# A Trigger/Timing Logic Unit (TLU) for AIDA-Innova

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# Outline

- What is a TLU?
  - (Why do I need one?)
- What exists now
  - (What are all those blue boxes?)
- Why it needs to be improved
  - (Why do I need a new blue box)
- Implementation
  - (Front end , back end).

# A Digression

- Without Particles ….
- Particle Physics is Philosophy, not Physics

Greek Philosopher
Democritus
c. 460-370 BCE

The universe is made
of particles
and the void



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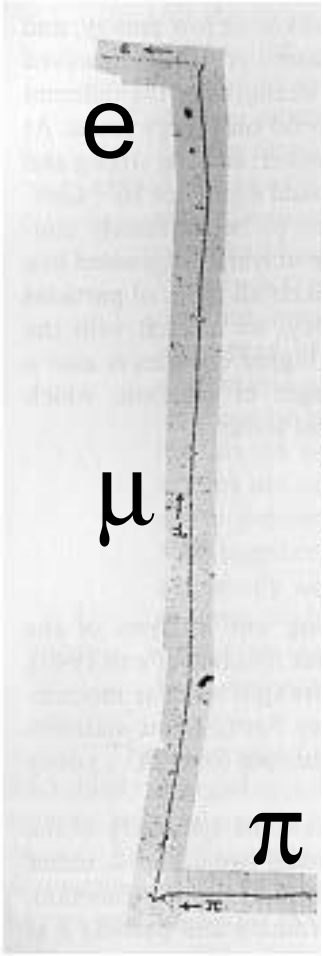
# A Digression

- Developing detectors is at the heart of Particle Physics.
- *"It was as if, suddenly, we had broken into a walled orchard, where protected trees had flourished and all kinds of exotic fruits had ripened in great profusion."*
  - Cecil Powell, 1950 Nobel Prize for "Emulsion Technique" of particle detection.

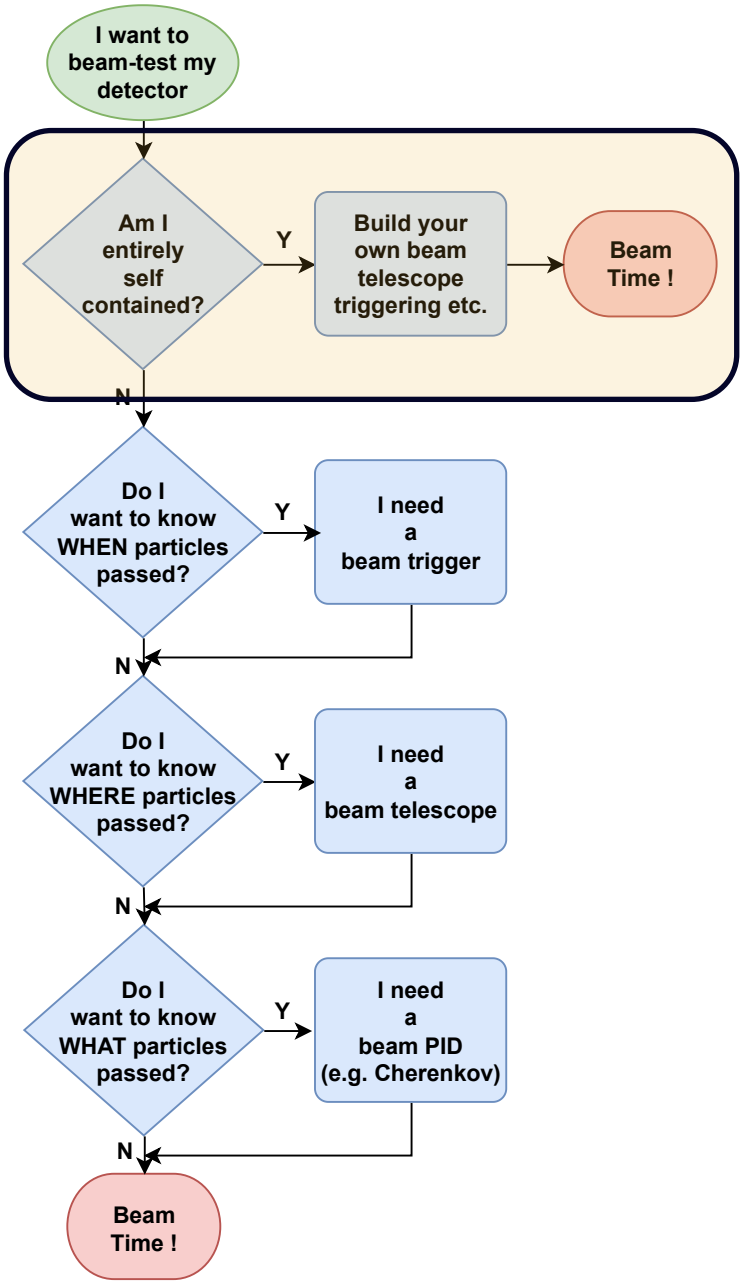


# Back to the TLU

- … Returning to the AIDA-Innova TLU

- Aiming to make Beam Tests Better.

# Why a TLU?




- May have entirely self-contained system.
  - In which case all you need is the beam.
- But often want to use existing beamline infrastructure.

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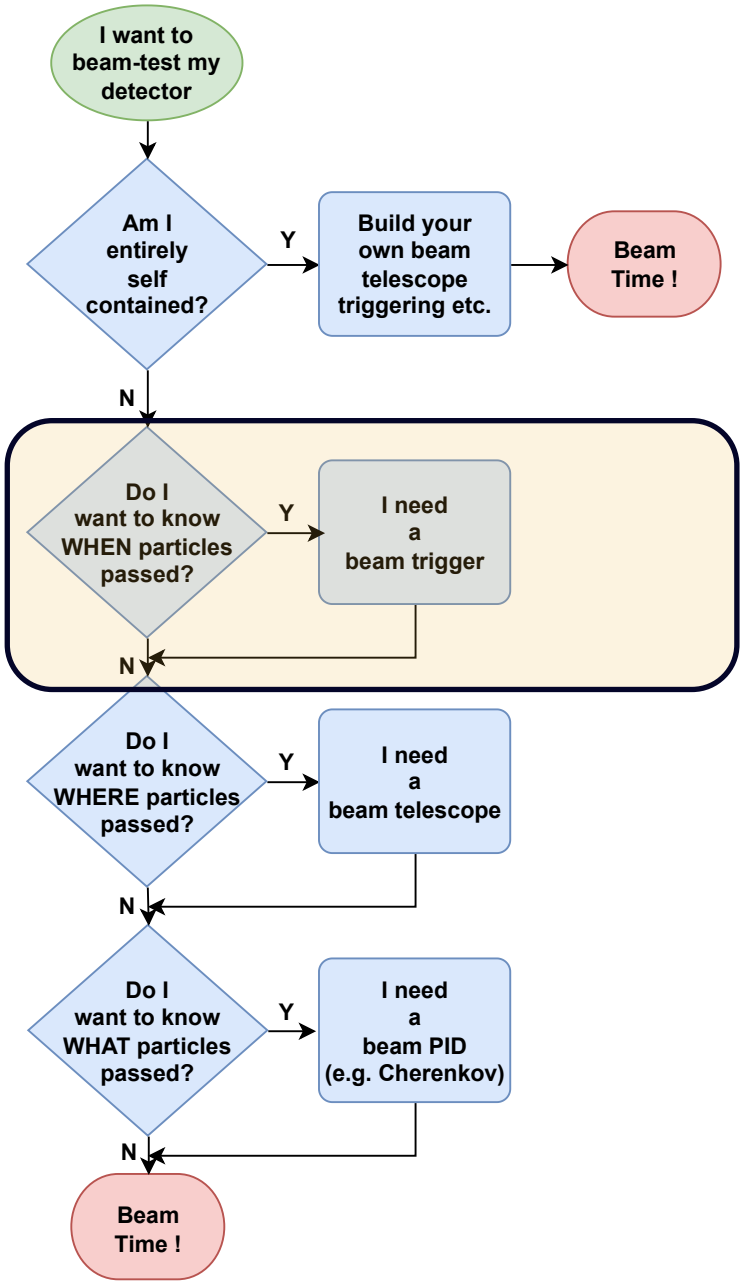


# Why a TLU?

- May want a signal to trigger read-out of detector
  - In which case you need a beam trigger
  - Can be helpful to have pre-installed scintillators etc.
  - And trigger logic (AND, OR, VETO, etc.)

