

Trigger and DAQ at FCC-ee

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A detector for the next CERN flagship project: ILD



The FCC-ee TDAQ Challenge

FCC-ee parameters		Z	W ⁺ W ⁻	ZH	ttbar
$\sqrt{s}$	GeV	91.2	160	240	350-365
Luminosity / IP	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	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

Z-pole most challenging experimentally:

- 100 kHz physics rate, ~200 kHz including backgrounds
- 25 ns bunch spacing (40 MHz BX rate) → only about 1 in 200 is a physics event
- No pileup / no underlying event (pile-up parameter $\sim 2.5 \times 10^{-3}$)

The FCC-ee TDAQ Challenge

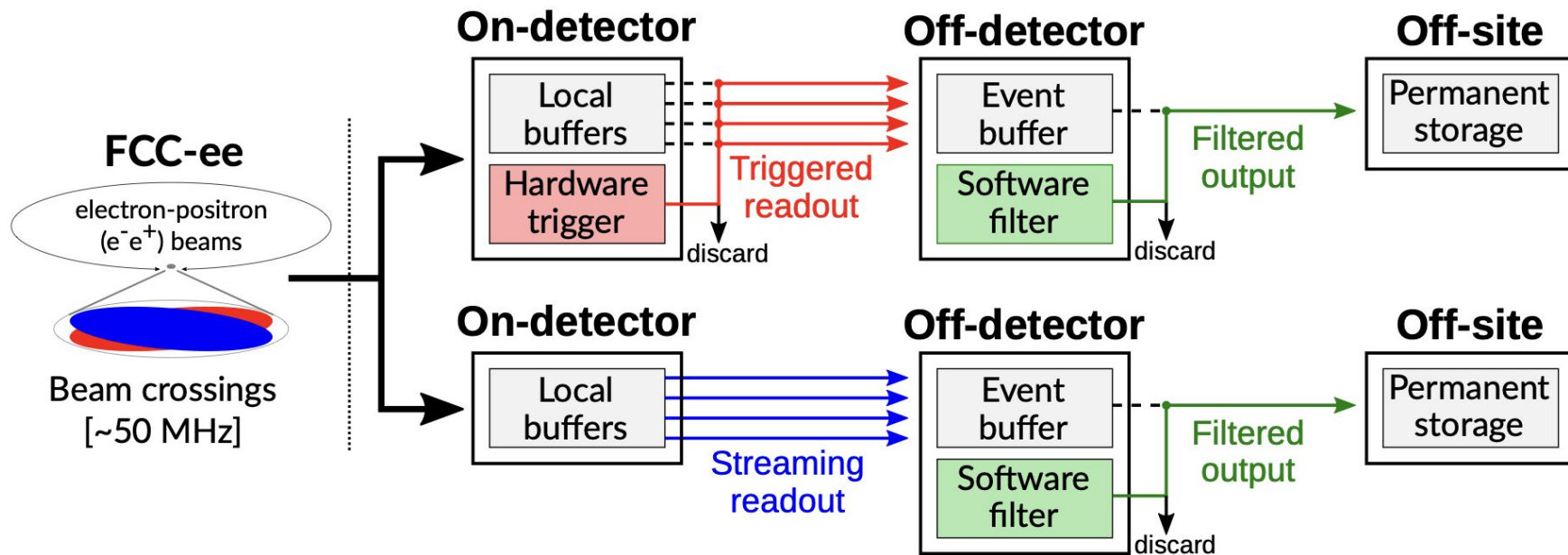
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Precision EW programme demands:

- trigger efficiency uncertainty negligible vs luminosity: $\delta R/R \approx 2 \times 10^{-5}$
- same dead time for all event types → EW precision relies on ratio of events
- Trigger bias control to **1 part in 10^6**

Trigger or Streaming Readout?

Three options: triggerless/streaming, minimal trigger, classical triggered



First question: Can we do it?

Can we? Yes. Is it optimal?

