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

Hanwen Wang

Beihang University

Outline

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

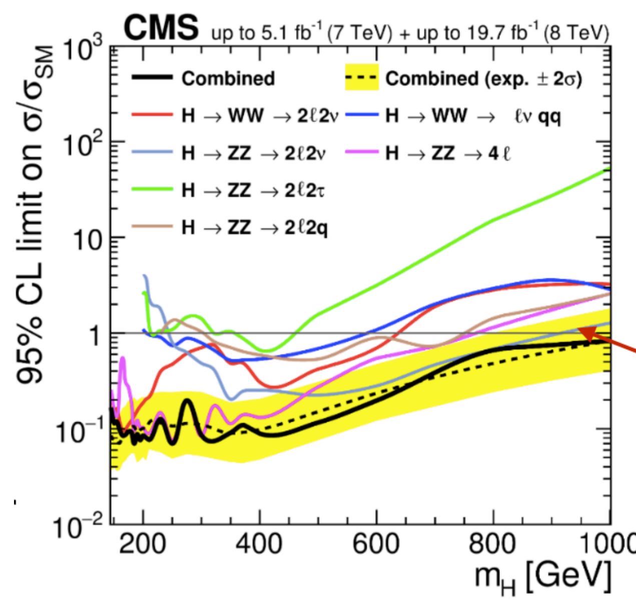
Introduction

- **A generic heavy scalar boson search with ZZ→2l2ν final state, but test with EWS**
  - Electroweak Singlet Model (EWS): additional heavy Higgs

□ Why 2l2ν is promising?

- **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 M_{ZZ} compared to ZZ→2l2q
  - Not sensitive to the width of heavy scalar

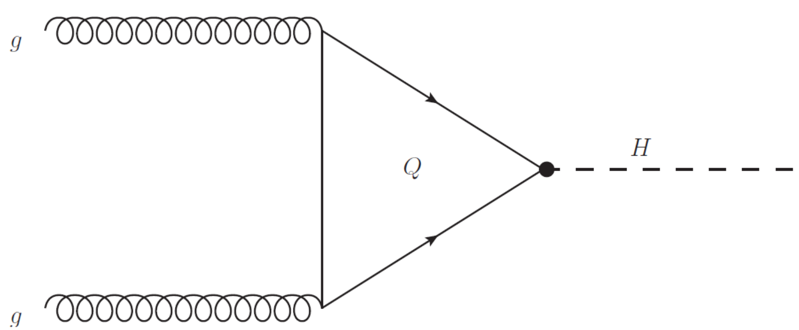


Best sensitivity using ZZ→2l2ν

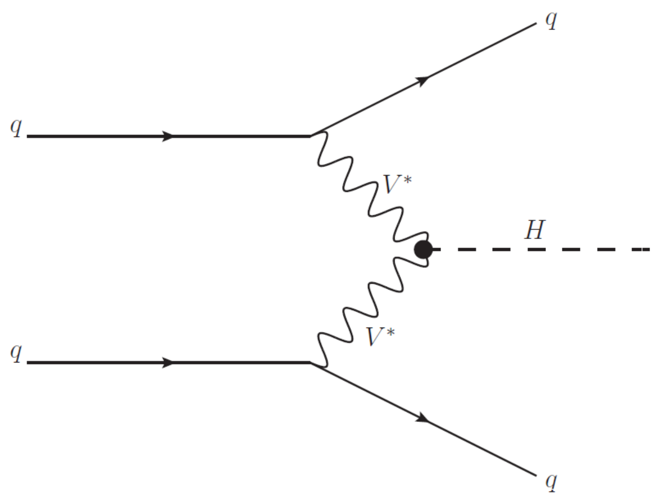
Signal and Backgrounds

Signal

SM-like heavy higgs



ggH



qqH

Signal and Backgrounds

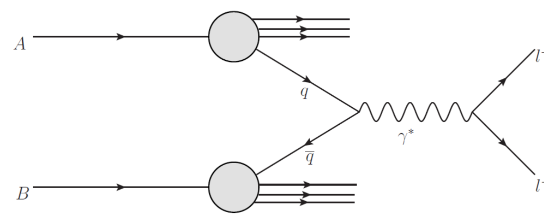
Backgrounds

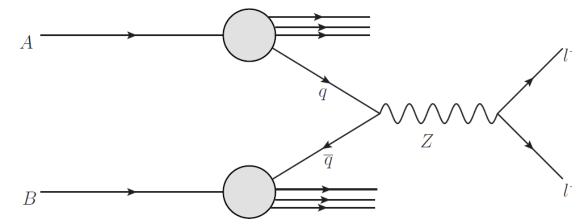
irreducible background

Diboson/Triboson: ZZ →2l2ν, WZ, ZVV

instrumental MET background

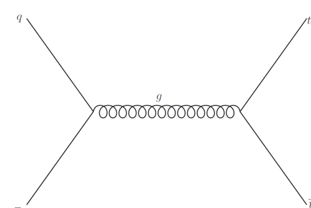
Drell-Yan

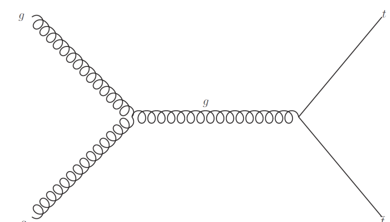




non-resonant background

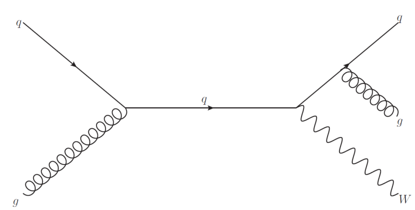
ttbar:

