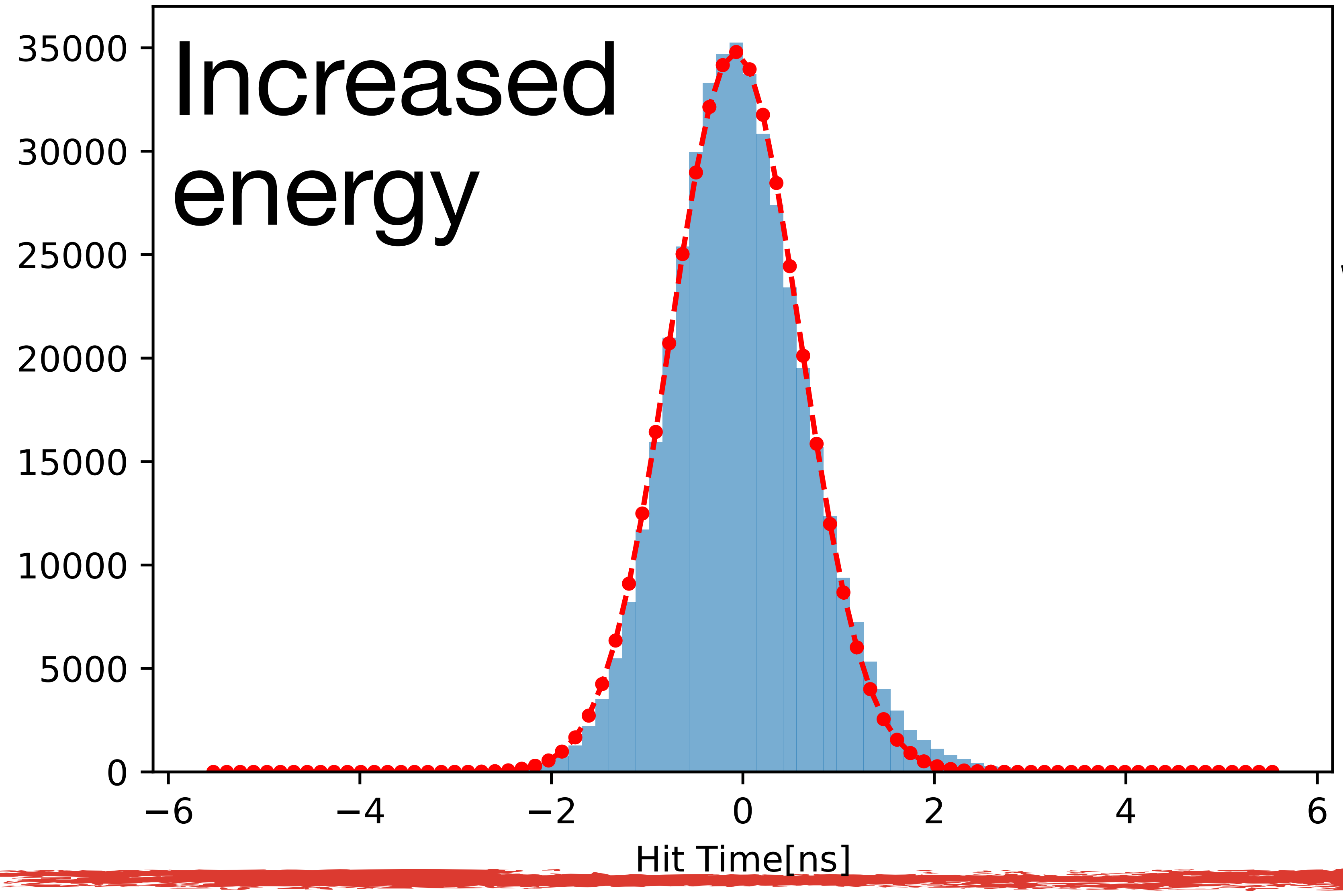
Motivation for the Test Beam 2021





Motivation for the Test Beam 2021

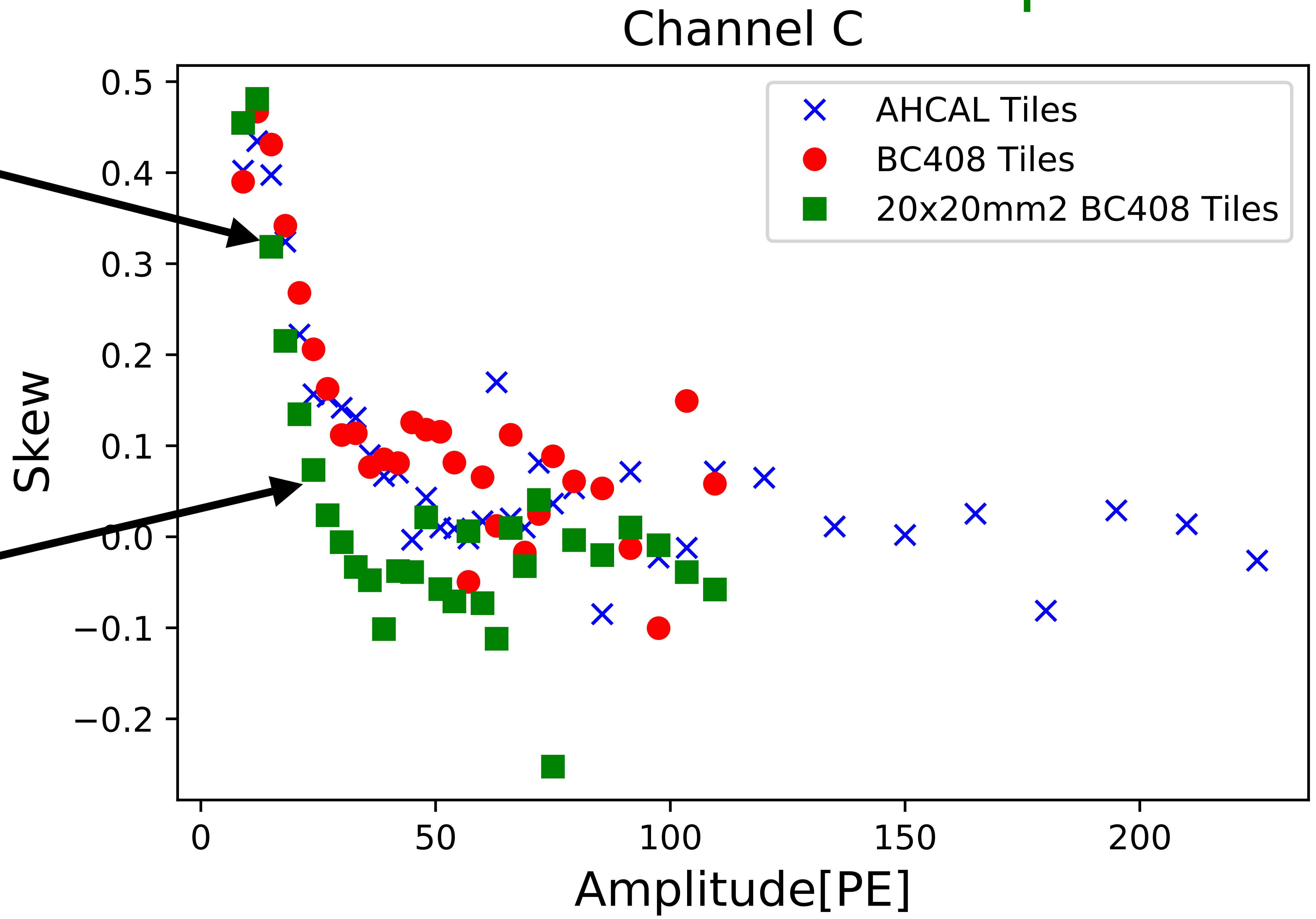




30 x 30mm² AHCAL:14.3 pe/MIP

30 x 30mm² BC408: 22.37 pe/MIP

20 x 20mm² BC408: 21.85 pe/MIP



Indication for influence of tile geometry on timing properties

Test Beam Program

Studied scintillator types

Properties	BC404	BC408	BC418	BC422Q
Light Output, %Anthracene	68	64	67	19
Rise Time	0.7ns	0.9ns	0.5ns	0.11ns
Decay Time	1.8ns	2.1ns	1.4ns	0.7ns
Pulse Width FWHM	2.2ns	2.5ns	1.2ns	0.36ns
Wavelength	408nm	425nm	391nm	370nm

From crystals.saint-gobain.com

Tile areas: 20x20mm^2, 30x30mm^2, 40x40mm^2

Goal: Investigate influence of scintillator and tile properties on timing

Test Beam Setup

Stack of up to 8 Tiles:

- Various Scintillators and sizes
- Hamamatsu S13360-1325PE

Ethernet Cat 7

Receiver Box:

- USB controlled power supply
- Split signal and power lines

BNC

BNC

Picoscope:

- Up to 5 GHz sampling rate on 2 channels
- 300kHz peak trigger rate
- Save complete analog waveform

MCX

Separate scope for coincidence trigger

Test Beam Setup

Stack of up to 8 Tiles:

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- Hamamatsu S13360-1325PE

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- USB controlled power supply
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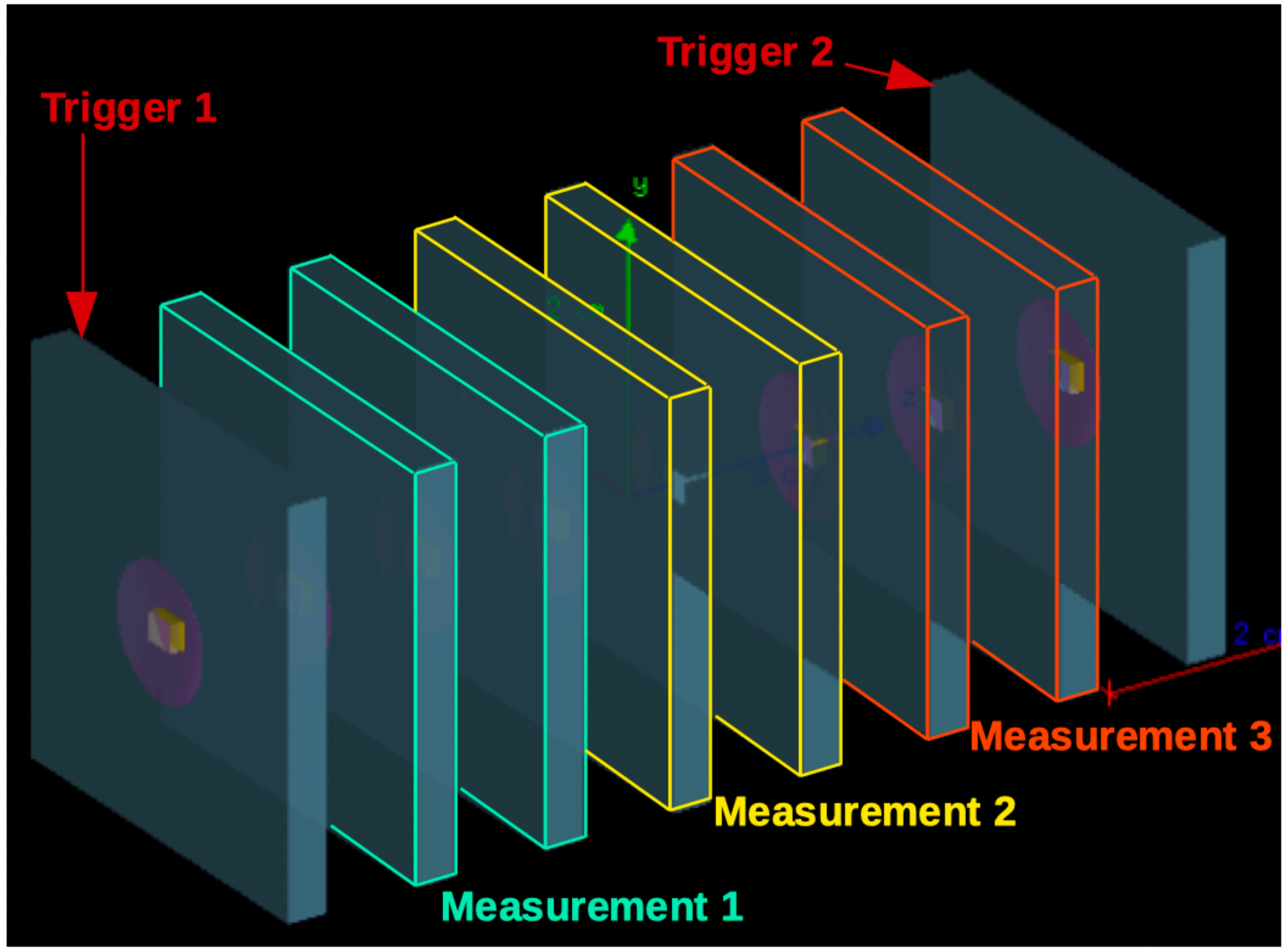
Picoscope:

- Up to 5 GHz sampling rate on 2 channels
- 300kHz peak trigger rate
- Save complete analog waveform

MCX

Keysight scope for triggering



Data Taking

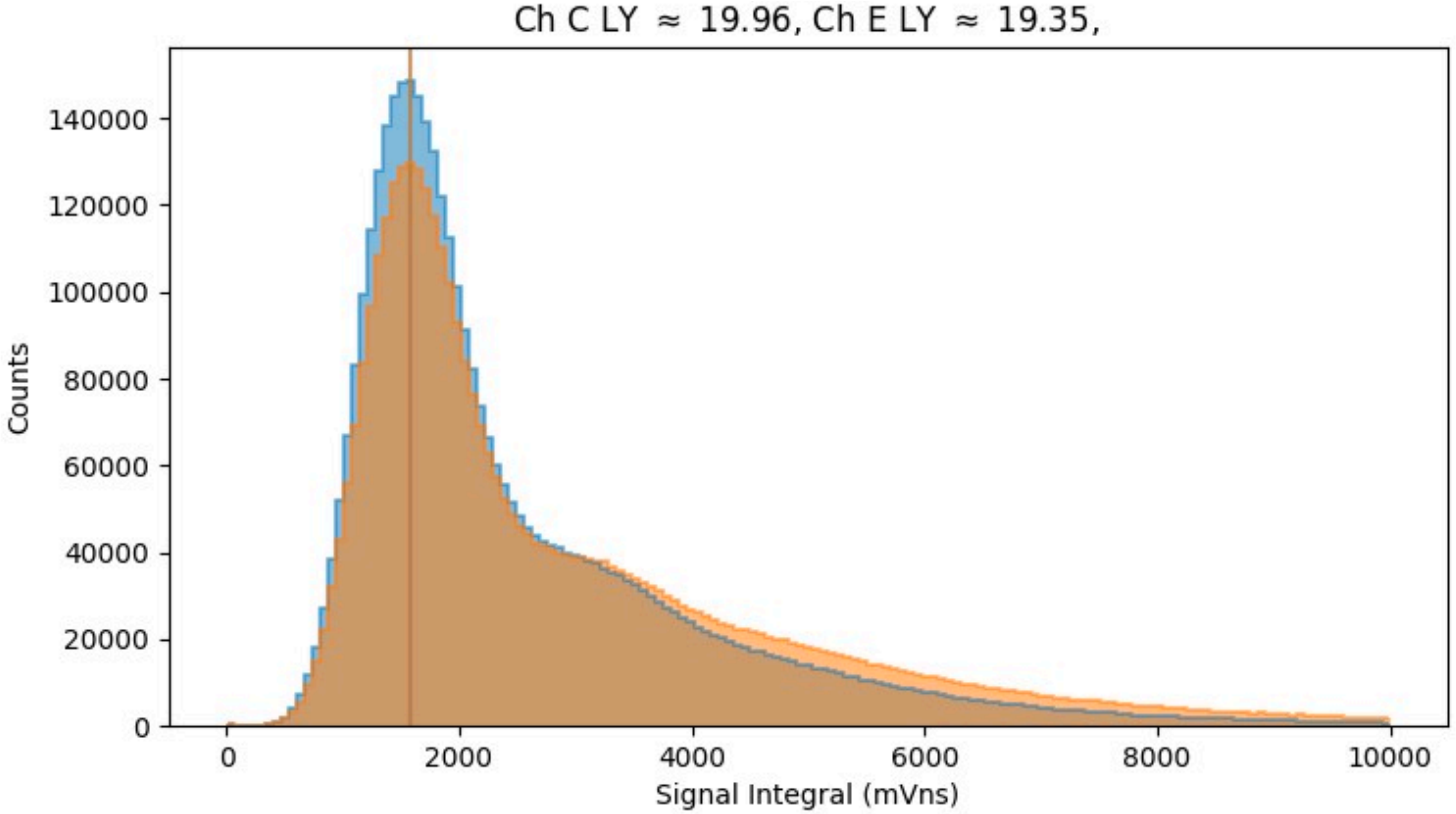
Effective data rate: ~5kHz

	BC404	BC408	BC418	BC422Q
20x20	12.3 E7 8.0 E7 (absorber)	4.9 E7	4.7 E7	5mm: 9.4 E7 (ESR) 8.4 E6 (teflon) 3mm: 1.87 E7 (ESR)
30x30	4.5 E7 9.0 E7 (absorber)	7.1 E7 5.3 E7 (absorber) 8.9 E7 (old tiles) 5.1 E7 (teflon)	9.6 E7 8.0 E6 (absorber)	1 E7 (3mm + 5mm) 5mm: 3.7 E7 (absorber) 5.2 E7 (ESR)
40x40	4.8 E7	6.4 E7	7.2 E7	3mm: 2.6 E7 (absorber) 1.8 E7 (ESR+teflon) 3.8 E7 (ESR)

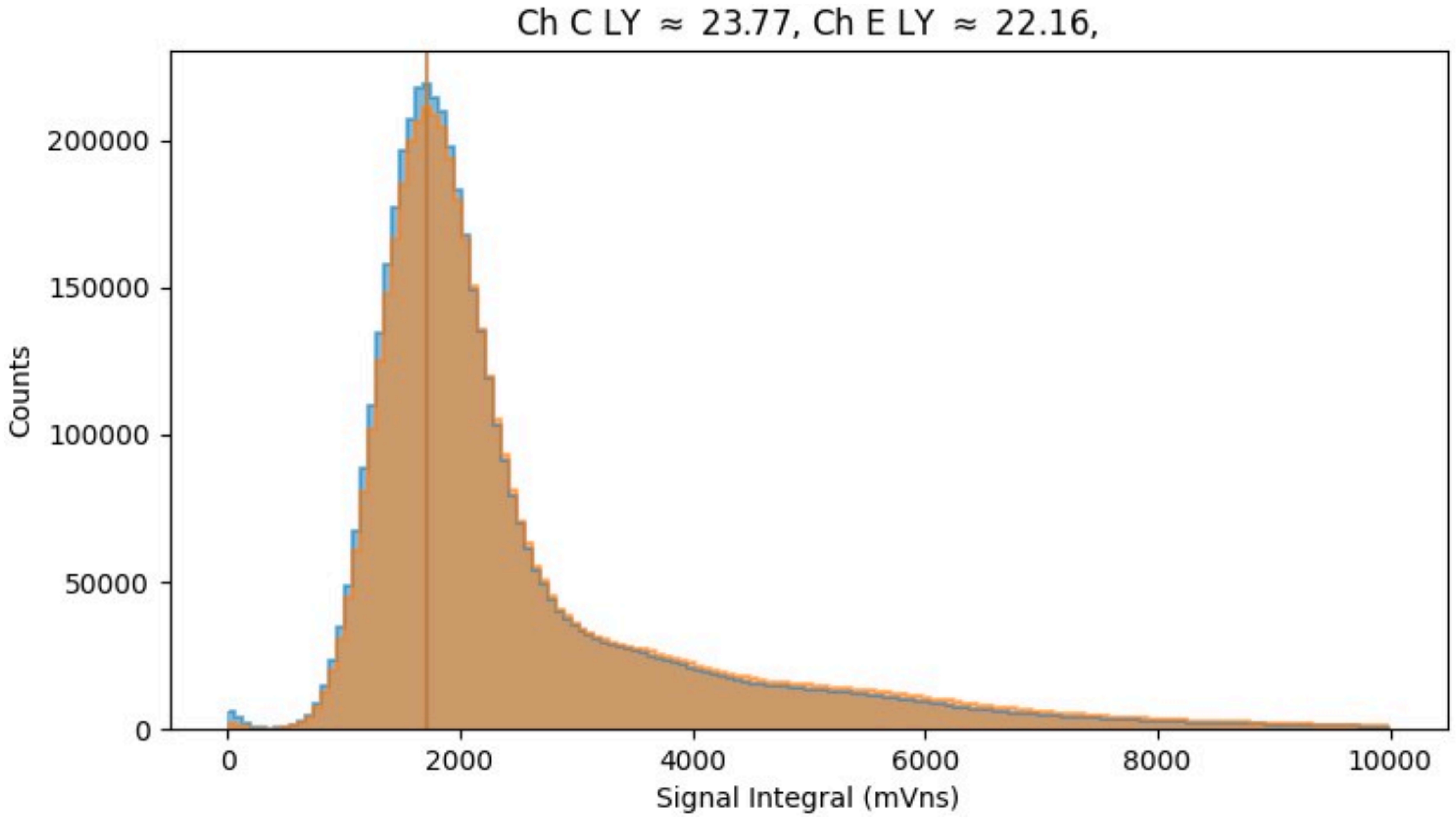
Normal run | Absorber run | Different reflective wrapping

