Invisible Higgs in weak bosons associative production with heavy quarks at LHC

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Standard Model. Problems.

- Experimental problems
  - Neutrino oscillations
  - Evidence for dark matter
  - Dark energy
- Theoretical problems
  - Naturalness — large loop corrections to m_H
  - Gauge hierarchy problem $m_{EW} < M_{Pl}$
  - Baryon asymmetry, strong CP problem, fermion mass hierarchy
  - Nature of electroweak symmetry breaking

Standard Model is incomplete!

SM extensions with invisible Higgs boson

Singlet scalar field (e.g. Burgess, Pospelov, ter Veldhuis, 2001):

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}(\partial_\mu S)^2 - \frac{m_0^2}{2}S^2 - \lambda S^2 H^\dagger H + ...$$

Decay $H \to SS$ is allowed if $m_S \equiv \sqrt{m_0^2 + \lambda v_{EW}^2} < \frac{1}{2}m_H$

$$\Gamma(H \to SS) = \frac{\lambda^2 v_{EW}^2}{8\pi m_H}\sqrt{1 - \frac{4m_S^2}{m_H^2}}$$

Other possibilities:

- Higgs decay into other new scalars, neutralinos, gravitinos ...

Combined LEP bound on invisible Higgs: $m_H > 114.4$ GeV at 95% C.L.

Invisible Higgs: strategies at LHC

The main idea: missing p_T signature. Main channels for LHC:

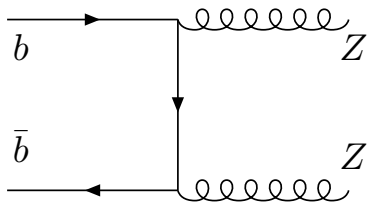
- Vector boson fusion $pp \to qqH$ (Eboli, Zeppenfeld, 2000)
- $pp \to t\bar{t}H$ (Gunion, 1994)
- Associated production $pp \to ZH$ or WH (Godbole at al. 2003)

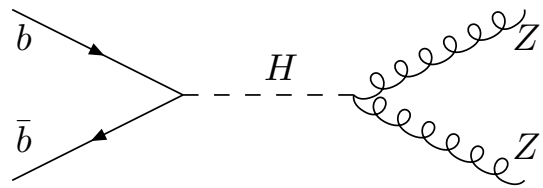
Questions:

- Why does missing p_T come from Higgs boson?
- Only m_H can be measured. Can we say something about Γ_H?

$pp \to q\bar{q}VV$

- Higgs boson is needed to restore unitarity in processes with massive gauge bosons and its contribution should change the cross sections of those processes.
- We consider $pp \to q\bar{q}VV$ via $q\bar{q} \to VV$ scattering where q is heavy (t or b) quarks.
- Higgs mass range $m_H < 2M_V$, virtual Higgs, probing the Higgs width Γ_H.

