

Retour des Conférences HEP

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On behalf of the ATLAS collaboration

First Mediterranean Conference on Higgs Physics, Tangier, Morocco

November 18, 2019



Selected Talks Grouped into 3 Themes

1 Higgs Physics at the LHC

2 SUSY Searches at the LHC

3 Neutrino Physics and Dark Matter

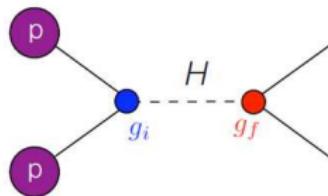
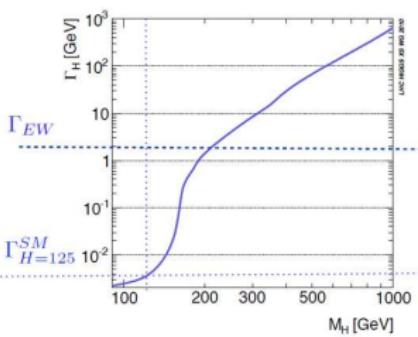
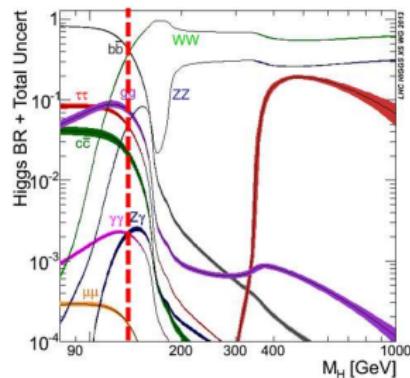
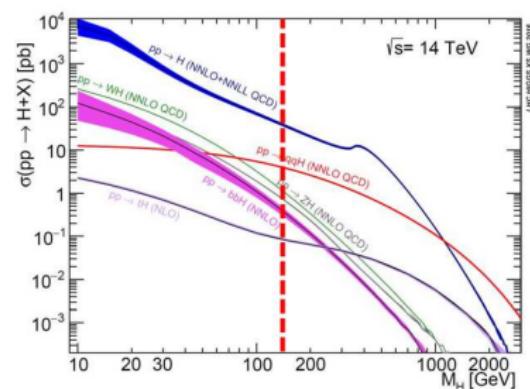
4 Back-Up

Session Talks

- ① "Higgs Physics at CMS",
N. Amapane (U. of Torino & INFN)
- ② "Measurements of the Higgs boson properties at the ATLAS experiment",
S. Olivares (P.U.C. of Chile)
- ③ "Searches for Exotic Higgs Production and Decay with the ATLAS detector",
K. Mankinen (Lund U.)
- ④ "New Features in FeynArts Friends, and how they got used in FeynHiggs",
T. Hahn (MPI Munich)
- ⑤ "Strongest signal for $pp \rightarrow A \rightarrow ZH$ in the 2HDM",
H. Day-Hall (U. of Southampton)
- ⑥ "Searches for invisible Higgs at the LHC",
X. Chen (Tsinghua U.)
- ⑦ "New Model for Radiative Neutrino Masses and Higgs LFV Decays",
S. Kanemura (Osaka U.)
- ⑧ "Light H^\pm with dominant decay to cb quarks and b-tagging search at e^+e^- colliders",
M. Song (U. of Southampton)
- ⑨ "A 3HDM with possible two dark matter candidates",
D. Rojas Ciofalo (U. of Southampton)

1. Higgs Physics at the LHC

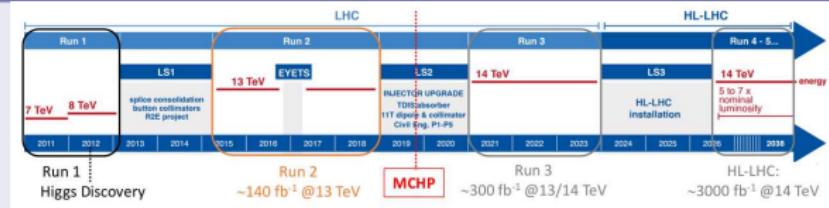
Introduction



$$g_{Hff} = \frac{m_f}{v} \quad g_{HVV} = \frac{2m_V^2}{v}$$

1. Higgs Physics at the LHC

Context



SM Higgs: Mass Measurements

Higgs properties: the mass

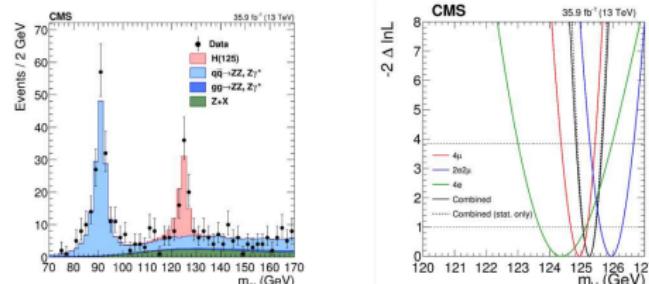
JHEP 11 (2017) 047

The single parameter that determines all SM couplings and x-sections

- Measured from peaks in high-resolution channels $H \rightarrow ZZ \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$

