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

Markus Preston, Per-Erik Tegnér

Stockholm University

On behalf of the PANDA Collaboration

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The Facility for Antiproton and Ion Research (FAIR)

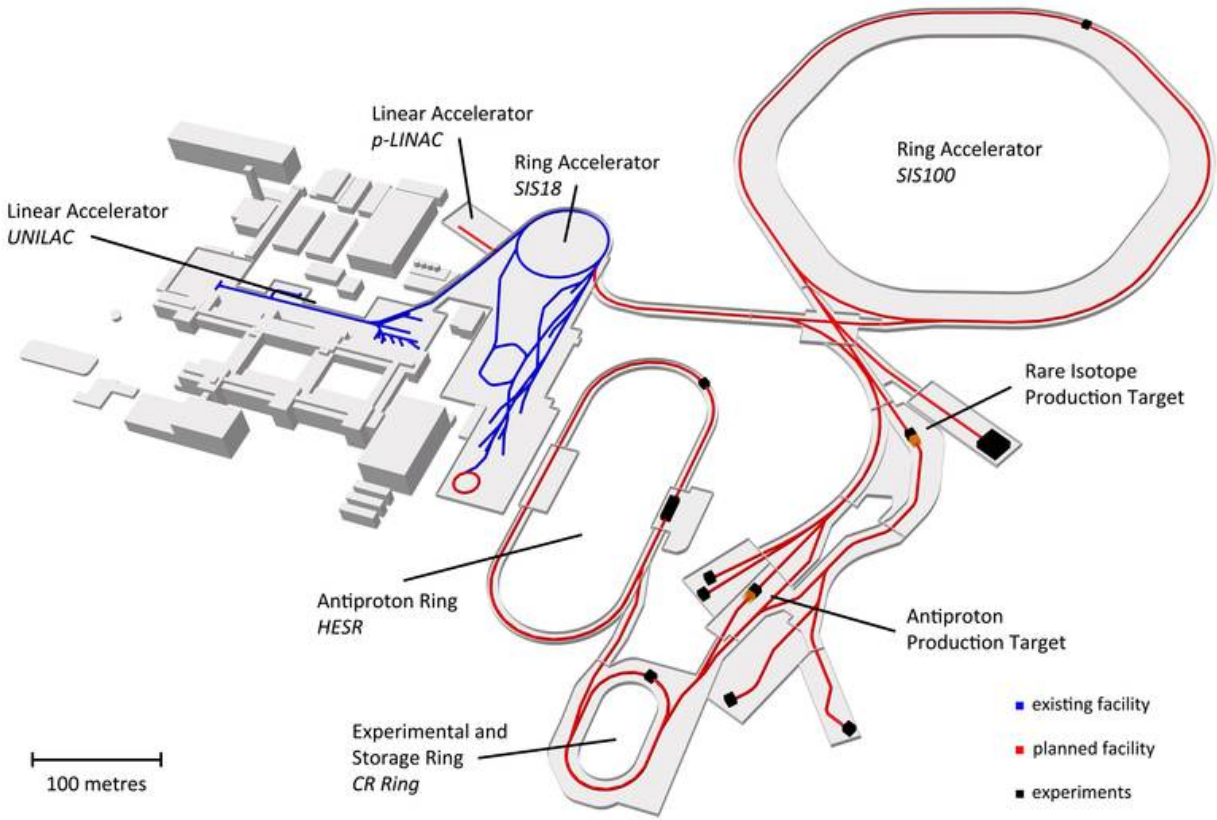

Figure from FAIR website, https://fair-center.eu/

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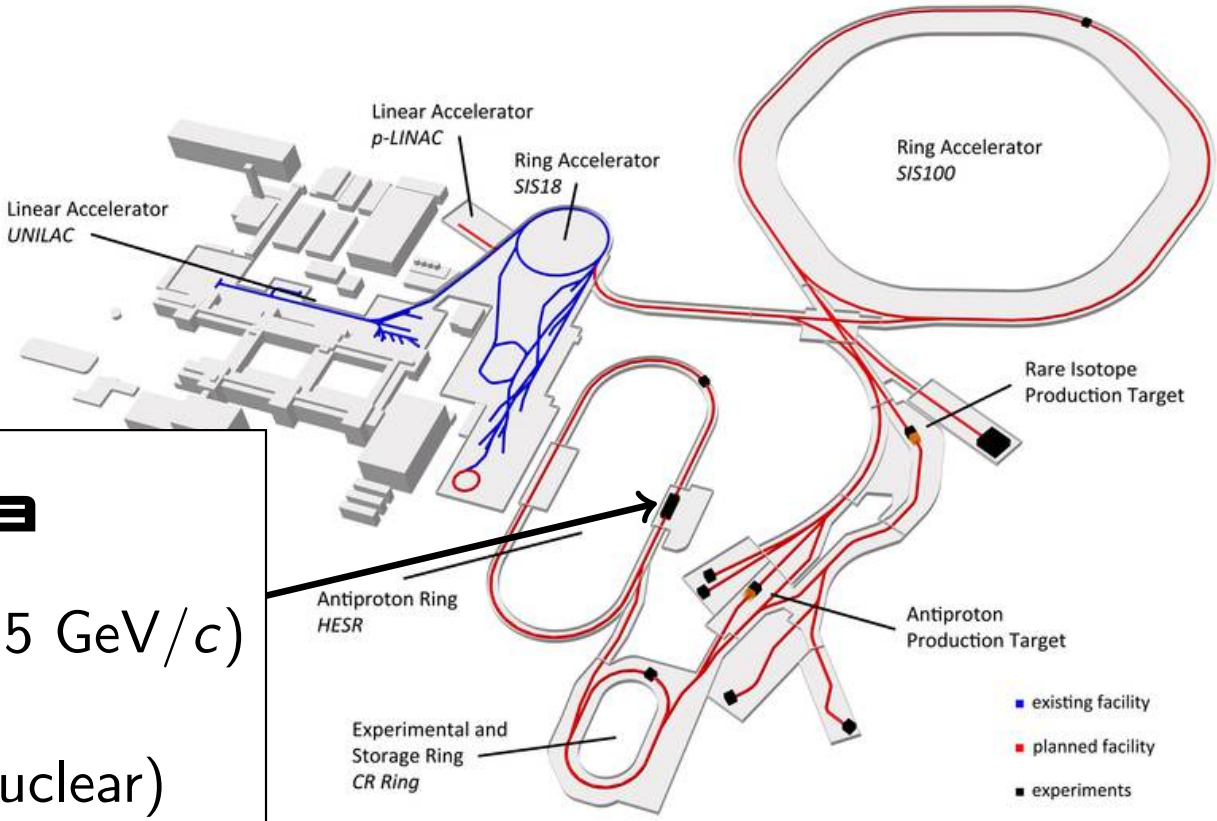

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$\bar{\text{P}}$anda

Antiprotons ($p_{\bar{\text{p}}} = 1.5 - 15$ GeV/c)

