Test Beam on monolithic pixel sensors test structures in the 65 nm technology for the ALICE ITS3 upgrade

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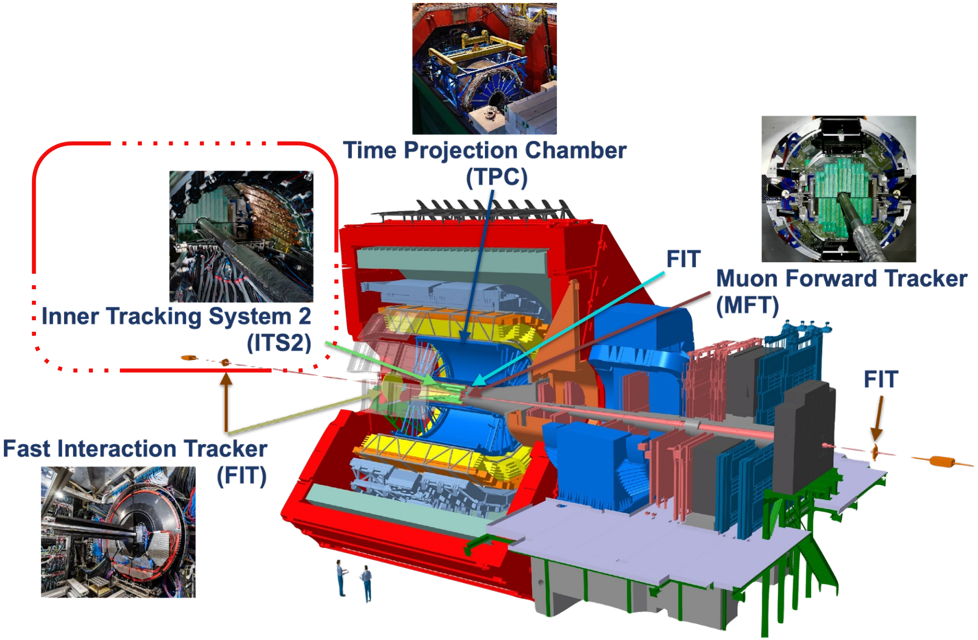
12th Beam Telescopes and Test Beams Workshop 2024 – Edinburgh 15-19 April

ALICE Inner Tracking System (ITS)



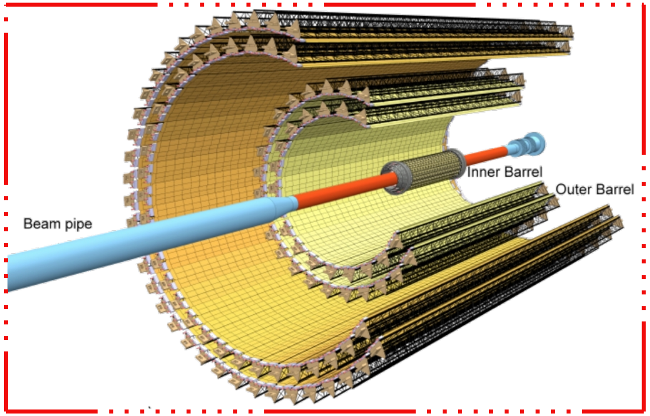
- properties of the **quark-gluon plasma** produced in **heavy-ion collisions**
- low momentum (≲1 GeV/c) particle reconstruction

ITS2 first large-area (~10 m^2) **silicon tracker** → MAPS

ALPIDE chip: TowerJazz **180 nm CMOS** imaging process

Main characteristics:

- **7 layers** of MAPS (3 inner - 4 outer barrel)
- close to interaction point (**23 mm**)
- improved single point **resolution** (pixel ~ 29×27 μm^2)
- low material budget: **0.36% X_0/X**
- **fast readout**:
  - Pb-Pb collisions at 50 kHz (ITS1: 1 kHz)
  - p-p at 400 kHz

