

Introduction to trigger concepts

ISOTDAQ 2017
Amsterdam

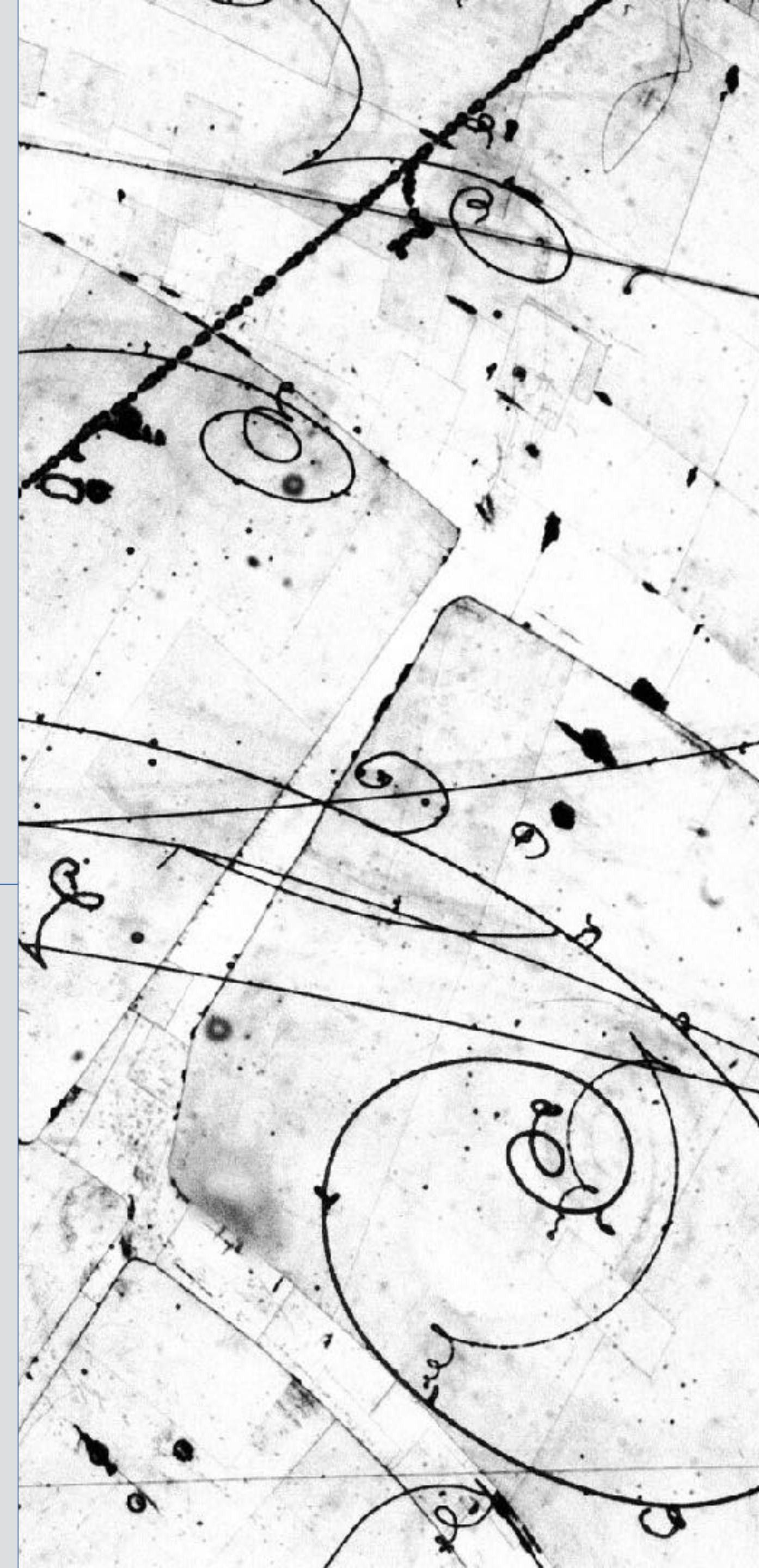
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Science & Technology
Facilities Council



Acknowledgments & References

Lecture (and material) inherited from **Francesca Pastore**

References

- *N. Ellis*, “**Trigger and Data Acquisition**”, Proceedings from the 5th CERN-Latin American School of High-Energy Physics, 15 - 28 Mar 2009, Colombia, CERN Report Number CERN-2010-001.
- *A. Hocker*, “**Trigger and Data Analysis**”, Lectures at HCPSS, 8-17 June 2009, CERN.
- *R. Frühwirth, M. Regler, R.K. Bock, H. Grote and D. Notz*, “**Data Analysis Techniques for High-Energy Physics**”, Cambridge University Press, 2nd Edition, August 2000, ISBN 0521635489.
- F. Winklmeier “**Particle Detectors – Trigger/DAQ**”, CERN Academic Training Lecture Programme, 12th May 2016.

Slide theme courtesy of *J.Lingemann*

Today's trigger menu

Introduction to trigger concepts

- What is all this triggering fuss about?
- Requirements and constraints
- Efficiencies and how to measure them
- Examples, examples, example...

Trigger architectures and hardware

- From simple, home-made trigger systems...
- ...to highly complex, multi-level triggers
- Dead time
- First-level trigger systems
- High-level trigger systems

Today's trigger menu

Introduction to trigger concepts

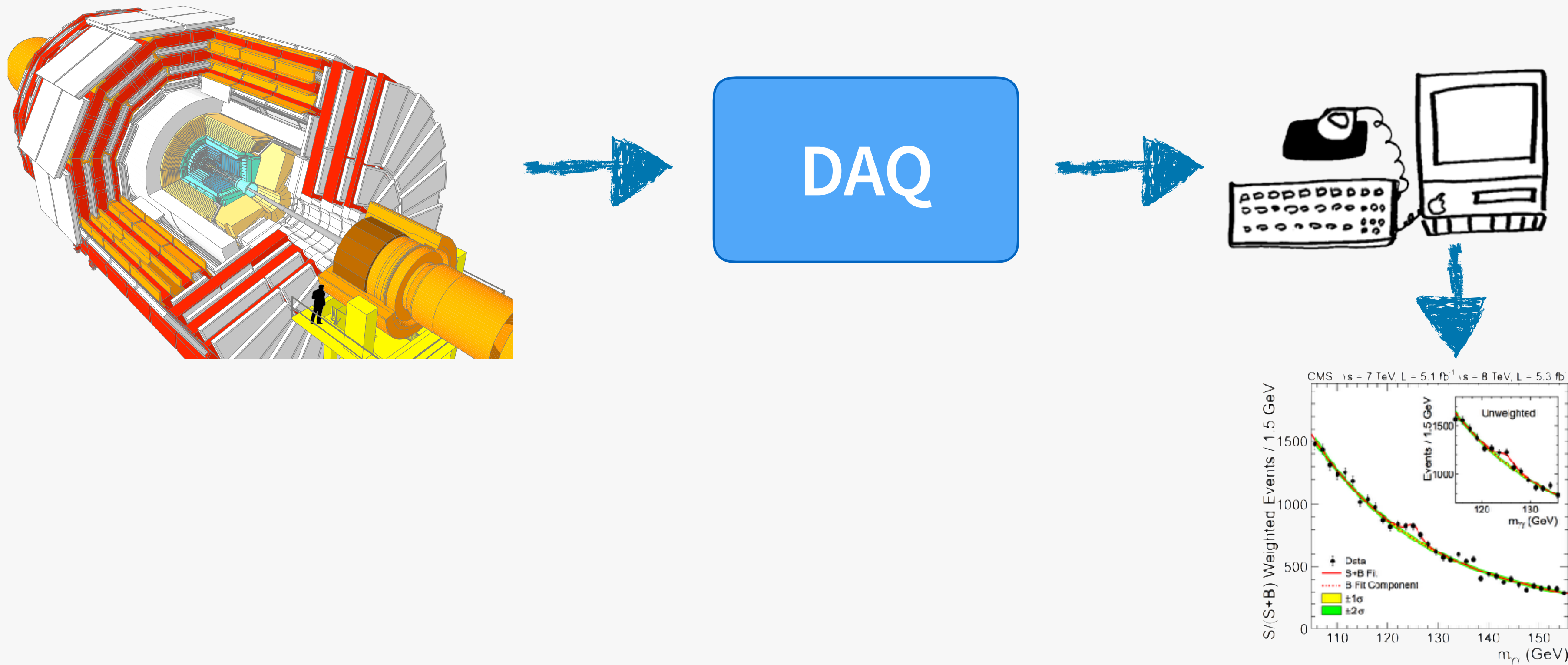
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Reminder - DAQ

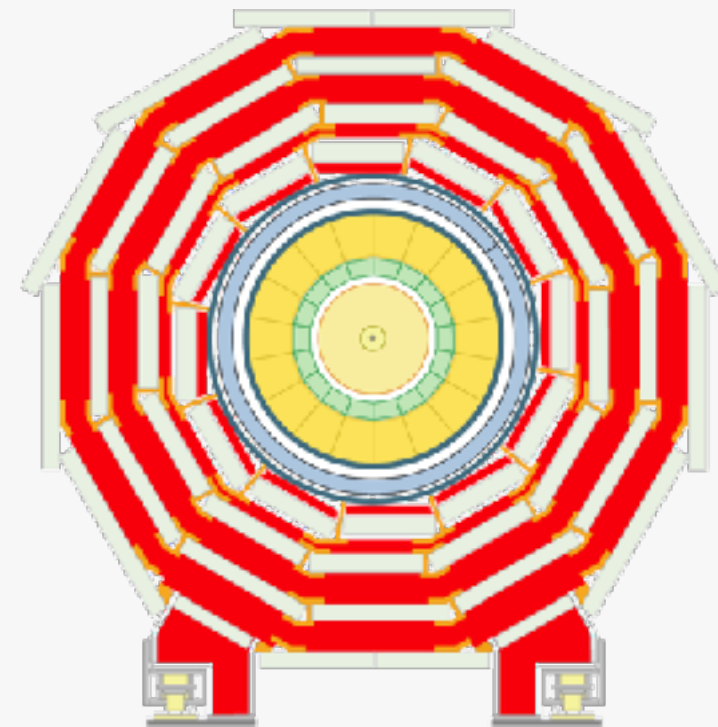
The **Data AcQuisition (DAQ)** system collects the data from the different parts of the detector, converts the data in a suitable format and saves it to permanent storage



The problem is...

[Slide taken from from *F. Winklmeier*, CERN, 2016]

...that modern large-scale experiments are **really BIG**



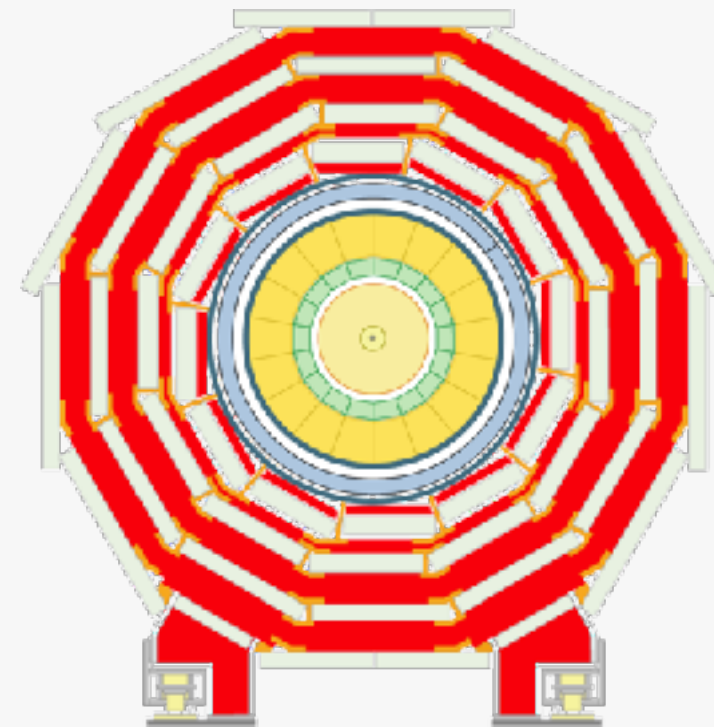
i.e. LHC experiments (ATLAS/CMS)

- ▶ **~100M channels**
- ▶ **~1-2 MB** of RAW data per measurement

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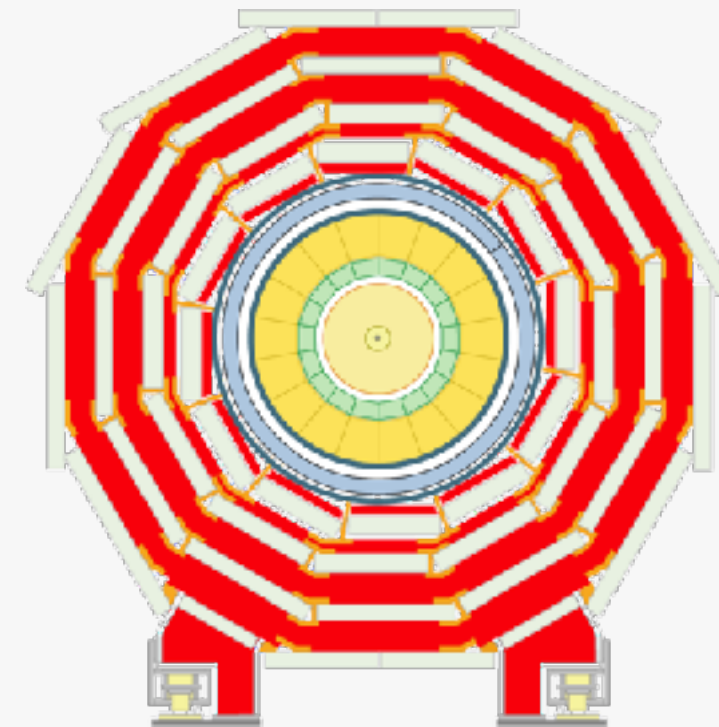
... and **really FAST**

- ▶ **~40 MHz** measurement rate (every 25 ns - @ the LHC)

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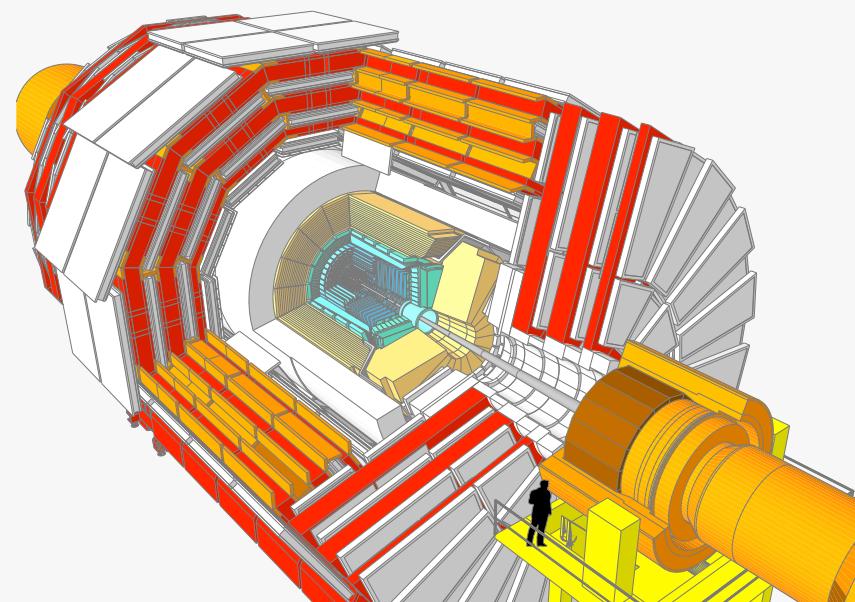


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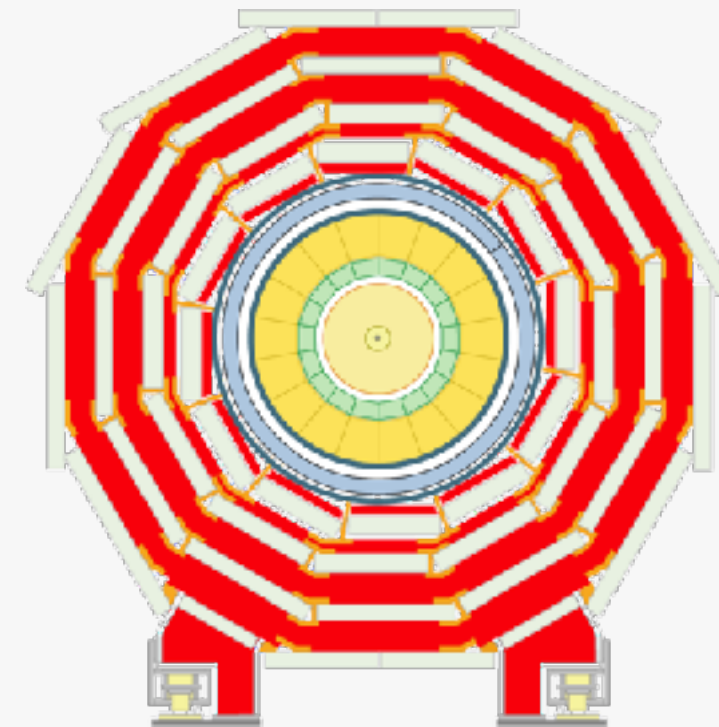
DAQ



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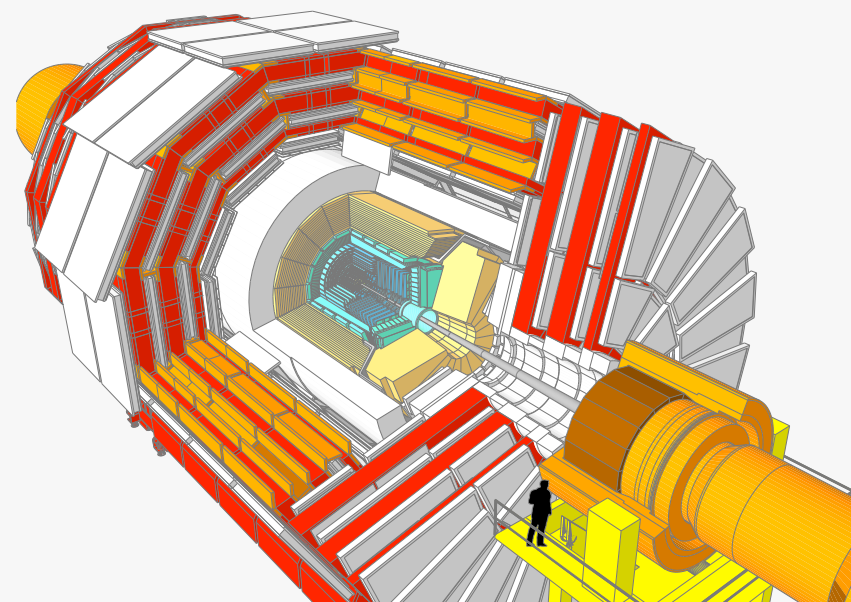


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DAQ

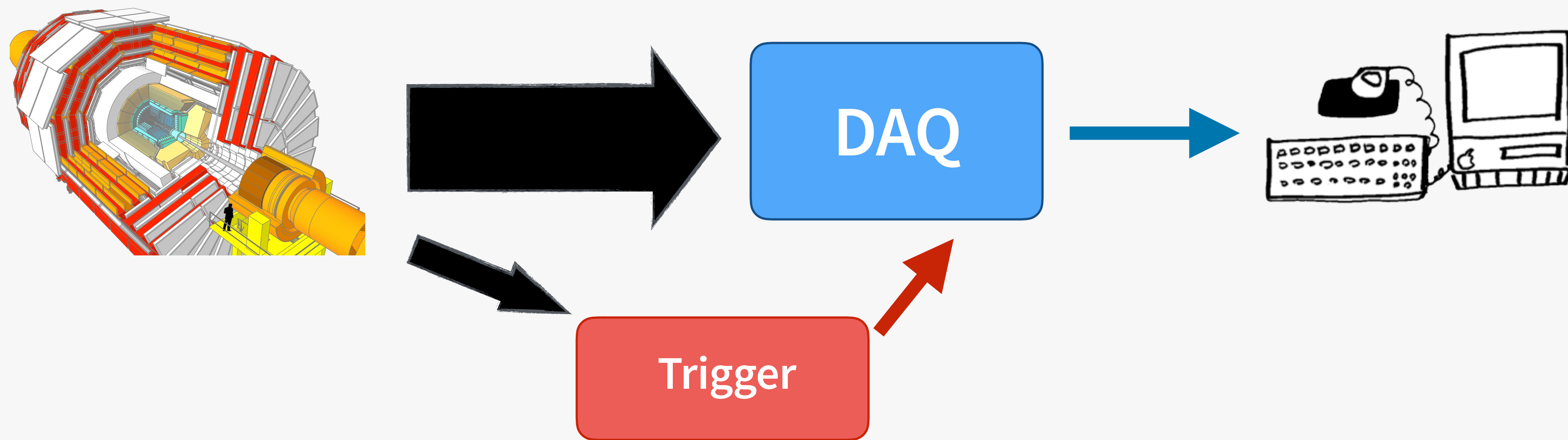


Data volume is a *key problem* in modern large-scale experiments

Definitions - Trigger

The **Data AcQuisition (DAQ)** system collects the data from the different parts of the detector, converts the data in a suitable format and saves it to permanent storage

The **Trigger** is the system that decides, in real time, whether to read out or discard the measurements corresponding to each observed interaction for offline analysis.



