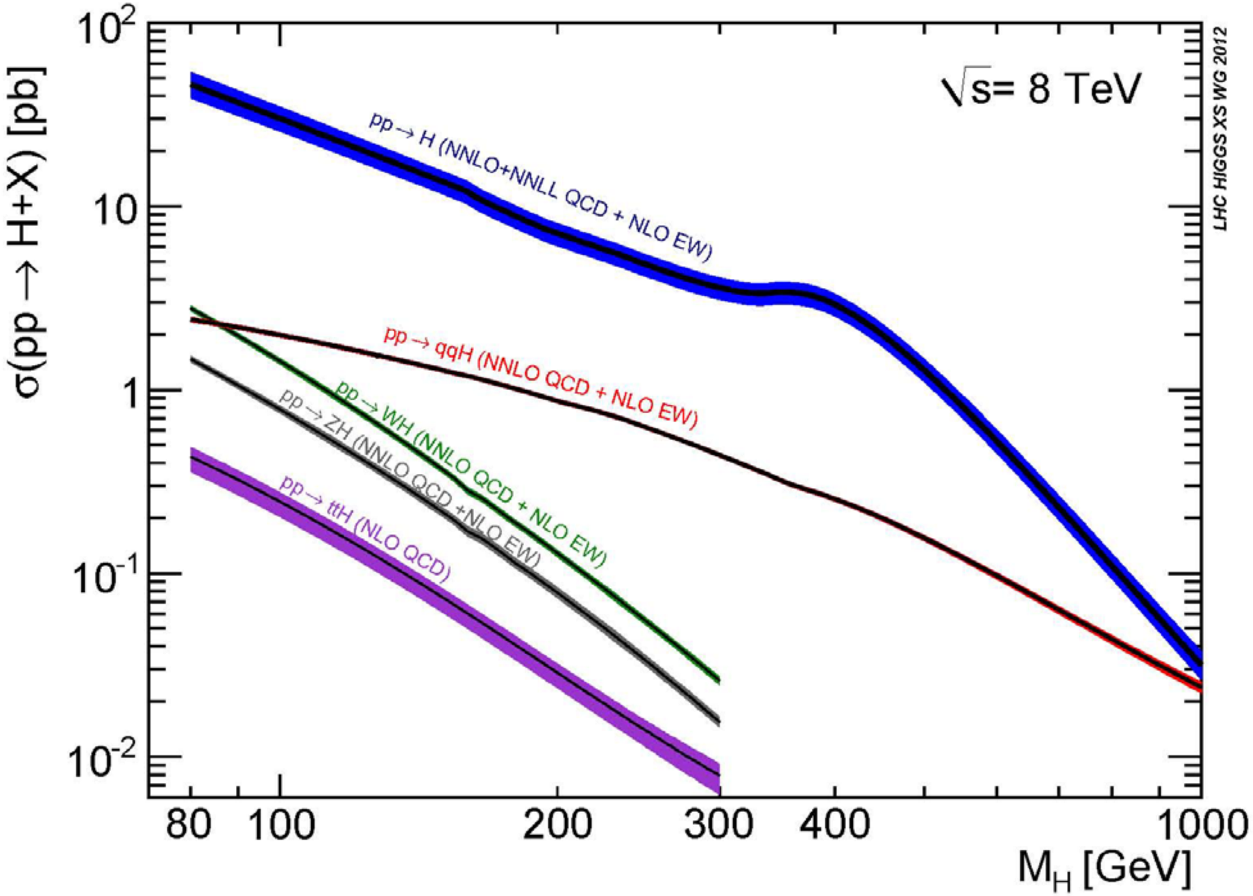
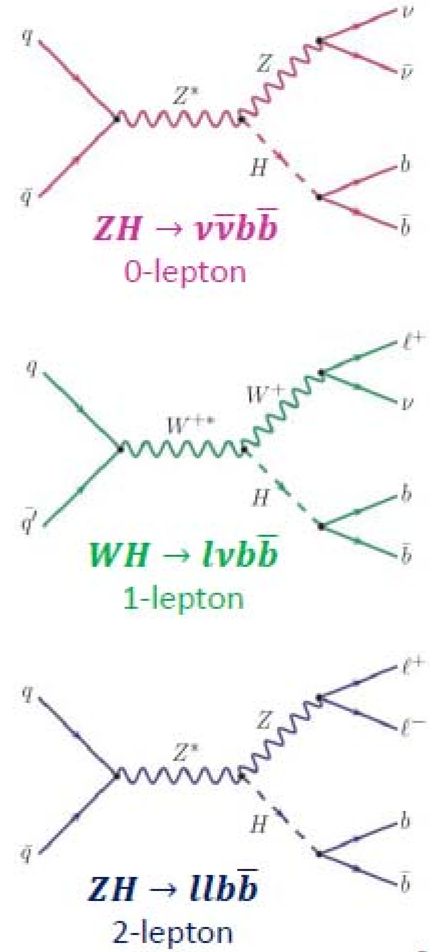
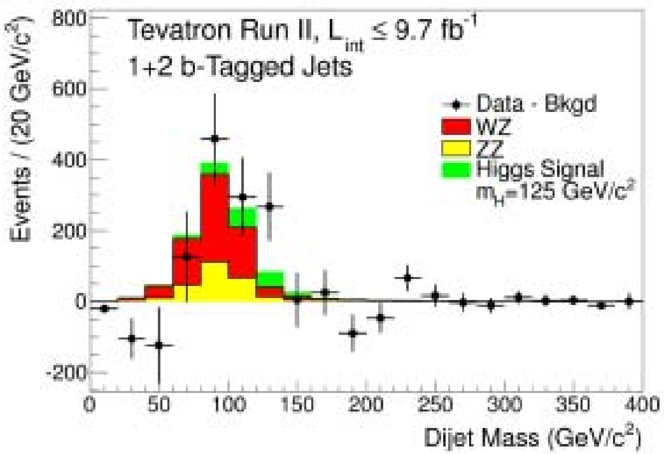
$Z(\nu\nu)H(bb)$ vs $Z(\nu\nu)H(\tau\tau)$ measuring also H(bb)H(tautau)?

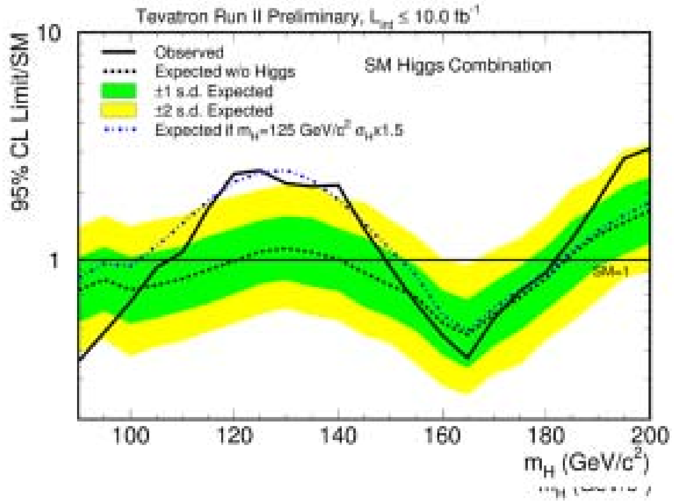
Associated production: Z(W)H





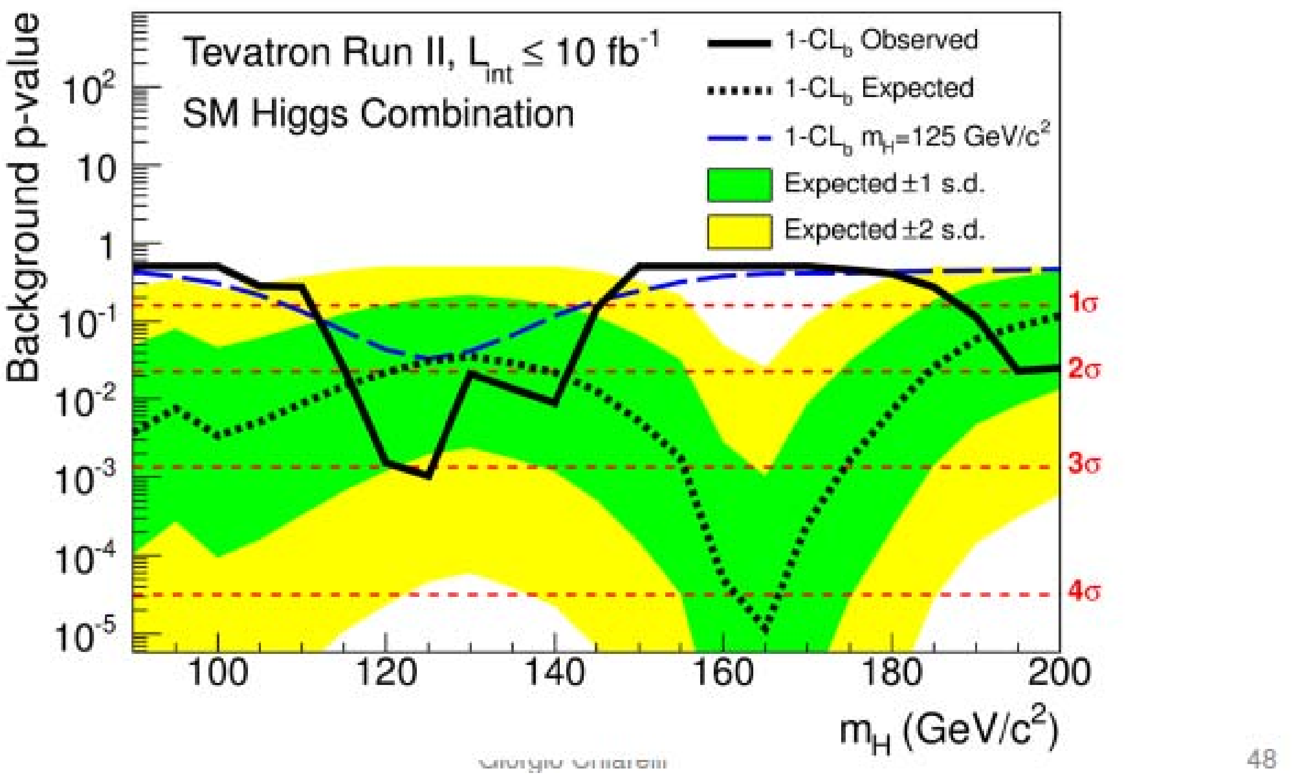
Higgs to fermions coupling Tevatron result: many combined channels: most powerful: VH(bb)