Compare triggered HL-LHC (ATLAS/CMS) vs FCC-ee T/DAQ relevant quantities

- Assume a single HL-LHC event is 4 MB, and a single FCC-ee event is 0.2 MB
- Assume the full FCC-ee physics rate at the Z pole is 200 kHz

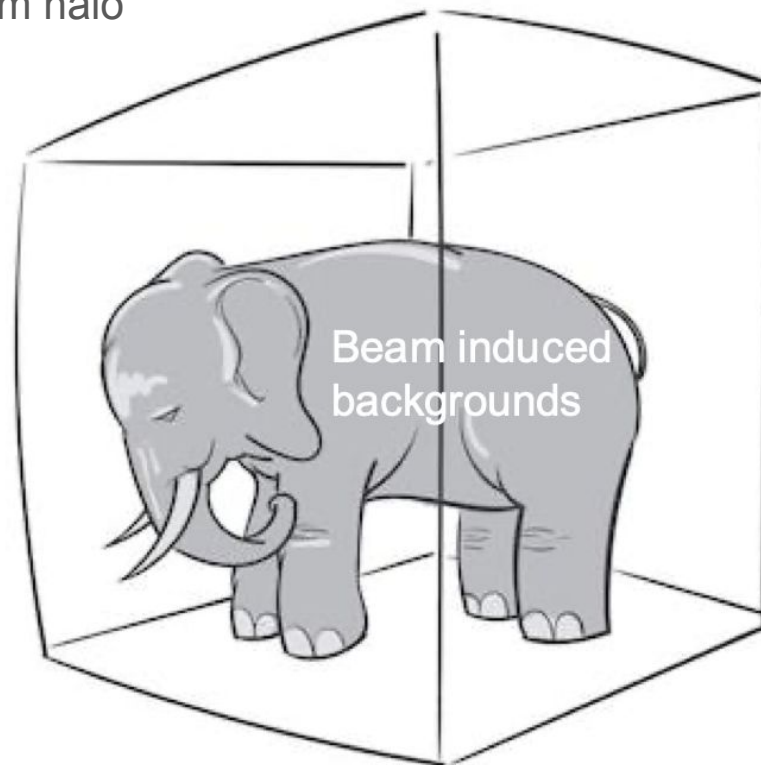
	Raw input		Trigger	Filter input		Filter	Storage input	
HL-LHC	40 MHz	160 TB/s		1 MHz	4 TB/s		10 kHz	40 GB/s
FCC-ee	50 MHz	10 TB/s		0.5 MHz	0.1 TB/s		200 kHz	40 GB/s
	Streaming, with filter			50 MHz	10 TB/s		500 kHz	100 GB/s
	Streaming, no filter			50 MHz	10 TB/s		50 MHz	10 TB/s

- HL-LHC DAQ hardware is capable of FCC-ee streaming readout
- Streaming means more material & power on-detector → may degrade physics

Elephant in the room: Beam Induced Backgrounds

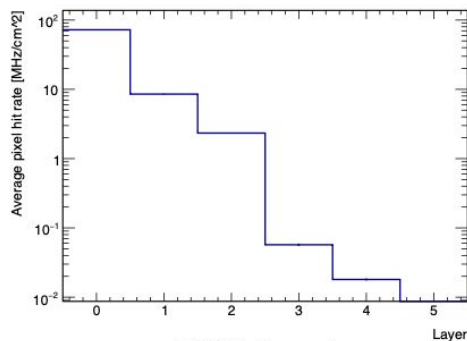
Several sources of beam-induced background: incoherent pair creation (IPC), synchrotron radiation (SR), top-up injection losses, beam-gas, beam halo

- *IPC* is the largest irreducible. Mostly very soft (1–2 MeV), only a small fraction reaches detector in 2T field but ***enough to dominate vertex detector occupancy***. Typically *~30 hits on the first vertex layer per BX* → *hit rates of ~70 MHz/cm²*
- *SR* can saturate the innermost vertex layer if shielding/masks not optimized
- *Top-up injection*: up to 1% of full beam intensity replaced every 10 seconds, 12% of injected beam lost around ring

