Trigger and Data Acquisition plans for FCCee

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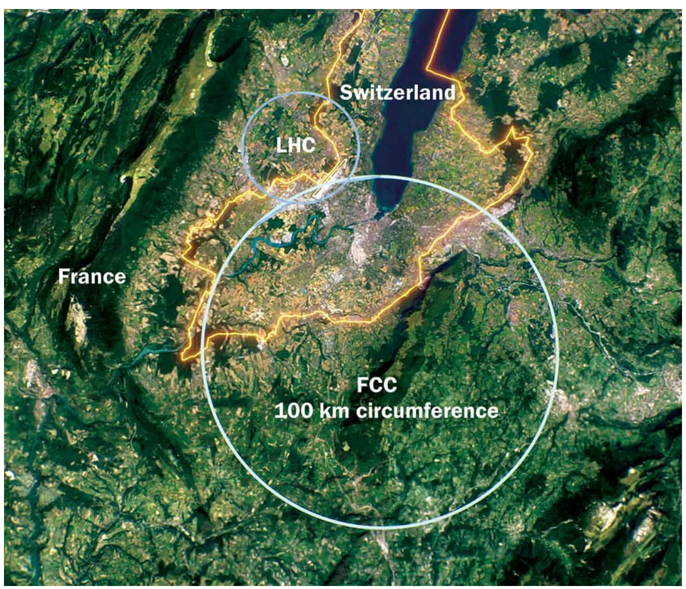
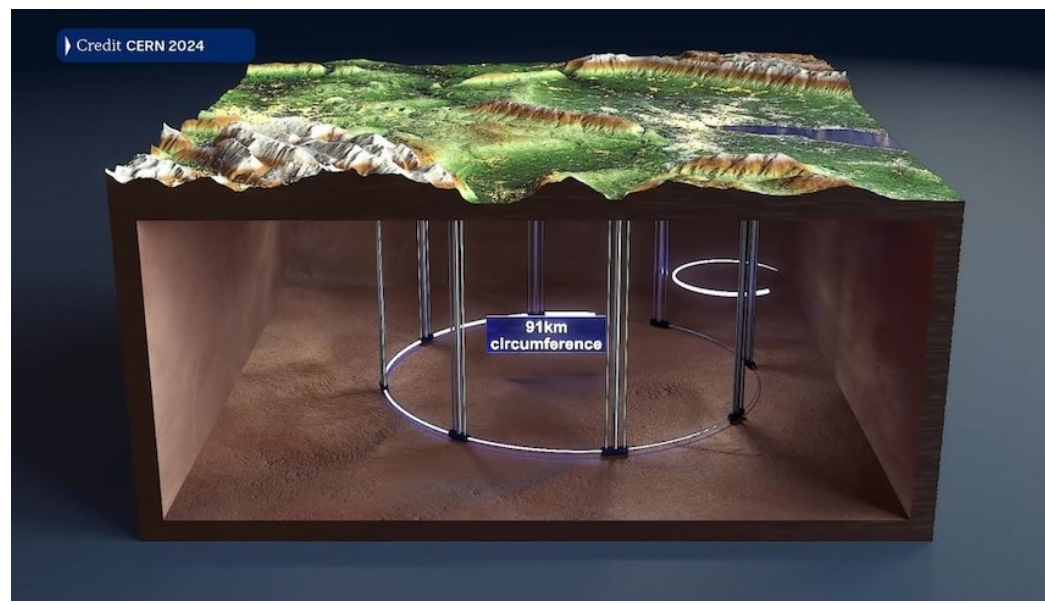
for FCCee TDAQ interest group

