Physics at LHC 2008 Conference
Split (Croatia), 29/09/2008

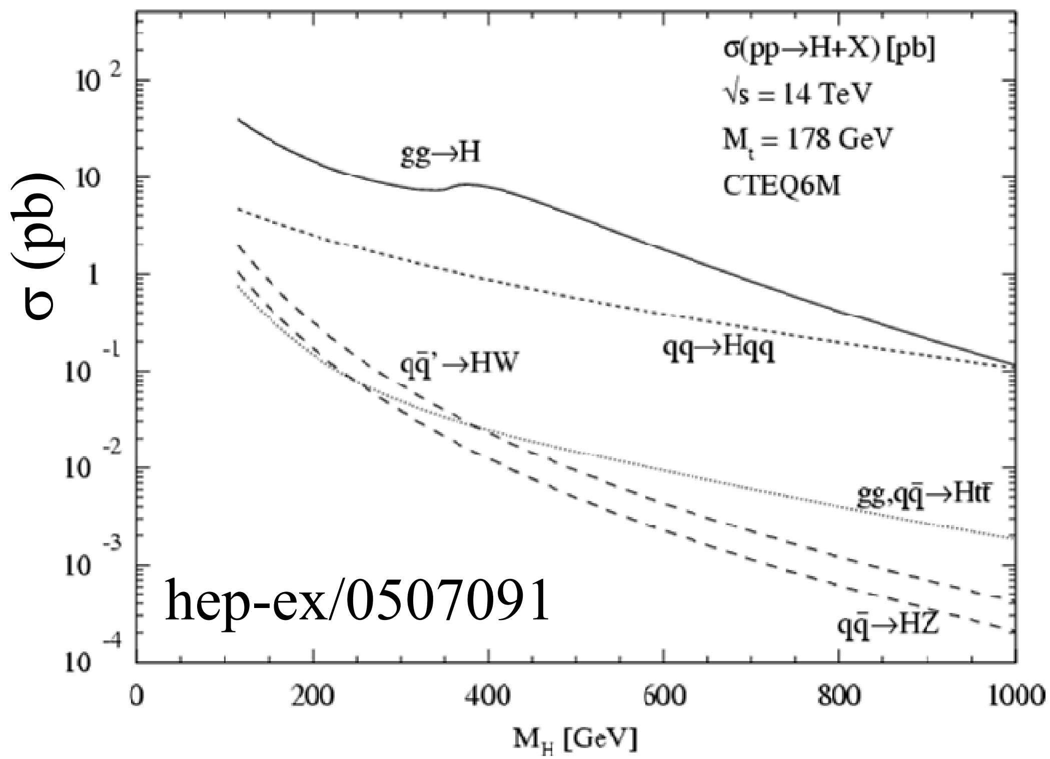
Vector Boson Fusion Production of the SM Higgs at the LHC

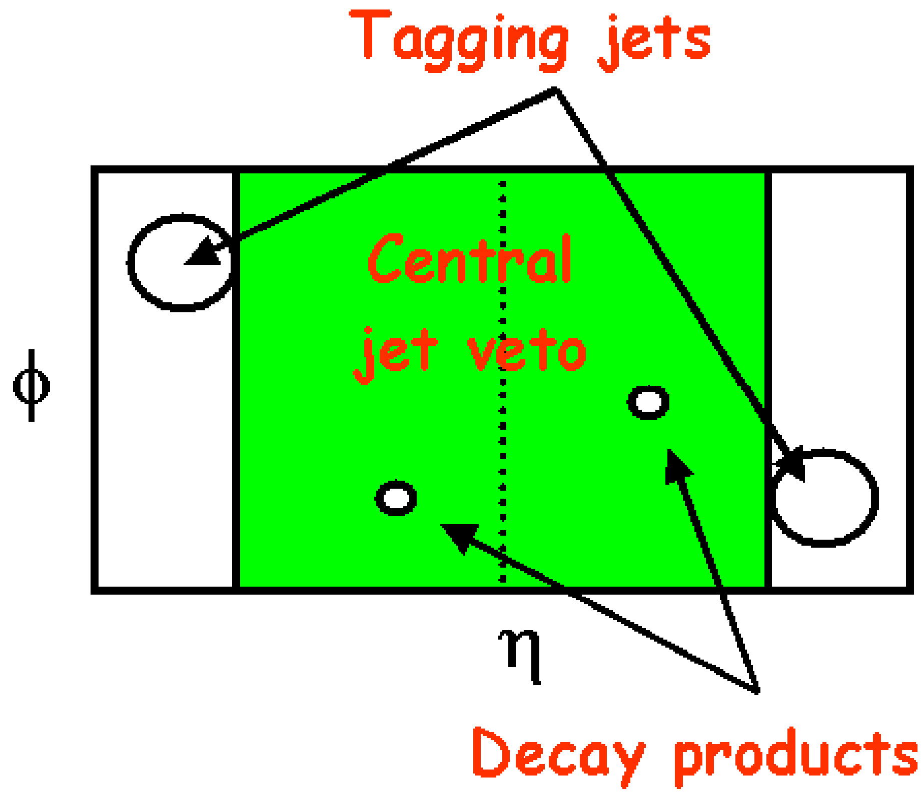
Mónica L. Vázquez Acosta

(Imperial College London)

On behalf of the CMS Collaboration

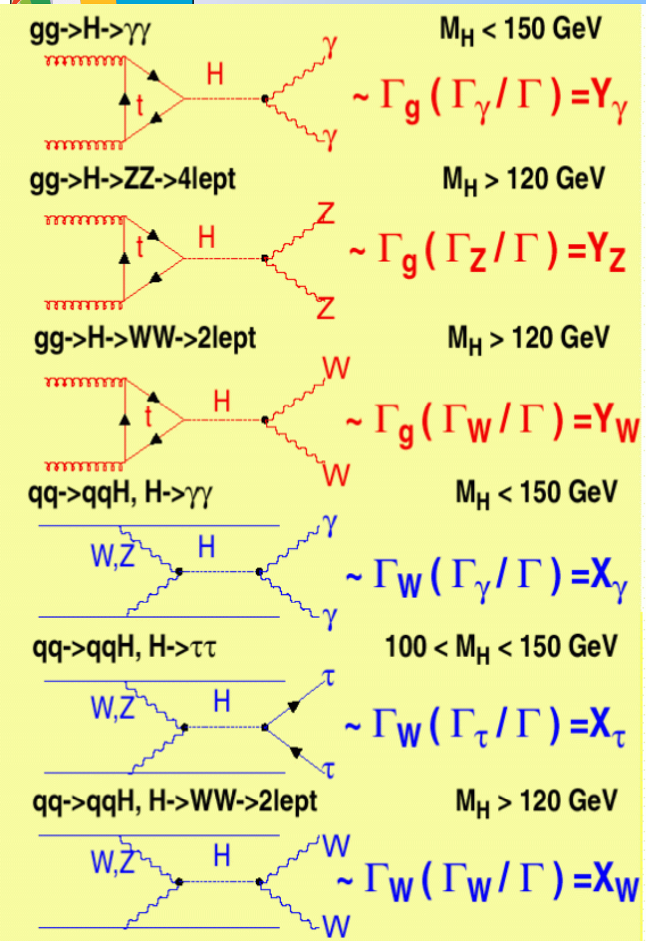
Higgs Production via Vector Boson Fusion

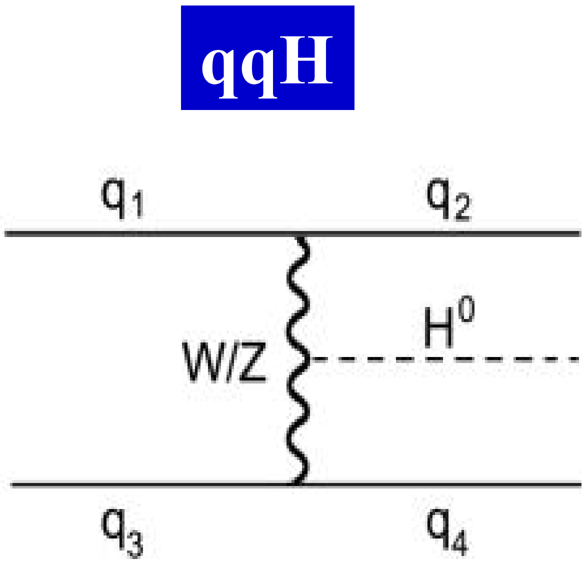


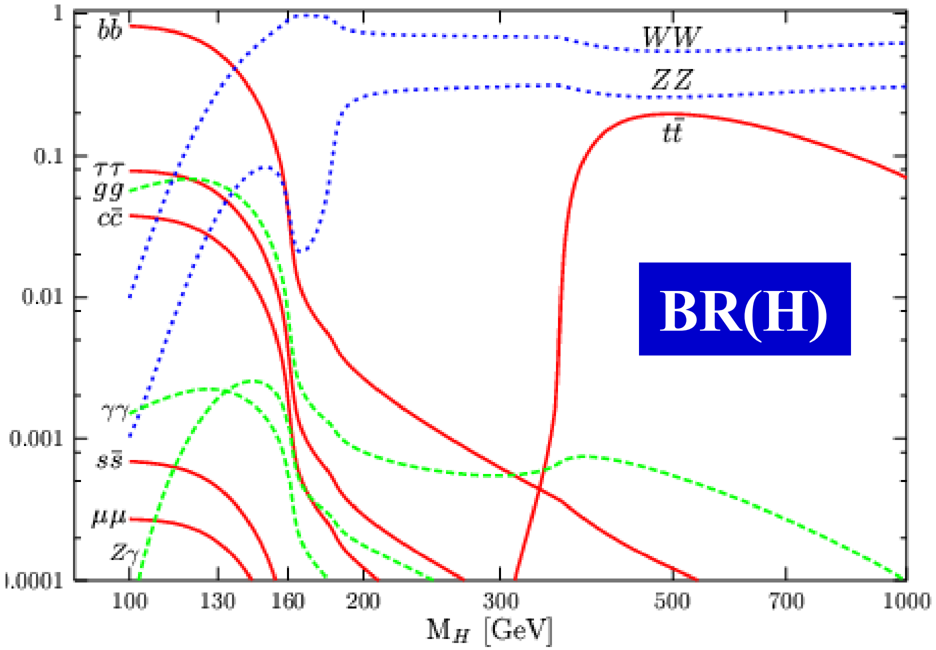


- Second largest Higgs production mechanish at the LHC
- Distinct topology of final state: two forward jets with little extra hadronic activity and the decay products of the Higgs
- Background expected small
- Central Jet Veto allows to reduce the QCD backgrounds