G. Chiarelli : fisica del Higgs 2013

Minimum p-value corresponding to 3.1σ at m=125 GeV



ATLAS NOTE

ATLAS-CONF-2013-108

November 28, 2013

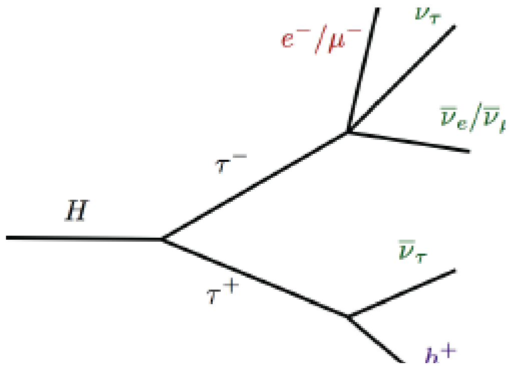
Evidence for Higgs Boson Decays to the $\tau^{+}\tau^{-}$ Final State with the ATLAS Detector

Z. Zinonos[1], D. Zanzi[2], S. Xella[3], S.L. Wu[3], N. Wermes[14], M. Volpi[5], T. Vickey[6], D. Varouchas[7], J. Valls[8], A. Tuna[9], S. Tsuno[10], M. Trottier-McDonald[11], A. Tanasijczuk[11], K.G. Tan[5], B. Stugu[12], R. Simoniello[13], F. Scutti[14], T. Schwindt[14], C. Schillo[15], D. Sammel[15], P. Sales de Bruin[28], Y. Sakurai[16], N. Ruthmann[15], D. Rousseau[17], S. Resconi[13], A. Quadt[1], A. Pranko[7], C. Pizio[13], M. Pitt[18], A. Pingel[4], E. Pianori[19], C.E. Pandini[13], Y. Pan[3], D. O'Neil[11], H. Öhman[20], F. Nuti[5], G. Nunes Hanninger[5], J. Novakova[21], K. Nakamura[10], M. Morinaga[22], M. Morgenstern[23], T. Mitani[16], B. Mellado[6], L. March[8], P. Malecki[24], A. Magitteri[13], H. Maddocks[25], R. Madar[15], J. Liebal[14], K. Leney[6], A. Leister[26], S. Lai[15], M. Kruskal[27], J. Kroseberg[14], J. Kraus[14], J. Keller[28], C. Jeske[19], D. Jennens[5], G.-Y. Jeng[29], M. Janus[19], J. Howard[30], Y. Heng[3], L. Helary[27], H. Hass[15], K. Hanawa[22], K. Grimm[25], F. Friedrich[23], M. Flechl[15], H. Fox[25], L. Fiorini[8], S. Farrington[19], L. Dell'Asta[27], E.N. Dawe[11], W. Davey[14], Z. Czyczula[26], S. Consonni[13], E. Coniavitis[20], L. Colasurdo[32], X. Chen[3], V. Cavasinni[34], D. Cavalli[13], E. Castaneda-Miranda[31], K. Bristow[6], A. Brennan[5], E. Bouhova-Thacker[25], M. Boehler[15], K. Black[27], J. Biesiada[7], J. Beringer[7], M. Beckingham[28], E. Barberio[5], S. Banerjee[3], A. Andreazza[13], D. Álvarez Piqueras[8]

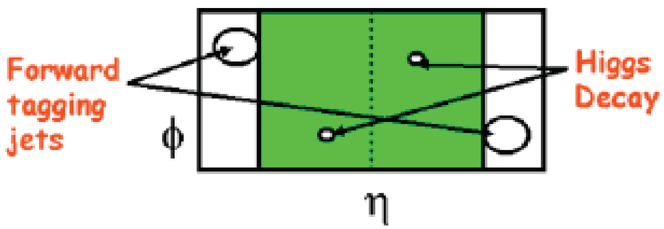
+ D. Puddu (2012)

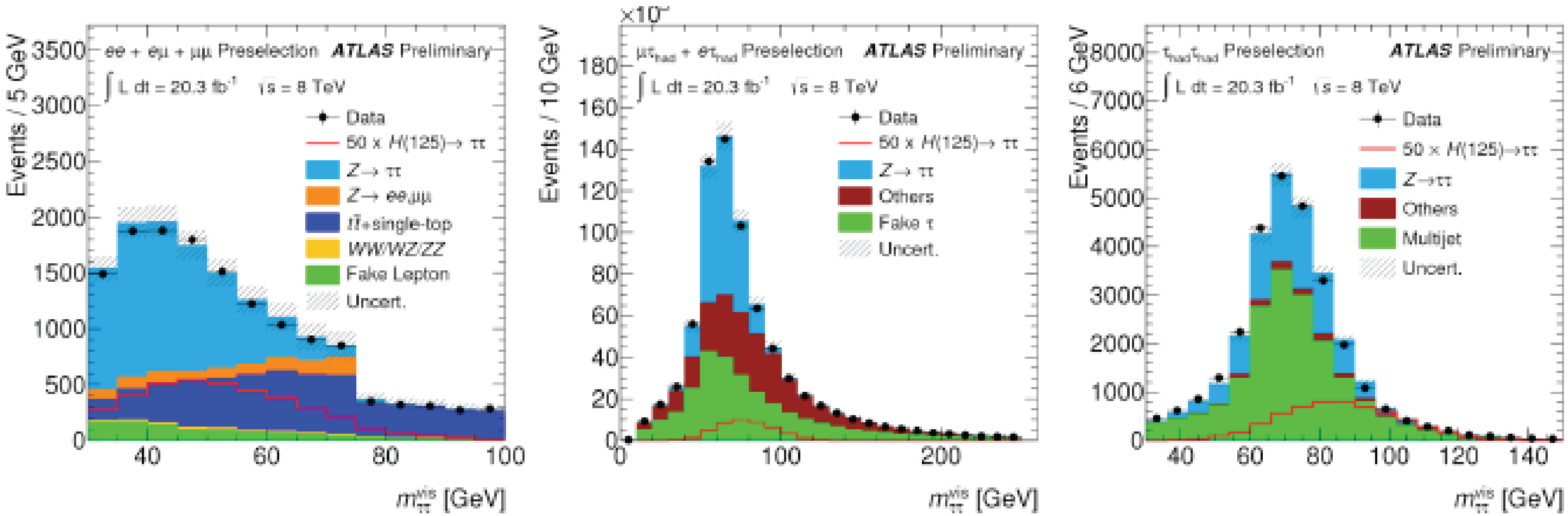
Higgs production and decay

- Lep-lep: H→ ττ → 2l + 4ν BR = 12.4%
- Lep-had: H→ ττ → l + $\tau_{had\text{-}vis}$ + 3ν BR = 45.6%
- Had-had: H→ ττ → 2$\tau_{had\text{-}vis}$ + 2ν BR = 42%



- Concentrating on highest sensitivity phase space regions
  - VBF category, target VBF production mode: 2 jets with leading (sub-leading) p_T > 40-50 (30-35) GeV, $\Delta\eta_{jj}$ cut
  - Boosted category, making the most of ggF production: Higgs p_T > 100 GeV
  - Rest category used in had-had to constrain backgrounds

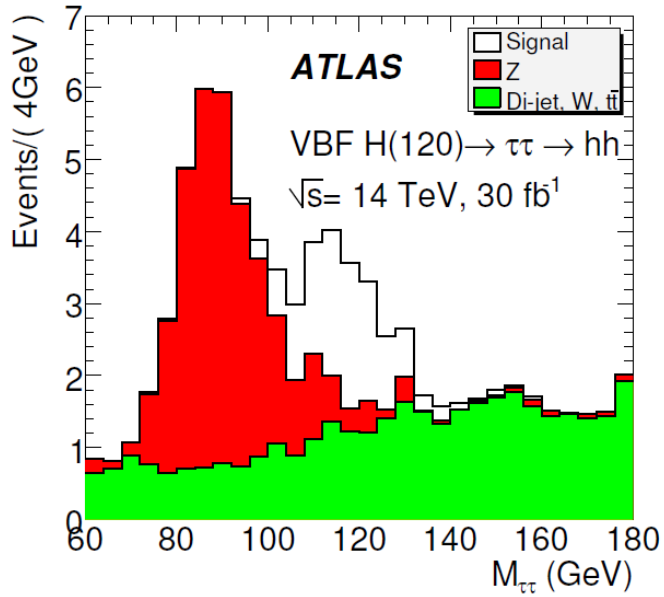




- VBF vs ggF results consistent with SM expectation
- Best-fit values: $\mu_{ggF} = 1.1^{+1.3}_{-1.1}$, $\mu_{VBF+VH} = 1.6^{+0.8}_{-0.7}$

Uncertainties on μ:

- Statistical: ± 0.3
- Systematic: +0.3/-0.2
- Theory: +0.3/-0.2

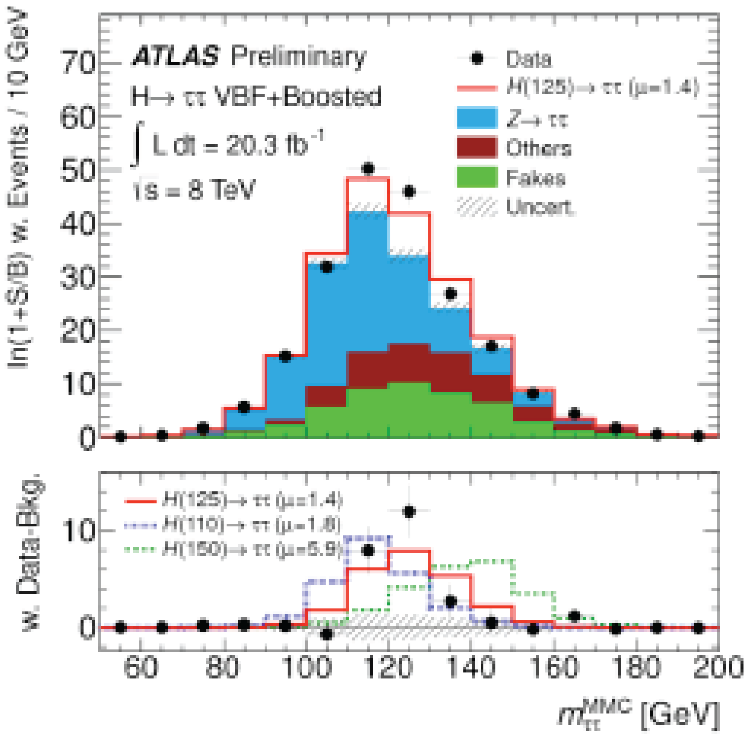


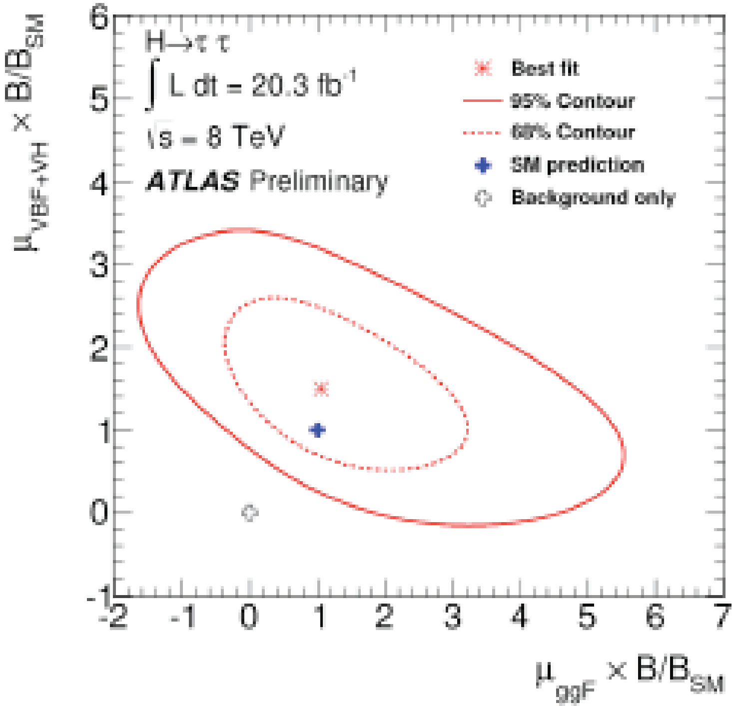
2008 F.Sarri's PHD Thesis
Significance ~3σ

