FPGA-based algorithms for feature extraction in the PANDA shashlyk calorimeter

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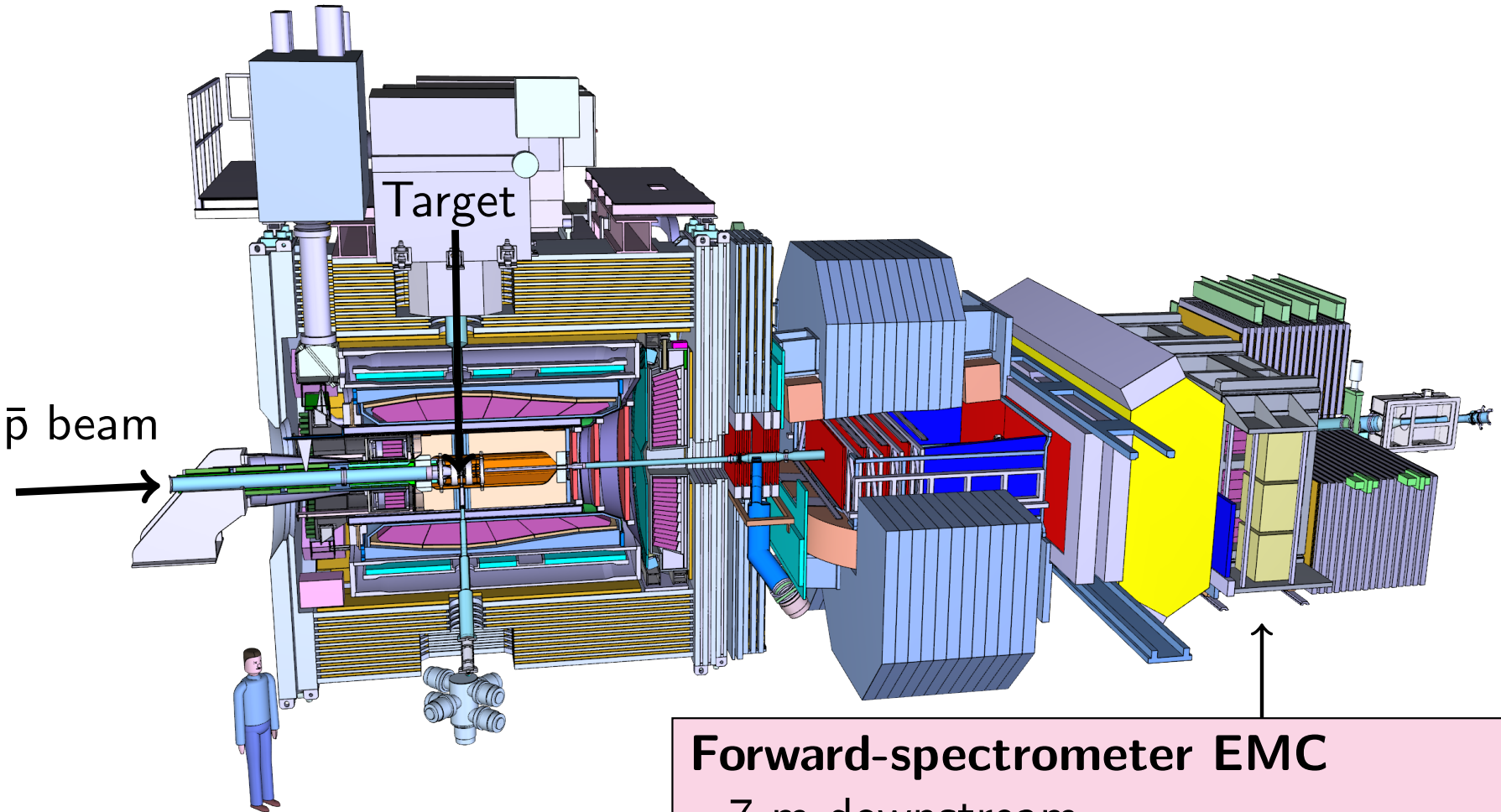
PANDA Collaboration Meeting 20/1

Location of the shashlyk calorimeter



Forward-spectrometer EMC

$\sim$7 m downstream

1512 shashlyk cells $\Rightarrow$ Area $\approx 3 \times 1.5$ m^2

Figure from PANDA website, https://panda.gsi.de/

Front-end digitiser module

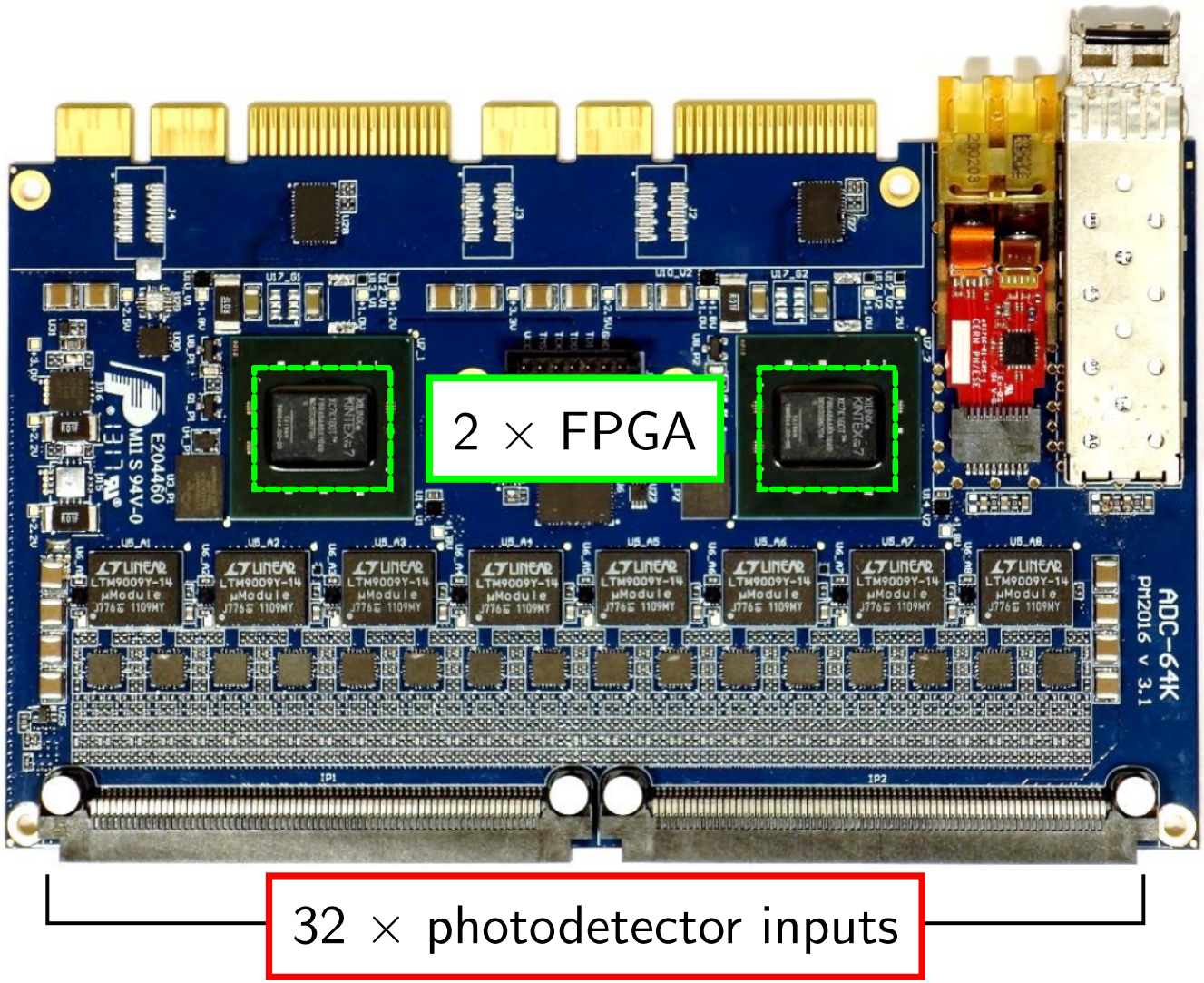


Figure courtesy of Pawel Marciniewski, Uppsala University.