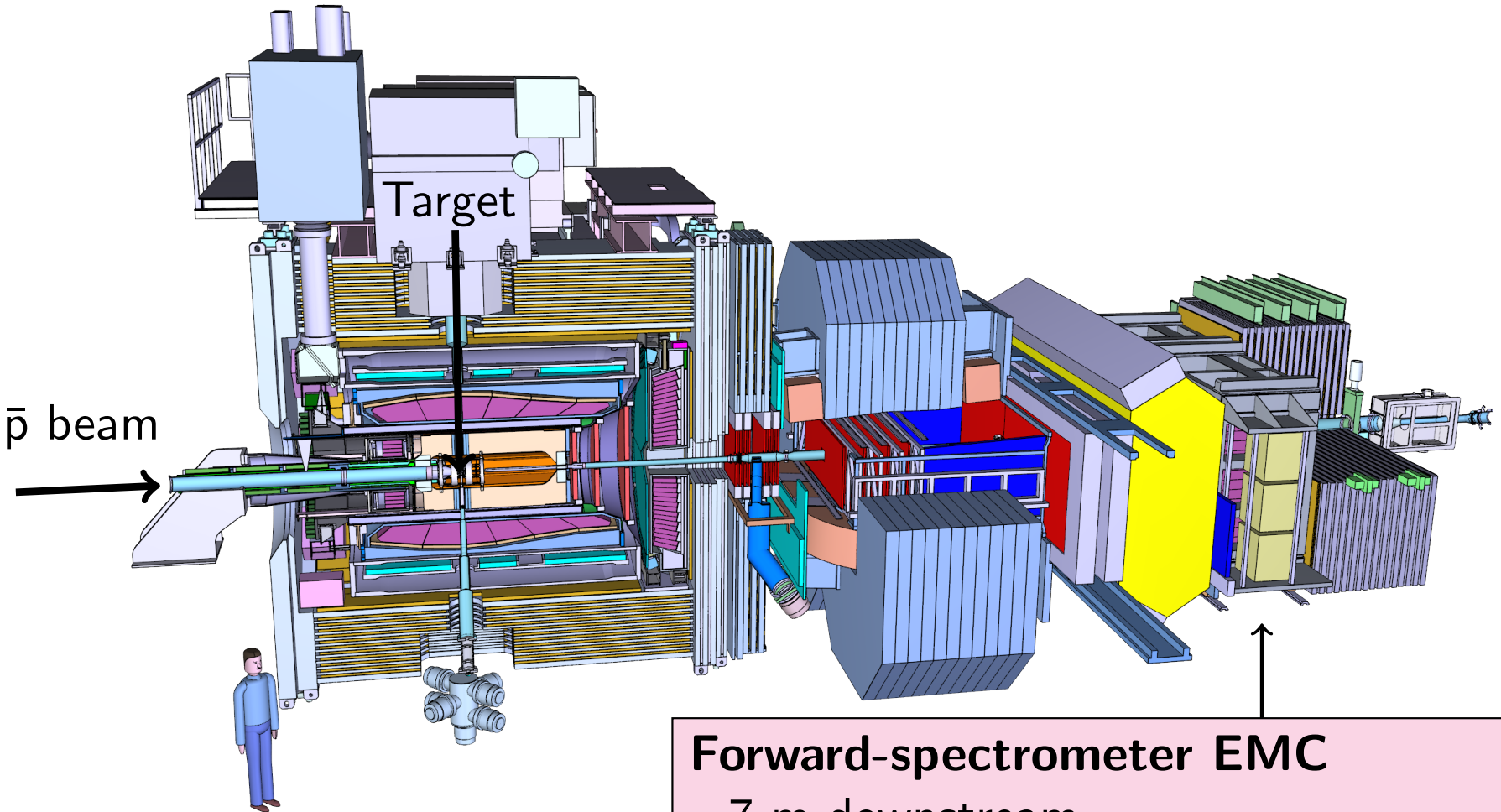
$+$

Fixed target (proton/nuclear)

$\Rightarrow$

Studies of non-perturbative QCD

The PANDA detector system



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/

Detector characteristics

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- Mainly achieved by optimising (lead/scintillator) sampling ratio (design adapted from work done in the KOPIO Collaboration)
- Detector read out by PMT $\rightarrow$ FPGA-based front-end digitiser ($\sim$ 125 MHz).

Front-end digitiser module

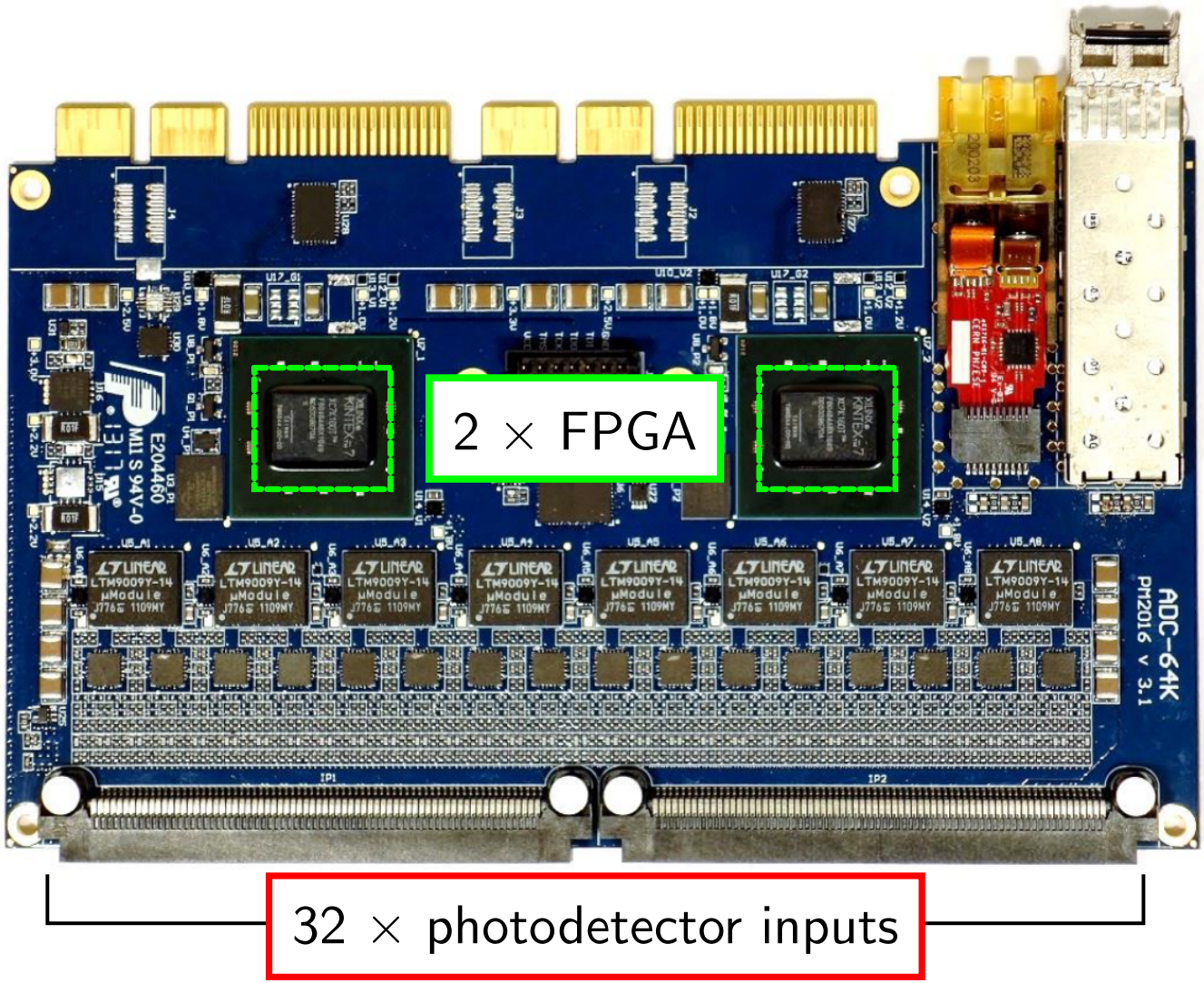

Figure courtesy of Pawel Marciniewski, Uppsala University.

