Scintillator Timing Study
New Insights and Outlook

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Contribution to
AHCAL Meeting

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MAX-PLANCK-INSTITUT FÜR PHYSIK

Scintillator Timing Study: Outline

Presented in Orsay:

- Simulations
  - Time resolutions were off by 30-45%
  - *Now I found correct parameters!*
- Laser measurements
  - Showed that time resolution of electronics is negligible wrt. tile measurements
  - *New measurements and methods bring even more insights*

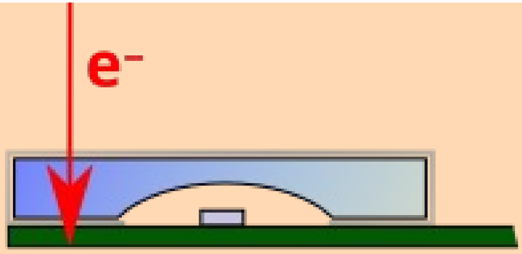
Today we will discuss:

1. Which methods are used?
2. Understanding signals at the photon level
3. Simulating the setup
4. What can we learn from the results?

Part 1: Methods used in the Scintillator Timing Study

How can we disentangle the different factors that contribute to time resolution?

Understanding the Signal Creation



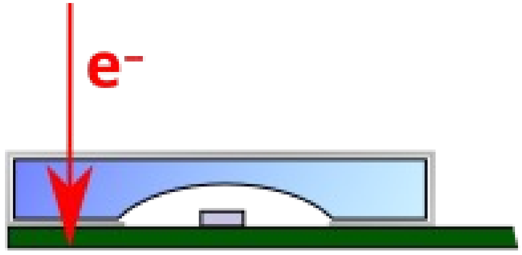
Full System Test Beam Measurements

1. Particle depoists energy in the scintillator, emission of light

2. Light collection and transport to SiPM

3. SiPM creates electrical signal

Understanding the Signal Creation



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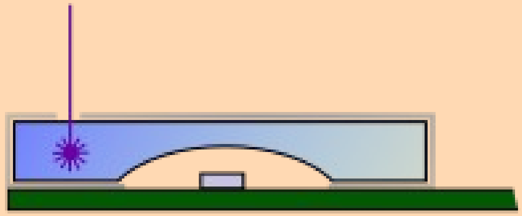

Inject pulsed laser beam into scintillator tile

NEW

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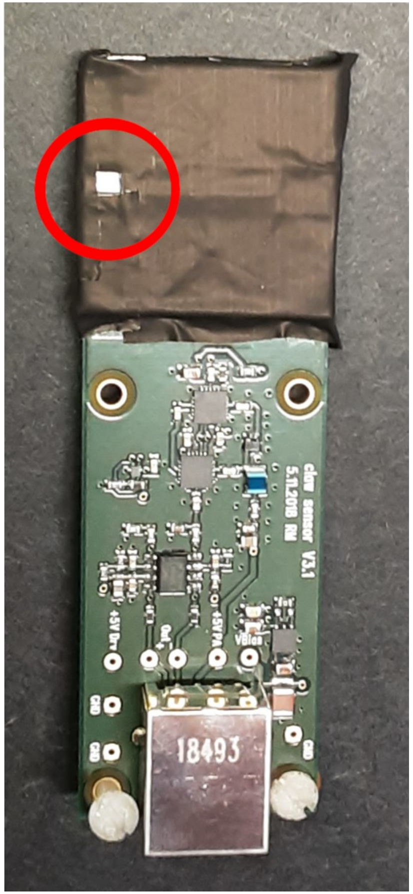

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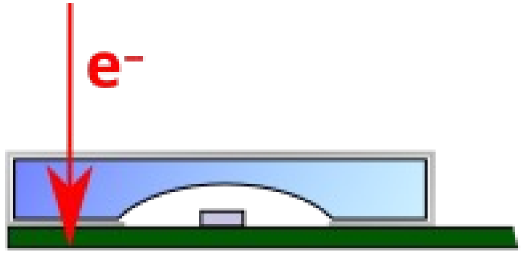

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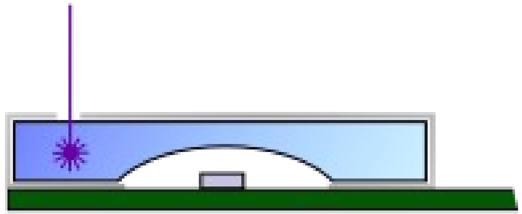

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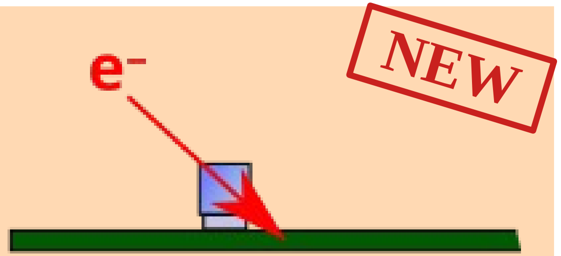
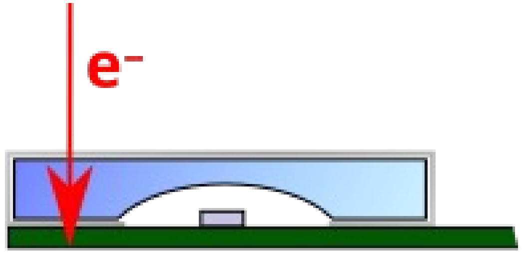


Emission measurements with small scintillators

Understanding the Signal Creation



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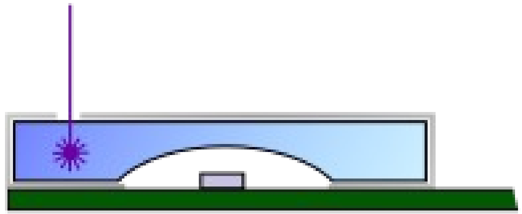

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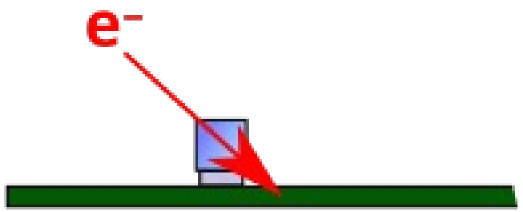
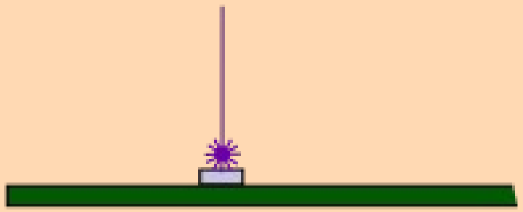


Emission measurements with small scintillators



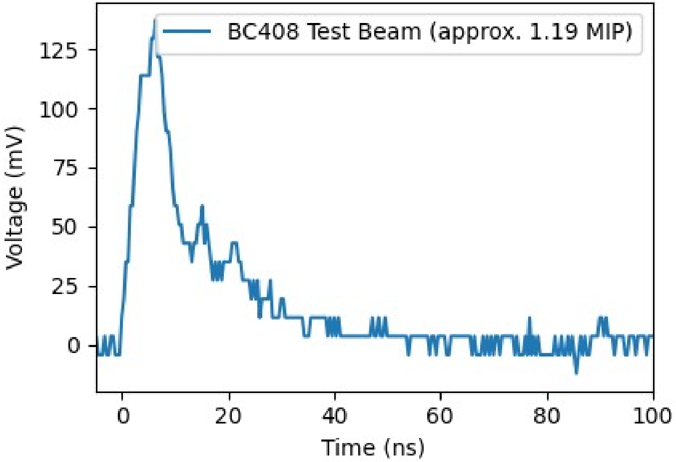
Induce signal on SiPM with laser pulses

Part 2: Understanding Time Resolution on the Photon Level

What can we learn from single waveforms?

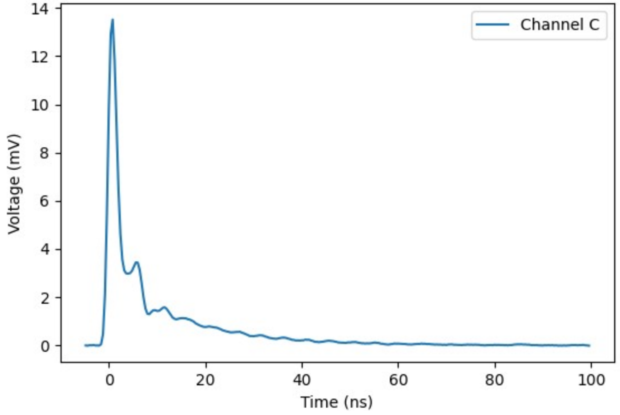
Since all photoelectrons produce the same signal, can we determine when single photons hit?

