Interference effects in Higgs-mediated ZZ+jet production

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Based on J. M. Campbell, R. K. Ellis, EF and R. Rontsch, Phys. Rev. D 90 (2014) 9, 093008

Motivation

* In Higgs decays to vector bosons,

  pp -> H(-> VV) + X

  a large fraction of events lies in the high-mass tail, $M_{VV} > 2\, m_V$

  Kauer, Passarino, JHEP 1208, 116 (2012)

* The cross section in the tail is independent of the Higgs boson width Γ_H, while in the on-shell region it scales as $1/\Gamma_H$

  ➡ use the ratio to bound the Higgs width!

$$\Gamma_H \propto \frac{\sigma^{tail}}{\sigma^{peak}}$$

Caola, Melnikov, PRD88, 054024 (2013); Campbell et al., JHEP 1404, 060 (2014), PRD89,053011 (2014)

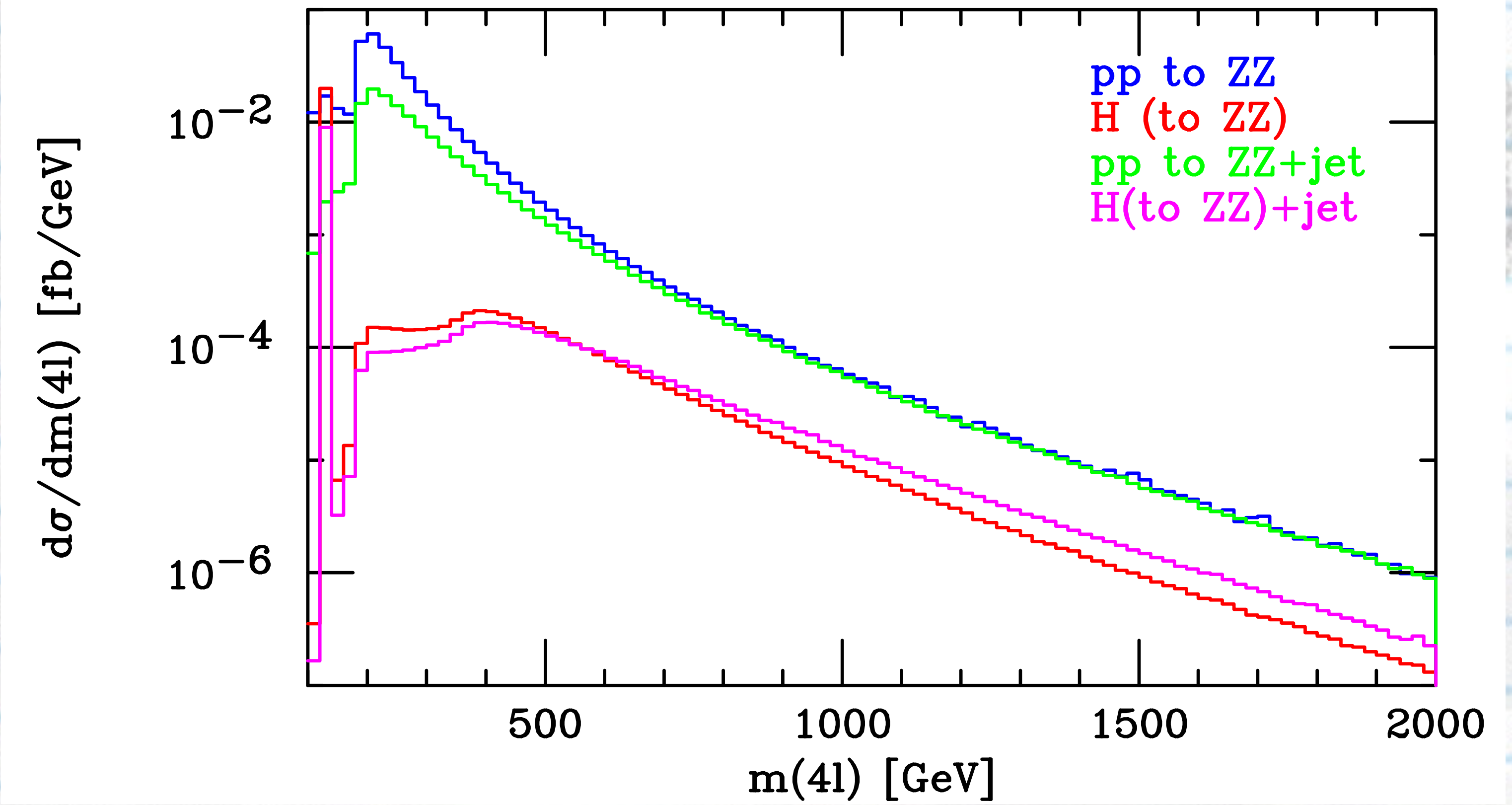
$\Gamma_H \lesssim$ 20 - 40 MeV (SM: Γ_H = 4.15 MeV)

Khachatryan et al. (CMS), PLB 736, 64 (2014), PRD 92 072010 (2015); Aad et al. (ATLAS), Eur. Phys. J. C75, 335 (2015)

Motivation

Why the extra jet?