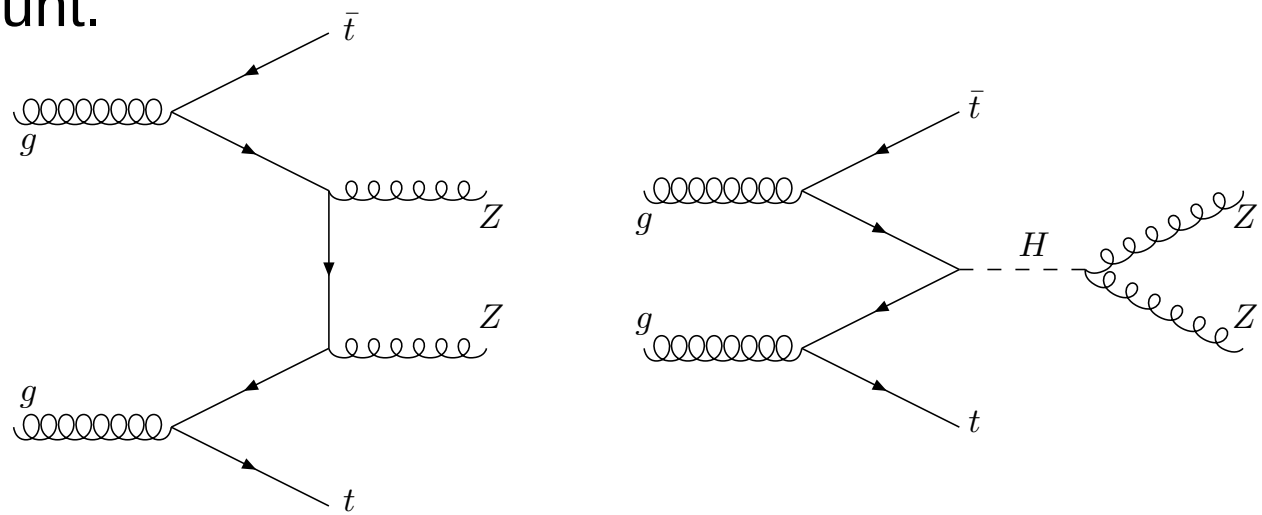




$pp \to t\bar{t}ZZ$: framework

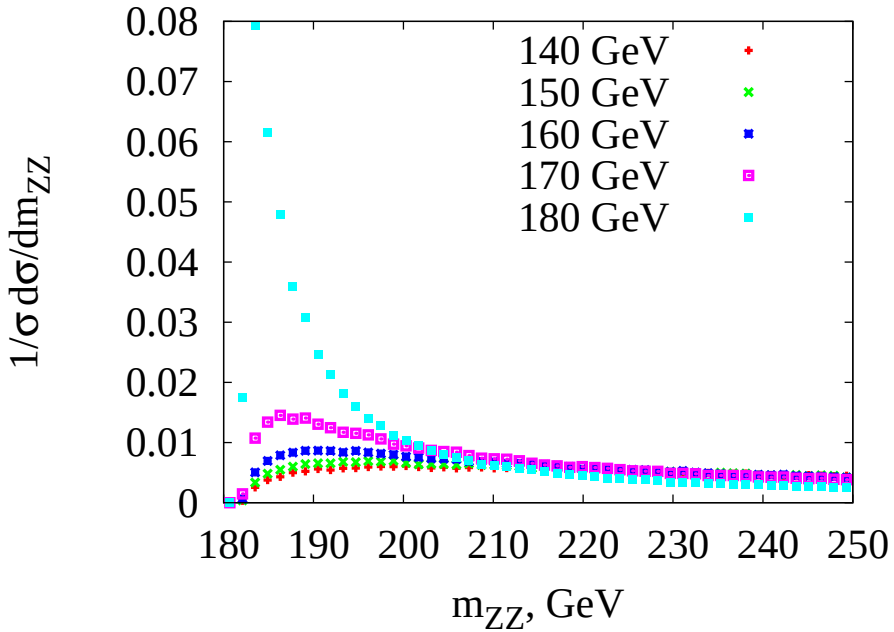
Assumptions and calculational framework

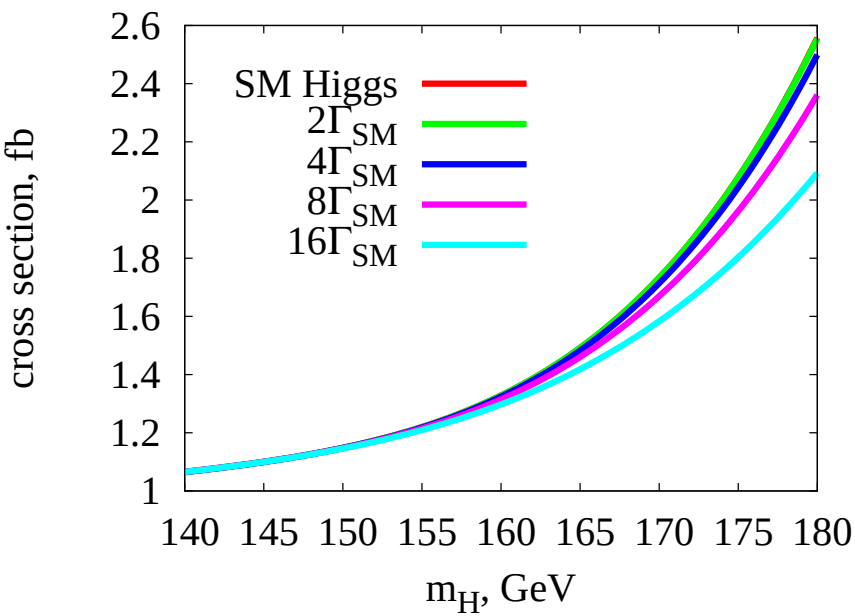
- Higgs boson production rate is as in Standard Model
- Partonic analysis in LO using CompHEP 4.5 (Boos at al., 2009)
- Only the main subprocess $gg \to t\bar{t}ZZ$
- No phase space cuts, $\sqrt{s} = 14$ TeV, CTEQ5L1
- Amplitudes with and without virtual Higgs boson were taken into account.



