Higgs + 2 jets via gluon fusion

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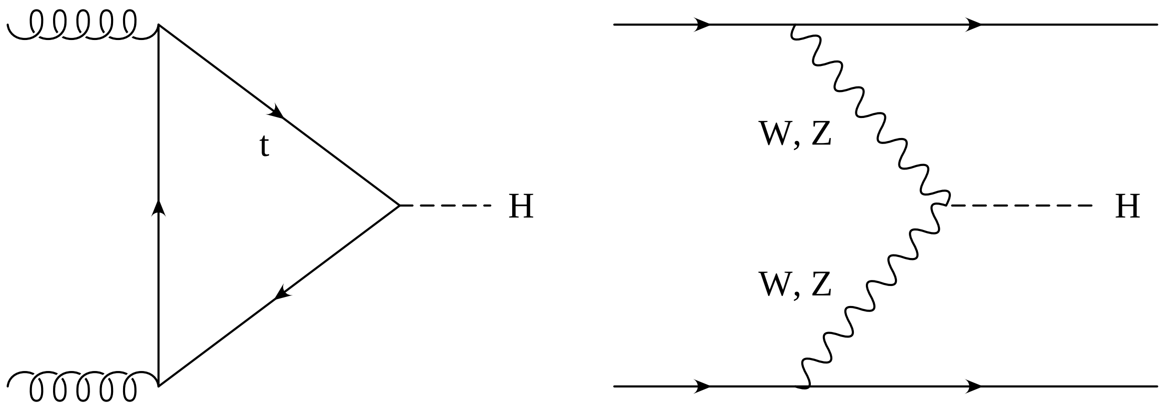
Introduction



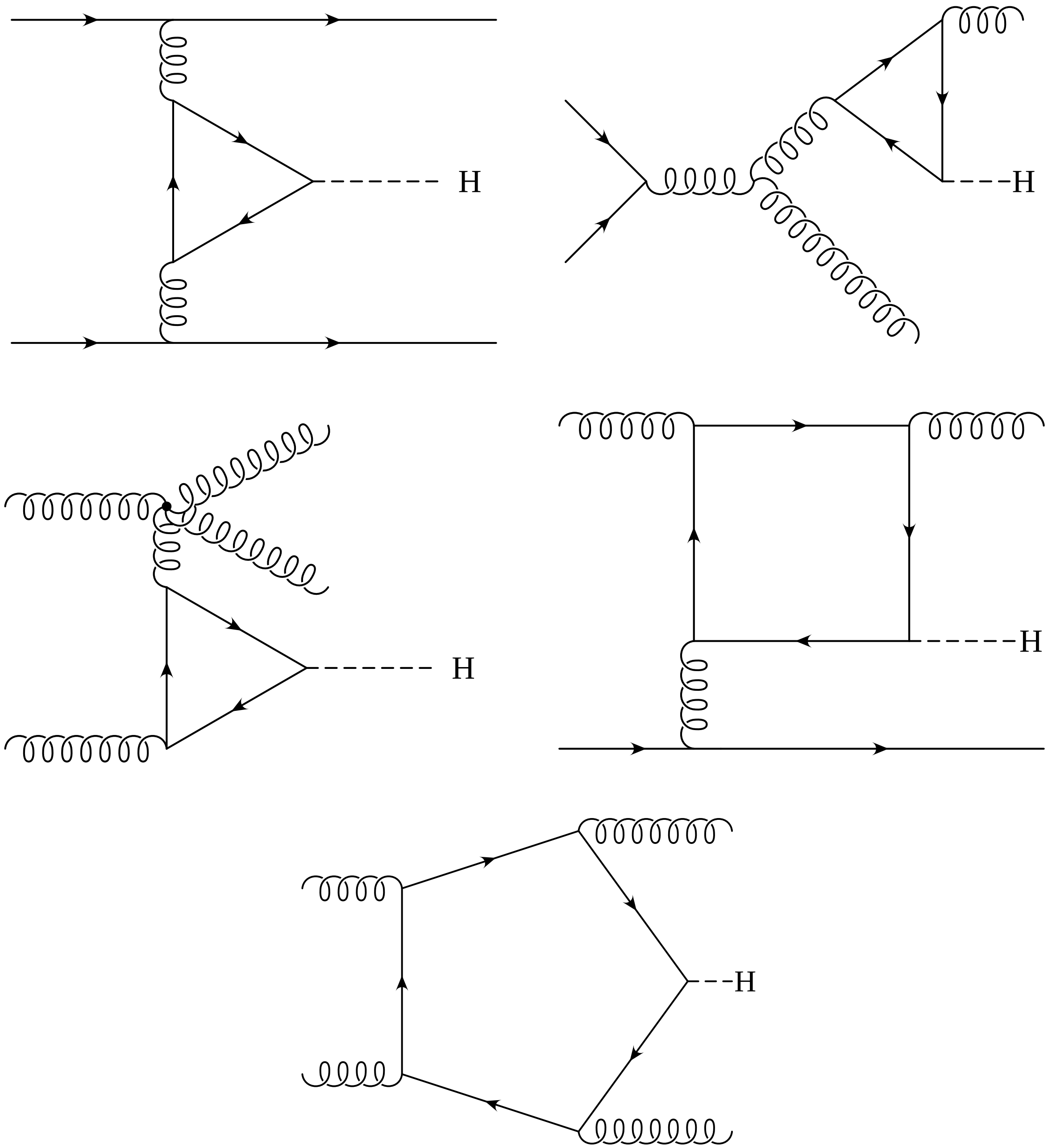
At values of $m_H > 100\ \mathrm{GeV}$, and at LHC energies, these are the two dominant processes for Higgs production: gg fusion and weak-boson fusion (WBF).