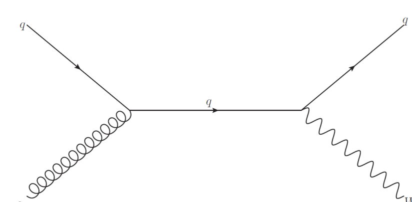




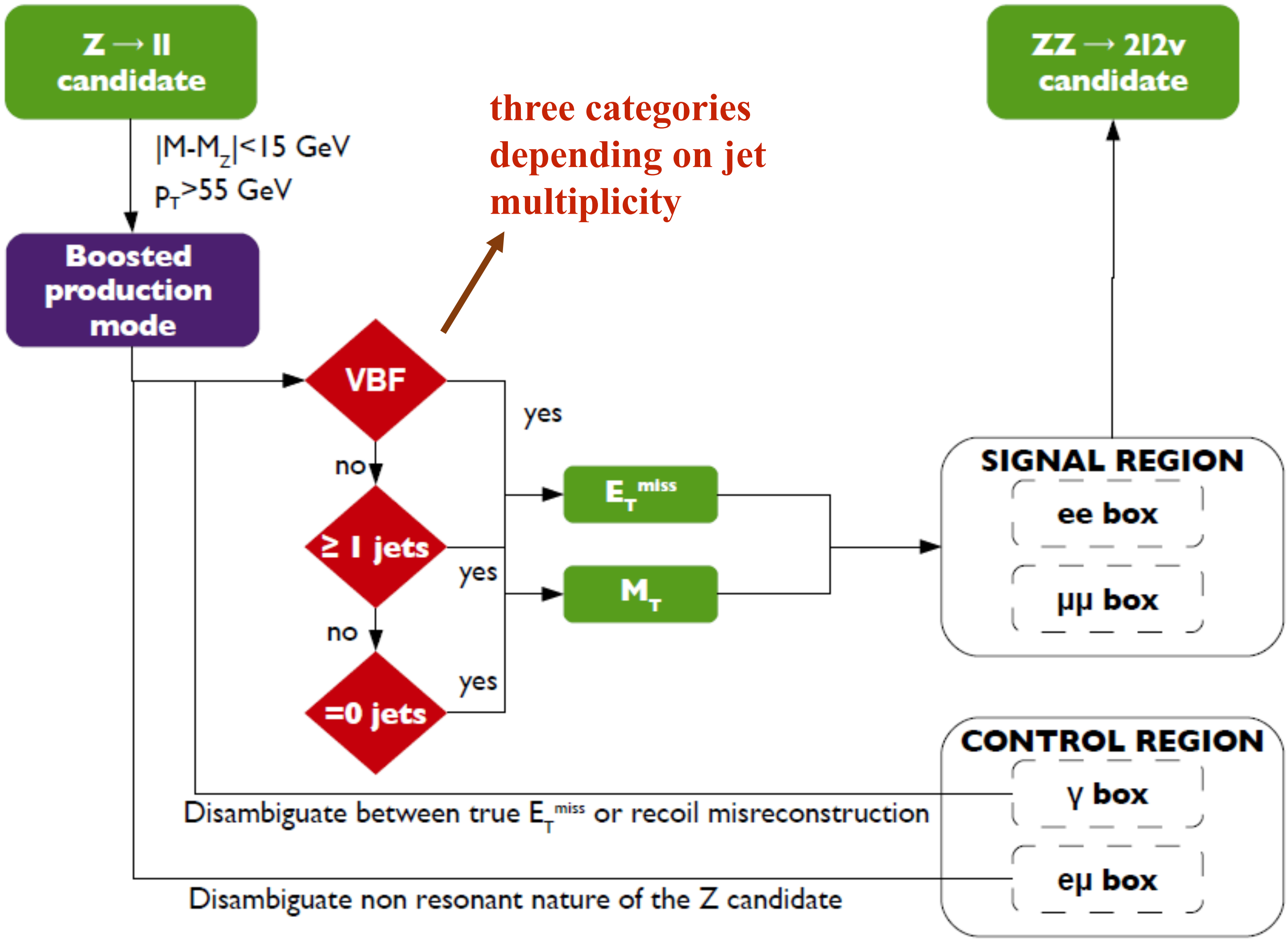
Single top, WW, WWW

W+jets:





