Summary of the 1st FCC-ee TDAQ workshop

6 nov. 2025

Vincent Boudry

LLR

Institut Polytechnique de Paris

FCC-France WS, Paris, 26/11/2025

FCC-ee TDAQ Working Group and WS

TDAQ Working group:

- Who ? Organisers: Thorsten.Wengler@cern.ch, Aimilianos.Koulouris@cern.ch,Thilo.Pauly@cern.ch, Anna.Sfyrla@cern.ch Rosa.Simoniello@cern.ch :
- Bi-weekly meeting: e-group = FCC-PED-DetectorConcepts-TDAQ@cern.ch

1st TDAQ workshop: https://indico.cern.ch/event/1583755/timetable/?view=standard

- Nov. 6, 2025 9h–18h, @CERN + Zoom, 125 registered participants
- Semi-individual pre-meeting for each experiments in previous weeks. (ILD, CLD, ALLEGRO, IDEA)

Programme Committee:

- TDAQ: Sasha Paramonov and Steven Schramm
- DRD7: Frank Simon
- Computing and software: Brieuc Francois
- Machine-detector interface: Manuela Boscolo, Fabrizio Palla
- Detector concepts: Martin Aleksa, Ties Behnke, Franco Bedeschi, Jinlong Zhang
- Detector concepts WG: Mogens Dam

Local Organisation Committee:

- Stefano Franchellucci
- Aimilianos Koulouris
- Thilo Pauly
- Steven Schramm
- Anna Sfyrla
- Rosa Simoniello
- Thorsten Wengler

Goal of the Workshop [Mogens Dams]

The workshop brings together several communities, with the goal of **gathering key information on TDAQ constraints, dependencies, and expectations** that may inform detector and accelerator design, and ultimately impact the physics potential of the FCC-ee.

- Example of LEP
  - Accept all annihilation events → L1 < 11 μs, Trigger: L2 ≤ 10 Hz, typical@Z-pole: 5 Hz

- The **trigger rate at the Z was typically 5 Hz**, luminosity triggers accounted for 2-3 Hz, Z events 0.5 Hz and γγ 0.5 Hz
- **Efficiency for hadronic Z decays 99.999 %** with an **uncertainty of 0.001%** determined by comparing independent triggers
- **Inefficiency for leptonic channels (e,μ,τ)** in fiducial region **< 3×10^{-5}**
  - as a backup even ECAL was used to trigger muons with a threshold of 200 MeV (!!)

50 years of tech dev't

Z pole	Lumi / IP	Z rate	Bunch spacing
	10^{34} cm^{-2} s^{-1}	Hz	ns
LEP	0.0023 (max)	1	22000
FCC-ee	140	50.000	25

Trigger(?) and Readout System

Slide from 2025 FCC Week

Goal of readout system

- *Full efficiency* to all SM annihilation physics events
  - Reminder: Aiming at $\mathcal{O}(10^{-5})$ (relative) normalisation
- No loss of potential BSM signatures
  - e.g., heavy (slow-movin) particles decaying late, LLPs

In particular at Tera-Z, challenging conditions

- 40 MHz BX rate
- Physics rate at $\mathcal{O}$(200 kHz)
  - Physics event in every 1/200 BX
- Example (perhaps the most challenging):
  - Pixel hit rate: ~200 MHz/cm^2 in VXD inner layer
    - Incoherent pairs from beam-beam interactions
    - Including cluster size of 5 and safety factor of 3
    - ⇒ **$\mathcal{O}$(5 Gbit/cm^2/sec)**
    - Would saturate "standard" 1 Gbit/cm^2/sec link

How to organise readout?

- **Hardware** (or software?) **trigger** as at LEP and LHC ?
  - Which sub-detectors can a trigger decision be based on?
  - High BX rate: Need for local **latency buffering** a la LHC?
    - Space/power/cooling for on-detector buffering?
- **Free streaming** of "self-triggered" sub-detectors ?
  - Off-detector event building based on BX ID via time stamping ?
  - Potential enormous data rate out of sub-detectors
    - Easily Tbit/sec from VXD alone
    - Is that at all technologically feasibly? Power needs,…?
      - c.f.: EiC will be streaming at max of 100 Gbit/sec
- **Hybrid Solution** possible **?**

Need to consider TDAQ architecture as integral part of detector design

Intro: Trigger strategy and data [Thorsten Wengler]

Trigger strategies @FCC-ee cont.

