Higgs Boson and SM interferences in MCFM.

see 1107.5569

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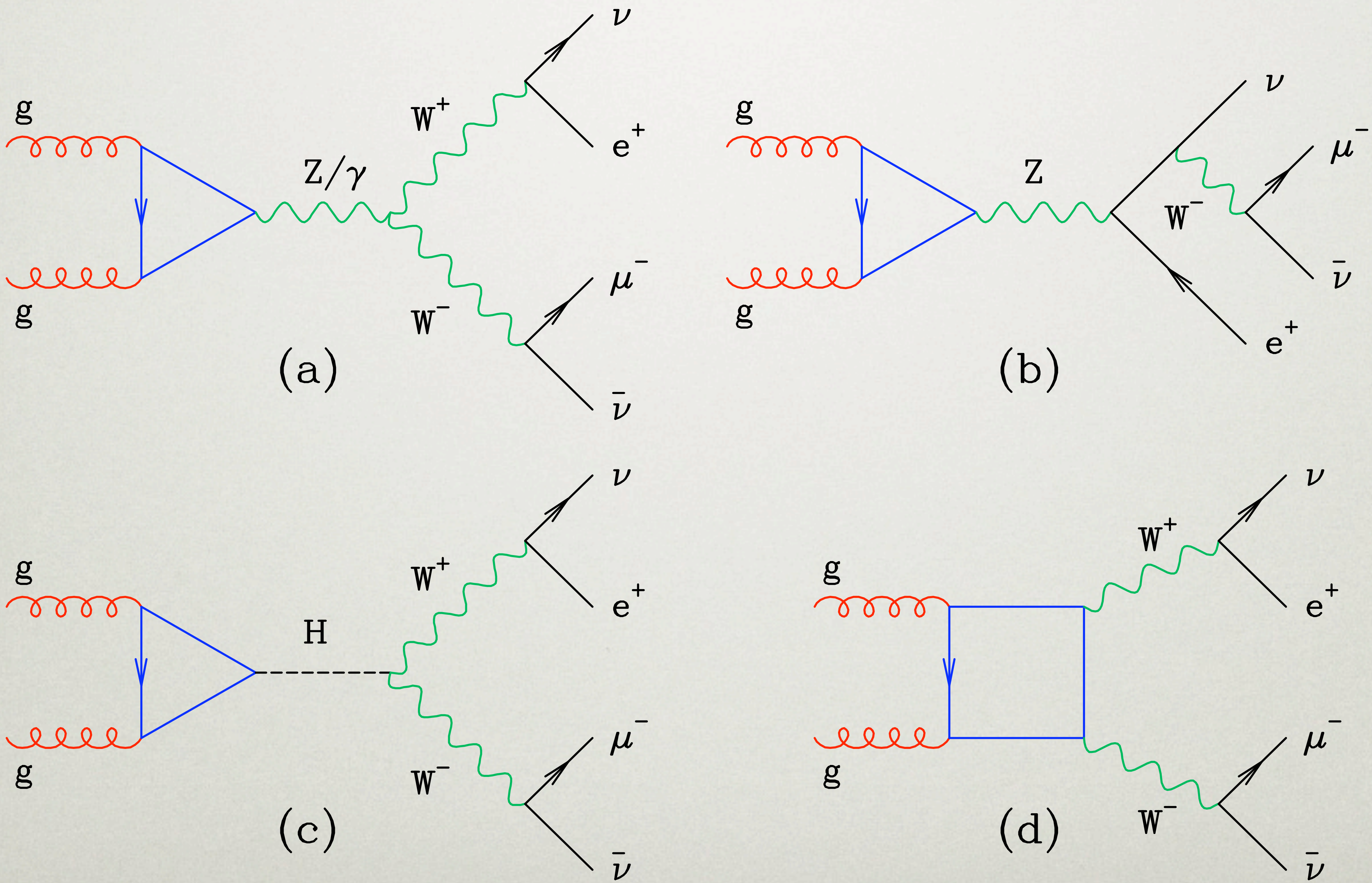
Higgs boson Processes in MCFM

- MCFM is a parton level MC code.
- Contains many EW + jets processes at NLO including :
- gg=>Higgs => (ZZ,WW, 2 gamma, bb) + 0,1,2 jets (NLO)
- VBF, Associated Higgs production (NLO)
- Diboson pp=> VV (including gg initiated loops WW full result, ZZ 5 massless flavours.