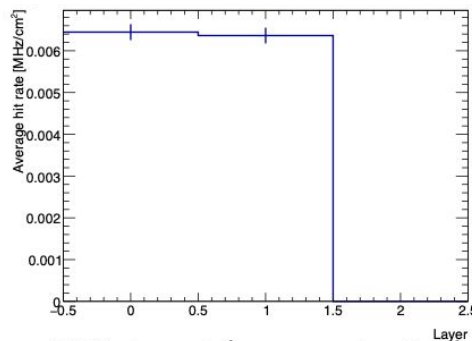


Occupancy: The innermost layer drives it all

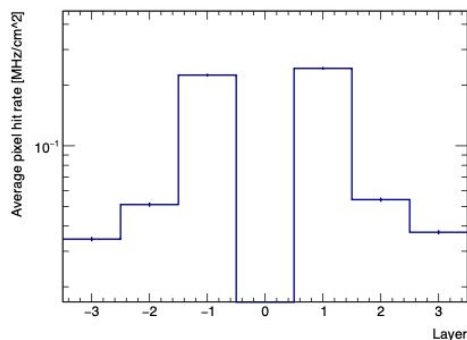
Vertex detector innermost layer dominates across all concepts: driven by incoherent pair creation (IPC)



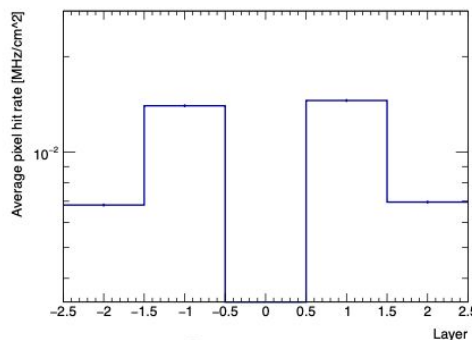
VXD barrel



SiWr barrel (own production)



VXD disks



SiWr disks

*IDEA/ALLEGRO stave-based VXD, 2 T,
(Newest) LCCv106 beam optics*

First-layer IPC hit rate down to

- *~70 MHz/cm² (avg),*
- *~100 MHz/cm² (module max)*

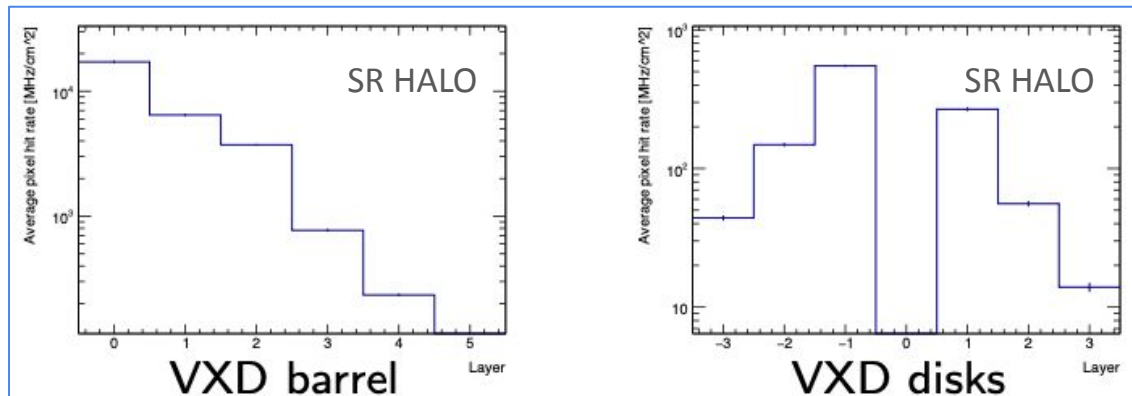
*reduced from ~140/170 on the GHC optics
VXD disks & silicon wrapper: ≥ 10× lower*

*But: not all background sources included
yet, not all concepts at the same stage,
estimates can vary by ×10 depending on
assumptions (cluster size, safety factors,
noise thresholds, which optics)*

SR: the new elephant in the room?