Waveform Decomposition



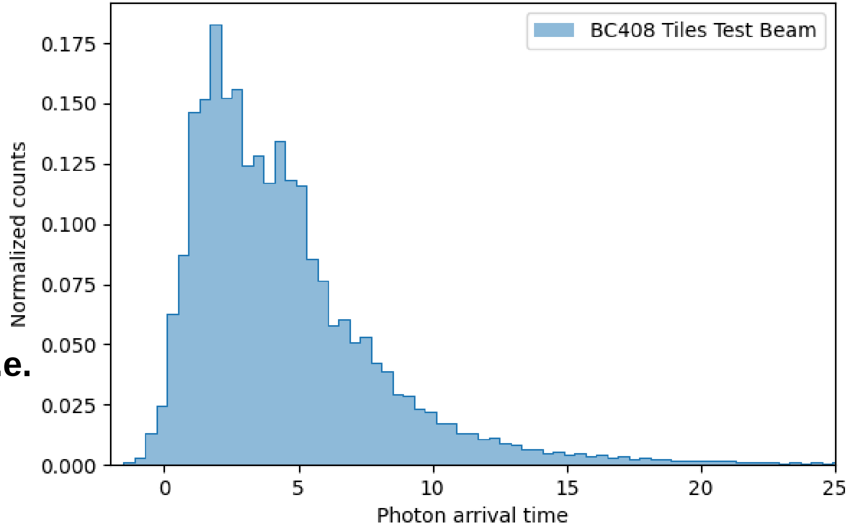
SiPM response for each measured event.

minus



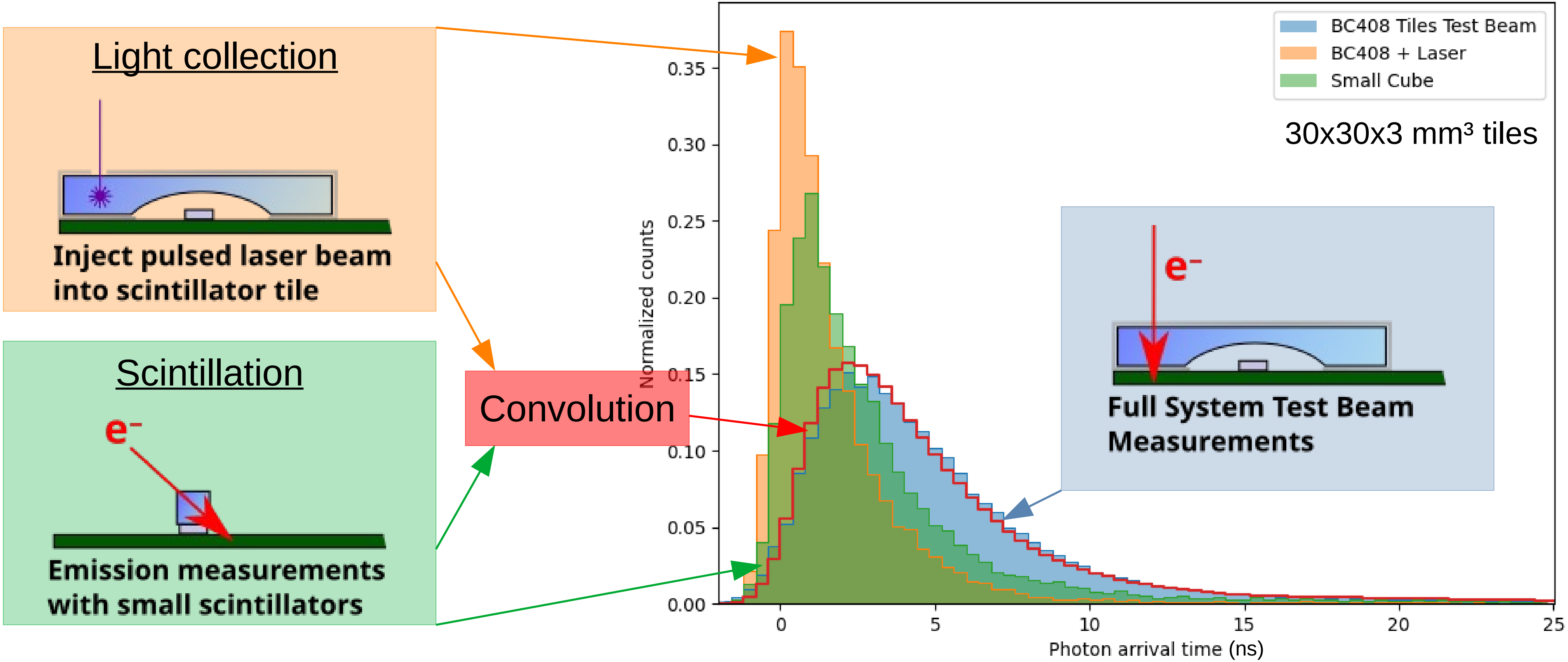
Average 1 p.e. waveform from a measurement

Subtract 1p.e. waveforms



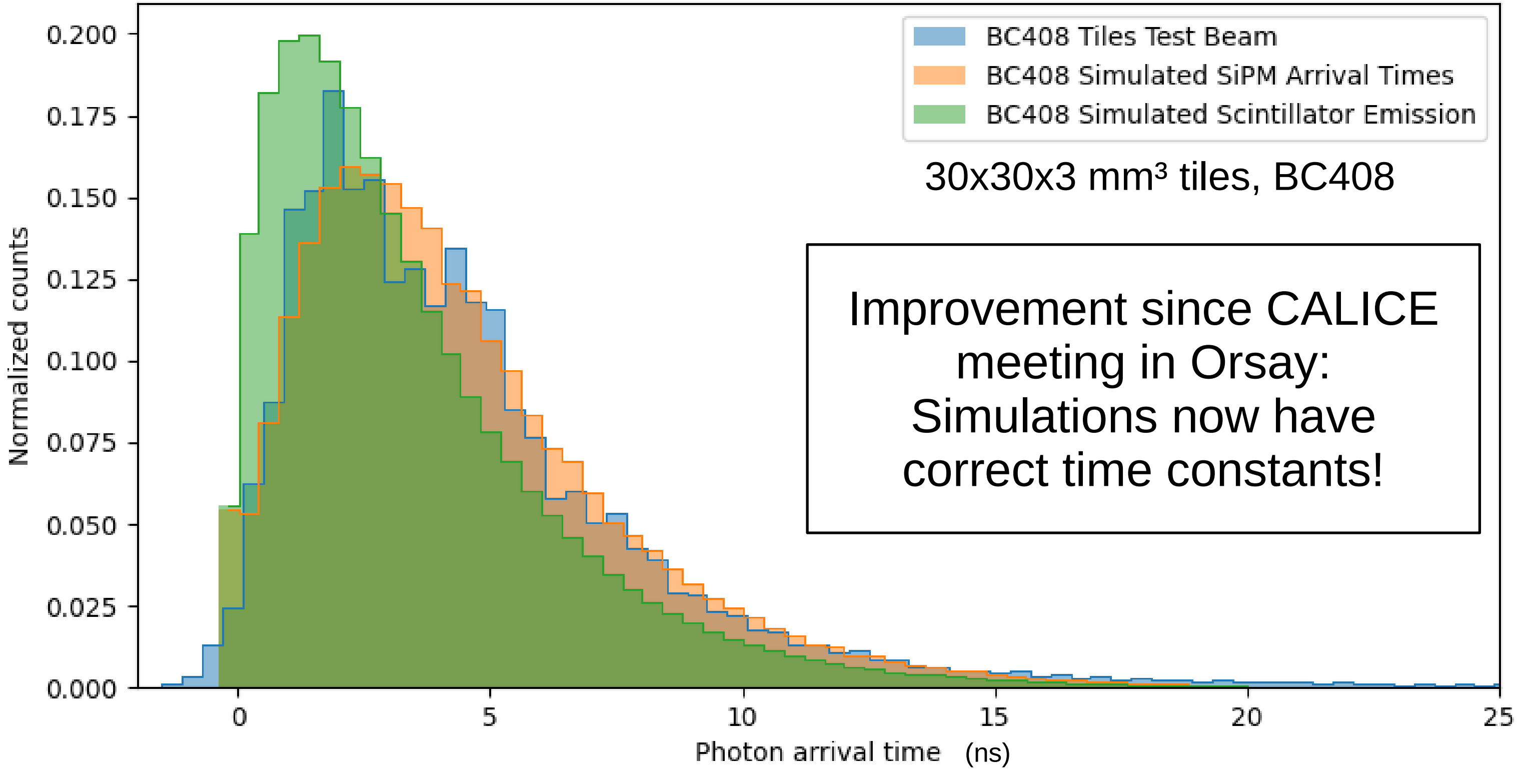
Extrapolate photon arrival times at the SiPM

Scintillation and Light Collection



Simulation: Scintillator Emission Time

- Waveform decomposition allows us to find timing parameters for the simulation:



Improvement since CALICE meeting in Orsay: Simulations now have correct time constants!

