Rescuing $H \rightarrow bb$ in VBF at LHC by requiring a further central γ

- measuring g_{Hbb} at LHC : known facts
- $pp \rightarrow H(\rightarrow bb)\, 2j + \gamma$: a new handle on g_{Hbb}
- signal rates versus main bckgs at LHC

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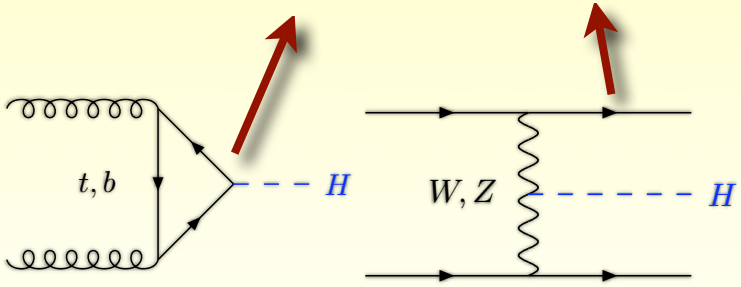
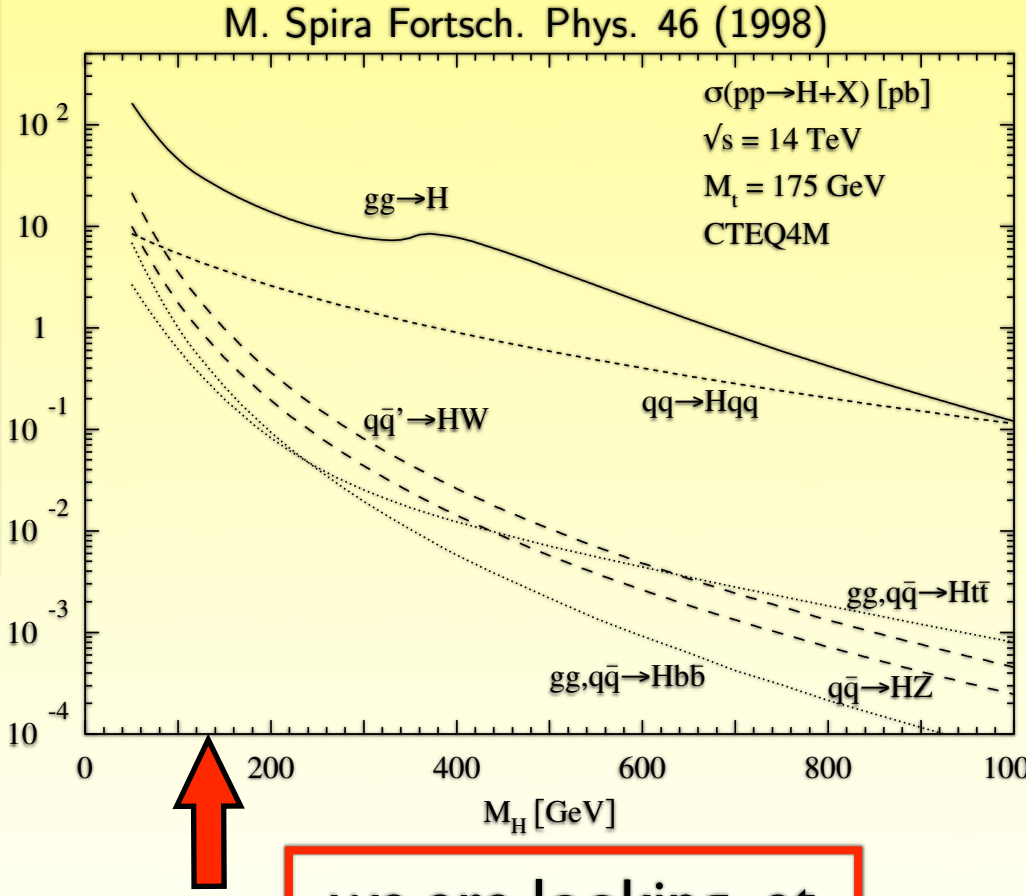
Gabrielli, Maltoni, B.M., M.Moretti, Piccinini, Pittau, hep-ph/0702119

HIGGS TOTAL CROSS SECTIONS

m_H (GeV)	σ_{gg} [pb]	σ_{VBF} [pb]
120	42	4.4
140	33	3.8
200	18	2.5
300	10	1.4



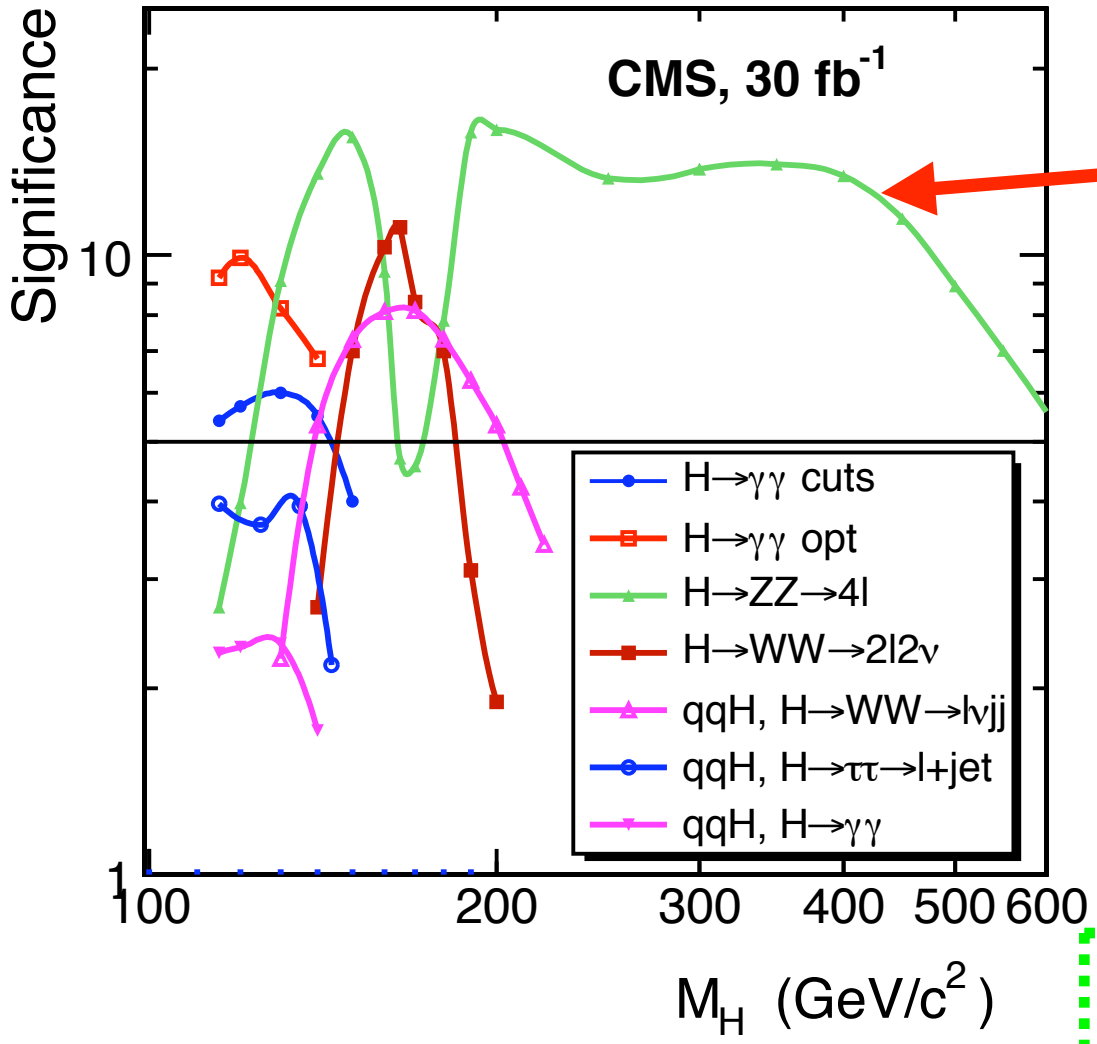
different final states !



we are looking at
m_H ~ 120 -140 GeV

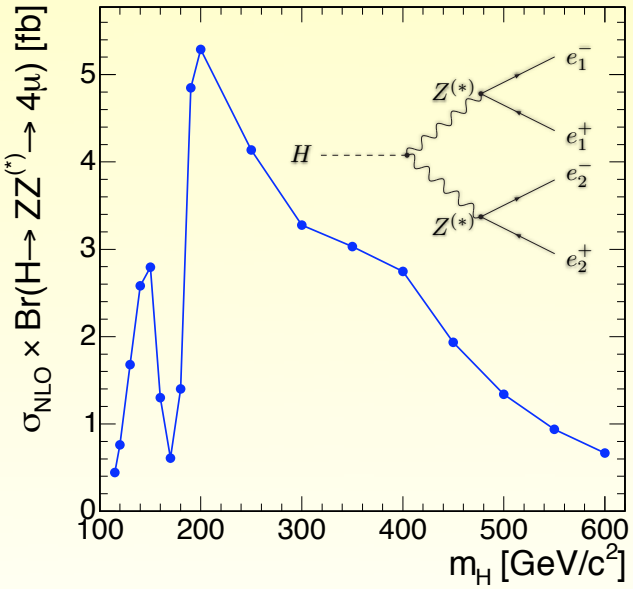
interesting σ's are of the order of few fb's

(after BR's + cuts for enhancing signal/bckg)



GOLDEN CHANNEL !