...a bit like...



the elusive subject
New physics
(somewhere in there)

bystanders, obtrusions,
lookalikes
“Old” physics

the shutter release
Trigger signal

the photographer
Trigger

the camera
Detector & DAQ



... taking a photo...

- ▶ Tune **aperture**, **timing**, **focus**
- ▶ Check **light levels**
- ▶ Hold your hand **steady**
- ▶ Continuously **monitor** the camera screen
- ▶ **Shoot** when the subject in position



Ensure good accuracy

Ensure good sensitivity

Ensure good synchronisation

Analyze the stream of data

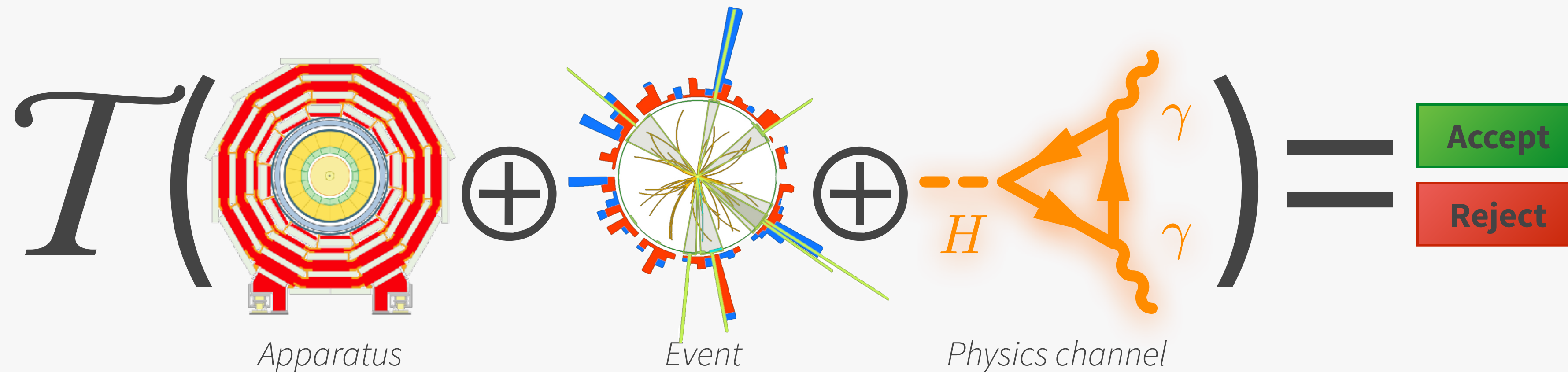
Start capturing the ‘event’

What is a trigger system, in practice?

[Slide taken from from A. Hocker, CERN, 2009]

Hardware/software processor filtering the event stream based upon a ‘quick look’ at the data

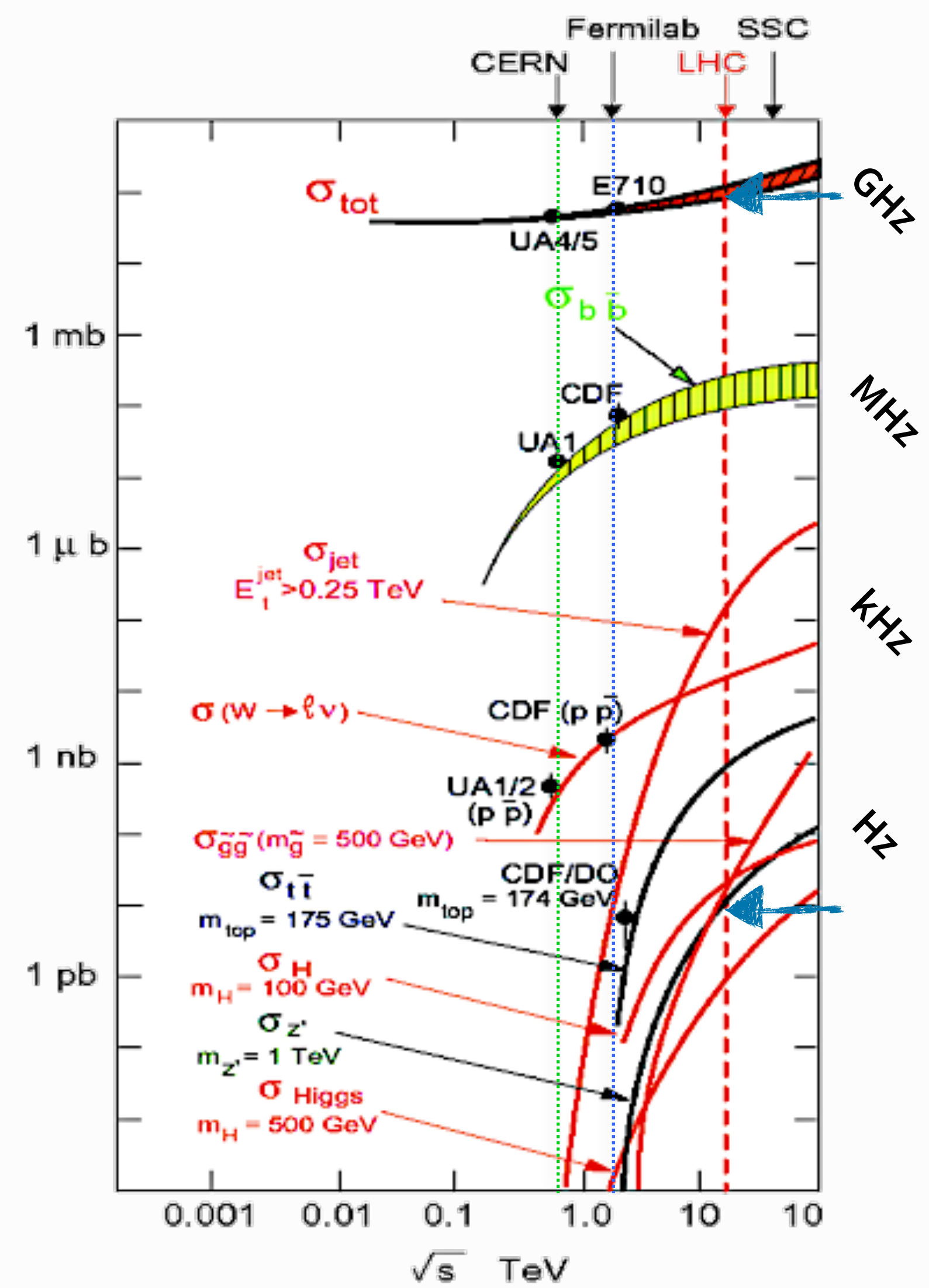
- ▶ Look at (almost) **all events**, select **most interesting** ones, collect **all detector information** and **store it** for offline analysis (for a **reasonable amount of money**)
- ▶ It must accept interactions at a **rate low enough** for storage and reconstruction



Key questions:

- ▶ What is “interesting” and what not?
- ▶ How selective must it be?
- ▶ How fast must it to be?

What to trigger on (at the LHC)?



Expected production rate for process X:

$$R_X^{\text{prod}} = \sigma_X \times \mathcal{L}$$

Process	Cross section (nb)	Production rates (Hz)
	@ 14 TeV	@ $\mathcal{L} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
inelastic	10^8	10^9
$b\bar{b}$	5×10^5	5×10^6
$W \rightarrow \ell \nu$	15	150
$Z \rightarrow \ell \ell$	2	20
$t\bar{t}$	1	10
H	0.05	0.5

Many orders of magnitude between QCD background and primary physics channels rates

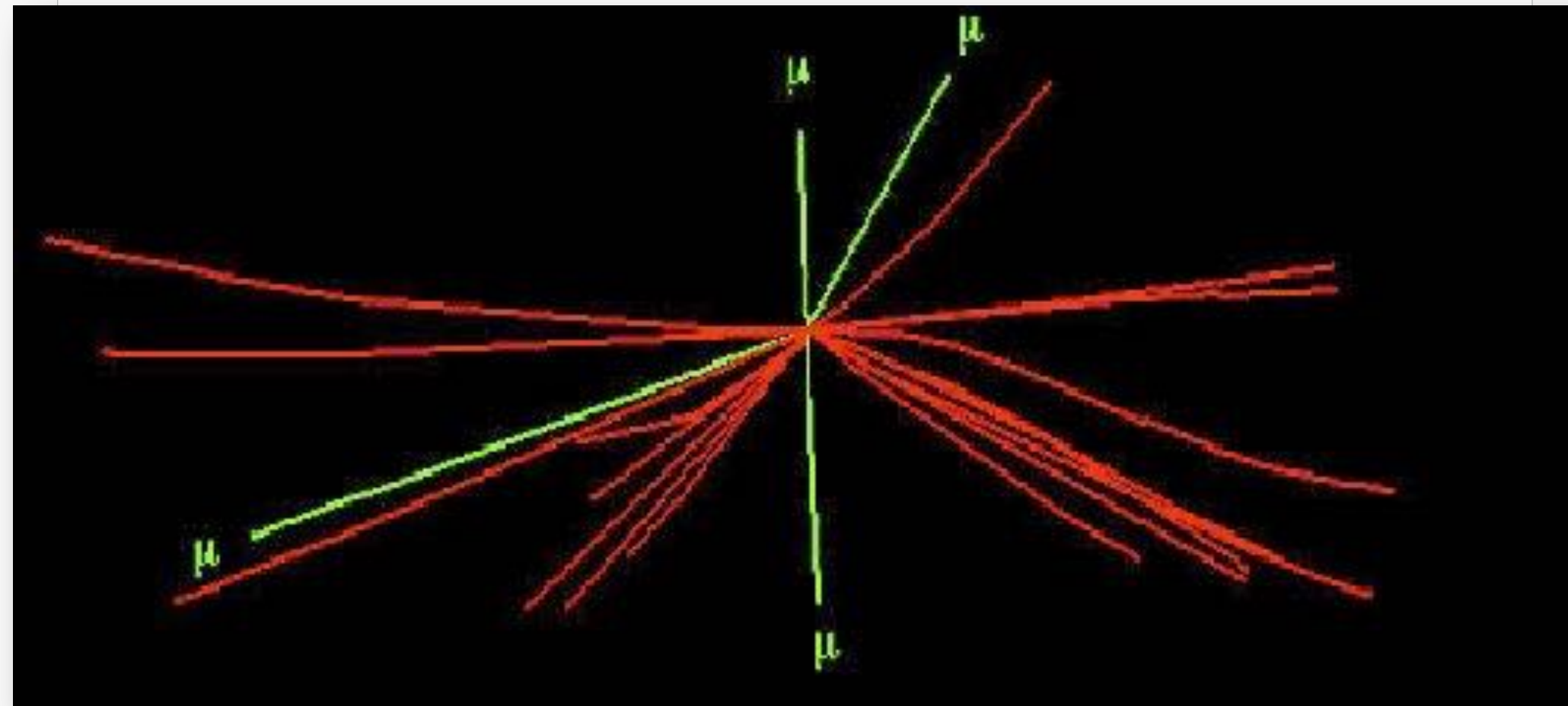
$$\frac{\sigma_{\text{tot}}}{\sigma_H} \approx 10^{11}$$

Even if it would be feasible, saving all events at hadron collider is not useful

How to identify the interesting events?

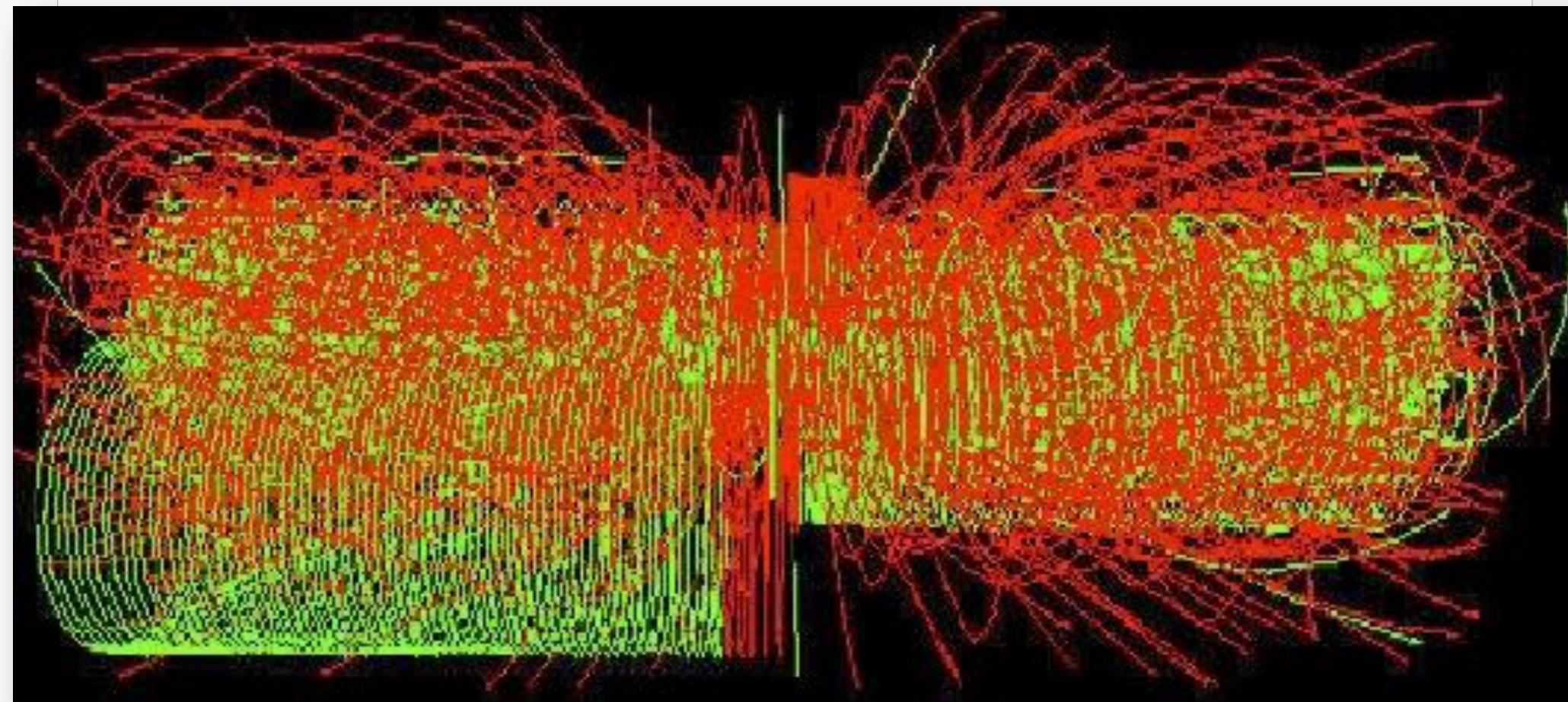
Only high- p_T tracks

Higgs $\rightarrow 4\mu$



High- p_T tracks

+30 MinBias

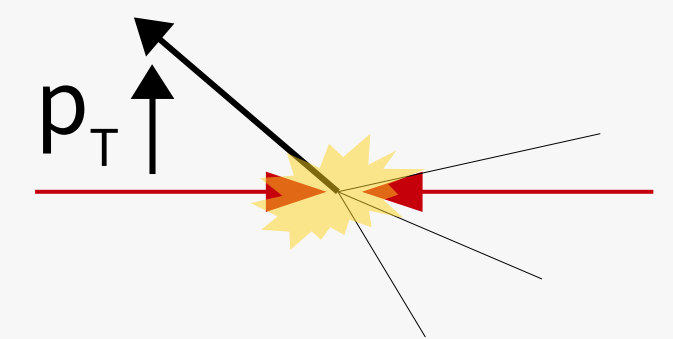


Example: Higgs $\rightarrow 4\mu$ events

- ▶ “Pretty interesting” process
- ▶ Key to the 2012 Higgs discovery

In practice:

- ▶ Hidden under tons of “old” physics
 - Lots of low momentum particles
- ▶ Exploit the physics signature to identify the underlying Higgs decay
 - 4 high-momentum μ



“Interesting” physics usually is high- p_T

What trigger rate can be afforded?

The **Data AcQuisition (DAQ)** system collects the data from the different parts of the detector, converts the data in a suitable format and saves it to permanent storage.

DAQ Bandwidth mainly constraint by available technologies, size and costs:

- ▶ **Finite storage capabilities**
- ▶ **Finite computing power** (available for online and offline processing)

Maximum allowed trigger rate determined by typical event size:

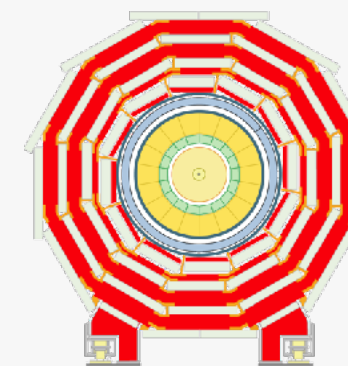
$$B_{DAQ} = R_T^{max} \times S_E$$

DAQ Bandwidth **Maximum Trigger rate** **Event size**

How many particles per event?

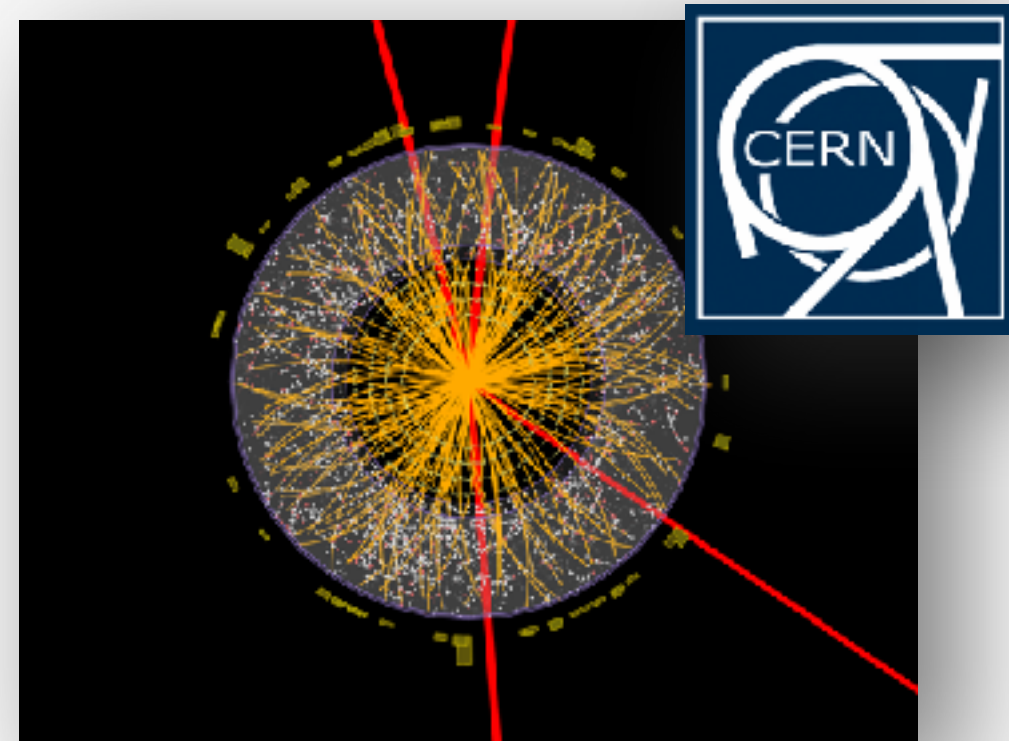
How many FE channels?

