Trigger/DAQ Planning

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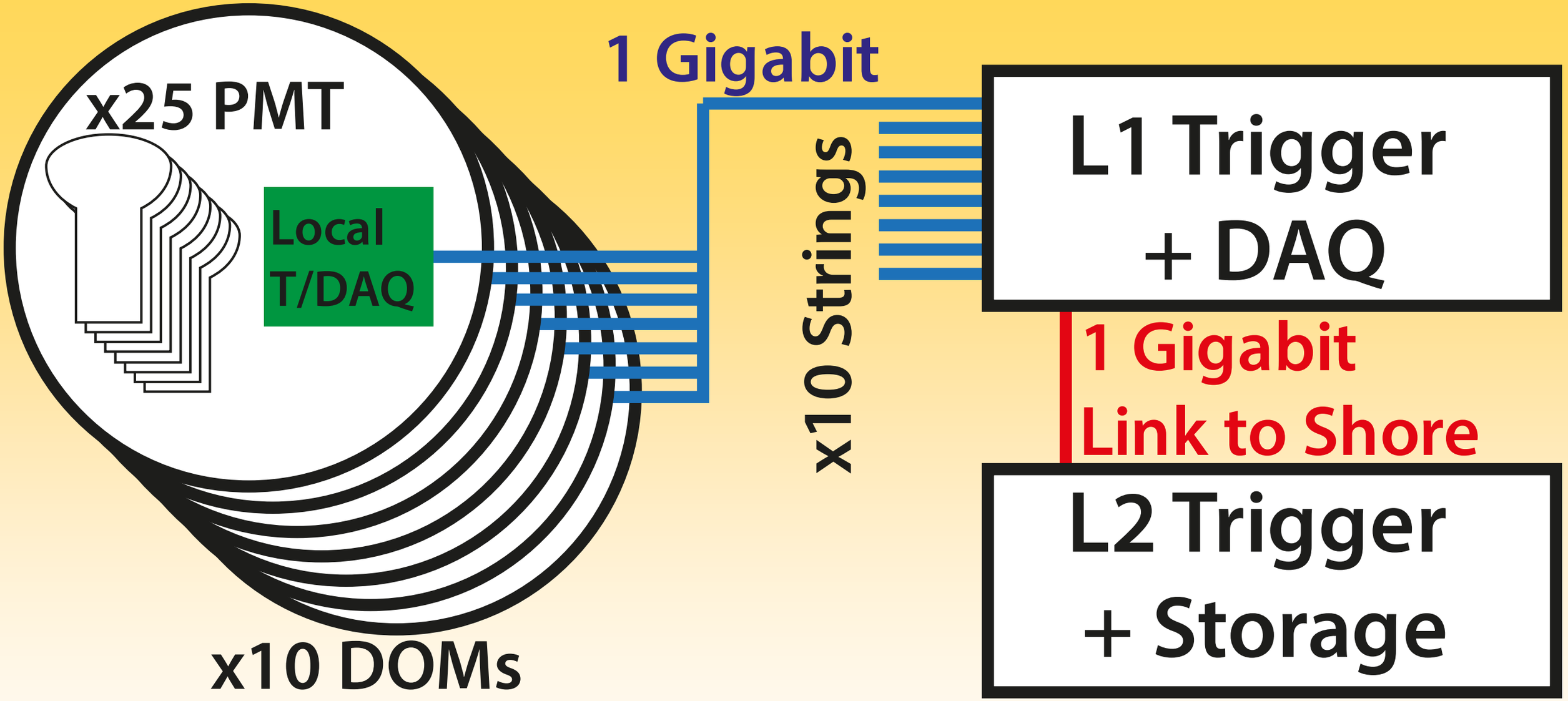
Trigger Principles

- General principle of triggering at colliders in a high-background environment
  - Do the least that you can to meet the hardware/funding bottlenecks on bandwidth
    - Trigger algorithms have limited time and/or data
    - Cannot undo mistakes: all algorithms need validation
  - Trigger rates are almost always determined by background
- IceCube is different: low backgrounds
  - Exceptionally low noise rates and easily rejected backgrounds mean simple triggers can rapidly reduce rates well below hardware and bandwidth limitations
- P-ONE likely somewhere in between
  - PMT rates ~100 times greater and correlated local backgrounds from Potassium-40 and bioluminesence
  - Start analysis from a noise/background perspective since signal rate not likely to be an issue (cosmic muons ~100 Hz)

