



Preselekcja, zbieranie danych, sterowanie i monitorowanie nowoczesnego eksperymentu FWE



Co wykładamy

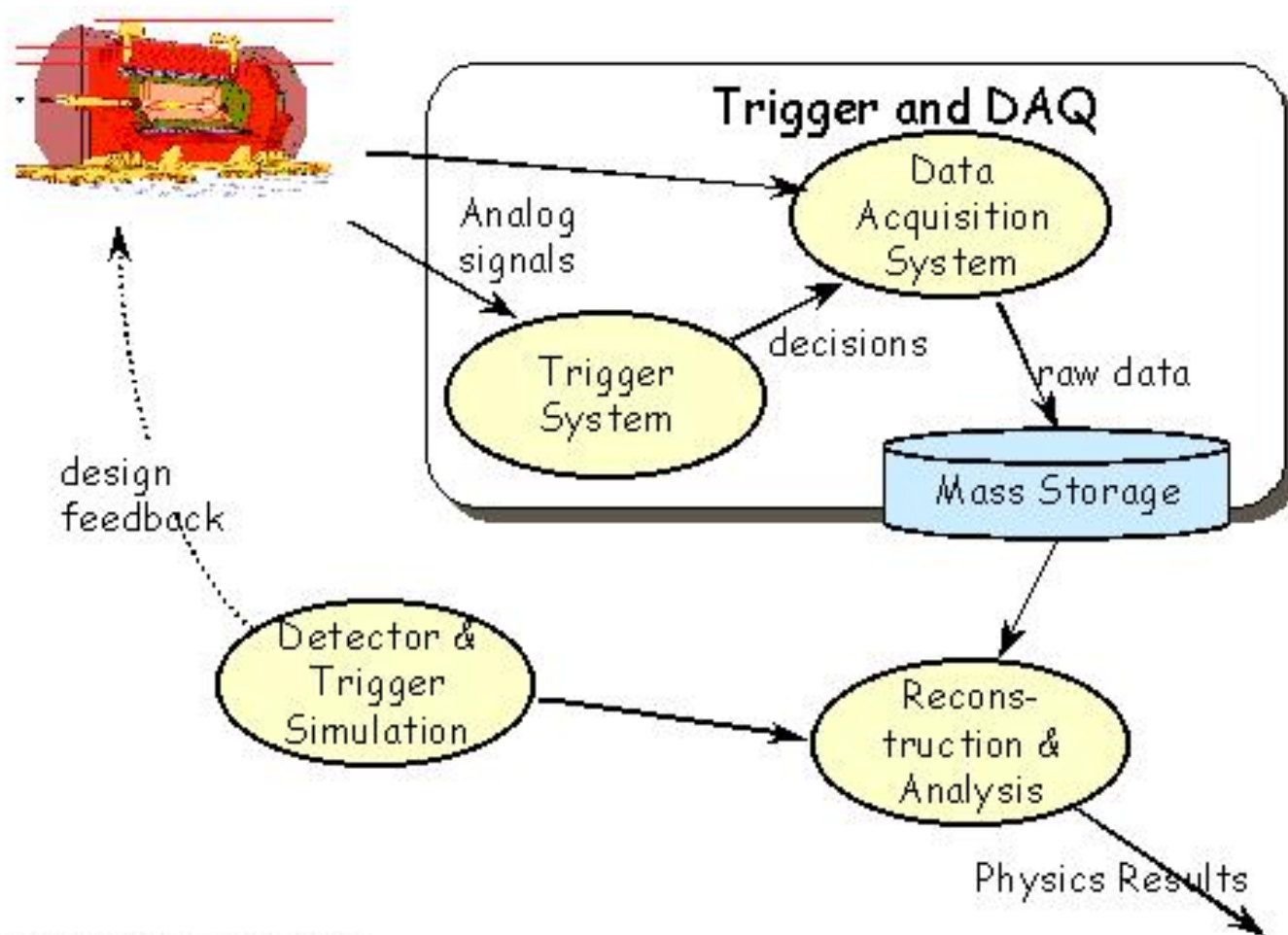
- **Overview**
 - General framework
 - Rates and data at collider experiments
- **Basic concepts**
 - Multi-level trigger systems and readout structures
- **Front-end essentials**
 - Digitizers
 - Signal processing
- **Trigger algorithms and implementations**
 - Trigger design and performance
 - Fast hardware trigger (Level-1)
 - Software triggers (Level-2, Level-3, etc.)
- **Data Acquisition**
 - Readout networks (buses, switches, etc.)
 - Event building and event filters
 - Data storage
- **Configuration, Control and Monitoring**
 - Operating modes
 - Run Control
 - Data monitoring and quality control



Przegląd



Zobaczmy gdzie jesteśmy ?

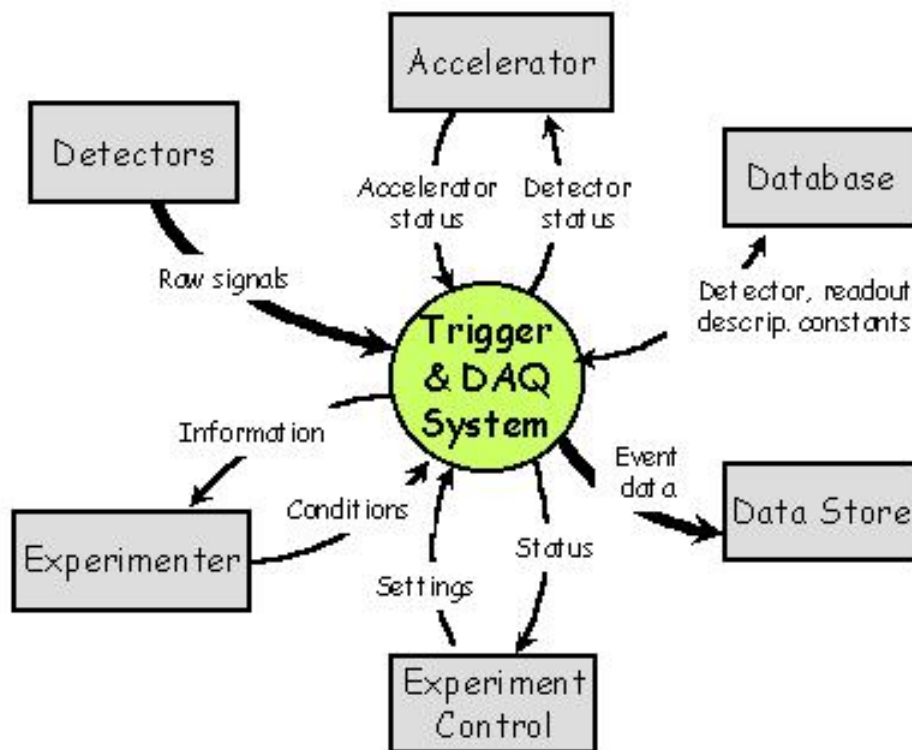


DAQ = Data Acquisition



Patrzymy dalej na otoczenie !

- The main role of T & DAQ is to process the signals generated in the detector and write the information onto data storage, but:





Ciągle jesteśmy we wstępie !

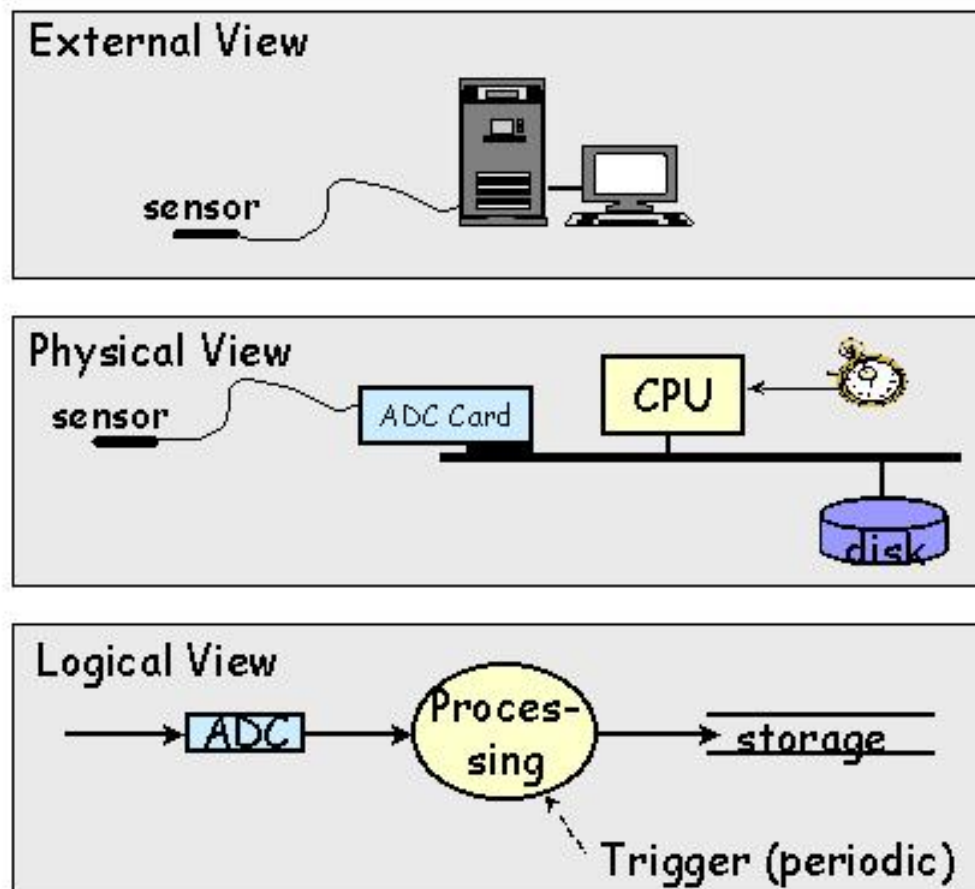
- **Trigger System:**
 - Selects in Real Time “interesting” events from the bulk of collisions. - Decides if YES or NO the event should be read out of the detector and stored
- **Data Acquisition System**
 - Gathers the data produced by the detector and stores it (for positive trigger decisions)
 - Front End Electronics:
 - Receive detector, trigger and timing signals and produce digitized information
 - Readout Network
 - Reads front end data and forms complete events (sometimes in stages) - Event building
 - Central DAQ
 - Stores event data, can do data processing or filtering
 - Overall Configuration Control and Monitoring