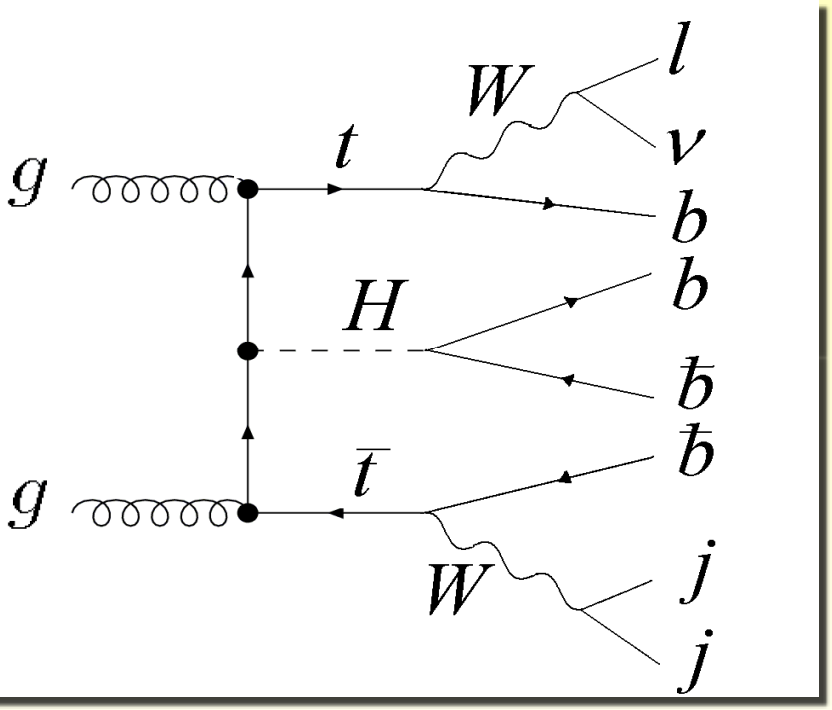
$$H \rightarrow ZZ \rightarrow 4l$$



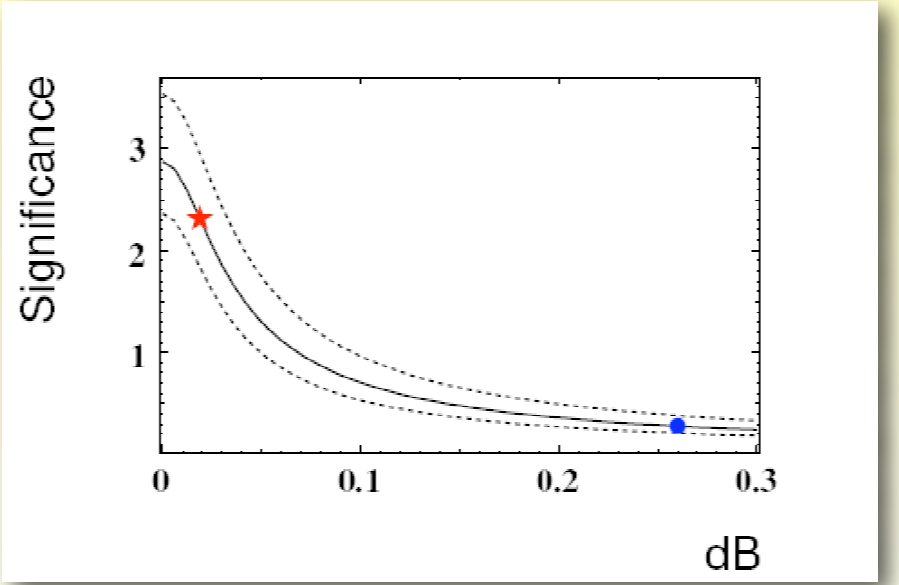
σ × BR (H→ 4 μ) < 6 fb

Constraining Hbb coupling at LHC

- more promising channel : $pp \rightarrow t\,t\,H$ $(H \rightarrow bb)$



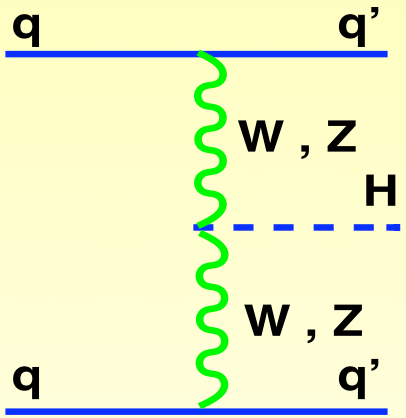
(CMS Phys TDR, Vol. II, CERN/LHCC 2006-021)

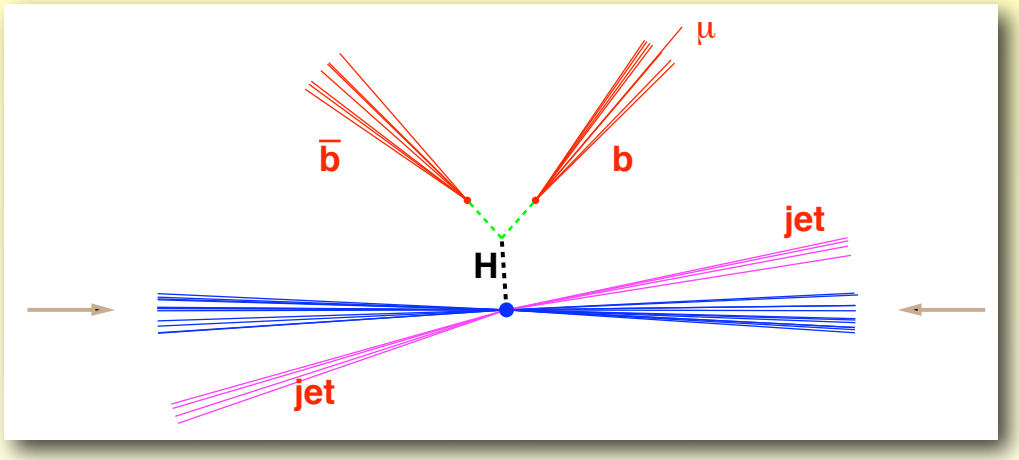


- CMS PTDR 2006 → including detector simulation lowers previous expectations on its discovery potential !

pp → H (→bb) + 2j (VBF fusion)

- potential <u>difficult</u> to assess (4 j final state ...)