WBF, characterized by two forward-backward jets, is important for the extraction of Higgs couplings with gauge bosons.

Double real corrections to $gg \to H$ can "fake" WBF $\Longrightarrow$

- accurate evaluation of these corrections
- investigate the "goodness" of the large m_t limit.

Diagrams



$$
\begin{array}{ccc}
q\,Q & \to & q\,Q\,H \qquad\qquad Q = q, q' \\
q\,g & \to & q\,g\,H \\
g\,g & \to & g\,g\,H
\end{array}
$$

plus crossed processes.

Tensor integrals

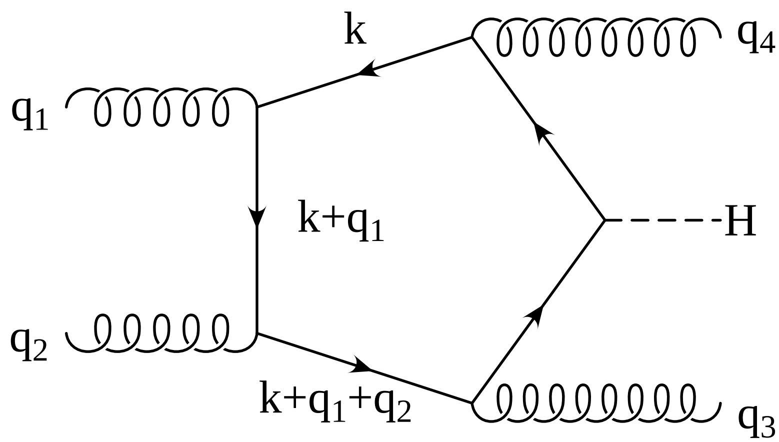
All the scalar integrals (triangles, boxes and pentagons) are finite (the top mass m_t protects from divergences)
$\Longrightarrow$ we work in $D = 4$ dimensions.

Due to the presence of the H vertex, we have for the tensor integrals

- triangles: at most two loop-momenta in the numerator $(k^\alpha k^\beta)$
- boxes: at most three loop-momenta in the numerator $(k^\alpha k^\beta k^\gamma)$
- pentagons: at most four loop-momenta in the numerator $(k^\alpha k^\beta k^\gamma k^\delta)$

For triangles and boxes we directly apply Passarino-Veltman formulae and we express the tensor integrals in the amplitudes as combination of scalar triangles and boxes.

Tensor pentagons



Write the polarization vectors of the external gluons as a linear combination of external momenta. For the i-th gluon we have

$$\epsilon_i = \epsilon_{i1}\, q_1 + \epsilon_{i2}\, q_2 + \epsilon_{i3}\, q_3 + \epsilon_{i4}\, q_4$$

and contract the amplitudes. In this way, the tensor integrals depend only on scalar products of the type $q_i \cdot q_j$ and $k \cdot q_i$.

The ϵ_{ij} coefficients are computed from the knowledge of the products $\epsilon_i \cdot q_j$, once one assigns a definite polarization for the gluons.

