Karlsruhe Institute of Technology

Institute for Data Processing and Electronics

Towards Detector Readout Concepts

Introduction + a few Words on CLD

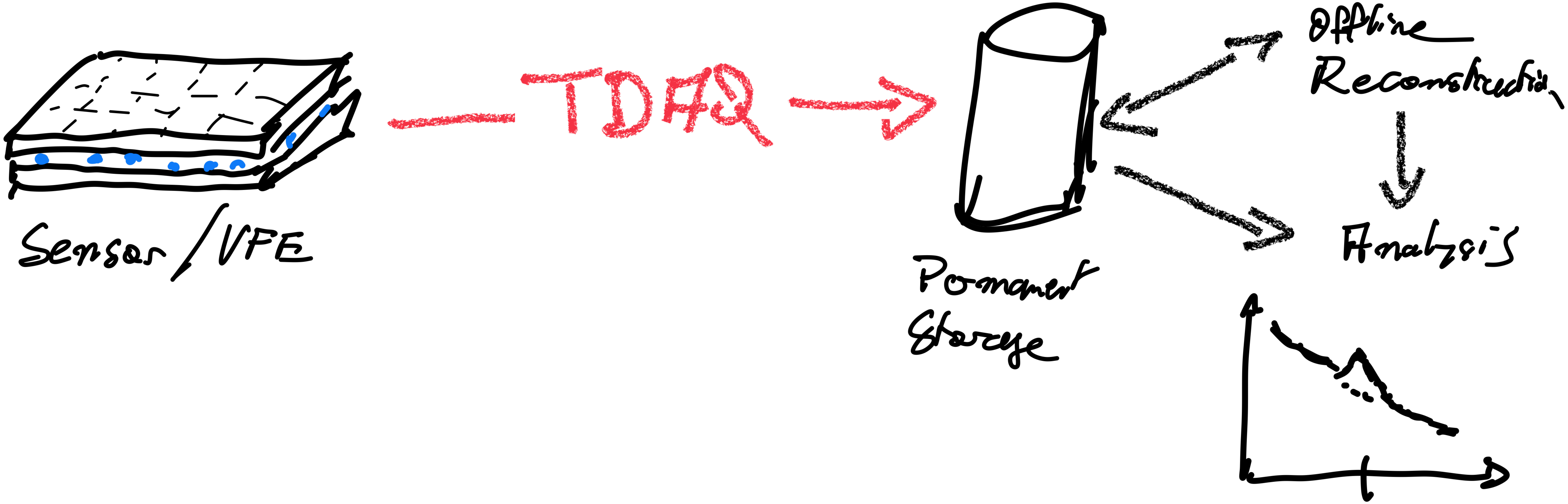
Frank Simon

FCC Physics Workshop, January 2024

image: CERN

Detector Readout

In Perspective



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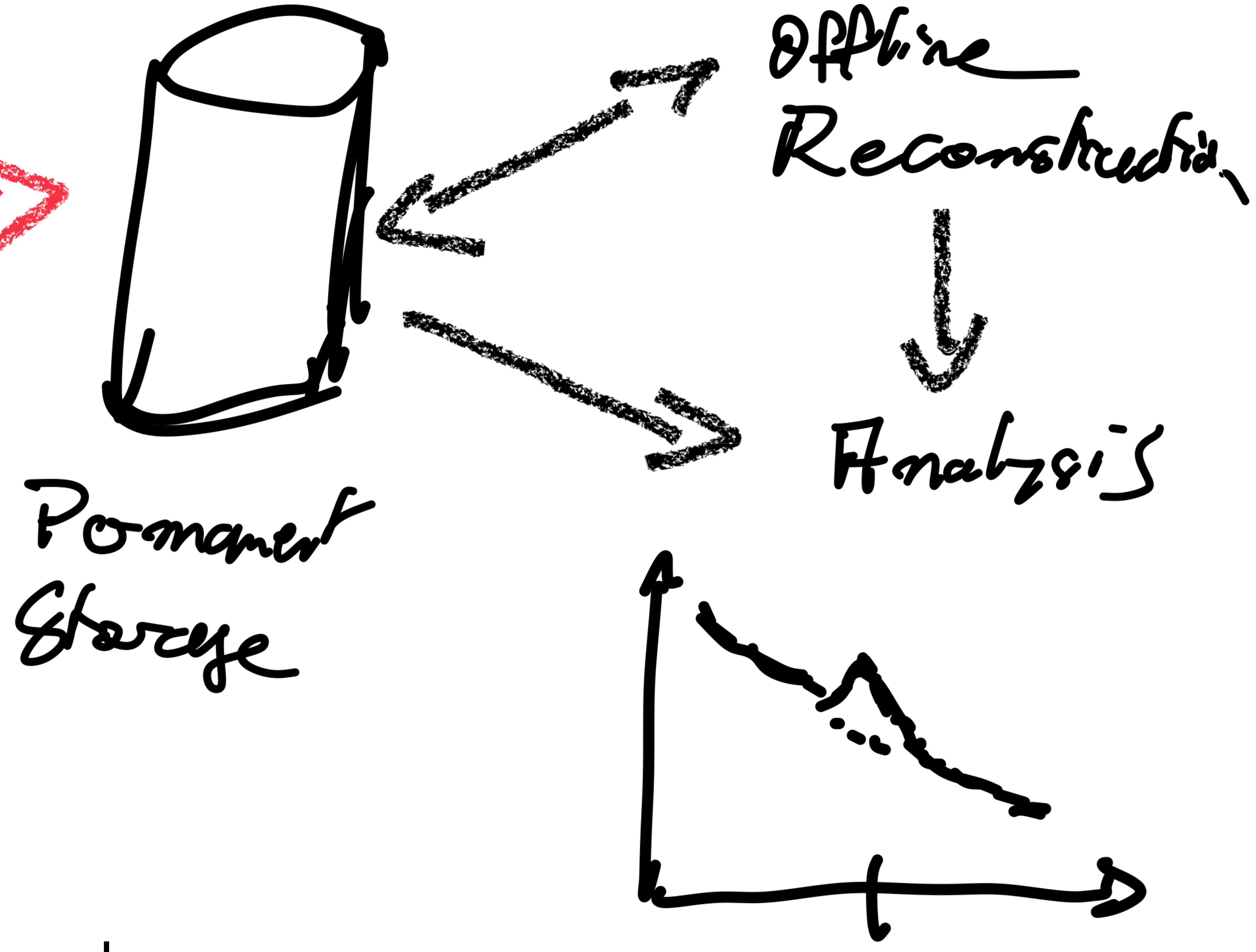

