Hit position reconstruction and general analysis of scintillator bars with two SiPM readout

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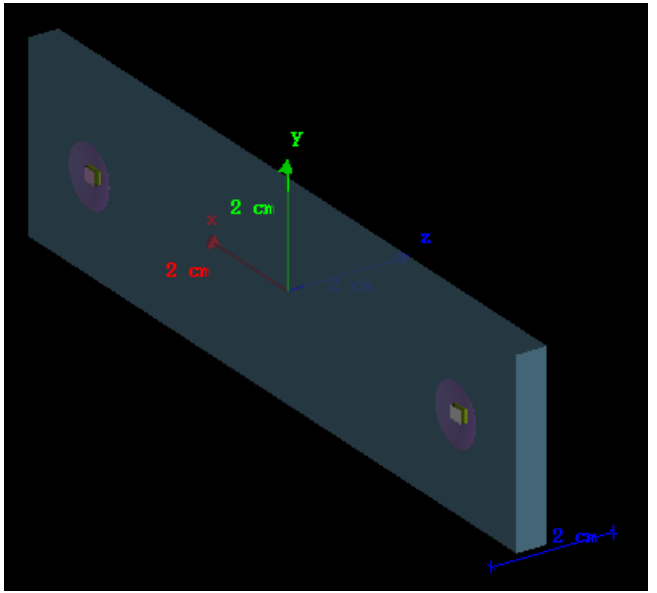
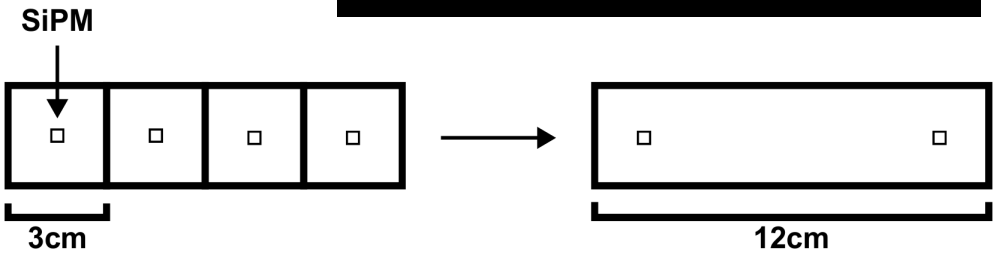
Scintillator Bars

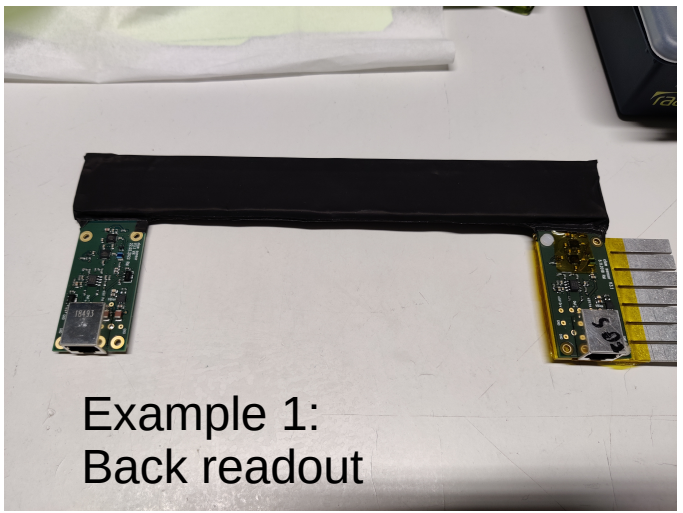
- Differences in geometry relative to AHCAL tiles
  - Bar shaped instead of square shaped with width = 30 mm, height = 5 mm and varying length between 120 and 500 mm
  - 2 dimples, located 15 mm from the edge of the bar
  - 2 SiPMs corresponding to each dimple
- Similarities:
  - Same materials used
  - Dimples of same size, despite thicker tile

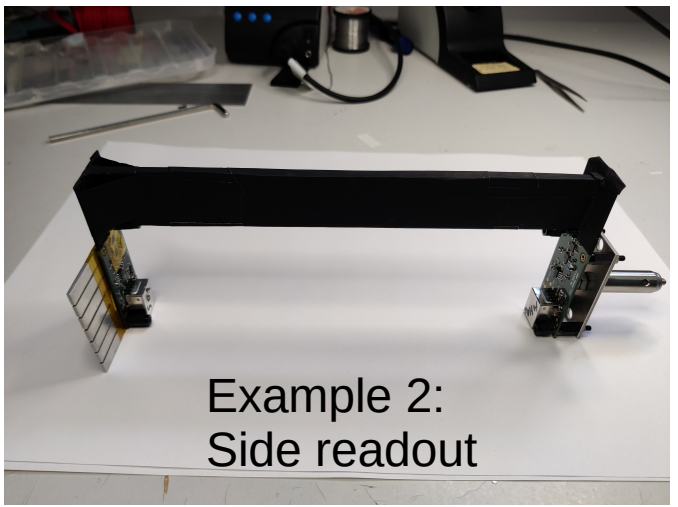




Bar Shaped Design Approach

- Three main goals:
  - 1. Simulation study: Investigate different bar geometries and dimple positions
  - 2. Test beam campaign: Test different bars in DESY test beam
  - 3. Hit position reconstruction: Develop a method to regain granulartiy, by „guessing“ the hit position of the particle on the bar