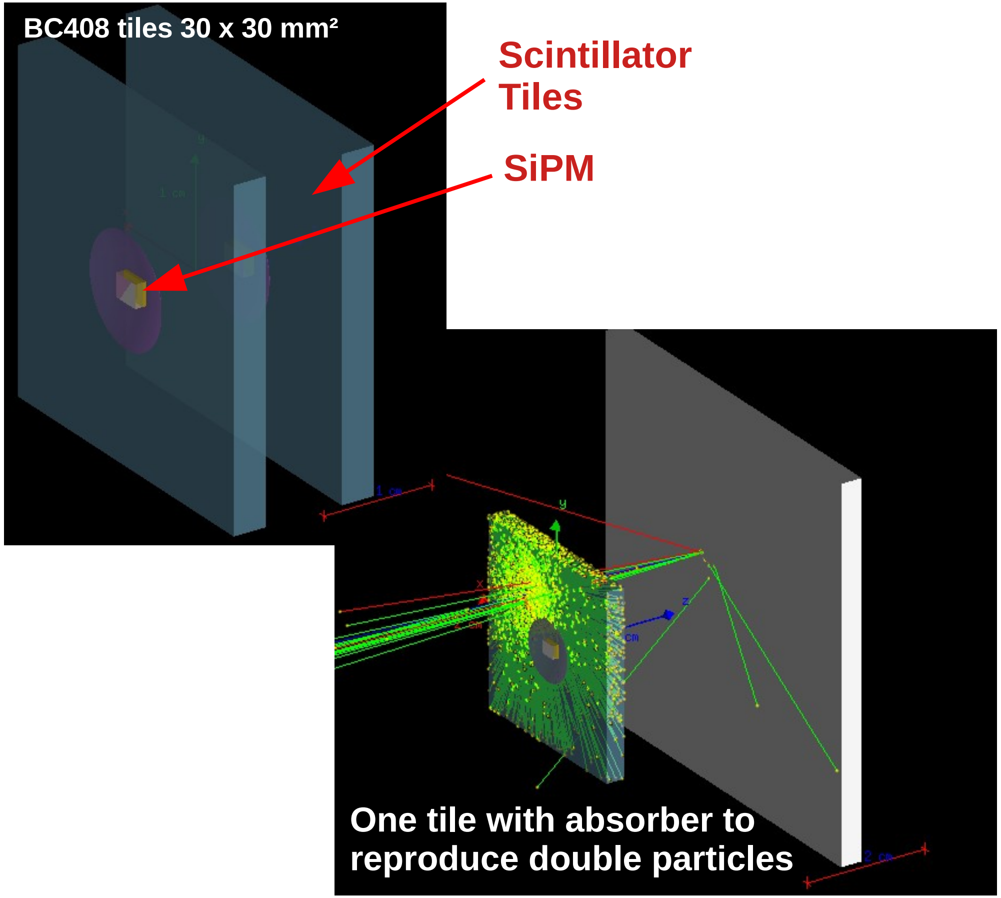
Part 3: Simulations

Understanding the signal creation allows us to simulate the measurements.

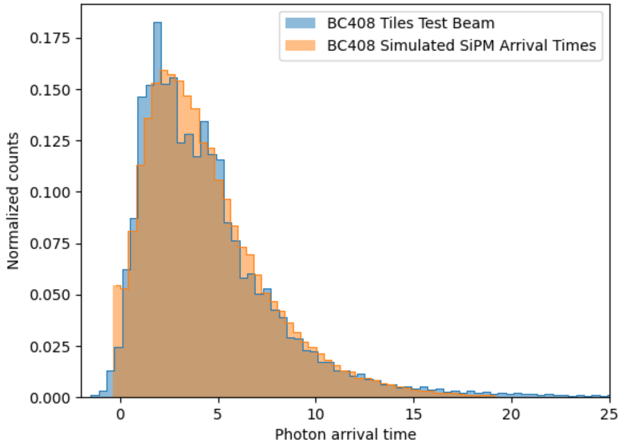
Geant 4 gives us photon hit times, let's invert waveform decomposition to build signals.

Geant 4 Simulations

- Two scintillator tiles in detector geometry → hit time difference
- Optical photons are tracked until they reach the SiPM → signal creation in a later step
- In test beam conditions, there are double particles
  - Due to beam parameters (collimator)
  - This changes the energy distribution of the signals
  - Emulate using a tungsten absorber in Geant 4

