Challenges and R&D for DAQ in Particle Physics Experiment

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December 3, 2019

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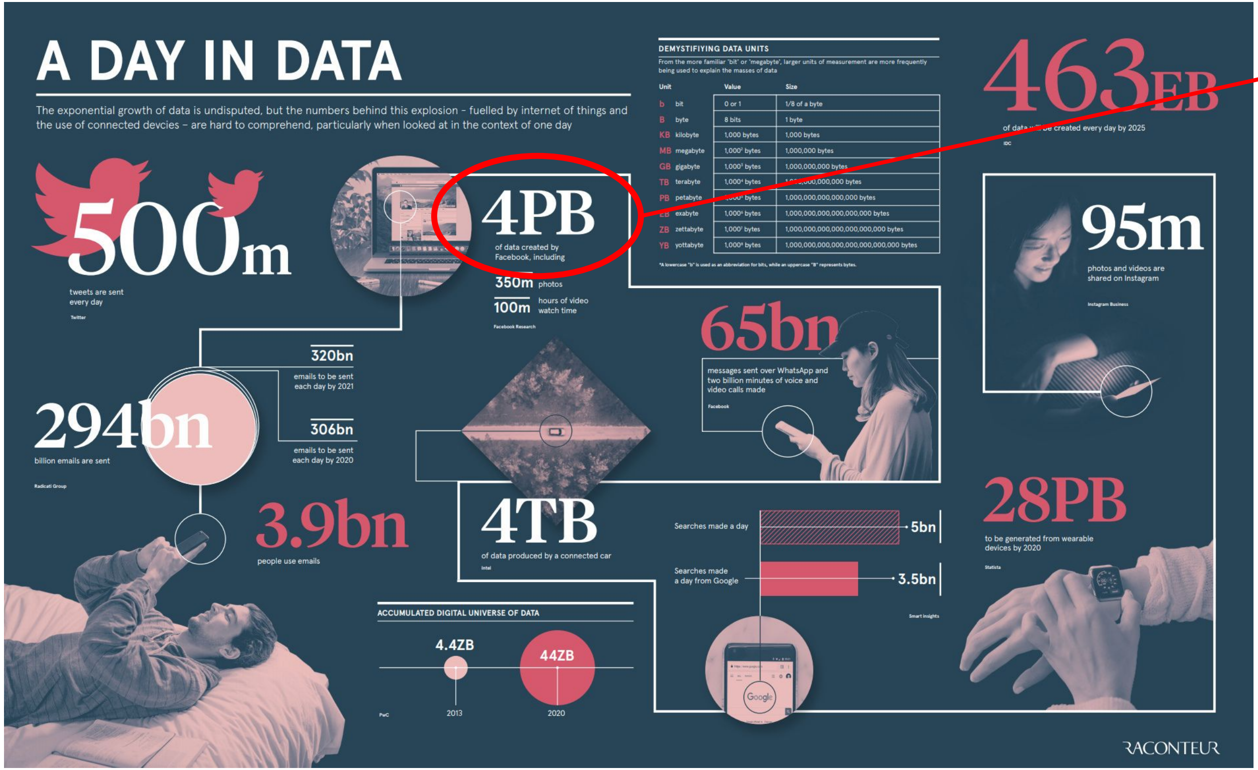
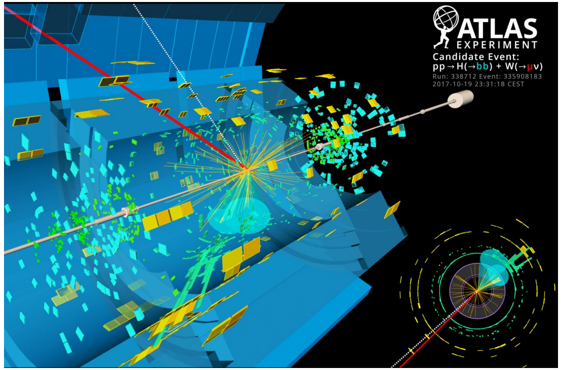
How Much Data is Generated?