Run 1 LHC combination: $m_H = 125.09 \pm 0.21 \text{ (stat)} \pm 0.21 \text{ (sys)} \text{ GeV}$

Most recent CMS result from $H \rightarrow ZZ \rightarrow 4\ell$ with 2016 data: $m_H = 125.26 \pm 0.20 \text{ (stat)} \pm 0.08 \text{ (sys)} \text{ GeV}$



SM Higgs: Total Width Measurements

Higgs properties: the width

PRD 99 (2019) 112003

- Direct measurements in $H \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ is spoiled by detector resolution
- Indirect constraints from couplings, or from **ratio of on-shell and off-shell production**

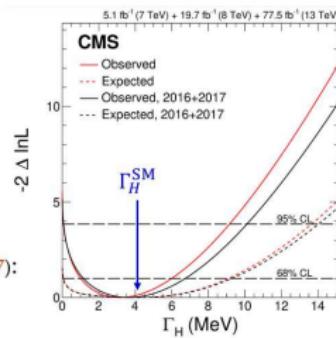
Off-shell H tail is sizeable (~10% in SM)

$$\sigma_{gg \rightarrow H \rightarrow VV}^{on-shell} \propto \frac{g_g^2 \cdot g_V^2}{\Gamma_H}, \quad \sigma_{gg \rightarrow H \rightarrow VV}^{off-shell} \propto g_g^2 \cdot g_V^2$$

Assuming **identical on-shell and off-shell couplings** (no new physics in loops, ...), Γ_H can be extracted from the ratio

- Most recent CMS result ($H \rightarrow 4\ell$, Run I + 2016-17):

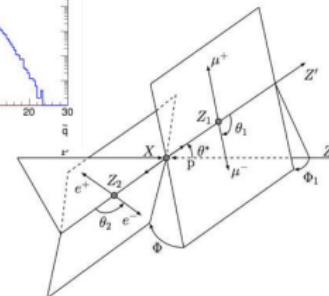
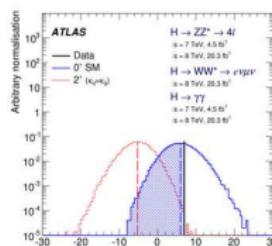
$0.08 < \Gamma_H < 9.16 \text{ MeV} @ 95\% \text{ CL}$



SM Higgs: Spin & CP

Spin/CP

- The Standard Model (SM) Higgs boson hypothesis, corresponding to the quantum numbers $J^P = 0^+$, was tested against several alternative spin scenarios, including non-SM spin-0 and spin-2 models with universal and non-universal couplings to fermions and vector bosons
- ATLAS combined bosonic channels ($H \rightarrow ZZ^* \rightarrow 4l$, $H \rightarrow WW^* \rightarrow 2l2\nu$ and $H \rightarrow \gamma\gamma$) **excluded all tested alternative hypothesis in favour of the SM Higgs boson at more than 99.9% confidence level (CL)**
- A first direct test of CP invariance in Higgs boson production via vector-boson fusion (VBF) with the $H \rightarrow \tau^+\tau^-$ decay channel showed no sign of CP violation
- Compatible with CMS results**



- Eur.Phys.J. C75 (2015) no.10, 476
- Eur.Phys.J. C76 (2016) no.12, 658

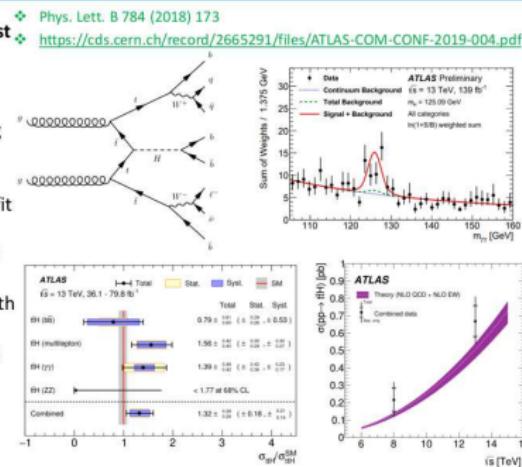


SM Higgs: Top Yukawa Coupling

Observation of $t\bar{t}H$ production

- Particular interest is its coupling to the top quark, the **heaviest particle in the SM**
- The strength of this interaction can be studied through the analysis of top-associated Higgs production ($t\bar{t}H$) events, which provides a **tree-level probe** of the top Yukawa coupling
- Channels considered: $b\bar{b}$, WW^* , $\tau^+\tau^-$, $\gamma\gamma$ and ZZ^*
- Output distributions are combined in a maximum-likelihood fit
- Data corresponds to an integrated luminosity of 79.8 fb^{-1} at $\sqrt{s} = 13 \text{ TeV}$ combined with previous analyses
- An **excess over the expected SM background is observed**, with a significance of **6.3 standard deviations**
- Updated result** for the $H \rightarrow \gamma\gamma$ channel with updated photon identification and jet calibration with **4.9 standard deviation**
- Results consistent with the SM**

$$\sigma_{ttH}(13 \text{ TeV}) = 670 \pm 90(\text{stat})^{+110}_{-100}(\text{syst}) @ 95\% \text{ CL}$$



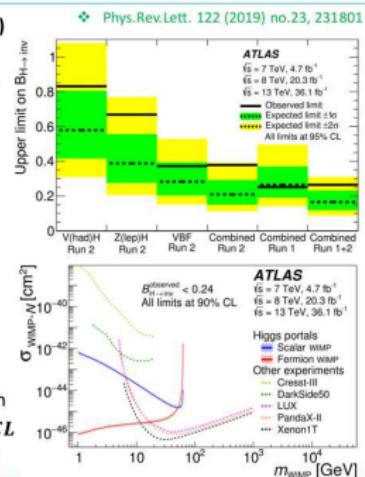
BSM Higgs: Invisible Decays

For more details check Xin presentation!

