Higgs Couplings to Leptons at ATLAS

-An Overview-

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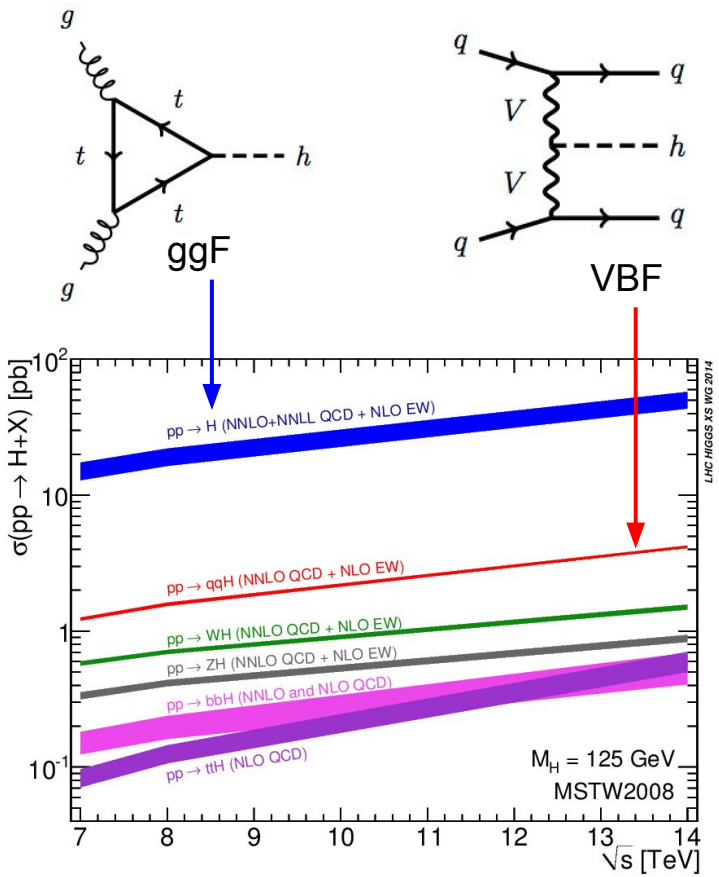
Higgs Couplings at LHC

★ measurement of Higgs mass → **calculation** of:
- → production cross sections (CS)
- → decay branching ratios (BR)

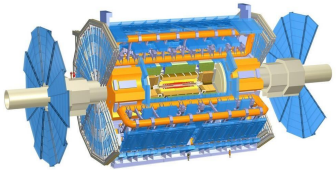
m_H = 125.09 ± 0.21(stat.) ± 0.11(syst.) GeV

★ LHC: **sensitivity to couplings**
- → bosons W, Z (direct), g,γ (indirect)
- → fermions τ, b and top

Decay channel	Branching ratio [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001



Higgs Couplings to Leptons in ATLAS



hh→bbττ
JHEP92,092004
8TeV data
limits

H±→ντ
JHEP03(2015)088
8TeV data
Limits

ttH→ττ
JHEP749(2015)519-541
8TeV
limits

H→aa→μμττ
arXiv:1505.01609
8TeV
limits

ATLAS

H→μτ
arXiv:1508.03372
8TeV data
Limits

H→ττ
JHEP04(2015)117
7+8TeV data
Evidence paper

combination
ATLAS-CONF-2015-044
7+8 TeV + CMS
Discovery H→ττ/VBF
production
Coupling measurements

H→μμ
JHEP738(2014)68-86
7+8 TeV data
Limits

Analysis Strategy - Categorisation

- common strategy to **improve sensitivity**

$$\sqrt{\frac{S_1^2}{B1}+\frac{S_2^2}{B_2}} >> \frac{S_1+S_2}{\sqrt{B_1+B_2}}$$

- categories chosen according to e.g.
  - signal production mechanism
  - background type
  - resolution & uncertainties

