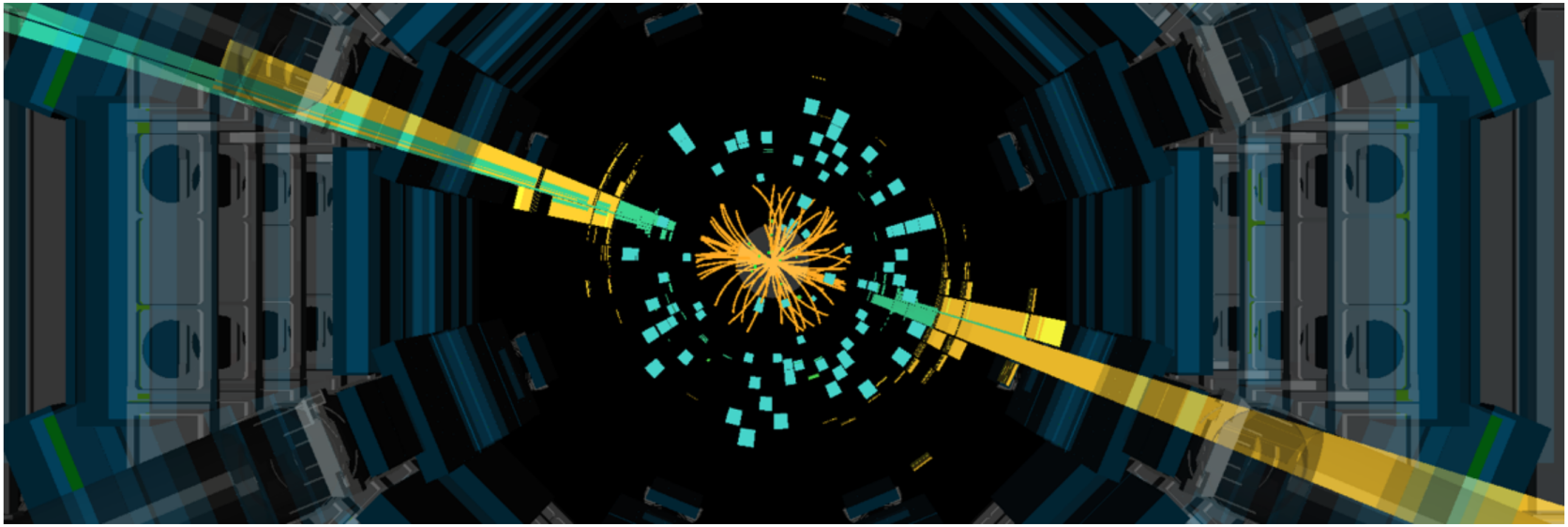
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

LHC Open Data

ATLAS data analysis using an internet browser

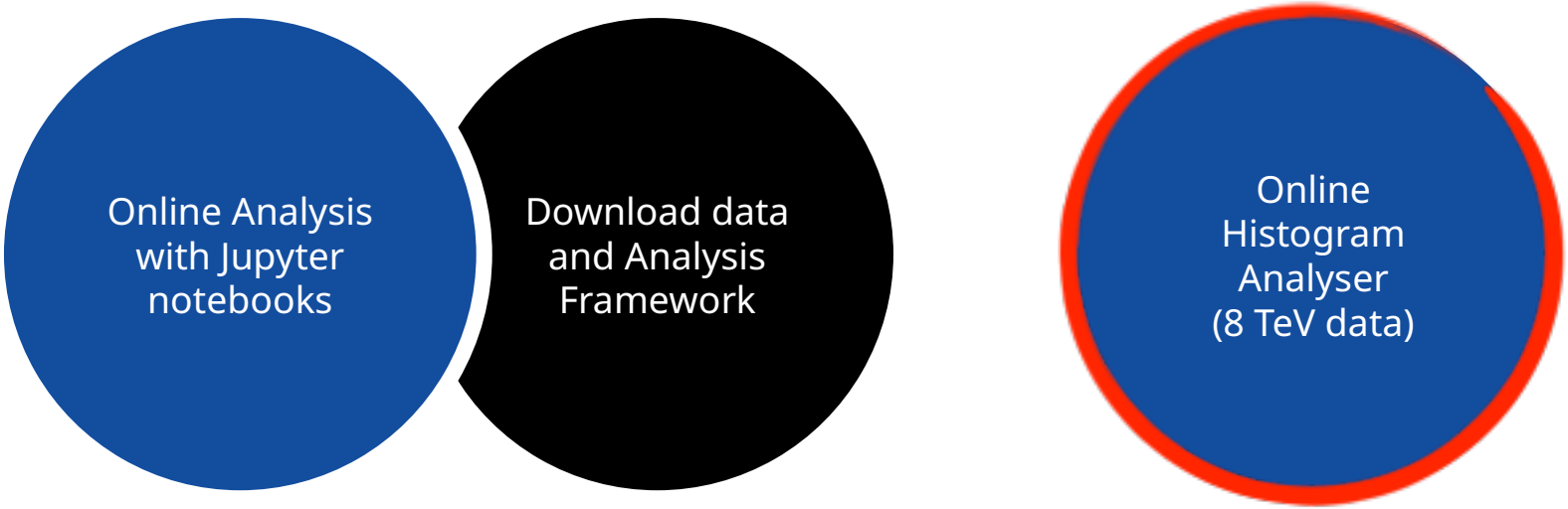
Joao Gentil Saraiva, Marcin Stolarski | 14th July 2022
(Thanks! Rute Pedro and Patricia Muiño for the slides)
LIP Internship Program | Summer 2022

ATLAS
Open Data Set



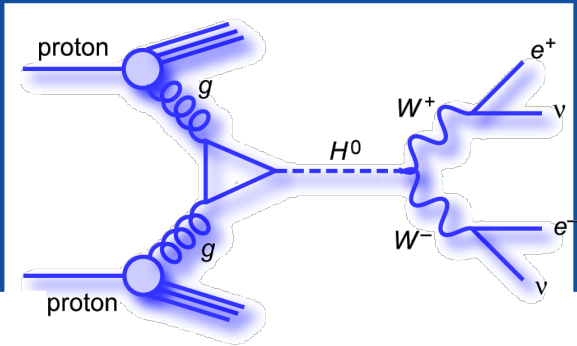
10 fb^{-1} @ 8 TeV+100 fb^{-1} @ 13 TeV of ATLAS proton-proton collision data is now public!

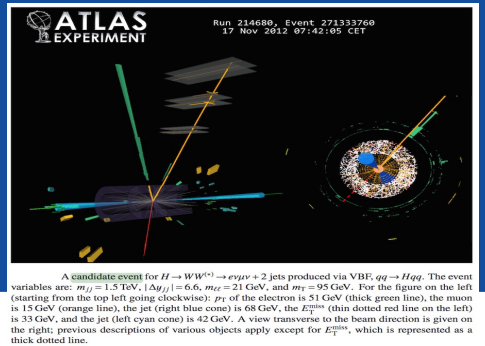
ATLAS
Open Data - online resources



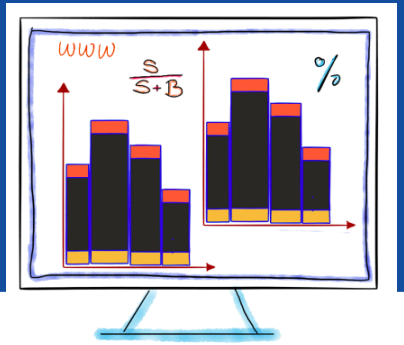
+ Documentation

Rediscovering the Higgs with a simple online analysis





A candidate event for $H \to WW^{(*)} \to e\nu\mu\nu + 2$ jets produced via VBF, $qq \to Hqq$. The event variables are: $m_{jj} = 1.5$ TeV, $|\Delta\eta_{jj}| = 6.6$, $m_{e\mu} = 21$ GeV, and $m_T = 95$ GeV. For the figure on the left (starting from the top left going clockwise): p_T of the electron is 51 GeV (thick green line), the muon is 15 GeV (orange line), the jet (right blue cone) is 68 GeV, the E_T^{miss} (thin dotted red line on the left) is 33 GeV, and the jet (left cyan cone) is 42 GeV. A view transverse to the beam direction is given on the right; previous descriptions of various objects apply except for E_T^{miss}, which is represented as a thick dotted line.



1.
Getting to know the “signal”

2.
How does it look like in our detector?
What are the main backgrounds?

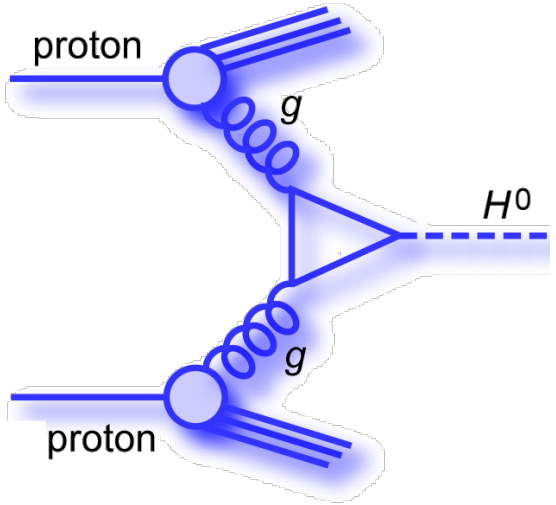
3.
Online Histogram Analysis
How do we isolate signal from background?
Your task!

