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HH production for scalar Higgs sector extensions

17/10/2019

16th workshop of the LHC Higgs Cross Section Working Group

Based on
[Basler, Dawson, CE, Mühlleitner 1812.03542]
[Basler, Dawson, CE, Mühlleitner 1909.09987]

Higgs physics as a probe of (B)SM physics

- Lack of CP violation, hierarchy, ...

Key Question: Where's the new physics

Effective Field Theory

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \ldots$$

concrete models

- 2HDMs
- (N)MSSM

- Can di-Higgs phenomenology pinpoint BSM solutions?

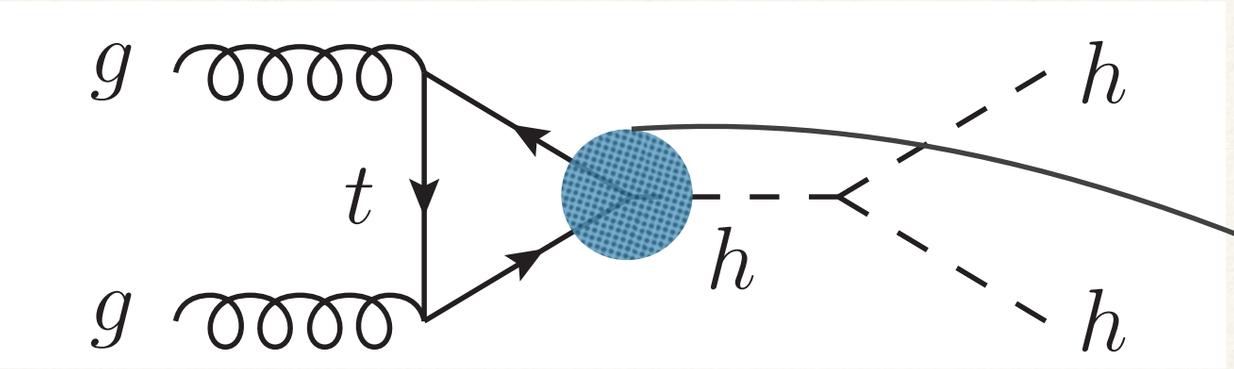
Need new degrees of freedom, e.g. extra Higgs bosons

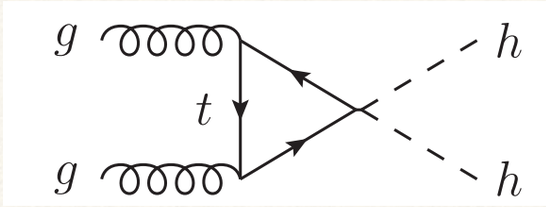
Why have we not seem them yet?

Case for di-Higgs at 3/ab

[Basler,Dawson, CE, Mühlleitner `18]

Di-Higgs anatomy at 3/ab





e.g. [Gröber, Mühlleitner `10]

correlated with on-shell Higgs phenomenology broken by $\sim \bar{t}th^2/\Lambda$ ....

[HXSWG YR 4]

- easy to arrange EFT coefficients in a way to get spectacular rates, but can doubt physical relevance of such limits (→ matching)