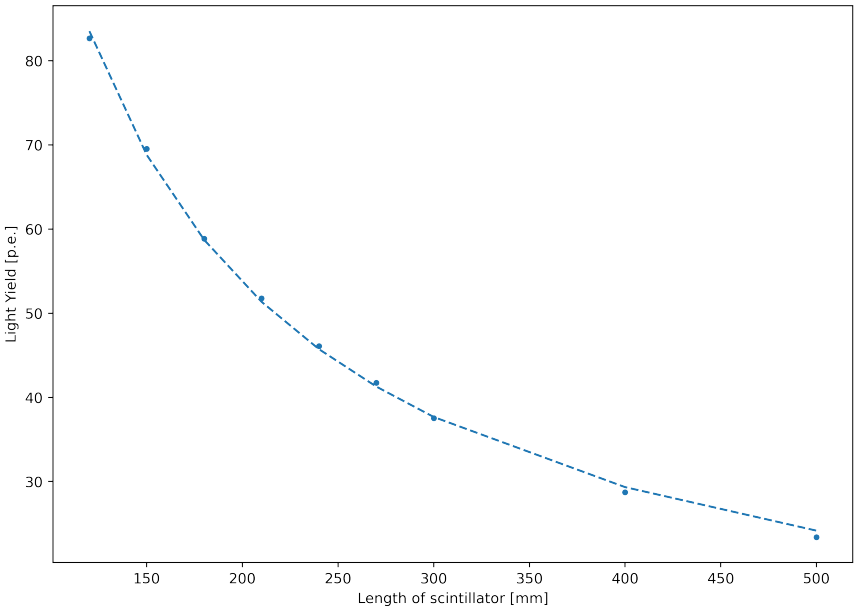


Simulation: Light yield

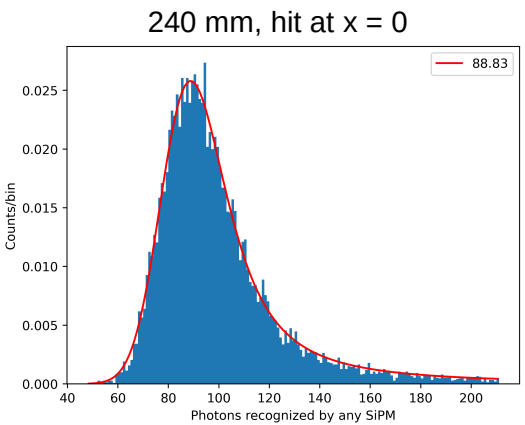
- Good light yields for lengths < 500 mm
- E.g. : 240 mm bar:

  Approx. 89 photons recoginzed by either of the SiPMs

  → ca. 44 Photons detected per SiPM for a middle hit



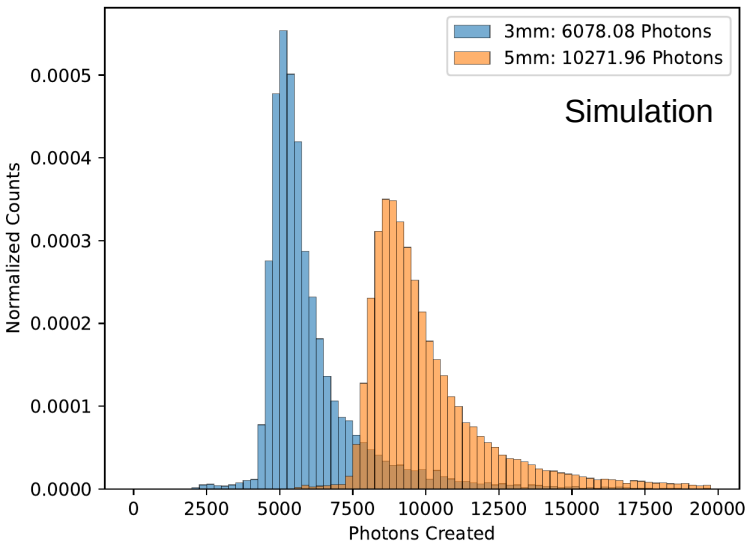
$LY(x) = 5358 * x^{-0.87}$



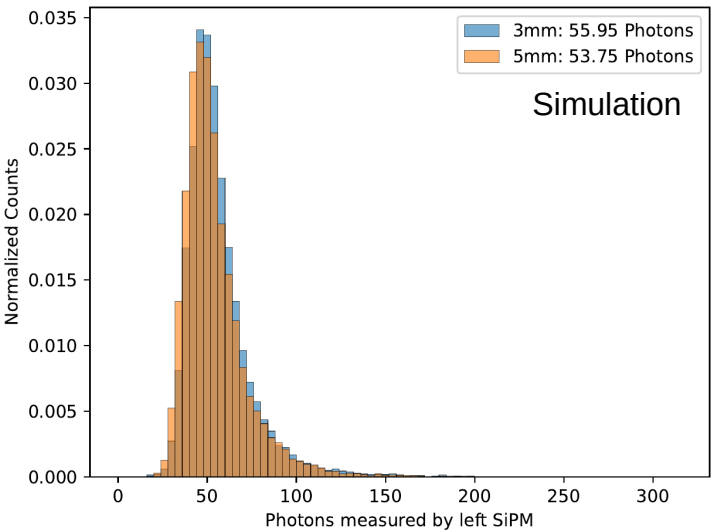
→ Promising results for a test beam campaign!

Simulation: Thickness

- Initial idea: Increase thickness from 3mm → 5mm to increase light yield for long bars
- More photons get produced, **but** similar numbers measured at the SiPM for a 240mm bar