Podstawowe pojęcia

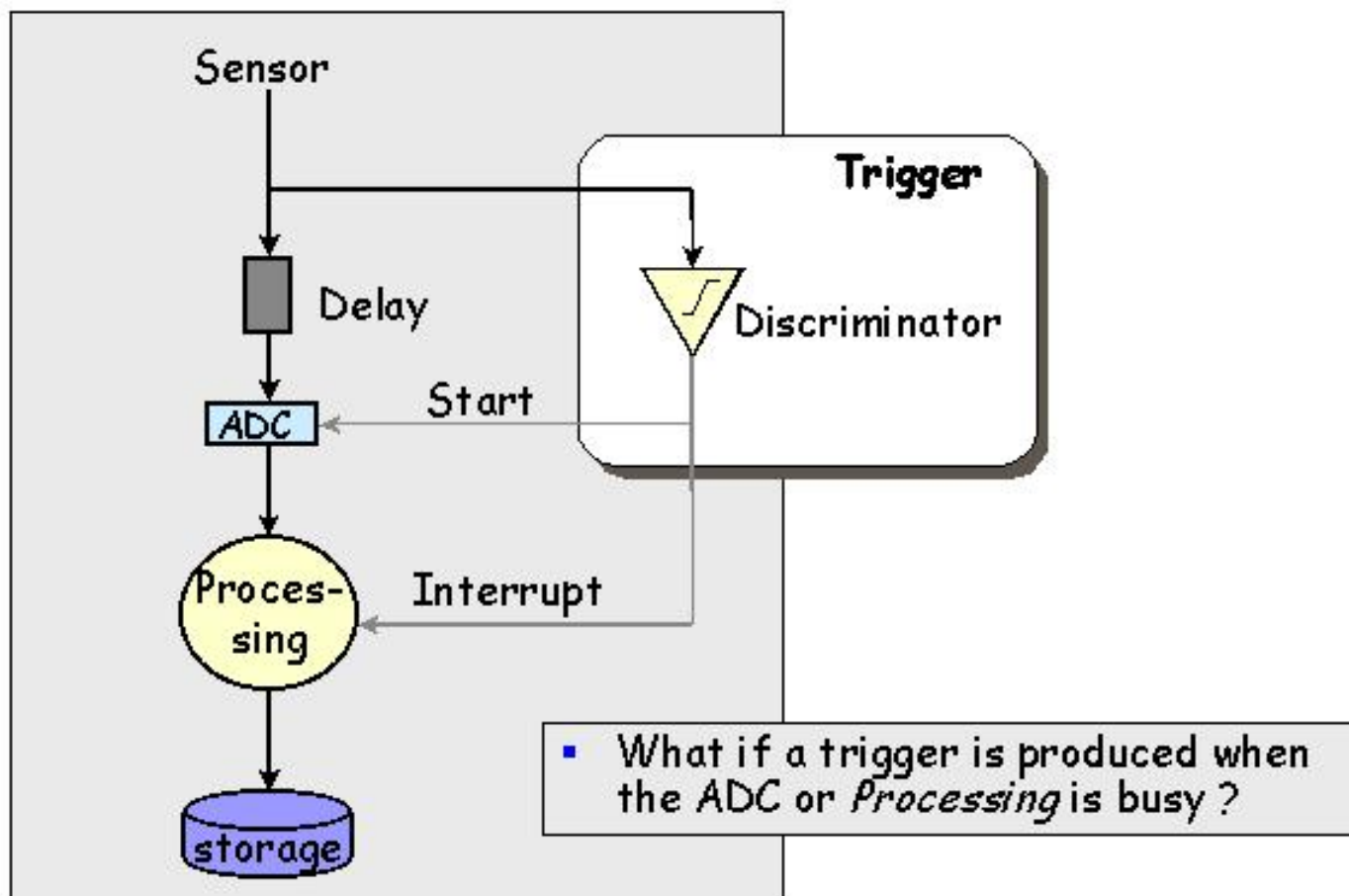


Zbieranie danych – najprostsze

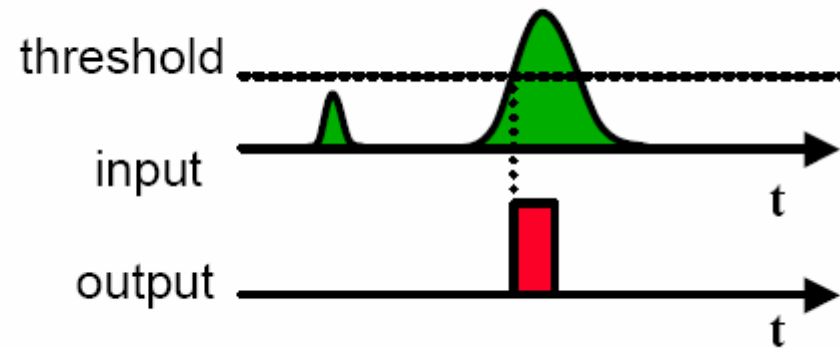




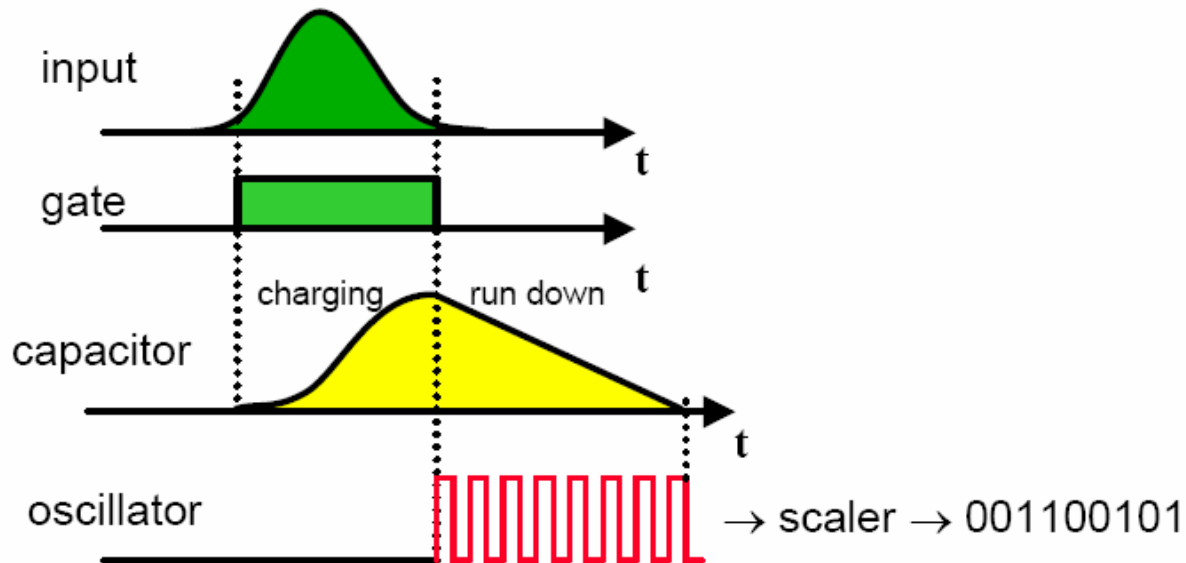
Zbieranie danych ale selektywne 1



- Discriminator

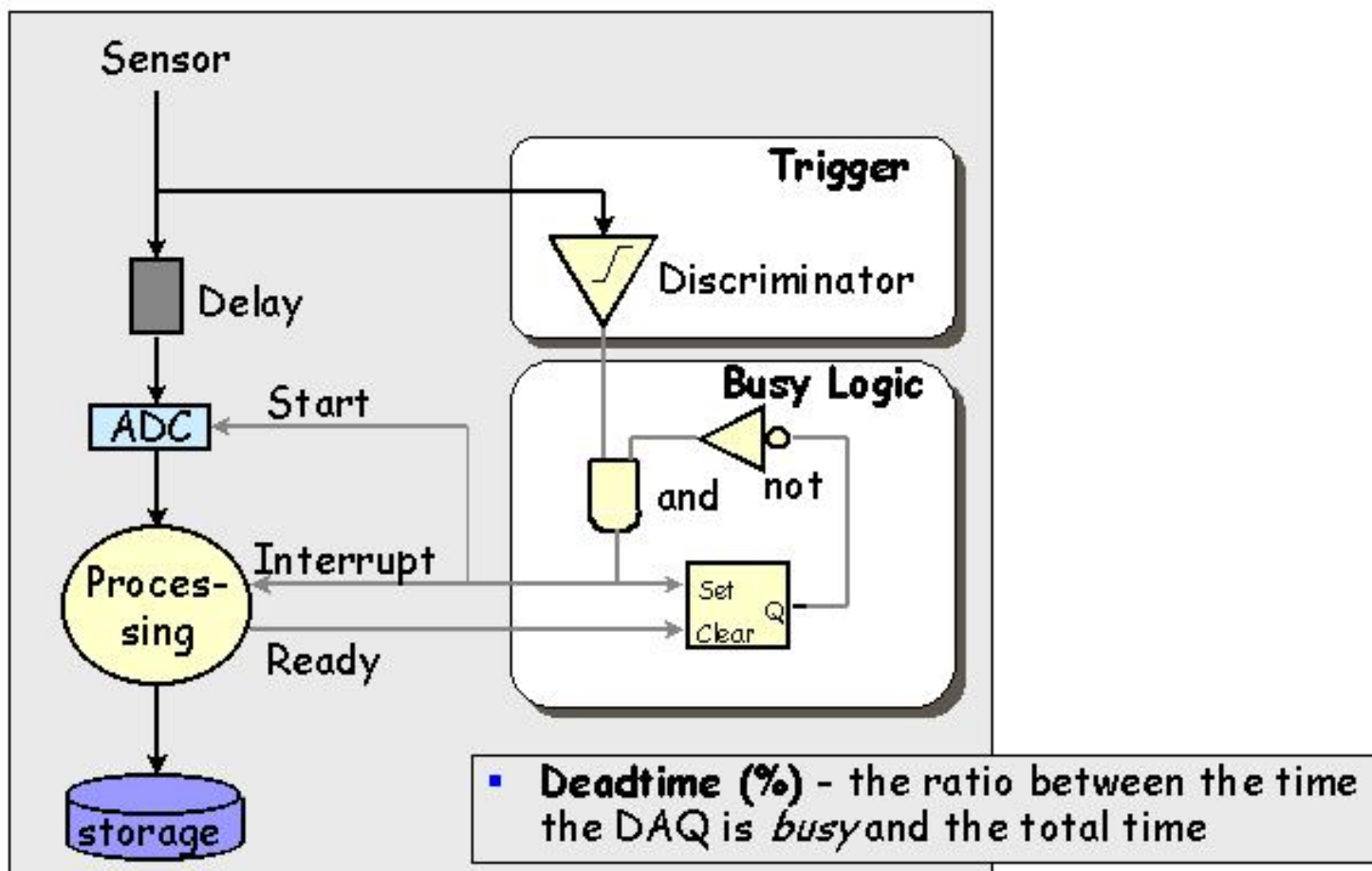


- Analog-to-Digital Converter (ADC)

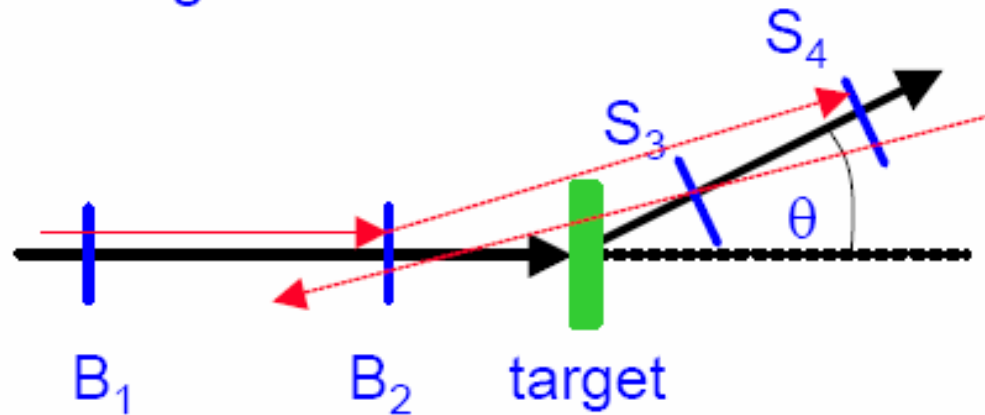




Zbieranie danych ale selektywne 2



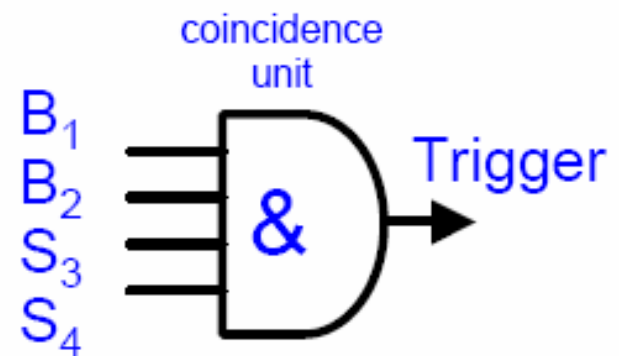
A very simple example of a trigger: A scattering experiment where only beam particles scattered from the target under the angle θ shall be recorded



Condition for recording:

$$T = B_1 \cap B_2 \cap S_3 \cap S_4$$

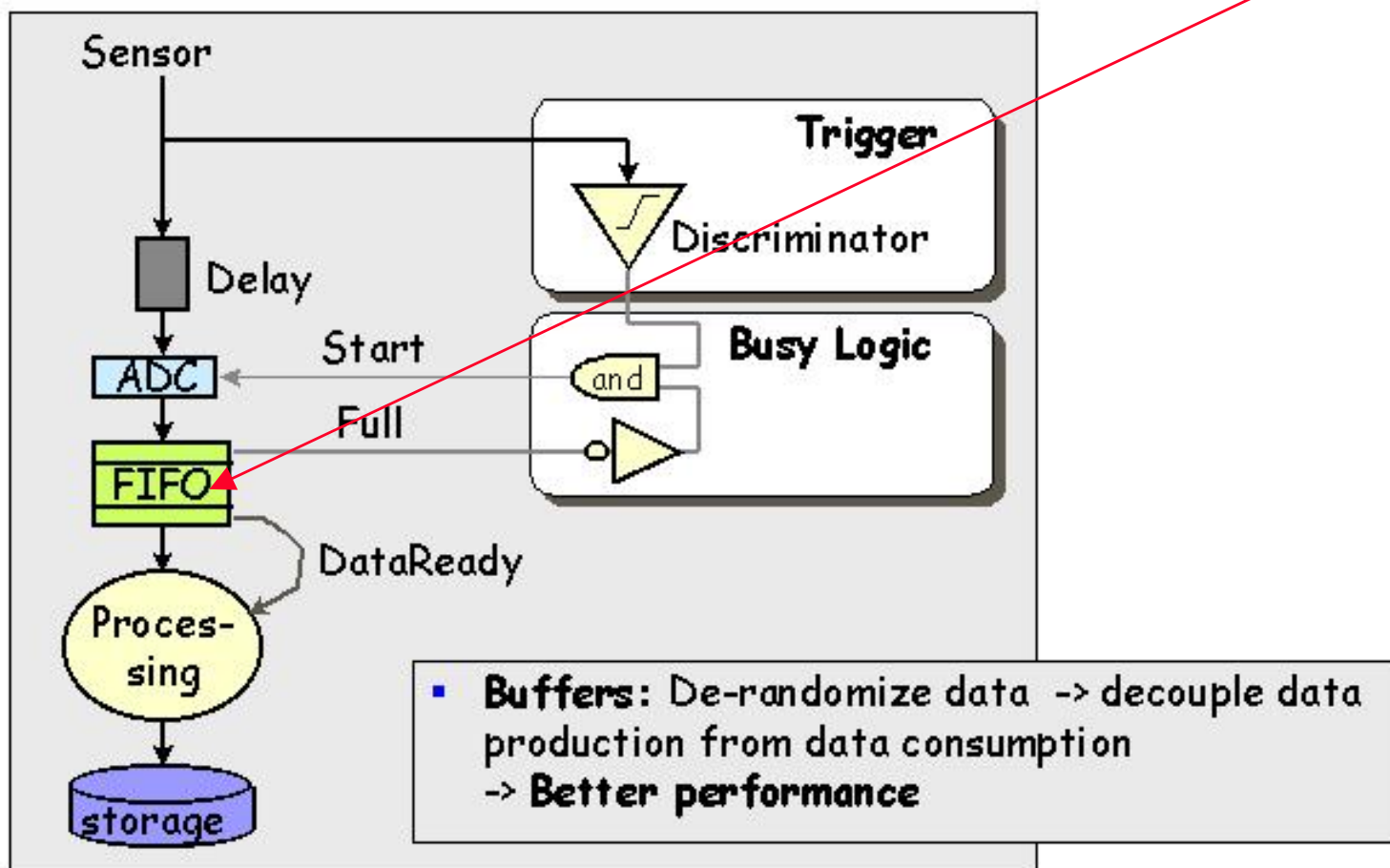
All other events $\longrightarrow$ will be rejected.





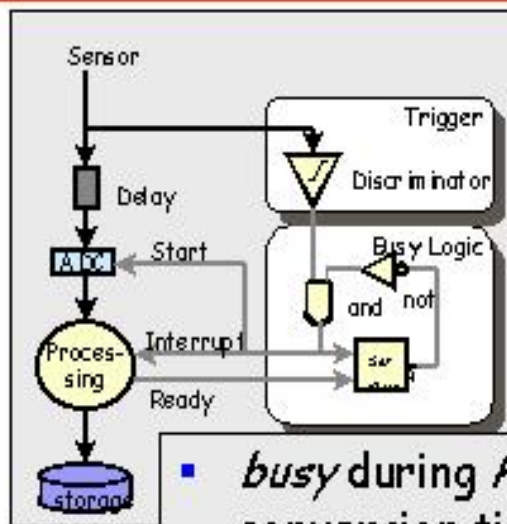
Prawdziwe wyzwanie !

First in First Out

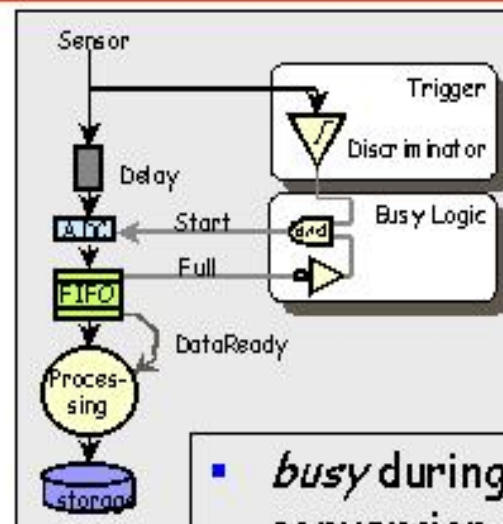




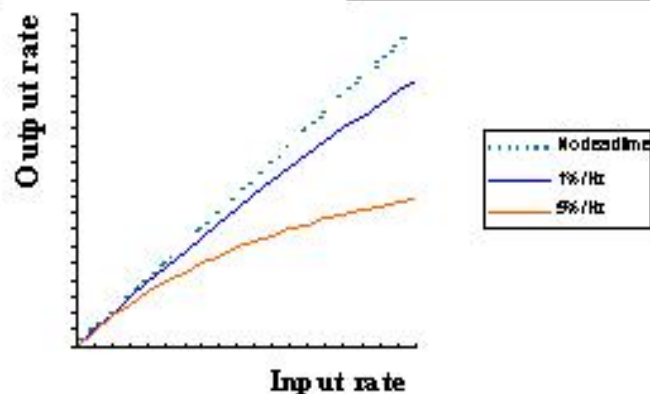
Dlaczego prawdziwe ??



- *busy* during ADC conversion time + processing time



- *busy* during ADC conversion time if FIFO not full





Krótko o kolejkach

Arrival time following exponential distribution (Poisson process)

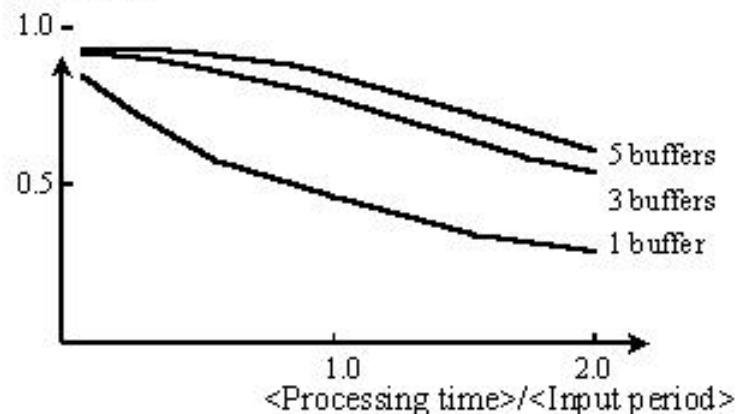


Depth 1, 3, 5



Processing time following gaussian distribution

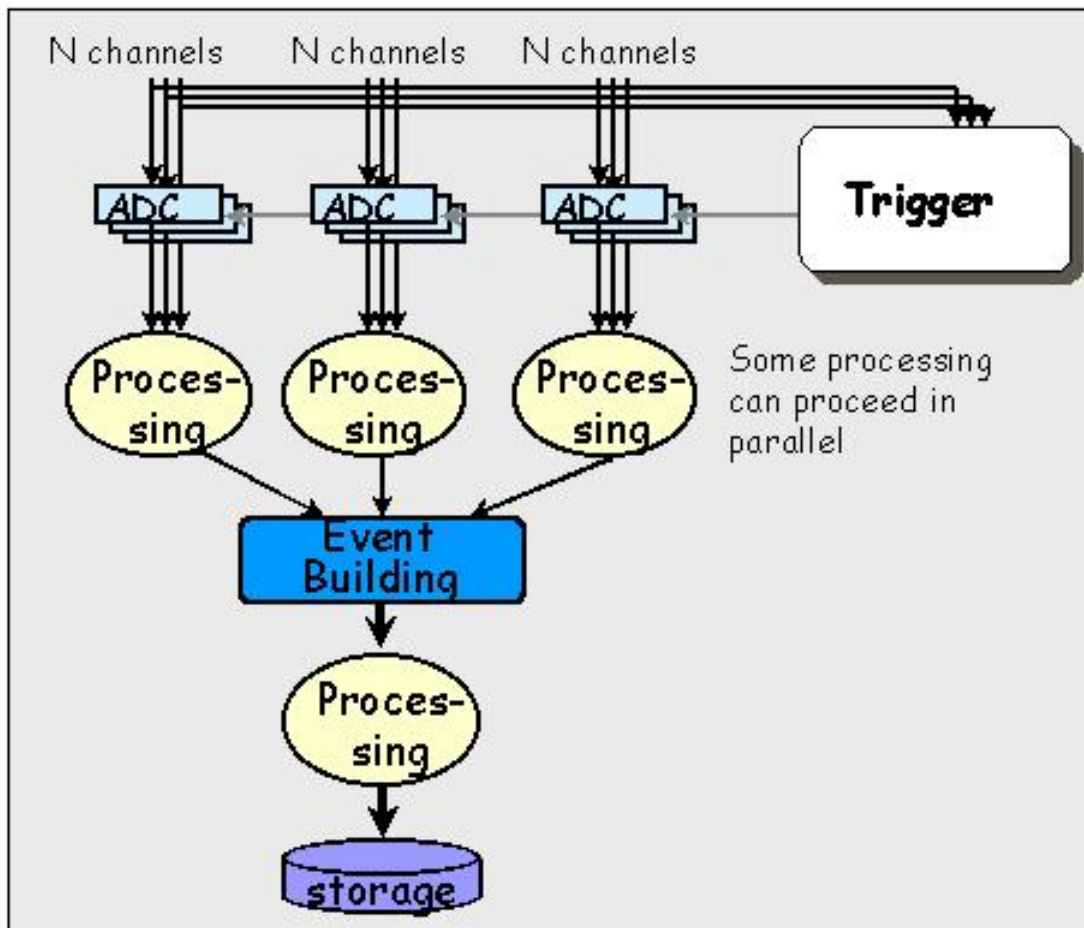
Efficiency



- For simple cases, the behavior of the system can be calculated analytically using *queue theory*. Soon you have to use simulation techniques.