FE channels in ATLAS/CMS



- ▶ $O(10^7)$ in inner detector
- ▶ $O(10^5)$ in calorimeters
- ▶ $O(10^6)$ in muon detectors

Nota bene: Data reduction *not* always feasible



LHC – ATLAS

Project started in 1996
Technology chosen in 2000
Start data-taking 2008

Full p-p collision rate: 40 MHz
Average event size: 1.5 MB
Full data rate: ~60 TB/s

Defined physics channels
Complex trigger: reduces 5 orders of magnitudes to
1 kHz

Affordable DAQ rate: ~1.5 GB/s -> 1 KHz
Data distribution (GRID)



SKA (Square Km Array)

Project started in 2011
Technologies under evaluation now
Start operations in 2024

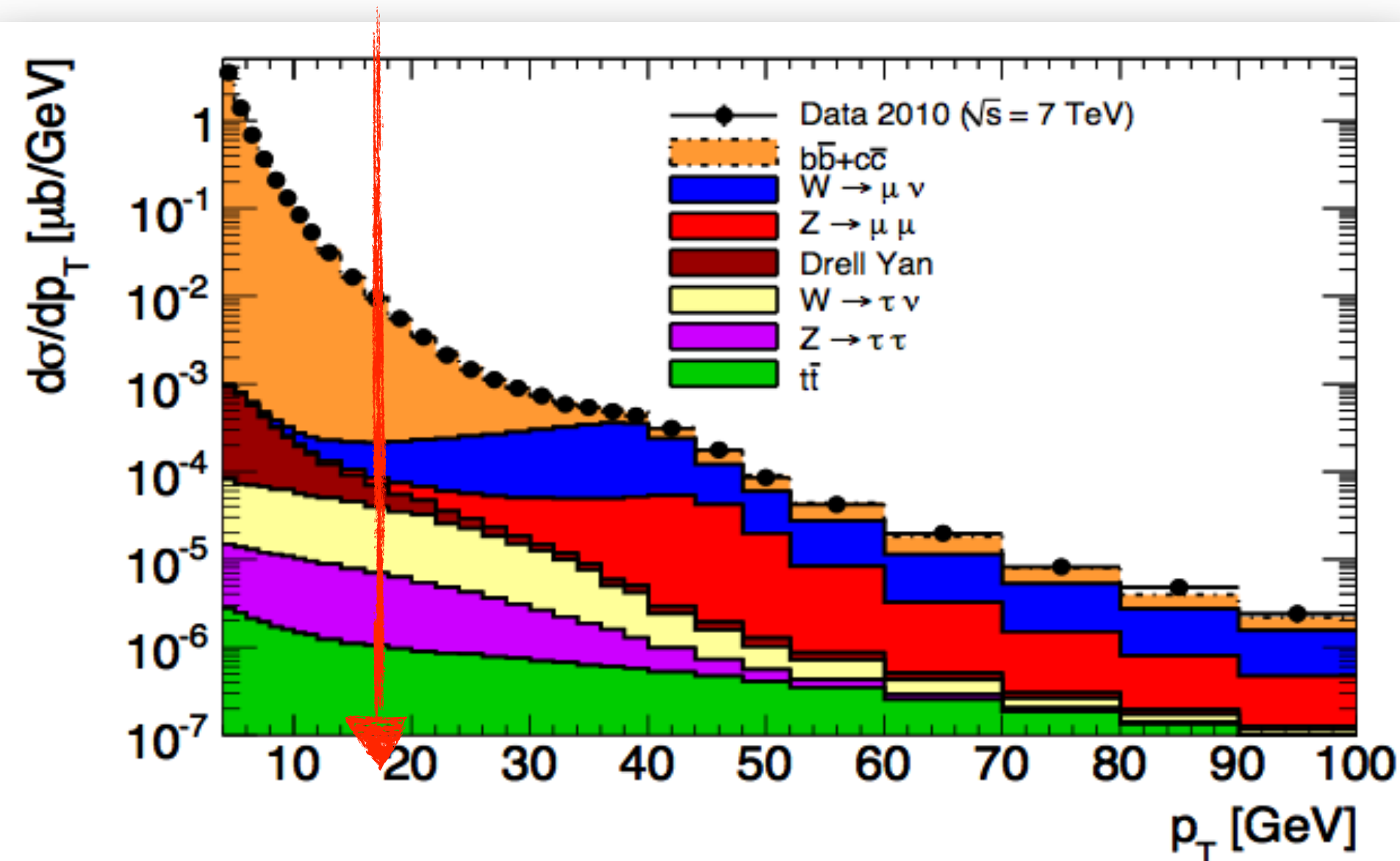
Photograph the sky continuously
1.12 PB/s of photons collected

EXASCALE system: 10^{18} operations for correlation
and imaging
Simple correlator : 10 TB/s
Total Internet Traffic \approx 8 TB/s in 2010

Required large computing power
Big-data and cloud-computing drive market

Requirement 1: High Background Rejection

Inclusive single muon p_T spectrum



μp_T

background

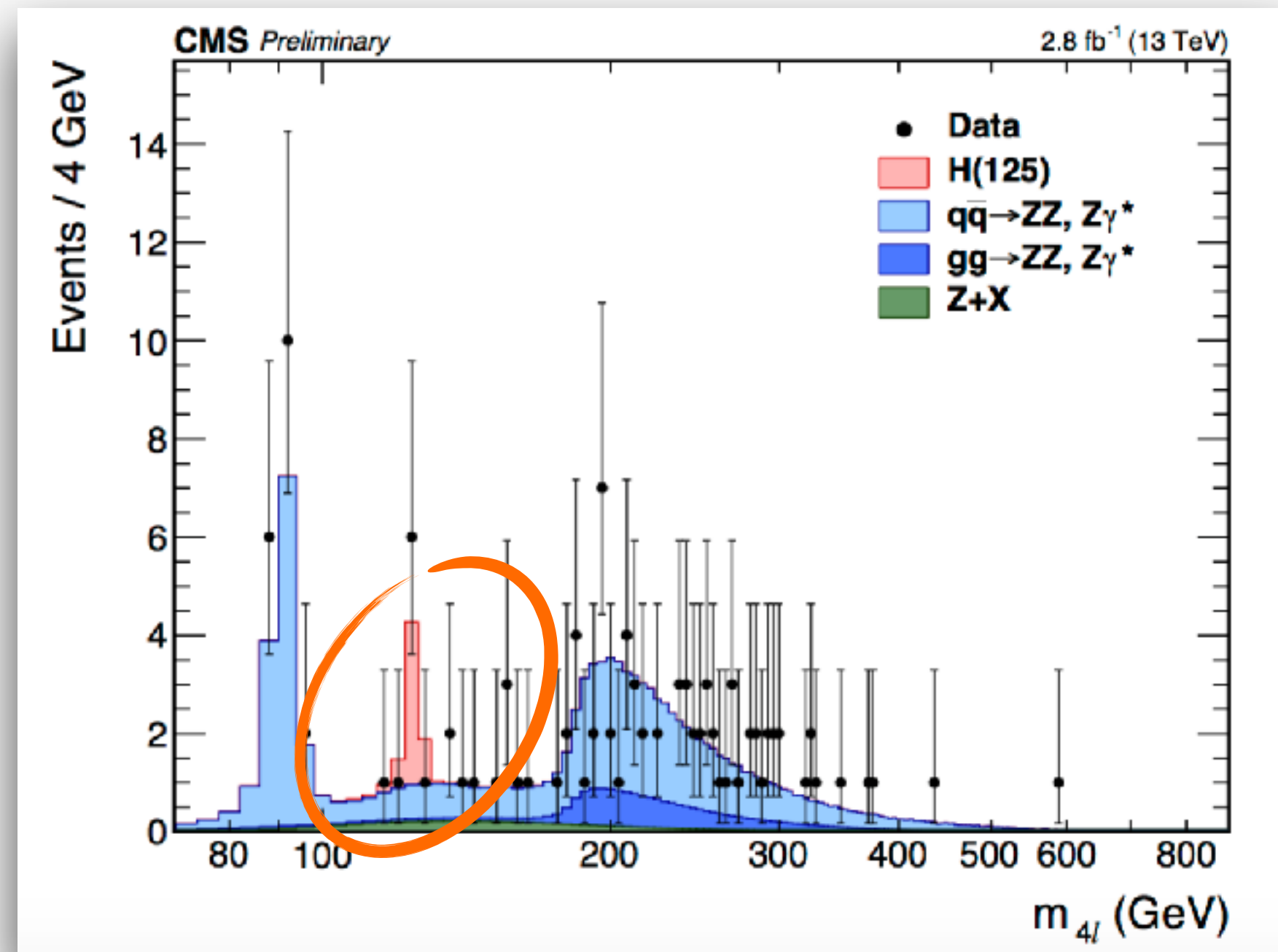
signal

$$R_{bkg} = 1 - \frac{N_{bad}^{accepted}}{N_{bad}^{prod/exp}}$$

Background rejection (Rate control)

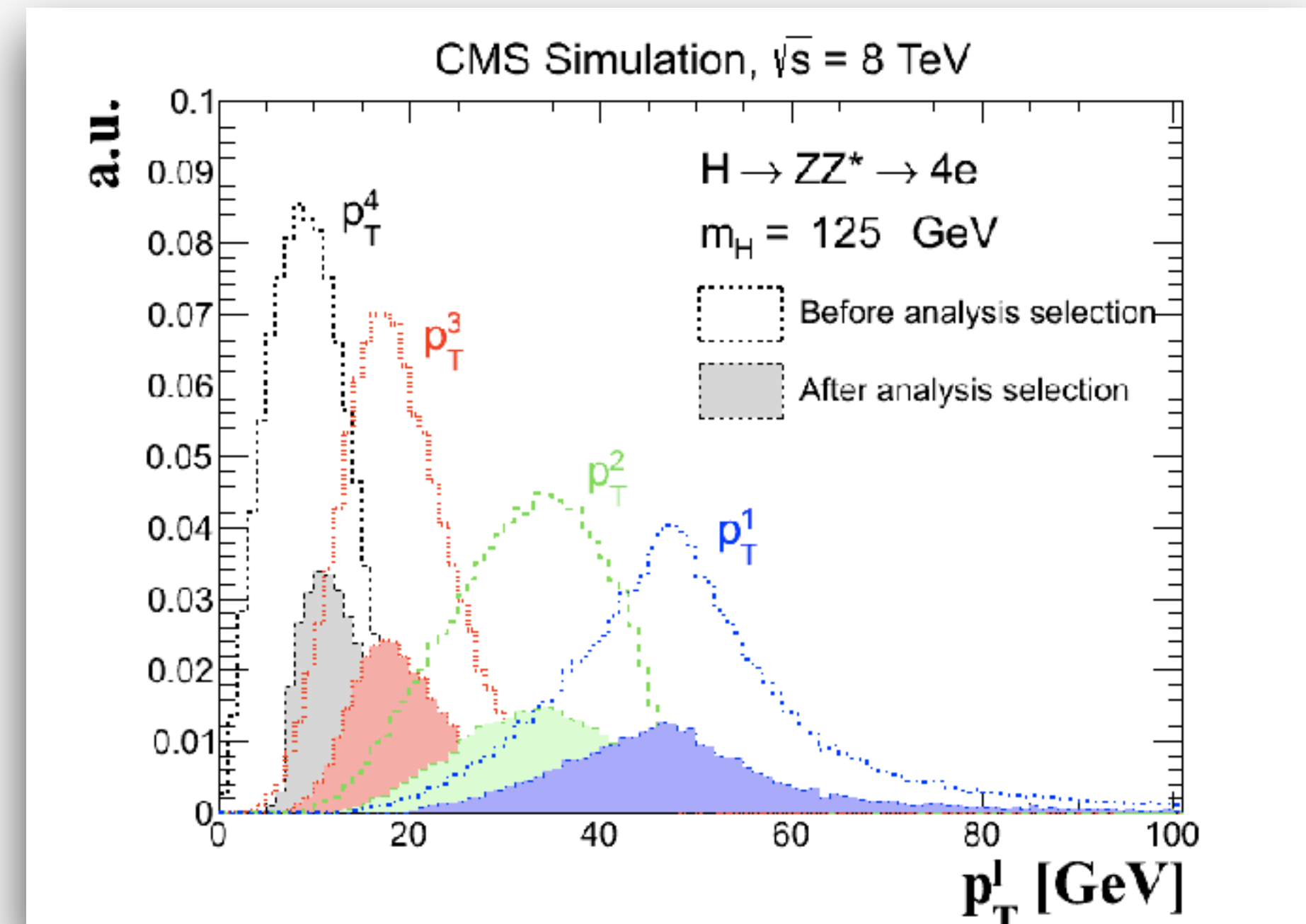
- Instrumental or physics background
 - ▶ Need to identify characteristics which can suppress the background
 - ▶ Need to demonstrate solid understanding of background rate and shapes
- Backgrounds sometimes known with large uncertainties
 - ▶ Make your trigger flexible and robust

Requirement 2: High Signal Efficiency



4-leptons invariant mass,
selected events for H→ZZ*→4l

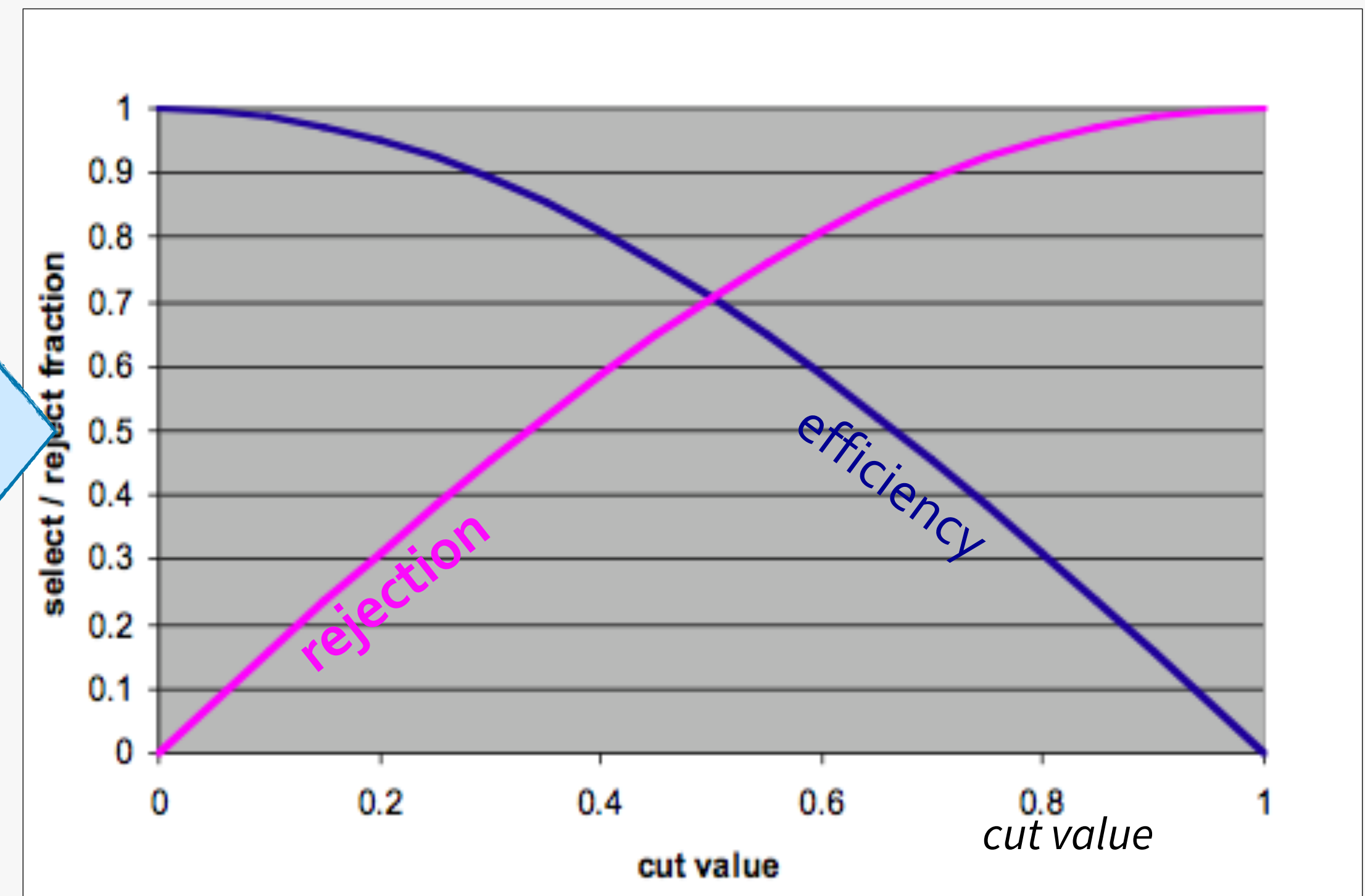
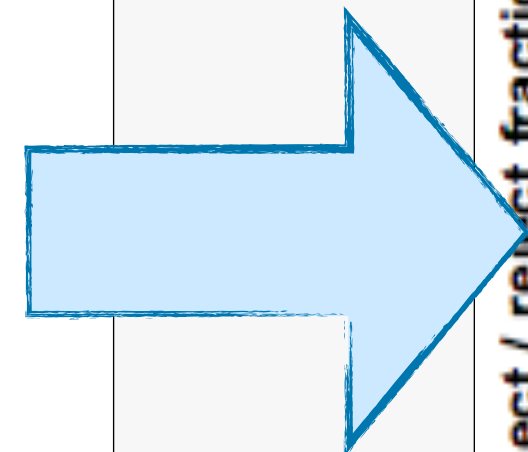
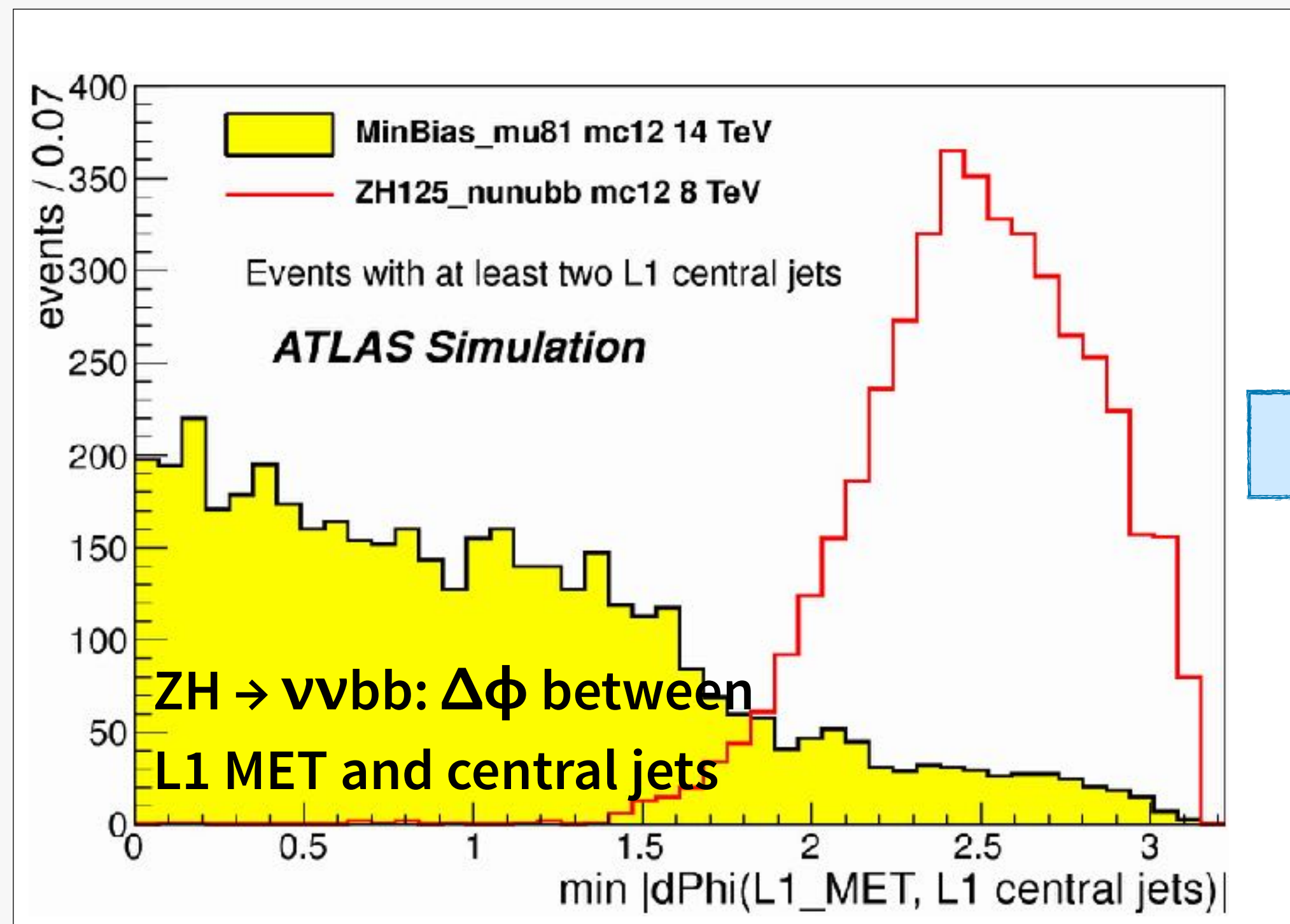
$$\epsilon_{trg} = \frac{N_{good}^{accepted}}{N_{good}^{prod/exp}}$$



Maximise trigger acceptance

- **Ideal:** complete acceptance for all events of interest
- **In practice,** aim for: trigger thresholds lower than any conceivable analysis cut

In real life: find the best compromise possible



Basic requirements (I)

Need **high efficiency** for selecting processes for physics analysis

- ▶ Selection should not have biases that affect physics results
- ▶ Event losses must be low (and known)
- ▶ ...