Combined results

- **Mass compatibility** studied building a mass spectrum weighting each event by ln(1+S/B) (S/B) from corresponding BDT score bin
- **Excess consistent with m_H = 125 GeV**

Significance: 4.1σ (3.2σ expected)





- **VBF vs ggF** results consistent with SM expectation
- **Best-fit values:** $\mu_{ggF} = 1.1^{+1.3}_{-1.1}$, $\mu_{VBF+VH} = 1.6^{+0.8}_{-0.7}$

Systematics

- Main systematics ranked by their impact on μ in the fit
- MC statistics uncertainty Δμ = 0.5

Source of Uncertainty	Uncertainty on μ
Signal region statistics (data)	0.30
$Z \to \ell\ell$ normalization ($\tau_{\rm lep}\tau_{\rm had}$ boosted)	0.13
ggF $d\sigma/dp_T^H$	0.12
JES η calibration	0.12
Top normalization ($\tau_{\rm lep}\tau_{\rm had}$ VBF)	0.12
Top normalization ($\tau_{\rm lep}\tau_{\rm had}$ boosted)	0.12
$Z \to \ell\ell$ normalization ($\tau_{\rm lep}\tau_{\rm had}$ VBF)	0.12
QCD scale	0.07
di-$\tau_{\rm had}$ trigger efficiency	0.07
Fake backgrounds ($\tau_{\rm lep}\tau_{\rm lep}$)	0.07
$\tau_{\rm had}$ identification efficiency	0.06
$Z \to \tau^+\tau^-$ normalization ($\tau_{\rm lep}\tau_{\rm had}$)	0.06
$\tau_{\rm had}$ energy scale	0.06

Immediate perspectives

- Goal is now a paper, plan to circulate draft in March → in time for the combination schedule
  - Minimal changes planned, mostly consolidation, inclusion of 7 TeV data and finalisation of cut-based results.
  - Not tighting the schedule re-inclusion of low sensitivity categories and VH channels.

Pisa: be acquainted with the analysis tools developed by Z. Zenonos, now at Gottingen.

A collaboration with the GottingenUniversity could be also feasible.

ATLAS-CONF-2013-079

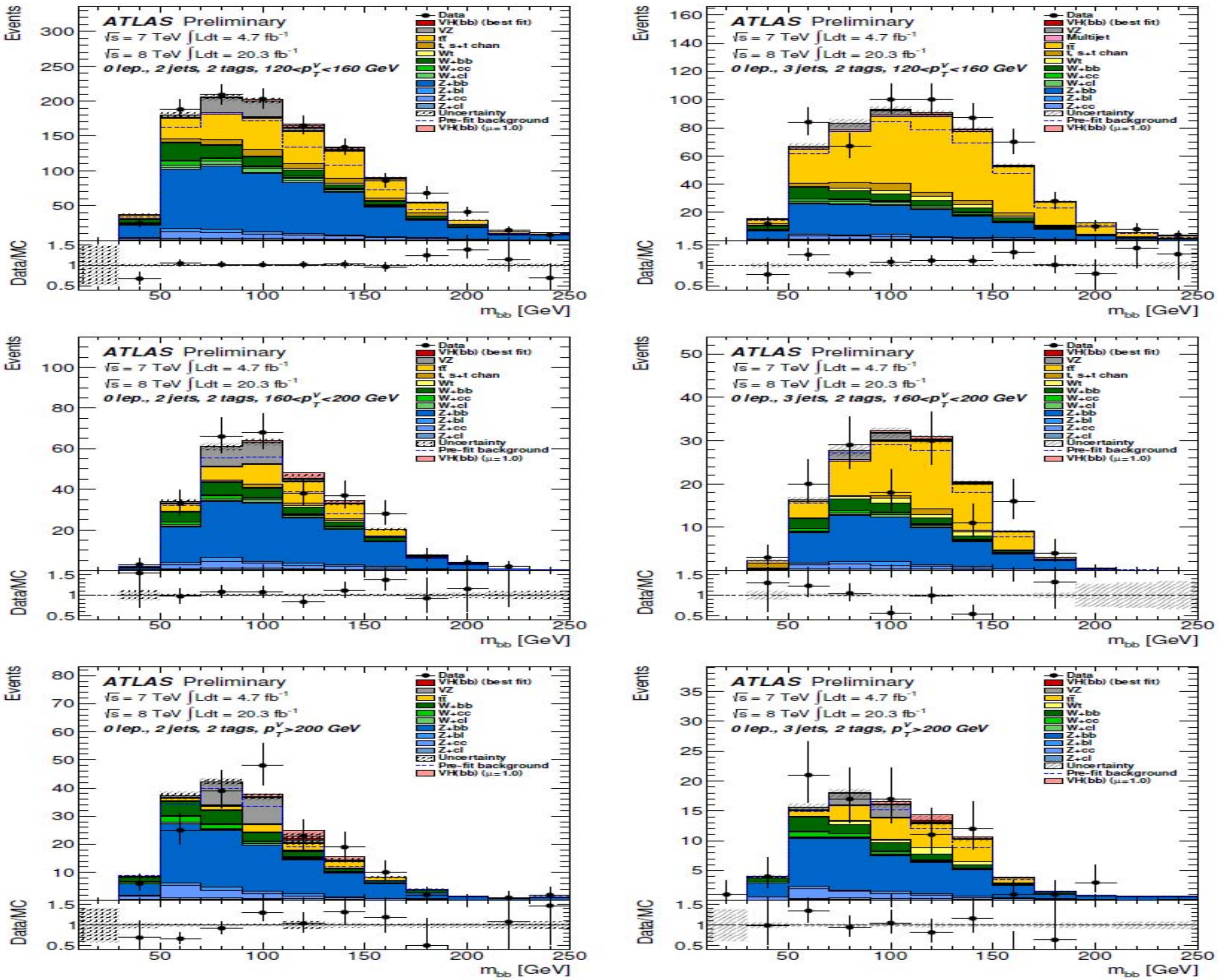
Search for the bb decay of the Standard Model Higgs boson in associated (W/Z)H production with the ATLAS detector

- W/Z leptonic decay, H bb decay

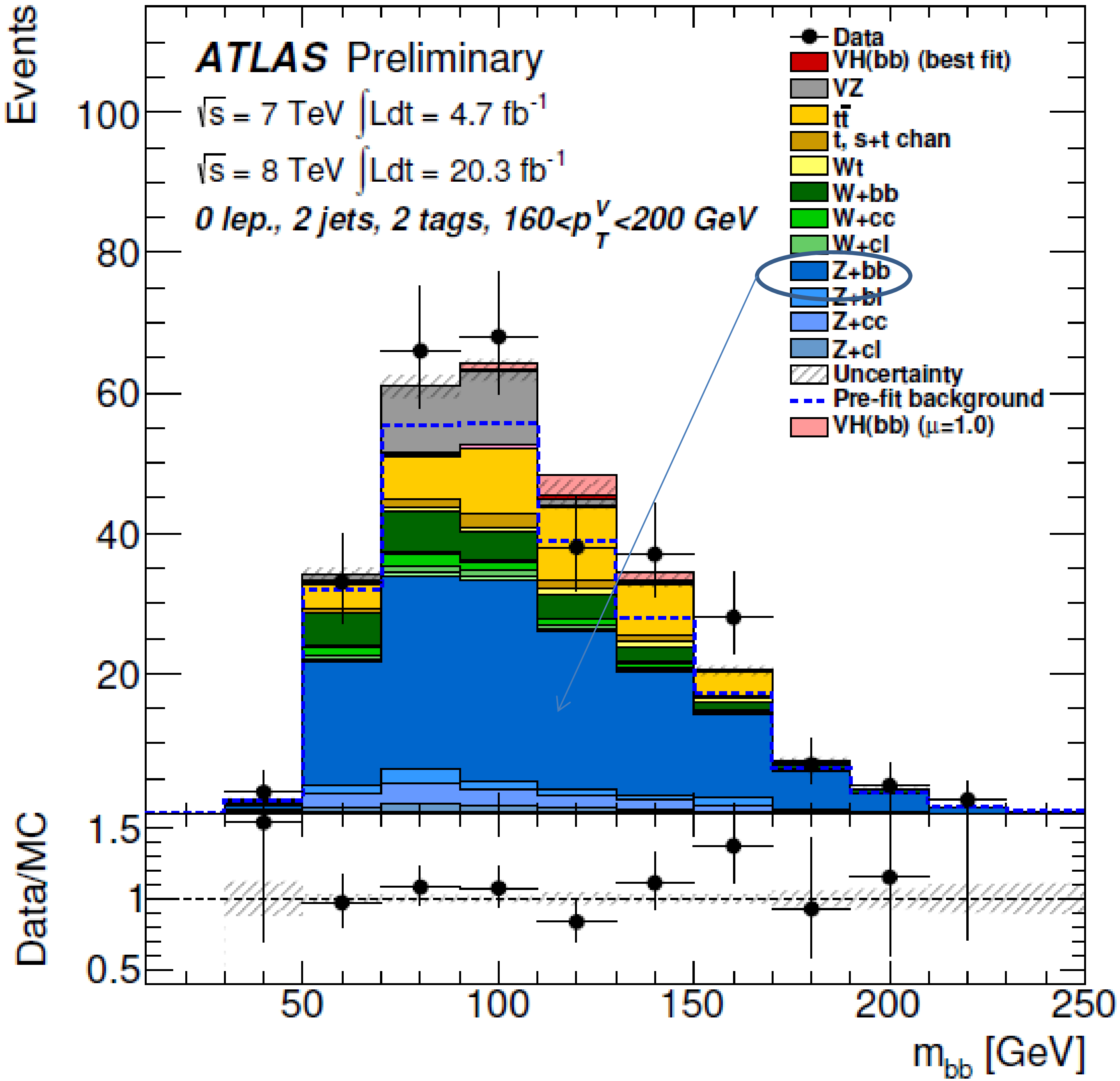
m_H = 125 GeV at 7 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	12.3	0.0	0.7	8.2
$W \to \ell\nu$	107.1	0.2	3.5	-
$Z \to \nu\nu$	36.4	2.2	-	-
m_H = 125 GeV at 8 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	15.3	0.0	0.9	8.4
$W \to \ell\nu$	130.2	0.2	3.3	-
$Z \to \nu\nu$	45.5	2.5	-	-