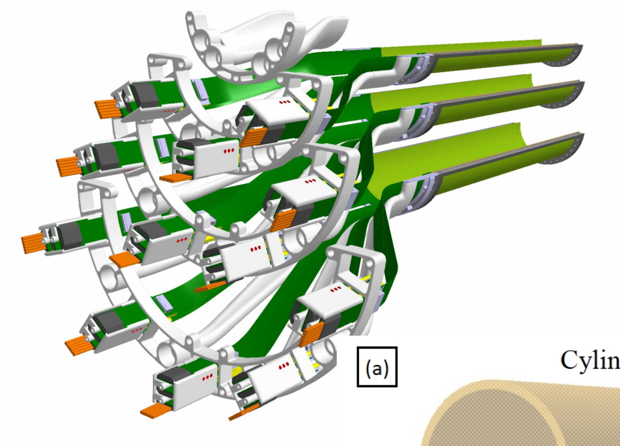


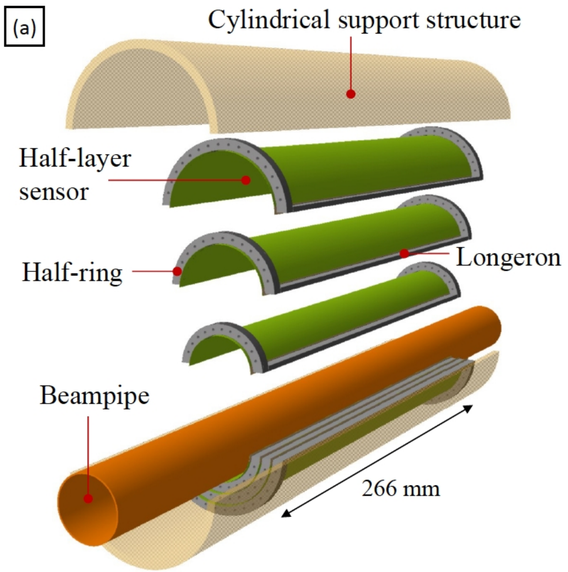
ITS3 – truly cylindrical wafer-scale MAPS tracker

Layout:
3 layers → replace ITS2 Inner Barrel
- beam pipe inner radius (to 16 mm with 500 μm thickness)

Technology:
- **65 nm CMOS** from TPSCo (Tower Partners Semiconductor):
  - 300 mm **wafer-scale chips**, fabricated using **stitching**
- thinned down to **50 μm**
  - flexible (bent to target radii)
- mechanically held by carbon foam ribs with low density and high thermal conductivity

Benefits:
- extremely low material budget: **0.07% X_0/X**
- homogeneous material distribution

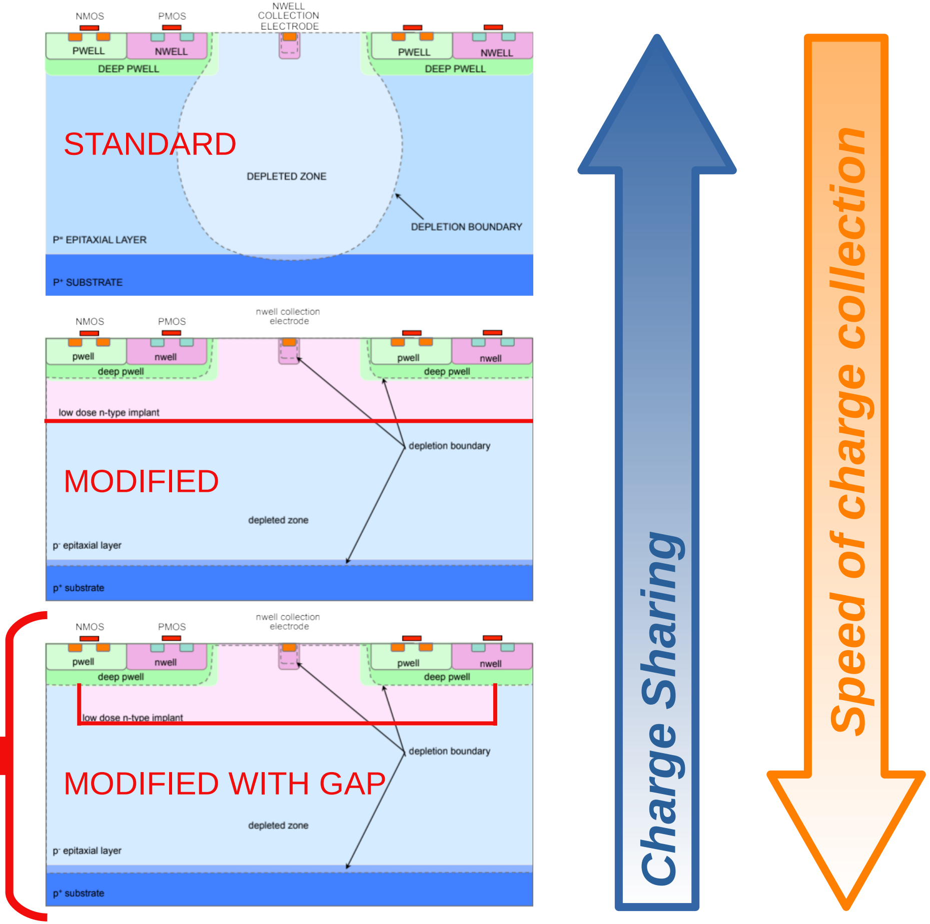




MAPS in the 65 nm CMOS technology

Process modification for fully depleted sensor:

