SpinQuest/E1039 FPGA Trigger

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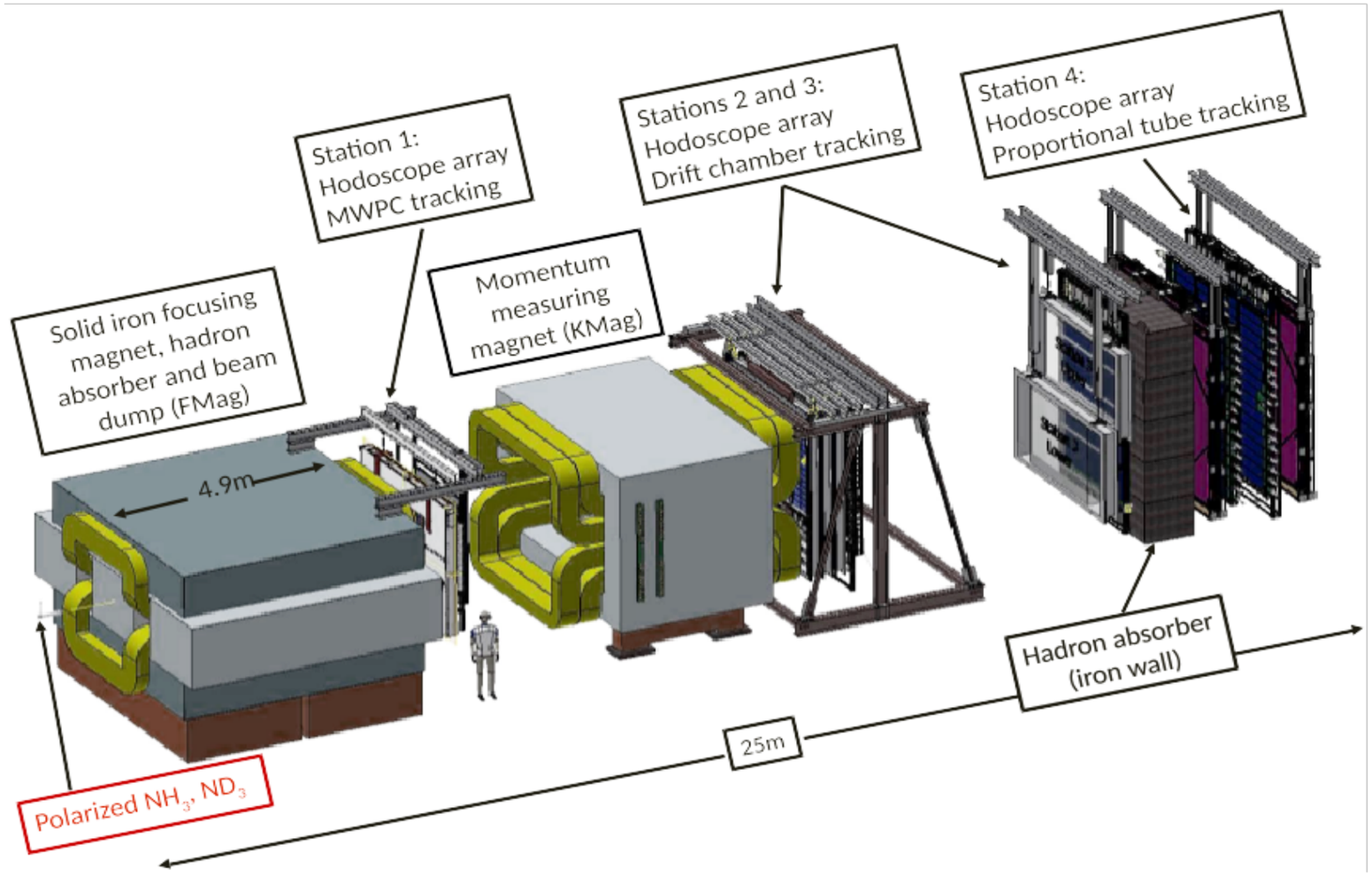
On behalf of SpinQuest collaboration

