Time Resolution of the SiPM-on-Tile Technology

Simulations and Laser Measurements

Fabian Hummer, Lorenz Emberger, Ivan Popov, Frank Simon

Contribution to the
CALICE Collaboration Meeting

Sep 9, 2021

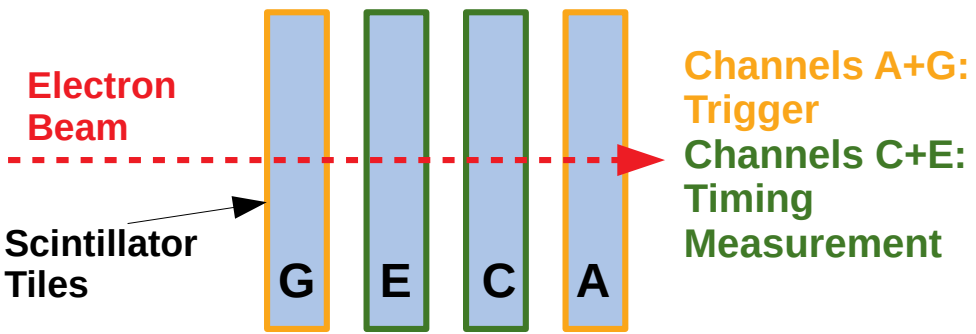
Part I: Simulation of Test Beam Results

Motivation: How well do we understand the processes involved in our measurement results?

Scintillator Timing Study Setup

Concept of the Measurement:

- Scintillator telescope with two coincidence triggers (**Ch A+G**)
- Two additional scintillator tiles (**Ch C+E**) to determine the time resolution as hit time difference of the channels



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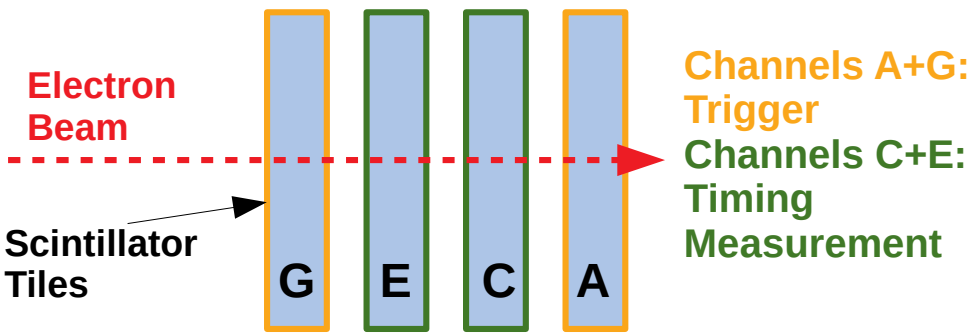
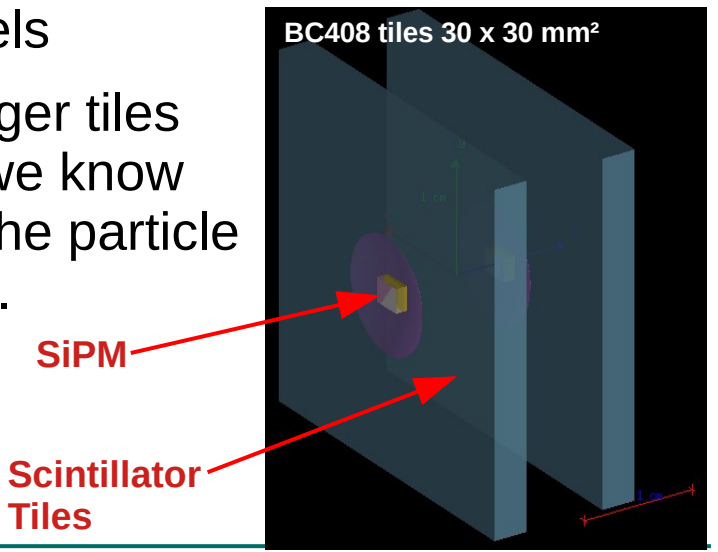


Concept of the Simulation:

- Adapted code from Yong Liu
- Two scintillator tiles (**Ch C+E**) to determine the time resolution as hit time difference of the channels
- No trigger tiles since we know when the particle arrives.



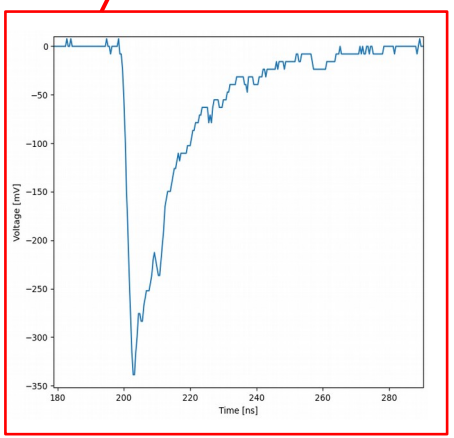
Data Analysis

Real Data

DESY TEST BEAM.

Binary files

Waveforms

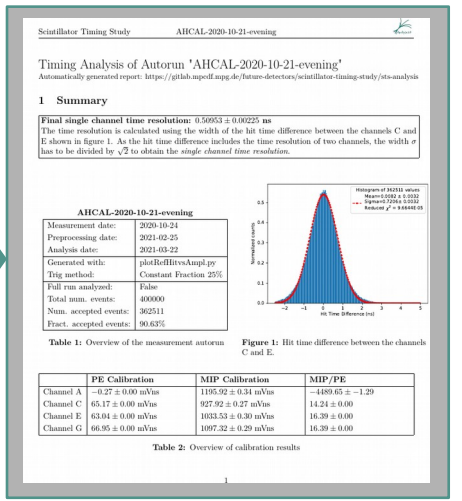


Preprocessing:
Event-based analysis,
MIP calibration

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://github.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 √2 to obtain the *single channel time resolution*.

AHCAL-2020-10-21-evening

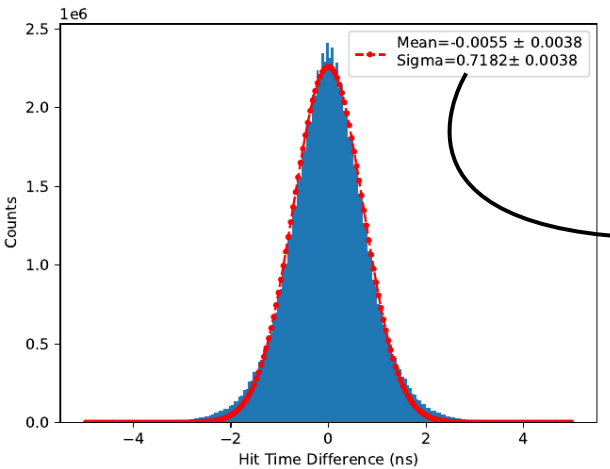
Measurement date:	2020-10-24
Preprocessing date:	2021-02-25
Analysis date:	2021-03-22
Generated with:	plotRelHitvsAmpl.py
Trig method:	Constant Fraction 25%
Full run analyzed:	False
Total num. events:	400000
Num. accepted events:	362511
Fract. accepted events:	90.63%

Table 1: Overview of the measurement autorun

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

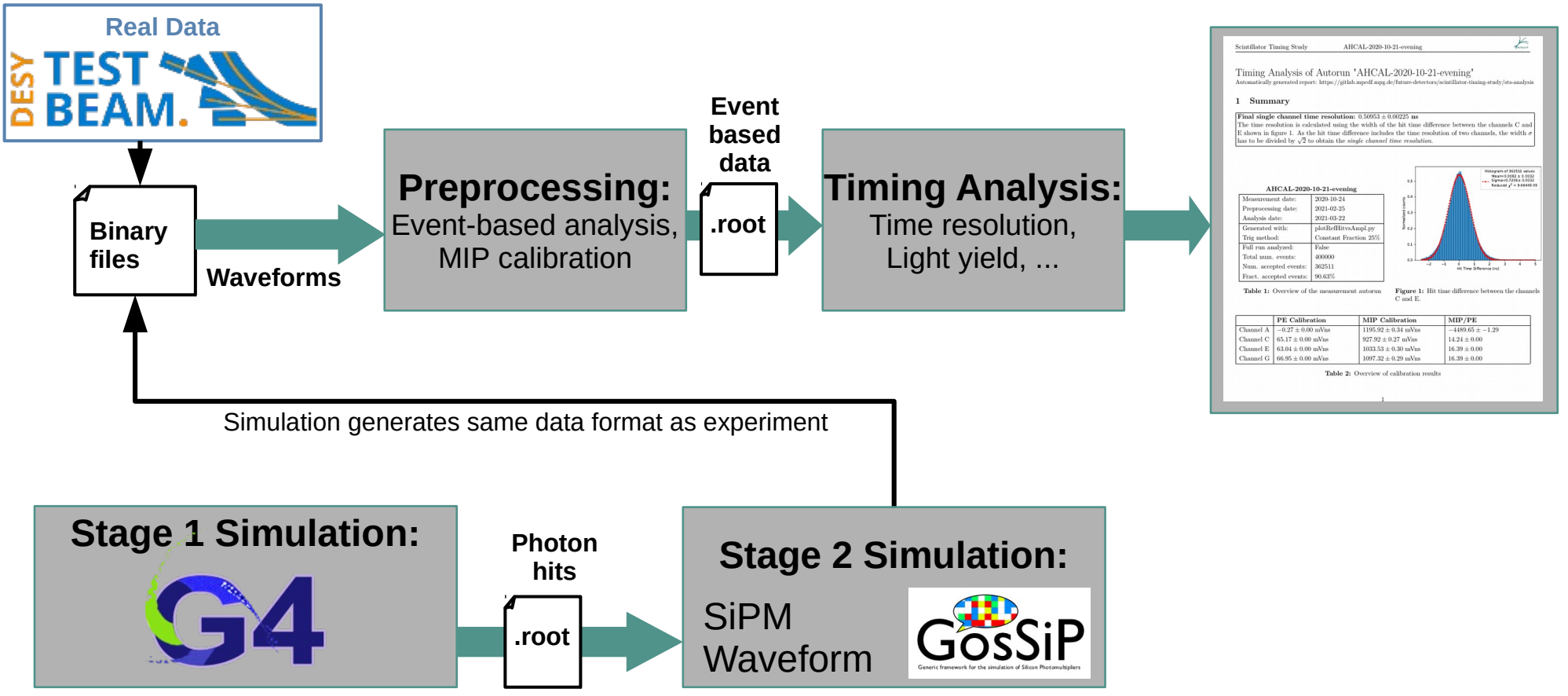
	PE Calibration	MIP Calibration	MIP/PE
Channel A	−0.27 ± 0.00 mVns	1195.92 ± 0.34 mVns	−4489.65 ± −1.29
Channel C	65.17 ± 0.00 mVns	927.92 ± 0.27 mVns	14.24 ± 0.00
Channel E	63.04 ± 0.00 mVns	1033.53 ± 0.30 mVns	16.39 ± 0.00
Channel G	66.95 ± 0.00 mVns	1097.32 ± 0.29 mVns	16.39 ± 0.00

