Lessons from FPGA-based trigger systems in VERITAS

Frank Krennrich
Matt Orr
Skyler Scott
Amanda Weinstein

Argonne NATIONAL LABORATORY

John Anderson
Karen Byrum
Gary Drake
Michael Oberling
Ben Zitzer

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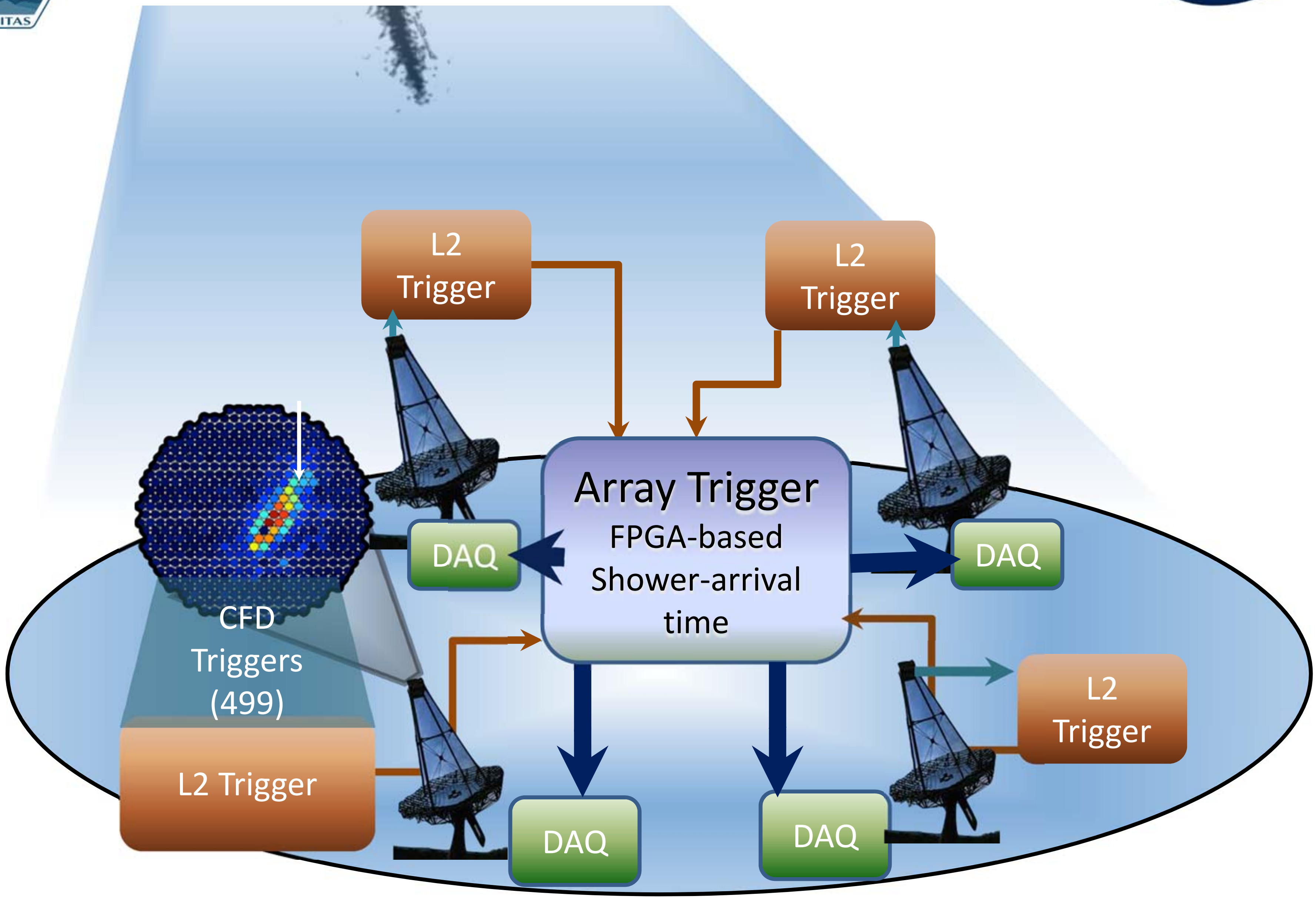
Outline

- Introduction to VERITAS trigger system
- ANL/ISU L2 trigger system:
  - Features
  - Parasitic performance studies
- Implications and lessons for the future