$pp \to t\bar{t}ZZ$: results I

Invariant mass m_{ZZ} distribution and total cross section

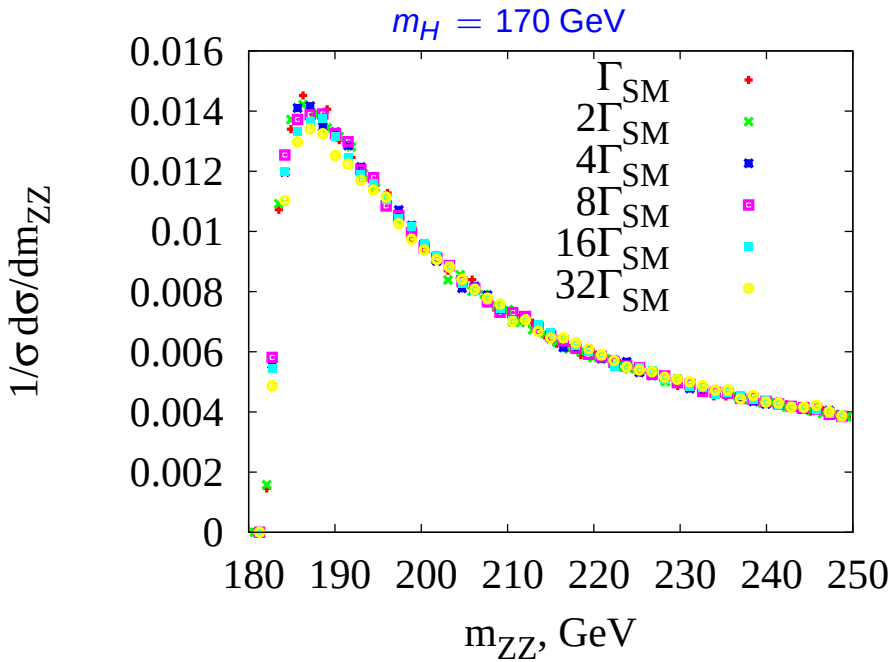


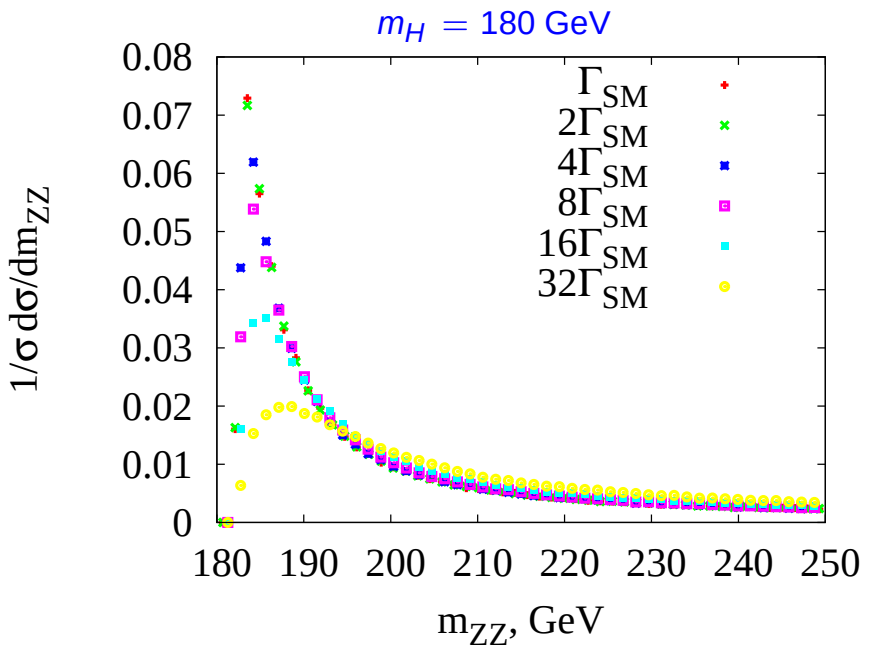


The shape of m_{ZZ} invariant mass distribution is very sensitive to m_H