SpinQuest/E1039 experiment

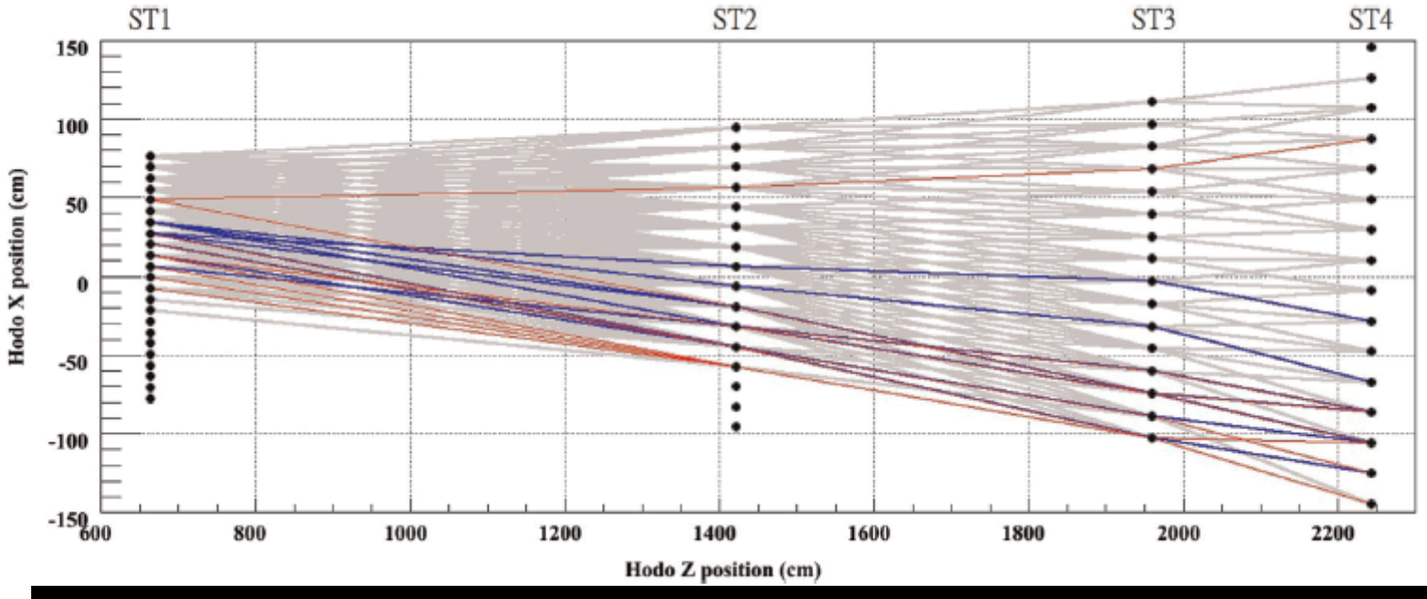


- To extract **Sivers** function of **ubar** & **dbar** in a nucleon through **DY decayed dimuon asymmetry** measurement
- Dimuon detection by 4 stations of tracker & hodoscope scintillators and hadron absorber
- Requires a trigger to select DY dimuon under **high fraction & rate of background in total muon flux** (due to interaction with beam dump, rareness of DY process): designed to select **oppositely-charged muon pairs at 4-9 GeV** mass range

