Il problema dell Trigger
The need for Trigger & Data Acquisition

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SEVENTH FRAMEWORK PROGRAMME

Aristotle University of Thessaloniki

CAEN Tools for Discovery

UNIVERSITÀ DI PISA

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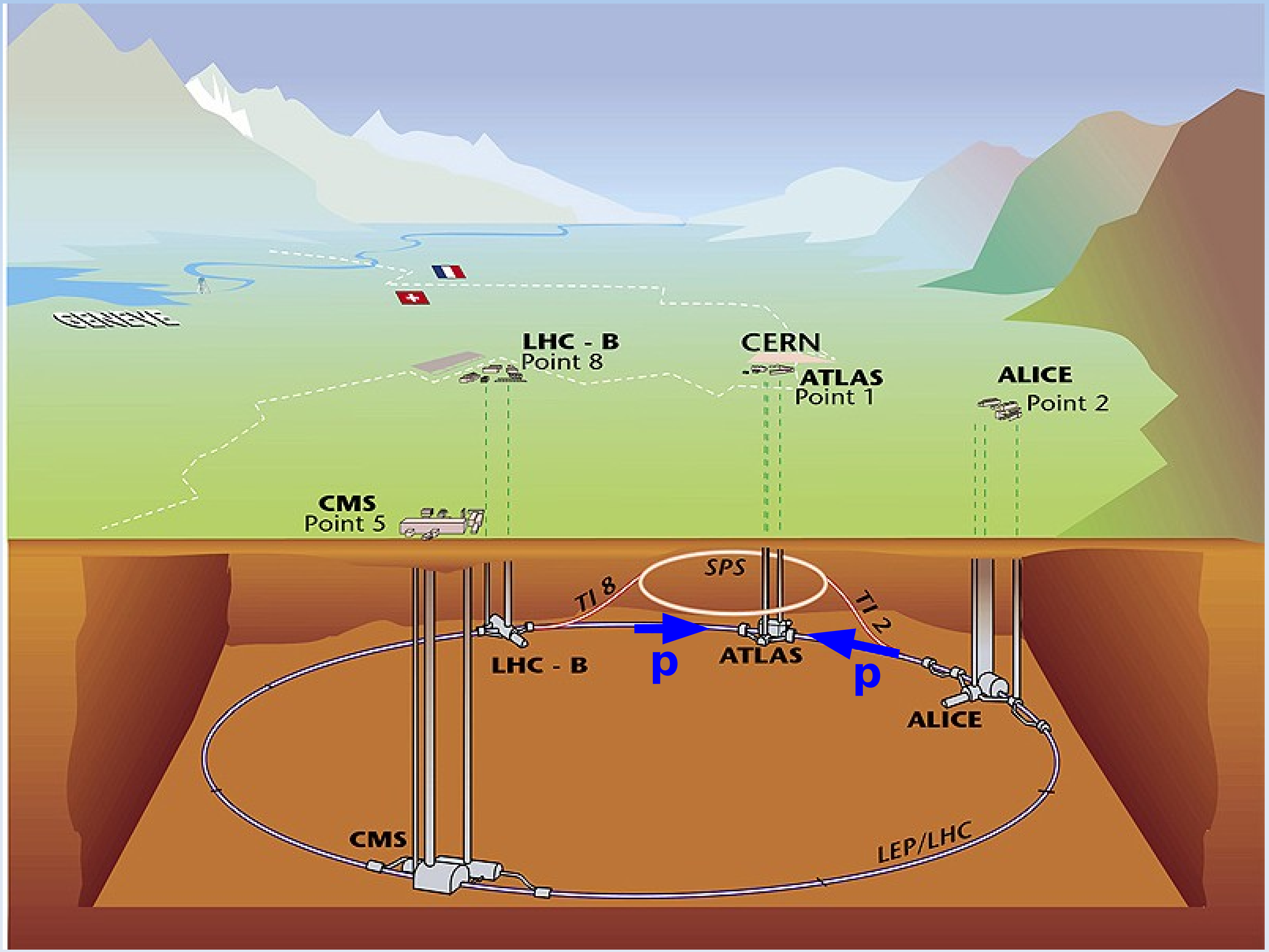
What we'll discuss today

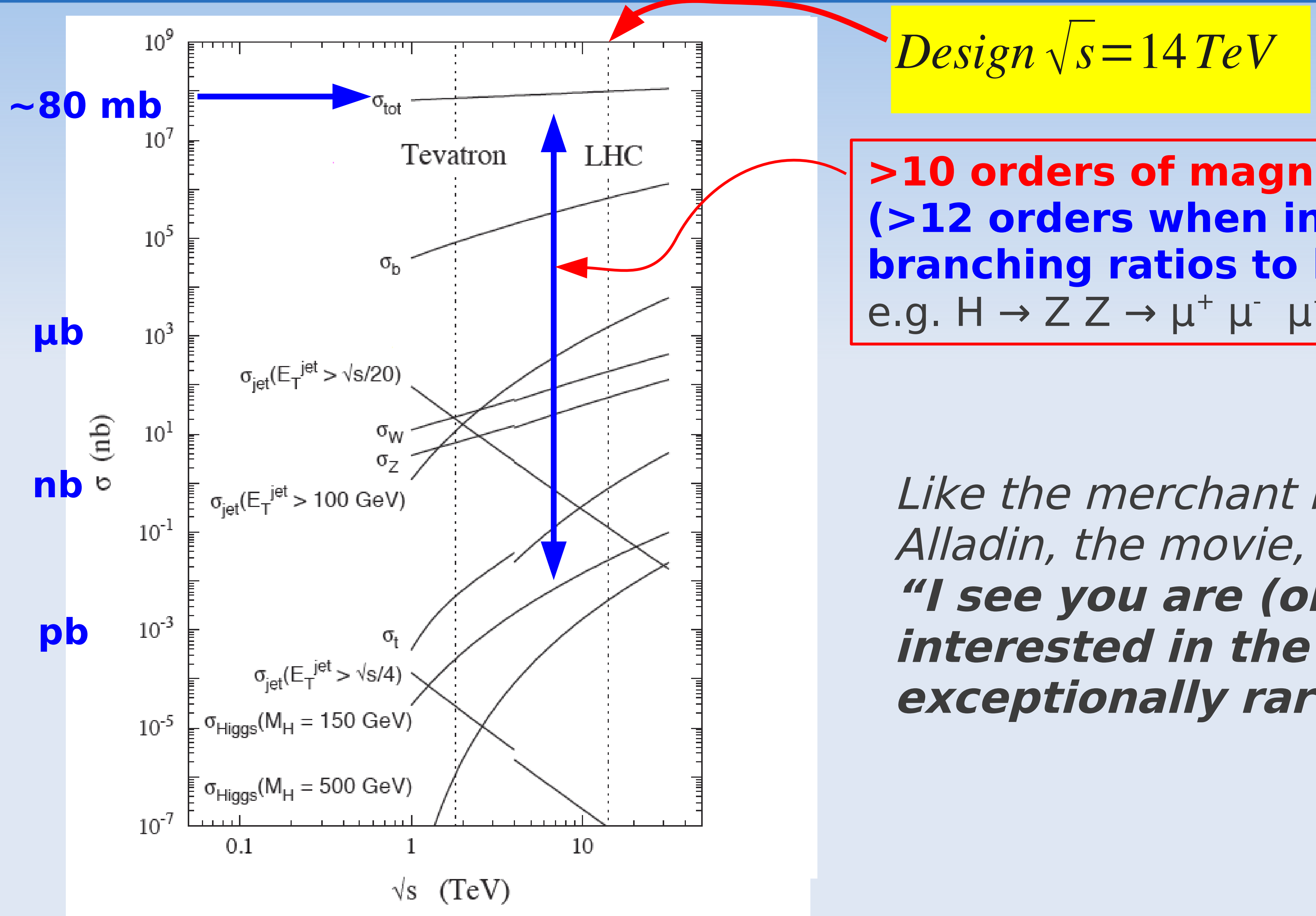
- The processes we are interested in are relatively rare at the LHC
- The challenge and job description of a Trigger & DAQ (TDAQ) system
- An analogy to see the ATLAS Triggering strategy

