Trigger and Data AcQuisition

Zeynep Demiragli and Sasha Paramonov
+
Wade Fisher and Peter Wittich

us-hfcc-tdaq@cern.ch

FCC-ee accelerator program

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1280	135	26.7	5.0
number bunches/beam	10000	880	248	36
bunch intensity $[10^{11}]$	2.43	2.91	2.04	2.64
SR energy loss / turn [GeV]	0.0391	0.37	1.869	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.08/0	4.0/7.25
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.1	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	8	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
luminosity per IP $[10^{34}\ cm^{-2}s^{-1}]$	182	19.4	7.3	1.33
total integrated luminosity / year $[ab^{-1}/yr]$ 4 IPs	87	9.3	3.5	0.65
beam lifetime (rad Bhabha + BS+lattice)	8	18	6	10
	4 years	2 years	3 years	5 years

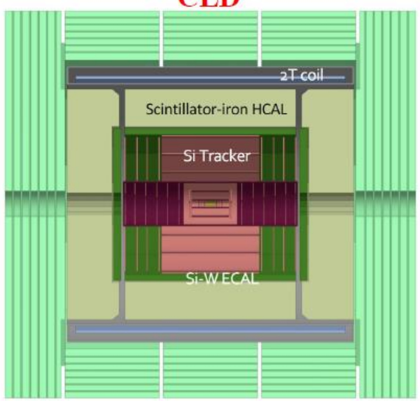
Lumi is the highest during the giga-Z program. However, not every BC contains a Z-boson.

Detector concepts and TDAQ

- All the detectors are instrumented with an innermost Si trackers. These are challenging to readout and may require fixed-latency triggering.
- There may be other sub-detectors that may require triggering.
- We need to cooperate with the detector sub-groups to identify readout bottlenecks.

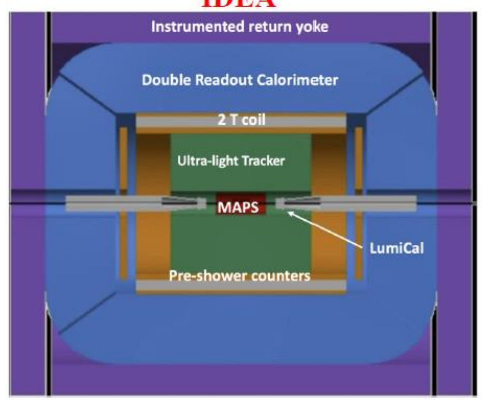
Detector benchmarks

CLD



- Full silicon vertex + strip tracker
- CALICE-like 3D-imaging high-granular calorimetry with Si-W for ECAL and Sci-iron for HCAL
- Muon system with RPCs
- Coil outside of calorimeters

IDEA



- Silicon vertex + ultra-light tracker
- Monolithic dual readout calorimeter with Cu-fibers (possibly augmented by dual-readout crystal ECAL)
- Muon system with μ-RWELL
- Coil inside calorimeters

ALLEGRO

- Silicon vertex + ultra-light tracker
- High granularity noble liquid ECAL (LAr or LKr with Pb or W absorbers)
- CALICE-like or TileCal-like HCAL
- Muon system
- Coil outside of ECAL

From: https://indico.cern.ch/event/1298458/contributions/5975666/attachments/2874286/5033190/DetectorRequirements_Zhu.pdf

TDAQ Architecture decision tree

Do we need a fixed-latency trigger?

No. There is enough bandwidth to readout all the sub-detectors for every bunch crossing.

Develop off-detector data post-processing with commodity compute.

- Filtering of trivial bunch crossings.
- Removal of beam backgrounds.
- Formatting data.
- Storing data.

Yes. A sub-detector needs a trigger

What are the parameters of the TDAQ system?

- Which sub-detectors can be used for triggering?
- What experimental signatures can we trigger on?
- What would be the trigger latency?
- Can the sub-detector accommodate the buffer?

The triggerless readout is easier to develop and support that a fixed-latancy trigger but it requires more off-detector compute.

Disruptive Innovation

- The ability to read-out the sub-detectors for every bunch crossing can be enabled by several key technologies
  - Intelligence on detector: advance data reduction (ML/AI, etc)
  - High-rate sampling and timing (4D readout, etc)
  - Levering emerging technologies (high-speed optical link/Si-Pho, etc)

Requires coordination with the AIM and detector groups.

- The off-detector post-processing can also benefit from modern computing architectures
  - AI/ML accelerators like Google TPU
  - GPUs or IPUs (e.g. Graphcore Intelligence Processing Units)

Requires coordination with the software and computing group.

Data rates and up-link bandwidth

- Data volume in some sub-detectors is driven by the beam backgrounds.
- Accurate simulations of the backgrounds and detector response are key to the TDAQ architecture decision process.
- It is desirable to have realistic GEANT4-based detector simulation of all the detector concepts.

Requires coordination with the software and simulations group.

