LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

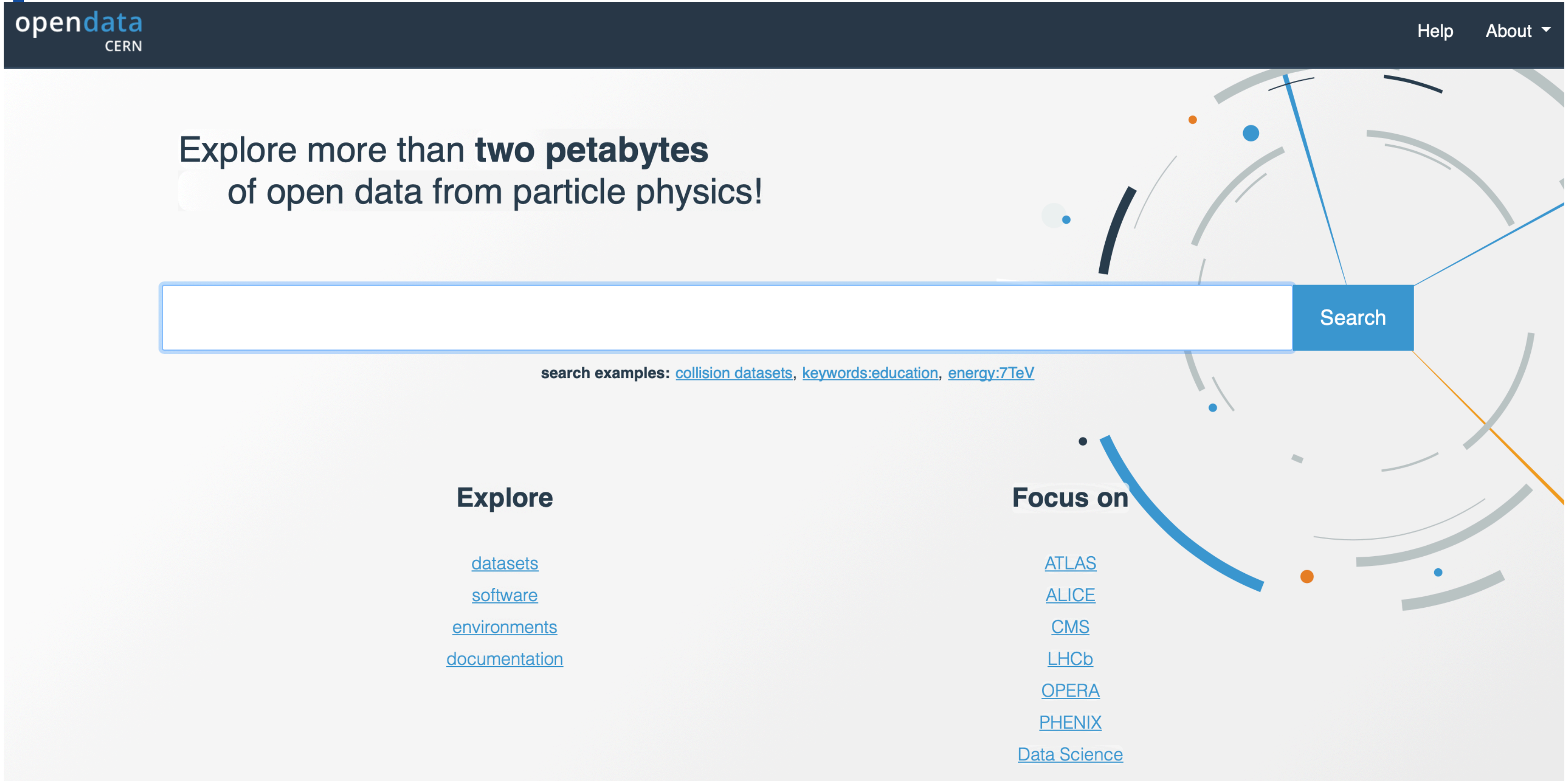
# [ Visual **LHC** *Data Analysis with* **ATLAS Open Data** ]

Rute Pedro, Patricia Conde | 8th July 2020

LIP Internship Program | Summer 2021

# LHC Open Data

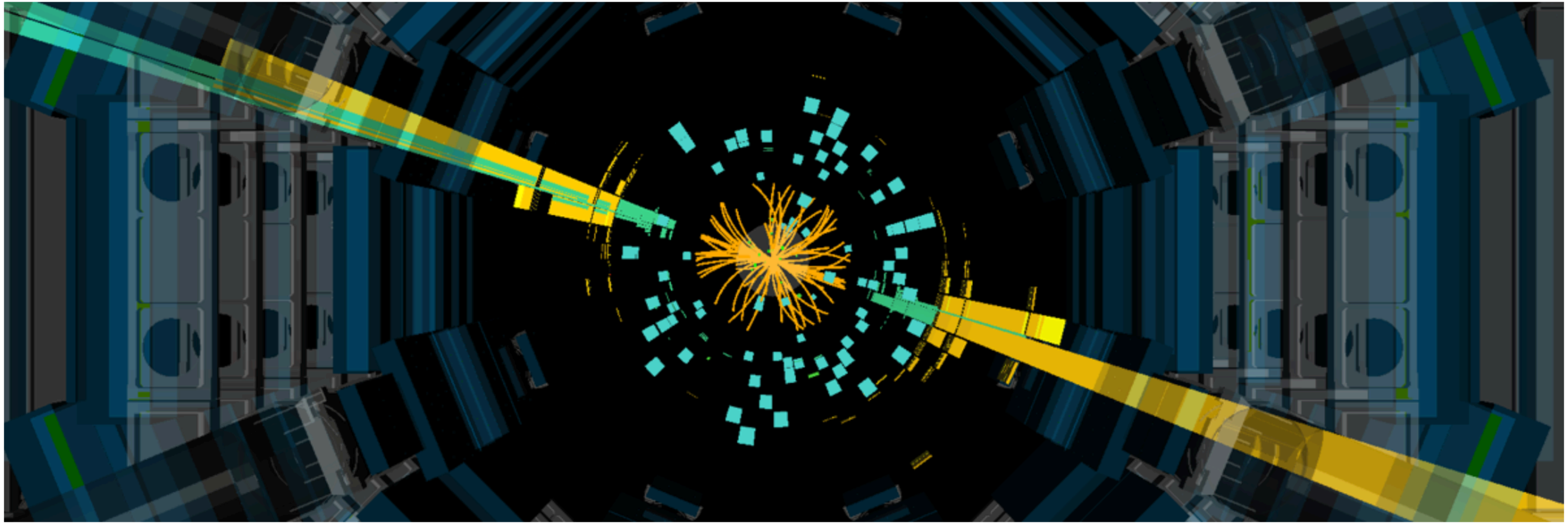
https://opendata.cern.ch



# ATLAS

## Open Data Set

http://atlas.cern/resources/opendata



**10 $fb^{-1}$ of ATLAS proton-proton collision data is now public!**

# ATLAS

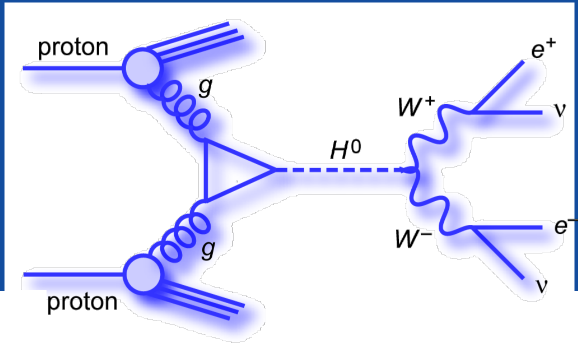
## Open Data - online resources

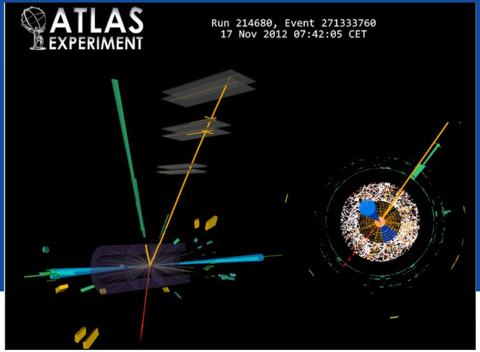
Online Analysis with Jupyter notebooks

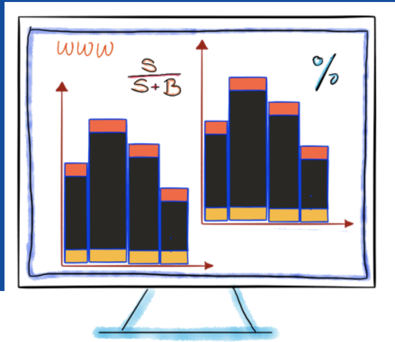
Download data and Analysis Framework

Online Histogram Analyser (8 TeV data)

# Rediscovering the Higgs
# with a simple online analysis




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?

