Observing Heavy Higgs in Weak Boson Fusion with Forward Jet Tagging at the CERN CMS Experiment

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Outline

- Standard Model & Higgs Mechanism
- Higgs Observation
- LHC-CMS experiment
- Weak Boson Fusion (WBF)
- Analysis of

  $qq \rightarrow qqH,\ H \rightarrow WW \rightarrow l\nu jj$
  $qq \rightarrow qqH,\ H \rightarrow ZZ \rightarrow llqq$
  $qq \rightarrow qqH,\ H \rightarrow ZZ \rightarrow ll\nu\nu$

  } $m_H \geq 300$ GeV
- Results

Limits of the Higgs Mass :

- **The mass of the Higgs boson is a free parameter because of the unknown coupling λ, but**
- **SM gives us information about the allowed mass range, by choosing** $\lambda \to (+)$ **& finite &** $m_H \propto \sqrt{2\lambda}$

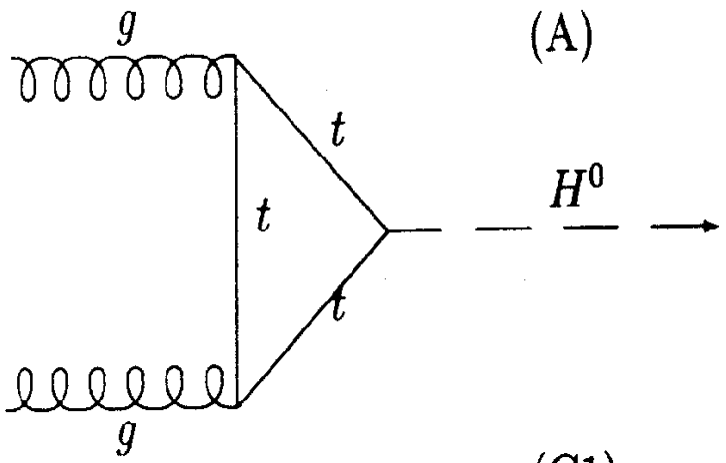
Theoretical constraints & experimental limits :

$m_H < 1 \ \ TeV$ **: unitarity purpose**

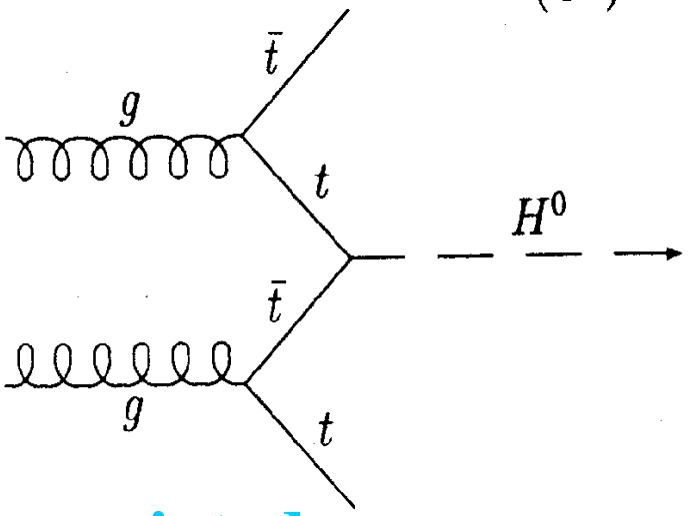
Above this value, perturbation theory is not valid.

- **Another hint for the mass of the H boson comes from the precision fits to electroweak observables :** $98\ GeV < m_H < 212\ GeV$
- **Direct experimental search at LEP2 gives the lower bound on Higgs mass as :** $m_H > 114.1\ GeV$.

gg fusion



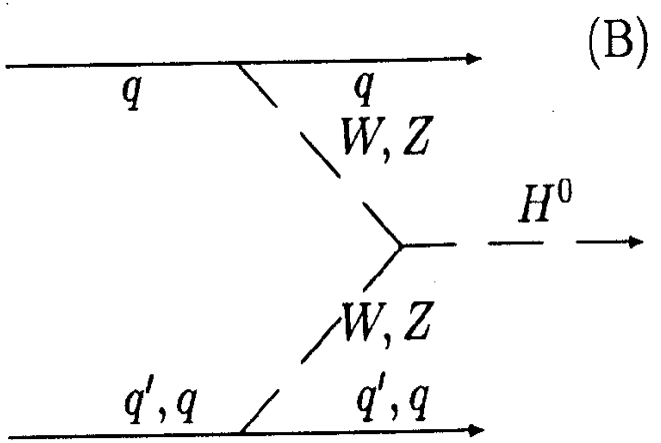
(A)