Invisible Higgs boson decays



- Numerous models predict detectable production rates of such **Dark Matter (DM)** particles at the Large Hadron Collider (LHC)
 - In a wide class of those models, the Higgs boson acts as a portal between a dark sector and the SM sector, either through **Yukawa-type couplings to fermionic dark matter**, or other mechanisms
 - Higgs boson decays to DM particles can only be indirectly inferred through **missing transverse momentum (MET)** due to DM particles escaping detection, and are therefore termed “invisibles”
 - Production channels considered: VBF and $VH(Z_{lep}H$ and $V_{had}H$)
 - Output distributions are combined in a maximum-likelihood fit
 - Data corresponds to an integrated luminosity of 36.1 fb^{-1} at $\sqrt{s} = 13 \text{ TeV}$ combined with previous analyses
 - Under the assumption that the Higgs (effective model) decays to a pair of scalar or fermion weakly interactive massive particle (WIMP) using a nuclear interaction
- $B(H \rightarrow inv) < 0.26 @95\%CL$ $\sigma_{WIMP-N}(\text{scalar}) > 2 \times 10^{-45} \text{ cm}^2 @90\%CL$
- $\sigma_{WIMP-N}(\text{fermion}) > 10^{-46} \text{ cm}^2 @90\%CL$



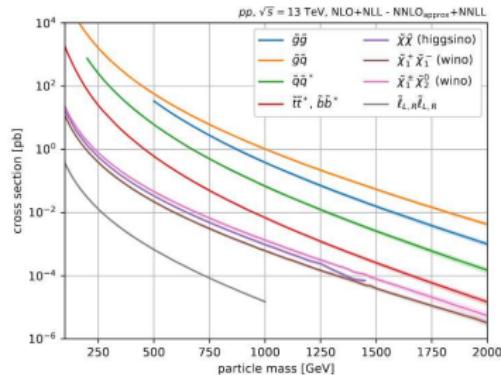
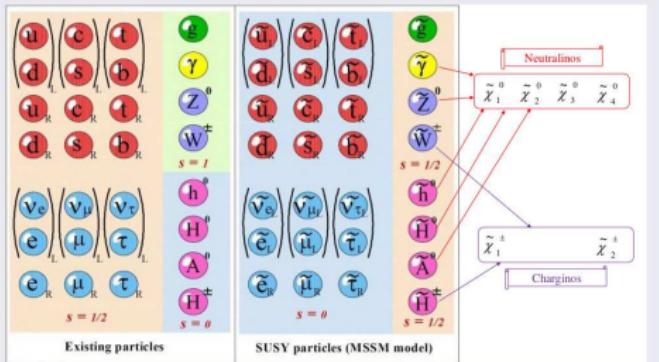
Session Talks

- ① "Phenomenology of SUSY Higgs Bosons",
(S. Heinemeyer, IFT Madrid)
- ② "Standard Model Scalar Singlets and Hard Susy Breaking in N=1 Supergravity",
(G. Moultaka, L2C Montpellier)
- ③ "Higgs Sector in Non-Minimal Supersymmetric Standard Model",
(S. Khalil, ZCST Cairo)
- ④ "ATLAS SUSY searches using a Higgs boson in the final state",
(S. Muanza, CPPM Marseille)
- ⑤ "Using dimensional analysis as a measure of fine tuning",
(S. Recksiegel, TUM Munich)
- ⑥ "Hybrid seesaw neutrino model in SUSY $SU(5) \times A4$ ",
(M.A. Ouahid, M5 Rabat)

2. SUSY Searches at the LHC

2.a Introduction

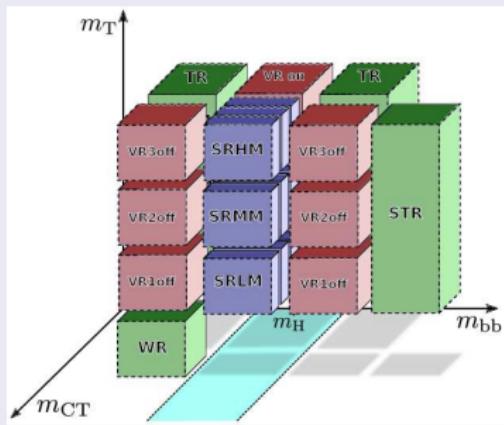
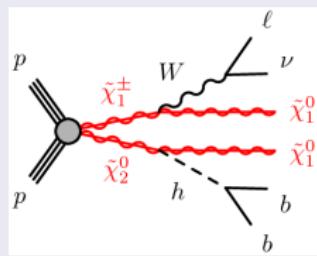
2.a MSSM: Particle Content