- light Jets with large invariant mass $p_T(j) \approx 40\ \mathrm{GeV}$
- widely separated in rapidity (forward/backward)
- Higgs decay products lying at intermediate rapidity

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

Signal and background events at 30 fb^{-1}(fast simulation)

Expected $qqH, H \rightarrow b\bar{b}$ signal and background events in m_{bb} mass window of $\pm 30 GeV/c^2$

Decay channel	$N_{final\ events}$		Efficiencies		$N_{normalized\ to \mathcal{L}=\ 30\ fb^{-1}}$	
	Fast	Full	Fast	Full	Fast	Full
qqH H$\rightarrow b\bar{b}$	5354	365	4.5×10^{-3}	3.2×10^{-3}	328	243
single t	2689	-	9.0×10^{-5}	-	881	-
bb	25	-	2.5×10^{-8}	-	315000	-
W+jets	18	-	3.2×10^{-8}	-	331	-
Z+jets	311	-	1.2×10^{-6}	-	681	-
$t\bar{t} \rightarrow WWb\bar{b}$	404	-	1.4×10^{-5}	-	203	-
Total Background					317096	-
$S/\sqrt{B}$					0.6	-

HLT efficiency after all reconstruction cut

Trigger menu	trigger efficiency(%)
e25i	0.0
2e15i	0.0
μ6	79.7(after prescale:4.0)*
μ20i	21.9
1j400	1.6
3j165	0.0
4j110	0.0
Any trigger	80.0(25.6)

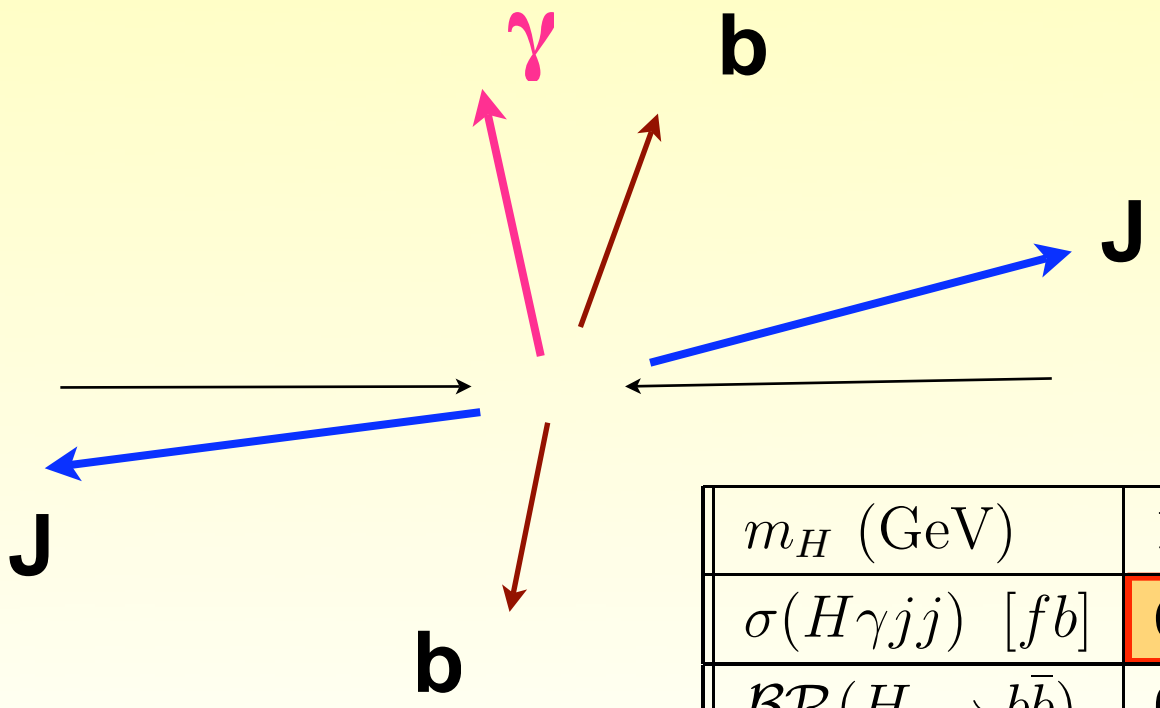
*Assuming the prescale factor of 20, from John Baines slide of the TAPM open meeting on 13th of February

New Promising Channel :

(Gabrielli, Maltoni, B.M., M. Moretti, Piccinini, Pittau, hep-ph/0702119)

- require a further central photon from VBF

$pp \to H(\to b\bar{b}) + 2j + \gamma$

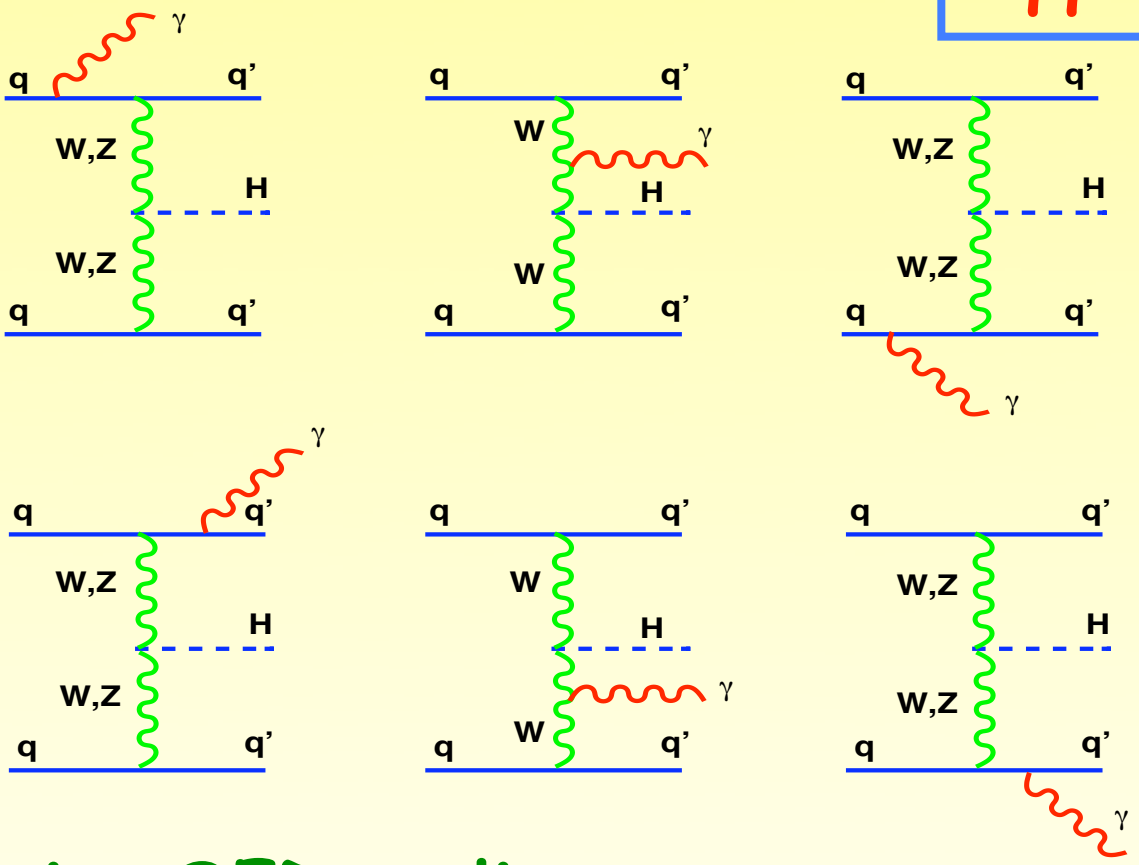


should increase triggering efficiency

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

$(\Delta R_{\gamma j} > 0.4,\ p_{\mathrm{T}}^{\gamma} \geq 20\ \mathrm{GeV},\ \mathrm{and}\ m_{jj} > 100\,\mathrm{GeV})$

$qq \to qq\,H + \gamma$



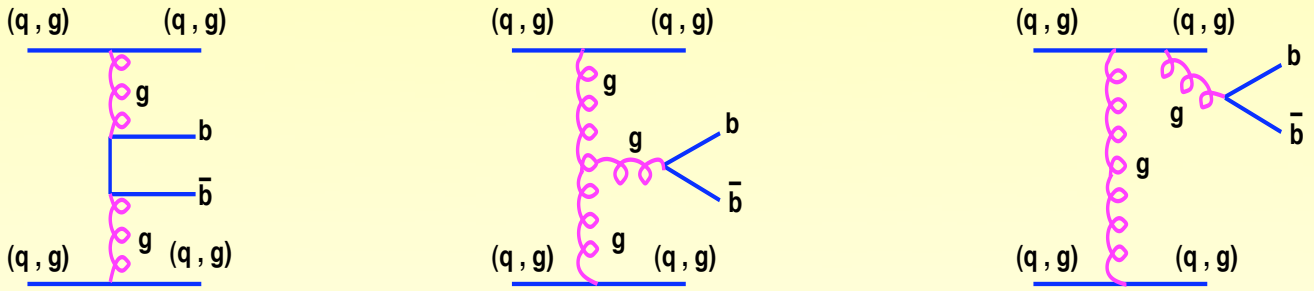
from naive QED scaling :

$$(S/\sqrt{B})|_{H\gamma\,jj} \sim \sqrt{\alpha}\,(S/\sqrt{B})|_{H\,jj} \lesssim 1/10\,(S/\sqrt{B})|_{H\,jj}$$