# $H \to WW^* \to \ell\nu\ell\nu$

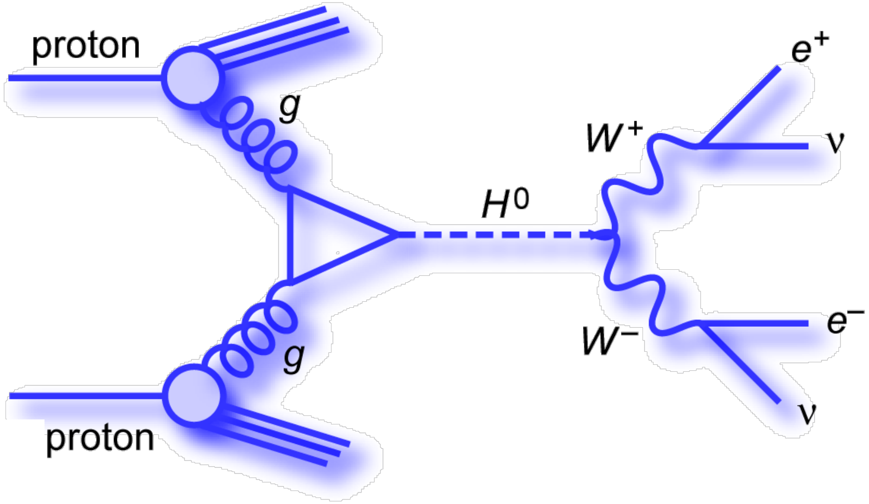
Dominant 125 GeV Higgs production through “gluon fusion”

- $gg \to H$

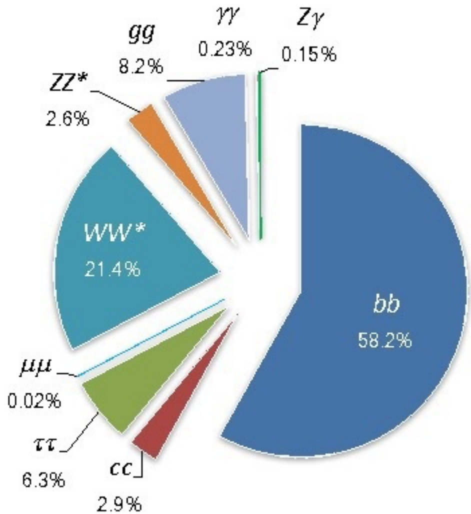
Followed by Higgs decay into W bosons

- $H \to W^+W^-$
- ~21% of the times

| $W^+$ DECAY MODES | | Fraction ($\Gamma_i/\Gamma$) |
|---|---|---|
| $\ell^+\nu$ | [b] | (10.86 ± 0.09) % |
| $e^+\nu$ | | (10.71 ± 0.16) % |
| $\mu^+\nu$ | | (10.63 ± 0.15) % |
| $\tau^+\nu$ | | (11.38 ± 0.21) % |
| hadrons | | (67.41 ± 0.27) % |