Need **large reduction** of rate from unwanted high-rate processes
(according to the capabilities of DAQ and also offline!)

- ▶ Instrumental background
- ▶ High-rate physics processes that are not relevant for analysis

System must be **affordable**

- ▶ e.g algorithms executed at high rate must be fast

Basic requirements (II)

Robustness is essential

- ▶ Trigger is a ‘mission critical’ system; no data can be taken without it
 - It must function, and function predictably, under all experimental conditions
- ▶ **Simple** and **inclusive** triggers are preferable, whenever possible

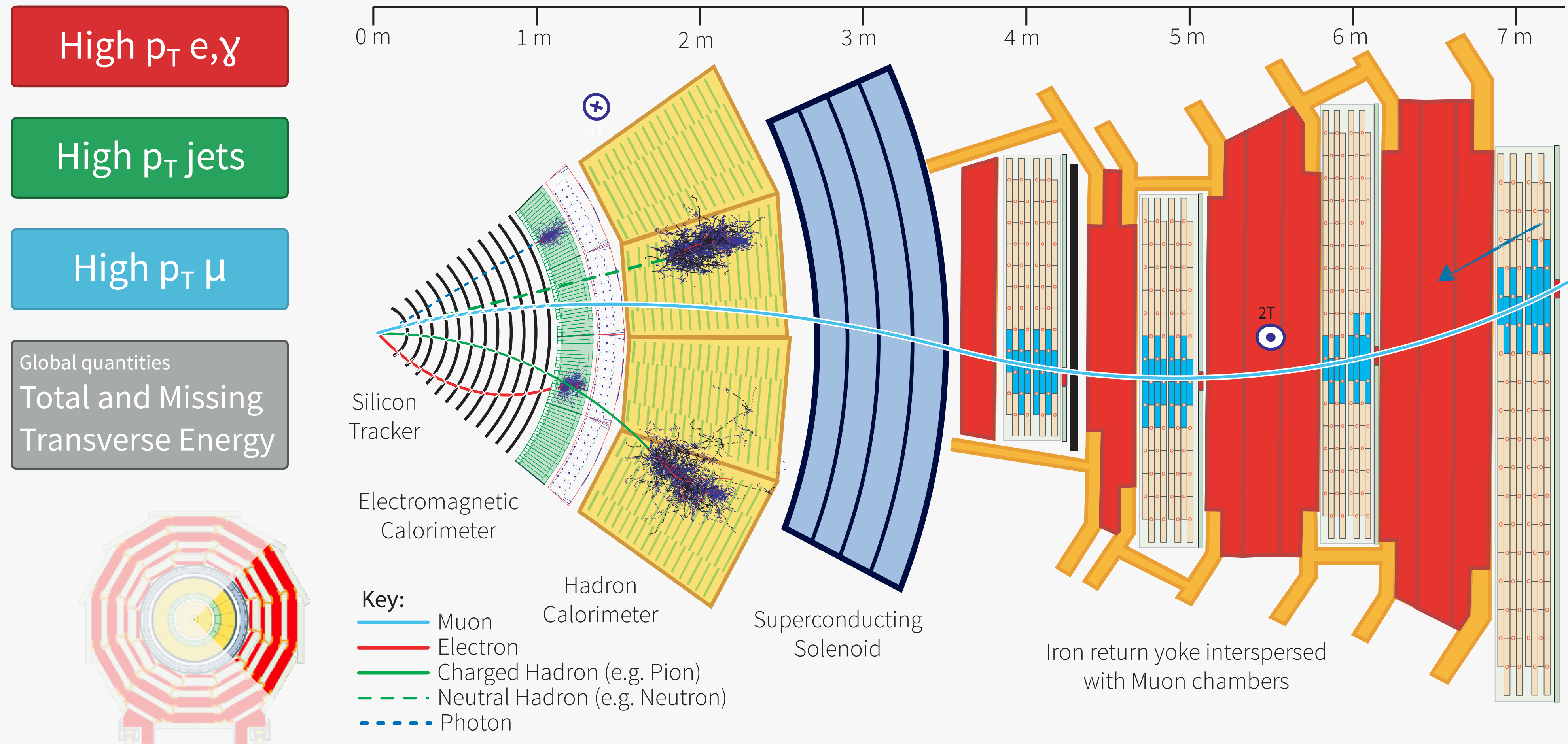
Highly flexible, to react to changing conditions (e.g. wide luminosity range)

- ▶ Programmable thresholds, high granularity to maintain uniform performance, ability to follow luminosity, beam-size and vertex position changes
- ▶ Long term effectiveness, to reach physics results even after >10 years of data taking

And now, into
the details...

What is the trigger looking for?

Trigger Signatures: Features distinguishing new physics from the bulk of the SM cross-section



Trigger algorithms

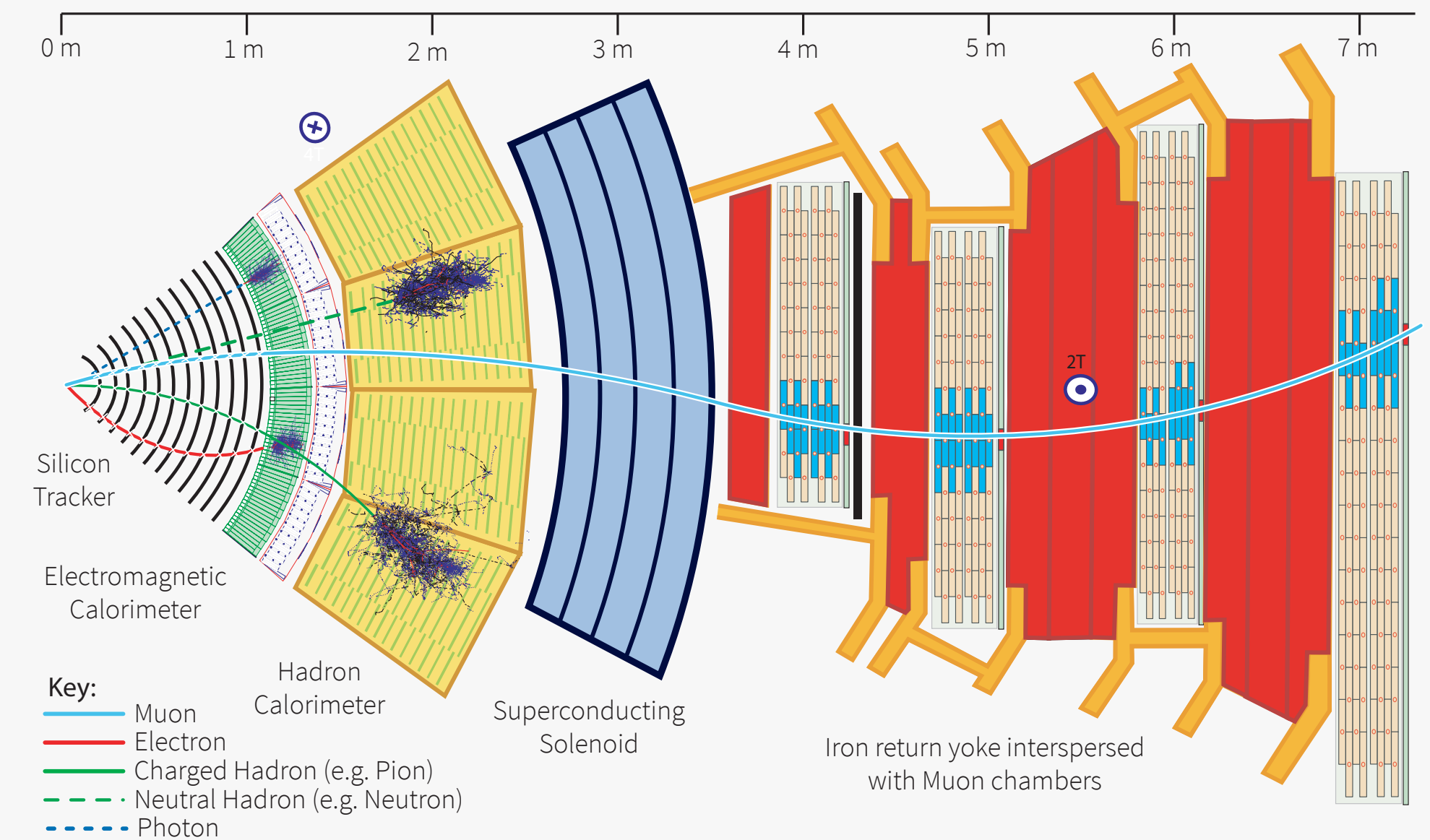
Trigger system composed by several **trigger algorithms**

- ▶ Operate on trigger information from subdetector(s) to identify signatures
- ▶ Generally, **several algorithms operate in parallel to find different signatures***
 - e.g. calorimeter information used to find electrons + jets in parallel
- ▶ Algorithms must cover whole detector in an unbiased way
- ▶ Output is a count or list of trigger signatures, possibly with additional information
 - Object pt, position, charge, 'quality', etc

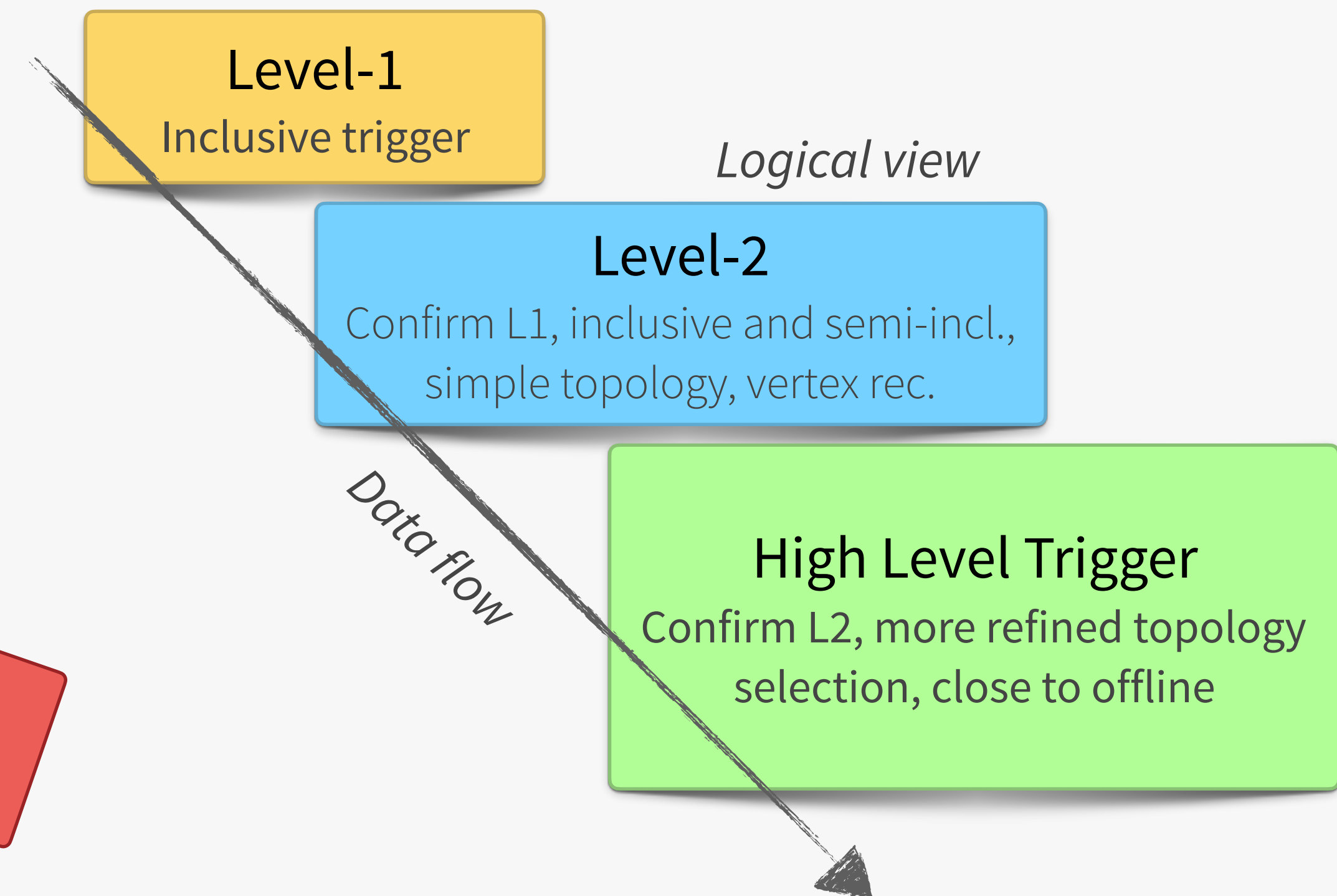
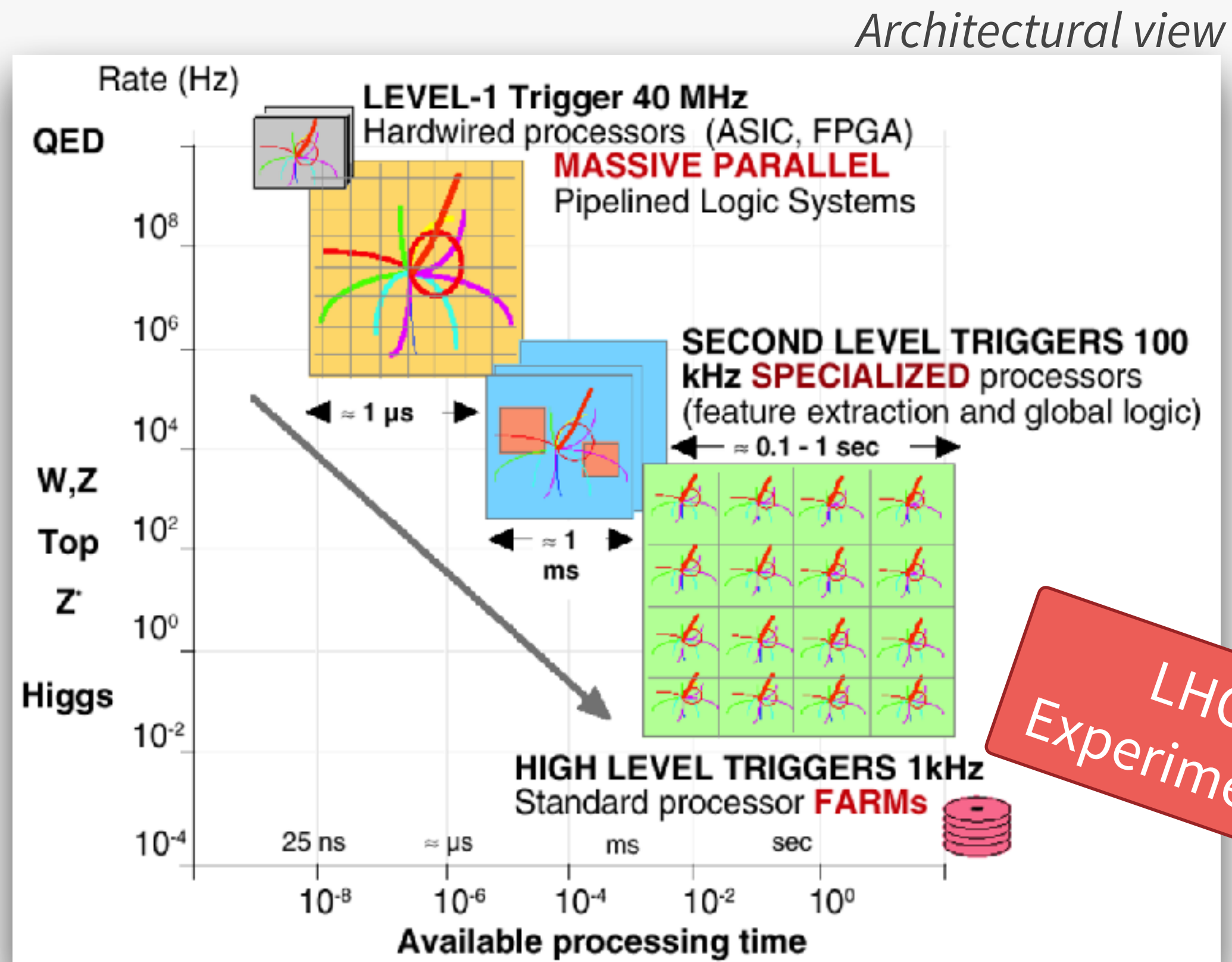
Some algorithms are 'global' over the whole detector

- ▶ Examples: Missing Et, Total Et, Ht, global object counts

* or, to be precise, objects



Multi-level triggers

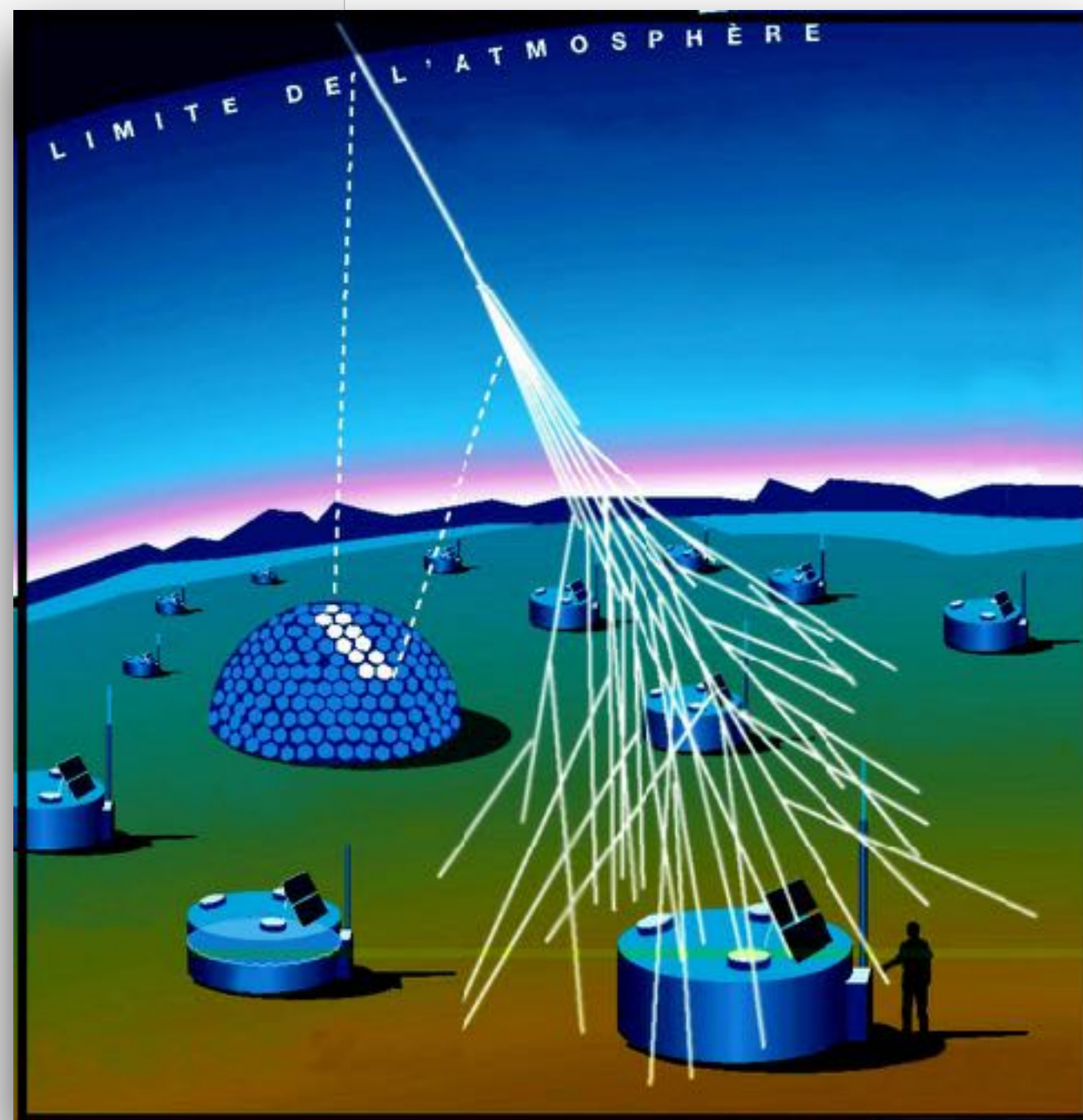


Trigger decision divided in **multiple sequential stages**

Progressive reduction in rate after each stage of selection.