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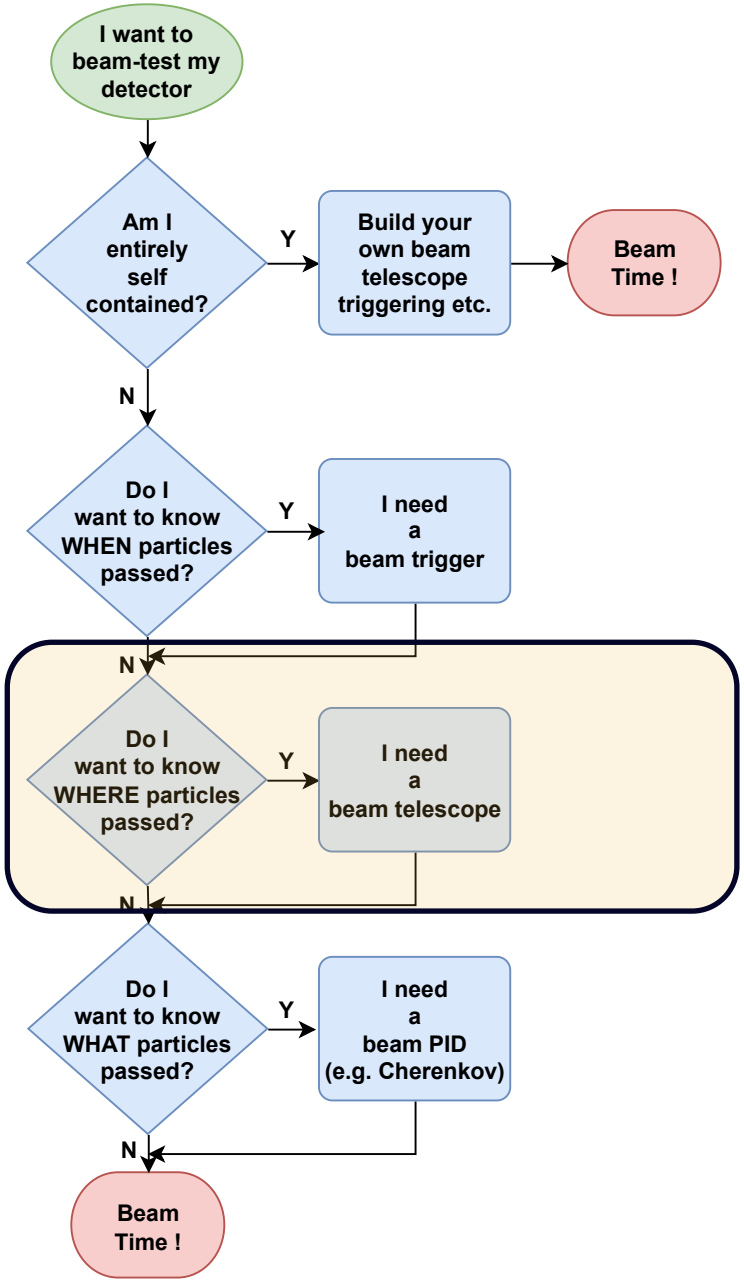
# Why a TLU?




- May want to know where each particle hit your detector
  - In which case you need a beam telescope
  - Need a way of matching tracks in telescope with hits in your detector
    - → Hardware correlation through TLU

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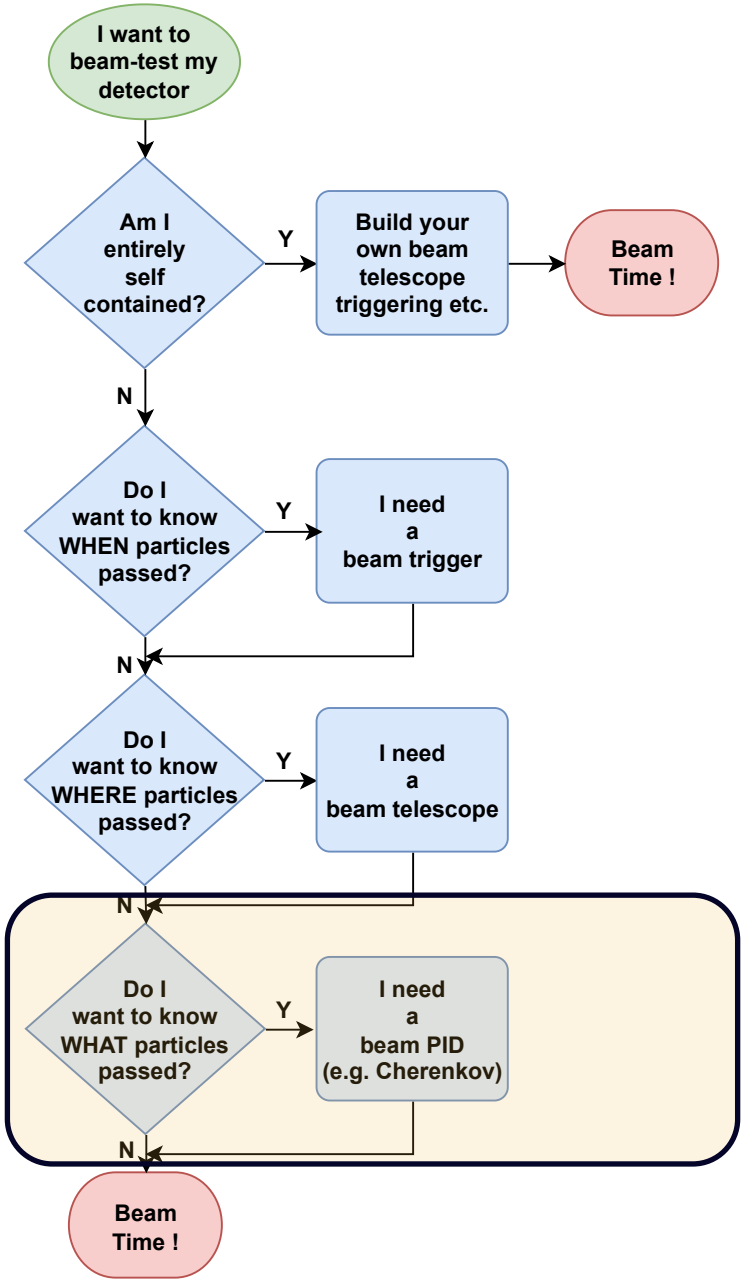
# Why a TLU?




- May want particle ID
  - In which case you need beam instrumentation (e.g. Cherenkov detector)
  - Want to tag events with PID information (e.g. p/pi/K from threshold Cherenkov)
    - → Hardware correlation through TLU

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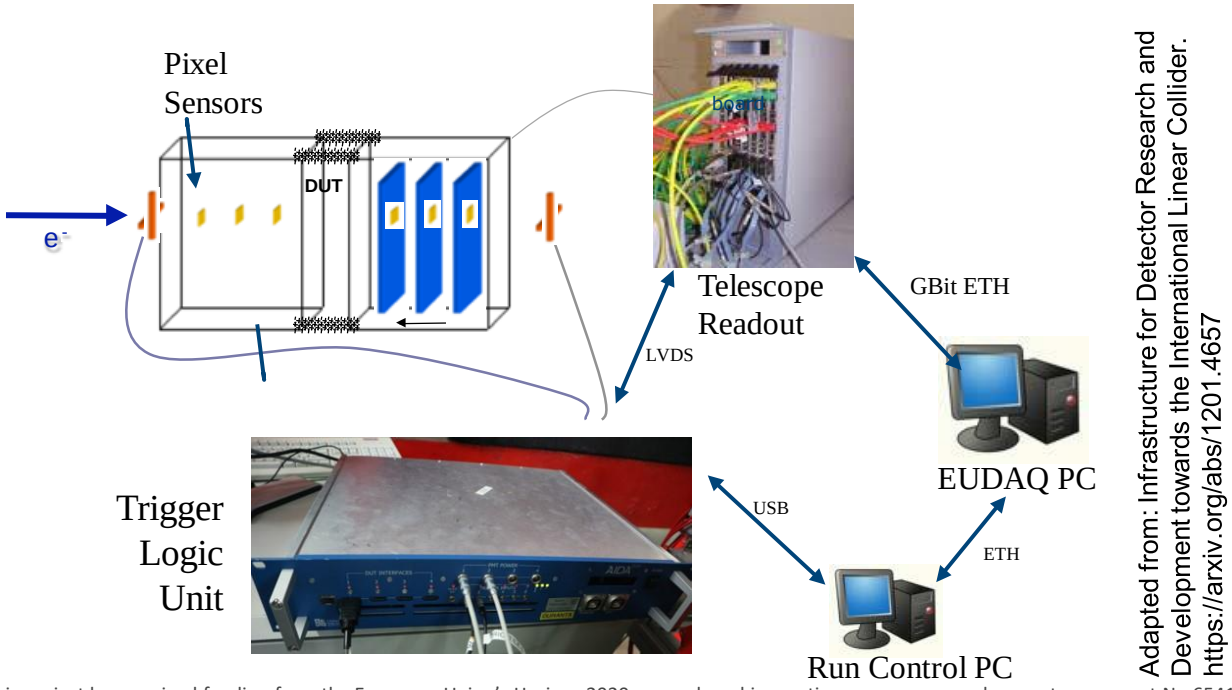
# Why a TLU?

