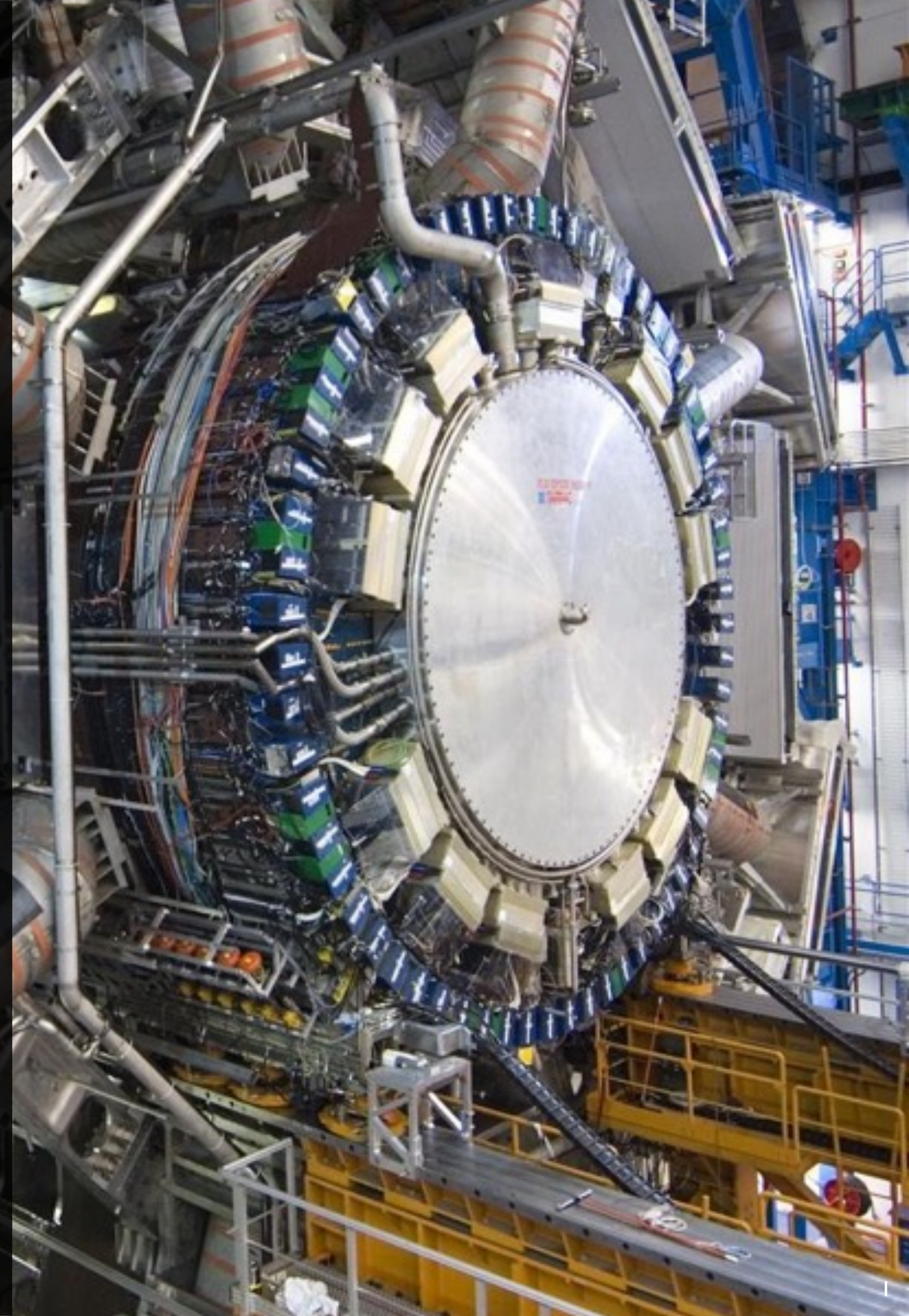
Search for Exotic Higgs Decays with ATLAS Detector

University of Illinois
Philip Chang

SUSY 2016
July 5, 2016



Outline

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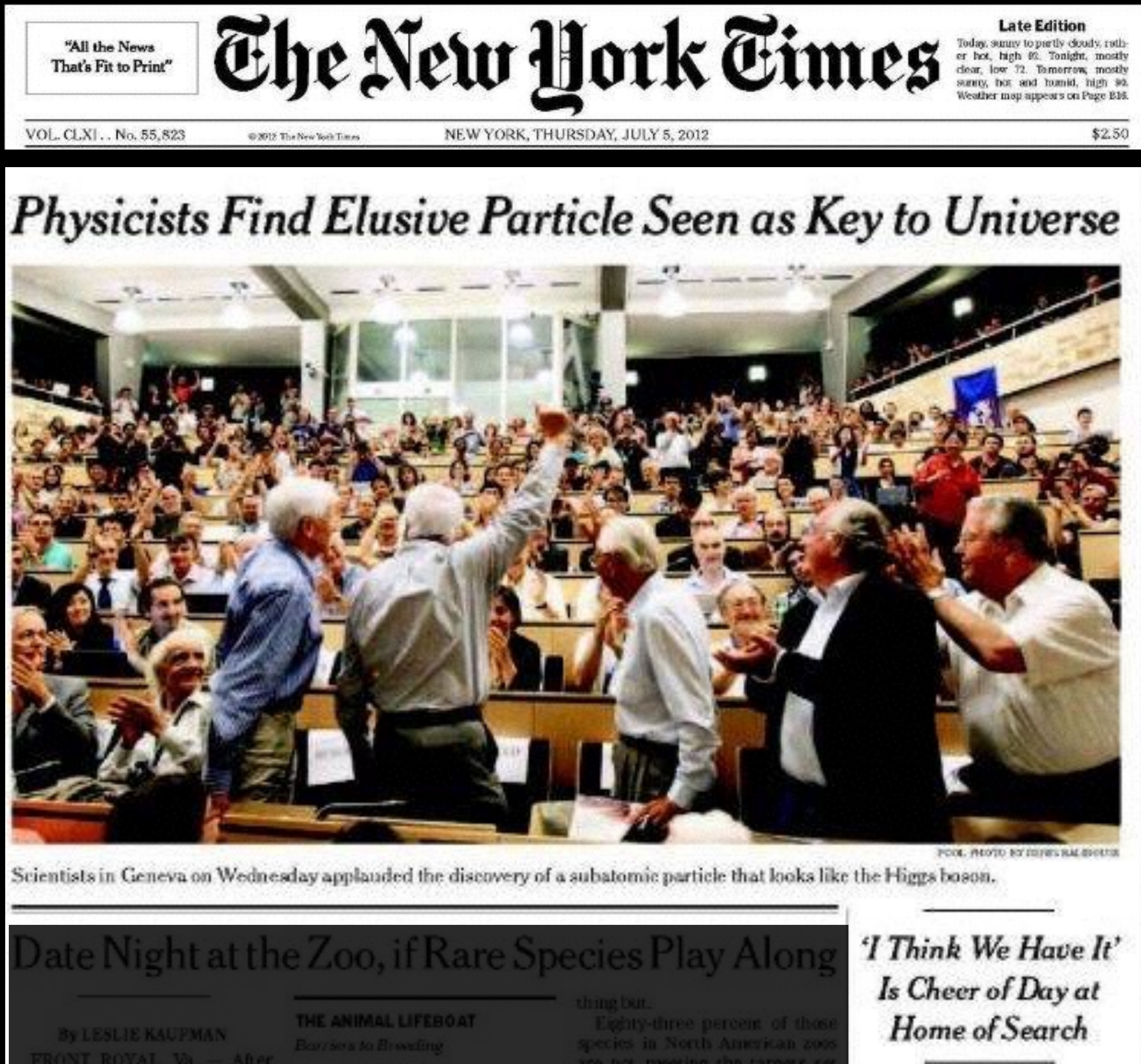
- Motivation
- Analyses at ATLAS
- Future challenges
- Summary

Higgs discovery



"All the News That's Fit to Print"

The New York Times

Late Edition

Today, sunny to partly cloudy, rather hot, high [illegible]. Tonight, mostly clear, low 72. Tomorrow, mostly sunny, hot and humid, high [illegible]. Weather map appears on Page B16.

VOL. CLXI . . No. 55,823 — ©2012 The New York Times — NEW YORK, THURSDAY, JULY 5, 2012 — $2.50

Physicists Find Elusive Particle Seen as Key to Universe

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

Date Night at the Zoo, if Rare Species Play Along

By LESLIE KAUFMAN

FRONT ROYAL, Va. — After

THE ANIMAL LIFEBOAT

Barriers to Breeding

thing but.

Eighty-three percent of those species in North American zoos are not meeting the targets set

'I Think We Have It' Is Cheer of Day at Home of Search

Could Higgs boson lead to another discovery?

Yes.

To see why, let's look at its properties.

SM Higgs decay

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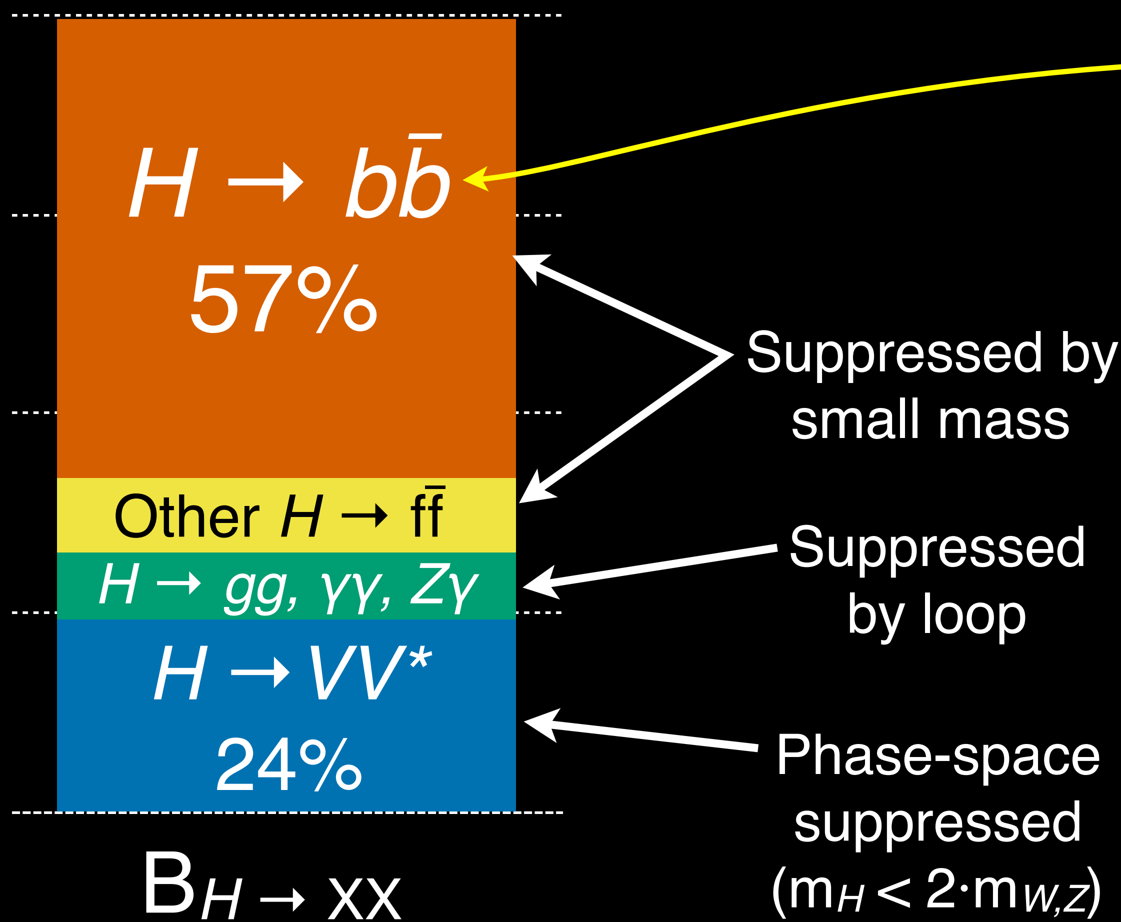

Largest partial width is to $\Gamma_{b\bar{b}}$

Yet this has a tiny coupling of $\mathcal{O}(0.01)$

Curtin et al. 1312.4992 (2014)
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR2014

Exotic Higgs decay

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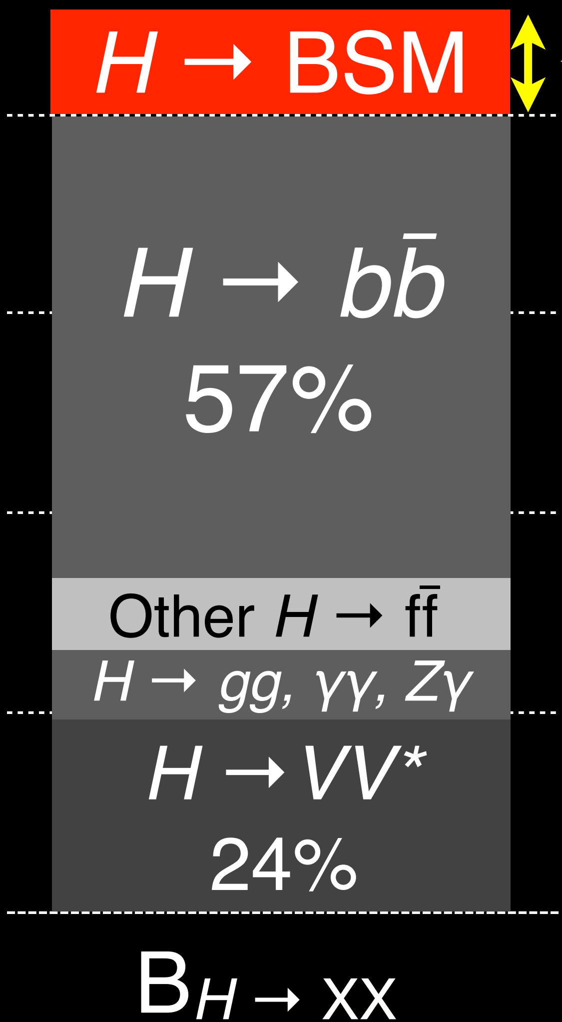
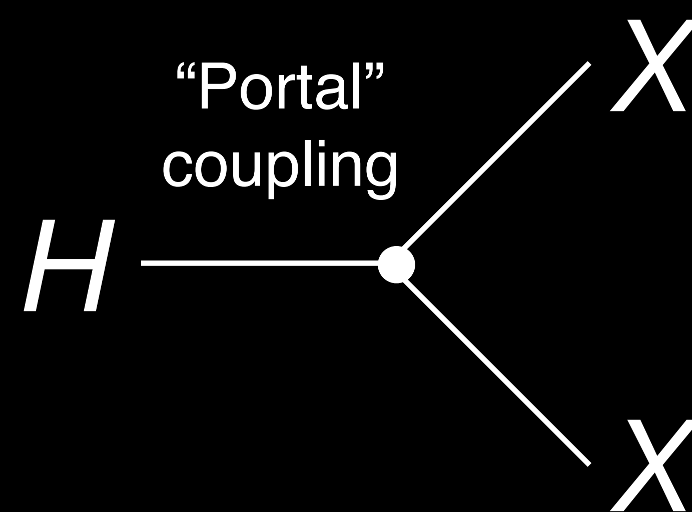


A new coupling of $\mathcal{O}(0.01)$ can easily add $B_{H \to BSM} = \mathcal{O}(10\%)$



Curtin et al. 1312.4992 (2014)
Chang et al. 0801.4554 (2008)
Silveira & Zee, PL B 161 (1985) 136
+ many more

Exotic Higgs decay

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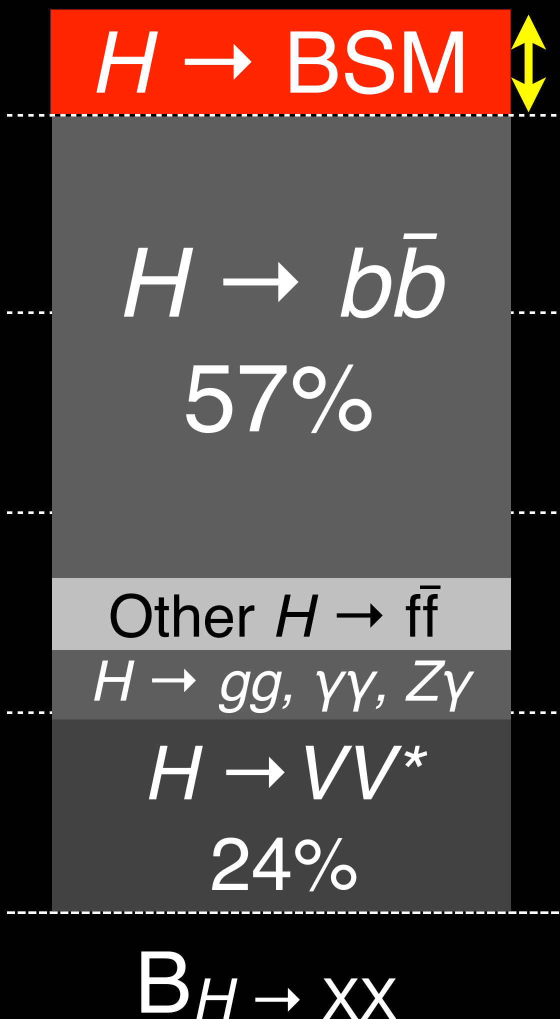
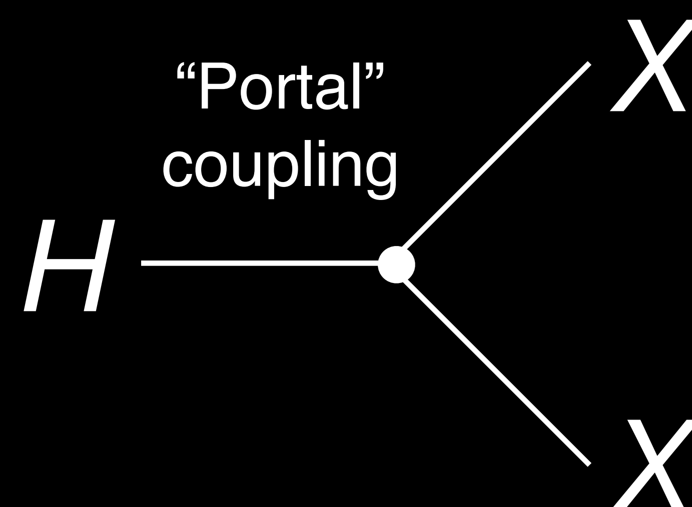


c.f. LHC produced 2M Higgs events so far

A new coupling of $\mathcal{O}(0.01)$ can easily add $B_{H\to BSM} = \mathcal{O}(10\%)$



Curtin et al. 1312.4992 (2014)
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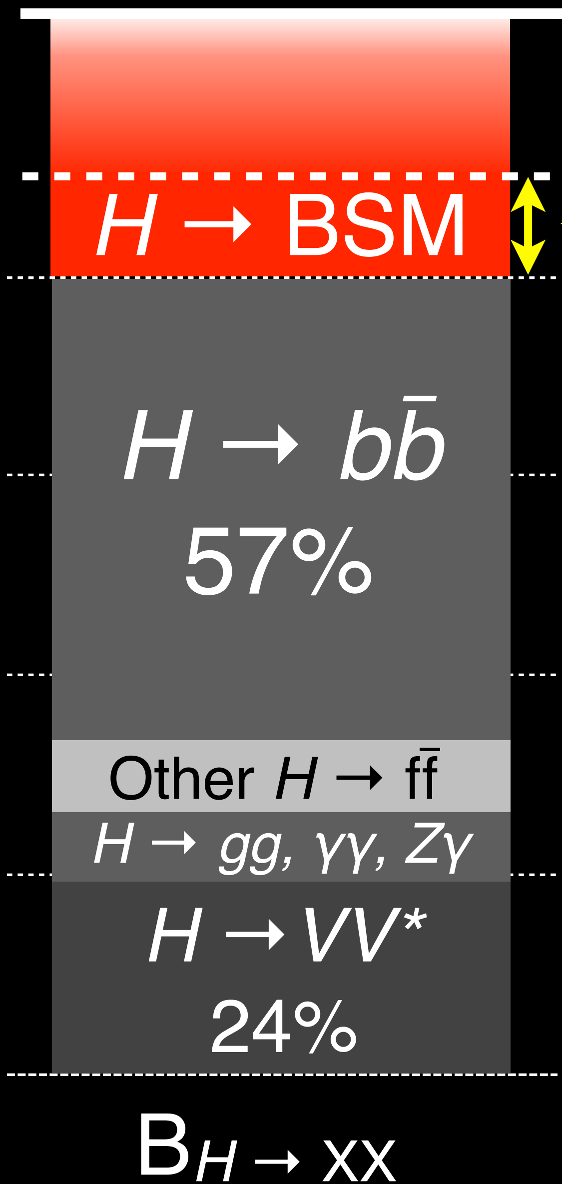
Exotic Higgs decay

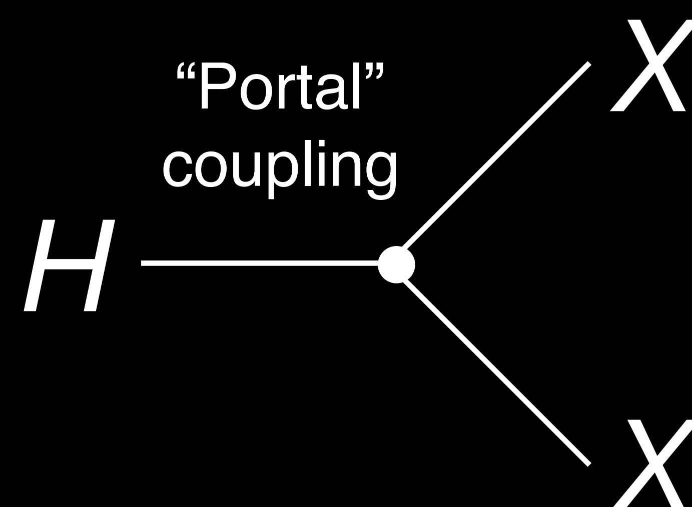


*Current limit is only at **34%***

*3 ab^{-1} projection is $\approx$ **10%***

i.e. 300M Higgs events

A new coupling of
$\mathcal{O}(0.01)$ can easily add
$B_{H \to BSM} = \mathcal{O}(10\%)$



ATLAS+CMS combination 1606.02266
ATLAS projection ATL-PHYS-PUB-2014-016

Higgs “portal” ⟵ coined by Brian Patt, Frank Wilczek

$$\zeta \; \underbrace{|H|^2}_{} \; X^2$$

Dim 2 → $|H|^2$

“Portal” interaction

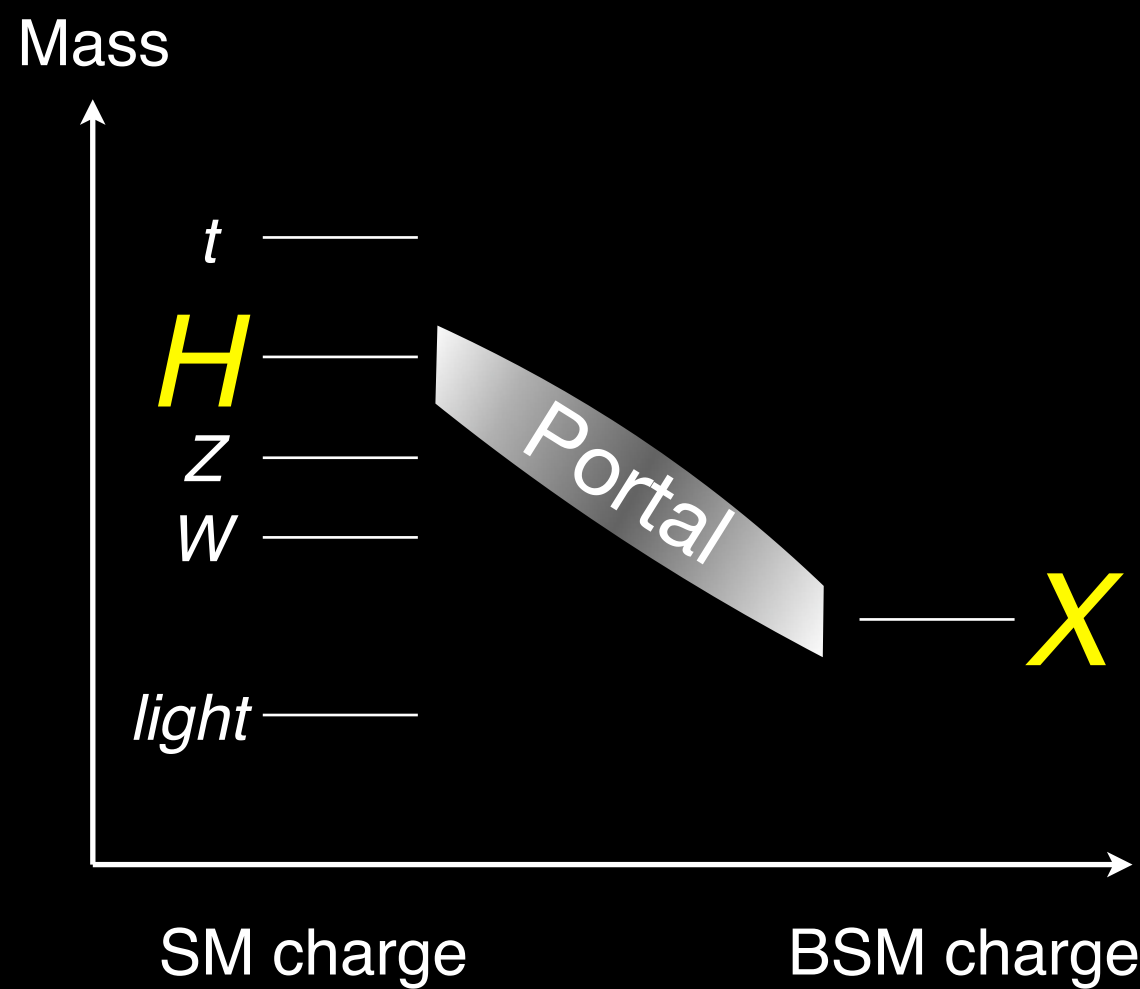
Patt, Wilczek hep-ph/0605188 (2006)

