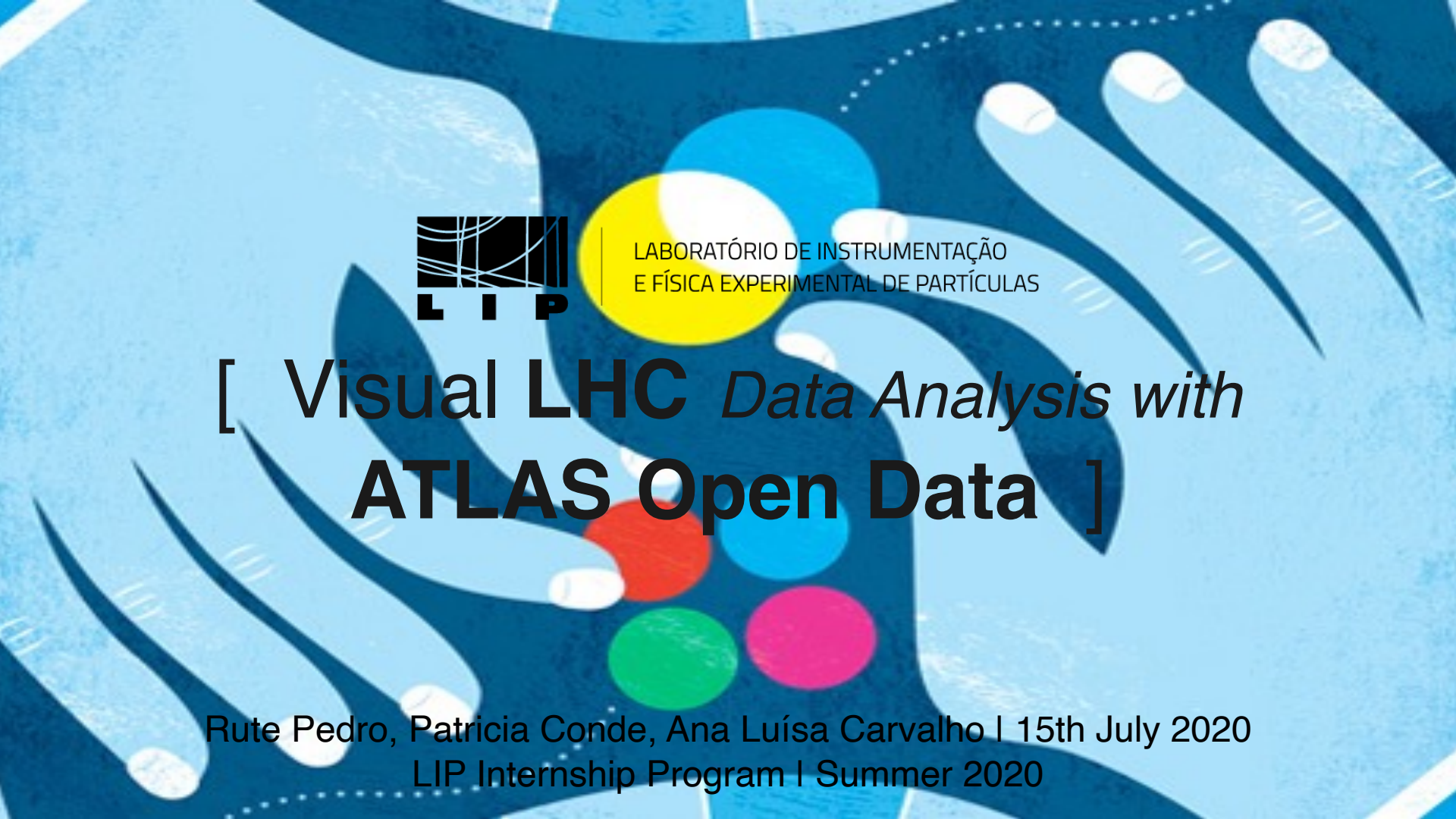
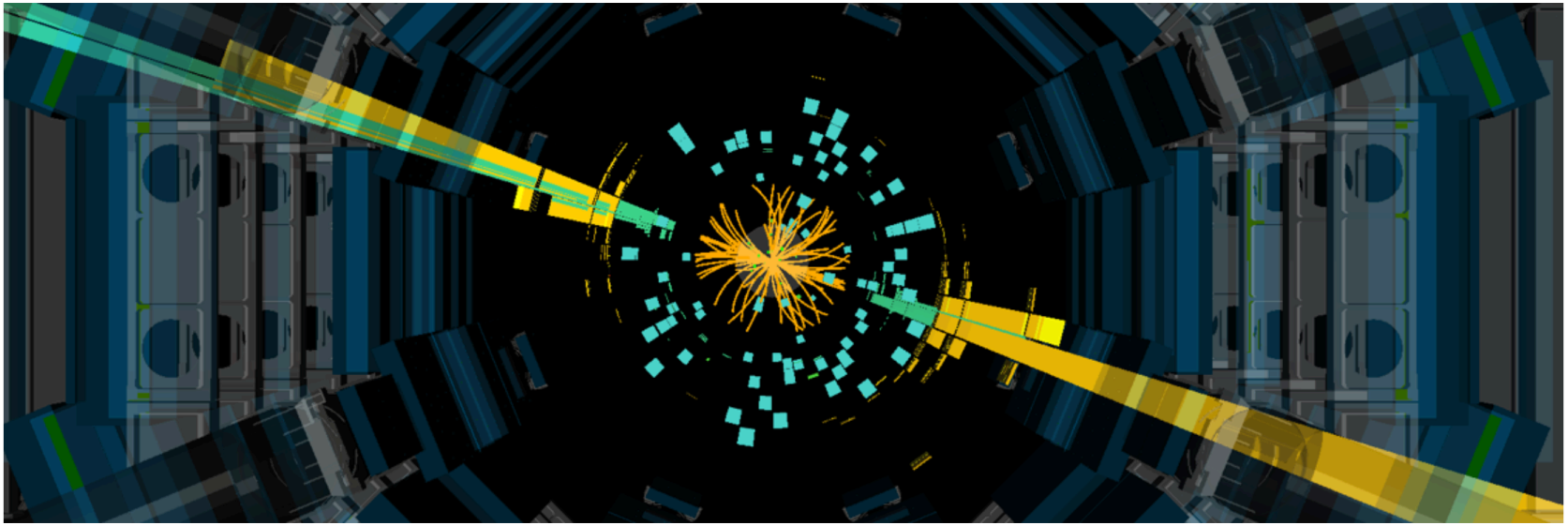

LIP
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
[Visual LHC Data Analysis with
ATLAS Open Data]
Rute Pedro, Patricia Conde, Ana Luísa Carvalho I 15th July 2020
LIP Internship Program I Summer 2020

ATLAS
Open Data

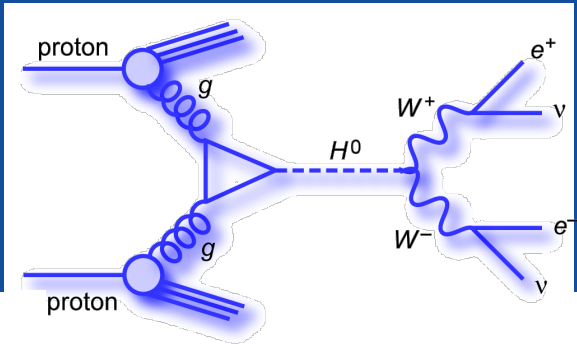
http://atlas.cern/resources/opendata

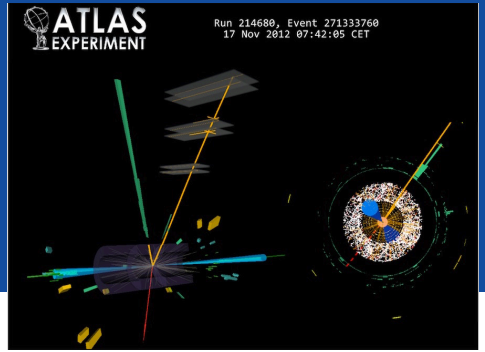


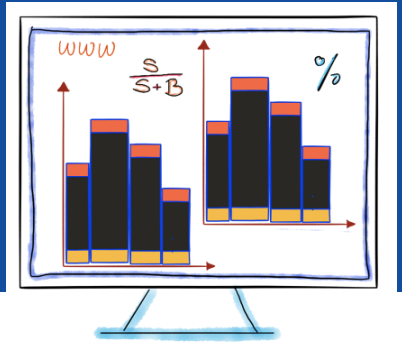
10 fb^{-1} of ATLAS proton-proton collision data is now public!

ATLAS
Open Data - online resources

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?