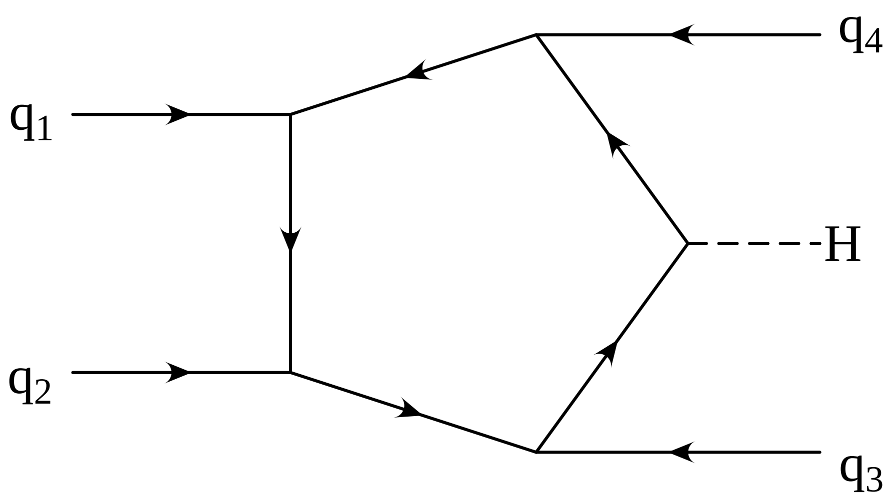
All dot-products in the numerator of the tensor pentagons can be rewritten as a combination of propagators. For example:

$$k \cdot q_2 = \frac{1}{2} \left\{ \left[(k + q_1 + q_2)^2 - m_t^2 \right] - \left[(k + q_1)^2 - m_t^2 \right] \right\} - q_1 \cdot q_2$$

The tensor pentagons with 4 loop momenta in the numerator are written as a combination of

- tensor boxes with at most 3 loop momenta in the numerator $\Longrightarrow$ Passarino-Veltman tensor reduction formulae
- scalar pentagons

Scalar pentagons



It can be shown that the generic scalar pentagon in D dimension, P^D, can be written as

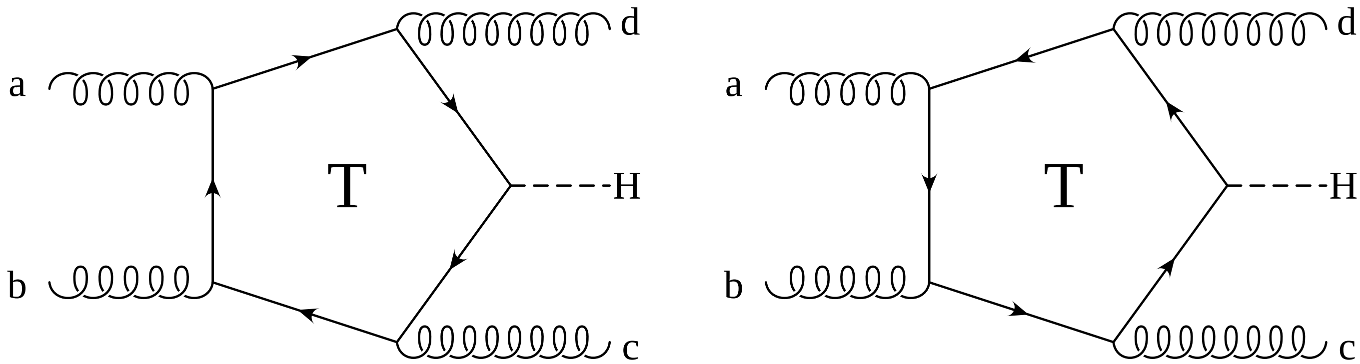
$$P^D(q_i \cdot q_j, m_t) = c_0\,(D-4)\,P^{D+2}(q_i \cdot q_j, m_t) + \sum_{k=1}^{5} c_k {B^D}_k(q_i \cdot q_j, m_t)$$

where B_k^D is the k-th box obtained by pinching the k-th propagator in the pentagon.

Since $P^6(q_i \cdot q_j, m_t)$ is finite, we can safely put $D = 4$ and the scalar pentagon can be rewritten in terms of box integrals only, in 4 dimensions.

Colour structure ($gg \to ggH$)

Pentagons



These two diagrams contribute

$$\mathrm{Tr}\left(t^a t^b t^c t^d\right) T + \mathrm{Tr}\left(t^d t^c t^b t^a\right) T$$

T is the same (Furry's theorem).

4 gluons $\Longrightarrow$ $4! = 24$ diagrams. But cyclic permutations give the same trace $\Longrightarrow 3! = 6$ non-cyclic permutations.

