Trigger and DAQ

Part I – Introduction to triggering

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trig•ger |ˈtrɪgə|

noun

a small device that releases a spring or catch and so sets off a mechanism, esp. in order to fire a gun : *he pulled the trigger of the shotgun.*

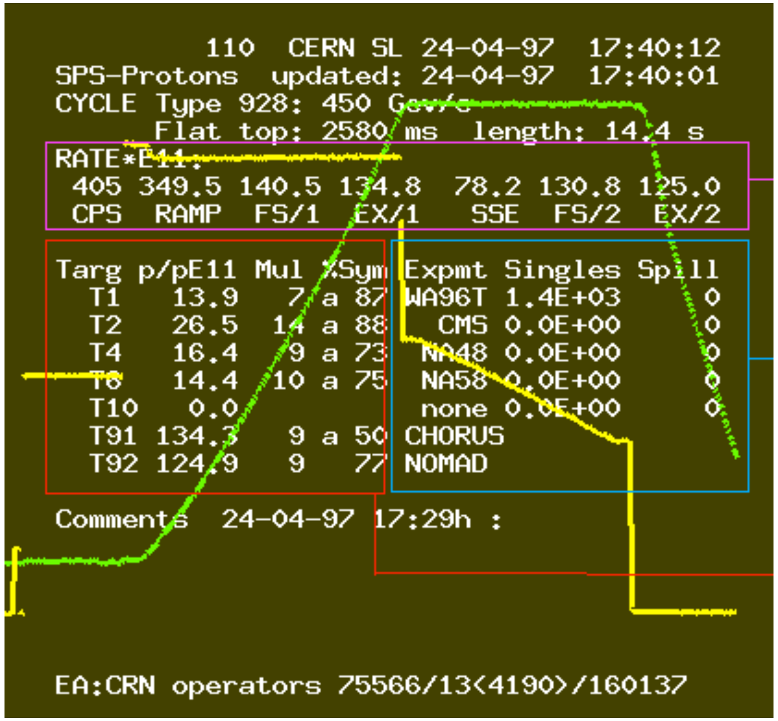
- an event or thing that causes something to happen : *the trigger for the strike was the closure of a mine.*

verb [trans.]

(often **be triggered**) cause (an event or situation) to happen or exist : *an allergy can be triggered by stress or overwork.*

- cause (a device) to function.

This checks well with the original purpose of ”triggers” in particle physics …



During a ”slow spill” (around 2 s) a large number of particles passed through the experiments, but only a small fraction even interacted

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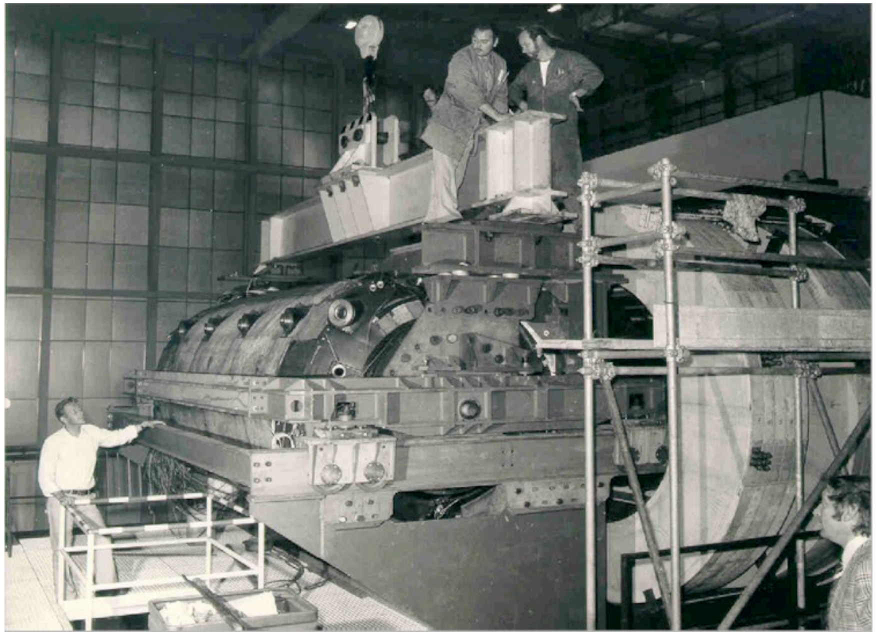
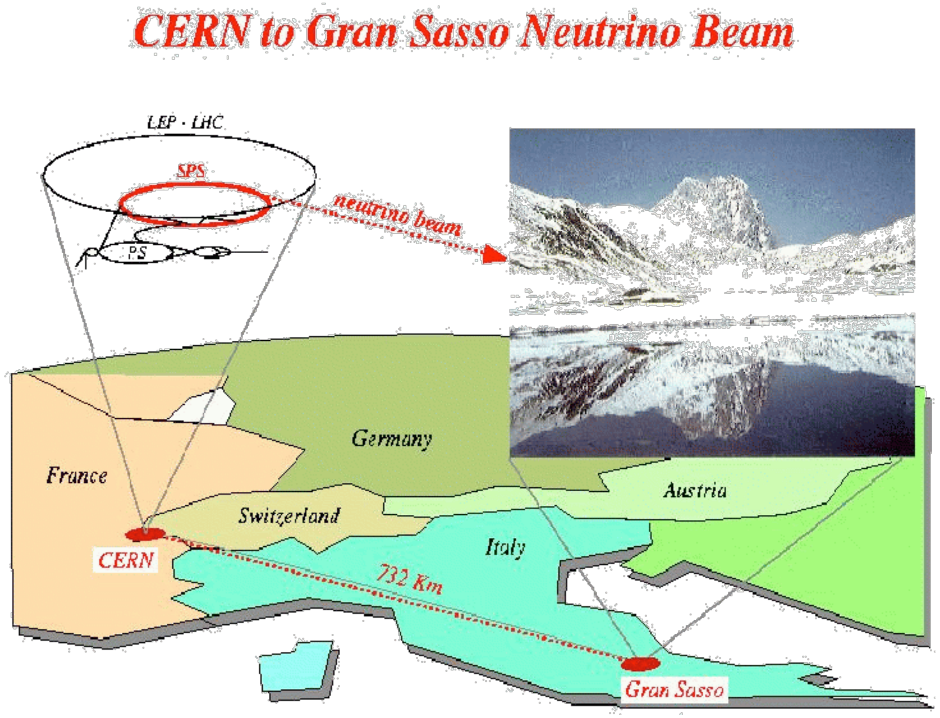
So the **trigger** was designed to make a fast decision on when there had been an interaction and that data should be read out.



..still many experiments need a trigger to indicate when an interaction took place…



At a collider, of course, things are different

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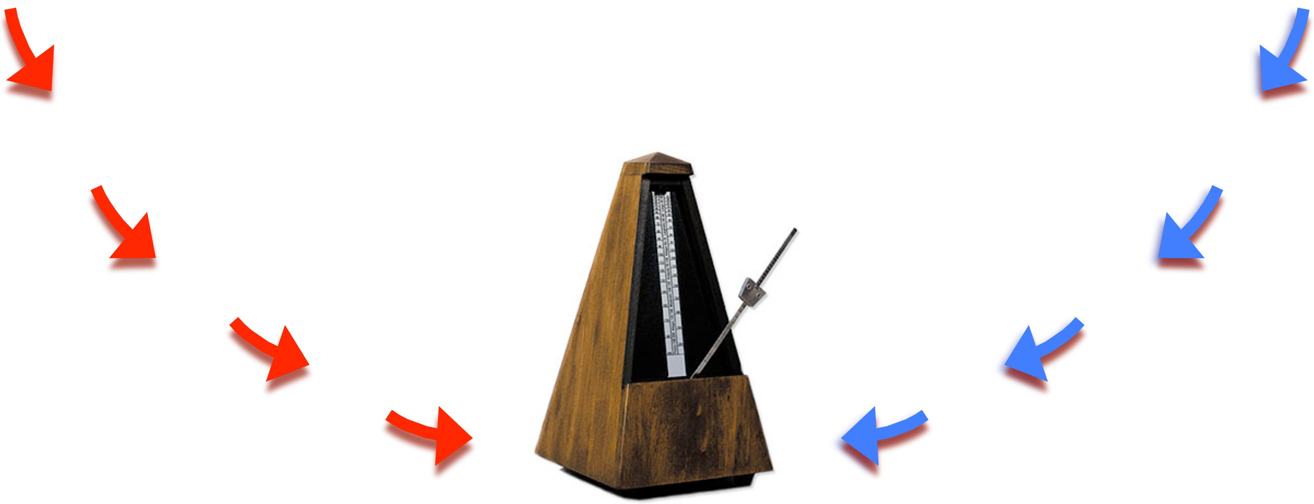
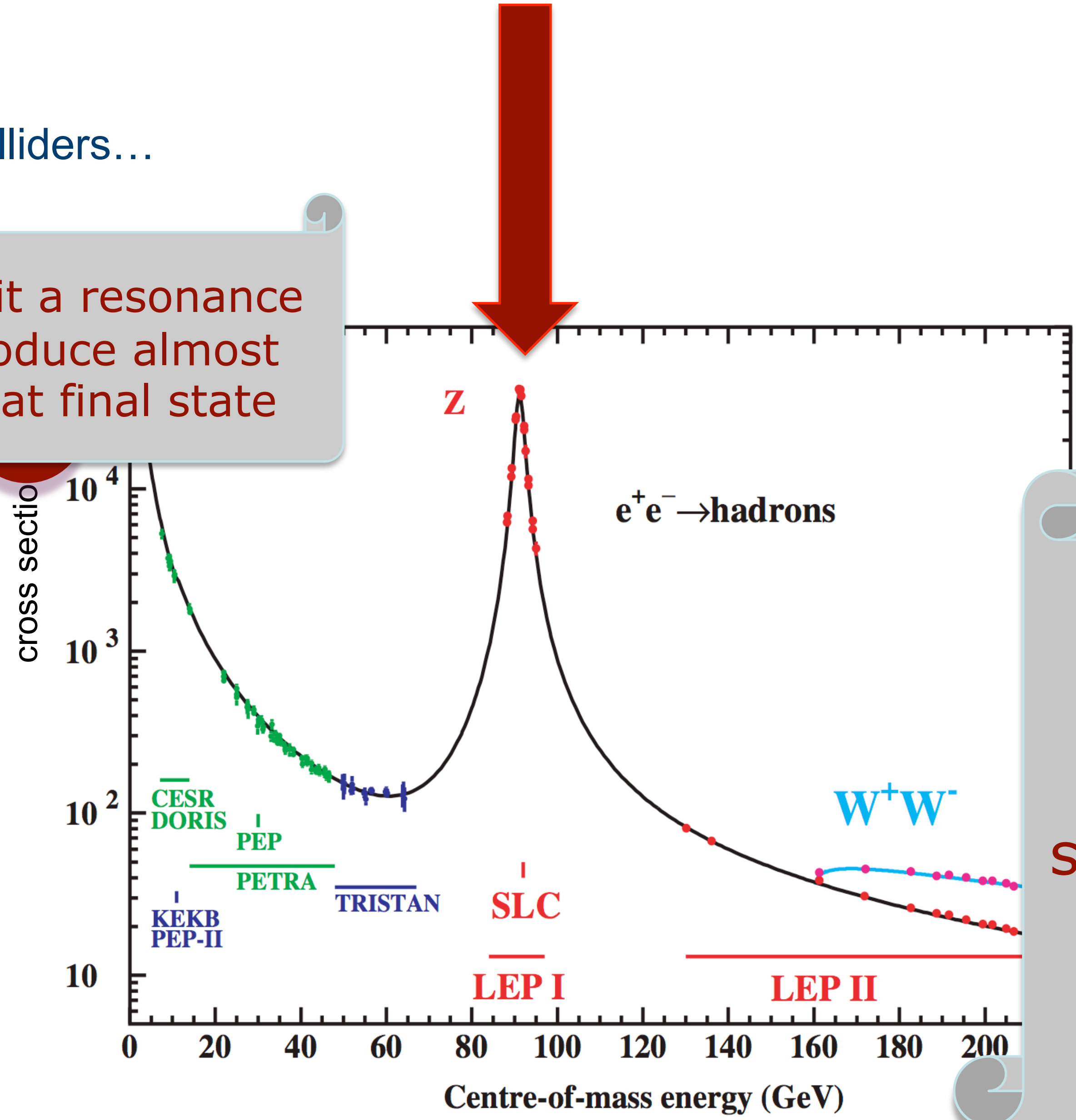