Event Category

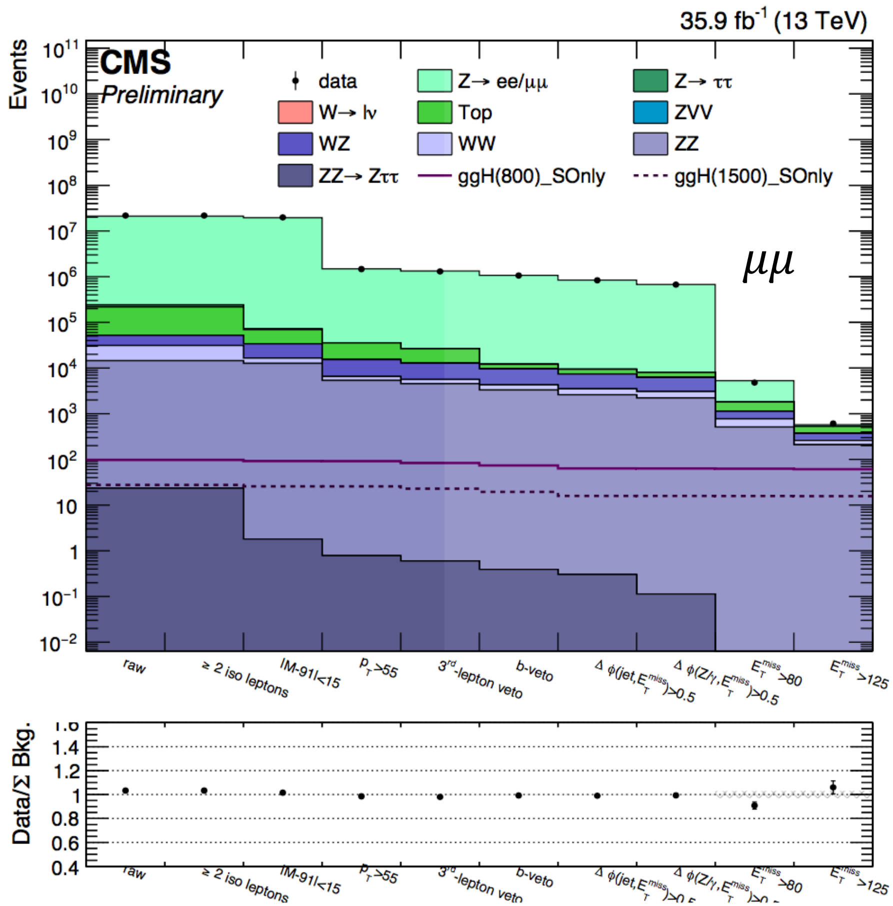


Object and Event selection

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

- $\mathbf{MET} > \mathbf{125GeV}$
- **Transverse Mass distribution is used to set shape based limits**

Event cut flow



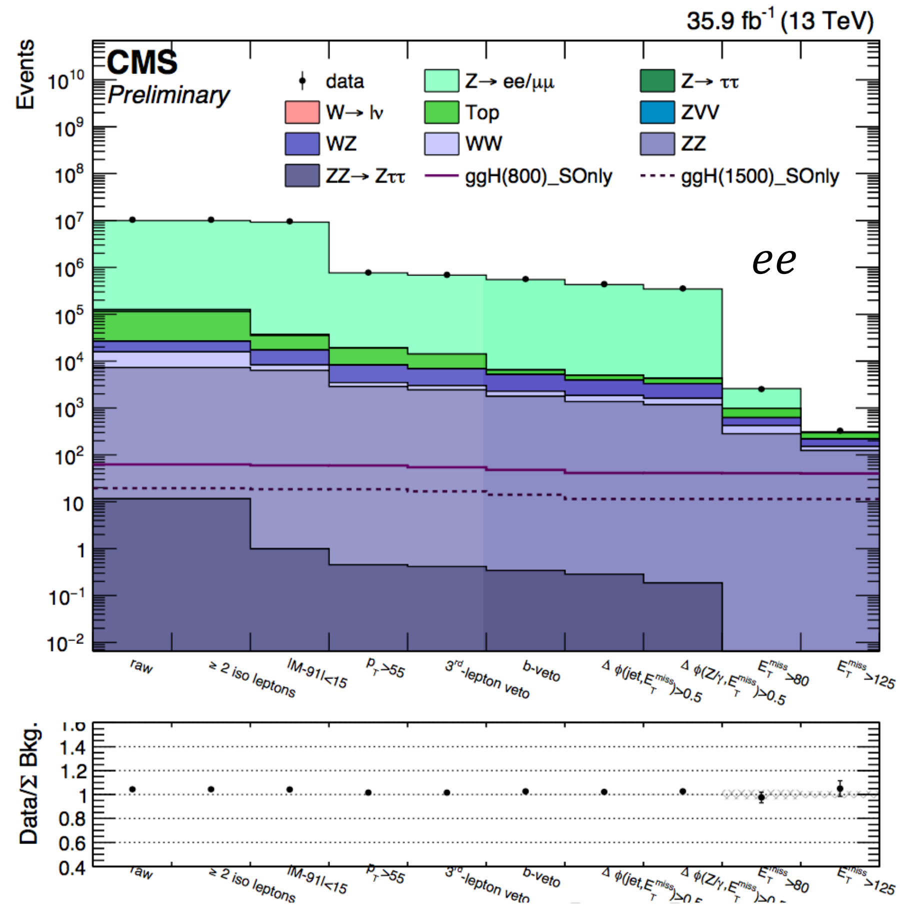


Figure: Event flow vs. different cuts in each bin

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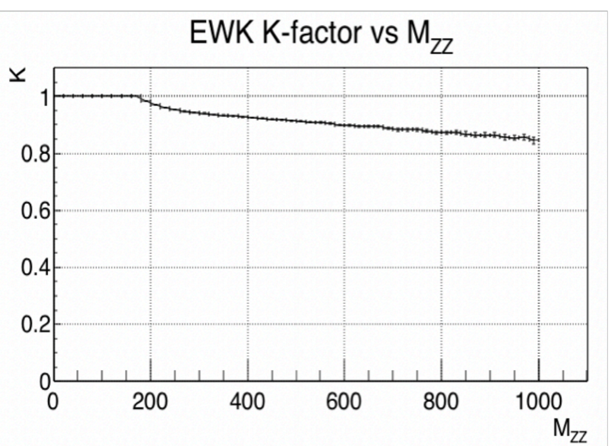
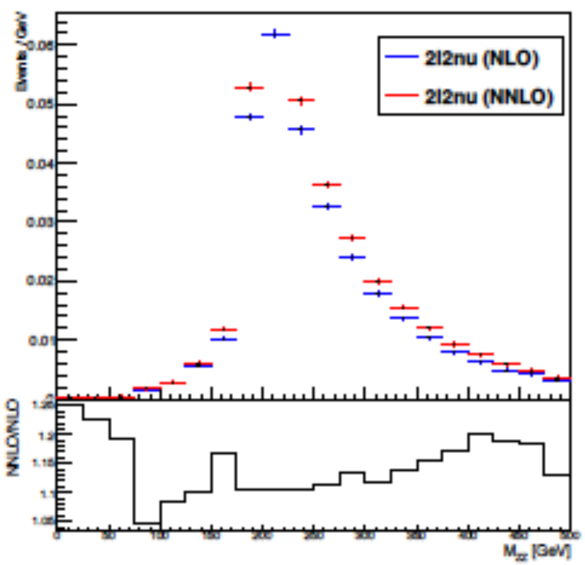
All Background estimated with MC samples as first check