Acceptances O(≈ %)

0-lepton analysis



Main background: Zbb irriducible



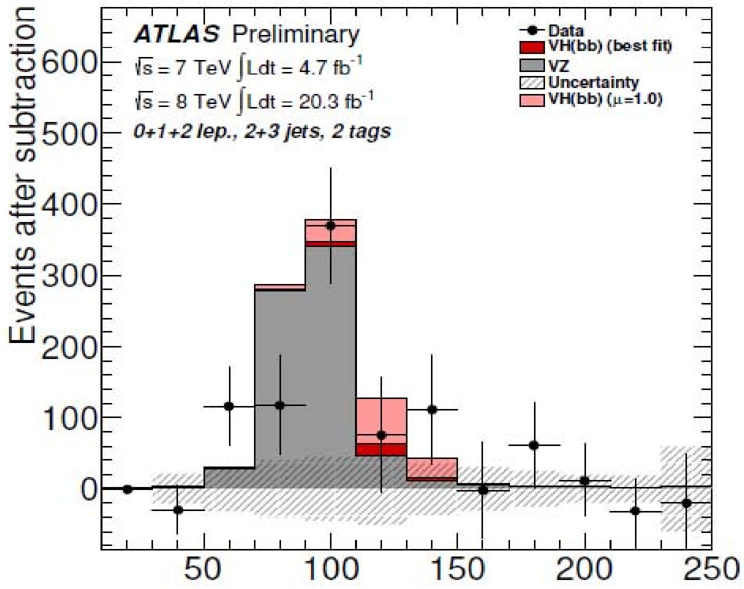
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV $\int Ldt$ = 4.7 fb^{-1}
$\sqrt{s}$ = 8 TeV $\int Ldt$ = 20.3 fb^{-1}
0 lep., 2 jets, 2 tags, 160<p_T^V<200 GeV
Data
VH(bb) (best fit)
VZ
$t\bar{t}$
t, s+t chan
Wt
W+bb
W+cc
W+cl
Z+bb
Z+bl
Z+cc
Z+cl
Uncertainty
Pre-fit background
VH(bb) (μ=1.0)
Events
Data/MC
m_{bb} [GeV]

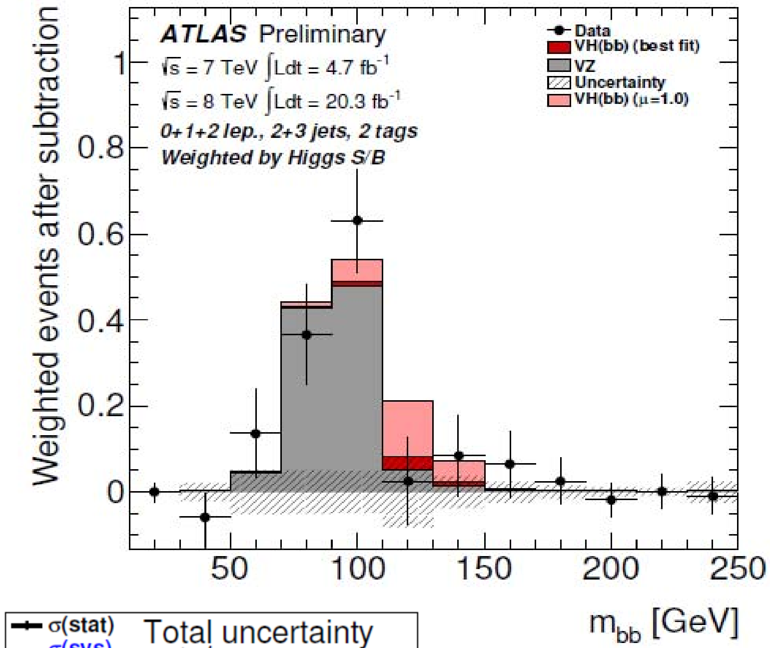
0,1,2-leptons analysis
in 0-lepton expected : 30, «mesured »: 5.4
effect of the global μ=0.2

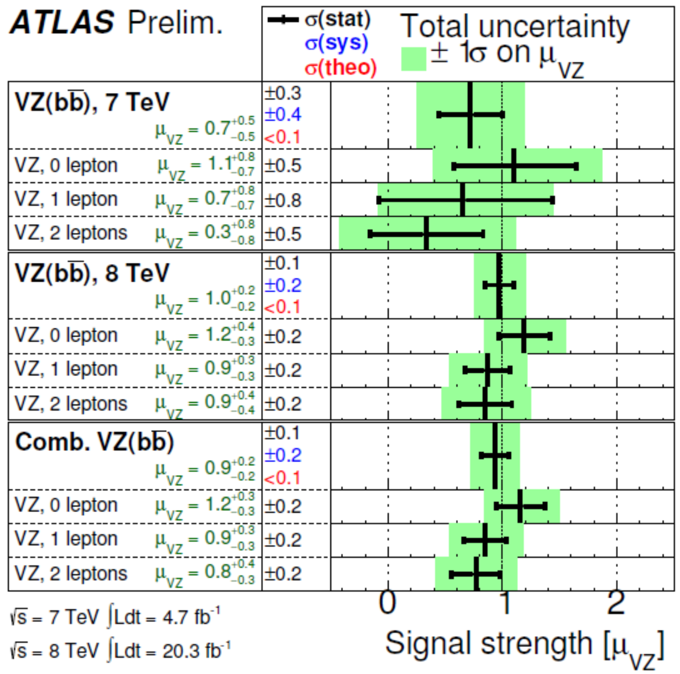
2-jet, 2-tag sample													
	0-lepton			1-lepton					2-lepton				
Process	E_T^{miss} [GeV]			p_T^W[GeV]					p_T^Z[GeV]				
	120-160	160-200	>200	0-90	90-120	120-160	160-200	> 200	0-90	90-120	120-160	160-200	>200
$Z \to \nu\nu$	1.6	0.9	1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
$Z \to \ell\ell$	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	2.1	0.5	0.4	0.2	0.2
$W \to \ell\nu$	0.4	0.2	0.2	7.6	1.7	1.2	1.0	1.1	<0.1	<0.1	<0.1	<0.1	<0.1
VH total	2.0	1.1	1.1	7.8	1.8	1.2	1.1	1.1	2.1	0.5	0.4	0.2	0.2
VH expected	11	5.8	6.1	42	9.5	6.6	5.6	6.1	11	2.7	2.2	1.1	1.2
Top	159	33	8	2763	729	359	113	40	166	32	8.0	0.5	<0.1
W+c, light	21	5.3	2.7	616	65	27	12	7.8	<0.1	<0.1	<0.1	<0.1	<0.1
W+b	30	10	6.1	909	106	49	25	19	<0.1	<0.1	<0.1	<0.1	<0.1
Z+c, light	23	8.1	5.2	22	2.1	0.5	0.3	0.1	91	12	5.6	1.6	1.0
Z+b	226	71	39	97	13	3.9	1.8	0.5	938	146	64	14	8.3
WW	0.5	0.1	0.1	11	1.0	0.7	0.3	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
VZ	26	11	10	145	20	12	7.6	6.5	60	8.6	4.5	2.2	2.1
Multijet	4.8	1.1	0.7	1306	45.6	8.7	4.8	0.4	<0.1	<0.1	<0.1	<0.1	<0.1
Total Bkg.	491 ± 10	141 ± 3	72 ± 2	5869 ± 64	981 ± 16	460 ± 9	165 ± 4	74 ± 3	1255 ± 24	199 ± 4	82 ± 2	18 ± 1	11.4 ± 0.5
Data	502	143	90	5916	990	458	162	79	1282	204	70	22	6
S/B	0.004	0.008	0.02	0.001	0.002	0.003	0.006	0.02	0.002	0.003	0.005	0.01	0.02

3-jet, 2-tag sample													
	0-lepton			1-lepton					2-lepton				
Process	E_T^{miss} [GeV]			p_T^W[GeV]					p_T^Z[GeV]				
	120-160	160-200	>200	0-90	90-120	120-160	160-200	> 200	0-90	90-120	120-160	160-200	>200
$Z \to \nu\nu$	0.4	0.2	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
$Z \to \ell\ell$	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.9	0.3	0.2	0.1	0.1
$W \to \ell\nu$	0.1	0.1	<0.1	2.1	0.6	0.5	0.5	0.6	<0.1	<0.1	<0.1	<0.1	<0.1
VH total	0.5	0.3	0.4	2.2	0.6	0.5	0.5	0.6	0.9	0.3	0.2	0.1	0.1
VH expected	2.7	1.6	1.9	12	3.2	2.6	2.8	3.4	4.9	1.4	1.1	0.6	0.7
Top	169	44	13	4444	1171	592	238	121	114	22	5.5	0.3	<0.1
W+c, light	7.1	2.1	1.2	189	23	11.7	6.8	5.4	<0.1	<0.1	<0.1	<0.1	<0.1
W+b	12	4.7	3.3	318	36	21	14	12	<0.1	<0.1	<0.1	<0.1	<0.1
Z+c, light	6.3	2.8	2.5	8.8	0.9	0.4	0.2	0.1	53	9.6	4.5	1.4	1.2
Z+b	59	26	17	56	6.9	2.5	1.4	0.7	509	91	45	12	7.6
WW	0.2	0.1	0.1	4.0	0.5	0.3	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
VZ	3.7	1.8	2.3	31	4.7	3.1	2.5	3.7	20.1	3.1	1.6	0.9	1.2
Multijet	3.1	0.6	0.4	425	17	5.5	3.0	0.8	<0.1	<0.1	<0.1	<0.1	<0.1
Total Bkg.	260 ± 6	82 ± 2	40 ± 1	5476 ± 57	1260 ± 17	637 ± 11	266 ± 7	143 ± 5	696 ± 16	125 ± 3	57 ± 2	15 ± 1	10 ± 1
Data	287	59	40	5523	1233	639	249	154	734	119	56	13	9
S/B	0.002	0.004	0.009	0.0004	0.0005	0.0008	0.002	0.004	0.001	0.002	0.004	0.008	0.01