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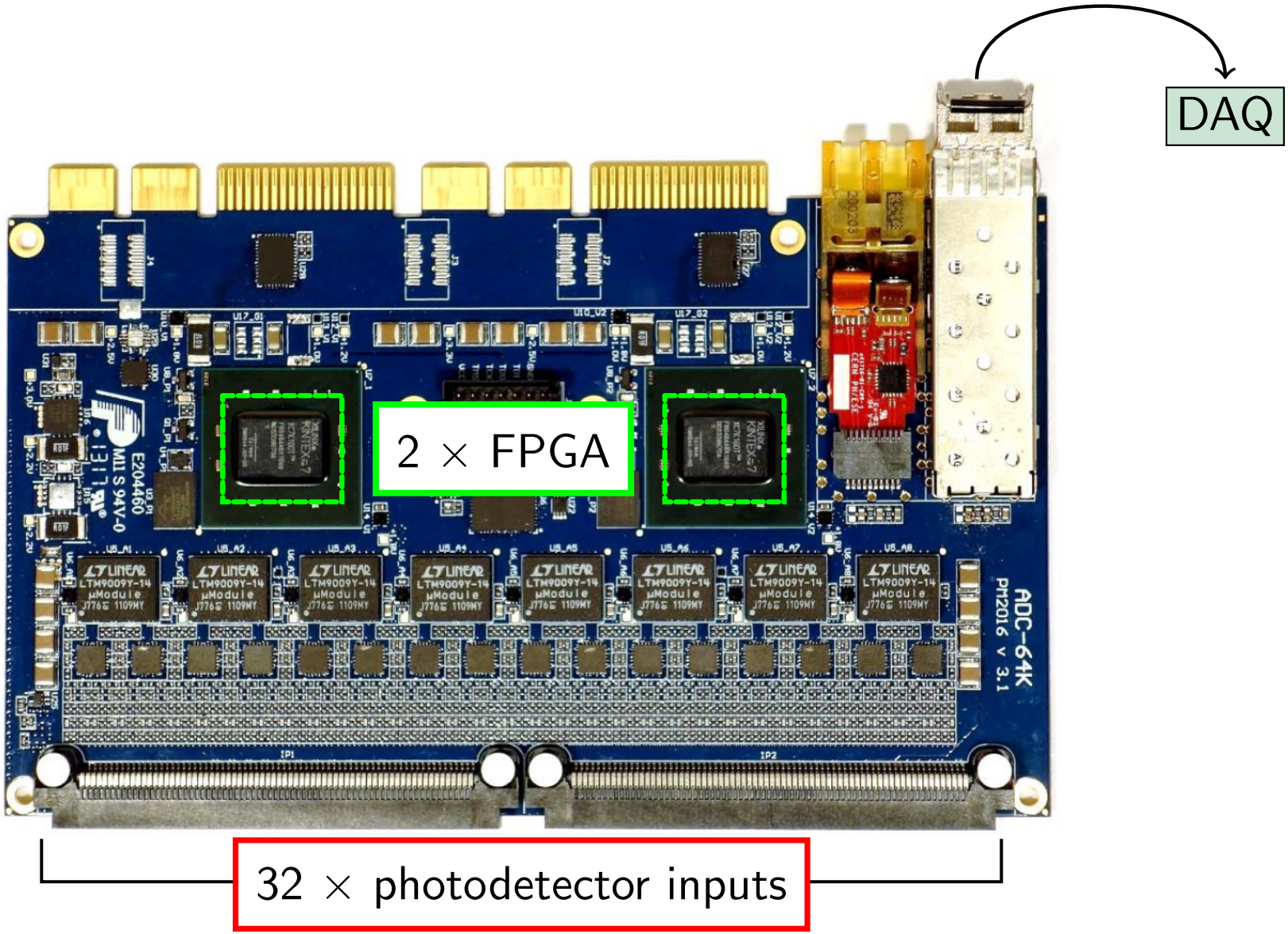

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Tasks of the front-end digitiser

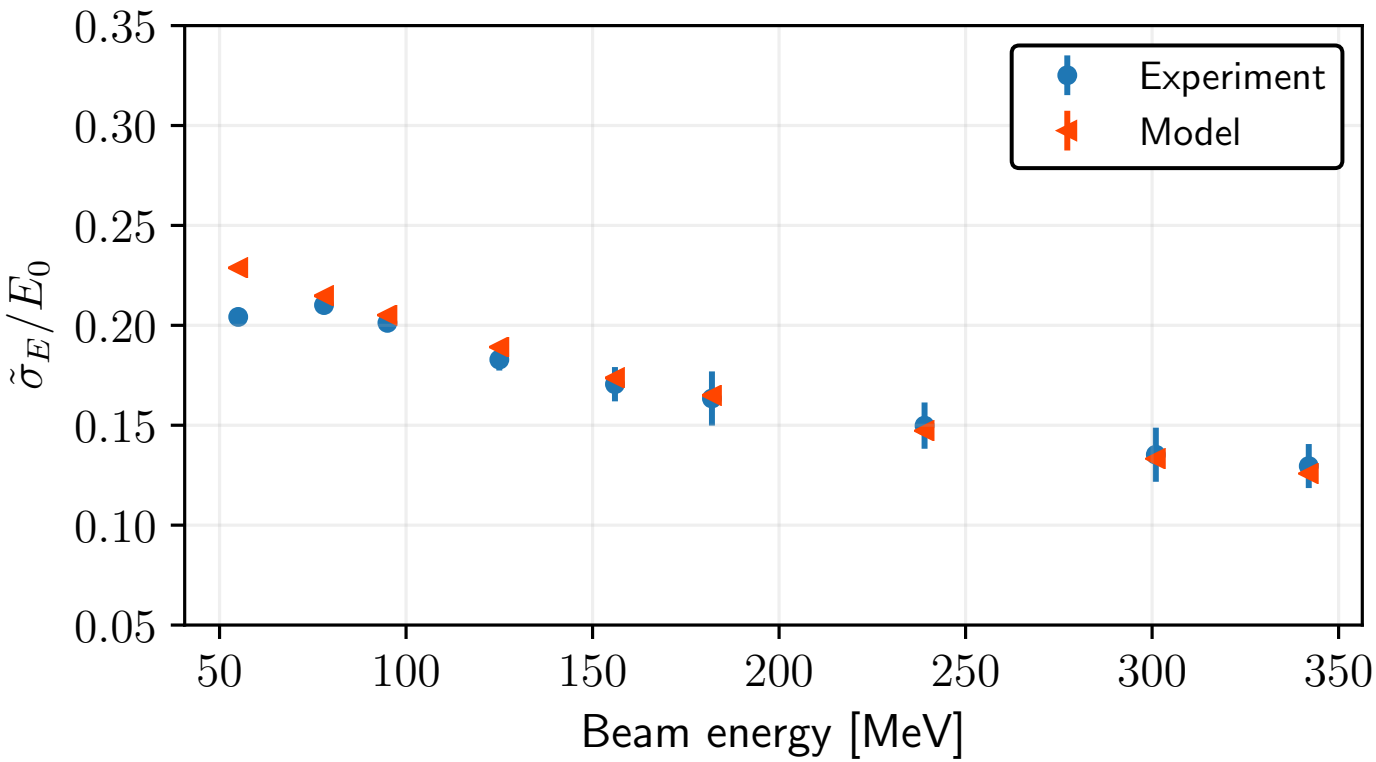
- PANDA DAQ scheme $\Rightarrow$ real-time "feature extraction" in FPGAs.

Tasks of the front-end digitiser

- PANDA DAQ scheme $\Rightarrow$ real-time "feature extraction" in FPGAs.
  1. Identify signals
  2. Extract pulse-height information.
  3. Extract timing information.
  4. Recover/reconstruct pile-up pulses.
  5. Transmit only these extracted features.
- Aim of our work: Develop an FPGA triggering/feature extraction algorithm for these tasks.

