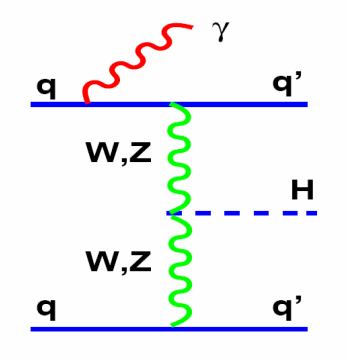
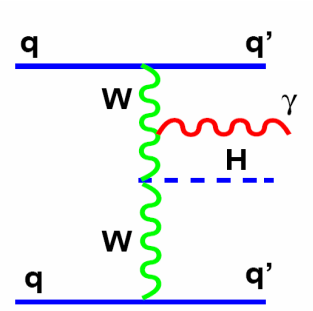
Higgs boson production in association with a photon in Vector Boson Fusion at LHC





Emidio Gabrielli

Uppsala University

and Helsinki Institute of Physics

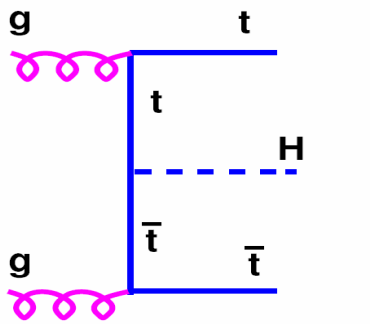
work made in coll. with

F.Maltoni, B. Mele, M.Moretti, F.Piccinini, R.Pittau

(hep-ph/0702119) to appear on NPB

Higgs boson decay in bb(bar)

- not a discovery channel, but very important for measuring the Yukawa Hbb coupling at LHC
- up to now, more serious studies only for $Ht\bar{t}$



- optimized x-sections of signal are of the order of O(10 fb). Htt has been disfavored by recent CMS analyses

A new promising channel to measure bbH coupling at LHC

E.G., F. Maltoni, B. Mele, M. Moretti, F.Piccinini, R.Pittau

(hep-ph/0702119)

$pp \to H\ \gamma + j\ j$

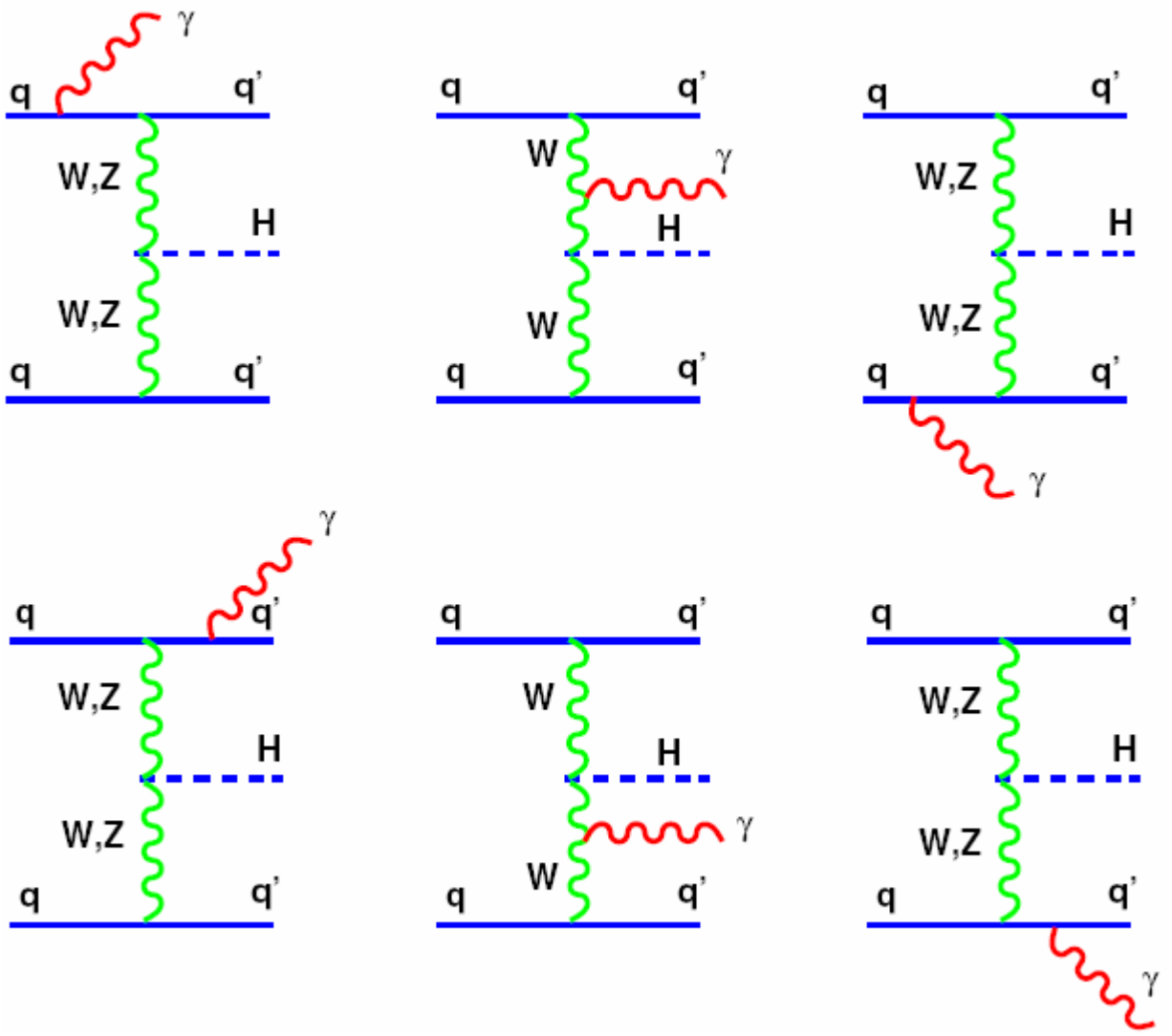
$\to b\bar{b}$

same mechanism of H production

by VV fusion + emission of a γ

signal at partonic level

$qq \rightarrow qq\,H + \gamma$



main advantages

- trigger on gamma at high p_T
- the large gluon component in QCD bckg is idle in radiating a photon
- dynamical effects suppress radiation of central photon with respect to signal
- O(10fb) x-section
- could provide a new independent test of Hbb and HWW couplings

signal cross section pp→H γ jj

minimal set of kinematical cuts

$\Delta R_{\gamma j} > 0.4$ $\quad p_T^{\gamma} \geq 20\ \mathrm{GeV}$ $\quad Q^{2}{}_{\mathrm{ik}} > 100\ \mathrm{GeV}^2$

m_H (GeV)	110	120	130	140
$\sigma(H\gamma jj)$ $[fb]$	67.4	64.0	60.4	56.1
$\mathcal{BR}(H \to b\bar{b})$	0.770	0.678	0.525	0.341

