Analysis of shashlyk-calorimeter signals on the way to feature extraction

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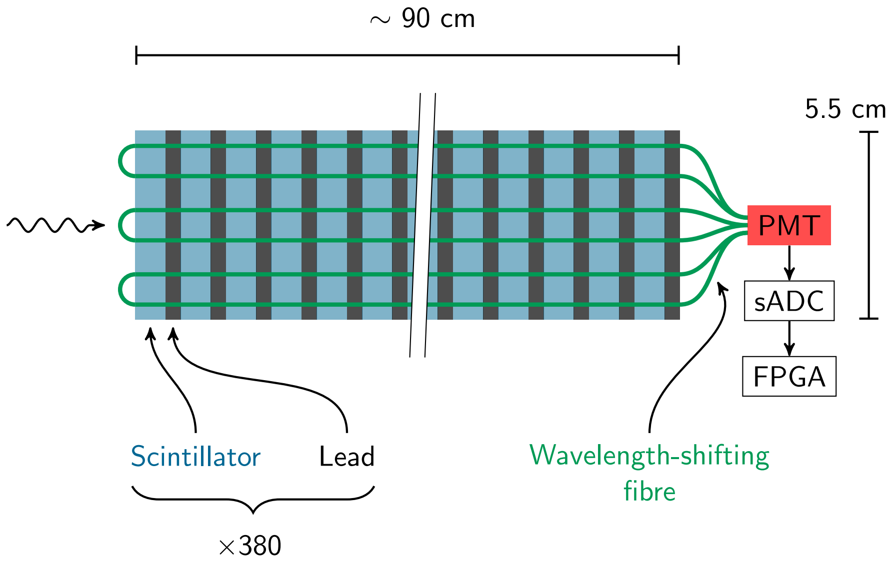
PANDA Collaboration Meeting, GSI, 2019-06-26

Detector structure

Side view of cell



2014 testbeam @ MAMI

- 4×4 prototype placed in 50-350 MeV tagged-photon beam.
- Previously analysed and used to evaluate prototype.

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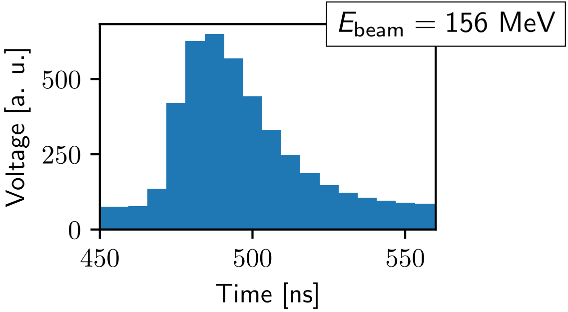
- PMT signal digitised with commercial 12-bit, 160 MSPS sampling ADC:



Aim of this work

- Want to optimise FPGA triggering/feature extraction algorithms with respect to:
  - Pulse identification (triggering)
  - Energy resolution
  - Time resolution
  - Pile-up identification/reconstruction

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- Want to optimise FPGA triggering/feature extraction algorithms with respect to:
  - Pulse identification (triggering)
  - Energy resolution
  - Time resolution
  - Pile-up identification/reconstruction
- To do this: develop Monte Carlo model of 4×4 prototype (starting with Geant4). **This talk**.
- Enables generation of pulses with known underlying energy, time and pile-up information. Then: evaluate feature extraction.

