

Higgs - some highlights and open questions

SM@LHC summary session
13.04.2018

- Roberto Covarelli, Sarah Heim, Tilman Plehn -

Thanks to the organizers for this very well-organized conference!

- The boat trip was great!



These slides are

- not a complete summary
- meant to be discussion starters

Please interrupt any time!

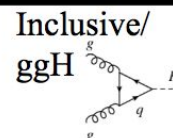
Status of Higgs prod. modes observation at LHC

☒ Observation

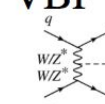
☒ Evidence

☐ Analysis exists

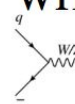
prod. mode



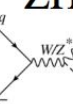
VBF



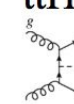
WH



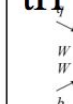
+ ZH



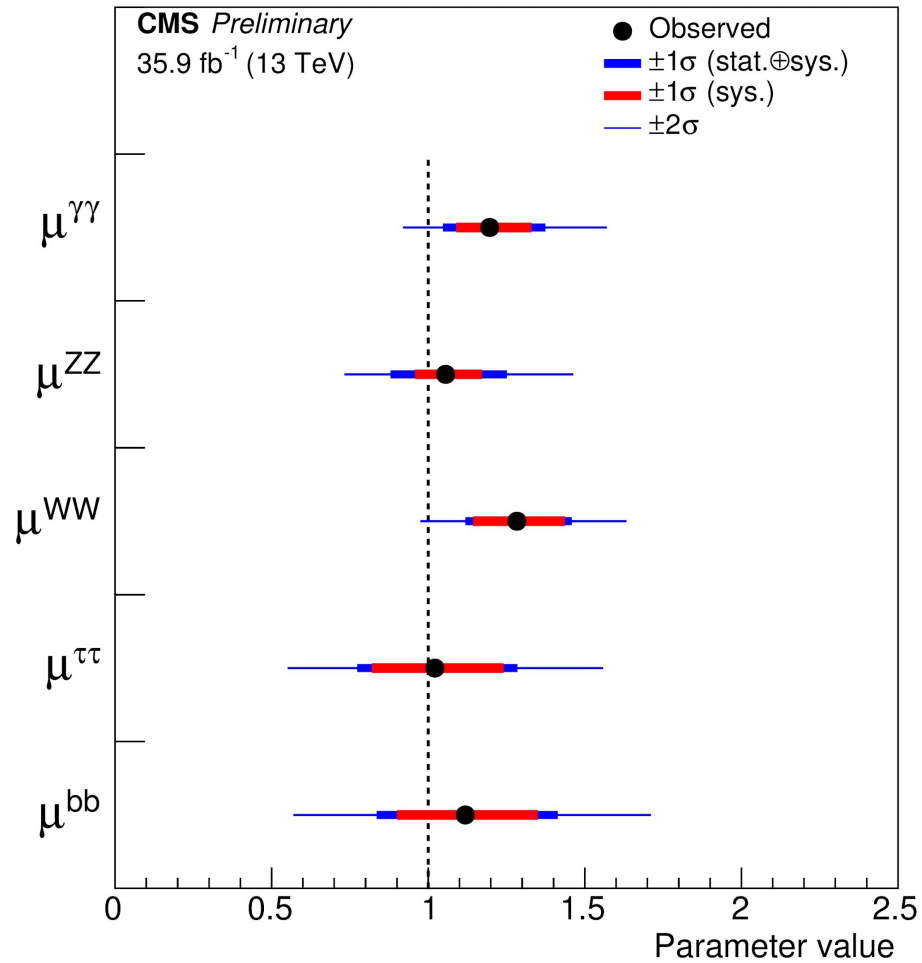
ttH



tH



Decay channel	Inclusive/ ggH	VBF	WH + ZH	ttH	tH
combination	A+C: <input checked="" type="checkbox"/>	A+C: <input checked="" type="checkbox"/>	A+C: <input checked="" type="checkbox"/>	A: <input checked="" type="checkbox"/> , C: <input checked="" type="checkbox"/> A+C: <input checked="" type="checkbox"/>	
$H \rightarrow \gamma\gamma$	A: <input checked="" type="checkbox"/> C: <input checked="" type="checkbox"/>	A: <input checked="" type="checkbox"/>	A: <input type="checkbox"/>	A: <input type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>
$H \rightarrow Z\gamma$	A: <input type="checkbox"/> C: <input type="checkbox"/>				
$H \rightarrow ZZ^{(*)} \rightarrow 4l$	A: <input checked="" type="checkbox"/> C: <input checked="" type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>	
$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$	A: <input checked="" type="checkbox"/> C: <input checked="" type="checkbox"/>	A: <input checked="" type="checkbox"/> C: <input type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>	C: <input type="checkbox"/>
$H \rightarrow b\bar{b}$	C: <input type="checkbox"/> boosted	A: <input type="checkbox"/> C: <input type="checkbox"/>	A: <input checked="" type="checkbox"/> C: <input checked="" type="checkbox"/>	A: <input type="checkbox"/> C: <input type="checkbox"/>	C: <input type="checkbox"/>
$H \rightarrow Y(1S)\gamma$	A: <input type="checkbox"/> C: <input type="checkbox"/>				
$H \rightarrow c\bar{c}$				A: <input type="checkbox"/>	
$H \rightarrow J/\psi\gamma$	A: <input type="checkbox"/>				
$H \rightarrow \phi\gamma$	A: <input type="checkbox"/>				
$H \rightarrow \rho\gamma$	A: <input type="checkbox"/>				
$H \rightarrow \tau\tau$	A+C: <input checked="" type="checkbox"/>			C: <input type="checkbox"/>	
$H \rightarrow \mu\mu$	A: <input type="checkbox"/> C: <input type="checkbox"/>				
$H \rightarrow e\bar{e}$	C: <input type="checkbox"/>				



Measurement uncertainties

~14%

~19%

~13%

1st	2nd	3rd
u+d BR SM: ? BR limit (rho gamma): 52*SM	c BR SM: 2.9% BR limit: ~SM * 110	t BR SM: --- Measured ttH mu: ~1.25
