TRIGGER & DAQ

D. ACOSTA, UNIVERSITY OF FLORIDA

T. BOSE, UNIVERSITY OF WISCONSIN-MADISON

G. KARAGIORGI, COLUMBIA UNIVERSITY

W. KETCHUM, FERMI NATIONAL ACCELERATOR LABORATORY

P. O'CONNOR, BROOKHAVEN NATIONAL LABORATORY

M. WILLIAMS, MIT

J. ZHANG, ARGONNE NATIONAL LABORATORY

TDAQ BRN WORKING GROUP

- The Trigger & DAQ (TDAQ) BRN working group has been active since September in gathering community input related to TDAQ R&D priorities
- TDAQ Google Form:
  - https://forms.gle/jZ1aqDTm2PtCvcJT9
  - Survey to collect input specifically from the TDAQ community
    - A very brief summary later in this talk
    - If you have not provided input yet and would like to, there is still time!
- TDAQ Community meeting held on Tues, Dec 3rd (via Zoom)
  - https://agenda.hep.wisc.edu/event/1430/overview
  - Video recording here
  - Several interesting presentations, good discussion
  - The townhall tomorrow will be another venue for providing input

TDAQ R&D GRAND CHALLENGE

- "Streaming DAQ" or "Can a "trigger-less" readout and DAQ system be a common solution for future large-scale HEP experiments ?"
  - **Revolutionary!** Will provide unprecedented flexibility/possibilities
- Read out data from experiments at natural rate (w/o hardware trigger)
  - First strides being made by LHCb and ALICE during Run 3 (2021+)
    - Two-stage approach: (i) processing the data during data taking for a first data reduction and (ii) storing it to an on-site disk-buffer for a second processing when there is no beam.
    - Huge data rates (up to 40 Tbit/s) ➔ alternative hardware technologies (GPUs)
- For a common solution and for the next generation experiments, require high bandwidth technology, data compression, on-detector intelligence, and high performance software-based triggers

STREAMING DAQ R&D

- Radiation-hardened, high bit-rate optical transmitter modules
  - support data rates of 10 Gbps, 25 Gbps or higher per link
  - Radiation-hardened for use in a high radiation environment, such as the innermost area of the tracking detector for future HEP collider experiments.
  - Low-cost
  - Optical links management: incl. how to monitor links and predict errors
- R&D towards wireless data transmission (revolutionary)
- Data compression and on-detector intelligence
- Development of a scalable DAQ system to enable the transition from custom hardware to commodity networking and computing as much as possible
- Alternative hardware technologies instead of traditional CPU computing farms: GPUs, FPGAs, CPU-FPGAs, GPGPUs, FPGAs with AI cores
- Fast machine learning for improving performance of software-based triggers

MACHINE LEARNING

- Essential for data reduction and data processing
  - Both with and without streaming DAQ instrumentation
- R&D needed for low latency, high data volume ML algorithms to achieve unprecedented data reduction
- In many cases need custom designs for extremely low, sub-microsecond latency requirements
- On-detector algorithms need to work in extreme environments (low-power, cryogenic, high-radiation and infrastructure)
- Off detector: Integrate heterogenous computing platforms

TOOLS

- In parallel, develop tools that leverage new technology
  - Tools to make use of new FPGA technologies, or more generally heterogeneous computing hardware, for real-time and power constrained applications
  - Tools such as hls4ml that allow physicists to prototype ML algorithms for both firmware feasibility and physics performance without extensive Verilog/VHDL experience
    - greatly decreasing the time for algorithm development cycles while preserving engineering resources.
- Automated, self-running DAQ systems
  - Fast collection and processing of conditions data to detect and respond to faults in order to improve data collection efficiency for increasingly complex detectors
    - E.g. anomaly detection, transient detection algorithms, neuromorphic algorithms…
  - Could take advantage of AI