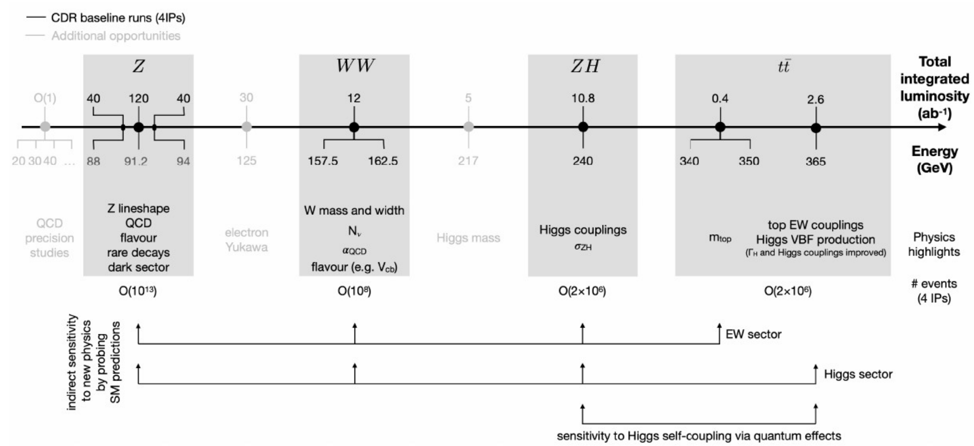
FCC week, Vienna, 22/5/2025





Introduction

- Experiments at FCCee will need some kind of Data Acquisition:
  - Lower expected data rates and background rates compared to the LHC
  - High granularity detectors may generate large data volumes
  - Unprecedented precision goals:
    - Constraints on material budget
    - "relative normalisation uncertainty <10^{-5}"
  - Several energy steps with vastly different running conditions (energy, collision rate)
  - Openness to possible BSM scenarios
- Plan of the talk:
  - Operation parameters
  - Basic TDAQ architectures
  - Few example questions that need to be studied
  - Next steps



- <u>In this talk I will use term TDAQ (Trigger and Data Acquisition) for everything that comes between detector and permanent storage, whatever architecture is selected …</u>

FCCee – detectors and data taking environment

FCCee parameters (emphasis on Data Acqusition)

- FCC physics programme is split into several energy steps (Z, WW, ZH, tt)
- With rising energy:
  - Cross section goes down
  - Bunch spacing increases significantly
    - Need flexible TDAQ
- Most challenging is running on Z peak, will focus on this scenario
  - 25 ns (40 MHz) bunch crossing rate
  - 100 kHz interaction rate
  - ~100 KHz background (mainly IPC ...)
    - Interaction in ~1 BC out of 400 (~1 event in M BCs for other data taking modes)

FCC-ee parameters		Z	W^+W^-	ZH	ttbar
$\sqrt{s}$	GeV	91.2	160	240	350-365
Luminosity / IP	10^{34} cm^{-2} s^{-1}	**140**	20	7.5	1.5
Bunch spacing	ns	25	160	680	5000
"Physics" cross section	pb	35,000	10	0.2	0.5
Total cross section	pb	70,000	30	10	8
Event rate	Hz	**100,000**	6	0.5	0.1
"Pile up" parameter [μ]	10^{-6}	2,500	1	1	1

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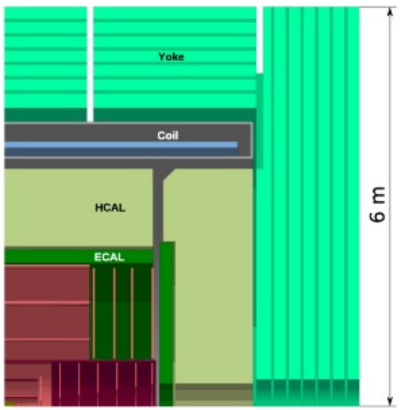
Possible experiments