- Higgs BR to bb(bar)→HDECAY
- full EW tree-level matrix element to pp→ H γ jj computed with ALPGEN + MADEVENT
- PDF set is CTEQ5L

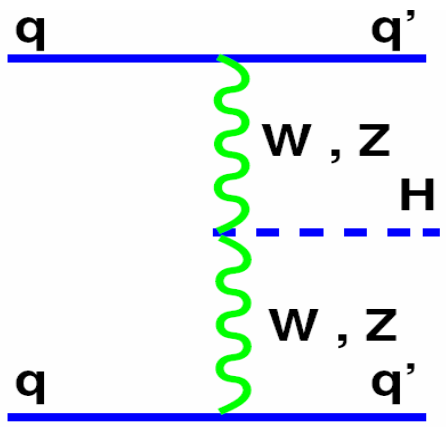
$$\Delta R_{ij} \equiv \sqrt{(\Delta\eta_{ij})^2 + (\Delta\varphi_{ij})^2}$$

Higgs production in VBF signal (no photon)

the basic partonic process is qq → qq H

Mangano, Moretti, Piccinini, Pittau, Polosa (2003)

$$p_T(j) \approx 40 \text{ GeV}$$

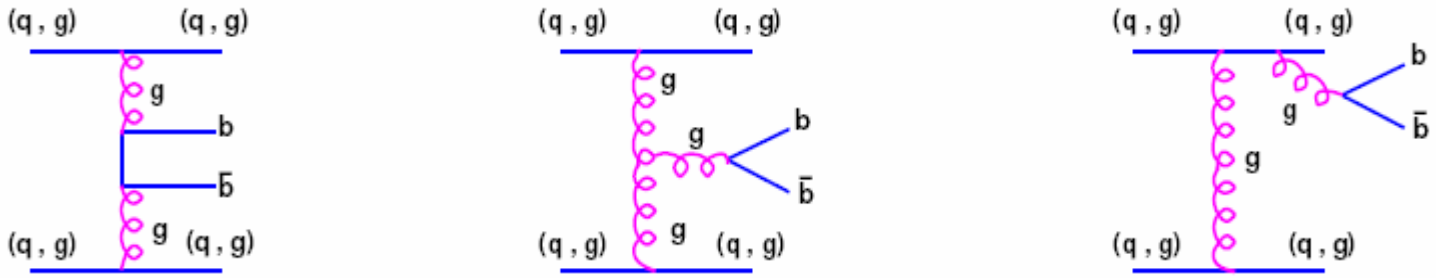


characteristic of the signal: pp→ H(→$b\bar{b}$) + 2j

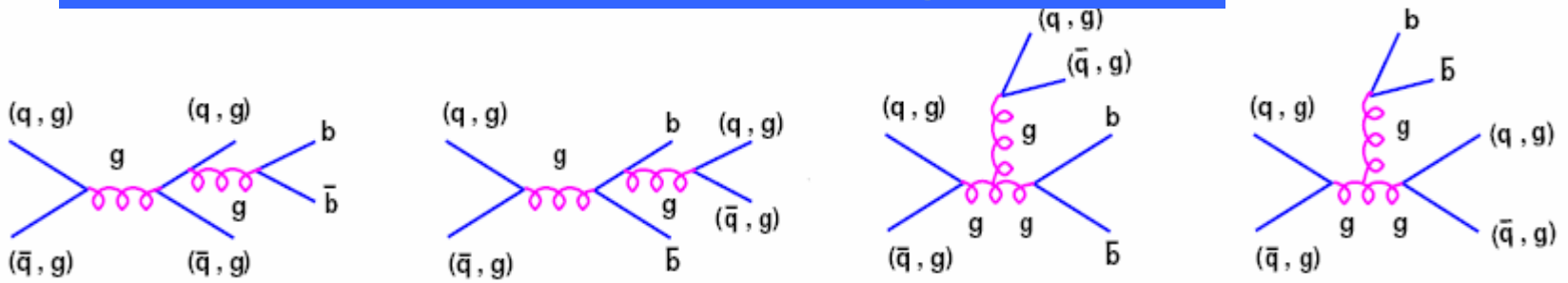
- two Jets with large invariant mass
- widely separated in rapidity (forward/backward)
- typical transverse momentum of jets $p_T(j) \sim 40$ GeV
- Higgs decay products lying at intermediate rapidity

QCD background to Higgs boson production via VBF

- the signal has large x-section, BUT it is difficult to measure due to the huge QCD background



a set of t,u-channel diagrams



s-channel diagrams suppressed by m(jj) > TeV

how the emission of a photon affects the background

- one would expect by naive QED rescaling

$$(S/\sqrt{B})|_{H\gamma jj} \sim \sqrt{\alpha}\,(S/\sqrt{B})|_{H\,jj}$$

- if so, then there would be no advantage in considering a photon emission

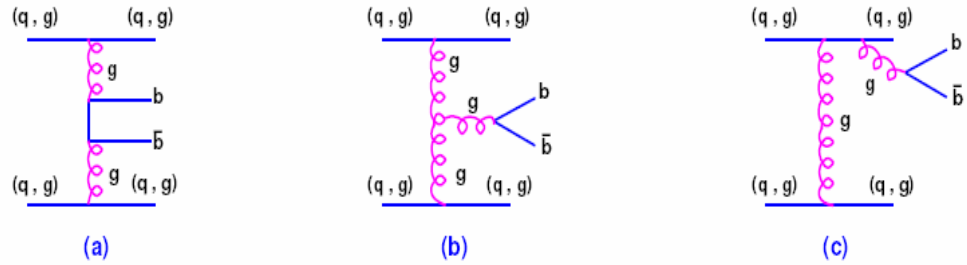
- QED naive rescaling holds for inclusive processes but not always when restricted regions of phase space are considered !