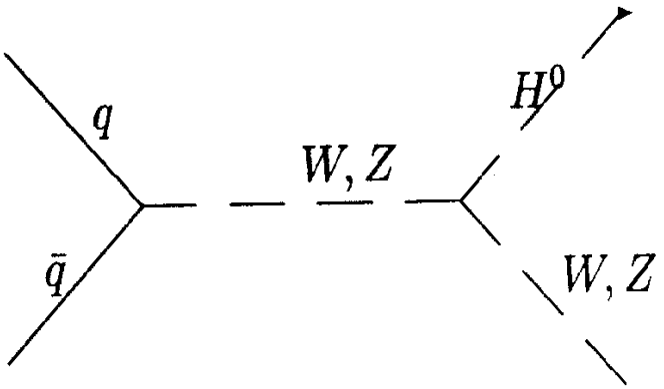
(C1)

associated $t\bar{t}H$

WW/ZZ fusion

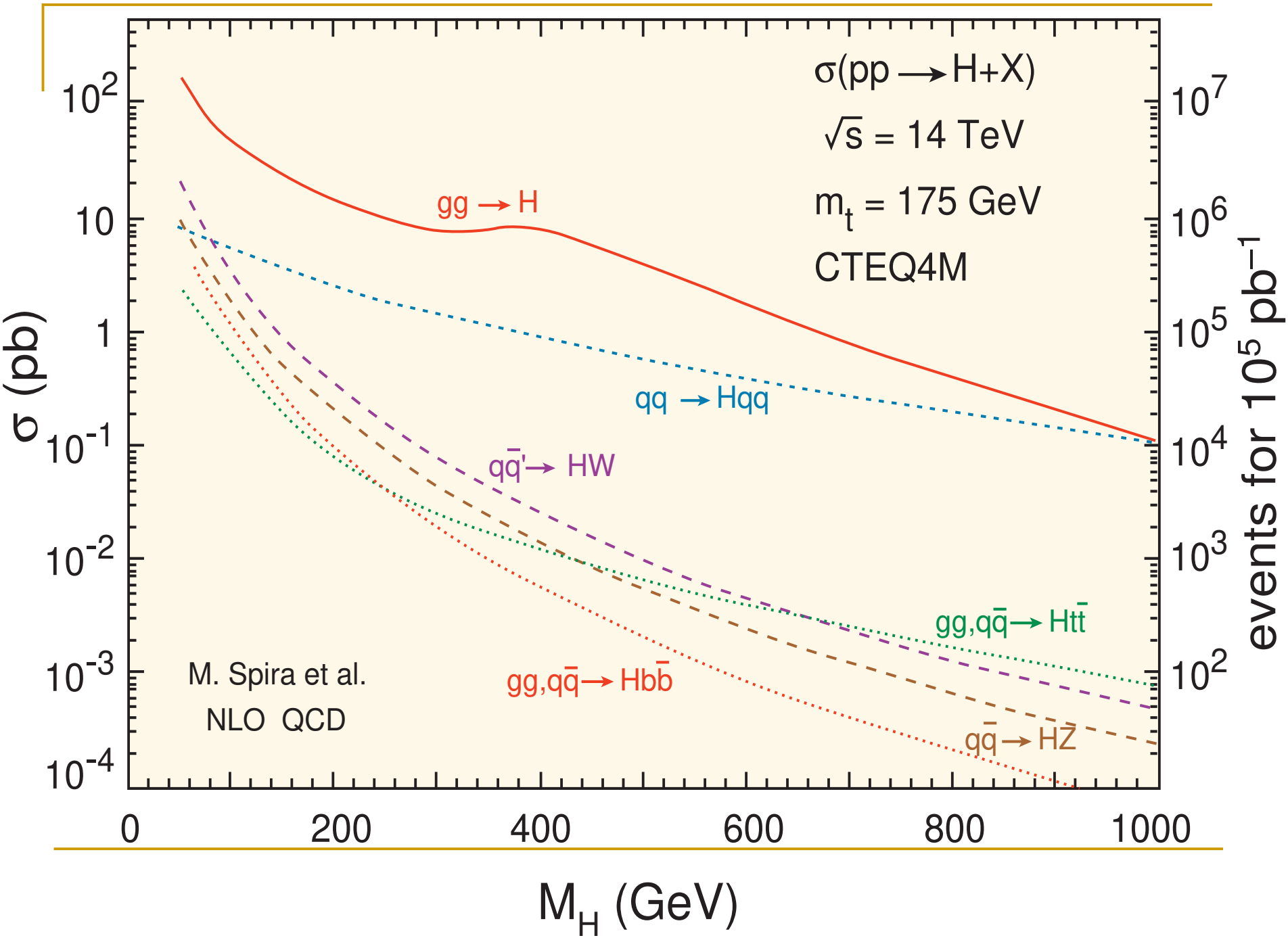


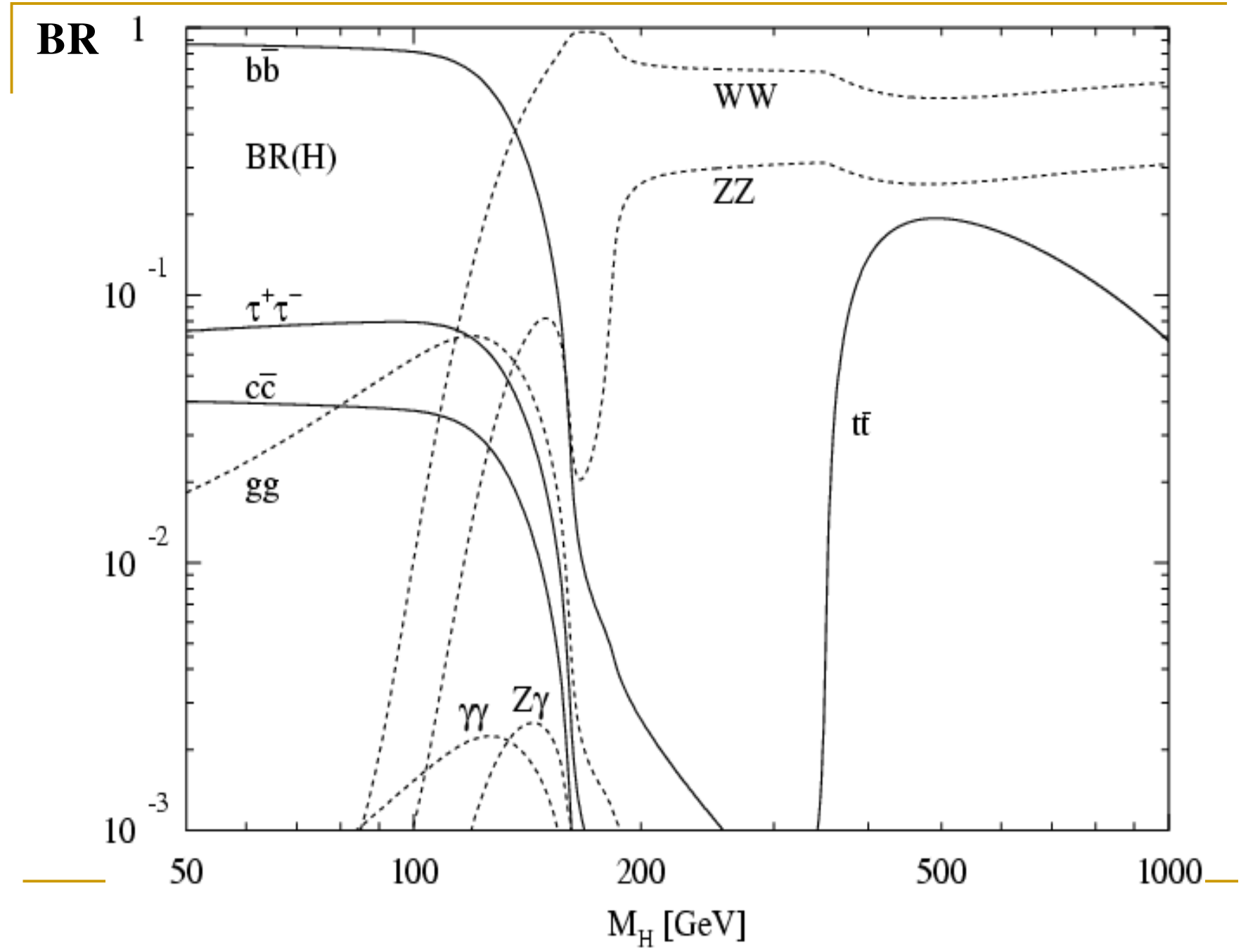
(B)