H→μμ

$\sqrt{s}$ [TeV]	Category	N_S
8	non-cen. low $p_T^{\mu^+\mu^-}$	6.1
8	cen. low $p_T^{\mu^+\mu^-}$	2.6
8	non-cen. medium $p_T^{\mu^+\mu^-}$	10.4
8	cen. medium $p_T^{\mu^+\mu^-}$	4.7
8	non-cen. high $p_T^{\mu^+\mu^-}$	5.5
8	cen. high $p_T^{\mu^+\mu^-}$	2.6
8	VBF	0.8

H→ττ

	VBF	Boost	Rest
lep-lep	p_T^j > 40, 30 GeV $\Delta\eta_{jj}$ > 2.2	Fail VBF p_T^H > 100 GeV	
lep-had	p_T^j > 50, 30 GeV $\Delta\eta_{jj}$ > 3		
had-had	p_T^j > 50, 30 GeV $\Delta\eta_{jj}$ > 2		Fail VBF, Boost

H→μτ

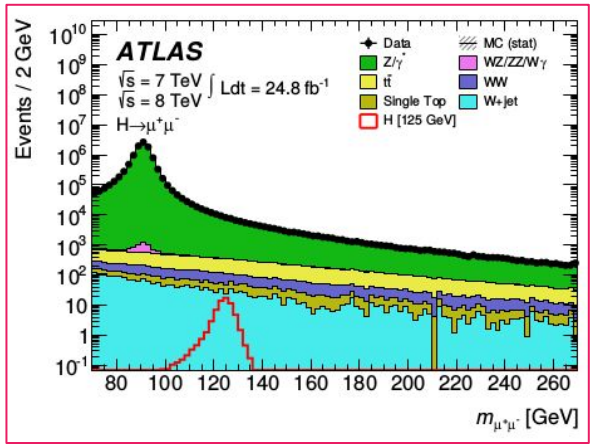
Cut	SR1	SR2
$p_T(\mu)$	>26 GeV	>26 GeV
$p_T(\tau_{had})$	>45 GeV	>45 GeV
$m_T(\mu, E_T^{miss})$	>40 GeV	<40 GeV
$m_T(\tau_{had}, E_T^{miss})$	<30 GeV	<60 GeV
$\lvert\eta(\mu)-\eta(\tau_{had})\rvert$	<2	<2
N_{jet}	–	–
N_{b-jet}	0	0

[JHEP04(2015)117,JHEP738(2014)68-86,arXiv:1508.03372]

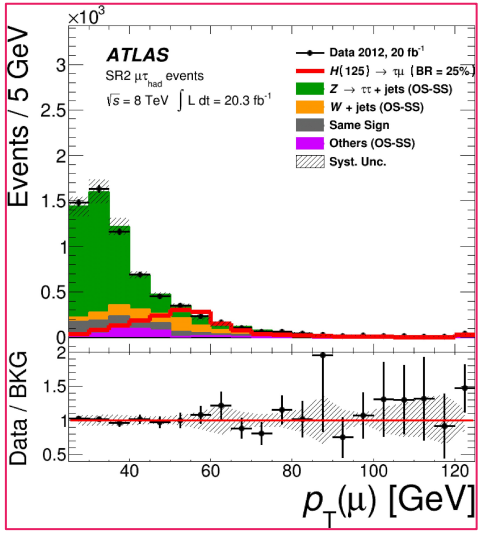
Analysis Strategy - Background Estimation

- **irreducible backgrounds** from Z-boson
  - embedding of taus in Z→μμ data sample (2015 JINST 10 P09018)
- data-restrained simulation
  - scaling in **control regions**
- Multijet **QCD** backgrounds
  - OS-SS (H→μτ), fake factor method (lephad), template fit (hadhad)