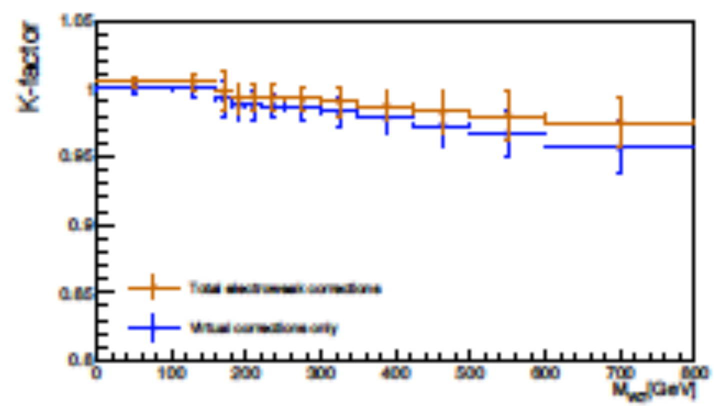
All jet categories summed up

Irreducible Backgrounds

- **Diboson/Triboson: ZZ, WZ, ZVV with Z decaying into lepton pairs**
- **Similar topology as signal H→ZZ→2l2v, Estimated with MC prediction**
- **qq→ZZ , apply the following corrections:**
  - EWK(NLO/LO) as a function of the quark flavor and Mandelstam variables
  - QCD (NNLO/NLO) corrections are computed as a function of M_{zz}
- **gg→ZZ: QCD(NNLO/NLO) k-factors applied, as like signal**
- **WZ: No EWK corrections applied (assign 3% uncertainty to cover this)**

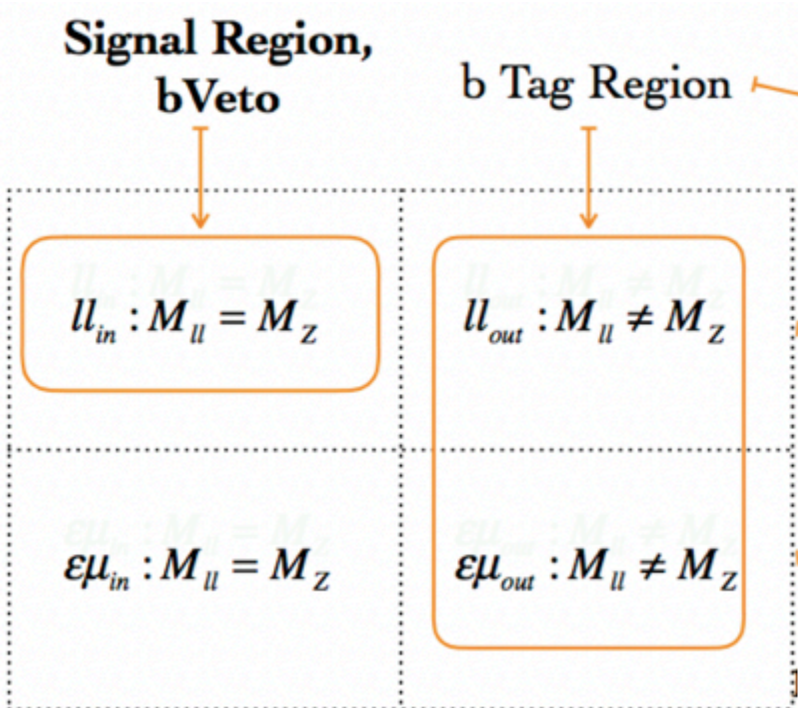






Non-Resonant backgrounds

- **ttbar, tW, WW, Wjets, ττ: flavour symmetric**
- **Fully data-driven estimation**
  - use Z mass sideband regions to define a **α** factor