Modelling the pulse shape

Geant4 model

Shower profile in detector

Shower development timing

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Literature

Scintillator time constants

Fibre time constant

Fibre attenuation

PMT response

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Scintillator time constants

Fibre time constant

Fibre attenuation

PMT response

Free parameters

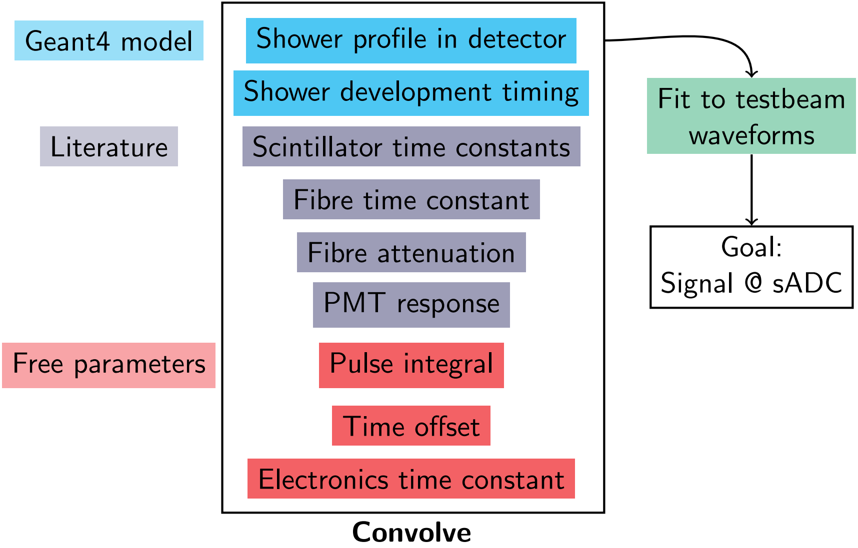
Pulse integral

Time offset

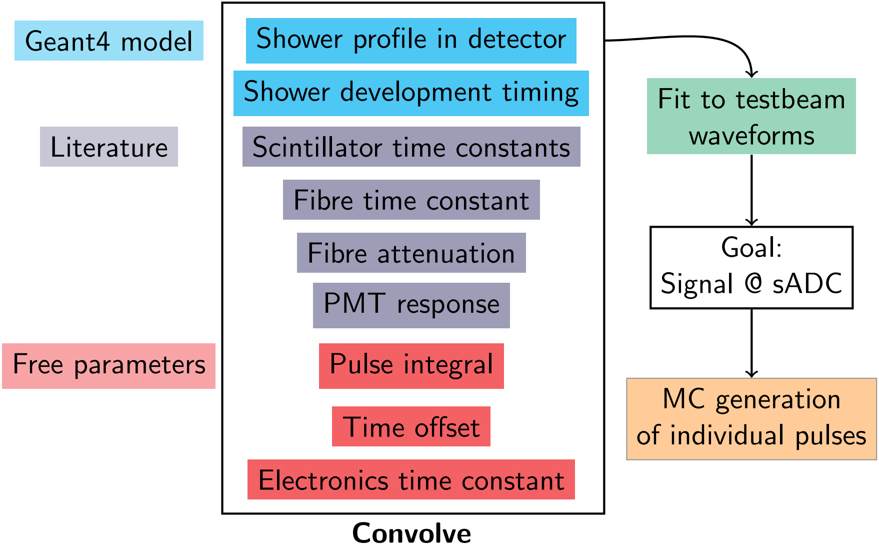
Electronics time constant

Goal:
Signal @ sADC

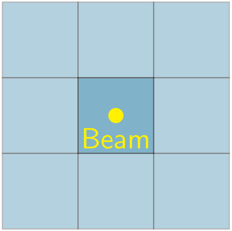
Modelling the pulse shape



Modelling the pulse shape



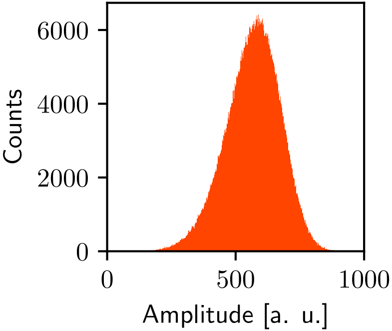
Energy resolution



Analyse *single detector cell*.

