Challenges and opportunities in ttbar resonance searches

Zhen Liu (Fermilab)

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Based on work with M. Carena, to appear

Motivation

Heavy scalars very common in new physics models (SUSY,2HDM,Composite Models, Hidden-valley, Gauge symmetry extensions, scalar-assisted EWBG, etc.)

Couples to fermions proportional to their masses, dominantly to ttbar

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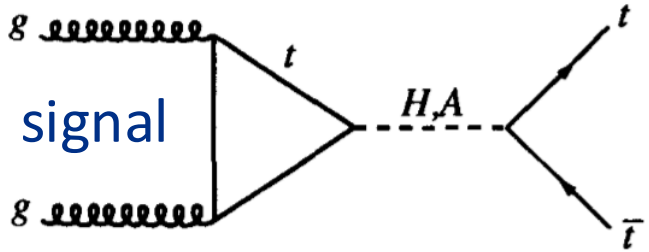
This channel is **challenging** in some ***interesting*** way and we try to seek for physics opportunities through this challenge

Challenges



signal

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However, the challenges lie in the interference effect.

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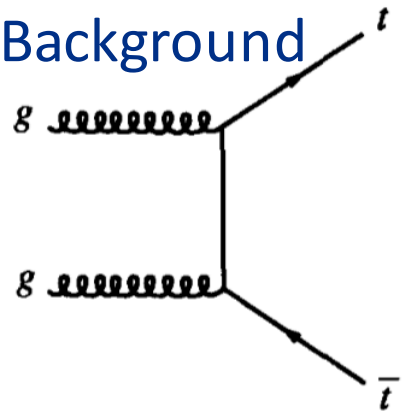
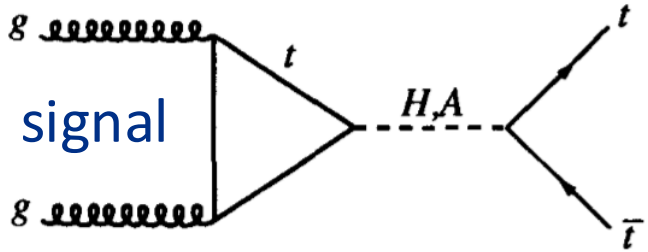


Plus s- and u-channel
Plus s-channel qqbar->ttbar

Challenges



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D. Dicus, A. Stange, S. Willenbrock, 1991

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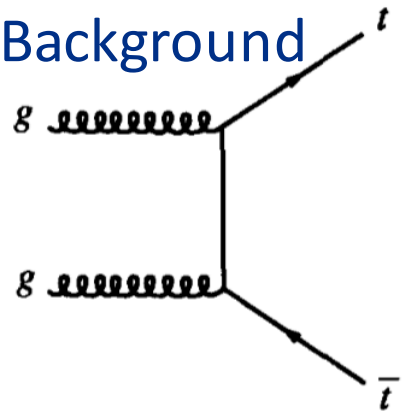

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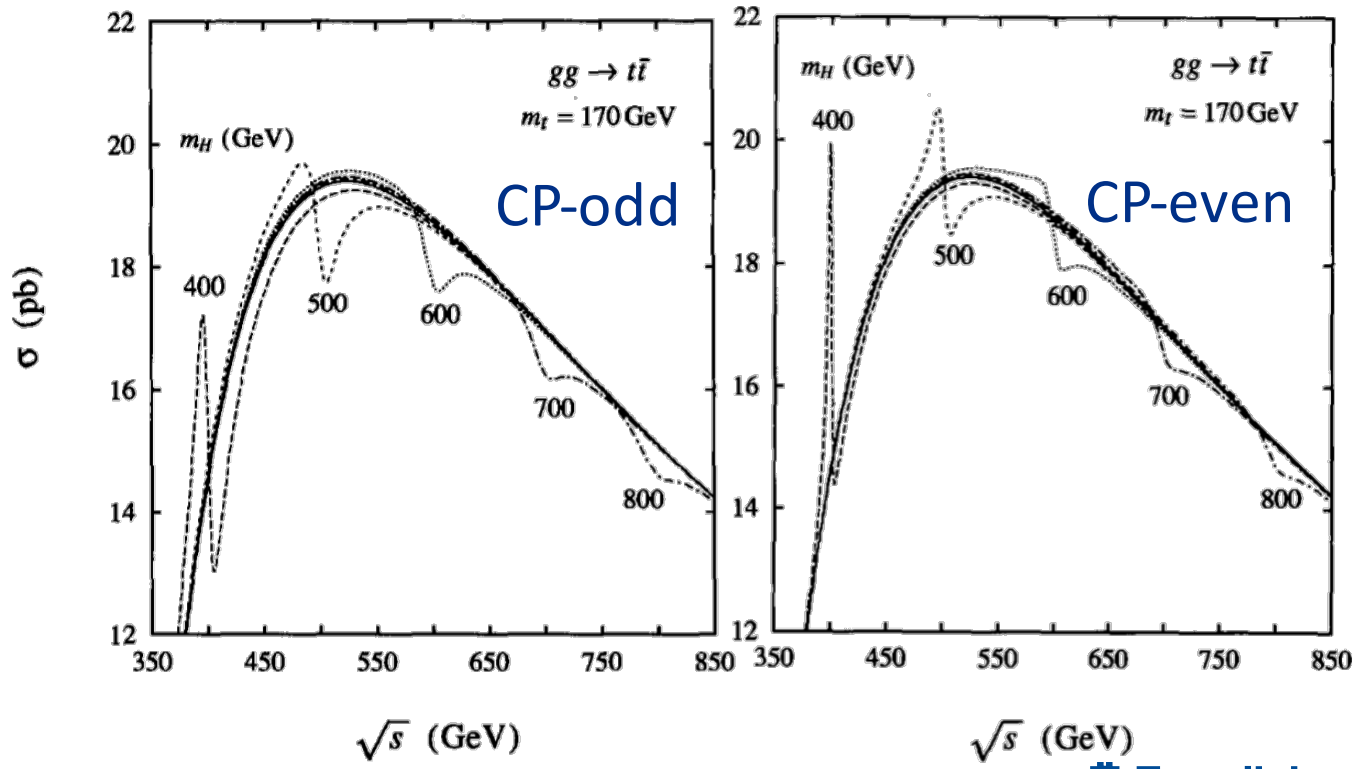
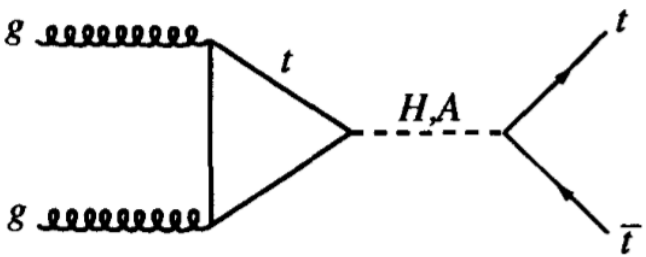
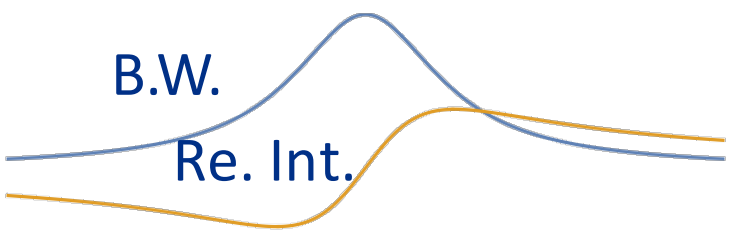