Model development

- Detailed Geant4-based Monte Carlo model of detector (shower profile, time constants, attenuation, PMT response, electronic noise)
- Model has been validated against testbeam data (pulse height and time resolution).



New feature-extraction method

Basic considerations

- May first consider "reference" option:
  - Waveform maximum $\Rightarrow$ pulse height distribution
  - (Digital) CFD $\Rightarrow$ timing distribution
  - Pile-up rejection

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  - Waveform maximum $\Rightarrow$ pulse height distribution
  - (Digital) CFD $\Rightarrow$ timing distribution
  - Pile-up rejection
- Can one do better?
  - Methods based on "Optimal Filter" (OF) are well known in high-energy physics.
  - Finite impulse response (FIR) filter $\Rightarrow$ pulse amplitude and time.
  - Assume fixed pulse shape.
  - Equivalent to χ^2 fit of known pulse shape to data.

New feature-extraction method

Adapting the OF

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  - No bunch-crossing information from accelerator $\Rightarrow$ phase between data and sampling clock not known.
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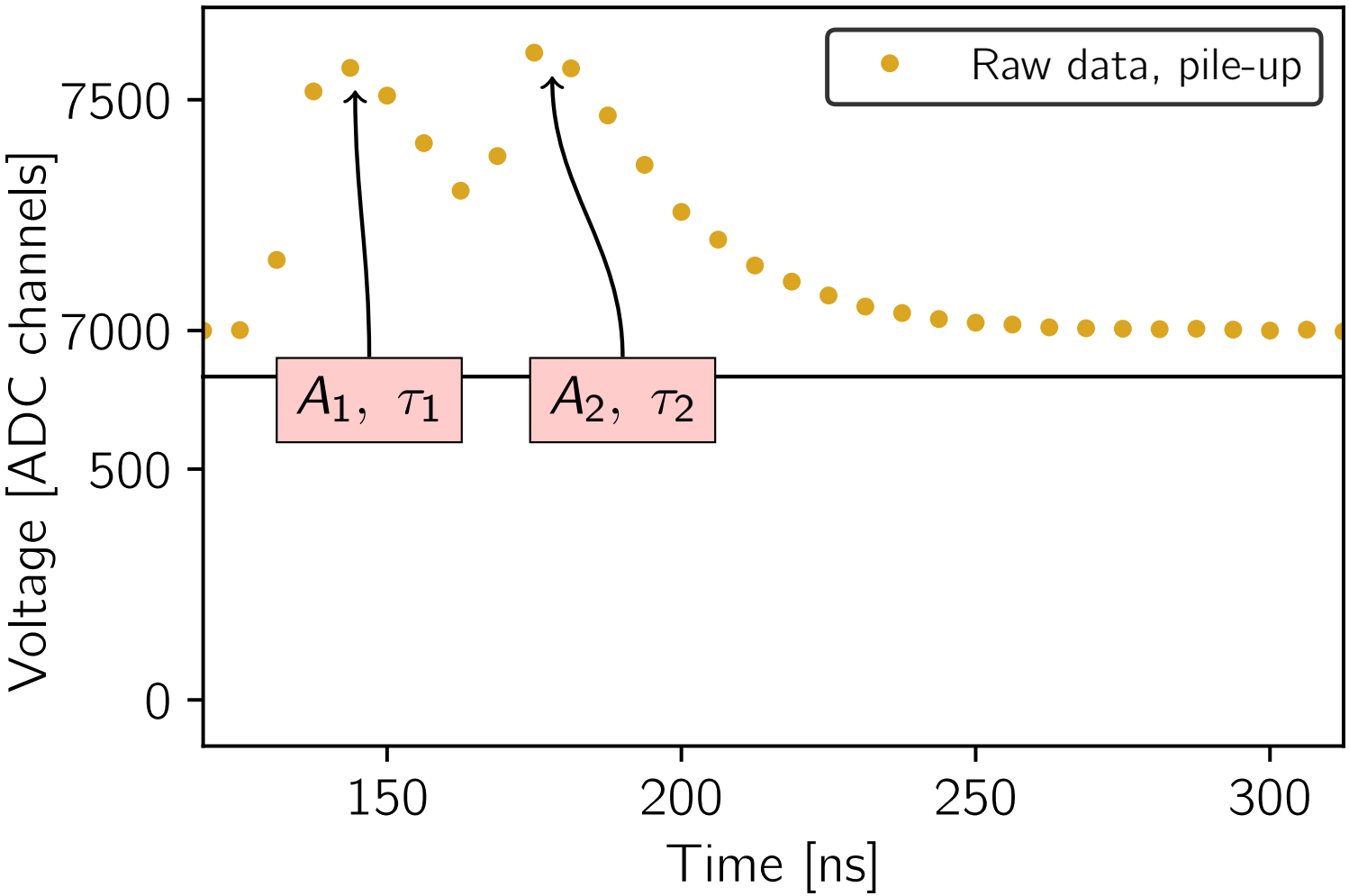
Adapting the OF

- Two main issues with using an OF in PANDA:
  - No bunch-crossing information from accelerator ⇒ phase between data and sampling clock not known.
  - No pile-up reconstruction.
- To solve this, we propose:
  1. Only include initial part of pulse (rising edge + maximum) in OF "fit" ⇒ no contamination from pile-up.
  2. Store several assumed pulse shapes, for different signal/clock phases.
  3. Analyse incoming data with digital CFD ⇒ estimate phase.
  4. "Fit" correct assumed pulse shape ⇒ amplitude + more accurate timing.

New feature-extraction method

Modified OF



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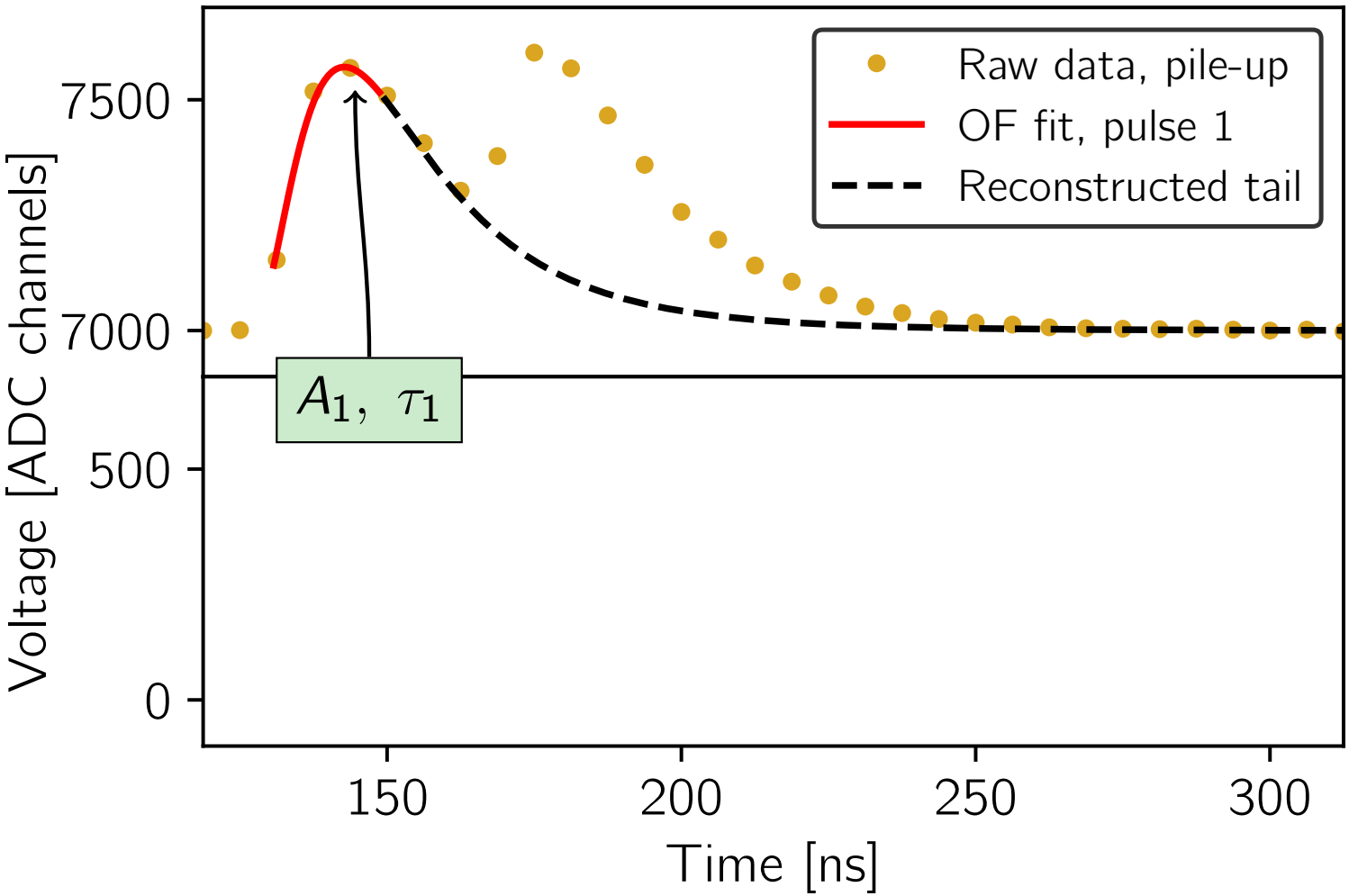