Motivation to study VBF Higgs production







Djouadi, Kalinowski, Spira

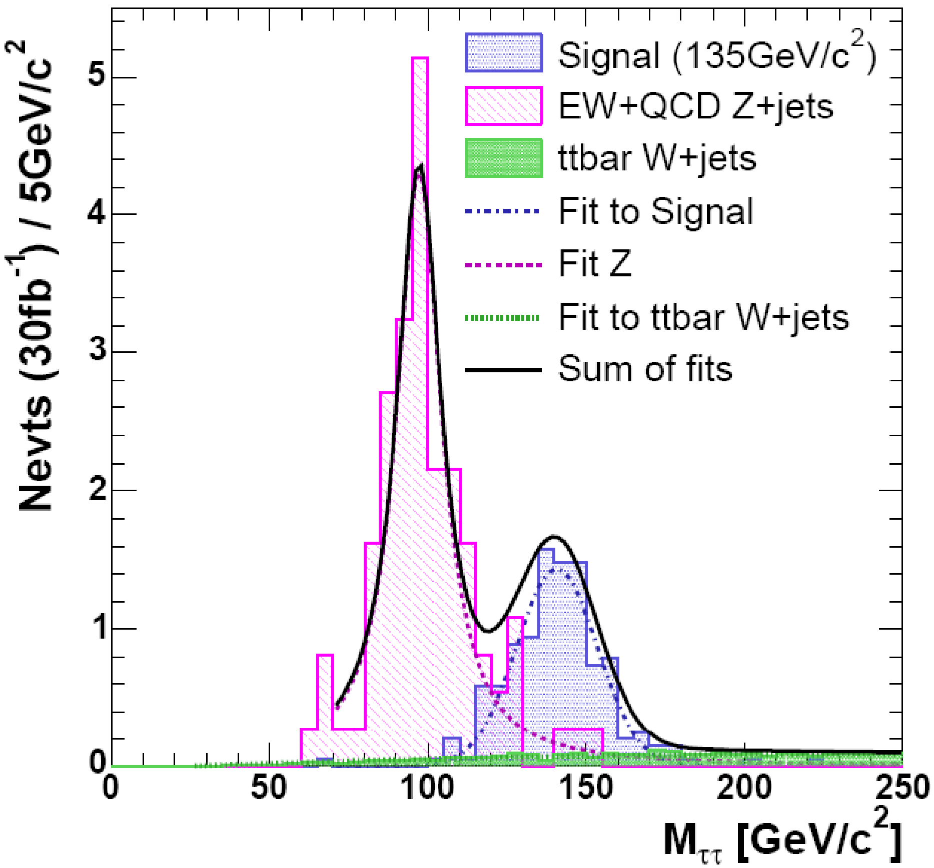
Proof of trilinear couplings at tree level (consequence of the Higgs Mechanism)

Significantly extend possibility of Higgs boson coupling measurements
Provide possibility of indirect measurement of light Higgs boson width

D. Zeppenfeld et al., Phys.Rev. D62 (2000) 013009. M. Duehressen et al., Phys.Rev. D70 (2004) 113009

Physics TDR VBF Higgs Studies with 30 fb^{-1} of CMS data

Expected ττ mass distribution for 30 fb^{-1} 115 < M_{HIGGS} < 145 GeV

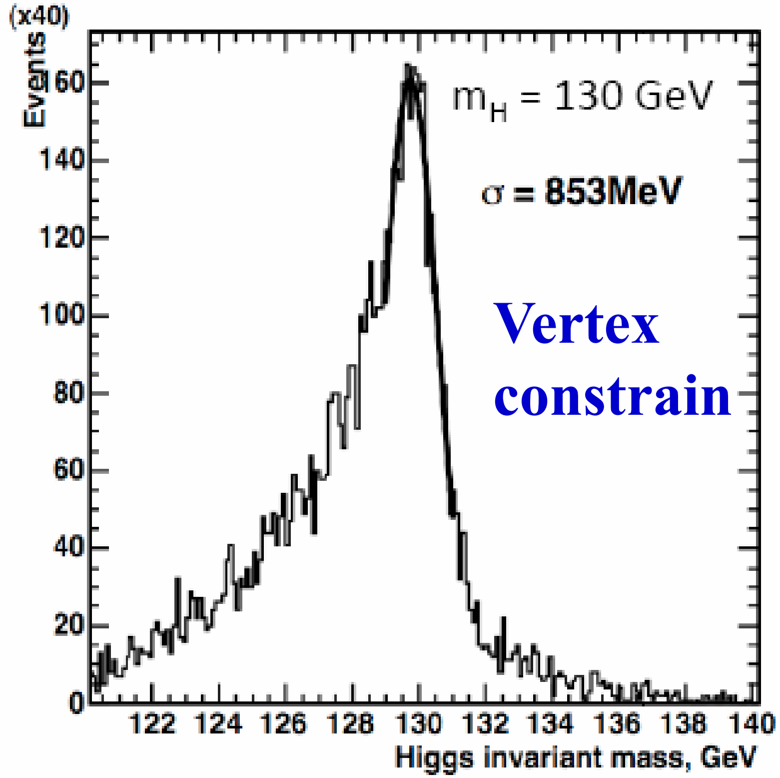


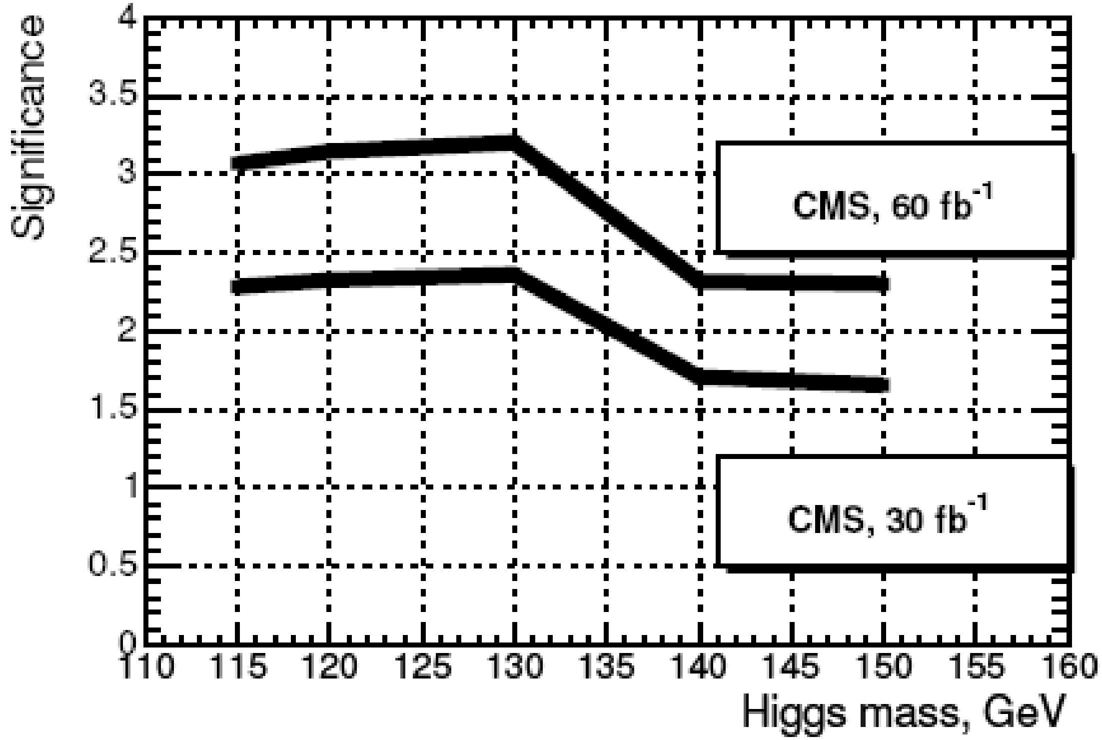
Full di- τ mass using collinear approximation of neutrinos from the τ decays and the visible τ decay products

M_H [GeV]	115	125	135	145
N_S ($30fb^{-1}$)	10.47	7.79	7.94	3.63
N_B ($30fb^{-1}$)	3.70	2.21	1.84	1.42
S_{cP} at $30fb^{-1}$ (no uncertainty)	4.04	3.71	3.98	2.19
S_{cP} at $30fb^{-1}$ ($\sigma_B = 7.8\%$)	3.97	3.67	3.94	2.18
S_{cP} at $60fb^{-1}$ ($\sigma_B = 5.9\%$)	5.67	5.26	5.64	3.19

The number of signal events expected for 30fb^{-1} is ~ 10
The statistical significance for discovering the Higgs boson is 3.9σ for M_{HIGGS} =135 GeV

Expected VBF H→γγ signal with 30 fb^{-1} & 60 fb^{-1} 115 < M$_{HIGGS}$ < 150 GeV





60 fb^{-1}

	$m_H = 115$ GeV/c^2	$m_H = 120$ GeV/c^2	$m_H = 130$ GeV/c^2	$m_H = 140$ GeV/c^2	$m_H = 150$ GeV/c^2
N_s	20.2	21.1	19.1	15.7	11.2
γ+3jets (QCD)	2.7	4.7	3.5	2.0	5.8
γ+3jets (EW)	2.5	2.5	2.5	2.5	2.5
γγ + 2jets (QCD)	11.2	13.2	9.85	8.9	4.6
γγ + 2jets (EW)	10	7.0	7.0	11.0	2.0
Drell Yan	0	0	0	0	0
N_b	26.0	26.2	21.4	28.2	14.9
ΔN_b	2.8	3.2	2.4	3.0	1.8
S	3.07	3.15	3.21	2.32	2.30

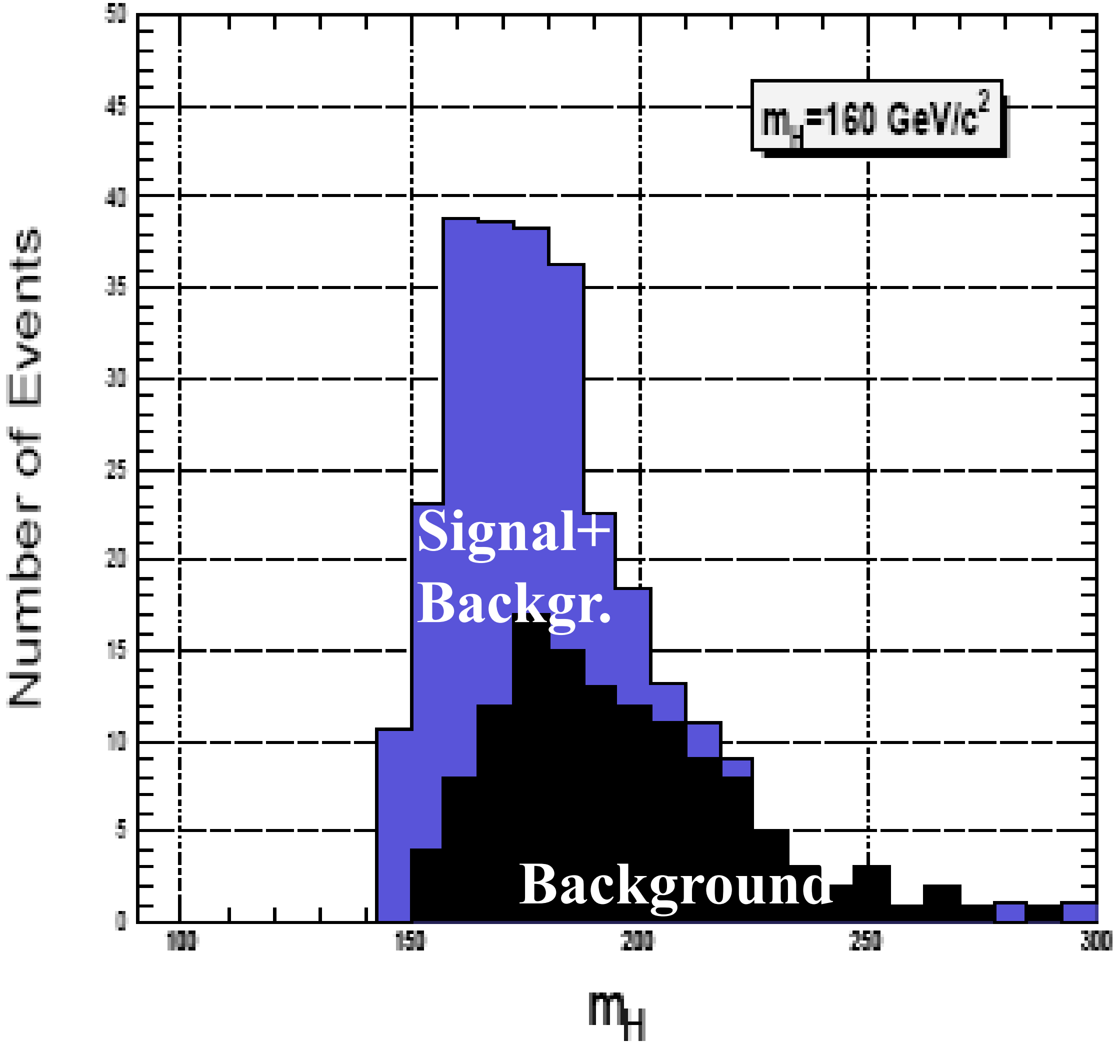
Expected number of signal & background events in a 5 GeV mass window

