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Estágios de Verão  
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# ATLAS Open Data

Data of pp collisions @ 8 TeV shared with public



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

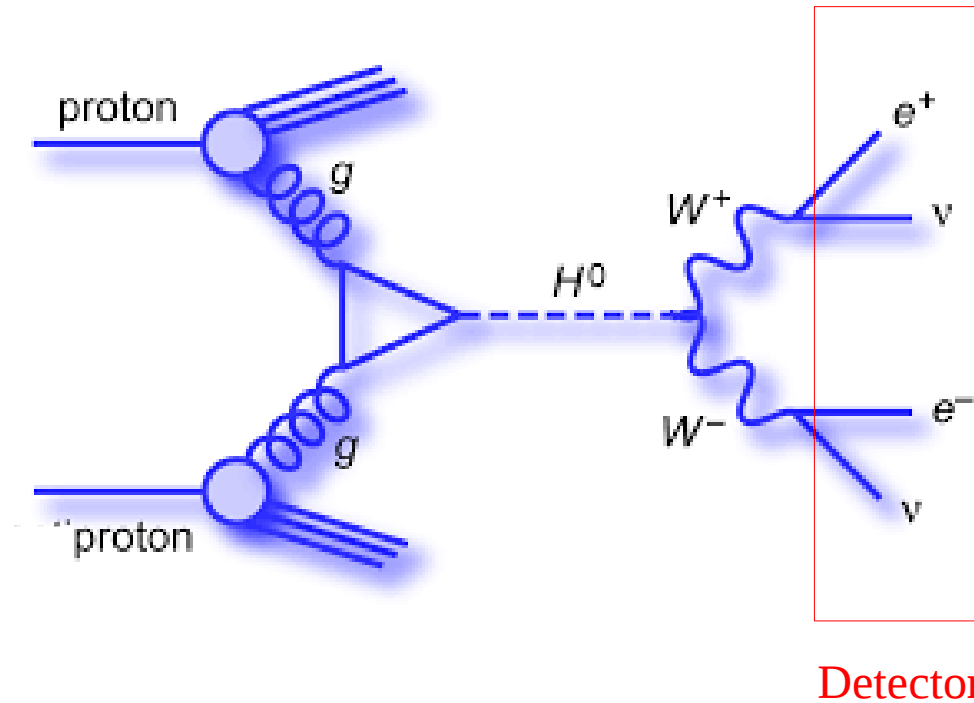
The [ATLAS](#) data from 100 trillion proton collisions is now public! This marks the world's first open release of 8 TeV data, gathered from the [Large Hadron Collider](#) in 2012.

**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**

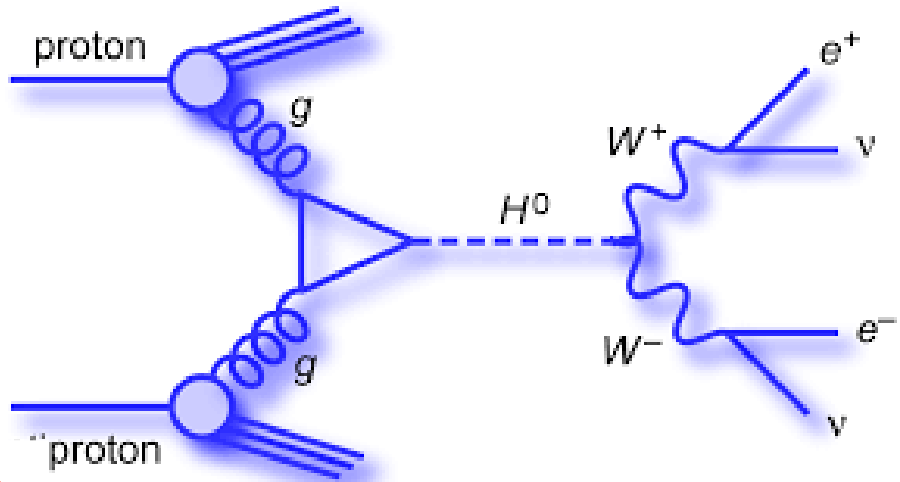
$$H \rightarrow W^+W^- \rightarrow l^+l^-\bar{\nu}\nu \quad (l = \text{electron or muon})$$



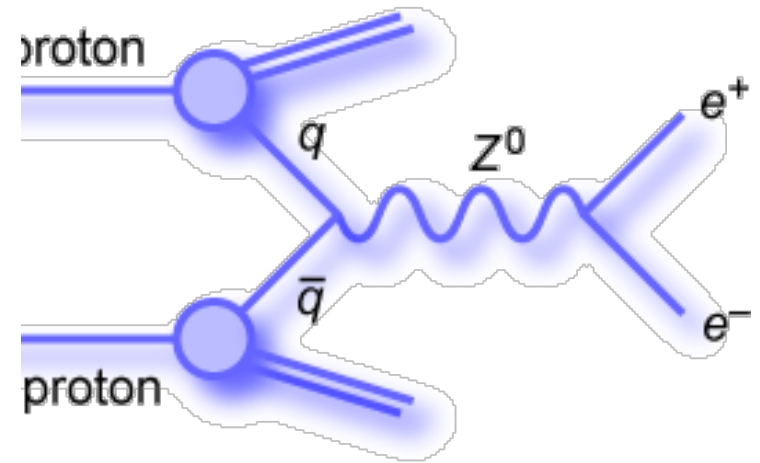
- **Higgs boson**, with mass 125 GeV, decays to a pair of  $W$  bosons in 23% of the cases.
- **Main backgrounds:**  $t\bar{t}$  production,  $WW$  and  $Z$ +jets. All these processes contain **2 high  $p_T$  isolated leptons** that **mimic the signal**.
- The **isolation** is important as suggests where 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

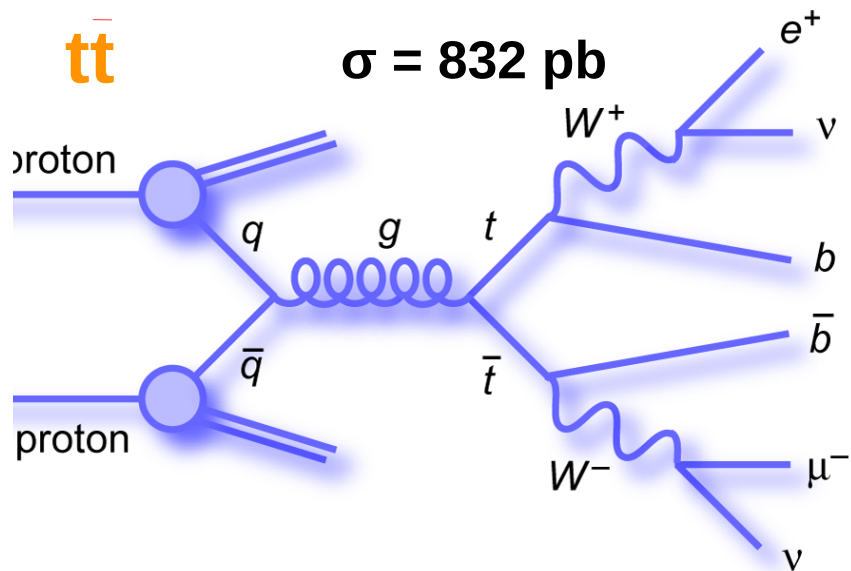
**H**  $\rightarrow$   **$W^+W^-$**   $\sigma = 9.35 \text{ pb}$



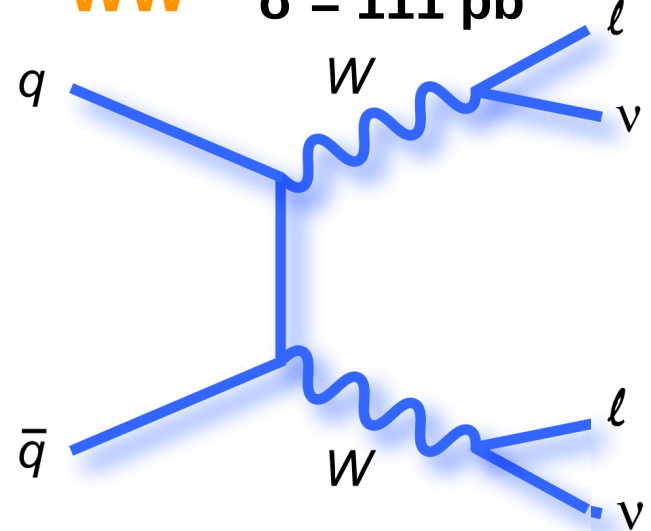
**Z**  $\sigma = 56.1 \times 10^3 \text{ pb}$



**$t\bar{t}$**   $\sigma = 832 \text{ pb}$



**WW**  $\sigma = 111 \text{ pb}$

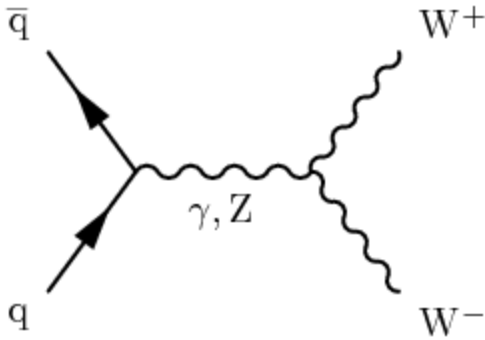




## Background from $W^+W^-$

These pairs are produced by:

quark–antiquark annihilation:  $q\bar{q} \rightarrow W^+W^-$  (dominant process at LHC)