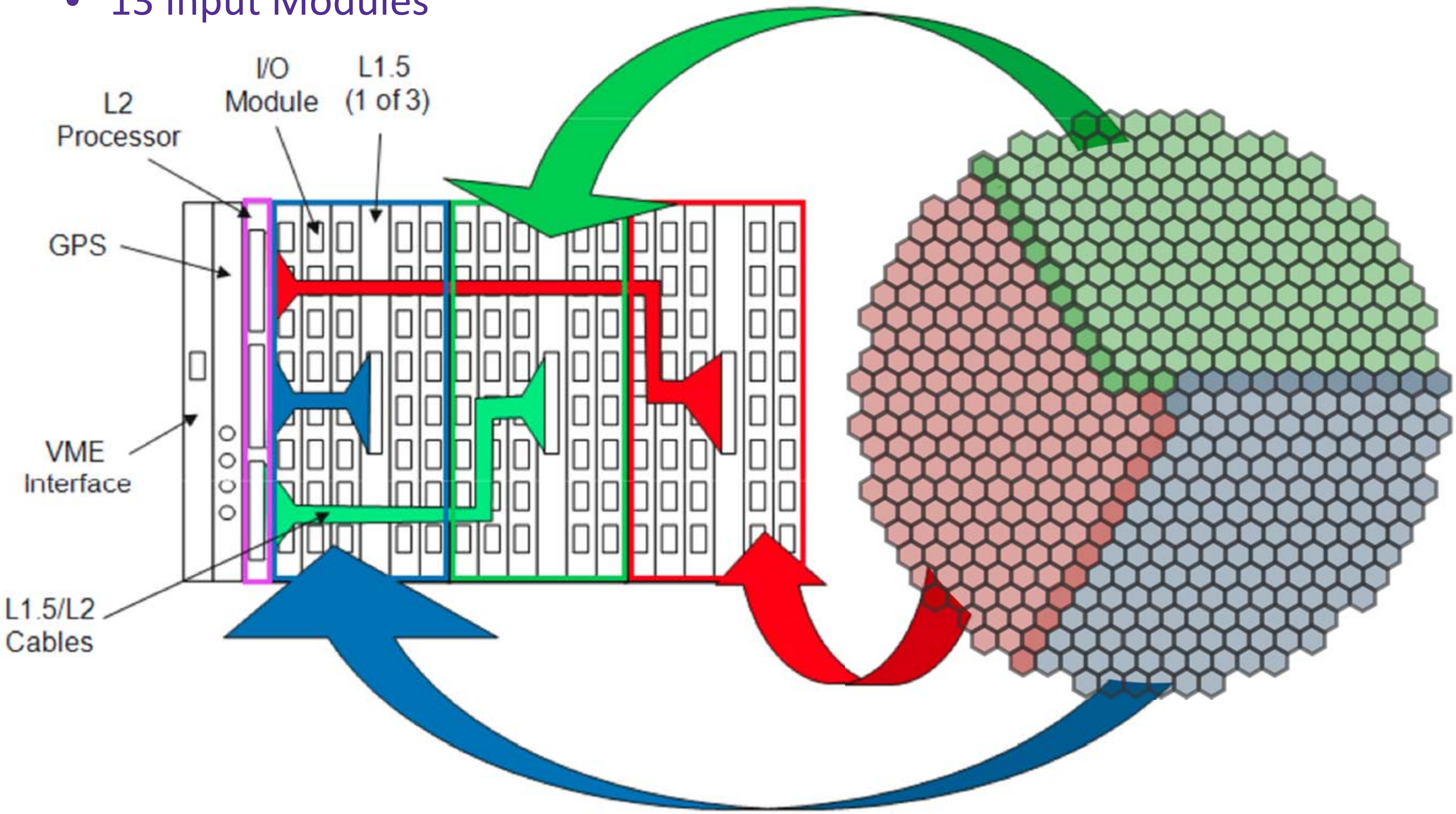
VERITAS Trigger System



ANL/ISU L2 Trigger

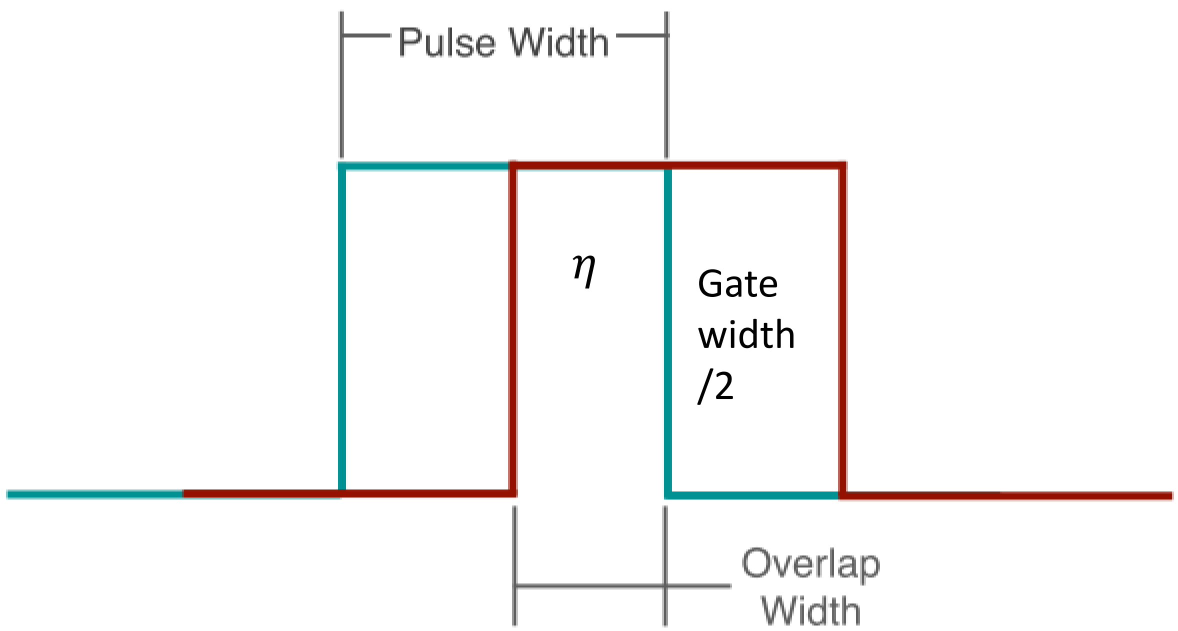
- 1 VME Controller
- 1 L2 Module
- 3 L1.5 Modules
- 13 Input Modules

