Search for a heavy scalar boson decaying into a pair of Z bosons in the *2l2ν* final state in CMS

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Outline

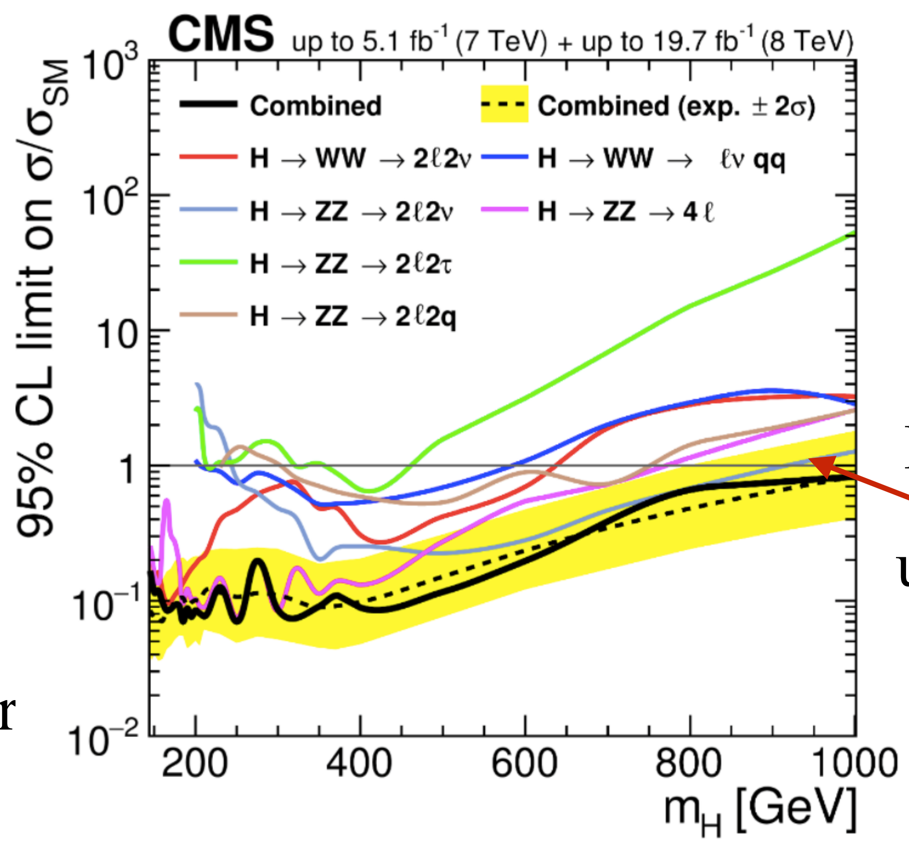
- Introduction
- Overview
- Analysis Strategy
    - Event selection
    - Category
    - Backgrounds estimation
    - Results
- Conclusion

Introduction

- **A generic heavy scalar boson search with ZZ→2l2ν final state, but test with two benchmark models**
  - Electroweak Singlet Model (EWS): additional heavy Higgs
  - Two Higgs Doublet Model (2HDM): 5 Higgs (2 charged, 3 neutral)

- **New physics manifest itself in a change of the transverse mass (or MET) spectrum**

- **ZZ→2l2ν search channel — a promising channel for heavy resonance search:**
  - BR(ZZ→2l2ν) ~ 6 BR(ZZ→4l)
  - reduced background in High Mzz compared to ZZ→2l2q
  - Not sensitive to the width of heavy scalar

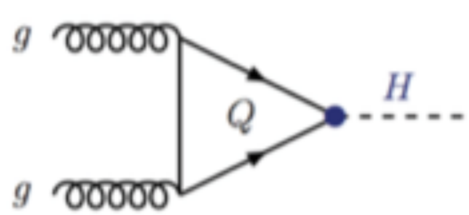


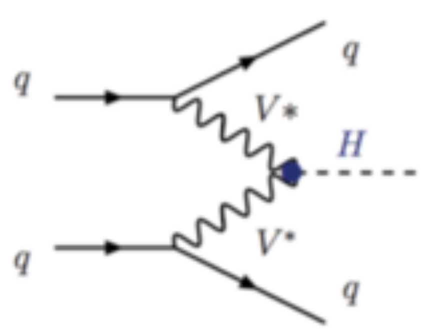
Best sensitivity using ZZ→2l2ν

Signal and backgrounds

signal

SM-like heavy higgs



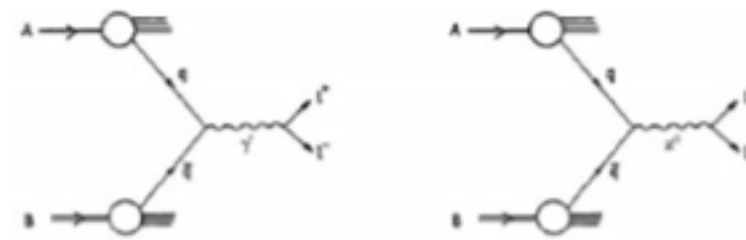


backgrounds

Diboson/Triboson: **ZZ** $\rightarrow 2l2\nu$, WZ, ZVV

irreducible background

DY:



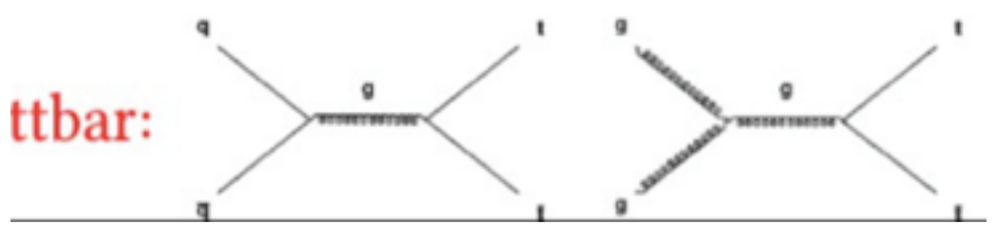
instrumental MET background

multi-jets:

W+jets:

jet(s) mis-identified as leptons

ttbar:



tW, WW, ττ …

non-resonant background

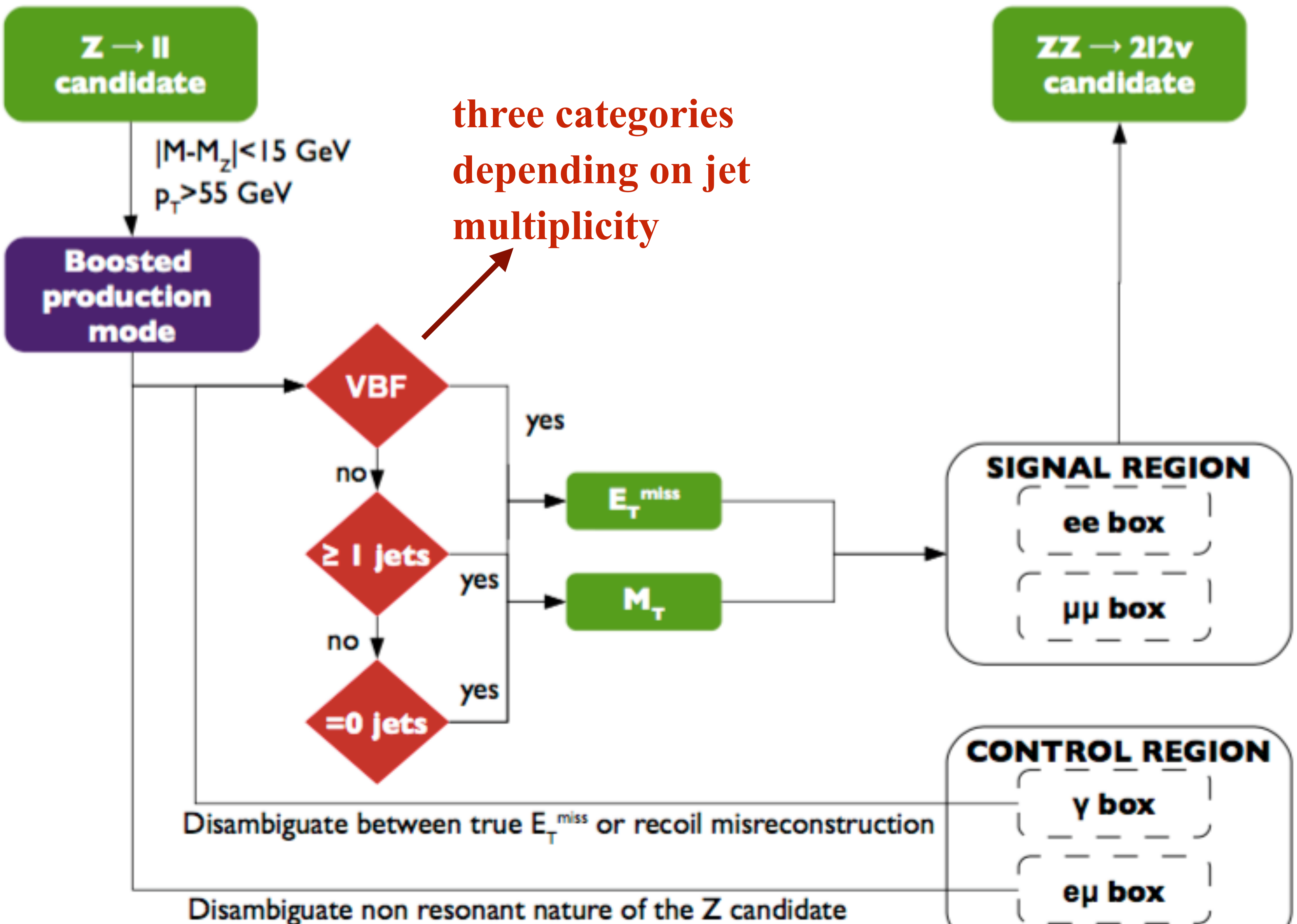
Object and Event selection

- **Trigger: single lepton or di-lepton trigger**
- **Offline Electron/Muon selection:**
  - $p_T > 25$ GeV
  - $|\eta_e| < 2.5$, $|\eta_\mu| < 2.4$
  - Tight ID and Isolation
- **$p_T^Z > 55$ GeV**
- **$|m_{ll} - 91| < 15$ GeV**
- **3rd lepton veto**
- **$\Delta\phi$(jet, MET) > 0.5**