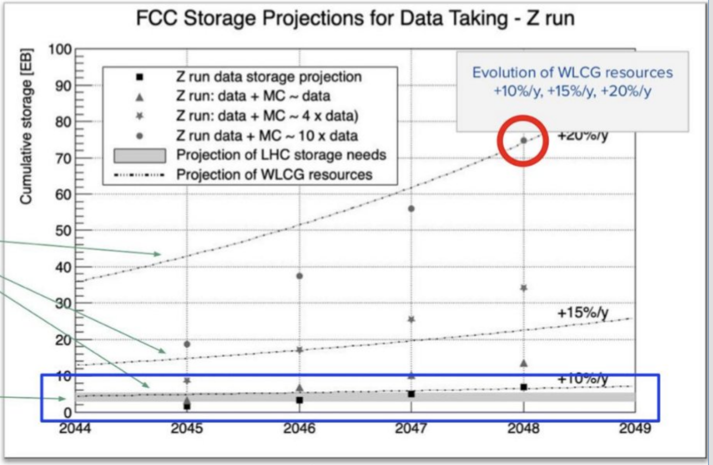
- Can we (and do we want to) afford triggerless readout?
  - Including 10x MC → could end up with ~ 20 x overall HL-LHC storage needs
- Affects the DAQ systems as much as the trigger of course
  - Precision measurements → low mass / low power systems
  - Deal with 10^{13} physics events without throwing any away F. Simon @ FCC week Jan'24

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

G. Ganis,
FCC physics workshop, Jan '25

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)



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Note this is physics only!

- The real question is the impact of beam related background
  - Can easily produce TB/s per region
  - Preliminary estimates vary easily by x10
- A lot of rate is coming from detectors with severe constraints on material / access
  - Example – 3TB/s for Allegro Vertex Detector

J. Bracinik @ FCC week May '25

Electronics: Update from DRD7 [Niko Neufeld]

Out of this vast menu the following seem relevant for FCCee-*DAQ

DRD7

- 7.1a: Silicon Photonics Transceiver Development
- 7.1c: WADAPT (Wireless Allowing Data and Power Transmission)
- 7.2b: Rad-tolerant RISC-V System-on-Chip
- 7.3c: Timing Distribution Techniques
- 7.5a: DAQOverflow
- 7.5b:From Front-End to Back-End with 100GbE

*: note the **deliberate** omission of the 'T' in TDAQ – I do not see a need for any hardware trigger for FCCee

- From a claimed 1.7 EB / year and assuming 10^7 seconds of running for FCC-ee I derive an event-size of about 1.5 MB for a physics event (which seems large for a lepton machine, c.f. LHCb's event-size during LHC Run3 is about 100 kB)

Despite some guessing on event sizes,

Electronics in 20 years ?

→ no show stopper

(cf. LHCb 40 MHz readout, for 8 MCHF)

→ just minimize power and space…

- IMHO the only question is if you can get all the data out within the material and power-budget
- If the answer to the previous question is yes, then there is no need for any kind of hardware trigger
- From the numbers known so far, no requirement seems to go beyond what the LHC experiments have studied and solved

Some picked elements from [Niko]

Silicon Photonics links (7.1 a)

- Already have 100 Gbit/s, single single-mode-fibre, radiation-hard (might be used for VeloPix LHCb U2) relatively low-power, laser outside detector volume (modulator inside only)
  - << COTS FPGA technology; COTS = Commercial-Off-The-Shelf.
  - Work cost effective back end for such fast links is conducted in 7.5b
- might be "overkill" for sparse detectors. => Depends on possibility to aggregate data locally
  - This needs dev’t (part of OTELLO)

Wireless readout 7.1c is clearly more “experimental”

- “potentially interesting for the innermost, high granularity detectors”
- Should have time to establish the feasibility before final decisions

Data processing on detector → Inline data reduction (common mode, cluster finding, etc …)

- ⚠ Depending on radiation levels could be done by COTS FPGAs (not part of DRD7) or RISC V radiation hard CPU for more complex tasks (7.2b)
- Some more advanced processing in 7.5a: e.g DAQ Overflow ” or “intelligence on/close to the detector”.