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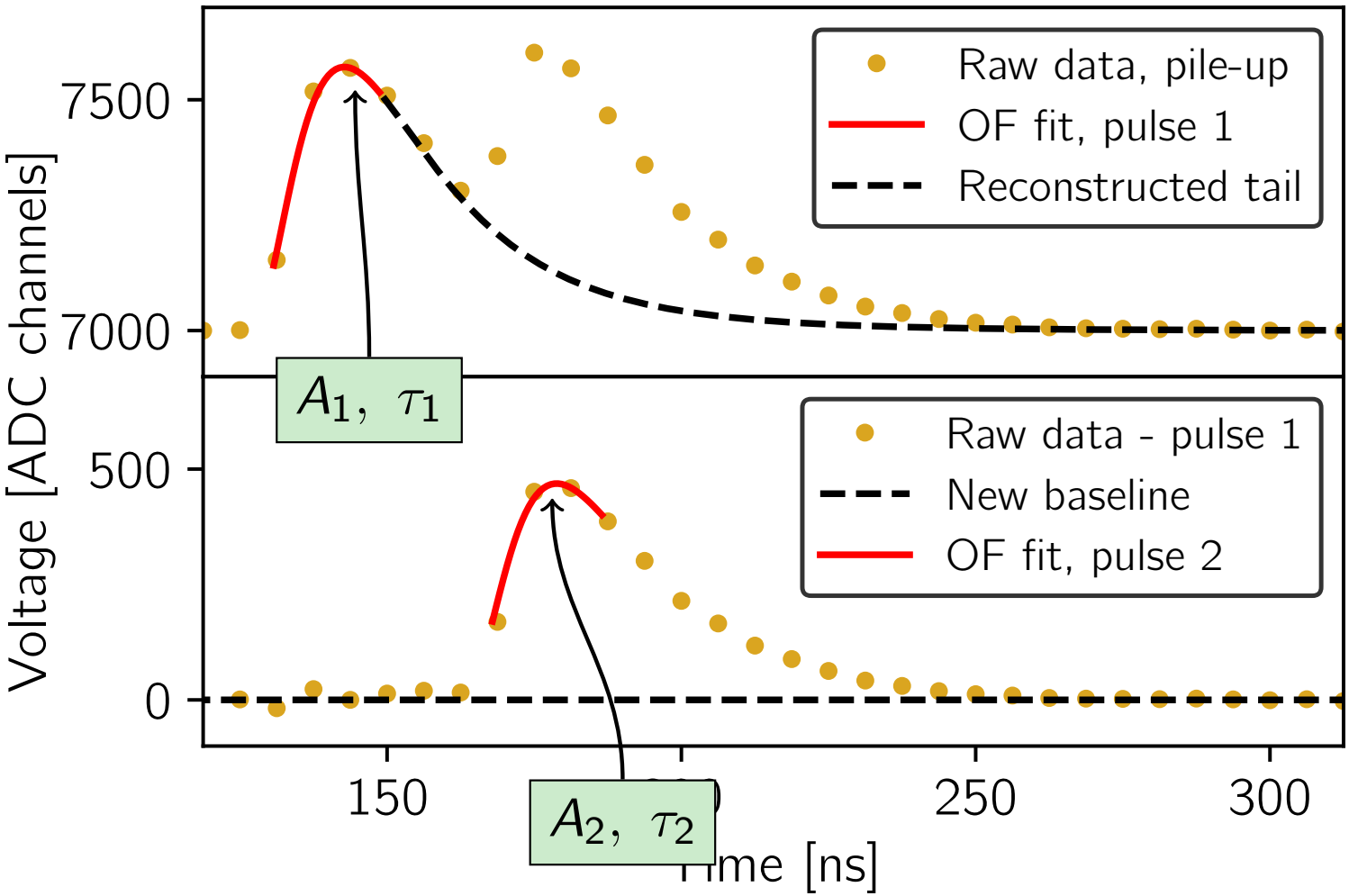