	s BR SM ? BR limit (phi gamma): 200 * SM	b BR SM: 57.5% Measured mu: ~ 1
e BR SM: $\sim 10^{-5}$ BR limit: only at 8 TeV	mu BR SM: 0.02% BR limit: ~SM * 3	tau BR SM: 6.30% Measured mu: ~ 1

- Measure $H \rightarrow \mu\mu$, $H \rightarrow cc$ and **rare decays** (e.g. invisible, $\gamma + \text{onia}$, $\gamma + \text{light meson} \dots$)
 - Are some of them detector-limited? Especially from trigger?
- In general **measure couplings as precisely as possible**
 - Clearly still big room for improvement on couplings to τ , b , t
 - $H \rightarrow WW$ and $\gamma\gamma$ already with some systematic limitations, $H \rightarrow 4l$ not yet
 - did $H \rightarrow VV$ already hit the limits on k_f constraints?
- **Differential distributions** (probe FO and resummation results, now becoming precise, $< 10\%$ on the spectra)

Some other ideas

- m_H measurement in different p_T bins (model-independent width measurement with interferometry)
- Differential measurements with $H \rightarrow \tau\tau$, $H \rightarrow b\bar{b}$?
- CP with $H \rightarrow \tau\tau$, ZH/VBF (more sensitivity than $4l$)

More ideas for measurements?

- ggH, VBF very precise, where are theory uncertainties limiting?
- Mass effects in distributions for loop-induced vertices?
- Need even more precise low and high Higgs boson transverse momentum calculations to search for new physics
- Offshell measurements: better gg- \rightarrow VV theory predictions + guidance on best observables
- ttbb modelling recommendations (crucial for ttH)
- Implementations in MC codes sufficient?
- How reliable is a quoted 0.5% theory uncertainty?
- **More wishes?**

- Data calling the shots these days!
BSM Higgs papers rare on hep-ph
- CP: measurement needed, to define e.g. effective Lagrangian
 - VBF and VH potentially powerful
 - experimental/theoretical limitations?
 - Framework to combine channels (crossing symmetry – combine ZH and VBF p.ex.)?
 - Uncertainties for distributions (multidimensional)?
- EFT
 - Linear (HEFT) and non-linear (SMEFT) both needed?
 - More systematic SMEFT studies needed? D8 operators?
 - Available EFT tool chains sufficient?
 - Electroweak corrections???
 - When will we need to consider fermion couplings?
- General BSM
 - Guidance from theory welcome!
 - (Which observables to look at, etc.)

- Link to testable models? Dark matter? Extended Higgs sectors? Higgs physics more than SM-like couplings measurements?!
- Do theorists need to do EFT and similar analyses? How can theory analyses be useful? Are ATLAS/CMS actually using theory experience?
- Which data should theorists use? p_T distributions? STXS? How do we do correlations (8, 13 TeV, different measurements)?
- How can theorists understand/use complex analyses?
- When will ATLAS/CMS combine gauge and Higgs in SMEFT?
- Why are 13 TeV results not more constraining than 8 TeV?
 - Probably because of lacking correlations etc.