- requirement of centrality dramatically increases S/B ratio, while signal cross section roughly follows QED naive rescaling

- cuts made at partonic level (we considered also partonic shower effects)
- optimized sub-set of kinematical cuts enhancing S/B

  - m(jj) > 800 GeV
  - mH(1-10%) < m(bb) < mH(1+10%)
  - $p_T(\gamma)$ > 20 GeV

leading contribution to bckg of VVB fusion



$g\,g \rightarrow b\bar{b} + g\,g$

$g\,q \rightarrow b\bar{b} + g\,q$

$q\,q' \rightarrow b\bar{b} + q\,q'$

sub-processes	σ_i (pb)	σ_i/σ	σ_i^γ (fb)	$\sigma_i^\gamma/\sigma^\gamma$
$gq \to b\bar{b}\, gq\, (\gamma)$	57.2(1)	55.3 %	17.3(1)	51.6 %
$gg \to b\bar{b}\, gg\, (\gamma)$	25.2(1)	24.4 %	3.93(3)	11.7 %
$qq' \to b\bar{b}\, qq'\, (\gamma)$	7.76(3)	7.5 %	4.04(2)	12.1 %
$qq \to b\bar{b}\, qq\, (\gamma)$	6.52(2)	6.3 %	4.49(3)	13.4 %
$q\bar{q}' \to b\bar{b}\, q\bar{q}'\, (\gamma)$	4.60(2)	4.4 %	2.28(2)	6.8 %
$q\bar{q} \to b\bar{b}\, q\bar{q}\, (\gamma)$	2.13(2)	2.1 %	1.21(2)	3.6 %
$gg \to b\bar{b}\, q\bar{q}\, (\gamma)$	0.0332(7)	0.03 %	0.124(3)	0.37 %
$q\bar{q} \to b\bar{b}\, gg\, (\gamma)$	0.0137(2)	0.01 %	0.094(2)	0.28 %
$q\bar{q} \to b\bar{b}\, q'\bar{q}'\, (\gamma)$	0.000080(3)	0.00007 %	0.00080(8)	0.002 %

bckg(γ) / bckg ~ 1/3000

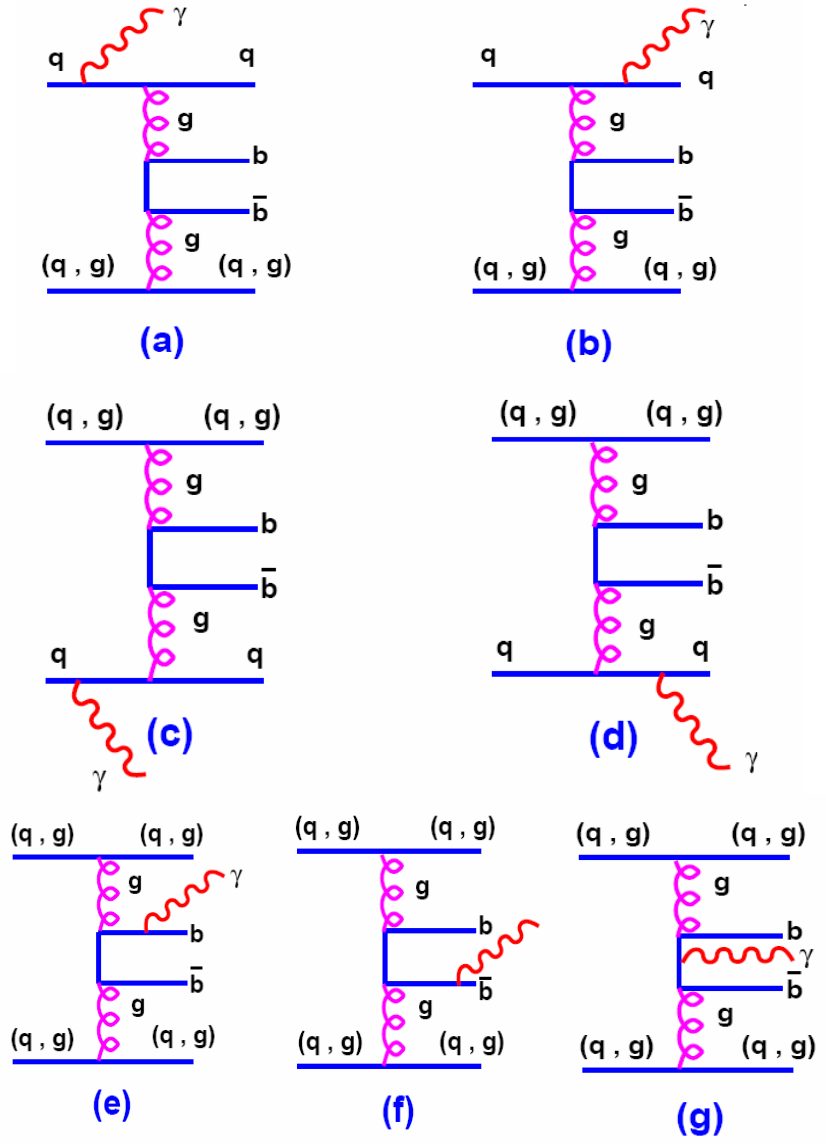
signal(γ) / signal ~ 1/100

main bckg to pp → H γ + j j

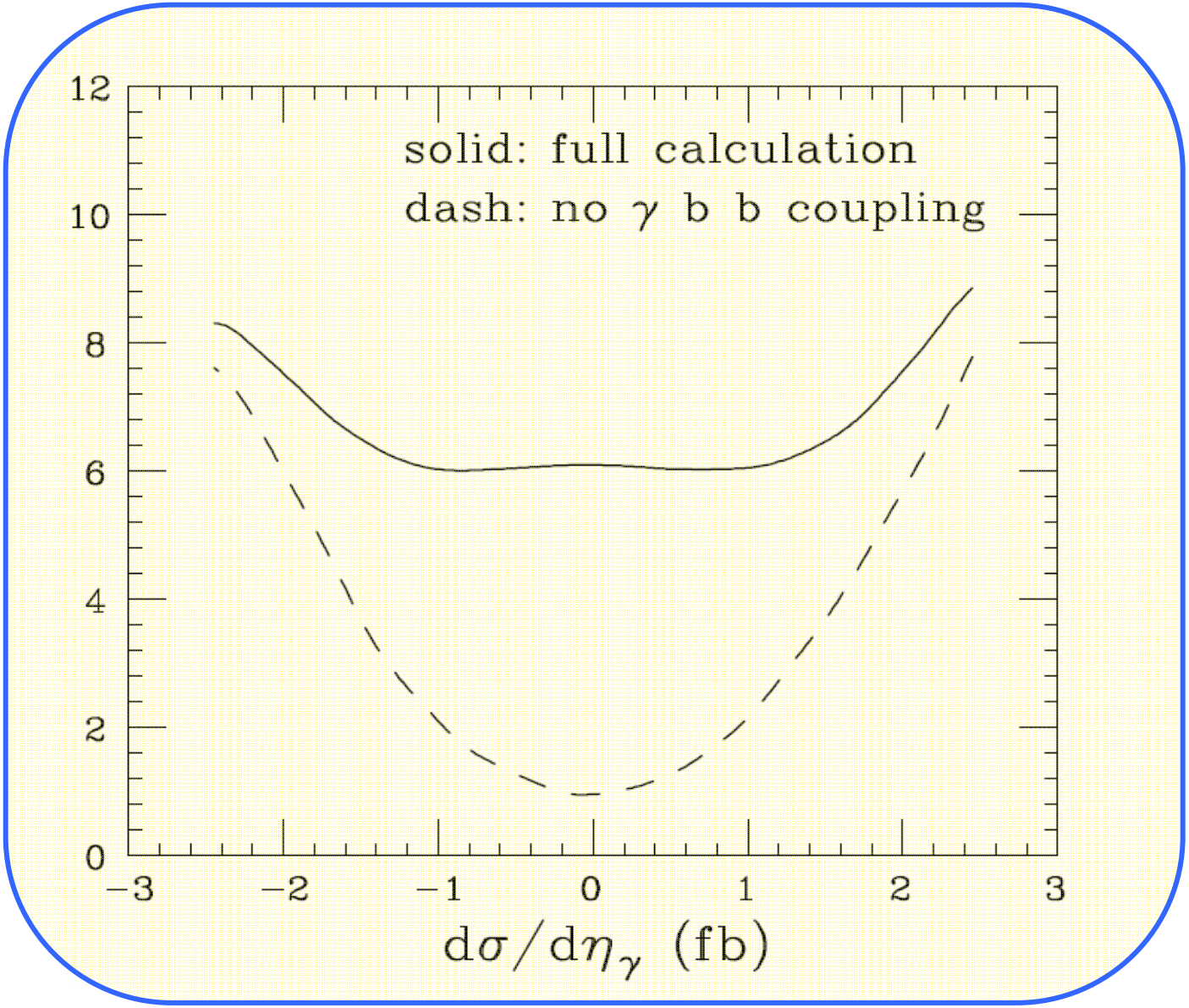
bckg is less active by requiring a central photon

