

Higgs/ttH – Roadmap

Ricardo Gonalo

Reunio ATLAS-Pt
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Introdução

- Características do Run II:
 - $\sqrt{s} = 14 \text{ TeV} \Rightarrow$ crescem mais σ 's limitadas por espaço de fase \Rightarrow nova física, top, ttH
 - Precisão da reconstrução:
 - Mais luminosidade integrada \Rightarrow mais estatística, melhores sistemáticos a médio prazo
 - $\Delta t = 25 \text{ ns} \Rightarrow$ menos carga/bunch para L instantânea fixa \Rightarrow menos (on-time) pileup / L \Rightarrow mais precisão
 - Mas o plano é que L vai crescer \Rightarrow menos precisão
- O que vale a pena (Tudo, se a alma não é pequena...)
 - O Higgs é a mais nova partícula conhecida: temos que estudar as suas propriedades
 - Produto da quebra de simetria electrofraca e primeiro escalar fundamental conhecido
 - Propriedades ainda mal conhecidas \Rightarrow espaço para encontrar efeitos de física nova
 - Sector de Higgs não mínimo em muitos modelos de nova física
 - LHC/HLumi-LHC é a **ferramenta** para o estudar, até ao Linear Collider(*)
 - Alternativa:
 - Usar o \sqrt{s} mais alto do run II para procuras directas de nova física – partículas pesadas
 - Mas procurar onde? (discussão interessante!...)

(*) HEnergy-LHC não é ideal (baixa massa do Higgs...): queremos precisão e novos canais em vez de espaço de fase para novas partículas pesadas.

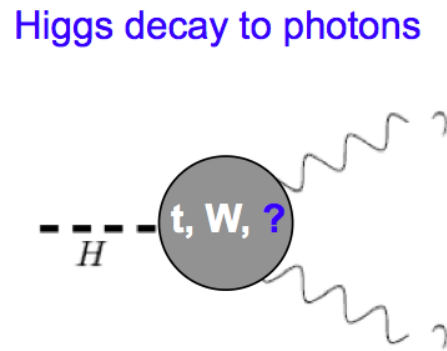
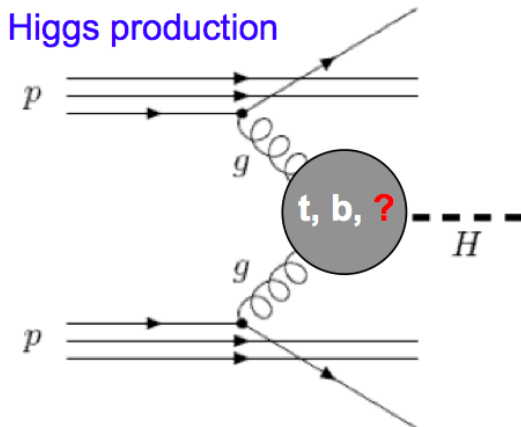
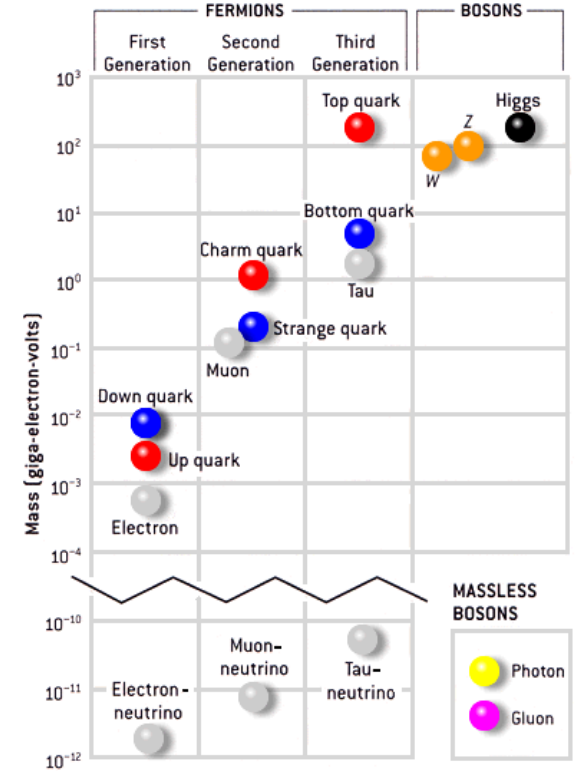
Visão Geral

- Objectivo:
 - Pôr o ATLAS-PT na primeira liga de algumas análises do Higgs(**)
- Futuro próximo (1 ano) para preparar análises de run II:
 - Estudos de ttH (projecto exploratório)
 - Investigar outras possibilidades e preparar as análises: HH?
- Run II (>2015):
 - Leading contribution para análises das propriedades do Higgs

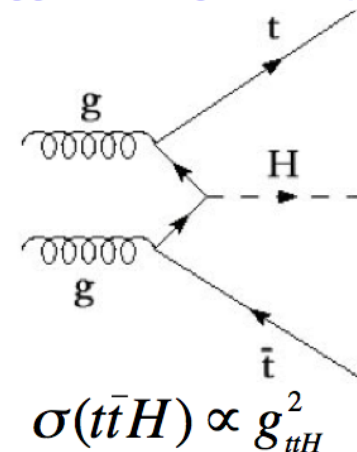
(**) N.B.: equilibrar ambição com realismo, mas apontar para cima!