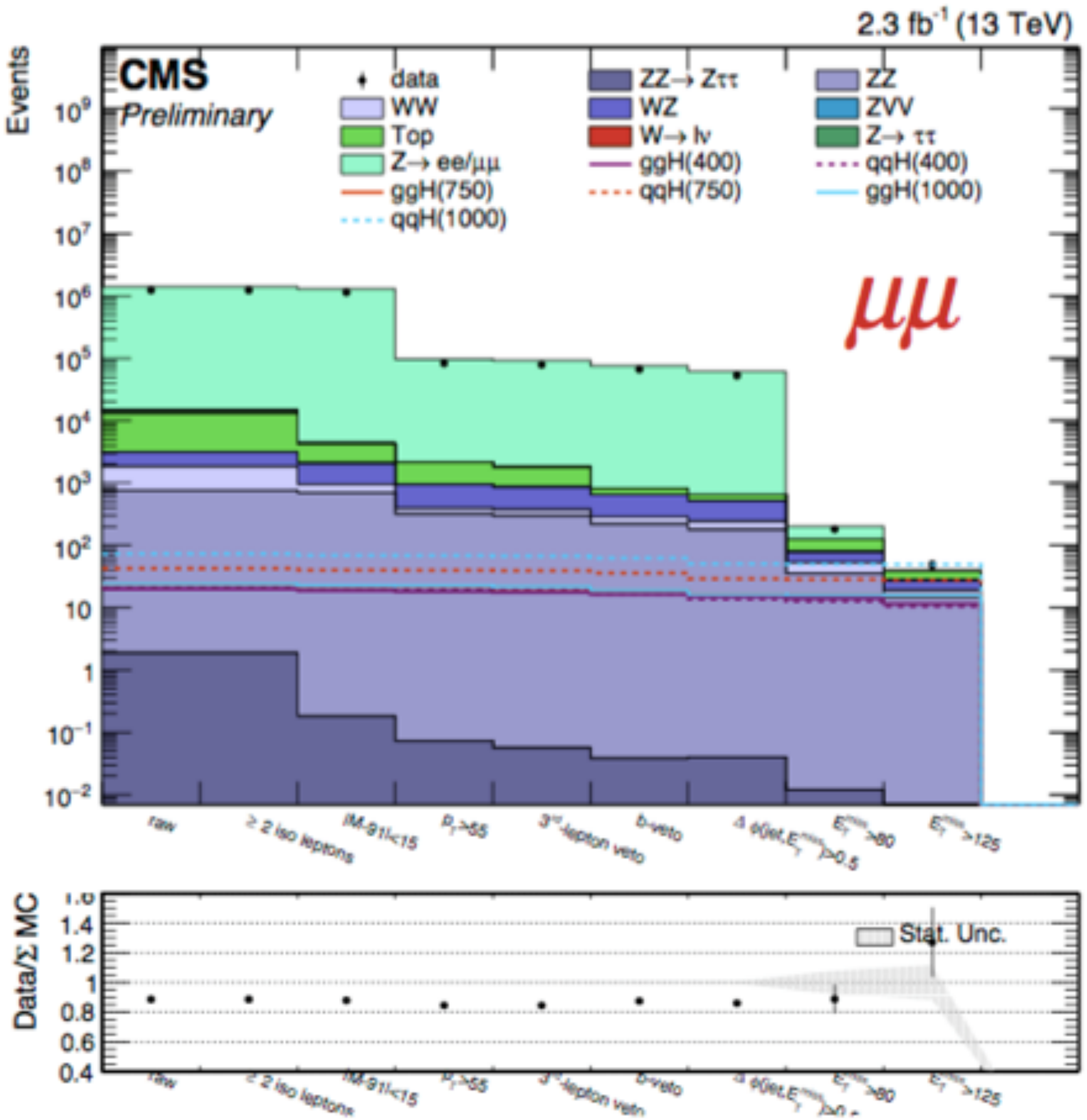
- **MET > 125 GeV**
- **Transverse Mass distribution is used to set shape based limits**