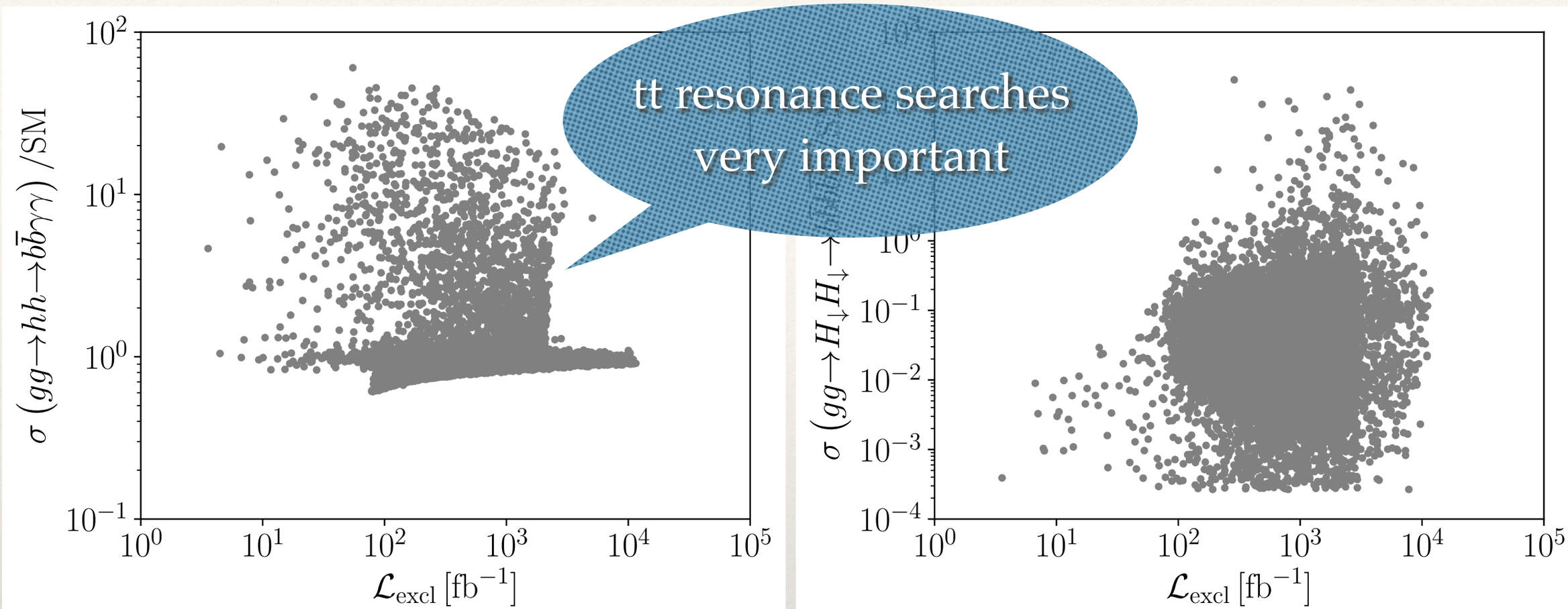
- here: use concrete Higgs sector extensions (2HDM/CxSM/...)
  - extrapolate 125 GeV signal strengths
  - extrapolate exotic Higgs searches
  - additional constraints (*electron EDMs, flavor, perturbativity, ...*)

What's left for HH?

for details see Maggie's talk

[Basler,Dawson, CE, Mühlleitner `18]

e.g. C2HDM



tt resonance searches very important

luminosity at which non-HH searches

SM-like measurements can show a plethora resonant anomalies
diHiggs final states important for BSM discovery

...di Higgs final states quickly lose relevance when approaching EFT limit

Benchmarks

	T1BP1	T1BP2	T1BP3	T1BP4
m_{H_1} [GeV]	125.09	125.09	125.09	119.73
m_{H_2} [GeV]	130.24	131.52	233.86	125.09
$m_{H^\pm}$ [GeV]	169.99	282.75	164.87	185.41
$\mathrm{Re}(m_{12}^2)$ [GeV^2]	679	12376	11473	7522
α_1	1.300	1.249	1.268	1.276
α_2	-0.075	-0.032	0.00262	1.494
α_3	1.306	1.570	-0.809	-1.460
$\tan\beta$	4.05	3.23	3.32	5.30
m_{H_3} [GeV]	132.95	290.17	234.51	211.43
R_{13}^2	$5.558 \cdot 10^{-3}$	$1.027 \cdot 10^{-3}$	$6.863 \cdot 10^{-6}$	0.994
R_{23}^2	0.926	0.999	0.523	$5.819 \cdot 10^{-3}$
R_{33}^2	0.068	$1.217 \cdot 10^{-6}$	0.477	$7.140 \cdot 10^{-5}$
$\mathcal{L}_{\mathrm{excl}}$ [fb^{-1}]	11500	1641	1365	2628
$\sigma_{hh}^{\mathrm{NLO}}$ [fb]	36.52	36.59	37.88	38.21
K-factor	1.95	1.95	1.95	1.95