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

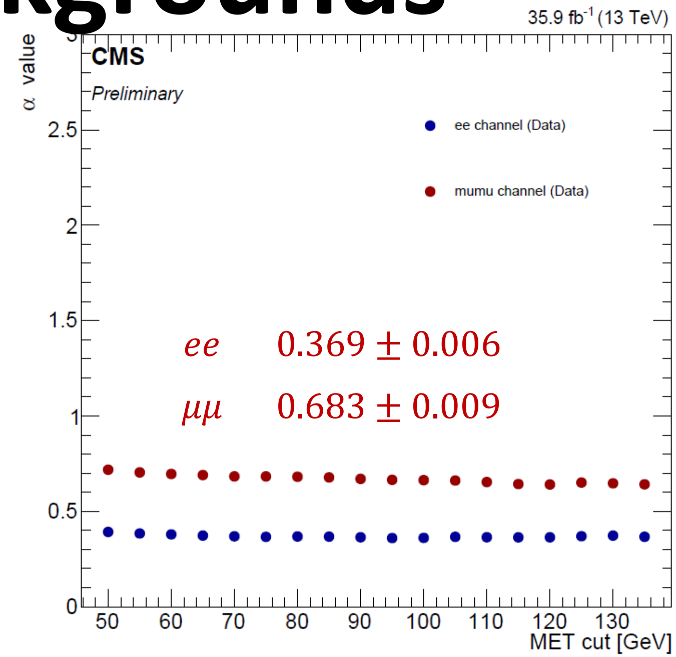
$$In \rightarrow |M_{*} - 91| < 15$$

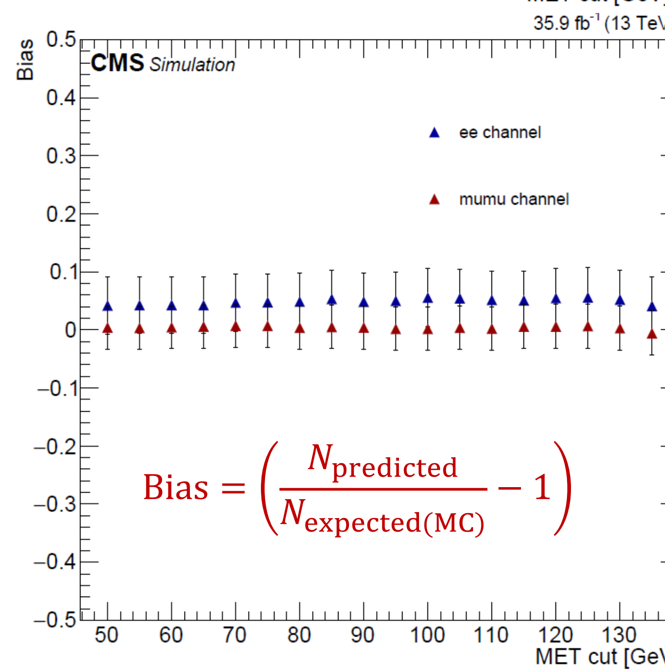
$$\frac{N_{ll_{out}}}{N_{e\mu_{out}}} = \alpha$$

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

Non-Resonant backgrounds

- **α computed from:**
  - inclusive jet category (α is independent of jet category)
  - b jet tag events (top enriched region)
  - MET > 70 GeV (independent of the MET cut)
- **We can also cross check α-Method using k-Method**
  - $k_{ee} = \frac{1}{2}\frac{\epsilon_{ee}}{\epsilon_{e\mu}} = \frac{1}{2}\frac{\epsilon_{e}}{\epsilon_{\mu}} = \frac{1}{2}\sqrt{\frac{N_{ee}^{\text{peak}}}{N_{\mu\mu}^{\text{peak}\prime}}}$ similarly $k_{\mu\mu} = \frac{1}{2}\sqrt{\frac{N_{\mu\mu}^{\text{peak}}}{N_{ee}^{\text{peak}\prime}}}$
  - **α and k give the same results**
- **Systematic uncertainties are computed via MC closure test**
- **The systematic of this procedure is found to be 13%**





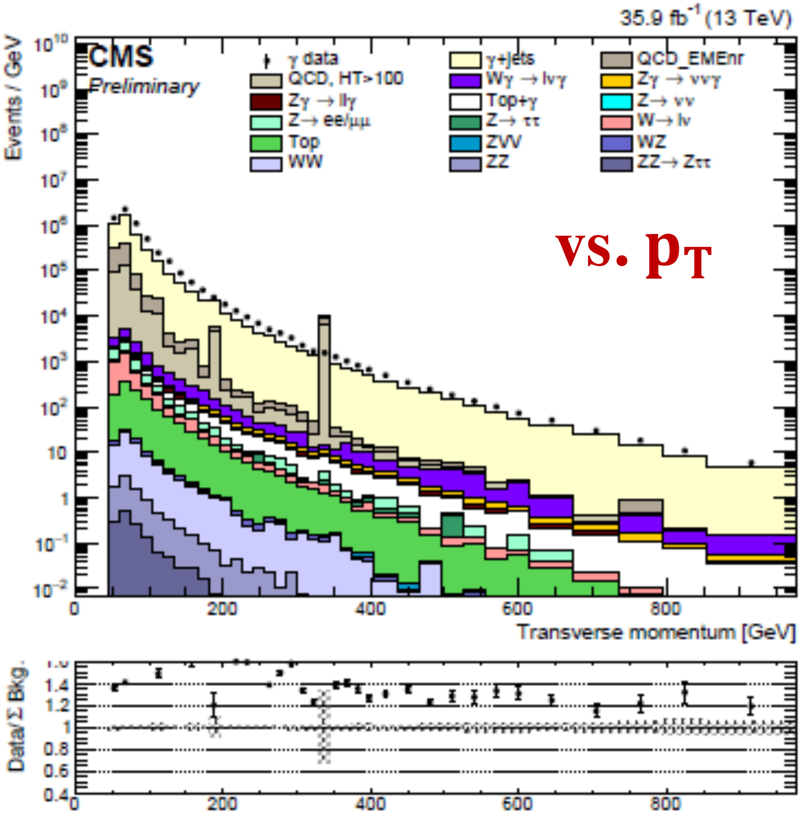
Z+Jets background

- Data-driven estimate of “fake MET” from Z+jets using a photon Control Region:
  - Simulation does not reliably describe instr. MET especially in the tails
  - Simulation has limited statistics
  - γ+jets and Z+jets events show similar jet activity and thus “fake MET” sources