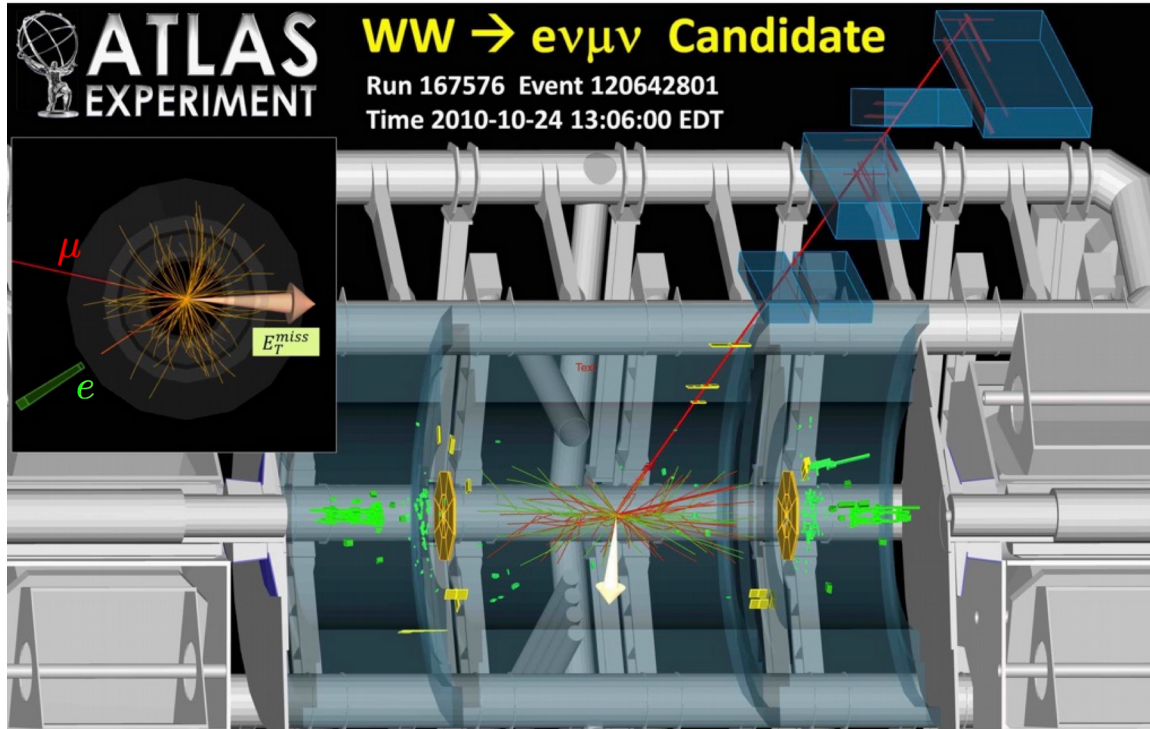


Diphotons:  $\gamma\gamma \rightarrow W^+W^-$

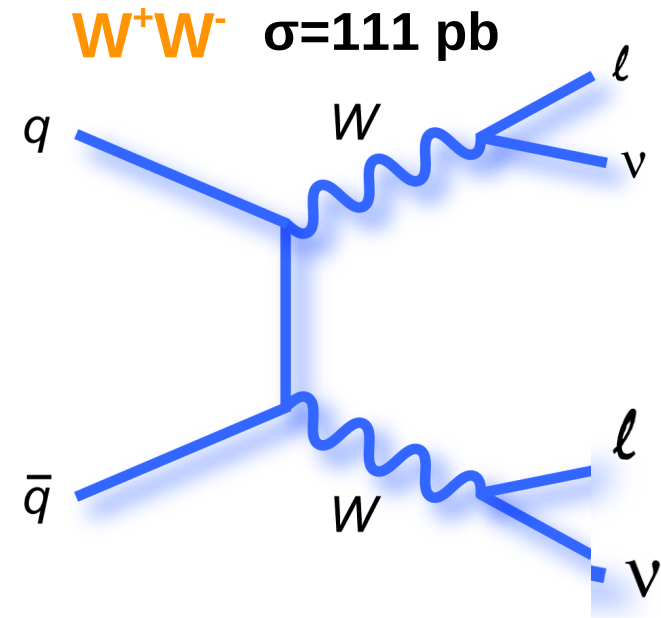
Gluon fusion:  $gg \rightarrow W^+W^-$

# Background from $W^+W^-$

$W$  boson can decay leptonically or hadronically. In the latter case in a  $q\bar{q}$  pair originating 2 jets.



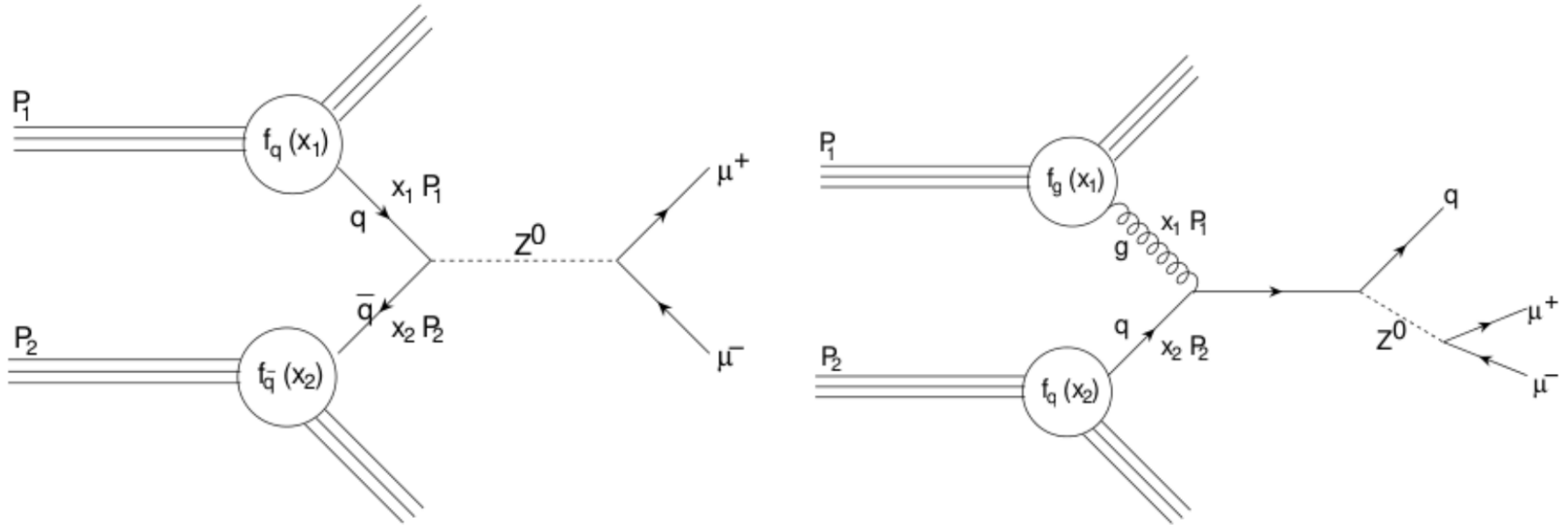
electron  $p_T$  (green): 21 GeV; muon  $p_T$  (red): 68 GeV;  
MET(arrow): 69 GeV



Constitute 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 boson is produced at LHC through Drell-Yan process (65% of the cases) or through quark-gluon scattering (35%)

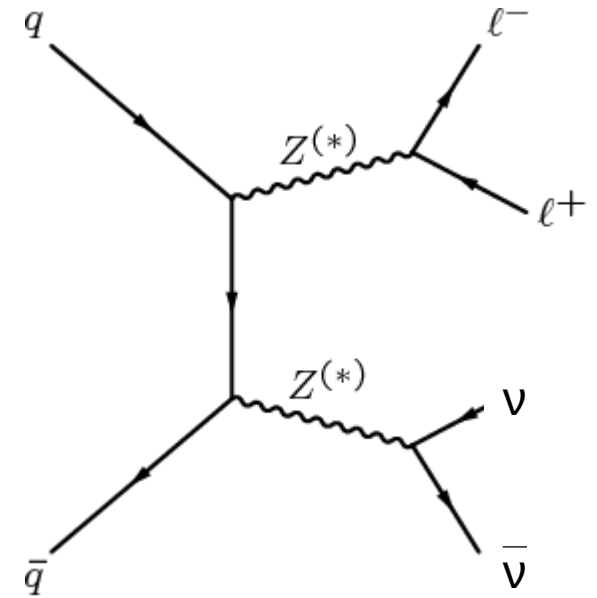
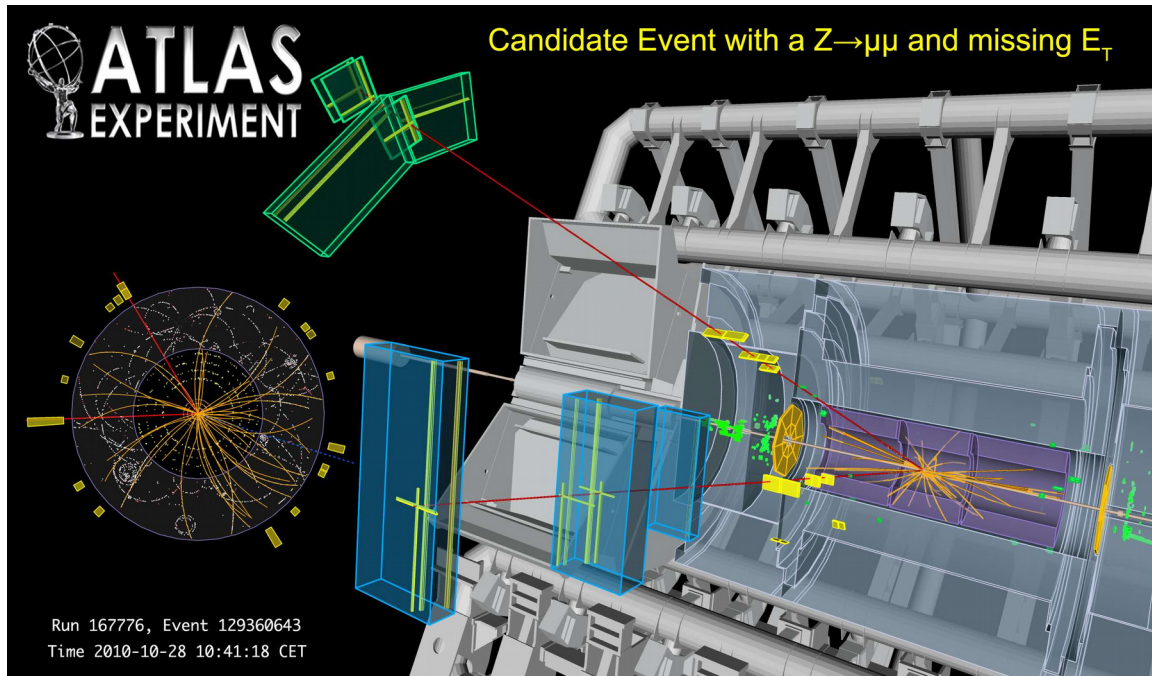


Z boson is neutral  $\rightarrow$  the sum of electric charge of its decay products is zero. Z Decays through:

- Quark-antiquark pair (70%)  $\rightarrow$  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.