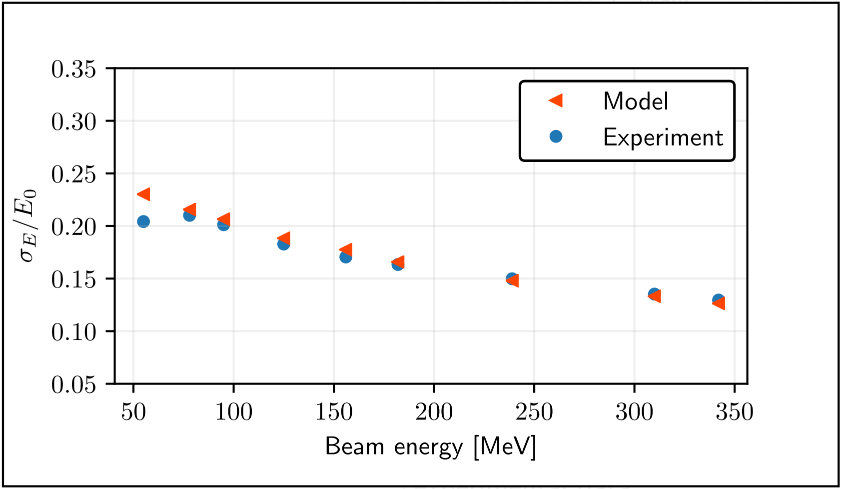
→

Generated data ($E_{\text{beam}} = 156$ MeV):

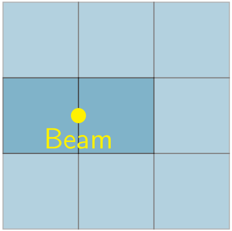


Fit Novosibirsk $\rightarrow \sigma_E / E_0$
Same analysis as on experimental data.

Energy resolution

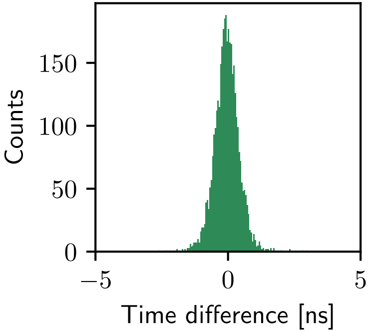


Time resolution



→

Generated data ($E_{\text{dep}} = 100$ MeV):



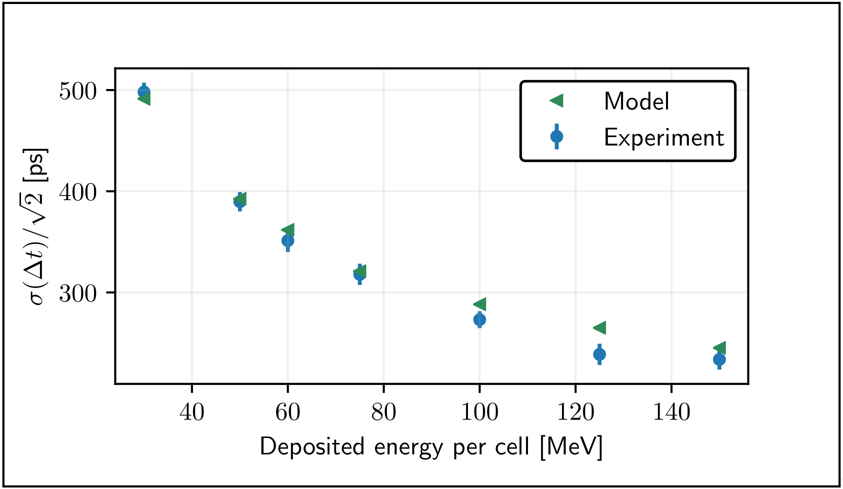
Fit Gaussian → $\sigma(\Delta t)$
Same analysis as on experimental data.

Experimental data analysed in Gießen:

- Require similar E_{dep} in cells.
- Constant Fraction timing
- Calculate Δt
- Assume: $\sigma_t = \sigma(\Delta t)/\sqrt{2}$

Time resolution

Generated data ($E_{\mathrm{dep}} = 100$ MeV):



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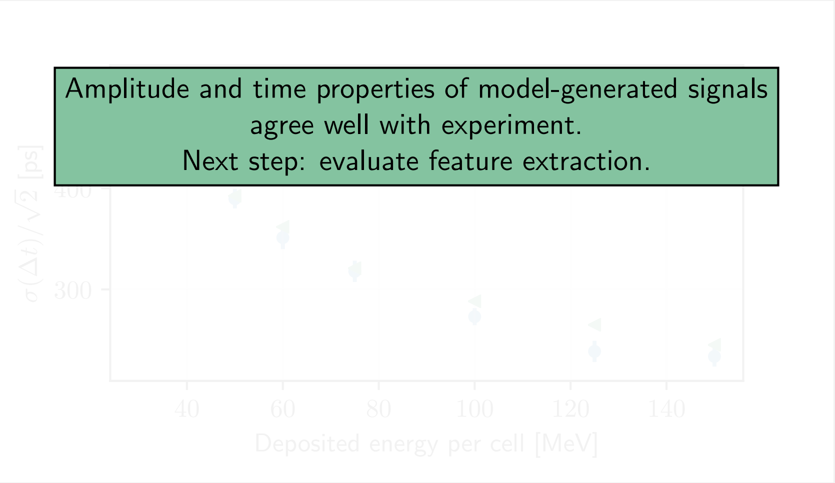