Overlap pixels: potential source of trigger non-uniformity. Belong to two boards; not bi-directional



ANL/ISU Trigger:Features

- Basic functionality:
  - Coincidence requirement: 3 contiguous pixels overlapping for η ns.
  - Programmable overlap width (η) + programmable CFD pulse width → gate width
  - Gate width range (current operating parameters) is effectively programmable between ~2ns and 13 ns

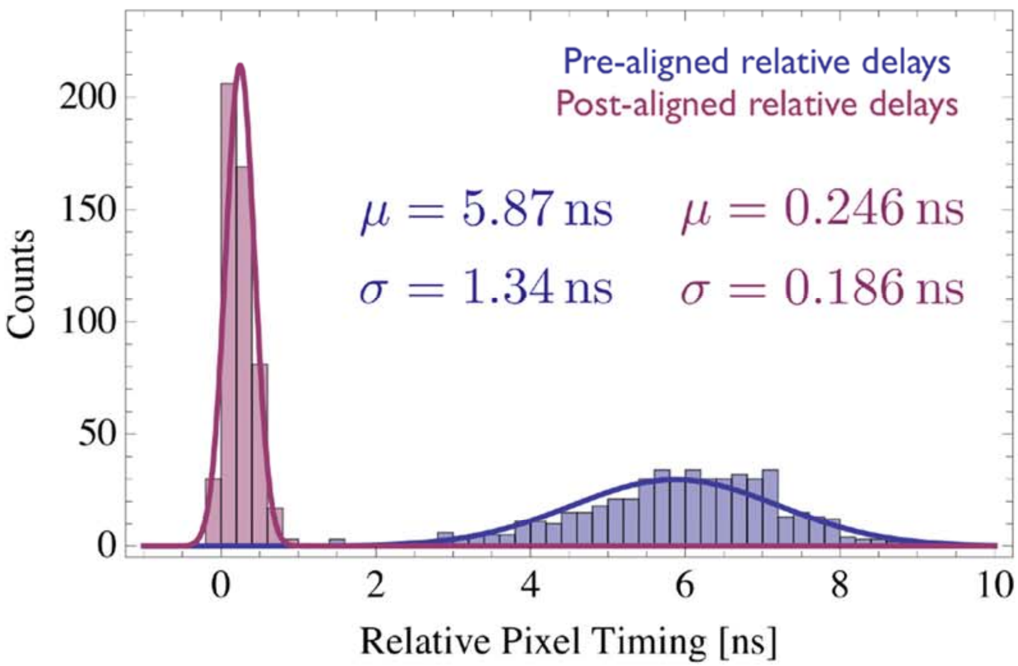


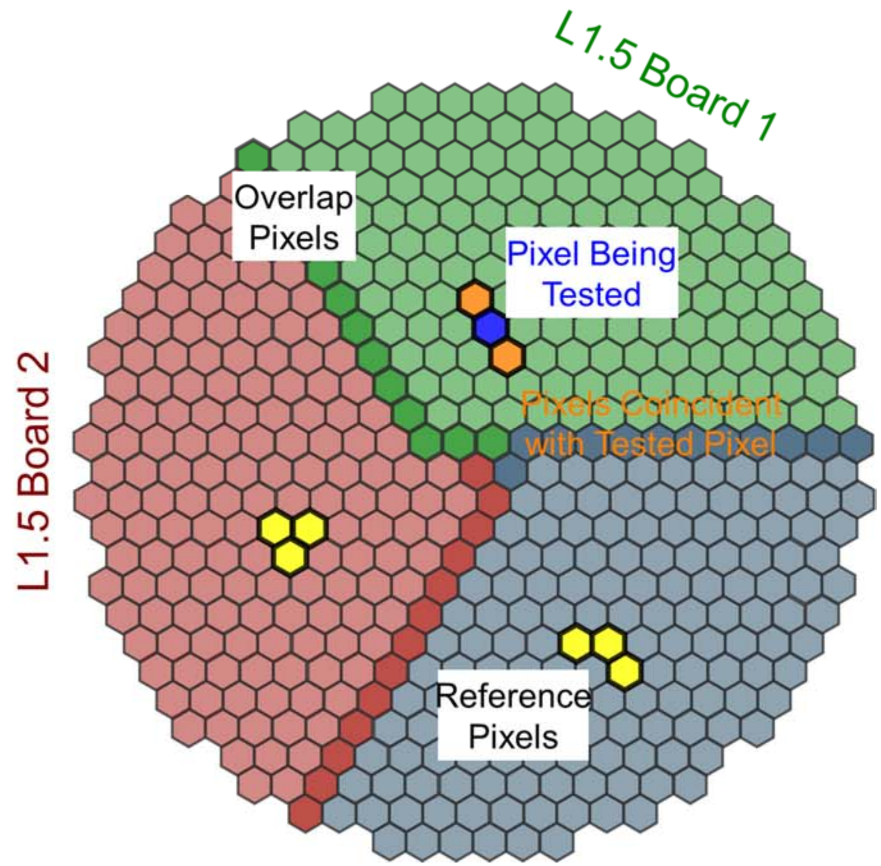
ANL/ISU Trigger: Special Features

- Notable features:
  - Individual, pixel-level controls (enable/disable)
  - Pixel-level (L1) rate monitoring
  - Adjustable internal delays (10ns range).