# 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.

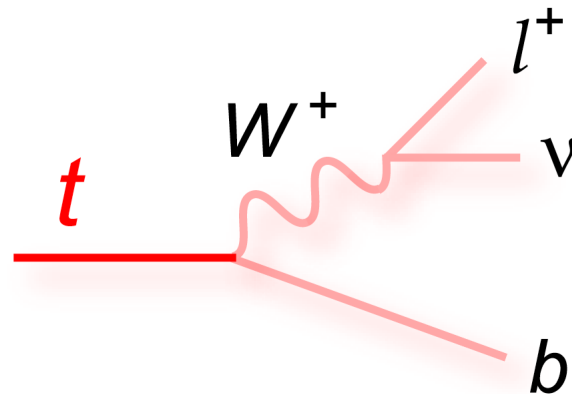
# Background from $t\bar{t}$

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).

$t\bar{t}$  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 decays to W boson and a  $b$ -quark in 91% of the cases.

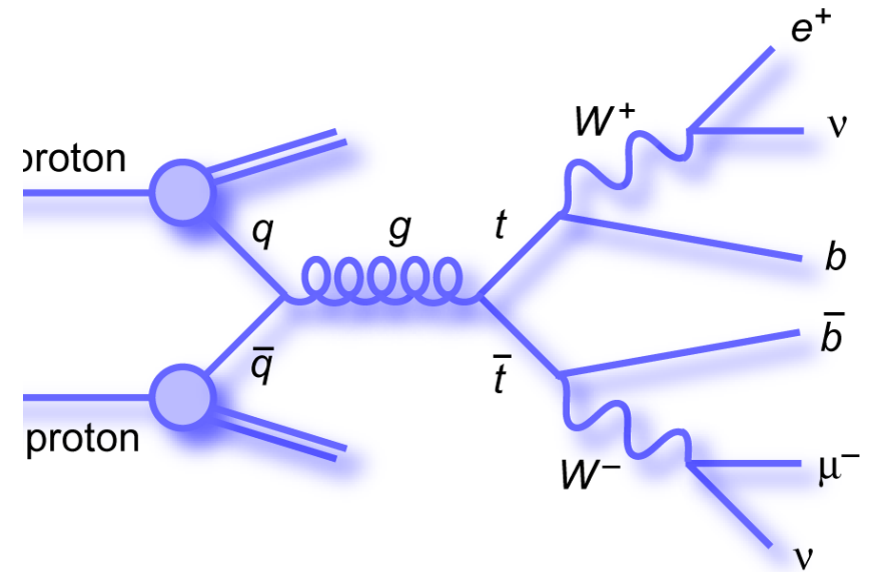
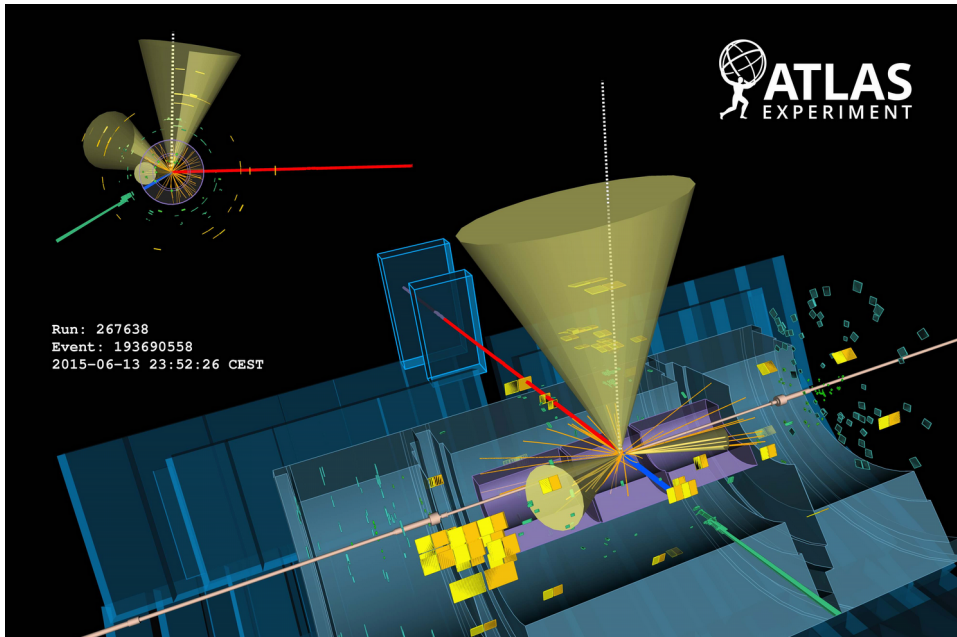


The  $b$ -quark hadronizes and will be detected through a jet.

# Background from $t\bar{t}$

The  $t\bar{t}$  signature has 3 channels defined by W and b-quark decay:

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



$t\bar{t}$  event candidate.

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

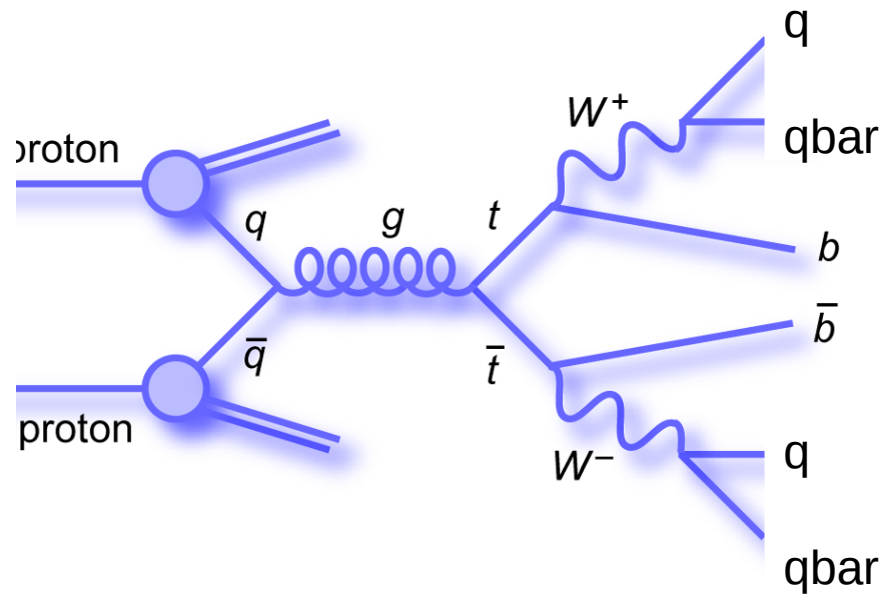
electron (green)  $p_T \approx 170$  GeV.

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.

# Background from $t\bar{t}$

The  $t\bar{t}$  signature has 3 channels defined by W and b-quark decay:

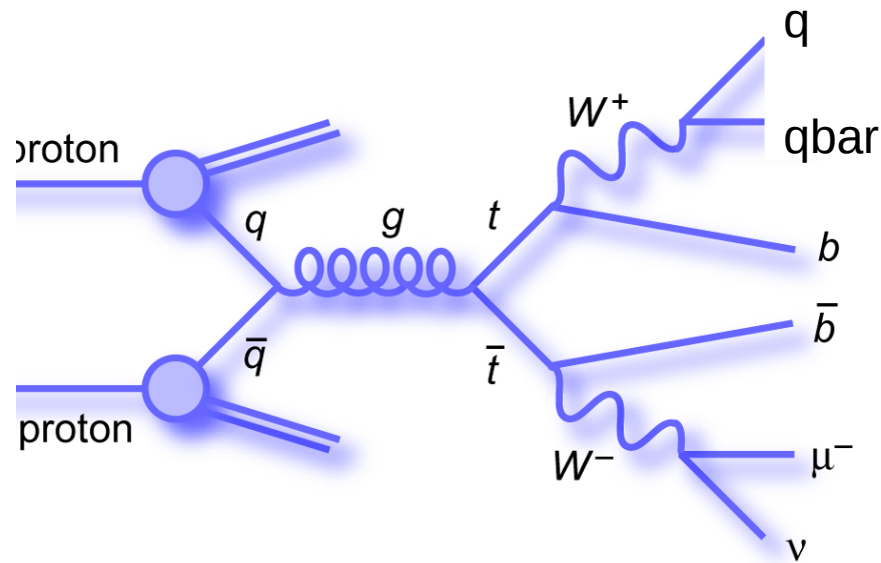
- If both W decay hadronically, 6 jets will be observed;



# Background from $t\bar{t}$

The  $t\bar{t}$  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.**





# Histogram analyser



## Get Started

Documentation, Histogram  
Analyser, ROOTbrowser

## Web Analysis

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## Data & Tools

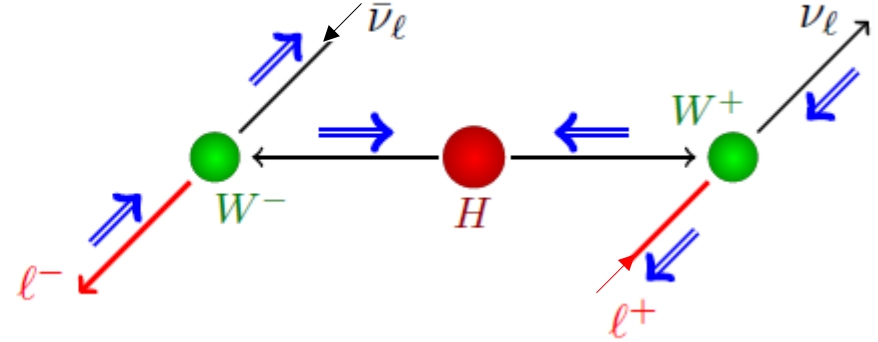
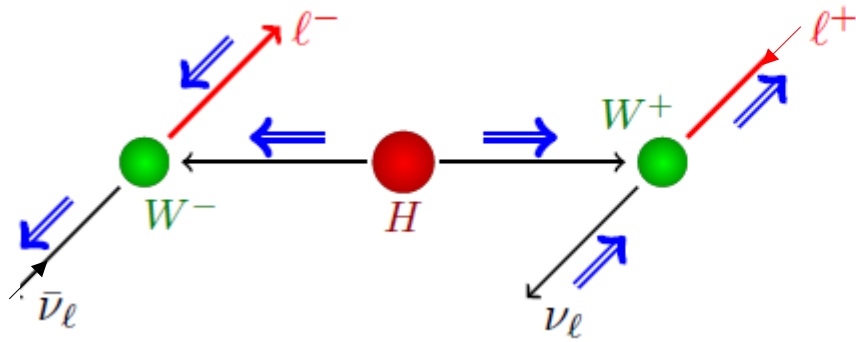
Documentation, Datasets,  
Software, Virtual Machines

[atlas-opendata.web.cern.ch/atlas-opendata/](https://atlas-opendata.web.cern.ch/atlas-opendata/)

- Which cuts should we apply to select signal events?