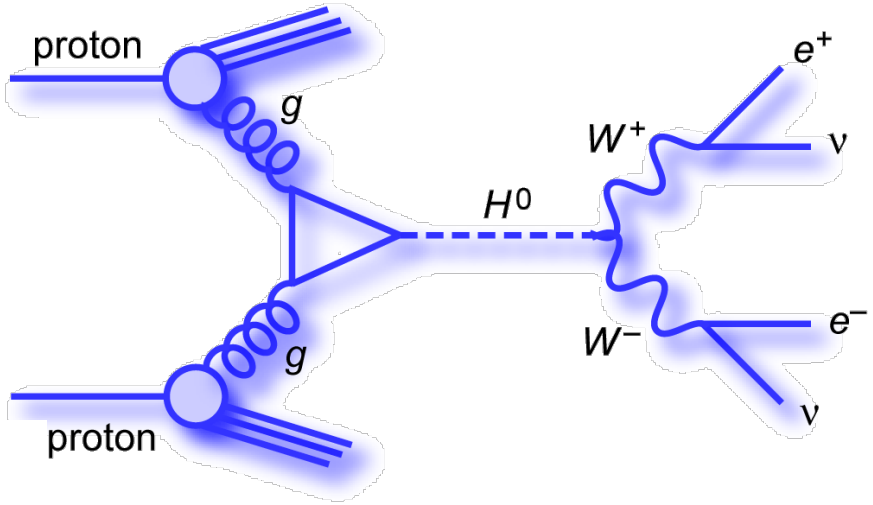
H→WW*→lνlν

Dominant 125 GeV Higgs production through “gluon fusion”
- gg→H

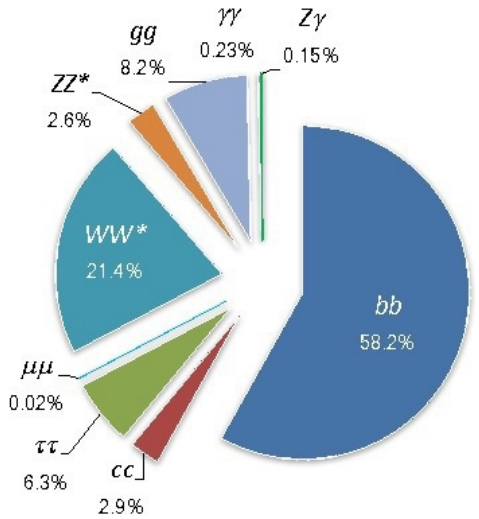
Followed by Higgs decay into W bosons
- H→W⁺W⁻
- ~21% of the times

W bosons are not stable either…

W^+ DECAY MODES		Fraction (Γ_i/Γ)
$\ell^+\nu$	[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