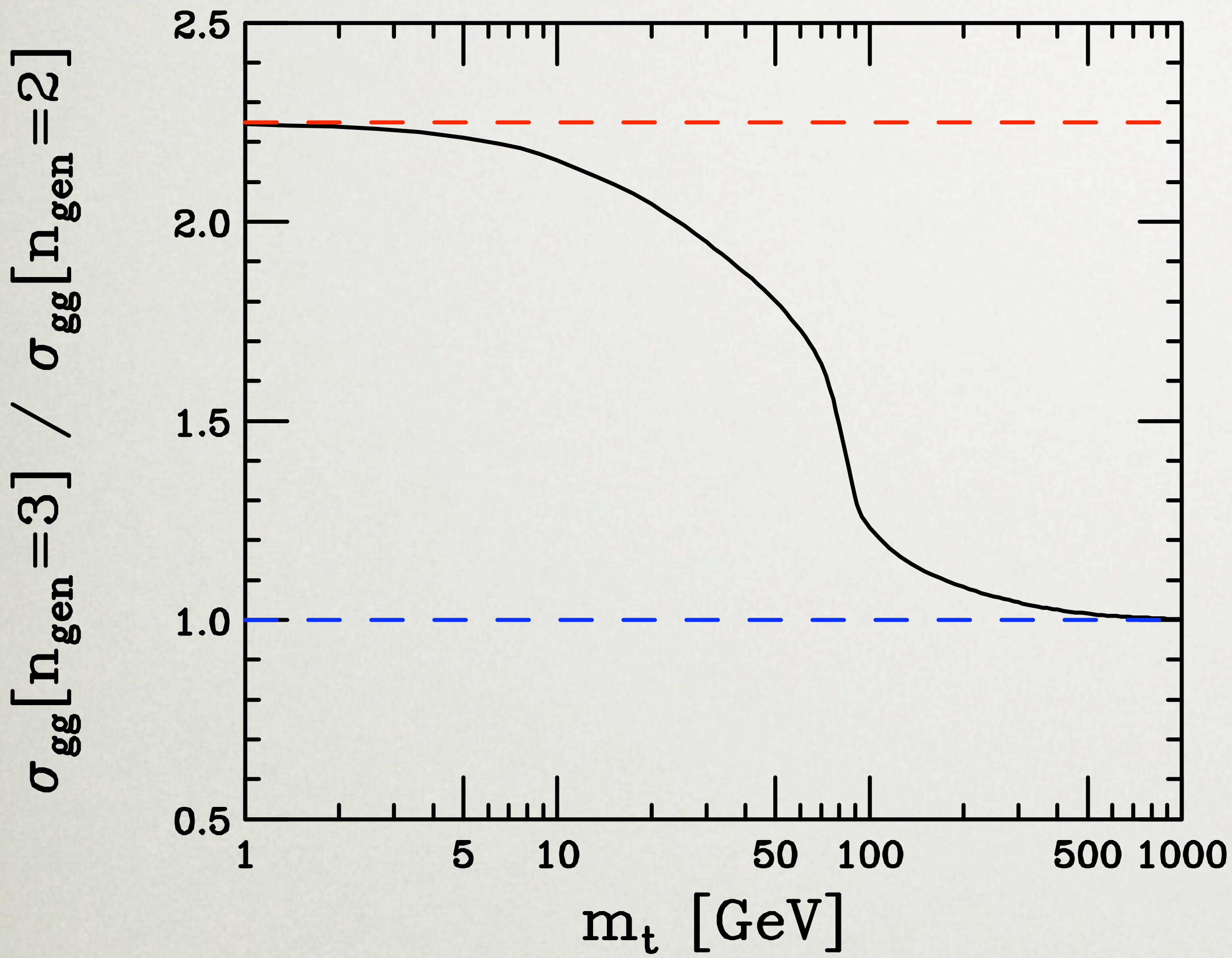
WHATS NOT IN MCFM?

- Of course MCFM doesn't do everything!
- Compared to some dedicated Higgs codes we are an order in perturbation theory behind (i.e. no NNLO or resummation in Higgs production). Note no NLO interference calculation yet.
- No gg=>ZZ * gg=> H=>ZZ interference, for reasons I will discuss in this talk. We don't have the top loop so including the interference may be unreliable...

GG Initiated WW Loops



3rd Generation Results



- Impact of the 3rd generation loop is very small at the level of total cross sections.

$\sqrt{s}$ [TeV]	1.96 ($p\bar{p}$)	7	8	10	12	14
$\sigma_{gg}[n_{\text{gen}} = 2]$	0.460(0)	13.74(1)	18.19(1)	28.37(2)	40.06(3)	52.99(4)
$\sigma_{gg}[n_{\text{gen}} = 3]$	0.490(1)	15.16(1)	20.12(2)	31.61(3)	44.84(4)	59.59(4)
$\sigma_{gg}[n_{\text{gen}} = 3]/\sigma_{gg}[n_{\text{gen}} = 2]$	1.065	1.103	1.106	1.114	1.119	1.125
σ_{tot}^{NLO}	134.6(2)	539(1)	657(1)	904(1)	1162(1)	1429(2)
$\sigma_{gg}[n_{\text{gen}} = 3]/\sigma_{tot}^{NLO}$	0.0036	0.028	0.030	0.035	0.039	0.042

Defining Interference Quantities

$$\sigma_B \longrightarrow |\mathcal{A}_{\text{box}}|^2 \;, \qquad \mathcal{A}_{\text{box}} = 2\mathcal{A}_{\text{massless}} + \mathcal{A}_{\text{massive}} \;,$$

$$\sigma_H \longrightarrow |\mathcal{A}_{\text{Higgs}}|^2 \;,$$

$$\sigma_i \longrightarrow 2\text{Re}\left(\mathcal{A}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right) \;,$$