    - Timing can be brought into very tight alignment, allowing consideration of very narrow gate widths.
  - Parasitic installation (currently one telescope out of four)
    - Non-disruptive commissioning studies
    - Performance tuning
  - Extensible
    - Optical fiber outputs and FPGA resources permit these systems to feed an “L4” topological trigger of the type proposed for CTA

Timing Alignment

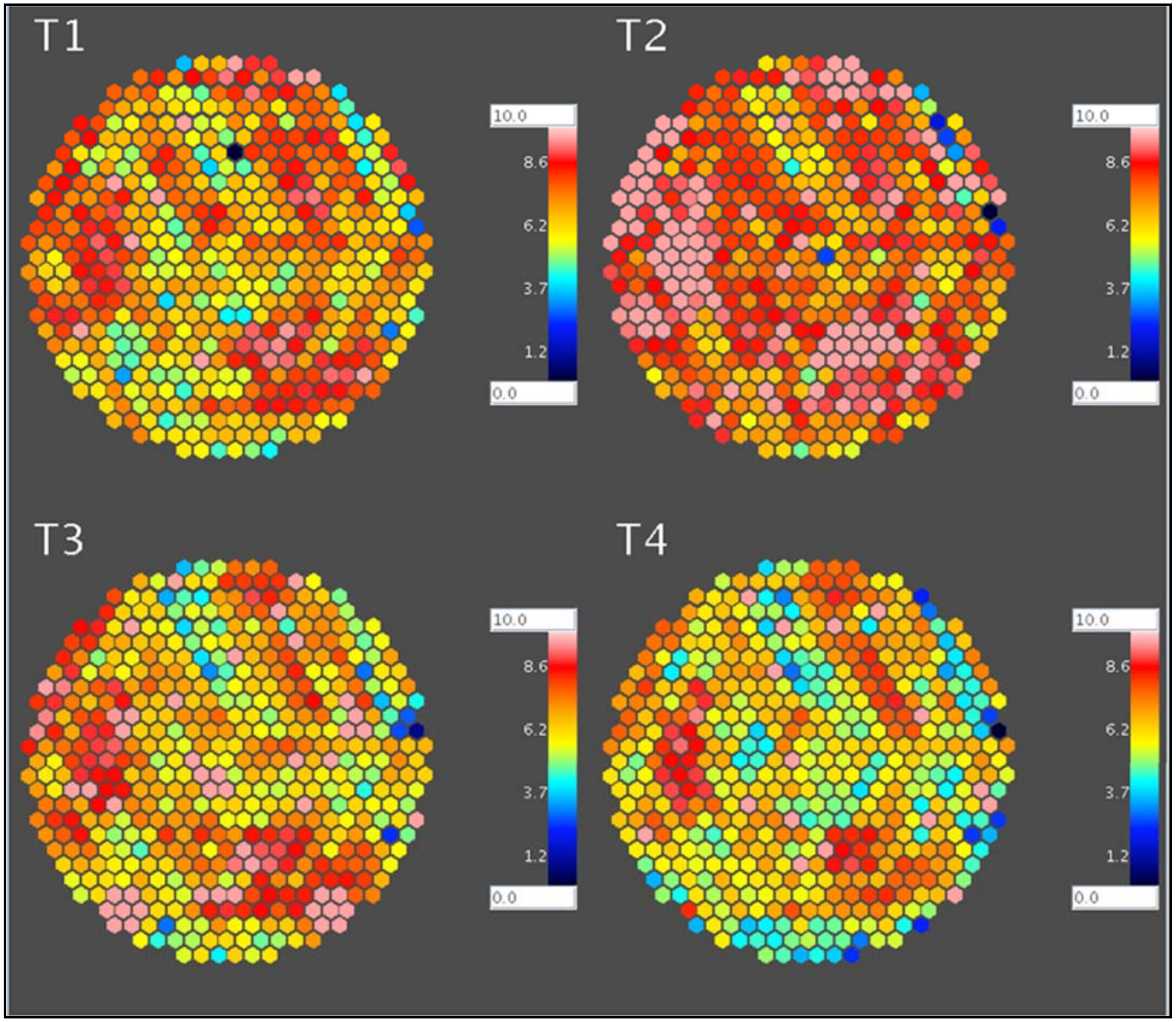
- Natural spread in timing: due both to signal paths within the FPGA and within the system as a whole.
- Internal delays permit a high level of compensation.
- Timing calibration easily done on all telescopes simultaneously.