See also recent work by N. Craig, F. D'Eramo, P. Drapper, S. Thomas, H. Zhang arXiv:1504.04630 and also Jung, Sung, Yoon arXiv:1505.00291

Challenges (interferences)





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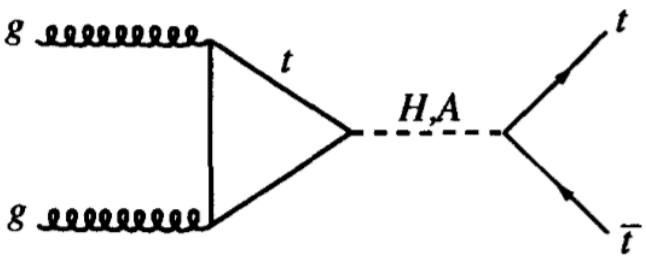

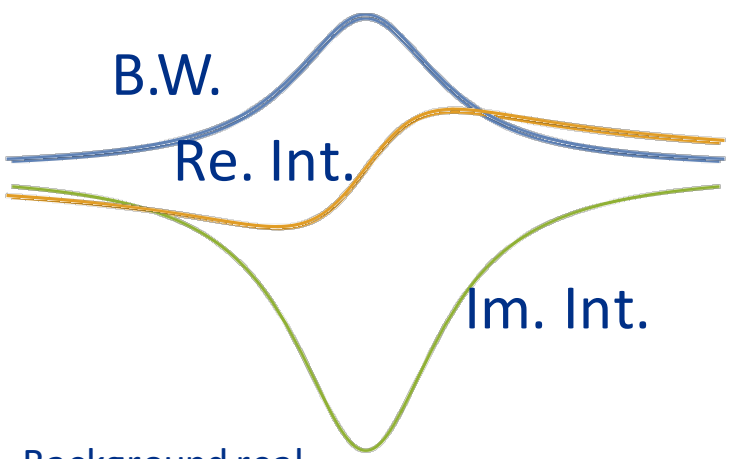

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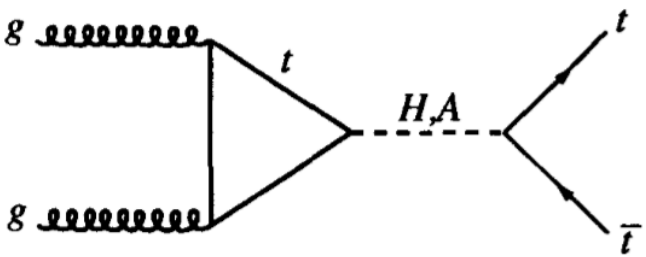
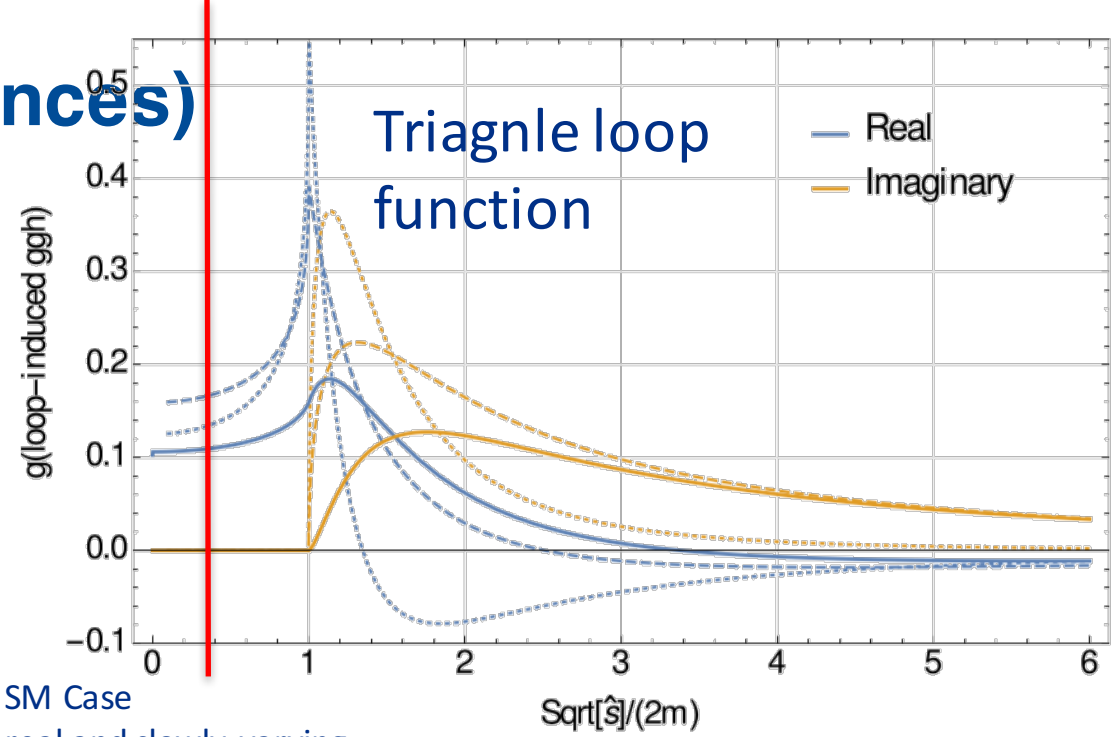
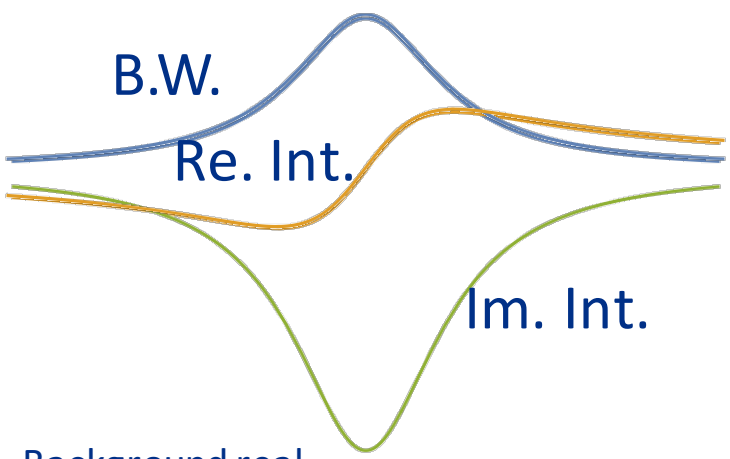




SM Case
real and slowly varying
heavy fermion decoupling theorem (with Yukawa proportional to the mass)