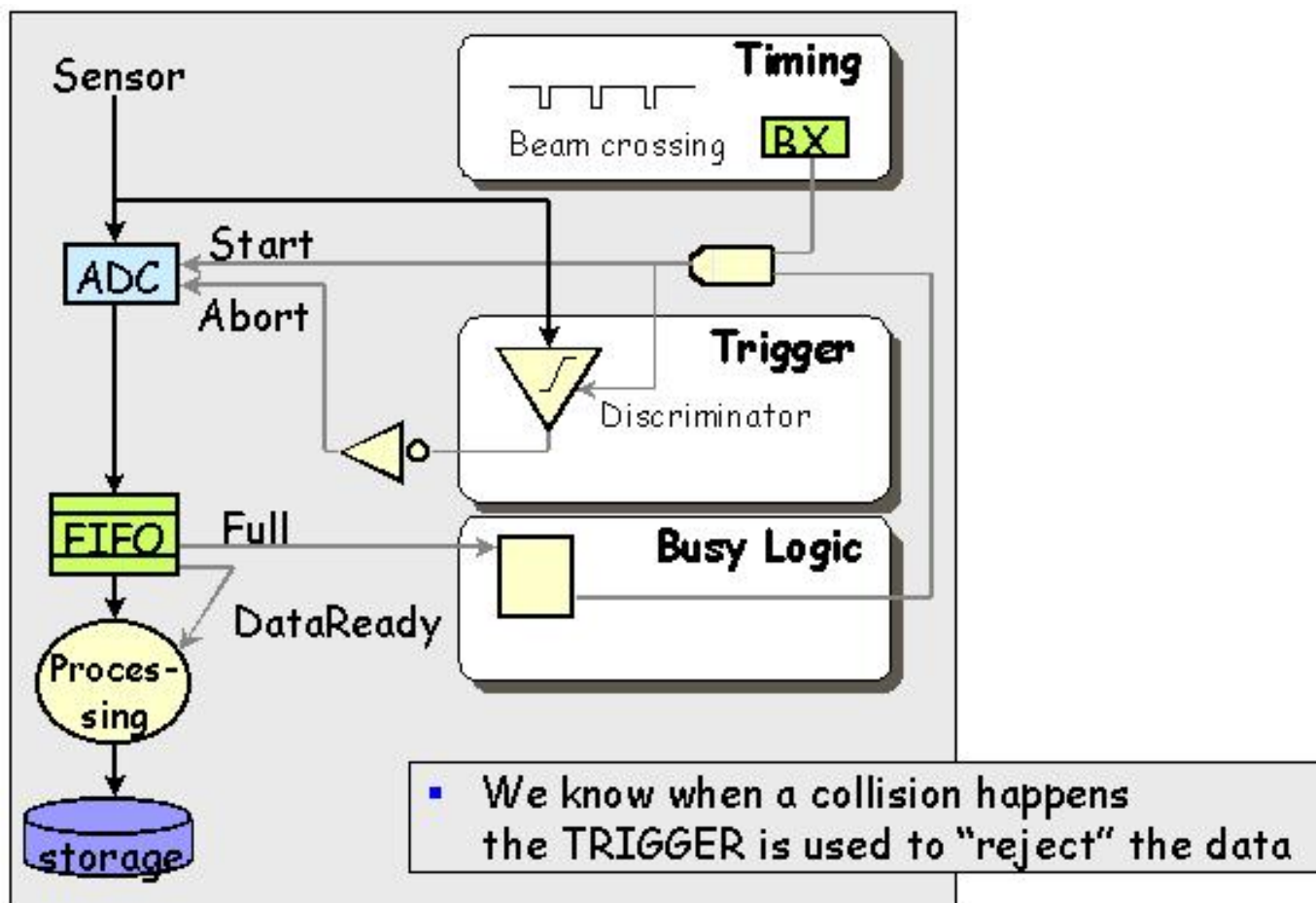


Życie jest bardziej skomplikowane



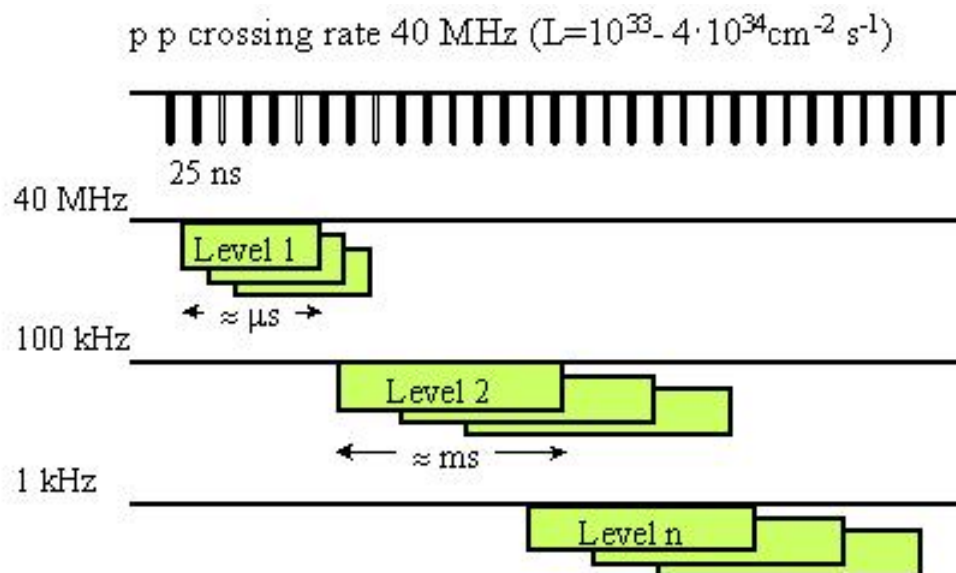


Proste zbieranie – na zderzaczu !





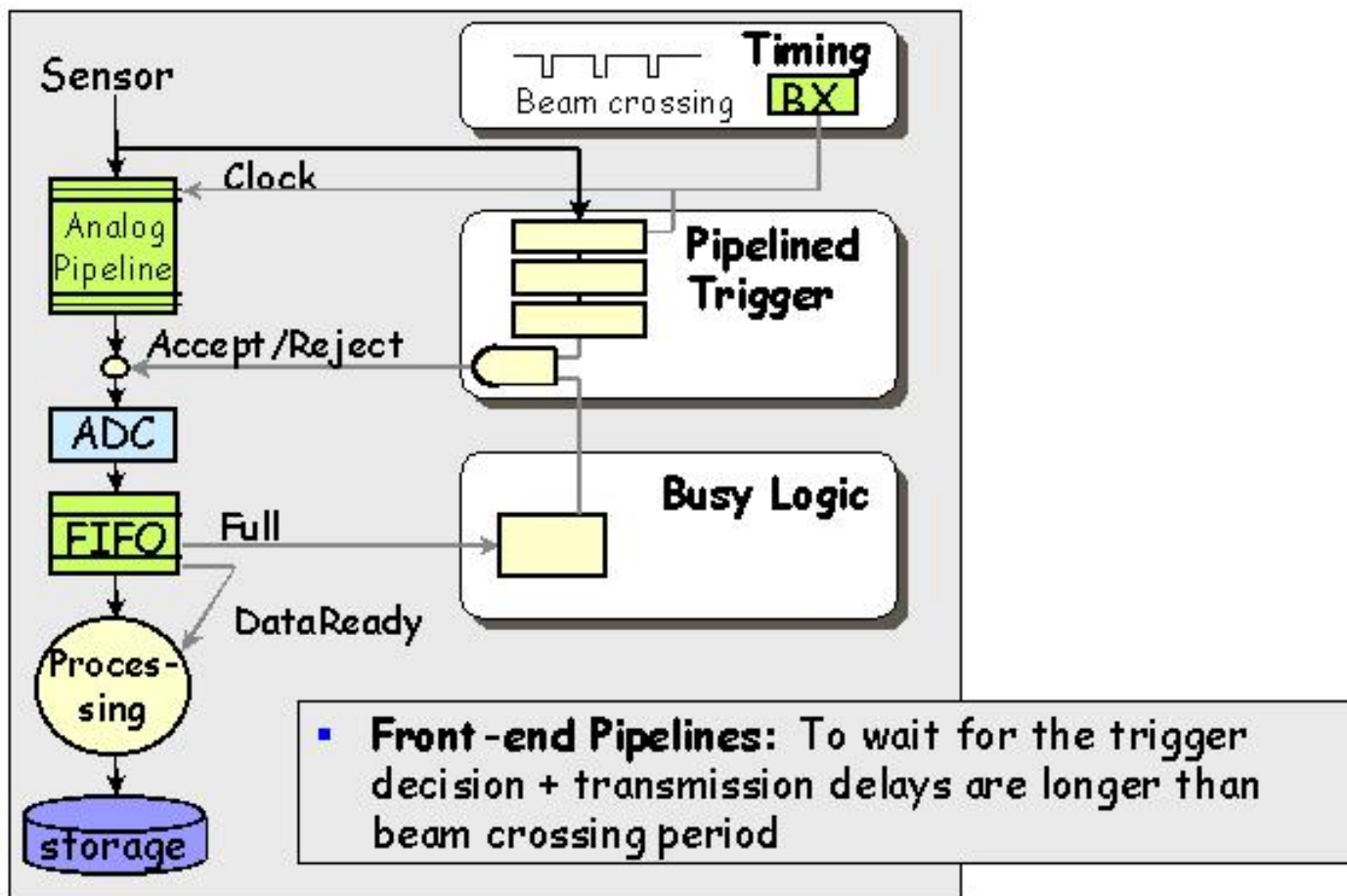
Zależności czasowe - LHC



- Level 1 trigger time exceeds bunch interval
- Event overlap & signal pileup (multiple crossings since the detector cell memory greater than 25 ns)
- Very high number of channels

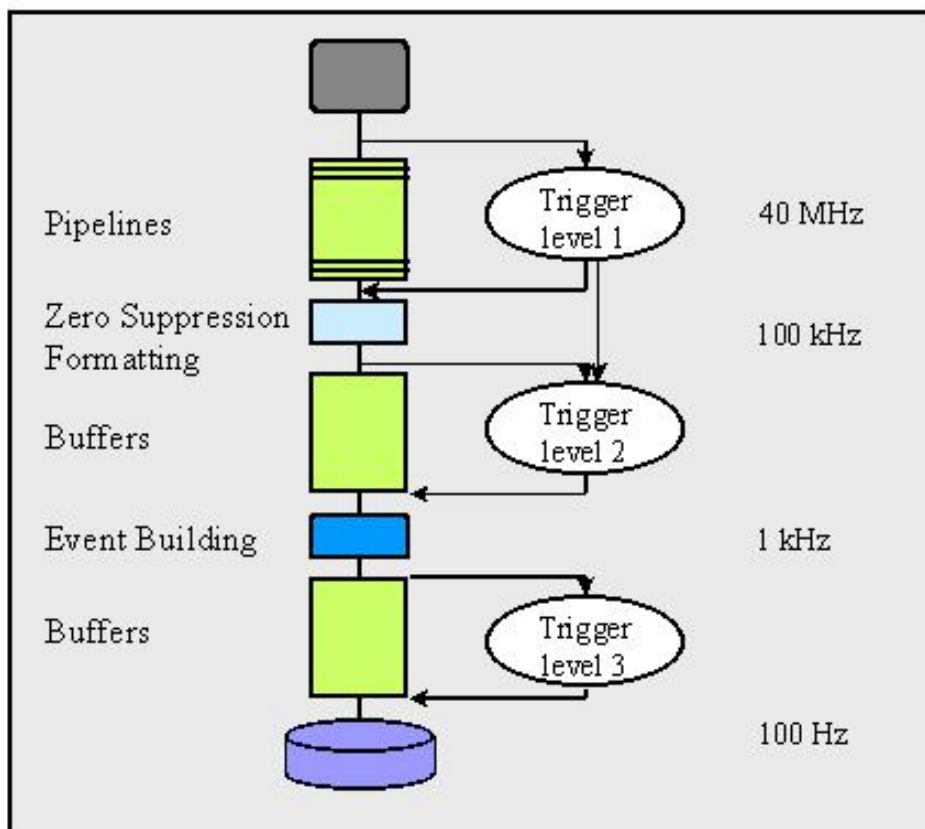


Jak na LHC – najprościej ?





Struktura odczytu na LHC





System trygera

The trigger system is the system which triggers the recording of the data in an experiment.

The trigger is a function of:



Since the detector data are not promptly available and the function is highly complex, $T(\dots)$ is evaluated by successive approximations called:

TRIGGER LEVELS



Cele trygera - fizyczne 1

- **Leptonic Collisions (e^+e^- colliders)**
 - **Cross Section** - probability of interaction
(unit = barn = 10^{-24} cm^2)
 - $\sigma_{\text{tot}} = 30 - 40 \text{ nb}$ ($30-40 \cdot 10^{-33} \text{ cm}^2$)
 - **Luminosity** - density of crossing beams
(~ nb. of particles per section)
 - $L = 10^{31} \text{ cm}^{-2}\text{s}^{-1}$ (LEP)
 - ➔ **Event rate ($L \cdot \sigma$) 0.1 - 1 events/s**
 - $\sigma_{\text{interesting}} \approx \sigma_{\text{tot}}$ (All interactions are interesting)
 - ➔ **No physics rejection needed**
 - But background rejection is crucial to perform precision measurements:
 - Cosmics, Beam-gas, Off-momentum $e^\pm$, Detector noise



Cele trygera - fizyczne 2

- **Hadronic collisions (fixed target or pp)**
 - **Cross Section**
 - $\sigma_{\text{tot}} = 30 - 40 \text{ mb} \quad (30-40 \cdot 10^{-27} \text{ cm}^{-2})$
 - **Luminosity**
 - $L = 10^{30} \text{ cm}^{-2}\text{s}^{-1}$ (SPS), $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (fixed target),
 $10^{34} \text{ cm}^2\text{s}^{-1}$ (LHC)
 - ➔ **Event rate $10^5 - 10^9 \text{ events/s}$**
- $\sigma_{\text{interesting}} \approx \text{nb} \rightarrow \text{pb}$
 - ➔ **Rejection needed of $10^{-6} \rightarrow 10^{-13}$ (LHC)**



Projektowanie trygera 1

- **Leptonic interactions**

- High rejection of background
- Criteria:
 - Very good efficiency for selected channel $\approx 100\%$
 - Good rejection background. Depends on physics/background ratio, i.e. on machine conditions. ≈ 10
 - Good monitoring of efficiency $\pm 0.1\%$



Projektowanie trygera 2

- **Hadronic Interactions**

- High rejection of physics events

- Criteria:

- Good efficiency for selected channel $\geq 50\%$

- Good rejection against uninteresting events $\approx 10^6$

- Good monitoring of efficiency ± 0.1

- **For High precision measurements:**

- "A 60% well known efficiency is much better than a 90% uncertain efficiency"

- **Similar criteria, but in totally different ranges of values**



Projektowanie trygera 3

- **Simulation studies**
 - It is essential to build into the experiment's simulation the trigger simulation.
 - For detector/machine background rejection
 - Try to include detector noise simulation
 - Include machine background (not easy).
 - For example at LEP the trigger rate estimates were about 50-100 times too high.
 - For physics background rejection, the simulation must include the generation of these backgrounds

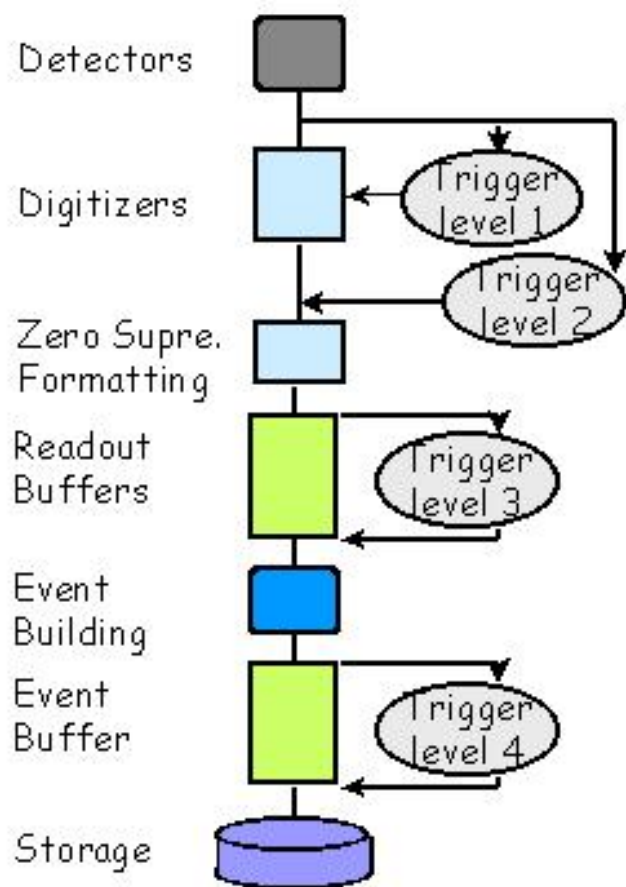


Tryger wielopoziomowy

- Since the detector data is not promptly available and the trigger function is highly complex, it is evaluated by **successive approximations**.
- We need to optimize the amount of data needed and the time it takes to provide a decision.
- Trigger levels
 - Hardware trigger: *Fast* trigger which uses crude data from few detectors and has normally a limited time budget and is usually implemented using hardwired logic.
⇒ **Level-1** sometimes **Level-2**
 - Software triggers: Several trigger levels which refines the crude decisions of the hardware trigger by using more detailed data and more complex algorithms. It is usually implemented using processors running a program.
⇒ **Level-2, Level-3, Level-4, ...**