Table 2: Overview of calibration results



Hit time difference
→ time resolution

Data Analysis + Simulation



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Stage 1: Geant4 Simulation

- Simulates events of particles passing through two scintillator tiles
- Saves the hit position of optical photons at the SiPM
- Currently only for scintillation material BC408 because properties of AHCAL scintillator not known
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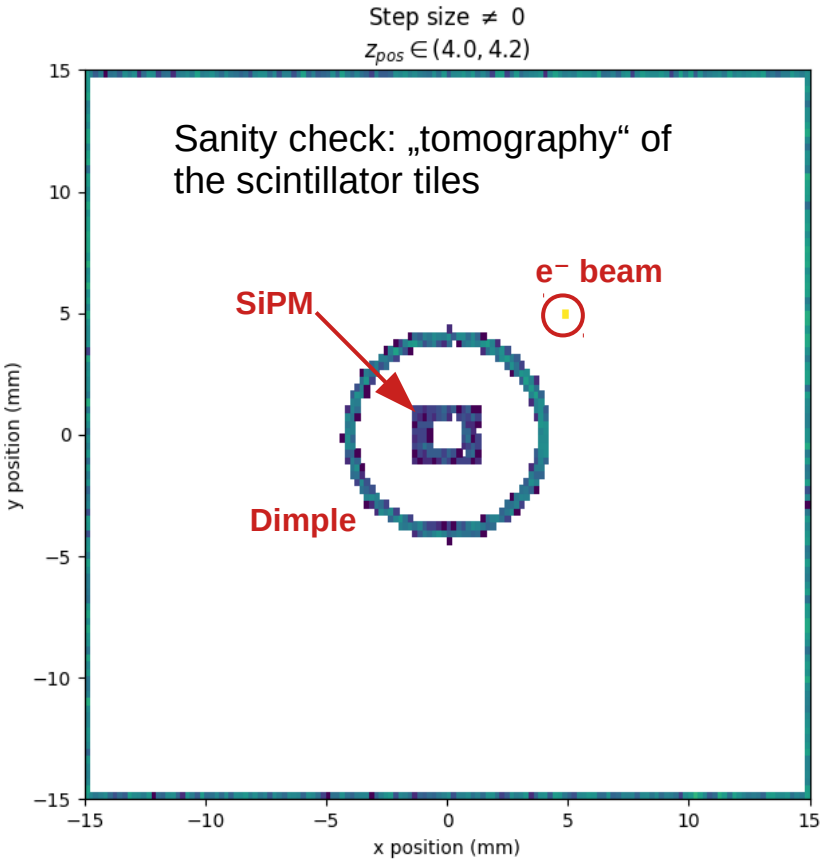
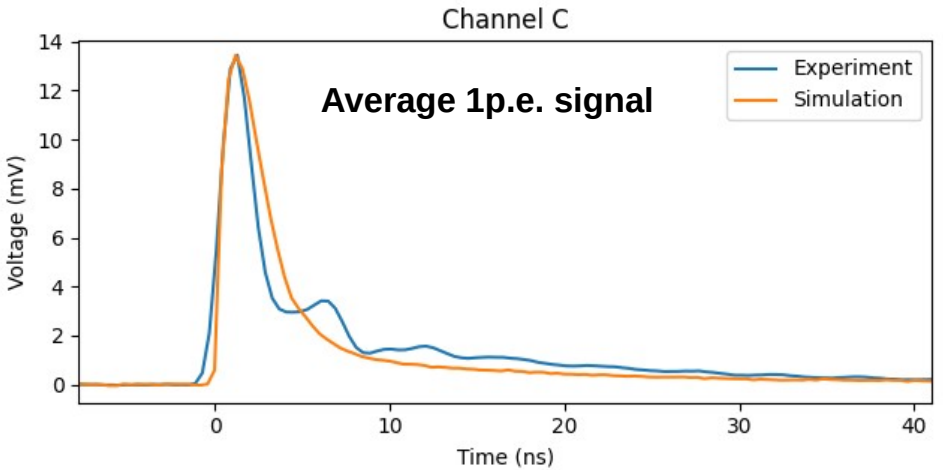


Stage 2: Simulation of the SiPM

- Using the GosSiP framework by Patrick Eckert https://bitbucket.org/kip-hep-detectors/gossip/src/master/
- Simulates the response of an SiPM to incoming photons
- Simulation includes
  - Afterpulses, dark rate, jitter, rise and fall time
  - Pixel geometry of the SiPM
  - Time and voltage resolution of the Oscilloscope
- Input parameters:
  - Photon detection efficiency, time constants, probabilities (for afterpulses, etc.), noise rates, pixel geometry

Fixing SiPM Parameters

- Not all parameters required by GosSiP are available in the SiPM datasheet
- Strategy: Fix missing parameters using single photon hits (compare with 1 p.e. calibration measurements)
- 1p.e. waveform modelled as double exponential function



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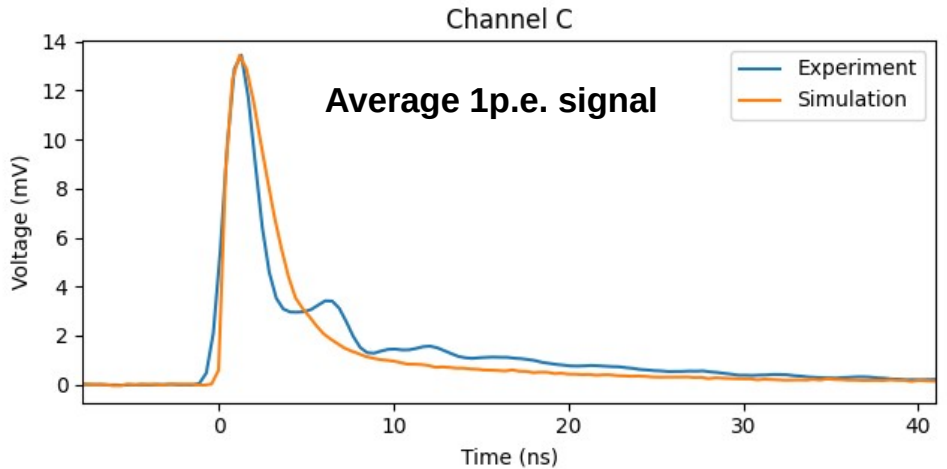
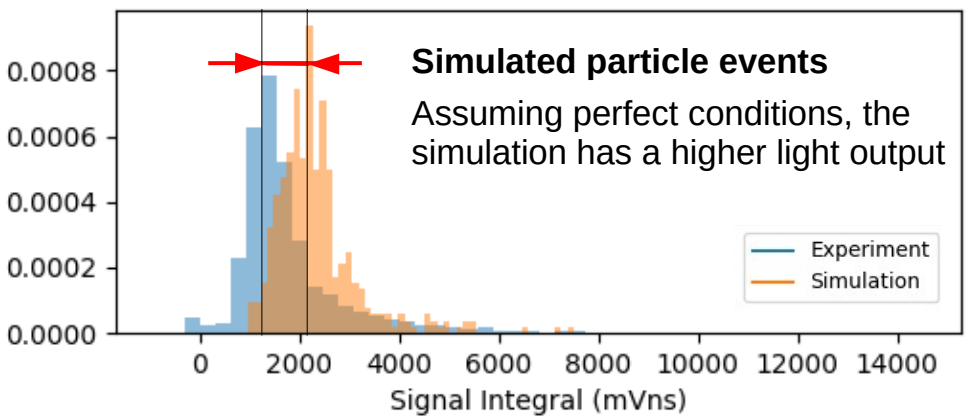
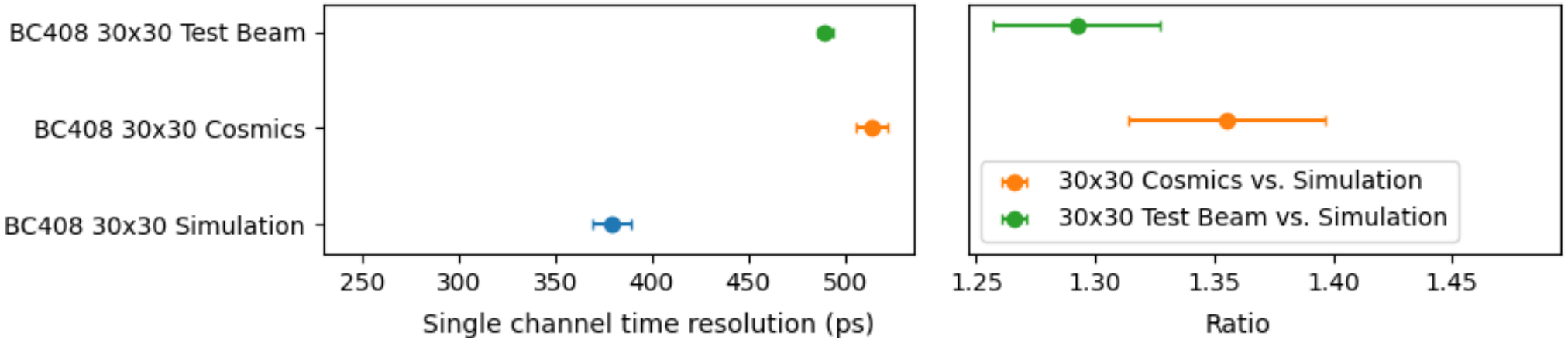
- Need to set individual detection efficiency for each CLAWS sensor to account for light yield and losses