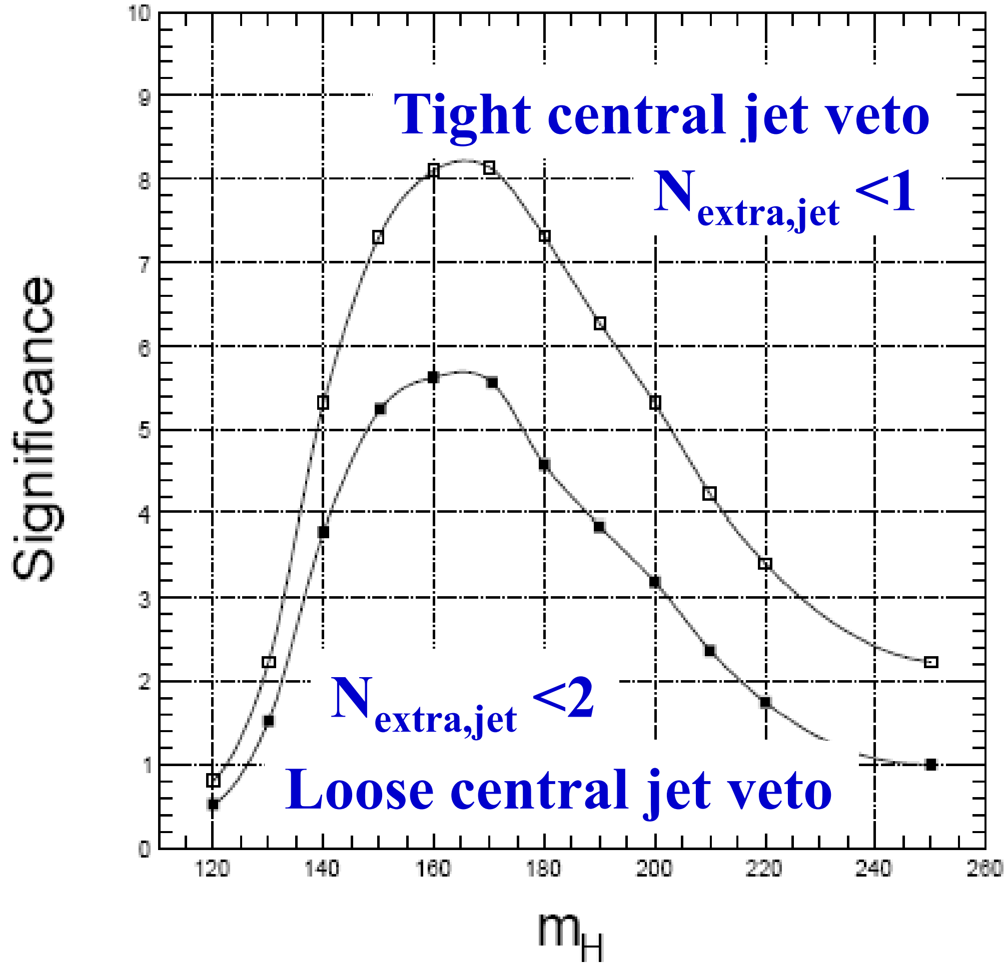
Background uncertainty estimated from side bands

Signal significance for 60 fb^{-1} :

3σ for low mass Higgs

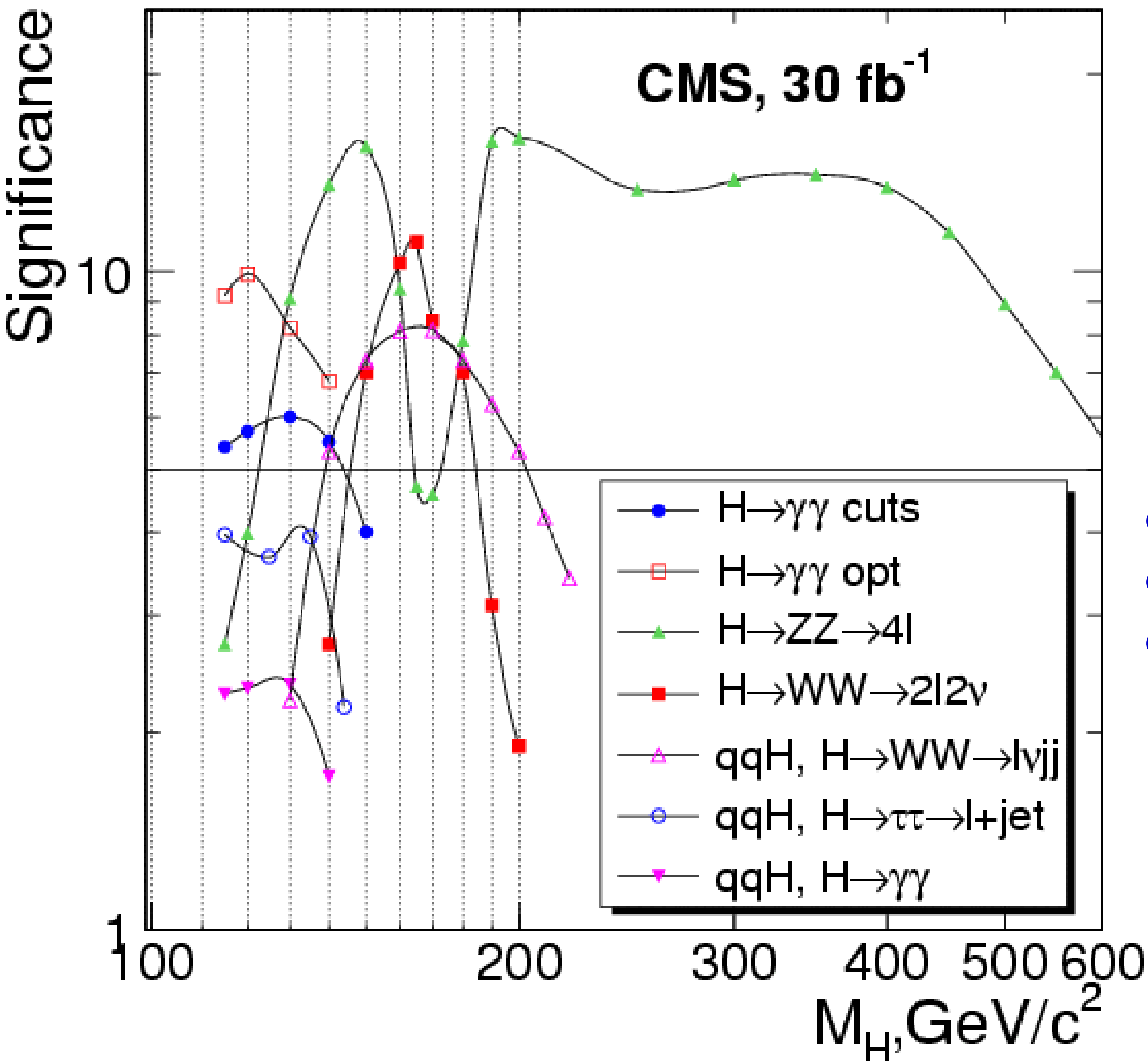
Expected VBF $H \rightarrow WW^* \rightarrow l\nu jj$ with 30 fb^{-1}
$120 < M_{HIGGS} < 250$ GeV





In the mass range 140-200 GeV a 5σ significance of the Higgs boson discovery can be achieved with an integrated luminosity of 30 fb^{-1}

