Helena Santos, João Gentil (LIP & FCUL)
Estágios de Verão
Julho 2018

http://opendata.atlas.cern/

ATLAS Open Data

Data of pp collisions @ 8 TeV shared with public

open data ATLAS

Get Started
Documentation, Histogram Analyser, ROOTbrowser

Web Analysis
Documentation, Online ROOTbooks

Data & Tools
Documentation, Datasets, Software, Virtual Machines

Access Open Data from the ATLAS Experiment at CERN

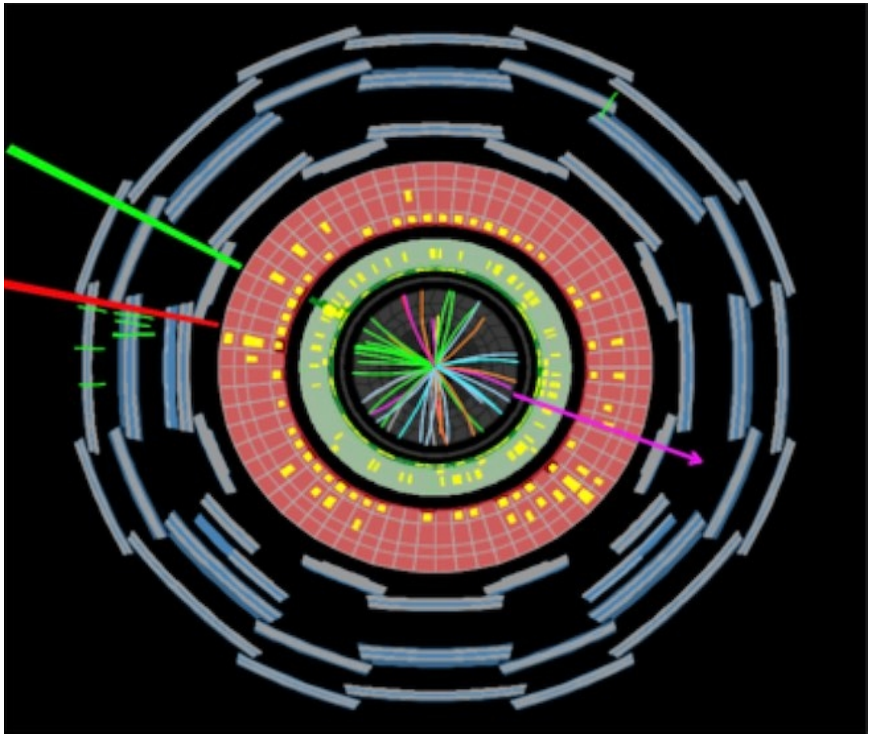
The ATLAS data from 100 trillion proton collisions is now public! This marks the world's first open release of 8 TeV data, gathered from the Large Hadron Collider in 2012.

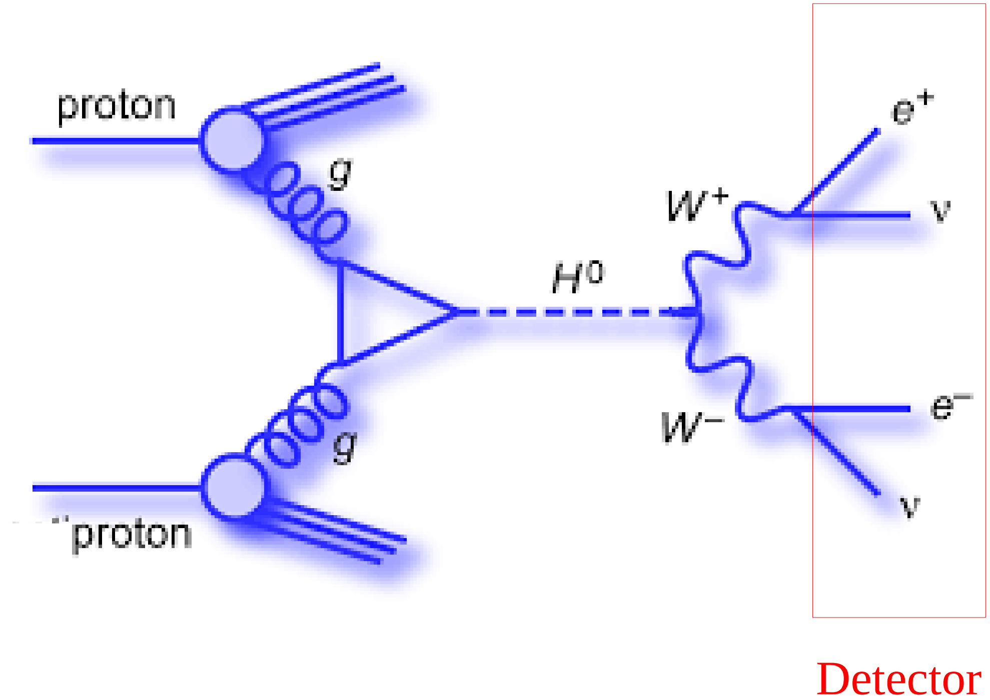
ATLAS Open Data guides you through how to visualise the data, how to download and use the data, and even provides open-source software for you to make your own discoveries. **Check the introductory video and get started now!**

$H \rightarrow W^+W^- \rightarrow l^+l^-\nu\bar{\nu}$ study

Goal of this exercise: understand the role of the kinematic variables

$H \rightarrow W^+W^- \rightarrow l^+l^-\nu\bar{\nu}$ (l = electron or muon)

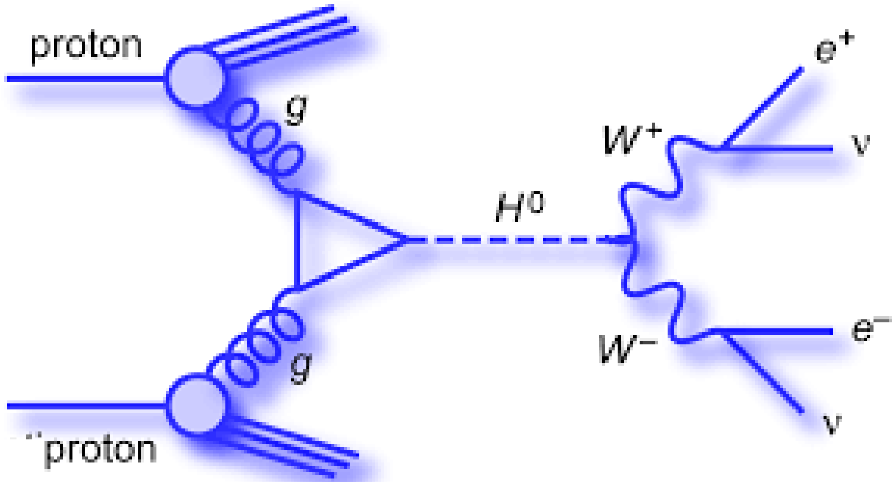




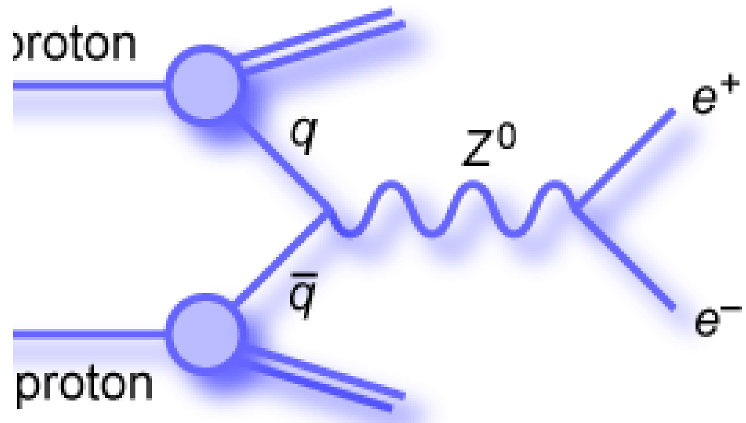
- **Higgs boson**, with mass 125 GeV, decays to a pair of W bosons in 23% of the cases.
- **Main backgrounds:** ttbar production, WW and Z+jets. All these processes contain **2 high p_T isolated leptons** that **mimic** the **signal**.
- The **isolation** is important as suggests where the **lepton** originates. Leptons from Z or W decays (or taus) are generally isolated, on the contrary to leptons that originate in b or c quarks (leptons inside jets).

