Overview of an Array Trigger for CTA

CTA Collaboration Week
Camera Electronics Meeting

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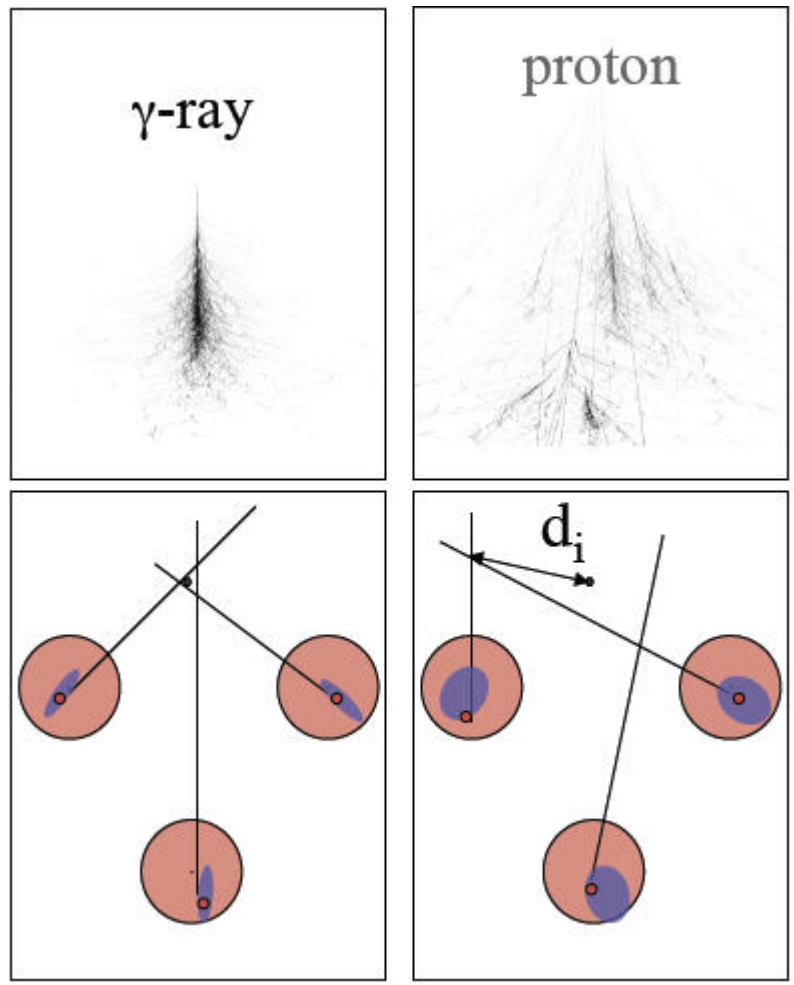
Motivation

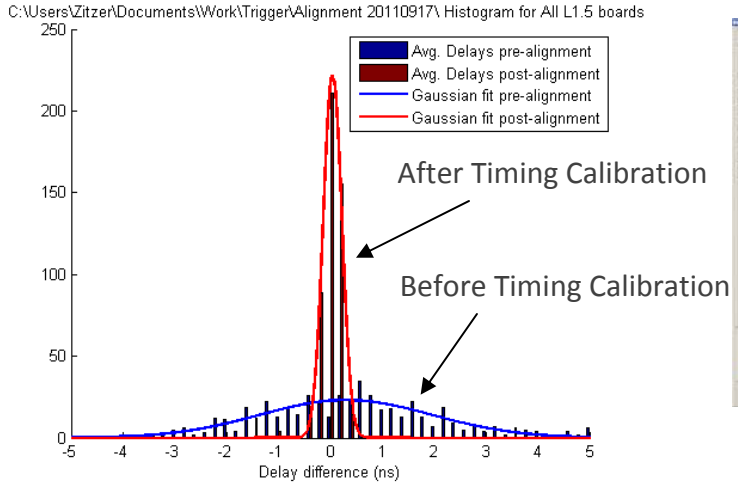
- **Primary Motivation:**
  - **Trigger camera readout on gamma rays**
  - **Reject background events from cosmic rays and muons**
    - ⇨ ***Events have very different signatures***
      - **Gamma rays are compact**
      - **Hadrons have a large spread in lateral and longitudinal shower profile**
      - **Muons produce rings**
    - ⇨ ***Can make use of event topology at the trigger level to improve trigger efficiency***
      - ⇨ ***Centroid moments***
      - ⇨ ***Parallax Width Displacement [1]***
  - **Preliminary study: When implemented requiring correlation between a multiplicity of telescopes, can improve rejection of CR by X10, while keeping > 90% of gamma showers**
    - **Need large array to be truly effective**
    - ⇨ ***CTA is ideal for this technology!***
    - ⇨ ***Implement using high-performance FPGAs***