H^0 production

$M_{H^0} = 125$ GeV

Higgs dominant production is through “gluon fusion”

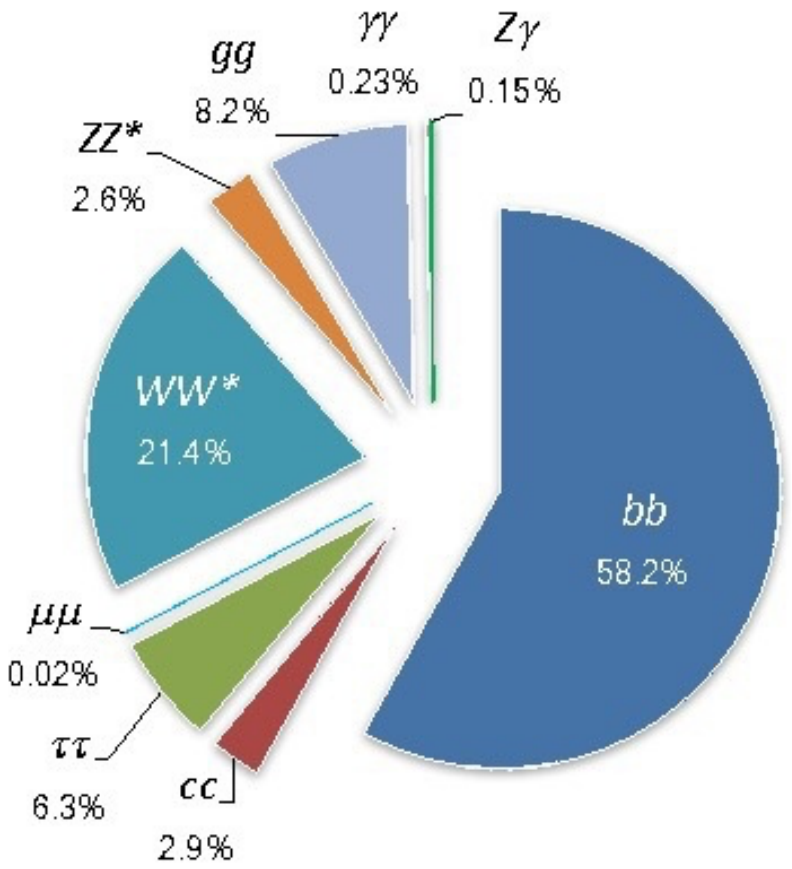
A quark loop between the H^0 and gluons since Higgs boson only couples to massive particles



H^0 decays

Higgs will decay to several particles pairs

Imperative to have a combined neutral charge e.g. opposite charge W bosons

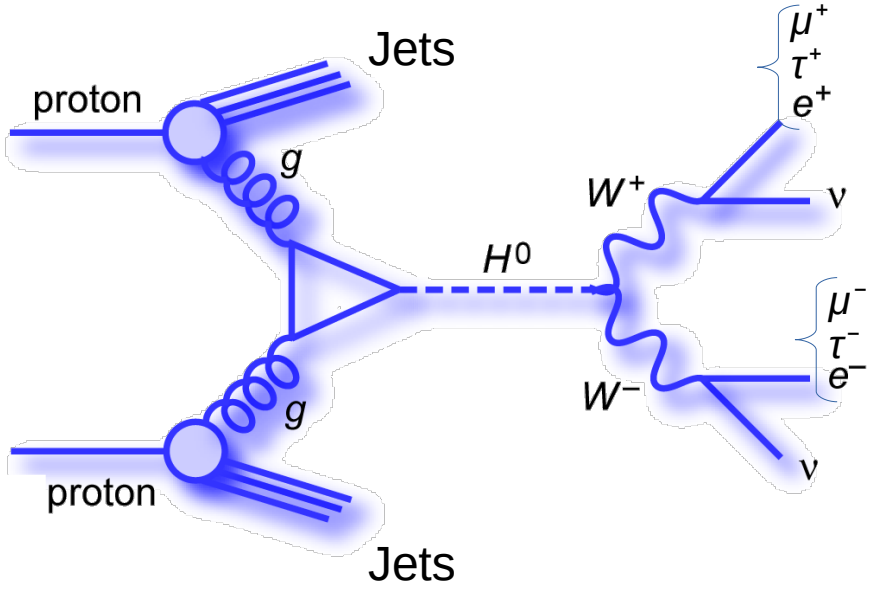


$H^0 \rightarrow W\,W^* \rightarrow l^+\,\nu\;l^-\,\bar{\nu}$

W bosons will eventually decay

$e^+\,\nu$	(10.71 ± 0.16) %
$\mu^+\,\nu$	(10.63 ± 0.15) %
$\tau^+\,\nu$	(11.38 ± 0.21) %
hadrons	(67.41 ± 0.27) %

For a first analysis the most attractive are the cleanest possible channels: electron and muon.



Final state particles

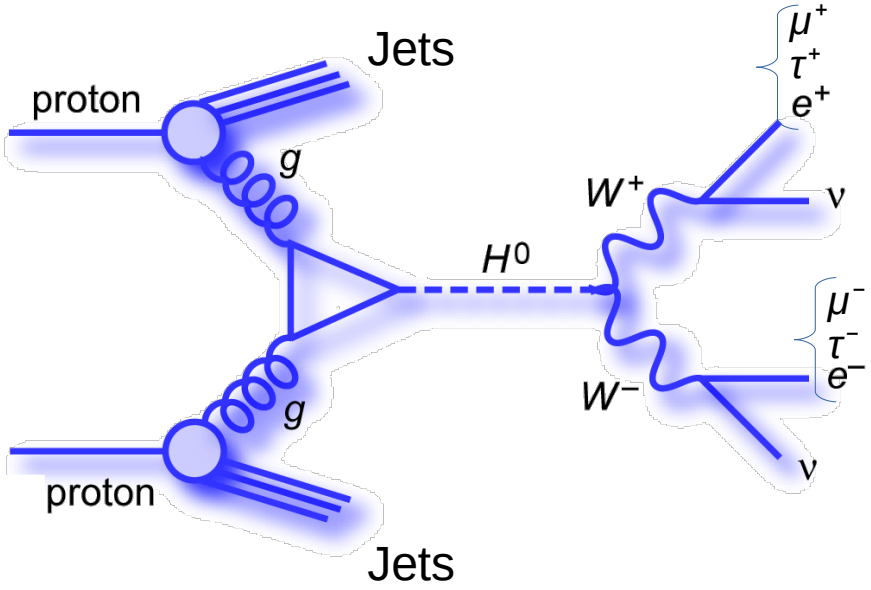
What can we see in the detector!

2 high momentum leptons

Opposite electrical charge

2 neutrinos

jets from quark/gluon hadronisation



In the detector

What do we see in the detector?

2 high momenta charged leptons

- Electrons track + full energy deposit
- Muons track all through the detector
- Taus decay either to leptons/hadrons