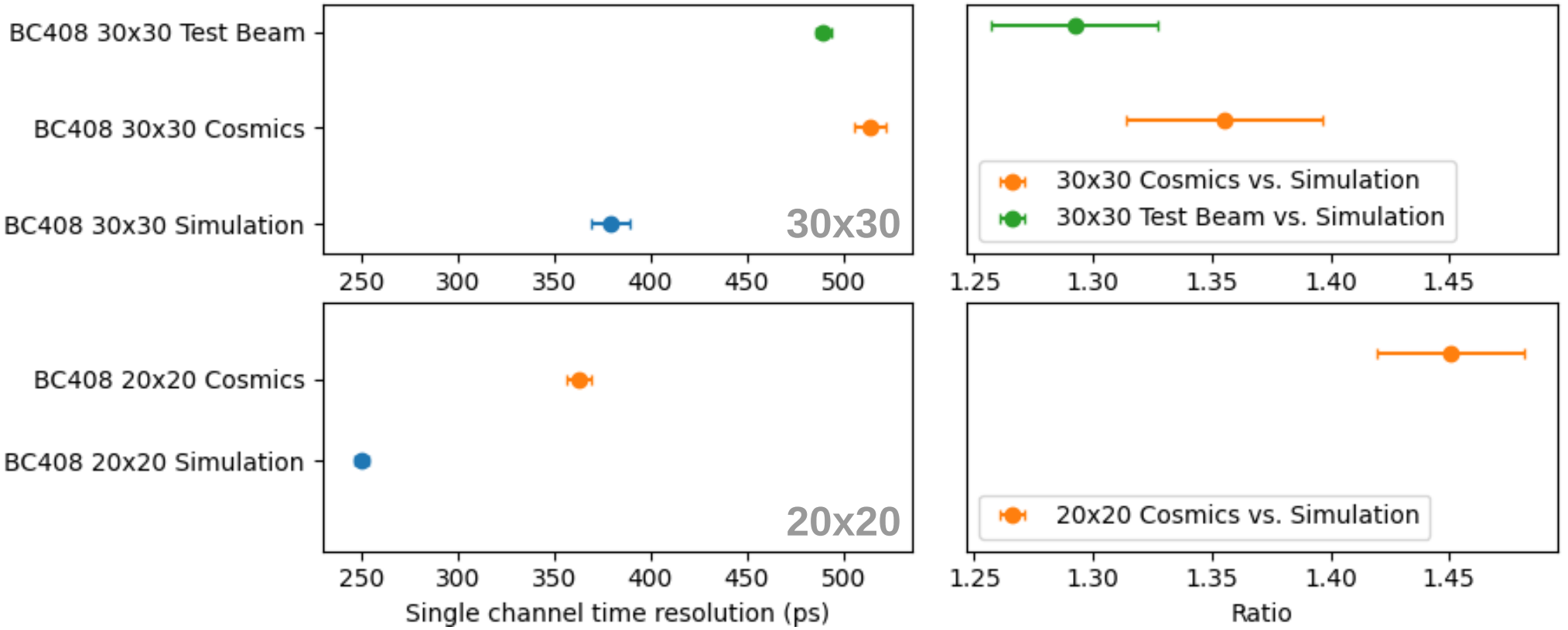


Simulation Results: Time Resolution



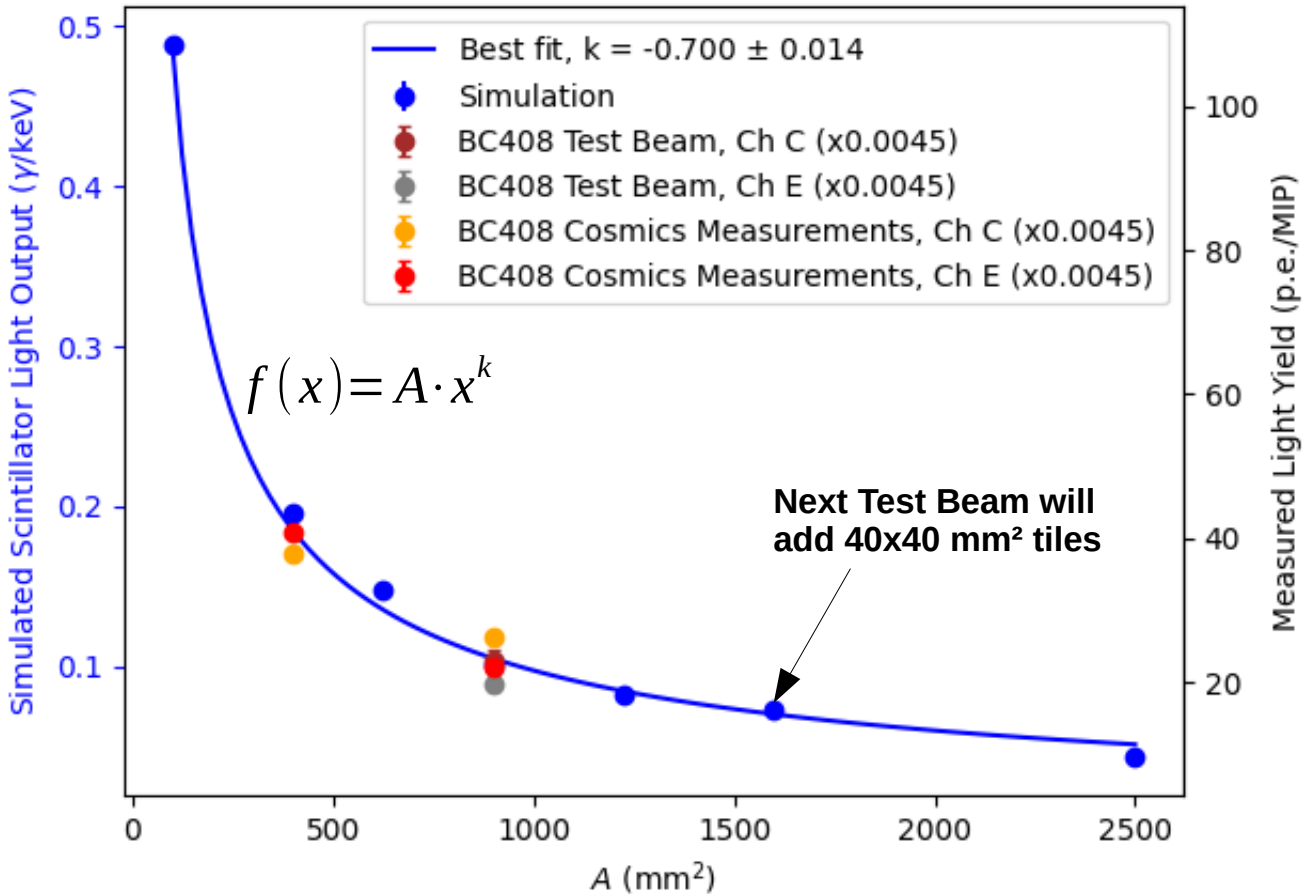
- Simulated time resolutions are approx. 30...45% better than in the experiment
- Difficult to make exact comparison because each module is a little bit different (e.g. tile wrapping, gain, ...)

Simulation Results: Time Resolution



Simulation Results: Light Yield

- Plot: Simulated light output of scintillator compared to measured light yield
- Measurements scaled by a constant factor for comparison
- Measurements not included in fit
- The trend is consistent in simulation and experiment

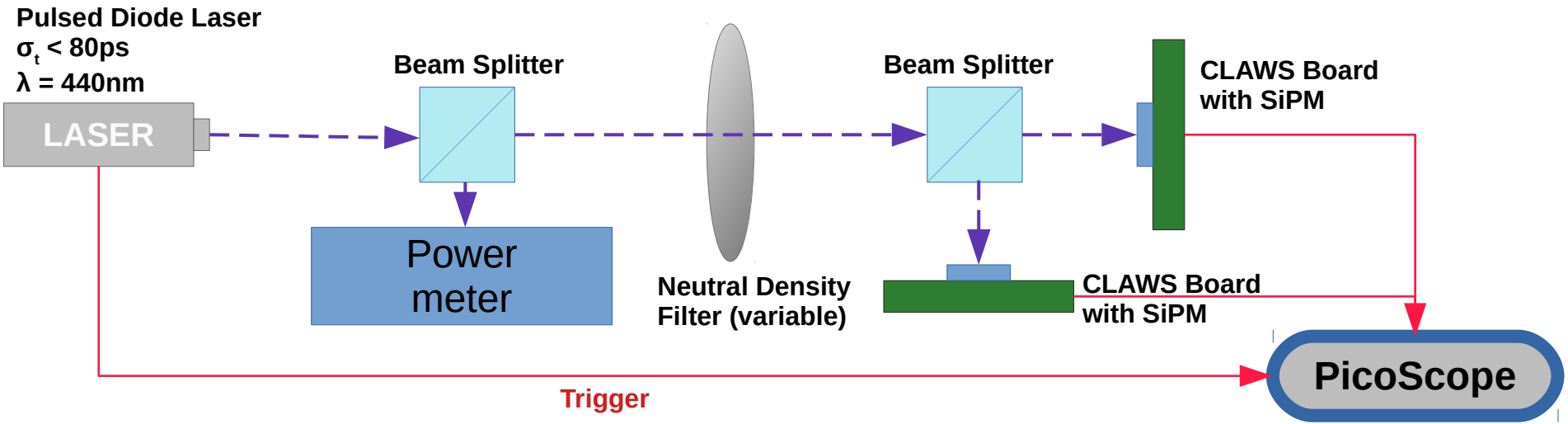


Part II: Laser Measurements

Motivation: How much do the SiPMs and electronics contribute to the time resolution?