Higgs decays



$$H \to WW^* \to \ell\nu\ell\nu$$

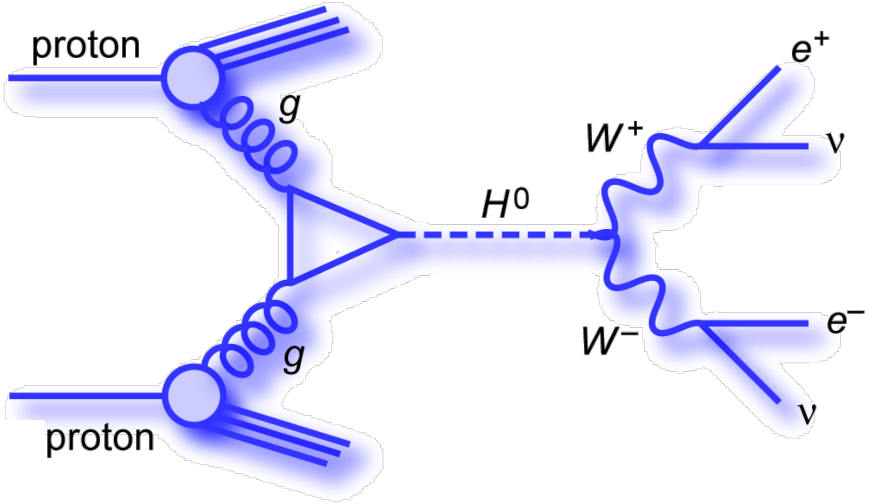
# Final state particles

2 high momenta leptons

Opposite electrical charge

2 neutrinos

May have jets from quark/gluon hadronisation



## $H \to WW^* \to \ell\nu\ell\nu$

# In the detector

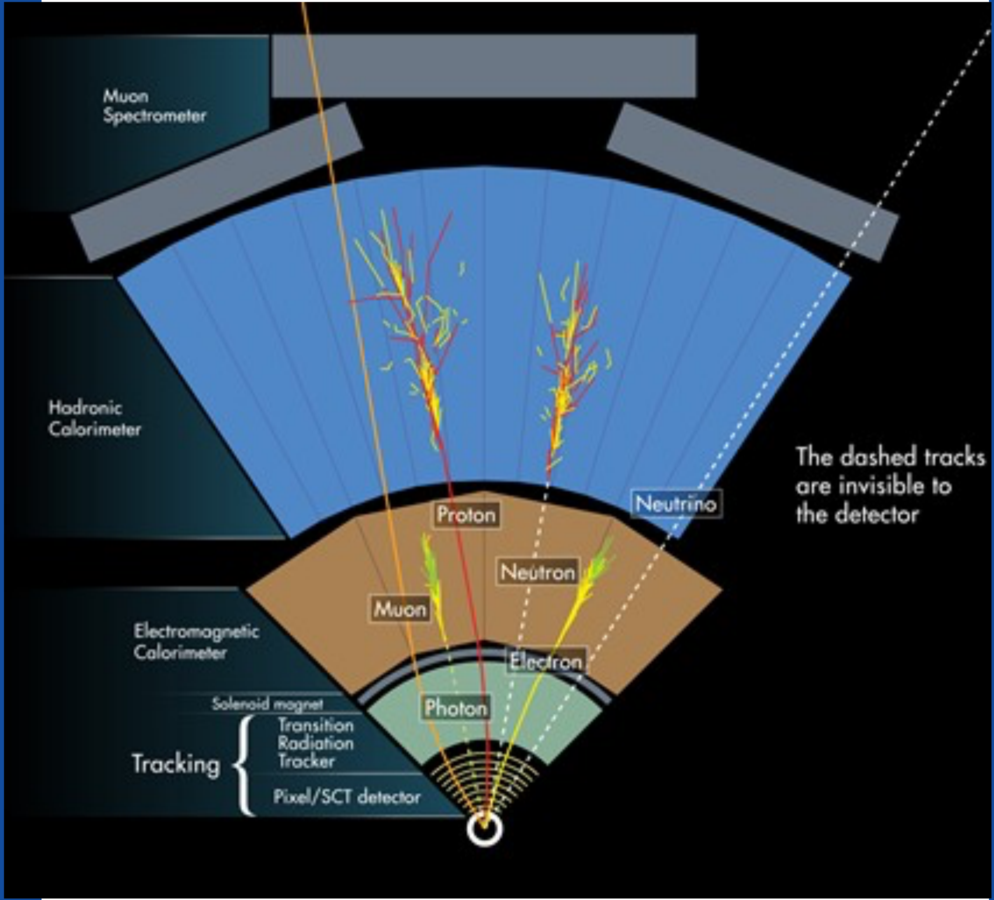
2 high momenta leptons

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

Opposite electrical charge

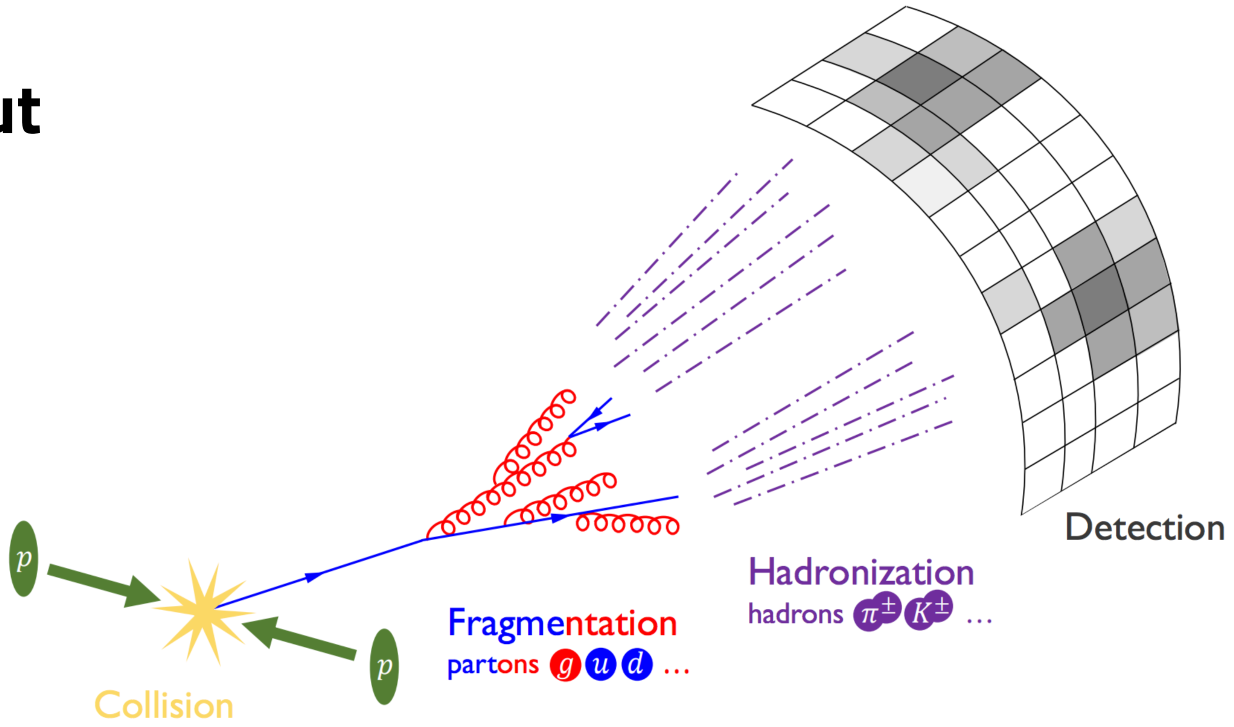
2 neutrinos

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



# A word about

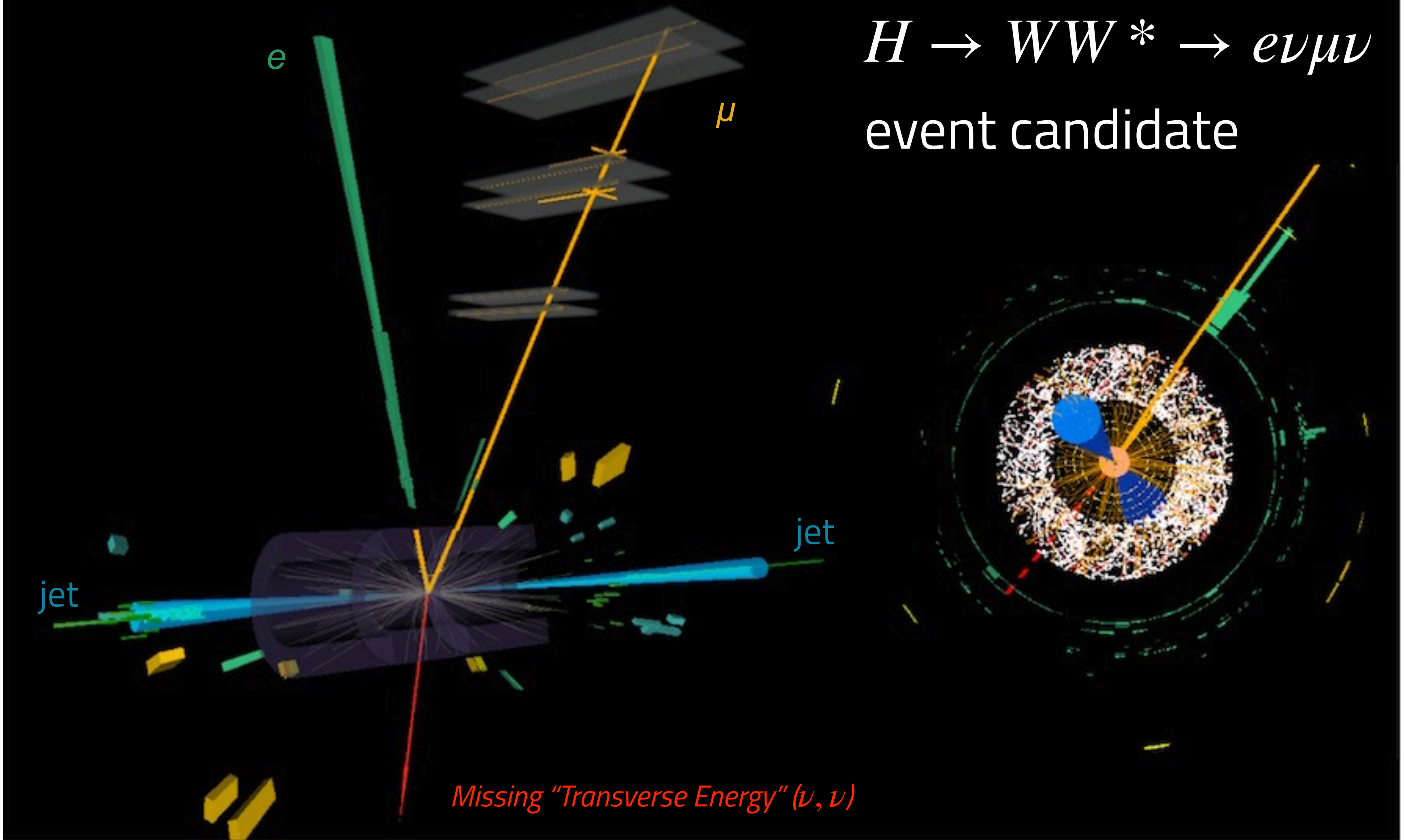
## Jets



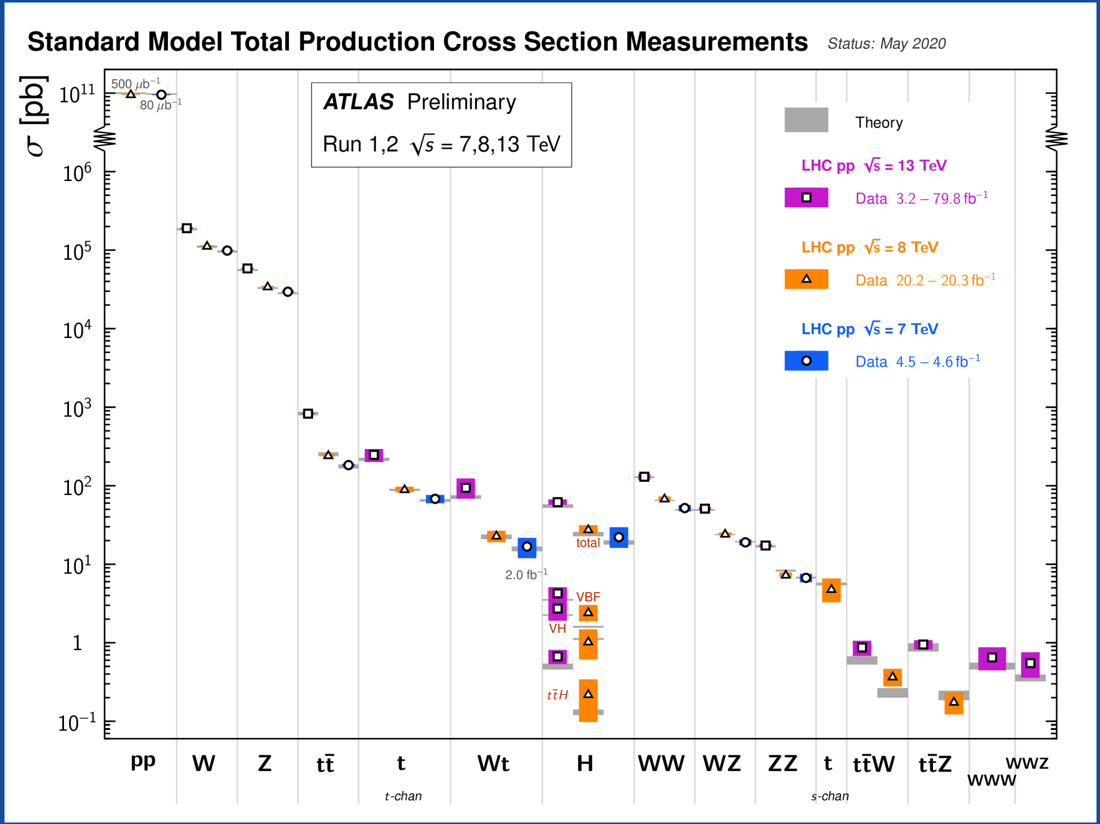

Jets arise from the hadronization of quarks/gluons leading to

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

# $H \to WW* \to e\nu\mu\nu$ event candidate



# “ *Finding a needle in a haystack*



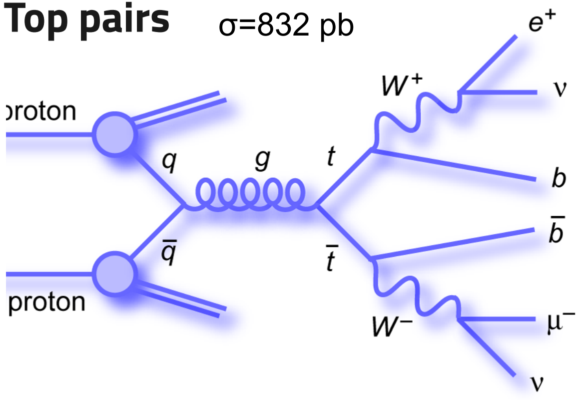
# Background processes

Many other processes have similar final states