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

- Events are required to have two opposite-charge leptons ( $e$  or  $\mu$ ) 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.



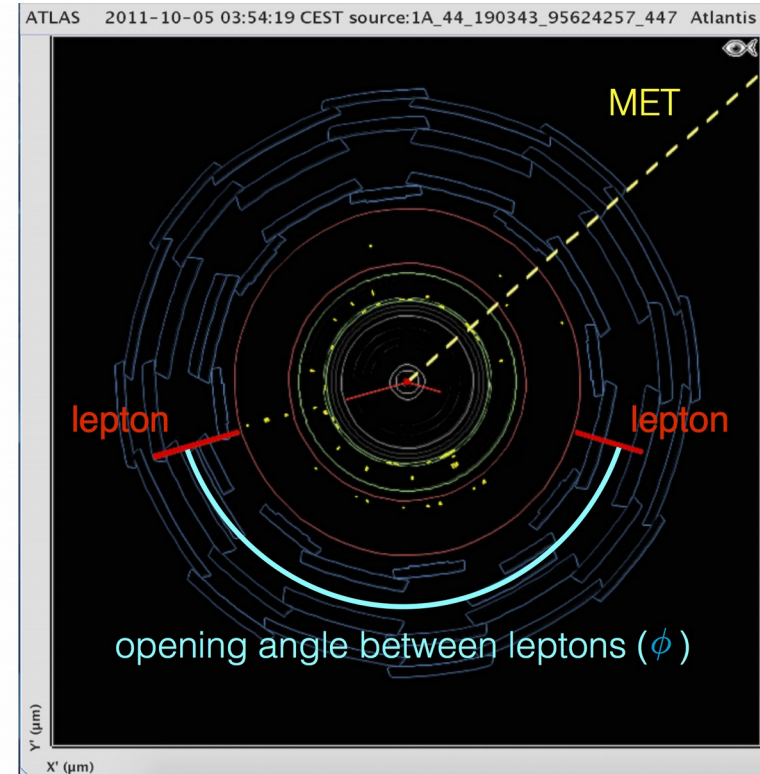
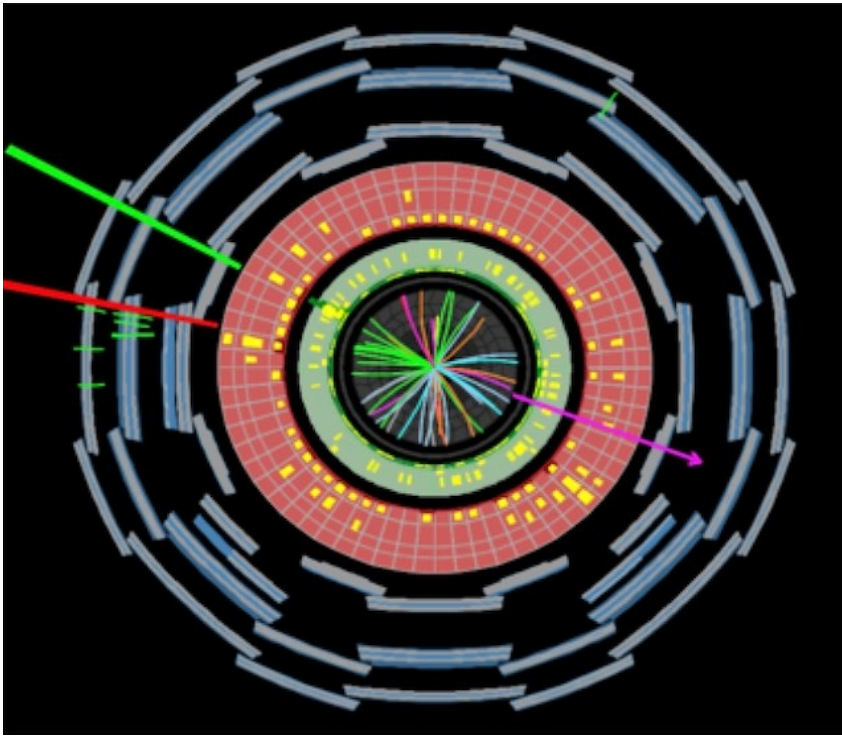
Blue arrows – direction of the spin

Black and red arrows – direction of the momentum.

Higgs has spin 0,  $W$  bosons have spin 1, leptons have spin  $\frac{1}{2}$ .

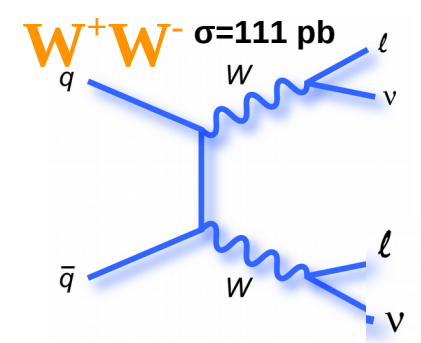
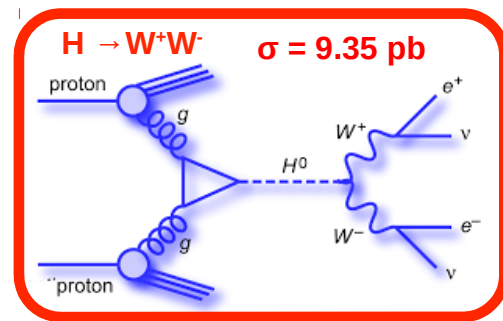
→ spins of the  $W$ s must be anti-parallel and spins of each lepton pair must be parallel.

Only left-handed (right-handed) leptons (anti-leptons) participate in the decay of the  $W$  bosons → leptons ( $\ell^-$  and  $\nu$ ) emerge in directions anti-parallel to their spin.

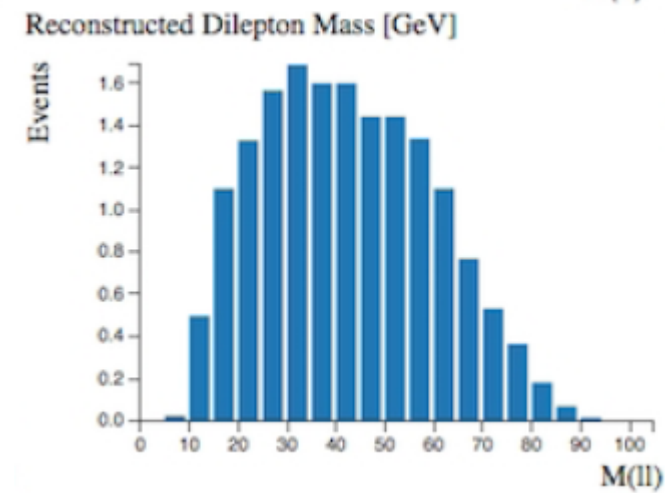
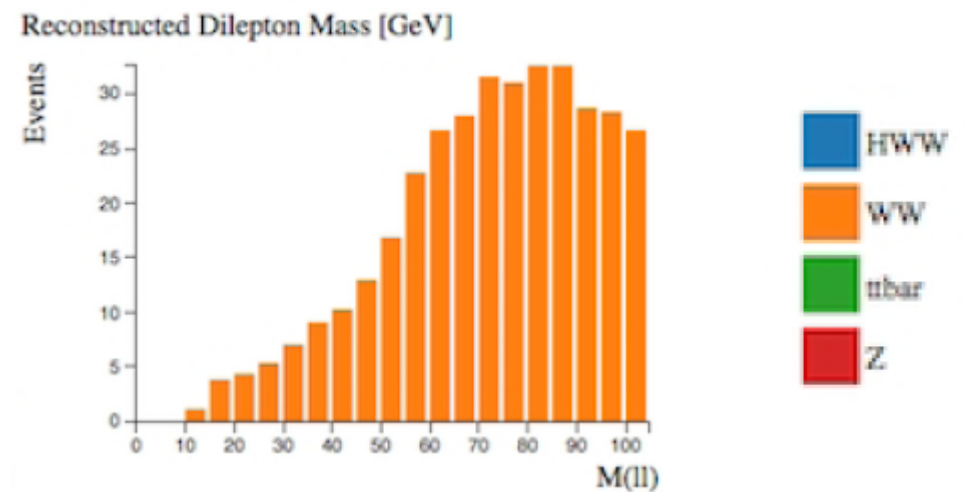


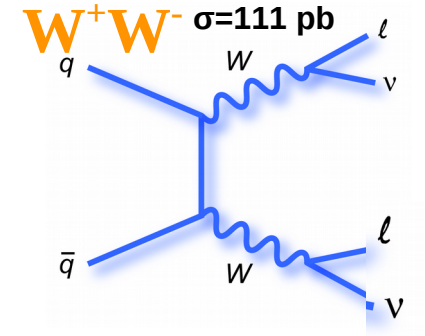
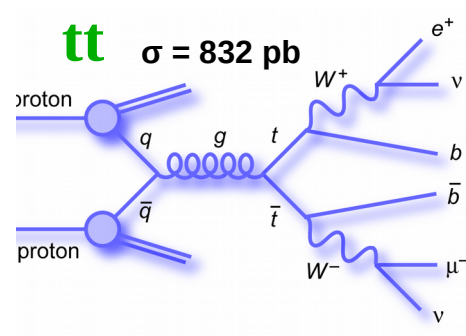
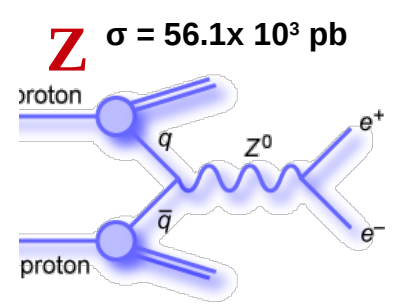
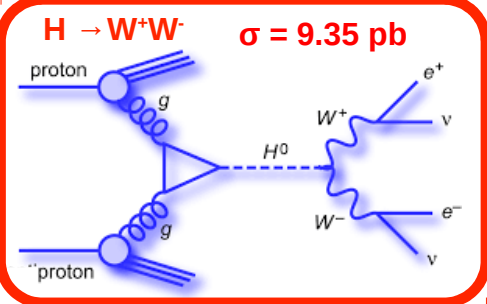
Spin 0 of the Higgs and the structure of W boson decays imply a final state characterised by a small angular separation between leptons (low  $\Delta\phi_{ll}$ ), small invariant mass of the dilepton system (low  $m_{ll}$ ) and large missing transverse momentum in the opposite direction of the lepton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

Prompt WW do not need to obey to these requirements!