$pp \to t\bar{t}ZZ$: results II

Invariant mass m_{ZZ} distribution for different masses



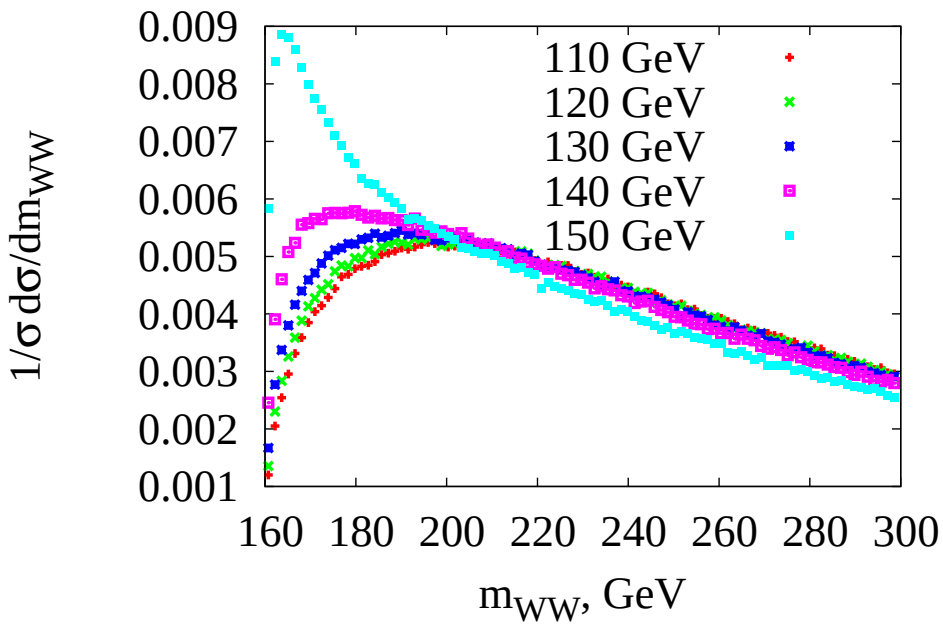


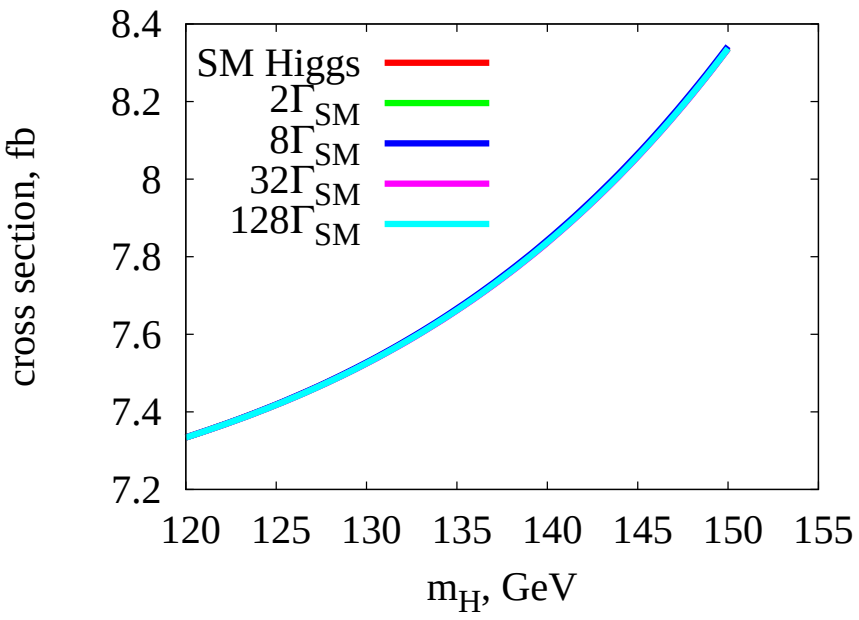
The shape of invariant mass m_{ZZ} distribution is very sensitive to Γ_H only when $m_H \sim 2m_Z$

