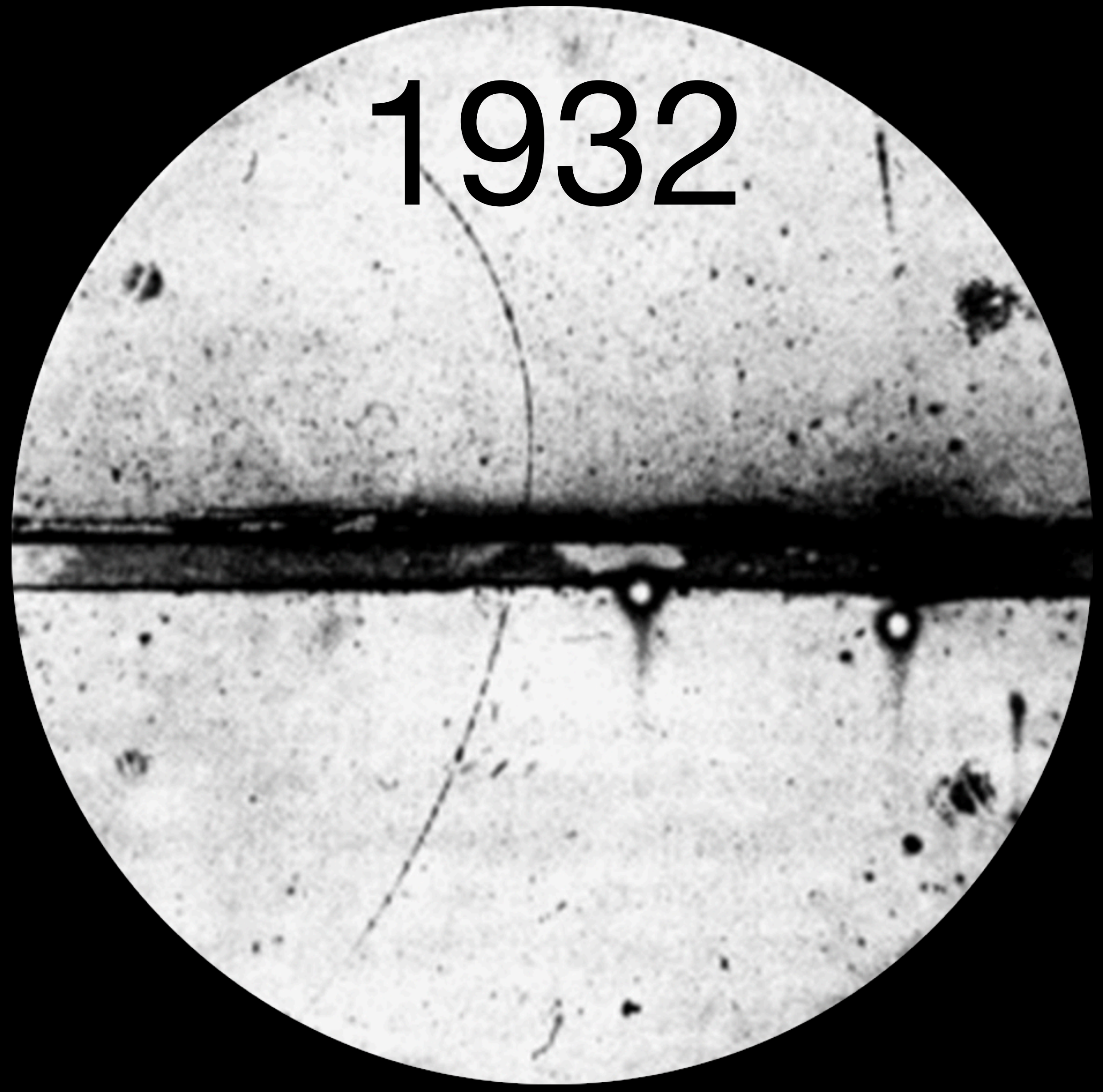
PHYS 7363 - Experimental Particle Detection and Detectors I



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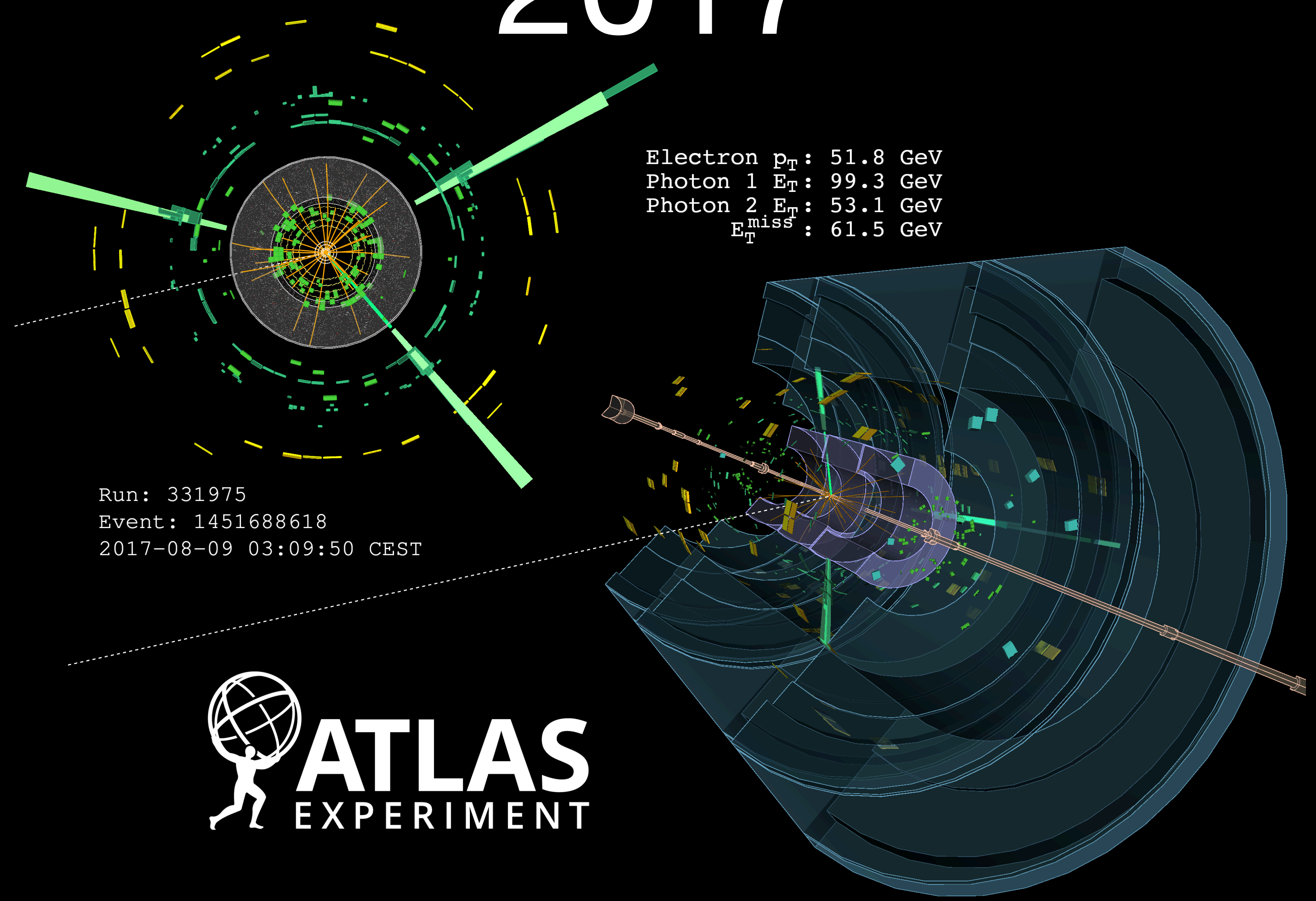


Particle detectors are the workhorses of experimental physics. In this course, we'll dive deep into their physics, exploring the incredible evolution of our experimental techniques over the past nine decades. You'll gain a solid understanding of *particle detection* and *identification*, examine the intricate designs of modern detectors, and learn how machine learning is being harnessed to push the boundaries of detector design. If you're intrigued by how we “see” subatomic particles, this course is for you!

Detect Identify Measure

To discuss prerequisites (and any questions on the content of the course), please contact me: saptaparnab@smu.edu

Schedule

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
October	6 ✅ 1.5 hours	7	8 ✅ 1.5 hours	9	10	11	12
	13 ✅ 1.5 hours	14	15 ✅ 1.5 hours	16	17 ✅	18	19
	20	21	22	23 ✅ 1.5 hours	24 ✅ 1.5 hours	25	26
	27: Midterm	28	29 ✅ 1.5 hours	30	31 ✅ 1.5 hours	1	2
November	3 ✅ 1.5 hours	4	5 ✅ 1.5 hours	6	7 ✅ 1.5 hours	8	9
	10 ✅ 1.5 hours	11	12 ✅ 1.5 hours	13	14 ✅ 1.5 hours	15	16
	17 ✅ 1.5 hours	18	19 ✅ 1.5 hours	20	21 ✅ 1.5 hours	22	23
	24	25	26	27	28	29	30
December	1	2	3	4	5	6	7
	8	9	10	11	12	13	14