ATLAS around the LHC

colliding protons in a 27 km ring



ATLAS at the LHC, at a new energy frontier
interested in rare processes

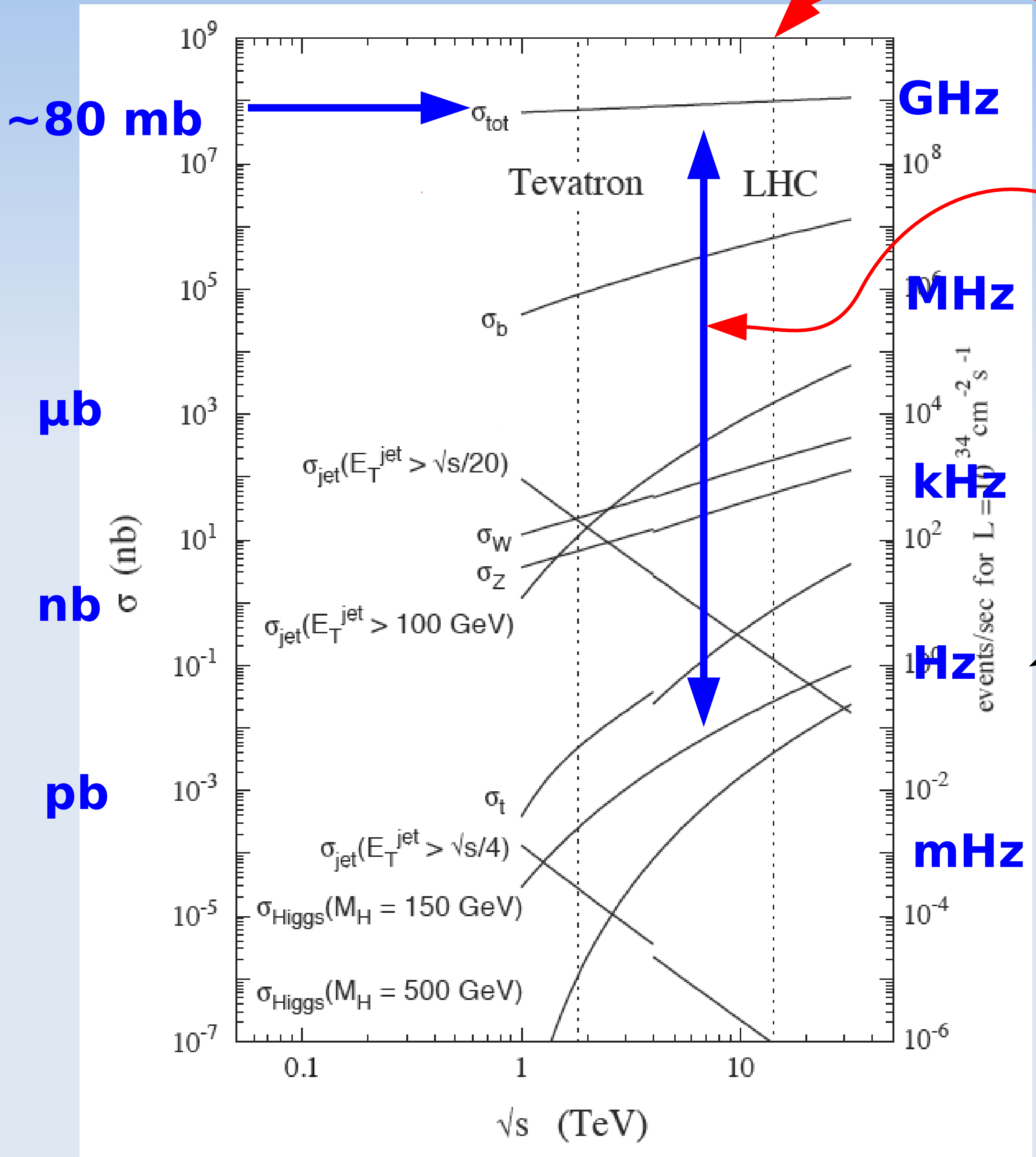


>10 orders of magnitude!
(>12 orders when including branching ratios to leptons,
e.g. $H \to Z\,Z \to \mu^+\mu^-\ \mu^+\mu^-$) !!!

Like the merchant in Alladin, the movie, says:
"I see you are (only) interested in the exceptionally rare"

ATLAS at the LHC, at a new energy frontier

rare indeed, but still need statistics to study them



$$Design: \sqrt{s} = 14\,TeV$$

>10 orders of magnitude!

(>12 orders when including branching ratios to leptons,

e.g. H → Z Z → $\mu^+ \mu^- \; \mu^+ \mu^-$) !!!

In order to have reasonable number of observed events, we need high luminosity

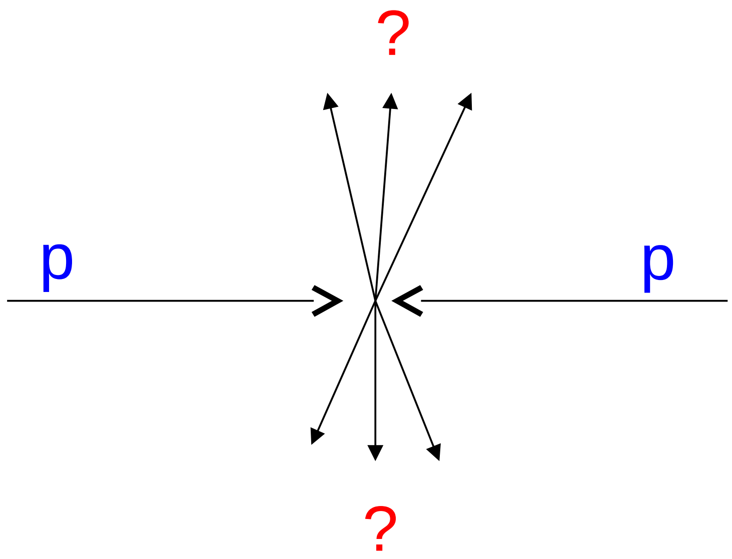
$$Design: L = 10^{34}\, cm^{-2}\, s^{-1}$$

L = No di volte per secondo que 2 protoni si trovano Dentro in cm2

Come produre le particelle?

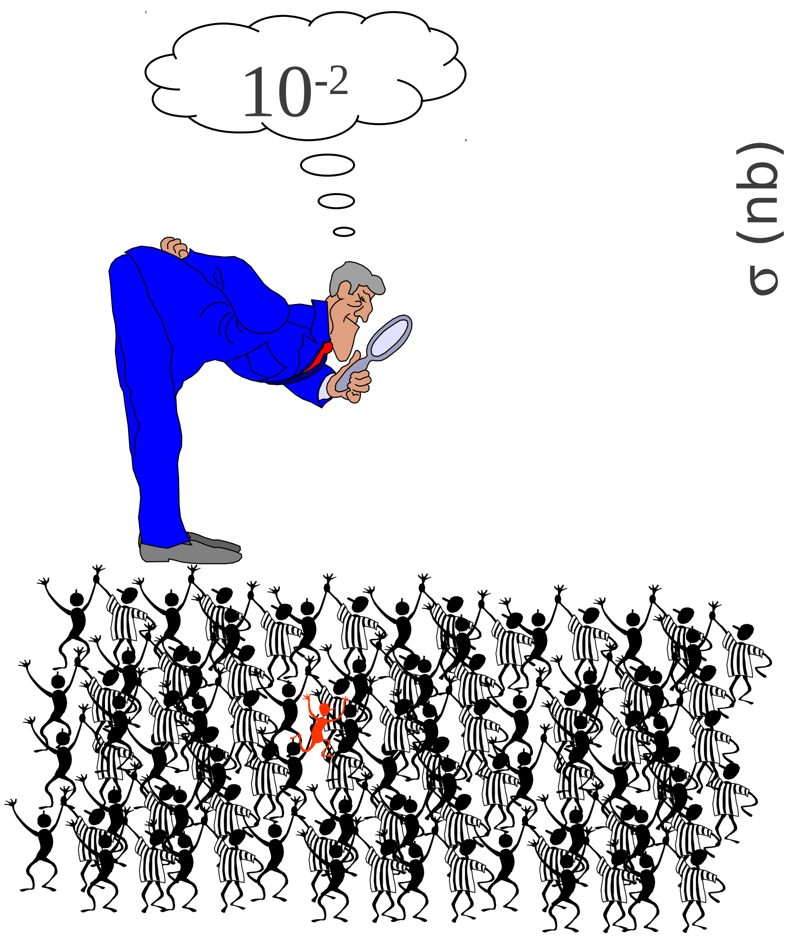
- Produzione con collisioni ad alta energia: $e^+ + e^-$, p+p, $e^- + p$, $\mu^+ + \mu^-$, …

- Produzione non specifica: si possono casualmente produrre le particelle da studiare, ma particelle non interessanti si producono in genere con probabilita` assai maggiore

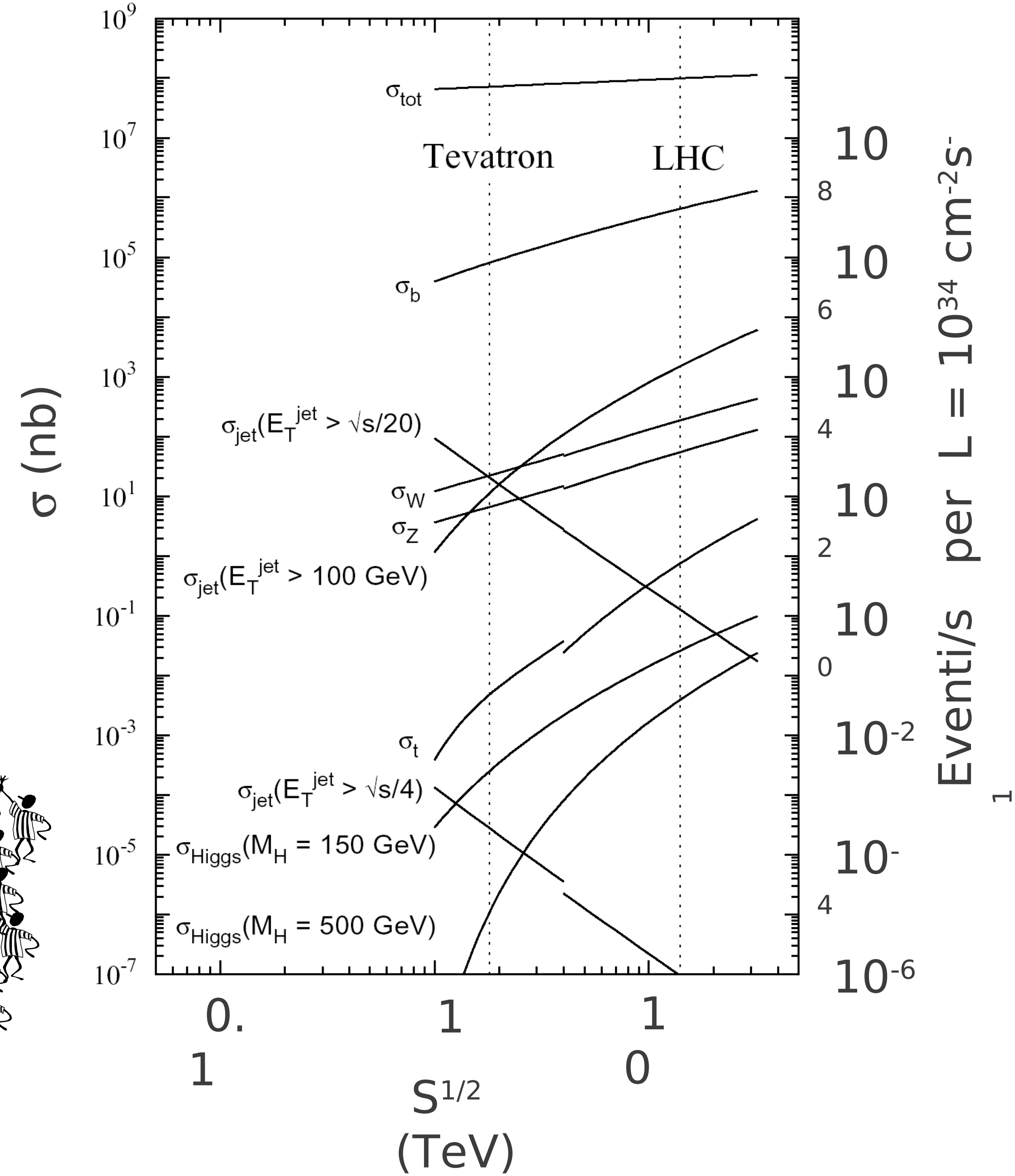


L’evento !

