Faculté de physique et ingénierie Université de Strasbourg

CMS

Study of Higgs boson pair production in the bbττ channel with CMS Experiment

Léa-Maria Rabour

Under the supervision of Louis Portalès

20/06/2024

Outline

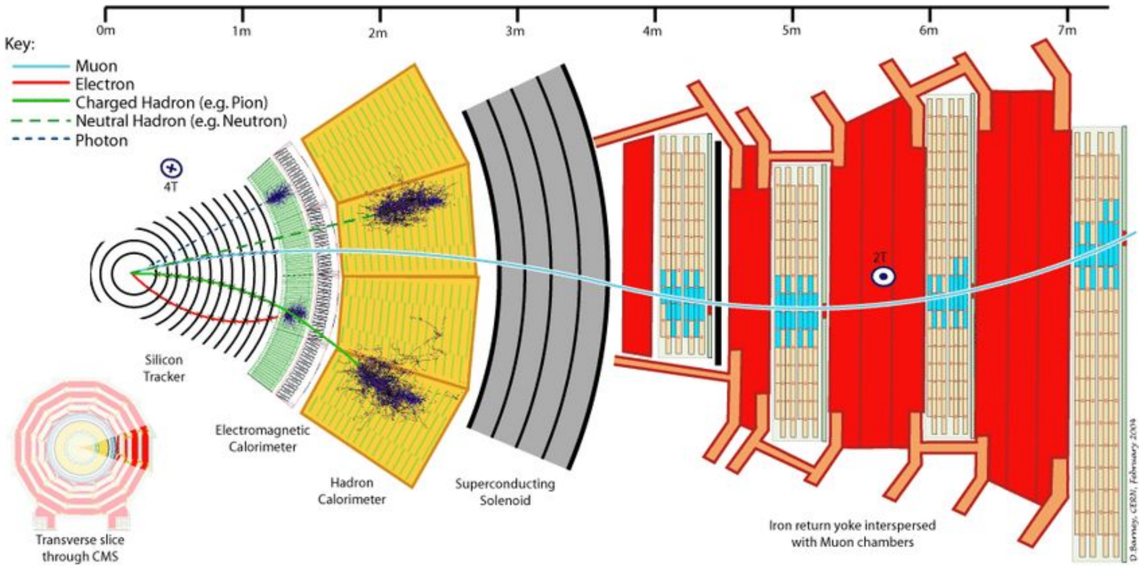
I. Introduction : LHC, di-Higgs and $bb\tau\tau$

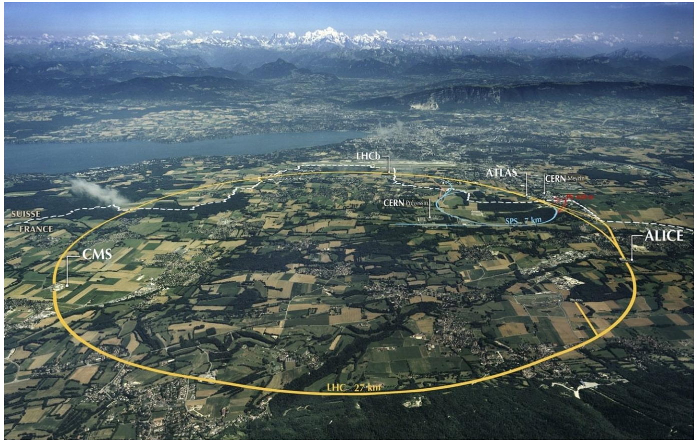
II. Impact study of Powheg bug on Run 2 analysis

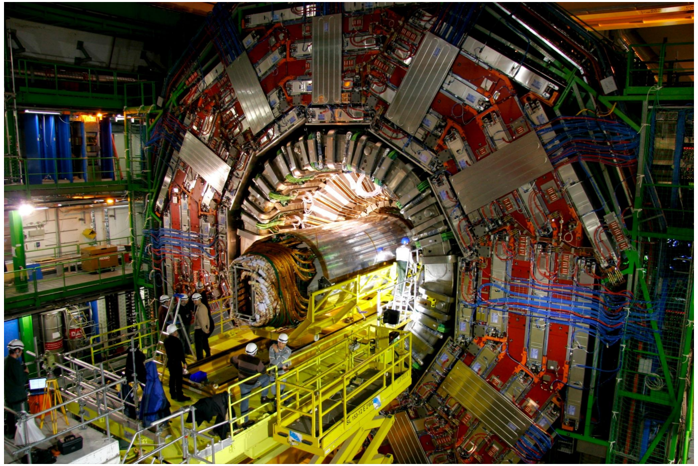
III. Trigger selection for Run 3 analysis

