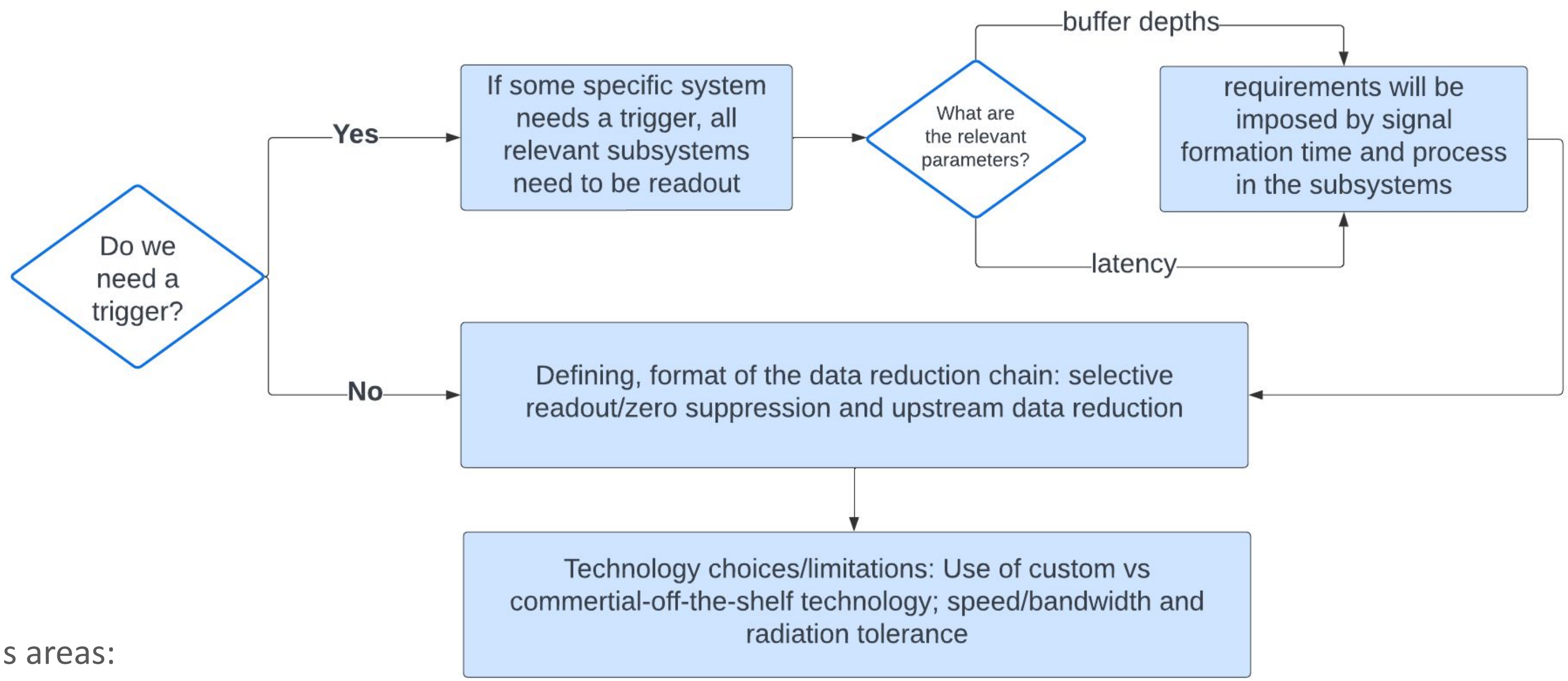
Trigger and DAQ at Higgs Factories

US Higgs Factory Planning

Zeynep Demiragli (Boston University), Sasha Paramonov (ANL)
Peter Wittich (Cornell University), Wade Fisher (Michigan State University)

Fundamental Concepts to Address: Do we need a trigger?



Focus areas:

- Intelligence on detector: advance data reduction (ML/AI, etc)
- High performance sampling and timing (4D readout, etc)
- Levering emerging technologies (high-speed optical link, etc)

Common R&D Collaborations and Initiatives

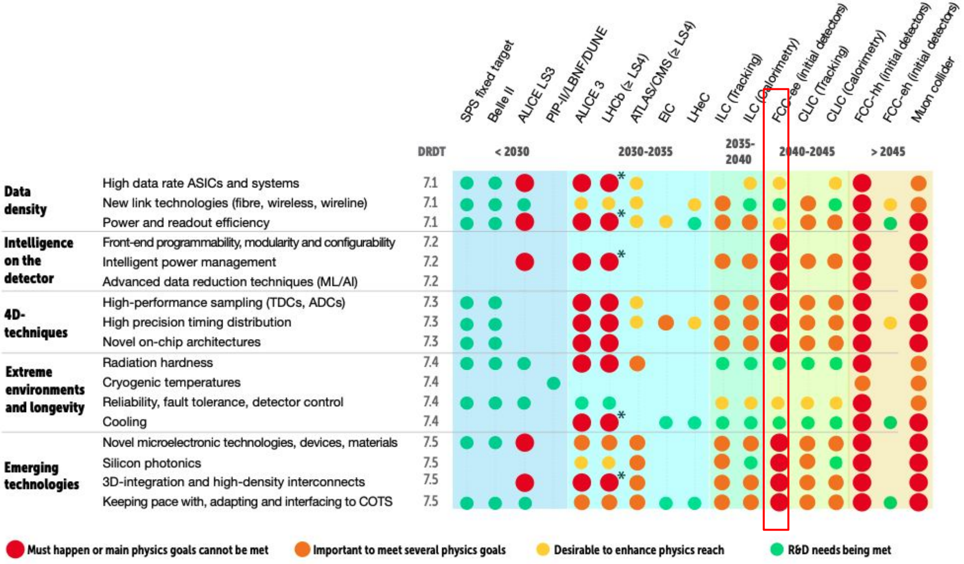
LHC Experience: High system complexity of DAQ systems requires experienced personnel (often not available in sufficient quantities). For simpler systems TDAQ should be part of the detector design concepts from the start