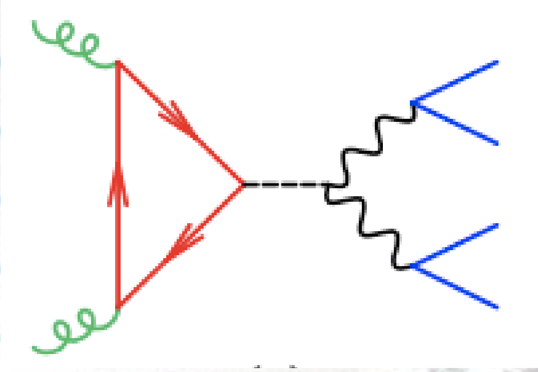
* production xsec in H + 1 jet and H + 0 jet comparable



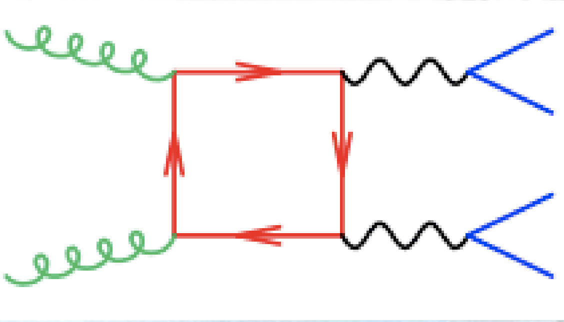
* this result is part of the (real) NLO corrections to gg -> ZZ

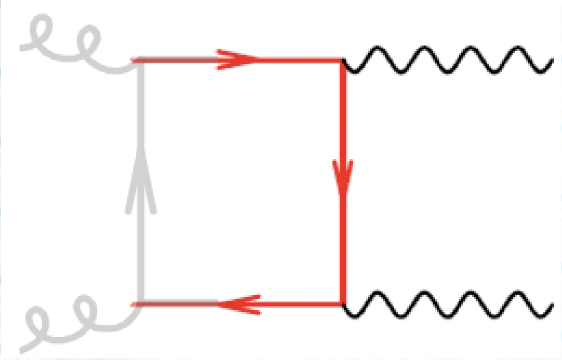
Introduction

* Look at Higgs-mediated Z pair production
  gg -> H -> ZZ

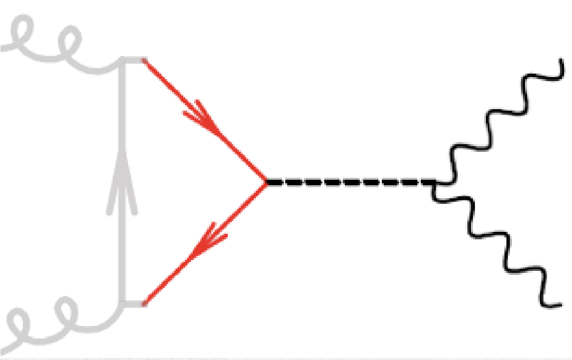


* Interference effects with the background process
  gg -> ZZ
  are large in the high invariant mass region due to unitarity requirements for the $t\bar{t}$ -> ZZ scattering





