The Abdus Salam
International Centre
for Theoretical Physics

IAEA

Joint ICTP-IAEA School on
Systems-on-Chip based on
FPGA for Scientific Instrumentation
and Reconfigurable Computing

Introduction to Project 1

Digital Pulse Processing for Isotope Identification

Prepared by
Iván Morales, Mladen Bogovac, and Romina Molina

Multidisciplinary Laboratory
STI Unit, ICTP

Trieste - Italy
2023

Lab Project 1 - Goals and methodology

Main objective

- Build a radiation detection and processing system in the SoC/FPGA to identify a gamma source

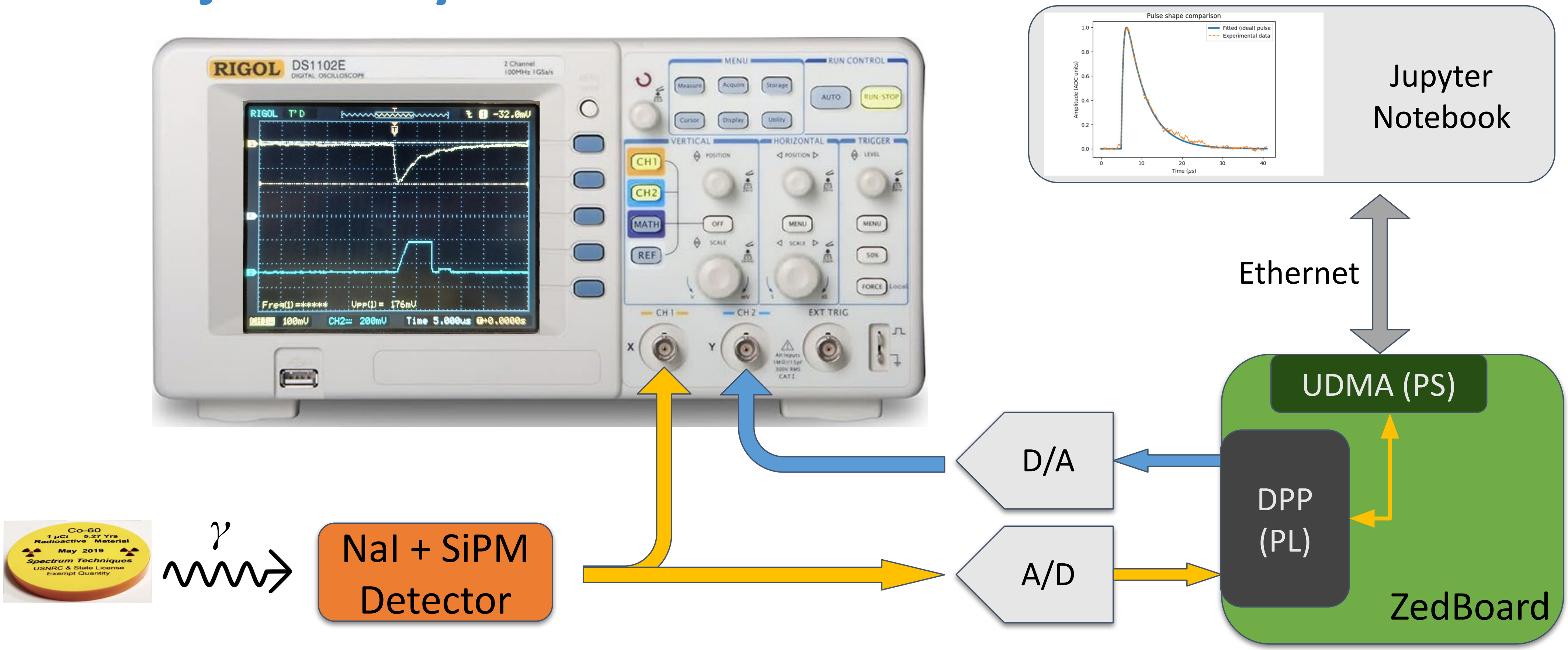
Methodology

- Model the detector behavior using experimental data (offline processing)
- Use the detector characteristics to fine-tune the digital pulse processing (DPP) system
- Determine an unknown isotope type from its energy spectrum information (fingerprint)
- (Challenge) Update the DPP to improve its reliability in aggressive environments

Lab Project 1 - Two stages + challenge

- Stage 1 - Modeling the detector
  - Build a data acquisition system (DAQ) using the SoC/FPGA to record several pulses from the gamma radiation detector
  - Use the recorded pulse shapes to fit the parameters that better describe the detector
- Stage 2 - Identifying the isotope
  - Build and fine-tune a digital pulse processing (DPP) system in the SoC/FPGA to:
    - Compute the energy deposited in the detector of each interaction with a gamma radiation source (energy spectrum)
    - Assess the functionality of the multiple DPP stages using a Python-based interface
- Stage 3 - Challenge
  - Improve the DPP with a baseline restorer and pile-up rejector

Lab Project 1 - System overview



Stage 1

Data acquisition system for detector characterization

Lab Project 1 - stage 1: specific objectives

- Compute the parameters that better fit the behavior of the detector

Methodology

- Acquire and record a dataset of several raw pulses from the detector, using the SoC/FPGA DAQ via UDMA
- Wrangle the experimental dataset to remove unwanted pulses and restore their baseline.
- Fit the recorded pulses to get the average parameters that better represent the ideal pulse model of the detector.