Introduction

CMS Experiment at LHC

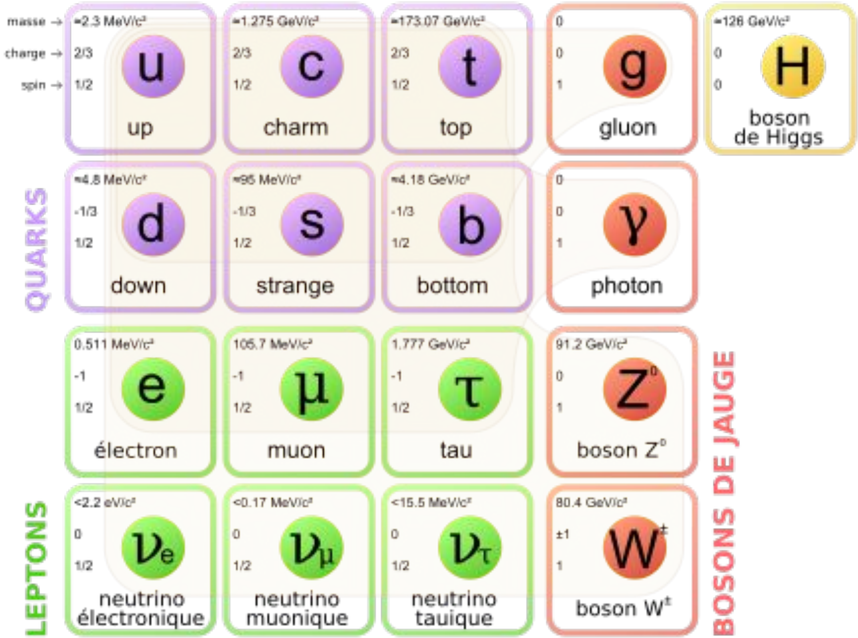






CMS : 22x15x15 m, 14000 t

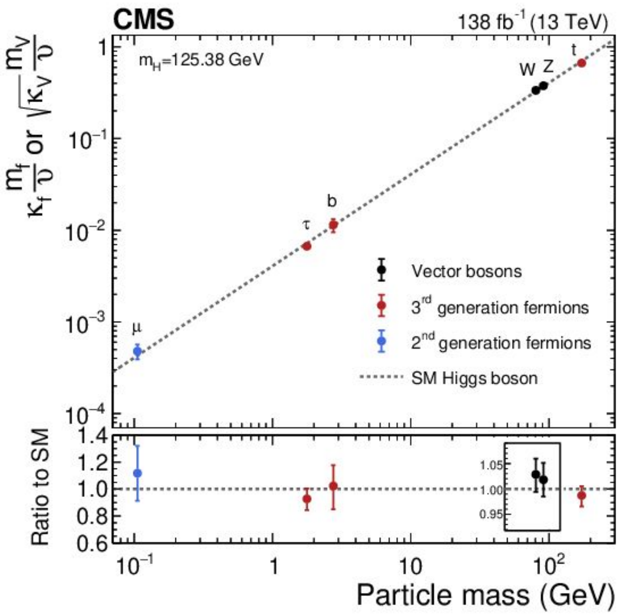
Higgs boson : discovered in 2012 and studied since



Higgs mechanism explains how elementary particles acquire their mass

Cham, Jorge, PhD Comics

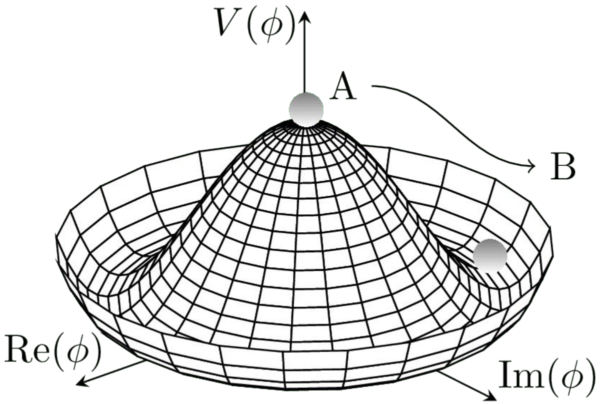
Higgs potential and self coupling



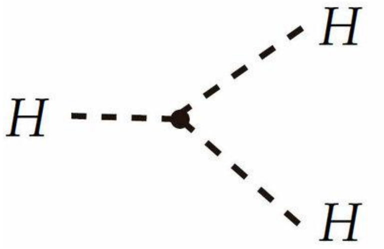
réf: Nature

$$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_3 v H^3 + \lambda_4 H^4 - \frac{1}{8} m_H^2 v^2$$

not yet measured!

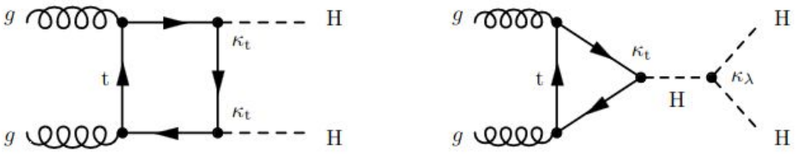


$$\lambda = \frac{m_H^2}{2v^2}$$

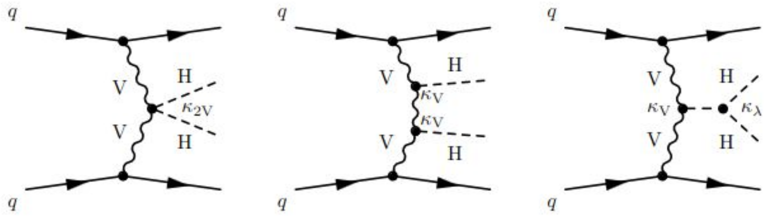


Higgs boson pair production at LHC

ggF : ~ 90%



VBF : ~ 5%



σ(HH)~30 fb 1000x lower than σ(H)~40 pb : very rare process never measured!