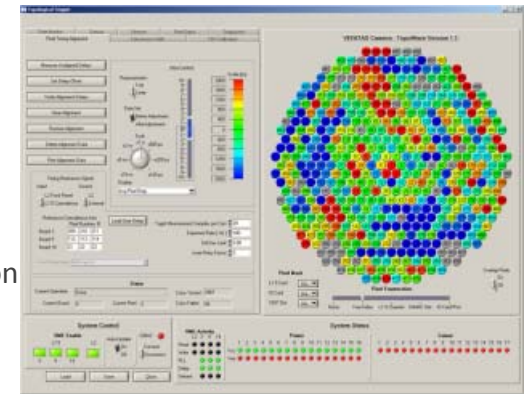


[1] Krennrich, F. and Lamb, R.C.Experimental Astronomy, 6, 285-292 (1995a)

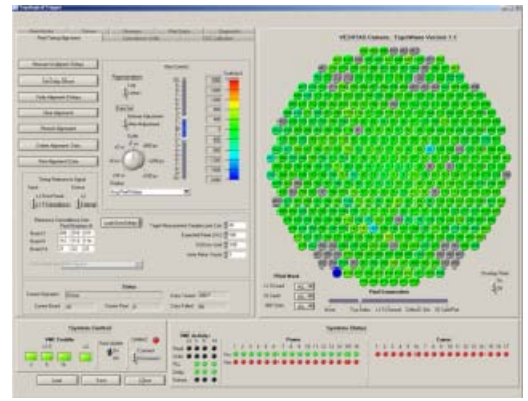
Motivation (Cont.)

- **Secondary Motivation:**
  - With good timing resolution across the telescope, can reduce energy threshold
  - Example: Veritas

