Ideas on getting started on FCCee TDAQ activities

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Introduction

- When speaking with FCCee experts, seems to be a prevailing assumption that it will be **triggerless**
  - This would of course be fantastic, and everyone would be happy if possible
- In reality, a truly **triggerless system is not a foregone conclusion**
  - Most FCCee beam crossings may not involve a physics event, but beam background is not negligible
  - FCCee demands extreme precision, and we need to be very careful we don't neglect the impact of TDAQ
- TDAQ requirements can have an impact on detector technology decisions and physics potential
  - It is therefore important to start thinking about how to read out the detectors under design

- A small number of groups have recently started to think about TDAQ for FCCee
  - In order to do this properly, we need to better understand the physics requirements and detector characteristics
  - These slides are an effort to do that: mostly setting the stage and asking questions!

A few benchmark trigger strategies

- In order to think about the impact, it is worth considering a few trigger strategies
  - Triggerless readout: every beam crossing, 50 MHz
    - Technically still triggered by the beam crossing rate, either full 50 MHz or only filled crossings
  - Minimally triggered: all “physics” events, ~200 kHz
  - Classically triggered (a la LHC): a subset of events, rate can vary as desired
- These are not actual proposals, but rather benchmarks to start discussion
  - We need the input from the detector communities before real proposals could be made

- What is important is to use these to understand the real constraints and expectations
  - Some options may rule out certain types of detector choices
  - Other options may require substantial material/power/etc budgets
  - Choices may also impact physics sensitivity to specific scenarios, especially for BSM

The triggerless strategy

- A truly **triggerless system** should read out and store **every single beam crossing** (BX)
  - Writing out "all" physics events (~200 kHz at Z pole) is not triggerless; you need to identify the physics events

- Can every sub-detector be read out at 50 MHz?
  - Does not have to readout each BX as it arrives, could also group (buffer) for later multi-event readout
    - If grouped, need timestamps for trackers + calorimeters (photons/BSM may not be seen in trackers)
    - Muon systems may be able to escape this, as could rely on tracker extrapolation, at a cost to some BSM
  - The readout system of <u>all</u> sub-detectors would need to be able to support such functionality
- Is the corresponding data volume to be stored offline manageable?
  - Current LHC detectors are > 1 MB per event, and 1MB @ 50 MHz = 50 TB/s
  - FCCee detectors likely will have many more channels = much larger *potential* data volume
    - Lower occupancy reduces this (compression), and collisions are rare (200 kHz / 50 MHz = 1/250)...
    - ...but beam background is expected to be large (with large uncertainty), and may dominate data volume
    - Efficient pre-storage denoising could mitigate this, but then cannot undo processing if issues arise
  - Need reasonable estimates of beam background rates and detector occupancy to answer this

The minimally triggered strategy

- Triggering **all physics events** (~**200 kHz at Z pole**) is an often-stated target
  - Accepts 1 in 250 beam crossings, thus significantly reduces the challenge
- Recall that if we want to record every physics event, we need to be conservative
  - In reality, a physics-inclusive trigger would have a rate > 200 kHz, including some beam-only events
  - Depending on how well beam vs physics events can be differentiated, the rate may be much higher than 200 kHz
  - 500 kHz would give a 1/100 BX acceptance and a 2.5x safety factor, so could be a good conservative benchmark

- Which sub-detectors need to be read out + processed at 50 MHz to make this possible?
  - Processing of all sub-detectors at 50 MHz is required to identify which collisions are physics events
  - At least the tracker and calorimeter, muons depend on the BSM cases you want to support
- How much real-time processing is required for the minimal trigger decision?
  - Trade-off in how complex the real-time processing needs to be, and how much extra to record “to be safe”
- Is the corresponding data volume to be stored offline manageable?
  - 1 MB @ 500 kHz = 500 GB/s, which should be reasonable by FCCee, but 1 MB/event is only a simple estimate