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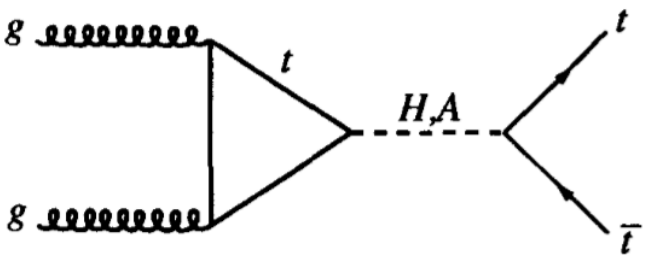

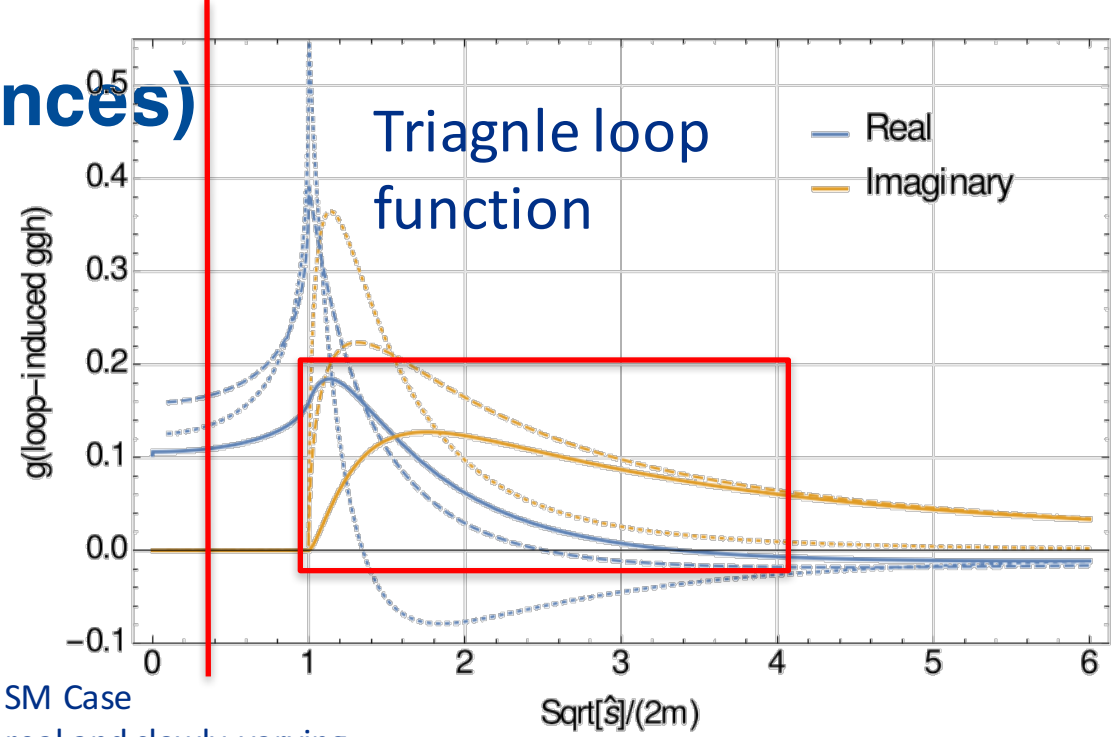

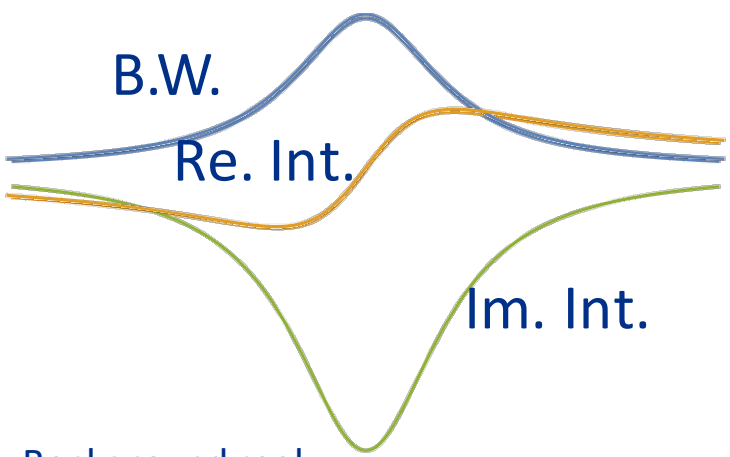

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Once across the threshold, imaginary piece arises drastically and the real piece decreases.

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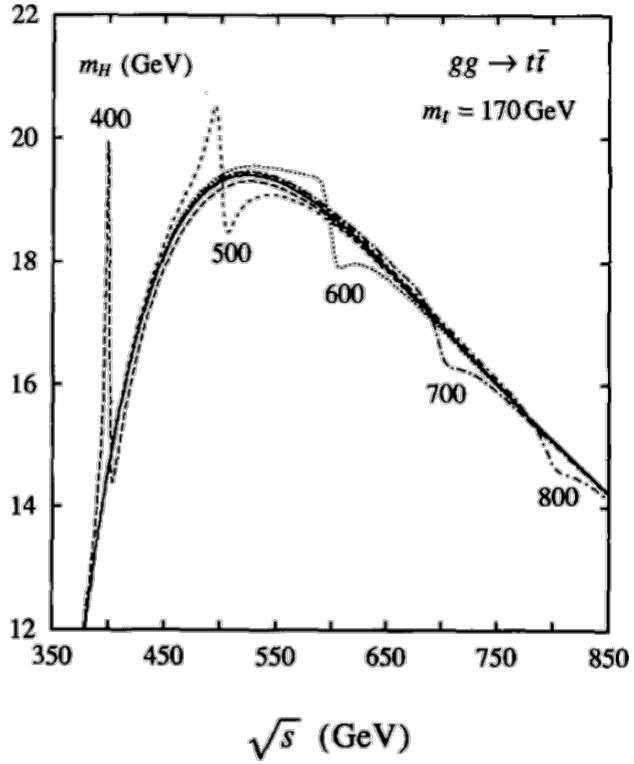
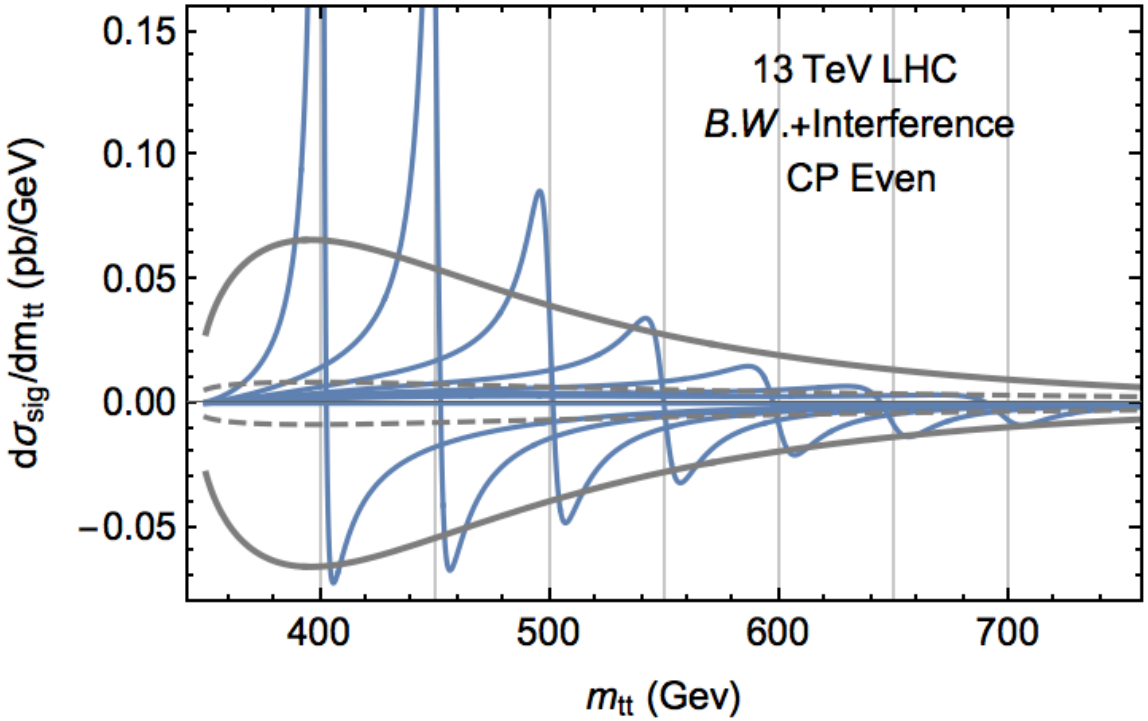
Im. Int.– Interference from the imaginary par of propagator (rare case, changes signal rate)