2. SUSY Searches at the LHC

2.b Search for $\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \rightarrow W^\pm(\rightarrow \ell^\pm \nu) + h^0(\rightarrow b\bar{b}) + \cancel{E}_T$ with $L = 139 \text{ fb}^{-1}$

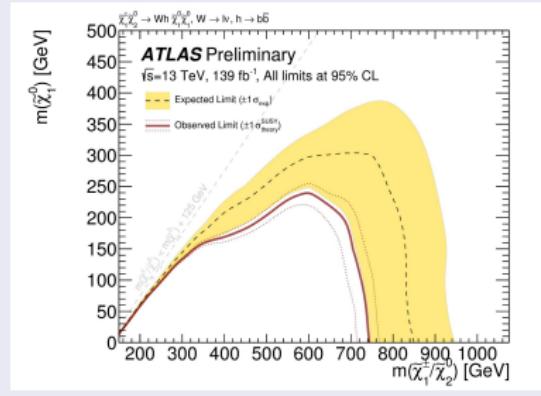
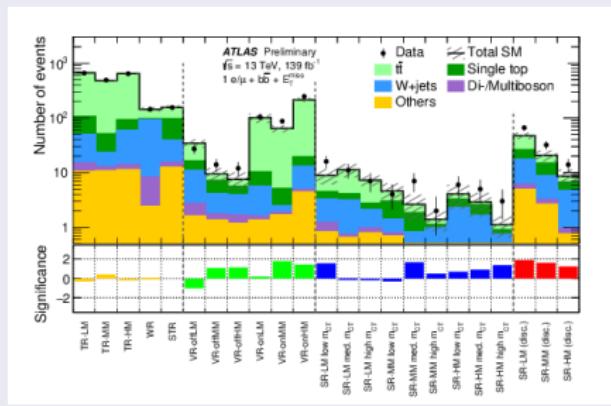
- Ref: ATLAS-CONF-2019-031



2. SUSY Searches at the LHC

2.b Search for $\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \rightarrow W^\pm(\rightarrow \ell^\pm \nu) + h^0(\rightarrow b\bar{b}) + \cancel{E}_T$ with $L = 139 \text{ fb}^{-1}$

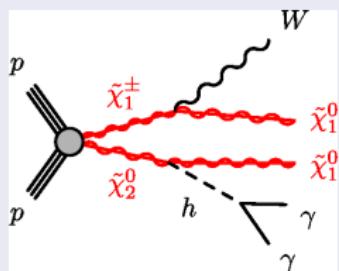
- Ref: ATLAS-CONF-2019-031



2. SUSY Searches at the LHC

2.c Search for $\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \rightarrow W^\pm + h^0 (\rightarrow \gamma\gamma) + \cancel{E_T}$ with $L = 139 \text{ fb}^{-1}$

- Ref: ATLAS-CONF-2019-019

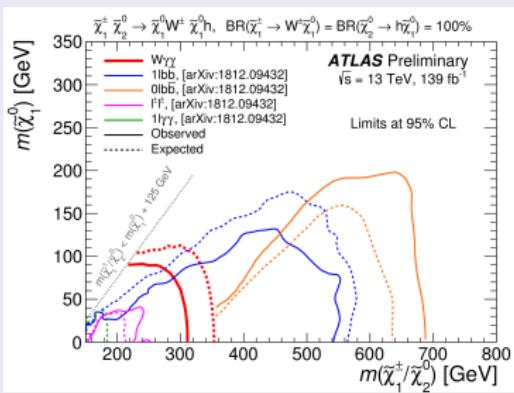
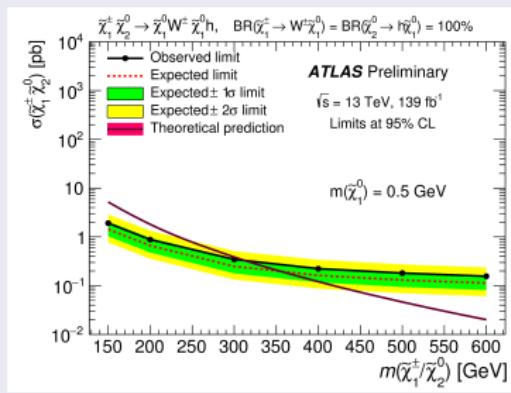


