The HH$\rightarrow$bb$\tau\tau$ analysis

Why? What? How?

Jona Motta
jona.motta@polytechnique.edu

PHY584 Ministage - 12 January 2021

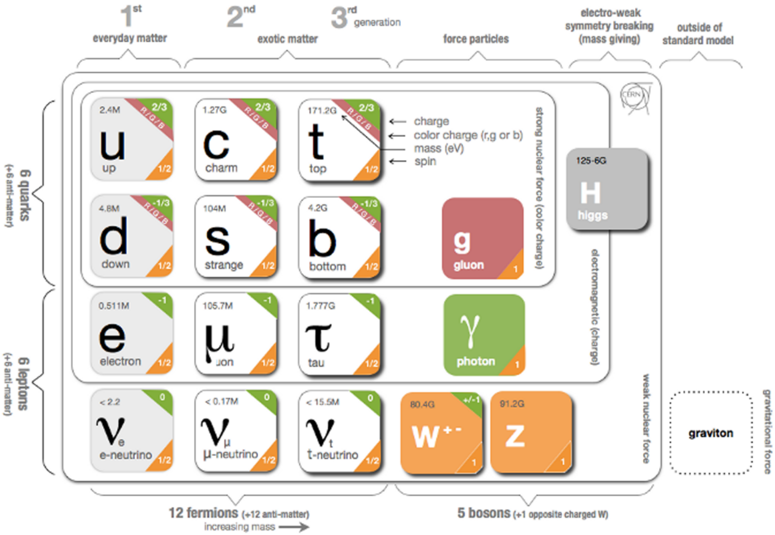
The Sandard Model and the Higgs boson

- The Standard Model (SM) is an $SU(2)_L \otimes U(1)_Y \oplus SU(3)_C$ renormalizable gauge quantum field theory
- Brout-Englert-Higgs mechanism postulates the existence of an omnipervasive scalar field $\Rightarrow$ Higgs bosons (H) are its excitations
- The BEH mechanism induces the Electroweak Symmetry Breaking (EWSB) and gives mass to the particles of the SM
- H discovered in 2012 and $m_H = 125.09 \pm 0.21(stat.) \pm 0.11(syst.)$ GeV (CMS + ATLAS combination at $\sqrt{s} = 7$ and 8 TeV)

$\Rightarrow$ the full characterization of the H is of foremost importance for the understanding of EWSB and fathom the fabric of the Universe

$\Rightarrow$ the European Strategy for Particle Physics deems the study of the H and Higgs boson pairs (HH) as the most important topic for the next 50 years HEP studies

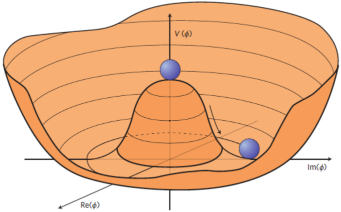
The Standard Model of Particle Physics



Higgs boson pairs and Higgs potential

The Higgs potential can be written as:

$$V(\Phi) = \frac{1}{2}(2\mu)^2 + \frac{\mu^2}{v}H^3 + \frac{\mu^2}{4v}H^4$$
$$= \frac{1}{2}m_H^2 H^2 + \lambda_{HHH} v H^3 + \lambda_{HHHH} H^4$$



where:

$$\lambda_{HHH} = 4\lambda_{HHHH} = \frac{m_H^2}{v^2}$$

We can then define the modifier $\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{HHH}^{SM}}$ to look for deviations from the SM

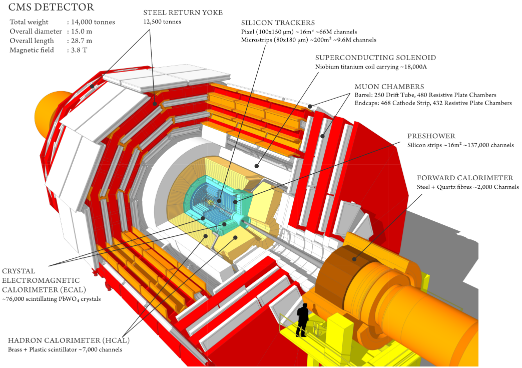
$\Rightarrow$ goal of today's physics is to put limits on κ_λ (and in the future measure it)