(C2)

associated WH, ZH

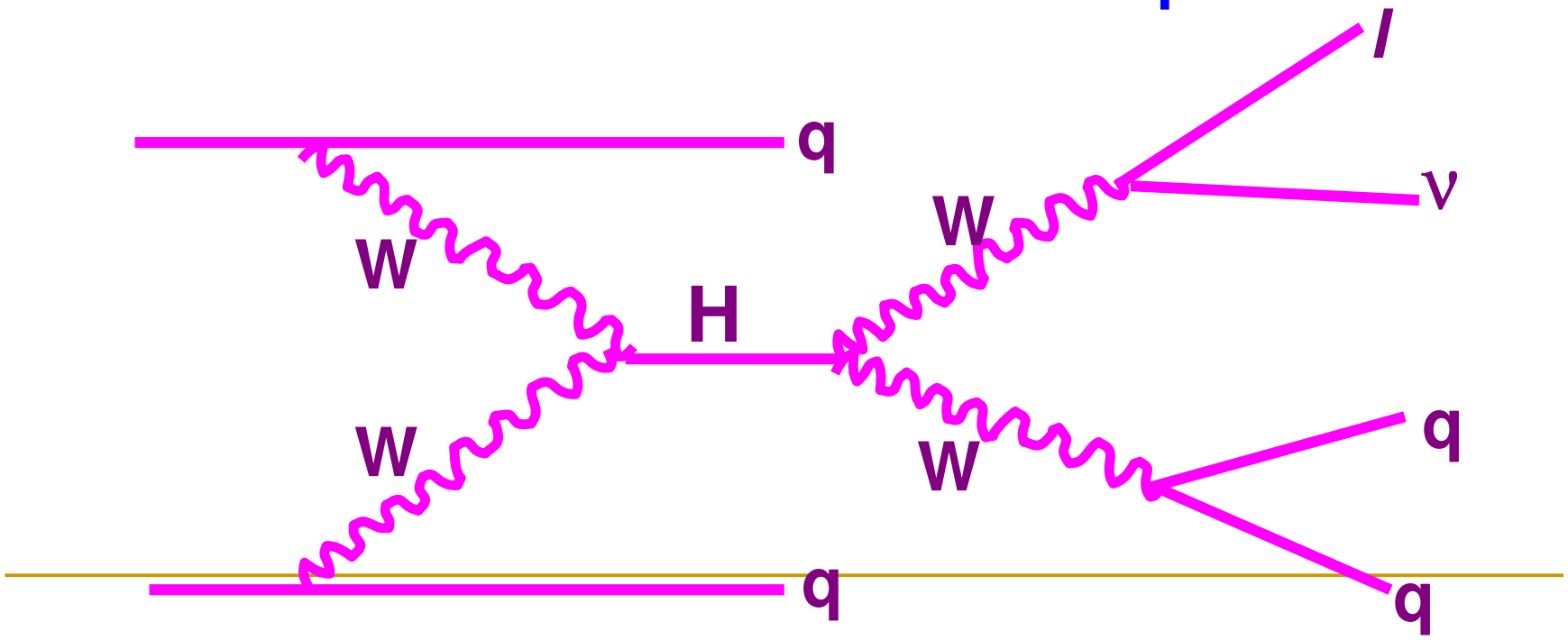

σ(pp → H+X)
√s = 14 TeV
m_t = 175 GeV
CTEQ4M
gg → H
qq → Hqq
qq̄' → HW
gg,qq̄ → Htt̄
gg,qq̄ → Hbb̄
qq̄ → HZ
M. Spira et al.
NLO QCD
σ (pb)
events for 10^5 pb^-1
M_H (GeV)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^7
10^6
10^5
10^4
10^3
10^2
0
200
400
600
800
1000


BR
1
10^{-1}
10^{-2}
10^{-3}
$b\bar{b}$
BR(H)
$\tau^+\tau^-$
$c\bar{c}$
gg
$\gamma\gamma$
$Z\gamma$
WW
ZZ
$t\bar{t}$
50
100
200
500
1000
M_H [GeV]

Characteristics of WBF

$qq \rightarrow qqH,\ H \rightarrow WW \rightarrow l\nu jj$

- Forward Jets
- Centrally produced Leptons
- Color coherence between forward quarks



Simulation of Events

Events are generated with PYTHIA (6152).