Channels	Names	Selection
Leptonic	Category 1	$0 < S_{E_T^{\text{miss}}} \leq 2, N_\ell \geq 1$
	Category 2	$2 < S_{E_T^{\text{miss}}} \leq 4, N_\ell \geq 1$
	Category 3	$4 < S_{E_T^{\text{miss}}} \leq 6, N_\ell \geq 1$
	Category 4	$S_{E_T^{\text{miss}}} > 6, N_\ell \geq 1$
Hadronic	Category 5	$5 < S_{E_T^{\text{miss}}} \leq 6, N_\ell = 0, N_j \geq 2, M_{jj} \in [40, 120] \text{ GeV}$
	Category 6	$6 < S_{E_T^{\text{miss}}} \leq 7, N_\ell = 0, N_j \geq 2, M_{jj} \in [40, 120] \text{ GeV}$
	Category 7	$7 < S_{E_T^{\text{miss}}} \leq 8, N_\ell = 0, N_j \geq 2, M_{jj} \in [40, 120] \text{ GeV}$
	Category 8	$S_{E_T^{\text{miss}}} > 8, N_\ell = 0, N_j \geq 2, M_{jj} \in [40, 120] \text{ GeV}$
Rest	Category 9	$6 < S_{E_T^{\text{miss}}} \leq 7, N_\ell = 0, N_j < 2 \text{ or } (N_j \geq 2, M_{jj} \notin [40, 120] \text{ GeV})$
	Category 10	$7 < S_{E_T^{\text{miss}}} \leq 8, N_\ell = 0, N_j < 2 \text{ or } (N_j \geq 2, M_{jj} \notin [40, 120] \text{ GeV})$
	Category 11	$8 < S_{E_T^{\text{miss}}} \leq 9, N_\ell = 0, N_j < 2 \text{ or } (N_j \geq 2, M_{jj} \notin [40, 120] \text{ GeV})$
	Category 12	$S_{E_T^{\text{miss}}} > 9, N_\ell = 0, N_j < 2 \text{ or } (N_j \geq 2, M_{jj} \notin [40, 120] \text{ GeV})$

2. SUSY Searches at the LHC

2.c Search for $\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \rightarrow W^\pm + h^0 (\rightarrow \gamma\gamma) + E_T$ with $L = 139 \text{ fb}^{-1}$

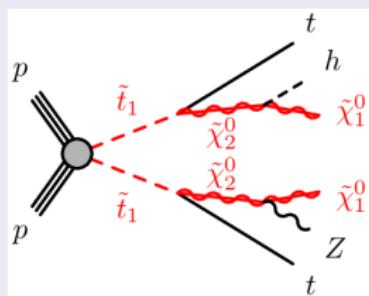
- Ref: ATLAS-CONF-2019-019



2. SUSY Searches at the LHC

2.d Search for stop pairs in $t\bar{t} + hZ + \cancel{E}_T$ final states with $L = 139 \text{ fb}^{-1}$

- Ref: ATLAS-CONF-2019-016

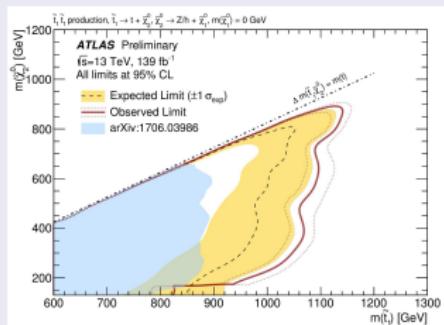
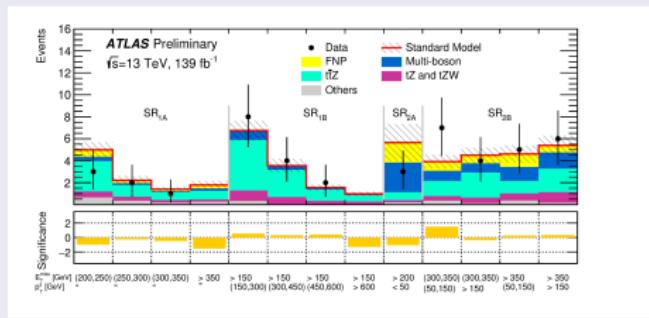


Pre-selection				
Requirement / Region	SR _{1A}	SR _{1B}	SR _{2A}	SR _{2B}
Number of signal leptons	≥ 3			
Number of SF-OS pairs	≥ 1			
Leading lepton p_T [GeV]	> 40			
Subleading lepton p_T [GeV]	> 20			
$ m_{\ell\ell}^{\text{SF-OS}} - m_Z $ [GeV]	< 15			
Third leading lepton p_T [GeV]	> 20	> 20	< 20	< 60
n_{jets} ($p_T > 30$ GeV)	≥ 4	≥ 5	≥ 3	≥ 3
$n_{b\text{-tagged jets}}$ ($p_T > 30$ GeV)	≥ 1	≥ 1	–	≥ 1
Leading jet p_T [GeV]	–	–	> 150	–
Leading b -tagged jet p_T [GeV]	–	> 100	–	–
E_T^{miss} [GeV]	> 250	> 150	> 200	> 350
$p_T^{\ell\ell}$ [GeV]	–	> 150	< 50	> 150
$m_{T2}^{3\ell}$ [GeV]	> 100	–	–	–

2. SUSY Searches at the LHC

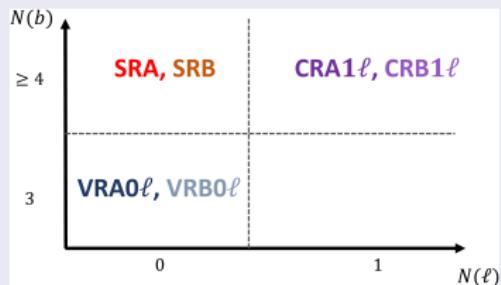
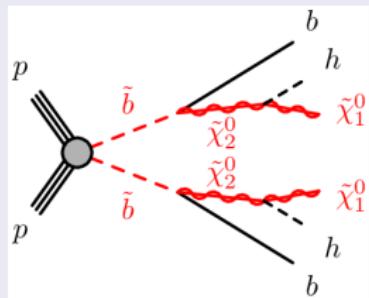
2.d Search for stop pairs in $t\bar{t} + hZ + \cancel{E}_T$ final states with $L = 139 \text{ fb}^{-1}$

