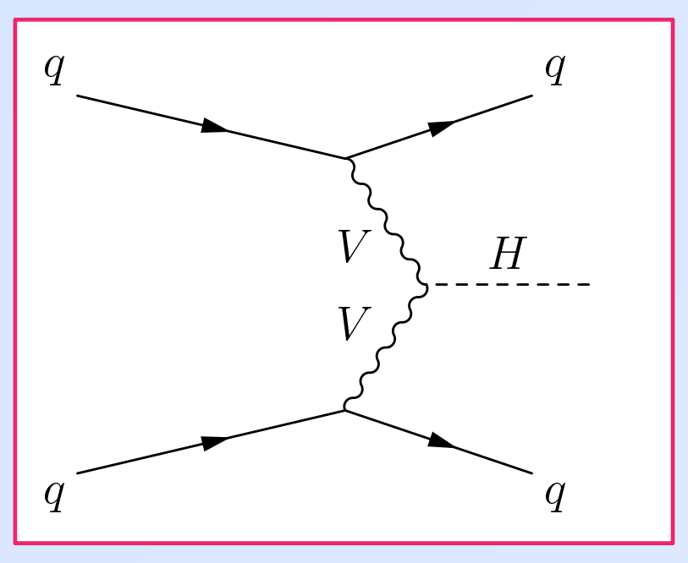
(37) Search for invisible Higgs decays in the VBF channel

Chayanit Asawatangtrakuldee on behalf of the CMS Collaboration
Peking University

Motivation

- SM H → invisible only possible via H → ZZ*→ νννν (~0.1%)
- Despite the observation of 125 GeV SM Higgs boson, the possibility for non-SM properties remains
- Visible SM decay modes constrain BF(H → BSM) < 64%
- Significant BF(H → invisible) would be a strong sign of the BSM theories, e.g. H → 2LSPs in SUSY, Graviscalars in the ADD model, Dark matter and etc.
- VBF production has larger cross-section than VH and ttH - potentially better sensitivity
- Major challenge in backgrounds estimation



Feynman diagrams of VBF production

Analysis Strategy

- Data from 8TeV collision corresponding to an integrated luminosity of 19.5 fb^{-1} was collected by dedicated triggers requiring jet pair in a loose VBF-like topology and MET (missing transverse energy)
- Signal extraction :
  - ✧ Leptons (e,μ) veto $p_T > 10$ GeV
  - ✧ Tighter selection of VBF tag jet pair
    - $p_{T,j} > 50$ GeV and $|\eta_j| < 4.7$
    - $\eta_{j1} \cdot \eta_{j2} < 0$
    - $|\eta_{j1} - \eta_{j2}| > 4.2$
    - $M_{j1j2} > 1100$ GeV
  - ✧ MET > 130 GeV
  - ✧ Central-jet ($\eta_{j1} < \eta_{cj} < \eta_{j2}$) veto $p_T > 30$ GeV
  - ✧ $\Delta\Phi_{j1j2} < 1.0$
- Perform a single-bin counting experiment using the observed yield in signal region and estimated backgrounds by data-driven method

Data-driven Backgrounds Estimation

- The dominant backgrounds arise from V+jets processes, Z(νν)+jets and W(lν)+jets when the charged lepton is outside acceptance or not identified, contributing similar topology to VBF (H → invisible) production
- Data-driven for V+jets : identify background rich control regions and extrapolate to signal region using factors derived from MC simulation
- The background from QCD multijet processes is also estimated from data due to lack of MC statistic

Z(νν)+jets Background

- ✧ Define Z(μμ) control region as signal region but :
  - ✓ require $\mu^+\mu^-$, each $p_{T,\mu} > 20$ GeV and $60 < M_{\mu\mu} < 120$ GeV
  - ✓ veto any additional leptons not from Z
  - ✓ redefine MET to exclude Z and require > 130 GeV
- ✧ The number of Z(νν) events is predicted from :

