AIDA-2020
Trigger Logic Unit (TLU)

David Cussans
BTTB7 , CERN , 17th January 2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168.

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Introduction

- During beam-test frequently want to:
  - Synchronize a detector under test (DUT) with external signals
    - E.g. scintillators to trigger on beam particles
    - Cherenkov detectors (for PID)
    - Accelerator (e.g. Spill signals, max-energy)
  - Synchronize with other detectors
    - E.g. With beam-telescope

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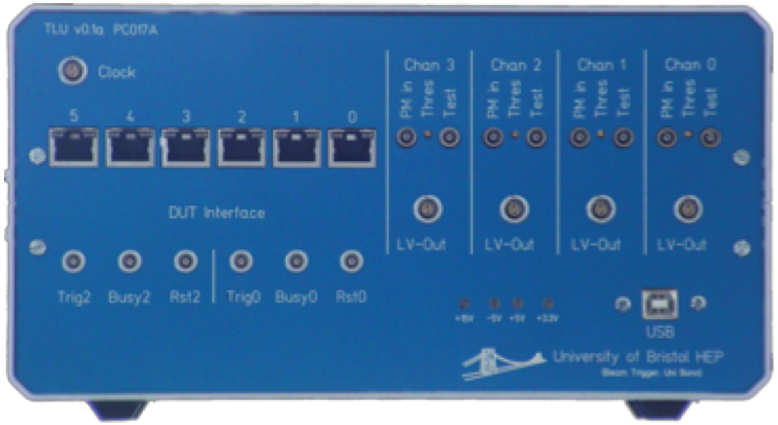
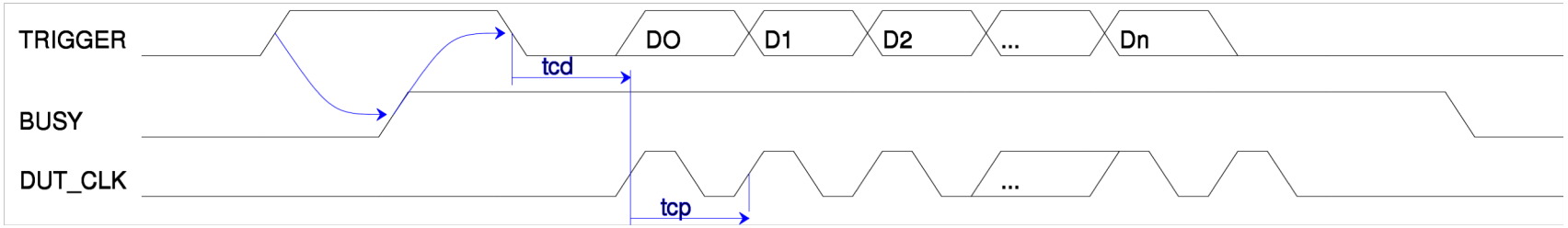
EUDET TLU

- Originally designed for use with beam-telescope with low beam rate
- Handshake designed to allow independent clocks
  - (Optional) transfer trigger number from TLU → DUT





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AIDA-2020 TLU

- EUDET TLU designed for ILC tests.
  - Telescope with “rolling shutter” MAPS pixel sensors (Mimosa family).
  - Trigger rate of EUDET system limited by frame readout to ~ 5kHz
    - → increasing use of beam telescopes by LHC detectors. Want higher trigger rate
  - No common clock → Difficult to interface to self-triggering detectors
    - E.g. some calorimeters.
  - FPGA inside EUDET TLU becoming obsolete.
- →New TLU designed as part of AIDA-2020 project
  - Open hardware, Open firmware (https://www.ohwr.org/projects/fmc-mtlu)

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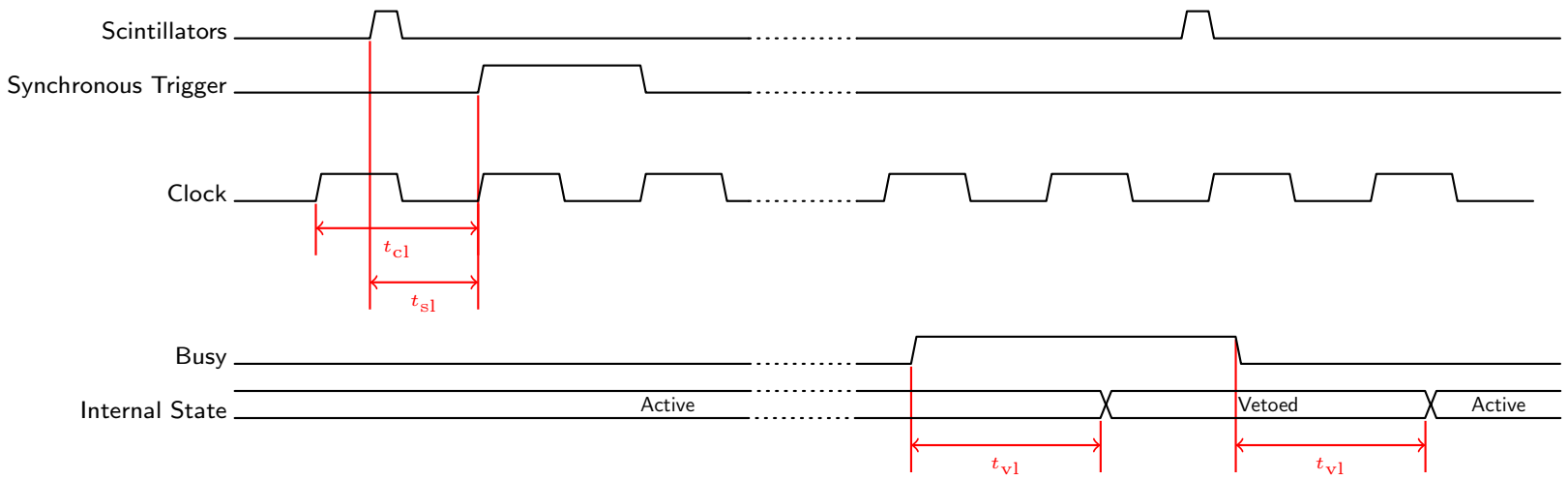
Synchronous (“AIDA”) Interface



- DUT operates with same clock at TLU
- Allows faster interface
- Cross check by matching time-stamp and trigger number
- AIDA TLU can mix asynchronous (EUDET) and synchronous (AIDA) mode interface

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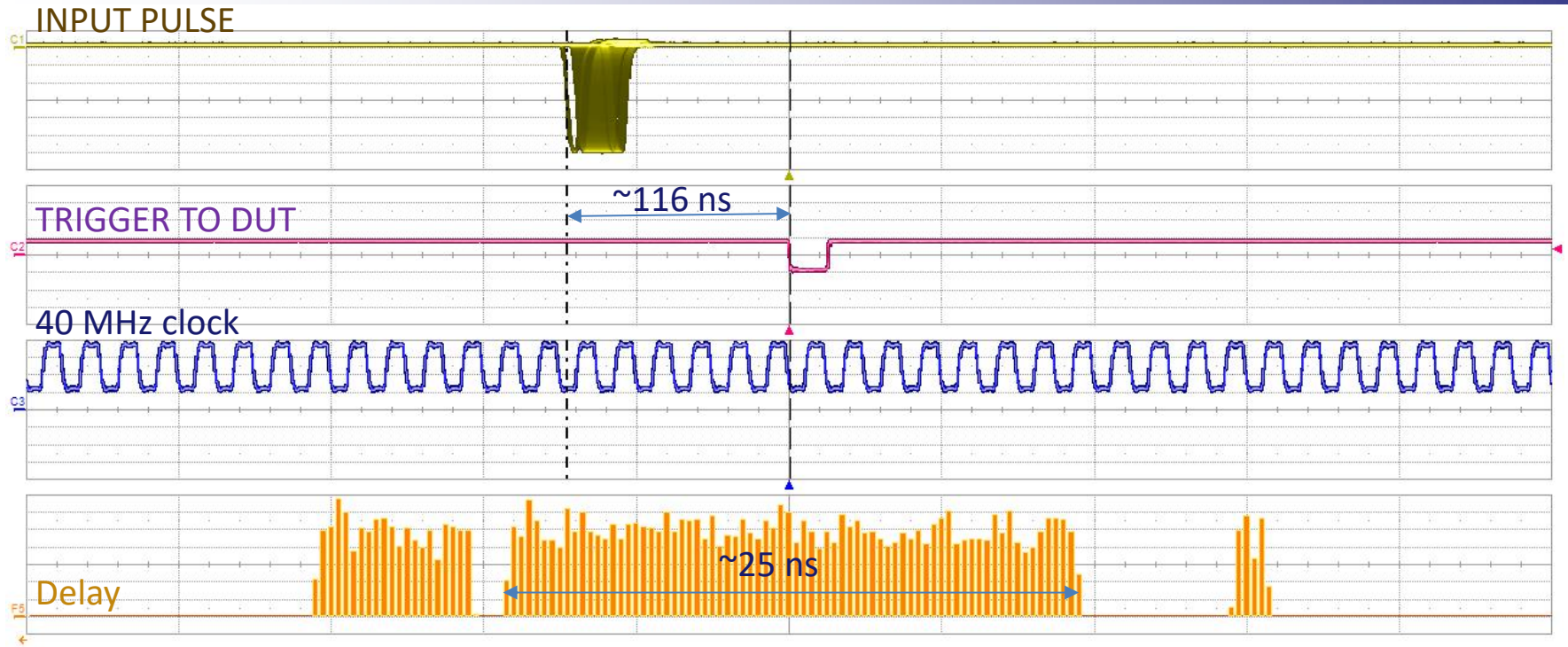
Synchronous Interface latency



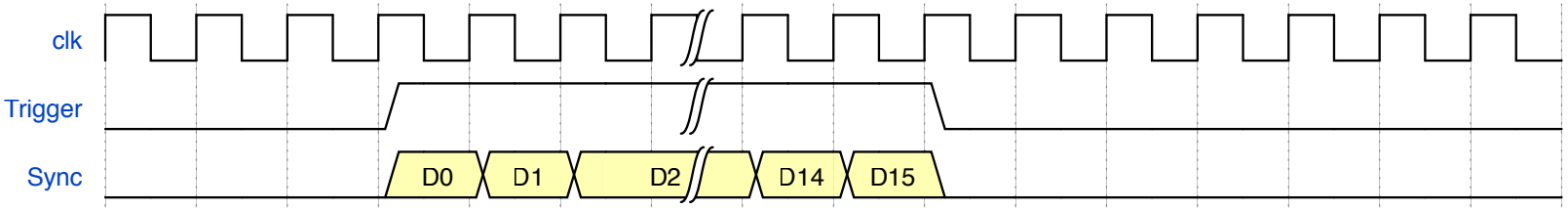
Measure	P1:dt@lv(C1,C2)	P2:freq(C4)	P3:- - -	P4:- - -	P5:freq(C4)	P6:- - -	P7:- - -	P8:- - -
value	135.0389 ns	39.6383 MHz						
mean	128.499 ns	40.0063 MHz						
min	114.7949 ns	38.8166 MHz						
max	146.1616 ns	41.2087 MHz						
sdev	7.984 ns	271.6 kHz						
num	14.050e+3	607.737e+3						
status	✔	⚠						

C1 DC1M 200 mV/div 595.0 mV | C2 DC50 1.00 V/div 0 mV offset | C3 DC1M 500 mV/div 0 mV offset | F5 hist(P1) 10.0 #/div 5.00 ns/div 5.000 k#

Timebase 0 ns 100 ns/div 20 kS 20 GS/s | Trigger C2 DC Stop 280 mV Edge Neg
X1= -146.10 ns ΔX= 146.60 ns
X2= 500 ps 1/ΔX= 6.821 MHz

Synchronous Interface with Trigger Number

- Synchronous (“AIDA”) interface mode will be extended to transmit trigger number
  - Transmitted by TLU
  - Synchronous with transmitted clock.