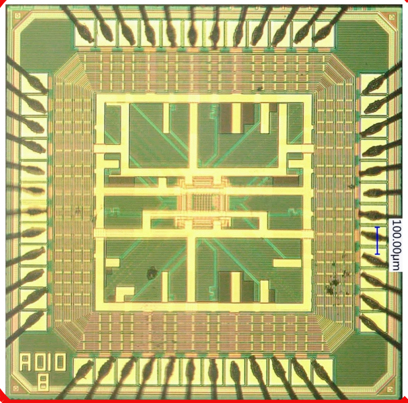
- **standard** → ALPIDE like design
- **Modified** → completly depleted
- **modified with gap** → increase the lateral field to speed up the charge collection process

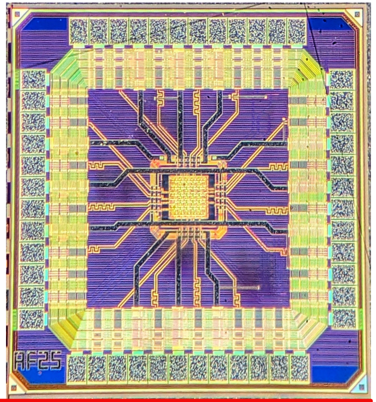


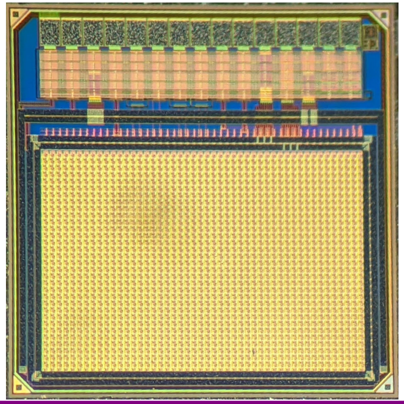
Selected for time resolution studies

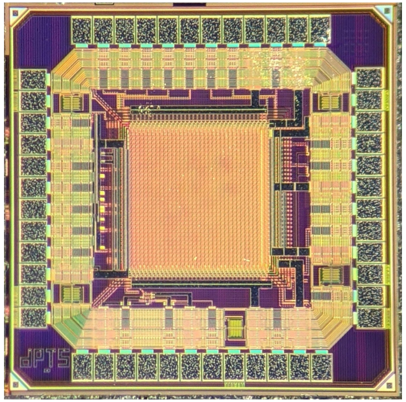
MLR1 Test Structures

MLR1: Multi Layer Reticle 1 → first submission in the TPSCo 65 nm technology









APTS (Analogue Pixel Test Structure)

- **aim**: explore different pixel designs
- **matrix sizes**: 4×4
- **pixel pitch**: (10, 15, 20, 25) µm

Two types of **output drivers**:

- Source follower (APTS-SF)
- **Operational Amplifier (APTS-OA)**
  → **preserve timing information**