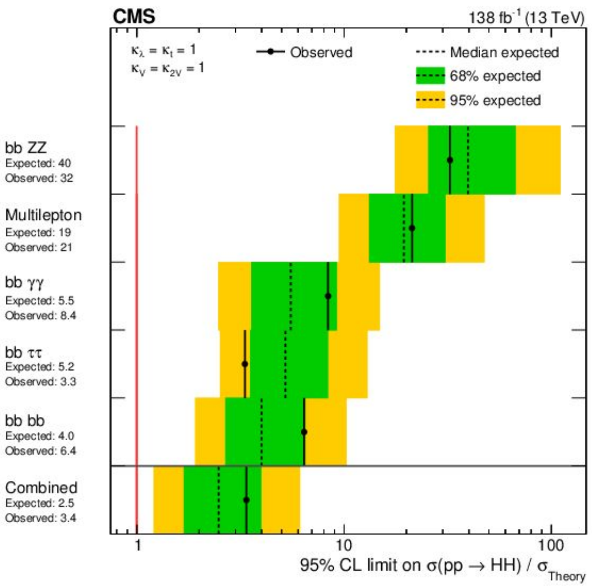
BRs (H_1 ↓ / H_2 →)	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

$$\kappa_\lambda = \frac{\lambda}{\lambda^{SM}}$$

Mainly :

- ★ **bbbb** : largest branching ratio but large QCD background
- ★ **bb$\gamma\gamma$** : excellent resolution on diphoton H mass but very low branching ratio
- ★ **bb$\tau\tau$:** intermediate branching ratio and background

Status of HH analyses



We are now starting Run 3 (2022-2025) analysis, and we plan to combine it to Run 2 (2015-2018) for better statistics

Current CMS limits 95%CL :

σ/σ_{SM} < 3.4 (expected σ/σ_{SM} < 2.5)

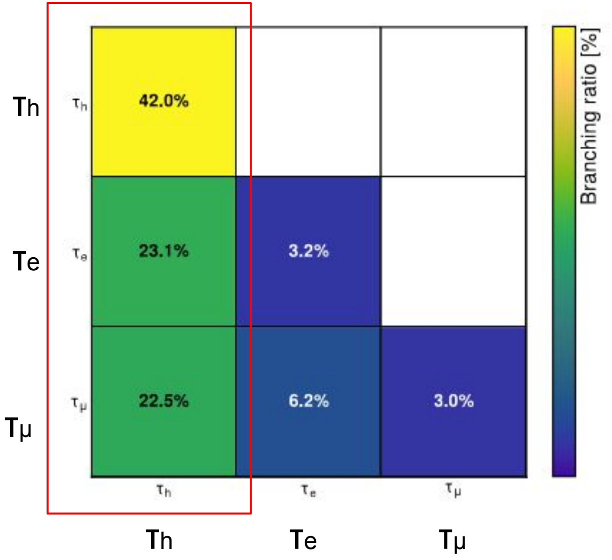
-1.24 < κ_λ < 6.49

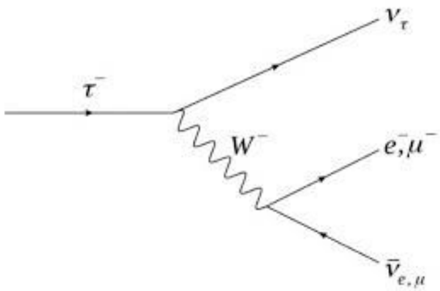
2 ways to improve statistics :

- **take more data**
- **improve data selection →triggers**

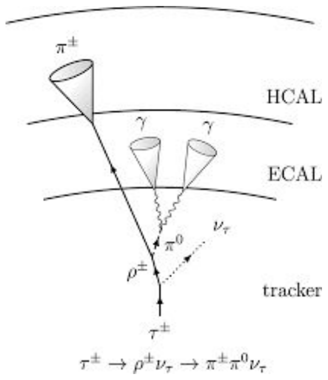
HH→bbττ

3 channels considered for diTau decays : **eτ** (τ_e τ_h), **μτ** (τ_μ τ_h) & **ττ** (τ_h τ_h)
(87.6% of all diTau decays)





leptonic tau decay



hadronic tau decay

Impact study of Powheg bug on Run 2 HH→bbττ analysis

Impact study of Powheg bug

see G.Heinrich presentation
for more details on the bug

Monte Carlo events generators produce simulations used in the analyses

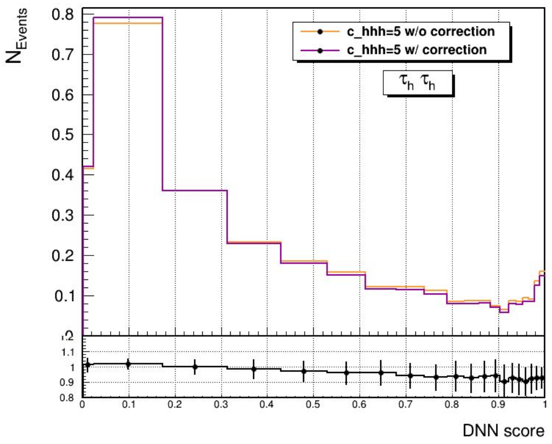
Bug on MC generator POWHEG for ggHH events, used in both CMS and ATLAS Run 2 HH analyses **already published**