4PB/day for Facebook

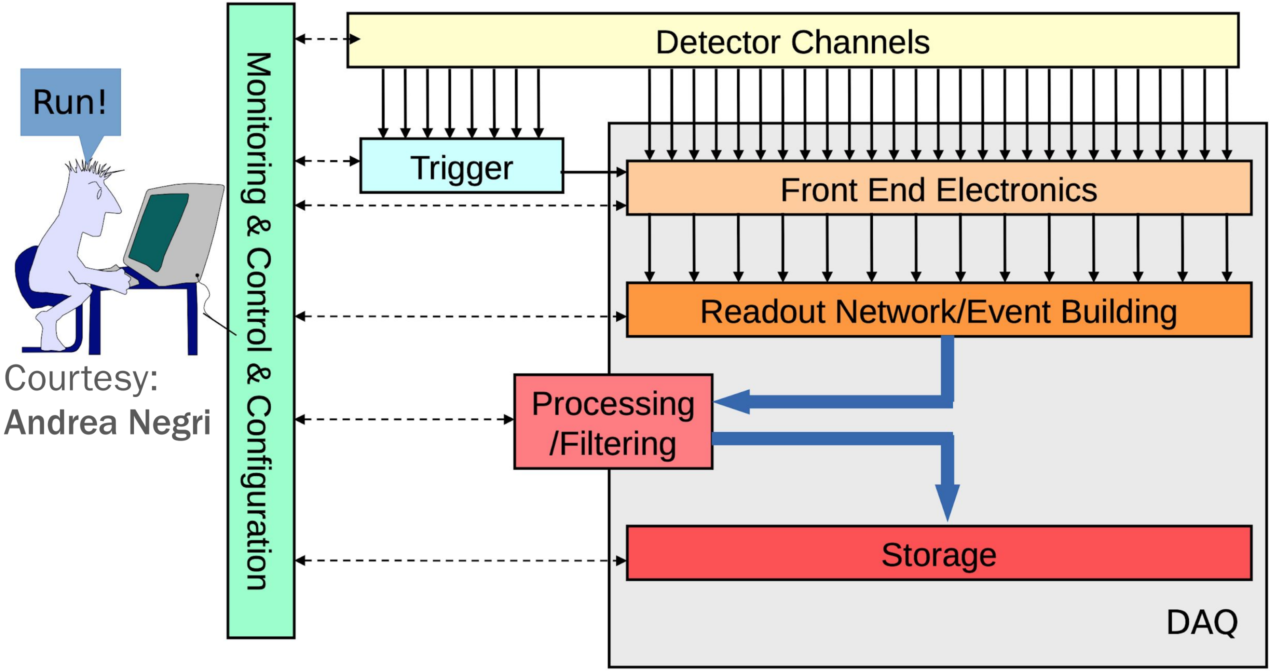


ATLAS raw data: *~1PB/s*
after zero-suppression:
~0.5Pb/s

FCC-hh: ~10Pb/s

Image: **Raconteur**

Typical Data Acquisition System



- Triggered readout
  - ATLAS
  - CMS
  - ALICE
- Streaming readout
  - LHCb (Run-3)
  - EIC (in R&D)
- Hybrid readout
  - sPHENIX
  - ProtoDUNE-SP
  - SBND
  - DUNE