Summary of Higgs Boson Discovery Potential in the CMS Experiment with 30 fb^{-1}



Higgs discovery potential in VBF with 30 fb^{-1}

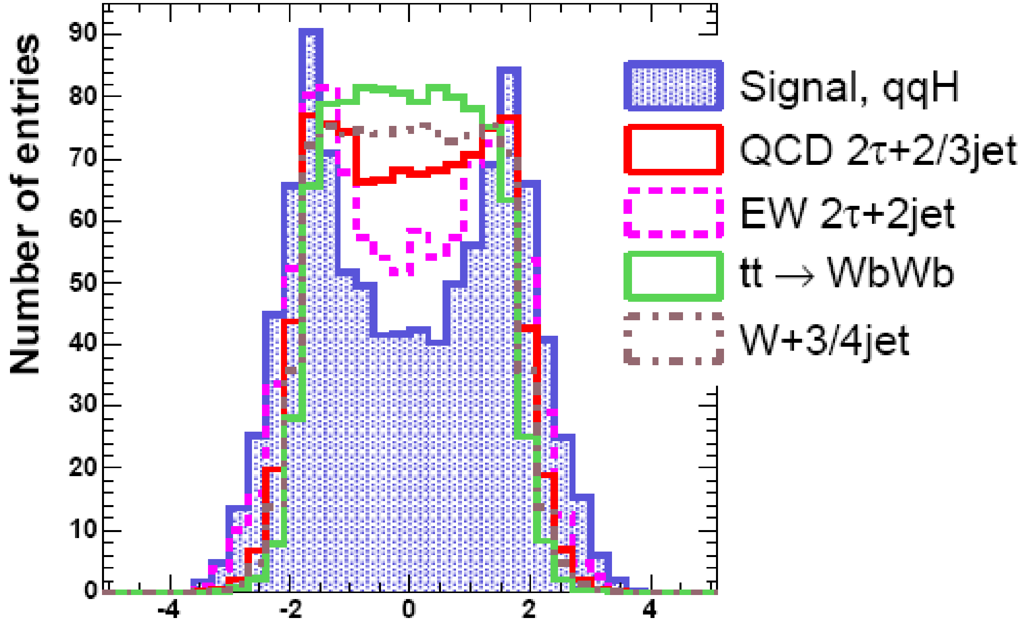
qqH,H→ττ→lj: 4σ 115-145GeV

qqH ,H→γγ: 2σ 115-135GeV

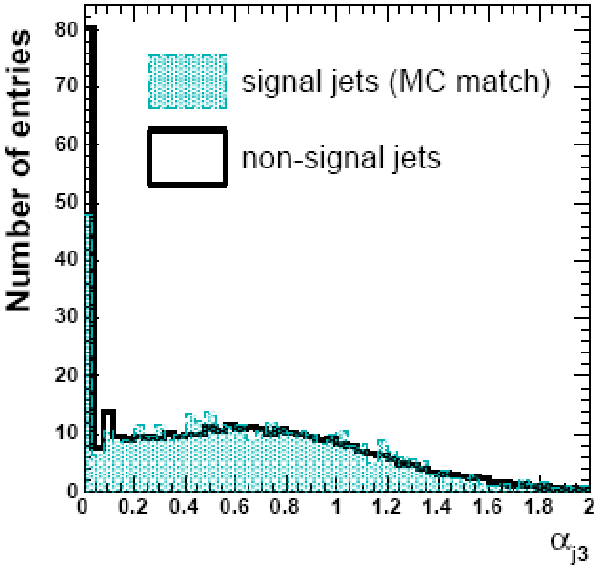
qqH ,H→WW→lνjj: 5σ 140-200GeV

VBF $H \rightarrow \tau\tau \rightarrow$ lepton jet with 1 fb^{-1} of CMS data

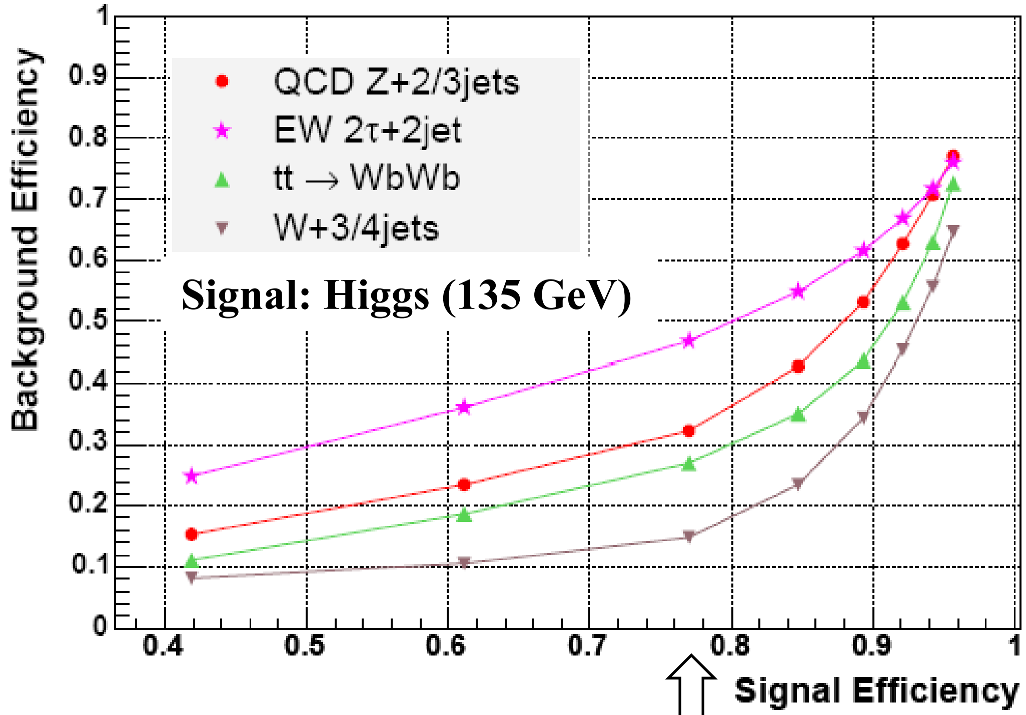
Central Rapidity Gap Selections: Central Jet Veto



$\eta_Z = \eta^{jet3} - 0.5(\eta^{jet1} + \eta^{jet2})$



$E_T^{MC} > 10, 15, 20, 25, 30, 35, 40, 45$ GeV



$E_T^{RAW} \sim 10$ GeV

$$\alpha_{j3} = \Sigma p_{Ttrk} / E_{Tj3}$$

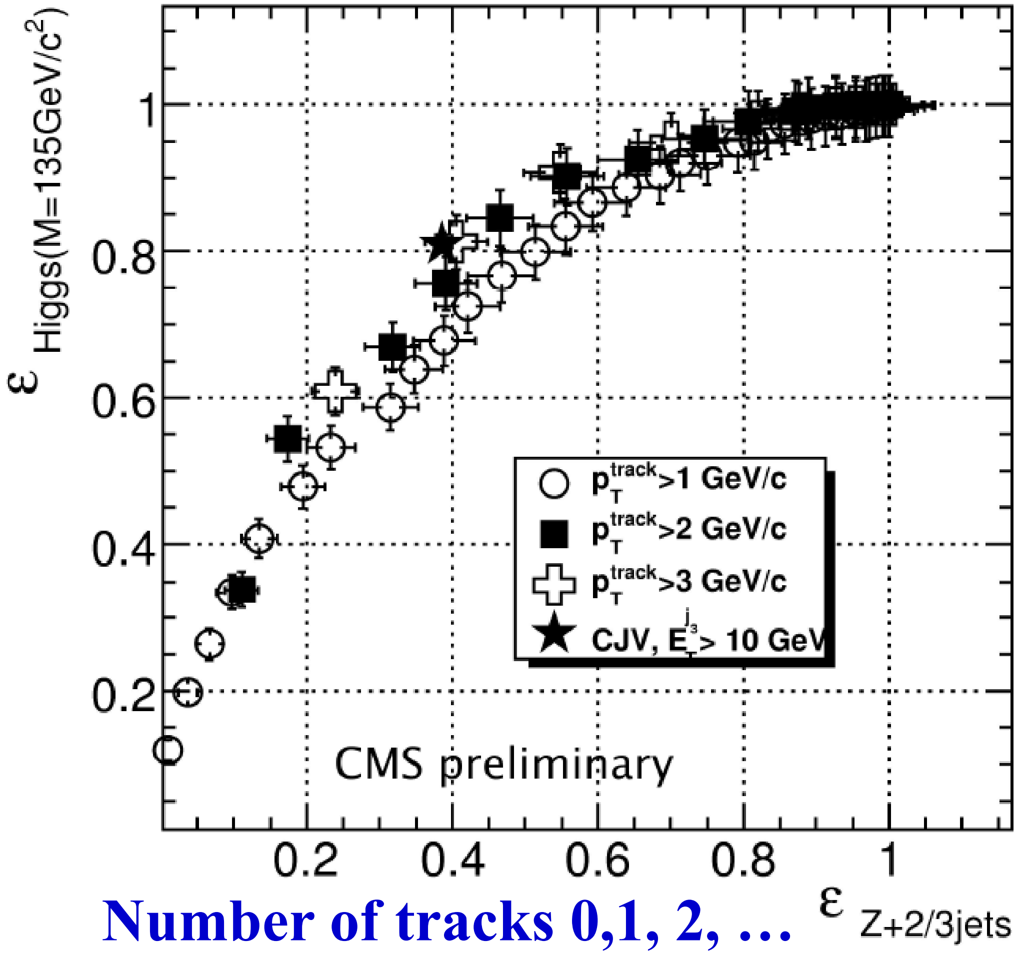
Tracks in the jet cone from signal vertex

Jets considered for Central Jet Veto if $\alpha_{3j} > 0.1$

Central Rapidity Gap Selections: Track Counting Veto

- $p_T^{\mathrm{track}} > p_T^{\mathrm{cut}}$ GeV/c
- $\eta^{j\ min} + 0.5 < \eta^{\mathrm{track}} < \eta^{j\max} - 0.5$

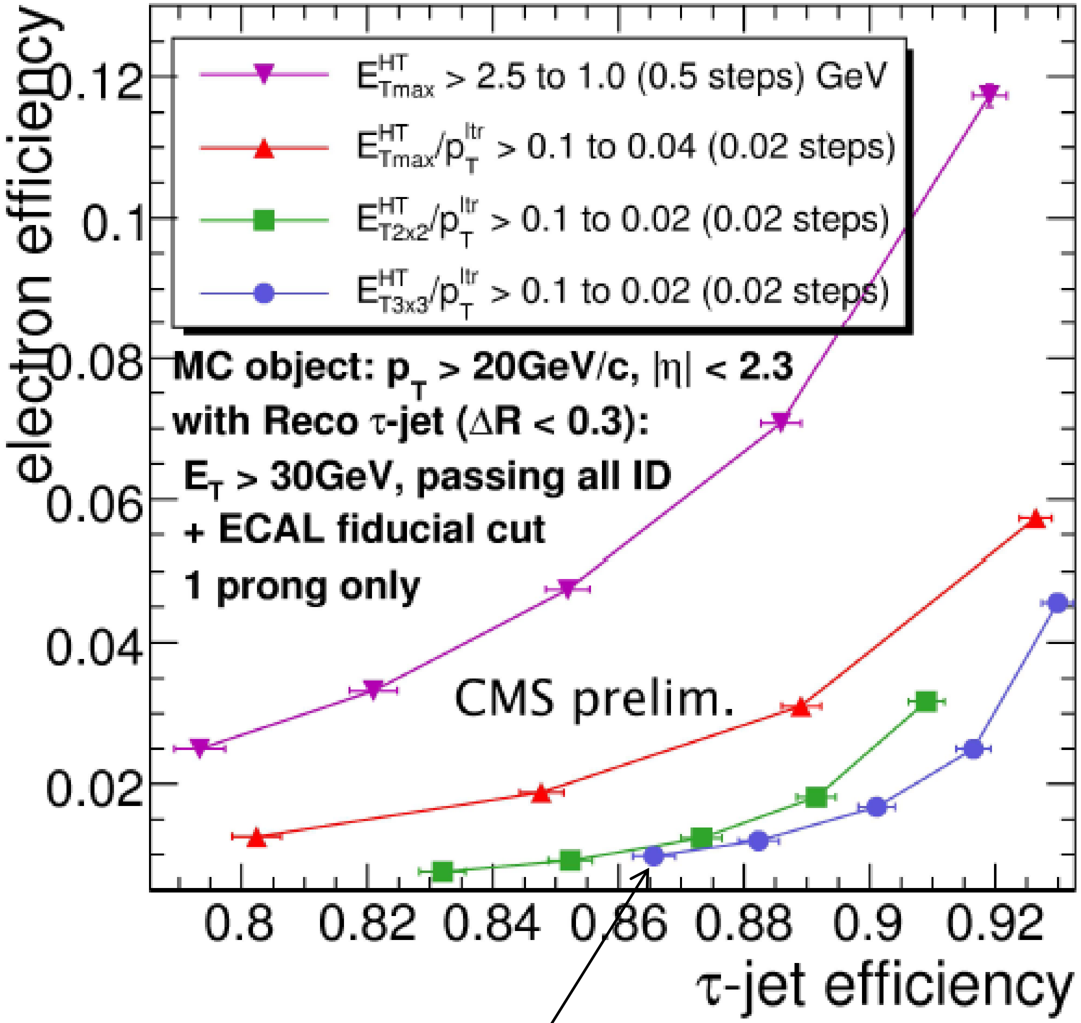
- **Tracks 8 hits and Z(track,vertex<2 mm)**
- **Lepton and τ_{had} tracks not included**