Signal and backgrounds

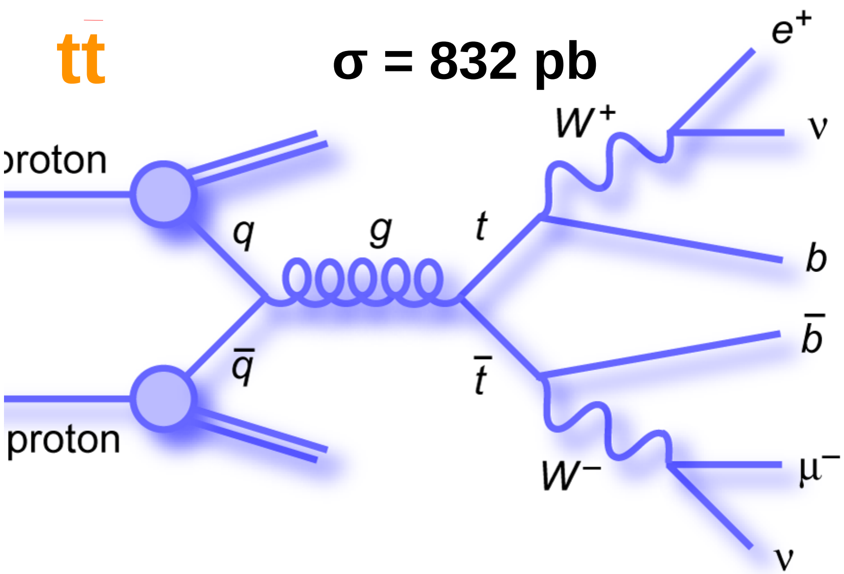
$H \rightarrow W^+W^-$ σ = 9.35 pb



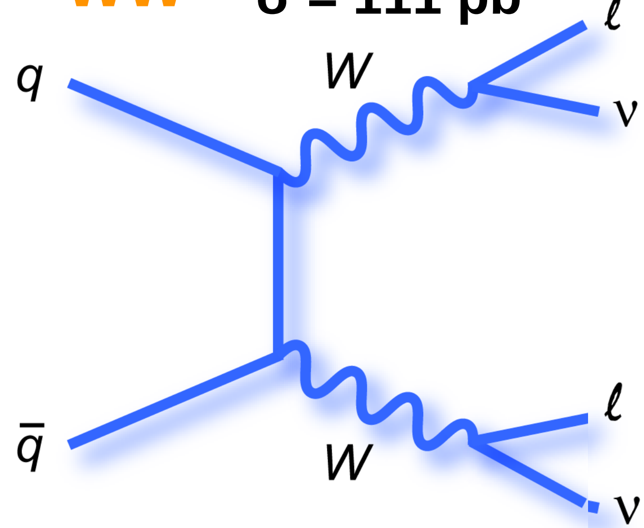
Z σ = 56.1x 10^3 pb

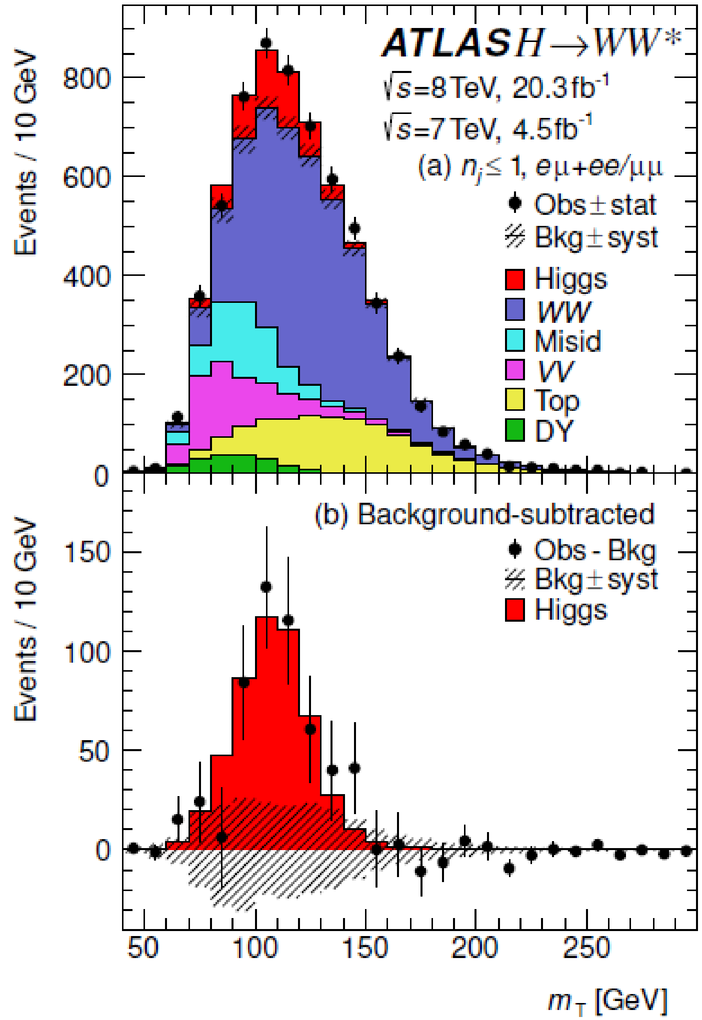


tt σ = 832 pb



WW σ = 111 pb

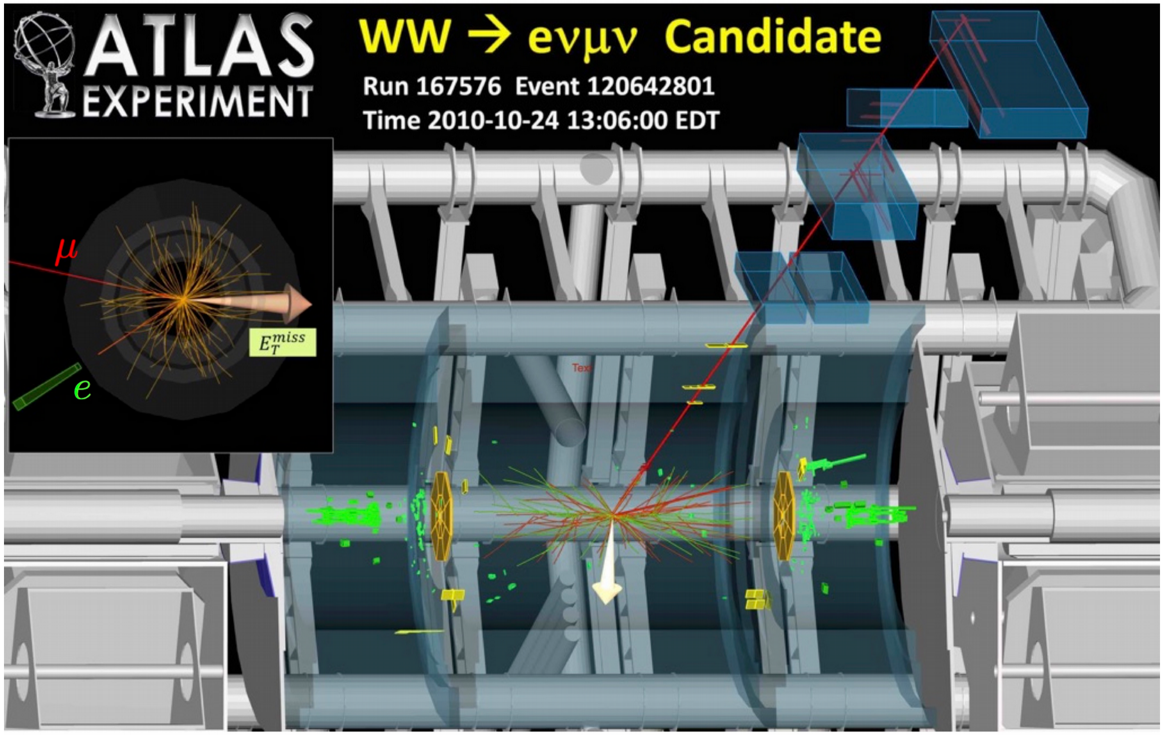


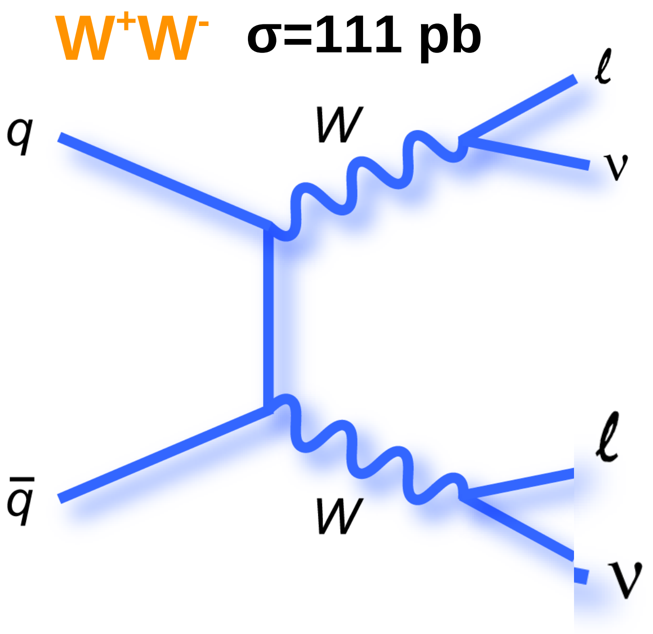


'IG. 35. Postfit combined transverse mass distributions 'or $n_j \leq 1$ and for all lepton-flavor samples in the 7 and 3 TeV data analyses. The plot in (b) shows the residuals of the data with respect to the estimated background com- pared to the expected distribution for an SM Higgs boson vith $m_H = 125$ GeV; the error bars on the data are statisti- cal ($\sqrt{N_{\rm obs}}$). The uncertainty on the background (shown as he shaded band around 0) is at most about 25 events per m_T bin and partially correlated between bins. Background processes are scaled by postfit normalization factors and the signal processes by the observed signal strength μ from the likelihood fit to all regions. Their normalizations also include effects from the pulls of the nuisance parameters.

Background from W^+W^-

W boson can decay leptonically or hadronically. In the latter case in a qqbar pair originating 2 jets.



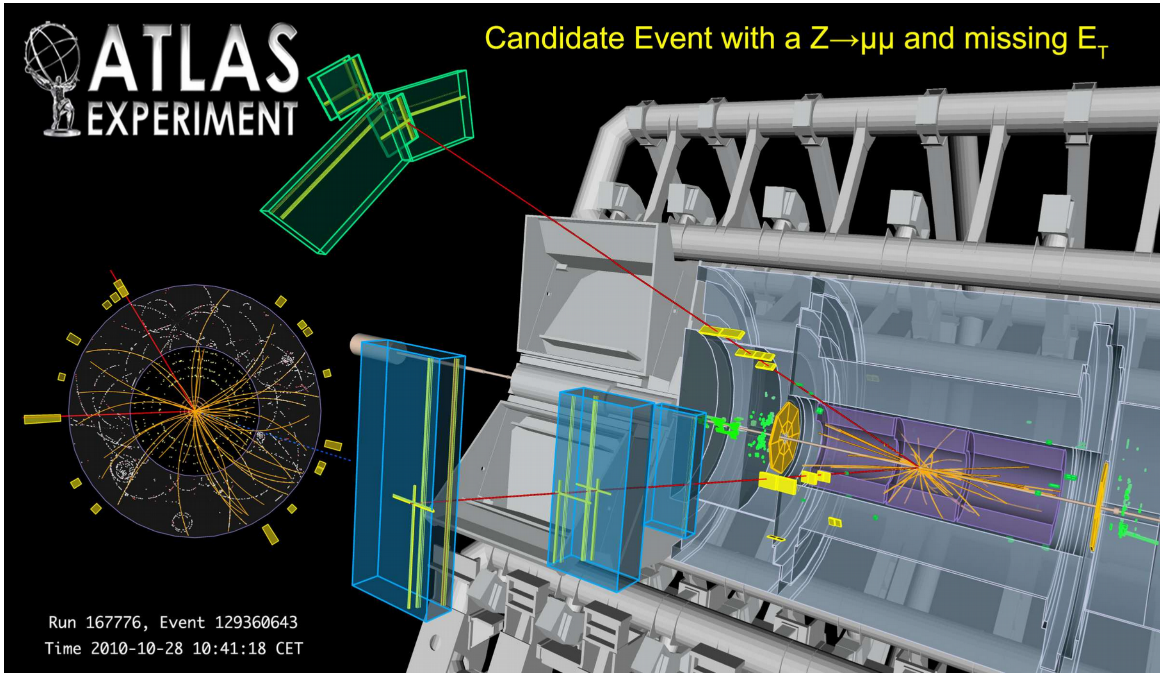


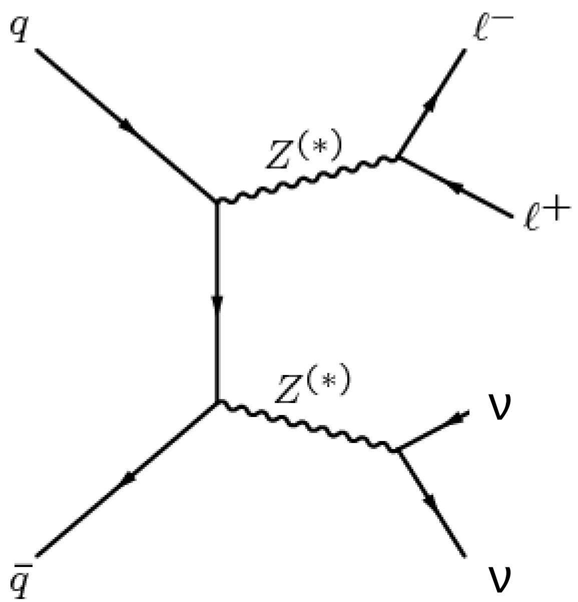
electron p_T (green): 21 GeV; muon p_T (red): 68 GeV;
MET(arrow): 69 GeV

The leptonic decay case constitutes an irreducible background in Higgs studies, but they are very important *per se*, as they test the Standard Model and play a role in new physics searches.

Background from Z

Z candidate decaying in a muon pair. MET is very high (MET) – 161 GeV, probably it is a double Z event with the other one decaying in a neutrino-antineutrino pair.