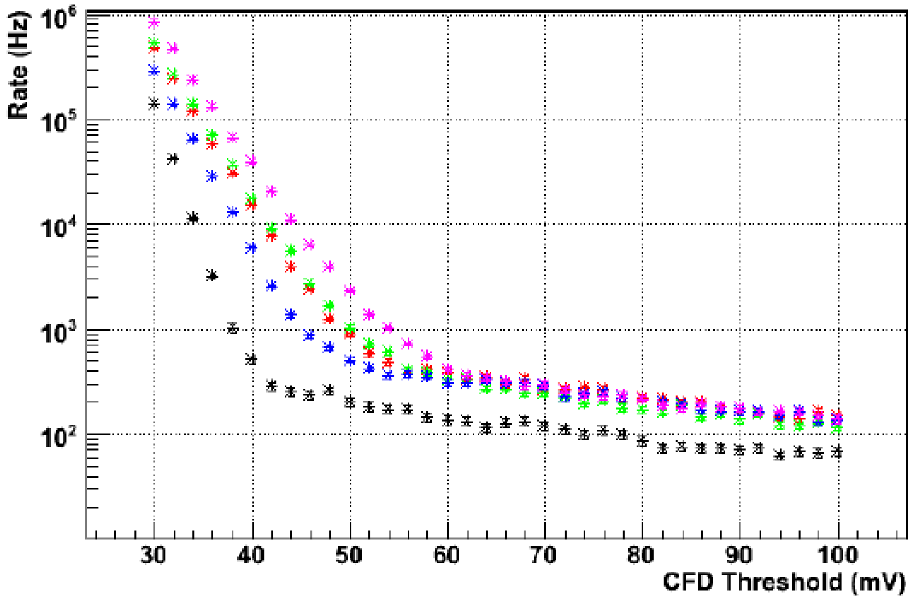


Timing alignment distributions

- Spatial distribution of the timing spread compensation

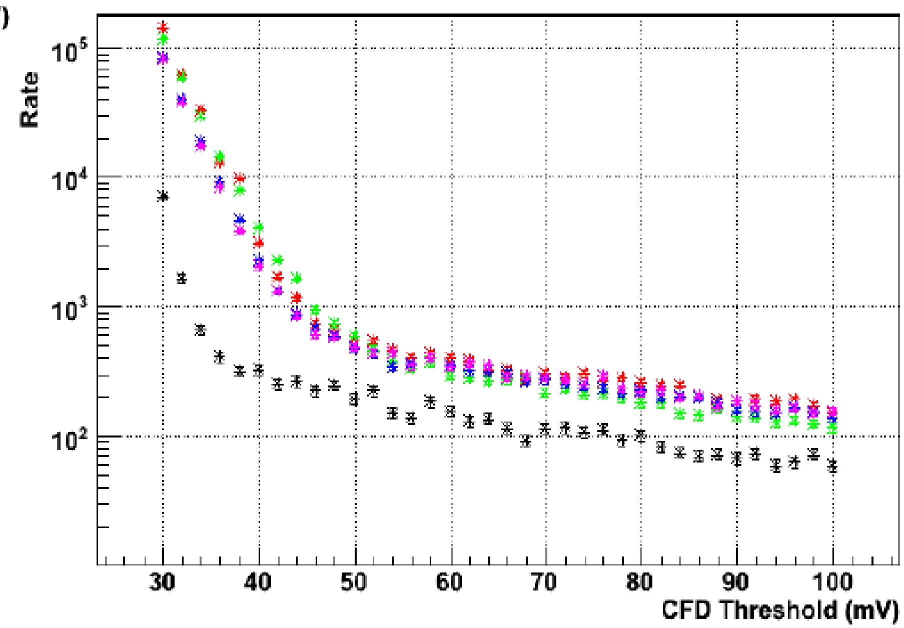


Bias Curves



- Before: mismatched telescope responses in noise-dominated regime

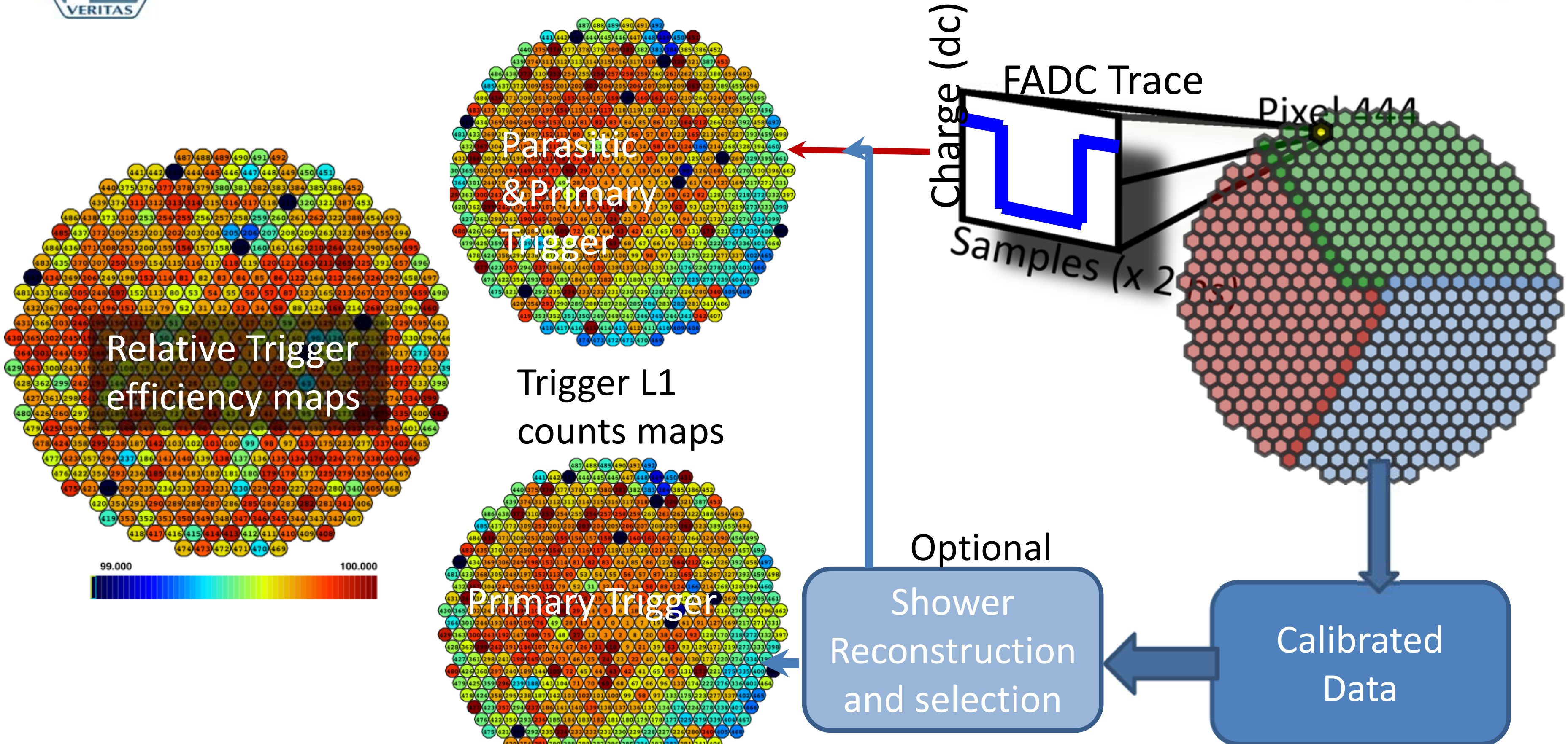
- After: pixel-level adjustment leads to stable and well-matched response → to lowered inflection point



Parasitic studies: Why?

- Lab tests never quite drive the system the same way data does.
  - May not catch subtle non-uniformities
- Simulations rarely model trigger performance perfectly
  - Only as good as a) our trigger model b) our data model