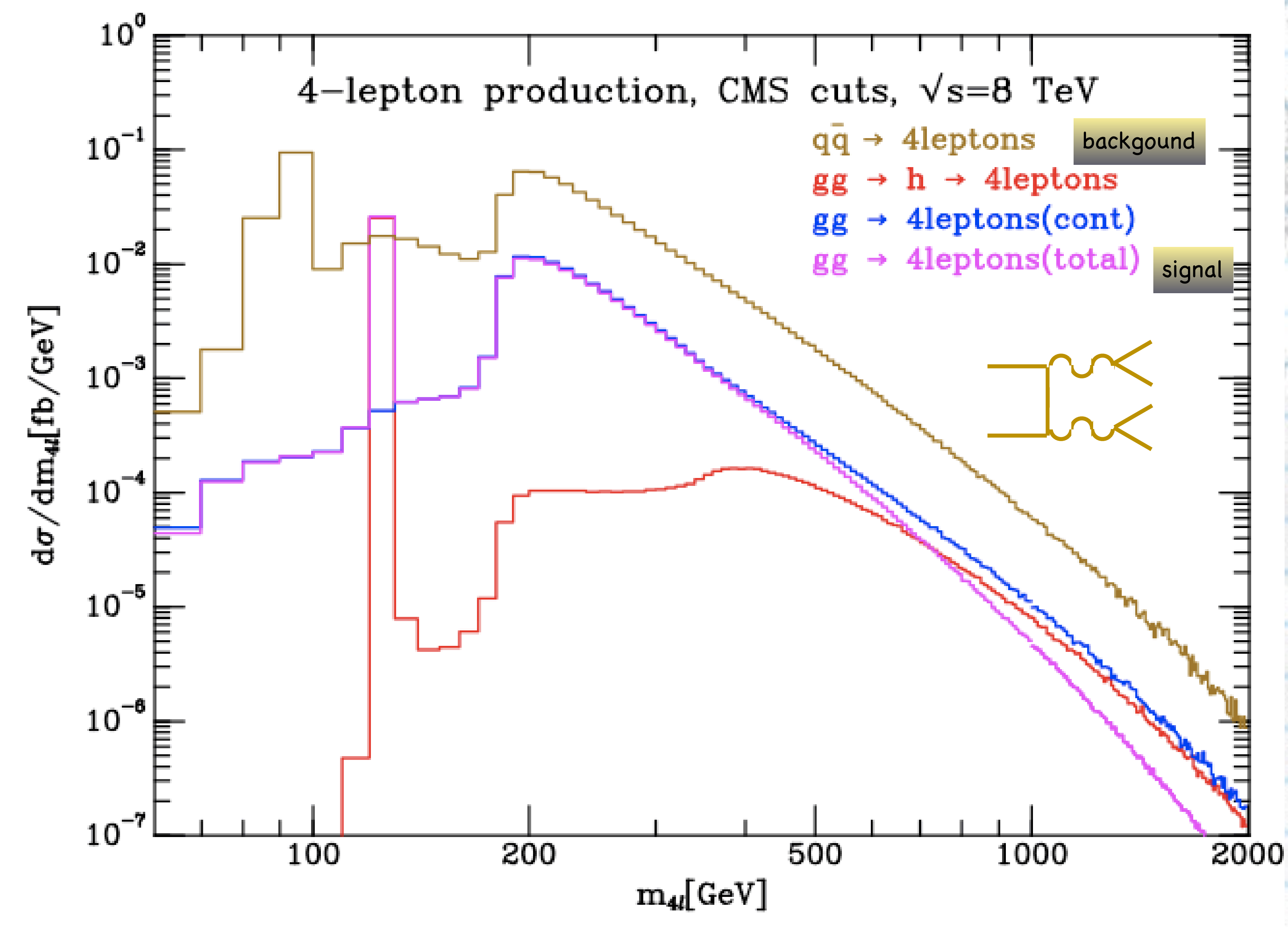
$\sim \kappa\, m_t \sqrt{s}$



$\sim -\kappa\, m_t \sqrt{s}$

Introduction

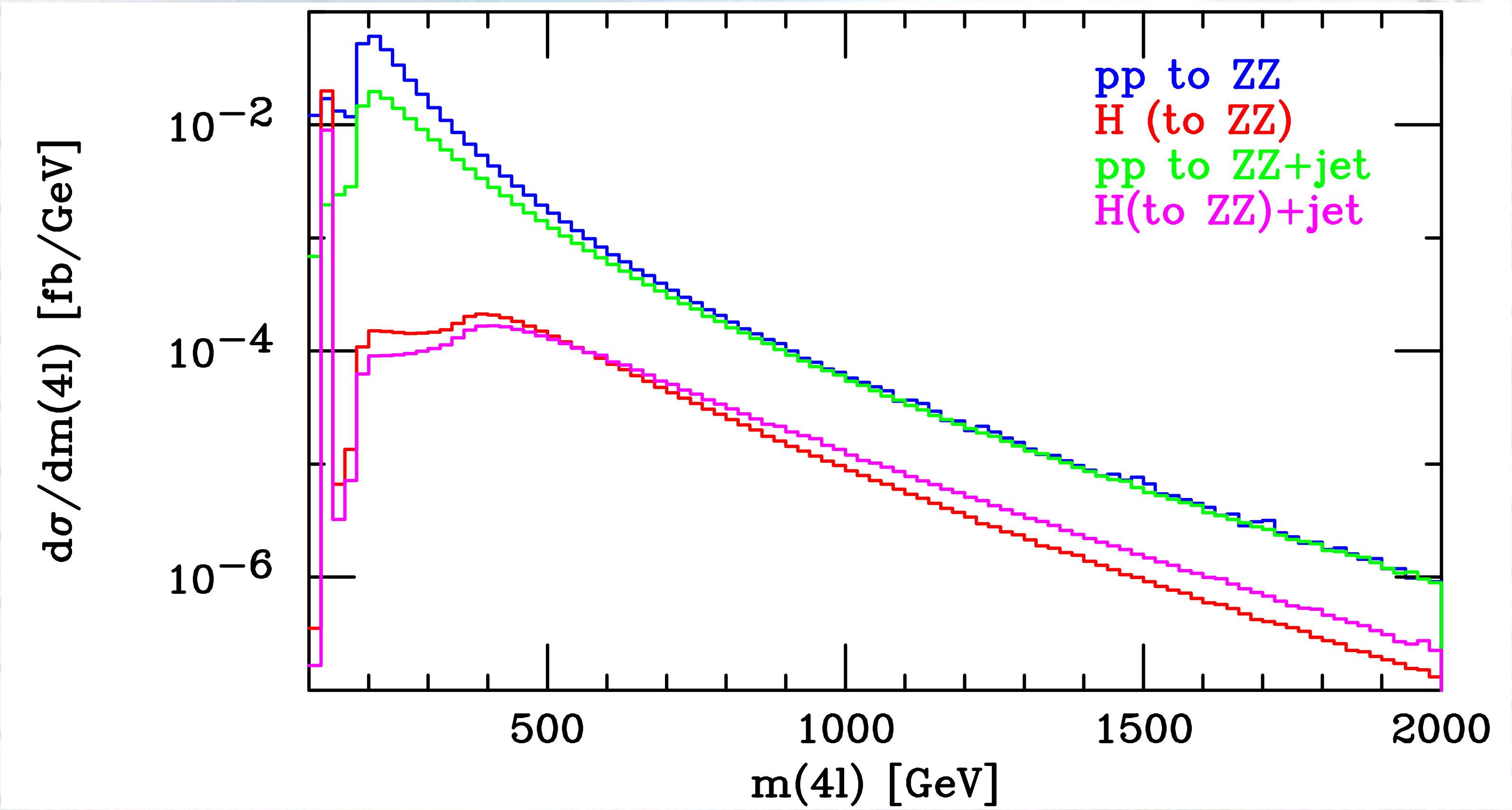
* this yields large destructive interference between gg -> H(->ZZ) -> 4l and gg -> ZZ -> 4l