Eventi rari



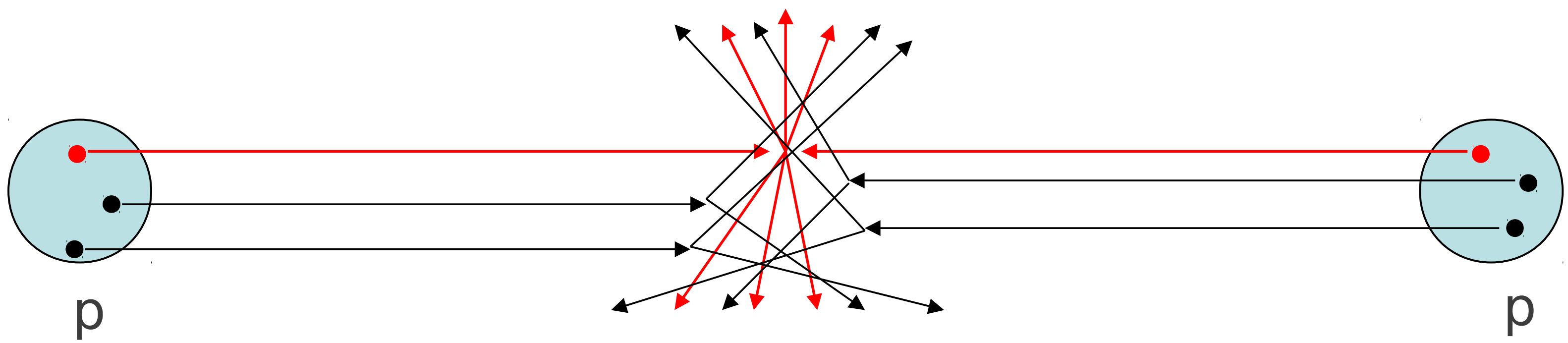
10-2



10^9
10^7
10^5
10^3
10^1
10^-1
10^-3
10^-5
10^-7
σ (nb)
σ_tot
Tevatron
LHC
σ_b
σ_jet(E_T^jet > √s/20)
σ_W
σ_Z
σ_jet(E_T^jet > 100 GeV)
σ_t
σ_jet(E_T^jet > √s/4)
σ_Higgs(M_H = 150 GeV)
σ_Higgs(M_H = 500 GeV)
0.
1
1
1
0
S^1/2
(TeV)
10
8
10
6
10
4
10
2
10
0
10-2
10-
4
10-6
Eventi/s per L = 10^34 cm^-2s^-
1

Segnale vs. Fondo

- Si parla quindi di eventi di segnale (buoni) e di eventi di fondo (cattivi)
- Ulteriore fondo e` generato dalla sovrapposizione di eventi o di frazioni di eventi non interessanti (specie ai collider adronici pp e $p\bar{p}$)



Event & Underlying event

Prima conclusione

- Puo` essere assai peggio che cercare un ago in un pagliaio !
  A LHC (Large Hadron Collider: pp a 14 TeV) $H_{(125\ GeV)} \rightarrow \gamma\gamma$ con frequenza 10^{-13} del totale
- La ricerca deve essere fortemente guidata dalla teoria
- La teoria deve caratterizzare al meglio gli eventi per distinguere quelli interessanti dal fondo

ATLAS at the LHC: a busy environment
many beam crossings, many interactions per crossing

- **High luminosity → lots of pp interations**
  - $L * \sigma_{tot} \sim 10^{34}\ cm^{-2}\ s^{-1} * 80\ mb$ ~ **800 MHz of pp interactions**
- **And, many "non-interesting" pp interactions superimposed at the same are pp bunch crossing**
  - Nominally, beams cross @ 40 MHz (each 25 ns) – next bunch is 7.5m behind

→ 800/40 = 20 pp interactions per 25ns

- BUT, only 2835 out of 3564 proton bunches around the LHC are full

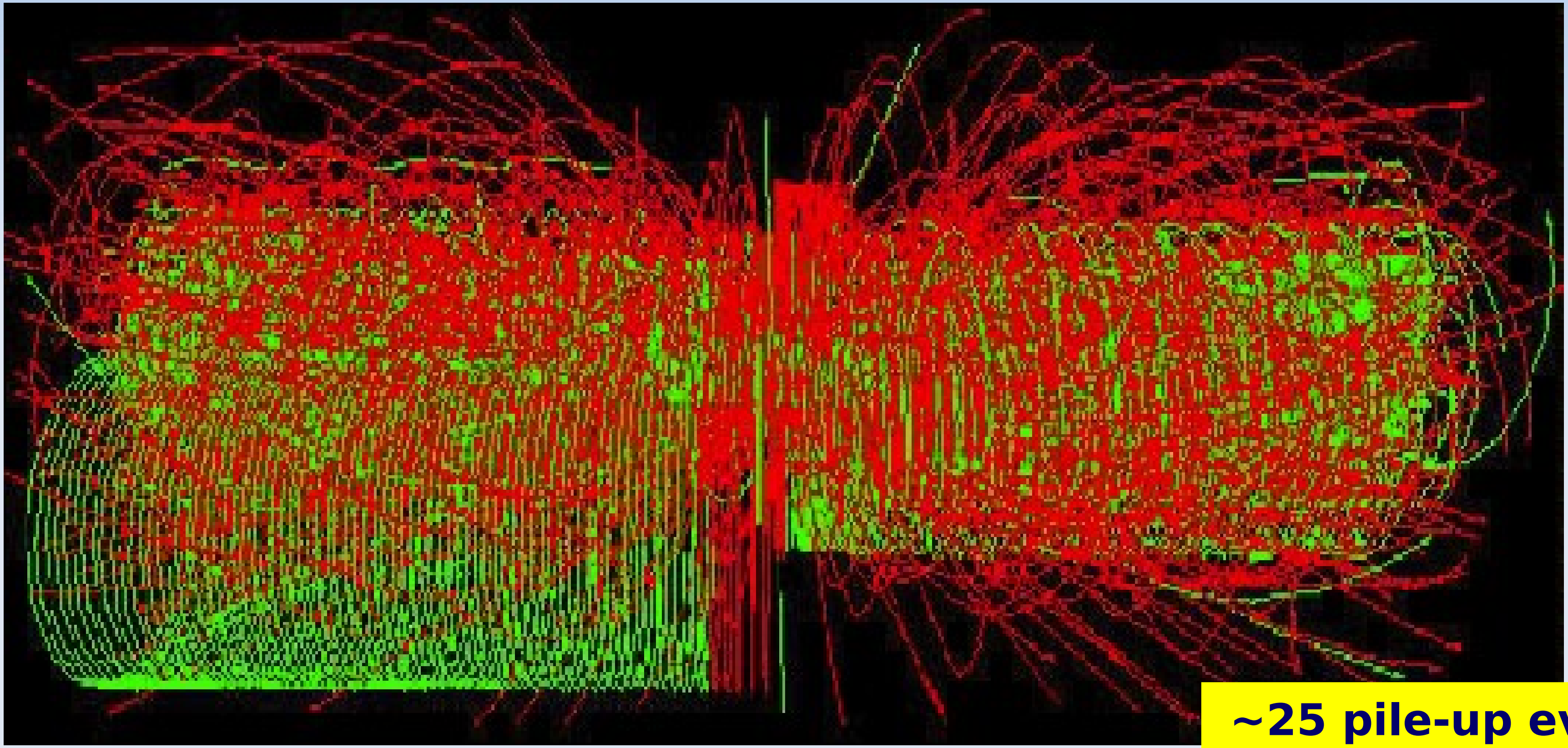
→ **25 pp interactions per beam crossing**

- a.k.a "pile-up" pp interactions or "pile-up events"

Looking at many & complex events

every 25ns look at a superposition of 25 pp collisions

You must be looking at this every 25ns...