The ‘classically’ triggered strategy

- LEP, Tevatron, LHC have all made use of more traditional multi-stage triggers
  - In principle, could do the same thing at FCC-ee, then the trigger rate can be adjusted as needed
- There are clear ramifications of such a strategy at the FCCee
  - **Would come with a loss of statistics for the physics events, which is strongly disfavoured**
  - Impact of a classic trigger approach on some BSM models could be much more significant (model-dependent)

- Depending on the trigger rate, may not be very different from the “minimally triggered” approach
  - Still need to read out at 50 MHz to perform trigger decision, but could be multi-stage (coarse then fine readout)
  - Amount of real-time processing required can vary from small to huge, depending on trigger complexity
  - Data volume to be stored is not reduced, unless physics events of interest are discarded (rate-dominant)
- Retain as a benchmark strategy for comparison with others, but disfavoured at FCCee
  - While disfavoured in isolation, **it could complement the minimal approach**: dedicated BSM triggers
  - Could be used for control samples, which could be written at higher precision: larger raw size, no denoising, etc

The big unknowns

- **Beam background ends up having an enormous role in the decision**
  - Impacts the data volume in all scenarios, especially the triggerless one
  - Viability of the minimally triggered approach depends on differentiating between beam background and physics
    - Currently not clear how difficult this task will be; requires study
  - Even in physics events, beam background may have a substantial impact on the event size
  - Denoising before recording can help, but requires care and non-trivial computation to not impact physics
  - **The impact will vary with each detector design, thus the impact needs to be studied**

- How definitive is the objective of recording all physics events?
  - The minimally triggered approach seems to be the one that we hear about the most
  - This necessitates a complex real-time processing system, especially if it's hard to differentiate signal and beam
  - Sensitivity to long-lived BSM models likely requires all sub-detectors to support 50 MHz readout and processing
- Also understand that full detector readout+storage is required, not only regional
  - Precision measurements involving neutrinos, BSM searches, etc require the full detector
- **Will such requirements impact the precision on Z/H/etc measurements?**

Input needed from each sub-detector

- General
  - What readout capabilities have you already demonstrated?
  - What readout capabilities are currently assumed?
  - Is readout already included in your projections for: material, power, thermal, etc?
- Sub-detector capabilities
  - **Can the sub-detector readout 50 MHz** of beam crossings, either BX by BX, or in groups with time-stamps?
    - What does this require in terms of material budget, power, thermal impact, etc?
    - Can the sub-detector also process the 50 MHz to generate a self-trigger indicating presence of physics?
  - **If the sub-detector cannot readout at 50 MHz**, can it readout based on an external trigger at 200+ kHz?
    - This would require a buffer and would be needed to support the minimally triggered approach
  - To what extent is the sub-detector able to differentiate between “physics” and “beam background” events?
  - How aggressive can you be with front-end zero-suppression before physics sensitivity is impacted?
- Sub-detector data volume
  - What is the occupancy and data volume/event for each of: Z, WW, ZH, ttbar, and beam background?
  - What is the number of channels in the sub-detector, and the typical data size per channel?
  - Is it safe to assume that the data volume is roughly (occupancy) x (number of channels) x (data size/channel), or are there particularities to be taken into account?

Outlook

- TDAQ activities for FCCee are in a very early state
  - Several groups have recently expressed interest via the recent call for ESPP EoIs
  - We have already met together, and look forward to working together to determine the best path forward
- An evaluation of what is or not feasible needs detector input
  - Input from detector design experts and beam background experts in particular will be critical
  - These slides are just a starting point; there will surely be the need for follow-up
- All options are on the table: need to find the right balance between physics goals and detectors+TDAQ
  - The different detectors may favour or require different TDAQ configurations
  - Different physics cases (especially some BSM models) may also favour different TDAQ configurations
- **We hope the FCCee community can provide such feedback to help guide the growing TDAQ effort**

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