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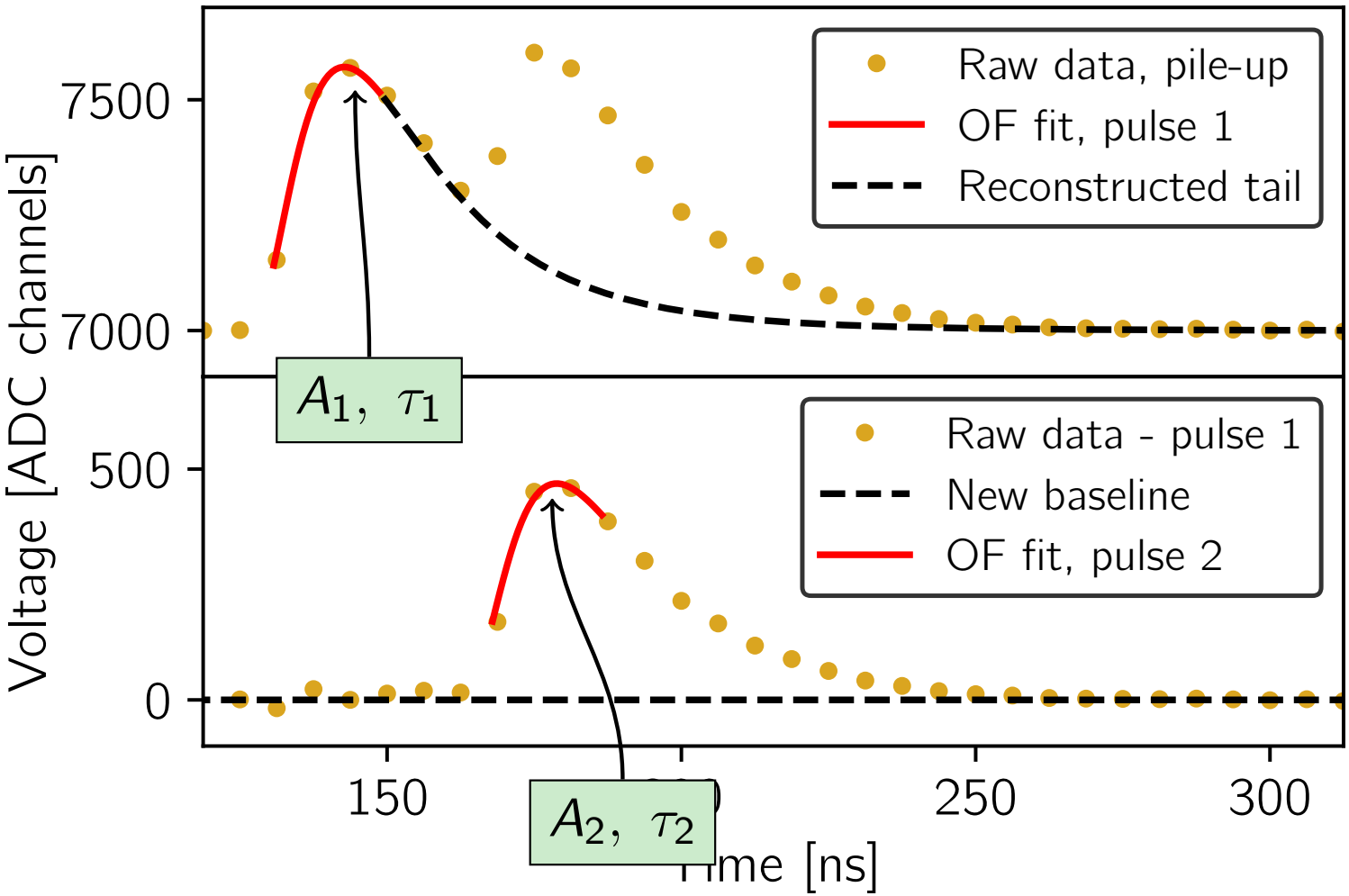
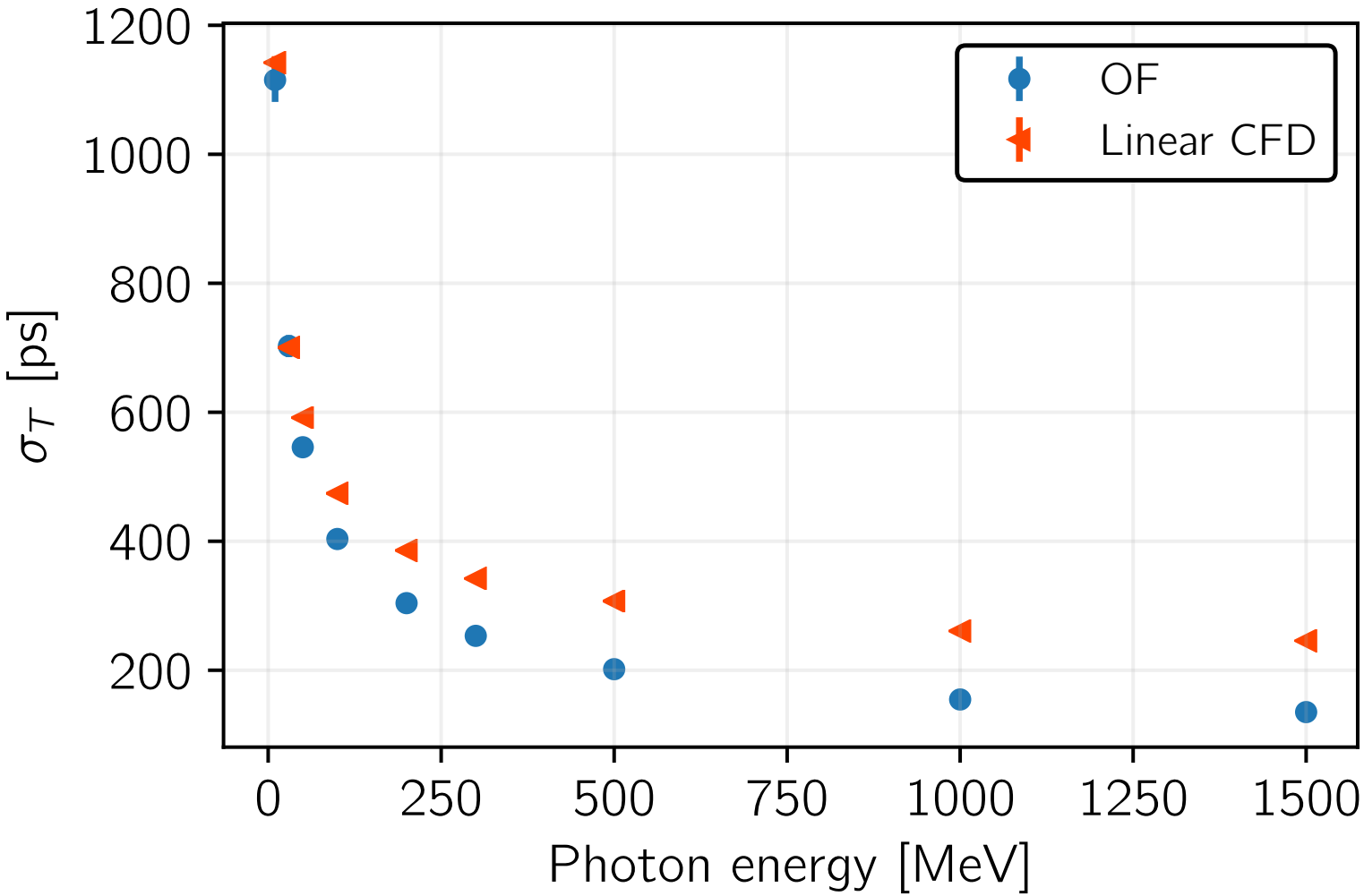