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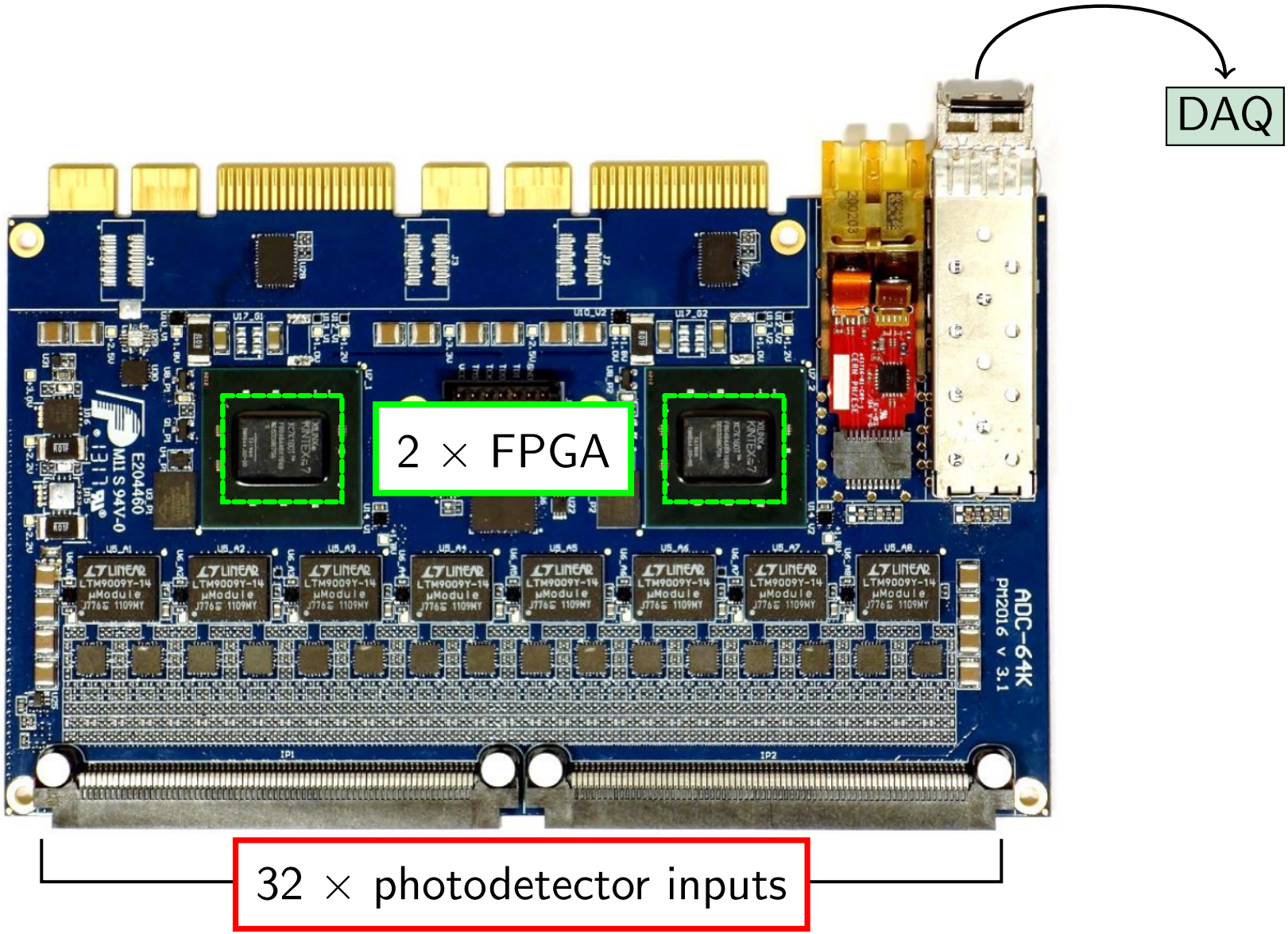

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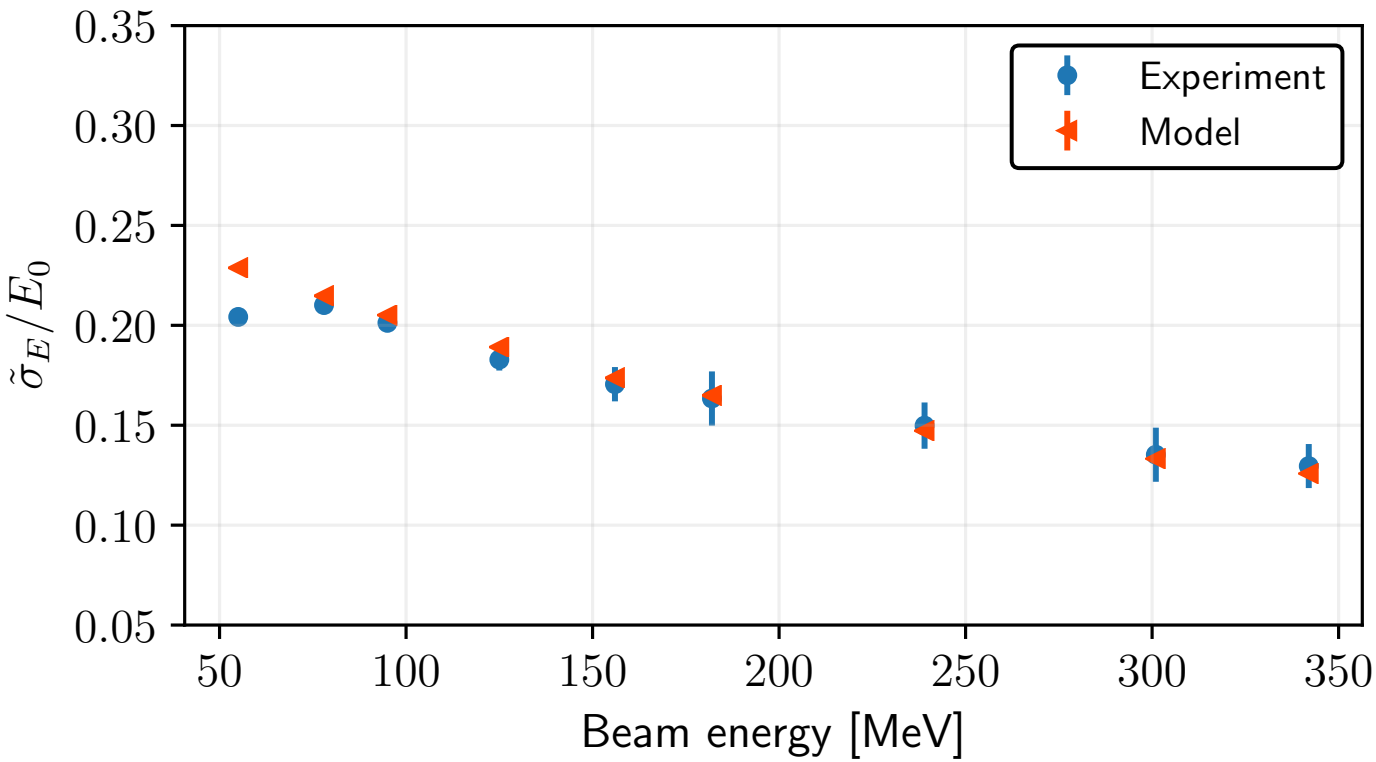
- In calorimeter: real-time "feature extraction" in FPGAs.
  1. Identify signals
  2. Extract pulse-height information.
  3. Extract timing information.
  4. Recover/reconstruct pile-up pulses.
  5. Transmit only these extracted features.
- Aim of our work: Develop an FPGA triggering/feature extraction 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:
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  - (Digital) CFD $\Rightarrow$ timing distribution
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- 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