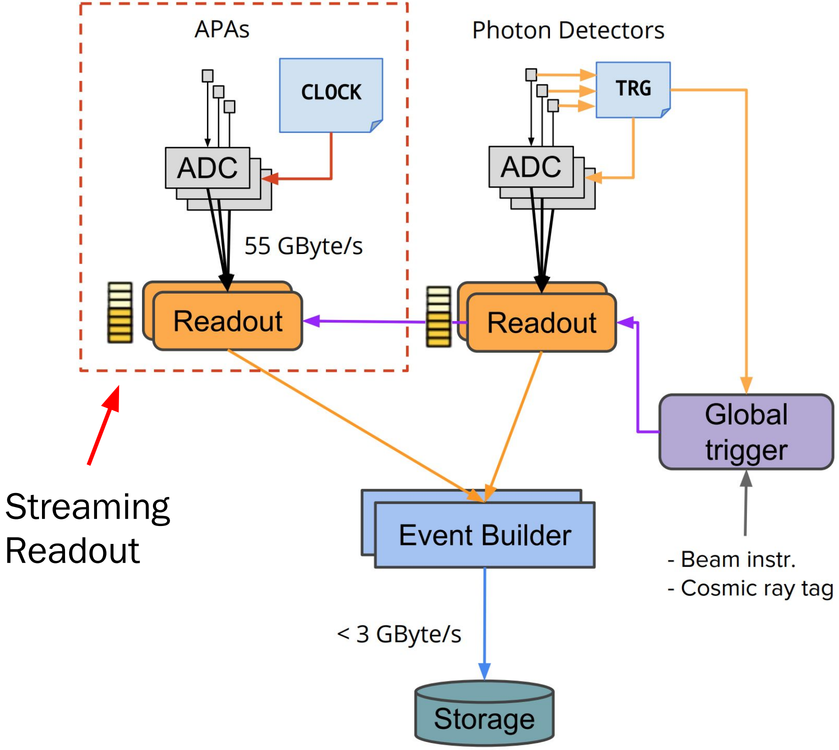
Intensity Frontier

Energy Frontier

R&D of **DAQ** system and **front-end readout electronics** is crucial

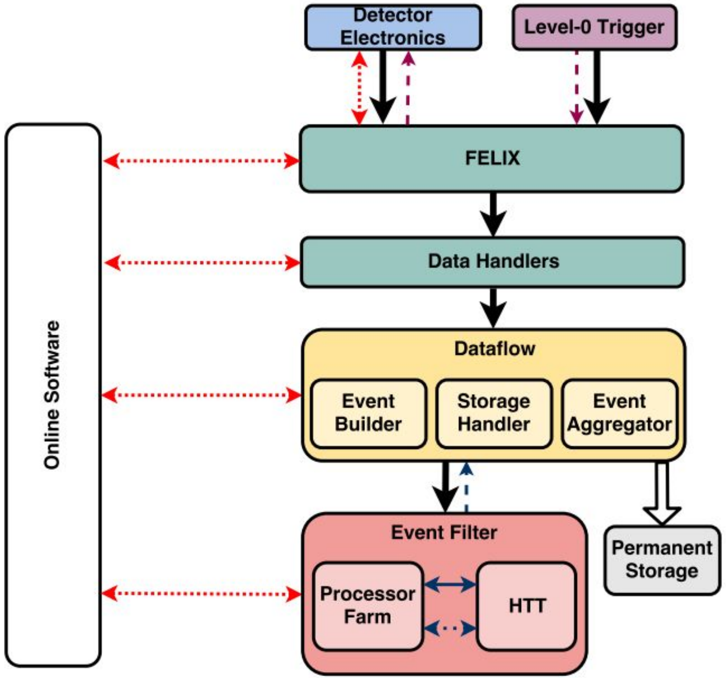
- **Energy frontier:** radiation environment, high counting rate
- **Intensity frontier:** cryogenic temperature, low noise

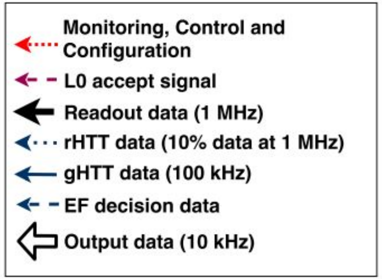
Example: ProtoDUNE-SP



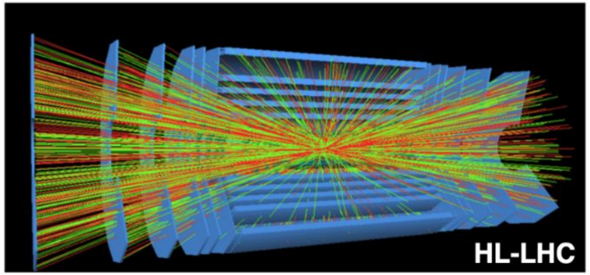
- Streaming readout for APAs
  - 2MHz sampling
  - **6** APAs
  - 15360 channels/APA
  - **~55GB/s**
- Local trigger (self triggering) for Photon detector
  - 150MHz sampling
  - 240 channels
- After global trigger: <20Gb/s
- For DUNE:
  - **150** APAs for one 10kTon module
  - ~1.5TB/s