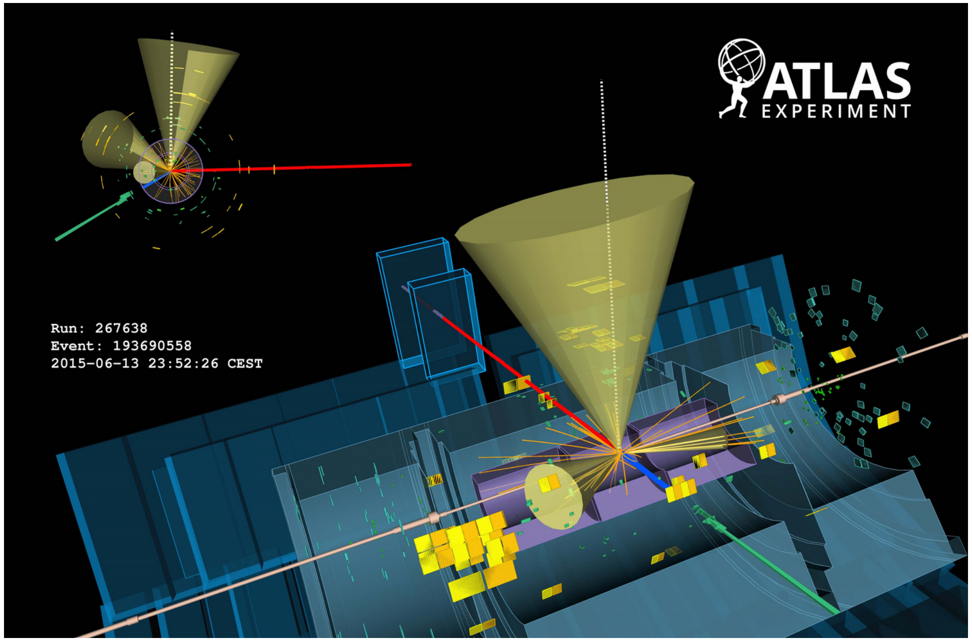
Muons have p_T of 50 and 126 GeV.

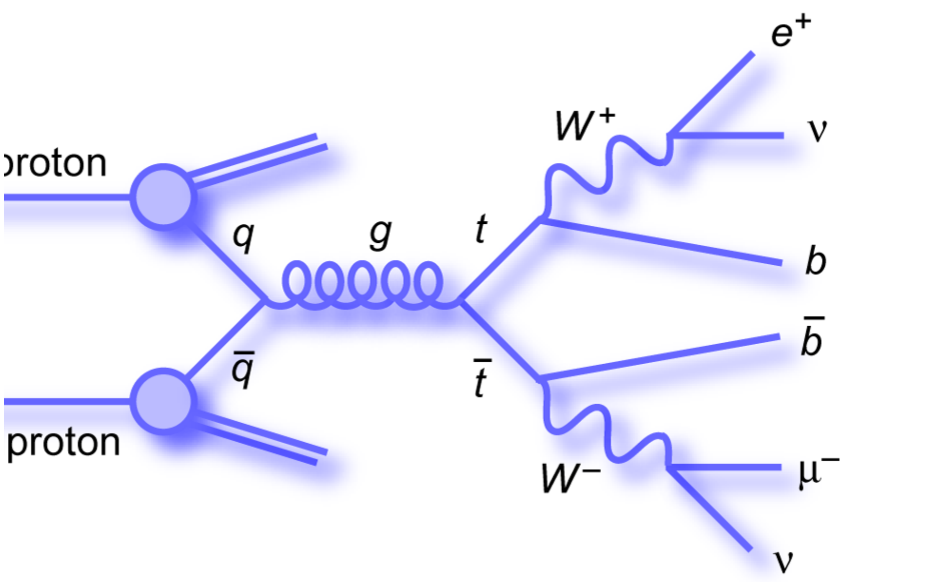
Its invariant mass is a 94 GeV.

Background from $t\bar{t}$

Top quark dacays to W boson and a *b*-quark in 99.8% of the cases.

- **If both W decay leptonically, 2 leptons + MET + 2 jets will be observed;**





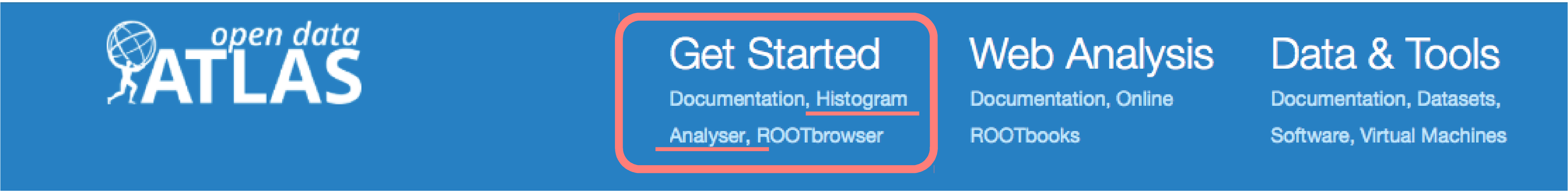
ttbar event candidate.

muon (red) $p_T \approx 140$ GeV.

electron (green) $p_T \approx 170$ GeV.

Yellow rectangles represent energy deposited in the calorimeters. From these deposits 3 jets are reconstructed, two of them are identified as originating in b-quarks.

Histogram analyser



atlas-opendata.web.cern.ch/atlas-opendata/

- Which cuts in the kinematic variables should we apply to select signal events?

- **Data selection in the real analysis:**

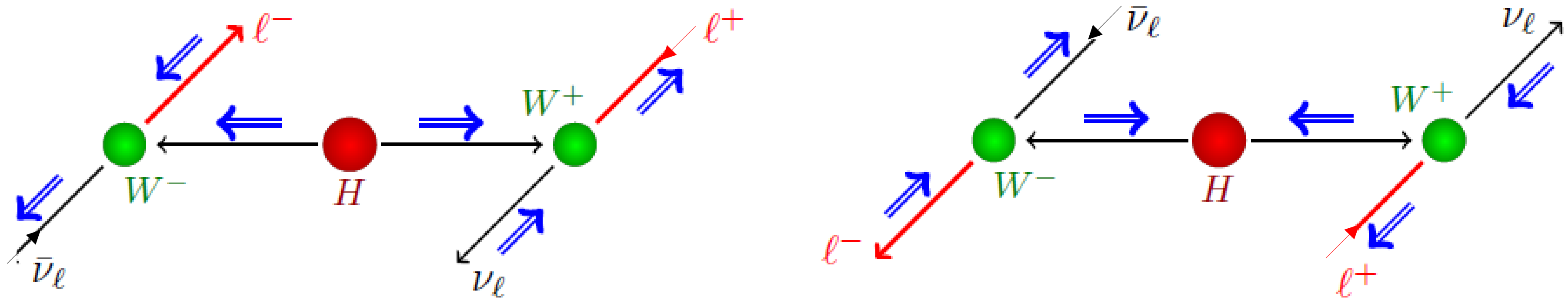
- Events are required to have two opposite-charge leptons (*e* or μ) and pass single-lepton trigger with threshold p_T = 24 GeV;

- Leading lepton $p_T > 25$ GeV;

- Sub-leading lepton $p_T > 15$ GeV;

- Electrons and muons must be isolated;

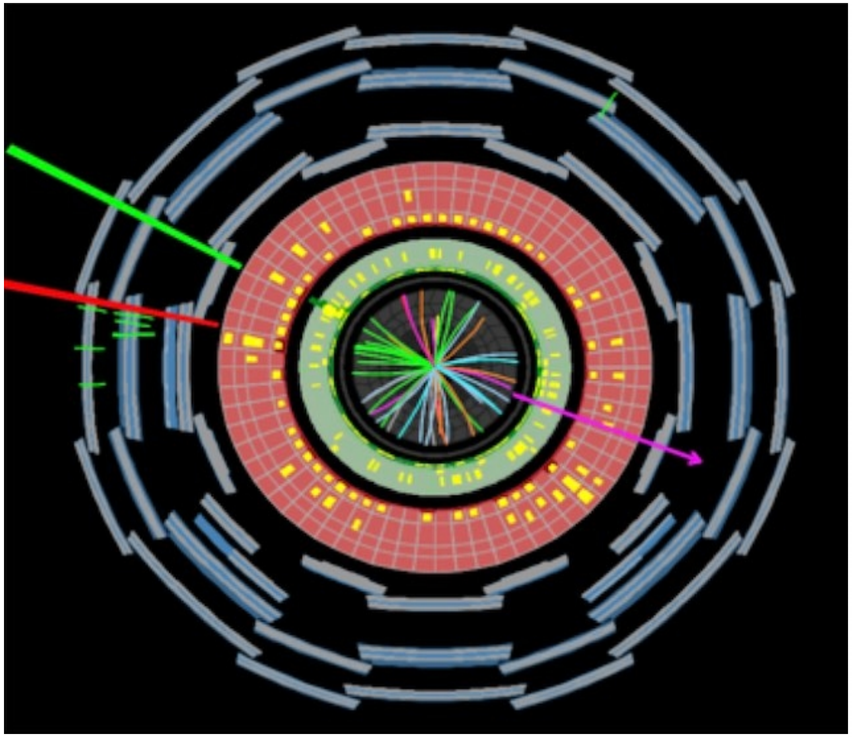
- Channel (*ee*, $\mu\mu$ *or* $e\mu$) dependent selection criteria apply.

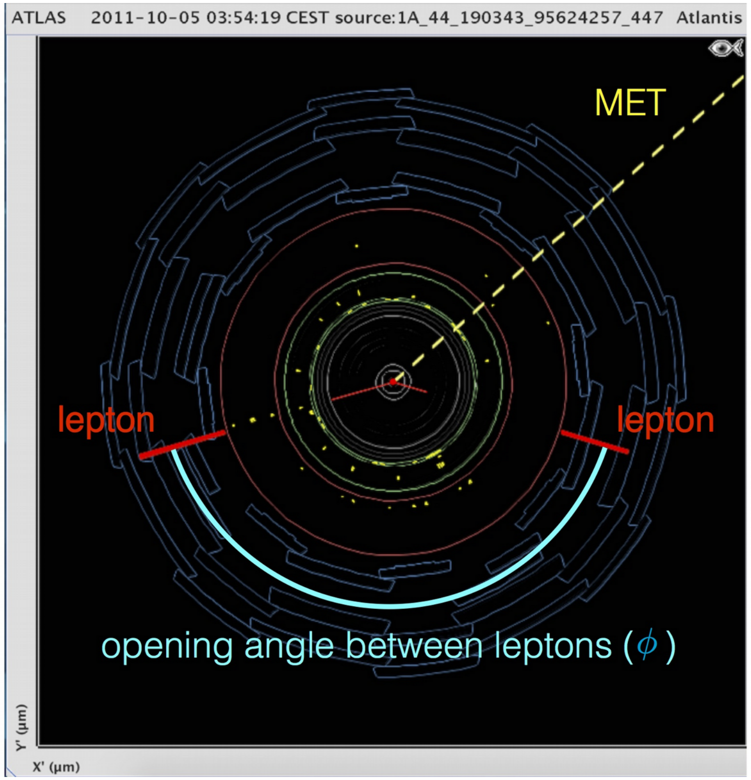


Blue arrows – direction of the spin
Black and red arrows – direction of the momentum.