- Ref: ATLAS-CONF-2019-016



2.e Search for sbottom pairs in $+E_T$ final states with $L = 139 \text{ fb}^{-1}$

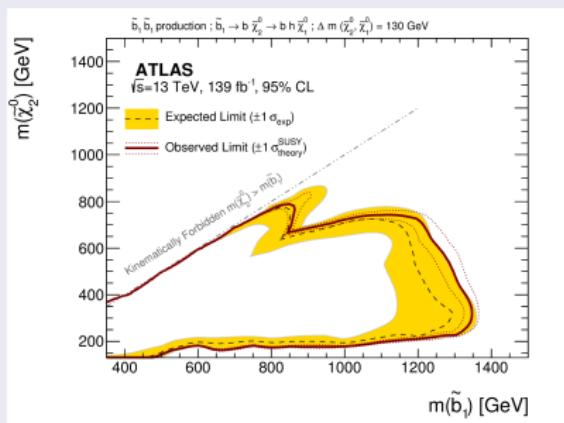
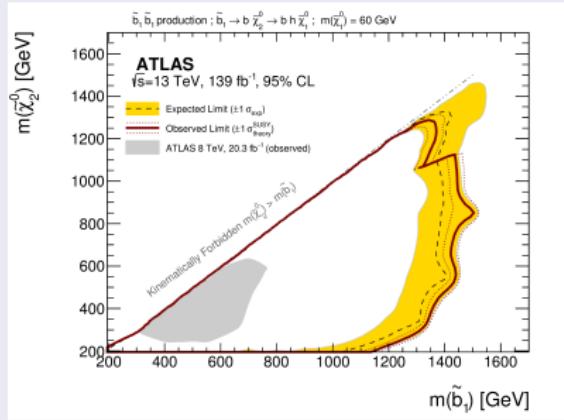
- Ref: ATLAS-CONF-2019-011



2. SUSY Searches at the LHC

2.e Search for sbottom pairs in $+E_T$ final states with $L = 139 \text{ fb}^{-1}$

- Ref: ATLAS-CONF-2019-011



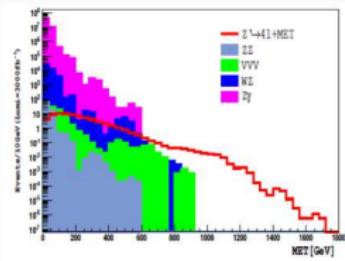
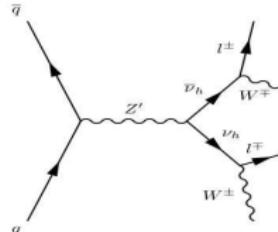
2. SUSY Searches in BLSSM

2.f Introducing BLSSM

- Extension of the MSSM with $G_{BLSSM} = SU(3)_C \otimes SU(2)_L \otimes U(1)_{CY} \otimes U(1)_{B-L}$
- $(B - L)$ and EW symmetry breakings imply neutrino mixing (explains neutrino masses)
- Predicts many new particles:
 - several new Higgs bosons: $h, h', H, H', H^\pm, A, A'$
 - a sterile neutrino: good candidate for Dark Matter
 - a Z'

2.f Suggested BLSSM Searches

- A truly smoking-gun signature of the BLSSMIS would be to produce a Z' and heavy neutrinos simultaneously.
- Once such a Z' state is produced and decays into $\nu_h \bar{\nu}_h \rightarrow WW\ell\ell \rightarrow 4\ell + 2\nu_\ell$.



- The transverse mass of the '4 lepton+ E_T^{miss} ' system. The expected SM backgrounds are included . The luminosity assumed here is $3000 \text{ fb}^{(-1)}$.

Huitu, SK, Okada, Rai (2008)

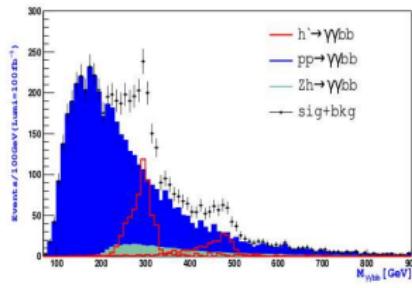
2. SUSY Searches in BLSSM

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- $(B - L)$ and EW symmetry breakings imply neutrino mixing (explains neutrino masses)
- Predicts many new particles:
 - several new Higgs bosons: $h, h', H, H', H^\pm, A, A'$
 - a sterile neutrino: good candidate for Dark Matter
 - a Z'

2.f Suggested BLSSM Searches

- The process $pp \rightarrow h' \rightarrow hh \rightarrow \gamma\gamma b\bar{b}$ has smaller cross section than $\sigma(pp \rightarrow h' \rightarrow hh \rightarrow 4b)$ but it is more promising due to the clean di-photons trigger with excellent mass resolution and low background contamination.