Model-generated data + VHDL implementation ⇒ evaluate method

New feature-extraction method

Time resolution — isolated pulse



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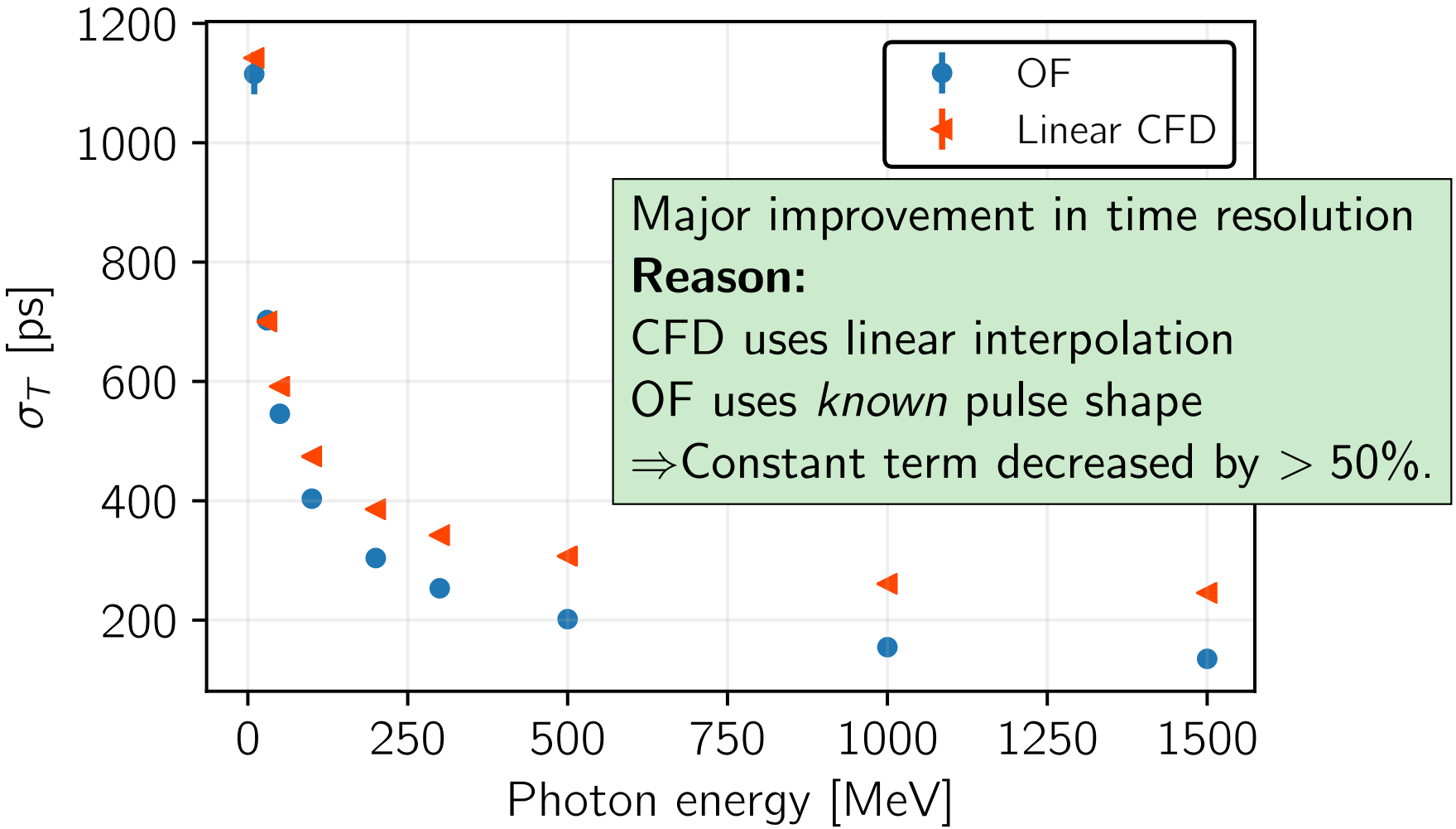
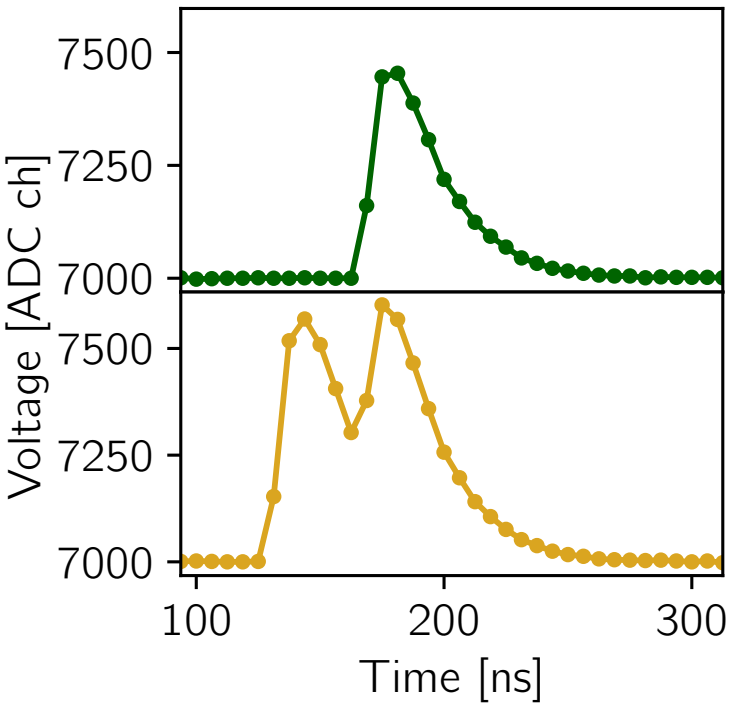


New feature-extraction method

Resolution under pile-up conditions



Without pile-up reconstruction:
Expect biased pulse-height estimate on second pulse.

New feature-extraction method

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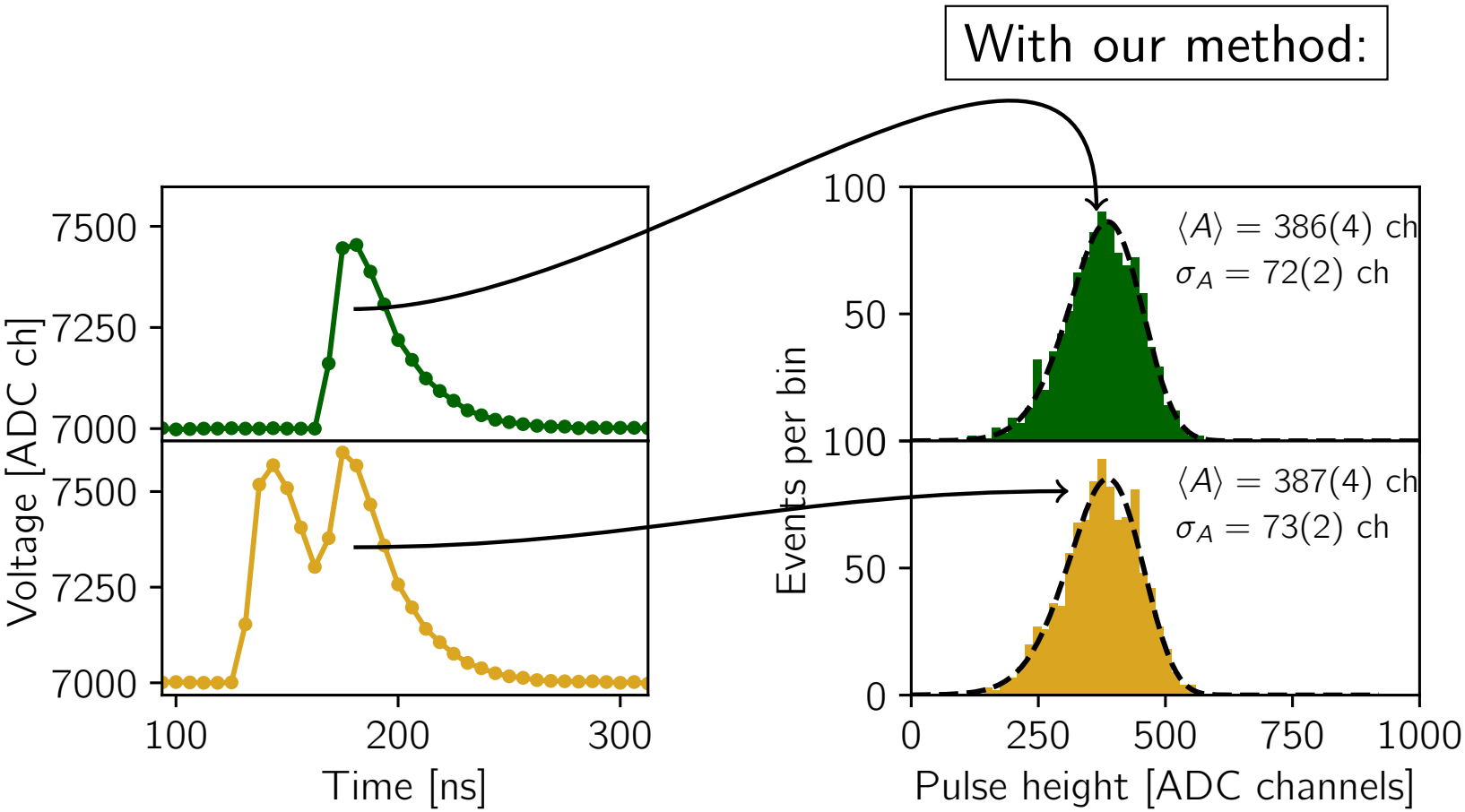