	T2BP1	T2BP2
m_{H_1} [GeV]	125.09	125.09
m_{H_2} [GeV]	858.09	814.56
$m_{H^\pm}$ [GeV]	835.85	894.84
$\mathrm{Re}(m_{12}^2)$ [GeV^2]	252703	227697
α_1	1.141	1.042
α_2	$-5.268 \cdot 10^{-4}$	$6.184 \cdot 10^{-4}$
α_3	1.198	-1.157
$\tan\beta$	2.16	1.71
m_{H_3} [GeV]	858.65	814.94
R_{13}^2	$2.775 \cdot 10^{-7}$	$3.824 \cdot 10^{-7}$
R_{23}^2	0.867	0.832
R_{33}^2	0.133	0.162
$\mathcal{L}_{\mathrm{excl}}$	2664	2016
$\sigma_{hh}^{\mathrm{NLO}}$ [fb]	37.82	38.02
K-factor	1.95	1.95

	NMBP1	NMBP2	NMBP3	NMBP4
M_1 [GeV]	638	457	608	313
M_2 [GeV]	1254	386	546	569
M_3 [GeV]	4169	6345	6778	3485
A_t [GeV]	2456	5134	1092	532
A_b [GeV]	-2213	-2908	-4015	2009
A_τ [GeV]	1443	-667	2370	354
$M_{\tilde{Q}_3}$ [GeV]	1293	3175	2574	3581
$M_{\tilde{L}_3}$ [GeV]	1147	1276	790	1188
$\tan\beta$	1.96	1.87	1.68	1.49
λ	0.55	0.50	0.60	0.54
κ	0.43	0.47	0.33	0.27
A_λ [GeV]	-55	33	425	-416
A_κ [GeV]	373	358	-672	667
μ_{eff} [GeV]	-293	-299	321	-327
m_{H_1} [GeV]	124.34	124.11	101.13	39.52
m_{H_2} [GeV]	335.27	409.70	125.88	125.64
m_{H_3} [GeV]	530.39	465.57	627.95	634.32
m_{A_1} [GeV]	487.34	406.66	608.57	580.42
m_{A_2} [GeV]	540.58	553.09	624.77	631.97
$m_{H^\pm}$ [GeV]	520.47	426.32	621.81	628.97
$\mathcal{L}_{\mathrm{excl}}$ [fb^{-1}]	1370	118	1192	101
$\sigma_{hh}^{\mathrm{NLO}}$ [fb]	69.29	131.83	43.62	42.31
K-factor	1.97	1.97	1.96	1.96

details in [Basler,Dawson, CE, Mühlleitner `18]

phenomenology at a glance

above Higgs pair threshold

- (multi) resonant diHiggs production (hh, hH,...)

opportunity for diHiggs

Higgs interactions dominant

exotics with large couplings to tops

top interactions dominant

above top pair threshold

- tt final states preferred
- analysis highly model-dependent due to dedicated S-B interference

more on the next slide

below top pair threshold

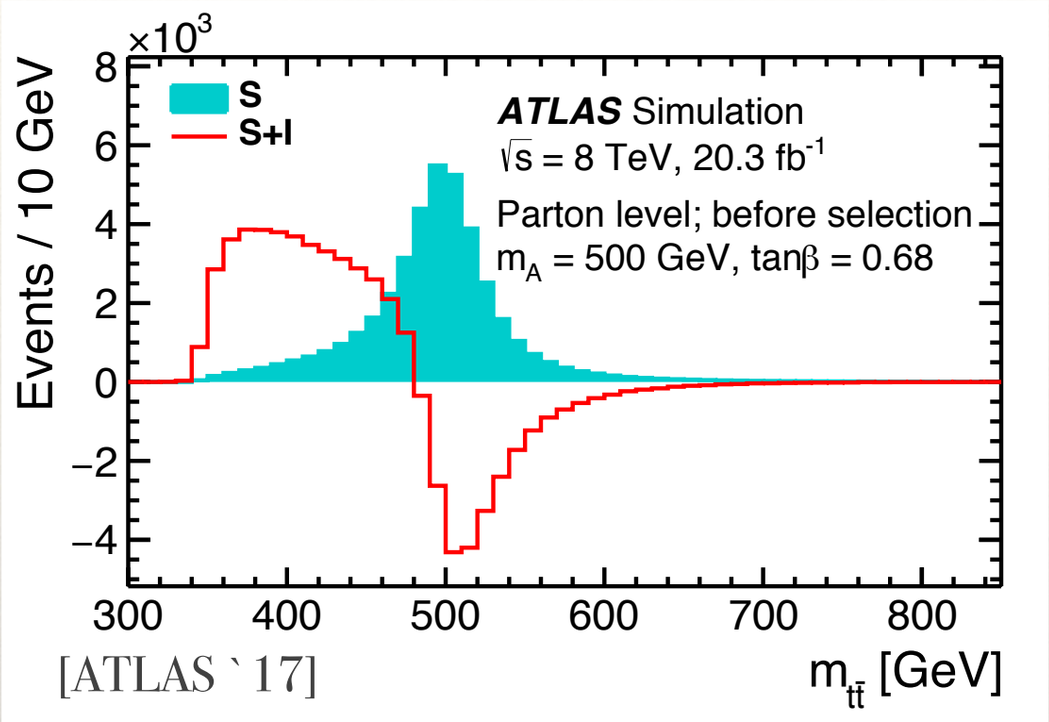
- compressed spectra
- single Higgs competitive except b-final states (*trigger etc...*)

