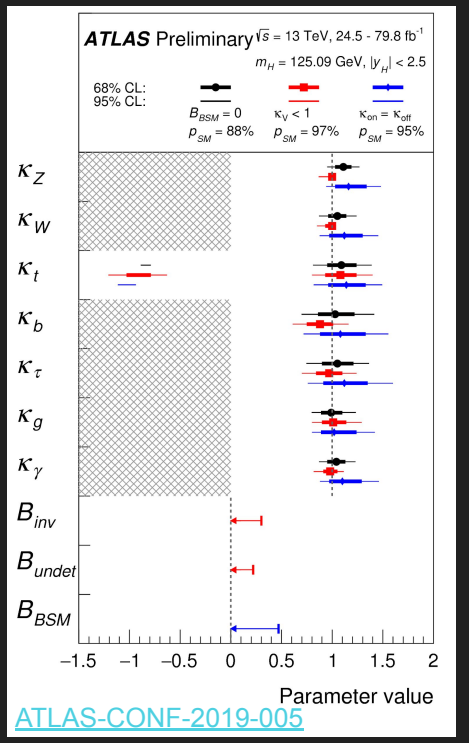
Searches for Higgs to invisible and other exotic/non-standard decays at ATLAS and CMS

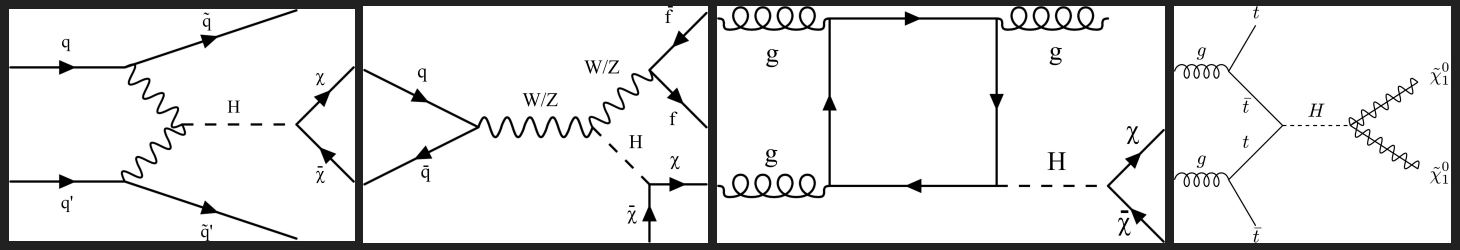
Andrés G. Delannoy [UT Knoxville]
on behalf of the ATLAS and CMS Collaborations
LHCP 2019, Puebla, Mexico, May 20-25, 2019

Introduction & Motivation

- Measurements of Higgs coupling to SM particles so far consistent with SM predictions
  - BSM scenarios not completely excluded by current limits
  - Deviations from SM expectations might provide hints for BSM physics
  - Many BSM models predict nonstandard Higgs decays
- SM only allows Higgs → Invisible via H → ZZ → 4ν
  - $\mathcal{B}$(H → ZZ → 4ν) ~0.1%
    - May be significantly enhanced if H decays to invisible BSM particles
    - e.g. Higgs → Dark Matter Portal
  - Invisible Higgs decay products recoil against visible system
    - Events with large p_T^{miss} selected
  - Production modes:
    - VBF (p_T^{miss} + 2 jets)
    - VH (p_T^{miss} + V → ℓℓ, qq')
    - ggH (p_T^{miss} + jets)
    - ttH (p_T^{miss} + jets + 0/1/2ℓ)

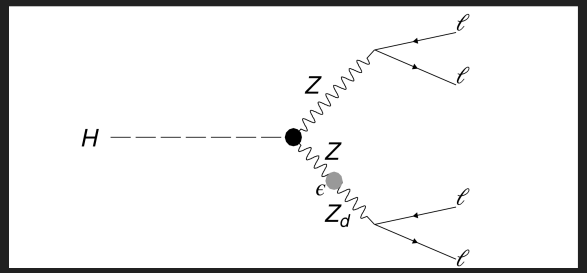


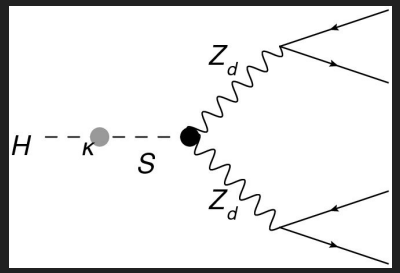
ATLAS-CONF-2019-005



Introduction & Motivation

- Lepton flavor violating (LFV) decays
  - Forbidden in SM
    - Clear indication of BSM physics
  - $H \rightarrow e\tau$ and $H \rightarrow \mu\tau$ most sensitive to new physics
    - LFV $H \rightarrow e\mu$ strongly constrained by $\mu \rightarrow e\gamma$ limit: $\mathcal{B}(H \rightarrow e\mu) < O(10^{-9})$
    - $\mathcal{B}(H \rightarrow e\tau)$ and $\mathcal{B}(H \rightarrow \mu\tau) < 10\%$ from rare τ lepton decays limits (e.g. $\tau \rightarrow e\gamma$, $\tau \rightarrow \mu\gamma$)
- Dark-sector $U(1)_d$ extensions of SM
  - Many dark-sector models couple to SM only via Higgs interactions
    - Unique sensitivity only accessible at the LHC
  - Leads to BSM vector boson, Z_d
  - Z_d branching ratios determined by gauge coupling
    - Significant fraction of decays (~15%) to pairs of electrons or muons
- Other Higgs exotic decay analyses (e.g. H→aa) covered by L. Finco's talk