→ necessity to study the impact on Run 2 bbττ analysis

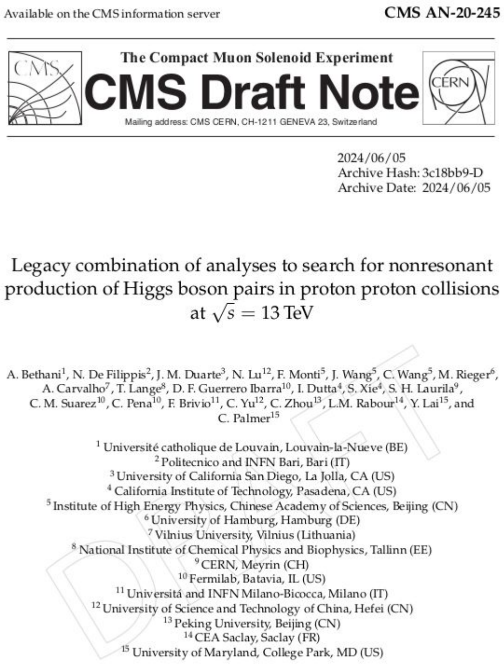
➔ Impact study on several variables for κλ=2.45 and κλ=5 comparing histograms with and without correction factors in the 3 channels : eτ, μτ, ττ. One of these variables is the score of the DNN used to discriminate signal from background

Impact on the yield

	κλ=2.45	κλ=5
eτ	1.4%	1.3%
μτ	1.1%	1.2%
ττ	2.3%	2.6%



Impact study of Powheg bug


Available on the CMS information server

CMS AN-20-245

The Compact Muon Solenoid Experiment

CMS Draft Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

2024/06/05
Archive Hash: 3c18bb9-D
Archive Date: 2024/06/05

Legacy combination of analyses to search for nonresonant production of Higgs boson pairs in proton proton collisions at $\sqrt{s} = 13$ TeV

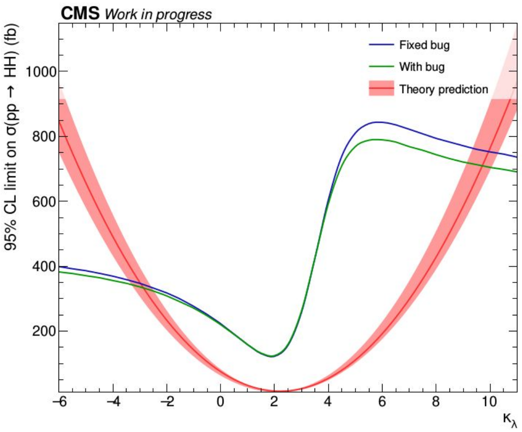
A. Bethani[1], N. De Filippis[2], J. M. Duarte[3], N. Lu[12], F. Monti[5], J. Wang[5], C. Wang[5], M. Rieger[6], A. Carvalho[7], T. Lange[8], D. F. Guerrero Ibarra[10], I. Dutta[4], S. Xie[4], S. H. Laurila[9], C. M. Suarez[10], C. Pena[10], F. Brivio[11], C. Yu[12], C. Zhou[13], L.M. Rabour[14], Y. Lai[15], and C. Palmer[15]

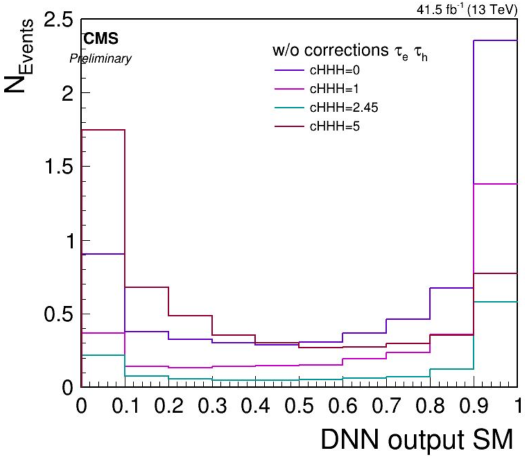
[1] Université catholique de Louvain, Louvain-la-Nueve (BE)
[2] Politecnico and INFN Bari, Bari (IT)
[3] University of California San Diego, La Jolla, CA (US)
[4] California Institute of Technology, Pasadena, CA (US)
[5] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing (CN)
[6] University of Hamburg, Hamburg (DE)
[7] Vilnius University, Vilnius (Lithuania)
[8] National Institute of Chemical Physics and Biophysics, Tallinn (EE)
[9] CERN, Meyrin (CH)
[10] Fermilab, Batavia, IL (US)
[11] Universitá and INFN Milano-Bicocca, Milano (IT)
[12] University of Science and Technology of China, Hefei (CN)
[13] Peking University, Beijing (CN)
[14] CEA Saclay, Saclay (FR)
[15] University of Maryland, College Park, MD (US)

DRAFT

Results

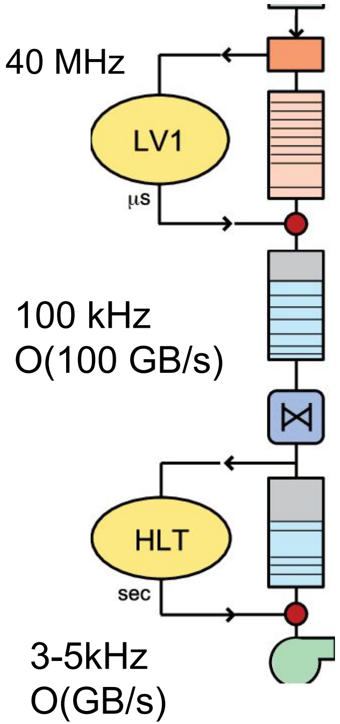
- Effect on the cross section and kl constraints of less than 3% : negligible
- Study added to an analysis note on HH Run 2 combination
- Proportion of high DNN score for κλ=5 lower than expected since DNN is trained for SM →to be improved for Run 3