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

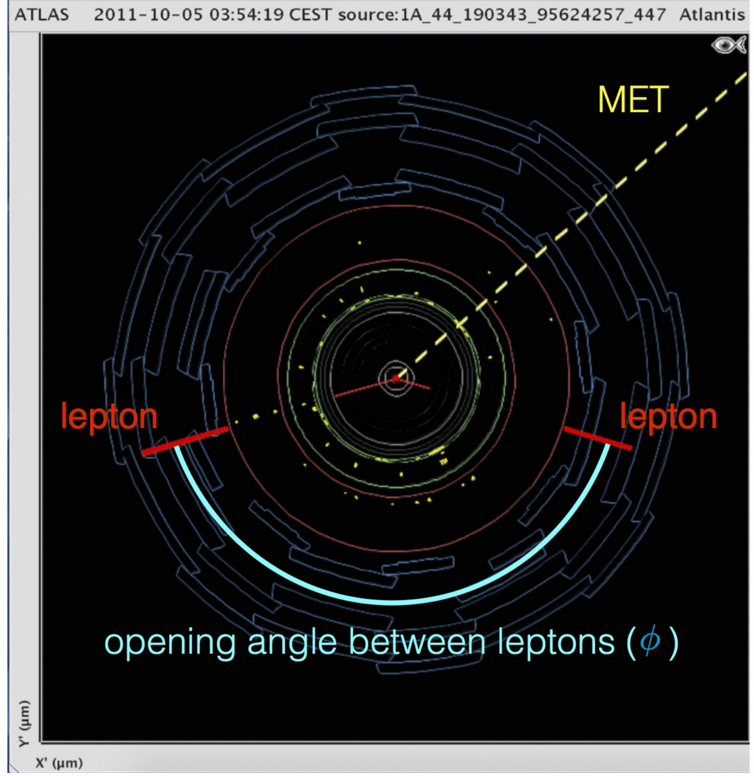
Only left-handed (right-handed) leptons (anti-leptons) participate in the decay of the W bosons → leptons (l and ν) emerge in directions anti-parallel to their spin.

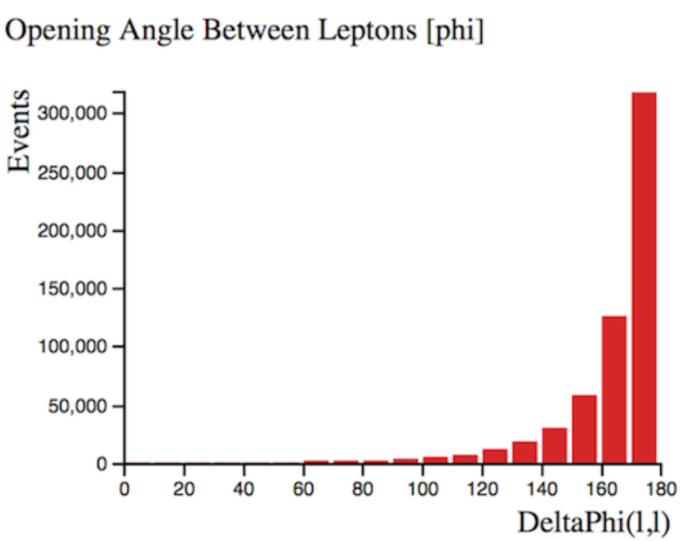


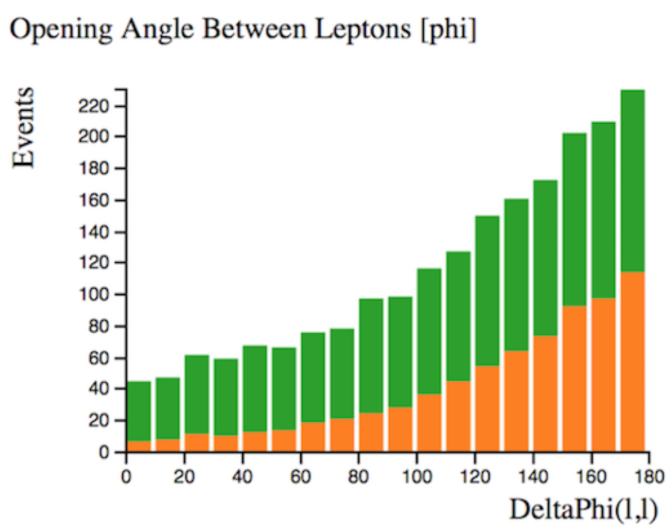


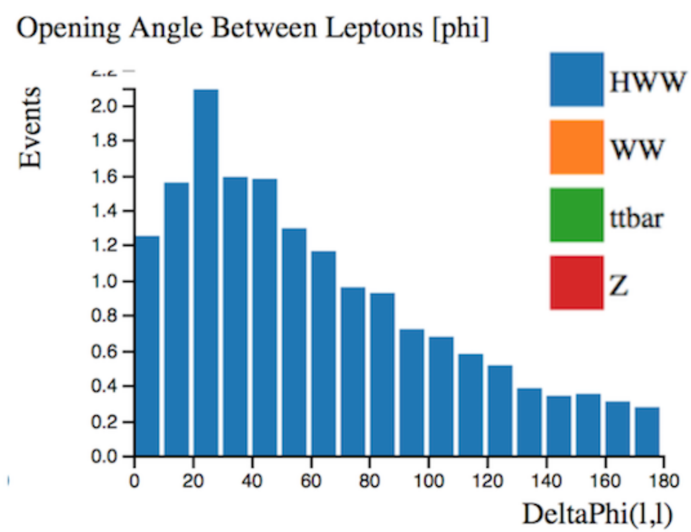
Spin 0 of the Higgs and the structure of W boson decays imply a final state characterised by a small angular separation between leptons (low $\Delta\varphi_{ll}$), small invariant mass of the dilepton system (low m_{ll}) and large missing transverse momentum in the opposite direction of the lepton pair.

Prompt WW do not need to obey to these requirements!

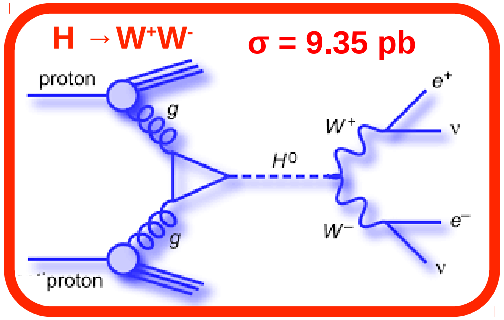


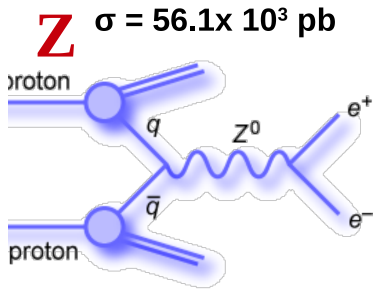


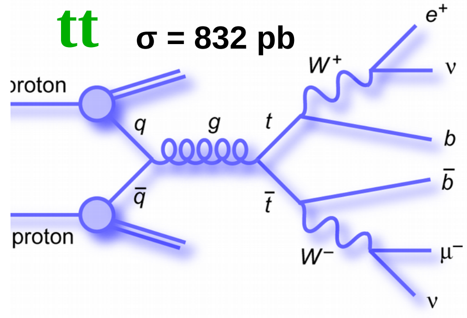


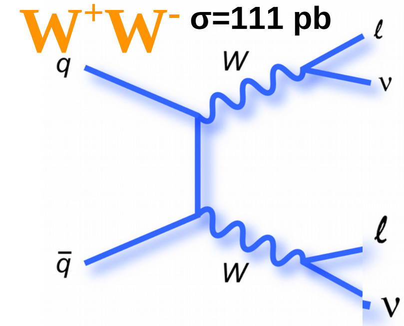


Reconstructed dilepton mass and angular separation are golden variables to reject WW