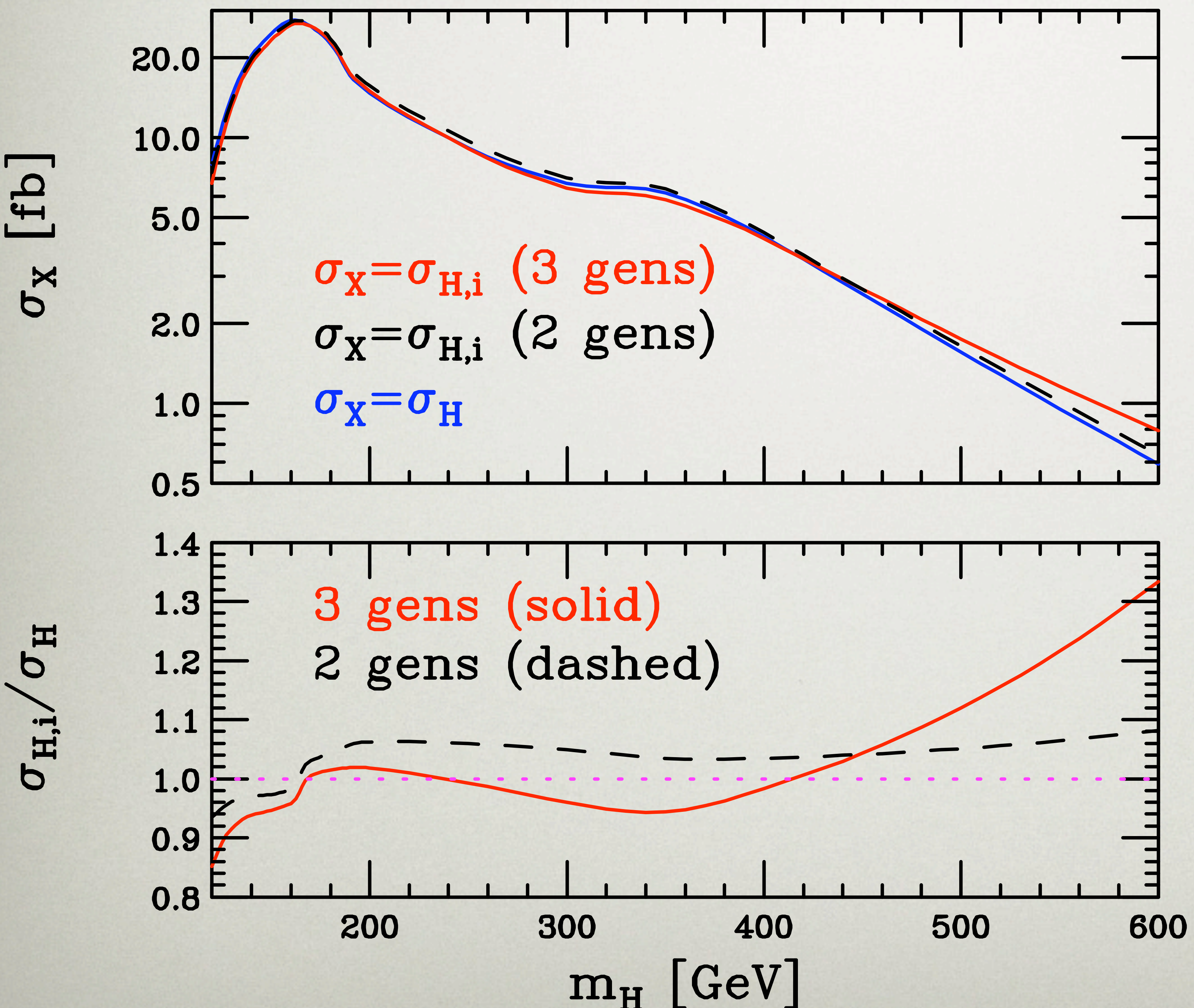
$$\sigma_{H,i} \;=\; \sigma_H + \sigma_i \;.$$

Typically experimental collaborations work with the first two quantities (with the Higgs cross section at NNLO)

Aim is to estimate the impact of neglecting the interference, i.e. we define the ratio of $\sigma_{H,i}$ to σ_H as the relative change in the expected signal (i.e. number of Higgs containing events) due to the interference

Higgs widths are calculated using HDECAY (Djouadi, Kalinowski, Spira 98)