Electronics cont'd

Timing

- An enormous amount of work has been done on timing for the LHC experiments
- 7.3c continues: Ambitious targets stated in terms of small number of picoseconds
  - distribution, distribution of timing reference via White Rabbit, phase stability and reproducibility of commercial FPGA serializers and much more.

System building

- Code DAQ processing even more fuzzy (mix CPU, GPU, AI-like, networking...)
- $\supset$ obsolescence: τ(experiment) > τ(technology)
- But try to remove custom HW (e.g. back-end layers) [7.5b]

Path toward a common DAQ [Giovanna Lehmann]

A DAQ experts impressions:

1) Its too early for devlopments

2) DAQ@FCC-ee comparable to LHC → no shower stopper

3) But time for:

- Maximize synergies
- But should leave some flexibilty
  - → Provide building blocks

Pre-design interface agreements

- **Designing the DAQ is not something for now, but:**
  - the timelines for designing FE electronics are different and those systems impact the DAQ,
  - achieving agreements on basic interfaces early on, will allow to optimally design detectors, electronics and DAQ systems.
- **Interfaces may be agreed upon at an abstract level, initially**

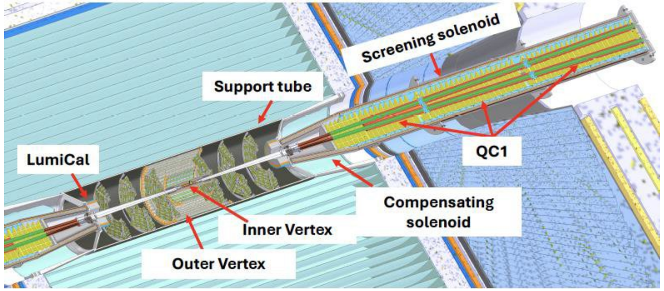
- **One data transmission protocol for all on-detector electronics towards the DAQ**
- **One protocol for configuration, control and monitoring of on-detector electronics**
  - Mandatory set of features to be implemented in FE for automated anomaly/error detection and recovery
- **A common timing distribution system**
- **Basic properties of data header fields, such as the keys for identifying and manipulating data**

Review of MDI & BiB
Machine Detector Interface & Beam Induced Background

Manuela Boscolo: inputs for the FCCee beam-optics decision

- decision in March 2026
  - Key Criteria:
    - **BIB in Experiments & MDI Mechanical layout**

Two optics currently under investigation:
- **GHC (Global Hybrid Correction) Optics – K. Oide**
- **LCC (Local Chromatic Correction) Optics – P. Raimondi**

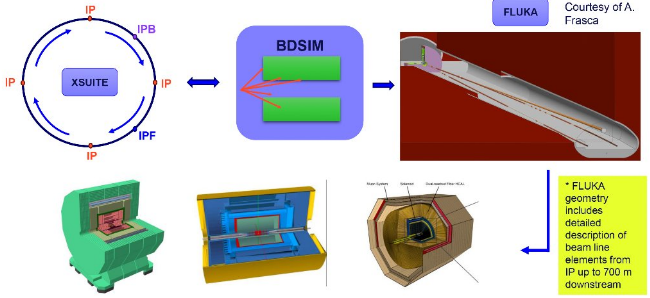


Giulia Nigrelli: overview of background sources and simulation status

- Detailled source of noise, modelling, Simulation workflow (now ready)
  - **Web page with tools in preparation**
- Example of BiB Mitigation studies

- Introduction
  - FCC-ee Beam loss scenarios
  - FCC-ee collimation system overview
- Beam-Induced Background Sources
  - Beam–gas interactions
  - Synchrotron radiation
  - Top-up injection