Trigger selection for Run 3 analysis

Triggers



Too many data to save all events at LHC : 40M BX/s and 1BX ~ 1MB → O(40TB/s)
In one year ~200 ZB ie 10^9 TB…

→Triggers needed to realise a first selection online (reconstruction more limited than during the analysis)

HLT : OR logic →more triggers = more data

3 Baselines (triggers we used in Run 2 and will continue using in Run 3) :

eτ : isolated e, pT>32 GeV OR
isolated e, pT>24 GeV, |η|<2.1 && tau, pT>30 GeV, |η|<2.1

μτ : isolated μ, pT>24 GeV OR
isolated μ, pT>20 GeV, |η|<2.1 && tau, pT>20 GeV, |η|<2.1

ττ : 2 taus, pT>35 GeV, |η|<2.1

Gain study

New triggers used in Run 3 : study of the improvement on the selection for κ_λ=0 and κ_λ=1 with 2023 samples

- 4 jets among which 2 tagged as b jets (**4jets2b**)
- single hadronic tau with high pT (**single tau**)
- a pair of hadronic taus and a jet (**diTau+jet**)
- missing transverse energy (**MET**)

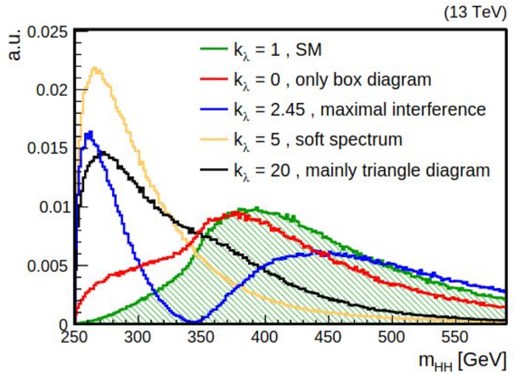
$$gain = \frac{\text{Trigger OR baseline}}{\text{baseline}} - 1$$

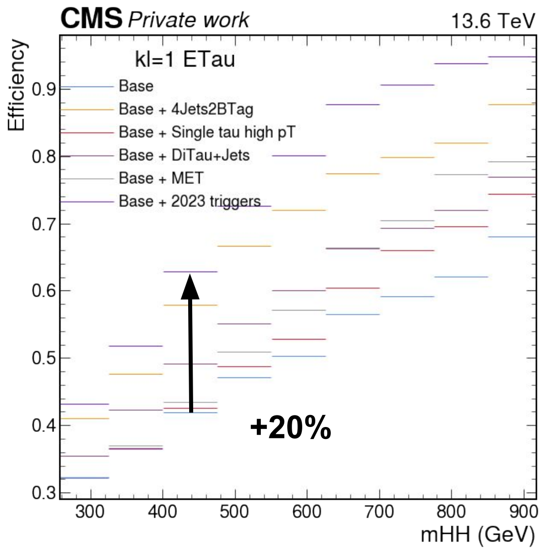
κ_λ=0	etau	mutau	tautau
4jets2b	0.35	0.16	0.82
single tau	0.03	0.02	0.05
diTau+jet	0.16	0.03	0.26
MET	0.07	0.08	0.06
all	0.48	0.23	1.01

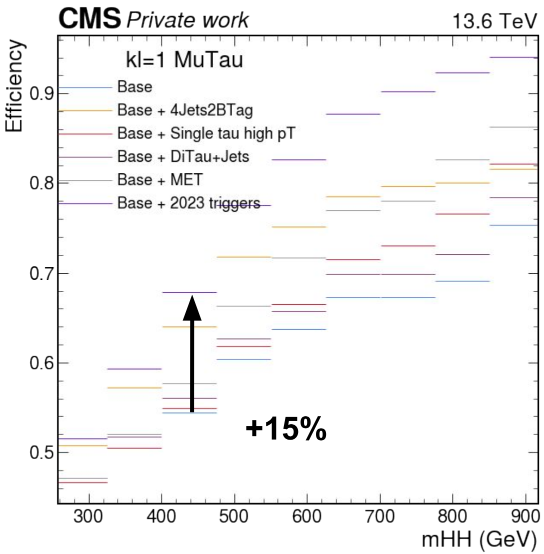
κ_λ=1	etau	mutau	tautau
4jets2b	0.37	0.16	0.80
single tau	0.04	0.03	0.07
diTau+jet	0.17	0.03	0.25
MET	0.08	0.08	0.07
all	0.50	0.25	0.98

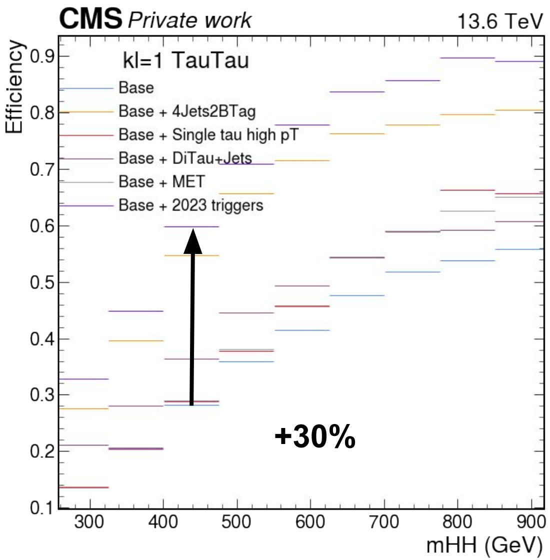
Acceptance study depending on mHH

$$\varepsilon = \frac{\text{Trigger AND Selection}}{\text{Selection}}$$









Summary

Summary

Impact study of Powheg bug

- Effect on the cross section and kl constraints of less than 3% →**impact negligible**
- Study added to an analysis note on HH Run 2 legacy combination
- Proportion of high DNN score for kl=5 lower than expected →to be improved for Run 3