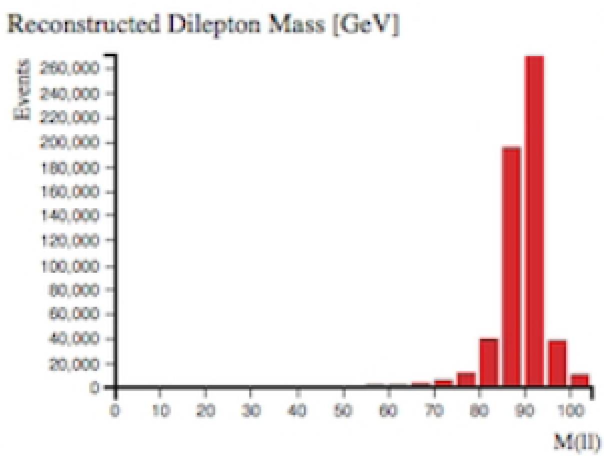


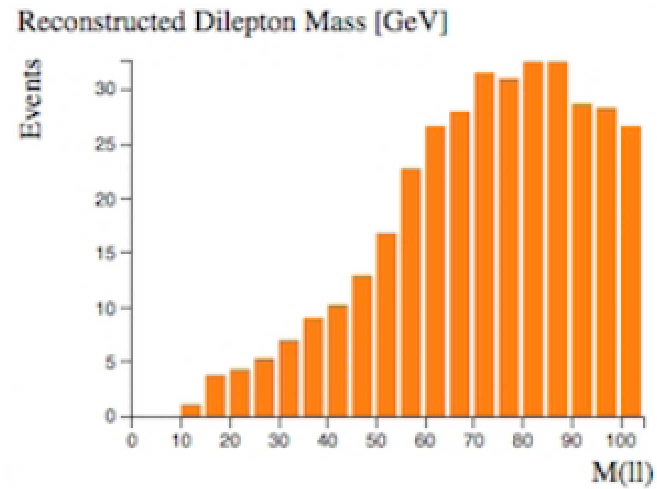


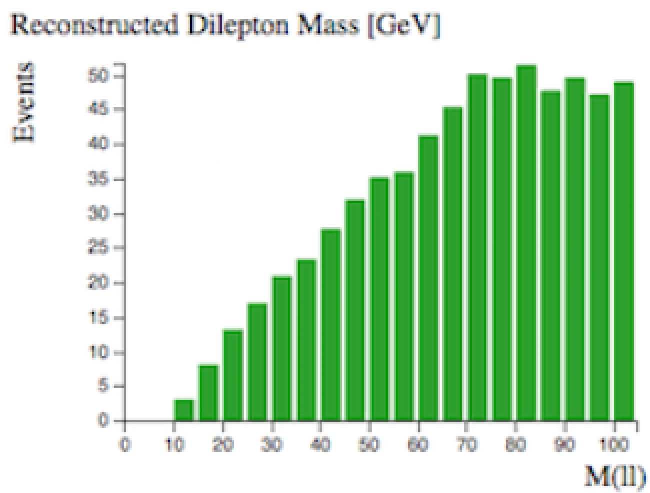


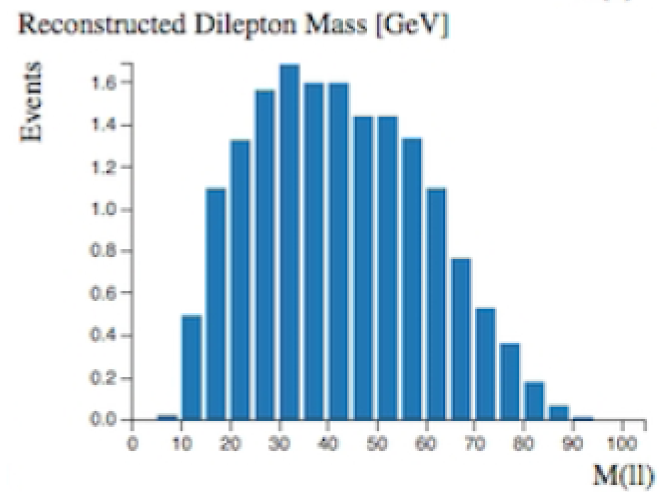


Reconstructed Dilepton Mass



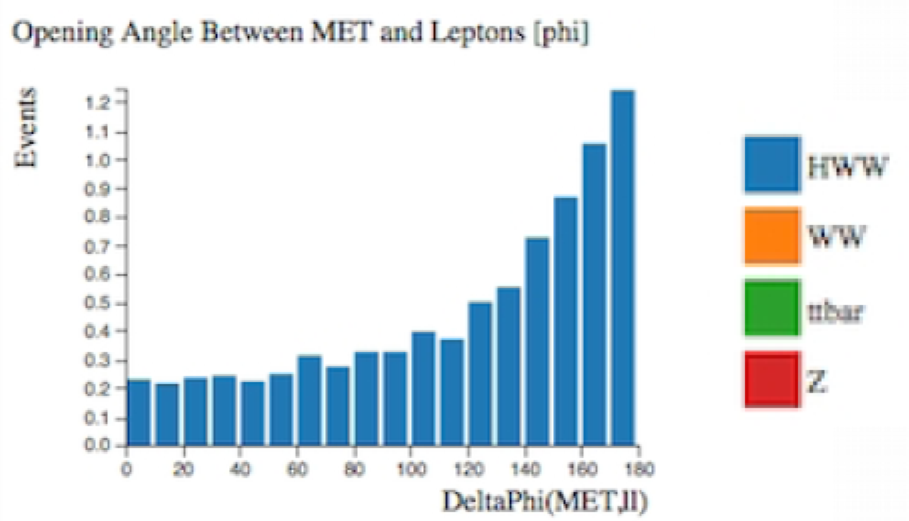


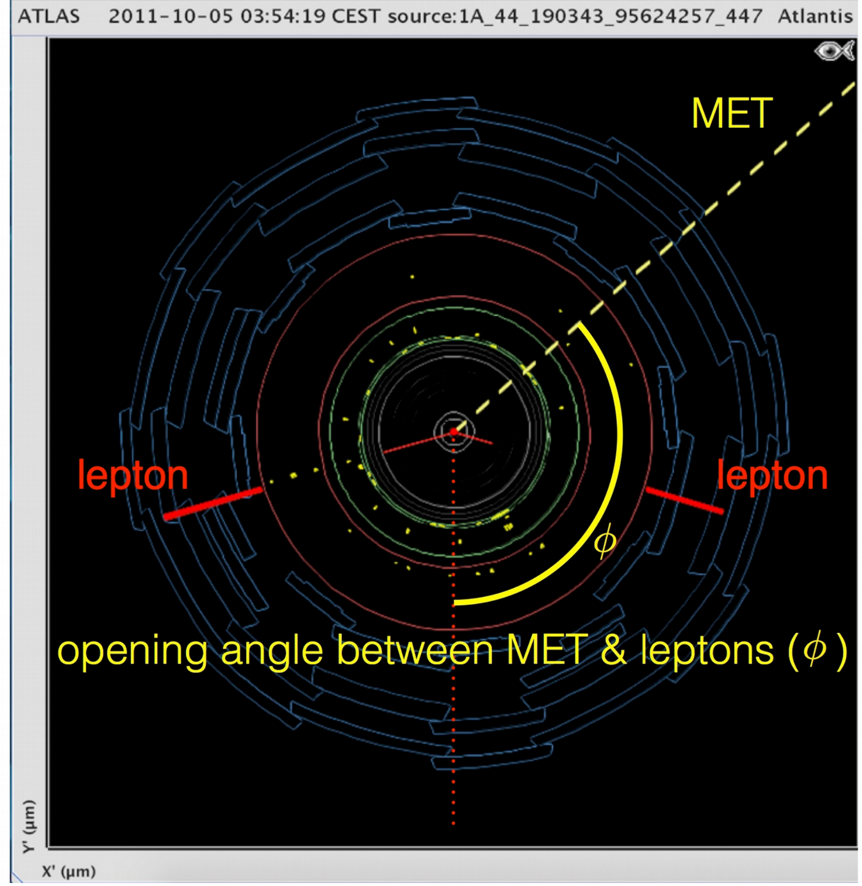


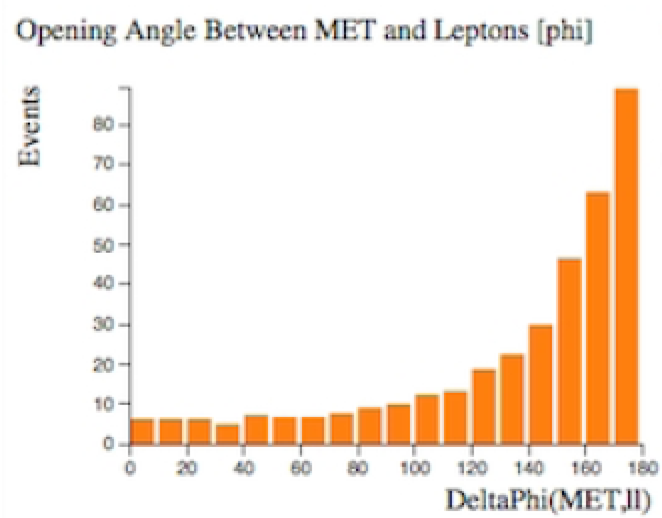


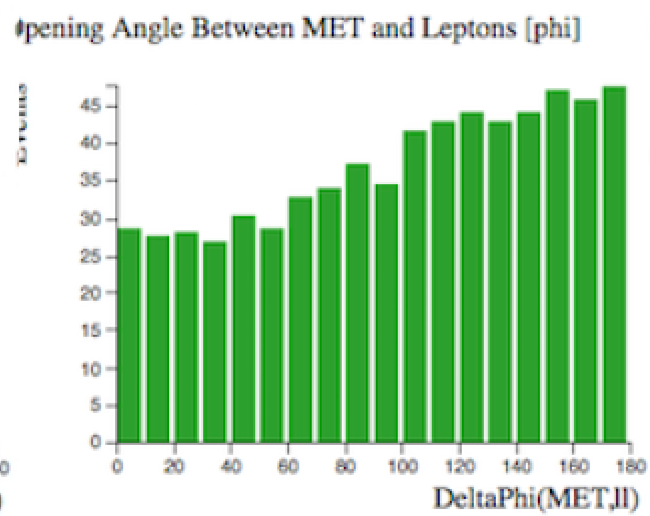
Reconstructed dilepton mass and angular separation are golden variables to reject WW, ttbar and Z.

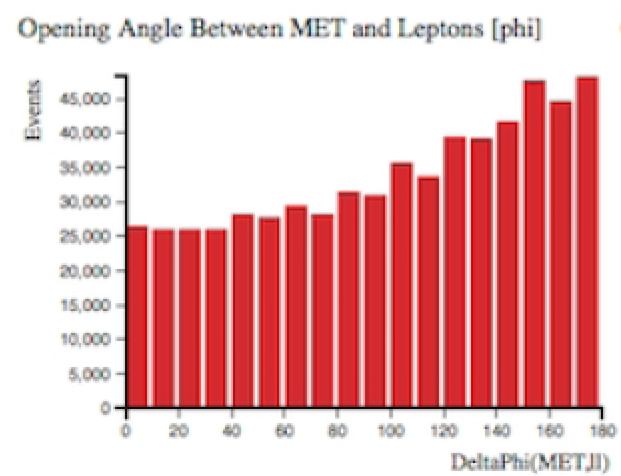
Opening angle between MET and leptons



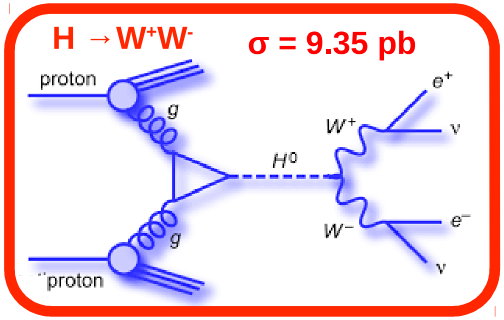


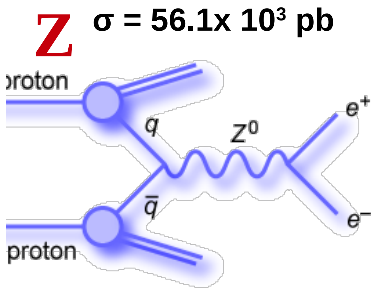


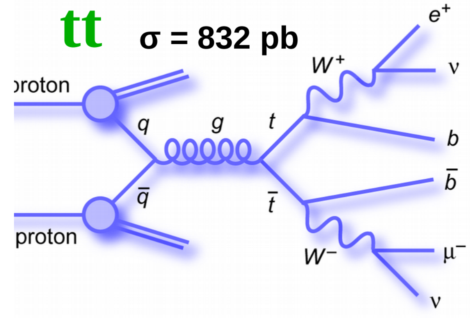


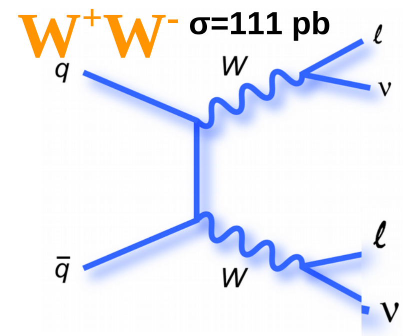


Variable not very useful.



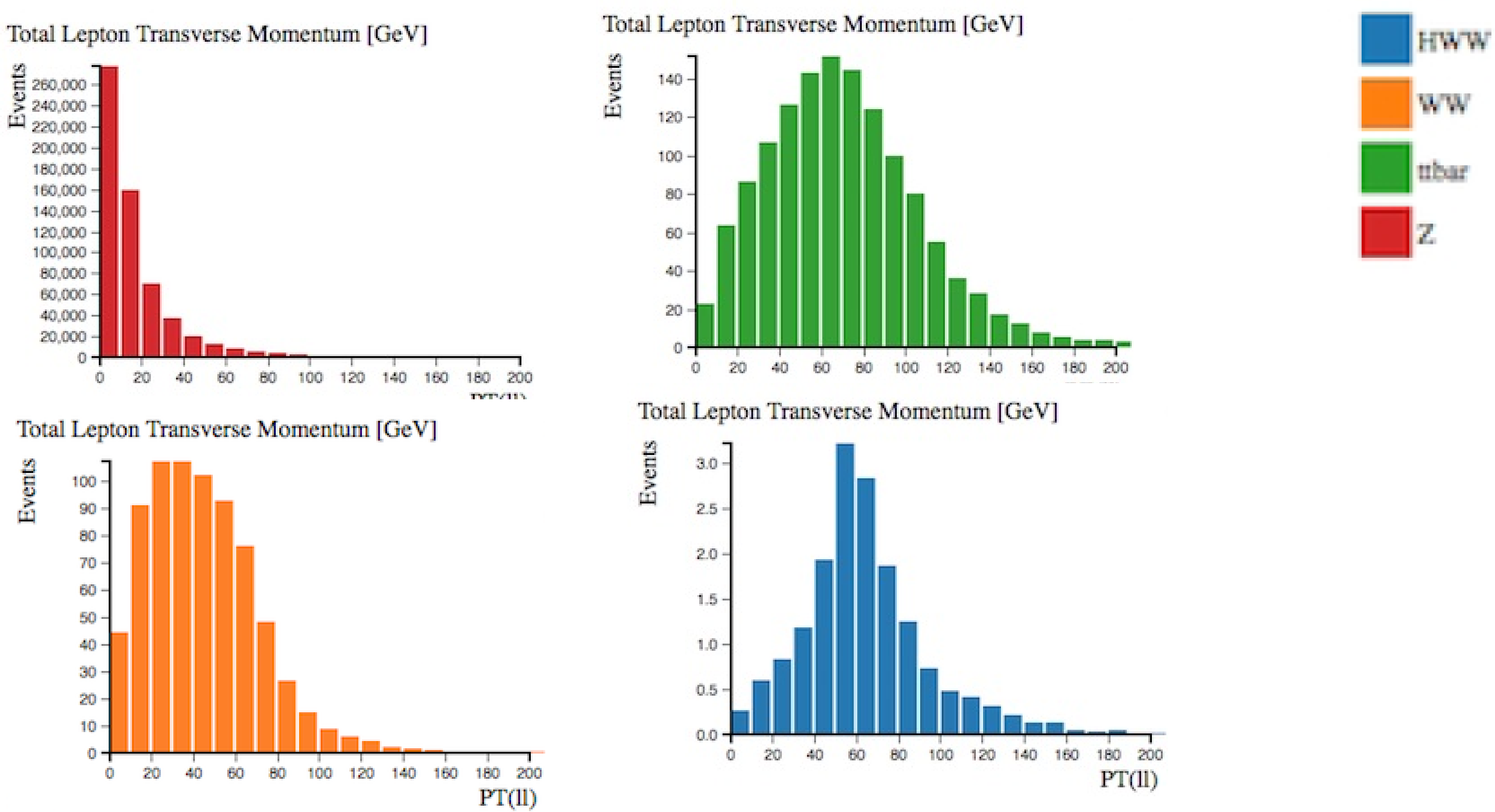






Total Lepton Transverse Momentum [GeV]