Two-stage Trigger

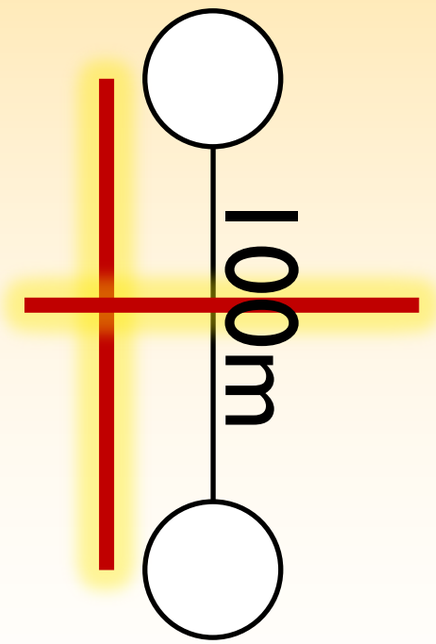
- Make some "back of the envelope" calculation
  - VERY rough estimates: order of magnitude (or worse!)
- Estimate trigger rates for simple inter-DOM coincidence scenarios
  - Keeps algorithm simple and easy to implement and understand
  - Reduces complexity of system on ocean floor
  - Just reduce rate to one that can be sent over the link to shore
- Do more complex processing on-shore
  - Level 1: at site, simple, meet site-to-shore bandwidth
  - Level 2: on-shore, complex, meet storage limits

Basic Design Assumptions



Rate Assumptions

- Hit rate from PMTs = 10kHz (~STRAW)
  - Coincidence rate due to K-40 really hard to estimate for mDOM configuration (as opposed to sDOM)
  - Antares claimed 14 Hz K-40 coincidence rate between two OMs: larger PMTs but also large 120° angle between them
    - ICRC '07, could not find numbers for KM3NET
- Coincidence Windows for Triggering
  - 3ns window within one DOM
  - Need at least 300ns between DOMs assuming a 100m spacing, probably more, to account for all possible trajectories
  - Estimate 500ns for coincidences between two neighbouring DOMs



Bandwidth Assumptions

- Data per hit 4x32 bits = 16 bytes
  - DOM ID
  - Time of hit to nearest ns
  - Charge/time over threshold(s)
- Max bandwidth for 1 Gbps ~ 100 MB/sec
  - Assume we get 50% of Gigabit link to shore i.e. ~50MB/s
- Readout window for full detector 4μs
  - If detector size is ~1km, light takes ~3μs to cross detector
- Minimum bias event size ie. just noise/K-40
  - 10 strings with 10 DOMs and 25 PMTS @10kHz: 1.6kB
  - Signal events larger due to more hits
  - …but cosmic rate ~100 Hz so bandwidth only an issue if we are dominated by noise: assume event size ~2 kB/event on average

Noise Rate Calculations

- 2kB/event and 50MB/s bandwidth to shore
  - Need trigger rate to be under ~25kHz
- Assume 14 Hz coincidence rate between any 2 PMTs in a DOM with 25 PMTs
  - Combinatorics gives 4.2kHz rate per DOM
  - But clearly an overestimate: assumes PMTs on opposite sides of the DOM have a 14 Hz coincidence rate
    - Only assume correlations with half PMTs: 2.1 kHz rate
  - Uncorrelated rate for DOM: 90 Hz (10 kHz/PMT, 3ns)
- Understanding the correlations due to K-40 and bioluminescence critical for understanding rates
  - Small changes in the correlated rates has huge impact

Noise Calculation

- Assume 2-PMT coincidence per DOM
  - Use 2.1 kHz per DOM rate…probably still on the high side
- Consider two algorithms
  - Neighbour DOMs (cubic lattice) with 500ns window
    - Good for cascades
  - Any DOMs within 4μs readout window
    - Good for tracks
- Noise rates in Hz for number of DOMs in coincidence (VERY rough estimate!)