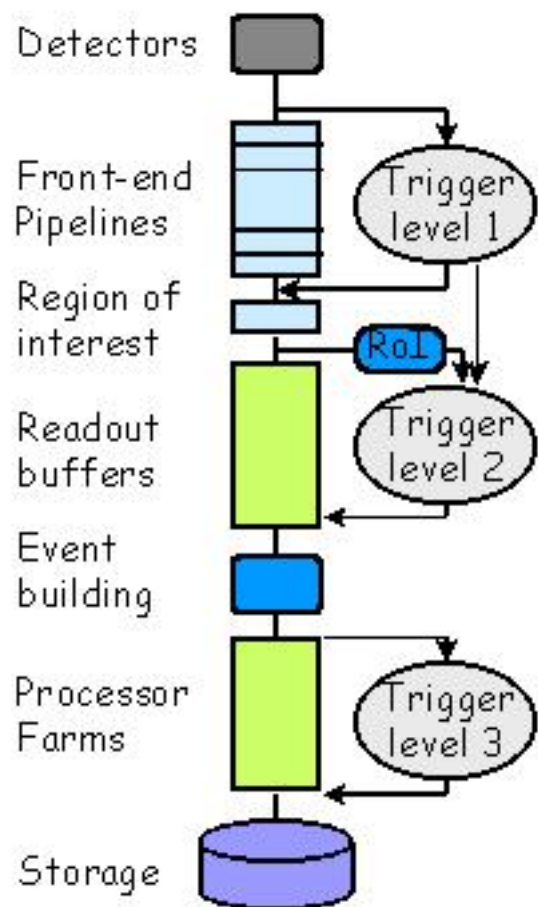
Wielopoziomowy tryger - DELPHI



- **Level-1 ($3 \mu s$) (hardware proc.)**
 - **Single detector Information:**
 - Energy: calorimeter (EM and Had.)
 - Tracks: counting, coincidences
 - Muons: Had. Cal. and Muon Chambers
 - Luminosity: analog sums
- **Level-2 ($36 \mu s$) (hardware proc.)**
 - **Detector Coincidences:**
 - Accept only tracks coming from the IP.
 - Beam-gas rejection. Uses the TPC
- **Level-3 ($\sim ms$) (In parallel for each sub-detector: 059 processors)**
 - Verifies L2 triggers with digitized data
- **Level-4 ($\sim ms$) (a small farm: 3 alpha CPU)**
 - Reconstructs the event using all data
 - Rejects Empty Events
 - Tagging of interesting physics channels



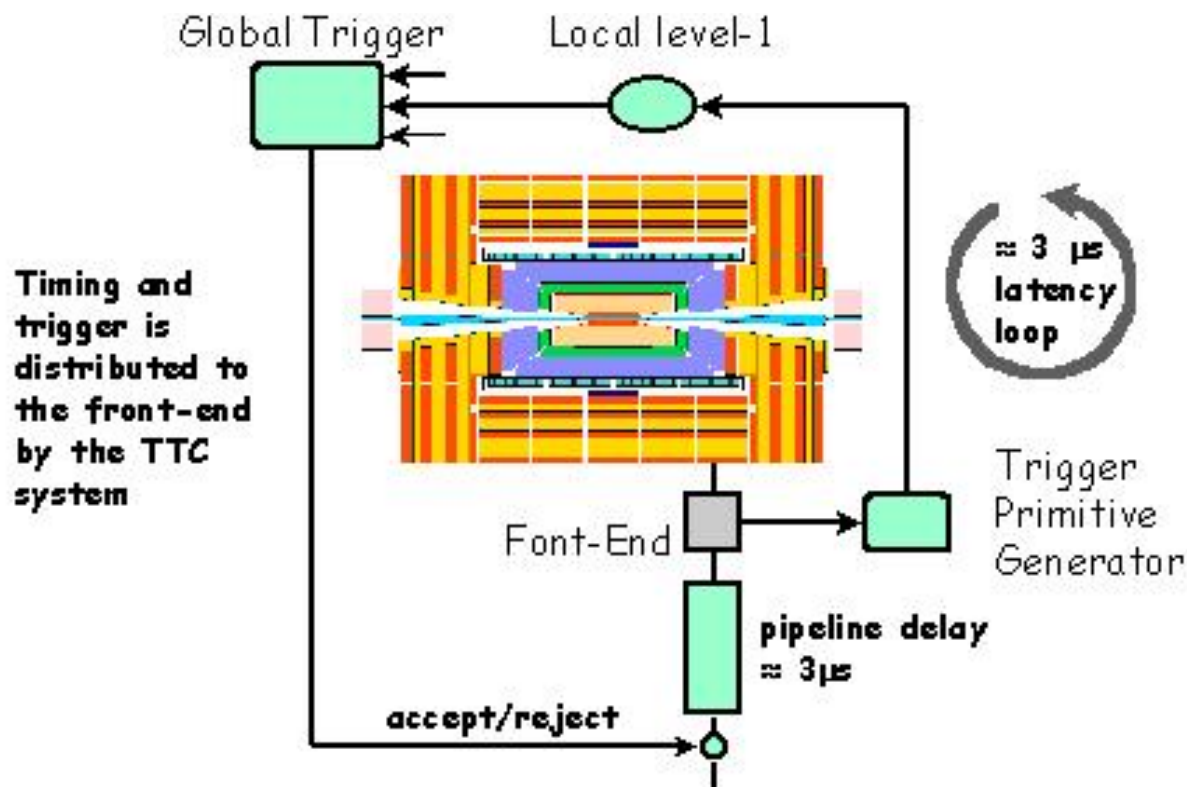
Wielopoziomowy tryger - ATLAS



- **Level-1 ($3.5 \mu\text{s}$) (custom processors)**
 - Energy clusters in calorimeters
 - Muon trigger: tracking coincidence matrix.
- **Level-2 ($100 \mu\text{s}$) (specialized processors)**
 - Few Regions Of Interest relevant to trigger decisions
 - Selected information (ROI) by routers and switches
 - Feature extractors (DSP or specialized)
 - Staged local and global processors
- **Level-3 ($\sim\text{ms}$) (commercial processors)**
 - Reconstructs the event using all data
 - Selection of interesting physics channels



LHC - pętla komunikacyjna



- 40 MHz synchronous digital system
- Synchronization at the exit of the pipeline non trivial.
⇒ Timing calibration



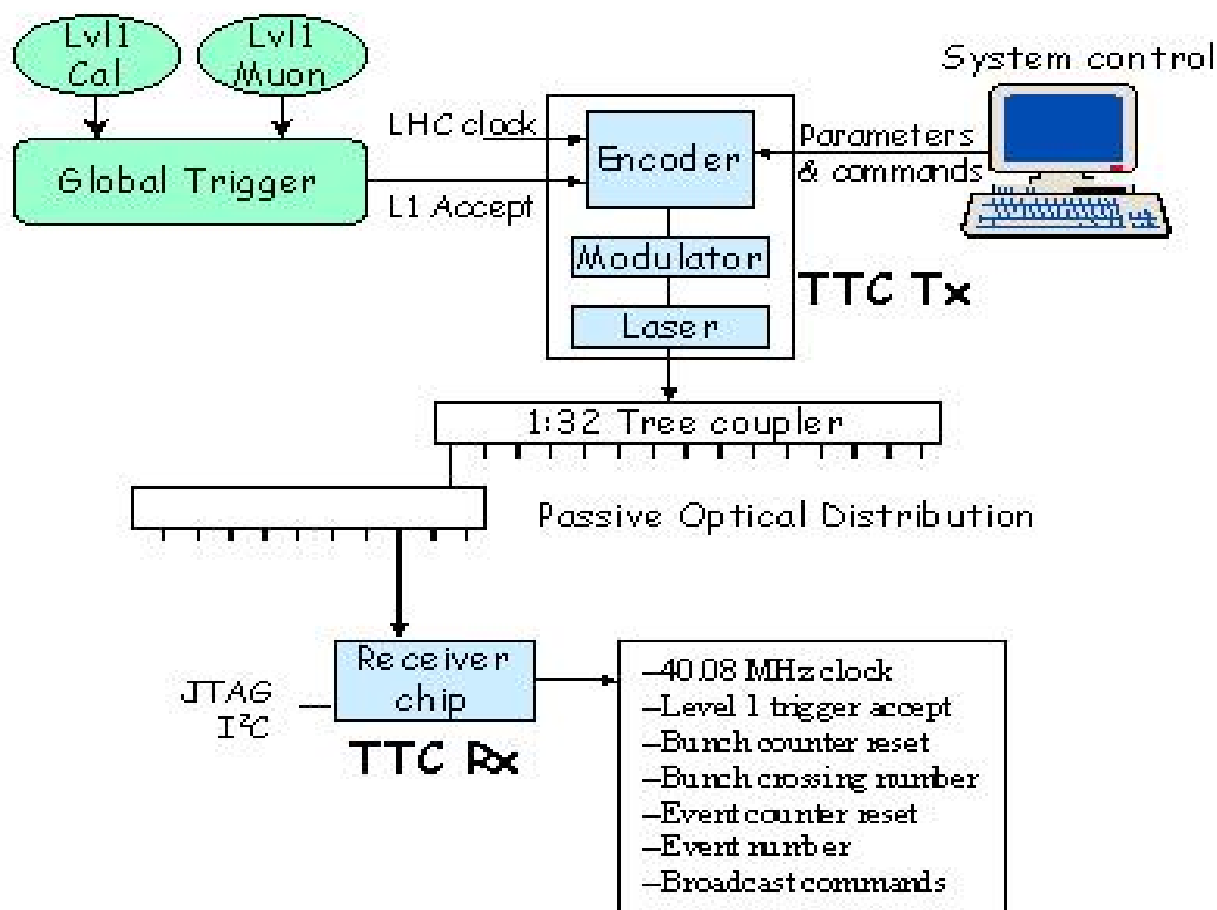
A ile tego wszystkiego mamy ?

	LEP (1989)	LHC (2007)	Factor
Nr. Electronic Channels	$\approx 100\ 000$	$\approx 10\ 000\ 000$	$\times 10^2$
Raw data rate	$\approx 1\ 000\ \text{GB/s}$	$\approx 1\ 000\ \text{TB/s}$	$\times 10^4$
Data rate on Tape	$\approx 1\ \text{MB/s}$	$\approx 100\ \text{MB/s}$	$\times 10^2$
Event size	$\approx 100\ \text{KB}$	$\approx 1\ \text{MB}$	$\times 10$
Bunch Separation	$22\ \mu\text{s}$	$25\ \text{ns}$	$\times 10^3$
Bunch Crossing Rate	$45\ \text{KHz}$	$40\ \text{MHz}$	$\times 10^3$
Rate on Tape	$10\ \text{Hz}$	$100\ \text{Hz}$	$\times 10$
Analysis	$0.1\ \text{Hz}$	$10^{-6}\ \text{Hz}$	$\times 10^5$
	(Z_0, W)	(Higgs)	