dynamical effect: destructive interference for gamma at large angles a) + b) and c)+ d)

dominant effect, but suppressed by the b-quark electric charge



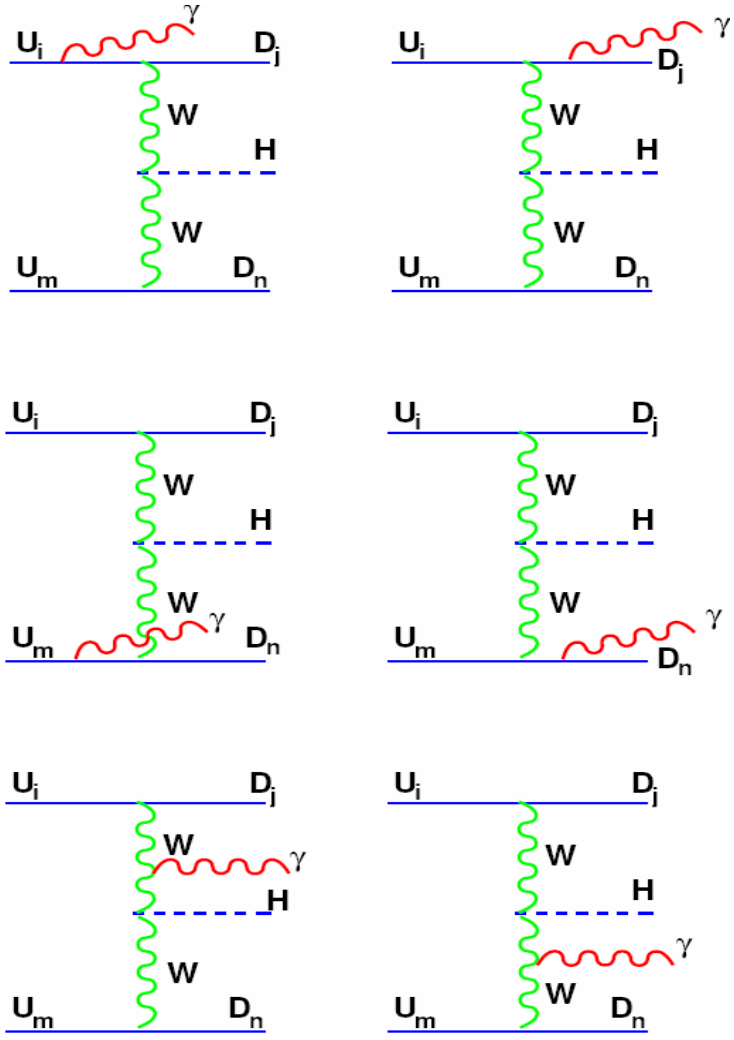
what happens if the radiation of a photon from b-coupling is switched off



radiation of photon from b-coupling is switched off. Partial cross sections

sub-processes	σ_i^γ[no b rad] (fb)	σ_i^γ[no b rad]/σ^γ[no b rad]
$gq \to b\bar{b}\, gq\gamma$	8.19(6)	47.8 %
$gg \to b\bar{b}\, gg\gamma$	0	0 %
$qq' \to b\bar{b}\, qq'\gamma$	2.80(2)	16.4 %
$qq \to b\bar{b}\, qq\gamma$	3.49(3)	20.4 %
$q\bar{q}' \to b\bar{b}\, q\bar{q}'\gamma$	1.57(2)	9.2 %
$q\bar{q} \to b\bar{b}\, q\bar{q}\gamma$	0.87(1)	5.1 %
$gg \to b\bar{b}\, q\bar{q}\gamma$	0.10(2)	0.6%
$q\bar{q} \to b\bar{b}\, gg\gamma$	0.096(2)	0.6 %
$q\bar{q} \to b\bar{b}\, q'\bar{q}'\gamma$	0.0009(1)	0.005 %

SIGNAL
no destructive interference at large angle, due to the charged gauge boson



- different angular photon distribution with respect to bckg

other advantages of requiring a central photon

- depletes HZZ amplitudes with respect to WWH

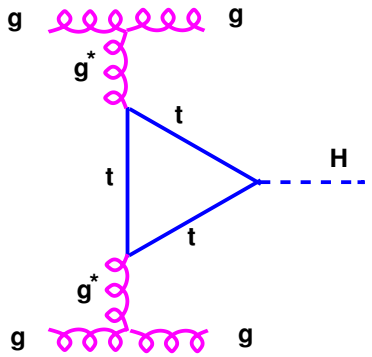
$$\frac{\sigma^{(N)}(H\gamma jj)}{\sigma^{(N)}(H jj)} = 0.0016$$

$$\frac{\sigma^{(C)}(H\gamma jj)}{\sigma^{(C)}(H jj)} = 0.013$$

$$p_{\mathrm{T}}^{\gamma} \geq 20\,\mathrm{GeV},\ |\eta_{\gamma}| \leq 2.5,\ \text{and}\ \Delta R_{j\gamma} \geq 0.7$$

- VBF is sensitive to both WWH and ZZH
- requiring a central photon in VBF increases sensitivity to WWH

- suppress contaminations from $g^* g^* \rightarrow H$ induced by loop of top



basic kinematical cuts (see next slide)