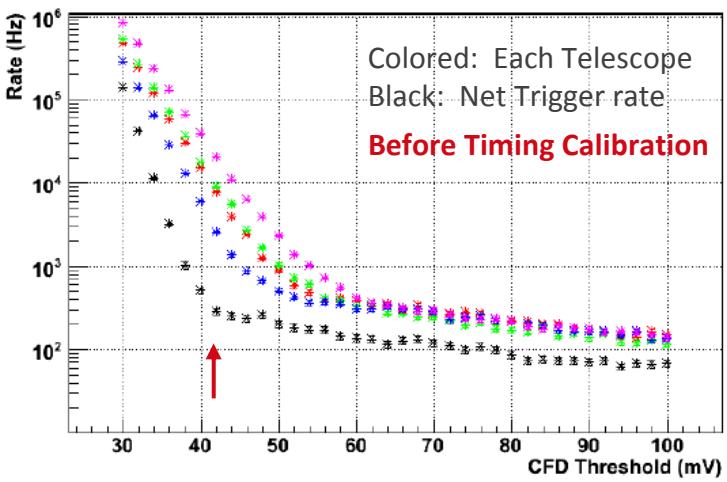


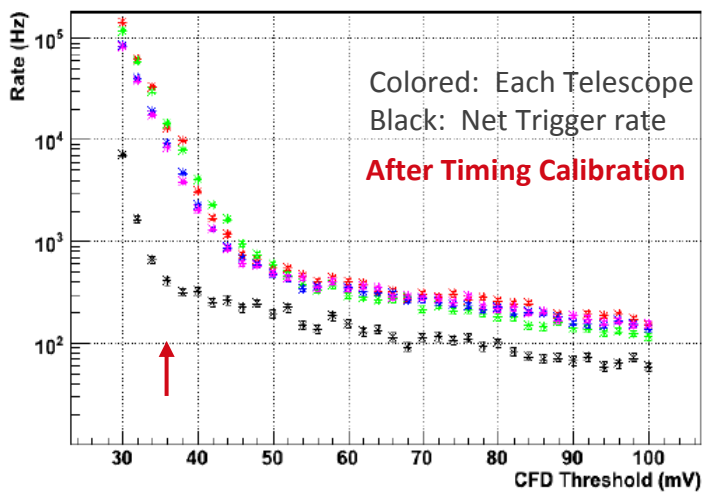


Before Timing Calibration



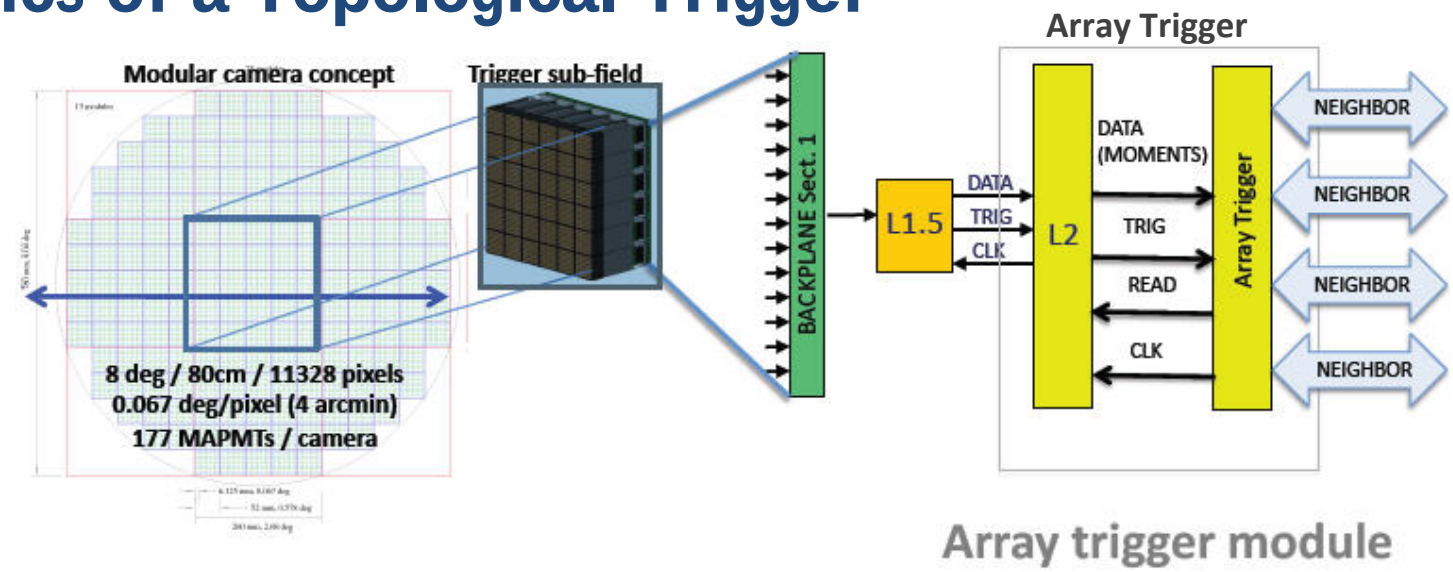
After Timing Calibration





⇨ ***Good timing alignment can reduce the energy threshold of trigger***

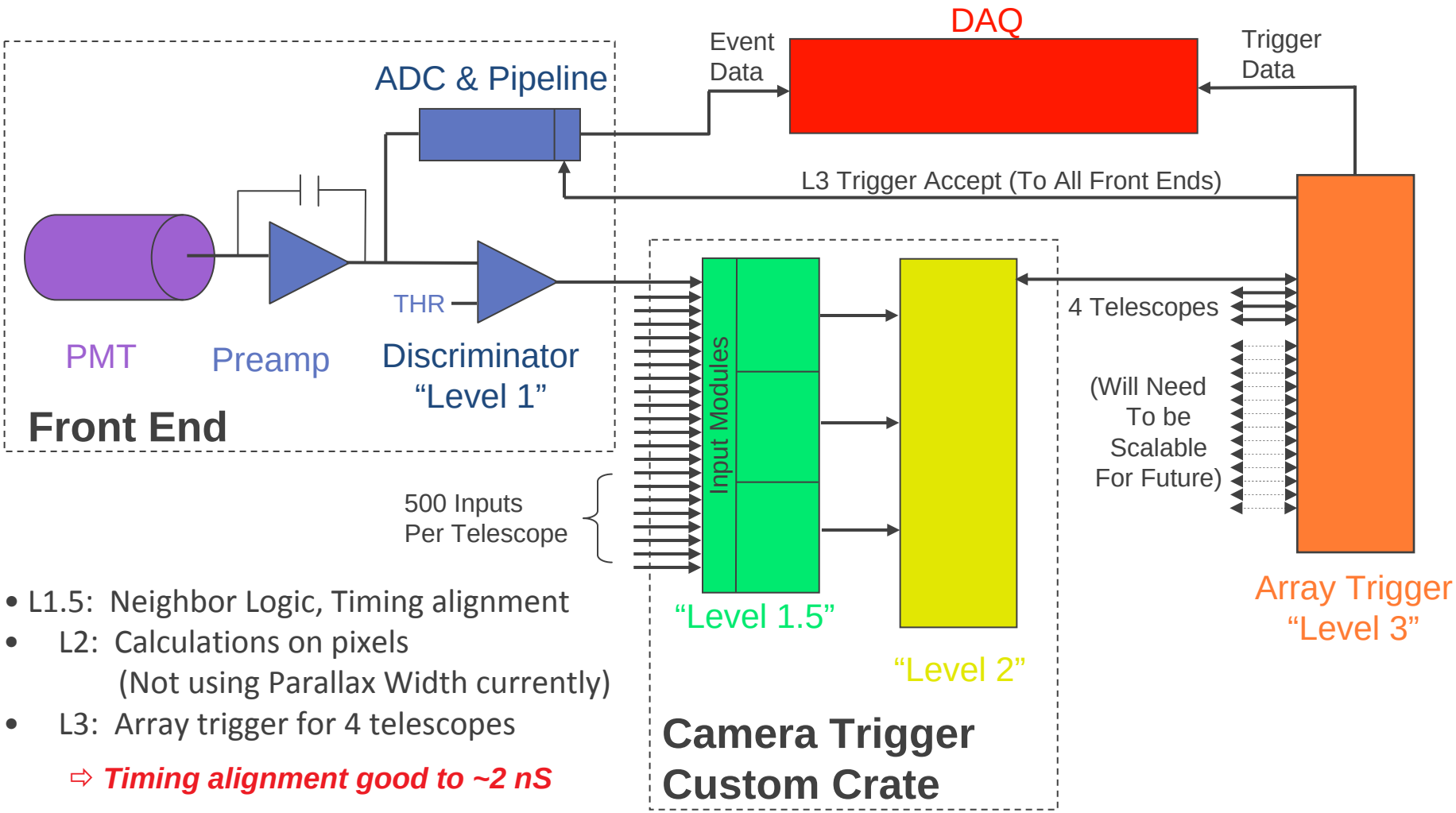
Basics of a Topological Trigger



- Begin with discriminated "hits" from each front-end channel
  - Use constant-fraction discriminator, comparison threshold set to ~1 p.e.
    - ⇨ *Yes – it's in the noise of the photo-detector…*
- Hits are collected by L1.5
  - Apply a sliding time window
  - Save hits that have neighboring pixels that are also hit within that time window (e.g. 3)
  - For hits that pass, timestamp and send to L2