- Two main issues with using an OF in PANDA:
  - No bunch-crossing information from accelerator $\Rightarrow$ phase between data and sampling clock not known.
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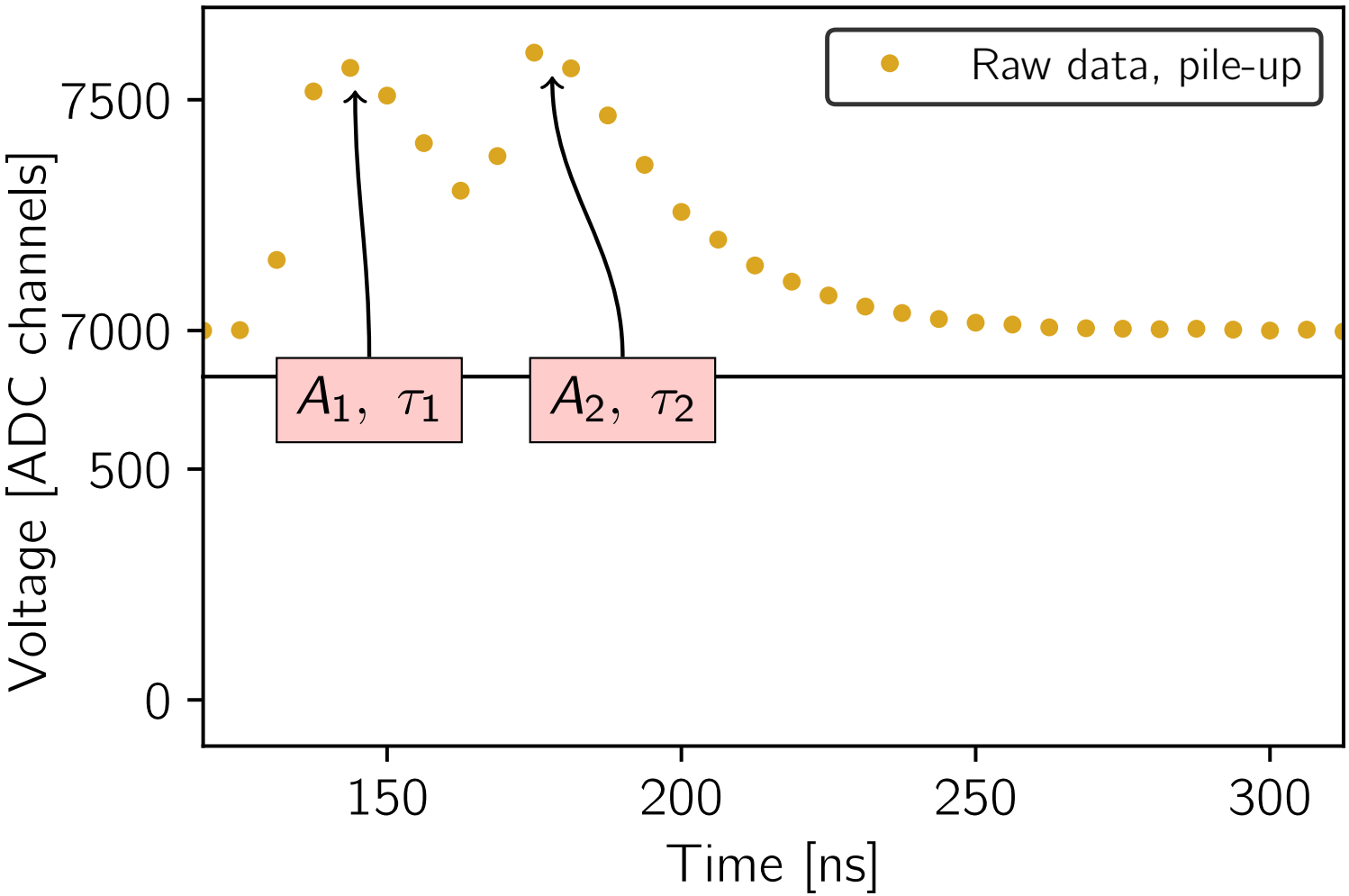
  - No bunch-crossing information from accelerator ⇒ phase between data and sampling clock not known.
  - No pile-up reconstruction.
- To solve this, we propose:
  1. Only include initial part of pulse (rising edge + maximum) in OF "fit" ⇒ no contamination from pile-up.
  2. Store several assumed pulse 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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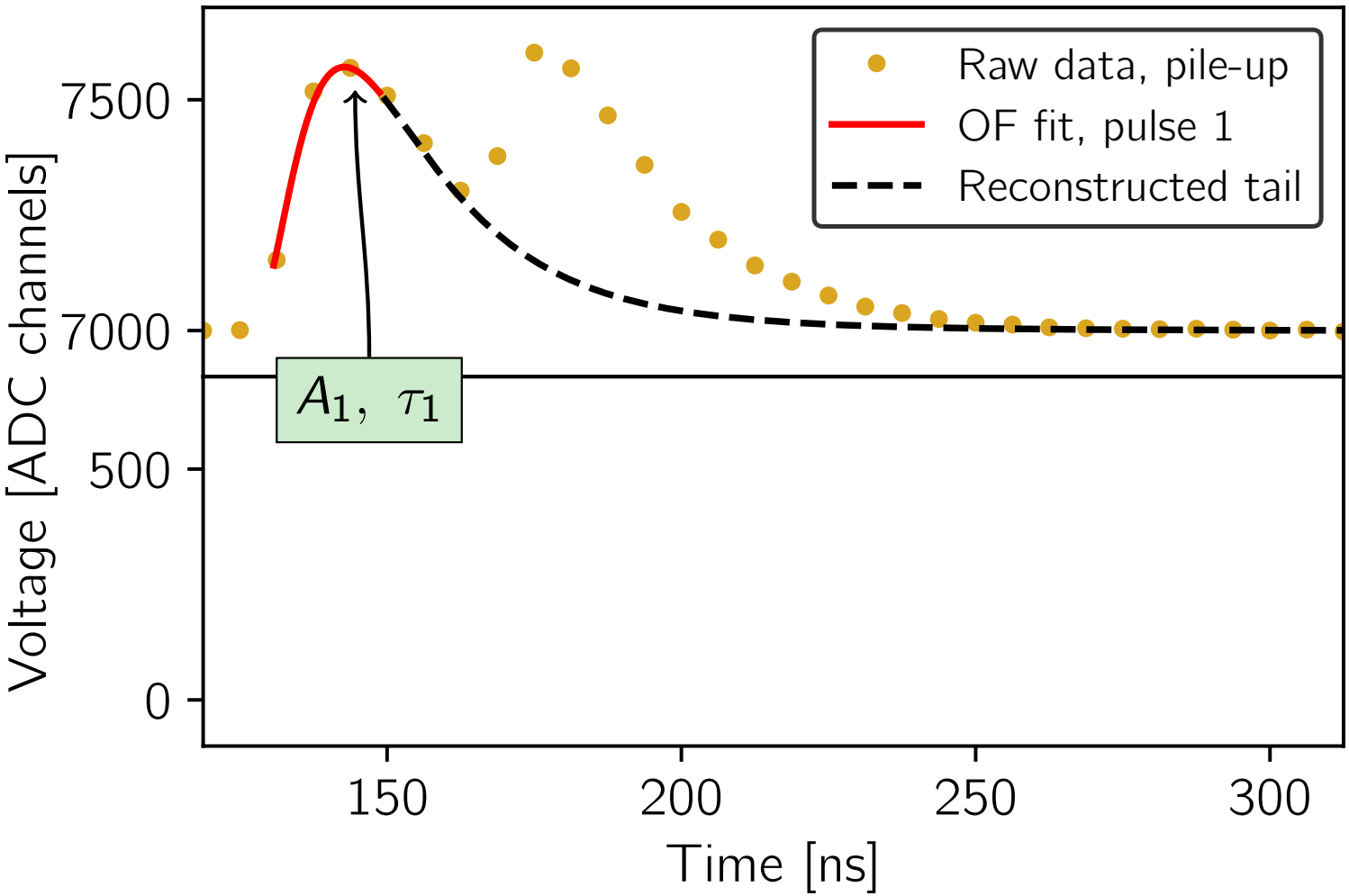

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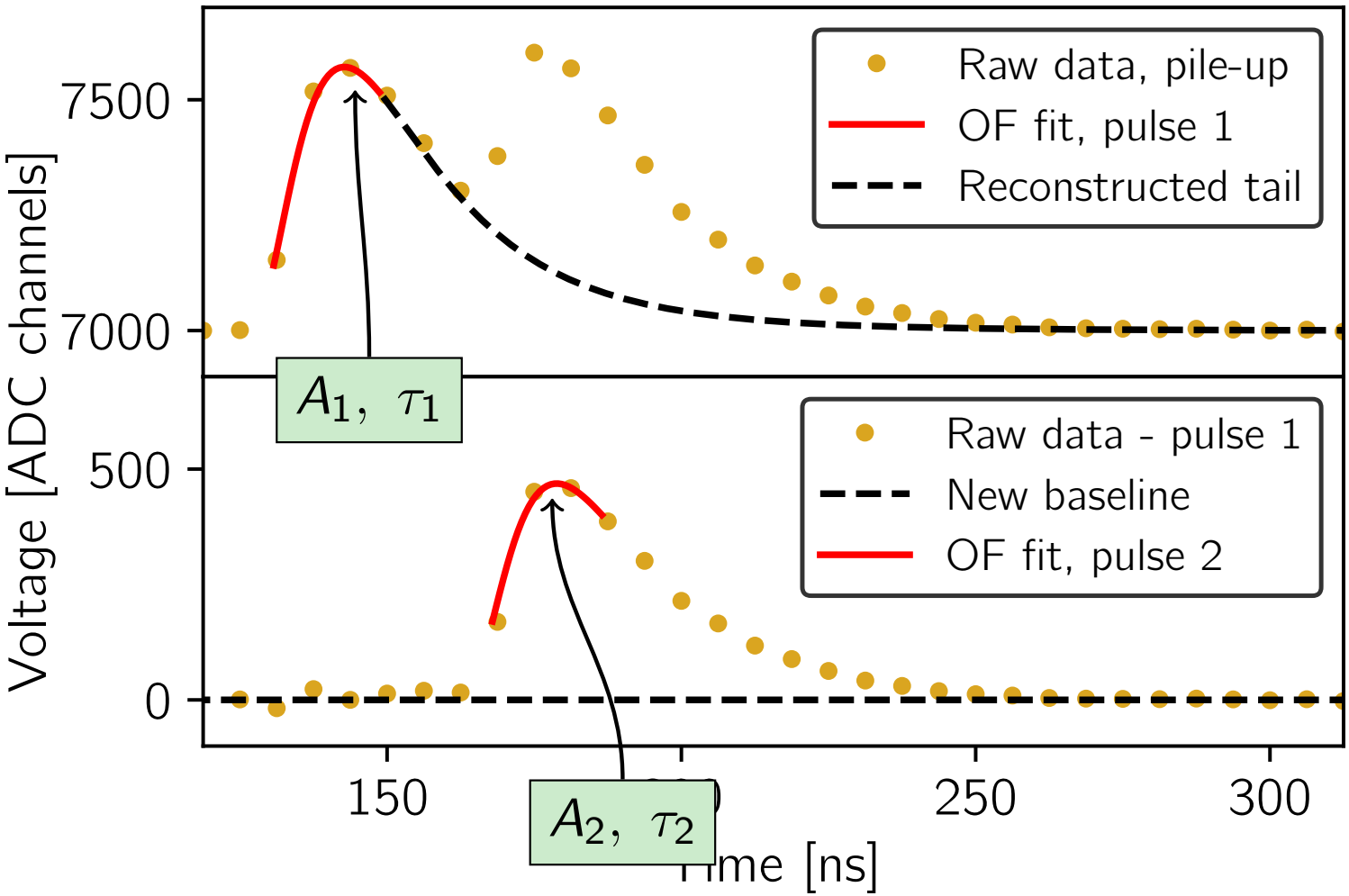

