Higgs to 4 lepton mass spectrum using CMS Open Data

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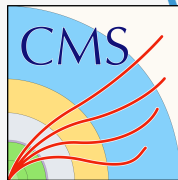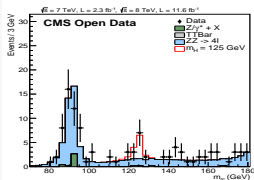Wuerzburg, Germany

March 19, 2018

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Introduction

- In 2012, the Higgs boson; the last piece of Standard Model was discovered at CERN
- Its discovery was crucial because Higgs mechanism explained how W and Z bosons acquire mass
- It can decay to 4 charged leptons through intermediate Z bosons and this decay channel is the cleanest experimentally
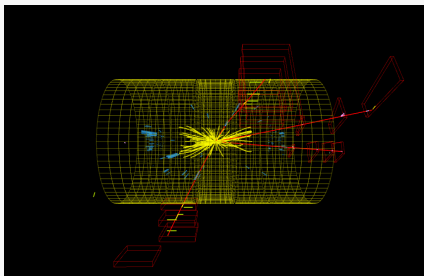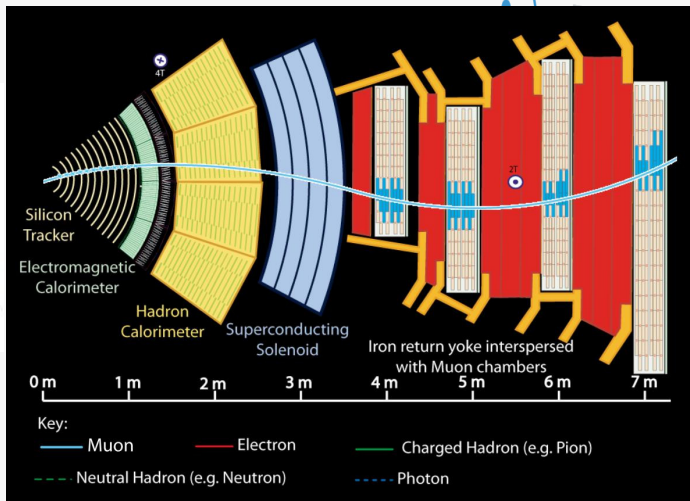