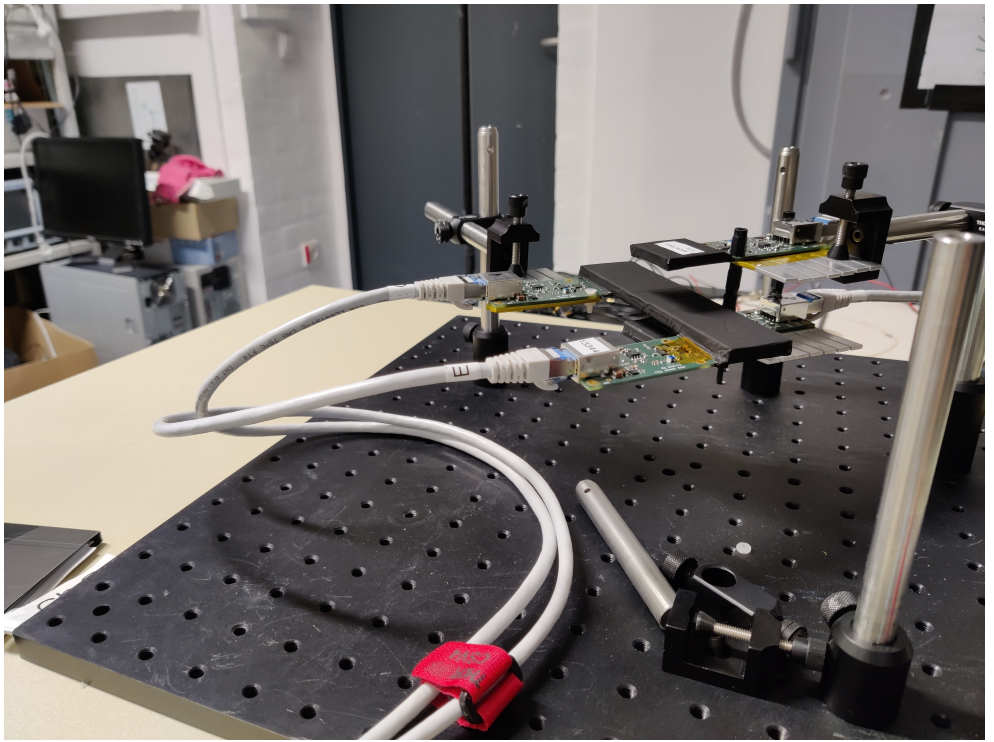
Number of photons created



Number of photons detected

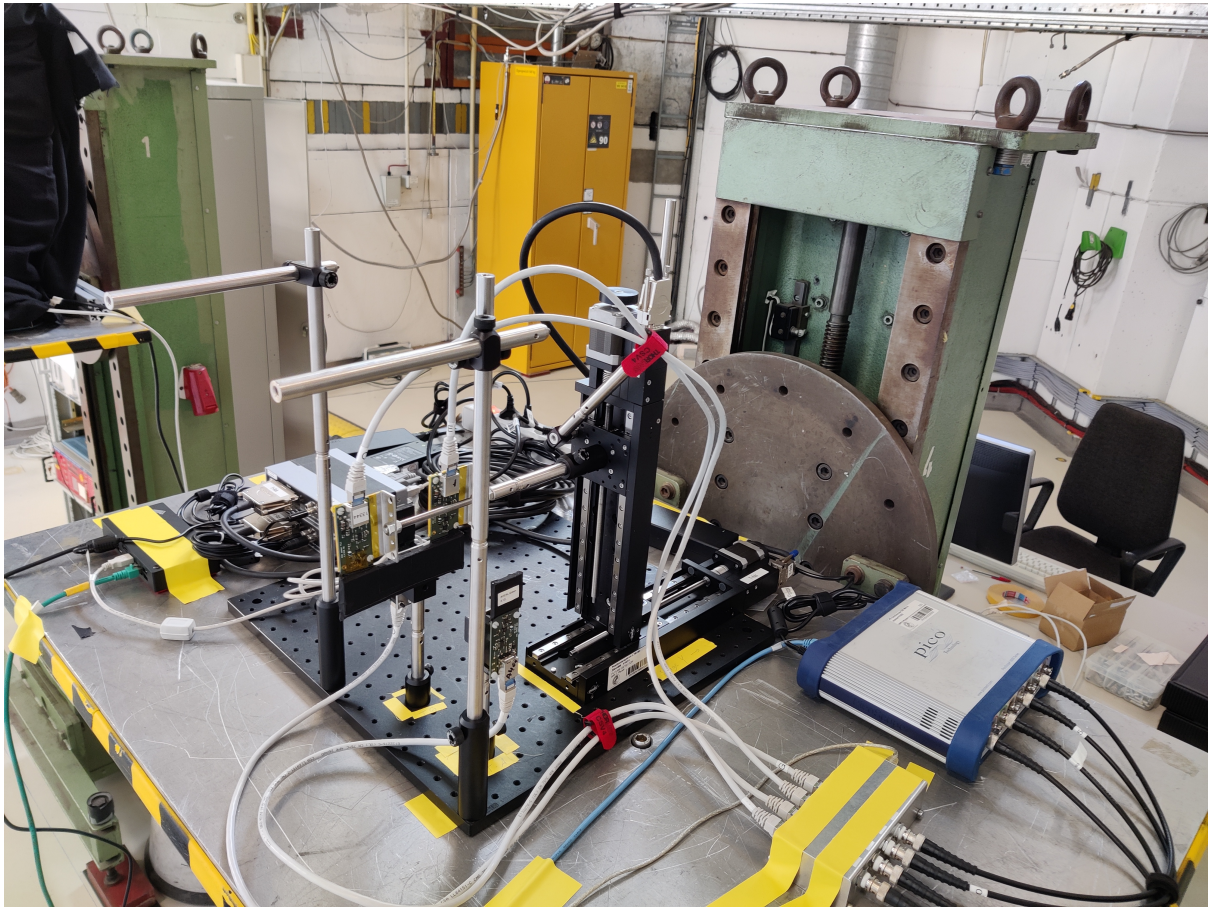
Experimental Setup

- 2 Bars:
  - 120 x 30 x 5 mm
  - 240 x 30 x 5 mm
- 2 Trigger scintillators with different geometries dependings on the measurement
- Moveable stage for easier operation