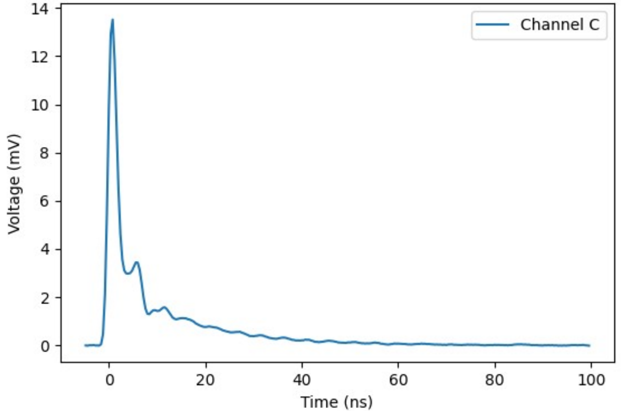


Simulation: Waveform Generation



Photon arrival times from Geant4 simulations

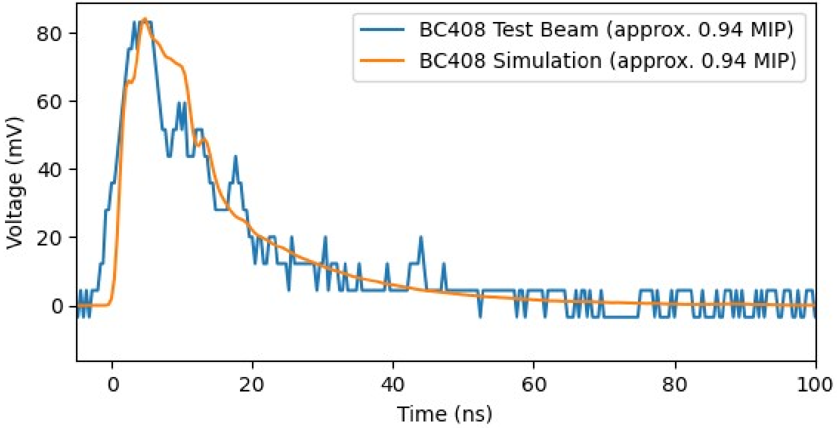
plus



Average 1 p.e. waveform from a measurement

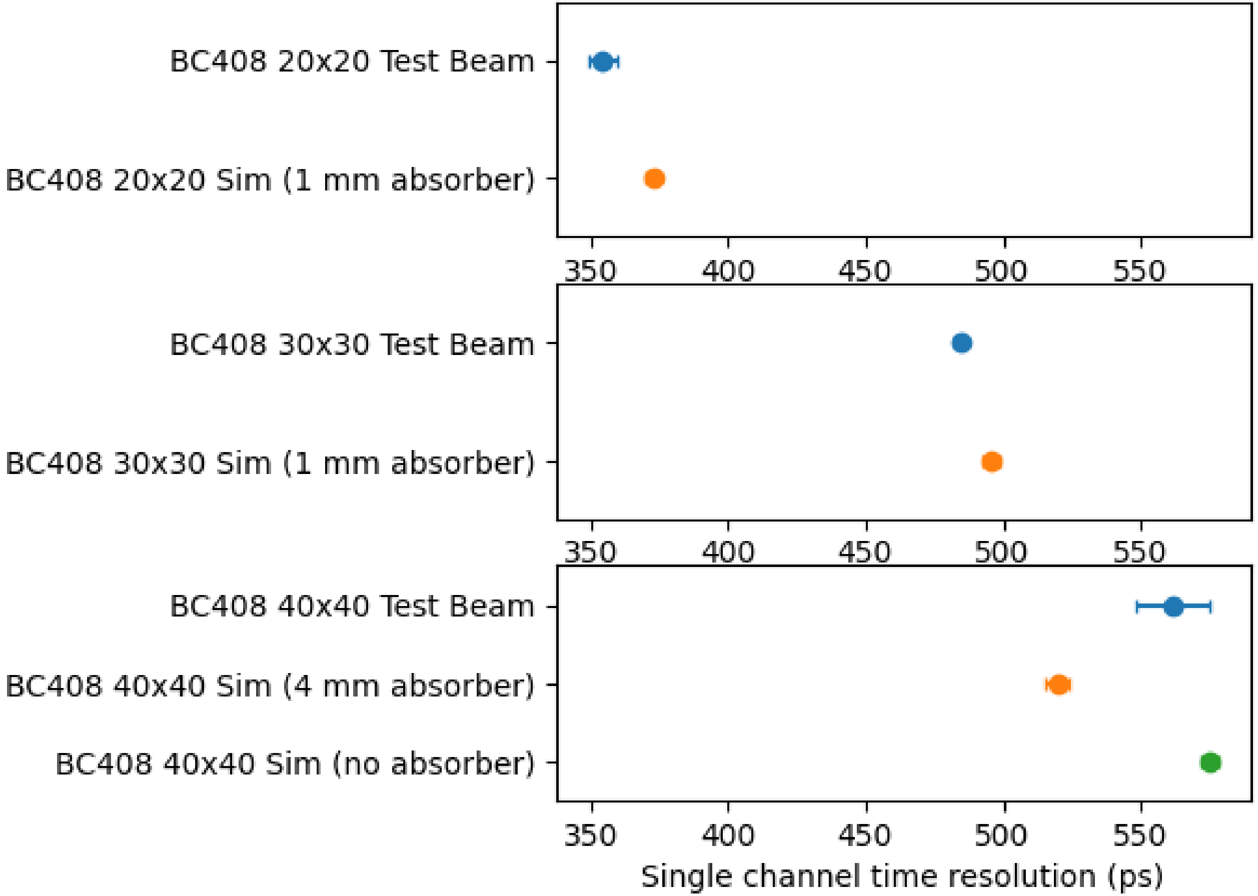
Stack 1p.e. waveforms

SiPM response for each simulated event.

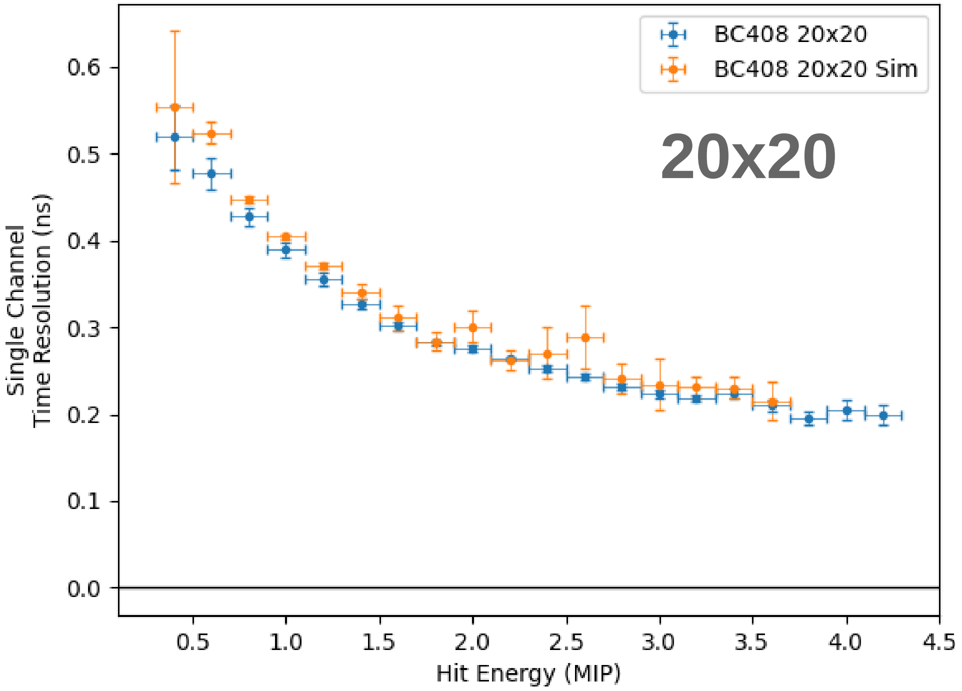


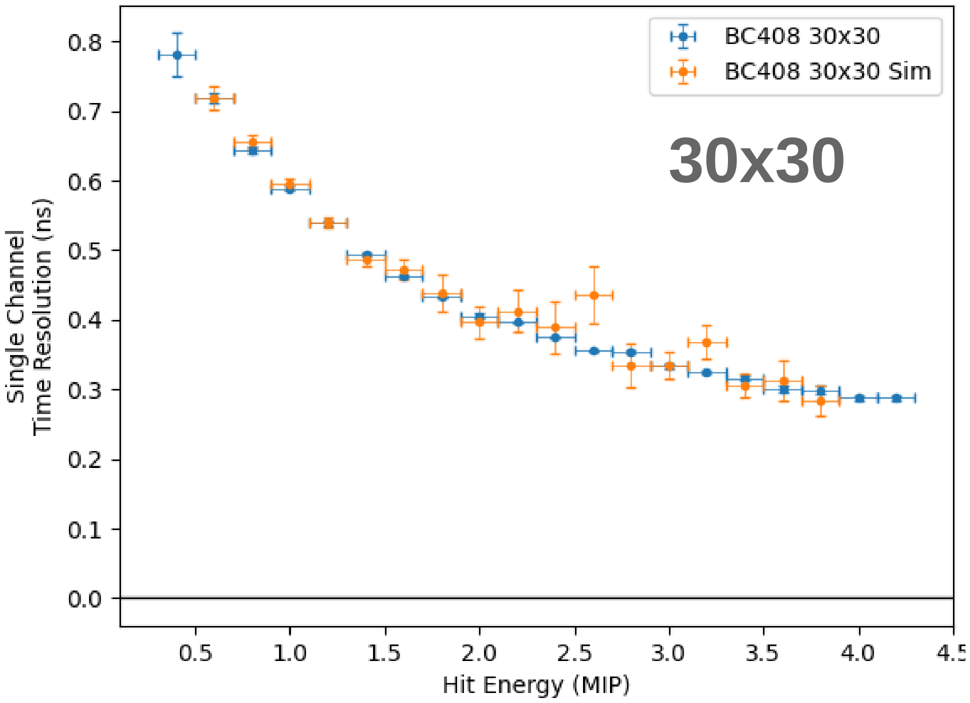
Caveat: „Detection efficiency“ needs to be adjusted to signal amplitude of each detector module (once)

Simulation: Average Time Resolutions



Energy Resolved Time Resolutions





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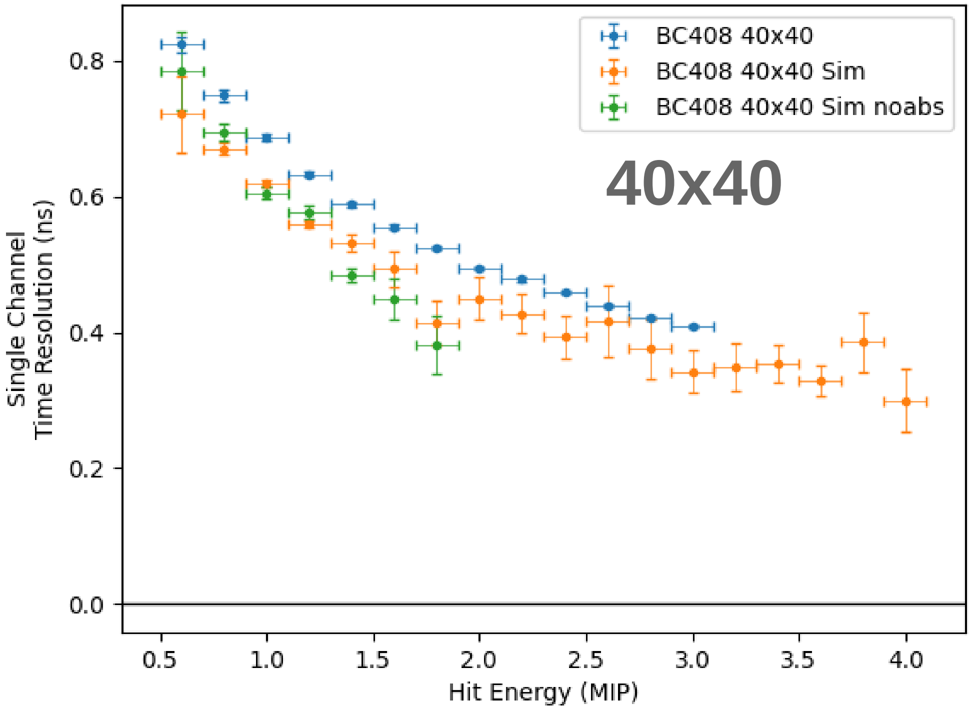
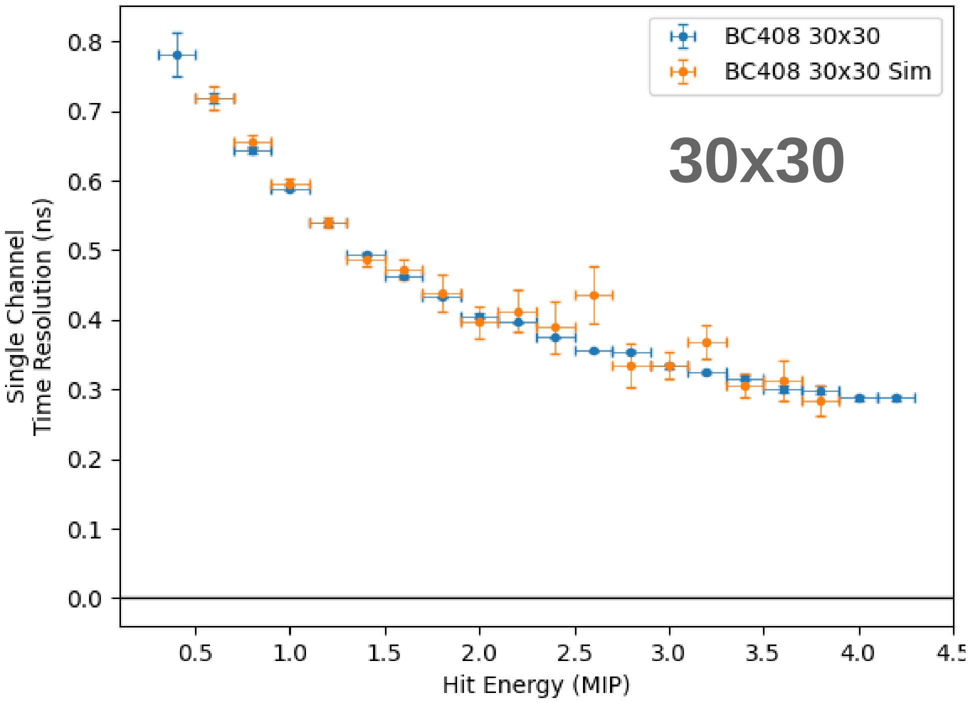