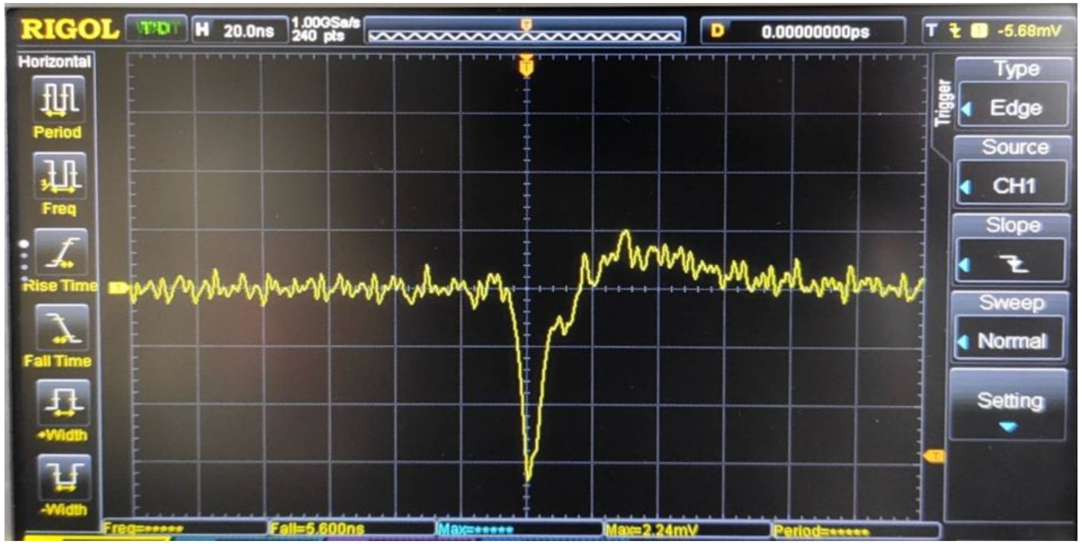
Lab Project 1 - stage 1: specific objectives

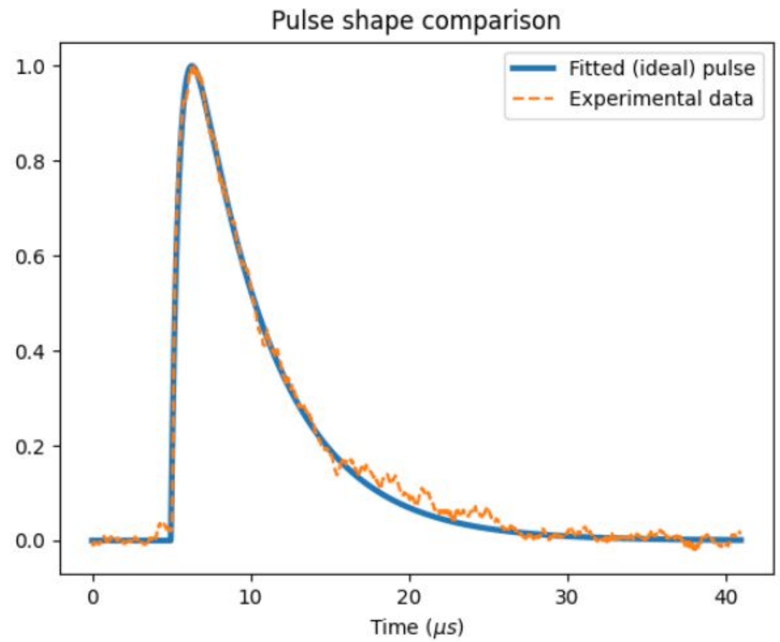
… but this is not a data science school!