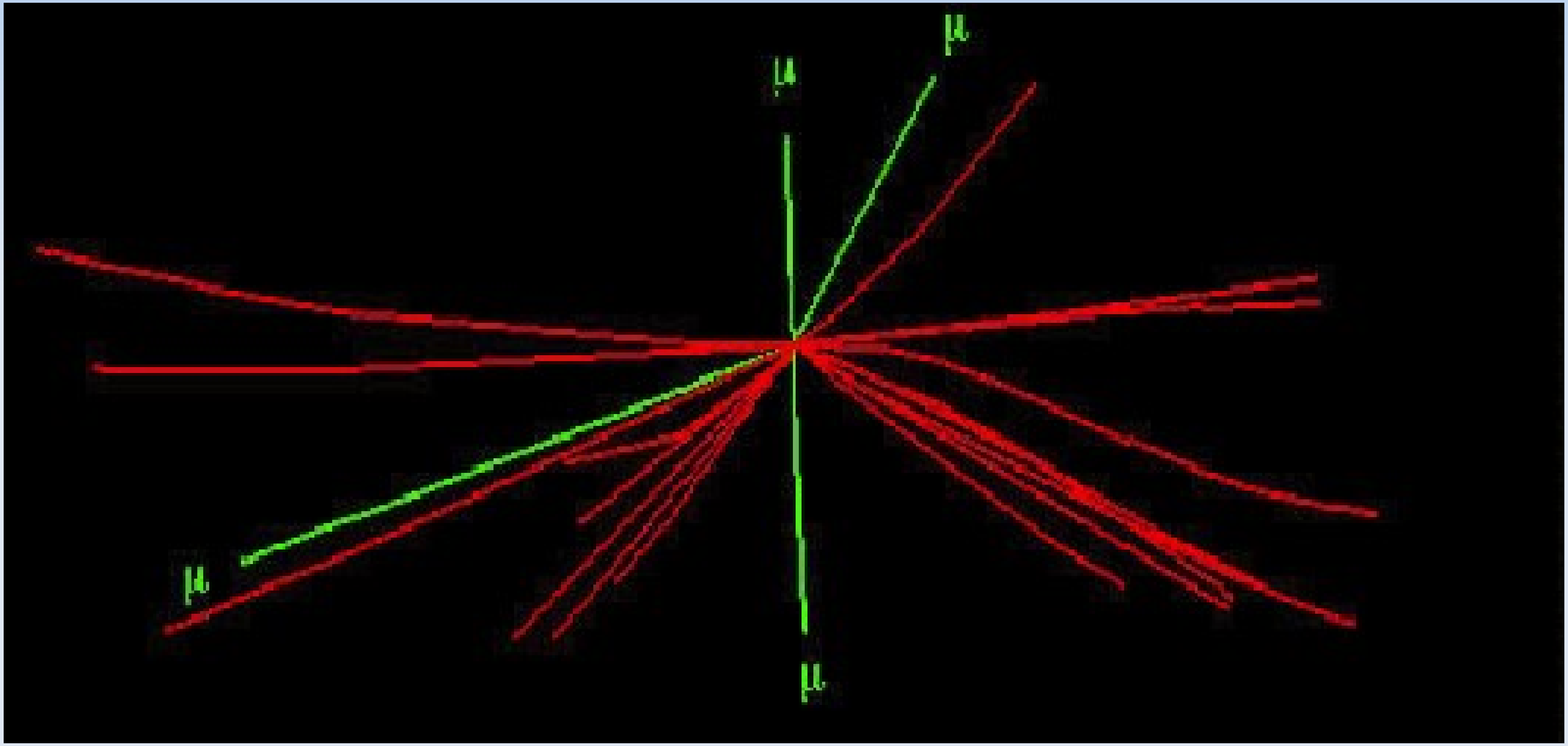
~25 pile-up events

~90 M channels in ATLAS, recording signals from these products

→ 1.5 MB of info per "event", i.e., every time I read this info

Looking at many & complex events
to find (and keep) the haystack

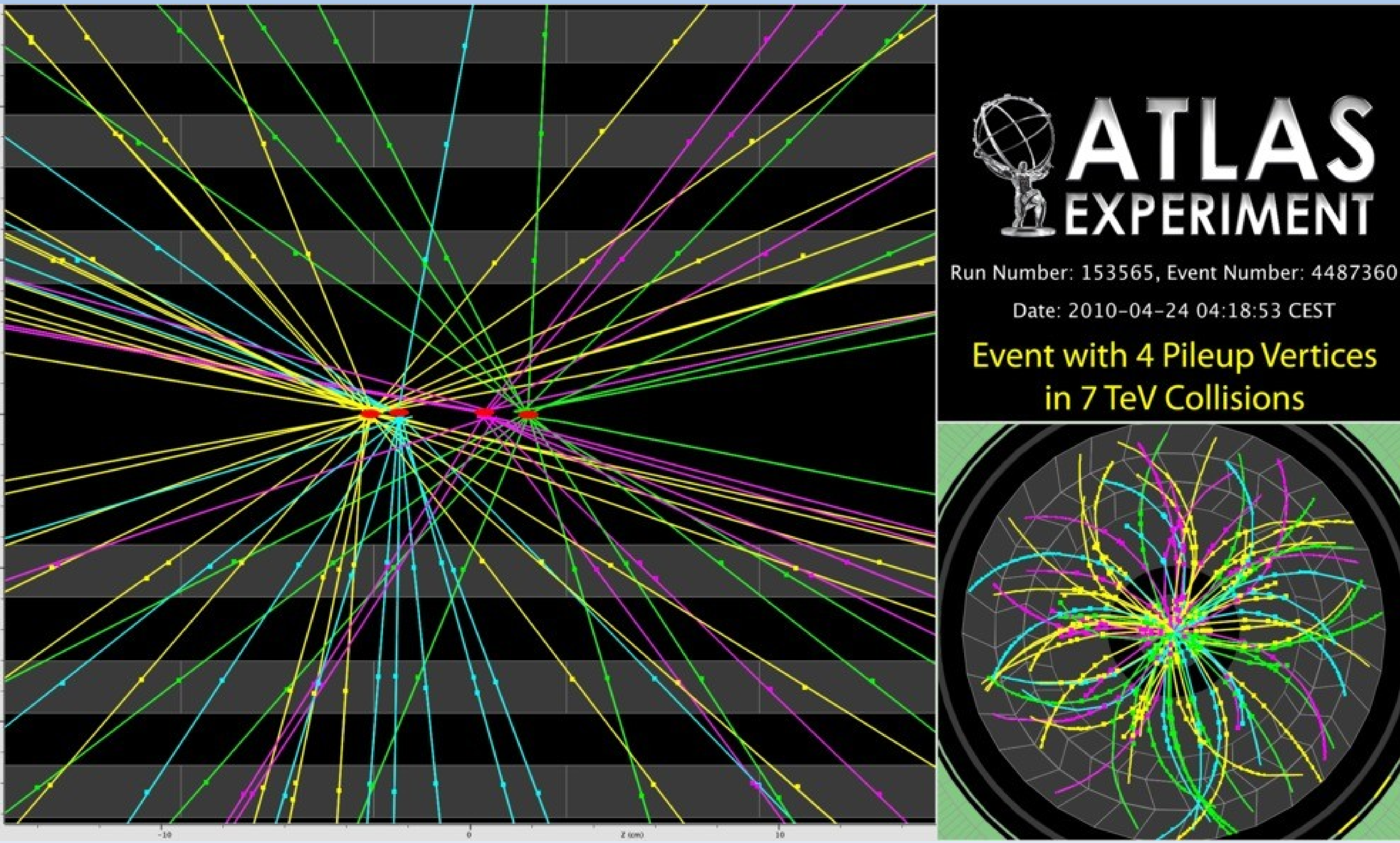
...and be able to realize that...
1 in 10^{13} of those pp collisions contain a decay like this:



Higgs → Z Z → 4 μ

A real example of pile-up events in ATLAS

4 pile-up events: see 4 primary verticies



Triggering on an event

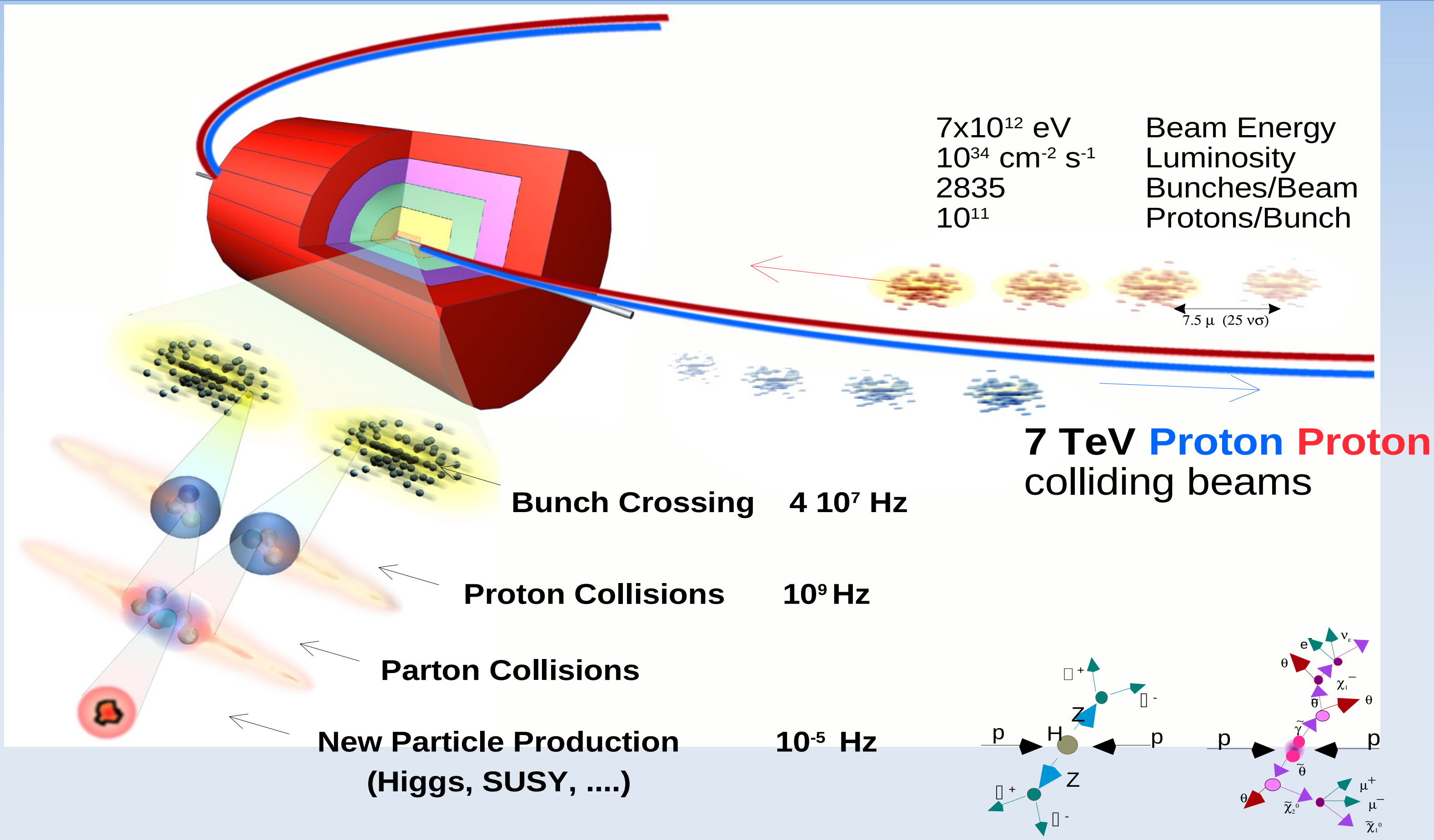
Triggering is the art of what can you achieve