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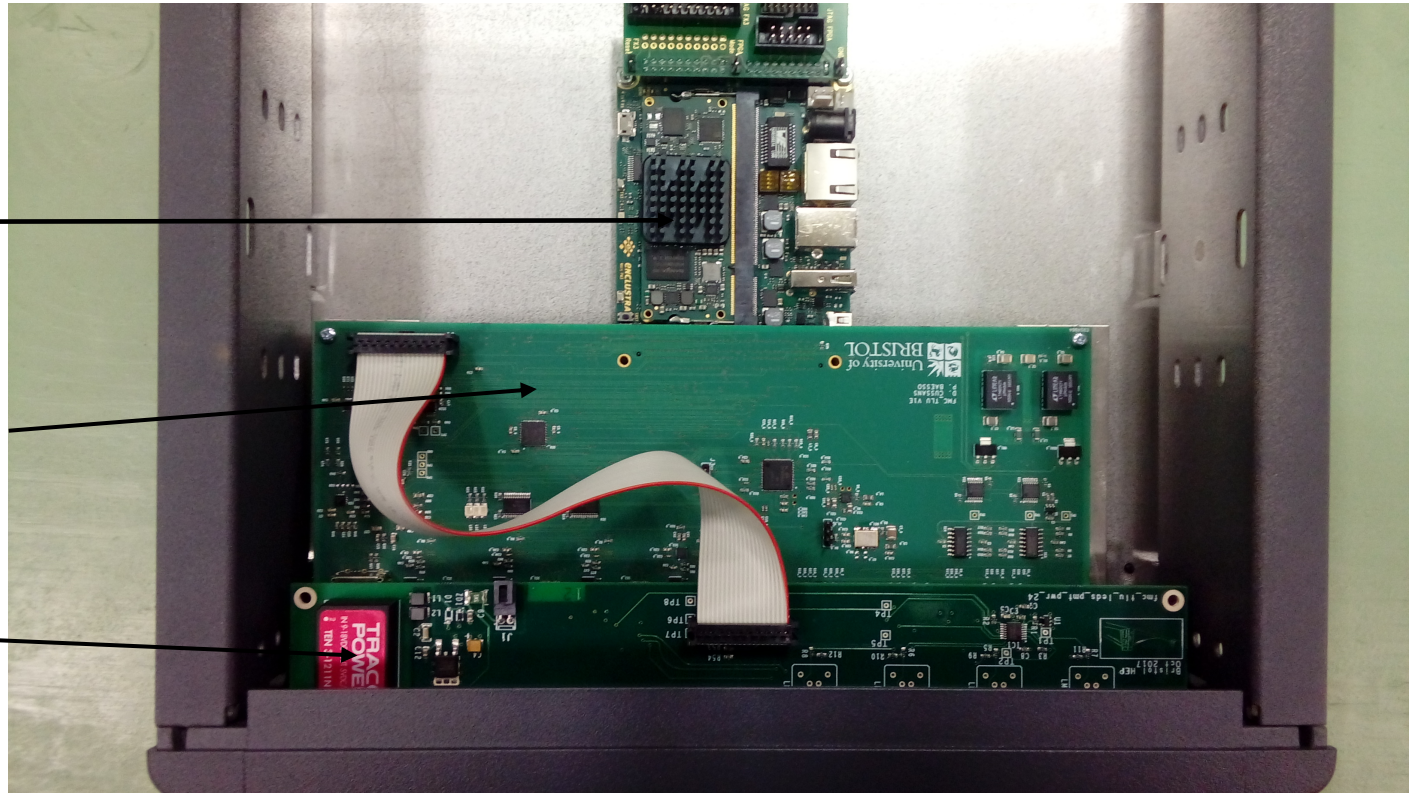
TLU Assembly

FPGA Carrier

TLU Daughter card

LED + PMT Power



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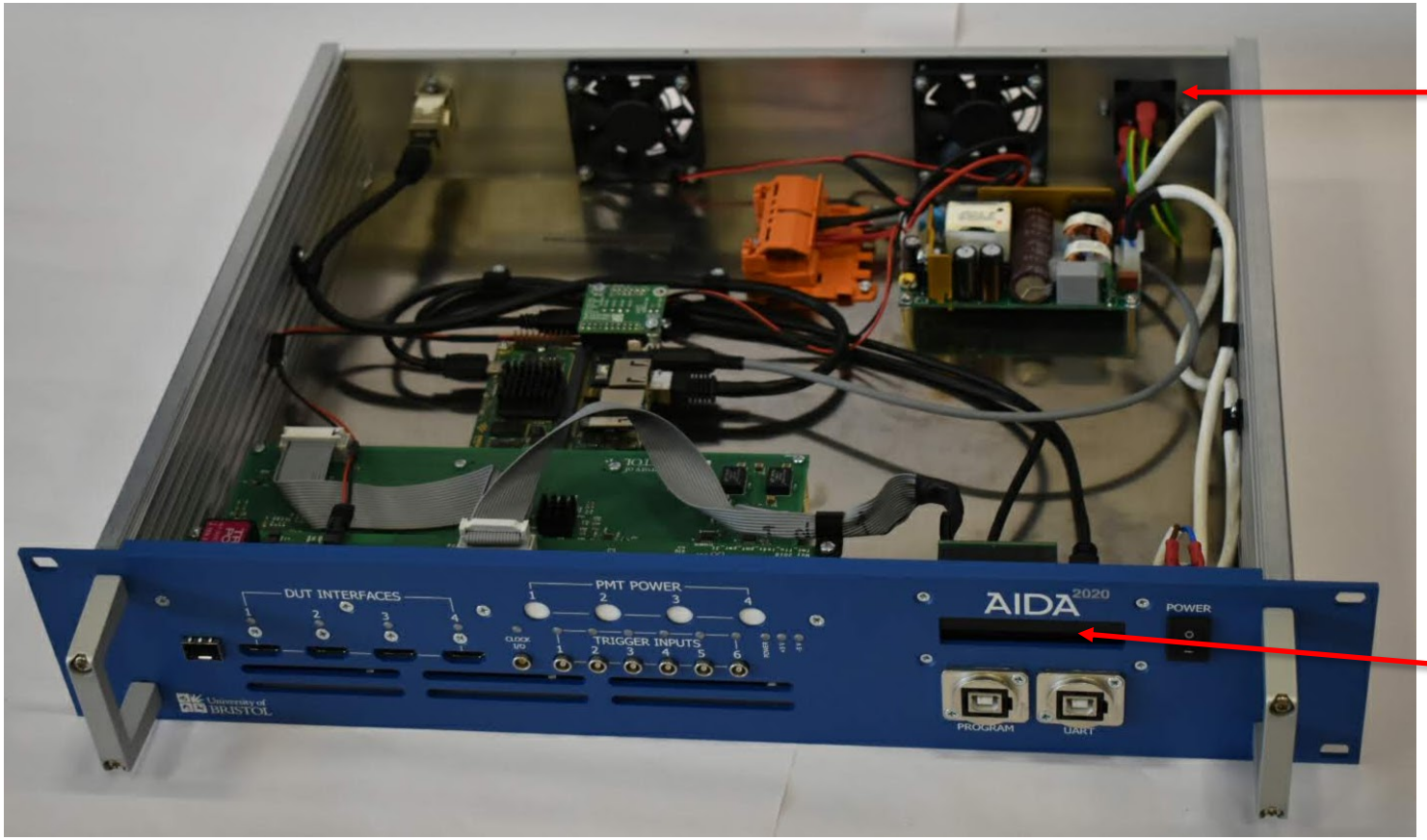
Desktop Enclosure

19-inch enclosure



110V – 240V power

2 x 16 character display

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TLU Parameters

- Four Device Under Test (DUT) Interfaces
  - Five LVDS signals on HDMI connectors
    - (chosen to be compatible with CALICE)
    - Converted by passive “dongle” to RJ45 interface used by EUDET TLU
    - Converter to/from LVDS available (thanks to CMS pixel upgrade group)
- Six trigger inputs
  - +/- 5V range
  - Adjustable threshold +/- 1.3V
  - Fully configurable trigger “mask”
- Clock input or output
  - Adjustable frequency, typically 40MHz
  - LVDS clock input. Either on 2-pole ”Lemo” or HDMI
- Optical I/O
  - Currently used for protoDUNE
  - Hardware compatible with LHC TTC format