Stage 1.1 - DAQ

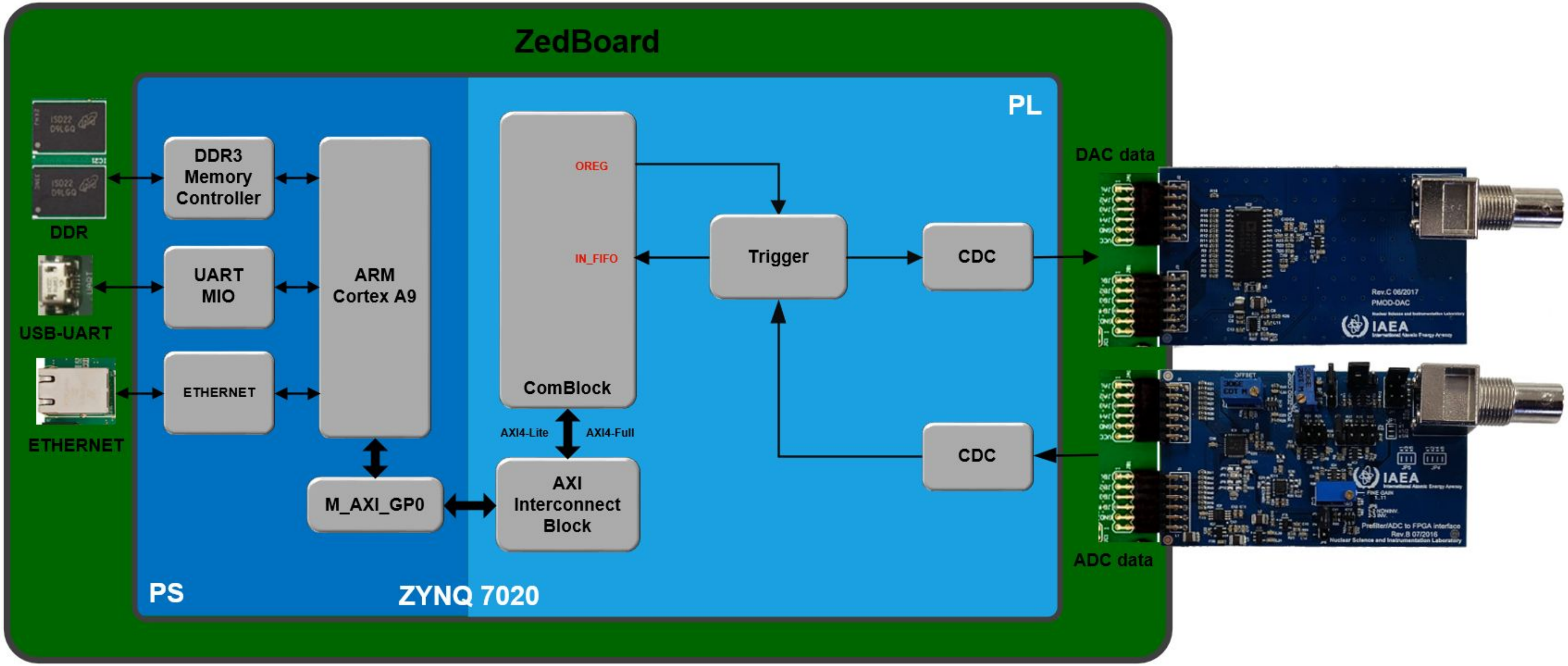
Lab Project 1 - stage 1: methodology

- Your task ← create the DAQ and acquire the data
- Our task ←semi-automatic data analysis library

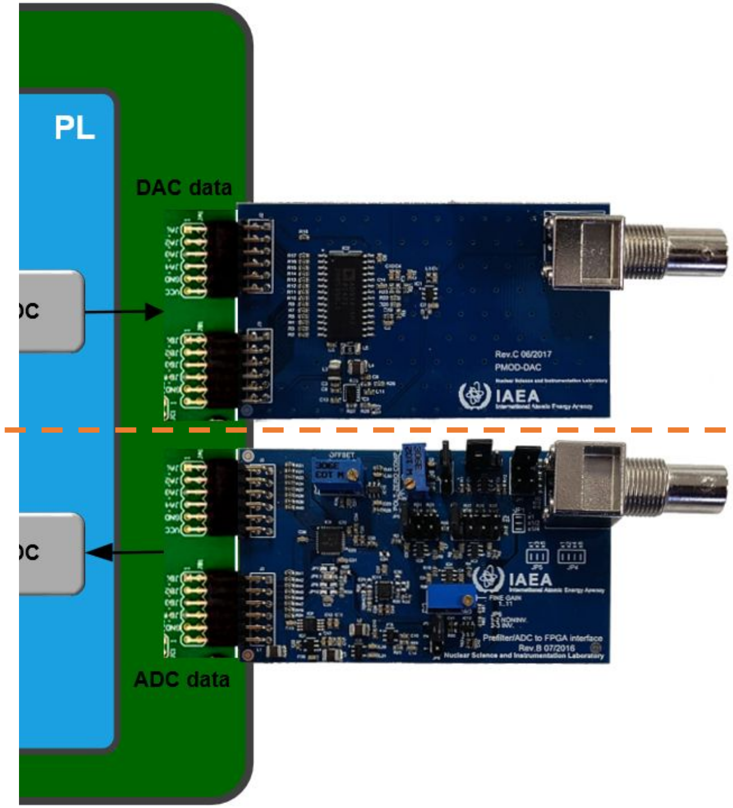




Design description - DAQ



Design description - analog front-end



Digital-to-analog converter (D/A)

PMOD C
PMOD D

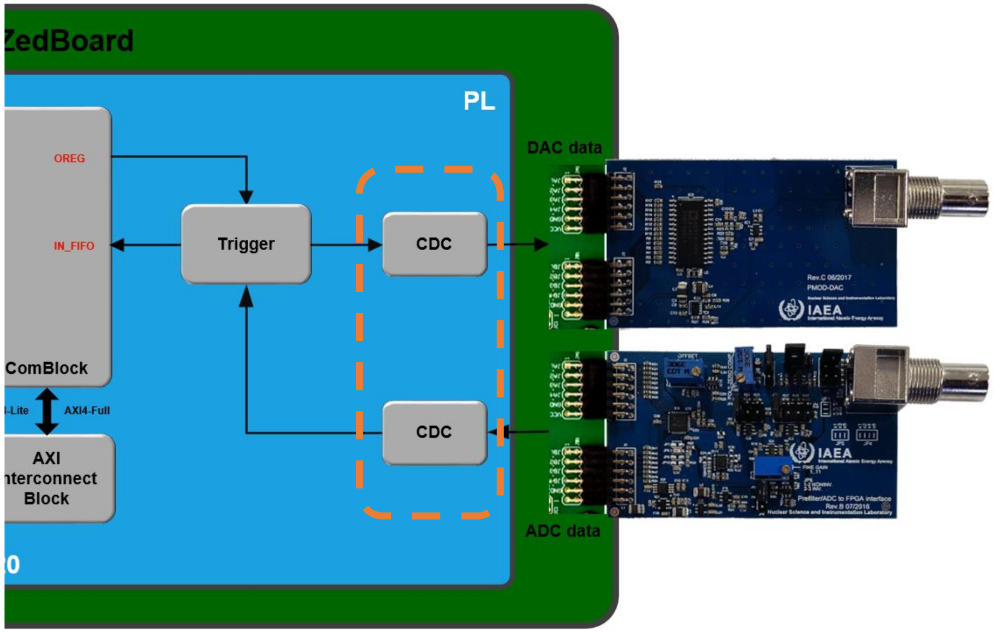
- 14 bits @ 50 Msps
- Current output - matched to 50 Ω
- Fixed output gain