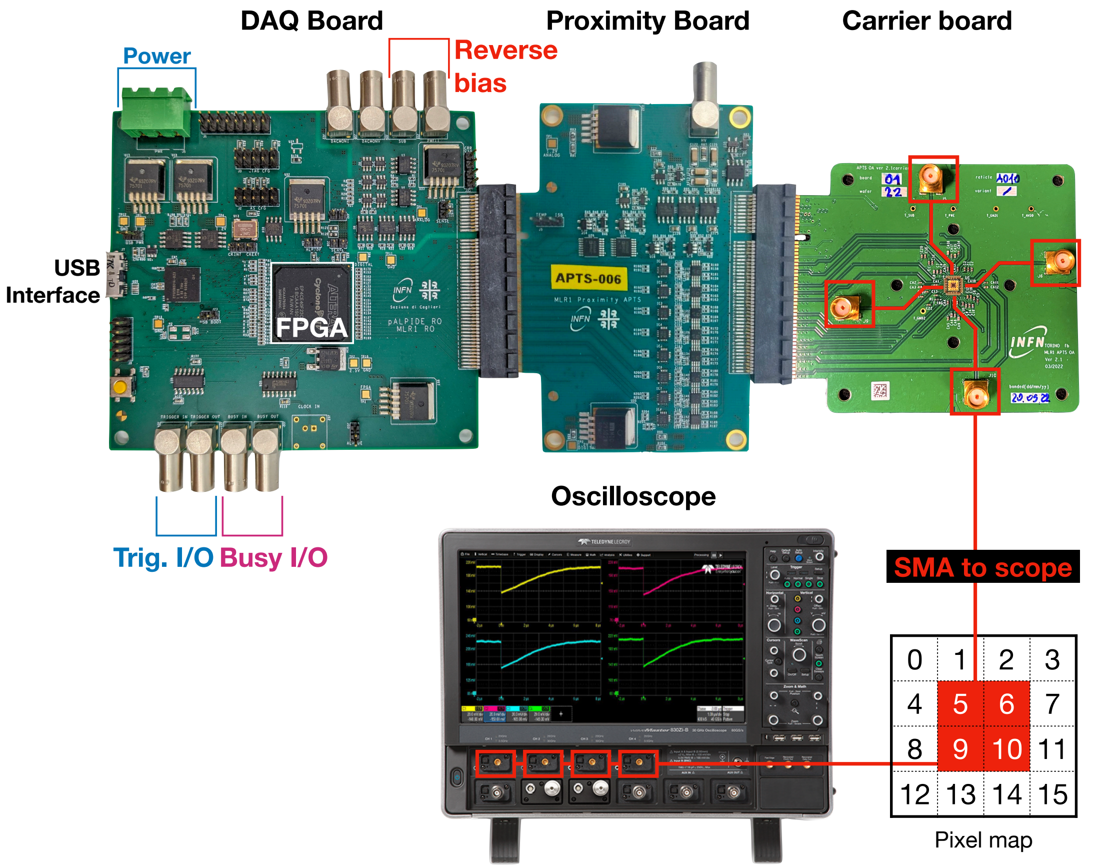
CE65 (Circuit Exploratoire)

- **aim**: study pixel matrix uniformity
- **matrix sizes**: 64x32, 48x32
- **pixel pitch**: 25, 15 µm

DPTS (Digital Pixel TS)

- **aim**: study in-pixel discrimination
- **matrix sizes**: 32×32
- **pixel pitch**: 15 µm

APTS-OA: setup

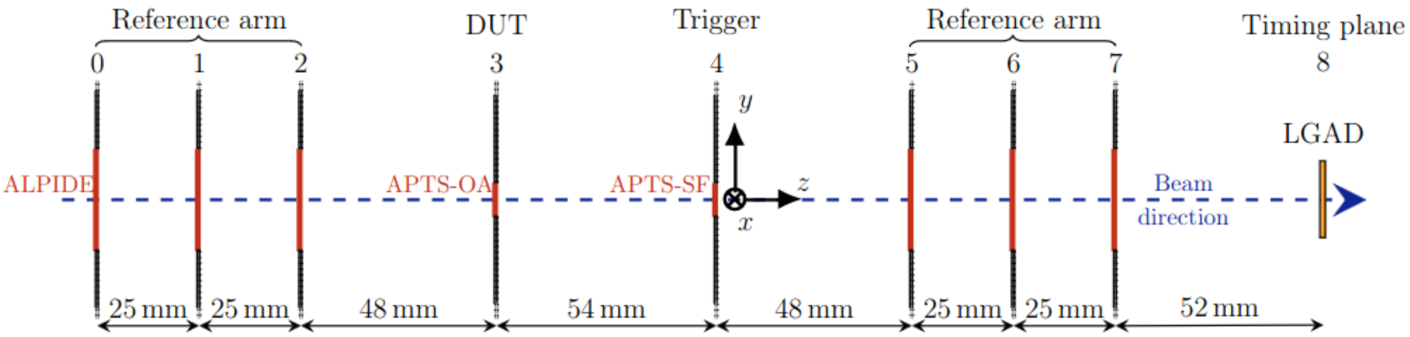


- **4 inner pixels** read out by the **Oscilloscope** → Sampling rate **40 GS/s**
- **12 outer pixels** read out by a custom made **proximity board** → Sampling rate **4 MS/s**