DOMs	Neighbour	Any
2	655	10,915
3	3	1,123
4	0	114

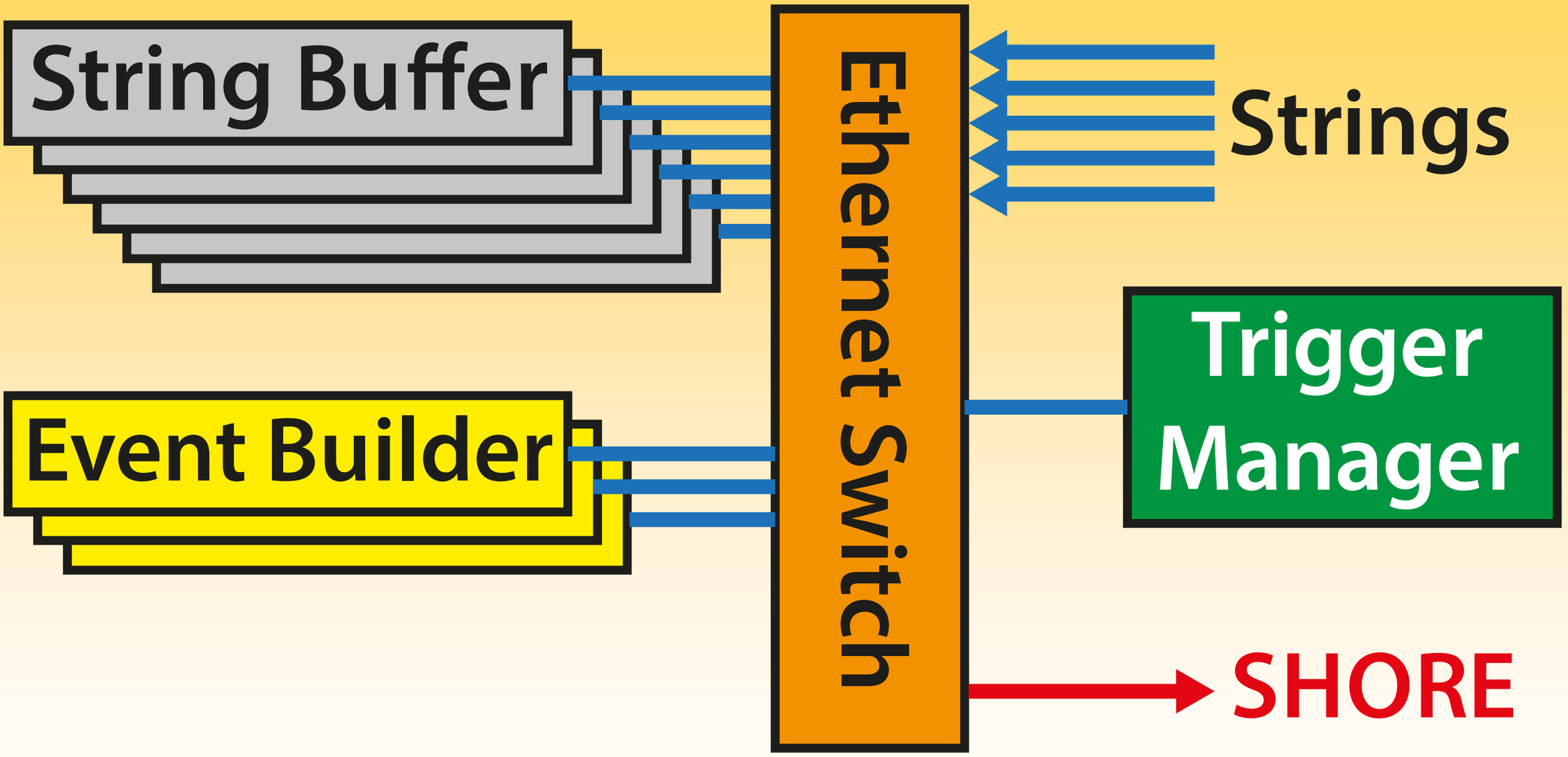
L1 Implementation

- Could send all PMT hits to L1 Trigger
  - 10 DOMs/string x 25 PMTs/DOM x 10 kHz x 16 bytes
  - = 38 MB/s per string
- Significant benefits
  - Keeps the DOM electronics simpler
  - Maximum flexibility to tweak L1 algorithm if needed
  - …but ~40% of max bandwidth, bioluminescence overload?
- Alternative:
  - DOMs send local coincidences and L1 triggers readout
  - DOM electronics more complex: will need to buffer data locally and respond to more network requests
  - Less flexible: could reprogram or upgrade L1 box, very unlikely to upgrade all DOMs