Opposite electrical charge

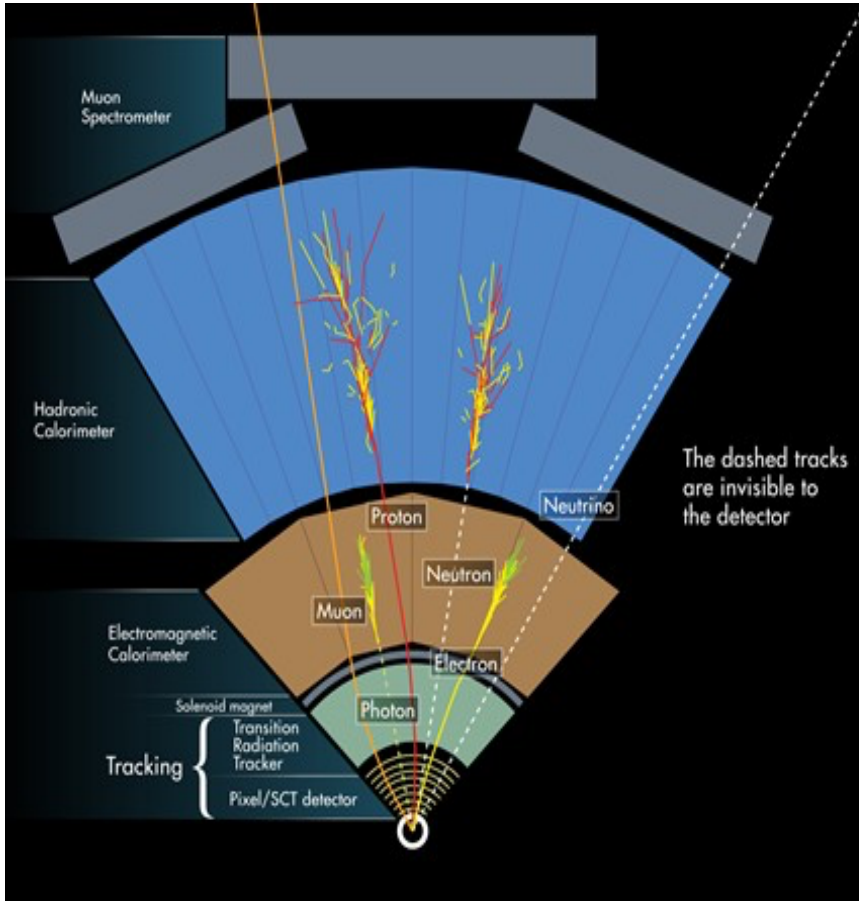
- MF + Tracking

2 neutrinos

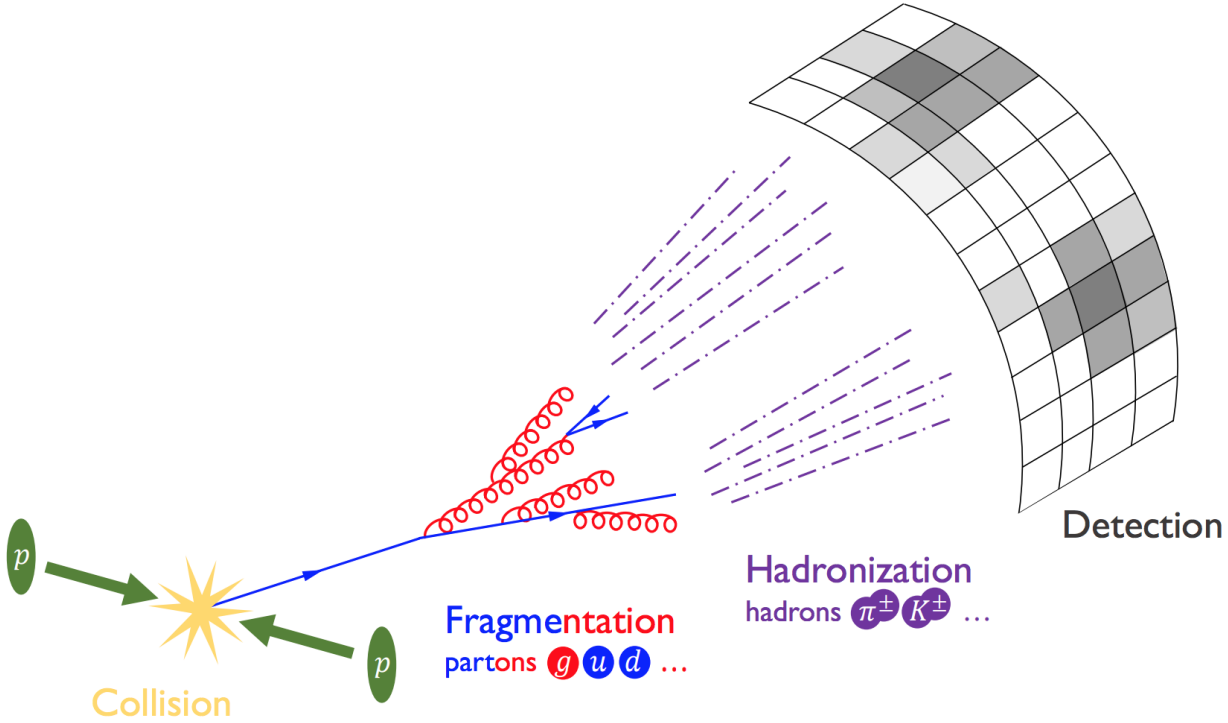
- Invisible to the detector
- Infer their presence through missing momentum in the transverse plane (MET)

Jets

- Present in the event … but not part of the Higgs decay!

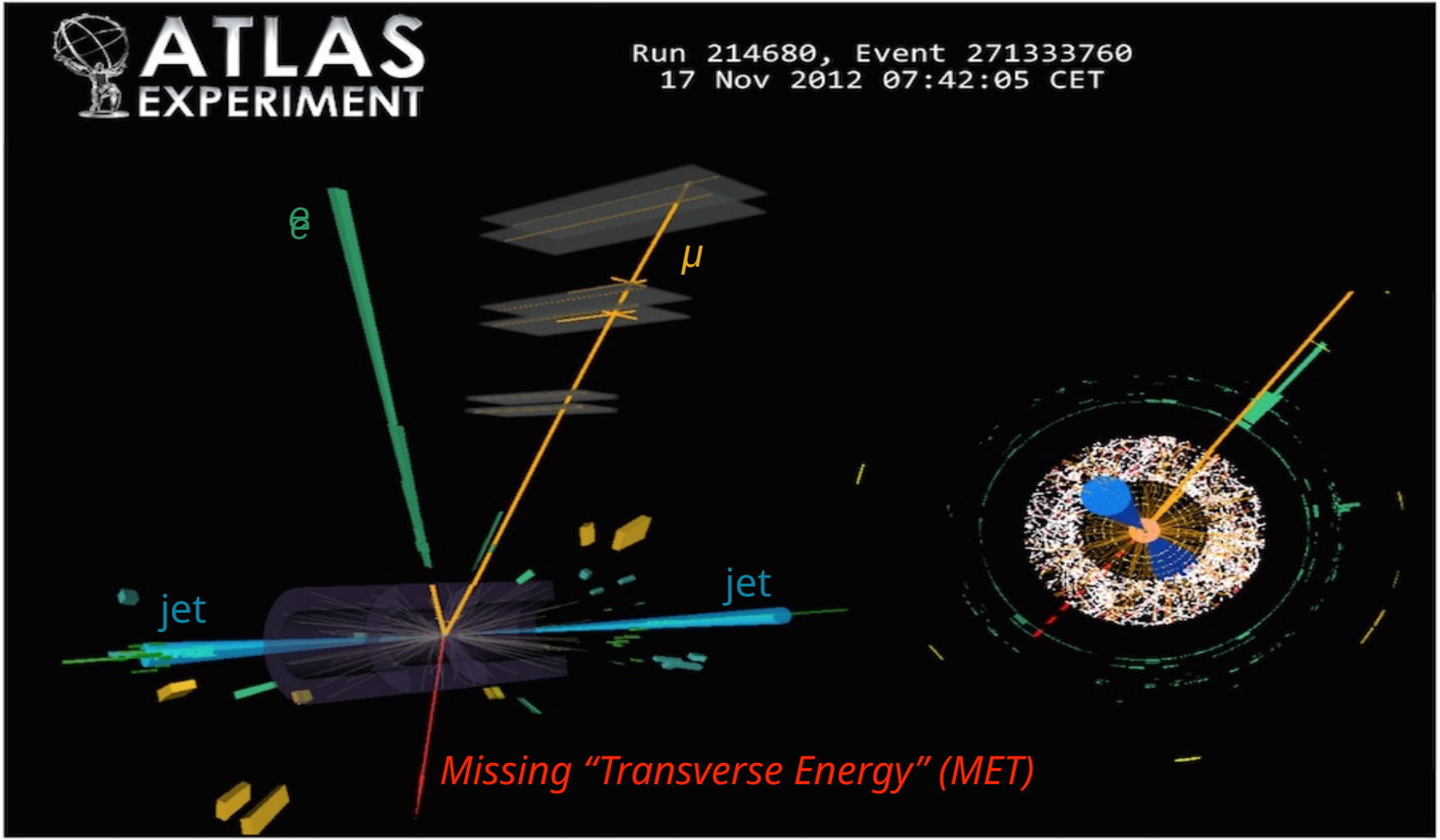


A word about
Jets

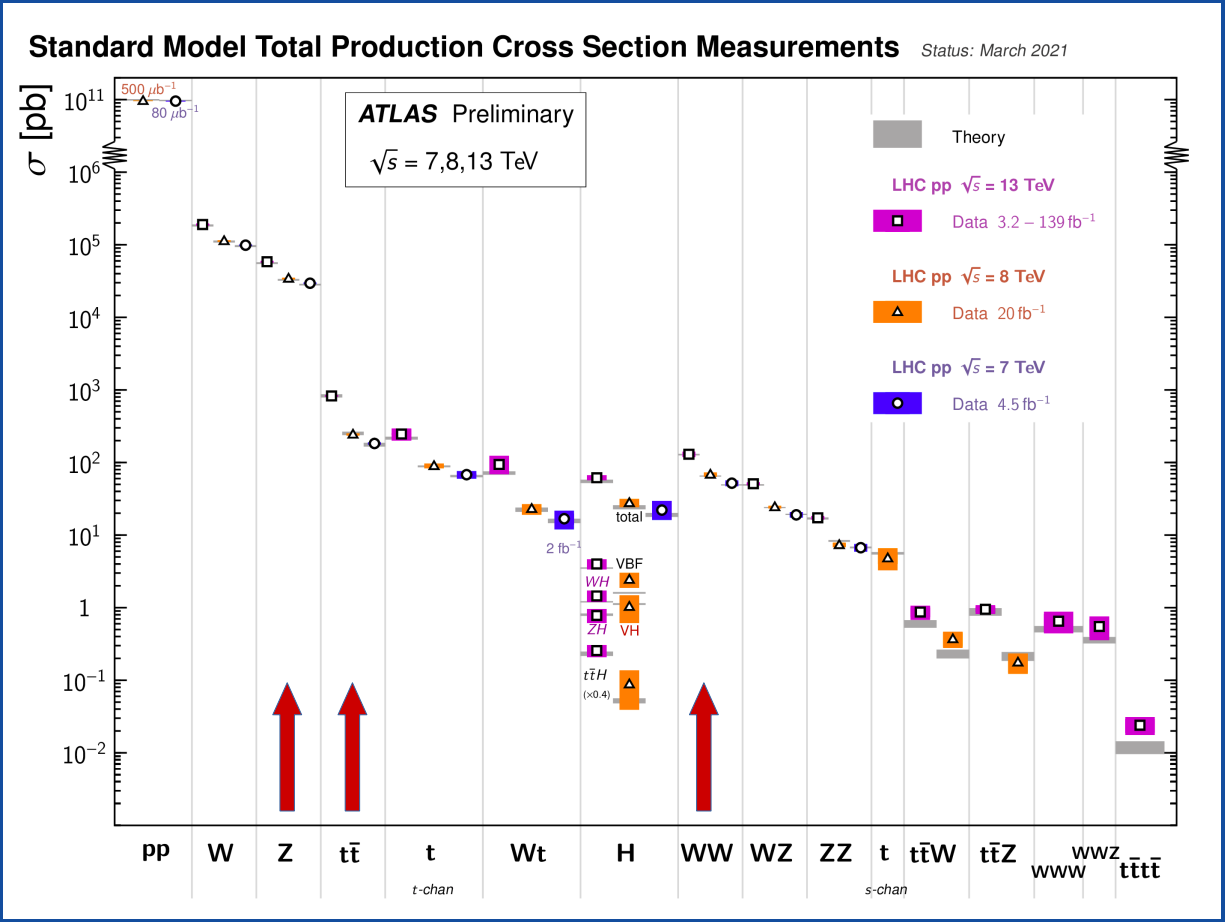


Jets arise from the hadronization of quarks/gluons leading to

- Collection of tracks from charged hadrons
- Energy deposits in the calorimeters