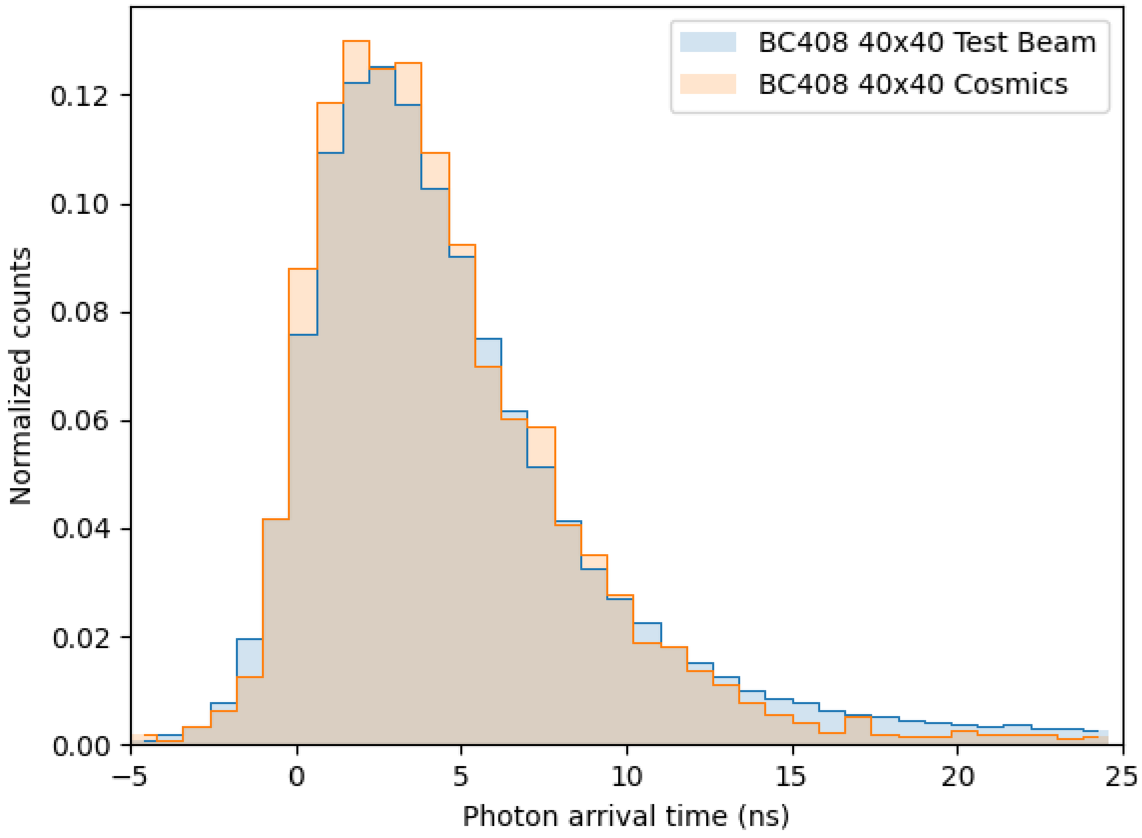


Energy Resolved Time Resolutions

- Simulation reproduces experimental results
  - First optimized for 30x30 tiles, then other sizes worked almost out of the box
- Absorber makes a difference: Energy distribution changes!
  - Significant for 4 mm, negligible for 1 mm
  - Energy distribution changes the *average* time resolution
- Slight disagreement for 40x40 tiles:
  - Simulation has better time resolution than experiment
- Possible reasons for this disagreement:
  - Bias in the simulation → less accurate for bigger tile sizes?
  - Probably due to wrong implementation of the ESR foil → analysis ongoing

Beam Parameters of 40x40 Tiles

- A larger beam collimator was installed in this run
  - More double particles
- But the hit time distribution of cosmics and test beam is very similar
- This rules out the option that the beam parameters lead to different timing (e.g. through delayed double particles)



Part 4: What can we learn?

Now that the simulations deliver good results, let‘s investigate the correlation between tile size, light yield and time resolution.

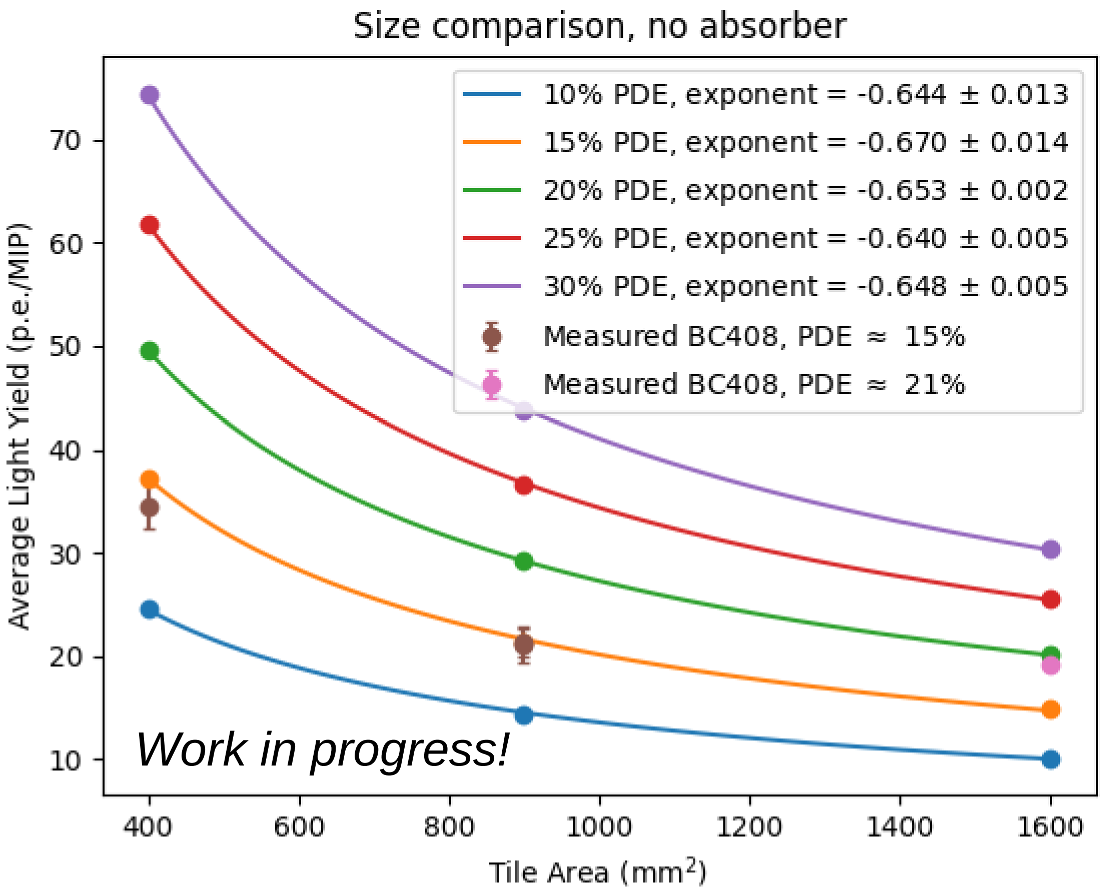
Simulations without absorbers → MIPs

Tile Size vs. LY

- Finding: $LY \propto A^{k_1}$

Exponents k	
A ↔ LY	-0.651 ± 0.010

- Instead of adjusting the PDE to experimental results, use different values
- Measurements agree with simulations (caution: no absorber, experimental PDEs estimated)