Setup with two 3 cm² trigger scintillators

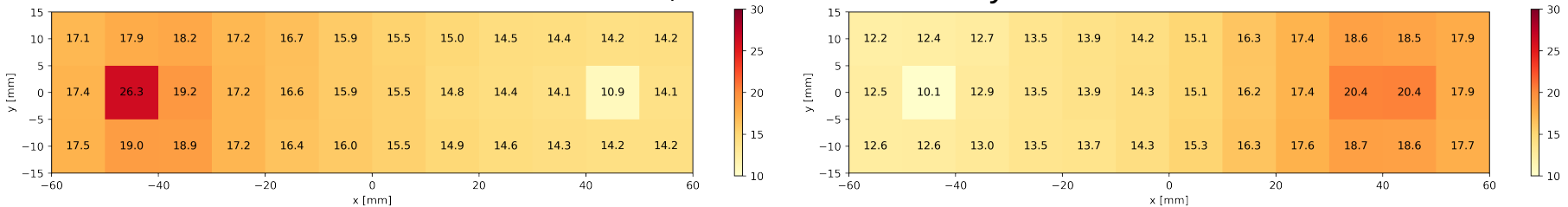
Experimental Setup: Testbeam



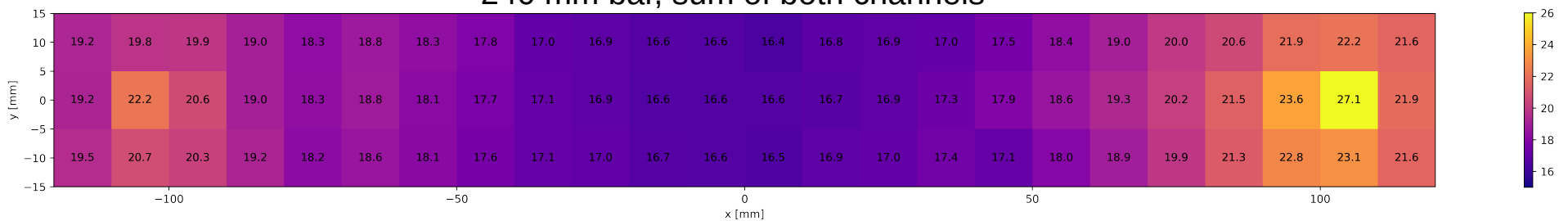
Testbeam Data: Light Yields

- Light yields overall considerably lower than expected from the simulations
  → persisting problem, that light yields are hard to judge from the simulations
- Still: Overall the light yields are high enough to speparate from the noise

120 mm bar, channels individually

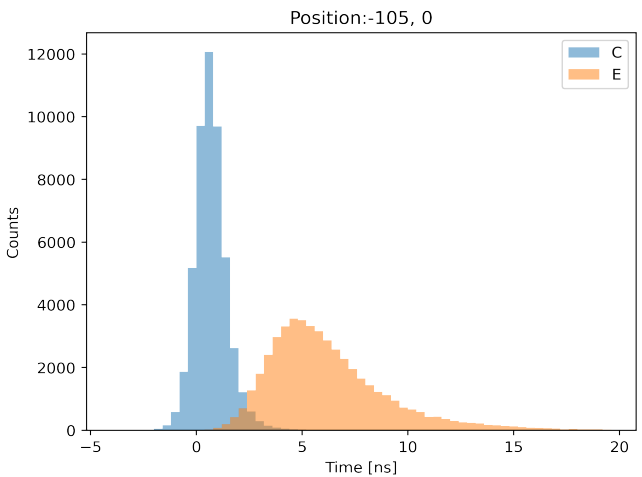


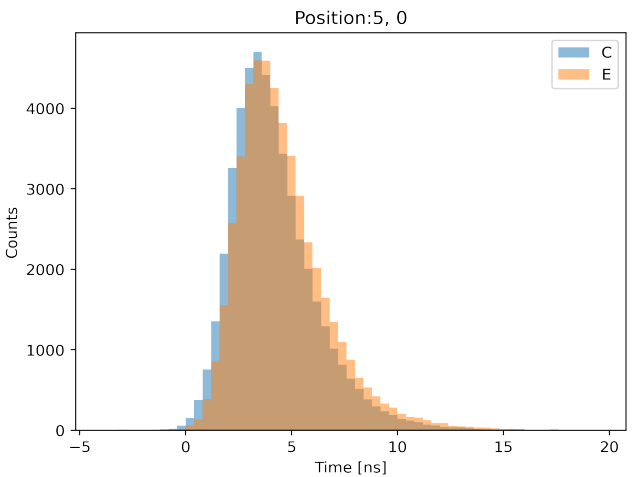
240 mm bar, sum of both channels

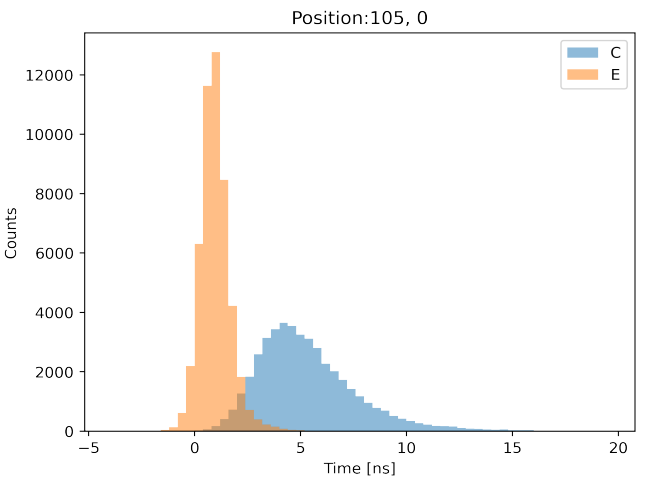


Testbeam Data: Timing

- Distinct time distributions depending on position
- In general the distribution get:
  - Broader with greater distance between hit and SiPM
  - Further from 0 (towards bigger times) with greater distance between hit and SiPM