Data Quality

Large Collimator



Small Collimator



Data Quality

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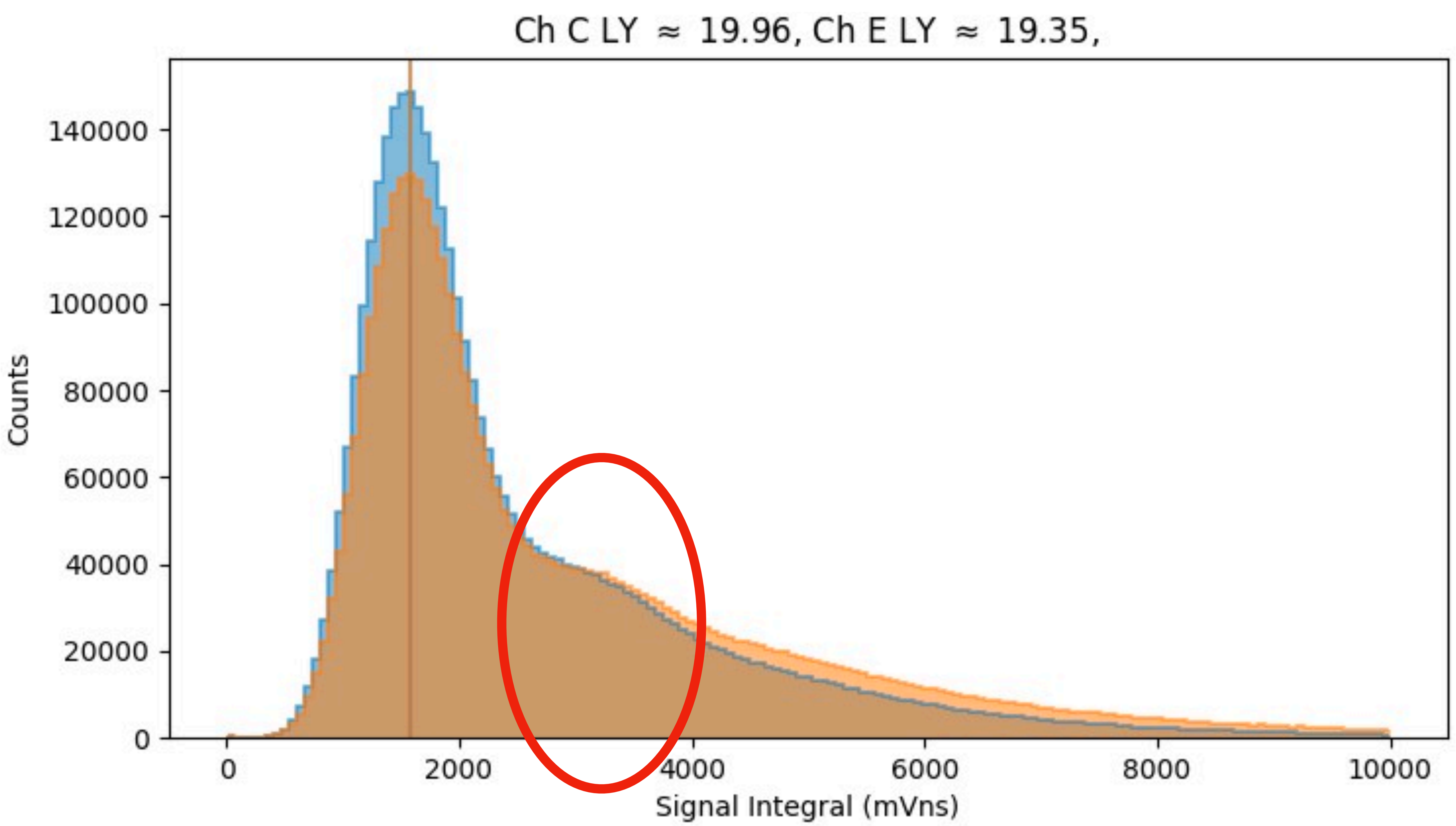
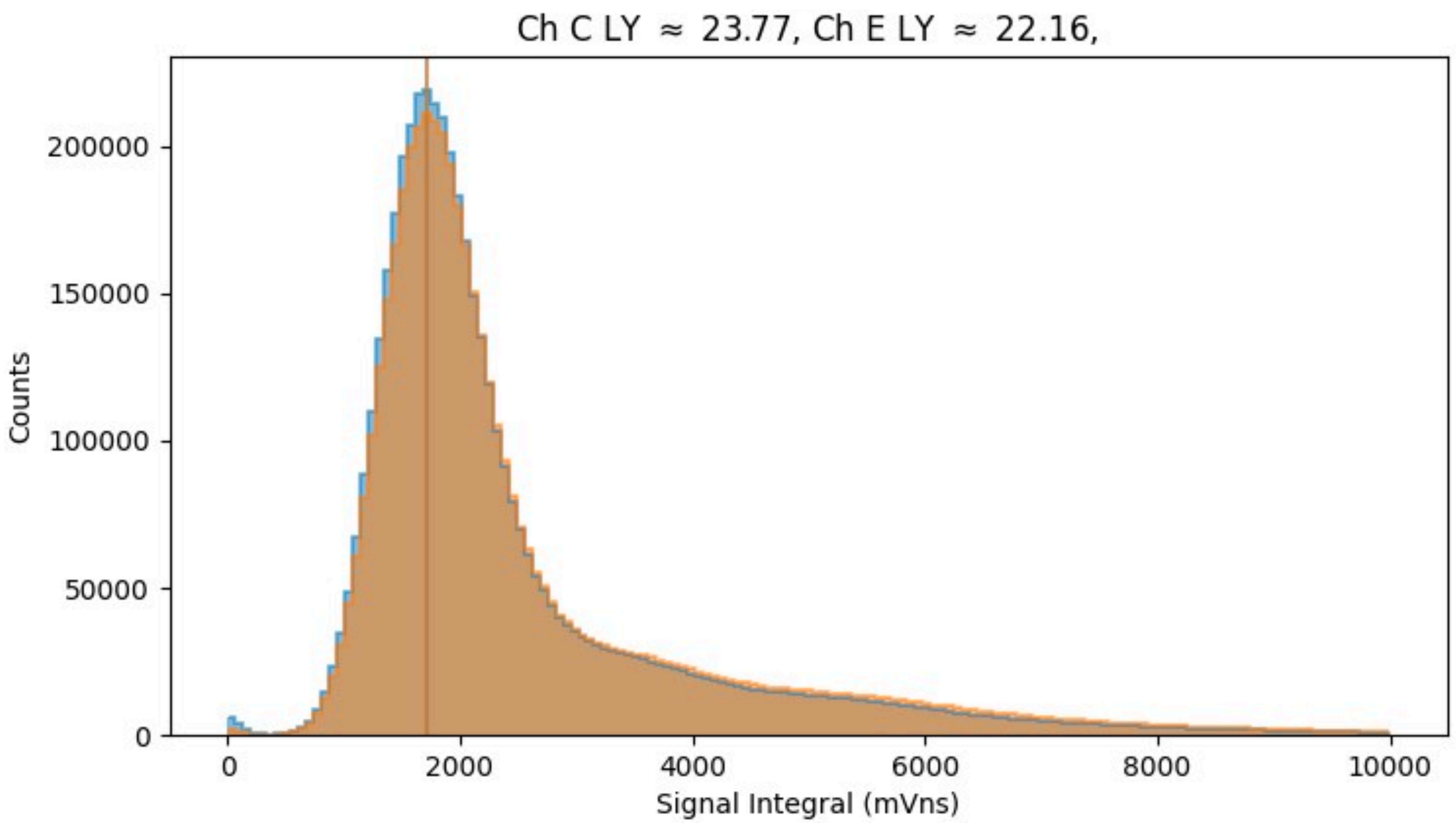


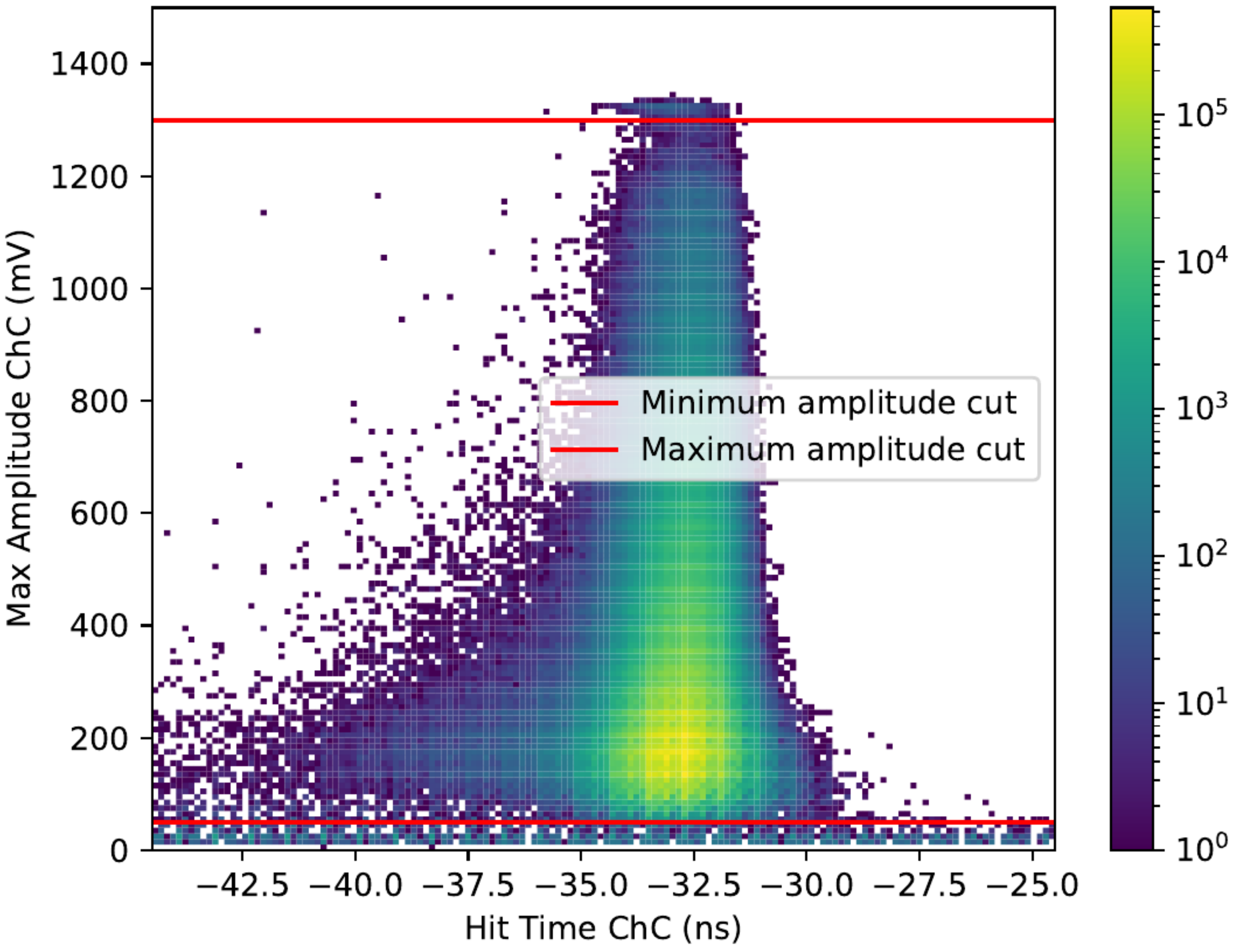
Small Collimator



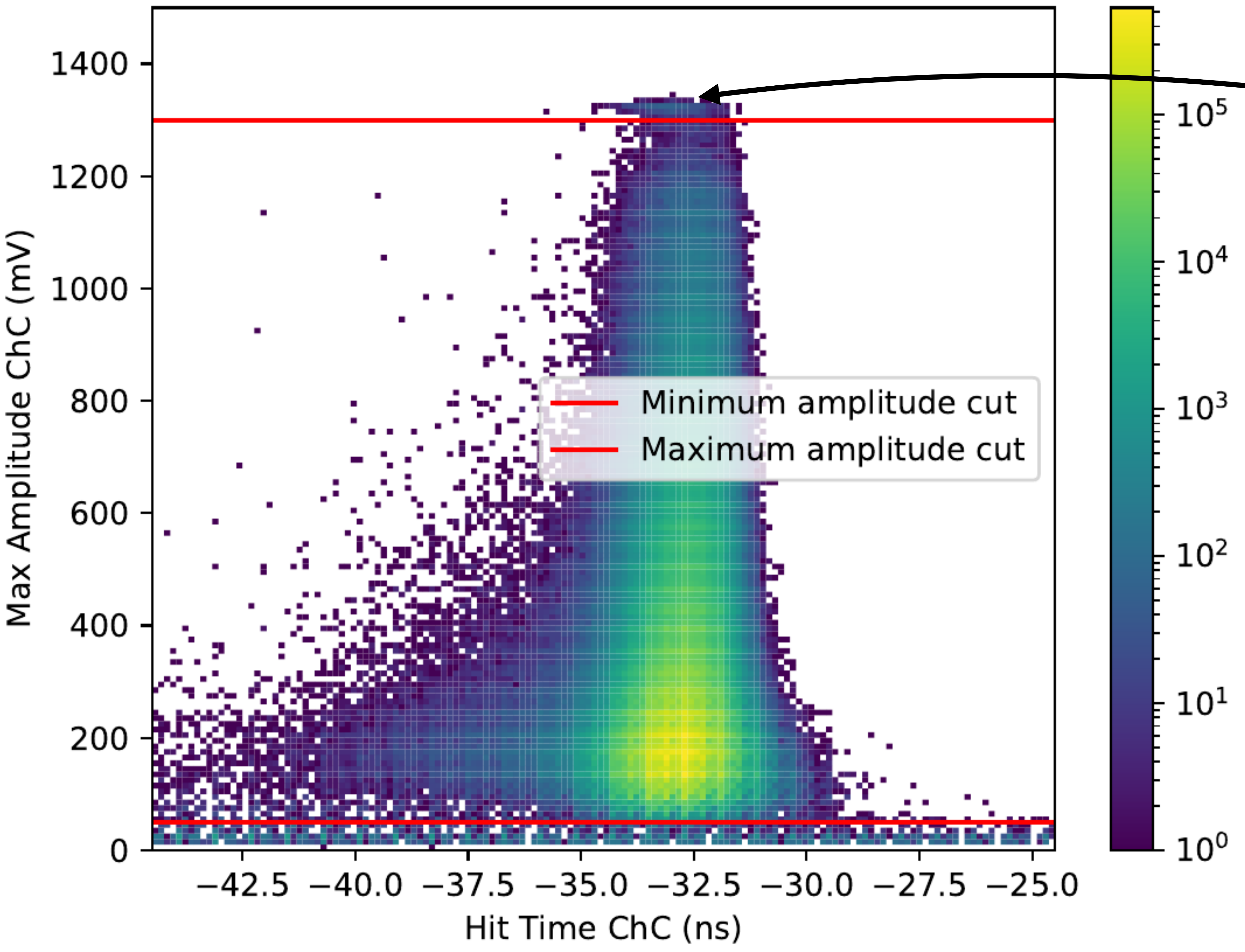
Double particles:

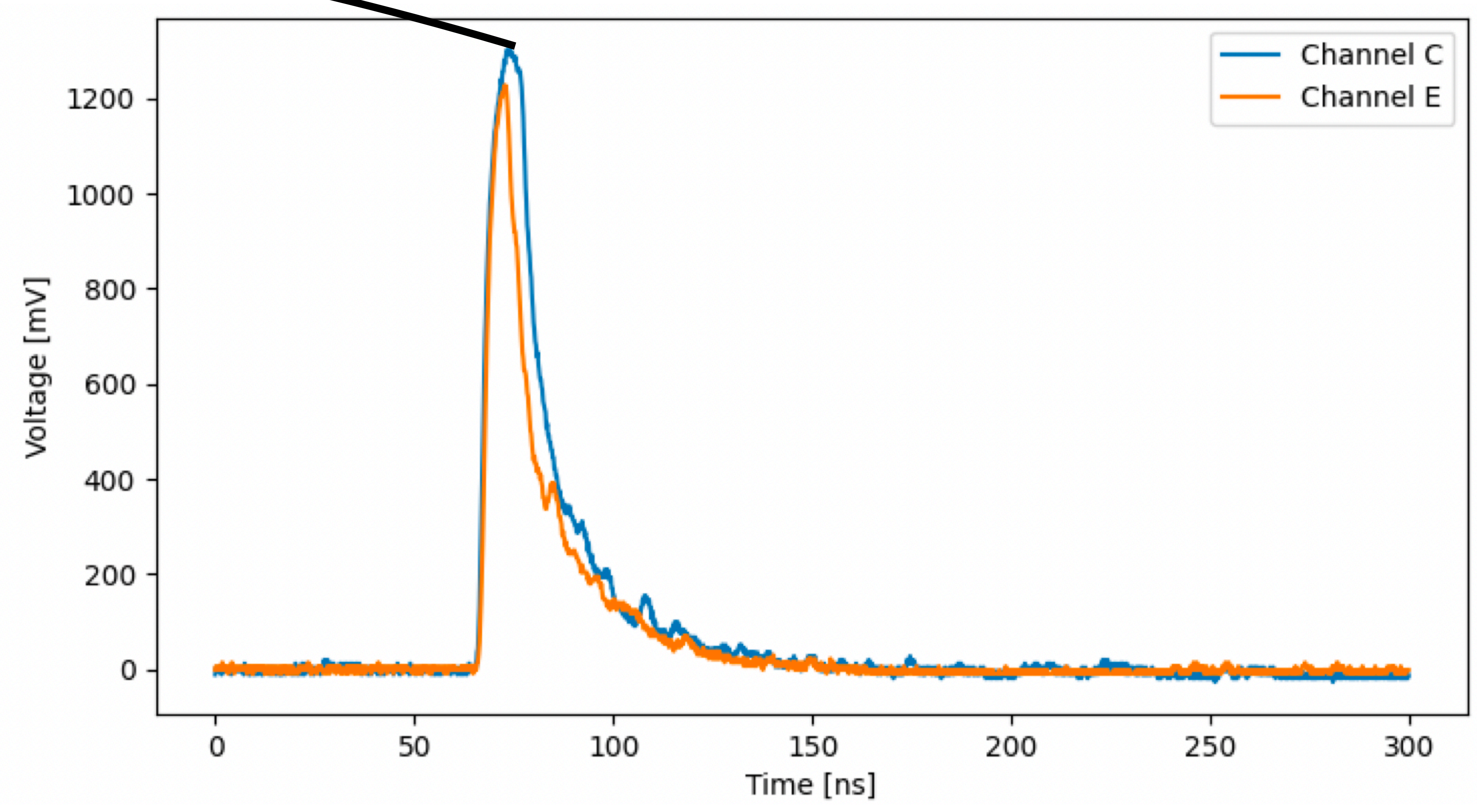
- may impact timing by broadening the waveform if out of time
- also noticeable in 2020 data, no negative impact observed

Data Quality



Data Quality

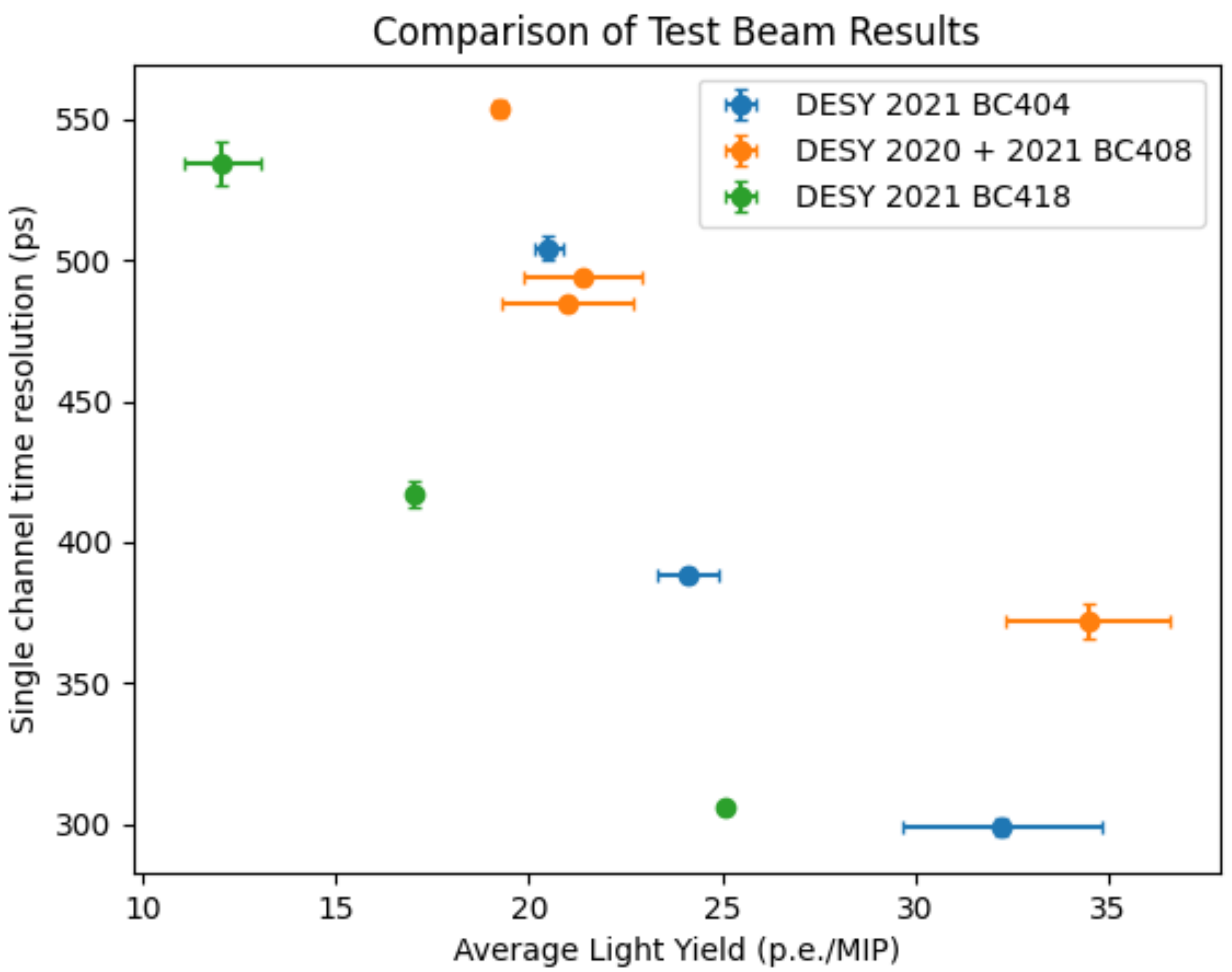




Effect of the electronics:

- Amplitude is limited
- Charge measurement gets “delayed”