Porquê ttH?

- Indirect constraints on top-Higgs Yukawa coupling from loops in ggH and ttH vertices
 - Assumes no new particles contribute to loops
- Top-Higgs Yukawa coupling can be measured directly
 - Allows probing for New Physics contributions in the ggH and $\gamma\gamma H$ vertices
- Top Yukawa coupling $Y_t = \sqrt{2}M_t/v_{\text{ev}} = 0.996 \pm 0.005$
 - Does this mean top plays a special role in EWSB?

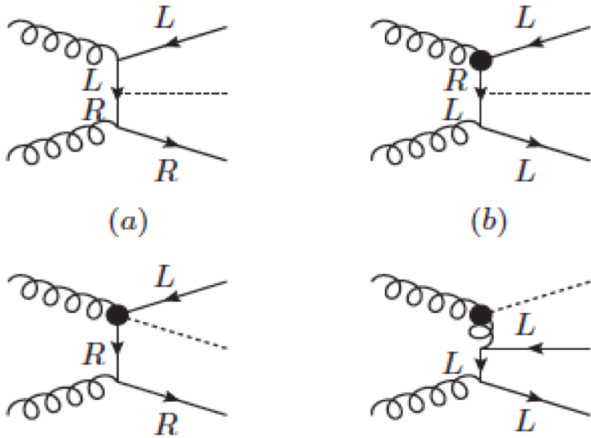


Higgstrahlung from top quark



Sensitivity to New Physics

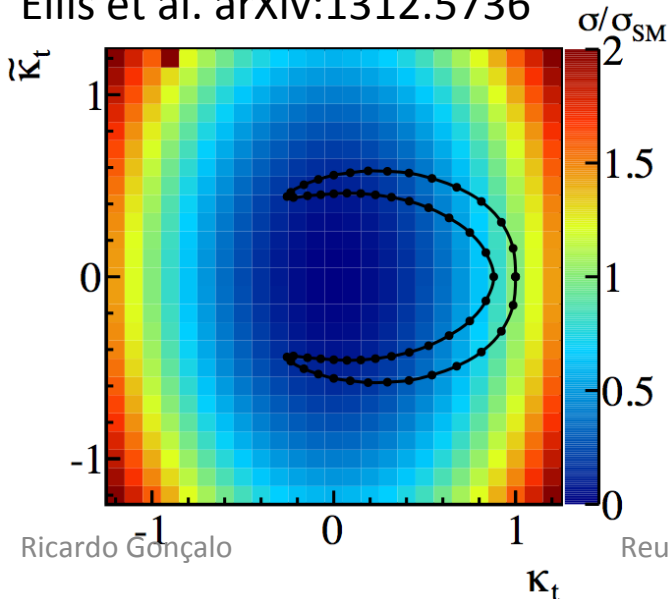
Degrande et al. arXiv:1205.1065



- Effective top-Higgs Yukawa coupling may deviate from SM due to new higher-dimension operators
 - Change **event kinematics** – go differential!

- ttH sensitive new physics: little Higgs, composite Higgs, Extra Dimensions,...

Ellis et al. arXiv:1312.5736



- In the presence of CP violation, Higgs-top coupling have scalar (κ_t) and pseudoscalar ($\tilde{\kappa}_t$) components
 - Strong dependence on ttH cross section
 - Note: Indirect constraints from electron electric dipole moment not taken into account (give $|\tilde{\kappa}_t| < 0.01$)

Run I Analyses

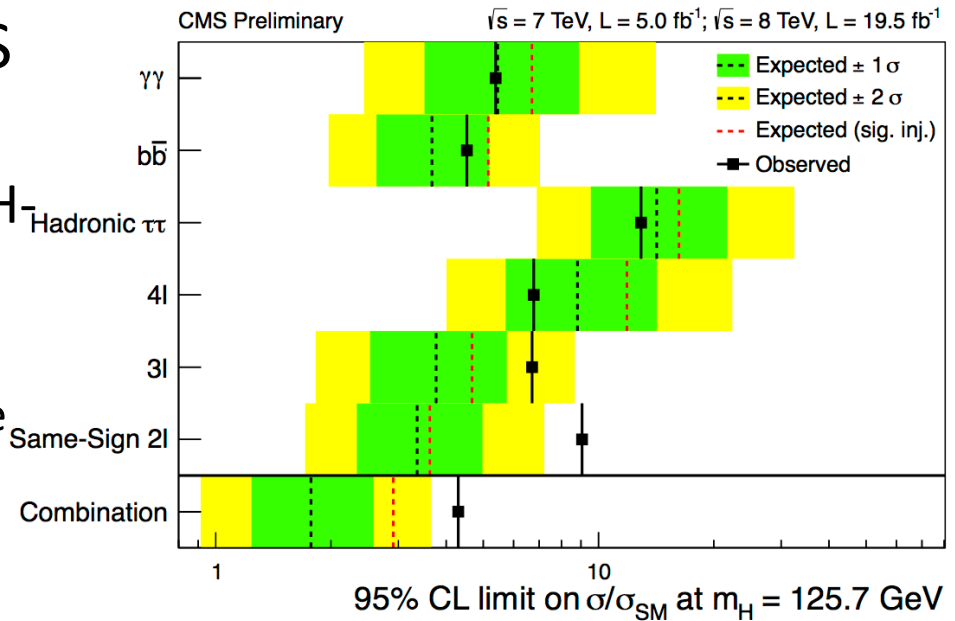
- Latest ttH results from CMS

- Combination of H -> bb, H -> $\tau\tau$, H -> $\gamma\gamma$ and multilepton ($H_{\text{Hadronic}} > WW/ZZ$)