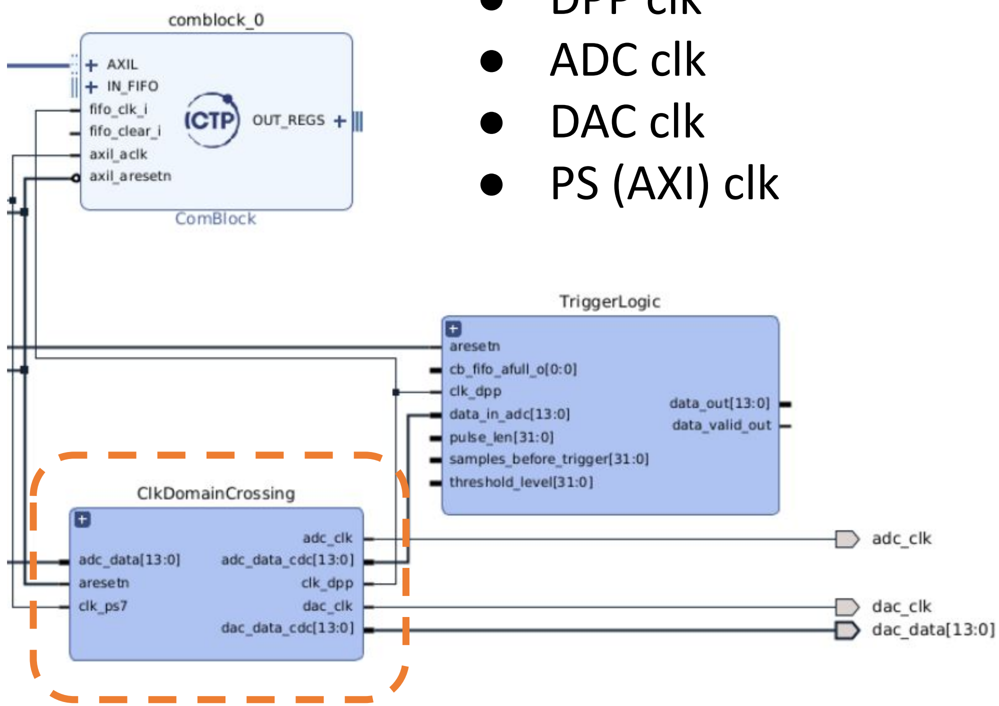
PMOD A
PMOD B

- 14 bits @ 50 Msps
- Bipolar input
- Coarse and fine gain/attenuation

Analog-to-digital converter (A/D)

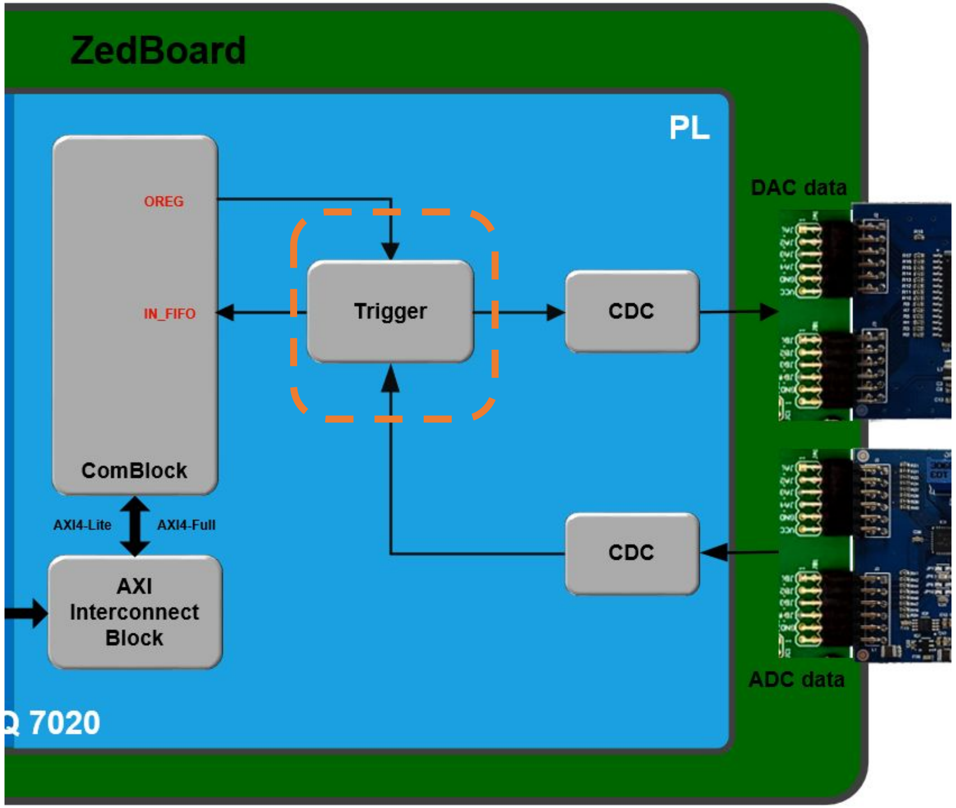
Design description - multiple clock domains