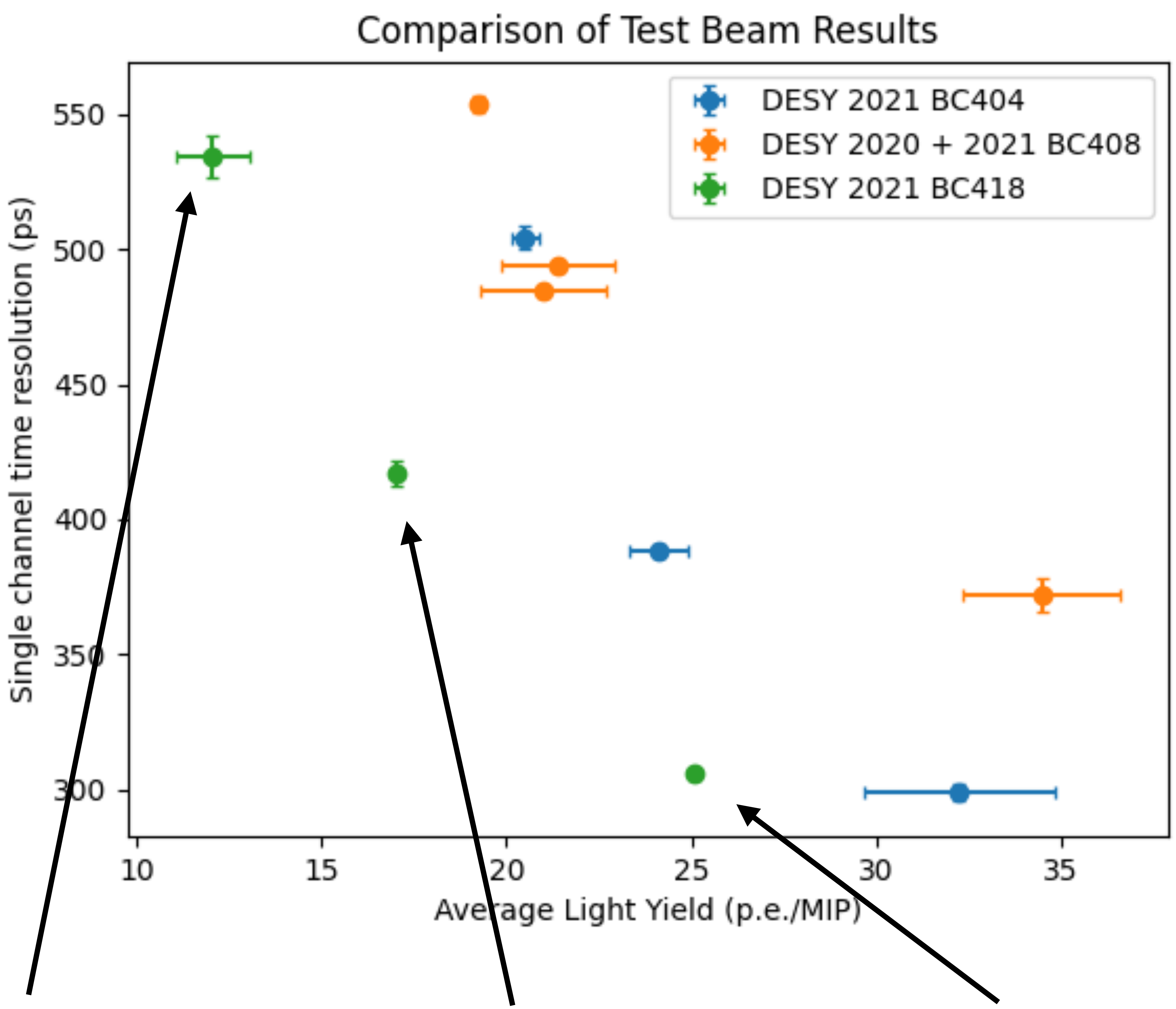
MIP time resolution



	BC404	BC408	BC418
Rise Time	0.7ns	0.9ns	0.5ns
Wavelength	408nm	425nm	391nm

Peak PDE of SiPM: ~450nm

MIP time resolution



40x40mm^2 30x30mm^2 20x20mm^2

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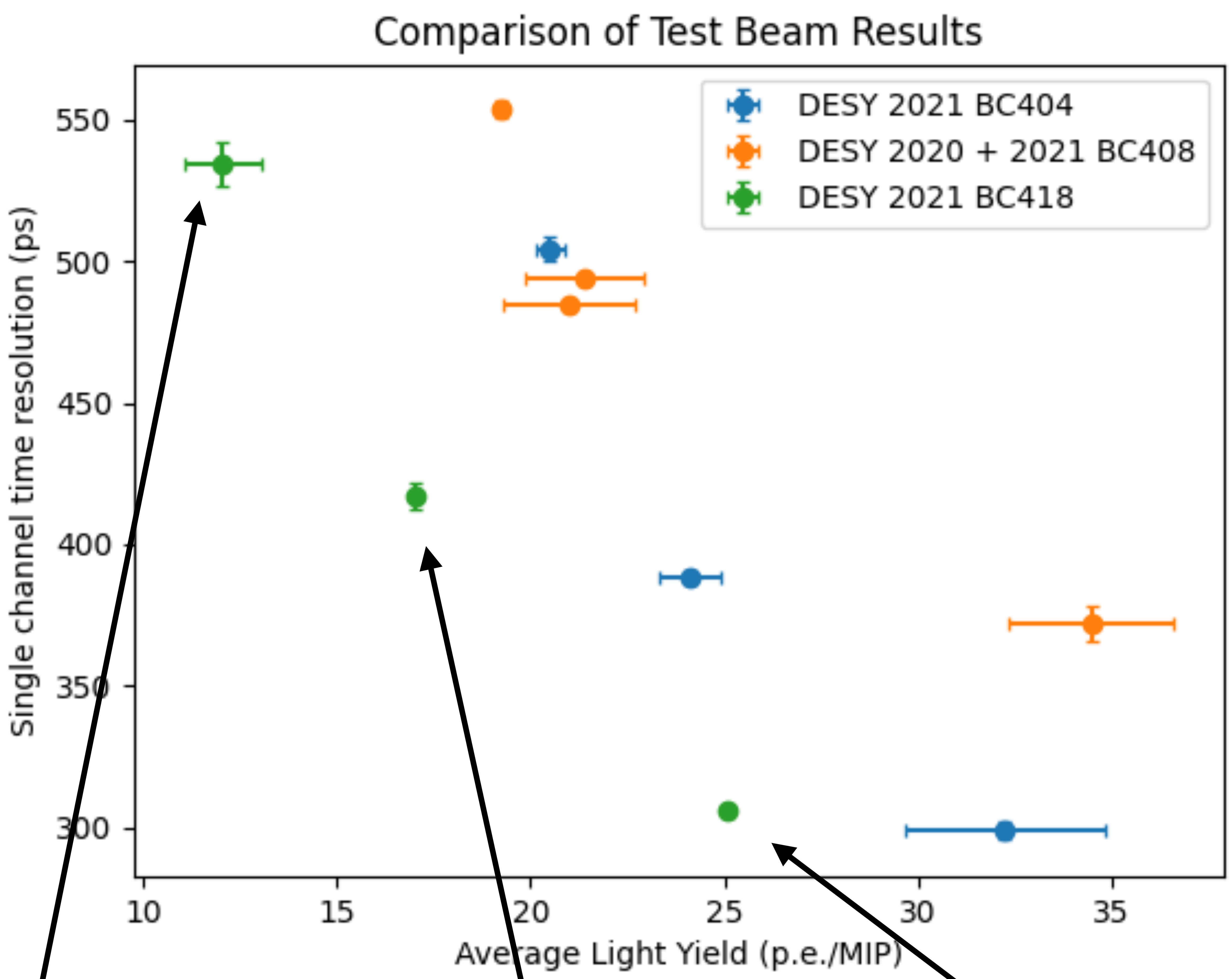


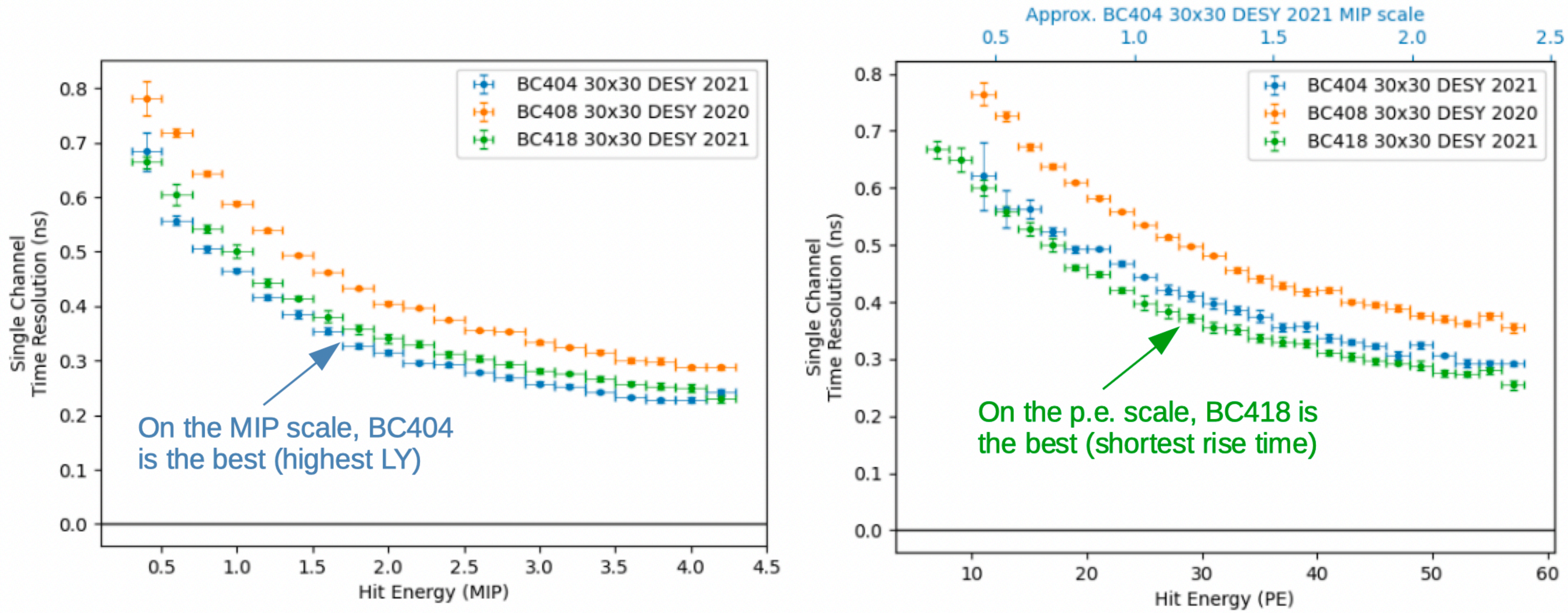
40x40mm²   30x30mm²   20x20mm²

	BC404	BC408	BC418
Rise Time	0.7ns	0.9ns	0.5ns
Wavelength	408nm	425nm	391nm

Peak PDE of SiPM: ~450nm

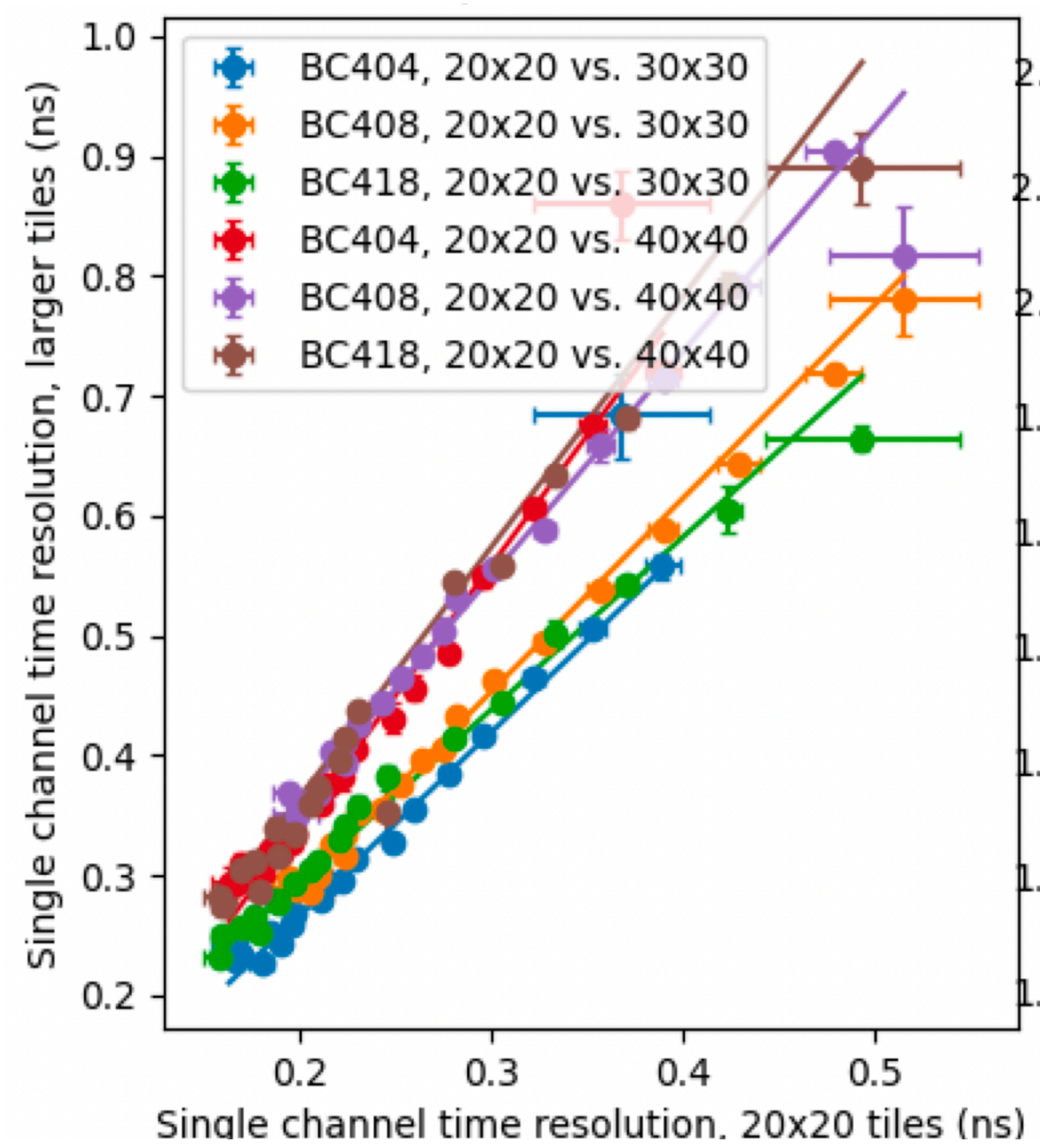
W.r.t. BC408, rise time of BC418 outweighs the wavelength mismatch

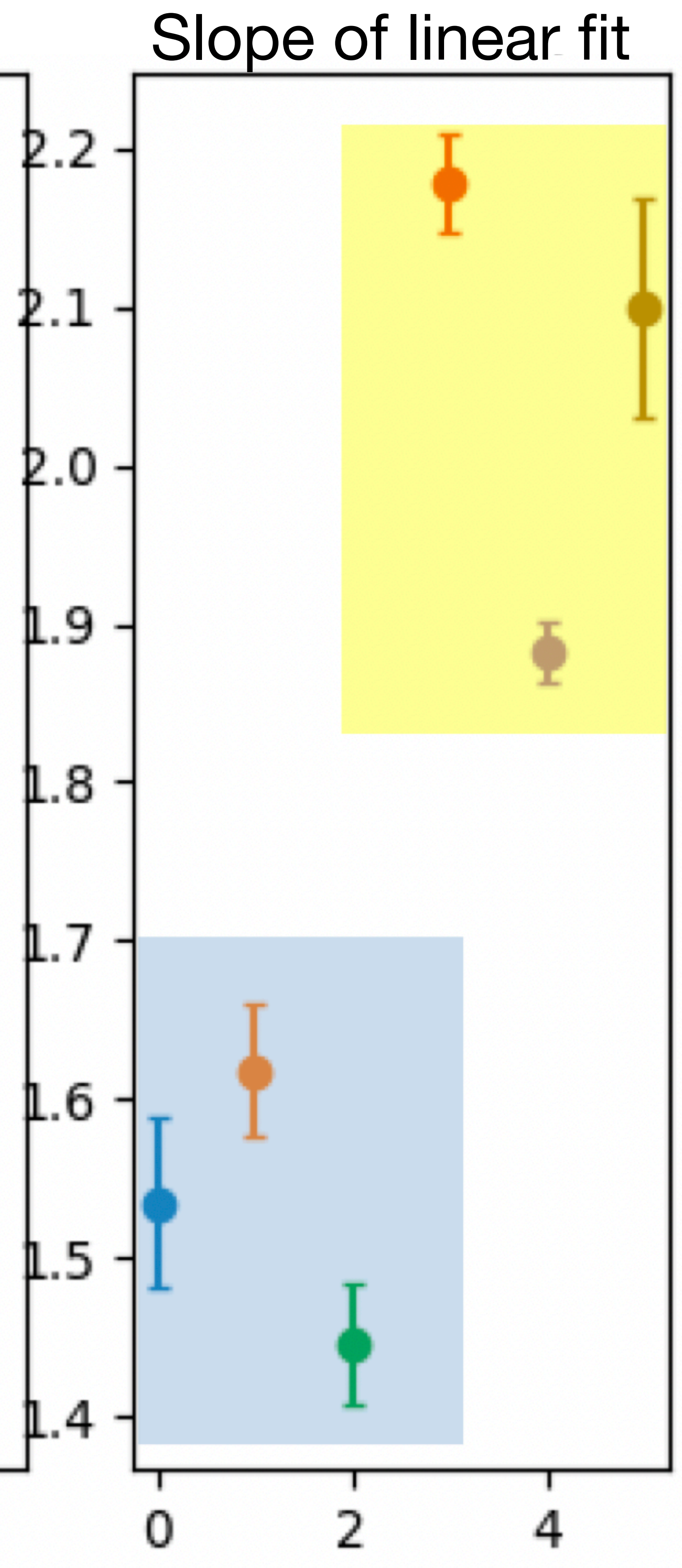
Energy Resolved Time Resolution



N.B: AHCAL scintillator is slightly worse than BC408

Tile Size Dependence





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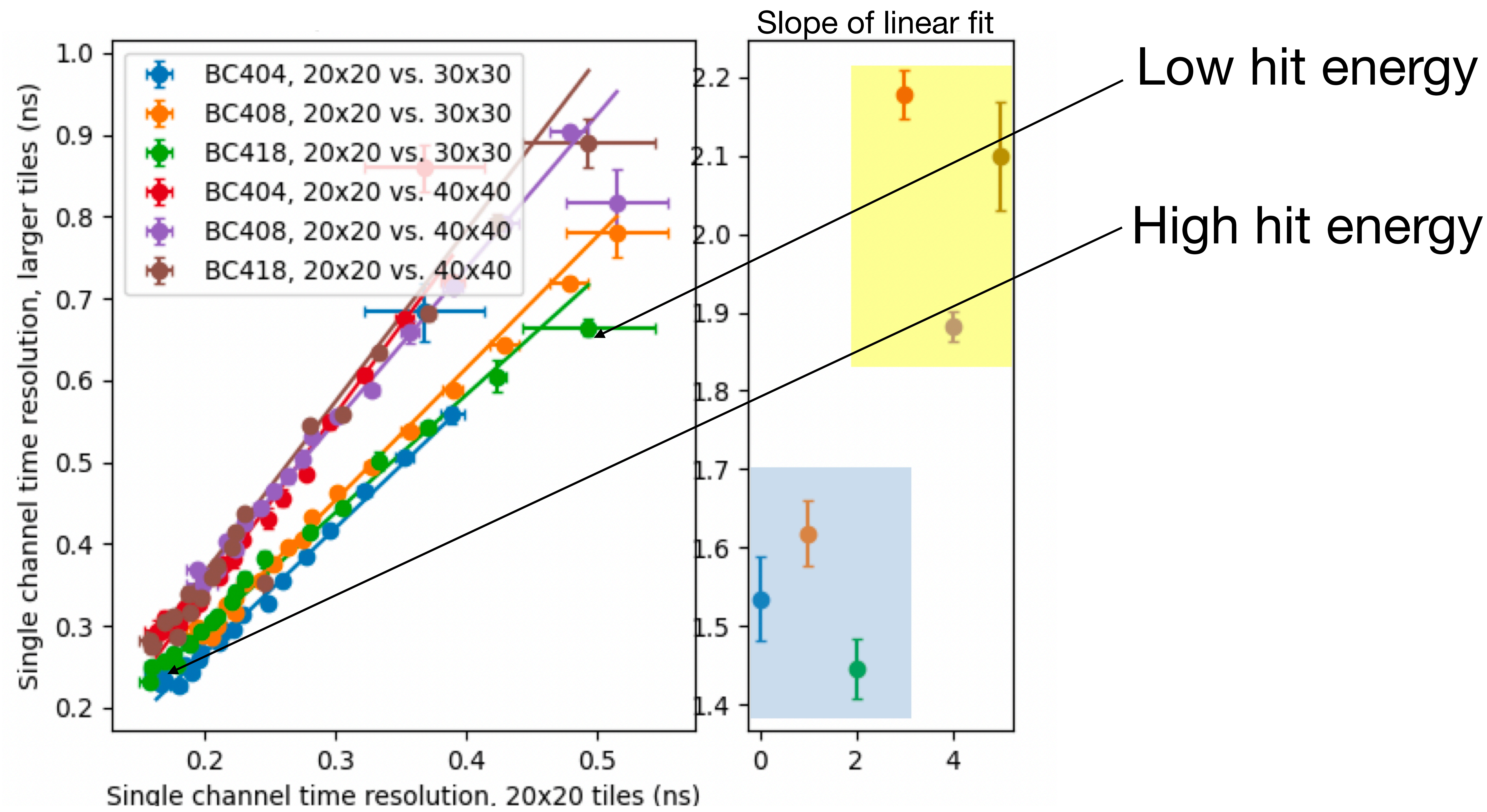
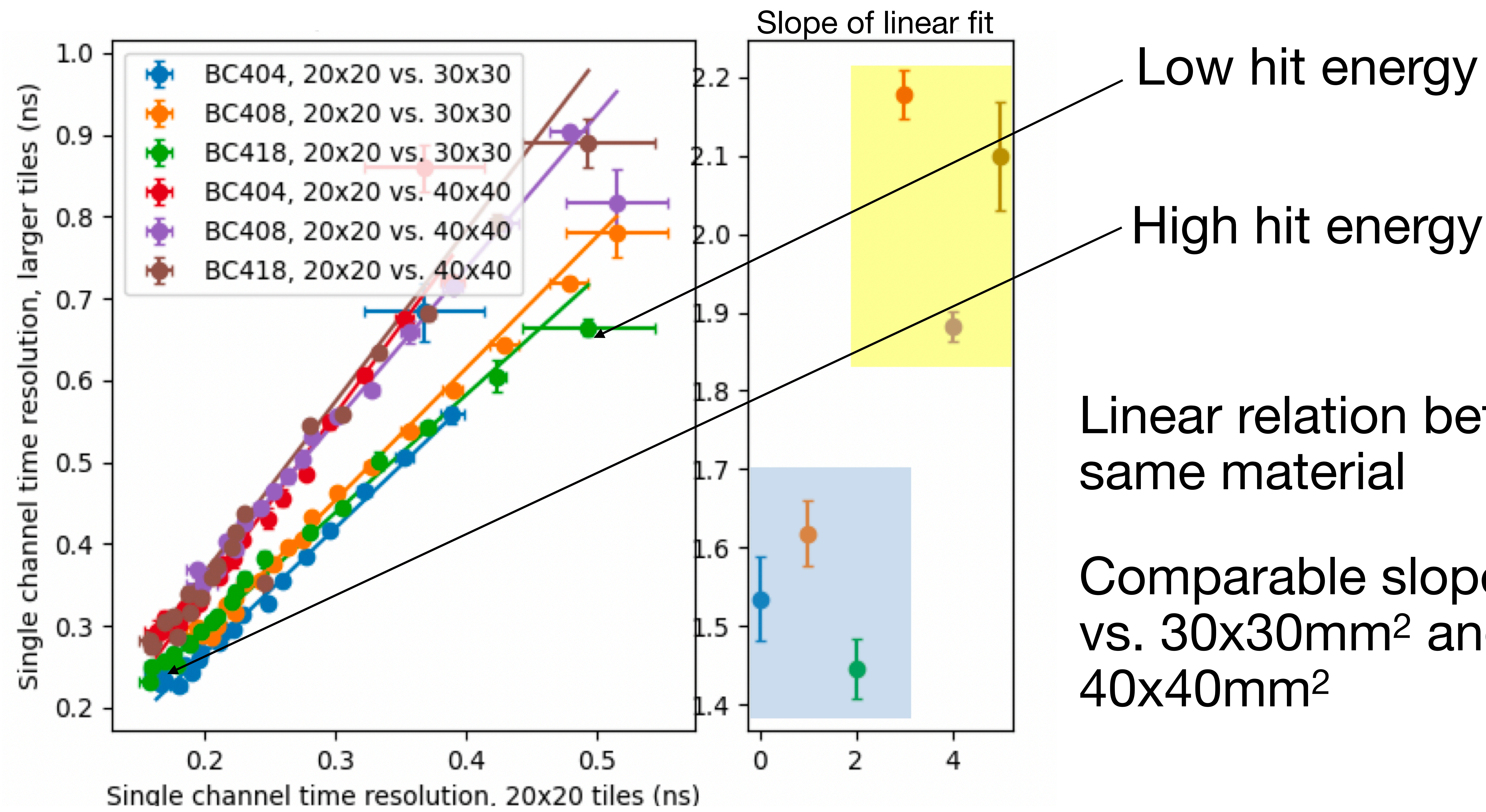