- HIG-12-035, HIG-13-015, HIG-13-019, CMS public page

- No statistically significant excess over background predictions

- Need LHC run II data!



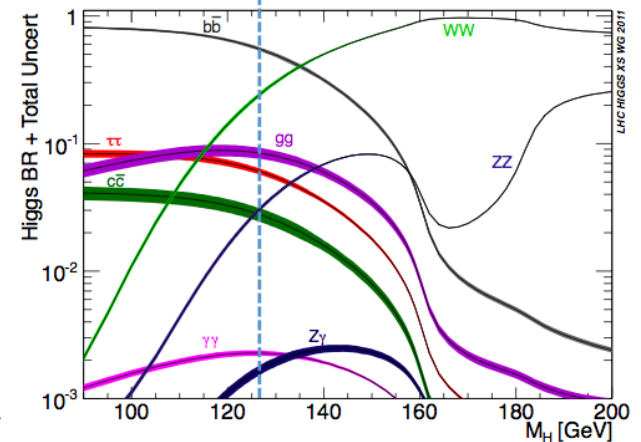
- Expectations from ATLAS ttH, H->bb analysis

- Getting near to ATLAS release for Moriond

Expected 95% C.L. limit ($\mu = \sigma/\sigma^{\text{SM}}$)	H_T^{had} only	MVA in signal regions
Stat. only	1.62	1.43
with sys (*)	7.06	2.94
CMS (20 fb^{-1})		4.7

Some numbers

- Branching ratios:
 - H→bb (57.8%), H→WW (21.6%), H→gg (8.6%), H→ττ (6.4%), H→ZZ (2.7%), H→γγ (0.23%), H→Zγ (0.15%)
- Cross sections at $\sqrt{s} = 8\text{TeV}$:
 - Signal: 75fb
 - Backgrounds: ttbb (order pb), ttZ (17fb)
- Effect of \sqrt{s} increase to 14TeV:
 - ttH signal σ increases from 0.13pb @ 8TeV
 - Main backgrounds: tt+jets, especially ttbb, ttcc
 - tt production σ increases from 249pb @ 8TeV to 965pb @ 14TeV
 - SM S/vB before cuts goes up by x2.4, from 0.82% to 1.96%



Trabalho em ttH e Projecto exploratório

- Tarefas/Equipa actual:
 - Correção Z+jets, análise HSG8: Susana Santos (PhD), Toni Onofre, Ricardo Gonçalo
 - Análise estatística: Emanuel Gouveia (Master) – Susana Santos (PhD)
 - Estudo da carga de jatos: Lia Moreira (Lic), Eduardo Dias (Lic)
 - Portabilidade do SW de análise: João Carvalho (PhD – MAP-fis)
- Projecto exploratório até Março 2015
 - Lista de estudos bem determinada (Muito a fazer! Próximo slide)
 - Tira partido de expertise no top e no Higgs
- Equipa:
 - Experimentalistas: Toni, Patricia, Susana, Eduardo Dias, Jahred Adelman, novo postdoc
 - Teóricos: Rui Santos, Fabio Maltoni, Jose Santiago,
 - Envolver equipa actual e Pedro Ferreira (teórico)

Tarefas

1. Estudo de observáveis angulares para discriminação de background:
 - Fundo principal é $t\bar{t}b\bar{b}$ (irreduzível): par $b\bar{b}$ produzido por gluon splitting ($g \rightarrow b\bar{b}$, spin 1)
 - Objectivo é procurar observáveis óptimos para distinguir do sinal ($H \rightarrow b\bar{b}$, spin 0)
 - Conhecimentos aplicáveis a outros canais de $t\bar{t}H$ ($H \rightarrow \gamma\gamma$, $H \rightarrow WW$, $H \rightarrow ZZ$)
2. Diminuição do fundo combinatório:
 - Reconstrução completa de $t\bar{t}H$ muito afectada por combinações erradas de jactos
 - Melhoramentos possíveis com mais informação? Carga de jatos evita emparelhamentos errados.
 - Também pode ser útil/possível melhorar a resolução de jatos?
3. Determinação dos números quânticos de CP do Higgs:
 - CP do Higgs determinado em $H \rightarrow ZZ$, mas método complementar com $t\bar{t}H$ (Gunion & He)
 - Estudado em simulação (Atlfast I...) – estudo realístico é necessário
 - Possibilidade de encontrar outros métodos
4. Teste em dados reais:
 - As técnicas desenvolvidas acima podem ser testadas em dados reais pelos membros de ATLAS
5. Modelos teóricos e computacionais:
 - Estudo do impacto das análises de $t\bar{t}H$ no conhecimento de nova física
 - Há mais informação a tirar do $t\bar{t}H$? Onde apostar? Quais são os cenários teóricos onde podemos ter impacto?
 - Falta informação nos modelos de Monte Carlo que usamos?