- Let's say you look for the Higgs boson
- You have to have triggered on events with the Higgs boson; otherwise you'll never see anything
- Triggering is the art of what can you achieve
  - The most abundant production or decay may be the hardest to trigger on
- Events in your sample:

N = L * σ(pp → H + X) * BR(H → products) * Geometrical_Kinematic_Acceptance * Efficiency

Trigger and Data Acquisition at LHC

job description: Select and Acquire the interesting events



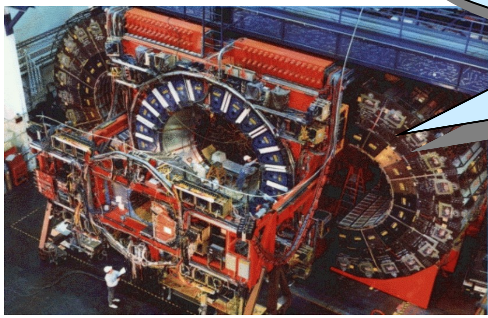
- The Trigger and Data Acquisition system, has to watch ~1 billion pp collisions per second (40M proton bunch crossings / sec),
- **select online "the most interesting" 200 events/sec,**
- **and log them for offline use with a resolution of a ~90 Mpixel camera.**

ATLAS Trigger & Data Acquisition (TDAQ)
need a brain (Trigger) and an arm (DAQ)

- The job of the Trigger and Data Aquisition (TDAQ) System:
  - Be very selective while preserving the full physics potential of the experiment
    - At nominal operating conditions, LHC provides ~1 GHz of proton-proton interactions

      ==> but, we retain only ~200 events/sec (practical limit by offline)
- You need:
  - A smart **Trigger**:
    - To decide which events to select
  - A powerful **Data Acquitition** system:
    - To provide the Trigger with the data it needs to take a decision
    - To react according to Trigger decisions: acquire the selected events, or eliminate rejected ones
- **ATLAS**: **3 trigger levels to keep the most interesting events**

Nel mezzo del cammin di nostra vita
mi ritrovai per una selva oscura
ché la diritta via era smarrita



DETECTOR

40 TB/s

2 "Divine Commedie"
ogni 25 nsec

TRIGGER & DAQ

$1/10^8$ interazioni

1 vincita/s
Super Enalotto

RECORDING

Problema formidabile:

- Data Handling
- Data Reduction
  es. trigger: $10^7 \rightarrow 1$ bit (si/no)

Trigger/DAQ:

-Ruolo analogo al detector
-Ideati con l'esperimento
determinano la fisica accessibile

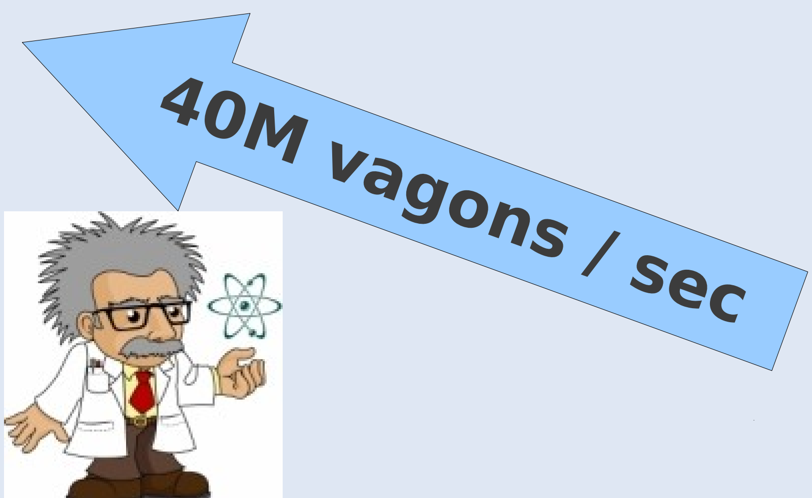
Conoscenze:

-Elettronica analogica/digitale
-Architetture complesse
-Aggiornamento tecnologico

~Analogy: a fast train transporting cars

want to pick out train vagons with “interesting cars”

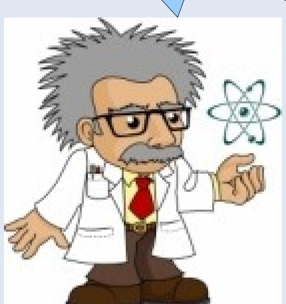
- Look at 40M train vagons /sec passing by, with each vagon having ~25 cars on it



~Analogy: a fast train transporting cars
want to pick out train vagons with “interesting cars”

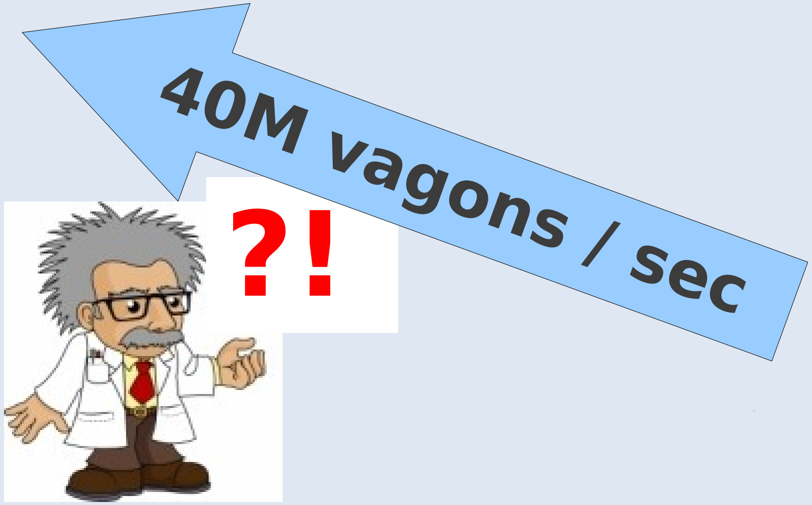
- Look at 40M train vagons /sec passing by, with each vagon having ~25 cars on it; want to find cars like this:
  - Yellow
  - **Ferraris, with a plate number ending in “4”**
  - Ferrari 360 Spyder, with brown leather seats,
    a new headlight at the right front,
    and a scratch on the driver's door.

40M vagons / sec



~Analogy: a fast train transporting cars
look for all car characteristics in one go?

- Let's say that in order to **examine a vagon**, to see if it has a car with **ALL these characteristics**, **takes you 1 sec**.
- **If you examine EACH vagon** to find such a car with ALL these characteristics, then you are checking only 1 vagon / sec, and you do **not even look at the rest 39,999,999 vagons per sec** !!!! → **doing something wrong, eh?!!**



~Analogy: a fast train transporting cars
pick out the interesting vagons in steps

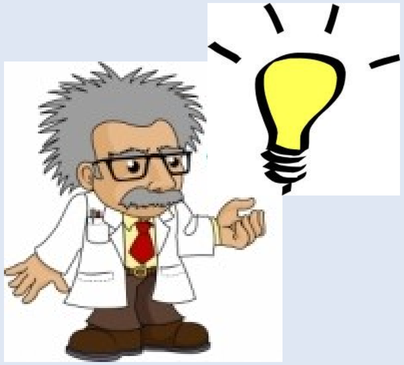
- Look at 40M train vagons /sec passing by, with each vagon having ~25 cars on it and want to find cars like this:

40 MHz

- **Yellow**

  → LVL1 decision: allow time to check all vagons

100 kHz



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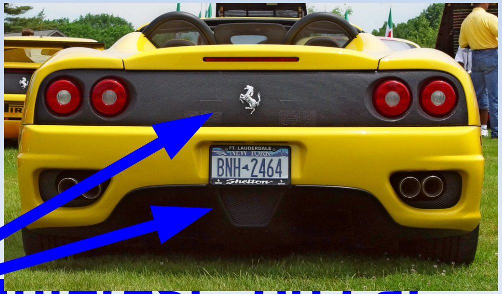
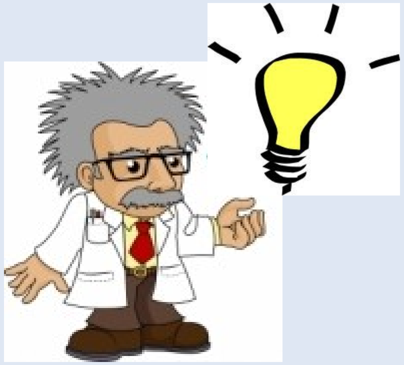
100 kHz

- **Ferraris, with a plate number ending in “4”**

  → LVL2 decision: have time to look at “regions of interest” on car

3 kHz





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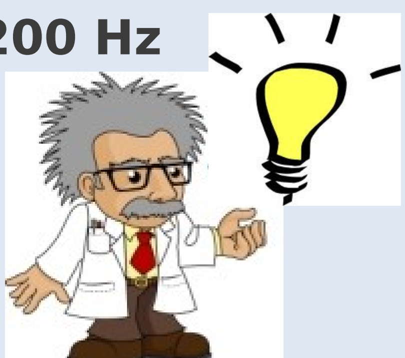
100 kHz

- **Ferraris, with a plate number ending in “4”**
  → LVL2 decision: have time to look at “regions of interest” on car