- Pre-selection cuts applied to both the dilepton and photon samples :
  - γ/Z pT >55GeV
  - No extra leptons and b-tag veto
  - Jet categorization : VBF, 1-jet, and 0-jet

Z+Jets background

- **Genuine MET are modeled by:**
  - Dominant: W+$\gamma \rightarrow l\,\nu\,\gamma$, Z+$\gamma \rightarrow \nu\,\nu\,\gamma$, Z+Jets $\rightarrow \nu\,\nu\,\gamma$, W+Jets$\rightarrow l\,\nu\,\gamma$
  - top+γ, Z → $\tau\tau$, WW, WZ, top
- **The above processes are subtracted from γ data using MC** CMS AN-16-325



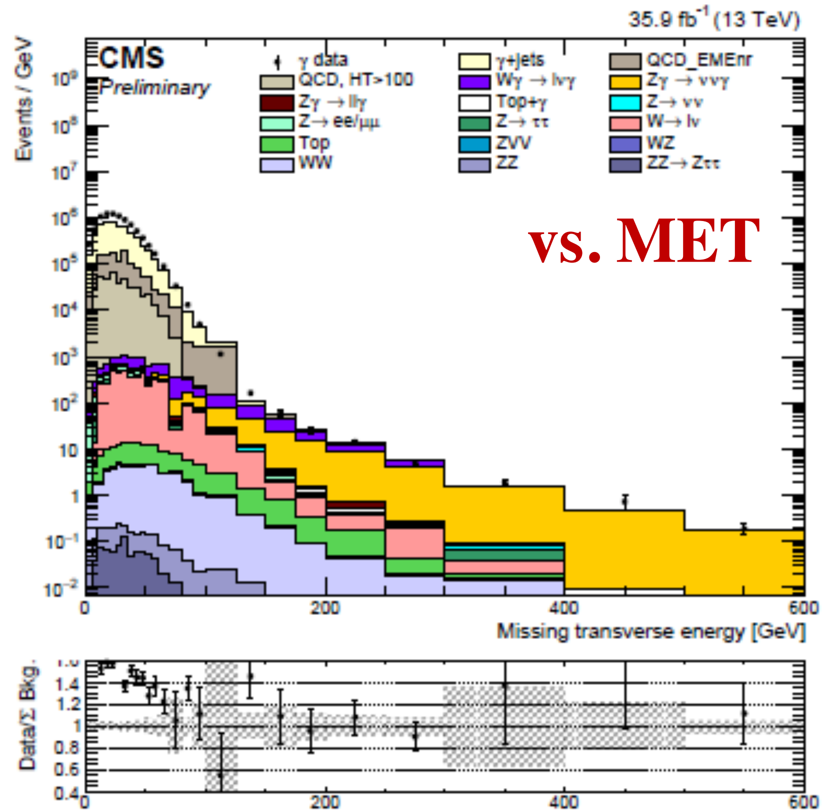


Figure: Decomposition of the γ data in genuine vs instrumental $E_{\mathrm{T}}^{\mathrm{miss}}$ using the MC truth

Z+Jets background

- **Photon + jet and Z + jet events similar in MC (except for the mass) :**
  - **Re-weight photon pT to match the dilepton pT distributions in data , separately for each category (0-jet , 1-jet and VBF) :**