  - Parasitic studies compare data to data: given a viable reference, tells us how the system responds to real events we actually care about.
  - Feedback: can tune trigger simulations more accurately based on parasitic data
- Non-disruptive nature of parasitic studies means studies easily cover a variety of sources and observing conditions.

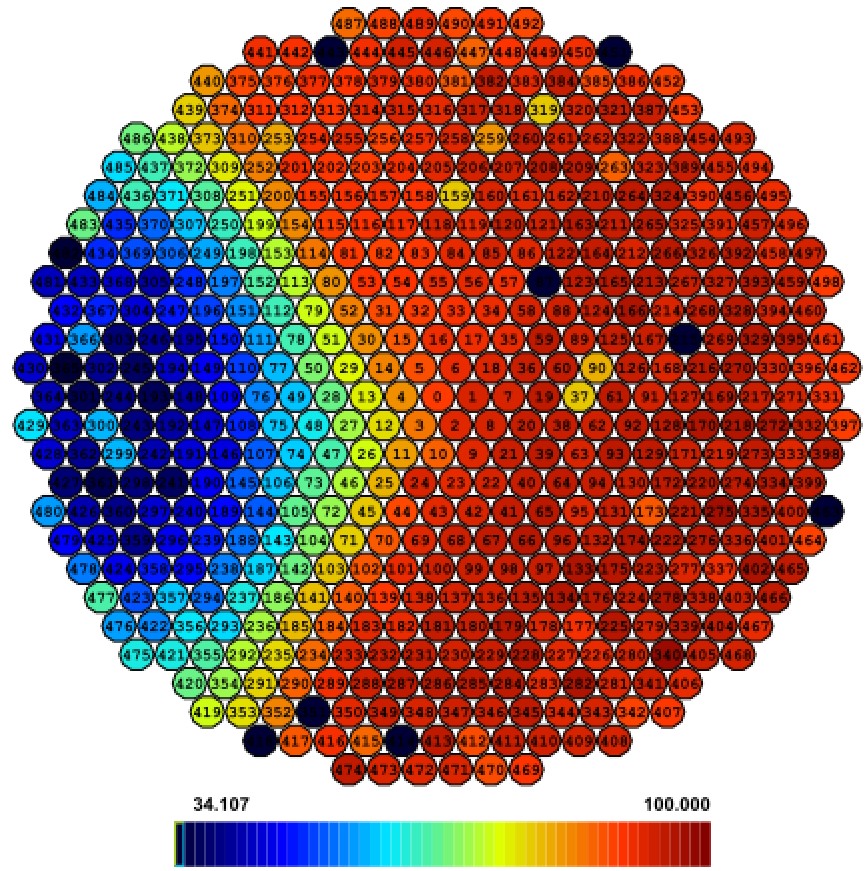
Parasitic efficiency studies: how



- Can reveal
  - Overall efficiency loss
  - Maps let us study potential non-uniformity/structure in trigger response
- Primary and parasite may be
  - Different triggers (as in commissioning period)
  - Two copies of the same trigger (performance tuning studies)
  - Reversed