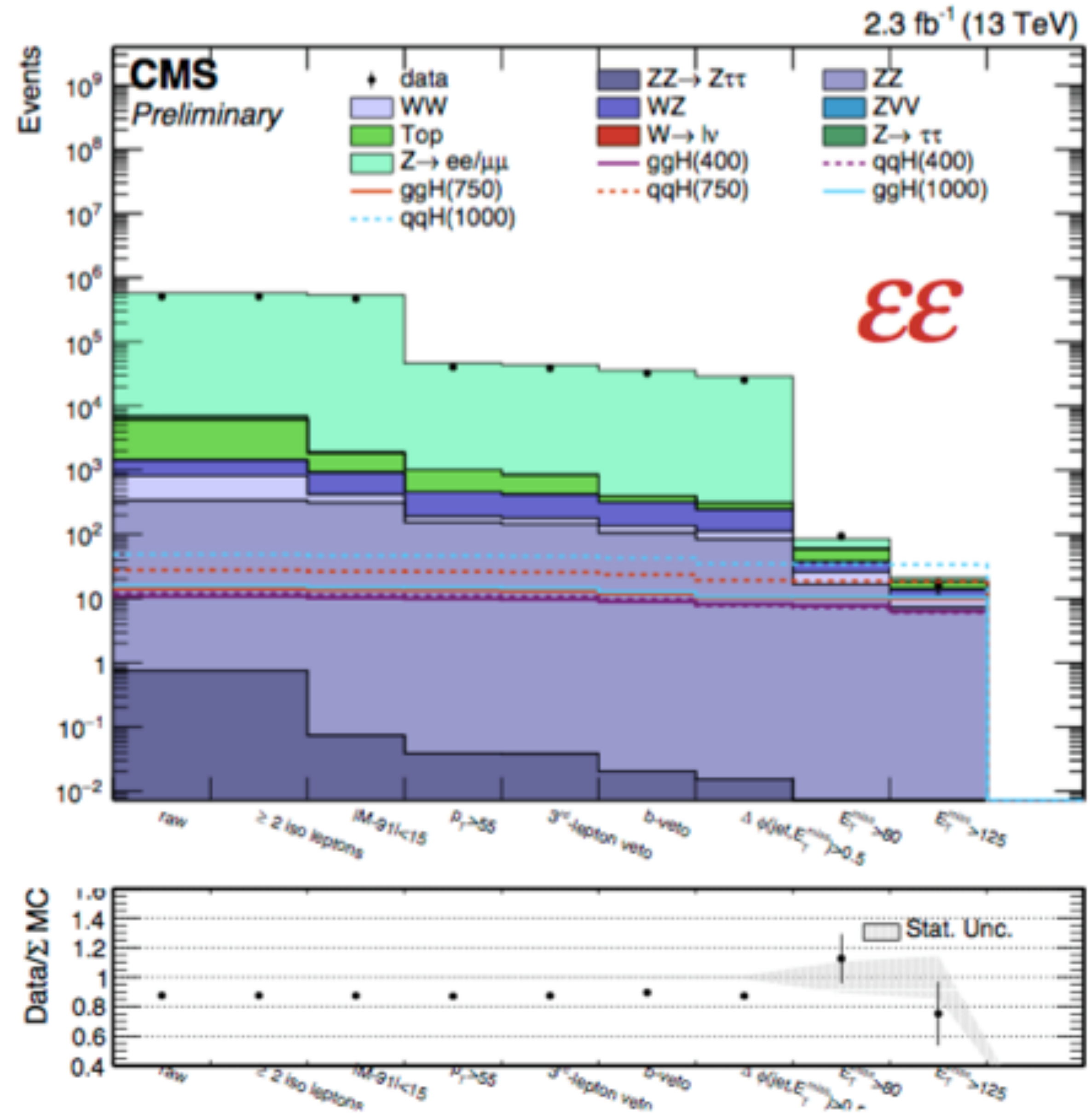
Event Category

three categories depending on jet multiplicity



Cutflow Plot



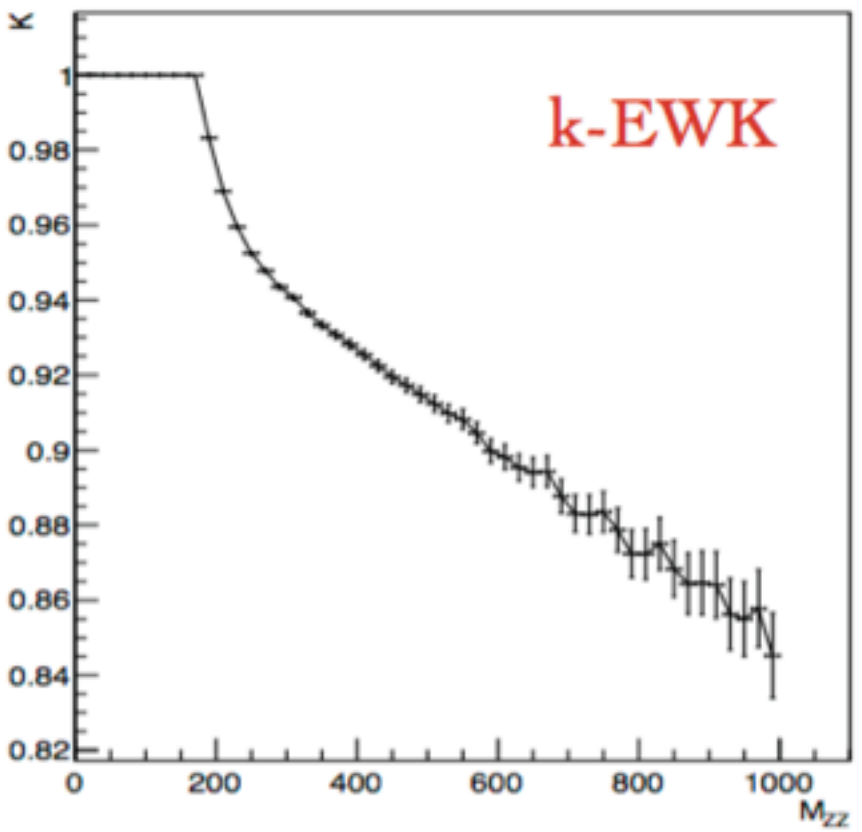


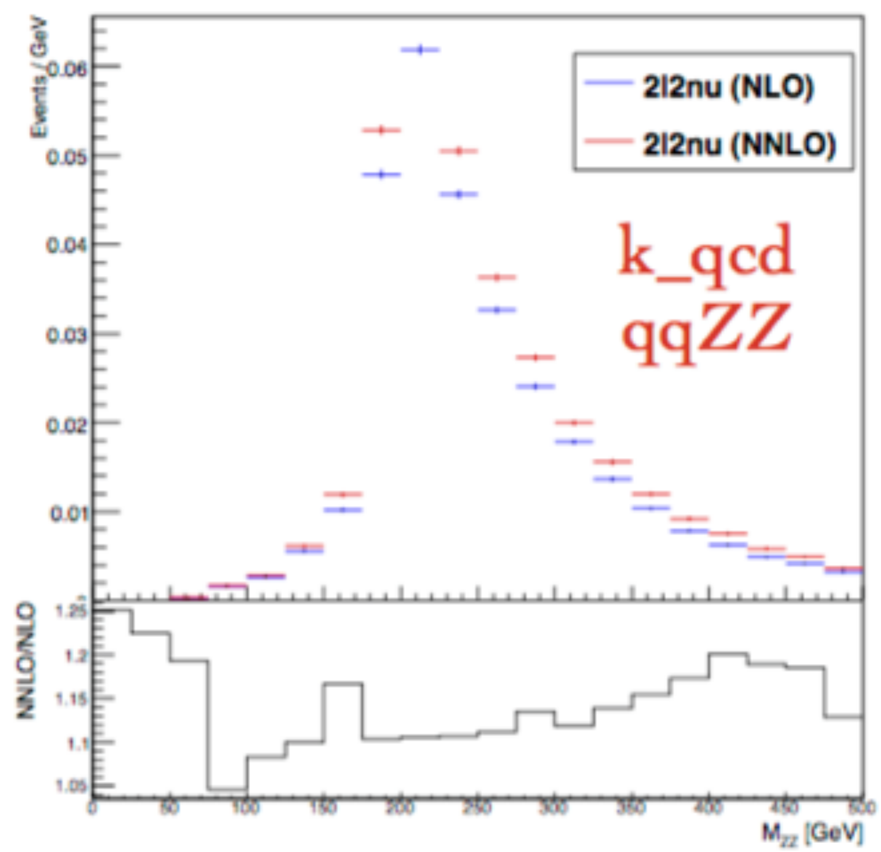
All Background estimated with MC samples as first check.

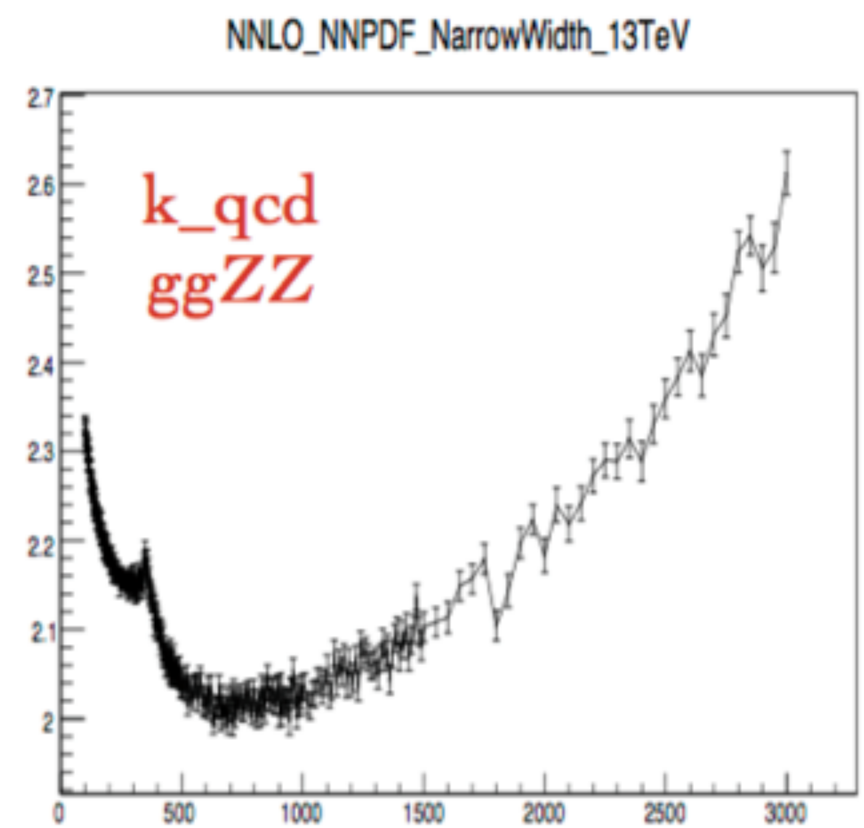
All jet categories summed up.

Irreducible Background

- **Diboson/Triboson: ZZ, WZ, ZVV with Z decay into lepton pairs**
- **Similar topology as signal H→ZZ→2l2ν, Estimated with MC prediction**
- **qq→ZZ processes, apply the following corrections:**
  - EWK(NLO/LO) as a function of the quark flavour and Mandelstam variables
  - QCD (NNLO/NLO) corrections are computed as a function of Mzz
- **gg→ZZ: QCD(NNLO/NLO) k-factors applied, as like signal**
- **WZ: No EWK corrections are applied (assign 3% uncertainty to cover this)**

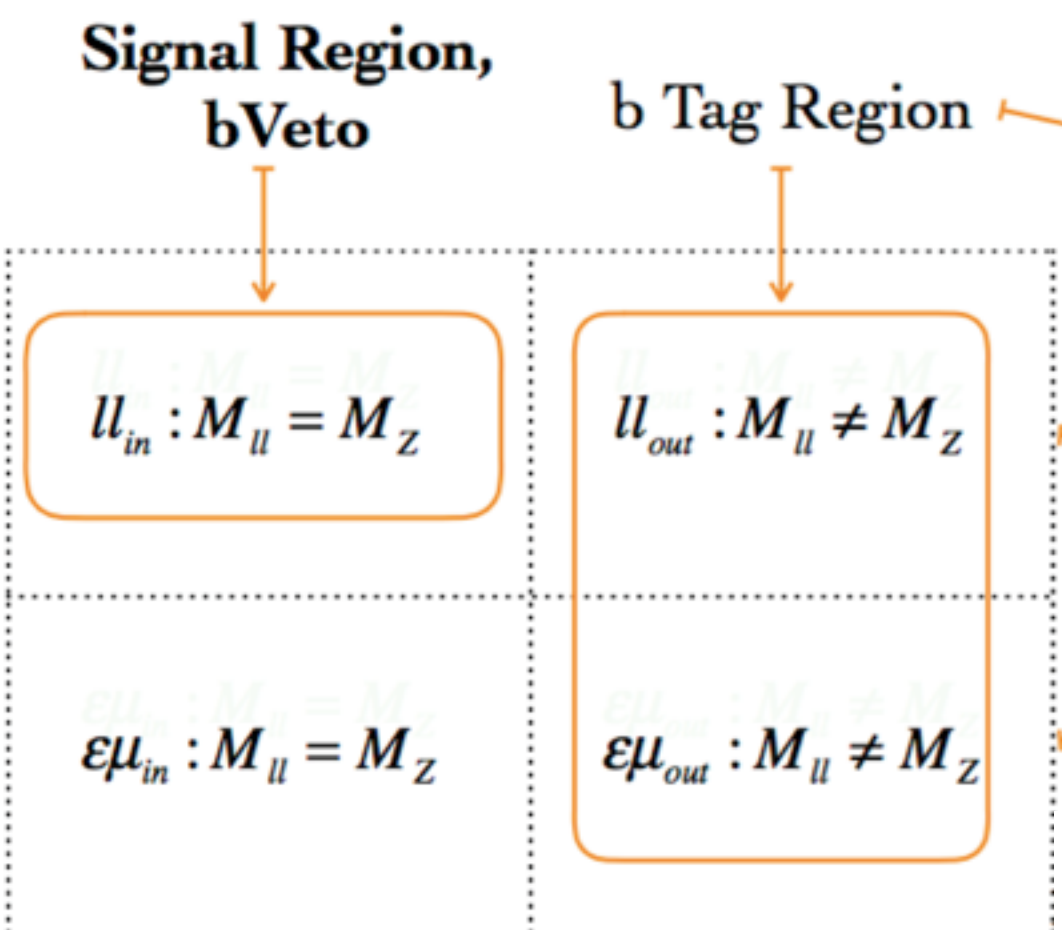






Non-Resonant backgrounds (1)