LY vs. Time Resolution

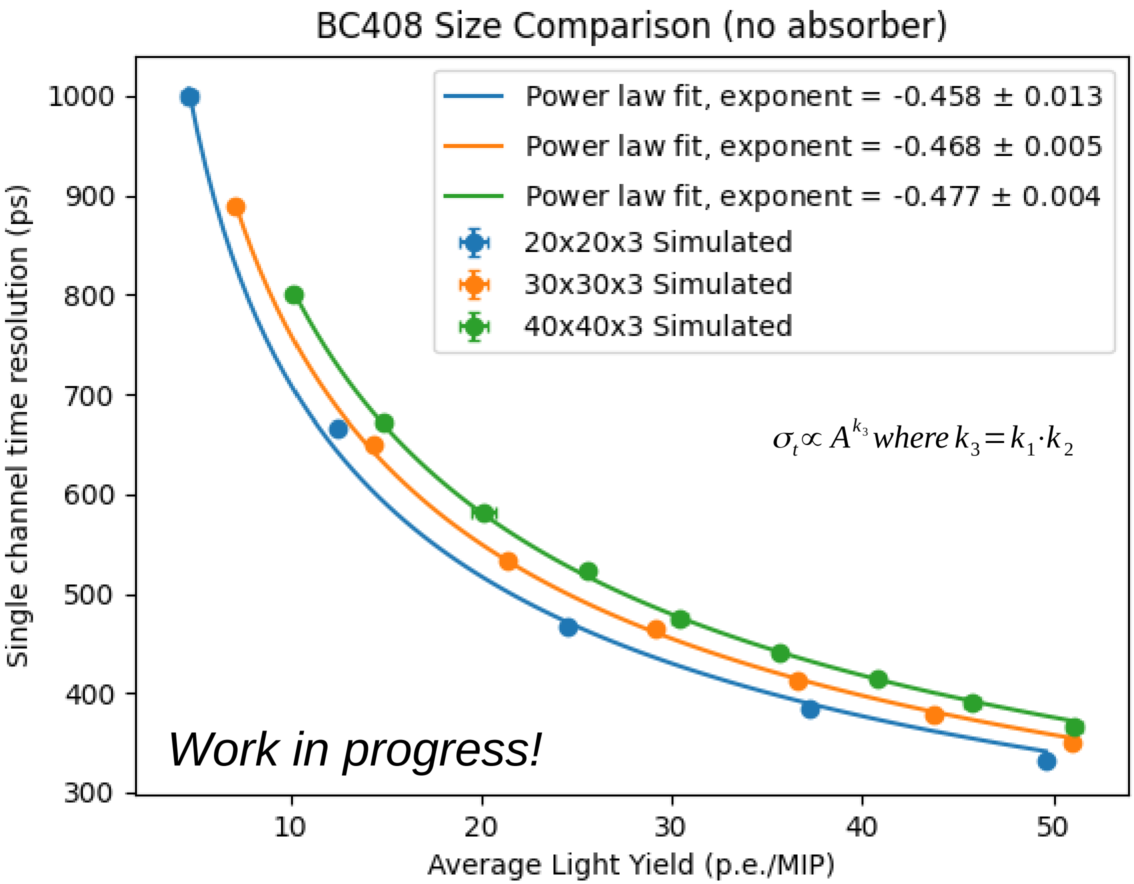
- Finding $\sigma_t \propto LY^{k_2}$

Exponents k	
A ↔ LY	-0.651 ± 0.010
LY ↔ σ_t	-0.468 ± 0.008

$$LY \propto A^{k_1} \wedge \sigma_t \propto LY^{k_2}$$

$$\sigma_t \propto A^{k_3} \text{ where } k_3 = k_1 \cdot k_2$$

Expect k3 = 0.305 ± 0.007

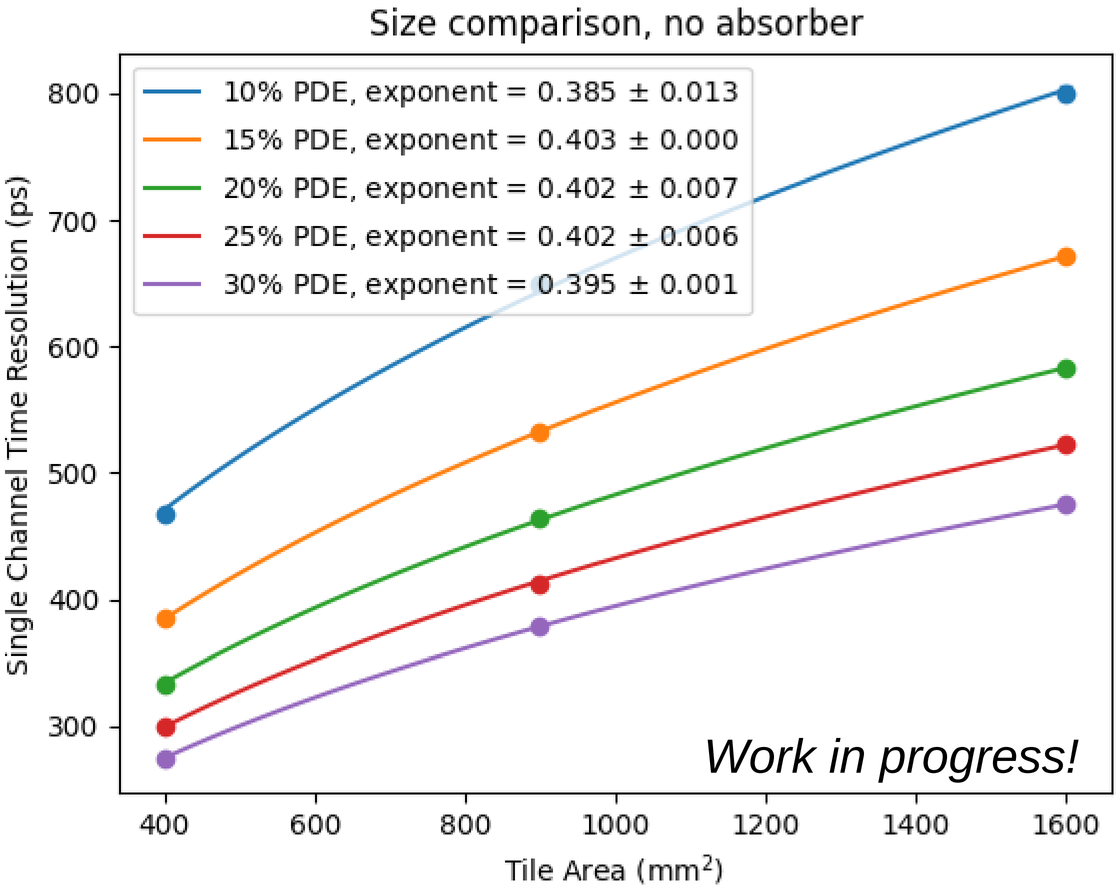


Tile Size vs. Time Resolution

- Finding: $\sigma_t \propto A^{k_3}$

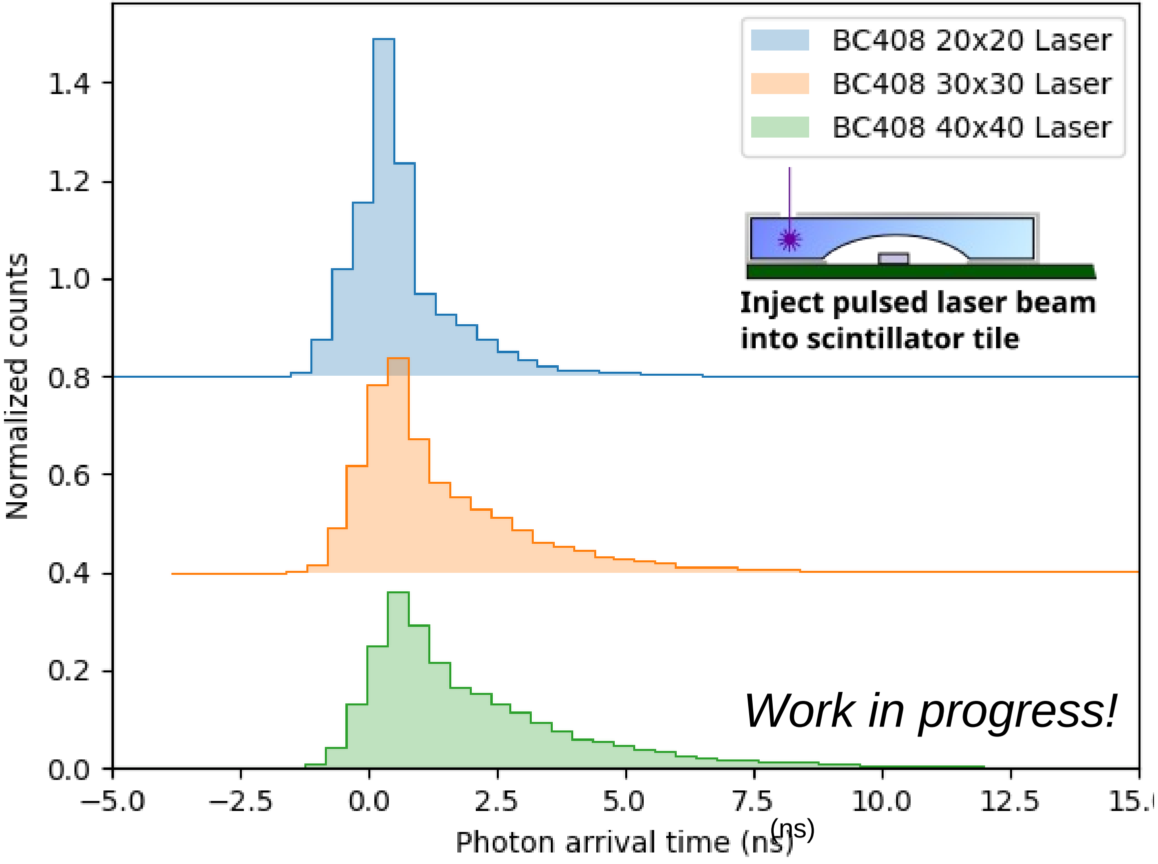
Exponents k	
A ↔ LY	-0.651 ± 0.010
LY ↔ σ_t	-0.468 ± 0.008
A ↔ σ_t	0.398 ± 0.007

Expect k3 = 0.305 ± 0.007
Missing factor ~ 1.3
→ Light collection effects?



Light Collection

- To investigate the effects of light collection, use laser measurements with scintillator tiles
- The **width** of the photon arrival time distribution **increases** for bigger tiles