Laser Setup

- Idea: Shoot short (<80ps) pulses on the SiPMs
  - Measure the time resolutions without scintillator installed
- Goal: Investigate hardware effects and their influence on time resolution



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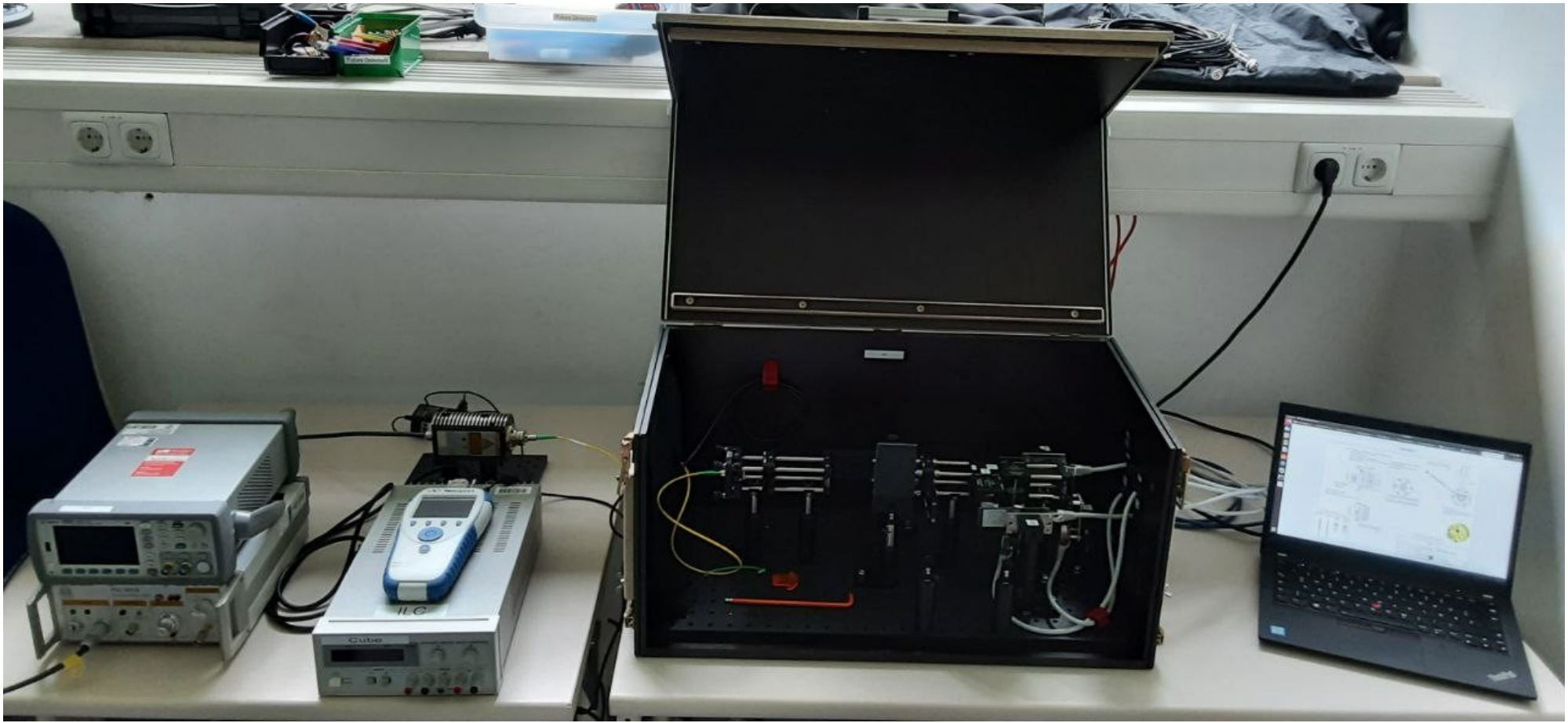
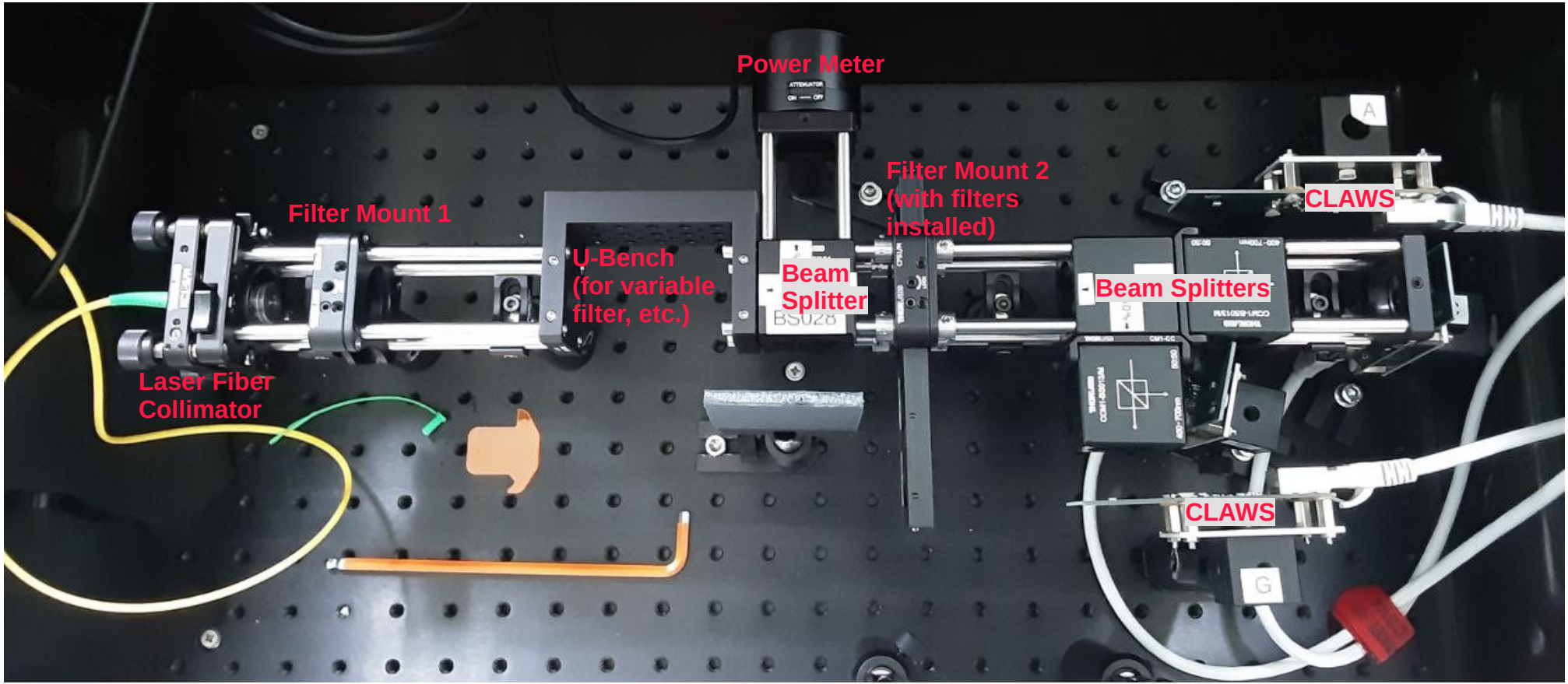
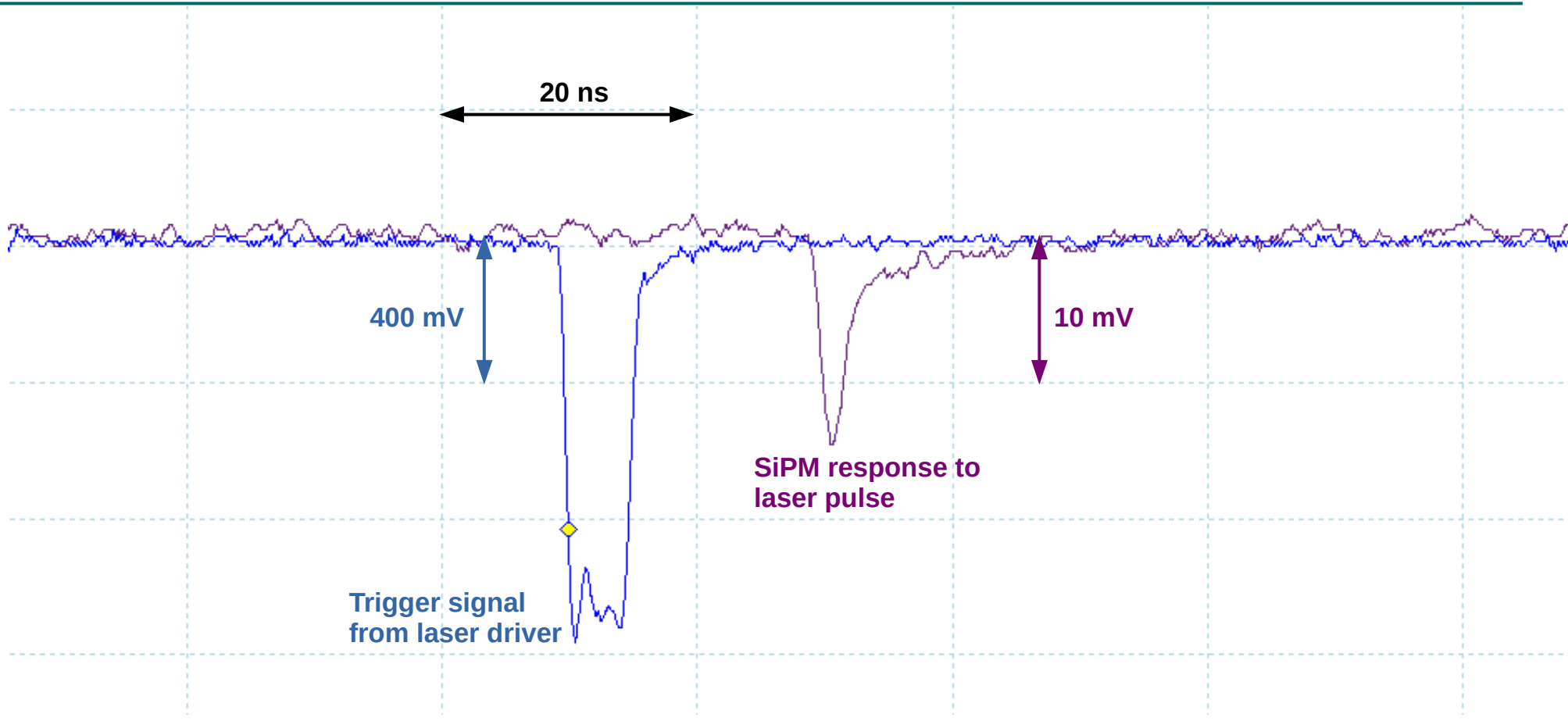