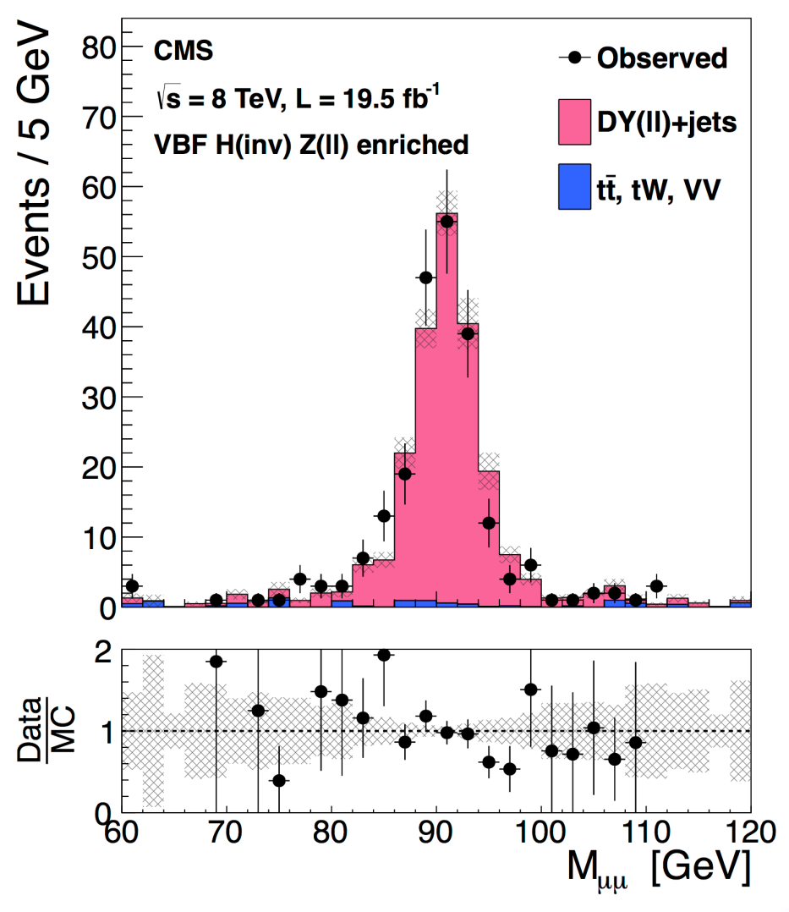
$$N^{s}_{\nu\nu} = (N^{c}_{\mu\mu\text{obs}} - N^{c}_{\text{bkg}}) \cdot \frac{\sigma(Z \to \nu\nu)}{\sigma(Z/\gamma^* \to \mu\mu)} \cdot \frac{\varepsilon^{s}_{\text{ZMC}}}{\varepsilon^{c}_{\text{ZMC}}}.$$

- MC factors

Ratio of BF = 5.651 ± 0.023 (MCFM)
$\varepsilon^{S}_{\text{ZMC}} = (1.65 \pm 0.27) \times 10^{-6}$
$\varepsilon^{C}_{\text{ZMC}} = (1.11 \pm 0.17) \times 10^{-6}$
from DY(μμ)+jets, EWK Z(μμ)

- Results

N^{C}_{obs} = 12 events
N^{C}_{bkg} = 0.23 ± 0.15 events
$N^{S}_{\nu\nu}$ = 99 ± 29 (stat.) ± 25 (syst.)



Invariant mass of dimuon pair

W(lν)+jets Background

W(μν)+jets and W(eν)+jets

- ✧ Define single-lepton control regions
- ✧ The number of W+jets background is estimated from

$$N^{s}_{\ell} = (N^{c}_{\ell\text{obs}} - N^{c}_{\text{bkg}}) \cdot \frac{N^{s}_{\text{WMC}}}{N^{c}_{\text{WMC}}},$$

from W→lν MC events

- Results : $N^{S}_{W(\mu\nu)}$ = 67 ± 5 (stat.) ± 16 (syst.)
  $N^{S}_{W(e\nu)}$ = 63 ± 9 (stat.) ± 18 (syst.)