Number of tracks 0,1, 2, …

Similar performance of central jet veto and track counting veto

Rejection of Electrons faking Taus



$E_{T\,max}^{HT}$ **Transverse energy of hottest HCAL tower in τ_{had}**

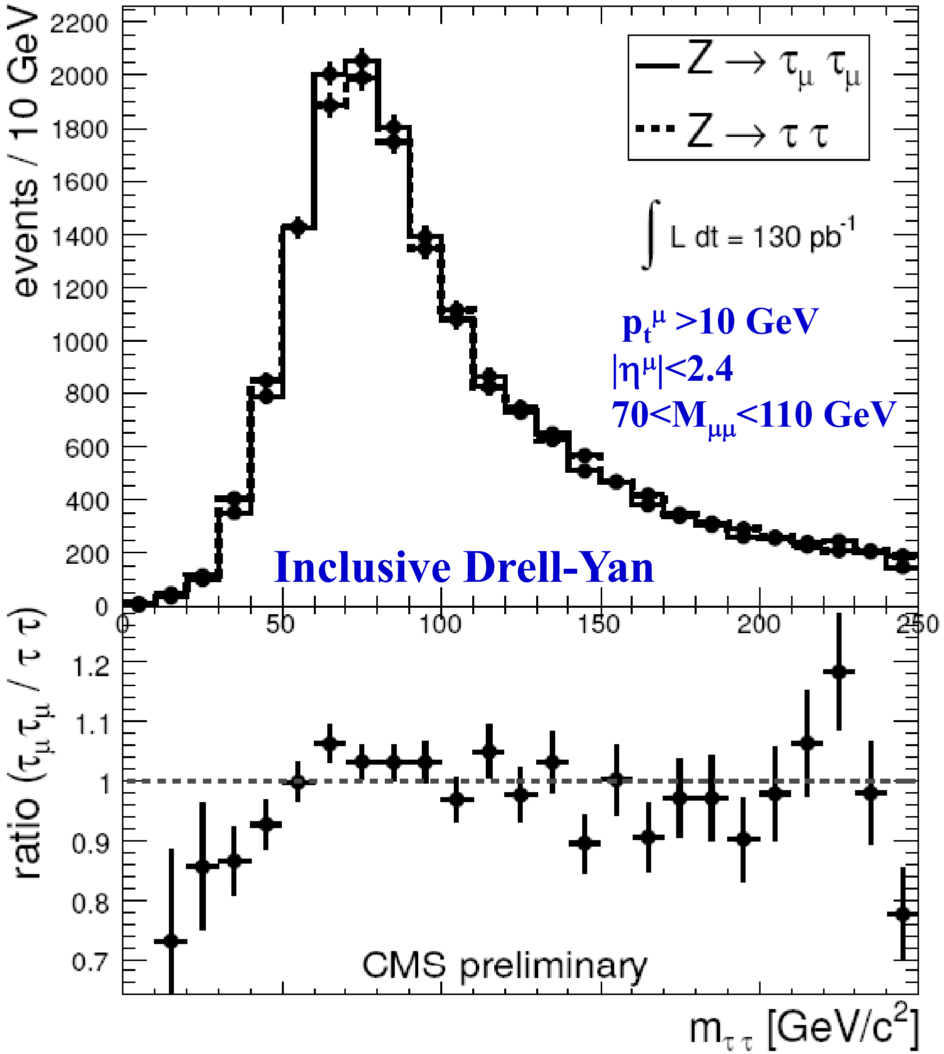
$E_{T\,n\times n}^{HT}$ (n = 2,3)

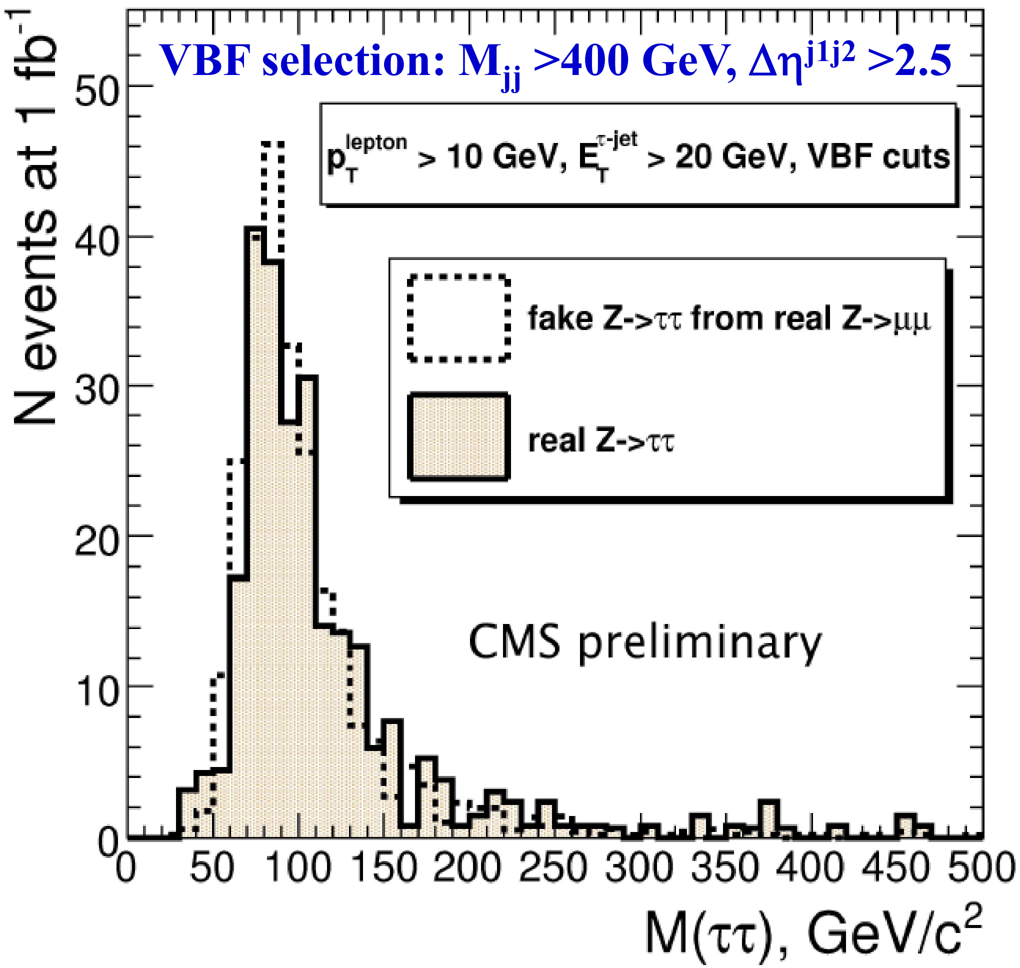
Sum of E_T of HCAL towers around leading track impact point in the CAL

p_T^{ltr} **p_T of leading track**

$E_T{}^{HT}{}_{3X3}$ /$p_T{}^{ltr}$ >0.1 : τ_{had} efficiency > 85%

Z→ττ mass shape from Z→μμ data



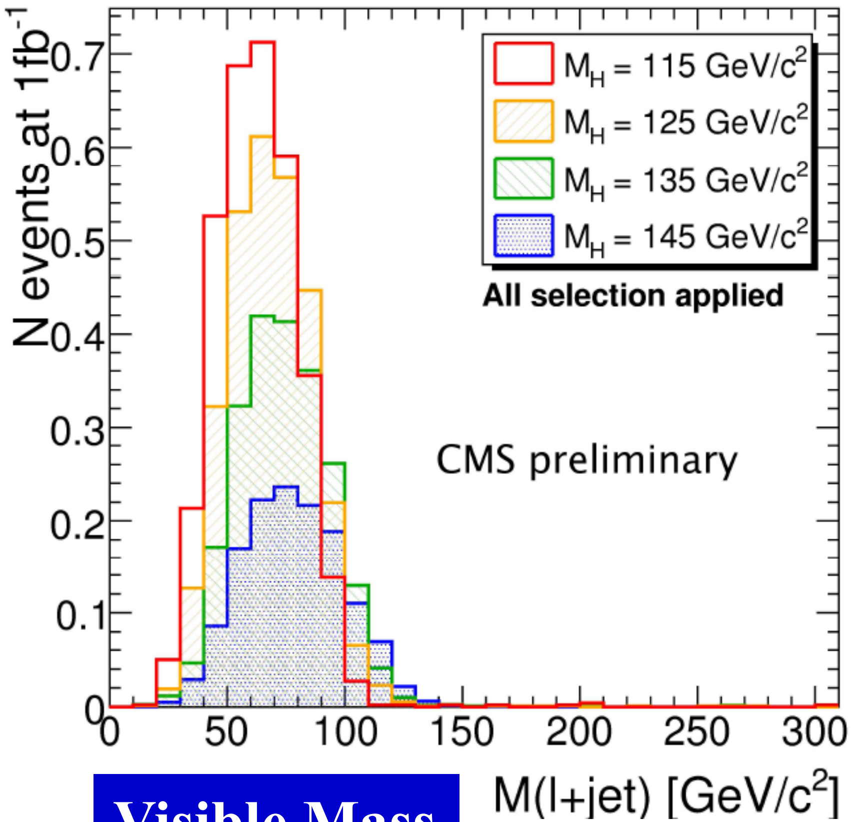


Search for Higgs boson signal above Z→ττ peak: understanding DY di-τ mass shape important