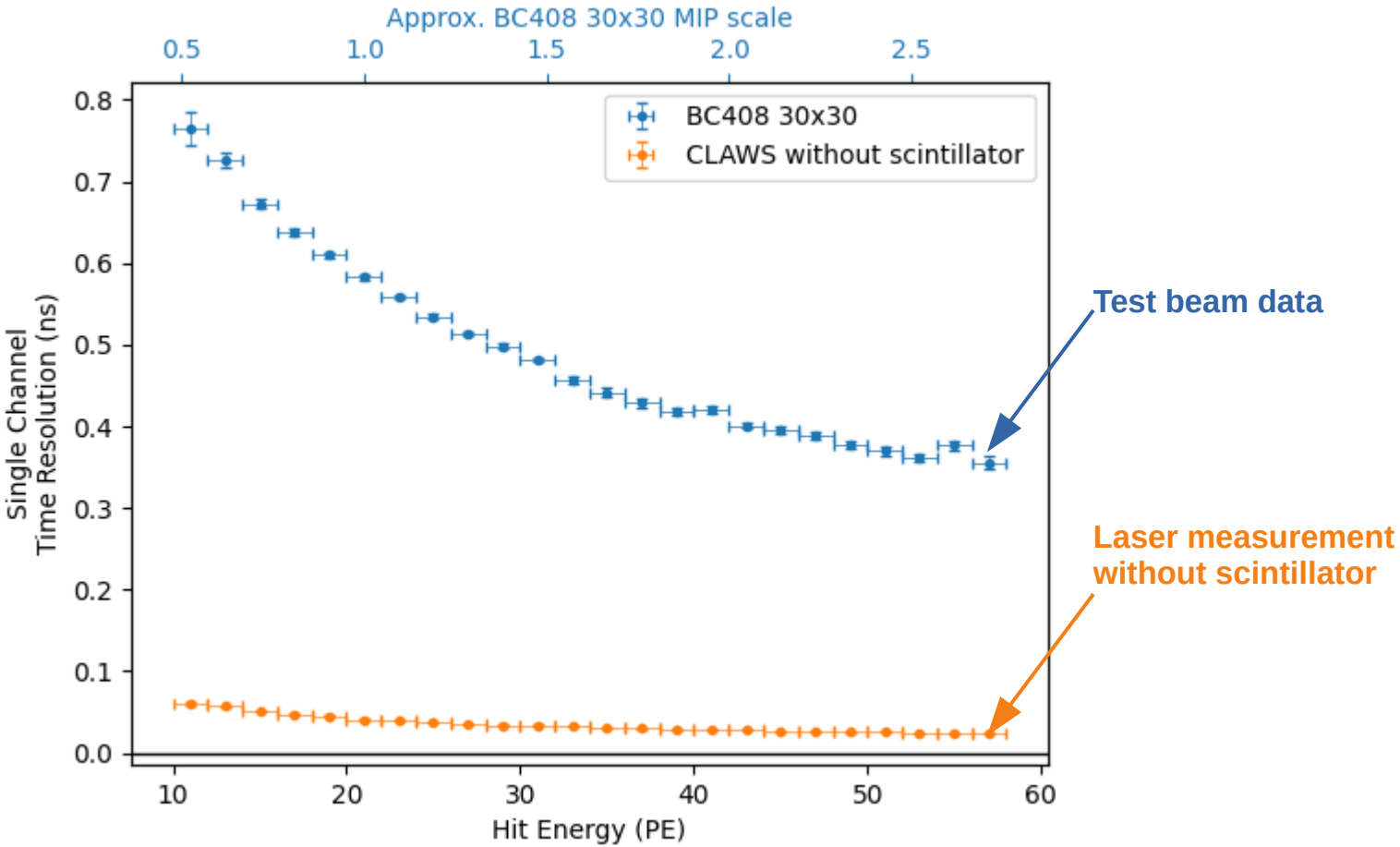
Laser Setup: Inside the Dark Box



First Laser Event



CLAWS Electronics Time Resolution



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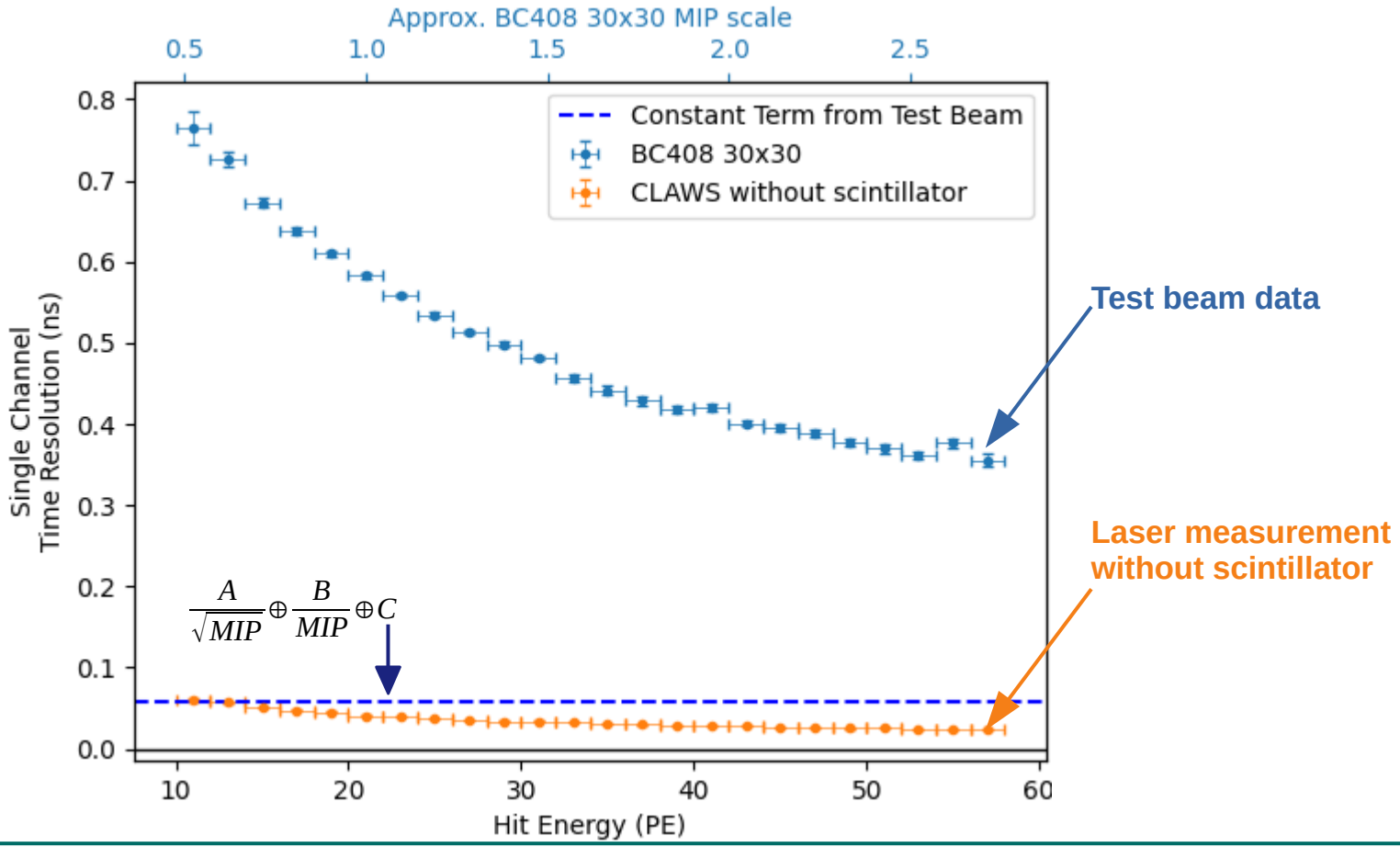

Simulation of Laser Measurements

- Generate randomly distributed photons, then simulate SiPM response with GosSiP
- Input parameters:
  - Beam profile
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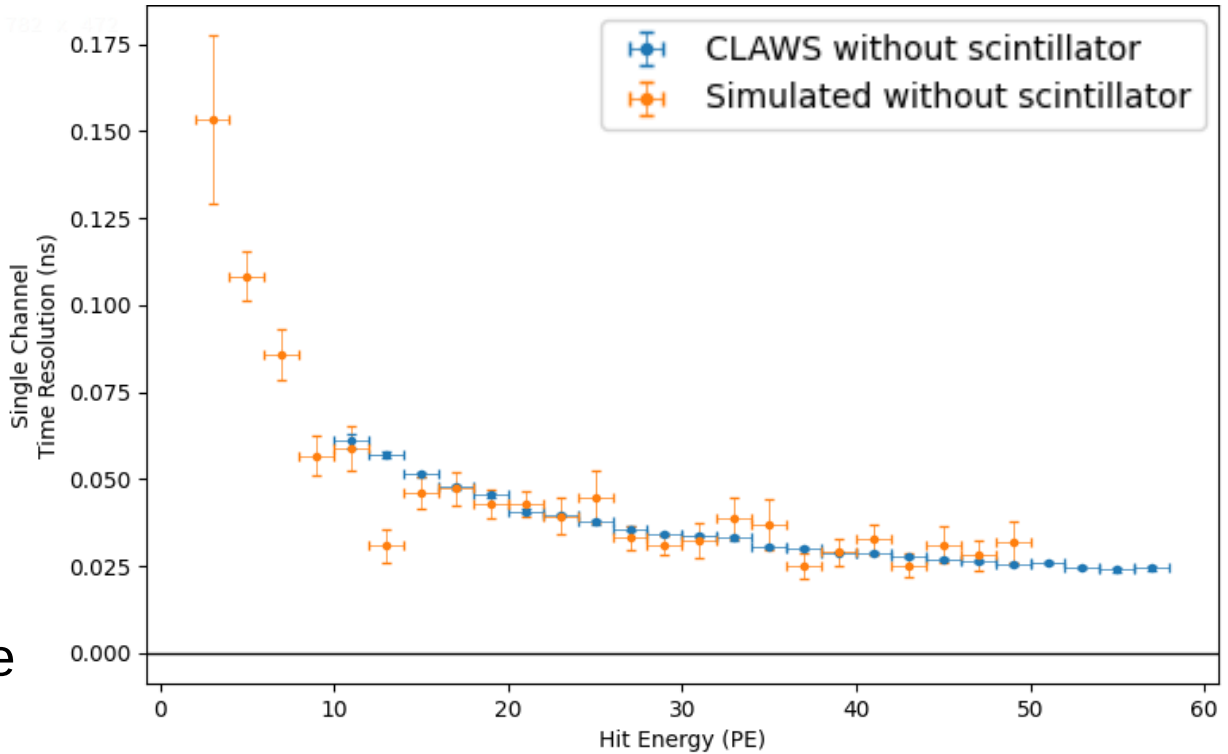
  - Pulse duration