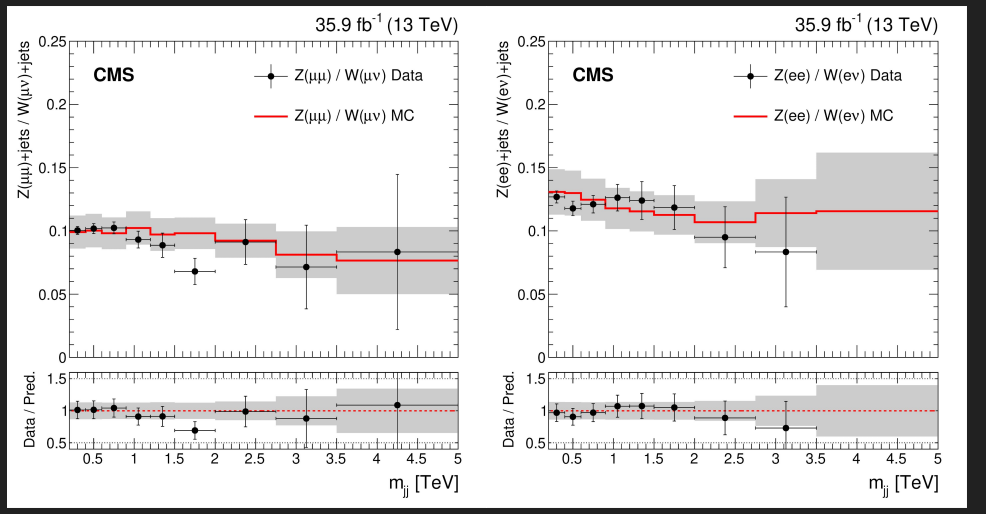


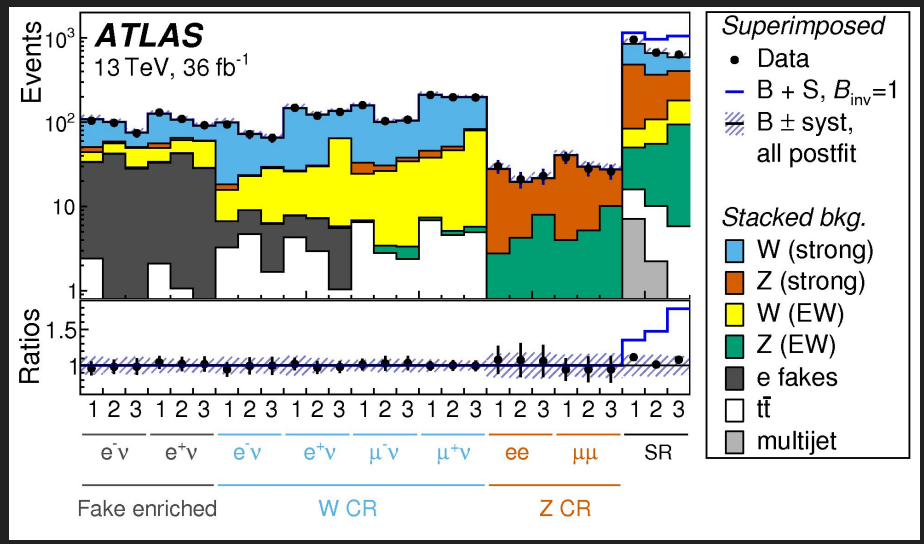
Higgs → Invisible [VBF]

CMS-HIG-17-023
10.1016/j.physletb.2019.04.025
arXiv:1809.05937

ATLAS-EXOT-2016-37
10.1016/j.physletb.2019.04.024
arXiv:1809.06682

- VBF topology: characteristic final states with two jets with large $\Delta\eta_{jj}$ and m_{jj}
  - Allows for suppression of SM backgrounds: most sensitive production mode
  - Main backgrounds: W+jets, Z+jets
  - CMS $m_{jj} > 200$ GeV, $|\Delta\eta_{jj}| > 1$, $p_T^{miss} > 250$ GeV; ATLAS $m_{jj} > 1$ TeV, $|\Delta\eta_{jj}| > 4.8$, $N_j = 2$, $p_T^{miss} > 180$ GeV
- Background estimated from high-purity 1 or 2 lepton CRs
  - p_T^{miss} in CRs calculated by excluding contribution(s) from identified lepton(s)
  - Statistically-richer 1ℓ CR kinematically similar to SR Z(νν)+jets if charged lepton is ignored
  - "Pre-fit" yields in CRs used as inputs for statistical fit to determine their normalization factors in SR