- Then, calculate moments using geometrical information from hits
  - Xavg, Yavg, σ_{xx}^2, σ_{yy}^2, σ_{xy}^2, N_{HIT}
- Array trigger
  - Uses centroid information and timing from L2 for correlation with neighboring telescopes
  - Performs parallax width calculation

Experience at Veritas

- We began as an R&D project → Implementation of a Parallax Trigger
- We ended up building an upgraded Trigger for Veritas
  - Without the Parallax Width Trigger… But all the hooks are there

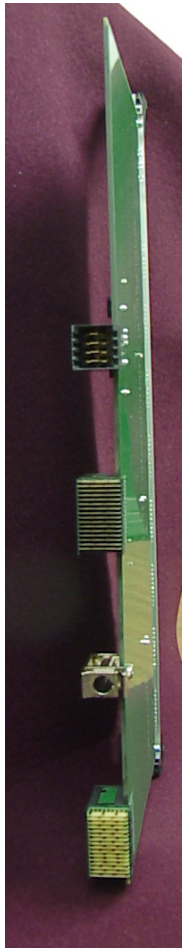


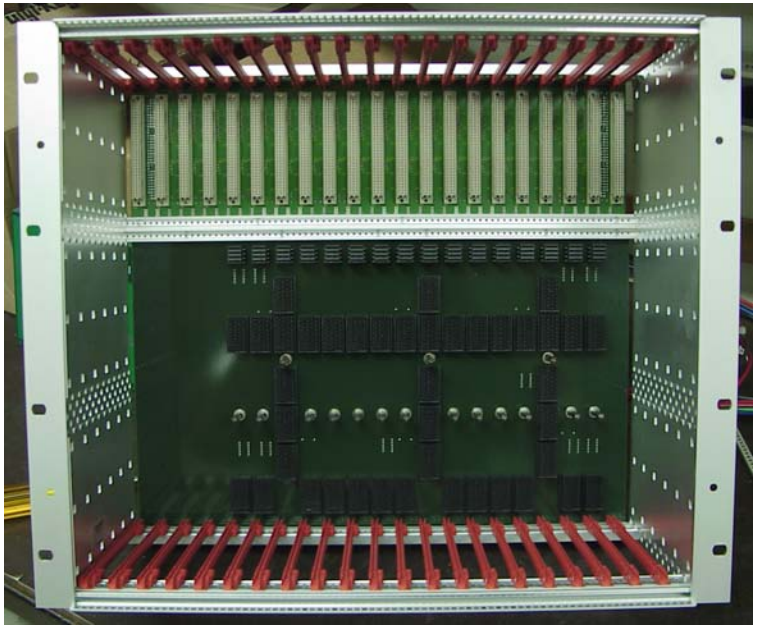
- L1.5: Neighbor Logic, Timing alignment
- L2: Calculations on pixels
  (Not using Parallax Width currently)
- L3: Array trigger for 4 telescopes