- **ttbar, tW, WW, Wjets, ττ: flavour symmetric**
- **Fully data-driven estimation**
  - use Z mass sideband regions to define a **α** factor
  - use different flavour control region: $e^+\mu^-$ or $e^-\mu^+$ (opposite sign)



$$Out \rightarrow M_{*} \in [40,70] \cup [110,120]$$

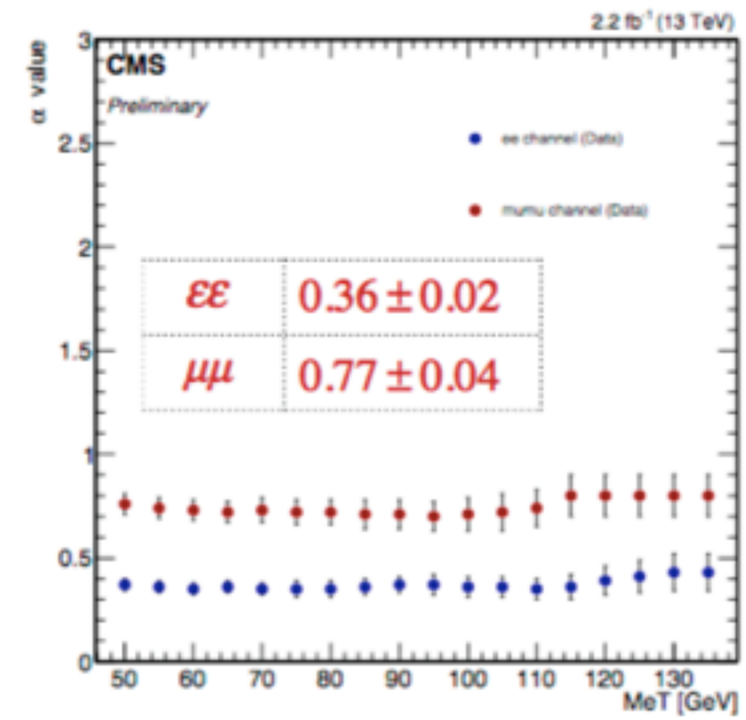
$$In \rightarrow |M_{*} - 91| < 15$$

$$\frac{N_{ll_{out}}}{N_{\varepsilon\mu_{out}}} = \alpha$$

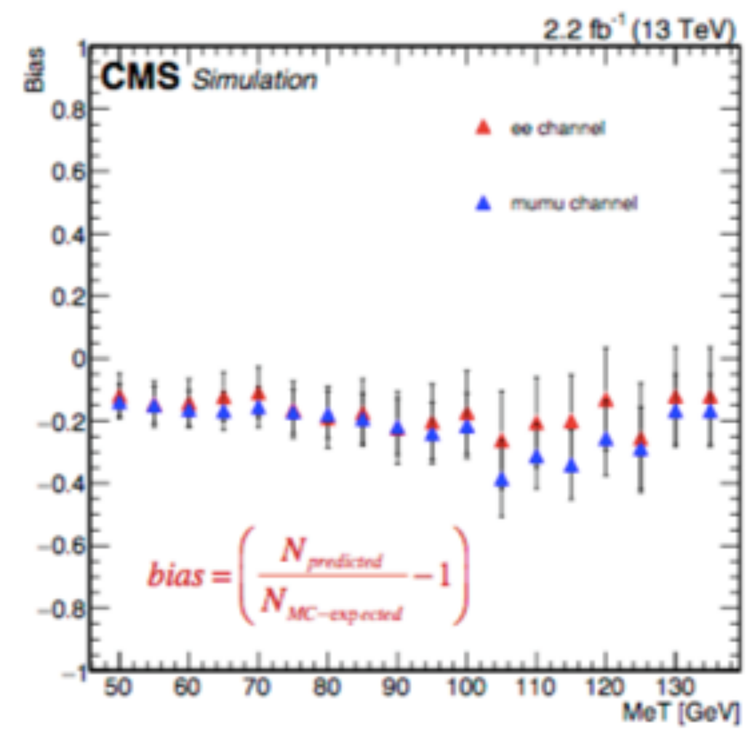
$$N_{ll_{in}} = \alpha \cdot \left(N_{\varepsilon\mu_{in}}\right)$$

Non-Resonant backgrounds (2)

- α computed from:
  - inclusive category (α is independent of jet category)
  - b jet tag events (top enriched region)
  - Met > 50 GeV (independent of the Met cut)



- α can also be cross checked by $k_{\varepsilon\varepsilon} = \frac{1}{2} \cdot \sqrt{\frac{N_{\varepsilon\varepsilon}^{In-Ctrl}}{N_{\mu\mu}^{In-Ctrl}}}$ $k_{\mu\mu} = \frac{1}{2} \cdot \sqrt{\frac{N_{\mu\mu}^{In-Ctrl}}{N_{\varepsilon\varepsilon}^{In-Ctrl}}}$
  - α and k give the same results

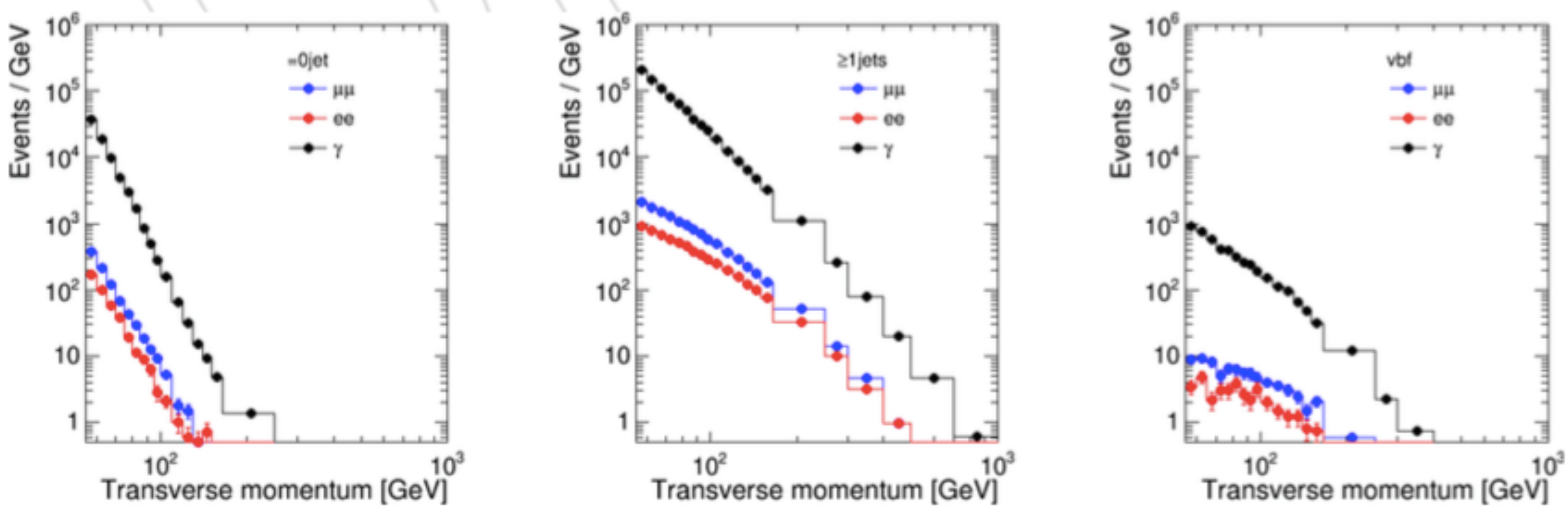


- Systematic uncertainties are computed via MC closure test
- Statistical errors are large due to the limited MC statistics
- The Systematic on the procedure is found to be 20%

Z+Jets background (1)

- **Instrumental bkg: Fake MET due to jets mis-reconstruction**
  - Simulation does not reliably describe MET distribution especially in the tails
  - Huge xs for Z+jets bkg, however, simulation has limited statistics
- **γ+jets and Z+jets show similar jet activity and thus similar Fake MET distribution.**

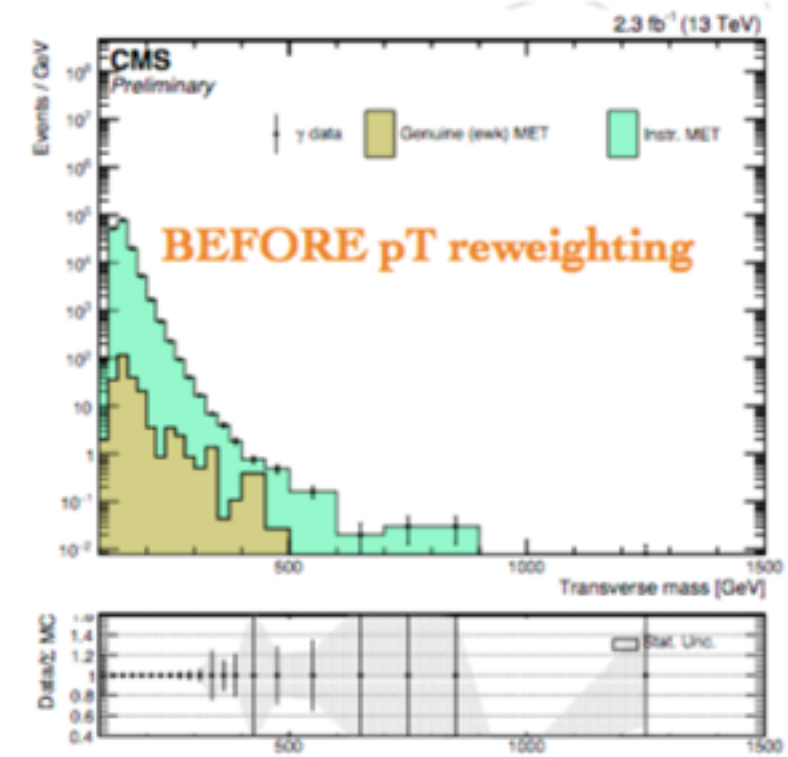
- **Data-driven estimation of Z+jets MET distribution**
  - apply same pre-selection cuts to both dilepton and photon samples
  - reweight photon pT to dilepton pT in data to account for mass and rate difference