- with pt >20 GeV → reduction factor of 8×10^{-4} for $\sigma(H\ \gamma\ jj)$ with respect to $\sigma(H\ jj)$ (induced by $g^* g^* \rightarrow H$)
- cross section ~ 0.21 fb (negligible !)

basic cuts

$$p_{\mathrm{T}}^{j} \geq 30\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{b} \geq 30\,\mathrm{GeV}, \quad \Delta R_{ik} \geq 0.7,$$

$$|\eta_\gamma| \leq 2.5, \quad |\eta_b| \leq 2.5, \quad |\eta_j| \leq 5,$$

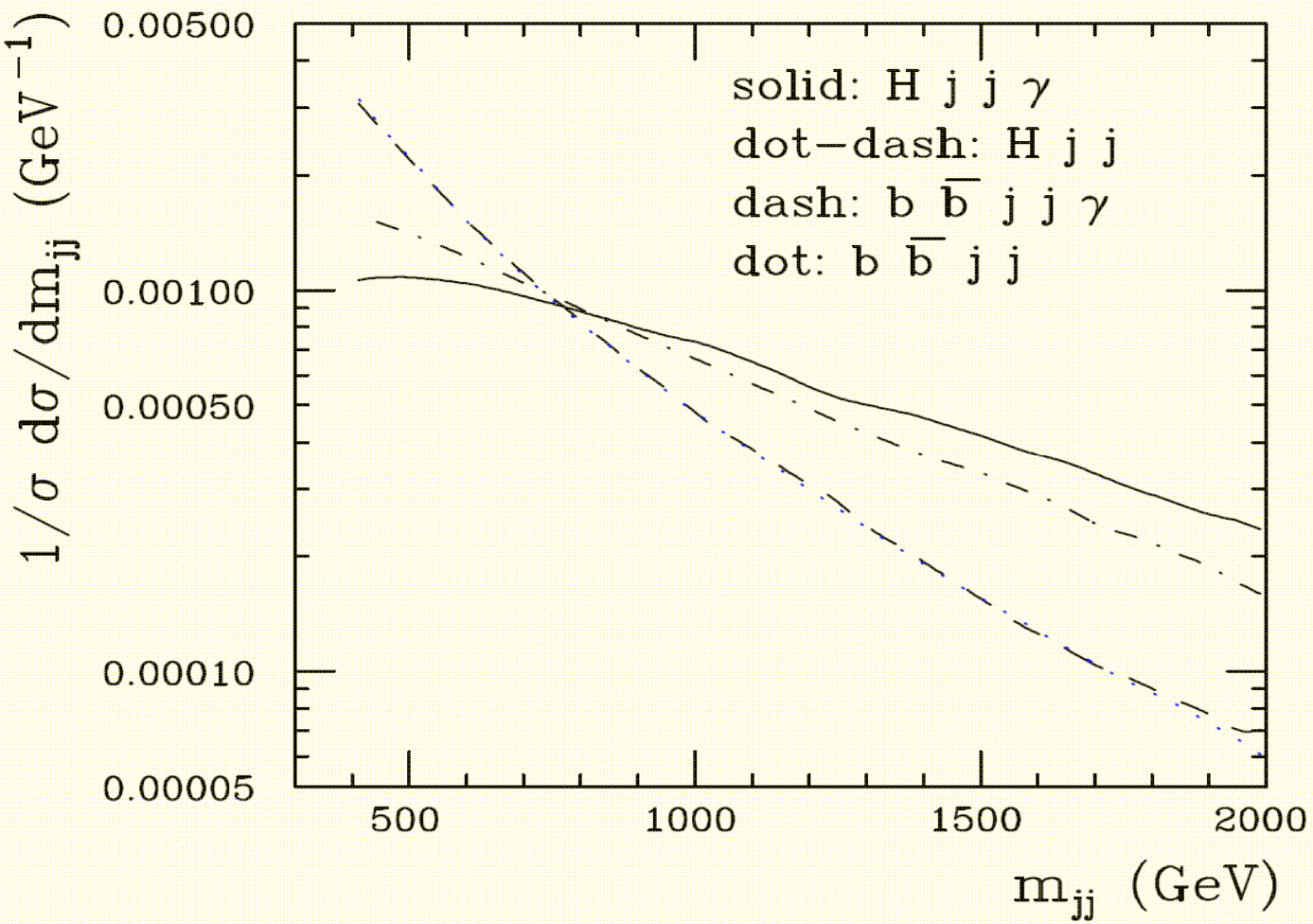
$$m_{jj} > 400\,\mathrm{GeV}, \quad m_H(1-10\%) \leq m_{b\bar{b}} \leq m_H(1+10\%)$$

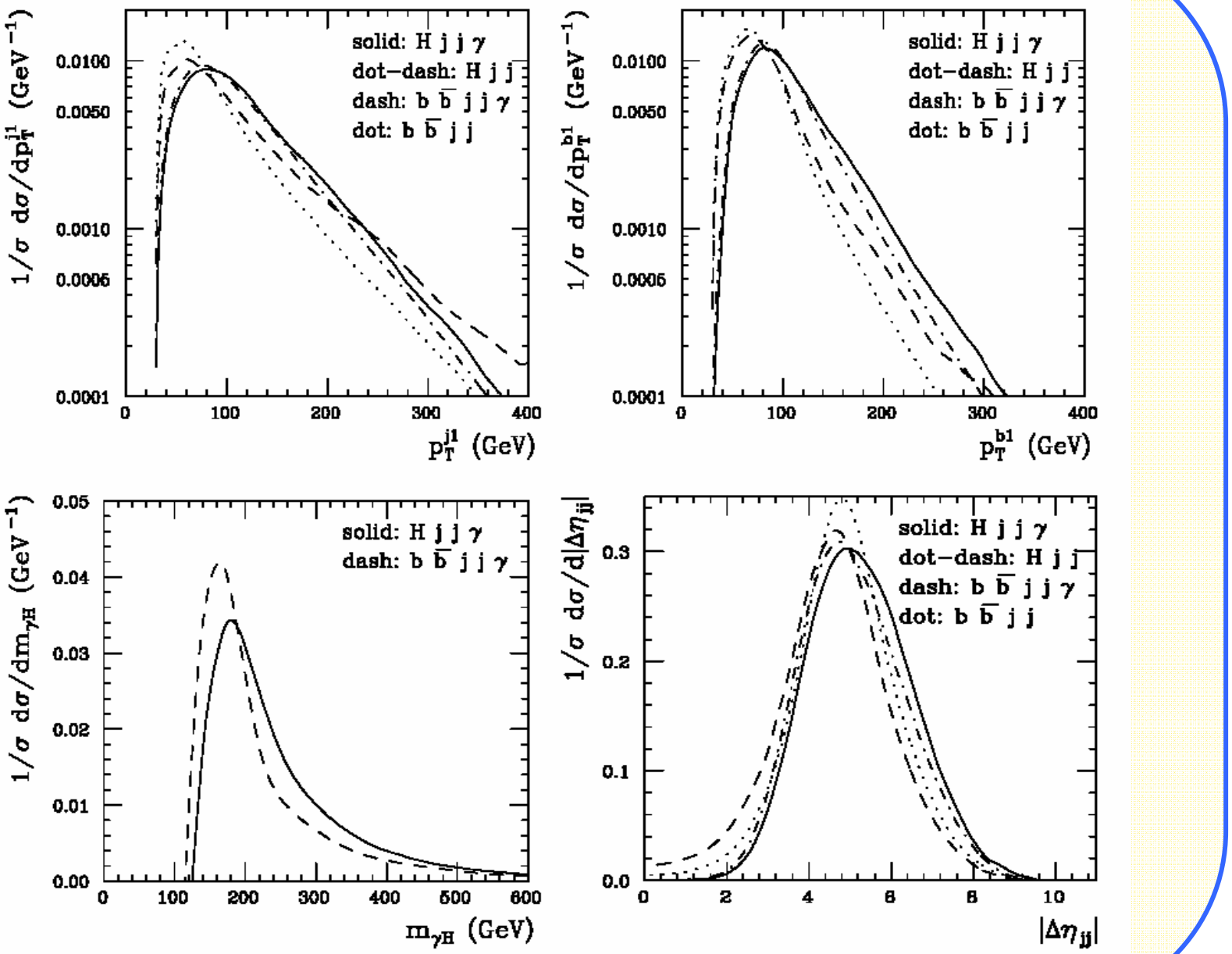
1) $p_{\mathrm{T}}^{\gamma} \geq 20\,\mathrm{GeV}$,