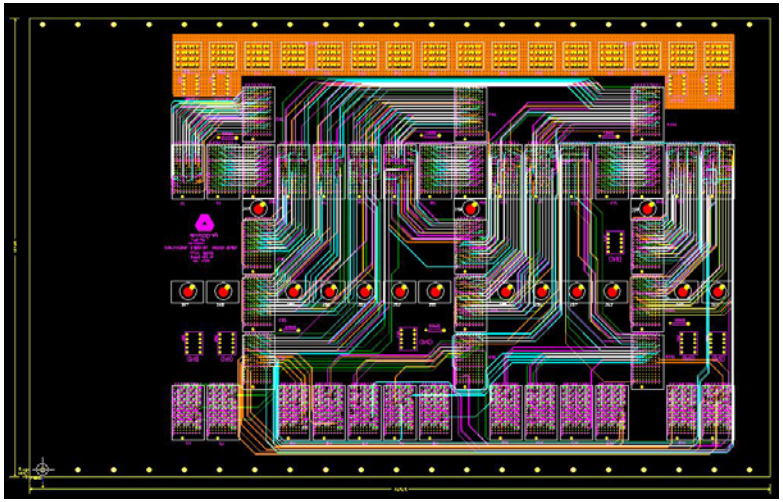
⇨ ***Timing alignment good to ~2 nS***

Experience at Veritas (Cont.)

- Backplane
  - **9U in size**
    - J1 is standard VME for slow control & diagnostics
    - J2 is used for point-to-point routing of L1 signals from I/O Modules to a particular L1.5 Processor
    - J3 is used for point-to-point routing of L1 signals in overlap regions
    - ⇨ ***100 ohm, Impedance-controlled***
  - **Uses Multi-GIG Connectors from Tyco**
    - Capable of ~3-10 Gbps





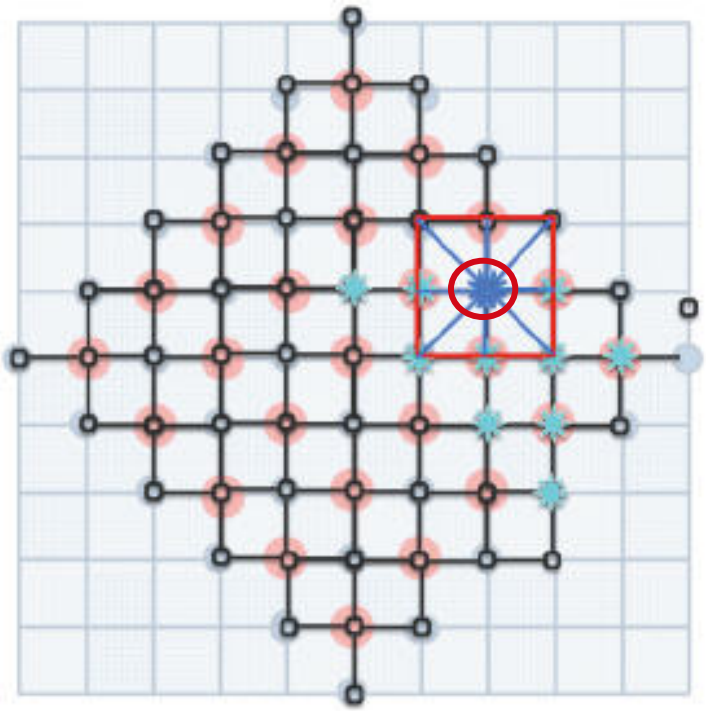


10-Layer Circuit Board Layout of Backplane Designed at Argonne

Configuration for CTA

- **For mixed array of MST's**
  - **Each telescope is the center of a Trigger Cell**
    - Trigger Cells have 9 telescopes except at edges
  - **Neighbors send centroid information to center telescope in a cell**
  - **Each central telescope uses information from it's own hits plus the centroid information from neighbors to trigger itself**