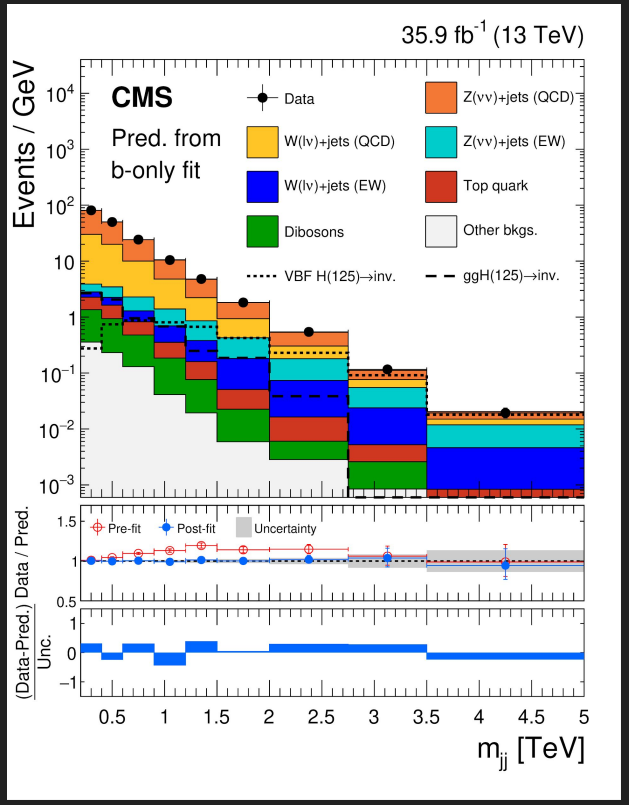
delannoy@cern.ch

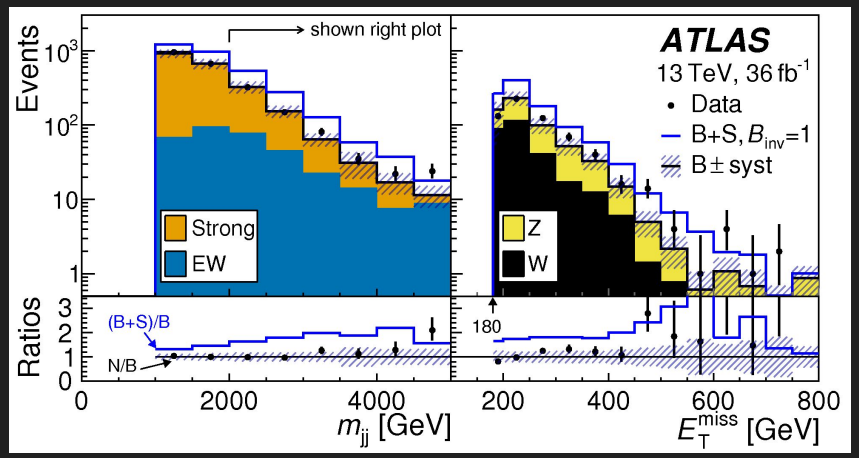
Higgs → Invisible [VBF]

CMS-HIG-17-023
10.1016/j.physletb.2019.04.025
arXiv:1809.05937

ATLAS-EXOT-2016-37
10.1016/j.physletb.2019.04.024
arXiv:1809.06682

- Improved sensitivity by fitting the shape of the m_{jj} distribution
  - Signal extracted by fitting sum of signal and BG shapes to binned m_{jj} distribution observed in data





Observed (expected) limit @ 95% CL [36 fb^{-1}]:
$\mathcal{B}$(H→inv) < 0.33 (0.25)

Observed (expected) limit @ 95% CL [36 fb^{-1}]:
$\mathcal{B}$(H→inv) < 0.37 (0.28)

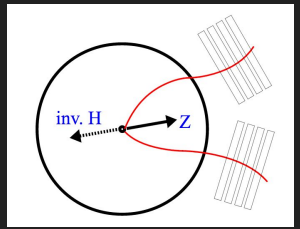
delannoy@cern.ch

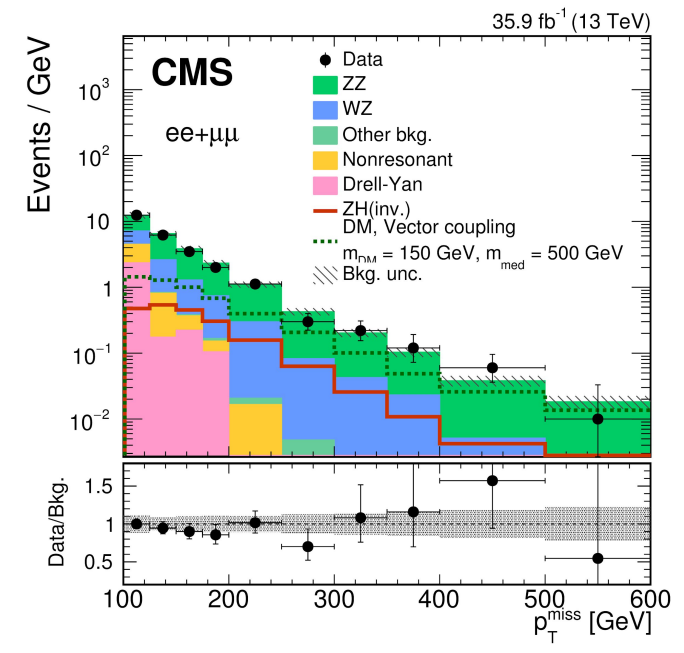
Higgs → Invisible [Z→ℓℓ]

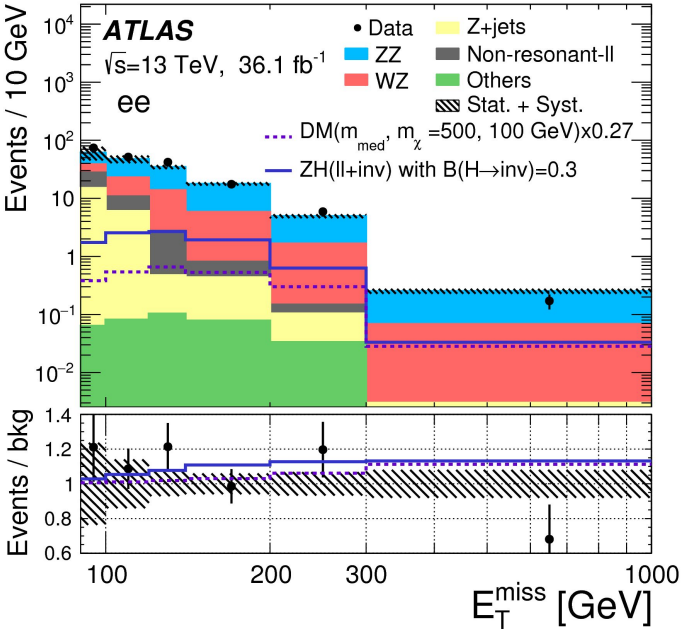
CMS-EXO-16-052
10.1140/epjc/s10052-018-5740-1
arxiv:1711.00431