When we sum the pairs of diagrams with the same "tensor" part, we have only three independent colour structures

$$\begin{aligned} c_1 &= \mathrm{Tr}\left(t^a t^b t^c t^d\right) + \mathrm{Tr}\left(t^a t^d t^c t^b\right) \\ c_2 &= \mathrm{Tr}\left(t^a t^c t^d t^b\right) + \mathrm{Tr}\left(t^a t^b t^d t^c\right) \\ c_3 &= \mathrm{Tr}\left(t^a t^d t^b t^c\right) + \mathrm{Tr}\left(t^d t^c t^b t^d\right) \end{aligned}$$

Boxes and Triangles

They have two independent colour structures: $(c_1 - c_2)$ and $(c_1 - c_3)$.

$$\begin{aligned} c_1 - c_2 &= -\frac{1}{2} f^{abl} f^{cdl} \\ c_3 - c_1 &= -\frac{1}{2} f^{adl} f^{bcl} \\ c_2 - c_3 &= -\frac{1}{2} f^{acl} f^{dbl} \end{aligned}$$

Gauge-invariance checks

We will concentrate on the $gg \to ggH$ processes, being the most articulate.

GAUGE CHECK: the amplitude MUST vanish if we set

$$\epsilon_i \text{ proportional to } q_i$$

Two gauge checks

- QED-type check. If we substitute all the gluons with photons, only the pentagon contributions survive in the $\gamma\gamma \to \gamma\gamma H$ process.

  The other contributions being zero, due to the presence of three and four gluon vertices

  $\Longrightarrow$ the sum of the contributions coming from the tensor reduction of pentagon diagrams (with no colour structure) MUST vanish.

- full QCD check. When we add all the diagrams with all their colour structure.

Applied cuts

The cross section diverges for

- final-state partons become collinear with one another
- final-state partons become collinear with initial-state partons
- final-state partons become soft

- Minimal set of cuts to define $H + 2$ jets

$$p_{Tj} > 20 \text{ GeV} \qquad |\eta_j| < 5 \qquad R_{jj} > 0.6$$

where R_{jj} describes the separation of the two partons in the pseudo-rapidity versus azimuthal angle plane.

$$R_{jj} = \sqrt{(\eta_{j_1} - \eta_{j_2})^2 + (\phi_{j_1} - \phi_{j_2})^2}$$

- WBF set of cuts. In addition to the previous ones, we impose

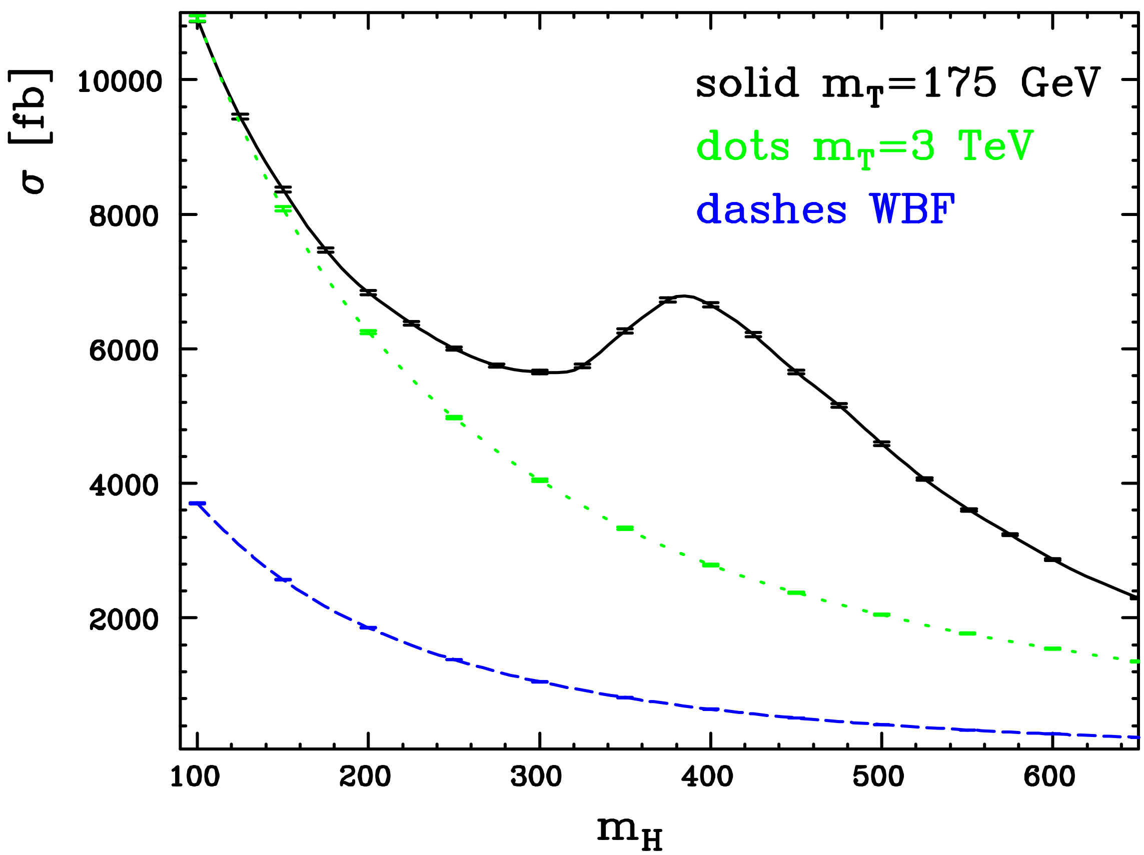
$$|\eta_{j_1} - \eta_{j_2}| > 4.2 \qquad \eta_{j_1} \cdot \eta_{j_2} < 0 \qquad m_{jj} > 600 \text{ GeV}$$