- EUDET, AIDA, AIDA-2020 and AIDAInnova programs aimed to provide a common interface (hardware, software) to beam-lines and beam-telescopes.
- → EUDET/AIDA(-2020/Innova) Trigger(Timing) Logic units developed

# Why?

- As part of EUDET/AIDA(-2020/Innova) beam telescopes provided for beamlines at DESY and CERN
- Hardware synchronization using TLU




Adapted from: Infrastructure for Detector Research and Development towards the International Linear Collider. https://arxiv.org/abs/1201.4657

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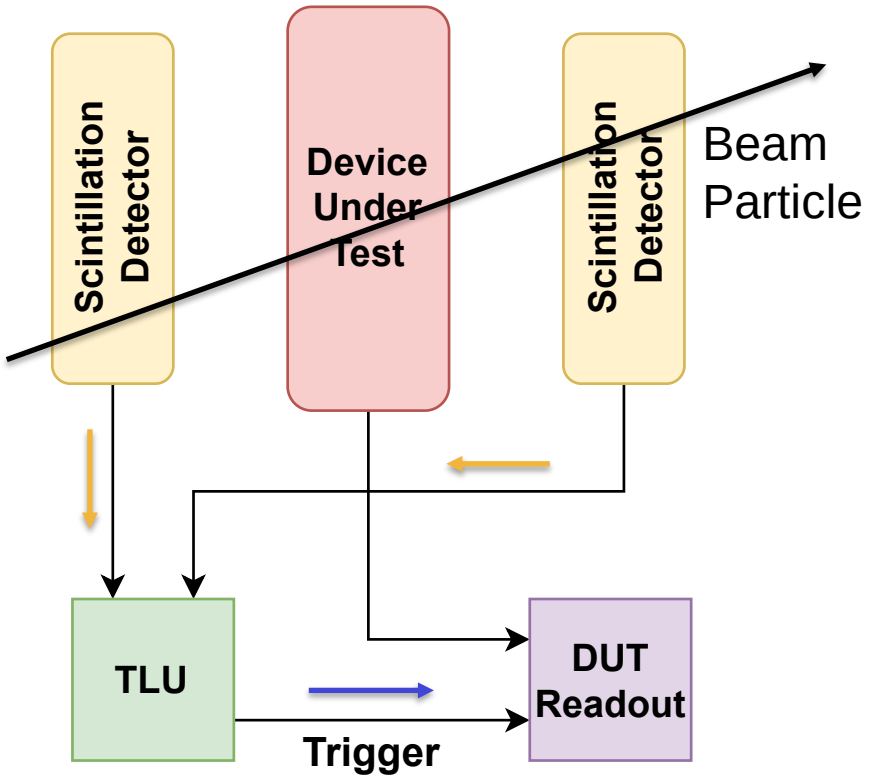
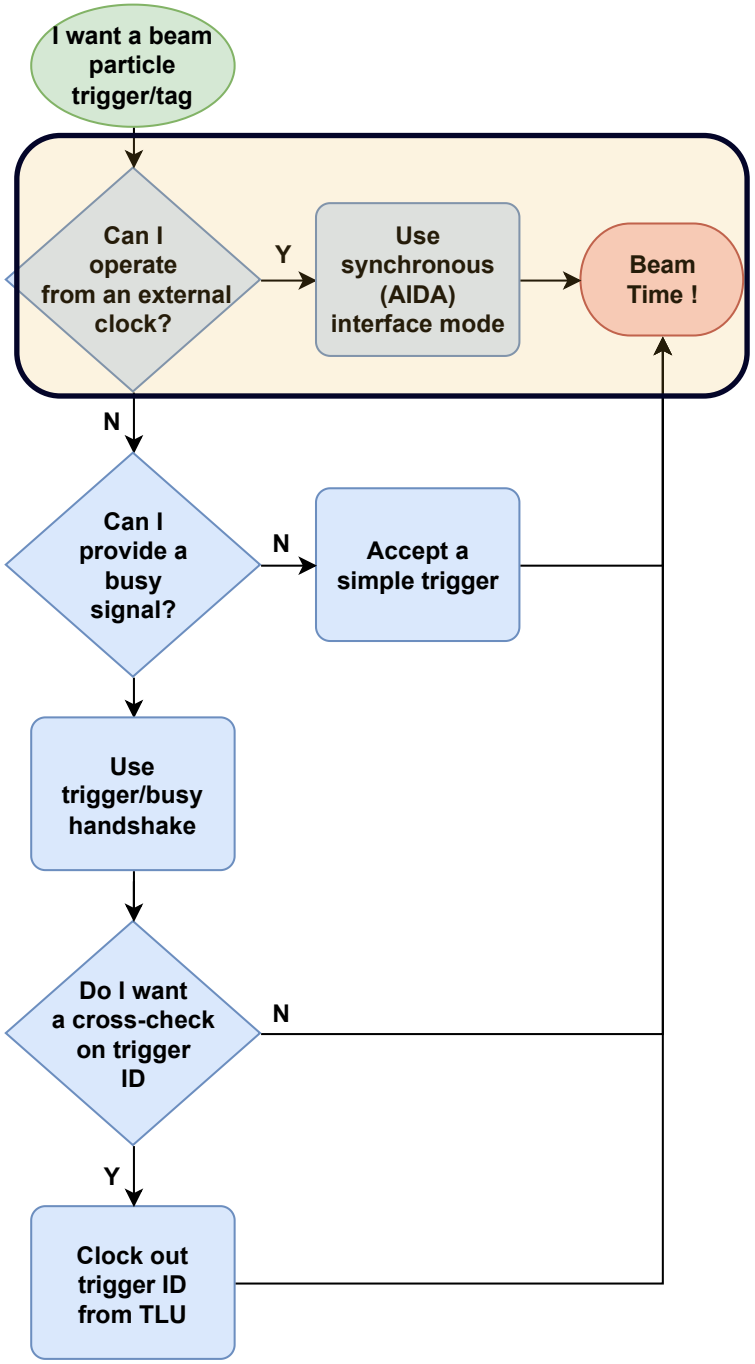
# What Does it Do?

- Sensors in beam to detect passage of particles.
  - → Electrical signals → conditioning → binary signal
- Combine signals from one or more beam sensors to produce a “trigger”
- Implementation: Box with signal conditioning and an FPGA inside



# AIDA-2020 TLU DUT Interfaces: Sync




- Can the Device Under Test accept (or provide) a clock?
  - Nominally 40MHz, can be adjusted.
- → Use synchronous ( “AIDA mode”) interface.

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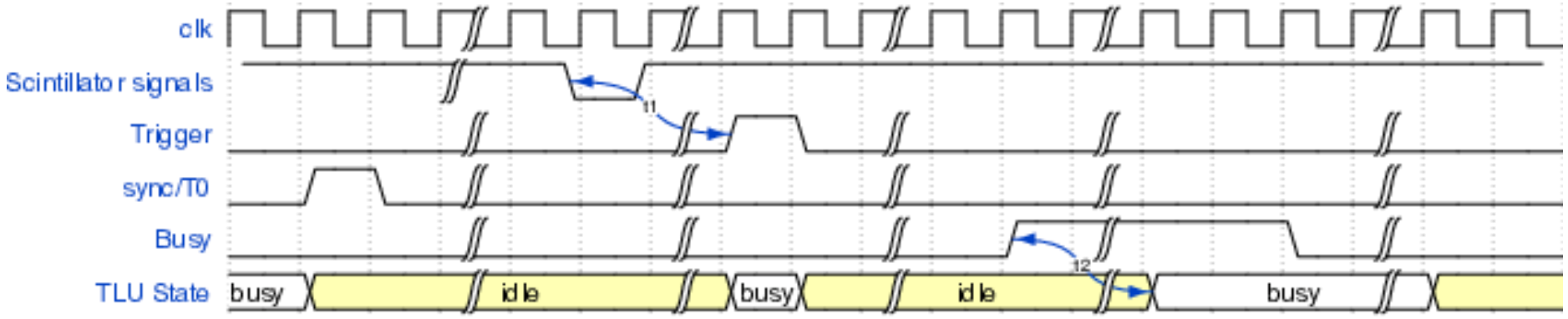
# AIDA-2020 TLU Synchronous Interface

- Common clock
- Permits higher trigger rate than asynchronous mode (no event-by-event handshake)
- Cross-check by matching trigger count and trigger time-stamp in both TLU and DUT.
  - Sync/T0 signal sent to DUT at start of run to reset timestamp

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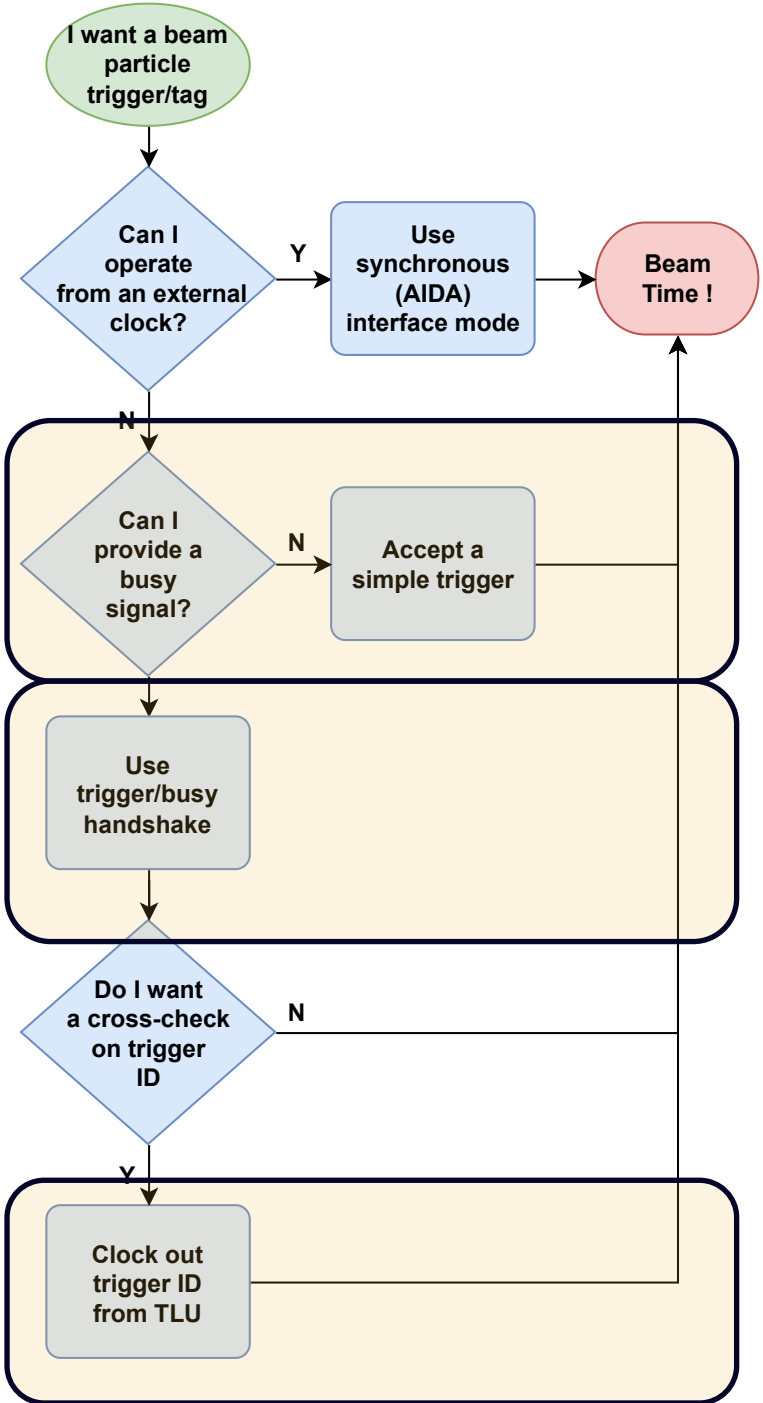
# AIDA-2020 TLU
# DUT Interfaces: Async