Calorimeter simulation, jet and E_T^{miss} reconstruction with CMSJET

Jet reconstructions cone size = 0.5 for m_H=600 GeV

= 0.7 for m_H=300 GeV

For pile-up:

--> 2 min. bias events superimposed at low luminosity

We assume 90% efficiency to account for lepton reconstruction and trigger

I have looked the final states of

One isolated lepton

Two central jets from W & Z

One forward jet + one backward jet

Main Backgrounds from

$t\bar{t}$ events

W + jets events

Z + jets events

We show our results;

For low luminosity only

For low (300 GeV) and for high mass (600 GeV) HIGGS

m_H = 200 & 800 GeV studied too

How to isolate Higgs events?

Signature, mass peak

Find two vector bosons in event as H $\rightarrow$WW, ZZ

- W$\rightarrow$lν and Z $\rightarrow\nu\nu$
- Z $\rightarrow$ll
- Z $\rightarrow$jj and W $\rightarrow$jj

Reconstructed Higgs ⇨ WW or ZZ system

Exploit special Kinematics

- P_t(WW,ZZ)
- P_t(W,Z)
- P_t(l)

Angular cuts

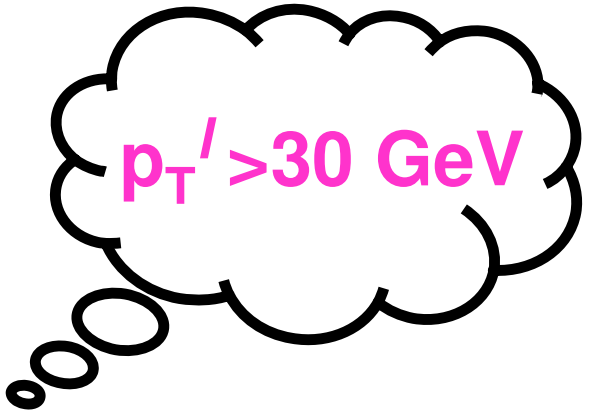
Higgs Production Mode

- Weak Boson Fusion: Tagging jets with very high mass

SELECTION CUTS:

⇨One isolated lepton

⇨No charged track with p_t>2 GeV in a cone $\Delta R<0.3$ around the lepton



Reconstruction of Leptonic W:

* P_l^{ν} is resolved from m_W constraint
* The smaller of the two solutions is selected

$P_T^{W \to l\nu} > 200$ GeV for 600 GeV & no cut for $m_H = 300$ GeV

Central jet cuts: No extra jet in $|\eta|\langle 2\, with\, E_T^{jet} \rangle 30\, GeV$

Top mass veto cut: Reconstruct top mass from 3 central jets

$$(W \rightarrow jj + 1\, jet)$$

cut on

$$120 \langle m_{top} \rangle 220\, GeV$$

$E_t^{jets} > 40$

Reconstruction of Hadronic W for 600 GeV

⇨ Start asking 2 jets, E_T > 40 GeV for W→jj and reconstruct m_{jj}

⇨No mass reconstructed since only 1j found (36%)

Reconstr. W mass in the calorimeter for events with 1 central j & for events in the tail mjj > 100 GeV.

Large tail due to merging jets

Start from the direction of harder jet (or single jet), add cells in a cone ΔR=0.9