A strong phase ``insensitive”* to phase in the Yukakwa as the signal amplitudes is proportional to |y|^2.

*subject to difference in loop functions

Challenges



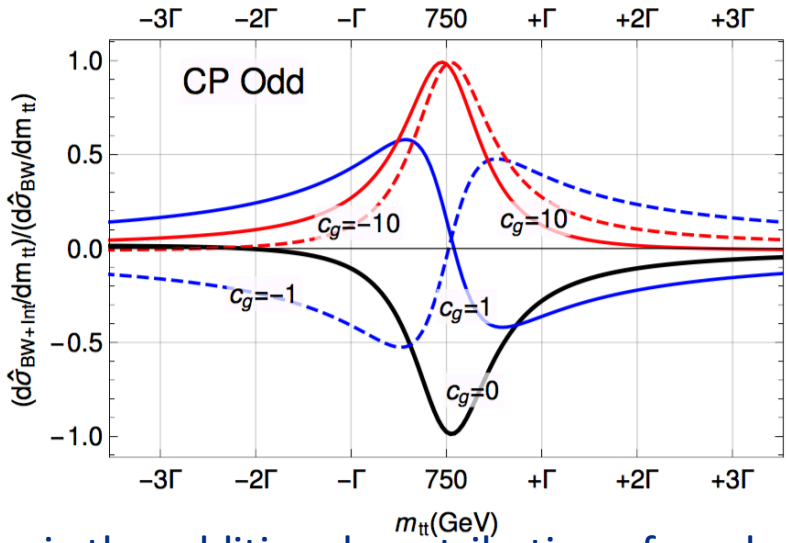


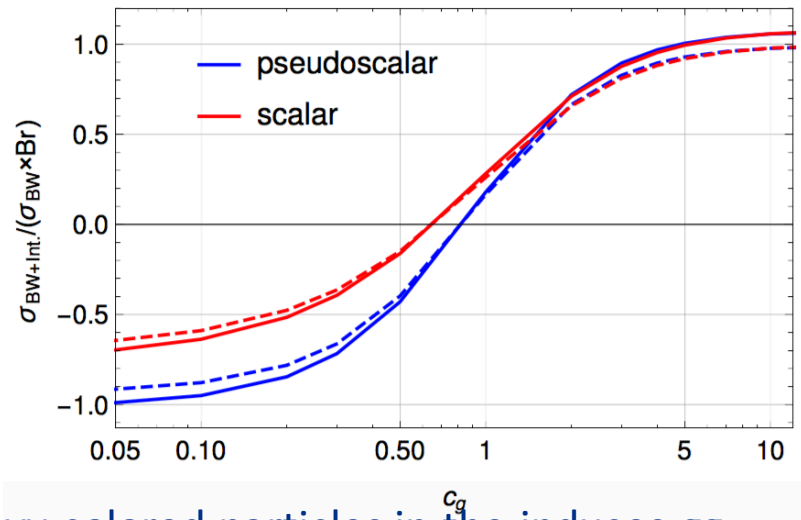
Special line shapes:

a) Bump search not designed/optimized for this, have to modify our current search;

b) Smearing effects fills the dips with the bumps, making this signal much harder.

“Random” example of a hypothetical 750 GeV scalar



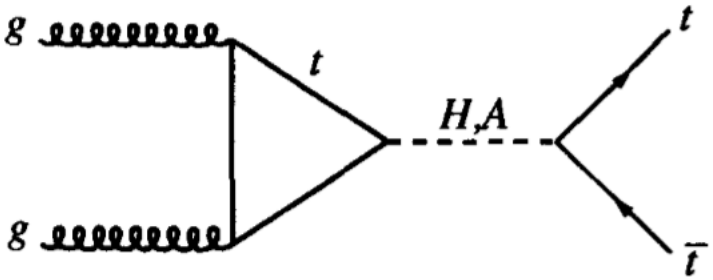


cg is the additional contributions from heavy colored particles in the induces gg-750scalar coupling.

Three cases:
a)dominated by top-loop, pure dip;
b) dominant by heavy particles in the loop, pure bump;
c) comparable contributions, bump-dip or dip-bump.

Even before proceed on the opportunities and observational aspects, already tells us the interpretations of current bounds for 750->ttbar should be with great care.
(Right panel) (see also recent overlapping discussion by Djouadi, Ellis and Quevillon **arXiv:1605.00542**)

Opportunities



- Nearly degenerate CP-even and CP-odd scalars (new interferences between them emerges)
- CP phases (new interferences emerges proportional to the loop-function difference between the even and odd one)
- Bottom-quark contributions (large tan\beta, changes the relative phase)
- New colored particle contributions and threshold effects (stops, VLQs, etc., reduce the relative phases and recovers the bump search)
- New channels (associated production with top(s), bottoms, jet(s), etc. Potentially reducing the interference effect.)

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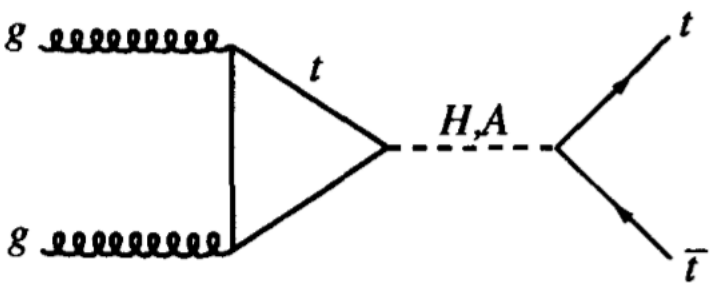

Covered in our study
I will skip the details here
and move on to the
observational aspect.