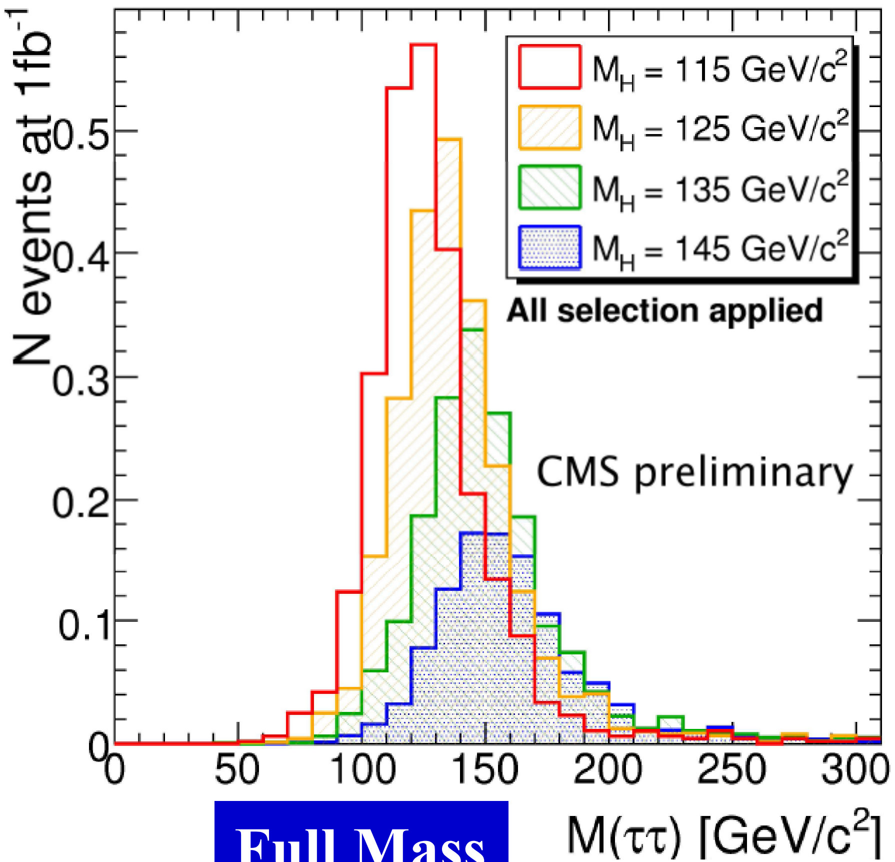
Uncertainty dominated by modeling of E_t^{miss} (pileup, underlying event, calorimeter noise & response, …)

Z→μμ events : μ's substituted by simulated τ's with μ's kinematics to model background shape

qqH, H→ττ mass reconstruction methods



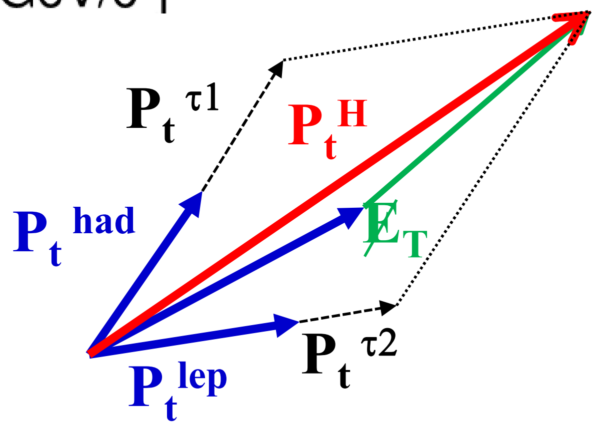
Visible Mass



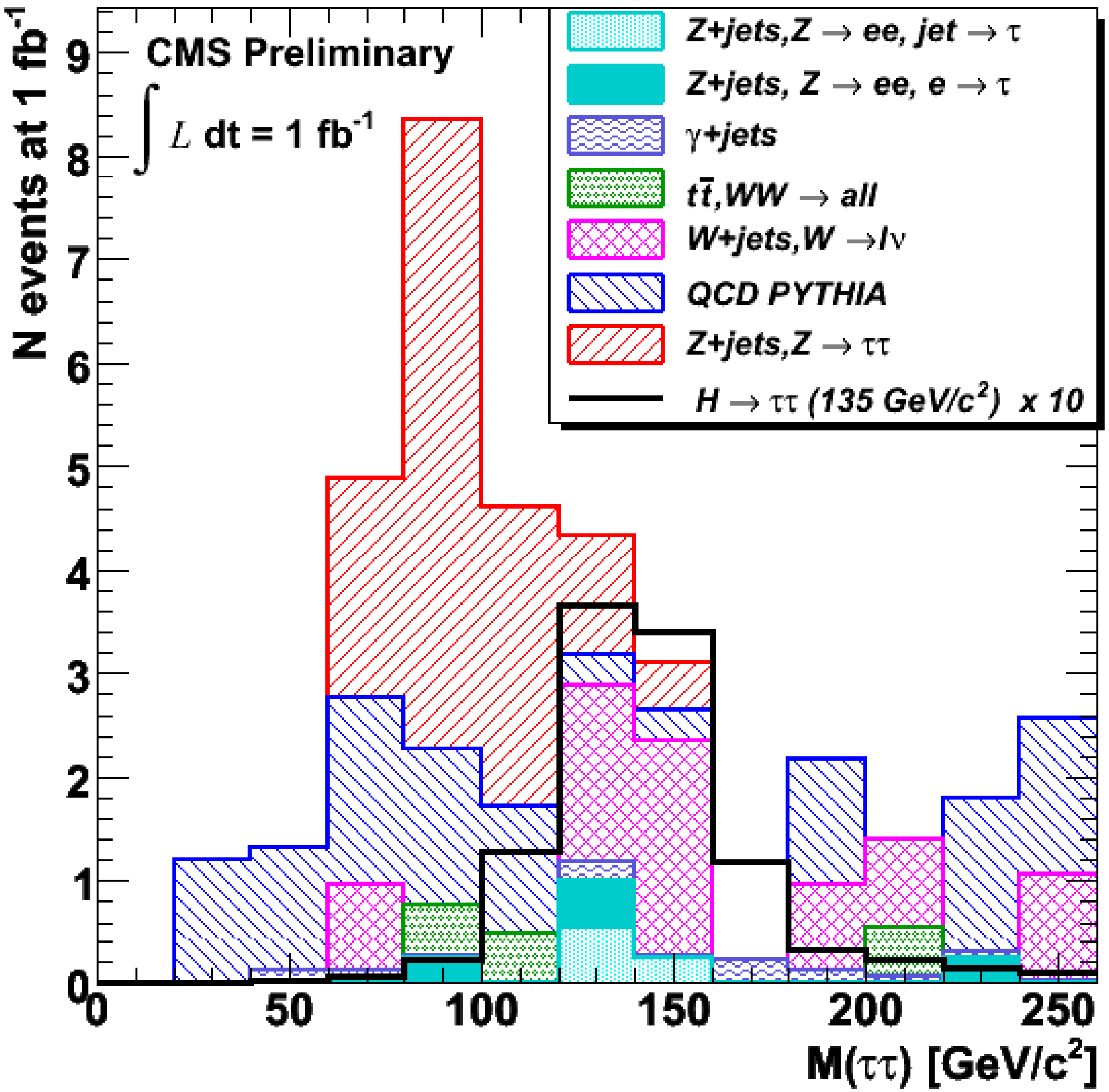
Full Mass

mass [GeV/c^2]	full mass, M(ττ)			visible mass, M(l+τ_{had})		
	mean	σ	σ/M	mean	σ	σ/M
115	123.0	17.0	0.138	63.1	16.1	0.255
125	133.3	18.6	0.140	68.4	17.1	0.250
135	144.1	20.6	0.143	73.5	18.9	0.257
145	152.9	21.6	0.141	78.0	21.0	0.269

Collinear Approximation



Expected ττ mass distribution for 1 fb^{-1}



Relaxed VBF selection for 1 fb^{-1} analysis

1 fb^{-1} Analysis	30 fb^{-1} Analysis
$\Delta\eta>2.5$	$\Delta\eta>4.2$
$M_{j1j2}>0.4$ TeV	$M_{j1j2}>1$ TeV
	$\Delta\varphi<2.2$

Full di- τ mass using collinear approximation of neutrinos from the τ decays and the visible τ decay products

Expected Number of Events: VBF l+τ_{had} Systematic uncertainties for 1 fb^{-1}

Background		$Z \to \tau\tau$	$Z \to \mu\mu$	$Z \to ee$		incl. $t\bar{t}$	W+jets	γ+jets
				$e \to \tau$	$jet \to \tau$			
Number of events for 1 fb^{-1}		13.2	0	0.9	0.8	3.5	11.1	2.3
source of uncertainty	value, %	background uncertainty, %						
JES	7	9		6	4	14	9	8
MET scale	10+7	27		42	18	12	27	24
τ_{had} id	5	5				1		
lepton selection	1	1		1	1	1	1	1
jet$\to$ τ_{had} fake rate	10				10	6	10	10
e$\to$ τ_{had} fake rate	1			12		0.2		
rapidity gap selection	5	5		5	10	16	4	4
normalization uncertainty, %		1				1	2	5
total uncertainty, %		29		44	23	25	30	28

Signal

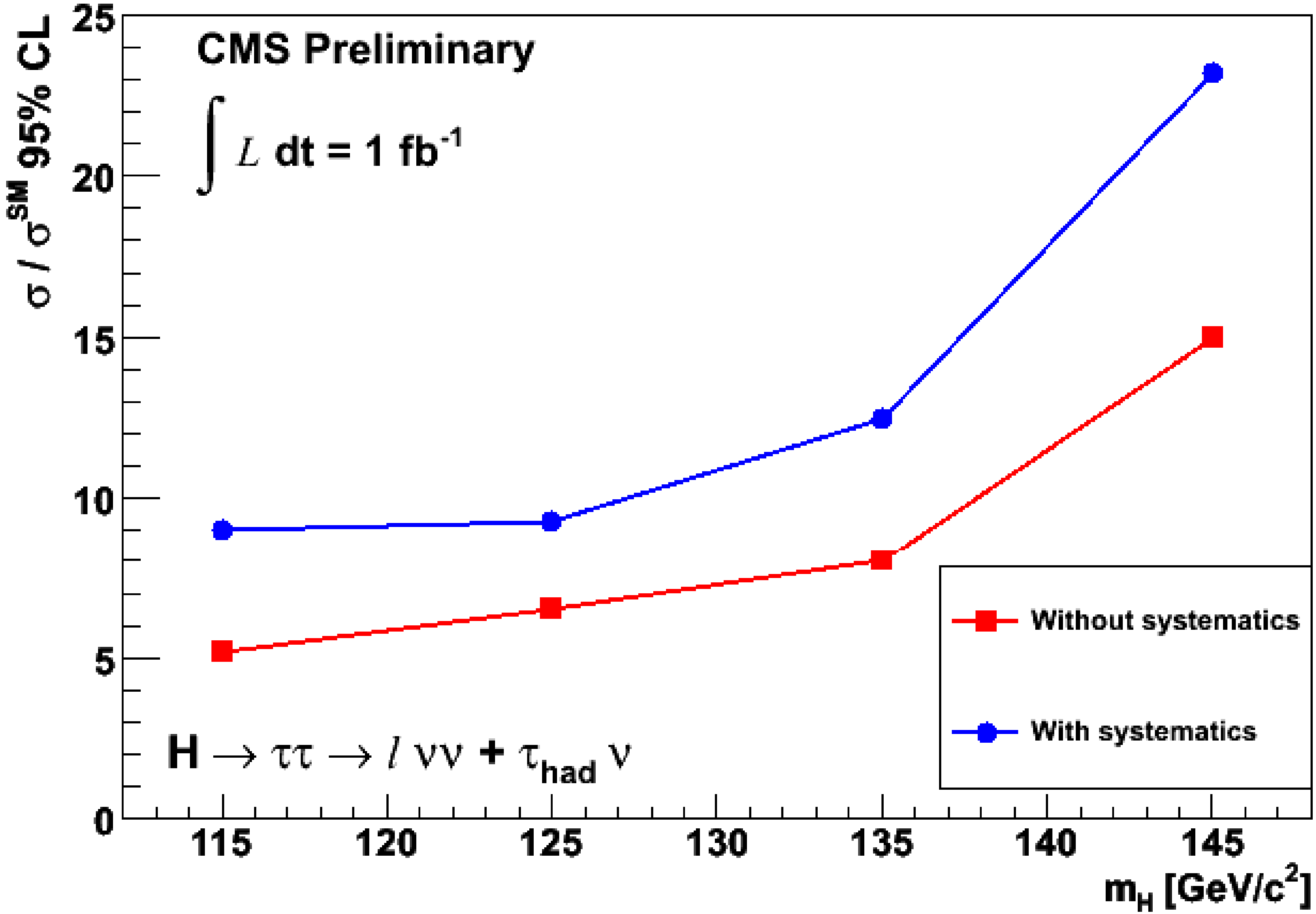
source of uncertainty	value, %	uncertainty, %
JES	7	10
MET scale	10+7	4
τ_{had} id	5	5
lepton selection	1	1
rapidity gap selection		2
Total uncertainty, %		12