Example: ATLAS in Run-4



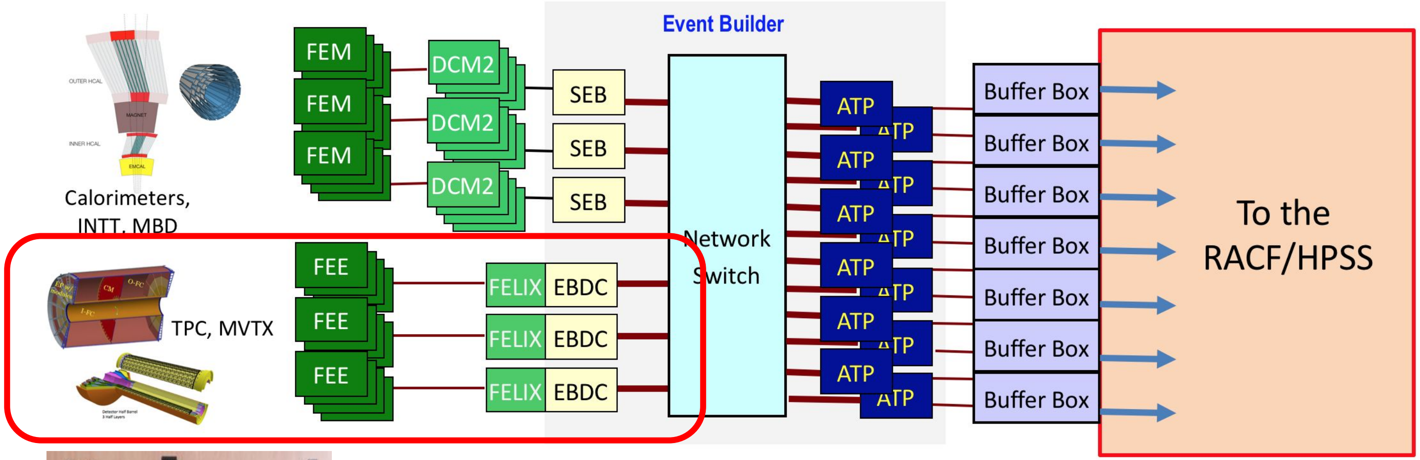


- Raw data from detector channels: ~Pb/s
- Billions of channels: 5,000,000,000 pixel channels
- FELIX for data readout after trigger
  - ~20,000 fiber optical links
  - ~**10 Gbps** radiational-hard links with front-end
  - ~**5.2 TB/s**



Pileup in 25ns: up to **200**

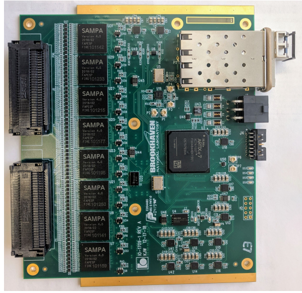
Example: sPHENIX



Hybrid with triggered calorimeters

https://indico.bnl.gov/event/6383/
Workshops for EIC streaming readout

MVTX RU, 200M ch ALPIDE



TPC FEE, 160k ch SAMPA

FELIX FLX-712, 48 links

R&D on Front-End Detector

Detector

Challenges:

- Radiation hard for energy frontier experiments
- Realize higher granularity with different solutions: nobel liquid; silicon; scintillator/crystal; gaseous
- Better amplitude/energy and timing resolution
- Low power and low noise electronics in Cryogenic environment

Examples:

- Pixelated Anode with charge readout
- PCB based APA (Anode Plane Assembly)
- Pixelated silicon detector (HGTD based on LGAD) in the end-cap for ATLAS, to provide timing information (~30ps) for pile-up contamination reduction.