- Does the Device Under Test have to run on its own clock?
- → Use asynchronous ("EUDET mode") interface.
  - Beam-tests can be electrically noisy.
    - Spurious triggers
    - Missed triggers
    - Can use a trigger busy handshake for increased reliability
  - DUT can clock out trigger ID to provide cross-check

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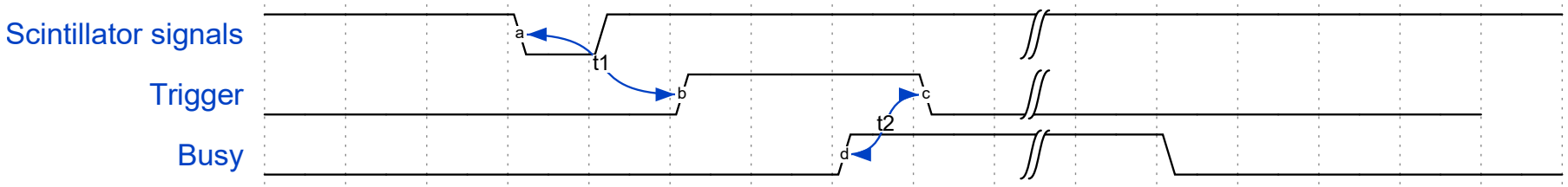
# AIDA-2020 TLU Asynchronous Interface

- Asynchronous “EUDET mode”
  - No common clock between TLU and DUT.
  - Trigger/Busy handshake
    - (Trigger is only released when DUT acknowledges)

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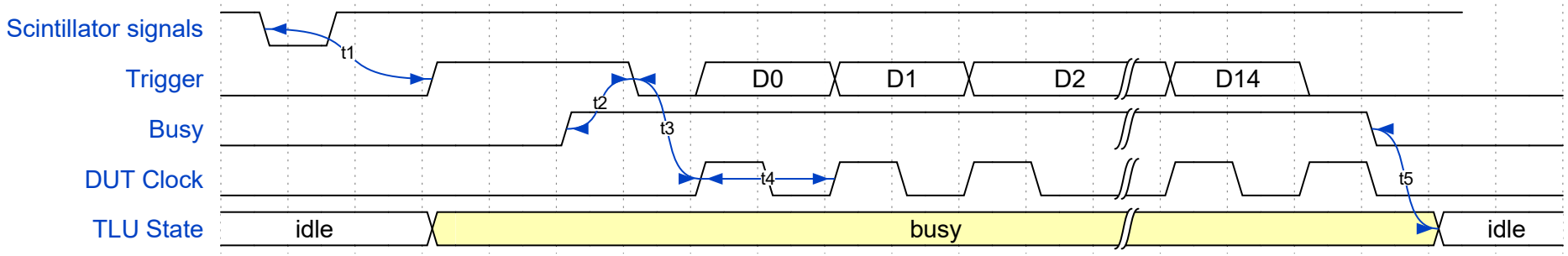
# AIDA-2020 TLU Asynchronous Interface

- Asynchronous “EUDET mode”
  - No common clock between TLU and DUT.
  - Trigger/Busy handshake (configurable)
  - DUT can clock out trigger number from TLU
    - Output on trigger line
    - Provides event-by-event cross-check

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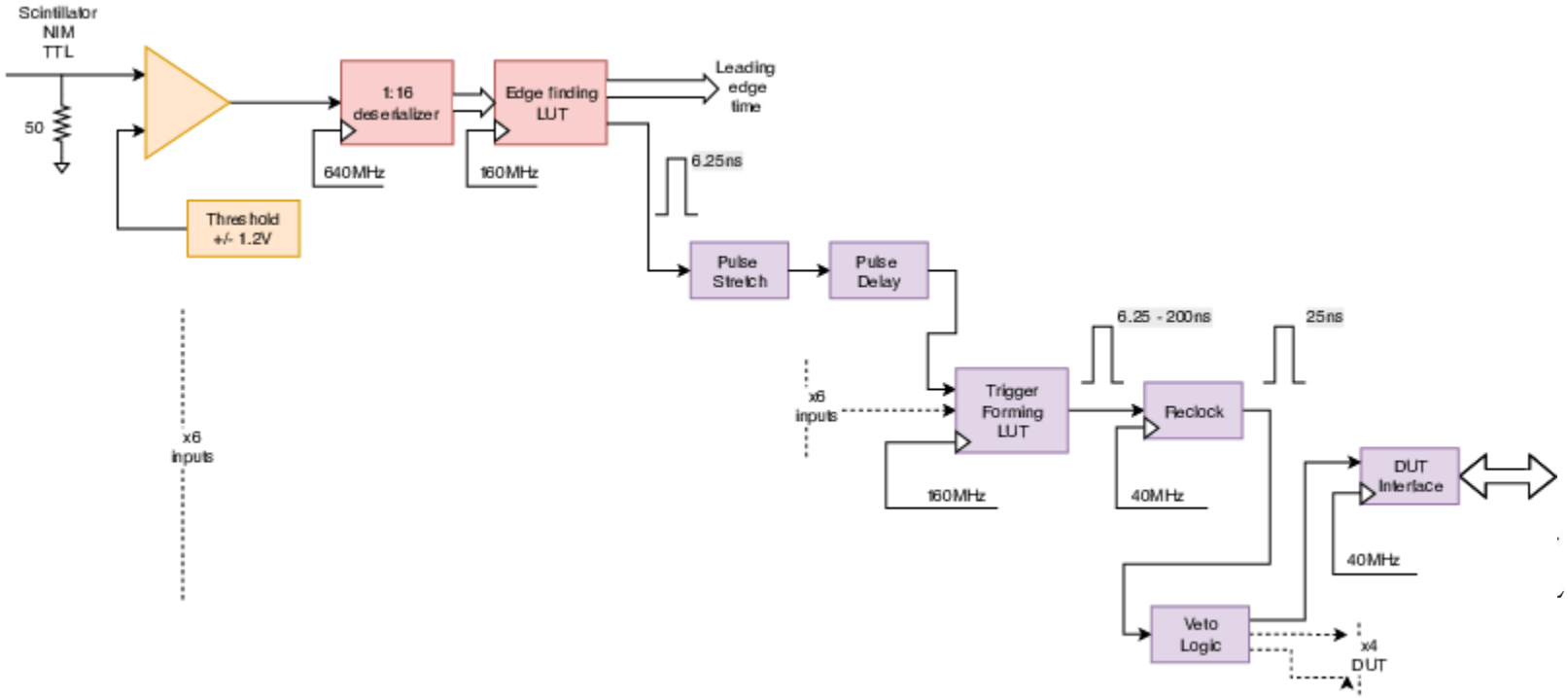
# Trigger Logic

- Inputs clocked at 160MHz (nominal)
- Input signals can be delayed and/or stretched in units of 1/160MHz
- Signals from the 6 inputs fed into a look-up table
- Trigger output synchronized to clock fed to DUT (40MHz nominal)
- State of all inputs recorded at point that trigger “fires”
  - Can be used to tag events – e.g. Cherenkov information.