Backup slides: data-driven method to estimate QCD background

expected QCD background for 1 fb^{-1}

$$N^{OS}_{QCD} = 13.4 \pm 4.5 \text{ events.}$$

Expected Exclusion limits for 1 fb^{-1} of data



Summary

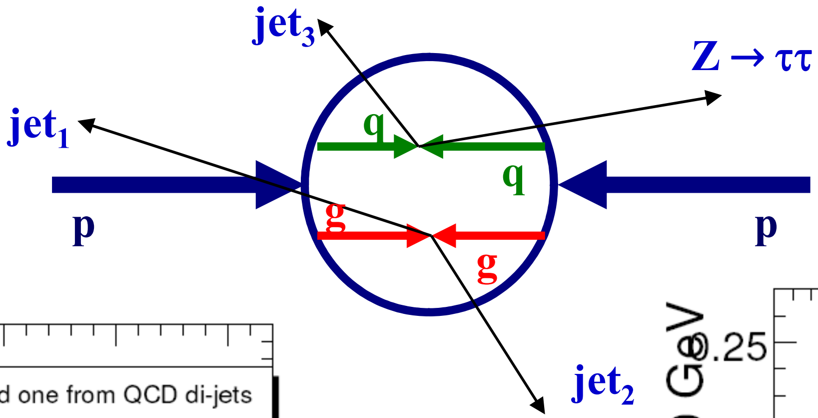
• An analysis strategy for the Standard Model Higgs boson produced in vector boson fusion (VBF) and decaying into a pair of τ leptons with a $l\nu\nu+\tau_{had}\nu$ final state in the mass range between 115 and 145 GeV/c^2 with 1 fb^{-1} of early CMS data at the LHC is developed

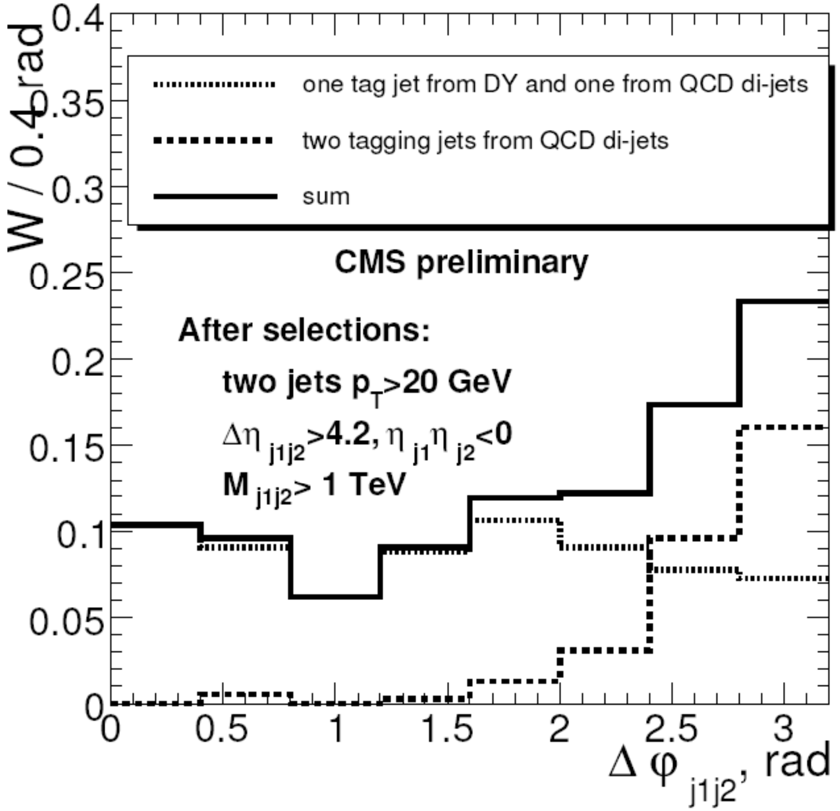
• No signal evidence is expected for a luminosity of 1 fb^{-1} and a cross section times branching ratio 5-10 larger than the SM expectations can be be excluded

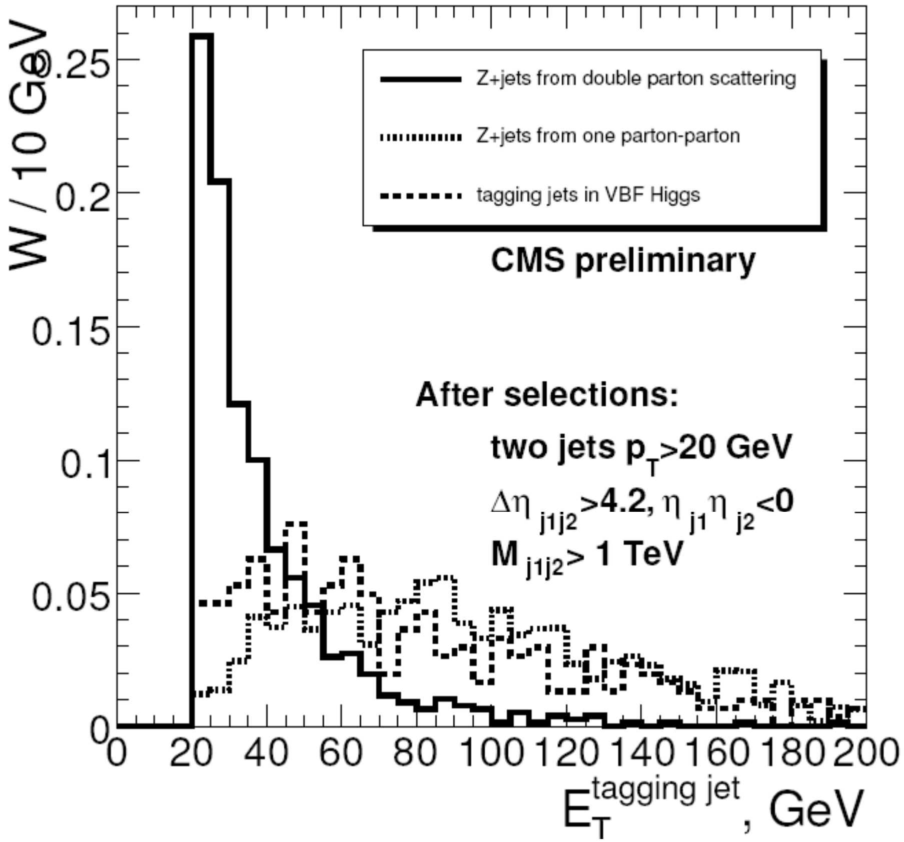
•The Higgs boson discovery in VBF can be achieved with 30 fb^{-1}
- qqH, $H\rightarrow\tau\tau$: 4σ significance in mass range 115-145 GeV
- qqH , $H\rightarrow\gamma\gamma$: 2σ significance in mass range 115-135 GeV
- qqH , $H\rightarrow WW$: 5σ significance in mass range 140-200 GeV

BACKUP SLIDES

Z+jets Background Contribution from Double Parton Scattering







After VBF Selections: Z+jets Double Parton Interaction is ~15% of Single Parton Interaction

Study the p_t unbalance in Z+jets events with VBF cuts allow to control/measure DPI

H→ττ →lepton-jet: Kinematic Selection

Lepton :

$p_T > 15$GeV, $|\eta| < 2.5$

τ_{had} :

$E_T > 30$GeV, $|\eta| < 2.3$

VBF jets :

$\eta_{j1} \times \eta_{j2} < 0$, $|\eta| < 4.5$

$E_T > 30$GeV

VBF cuts :

soft (hard for $30fb^{-1}$)

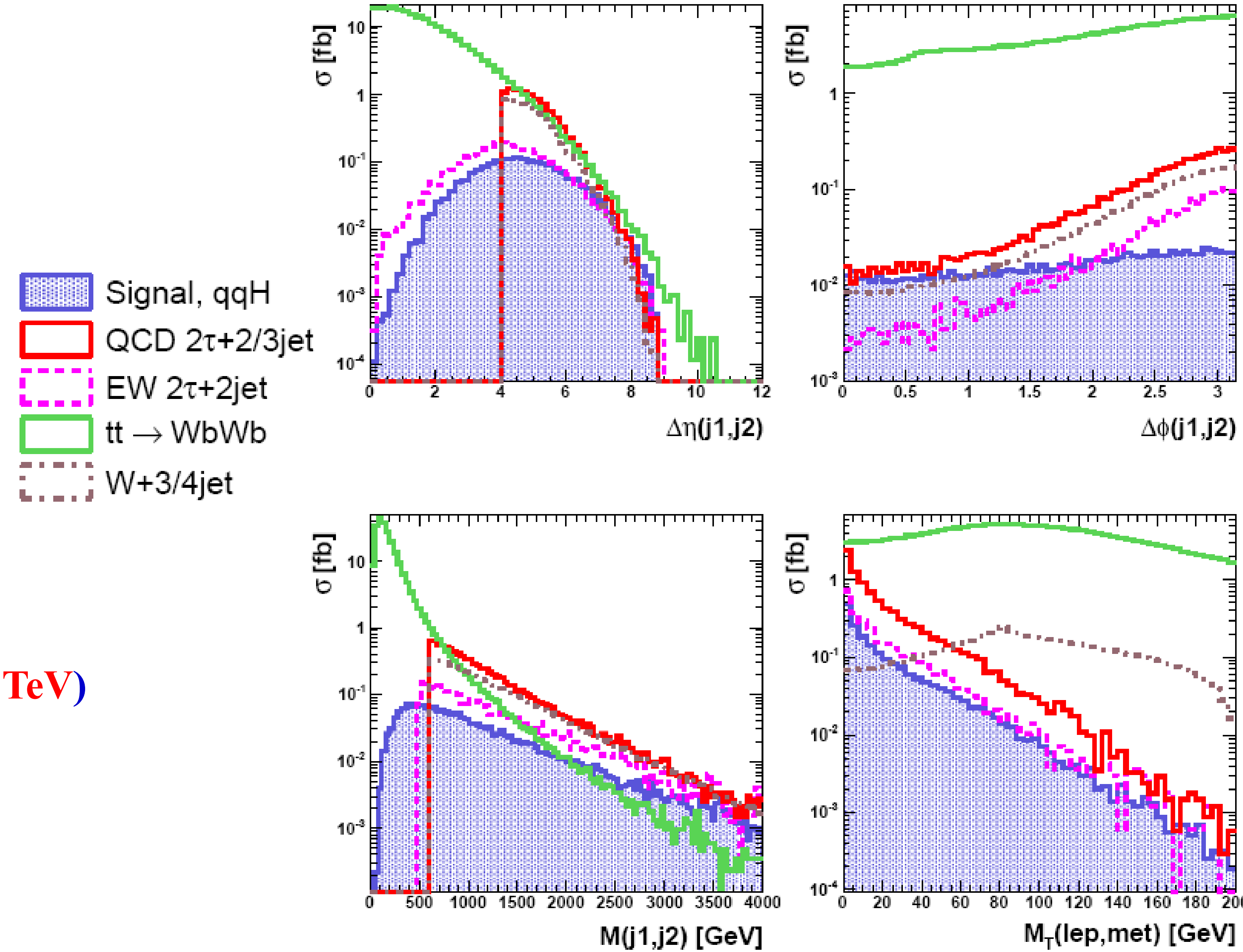
$\Delta\eta > 2.5$ (4.2)