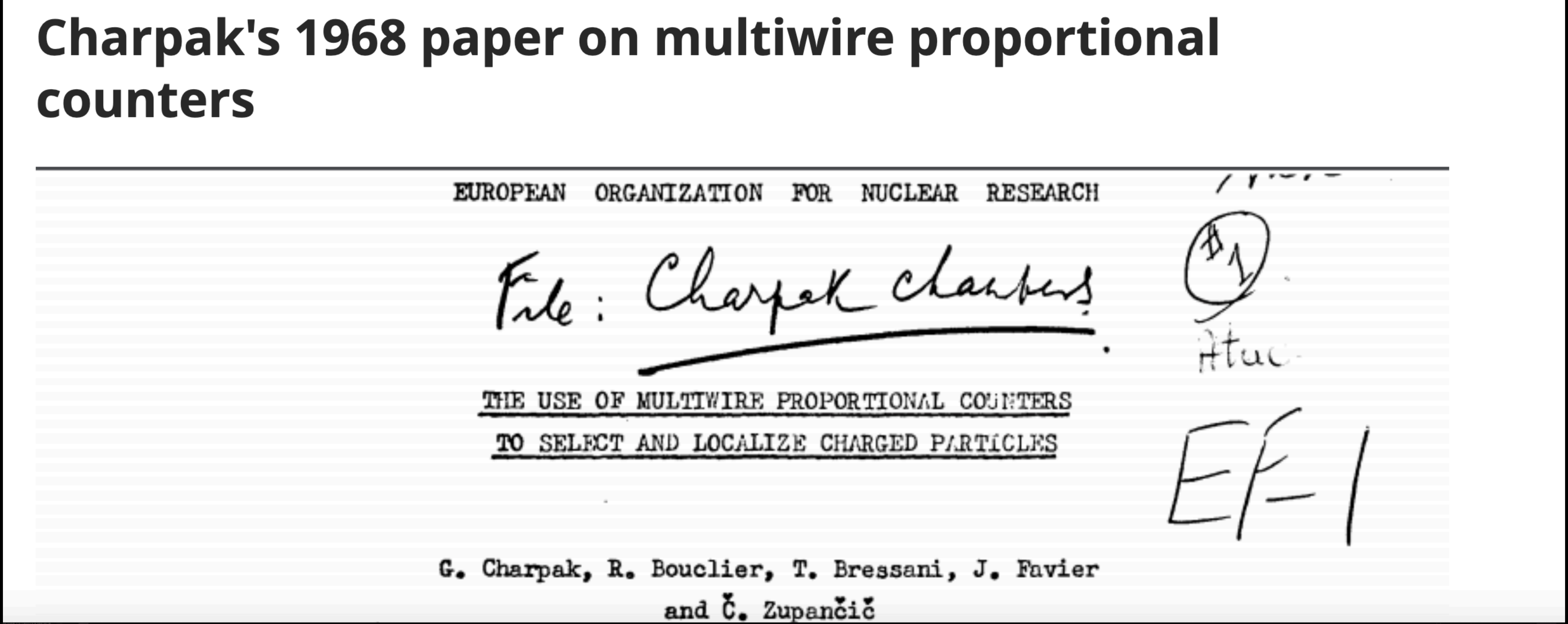
Choice of gaseous medium

- Main criteria dictated by:
  - high ionization density
  - little charge loss
  - low voltage at the required amplification
  - stable operation, safety against spark discharge
  - proportionality between ionization and output signal
  - low diffusion (in particular for detectors with position resolution)
  - suitable drift velocity (again for detectors with position resolution)
  - rate tolerance and low or minor dead time (low space charge accumulation)
  - radiation resistance
  - safety: nonflammable, non-toxic, environmentally acceptable
  - costs

Multi-wire proportional chambers

- A multiwire proportional chamber (MWPC) functions like proportional counter with tubes that are arranged in a plane side by side
- Such an arrangement provides spatial resolution perpendicular to the wires for particles passing the wire plane
- With several MWPC planes stacked behind each other the trajectories of charged particles can be electronically registered (in contrast, for example, to bubble chambers which are read out photographically)
- The MWPC was developed by George Charpak at CERN in the late 1960s
- This detector type and variants of it, like the drift chamber, have been crucial for progress in particle physics
- George Charpak received the Nobel Prize in 1992 ‘for his invention and development of particle detectors, in particular the multiwire proportional chamber’

Multi-wire proportional chambers



Charpak's 1968 paper on multiwire proportional counters

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

File : Charpak chambers

#1

Atuc

EF-1

THE USE OF MULTIWIRE PROPORTIONAL COUNTERS

TO SELECT AND LOCALIZE CHARGED PARTICLES

G. Charpak, R. Bouclier, T. Bressani, J. Favier
and Č. Zupančič

https://home.cern/resources/publication/accelerators/charpaks-1968-paper-multiwire-proportional-counters

Multi-wire proportional chambers

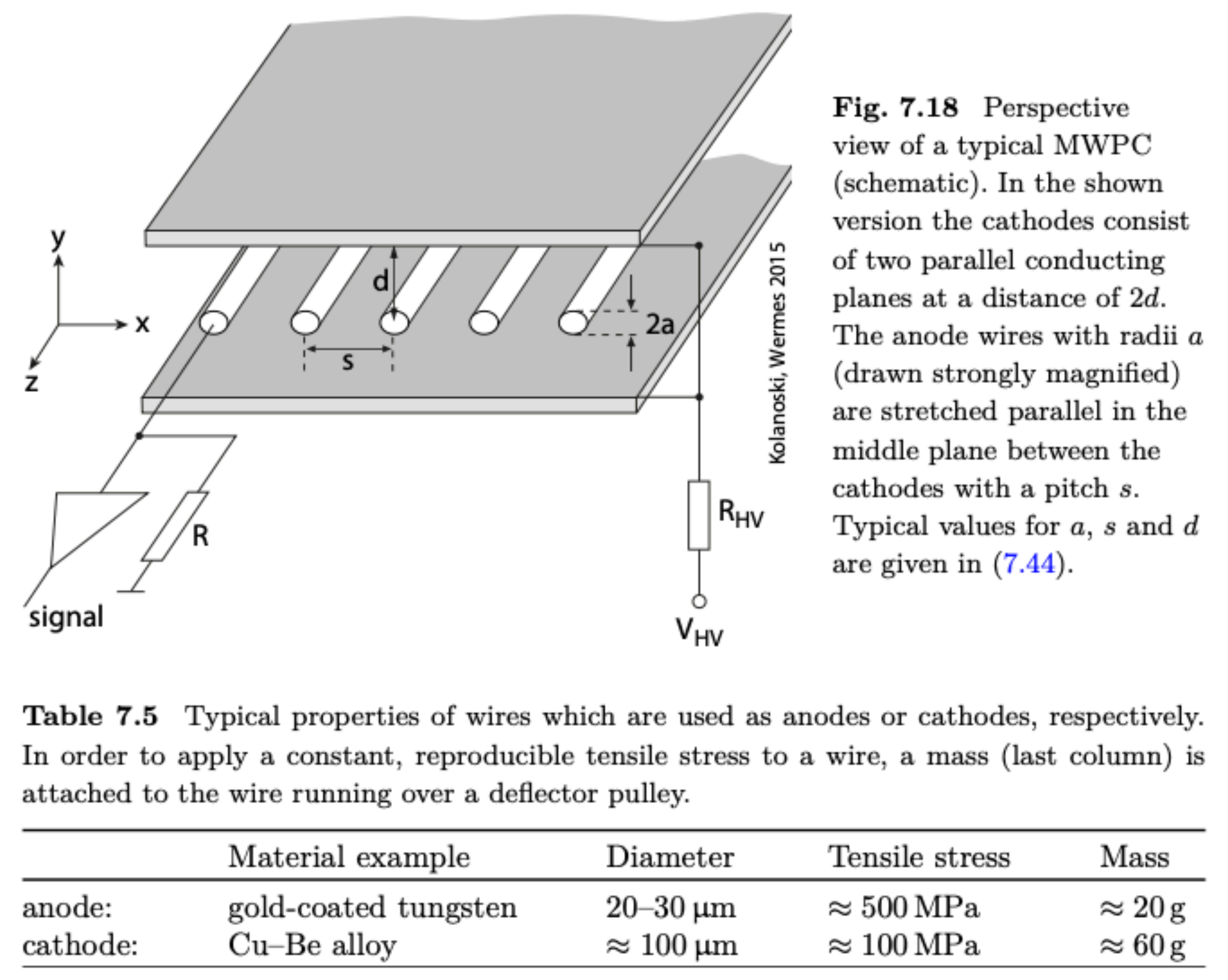


Fig. 7.18 Perspective view of a typical MWPC (schematic). In the shown version the cathodes consist of two parallel conducting planes at a distance of $2d$. The anode wires with radii a (drawn strongly magnified) are stretched parallel in the middle plane between the cathodes with a pitch s. Typical values for a, s and d are given in (7.44).

Table 7.5 Typical properties of wires which are used as anodes or cathodes, respectively. In order to apply a constant, reproducible tensile stress to a wire, a mass (last column) is attached to the wire running over a deflector pulley.

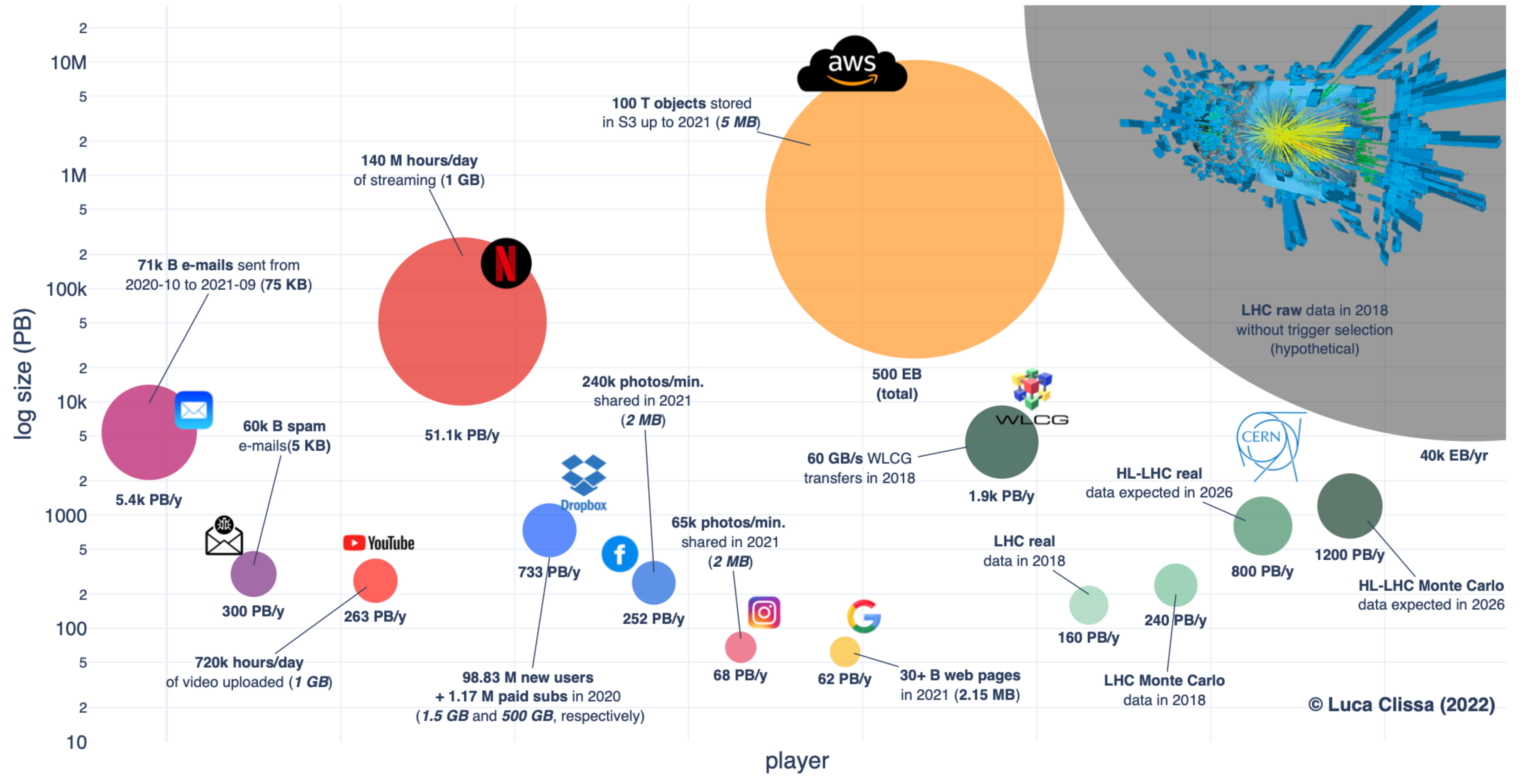
	Material example	Diameter	Tensile stress	Mass
anode:	gold-coated tungsten	20–30 µm	≈ 500 MPa	≈ 20 g
cathode:	Cu–Be alloy	≈ 100 µm	≈ 100 MPa	≈ 60 g