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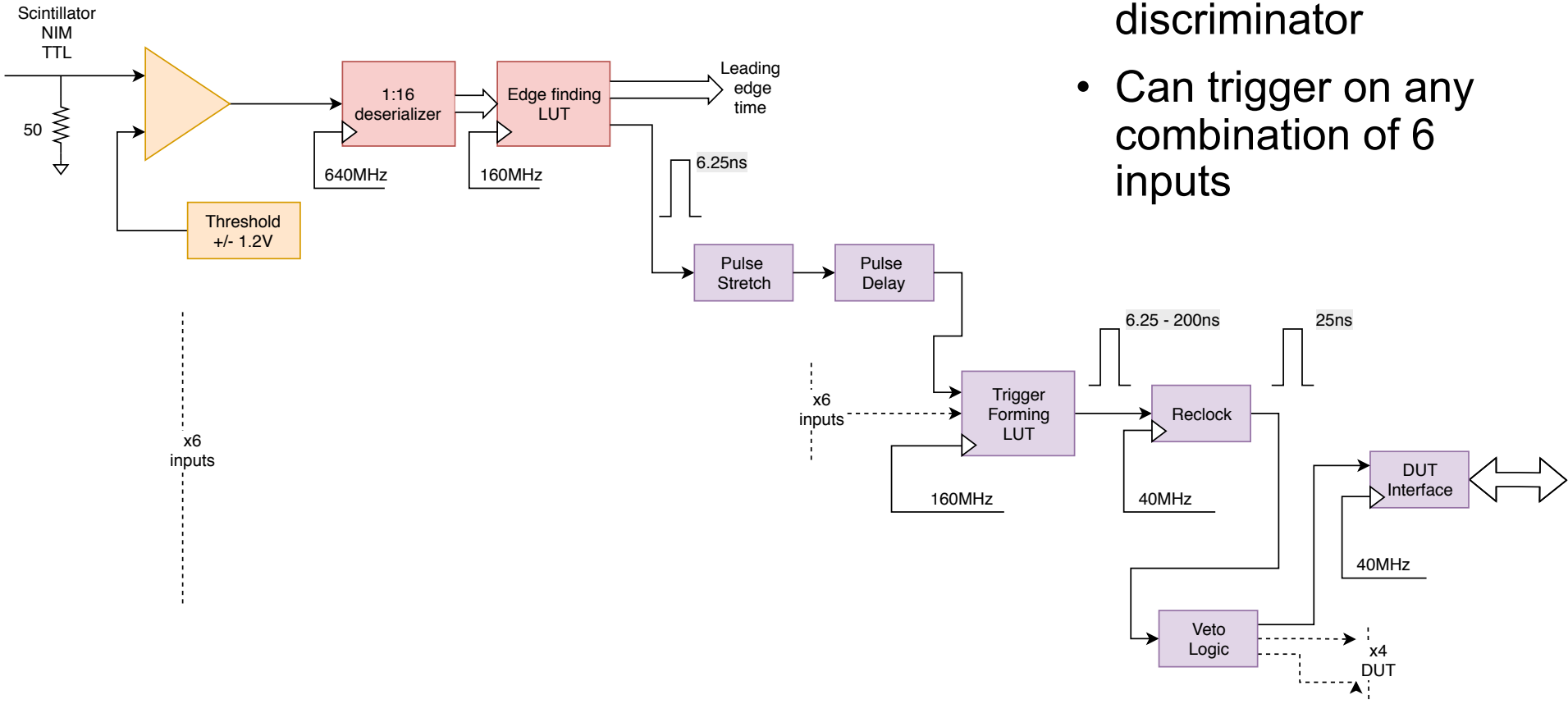
Triggering

- Simple threshold discriminator
- Can trigger on any combination of 6 inputs



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Production Status

- 19 units produced
  - 10 in benchtop , 9 in 19-inch enclosures
- Units delivered to DESY and CERN
- Available to other groups at Euro 2.2k each.
- Completed porting of firmware from old to new hardware
  - Maintain all functionality from old TLU
  - Tested new functionality (clock generator, discriminators, trigger)
  - Serial encoded clock / sync / trigger over optical fibre implemented for protoDUNE (not TTC format)

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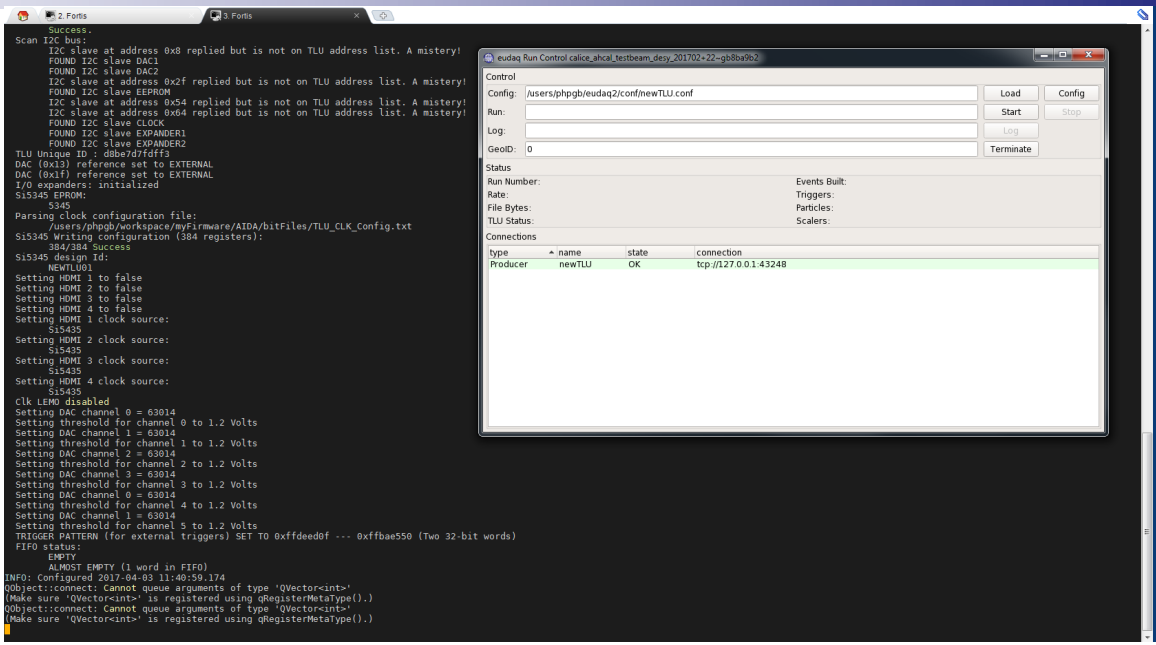
AIDA TLU integration with EUDAQ2

- Integrated with EUDAQ2:
  - Current version of TLU producer stable and working with EUDAQ2
  - Allows to configure the TLU and read data
  - Tested at CERN and DESY
  - Aiming for up to 1MHz average trigger rate
  - Testing/debugging ongoing



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Tests

- DESY, October 2017
  - Interfaced AIDA-2020 TLU with Mimosa telescope
    - Used EUDET (trigger/busy/trigger-number) hand-shake
  - Successfully took data with telescope
    - Demonstrated backwards compatibility with EUDET TLU

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Tests

- CERN, PS (East Area) T9, November 2017
  - Interfaced AIDA-2020 TLU with
    - Mimosa telescope (EUDET handshake)
    - FE-I4 fast pixel plane (EUDET handshake)
      - Thanks to Andre Rumler
    - “TORCH” project (AIDA / Synchronous handshake)
      - AIDA/Synchronous handshake
  - Successfully took data with telescope, FE-I4 and TORCH
  - TLUProducer took data
    - Records time-stamp of each trigger issued (25ns)
    - Records fine-grained time-stamp of each trigger input
    - Records which inputs fired (trigger mask may not demand all inputs fire)
      - Some inputs connected to Cherenkov detectors.

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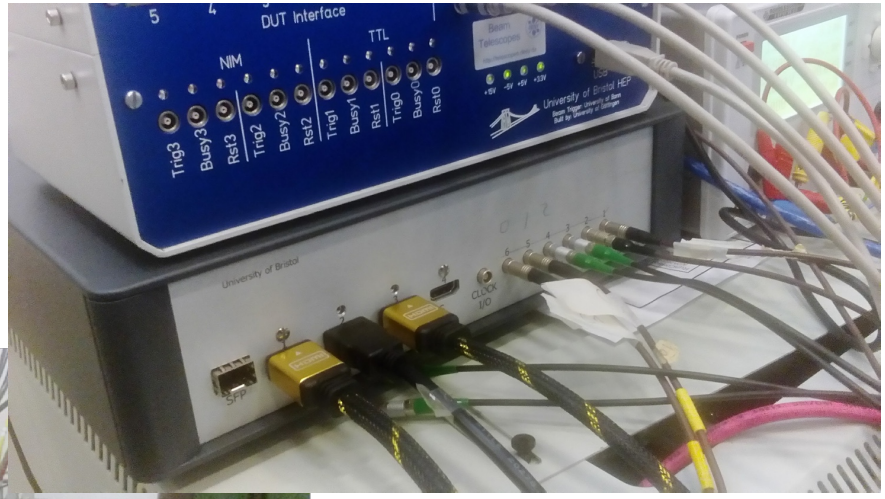
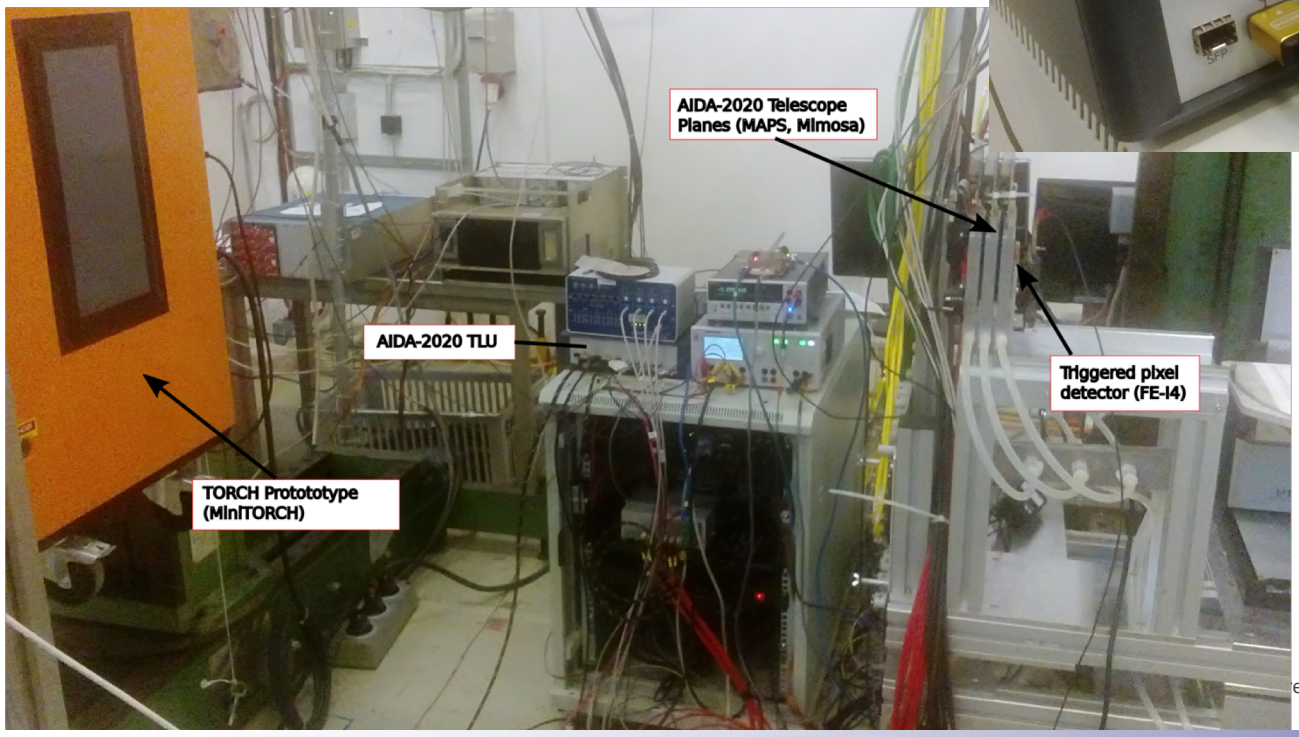
CERN East Area T9