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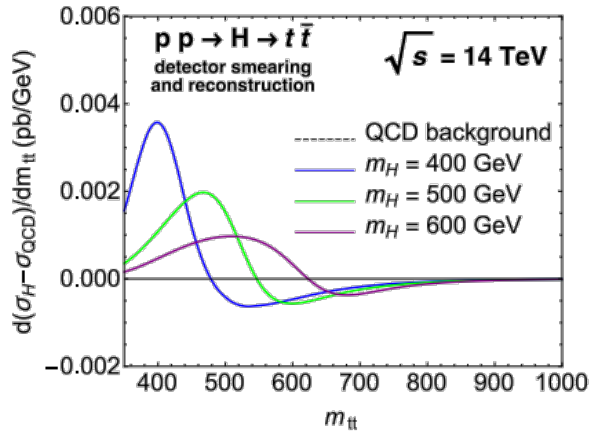
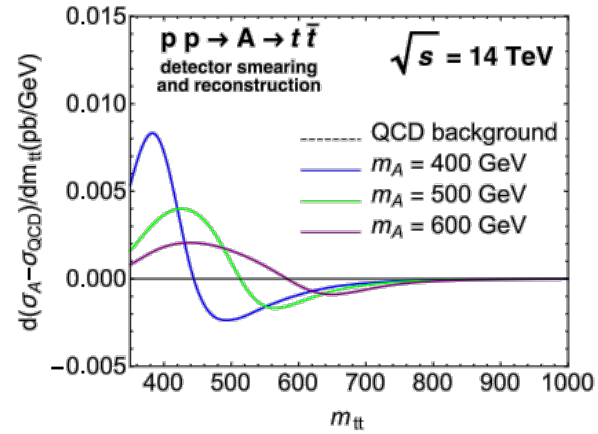
LHC perspectives--challenge

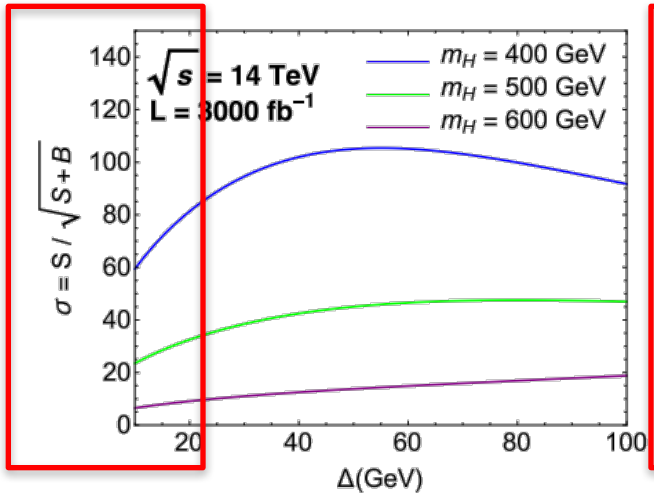
Statistically promising; Systematically, challenging.

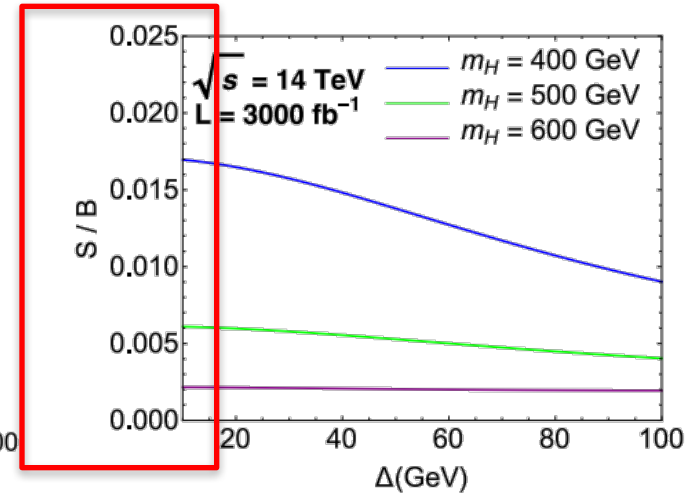




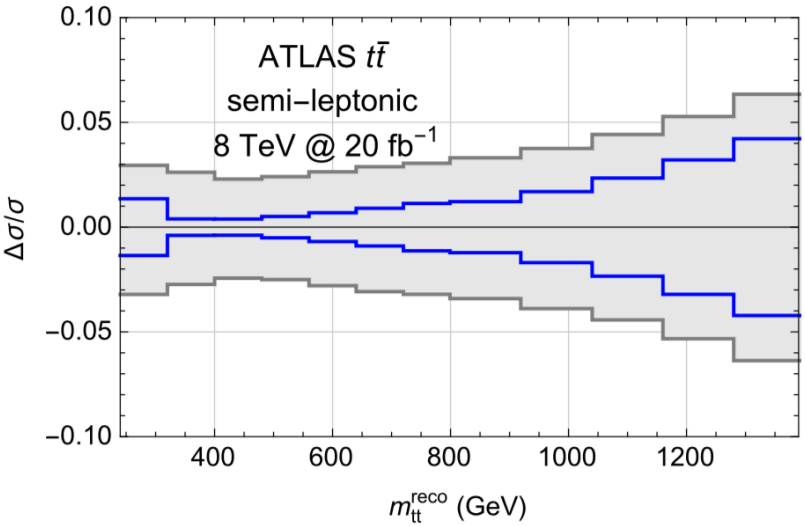
Slide from C. Wagner's plenary talk in Pheno 2016