opportunity for diHiggs

special role of tops

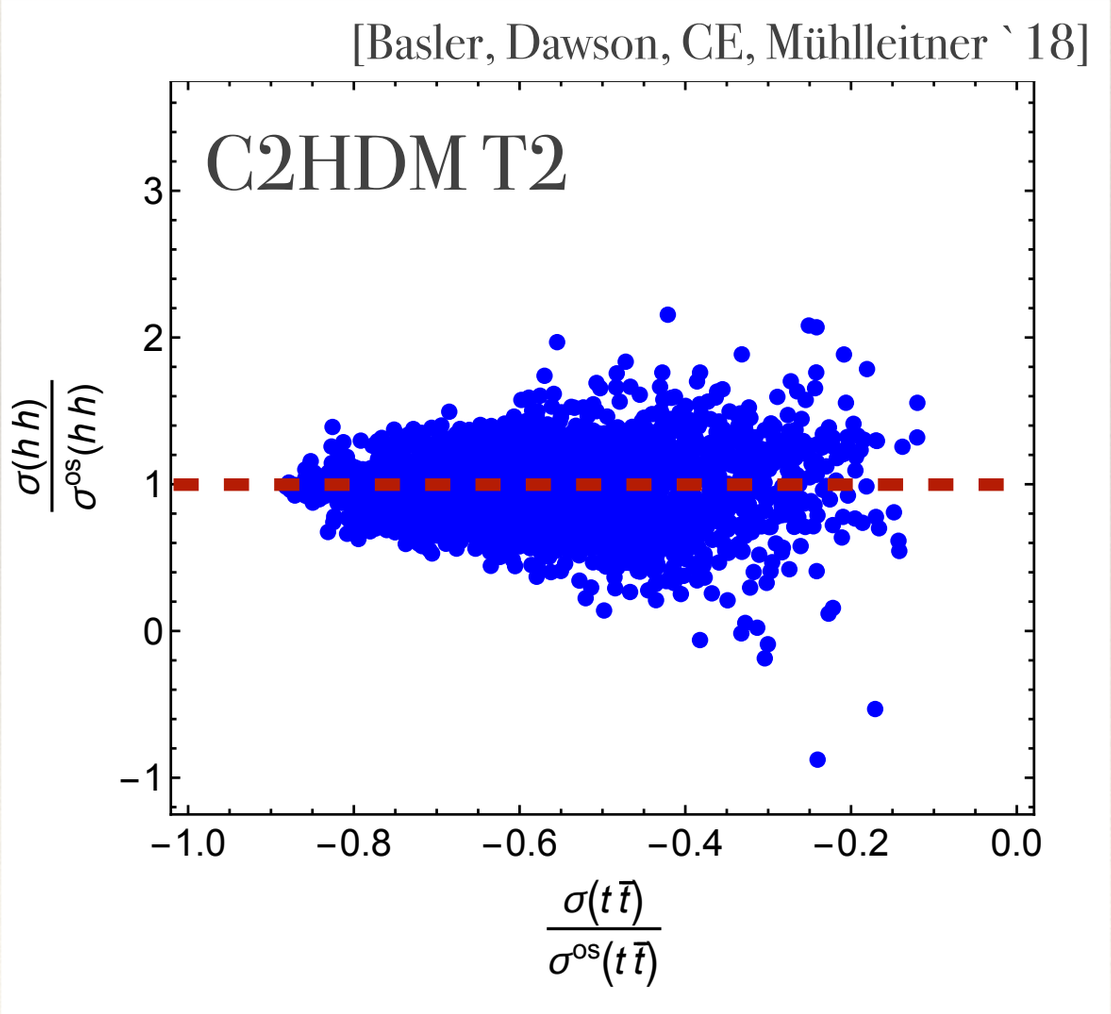
- large interference effects of Higgs "signal" with QCD background