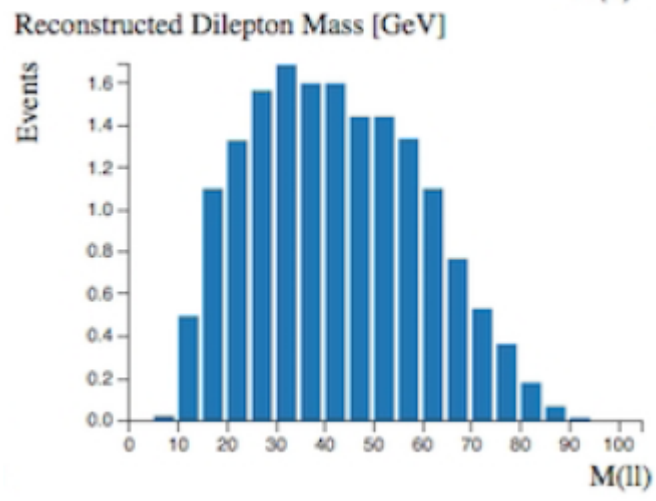
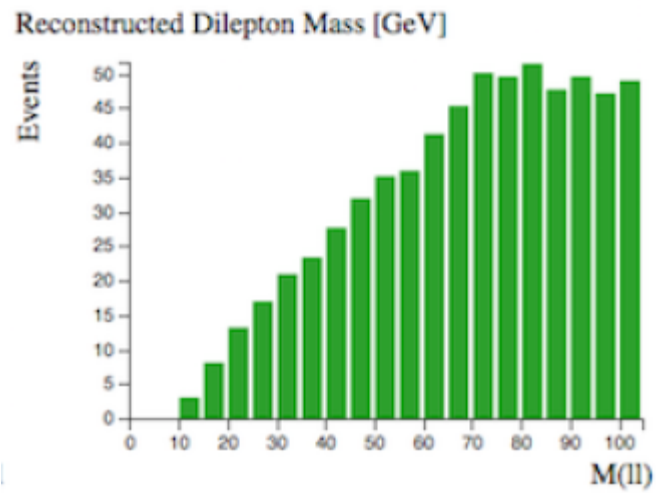
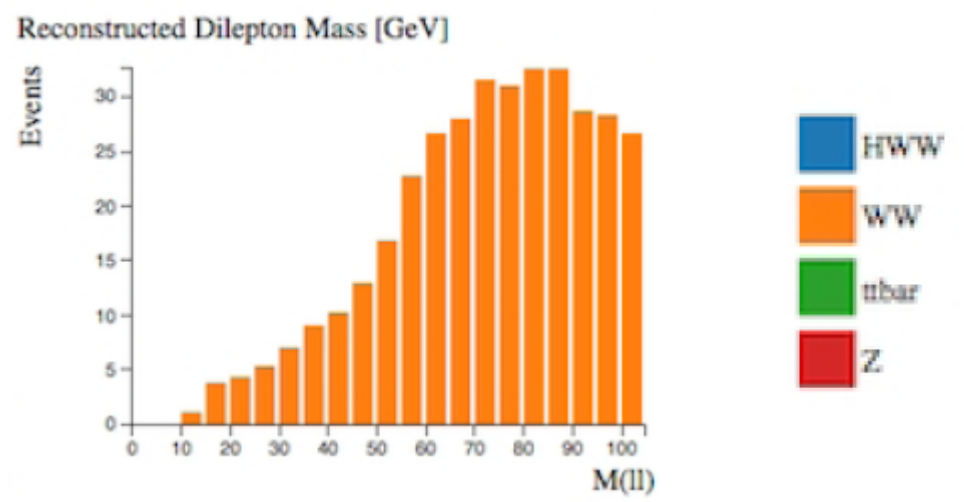
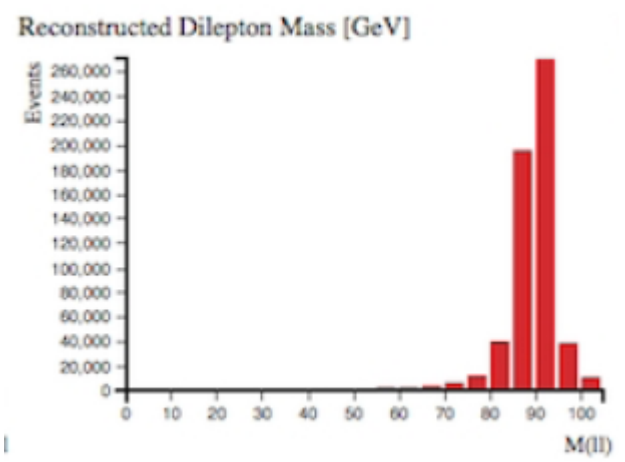


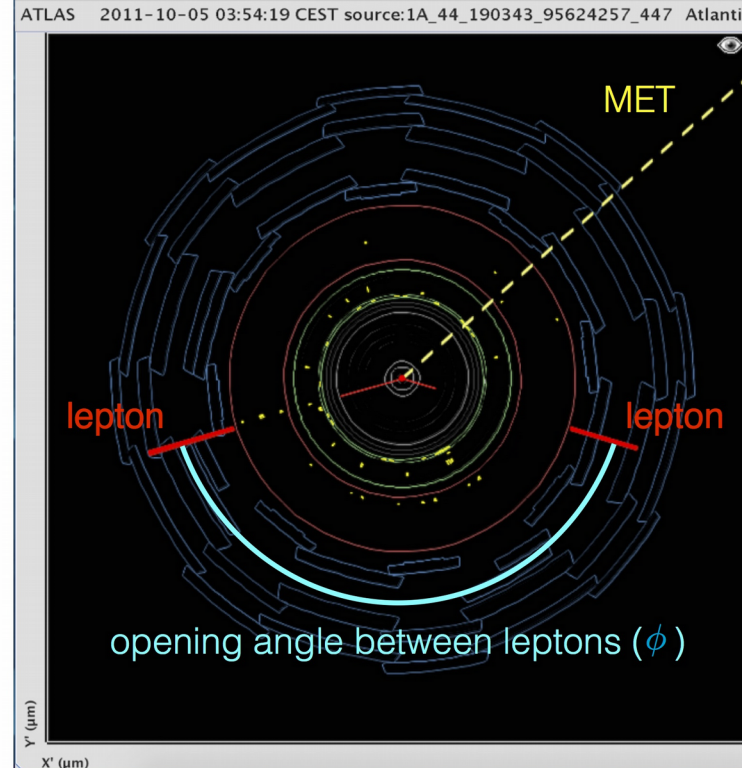
## Reconstructed Dilepton Mass [GeV]



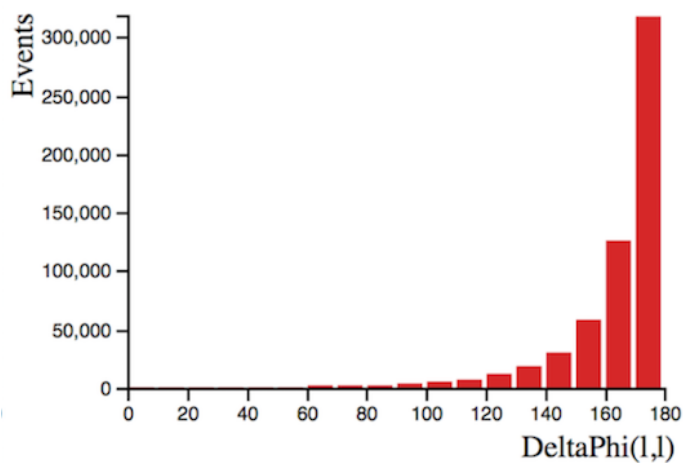


# Reconstructed Dilepton Mass [GeV]

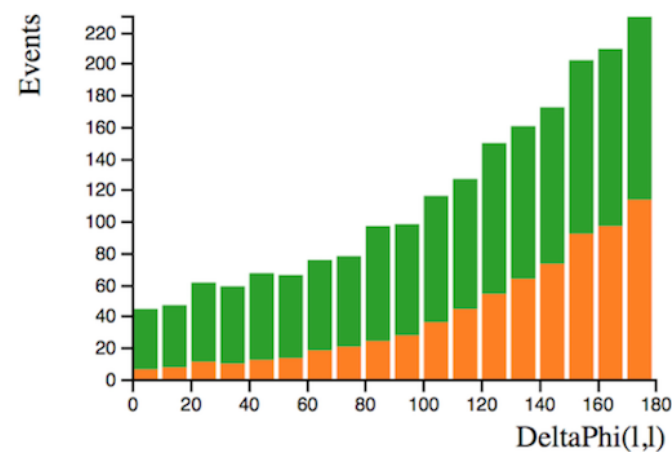




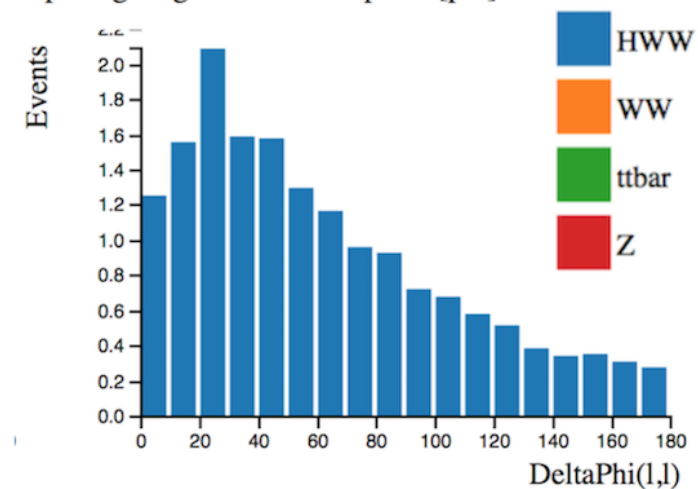
Opening Angle Between Leptons [phi]



Opening Angle Between Leptons [phi]