$\Rightarrow$ goal of your work is to get a glimpse of how we can achieve that

The CMS experiment

The Compact Muon Solenoid experimental apparatus:

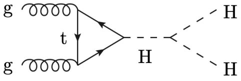
- Multi-purpose apparatus (SM and BSM)
- Superconducting solenoid $\rightarrow$ 3.8T field parallel to the beam
- Tracking and momentum measurements:
  - silicon tracker
  - μ-chambers
- Energy measurements:
  - ECAL
  - HCAL



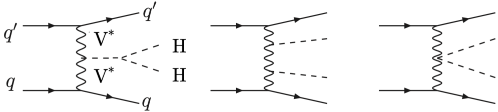
Channel of interest: Higgs bosons pairs

The channel of interest is the Higgs bosons pairs (HH) production

The main contribution is gluon fusion (ggF) via a quark loop (mainly top):
$\sigma_{ggF}^{NNLO}(13\,TeV) \approx 31\text{fb}$



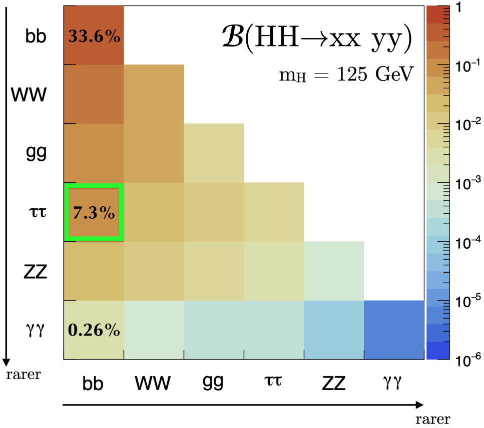
The second contribution is Vector Boson fusion (VBF): $\sigma_{VBF}^{N3LO}(13\,TeV) \approx 1.7\text{fb}$



The bb$\tau\tau$ channel

The selected final state is HH$\rightarrow$ $bb\tau\tau$ which has $\mathcal{B}(HH \rightarrow bb\tau\tau) = 7.3\%$

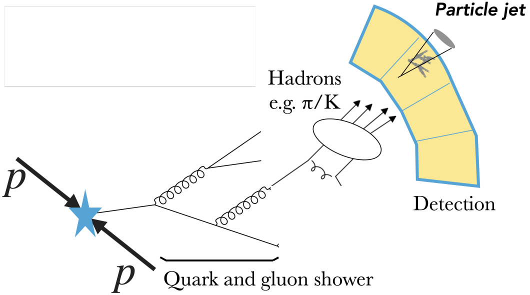
The bb$\tau\tau$ final state gives a good compromise between the branching ratio $\mathcal{B}$ and the selection purity

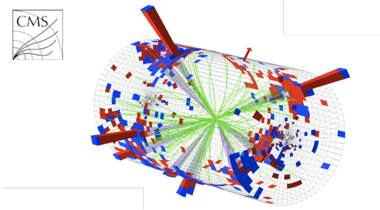


$\Rightarrow$ use the purity of the $\tau\tau$ channel to tag the event

Hadronic jets

Quarks and gluons give rise to the so-called jets, which are their typical signature in CMS $\Rightarrow$ the b quarks in our work will always be reconstructed as so-called **b jets**





BUT quarks and gluons are not the only particles that give rise to jets!!