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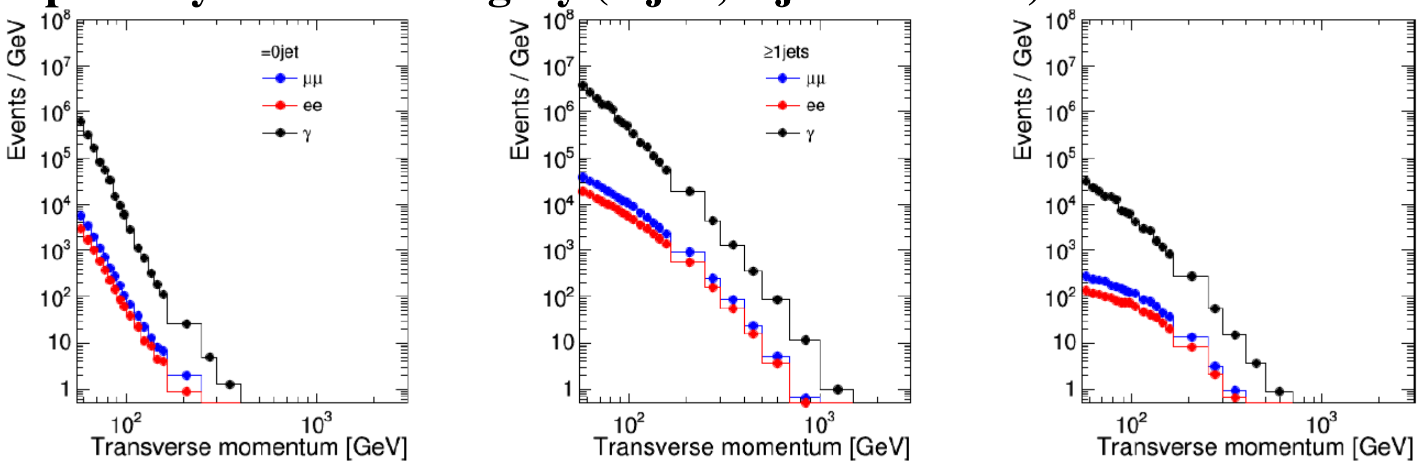
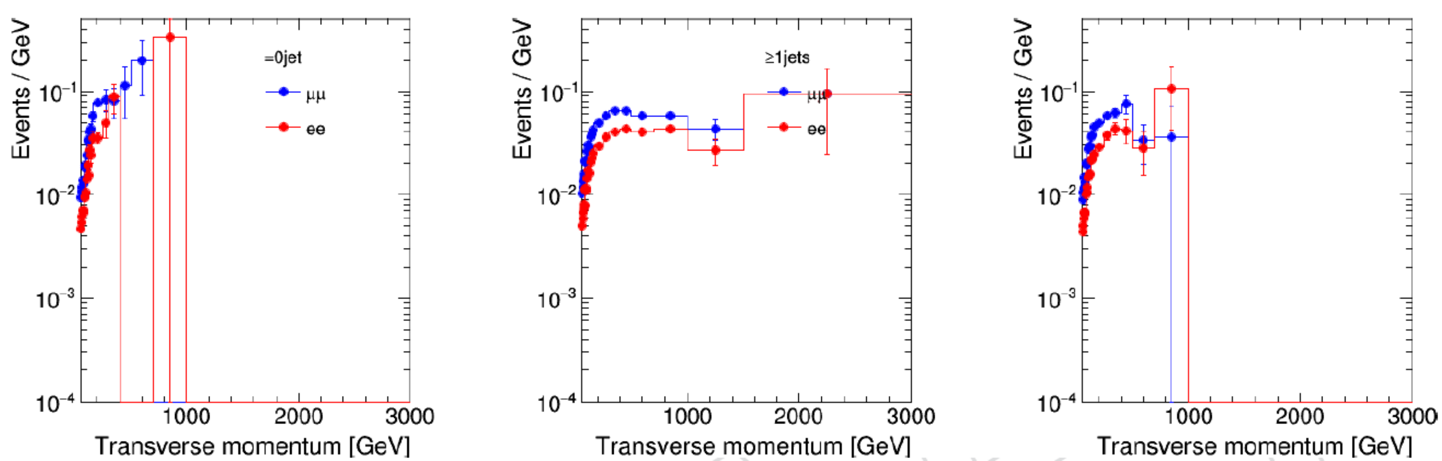
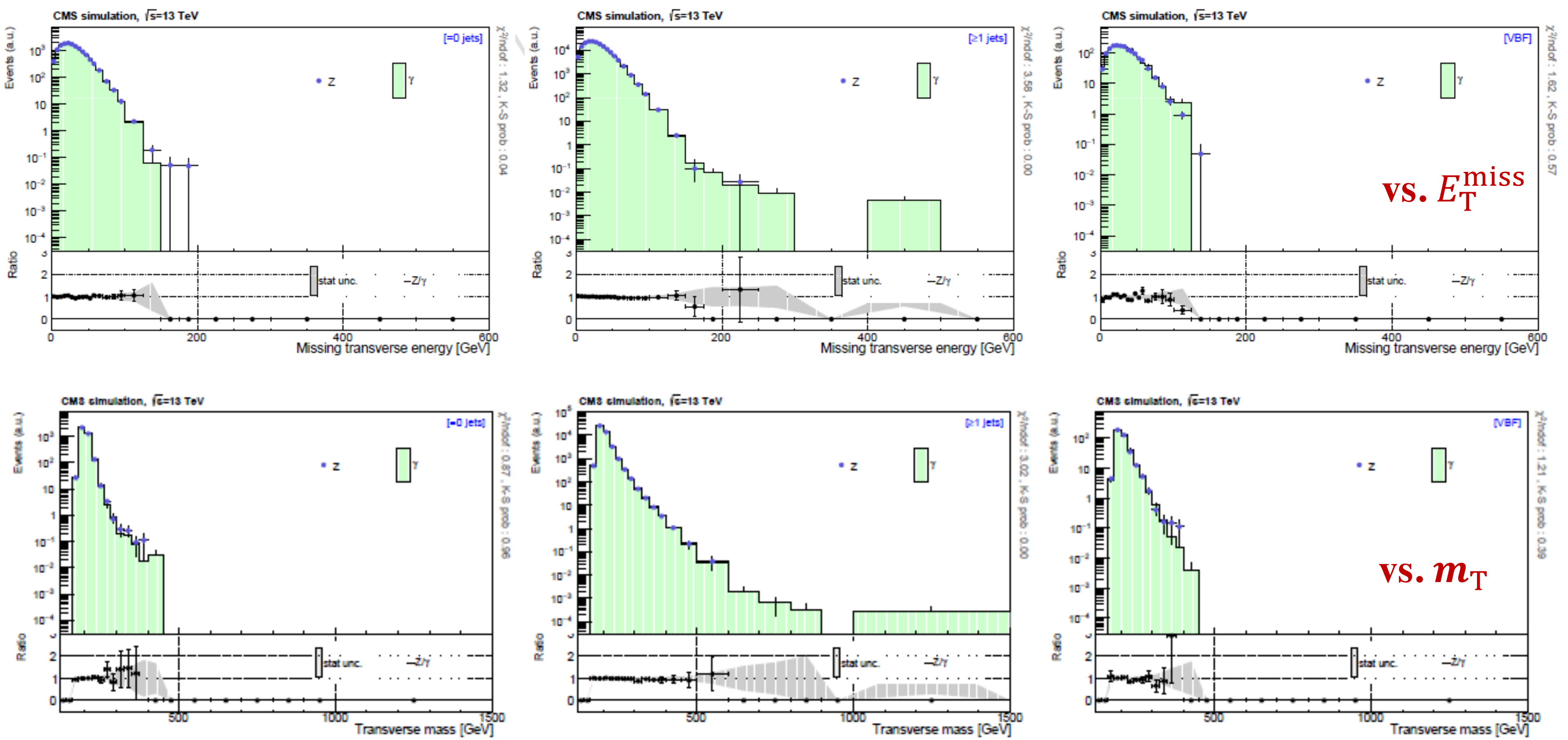