Literature survey

- Do some literature survey and identify current or older particle physics experiments that used gas filled detectors in prominent ways

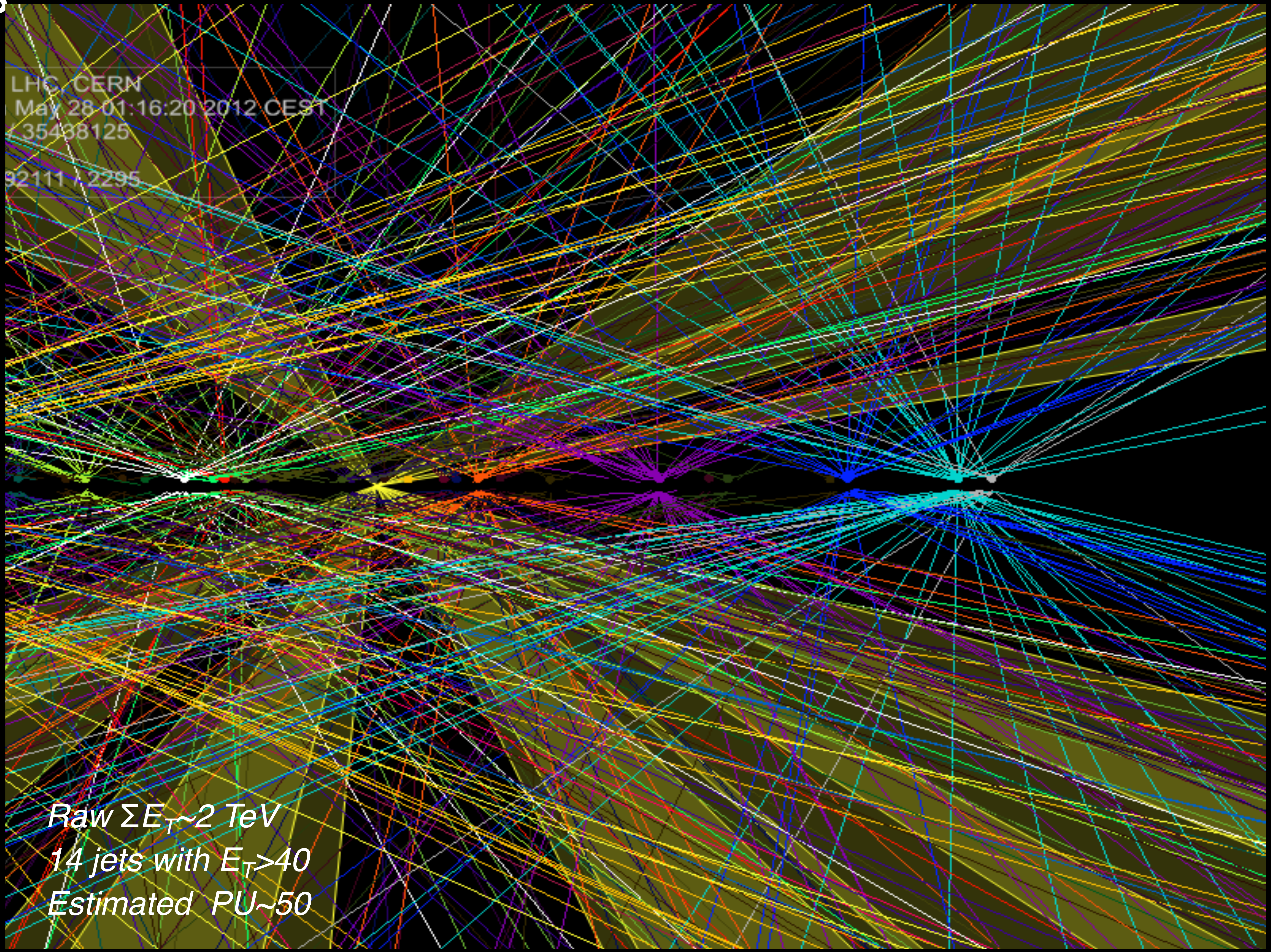
Trigger and readout

Data Collection



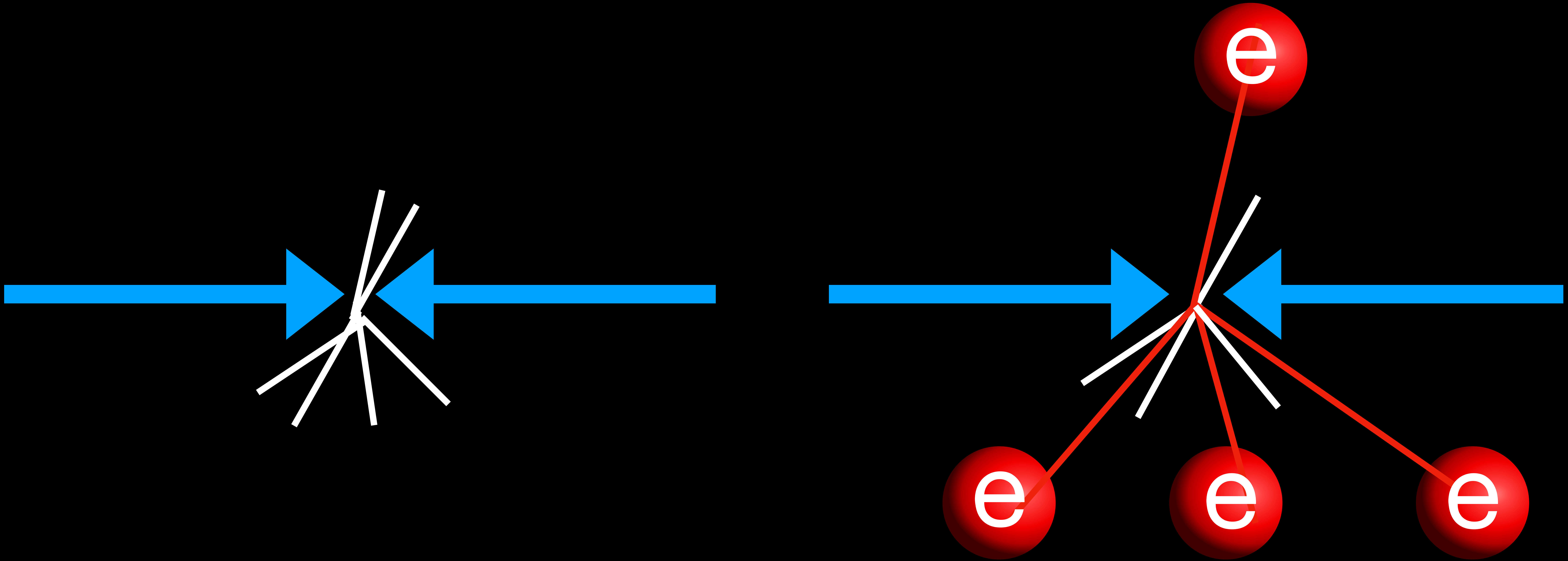
Triggering on events

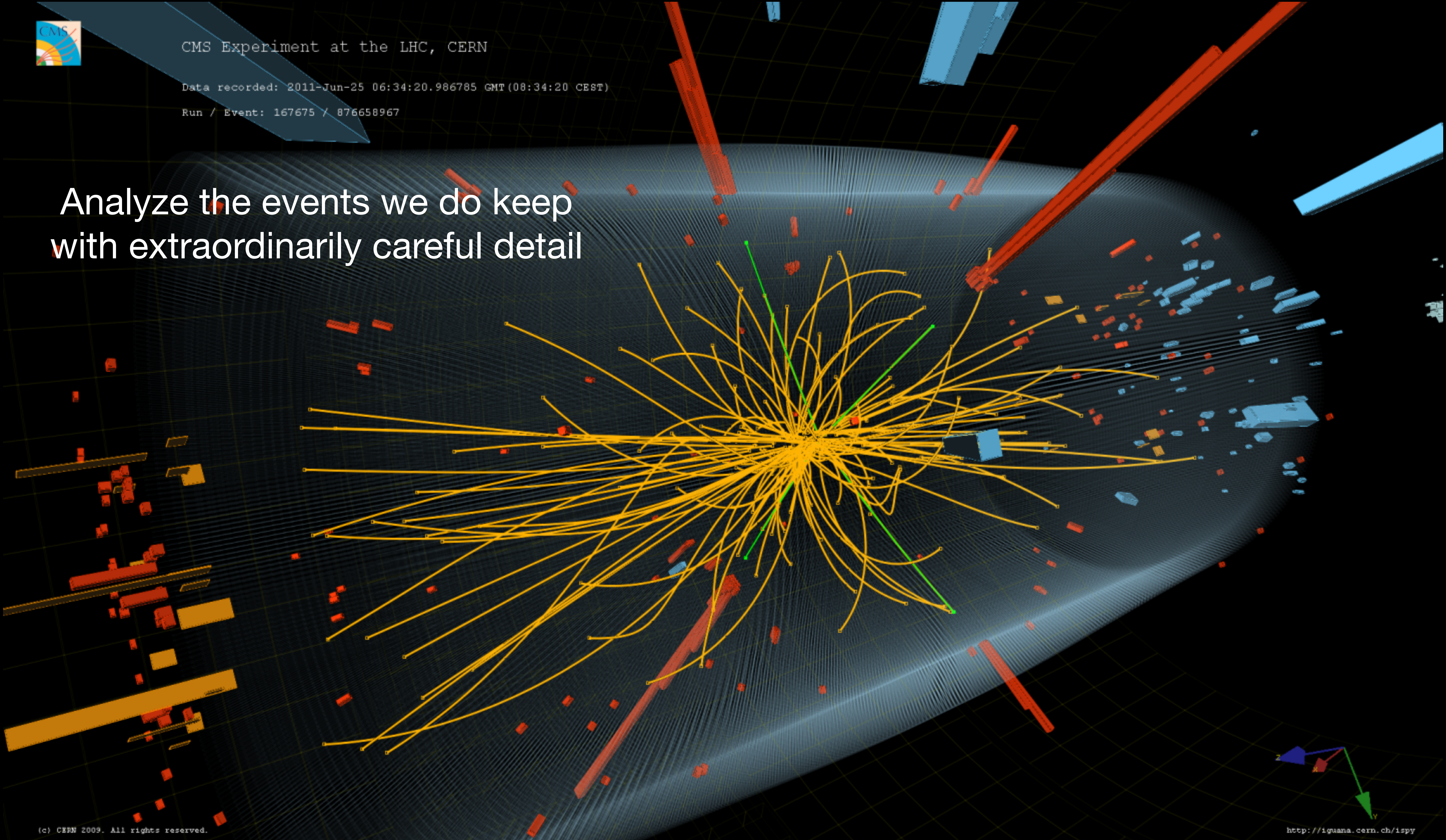
- The bunch structure of the LHC → groups of protons colliding 40 million times per second
- Only 25 nanoseconds (25 billionths of a second) before the next lot arrive → new waves of particles are being generated before those from the last bunch left the detector
- CMS records and analyses several petabytes of data → same amount of information as in 10,000 Encyclopaedia Britannica *every second*



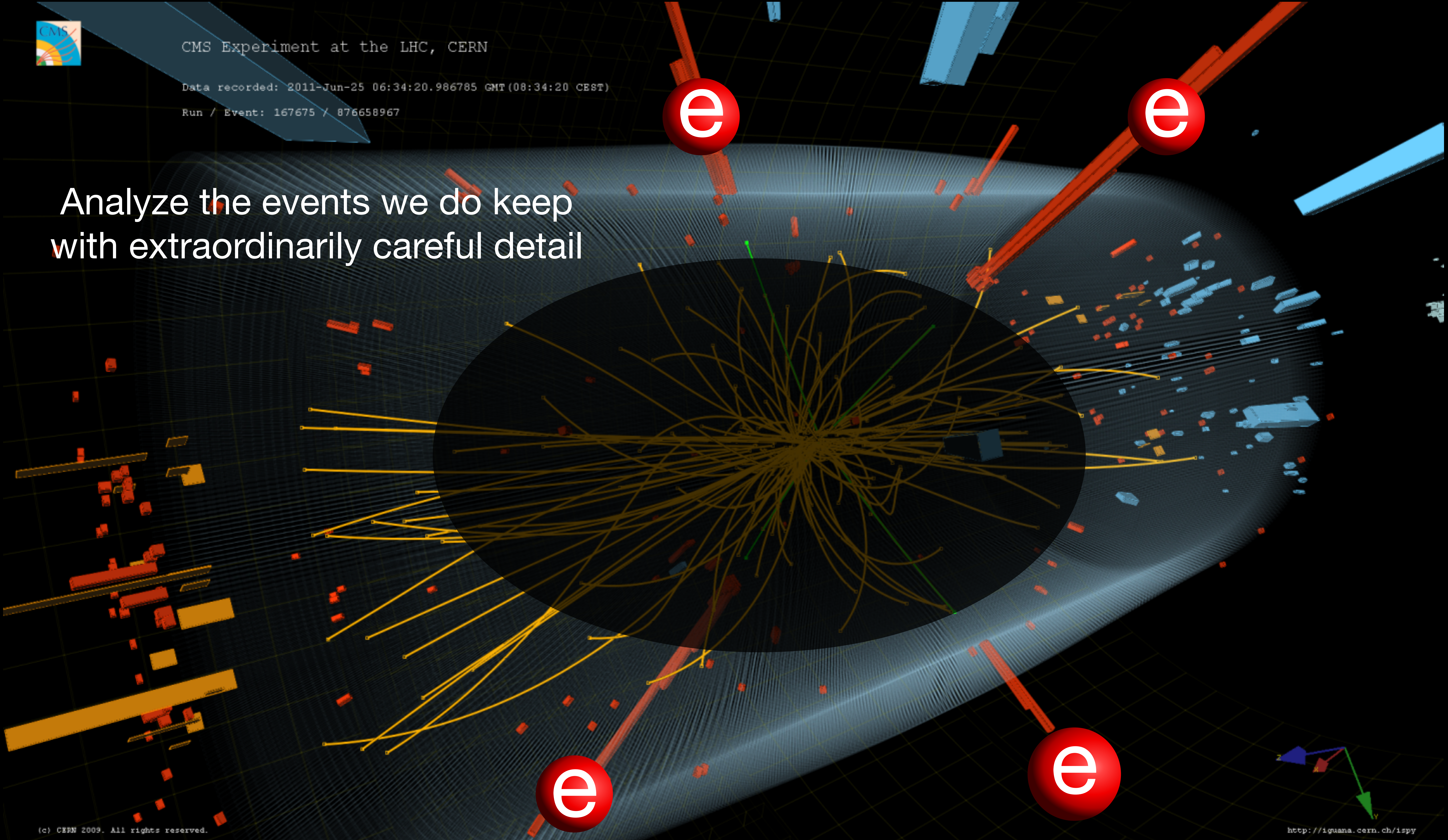
Triggering on events

- The CMS detector has 80 million electronics channels each acquiring information of the collision → 30 million ‘photos’ per second
- Perform quick analysis → throw away most of the 99.997% of the data