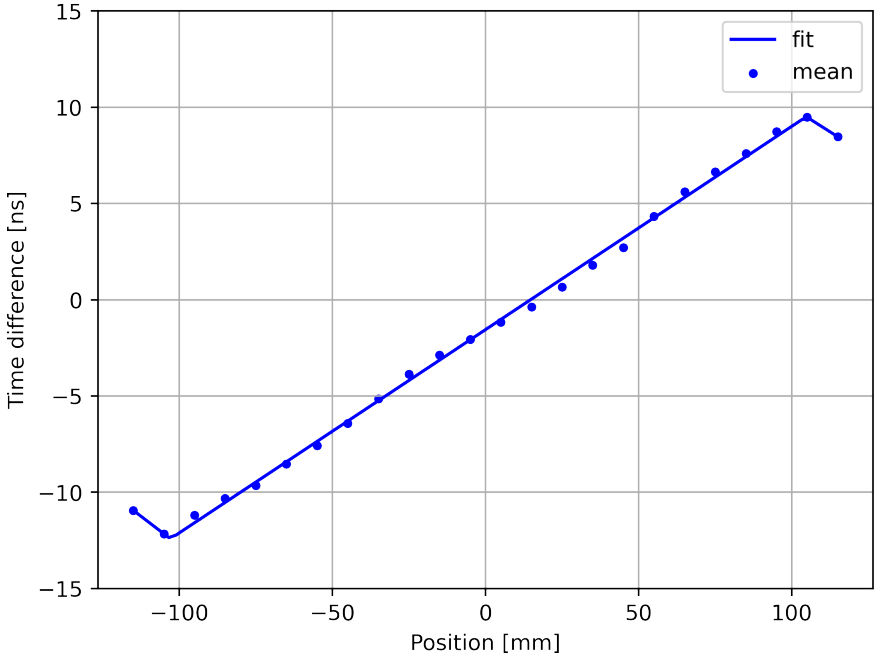


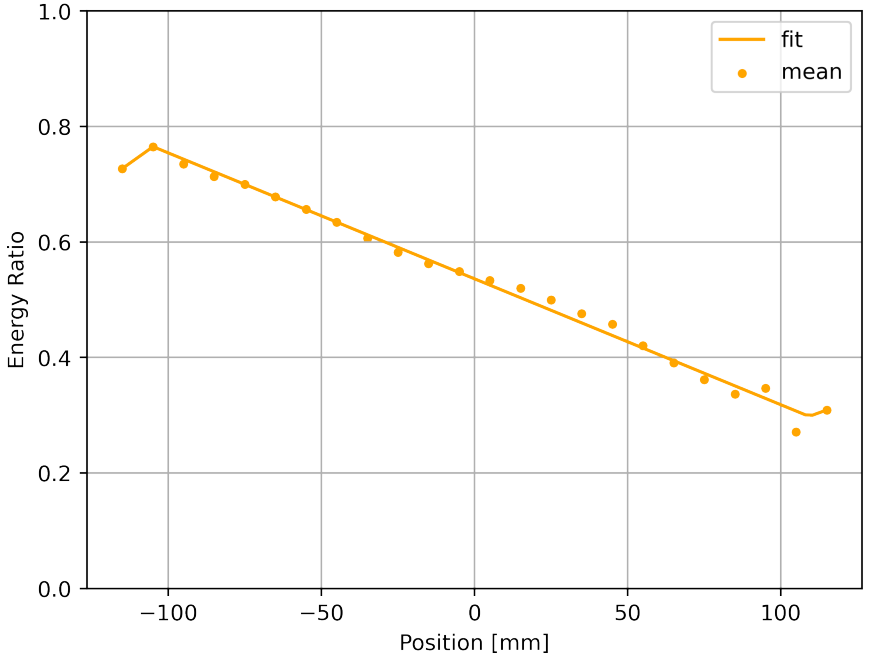
All time measurements are done with 0.4 constant fraction

Hit Position Reconstruction: Linear

- Goal: Reconstruct the position of the hit from characteristics of the waveform, mostly hit times and energies at both SiPMs

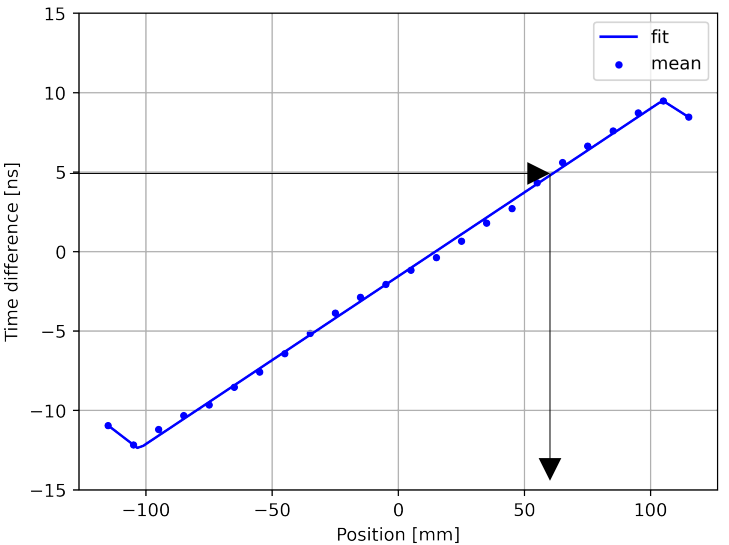
1. Approach: Linear Interpolation





Hit Position Reconstruction: Linear

- E.g. time difference measured 5 ns would result in a guess of ≈ +60 mm
- Combining both functions for time and energy and minimize for the best guess
- Problems:
  - Only can guess positions between SiPMs
  - Limited range for input values
- Overall: Good results, but only for very limited cases