ATLAS-HIGG-2016-28
10.1016/j.physletb.2017.11.049
arxiv:1708.09624

- Signature: 2 opposite-sign, same-flavor electrons or muons + p_T^{miss}
  - Main backgrounds: Z(ℓℓ)Z(νν), Z(ℓℓ)W(ℓν)
- Require dilepton system be back-to-back wrt p_T^{miss}
- CMS 12-variable BDT; ATLAS Fit to p_T^{miss} shape distribution







CMS Observed (expected) limit @ 95% CL [36 fb^{-1}]:
$\mathcal{B}$(H→inv) < 0.40 (0.42)

ATLAS Observed (expected) limit @ 95% CL [36 fb^{-1}]:
$\mathcal{B}$(H→inv) < 0.67 (0.39)

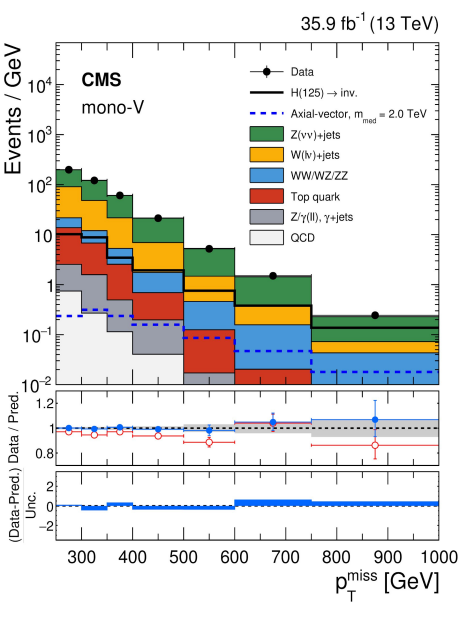
delannoy@cern.ch

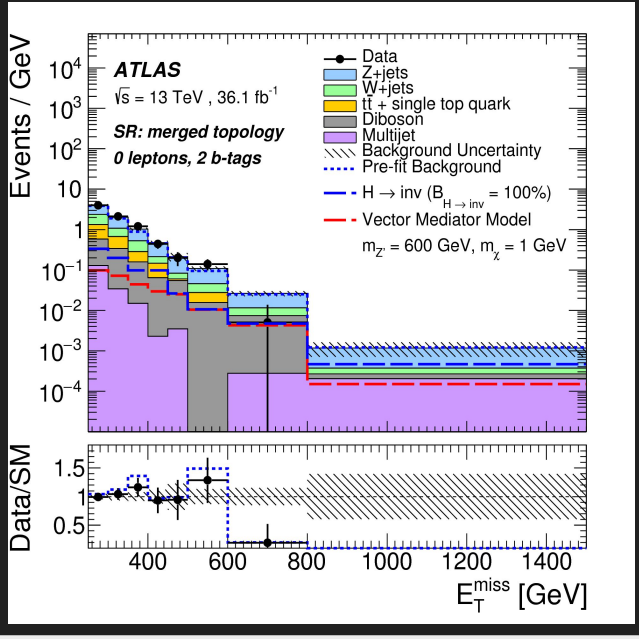
Higgs → Invisible [V→qq']

CMS-EXO-16-048
10.1103/PhysRevD.97.092005
arxiv:1712.02345

ATLAS-EXOT-2016-23
10.1007/JHEP10(2018)180
arxiv:1807.11471

- Invisible decays (p_T^{miss}) in association with jet(s)
  - Main backgrounds: Z(νν)+jet(s), W(ℓν)+jet(s), ttbar
- Background normalization and shapes estimated from 1 or 2 lepton CRs
  - p_T^{miss} in CRs calculated by excluding contribution(s) from identified lepton(s), i.e. $p_T^{miss(no\ lepton)}$
  - Jet topology: "merged" vs "resolved"; Three categories with different b-tagged jet multiplicities
- Signal extraction based on fit of $p_T^{miss(no\ lepton)}$ distribution





Observed (expected) limit @ 95% CL [36 fb^{-1}]:
[Monojet, mono-V] $\mathcal{B}$(H→inv) < 0.53 (0.40)

Observed (expected) limit @ 95% CL [36 fb^{-1}]:
[VBF, VH, ggH] $\mathcal{B}$(H→inv) < 0.83 (0.58)