Here we don't need to know when but ***if*** an interaction took place (LEP, HERA),
or if an ***interesting*** interaction took place (Tevatron, LHC)

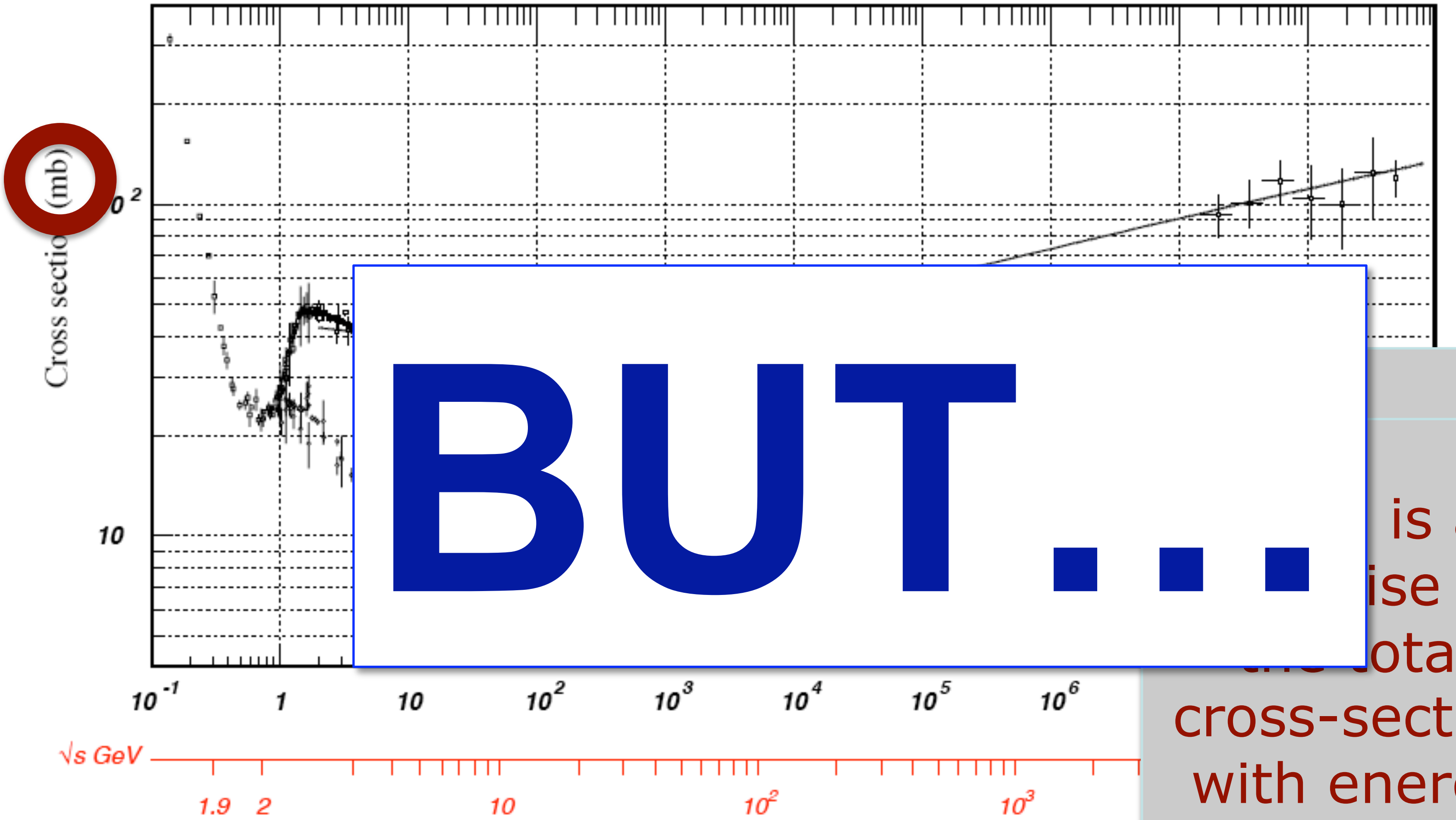
$e^+ e^-$ colliders…

If you hit a resonance you produce almost only that final state



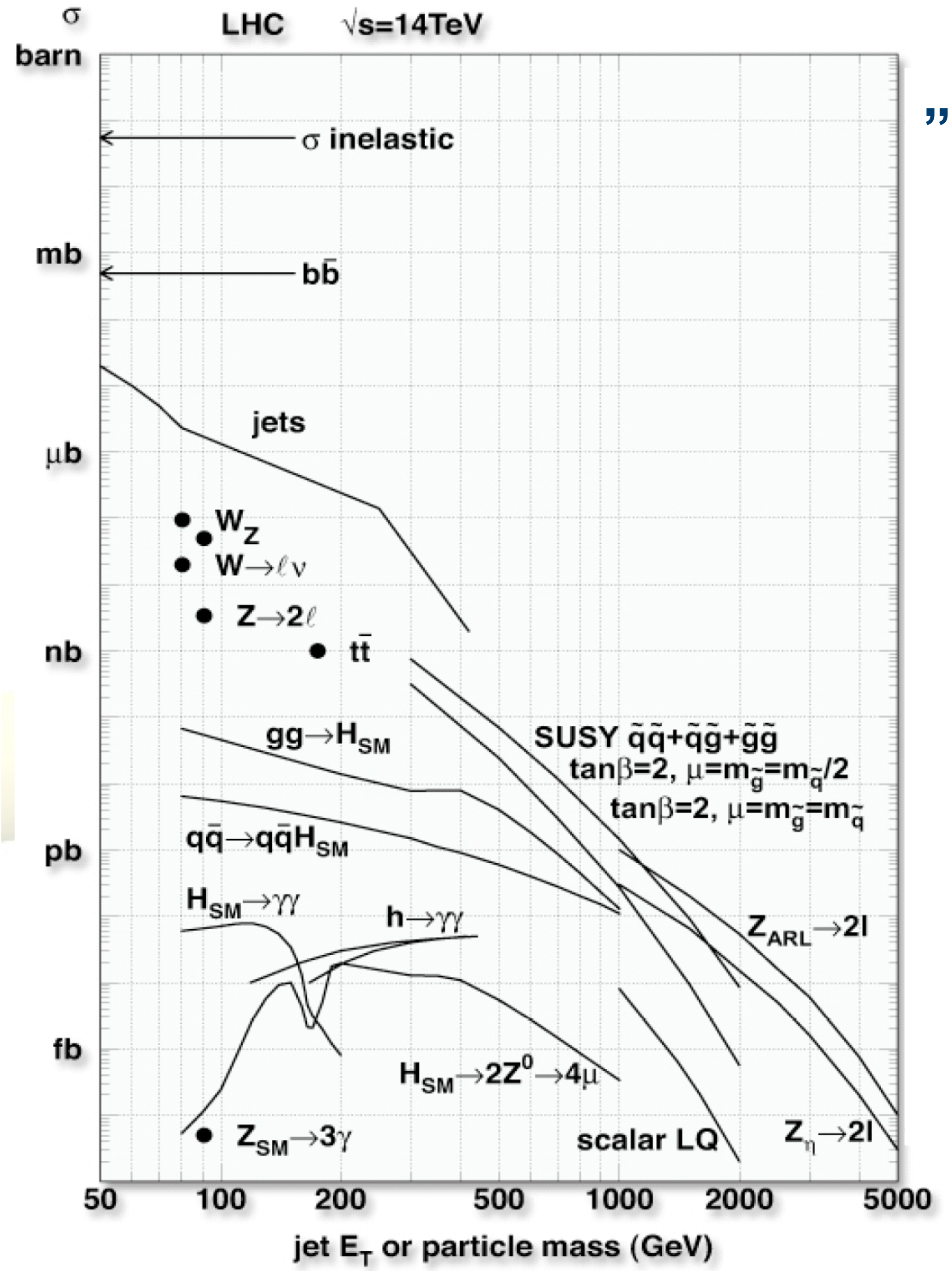
The point-like cross-section goes as 1/s

… in proton-proton collisions…



BUT…

is a
ise in
the total
cross-section
with energy



"Interesting" physics is one event in $10^6 - 10^{13}$

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One ATLAS event is about 1.5 MB at 40 MHZ that makes 60 TB/s

- We can't read out data at that rate
- We can't store that much data
- We can't process that much data

Target is to store data at 200-300 Hz

So at ”parton colliders” the trigger ”just” needs to find out if there was a real interaction

Easy

At hadron colliders the trigger needs to determine if an ”interesting” interaction took place

Not easy

The rest of this presentation will deal with what handles are available and how we can use them – actual impementation will be discussed by Sam Silverstein

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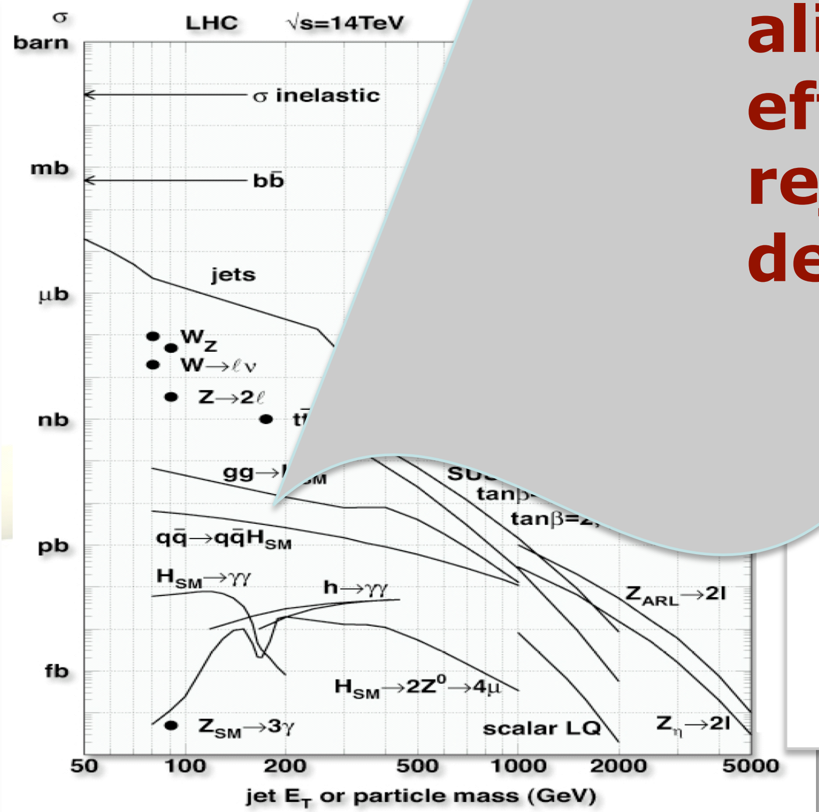
So how to select the needles in the haystack?