Higgs Interference at the LHC

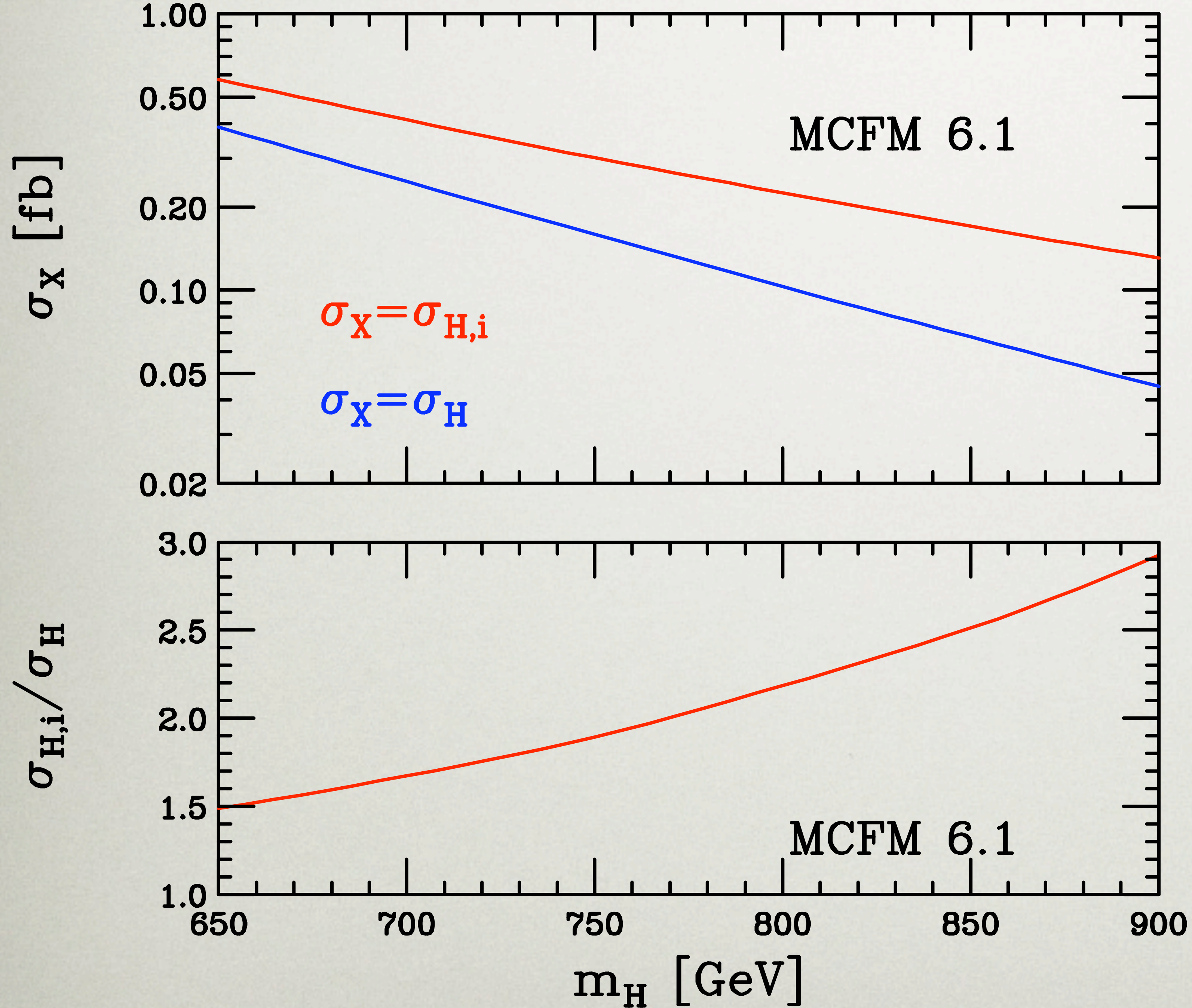


LHC at 7 TeV, no final state lepton cuts.

Clearly including only the first two generations does a miserable job of describing the full interference effects.

Interference is dynamic in Higgs mass with local maxima and minima at WW and tt thresholds.

The (very) Heavy Higgs Realm.



- For a very heavy Higgs the interference term dominates in the "signal" part of the cross section.
- Note the effect on the total cross section is always constructive.

Structure of the int.

- Could have anticipated much smaller effects by assuming that the interference was proportional to the width i.e.