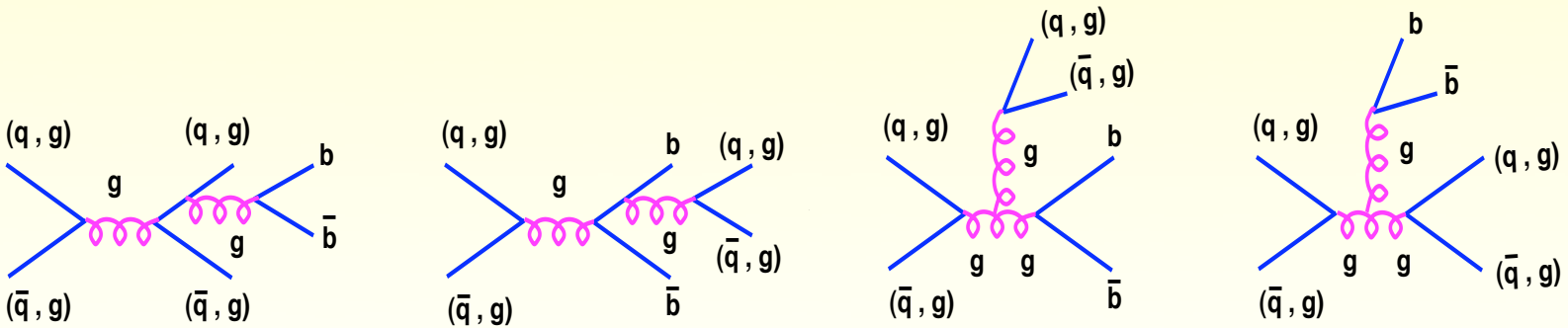
but this is not the case ! **S/√B much better than this !**

IRREDUCIBLE BCKGD

add a photon to ⬇ (gluons are idle !)



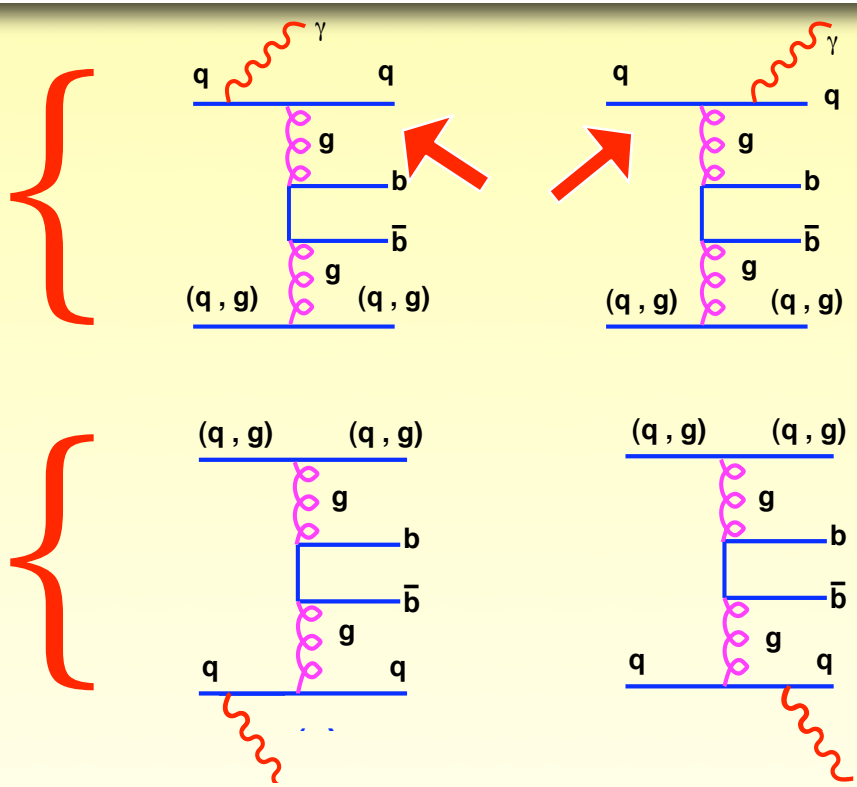
t,u-channel (most relevant !)



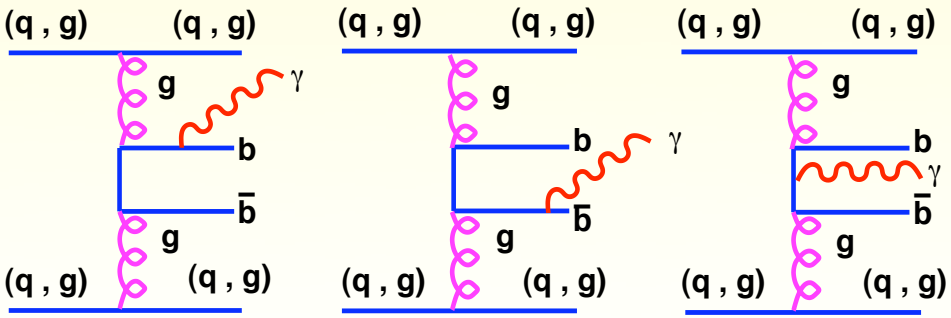
s-channel (suppressed by M_{jj} ~ 1TeV)

+ destructive interf.s in central γ emissions off q_{in} and q_{fin} in a t-channel gluon diagram

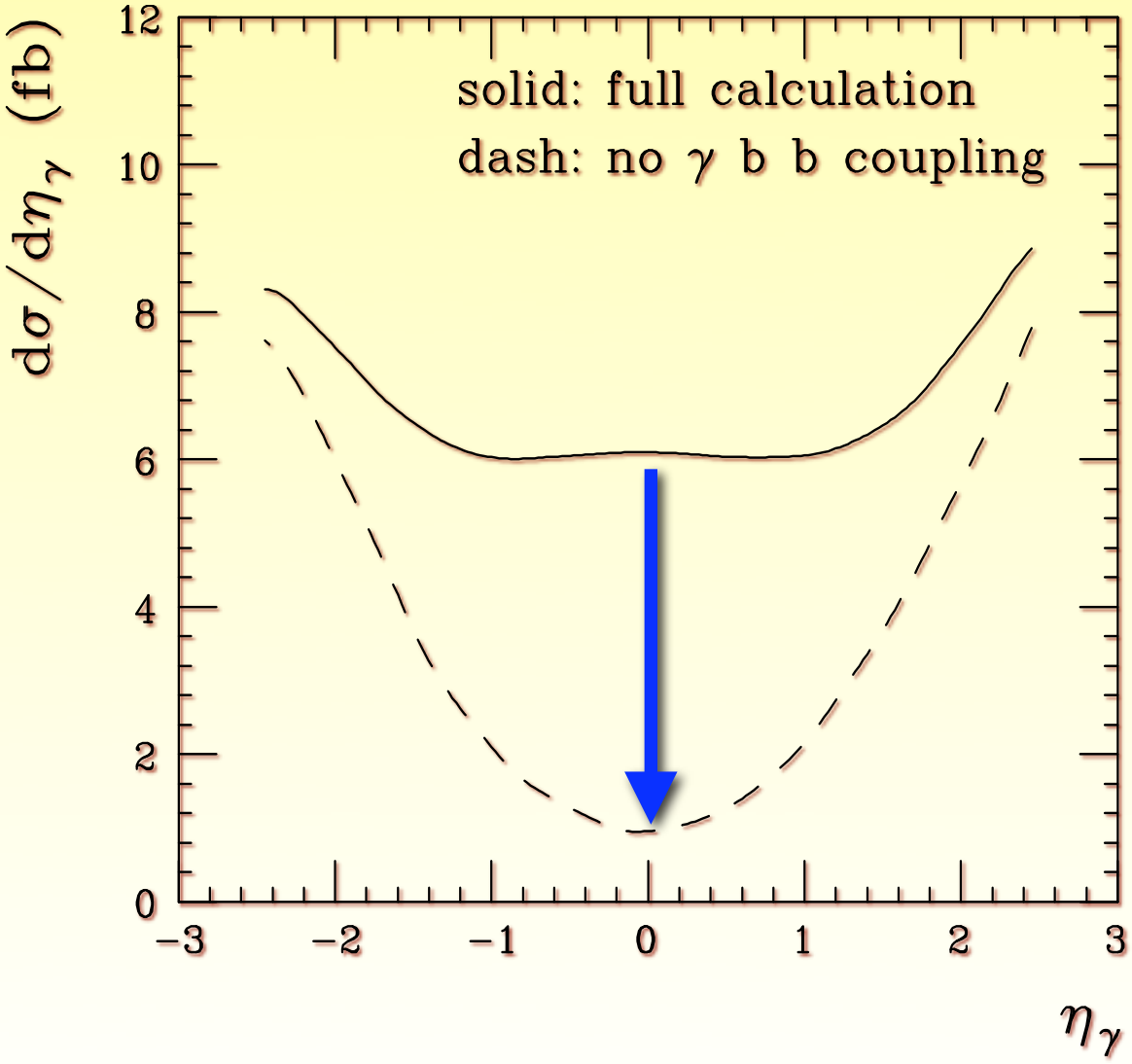
→ bckg suppressed by requiring a central photon by O(1/10) compared to naive QED scaling!