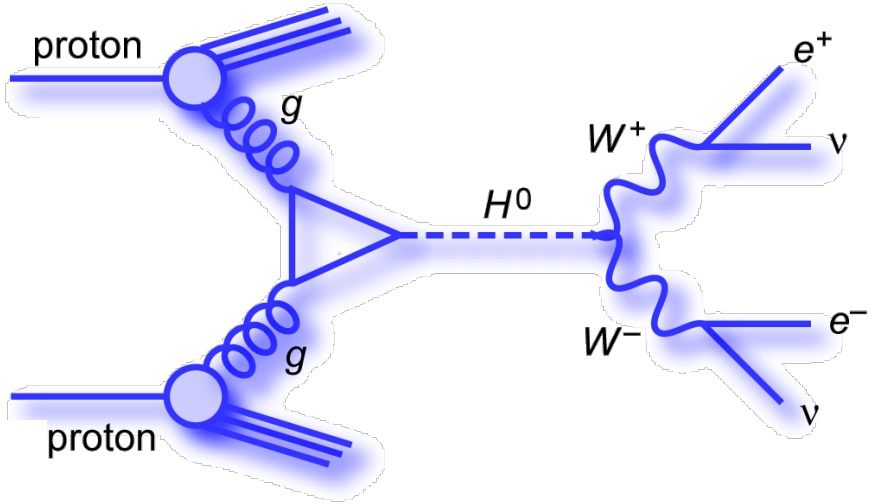
H→WW*→lvlv
Final state particles

2 high momenta leptons

Opposite electrical charge

2 neutrinos

May have jets from quark/gluon hadronisation

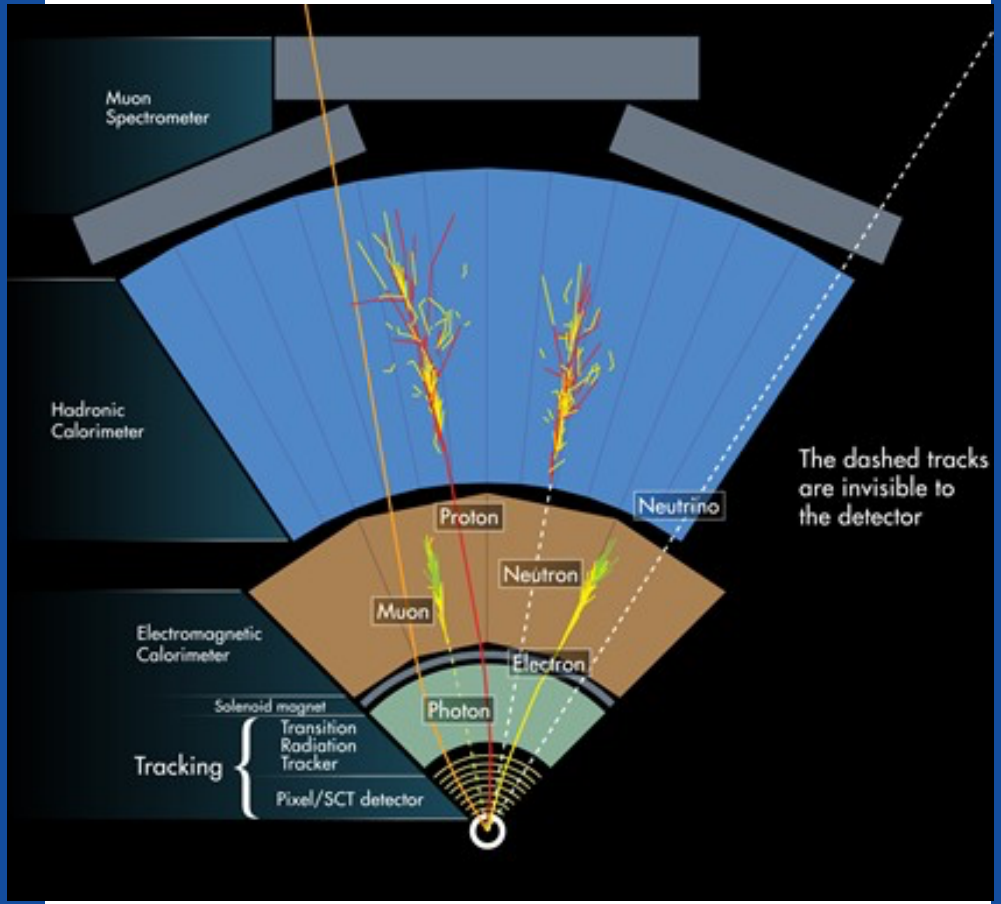


H→WW*→lνlν
In the detector

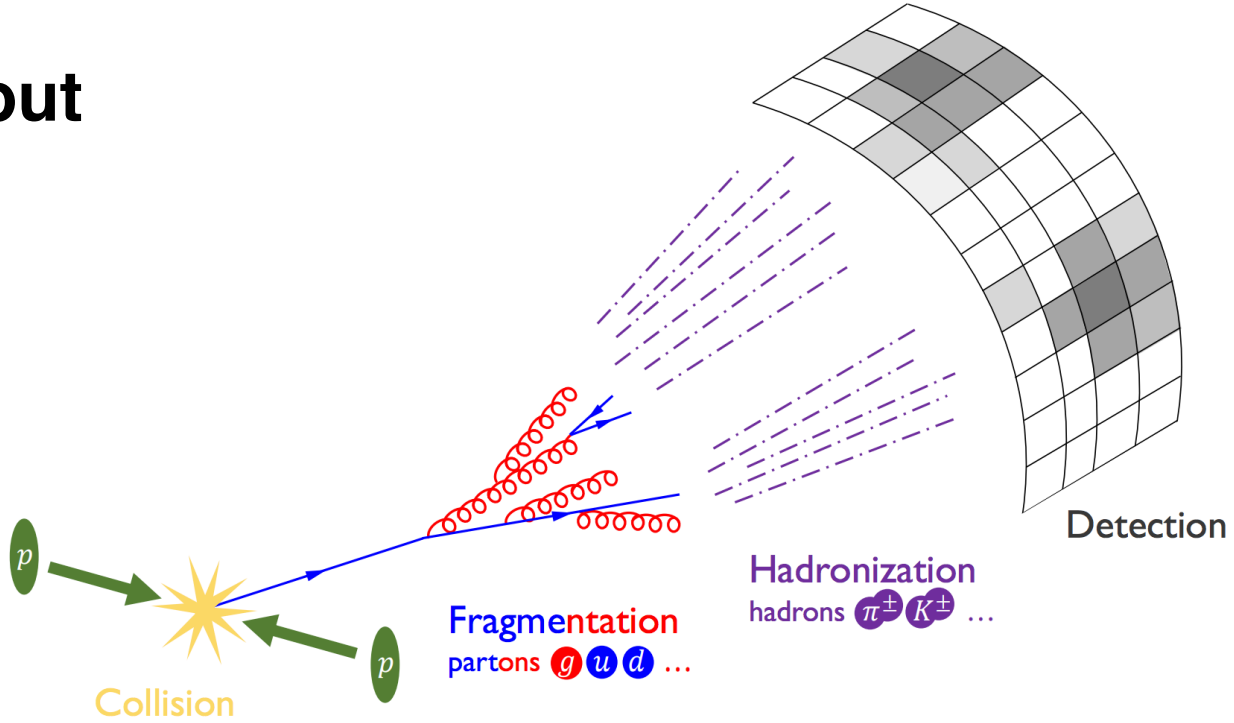
2 high momenta leptons
- Electrons: track + full energy deposit
- Muons: track all through the detector
- Taus: decay inside the beam pipe either to leptons/hadrons

Opposite electrical charge

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

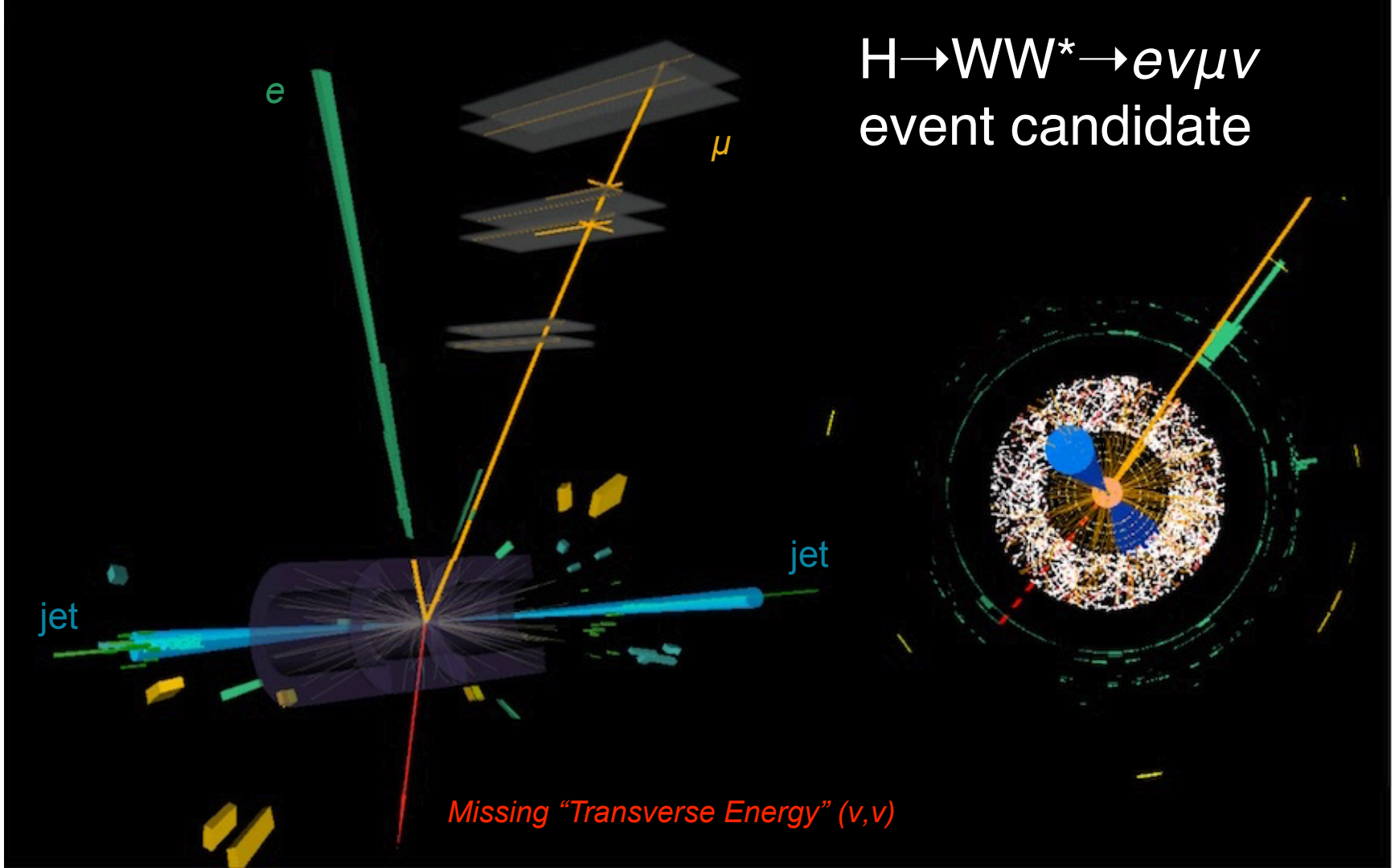


A word about
Jets

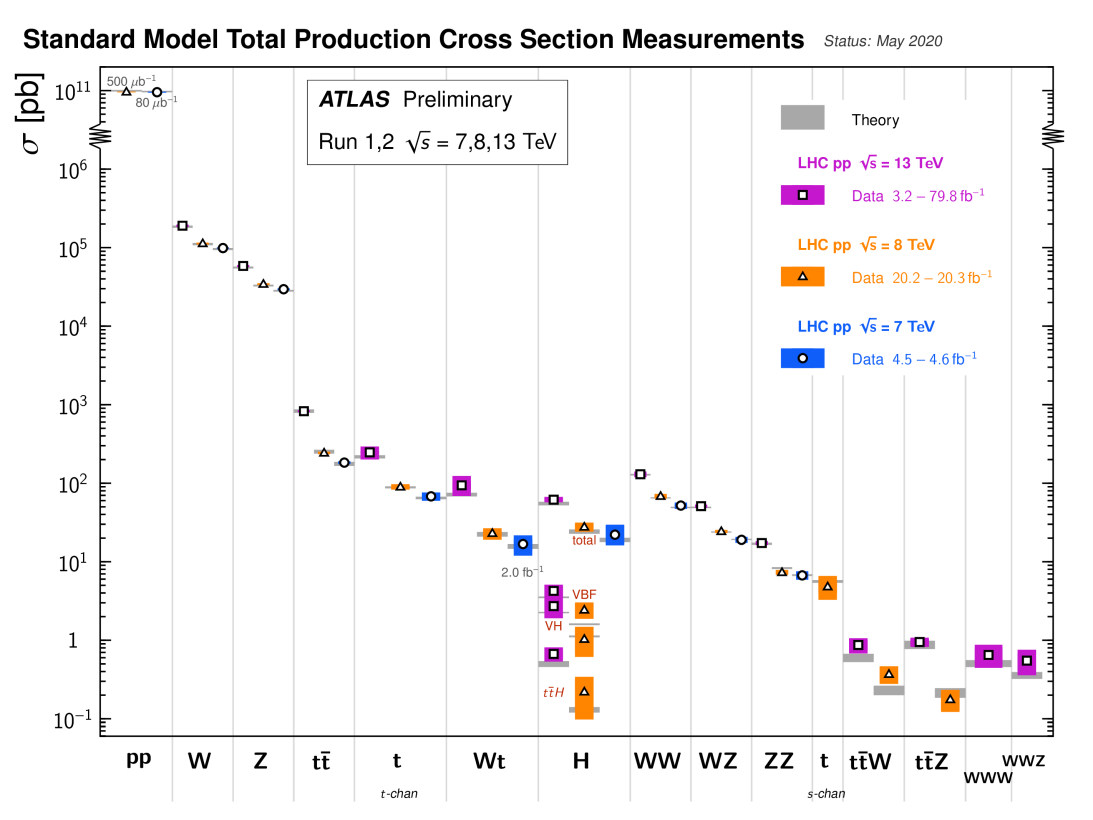


Jets arise from the hadronization of quarks/gluons leading to

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


H→WW*→evμv
event candidate
e
μ
jet
jet
Missing "Transverse Energy" (v,v)