- Used to provide clock and trigger to non-AIDA2020 beam-test readout (TORCH)





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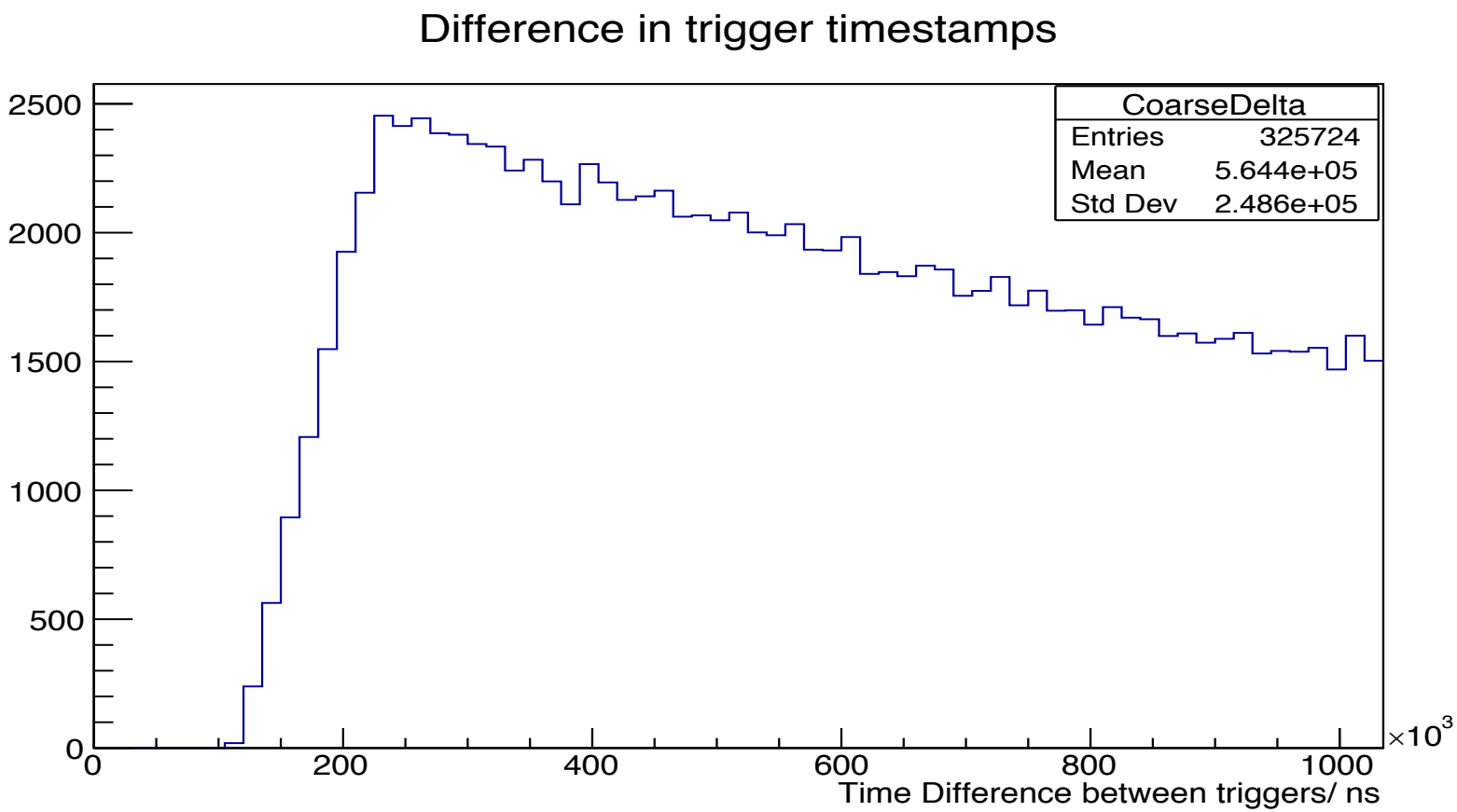
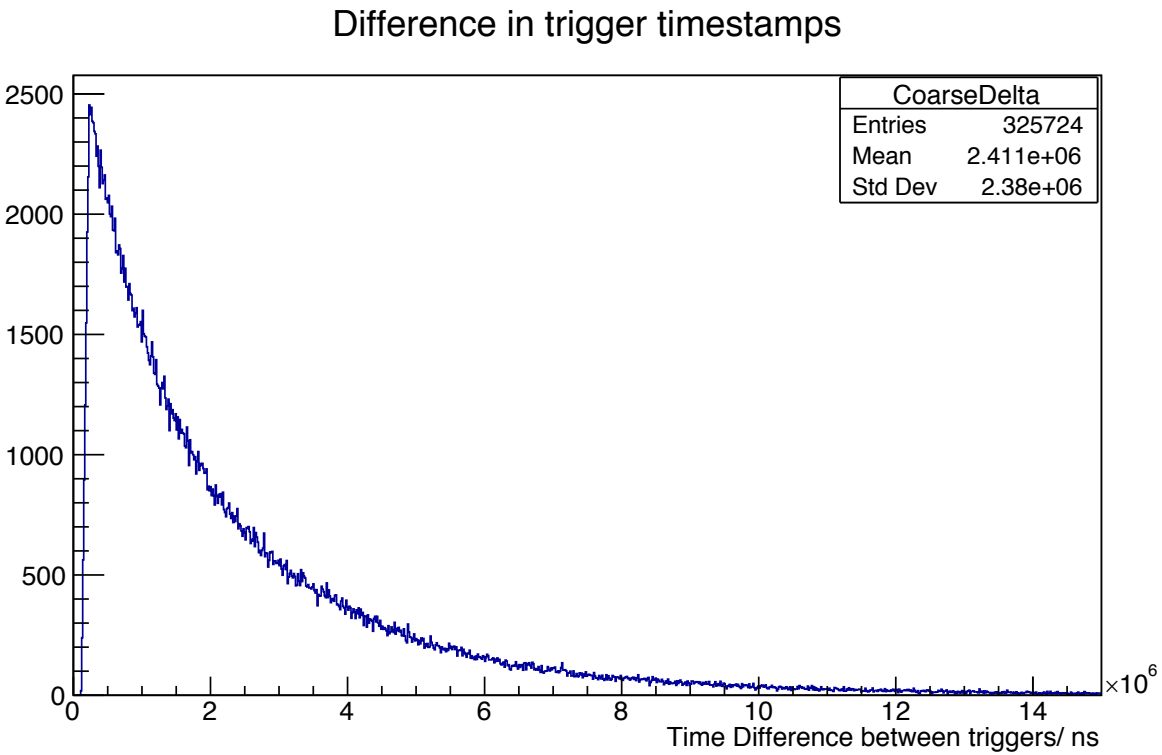
Difference between timestamps

- Mimosa telescope sets busy until two frames read out (minimum time 115μs, max 230μs)
- … this is what we are trying to avoid with “mixed mode”



Difference between timestamps

- Telescope scintillators in coincidence with downstream timing detector
- Low trigger-rate
  - Most frames contain a particle, few point to timing detector
- Not quite exponential – gap between spills gives high side tail



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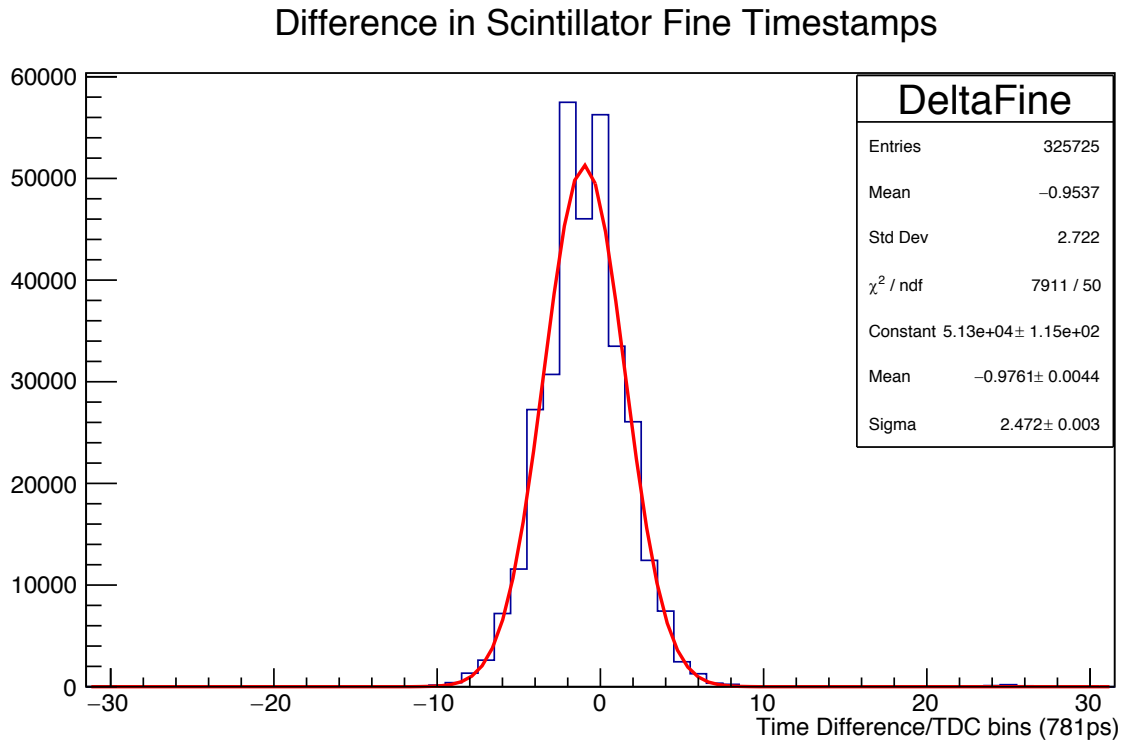
TLU Timing

