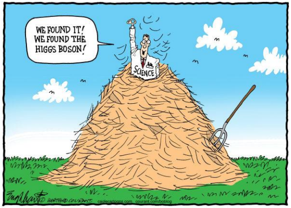
Higgs τ−lepton Yukawa coupling measurement and the τ embedding method for background estimation

anna bożena kowalewska
on behalf of the ATLAS Collaboration

Cracow Epiphany Conference

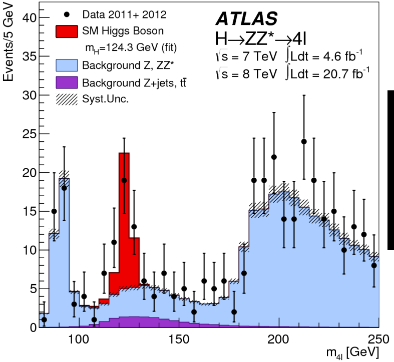
Institute of Nuclear Physics
Polish Academy of Sciences

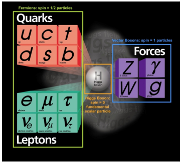
We Found it!



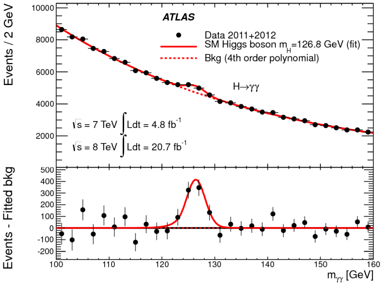
$$\mathbf{M_H = (125.09 \pm 0.21 \pm 0.11)\ GeV}$$

preliminary





preliminary



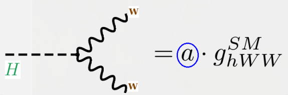
Motivation

- **from the above results we can't say anything about the new particle coupling to fermions hence, to determine whether it is SM H, it is so important to measure it.**

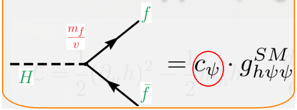
To establish the mass generation mechanism for fermions as implemented in the SM, we need to measure the direct coupling of the Higgs boson to fermions.

$$\mathcal{L} \supset -\left(1 + 2a\frac{h}{v}\right)\left(m_W^2 W_\mu W^\mu + \frac{1}{2} m_Z^2 Z_\mu Z^\mu\right) - \sum_\psi \left(1 + c_\psi \frac{h}{v}\right) m_\psi \bar{\psi}\psi$$

Controls the hWW, hZZ couplings

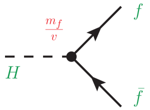


Controls the $h\psi\psi$ coupling



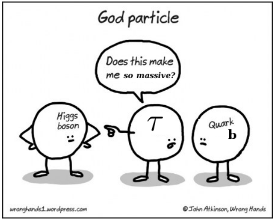
in Standard Model:

- $c_\psi = 1$
- $a = 1$



Why $H \to \tau\tau$

- **heaviest lepton $\to$ strongest coupling: couplings are proportional to masses**
- **lower background than in $b\bar{b}$ (*leptonic versus hadronic channels*)**

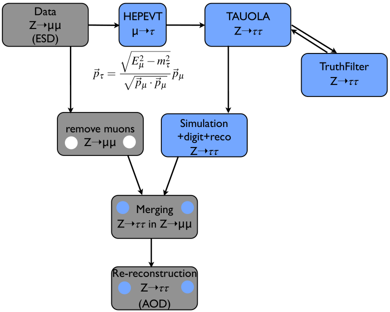


to find signal of new physics we need to know all SM and QCD processes ⇒ background, as precisely as we can.