First large SR samples → SR can now be properly evaluated for the first time.

Two concepts, same warning

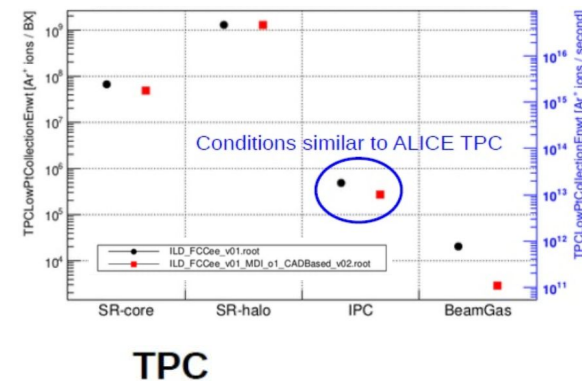


IDEA/ALLEGRO

SR halo (outermost ~1% of bunch): >10 GHz/cm² in the VXD barrel.

This is orders of magnitude above the IPC rate!

- SR photons survive through the beam pipe, deposit above threshold; raising threshold doesn't help
- Partly-insensitive sensor buys $\sim \times 3$ (halo), not a fix



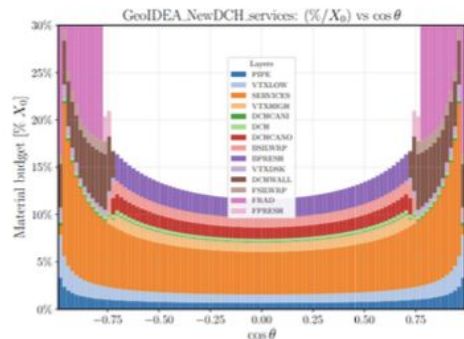
ILD

TPC, optics LCC v106.2 @ 91 GeV.

ILD_FCCee_v01

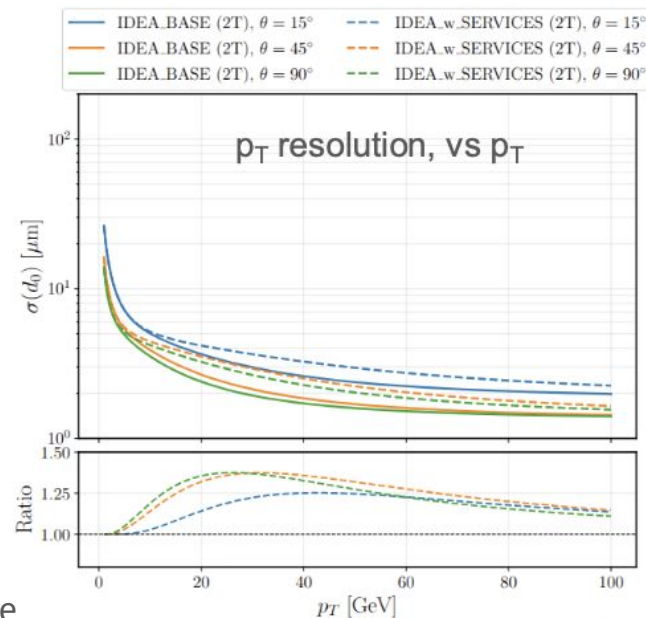
New MDI description show modest improvement for some sources, but no change for dominant SR

We cannot optimise in isolation (bandwidth, hit rate, and resolution are all intertwined)



Material budget ($\%/X_0$) vs $\cos \theta$: IDEA_BASE & IDEA_w_SERVICES

- Material sensitivity: adding service material in the vertex region degrades $\sigma(pT)$ by $\sim 25\text{--}50\%$ (see above 4 mm Al study, IDEA)
- Geometry & charge sharing goes both ways:
 - moving layers closer improves impact parameter but raises hit rate
 - bigger clusters $\rightarrow$ better resolution but more bandwidth