- LY does not matter here: arrival times are indepenent of energy
- In bigger scintillator tiles the photons travel longer paths
  - Light collection „takes longer“



Summary

Two significant improvements since the collaboration meeting in September:

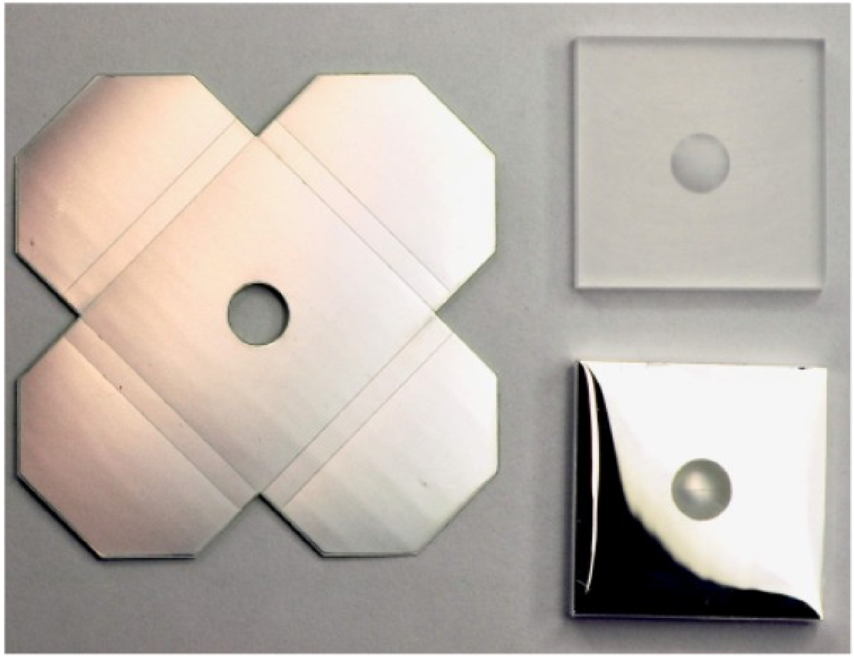
1. New measurement techniques allow us to investigate scintillation and light collectin separately
2. Waveform Decomposition
   - Understand timing at the microscopic level
   - Find correct timing parameters for simulations

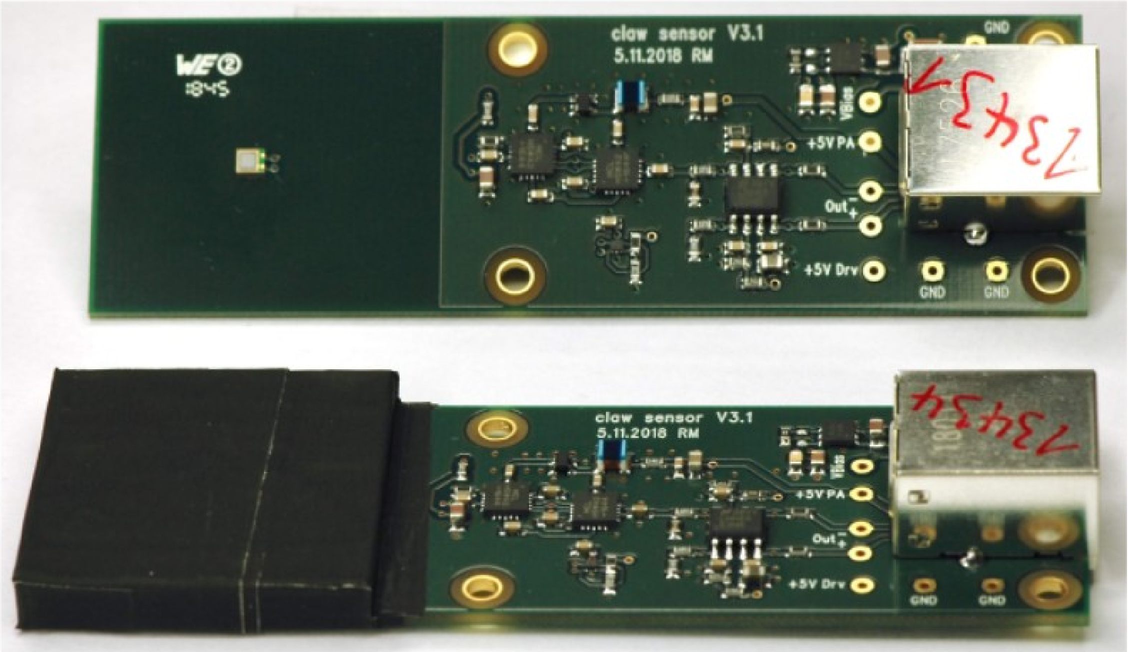
Simulations now give very good results

- Now look at the correlation between tile size, light yield and time resolution
- Independent of experimental effects (e.g. double particles, ...)