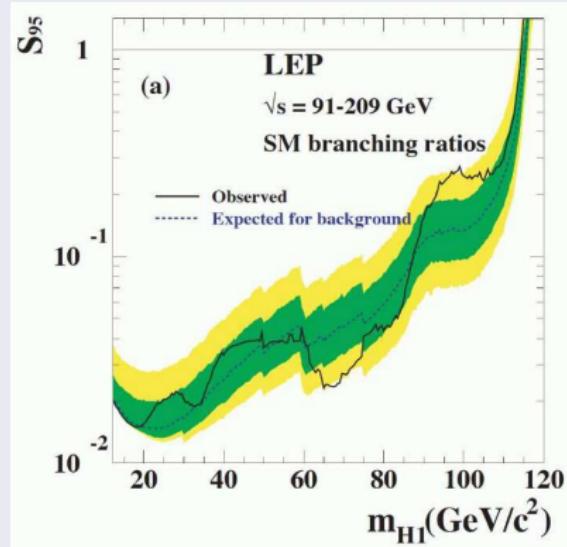


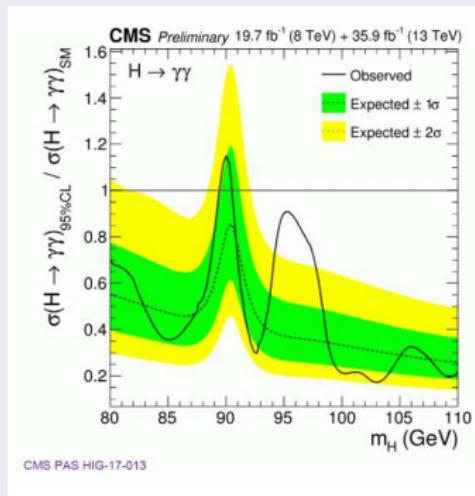
2. "Still in Love with SUSY"

2.g $m_h \approx 96$ GeV Scenario



2.g $m_h \approx 96$ GeV Scenario



2.g $m_h \approx 96$ GeV Scenario

New!

CMS PAS HIG-17-013

8 TeV: Excess with $\sim 2.0 \sigma$
local significance at $m=97.6$ GeV

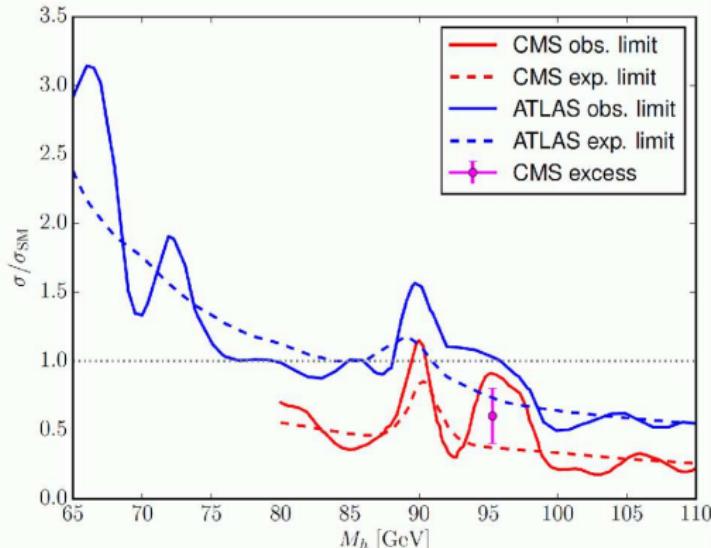
13 TeV: Excess with $\sim 2.9 \sigma$
local (1.47σ global)
significance at $m=95.3$ GeV

8TeV+13TeV: Excess with
 $\sim 2.8 \sigma$ local (1.3σ global)
significance at $m=95.3$ GeV

2.g $m_h \approx 96$ GeV Scenario

CMS and ATLAS in direct comparison:

[T. Stefaniak et al. '18]



⇒ everything well compatible with the excess!

- A light Higgs at 96 GeV?
new CMS/ATLAS result (and old LEP result) possibly interesting!
 - MSSM cannot explain the excesses
 - NMSSM/ $\mu\nu$ SUSY can explain CMS(/ATLAS) and LEP excesses
- ⇒ perfect physics case for the ILC: 96 GeV direct \oplus 125 GeV coupl.

Session Talks

- ① "New model for radiatively generated Dirac neutrino masses and lepton flavor violating decays of the Higgs boson",
(S. Kanemura, U. of Osaka)
- ② "Neutrino telescopes in the Mediterranean Sea: status and perspectives",
(A. Margiotta, INFN & U. of Bologna)
- ③ "Dark Matter, Neutrino Mass, Gravitational waves with Singlet Scalars",
(A. Ahriche, U. of Jijel)
- ④ ...