A. Koulouris

These trade-offs freeze into the front-end early

Realistic digitisation: the tools to actually decide

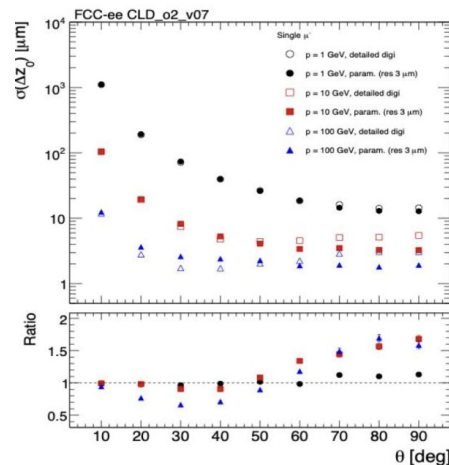
Occupancy, data-rate and readout numbers are only as good as the digitisation behind them.

A coordinated FCC effort now provides two complementary digitisers (to be merged into one Gaudi algorithm):

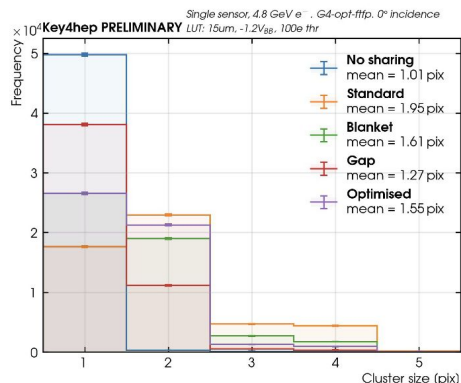
- Projection-based: simple, technology-agnostic, minimal parameters; general use; merged & tested in CLD
- LUT-based: maximum precision; sensor-design & BIB hit-rate studies; merge in progress

Together they span everyday physics studies → expert sensor/layout optimisation, also feeding realistic data rates

Longitudinal impact parameter resolution



sharing the charge deposited in the sensor across neighboring pixels



	Projection-based	Lookup table-based
Design goal	Simple usage, minimal free parameters	Maximum precision
Target	General usage	Detector layout optimisation; pixel hit-rate estimation
Optimal sensor	Tall, uniform pixel geometries	Thin, complicated pixel geometries
Requirements	Few, predefined numbers to describe charge transport	Pre-calculated lookup tables from sensor R&D simulations
Current status	Fully usable, tested with CLD	Merge to stack in progress, used in BIB-studies
Validation	Compared to previous digitiser, possibly on data in future	Cluster size validation on data planned
Timing	Basic Gaussian smearing	Basic Gaussian smearing

Plans & Priorities

Too early to fix a TDAQ design, but the groundwork is being laid now:

- Occupancy & bandwidth database: collect TDAQ-relevant numbers consistently across all concepts, as optics & layouts evolve building on the [Google Sheets](#)
- Refined background simulation: newest optics (LCC), updated IPC & SR samples, realistic digitisation feeding the numbers
- Hardware, via [DRD7](#) light-weight/high-throughput readout links (silicon photonics, wireless), timing distribution, on-detector/on-FPGA ML

Common TDAQ(base) functions needed regardless of trigger choice:
zero-suppression at source, timing distribution, bunch-crossing ID, unstable-bunch veto

Commonality is the priority! We solve the same problems across concepts

Summary

Moving the physics data is a solved problem: the rates are modest vs HL-LHC.

The open questions are: can we survive the background rate, and what's the optimal operating mode given material/power/selection trade-offs?

Backgrounds drive it:

- IPC sets the innermost-layer occupancy ($\sim 70 \text{ MHz/cm}^2$, newest optics);
- SR halo is the new open question ($\sim \text{GHz/cm}^2$, both IDEA/ALLEGRO and ILD)

Readout couples to detector design: bandwidth, hit rate and resolution are intertwined, and choices freeze into the front-end early

The tools are getting realistic: per-pixel & LUT-based digitisation now let us decide on physics terms, not guesses

The *optimum* will shift with readout & detector R&D so we build common foundations now