- DPP clk
- ADC clk
- DAC clk
- PS (AXI) clk

Design description - data recording interface

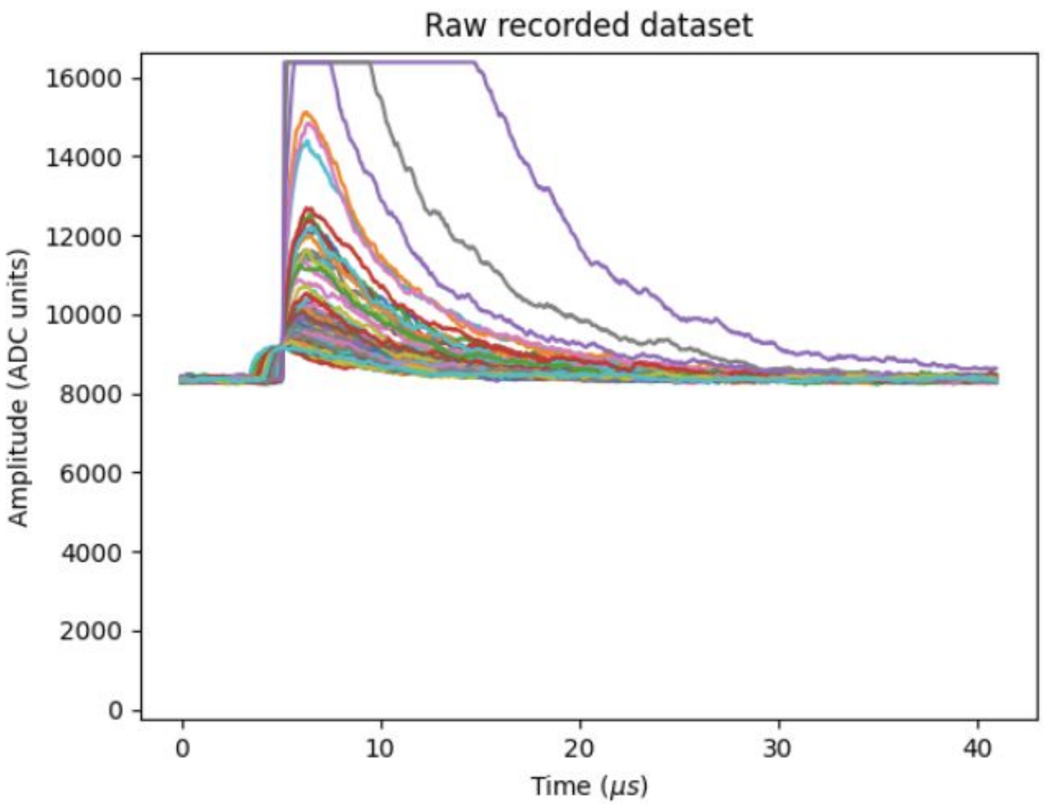


Trigger logic - basic oscilloscope core

- Input registers
  - Pulse length (in sample units)
  - Threshold level (in ADC units)
  - Samples before trigger (delay)
- Output stream
  - Captured pulse