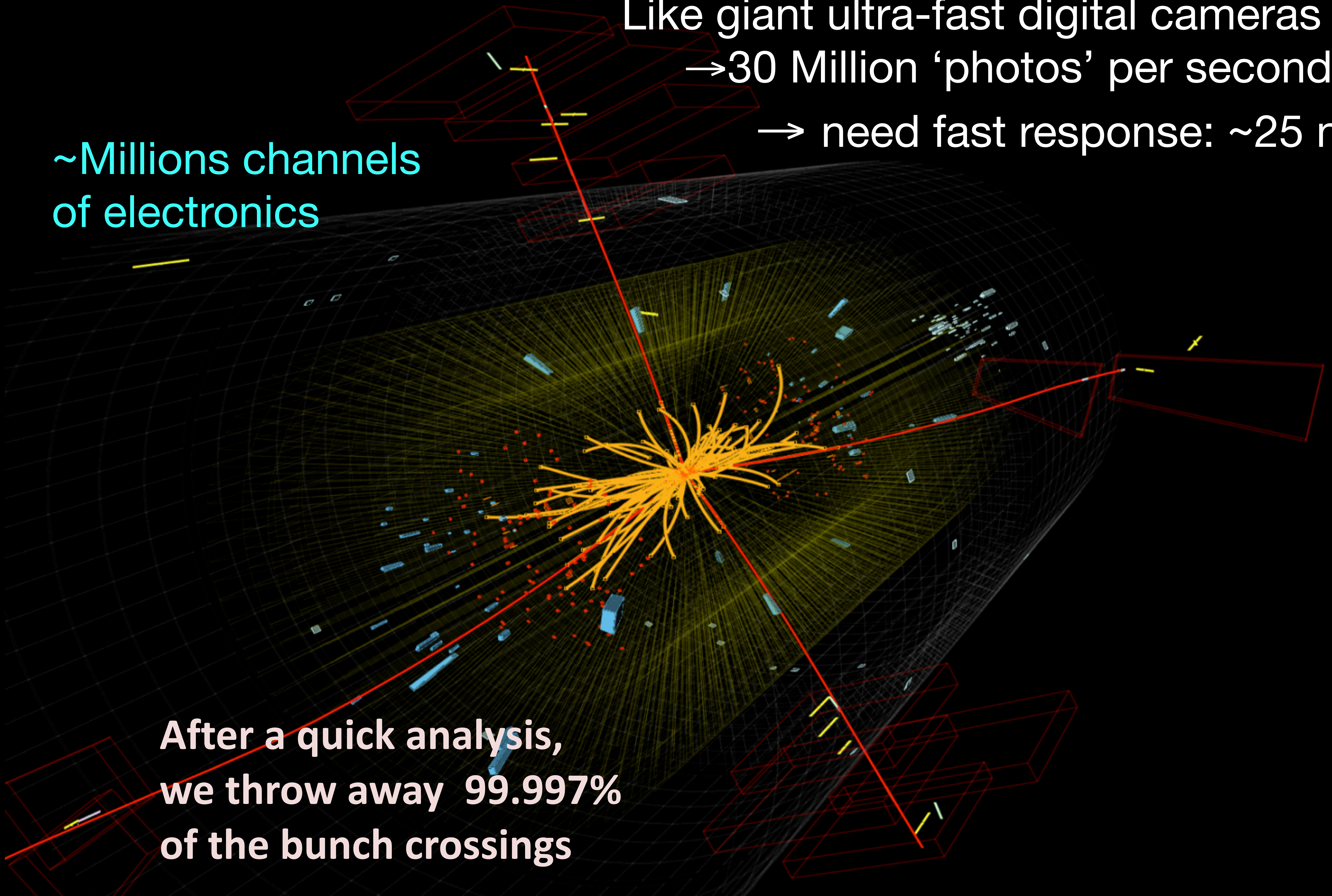




Analyze the events we do keep with extraordinarily careful detail



Analyze the events we do keep
with extraordinarily careful detail



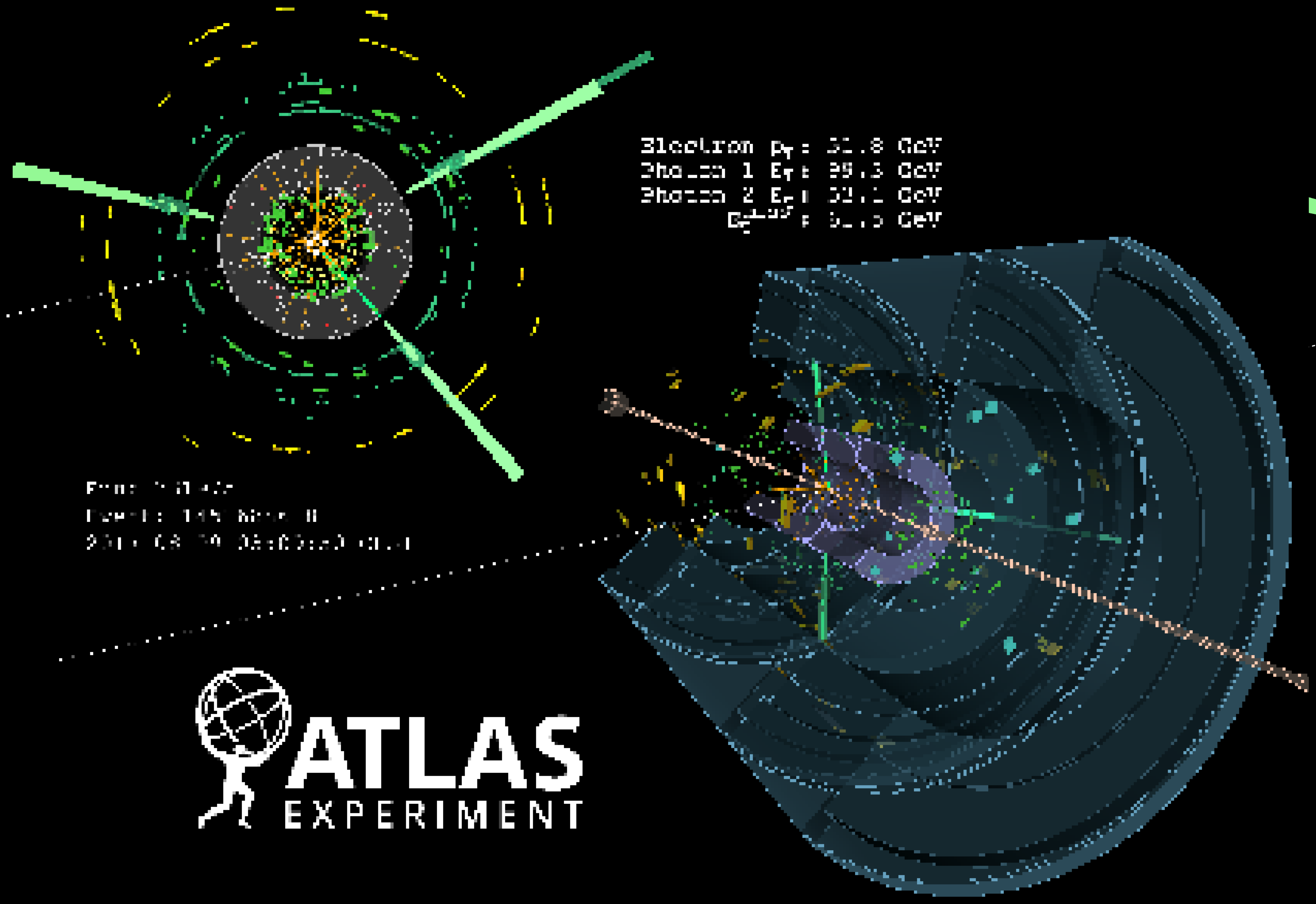
Like giant ultra-fast digital cameras
→30 Million ‘photos’ per second