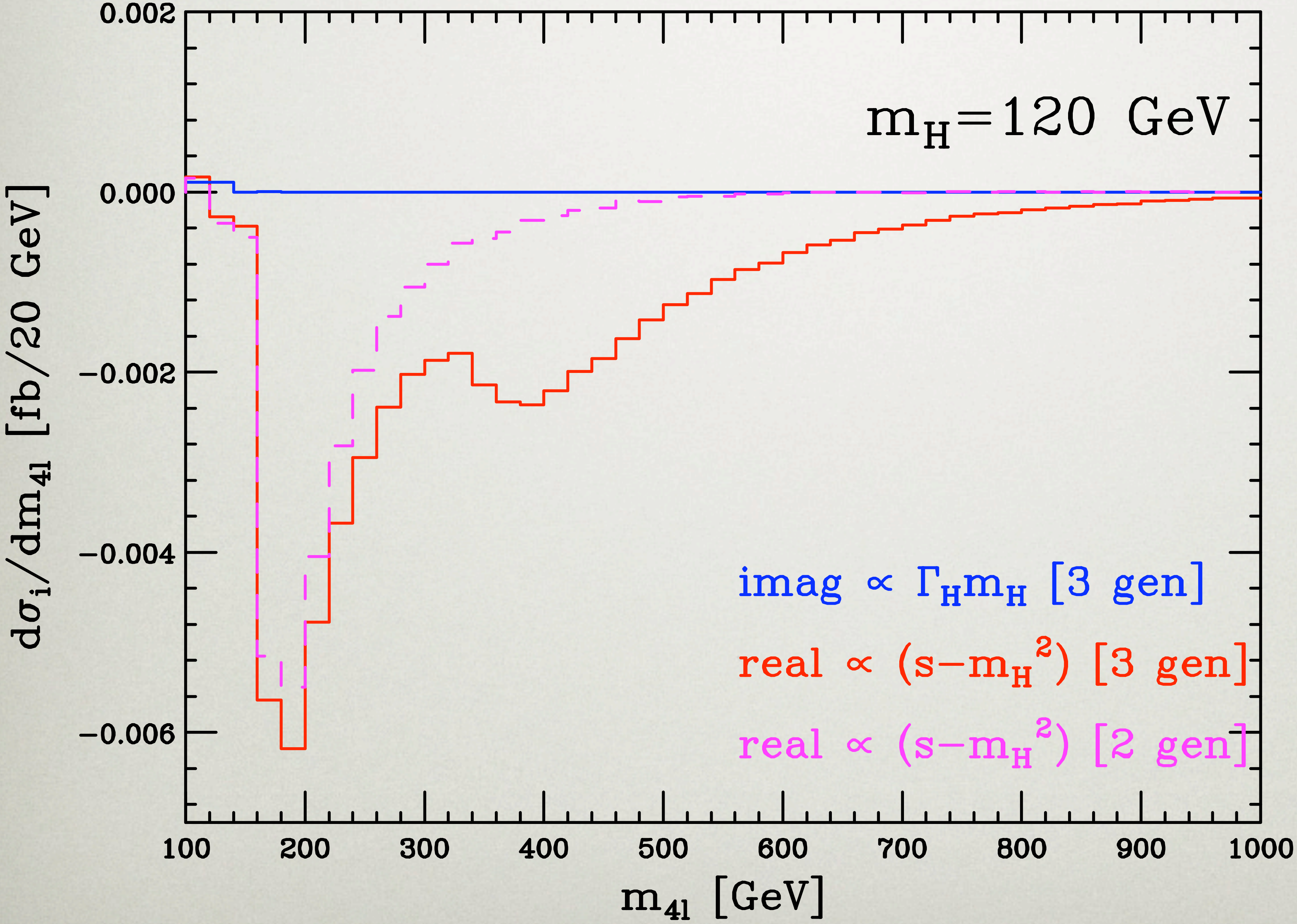
$$\delta\sigma_i = \frac{(\hat{s} - m_H^2)}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2} \mathfrak{Re}\left\{2\widetilde{\mathcal{A}}_{\text{Higgs}}\mathcal{A}_{\text{box}}^*\right\} + \frac{m_H\Gamma_H}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2} \mathfrak{Im}\left\{2\widetilde{\mathcal{A}}_{\text{Higgs}}\mathcal{A}_{\text{box}}^*\right\}$$

- Clearly first term in the above is odd (in s) around the Higgs mass, if we integrate in s there will be a net cancellation between regions above and below threshold

- This argument works provided that the functional form of s in the region we integrate over is fairly flat.

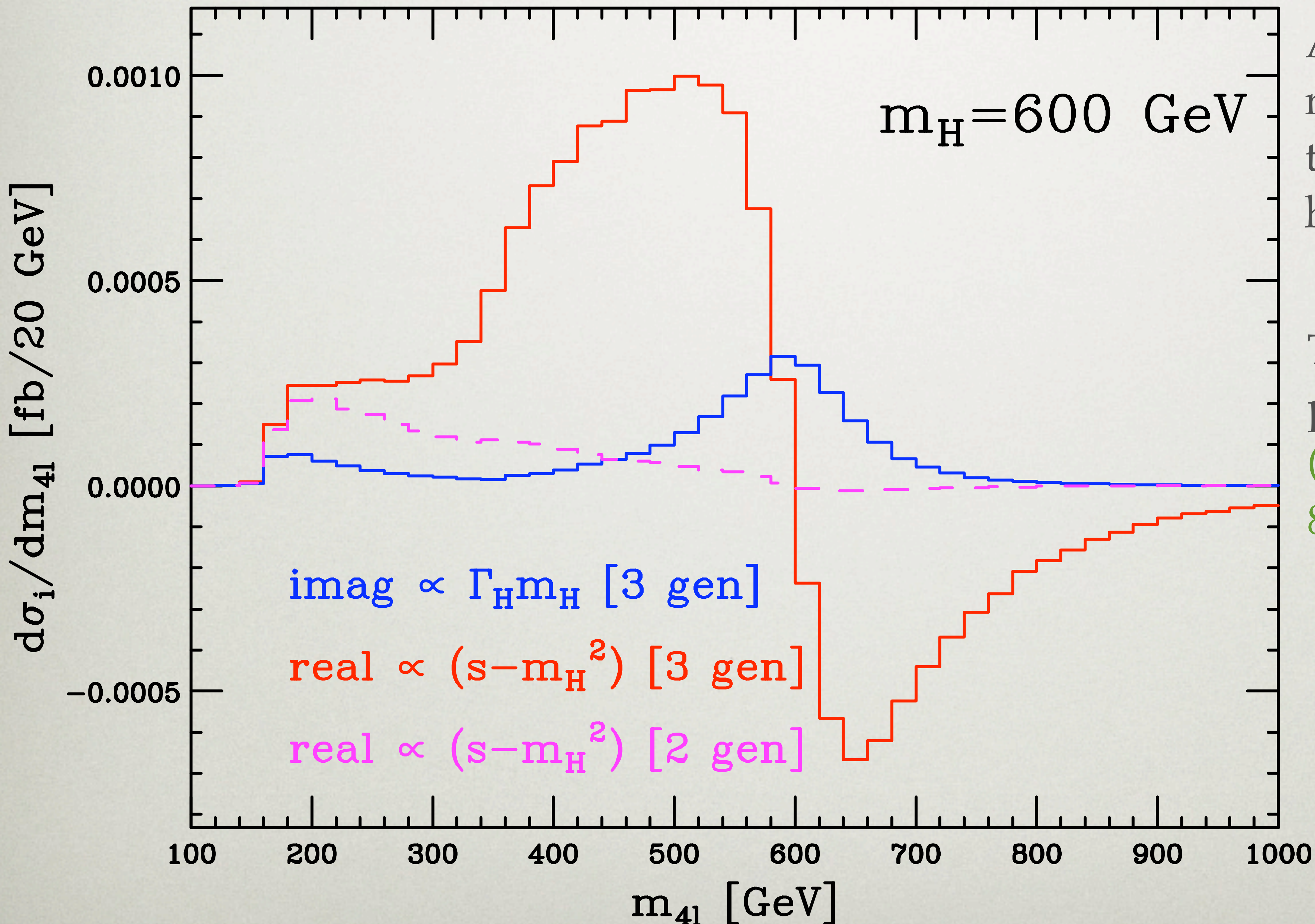
- This is the case for golden channel type modes e.g. Interference effects in di-photon channel (Dixon, Siu 03)