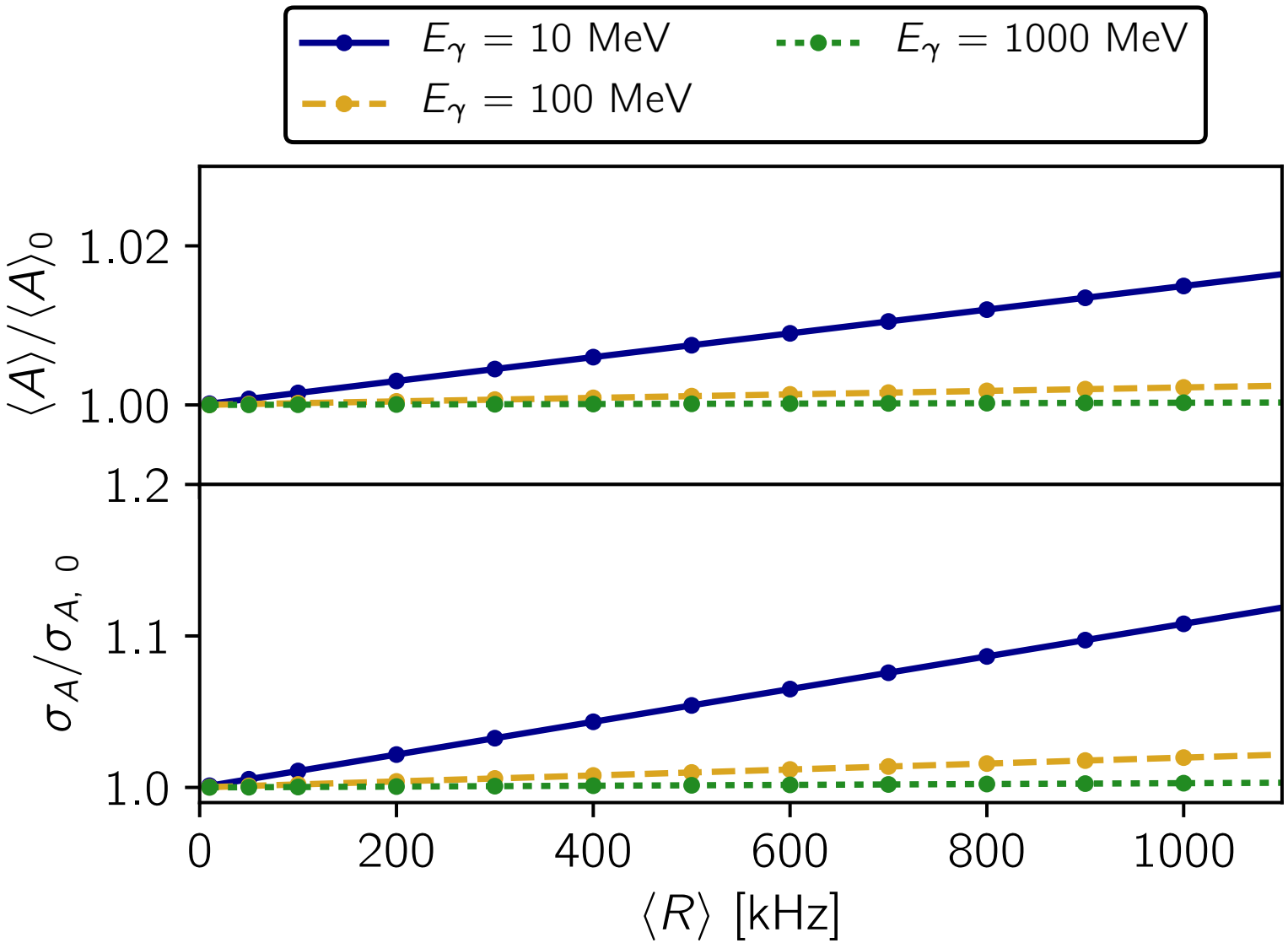
New feature-extraction method

Performance in the PANDA environment

1. PandaRoot Monte Carlo simulation of PANDA $\Rightarrow$ energy deposition from "background events" in the detector.
2. Task: detect a particular photon (E_γ)
3. Study resolution and efficiency for different average rates $\langle R \rangle$ in detector. Worst-case scenario: $p_{\bar{\mathrm{p}}} = 15$ GeV$/c$.

New feature-extraction method

Pulse height resolution — pile-up pulse



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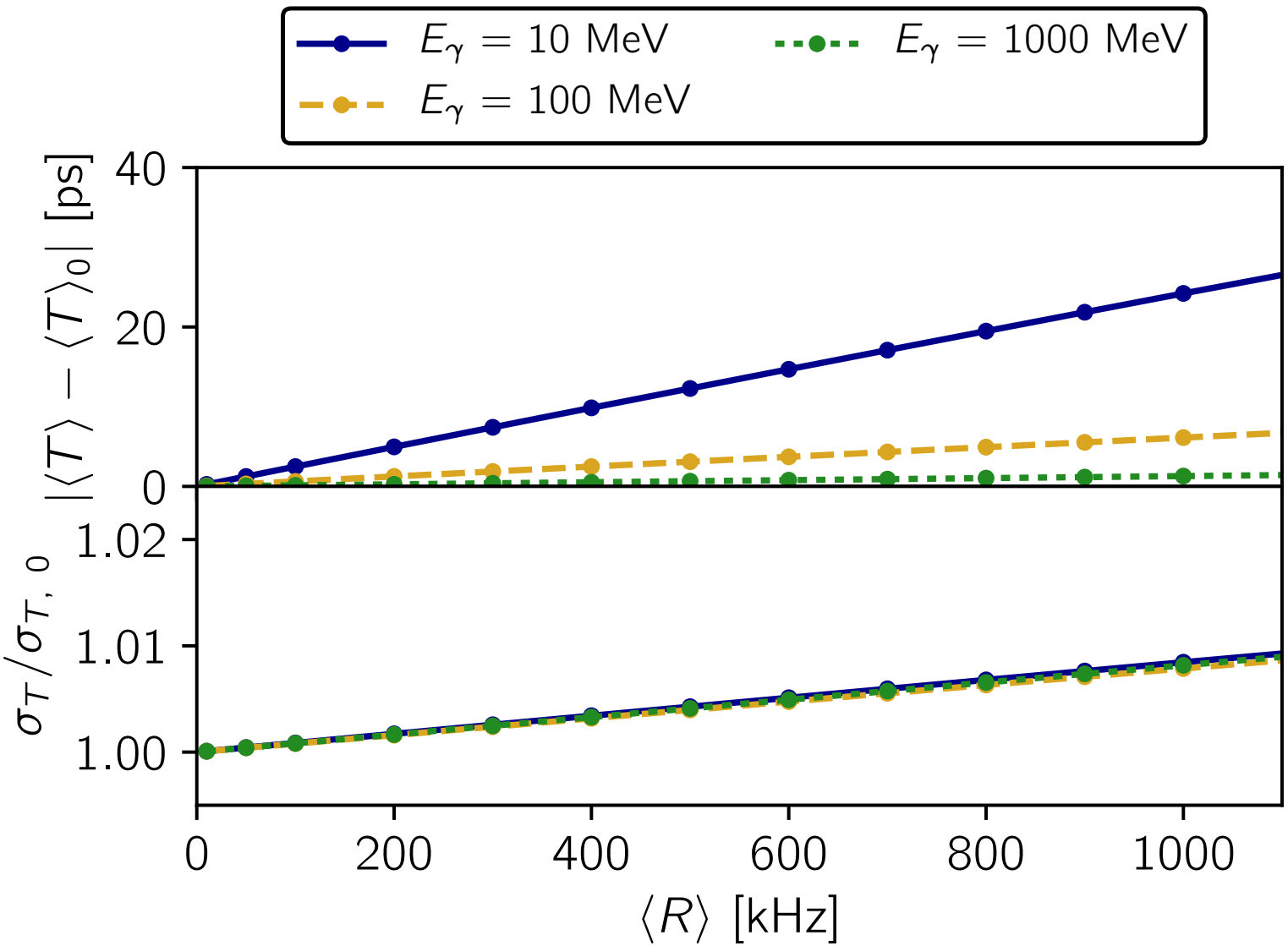