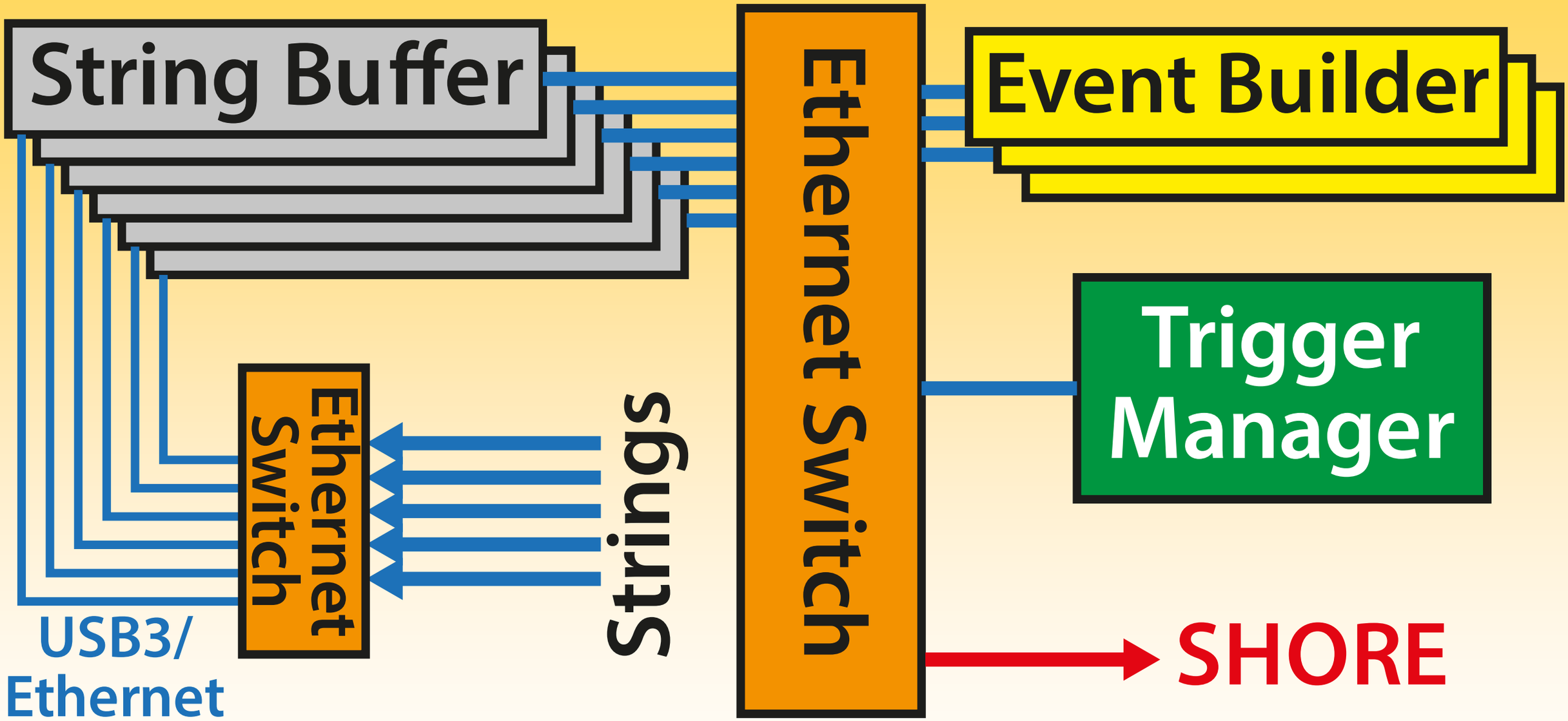
L1 Implementation

- Use commodity hardware
  - Gigabit ethernet switch to buffer and store events
  - Connected to "Raspberry Pi-like" ARM-based SBCs
    - Thermal load a serious consideration
  - Connect strings to switch: any SBC can buffer data
    - Could use USB3 ports (5Gpbs) for dedicated SBC buffers if needed
- SBC functions
  - String buffer: buffers hit data from a string, sends coincidences to trigger manager, data to event builder
  - Event Builder: collects hit data in read out window from all strings, sends completed event to Shore
  - Trigger Manager: receives coincidences from string buffers, triggers event readout
- All SBCs have identical hardware configurations
  - Avoids single-point of failure, can include spares
  - Ideal: two network switches, everything connects to both

L1 Implementation



L1 Alternative



L2 Implementation

- Need to reduce data rate for storage
  - Assuming maximum 50MB/s data rate for 300 days/year gives 1,236 TB/year
- Run on-shore Linux farm to act as L2 trigger
  - Full detector data, run more complex algorithms
  - Fit tracks, cascades etc.
- Should reduce event rate…but increase size
  - Assuming a 100 Hz cosmic muon rate with a 10 kB event size gives only about 24 TB/year
  - Easily storable on disk with tape for archive

Conclusion

- Simple L1 coincidence trigger between DOMs should reduce the rate enough to fit in the bandwidth
  - …but lots of unproven assumptions went into this!
  - Simple strategy to implement and easy to expand to coincidences between multiple, more wide-spaced DOMs
- L2 trigger on shore should be easily able to reduce date rate to an easily storable volume
- Next steps
  - Pin down the assumptions, particularly K-40 noise for the mDOM (not sDOM) PMT configuration
    - Noise rates are **VERY SENSITIVE** to assumptions about the coincidence for K-40 events
    - Factor two increase in rate can give x4, x8 or x16 etc. on overall trigger rate depending on number of coincidences
  - Look at efficiencies for track and cascade events
  - Start to look at potential L1 trigger hardware