Outras possibilidades

- Outras possibilidades:
 - HH (Higgs self-coupling)
 - tH?
 - A, h, H[±]

Miscellanea

- ECFA HL-LHC Workshop Sep.-Oct. 2014
- PUB notes nearing approval for VH, $H \rightarrow bb$ and ttH , $H \rightarrow \gamma\gamma$ at 14TeV
- HH Mini Workshop:
<https://indico.cern.ch/conferenceDisplay.py?confId=285470>

Bonus slides



Evolution with \sqrt{s}

- ttH signal σ increases from 0.13pb @ 8TeV to 0.6113pb @ 14TeV
- Main backgrounds: tt+jets, especially ttbb, ttcc
- tt production σ increases from 249pb @ 8TeV to 965pb @ 14TeV
- SM S/ ν B before cuts goes up by x2.4, from 0.82% to 1.96%

Ttbar cross section

- PDG: $m_{\text{top}} = 173.07 \pm 0.52 \pm 0.72$ GeV
- HATHOR 1.3 (approx. NNLO) with MSTW2008 PDFs:
<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsEuropeanStrategy2012>

$\sqrt{s} = 8$ TeV						$\sqrt{s} = 14$ TeV					
M_{top}	σ	scale uncertainty		PDF uncert.		M_{top}	σ	scale uncertainty		PDF uncert.	
[GeV]	[pb]	[pb]	[pb]	[pb]	[pb]	[GeV]	[pb]	[pb]	[pb]	[pb]	[pb]
172.5	252.6	+13.6	-	+6.2	-6.4	172.5	977.7	+42.2	-	+16.2	-
			18.1						60.3		17.9
173.0	248.9	+13.5	-	+6.2	-6.3	173.0	964.6	+41.6	-	+16.1	-
			17.9						59.5		17.6
173.5	245.3	+13.3	-	+6.1	-6.2	173.5	951.7	+41.1	-	+15.9	-
			17.6						58.8		17.4