W(τν)+jets -- tau decays hadronically

- ✧ Define control region as signal region and require one hadronic tau $p_T > 20$ GeV $|\eta| < 2.3$ but without CJV to increase the yield, therefore :

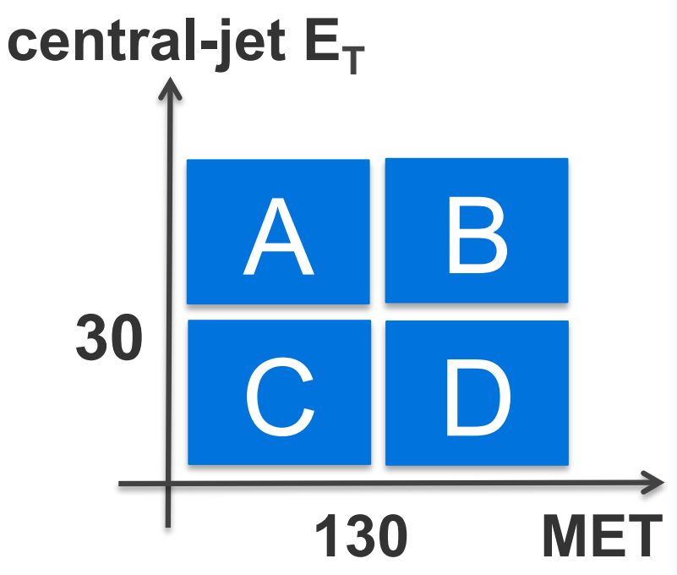
$$N^{s}_{\tau_h} = (N^{c}_{\tau\text{obs}} - N^{c}_{\text{bkg}}) \cdot \frac{\varepsilon_{\text{CJV}}}{\varepsilon_{\tau}},$$

from W→τ_{had} MC events

- Results : $N^{S}_{W(\tau\nu)}$ = 53 ± 18 (stat.) ± 18 (syst.)