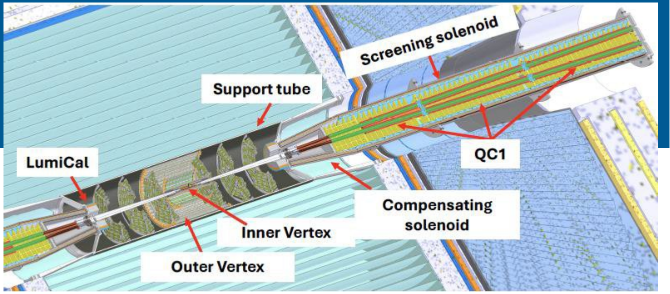
Background simulation workflow



Jan Eysermans: beam and detector simulation interface studies

- Example of IPC (incoh. Pair Prod) using Ginea-Pig
  - Tracking in beam EM field → Grid
- Still To be treated:
  - B from experiments, beampipe

Software



Andrea Ciarma: Software: MDI geometries and detector simulation

– Two versions of the geometry; almost common elements : B fields

MDI_o1_ShapeBased_v01
- all euclidean solids available in ddsim
- faster to run
- parametric
- complex shapes and profiles of MDI elements cannot be replicated

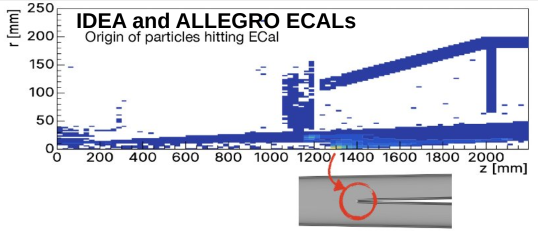
MDI_o1_CADBased_v01
- import of STL from engineered CAD design of MDI elements
- modifications of the design requires a new CAD model to be produced
- mesh handling can be complex
- 1:1 correspondence to real design

Detector 2T solenoid field
Defined directly in each detector main xml via ddsim constructors. Description should be taken care by each detector group.

IR antisolenoids field
Transverse beam coupling compensation is achieved at FCCee via a -5T compensating solenoid (±1.23m to ±2.00m from IP) and a -2T screening solenoid (±2.00m to ±5.40m from IP).
This is imported via a detailed field map. For the moment the map does not consider the fields at the return yoke of the detectors as they are not yet fixed in design. (except ILD)

Final Focus Quadrupoles
Defined via ddsim constructors. Dimensions and gradients depend on optics version and energy point. Definitions in

– Optimisation studies:
- BP material, geometry, septum, tungsten shielding

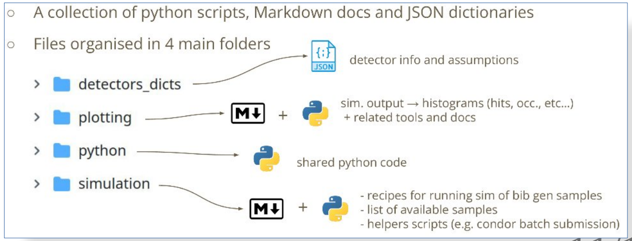


Sang Hyun Ko : sub-detector digitisers for rate studies

– Review of digitiser in Key4HEP for Generic (planar: VTX, μDet), Detailled Silicon (VTX, Calo’s), Drift Chamber, Calo (SiPM, ℓ Ar)

Stefano Franchellucci : common GitHub for simulation and occupancy studies

– https://github.com/HEP-FCC/bib-studies



Detectors: ALLEGRO, CLD, IDEA, ILD (alpha. order)

On-going work, no detector has a complete scheme, some more advanced but complementary

Stefano Franchellucci

ALLEGRO

Sub-system	Full readout rate	Trigger capable?	DetSim Status	TDAQ services in material budget?
Vertex detector	200 kHz interaction rate		FullSim + Digitiser	placeholder layers for cooling pipes & on-detector, but not off-detector tdaq services
Drift Chamber			FullSim + Digitiser	NO
Silicon Wrapper/ToF			FullSim	placeholder layers for cooling pipes & on-detector, but not off-detector tdaq services
ECAL	>200 kHz	YES	FullSim + Digitiser	placeholder layers for services (catchall)
HCAL			FullSim + Digitiser	NO
Muon Tagger		YES?	N/A (volume placeholder only)	NO