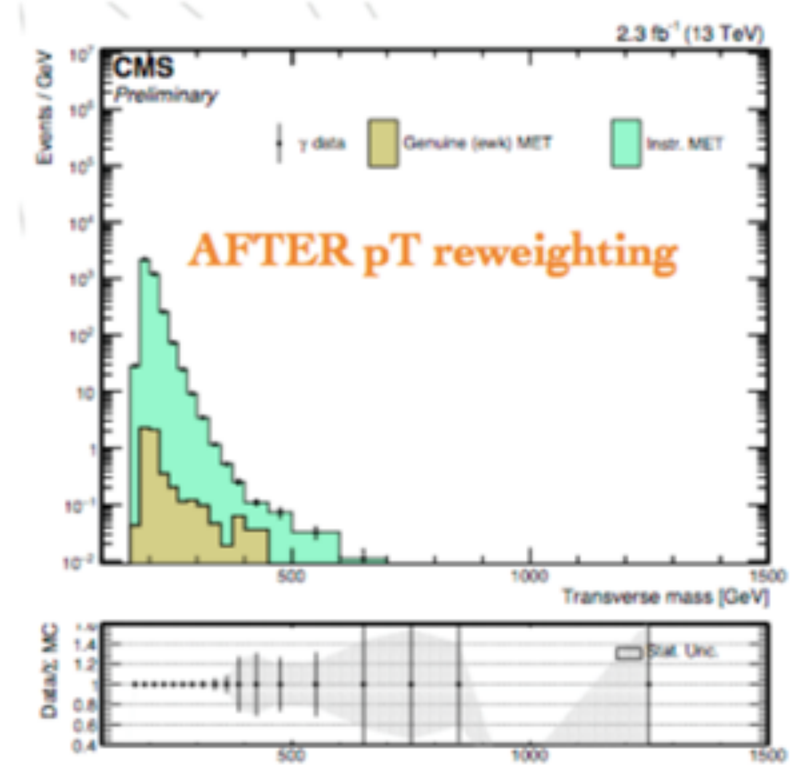


Z+Jets background (2)

- Genuine MET are modeled by:
  - W+γ—> l ν γ
  - Z+γ—> ν ν γ
  - Z+Jets—> ν ν γ
  - W+Jets—> l ν γ
- The above processes are subtracted from γ data using MC

- The Genuine MET contributes <10% in both channels
- The Systematic is compute by MC closure test and is found to be 25%





Systematic Uncertainties

Source	Uncertainty [%]
Luminosity	2.7
PDF, gluon-gluon initial state	4
PDF, quark-quark initial state	10
QCD scale, gluon-gluon initial state (ggH)	10
QCD scale, quark-quark initial state (VBF)	10
QCD scale, gluon-gluon initial state (ggZZ)	20
QCD scale, quark-quark initial state (qqVV)	5.8–8.5
Higgs boson line shape	10–30
Signal cross-section	4.5
Anti b-tagging	1–3
Lepton identification and isolation	4-5
Jet energy scale	4-10
Pile-up effects, E_T^{miss}	1-2
Non-resonant background	20
Z+jets	25

PAS

Final Yields

PAS

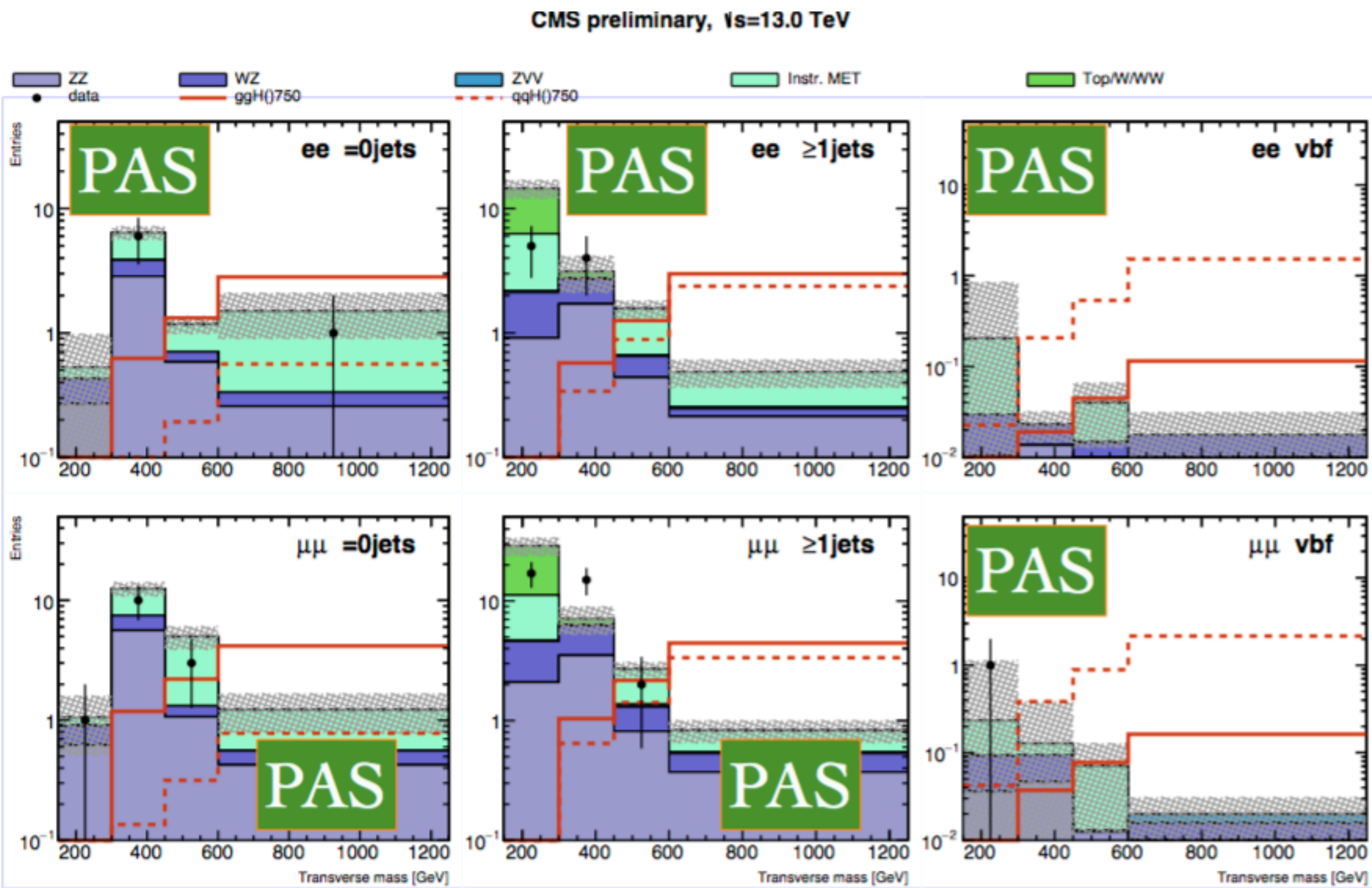
channel	Inc.	$= 0jets$	$\geq 1jets$	vbf
ZZ	$\mathbf{21.88 \pm 0.10}$	11.69 ± 0.07	10.06 ± 0.07	0.133 ± 0.009
WZ	$\mathbf{12.4 \pm 0.4}$	3.9 ± 0.2	8.3 ± 0.3	0.17 ± 0.05
ZVV	$\mathbf{0.47 \pm 0.05}$	0.038 ± 0.008	0.42 ± 0.05	0.005 ± 0.004
Instr. MET	$\mathbf{27.5 \pm 2.6 \pm 3.5}$	$13.7 \pm 1.4 \pm 2.6$	$13.3 \pm 2.2 \pm 2.4$	$0.43 \pm 0.16 \pm 0.08$
Top/W/WW	$\mathbf{27.1 \pm 4.4 \pm 3.8}$	0.0 ± 0.74	$27.1 \pm 4.2 \pm 4.1$	0.0 ± 1.132
total	$\mathbf{89.3 \pm 5.1 \pm 5.4}$	$\mathbf{29.3 \pm 1.6 \pm 2.6}$	$\mathbf{59.2 \pm 4.7 \pm 4.7}$	$\mathbf{0.74 \pm 1.14 \pm 0.08}$
data	65	21	43	1
ggH(200)	$\mathbf{0.20 \pm 0.03}$	$(0.003 \pm 0.003) \times 10^{-2}$	0.20 ± 0.03	0.006 ± 0.004
qqH(200)	$\mathbf{0.088 \pm 0.005}$	$(0.008 \pm 0.003) \times 10^{-3}$	0.055 ± 0.004	0.034 ± 0.003
ggH(400)	$\mathbf{17.83 \pm 0.08}$	10.54 ± 0.06	7.09 ± 0.05	0.209 ± 0.009
qqH(400)	$\mathbf{1.548 \pm 0.010}$	0.161 ± 0.003	0.877 ± 0.007	0.510 ± 0.005
ggH(750)	$\mathbf{25.4 \pm 0.1}$	12.36 ± 0.08	12.60 ± 0.08	0.46 ± 0.01
qqH(750)	$\mathbf{16.95 \pm 0.10}$	2.06 ± 0.03	9.12 ± 0.07	5.76 ± 0.06
ggH(800)	$\mathbf{25.6 \pm 0.1}$	12.14 ± 0.07	12.96 ± 0.08	0.49 ± 0.01
qqH(800)	$\mathbf{23.8 \pm 0.1}$	2.94 ± 0.05	12.8 ± 0.1	8.09 ± 0.08
ggH(1000)	$\mathbf{26.25 \pm 0.10}$	11.26 ± 0.07	14.41 ± 0.07	0.58 ± 0.01
qqH(1000)	$\mathbf{73.8 \pm 0.4}$	9.4 ± 0.1	39.4 ± 0.3	25.0 ± 0.2
ggH(1500)	$\mathbf{15.4 \pm 0.2}$	5.8 ± 0.1	9.2 ± 0.1	0.34 ± 0.03
qqH(1500)	$\mathbf{45.5 \pm 1.1}$	6.7 ± 0.4	24.5 ± 0.8	14.3 ± 0.6

After applying the final selection and the data-driven methods.