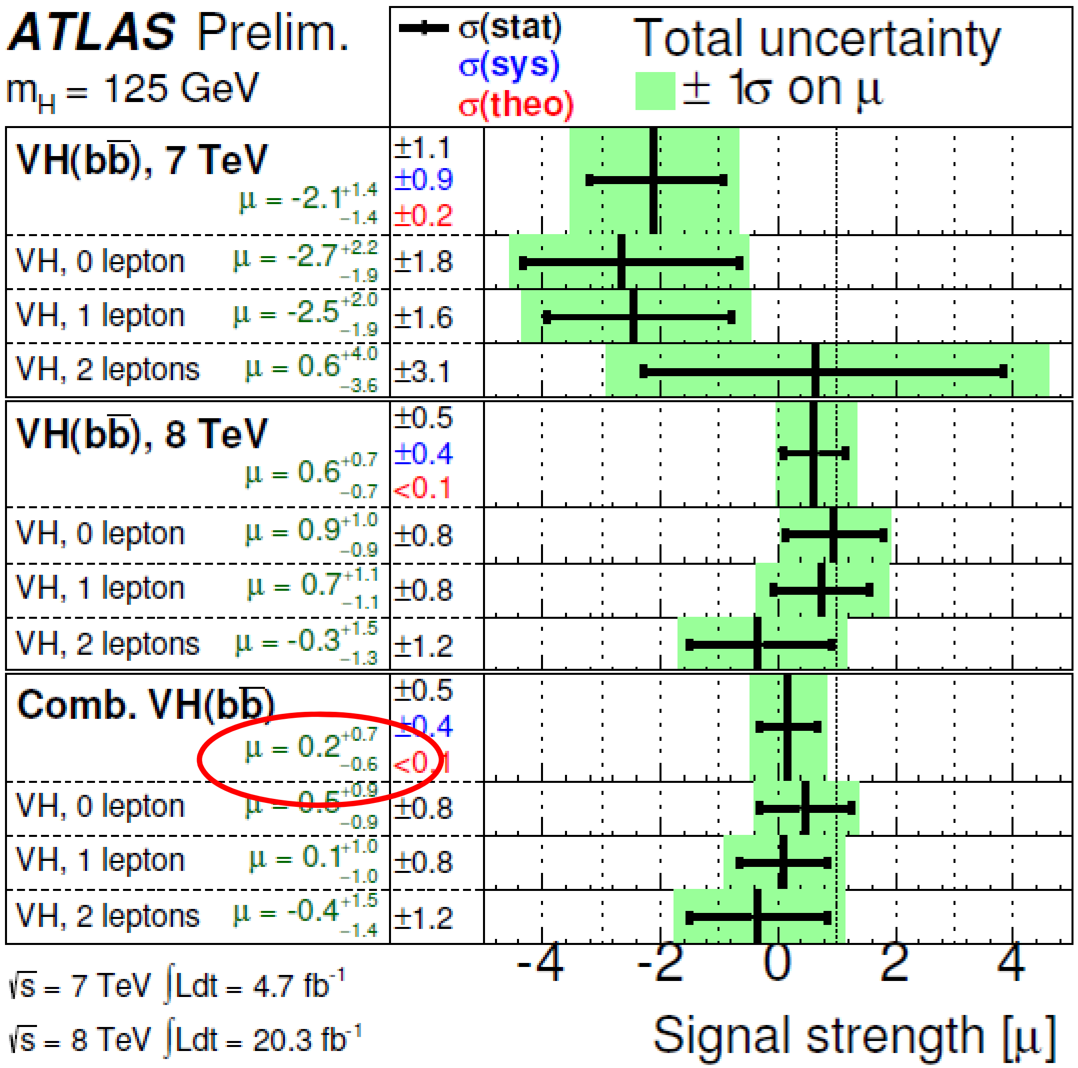
Check with (W/Z)Z



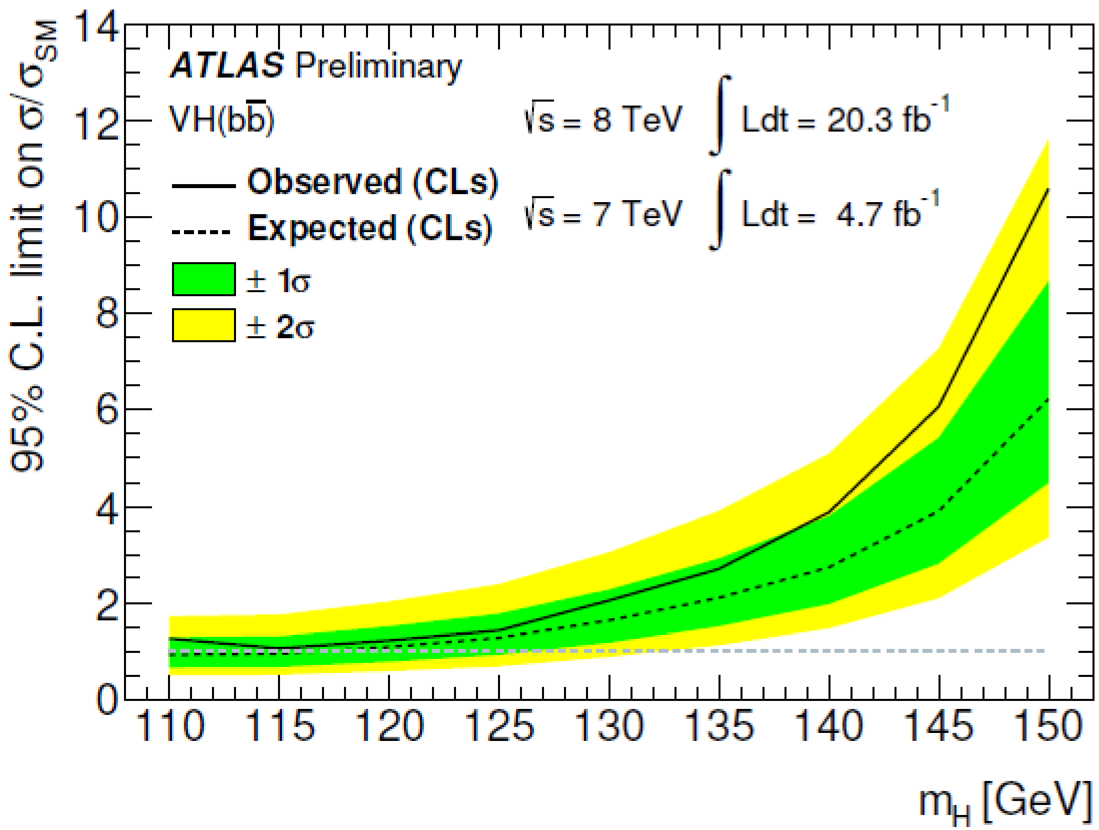




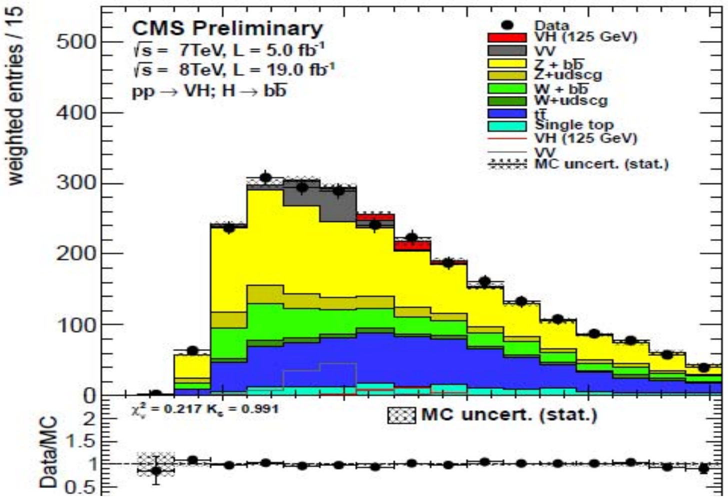
(W/Z)H strength

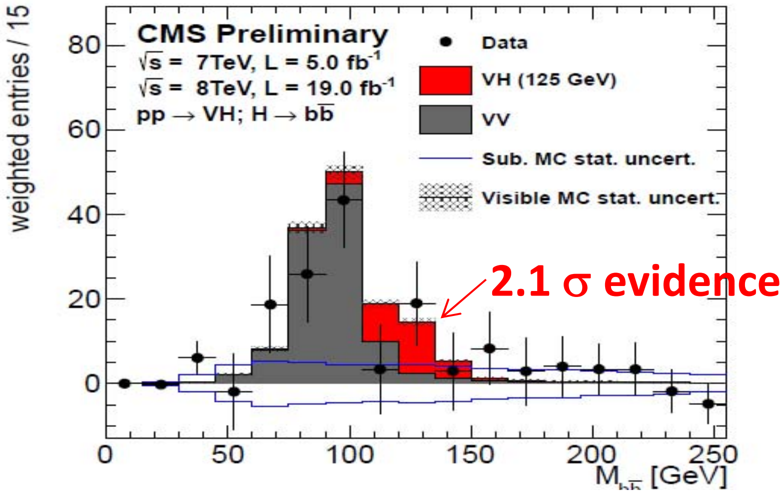


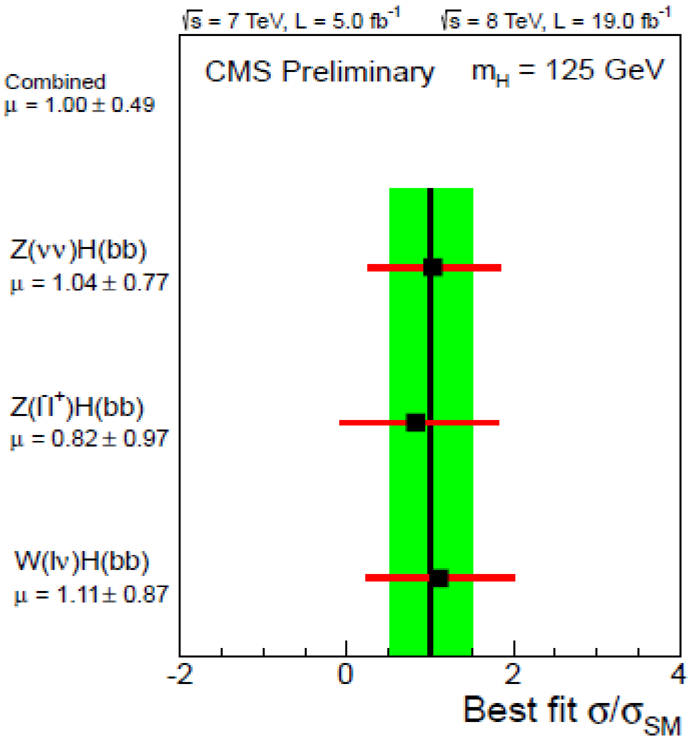
Higgs exclusion plot

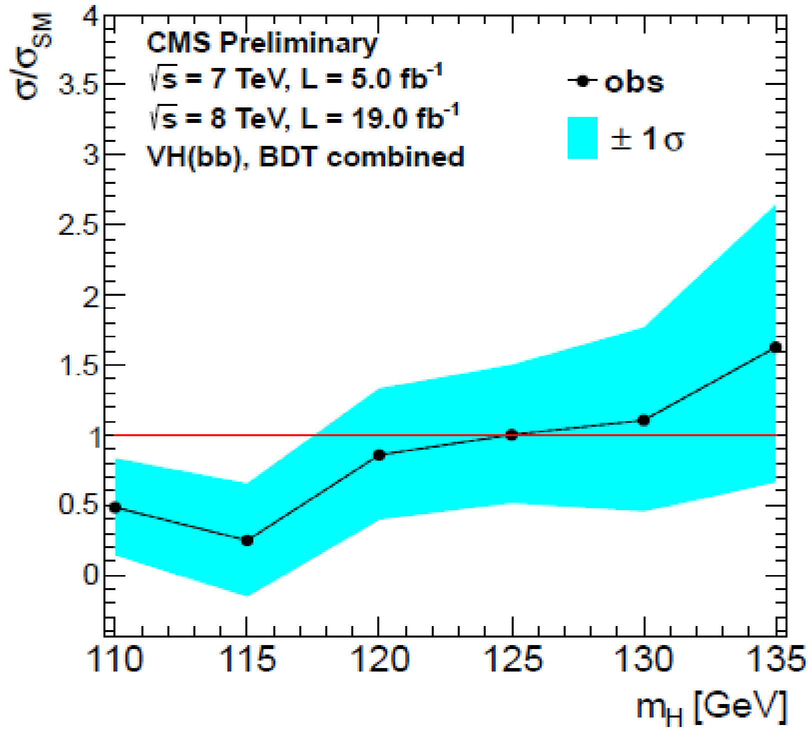


CMS: result OK with the SM Higgs CMS PAS HIG-13-012

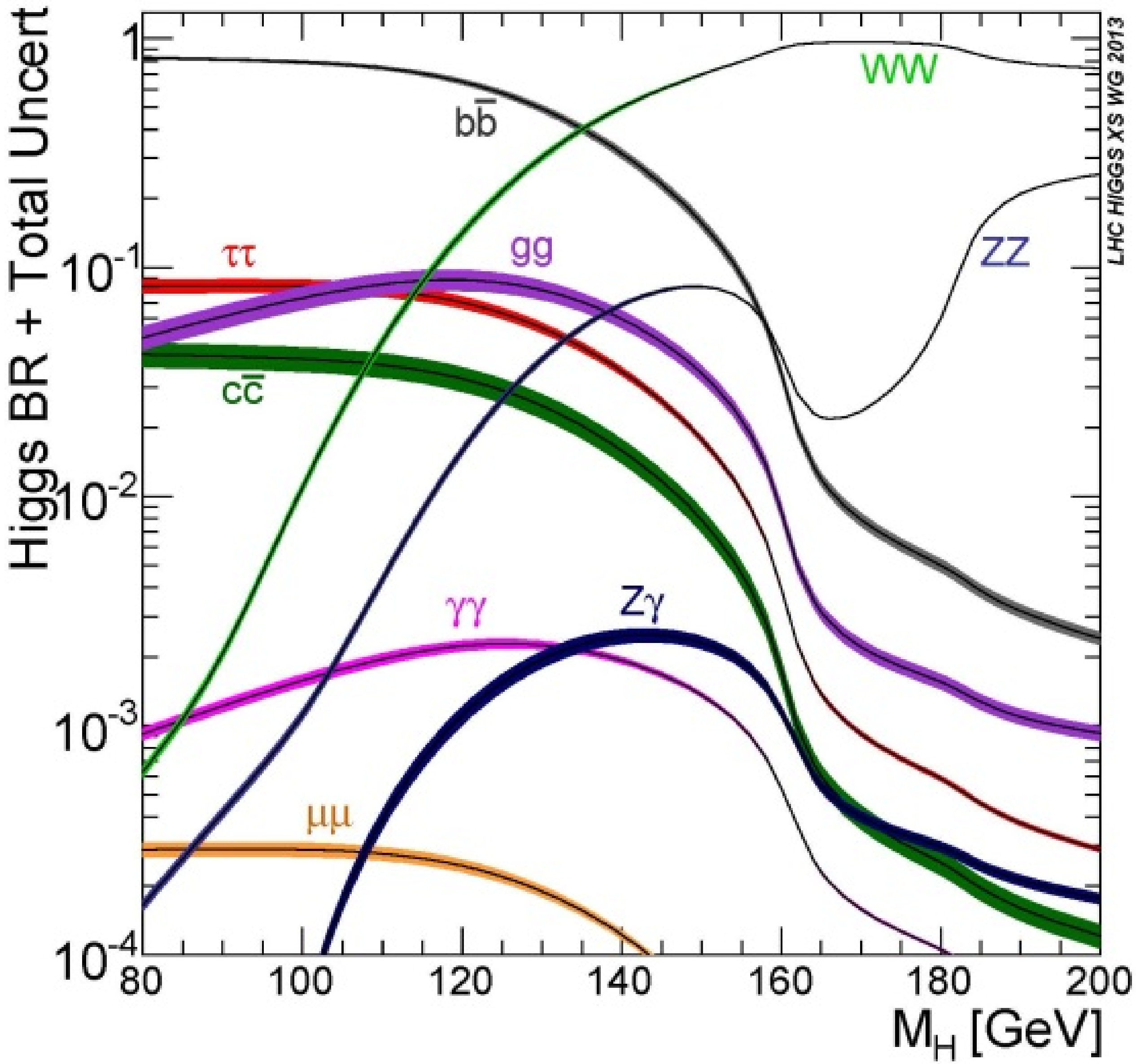








Second important fermionic decay: ττ (7%)



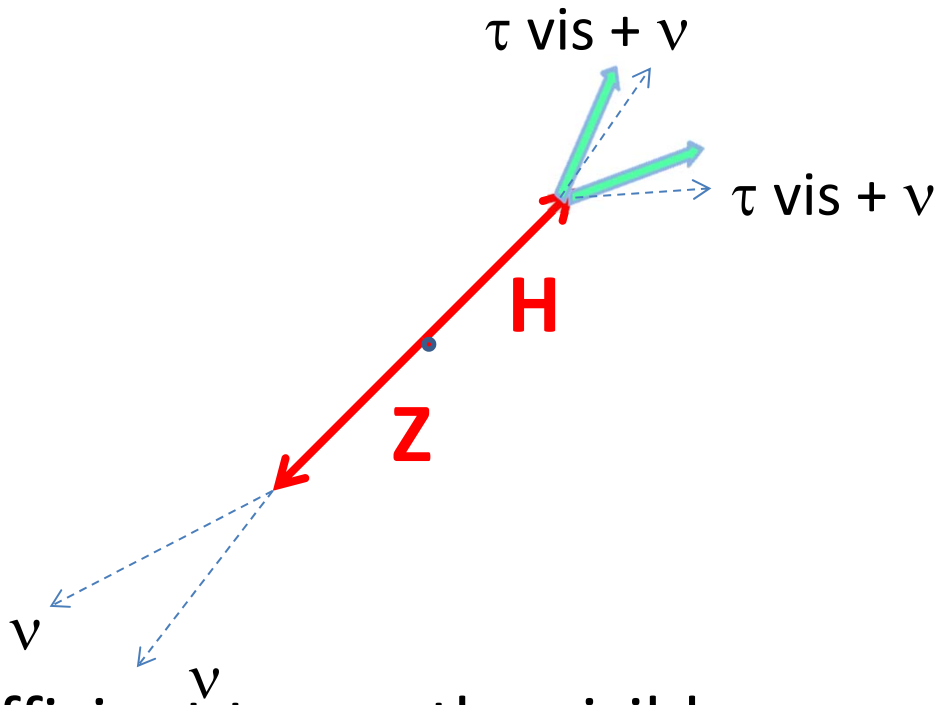
H->tau-tau instead of H->bb ?

- $\sigma(Z(\nu\nu)H(\tau\tau))$ is 6 fb instead of 45 a 8 TeV
- $\sigma(Z(\nu\nu)Z(\tau\tau))$ is 80 fb instead of 429 a 8 TeV
- S/B≈0.1 (bb) ; S/B≈0.07 (ττ)
- **Irriducible background (QCD) Zbb absent in ττ**

- Efficiency in (bb) ≈ 2% (0.5 da b-tag, 20% da (trigger MET)
- Efficiency (ττ) Trigger + better ID???
- FTK at work to improve the trigger efficiency:

  MET threshold lower + (b,tau)jets