Why care?

Electronics specs drive many aspects of detector design

- data bandwidth and data concentration, power and cooling needs
- space requirements, material budgets, compactness

Pivotal role in overall system design!

A better readout system gives you better physics reach: Statistics, precision, …

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Readout at Higgs Factories

- Often heard: We are managing (HL-)LHC - e^+e^- should be trivial by comparison.

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  From a pure data rate and event rate perspective this clearly is true. Technology to read out FCC-ee data is already available already today.

  But: Very different requirements!

  - Systems capable to deliver the experimental systematics commensurate with the Z-pole program: Absolute rates with 10^{-4} precision (or better…)!
  - Low mass and low power: Enabling precision measurements
  - Deal with ~ 10^{13} physics events - without throwing away any.

Readout Concept & Technology

Fundamental for overall Experiment Design

- Important to address central items early:

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  Do we need a trigger?

  - If some detectors need an explicit trigger all relevant systems have to be read out with sufficient speed, processing with sufficiently low latency is required, and specific trigger data paths have to be foreseen.
    - What buffer depths / latencies are required / acceptable?
      Requirements imposed by signal formation time in subsystems?

  What form will the online data reduction chain (trigger in a wider sense, selective readout) take?

  - The need and appetite for upstream data reduction.

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  - Where does it make sense to use them - where not?
  - What level of radiation tolerance is required where in the system?

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  Which new technologies will be adopted?
  - 4D / 5D readout,…
  - Is fundamental R&D required, or should the focus be on scale and implementation?
  - What can new COTS hardware provide? Think FPGAs with integrated AI, …

A few Thoughts on the Way forward

Connecting to R&D Efforts

- Crucial to learn from LHC experience:
  - DAQ has to be part of the detector concept from the start, don't leave it for later.
  - Need to change the approach compared to LHC: high system complexity of DAQ systems requires experienced personnel, often not available in sufficient quantities (1000s of FTEyears going in LHC systems)
    - Common standards - already in the R&D phase -> common technological platforms

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A framework for common R&D: DRD7 collaboration on on electronics and on-detector processing.

Most or all working groups of high relevance for FCC-ee detectors:

- Data density and power efficiency
- Intelligence on detector
- 4D and 5D techniques
- Extreme environments
- Backend systems and commercial off-the-shelf components
- Complex imaging ASICs and technologies

Discussion welcome!