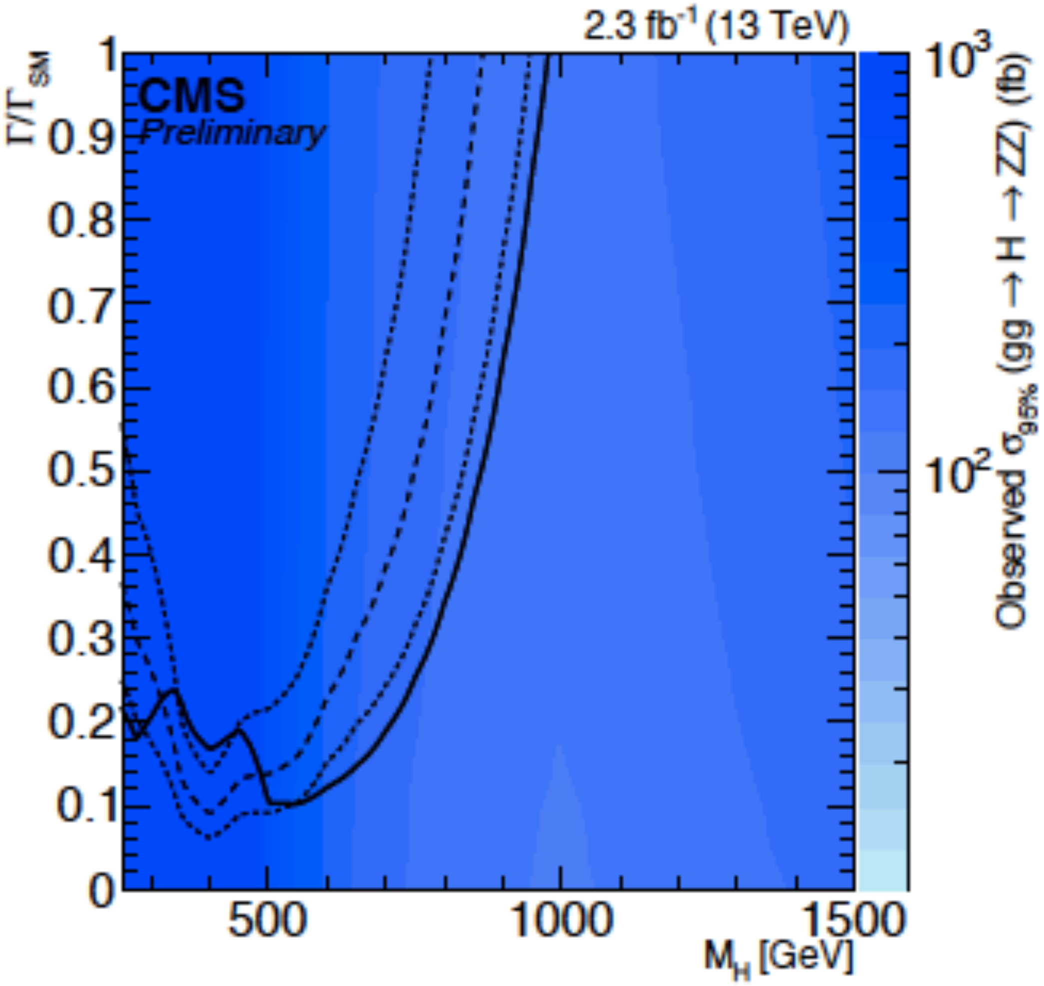
Signal xs is scaled to 1pb.

The uncertainties are statistical only except the data-driven bkg (+systematics).

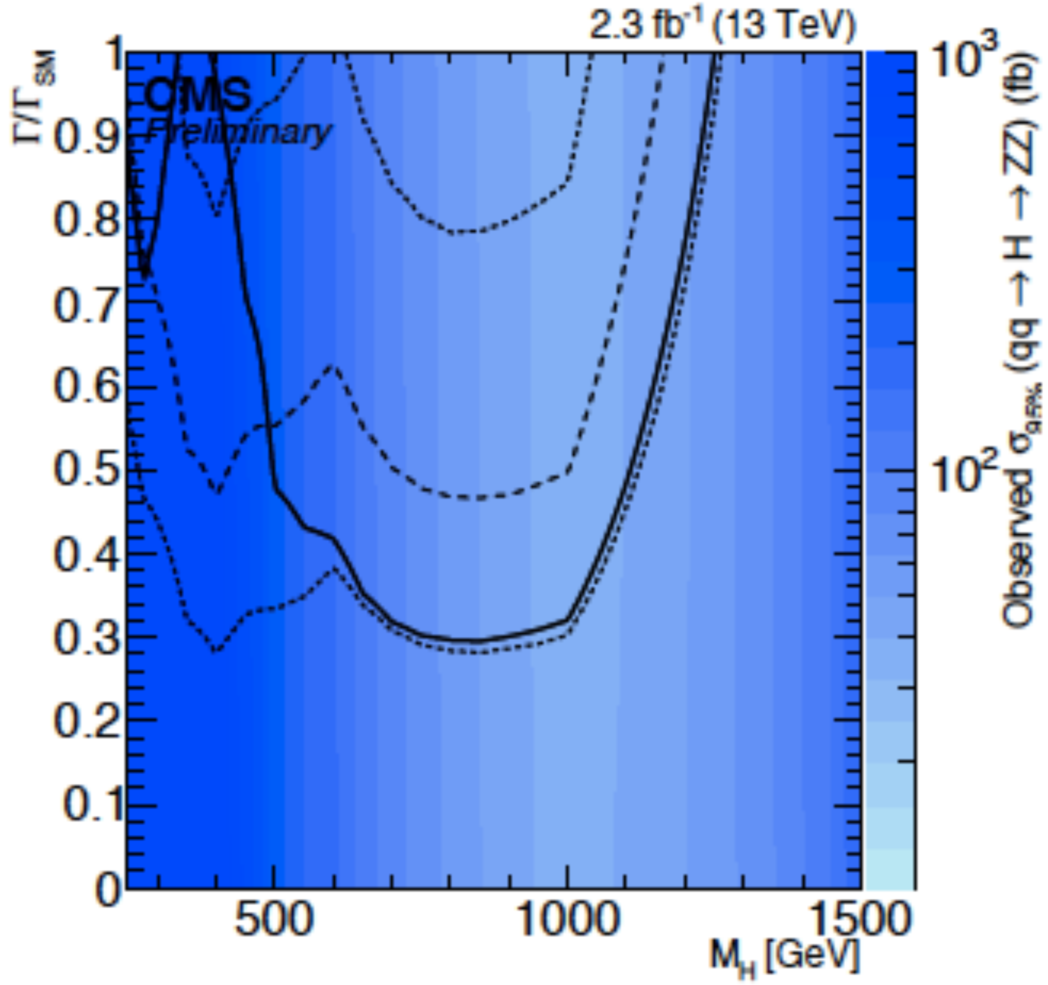
Final M_T distribution



Limits on a General Scalar Boson



ggF



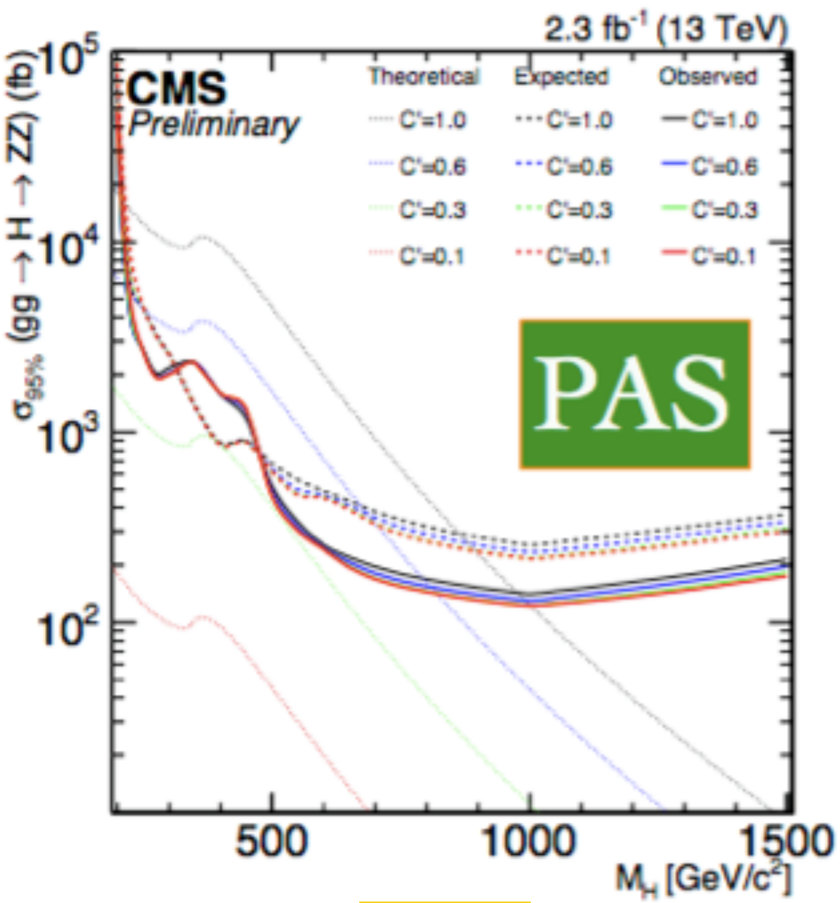
VBF

2D limits are totally model independent.