FCC-ee Detector Concepts

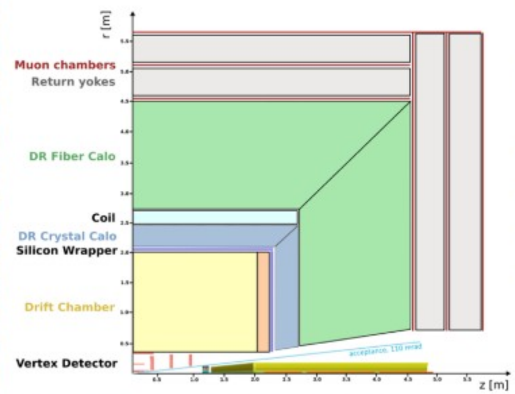
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si VTX + tracker
- CALICE-like calorimetry – very high granularity
- Coil outside calorimetry, muon system
- Possible detector optimizations
  - Improved σ_p/p, σ_E/E
  - PID: precise timing and RICH

arXiv:1911.12230

IDEA



- Design developed specifically for FCC-ee and CEPC
- Si VTX detector; ultra-light drift chamber with powerful PID
- Crystal ECAL w. dual readout
- Compact, light coil;
- Dual readout fibre calorimeter
- Muon system

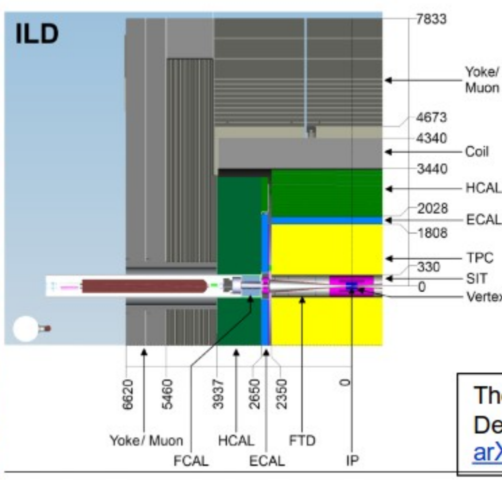
https://doi.org/10.48550/arXiv.2502.21223

Allegro

- Still in early design phase
- Design centred around High granularity **Noble Liquid ECAL**
  - Pb+LAr (or denser W+LKr)
- Si VTX detector
- Tracker: Drift chamber, straws, or Si
- Steel-scintillator HCAL
- Coil outside ECAL in same cryostat
- Muon system

Eur.Phys.J.Plus 136 (2021) 10, 1066, arXiv:2109.00391

ILD



- Designed originally for operation at the ILC
- Together with SiD, ancestor of CLD.
- Main difference and signature element:
  - Large-volume time projection chamber (TPC)

The International Linear Collider Technical Design Report - Volume 4: Detectors arXiv:1306.6329

Mogens Dam / NBI Copenhagen   FCC Week, Vienna   19.05.2025   8

link

Basic possible TDAQ architectures

TDAQ architectures I

- Basic parameters of FCCee data acquisition system fixed by the accelerator and physics:
  - Fixed (and known) frequency of collisions
    - Can trigger by frequency of filled bunches
    - Can tag data by time stamps (like BC number, Orbit number ...)
  - Need full events (for Etmiss, searches, …)
    - No partial event building
    - Need to synchronise fragments from individual detectors
- Basic trigger strategies:
  - Trigger-less readout
  - Minimally triggered system
  - Classically triggered system
- These are convenient benchmarks to think about DAQ, in reality can consider mixed approaches
    - Physics pushes us towards trigger-less
    - Several practical considerations (data volume, material and power budget, ...) in opposite direction