ATLAS
EXPERIMENT
Run 214680, Event 271333760
17 Nov 2012 07:42:05 CET
e
μ
jet
jet
Missing "Transverse Energy" (MET)

“Finding a needle in a haystack



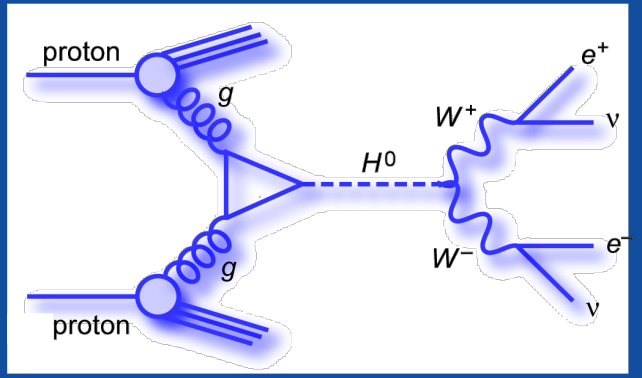
Background processes

Many other processes have similar final states

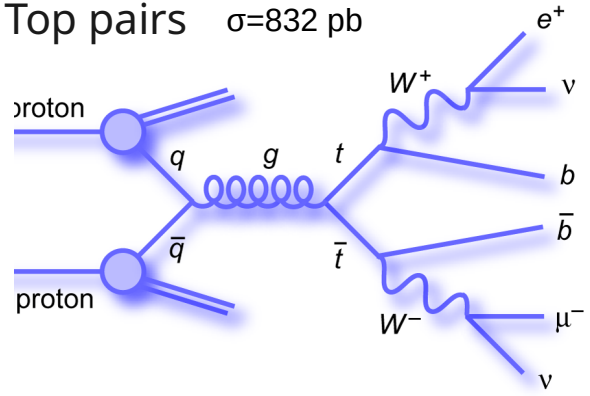
With much larger cross sections!

The particle hunter must optimize signal selection!

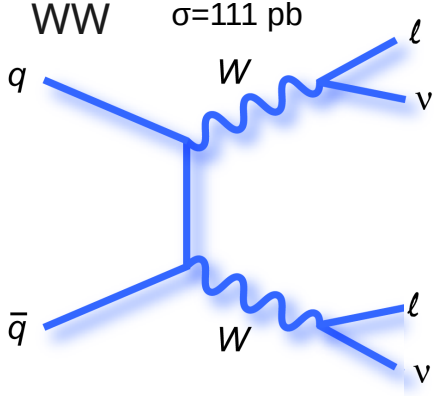
In particular by discarding background events.



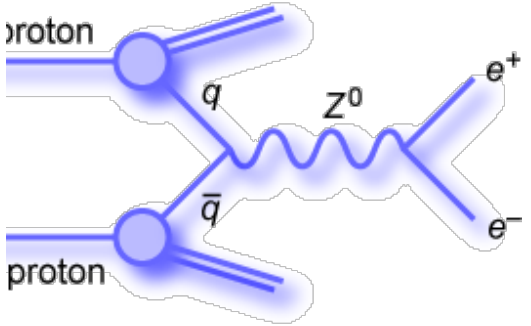
Top pairs σ=832 pb



WW σ=111 pb



Z σ=56.1x 10^3 pb

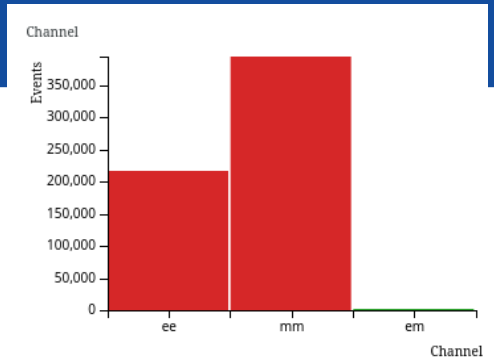


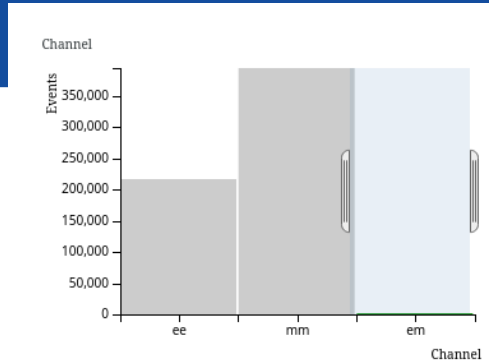
Signal significance

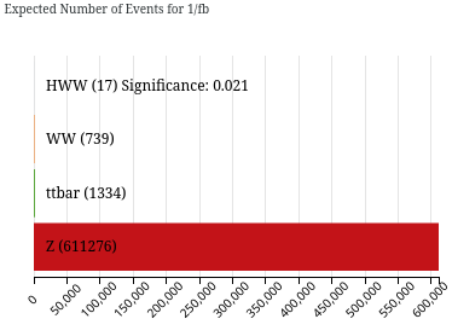
Select interesting events and discard background events => increase sensitivity

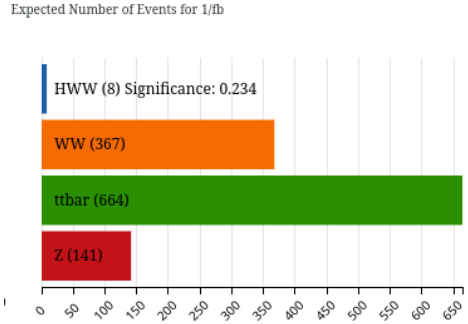
Knowing S (number of signal events) and B (number of background events) the signal significance is:

$$\frac{S}{\sqrt{S+B}}$$









Di-boson WW background

Ws with opposite electric charge

Production:

q\q→W^+W^- (dominant)