Higgs “portal” ⟵ coined by Brian Patt, Frank Wilczek

Dim 2

$$\zeta \; \underset{\uparrow}{} |H|^2 \, X^2$$

“Portal” interaction



Patt, Wilczek hep-ph/0605188 (2006)

Higgs "portal" ⟵ coined by Brian Patt, Frank Wilczek

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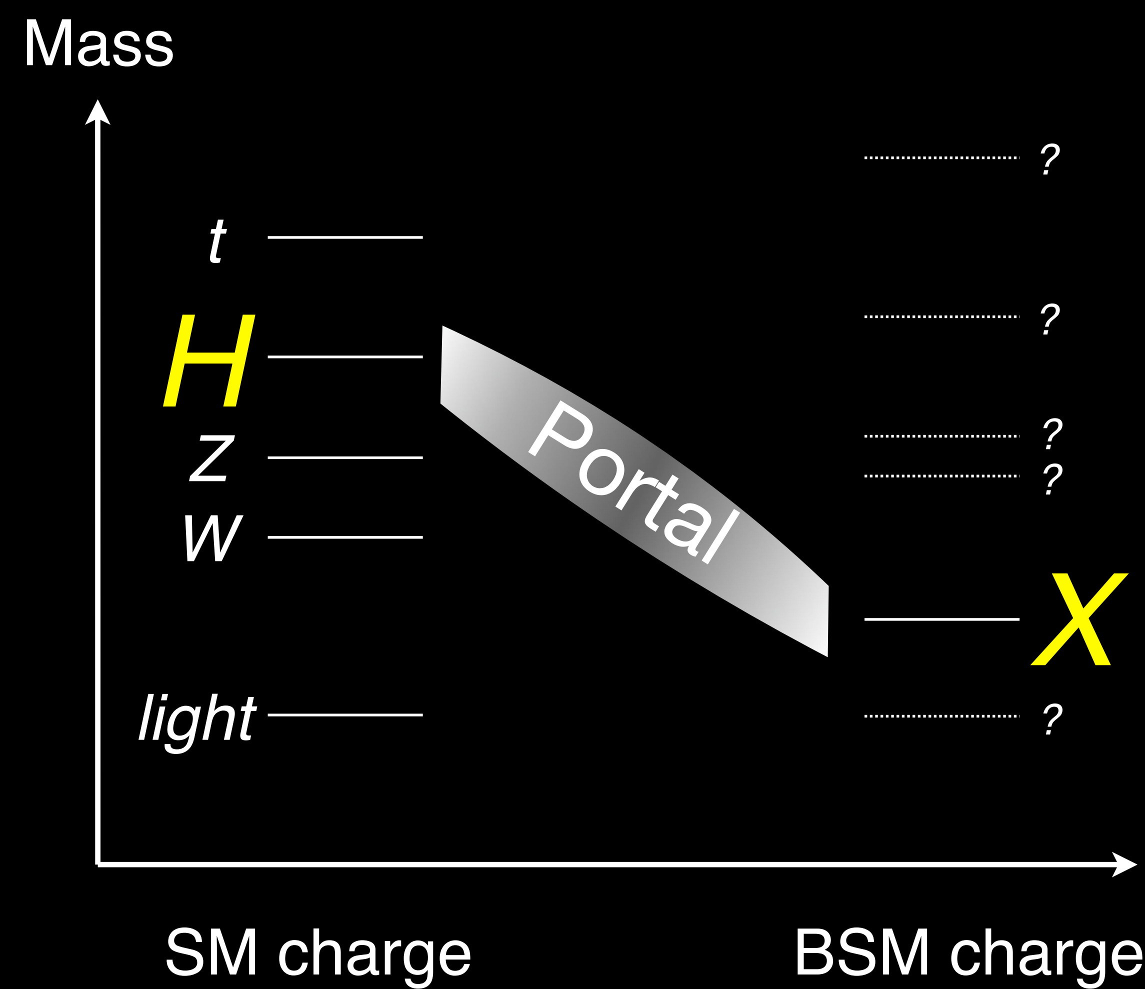
Dim 2

$$\zeta \ |H|^2 \ X^2$$

"Portal" interaction



Patt, Wilczek hep-ph/0605188 (2006)

Higgs “portal” ⟵ coined by Brian Patt, Frank Wilczek

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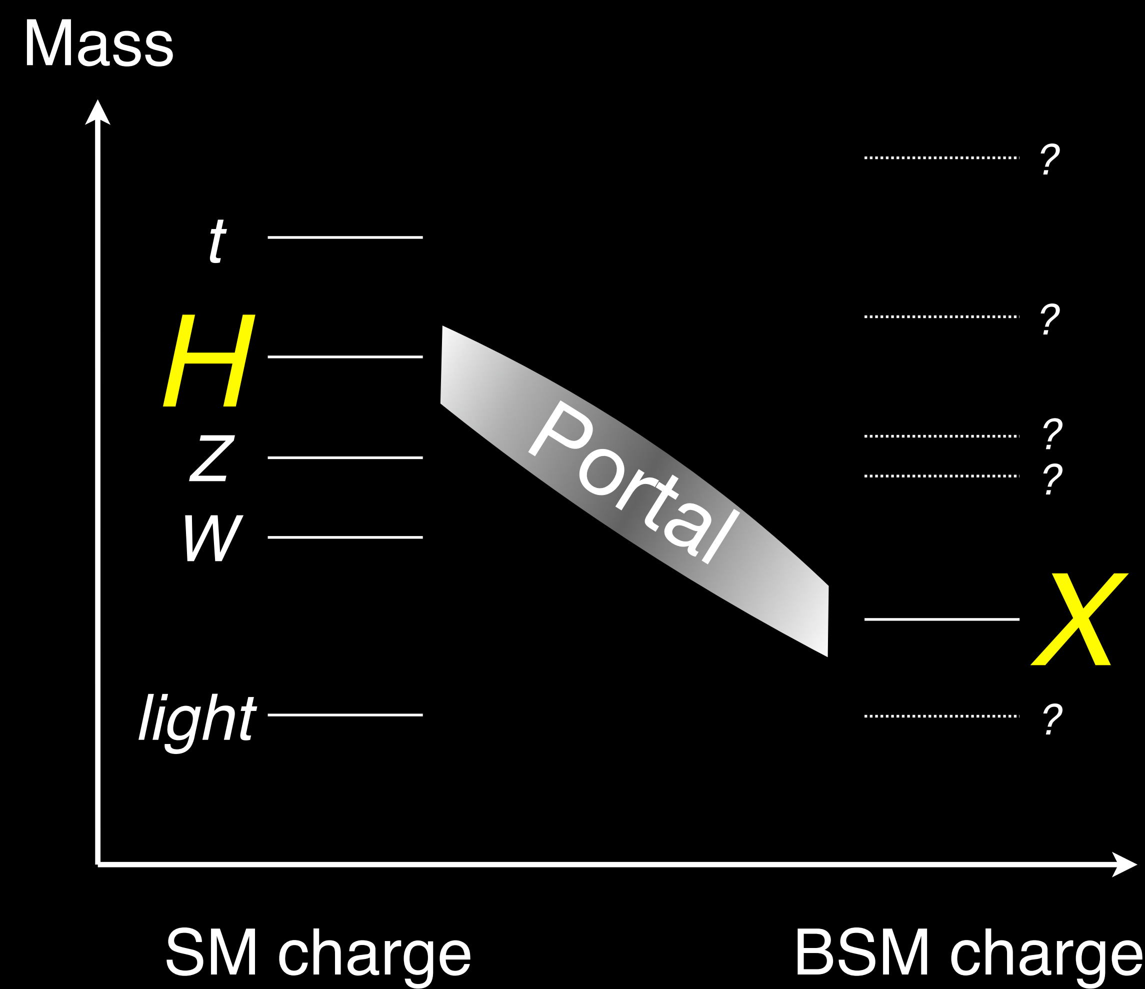
Dim 2

$$\zeta\ |H|^2\ X^2$$

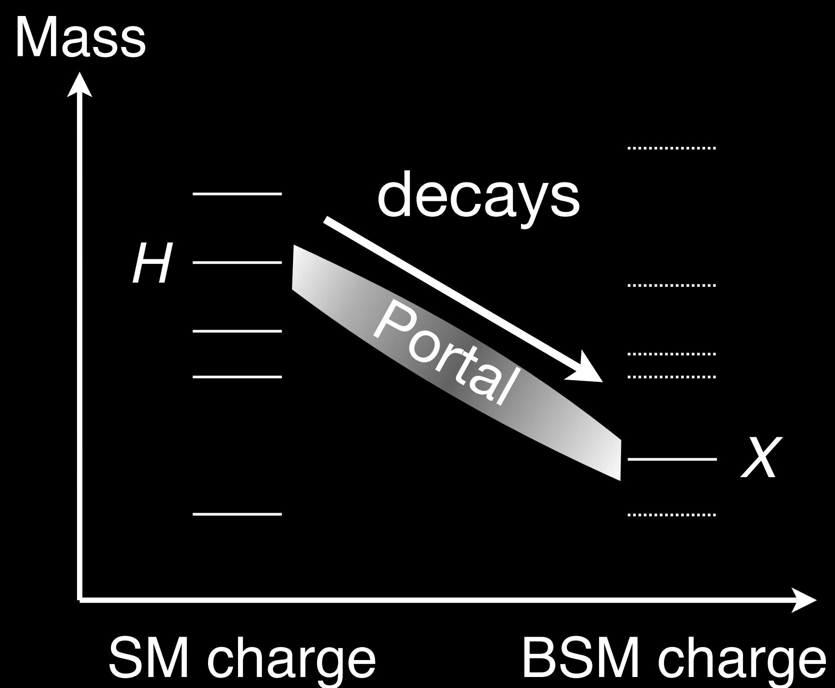
“Portal” interaction

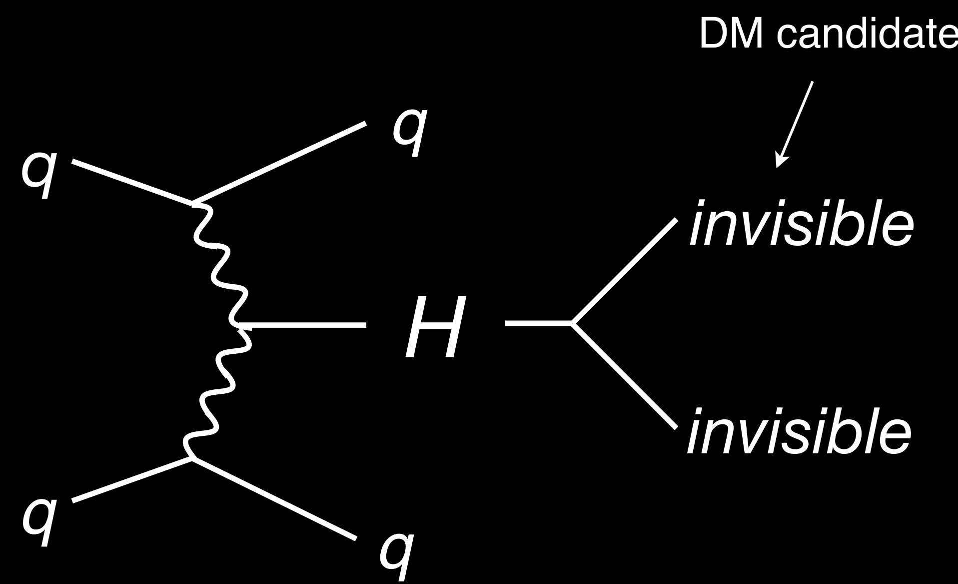


Can explore Hidden BSM structures via Higgs portal

Patt, Wilczek hep-ph/0605188 (2006)

Case 1: Invisible Higgs decay





H decays away to hidden sector
⇒ leaves missing energy

e.g. Curtin et al. 1312.4992 (2014) + many more

Invisible Higgs decay

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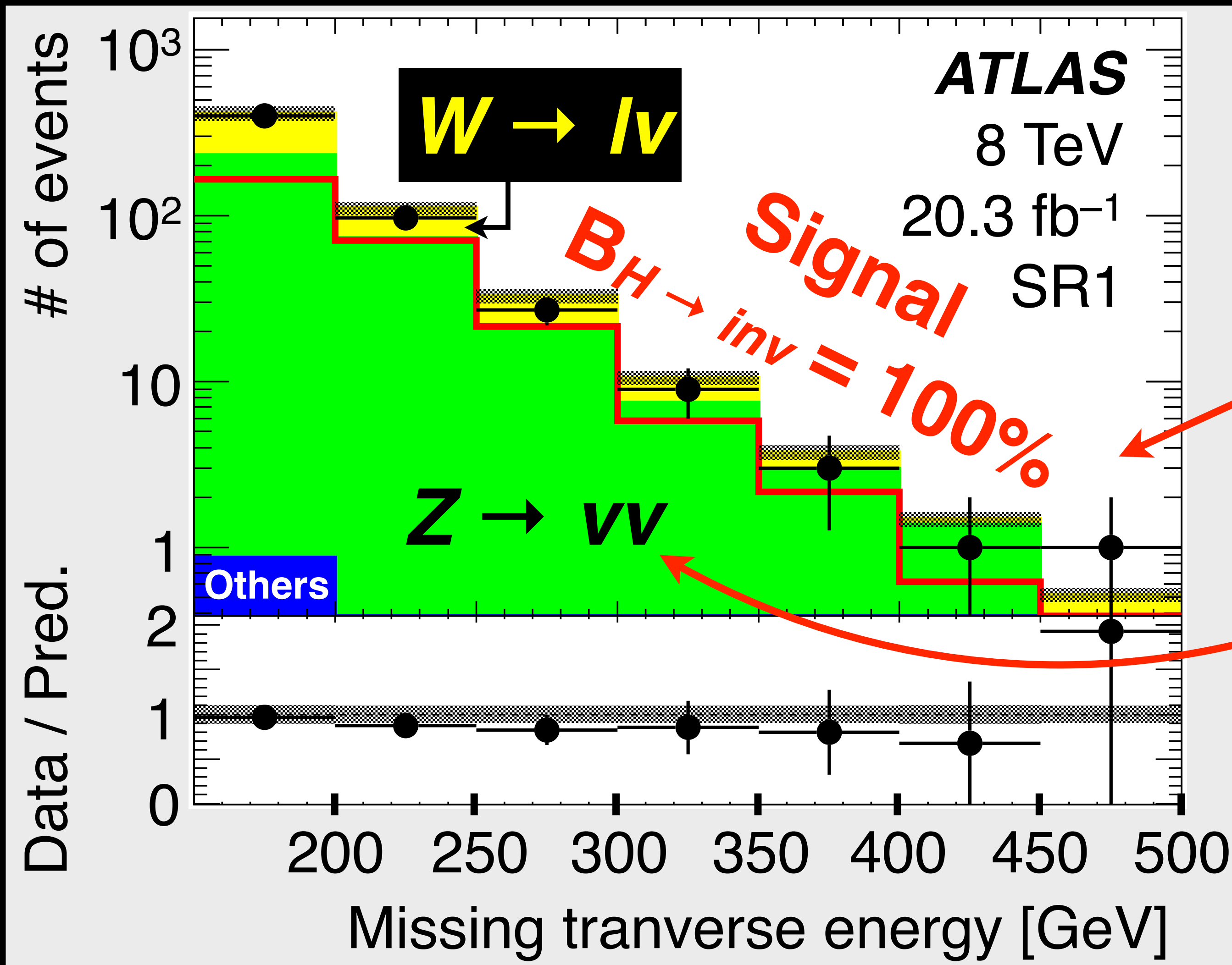


VBF $H \to$ inv analysis example

Probe missing energy spectrum

Understanding $Z \to \nu\nu$ crucial (becoming the main limitation)

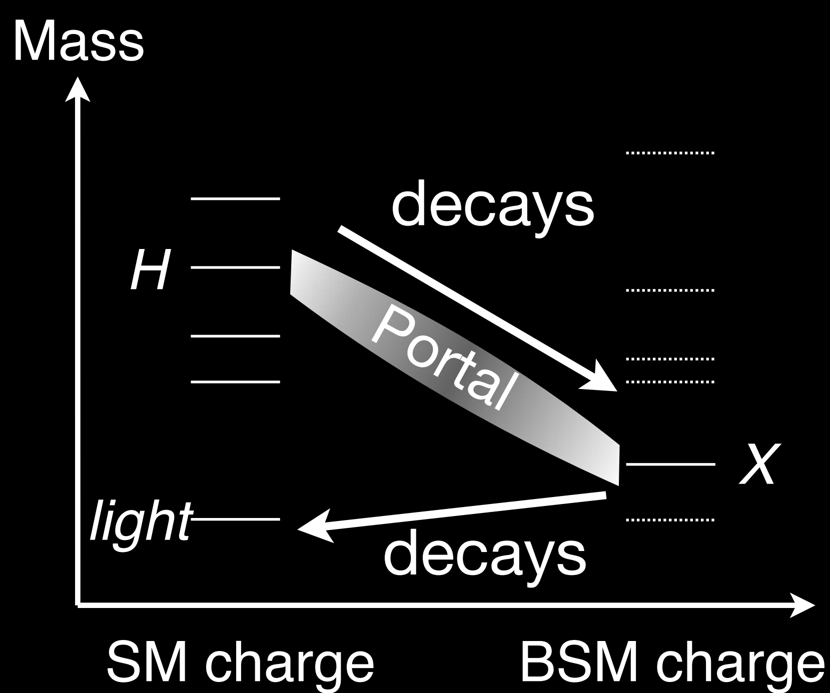
No significant excess observed

Various invisible Higgs decay analyses from ATLAS: PRL 112, 201802 (2014), EPJ C 75:337 (2015), JHEP01 (2016) 172, JHEP11 (2015) 206

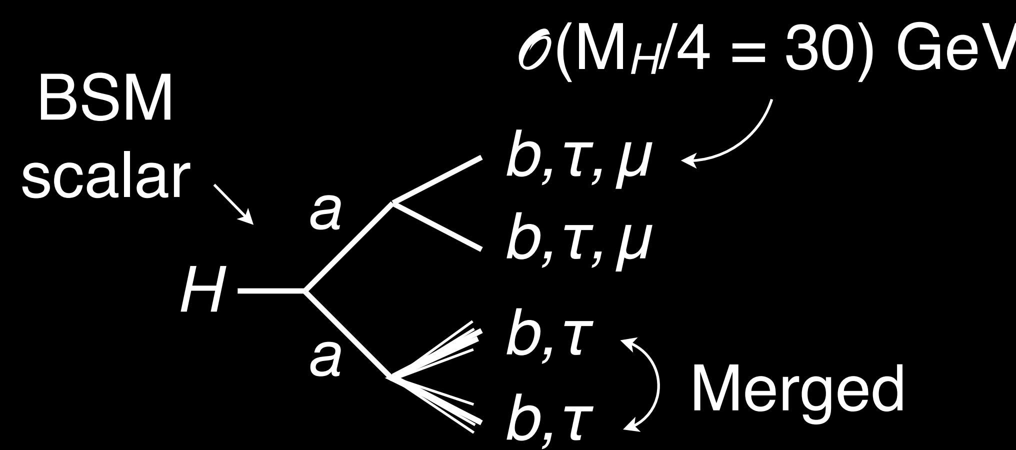
Combining $H \to inv$ analyses constrain $B_{H \to inv} < 25\%$ (95% CL)

~~In~~visible Higgs decay

But soft



Hidden sector particles decay back to visible but soft SM final states



Low transverse momentum final states

⇒ Trigger challenges

⇒ Relatively "Boosted" merged jets tagging

e.g. Curtin, Essig, Zhong 1412.4779 (2015) + many more

ATLAS: $H \to aa \to b\bar{b}b\bar{b}$

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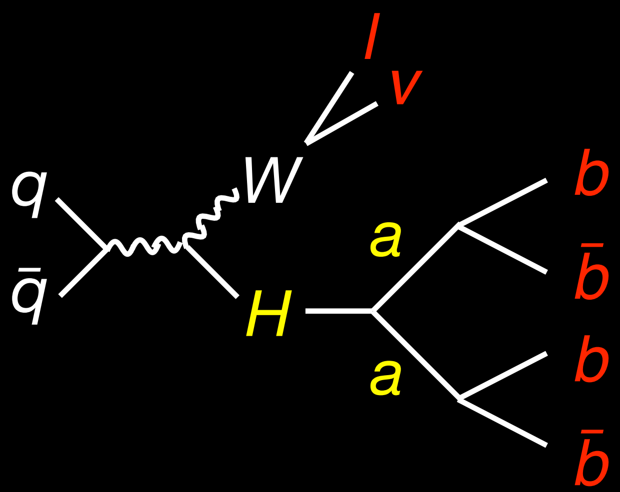
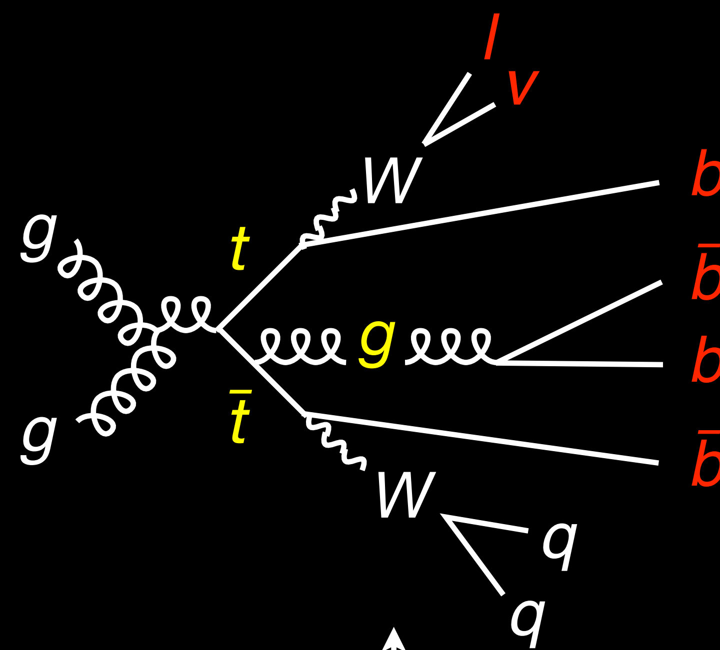
Signal



SM background



$\sigma_{x\text{-}sec}$ much larger

Use multivariate analysis

ATLAS: $H \to aa \to b\bar{b}b\bar{b}$

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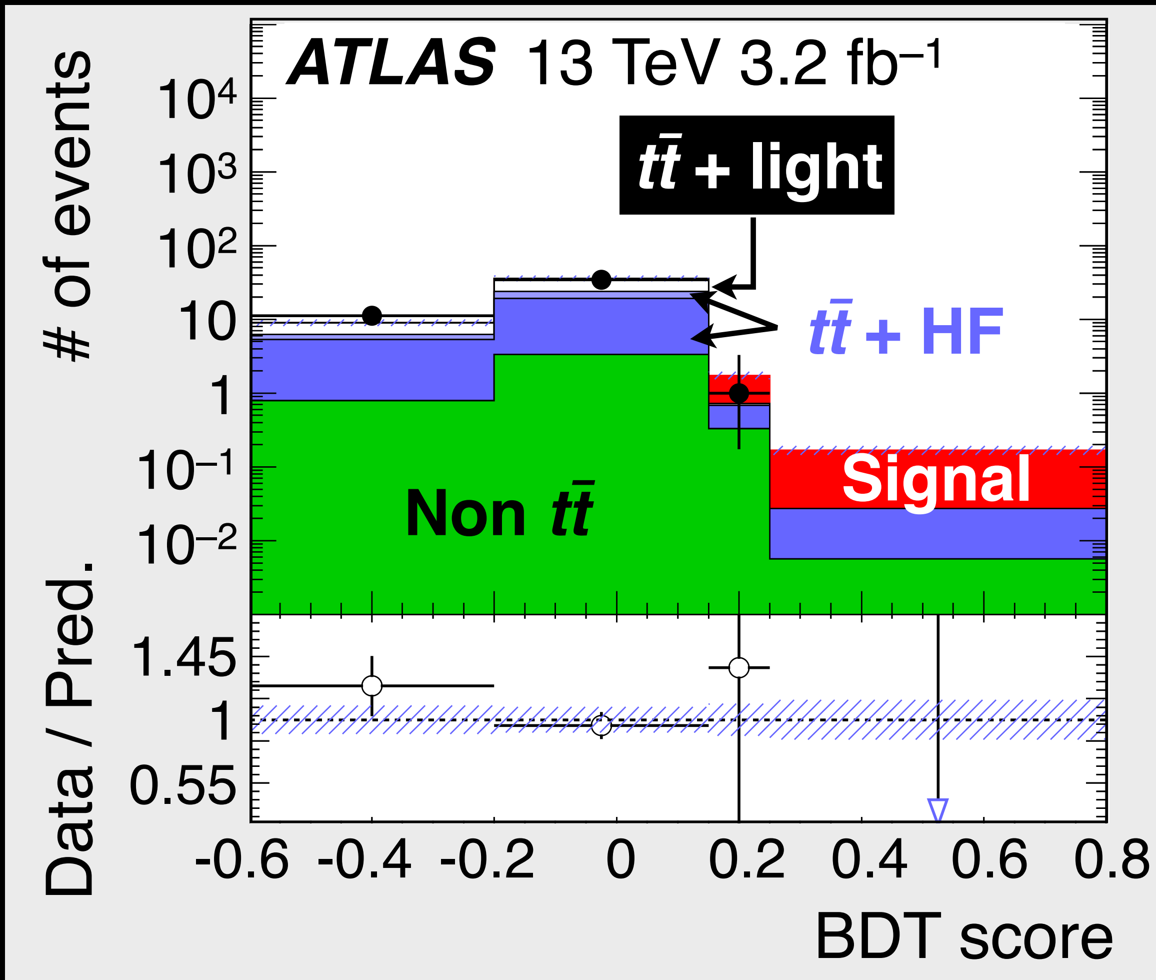

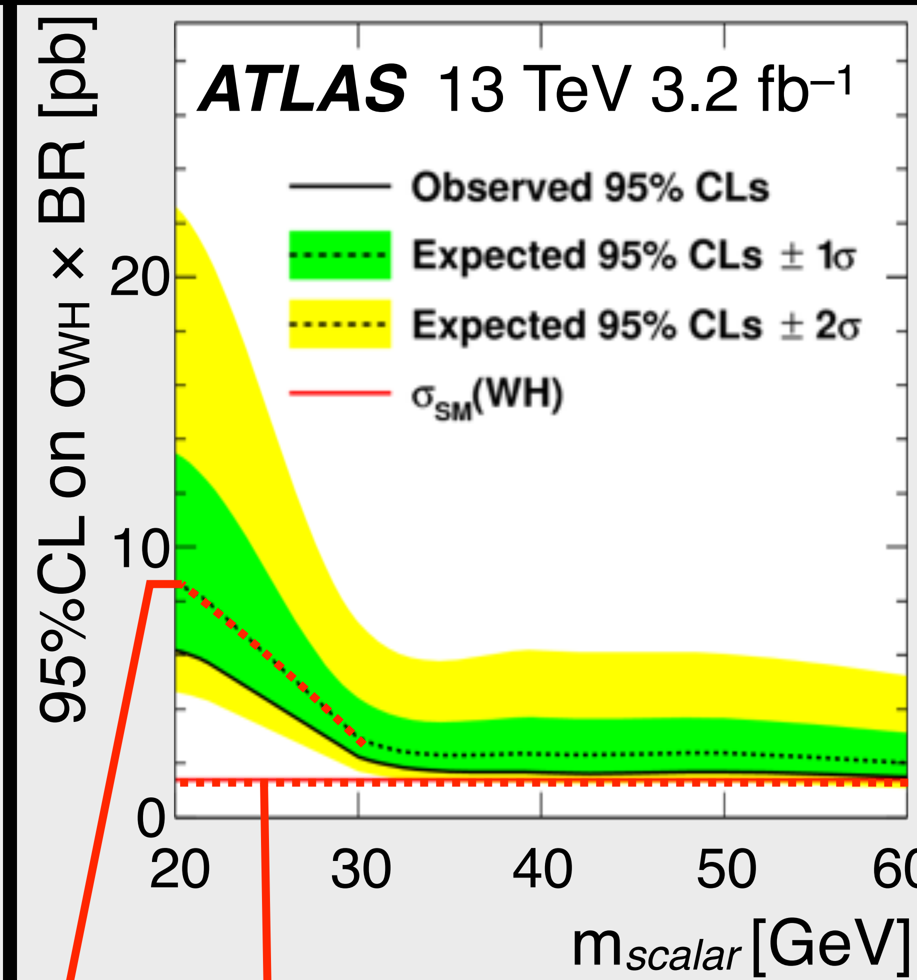

- Sensitivity loss at low m_{scalar} due to merged jet
- $B_{H \to 4b} = 100\%$ line

More data being analyzed. Stay tuned.