TDAQ architectures II

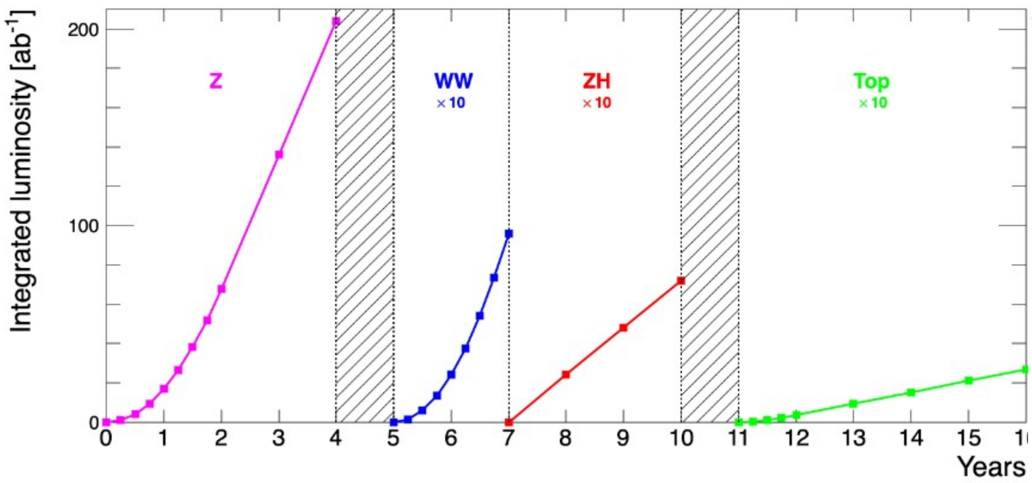
- Trigger-less architecture:
  - All the data that leave the detector end up on tape
- Dream of every data analyst!
- Means reading out all detectors at (at least) 40 MHz
  - Some sort of front-end data suppression should be possible
    - Intelligence at Front End (FE), noise filtering, zero supression, …
  - But this adds complexity to FE electronics
  - FE boards typically see only small part of the event
  - De-noising on FE can be dangerous if not done properly
- May end up with a lot of noise and background hits in the data acquisition system
- A lot of bandwidth comes from areas with bad access and severe material budget constraints (tracker, vertex detector)
- Challenge for off-line computing and long-term storage