Efficiency study of Run 3 triggers

- Gain up to 80% for 4jets2b trigger
- Overall gain of 100% and +30% absolute efficiency in ττ channel → **clear improvement for Run 3 analysis!**

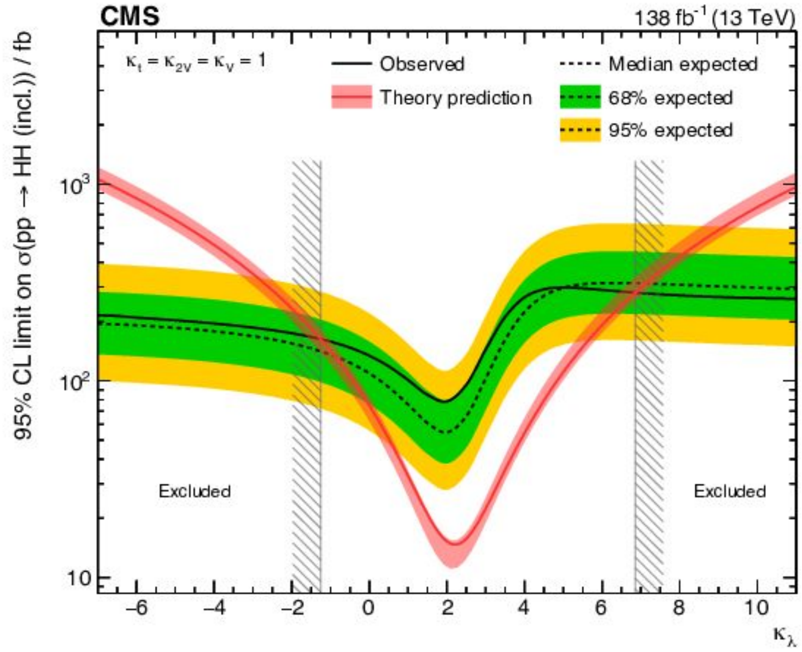
Remaining work :

- Overlaps to be studied
- VBF triggers to be studied
- Implementation in the analysis

Thank you!
Questions?

Backup

Constraints on lambda



Cuts

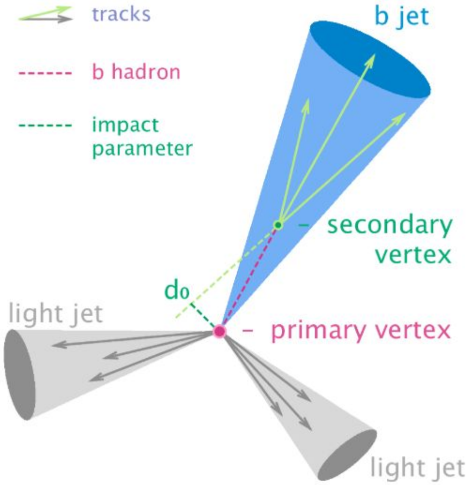
Electron : pT>10 GeV, |η|<2.5, ΔR(e, tau)<0.5

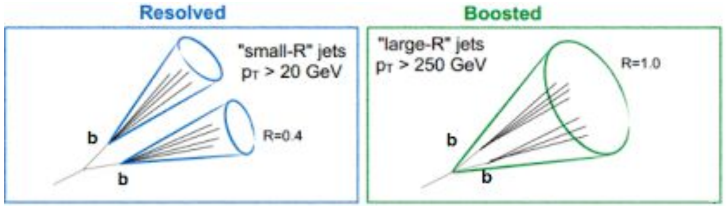
Muon : pT>15 GeV, |η|<2.4, ΔR(mu, tau)<0.5, dR<0.15

Tau : pT>20 GeV, |η|<2.3, DeepTauVSJet >5

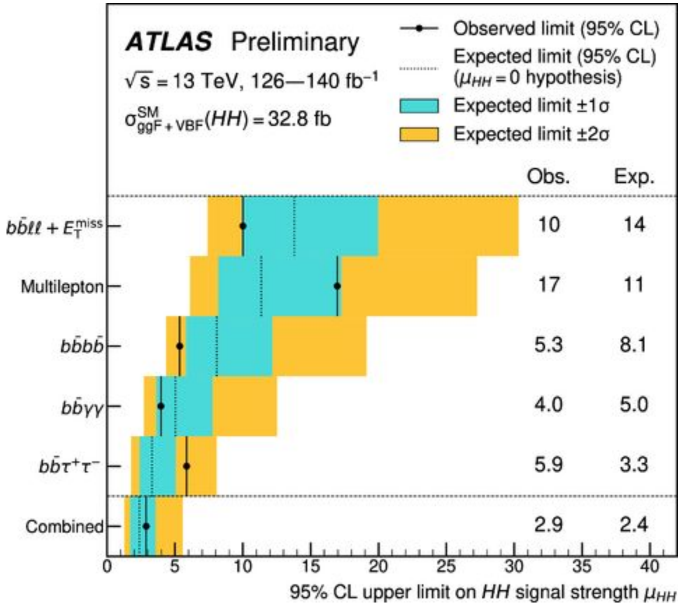
b jets : 2 jets w/ pT>20 GeV, |η|<2.4 (not yet identified as b)