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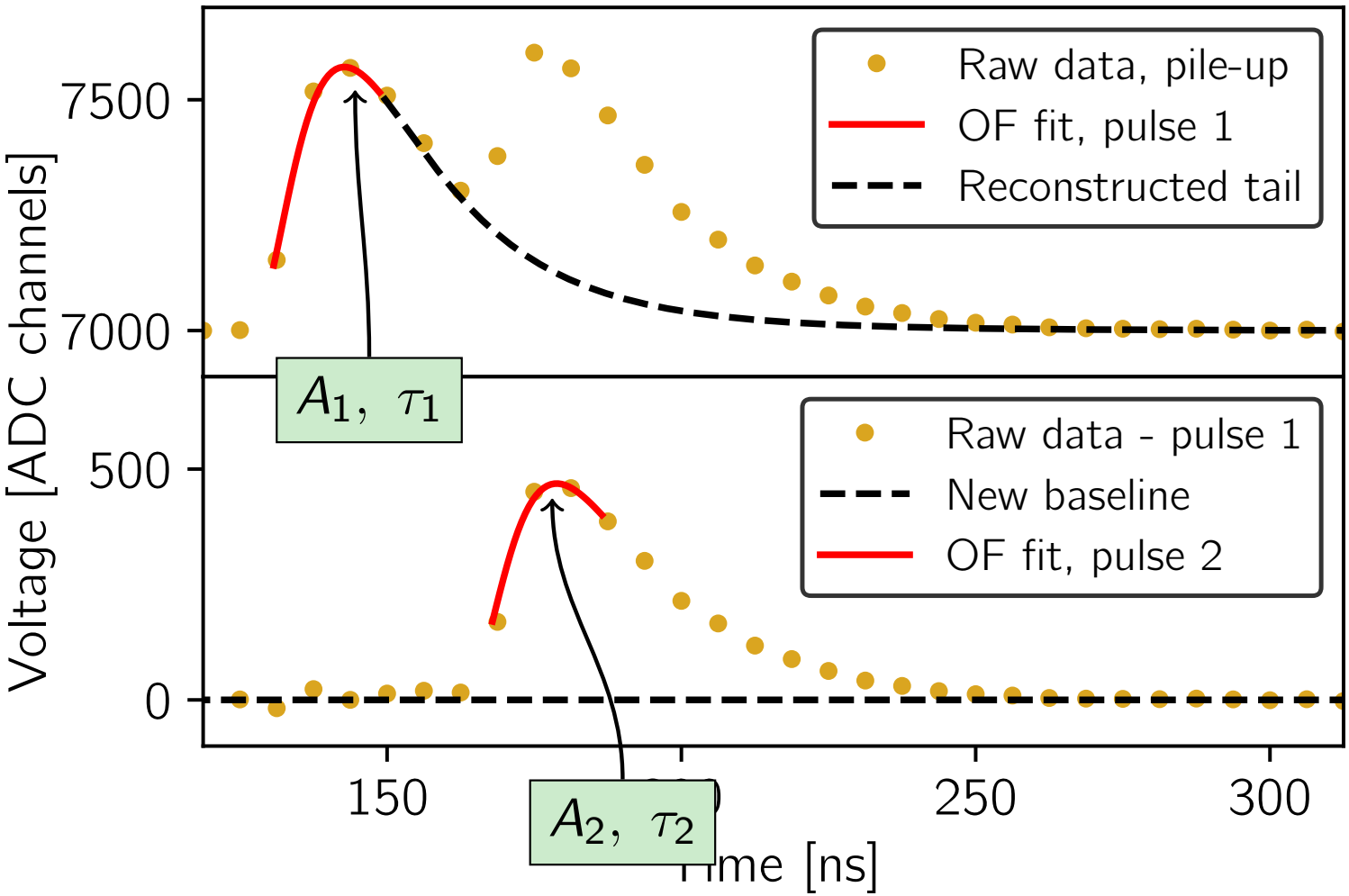
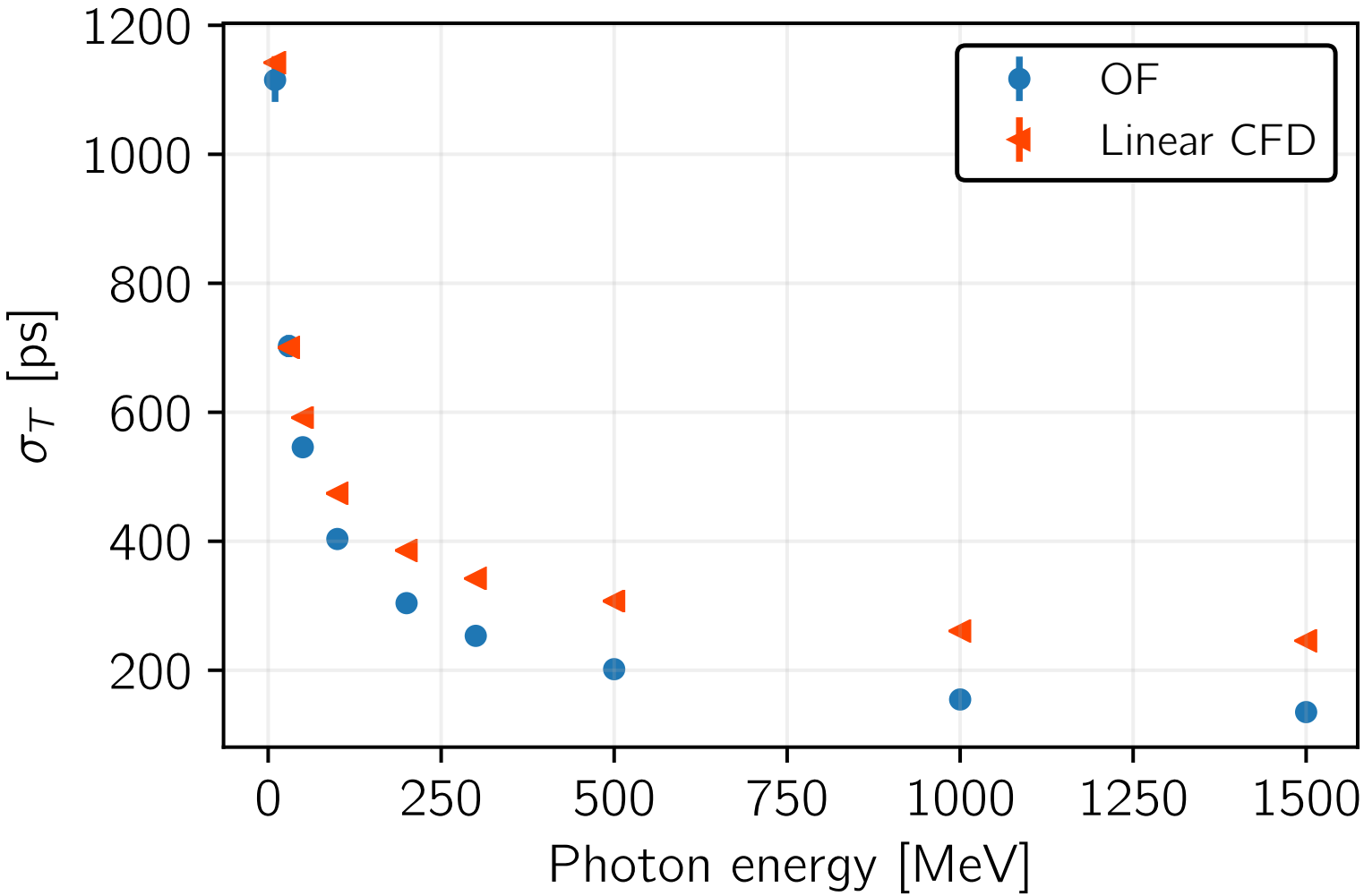