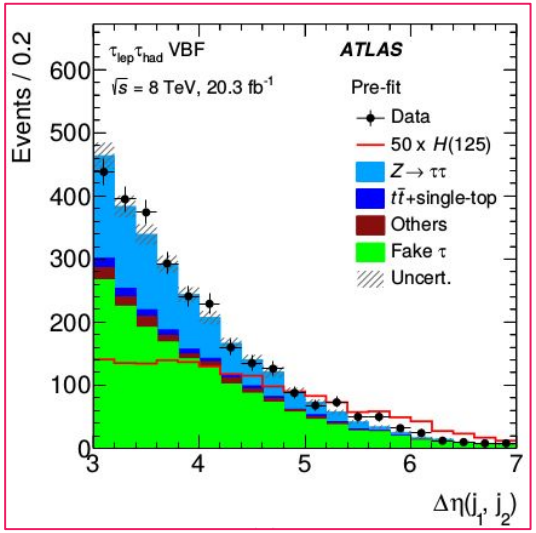
H→μμ



H→μτ



H→ττ

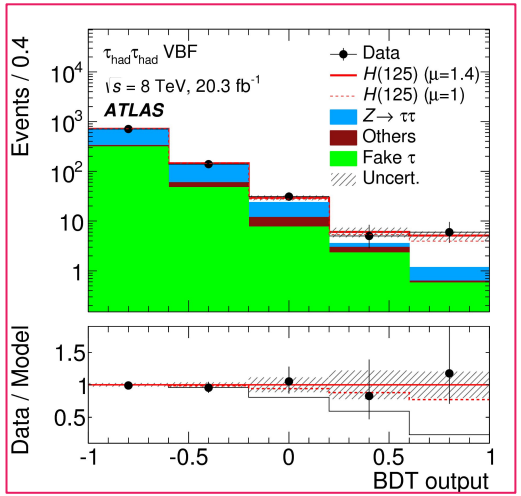


[JHEP04(2015)117,JHEP738(2014)68-86,arXiv:1508.03372]

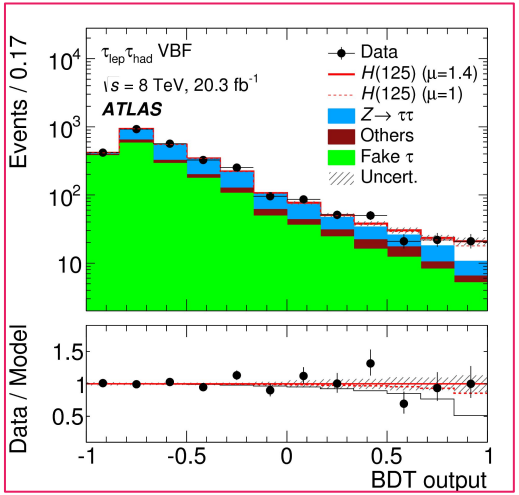
Analysis Strategy - Signal Extraction

- H→μμ & H→μτ: **mass** as discriminating quantity
  - perform fit to $m_{\mu\mu}$/$m_{\mu\tau}$ spectrum
- H→ττ: construct **BDT discriminator**
  - use set of discriminating variables
  - optimise S/B
  - assign BDT score per event

H→ττ (hadhad)



H→ττ (lephad)



Variable	VBF		
	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
$m_{\tau\tau}^{MMC}$	•	•	•
$\Delta R(\tau_1,\tau_2)$	•	•	•
$\Delta\eta(j_1,j_2)$	•	•	•
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^{j1}			
$E_T^{miss}/p_T^{\ell_2}$			
m_T		•	
$\min(\Delta\eta_{\ell_1\ell_2,jets})$	•		
$C_{\eta_1,\eta_2}(\eta_{\ell_1})\cdot C_{\eta_1,\eta_2}(\eta_{\ell_2})$	•		
$C_{\eta_1,\eta_2}(\eta_\ell)$		•	
$C_{\eta_1,\eta_2}(\eta_{j_3})$	•		
$C_{\eta_1,\eta_2}(\eta_{\tau_1})$			•
$C_{\eta_1,\eta_2}(\eta_{\tau_2})$			•

[JHEP04(2015)117,JHEP738(2014)68-86,arXiv:1508.03372]

Analysis Strategy - Uncertainties

H→μμ

Source (experimental)	Uncertainty (%)
Luminosity	±1.8 (7 TeV), ±2.8 (8 TeV)
Muon efficiency	±1
Muon momentum res.	±1
Muon trigger	±1.5
Muon isolation	±1.1
Pile-up reweighting	±1
Jet energy scale	$^{+3.4}_{-4.5}$ (VBF)
Source (theory)	**Uncertainty (%)**
Higgs boson branching ratio	±7
QCD scale	±8 (ggF), ±1 (VBF, VH)
PDFs + α_s	±8 (ggF), ±4 (VBF, VH)
ggF uncert. in VBF	±22
Multi-parton inter. in VBF	±9 (ggF), ±4 (VBF)

