



1st FCC-ee TDAQ workshop follow-ups

Steven Schramm
19 November 2025



To TDAQ or to DAQ

- One of the main outcomes of the workshop was the discussion around TDAQ or DAQ
 - Do we need a hardware trigger, or will we stream out of the detector?
 - If we stream out of the detector, will there be an event filter, or direct to storage?
- EIC ePIC talk provided an example of the streaming DAQ approach
 - No hardware trigger, software filter (Echelon-0)
 - Data is directly streamed to two other computing centres for reconstruction (Echelon-1)
 - Data passing filter also goes to tape, but aim is to never go back to tape
- Could be an interesting model for FCC-ee, if we can demonstrate it is feasible
 - That said, even a software filter will introduce limitations/inefficiencies
 - Need to be careful, FCC-ee TDAQ efficiency requirements are very strict, must be accurate to 1 part in 10^6
- We have received some interesting follow-up questions related to this discussion from Mogens

Caveats to the no-trigger approach

- What if we significantly underestimate the FCC-ee backgrounds?
 - If we turn on the machine and it's 10x higher background than prepared for, can we still read out the detector?
 - Do we not want a trigger system to be able to mitigate such a risk?
- Personal view: it is unlikely that there will truly be no trigger at FCC-ee
 - Focus on crossings, likely mostly filled crossings, not continuous readout
 - Veto crossings post top-up before they reach nominal operating state
- This system could also mitigate such a risk
 - If background is 10x higher than expected, could read out only 1/X beam crossings
- In essence, this “trigger” is a clock trigger with a conditional veto
 - No actual detector information is used for the trigger decision
 - As such, believe this is still “triggerless” / streaming readout in the way that has been discussed so far
- A future activity on our radar is to investigate what this may look like more concretely
 - No in terms of defining the hardware, rather minimal requirements on front-end systems to support such usage

Local latency buffering

- If we do not go with a streaming readout, should we foresee local latency buffering?
 - Would have to be at the sensor level to solve the local bandwidth challenge
 - For the vertex detector, this means inside the 50 um Si
 - If buffered in this way, probably no zero suppression?
 - That would be a lot of data though pending L1 accept! Even $O(500)$ bunch crossings if Z rate defines L1 accept
- Here I have less of a feeling, and would request the feedback of others

What about on-site computing needs?

- Patrick raised a question about the on-site computing needs for FCC-ee and FCC-hh
 - How do the projected on-site computing farms compare to HL-LHC?
- I find this very challenging to give a solid answer given the current level of FCC-ee TDAQ activities
 - My view is this will depend a lot on information we don't yet have
 - The next slides are thus my vision of possible outcomes

My assumptions

- We will only trigger/filter if we need to do so, given the FCC-ee precision requirements
 - If you trigger/filter, usually due to the need to meet a given system rate/bandwidth constraint
 - Maybe can be met with looser/no trigger and tighter filter, but ultimately need same overall reduction factor
 - Event filter usually needs to be run on a local computing cluster due to latency considerations
 - In other words, the presence of a filter normally implies a reasonably sized local computing farm
 - Caveat: if network is sufficient, can stream all data off-site and decide what to keep at that time, not on-site
- We will store the raw data if possible, not just reconstructed data
 - Given the FCC-ee precision requirements, likely we will want to reprocess from raw
 - As such, unlikely to run final-pass reco directly on-site, distributed approach more plausible
 - Even if storing processed data (not raw), hope this would be mostly off-site
 - Benefits of scale, redundancy, etc from sharing computing resources between experiments
 - That said, this is a lot of data, we may need to find some intermediate approach to data storage

Overview of possible options

- The FCC-ee data collection strategy is currently unclear
 - Will there be a hardware trigger, or will it be triggerless?
 - Will there be a software “trigger” (filter), or will it be filterless?
 - Will we be aiming to record “every” beam crossing (40-50 MHz) or only Z+Bhabha events (~200 kHz)?
 - Note: focusing on Z-pole, which seems to be the most challenging for TDAQ and on-site computing
- The answers to the above questions will significantly impact the on-site computing needs
 - Large variation due to the beam background being dominant and physics sub-dominant before selections
- In contrast, on-site computing for FCC-hh is more predictable
 - Physics-dominated rather than background-dominated: would record every event if possible
 - Either by triggering and/or filtering, we will need to select only a fraction of events to be recorded

Triggering vs filtering

- In an LHC-style setup, there is a balance between hardware triggers and software filters
 - For a fixed output: looser hardware trigger = more need for software filters
 - If the FCC-ee also has a trigger-then-filter approach, reasonable to expect a similar balance
- However, FCC-ee has much more strict precision requirements
 - Not aiming for a representative subset of events, and only all events above a high kinematic threshold
 - Instead, want to record all of the Z bosons; some measurements need efficiency uncertainties below 10^{-6}
- Goal of FCC-ee TDAQ will therefore be to make the trigger as minimal as possible
 - Hardware triggers are bound to introduce difference between the trigger and offline analysis
 - Software filters are closer to offline, so less impact, but still not zero

Streaming

- One of the big questions at recent FCC-ee TDAQ workshop was whether we can move to streaming
 - **Variant 1:** trigger and software filter → HL-LHC style setup, likely similar on-site computing requirements
 - **Variant 2:** no trigger, but still a software filter → may require a huge amount of on-site computing
 - **Variant 3:** no trigger and no software filter → should significantly reduce on-site computing
 - Variant 2 and 3 can both be considered to be streaming, thus terminology is a bit confusing
- No trigger does not mean no hardware selection
 - Still zero-suppression thresholds, compression, etc
 - May also veto some beam crossings (recent beam top-up injections, etc)
 - When I say “no trigger”, I mean “no detector-readout-based trigger”
- The EIC ePIC streaming DAQ is somewhere between Variant 2 and 3
 - No hardware trigger, light software filter → data shipped to and reconstructed (offline) at separate sites
 - An interesting model for us to investigate more, but too early to conclude on its potential for FCC-ee