QCD Background

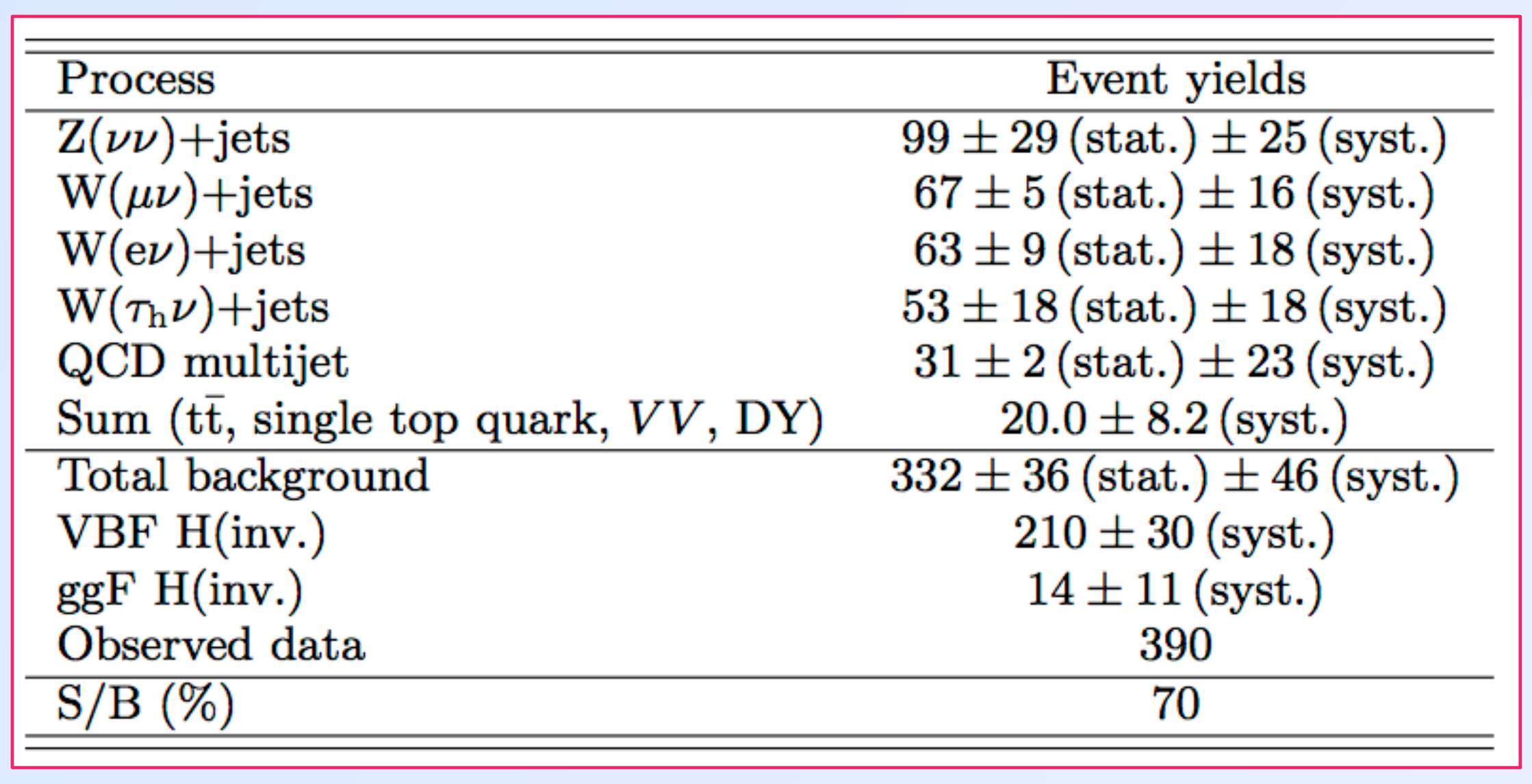
- ✧ Effectively reduced to small level by MET, CJV and ΔΦ
- ✧ "ABCD" method of MET vs. CJV, assuming they are uncorrelated
  - ✓ A : fail MET selection, fail CJV selection
  - ✓ B : pass MET selection, fail CJV selection
  - ✓ C : fail MET selection, pass CJV selection
  - ✓ D : pass MET selection, pass CJV selection -- *Signal*
- ✧ Numbers of region A,B,C are estimated from data subtract electroweak backgrounds from MC



- ✧ Number of QCD background is therefore given by : $N_D = N_B N_C / N_A$
- ✧ Results :
  N^{S}_{QCD} = 31 ± 2 (stat.) ± 23 (syst.)

Signal vs. Backgrounds

- Signal of 125 GeV Higgs boson with 100% BF(H → inv) produced via VBF and gluon-fusion processes are based on POWHEG simulation
- Minor backgrounds are estimated from MC simulation