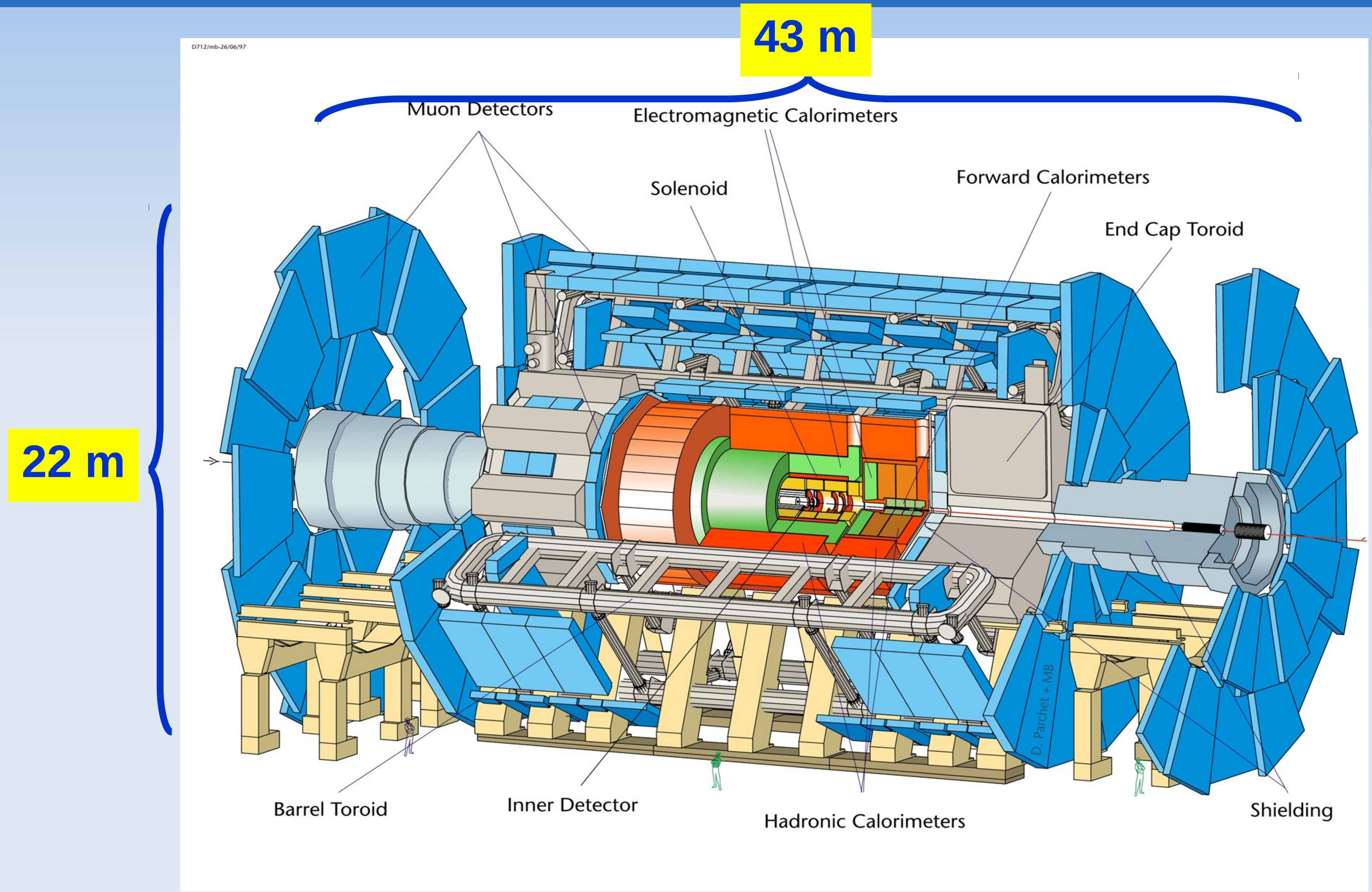
3 kHz

- **Ferrari 360 Spyder, and details**
  → LVL3 decision: have time to check whole car