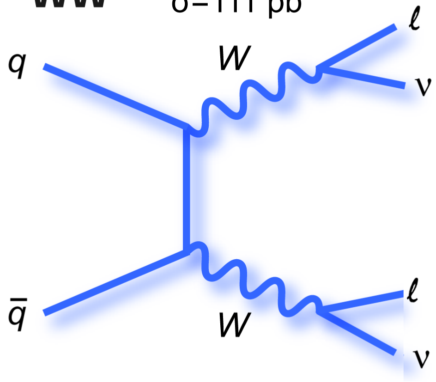
And they have much larger cross sections

The task of particle physics experimentalists is to find ways to select signal and discard background events

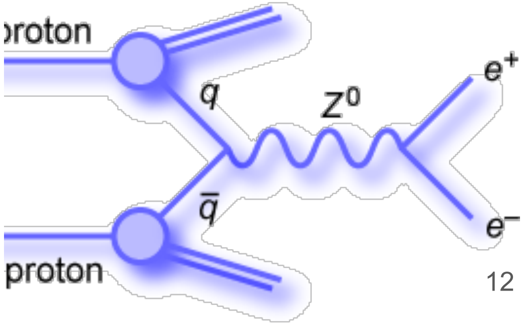
**Top pairs** $\sigma$=832 pb




**WW** $\sigma$=111 pb




**Z** $\sigma$=56.1x $10^3$ pb

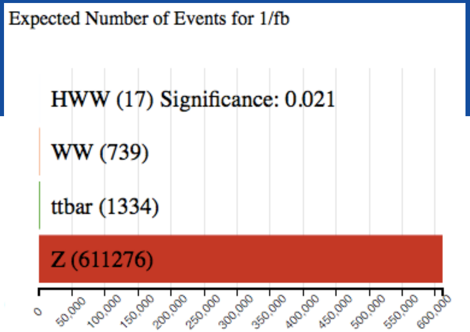


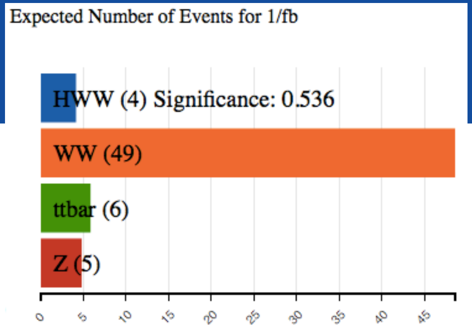
# Signal significance

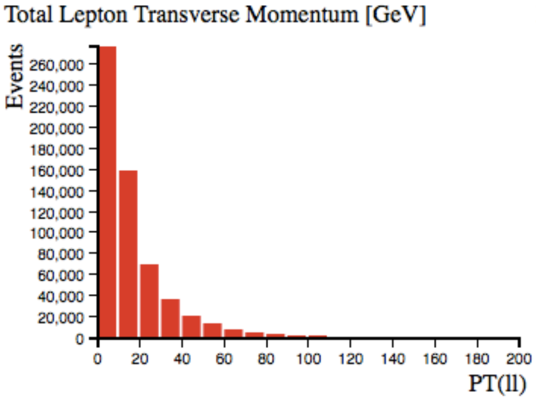
Physicists study how to select events of interest and discard background events => increase sensitivity

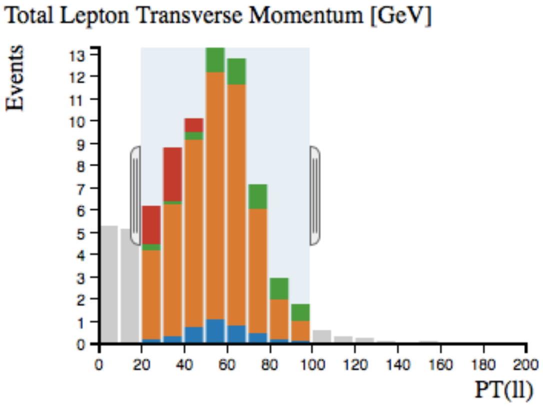
If S is the number of signal events and B the number of background events, the signal significance is:

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



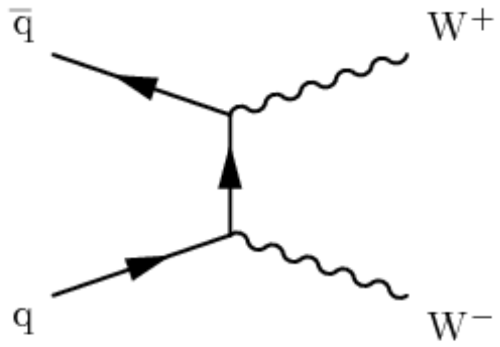



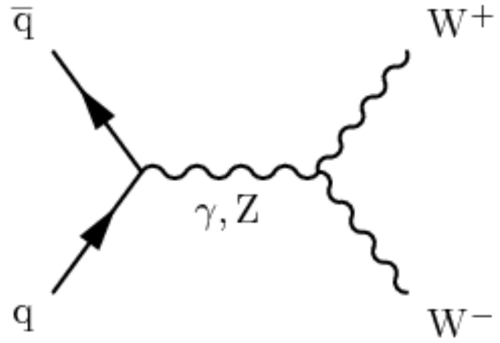
# WW background

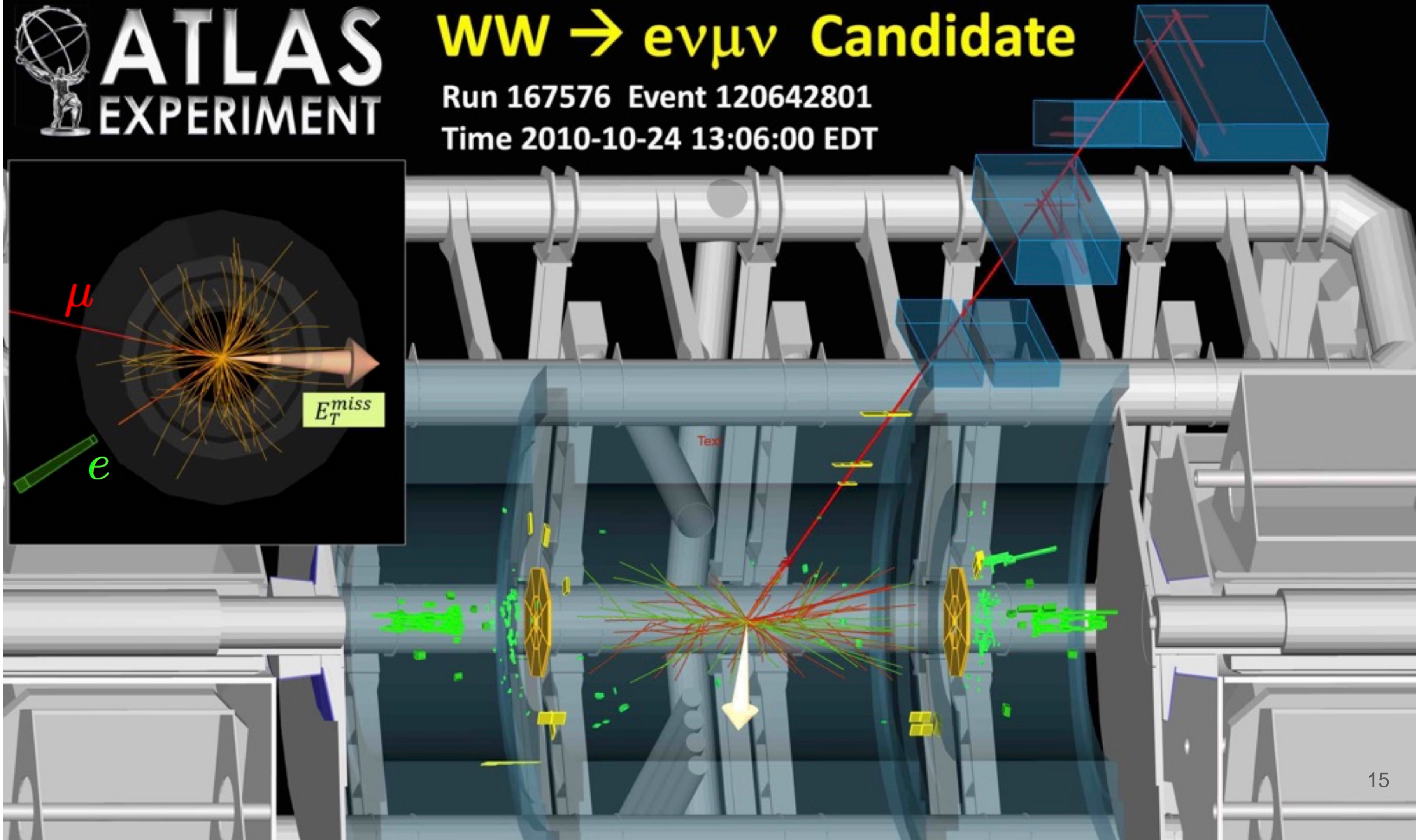
More than one production mechanism:

- q\q→$W^+W^-$ (dominant)
- gg→$W^+W^-$

Ws have opposite electric charge (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

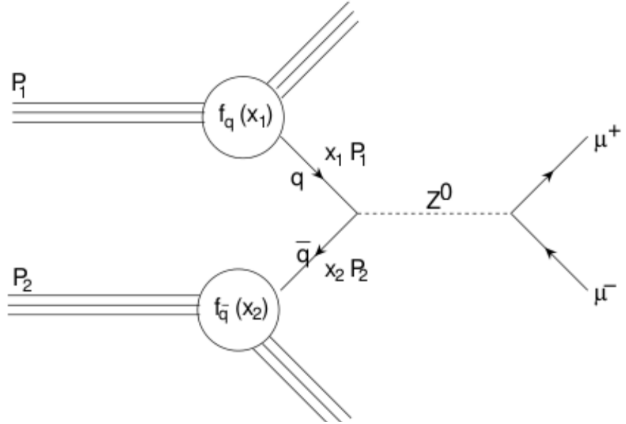
# Z background

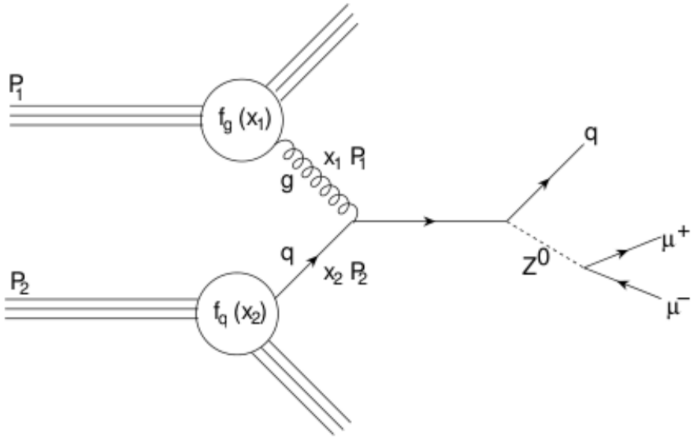
Production:

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

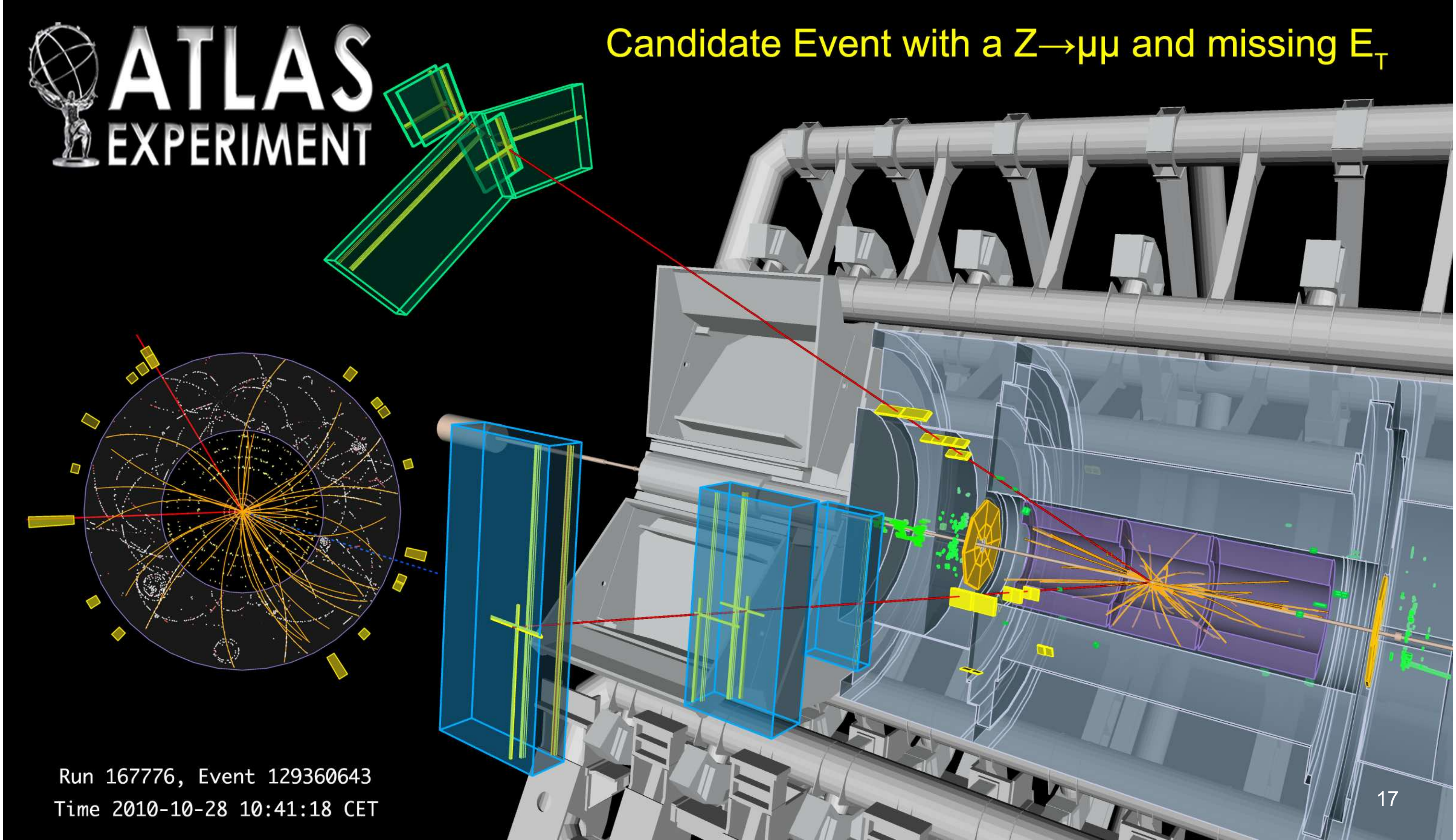
The Z boson has 0 electric charge and decays to:

- quark-antiquark pairs (~70%)
- neutrino-antineutrino (~20%)
- same flavour charged lepton pairs (10%)