Backup Slides

Sensors for the Scintillator Timing Study





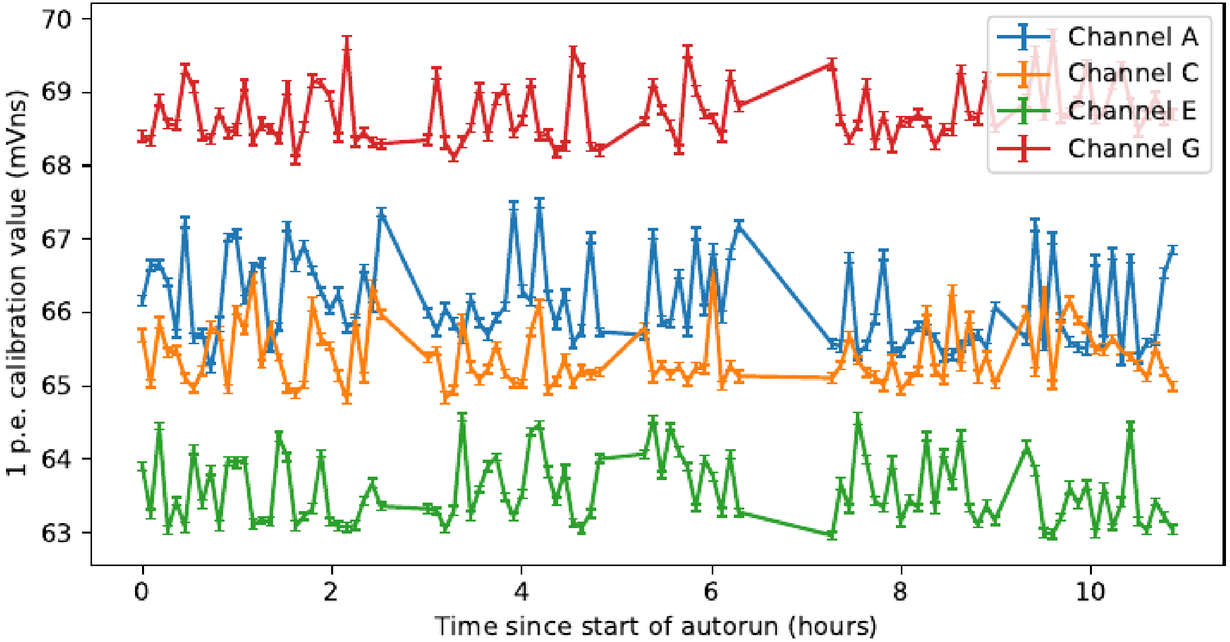
SiPM: Hamamatsu S13360-1325PE

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)

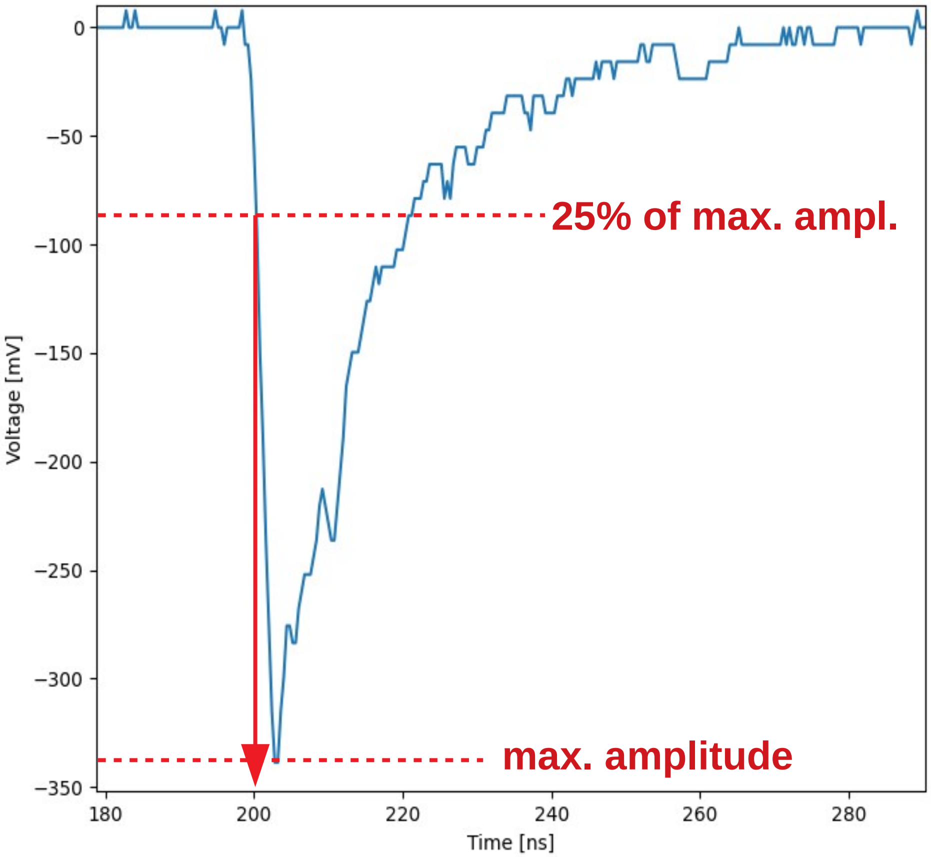
Constant Fraction Discrimination:

- 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

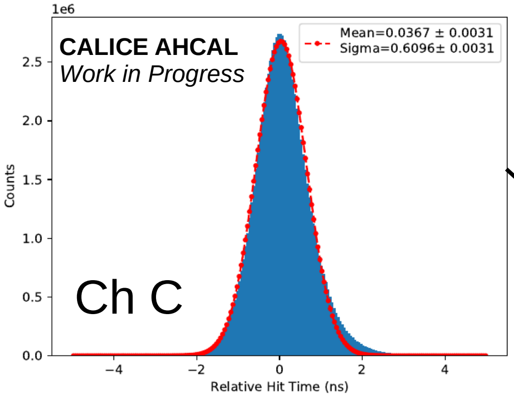
Leading Edge Method:

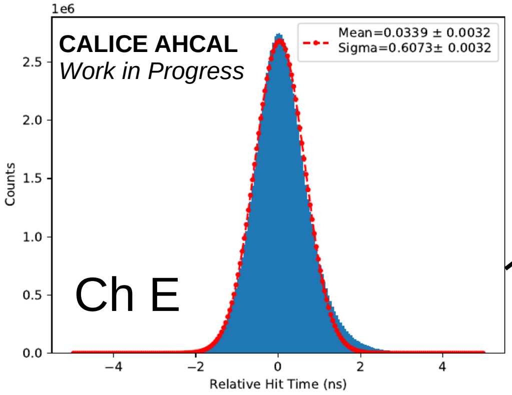
- Set threshold to fixed voltage

Typical SiPM response



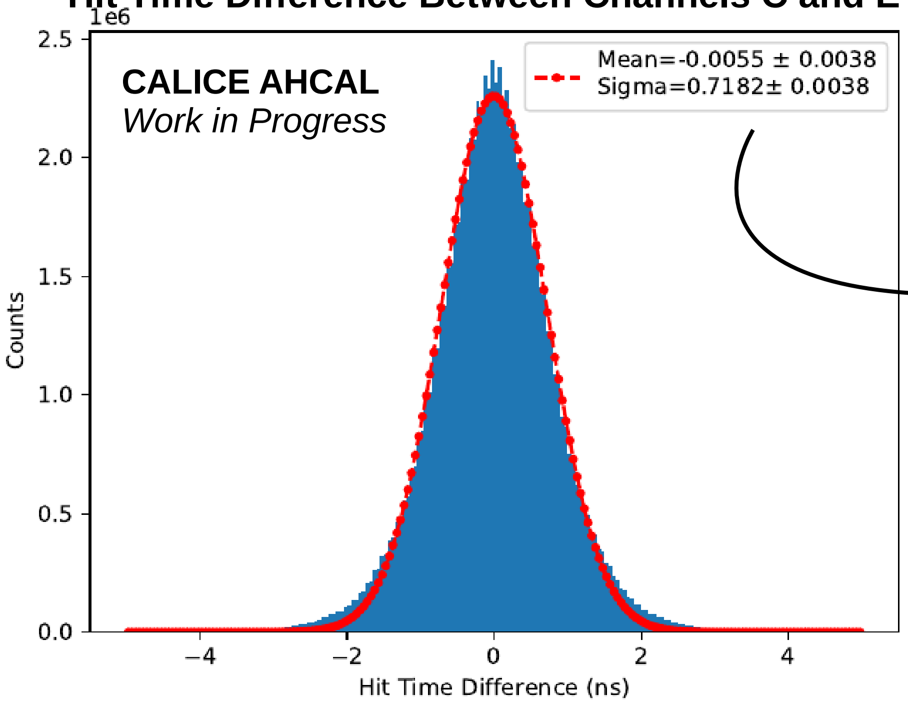
Defining the Time Resolution (2)





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

Hit Time Difference Between Channels C and E

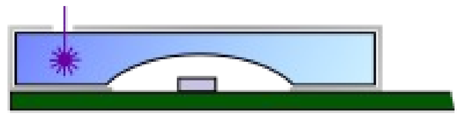


Single Channel
Time Resolution:

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

Remarks on Laser Measurements

- The laser has a wavelength of 440nm
  - Target wavelength for SiPM, no fluorescence in BC408
- Arrival time distribution does not depend on the energy deposition in the scintillator
  - „Laser into tile“ measurements are not sensitive to LY effects
- Only geometric effects



Inject pulsed laser beam into scintillator tile

- „Laser on SiPM“ measurements have shown that the electronics are significantly faster than tile