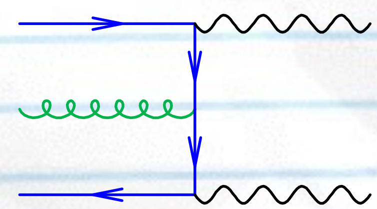
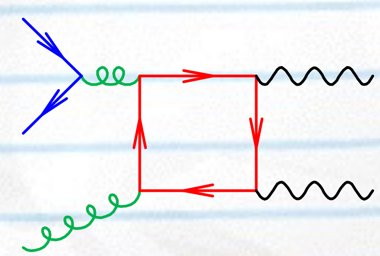
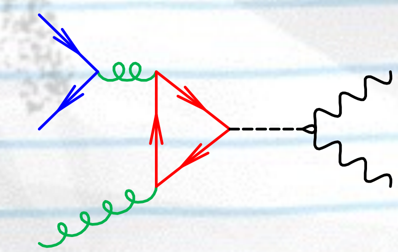
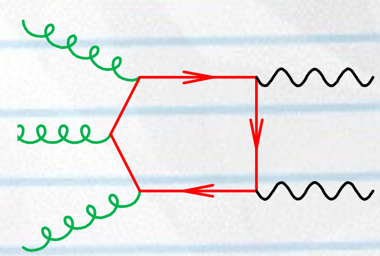
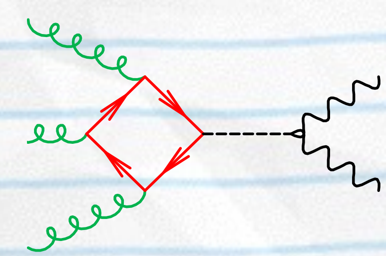
Campbell et al., JHEP 1404, 060 (2014)

Introduction

* Similar ideas for interference effects in pp -> ZZ+1 jet
  - ➡ in the tail, the ratio of Higgs signal to LO background even (slightly) better than for pp -> ZZ