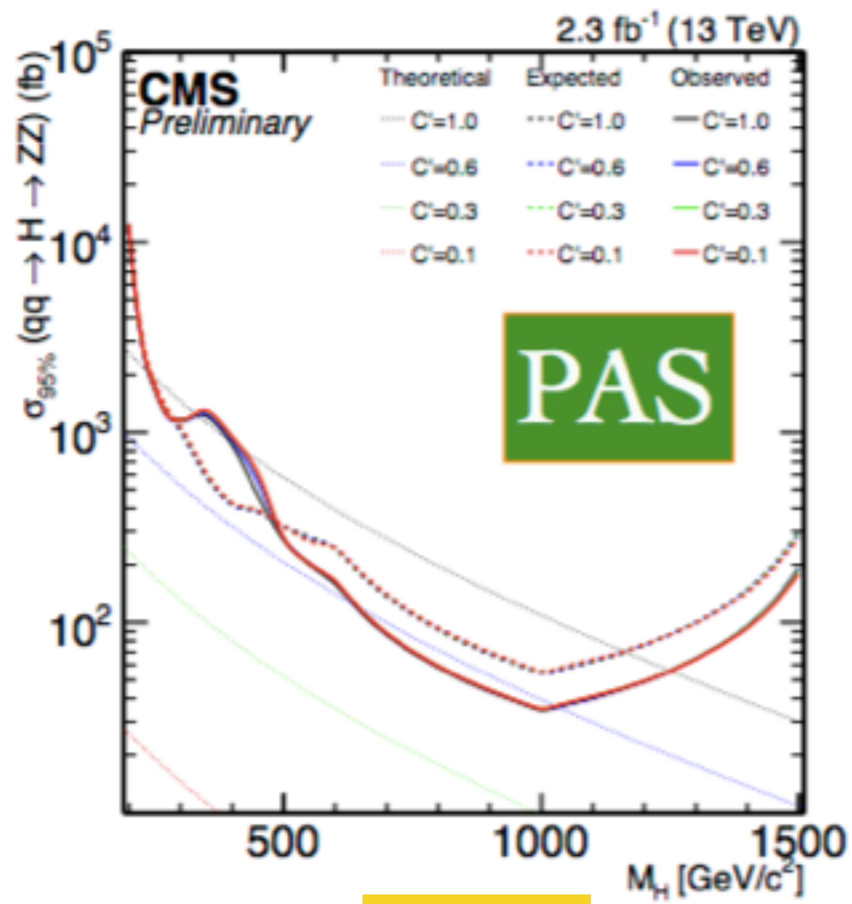
Small dependence on the width: due to m_T and MET resolution.

The black solid and Dashed contour show the observed and expect limit on heavy Higgs mass for EWS model.

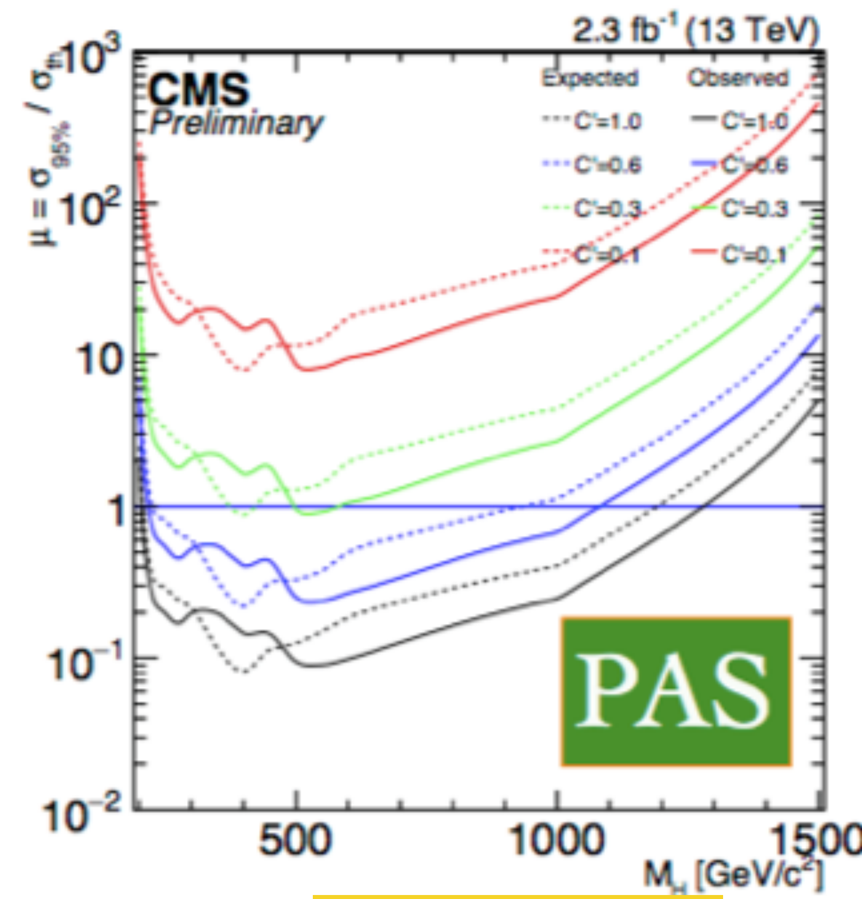
Limits on Heavy Scalar Boson EWS Model



ggF



VBF

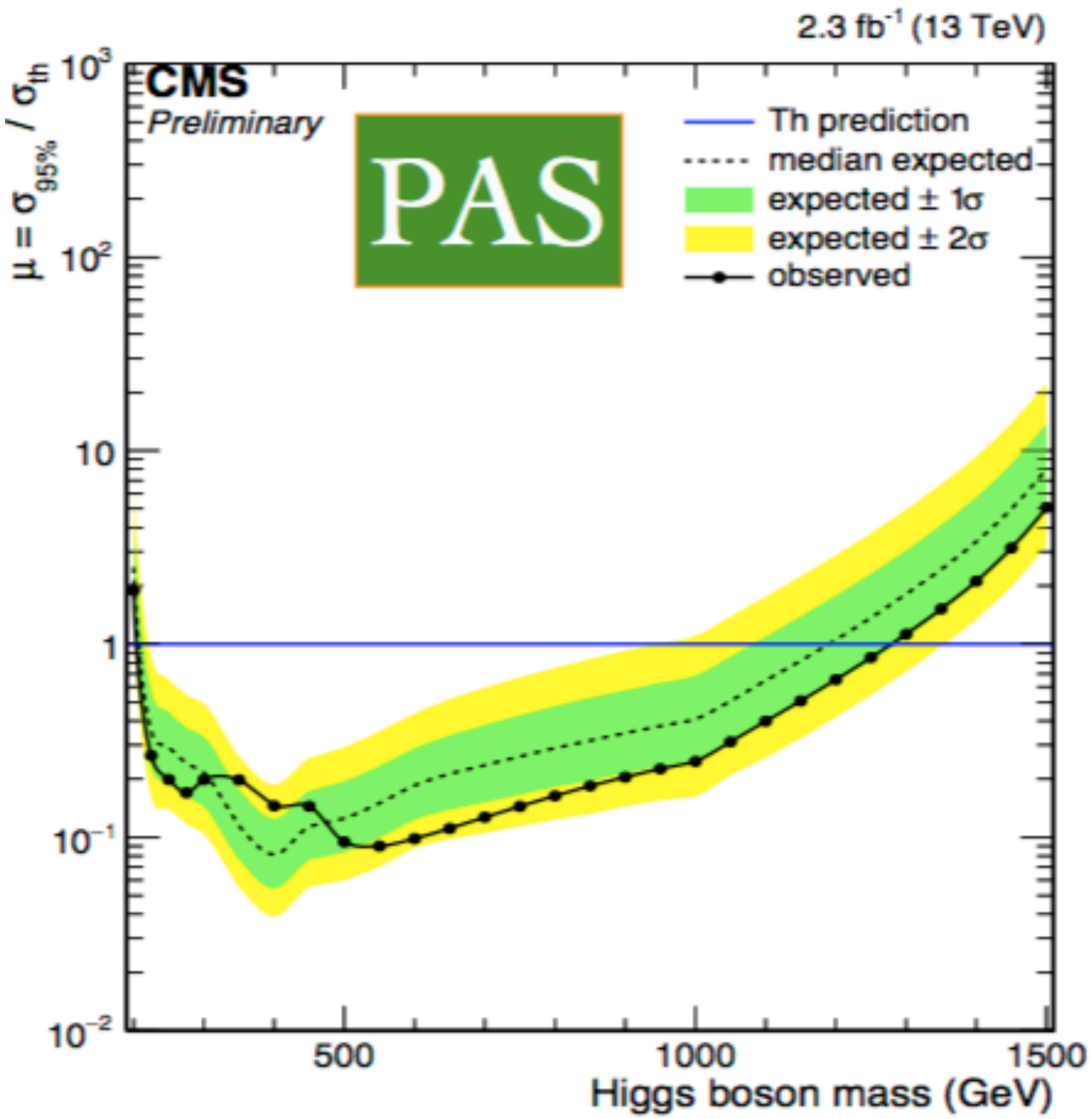


ggF+VBF

Small dependence on the width: due to m_T and MET resolution.