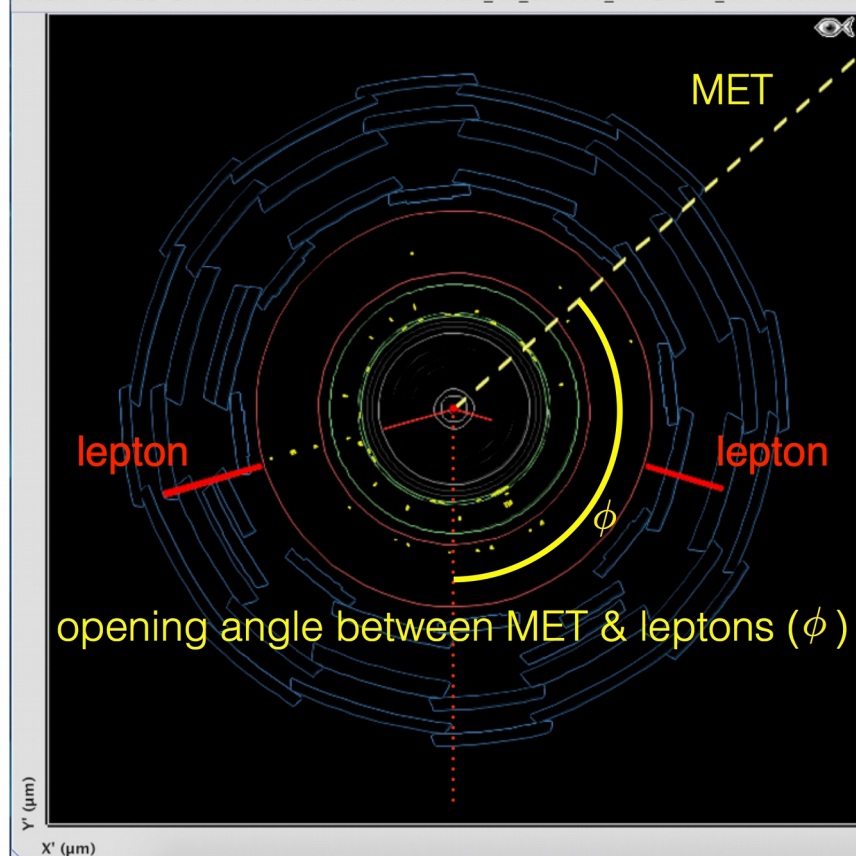
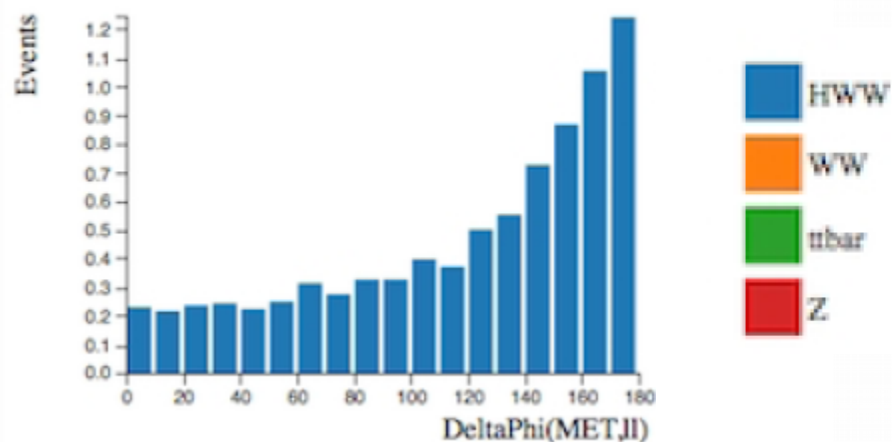
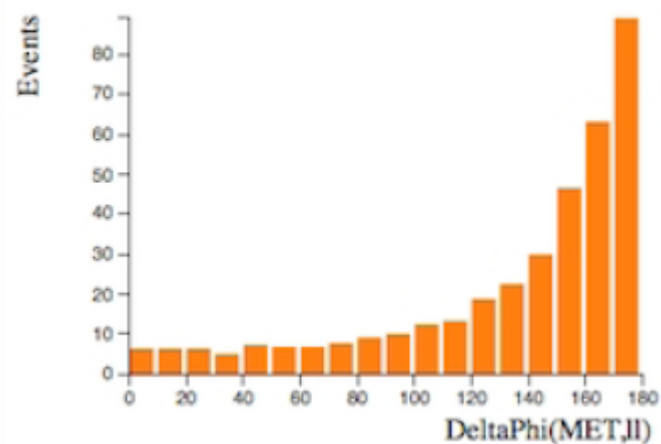
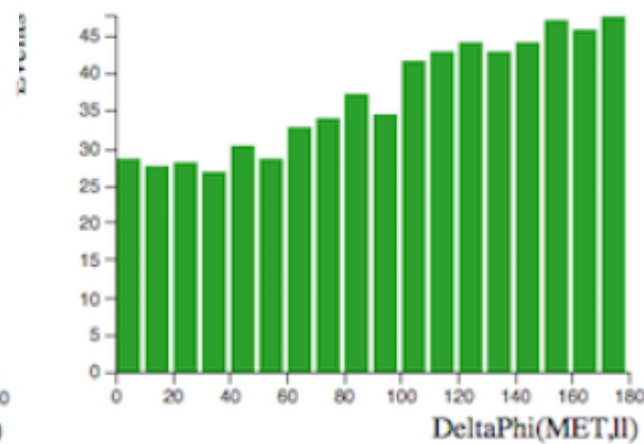
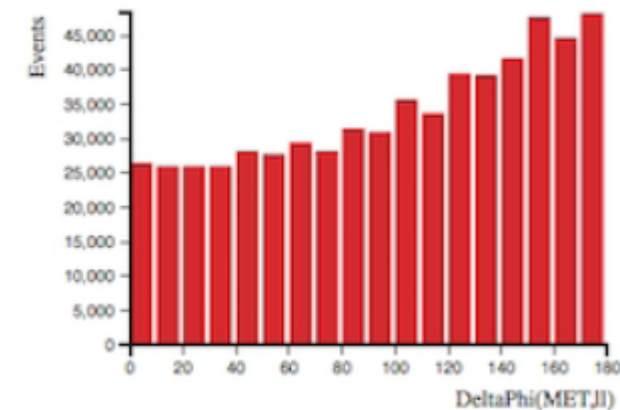


Opening Angle Between Leptons [phi]

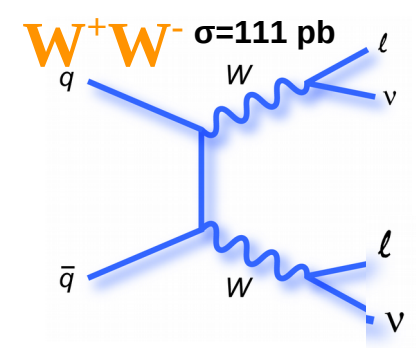
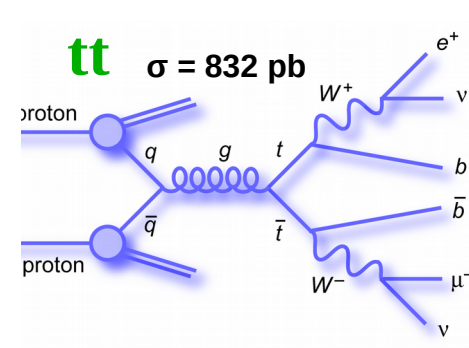
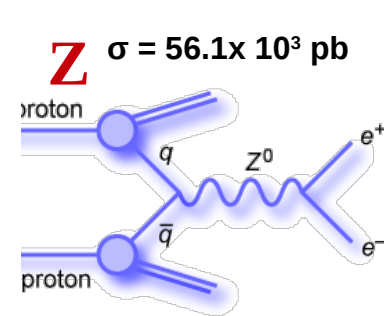
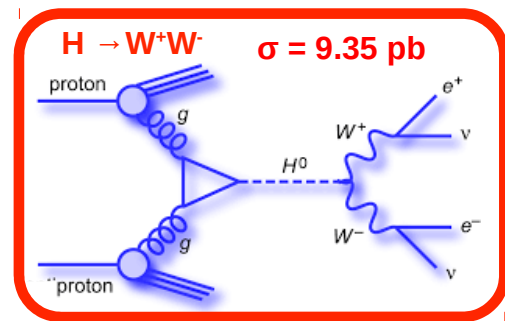


**Reconstructed dilepton mass and angular separation are golden variables to reject **WW****



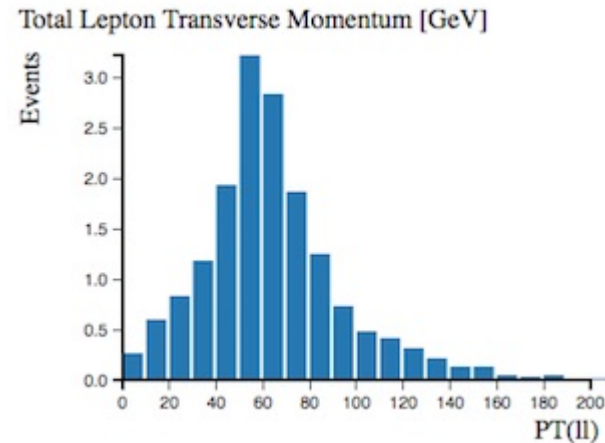
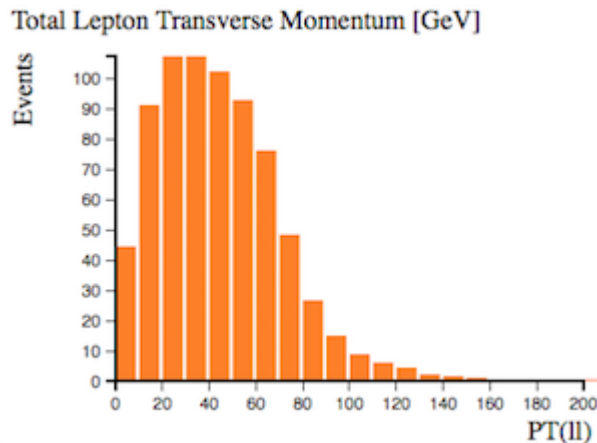
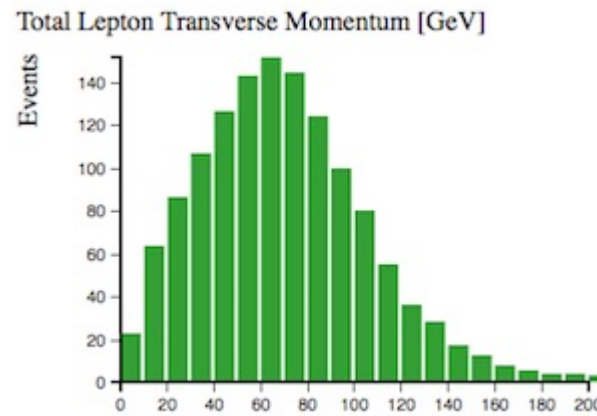
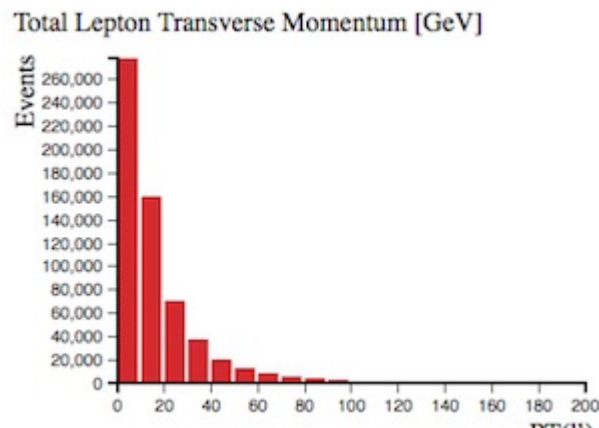
Opening Angle Between MET and Leptons [ $\phi$ ]Opening Angle Between MET and Leptons [ $\phi$ ]Opening Angle Between MET and Leptons [ $\phi$ ]Opening Angle Between MET and Leptons [ $\phi$ ]