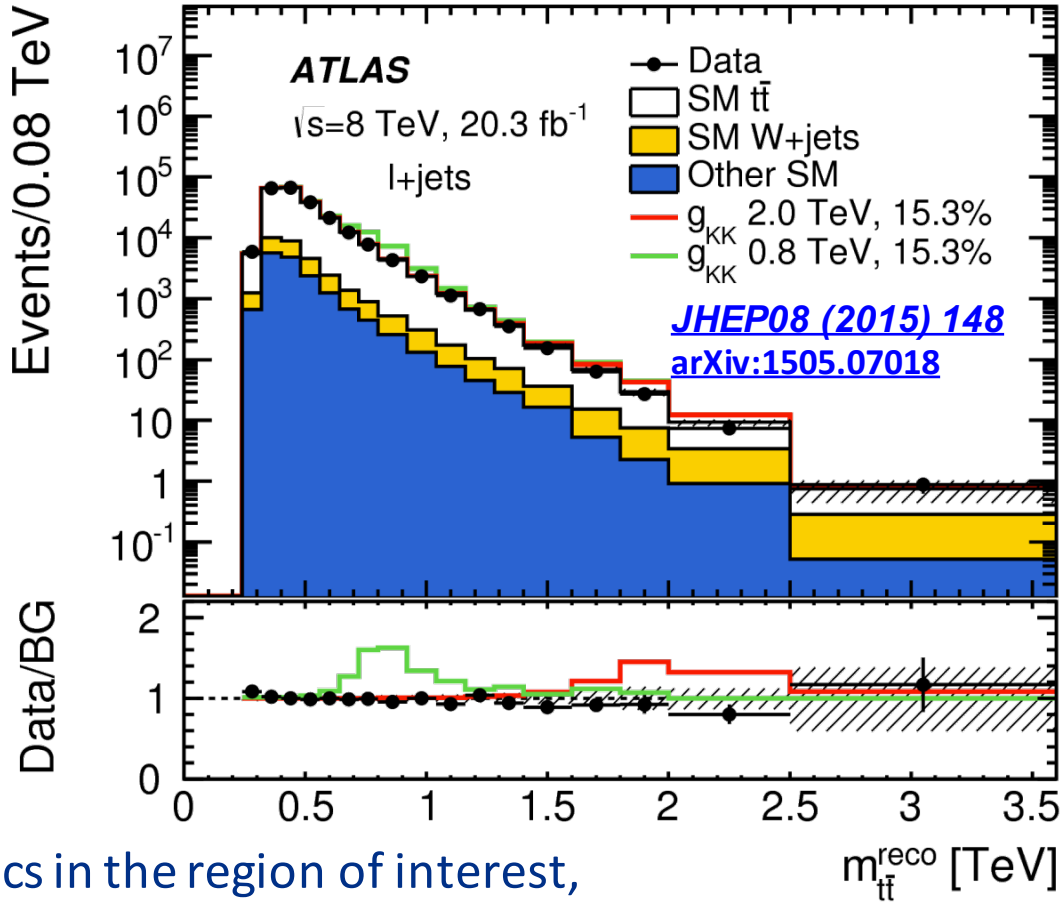
Craig, Draper, Erasmo, Thomas, Zhang '15





LHC perspectives

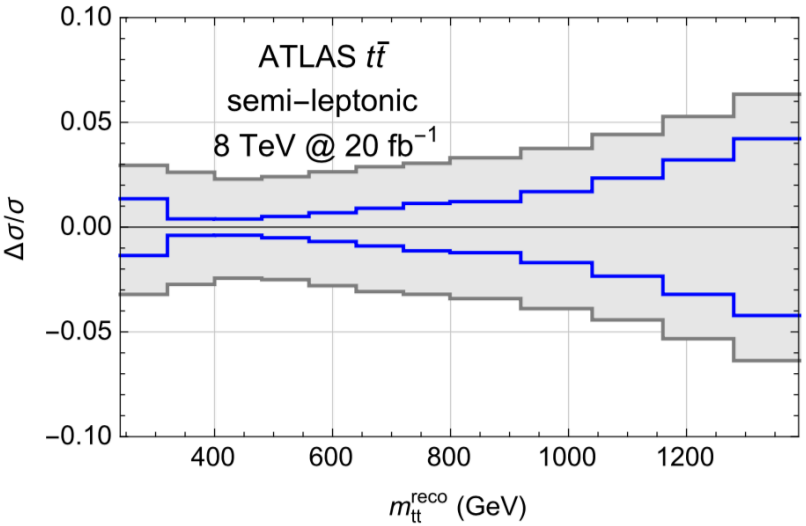


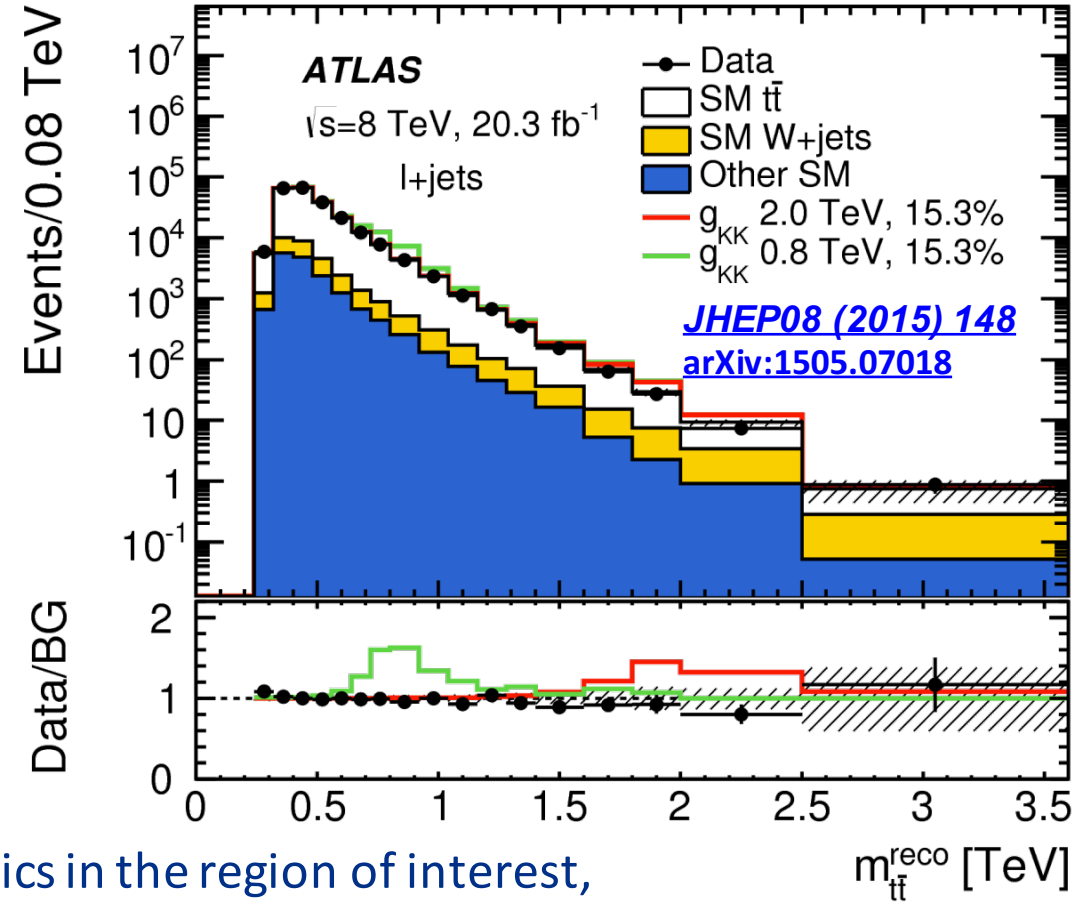


Already achieved sub 3% systematics in the region of interest, we see hope in this channel.

This is a crucial channel universally important for the understanding of heavy new resonances.