ttV

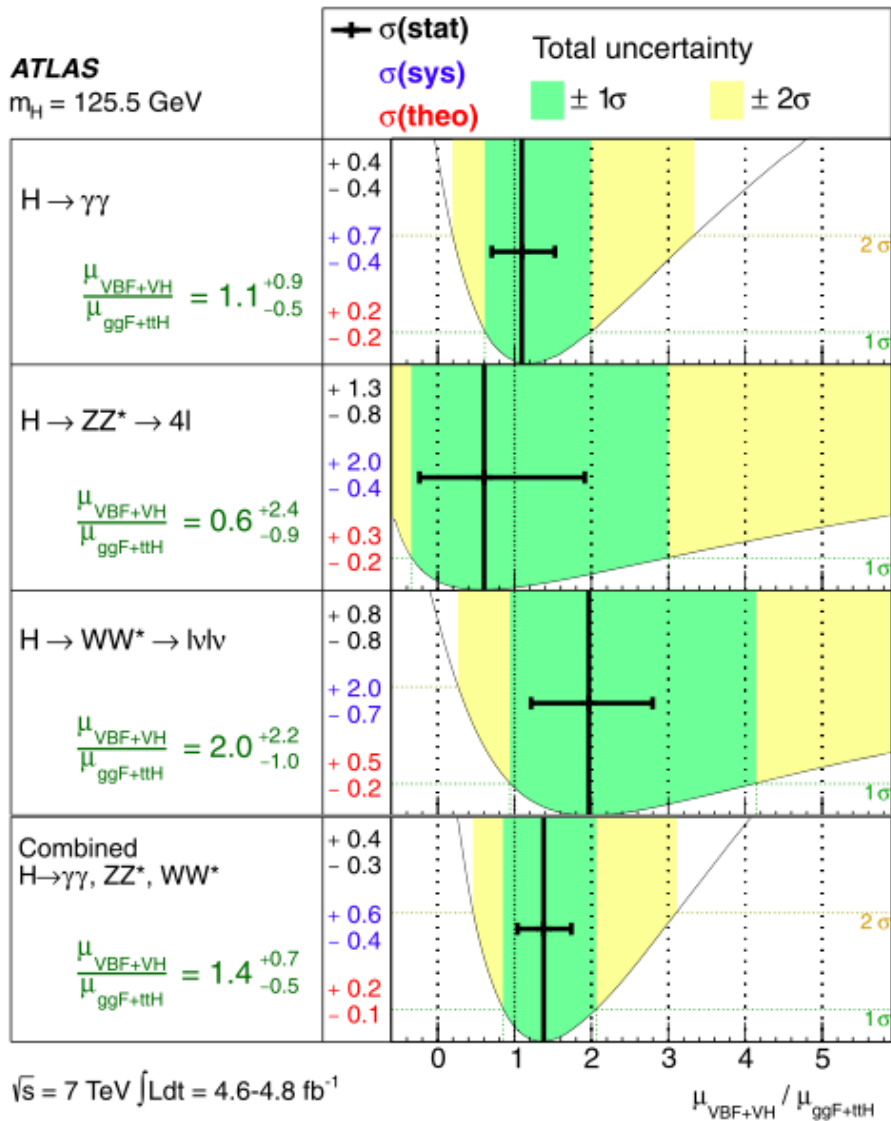


Complications



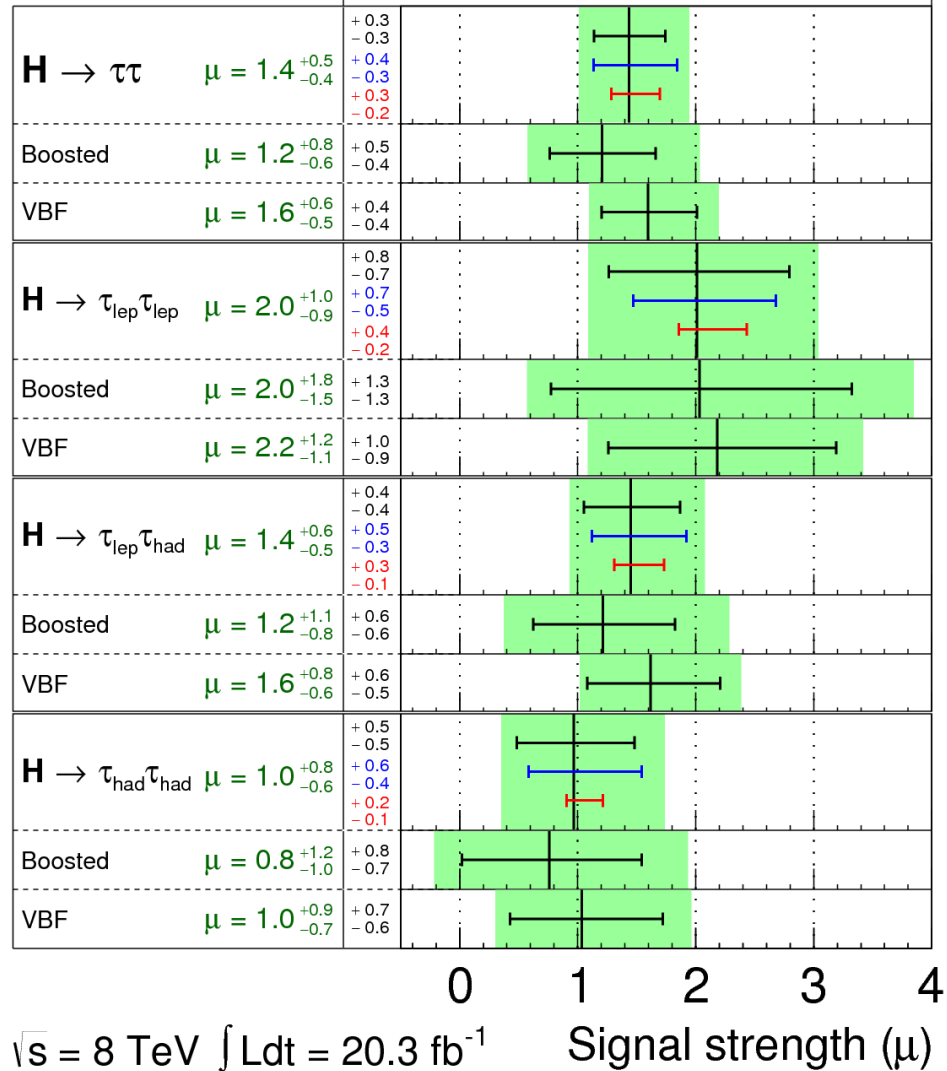
- ▶ Only one calculation for ttZ,
 - ▶ which does not include PDF uncertainty.
- ▶ Different choices of central value and envelope for scales are made in ttW calculations.
- ▶ Recipe used by SUSY group:
 - ▶ Take ttW cross section and uncertainty from [arXiv:1204.5678 - Campbell et al.](#) as it has the most information.
 - ▶ Take ttZ cross section from [arXiv:1208.2665 - Garzelli, Kardos, Papadopoulos, Trocsanyi.](#)
 - ▶ Assume uncertainties for ttW and ttZ are approximately the same.