Other channels

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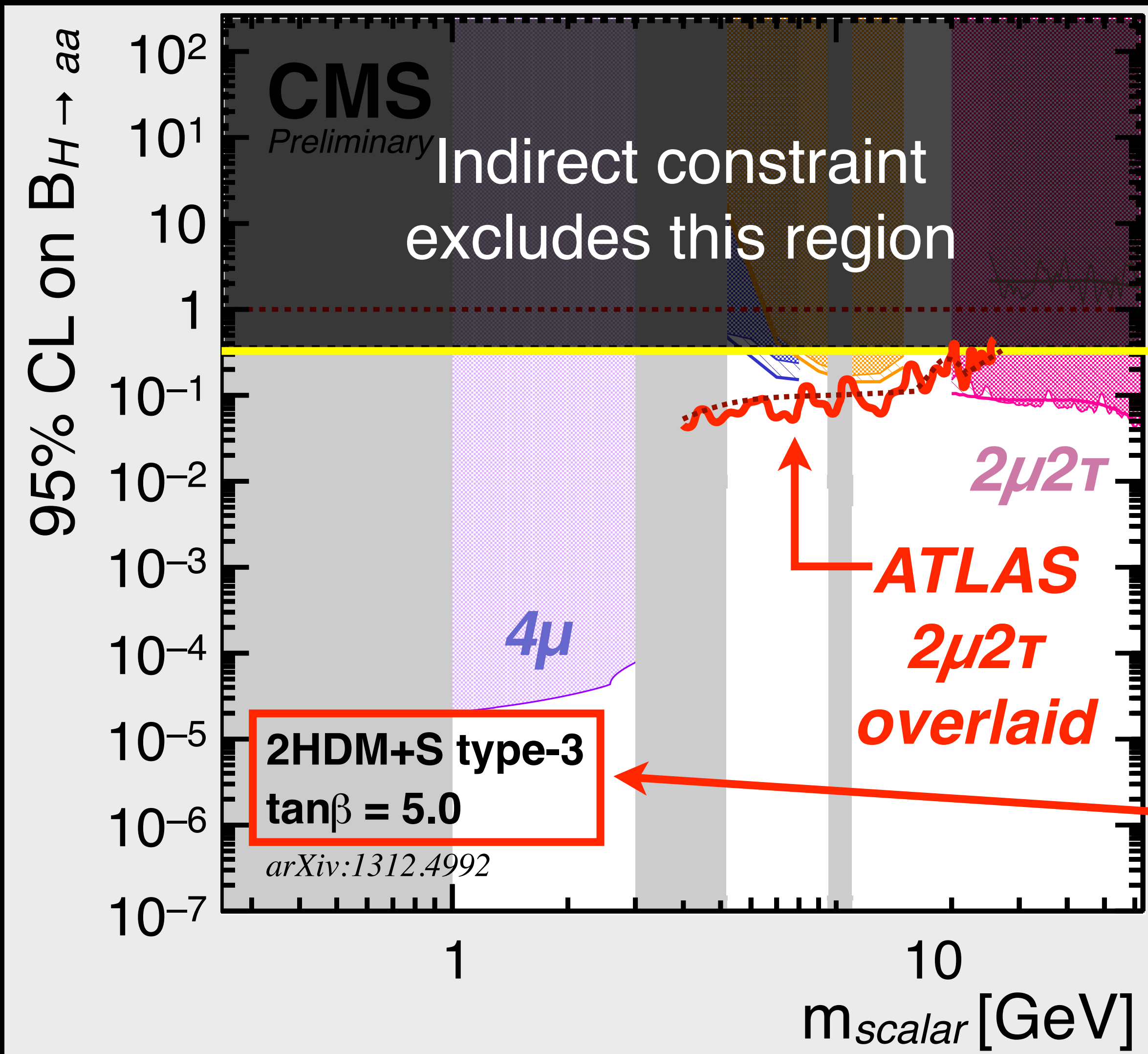


$B_{H\to aa} = 34\%$ (indirect)

This is CMS result to illustrate what other channels exist

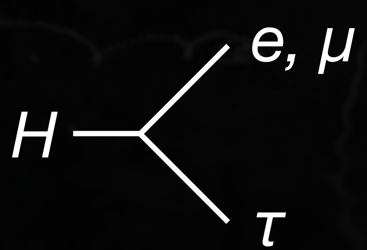
Some channels reach beyond the indirect constraint

However, these are model dependent

Direct searches are constraining beyond indirect constraint for some parameter space

Lepton flavor violating Higgs decay

Many BSM models predict non-diagonal Yukawa couplings up to $\mathcal{O}(10\%)$ while satisfying experimental constraints



Diaz-Cruz, Toscano, PR D 62, 116005 (2000)
Blankenburg, Ellis, Isidori PL B 712 (2012) 386
Arhrib, Cheng, Kong PR D 87 015025 (2013)
Arana-Catania, Arganda, Herrero JHEP10 (2015) 192
+ many more

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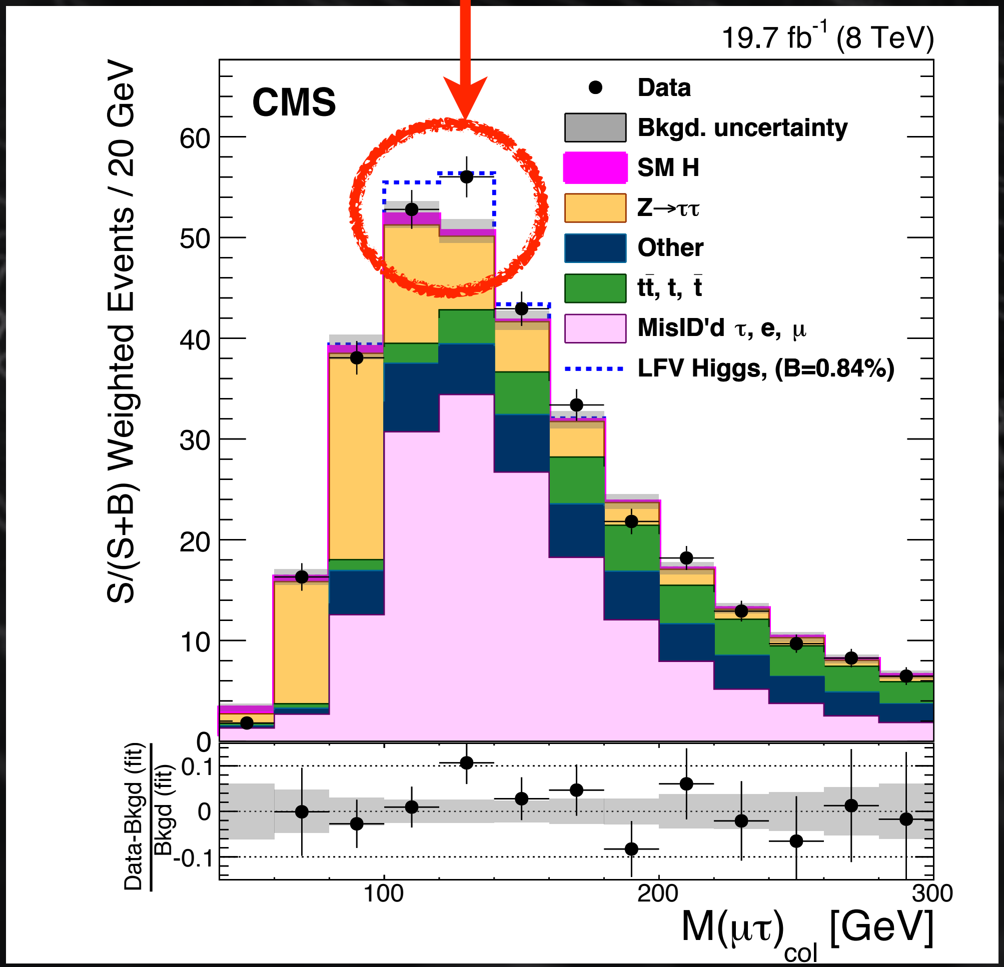
CMS reported 2.4σ excess at Run 1 (13 TeV 2.3/fb shows no excess)

PL B 749 (2015) 337



Mass reconstructions in $H \to l\tau$

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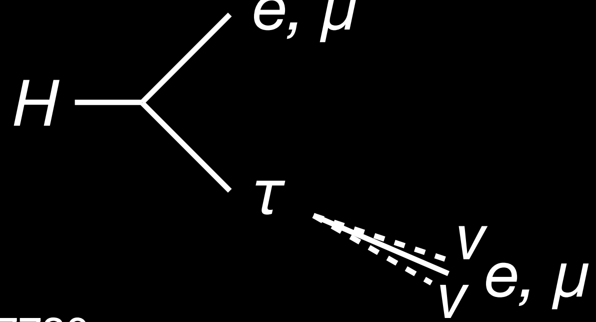
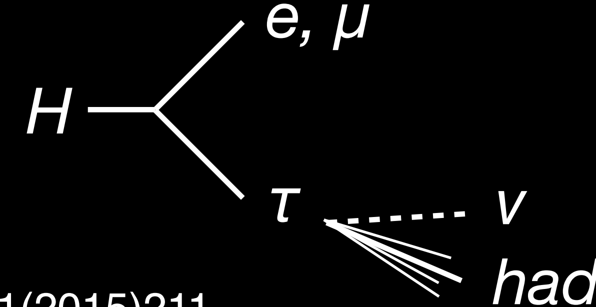
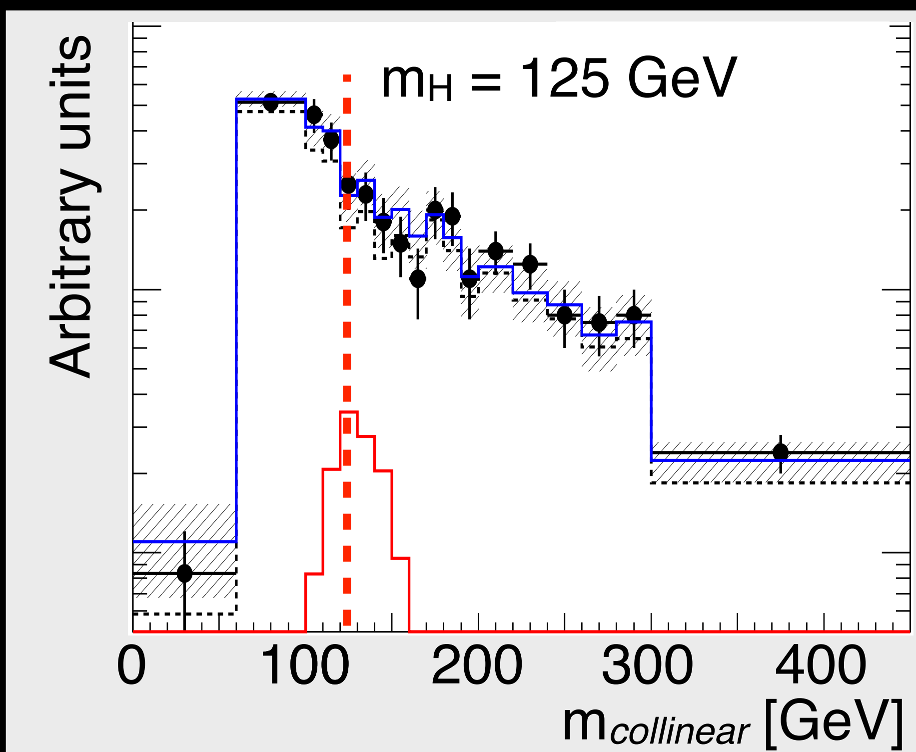
Assume ν's are collinear



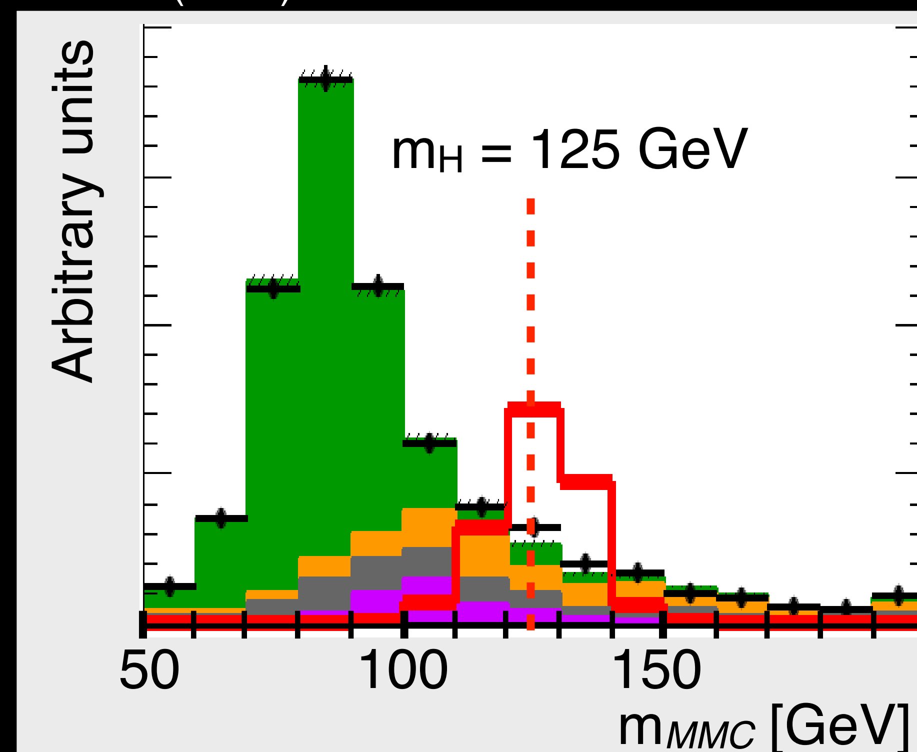
Relative orientations of $\vec{\nu}$ and $\overrightarrow{had}$ consistent with τ decay



1604.07730



JHEP11(2015)211



Well reconstructed $H \to l\tau$ peak

Focusing on H→$\mu\tau$ results

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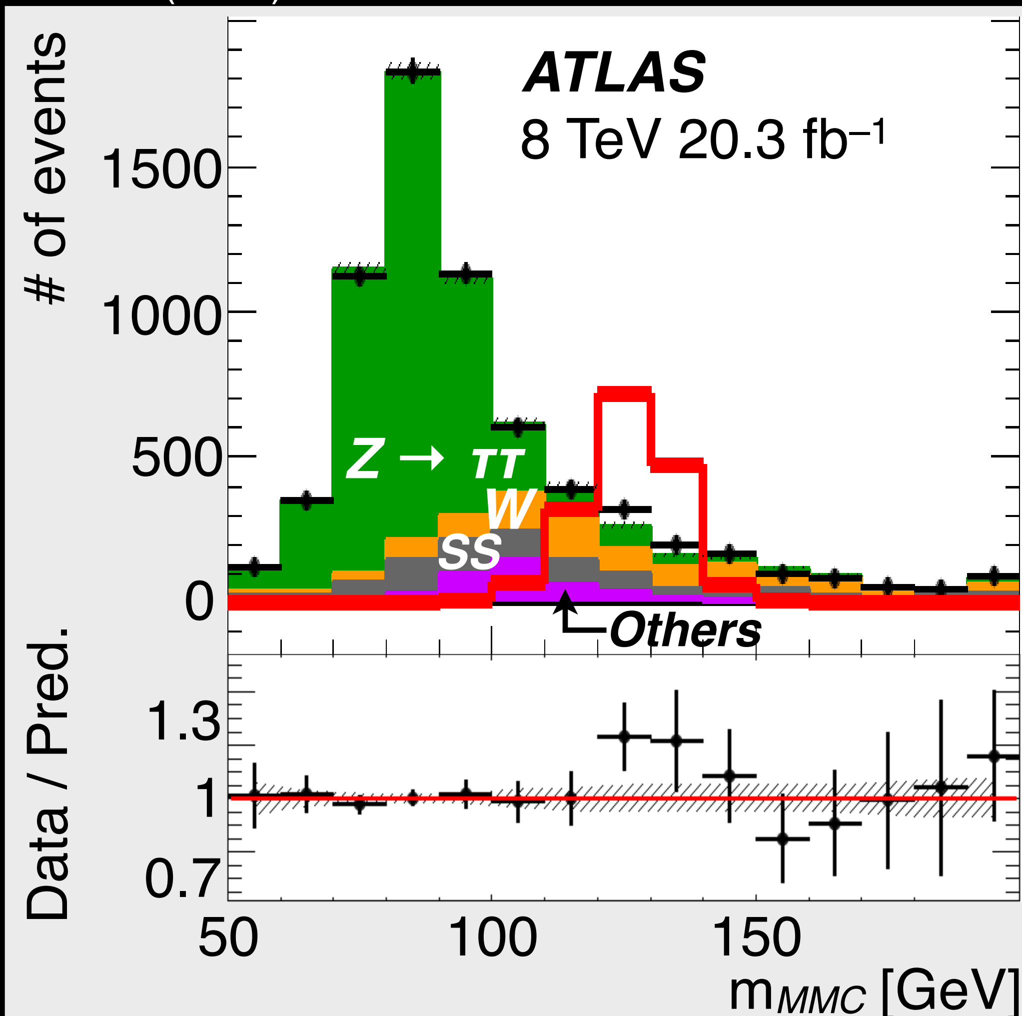
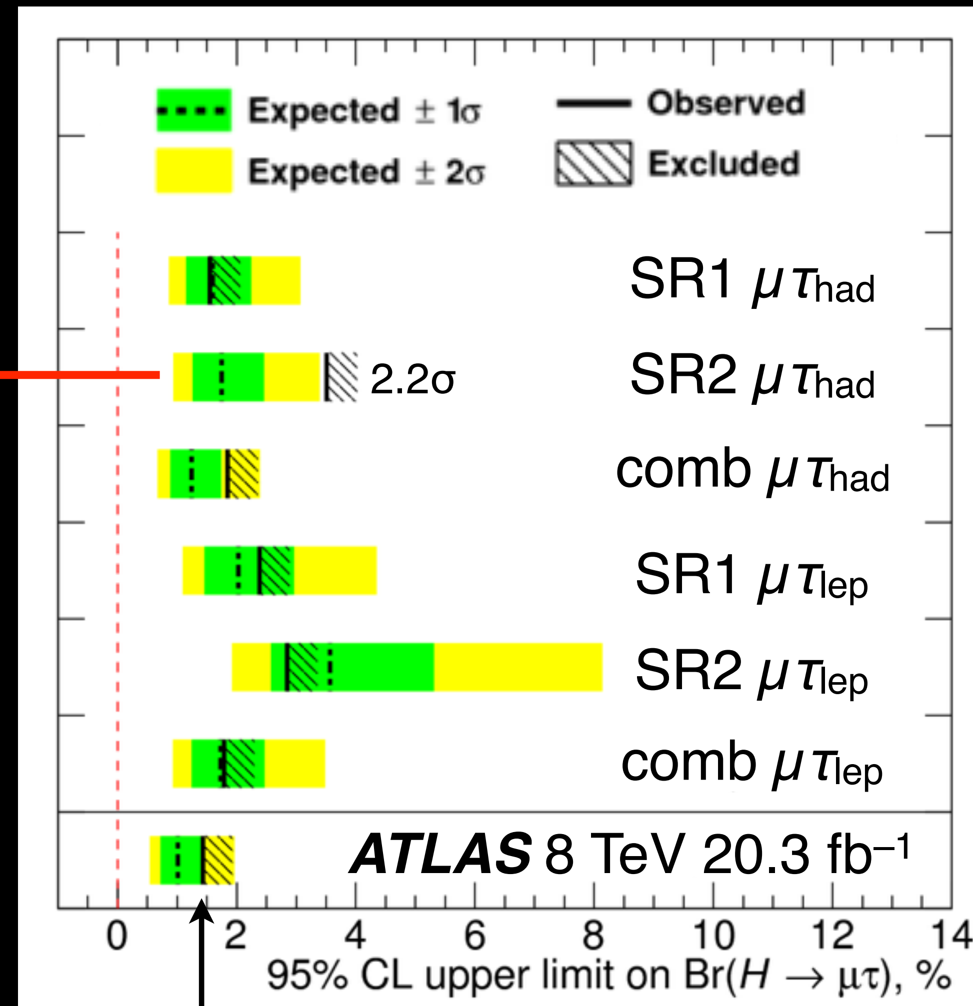


1604.07730



$B_{H\to\mu\tau} < 1.43\%$ (95%CL)

One signal region reports 2.2σ

But combination shows no excess

Interesting challenges ahead

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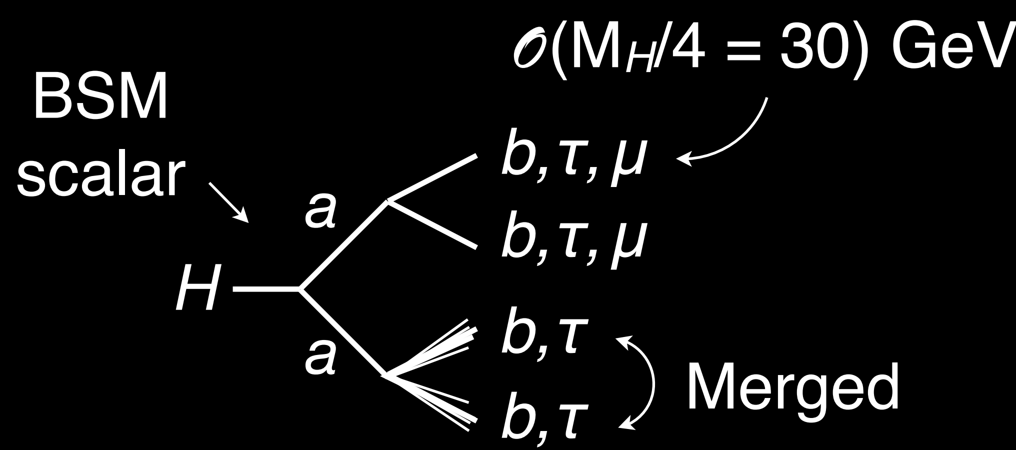
If $B_{H\rightarrow BSM} = \mathcal{O}(10\%)$, we already have 200k exotic higgs decay events