Aims of Test Beam 06/2023

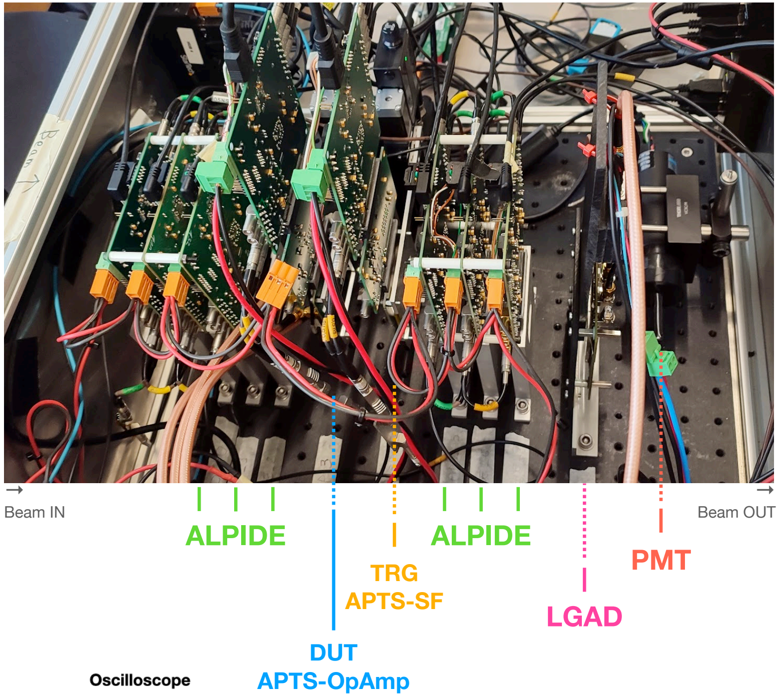
A Test Beam **@SPS CERN** with **120 GeV/c positive hadrons** has been conducted in June 2023

Main **Test Beam Purposes**:
- **Time resolution** of the modified with gap design
- **Detection efficiency** associated to time resolution



What we need:
- **Tracking resolution < 3µm**
- Time reference layer with **time resolution < 50 ps**
- **Trigger plane** with a small area to collect the least amount of events without signal

Telescope Test Beam 06/2023



Setup:

- **6 ALPIDE** planes: pixel pitch ~ 29×27 μm^2, 5 μm spatial resolution
- Device Under Test (**DUT**): **APTS-OA 10μm** pitch **modified with gap type**
- **Trigger plane: APTS-SF 15μm pitch** with the 12 outer pixels masked to mimimize the trigger area
- **Time reference:** Low Gain Avalanche Detector (**LGAD** produced by Fondazione Bruno Kessler)*, quoted **time resolution = 30 ps**, readout by the oscilloscope
- **PMT** and scintillator to localize the beam

Oscilloscope

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

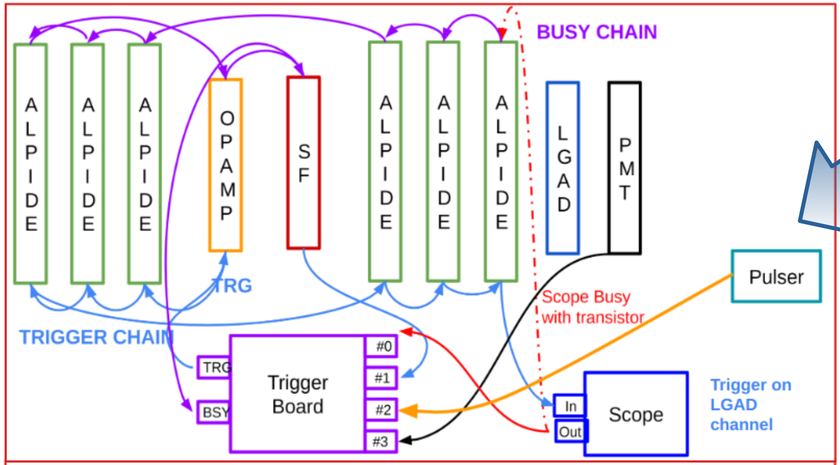
Pixel map

1.9 μm spatial resolution on the DUT plane

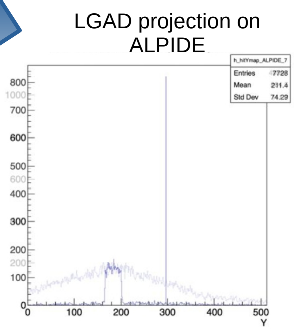
Problem for eudaq2 integration:
Merge both readout systems without mismatch between events