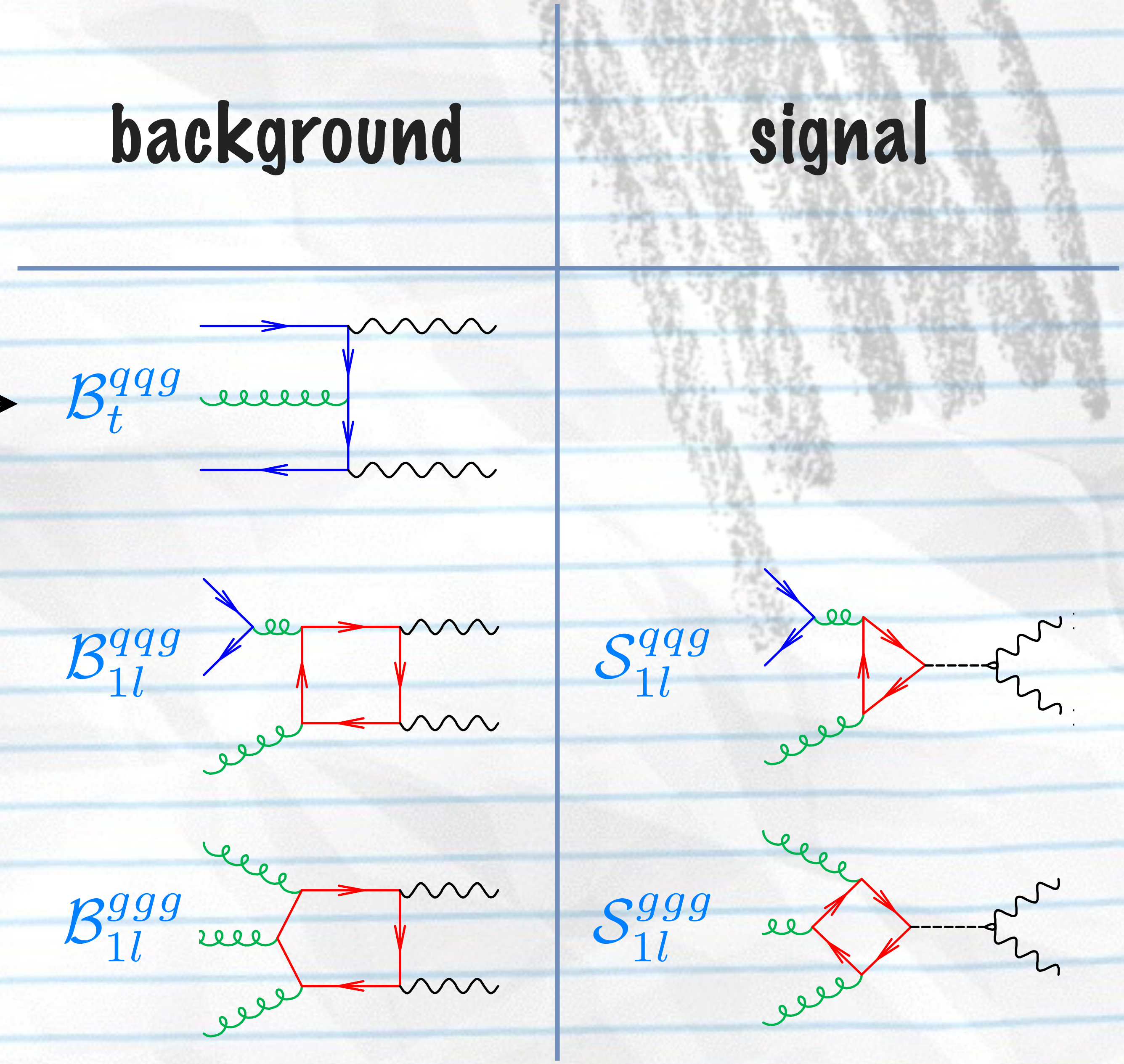


Ingredients

order	process	background	signal
$g_w^2 g_s$	$q\bar{q} \to ZZ + g$ $qg \to ZZ + q$	$\mathcal{B}_t^{qqg}$ 	
$g_w^2 g_s^3$	$q\bar{q} \to ZZ + g$ $qg \to ZZ + q$	$\mathcal{B}_{1l}^{qqg}$ 	$\mathcal{S}_{1l}^{qqg}$ 
	$gg \to ZZ + g$	$\mathcal{B}_{1l}^{ggg}$ 	$\mathcal{S}_{1l}^{ggg}$ 