Model-generated data + VHDL implementation ⇒ evaluate method

New feature-extraction method

Time resolution — isolated pulse



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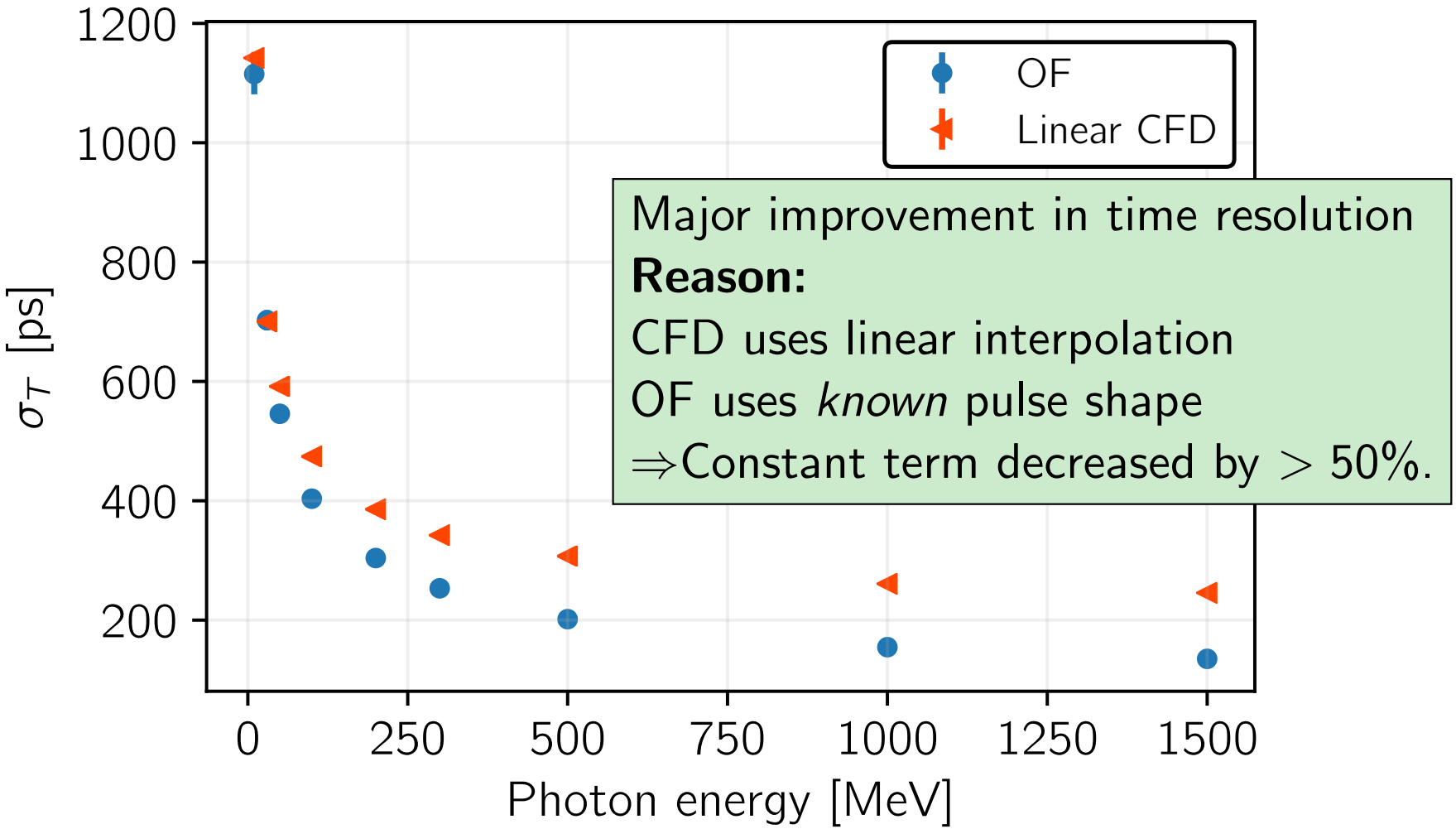
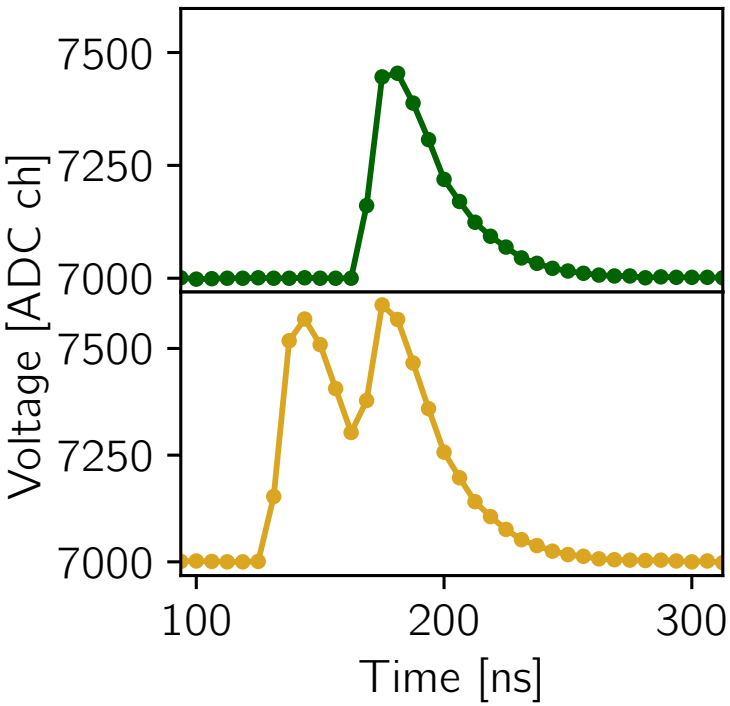


New feature-extraction method

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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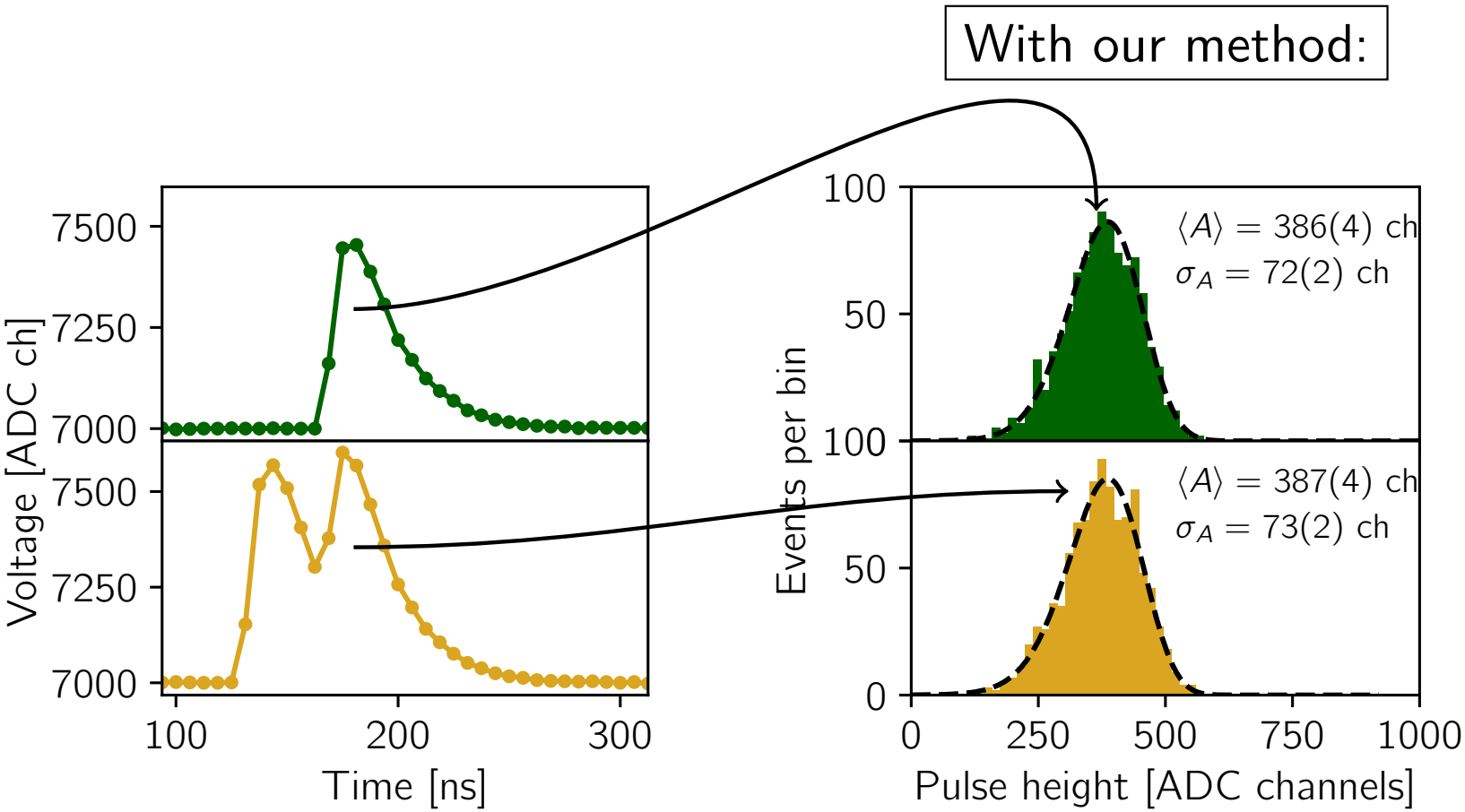