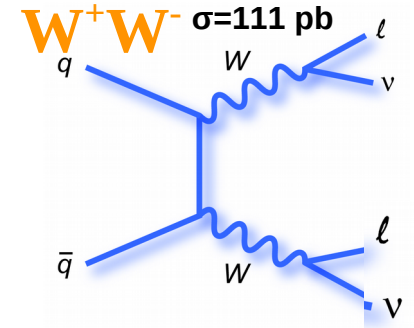
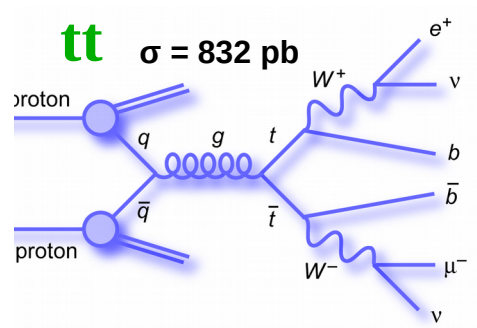
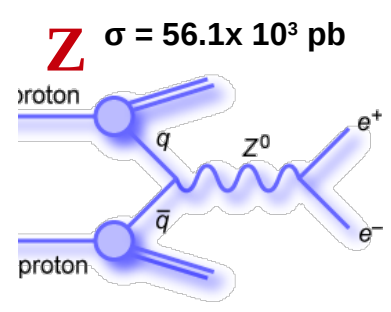
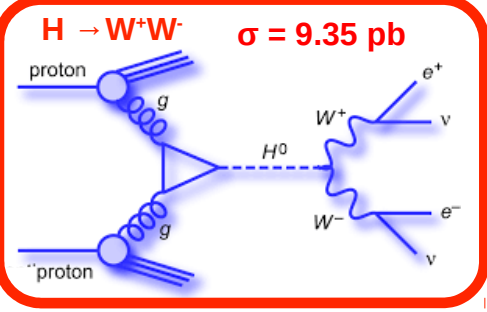


## Total Lepton Transverse Momentum [GeV]

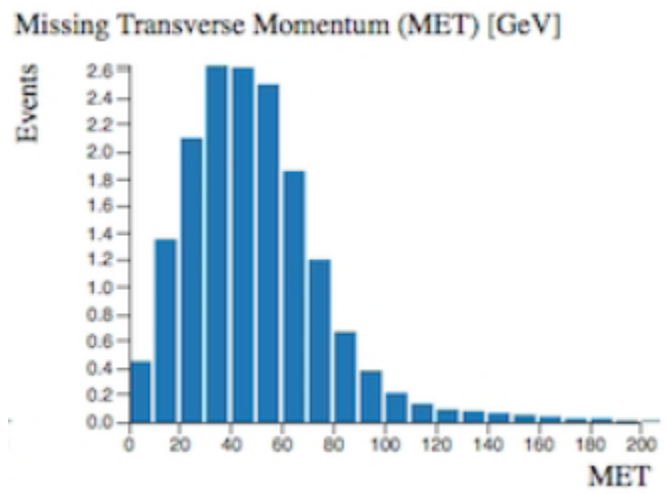
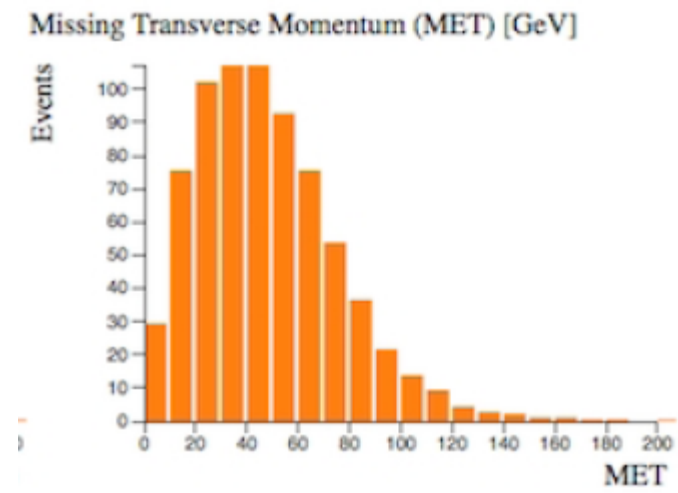
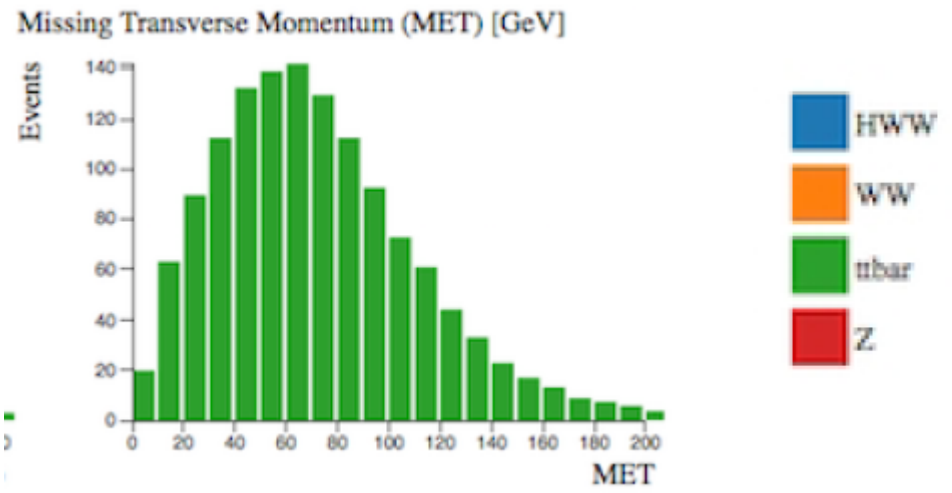
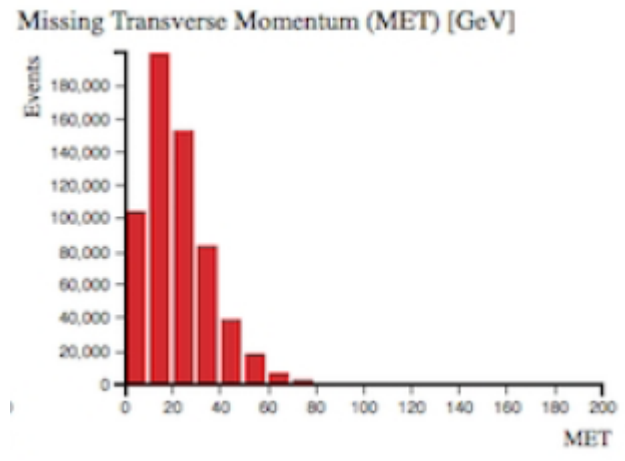
Vectorial sum of the transverse momenta of the observed charged leptons.



Important variable to remove Z backgrounds



# Missing Transverse Momentum (MET) [GeV]

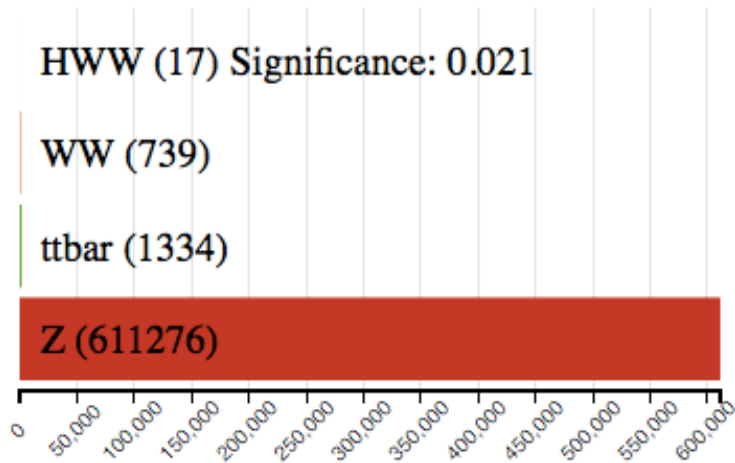


The presence of neutrinos in the final state does not allow for the full reconstruction of the Higgs boson mass. Transverse mass,  $m_T$ , is used, instead.

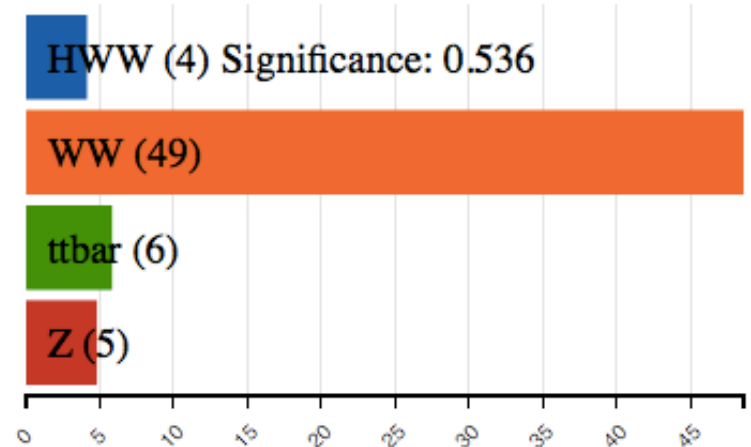
# Histogram analyser

The **significance** of the  $H \rightarrow W^+W^-$  events quantifies how "significant" the Higgs sample is with respect to the **background**. It is calculated by  $(\text{Number of } H \rightarrow W^+W^- \text{ events}) / \sqrt{\text{Number of background events}}$ . The larger the significance value is, the better job you have done extracting the Higgs **signal**.