LHC perspectives





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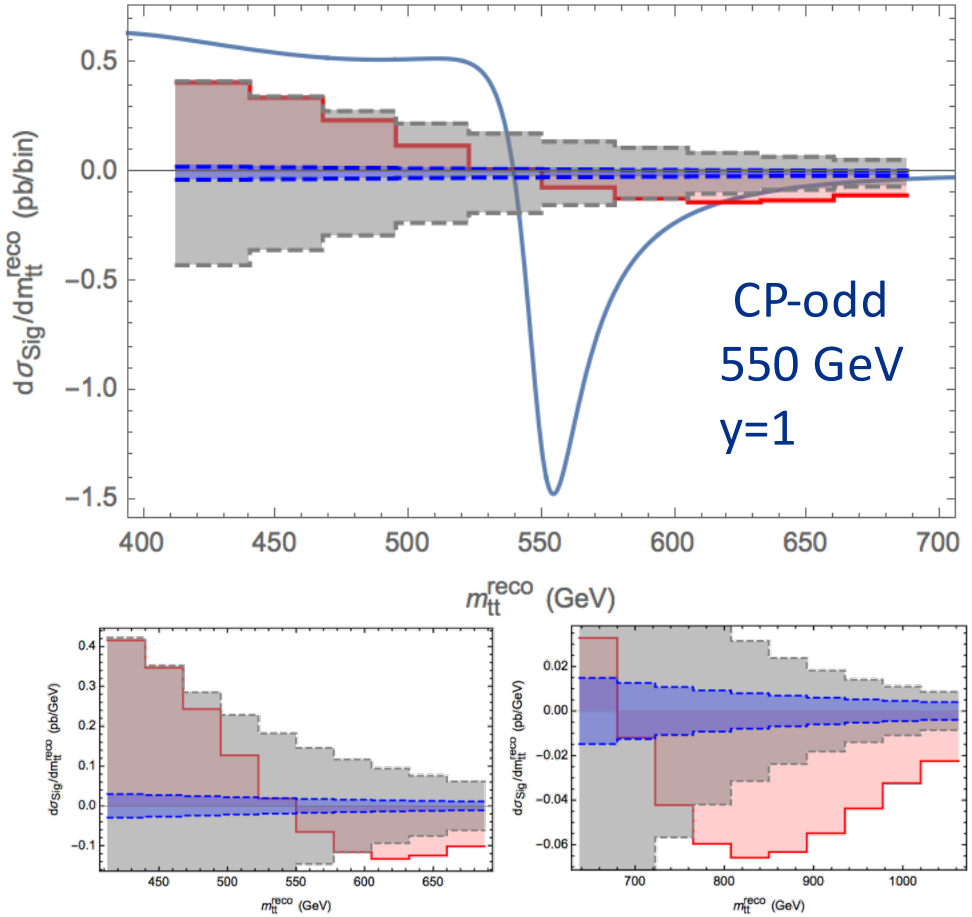
``Hitting a systematics wall'' (mentioned in yesterday's top session) is not an option, we need to try hard to improve the systematics by using the abundant data to calibrate and by selecting the data with best quality.

This is a crucial channel universally important for the understanding of heavy new resonances.

LHC perspectives

	$\Delta m_{t\bar{t}}$	Efficiency	Systematic Uncertainty
Scenario A	15%	8%	4% at 30 fb^{-1}, halved at 3 ab^{-1}
Scenario B	8%	5%	4% at 30 fb^{-1}, scaled with $\sqrt{L}$



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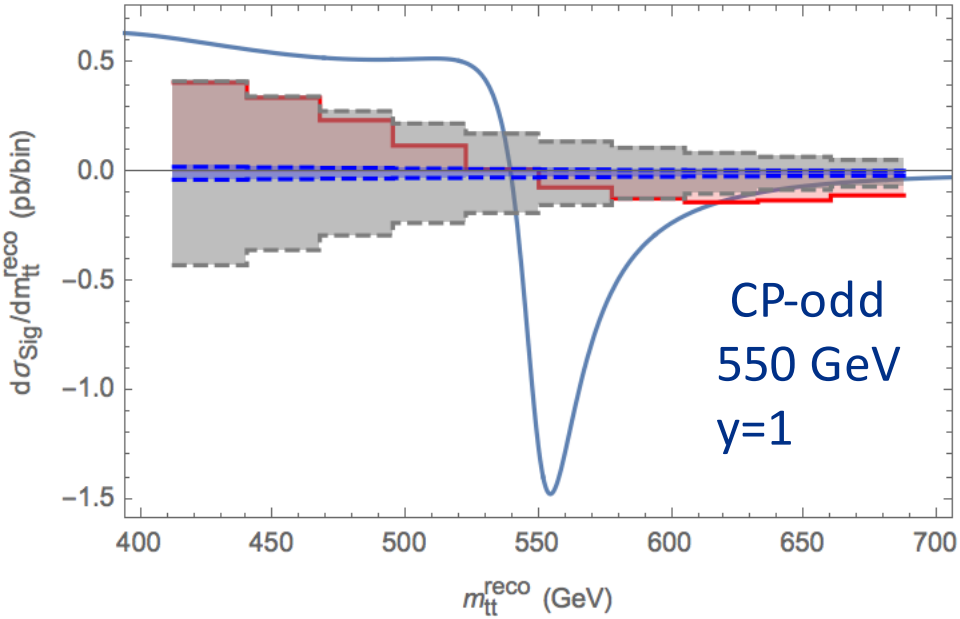
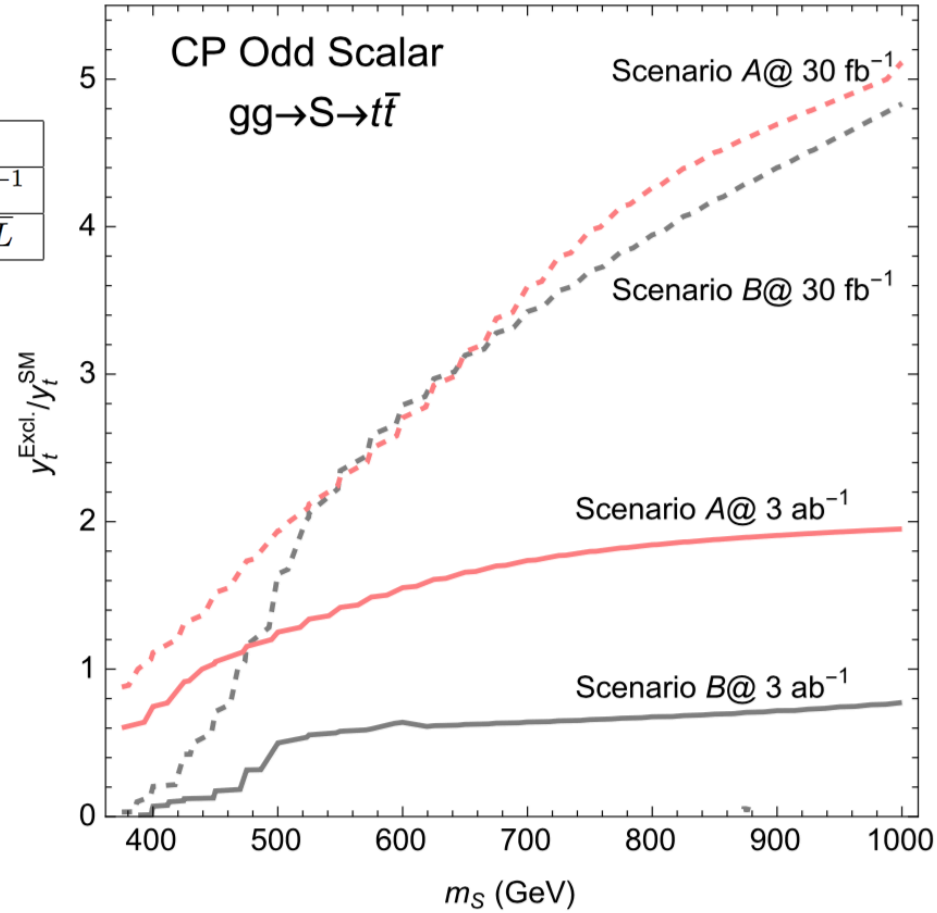
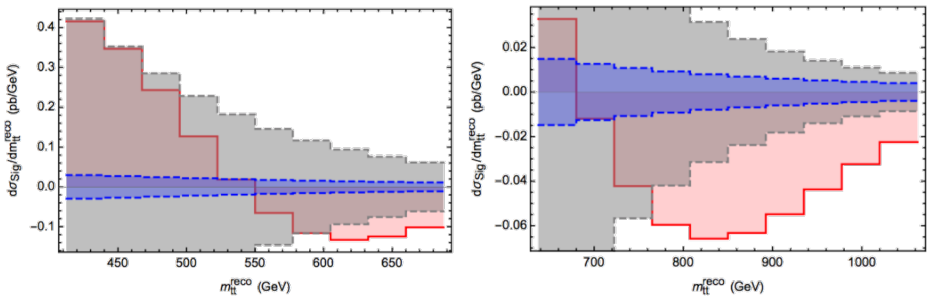