Further problem for Z(νν)H(ττ)



Is it sufficient to use the visible ττ mass?

To recontruct the full tau momentum we need $\vec{p}_T^{\nu\tau}$

:Collinear approximation : «MMC»

can we assume thay in average , $\vec{p}_T^{\nu\tau} = \vec{p}_T^{\tau vis} \Rightarrow \vec{p}_T^{\nu\tau} = \vec{p}_T^{meas}$?

can the use of a "global" transverse mass be useful"?

we would like to check these correlations with a MC truth..

H->tau-tau instead H-> bb with hadronic W and Z ?

- σ(Z/W(hadrons)H($\tau\tau$)) is 53 fb instead of 470 at 8 TeV
- σ(Z/W(hadrons)Z($\tau\tau$)) e' 560 fb instead of 2800 at 8 TeV
- S/B$\approx$0.2 (bb) ; S/B$\approx$0.1 ($\tau\tau$)
- **Irreducible background (QCD) Zbb absent in $\tau\tau$**

  Note that in previous VBF H(tautau) analysis was included also W/Z(jets)+H(tautau) but not optimized

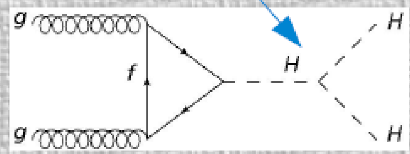
- Which trigger to be used?
- What the role of FTK in the future data taking?