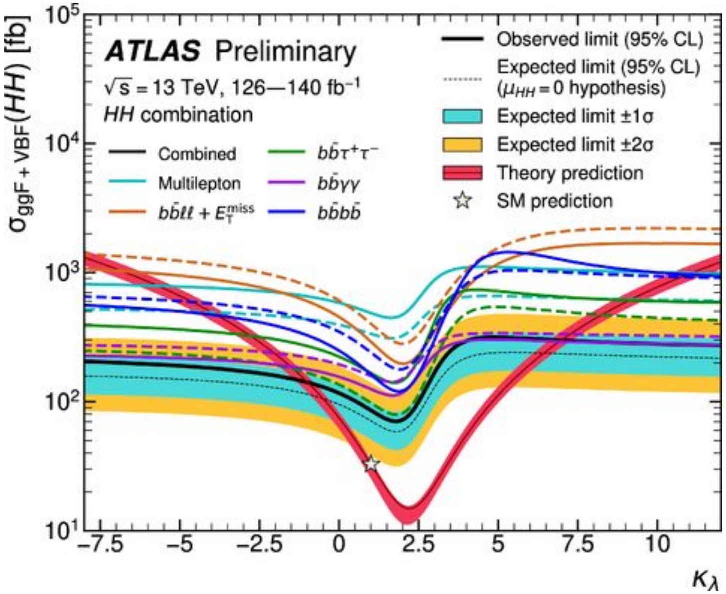
b tagging


tracks
b hadron
impact parameter
b jet
secondary vertex
d0
light jet
primary vertex
light jet

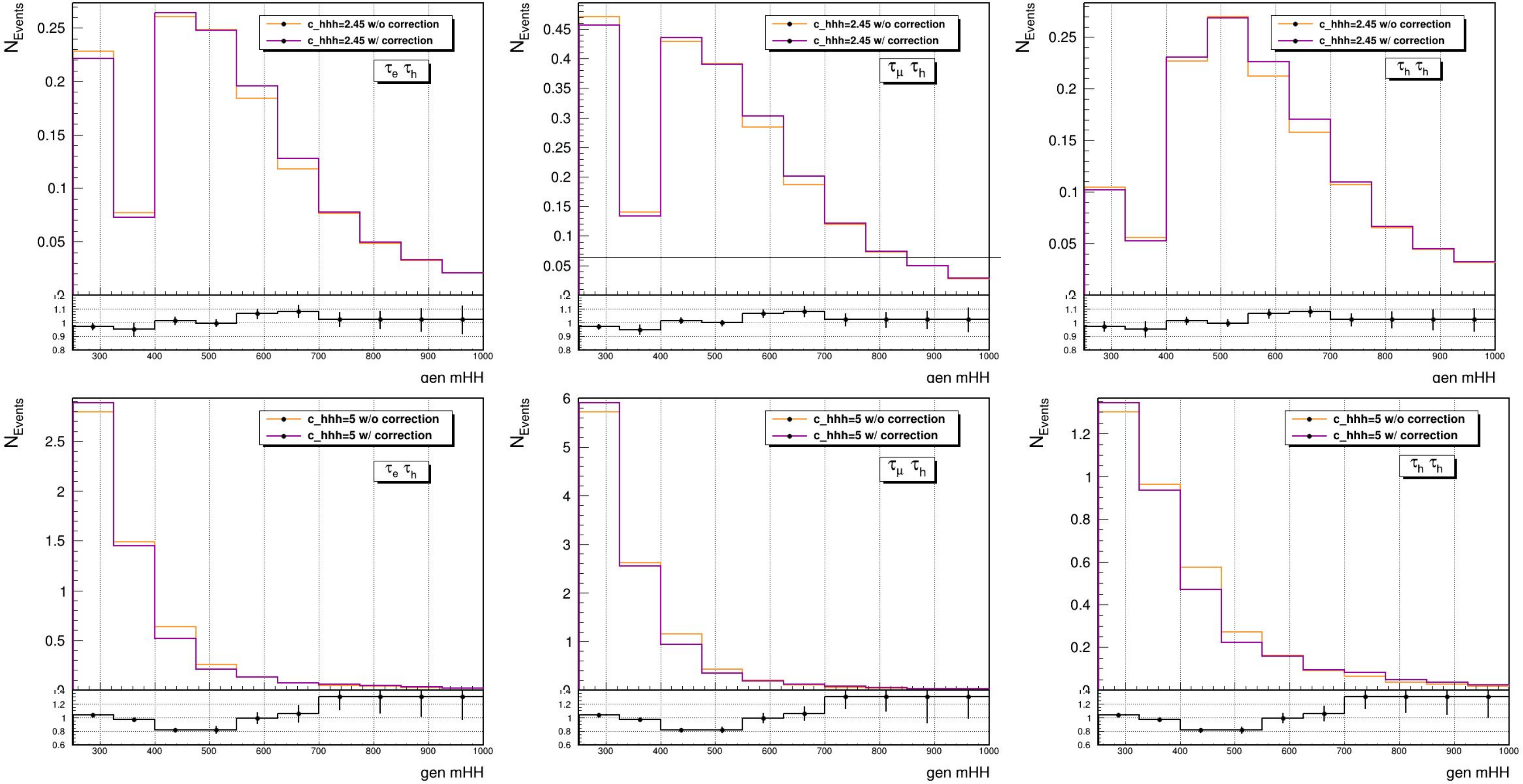

Resolved
"small-R" jets
pT > 20 GeV
R=0.4
b
b
Boosted
"large-R" jets
pT > 250 GeV
R=1.0
b
b