Tile Size Dependence



Linear relation between tile size for same material

Comparable slope for 20x20 mm² vs. 30x30mm² and 20x20 mm² vs. 40x40mm²

Summary

In the AHCAL: Front-end and scintillator have a comparable impact on timing

Test Beam Setup: Timing is almost entirely determined by scintillator

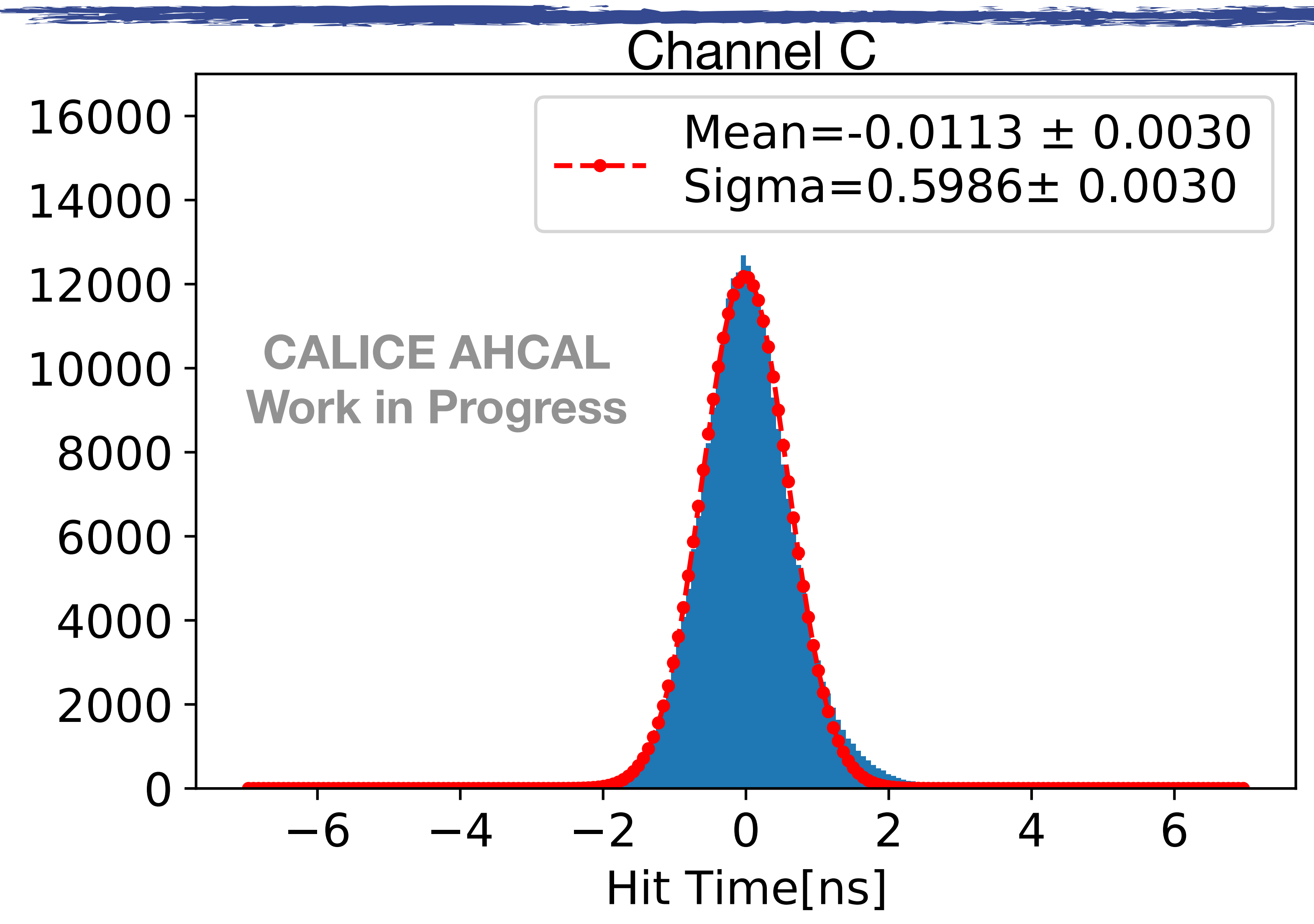
→Suited for detailed investigation of the scintillators and tiles

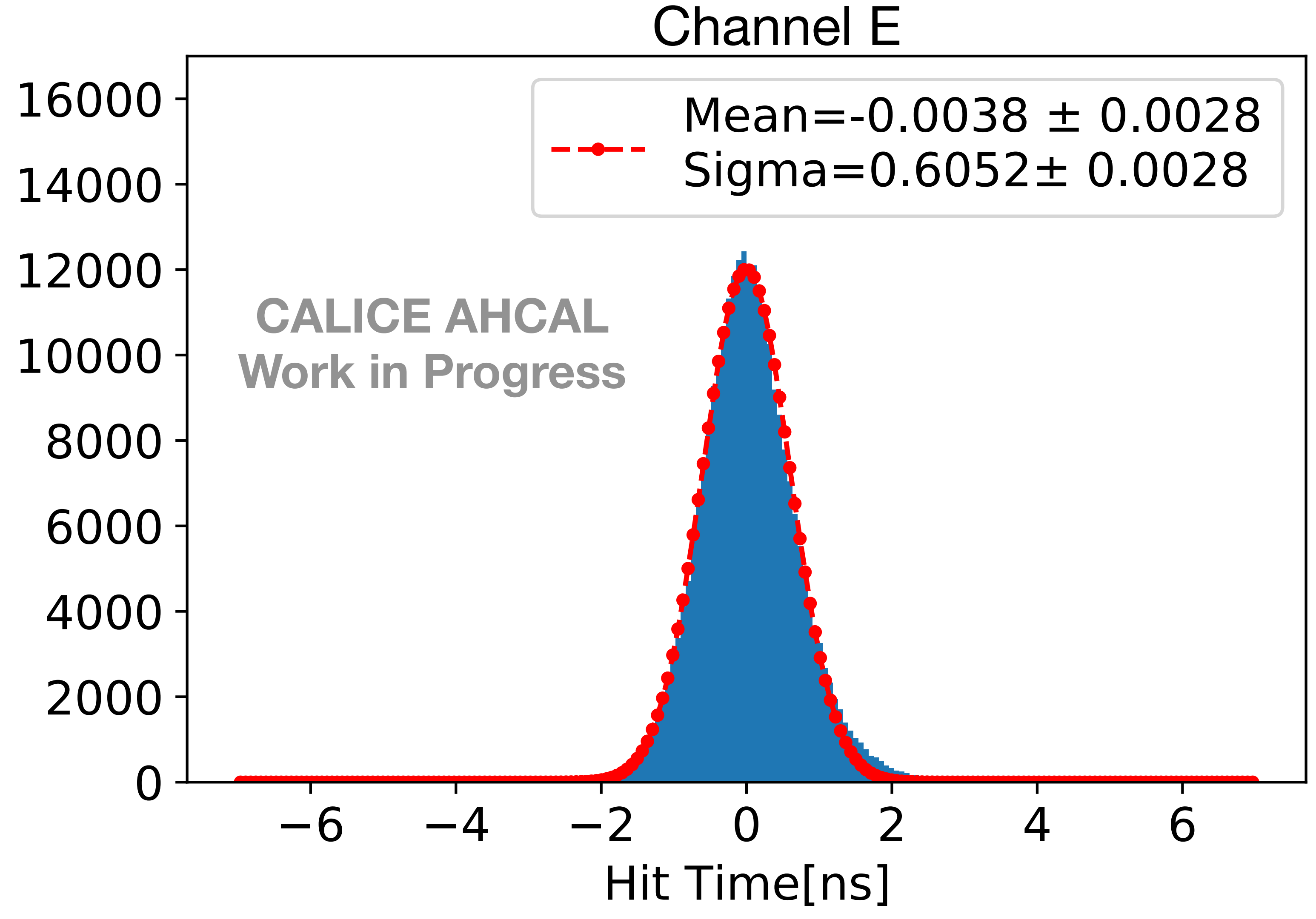
Successful second TB at DESY in October 2021:

- $O(10^7)$ recorded events per (size, material) combination
- Investigation of scintillator properties (e.g. light yield/PDE vs. rise time)
- Energy resolved time resolution for all studied scenarios
- Ongoing: disentangle contribution of PDE, tile dimension, rise time, …

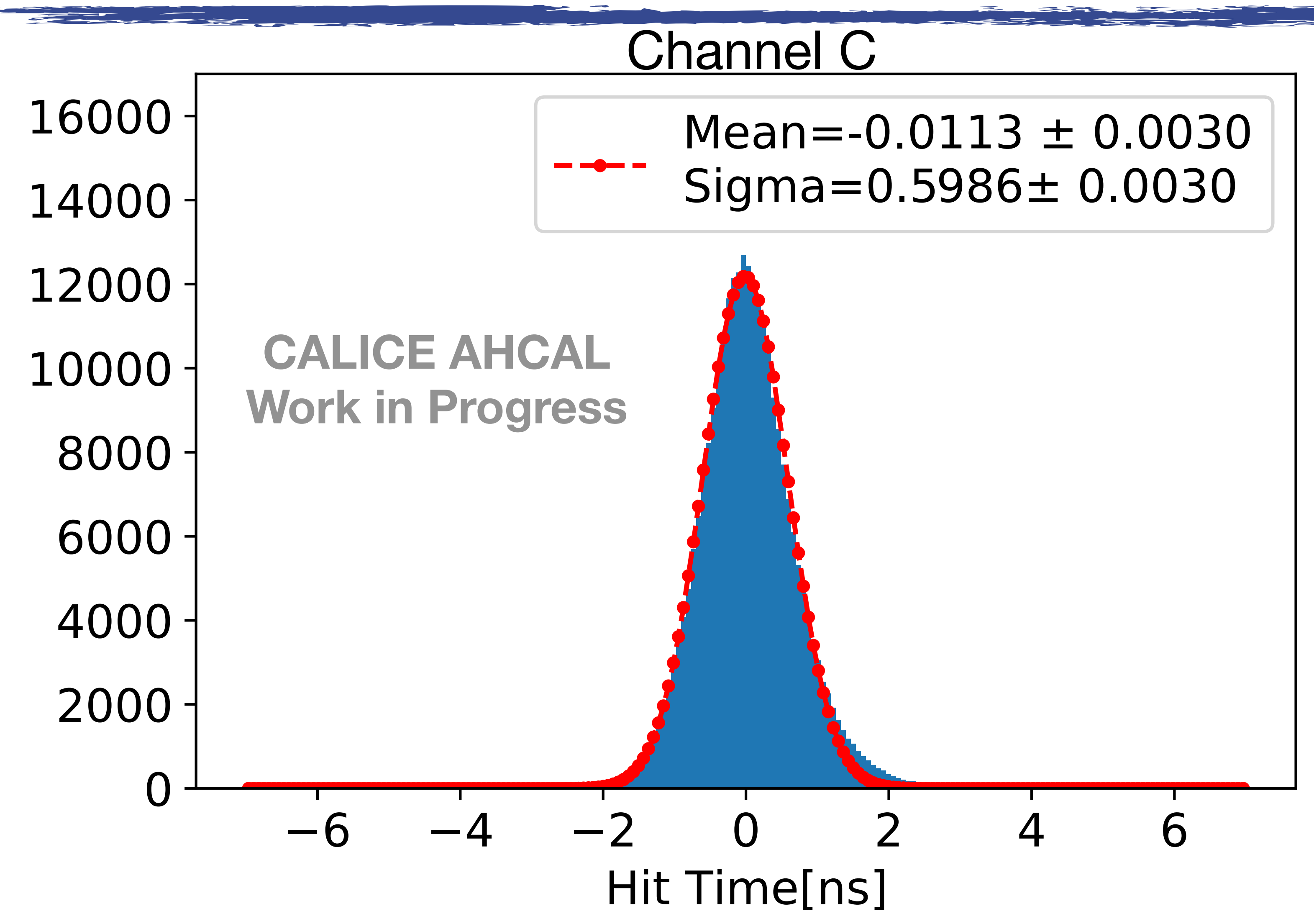
Backup

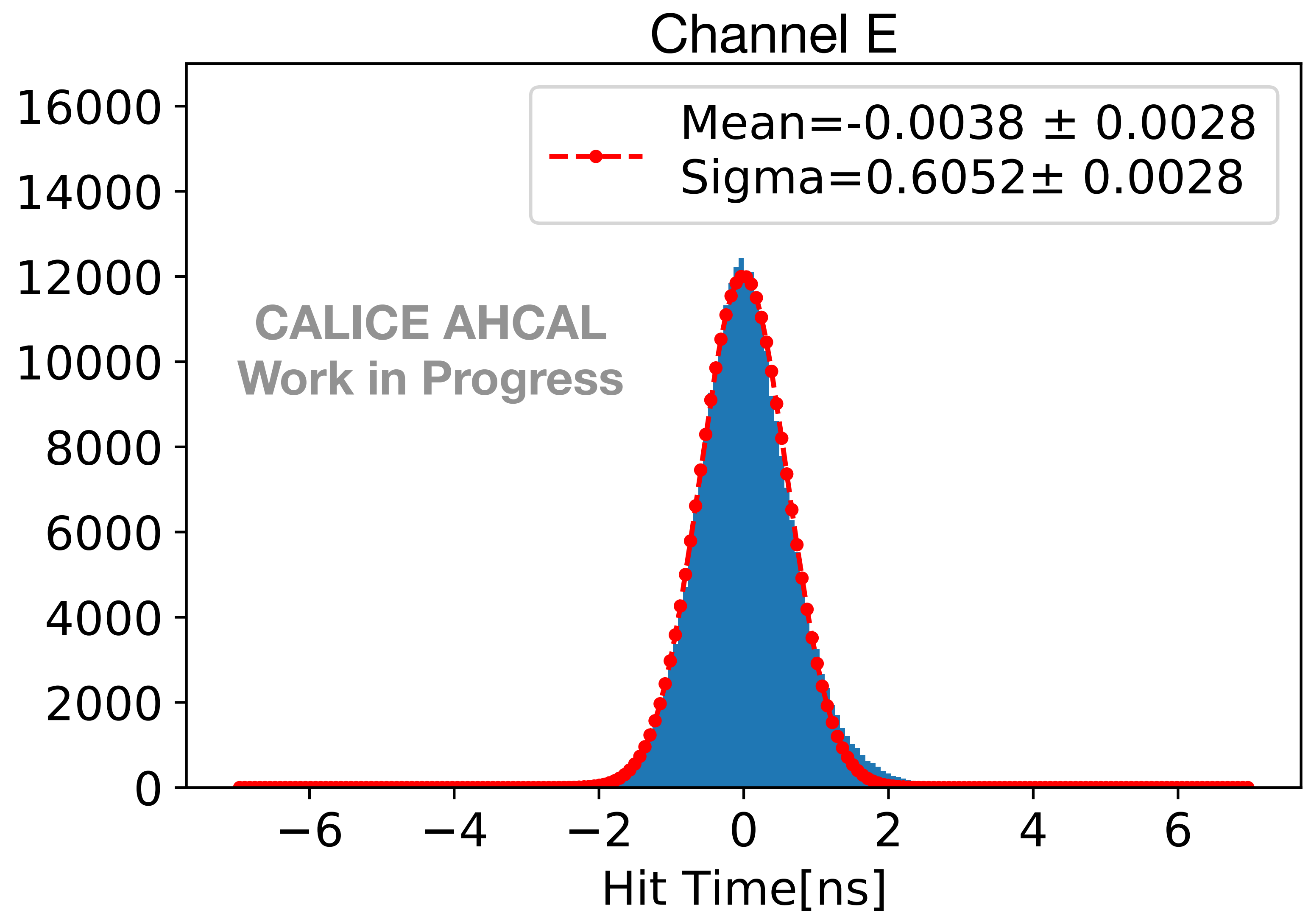
MIP Time Resolution - AHCAL Scintillator