Event rates significantly lower than a hadron collider

- but precision requirements are different and and material budget is tighter.
- Low mass and low power will enable precision measurements (10^{-4}).

If we start now, <u>we can reduce the system complexity of the readout</u>

- Enables developing common standards using common technological platforms.



Higgs Factory Example FCC-ee: Physics Processes & Backgrounds

At FCC-ee the instantaneous luminosity per interaction point for all running scenarios are:

- Z pole: 230 x 10^{34} $cm^{-2}s^{-1}$ => Most rate demanding scenario
- WW: 28, ZH: 8.5, and tt: 1.8

At the Z pole, expected total event rate ~200 kHz, beam background expected to be 10% of the rate.

Physics process	Rate (kHz)
Z decays	100
$\gamma\gamma \to$ hadrons	30
Bhabha	50
Beam background	20
Total	~ 200

https://arxiv.org/pdf/2111.04168v1.pdf

Process Rates dominated by two sources:

- Physics events (Z boson)
- Backgrounds:
  - Interaction Region Backgrounds: Beamstrahlung induced bkgs (coherent/incoherent pair creation $\gamma\gamma \to$ e+e- pairs), $\gamma\gamma \to$ hadrons and radiative Bhabha (small)
  - Beam Effects: Synchrotron radiation (dominant for top but can be shielded), beam-gas (small), etc.

Bandwidth calculations

For TDAQ systems, the parameters of interests are:

- Rate of interesting physics events
- Rate of irreducible backgrounds (beam and physics)
- Average event size
  - Occupancy of the detector
  - Data per unit detector cell (buffer length/depth)

Bandwidth = Process rate x Average Event Size

Bandwidth = Process rate x Occupancy x Buffer size

Detector input:

- Occupancy ⟶ depends on the implementation of zero suppression & integration time
- Buffer size ⟶ data format is subdetector dependent

Who is involved?

Who's involved:

- L2 Managers are: Zeynep Demiragli (Boston University) & Sasha Paramonov (ANL)
- L3 Managers are: Peter Wittich (Cornell University), Wade Fisher (Michigan State University)

List of Institutions interested (based on MIT meeting)

- Florida Tech, Princeton, Boston U, Northwestern U, Cornell, U of Pitt, CMU, The Ohio State U, MIT, UC Irvine, SMU, Duke, BNL, FNAL, SLAC, ANL
- The US institutions contributed pretty much to all the areas of TDAQ of the CMS and ATLAS experiments. There is existing expertise to make a comparable contribution to FCCee experiments.

Common themes in the US-led EOIs:

- Embedded FPGAs
- Heterogeneous hardware for both on and off detector processing (also hosting realtime ML)
- Autonomous systems

Opportunity for PIs to collaborate on many of the submitted EOIs!

Needs

Past, current, and planned simulation projects:

- Past projects / studies are mostly from European colleagues and rely on various assumptions: Rates at Z Pole, arxiv:2111.04168v1, Annecy FCC - Idea, Annecy FCC - Allegro
  - See MIT TDAQ presentation for a summary of these results
- Need more active people to establish a US based group to evolve these studies!

Challenges and/or needs of the TDAQ group:

- Active person power
- Documentation and training on running simulations (including the simulation of machine induced backgrounds)
- Close collaboration with the subdetector groups for bandwidth, rate, sampling, noise, data formats, etc

Conclusions

General design principle is to the readout the data with low material and low power budget

with nearly ~100% efficiency..

The current detector concepts have various similarities and also differences. Regardless, each subdetector needs to evaluate occupancies and data buffer needs, so that bandwidths can be estimated.

This requires:

- simulations to estimate the machine-induced & physics backgrounds. It is shown that there are large contributions also from beamstrahlung induced bkgs (coherent/incoherent pair creation)
- detailed signal formation studies (times) to understand latencies

Preliminary studies (shown in the Annecy workshop): on-detector processing beyond zero suppression is necessary for data reduction.

Outlook

For TDAQ, the requirements are driven by the Z pole running with physics rates up to 200 kHz.

The big picture question is still to understand if we need a “hardware” trigger

- this then evolves into more questions on buffer size and latency requirements
- whether all or subset of detectors to provide triggers …

Nevertheless the obvious need/question are:

- On-detector processing beyond zero suppression
- What to record on the tape? (a high level software trigger)

Moving forward, the focus on technology R&Ds:

- High performance sampling & novel on-chip architectures
- Intelligence (AI/ML) on/off detector for: data reduction, power management, autonomous control/calibration
- Emerging technologies → microelectronics, high density data links and COTS (heterogeneous computing)

Back up