JHEP 04 (2015) 117

Signal ($m_H = 125$ GeV)	MC generator	$\sigma \times \mathcal{B}$ [pb] $\sqrt{s} = 8$ TeV		
ggF, $H \to \tau\tau$	Powheg [42–45] + Pythia8 [46]	1.22	NNLO+NNLL	[48–53, 84]
VBF, $H \to \tau\tau$	Powheg + Pythia8	0.100	(N)NLO	[57–59, 84]
WH, $H \to \tau\tau$	Pythia8	0.0445	NNLO	[62, 84]
ZH, $H \to \tau\tau$	Pythia8	0.0262	NNLO	[62, 84]
Background	**MC generator**	**$\sigma \times \mathcal{B}$ [pb] $\sqrt{s} = 8$ TeV**		
$W(\to \ell\nu)$, $(\ell = e, \mu, \tau)$	Alpgen [77]+Pythia8	36800	NNLO	[85, 86]
$Z/\gamma^*(\to \ell\ell)$, 60 GeV$< m_{\ell\ell} < 2$ TeV	Alpgen+Pythia8	3910	NNLO	[85, 86]
$Z/\gamma^*(\to \ell\ell)$, 10 GeV$< m_{\ell\ell} < 60$ GeV	Alpgen+Herwig [87]	13000	NNLO	[85, 86]
VBF $Z/\gamma^*(\to \ell\ell)$	Sherpa [88]	1.1	LO	[88]
$t\bar{t}$	Powheg + Pythia8	253†	NNLO+NNLL	[89–94]
Single top : Wt	Powheg + Pythia8	22†	NNLO	[95]
Single top : s-channel	Powheg + Pythia8	5.6†	NNLO	[96]
Single top : t-channel	AcerMC [80]+Pythia6 [73]	87.8†	NNLO	[97]
$q\bar{q} \to WW$	Alpgen+Herwig	54†	NLO	[98]
$gg \to WW$	gg2WW [79]+Herwig	1.4†	NLO	[79]
WZ, ZZ	Herwig	30†	NLO	[98]
$H \to WW$	same as for $H \to \tau\tau$ signal	4.7†		

- $Z/\gamma^* \to \tau\tau$ main and large irreducible background



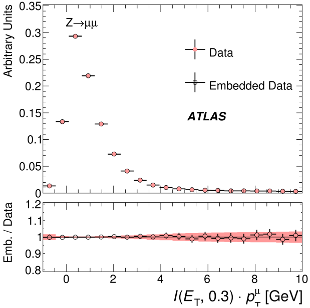
- EMBEDDING:: *data-driven method* to estimate it.

- for $\tau_{lep}\tau_{lep}$ and $\tau_{lep}\tau_{had}$ ⇒ W+jets contributions are determined by inverting the isolation requirements or fake-factor method,
- for $\tau_{had}\tau_{had}$ ⇒ multijet background is modelled using a template extracted from data.
- for $\tau_{lep}\tau_{lep}$ and $\tau_{lep}\tau_{had}$ ⇒ normalisation for background contributions from $t\bar{t}$ is obtained from data control regions.

⇒ embedding:

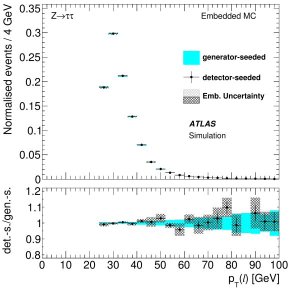
- ***kinematics of Z boson, Jets and underlying events as well as contributions from pile-up*** **are taken from data**
- ***Only τ decays and the detector response to the τ decay products*** **are based on simulation**

JHEP 04 (2015) 117



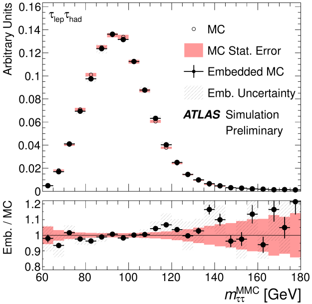
- distribution of the calorimeter isolation energy, within $\Delta R = 0.3$ around muons in $Z \to \mu\mu$ events from data, before and after embedding of simulated muons.

arXiv:1506.05623v1



- p_T of the leading lepton → checking the influence of input muon radiation and reconstruction effects on embedded mini event

JHEP 04 (2015) 117



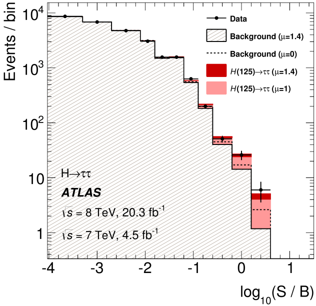
- reconstructed invariant $\tau\tau$ mass: comparison between kinematic distribution of the embedded sample to the fully simulated one.