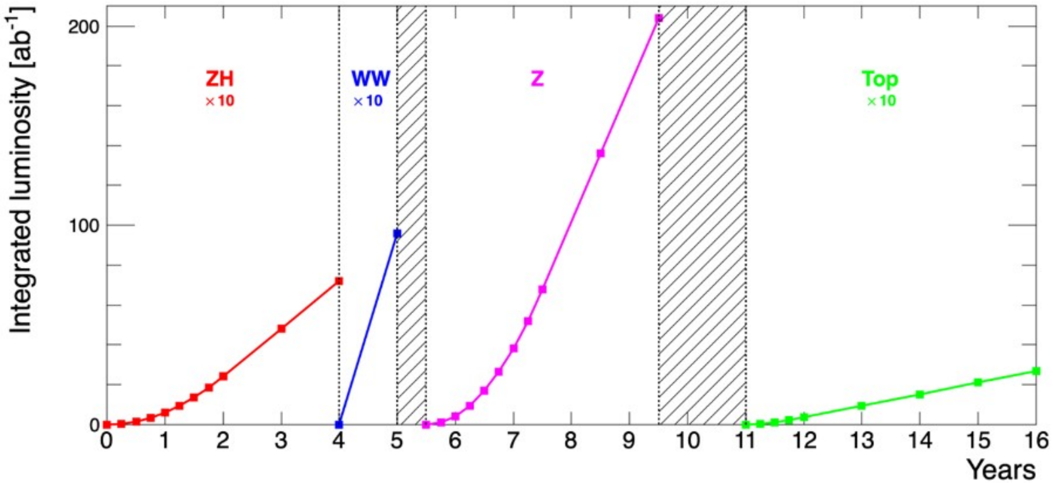
TDAQ architectures III

- Minimally triggered architecture:
  - Record all physics events (100 kHz at Z pole)
  - Accepting only 1 in 400 events, significantly reduces the challenge
    - In reality we need to be conservative and accept higher rate (non perfect selection, monitoring triggers, ...)
  - But how to know which BC to read out???
    - Stream everything from Front End and then decide what to store?
    - Use subset of detectors at 40 MHz to determine what to read-out and read out the rest at 100kHz?
    - (This is typically done with calorimeters and muon system, are all physics cases covered? Do we need trackers for decision making?)
- Classically triggered architecture:
  - TEVATRON, HERA, LHC, … used classical multi-stage triggers
  - With very loose selection can be close to minimally triggered architecture
  - Possible to reduce rate of certain physics channels
    - Give more bandwidth (and looser selection) to rare and BSM channels
- Note: Although LEP experiments used multi-stage triggers, their philosophy was closer to Minimally triggered architecture

Few (example) questions to adress ...

FCCee per-detector offline data volumes I



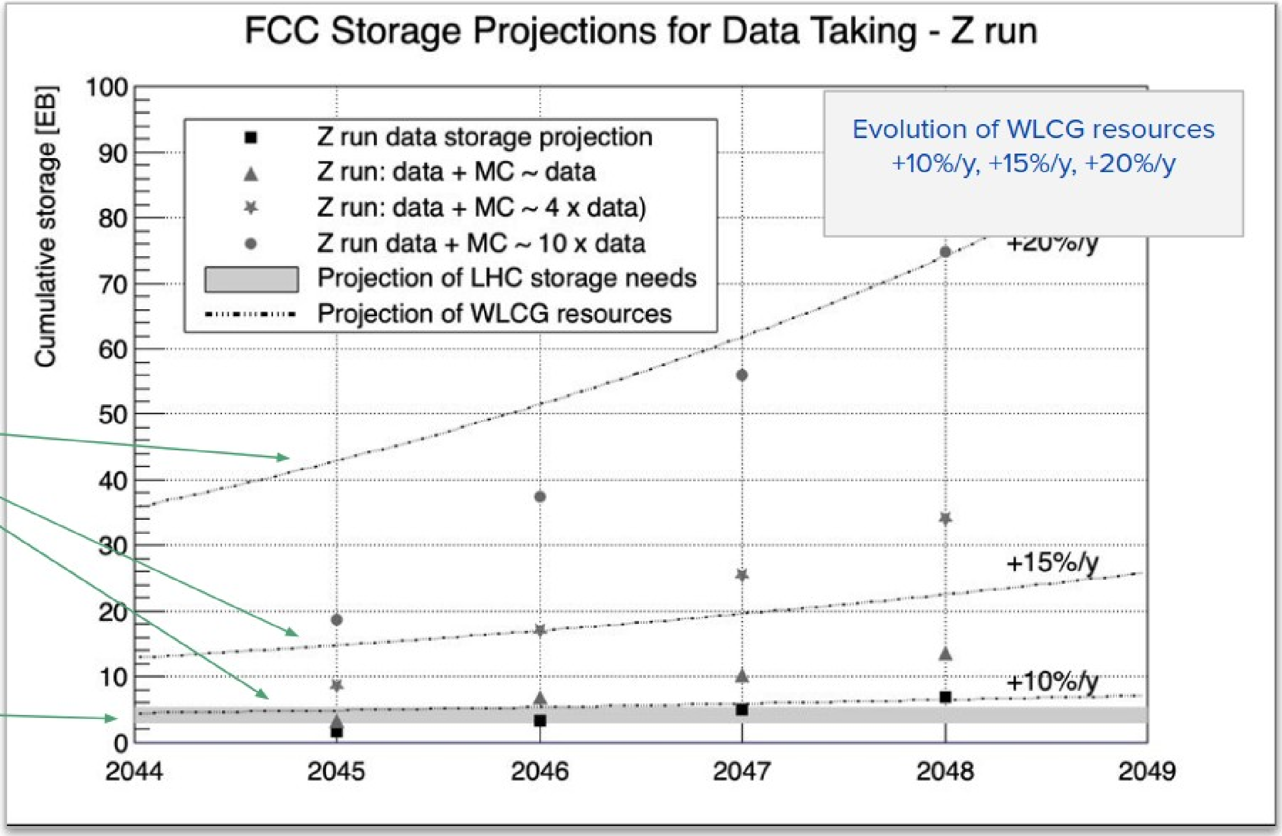


link

- There are several data taking scenarios
- In all cases expect significant data samples
  - Please don't think I am complaining about that!
  - Expect 200 ab-1 of integrated luminosity at Z pole over four years
  - Other runs on the level of 10 ab-1
    - That's a lot of data to record and save