A "trivial" starting point:

there is no meanin the trigger selec hich eventually will not be used in an ana

So a reasonable star

What dete

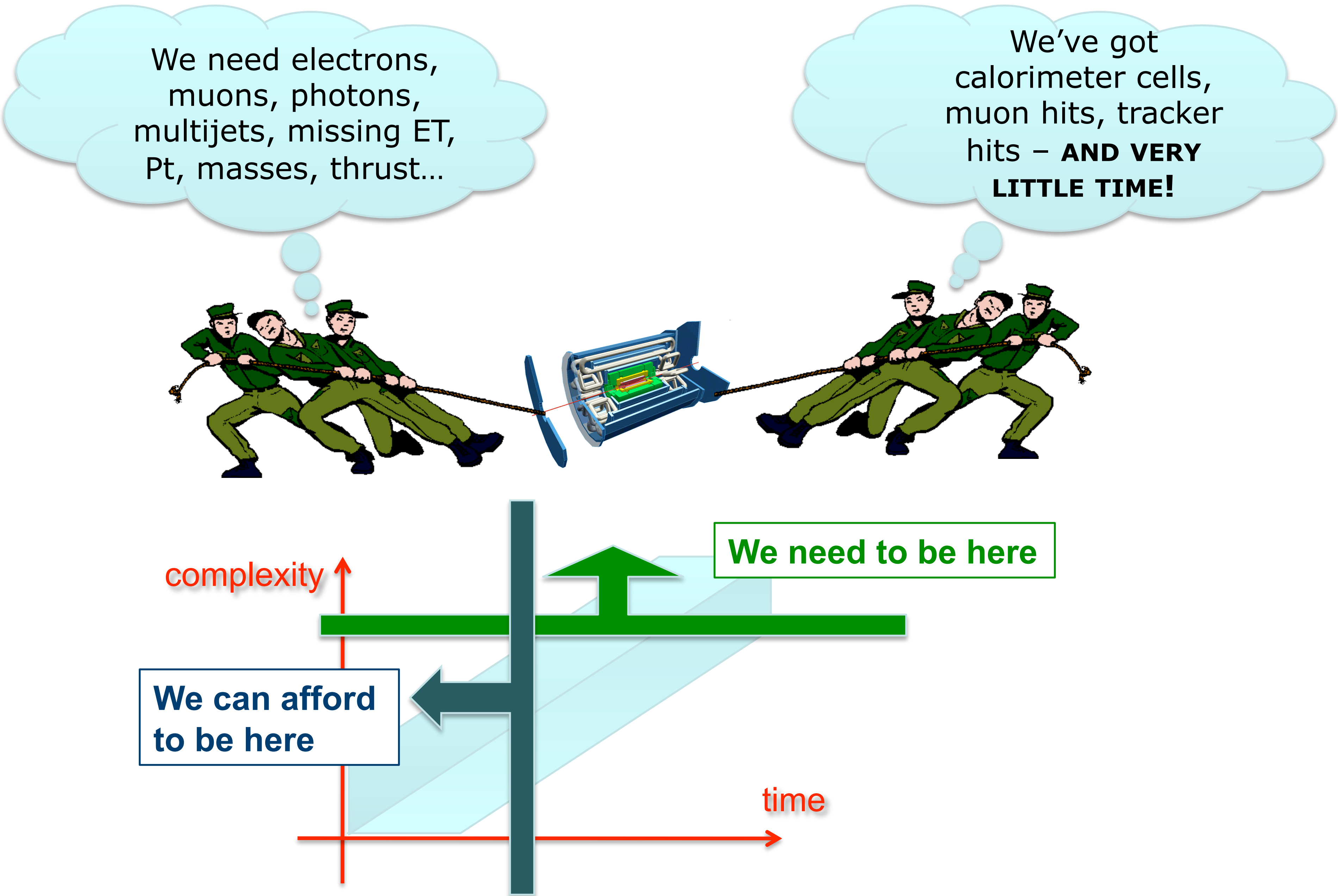


p_T

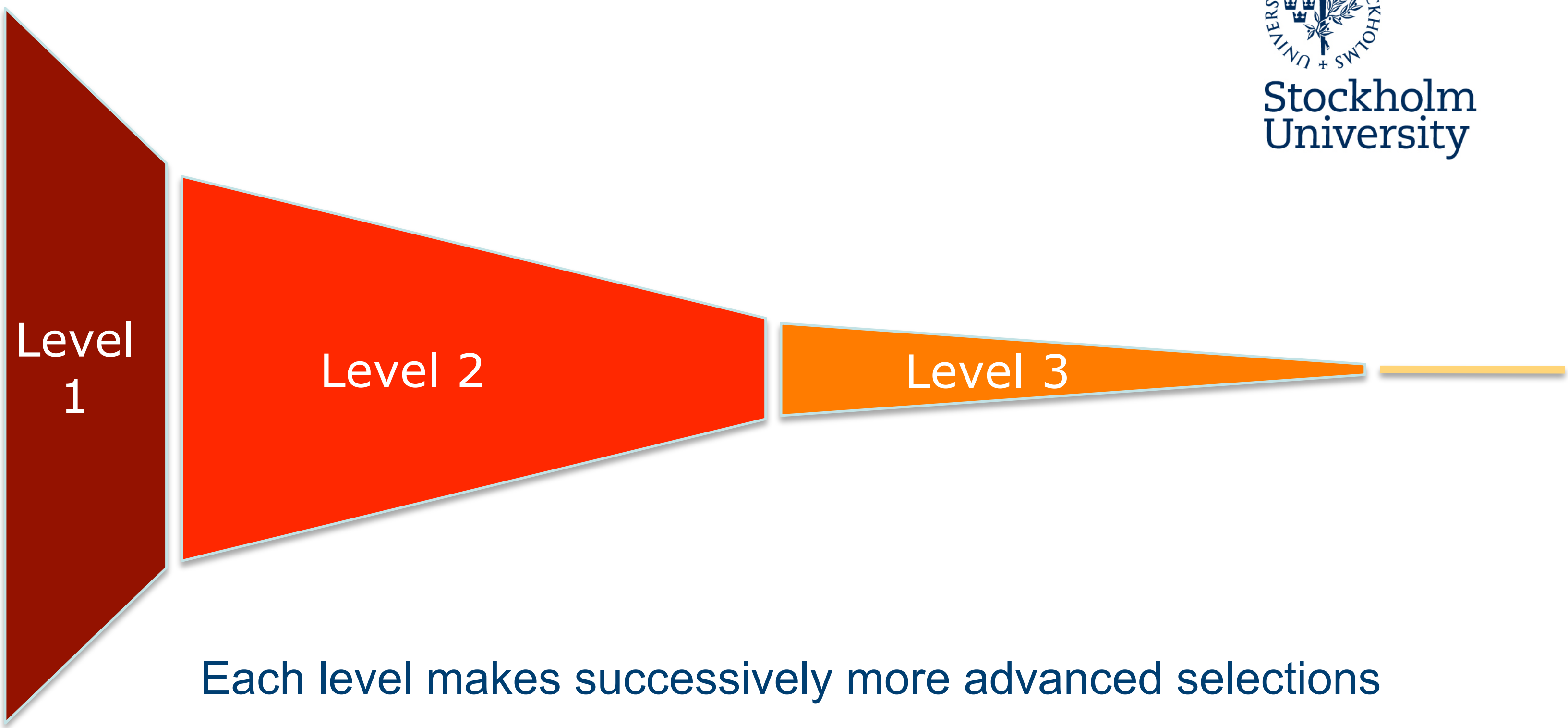
r of high-p_T

calibration
alignment
efficiency studies
rejection studies
detector studies

……


We need electrons, muons, photons, multijets, missing ET, Pt, masses, thrust…
We've got calorimeter cells, muon hits, tracker hits – AND VERY LITTLE TIME!
We need to be here
complexity
We can afford to be here
time

The way out – multilevel triggering:



Each level makes successively more advanced selections

The higher up in the chain you are placed, the fewer events you process -> processing complexity can increase at higher levels

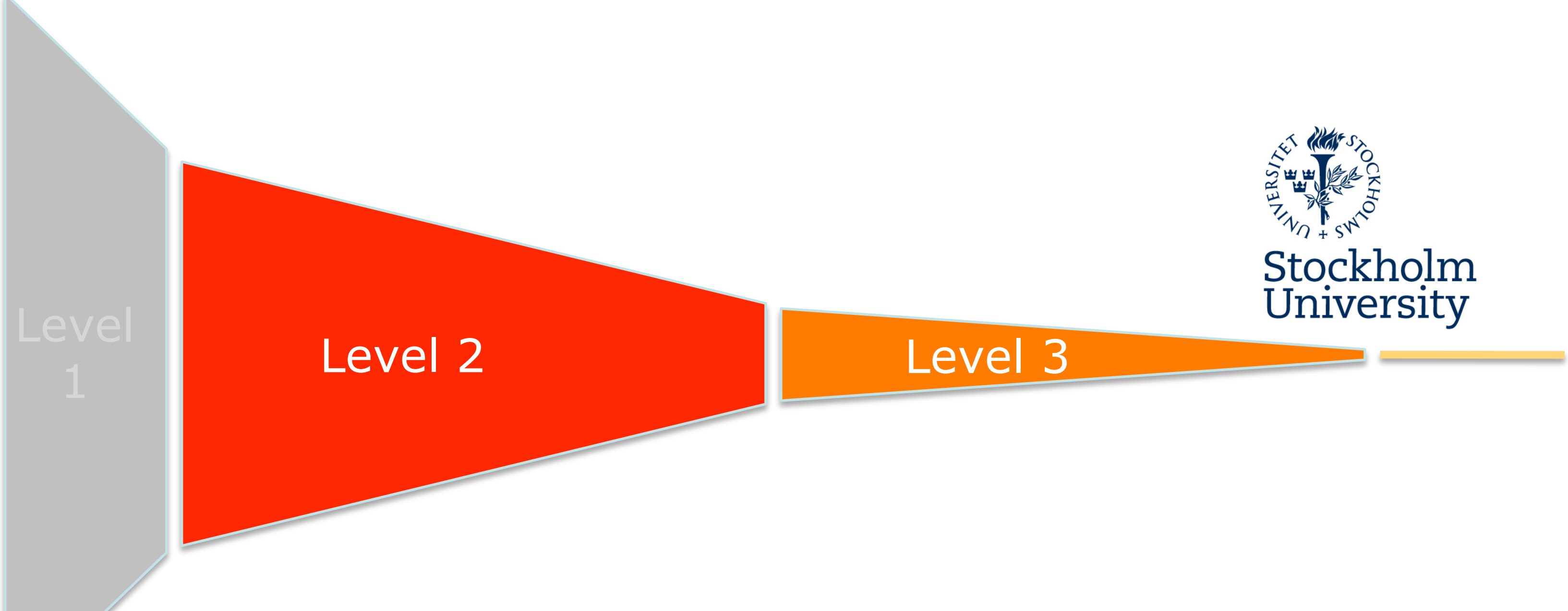
Level 1 – Quick first look while data still resides in pipe-lines on detector

- most easily implemented with *fixed latency* processing

Often dedicated hardware and partial or specially prepared (reduced granulatrity) data

- fixed, and minimal, latency implies that same algorithm is run on every event
- also essentially only inclusive trigger signatures are investigated, i.e. no mass cuts or other correlations between the triggering objects

Typically the first level operates on electrons, muons, jets, stiff tracks, summed E_T and missing E_T, counting number of objects above p_T or E_T thresholds.