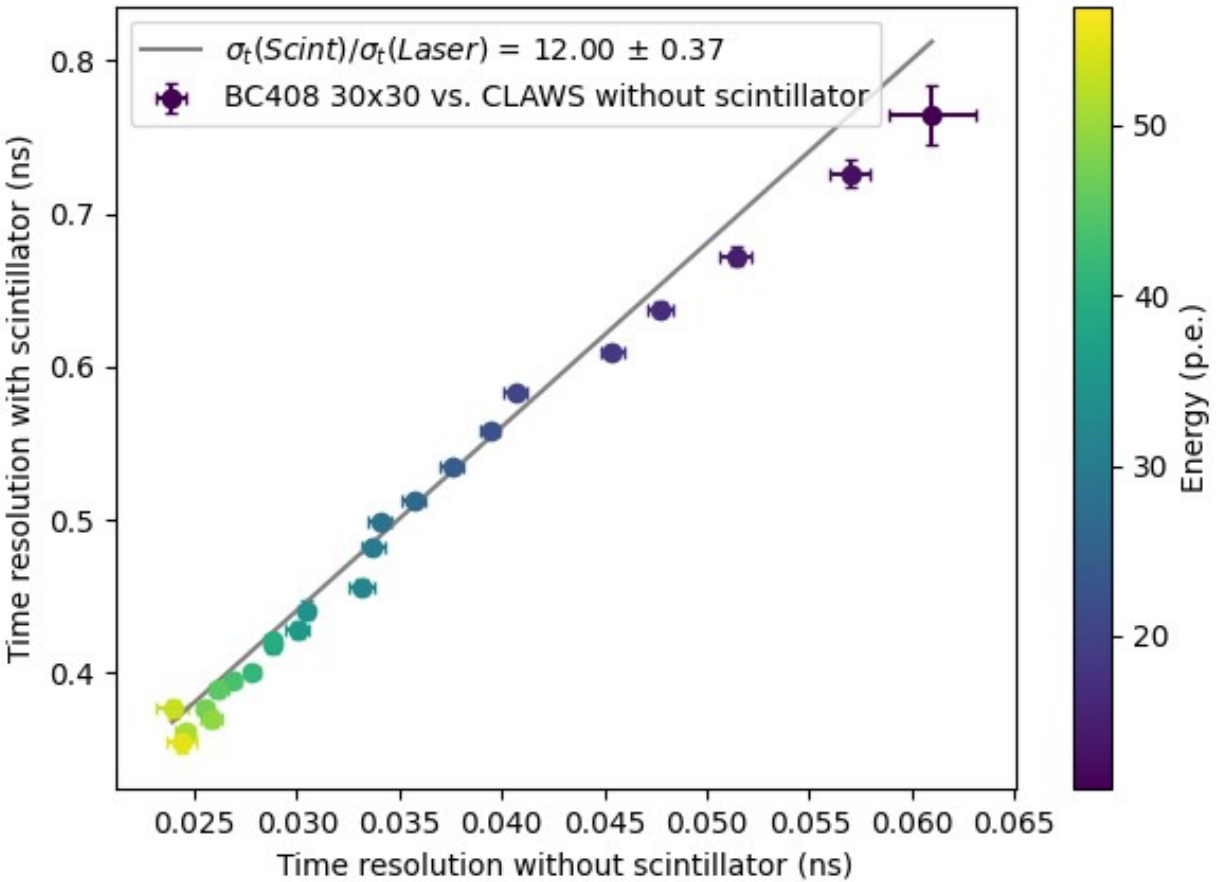
Simulation of Laser Measurements

- Generate randomly distributed photons, then simulate SiPM response with GosSiP
- Input parameters:
  - Beam profile
  - Wavelength
  - Pulse duration
- Simulation agrees with measurement
- Higher uncertainties because fewer simulated events



CLAWS Time Resolution

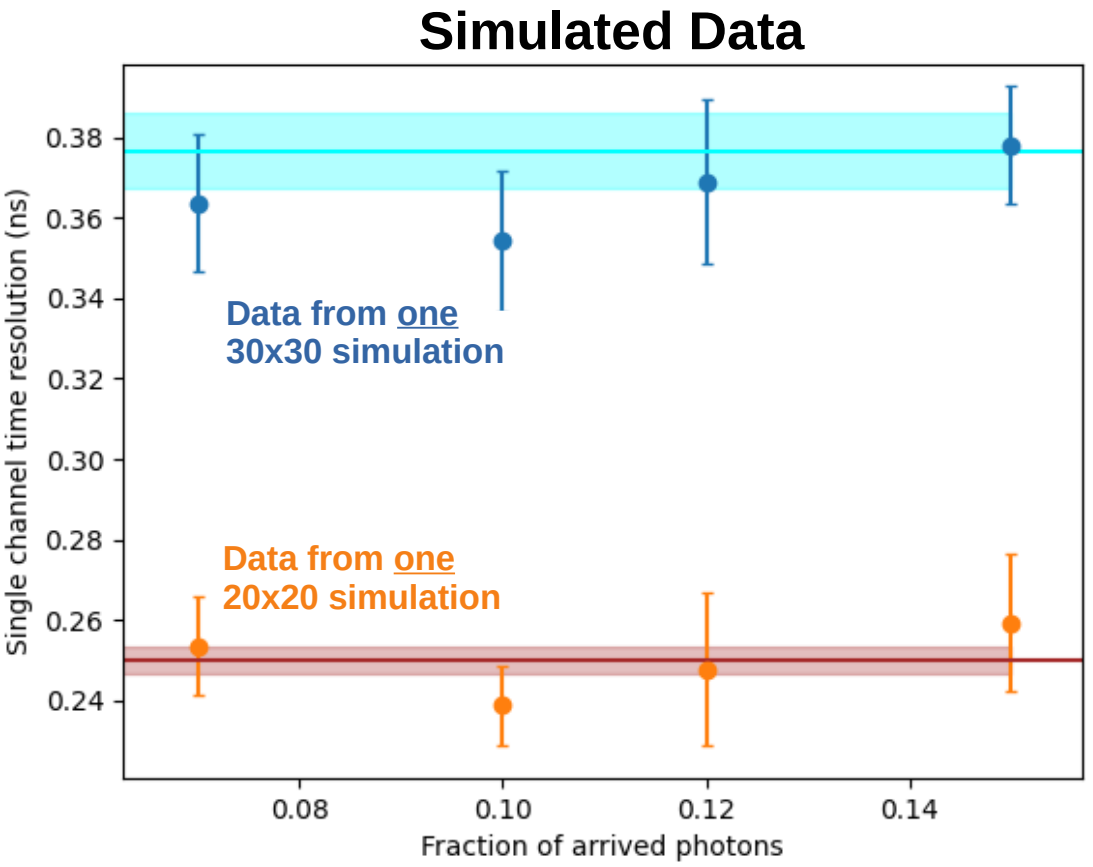
- Contribution from scintillator is an order of magnitude larger than contribution from SiPM + Electronics
- Approximately constant over a large energy range
- Uncertainties are added in quadrature: $\sigma = \sqrt{\sigma_{Scint}^2 + \sigma_{SiPM}^2}$
- So for our scintillator tiles the impact of SiPM + electronics on time resolution is negligible



GosSiP change the Time Resolution?

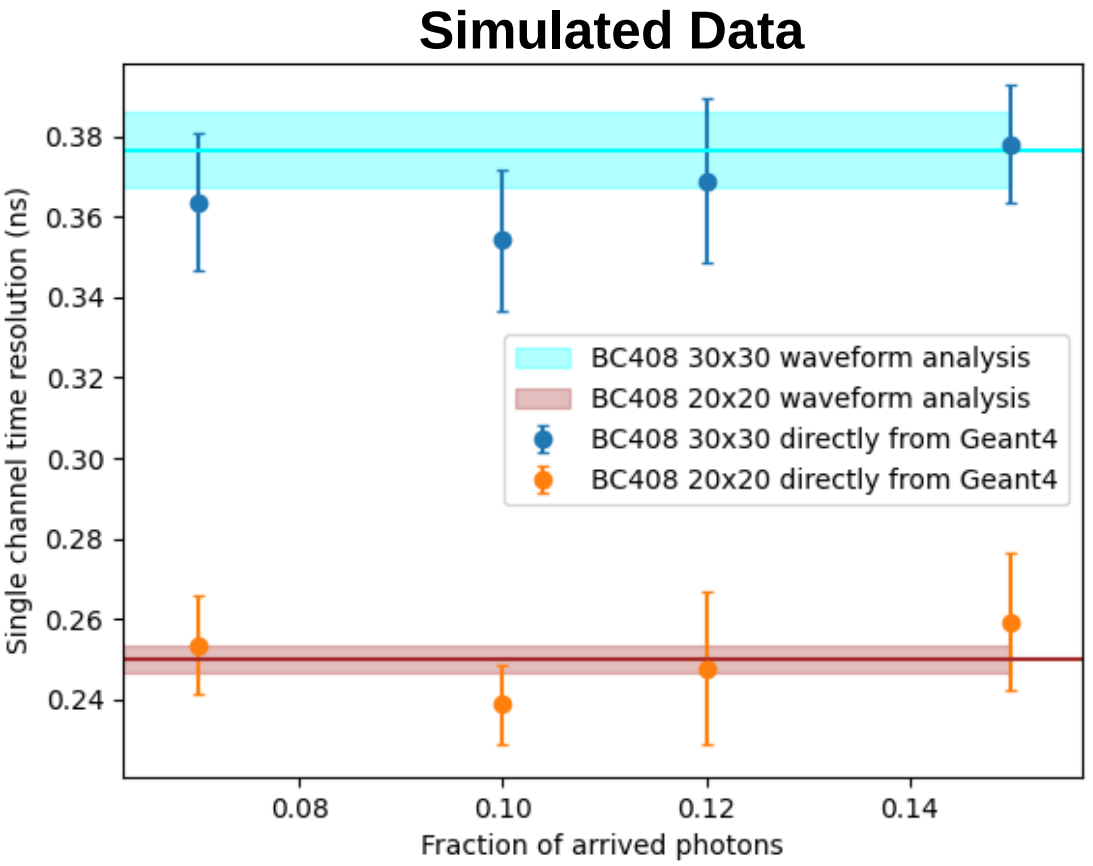
Evaluate the same simulation using two different methods:

- Data Points: Directly from Geant4
  - Define arrival time as time when a certain fraction of photons has arrived
- Solid line: Generate waveform with Stage 2 Simulation (GosSiP), calculate time resolution like for test beam data
  - Amplitude-dependent hit time definition