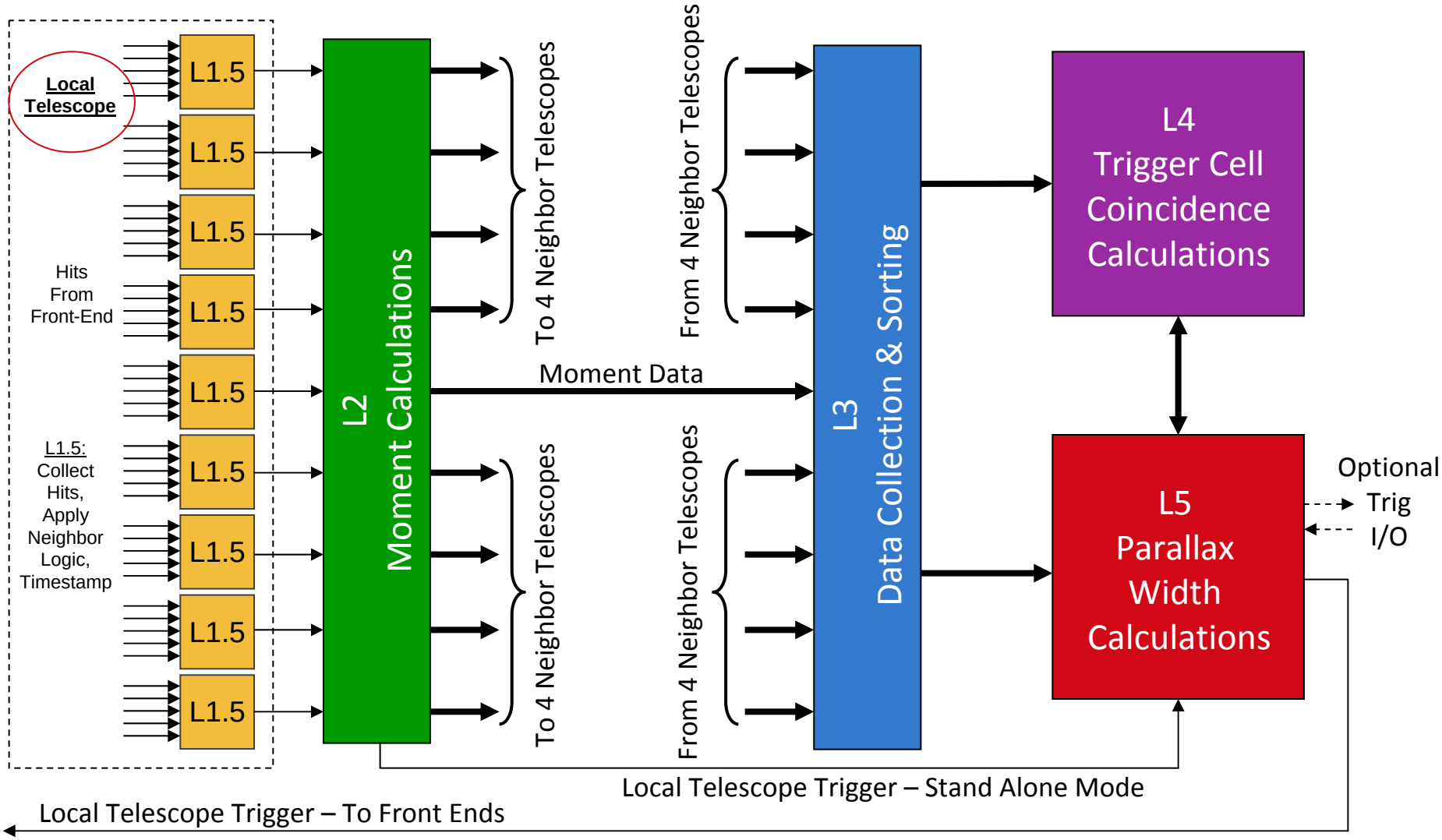
    ⇨ ***De-centralized trigger***
  - **Additional coordination with triggering the array is possible…**



(Example Array Configuration)