H→ττ

Source of Uncertainty	Uncertainty on μ
Signal region statistics (data)	$^{+0.27}_{-0.26}$
Jet energy scale	± 0.13
Tau energy scale	± 0.07
Tau identification	± 0.06
Background normalisation	± 0.12
Background estimate stat.	± 0.10
BR ($H \to \tau\tau$)	± 0.08
Parton shower/Underlying event	± 0.04
PDF	± 0.03
Total sys.	$^{+0.33}_{-0.26}$
Total	$^{+0.43}_{-0.37}$

★ various **experimental** and **theoretical uncertainty** sources

★ furthermore: uncertainties on **bkgd modelling**, e.g. for H→μτ

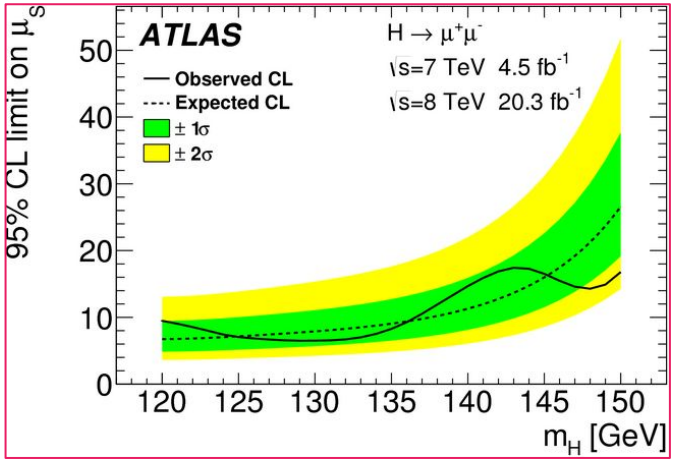
➢ normalization (±10%) & modelling of W+jets/Z→ττ background

➢ Multijet: rQCD (±12.7%)