FCCee per-detector offline data volumes II

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)

- Recent estimates of offline data volumes give roughly 1.7 EB/y
  - This is signal only, Zqq is the dominant contribution
  - If we assume 10x more MC than data, end up with 19 EB/y
    - This is about 20x more than HL-LHC overall storage needs
  - This doesn't include Bhabha scattering, beam backgrounds, …
    - How much bandwidth is added by background?
- What exactly we want to save?

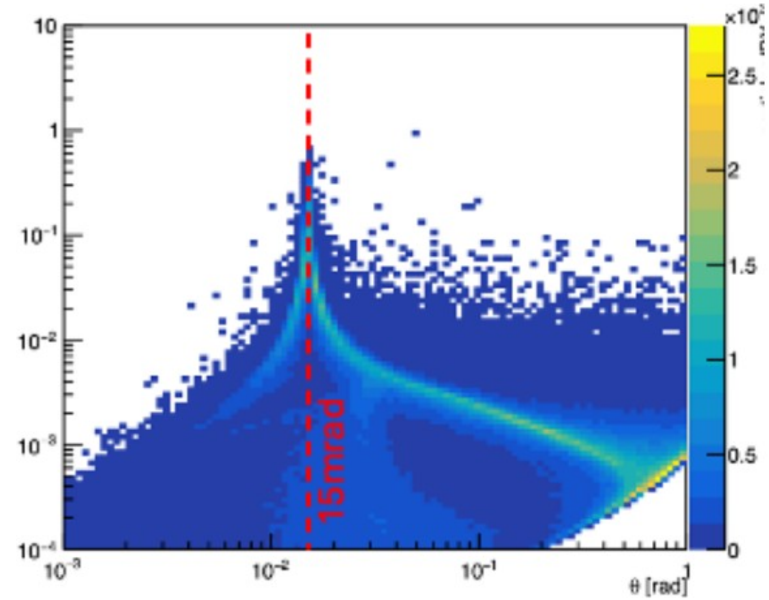
link

Can we stream all the data from the detector? Do we want to?

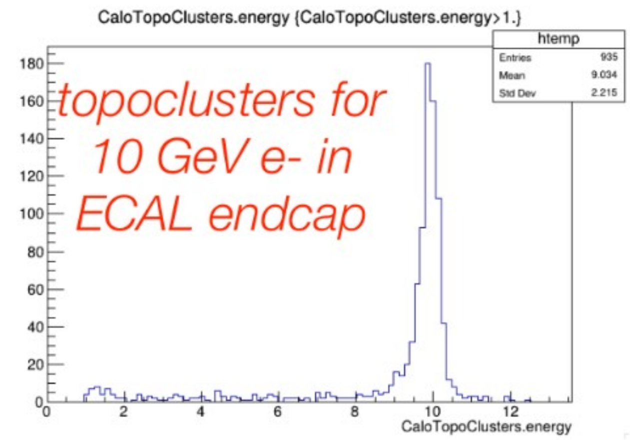
- Estimating full data rate to be streamed from the detector is non-trivial
  - Huge impact on possible TDAQ architectures
- Signal data rates are huge, but easier to estimate
  - CLD example, 1.1 MB/event Zqq, 0.16 MB/event Zll link
    - If we assume Bhabha event size similar to Zll and γγ similar to Zll, end up with around 260 GB/s
- Real question is the impact of beam related background and noise
  - Can easily produce data rates in TB/s region
  - Preliminary estimates for data rate from detector including background vary considerably
    - 1.3 TB/s link vs 11 TB/s link vs 14 TB/s link
- A lot of rate is coming from detectors with very difficult access and strict material budget constraints
  - Recent study for Allegro estimates link :
    - 3TB/s from Vertex Detector
    - 7.5 TB/s from Drift Chamber (assuming Idea geometry)
- All these numbers depend on good simulation of background and good understanding of detector readout