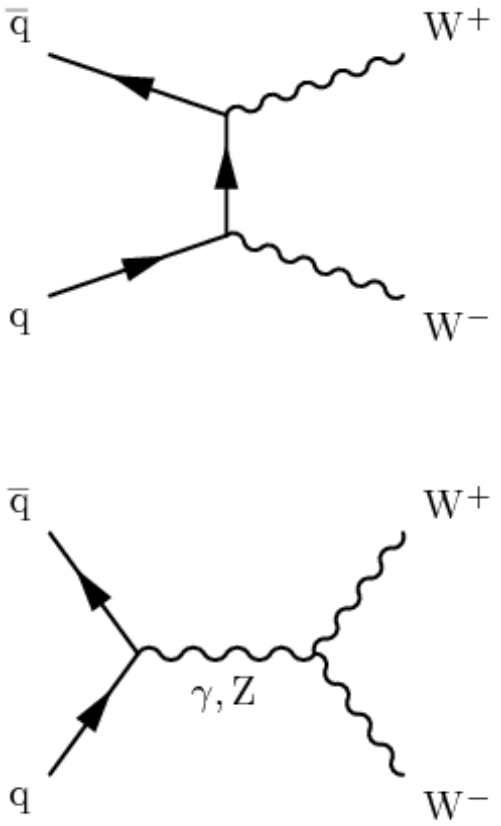
gg→W^+W^-

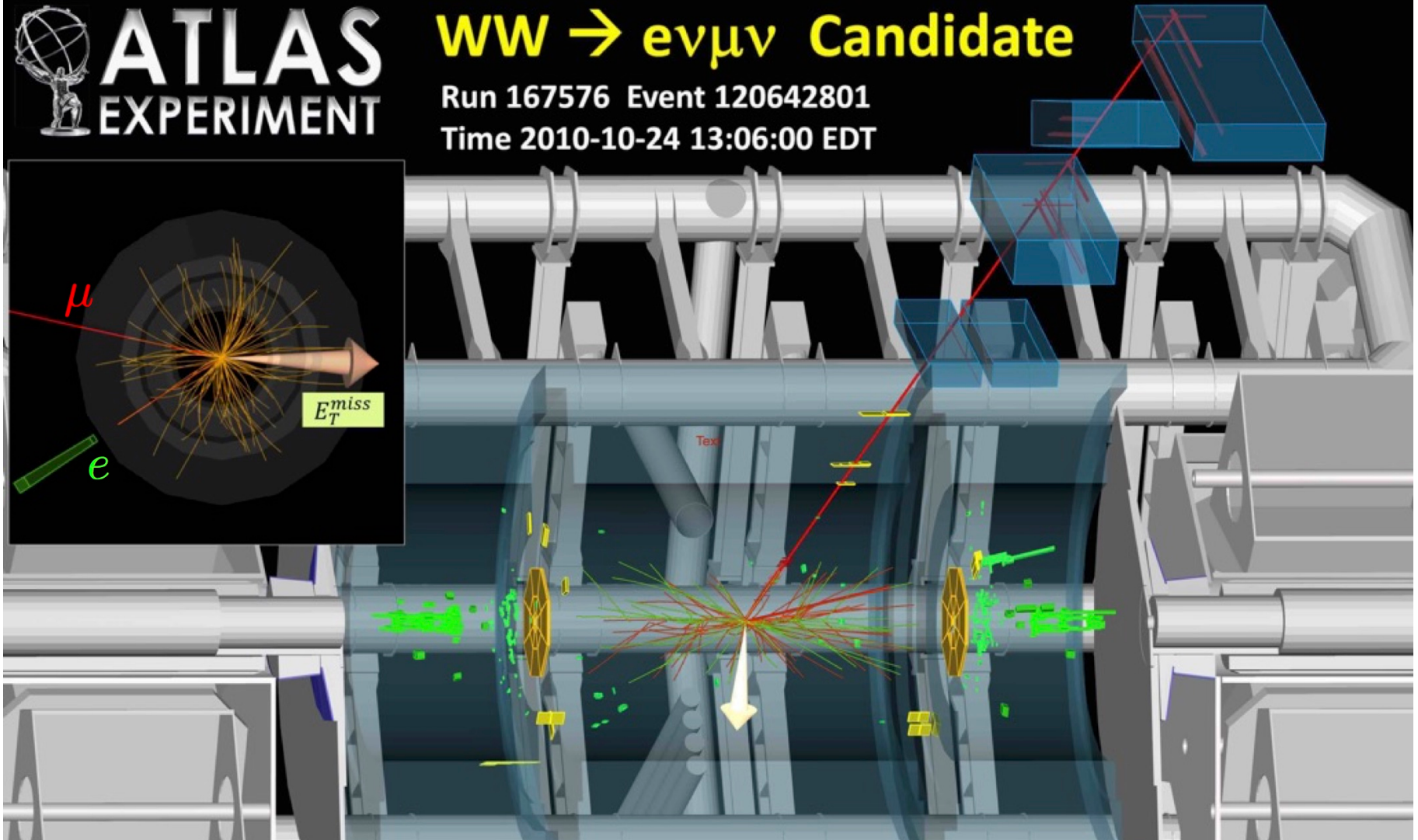
Decays:

$W^+ \rightarrow l^+ \nu$

$W^- \rightarrow l^- \bar{\nu}$

Same sign production is also possible but at much lower rate




ATLAS
EXPERIMENT
WW → eνμν Candidate
Run 167576 Event 120642801
Time 2010-10-24 13:06:00 EDT
μ
E_T^{miss}
e

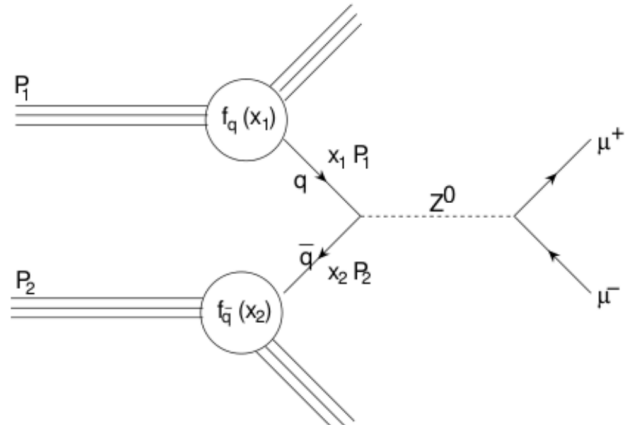
Z boson background

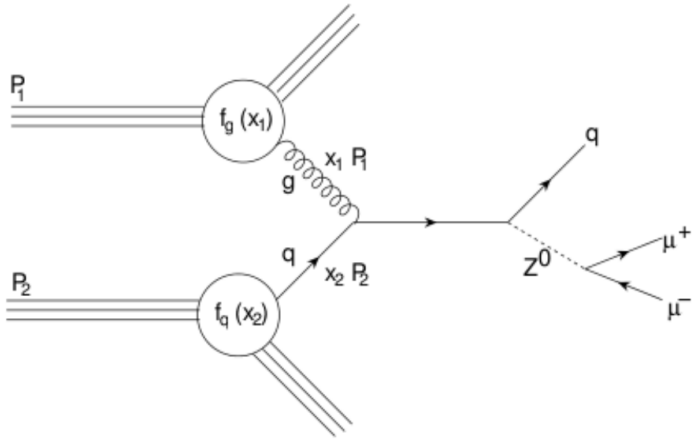
Production:

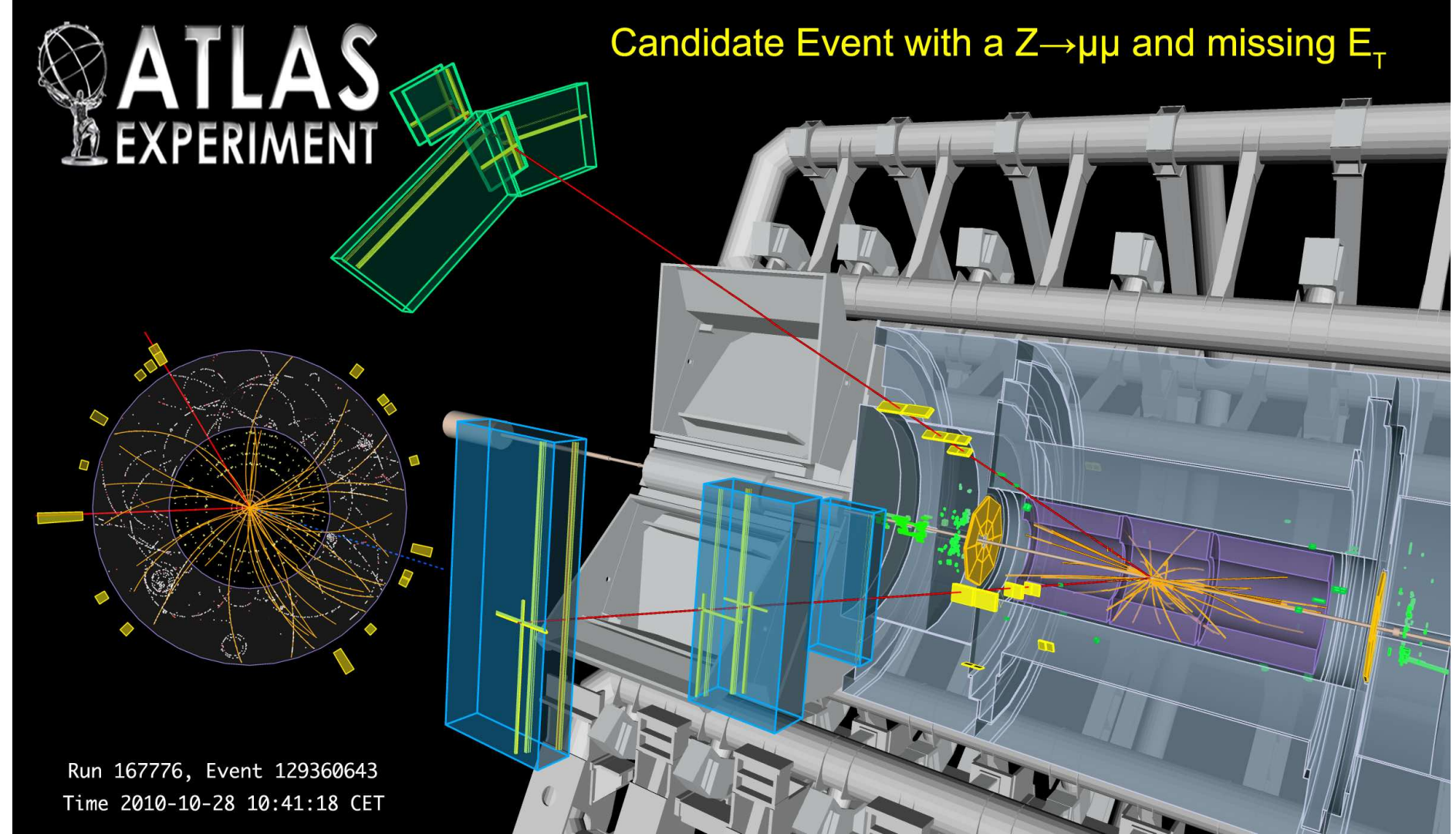
- $q\bar{q} \rightarrow Z$ (65%) [Drell-Yan]
- $qg \rightarrow Zq$ (35%)

Decays:

- quark-antiquark pairs (~70%)
- charged lepton-antilepton pairs (~10%)





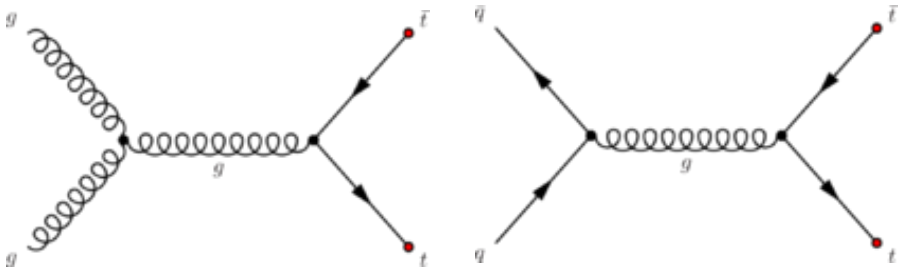

ATLAS
EXPERIMENT
Candidate Event with a Z→μμ and missing E_T
Run 167776, Event 129360643
Time 2010-10-28 10:41:18 CET