“ Finding a needle in a haystack

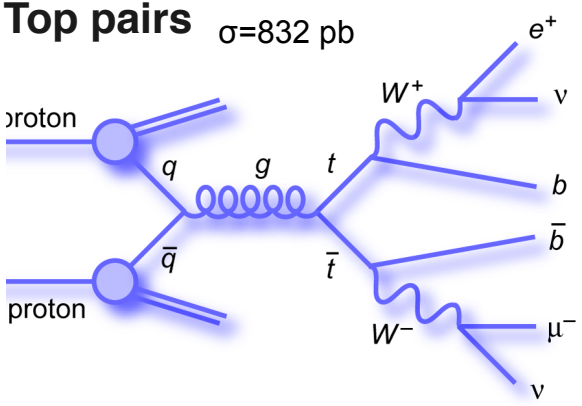


Background processes

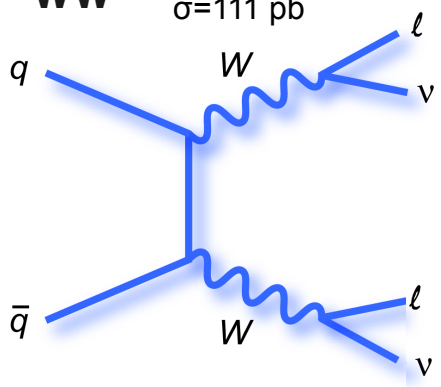
Many other processes have similar final states And they have much larger cross sections

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

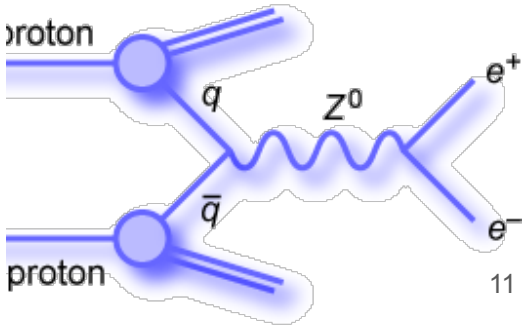
Top pairs σ=832 pb



WW σ=111 pb



Z σ=56.1x 10^3 pb

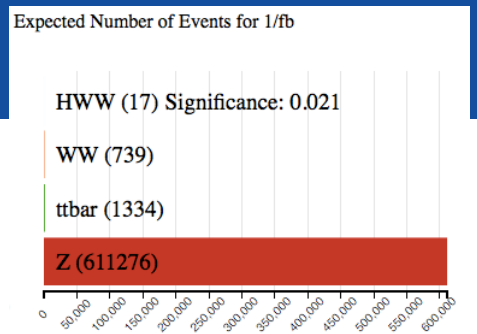


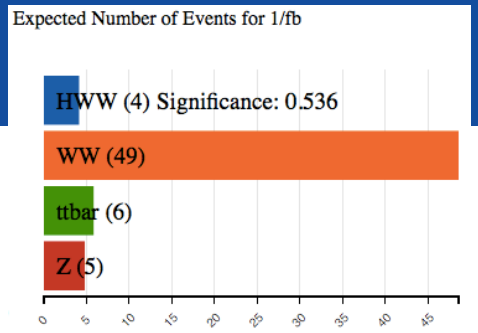
Signal significance

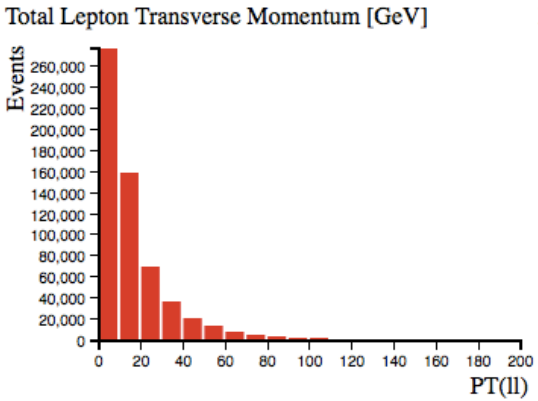
Physicists study how to select events of interest and discard background events => increase sensitivity

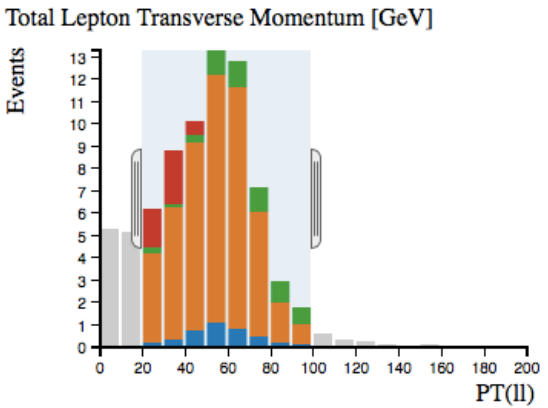
If S is the number of signal events and B the number of background events, the signal significance is:

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







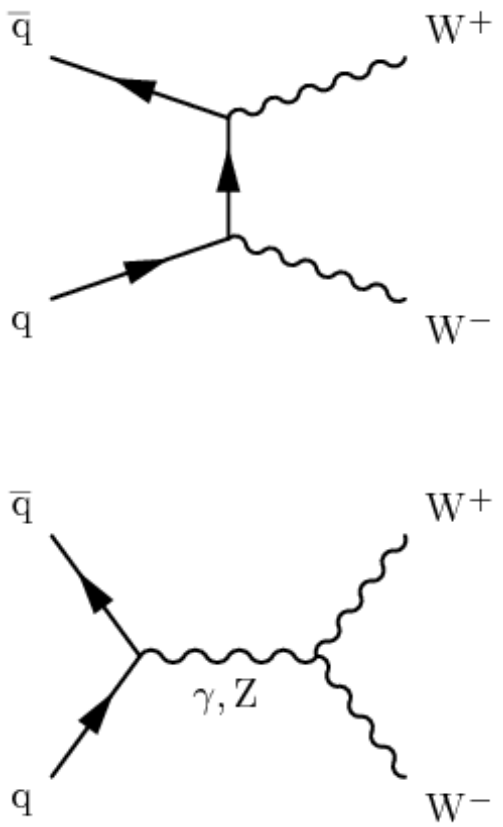


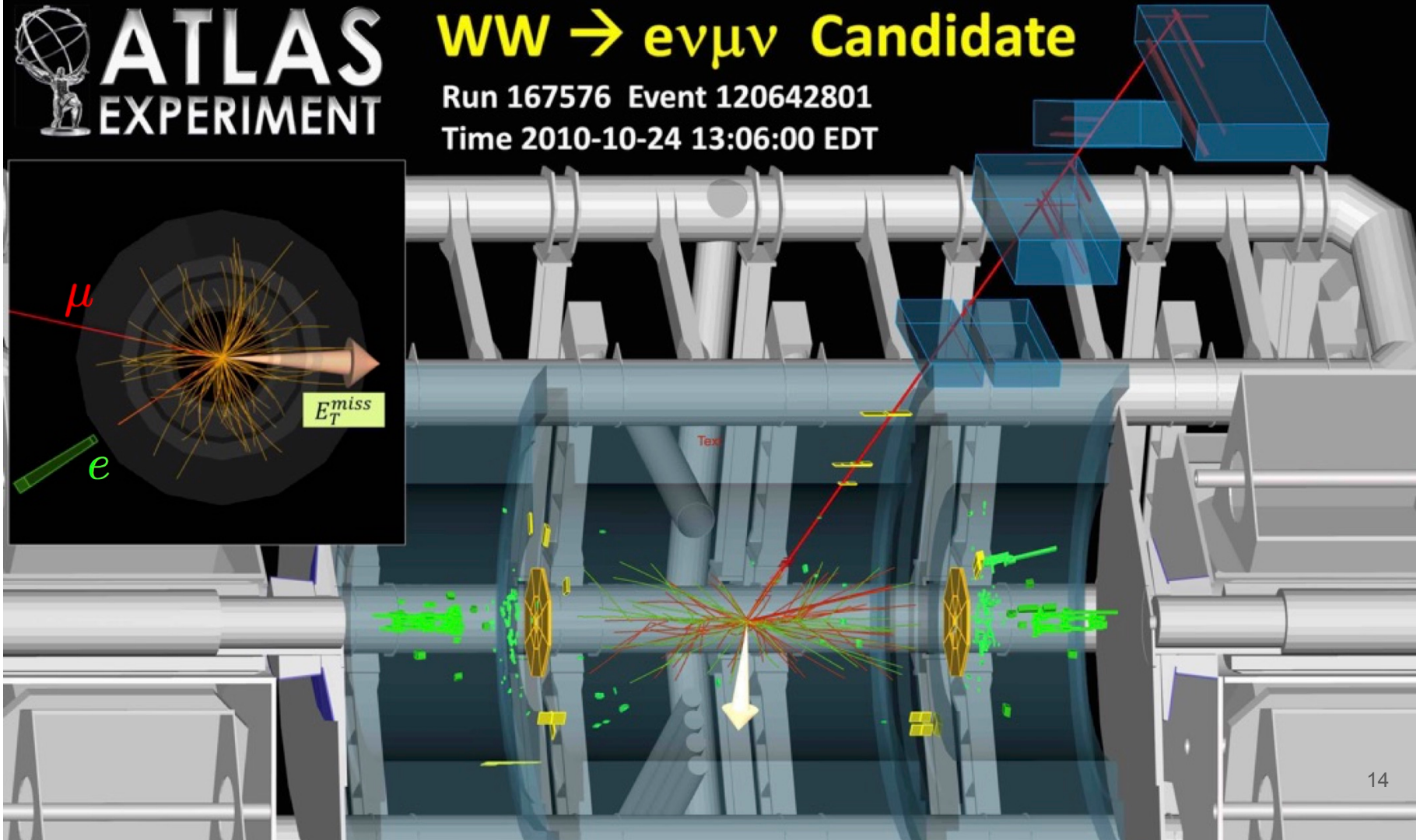
WW background

More than one production mechanism:

- $q\bar{q} \rightarrow W^+W^-$ (dominant)
- $gg \rightarrow W^+W^-$

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

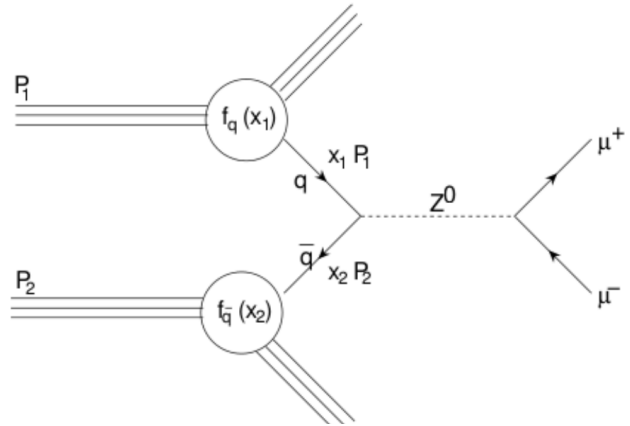
Z background

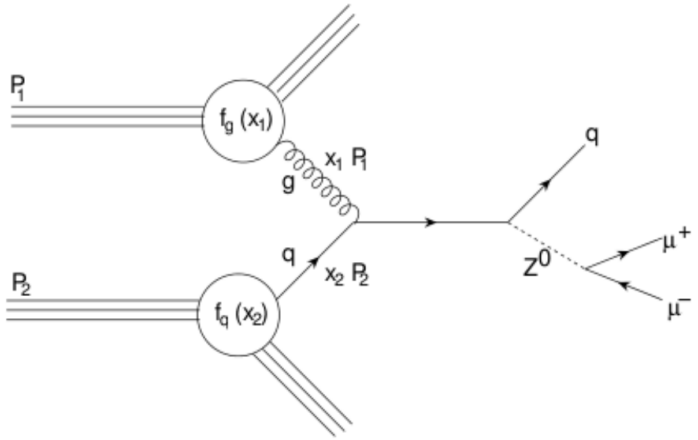
Production:

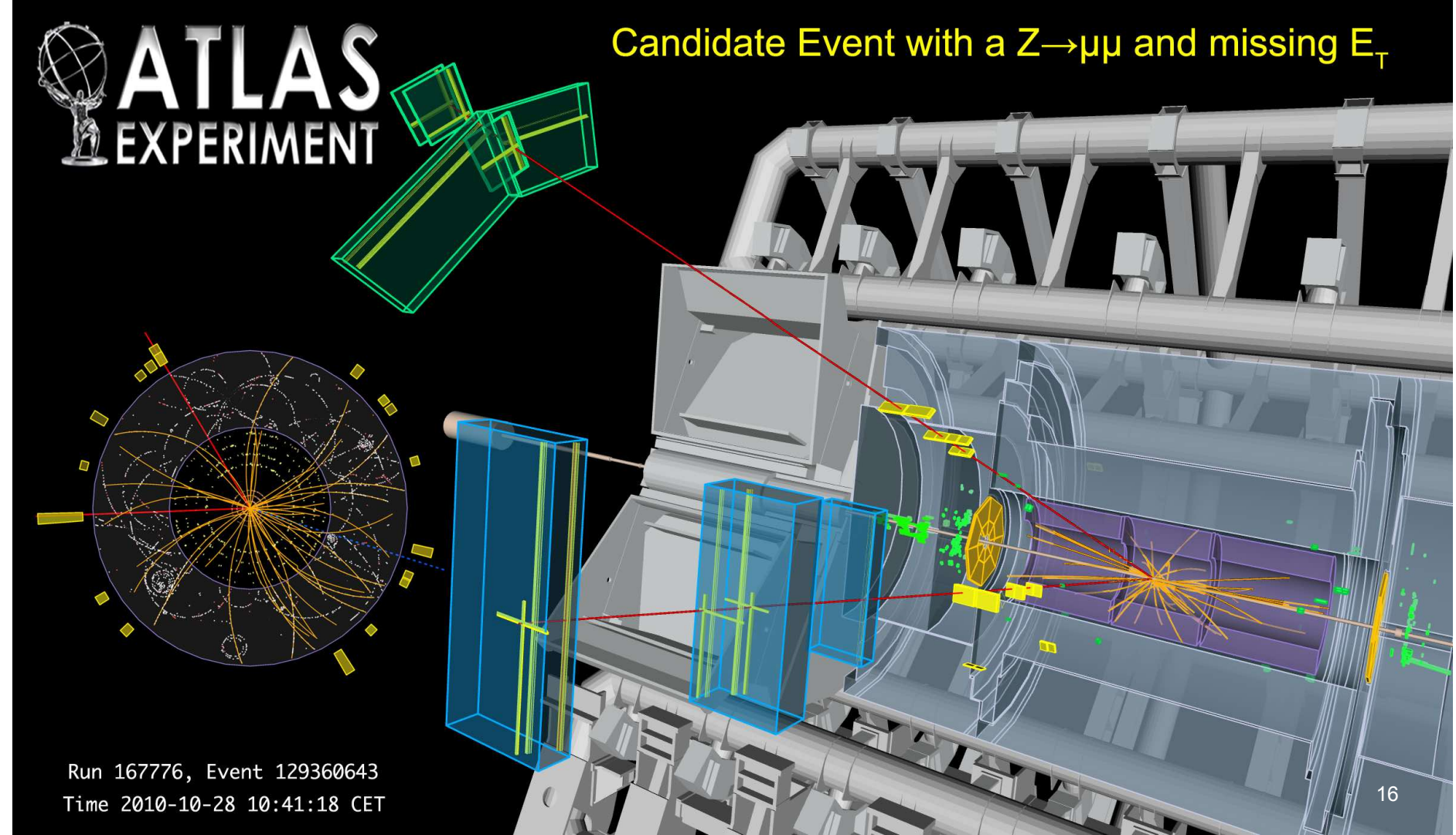
- Drell-Yan q\q→Z (65%)
- qg→Zq (35%)

The Z boson has 0 electric charge an decays to:

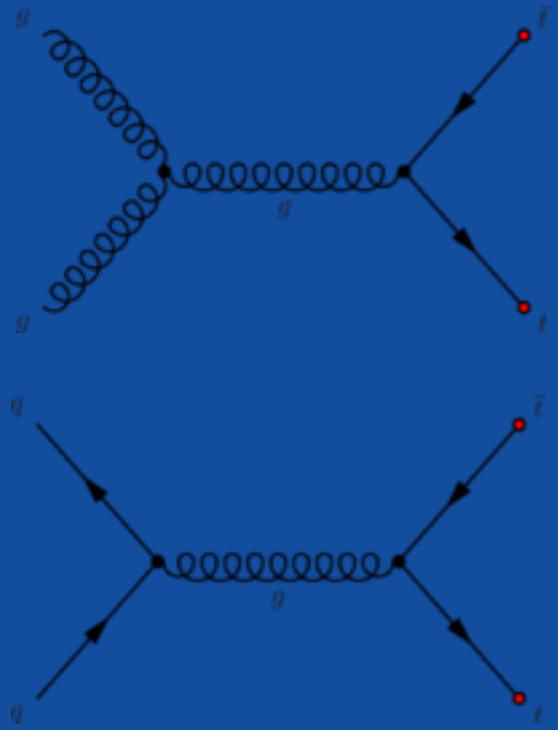
- quark-antiquark pairs (~70%)
- neutrino-antineutrino (~20%)
- same flavour charged lepton pairs (10%)