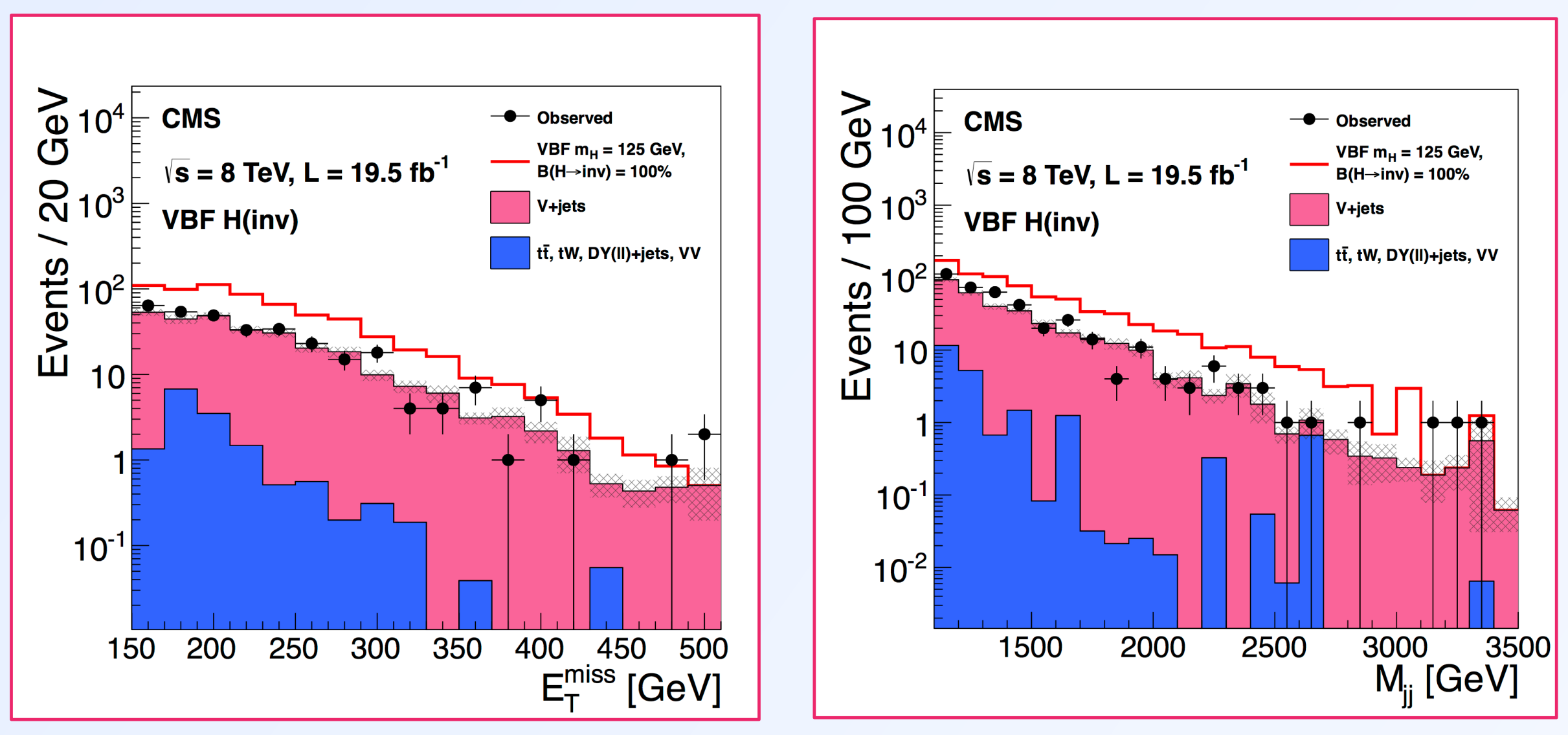


Process	Event yields
Z(νν)+jets	99 ± 29 (stat.) ± 25 (syst.)
W(μν)+jets	67 ± 5 (stat.) ± 16 (syst.)
W(eν)+jets	63 ± 9 (stat.) ± 18 (syst.)
W($\tau_h\nu$)+jets	53 ± 18 (stat.) ± 18 (syst.)
QCD multijet	31 ± 2 (stat.) ± 23 (syst.)
Sum (tt̄, single top quark, VV, DY)	20.0 ± 8.2 (syst.)
Total background	332 ± 36 (stat.) ± 46 (syst.)
VBF H(inv.)	210 ± 30 (syst.)
ggF H(inv.)	14 ± 11 (syst.)
Observed data	390
S/B (%)	70