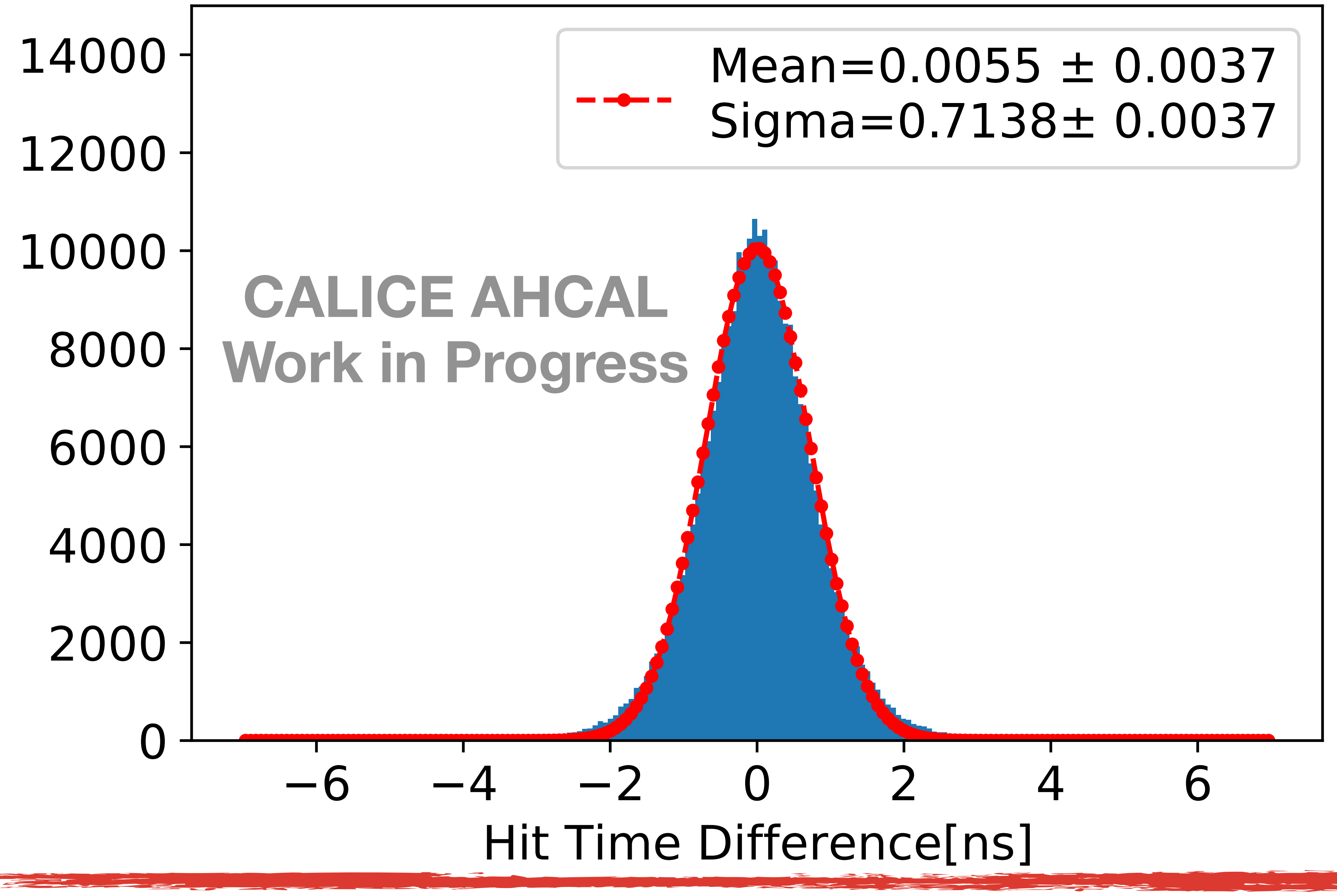




MIP Time Resolution - AHCAL Scintillator







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

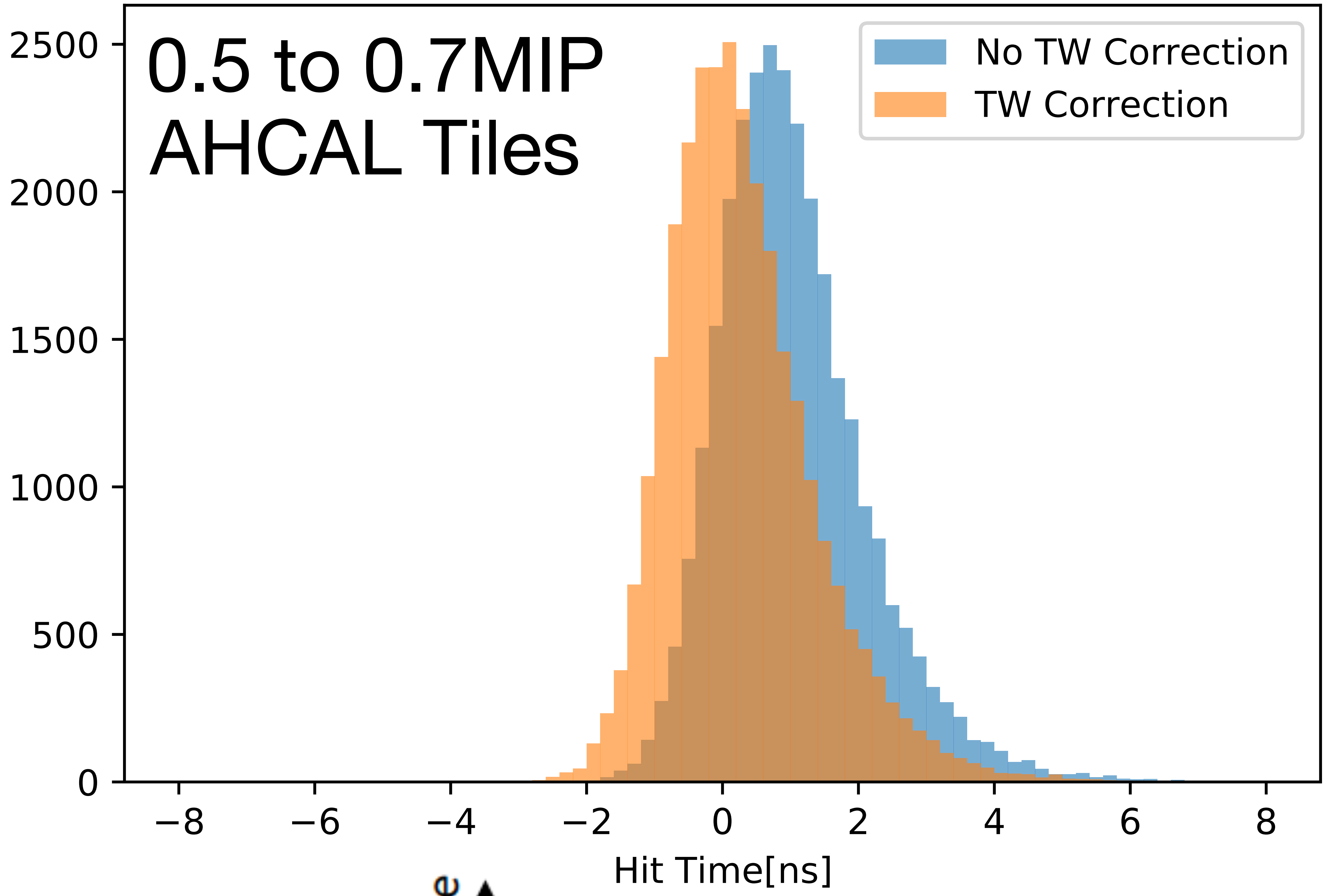
MIP Time Resolution - Comparison

	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

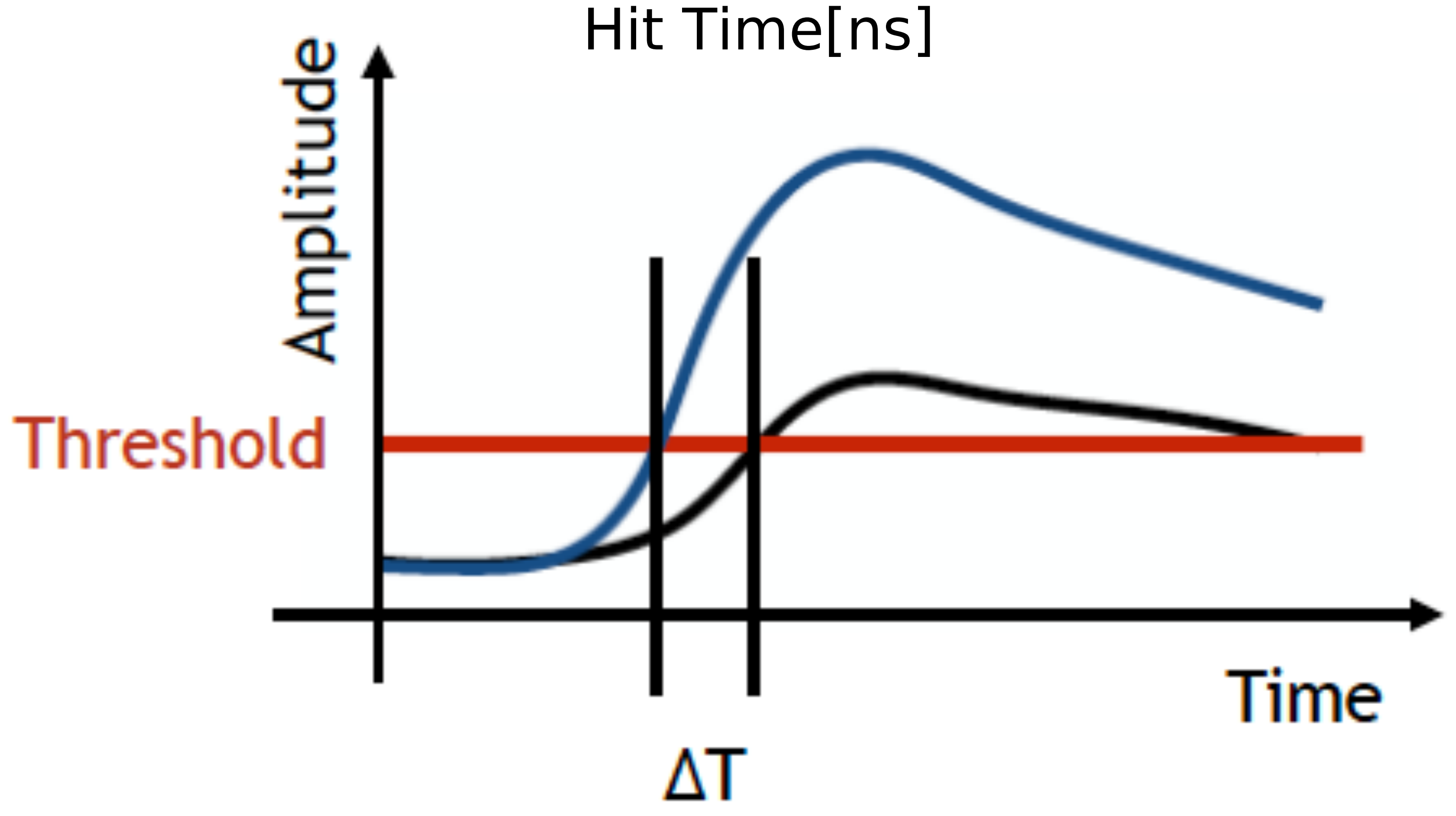
Asymmetric Hit Time Distribution



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

Two (or more?) possible reasons:

1. Timewalk

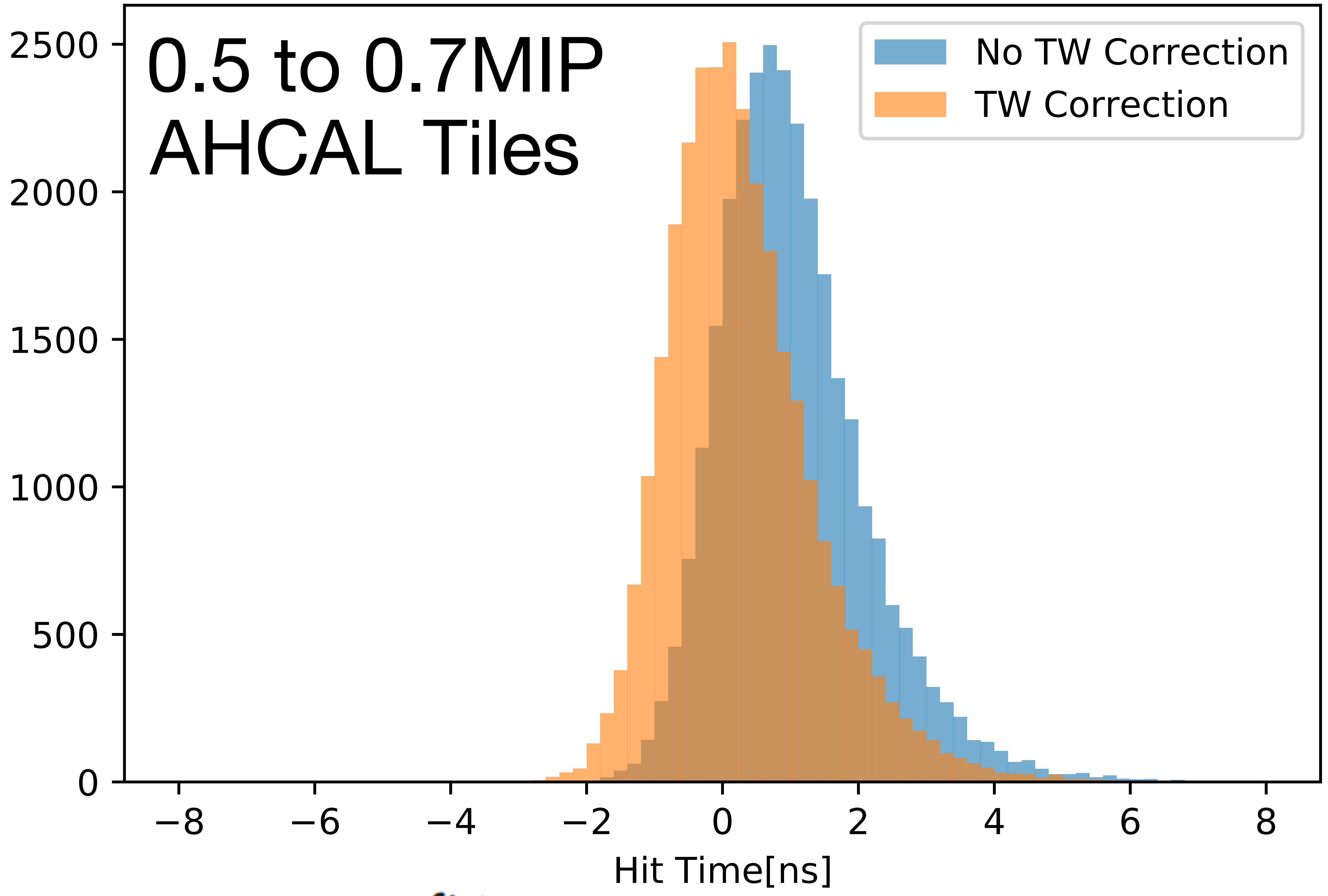


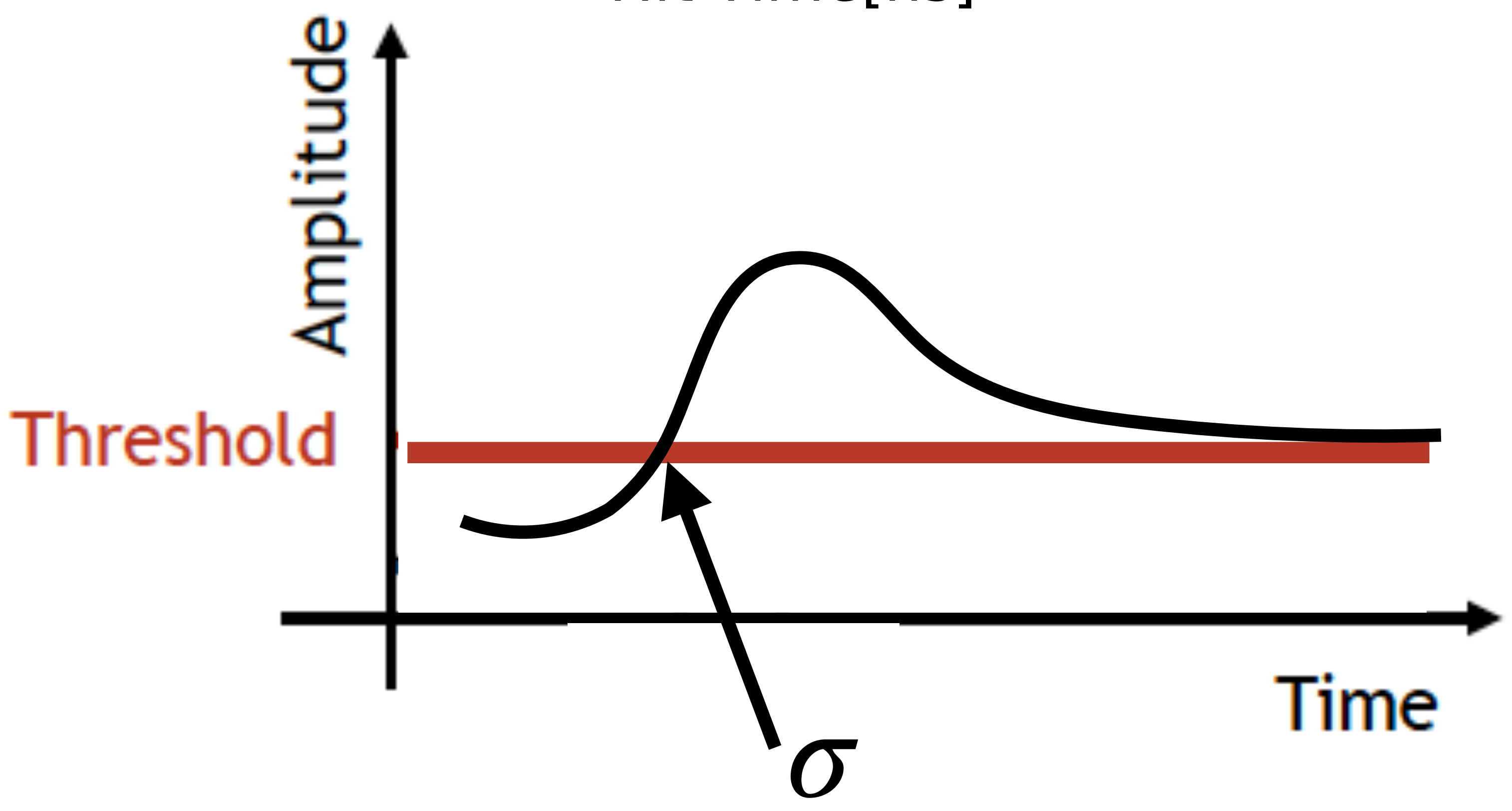
Higher amplitude —> faster rise time:

- 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)

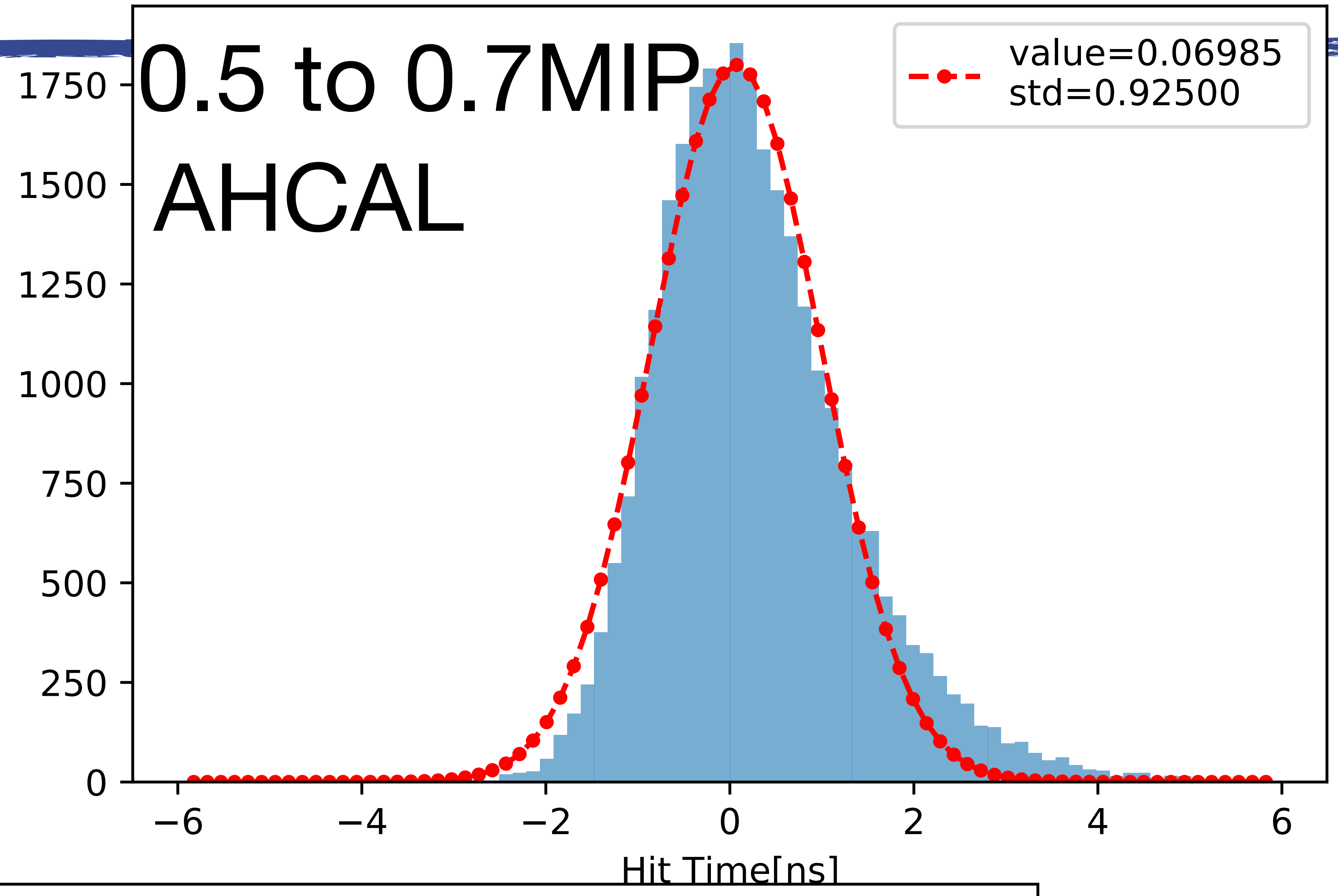
Only accept events with both hits within the same energy bin (only 10% of events)

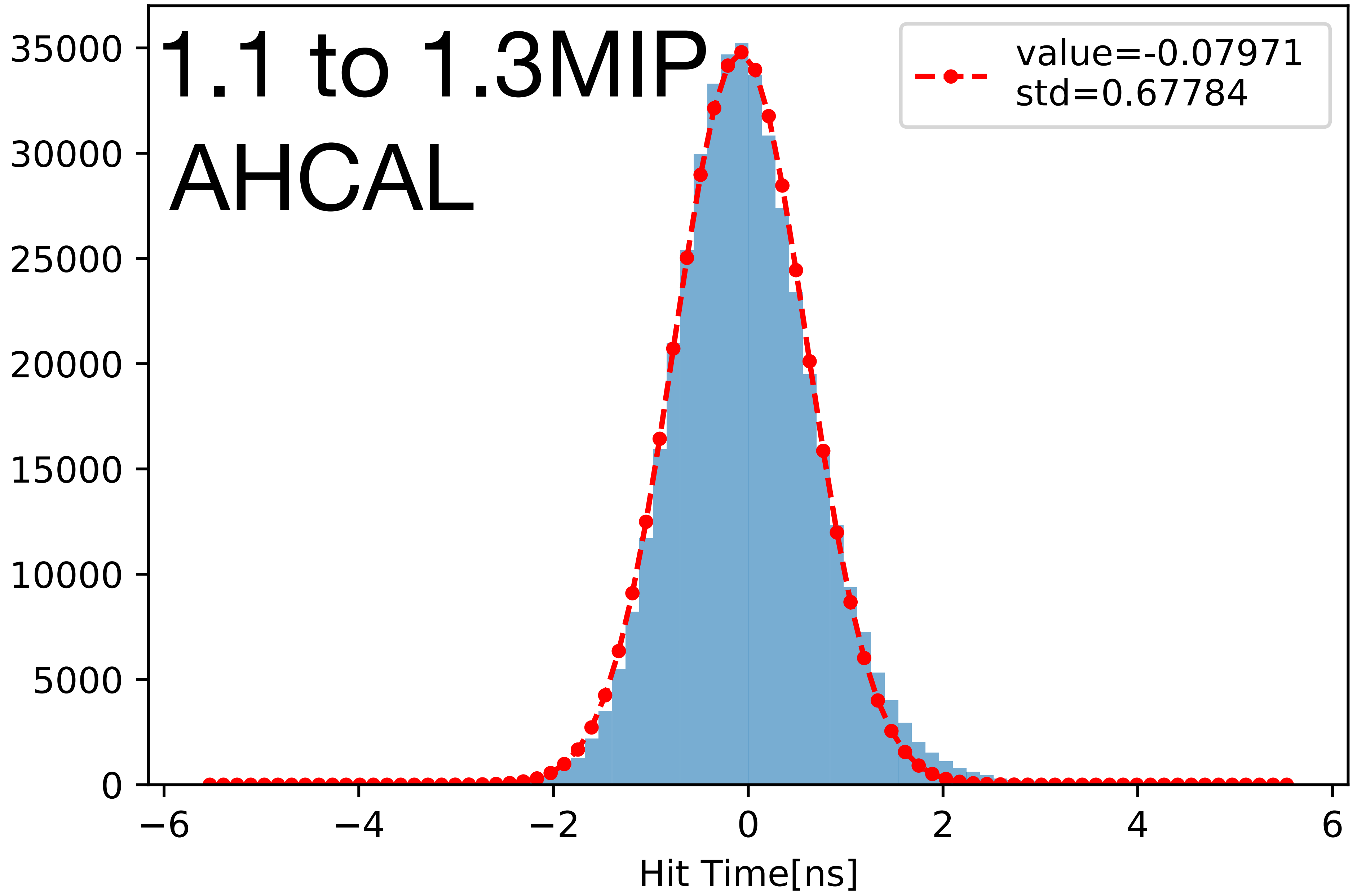
Trigger time obtained with constant fraction discrimination (elim. time walk in trigger)

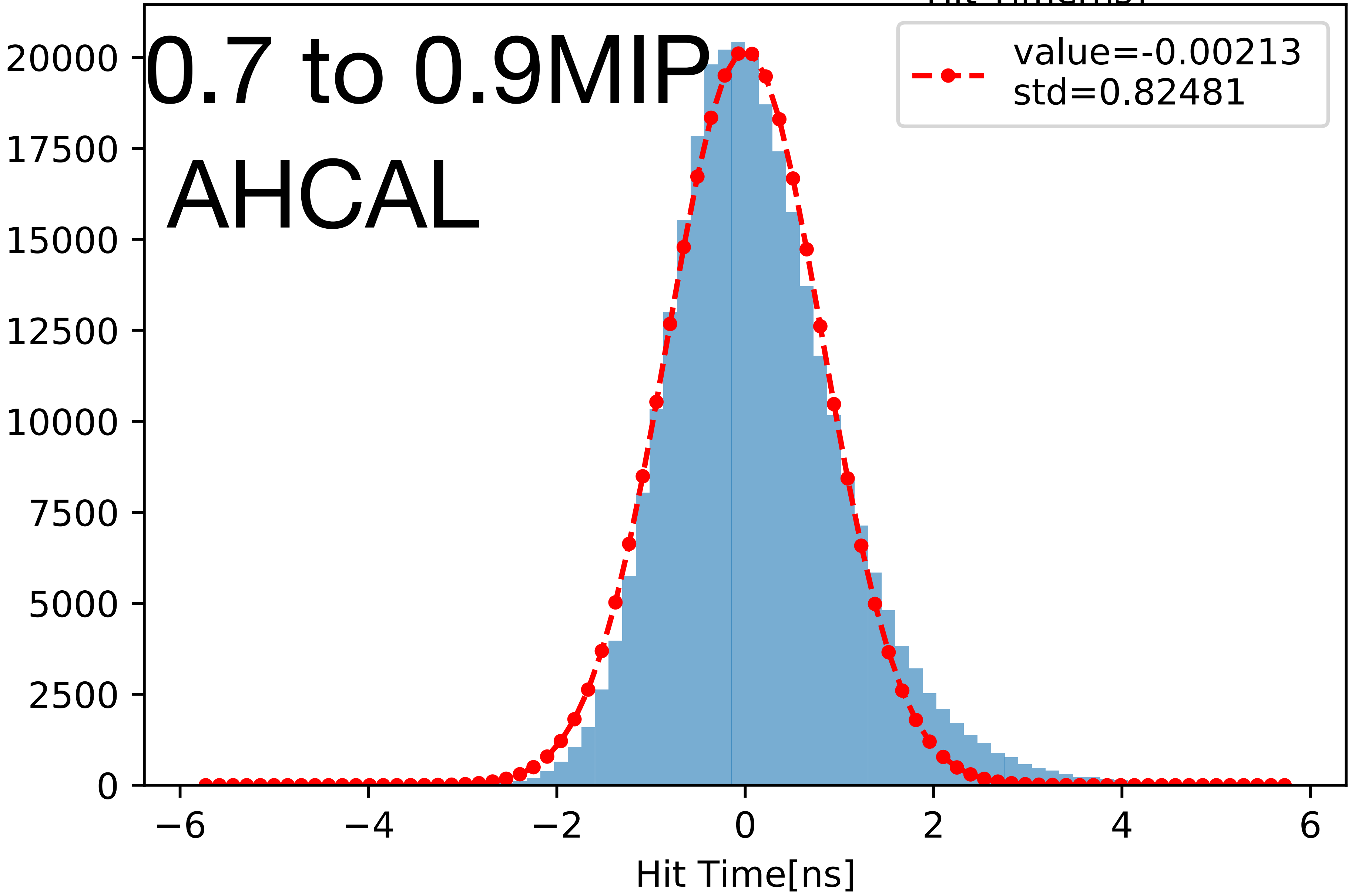
Signal times obtained with fixed amplitude threshold (25 mV = ~3 pe) to :