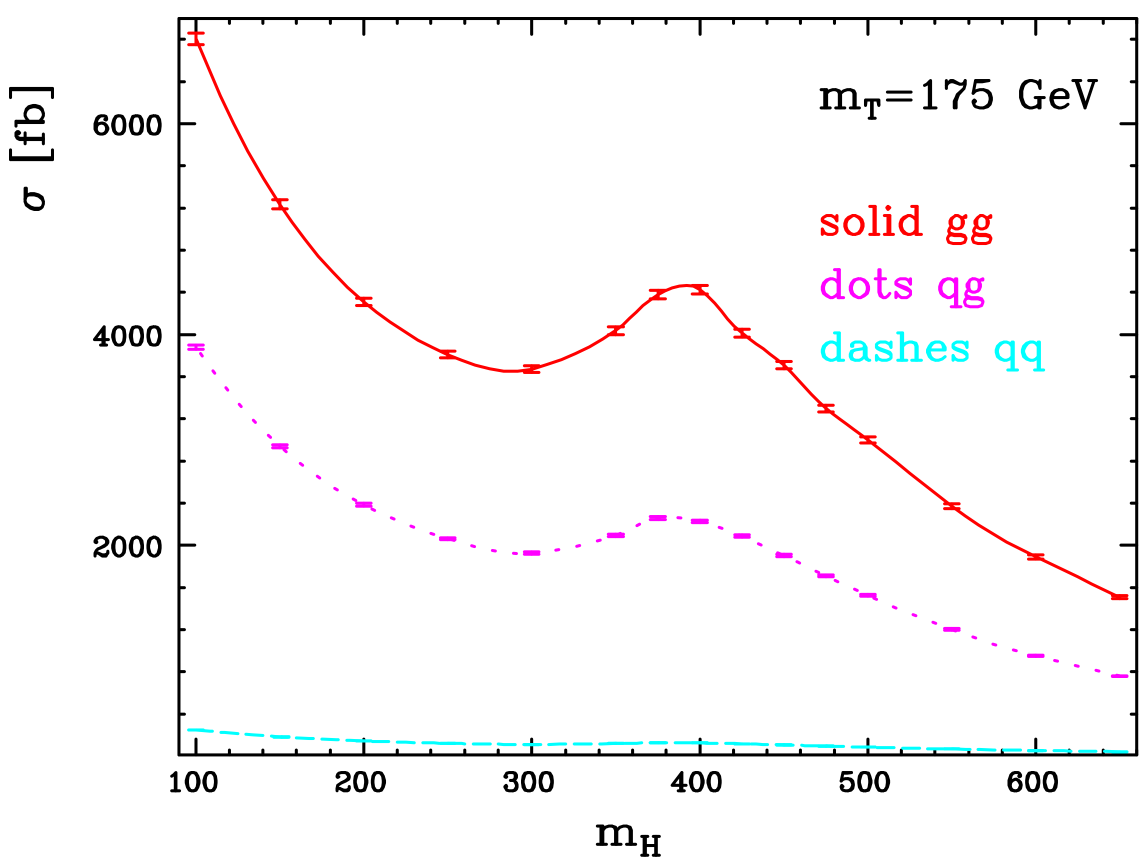
  – the two tagging jets must be well separated, with 3 units of pseudo-rapidity between the jet definition cones
  – they must reside in opposite detector hemispheres
  – they must possess a large dijet invariant mass.