They have topology different from typical analyses' phase-space



Key objects to study

low P_T "merged" jets

low P_T b-tagging algorithms

soft lepton final states

b-tagging efficiency

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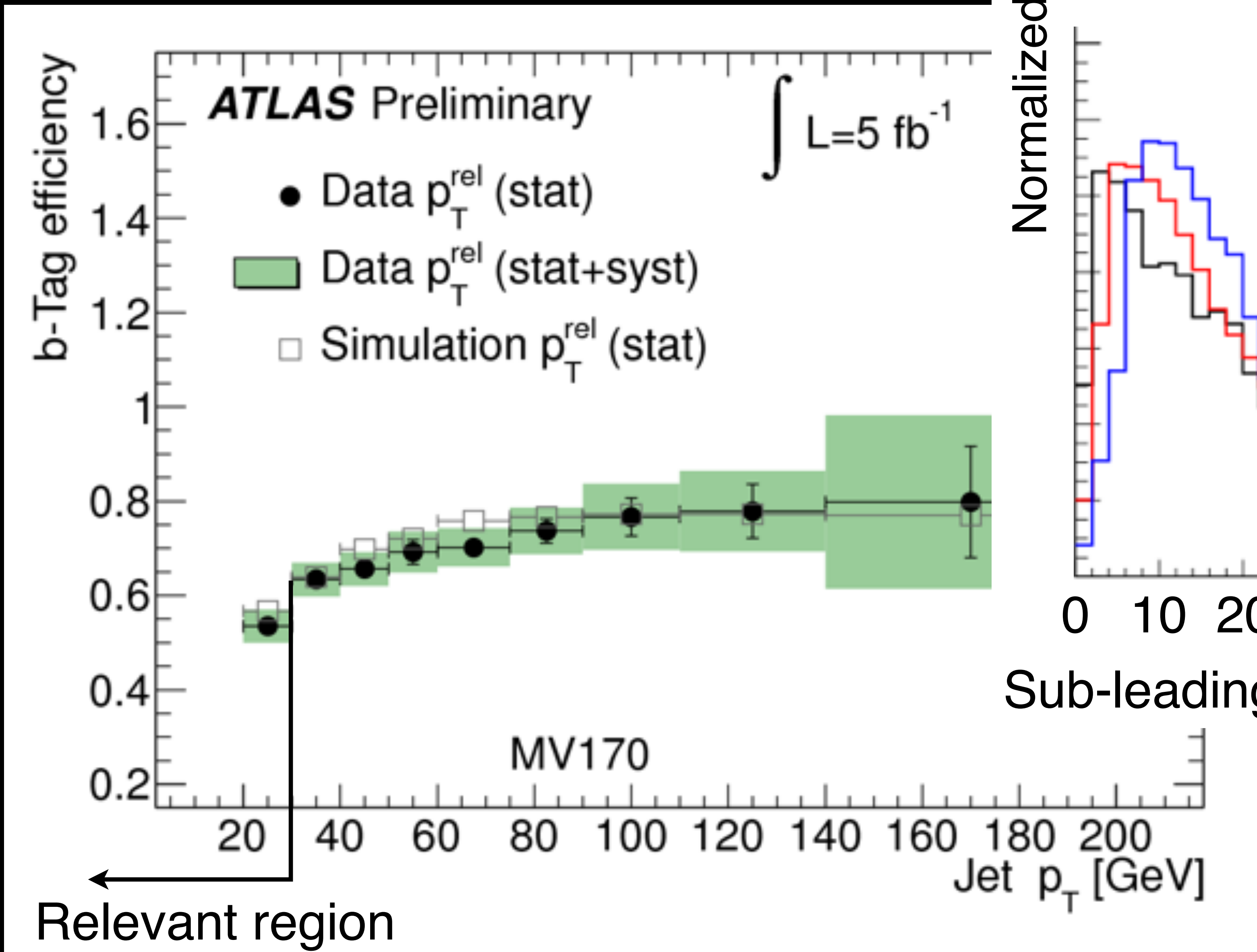

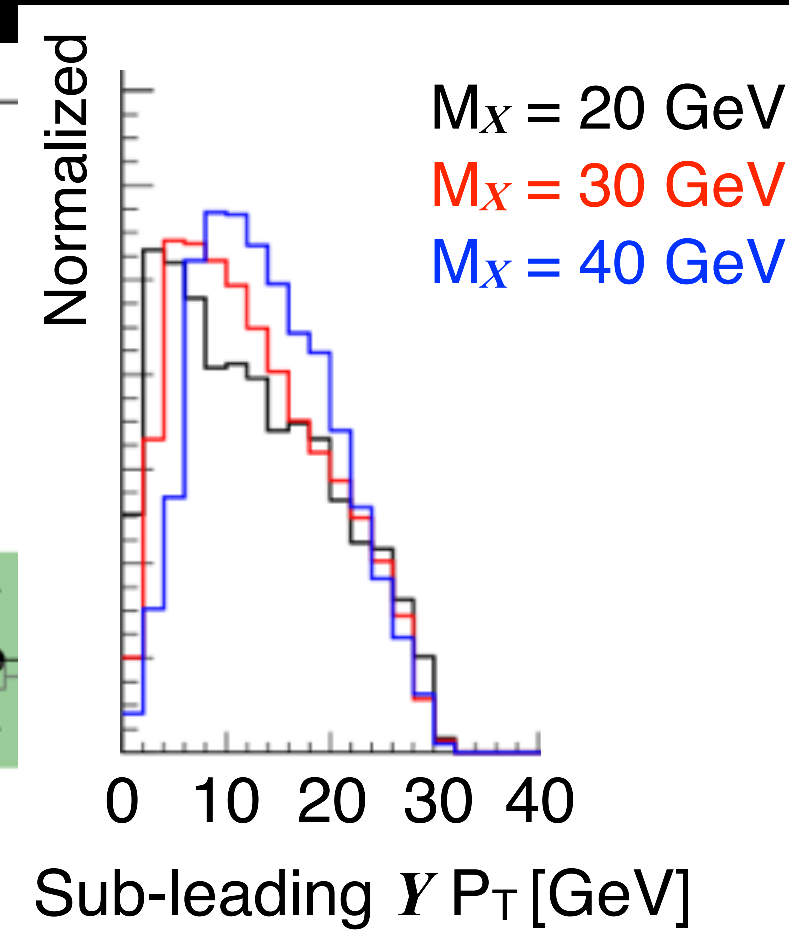

Low P_T b-tagging in SUSY

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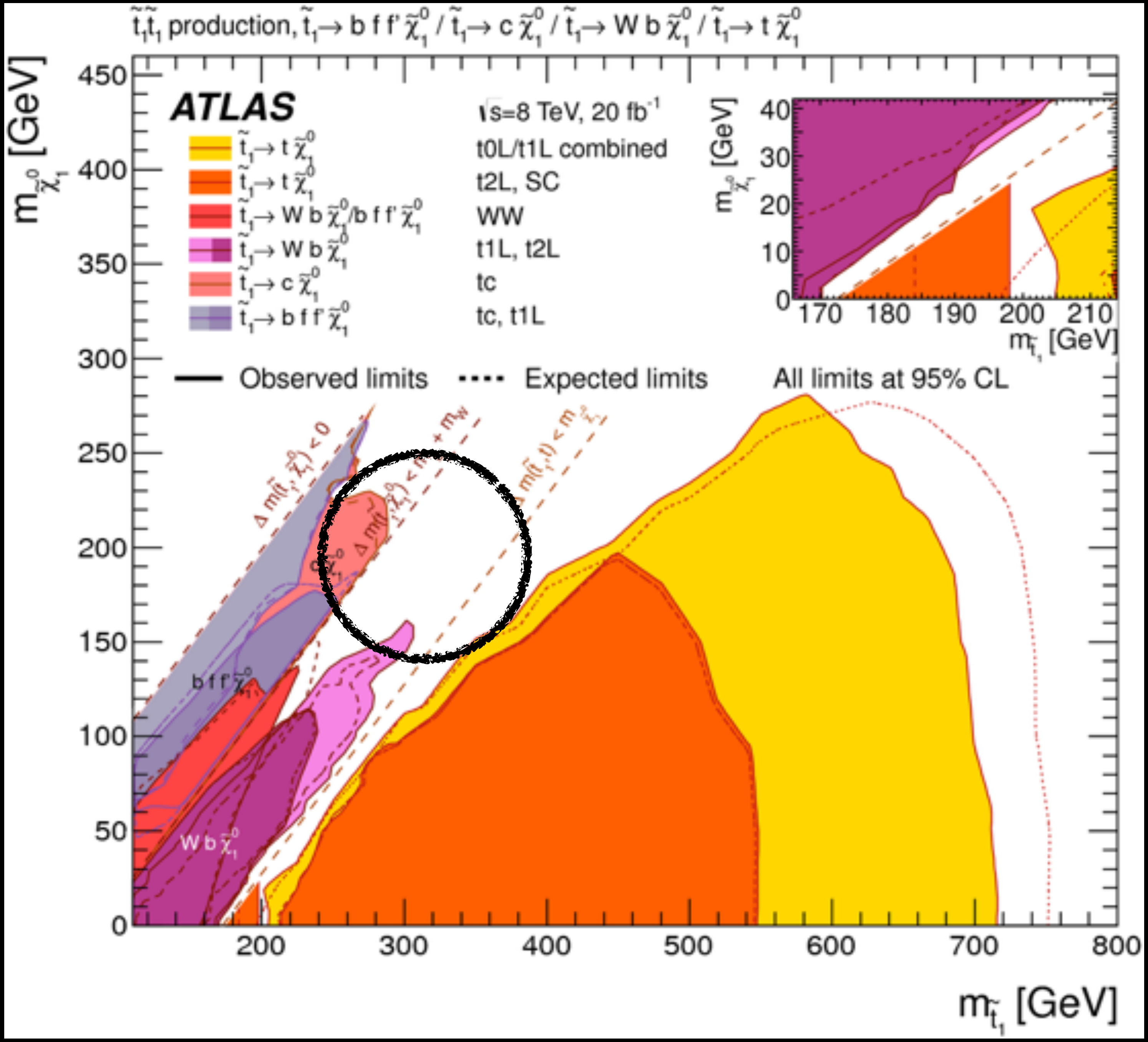

“Catch-all” analysis

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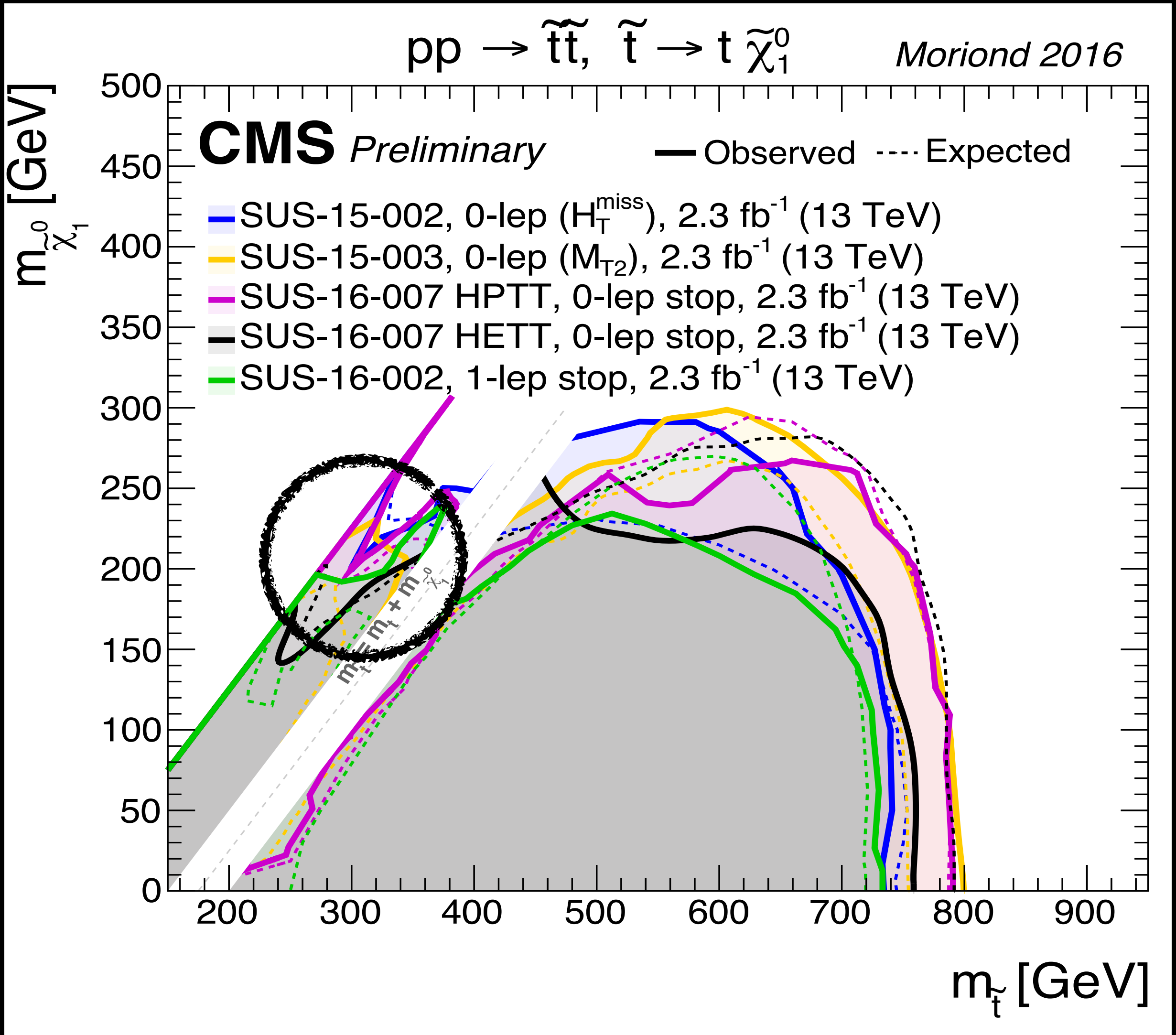
Difficult topology is targeted with all hadronic channel



Soft b-jets tagging will be helpful in this area

Summary

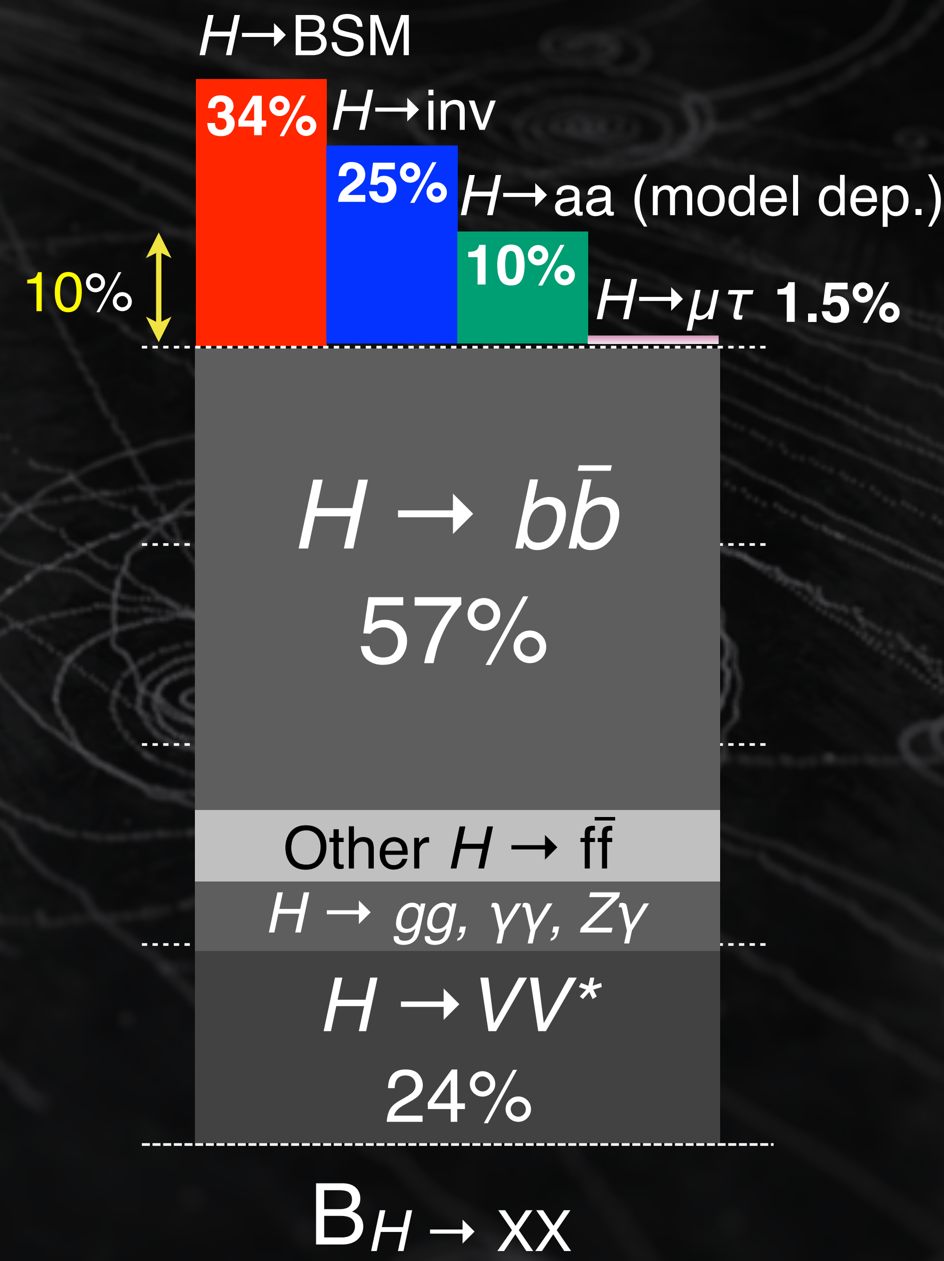
A new coupling of $\mathcal{O}(0.01)$ can easily add $B_{H\to \mathrm{BSM}} = \mathcal{O}(10\%)$

Indirect constraint is 34%

Various direct searches have put stringent constraints

Low P_T objects are very important

Stay tuned for more updates



Back Up

Large $B_{H\to BSM}$

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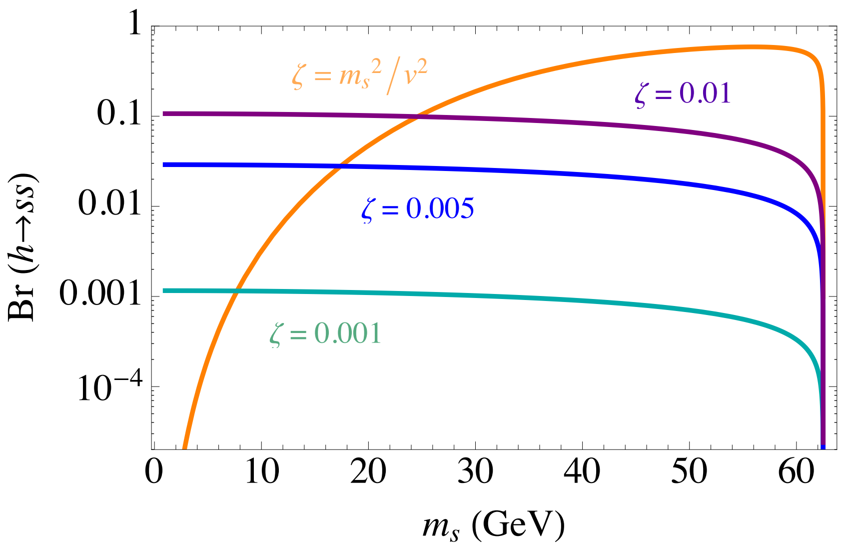


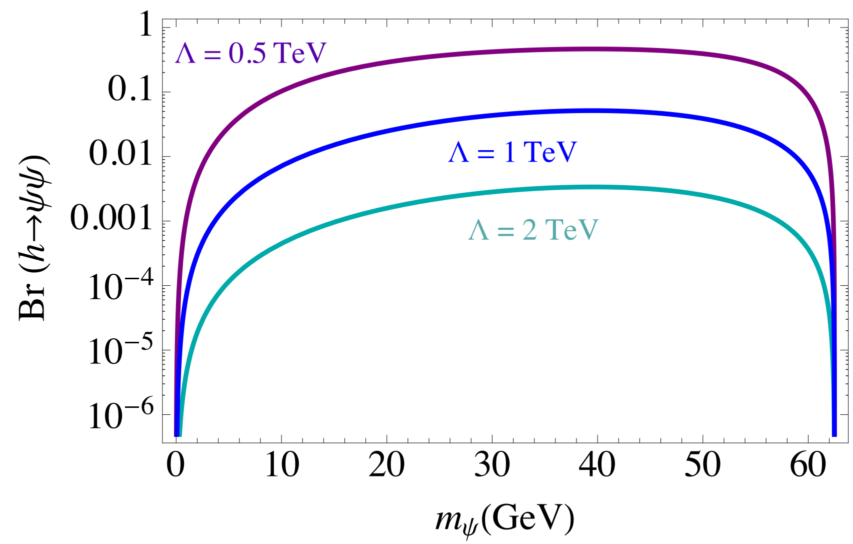


FIG. 1: Sensitivity of a 125 GeV Higgs to light weakly coupled particles. **Left:** Exotic Higgs branching fraction to a singlet scalar s versus the singlet's mass m_s, assuming the interaction Eq. (1) is solely responsible for the $h \to ss$ decay. If the interaction in Eq. (1) generates the s mass, the result is the orange curve; the other curves are for fixed and independent values of ζ and m_s. **Right:** Exotic Higgs branching fraction to a new fermion ψ interacting with the Higgs as in Eq. (2) to illustrate the sensitivity of exotic Higgs decay searches to high scales, here Λ. We take here $\mu = m_\psi$.

Large $B_{H\to \mathrm{BSM}}$

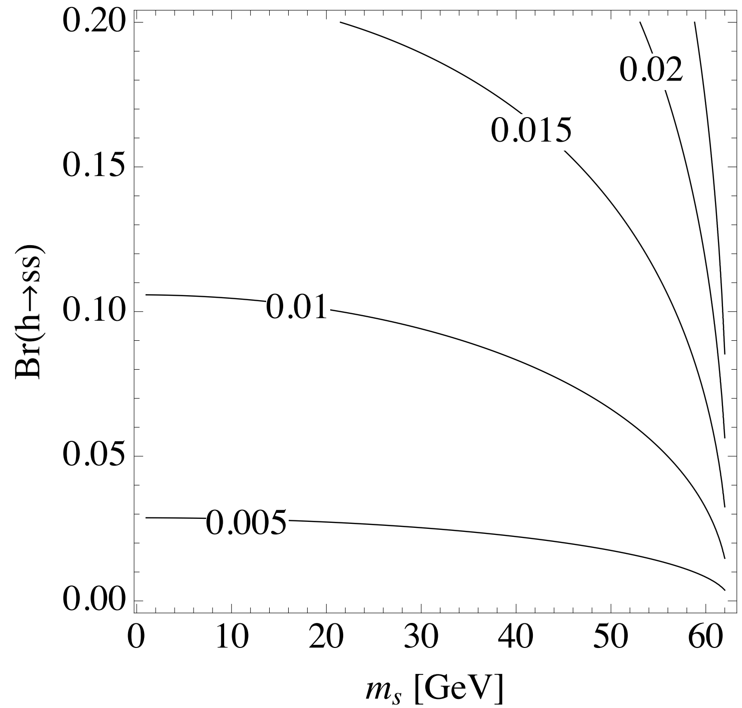


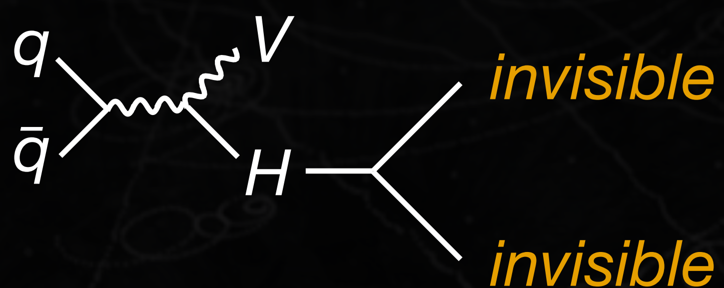
FIG. 3: Size of the cubic coupling μ_v in units of Higgs expectation value v to yield the indicated $h \to ss$ branching fraction as a function of singlet mass, as given by Eq. (8).