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# Documentation

- https://doi.org/10.1088/1748-0221/14/09/p09019 "The AIDA-2020 TLU: a flexible trigger logic unit for test beam facilities" , JINST
- Open Hardware project "AIDA-2020 TLU"
  - https://ohwr.org/project/fmc-mtlu
  - Hardware design files https://ohwr.org/project/fmc-mtlu-hw/
  - Firmware source code https://ohwr.org/project/fmc-mtlu-fw/
- User manual https://ohwr.org/project/fmc-mtlu/blob/master/Documentation/Main_TLU.pdf

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# Firmware

- Control and readout of time-stamps with UDP/IP 1 Gbit/s Ethernet
  - IPBus: https://ipbus.web.cern.ch/
- Ipbb build system
  - Scriptable build. Working on CI
- Open Source
  - https://ohwr.org/project/fmc-mtlu-fw/

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# Software

- All versions of TLU integrated with EUDAQ DAQ software.
  - Run control
    - Configuration
    - Monitoring
  - Readout of trigger timestamps
  - https://eudaq.github.io/

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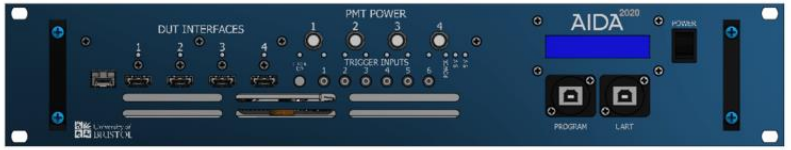
# Existing - AIDA-2020

- Current production version
- 6 trigger inputs
- 4 DUT connections
  - LVDS on HDMI
    - But direction of each line can be swapped in hardware to allow different firmware mapping
- Low jitter clock
- Hardware permits optical distribution of clock/trigger
- In small desktop case or rack-mount case



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# Why a New TLU?

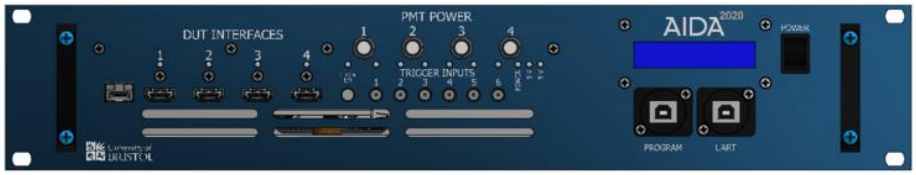
- Increasing need for more precise timing
  - (AIDA-2020 TLU has ~ 1ns time-stamping accuracy)
- User requests for more trigger inputs
  - (Number of DUT interfaces can be increased in common clock mode using external fanout – up to 30 DUTs)
- A “PicoSecond TLU” being developed as part of the AIDAInnova programme.

# Picosecond TLU


AIDA-2020 TLU connected to beam telescope

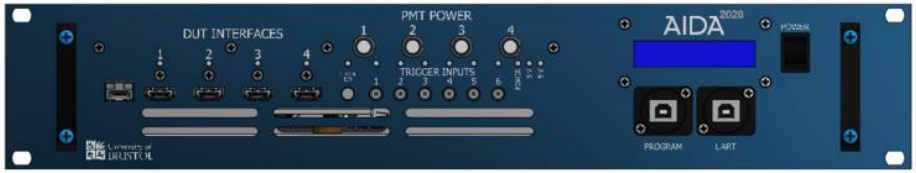
- Timing specification:
  - Clock jitter < 10ps RMS
  - Timing-stamping of input signals O(10ps) RMS
- Backwards compatible with AIDA-2020 TLU
  - Same signals on DUT connections
    - trigger/busy/DUT-clk in EUDET-mode
    - Global-clk, trigger, busy, shutter, T0 in common-clock mode

# Picosecond TLU - I/O




- Trigger inputs
  - Probably 8
    - (c.f. 6 for AIDA-2020 TLU)
  - ADC for time-walk correction
    - (c.f. threshold discriminator in AIDA-2020 TLU)
  - TDC with O(10ps) bins
    - Either implemented in FPGA or external PicoTDC (3ps bins)
  - Aim to contribute less to timing uncertainly than detector.

# Picosecond TLU - I/O




- Device Under Test (DUT) connectors
  - Compatible signal definitions as AIDA-2020 (also LVDS)
  - Increase number from 4 to 6
  - Move to “Display Port” from HDMI
    - Mechanically more robust.
    - Five differential pairs (c.f. 4 in HDMI)
    - Passive adaptor to HDMI if needed
- Run internal logic faster →reduce latency (currently O(100ns))

# PicosecondTLU - Rate Capability

- Same goal for rate capability as AIDA-2020 TLU:
  - Instantaneous rate ~ 10MHz:
  - Sustained rate ~ 1MHz
    - Internal buffer in current AIDA-2020 TLU only 4k events.
      - Aiming to expand to O(10M events)

# Picosecond TLU - Optical Interface

- Retain optical interface introduced in AIDA-2020 TLU
  - Can distribute timing information over fibre
  - Used for ProtoDUNE-SP
    - https://doi.org/10.1016/j.nima.2019.04.097
  - fibre bandwidth much larger than copper cable.
    - Possibility of more precise timing over longer distances
      - Clock jitter (endpoint w.r.t. master) of ~ 2ps (sigma) measured

# Picosecond TLU - Timing reference

- Testing pico-second detectors requires pico-second time reference
  - TLU timing only as good as reference
- Some beam-line users will bring their own time reference detectors. Some would benefit from precise time reference at beam-line.
- Could use, e.g. Cherenkov light and high-speed photo-detector
  - Used for “TORCH” LHCb upgrade beam-tests
  - MCP-PMT single photon jitter 66ps FWHM
    http://www.photek.co.uk/pdf/datasheets/detectors/DS006%20Photomultiplier%20Tube%20Datasheet%20issue%202.pdf
  - With many photons, timing precision ~ 10ps

Bare MCP-PMT module
(photo-cathode facing down)

Taken from
http://dx.doi.org/10.1016/j.nima.2016.06.087

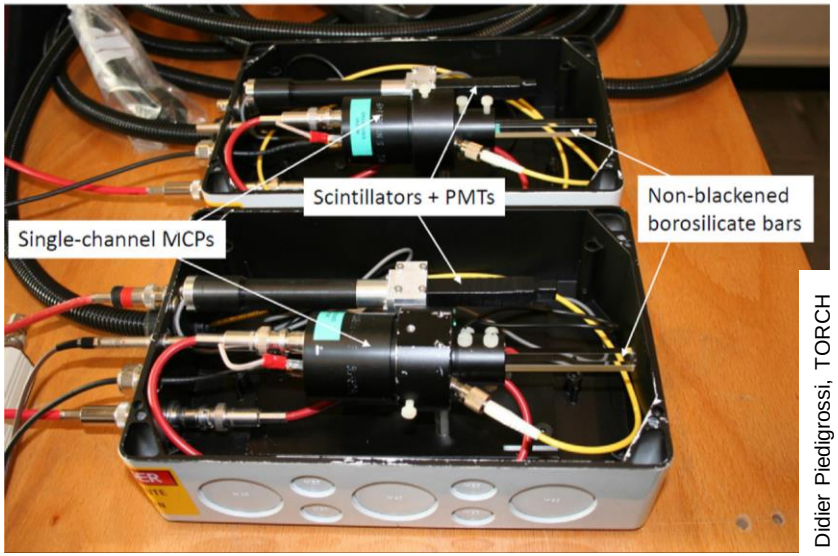
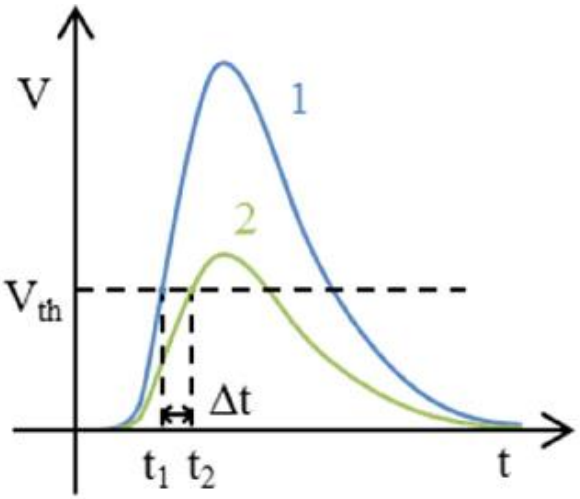



Photo: Didier Piedigrossi, TORCH

# Trigger Inputs

- Combine threshold comparator with 160MSample/s ADC for time-walk correction
- Prototyping analogue part
- CERN PicoTDC ASIC for time-stamping
- Optimizing timing resolution for small amplitude fast rise signals.
- Use case: single-anode MCP-PMT used as a timing detector