Amplitude and time properties of model-generated signals agree well with experiment.
Next step: evaluate feature extraction.

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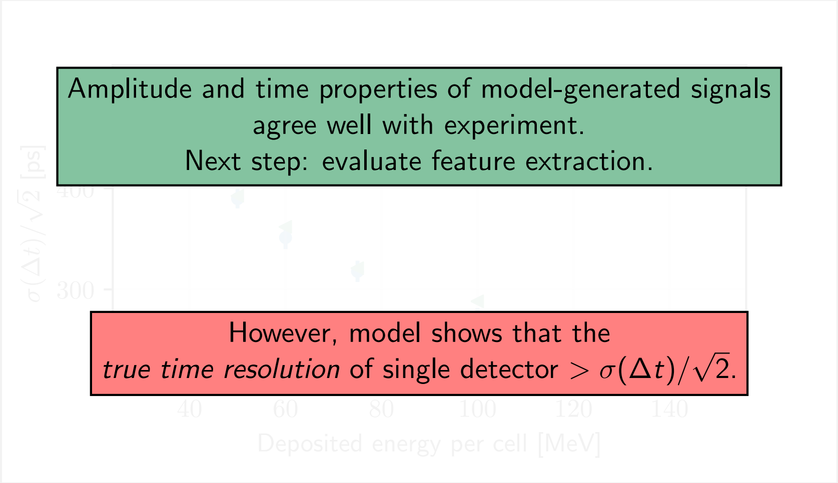

Amplitude and time properties of model-generated signals agree well with experiment.
Next step: evaluate feature extraction.

However, model shows that the *true time resolution* of single detector $> \sigma(\Delta t)/\sqrt{2}$.

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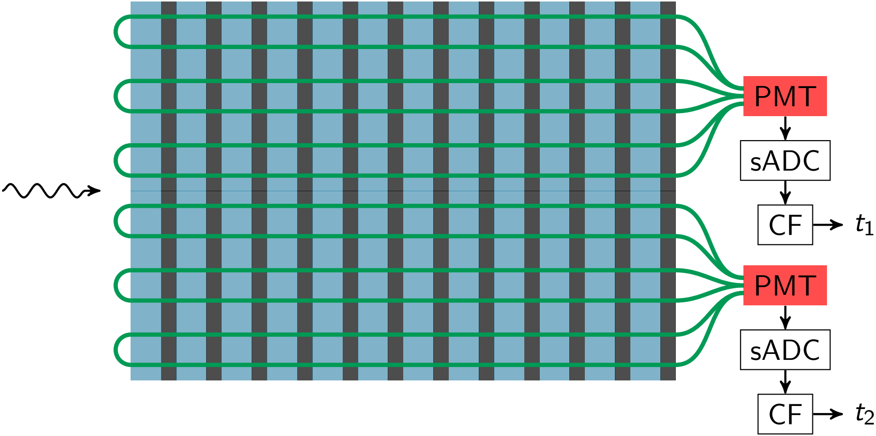
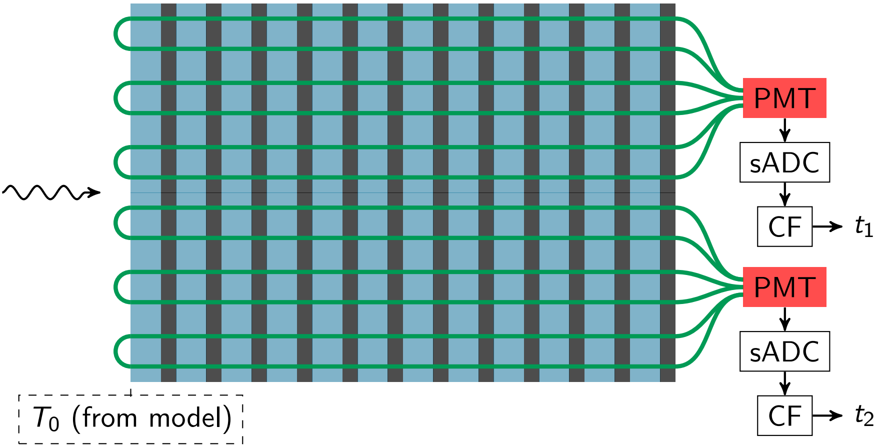
- Calculate Δt
- Assume: $\sigma_t = \sigma(\Delta t)/\sqrt{2}$