200 Hz



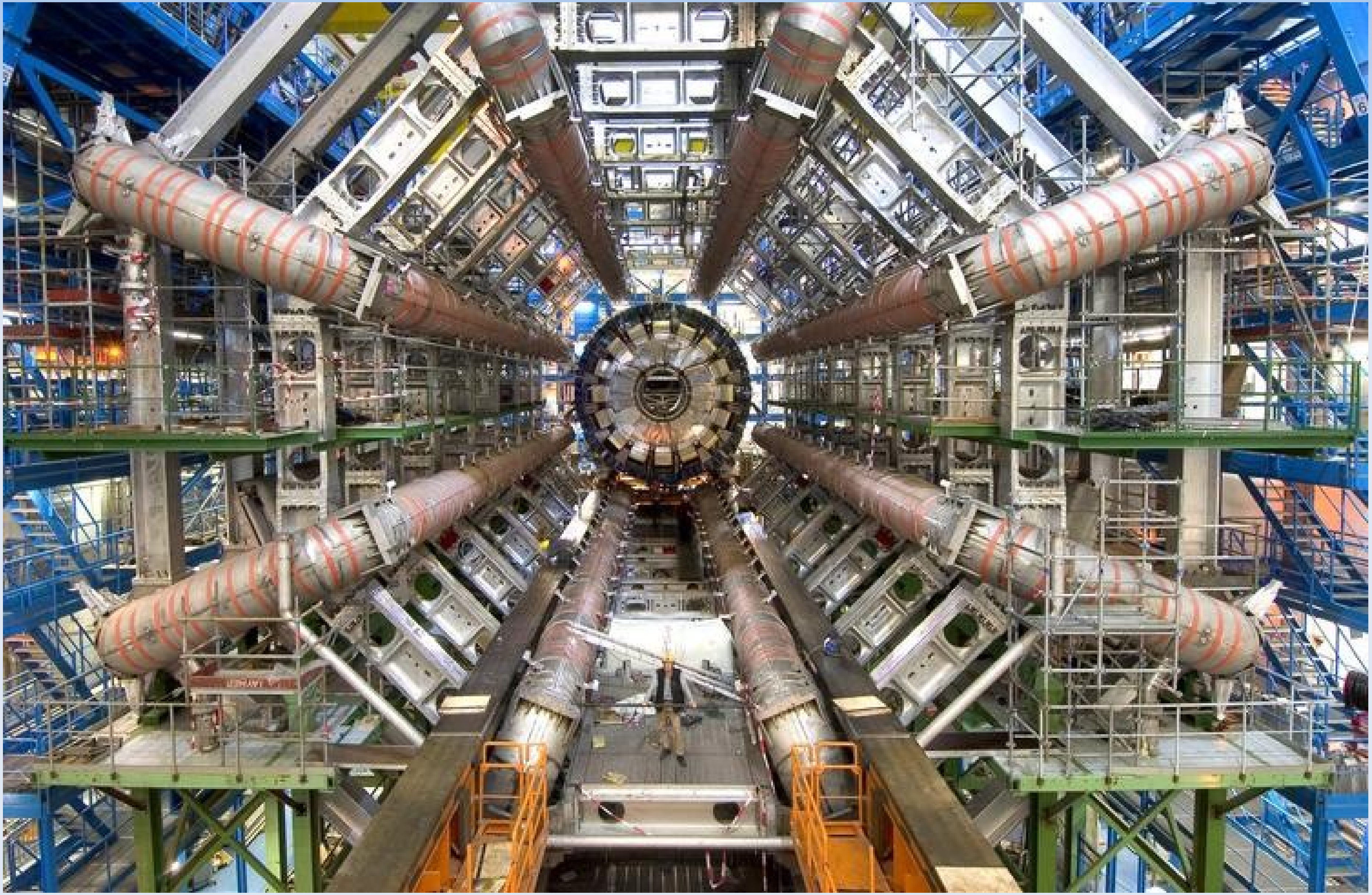
ATLAS sees pp collision products



ATLAS sees pp collision products

specific detectors for each particle type

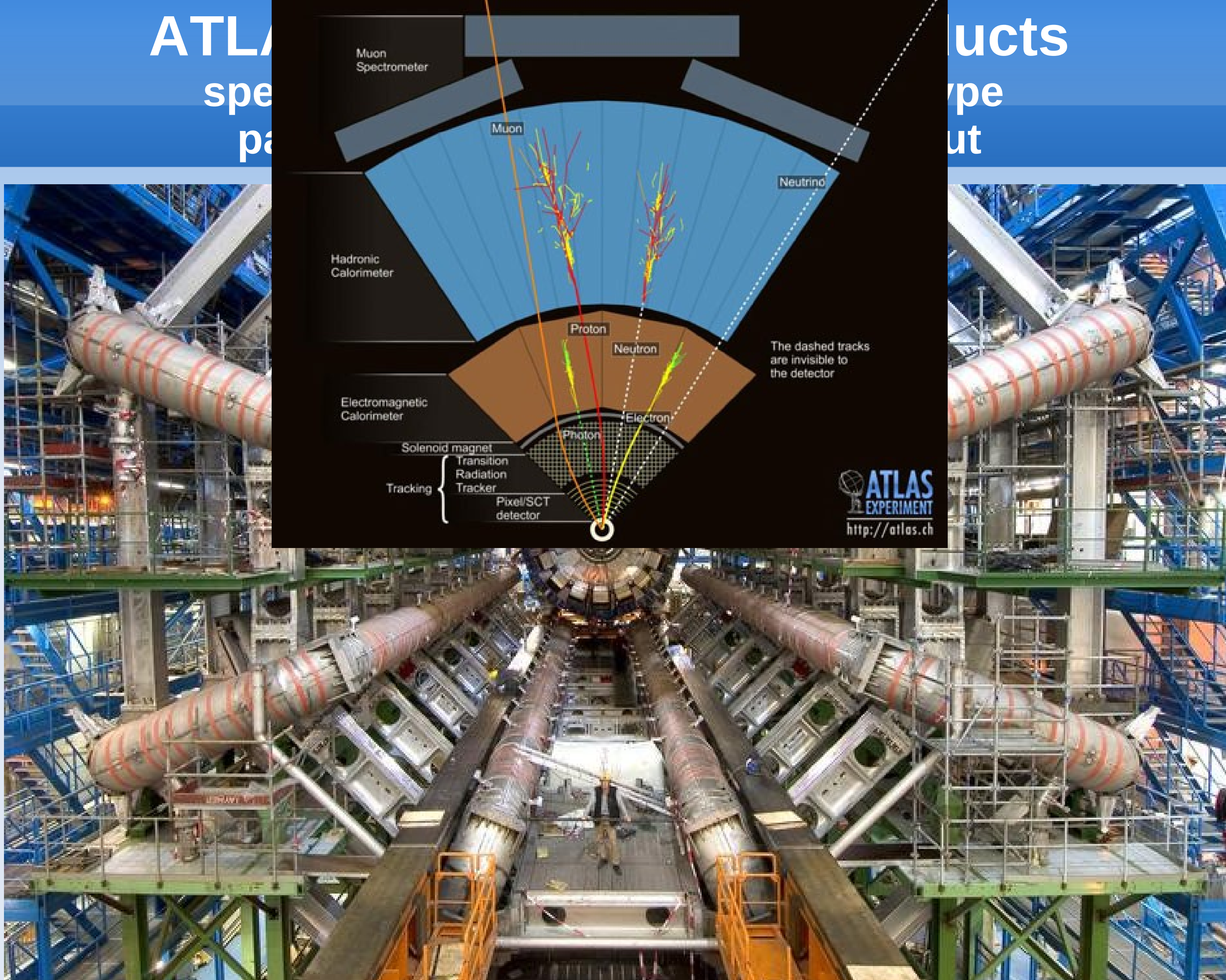
particle density drops by moving out



ATL… ucts

spe… ype

pa… ut



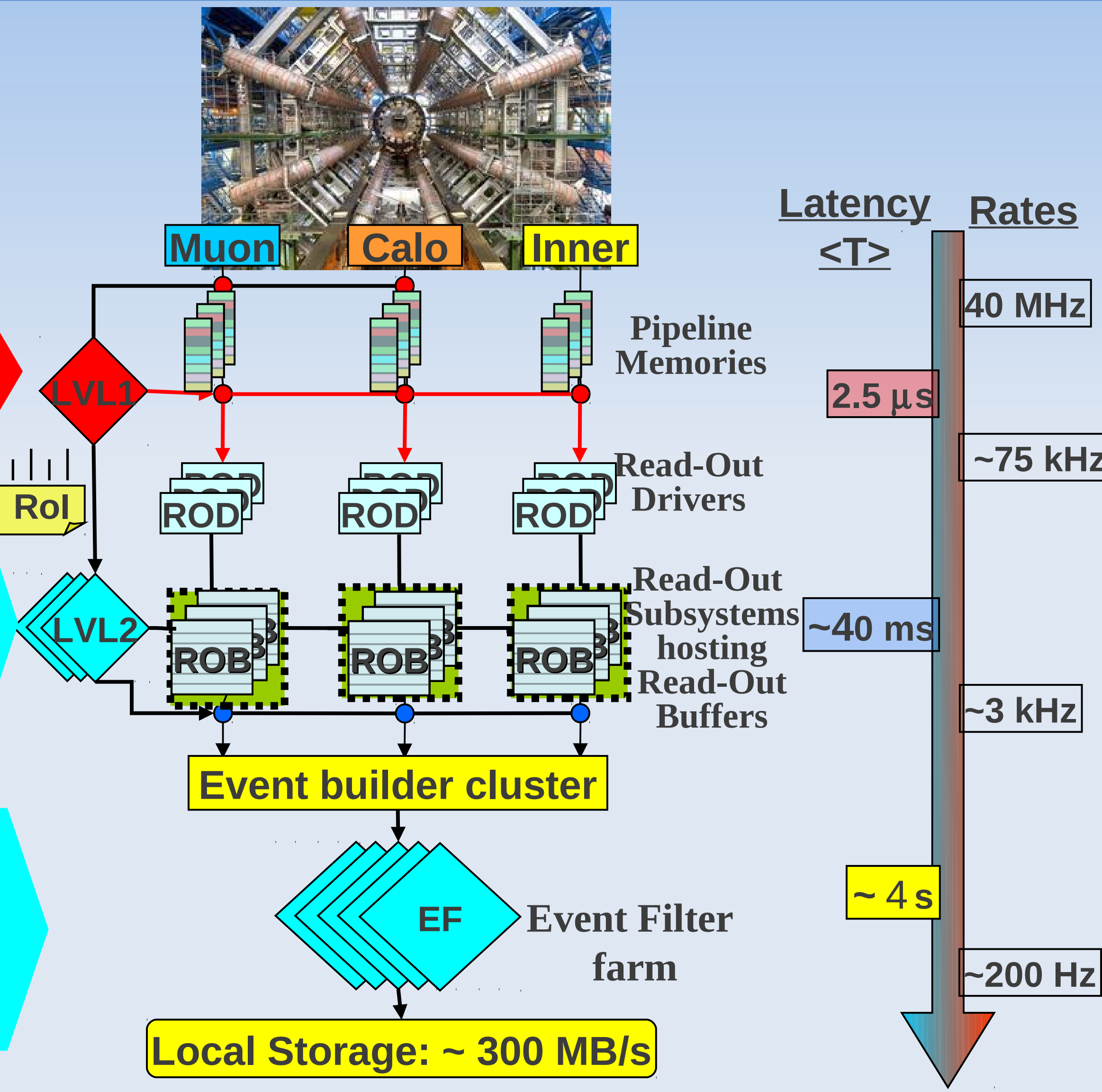
TDAQ at a glance
top to bottom drawing

Hardware based (FPGA, ASIC)
Calo/Muon (coarse granularity)

HLT

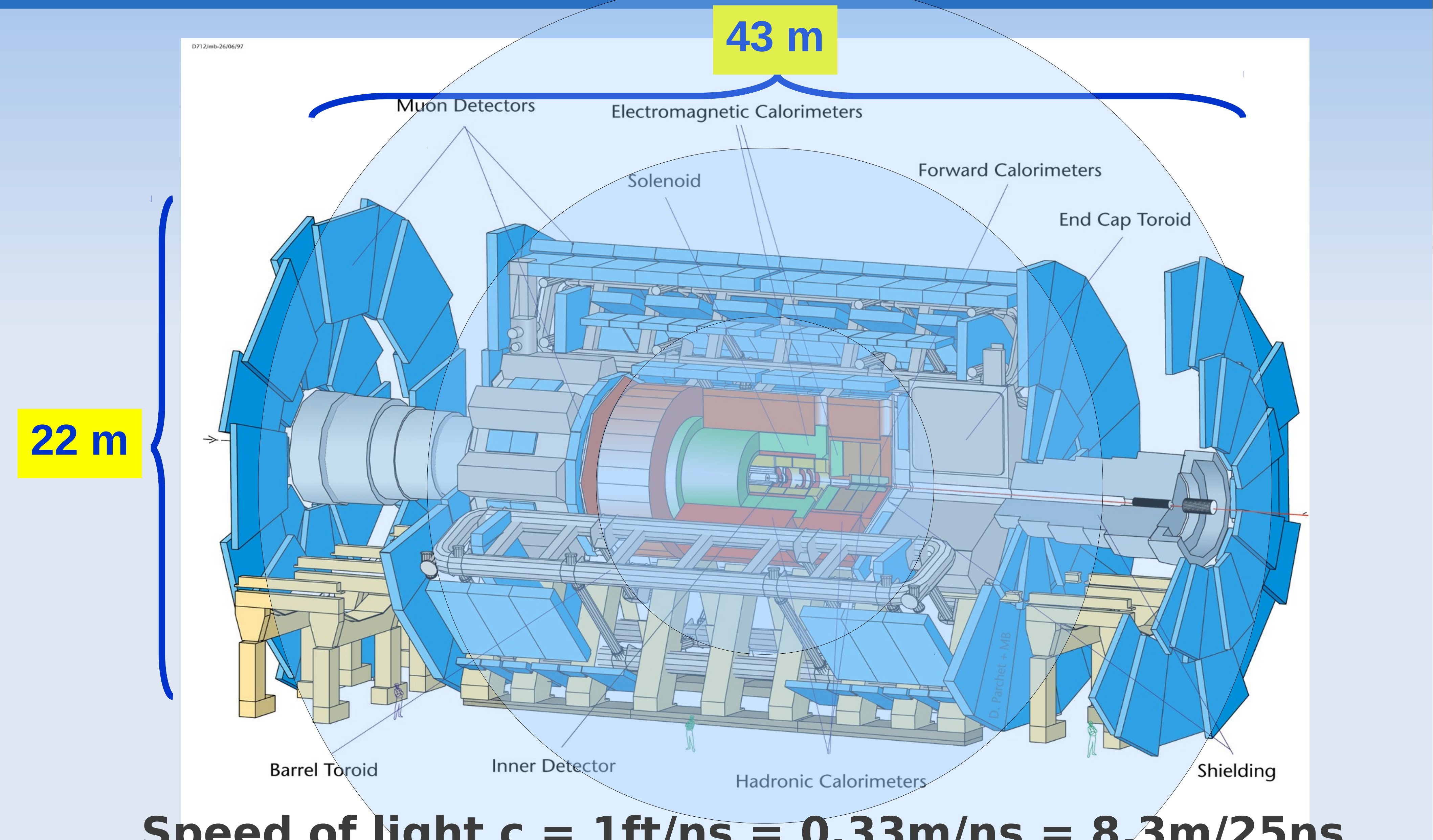
Software (specialised algs)
Uses LVL1 *Regions of Interest*
All sub-dets, *full* granularity
Emphasis on early rejection

Offline algorithms
Seeded by *LVL2 result*
Work with *full event*
Full calibration/alignment info