$pp \to t\bar{t}W^+W^-$: results

Invariant mass m_{WW} distribution and total cross section

$\Gamma_H = \Gamma_{SM}$



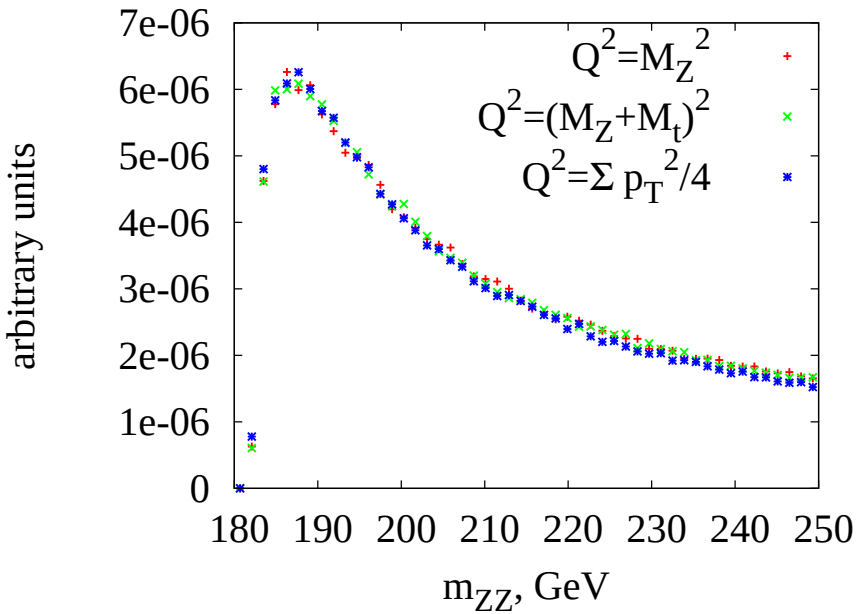


Clear dependence on m_H and rather weak dependence on Γ_H

QCD corrections: crude estimate

$pp \to t\bar{t}ZZ$: dependence on the renormalization scale Q^2

Q^2	σ, fb
M_Z^2	0.43
$(M_Z + M_t)^2$	0.24
$\sum_f p_T^2/4$	0.32

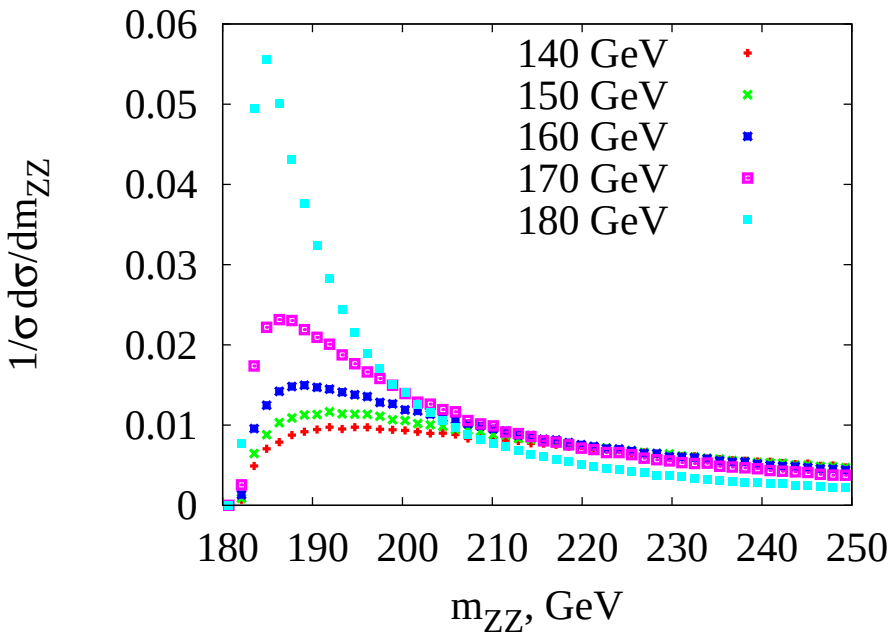


$pp \to b\bar{b}VV$: framework