Collisions vs background -energy distribution

- Background dominated by Incoherent Pair Production (IPC)
  - Then radiative Bhabha, beam gas, …
  - Mostly going forward and low Pt
    - Should be quite easy to identify interaction events!
  - Argument for minimally triggered or fully triggered TDAQ
    - Traditional approach is to use calorimeter and muons
  - Are trackers needed in trigger?
    - Very likely they are, for example for LLPs
    - Impact on tracker design
- Can control all systematics? Can we know trigger efficiencies with sufficient precision?
  - Trigger efficiencies at LEP (for hadronic Z) known on 10-3 level link
- What about BSM signals? Long-lived particles, out of time signals?



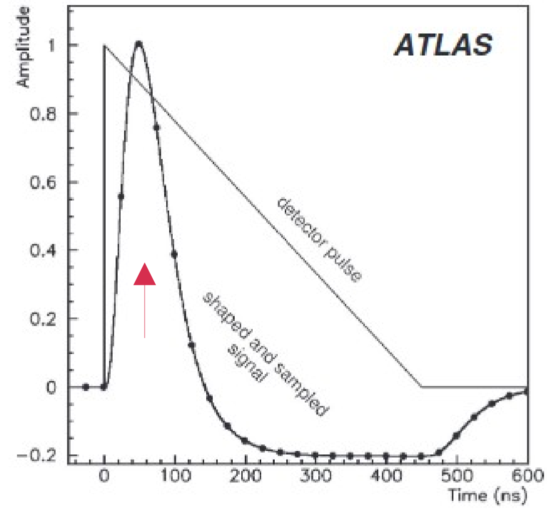
IPC background simulation link



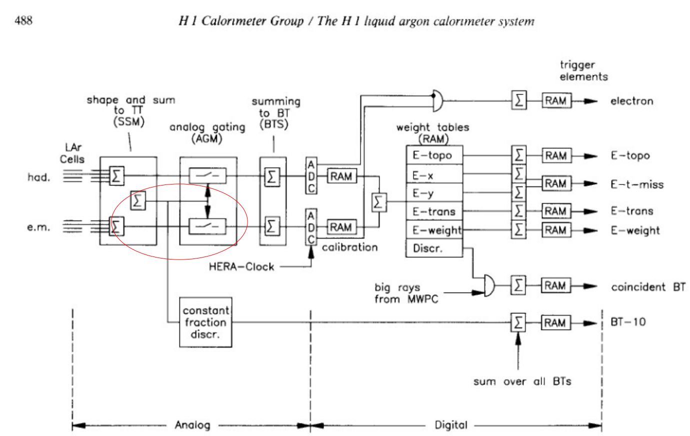
Allegro, simulation link

Collisions vs background - timing

- Bunch crossing identification is notorious problem when bunch crossings are close
  - At 40 MHz several detectors may have longer signals that BC spacing
- There are several approaches on the market, for example:
  - H1 used constant fraction discriminator
  - ATLAS calorimeter trigger:
    - Filter matched to signal+peak finder
    - Matched filter+autocorrelation+peak finder
    - Above mentioned with baseline correction
    - Timing cut using OFC
    - Possibly RNN in the future
- Will any of these suffice at FCCee?
- Especially for BSM scenarios (out of time particles, ...)
- Room for innovative approaches