W Reconstruction of hadronic W for m_H=300 GeV

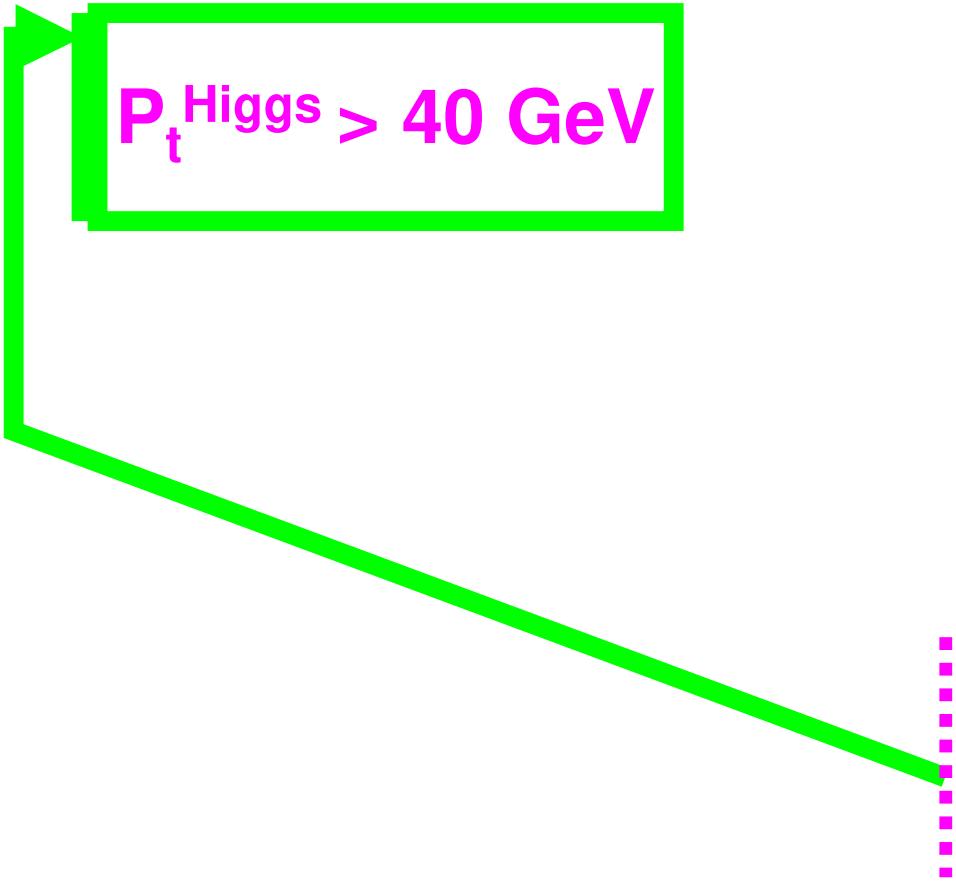
- Two central jets with $|\eta^{jet}| < 2$

$$E_T^{jet} > 40 \text{ GeV}$$

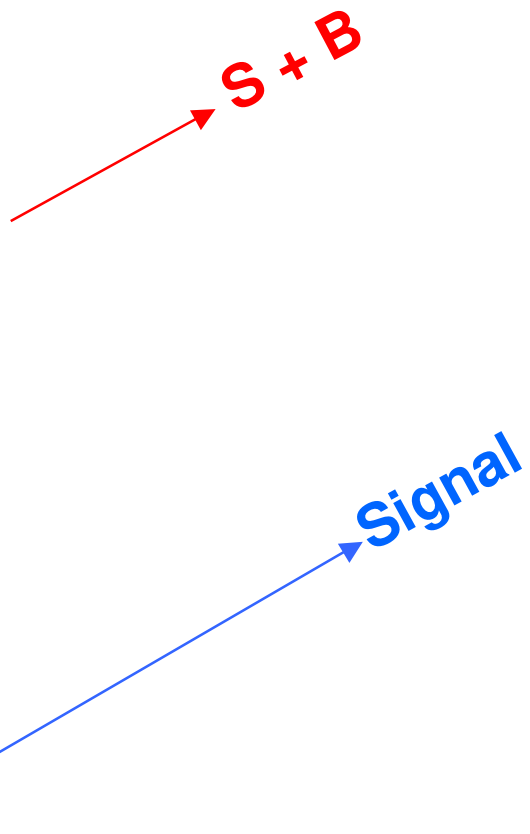
- Problem of merged jets not too serious for m_H=300 GeV