2) $p_{\mathrm{T}}^{\gamma} \geq 30\,\mathrm{GeV}$,

$$\frac{d\sigma}{dm_{jj}}, \quad \frac{d\sigma}{dp_{\mathrm{T}}^{j1}}, \quad \frac{d\sigma}{dp_{\mathrm{T}}^{b1}}, \quad \frac{d\sigma}{dm_{\gamma H}}, \quad \frac{d\sigma}{|\Delta\eta_{jj}|};$$

crucial distribution m(j,j)




solid: H j j γ
dot–dash: H j j
dash: b b̄ j j γ
dot: b b̄ j j
1/σ dσ/dp_T^{j1} (GeV^{-1})
p_T^{j1} (GeV)
1/σ dσ/dp_T^{b1} (GeV^{-1})
p_T^{b1} (GeV)
1/σ dσ/dm_{γH} (GeV^{-1})
m_{γH} (GeV)
1/σ dσ/d|Δη_{jj}|
|Δη_{jj}|

→ optimized cuts follow:

$$m_{jj} \geq 800\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{j1} \geq 60\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{b1} \geq 60\,\mathrm{GeV},$$
$$|\Delta\eta_{jj}| > 4, \quad m_{\gamma H} \geq 160\,\mathrm{GeV}, \quad \Delta R_{\gamma b/\gamma j} \geq 1.2,$$

$$N(B) = \mathrm{L}\,\sigma_B\,\mathrm{BR}\,\varepsilon(b)\varepsilon(\bar{b})\varepsilon(b\bar{b})$$

$$N(S) = \mathrm{L}\,\sigma_S\,\mathrm{BR}\,\varepsilon(b)\varepsilon(\bar{b}) \quad \Rightarrow \quad \mathrm{signf} = \frac{N(S)}{\sqrt{N(B)}}$$

we used

L = 100 fb^{-1}

ε(b) = 60% →eff. b-tag

ε(bb) = 70% →due to (+/-10 %) bb mass resolution

pp → H γ + j j : optimized cross sections

	$p_{\mathrm{T}}^{\gamma,cut}$	$m_H = 120$ GeV	$m_H = 130$ GeV	$m_H = 140$ GeV
$\sigma[H(\to b\bar{b})\gamma jj]$	20 GeV	3.59(7) fb	2.92(4) fb	1.98(3) fb
	30 GeV	2.62(3) fb	2.10(2) fb	1.50(3) fb
$\sigma[b\bar{b}\gamma jj]$	20 GeV	33.5(1) fb	37.8(2) fb	40.2(1) fb
	30 GeV	25.7(1) fb	27.7(1) fb	28.9(2) fb
$\sigma[H(\to b\bar{b})jj]$		320(1) fb	254.8(6) fb	167.7(3) fb
$\sigma[b\bar{b}jj]$		103.4(2) pb	102.0(2) pb	98.4(2) pb

	$p_{\mathrm{T}}^{\gamma,cut}$	$m_H = 120$ GeV	$m_H = 130$ GeV	$m_H = 140$ GeV
$S/\sqrt{B}\vert_{H\gamma jj}$	20 GeV	2.6	2.0	1.3
$S/\sqrt{B}\vert_{H\gamma jj}$	30 GeV	2.2	1.7	1.2
$S/\sqrt{B}\vert_{Hjj}$		3.5	2.8	1.9

L=100 fb^{-1}

S/B(γ) ~ 1/10

S/B ~ 1/300

Reducible backgrounds

- $pp \rightarrow \gamma + 4\,jets$ where two among the light jets are faked-tagged as b-jets
- $pp \rightarrow b\bar{b} + 3\,jets$ where one of the light jets is misidentified as a photon
- $pp \rightarrow 5\,jets$ where one of the light jets is misidentified as a photon and two light jets are fake-tagged as b-jets

number of events (mH=120 GeV)

	$p_{\mathrm{T}}^{\gamma} \geq 20$ GeV	$p_{\mathrm{T}}^{\gamma} \geq 30$ GeV
$pp \to \gamma H(\to b\bar{b}) + 2j$	90	66
$pp \to \gamma b\bar{b} + 2j$	1206	925
$pp \to \gamma + 4j$	23	17
$pp \to b\bar{b} + 3j$	440	324
$pp \to 5j$	14	11
$S/\sqrt{B}$	2.2	1.8

ε_{fake} → for mistagging light-jet as a b-jet

$$\varepsilon_{\mathrm{fake}} = 1 \qquad \varepsilon_{\gamma\, \mathrm{j}} = 1/5000$$ (ATLAS)