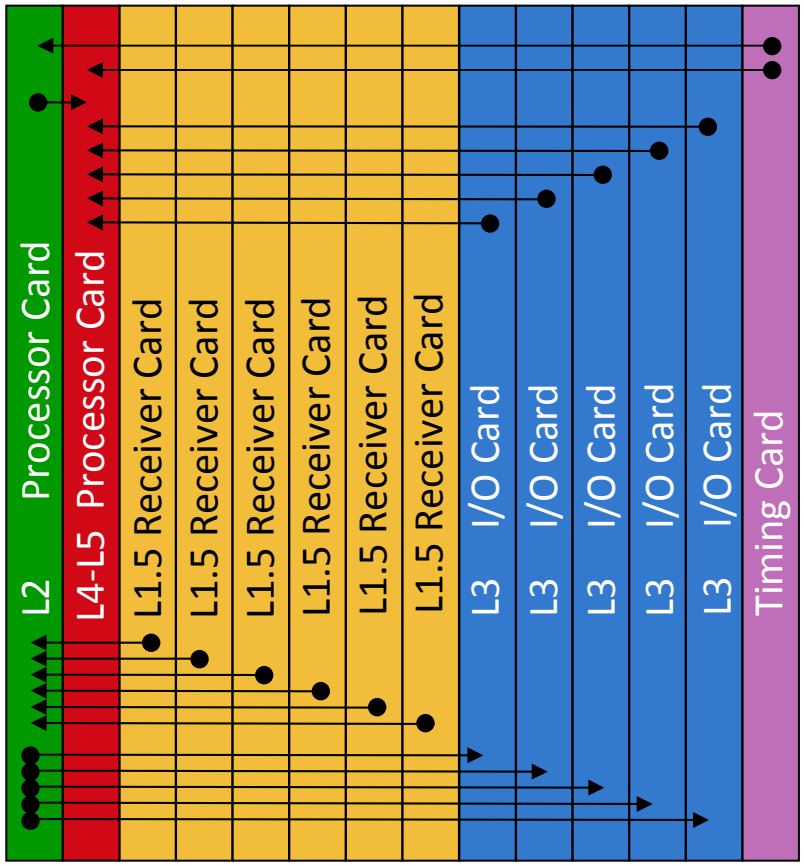
Block Diagram of a Distributed Topological Trigger for CTA

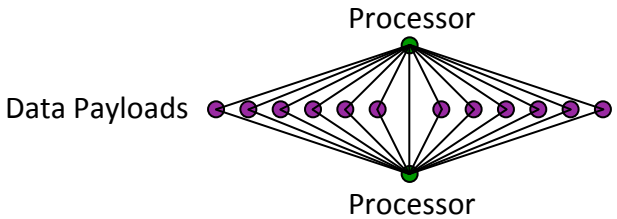
- Multi-Tiered Trigger System – Trigger for each Telescope



Implementation of a Distributed Topological Trigger for CTA

- Uses Advanced Telecommunication Computing Architecture (ATCA) [2]
  - Dual Star Topology
  - A possible, very flexible implementation:





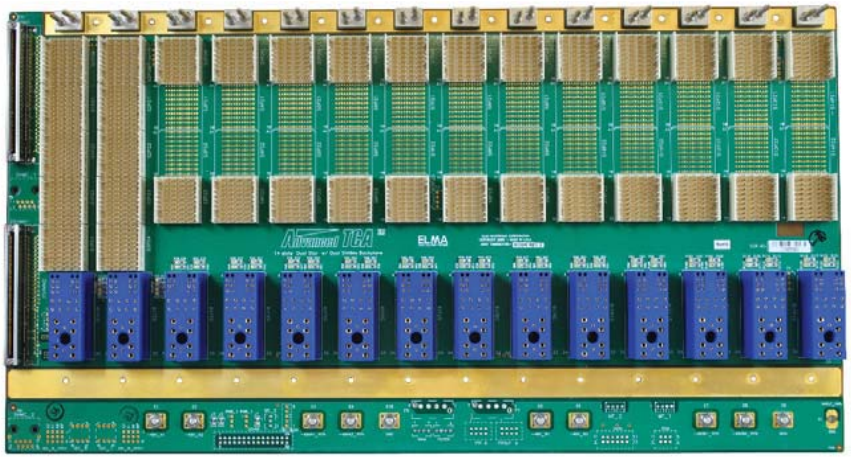


Photo Courtesy of Bustronic
http://www.bustronic.com/pdf/ATCA_DualStar.pdf

⇨ ***Based on work ongoing for Atlas TDAQ Upgrades (LHC @ CERN)***

⇨ ***Note: This is one possible implementation***

⇨ ***We are still working out details of connectivity, bandwidth, and functionality - A work in progress…***

[2] http://www.a-tca.com/

Summary

- **The physics of the universe may never shut off (unlike an accelerator),**

  But Mother Earth is sometimes uncooperative
  - **Data collection efficiency is important until:**
    - Disk writing latency is 0 nS
    - Cost of Pipeline depth is $0
    - Computing bandwidth is infinite