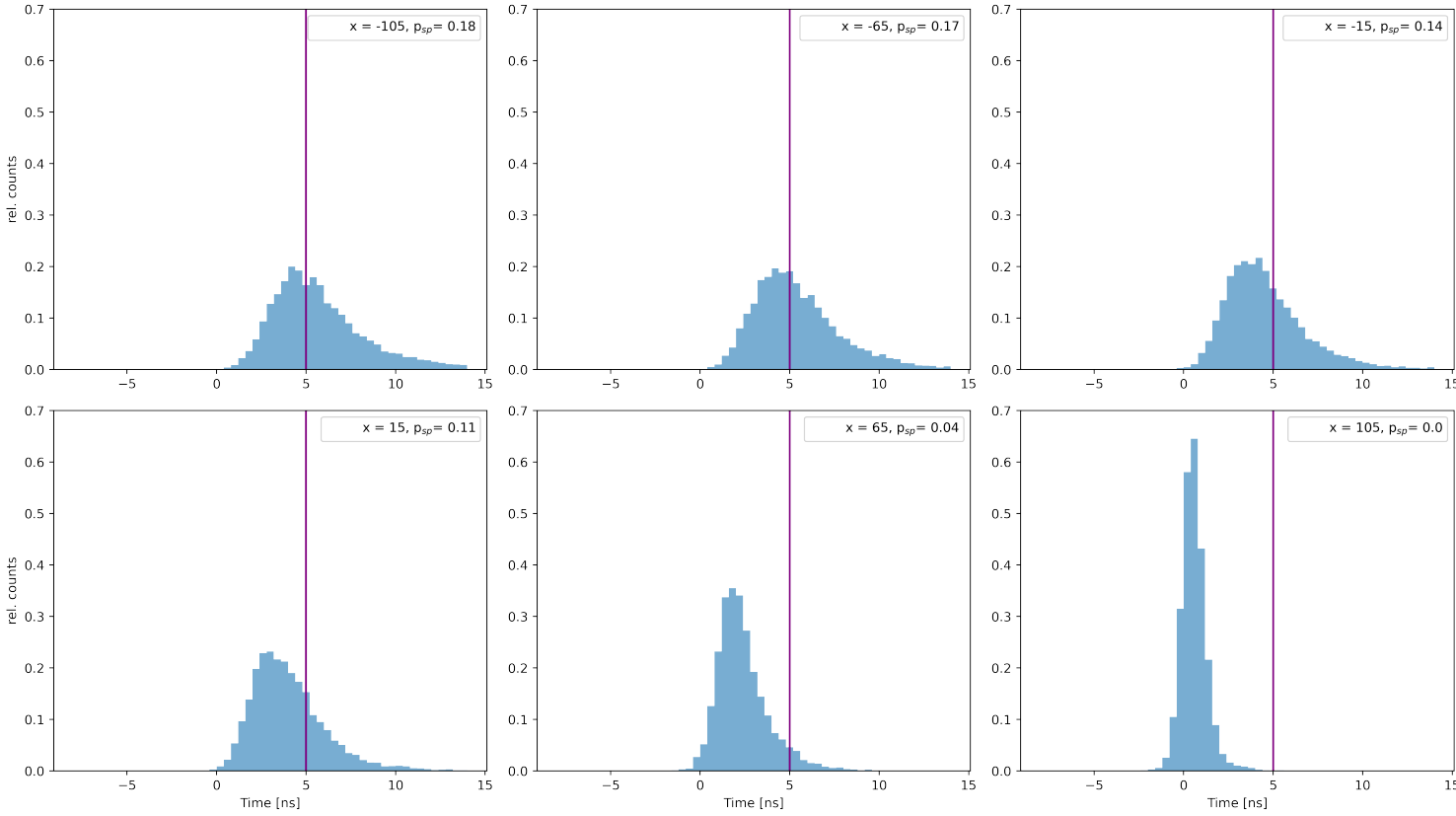
Position Reconstruction: Lookup Table

Data set, based on previously measured data.

E.g. $t_E = 5$ ns

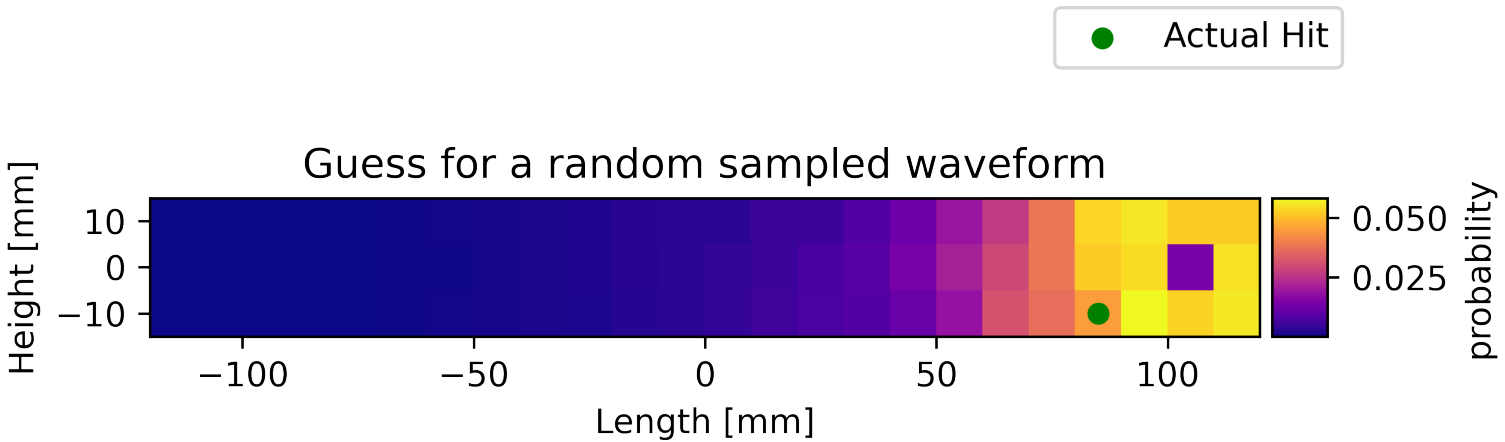
→ Search for distribution with highest magnitude at t = 5 ns