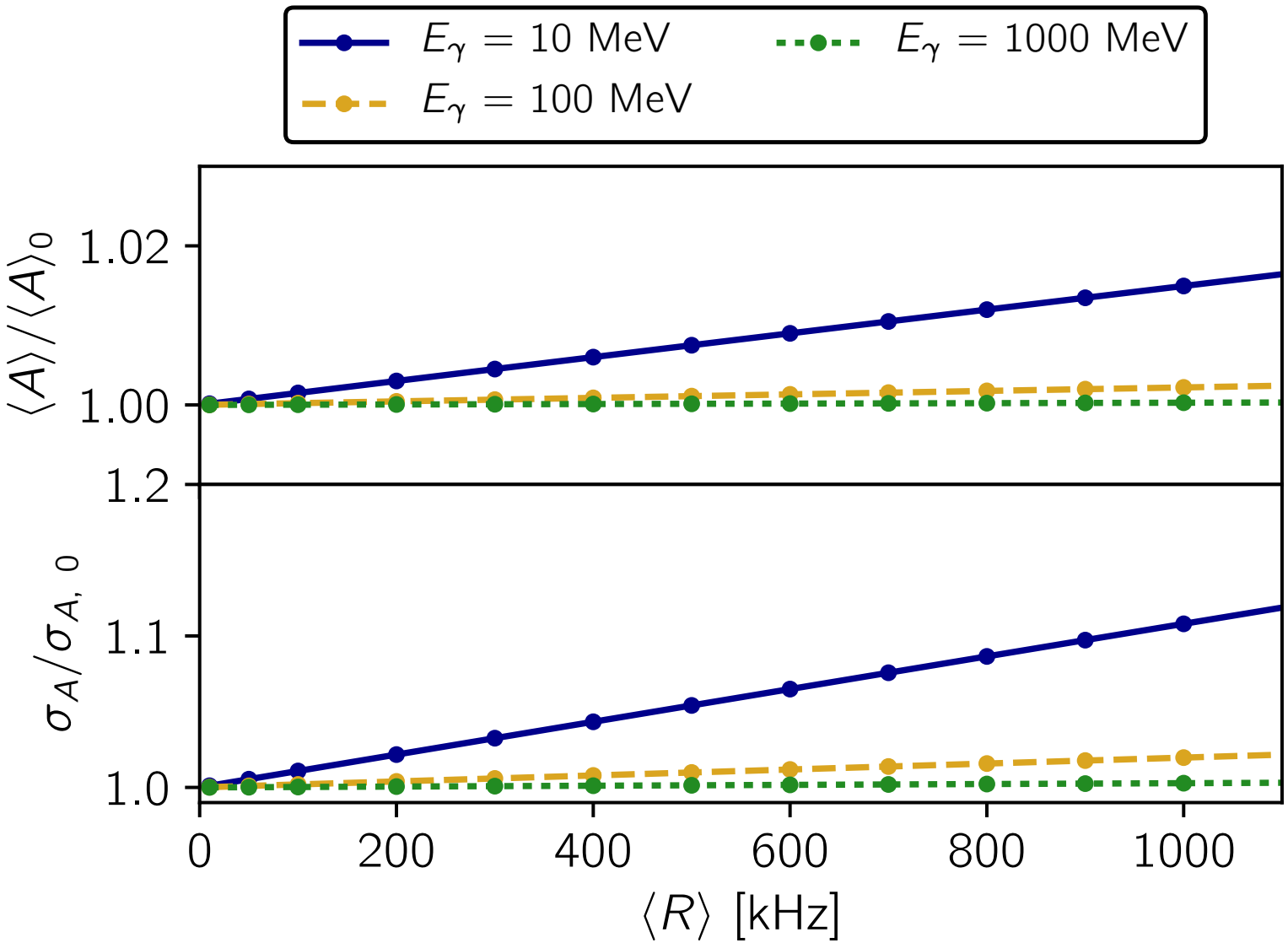
New feature-extraction method

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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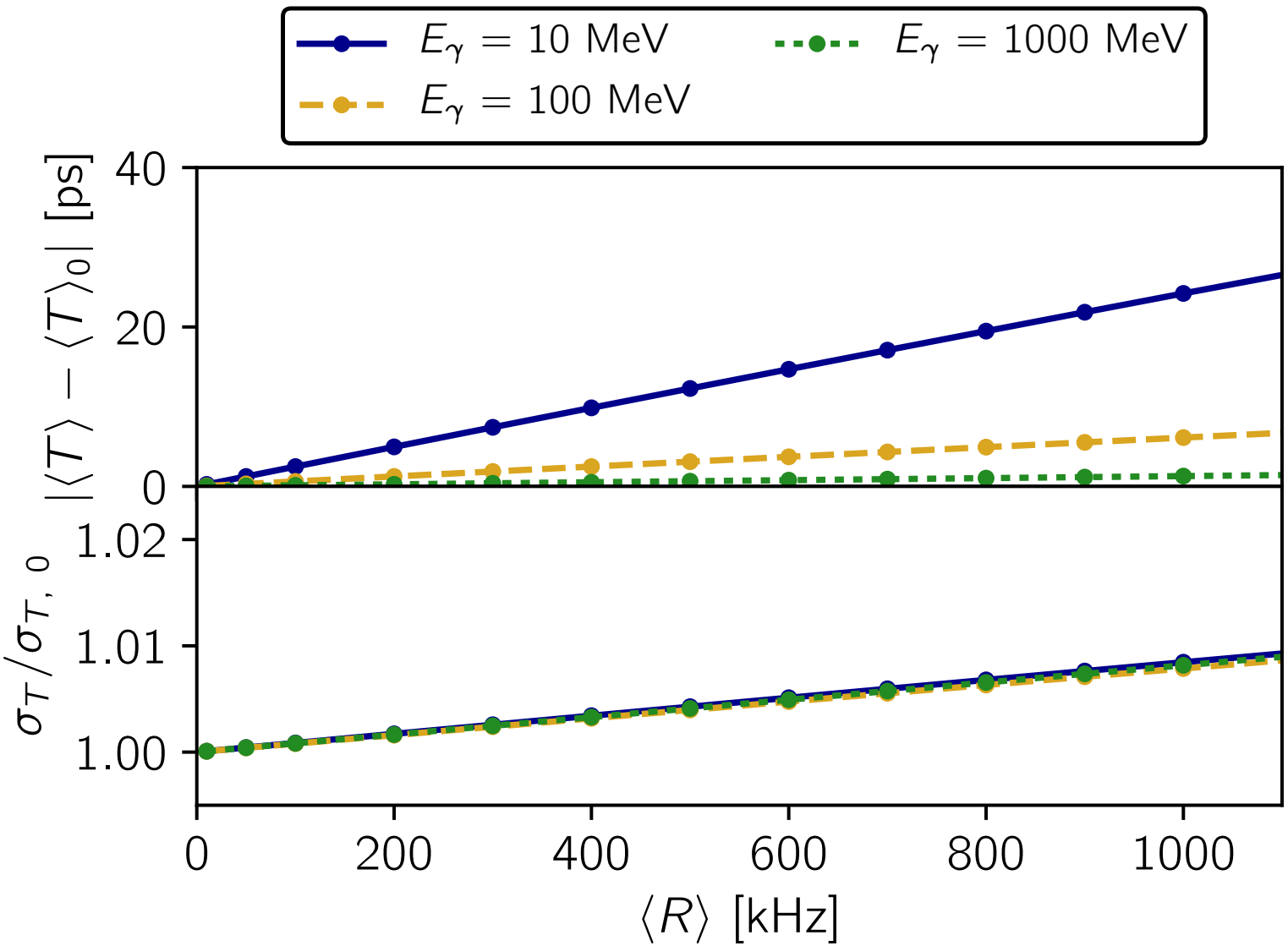
Time resolution — pile-up pulse