Data handling in front-end electronics

Reduce the transmitted data (position, amplitude, timing) volumn:

- Self-triggering
- Data compression
- On-detector intelligence

Data transmission

Challenges:

- High bandwidth, radiation hard, limited space and power constraints

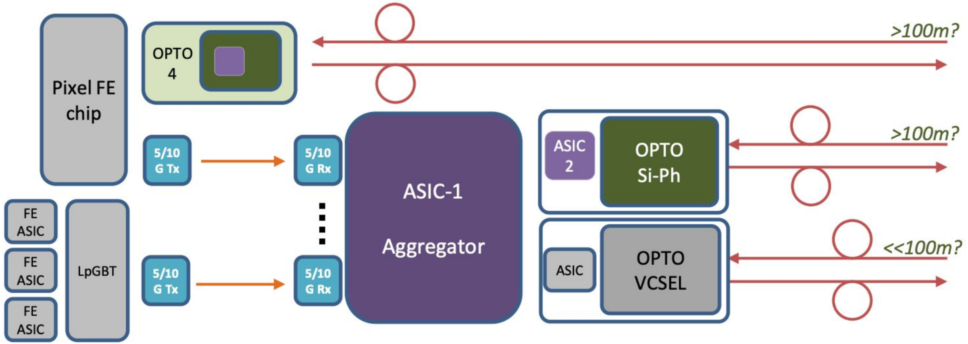
Transmission via optical fiber:

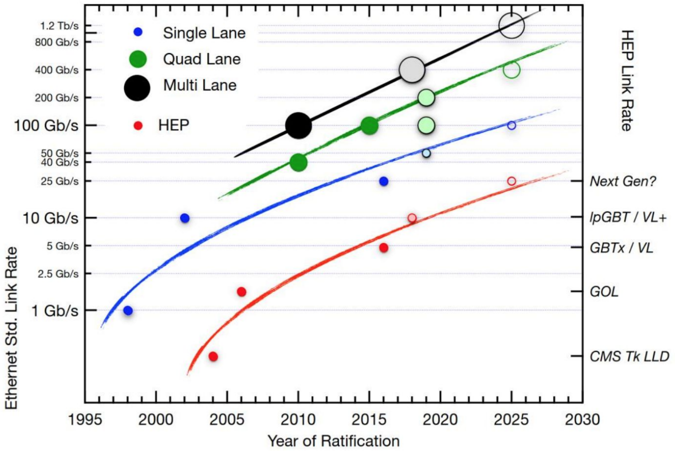
- Towards 28G/56G

Wireless transmission:

- R&D by groups like WADAPT for tracking detector: 60G band and 240G band are demonstrated.

High Speed Links Development @ CERN





Activity	Task	Description
ASICs	ASIC-1	Very high data rate aggregator/transmitter
	ASIC-2	Optoelectronics drivers
	ASIC-3	Low-mass electrical cable transmission (active cable)
FPGA	FPGA-1	FPGA-based system testing and emulation
OPTO	OPTO-1 & 2	Silicon Photonics System & Chip Design
		Silicon Photonics Radiation Hardness
	OPTO-3	Next-generation VCSEL-based optical link
	OPTO-4	Silicon Photonics packaging