Higher levels work on the reduced number of events accepted by Level 1

Usually works with full granularity data from all detector systems. In som cases only with regions in detector where previous levels have indicated interesting objects. (Region of Interest, ROI)

At this level data resides in adressable memory which allows for varying sequences of algorithms, adapted to each individual event.

These triggers are usually implemented in standard commercial computers. Higher level triggers morph into each other, and also interacts heavily with DAQ, much of effort and resources goes into networking and data transport.

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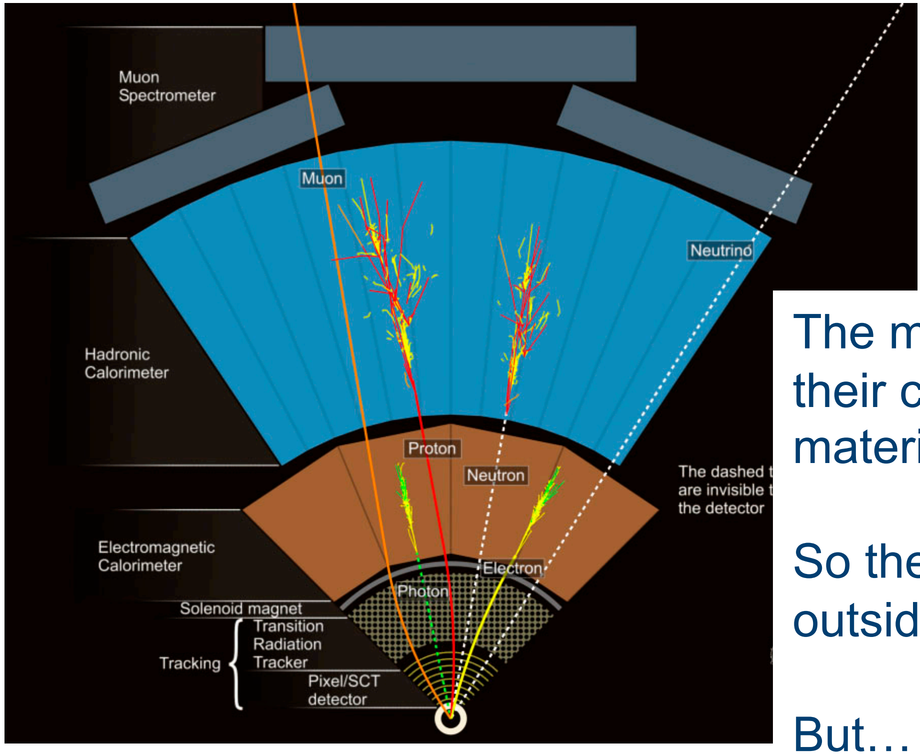
So what can be done
what characteristics will help us trigger on

- muons
- electrons
- jets
- missing transverse energy

?

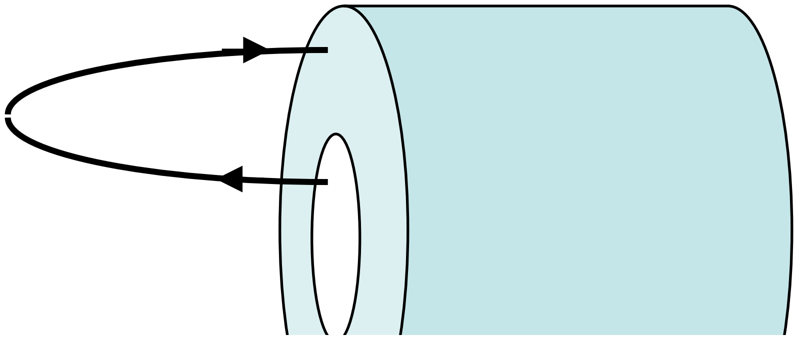
Muons

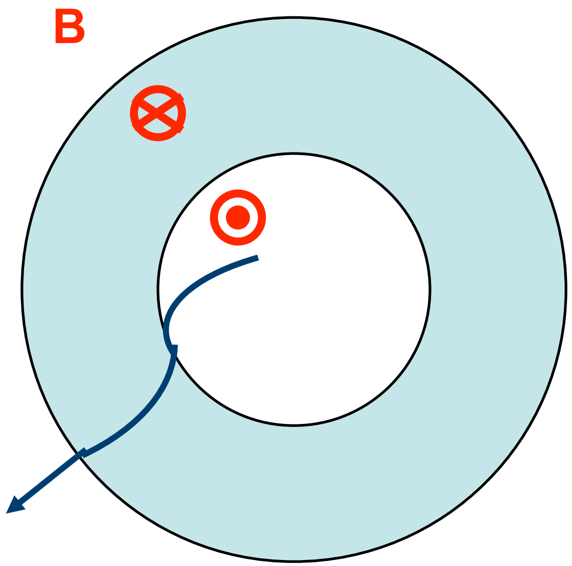


The most characteristic property of muons is their capability to penetrate large amounts of material - they exit through the calorimeters.

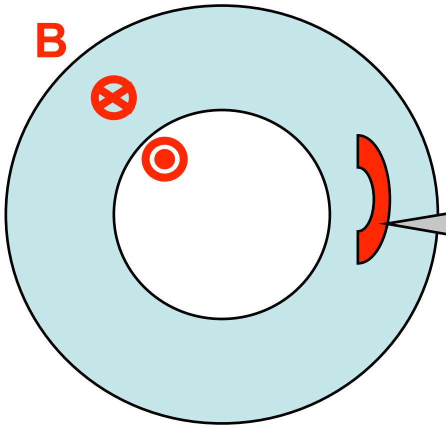
So the easy way is to position tracking detectors outside the calorimeters and look for bent tracks

But…

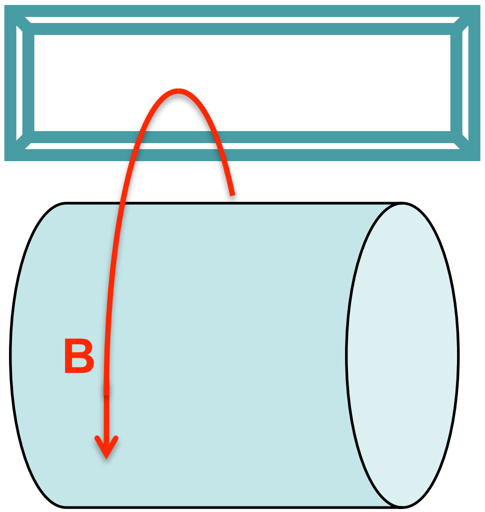




In a solenoidal detector all tracks exiting from the calorimeters point back to the i.p.



So if you build a solenoidal detector you have to ”get in there”



if you build a toroidal detector you have to ”get out there” - you are not ”compact”

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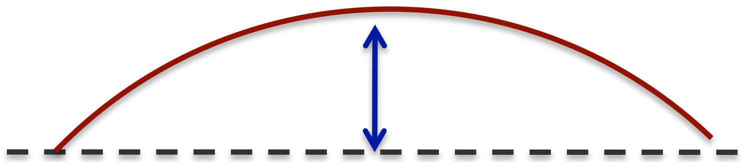
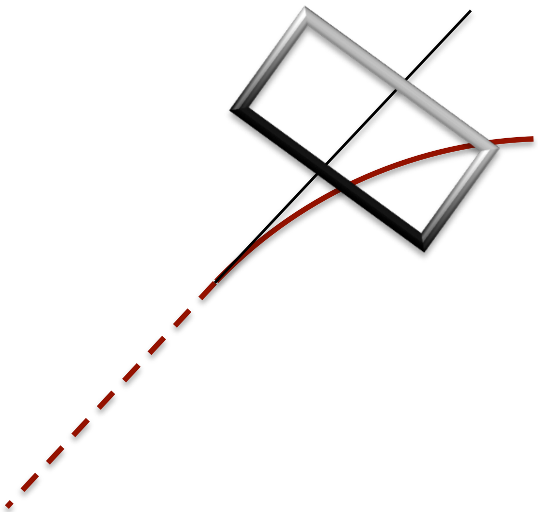
Essentially there are two ways to get an estimate of p

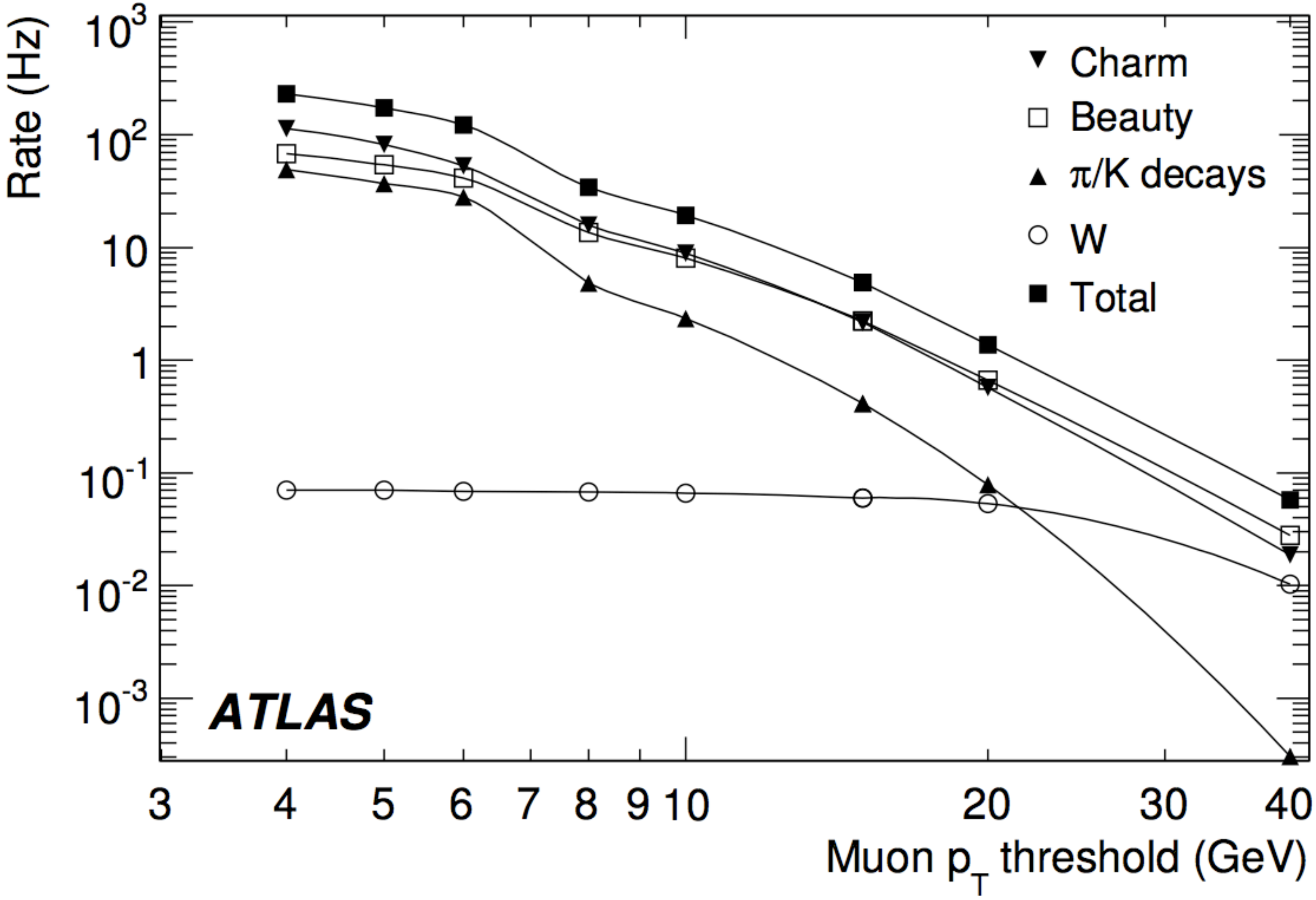


you reconstruct the track and measure the sagitta



if you know the direction of the track at some point you can open up a window downstream to see if the track is ”stiff enough” to pass inside the window.