Parton shower effects and central jet veto

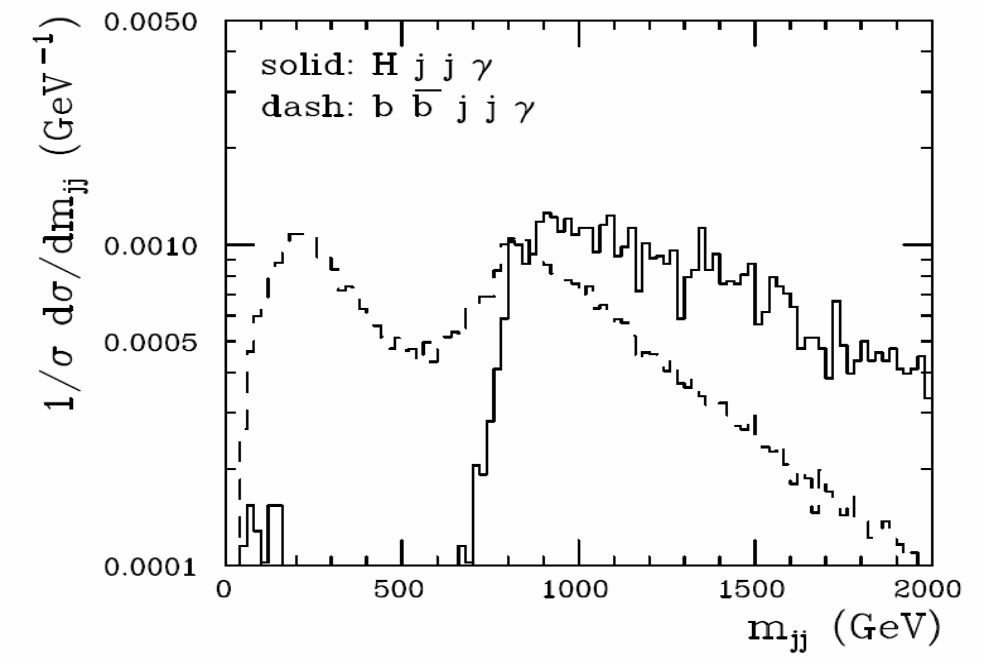
- no color is exchanged in the signal between initial and final fermionic lines
- on the contrary, bckg is characterized by the presence of t-channel virtual gluons
- more QCD radiation is expected for background
- invariant mass and rapidity separation between the tagging jets are expected to decrease in the bckg events with respect to partonic configurations.

two different algorithms for jets

- the identification of light tagging jets not uniquely defined, due to extra QCD radiation

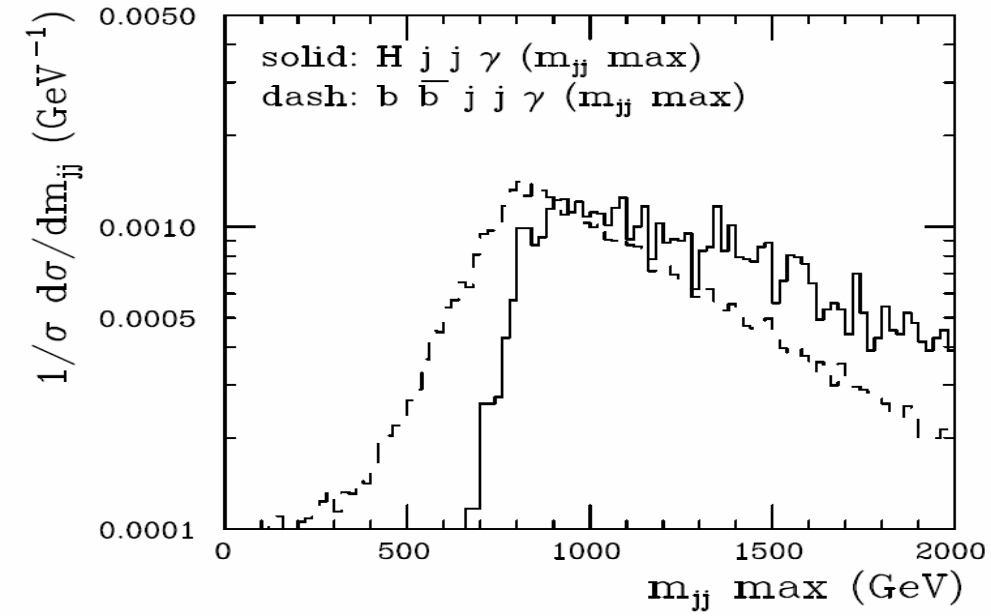
a1- highest and second highest pT with pT(j1)> 60 GeV pT(j2)> 30 GeV