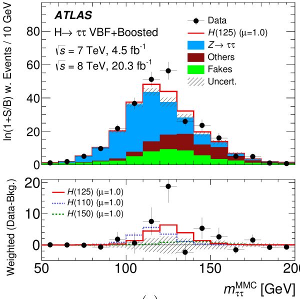
results

⇒ **an excess of events over the expected background is found with an observed significance of 4.5 standard deviations**

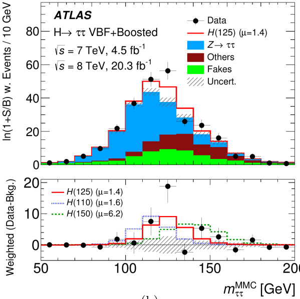
⇒ **it provides evidence for the direct coupling of the Higgs to fermions.**

JHEP 04 (2015) 117





(a)

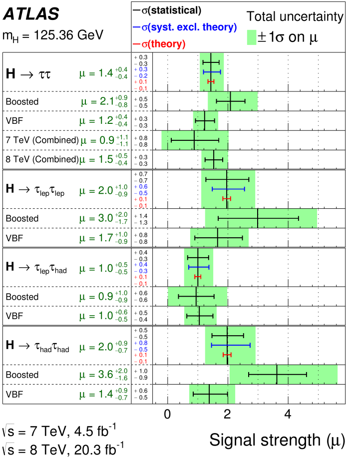


(b)

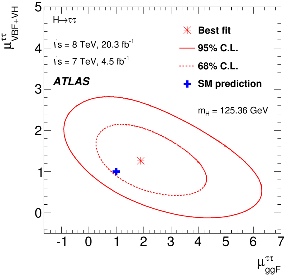
- $\mu = 1.43^{+0.27}_{-0.26}(stat.)^{+0.32}_{-0.25}(syst.) \pm 0.09$ (theory syst.)

The measured signal strength, normalised to the Standard Model expectation, is consistent with the predicted Yukawa coupling strength in SM.

JHEP 04 (2015) 117



- $\mu = 1.43^{+0.43}_{-0.37}$



ATLAS-CONF-2015-044

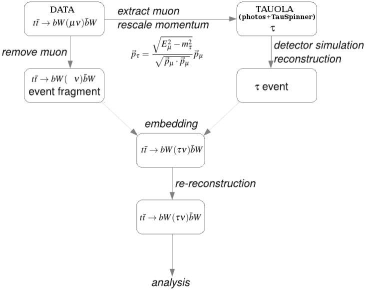
Decay channel	ATLAS+CMS
$\mu^{\tau\tau}$	$1.12^{+0.25}_{-0.23}$
μ^{bb}	$0.69^{+0.29}_{-0.27}$

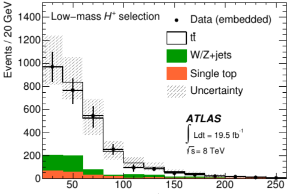
	Measured significance (σ)
$H \to \tau\tau$	5.5
$H \to bb$	2.6

footnote

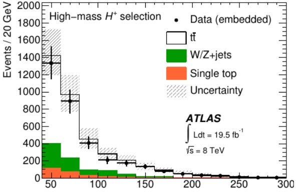
embedding was also used in Run-1 in searches for charged Higgs in $H \to \tau\nu$ channel JHEP03 (2015) 088.

- **It is hard to distinguish the signatures of the $H^{\pm} \to \tau^{\pm}\nu$ from the ones of SM $W^{\pm} \to \tau^{\pm}\nu$: *the dominant part of the irreducible background in $\bar{t} \to bH(\tau\nu)\bar{b}W$ ch.***





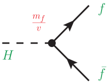
Low-mass H^+ selection



High-mass H^+ selection

- ***comparison of the backgrounds obtained through embedding (black points) with simulation (histogram) for m_T,***
- ***statistical and systematical errors of the embedding method are given by the black error bars, while of the simulation by gray hashed area.***

Conclusion

- evidence for decays of H boson into $\tau\tau$ pairs ,

- measured signal strength, normalised to SM expectation, is found to be

$$\mu = 1.43^{+0.27}_{-0.26}(stat.)^{+0.32}_{-0.25}(syst.) \pm 0.09(theorysyst.),$$

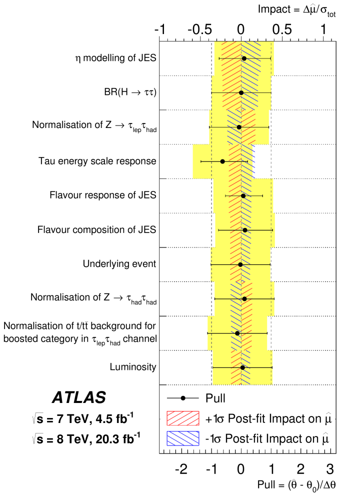
which is consistent with the predicted Yukawa coupling in SM.

- embedding method helps to determine it with such precision,
- embedding as a largely data-driven method to set background.

Thank you for your attention

BACKUP

Impact of systematic uncertainties on the fitted signal-strength parameter μ for the combined fit for all channels and both centre-of-mass energies. The systematic uncertainties are listed in decreasing order of their impact on μ on the y-axis.