"Down scaled" Activity

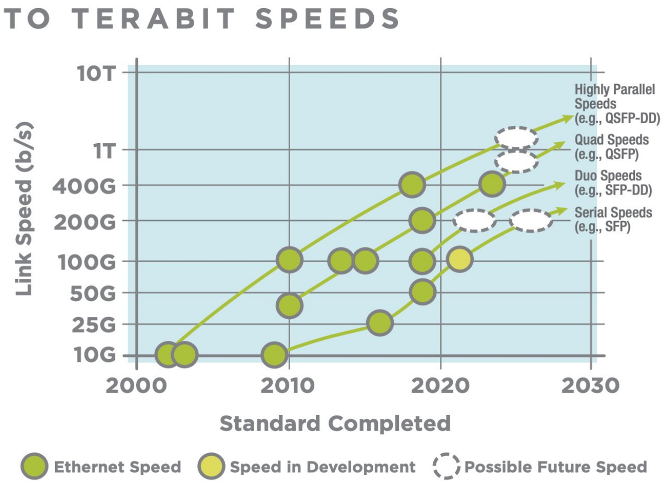
"Dropped" Activities

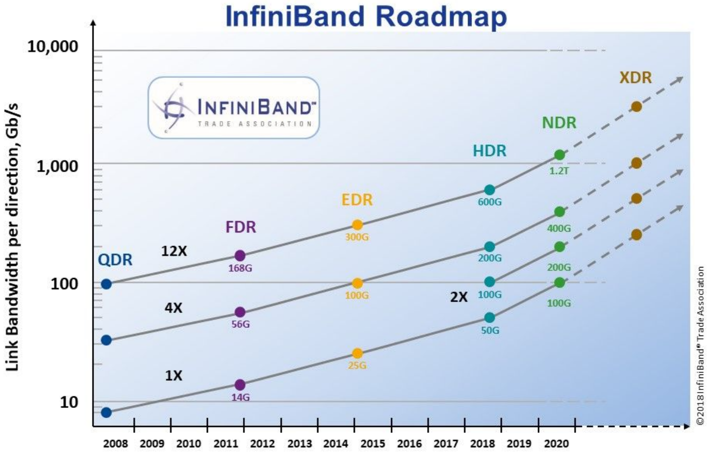
Sources from **CERN EP Department**

- 28 Gbps NRZ / 56 Gbps PAM4 Transmitter
- **Radiation:**
  - LHC: up to 100 Mrad (10^{14} 1MeV n_{eq}/cm^2)
  - HL-LHC: up to 1 Grad (10^{16} 1MeV n_{eq}/cm^2)

Trends of COTS Solutions for Back-End

- Higher bandwidth
  - Xilinx: 112Gb/s PAM4 serdes will be supported by Versal devices; Intel has also demonstrated 112Gb/s PAM-4 Transceiver I/O
  - 200G/400G will be available for single lane with coherent optical transmission
  - Terabit Ethernet: 800 Gbit/s and 1.6 Tbit/s may become IEEE standard in 2025
  - PCIe Gen 6 with PAM4: 128GB/s per 16 lanes (specification to land in 2021); Extended PCIe like CCIX >200GB/s is possible.