Higgs Couplings in ATLAS - Results Run I

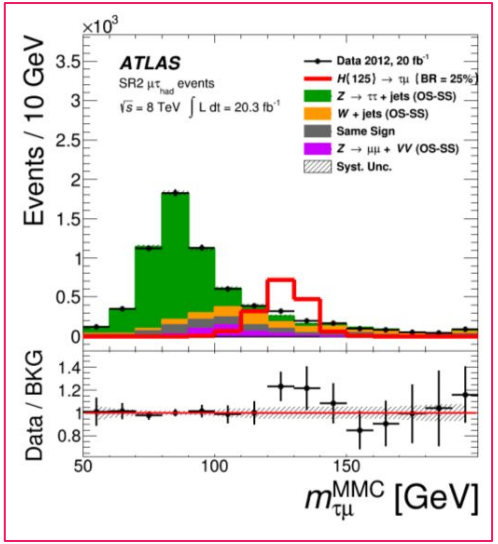
H→μμ

✓ 7.0 (7.7 exp) x SM limit for μμ coupling



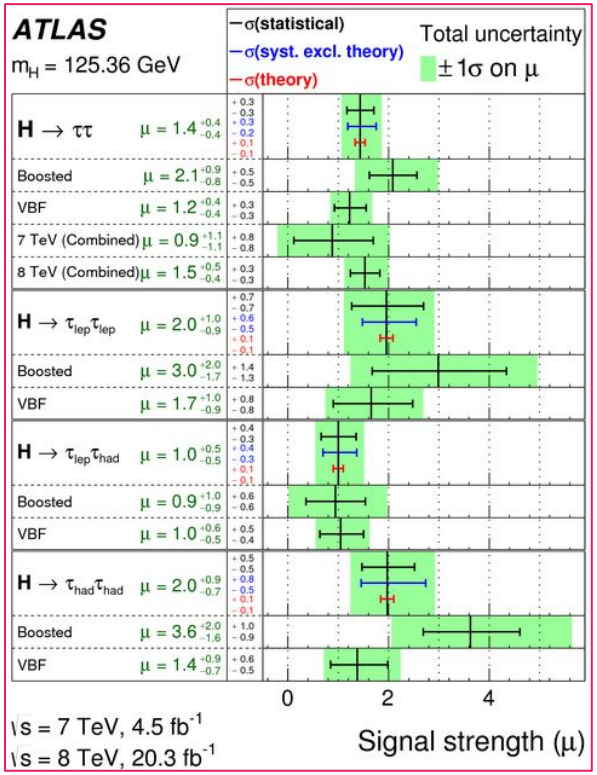
H→μτ

✓ **local 2.2σ** in SR2
✓ 1.3σ global
✓ B(H → μτ)<1.85% @ 95%CL



H→ττ

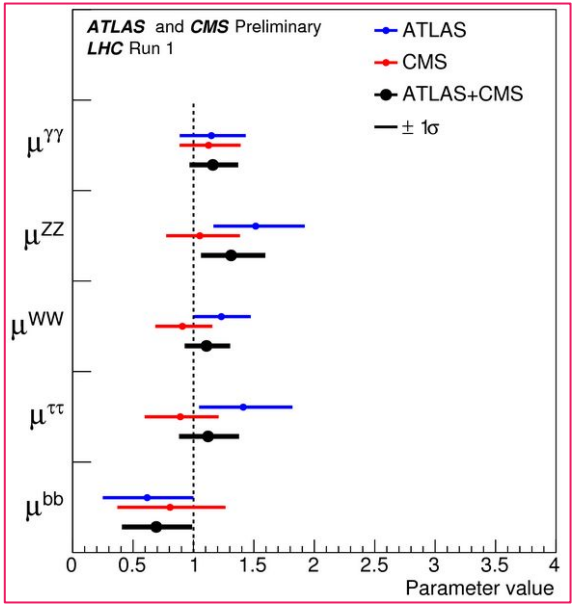
✓ 4.5σ (3.4σ exp) evidence for ττ coupling

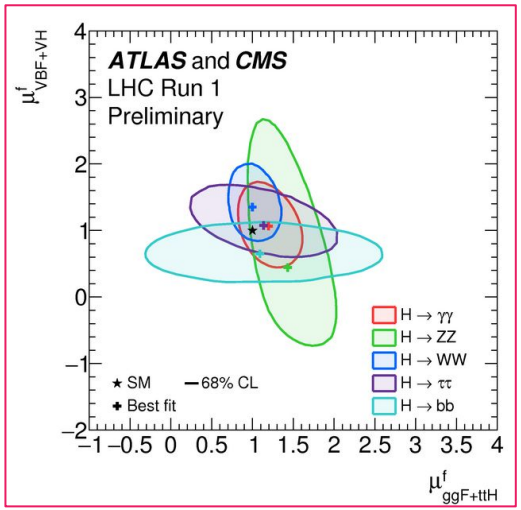


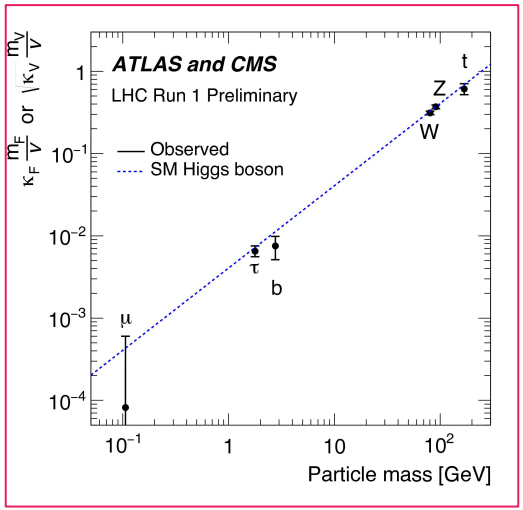
[JHEP04(2015)117,JHEP738(2014)68-86,arXiv:1508.03372]

Higgs Couplings - Combination ATLAS & CMS

- ATLAS+CMS combination → up to √2 precision
  - **H→ττ excess** with **5.5σ** significance - discovery
  - **VBF production** discovered with **5.4σ**
  - most stringent **constraints** on production, decay and couplings yet
  - all in accordance with SM