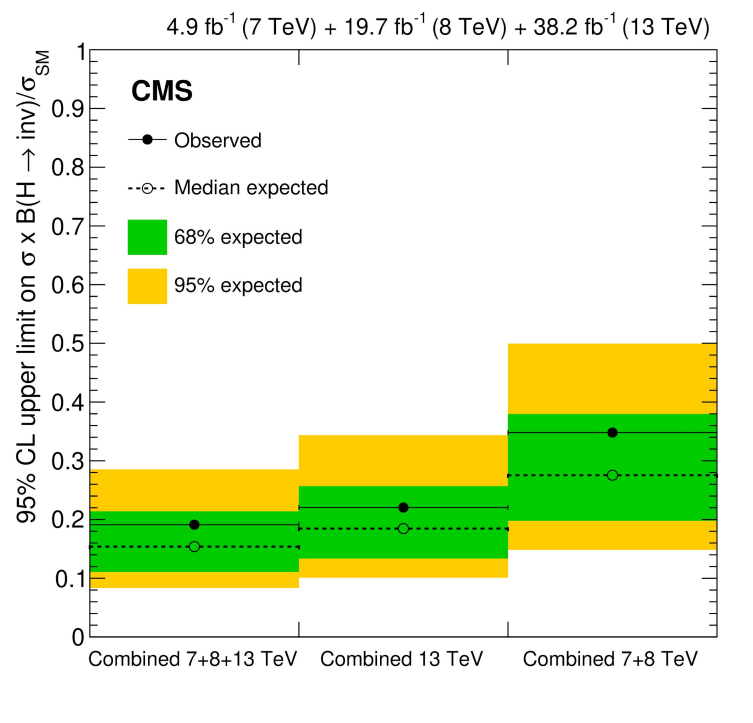
delannoy@cern.ch

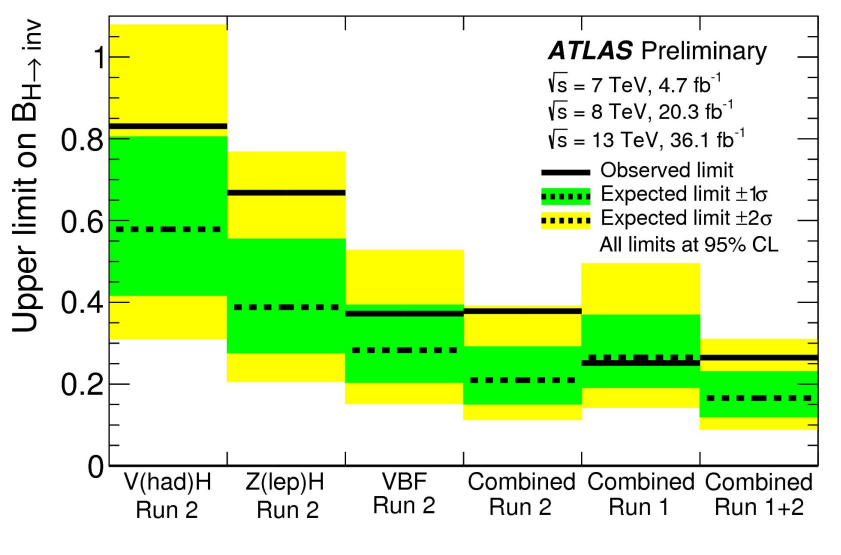
H → Invisible [Combination]

CMS-HIG-17-023
10.1016/j.physletb.2019.04.025
arXiv:1809.05937

ATLAS-CONF-2018-054
Accepted to Phys. Rev. Lett.
arXiv:1904.05105

- VBF, VH, ggH combination
- Run1 + Run2





Analysis	$\sqrt{s}$	Int. luminosity	Observed	Expected	p_{SM}-value	Reference
Run 2 VBF	13 TeV	36.1 fb^{-1}	0.37	$0.28^{+0.11}_{-0.08}$	0.19	[33]
Run 2 ZH	13 TeV	36.1 fb^{-1}	0.67	$0.39^{+0.17}_{-0.11}$	0.06	[34]
Run 2 VH	13 TeV	36.1 fb^{-1}	0.83	$0.58^{+0.23}_{-0.16}$	0.12	[35]
Run 2 Comb.	13 TeV	36.1 fb^{-1}	0.38	$0.21^{+0.08}_{-0.06}$	0.03	this note
Run 1 Comb.	7, 8 TeV	4.7, 20.3 fb^{-1}	0.25	$0.27^{+0.10}_{-0.08}$	—	[32]
Run 1+2 Comb.	7, 8, 13 TeV	4.7, 20.3, 36.1 fb^{-1}	0.26	$0.17^{+0.07}_{-0.05}$	0.10	this note

CMS: Observed (expected) limit @ 95% CL:
[Run1+Run2] $\mathcal{B}$(H→inv) < 0.19 (0.15)

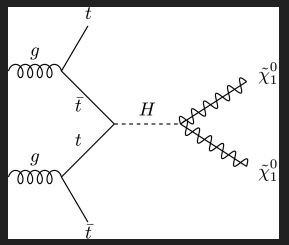
ATLAS: Observed (expected) limit @ 95% CL:
[Run1+Run2] $\mathcal{B}$(H→inv) < 0.26 (0.17)