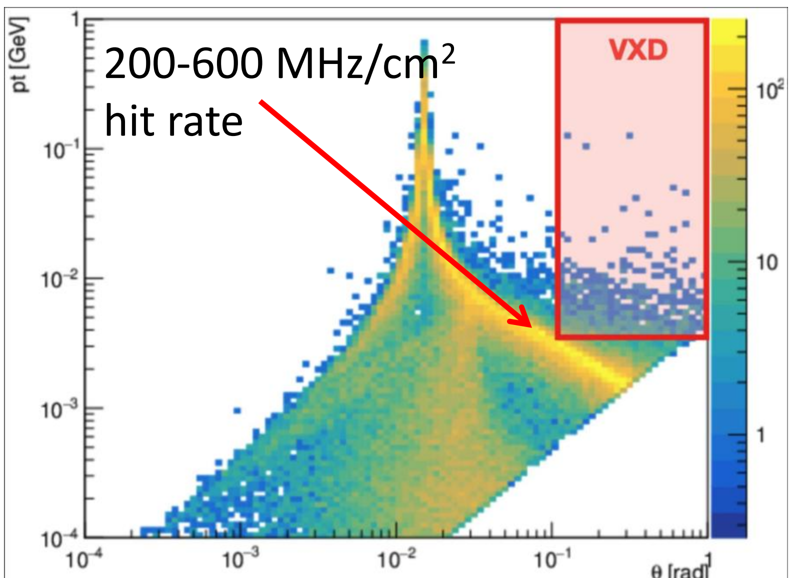
Of course, all will done in close cooperation with our international partners.

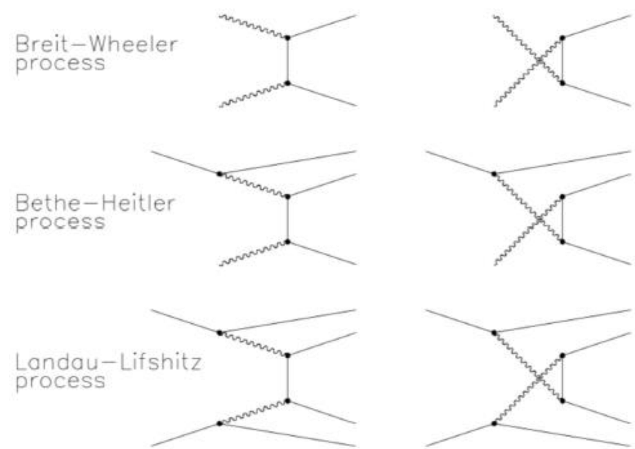
Hard scatter and background rates

- At the Z pole, expected total ee collision/event rate is ~200 kHz. The bunch crossing rate is 50 MHz.
- Incoherent pair production is the main source of beam backgrounds.

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





See https://indico.cern.ch/event/1307378/contributions/5727164/attachments/2791569/4869322/Bedeschi_Annecy_2024.pdf and
https://indico.mit.edu/event/876/contributions/2856/attachments/1066/1752/Trigger%20and%20DAQ%20at%20FCC.pdf
https://indico.cern.ch/event/1298458/contributions/5987291/attachments/2875496/5035607/Silicon%20tracker%20optimisation_Armin%20Ilg.pdf

EoIs so far

- The collection of the expressions of interests is ongoing. We will meet at SLAC in December to further refine the scope.

ID0045	**Embedded FPGAs offer reconfigurable digital logic in an ASIC, enabling machine learning for low-latency/low-power applications. We aim to explore eFPGA applications to FCCee, from front-end readout to common electronics and hardware accelerators.**	Julia Gonski	SLAC National Accelerator Laboratory	SLAC, LBNL, Baylor, Fermilab, UHawaii, UMichigan
ID0058	**Emerging heterogeneous processing for future HEP experiments. This R&D project will evaluate modern and emerging computing architectures for future HEP data processing systems. Such computing would be beneficial for triggerless readout DAQ systems.**	Zeynep Demiragli	Boston University	BU, The Ohio State, FNAL, ANL, BNL, SLAC
ID0017	**Study of trigger concepts (e.g. FPGA vs. CPU/GPU farm)**	Sandra Kortner	Max Planck Institute for Physics	UMass Amherst (t.b.c)
ID0046	**The development of real-time machine learning can enable advanced trigger and data acquisition systems capable of intelligent, efficient, and/or autonomous operations. Studies are planned for online ML in heterogenous hardware systems.**	Julia Gonski	SLAC National Accelerator Laboratory	SLAC
ID0048	**Autonomous systems are essential for near-100% uptime, rapid calibrations, and minimal intervention amid rising data rates and detector complexity. We aim to leverage AI/ML to develop self-diagnosing, self-calibrating, and self-running DAQ systems.**	Rainer Bartoldus	SLAC National Accelerator Laboratory	SLAC, UChicago

Outlook

- The EoI collection process started recently and we need to continue discussing the scope and capabilities with the US and international communities.
- There are some cross-cutting EoIs that can make major impact on the TDAQ architecture.
- Emerging/disruptive technologies can also impact the architecture.
- The work related to the detector concepts needs to be coordinated with the other sub-groups
    1. GEANT4 Simulations of the detectors and physics processes (hit rates, data rates, data link bandwith). These need to be holistic since physics performance is our top priority.
    2. Detector and technology groups need to inform us if the triggerless readout is feasible (link speed, power, radiation tolerance).
    3. Get a tentative estimate for off-detector compute requirements to filter and format the collision data before storage.
- That's an iterative process as the detector concepts get more optimized and technologies become available.