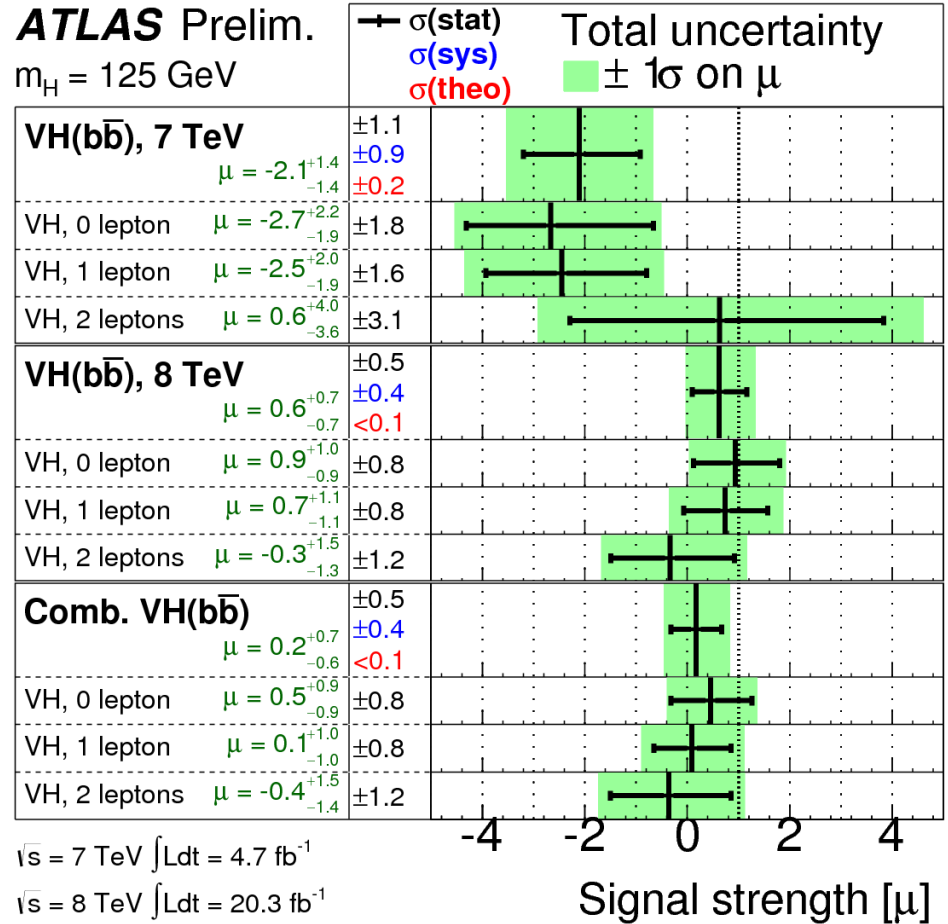
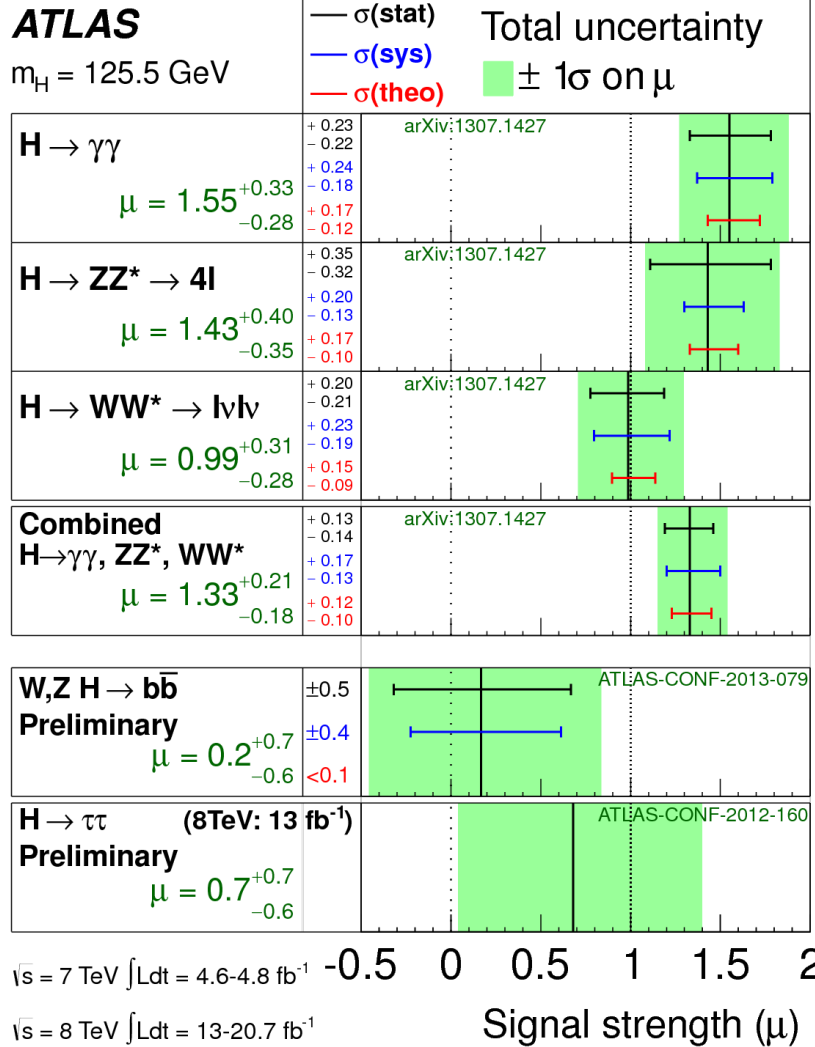
Process	σ_{NLO} [fb]	k-factor	Uncertainties		
			scale	PDF	Total
tt+W	232	1.18	21%	8%	22%
tt+Z	205.7	1.33	21%	8%	22%



ATLAS Prelim.