Real and Imaginary B.W.



Two pieces of the interference plotted separately. Results for 2 massless generations are shown in magenta for the real pieces

More Re and Im B.W.

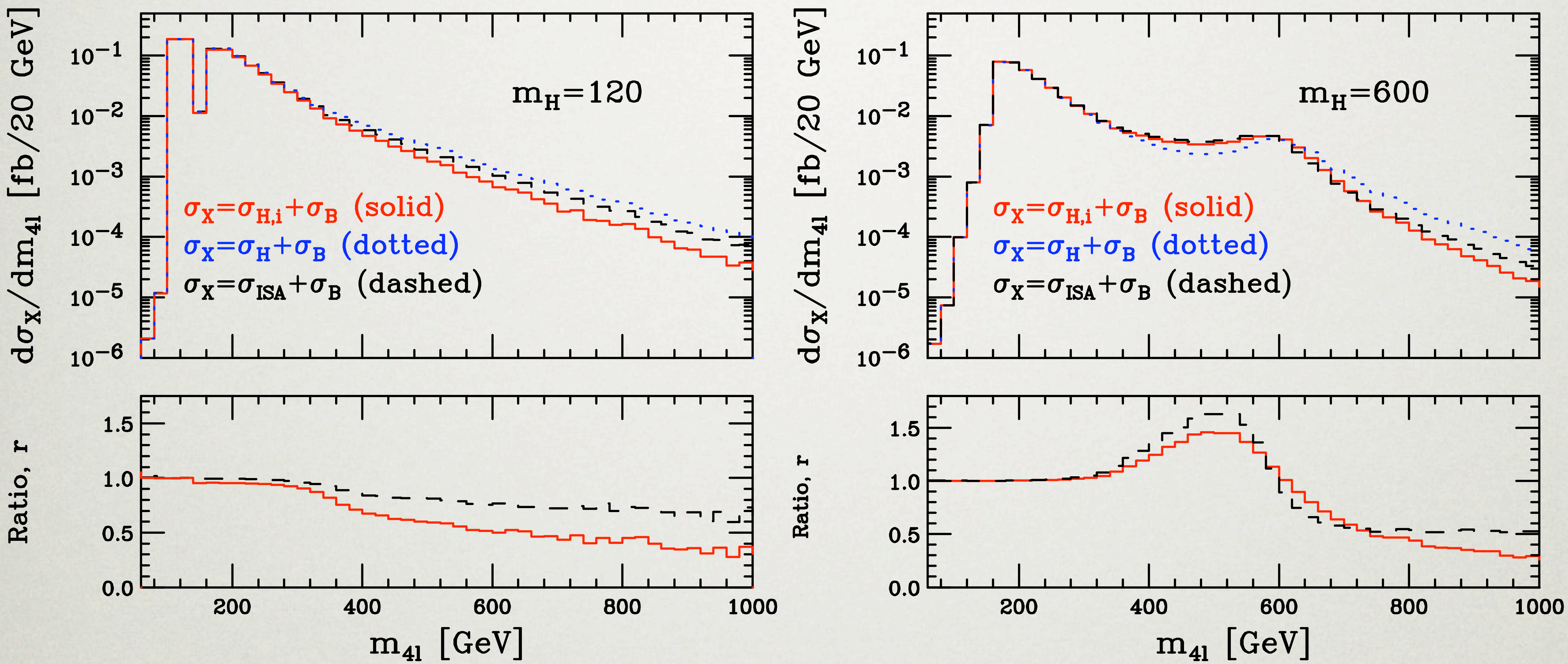


Although there is a net constructive effect the interference still has a destructive tail