The partial width for exotic Higgs decays is given by

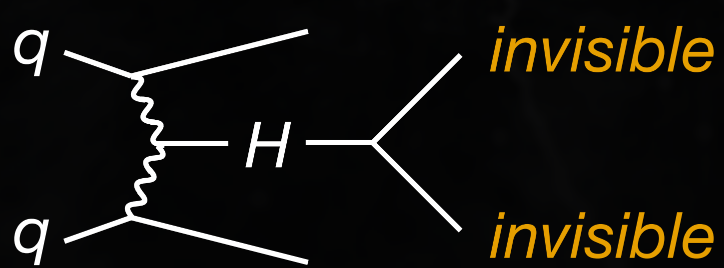
$$\Gamma(h \to ss) \;=\; \frac{1}{32\pi}\frac{\mu_v^2}{m_h}\sqrt{1-\frac{4m_s^2}{m_h^2}} \;\approx\; \left(\frac{\mu_v/v}{0.03}\right)^2 \Gamma(h \to \mathrm{SM})\,, \tag{8}$$

$H\rightarrow$*invisible decay*

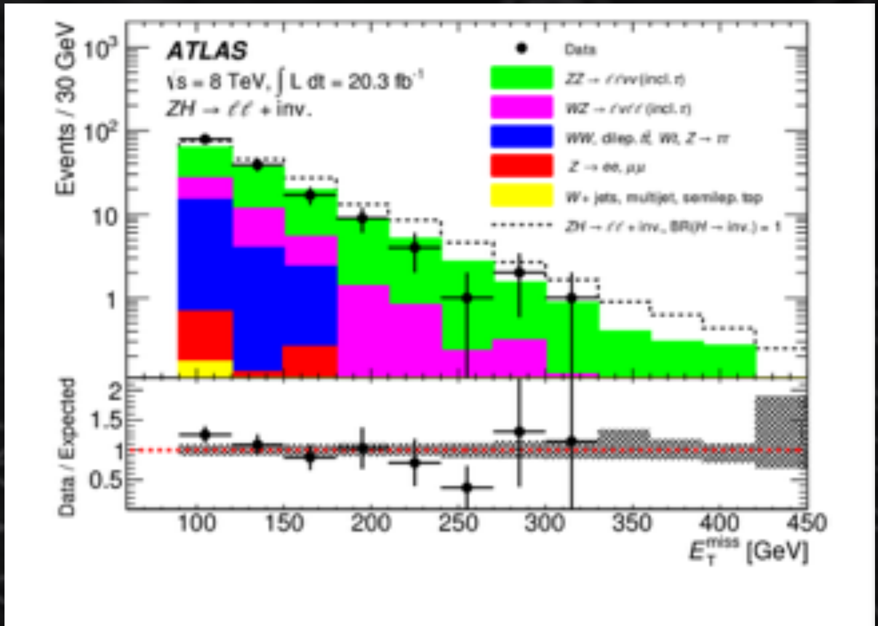
Missing energy spectrum in two production modes are studied

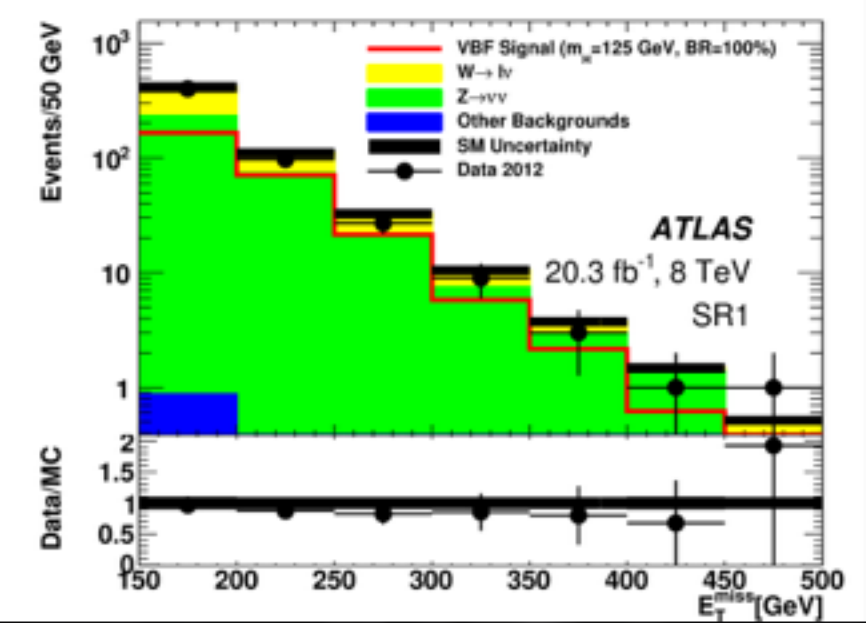


VH: $B_{H\rightarrow\mathrm{inv}} < 75\%$



VBF: $B_{H\rightarrow\mathrm{inv}} < 28\%$





VBF H→invisible

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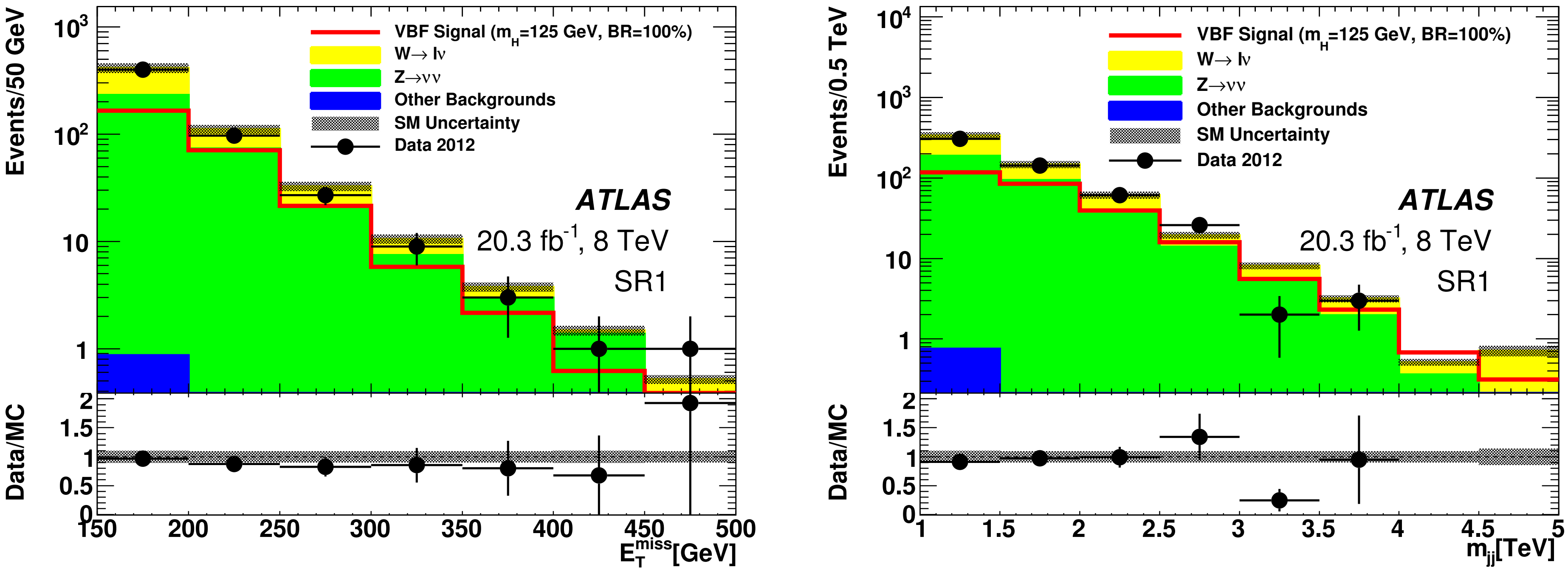
JHEP01 (2016) 172

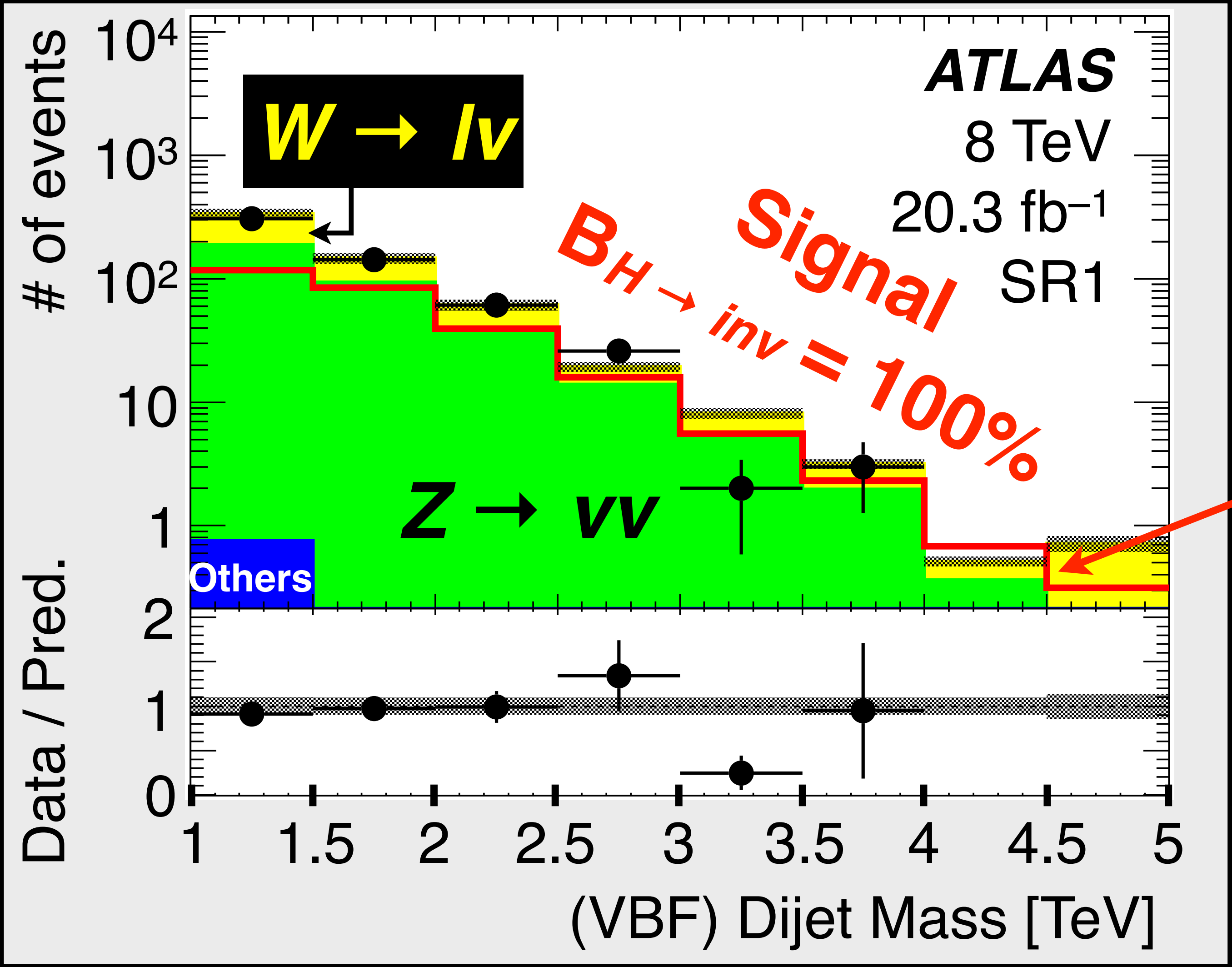


(a) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution.

(b) m_{jj} distribution.

Figure 6. Data and MC distributions after all the requirements in SR1 for (a) $E_{\mathrm{T}}^{\mathrm{miss}}$ and (b) the dijet invariant mass m_{jj}. The background histograms are normalized to the values in table 8. The VBF signal (red histogram) is normalized to the SM VBF Higgs boson production cross section with BF$(H \to \text{invisible}) = 100\%$.

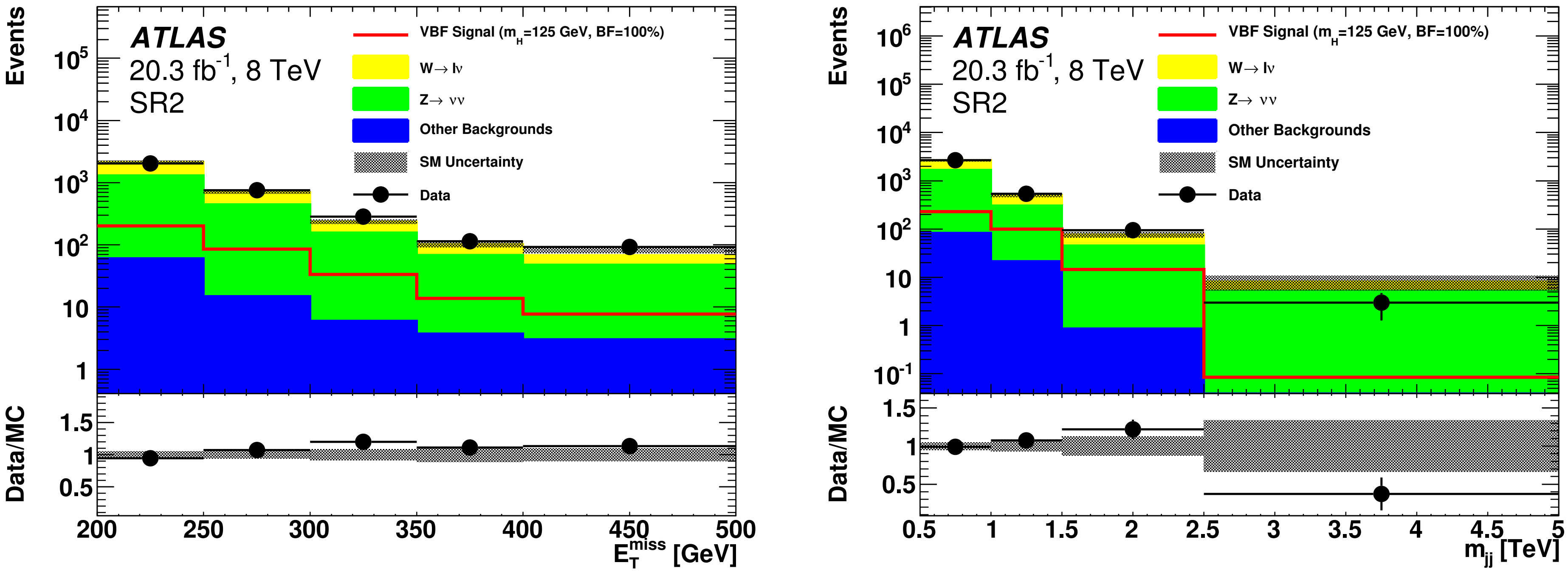
Invisible Higgs decay



Sig. and bkg. shape differ in VBF dijet distribution

VBF H→invisible

JHEP01 (2016) 172



(a) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution. **(b)** m_{jj} distribution.

Figure 7. Data and MC distributions after all the requirements in SR2 for (a) $E_{\mathrm{T}}^{\mathrm{miss}}$ and (b) the dijet invariant mass m_{jj}. The background histograms are normalized to the values in table 8. The VBF signal is normalized to the SM VBF Higgs boson production cross section with BF($H \to$ invisible) = 100%.

VBF H→invisible

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JHEP01 (2016) 172

Signal region Process	SR1	SR2a	SR2b
ggF signal	20± 15	58± 22	19± 8
VBF signal	286± 57	182± 19	105±15
$Z(\to \nu\nu)$+jets	339± 37	1580± 90	335±23
$W(\to \ell\nu)$+jets	235± 42	1010± 50	225±16
Multijet	2± 2	20± 20	4± 4
Other backgrounds	1±0.4	64± 9	19± 6
Total background	577± 62	2680±130	583±34
Data	539	2654	636

Table 8. Estimates of the expected yields and their total uncertainties for SR1 and SR2 in 20.3 fb^{-1} of 2012 data. The $Z(\to \nu\nu)$+jets, $W(\to \ell\nu)$+jets, and multijet background estimates are data-driven. The other backgrounds and the ggF and VBF signals are determined from MC simulation. The expected signal yields are shown for $m_H = 125$ GeV and are normalized to BF($H \to$ invisible) = 100%. The W+jets and Z+jets statistical uncertainties result from the number of MC events in each signal and corresponding control region, and from the number of data events in the control region.

Results	Expected	$+1\sigma$	-1σ	$+2\sigma$	-2σ	Observed
SR1	0.35	0.49	0.25	0.67	0.19	0.30
SR2	0.60	0.85	0.43	1.18	0.32	0.83
Combined Results	0.31	0.44	0.23	0.60	0.17	0.28

Table 9. Summary of limits on BF($H \to$ invisible) for 20.3 fb^{-1} of 8 TeV data in the individual search regions and their combination, assuming the SM cross section for $m_H = 125$ GeV.

VBF H→Invisible

Model is from Phys. Lett. B 709 (2012) 65

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JHEP01 (2016) 172

$$\Gamma^{\text{inv}}_{H\to SS} = \frac{\lambda^2_{HSS} v^2 \beta_S}{64\pi m_H}, \tag{8.2}$$

$$\Gamma^{\text{inv}}_{H\to VV} = \frac{\lambda^2_{HVV} v^2 m_H^3 \beta_V}{256\pi m_V^4}\left(1 - 4\frac{m_V^2}{m_H^2} + 12\frac{m_V^4}{m_H^4}\right), \tag{8.3}$$

$$\Gamma^{\text{inv}}_{H\to ff} = \frac{\lambda^2_{Hff} v^2 m_H \beta_f^3}{32\pi\Lambda^2}, \tag{8.4}$$

for the scalar, vector and Majorana-fermion dark matter, respectively. The parameters λ_{HSS}, λ_{HVV}, λ_{Hff}/Λ are the corresponding coupling constants, v is the vacuum expectation value of the SM Higgs doublet, $\beta_\chi = \sqrt{1 - 4m_\chi^2/m_H^2}$ ($\chi = S,\ V,\ f$), and m_χ is the WIMP mass. In the Higgs-portal model, the Higgs boson is assumed to be the only mediator in the WIMP-nucleon scattering, and the WIMP-nucleon cross section can be written in a general spin-independent form. Inserting the couplings and masses for each spin scenario gives:

$$\sigma^{\text{SI}}_{SN} = \frac{\lambda^2_{HSS}}{16\pi m_H^4}\frac{m_N^4 f_N^2}{(m_S + m_N)^2}, \tag{8.5}$$

Vacuum expectation value	$v/\sqrt{2}$	174 GeV
Higgs boson mass	m_H	125 GeV
Higgs boson width	Γ_H	4.07 MeV
Nucleon mass	m_N	939 MeV
Higgs-nucleon coupling form factor	f_N	$0.33^{+0.30}_{-0.07}$

Table 11. Parameters in the Higgs-portal dark-matter model.

$$\sigma^{\text{SI}}_{VN} = \frac{\lambda^2_{HVV}}{16\pi m_H^4}\frac{m_N^4 f_N^2}{(m_V + m_N)^2}, \tag{8.6}$$

$$\sigma^{\text{SI}}_{fN} = \frac{\lambda^2_{Hff}}{4\pi\Lambda^2 m_H^4}\frac{m_N^4 m_f^2 f_N^2}{(m_f + m_N)^2}, \tag{8.7}$$

where m_N is the nucleon mass, and f_N is the form factor associated to the Higgs boson-nucleon coupling and computed using lattice QCD [10]. The numerical values for all the parameters in the equations above are given in table 11.

ZH→Invisible
↓
ll

PRL 112, 201802 (2014)

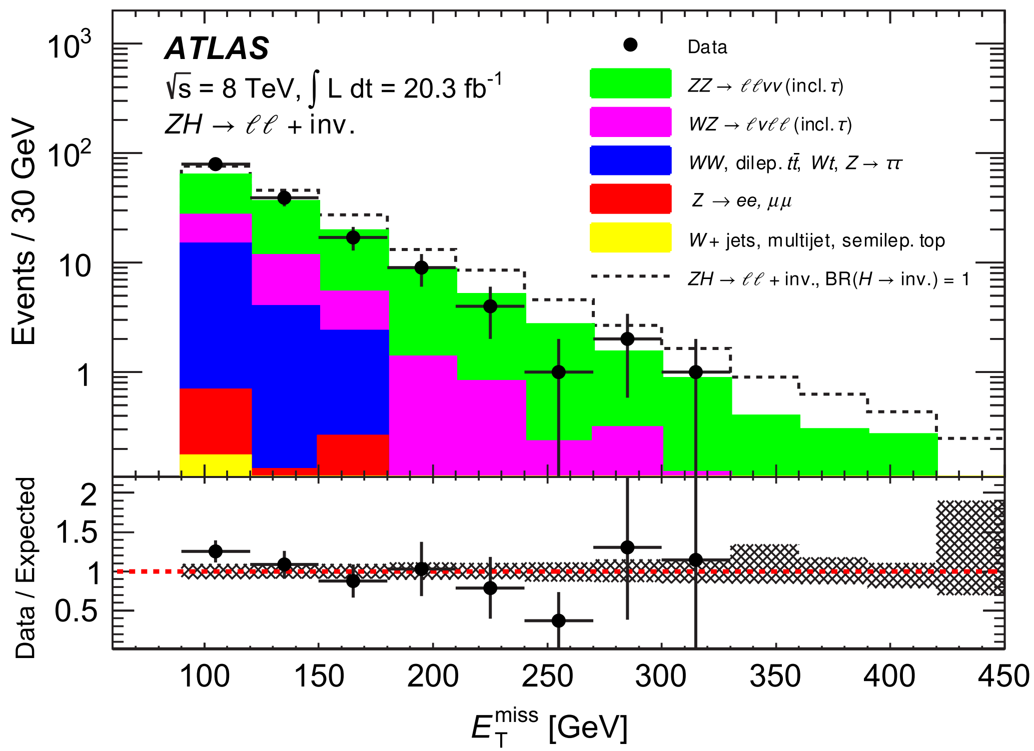

FIG. 2 (color online). Distribution of E_T^{miss} after the full selection in the 8 TeV data (dots). The filled stacked histograms represent the background expectations. The signal expectation for a Higgs boson with $m_H = 125.5$ GeV, a SM ZH production rate and $\mathrm{BR}(H \to \mathrm{inv.}) = 1$ is stacked on top of the background expectations. The inset at the bottom of the figure shows the ratio of the data to the combined background expectations. The hashed area shows the systematic uncertainty on the combined background expectation.

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ZH→Invisible
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PRL 112, 201802 (2014)

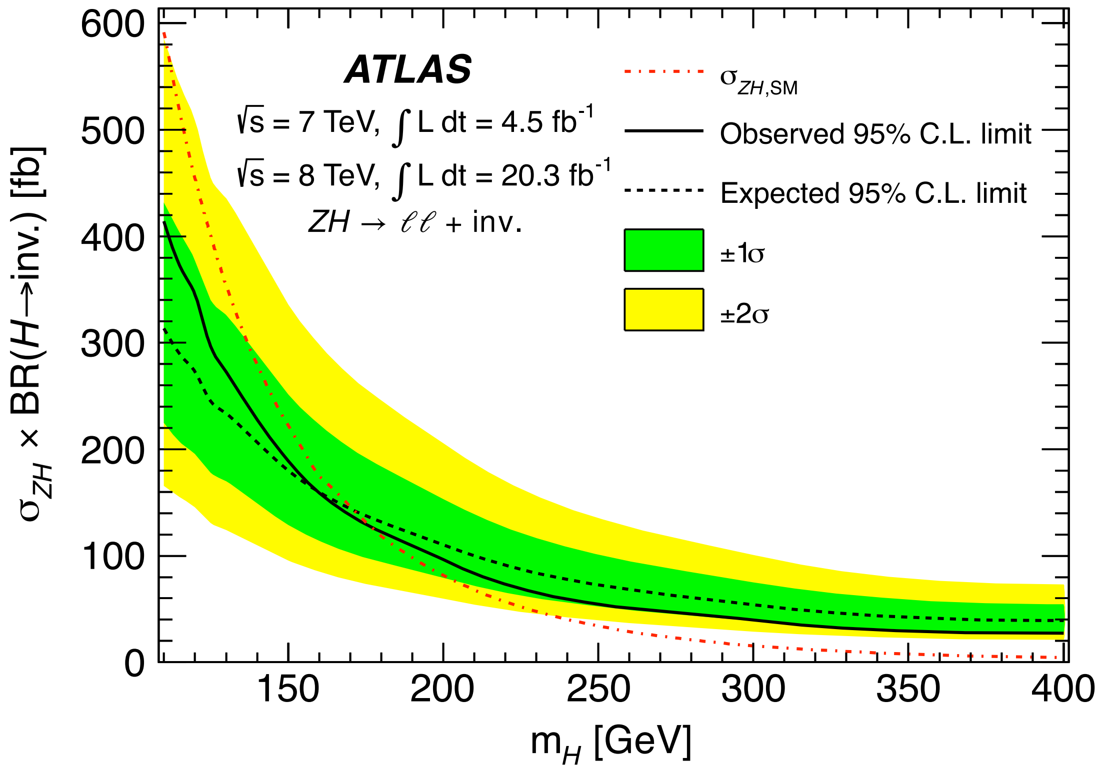

FIG. 3 (color online). Upper limits on $\sigma_{ZH} \times \mathrm{BR}(H \to \mathrm{inv.})$ at 95% C.L. for a Higgs boson with $110 < m_H < 400$ GeV, for the combined 7 and 8 TeV data. The full and dashed lines show the observed and expected limits, respectively.

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PRL 112, 201802 (2014)

TABLE I. Number of events observed in data and expected from the signal and from each background source for the 7 and 8 TeV data-taking periods. Uncertainties on the signal and background expectations are presented with statistical uncertainties first and systematic uncertainties second.