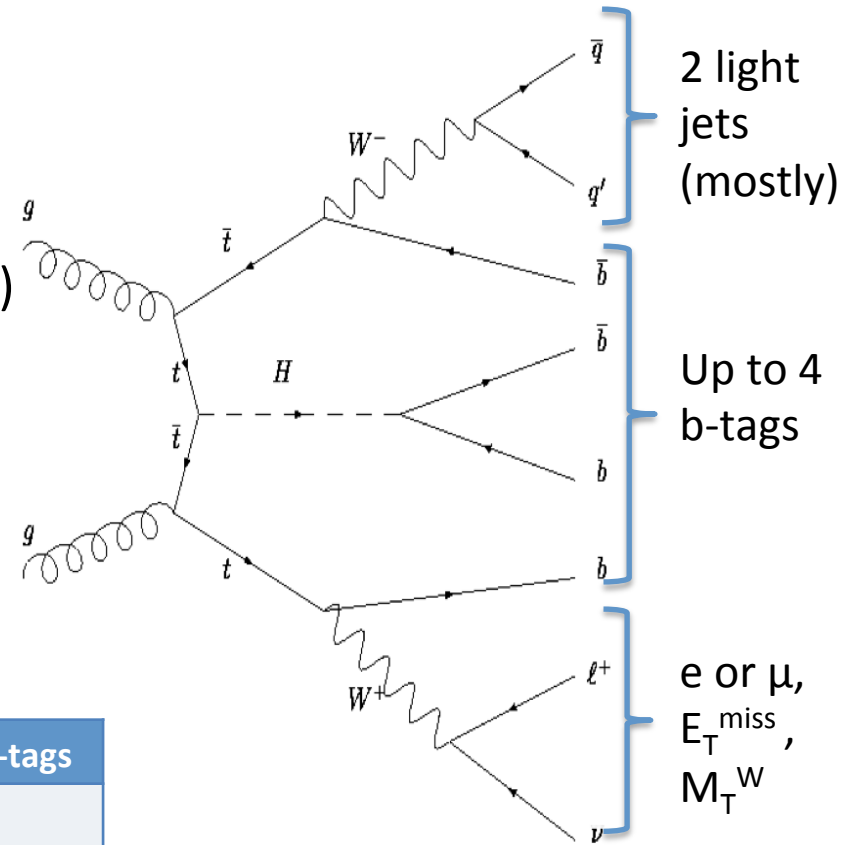
$m_H = 125$ GeV





ATLAS Analysis – lepton+jets

- Cut-based analysis
- For ≥ 6 jets & ≥ 3 b-tags:
 - Use m_{bb} , as discriminating variable
 - Kinematic fit to reconstruct $t\bar{t}$
 - Use leftover b-jets for $H \rightarrow bb$
- Elsewhere: use H_T^{had} (scalar sum of jet p_T)
- Fit **Signal** and **Background** regions to get limits
- Get final background normalizations and systematic uncertainties (“nuisance parameters”) from fit to data – **profiling**
- Use control regions to check fit is ok



	0 b-tags	1 b-tag	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets	H_T^{had}	H_T^{had}		H_T^{had}	
5 jets	H_T^{had}	H_T^{had}	H_T^{had}	H_T^{had}	H_T^{had}
≥ 6 jets	H_T^{had}	H_T^{had}	H_T^{had}	m_{bb}	m_{bb}

Signal
Background
 Control regions

Direct BSM Higgs Searches (ATLAS)

- FCNC in $t \rightarrow cH$, $H \rightarrow \gamma\gamma$ - upper limit on BR: Obs.(Exp.): 0.83%(0.53%) x SM for 125 GeV at 95% CL [ATLAS-CONF-2013-081]
- $H \rightarrow ZZ \rightarrow ll\nu\nu$: Excl. 320 - 560 GeV [ATLAS-CONF-2012-016]
- $H \rightarrow ZZ \rightarrow llqq$: Excl. 300 - 310, 360 - 400 GeV. at 145 GeV 3.5 x SM [ATLAS-CONF-2012-017]
- $H \rightarrow WW \rightarrow lljj$: at 400 GeV Obs.(Exp.) 2.3(1.6) x SM [ATLAS-CONF-2012-018]
- Higgs in SM with 4th fermion generation: model ruled out [ATLAS-CONF-2011-135]
- Fermiophobic H to diphoton Model ruled out [ATLAS-CONF-2012-013]
- MSSM neutral H [JHEP: JHEP02(2013)095]
- NMSSM a_1 to $\mu\mu$ [ATLAS-CONF-2011-020]
- NMSSM H to a_0a_0 to 4γ [ATLAS-CONF-2012-079]
- $H_{\pm} \rightarrow cs$ [EPJC73 (2013) 2465]
- 2HDM $WW(ll\nu\nu)$ [ATLAS-CONF-2013-027]

'It is an old maxim of mine that when you have excluded the impossible, whatever remains, however improbable, must be the truth.'