Mass window cut
$65 < m_{jj} < 100$

Cut on P_T^W Hadronic >200 for m_H=600 GeV
>100 for m_H=300 GeV


$P_t^{Higgs} > 40$ GeV

$$H \rightarrow WW \rightarrow l\nu jj$$



Forward Jet Tagging

One forward & one backward jet with

For m_H=600 GeV

$2.0<|\eta^{jet}|<5$

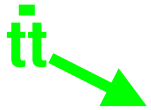
$E_T^{jet}>20$ GeV

Forward jet selection for m_H=300 GeV

Forw. jet: Take the most energetic jet with η>0 not in W→jj

Back. jet: Take the most energetic jet with η >0 not in W→jj

⇨ **Cut in $|\eta^{forw}-\eta^{back}|$>5**



W+jets

signal

Cut in $|\eta^{forw}-\eta^{back}|$>5

Forward jet energies for signal and backgrounds

Tagging cuts:

$$\rightarrow E^{forw.jet} \rangle 300\, GeV$$

$$\rightarrow E_T^{j1} \rangle 30\, GeV\,,\, E_T^{j2} \rangle 50\, GeV \;\; Asym.cut$$

$$\rightarrow m_{jj} \rangle 1\, TeV$$

$$\rightarrow \left|\eta^{l} - \eta^{forw.jet}\right| \rangle 1$$

We have also tried $\Delta\eta^{jj}$, $\Delta\varphi^{jj}$

Efficiency for forward jet tagging

	300 GeV	600 GeV
Signal	25.3%	23.9%
$t\bar{t}$	1.13%	1.6%
W + Jets	0.38%	0.6%

Event Selection for $H \rightarrow WW \rightarrow l\nu jj$ for m_H=300 GeV

Cuts	Signal	$t\bar{t}$	W + jets
$\sigma \times BR$	0.14 pb	90.7 pb	7814 pb
Events for $30 fb^{-1}$	7815	4.89×10^6	2.11×10^7
Lepton selection	5367	2.5×10^6	9.7×10^6
Central jet selection	1260	400061	134442
Higgs reconstruction from WW system	1098	322751	121204
Tagging jet selection	180	4079	527
Central jet veto	142	342	147
m_H window $250 < m_H < 360$ GeV	121	98	42

Compare ?

X 1000 Tagging jet reductions

Event Selection for *H→WW→lνjj for* mH=600 GeV

Cuts	Signal	$t\bar{t}$	W + *jets*
$\sigma \times BR$	0.03 pb	90.7 pb	108.6 pb
Events for $30 fb^{-1}$	1599	4.89×10^6	2.9×10^6
Lepton selection	1308	2.5×10^6	1.7×10^6
Central jet selection	679	105973	110347
Central jet veto	443	12928	72769
Higgs reconstruction from WW system	221	2281	8497
Tagging jet selection	66	29	76
m_H window $450 < m_H < 750$ GeV	56	15	38

Compare ?

X 100

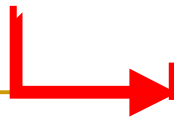
Event Selection for $H \to ZZ \to lljj$ for m_H=300 GeV

Cuts	$H \to ZZ \to lljj$	$Z + jets$	$H \to ZZ \to ll\nu\nu$	$Z + jets$
$\sigma \times BR$	0.04 pb	105.6 pb	0.008 pb	105.6 pb
Events for $30 fb^{-1}$	2234	2.85×10^6	428	2.85×10^6
Lepton selection	1321	961354	250	959434
Z mass window	1067	702172	205	700030
Central jet selection	250	26393		
$E_t^{miss} > 100$ GeV			111	2559
Higgs reconstruction from WW system	250	26393		
Tagging jet selection	41	171	19	29
Central jet veto	31	43		
m_H window $250 < m_H < 360$ GeV	29	14		

Event Selection for $H \to ZZ \to lljj$ for m_H=600 GeV

Cuts	$H \to ZZ \to lljj$	$Z + jets$	$H \to ZZ \to ll\nu\nu$	$Z + jets$
$\sigma \times BR$	0.009 pb	13.5 pb	0.002 pb	13.5 pb
Events for $30 fb^{-1}$	498	413544	95	413544
Lepton selection	402	211501	76	211501
Z mass window	318	150908	61	150908
Central jet selection	156	8043		
Central jet veto	104	4677		
$E_T^{miss} > 150$ GeV			52	515
Higgs reconstruction from WW system	72	1071		
Tagging jet selection	25	12	11	4
m_H window	21	6.2		