Data period	2011 (7 TeV)	2012 (8 TeV)
$ZZ \to \ell\ell\nu\nu$	$20.0 \pm 0.7 \pm 1.6$	$91 \pm 1 \pm 7$
$WZ \to \ell\nu\ell\ell$	$4.8 \pm 0.3 \pm 0.5$	$26 \pm 1 \pm 3$
Dileptonic $t\bar{t}$, Wt, WW, $Z \to \tau\tau$	$0.5 \pm 0.4 \pm 0.1$	$20 \pm 3 \pm 5$
$Z \to ee$, $Z \to \mu\mu$	$0.13 \pm 0.12 \pm 0.07$	$0.9 \pm 0.3 \pm 0.5$
$W +$ jets, multijet, semileptonic top	$0.020 \pm 0.005 \pm 0.008$	$0.29 \pm 0.02 \pm 0.06$
Total background	$25.4 \pm 0.8 \pm 1.7$	$138 \pm 4 \pm 9$
Signal ($m_H = 125.5$ GeV, $\sigma_{ZH,\mathrm{SM}}$, $\mathrm{BR}(H \to \mathrm{inv.}) = 1$)	$8.9 \pm 0.1 \pm 0.5$	$44 \pm 1 \pm 3$
Observed	28	152

VH→Invisible EPJ C 75:337 (2015)

↓

jj

Table 4 Predicted and observed numbers of events for the six categories in the signal region. The yields and uncertainties of the backgrounds are shown after the profile likelihood fit to the data. In this fit all categories share the same signal-strength parameter. The quoted uncertainties combine the statistical and systematic contributions. These can be smaller for the total background than for individual components due to anti-correlations. The yields and uncertainties of the signals are shown as expected before the fit for $m_H = 125$ GeV and BR($H \to$ inv.) = 100 %. Signal contributions from VBF and $t\bar{t}H$ production are estimated to be negligible

b-tag category	0-tag	1-tag	2-tag
Process		2-jet events	
Background			
Z+jets	24400 ± 1100	1960 ± 200	164 ± 13
W+jets	20900 ± 770	1160 ± 130	47 ± 7
$t\bar{t}$	403 ± 74	343 ± 65	57 ± 10
Single top	149 ± 16	107 ± 14	11 ± 2
Diboson	1670 ± 180	227 ± 25	64 ± 7
SM VH(bb)	1.5 ± 0.5	6 ± 2	3 ± 1
Multijet	26 ± 43	8 ± 7	0.7 ± 0.9
Total	47560 ± 490	3804 ± 64	347 ± 15
Signal			
$gg \to H$	403 ± 95	25 ± 6	2.1 ± 0.5
$W(\to jj)H$	425 ± 45	44 ± 6	0.6 ± 0.1
$Z(\to jj)H$	217 ± 19	42 ± 4	26 ± 2
Data	47404	3831	344
		3-jet events	
Background			
Z+jets	9610 ± 580	795 ± 93	53 ± 7
W+jets	7940 ± 510	479 ± 70	21 ± 4
$t\bar{t}$	443 ± 53	437 ± 53	63 ± 7
Single top	97 ± 14	66 ± 9	6.4 ± 0.9
Diboson	473 ± 54	55 ± 6	13 ± 2
SM VH(bb)	0.8 ± 0.3	2.6 ± 0.9	1.4 ± 0.5
Multijet	22 ± 29	4 ± 4	0.6 ± 0.6
Total	18580 ± 200	1840 ± 40	158 ± 7
Signal			
$gg \to H$	224 ± 55	15 ± 4	1.2 ± 0.5
$W(\to jj)H$	110 ± 16	11 ± 1	0.14 ± 0.03
$Z(\to jj)H$	65 ± 7	12 ± 1	6.1 ± 0.7
Data	18442	1842	159

VH→Invisible
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jj

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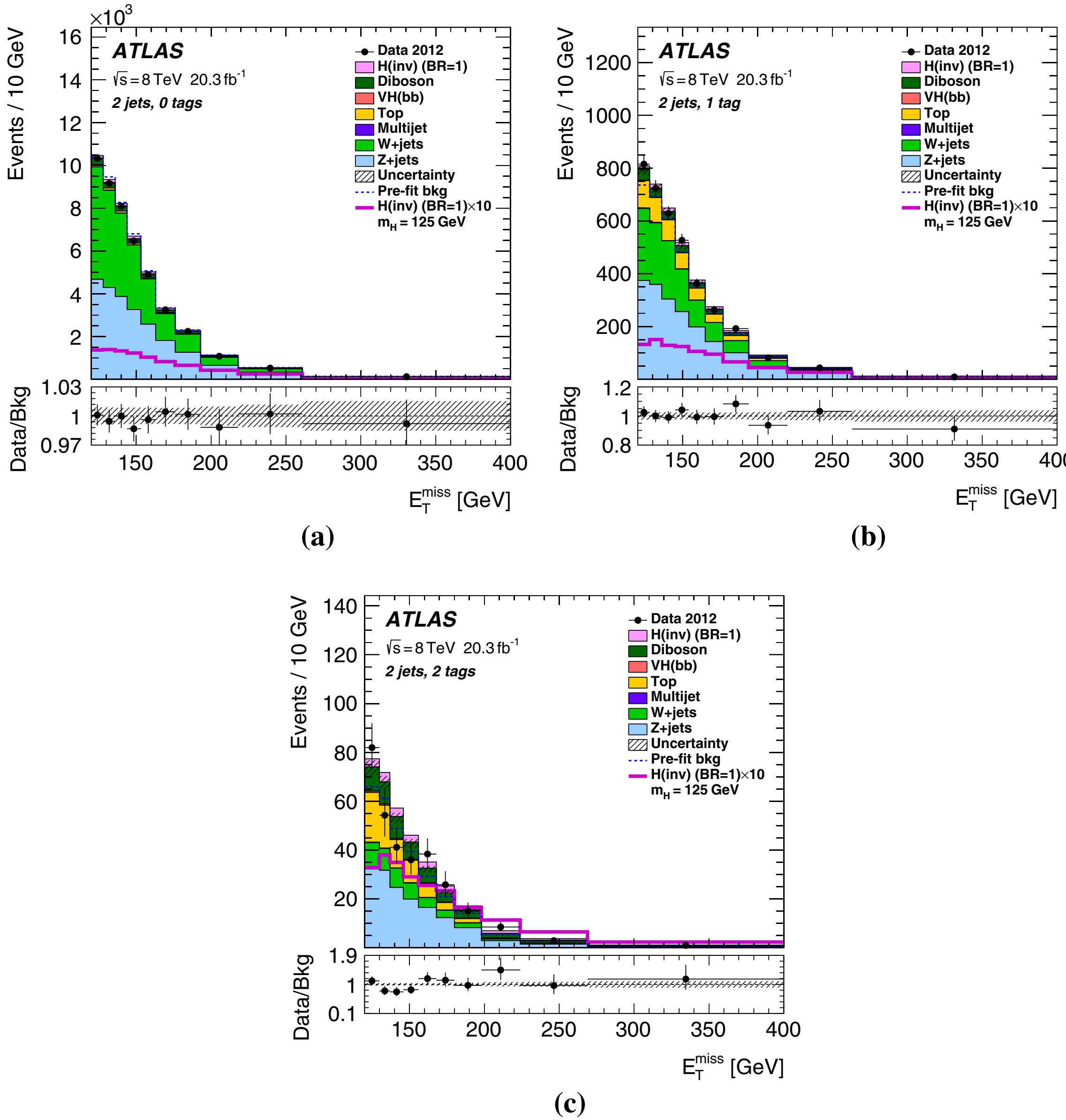

Fig. 1 The missing transverse momentum (E_T^{miss}) distributions of the 2-jet events in the signal region for the **a** 0-b-tag, **b** 1-b-tag and **c** 2-b-tag categories. The data are compared with the background model after the likelihood fit. The *bottom plots* show the ratio of the data to the total background. The signal expectation for $m_H = 125$ GeV and BR($H \rightarrow$ inv.) $= 100\,\%$ is shown on *top of the background* and additionally as an *overlay line*, scaled by the factor indicated in the *legend*. The total background before the fit is shown as a *dashed line*. The *hatched bands* represent the total uncertainty on the background

VH→Invisible EPJ C 75:337 (2015)

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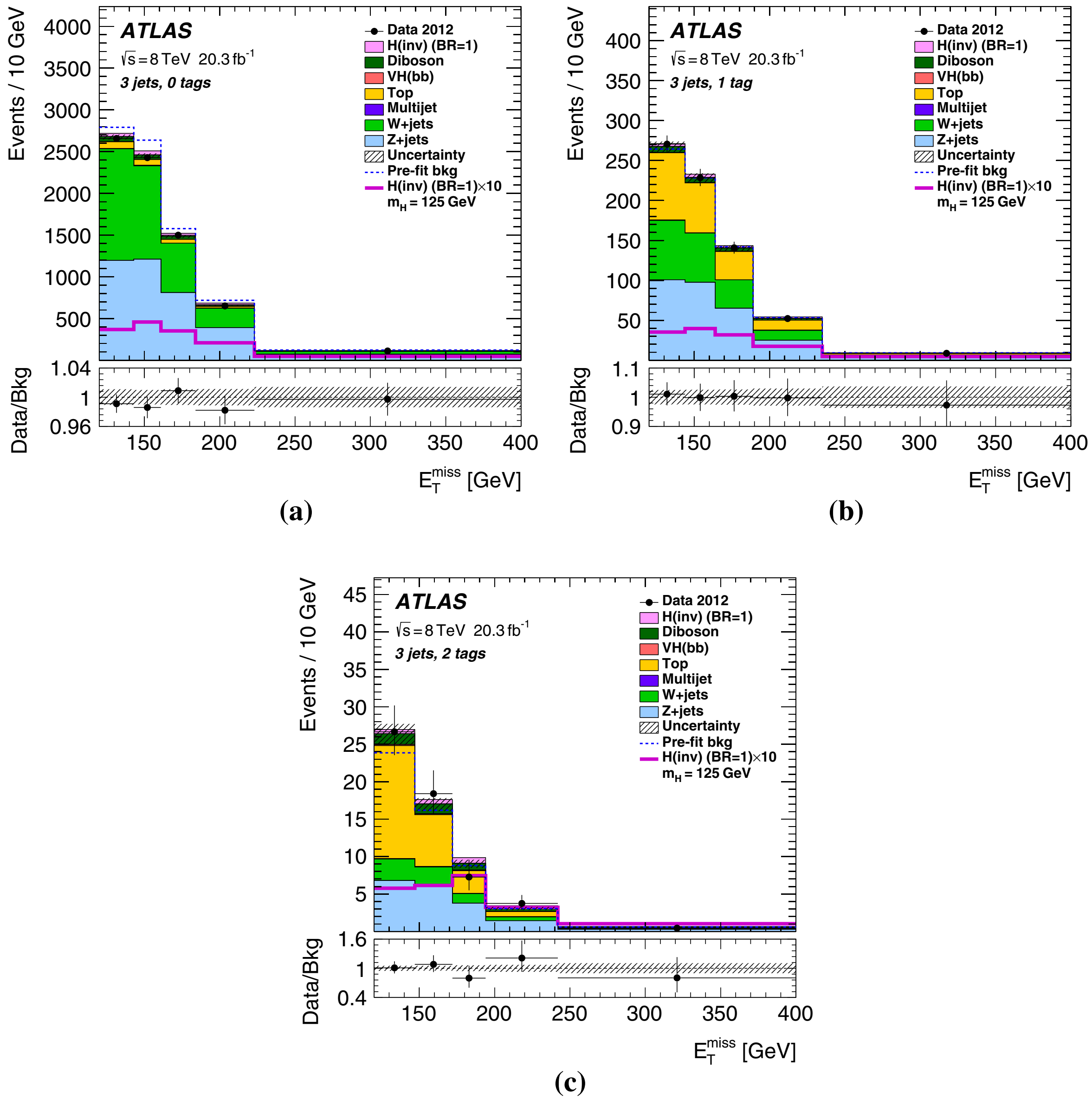

Fig. 2 The missing transverse momentum (E_T^{miss}) distributions of the 3-jet events in the signal region for the **a** 0-b-tag, **b** 1-b-tag and **c** 2-b-tag categories. The data are compared with the background model after the likelihood fit. The *bottom plots* show the ratio of the data to the total background. The signal expectation for $m_H = 125$ GeV is shown on *top of the background* and additionally as an *overlay line*, scaled by the factor indicated in the *legend*. The total background before the fit is shown as a *dashed line*. The *hatched bands* represent the total uncertainty on the background

Dark Matter interpretation

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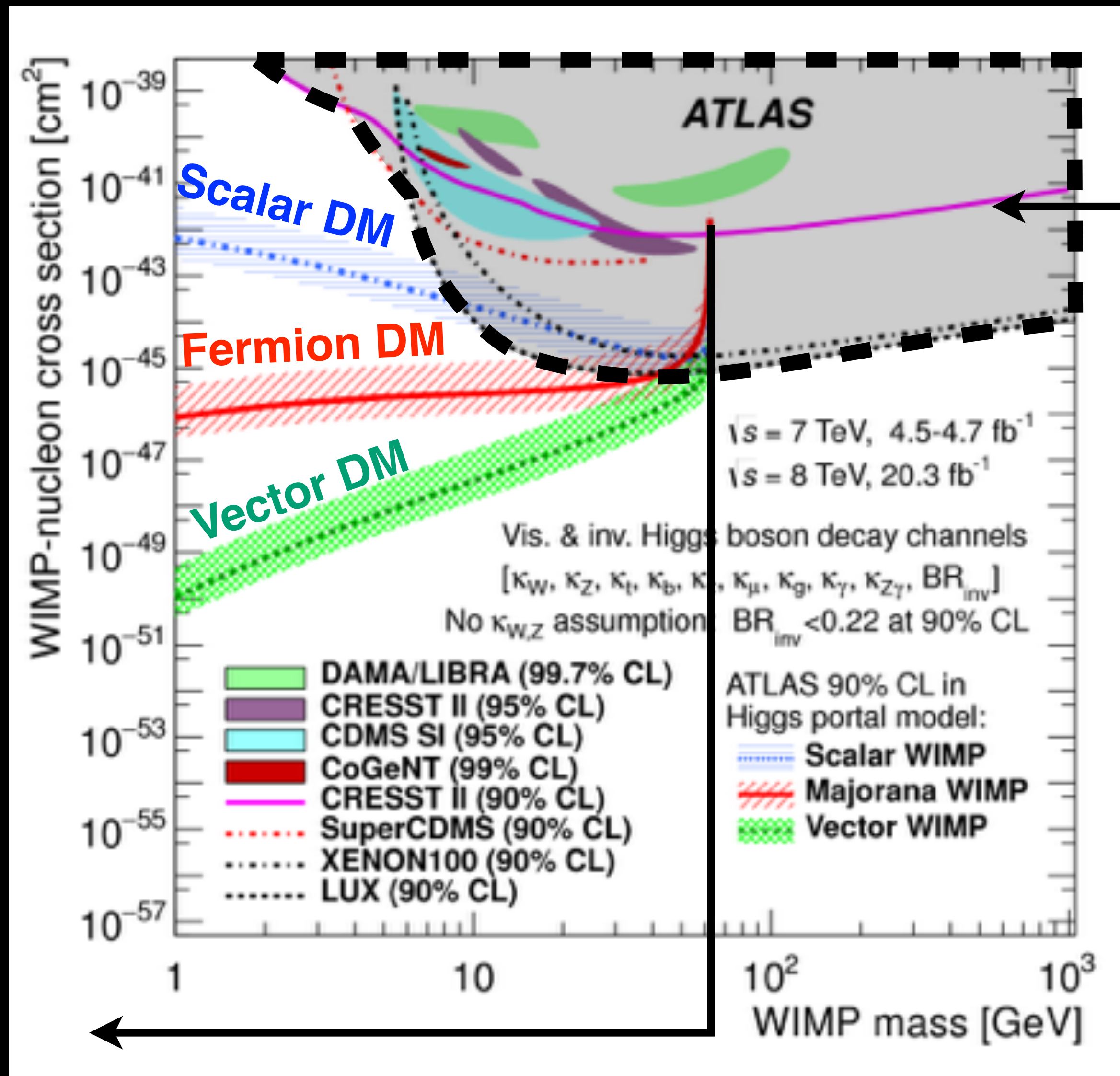
Recasting $B_{H\rightarrow inv}$ limit on DM model



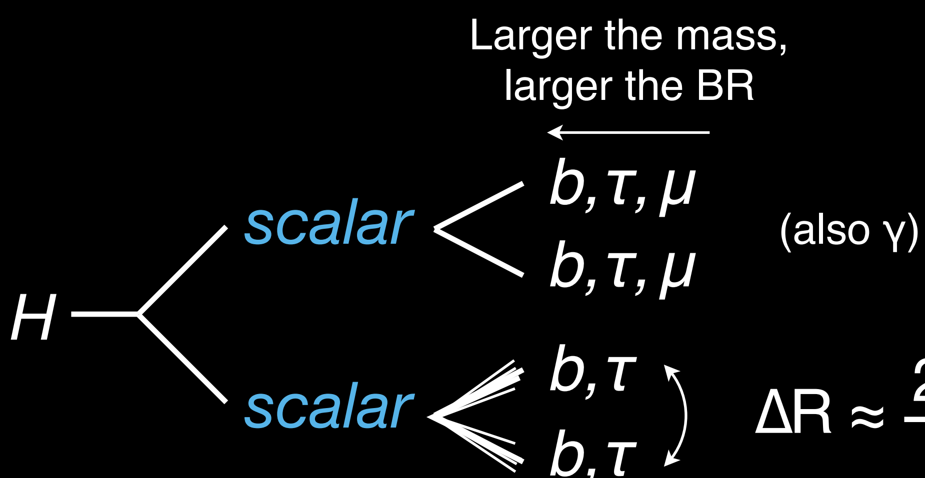
Direct detection Expt. limits

LHC limit dominates for $m_{WIMP} < m_H/2$

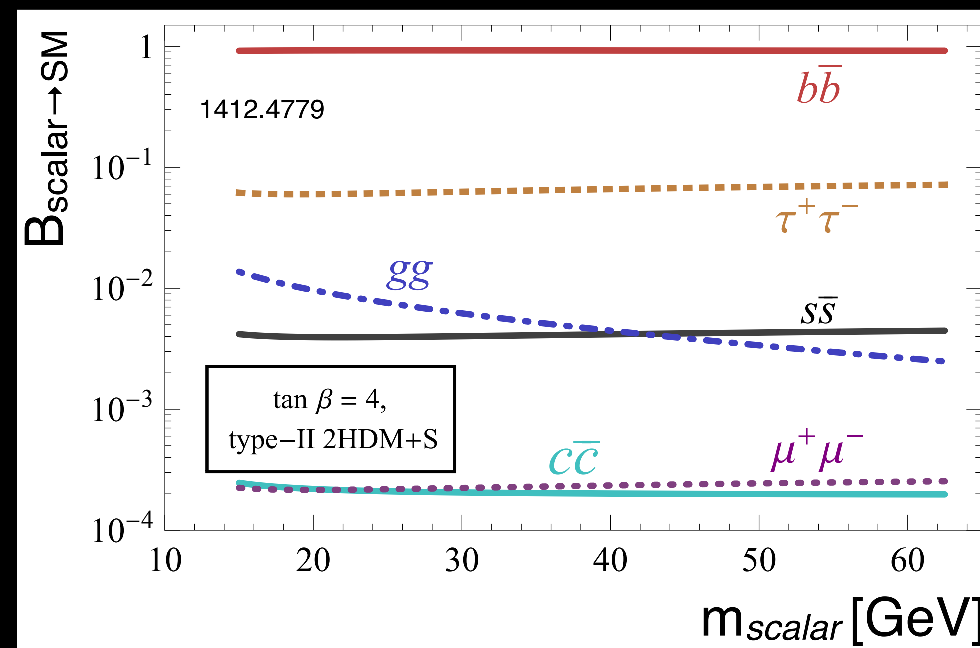
LHC limit complimentary to direct detection limits

H→aa searches

Higgs decaying to a light "hidden" sector is well motivated



$$\Delta R \approx \frac{2m}{P_T}$$



Low P_T merged jet tagging is an interesting area of research

Kinematics of $X \to YY$

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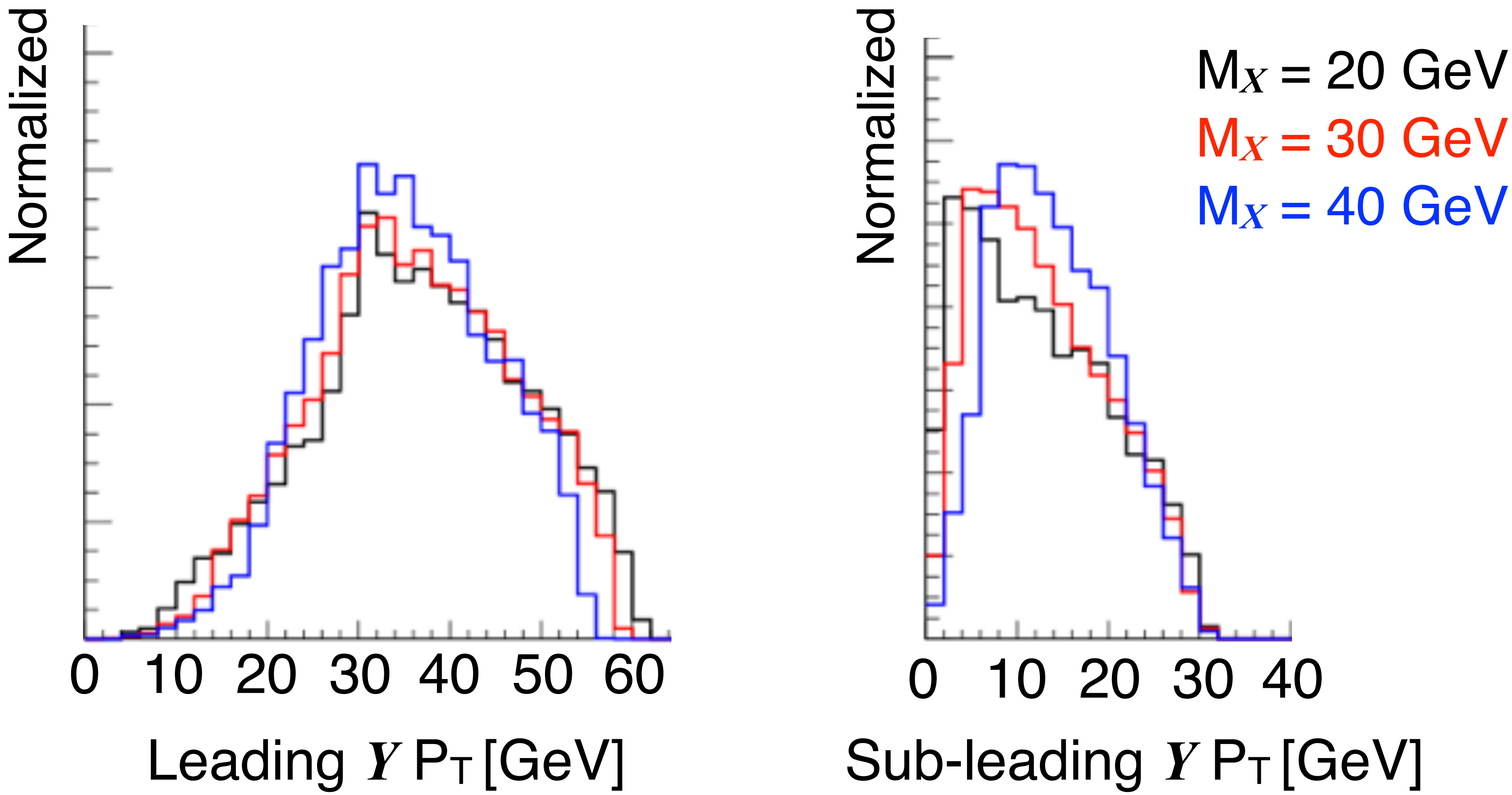
$H_{125} \to XX \to YYYY \longleftarrow$ Final states carry 125 GeV/4 ≈ O(30) GeV



Interesting experimental challenges of low P_T

Not-so-boosted merged jets

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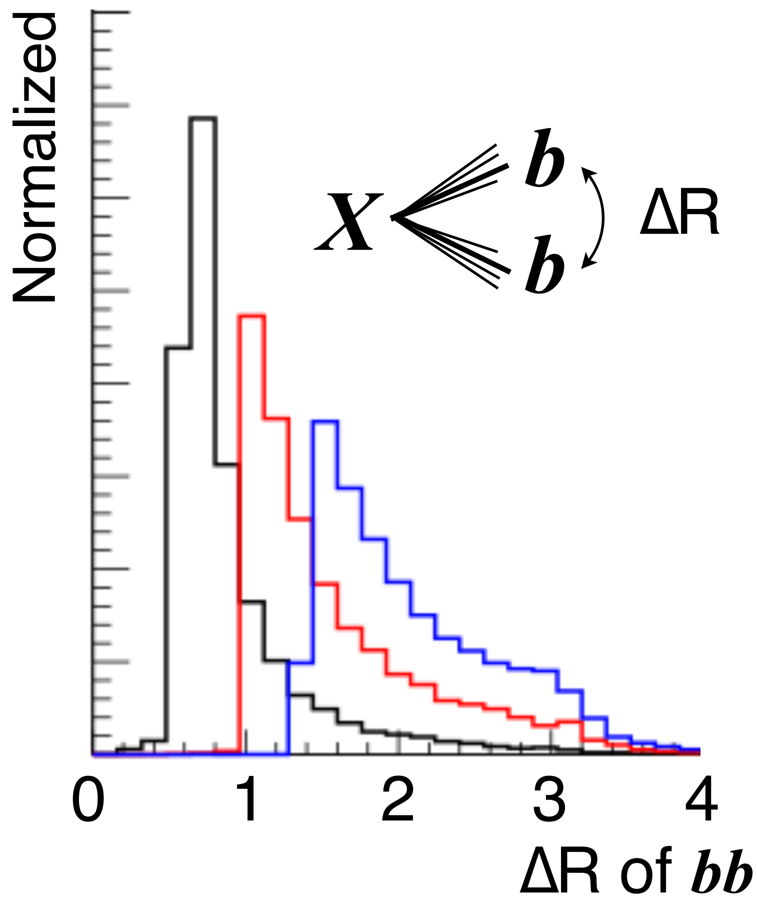
$H_{125} \rightarrow XX$ ⟵ X's carry 125 GeV/2 ≈ O(60) GeV