Sherlock Holmes

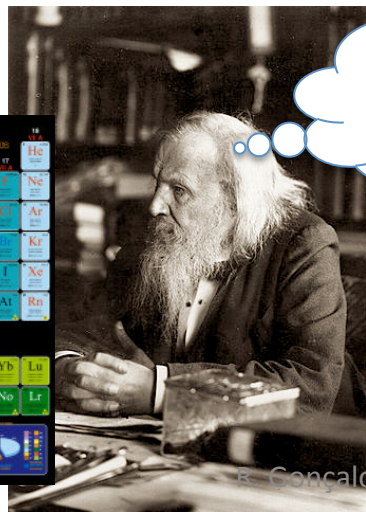
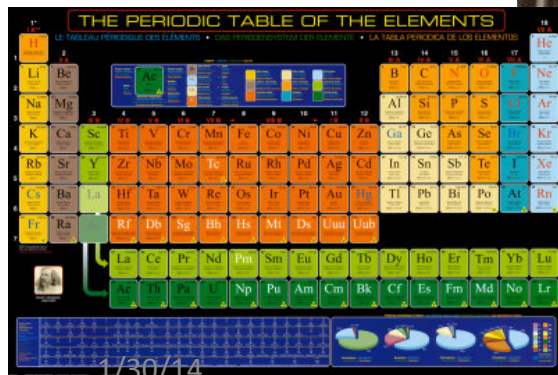
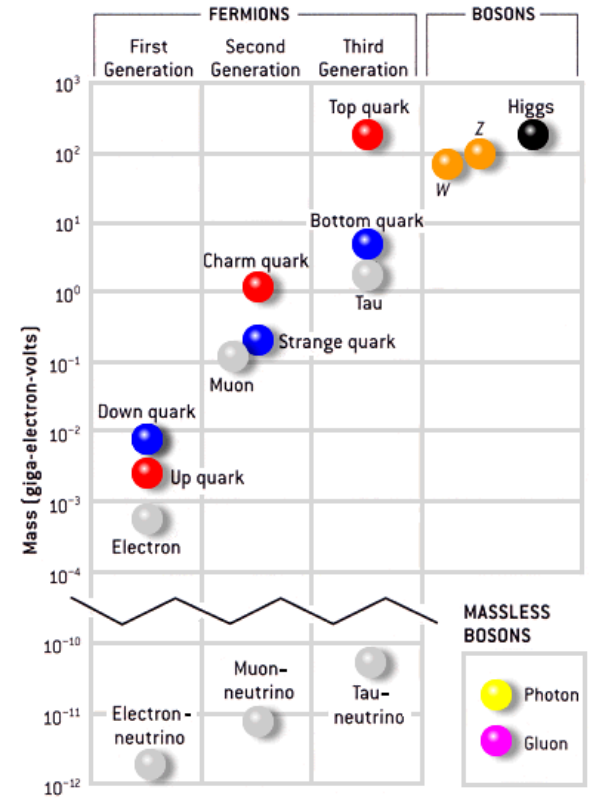
-*The Beryl Coronet*



Lateral Thoughts

Many questions...

- Higgs mechanism says **how** to give mass to fundamental particles
- It doesn't say **why** fermion masses and Yukawa couplings are so different: 10^{-10}GeV (ν) – 10^2GeV (t)
- Top mass at the EW scale. Does it play a special role in breaking it?
- (And by the way... why 3 families of leptons and quarks?)
- What is the underlying theory?



Eh! Eh! Eh!
Been there,
done that!

	I	II	III	
Quarks	mass: $2.4 \text{ MeV}/c^2$ charge: $2/3$ spin: $1/2$ name: u up	mass: $1.27 \text{ GeV}/c^2$ charge: $2/3$ spin: $1/2$ name: c charm	mass: $171.2 \text{ GeV}/c^2$ charge: $2/3$ spin: $1/2$ name: t top	mass: 0 charge: 0 spin: 1 name: Y photon
	mass: $4.8 \text{ MeV}/c^2$ charge: $-1/3$ spin: $1/2$ name: d down	mass: $104 \text{ MeV}/c^2$ charge: $-1/3$ spin: $1/2$ name: s strange	mass: $4.2 \text{ GeV}/c^2$ charge: $-1/3$ spin: $1/2$ name: b bottom	mass: 0 charge: 0 spin: 1 name: g gluon
Leptons	mass: $< 2.2 \text{ eV}/c^2$ charge: 0 spin: $1/2$ name: ν_e electron neutrino	mass: $< 0.17 \text{ MeV}/c^2$ charge: 0 spin: $1/2$ name: ν_μ muon neutrino	mass: $< 15.5 \text{ MeV}/c^2$ charge: 0 spin: $1/2$ name: ν_τ tau neutrino	mass: $91.2 \text{ GeV}/c^2$ charge: 0 spin: 1 name: Z^0 Z boson
	mass: $0.511 \text{ MeV}/c^2$ charge: -1 spin: $1/2$ name: e electron	mass: $105.7 \text{ MeV}/c^2$ charge: -1 spin: $1/2$ name: μ muon	mass: $1.777 \text{ GeV}/c^2$ charge: -1 spin: $1/2$ name: τ tau	mass: $80.4 \text{ GeV}/c^2$ charge: ± 1 spin: 1 name: W^\pm W boson