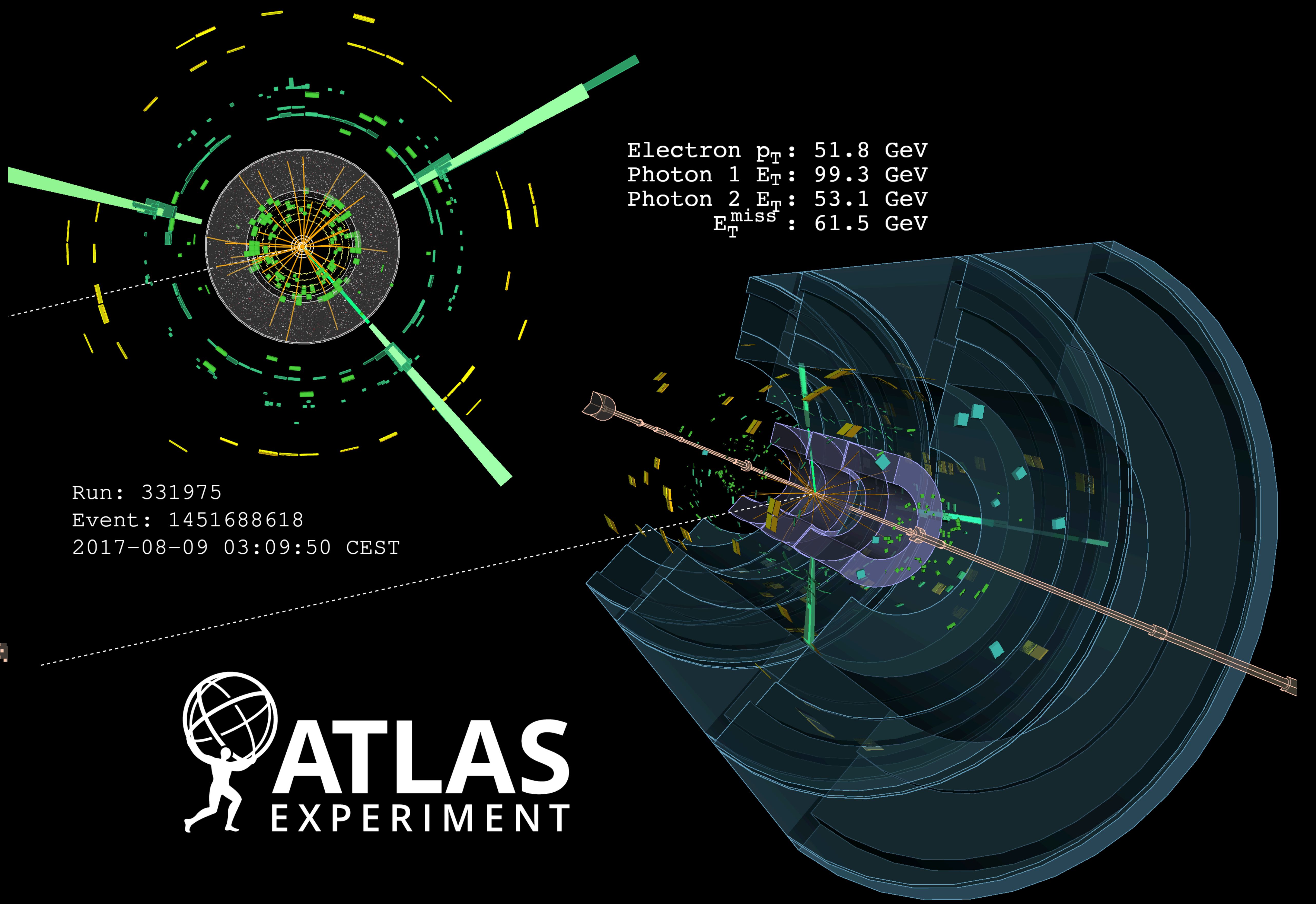
→ need fast response: ~25 ns

~Millions channels
of electronics

After a quick analysis,
we throw away 99.997%
of the bunch crossings

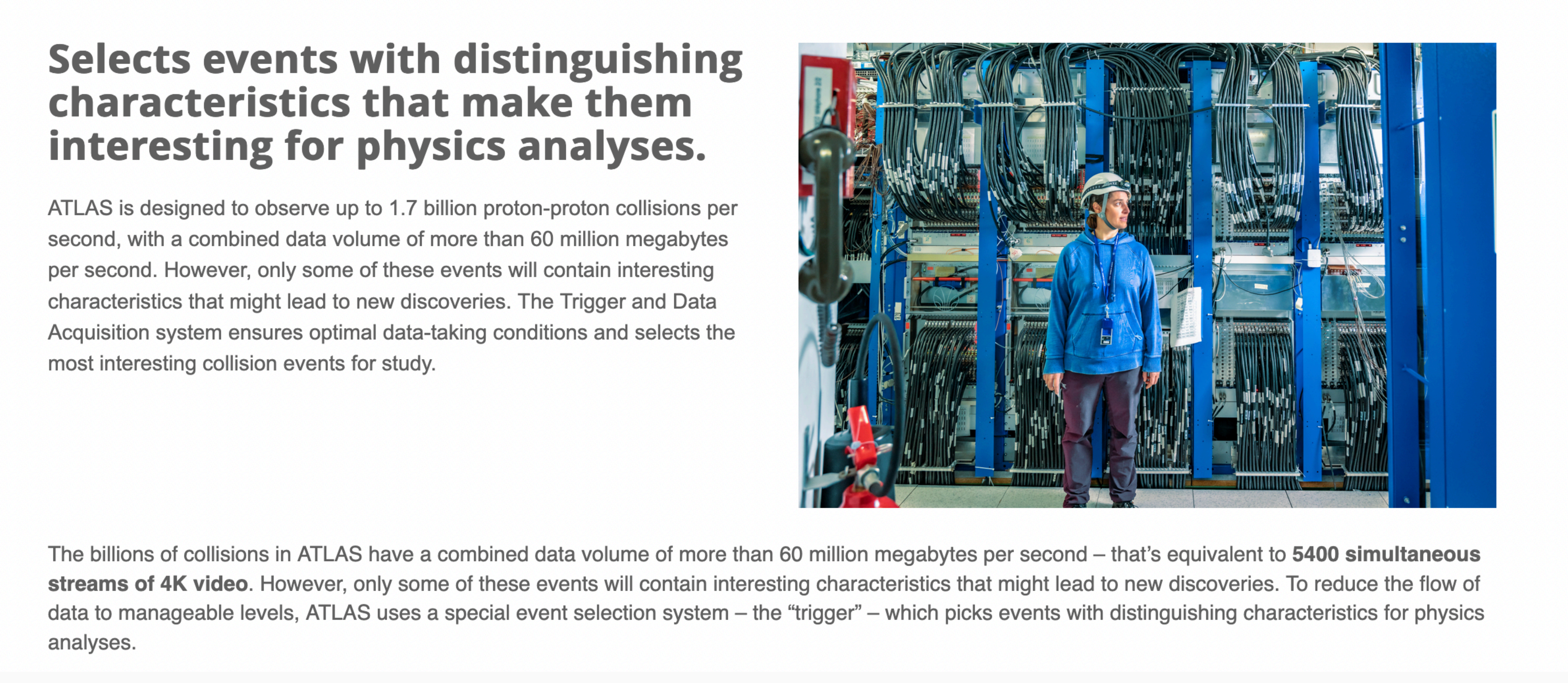
Trigger recapitulation





https://home.cern/science/computing/storage

Triggering on events in ATLAS

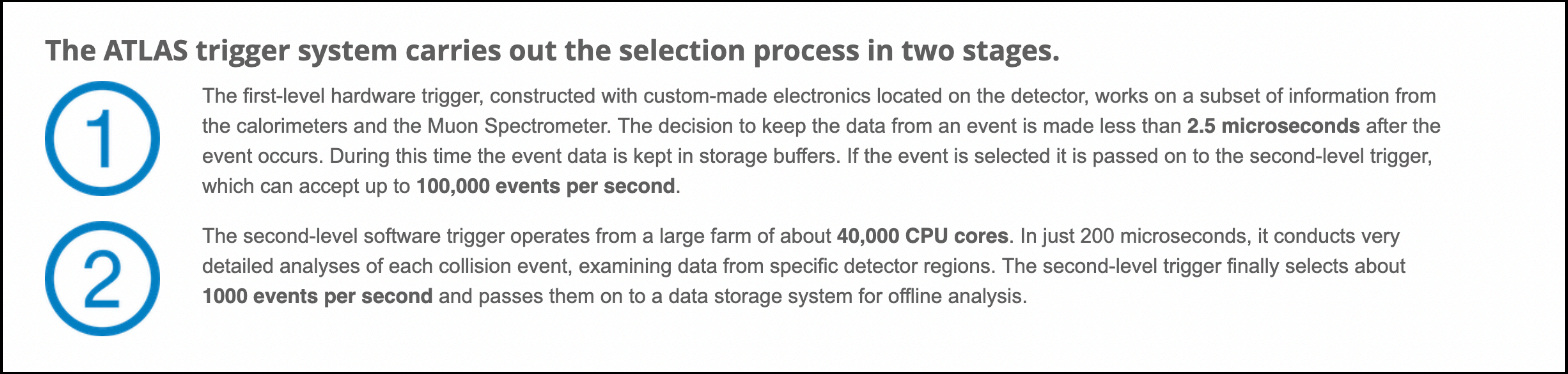


Selects events with distinguishing characteristics that make them interesting for physics analyses.

ATLAS is designed to observe up to 1.7 billion proton-proton collisions per second, with a combined data volume of more than 60 million megabytes per second. However, only some of these events will contain interesting characteristics that might lead to new discoveries. The Trigger and Data Acquisition system ensures optimal data-taking conditions and selects the most interesting collision events for study.