Parasitic efficiency studies: virtues

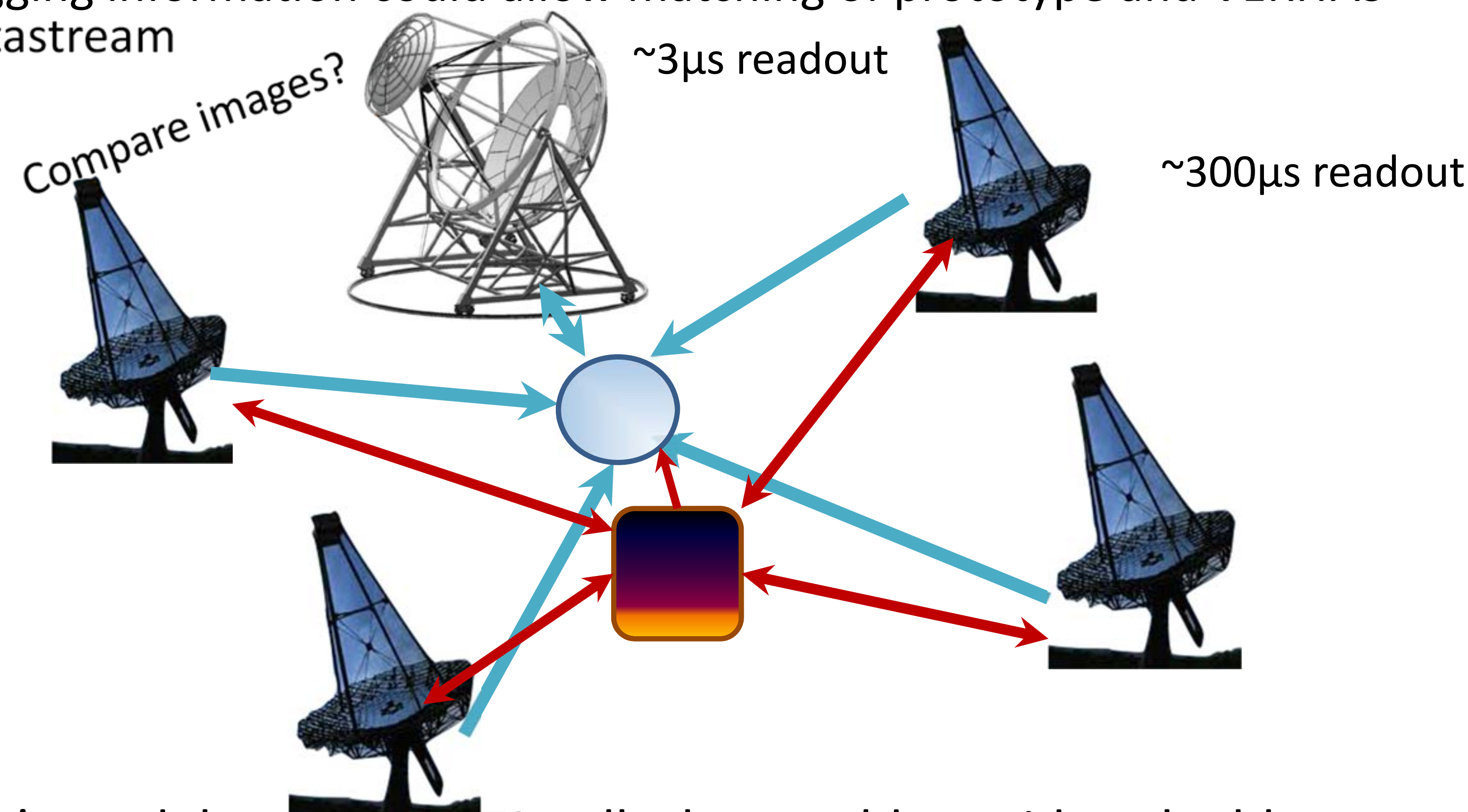
- Non-disruptive to an operating instrument.
- Can perform studies with data otherwise only possible with simulations
- Comparison of two systems responding to **identical set of events** more effective in exposing subtle non-uniformities
  - Similar studies with independent datasets generally failed to reveal structure that the parasitic approach reveals easily.
- Pre-commissioning parasitic efficiency studies reliably predicted the new system's performance as a function of operating gate width above and below threshold (checked with post-commissioning Crab Nebula data)
- Studies ongoing.