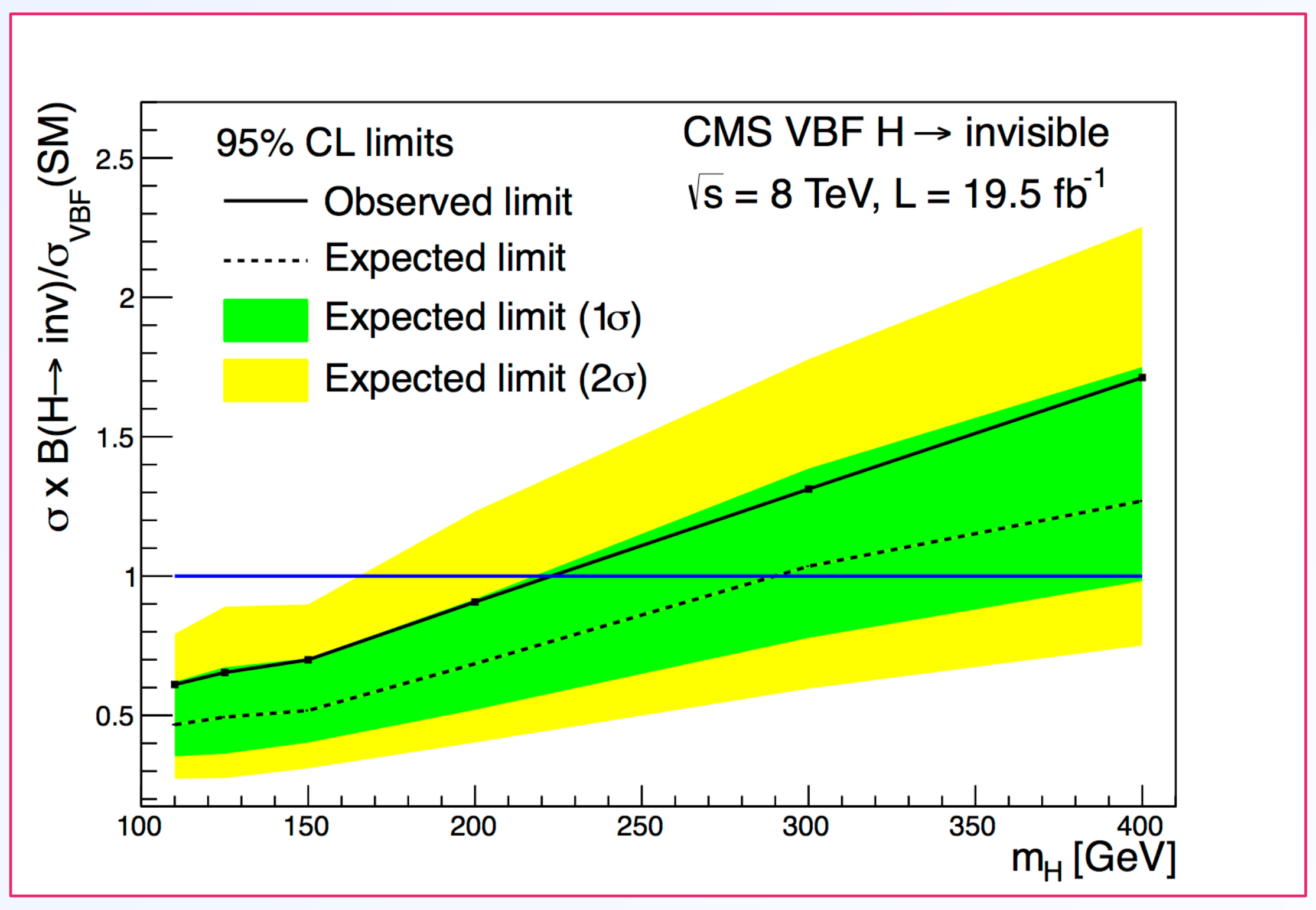
Results

- The main sources of uncertainty are statistics from control samples in data and MC samples
- Systematic uncertainties include jet/MET scale/resolution, leptons efficiency, CMS cross-section measurements in minor backgrounds, PDFs and factorization/renormalization scale in signal yields and etc.
- Limits are set using an asymptotic CL_s method
- Results : for m_H = 125 GeV at 95% CL

Observed limit = 0.65
Expected limit = 0.49



MET and M_{jj} distributions in signal region



Expected and observed 95% CL upper limits on the production cross-section times invisible Higgs branching fraction normalized to the SM VBF production cross-section, as a function of m_H

References & Acknowledgements

[1] arXiv:1404.1344 [2] CMS PAS HIG-13-005 [3] CMS PAS HIG-13-013

Personal funding by the royal patronage of H.R.H Princess Maha Chakri Sirindhorn of Thailand and Peking University Beijing, China

chayanit@cern.ch