dominant contribut. →
(suppressed by b-quark electric charge)



switching off the γbb coupling in irr. bckg



photon rapidity distr.s

(optimized cuts)

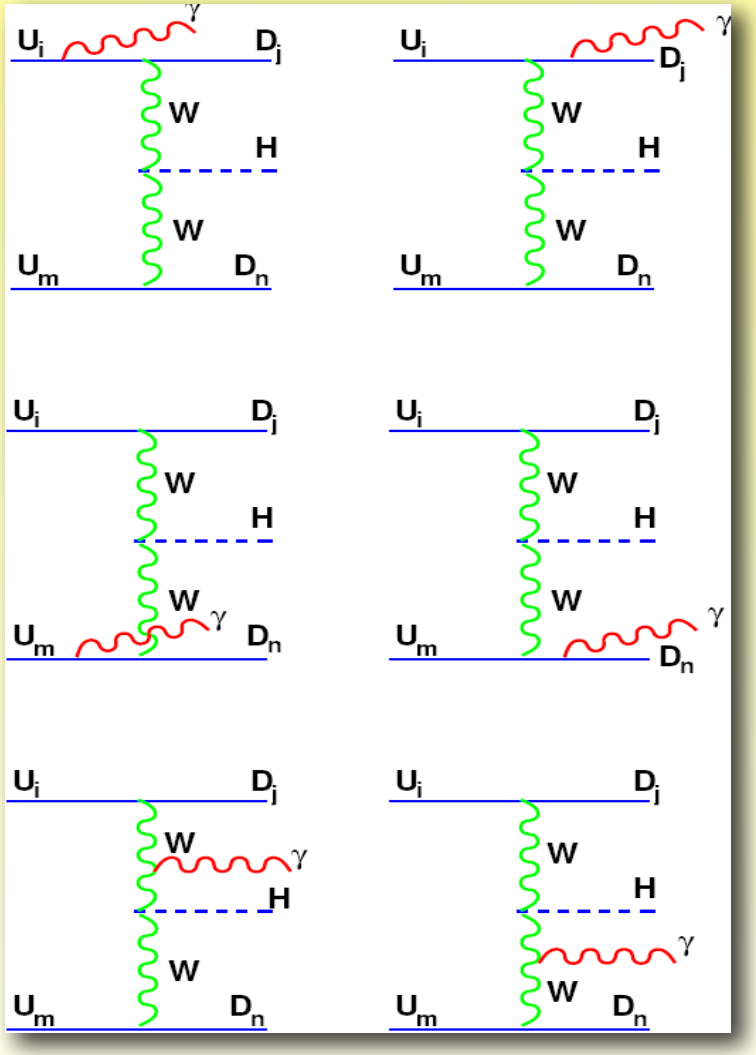
what about signal ?

W charged current spoils destructive interference at large angle !

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

but Z neutral current follows BCKG pattern !!!

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



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

central photon singles out WW over ZZ fusion !!!

basic cuts :

EVENT SELECTION

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

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

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

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

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

then, look at distrib's :

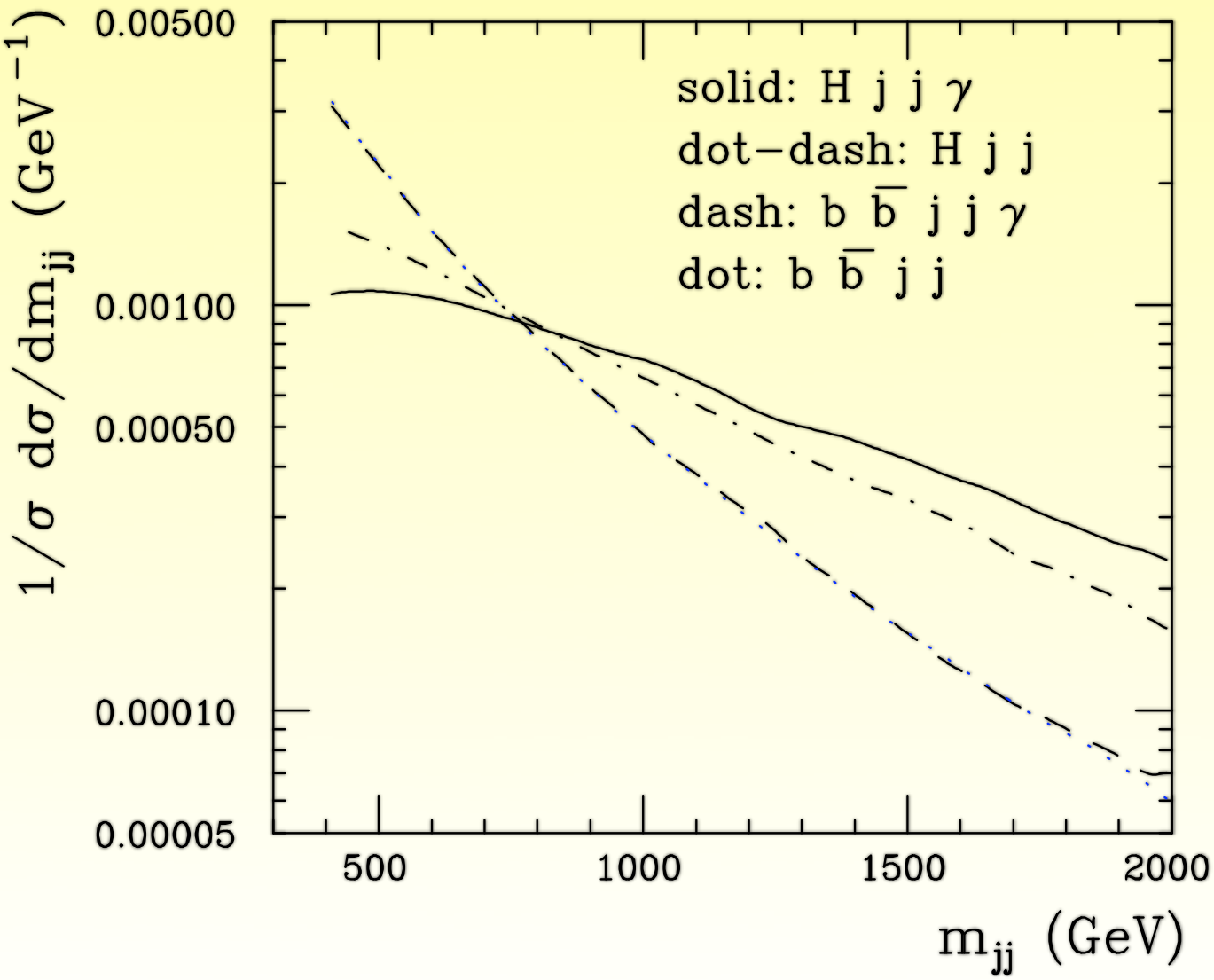
$$\frac{d\sigma}{dm_{jj}}, \quad \frac{d\sigma}{dp_{\mathrm{T}}^{j1}}, \quad \frac{d\sigma}{dp_{\mathrm{T}}^{b1}}, \quad \frac{d\sigma}{dm_{\gamma H}}, \quad \frac{d\sigma}{|\Delta\eta_{jj}|},$$