Time of flight: 8.3m per 25ns

3 LHC clock tics till collision products reach far detectors

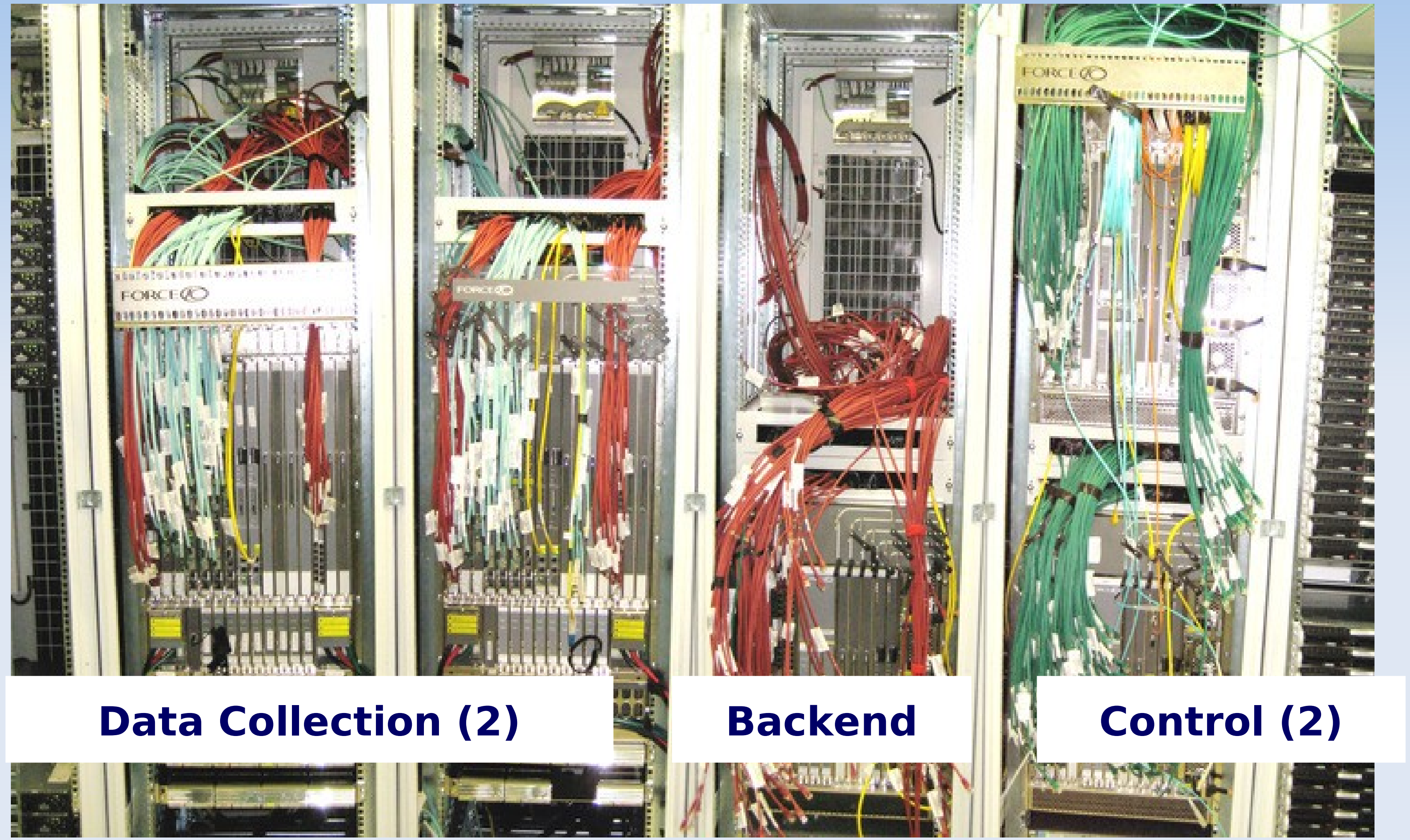


Speed of light c = 1ft/ns = 0.33m/ns = 8.3m/25ns

Farms of PCs for the HLT
one event per core: perfect scaling

- **PC farm: one event per CPU core**
  - Perfect scaling of processing power (kHz) with # of cores
  - **Increasing the PC farm we reach the necessary performance**
  - One event per core → high memory needs per PC box
  - “low clock speed” per core → larger latency (ave. processing time)

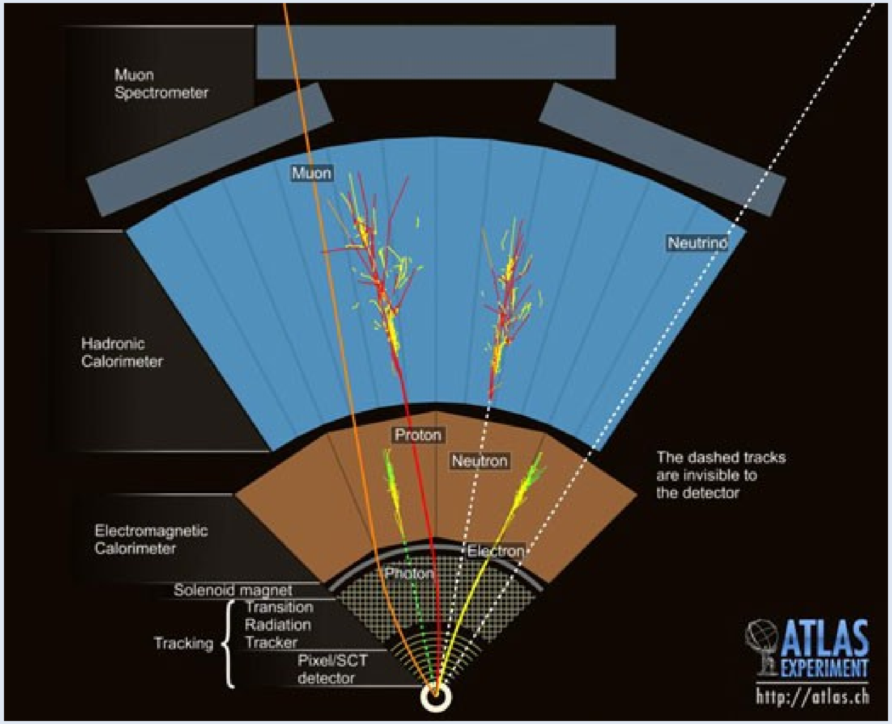
DAQ/HLT: non trivial switches
Force-10 Ethernet switches



TDAQ Core Switches

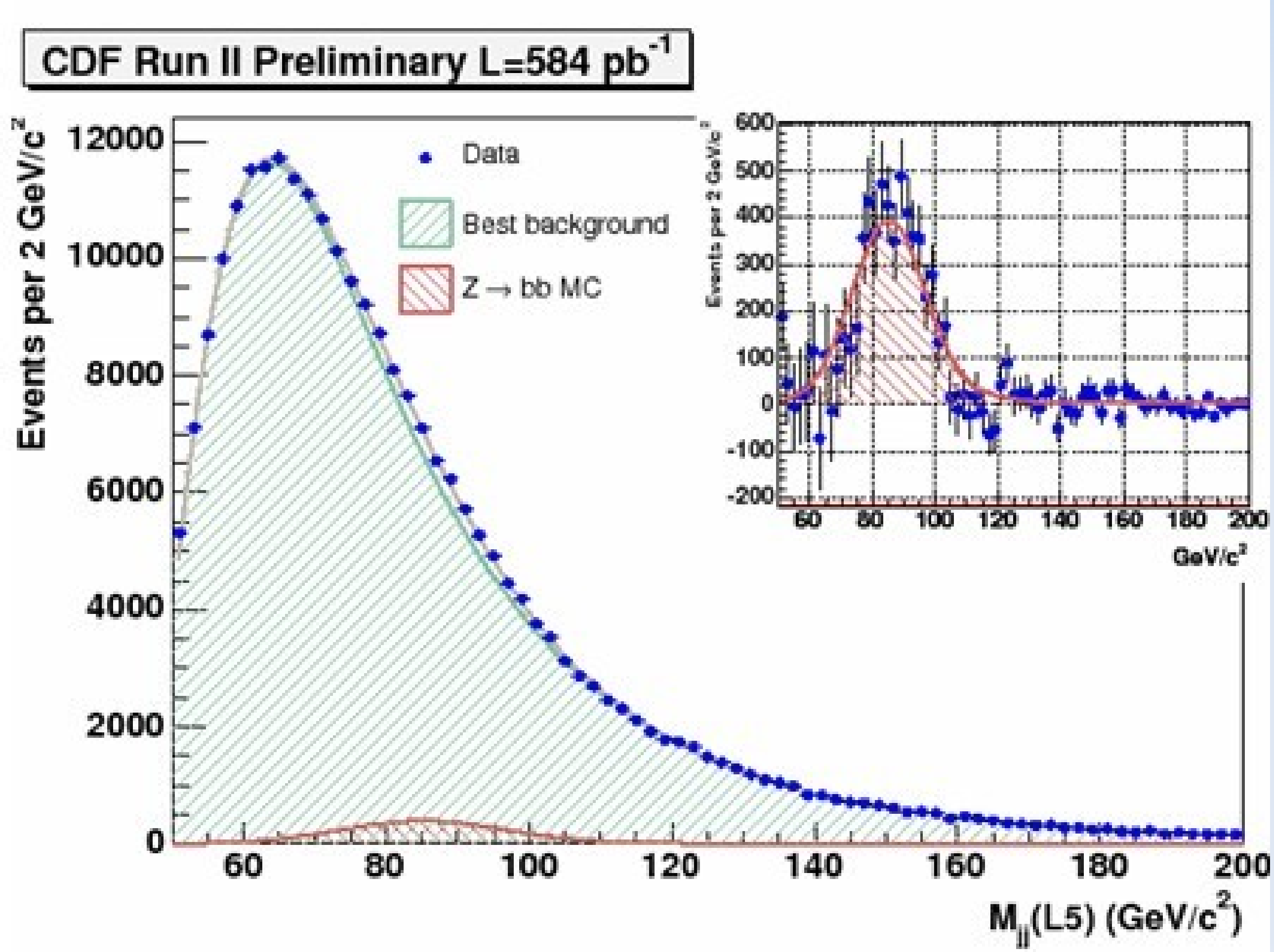
Evolution for the luminosity upgrades
directions under investigation - LVL1

- **Trigger in general: has to become more sophisticated**
- **LVL1: Track trigger at LVL1? – long term**
  - to confirm electrons (~1/1000 jets fakes an electron when you look at calorimeter only);
  - to reject accidental muon tracks (cavern background to increase)



Triggering on an event
example: Z → b bbar sample in CDF

- **To trigger on something, <u>you have to have the proper hanldes</u>**
- E.g. CDF was triggering on two jets, which were "tagged" as b-jets (seen with tracking/vertexing info of jets: **see Mauros' talk on how to do this online**)



In two words

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Thank you!