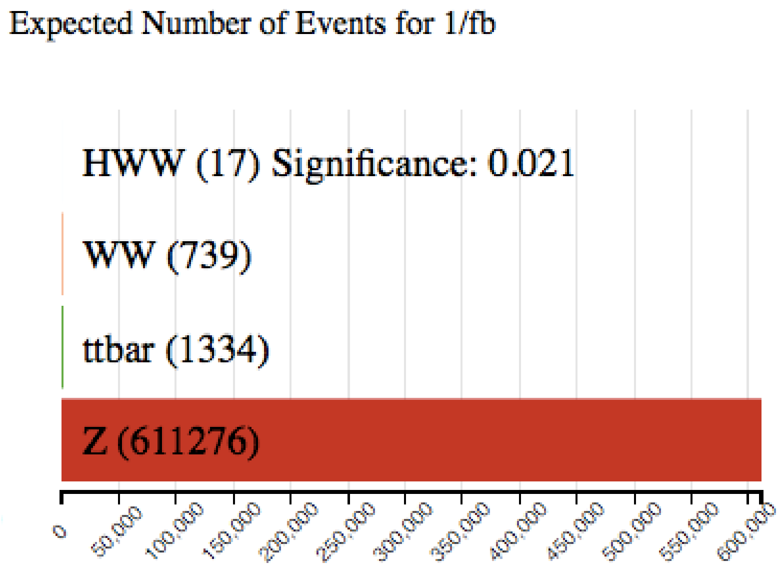
Vectorial sum of the transverse momenta of the observed charged leptons.

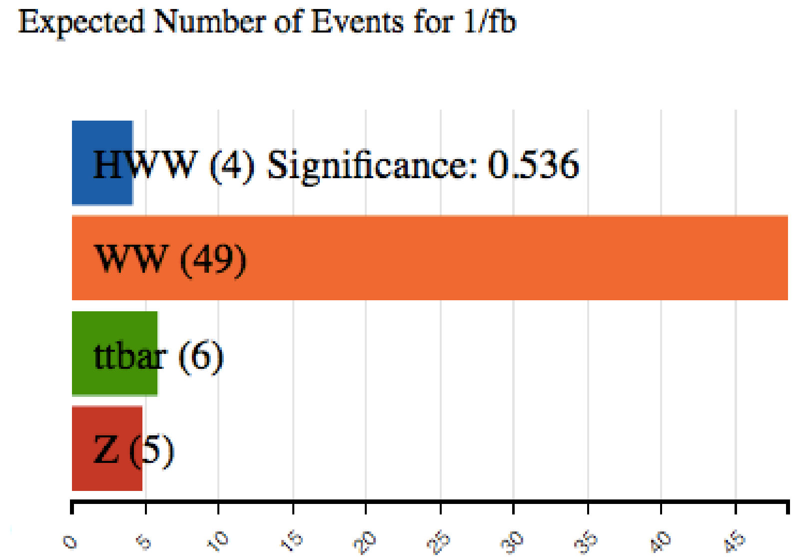


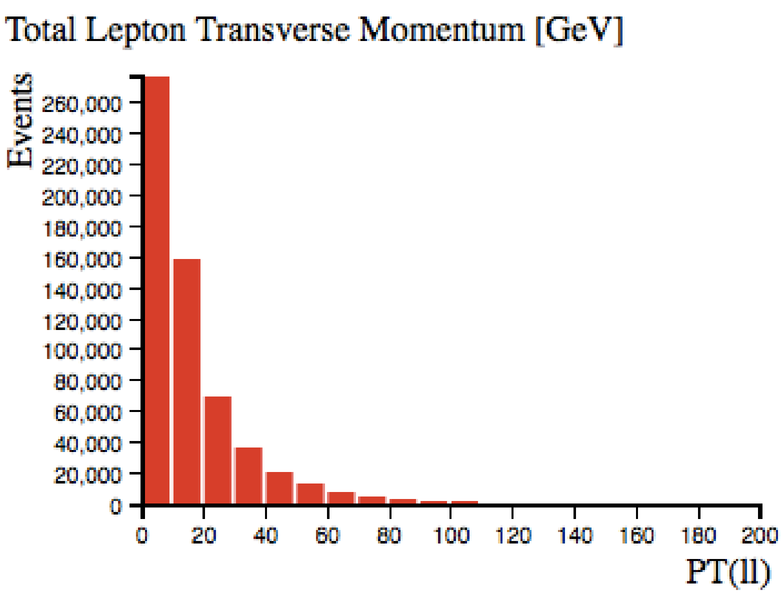
Important variable to remove Z backgrounds

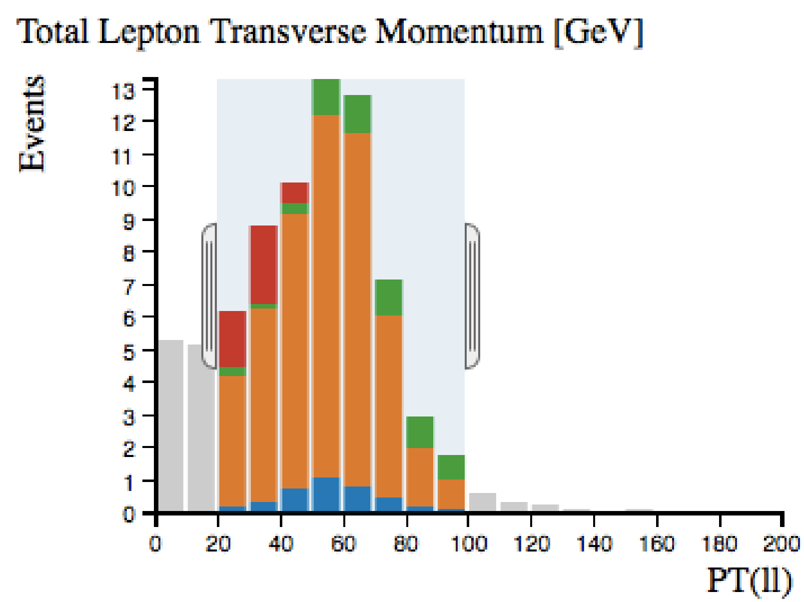
Histogram analyser

The significance of the H → W+W− events quantifies how "significant" the Higgs sample is with respect to the background. It is calculated by (Number of H → W+W−events)/sqrt(Number of background events). The larger the significance value is, the better job you have done extracting the Higgs signal.







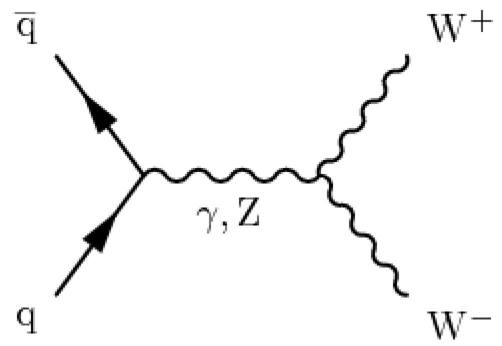


Backup

Background from W^+W^-

These pairs are produced by:

quark–antiquark annihilation: qqbar → W+W− (dominant process at LHC)

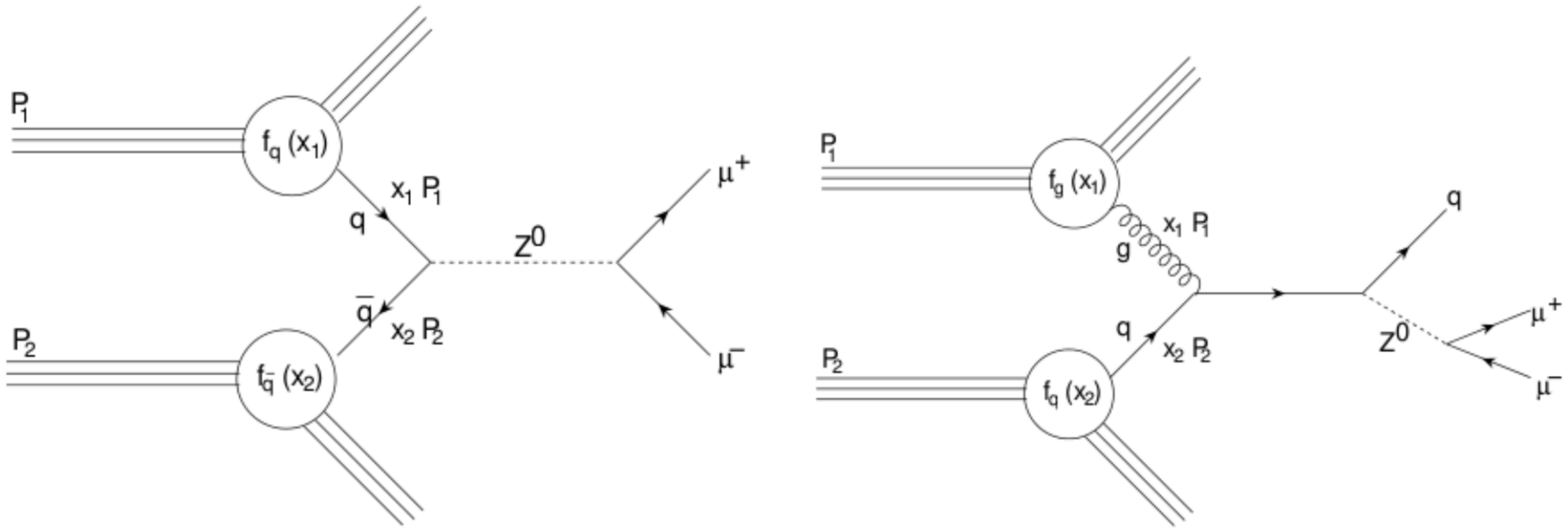


Diphotons: $\gamma\gamma \rightarrow W^+W^-$

Gluon fusion: $gg \rightarrow W^+W^-$

Background from Z

Z boson is produced at LHC through quark-antiquark anihilation (65% of the cases) or through quark-gluon scattering (35%)



Z boson is neutral → the sum of electric charge of its decay products is zero. Z Decays through:

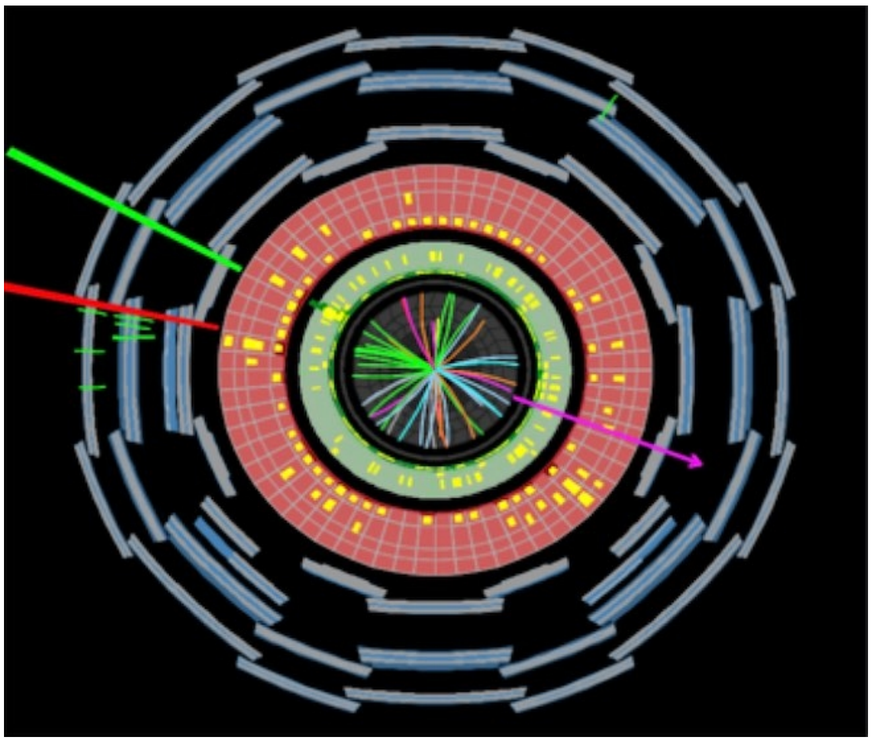
- Quark-antiquark pair (70%) → identified by jets in the calorimeter;

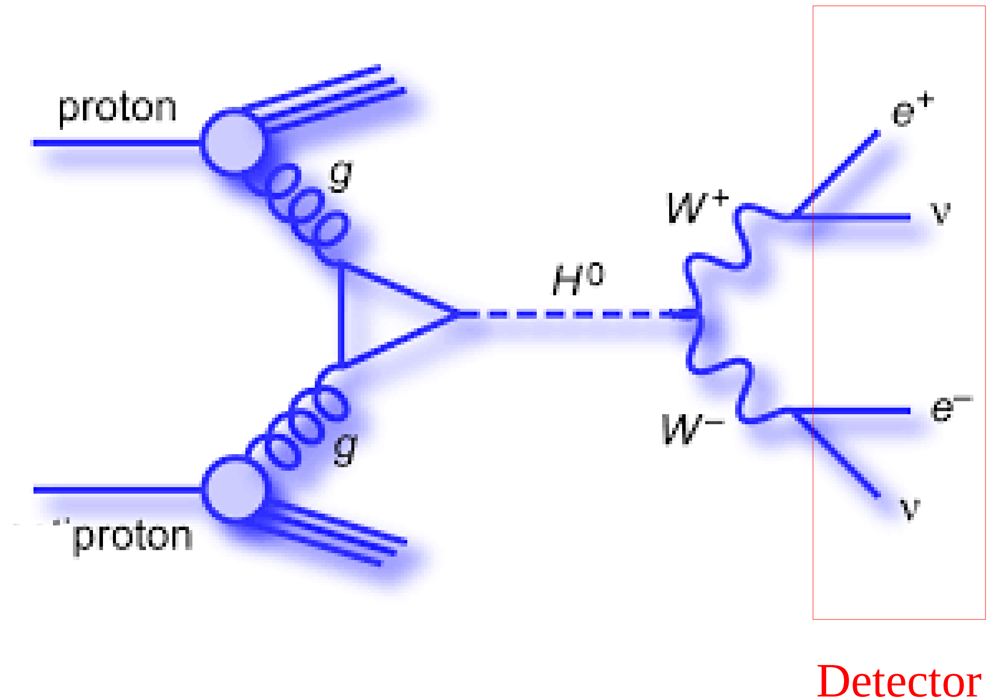
- Neutrino-antineutrino pair (20%). Neutrinos cross the detector untouched. This decay mode may be identified if missing transverse momentum (MET) is high.

- Lepton-antilepton pair (10%). The three lepton types (electron, muon, tau) are equally probable.

$H \to W^+W^- \to l^+l^-\nu\bar{\nu}$ (l=electron or muon)

Higgs event candidate satisfying the requirements: isolated leptons and 0 jets.





electron p_T (green): 33 GeV; muon p_T (red): 29 GeV;
MET(purple): 35 GeV

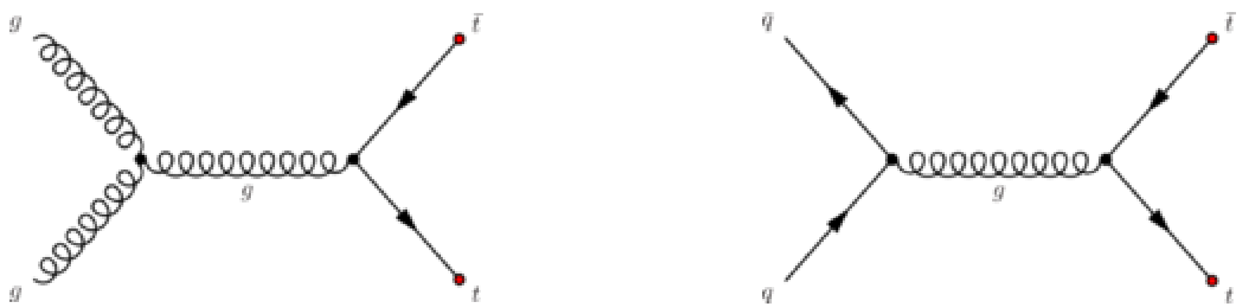
$$m_T^{\ell\ell\nu} = \sqrt{2 p_T^{\ell\ell} E_T^{\mathrm{miss}} \left(1 - \cos\Delta\phi\right)}$$

The signature of this process is two isolated leptons + MET.

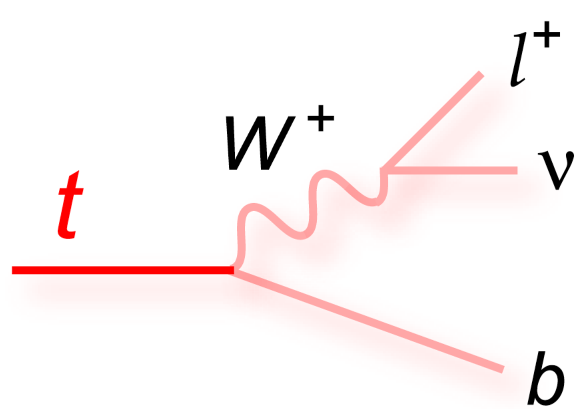
Background from $t\bar{t}$

The top quark, beyond object of study due to unique properties (huge mass and short lifetime), is used in the optimization of Monte Carlo generators, QCD models and parton distributions inside the nucleon (Parton Density Functions – PDF).

tt production constitutes an important background in several Higgs analyses and beyond Standard Model searches. Its production is intrinsically Strong:



but its decay is mainly through Weak interaction – top quark dacays to W boson and a *b*-quark in 99.8% of the cases.

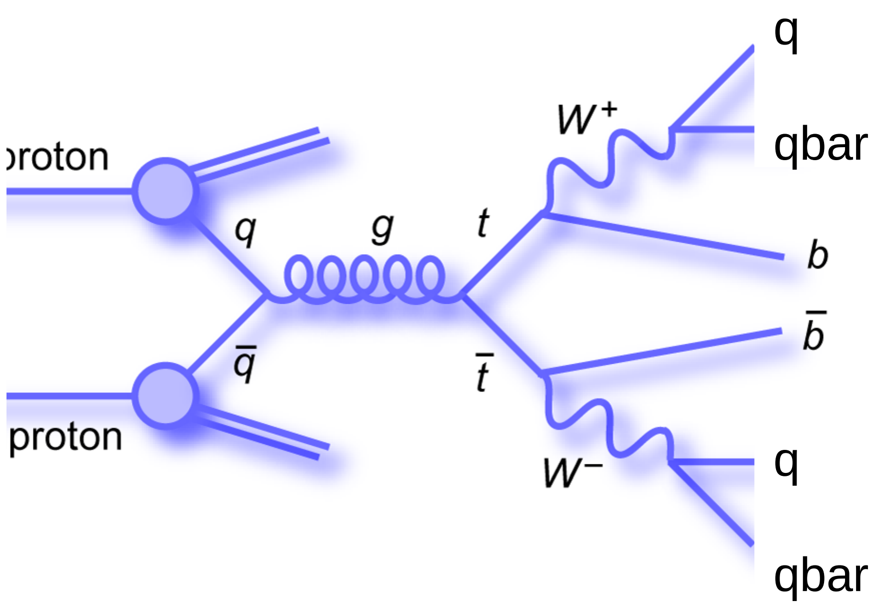


The *b*-quark hadronizes and will be detected through a jet.

Background from $t\bar{t}$

The ttbar signature has 3 channels defined by W and b-quark decay:

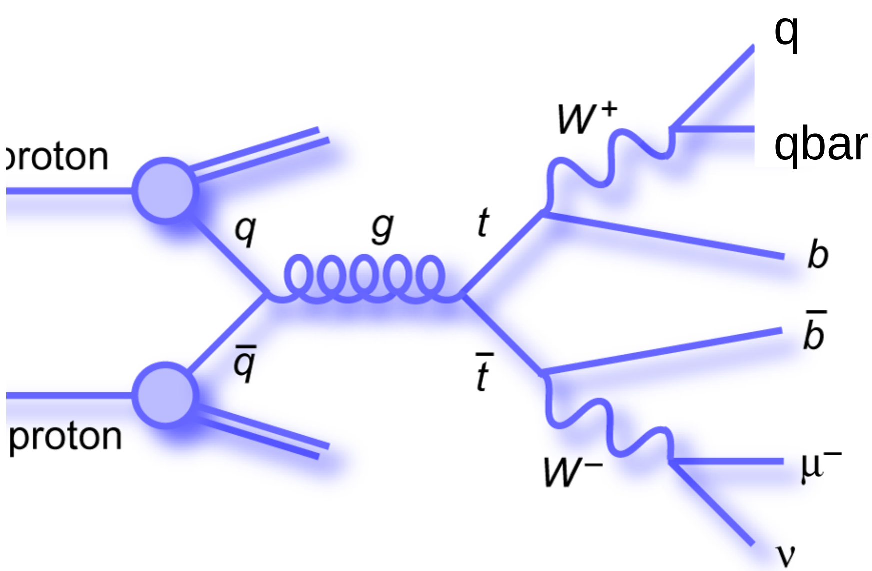
- **If both W decay hadronically, 6 jets will be observed;**

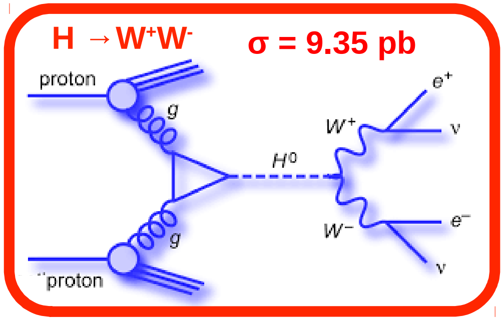


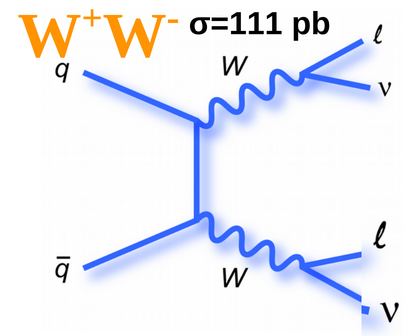
Background from $t\bar{t}$

The ttbar signature has 3 channels defined by W and b-quark decay:

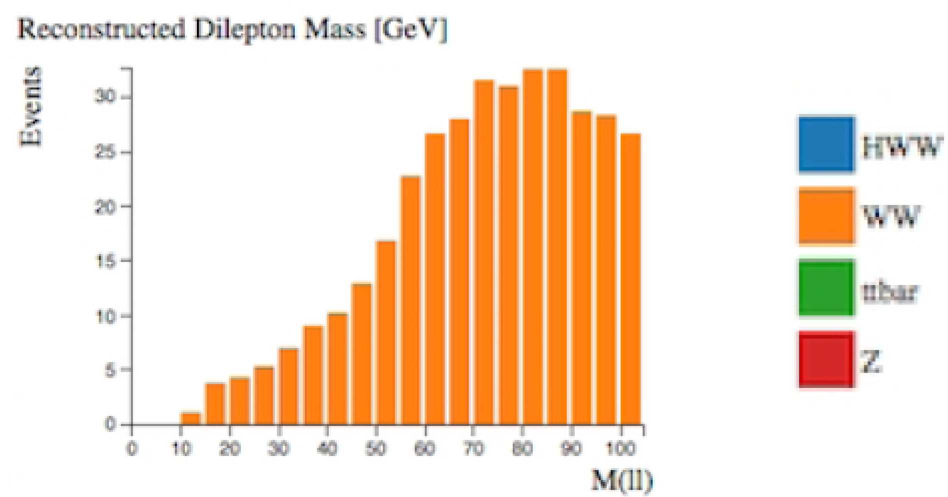
If the decay is semi-leptonic (one W decays leptonically, the other hadronically), 1 lepton + MET + 4 jets will be observed.