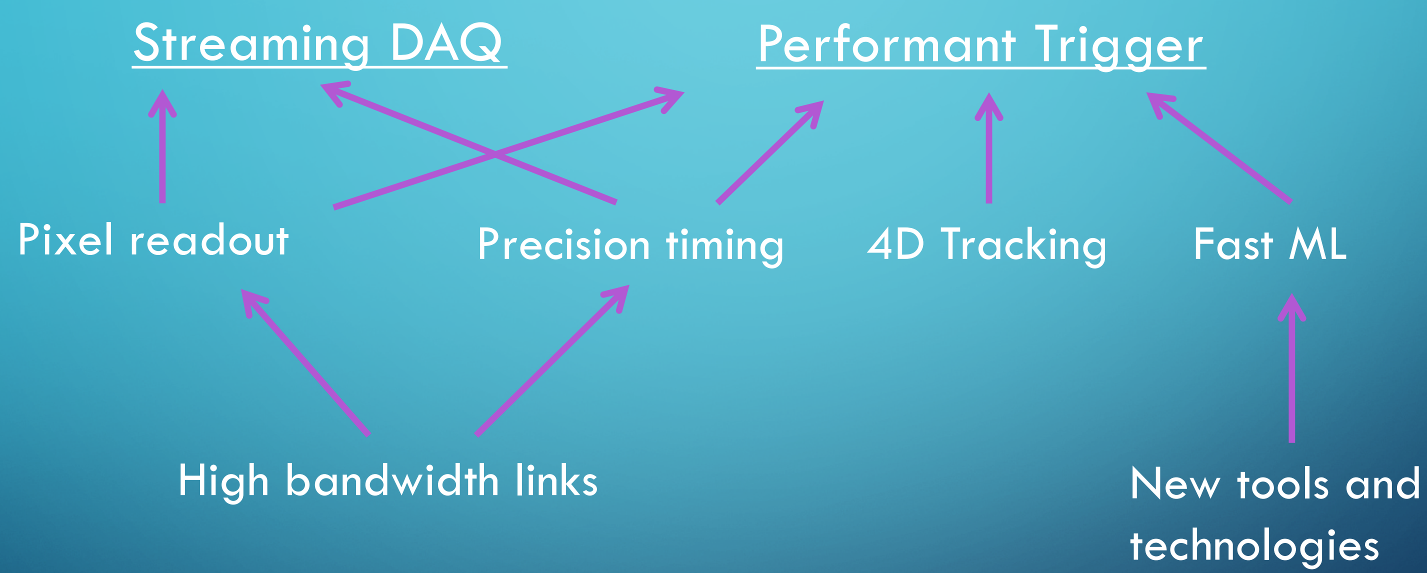
PIXEL DETECTOR FOR TRIGGERING ?

- Challenges for reading out a pixel detector at a reasonable rate for trigger
  - Future EF experiments will require highly granular detectors, yielding large data rates
  - A tracking trigger, or b-tag trigger, at Level-1 will require incorporation of pixel data, improve primary vertex reco, provide vertex separation for pileup mitigation…
  - Requires high bandwidth data links (perhaps wireless), rad-hard, low power, low material; next generation ASICs w/ local processing for data reduction, more logic density
  - System level complexity (e.g. if using region-of-interest readout for reducing bandwidth)

PRECISION TIMING & SYNCHRONIZATION

- Precision timing in trigger, and precision synchronization
  - Cosmic and Intensity Frontier experiments rely on self-generating and distributing a master timing reference over large distances (km's, even 1000s of km's for multi-messenger)
  - Energy Frontier experiments will incorporate highly granular precision timing detectors to handle high pileup, requiring precise timing to 10's of ps. Use for real-time trigger faces same challenges as for pixel trigger
- 4D tracking with spatial and timing readout
  - Incorporate precision timing with spatial readout in real-time applications to improve tracking performance in high pileup conditions in EF experiments
- Rad-hard high bandwidth data links, high bandwidth wireless transmission
  - Fundamental for future EF hadron collider experiments