Time resolution issue



In experiment: $\Delta t = t_1 - t_2$ determined.

Time resolution issue

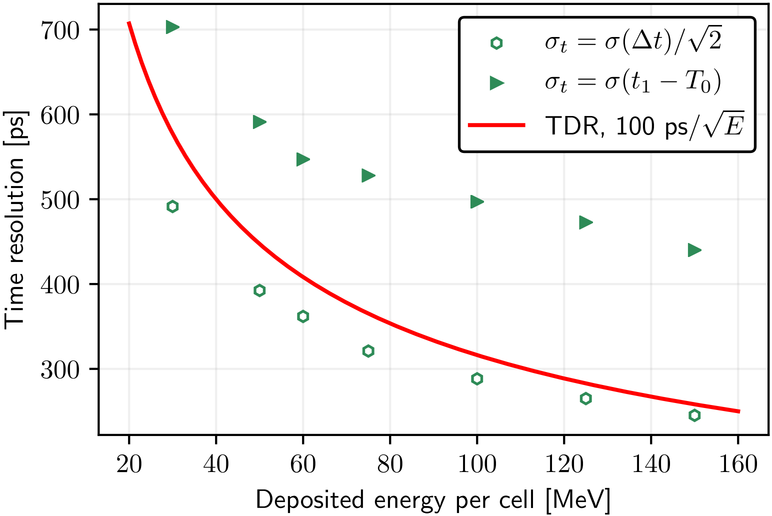


In experiment: $\Delta t = t_1 - t_2$ determined.

Fundamental time resolutions come from $(t_1 - T_0)$ and $(t_2 - T_0)$.

Updated time resolution

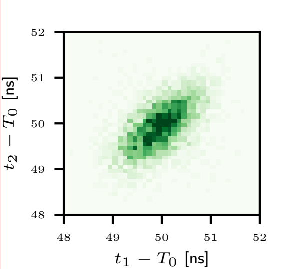
Beam directed between two cells



Updated time resolution

Beam directed between two cells

Reason: $(t_1 - T_0)$ and $(t_2 - T_0)$ correlated.



Due to physics — shower development is correlated in adjacent cells.
Affects time structure of signal.

Consequence: $\sigma(\Delta t)/\sqrt{2}$ is a too optimistic estimate of σ_t.
A more correct estimate is based on $\sigma(t_1 - T_0)$ from model.

Conclusions

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- Amplitude and time structures of generated pulses agree well with experiment.
- Model reveals correlations in timing of signals in adjacent detectors. Affects present analysis of time resolution.

Outlook

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- Questions to be addressed:
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  - What is required when it comes to pile-up events? Reconstruction, flagging event?

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- Evaluate algorithms for triggering + feature extraction (suggestions welcome).
- Questions to be addressed:
  - How much can the time resolution be improved? Time resolution depends on algorithm, but also on **sampling frequency** and **shaping time**.
  - What is required when it comes to pile-up events? Reconstruction, flagging event?
- Implementation in FPGA. Has to be feasible for chosen algorithm.

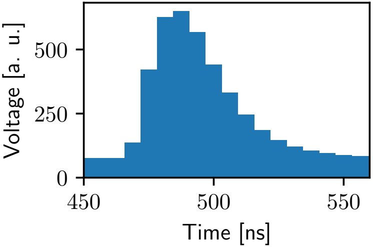
Thank you for your attention!