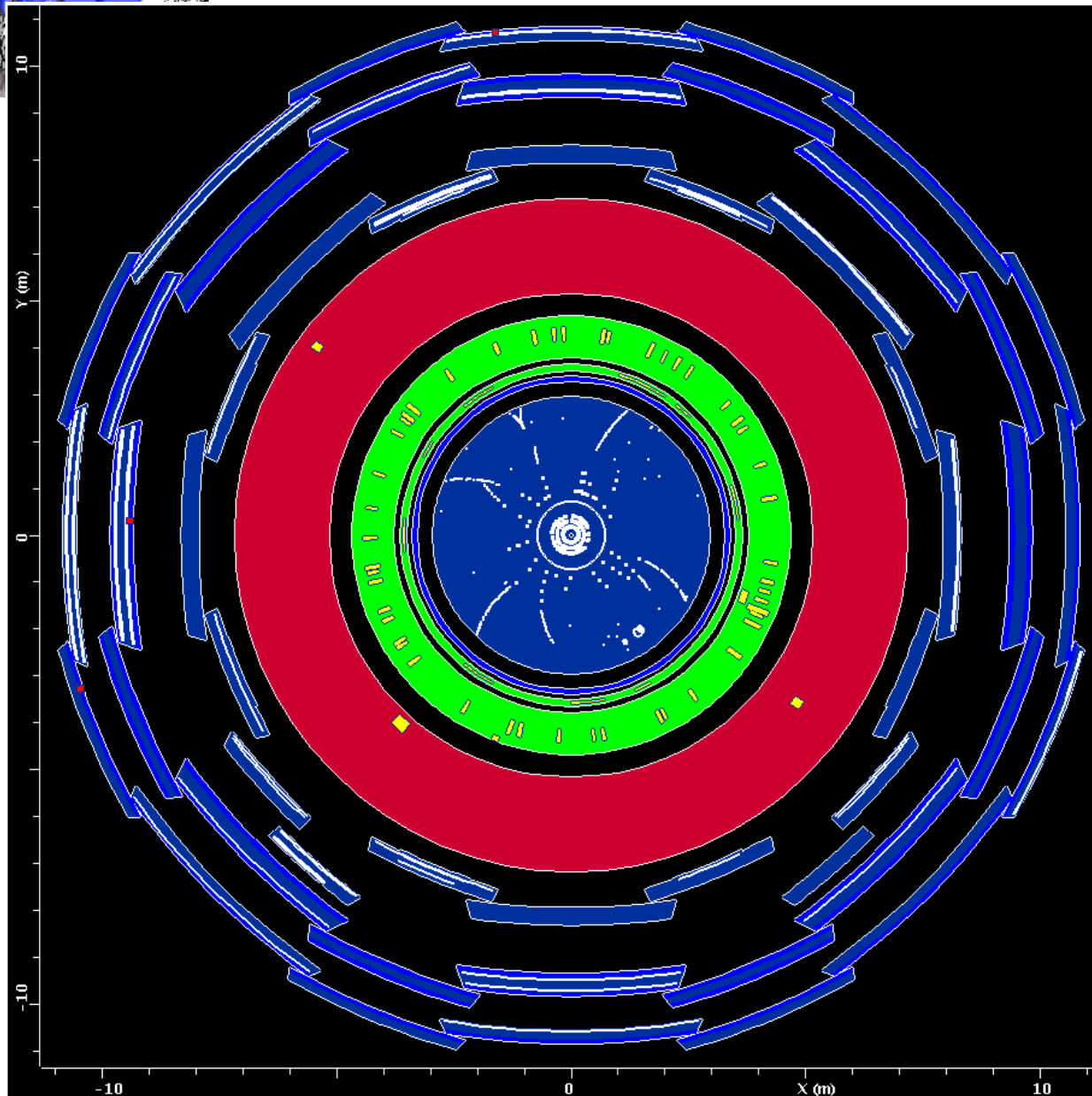


Rozprowadzenie decyzji - TTC

■ The TTC system



ATLAS online event selection

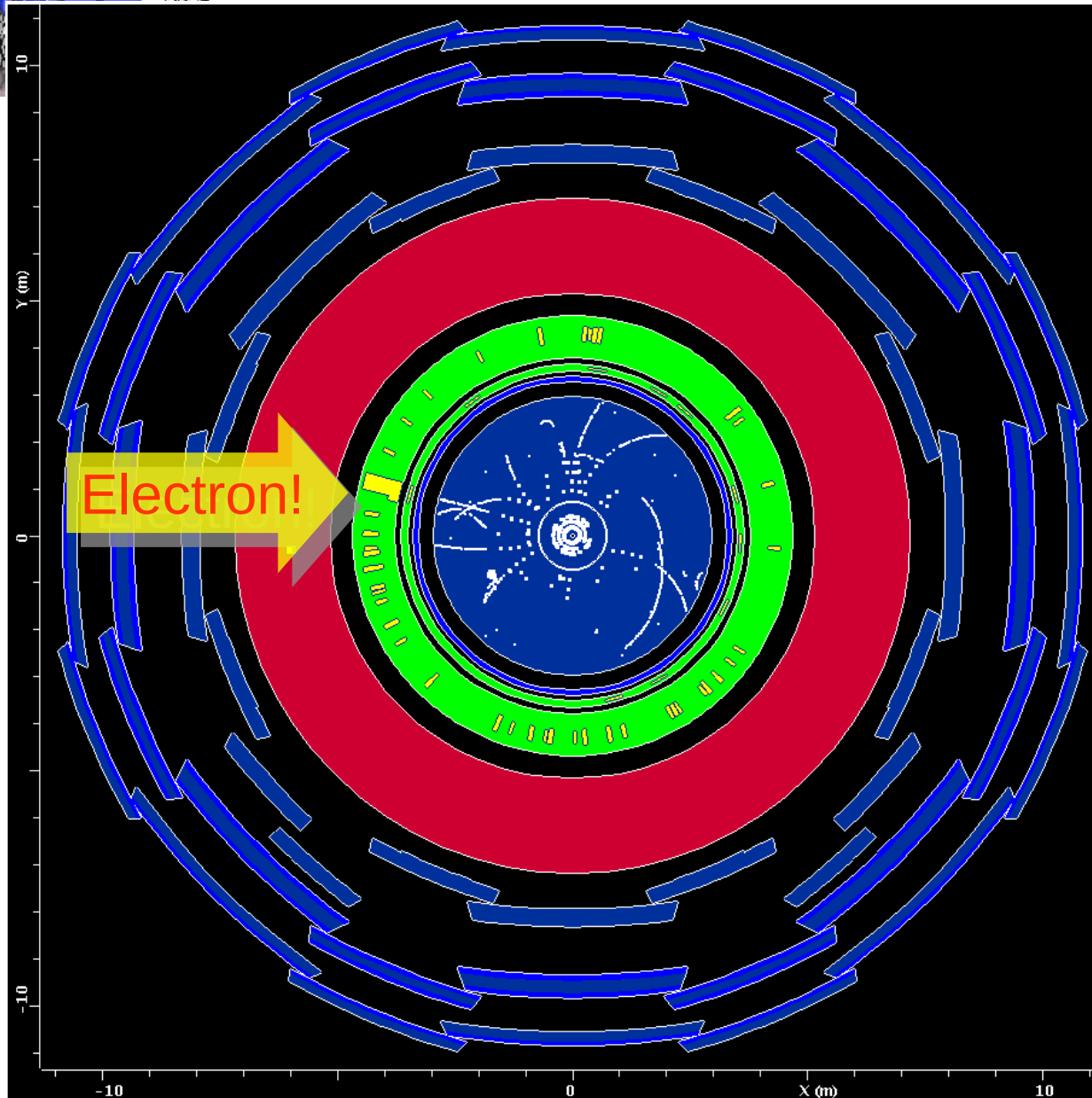


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection



1 in 5 000 000
events can be
recorded

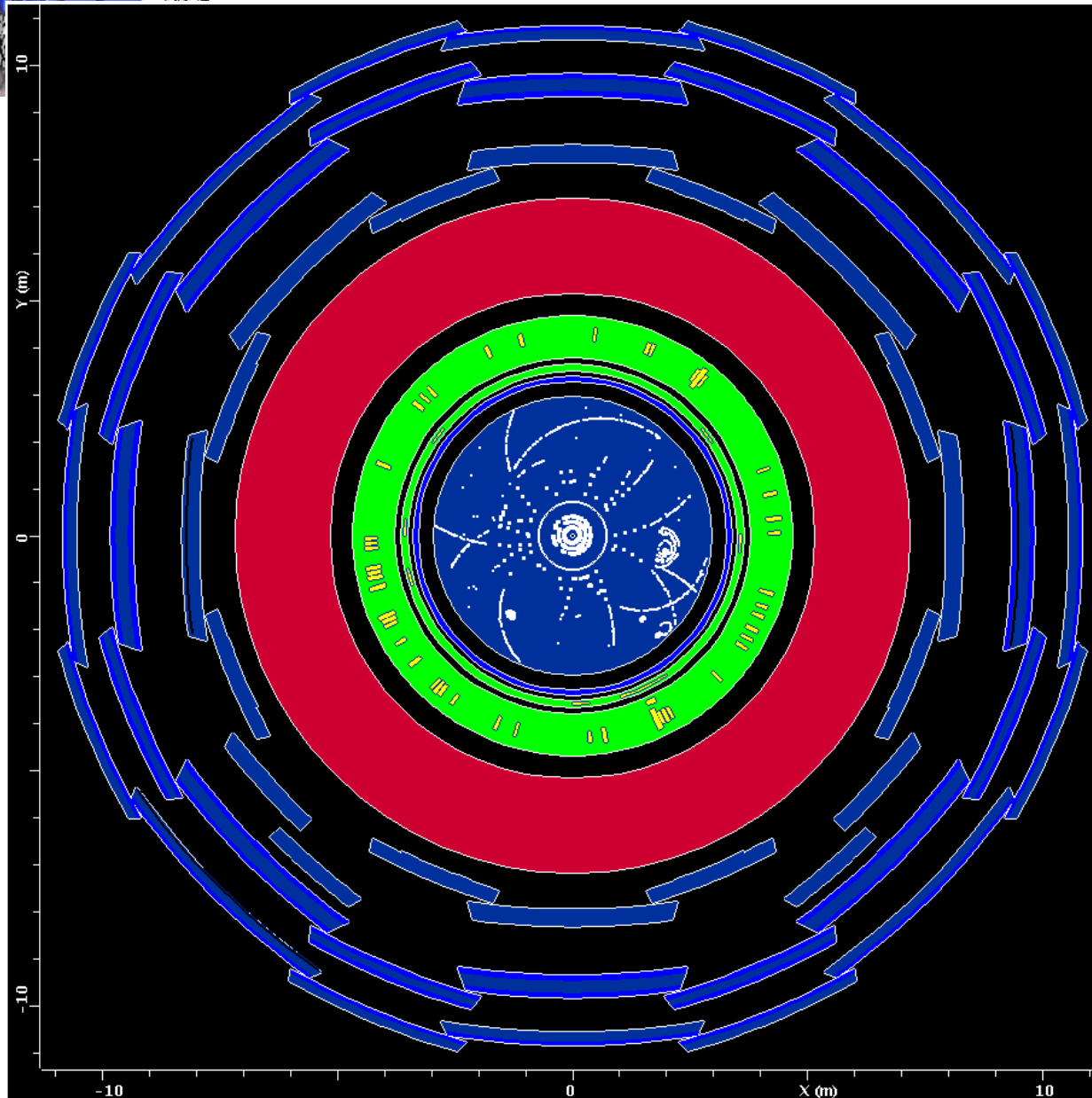
Accept or
reject?

Accept!

Z boson

$Z^0 \rightarrow e^+e^-$

ATLAS online event selection

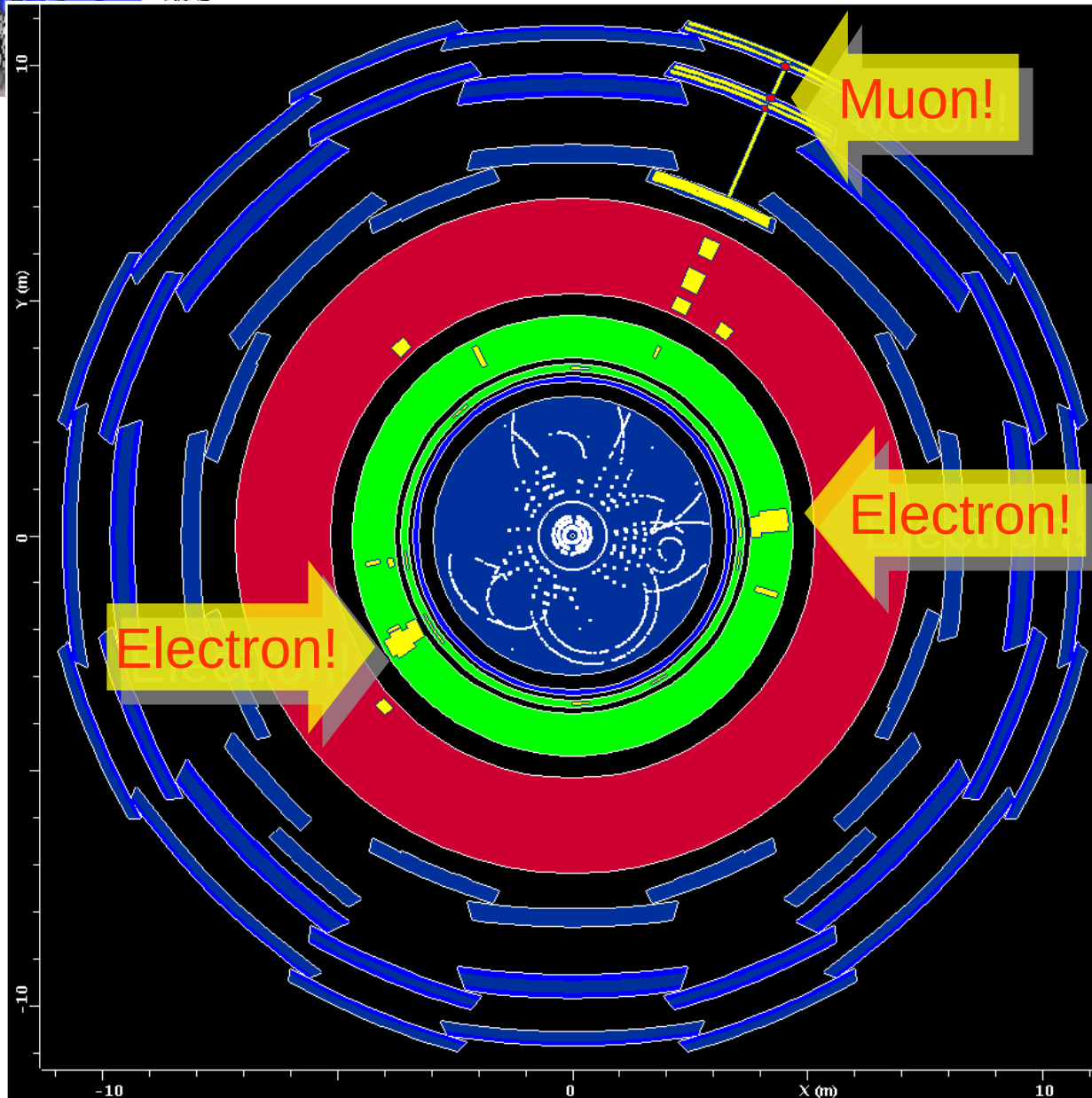


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection



1 in 5 000 000
events can be
recorded

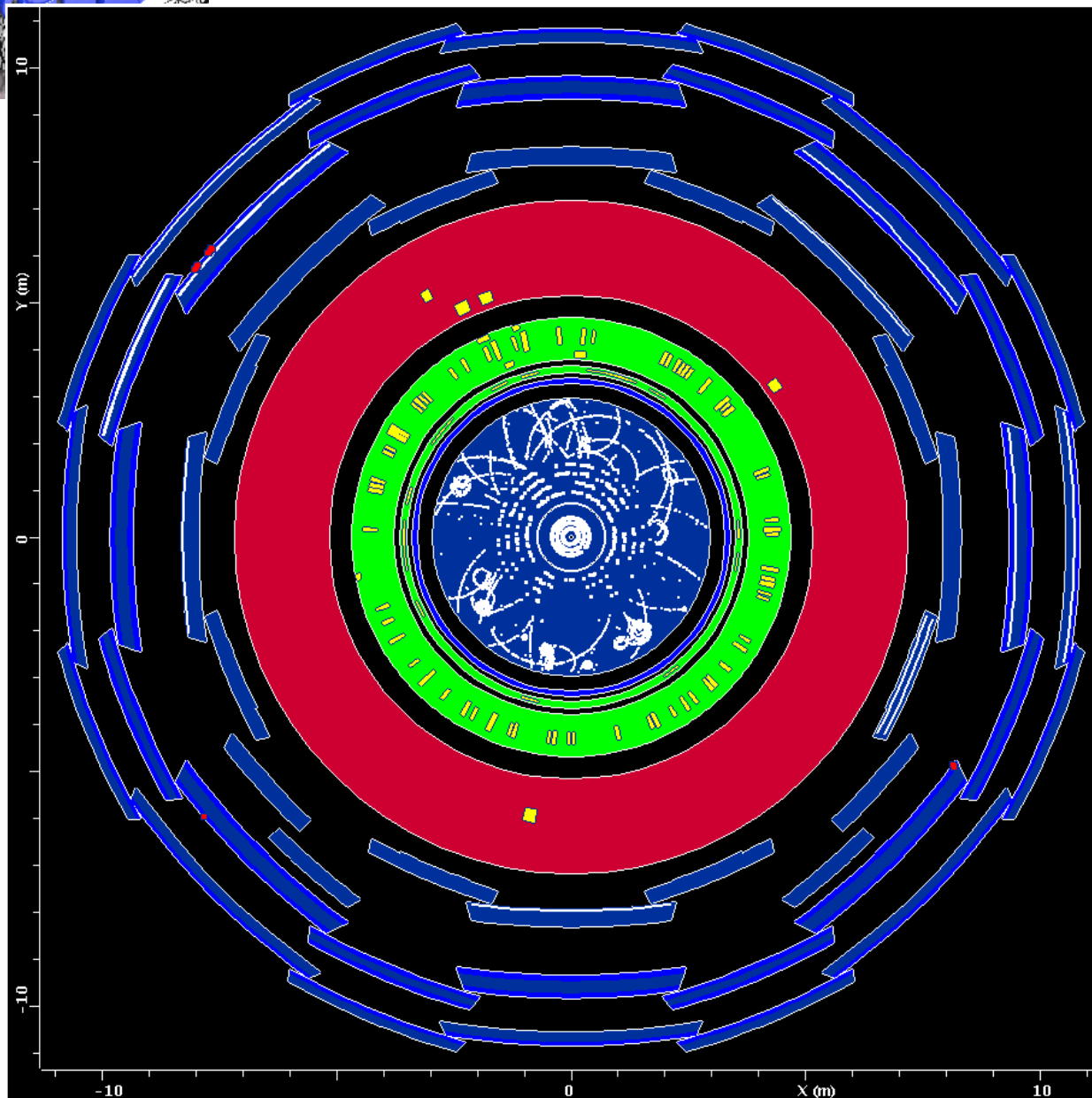
Accept or
reject?

Accept!

Higgs boson

$$H \rightarrow \mu^+ \mu^- e^+ e^-$$

ATLAS online event selection

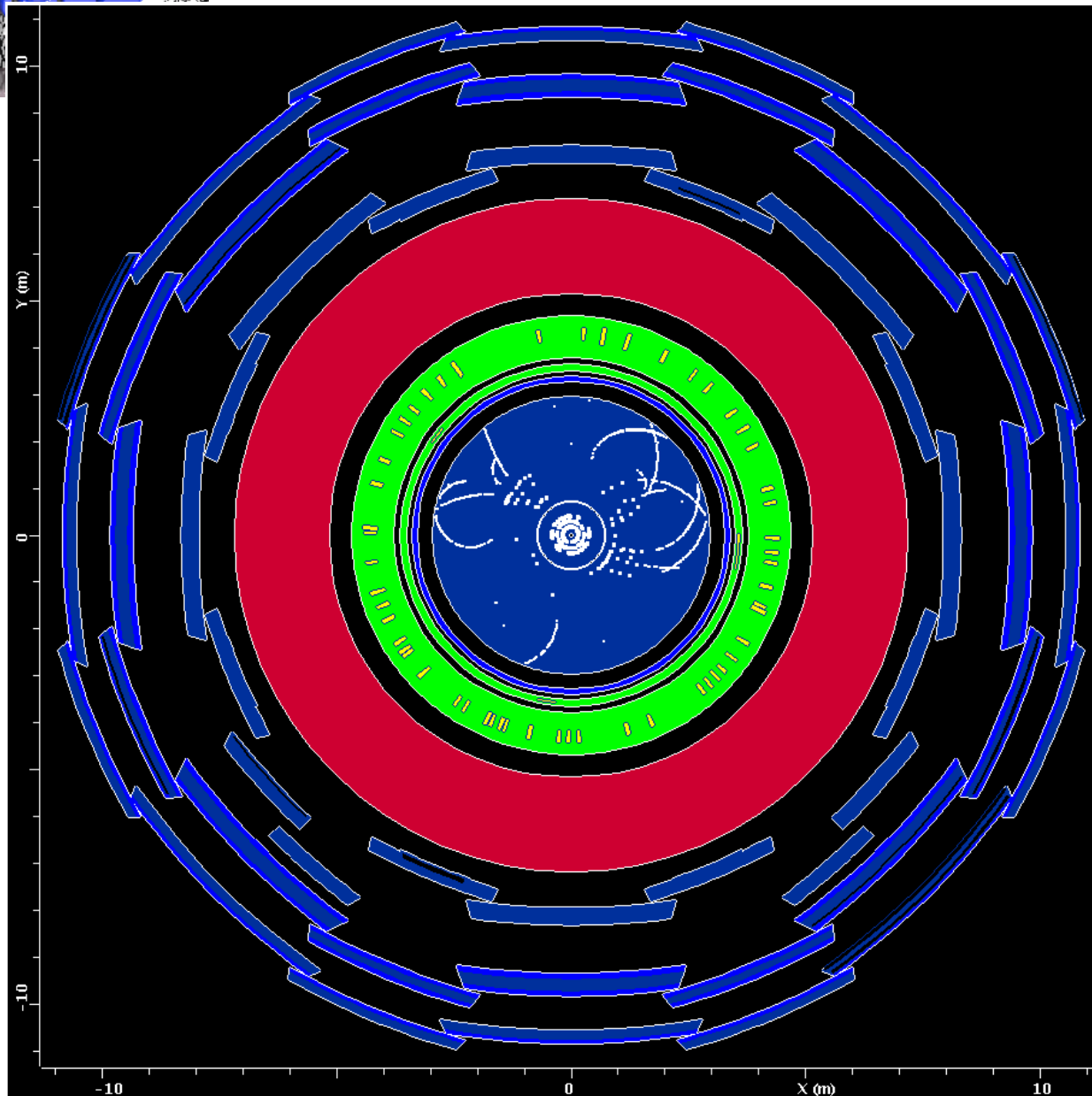


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection

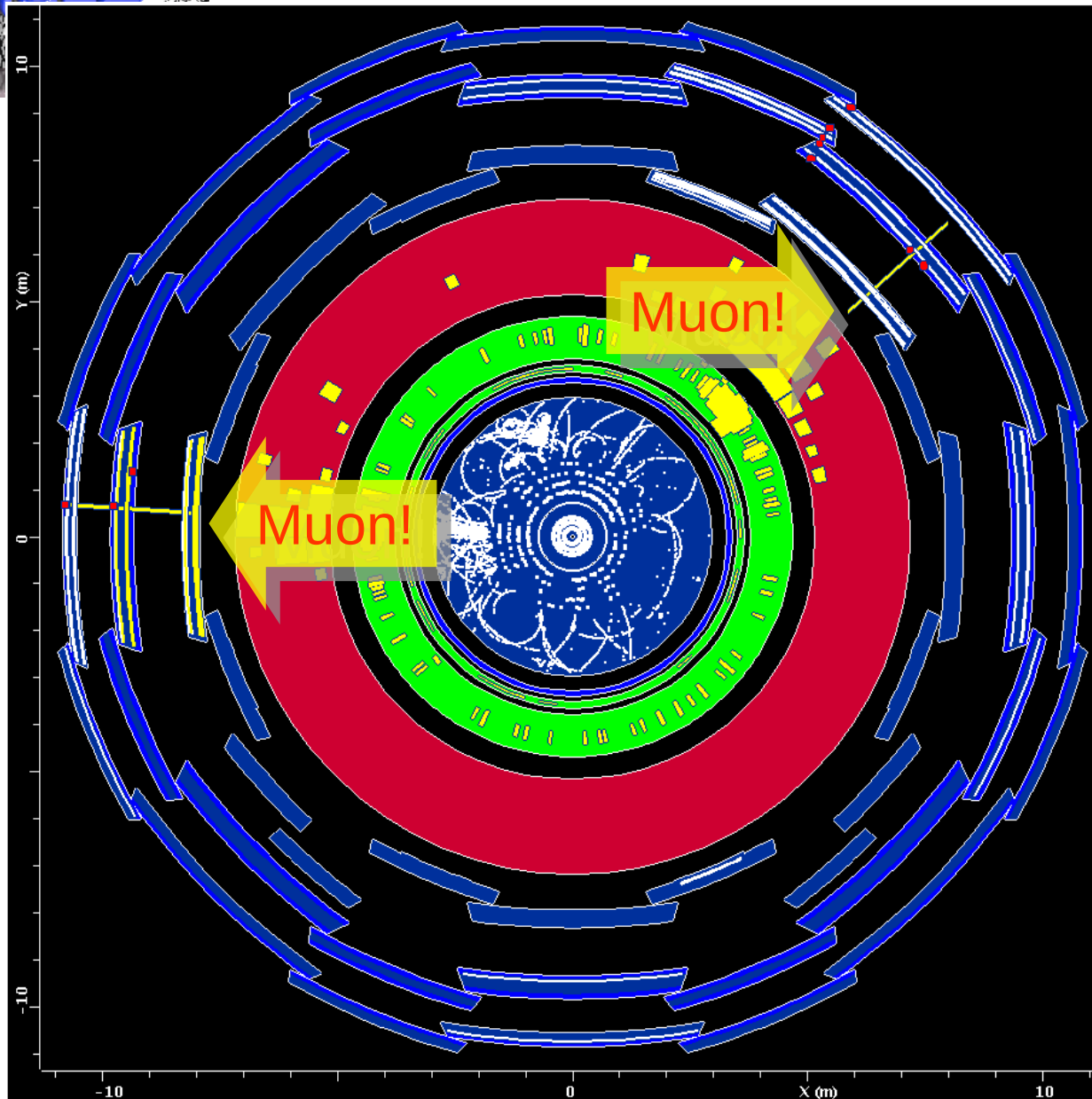


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Accept or
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Reject!