SOME INTERCONNECTION EXAMPLES, ENERGY FRONTIER EXPERIMENTS

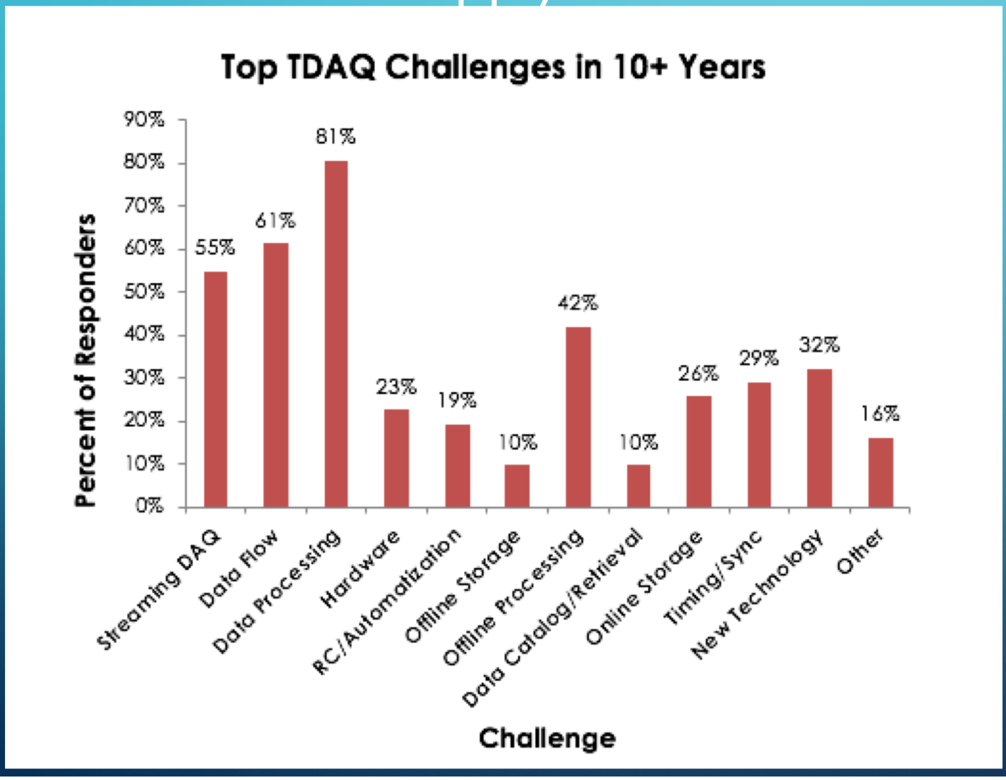


BRN TDAQ SURVEY RESULTS

- We conducted a community survey during November 2019
- 31 responses as of Dec 8th, 2019, from cross-experimental/frontier HEP community
- Thank you to many of you who provided input!

Q1: TOP TDAQ CHALLENGES THE HEP COMMUNITY WILL BE FACING IN 10+ YEARS, THINKING ABOUT FUTURE-GENERATION HEP PROJECTS

- A list of identified challenges was provided for responders to select all that apply



"Other" responses included:

- Visualization technology to improve uptime and reduce operational support (related to Run Control)
- Energy economy in machine learning or computing systems
- Cooling
- Data links for challenging environments (related to Hardware)
- Data Quality Monitoring

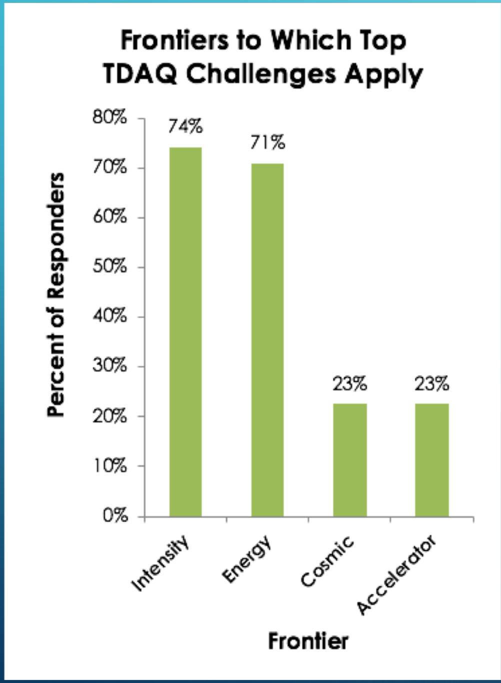
Q2: RESPONDERS WERE ASKED TO ELABORATE ON THE CHALLENGES COLLECTIVELY IDENTIFIED IN Q1