- Allows use of more and more complex algorithms at affordable cost

Simple signatures: Auger observatory (fluorescence)



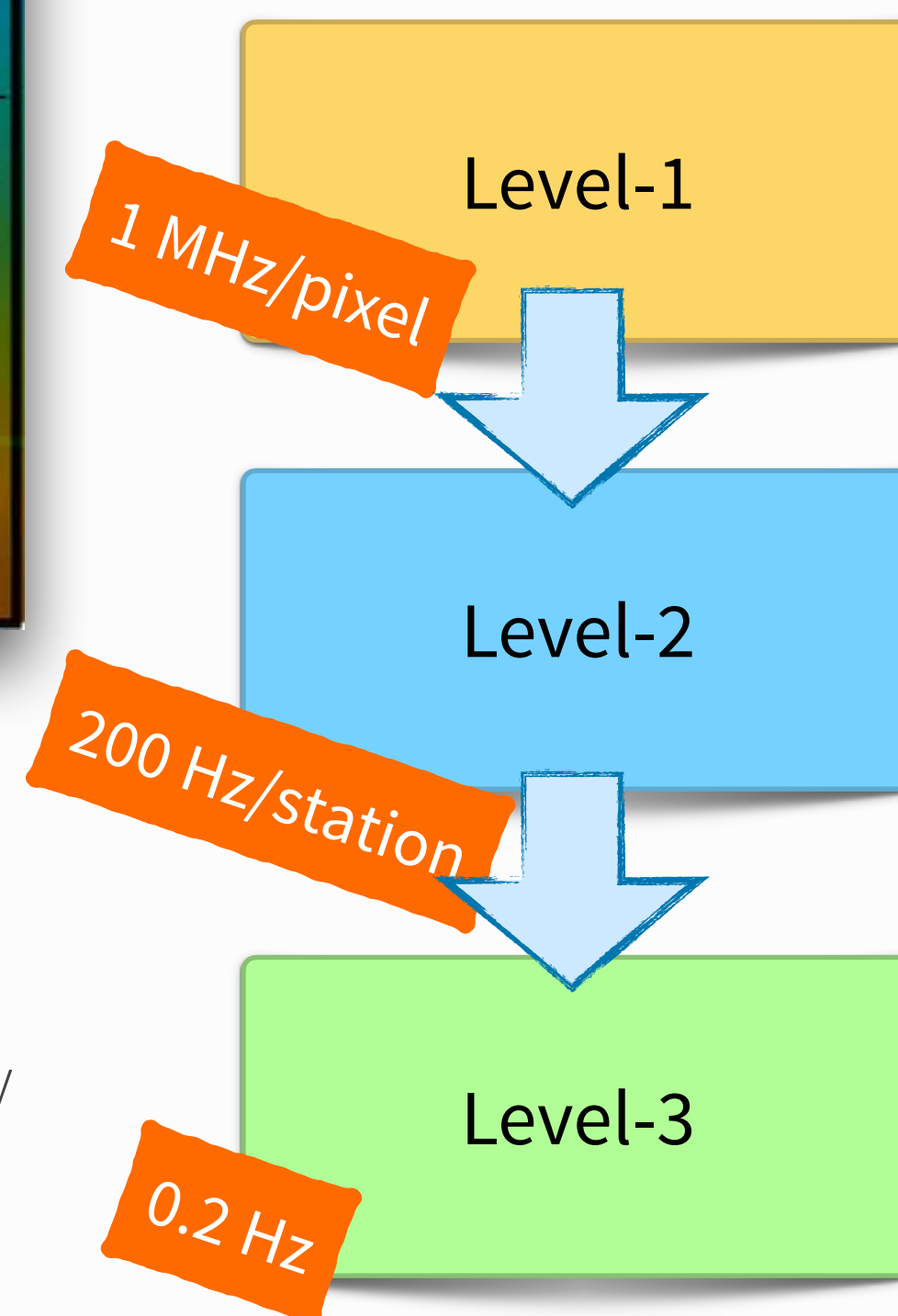
Surface Detector: array of ~1600 water Cherenkov stations over 3000 km² on ground, to identify secondary particles

Florescent Detector: 4 UV telescopes measure the shower Energy longitudinally

Detect air showers generated by cosmic rays above 10^{17} eV

- ▶ Expected rate < 1/km²/century.
- ▶ 2 large area fluorescence detectors

3-level trigger installed on each detector



L1: (local) select active pixels

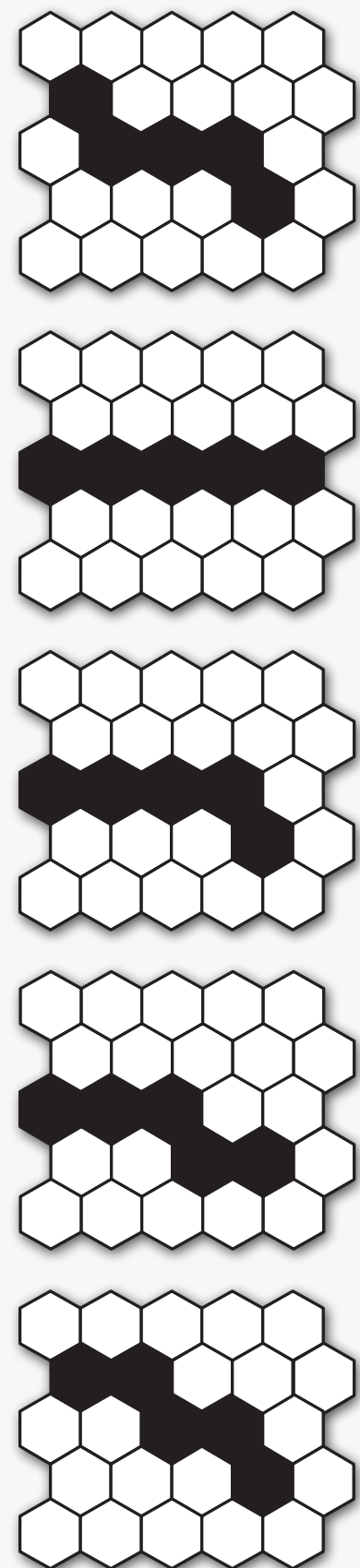
- ▶ ADC counts > threshold
- ▶ ADC digitises every 100 ns (time resolution)
- ▶ ADC values stored for 100 μ s in local buffers
- ▶ Synchronised via GPS clock signal

L2: (local) identifies track segments

- ▶ Geometrical criteria with programmable pattern recognition algorithms

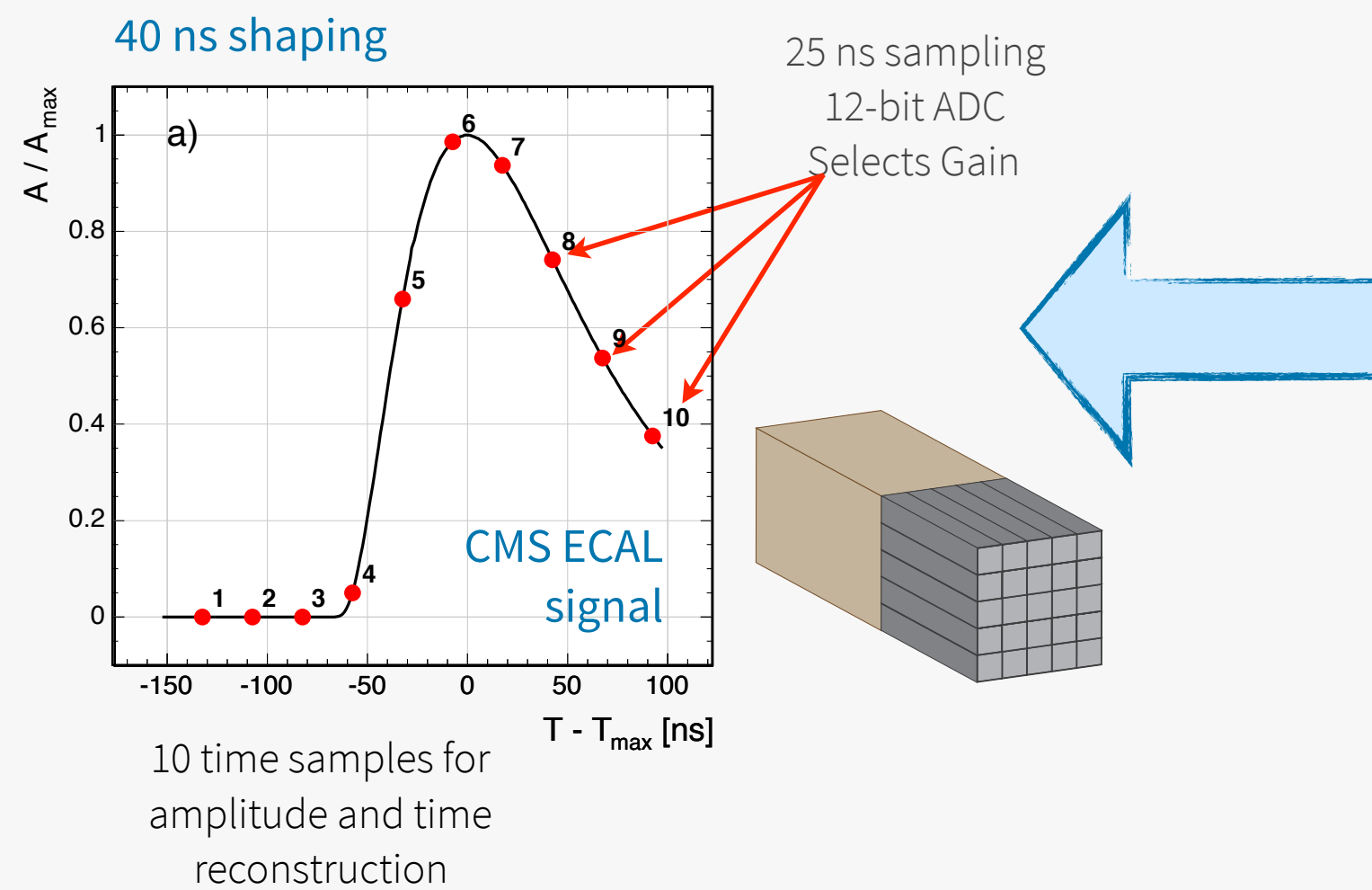
L3: (central) 3-D correlation between L2 triggers

Example of L2 patterns



Multiple signatures: the CMS calorimeter trigger

High energy e , γ , τ , jets, missing E_T , ΣE_T identification



1: Dedicated Front-End electronics

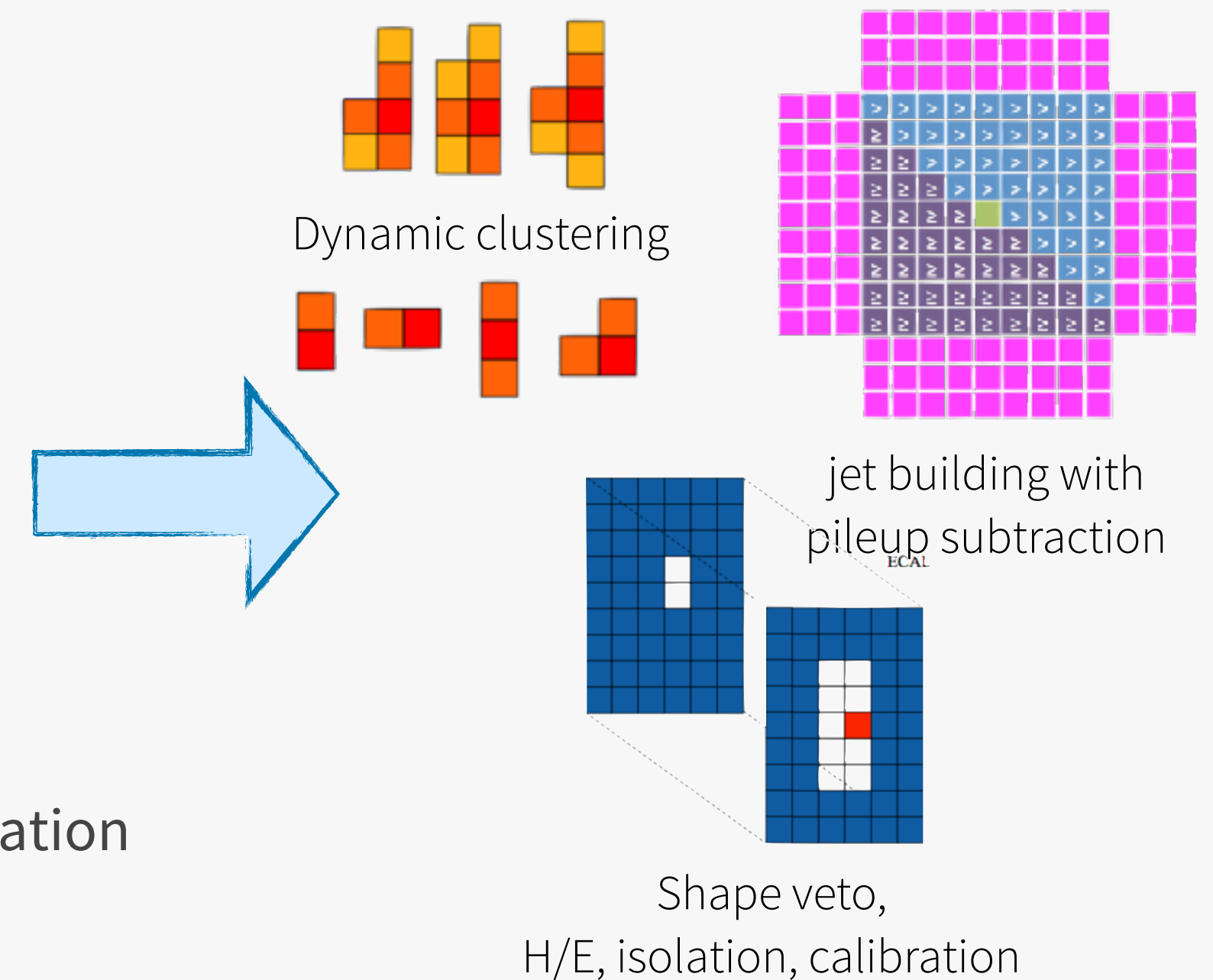
- ▶ ECAL/HCAL front-end, **shapes**, **digitises** and **sums** energy in trigger primitives

2: Level-1 Trigger

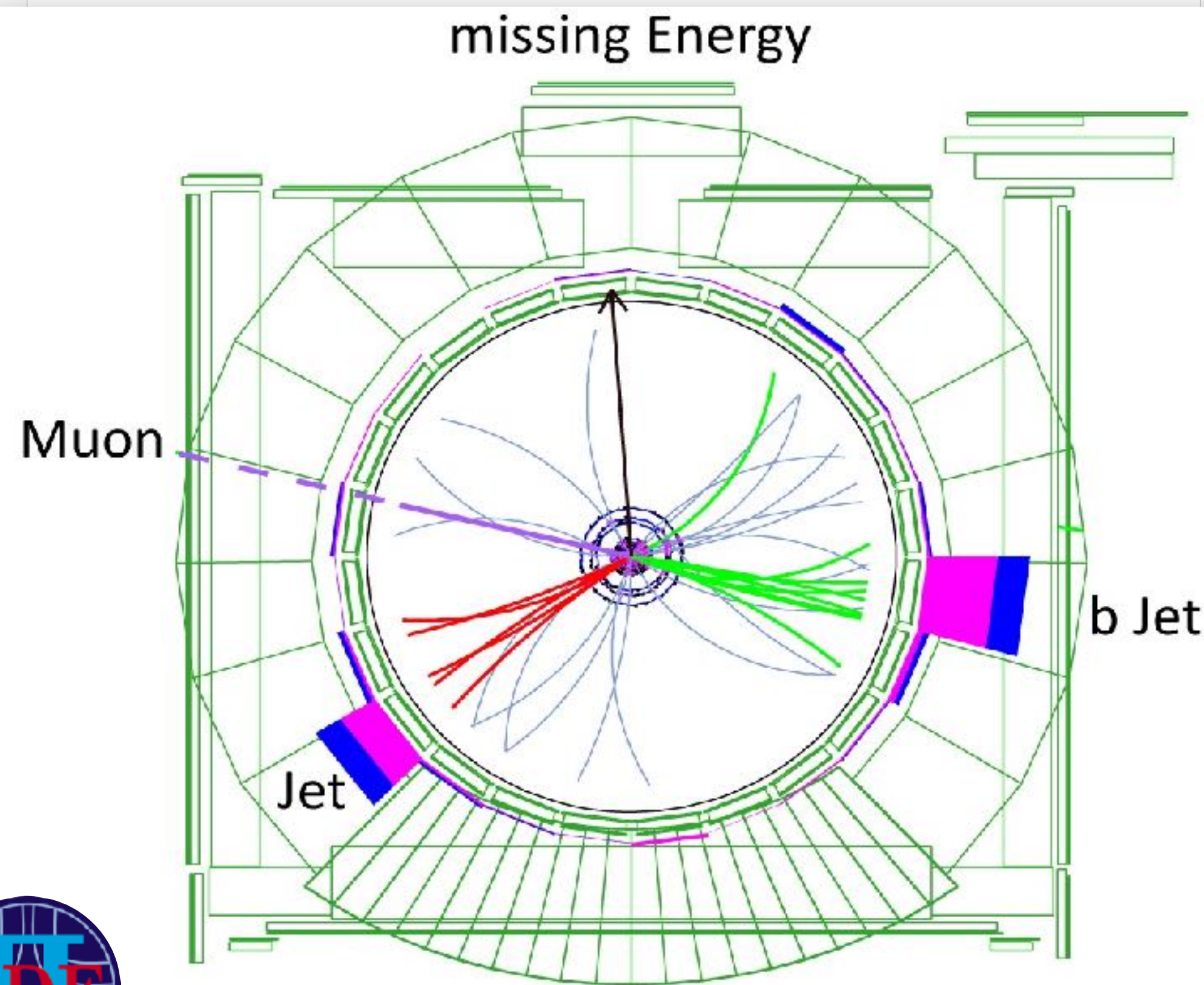
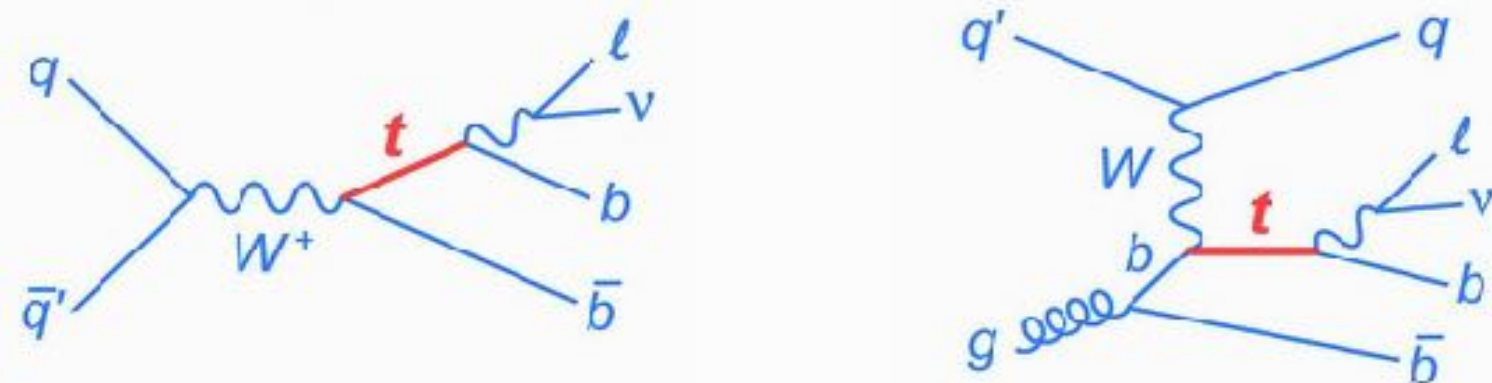
- ▶ Dedicated **high-speed processors** to apply **clustering algorithms** and programmable E_T thresholds