ATLAS online event selection



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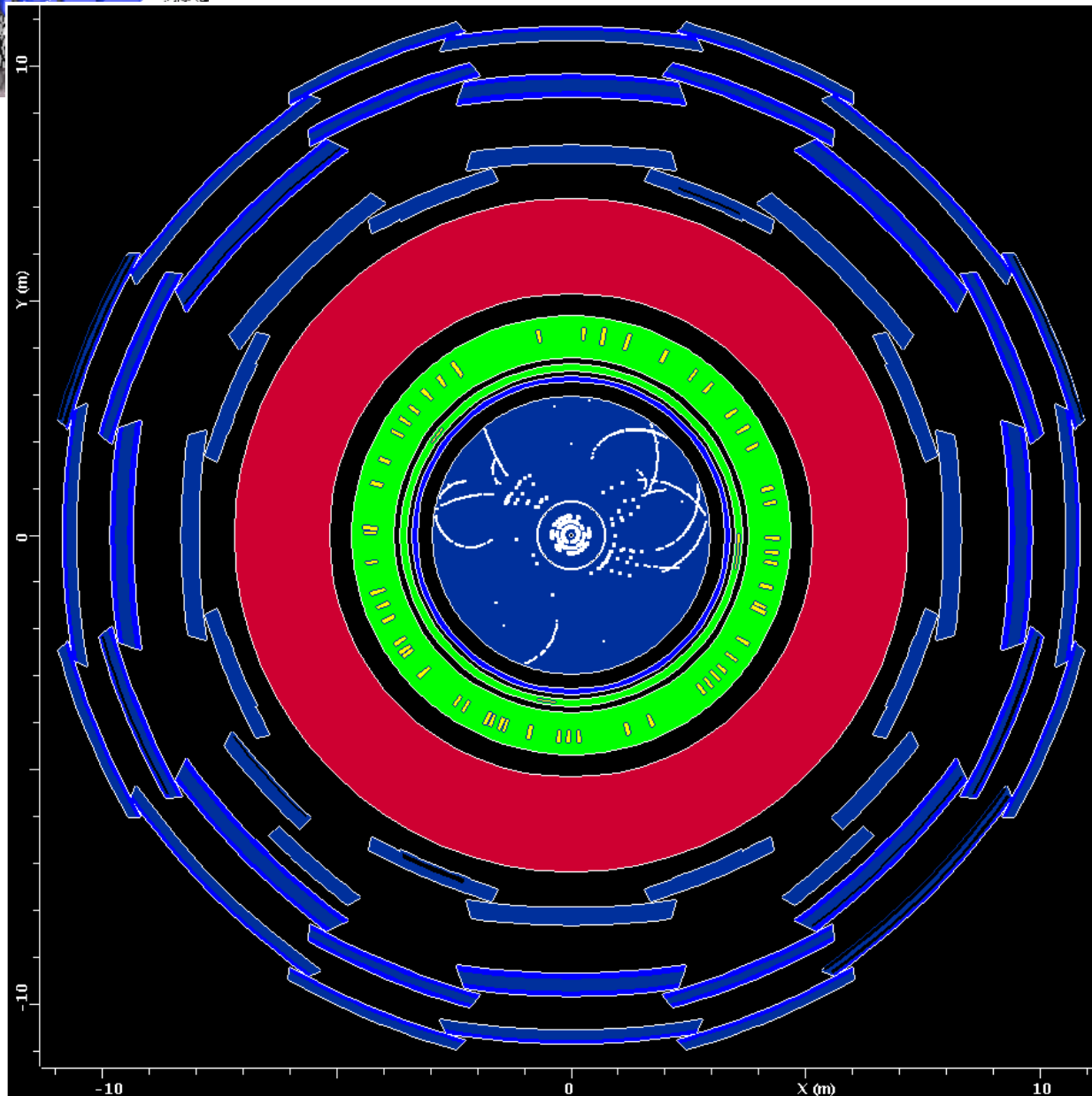
Accept or
reject?

Accept!
supersymmetry

$$\tilde{u}_R \rightarrow \bar{u} + \tilde{\chi}_1^0$$

$$\tilde{d}_L \rightarrow d + \tilde{\chi}_2^0 \rightarrow d + \mu^+ + \mu^- + \tilde{\chi}_1^0$$

ATLAS online event selection

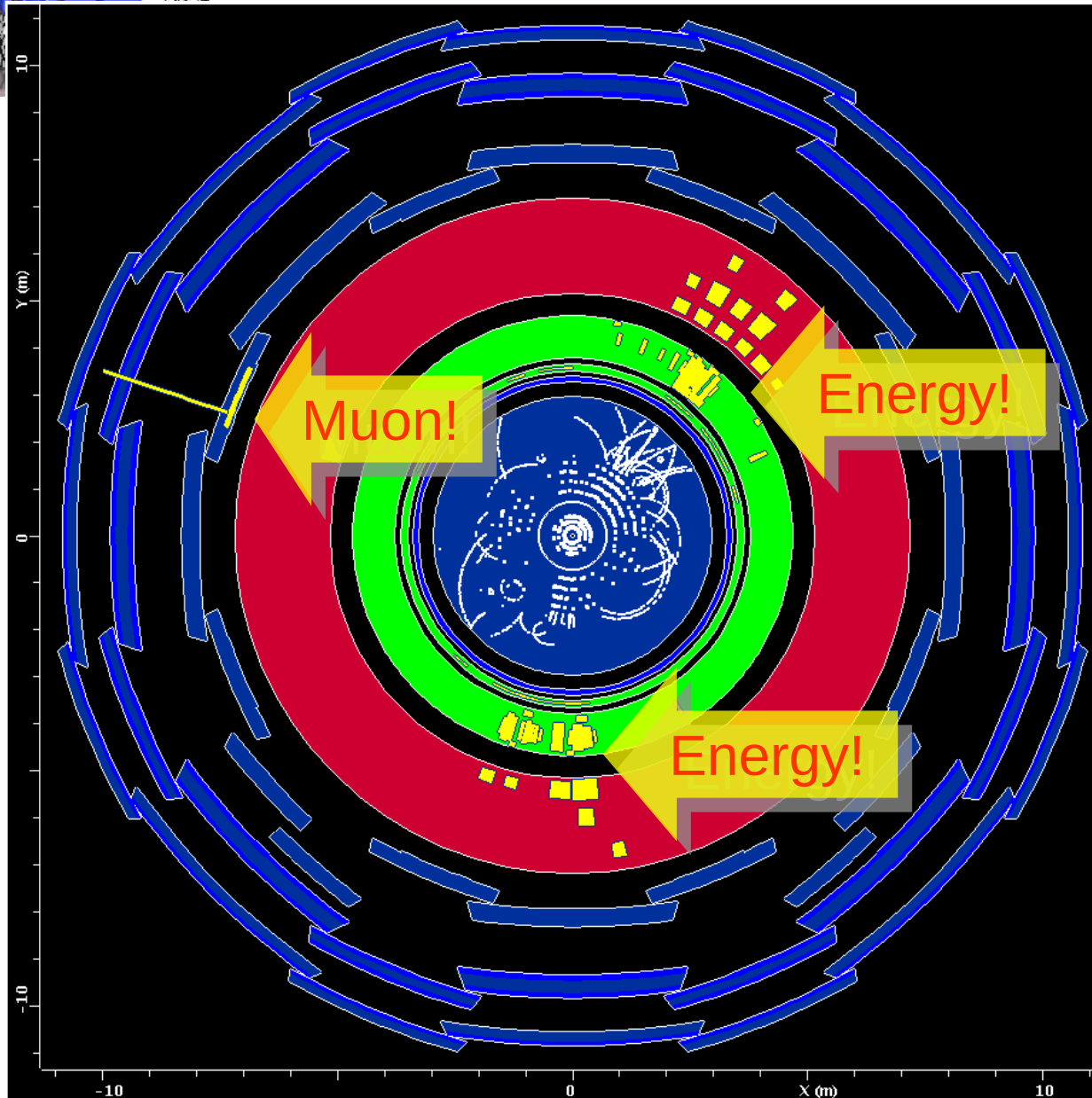


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection



1 in 5 000 000
events can be
recorded

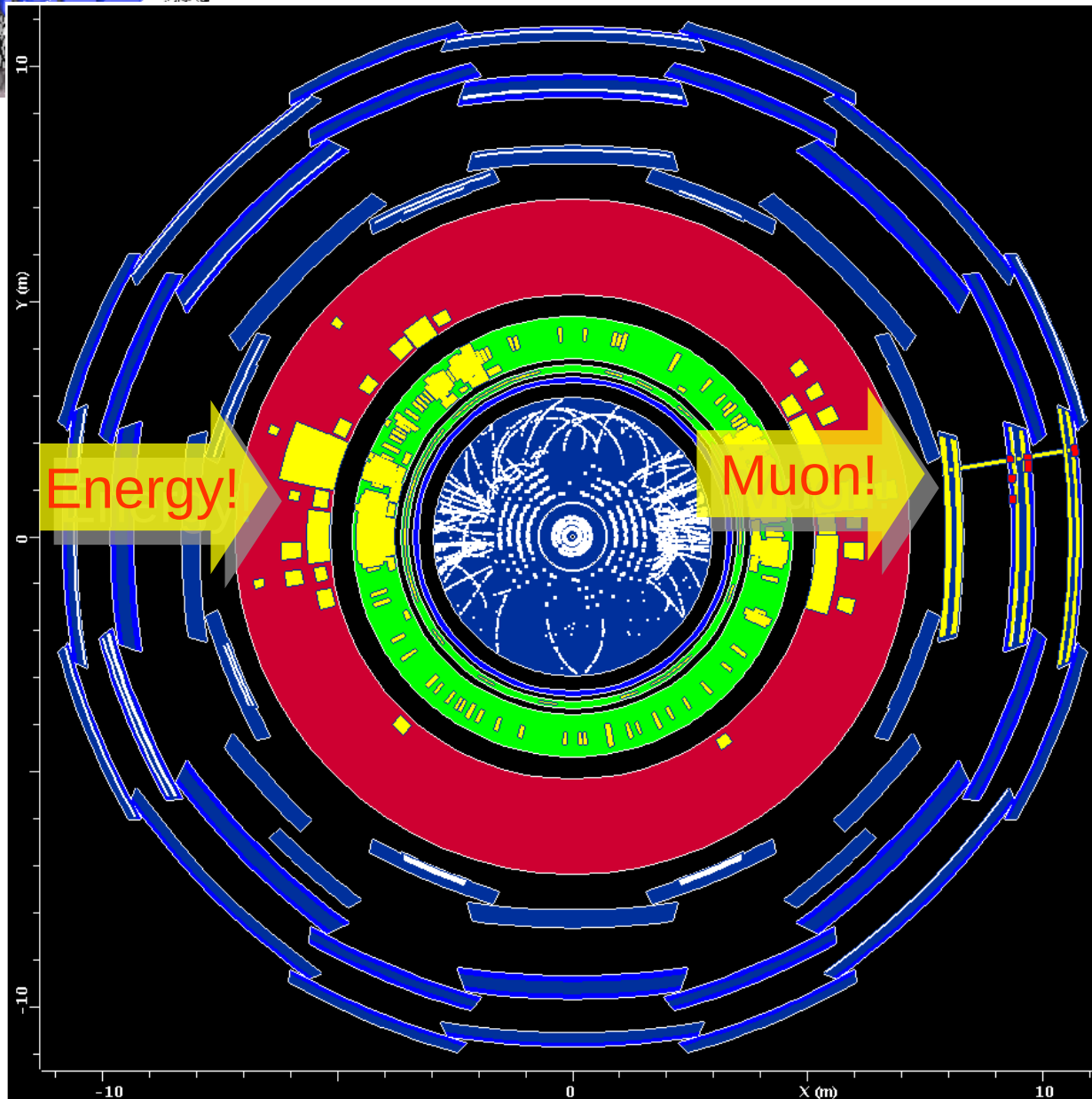
Accept or
reject?

Accept!

Higgs boson

$$W^+H \rightarrow \mu^+ \nu_\mu b \bar{b}$$

ATLAS online event selection



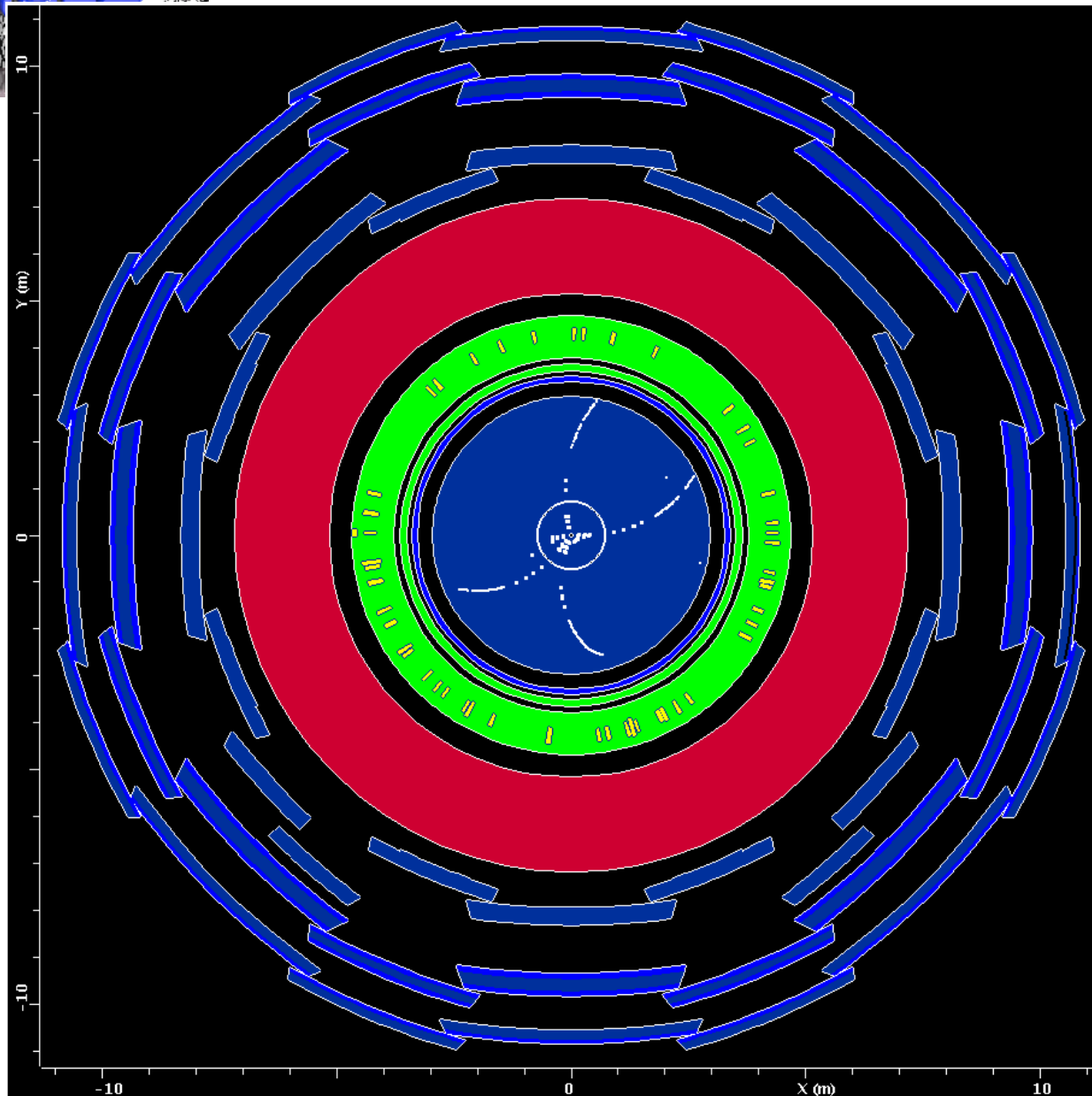
1 in 5 000 000
events can be
recorded

Accept or
reject?