Simple example: malfunctioning board

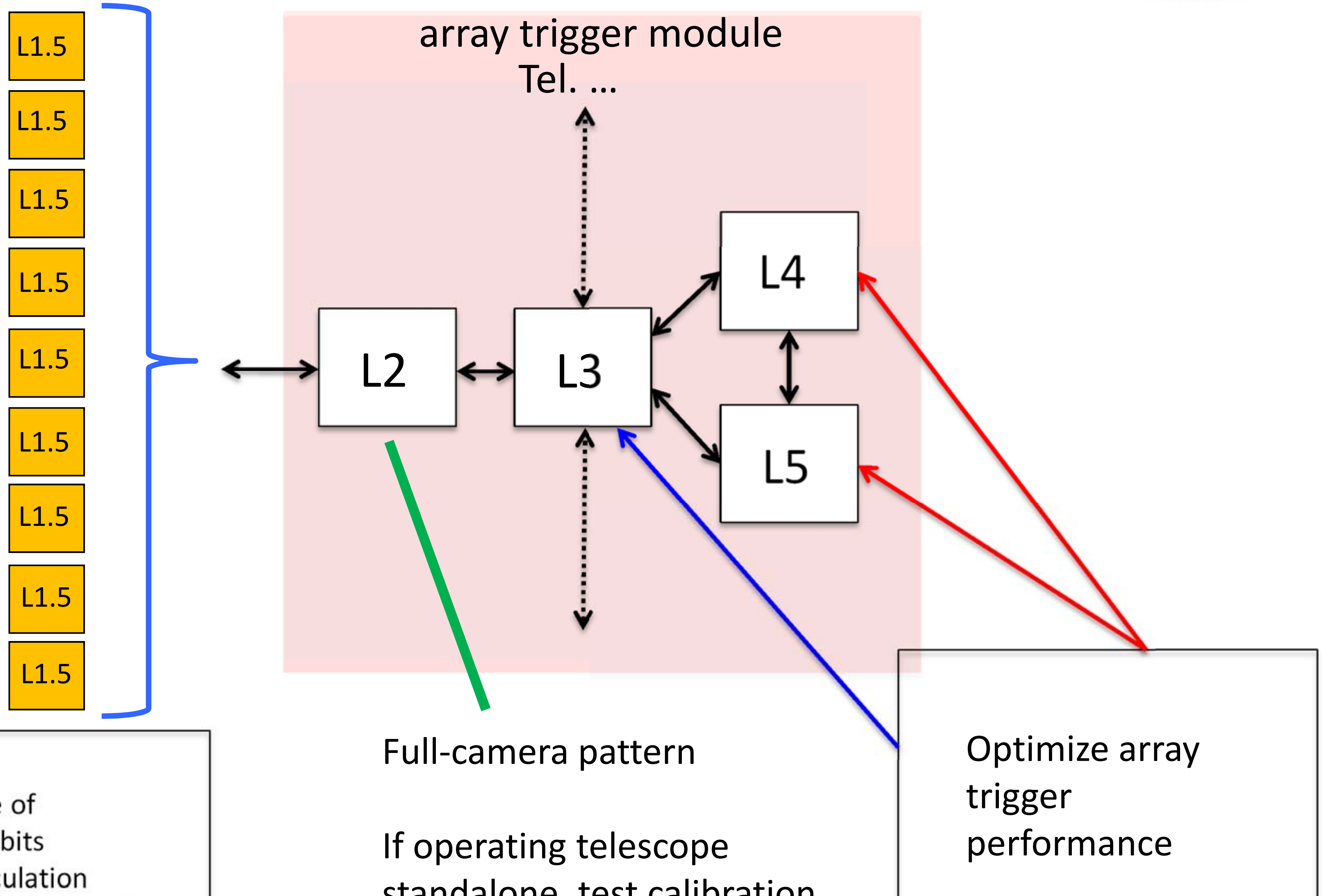
Parasitic array trigger "cell"

- Array-cell level studies: possible w/parasitic testing model if we operate the prototype at the VERITAS site
  - Parasitic systems ship "topological" trigger information to prototype
  - Tagging information could allow matching of prototype and VERITAS datastream



- Won't model a normal CTA cell—but could provide valuable information about an array trigger response to mixed-telescope and boundary cells. (Trigger pixels are of comparable size)

Parasitic testing modes



L1 Discriminator
L1.5 Coincidence of discriminator bits
L2 moments calculation
L3 Data collector/t-corrections
L4 Pattern/Multiplicity
L5 Parallax of sub-array

If operating telescope standalone, test calibration pass-through (e.g. muons)

Food for thought

- Mechanical design of camera has implications for trigger uniformity.
  - No overlaps = small non-uniformities near threshold.
  - Smaller modules = bigger non-uniformities
  - Gamma-ray events only see impact near energy threshold.
  - For CR background: trigger threshold != energy threshold. Trigger threshold events influence background in VERITAS up to multi-TeV.
- Datastream design
  - What trigger information should we pass down the line to debug the decision process? Timing information?
- Parasitic capabilities could be used to
  - Study camera-level trigger algorithms with VERITAS
  - facilitate study of array trigger behavior in R&D phase (not part of MRI)
- Can (should?) we design parasitic capabilities into final system?
  - The SC-MST L1.5? L2? At array level?
- At array level, parasitic studies of a few trigger cells could be useful during commissioning
  - Provides feedback to simulations