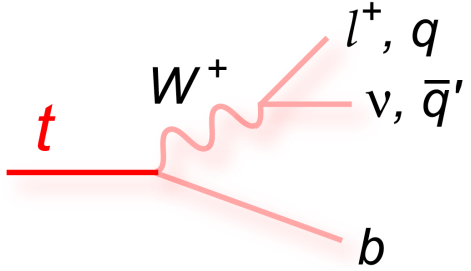

ATLAS
EXPERIMENT
Candidate Event with a Z→μμ and missing E_T
Run 167776, Event 129360643
Time 2010-10-28 10:41:18 CET

Top pairs background

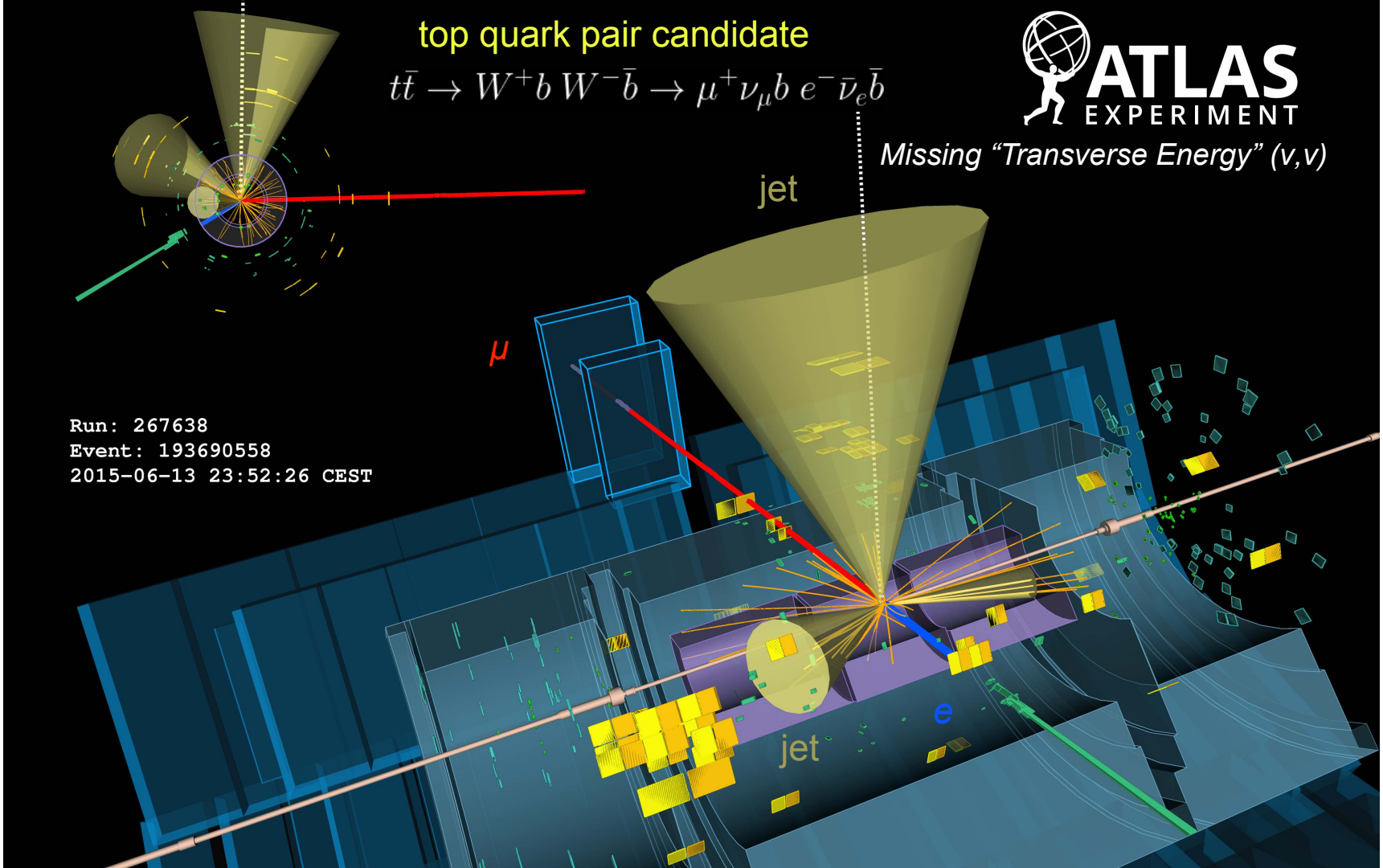


Other quarks hadronize when produced freely

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

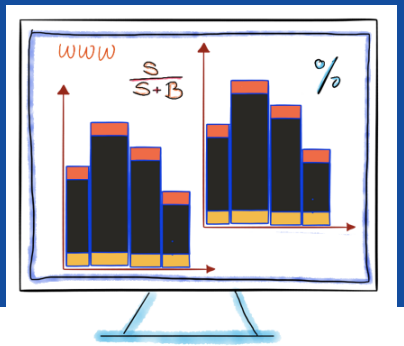


Top pairs have multiple possible final states


top quark pair candidate
$t\bar{t} \to W^+ b\, W^- \bar{b} \to \mu^+ \nu_\mu b\, e^- \bar{\nu}_e \bar{b}$
ATLAS EXPERIMENT
Missing "Transverse Energy" (v,v)
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

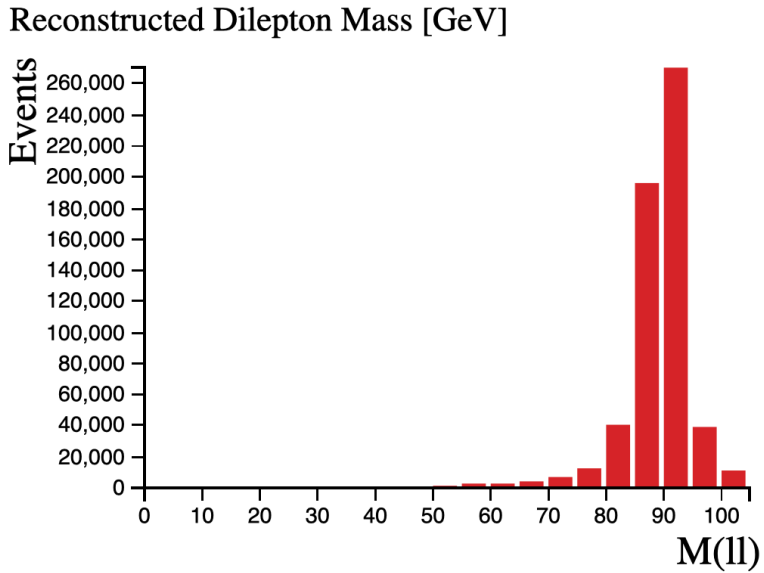


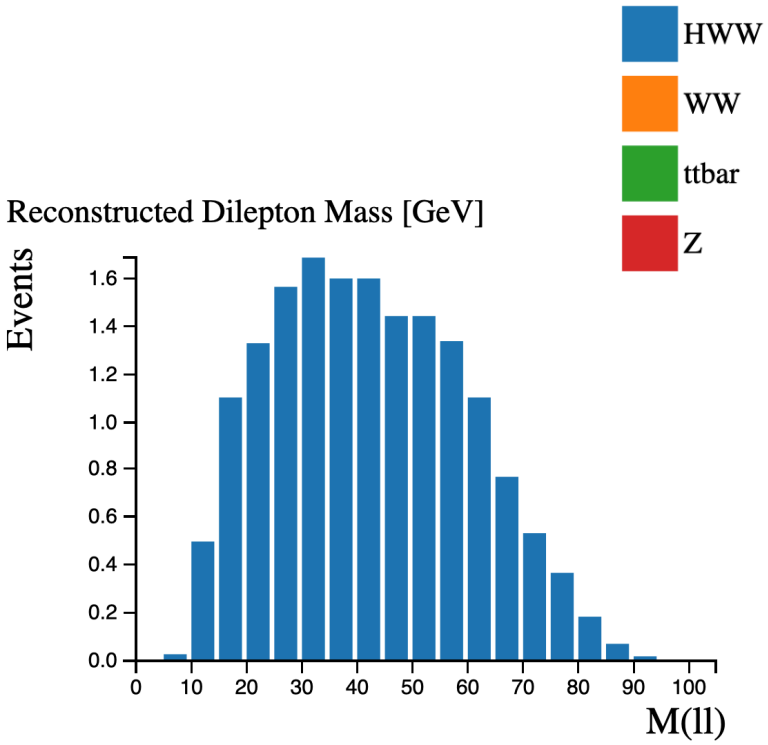
What variables and cuts did you use to select the signal and improve its significance?