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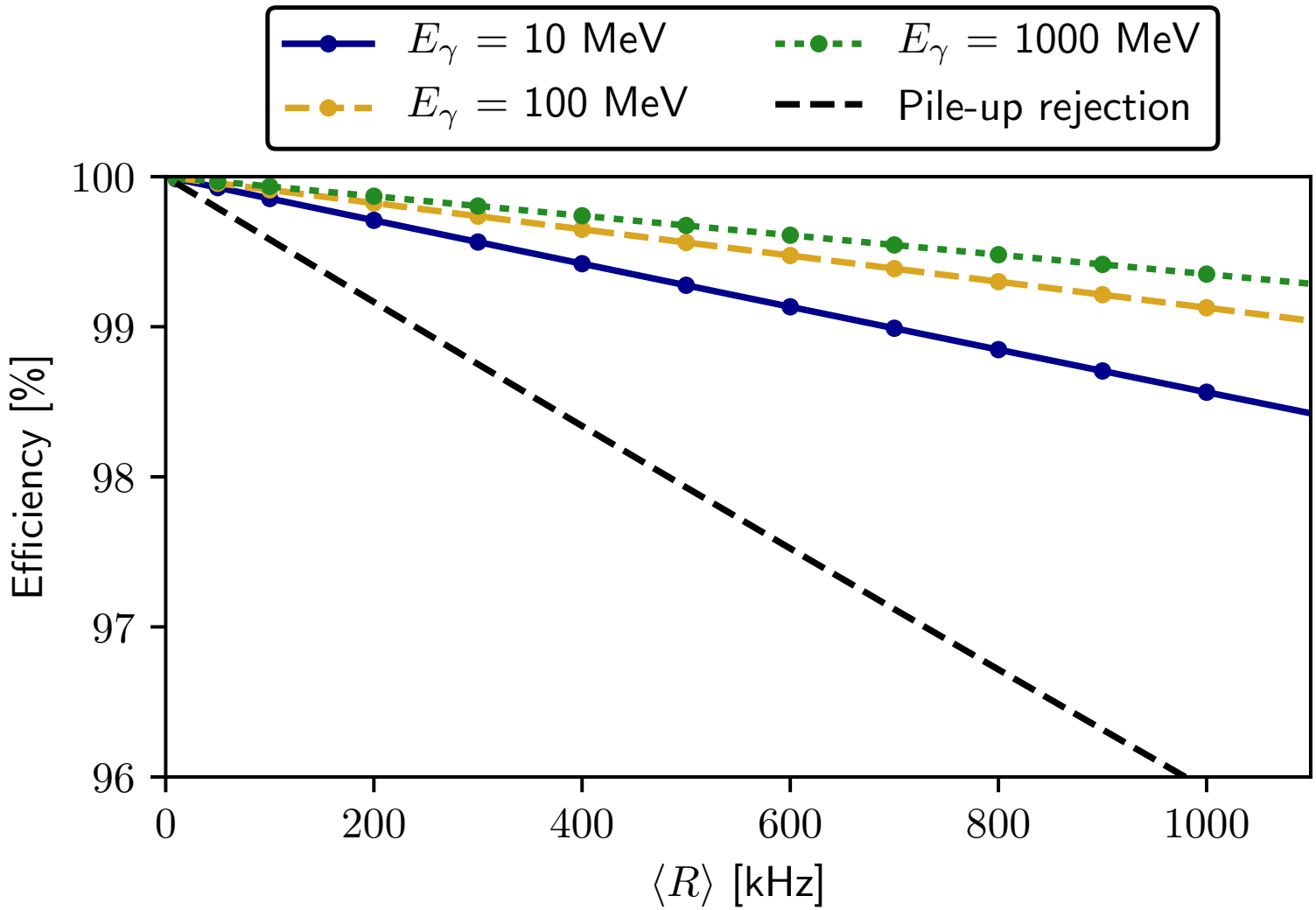
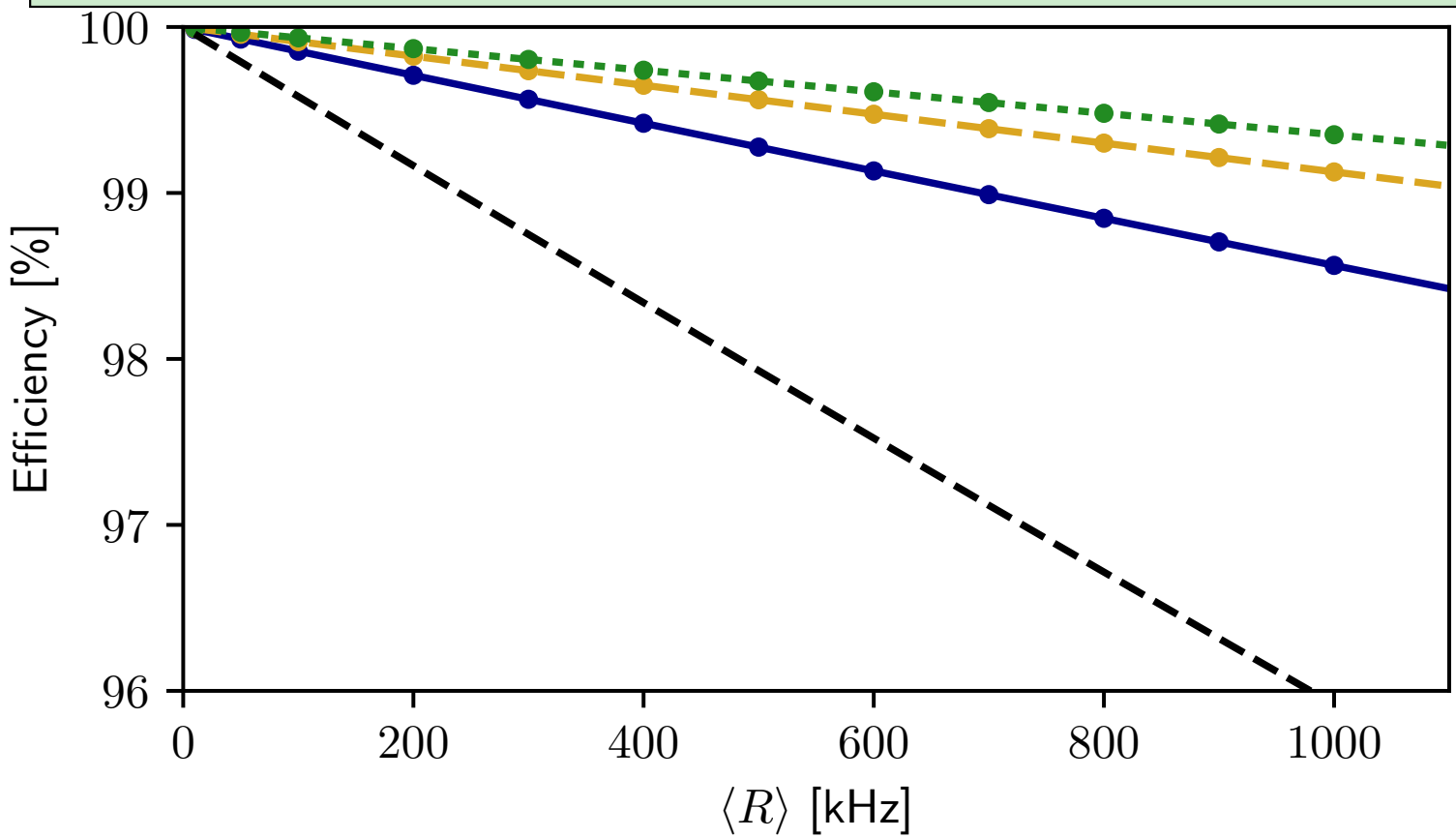
Pulse-detection efficiency — pile-up pulse



New feature-extraction method

Pulse-detection efficiency — pile-up pulse

Considerable improvement (over pile-up rejection)
In PANDA: hit rates > 100 kHz expected.
This method meets the requirements on pile-up reconstruction.



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- Method allows for reconstruction of pile-up events.
- Good resolution and efficiency for reconstructing pile-up events at high rates ($>$ 100 kHz).
- Fulfills the PANDA requirements.

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- Method allows for reconstruction of pile-up events.
- Good resolution and efficiency for reconstructing pile-up events at high rates ($>$ 100 kHz).
- Fulfills the PANDA requirements.
- Next steps:
  - Implement in FPGA.
  - Verify experimentally.

Thank you for your attention!

Special thanks to the PANDA group at the University of Gießen for providing experimental data.

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