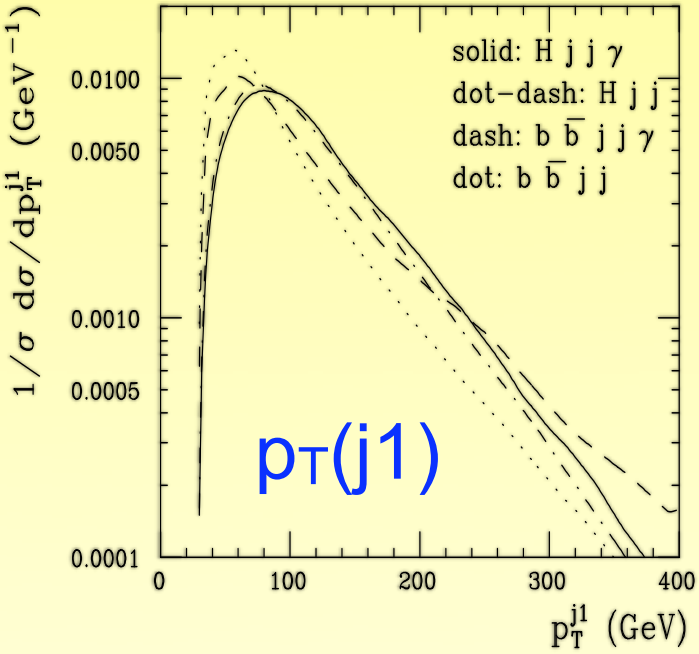
→ **add optimized cuts :**

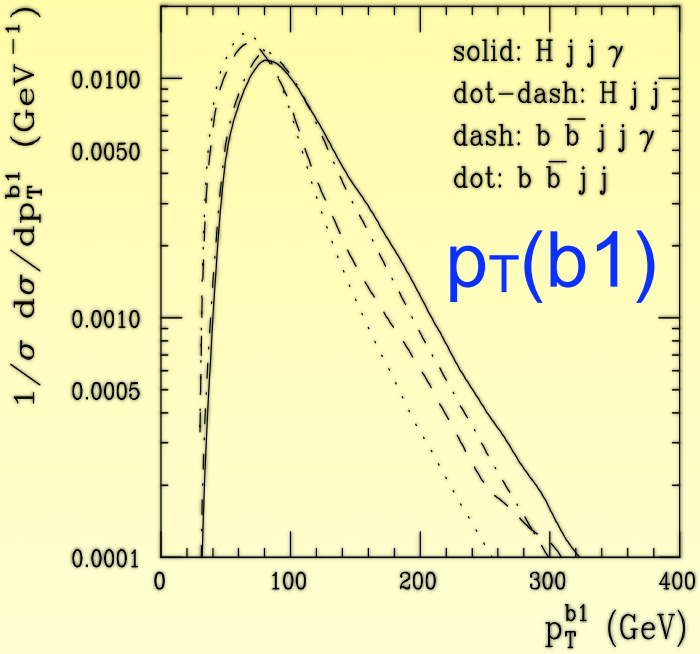
$$m_{jj} \geq 800\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{j1} \geq 60\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{b1} \geq 60\,\mathrm{GeV},$$

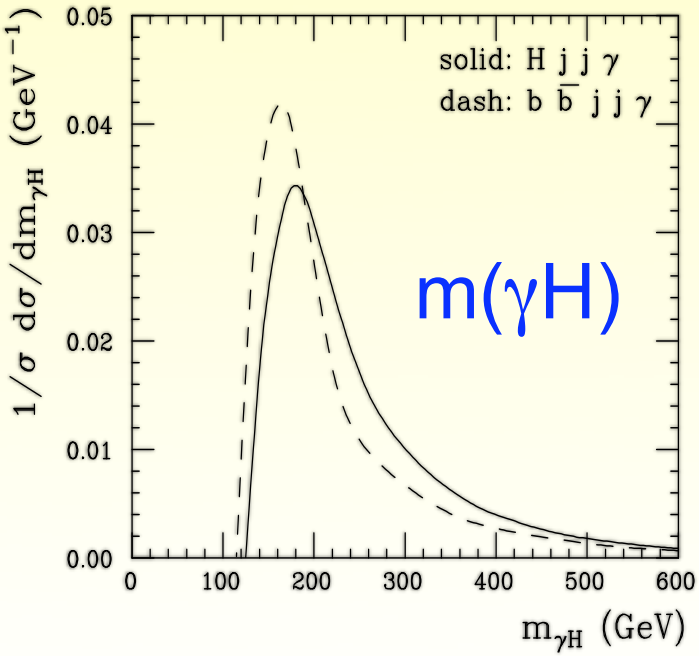
$$|\Delta\eta_{jj}| > 4, \quad m_{\gamma H} \geq 160\,\mathrm{GeV}, \quad \Delta R_{\gamma b/\gamma j} \geq 1.2\,.$$

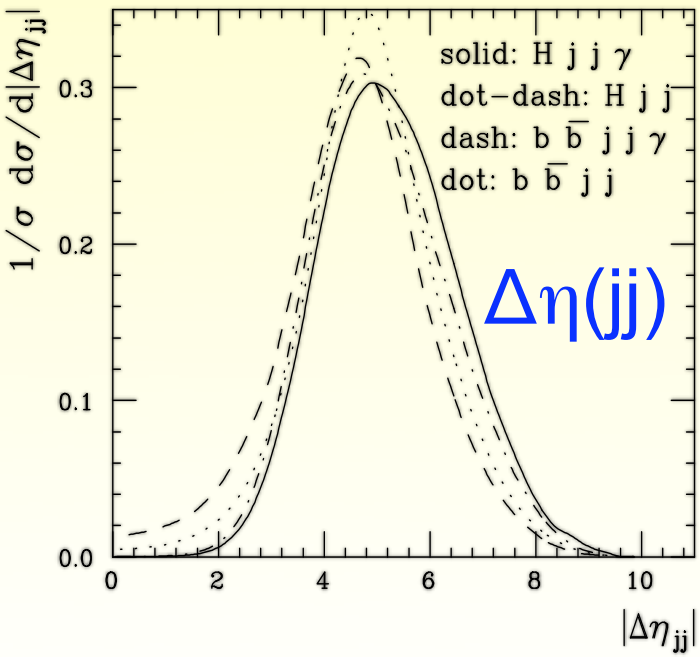
m_{jj} distribution critical to enhance S/B




solid: H j j γ
dot–dash: H j j
dash: b b̄ j j γ
dot: b b̄ j j
pT(j1)
1/σ dσ/dp_T^j1 (GeV^-1)
p_T^j1 (GeV)


solid: H j j γ
dot–dash: H j j
dash: b b̄ j j γ
dot: b b̄ j j
pT(b1)
1/σ dσ/dp_T^b1 (GeV^-1)
p_T^b1 (GeV)


solid: H j j γ
dash: b b̄ j j γ
m(γH)
1/σ dσ/dm_γH (GeV^-1)
m_γH (GeV)


solid: H j j γ
dot–dash: H j j
dash: b b̄ j j γ
dot: b b̄ j j
Δη(jj)
1/σ dσ/d|Δη_jj|
|Δη_jj|

irreducible bckgr σ's (optimized cuts) $p_T^\gamma \geq 20\,\mathrm{GeV}$

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 %

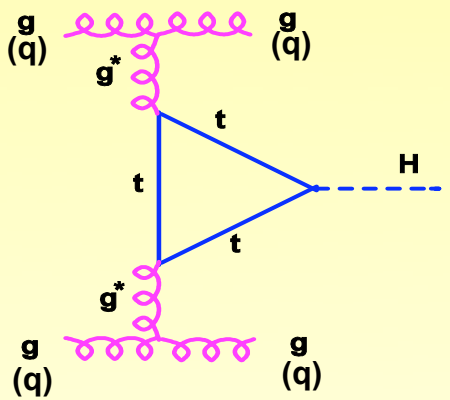
bckg(γ)/bckg ~ *33 fb / 103 pb ~ 1/3000*

cf. signal(γ)/signal ~ 1/100

- requirement of a central photon also suppresses contamination from $g^*g^* \rightarrow H\ jj\ \gamma$

(induced by top loop)

("bckg" to Higgs from VBF)



(basic cuts, p_T^{γ} >20 GeV)

- $\sigma(H\ \gamma\ jj) \sim 8\times10^{-4}\ \sigma(H\ jj)_{g^*g^* \rightarrow H}$
- $\sigma(H\ \gamma\ jj) \sim 0.21$ fb negligible !

