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• The Trigger & DAQ (TDAQ) BRN working group has been active since September in gathering community input related to TDAQ priorities, including:

• TDAQ Google Form:
  • https://forms.gle/jZ1aqDTm2PtCvcJT9
  • Survey to collect input specifically from the TDAQ community

• TDAQ Community meeting held on Tues, Dec 3rd (via Zoom)
  • https://agenda.hep.wisc.edu/event/1430/overview
  • Several interesting presentations, good discussion

• CPAD TDAQ session, townhall, and one-on-one discussions
BLUE SKY IDEAS (EVEN BEYOND BLUE, UV!)
KEY CHALLENGE: EXCEEDING EXASCALE DATA PROCESSING RATES

- Exabytes/sec ($10^{18}$/sec, or a million terabytes/sec) real-time data processing throughput
  - This is the scale of the unsuppressed data rate generated by a future hadron collider experiment ("FCChh")
  - This is also the scale of the raw data rate expected from the PUMA 21cm experiment
  - Contrast FaceBook: 4 Petabytes/day = 0.05 terabytes/sec ($10^{10}$/sec)

- Experiments across the Frontiers need the ability to process enormous data throughputs to reach the next energy frontier, observe further out in the universe, etc.
  - And typically in extreme environments (radiation, magnetic fields, cryogenic temps, …)
STREAMING DAQ CONCEPT

- Two axes to pursue in order to handle enormous data rates:
  - Trigger: select only specific raw data to store (small fraction, high physics content)
  - Streaming: summarize all data by storing only high-level objects (data reduction)

- Both require processing on the fly:
  - Real-time analysis at near offline resolution to extract the physics content

- For Streaming DAQ: read out data from experiments at its natural rate, or as high as achievable

- First strides being made by LHCb and ALICE for 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)
CMS STREAMING ("SCOUTING") FOR HL LHC
ENERGY FRONTIER DATA CHALLENGE NEEDS

- Streaming DAQ
  - Intelligent Strip/ Pixel readout
  - High bandwidth, rad tolerant links

- Trigger
  - Intelligent Precision timing
  - 4D Tracking
  - Fast Machine Learning
  - New tools and technologies
DETECTORS MUST BE DESIGNED WITH TDAQ IN MIND!

• We simply do not know how to read out a future hadron collider experiment (“FCChh”)
  • Too many cables, too much mass, too many cracks, too much power, too much radiation...

• We must build in data processing capability at the very front-end as part of our detector R&D
  • To get the precision data out, and to highly filter the data onslaught!

• And overall detector system design must accommodate TDAQ
  • We might build it, but we may not be able to instrument it…
EXAMPLE: CMS HL LHC STRIP TRACKER

• Doublet tracking layers as a first stage in filtering data volume
• Extend to finer pixels? With precision time readout? Streaming?
TRANSFORMATIONAL DEVELOPMENTS
STREAMING PIXEL DETECTORS

• Definitely a challenge for reading out a high channel count pixel detector at a sufficiently high rate for streaming or triggering
  • Future EF experiments will require highly granular detectors, yielding large data rates (pixel layers extended to larger radii and volumes)
  • A tracking trigger, or b-tagging trigger, for streaming or triggering will require incorporation of pixel data in the future
    • Also improves vertex reconstruction, vertex separation for pileup mitigation, electron ID, …
  • Requires high bandwidth data links (wireless?) that are rad-hard, low power, and low mass
  • Requires next generation ASICs with more logic density for local processing to achieve data reduction
  • Increases system level complexity (e.g. seeded region-of-interest (ROI) readout for reducing bandwidth)
PRECISION TIMING & SYNCHRONIZATION

• Precision timing in trigger, and precision synchronization
  • Energy Frontier experiments will incorporate highly granular precision timing detectors to handle high pileup, requiring precise timing at over a distributed system at picosecond level
    • Use for real-time trigger faces same challenges as for pixel trigger, but with additional complication of the distribution of synchronized fast (ps) time signals
  • Cosmic and Intensity Frontier experiments also rely on self-generating and distributing a master timing reference over large distances (km’s, even 1000s of km’s for multi-messenger)
    • e.g. phase stability of \(\sim 150\, \text{fs}\) is required across \(O(10^4)\) detectors over 2 sq. kilometers
NEW TRICKS UP OUR SLEEVE: A.I.

- Machine Learning is becoming essential to achieve maximal data reduction and data processing capability to achieve maximum science extraction
  - 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
OTHER USES FOR A.I. IN TDAQ

• 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
TRYING TO DISTILL THIS TO A FEW SPECIFIC PRIORITIES
PRIORITIZED RESEARCH DIRECTIONS

• High bandwidth data links, including high bandwidth wireless transmission, for extreme conditions
  • Extreme = low temperature, high radiation, low mass, constrained space, etc.
  • Crucial to design a silicon Photonics-based chip which could be used in integrated module to support data rates of 10 Gbps, 25 Gbps, or higher per link in high radiation environment, such as the innermost area of the tracking detector for the future HEP collider experiments.
  • This will require investment from the community, for the ASIC development, qualification, etc.
PRIORITy RESEARCH DIRECTIONS

- Trigger/Streaming capable pixel and timing sensors
  - Transformative capability (and necessary for future hadron colliders)
  - Again will require investment from the community for the sensor/module designs and for the front-end ASIC developments with trigger/streaming data needs built in
PRIORITIZE RESEARCH DIRECTIONS

• 4D real-time tracking with spatial and timing readout
  • Potential of sensor technologies such as LGAD for precise position and timing
  • Incorporate precision timing with spatial readout in real-time applications to improve tracking and particle ID performance in high pileup conditions in EF experiments
PRIORITy RESEARCH DIRECTIONS

• Precision timing signal distribution over extended detector systems down to picoseconds and synchronized across large distances:
  • meters (Energy Frontier), km’s (Cosmic Frontier), 1000 km (Intensity Frontier)
PRIORITY RESEARCH DIRECTIONS

• Tools for fast (sub-microsecond) machine-learning inferences for high data bandwidths using state-of-the-art technologies for real-time and power constrained applications
  • Evolve tools (like hls4ml) to newer industry FPGA/AI cores, platforms, and whatever shows up in coming decades to achieve potentially transformative real-time processing systems for HEP

• Note that the demands of TDAQ, sub-microsecond latencies, are not those commonly needed by industry. We are unique in that respect.

• This is also an important area for training young scientists for their careers
PRIORITY RESEARCH DIRECTIONS

• Dedicated ASIC development for low power, rad tolerant data processing/machine learning technologies on detector front-ends
  • e.g. RISC processors in front end ASICs
PRIORITY RESEARCH DIRECTIONS

• Automated, self-running TDAQ systems ("self aware, self-taught")
  • Next generation experiments will be more complex than today to:
    control, monitor, calibrate, align...
  • They also will live in extreme environments
  • Invest in techniques and tools, including machine learning, to quickly:
    • detect and respond to faults,
    • self-calibrate
    • self-align
    • etc.
  
for these next generation experiments
KEY CHALLENGE 1 AND PRDS

- High bandwidth rad-hard links
- Wireless data transmission
- On-detector processing (next gen ASICS ?)
- Fast ML, low-latency, extreme conditions
- Off-detector heterogenous computing (trigger)

Exascale frontier
KEY CHALLENGE 2 AND PRDS

- High bandwidth rad-hard links
- Next gen sensor/module/ASIC development
- Precision Synchronization

Breaking the ps timing barrier
KEY CHALLENGE 3 AND PRDS

- 4D transparent tracker
- High bandwidth rad-hard links
- Next gen sensor/module/ASIC development