3: High-Level triggers

- ▶ Topological variables and tracking information
 - **e /jet separation using cluster shapes**
 - **e/γ separation using tracking**
- ▶ Isolation criteria
- ▶ Close to offline



CDF - Multi objects trigger



CDF single top event

Signal characterisation:

- ▶ **1 high p_T lepton**, in general isolated
- ▶ **Large MET** from high energy neutrino
- ▶ **2 jets**, 1 of which is a **b-jets**

L1-Trigger objects

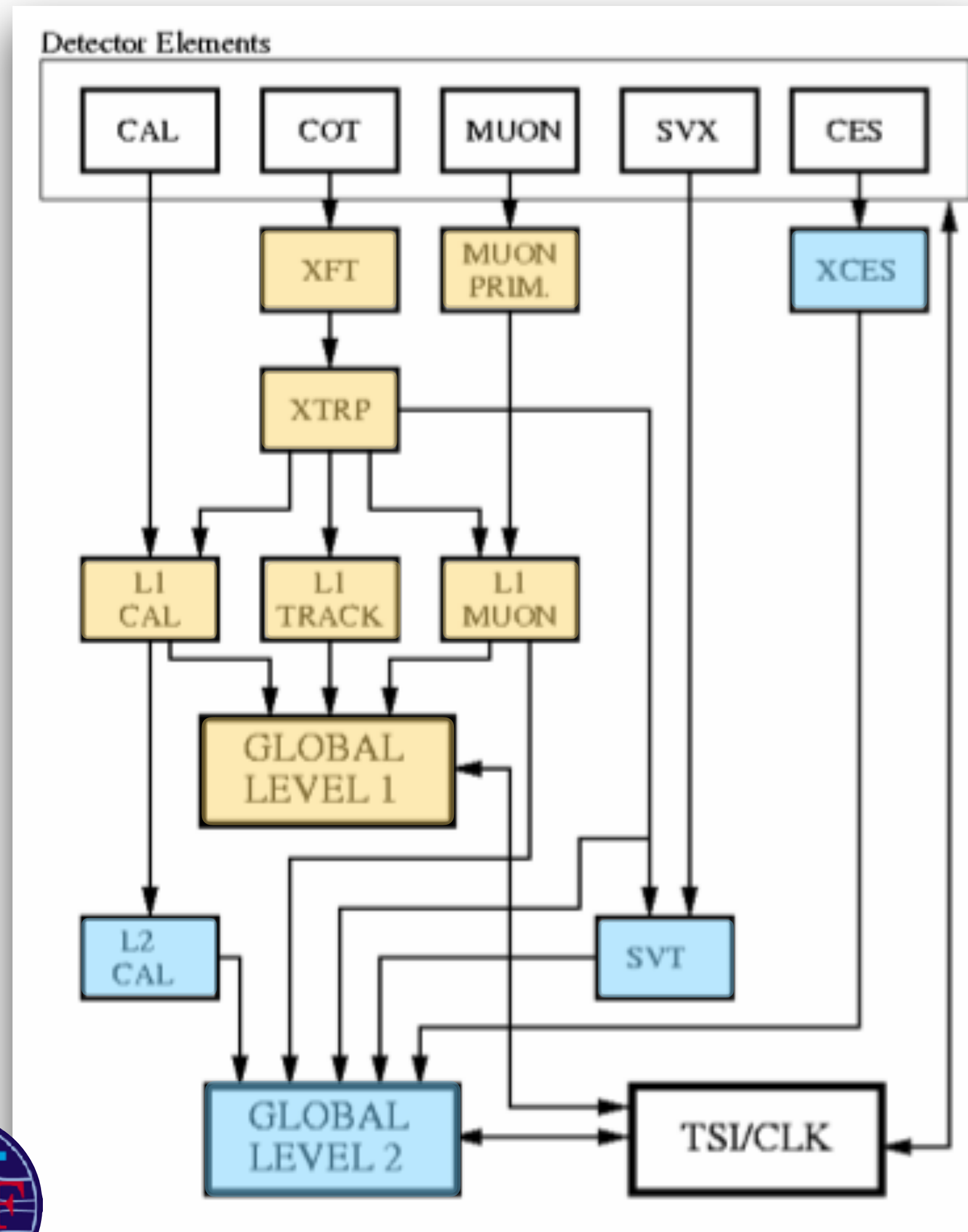
- ▶ Central tracking (XFT* $p_T > 1.5\text{GeV}$)
- ▶ Calorimeter
 - Electron (Cal + XFT)
 - Photon (Cal)
 - Jet (Cal EM+HAD)
- ▶ Missing ET, SumET
- ▶ Muon (Muon + XFT)

L2-Trigger objects

- ▶ L1 information
- ▶ SVT (displaced track, impact parameter)
- ▶ Jet cluster
- ▶ **Isolated** cluster
- ▶ Calorimeter **ShowerMax** (CES)

*XFT=eXtremely Fast Tracker

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- ▶ L1 information
- ▶ SVT (displaced track, impact parameter)
- ▶ Jet cluster
- ▶ Isolated cluster
- ▶ Calorimeter ShowerMax (CES)

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Trigger efficiency

Trigger is just another “cut” in the physics analysis event selection

- ▶ **Trigger efficiency must be precisely known** for cross-section measurements, etc.
 - For each trigger algorithm, at each trigger level

$$\sigma_X = \frac{N_{candidates} - N_{bkg}}{A \cdot \epsilon_{total} \cdot \int \mathcal{L} dt}$$

$$A \cdot \epsilon_{total} = A \cdot \epsilon_{Tracking} \cdot \epsilon_{Reco} \cdot \epsilon_{L1-Trg} \cdot \epsilon_{L2-Trg} \cdot \epsilon_{L3-Trg} \cdot \epsilon_{vertex} \cdot \epsilon_{analysis}$$

Trigger efficiency measurement

Definition

- ▶ Usually measured w.r.t. offline-reconstructed objects
 - e.g. # triggered electrons vs # offline electrons

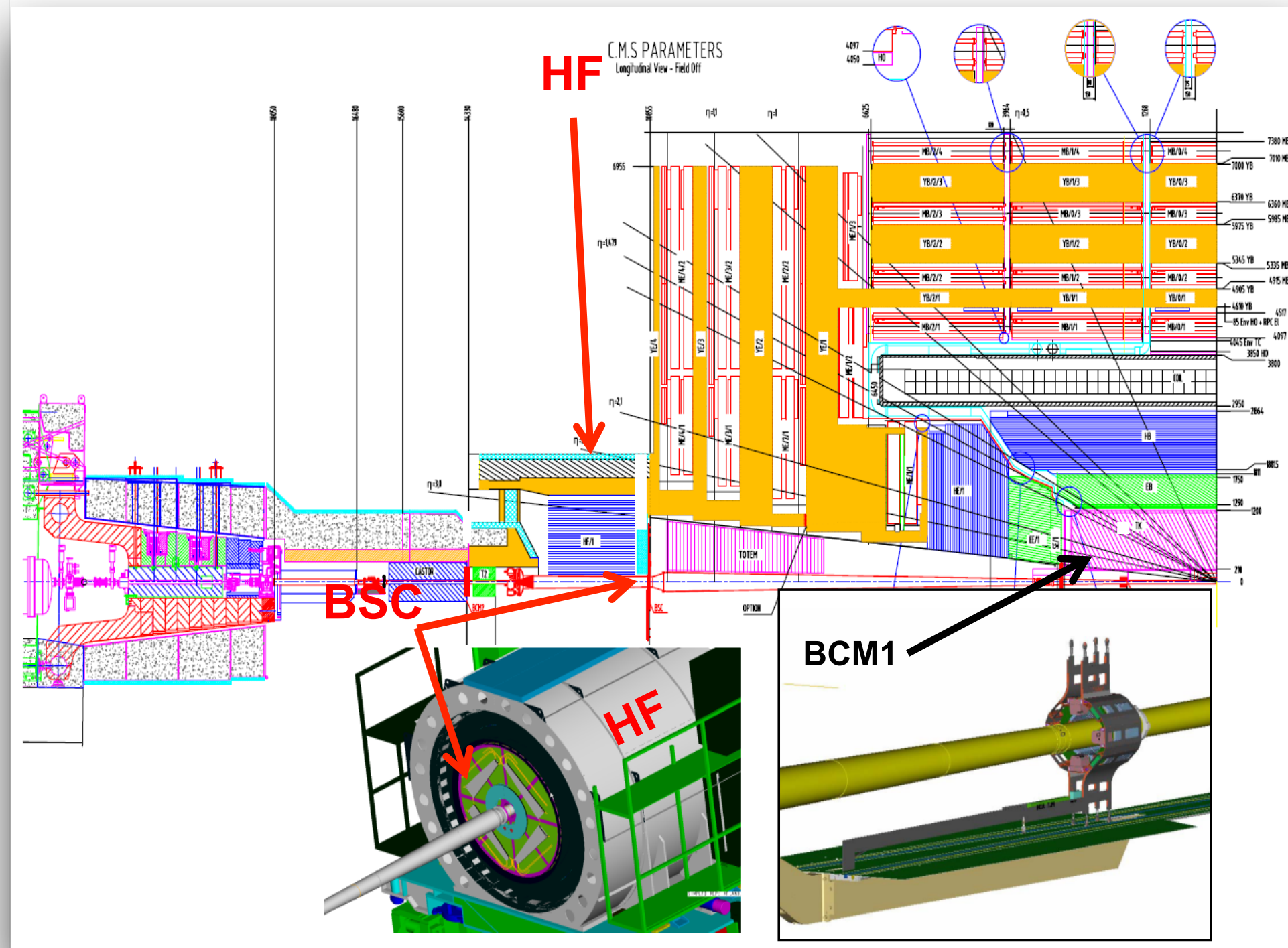
$$\text{efficiency}(\mathcal{A}) = \epsilon_{\mathcal{A}} = \frac{N_{\mathcal{A}}^{\text{trigger}}}{N_{\text{offline}}}$$

Measurement via

- ▶ Monte-Carlo simulation
 - This is not sufficient for analysis purposes; performance varies with lumi, time, detector performance
- ▶ Relative to a looser (prescaled) trigger
 - e.g. Use 40 GeV jet trigger to measure 60 GeV jet eff.
- ▶ Independent trigger
 - Trigger on one physics signature, measure a different one
- ▶ Tag-and-probe

Level-1 Trigger performance measurement

Forward, Beam scintillators (BSC), Beam pickups (BPTX)



$$\epsilon_{\mathcal{A}} = \frac{N_{\mathcal{A}}^{\text{trigger}}}{N_{\text{offline minbias}}}$$

- ▶ Relative to **zero and minimum bias** (MB) triggers:
 - i.e. triggers with no requirements at all - a.k.a. “did something happen yet?”
 - Recorded in small quantities (heavily prescaled) for offline trigger performance estimate
- ▶ **Zero bias**: e.g. trigger on random (filled) bunches
- ▶ **Minimum bias**: trigger on minimum detector activity

Trigger efficiency measurement - High Level Trigger

$$\epsilon_{\mathcal{A}} = \frac{N_{\mathcal{A}}^{\text{trigger}}}{N_{\text{offline passthrough}}}$$

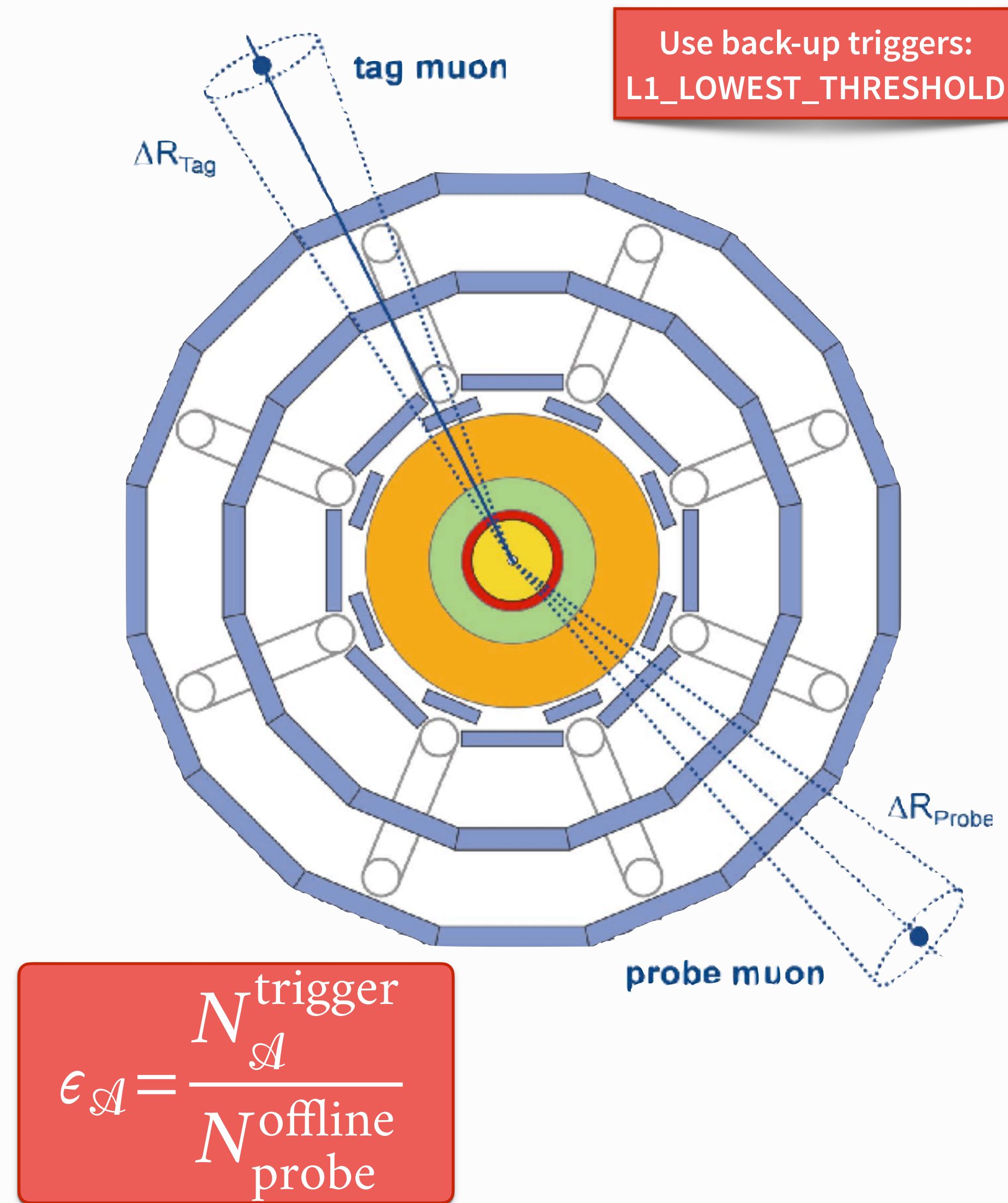
Efficiency easily measurable exploiting the L1 pass-through back-up triggers

L2 muon with $p_T > 10$ GeV

$$\text{Eff (L2MU10)} = \frac{\# \text{ Events passing L2MU10}}{\# \text{ Events passing L2MU10_PASSTHROUGH}}$$

“L2MU10_PASSTHROUGH” selected events
where the Level-1 trigger had already found a muon,
but **does not apply** L2MU10

Efficiency measurement with “Tag and Probe” technique



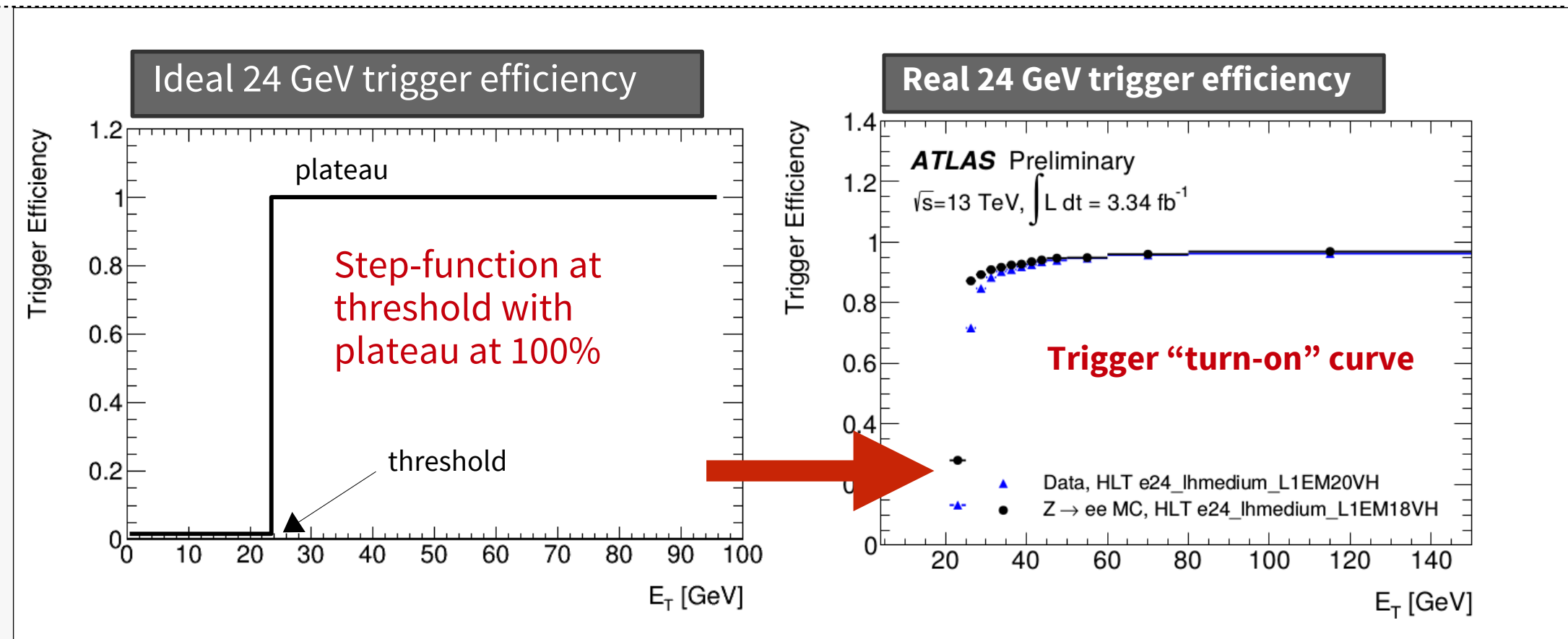
Exploit a well know physics process (e.g. $Z \rightarrow \ell\ell$) to select a very clean sample

- Applicable on specific signatures (typically leptons)
- Requires careful fake control

How?