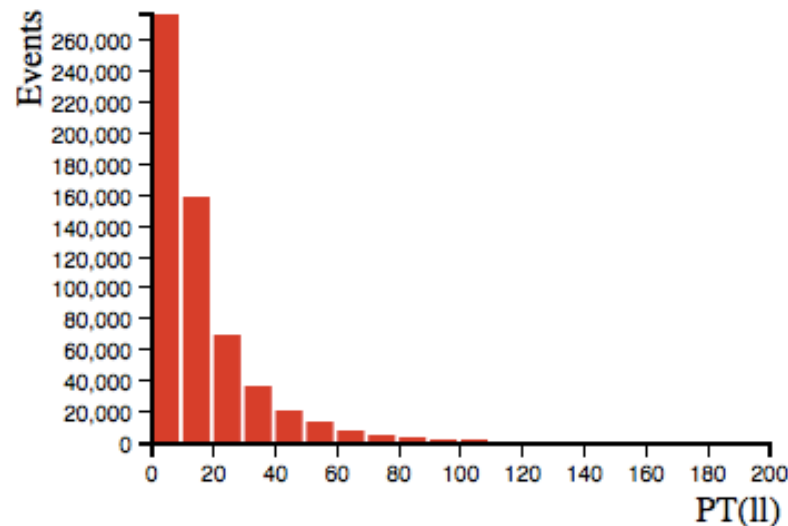
Expected Number of Events for 1/fb



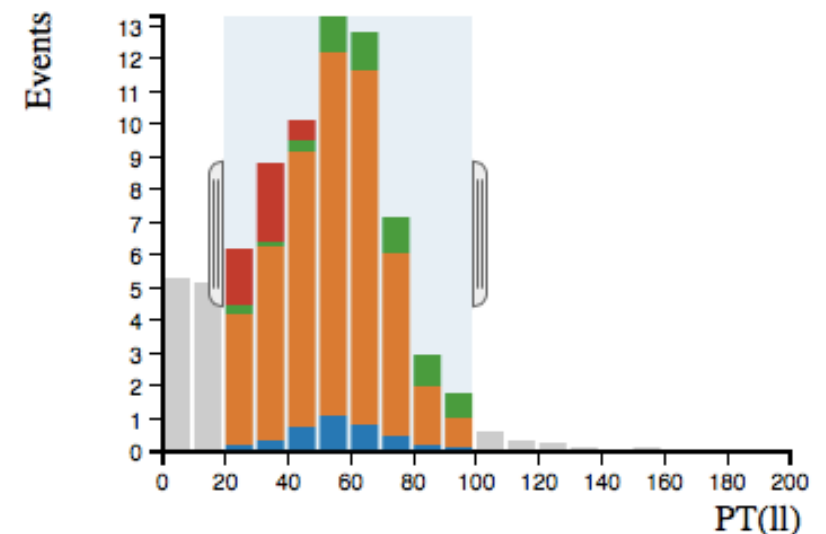
Expected Number of Events for 1/fb



Total Lepton Transverse Momentum [GeV]



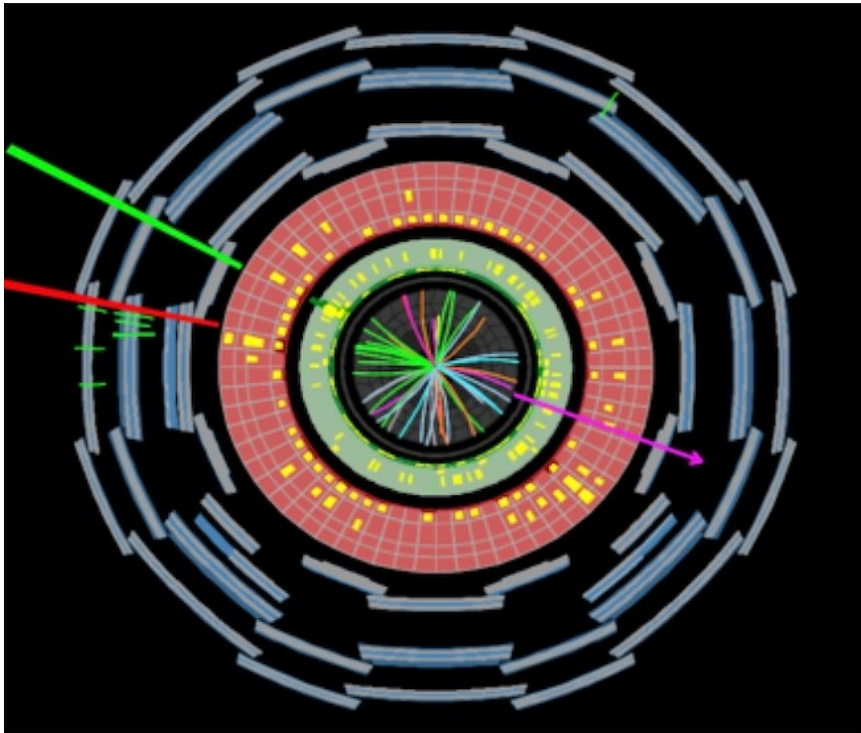
Total Lepton Transverse Momentum [GeV]



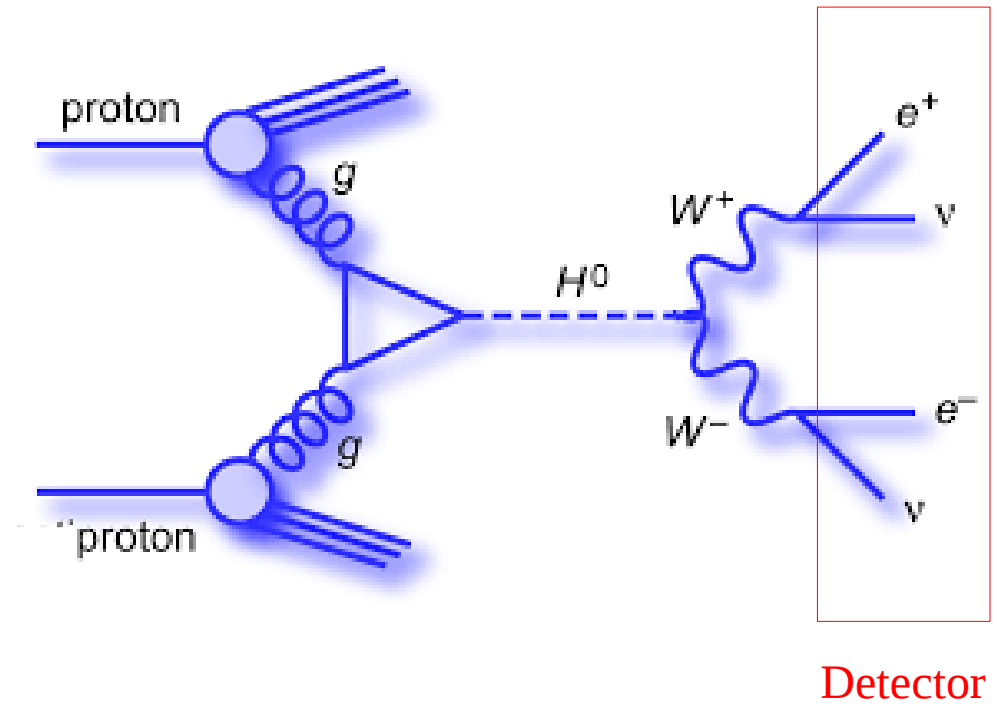
Backup

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

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



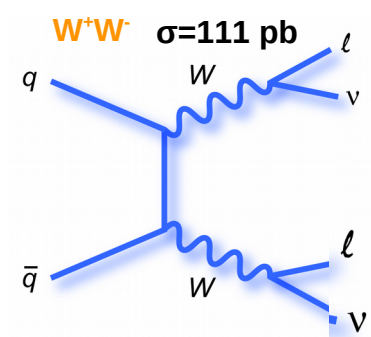
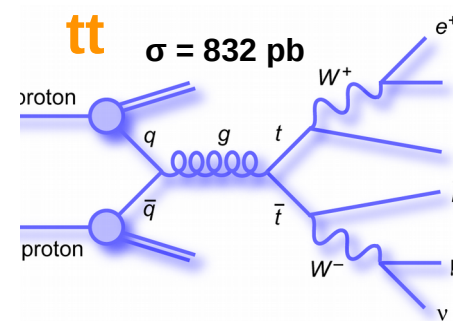
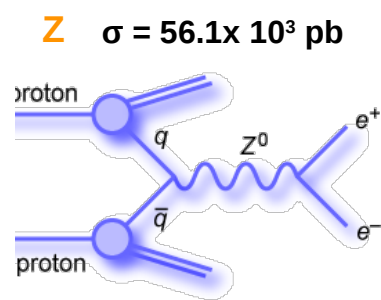
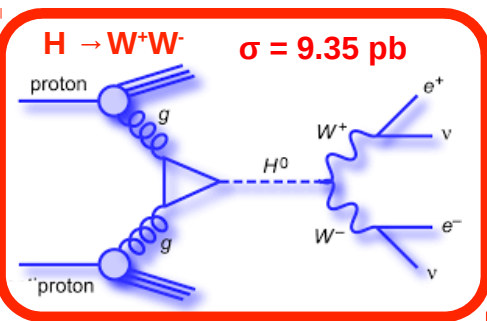
electron  $p_T$  (green): 33 GeV; muon  $p_T$  (red): 29 GeV;  
MET(purple): 35 GeV



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

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





**Significância:** A significância do processo H a decair num par de Ws, como o nome indica, mostra-nos quão significativo 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 decaimento 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 Transverse momentum** - Momento transversal dos dois leptões no estado final.

**Opening angle between leptons** - Ângulo de abertura entre os dois leptões - o ângulo 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 ângulo 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.