Lineshapes for a grid of mass and different Yukawas are generated (because the signal is line-shape and does not scale as simple powers of Yukawa couplings). **After smearing, using bins near the scalar mass window, taking both excess and deficits, exclusion potential extracted.**

Summary and outlook

gg->S->ttbar is a well—motivated channel for the hunt of heavy scalars

The interference effect augmented by the strong phase generated by the top loop generates funny shapes.

Opportunities to increase the observational aspects resides on both the theoretical side (including nearly degenerate bosons, CP phases, additional contributions form light quarks, and heavy colored particles) and experimental side (reducing the systematics with copious tops produced at the LHC, starting to face this challenge by using line-shape profile search, and move on from there.)

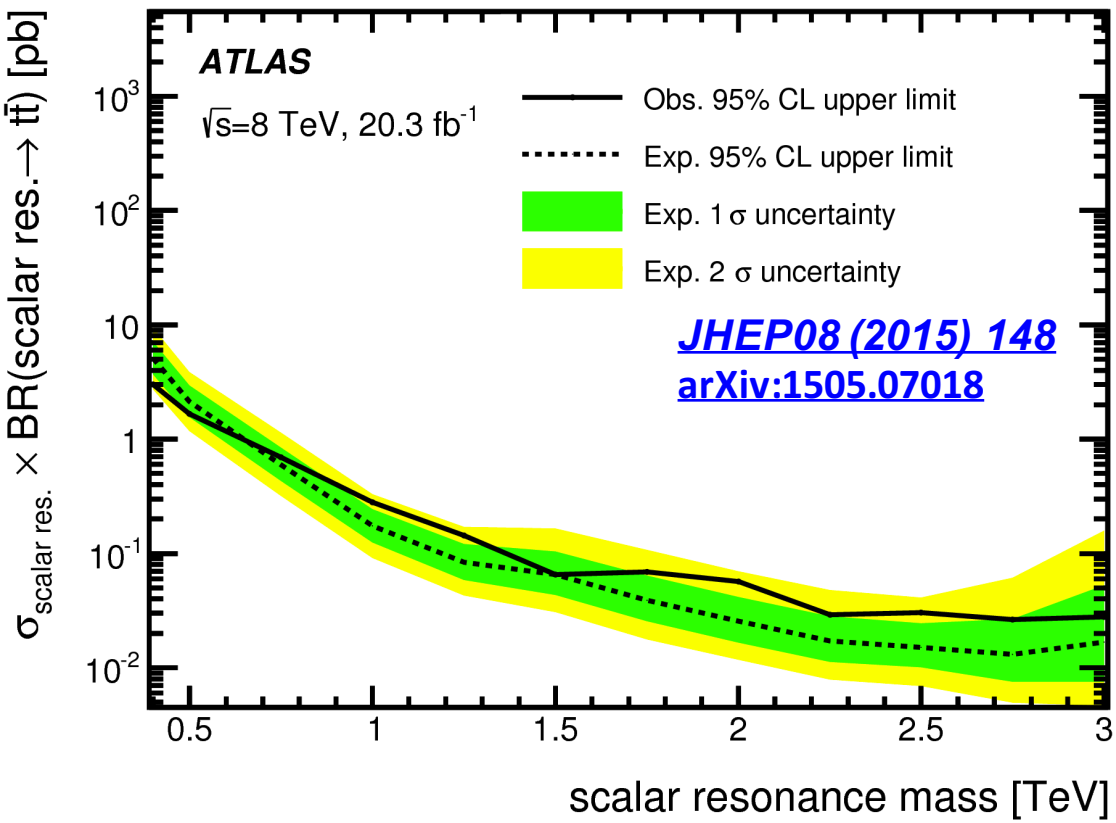
Other channels and effects, including ttH, tH (see in N. Craig, F. D'Eramo, P. Drapper, S. Thomas, H. Zhang **arXiv:1504.04630** and J. Hajer, Y.-Y. Li, T. Liu J. Shiu **arXiv:1504.07617**) and Hj and how stable such effects are against QCD corrections(see a case study in W. Bernreuther, P. Galler, C. Mellein, Z.-G. Si, P. Uwer **arXiv:1511.05584**), may have more potentials. Also other decay channels may have such effect large (see in Jung, Sung, Yoon, **arXiv:1510.03450**, **arXiv:1601.00006**).

This effect is important for 750 GeV and any new scalars couples to ttbar, especially for the case of better and better limits. (as the relative strength of the interference pieces increases relatively to the B.W. piece.)

Backup

2.4 Spin-0 colour singlet

The last class of models examined here produces colour-singlet scalar particles via gluon fusion which decay to $t\bar{t}$. The approach previously adopted by the CMS Collaboration [18] is followed, in which narrow scalar resonance benchmarks are generated while the interference with SM $t\bar{t}$ production is neglected. Even though such signals with negligible interference are not predicted by any particular BSM model, they can be used to evaluate the experimental sensitivities and set upper limits on the production cross-sections. The CMS Collaboration excluded such resonances with production cross-sections greater than 0.8 pb and 0.3 pb for masses of 500 and 750 GeV, respectively.



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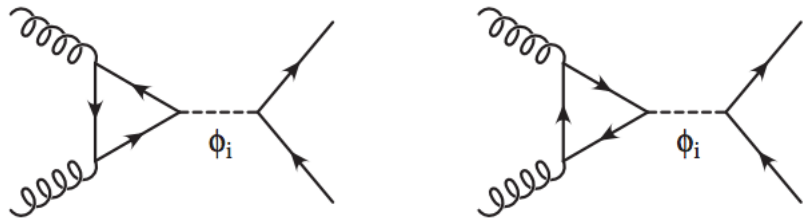

background