ALL THE RESULTS FOR LHC ENERGY

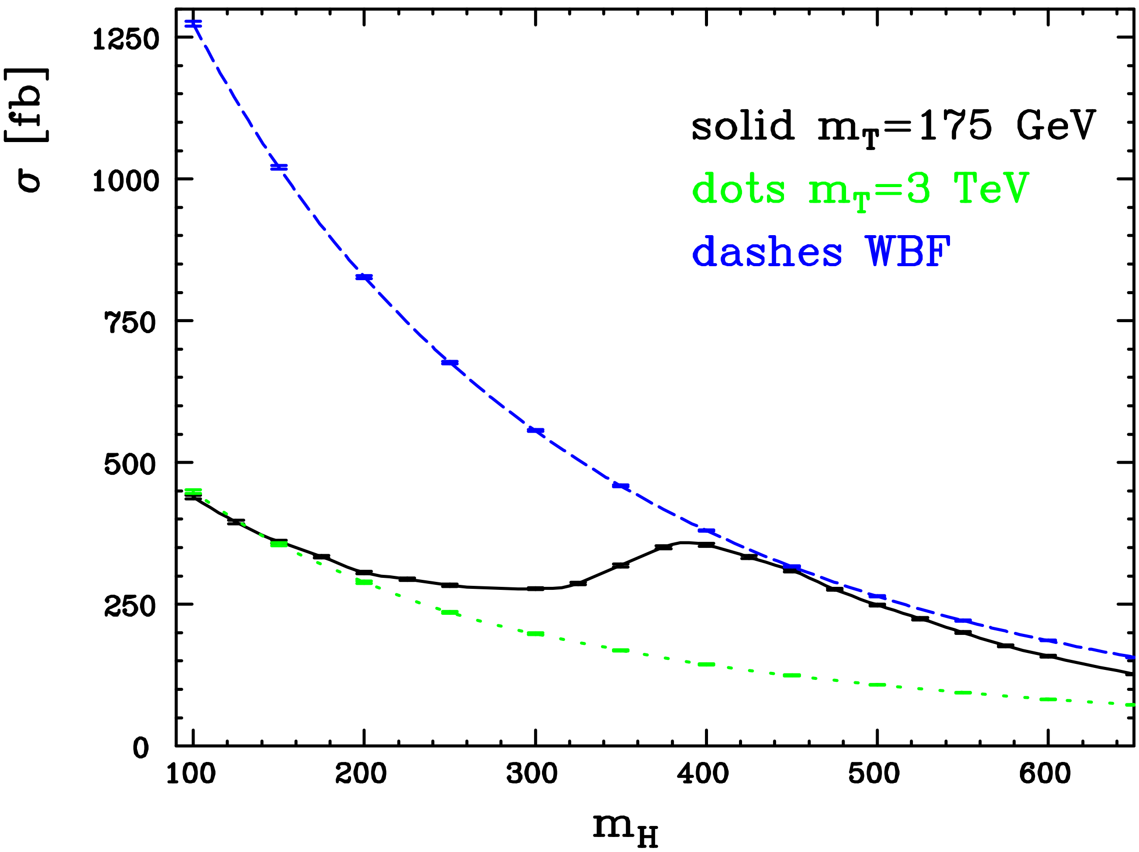
Total cross section: minimal cuts