a2- pair of jets with highest invariant mass, pT(j1)> 60 GeV pT(j2)> 30 GeV

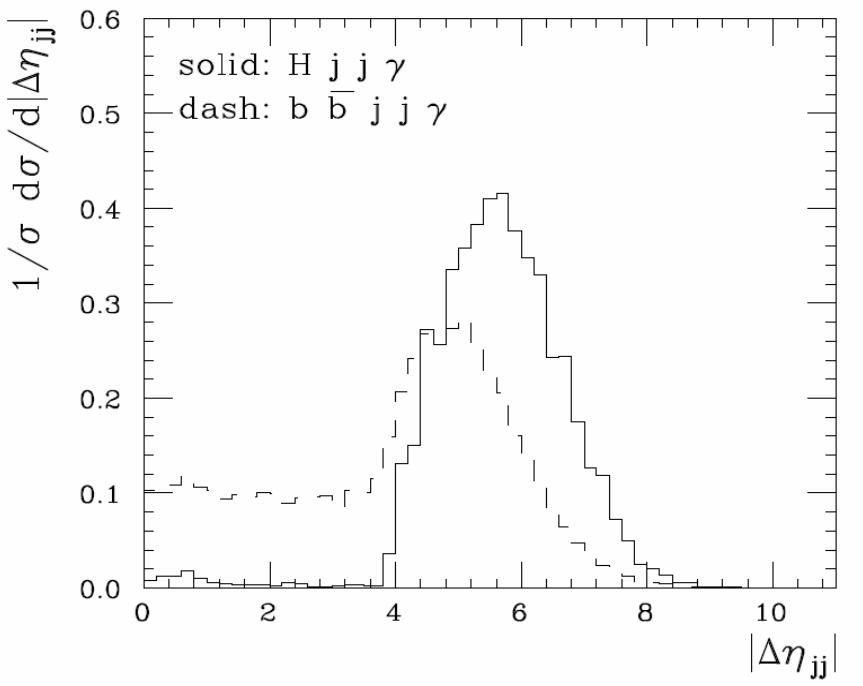


m(j1,j2)
j1=highest pT
j2=second highest pT

pT1> 60, pT2 >30

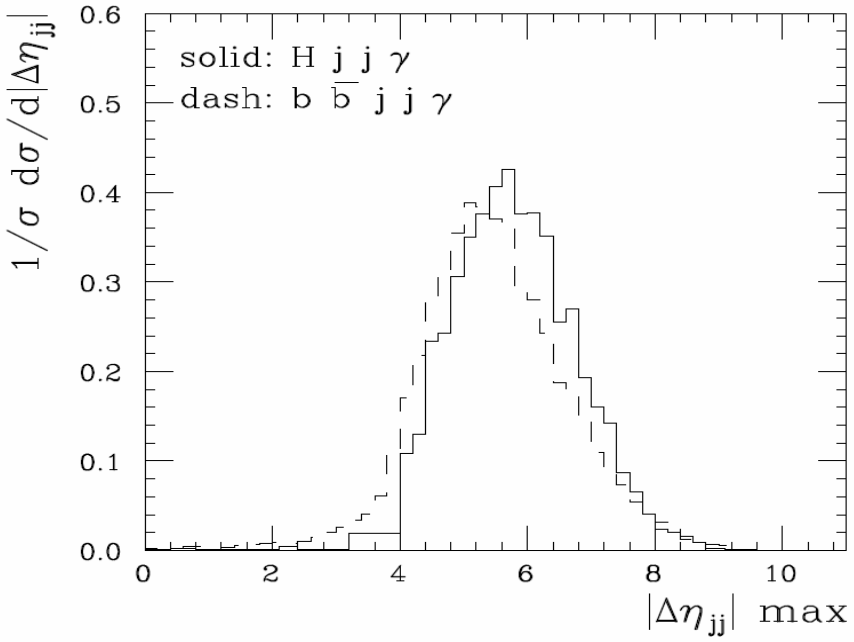


max[m(j1,j2)] among all jets

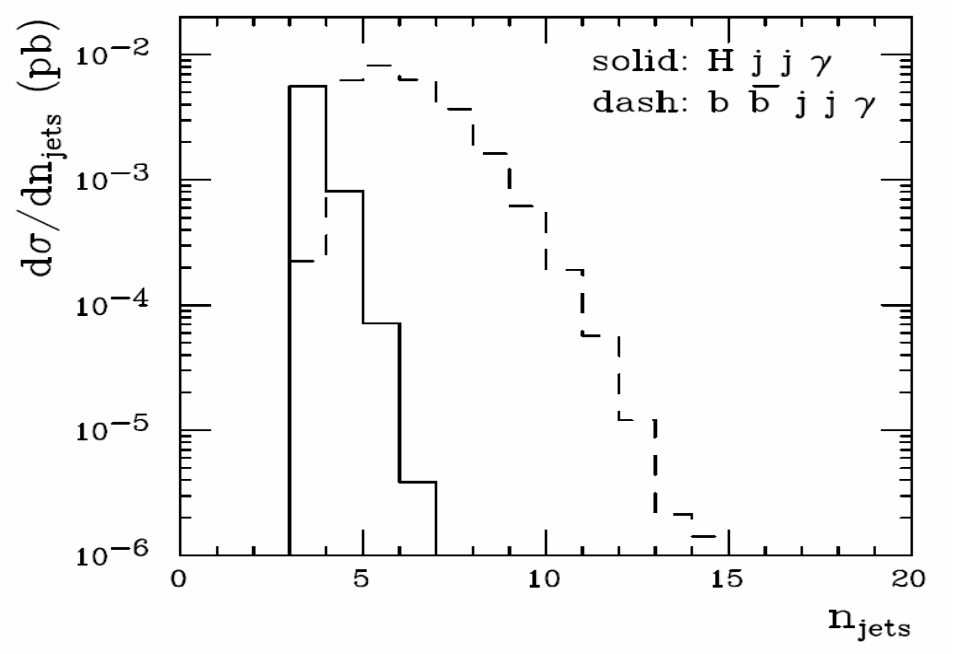


Δη(j1,j2)
j1=highest pT
j2=second highest pT

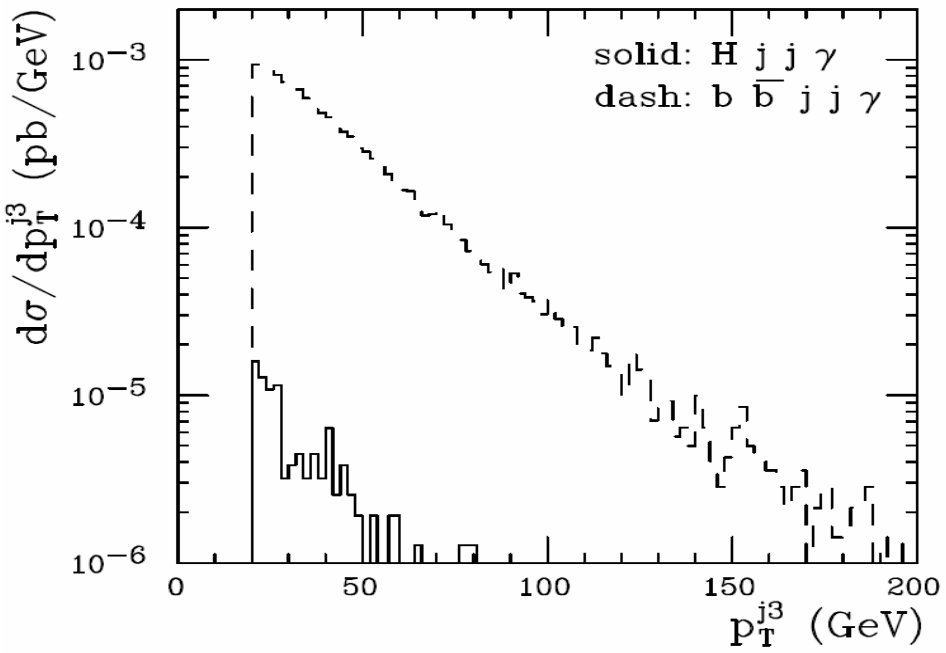
pT1> 60, pT2 >30



max[Δη(j1,j2)] among all jets



jet multiplicity distribution



pT distribution of the third highest pT jet

- A veto on additional jet activity in the central rapidity region could be very effective in suppressing bckg versus signal
- at least a factor 4 improvement is expected for S/B
- a more refined analysis will be necessary for quantitative statements

what if $\gamma \rightarrow W$: HW jj Rainwater (2001)

ν l=e,μ

- it could help in constraining bbH coupling
- however, accurate studies of background and parton shower effects are missing
- relevant cross section is smaller than H γ jj

with same optimized event selection criteria
(with constraints on photon applied to charged lepton)
for mH=120 GeV and pT(γ) > 20 GeV we get

$$\sigma(H\gamma jj) \sim 4.4 \times \sigma(HWjj)$$

ν l=e,μ

Conclusions

- The measure of Hbb coupling is challenging at the LHC
- we propose a promising channel

  $pp \rightarrow H\,jj + \gamma$ (VV fusion)
- main advantages with respect to Hjj in VBF
  - trigger on photon
  - less active bckg after requiring a central photon
- after suitable cuts → signf ~ 3
  (for L=100 fb^{-1} , mH= 120 GeV)
- can help in constraining both Hbb and HWW couplings