- TLU time-stamps triggers with 1.56ns bins
  - Will be changed to 781ps in later firmware
- Take difference between pulses from two trigger scintillators
  - Telescope scintillators, CERN East Area T9
- Assume errors in quadrature → precision of single scintillator = 1.5ns



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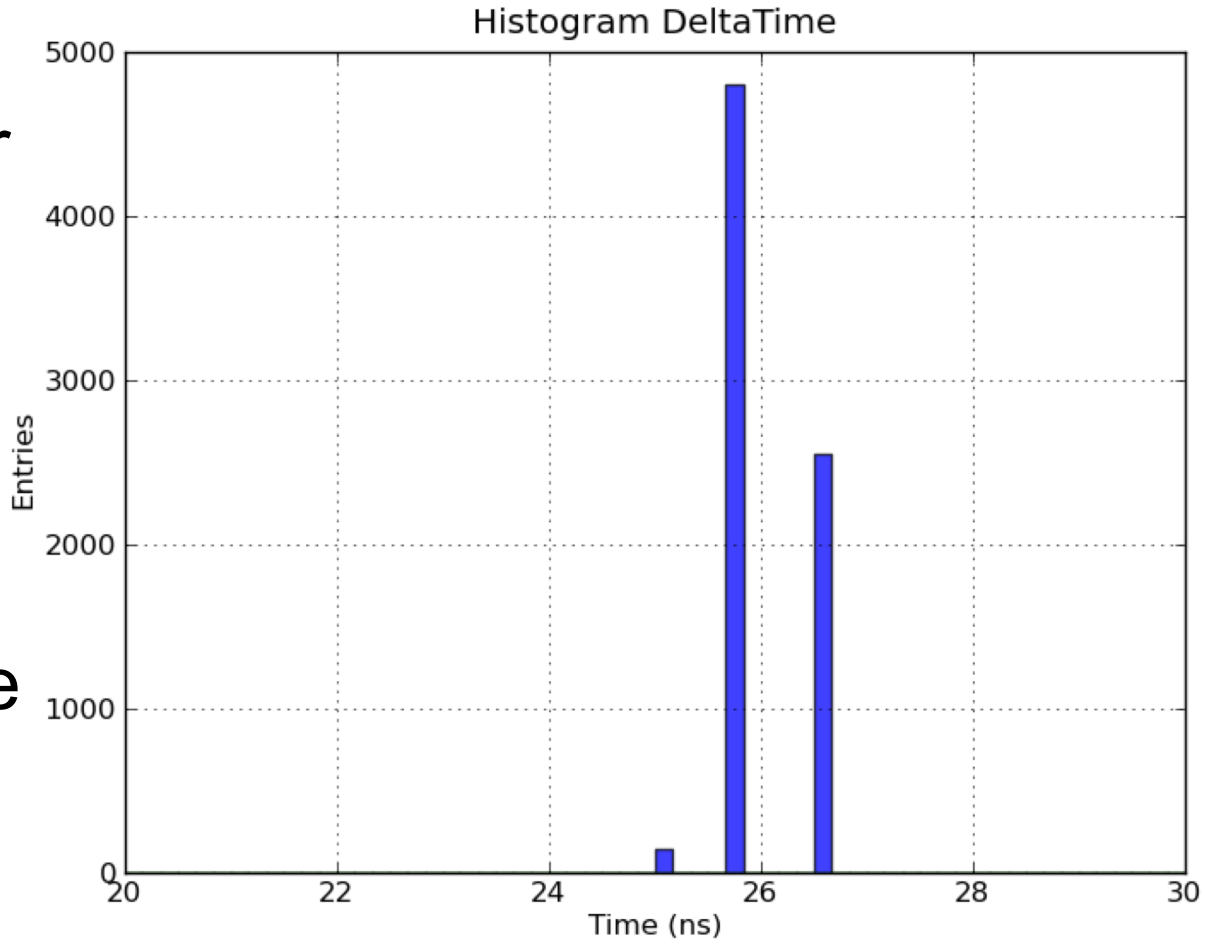
Timing – pulse generator

- Signal from pulse generator
  - Asynchronous from TLU clock.
- Feed into two channels with time offset
- Time difference as expected



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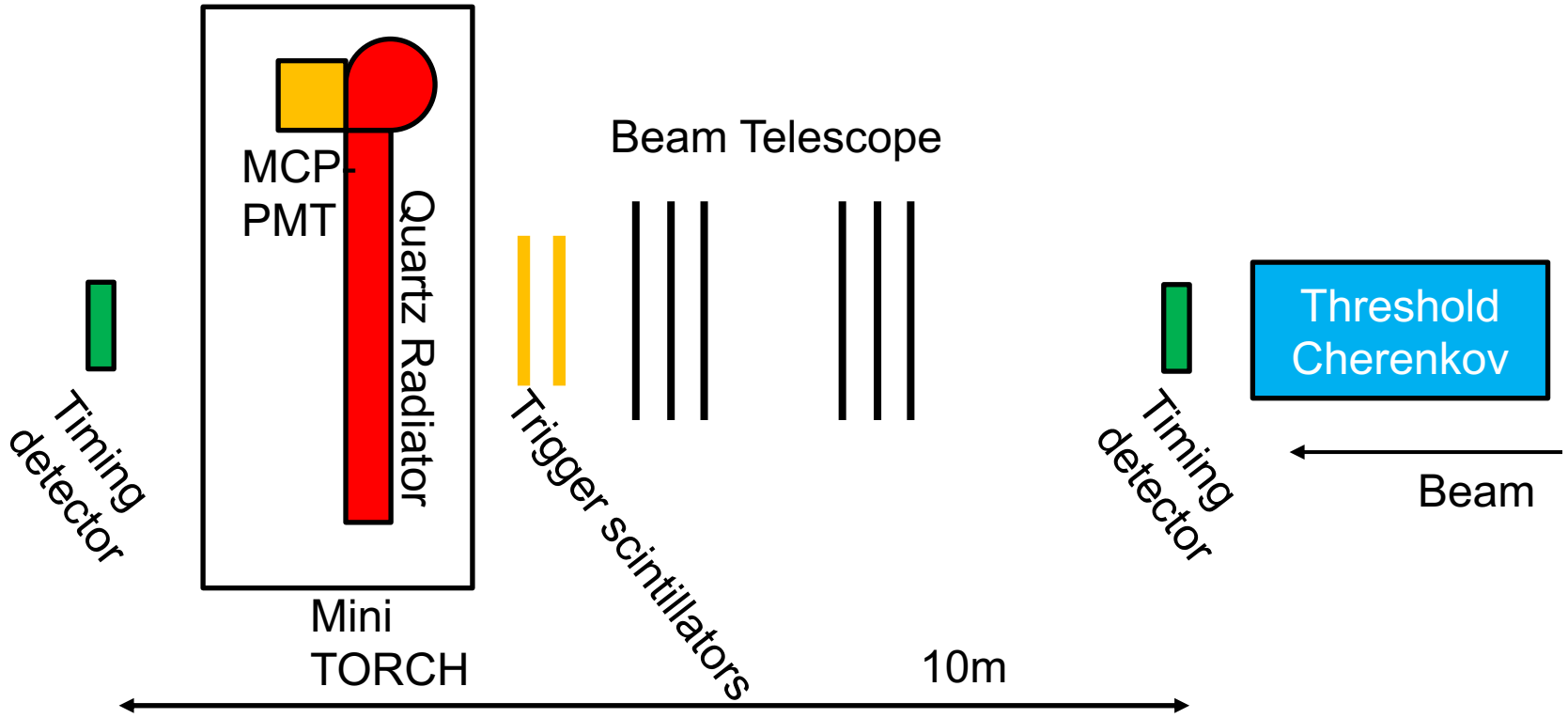
AIDA Beam Telescope + TORCH

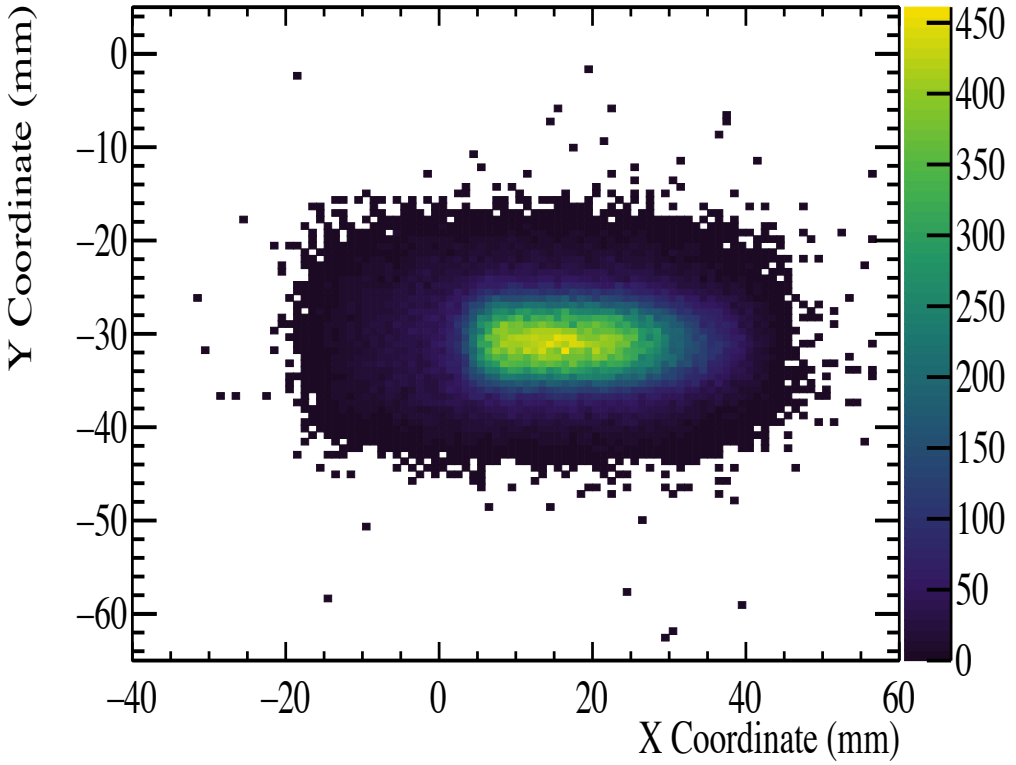
- TORCH project doing R&D on particle PID by ToF
  - Cherenov light in thin quartz sheet perpendicular to beam
  - Guided by TIR to edges.
  - Read out by pixelated Micro-Channel Plate based PMTs