FPGA trigger principle

Scintillation hodoscope arrays for X (horizontal) - position at station 3

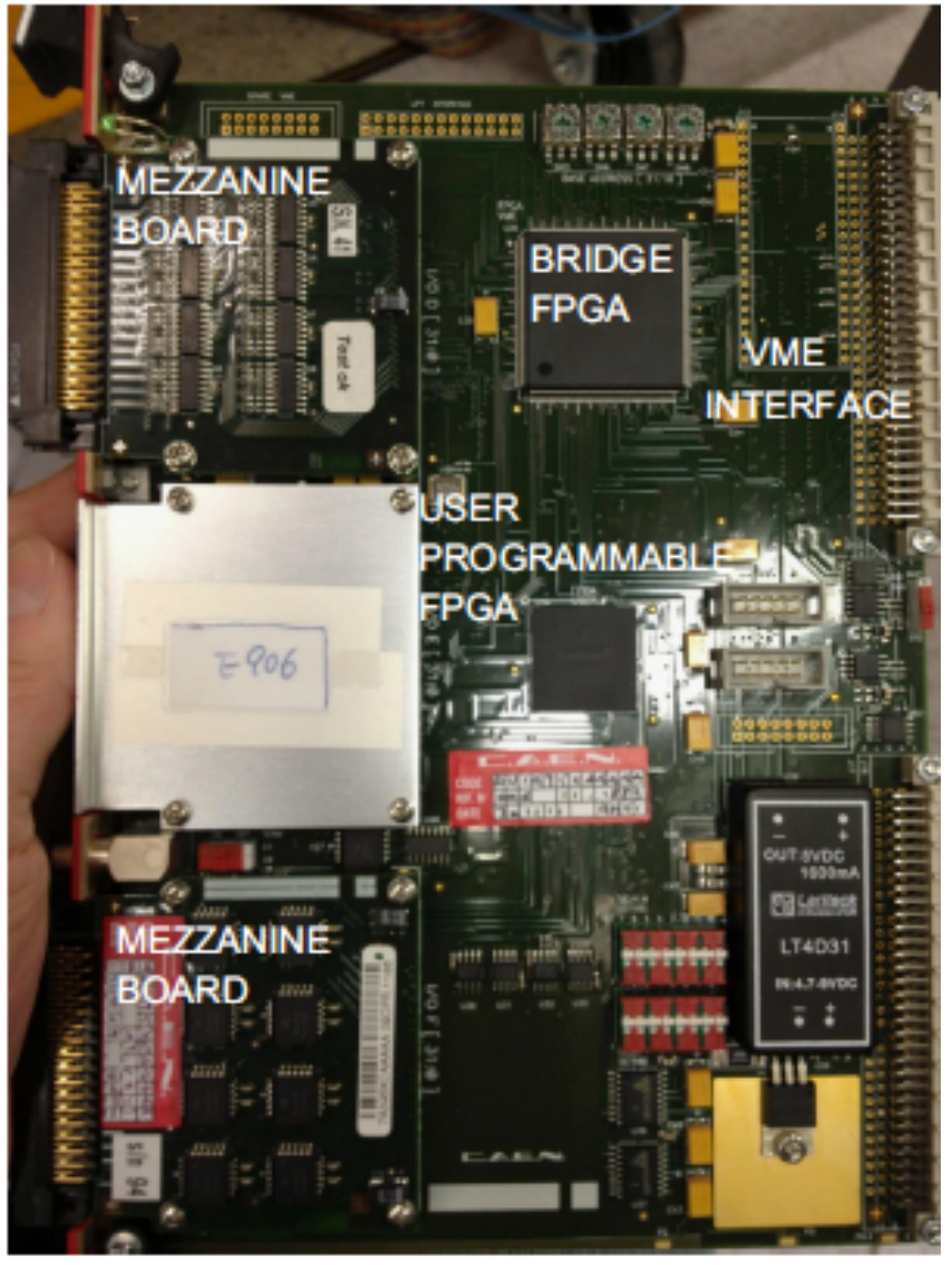
- Consist of scintillator **hodoscope + FPGA based VMEbus modules**
- Get **X-position of muon** from arrays of vertical **scintillators**
- Compare **hit patterns of 4 stations of hodoscopes** with **pre-defined hit patterns** **(DY dimuon "roads") obtained from Monte Carlo simulation** to generate **trigger decisions**
- These **roads** form a tiered **Look-up-table** in the FPGA



Visualized hit patterns (roads) of positive muons from E906/ SeaQuest MC simulation study
Black dots: scintillator paddles viewed from the top
Red (blue) lines: the 10 most (the next 10 most) frequent roads

Trigger board - CAEN V1495

- VMEbus module, contains **user programmable FPGA** with 20,060 logic elements (<1000 pre-defined roads per board)
- Takes up to 96 channels of inputs (16 channels x 4 stations = total 72 channels of hodoscope input for each top/ bottom board)
- Total 5 boards consists FPGA trigger system



Trigger hierarchy

Lvl. A
- Forward raw hit patterns to Lvl. B
- Test & diagnosis - Input can be switched to internal registers that hold pre-defined hit patterns and send them to Lvl. B

Lvl. B
- Tiered LUT compares hodoscope hit patterns with a set of single muon roads, then sends charge & pX bit to lvl. C

Lvl. C
- LUT compare +/- & Top/Bottom combination and send corresponding trigger bit to DAQ