The billions of collisions in ATLAS have a combined data volume of more than 60 million megabytes per second – that's equivalent to **5400 simultaneous streams of 4K video**. However, only some of these events will contain interesting characteristics that might lead to new discoveries. To reduce the flow of data to manageable levels, ATLAS uses a special event selection system – the "trigger" – which picks events with distinguishing characteristics for physics analyses.

Triggering on events in ATLAS

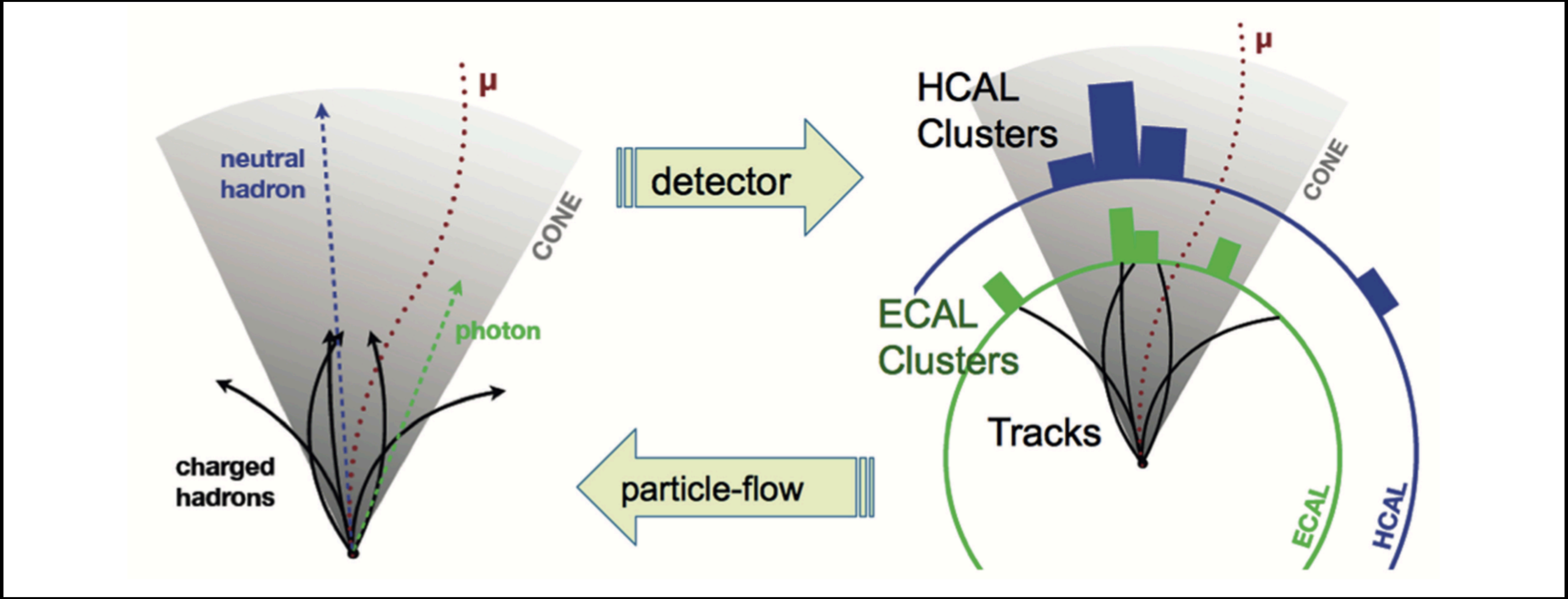


The ATLAS trigger system carries out the selection process in two stages.

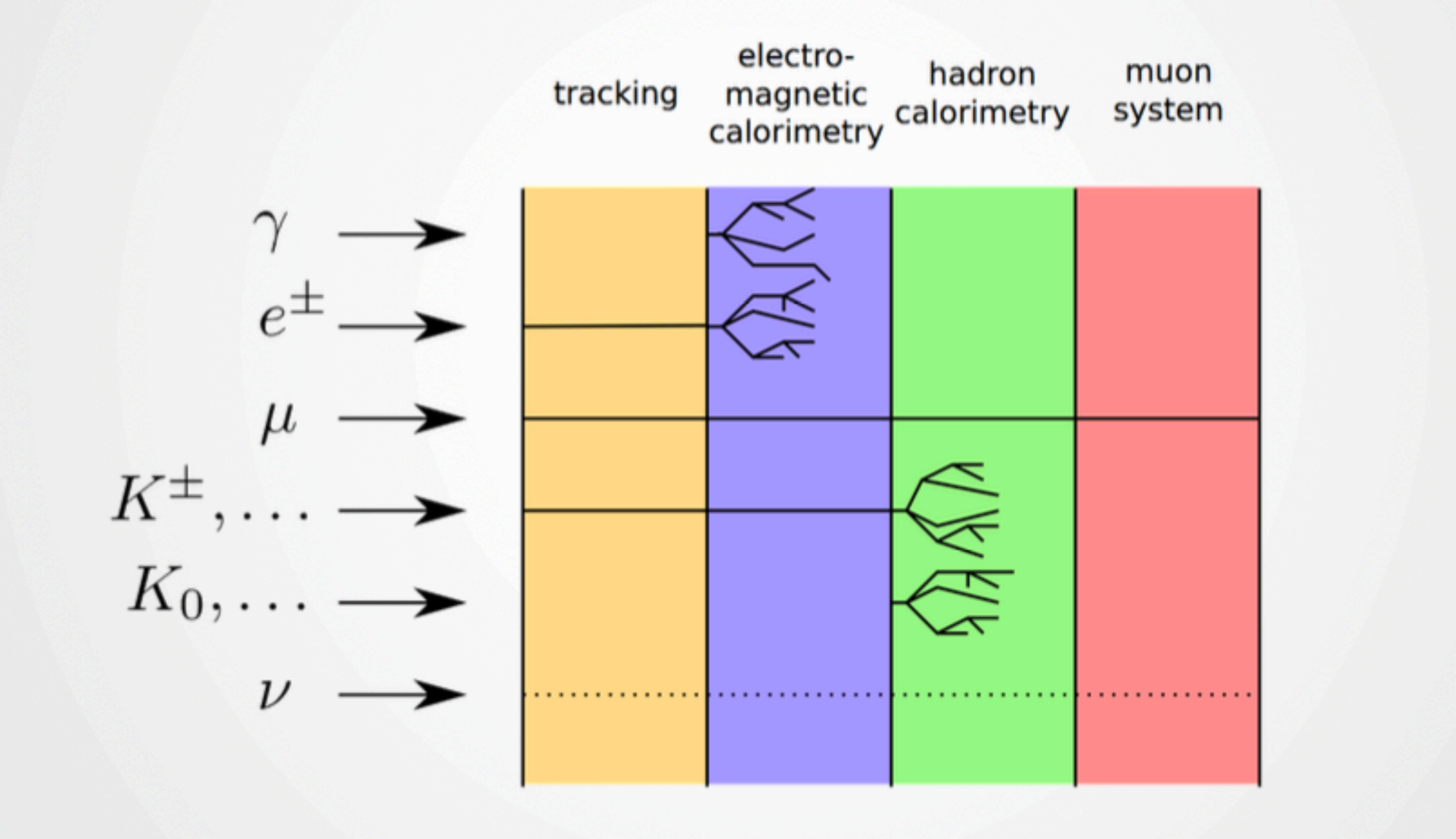
① The first-level hardware trigger, constructed with custom-made electronics located on the detector, works on a subset of information from the calorimeters and the Muon Spectrometer. The decision to keep the data from an event is made less than **2.5 microseconds** after the event occurs. During this time the event data is kept in storage buffers. If the event is selected it is passed on to the second-level trigger, which can accept up to **100,000 events per second**.