HH FINAL STATES

$$V(H) = \frac{1}{2} M_H^2 H^2 + \lambda_{HHH} v H^3 + \frac{1}{4} \lambda_{HHHH} H^4$$

$M_H \simeq 125\,\mathrm{GeV}$ established @LHC

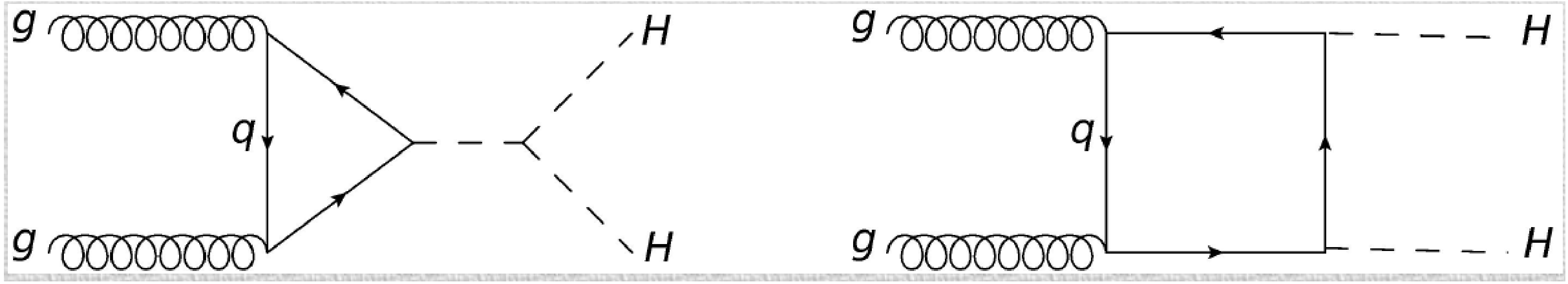
$$M_H^2 = 2v^2\lambda$$



Triple Higgs production
-Extremeley challenging @(V)LHC-
0.06 fb @ LHC14
9.45 fb @ VLHC (200 TeV)
Plehn, Rauch, hep-ph/0507321

$$\lambda_{HHH}^{SM} = \lambda_{HHHH}^{SM} = \frac{M_H^2}{2v^2} \approx 0.13$$

Let’s measure the self coupling λ
In the trilinear coupling :
Deviation from SM: new physics



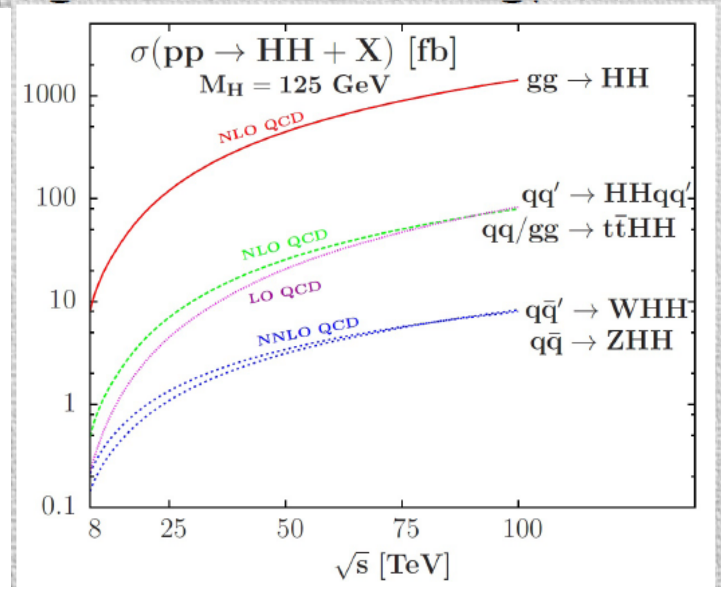
Eboli, Marques, Novaes, Natale, PLB 197(1987)269; Glover, van der Bij, NPB 309(1988)282
Dawson, Dittmaier and M. Spira, PRD 58(1998)115012

$$\sigma(gg \to HH)_{\rm LO} \sim 17\,{\rm fb}$$

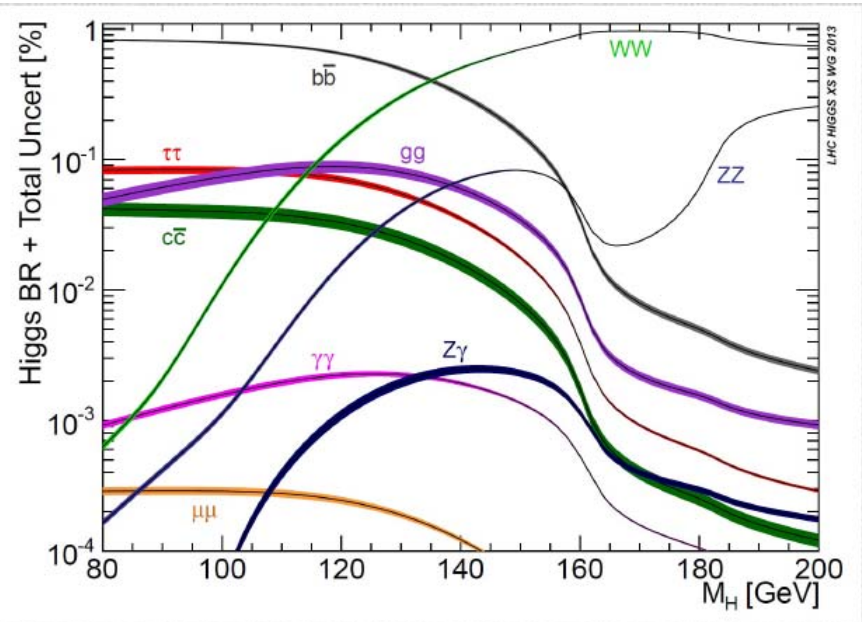
$$\sigma(gg \to HH)_{\rm NLO} \sim 33\,{\rm fb}$$

14TeV LHC
M_H~125 GeV

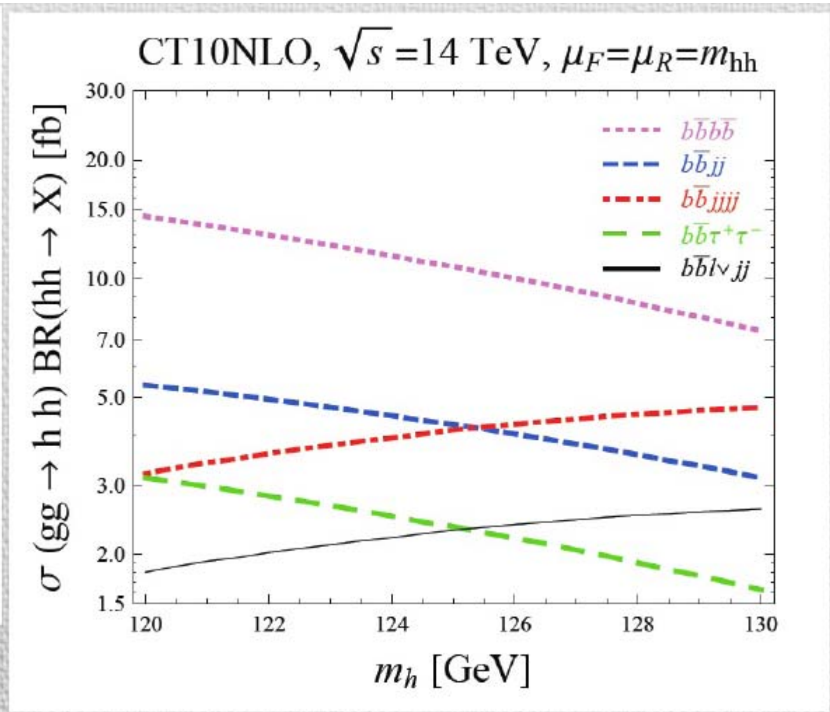
Theoretical error (mostly scale variation): ~ 20% @NLO



HH decays



Baur, Plehn, Rainwater, hep-ph/0310056



Papaefstathiou, Yang, Zurita, 1209.1489

Hadronic modes dominate

Most promising bb$\tau\tau$

First attemps of an analysis in ATLAS

(Danilo Enoque Ferreira de Lima, Cristina Oropeza Barrera)

3000 fb^{-1}

- HH → bbττ: B.R. = 0.57 × 0.06 ≈ 0.04
- lepton-hadron decay of the ττ system
- Backgrounds:

$t\bar{t}$

$Z \to \tau\tau$

$W \to \ell\nu$

WH

ZH

$t\bar{t}H$

$t\bar{t}W$

$t\bar{t}Z$

Yields (electron channel, MMC)

Presentation at the Higgs prospects Meeting 22/01/2014

Sample	Pre-sel.	e lepton	m_{bb}	$m_{\tau\tau}$	m_{T2}	$p_{T,bb}$
Signal (λ_{SM})	1738.07	900.69	427.54	203.84	167.78	124.36
Signal ($0\lambda_{SM}$)	3038.27	1542.59	720.68	329.37	265.91	182.81
Signal ($2\lambda_{SM}$)	930.40	476.16	229.32	112.97	103.19	84.64
$t\bar{t}$	6042540	3019670	145922	18424.5	4790.37	552.73
$Z \to \tau\tau$	979701	514296	41107.5	10639.7	5591.13	5407.86
$W \to \ell\nu$	12454.6	5229.28	534.63	0	0	0
WH	58.55	34.99	12.138	0	0	0
ZH	274.28	138.64	49.43	9.58	7.07	5.97
$t\bar{t}H$	1654.09	787.48	40.41	4.30	1.72	0.86
$t\bar{t}W$	2722.45	1335.12	64.699	8.64128	3.32	0.89
$t\bar{t}Z$	2491.57	1259.58	41.37	4.59	4.59	4.60
All backgrounds	7041900	3542750	187772	29091.3	10398.2	5972.91
$S/\sqrt{B}$ ($0\lambda_{SM}$)	1.14	0.82	1.66	1.93	2.61	2.36
S/B ($0\lambda_{SM}$)	0.00043	0.00043	0.0038	0.01	0.0255726	0.030607
$S/\sqrt{B}$ ($1\lambda_{SM}$)	0.65	0.48	0.99	1.19	1.64	1.61
S/B ($1\lambda_{SM}$)	0.00025	0.00025	0.0023	0.0070	0.016	0.021
$S/\sqrt{B}$ ($2\lambda_{SM}$)	0.35	0.25	0.53	0.66	1.01	1.09
S/B ($2\lambda_{SM}$)	0.00013	0.00013	0.0012	0.0038	0.0099	0.014

Yields (muon channel, MMC)

Sample	Pre-sel.	μ lepton	m_{bb}	$m_{\tau\tau}$	m_{T2}	$p_{T,bb}$
Signal (λ_{SM})	1738.07	837.40	370.14	188.38	169.98	132.45
Signal ($0\lambda_{SM}$)	3038.27	1495.75	623.98	279.50	229.64	173.74
Signal ($2\lambda_{SM}$)	930.39	454.24	200.31	95.43	89.02	72.84
$t\bar{t}$	6042540	3025380	139841	18240.2	5343.1	368.49
$Z \to \tau\tau$	979701	465436	14215.5	443.66	443.66	147.67
$W \to \ell\nu$	12454.6	7225.38	604.84	20.09	20.09	20.09
WH	58.54	23.56	9.28	0.71	0.71	0.71
ZH	274.27	135.66	44.34	9.05	6.76	5.84
$t\bar{t}H$	1654.09	866.57	35.24	8.59	4.29	1.72
$t\bar{t}W$	2722.45	1386.97	59.8244	4.87	1.55	0.44
$t\bar{t}Z$	2491.57	1232	64.358	13.791	0	0
All backgrounds	7041900	3501690	154875	18741	5820.18	544.982
$S/\sqrt{B}$ ($0\lambda_{SM}$)	1.14	0.79	1.58	2.04	3.01	7.44
S/B ($0\lambda_{SM}$)	0.00043	0.00042	0.0040	0.014	0.039	0.32
$S/\sqrt{B}$ ($1\lambda_{SM}$)	0.65	0.44	0.94	1.37	2.23	5.67
S/B ($1\lambda_{SM}$)	0.00024	0.00023	0.0023	0.010	0.029	0.24
$S/\sqrt{B}$ ($2\lambda_{SM}$)	0.35	0.24	0.51	0.70	1.17	3.12
S/B ($2\lambda_{SM}$)	0.00013	0.00013	0.0013	0.0051	0.015	0.13

Tensione in MSSM per h (125): NMSSM?