ATLAS limits

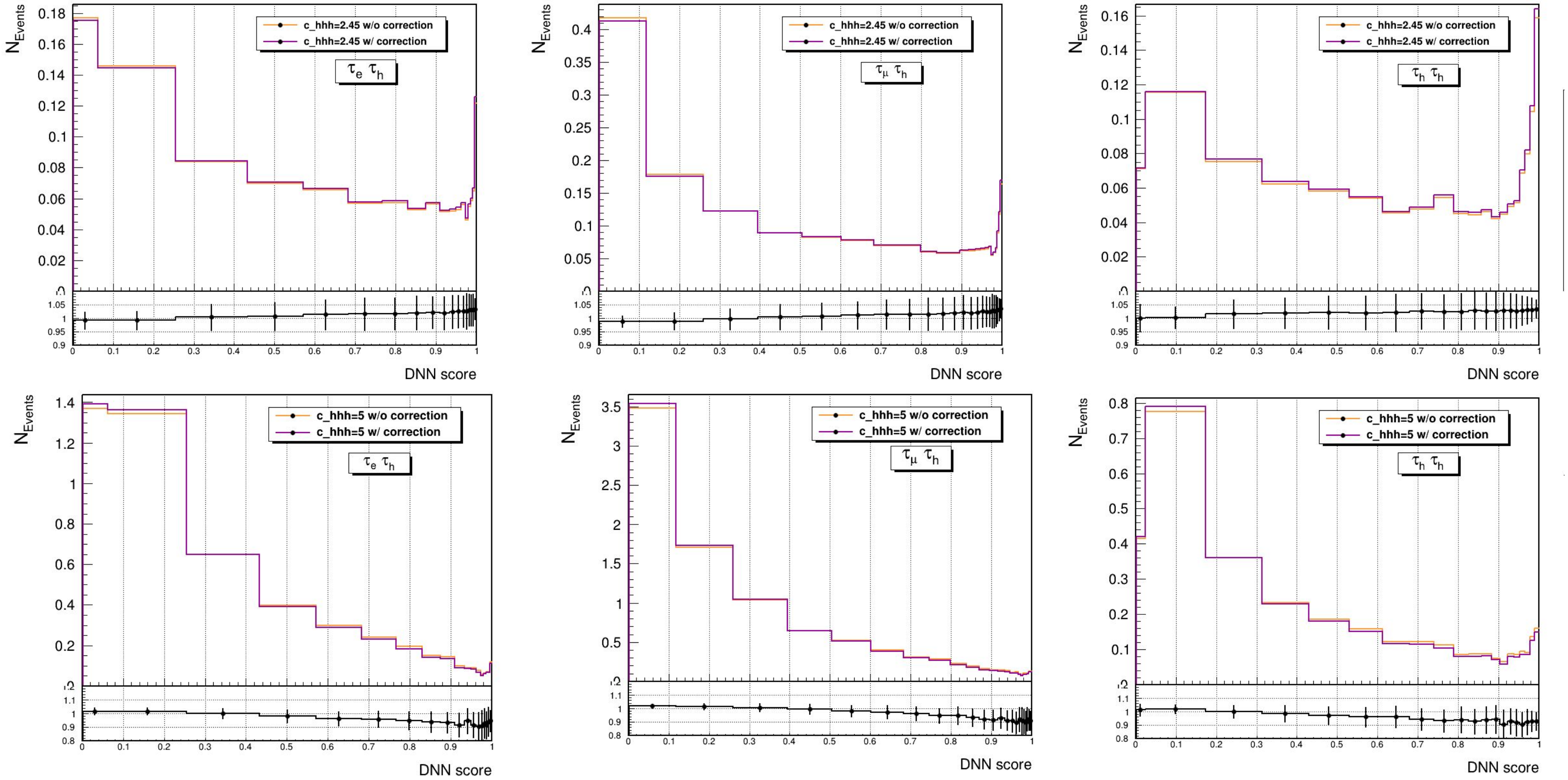




generated HH mass



DNN score


N_Events
c_hhh=2.45 w/o correction
c_hhh=2.45 w/ correction
$\tau_e\ \tau_h$
$\tau_\mu\ \tau_h$
$\tau_h\ \tau_h$
c_hhh=5 w/o correction
c_hhh=5 w/ correction
DNN score

Efficiency study

κ_λ=0	etau	mutau	tautau
4jets2b	0.34	0.24	0.38
single tau	0.03	0.02	0.03
diTau+jet	0.28	0.03	0.34
MET	0.05	0.21	0.02
all	0.43	0.55	0.28

κ_λ=1	etau	mutau	tautau
4jets2b	0.37	0.28	0.42
single tau	0.04	0.03	0.04
diTau+jet	0.31	0.03	0.38
MET	0.06	0.21	0.03
all	0.44	0.57	0.32