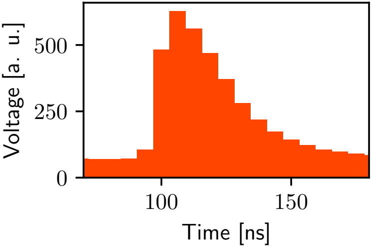
Backup slides

Example of a Monte-Carlo generated signal

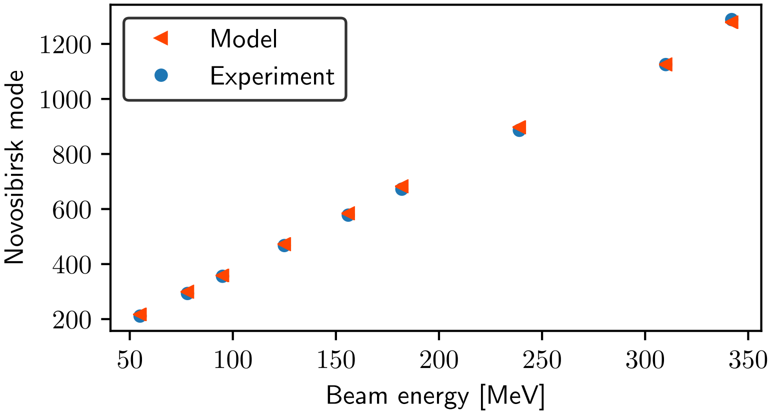
Testbeam signal:
$E_{\mathrm{beam}} = 156$ MeV

MC generated signal:
$T_0 = 70.7$ ns
$E_{\mathrm{beam}} = 156$ MeV
$E_{\mathrm{dep}} = 67.6$ MeV

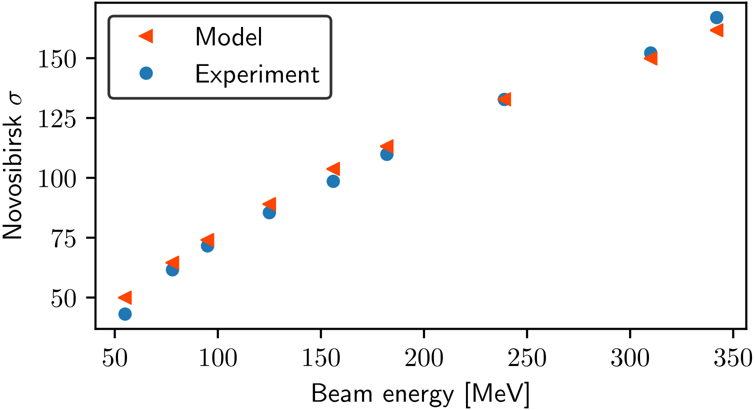




Mode of amplitude distribution — experiment and model

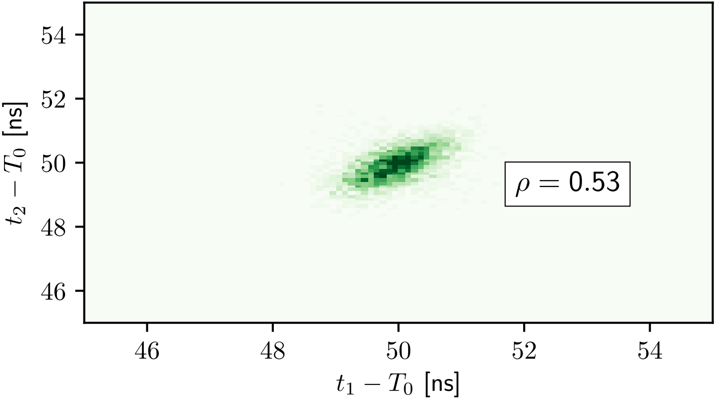


σ of amplitude distribution — experiment and model



Time correlation

Previous assumption: $\sigma(\Delta t) = \sqrt{2\sigma_t^2} \Rightarrow \sigma_t = \sigma(\Delta t)/\sqrt{2}$



$$\sigma(\Delta t) = \sqrt{\sigma(t_1 - T_0)^2 + \sigma(t_2 - T_0)^2 - 2\rho\sigma(t_1 - T_0)\sigma(t_2 - T_0)}$$