→ Proposed position would be x = -105



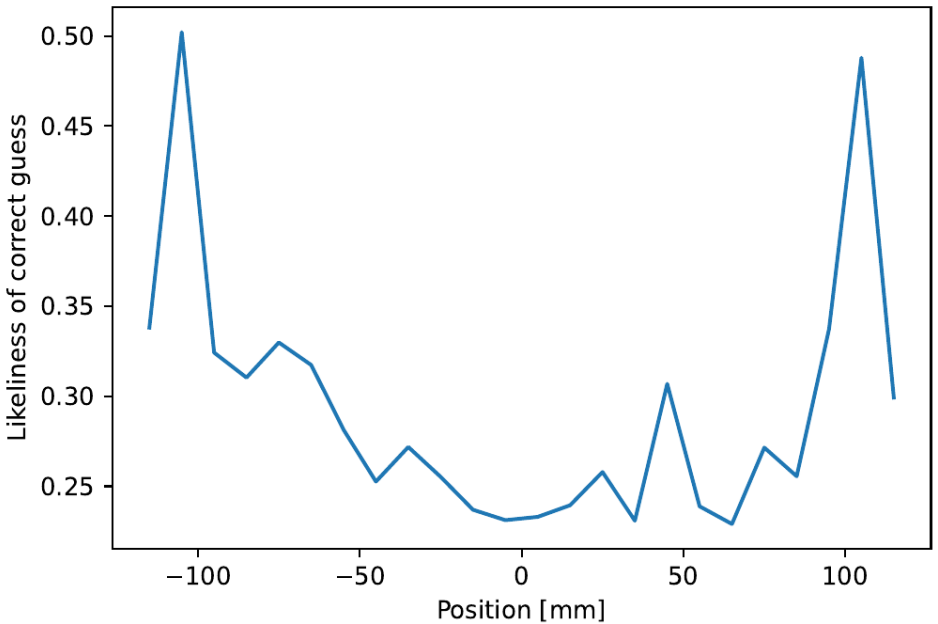
Position Reconstruction: Lookup Table

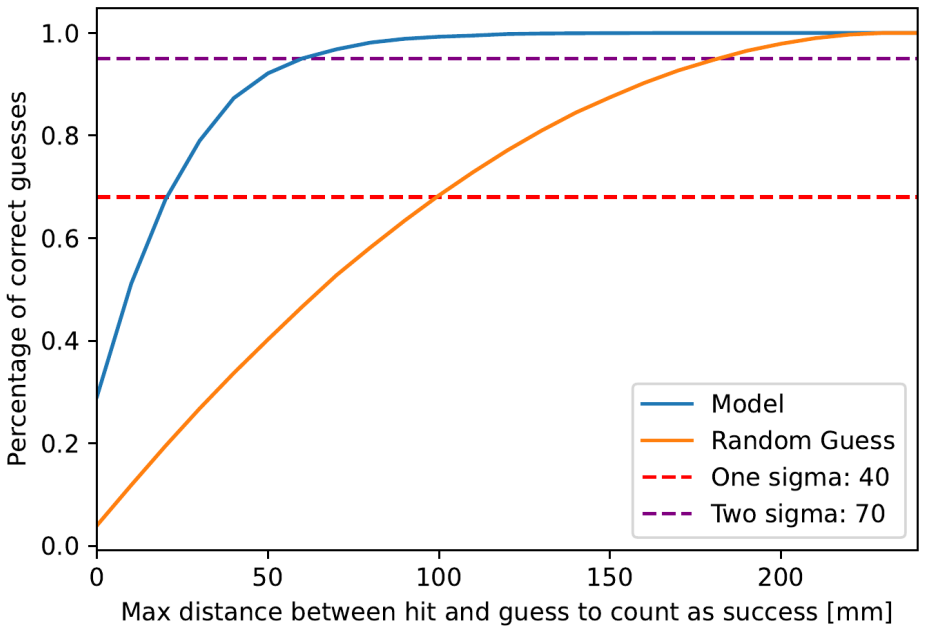
- Challenge: Best possible combination of all four measurements (t_C, t_E, E_C and E_E) to generate a score for each position.
- Advantages:
  - Clean representation of best guesses
  - No limitations to input and only viable locations as output



Position Reconstruction: Gradient Boosting

- Idea: Provide a data set with the waveforms most interesting characteristics e.g. times, energies, shape of waveform…
- After training with scikit's HistGradientBoostingClassifier:





Position Reconstruction: Comparison

- **Linear:** Only suitable for geometries with large distances between the SiPMs, overall mediocre performance
- **Lookup Table:** Best results (70%+ correct) in the vicinity of the SiPMs, mediocre results for the middle of the bar.
  Is driven by the design of the lookup table so doesn’t work as nicely out of the box
- **Gradient Boosting:** Best overall performance. Only algorithm that can reasonably distinguish in the middle of the bar. No easy visualization of results + less physical insights. Possibly a lot of room for improval with different ML algorithms or better training