See , e.g. https://doi.org/10.1016/j.nima.2018.10.099 https://doi.org/10.1016/j.nima.2018.12.007

Extrapolated Tracks

- Reconstruct data from Mimosa telescope with EUTelescope
- Select events with only one track
  - Average of ~ 1.5 tracks per event
- Extrapolate from telescope to position of timing detector
- See outline of timing detector
- See talk on East Area



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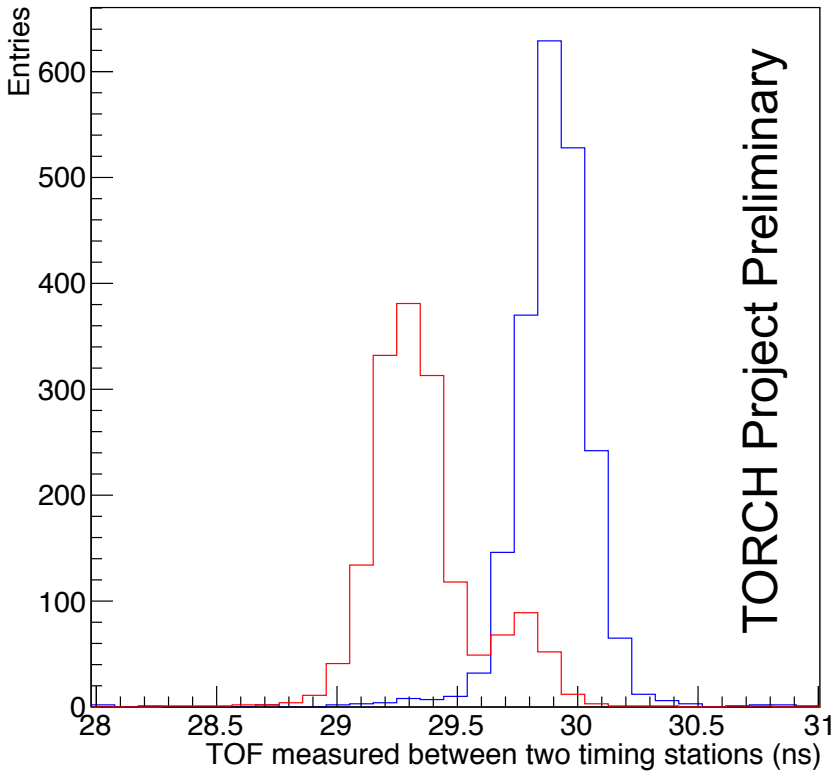
TORCH

- Aiming to measure single photons with a precision of σ ~ 70ps
  - →Need to know impact point of particle to O(mm)
- For some analysis want to know particle type (p/π)
  - Time of flight measured by small dedicated detectors
  - Threshold Cherenkov detectors in beam
    - Get signal for π , but not for protons
    - Fed into TLU. Tag event by event
  - Compare ToF with/without Chernkov tag:

Blue – light in Cherenkov
Red – no light in Cherenkov



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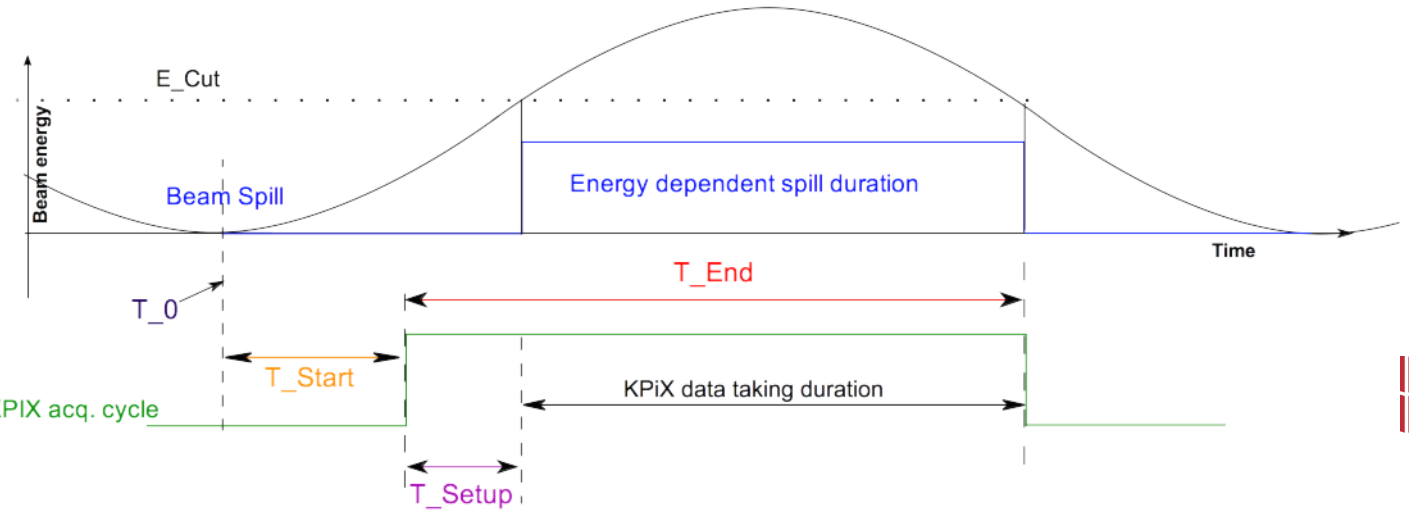
Interface to AIDA-2020 Silicon Tracker

- Readout chip designed for ILC
  - → Short active time, then readout
  - More details here
- To reduce dead-time, take data only when particles are present
  - Sinusoidal energy ramp in DESY accelerator.
    - Get particles in beam-line only at peak energy of accelerator



Mengqing Wu,
AIDA-2020 LYCORIS tracker

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Interface to Accelerator

- Provide a “spill” signal to AIDA-2020 Silicon strip tracker (SiTra)
  - See The LYCORIS Telescope at the DESY II Test Beam Facility
  - Use one of TLU inputs to monitor accelerator signal.
  - Parameters adjustable by setting registers.
  - Could be used at CERN PS/SPS
    - Use WWE , WE, EE
  - Could be used with Calorimeter readout systems
- Firmware tested in lab.

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Beam Telescope: Multiple tracks per frame

- Can configure TLU to ignore BUSY from an DUT with EUDET handshake
- E.g. Mimosa telescope + FE-4I:
  - Ignore busy from telescope
  - →Can have more than one trigger sent to FE-I4 during frame readout of Mimosa
  - Keep global trigger number (Same trigger number sent out to both Mimosa + FE-I4)
  - Whether DUT BUSY vetoes triggers is configurable.
    - For DUT where BUSY vetoes triggers, read out consecutive trigger numbers
    - For DUT where BUSY does not veto triggers, read out non-consecutive trigger numbers (if >1 particle per frame)
  - Firmware tested in lab
  - Tested at DESY
    - See Status of the EUDET-type beam telescope infrastructure

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Summary

- Two batches “production” AIDA-2020 TLUs have been assembled
  - Contact David.Cussans@Bristol.ac.uk for further requests
- Have tested with Mimosa Telescope and FEI-4
- Have tested simultaneous use of trigger/busy(EUDET) and synchronous(AIDA) interface
- Firmware in place to allow multiple triggers per Mimosa telescope frame
  - Tested in lab
  - Tested at DESY – Mimosa + FE-I4
  - Order(s) of magnitude higher trigger rate from AIDA beam telescopes
- Have tested simultaneous use of trigger/busy(EUDET) and synchronous(AIDA) interface
  - (Mimosa telescope + FE-I4) + TORCH
  - Allows interface beam telescope with CALICE calorimeter.
- Firmware written to interface with DESY accelerator
  - Programmable “spill” signal
  - allow interface with AIDA-2020 Silicon tracker.

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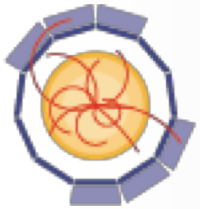