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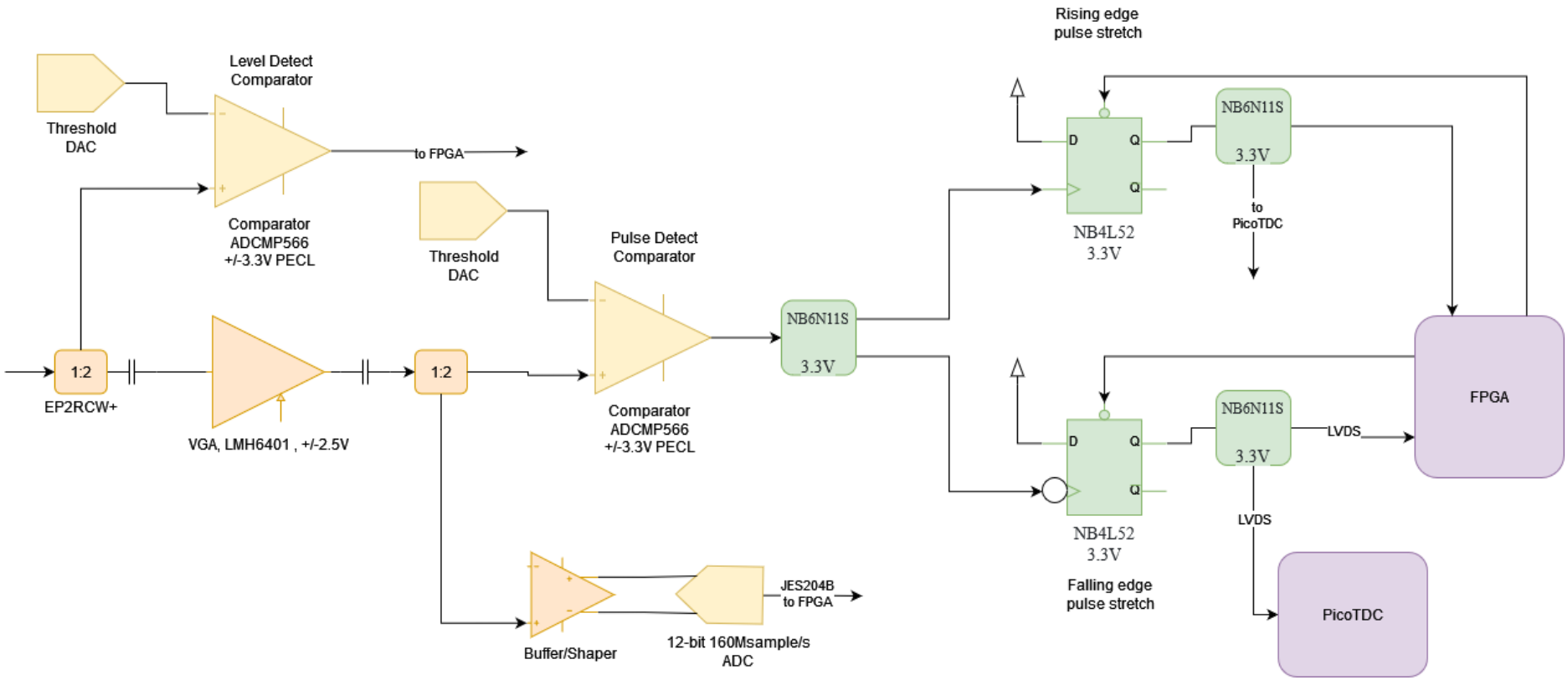

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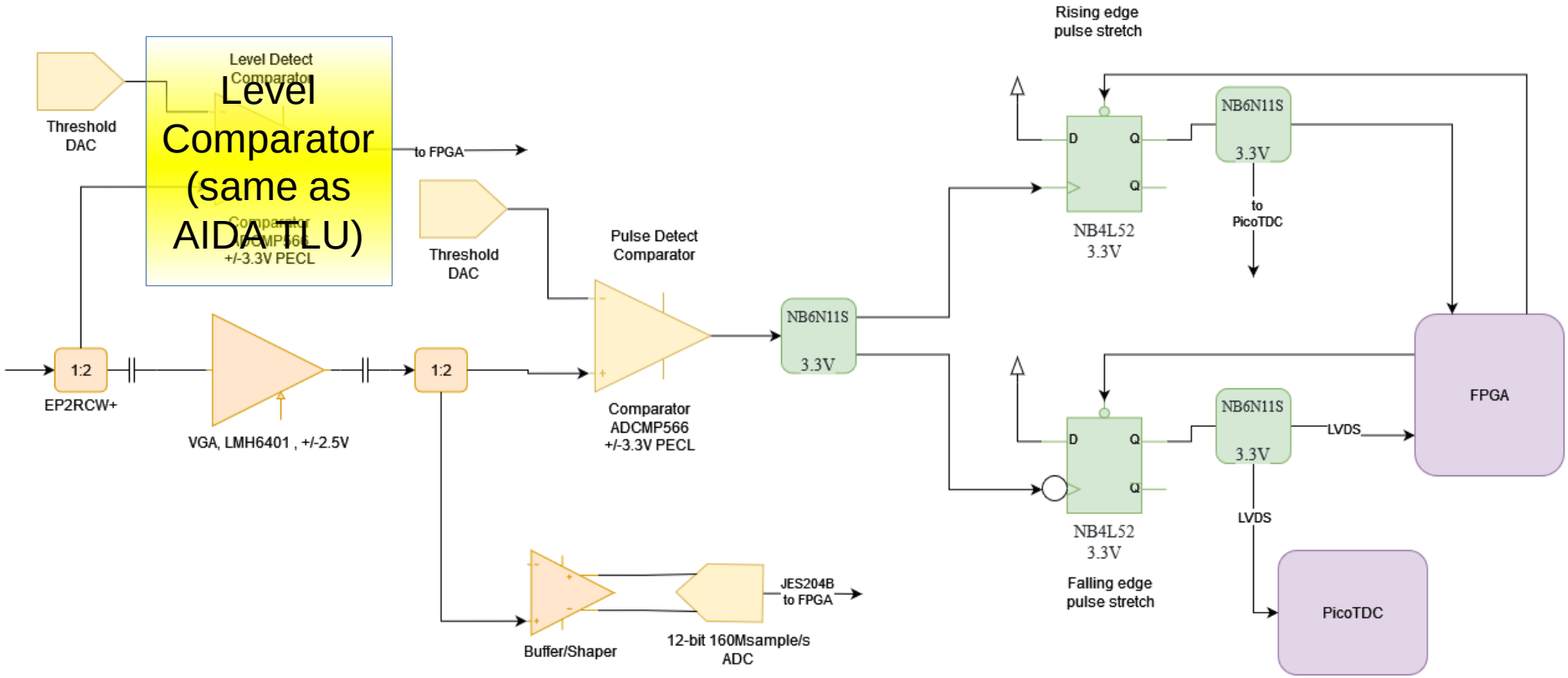

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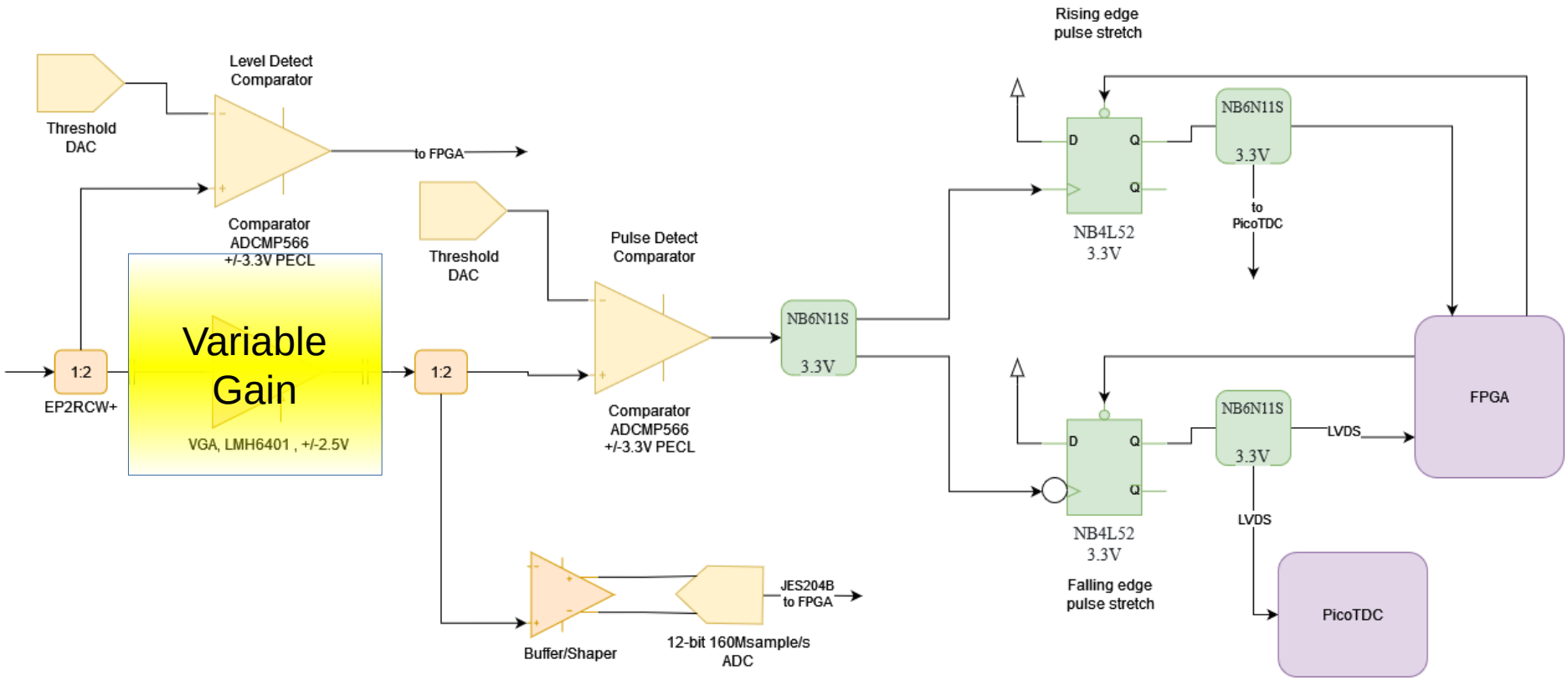