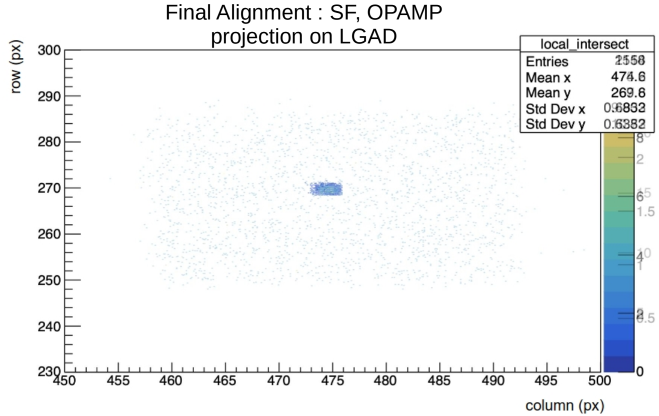
* https://doi.org/10.1140/epjp/s13360-022-03619-1

Trigger and busy chain

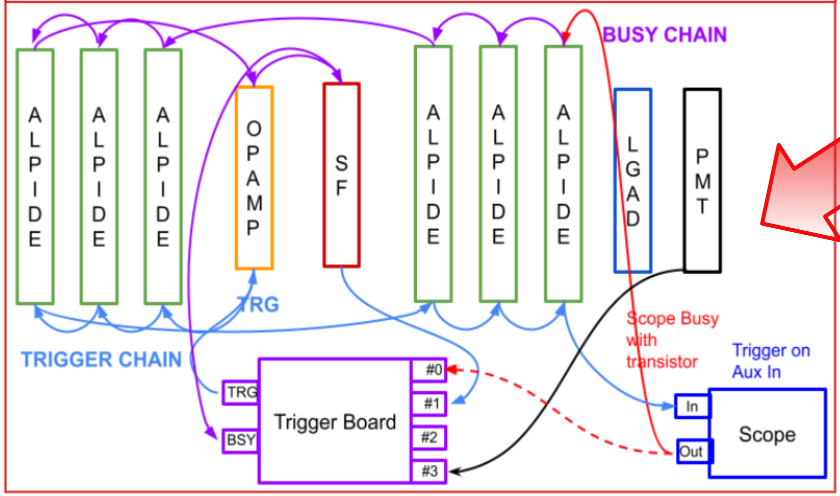


Alignment setup





Physics runs setup



Oscilloscope is read out using **sequence mode** in which acquires a **fixed number of events** and then **transfers in block to the computer**
Coincidence between events is guaranteed by the busy chain