Which cut helped you more removing the Z background?

What signal significance did you reach?

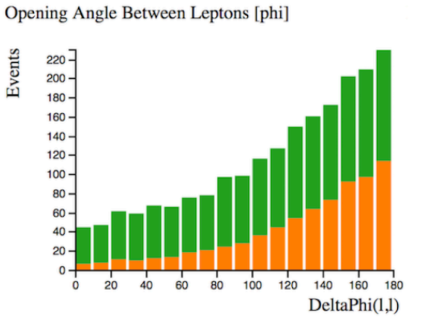
Invariant mass of the charged lepton pair

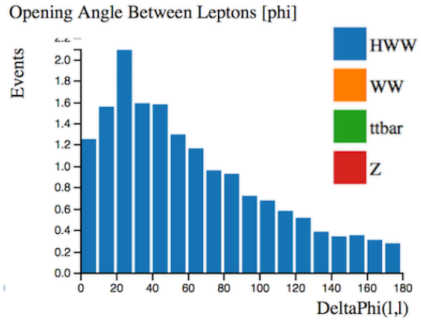




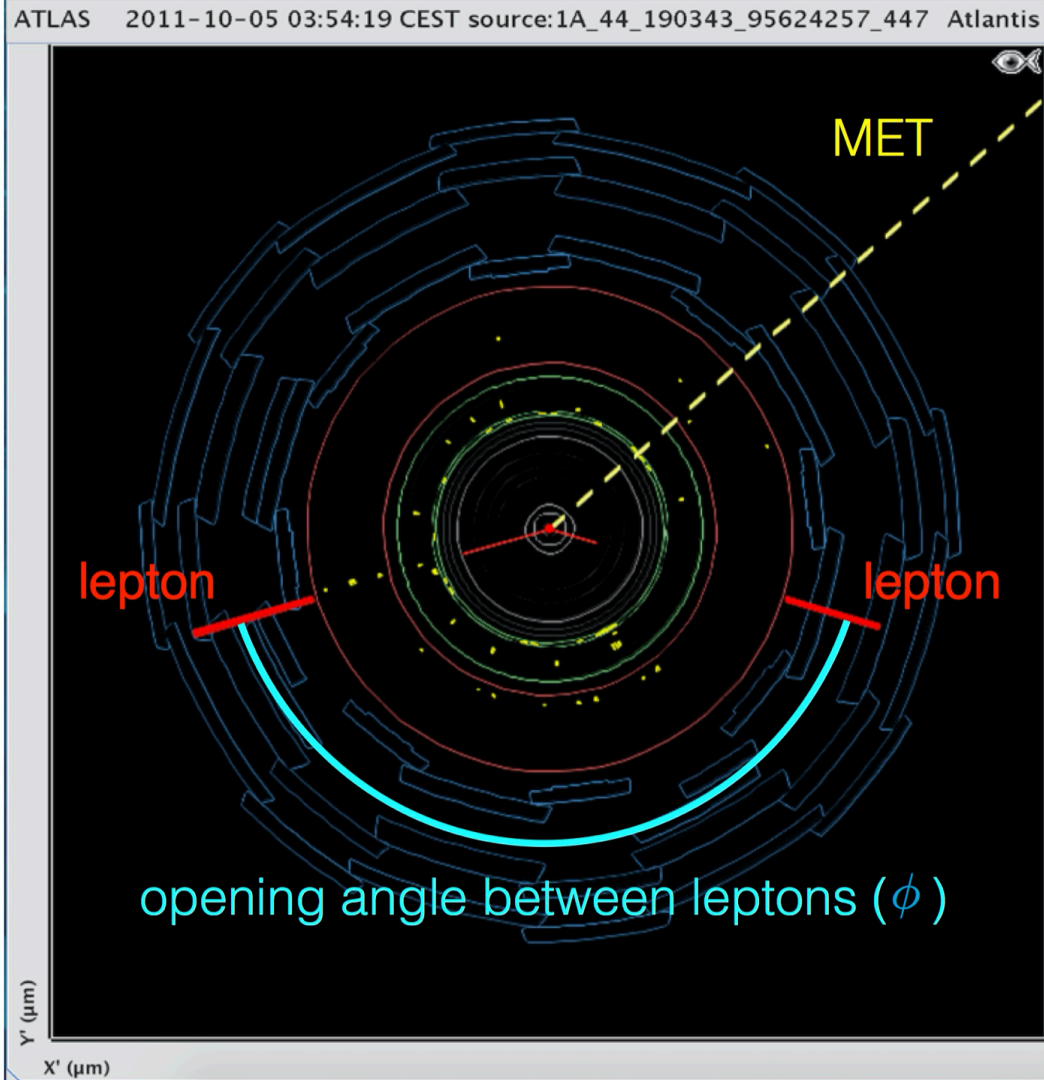
Z mass peak at 90 GeV, reconstructed from the lepton pair system ($Z \rightarrow ll$)

Opening angle between leptons

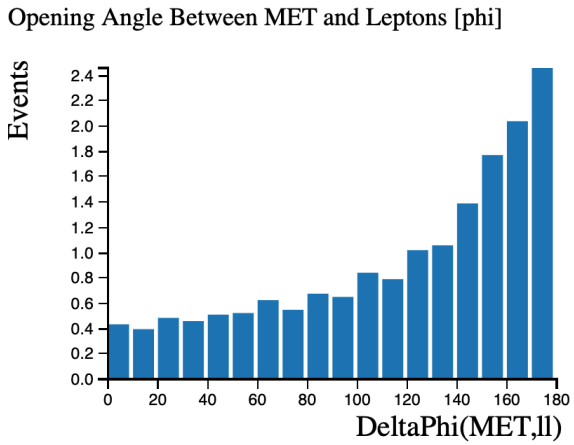




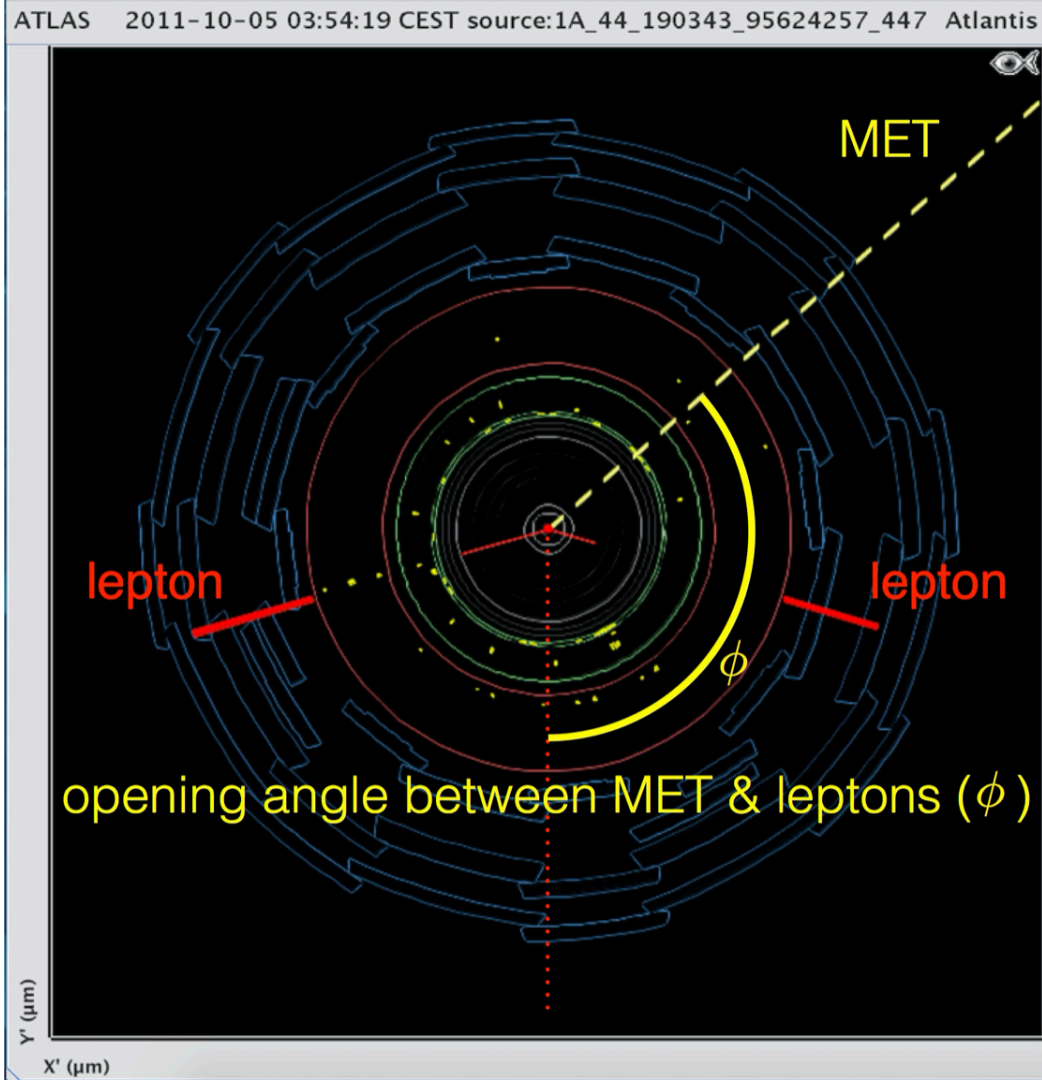
For signal, the two charged leptons have a small opening angle