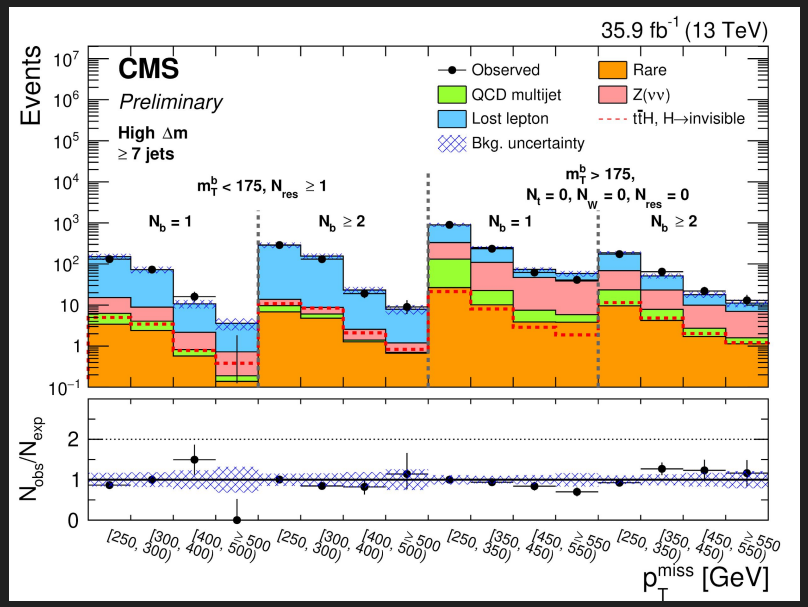
delannoy@cern.ch

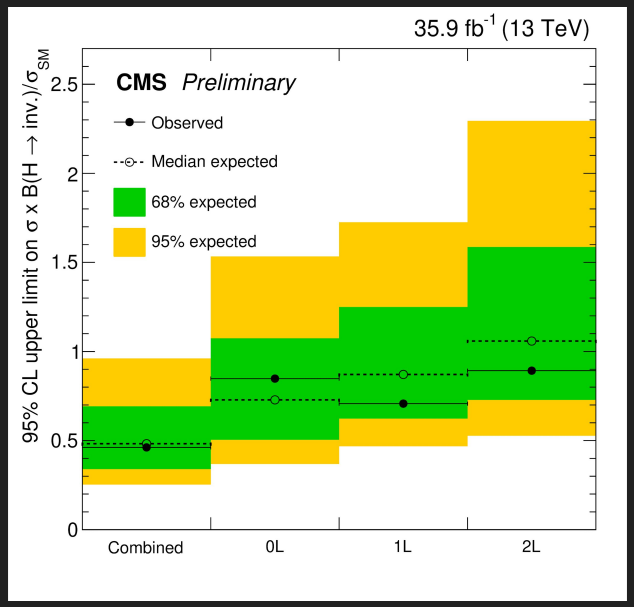
H → Invisible [ttH]

CMS-HIG-18-008

- Reinterpretation of results from 0/1/2ℓ stop searches (0/1/2ℓ + jets + p_T^{miss} + b-tag)
  - No modification to signal regions and background predictions
  - No re-optimization for ttH signals
- Multiple signal bins to cover large parameter space
- Major backgrounds constrained/validated in control regions







CMS Observed (expected) limit @ 95% CL [36 fb^{-1}]:

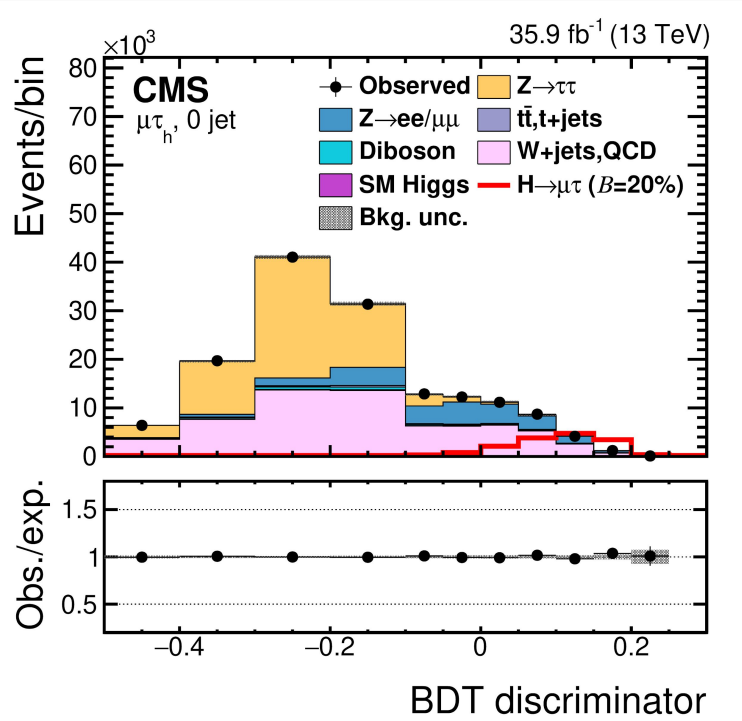
$\mathcal{B}$(H→inv) < 0.46 (0.48)

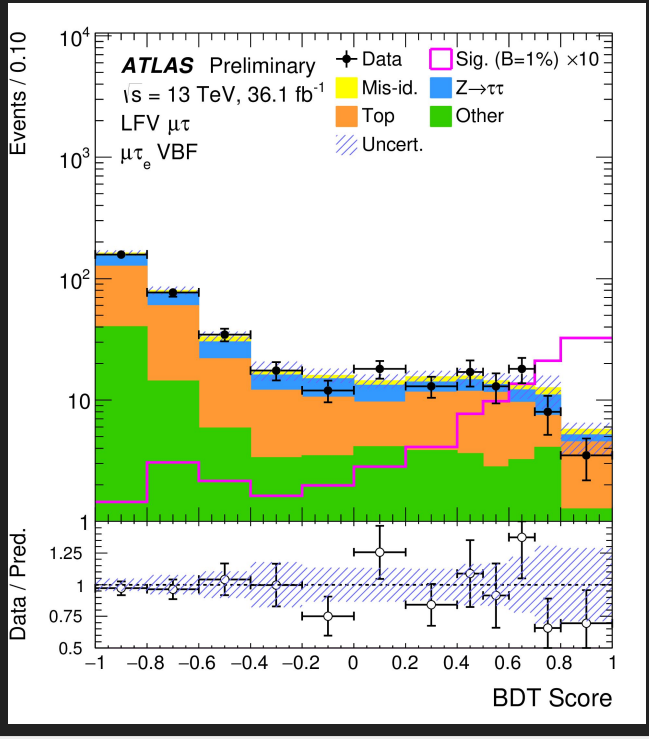
H→Exotic [LFV]

CMS-HIG-17-001
10.1007/JHEP06(2018)001
arxiv:1712.07173

ATLAS-CONF-2019-013

- H → e+τ / μ+τ
- Multiple τ-decay channels
- BDT fits to improve sensitivity





Observed (expected) limit @ 95% CL [36 fb^{-1}]:

$\mathcal{B}(H \to \mu\tau) < 0.25\ (0.25)$ %

$\mathcal{B}(H \to e\tau) < 0.61\ (0.37)$ %

Observed (expected) limit @ 95% CL [36 fb^{-1}]:

$\mathcal{B}(H \to \mu\tau) < 0.28\ (0.37)$ %

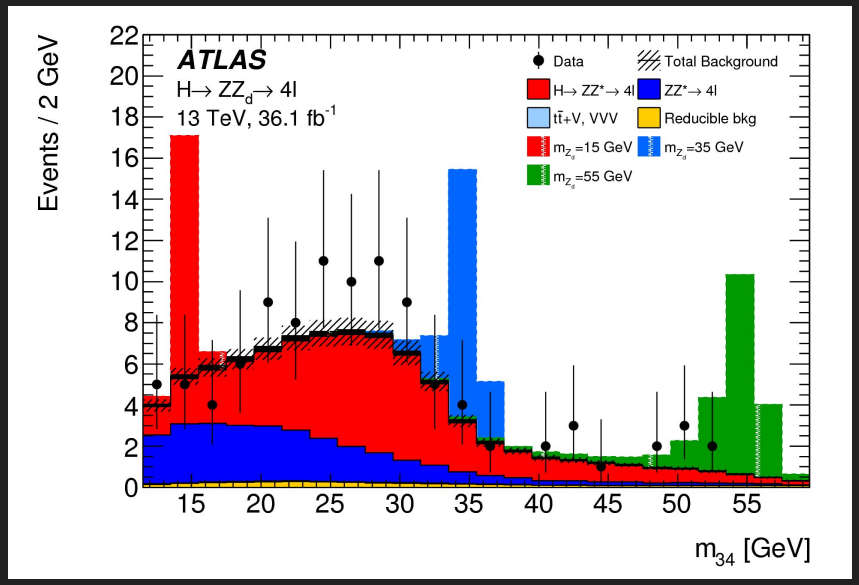
$\mathcal{B}(H \to e\tau) < 0.47\ (0.34)$ %

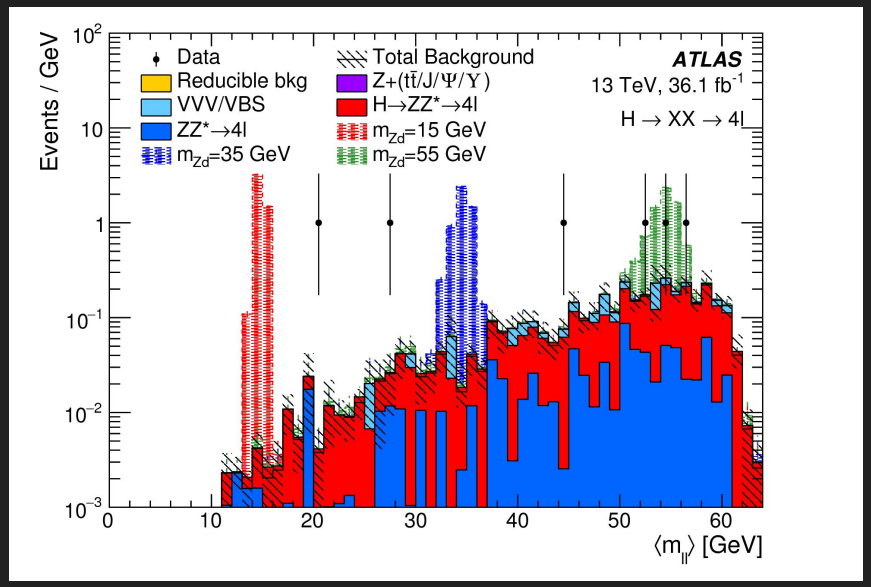
delannoy@cern.ch

H→Exotic [H→Z_dZ_d/ZZ_d→4ℓ]

ATLAS-EXOT-2016-22
10.1007/JHEP06(2018)166
arxiv:1802.03388

- Two same-flavour opposite-sign ℓ pairs (ee+ee, ee+μμ, μμ+μμ) with $m_{4\ell} \sim m_H$
- Main backgrounds: H → ZZ and ZZ
  - $H \to Z_dZ_d$: $m_{12}/m_{34} > 0.85$
  - $H \to ZZ_d$: $m_{12} \sim m_Z$





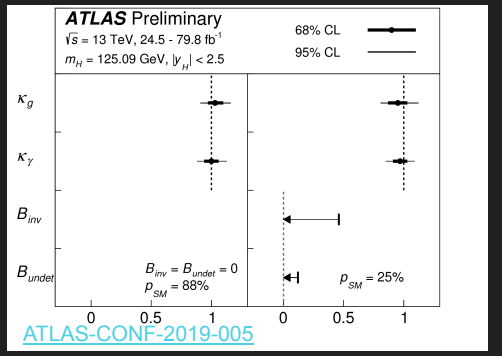
Process	$2\ell2\mu$	$2\ell2e$	Total
$H \to ZZ^* \to 4\ell$	34.3 ± 3.6	21.4 ± 3.0	55.7 ± 6.3
$ZZ^* \to 4\ell$	16.9 ± 1.2	9.0 ± 1.1	25.9 ± 2.0
Reducible background	2.1 ± 0.6	2.7 ± 0.7	4.8 ± 1.1
VVV, $t\bar{t}+V$	0.20 ± 0.05	0.20 ± 0.04	0.40 ± 0.06
Total expected	53.5 ± 4.3	33.3 ± 3.4	86.8 ± 7.5
Observed	65	37	102