σ's : pp → H γ j j vs irrid. bckgr

(ALPGEN + MADEVENT)

	$p_T^{\gamma,cut}$	$m_H = 120$ 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

	$p_T^{\gamma,cut}$	$m_H = 120$ GeV	$m_H = 130$ GeV	$m_H = 140$ GeV
$S/\sqrt{B}\|_{H\gamma jj}$	20 GeV	2.6	2.0	1.3
$S/\sqrt{B}\|_{H\gamma jj}$	30 GeV	2.2	1.7	1.2
$S/\sqrt{B}\|_{H jj}$		3.5	2.8	1.9

L=100 fb^{-1}

ε(b) = 60% PDF : CTEQ5L

S/B ~ 1/(10-20) !

N_{events} for reducible bckgs (mH=120 GeV)

L=100 fb^{-1}

	$p_T^\gamma \geq 20$ GeV	$p_T^\gamma \geq 30$ 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

$\varepsilon_{fake} = 1\%$

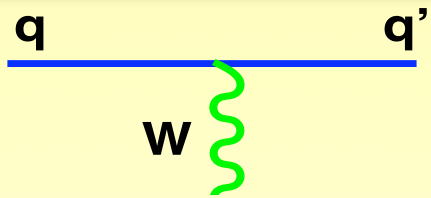
ε_{fake} → mistagging light-jet as a b-jet

$\varepsilon_{\gamma j} = 1/5000$

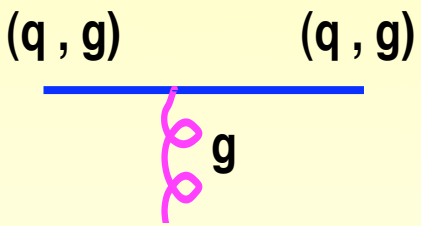
CMS can do better than this !

Parton shower effects and central jet veto help S/B

- no color exchanged in the signal between up and down fermionic lines



- on the contrary, in bckg t-channel virtual gluons



- higher-order QCD radiation much more relevant for bckg than for signal !

- in bckg, m_{jj} and $|\Delta\eta_{jj}|$ for light tagging jets expected to decrease with respect to partonic configurations

ALPGEN + HERWIG

jet cone as in GETJET $p_{\mathrm{T}}^{j} > 20\,\mathrm{GeV}$ $|\eta_j| < 5$ $R = 0.7$

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

tried 2 different algorithms for jets :

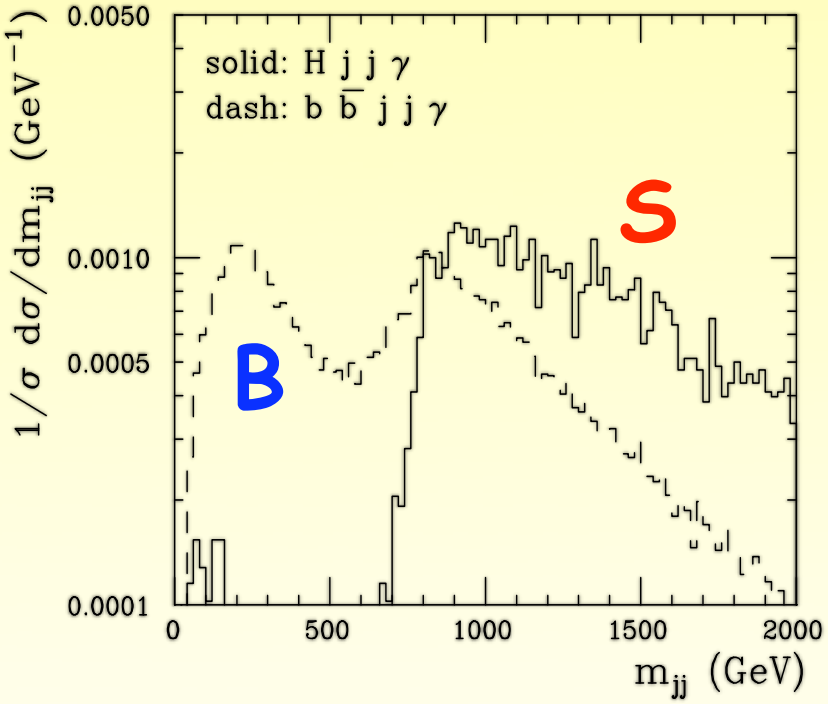
a1-highest and second highest pT with pT(j1)> 60 GeV pT(j2)> 30 GeV

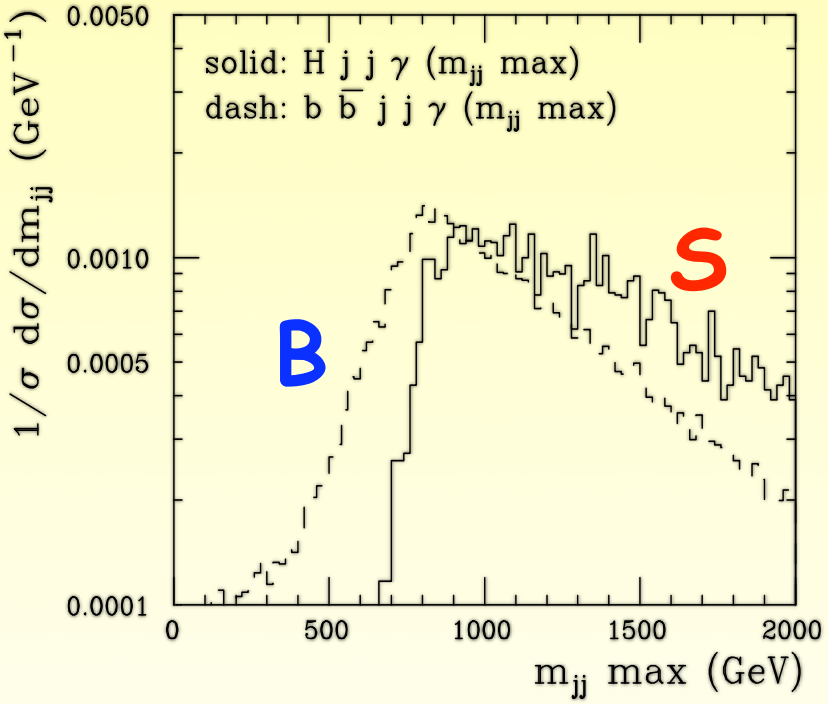
a2-pair of jets with highest invariant mass, pT(j1)> 60 GeV pT(j2)> 30 GeV

distributions after parton shower

jet 1-2 invariant mass distribution

pT1> 60, pT2 >30





a1

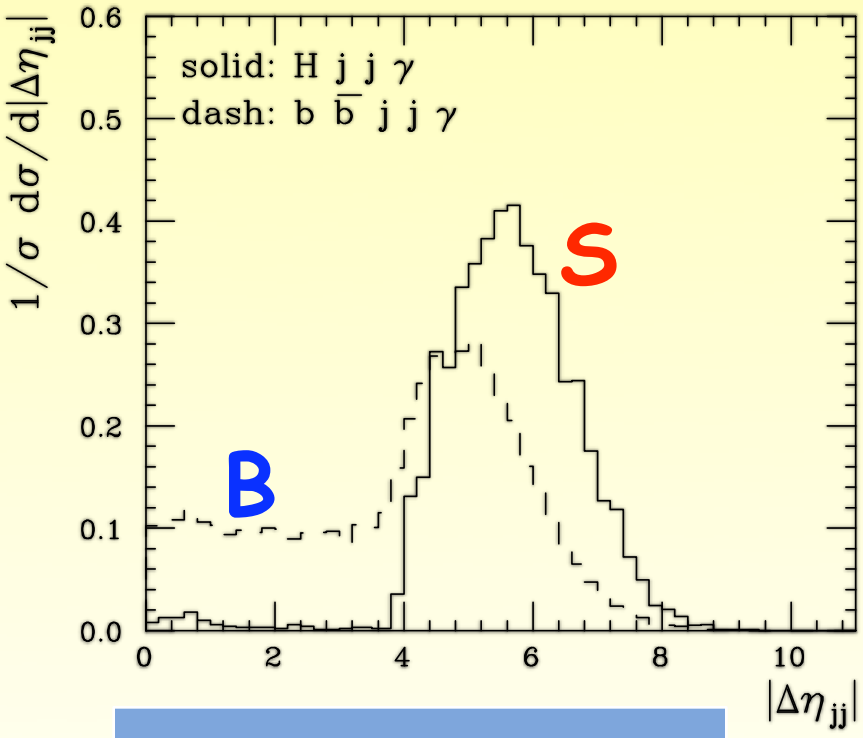
m(j1,j2)
j1=highest pT
j2=second highest pT