Oscilloscope Trigger Enable

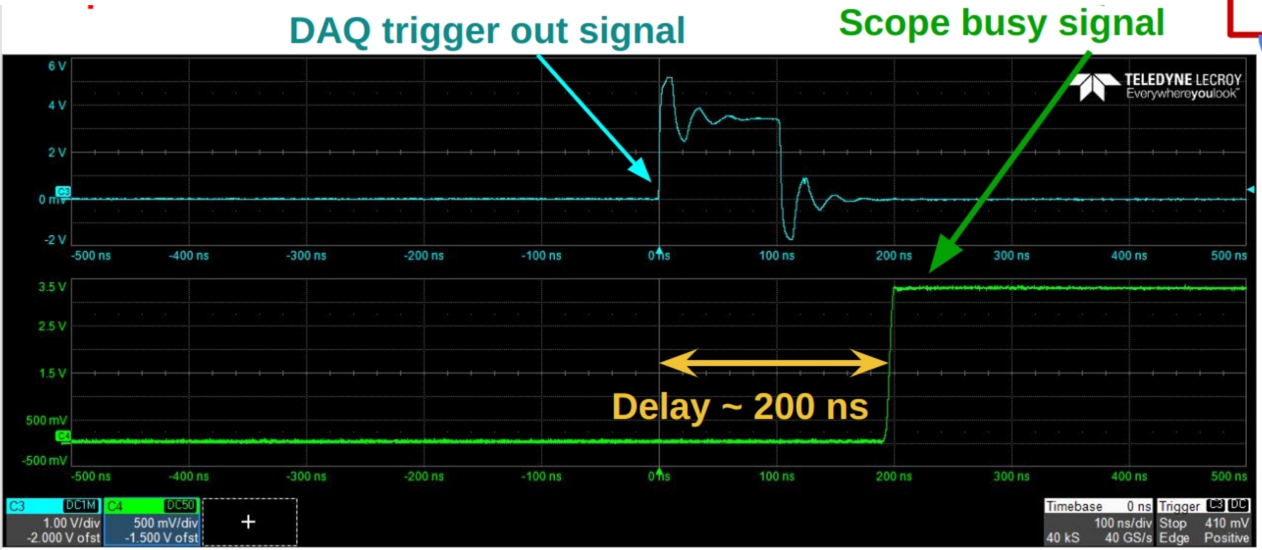
DAQ board trigger out signal

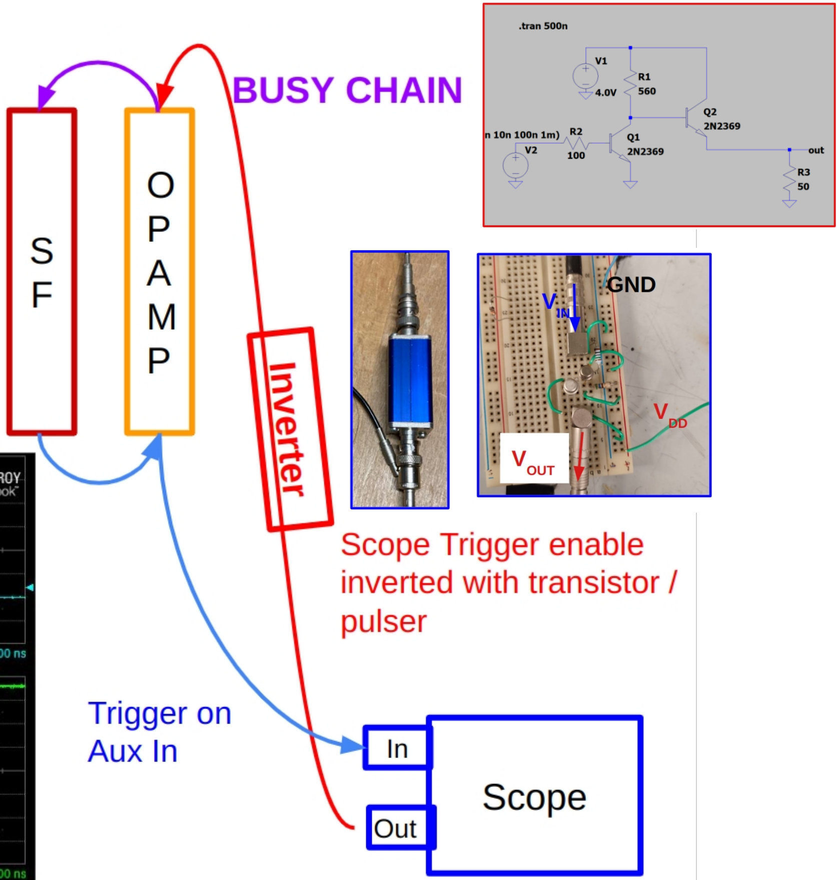
Oscilloscope trigger enable signal

- Signal from the DAQ that **triggers the oscilloscope**
- Output of the **trigger enable** from the oscilloscope that could be used as a busy signal