  [Gaemers, Hoogeveen `84] [Dicus et al. `94]....



[ATLAS `17]

- top resonance searches with using "os" narrow width approximation inadequate



[Basler, Dawson, CE, Mühlleitner `18]

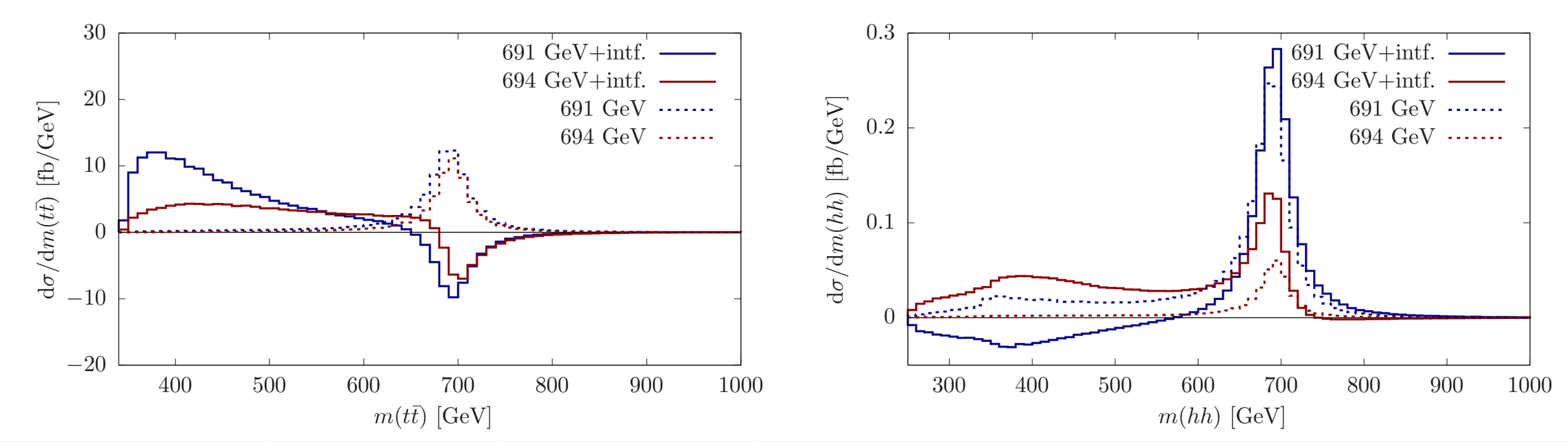
- can a case be made for HH?

  cf. HH whitepaper [Micco et al. 1910.00012]

- destructive interference in top final states can be correlated with constructive HH interference

special role of tops

- reason for phenomenologically viable parameter regions is signal-signal interference of compressed spectra



- non-degenerate spectra: HH narrow width approximations robust

- benchmarks for this behaviour in light of existing searches, but charged Higgs searches are looming over the model!

[Basler, Dawson, CE, Mühlleitner `18]

Conclusions

- HH final states can be enhanced in the C2HDM, NMSSM, etc.
- there are viable regions in these scenarios where extrapolations show that HH final states will be (one of) the main discovery channels
- however, HH sensitivity cannot be separated from from top resonance searches
- large destructive signal-background interference can be correlated with constructive signal-signal interference
- signal-signal interference particularly relevant when we cannot separate resonances experimentally