3.a Scotogenic Model with Majorana DM

Schotogenic Model with Majorana DM:

Here, the SM is extended by an inert scalar doublet Φ and three singlet Majorana fermions $N_i \sim (1, 1, 0)$, with new Yukawa interactions [Ma2006]:

$$\begin{aligned} \mathcal{L} \supset & \{ h_{ij} \bar{L}_i \epsilon \Phi N_j + \frac{1}{2} M_i \bar{N}_i^C N_i + h.c.\} - \mu_2^2 |\Phi|^2 \\ & + \frac{\lambda_2}{6} |\Phi|^4 + \lambda_3 |H|^2 |\Phi|^2 + \frac{\lambda_4}{2} |H^\dagger \Phi|^2 + \frac{\lambda_5}{4} [(H^\dagger \Phi)^2 + h.c.] , \end{aligned}$$

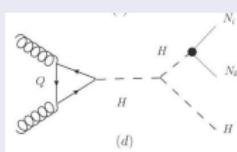
The tree-level masses are given by:

$$m_{H^\pm}^2 = \mu_2^2 + \frac{1}{2} \lambda_3 v^2, \quad m_{H^0, A^0}^2 = m_{H^\pm}^2 + \frac{1}{4} (\lambda_4 \pm \lambda_5) v^2.$$

These interactions lead to the one-loop neutrino mass diagram

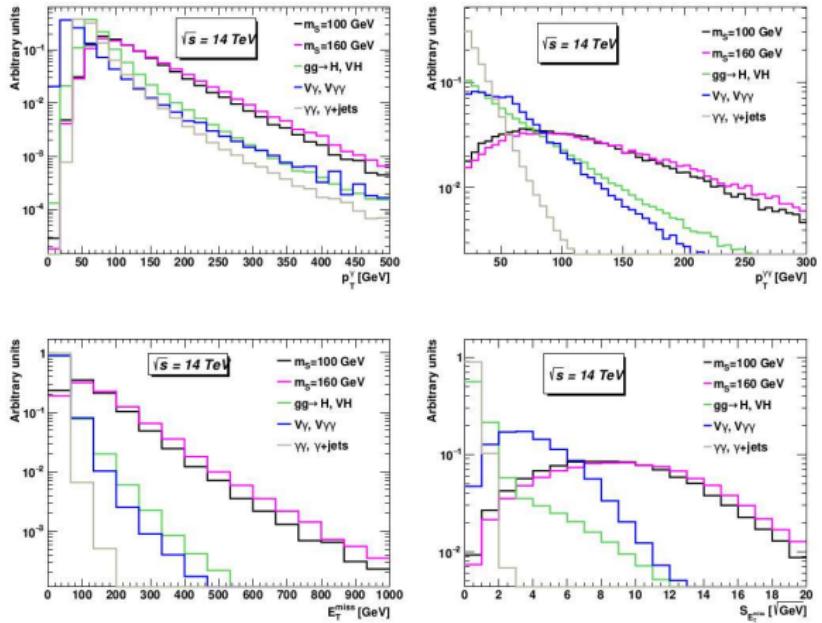
$$(\mathcal{M}_\nu)_{\alpha\beta} = \sum_k \frac{h_{\alpha k} h_{\beta k} M_k}{16\pi^2} \left[\frac{m_{\mu^0}^2}{m_{\mu^0}^2 - M_k^2} \ln \frac{m_{\mu^0}^2}{M_k^2} - \frac{m_{A^0}^2}{m_{A^0}^2 - M_k^2} \ln \frac{m_{A^0}^2}{M_k^2} \right]$$

3.b Mono-Higgs Production at the LHC



3.b Suggested Search: Mono-Higgs Production at the LHC

Mono-Higgs signature



BACK-UP

Higgs total width: direct constraints from off-shell couplings

The production cross section as a function of m_{ZZ} can be written as:

$$\frac{d\sigma_{gg \rightarrow H \rightarrow ZZ}}{dm_{ZZ}^2} \propto g_{ggH}^2 g_{HZZ}^2 \frac{F(m_{ZZ})}{(m_{ZZ}^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}, \quad (1)$$

where g_{ggH} (g_{HZZ}) is the coupling constant of the Higgs boson to gluons (to Z bosons), and $F(m_{ZZ})$ is a function which depends on the (virtual) Higgs and Z boson production and decay dynamics. In the resonant and off-shell regions, the integrated cross sections are

$$\sigma_{gg \rightarrow H \rightarrow ZZ}^{\text{on-peak}} \propto \frac{g_{ggH}^2 g_{HZZ}^2}{\Gamma_H}, \quad \sigma_{gg \rightarrow H \rightarrow ZZ}^{\text{off-peak}} \propto g_{ggH}^2 g_{HZZ}^2. \quad (2)$$

The on-peak cross section is therefore unchanged if the squared product of the coupling constants $g_{ggH}^2 g_{HZZ}^2$ and the total width are scaled by a common factor. On the contrary, away from the resonance the cross section is independent of the total width and therefore increases linearly with the above factor. From Eqs. (1, 2) it is evident that the ratio of off-shell and on-shell production and decay rates in the $H \rightarrow ZZ$ channel leads to a direct measurement of Γ_H as long as the ratio of coupling constants remains invariant, e.g. if there are no new light particles in the gluons fusion loop which would affect the coupling constants differently at the low and high m_{ZZ} values. The above formalism is presented for the gluon fusion process, but it equally applies to the vector boson fusion (VBF) production.