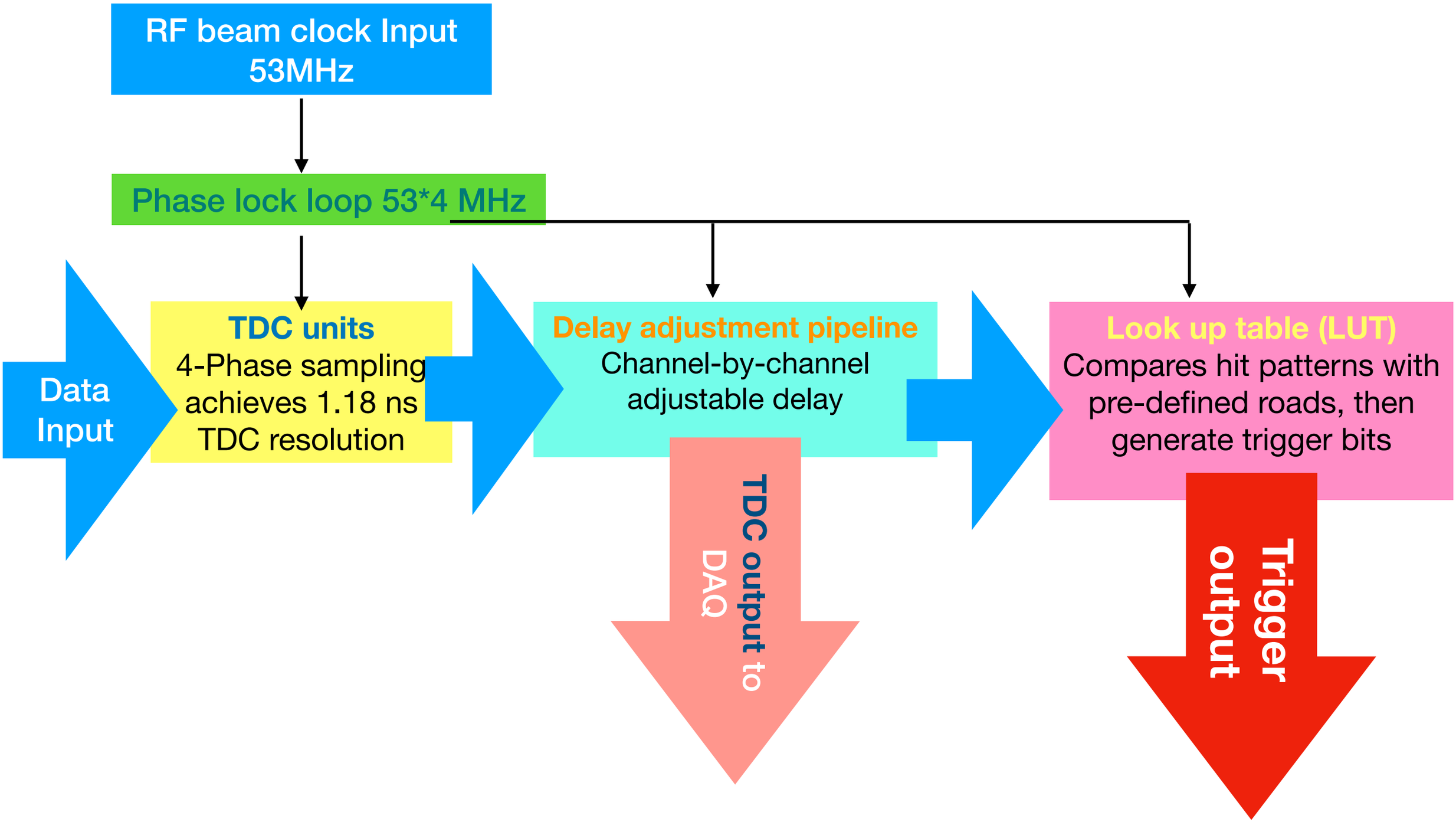
Lvl B
"AND" operation for each road
(ch st1 & ch st2 & ch st3 & ch st4)
Then "OR" operation for all roads
(road1 or road2 or …)

Lvl C
[Top mu+ & Bottom mu-] or
[Top mu- & Bottom mu+]

Main physics trigger:
TB/BT & +-/-+ (DY mu+/mu-)

Combinatorial background trigger:
TB/BT & ++/— (same charge)
T/B & +/- (single track)