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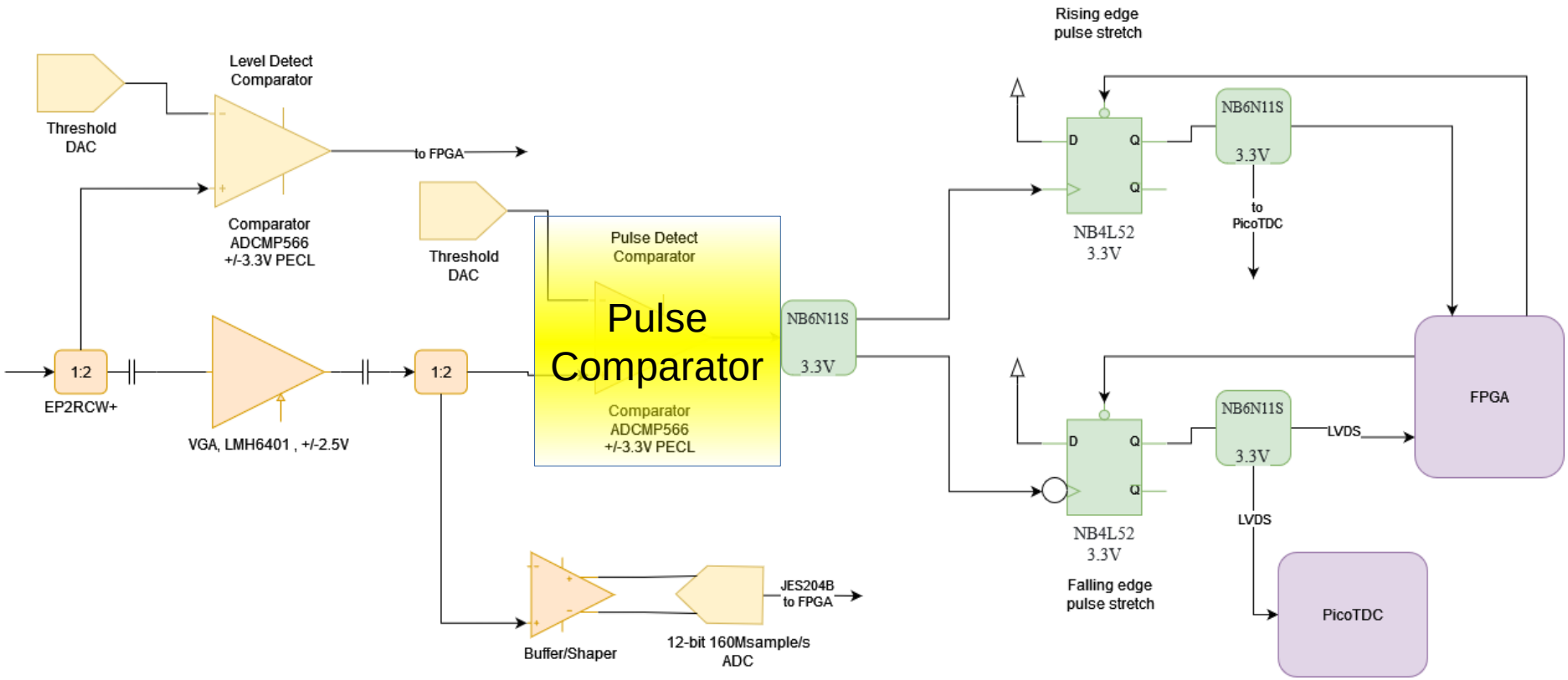

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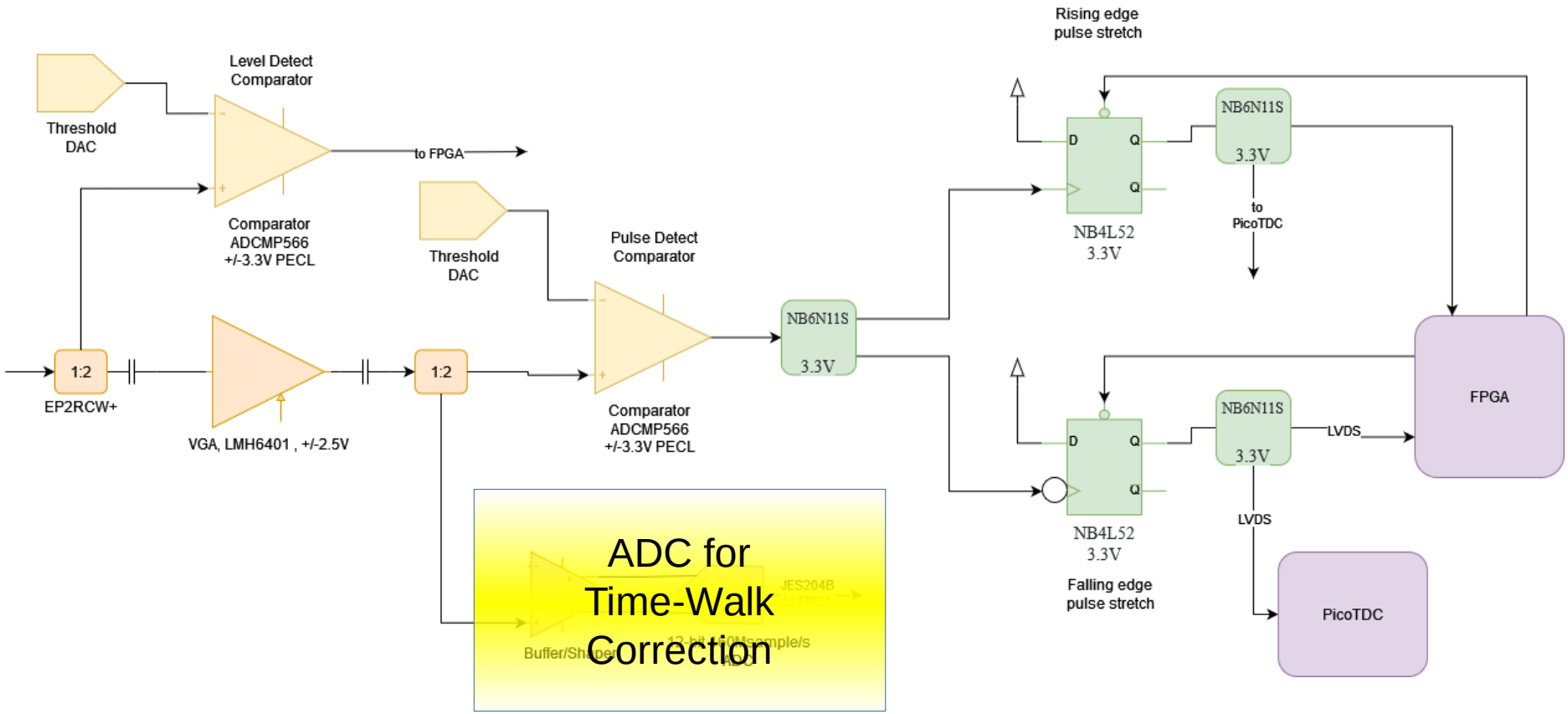

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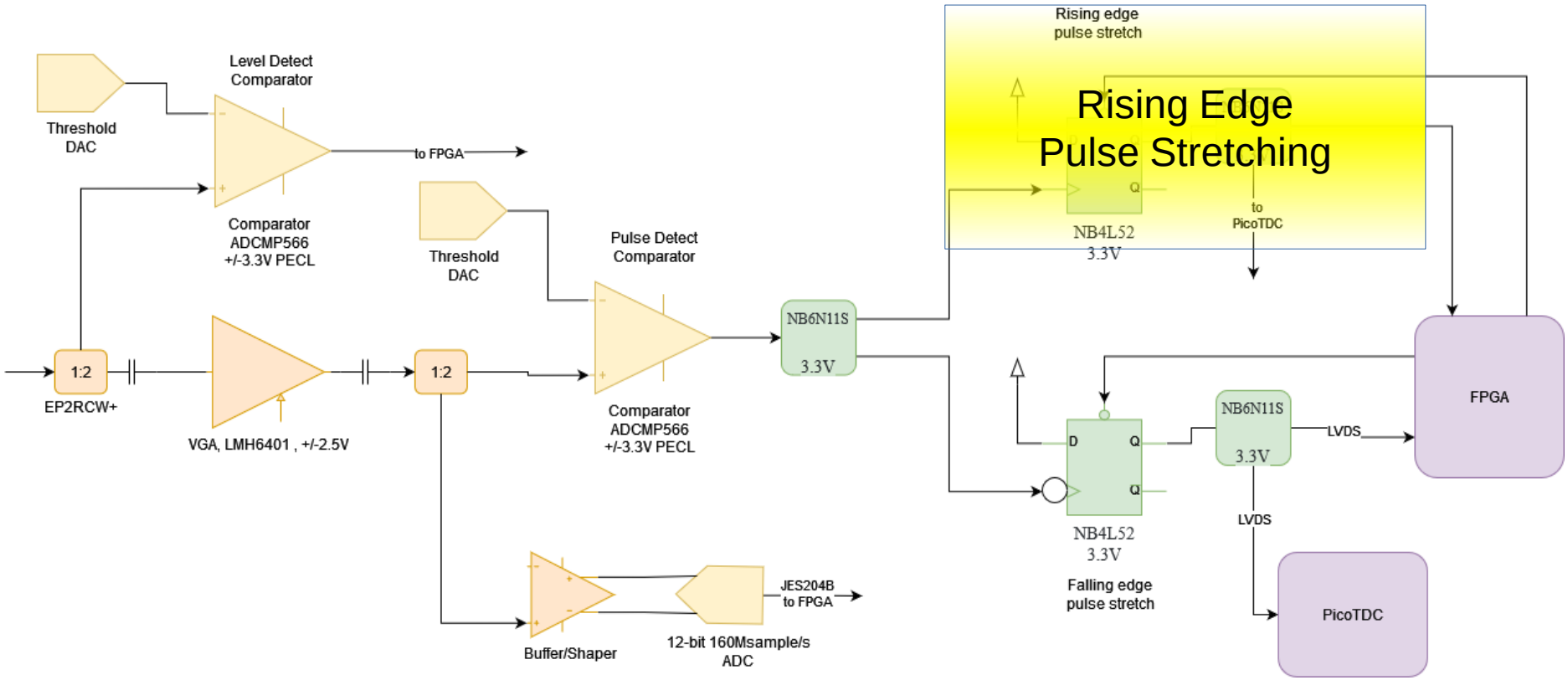