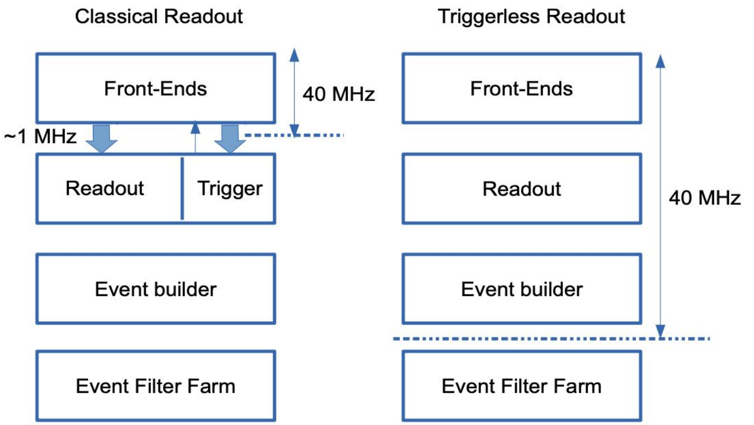


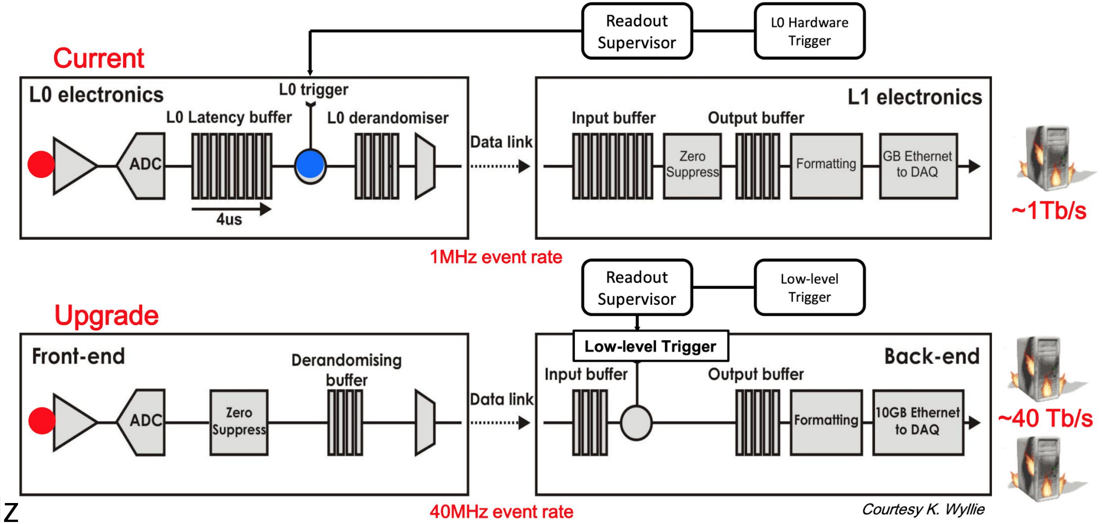
Summary

- The R&D for future detector will improve spatial granularity, energy and timing resolution. This will remarkably increase the raw data volume to be handled.
- Fast development of industry solutions provide inputs for R&D of the DAQ system.
- R&D of the DAQ system should be integrated with Front-End readout electronics, to meet the overall bandwidth requirement, power and space limit.
- For experiments with huge data like ATLAS, FCC-hh (~10PB/s, needs millions of links), to make the streaming readout (triggerless) be possible, R&D should also be carried out in the detector side.
    - *Wireless transmission*
    - *Radiation hard high-speed serializer and optoelectronics*
    - *Data compression*
    - *On-detector intelligence*
    - *Self-triggering*

Backup

Example: LHCb for Run-3





Triggerless readout, which can read out 40 MHz

- ~15000 optical links
- ~ 500 readout boards
- ~24 links in average on each board
- ~100 kbytes per event
- ~4 TB/s aggregate bandwidth

Data is compressed (zero-suppression) *in front-end ASIC (reduce # of 4.8 Gb/s links to about 1/6)*

Intent-Based Network Functions

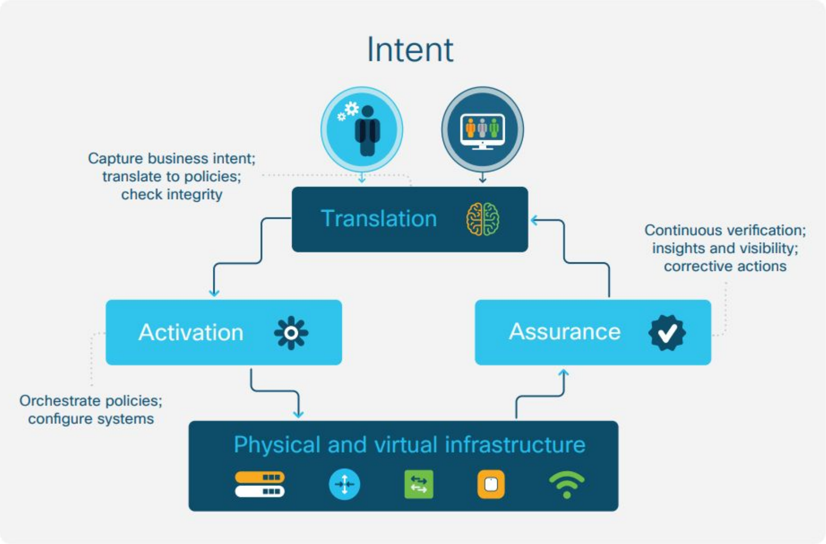


Image: **Cisco**

Intent-Based Network: use AI (Artificial Intelligence), ML (Machine Learning), MR (Machine Reasoning) to automate administrative tasks across a network.

Translation: enables network operators to express intent in a declarative and flexible manner, expressing what the expected networking behavior is that will best support the business objectives, rather than how the network elements should be configured to achieve that outcome.

Activation: installs these interpreted policies from captured intent into the physical and virtual network infrastructure using network-wide automation.

Assurance: maintains a continuous validation-and-verification loop, to continuously check that the expressed intent is honored by the network at any point in time.