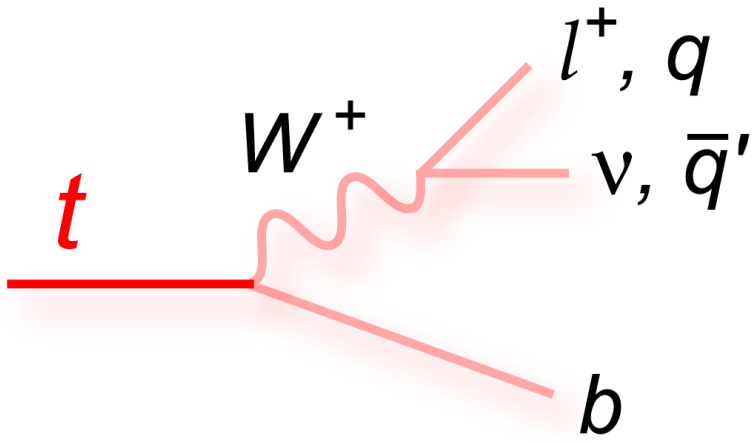
$t\bar{t}$ background

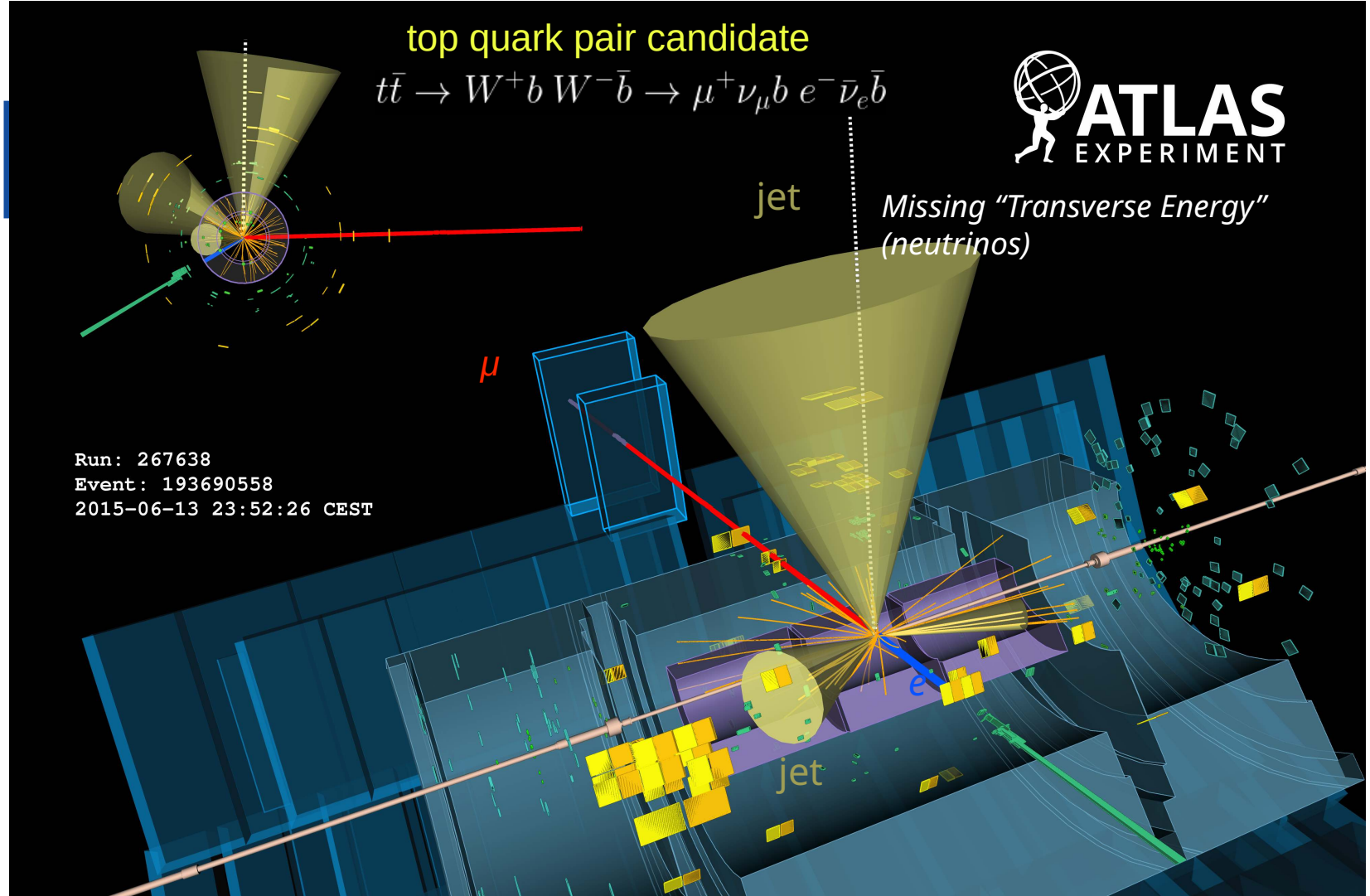
Quarks hadronise when produced freely

But the top decays basically immediately into a W and a b-quark (>99%) via weak interaction

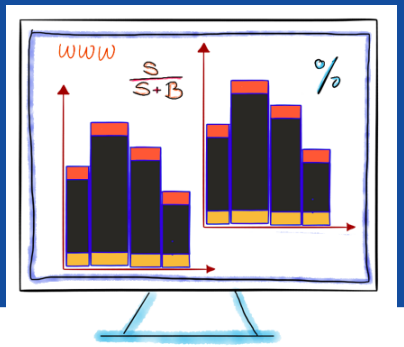
Top pairs have multiple possible final states but have a common element the presence of a b-quark → displaced secondary vertex b-tagged






top quark pair candidate
$t\bar{t} \to W^+ b\, W^- \bar{b} \to \mu^+ \nu_\mu b\, e^- \bar{\nu}_e \bar{b}$
ATLAS EXPERIMENT
jet
Missing "Transverse Energy" (neutrinos)
μ
Run: 267638
Event: 193690558
2015-06-13 23:52:26 CEST
e
jet

Online Histogram Analysis



http://opendata.atlas.cern/visualisations/analyser-js.php

Goal:

Tackle the best significance from a data selection for the Higgs boson and keep it for later discussion (you can even make a screen shot and send us (gentil@lip.pt))

Reminder:

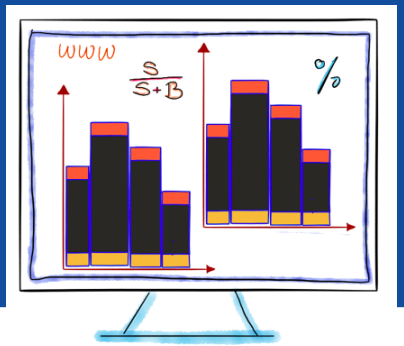
There are no wrong results! Just some will get a better significance … but maybe you all get the same …

Recommendations:

to see correctly displayed significance you may need to adjust font settings of your browser (font size 10 works for me!)

LET’S WORK and find the higgs boson!

Online Histogram Analysis

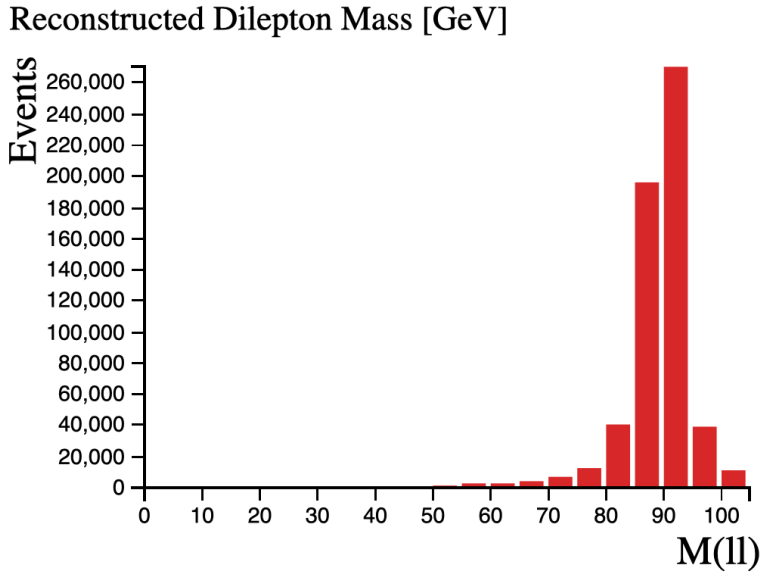


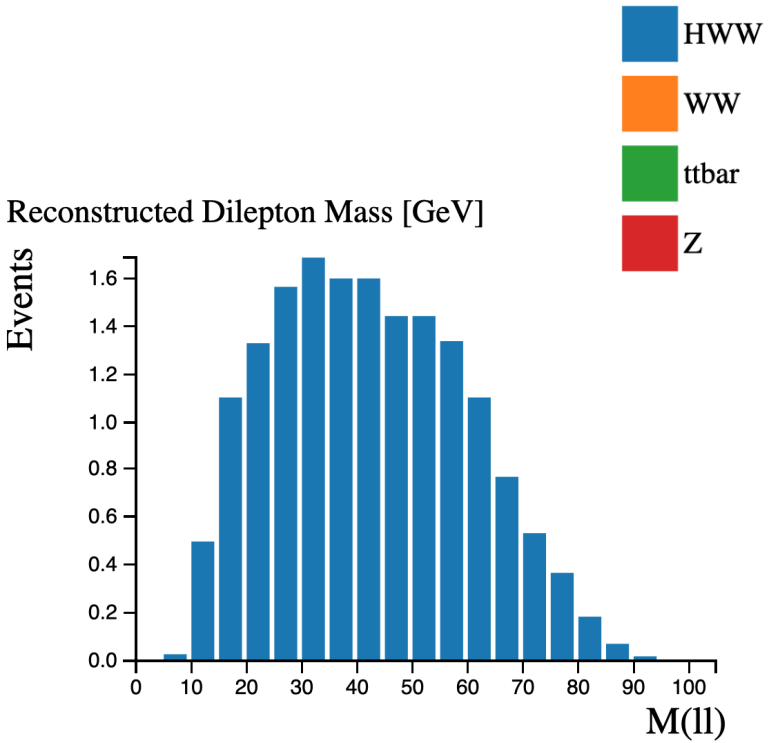
What variables selections (aka cuts) did you use to improve signal significance?