M(j1,j2) > 0.4 TeV (1 TeV)

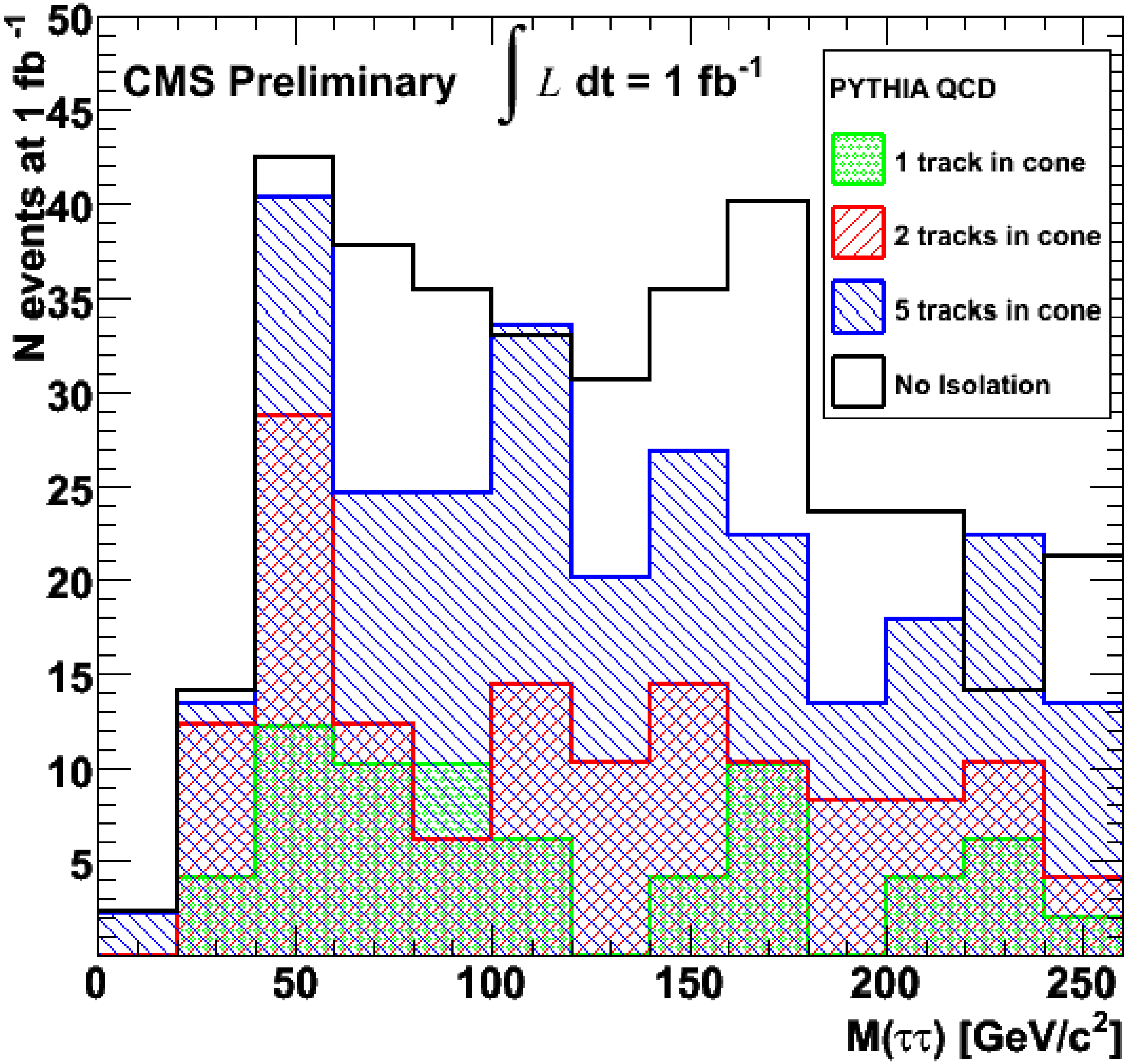
$\Delta\varphi$ not used (< 2.2)

Lepton-E_T^{miss} :

$M_T(l, E_T^{miss}) < 40$GeV



QCD pp→μ+X background shape from data with non isolated muons after all qqH selections



QCD background normalisation from data: D0 method

$$N^{SS}_{QCD} = N^{SS}_{data} - N^{SS}_{W+jets} - N^{SS}_{t\bar{t}} - N^{SS}_{Z+jets} - N^{SS}_{\gamma+jets'}$$

Hypothesis

$$R = \frac{N^{SS}_{QCD}}{N^{OS}_{QCD}} = \frac{N^{SS}_{QCD,\ non.isol.\ \ell}}{N^{OS}_{QCD,\ non.isol.\ \ell}}$$

PYTHIA QCD with real muon or electron p_t> 15 GeV

$$\frac{N^{SS}_{QCD,\ non.isol.\ \mu}}{N^{OS}_{QCD,\ non.isol.\ \mu}} = 1.06 \pm 0.01, \text{ and } \frac{N^{SS}_{QCD,\ non.isol.\ e}}{N^{OS}_{QCD,\ non.isol.\ e}} = 1.00 \pm 0.12$$

PYTHIA QCD with fake or real electron p_t< 15 GeV

$$\frac{N^{SS}_{QCD,\ non.isol.\ e}}{N^{OS}_{QCD,\ non.isol.\ e}} = 0.98 \pm 0.08 \text{ and } \frac{N^{SS}_{QCD,\ non.isol.\ e}}{N^{OS}_{QCD,\ non.isol.\ e}} = 1.17 \pm 0.14,$$

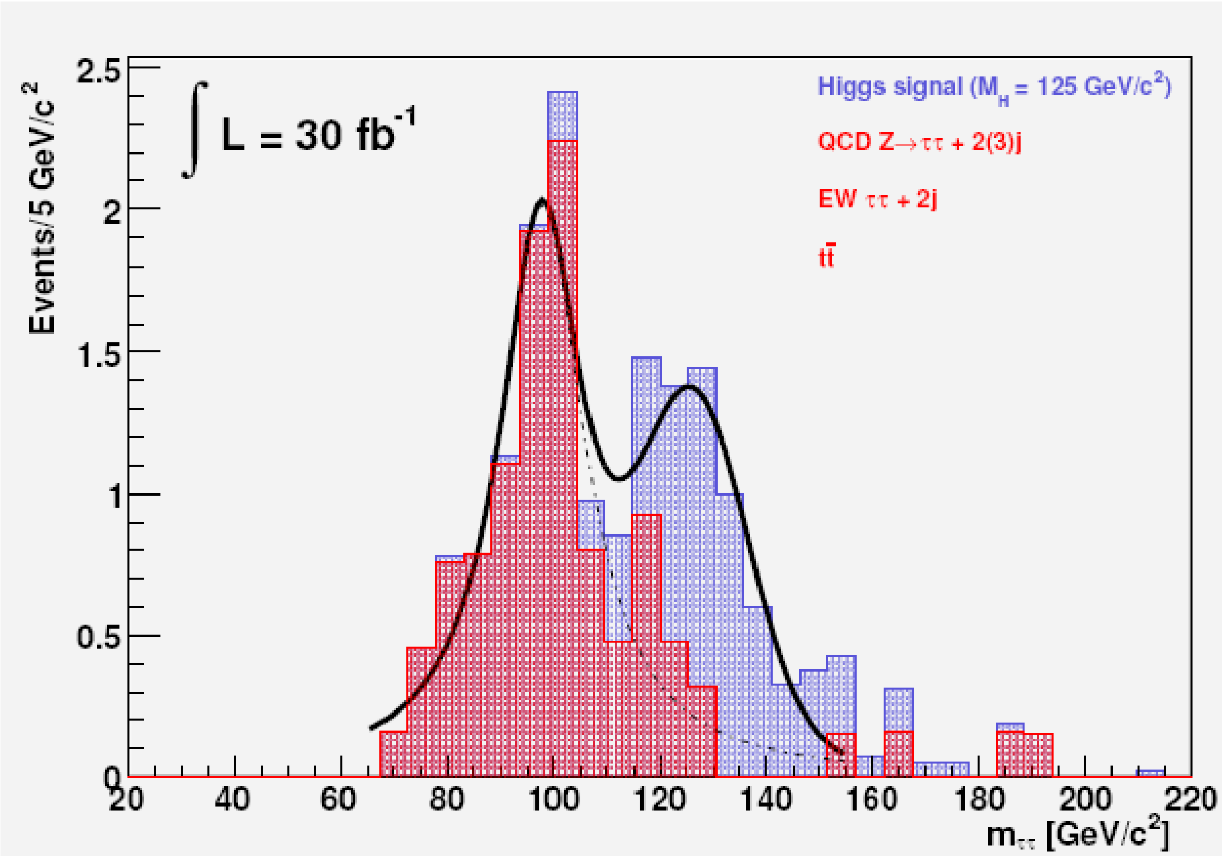
A value of R=1 for QCD multi-jet background estimation is used in this analysis

The total expected QCD background for 1 fb^{-1} is $N^{OS}_{QCD} = 13.4 \pm 4.5$ events.

Table 1: Expected number of events for 1 fb^{-1}

N^{SS}_{data}	N^{SS}_{W+jets}	$N^{SS}_{t\bar{t}}$	N^{SS}_{Z+jets}	$N^{SS}_{\gamma+jets'}$
20.1	4.6	0	0.8	2.1

VBF H→ττ → eμ channel



Higgs mass [GeV/c^2]	significance at 30 fb^{-1}	significance at 60 fb^{-1}
115	2.68	3.54
125	4.04	4.91
135	2.34	2.98
145	1.57	2.04