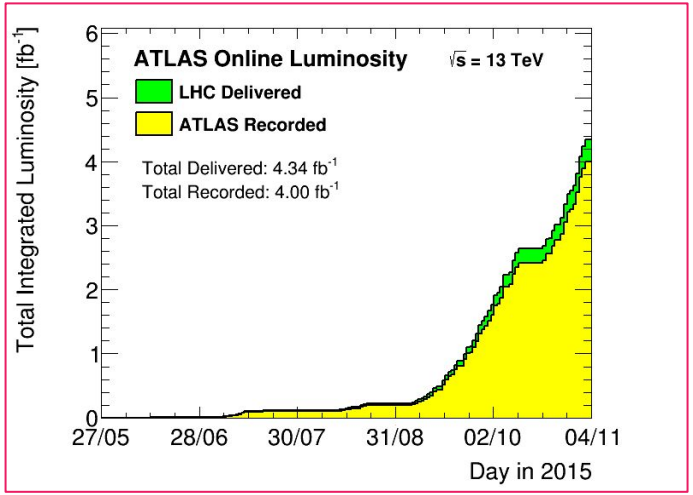


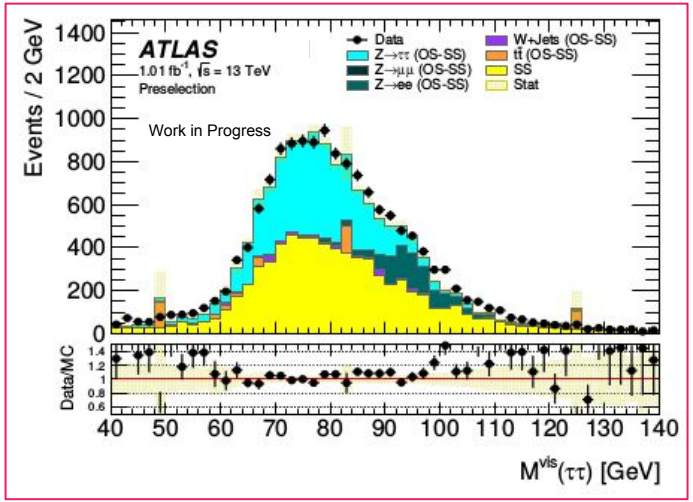




Higgs Couplings in ATLAS - Run II

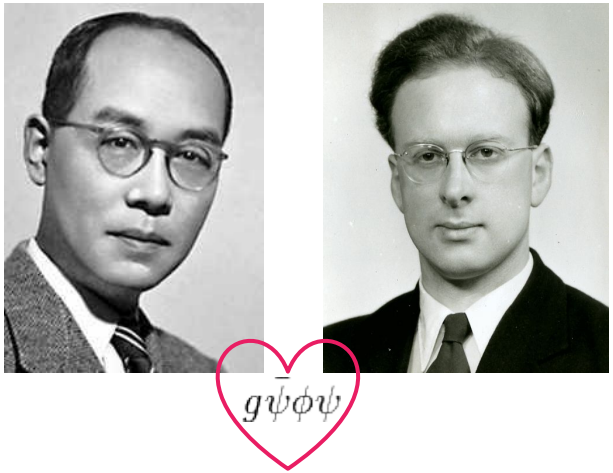
- full pp-data set **2015** recorded: **4.00fb^{-1}**
- **preparations** for **Run II H→ττ** ongoing
  - first data analysed
  - discussion on modelling and categorisation
  - physics objects still being studied
  - tau substructure
- revisiting of **embedding** method
- retuning mass reconstruction algorithm





Summary

- leptonic Higgs sector challenging and insightful
- overview of Run I ATLAS analyses was presented
  - analysis strategies
  - evidence of $H \to \tau\tau$
  - small excess in LFV $H \to \mu\tau$
  - agreement with SM so far
- ATLAS + CMS cross-collaborational combination
  - discovery of $H \to \tau\tau$
  - many constraints on Higgs properties
- Run II data promises many new insights
  - analyses preparations in full throttle



Backup