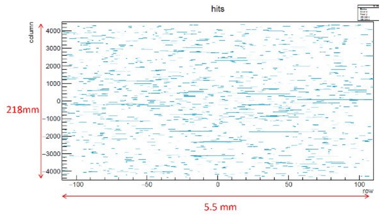
Todo:
Complete table
Refine trigger capability with rate

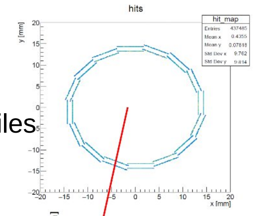
Alexander Paramonov

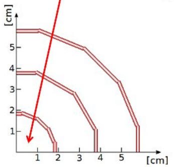
CLD

Very detailled (but prelim.) study of the VTX

- Slightly ≠ geometry from CLD paper
- With full digitizarion, ⊃ soft e–
- Prelim bandwidth, esp. L1 using dedicated BiB files







Lorenzo Capriotti

IDEA

Subdetectors	Throughput
Silicon Vertex Detector	~1 TB/s (untriggered) or ~10 GB/s (triggered)
Drift Chamber	< 1 TB /s (no clustering) or ~100 GB/s (w/ clustering)
Crystal calorimeter	< 1 GB/s
DR fibres calorimeter	10.2 TB/s (no threshold) - 4.2 GB/s (w/ threshold)
Luminometer	18 GB/s
Muon system	400 MB/s
Preshower (if no crystals)	350 MB/s

Drift Chamber with clustering algorithm

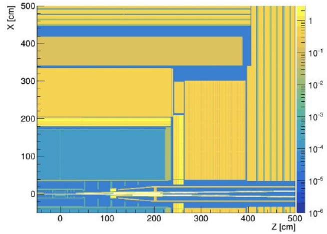
- Assume on-board cluster finding and reading out only peaks (assume 2.5 peaks/cluster)
  - ➢ Readout amplitude and time of peak (2 Bytes)
- Z decays:
  - ➢ 10^5 ev/s × 20 tracks/ev × 112 cells/track × 50 peaks/cell × 2 Bytes/peak ≈ **22 GB/s**
- $\gamma\gamma \to$ hadrons:
  - ➢ 3×10^4 ev/s × 10 tracks/ev × 112 cells/track × 50 peaks/cell × 2 Bytes/peak ≈ **3 GB/s**
- Bhabha:
  - ➢ 5×10^4 ev/s × 2 tracks/ev × 112 cells/track × 50 peaks/cell × 2 Bytes/peak ≈ **1 GB/s**
- Noise (assume filtered by clustering algo) **0 GB/s**

Total unfiltered rate (read both ends): 2 x 27 = **54 GB/s**

With safety factors ~ 100 GB/s

Vincent Boudry

ILD



common MDI:

- MDI_o1_v00 vertex, inner tracker adapted from CLD_o1_v07
- Remainder of ILD untouched

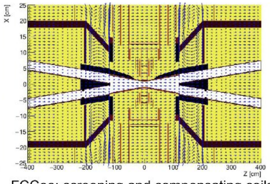
FullSim framework from ILD

- Adapted with common MDI
- Precise Magnetic Field map
- Optim of MDI shielding

Prelim. rates for:

- Beamcal
- VTX with Sync. Rad.
- Calorimeters (4 options)

Job was done for ILC TDR estim.