② The second-level software trigger operates from a large farm of about **40,000 CPU cores**. In just 200 microseconds, it conducts very detailed analyses of each collision event, examining data from specific detector regions. The second-level trigger finally selects about **1000 events per second** and passes them on to a data storage system for offline analysis.

Reconstructing physics processes from detector inputs



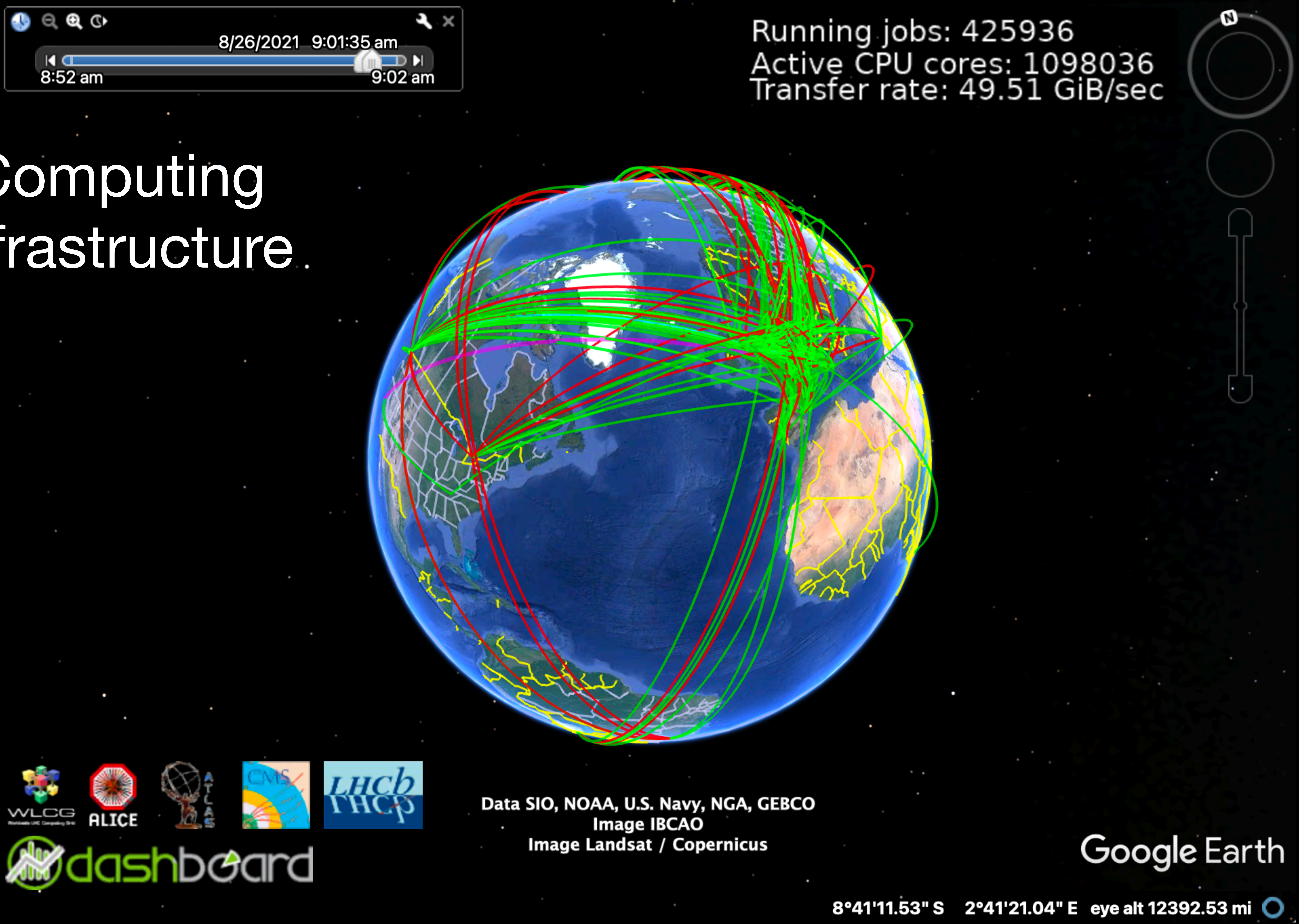
Reconstructing physics processes from detector inputs



Data storage

- Archiving the vast quantities of data is an essential function at CERN
- Magnetic tapes are used as the main long-term storage medium
- Custom CERN storage system created for the extreme LHC computing requirements
- Seven billion files (as of June 2022) stored → matching the exceptional performances of the LHC machine and experiments