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

Energy Binned Distributions







Distributions get narrow and approach a gaussian:

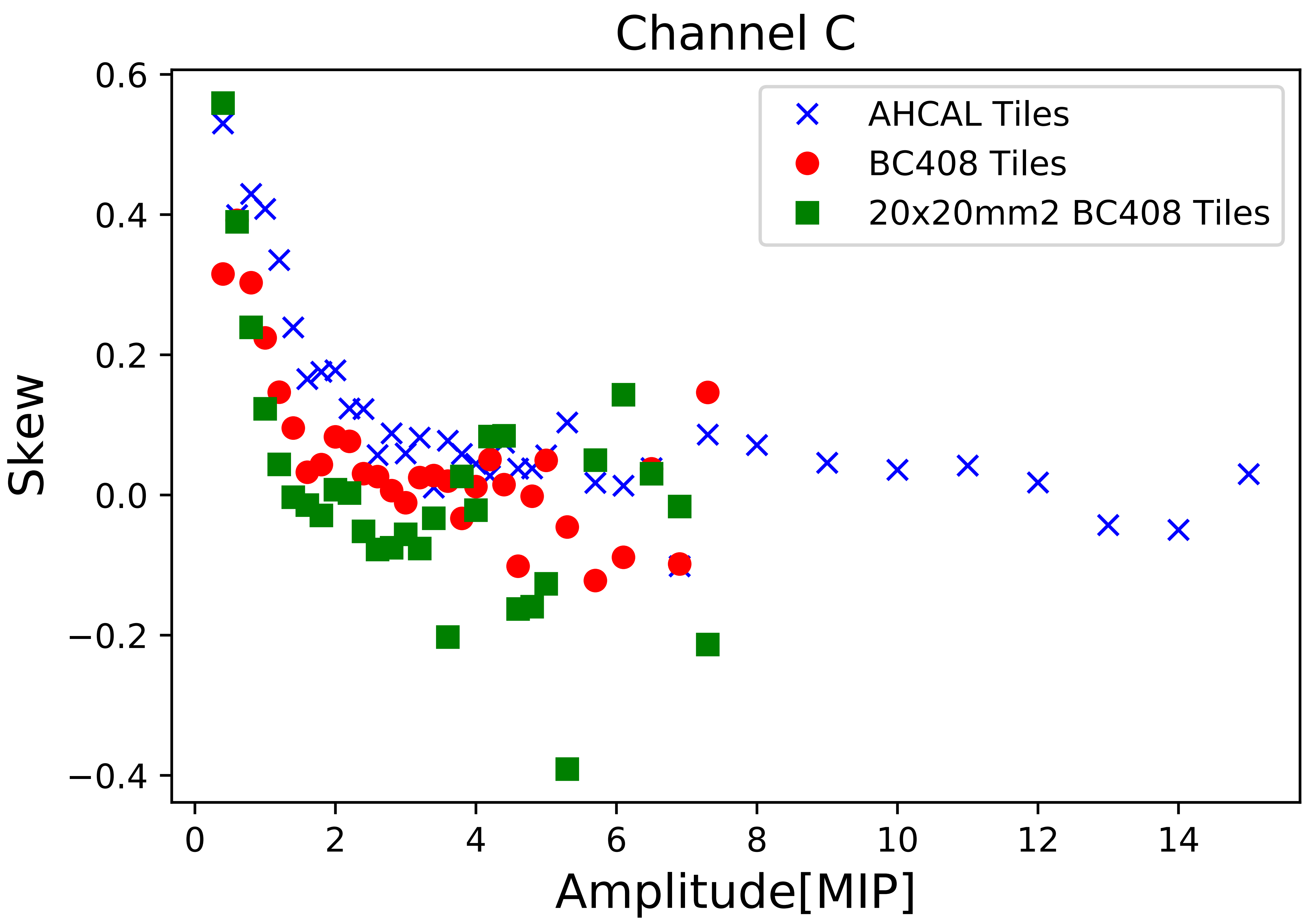
- Study evolution of skew with energy

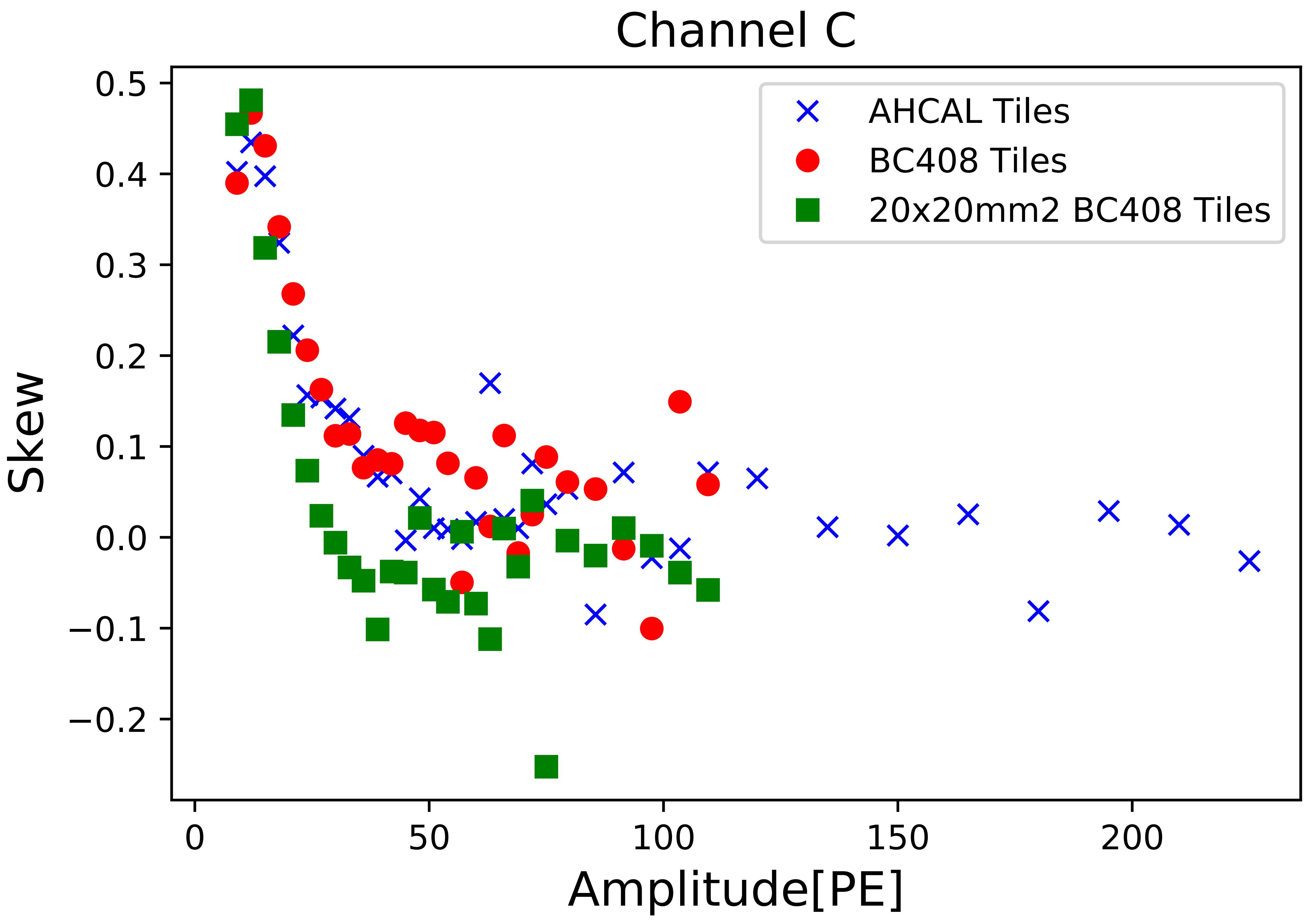
Asymmetric Hit Time Distribution

Studied Scenarios:

- AHCAL Scintillator 30 x 30 x 3 mm³
- BC408 30 x 30 x 3 mm³ and 20 x 20 x 3 mm³

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

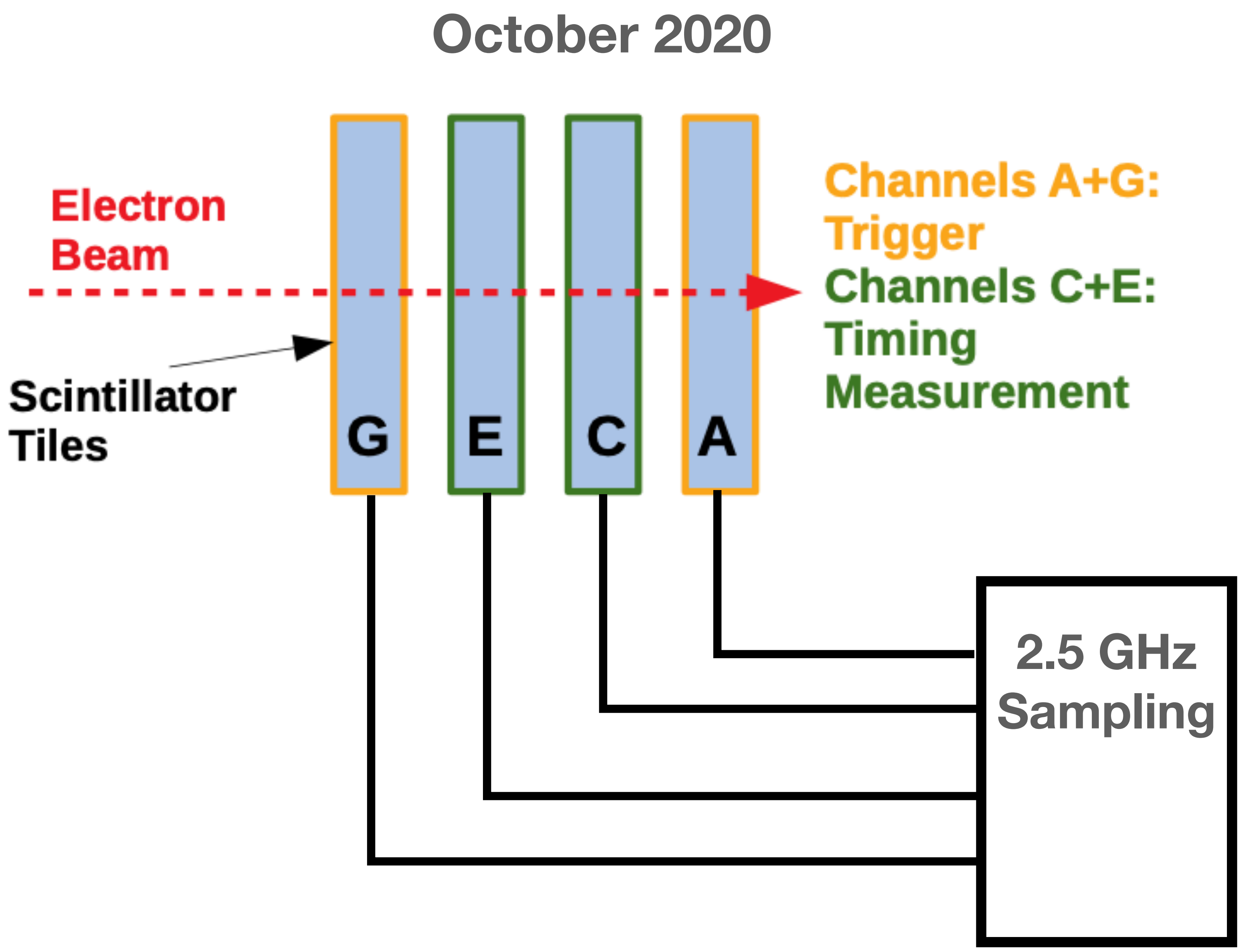


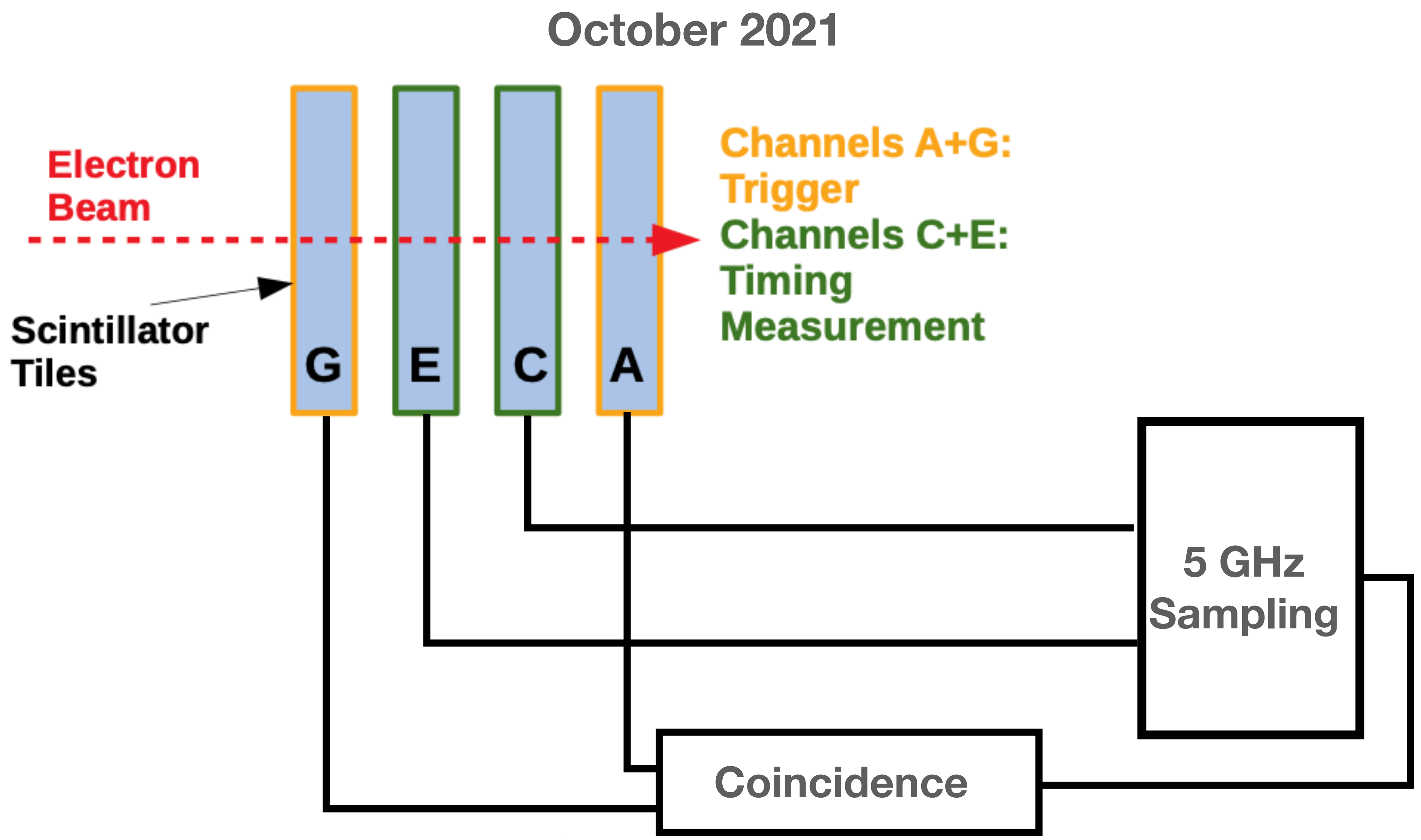


Plans for Upcoming Test Beam

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, …

Data Taking and Processing

Real Data

Binary files

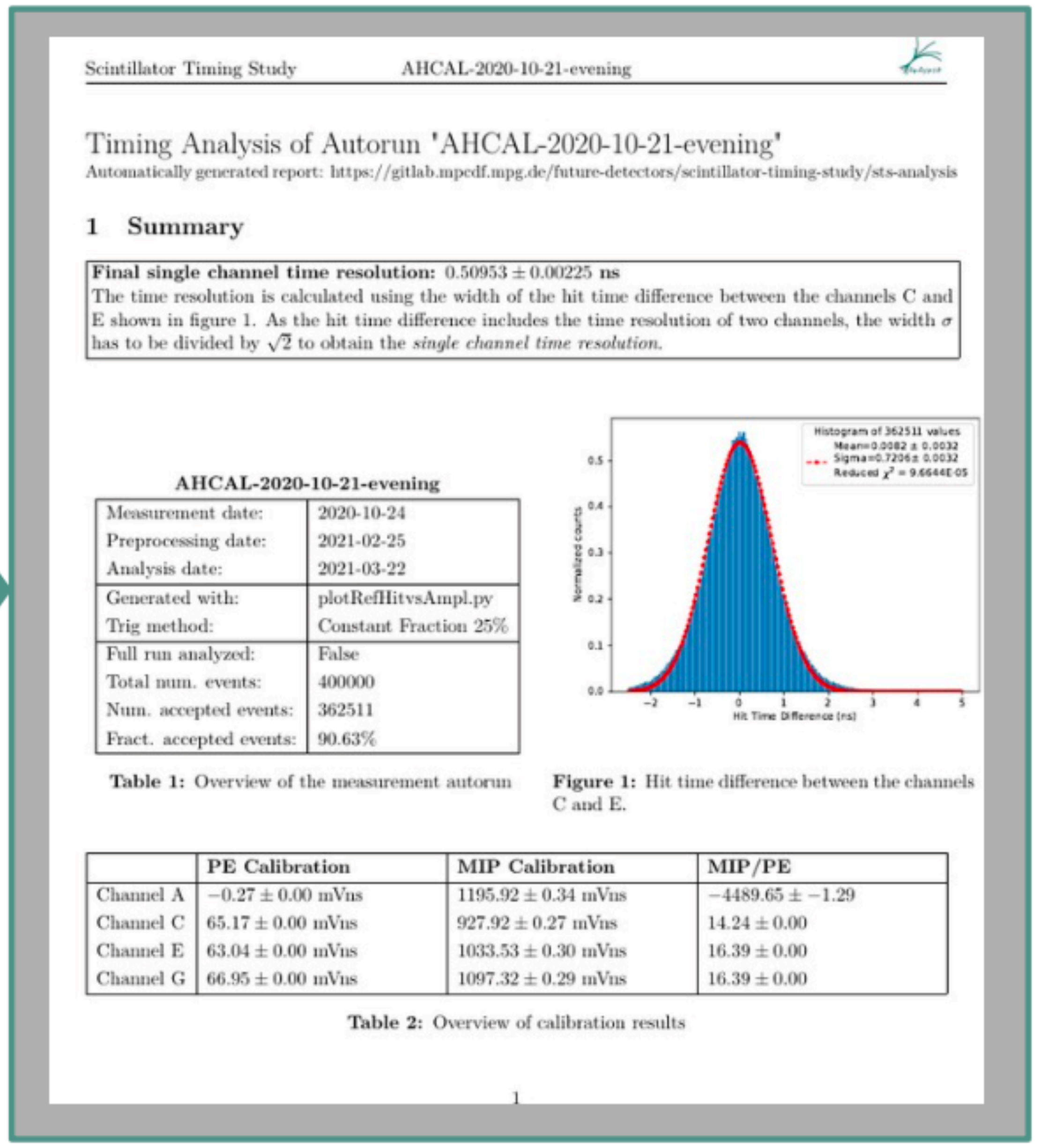
Waveforms

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:	plotRefHitvsAmpl.py
Trig method:	Constant Fraction 25%
Full run analyzed:	False
Total num. events:	400000
Num. accepted events:	362511
Fract. accepted events:	90.63%

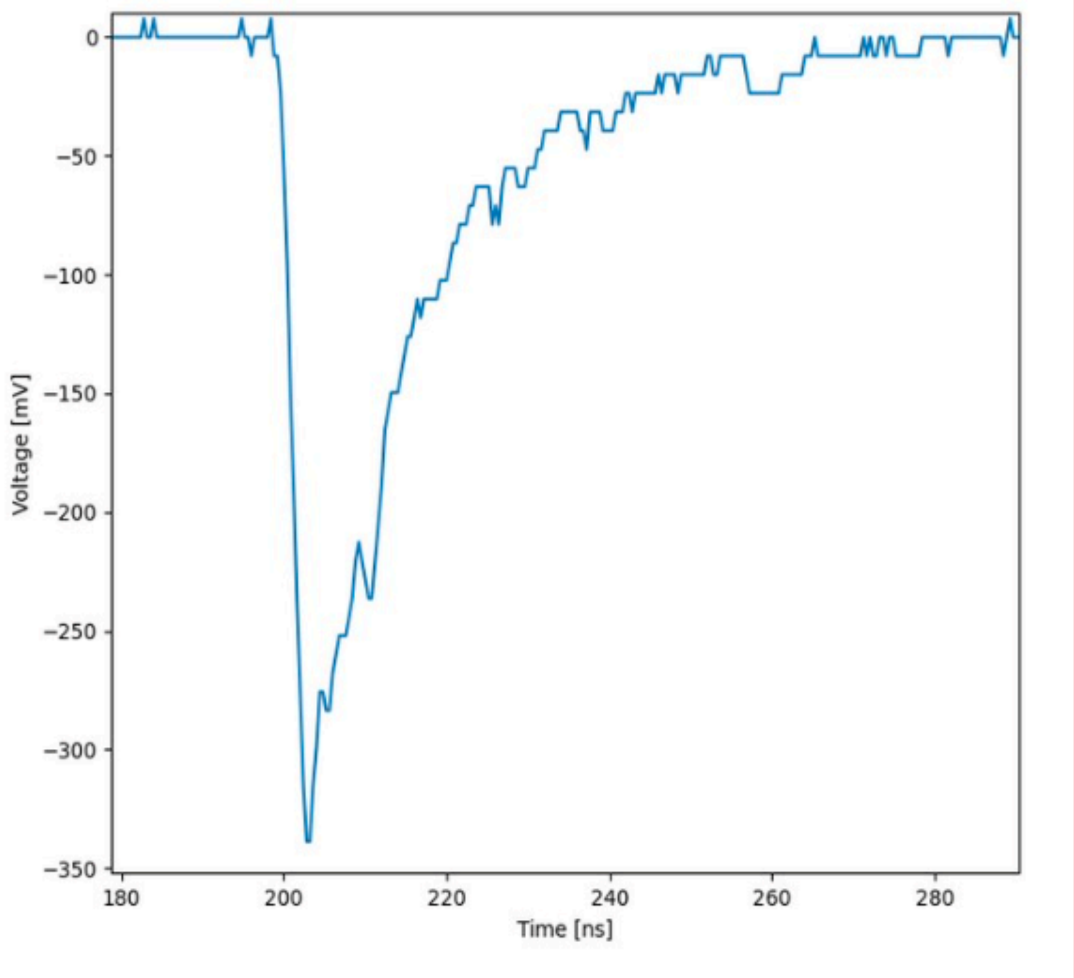
Table 1: Overview of the measurement autorun