FPGA trigger block diagram



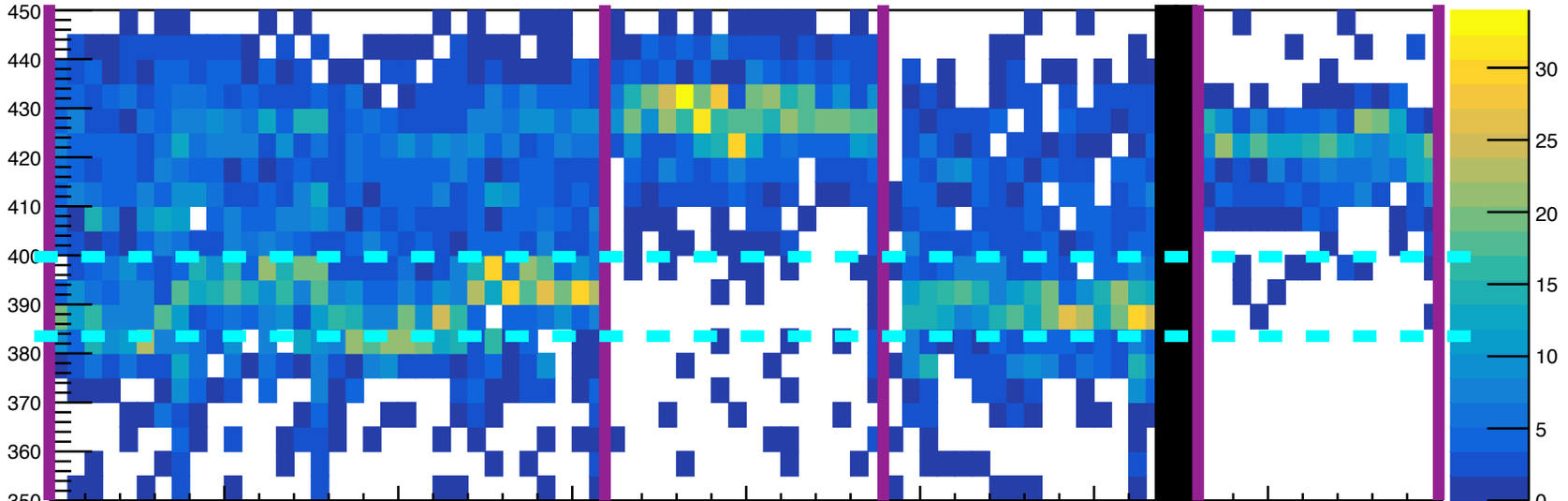
SpinQuest trigger status

- Took over decommissioned e906 trigger in 2019
- Tested trigger functionality at test bench setup
- Integrated to DAQ and tested with cosmic data
- TDC pipeline delay adjusted with cosmic muon & pulser generator
- Simulation study is ongoing to optimize Look Up Table

TDC delay adjustment

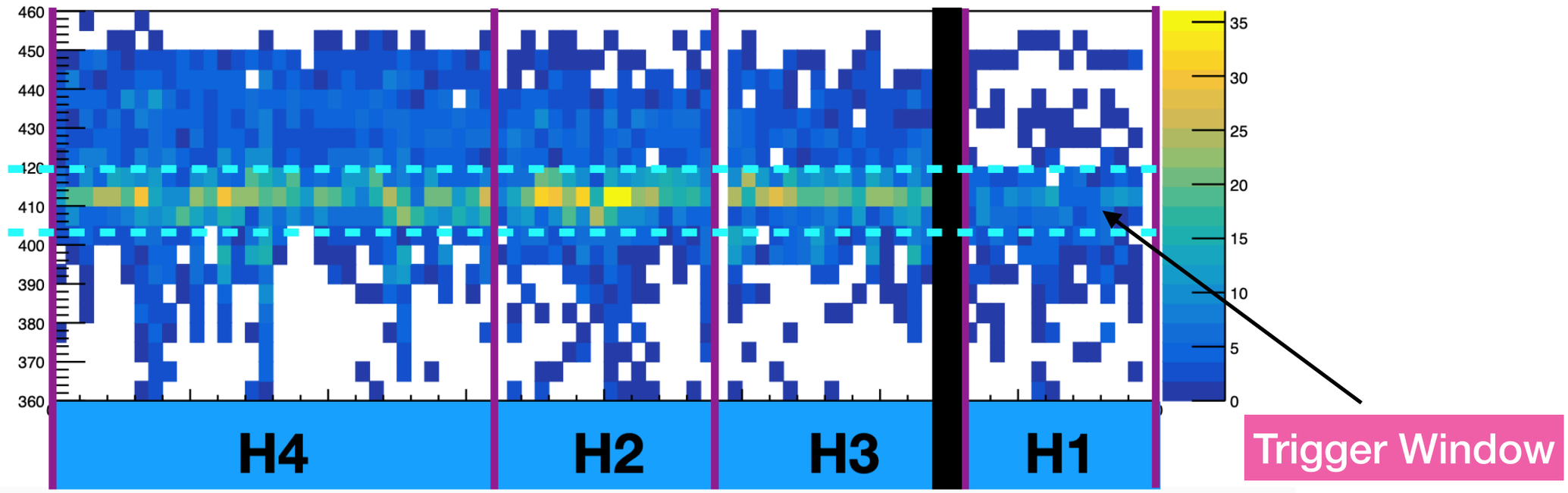
Hit timing
(TDC unit)

Before



Hodoscope Channel

After timing tuned



Look up table study

- Background in E906 setup: scattering at beam dump, combinatorial muons decayed from pions

  - E906 setup didn’t have enough vertex resolution to separate target and beam dump. Therefore, E1039 target was moved ~3 m upstream.