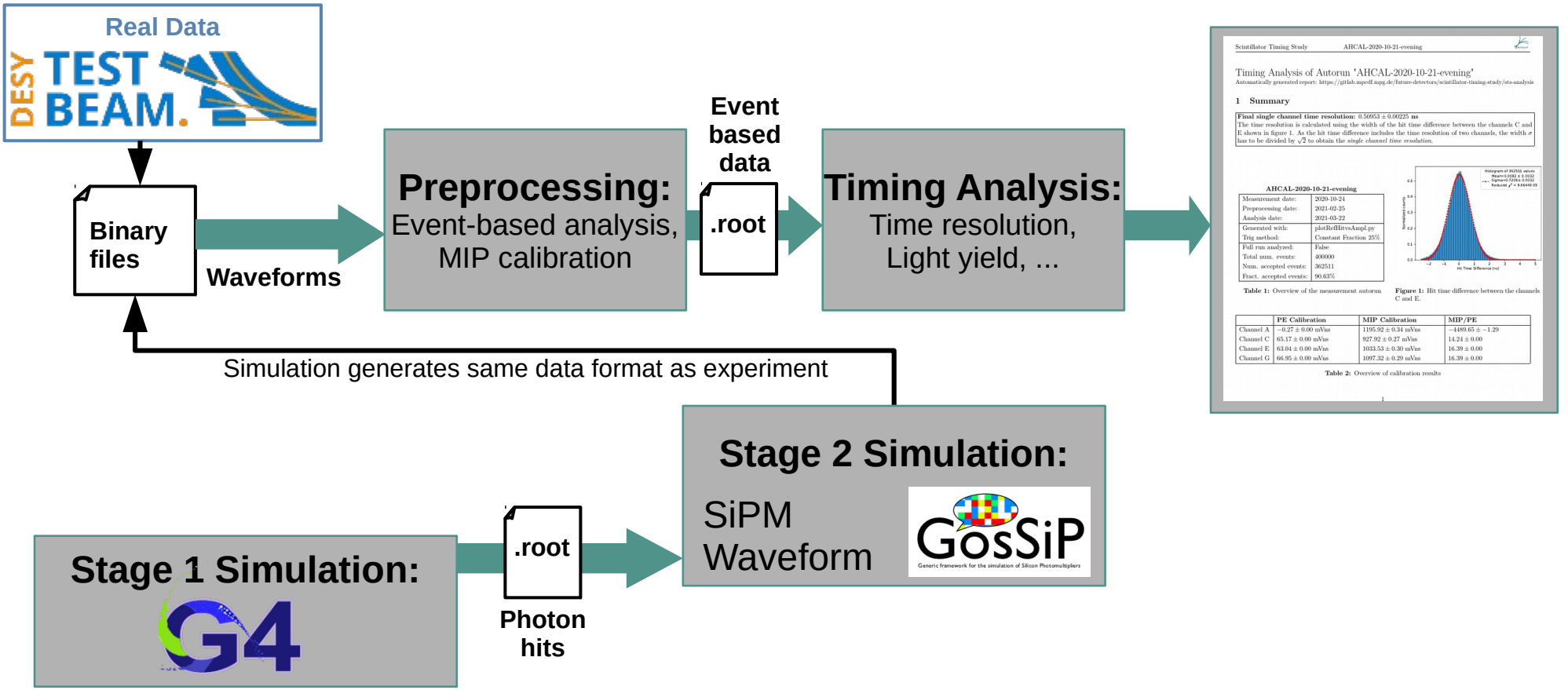


GosSiP change the Time Resolution?

- Comparison of simulated time resolution directly from Geant4 and with analysis of waveforms
- This shows that the GosSiP SiPM simulation does not change the time resolution



Summary of all Project Parts



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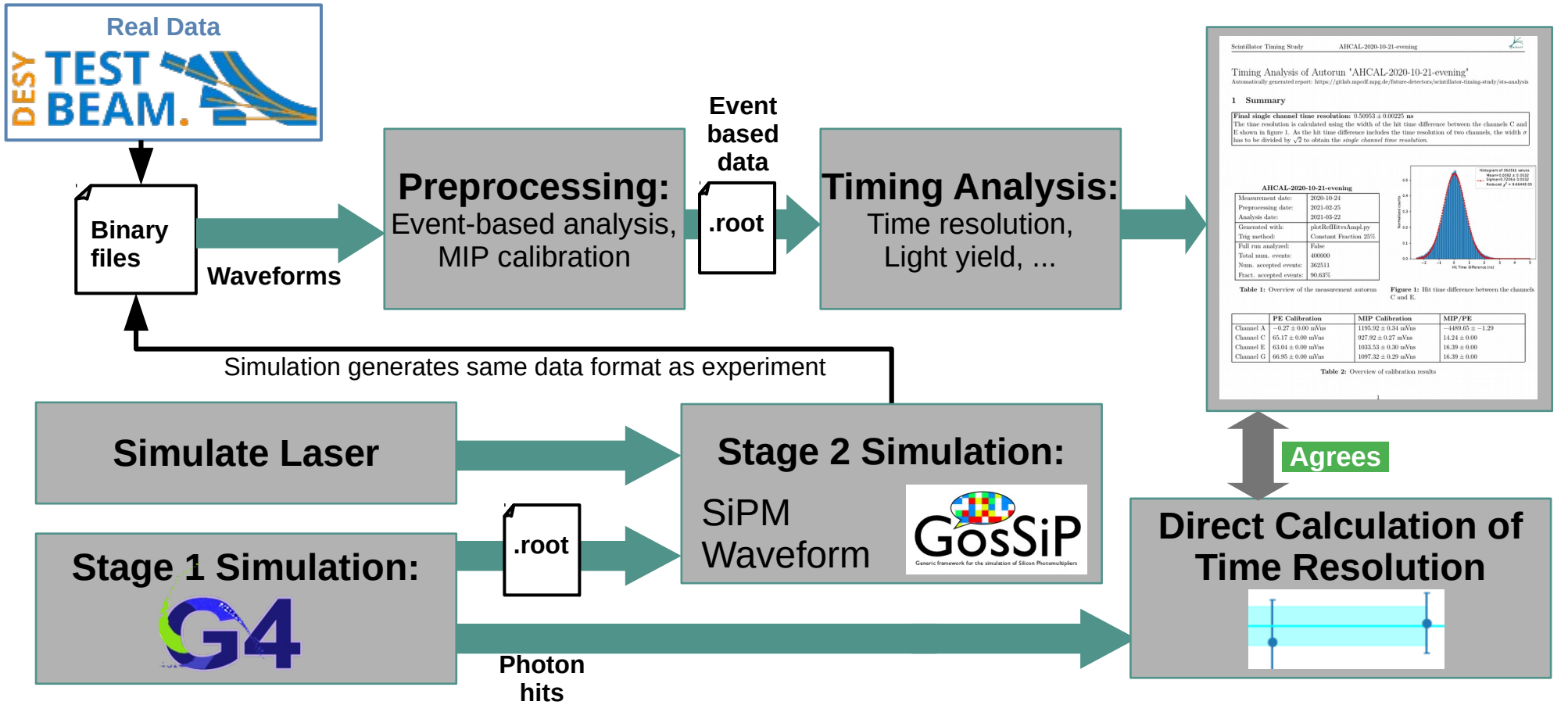

Outlook

Next Steps:

- The Geant4 simulation needs further adjustment
  - At the moment it is unclear which part requires tuning
- Next test beam with more different scintillator sizes and materials should bring further insights
  - Sizes: 20x20, 30x30, 40x40
  - Materials: BC404, BC408, BC418, BC422Q

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Once the Simulation gives good results:

Investigate relations between

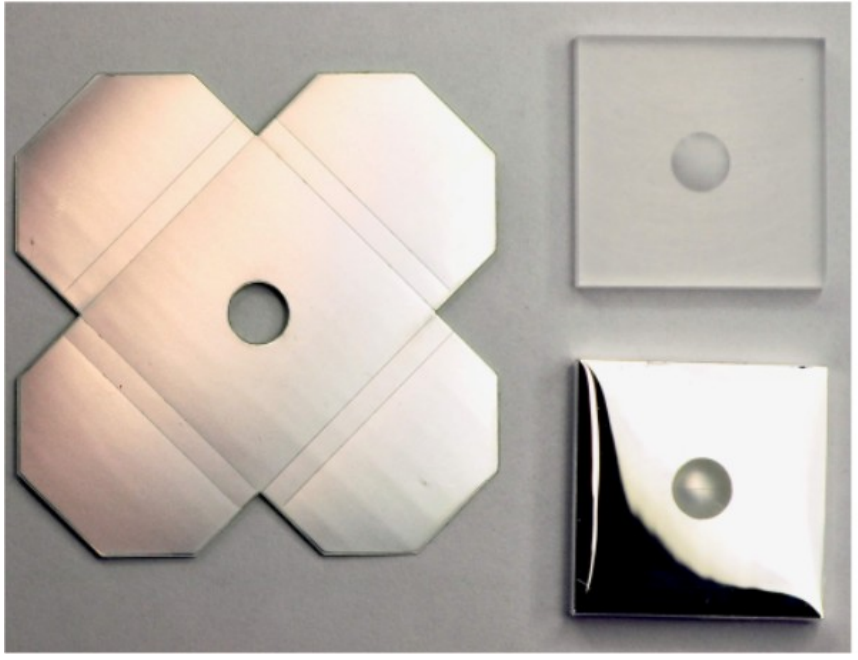
- Time Resolution
- Light Yield
- Tile Size
- Other parameters?