- The Compact Muon Solenoid (CMS) experiment is one of the experiments that confirmed the existence of the Higgs boson
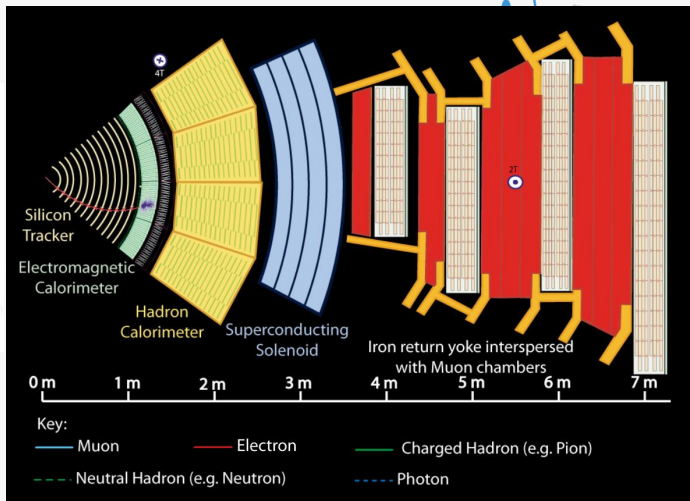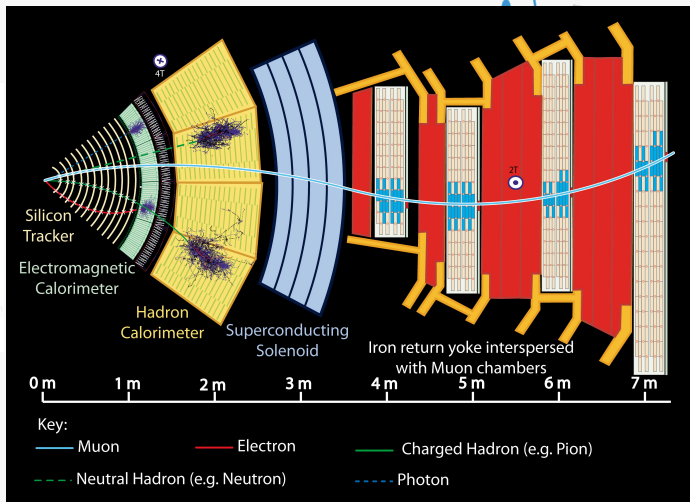
How does CMS detect particles?
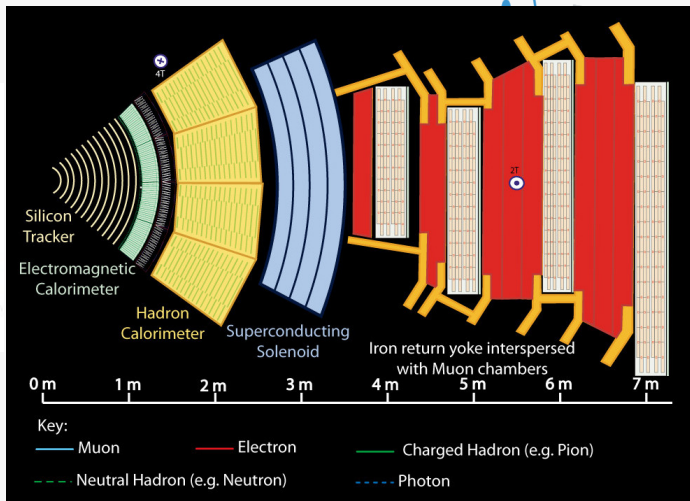
Transverse view of CMS detector

How does CMS detect particles?

Transverse view of CMS detector

How does CMS detect particles?

Transverse view of CMS detector

How does CMS detect particles?

Transverse slice through CMS

Silicon Tracker

Electromagnetic Calorimeter

Hadron Calorimeter

Superconducting Solenoid

Iron return yoke interspersed with Muon chambers

0 m   1 m   2 m   3 m   4 m   5 m   6 m   7 m

Key:
—— Muon —— Electron —— Charged Hadron (e.g. Pion)
- - - Neutral Hadron (e.g. Neutron) - - - Photon

Transverse view of CMS detector

CMS Open Data overview

- What is CMS Open Data?
  - CMS Open Data are original data used by CMS members that are released to the public via CERN Open Data portal: http://opendata.cern.ch/docs/about-cms
    (see also: https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSPublicData)
  - CMS made public around half of the Run1 data collected by the CMS detector at the Large Hadron Collider (LHC)

- Purpose?
  - **Research application**: to encourage people to **conduct and publish their own analysis** using original preserved data
  - **Educational application**: available to school pupils and university students for outreach and educational purposes using simplified data

- This talk focusses on **research application**

CERN Open Data portal

CERN Open Data homepage:
http://opendata.cern.ch/

CERN Open Data portal: CMS Experiment

Learn

Discover the world of open
data from particle physics

Welcome to our updated portal

**CMS Guide to education use of
CMS Open Data**

**Improving educational content
with high school teachers: A
field report from our summer
students**

Glossary

more

Visualise

Explore detector events and
run basic histogramming

CMS Event Display

CMS Histograms

Analyse

Run your own physics
analyses, start virtual
machines

**CMS Guide to research use of
CMS Open Data**

**ATLAS Higgs Machine
Learning Challenge**

**Getting Started with LHCb Open
Data**

**Getting Started with ALICE
Open Data**

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⇓ News ⇓

CERN Open Data homepage:

http://opendata.cern.ch/

Higgs to 4 lepton mass spectrum

- Higgs to 4 lepton is one of several examples available in CMS Open Data. This example is a strongly simplified analysis but similar to the one in the published paper
- Motivation:
  - To **approximately reproduce** H $\rightarrow$ ZZ $\rightarrow$ 4l (4e, 4μ & 2μ2e) mass spectrum using opendata source and compare with published paper Phys. Lett. B716 (2012) 30-61
  - To **provide example code** for Higgs search in CMS for educational and research purposes, to motivative feasability of new similar analyses
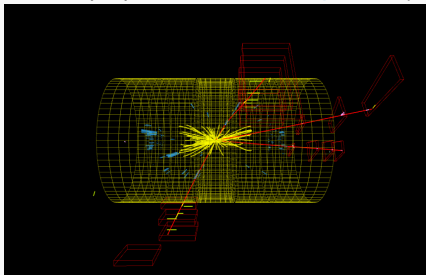
CMS event display of Higgs$\rightarrow$ 4μ event
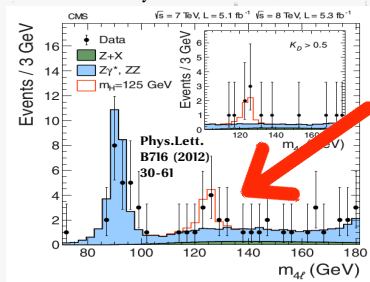
Higgs$\rightarrow$ 4l mass spectrum

The challenge

- Here is the list of challenges we met in order to setup this Higgs example:
  - How to pick up the right objects in the data and their documentation
  - How to know if there are additional selections, corrections etc.
  - Takes long time to complete a full analysis

# Original dataset and Monte Carlo (MC) samples, 2012 data

- Here are the lists of original dataset and MC samples in Analysis Object Data (AOD) format, same as used by CMS physicists

- For data: Muon and electron dataset (L = 11.6 fb^{-1})
  - /DoubleMuParked (for 4μ, $2\mu 2e$)
  - /DoubleElectron (for $4e$)
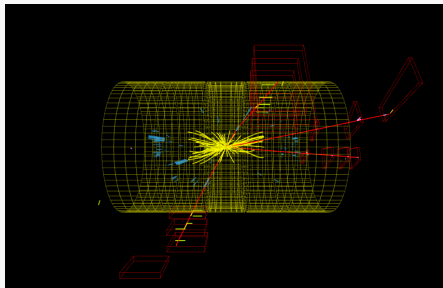
- For MC: To model the theory prediction
  - /ZZTo4mu_8TeV-powheg-pythia6
  - /ZZTo4e_8TeV-powheg-pythia6
  - /ZZTo2e2mu_8TeV-powheg-pythia6
  - /SMHiggsToZZTo4L_M-125_8TeV-powhegl5-JHUgenV3-pythia6
  - /DYJetsToLL_M-50_TuneZ2Star_8TeV-madgraph-tarball-tauola-tauPolarOff
  - /DYJetsToLL_M-10to50_HT-200to400_TuneZ2star_8TeV-madgraph-tauola
  - /DYJetsToLL_M-10to50_HT-400toInf_TuneZ2star_8TeV-madgraph-tauola
 - /TTbar_8TeV-Madspin_aMCatNLO-herwig
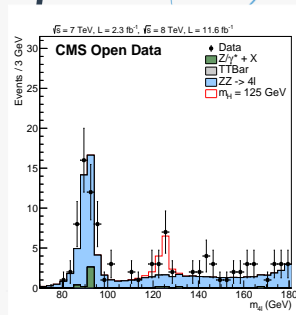
Similar for 2011 data

Object and Event Selection

- Muons and electrons selection
  - Muons and electrons are isolated
  - Transverse momentum, $p_T^\mu > 5$ GeV, $p_T^e > 7$ GeV
  - Geometrical acceptance, $|\eta_\mu| < 2.4$, $|\eta_e| < 2.5$
- Muons and electrons come from the same vertex
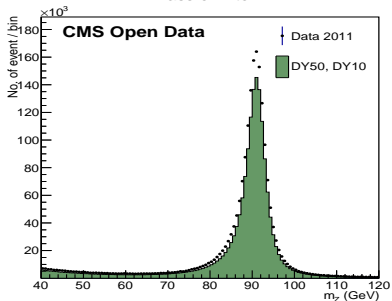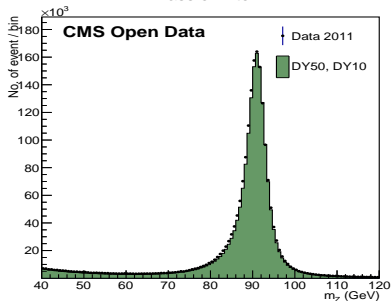- Ensure the total electrical charge and lepton number of $4l$ is 0