Ingredients

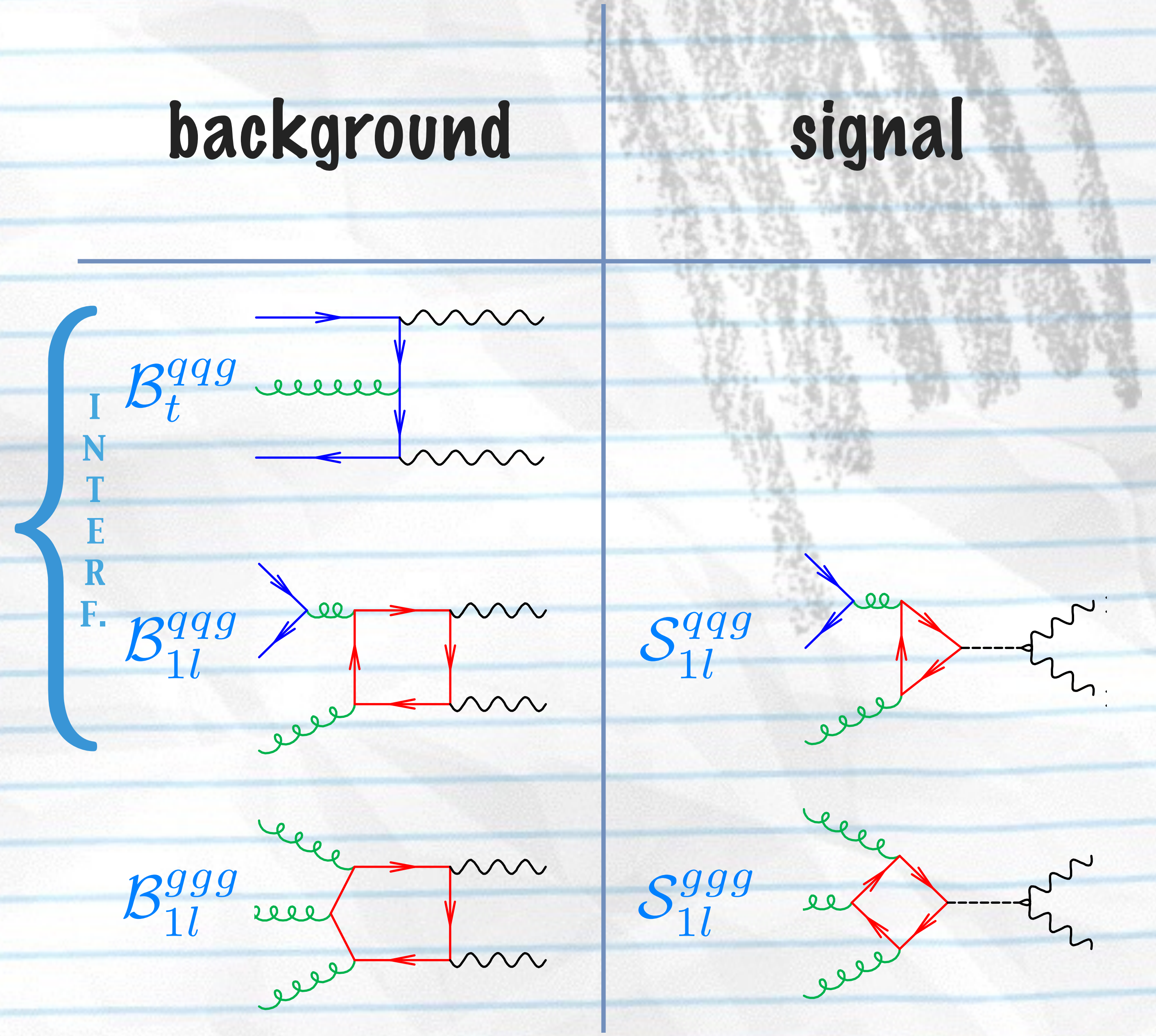
* LO cross section
* $O(g_W^4\, g_s^2)$



Ingredients

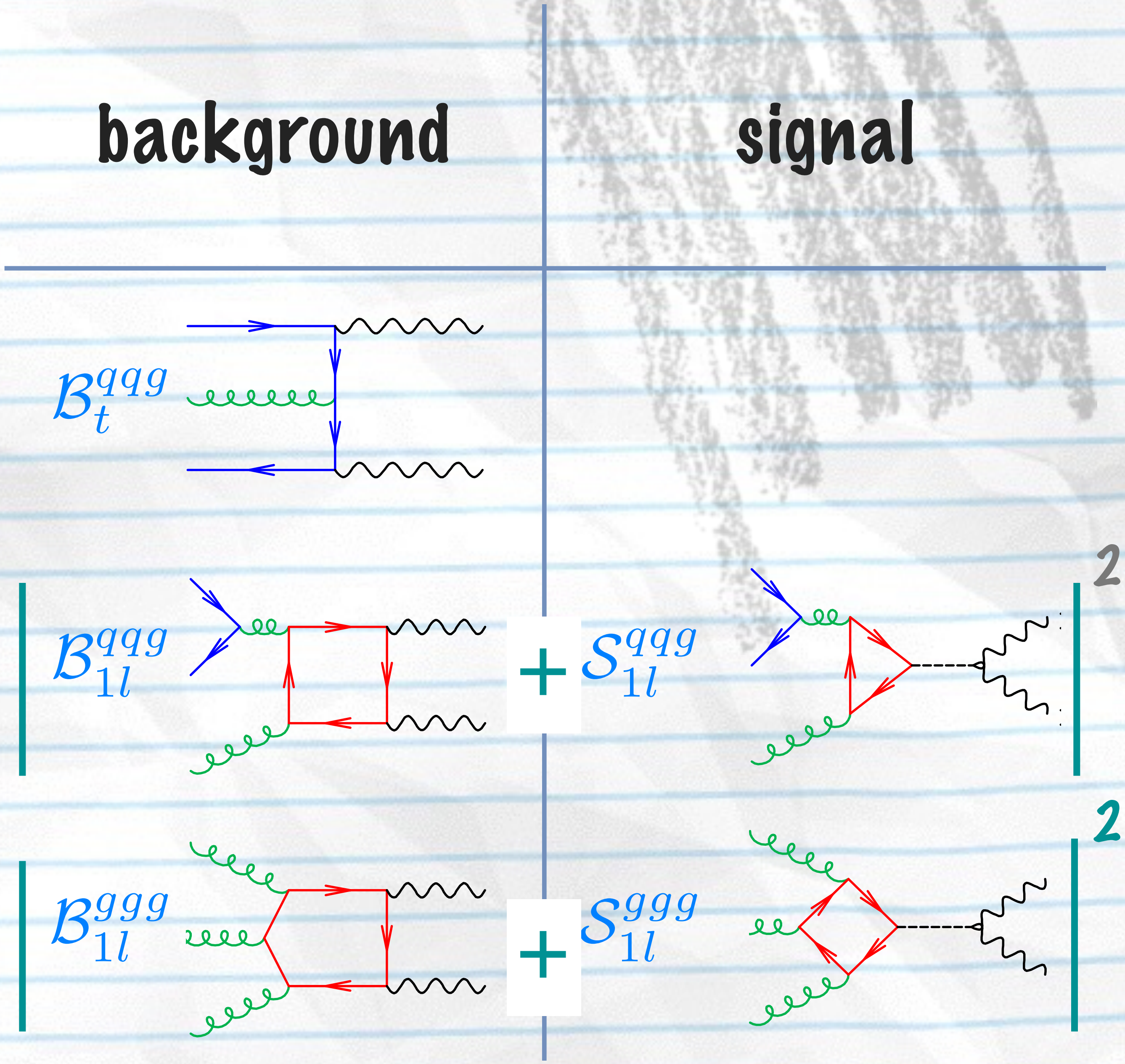
- NLO effects
- $O(g_W^4\, g_s^4)$
- this interference is small
  -> $k_{NLO}^{ZZj,\,B} \sim 0.98$ Binoth et al., PLB 683, 154 (2010)