This is essential to preserve unitarity (Glover, van der Bij 89)

Destructive interference ensures correct behaviour in $\log^2(s/m_t^2)$

Invariant mass of the four leptons



For comparison we have also presented the results with no interference but with the improved s-channel approximation (Seymour 95)

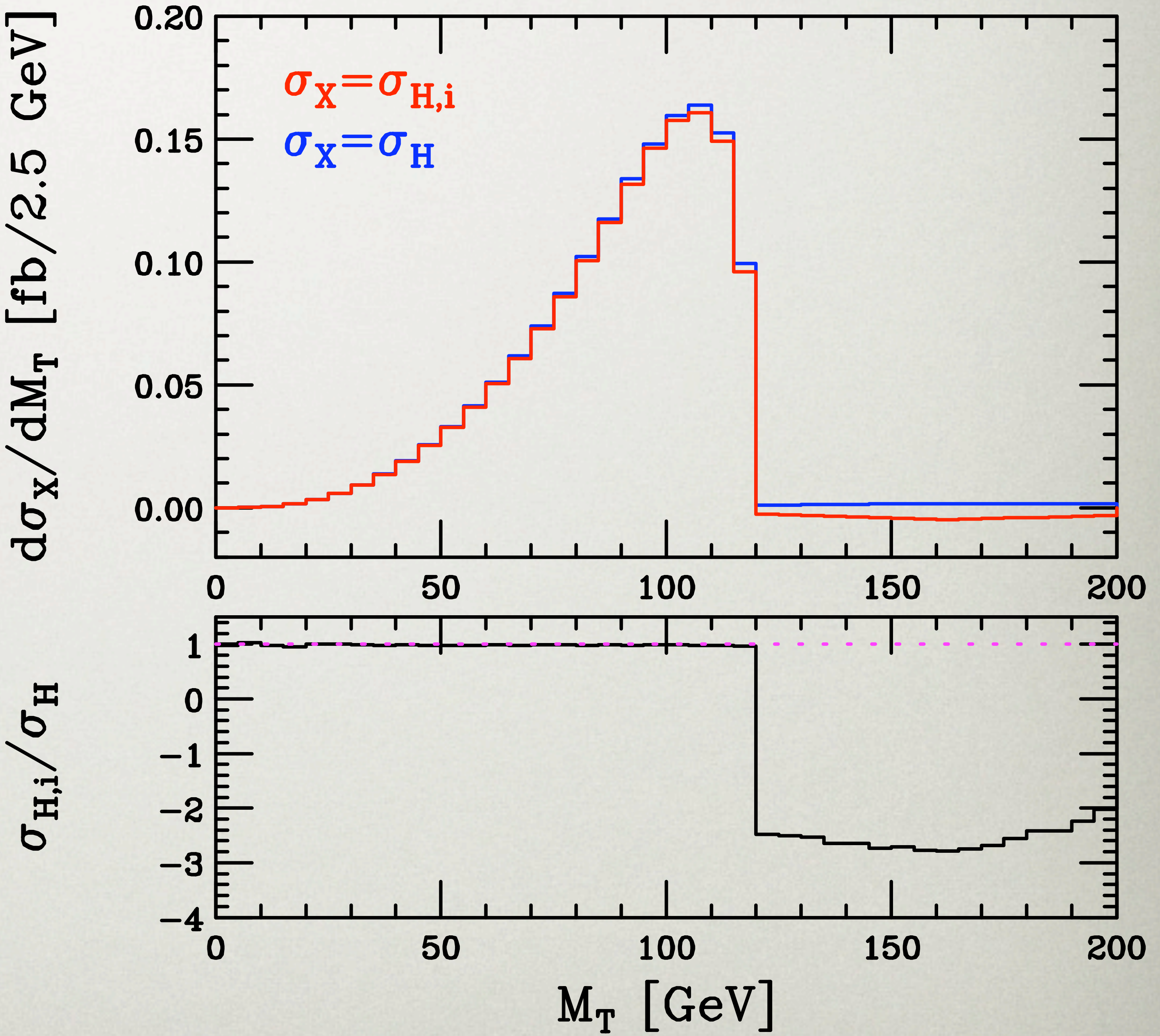
$$\frac{i\hat{s}}{\hat{s}-m_H^2} \rightarrow \frac{im_H^2}{\hat{s}-m_H^2+i\Gamma_H(m_H)\frac{\hat{s}}{m_H}}$$

Transverse Mass dist.