FCCee: screening and compensating coils

Conclusions

Very nice overview of all aspects

- Not mentionned, a bonus presentation:
  status and plans for EPIC (EIC) DAQ

My impressions

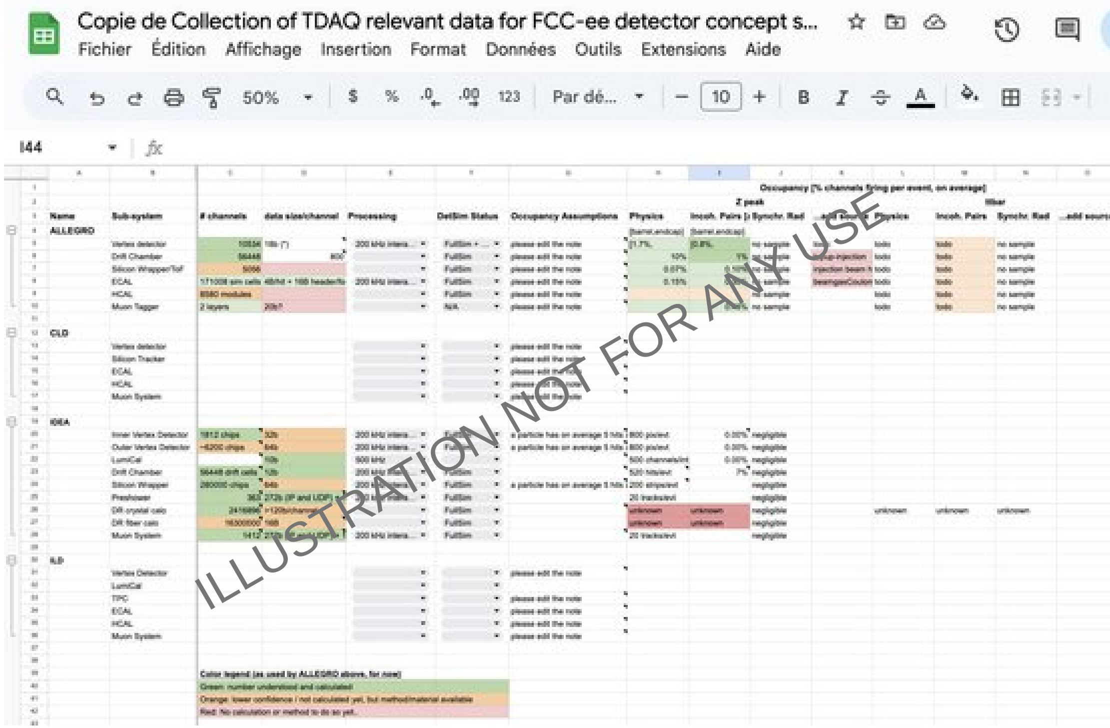
- Still in a early phase, but some answers needed soon for MDI choices (GHC vs LLC in March 2026)
  - Community is getting organised (Github, Web pages common files)
- Hard to extrapolate electronics performances in 20 years from now
  - Think of what was a PC in 2005…
  - BUT performances *
    computation cost –65%/year *
    optical transmission × 2 /1.5 year.

- Emerging: trigger is not mandatory (make things much simpler)
- DRD7 is a key player for this, to avoid duplication.
  - New readout methods; work on common concentrators…

Very complete “Official” workshop summary

- DAQ should not be a source of systematics.
- Streaming feasible but is it optimal if it affects sub-det. Performances ?
- Top-up injection is a major source of beam loss (12%) ➞ beam bgd

Collecting numbers…



* https://www.cambridge.org/core/journals/journal-of-economic-history/article/two-centuries-of-productivity-growth-in-computing/856EC5947A5857296D3328FA154BA3A3

Back-up

GHC/vs LLC [Manuela Boscolo]

High-level IR optics and beam parameters

These values primarily deliver the instantaneous luminosity

Values @Z	FSR	New value GHC/LCC	Comment
L* (free space IP-first quad)	2.2 m	**2.4 m**	New clearances at QC1 → impact to cryostat dimensioning; SR masks will be moved away as well
Crossing angle	30 mrad		large due to the crab-waist scheme
β^* @Z (mm)	110 / 0.7	**90** / 0.7	equal for GHC/LCC
Space between QC1-QC2	30 cm	**70 cm**	impact to cryostat dimensioning, larger value allows for two cryostats instead of one
Physical aperture at QC1	15 mm		internal beam pipe radius, impact on the cryostat dimension internal to detector
Physical aperture at QC2	20 mm	**25 mm**	internal beam pipe radius
Bunches/beam	11200	**12000**	bunch spacing changes

Some changes in the new optics reflect MDI hardware requirements