(rates computed for $\mathcal{L} = 10^{31}$)



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Electrons

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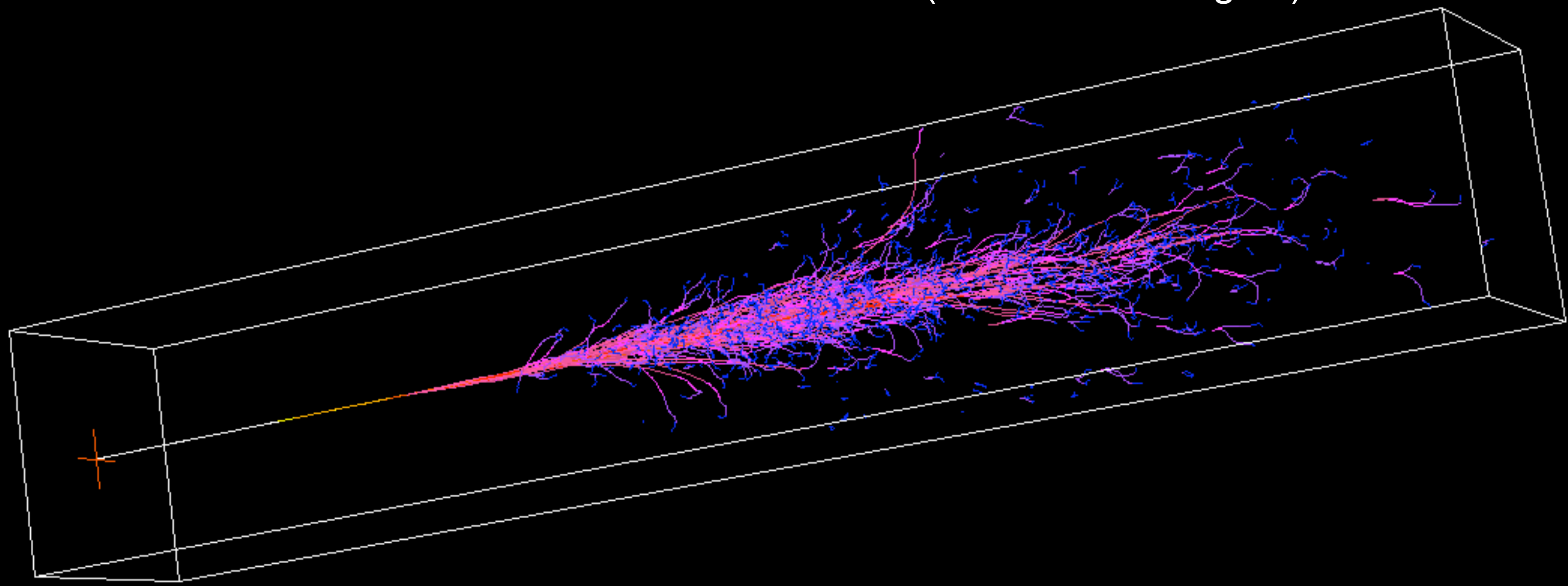
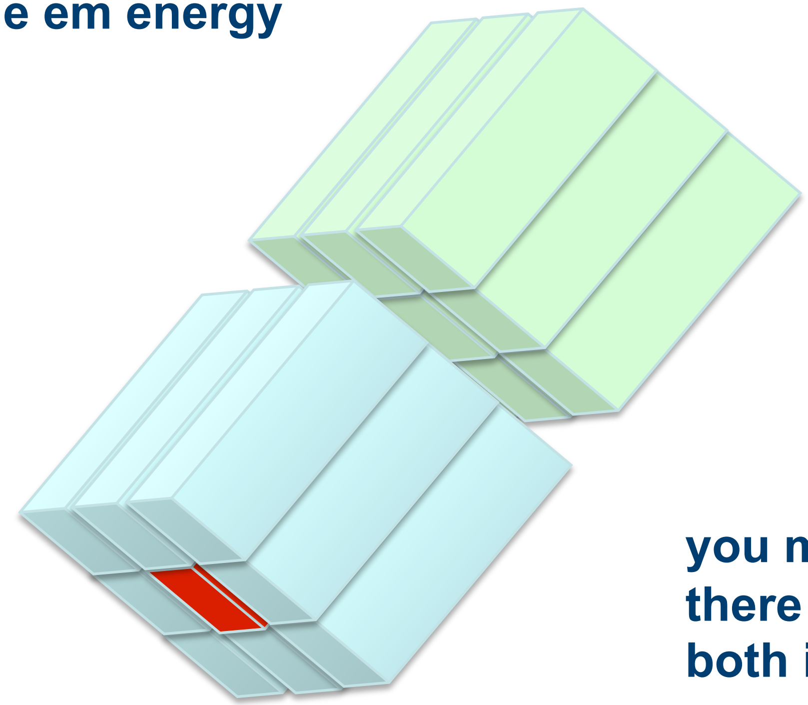
Interaction of 24 GeV electron in 5x5x30 cm of iron (17 radiation lengths)



	rad length (cm)	Molière rad. (cm)
lead	0.56	1.6
iron	1.76	1.7

Showers are narrow with limited longitudinal extension

So it is not enought to know that you have large em energy depositions



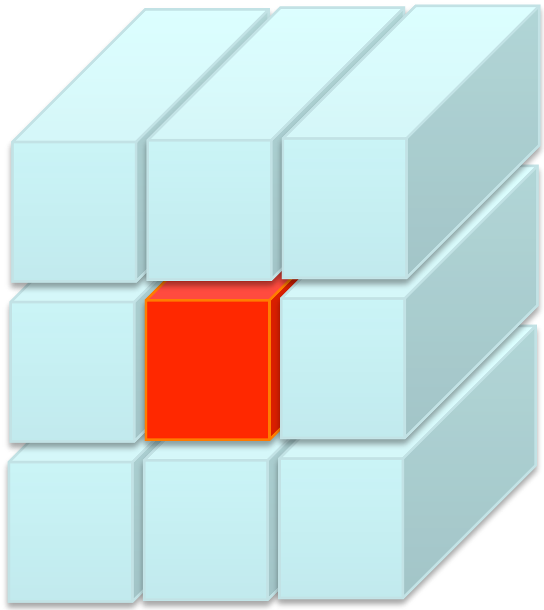
you must also make sure that there is little energy close by, both in em and hadron compartments

Containment of showers is usually expressed in *relative* terms

So is often analysis definitions of electrons

But thresholds are easier/faster to implement in hw than divisions

If trigger operates with thresholds isolation might need to be relaxed as energy goes up



ATLAS
Level-1 Trigger

Technical Design Report
24 June 1998

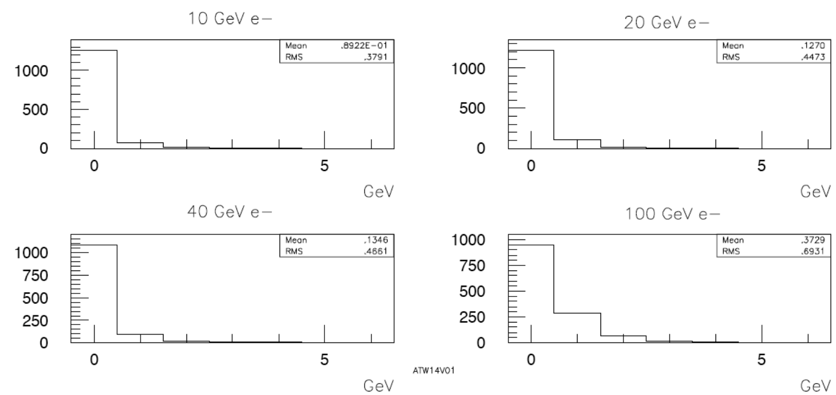
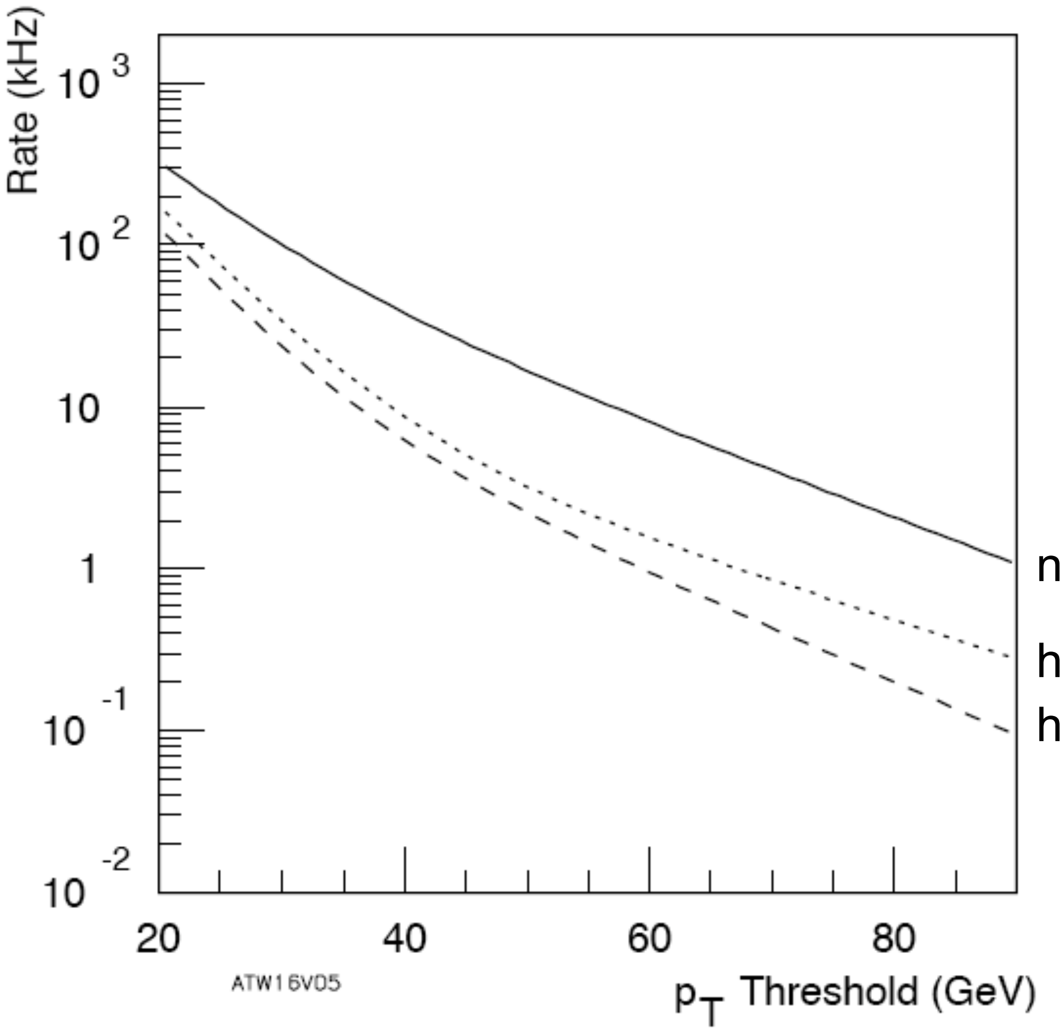


Figure 4-14 Electromagnetic isolation E_T distributions for electrons of different E_T.