- Singlet (SU(2)xU(1)) superfield S coupled (λ_S) to Higgs superfields H_u H_d (Yukawa : λ_S S H_u $H_{d)}$
- 3 neutral higgs CP+ (+ 2 CP -), h_1 (quello misurato) h_3 (H in MSSM)

  mixing matrix for the 3 scalar higgs: CP+

$$\mathcal{M}^2 = \begin{pmatrix} m_Z^2 \cos^2\beta + m_A^2 \sin^2\beta & (2v^2\lambda^2 - m_A^2 - m_Z^2)\cos\beta\sin\beta & vM_1 \\ (2v^2\lambda^2 - m_A^2 - m_Z^2)\cos\beta\sin\beta & m_A^2\cos^2\beta + m_Z^2\sin^2\beta + \delta_t^2 & vM_2 \\ vM_1 & vM_2 & M_3^2 \end{pmatrix}$$

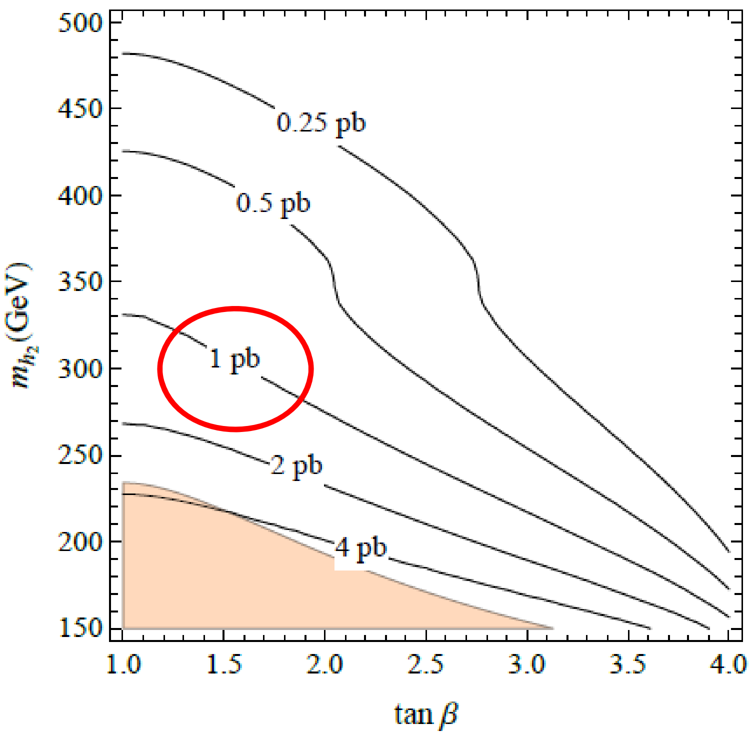
the basis $\mathcal{H} = (H_d^0, H_u^0, S)^T$.

Singlet decoupled: m_{h2} >>m_{h1} , m_{h3} (simile al MSSM)

- H decoupled m_{h3} >>m_{h1} , m_{h32}

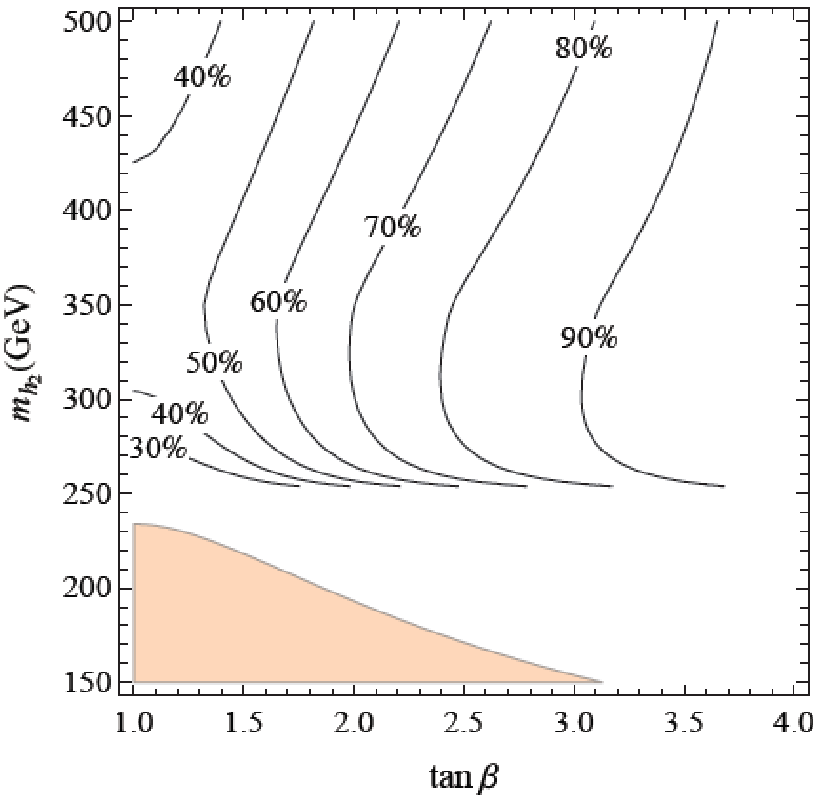
H-decoupled: the most interesting

σ(h_2)



(c) 14 TeV, $\lambda = 0.8$

BR(h_2->h_1h_1)



$h_2$width~0.5-10GeV

h_1 triple coupling

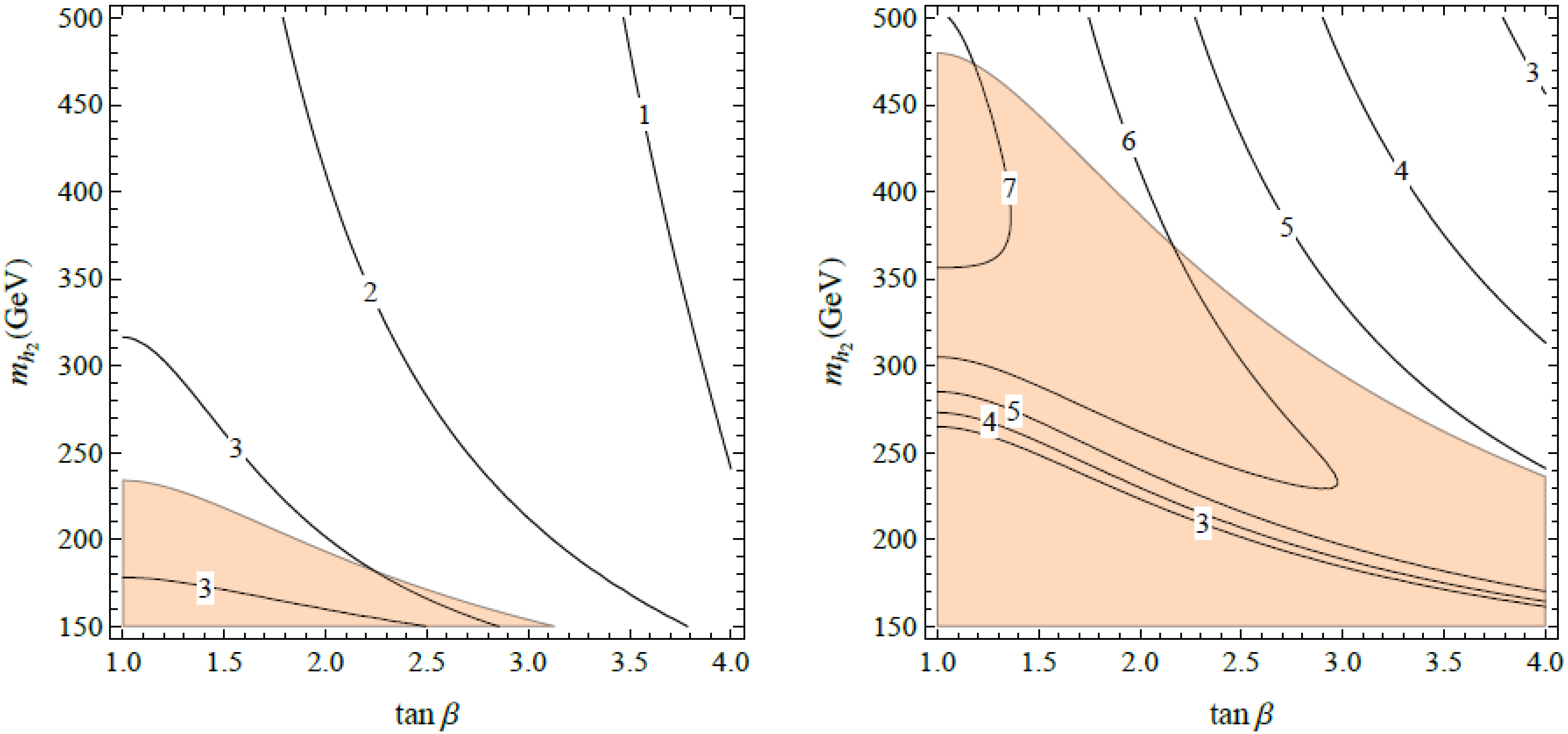


Figure 7. H decoupled. Isolines of $g_{hhh}/g_{hhh}^{\rm SM}$. Left: $\lambda = 0.8$ and $v_S = 2v$. Right: $\lambda = 1.4$ and $v_S = v$. The colored region is excluded at 95%C.L.

What next?

- run 2015-2021(300 fb-1)
  supersymmetric particles ? (sensitivity~ 2 TeV?)
  triple hhh coupling (SM) difficult
  couplings hVV hff (precision ~20%, CP Higgs in
  fermions)
  New Higgses (MSSM) or NMSSM: possible (hopeful)

. Run 2023-? (3000 fb-1) coupling hhh,
precision mesurements of hVV hff (~ %)