Summary of the triggers used to select events for the different analysis channels at the two centre-of-mass energies. When more than one trigger is used, a logical OR is taken and the trigger efficiencies are calculated accordingly.

$\sqrt{s} = 7$ TeV				
Trigger	Trigger level thresholds, p_T [GeV]	Analysis level thresholds [GeV] $\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
Single electron	20–22	$e\mu$: $p_T^e > 22-24$, $p_T^\mu > 10$	$e\tau$: $p_T^e > 25$, $p_T^\tau > 20$	–
Single muon	18	$\mu\mu$: $p_T^{\mu_1} > 20$, $p_T^{\mu_2} > 10$; $e\mu$: $p_T^\mu > 20$, $p_T^e > 15$	$\mu\tau$: $p_T^\mu > 22$, $p_T^\tau > 20$	–
Di-electron	12/12	ee: $p_T^{e_1} > 15$, $p_T^{e_2} > 15$	–	–
Di-τ_{had}	29/20	–	–	$\tau\tau$: $p_T^{\tau_1} > 35$, $p_T^{\tau_2} > 25$

$\sqrt{s} = 8$ TeV				
Trigger	Trigger level thresholds, p_T [GeV]	Analysis level thresholds [GeV] $\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
Single electron	24	$e\mu$: $p_T^e > 26$, $p_T^\mu > 10$; ee: $p_T^{e_1} > 26$, $p_T^{e_2} > 15$	$e\tau$: $p_T^e > 26$, $p_T^\tau > 20$	–
Single muon	24	–	$\mu\tau$: $p_T^\mu > 26$, $p_T^\tau > 20$	–
Di-electron	12/12	ee: $p_T^{e_1} > 15$, $p_T^{e_2} > 15$	–	–
Di-muon	18/8	$\mu\mu$: $p_T^{\mu_1} > 20$, $p_T^{\mu_2} > 10$	–	–
Electron+muon	12/8	$e\mu$: $p_T^e > 15$, $p_T^\mu > 10$	–	–
Di-τ_{had}	29/20	–	–	$\tau\tau$: $p_T^{\tau_1} > 35$, $p_T^{\tau_2} > 25$

Discriminating variables used in the training of the BDT for each channel and category at $\sqrt{s} = 8$ TeV. The filled circles indicate which variables are used in each case.

Variable	VBF			Boosted		
	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
$m_{\tau\tau}^{MMC}$	•	•	•	•	•	•
$\Delta R(\tau_1, \tau_2)$	•	•	•		•	•
$\Delta\eta(j_1, j_2)$	•	•	•			
m_{j_1,j_2}	•	•	•			
$\eta_{j_1} \times \eta_{j_2}$		•	•			
p_T^{Total}		•	•			
Sum p_T					•	•
$p_T^{\tau_1}/p_T^{\tau_2}$					•	•
$E_T^{miss}\phi$ centrality		•	•	•	•	•
m_{ℓ,ℓ,j_1}				•		
m_{ℓ_1,ℓ_2}				•		
$\Delta\phi(\ell_1, \ell_2)$				•		
Sphericity				•		
$p_T^{\ell_1}$				•		
$p_T^{j_1}$				•		
$E_T^{miss}/p_T^{\ell_2}$				•		
m_T		•			•	
$\min(\Delta\eta_{\ell_1\ell_2,jets})$	•					
$C_{\eta_1,\eta_2}(\eta_{\ell_1}) \cdot C_{\eta_1,\eta_2}(\eta_{\ell_2})$	•					
$C_{\eta_1,\eta_2}(\eta_\ell)$		•				
$C_{\eta_1,\eta_2}(\eta_{j_3})$	•					
$C_{\eta_1,\eta_2}(\eta_{\tau_1})$			•			
$C_{\eta_1,\eta_2}(\eta_{\tau_2})$			•			

The scale factors calculated in control regions (CR) for background normalisation. Only the statistical uncertainties are given.

Channel	Background	Scale factors (CR)	
		VBF	Boosted
$\tau_{\text{lep}}\tau_{\text{lep}}$	Top	0.99 ± 0.07	1.01 ± 0.05
	$Z \to ee$	0.91 ± 0.16	0.98 ± 0.10
	$Z \to \mu\mu$	0.97 ± 0.13	0.96 ± 0.08
$\tau_{\text{lep}}\tau_{\text{had}}$	Top	0.84 ± 0.08	0.96 ± 0.04