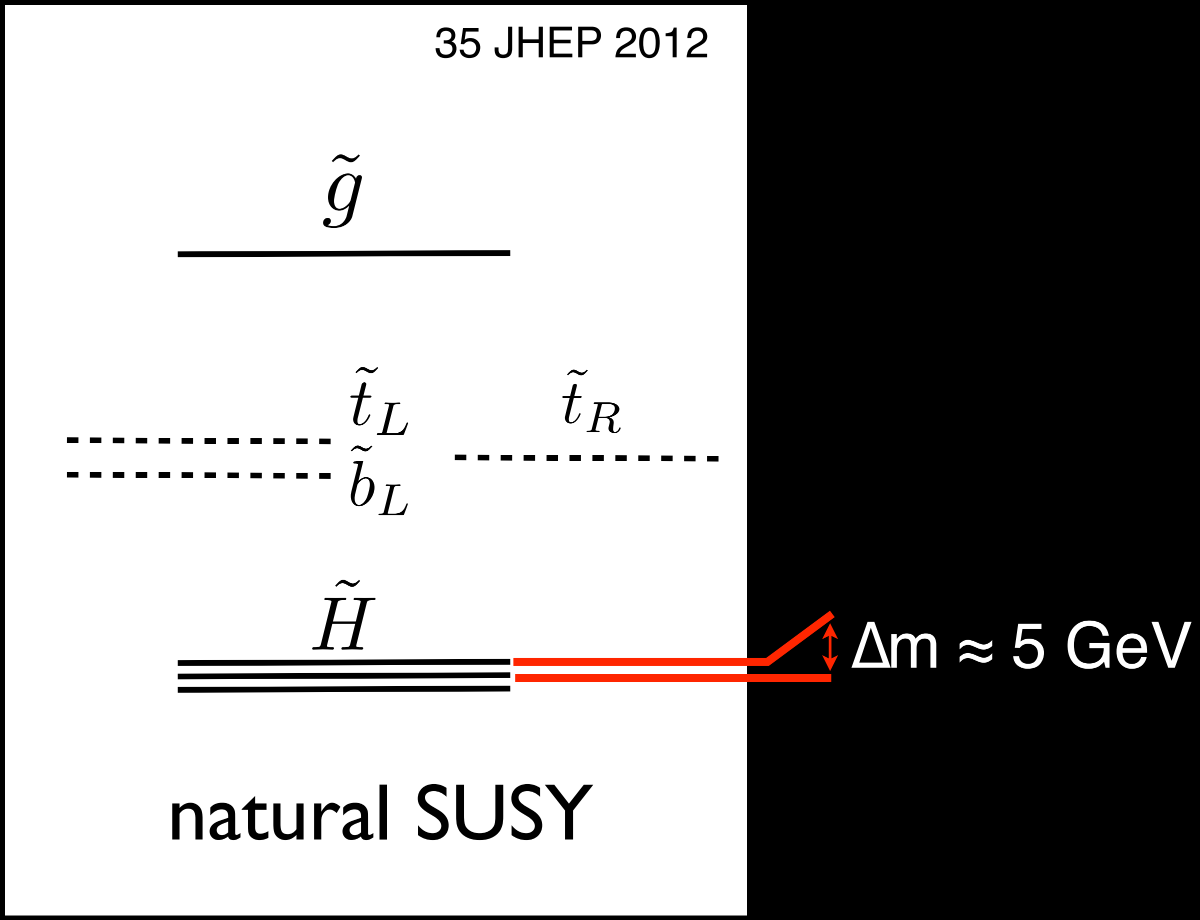
Rule-of-thumb for opening angle

$$\Delta R \approx \frac{2M}{P_T}$$

If M_X = 24 GeV, ΔR ~ 0.8

New area to develop a low P_T merged jet tagger + b-tagging

Natural SUSY



Fine mass splitting predicted for natural SUSY
⇒ Soft lepton important

SM + S : $B_{H\to ss}$

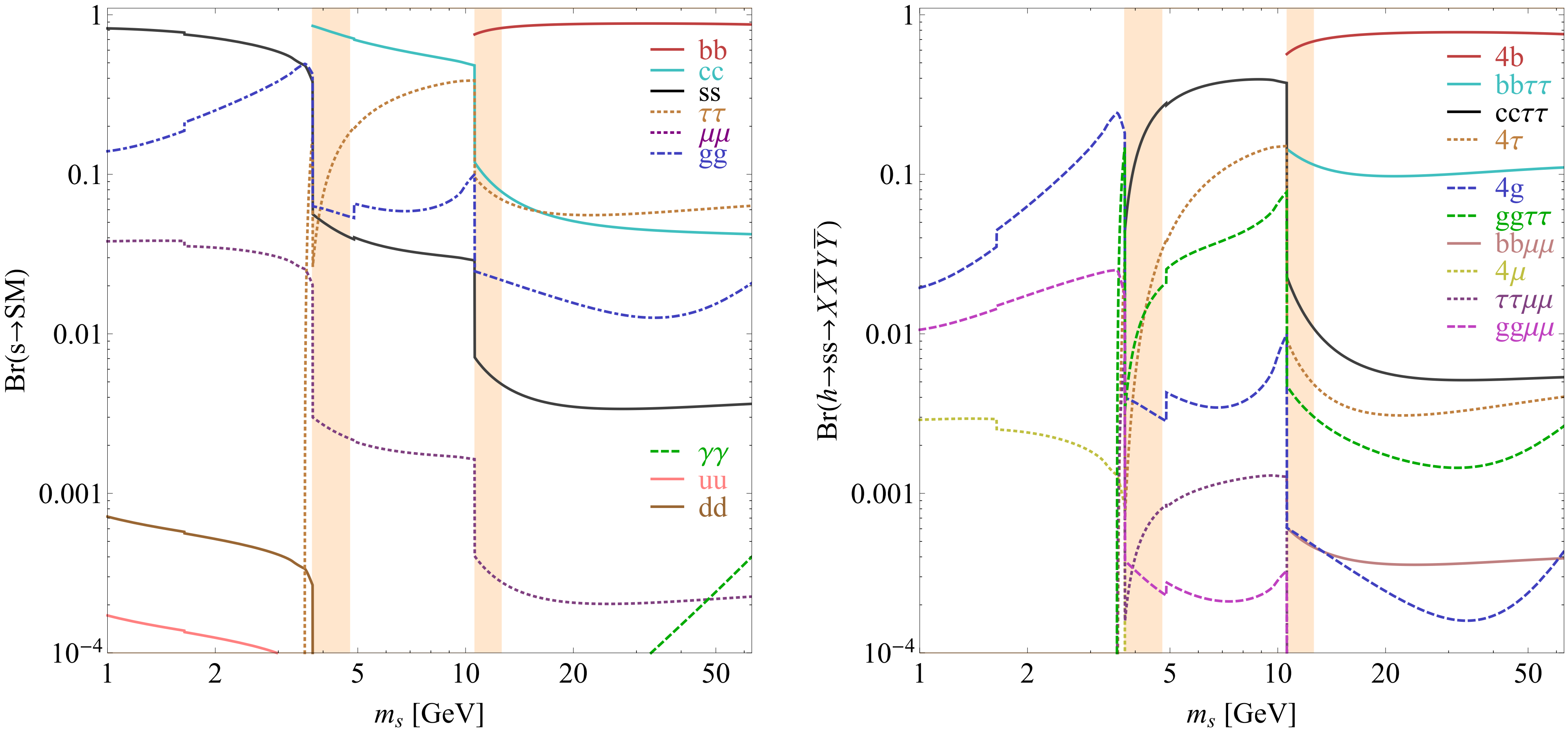


FIG. 4: **Left**: Branching ratios of a CP-even scalar singlet to SM particles, as function of m_s. **Right**: Branching ratios of exotic decays of the 125 GeV Higgs boson as function of m_s, in the *SM + Scalar* model described in the text, scaled to $\mathrm{Br}(h \to ss) = 1$. Hadronization effects likely invalidate our simple calculation in the shaded regions.

2HDM + S : $B_{H\to aa}$

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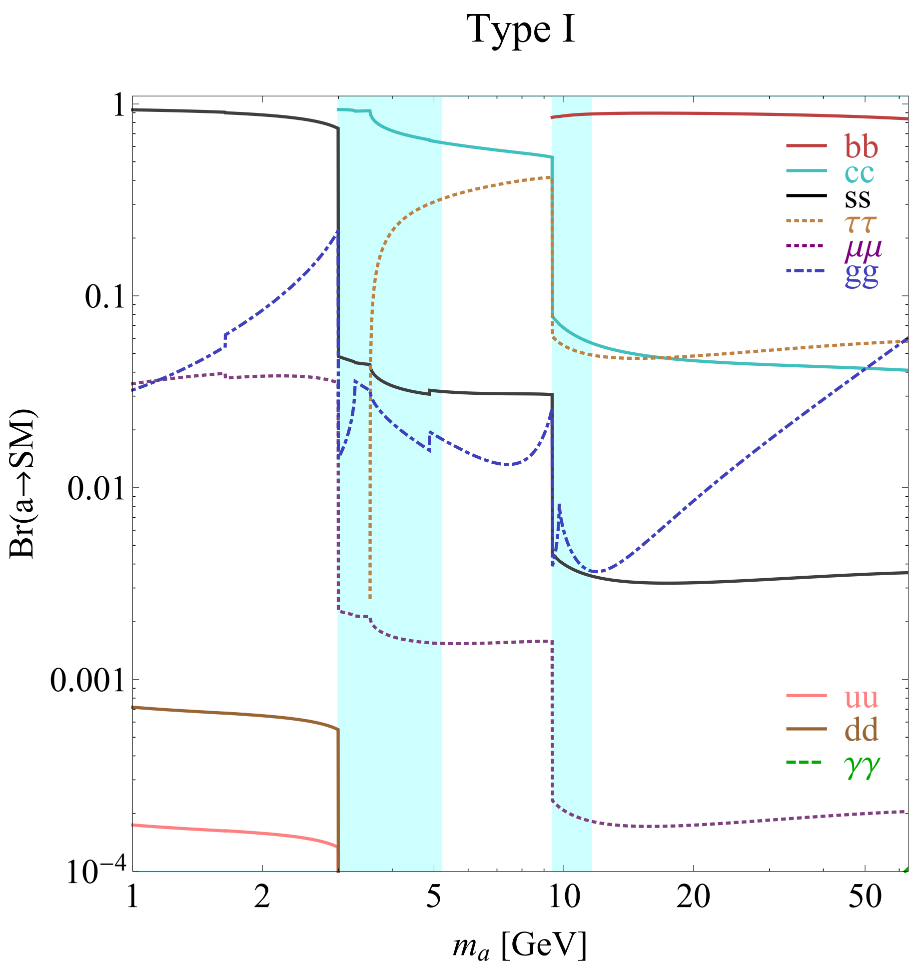

FIG. 6: Branching ratios of a singlet-like pseudoscalar in the 2HDM+S for Type I Yukawa couplings. Decays to quarkonia likely invalidate our simple calculations in the shaded regions.

2HDM + S : $B_{H\to aa}$

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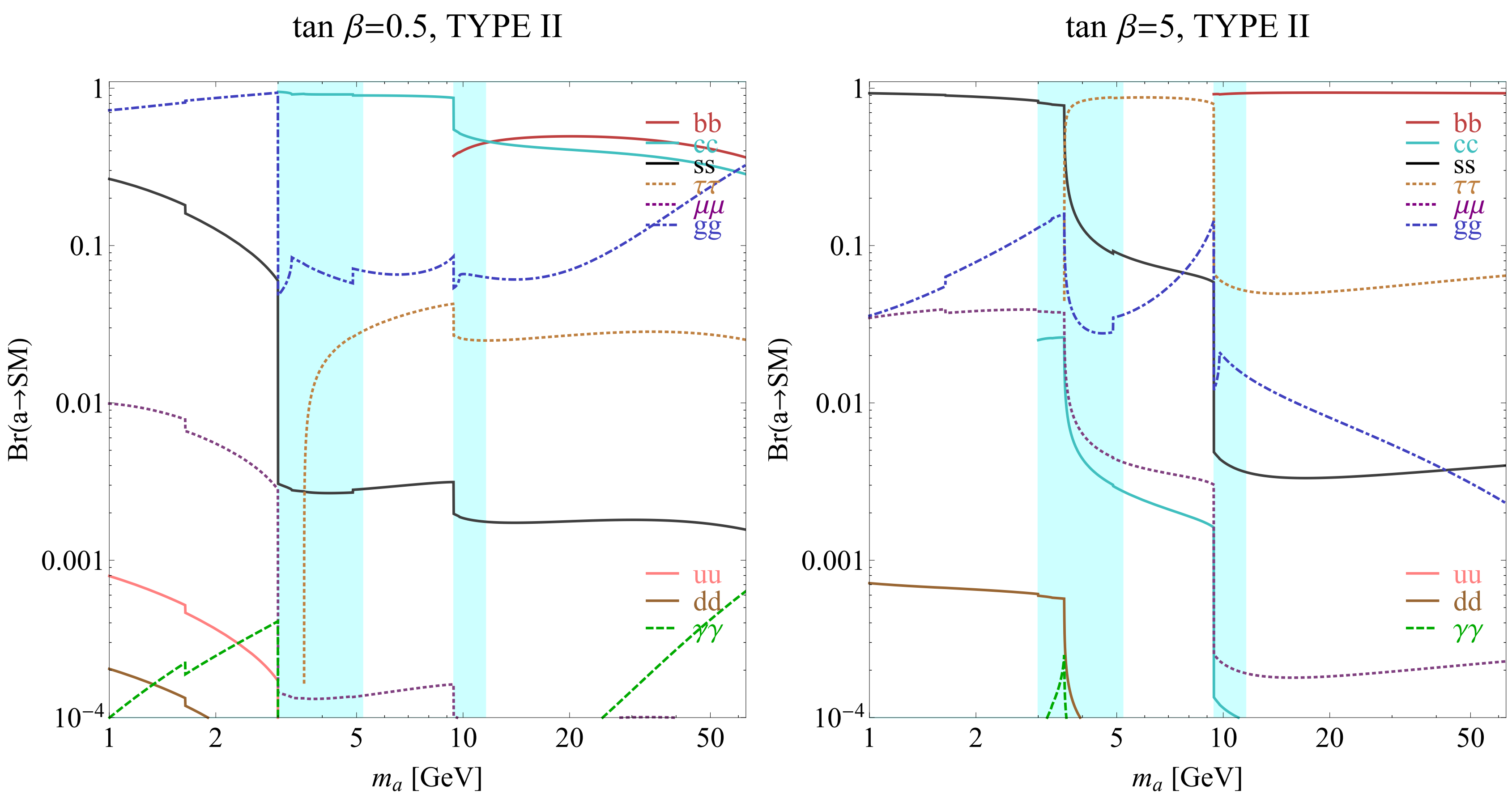

FIG. 7: Branching ratios of a singlet-like pseudoscalar in the 2HDM+S for Type II Yukawa couplings. Decays to quarkonia likely invalidate our simple calculations in the shaded regions.

2HDM + S : $B_{H \to aa}$

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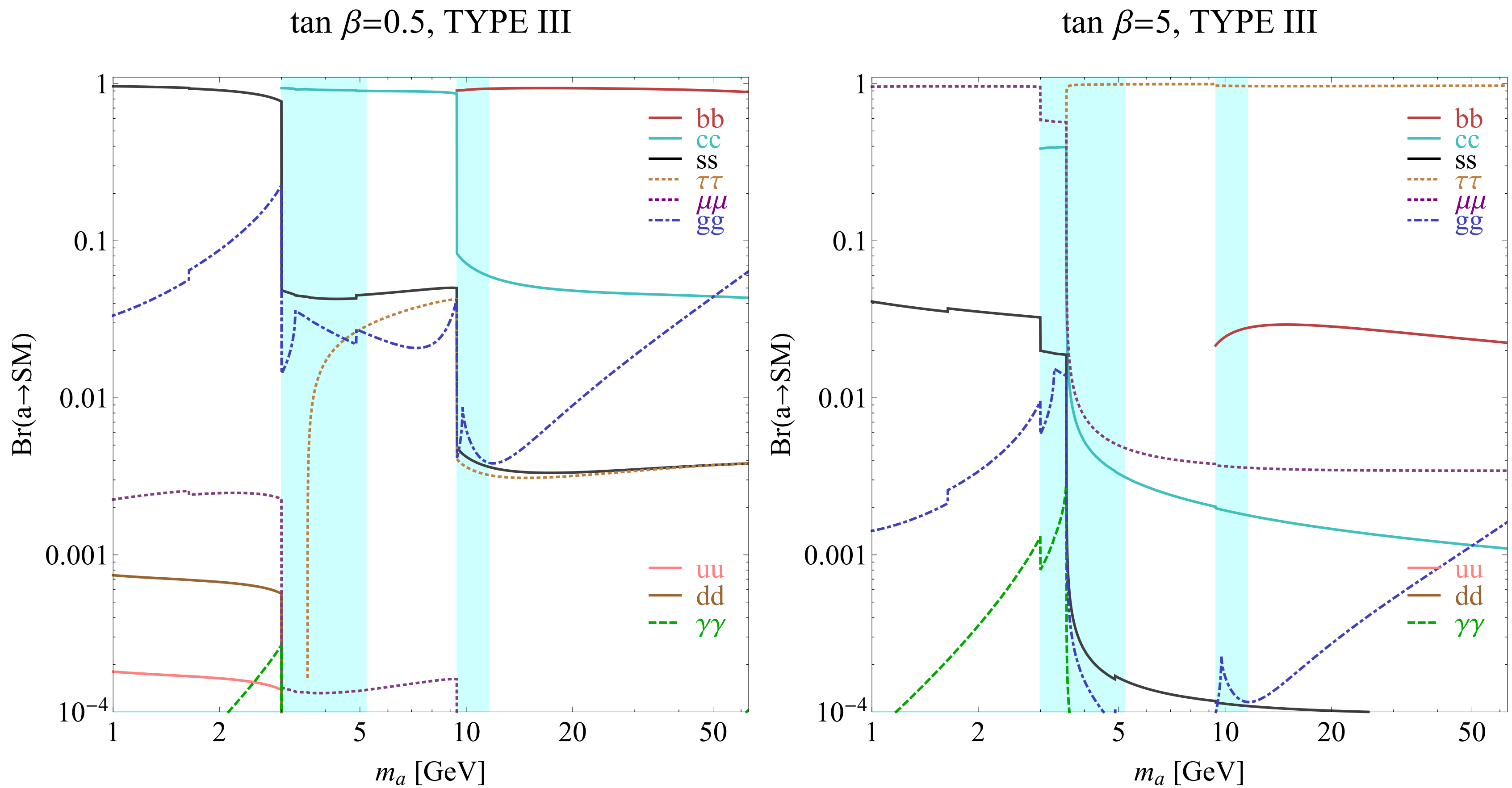


FIG. 8: Branching ratios of a singlet-like pseudoscalar in the 2HDM+S for Type III Yukawa couplings. Decays to quarkonia likely invalidate our simple calculations in the shaded regions.

2HDM + S : B$_{H\to aa}$

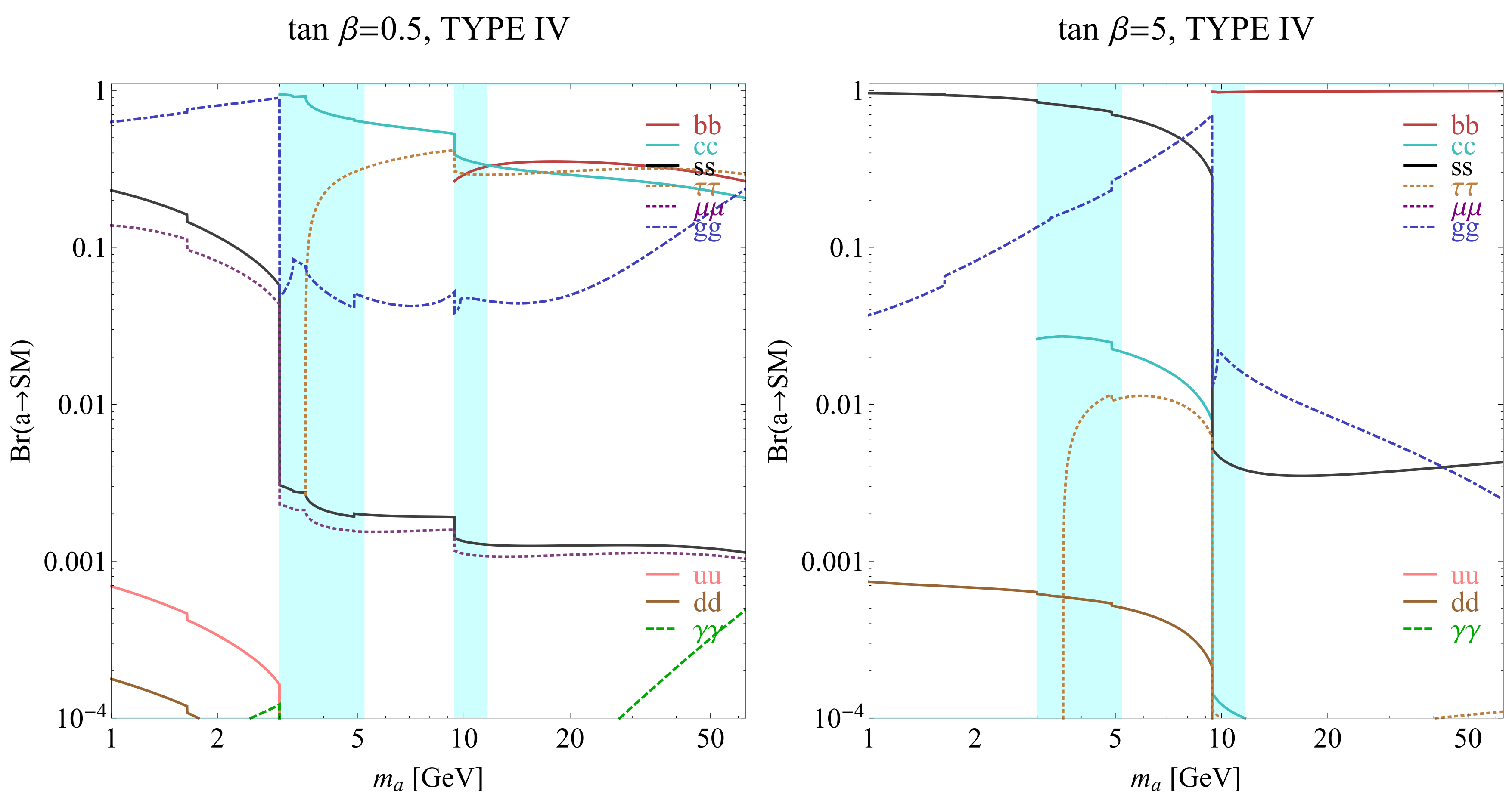


FIG. 9: Branching ratios of a singlet-like pseudoscalar in the 2HDM+S for Type IV Yukawa couplings. Decays to quarkonia likely invalidate our simple calculations in the shaded regions.

Title

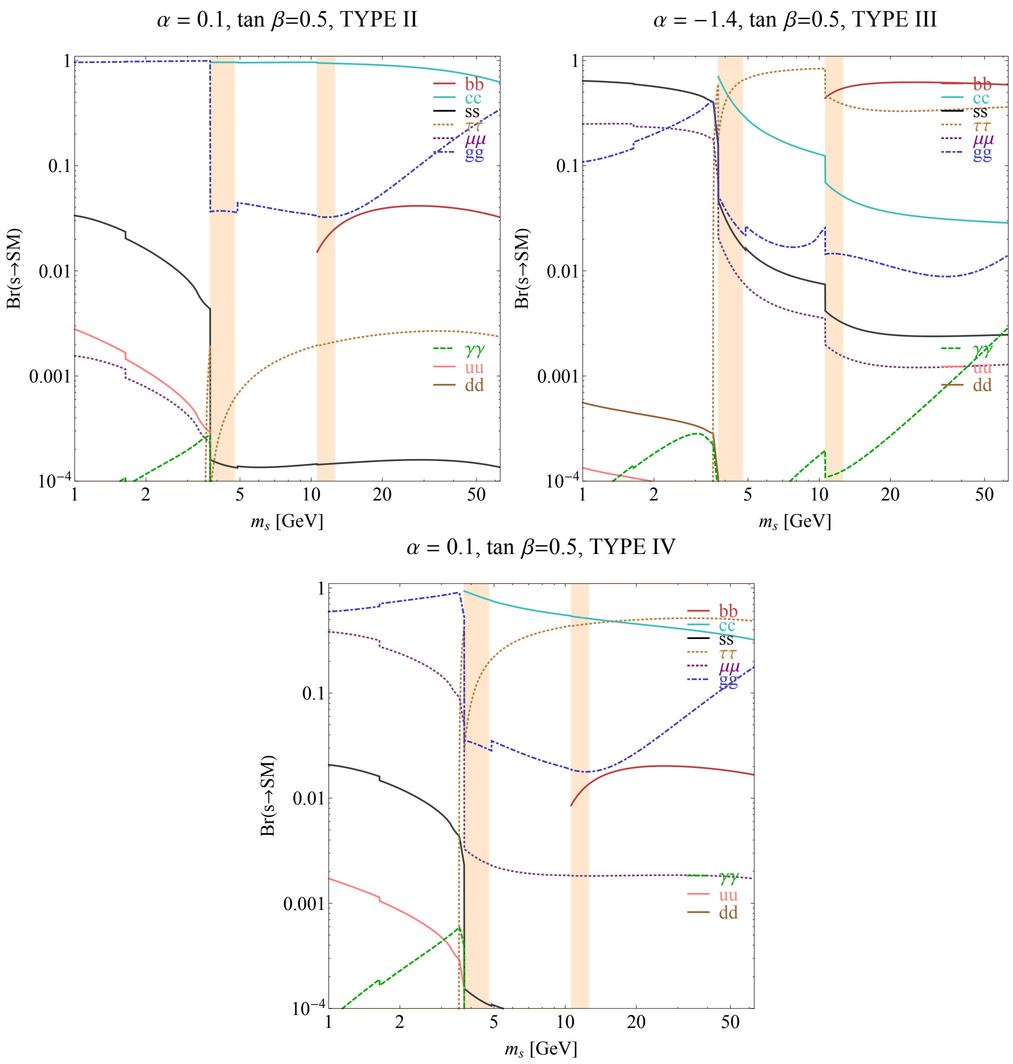
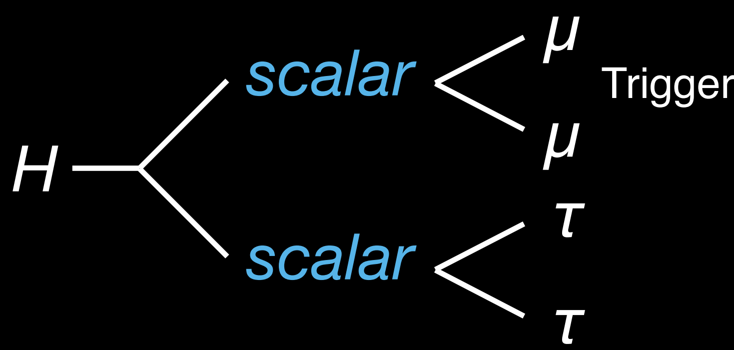
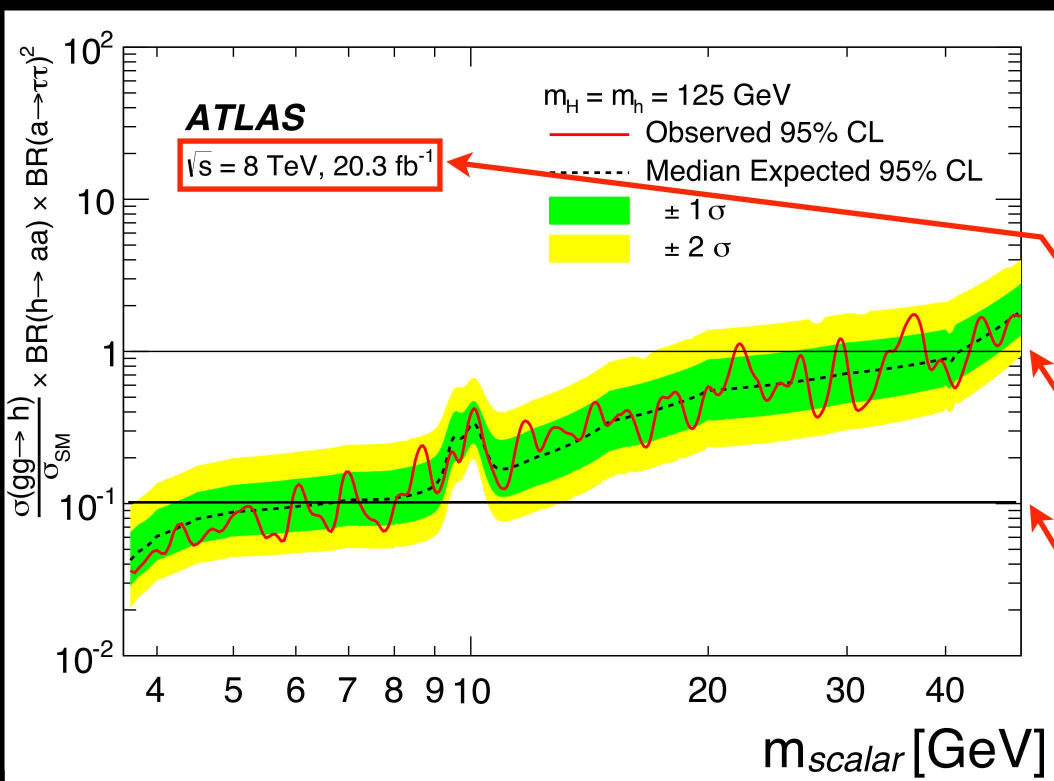


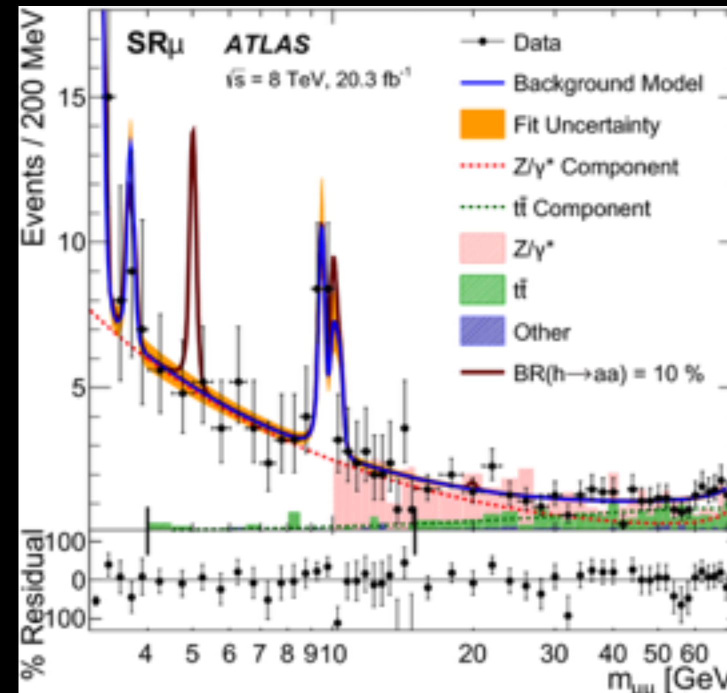
FIG. 10: Singlet scalar branching ratios in the 2HDM+S for different $\tan\beta, \alpha'$ and Yukawa coupling type. These examples illustrate the possible qualitative differences to the pseudoscalar case, such as dominance of $s \to c\bar{c}$ decay above $b\bar{b}$-threshold; democratic decay to $b\bar{b}$ and $\tau^+\tau^-$; and democratic decay to $c\bar{c}$ and $\tau^+\tau^-$. Hadronization effects likely invalidate our simple calculations in the shaded regions.