  - Pions have low pT, seem to come from soft processes. From naive guess, adding y-hodoscope information can reduce such coincidence background.

- To improve trigger performance by adding y-hodoscope information to LUT, simulation study is ongoing to estimate efficiency and purity. Expected to be done by the end of 2020.

Summary

- SpinQuest FPGA trigger is designed to select DY dimuon events at high background rate.

- The trigger decision is made based on hodoscope hit pattern compared with pre-defined hit patterns obtained from MC simulation (dimuon roads).

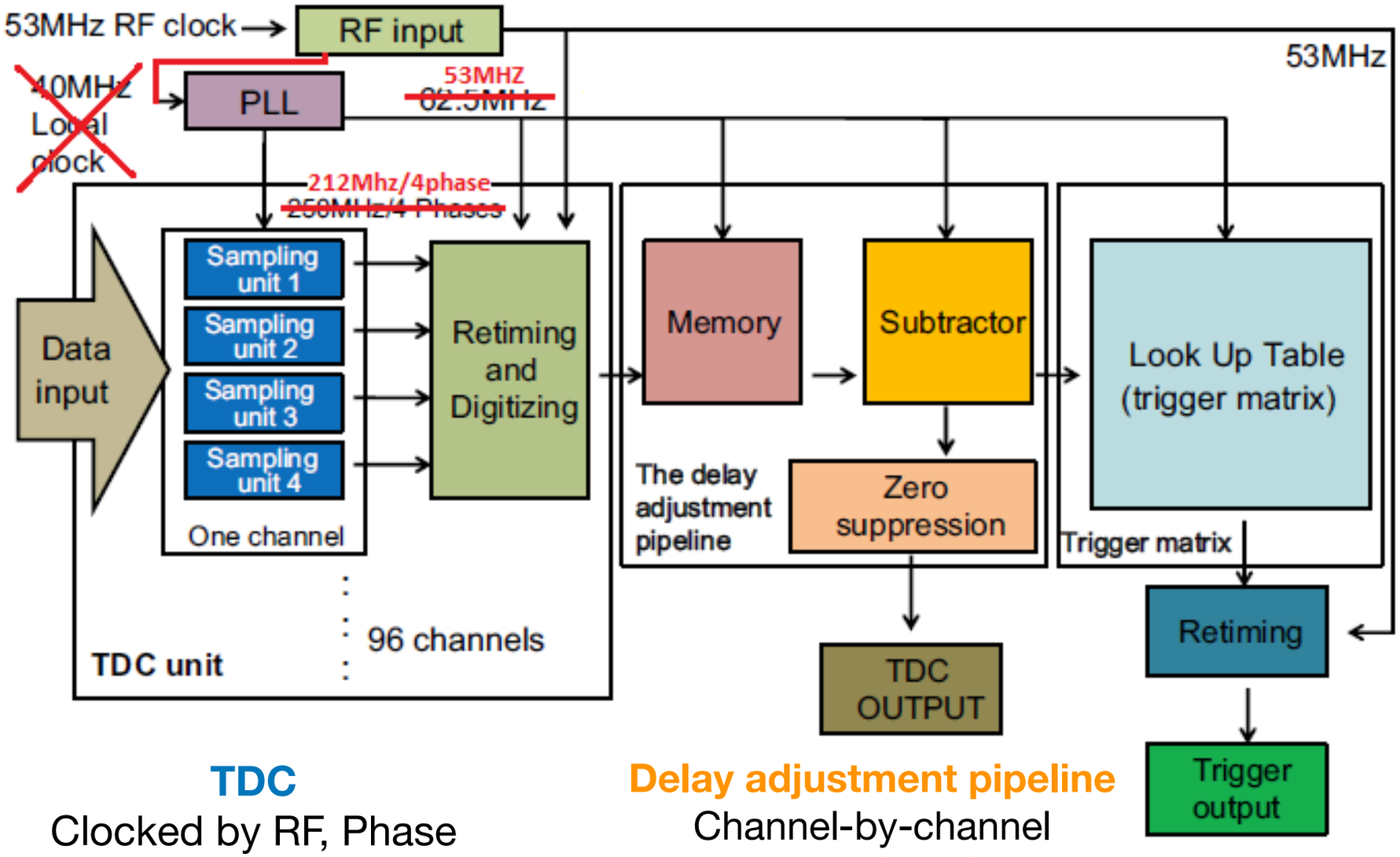
- Simulation study is ongoing to suppress high combinatorial background events efficiently.