Stage 1.2 - Offline data analysis

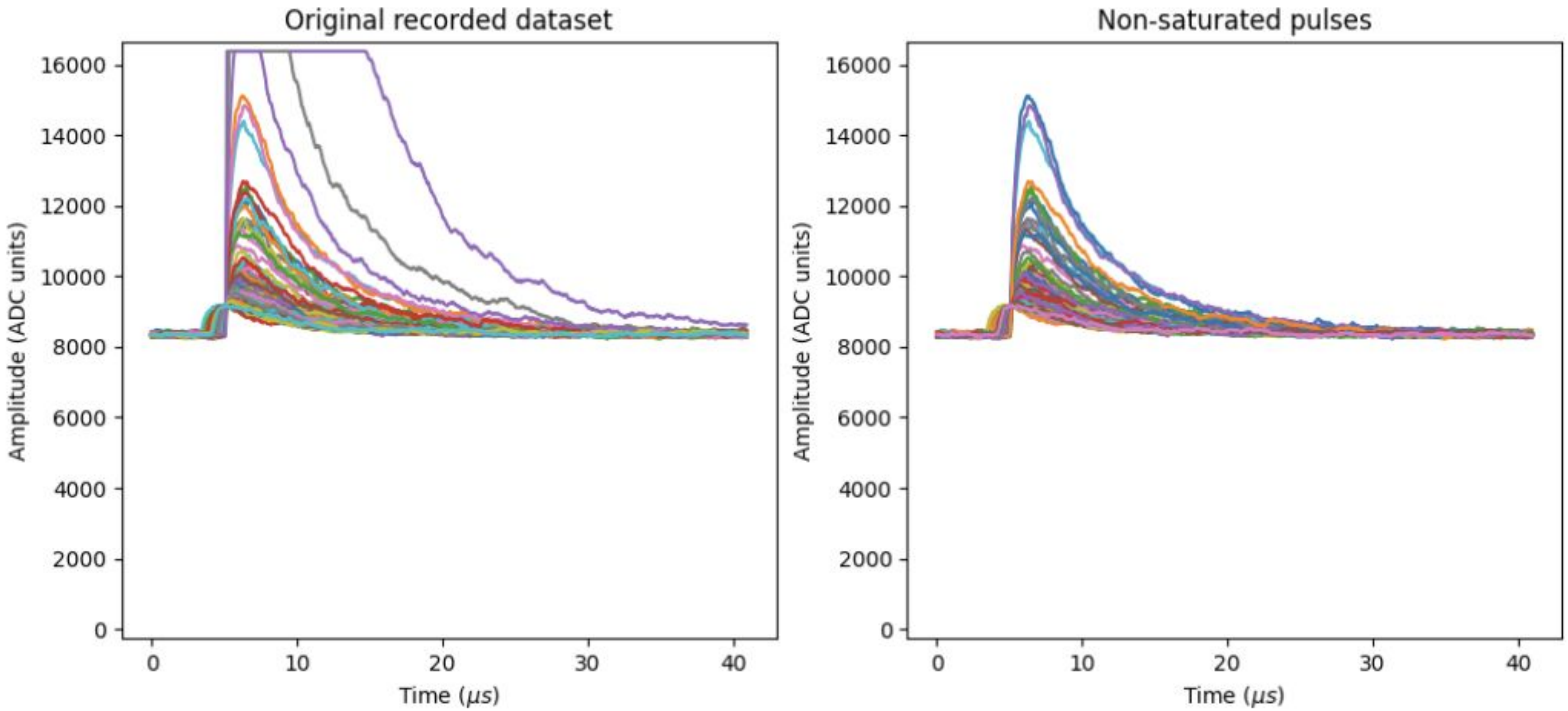
Data wrangling



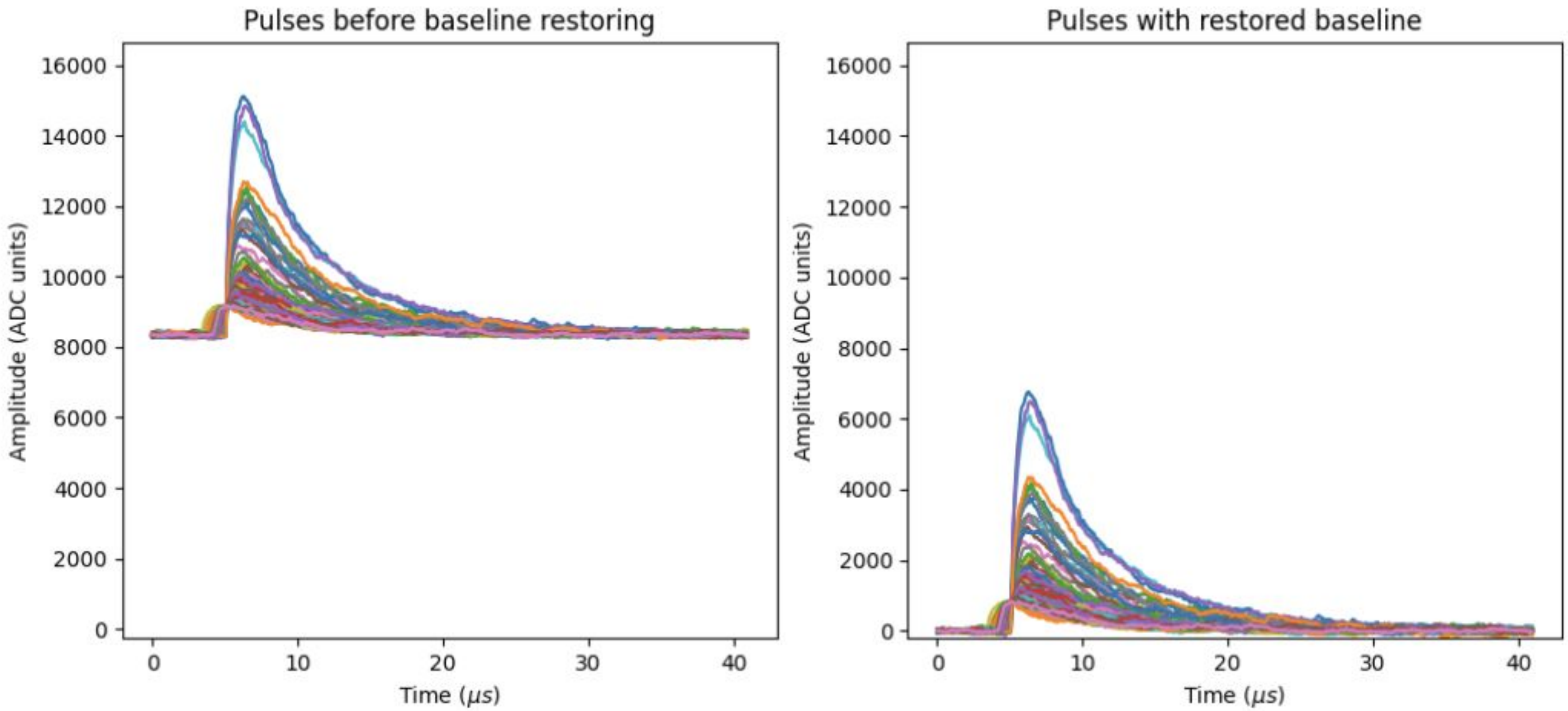
Raw dataset

- Saturation
- Baseline offset
- Small amplitude events

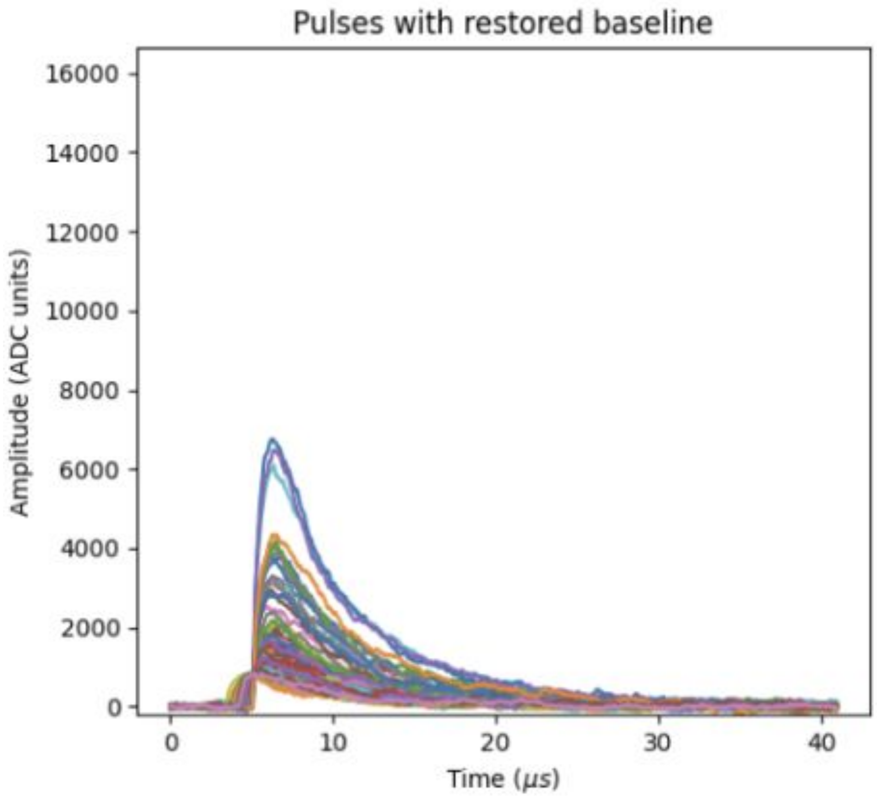
Data wrangling

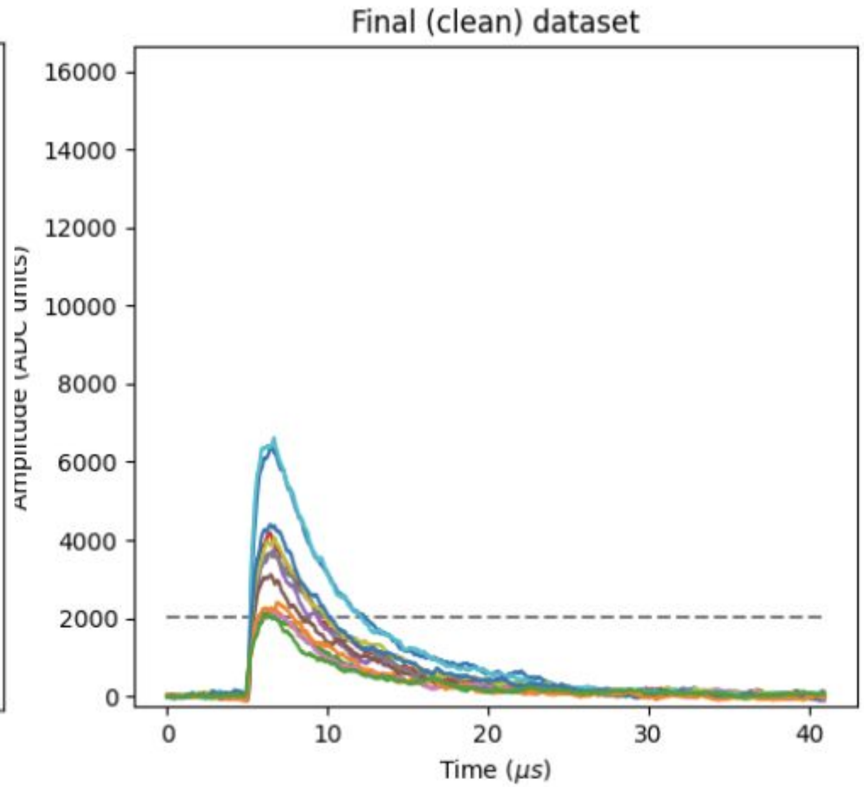


Data wrangling

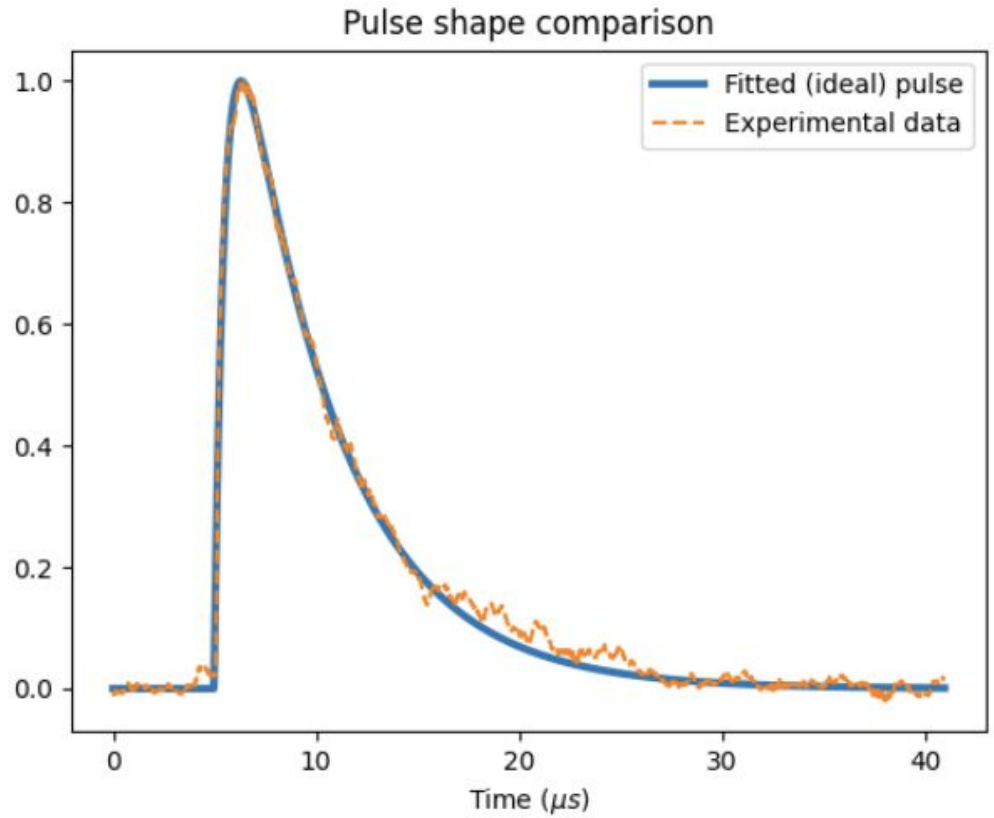