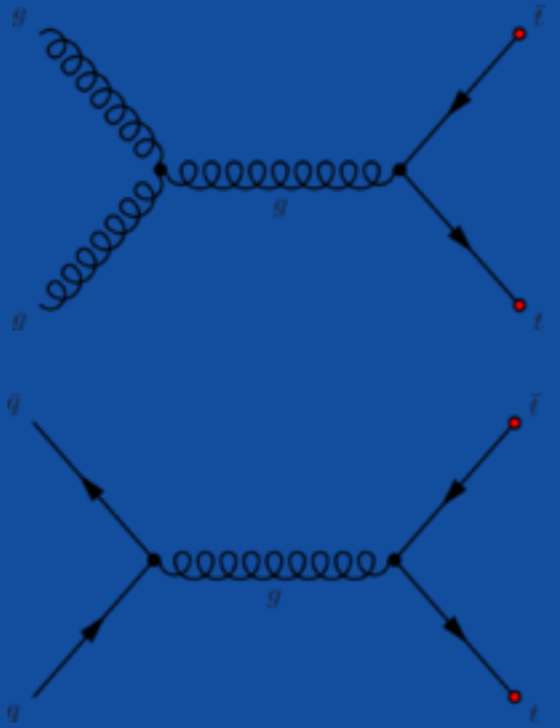


# Candidate Event with a Z→μμ and missing $E_T$

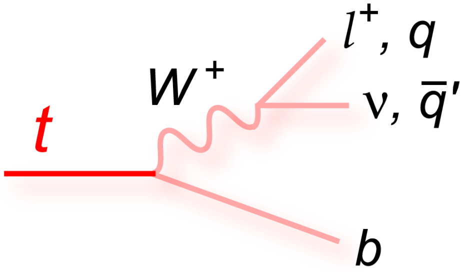


# Top pairs background

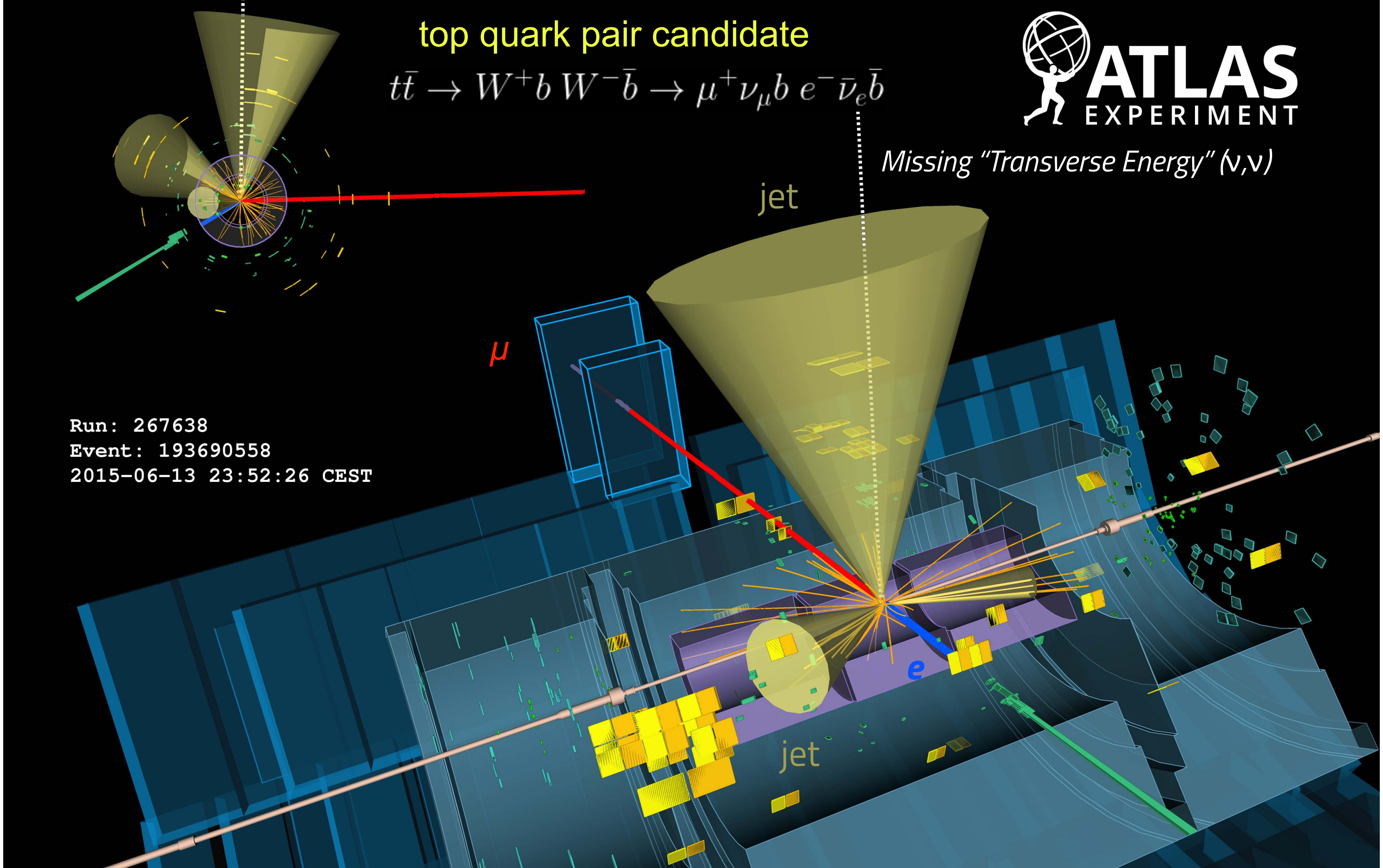


Other quarks hadronise when produced freely

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



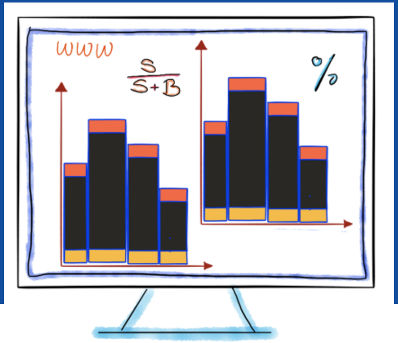

Top pairs have multiple possible final states



top quark pair candidate
$t\bar{t} \rightarrow W^{+}b\,W^{-}\bar{b} \rightarrow \mu^{+}\nu_{\mu}b\,e^{-}\bar{\nu}_{e}\bar{b}$
ATLAS
EXPERIMENT
Missing “Transverse Energy” (ν,ν)
jet
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

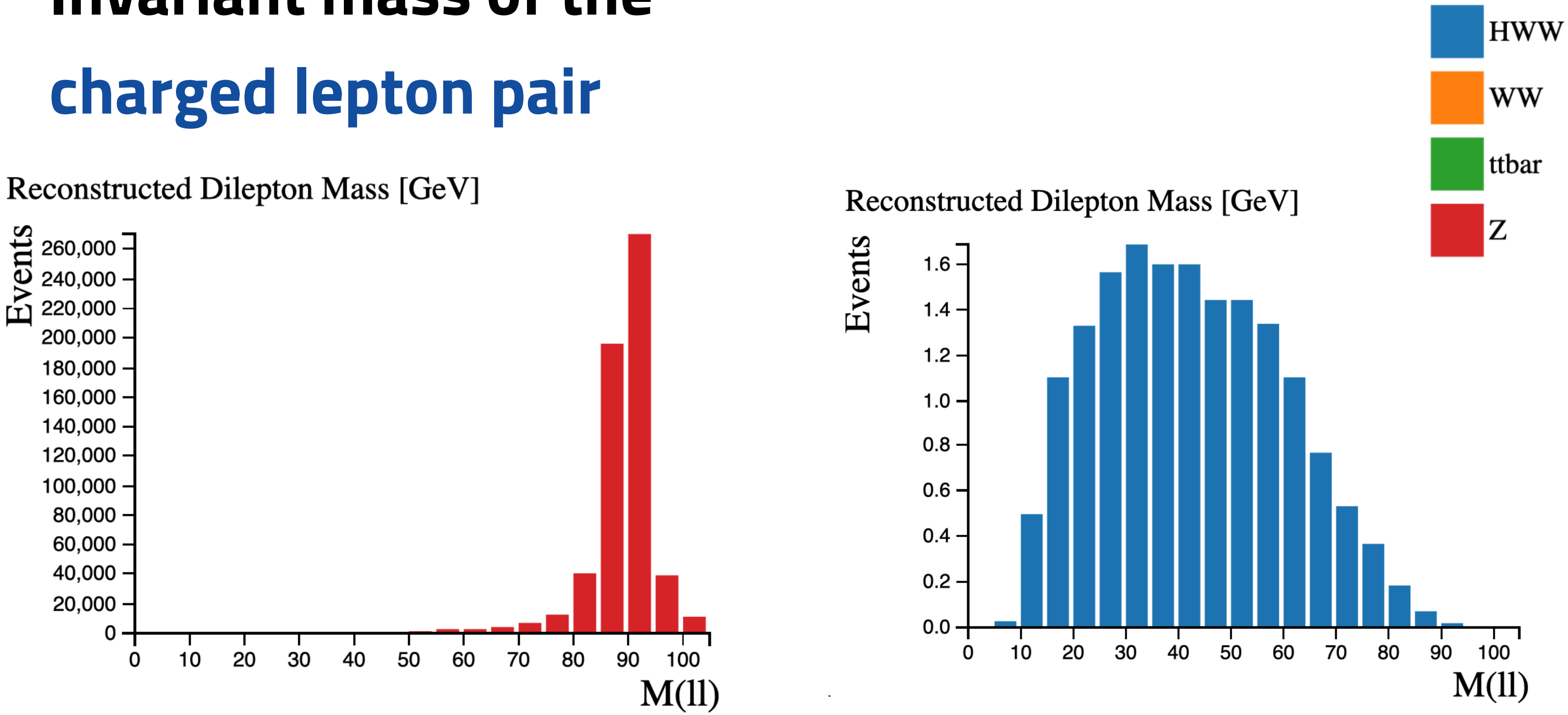



What variables and cuts did you use to select the signal and improve its significance?