Accept!
supersymmetry

$$\begin{aligned}\tilde{g} &\rightarrow c + \tilde{c}_R \rightarrow c + \bar{c} + \tilde{\chi}_1^0 \\ \tilde{g} &\rightarrow \bar{d} + \tilde{d}_L \rightarrow \bar{d} + \tilde{\chi}_1^0 + W^- + u \\ W^- &\rightarrow \mu^- + \bar{\nu}_\mu\end{aligned}$$

ATLAS online event selection

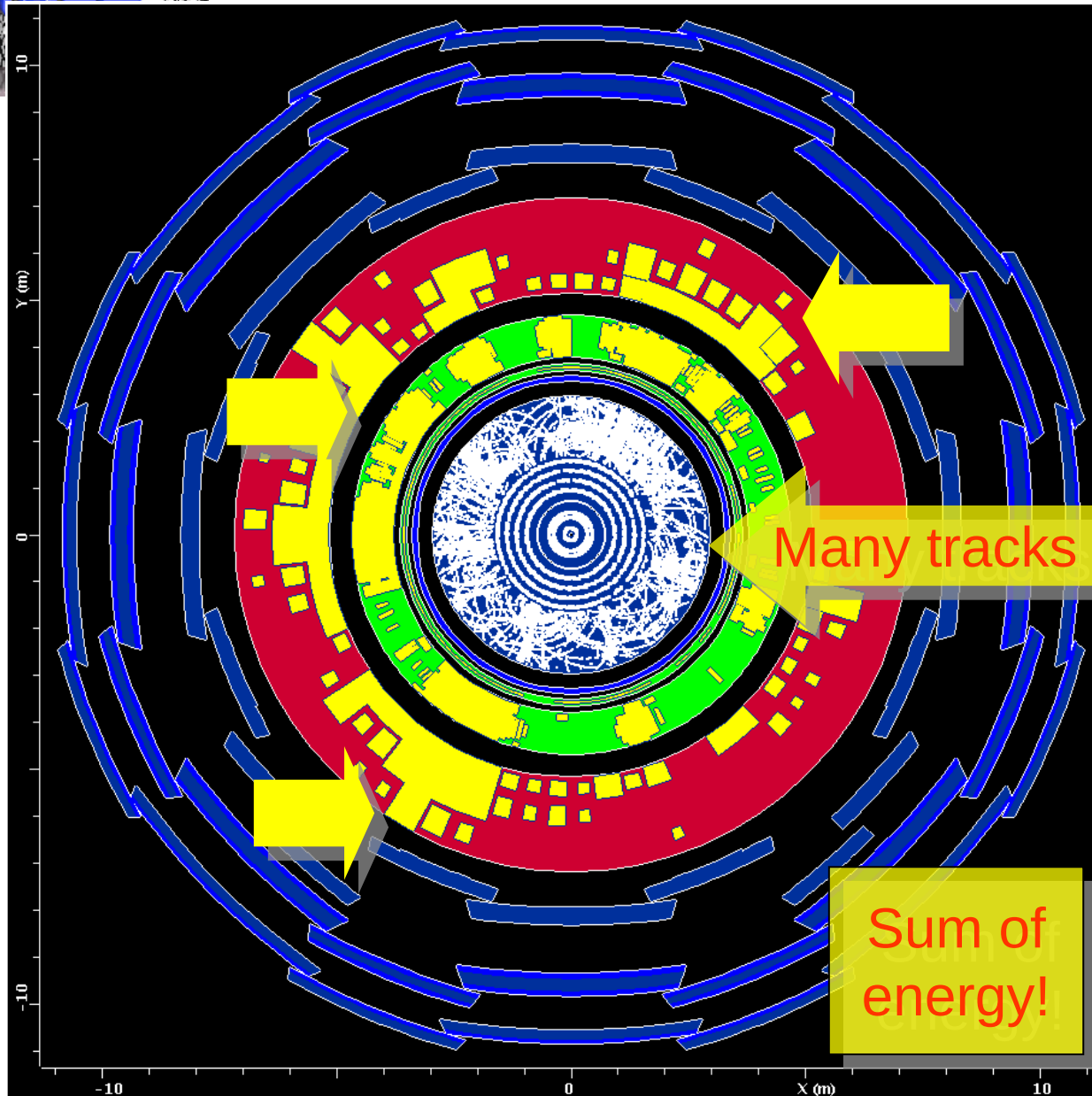


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection



1 in 5 000 000
events can be
recorded

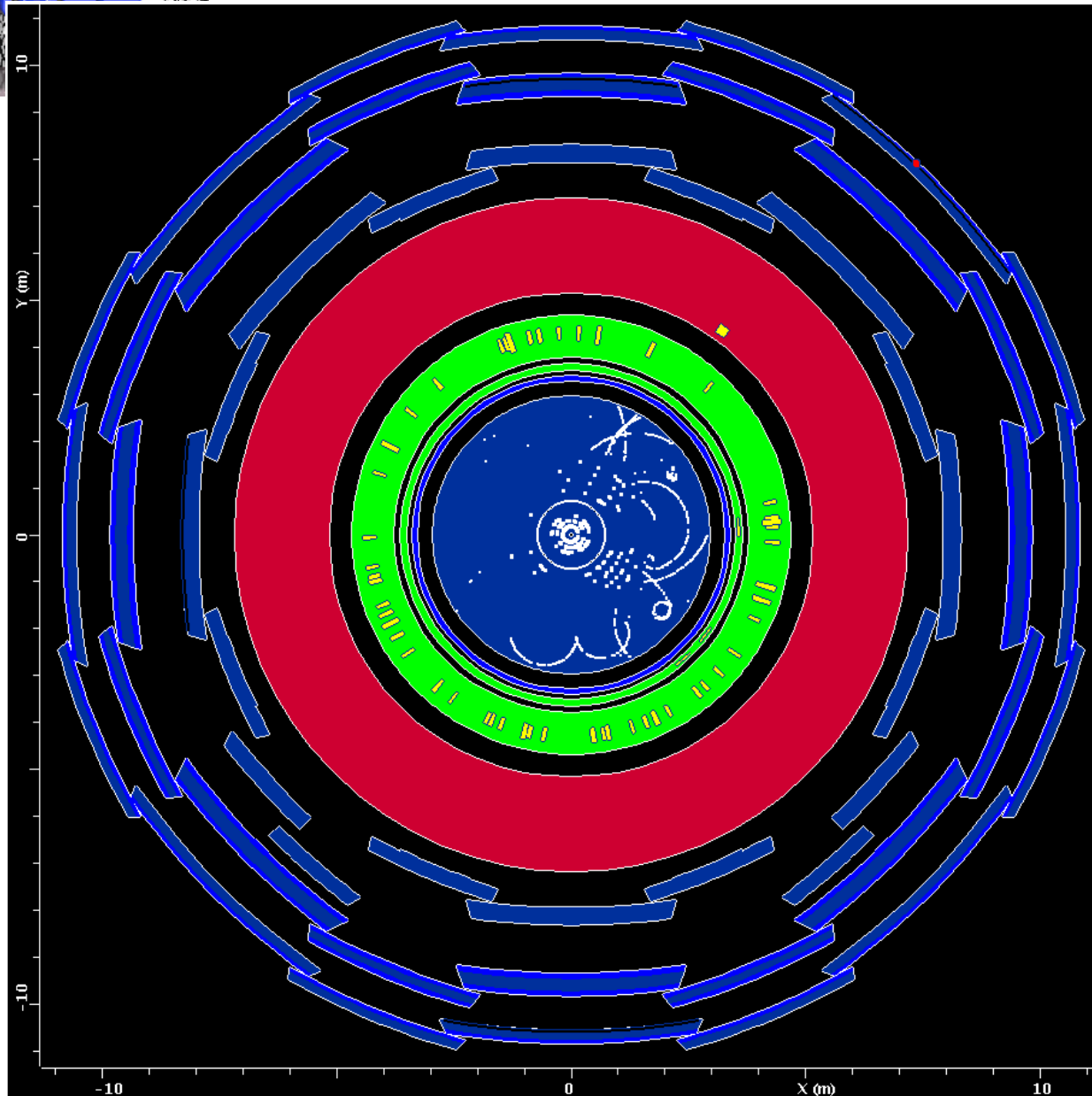
Accept or
reject?

Accept!

Black hole?

Sum of
energy!

ATLAS online event selection

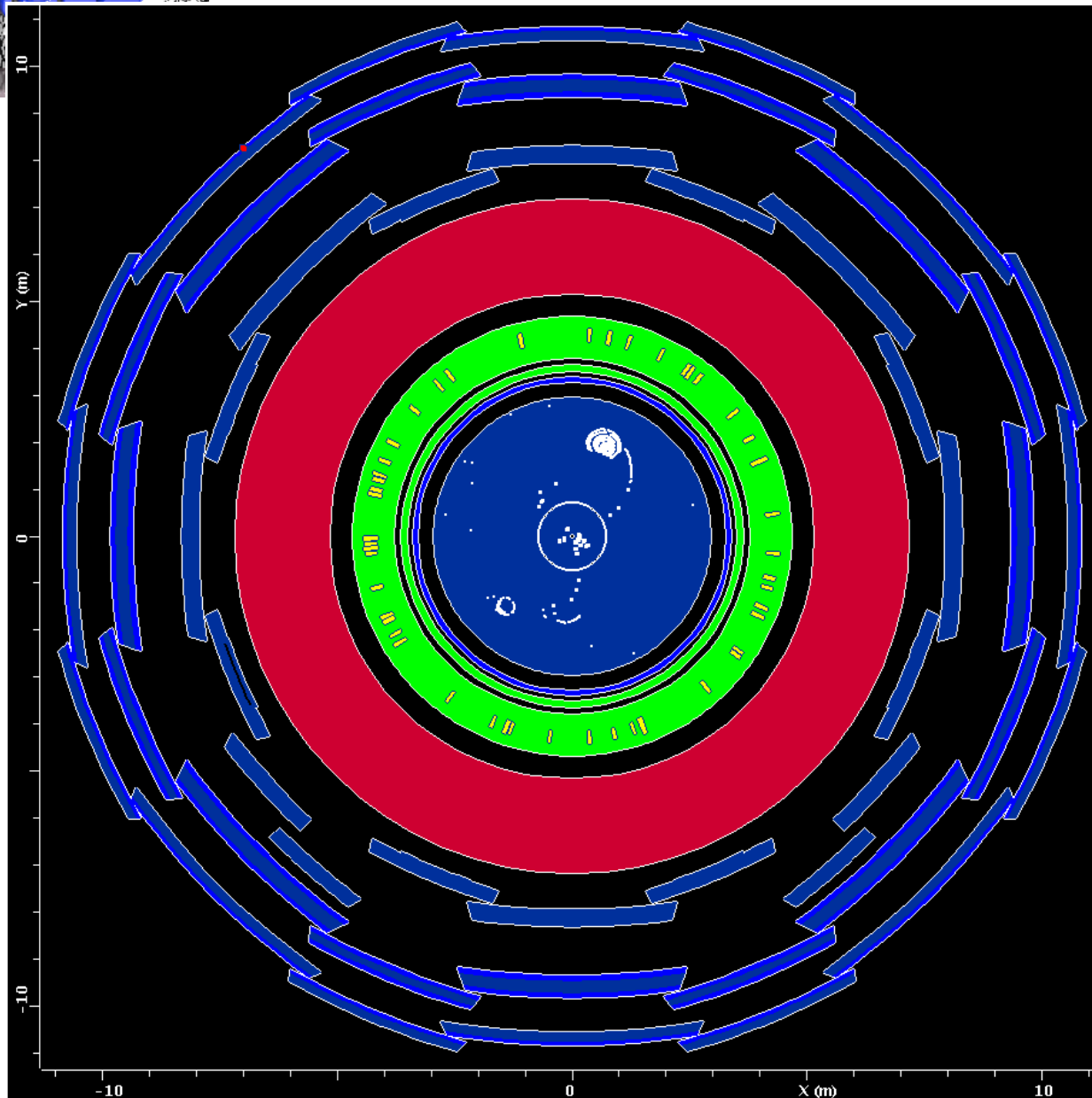


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection

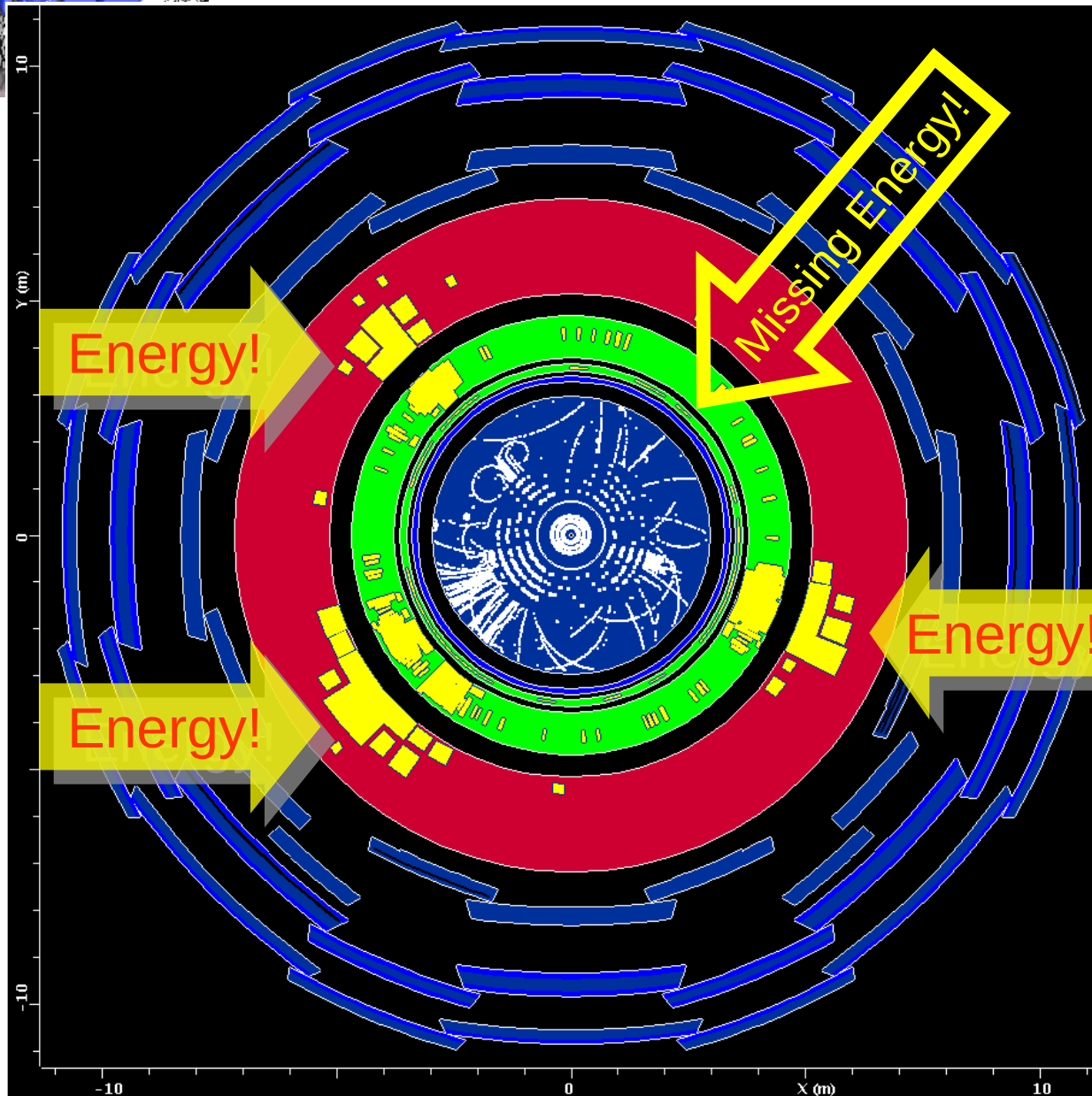


1 in 5 000 000
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Accept or
reject?

Reject!

ATLAS online event selection



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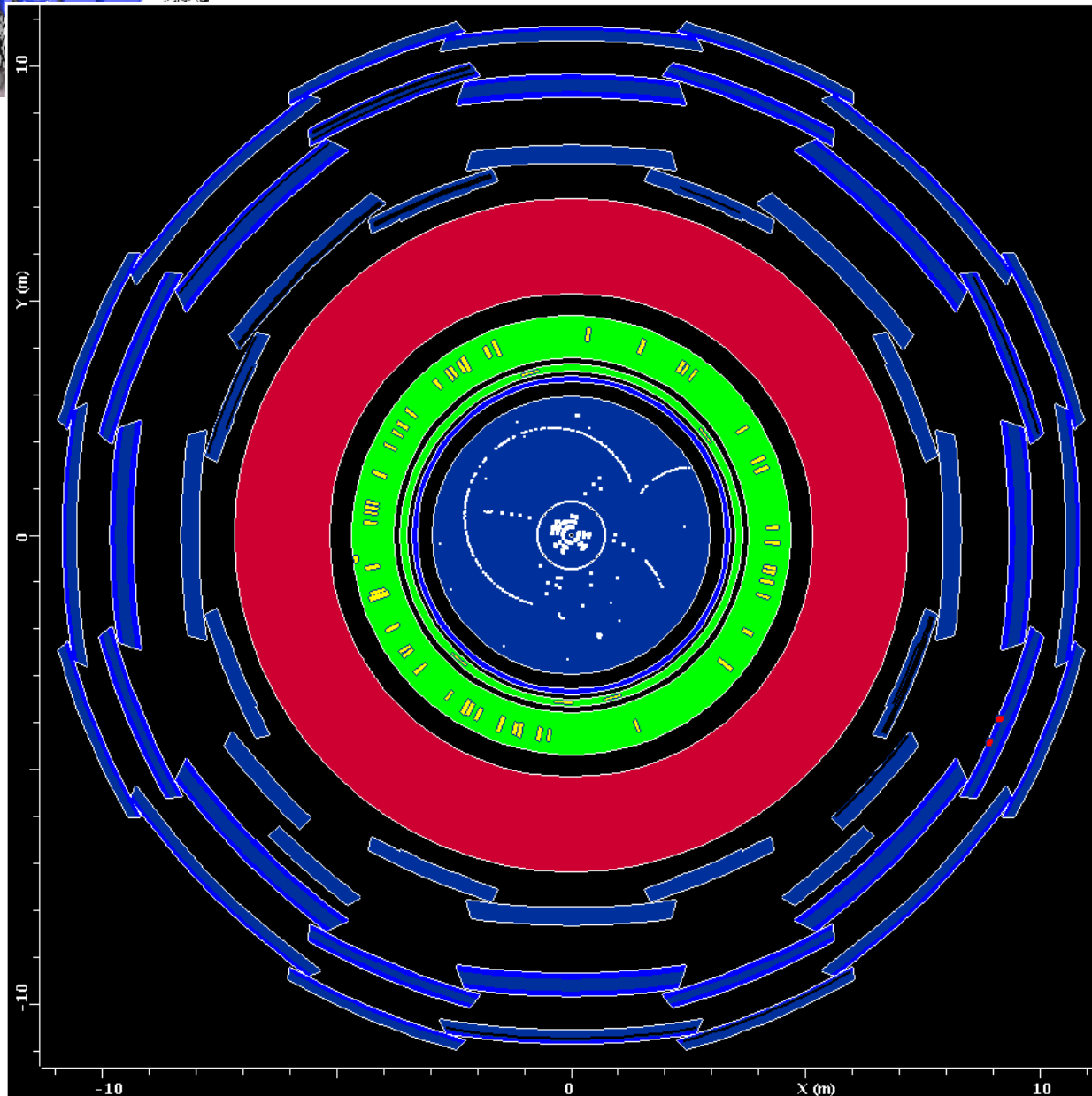
Accept or
reject?