- **Online:** Trigger on independent signature (the **Tag**)
- **Offline:** Reconstruct the event and identify the candidate signature (the **Probe**)
 - e.g, tight offline requirements and Z mass selection
- **Offline:** measure trigger efficiency on the Probe

Trigger turn-on curves



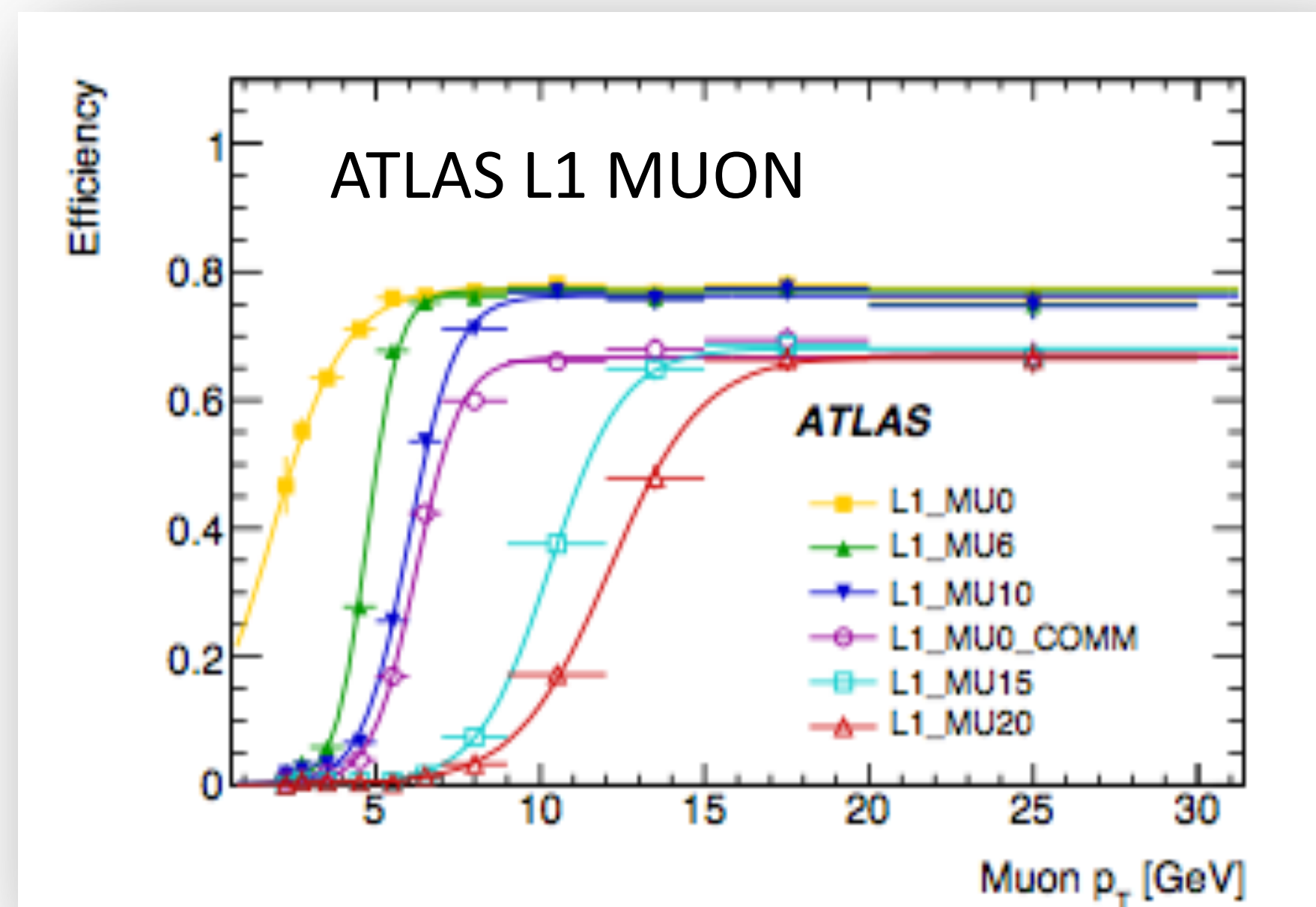
Trigger pT thresholds do not result step function in pT due to

- ▶ Resolution Inefficiencies
- ▶ Trigger/offline differences

Trigger behaviour better described by Error function, usually called **trigger turn-on**

Understanding of the step region is critical

- ▶ Efficiency changes very quickly and contamination from background can be important
 - **Sharp**, better background suppression
 - **Slow**, can be better extrapolated and systematic error can be reduced



Efficiency dependencies on...

The trigger behaviour, can vary rapidly due to significant changes in

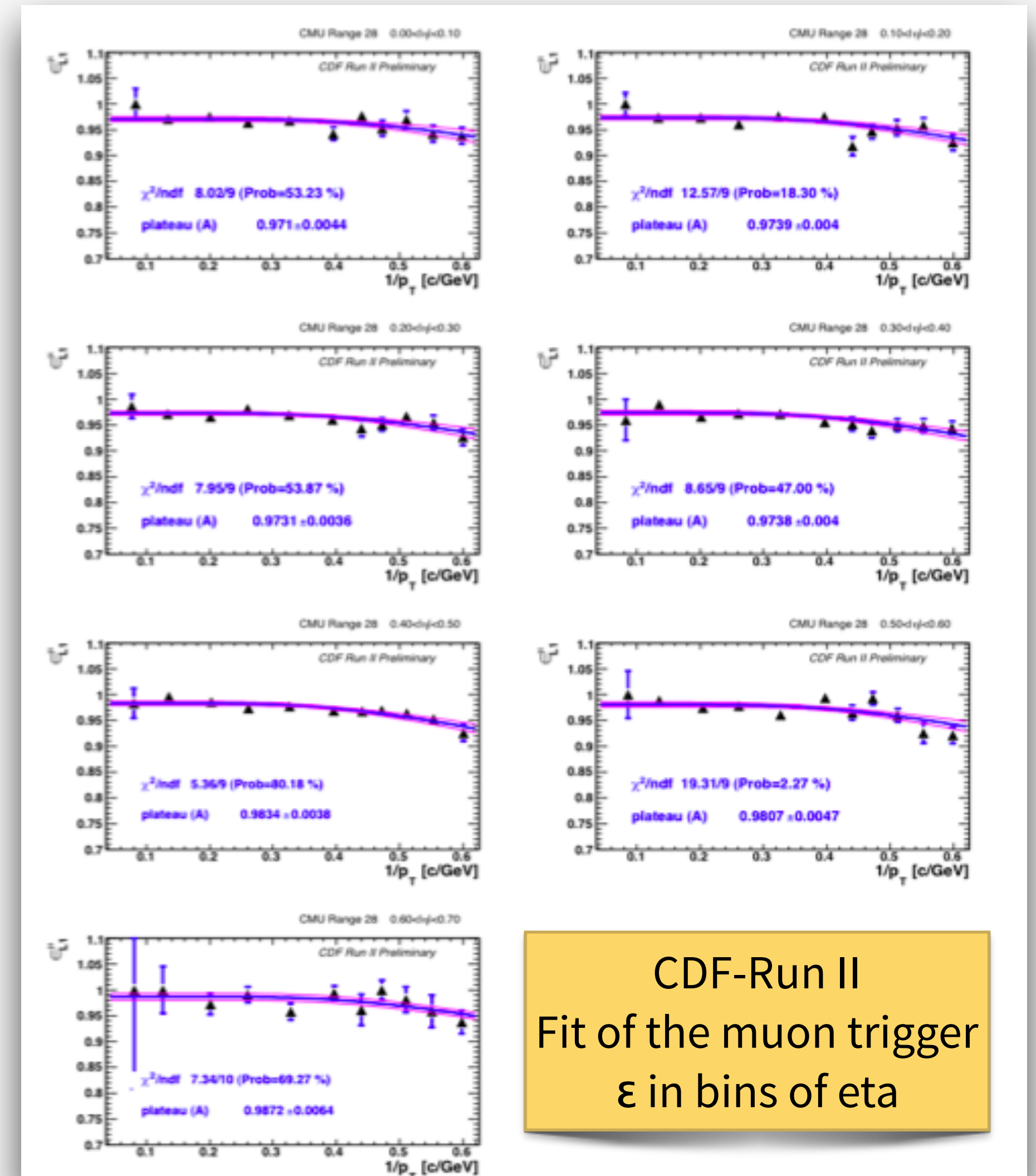
- ▶ Detector
- ▶ Trigger hardware
- ▶ Trigger algorithms
- ▶ Trigger definition

Analysis must track of all these changes

Multi-dimensional study of the efficiency:

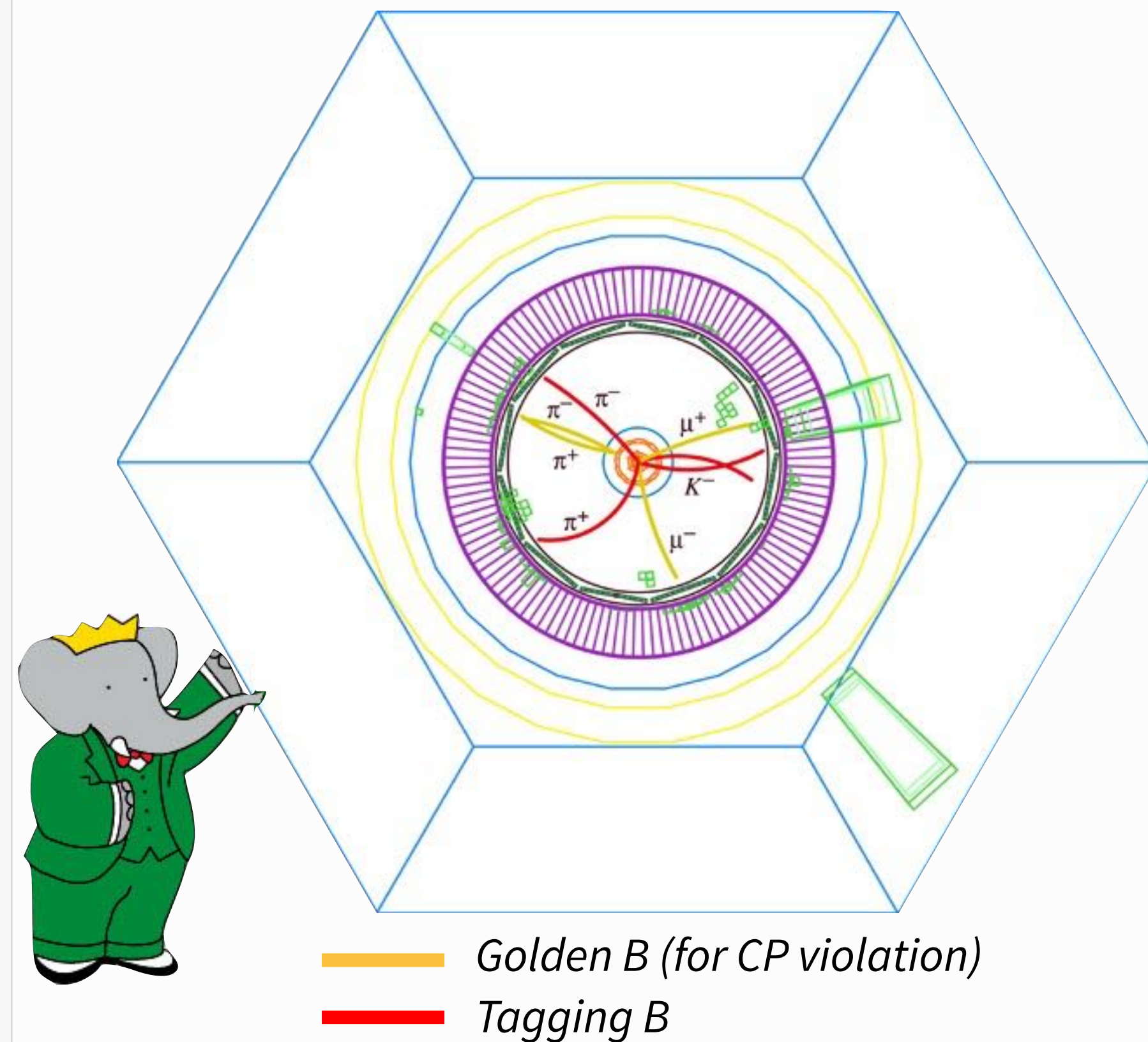
$$\varepsilon(p_T, \eta, \varphi, \text{run\#})$$

- ▶ Fit the turn-on curves for different bins of η , φ , p_T



CDF-Run II
Fit of the muon trigger
 ε in bins of eta

BaBar - exclusive trigger for precision measurements



Golden event in the BaBar Detector
 e^+e^- collision producing a B and an anti-B

Primary goal

minimise the trigger efficiency systematics by selecting a very specific signature to

Trigger objects

- ▶ Charged tracks in the drift chamber, with different pT cuts: long track (0.18 GeV), short track (0.12 GeV)
- ▶ EM calorimeter clusters with different ET cuts

Search for well-defined topology

- ▶ Number of objects, optional geometrical separation cuts or matching between tracks and clusters

Accurate studies on signal and background to determine the efficiency measurement error

How many signatures & algorithms?

Physics triggers

- ▶ **Discovery experiments:** multiple inclusive selections ensure wide open search windows
- ▶ **Precision experiments:** multiple triggers for multiple measurements

Calibration triggers

- ▶ Detectors calibrations
- ▶ Detectors and trigger efficiency measurements
- ▶ Tagging efficiency
- ▶ Energy scale measurements

Background triggers

- ▶ Instrumental and physics background
- ▶ Better description of the background can be extrapolated from data than from Monte Carlo
- ▶ Understand resolutions, including the under-threshold population

Monitor triggers

- ▶ To monitor the trigger itself (remember, lost events are lost for ever!)

***Bulk of the
recorded
events***



Rate allocation

Target : the final allowed DAQ bandwidth

The rate allocation to each trigger signature

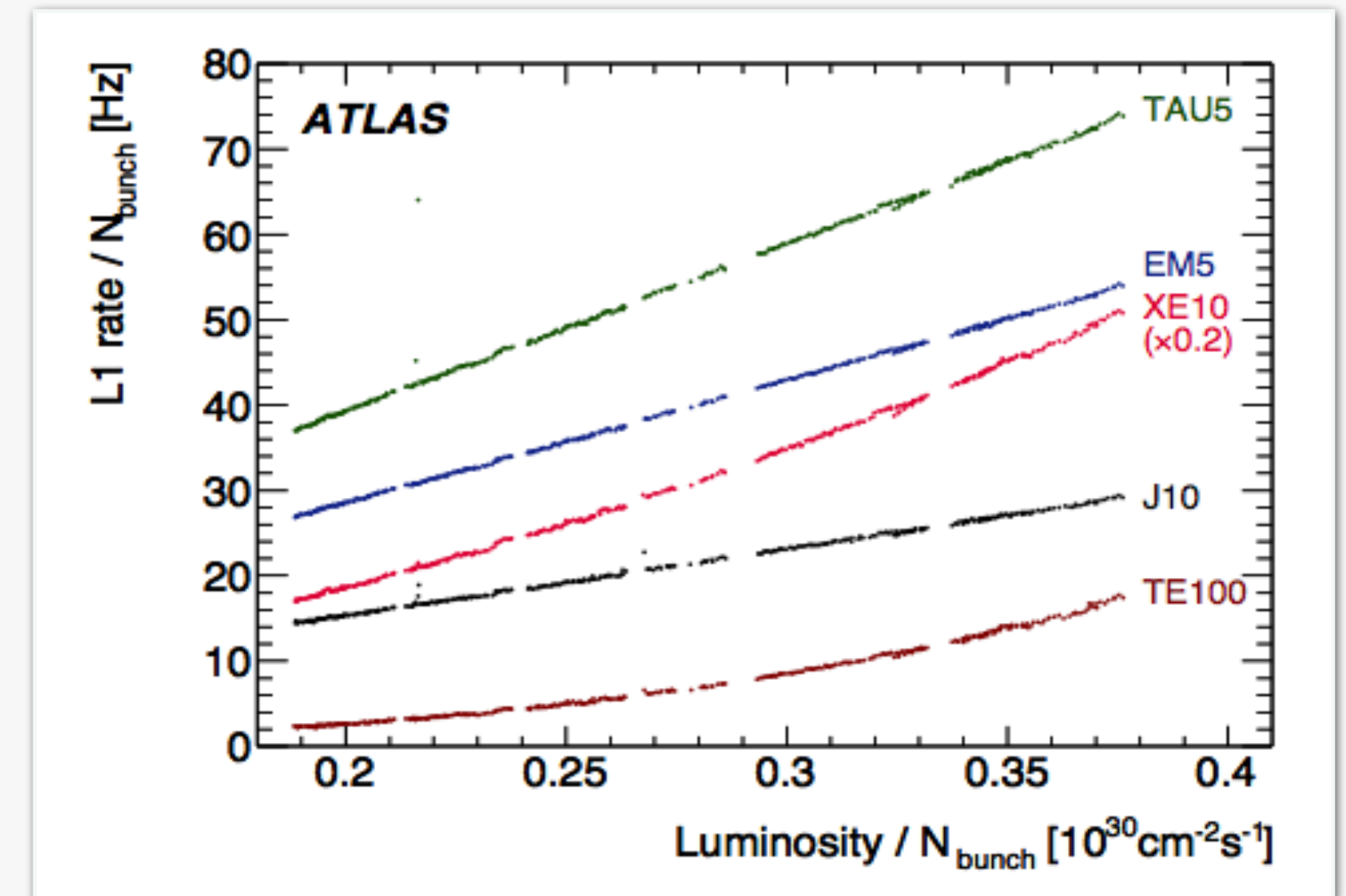
- ▶ Physics goals (plus calibration, monitoring samples)
- ▶ Required efficiency and background rejection
- ▶ Bandwidth consumption

$$R_i = \mathcal{L} \int \frac{d\sigma}{dp_T} \cdot \epsilon_i(p_T) dp_T$$

Rate extrapolation

- ▶ **Trigger design and commissioning:** use large samples of simulated data, including large cross-section backgrounds
 - Large uncertainties due to detector response and background cross-sections
- ▶ **During running** (at colliders), (some) rates can be extrapolated to higher Luminosity

*Rates scale linearly with luminosity,
Pile-up effects break linearity.*



The neverending struggle: Physics interest vs system bandwidth...

Lower thresholds would be desirable, but the physics coverage must be balanced against considerations of the offline computing cost

- ▶ How accommodate a broad physics program?
- ▶ And cope with increasing rates?



Trigger menus!