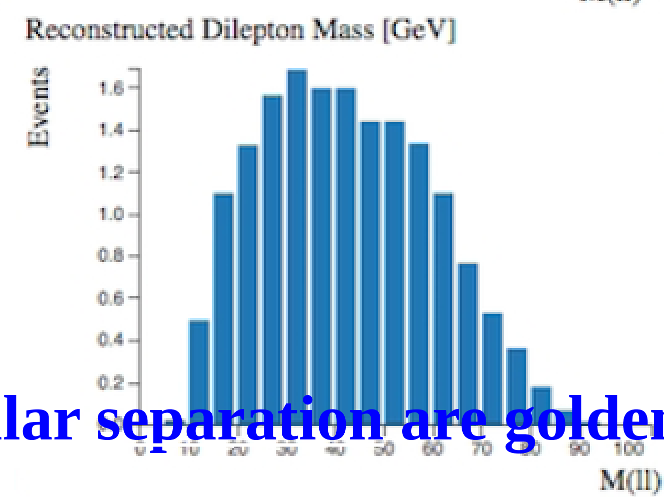




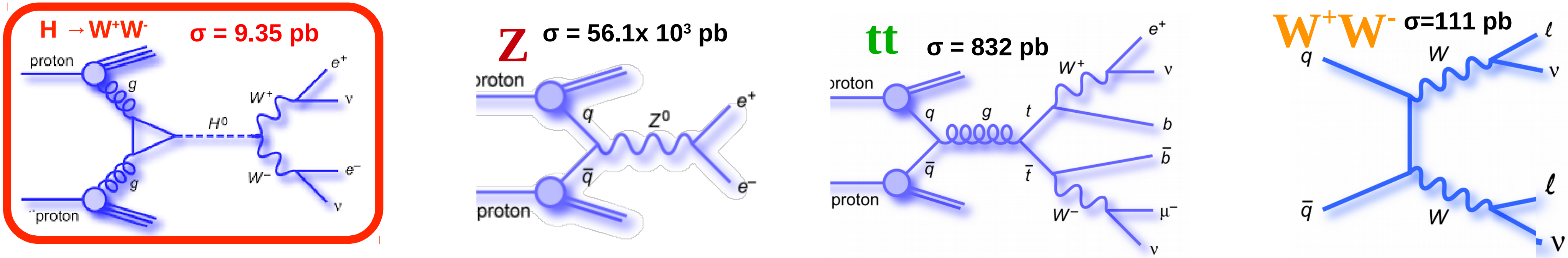


Reconstructed Dilepton Mass

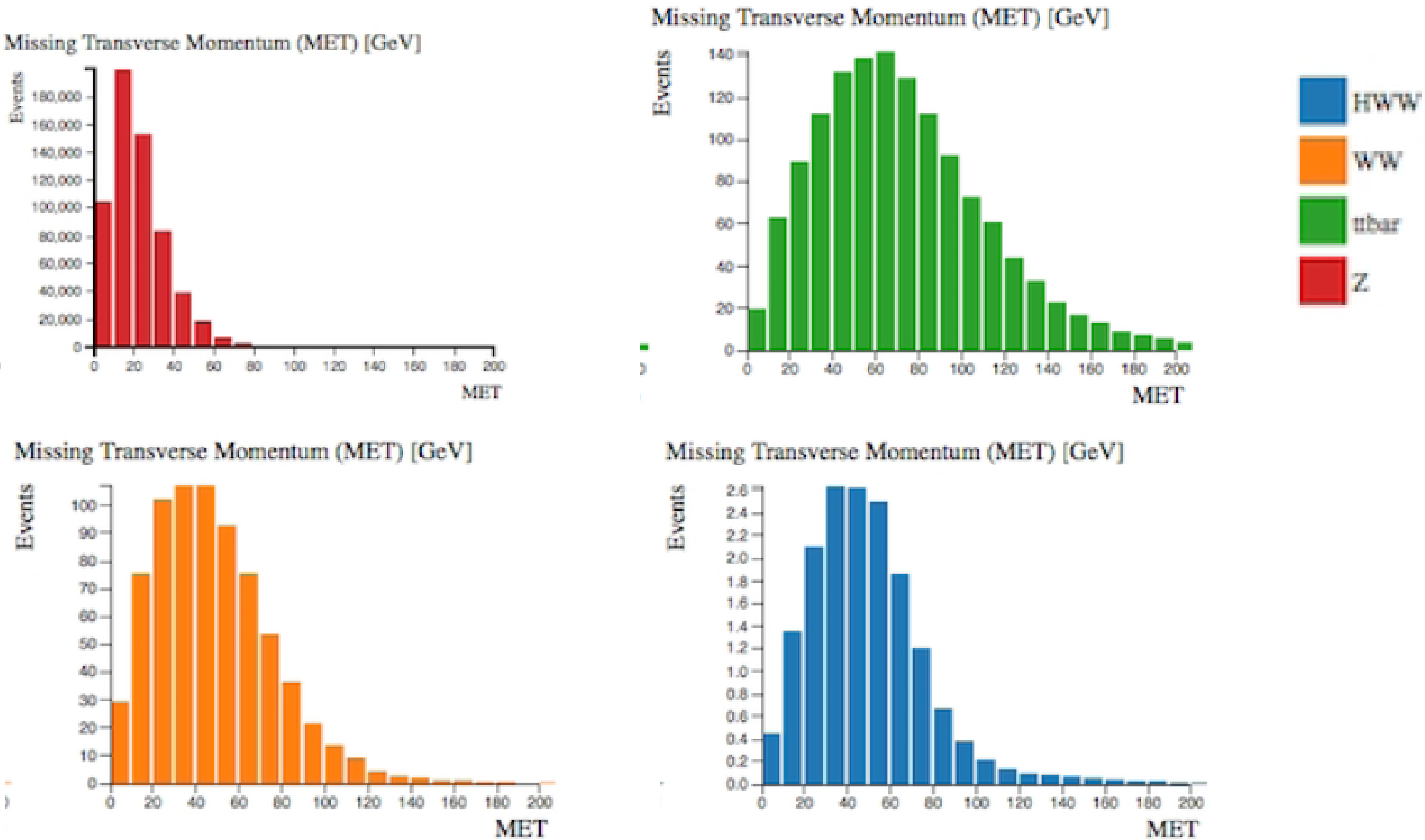




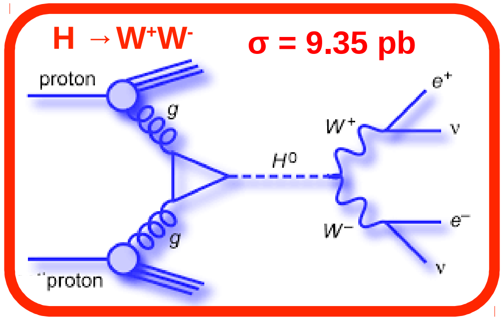
Reconstructed dilepton mass and angular separation are golden variables to reject WW

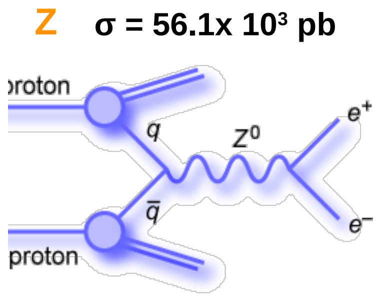


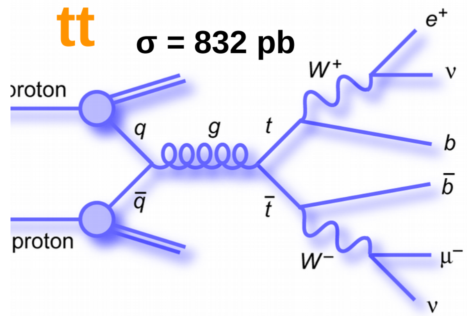
Missing Transverse Momentum (MET) [GeV]

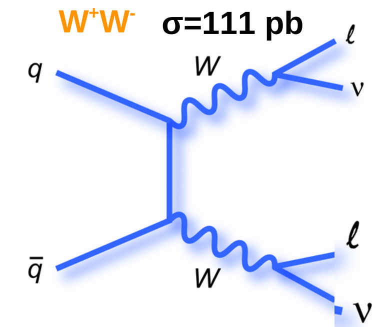


The presence of neutrinos in the final state does not allow for the full reconstruction of the Higgs boson mass. Transverse mass, m_T, is used, instead.









Significância: A significância do processo H a decair num par de Ws, como o nome indica, mostra-nos quão significante é o número de Higgs face ao número de eventos de fundo. Portanto, quanto maior a significância, melhor trabalho fazemos para destrinçar o Higgs do background. No entanto, não há cortes perfeitos, no sentido em que, qualquer corte que apliquemos, também vai cortar eventos de sinal. O Z domina completamente.

Channel - este histograma mostra os diferentes canais de decaimentos leptónicos - da mesma família, electrão ou muão, ou de famílias diferentes - um electrão e muão são detectados.

Reconstructed Dilepton Mass [GeV] - massa invariante dos dois leptões no estado final.

Jet multiplicity – Histograma do número de jactos em cada evento.

Jactos de b-tagging - Se os jactos forem identificados como jactos do quark bottom. Os jactos b-tagged são esperados no dacaimento do top, mas não no decaimento leptónico dos W e Z.

MET - a componente longitudinal (ao longo do eixo dos ZZ) do momento dos protões não é conhecida, pois está sempre a variar entre os constituintes do protão. No entanto a componente transversa do momento é nula, logo, por conservação do momento, antes e após a colisão, é possível medir a energia em falta.

Total Lepton Tranverse momentum - Momento transverso dos dois leptões no estado final.

Opening angle between leptons - Ângulo de abertura entre os dois leptões - o angulo phi é medido a partir do eixo do X, em redor do feixe. Se os dois leptões estiverem back-to-back isso corresponderá a um opening angle de 180 graus. No caso do Higgs o angulo entre os dois leptões é pequeno.

Opening angle between MET and leptons - Ângulo de abertura entre a direcção de MET e os dois leptões - Os eventos Z e ttbar têm uma distribuição relativamente plana nesta variável, ao contrário do nosso sinal (Higgs em WW) e da produção de pares de Ws.