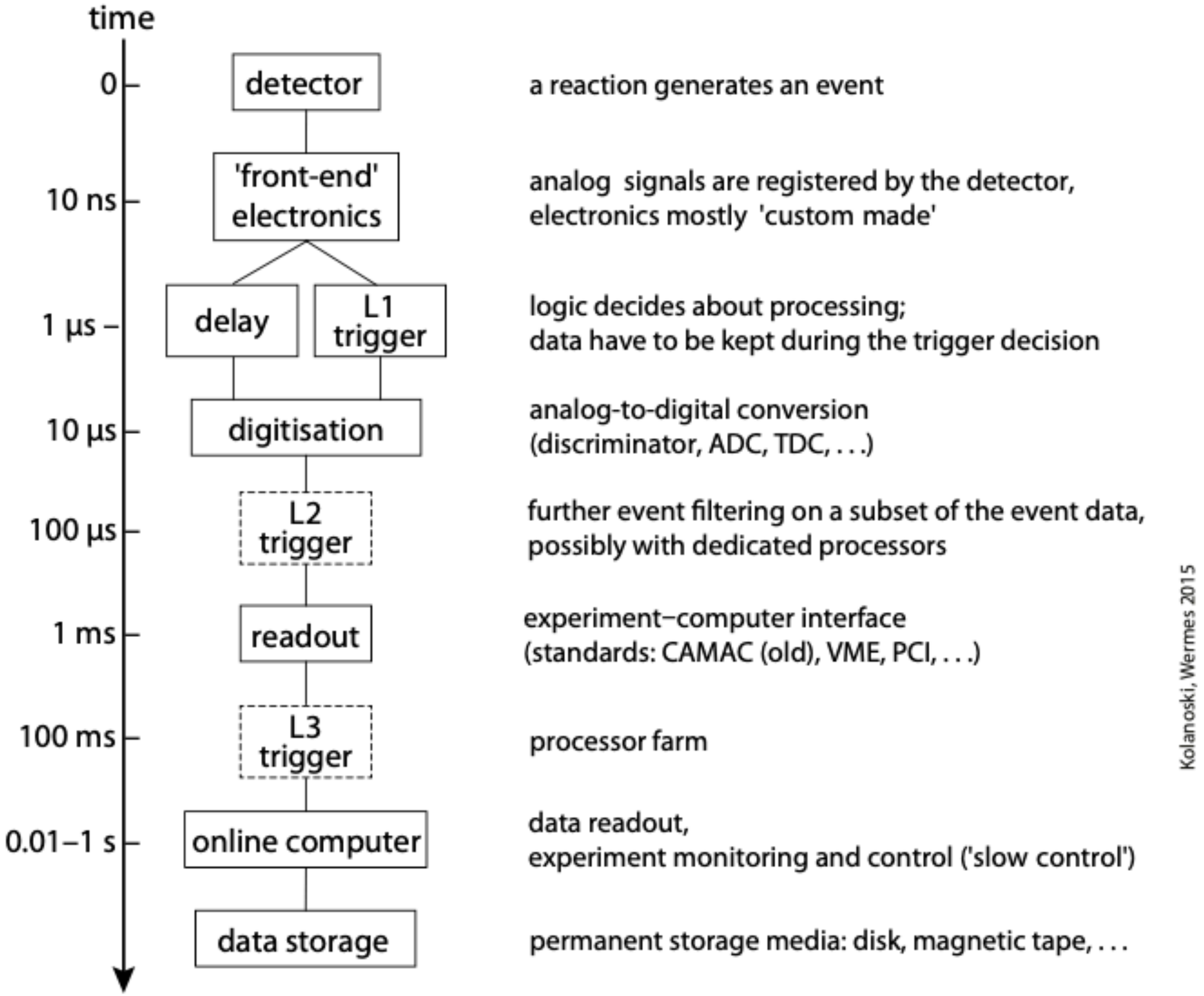
Computing infrastructure



Running jobs: 425936
Active CPU cores: 1098036
Transfer rate: 49.51 GiB/sec

More formally

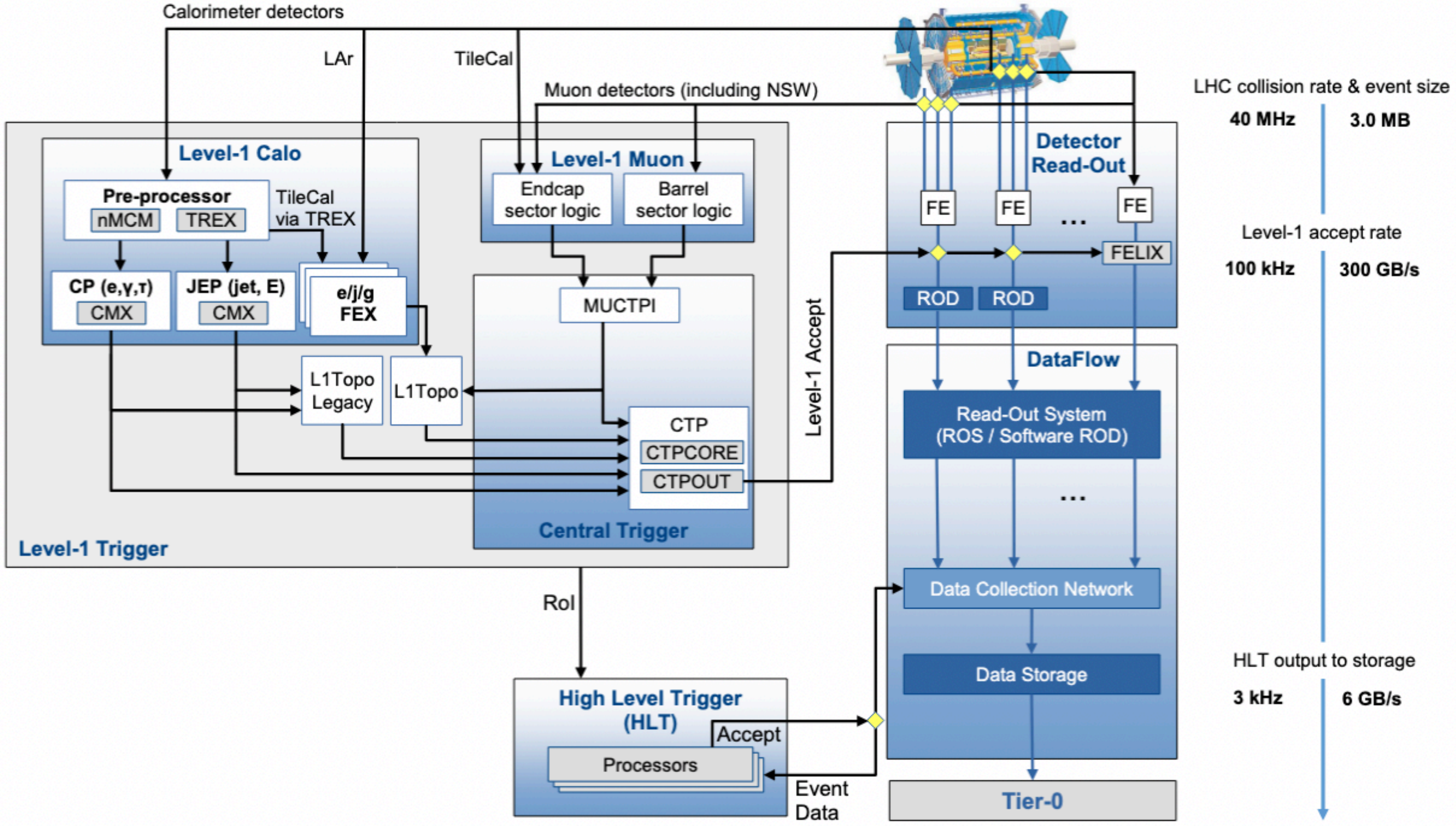
Data rate size reduction by a factor of 10^6

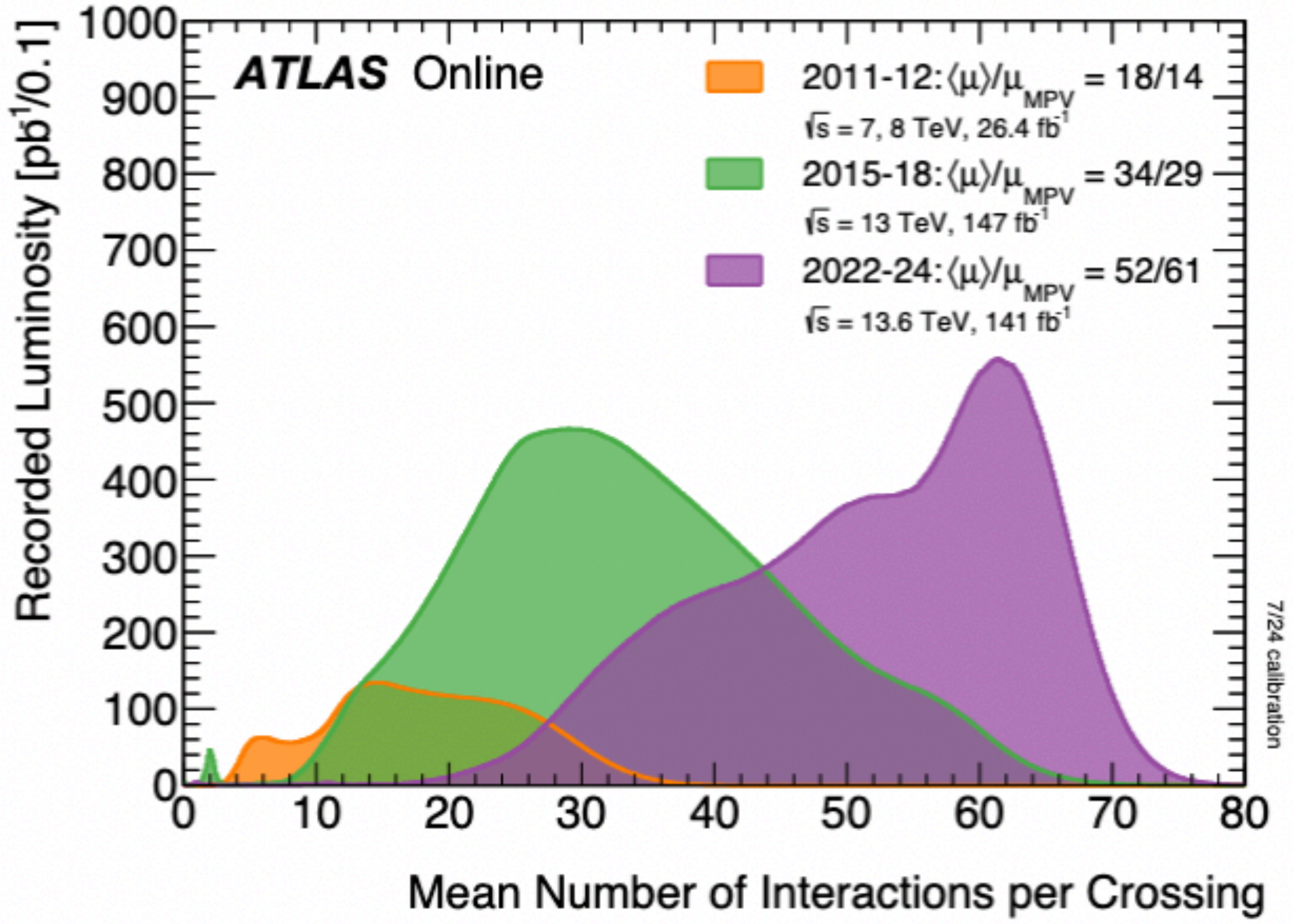


Kolanoski, Wermes 2015

Fig. 18.2 Typical time structure of a trigger and data acquisition system in a high-energy experiment. In each specific case the time sequence can be quite different, in particular also the number of trigger levels (here L1–L3) can vary.

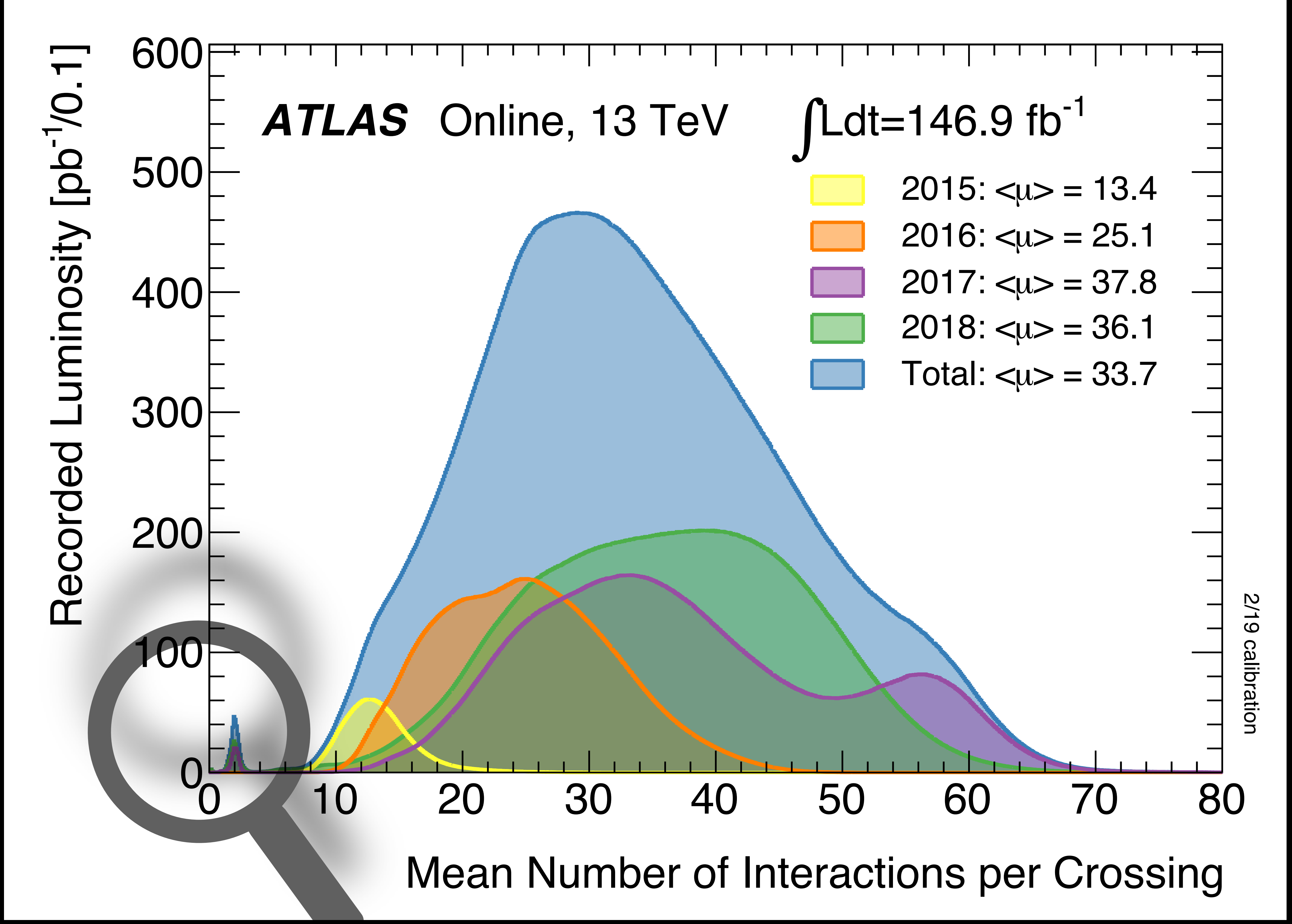
More formally





Single Boson Measurements

- Billions of W and Z bosons produced at the LHC
  - Enables precision tests of the electroweak theory
- To get to percent-level precision → multi-year effort
  - Low pileup runs are specially useful



Cross sections across several $\sqrt{s}$