Which cut(s) helped you more for removing the Z background?

What signal significance(s) did you reach?

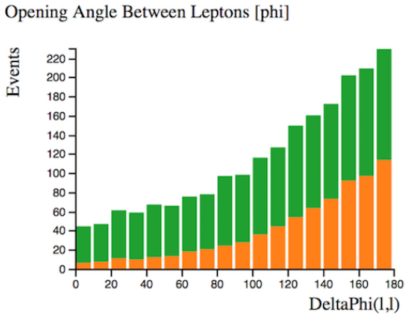
Invariant mass of the charged lepton pair

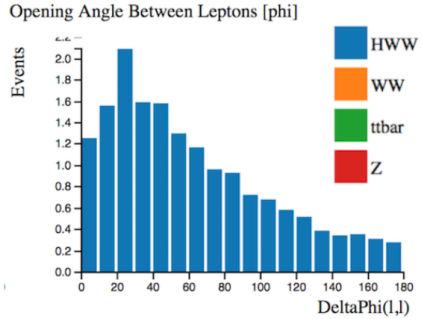




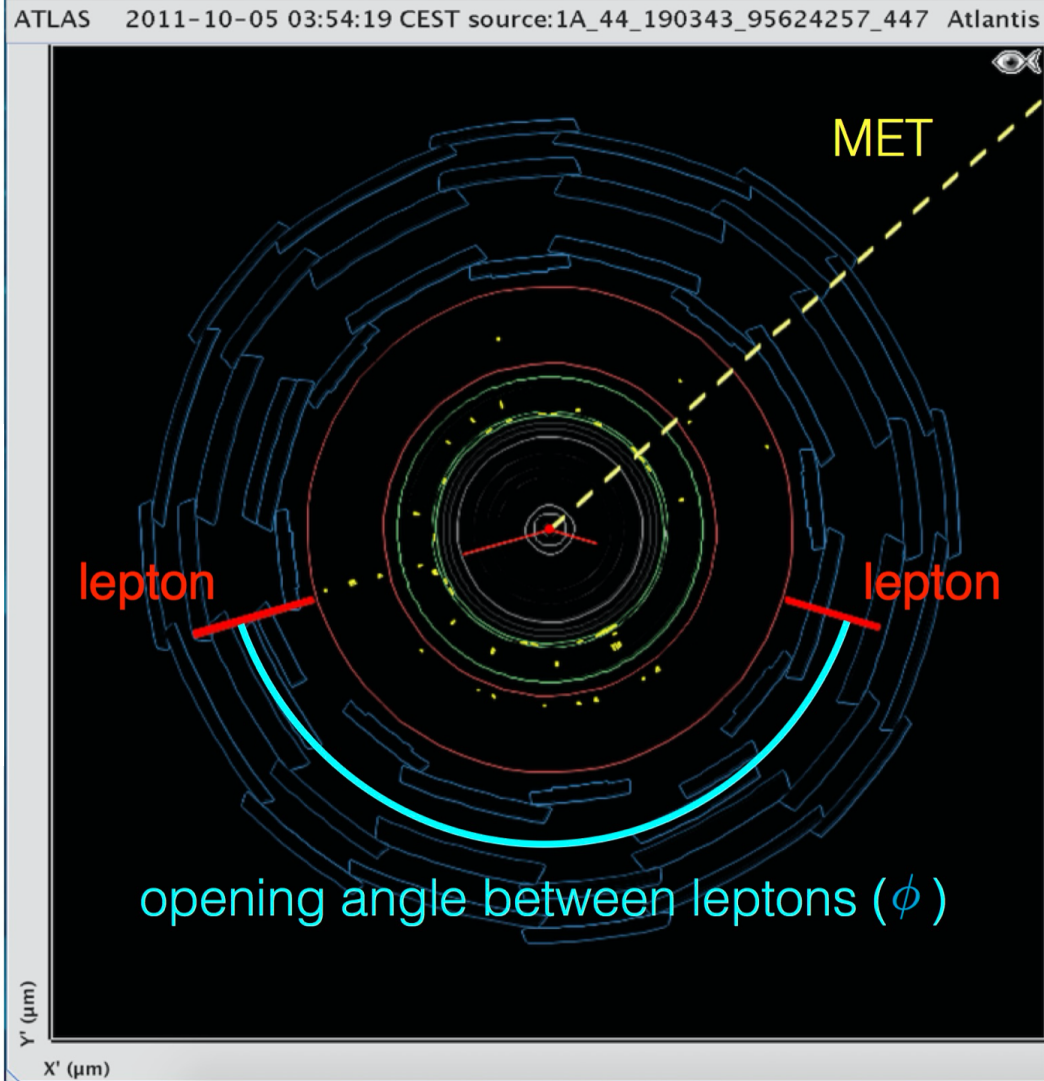
Z mass peak at 90 GeV, reconstructed from the lepton pair system

Opening angle between leptons

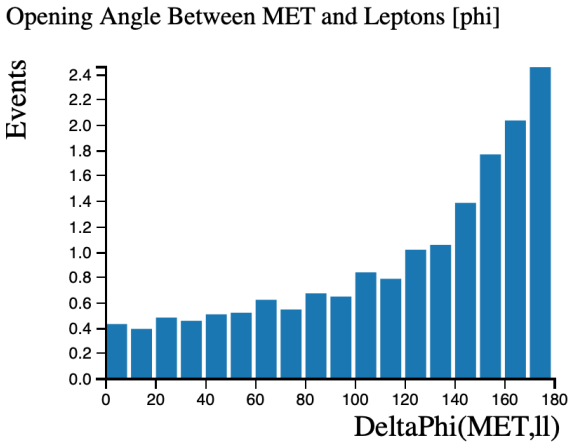




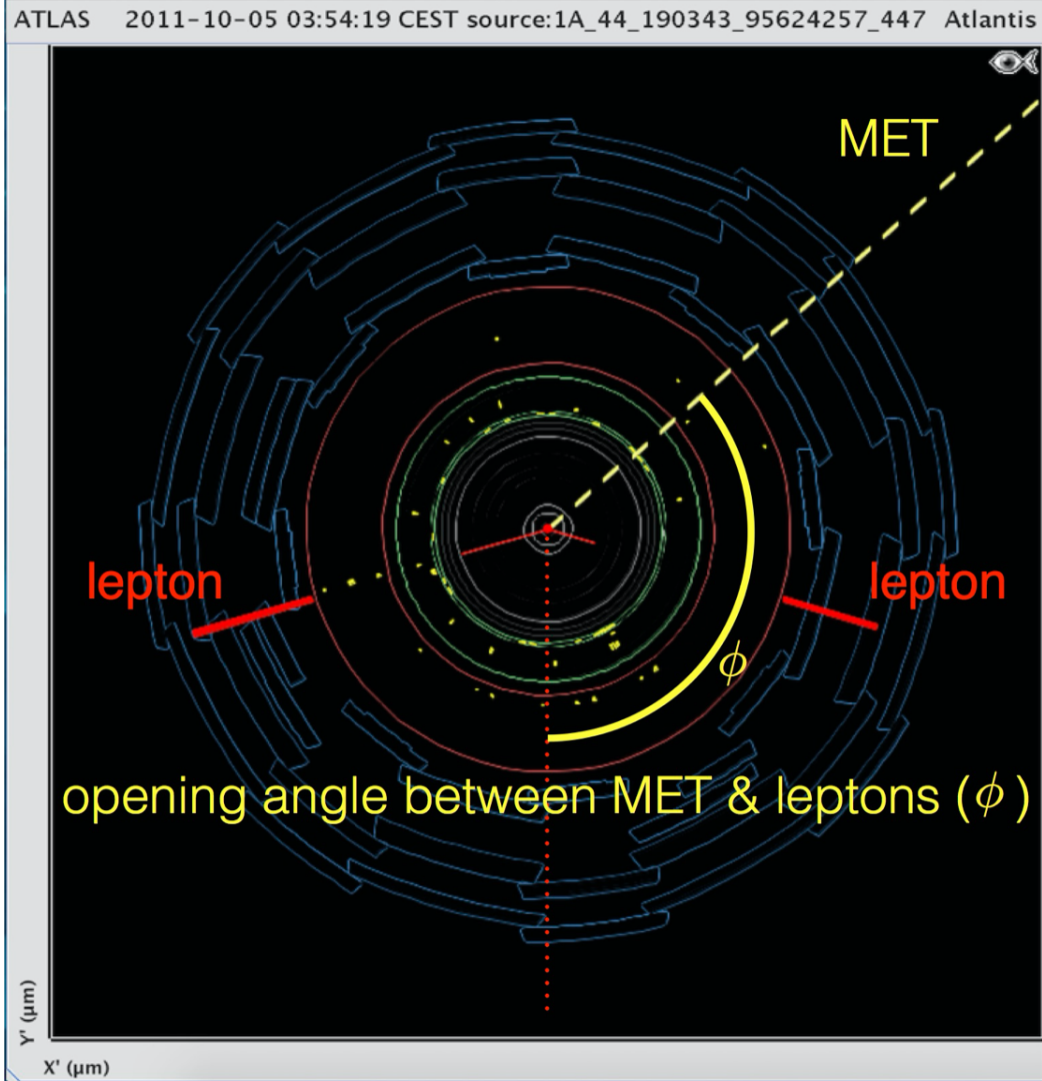
For signal, the two charged leptons have a small opening angle