(rates computed for $\mathcal{L} = 10^{34}$)

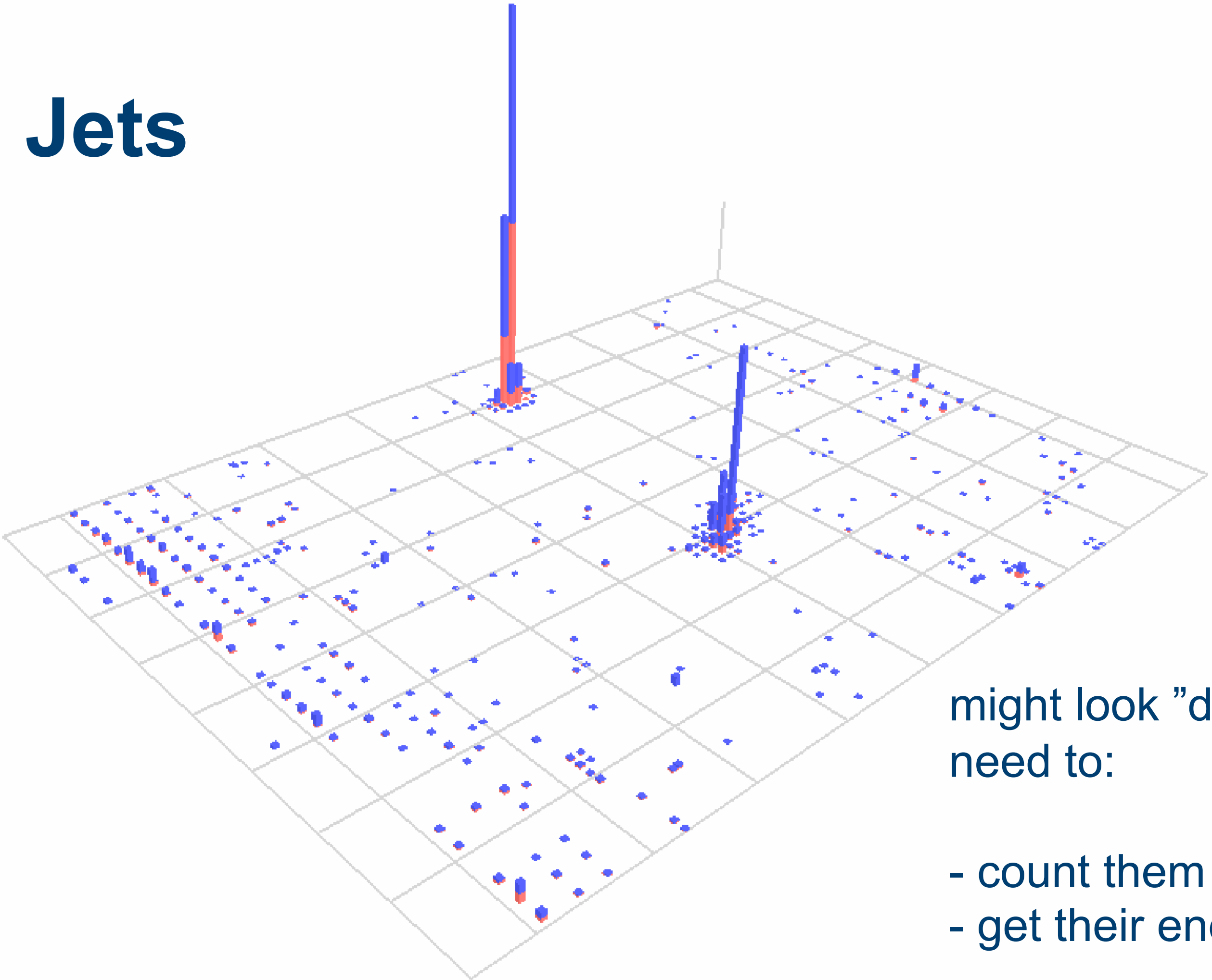


no isolation

hadronic isolation

had + em isolation

Jets



might look ”dead-easy”, but you need to:

- count them
- get their energy right

…without even knowing for sure how they will be defined at the analysis stage!

at $\mathcal{L} = 10^{34}$ 1 nb gives a rate of 10 Hz

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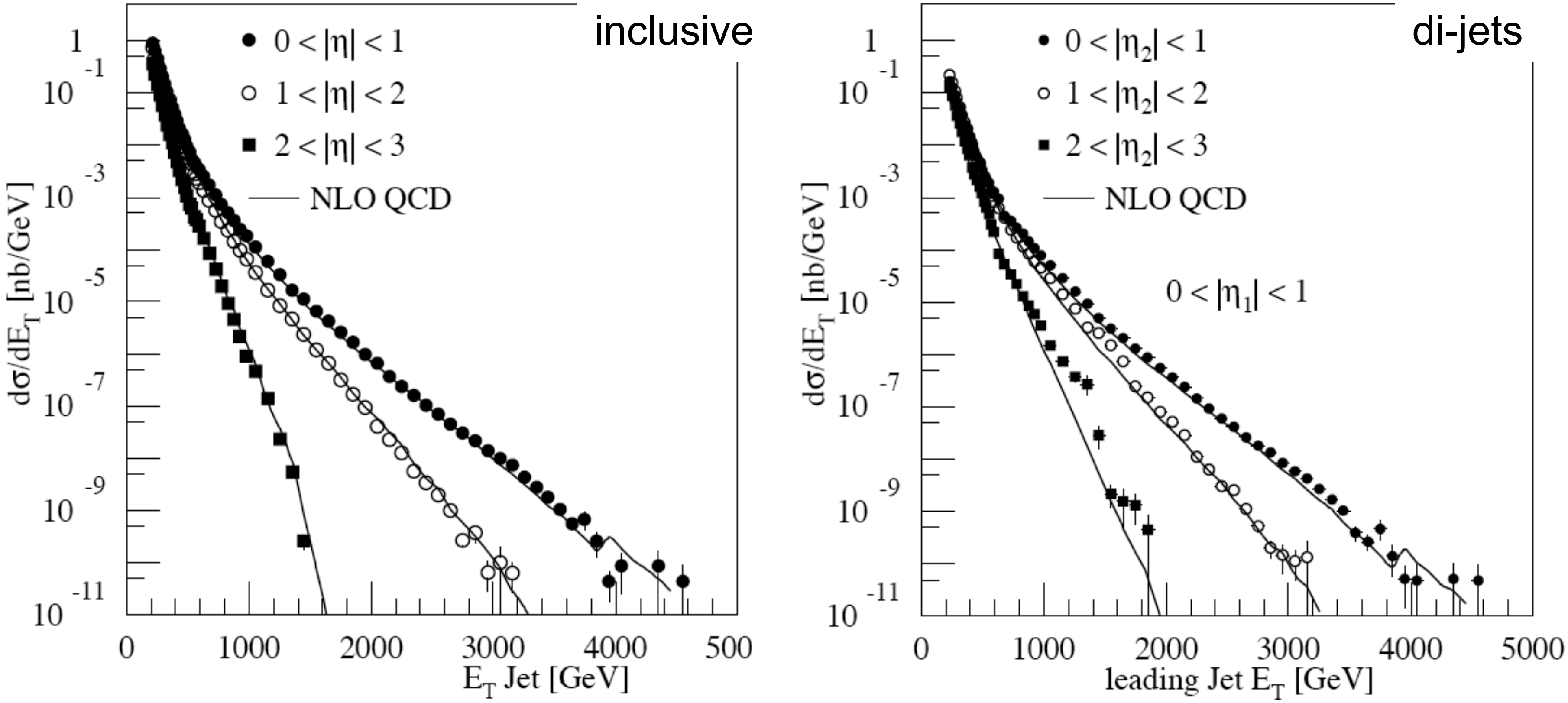
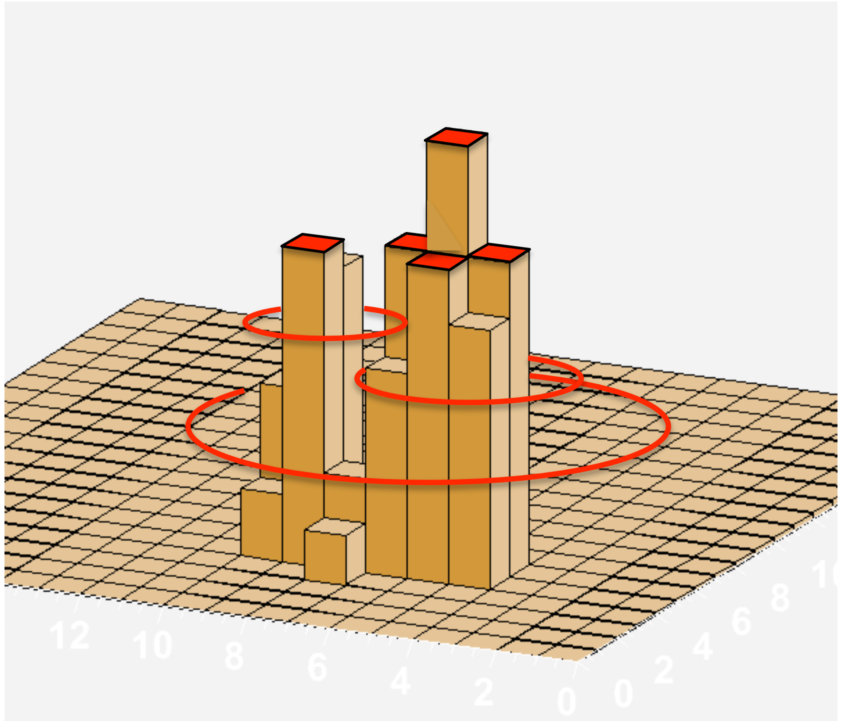
Cross sections are large and sink fast with number of jets and p_T of jets.



So how many jets is this?



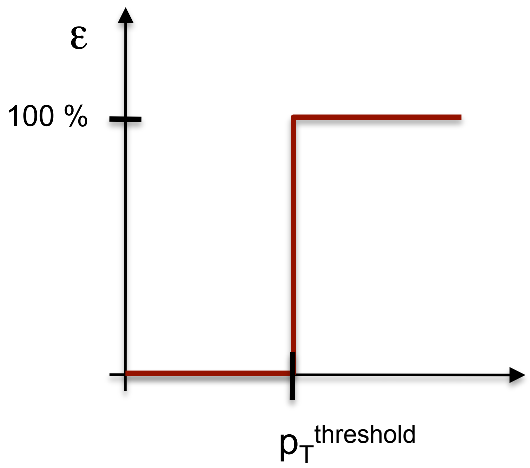
Just counting ”basic units” (cells, trigger towers…) above threshold vastly overestimates number of jets.