Computing hardware developments

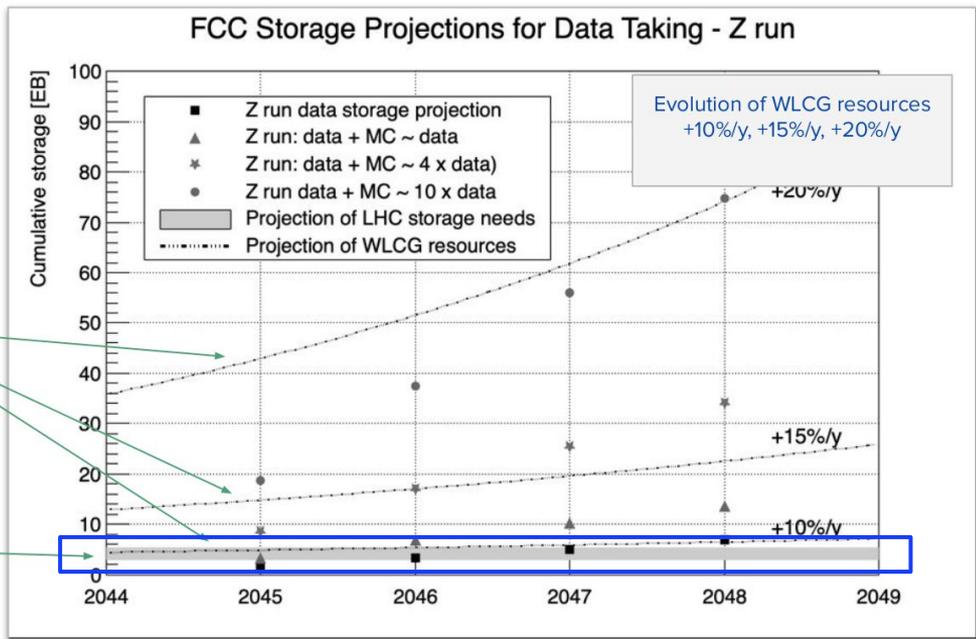
- HL-LHC and FCC-ee/hh are likely to live in different worlds of computing hardware
 - HL-LHC may end only a few years before FCC-ee is planned to start, but it has a lot of legacy software
 - FCC-ee and especially FCC-hh is likely to have a more modern software stack to leverage new hardware
- Very plausible that HL-LHC will rely on CPUs and/or GPUs
 - Answer of which technology is expected to be collaboration-specific
- For the FCC-ee, and especially FCC-hh, hardware may be radically different
 - Fast evolving field, hard to predict what new hardware will be used 20+ years from now
 - May also see a dramatic change in the usage of ML/AI to reduce compute resource requirements
- In other words, naive scaling from HL-LHC is likely not appropriate
 - FCC-hh may be a lot more instantaneous data than HL-LHC, but compute/algorithm developments may keep up

FCC-ee per-detector offline data volumes

4 experiments
4 equal runs (2045, 2046, 2047, 2048)

Evolution of WLCG resources
+10%/y, +15%/y, +20%/y
(starting point: 500 PB in 2020
≈ ATLAS+CMS + 10%)

LHC at the end of HL (≈ 5 EB)



[\[link\]](#)

- 1.7 EB/year of FCC-ee Z-pole **data**, nearly 0.5x storage volume of **entire HL-LHC data+MC**
 - Assuming size(data) ~ size(MC) at HL-LHC, this means 1-year FCC-ee Z-pole is entire HL-LHC data-taking volume
 - Note: FCC-ee is only Z events, no Bhabha + beam background → **minimal volume to record** (post-trigger/filter)

Bringing the options together for FCC-ee

- FCC-ee precision requirements will likely require dropping the T in TDAQ
 - Either no hardware trigger (streaming), or as loose of a hardware trigger as possible
 - Real question: will there still be a software filter or not, and if yes, how complex will it be?
- Computing challenge of a software filter is naively very significant
 - Huge FCC-ee data volume in Z-pole running compared to HL-LHC
 - However, events are individually much less complex, computational costs thus likely do not scale directly
 - Also need to be conservative to meet efficiency requirements
 - Need to record all Z events → lighter selection to keep also many Z-like events
 - More rate to storage, but less on-site computing requirements
 - Expect these to roughly cancel: HL-LHC on-site data centre likely also reasonable for FCC-ee filtered requirements
- No software filter at all = much less on-site computing
 - Still need some monitoring, data quality, etc but lighter than HL-LHC
 - This option instead imposes more off-site (but likely still CERN-based) long-term data storage resources

Summary of on-site computing needs

- FCC-ee on-site computing requirements are subject to the chosen readout strategy
 - Triggered + filtered: likely similar to or smaller than HL-LHC on-site computing requirements
 - No trigger + filtered: likely similar to HL-LHC on-site computing requirements
 - No trigger + not filtered: likely (much) smaller than HL-LHC on-site computing requirements
- FCC-ee on-site computing is thus likely at the level of HL-LHC on-site computing, or smaller

- FCC-hh is naively a scaling of HL-LHC on-site computing requirements
 - Likely a similar model, but many years in between, thus it may evolve
 - Computing hardware potential will plausibly keep up to evolving demands on the system
- FCC-hh on-site computing is thus likely at a similar level to HL-LHC on-site computing

- Disclaimer: everything stated here is very preliminary, and a lot will change before FCC-ee/hh
 - Electronics and computing is an area that is evolving at a rapid pace, and it's hard to predict 20+ years ahead