$H \rightarrow WW \rightarrow l\nu jj$



m_H=300 GeV

$H \rightarrow WW \rightarrow l\nu jj$

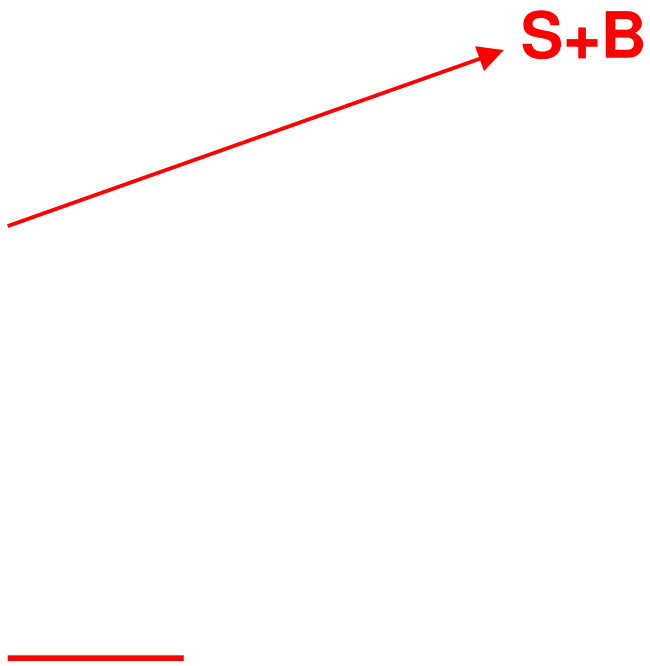
$H \rightarrow WW \rightarrow l\nu jj$

Same selection criterion used for Z→lljj except Z→ll

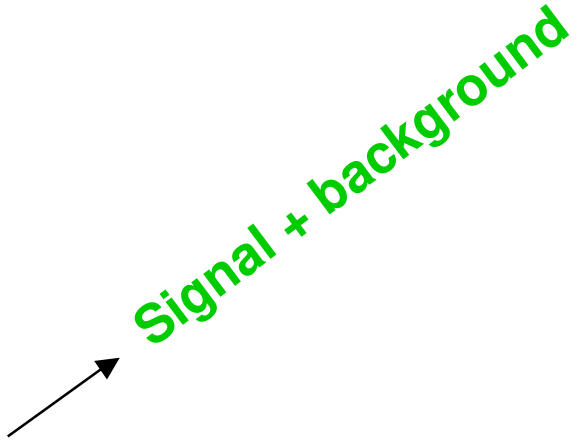
$H \rightarrow ZZ \rightarrow lljj$

$Z \rightarrow jj$

$H \rightarrow ZZ \rightarrow lljj$



$H \rightarrow ZZ \rightarrow lljj$



$H \rightarrow ZZ \rightarrow ll\nu\nu \; for \; m_H = 600 GeV$

$S/\sqrt{B}$ For an integrated luminosity of 30 fb^{-1}

Channel	m_H=300GeV	m_H=600GeV	m_H=800GeV	m_H=200GeV
$H \to WW \to lljj$	10.3	7.8	6.2	3.9
$H \to ZZ \to lljj$	7.8	8.5	6.3	
$H \to ZZ \to llvv$	3.6	5.5	3.2	

Expected luminosities in fb^{-1} for 5σ discovery

Channel	m_H=300 GeV	m_H=600 GeV	m_H=800 GeV
$H \to WW \to lljj$	7.1	12.3	19.5
$H \to ZZ \to lljj$	12.3	10.4	18.9
$H \to ZZ \to llvv$	57.8	24.8	73.2

Signal and background for $H \rightarrow WW / ZZ$ with m_H=800 GeV

Channel	Signal	$t\bar{t}$	W/Z+jets
$H \rightarrow WW \rightarrow l\,lvj$ $\sigma x\ BR$=0.015 pb	53	20	53
$H \rightarrow ZZ \rightarrow l\,ljj$ $\sigma x\ BR$=0.005 pb	16		6.2
$H \rightarrow ZZ \rightarrow l\,lvv$ $\sigma x\ BR$=0.0009 pb	6.4		4.1

CONCLUSIONS

- If Higgs Boson exists; $H \rightarrow WW \rightarrow l\nu jj$
  $H \rightarrow ZZ \rightarrow lljj$

  Channels via Weak Boson Fusion mechanism are potential Discovery channels at CMS experiment at CERN, LHC accelerator.

- In ~1 year of LHC running, CMS experiment would manifest with mass 300-800 GeV in WBF.

- The analysis, $H \rightarrow WW \rightarrow ll\nu j$ for m_H=200 GeV is still statistically acceptable.

- Channel is MSSM is hopeless to observe any Higgs signal.