Which cut helped you more removing the Z background?

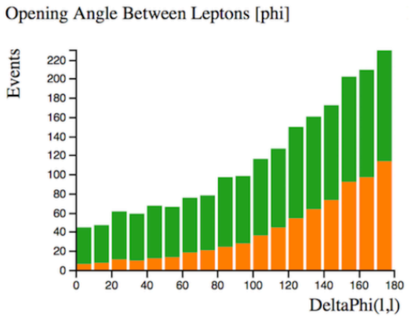
What signal significance did you reach?

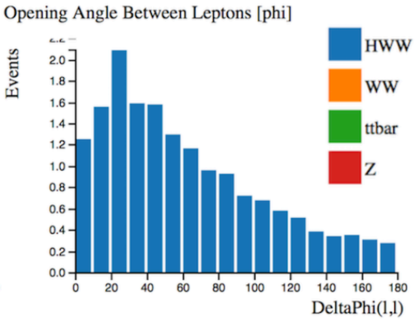
# Invariant mass of the charged lepton pair



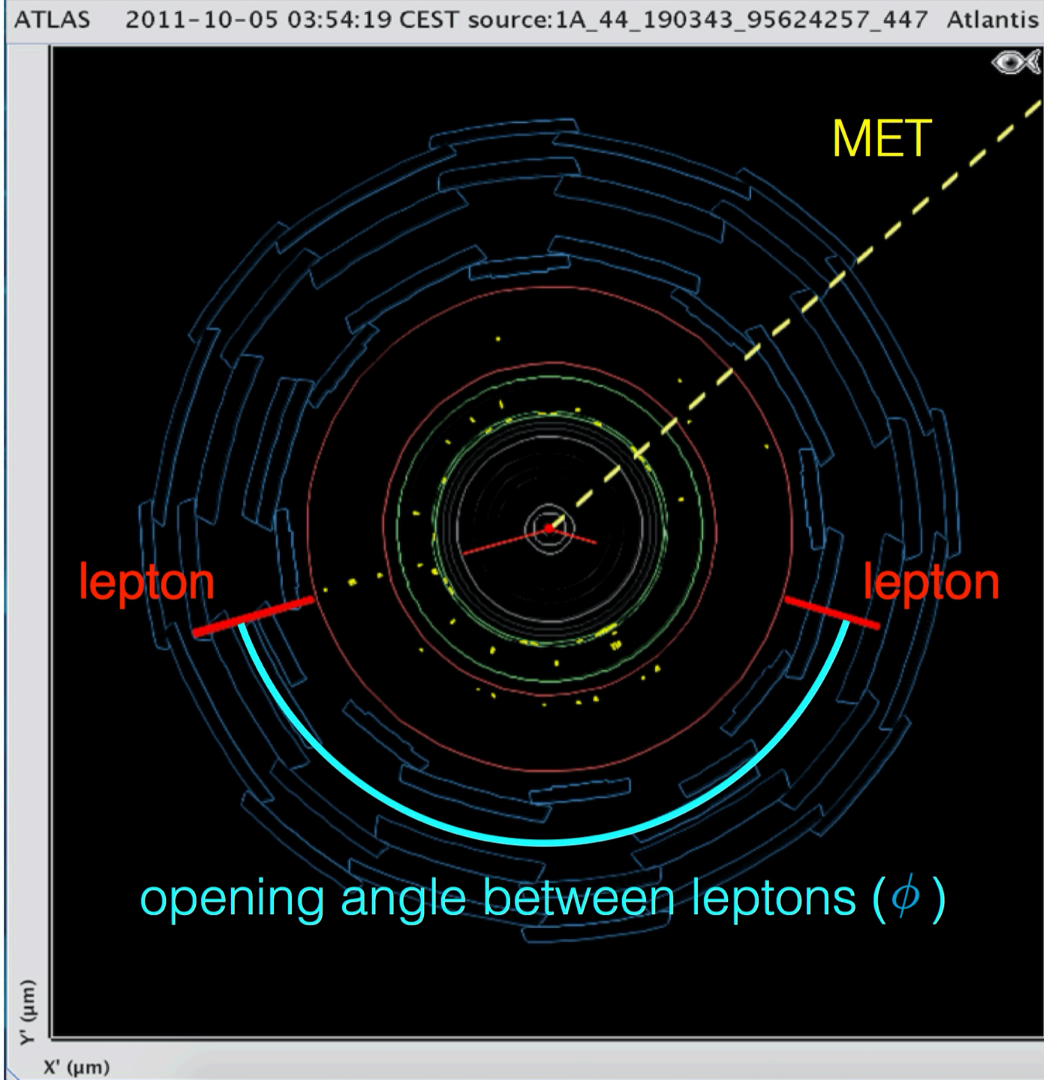

Z mass peak at 90 GeV, reconstructed from the lepton pair system ($Z \to \ell\ell$)