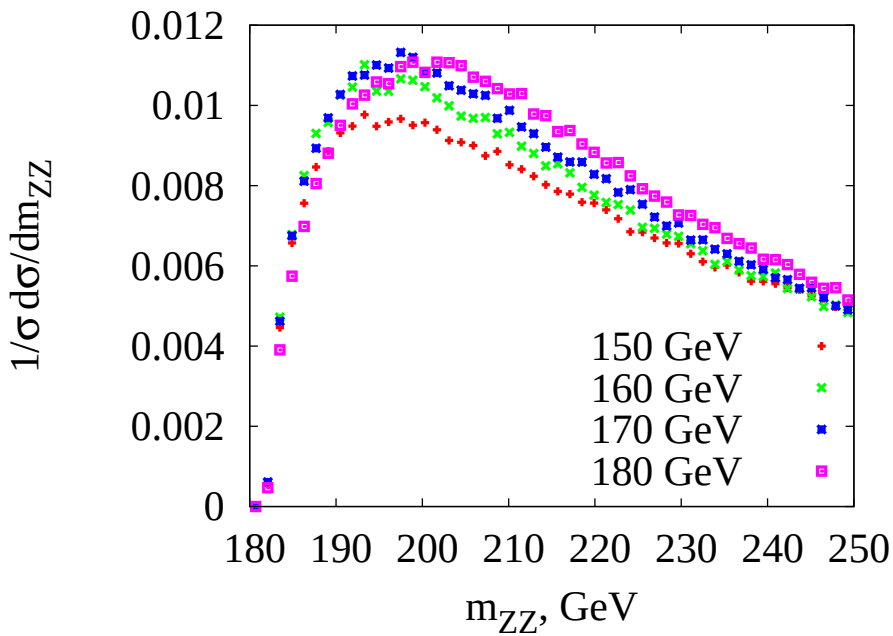
- Yukawa of b-quark is small — contributions with Higgs boson are suppressed
- Modification $\mathcal{L} = Y_b H\bar{b}b \to AY_b H\bar{b}b$, $A = 50$ (branching ratio $H \to b\bar{b}$ is also changed compared to SM case, new Higgs boson width Γ_0)
- For process $pp \to b\bar{b}W^+W^-$ we introduce cuts $m_t - 10\Gamma_t < m_{bW^+}, m_{\bar{b}W^-} < m_t + 10\Gamma_t$, to exclude large part of cross section with t and/or $\bar{t}$ production