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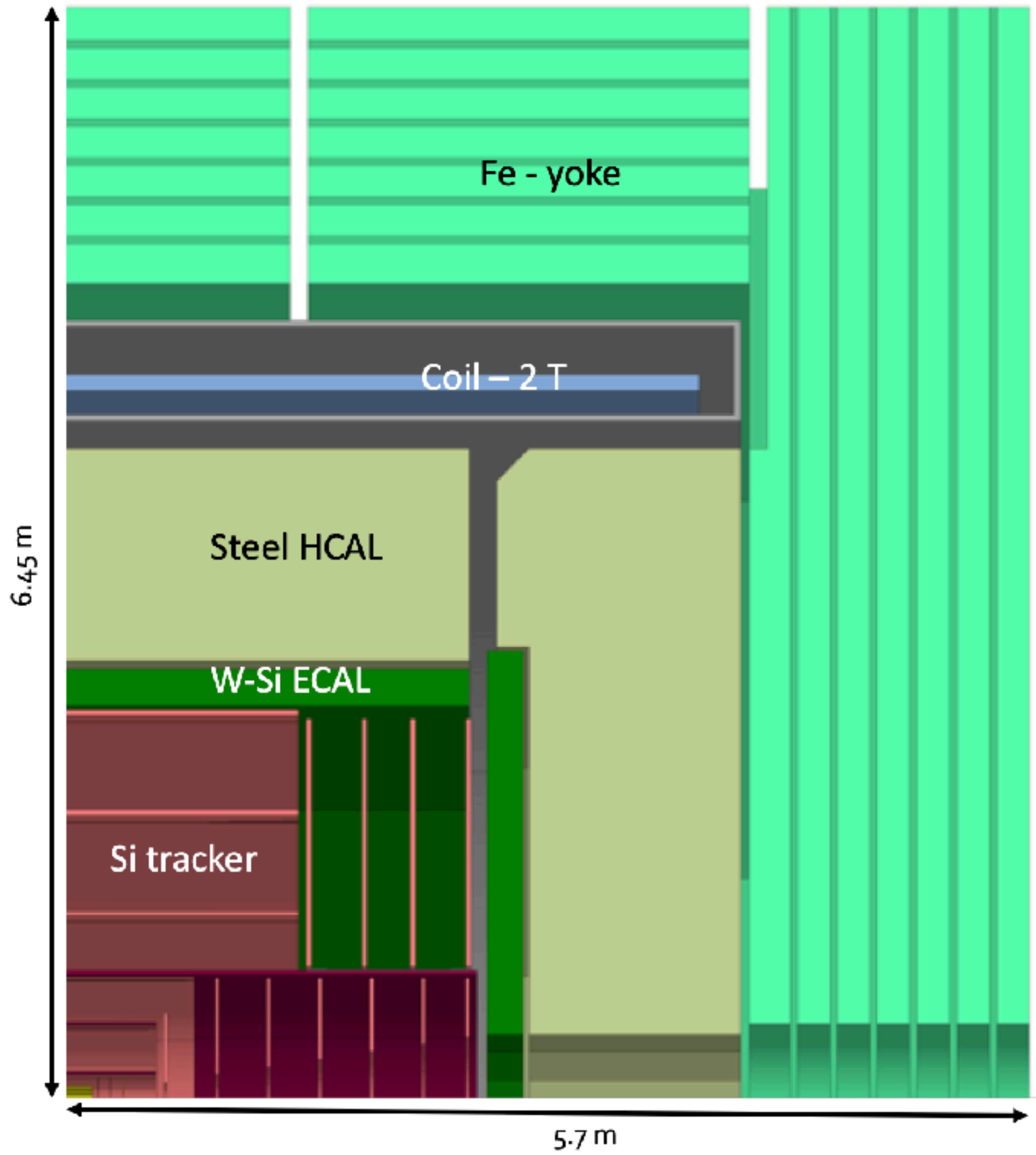
A few Words in CLD

Mostly based on CLICdet Studies

The CLD Detector Concept

And some Rate Estimates



- All-Si tracking. Highly granular sampling calorimeters: SiW, SiPM-on-tile

Eur. Phys. J. Plus (2021) 136:1198

Subdetector	Physics	Background/noise
CLD vertex detector	150 MB/s	6 GB/s
CLD tracker	160 MB/s	10 GB/s

assuming no 4D tracking

for 100 kHz physics rate at the Z pole, 50 MHz bx rate

CLICdet Rates

For CLIC Conditions…

- Thorough studies for CLICdet - For CLIC conditions. Not directly transferrable to FCC-ee, but can serve as a first impression.

Numbers for 3 TeV operations, with zero suppression.

Completely dominated by background (less than one physics event per train).

CLIC bunch train rate 50 Hz, bunch trains ~ 160 ns long.

Duty cycle 8 x 10^{-6} !