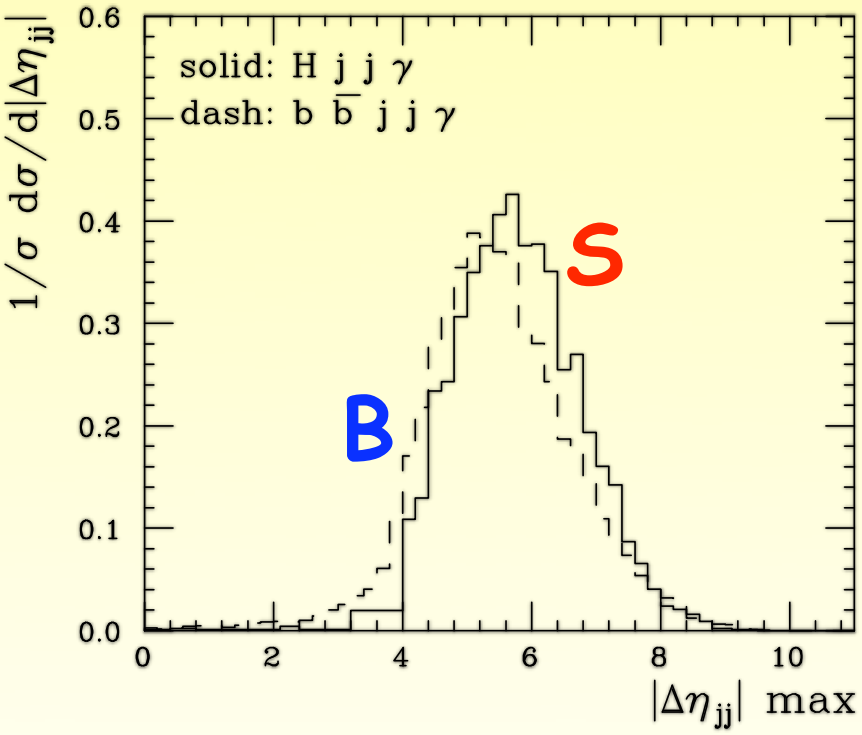
a2

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

jet 1-2 rapidity difference distribution

pT1> 60, pT2 >30



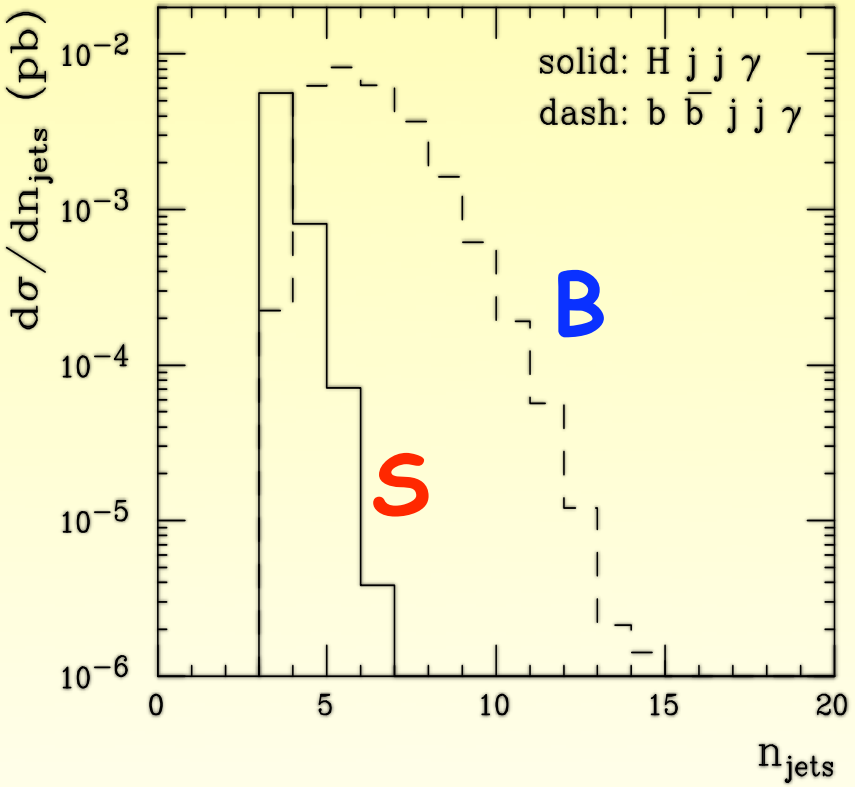


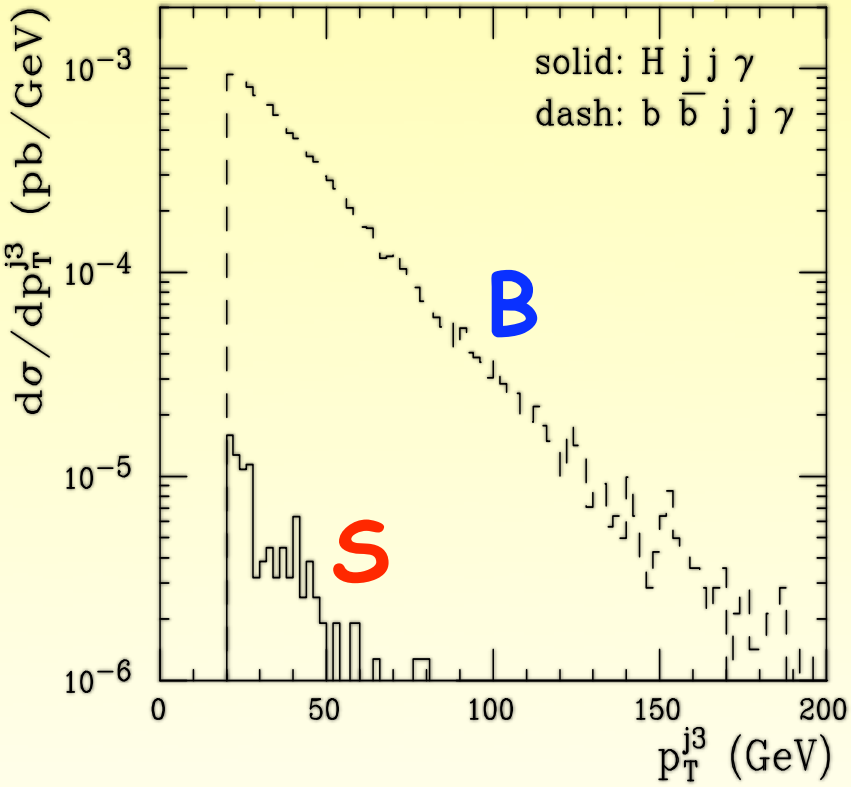
$\Delta\eta$(j1,j2)
j1=highest pT
j2=second highest pT

max[$\Delta\eta$(j1,j2)] among all jets

jet multiplicity distribution

pT distribution of the third highest pT jet





COMBINING ALL ==> bckg drops by a factor ~ 4 (signal almost unaffected !) ==> factor ~ 2 gain in significance !

what if γ -> W ? pp -> HW jj Rainwater (2001)

$\nu\, \ell = e, \mu$

- could also help in constraining **bbH coupling**
- accurate studies for bckg and parton shower effects are missing
- cross section smaller than for **pp -> H γ 2j**

for optimized event selection ($pT(\gamma) > 20$ GeV)
(with photon constraints applied to charged lepton)
and for mH=120 GeV, we get :

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

$\nu\, \ell = e, \mu$

Summary

- measure of g_{Hbb} challenging at LHC
- new promising channel in VBF

  $pp \rightarrow H\,jj + \gamma$
- main advantages versus Hjj in VBF
  - trigger on γ
  - much less active bckg after requiring a central γ
- signf ~ 3 at parton level (x 2 expected from parton shower effects) , for L=100 fb^{-1}, mH= 120 GeV
- could provide a new independent test of Hbb and HWW couplings (sensitivity to HZZ drops) !