Results

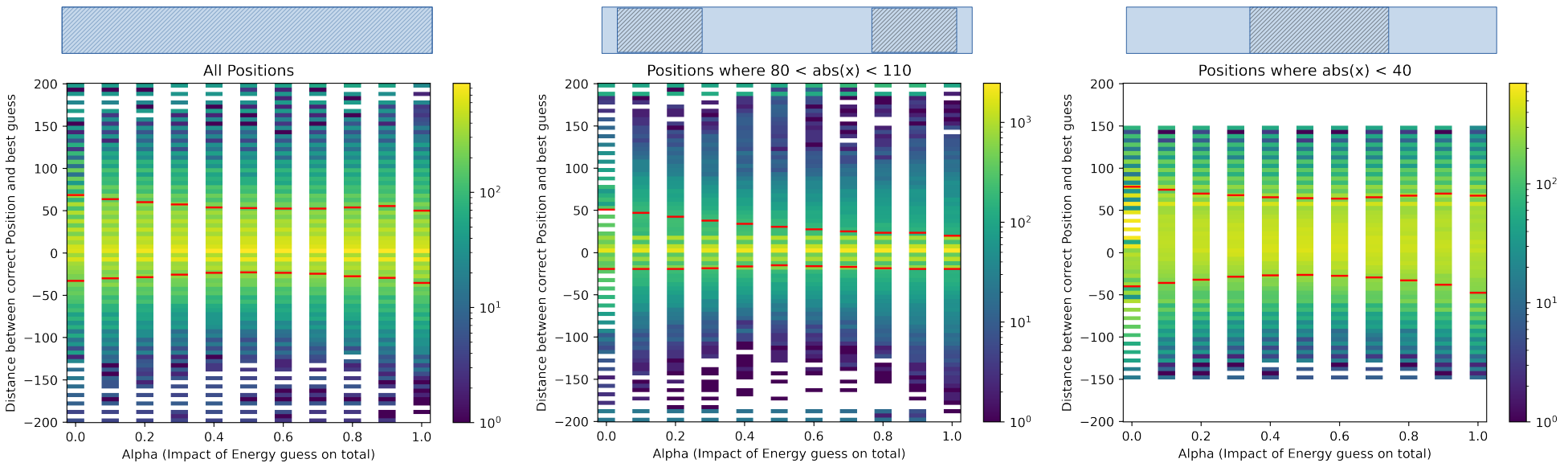
- Scintillator bar approach as viable design option for detectors where pile-up isn’t a problem, in order to reduce complexity
- Two SiPM readout, one on each side of the bar to enable position reconstruction
- Light yield depends on the length of the bar according to a power law (only based on simulations)
- 240 mm seems to be a good bar length
  - We can expect to be within ±4 cm for 68%, and ±7 cm for 95% of the actual hit positions
  - Improvements expected with side readout instead of back readout

Backup

Backup: Linear

- Accuracy of hit position strongly depends on position of hit within the bar

Minimize: $$\alpha \left(E_{exp}(x) - \frac{E_C}{E_C + E_E} \right)^2 + (1-\alpha)\left(\Delta t_{exp}(x) - \Delta t\right)^2$$

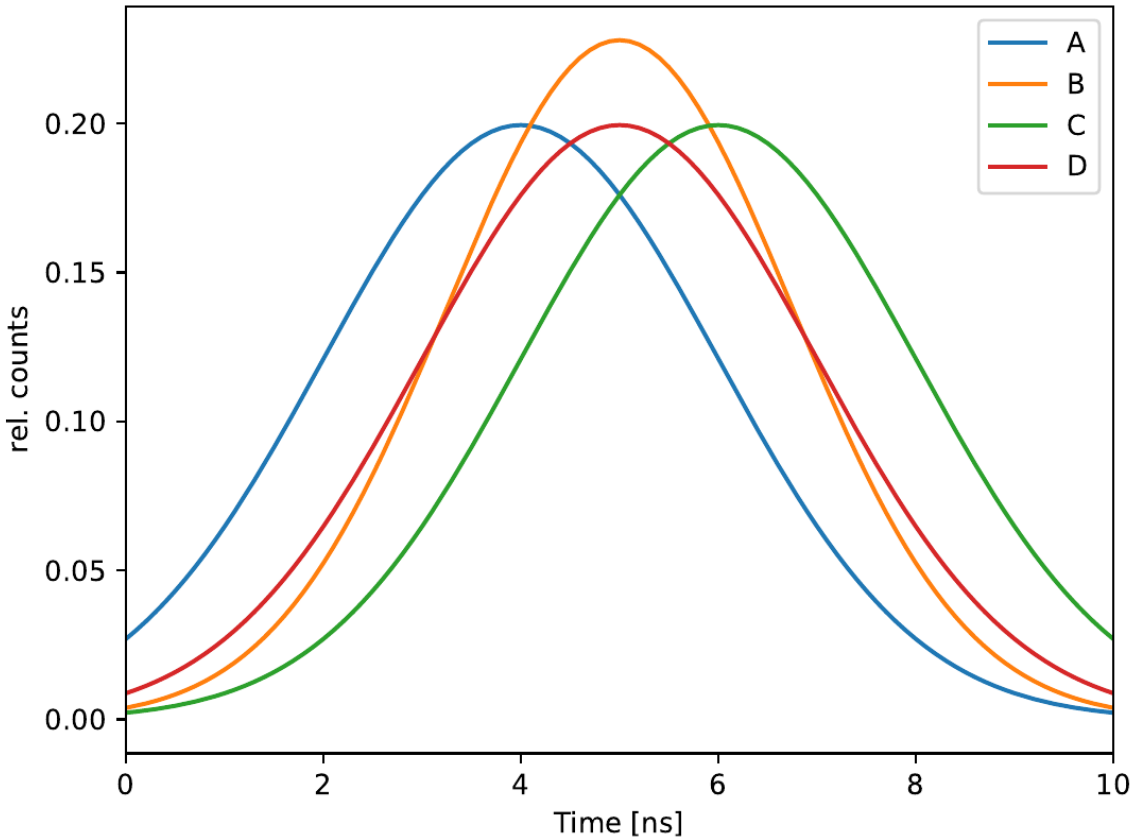


Backup: Overlap for Lookup Table

For the lookup table algorithm, Positions whose distributions are fully covered cannot be guessed

e.g. D is fully covered by A,B and C and therefore the corresponding position would be unavailable.

The effect is in the spirit of the algorithm. If the selected value is more likely to be from another position, than that one should always be preferred.



Backup: Lookup table improvements