Process	Yield
$ZZ^* \to 4\ell$	0.8 ± 0.1
$H \to ZZ^* \to 4\ell$	2.6 ± 0.3
VVV/VBS	0.51 ± 0.18
$Z + (t\bar{t}/J/\Psi) \to 4\ell$	0.004 ± 0.004
Reducible Background	Negligible
Total	3.9 ± 0.3
Data	6

delannoy@cern.ch

Summary & Conclusions

- CMS & ATLAS Collaborations hard at work on invisible and Higgs exotic decays
- Latest Run 2 results for H→invisible searches:
  - CMS combination of Run1+Run2 *invisible* decays sets 95% CL limit:
    - $\mathcal{B}$(H → invisible) < 0.19 (0.15)
  - ATLAS combination of Run1+Run2 *invisible* decays sets 95% CL limit:
    - $\mathcal{B}$(H → invisible) < 0.26 (0.17)
  - ATLAS Run2 [36 fb^{-1}] combined Higgs production & decay [ATLAS-CONF-2019-005]:
    - Additional contributions to the total width of Higgs with $\mathcal{B}_{inv}$, $\mathcal{B}_{undet}$ as independent parameters:
      - κ_γ = 0.97; κ_g = 0.95; $\mathcal{B}_{inv}$ < 0.46 (0.23) @ 95% CL; $\mathcal{B}_{undet}$ < 0.12 (0.32) @ 95% CL
    - Parameterization using (κ_γ, κ_g) with $\mathcal{B}_{inv}$, $\mathcal{B}_{undet}$ as independent parameters:
      - $\mathcal{B}_{inv}$ < 0.30 (0.18); $\mathcal{B}_{undet}$ < 0.22 (0.38)



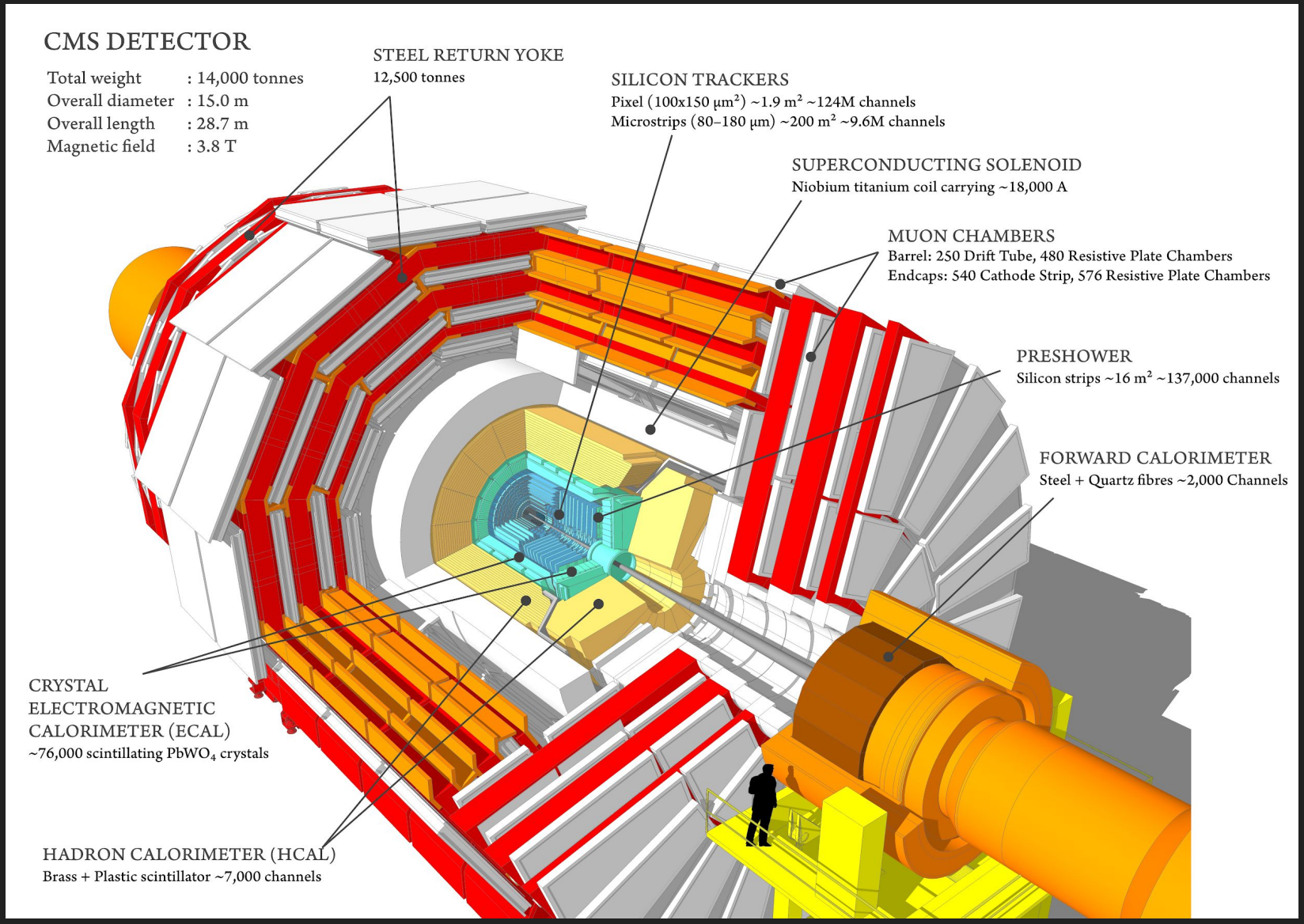
- Exotic Higgs decay searches have placed strong constraints on BSM models
  - Lots of work ahead!
- Lots of Run2 data [O(100 fb^{-1})] yet to be analyzed.
  - Stay tuned!

Resources

- CMS
  - Public Higgs Results:
    - Prelim: http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG/index.html
    - Publications: http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG/index.html
  - CMS Exotic Higgs Summary:
    - http://hexocms.com/
- ATLAS
  - Public Higgs Results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
    - Publications: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications
    - Public Notes: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/PUBnotes
    - Conference Notes: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CONFnotes

BACKUP

The CMS Detector



The ATLAS Detector