Phys. Lett. B716 (2012) 30-61

Data driven background normalization
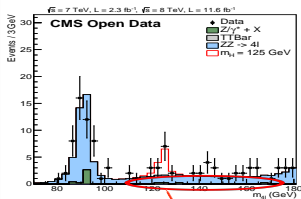
The MC is normalized to data
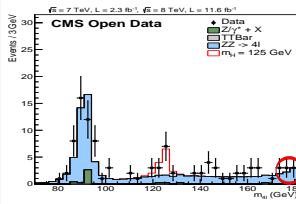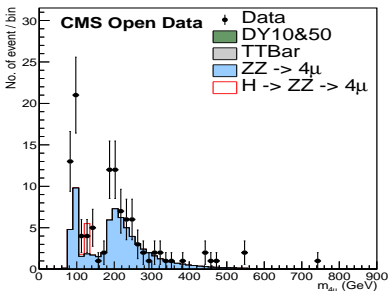
(From left) Mass of $Z \to 2l$ before and after the normalization

Data driven background normalization
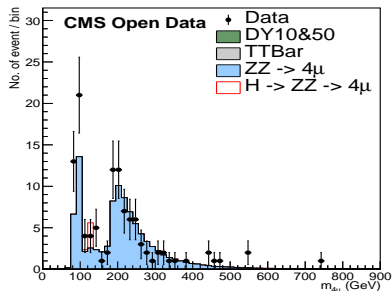

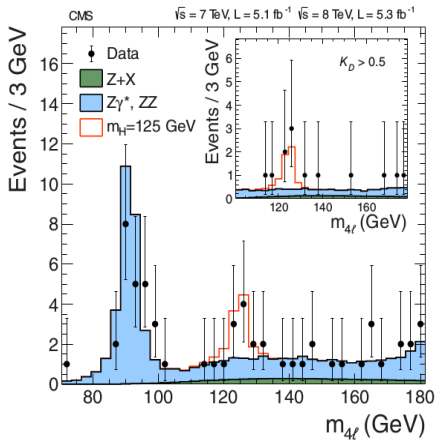The MC is normalized to data

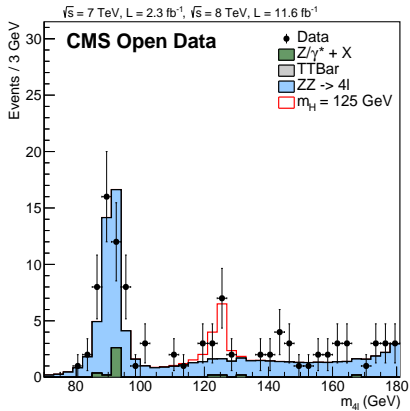mass of 4μ 2011 & 2012   mass of 4μ 2011 & 2012

(From left) Mass of 4μ before and after the normalization

4 lepton mass spectrum

Mass of 4l from published paper:
Phys. Lett. B716 (2012) 30-61

Mass of 4l from CMS Open Data. The Higgs contribution is normalized to the data in the signal region

How can YOU reproduce Higgs mass spectrum?

Step 1

CMS Guide to research use of CMS Open Data

`Documentation` `Guide`

If you are interested in step-by-step instructions to start working with CMS Open Data, please consult these pages:

- Install Virtual Machine ← *Install Virtual Machine*
- Get started with CMS Open Data

Get started with CMS Open Data

How can YOU reproduce Higgs mass spectrum?

Step 2

Higgs example

How can YOU reproduce Higgs mass spectrum?