$pp \to b\bar{b}ZZ$: results I

$\Gamma_H = \Gamma_0$

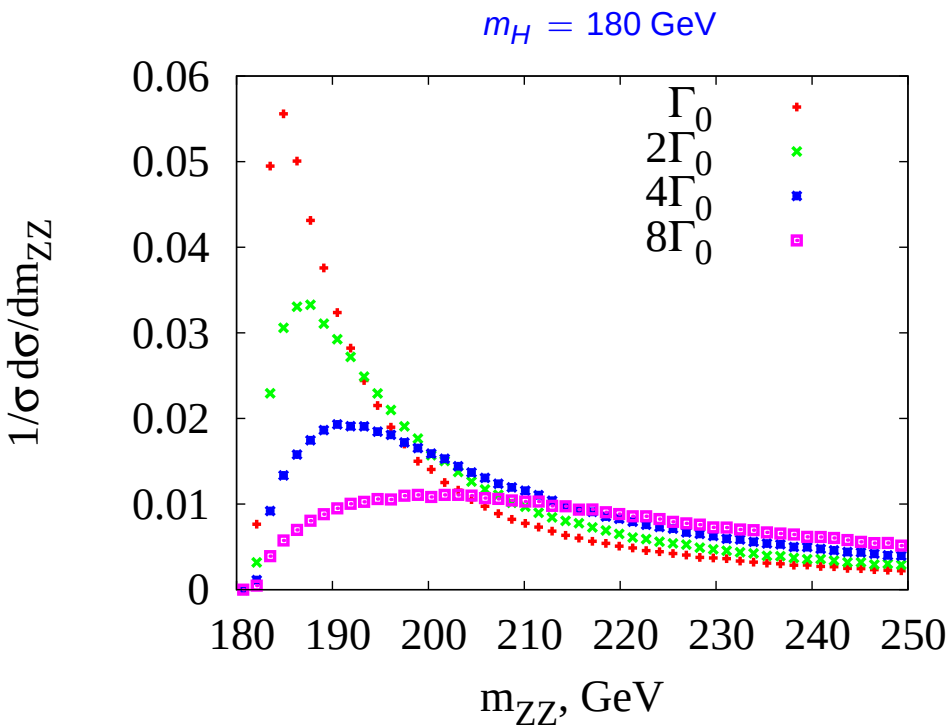


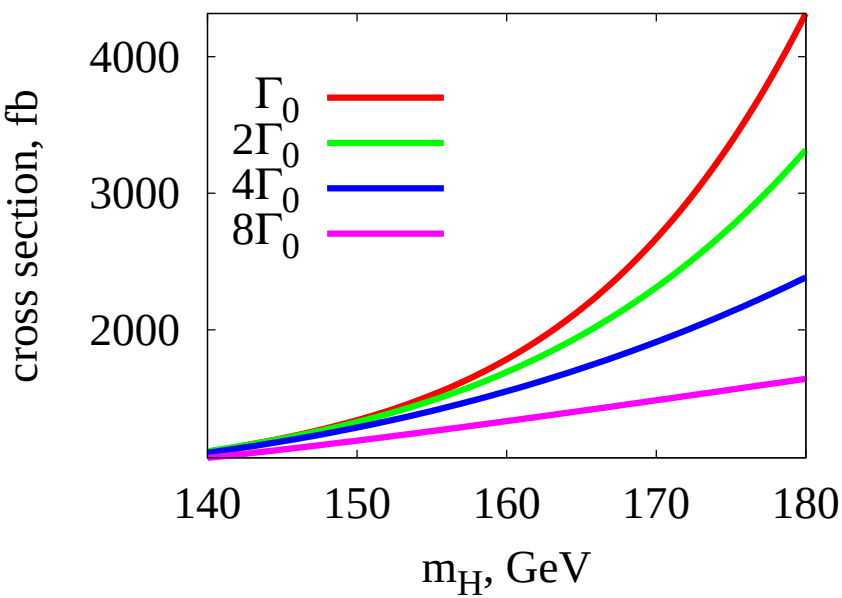
$\Gamma_H = 8\Gamma_0$



The shape is very sensitive to both m_H and Γ_H

$pp \to b\bar{b}ZZ$: results II





The cross section of $pp \to b\bar{b}ZZ$ is quite large. Interesting for LHC!!!

The similar results for $pp \to b\bar{b}W^+W^-$

Conclusions

- Channels $pp \to t\bar{t}ZZ$ and $pp \to t\bar{t}W^+W^-$ can in principle be used for measuring mass and width of invisibly decaying Higgs boson with mass around $120 - 180$ GeV.
- Channels $pp \to b\bar{b}ZZ$ and $pp \to b\bar{b}W^+W^-$ can be used for measuring mass and width of invisibly decaying Higgs boson in models with enchanced Yukawa of b-quarks.
- More involved analysis is needed (irreducible background, detector response, NLO corrections).

Thank you!

$pp \to b\bar{b}W^+W^-$: results