    ⇨ ***The nature of the trigger system affects this***
- **Writing good data to disk**
  - **The signatures of gamma ray events are very different from background events**
  - **Exploit this in the design of the system**
- **The use of a hardware-based trigger can significantly improve trigger efficiency**
  - **We are actively pursuing Parallax Width, implemented in a hardware-based algorithm**
- **ATCA technology is *THE FUTURE* of High-Performance DAQ**
  - **High-speed**
  - **Flexible**

  ⇨ ***All NEW large experiments should consider using this technology***

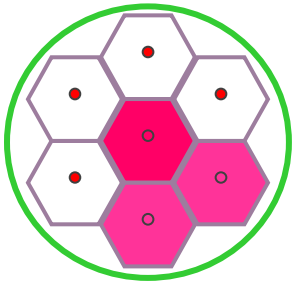
⇨ ***a Topological Array Trigger could significantly enhance the performance of CTA***

Backup Slides

Basics of a Topological Trigger (Cont.)

- **Receive *discriminated hits* (Level 1 Trigger) of each pixel in a camera from the FEE**
- **Form time window, & collect hits**
- **Process hits that have "3-fold neighbor coincidence" → Mostly rejects singles**
- **Calculate 1st & 2nd moments of images in each camera**
- **Use stereo view from multiple telescopes to project image back into the sky**
- **Identify γ-ray images by tight correlation of projection → Parallactic Displacement**
- **Do this with no dead time**

⇨ ***Goal is 1 nS timing resolution***



3-Fold Neighbor Coincidence, 7-pixel cell, Formed around primary pixel (Veritas)

→ List Of Hits + Time Stamp → X,Y Of Hits → 1st & 2nd Moments → Polar Coord. → Parallax Width

Basics of a Topological Trigger (Cont.)

- Method
  - **Calculate 1st moment of images in each telescope**

    $\Sigma x_i \qquad \Sigma y_i \qquad N_{HIT}$
  - **Convert to Polar Coordinates, & form vectors**

    $\bar{r} = \sqrt{\bar{x}^2 + \bar{y}^2}$

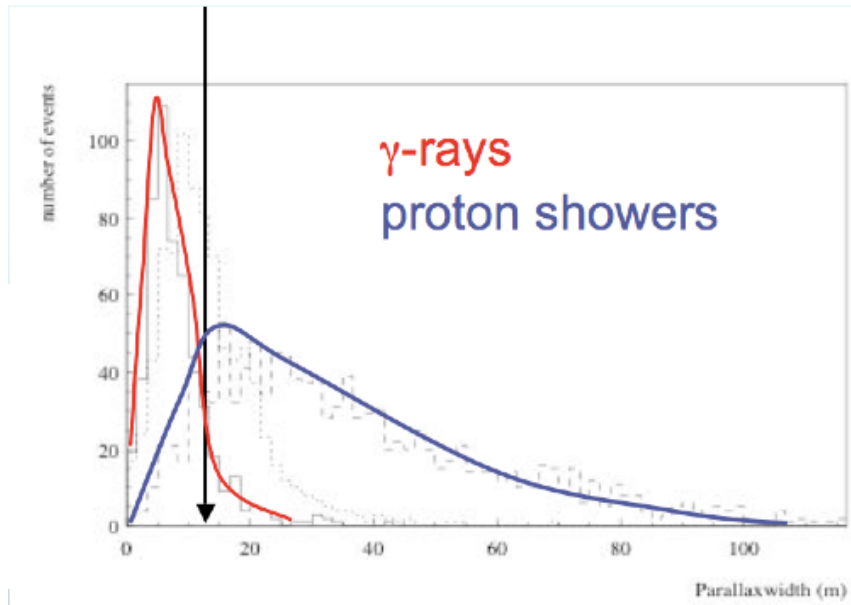
    $\phi = \arcsin(\bar{y} / \bar{r})$
  - **Calculate Parallaxwidth:**

$$Parallaxwidth \approx \sqrt{\frac{\sum_{i=1}^{n}(\vec{r}_i - <\vec{r}>)^2}{n}}$$

$$\vec{r}_i = location\ of\ intersection\ point\ i$$

$$<\vec{r}> = averaged\ core\ location$$

  - **Calculate 2nd Moments**
    - $\sigma_{xx}^2 \quad \sigma_{yy}^2 \quad \sigma_{xy}^2$
    - Evaluates "Goodness" of Fit



Monte Carlo simulation of γ / hadron separation capabilities using parallactic displacement. Simulation used array of (19) 10-meter telescopes spaced 60 meters apart.

⇨ ***Reject 90% of cosmic rays while retaining 90% of gamma-rays***