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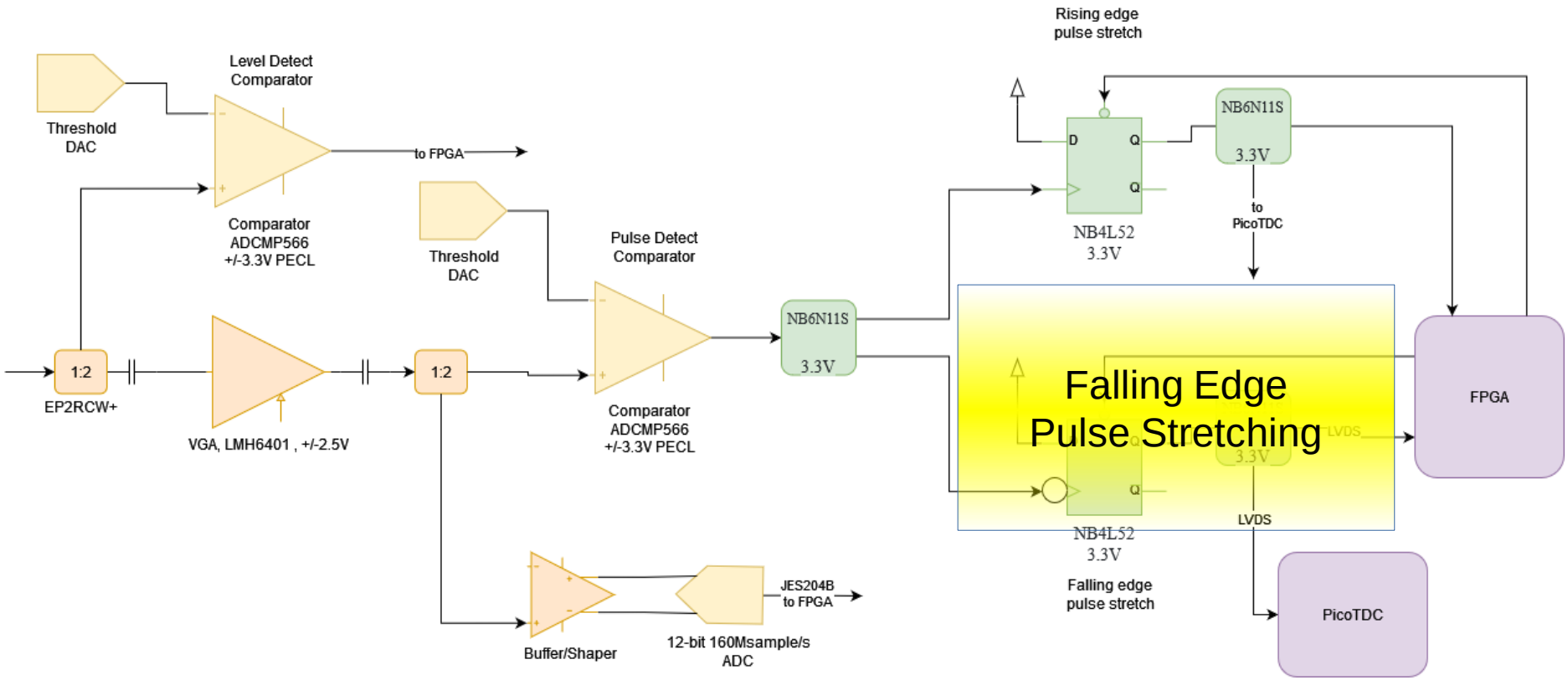

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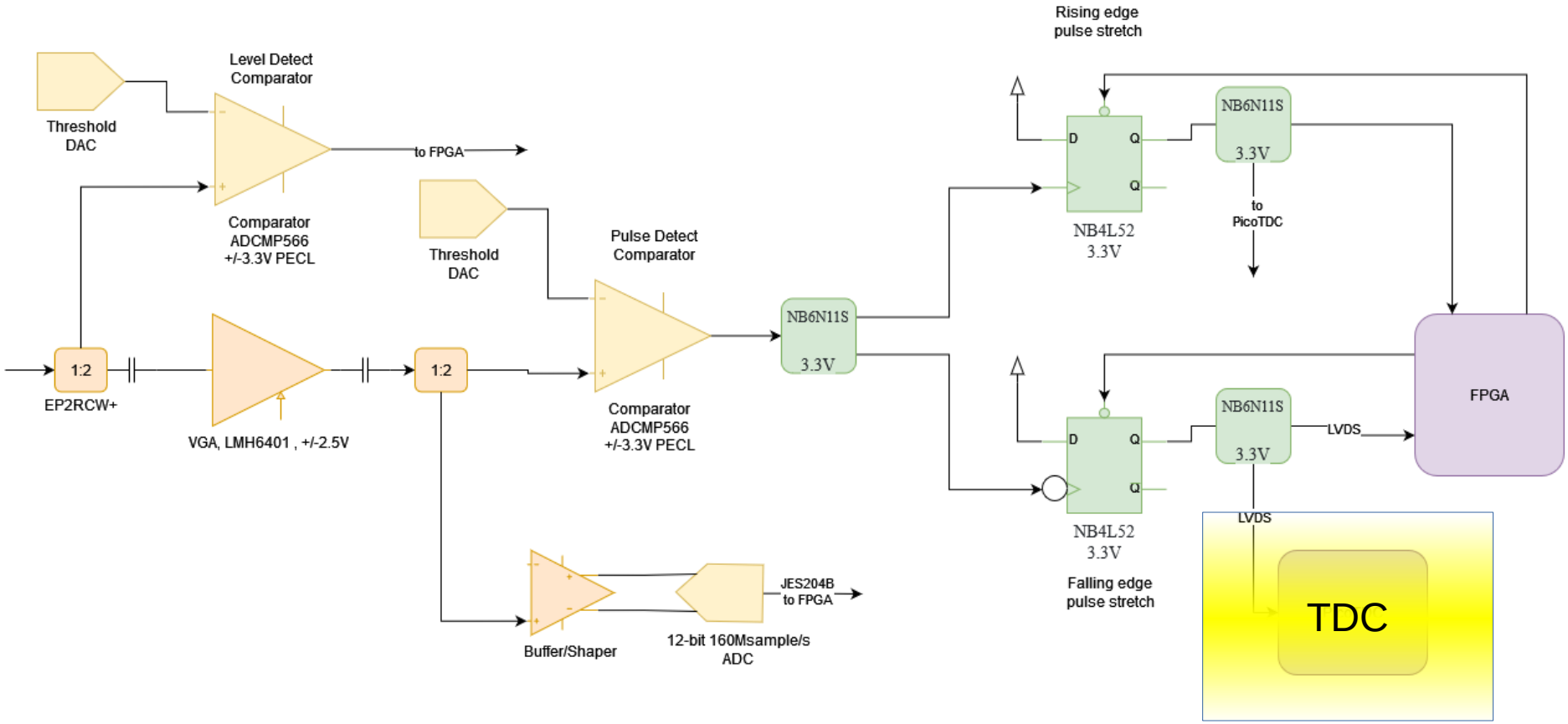

# AIDA-Innova TLU Schedule

- Test board for trigger inputs being produced
  - Ready June ‘24
  - Will be tested with MCP-PMT
- Prototype of full hardware ~ October
- Initial firmware and integration ~ Jan ‘25

# Summary

- The AIDA(-2020/Innova) TLU provides a common hardware and software interface to beamlines
- AIDA-Innova TLU backwards compatible at the hardware signal level with EUDET / AIDA-2020 / AIDA TLU
  - Data format different – will be “hidden” by EUDAQ
- Pico-second detectors need pico-second infrastructure
  - Aiming for < 100ps timing

# Backup

# Why a New TLU?

- From AIDAinnova grant agreement, part A:
  - "To provide a O (100) ps timing for particle hits, a dedicated timing layer as well as a trigger logic unit (TLU) with picosecond-timing support need to be developed, integrated and installed at both CERN and DESY. The precision timing layer will be provided by a TimePix4 plane, which will be fully integrated into the telescope hardware and the EUDAQ2 framework. We foresee having such planes available at all beam lines. To provide an ultimate timing resolution of 30 ps, an LGAD plane based on current developments for the HL-LHC will be included in the EUDET-style pixel telescopes. In order to benefit from this exquisite timing, the TLU needs to provide a stable clock with a 10 ps or better stable edge, which will be part of the AIDA TLU upgrade."
- NIKHEF/Nikhef, UNIVBRIS, CSIC-IFCA, DESY,UCL, USC

# AIDA-2020 TLU DUT “Shutter”

- Some detectors can only capture data with a low duty cycle
- In many beam-lines particle are only present a certain times
  - DESY – 50Hz cycle
  - CERN – SPS cycle
- Detectors active period should occur when particles are present
- → Signal from accelerator can be used to generate a “shutter” signal sent to DUT