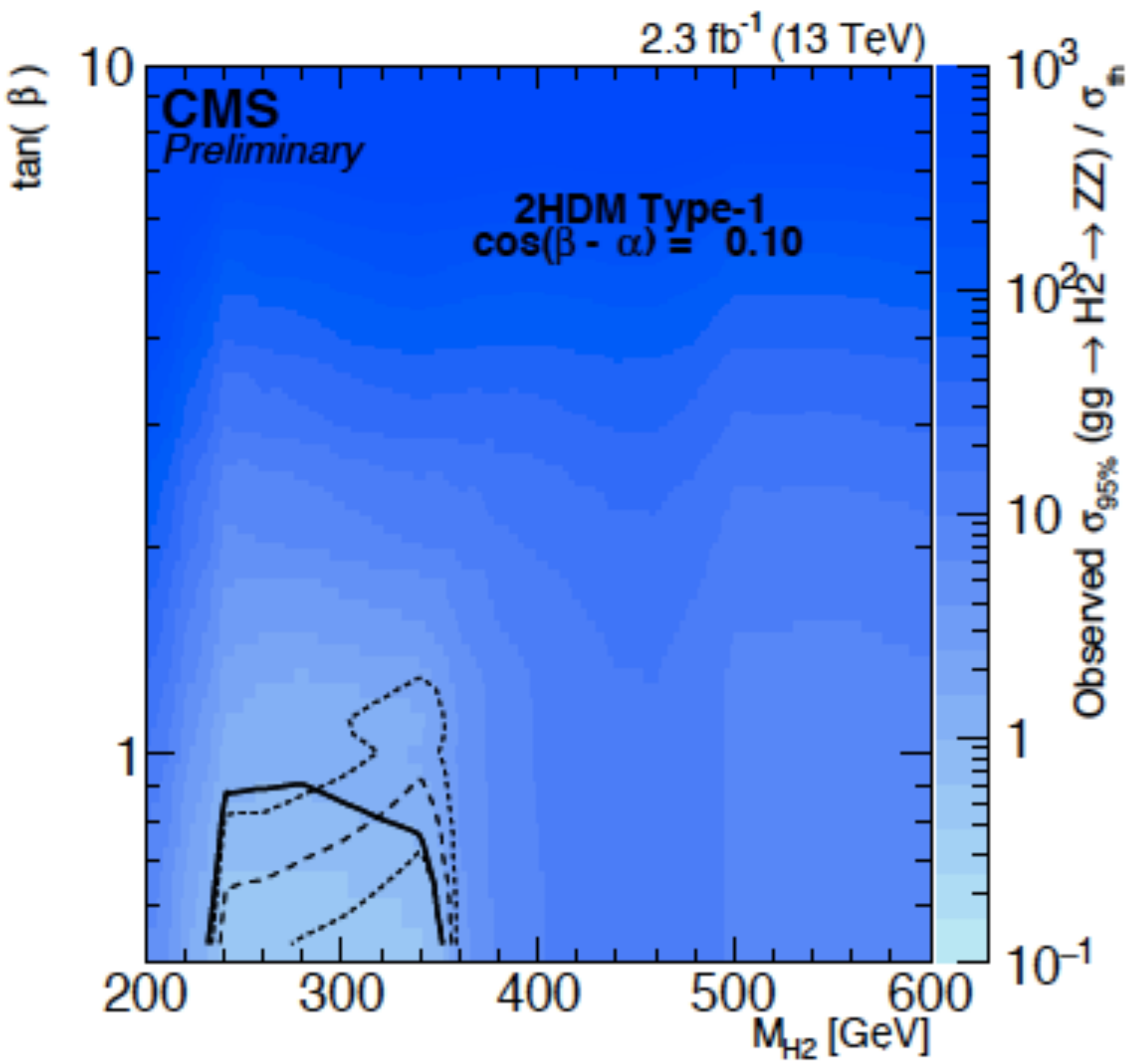
SM ratio between ggF and VBF production rates is assumed.

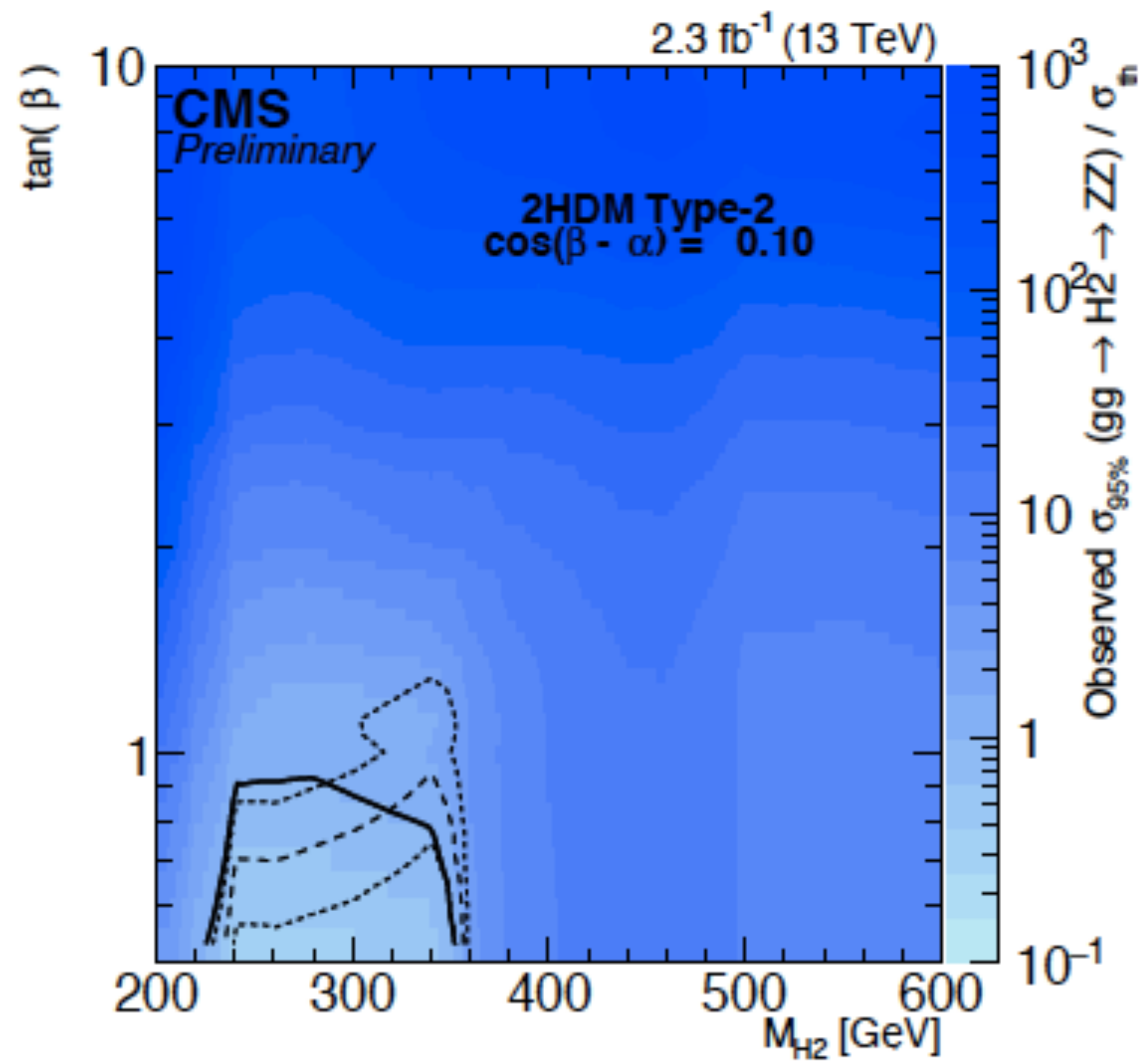
Limits on Heavy Scalar Boson



In the case of C' = 1.0 (i.e SM width), the analysis could exclude the Higgs mass range: [214 GeV, 1276 GeV]

Limits on 2HDM Model





Limits are set only on ggF process.

The black solid and dashed contour show the observed and the expected limit.

Conclusion

- 13TeV data with 2.3 fb^{-1} were analyzed.
- No excess found! More stringent limits set on the heavy scalar mass.
- Limits results:
    - generic production of heavy scalar of various width in ggF and VBF
    - on EWS model
    - on 2HDM type I and type II models
- Analysis with full 2016 data is on-going (aim for a paper for Moriond 17). Stay-tuned !

Beihang CMS Group

- **New member for CMS Collaboration**
  - joined CMS in September 2015

- **6 people working on CMS**
  - 1 Prof. 1 Associ. Prof. 2 Ph.D (1st year) 2 master (1st year)

- **Analyses Overview**
  - Run II Z'→2l search
  - Run II ZZ→2l2ν resonance search
  - Run II QBH search

- **Statistics for 2016**
  - **Paper: 2 under preparation**
  - **PAS: 2 (editor or approval talk)**
  - **AN: 6 (editor)**
  - **talks: 3 (international)**
  - **talks: 3 (national)**

- backup