ATLAS LAr link



H1 Calorimeter Trigger link

Next steps

Next steps I

Expression of Interest: Development and Implementation of Advanced TDAQ Systems for FCC-ee Experiments

Haider Abidi[6], Rainer Bartoldus[5], Juraj Bracinik[2], Dave Charlton[2], Davide Cieri[1,*], Zeynep Demiragli[7], Hal Evans[4], Francesco Gonnella[2], Julia Gonski[5], Steve Hillier[2], Oliver Kortner[1], Sandra Kortner[1], Aimilianos Koulouris[9], Sabine Lammers[4], Chris Meyer[4], Alexander Paramonov[8], Steven Schramm[3], Anna Sfyrla[3], Rosa Simoniello[9], Joeal Subash[2], Paul Thompson[2], Alan Watson[2], Miriam Watson[2], and Thorsten Wengler[9]

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March 20, 2025

- Recently several groups expressed interest in contributing to FCCee TDAQ studies
  - Several countries (Germany, Switzerland, US, UK)
  - Mainly involved in LHC experiments, trigger or data acquisition
  - Wide range of expertise, data acquisition, software and hardware triggering, ...
  - Contact person: Davide Cieri (davide.cieri@cern.ch)

Next steps II

- Group met few times, keen to collaborate
  - Exact organisational details need to be defined
- First steps:
  - Discuss TDAQ architectures that may be used at FCCee
  - General studies of interest for all Detector Concepts
  - Started formulating list of questions to groups working on individual Detector Concepts
  - Need to build communication channels, contact people, ...
- Later on:
  - Final TDAQ design will need strategic decisions affecting detectors, readout and physics potential
    - This can be done only on the level of individual Detector Collaborations
    - May not be as "plug&play" as other detector components
  - Most people involved in TDAQ EoI plan to join individual Detector Collaborations at some point
    - Some have joined already...

Next Steps III: Questions to experiments

- General:
  - What readout capabilities have been already demonstrated?
  - What readout capabilities are currently assumed?
  - (!) What is impact of readout on material budget, power budget, cooling power, ...
- Sub-detector capabilities:
  - Can your sub-detector read out at 40MHz?
    - If yes, can it *generate* (contribute to) trigger signal indicating presence of physics? To what extend can it differentiate between background and physics?
    - If not, can it buffer data to be read out on reception of external trigger?
- Sub-detector data volume:
  - What is the occupancy and data volume for each type of typical event: Z, WW, ZH, ttbar, beam background?
    - What is the number of channels and typical data size per channel?
    - Is it safe to assume that data volume is (occupancy)x(number of channels)x(data size/channel) or are things more complicated?

Summary and Conclusions

- Triggering and Data Acquisition at FCCee provide challenge of its own:
  - Large precision needed
  - Big event samples
  - ...
- Design of experiments have impact on TDAQ architecture and TDAQ architecture has impact on detector design
  - Need iterative process
- TDAQ activities for FCCee are in a very early stage
  - Several groups have recently expressed interest via ESPPU EoIs
  - TDAQ progress depends on close communication with FCCee detector communities

Many thanks to Anna Sfyrla, Davide Cieri, Alan Watson, Steven Schramm and Mogens Dam for useful comments and ideas [apologies for anyone forgotten]

Backup slides

Useful talks and references

- Davide Cieri, Concept of First Level Track-Trigger for FCCee, 15/10/2024, link
- Anna Sfyrla, Steven Schramm, Ideas on getting started on FCC ee activities, 8th FCC Physics Workshop, Jan 2025 link
- Anna Sfyrla, Steven Schramm, Thoughts for DAQ at FCCee, Third Joint Workshop on DAQ at LHC, Feb 2025 link
- CEPC workshop 2024 link
- CEPS baseline trigger design presentation at CEPC workshop link
- EoI Development and Implementation of Advanced TDAQ Systems for FCC-ee Experiments link