- There are four levels of increasing complexity for this example:
  - (1) **Compare** the provided final output plot
    - Takes ~seconds
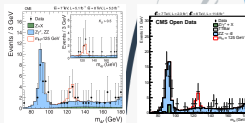
  - (2) **Reproduce** the final output plot from the predefined histogram files using a root macro
    - Takes ~few minutes to ~hours depending on setup and proficiency

  - (3) **Produce** root input files for the Higgs MC and for one data Higgs signal candidate
    - Takes ~1 hour if Virtual Machine is already installed
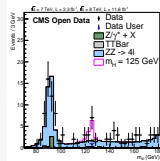
  - (4) **Reproduce** the full example analysis
    - Takes > 1 month on single CPU with fast internet connection

Conclusion

- CMS has **publicly** released 2010, 2011 and 2012 datasets and their corresponding MC, $\sim$half of the respective Run1 datasets
- **ANYONE** (public, external and internal researchers) can use CMS Open Data. e.g. reconstruct part of Higgs discovery!
- For research purposes, several analysis and validation examples are provided. (For educational purposes, there are a lot of fun activities too!)
- The provided higgs example is a simplified analysis. It was meant as a guide for people to **start, conduct and publish their own analysis**
- Feedback from users is always welcome :)

opendata.support@cern.ch

The end

backup

CMS Open Data additional information

- CMS Open Data for research: AOD format (CMS root)
  - 1st release: 28 TB of reconstructed 2010 7 TeV pp collision data in Nov. 2014
  - 2nd release: 130 TB of 2011 7 TeV pp collision data and >200 TB of corresponding MC data in April 2016
  - 3rd release: 8 TeV pp data + MC (∼2 PB) in Dec 2017

- CMS data preservation, re-use and open access policy: http://opendata.cern.ch/record/411

Original dataset and Monte Carlo samples for 2011

- Here are the list of original dataset and MC samples in Analysis Object Data (AOD) format, same as used by CMS physicists

- For data: */Run2011A-12Oct2013-v1/AOD (L = 2.3 fb^{-1})
  - /DoubleMu (for 4μ, $2\mu2e$)
  - /DoubleElectron (for $4e$)

- For MC: */Summer11LegDR-PU_S13_START53_LV6-v1/AODSIM
  - /ZZTo4mu_mll4_7TeV-powheg-pythia6
  - /ZZTo4e_mll4_7TeV-powheg-pythia6
  - /ZZTo2e2mu_mll4_7TeV-powheg-pythia6
  - /SMHiggsToZZTo4L_M-125_7TeV-powheg15-JHUgenV3-pythia6
  - /DYJetsToLL_M-50_7TeV-madgraph-pythia6-tauola
  - /DYJetsToLL_M-10To50_TuneZ2_7TeV-pythia6
  - /TTTo2L2Nu2B_7TeV-powheg-pythia6

Object and event selection

- Muon and electron selection
  - Relative isolation, rellso$_{\mu,e}$ < 0.4 with ΔR = 0.4
  - Transverse momentum, p_T^{μ} > 5 GeV, p_T^e > 7 GeV
  - Pseudorapidity, $|\eta_{\mu}|$ < 2.4, $|\eta_e|$ < 2.5
- Transverse impact parameter w.r.t. primary vertex, $|dx_T|$ < 0.5 cm
- Longitudinal impact parameter w.r.t. primary vertex, $|dz|$ < 1 cm
- 3D impact parameter significance, $|SIP_{3D}|$ < 4
- No. of $\mu, e \geq 4$ for case 4μ and $4e$
- No. of $\mu, e \geq 2$ for case $2\mu 2e$
- For Z_a[1], $p_T^{l_1}$ > 20 GeV and $p_T^{l_2}$ > 10 GeV
- 40 < m$_{z_a}$ < 120 GeV
- 12 < m$_{z_b}$ < 120 GeV
- m$_{4l}$ > 70 GeV
- Total charge and lepton number of $4l$ is neutral

[1]Z_a = The lepton pair that closest to Z mass