Counting contiguous objects will underestimate number of jets

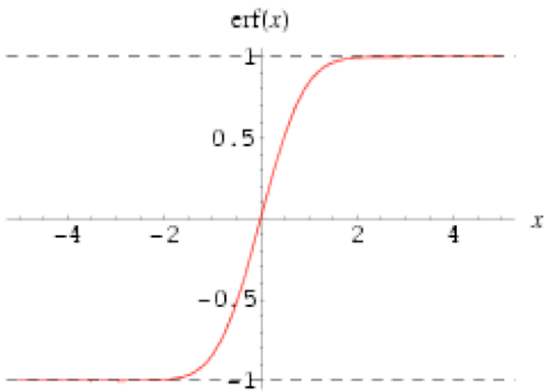
So prefererbaly you want to count some sort of local maxima above threshold

Turn-on curve

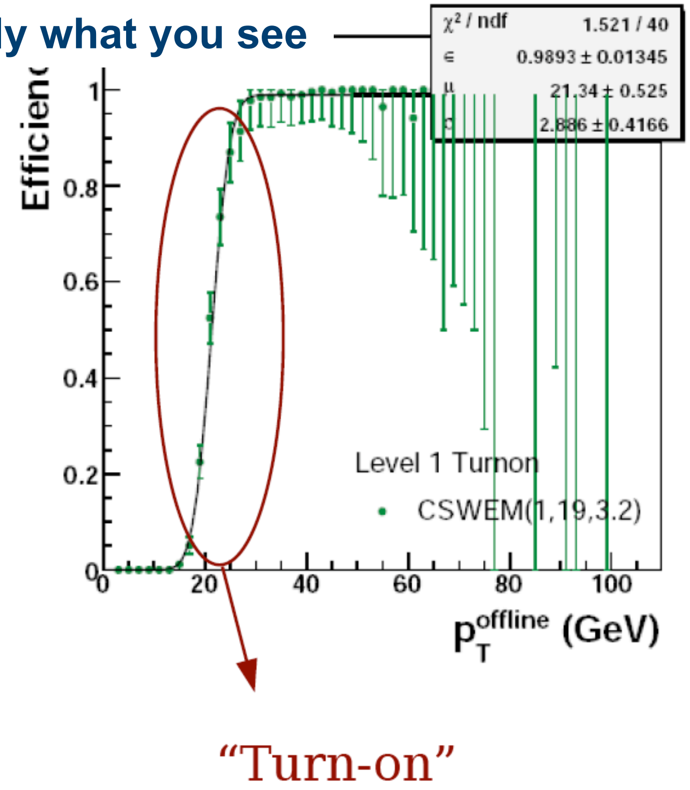
Ideally the trigger efficiency ε goes from 0 to 1 in one discrete step as soon as the energy is above the threshold value.

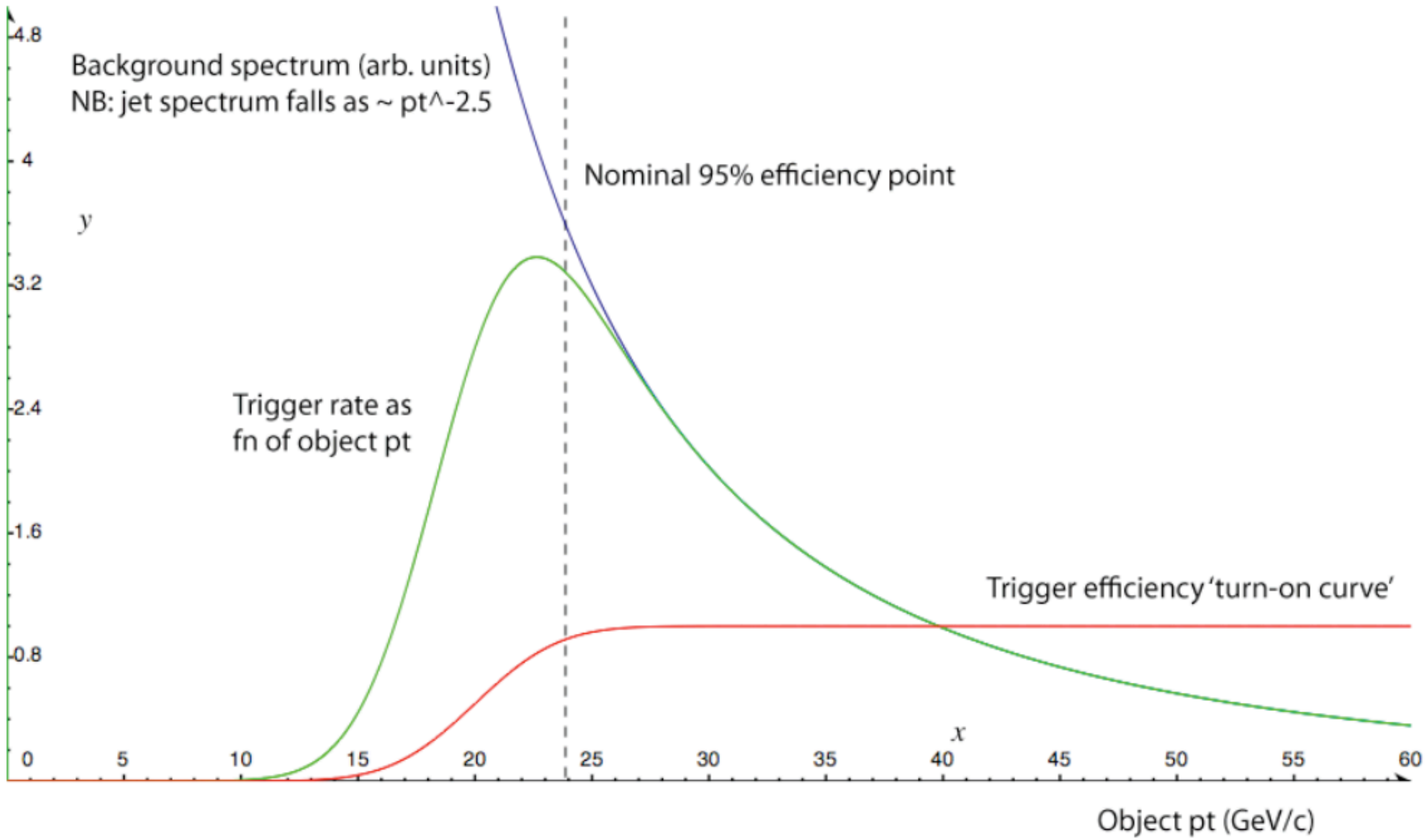


Folding the step with a gaussian resolution gives a theoretical expectation…



Which is actually what you see




Background spectrum (arb. units)
NB: jet spectrum falls as ~ pt^-2.5
Nominal 95% efficiency point
Trigger rate as
fn of object pt
Trigger efficiency 'turn-on curve'
y
x
4.8
4
3.2
2.4
1.6
0.8
0
5
10
15
20
25
30
35
40
45
50
55
60
Object pt (GeV/c)

Missing transverse energy, $\not{E}_T$

Even if things work as planned there is E_T-miss from instrumental effects:
(jets i p_T range 300-350 GeV)

Step	r.m.s. .
Particle level (after fragmentation)	3.8 GeV
Particle level $\lvert\eta\rvert < 5.0$	5.8 GeV
Calorimeter response and resolution	11.9 GeV
Non-compensating calorimeter	13.0 GeV
Addition of trigger tower noise	18.4 GeV
Digitise tt, 8 bits, 1 GeV cut	14.7 GeV

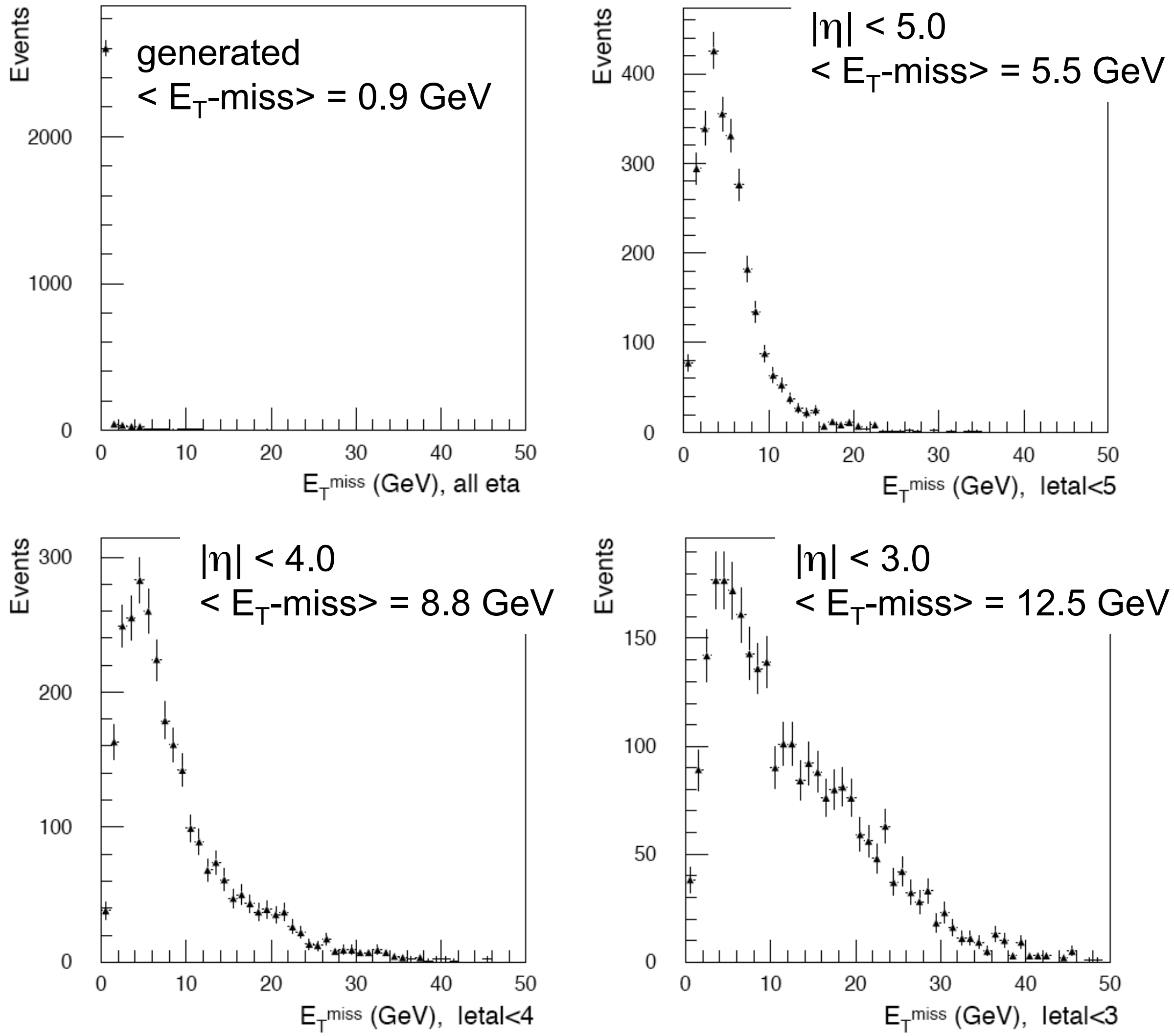
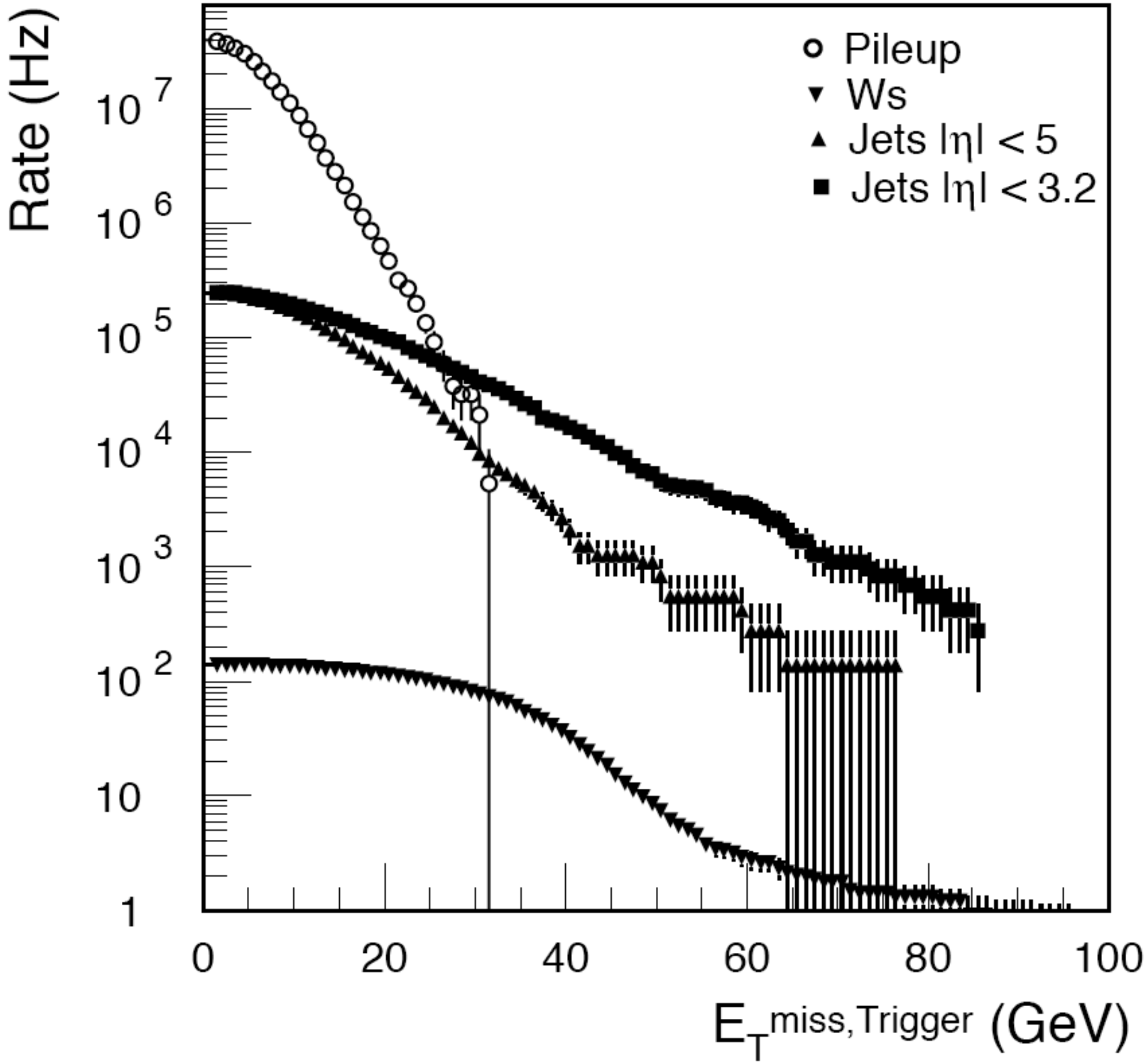
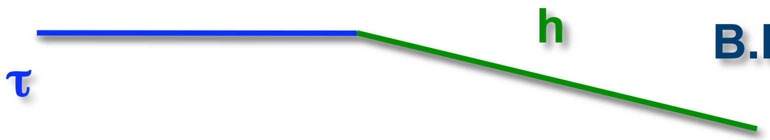