Accept!
supersymmetry

$$\tilde{u}_R \rightarrow u + \tilde{\chi}_1^0$$

$$\tilde{\bar{u}}_R \rightarrow \bar{u} + \tilde{\chi}_1^0$$

ATLAS online event selection

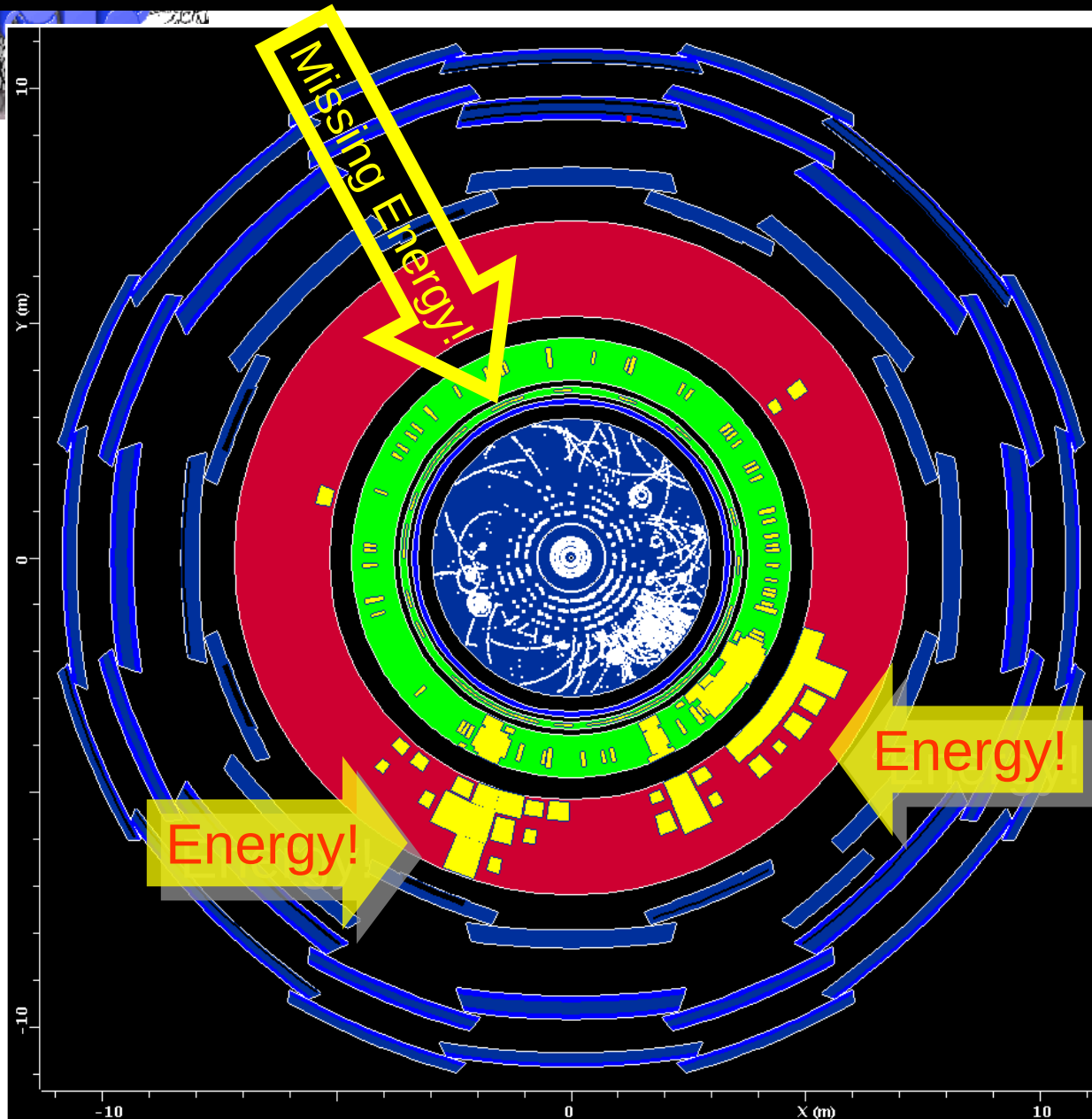


1 in 5 000 000
events can be
recorded

Accept or
reject?

Reject!

ATLAS online event selection



1 in 5 000 000
events can be
recorded

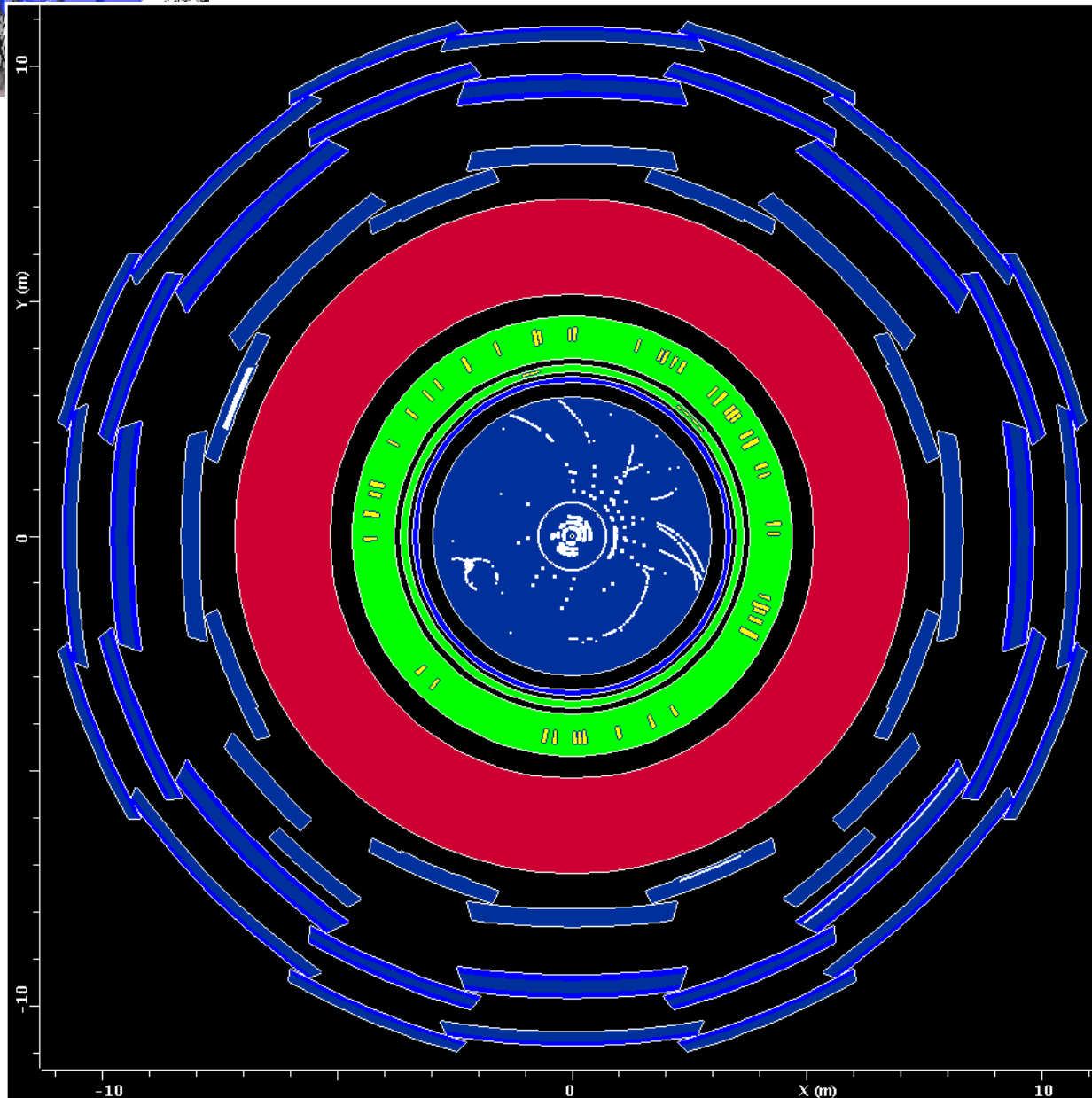
Accept or
reject?

Accept!
supersymmetry

$$\tilde{u}_R \rightarrow \tilde{\chi}_1^0 + u$$

$$\tilde{s} \rightarrow \tilde{\chi}_1^0 + Z + \bar{s} \rightarrow \tilde{\chi}_1^0 + d + \bar{d} + \bar{s}$$

ATLAS online event selection

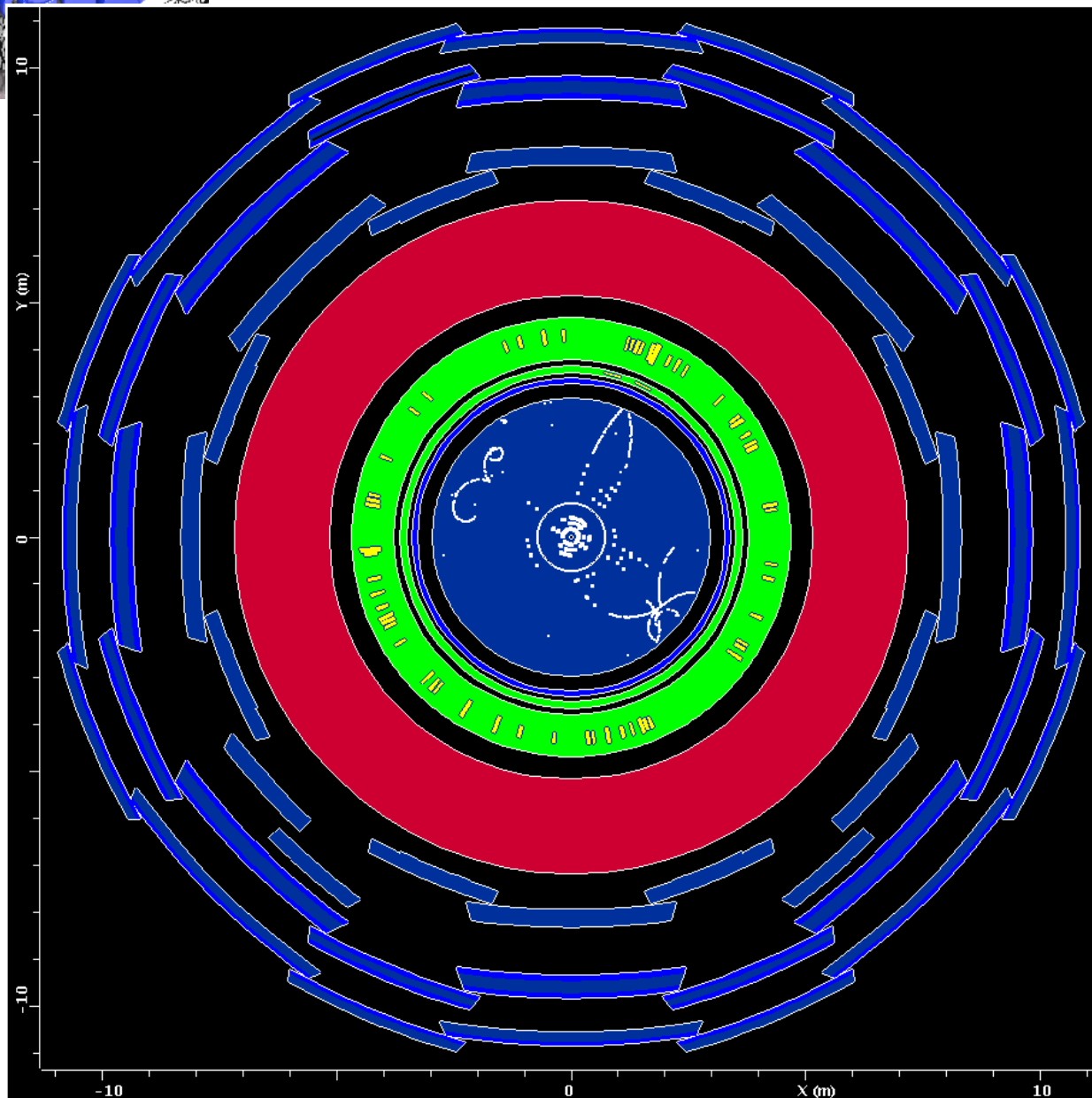


1 in 5 000 000
events can be
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Accept or
reject?

Reject!

ATLAS online event selection

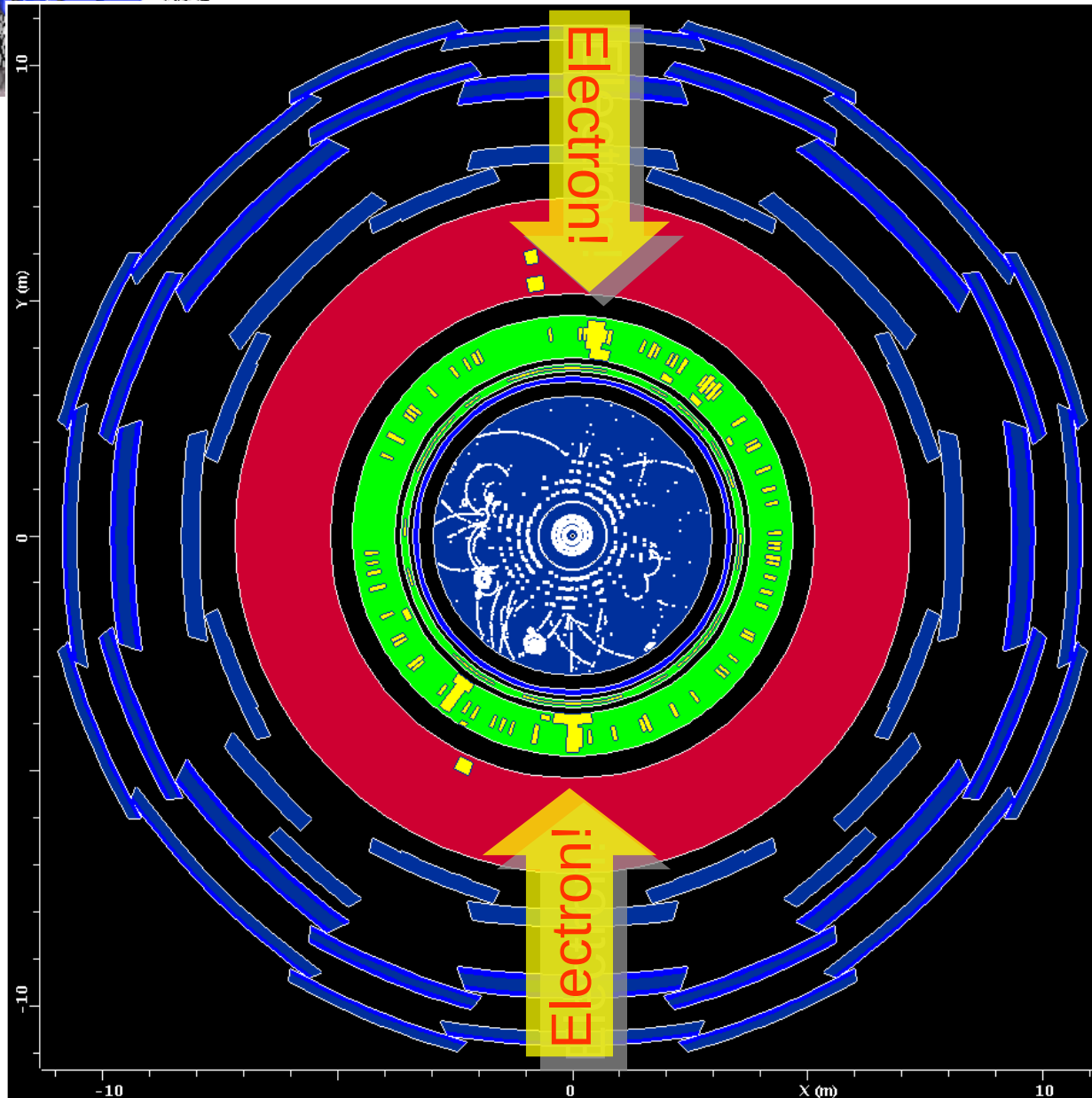


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Accept or
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Accept!

Z boson

$$Z^0 \rightarrow e^+e^-$$