Detector region	time sampling period [ns]	hit time resolution [ns]	cell size [mm^2]	number of channels [10^6]	average to max. train occupancy [%]	number of bits per cell [bits]	data volume per train [MByte]
Vertex barrel 1	10	~ 5	0.025×0.025	89	2.1 / 2.8	13	9.5
Vertex barrel 2	10	~ 5	0.025×0.025	95	1.6 / 2.1	13	7.7
Vertex barrel 3	10	~ 5	0.025×0.025	126	0.62 / 0.74	13	3.9
Vertex barrel 4	10	~ 5	0.025×0.025	132	0.52 / 0.61	13	3.4
Vertex barrel 5	10	~ 5	0.025×0.025	166	0.24 / 0.31	13	2.1
Vertex barrel 6	10	~ 5	0.025×0.025	172	0.21 / 0.25	13	1.8
Vertex disc 1	10	~ 5	0.025×0.025	93	0.39 / 2.1	13	1.8
Vertex disc 2	10	~ 5	0.025×0.025	93	0.39 / 2.1	13	1.8
Vertex disc 3	10	~ 5	0.025×0.025	93	0.43 / 2.4	13	2.0
Vertex disc 4	10	~ 5	0.025×0.025	93	0.43 / 2.4	13	2.0
Vertex disc 5	10	~ 5	0.025×0.025	93	0.47 / 2.7	13	2.2
Vertex disc 6	10	~ 5	0.025×0.025	93	0.47 / 2.8	13	2.2
Inner tracker barrel 1	10	~ 5	0.03×0.3	88	0.28 / 0.36	21	1.5
Inner tracker barrel 2	10	~ 5	0.03×0.3	244	0.096 / 0.13	21	1.4
Inner tracker barrel 3	10	~ 5	0.03×0.3	580	0.040 / 0.051	21	1.5
Outer tracker barrel 1	10	~ 5	0.03×0.3	1589	0.014 / 0.018	21	1.5
Outer tracker barrel 2	10	~ 5	0.03×0.3	2258	0.0080 / 0.011	21	1.2
Outer tracker barrel 3	10	~ 5	0.03×0.3	2893	0.0054 / 0.0070	21	1.0

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Inner tracker disc 1	10	~ 5	0.025×0.025	2000	0.019 / 0.18	13	2.1
Inner tracker disc 2	10	~ 5	0.03×0.3	252	0.098 / 0.71	21	1.5
Inner tracker disc 3	10	~ 5	0.03×0.3	244	0.090 / 0.42	21	1.3
Inner tracker disc 4	10	~ 5	0.03×0.3	228	0.084 / 0.37	21	1.2
Inner tracker disc 5	10	~ 5	0.03×0.3	218	0.070 / 0.36	21	0.93
Inner tracker disc 6	10	~ 5	0.03×0.3	208	0.050 / 0.14	21	0.64
Inner tracker disc 7	10	~ 5	0.03×0.3	202	0.046 / 0.073	21	0.57
Outer tracker disc 1	10	~ 5	0.03×0.3	1546	0.0070 / 0.025	21	0.70
Outer tracker disc 2	10	~ 5	0.03×0.3	1546	0.0072 / 0.029	21	0.73
Outer tracker disc 3	10	~ 5	0.03×0.3	1546	0.0066 / 0.026	21	0.67
Outer tracker disc 4	10	~ 5	0.03×0.3	1546	0.0071 / 0.026	21	0.71
ECAL barrel	25	1	5×5	72	0.36 / 2.4	16 × 8	5.0
ECAL endcap	25	1	5×5	29	1.1 / 33	16 × 8	6.1
HCAL barrel	25	1	30×30	4.8	0.11 / 0.86	16 × 8	0.10
HCAL endcap	25	1	30×30	4.5	5.4 / 100	16 × 8	4.6
HCAL rings	25	1	30×30	0.4	0.010 / 1.4	16 × 8	0.00075
LumiCal	10	5	3.75×13–44	0.25	90 / 100	16 × 20	9.3
BeamCal	10	5	8×8	0.093	100	16 × 20	3.7

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CLICdet Data Rates

Attempt at Interpretation

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- Total data volume for 3 TeV conditions - background dominated: ~ 88 MB/ bunch train -> 4.4 GB/s
- Important data sources:
  - Vertex Barrel: 32%
  - Vertex Discs: 14%
  - Main Tracker Barrel (inner + outer): 9%
  - ECAL: 13% (Barrel:Endcap 45:55)
  - HCAL: 5% (Barrel:Endcap 2:98)
  - Forward Calorimeters: 15%

0.3 MB/bx

Instantaneous rate during train:

550 TB/s

Take-away message: Average rates no problem - just for reference:

A single CMS Serenity S1 board has 124 25 GBit/s links: 3.2 TBit/s -> 400 GB/s

Data stream at FCC-ee more uniform - no trains, bx rate 50 MHz rather than 2 GHz.

Main challenges from my perspective:

- Concentration: How to get the data out with low material and power budget
- Latency requirements, need for separate trigger paths?

The End

No Conclusions yet.