Figure 4-47 Missing-E_T distributions for four rapidity ranges. (a) generated, (b) $|\eta| < 5$, (c) $|\eta| < 4$, (d) $|\eta| < 3$.

(rates computed for $\mathscr{L} = 10^{33}$)

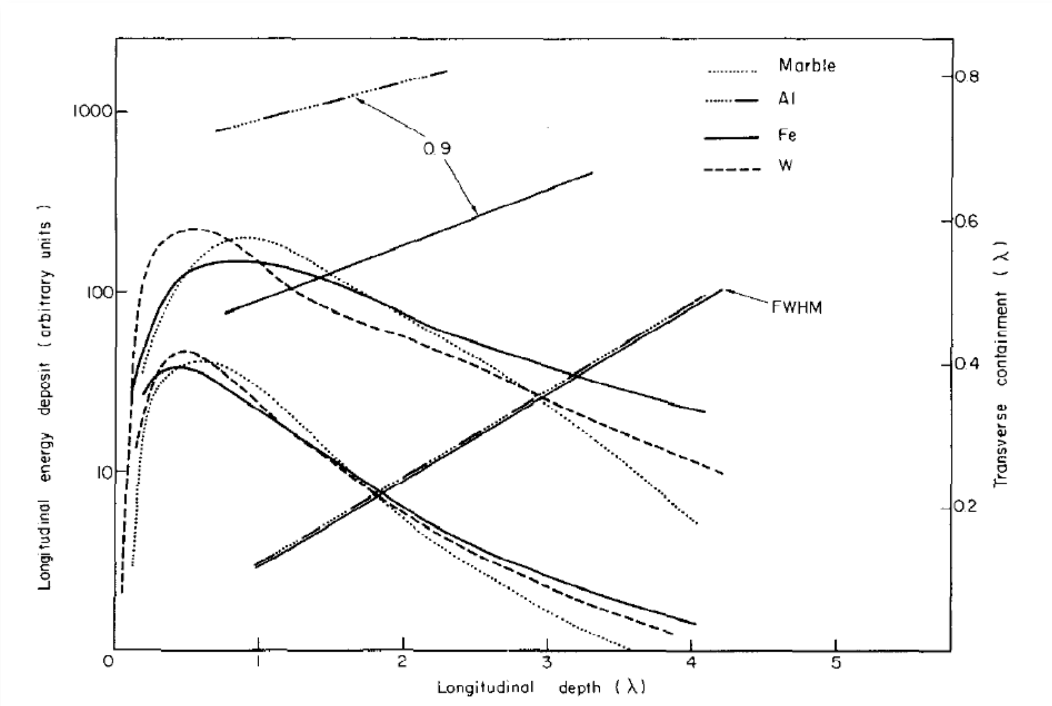


Tau

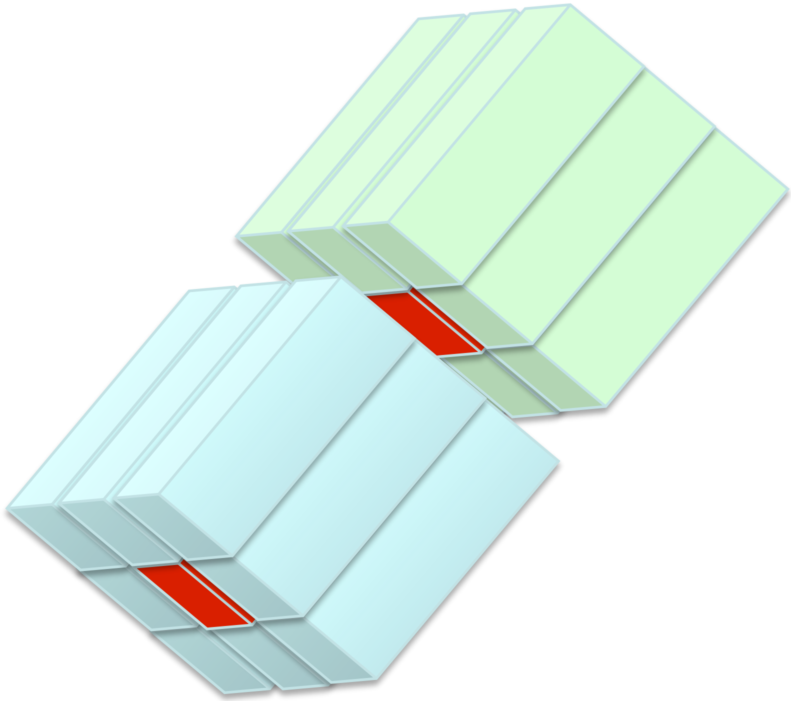


h
τ

B.R. ≈ 45%

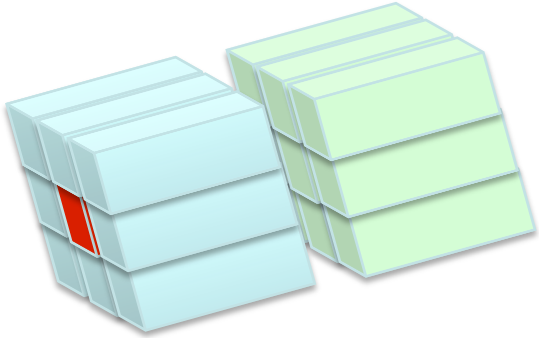


Marble
Al
Fe
W
0.9
FWHM
1000
100
10
0
1
2
3
4
5
0.8
0.6
0.4
0.2
Longitudinal energy deposit (arbitrary units)
Transverse containment (λ)
Longitudinal depth (λ)



Counting objects

Most jet-algorithms will accept a high p_T electron as a jet if it passes the p_T threshold



So one physical object generates ***two*** level one objects.

So if you want to trigger on e.g. one jet and one electron you would have to ask for two jets and an electron, where one of the two jets have so relaxed cuts such that the electron is guaranteed to pass.

What I didn't say

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Track triggers

Generally very difficult on level1, needs dedicated hw.
Consumes the bulk of processing power at higer levels.

ΣE_T

Sum over all calos (and muons). Resolution very noise sensitive.

Minimum bias

Normally either low threshold SET or scintillators to detect particles outside the beam pipe

Σ Jet p_T

”Granular”, but perhaps less prone to smearing from noise

Rapidity gap trigger

Trigger on 2 or more jets with empty eta-region between them

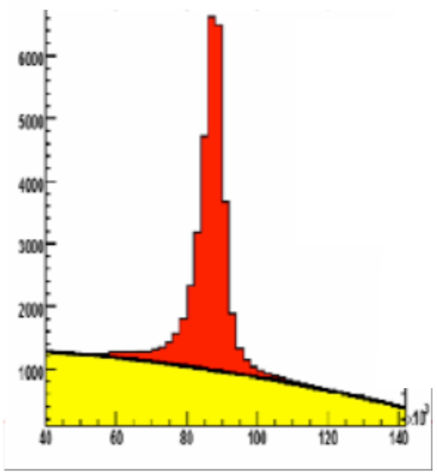
Efficiency

During analysis you need to know it. Measure it!
Two ways: ”tag-and-probe” or minimum bias triggers.

Tag and probe find one object to ”tag” the event as one where there ought to be another triggable object and ”probe” to see if it is triggered on.

For example –

1. Find one triggered electron.
2. Search for second electron.
3. Combine and compute mass
4. If M_{ee} within 15 GeV of M_Z check if second electron was triggered on.



Step 4 is there to ensure that the object we probe really is an electron

Difficult to avoid biases if efficiency depends on kinamtical properties if there is a bias on the probe.