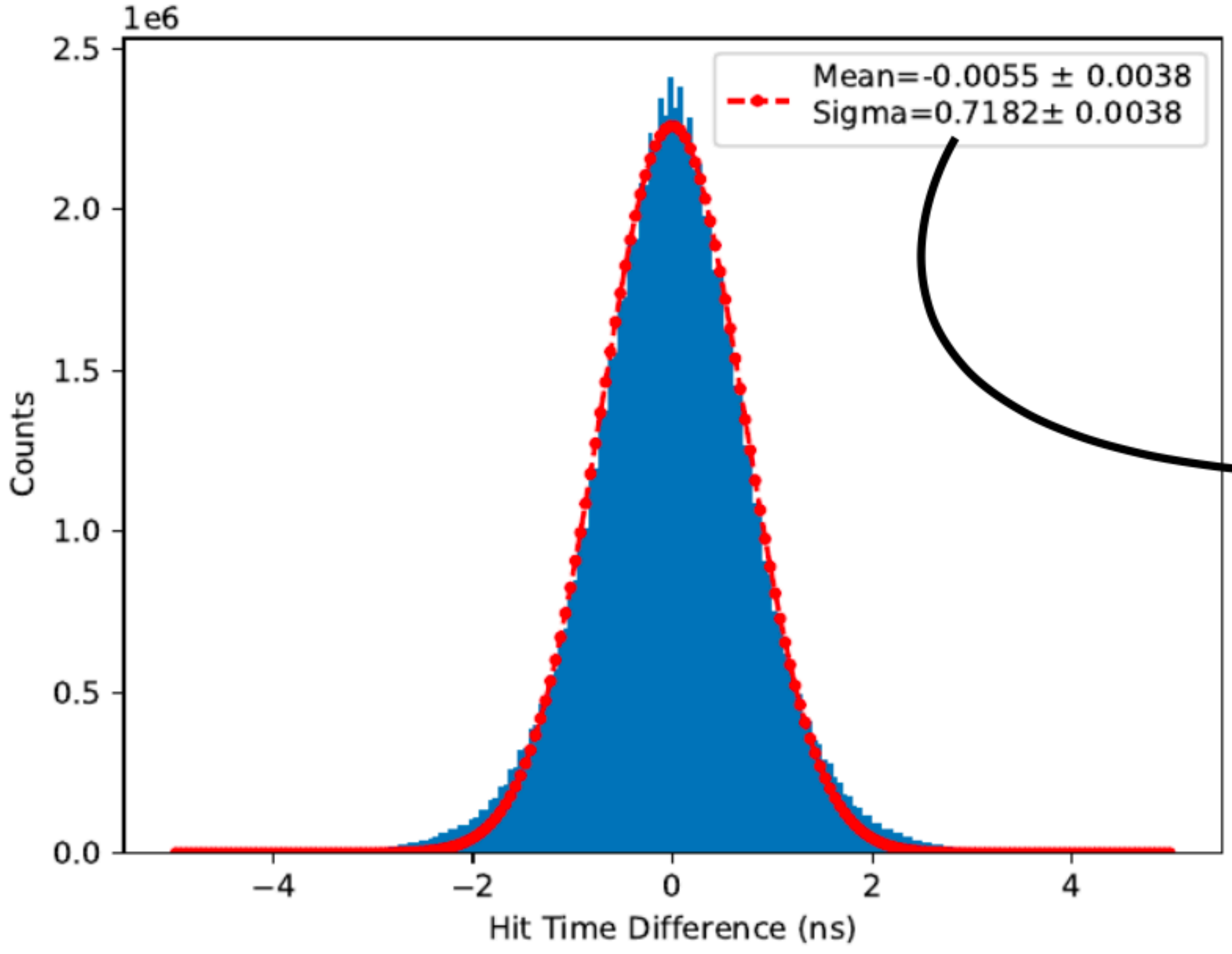
Figure 1: Hit time difference between the channels C and E.

	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

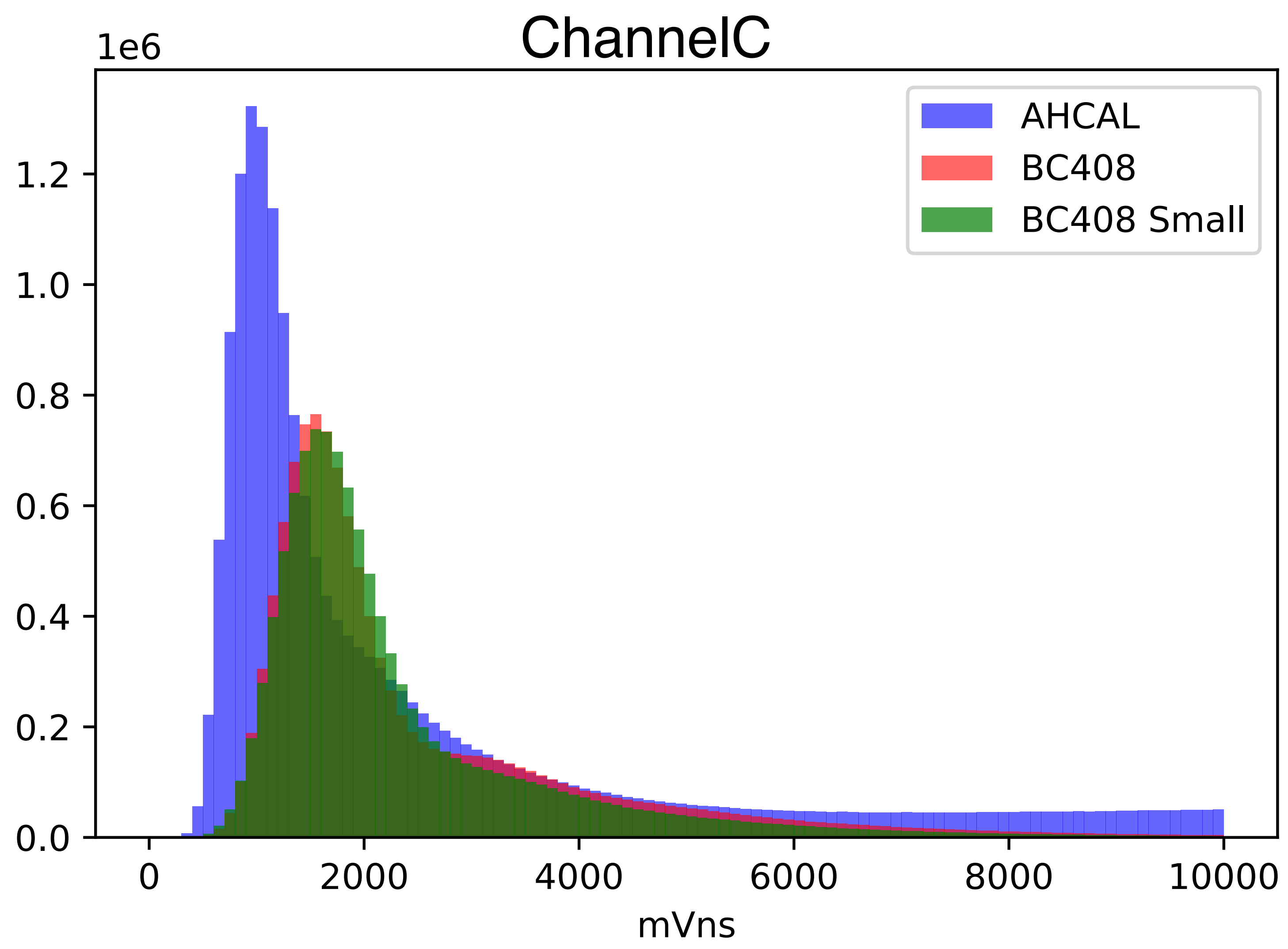
1



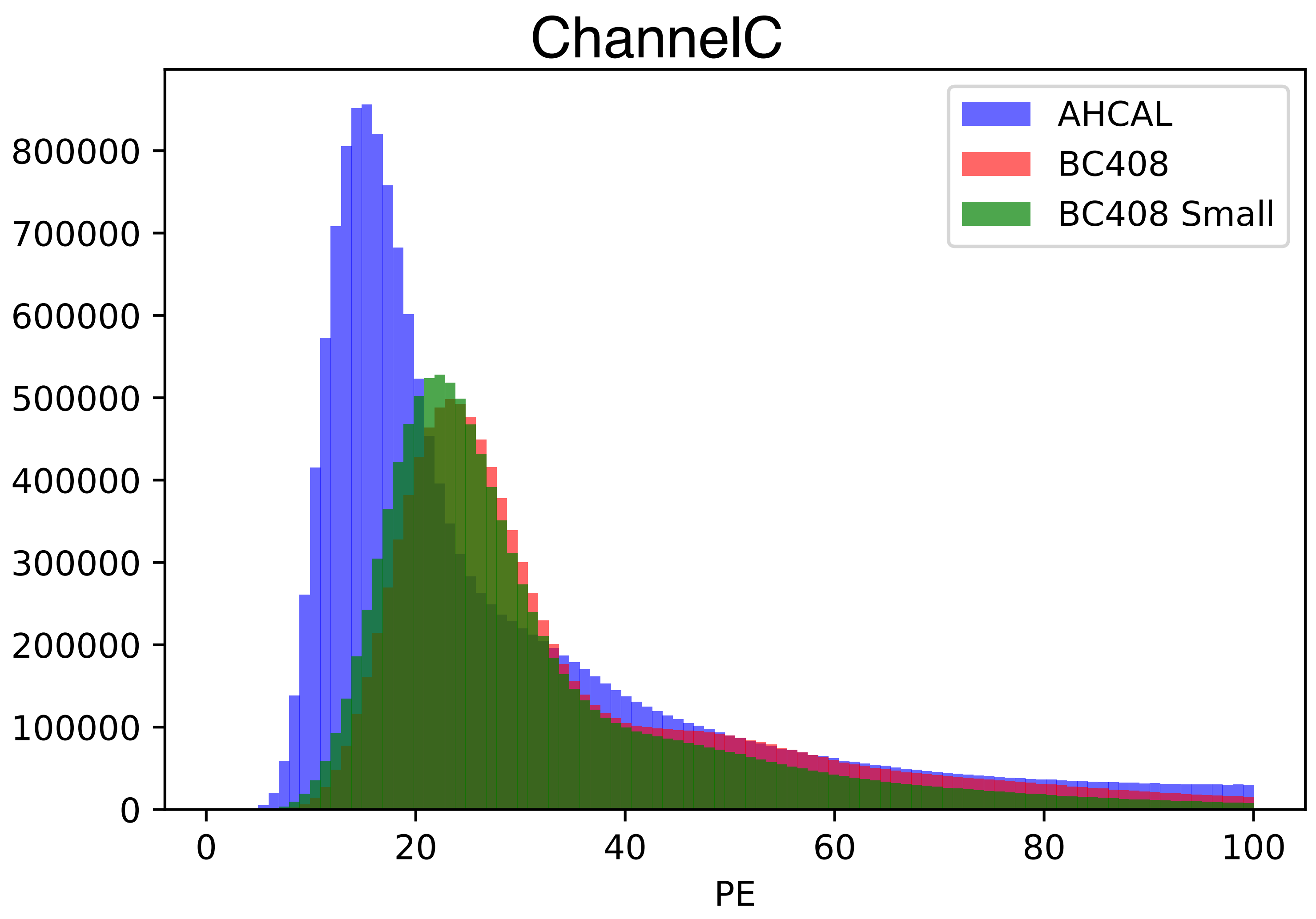


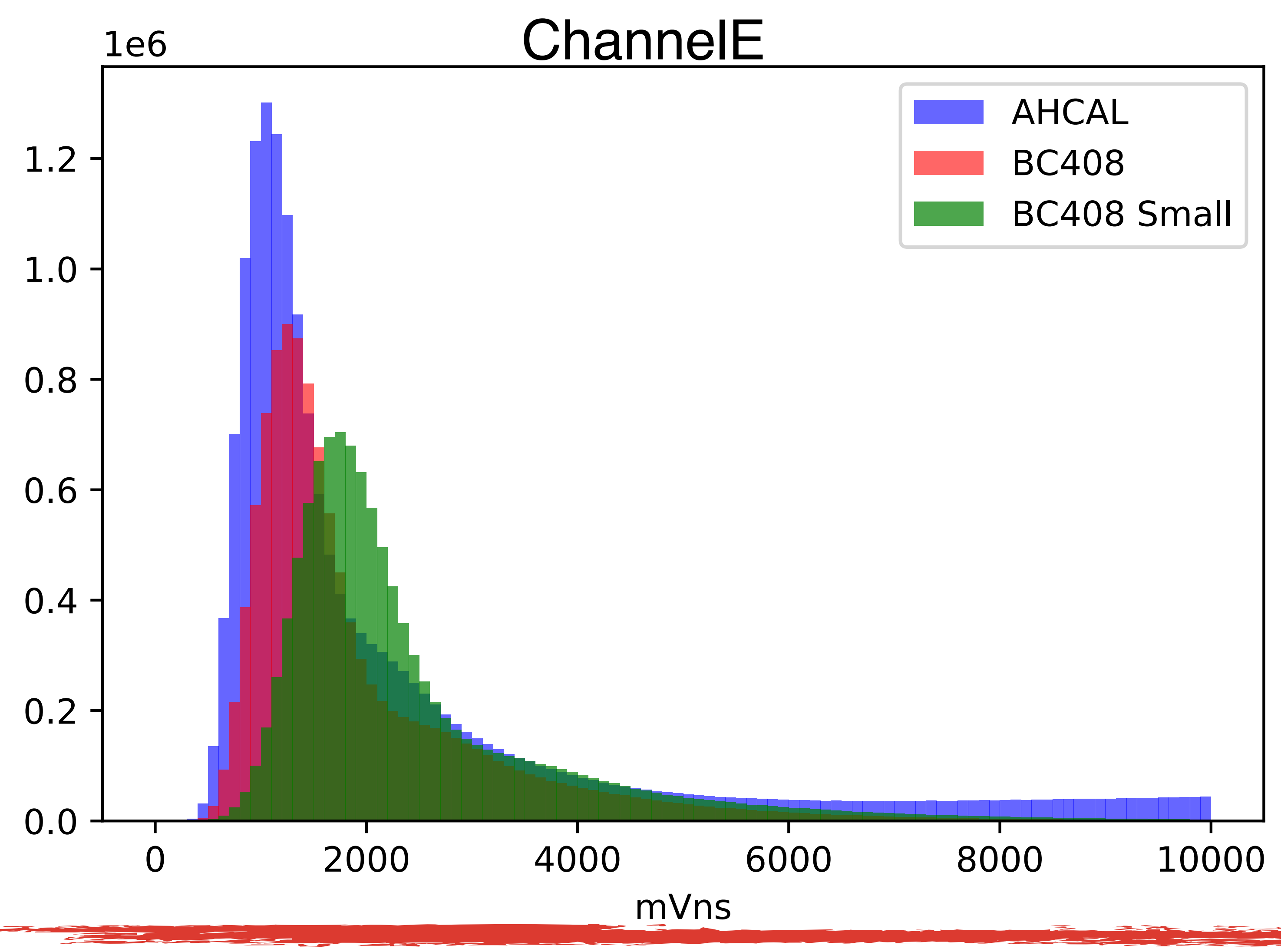
Hit time difference
→ time resolution

Comparison of PE Calibration

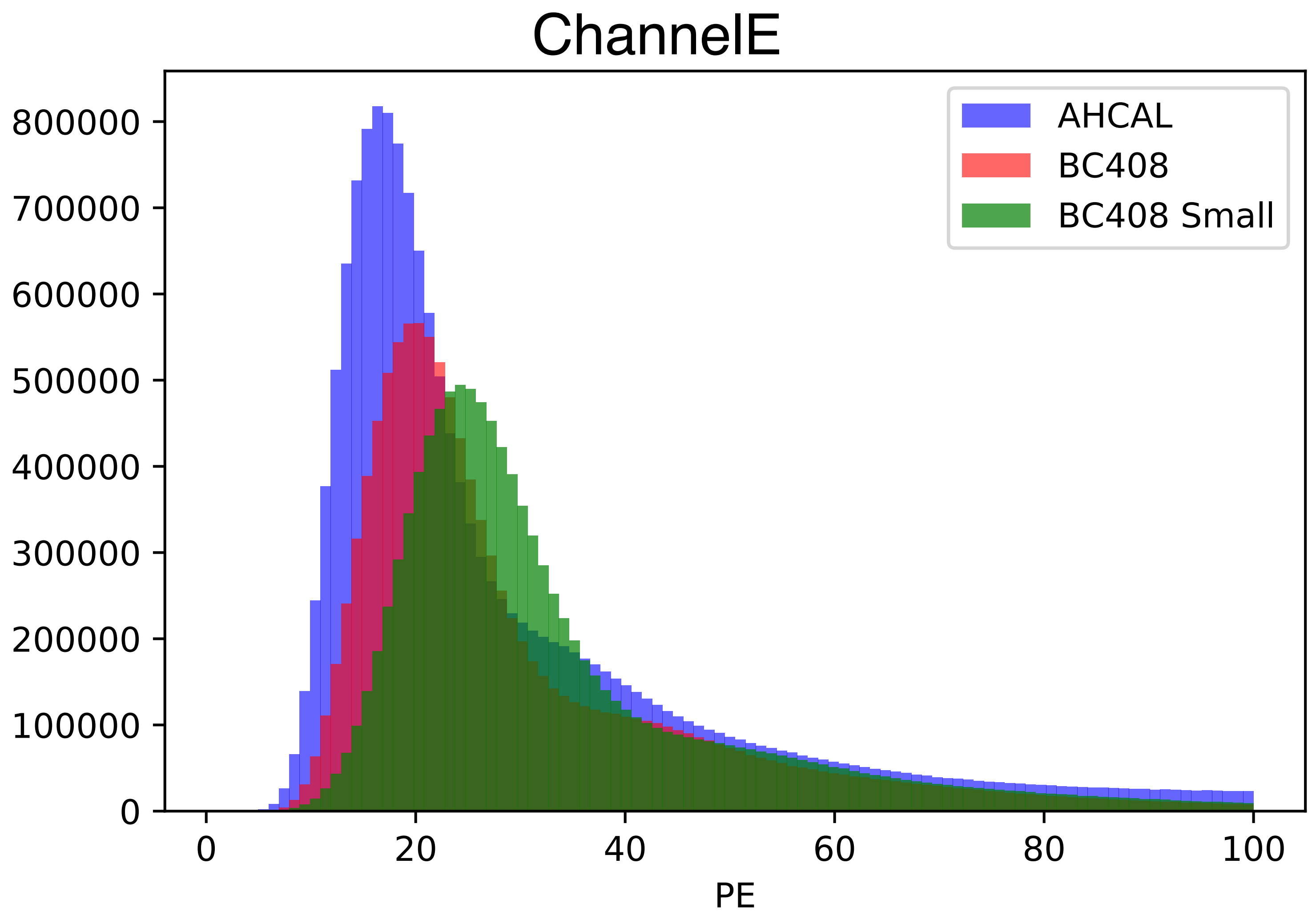


ChannelC:
AHCAL: 65.370mVns = 1PE
BC408: 65.680mVns = 1PE
BC408small: 71.930mVns = 1PE