  -> for S, expect the same due to unitarity



Ingredients

- NNLO effects
- $O(g_w^4\, g_s^6)$
- S-B interference for gg -> ZZg is large and negative in the high-mass tail Campanario et al., JHEP 1306, 069 (2013)
- we add the interference in qqg -> ZZ -> 25 - 50% effect



Results for pp -> ZZ + jet

Demand

- one single jet
- $|\eta_j| < 3 \quad , \quad p_{T,j} > p_{T,cut}$
- $m_{ZZ} > 300$ GeV **(high mass tail)**

		$\lvert\mathcal{S}_{1l}^{ggg}\rvert^2$	$\lvert\mathcal{S}_{1l}^{qqg}\rvert^2$			
	$p_{T,\mathrm{cut}}$ [GeV]	σ_H^{gg} [fb]	$\sigma_H^{qg+q\bar{q}}$ [fb]	σ_I^{gg} [fb]	$\sigma_I^{qg+q\bar{q}}$ [fb]	σ_I^{tree} [fb]
$\sqrt{s} = 8$ TeV	30	0.0212	0.00679	-0.0299	-0.00929	0.00230
	50	0.0124	0.00522	-0.0173	-0.00706	0.00182
	100	0.00467	0.00279	-0.00632	-0.00369	0.00097
	200	0.00104	0.00086	-0.00133	-0.00111	0.00026

$\mathcal{S}_{1l}^{ggg} \times \mathcal{B}_{1l}^{*,ggg}$ $\quad$ $\mathcal{S}_{1l}^{qqg} \times \mathcal{B}_{1l}^{*,qqg}$ $\quad$ $\mathcal{S}_{1l}^{qqg} \times \mathcal{B}_{t}^{*,qqg}$

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✓

Dixon et al., PRD 60, 114037 (1999)

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✓ ✓

* agree with Campanario et al., JHEP 1306, 069 (2013)
* strong cancellation as required by unitarity