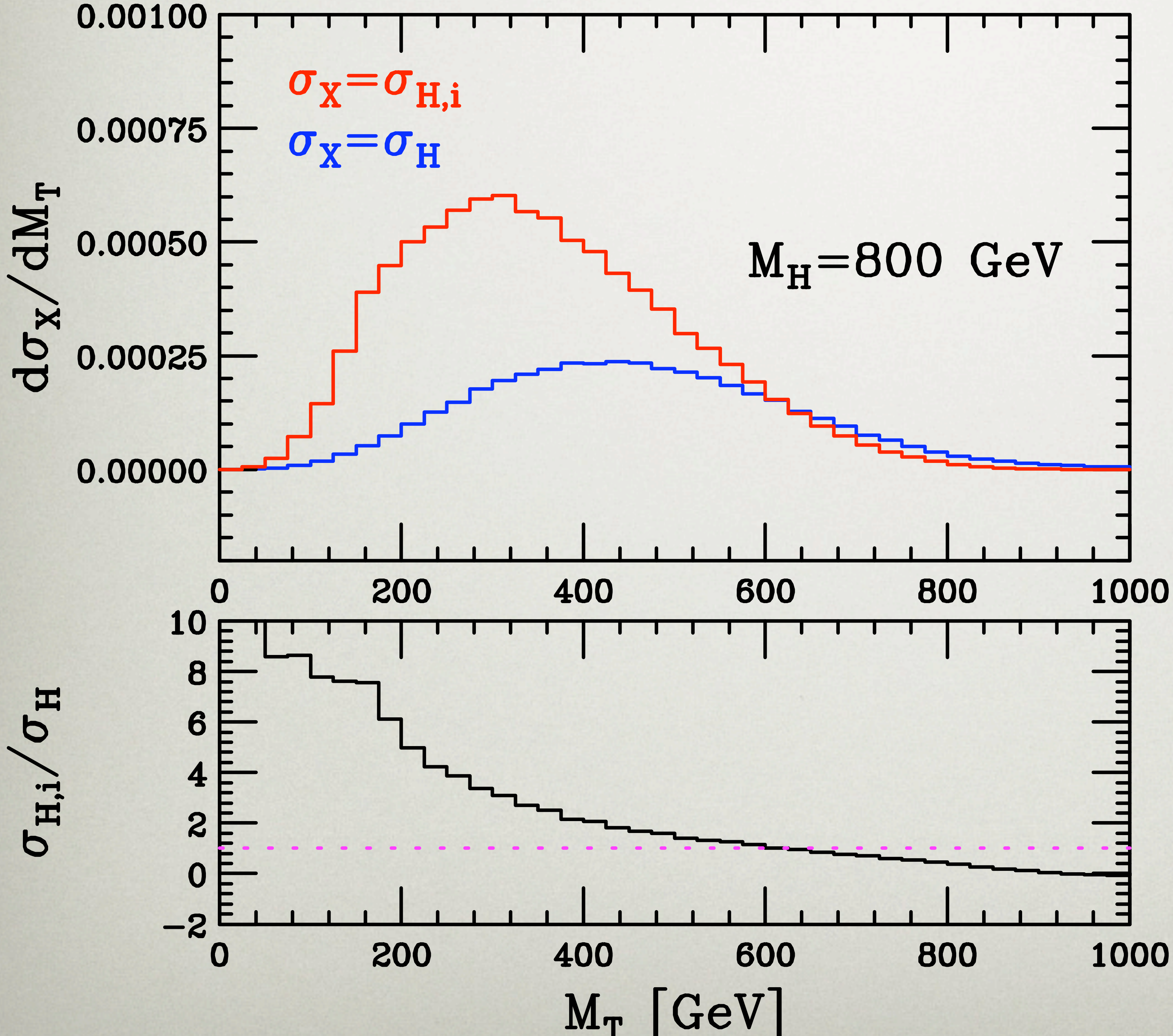
- Define the transverse mass as,

$$M_T = \sqrt{(E_T^{\ell\ell} + E_T^{\rm miss})^2 - (\mathbf{p}_T^{\ell\ell} + \mathbf{p}_T^{\rm miss})^2}$$

- Where
- $$E_T^{\ell\ell} = \sqrt{(\mathbf{p}_T^{\ell\ell})^2 + m_{\ell\ell}^2}.$$
- As a result the cut removes destructive region in the light Higgs case.



Transverse mass for Heavy Higgs



- Again tail is destructive (mandatory)
- Lower region shows considerable enhancement, (dwarfs NLO and NNLO K-factor in < 200 GeV).

Consolidation with NNLO

- A natural question arises about how to incorporate the LO results presented here with the NNLO cross section
- Simplest thing to do is to merely add as an absolute correction to the total cross section

$$\sigma_{H,i}^{NNLO} = \sigma_H^{NNLO} + (\sigma_{H,i}^{LO} - \sigma_H^{LO})$$

- This is natural from a theory point of view, in which we are used to incomplete perturbation series. The K-factor going from LO to NNLO is large the resulting impact of the interference terms is reduced by a factor of two.
- Other option is to re-weight predictions by the ratio

$$\sigma_{H,i}^{NNLO} = \sigma_H^{NNLO} \left(\frac{\sigma_{H,i}^{LO}}{\sigma_H^{LO}} \right)$$

- Certainly if a conservative approach in limit setting is desired this is better to do in the destructive region (since the true NNLO interference terms are some way off...)

Summary

- Interference with SM dominates VV modes for heavy Higgs.
- Take home point : m4l < mH Constructive, m4l > mH Destructive as required by unitarity.
- In fully reconstructed modes, not so much of an issue for discovery, only in accurate lineshape modelling.
- In 2l2nu channel more problematic, effects all distributions and shapes => needs to be well modeled for believable limits.
- MCFM can provide this for WW. (Signal (NLO) + background (NLO) + Signal*background (LO)).
- The calculation in MCFM is very fast, plots for this talk made in a few minutes.