- FPGA trigger expected to be ready for production data by end of 2020.

Thank you

Back up

FPGA trigger block diagram



TDC

Clocked by RF, Phase Lock Loop & 4-phase sampling achieves 1.18 ns TDC resolution

Delay adjustment pipeline

Channel-by-channel adjustable delay

TDC output written to DAQ machine decoded to online monitoring

Look up table (LUT)

Compares hit patterns with pre-defined roads, then generate trigger bits

Lvl B

"AND" operation for each road

(ch st1 & ch st2 & ch st3 & ch st4)

Then "OR" operation for all roads

(road1 or road2 or …)

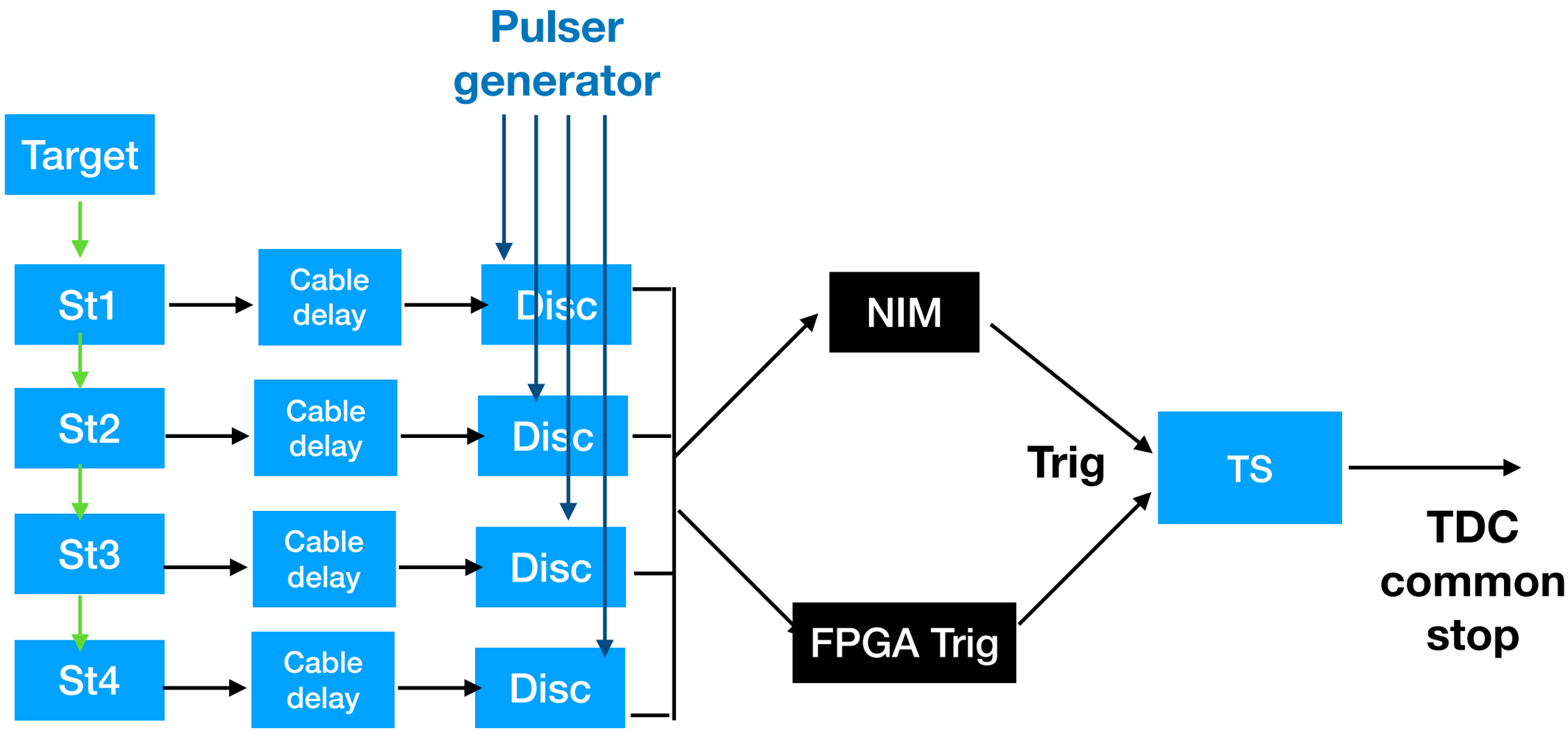
Lvl C

[Top mu+ & Bottom mu-] or

[Top mu- & Bottom mu+]