Trigger Menu

Defines the Physics program/reach of the experiment

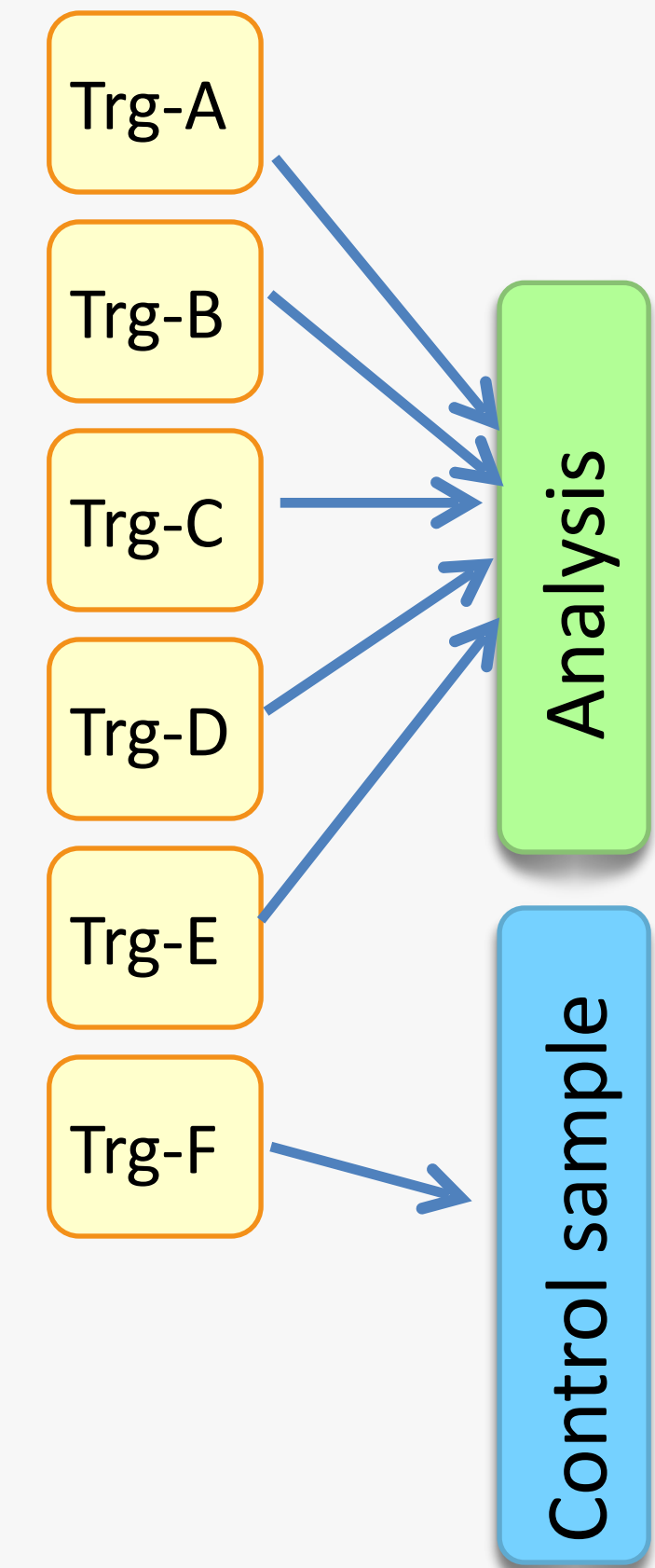
- ▶ Collection of physics trigger, associated back-ups, triggers for calibration and monitoring

It must be

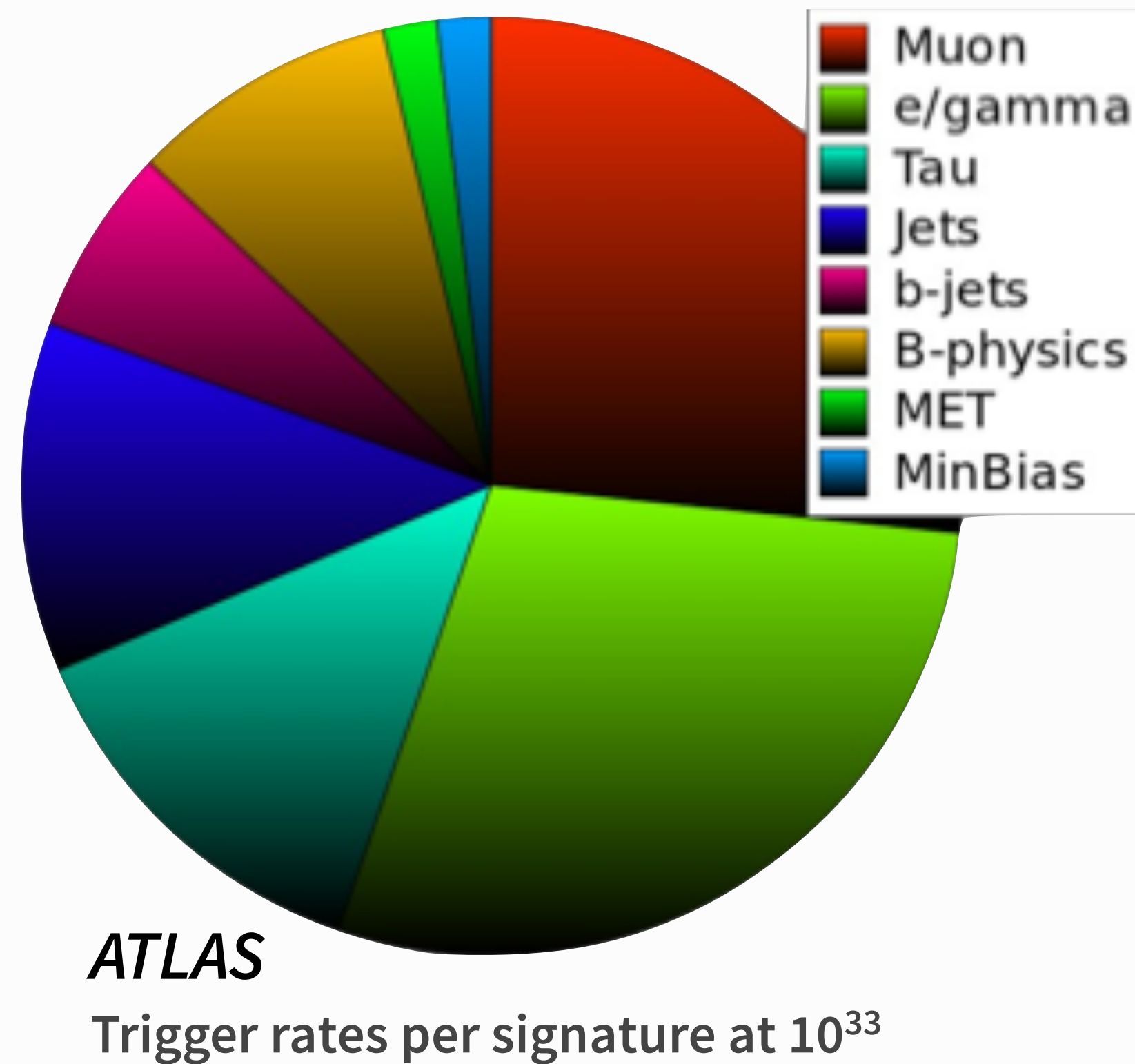
- ▶ Redundant to ensure the efficiency measurement
- ▶ Sufficiently flexible to face possible variations of the environment and physics goals
 - e.g. detectors, machine luminosity,...

Central to the physics program

- ▶ Each analysis served by multiple triggers and different samples
 - from the most inclusive to the most exclusive
- ▶ Ideally, it will collect events (some, at least) from all relevant processes
 - (to provide physics breadth and control samples)



Trigger strategy @ colliders: the ATLAS menu



Inclusive triggers for signal samples

- **Single high- p_T objects**

- ▶ $e/\mu/\gamma$ ($p_T > 20$ GeV)
- ▶ jets ($p_T > 100$ GeV)

- **Multi-object events**

- ▶ $e-e$, $e-\mu$, $\mu-\mu$, $e-\tau$, $e-\gamma$, $\mu-\gamma$, etc...
to further reduce the rate

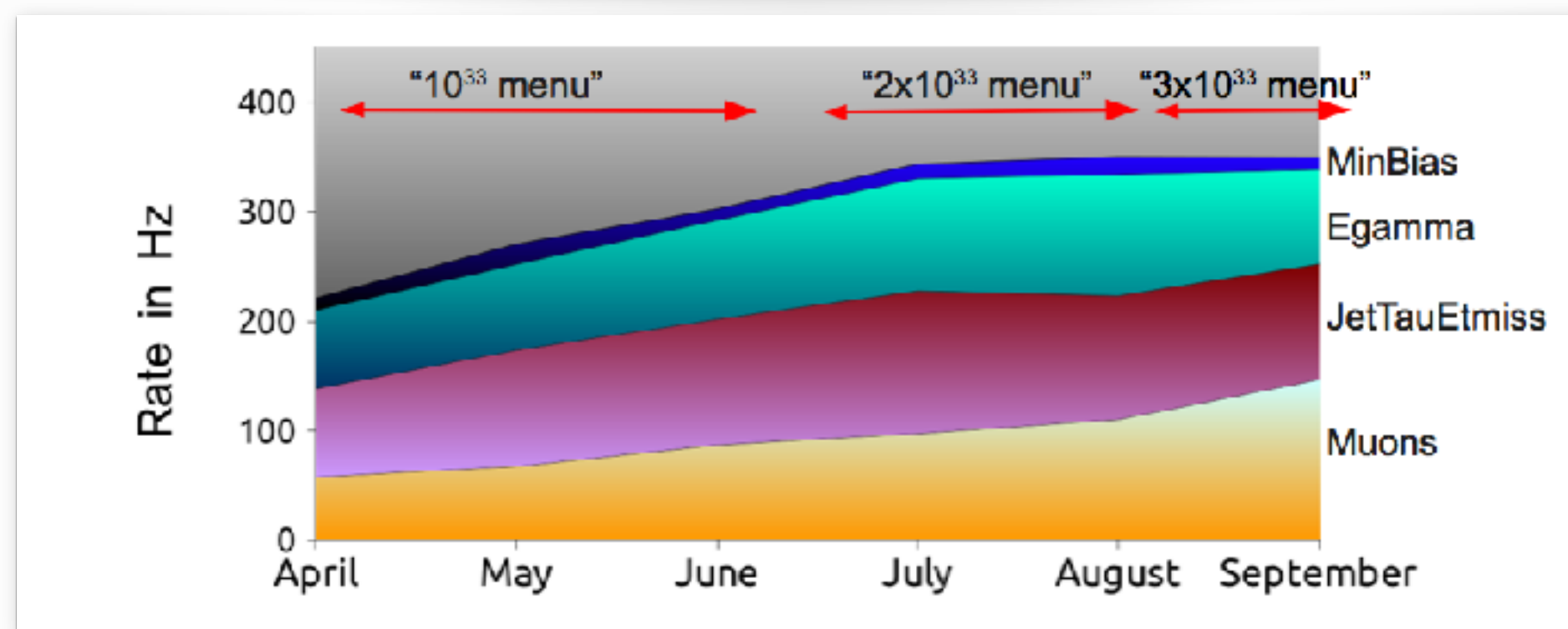
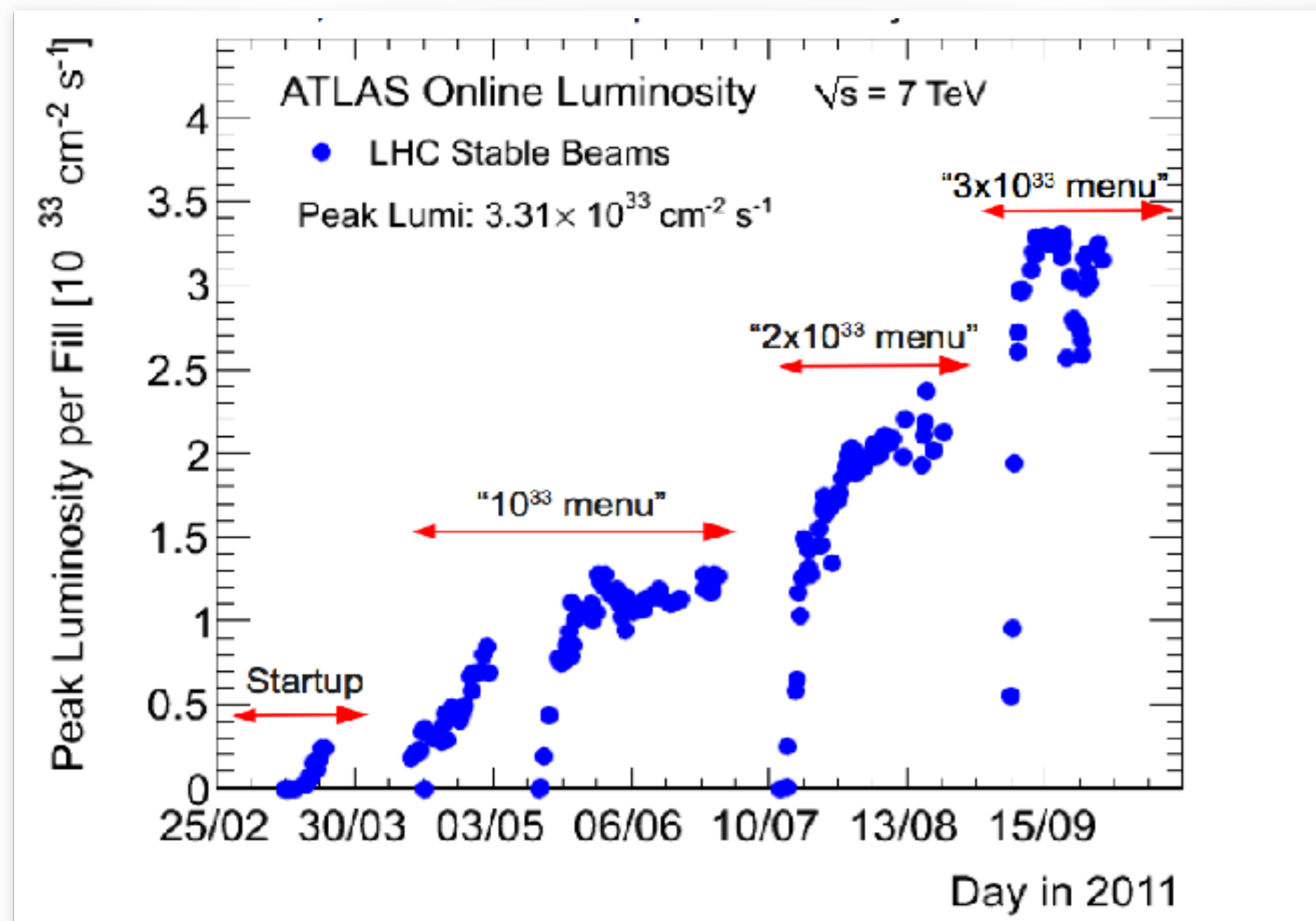
Back-up triggers for monitoring and performance studies (often pre-scaled)

- ▶ Jets ($p_T > 8, 20, 50, 70$ GeV)
- ▶ Inclusive leptons ($p_T > 4, 8$ GeV)
- ▶ Lepton + jet

Example: ATLAS menu 3×10^{33}

Priority List for >300 Hz		Unique rate L1 (Hz)	Unique rate L2 (Hz)	Unique rate EF (Hz)	Sorted by Problem level
Chain					
EF_xe60_verytight_noMu	SUSY/Exotics	0	0	0.5	EF (pileup)
EF_j100_a4tc_EFFS_ht400	SUSY	0	0	2.5	EF
EF_4j45_a4tc_EFFS	SUSY/SM	0	0	2	EF
EF_5j30_a4tc_EFFS		0	5	3	EF
EF_j240_a10tc_EFFS	Exotics/SM	0	0	1	EF
EF_tau29_loose1_xs45_loose_noMu_3L1J10	Higgs	0	40	5	EF
EF_b10_medium_4j30_a4tc_EFFS	Top/Higgs	0	4	10	EF
EF_2mu4_BmumuX	B-physics	0	7	0.9	EF
EF_2mu4_Jpsimumu		0	6	1.7	EF
EF_mu4mu6_DiMu		0	25	6.5	EF
EF_mu4mu6_DiMu_DY20	SM	0	10	5?	EF
EF_2MUL1_12j30_HV_allMS	Exotics	0	?	?	EF
EF_mu20i_medium	5×10^{33} prep.	0	15	3	EF
EF_mu18_MG_medium	Many	0	0	60	EF
EF_mu18_medium		0	0	60	EF
EF_e60_loose	(Exotics)	0	5	7	EF,client
EF_mu15/18/22_njX?	SUSY/??	100	10	?	EF,non-validated
EF_g22_hiptrt?	Exotics	0	?	< 1?	non-validated
EF_e15_medium_xe40_noMu	SUSY/Exotics	310	70?	1.3	L2 (pileup)
EF_j55_a4tc_EFFS_xe55_medium_noMu_dphi2j30xe10		70	210	1.5	L2
EF_e10_medium_mu6_topo_medium	Higgs	1200	9	1	L1
EF_tau20_medium_e15_medium	Higgs	3700	10	1	L1
EF_xe60_tight_noMu	SUSY	680?	150?	1	L1,L2 (pileup),EF
EF_e10_medium_mu6	Higgs/SUSY	1200	75	10	L1, EF
EF_12j30_Trackless_HV_L1MU6	Exotics	1500?	0.5	0.5	L1
Total extra rate		6500	600	100	Peak at 3×10^{33}

The ATLAS trigger during commissioning



ATLAS start-up in 2008: $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

- **Level-1:** Low p_T thresholds and loose selection
 - In parallel, deploy high thresholds and multi-objects triggers for validation (to be used as back-up triggers)
- **HLT:** running in pass-through mode for offline validation or with low thresholds

Evolved rapidly with the increase in LHC luminosity

- Increased p_T thresholds
- Algorithms for complex signatures added
- Maintain stable trigger conditions for important physics results (for conferences)
- Maintained the balance between physics streams
 - electrons, muons, jets, minimum-bias

Inclusive trigger example: from CDF

Trigger Chain: Inclusive High- p_T Central Electron

Level 1

- ▶ EM Cluster $E_T > 8$ GeV
- ▶ R ϕ Track $p_T > 8$ GeV

Level 2

- ▶ EM Cluster $E_T > 16$ GeV
- ▶ Matched Track $p_T > 8$ GeV
- ▶ Hadronic / EM energy < 0.125

Level 3

- ▶ EM Cluster $E_T > 18$ GeV
- ▶ Matched Track $p_T > 9$ GeV
- ▶ Shower profile consistent with e^-

To efficiently collect
W, Z, tt, tb, WW, WZ, ZZ,
W γ , Z γ , W', Z', etc...

✓ Use resolution at L2/L3 to improve
purity
✓ only really care about L1 efficiency
near L2 threshold

Back-up trigger example: from CDF

Back-up Triggers for central Electron 18 GeV

W_NOTRACK

- ▶ L1: EMET > 8 GeV && MET > 15 GeV
- ▶ L2: EMET > 16 GeV && MET > 15 GeV
- ▶ L3: EMET > 25 GeV && MET > 25 GeV

NO_L2

- ▶ L1: EMET > 8 GeV && r_{ϕ} Track pT > 8 GeV
- ▶ **L2: AUTO_ACCEPT**
- ▶ L3: EMET > 18 GeV && Track pT > 9 GeV && shower profile consistent with e-

NO_L3

- ▶ L1: EMET > 8 GeV && r_{ϕ} Track pT > 8 GeV
- ▶ L2: EMET > 8 GeV && Track pT > 8 GeV && Energy at Shower Max > 3 GeV
- ▶ **L3: AUTO_ACCEPT**

L2/L3 Passthrough

✓ Factorize efficiency into all the components:

- ✓ efficiency for track and EM inputs determined separately
- ✓ separate contributions from all the trigger levels

Redundant, inclusive trigger example: from CDF

L1_EM8_PT8 feeds - inclusive

- ▶ Inclusive high- p_T central electron chains
- ▶ Di-lepton chains (ee , $e\mu$, $e\tau$)
- ▶ Several back-up triggers
- ▶ 15 separate L3 trigger chains in total

A $t\bar{t}$ cross section analysis uses

- ▶ Inclusive high- p_T central e chains
- ▶ Inclusive high- p_T forward e chains
- ▶ MET + jet chains
- ▶ Muon chains

Trigger menus must be

Inclusive:

Reduce the overhead for the program analysis

Redundant:

Issues in a single one detector or in a trigger input do not affect physics (reduced efficiency but still the measurement is possible)

Concluding remarks

The trigger strategy is a trade-off between physics requirements and affordable systems and technologies

- ▶ A good design is crucial – then the work to maintain optimal performance is easy

Here we just reviewed the main trigger requirements coming from physics

- ▶ High efficiency – rate control
- ▶ Excellent knowledge of the trigger selection on signal and background
- ▶ Flexibility and redundancy

In the next lecture, we will see how to implement such a system, still satisfying these requirements