The τ lepton

The heaviest lepton of the SM: a mass of about 1.7 GeV

Lifetime of about $2.9 \cdot 10^{-13}$s $\rightarrow$ in CMS a τ with a momentum of 40 GeV flies on average 2 mm before decaying

	Decay mode	Resonance	$\mathcal{B}$ (%)
	Leptonic decays		35.2
≈ 1/3 of the decays **Covered by the standard e/μ algorithms**	$\tau^- \rightarrow e^-\bar{\nu}_e\nu_\tau$		17.8
	$\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau$		17.4
	Hadronic decays		64.8
≈ 2/3 of the decays **τ_h, or sometimes just "τ"** ‣ dedicated L1 and HLT triggers ‣ dedicated reconstruction algorithms ‣ dedicated analysis methods	$\tau^- \rightarrow h^-\nu_\tau$		11.5
	$\tau^- \rightarrow h^-\pi^0\nu_\tau$	$\rho(770)$	25.9
	$\tau^- \rightarrow h^-\pi^0\pi^0\nu_\tau$	$a_1(1260)$	9.5
	$\tau^- \rightarrow h^-h^+h^-\nu_\tau$	$a_1(1260)$	9.8
	$\tau^- \rightarrow h^-h^+h^-\pi^0\nu_\tau$		4.8
	Other		3.3

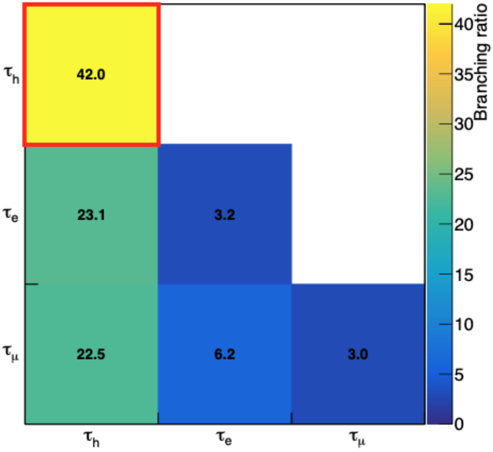
The tau is the only lepton whose study needs hadronic signatures

H$\rightarrow \tau\tau$ categorization

We categorize the H$\rightarrow \tau\tau$ channel depending on the decay mode of the τ

You will use only the hadronic decay $\tau_h\tau_h$

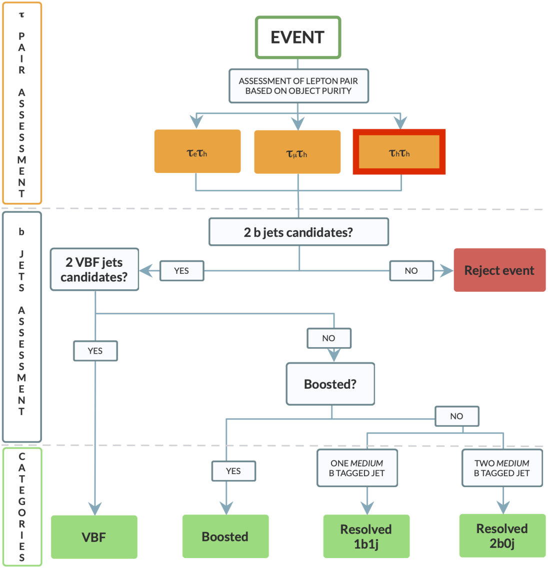
$\rightarrow$ only 42% of the total final states



Event categorization

We categorize the events depending on:

- $\tau\tau$ decay pair type
- presence of VBF jets candidates
- topology of b jets pair



What will we do

The main goal of the work you will do is to study:

- the selection criteria used in the analysis and to play around with them (understand efficiency and purity tradeoff)
- the kinematic variables of the Higgs decay products and understand their behaviour
- the kinematic differences between the two production modes (ggF and VBF)
- the backgrounds and to calculate the QCDbkg with the ABCD method
- the definition of a signal region (and comparison of your ideas with the actual definition of the analysis)
- OPTIONAL: do a maximum likelihood fit to obtain upper limits on the production cross section

For next time

Read these articles: τ reco and ID in CMS, jet reco in CMS, b-jet tagging in CMS (a support reference when you don't know the specific components of the CMS detector is CMS detector)

$\rightarrow$ understand them as much as possible, they are literally the basics of the entire work you will be doing! When you are completely stuck just write me an email or on Skype and I will answer ASAP.