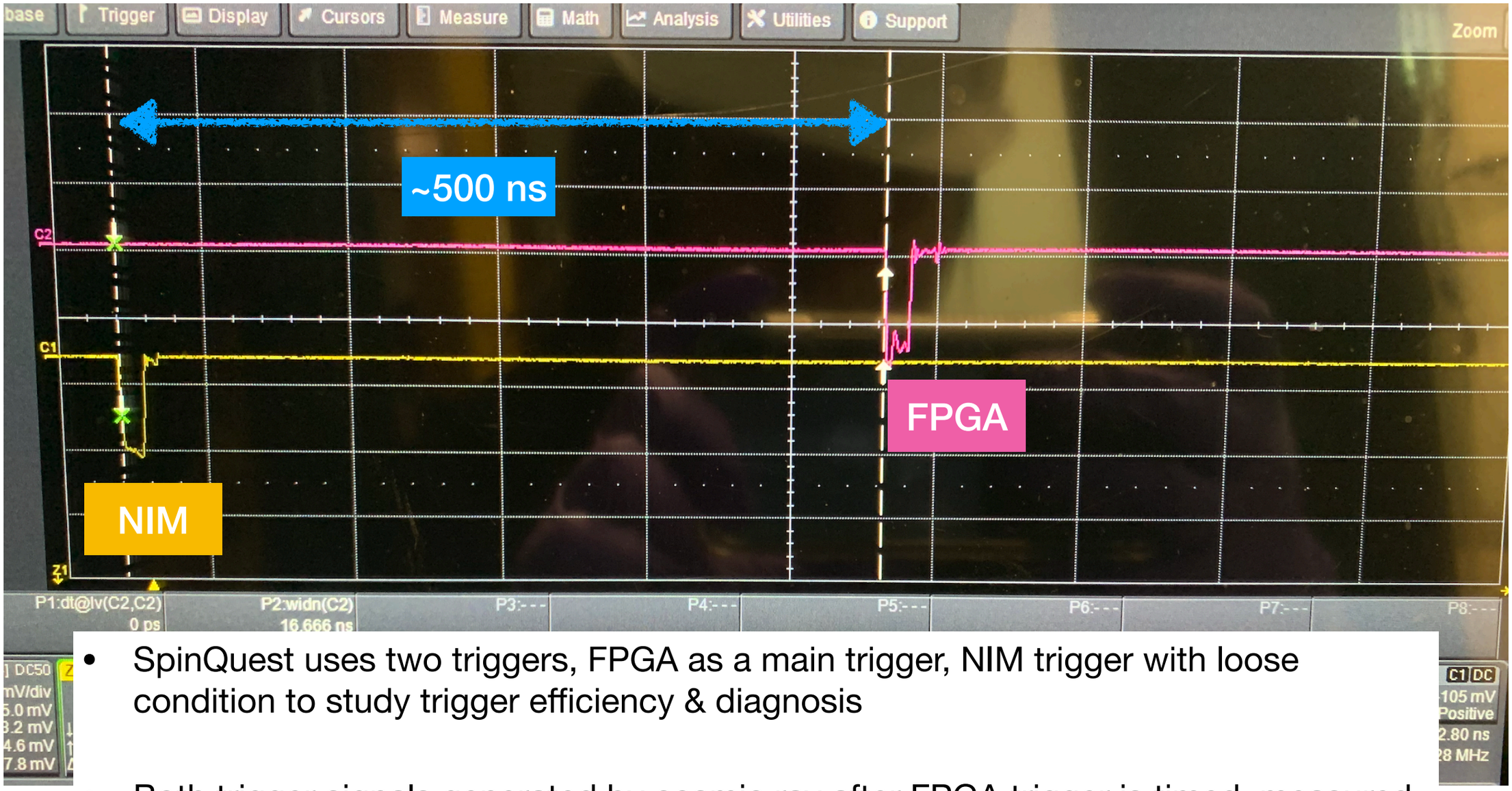
Old design crossed out

Pulser generator setup



Difficult to tune timing with cosmic ray due to high background that hits partial hodoscope stations
Emulate real muon signal timing using pulser generator

FPGA & NIM trigger timing



- SpinQuest uses two triggers, FPGA as a main trigger, NIM trigger with loose condition to study trigger efficiency & diagnosis

- Both trigger signals generated by cosmic ray after FPGA trigger is timed, measured at immediate upstream of Trigger Supervisor

- ~500 ns expected from FPGA delay due to trigger matrix (8+8+5 flip-flops @ 40 MHz)