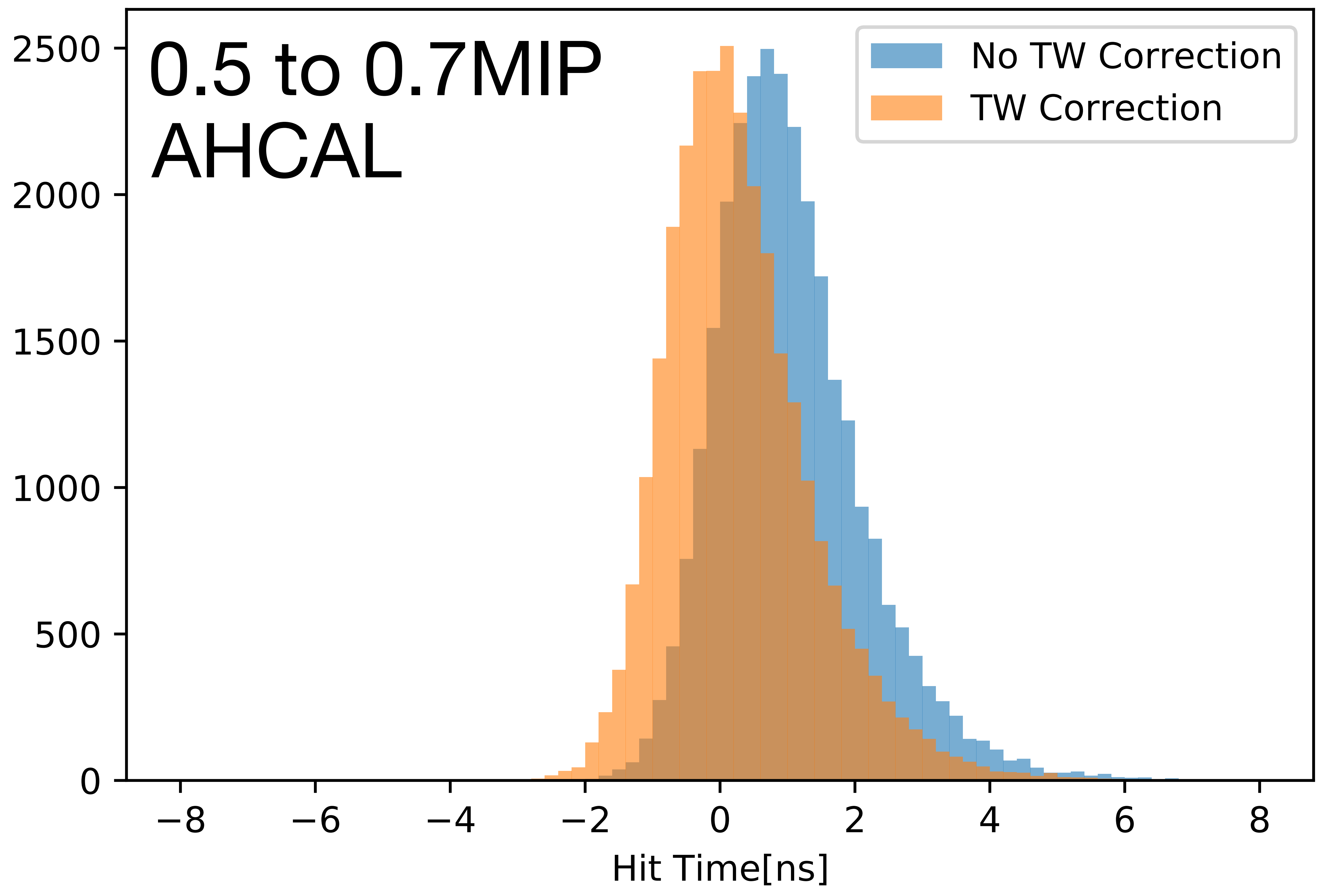


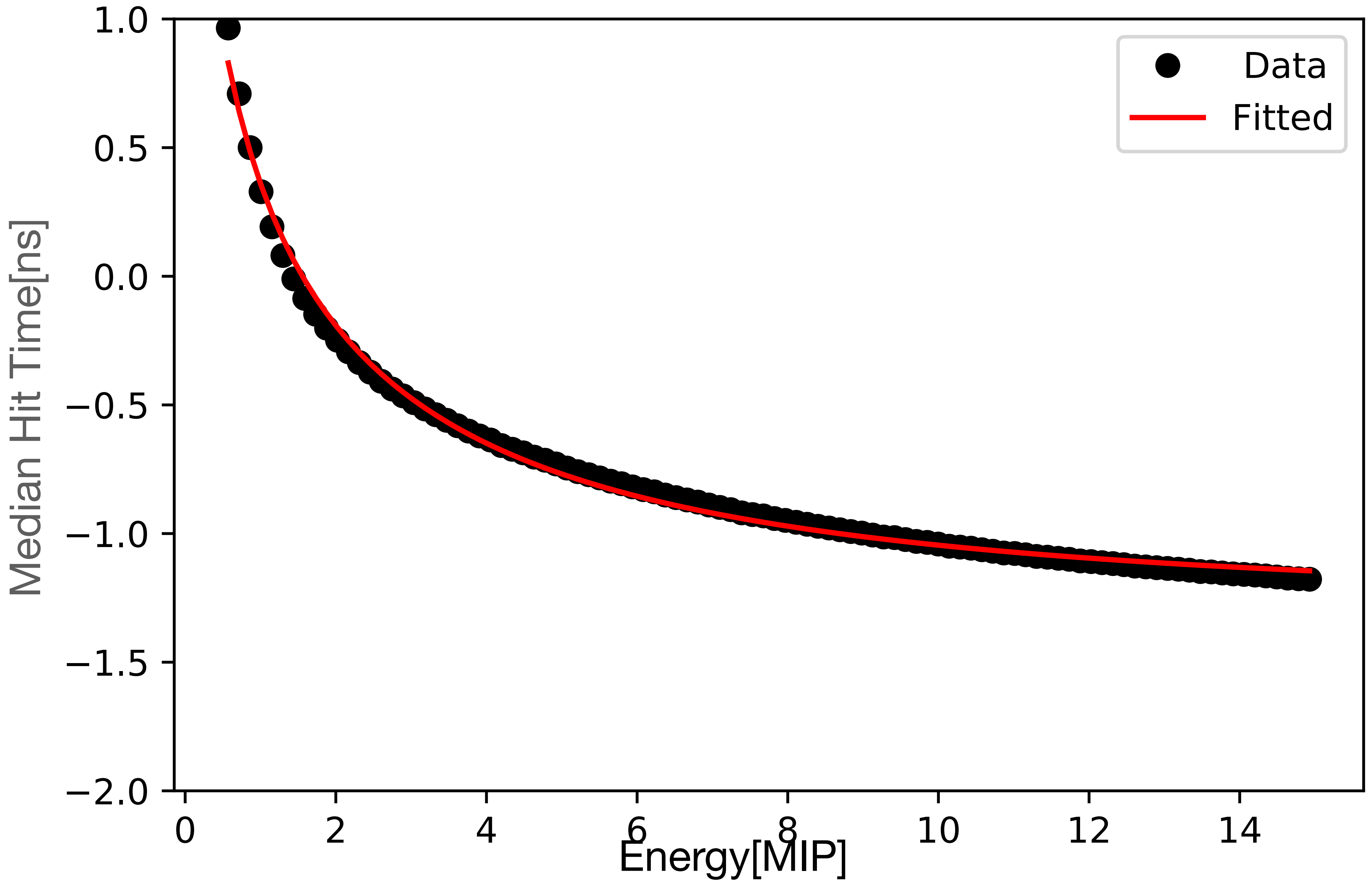


ChannelE:
AHCAL: 63.656mVns = 1PE
BC408: 63.534mVns = 1PE
BC408small: 70.717mVns = 1PE



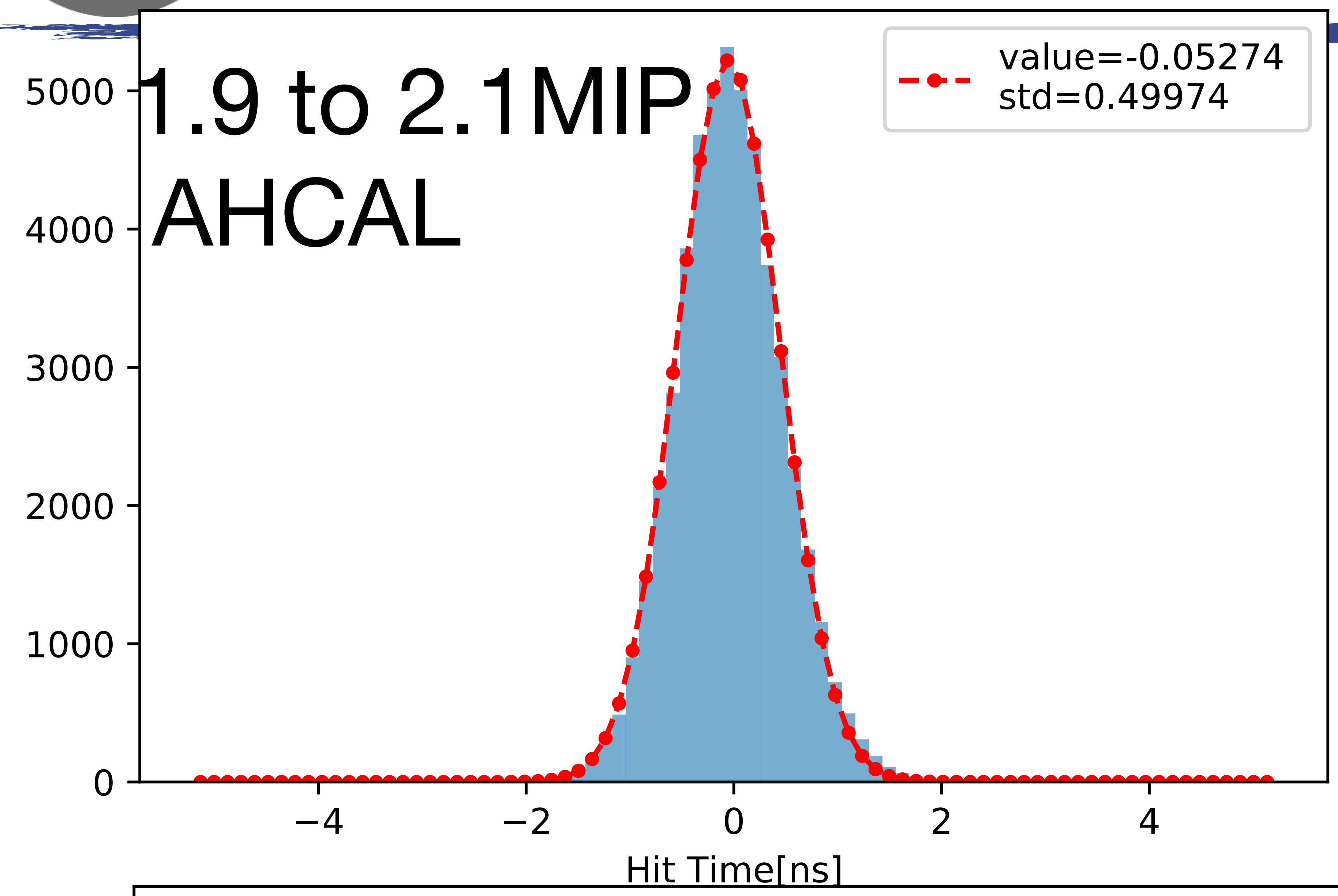
AHCAL Dataset - Time Walk

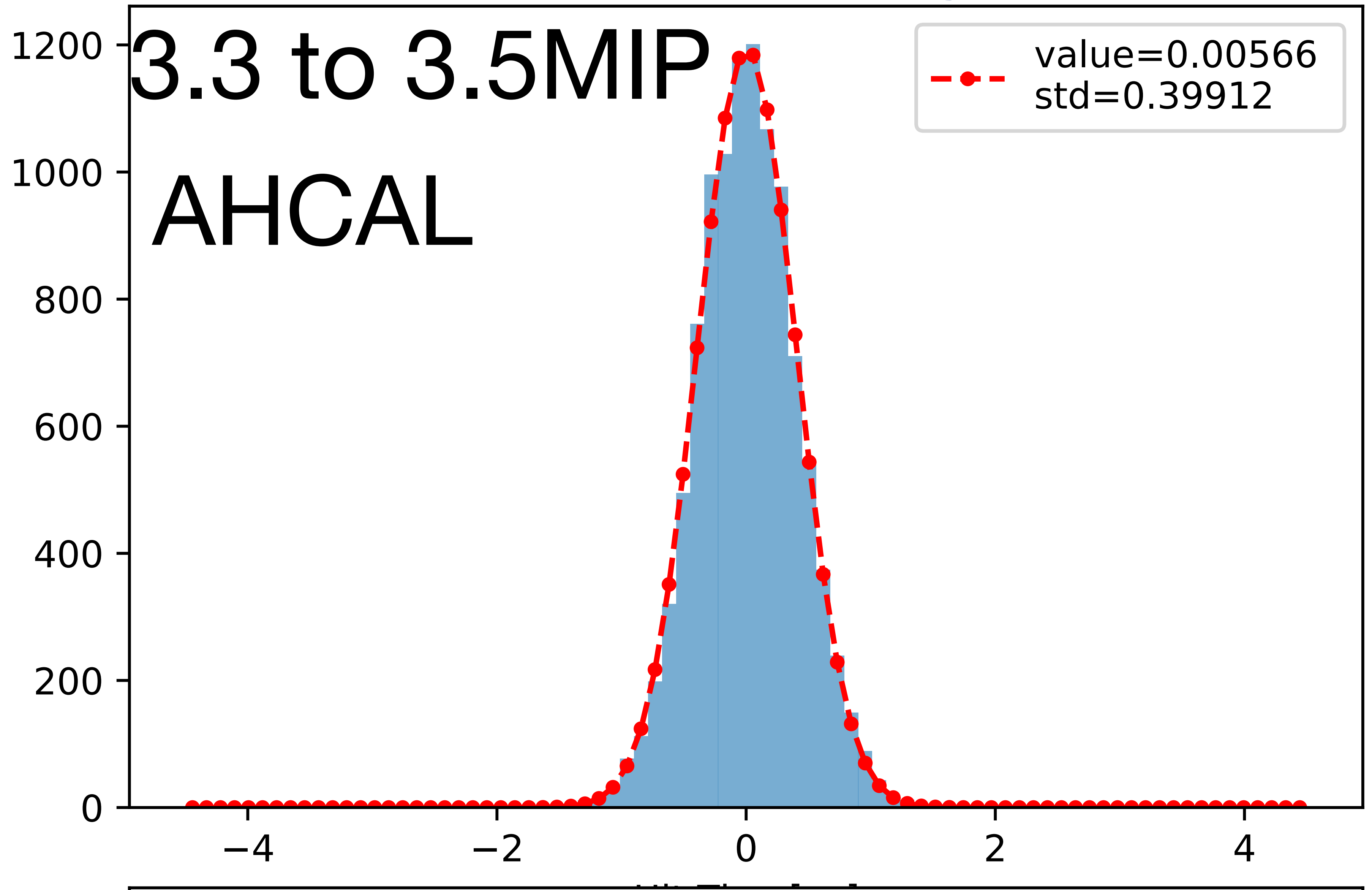




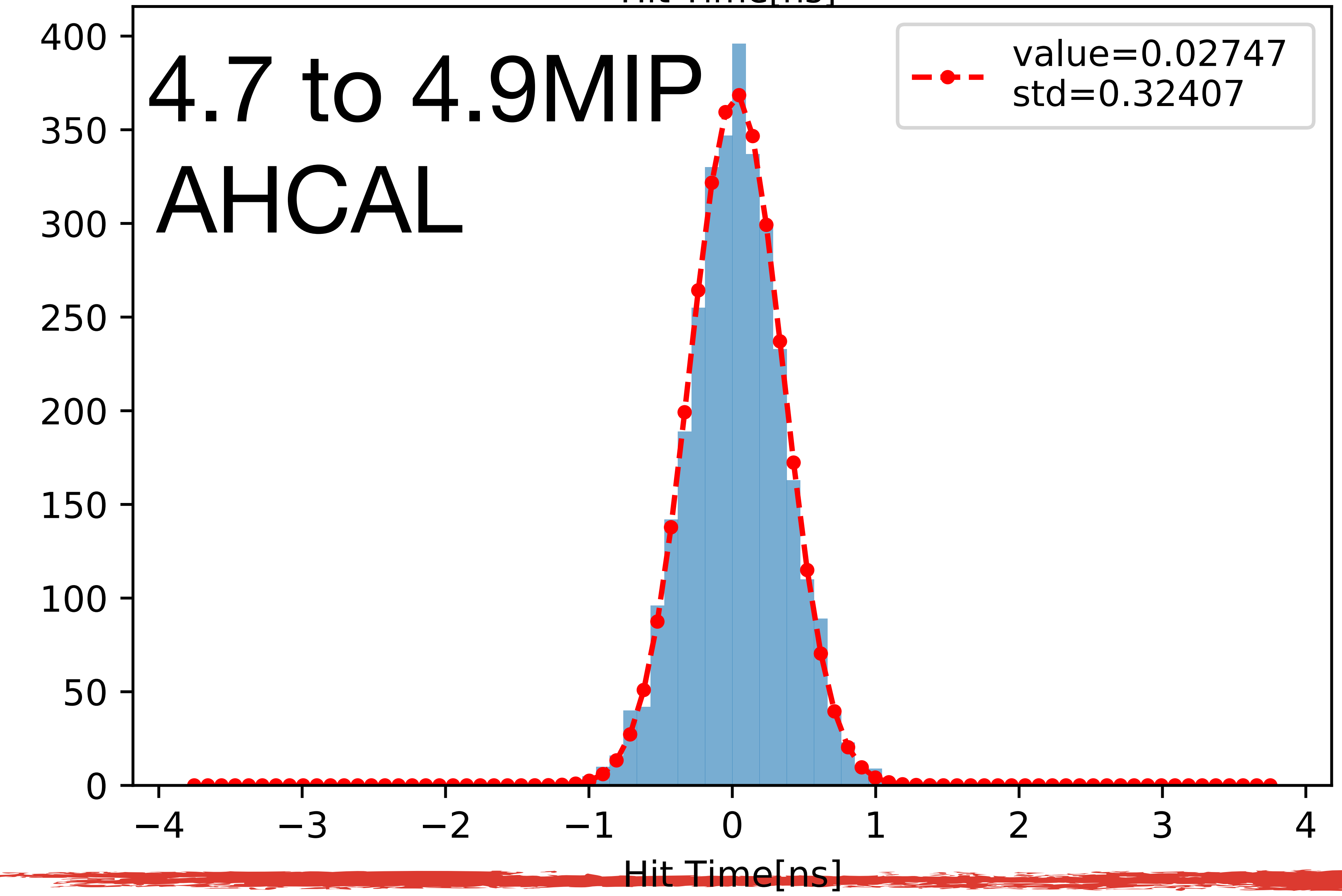
Time walk correction reduces width of distribution, but tail remains

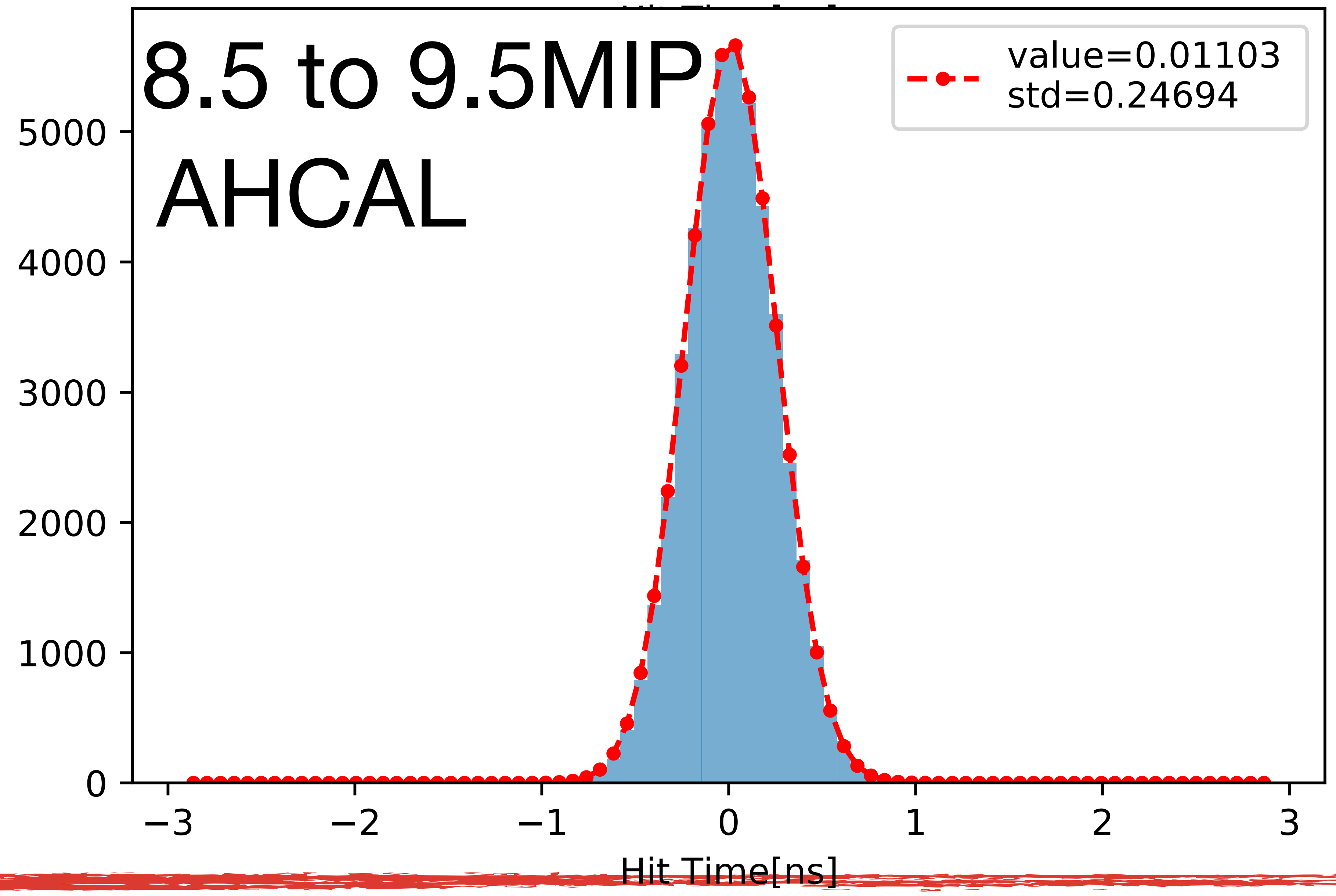
Energy Binned - Distributions

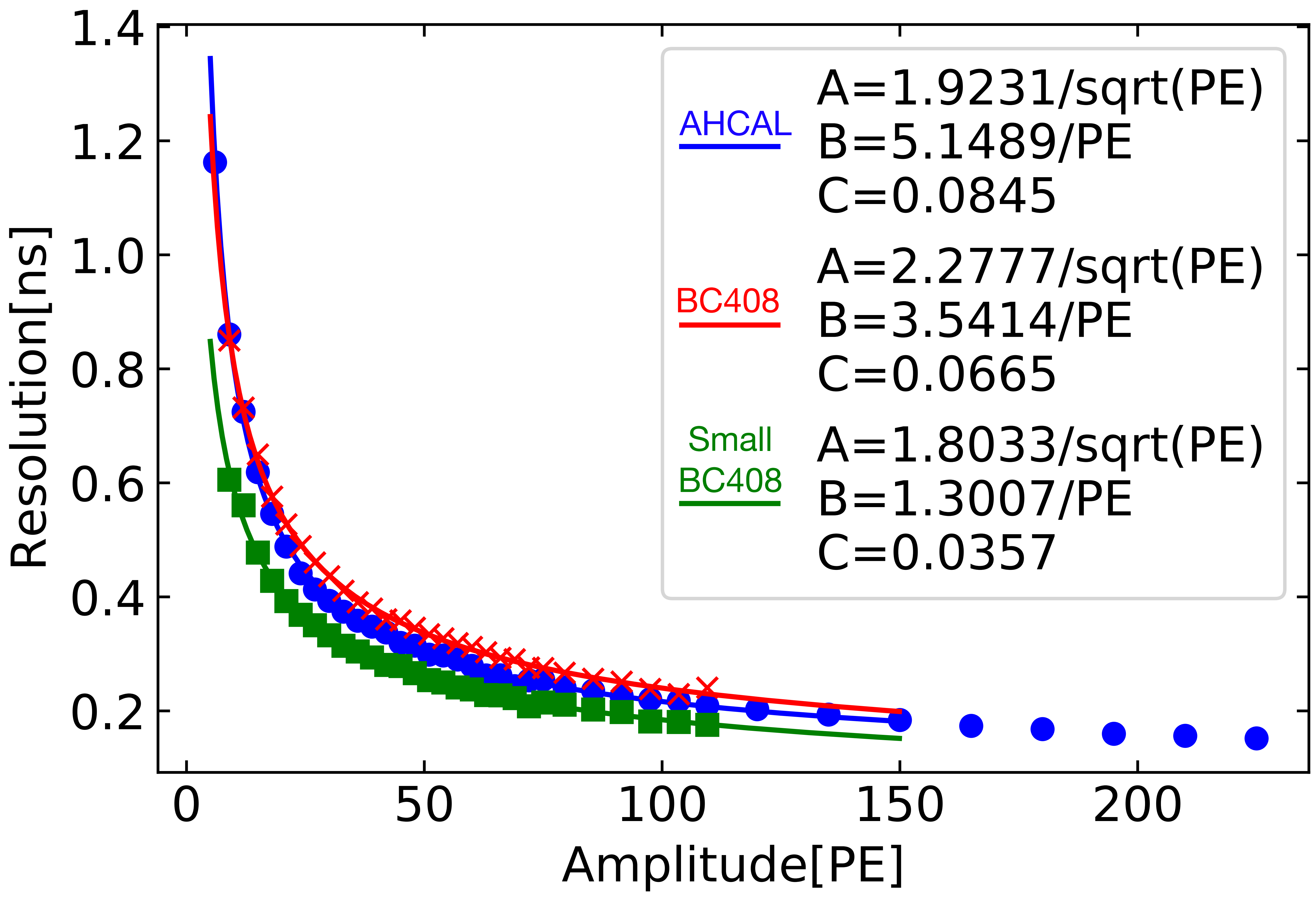




Distributions get narrow and more gaussian like







AHCAL
A=1.9231/sqrt(PE)
B=5.1489/PE
C=0.0845
BC408
A=2.2777/sqrt(PE)
B=3.5414/PE
C=0.0665
Small BC408
A=1.8033/sqrt(PE)
B=1.3007/PE
C=0.0357
Resolution[ns]
Amplitude[PE]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200