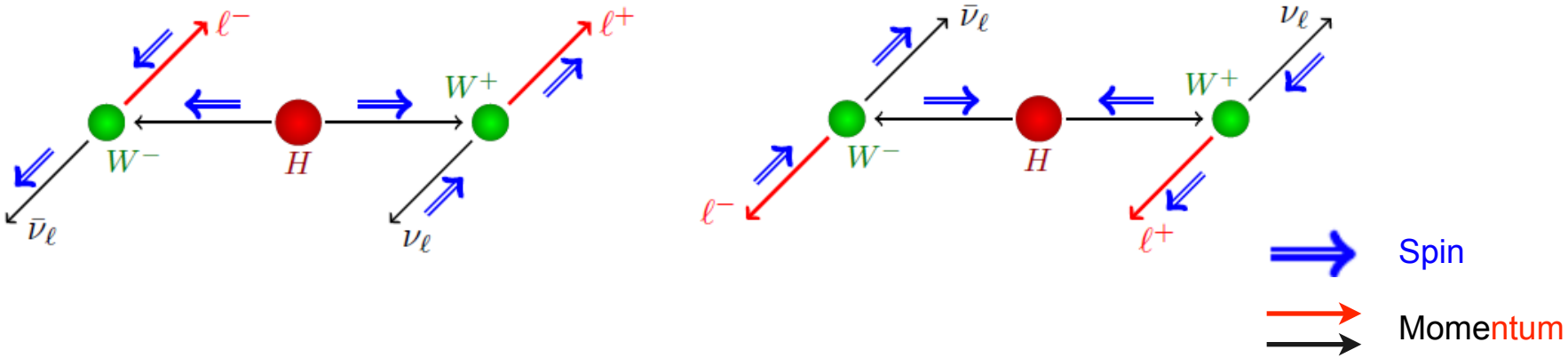
Opening angle
MET and leptons



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



Angular distributions in H→WW*→lνlν



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

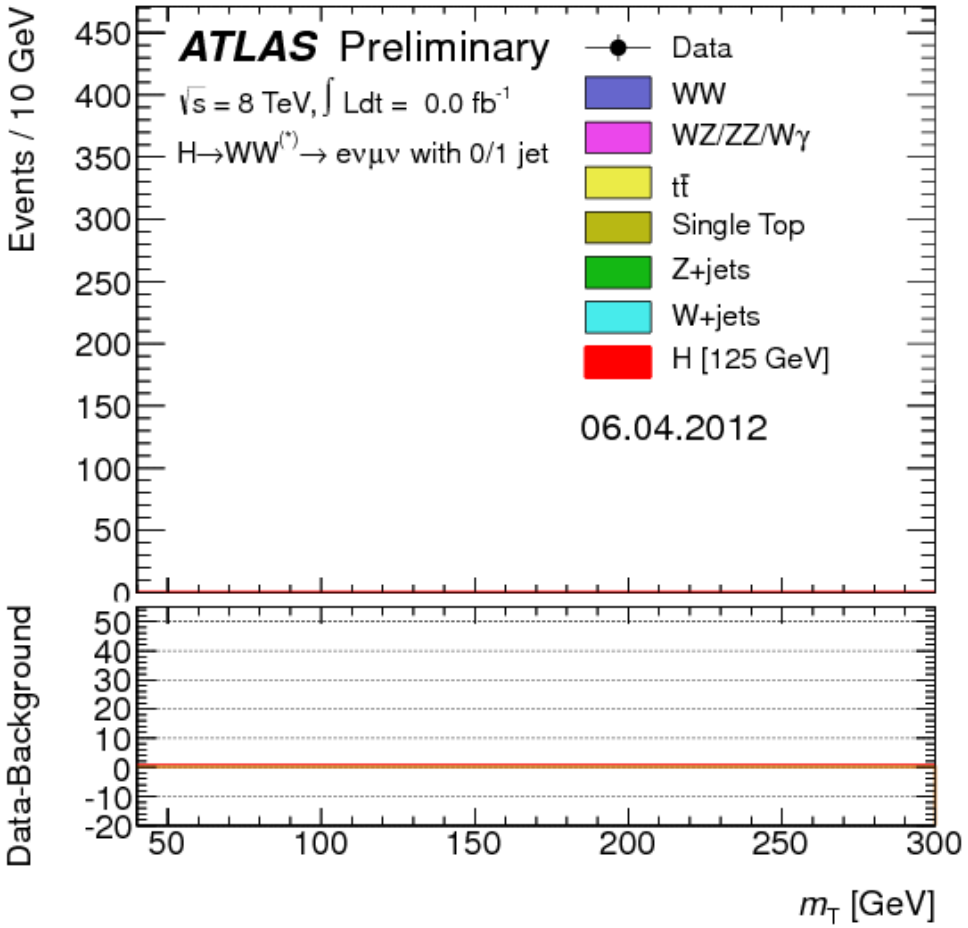
Only left-handed (right-handed) neutrinos (anti-neutrinos) exist, so:
→ the two charged leptons emerge in similar directions
→ the angle between the two charged leptons and the two neutrinos is ~ 180°

Higgs or not Higgs?
The statistical question

H→WW*→lvlv was one of the golden channels of the Higgs discovery in 2012

Not looking at one event…

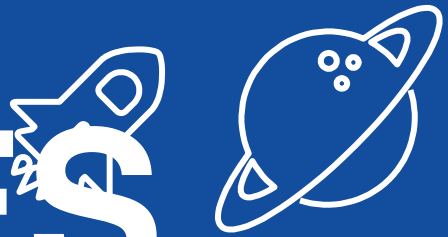
We had to accumulate enough data and compare it to the signal+background expectation



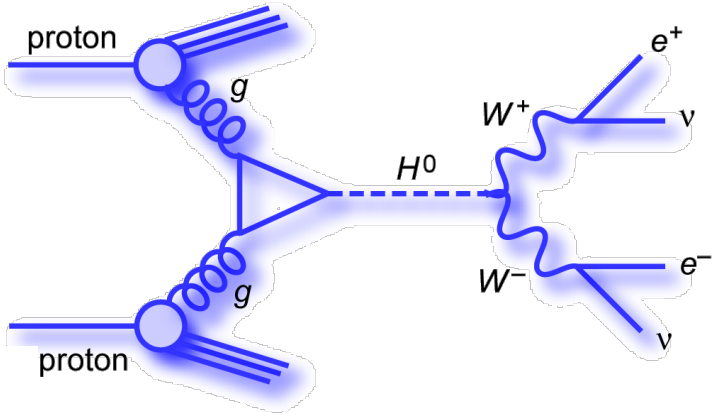
Acknowledgements

POCI/01-0145-FEDER-029147 PTDC/FIS-PAR/29147/2017

EXTRA SLIDES



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



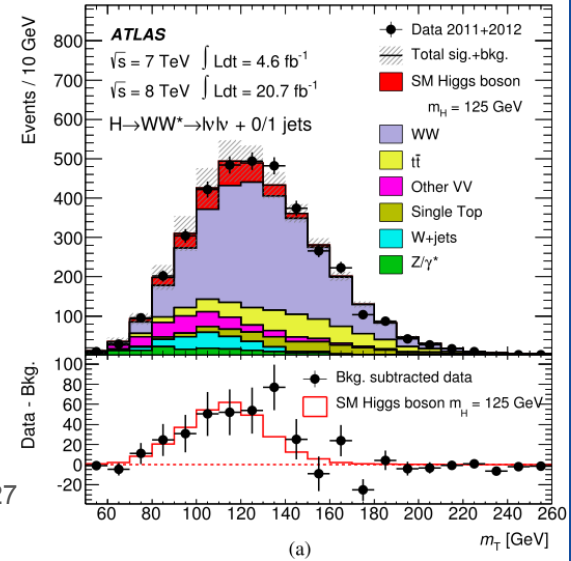
H→WW*→lνlν was one of the golden channels of the Higgs discovery in 2012

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