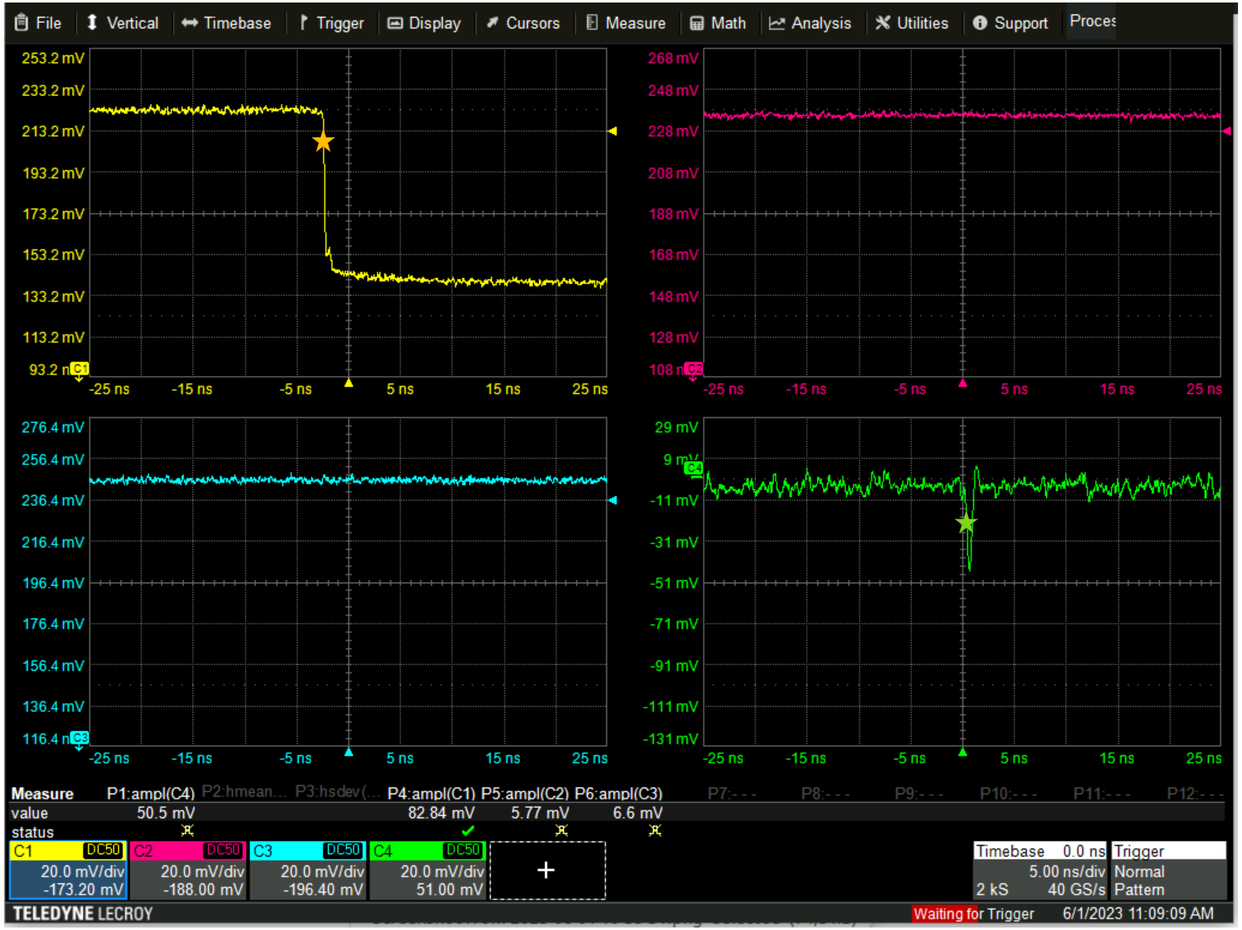
Solution for the busy chain

1) Implement an inverter with a pulser
2) Simulate an LTSpice circuit that will give the same output
3) Implement the circuit in a closed box





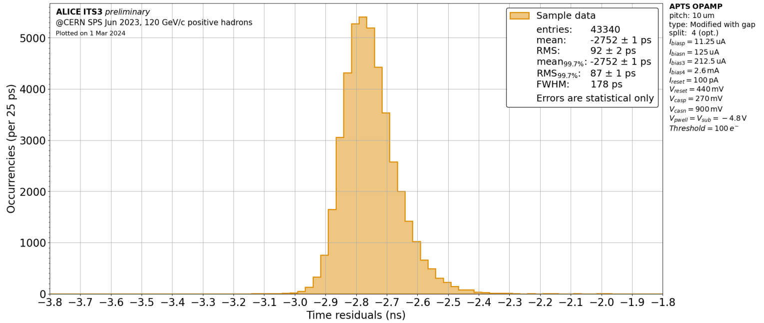
Test Beam measurements



Coincidence between LGAD and APTS-OA → reverse bias = -4.8V

Time residuals $\Delta t = t_{\text{APTS-OA 10\%}} - t_{\text{LGAD 40\%}}$

Time resolution = $\sqrt{\sigma_{\Delta t}^2 - \sigma_{LGAD}^2}$



With the **sequence mode** we **increased the acquisition rate of a factor ~ 40**

To summarize

- A **Test Beam @ SPS CERN** with 120 GeV/c positive hadrons has been conducted in June 2023 on the **APTS-OA test structure** to study the **detection efficiency** and the **time resolution**

- An **increase** in the acquired **statistics of a factor ~ 40** was achievable thanks to the use of the **sequence mode**

- The final **sensor intrinsic time resolution** obtained for the APTS-OA with a reverse bias of -4.8V is equal to **63 ps** for time walk corrected results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Thank you!