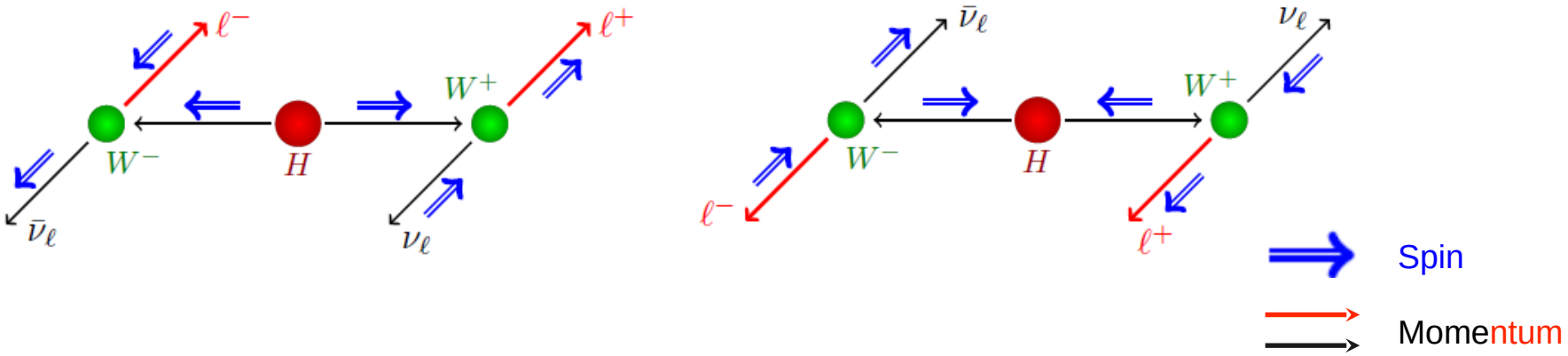
Opening angle
MET and leptons



For signal, the MET and the two charged leptons's system will be mostly back-to-back



Angular distributions H→ WW → lnulnu



Higgs has spin 0, W bosons have spin 1, leptons have spin ½.
→ Ws must have opposite spins and the spins of each lepton+neutrino pair must be parallel

Only left-handed (right-handed) neutrinos (anti-neutrinos) exist, so:
→ the two charged leptons emerge in similar directions
→ the angle between the two charged leptons and the two neutrinos is ~ 180°

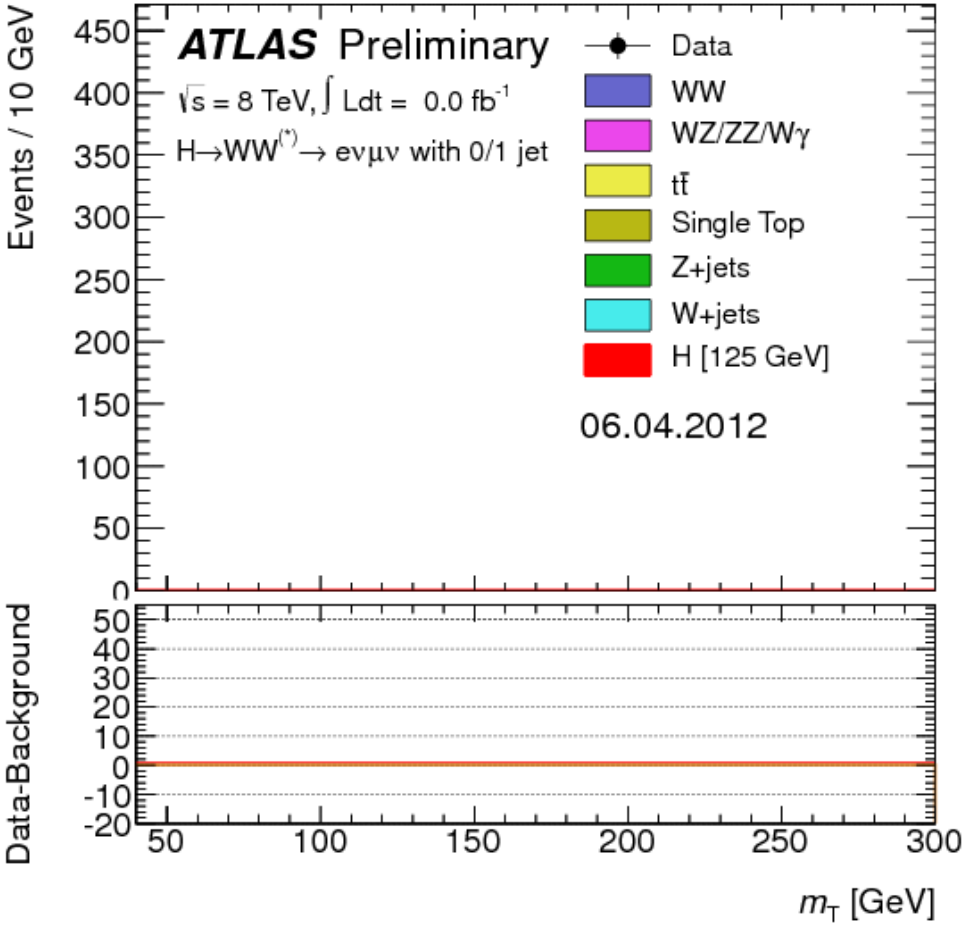
Higgs or not Higgs?
The statistical question

$$H^0 \rightarrow W\,W^* \rightarrow \nu l^+ \bar{\nu} l^-$$

One of the golden channels for the Higgs discovery in 2012

Not looking at one event…

We had to accumulate enough data and compare it to the signal+background expectation



LHC Open Data

http://atlas.cern/resources/opendata

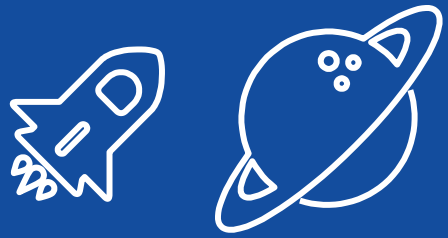
ACKNOWLEDGEMENTS

FCT Fundação para a Ciência e a Tecnologia

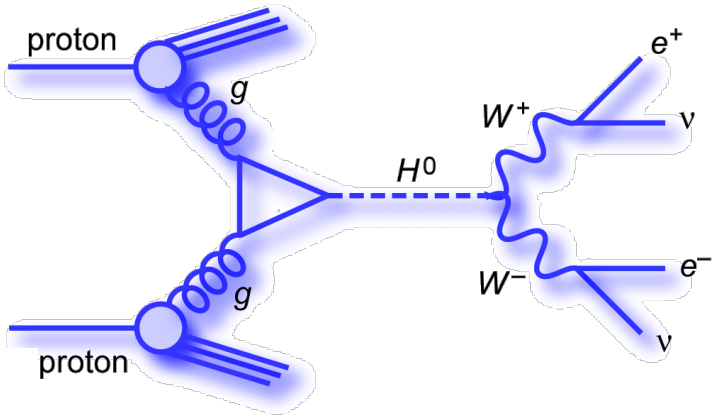
REPÚBLICA PORTUGUESA

CERN/FIS-PAR/0010/2021

EXTRA SLIDES



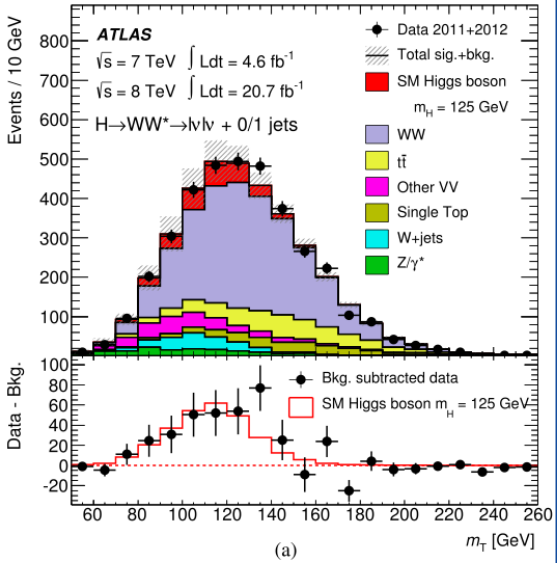
H→WW*→lνlν in the history of the Higgs discovery



H→WW*→lνlν was one of the golden channels of the Higgs discovery in 2012
Two other processes contributed:
- H→γγ
- H→ZZ*→llll

They provide clean signals in the detector:

- photons
- electrons, muons
- large missing energy (neutrinos)



https://arxiv.org/pdf/1207.7235.pdf

https://arxiv.org/pdf/1207.7214.pdf