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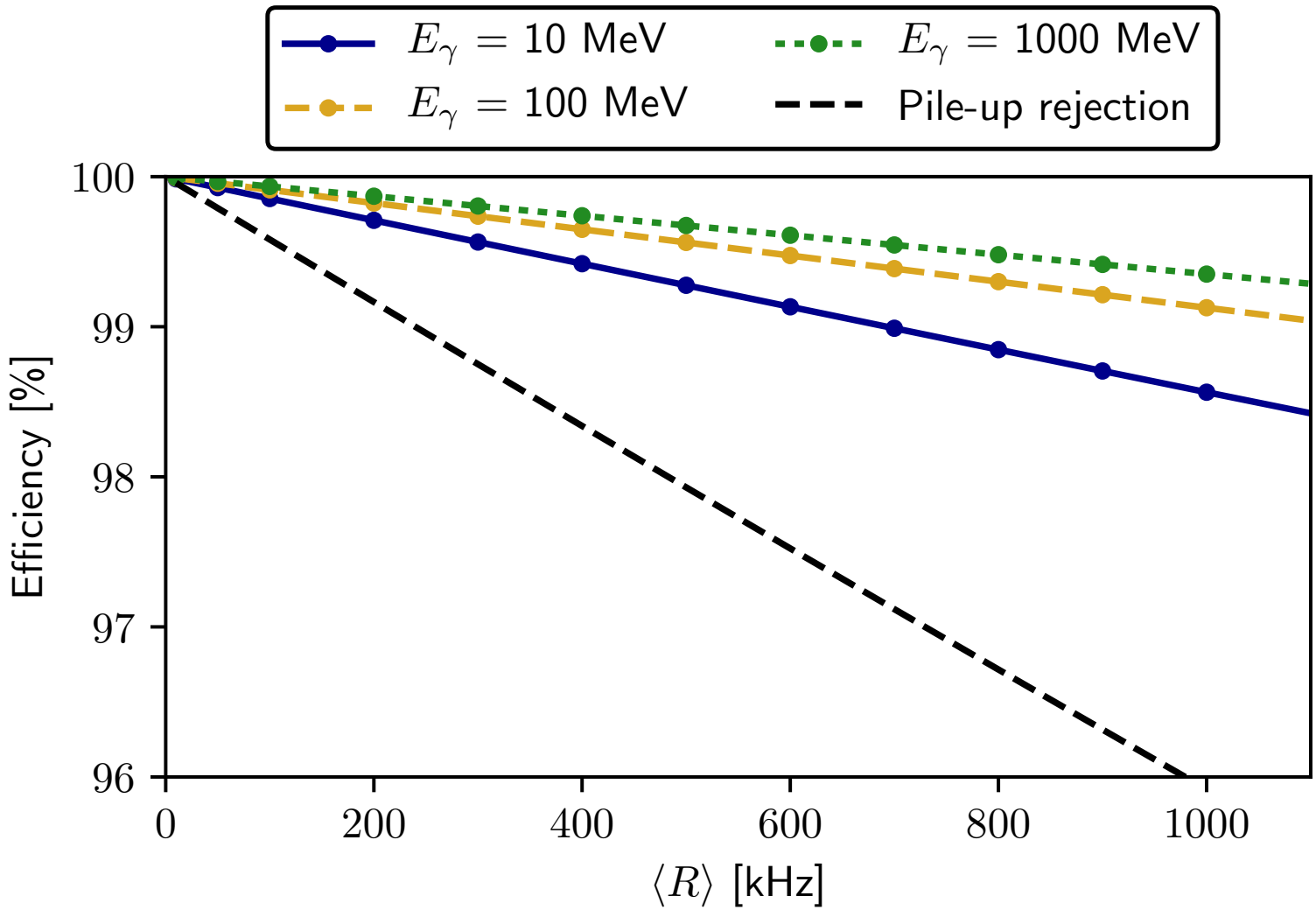
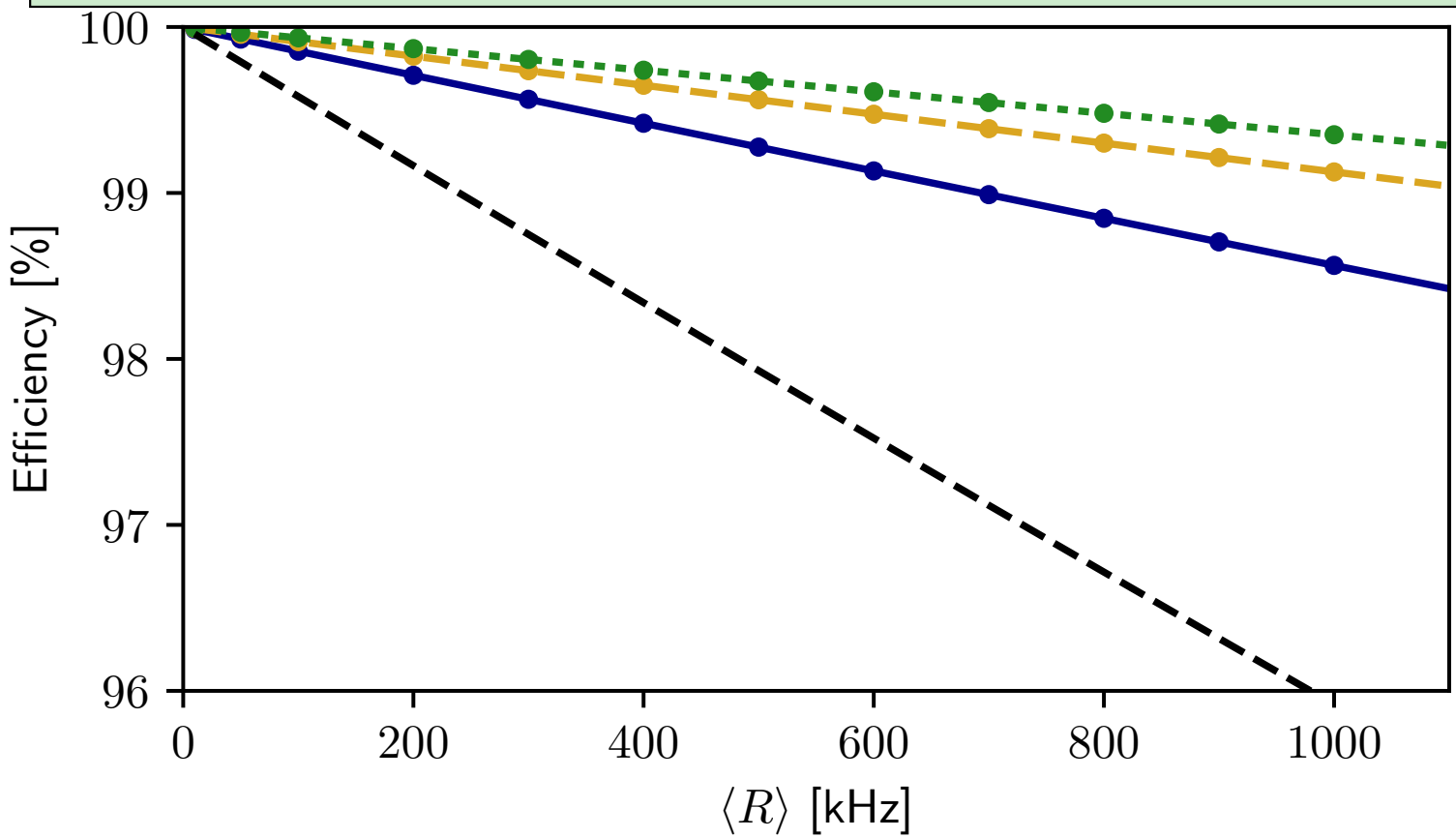
Pulse-detection efficiency — pile-up pulse



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

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- 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.

This work has been funded in part by the Swedish Research Council.