AIDA 2020

Backup Slides

- Backup Slides

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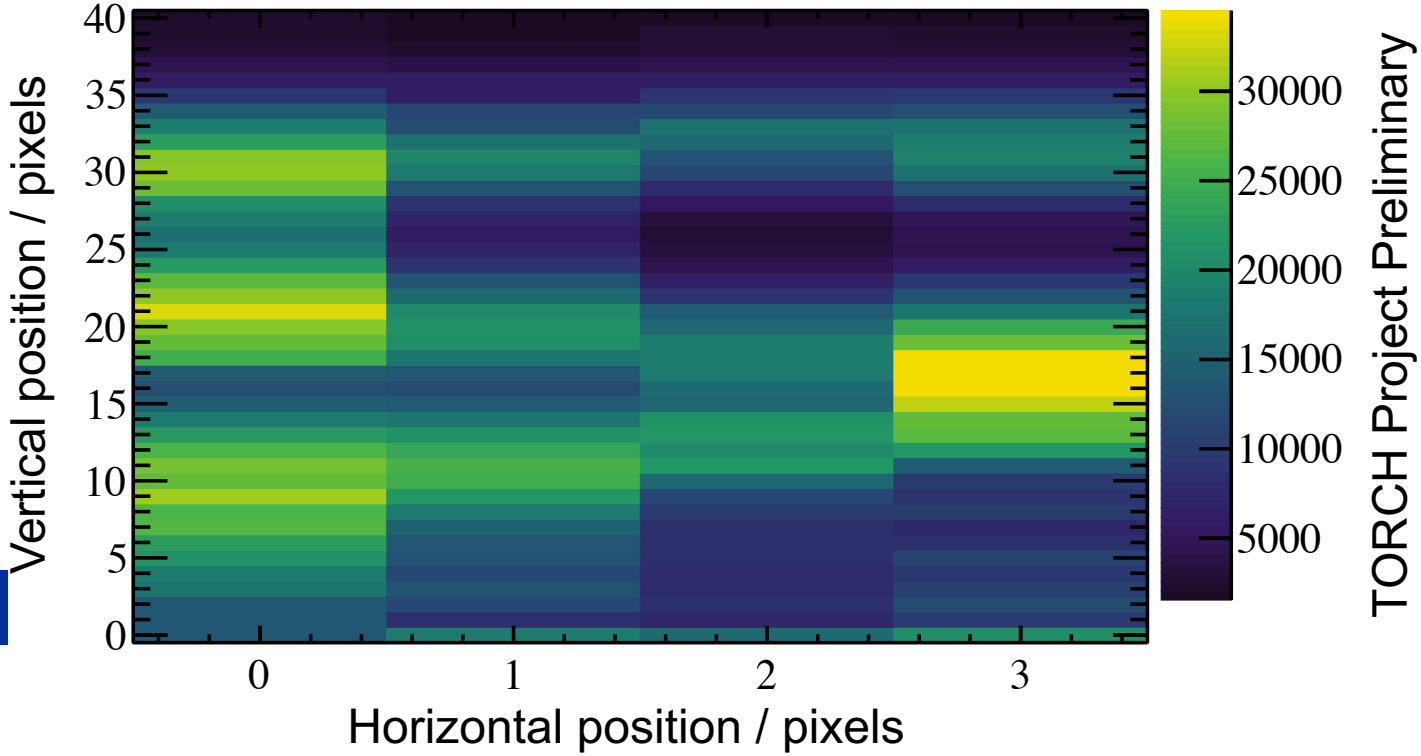
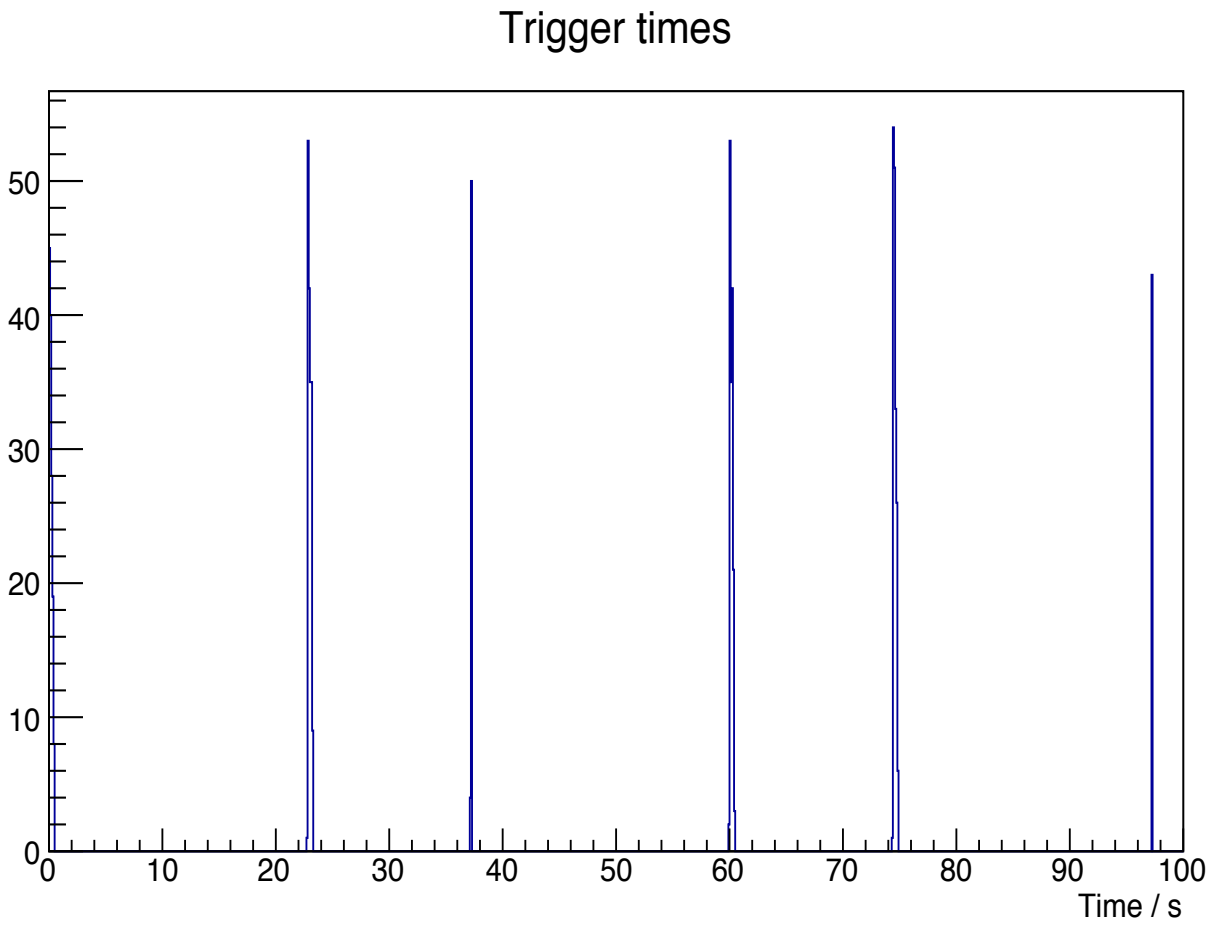
TORCH

Cone of Cherenkov photons trapped by TIR, guided to end of quartz sheet and focused on to MCP-PMT
Projection of cone folded by reflection at edges



SPS Spill Structure

- Trigger time-stamps of first few spills in a run



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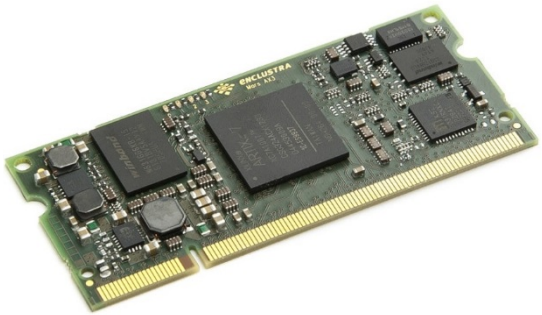
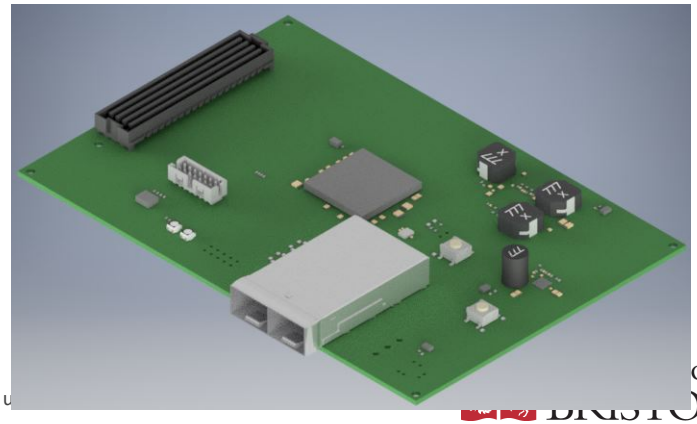
TLU logic

- Transition from FPGA Xilinx Series 6 (miniTLU) to Series 7 (v1C and later)



- Currently working on bench with Enclustra AX3 FPGA

- **ARTIX TRIVIAL FMC CARRIER (ATFC)**
  HTTP://WWW.OHWR.ORG/PROJECTS/ATFC
  - Designed by Samer Al-Kilani (UCL)
  - Stand-alone
    - … but design will eventually be be included in TLU
  - Bare PCBs produced
  - Waiting for components,
    - Then assembly of first two at UCL



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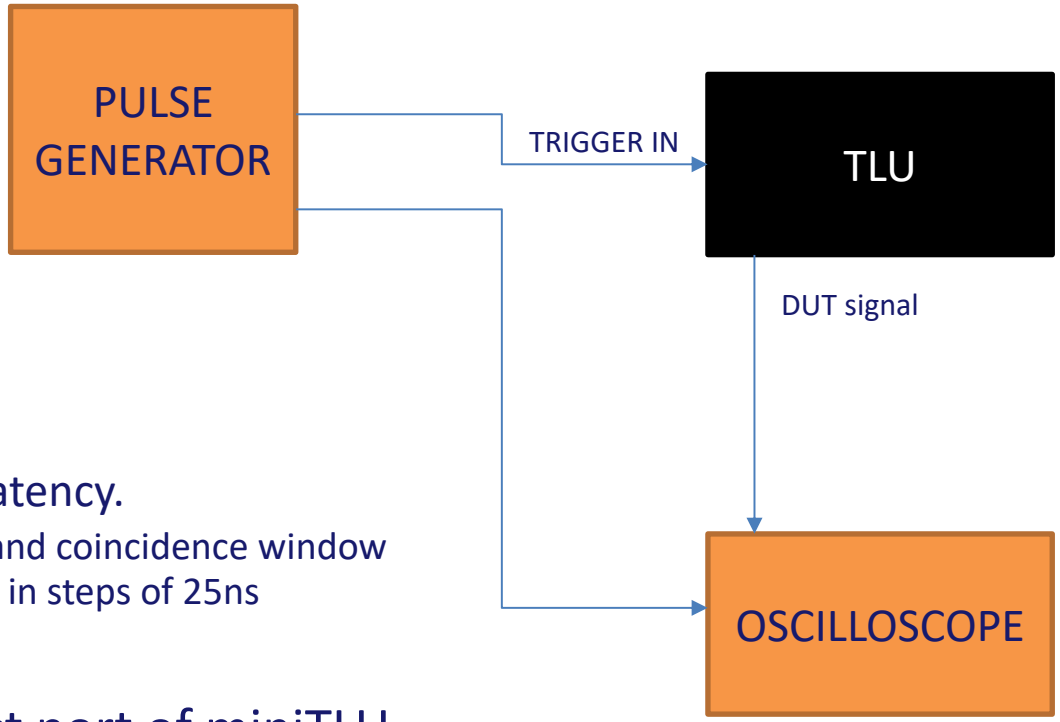
Latency test



- Testing TLU latency
  - Measuring minimum latency.
    - Latency of each input and coincidence window adjustable up to 400ns in steps of 25ns
- Current firmware direct port of miniTLU
  - Includes multiple registers to suppress meta-stability
  - Not yet optimized to reduce latency