Data wrangling





Pulse model fitting



Pulse model

$$y(t) = A\left(e^{(t-t_0)/\tau_d} - e^{(t-t_0)/\tau_r}\right)$$

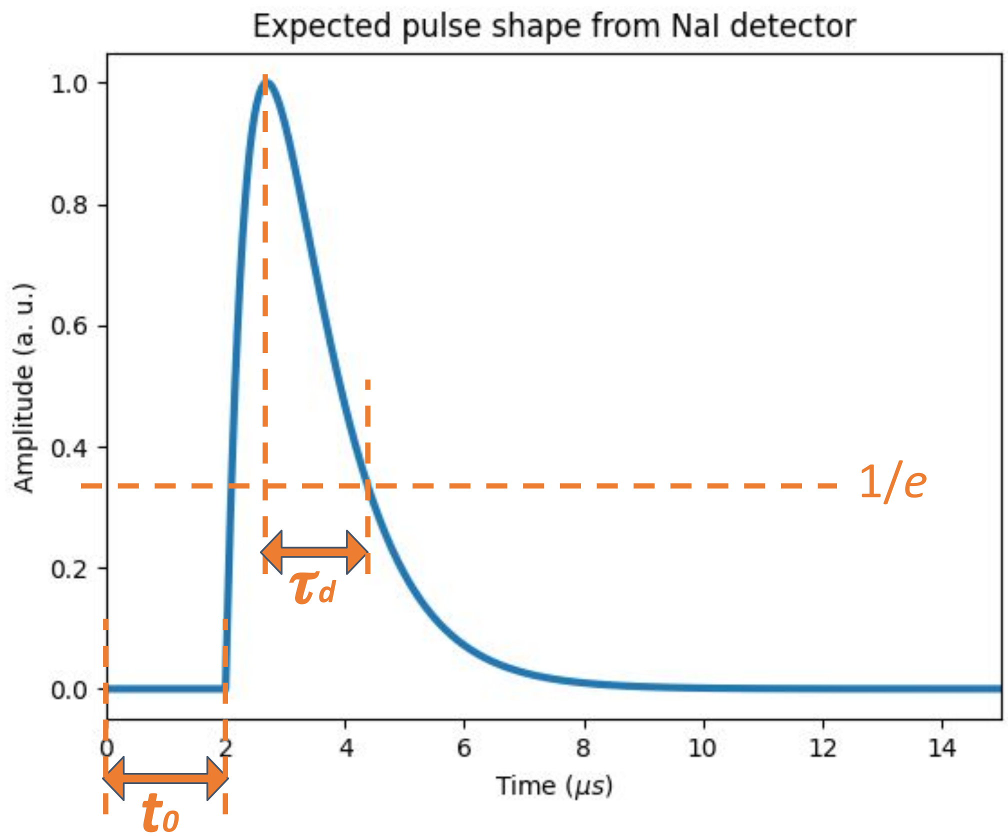
Fitting parameters

- Decay time constant (τ_d)
- Rise time constant (τ_r)
- Time of arrival (t_0)

Pulse model fitting

Pulse fitting: not magic

- Provide initial guesses
  - τ_d ~ 1.2 µs
  - τ_r ~ 0.2 µs
  - t_0 ~ depends on the trig. delay



Lab setup distribution

- Eight experimental setups
- One setup per row
- ictp_share_usb

The Abdus Salam International Centre for Theoretical Physics

IAEA

Joint ICTP-IAEA School on Systems-on-Chip based on FPGA for Scientific Instrumentation and Reconfigurable Computing

Thank you!

Trieste - Italy
2023