ATLAS $\mu\mu\tau\tau$ analysis

PRD 92, 052002 (2015)

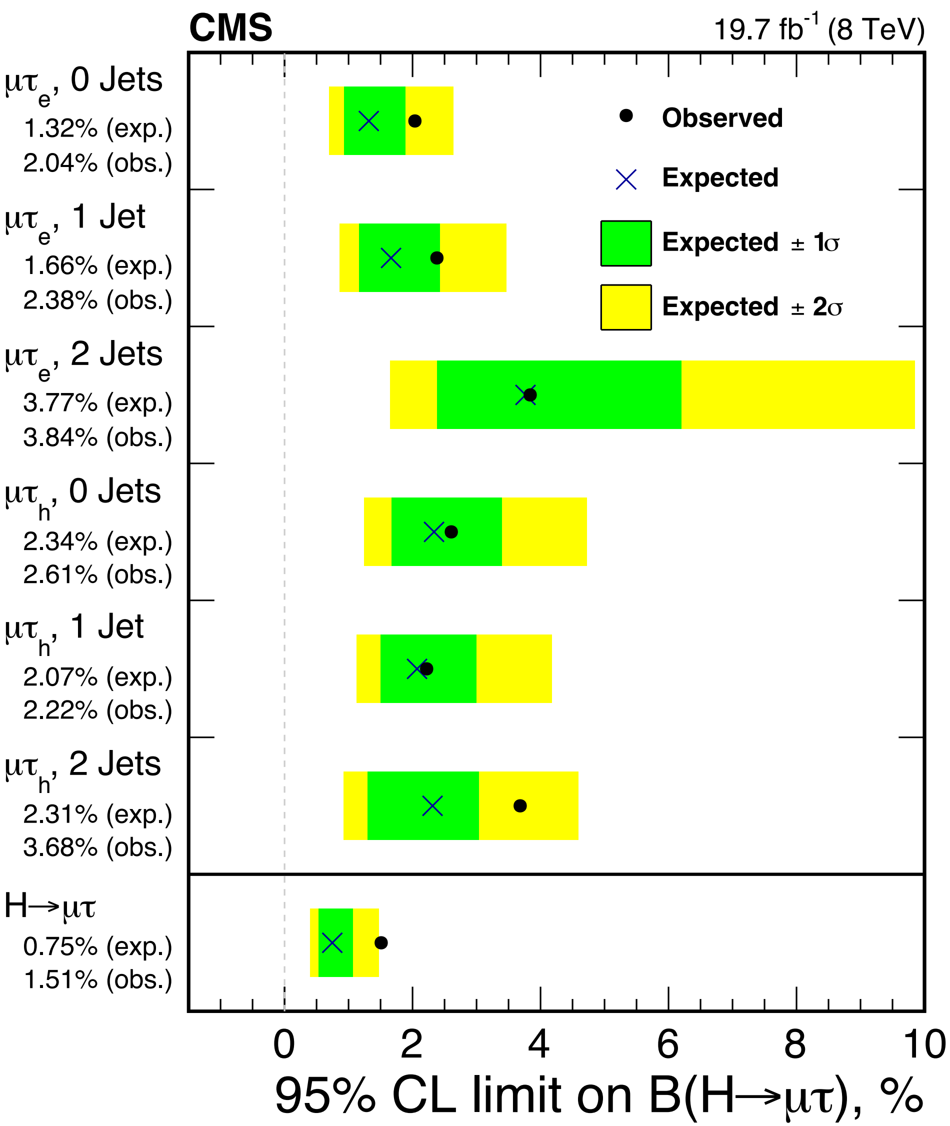


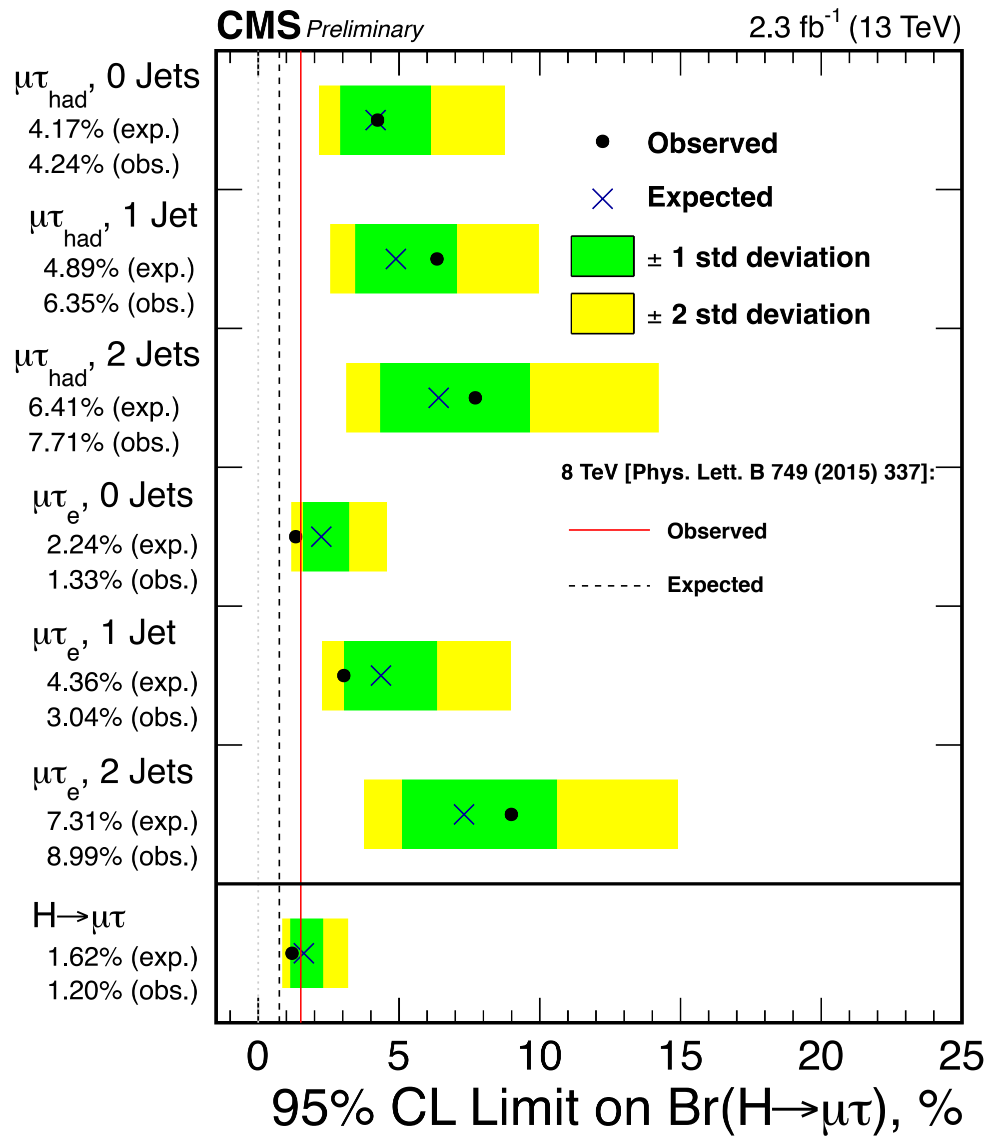




- Run 2 results will come
- $B_{H\to 4\tau}$ = 100% line
- $B_{H\to 4\tau}$ = 10% line

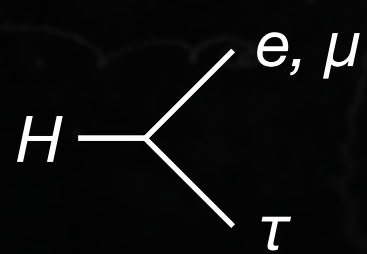
LFV: CMS 8 TeV v. 13 TeV





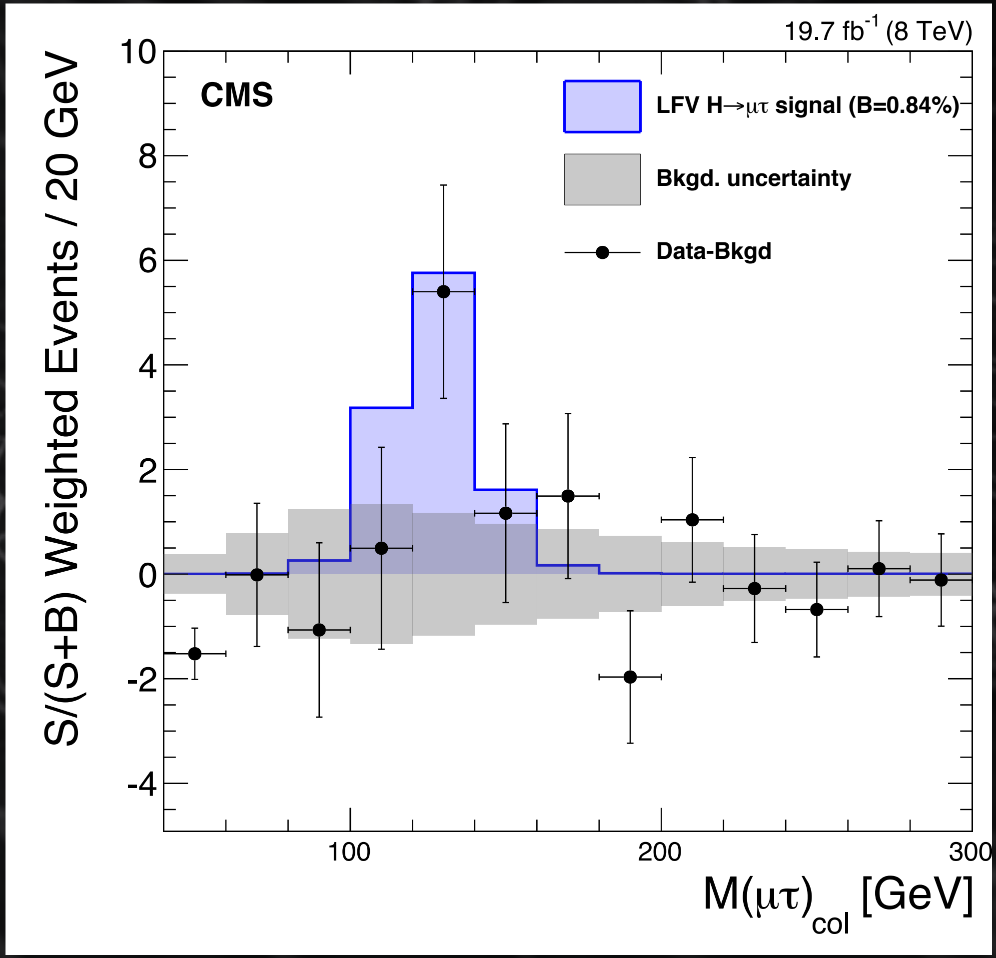
Lepton flavor violating Higgs decay

Many BSM models predict non-diagonal Yukawa couplings



Curtin et al. 1312.4992 (2014)
Chang et al. 0801.4554 (2008)
Silveira & Zee, PL B 161,136 (1985)
+ many more

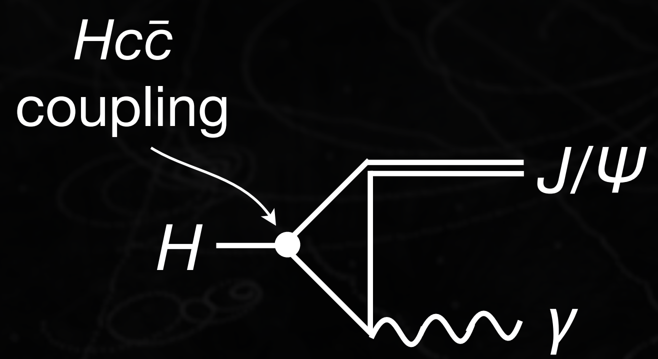
PL B 749 (2015) 337



CMS reported 2σ excess at Run 1

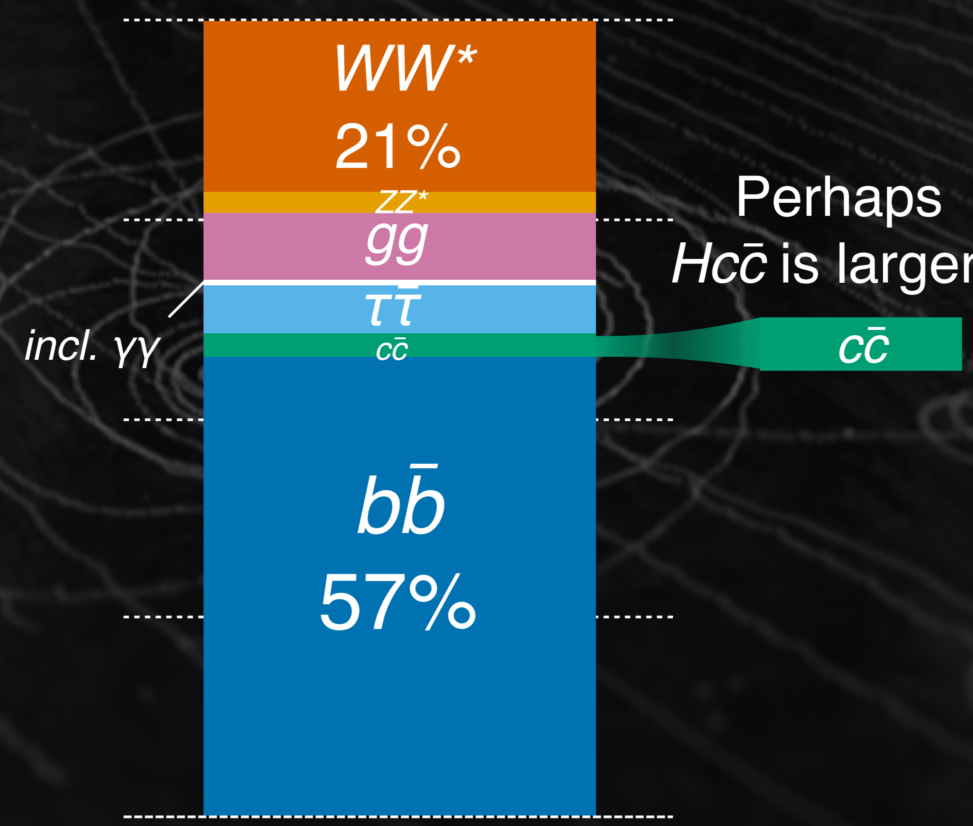
$H \to J/\Psi\gamma$

The process is very rare



If Hcc coupling is larger it can increase the rate (possibly more than 100%)

Searching for J/Ψ+γ probes the loop



Higgs decay branching fraction

Bodwin, Petriello, Stoynev, Velasco PR D 88, 053003 (2013)
Bodwin, Chung, Ee, Lee, Petriello et al. PR D 90, 113010 (2014)

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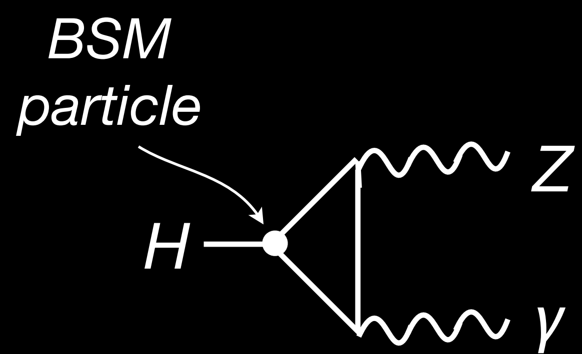
$H \to Z\gamma$

The process is very rare



BSM particle can contribute
in the loop

Searching for Zγ probes the loop

Projection

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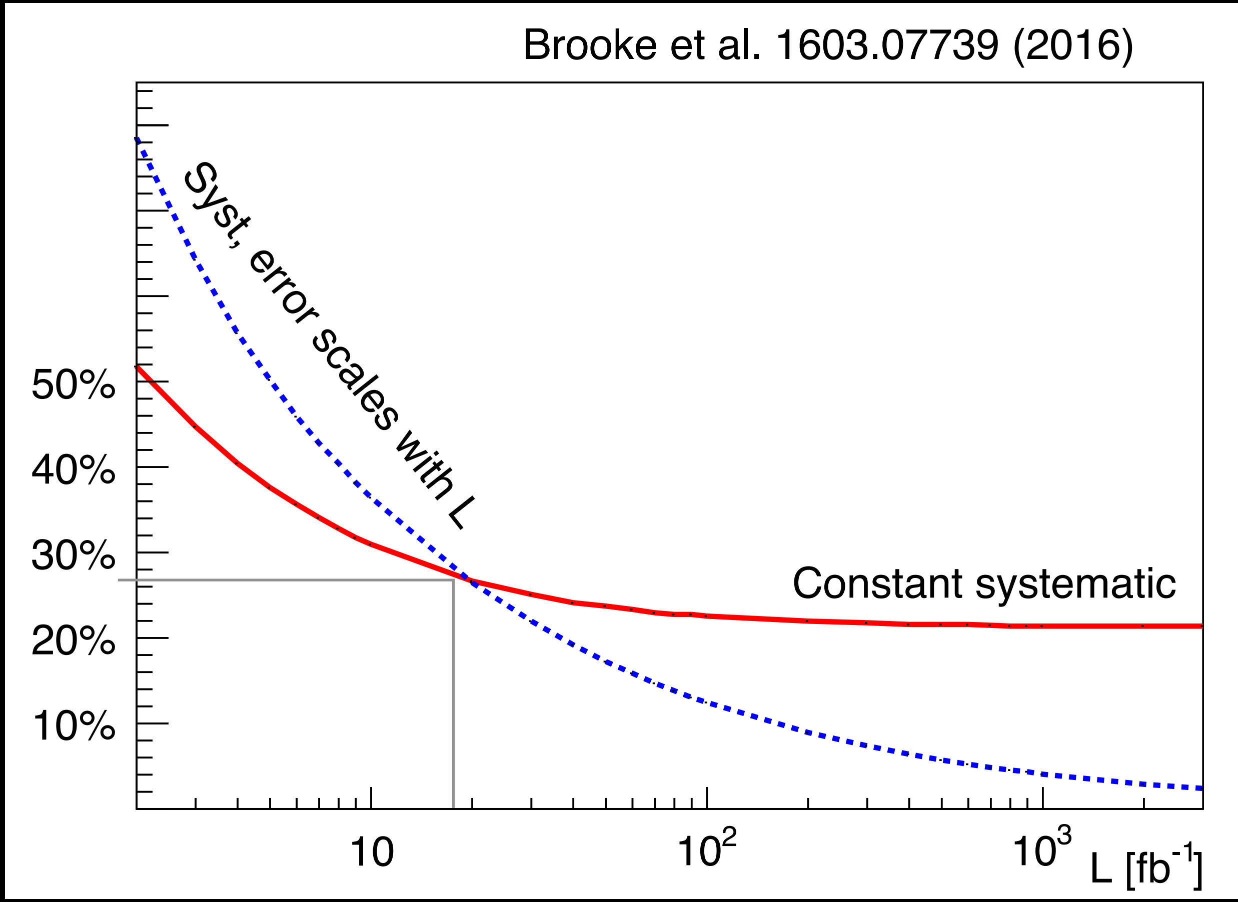

quickly systematic dominated (more work needed!)

ATLAS and CMS combination

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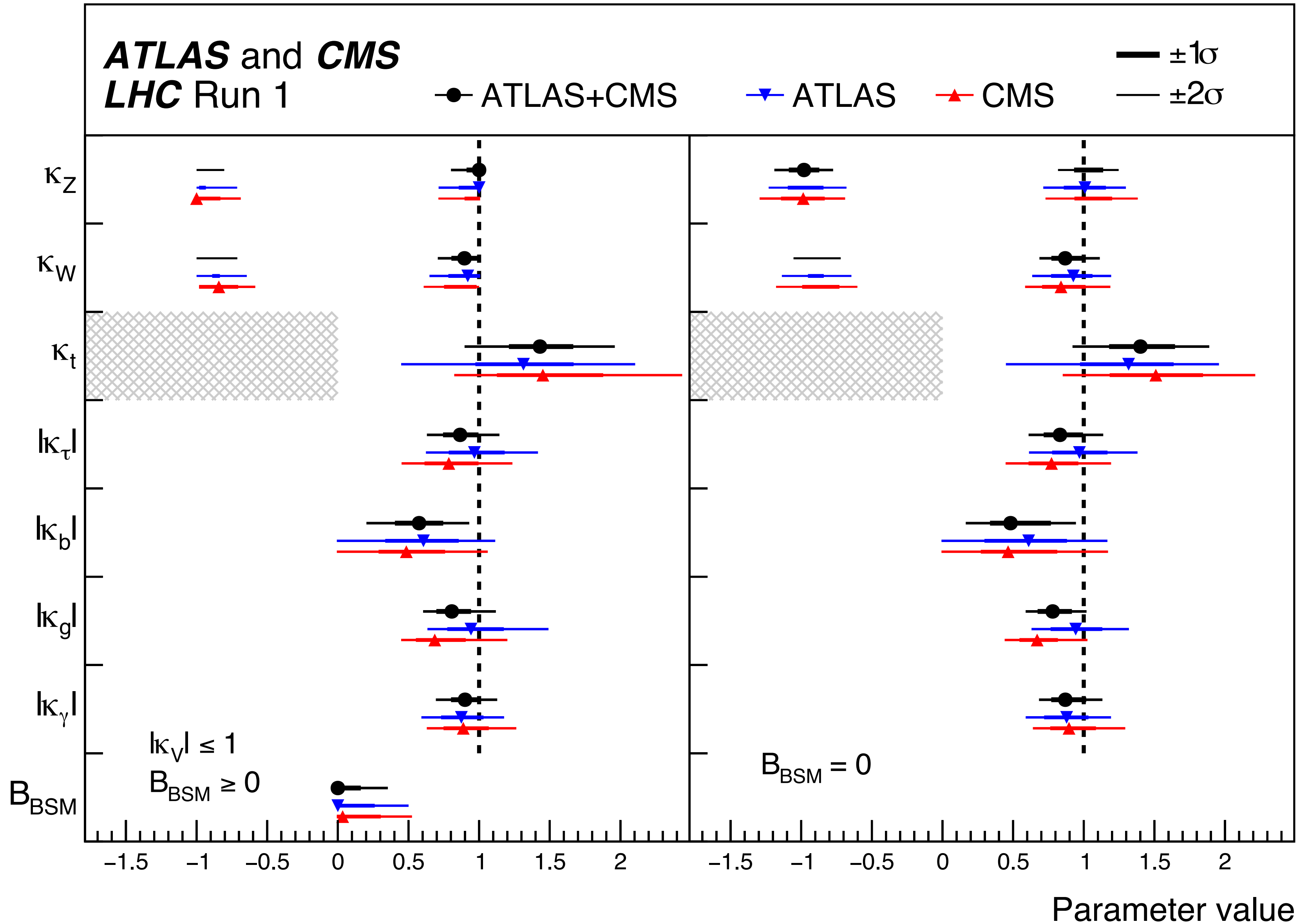
1606.02266



Why 0.5 million?

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$20\text{pb} \cdot 25/\text{fb} = 500\text{k}$
$50\text{pb} \cdot 10/\text{fb} = 500\text{k}$
$(500\text{k} + 500\text{k}) \cdot 2$ expt $= 2$ million Higgs events
2 million Higgs events $\cdot$ ($B_{H\rightarrow BSM} = 25\%$) = 0.5 million