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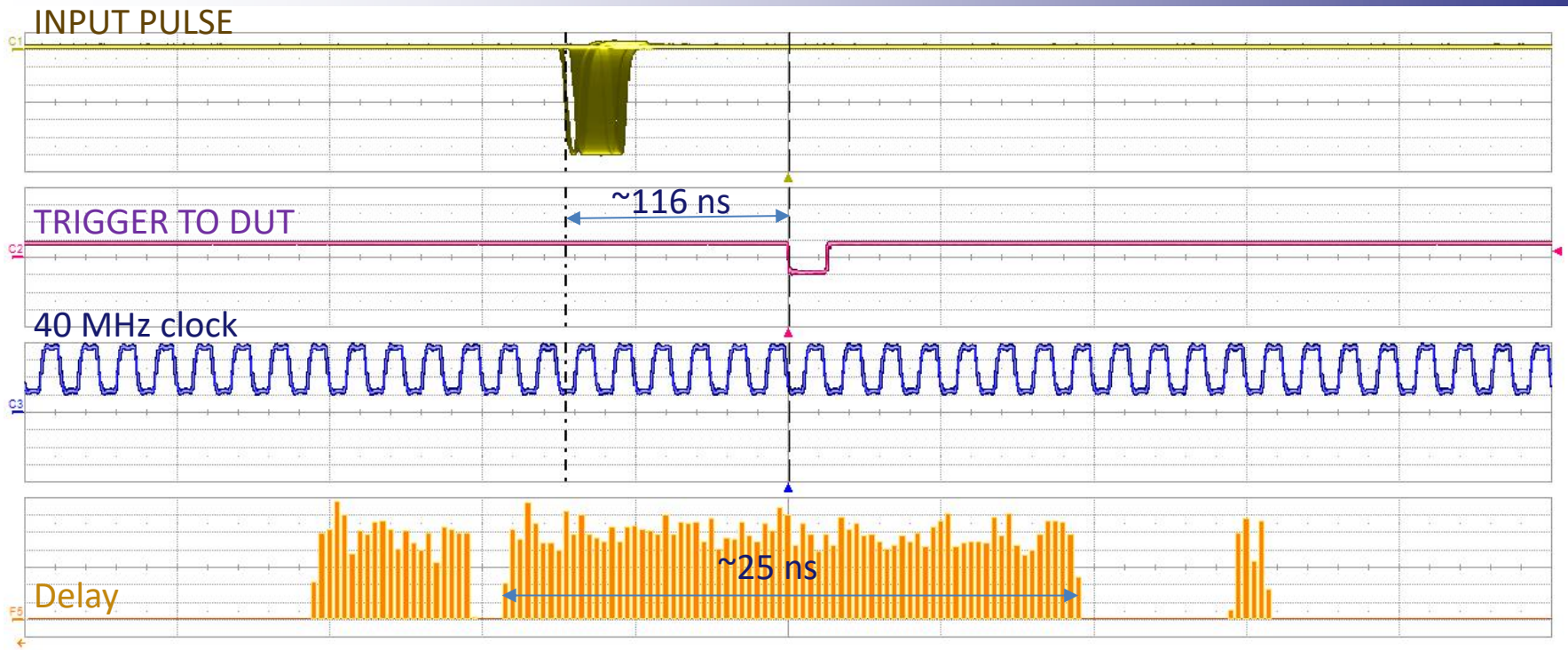
Latency test



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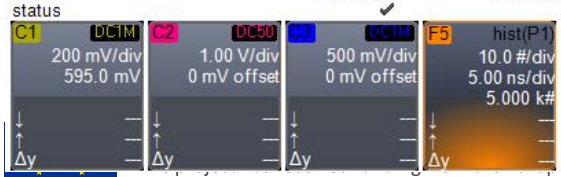
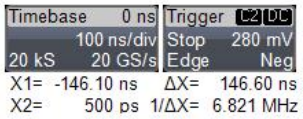
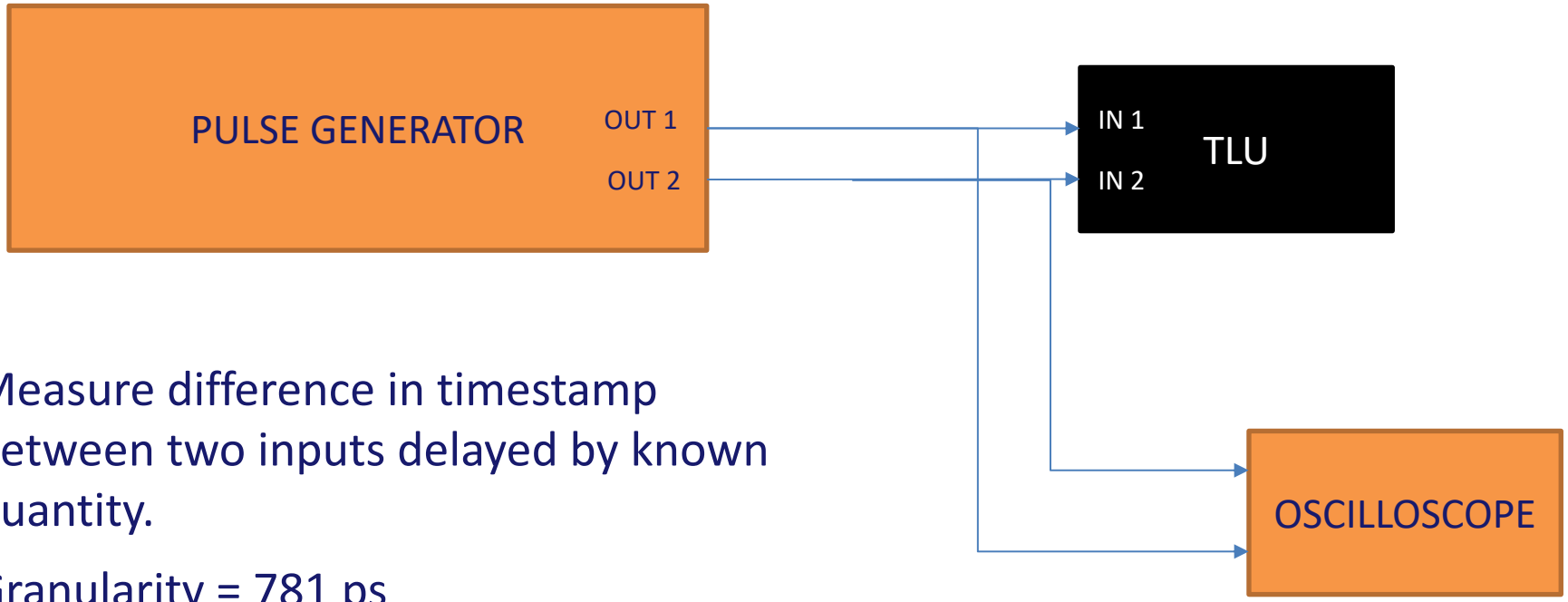
status	✔	⚠						



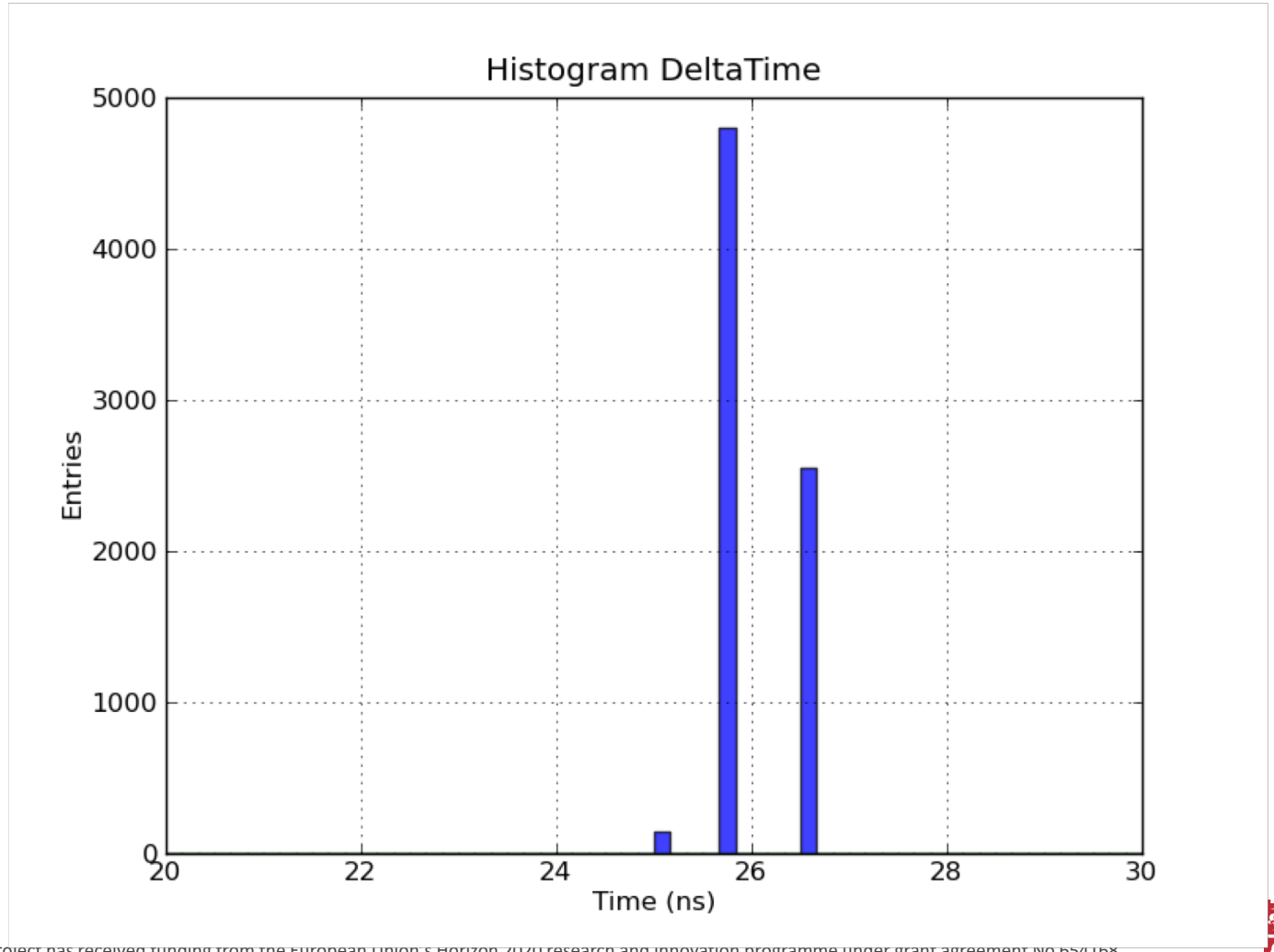


Time resolution test



- Measure difference in timestamp between two inputs delayed by known quantity.
- Granularity = 781 ps
- Work in progress

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168.



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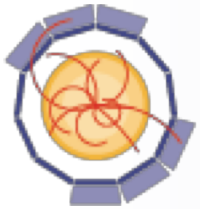

AIDA 2020

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