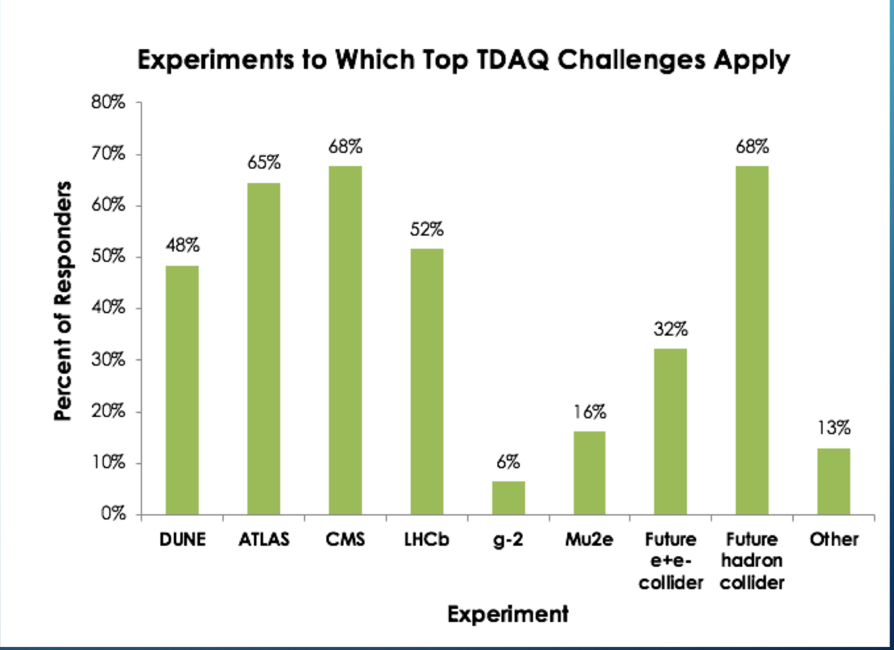
In summary, the prevalent message was that

nearly every future experiment or upgrade will face increasingly high rates that outpace the reduction in storage/processing cost over time, and this will require the combination of streaming DAQ architectures with preprocessing which allows for efficient online analysis of the data. This in turn will rely on more effective algorithms and architectures, better use of timing information, etc. Storage was identified as merely a cost-issue.

Q3: RESPONDERS WERE ASKED TO INDICATE WHETHER ANY OF THE CHALLENGES IDENTIFIED IN Q1 APPLY TO A CURRENT/FUTURE EXPERIMENT OR FRONTIER

- A list of identified challenges was provided for responders to select all that apply





Responses also broken down by frontier and experiment

Q4: RESPONDERS WERE ASKED TO IDENTIFY WHAT THEY THOUGHT WERE THE MOST PROMISING AREAS OF R&D FOR PROVIDING SOLUTIONS TO ABOVE CHALLENGES

- Common themes identified in responses:
  - Move of (traditionally) software-based processing into front-end, hardware
  - Integrated sensor and readout/processing technology
  - Real-time ML/DL implementation with hardware acceleration
  - Parallelization through new technologies/architectures
  - High-bandwidth, low-power wireless links

- New perspectives included:
  - New approaches to information flows
  - Use of ML for data quality monitoring

Q5: RESPONDERS WERE ASKED TO IDENTIFY OTHER AREAS OF R&D THAT, ALTHOUGH NOT TARGETING A PARTICULAR CHALLENGE, COULD BE TRANSFORMATIONAL FOR HEP TDAQ

- Received numerous responses; selected list deviating from lists provided:
  - Standardizing the electronics platform, with a more up to date, longer term, user-friendly option than CAMAC, VME, MicroTCA, ATCA
  - Higher-throughput multi-purpose I/O boards that can be used across the field, and interfaces with hardware (e.g. GPUs) for sophisticated data processing
  - Image-analysis-based triggering (without the need of object reconstruction)
  - Autonomous detectors; use of ML more broadly, e.g. error detection, data taking monitoring, trigger rate monitoring
  - Timing detector technologies to perform per-hit-timing in a cost effective manner to alleviate pile-up problems
  - Wireless readout; fiber transmission of power (reducing heat load due to copper in cryogenics, provides high voltage isolation)
  - Manipulation of experimental data in a new form

ANY QUESTIONS OR COMMENTS ?

- TDAQ related discussions will continue in the parallel sessions at this workshop and during the townhall discussions
- We welcome input from you via the google form (or email, in person…)
  - https://forms.gle/jZ1aqDTm2PtCvcJT9
- A draft, intermediate version of our report is available
  - https://agenda.hep.wisc.edu/event/1430/material/4/0.pdf
  - We welcome your input, comments and suggestions.