# Opening angle
## between leptons

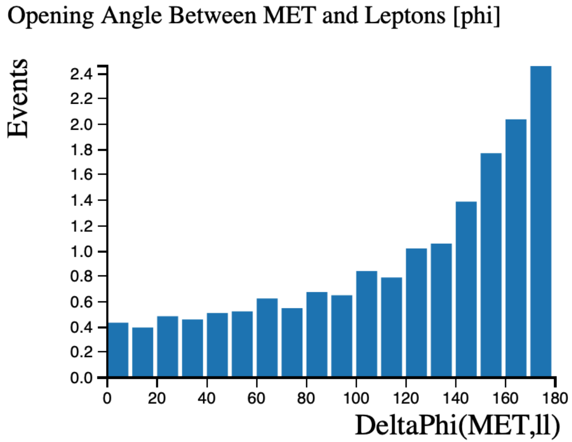


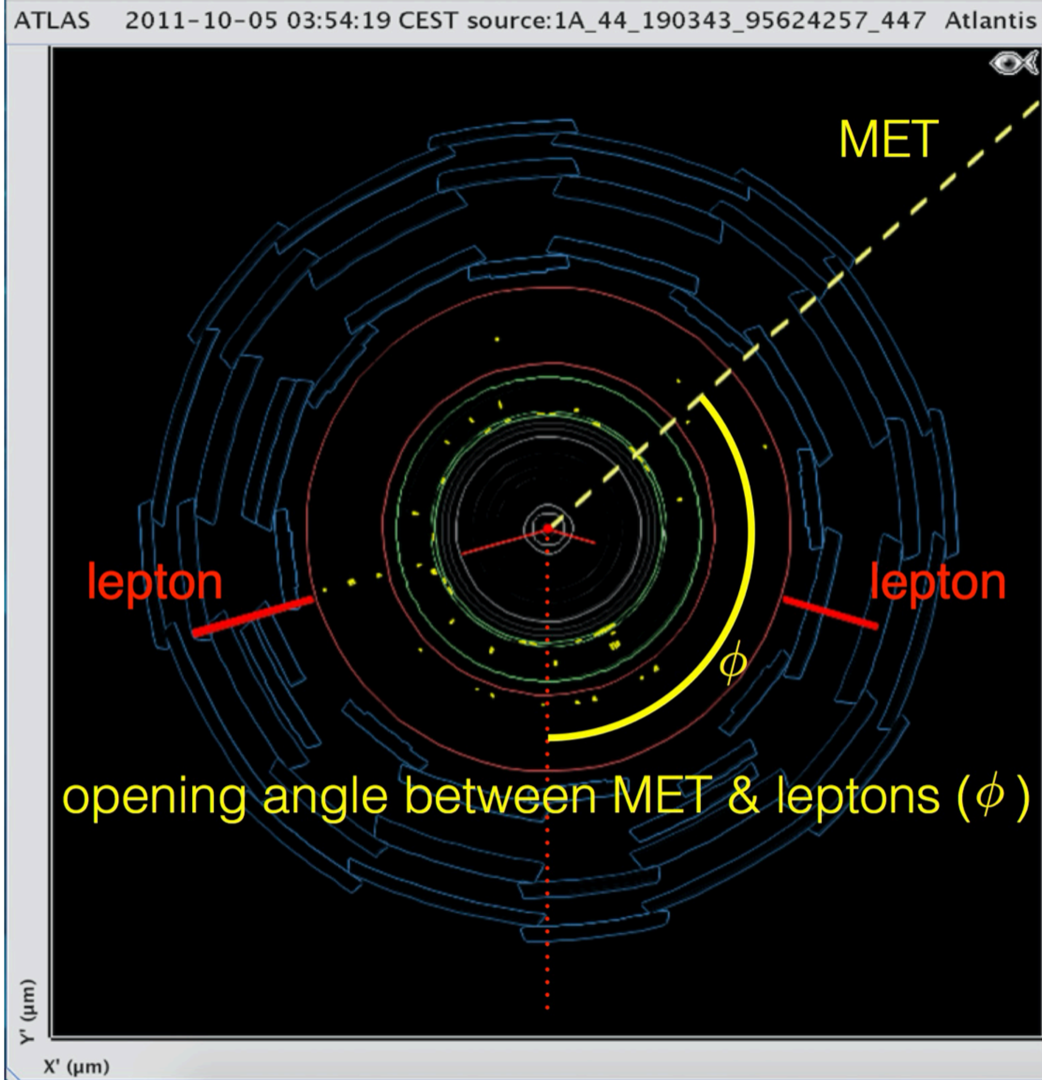

For signal, the two charged leptons have a small opening angle



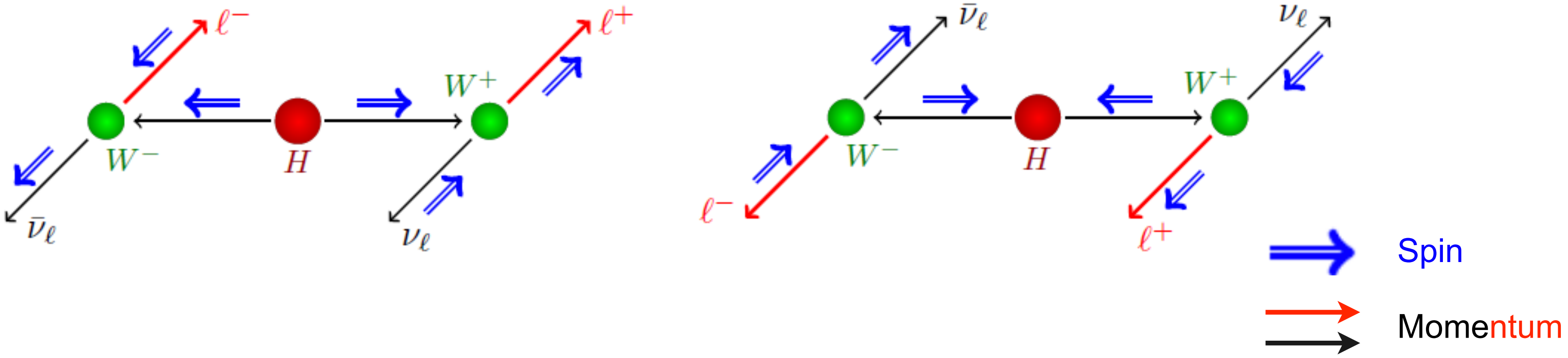
# Opening angle
## MET and leptons




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



# Angular distributions in $H \to W^+W^- \to \ell\nu\ell\nu$




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°

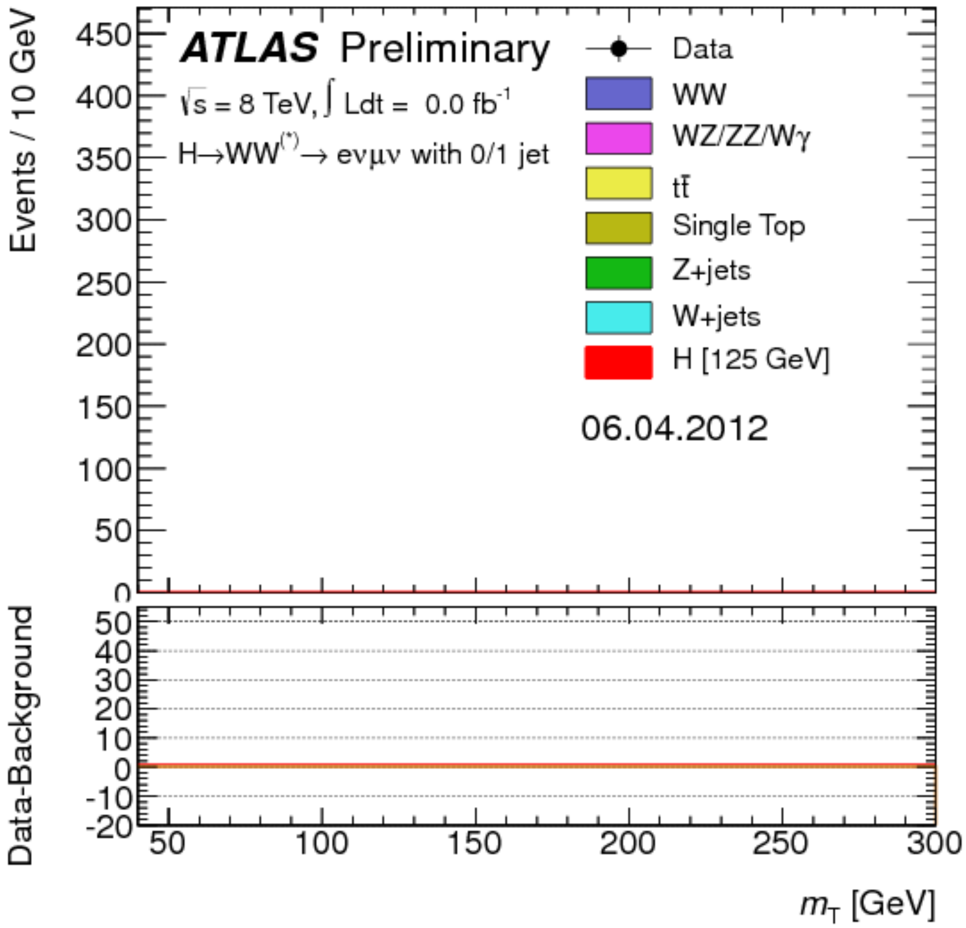
# Higgs or not Higgs?

## The statistical question

$H \to WW^* \to \ell\nu\ell\nu$ was 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



# ACKNOWLEDGEMENTS

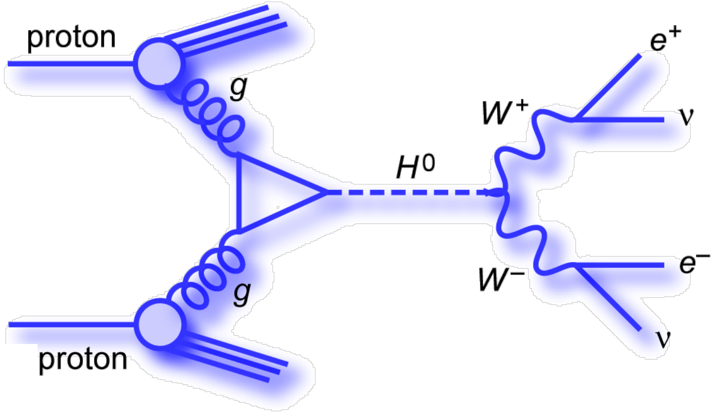
Fundação para a Ciência e a Tecnologia

REPÚBLICA PORTUGUESA

CERN/FIS-PAR/0002/2019

# 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:

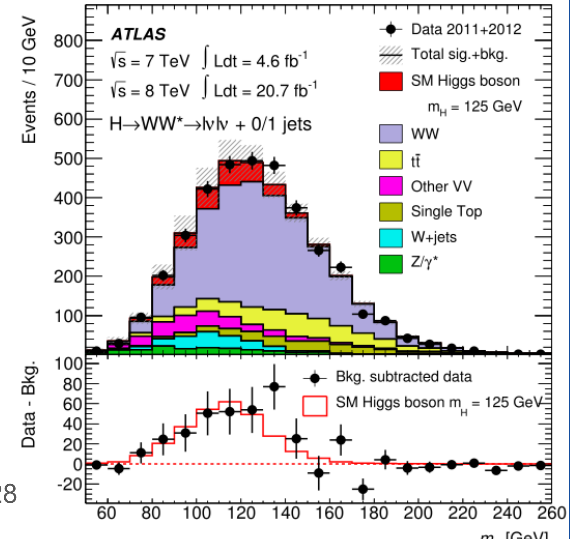
- H→γγ
- H→ZZ*→llll

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



(a)