Results for pp -> ZZ + jet

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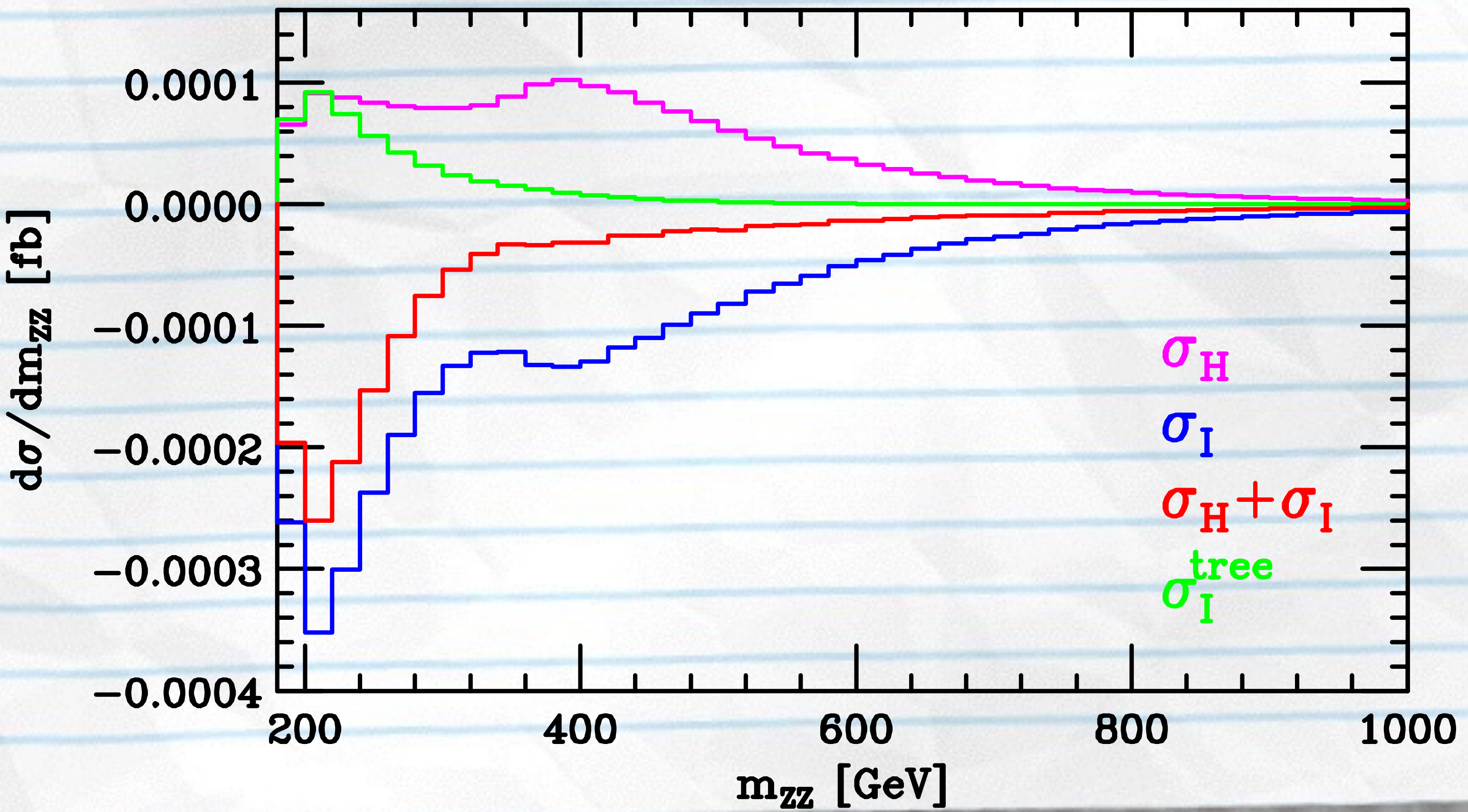
$$\frac{\sigma_H^{qg+q\bar{q}}}{\sigma_H} \sim \frac{\sigma_I^{qg+q\bar{q}}}{\sigma_I} \sim \begin{cases} 25\% & \text{for } p_{T,cut} = 30 \text{ GeV} \\ 50\% & \text{for } p_{T,cut} = 200 \text{ GeV} \end{cases}$$

➡ a harder cut probes regions of large x, where quark PDFs are relatively more important than gluon PDFs

Results for pp -> ZZ + jet

Importance of the interference term:

- the total distribution becomes negative
- its shape changes
- its magnitude is reduced in the high p_T tail



$p_{T,cut} = 30$ GeV

$\sqrt{s} = 8$ TeV

Results for pp -> ZZ + jet

* Analogous to the ZZ case, the ratio of peak and off-peak cross sections can be used to bound the Higgs width

$$\frac{\sigma^{H+I}_{off,ZZ+jet}(m_{ZZ} > 300\text{ GeV})}{\sigma^{H}_{peak,ZZ+jet}} = 0.02890\left(\frac{\Gamma_H}{\Gamma_H^{SM}}\right) - 0.0391\sqrt{\frac{\Gamma_H}{\Gamma_H^{SM}}}\quad (8\text{ TeV})$$

* In LHC run II, expect about 100 events to be produced in the high mass tail

  ➡ alternative extraction of the Higgs width

Conclusions

* Higgs width already constrained from interference in ZZ
* Similar analysis in the ZZ + jet channel is viable: in the high invariant mass tail signal and background rates in the zero and one jet bins are comparable
* As in the pp -> ZZ case, relate the ratio of peak and off-peak cross sections to the Higgs decay width relative to the Standard Model
* Study feasible at LHC Run II, where we expect about 100 pp->ZZj events at high invariant mass