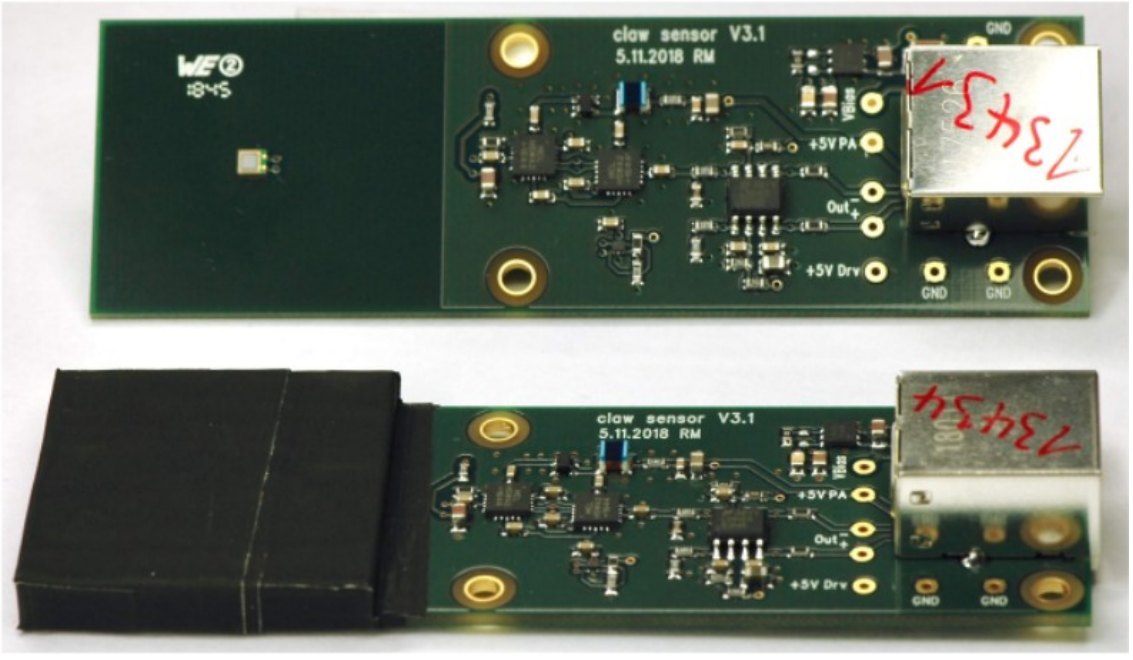
And more generally answer the question:

“What needs to be done to improve the time resolution?“

Backup Slides

Sensors for the Scintillator Timing Study





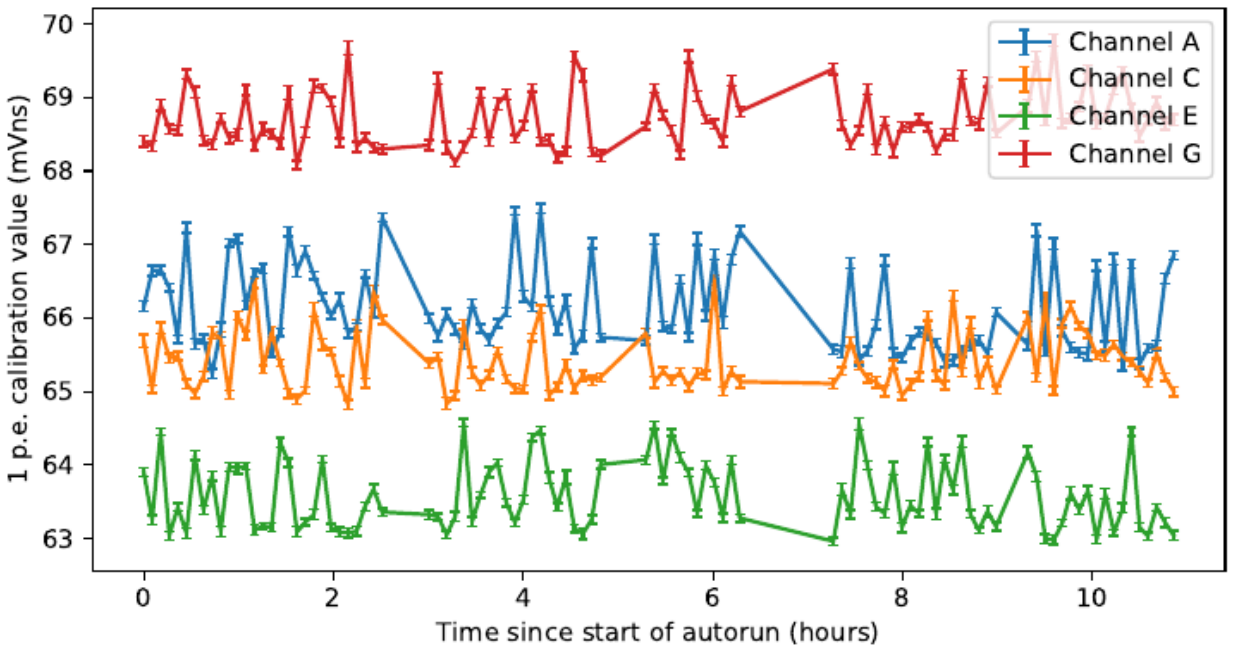
SiPM: Hamamatsu S13360-1325PE

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



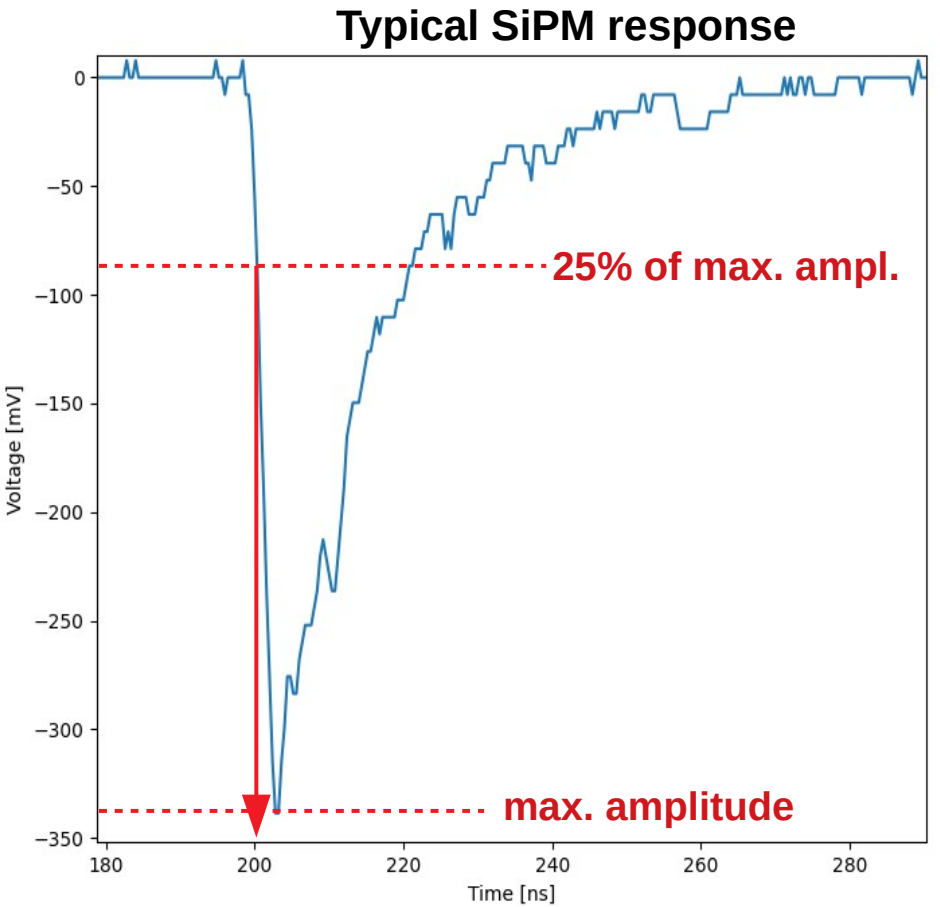
Defining the Time Resolution (1)

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

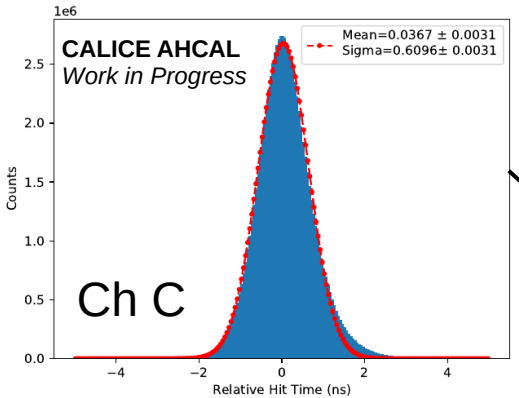
Leading Edge Method:

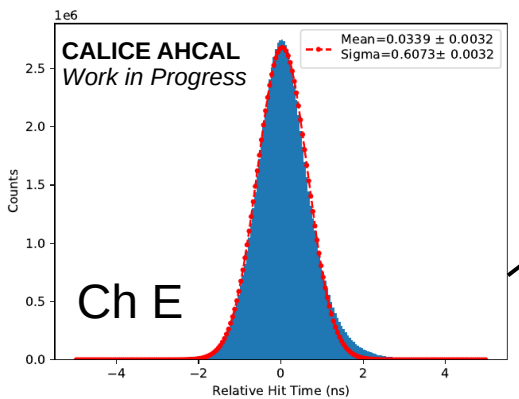
- Set threshold to fixed voltage



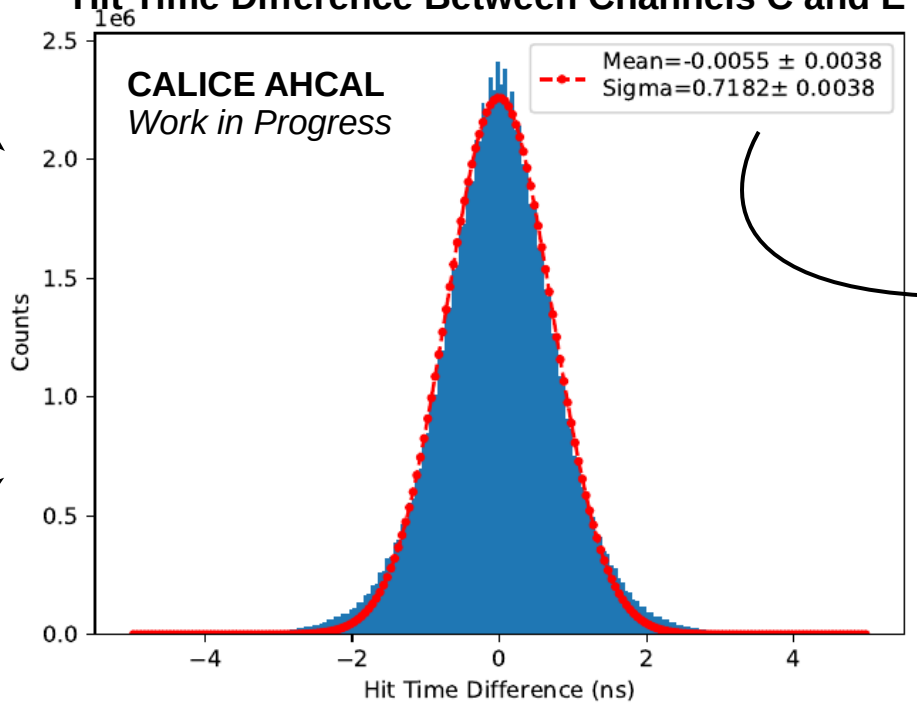
Defining the Time Resolution (2)

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 = 0.507 ns for AHCAL tiles (30x30 mm²)

Simulation of Laser Measurements

- Generate randomly distributed photons
- Input parameters:
  - Beam profile
  - Wavelength
  - Pulse duration
- Use Stage 2 (GosSiP) to generate waveforms