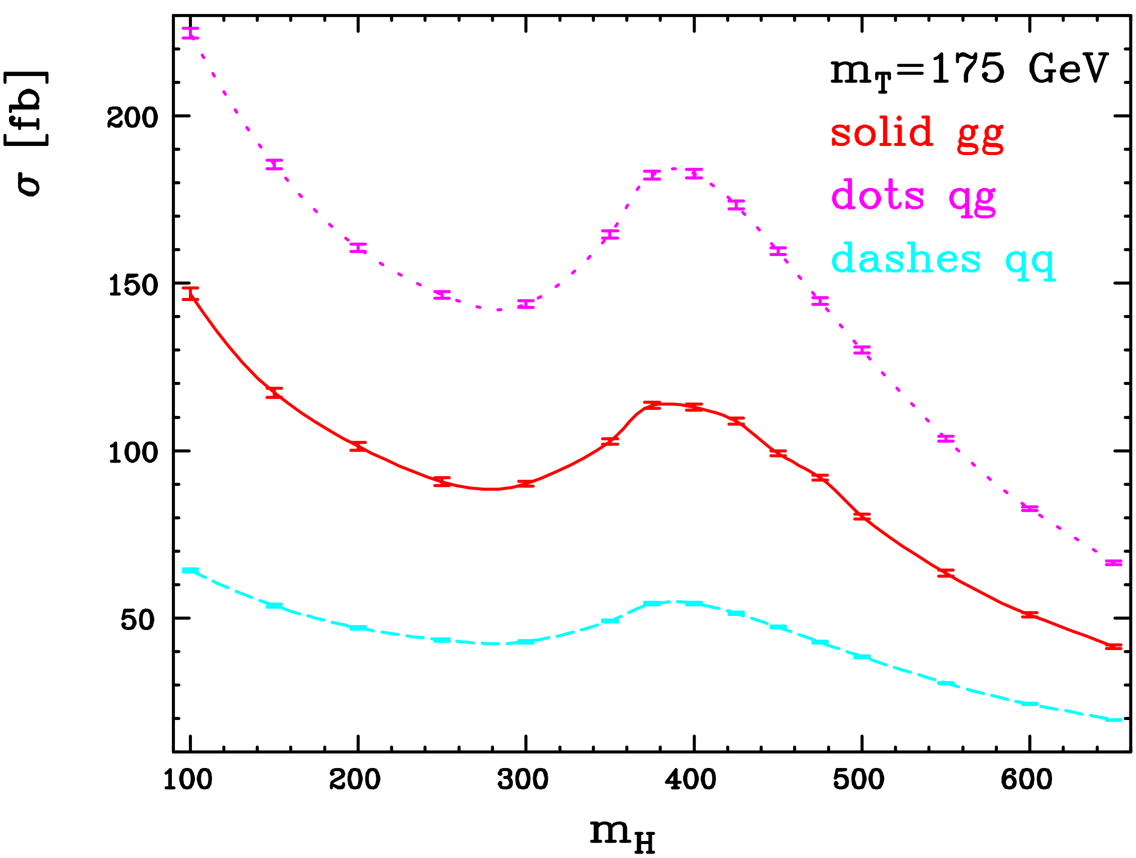
$\sqrt{s} = 14$ TeV



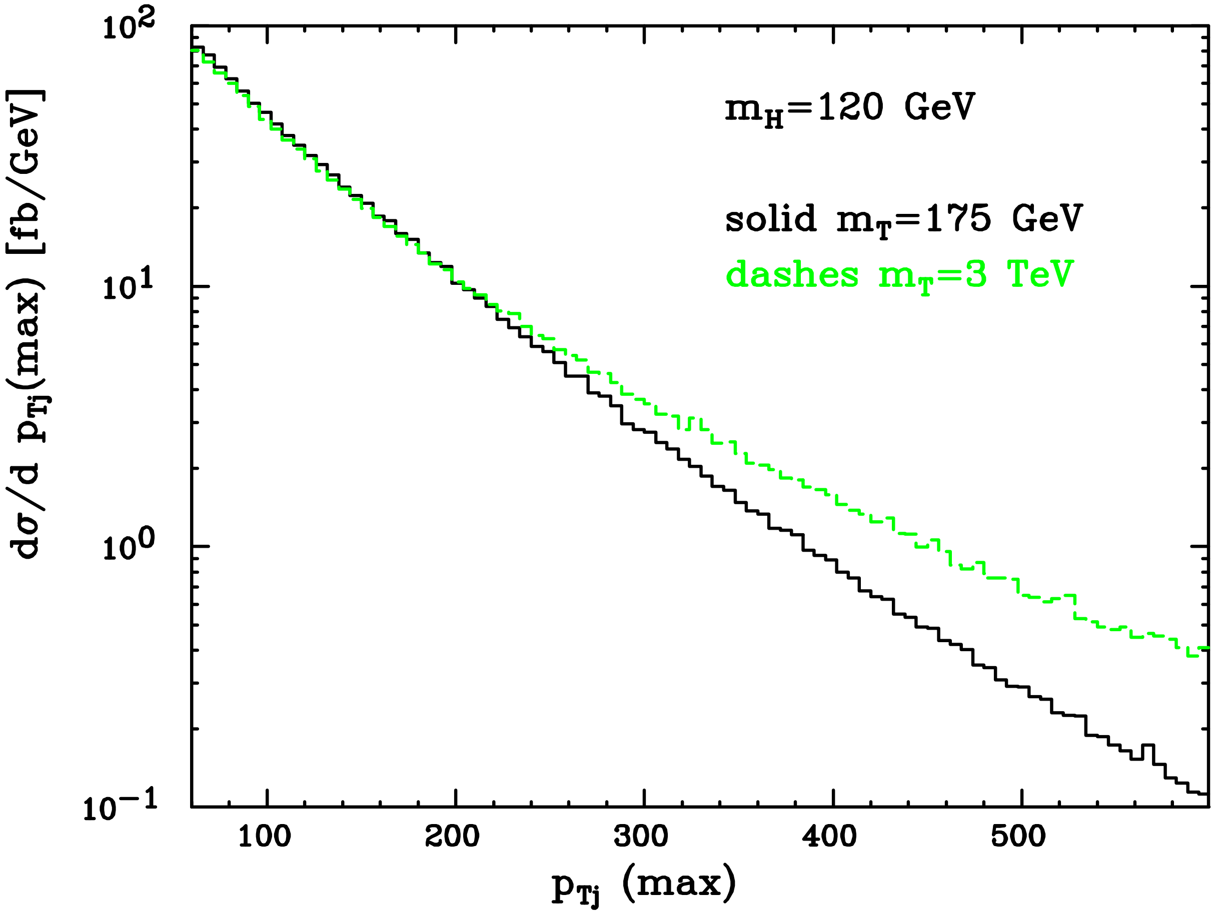


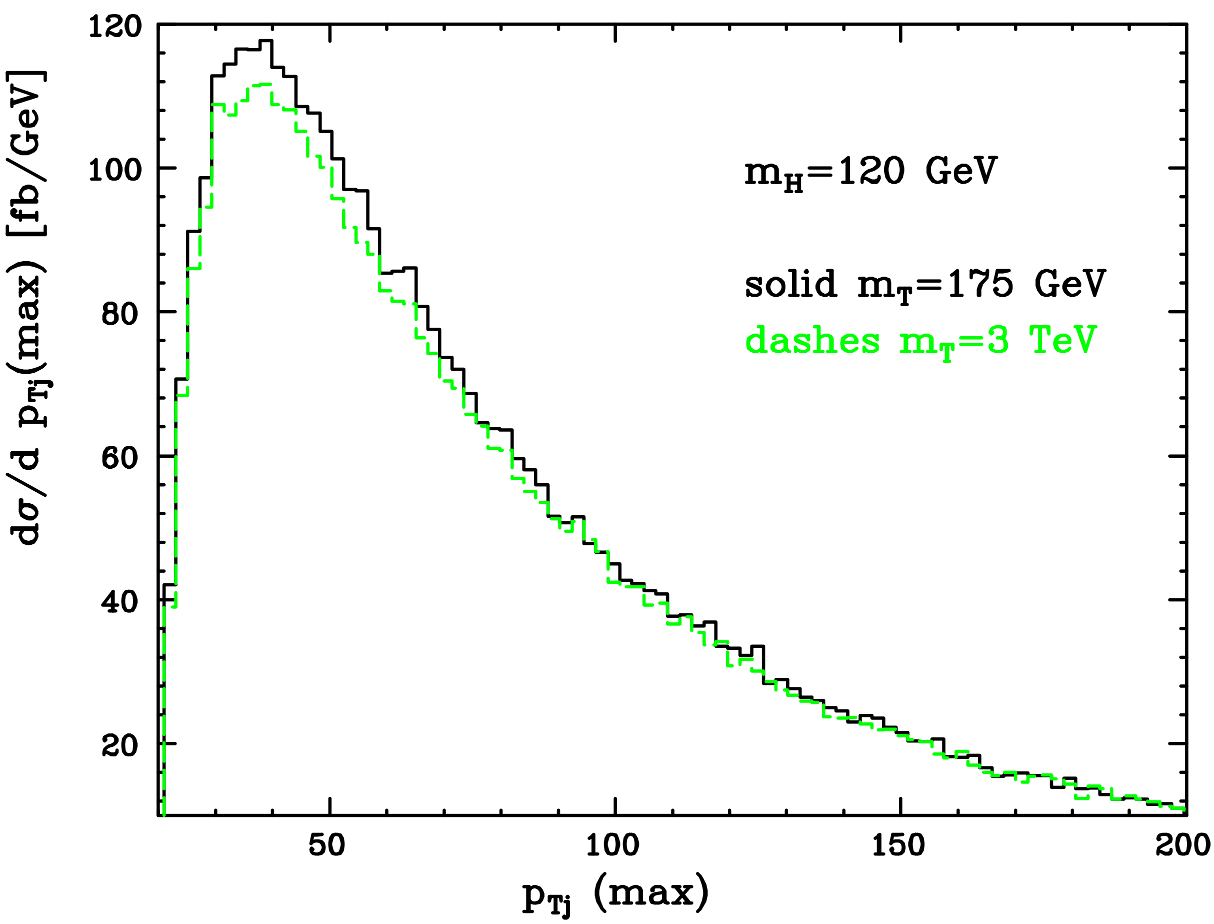
Total cross section: WBF cuts





P_{Tj} (max): minimal cuts





Azimuthal angle between jets ϕ_{jj}: WBF cuts