  - **Weights used to re-weight the photon sample using "bin-by-bin method" :**



Z+Jets background

- **To evaluate the validity of the method, we perform a closure test using simulated γ+jet and DY samples:**



The systematics are caculated via MC closure

Systematic Uncertainties

Experimental sources	
Luminosity	2.5
ℓ trigger and selection efficiency	6–8
ℓ mom./energy scale	0.01–0.3
ℓ resolution (*)	20
JES, JER, $E_{\mathrm{T}}^{\mathrm{miss}}$ (*)	1–30
b-tag/mistag	2–4
Background estimates	
Z+jets	20–50
Top, WW	10
WZ, Wγ^*	15
Theoretical sources	
QCD scales	5–10
PDF set	1–4
EW corrections ($q\bar{q} \rightarrow ZZ$) (*)	2
NNLO (ggZZ) K factor	10

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Final Yields

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channel	Inc.	$\mu\mu = 0jets$	$\mu\mu \geq 1jets$	$\mu\mu vbf$	$ee = 0jets$	$ee \geq 1jets$	$eevbf$
ZZ	$332.8 \pm 1.0^{+13.7}_{-13.6}$	$113.2 \pm 0.6^{+9.0}_{-8.4}$	$94.9 \pm 0.5^{+8.0}_{-7.7}$	$1.27 \pm 0.06^{+0.51}_{-0.35}$	$67.4 \pm 0.4^{+4.9}_{-5.6}$	$55.3 \pm 0.4^{+4.4}_{-4.9}$	$0.74 \pm 0.04^{+0.22}_{-0.22}$
WZ	$176.5 \pm 4.0^{+5.9}_{-5.4}$	$39.1 \pm 1.9^{+3.0}_{-2.5}$	$69.6 \pm 2.5^{+3.8}_{-4.0}$	$1.5 \pm 0.3^{+0.7}_{-0.1}$	$22.0 \pm 1.4^{+1.5}_{-1.2}$	$43.5 \pm 2.0^{+3.0}_{-2.3}$	$0.86 \pm 0.24^{+0.35}_{-0.09}$
ZVV	$6.8 \pm 0.4^{+2.1}_{-2.0}$	$0.45 \pm 0.10^{+0.20}_{-0.20}$	$3.8 \pm 0.3^{+1.8}_{-1.8}$	$0.06 \pm 0.03^{+0.03}_{-0.03}$	$0.22 \pm 0.05^{+0.06}_{-0.09}$	$2.1 \pm 0.2^{+1.0}_{-1.0}$	$0.04 \pm 0.03^{+0.05}_{-0.06}$
Instr. MET	$123.0 \pm 0.0^{+25.2}_{-18.4}$	$38.0 \pm 0.0^{+17.6}_{-11.9}$	$38.0 \pm 0.0^{+12.8}_{-10.7}$	$3.44 \pm 0.00^{+0.39}_{-0.04}$	$21.2 \pm 0.0^{+9.9}_{-6.8}$	$20.7 \pm 0.0^{+8.0}_{-6.2}$	$1.73 \pm 0.00^{+0.20}_{-0.02}$
Top/W/WW	$313.5 \pm 13.3 \pm 27.0$	$18.4 \pm 3.5 \pm 2.4$	$181.7 \pm 11.2 \pm 23.6$	$3.4 \pm 0.7 \pm 0.4$	$10.0 \pm 1.9 \pm 1.3$	$98.2 \pm 6.0 \pm 12.8$	$1.8 \pm 0.4 \pm 0.2$
total	$952.7 \pm 18.2^{+39.4}_{-35.4}$	$209.2 \pm 6.9^{+20.0}_{-14.8}$	$388.0 \pm 14.2^{+28.0}_{-27.1}$	$9.7 \pm 1.7^{+0.8}_{-0.6}$	$120.8 \pm 3.9^{+11.1}_{-8.9}$	$219.8 \pm 7.9^{+15.7}_{-15.0}$	$5.2 \pm 0.9^{+0.4}_{-0.3}$
data	938	194	405	11	115	209	4
ggH(800)	$(212.2 \pm 6.9^{+4.4}_{-7.5}) \times 10^1$	$561.9 \pm 36.0^{+20.4}_{-52.9}$	$697.0 \pm 40.5^{+16.9}_{-39.7}$	$21.3 \pm 3.8^{+8.1}_{-3.6}$	$349.6 \pm 24.3^{+26.4}_{-25.3}$	$478.2 \pm 34.5^{+21.5}_{-25.3}$	$14.2 \pm 2.2^{+2.8}_{-3.3}$
qqH(800)	$36.7 \pm 0.2^{+0.9}_{-1.0}$	$2.40 \pm 0.04^{+0.36}_{-0.47}$	$11.71 \pm 0.09^{+0.39}_{-0.33}$	$7.84 \pm 0.07^{+0.46}_{-0.51}$	$1.64 \pm 0.03^{+0.25}_{-0.31}$	$7.85 \pm 0.07^{+0.26}_{-0.28}$	$5.26 \pm 0.06^{+0.32}_{-0.40}$
ggH(1000)	$(168.2 \pm 3.7^{+3.4}_{-4.9}) \times 10^1$	$408.6 \pm 17.8^{+22.7}_{-30.5}$	$581.3 \pm 21.8^{+14.0}_{-26.0}$	$23.5 \pm 4.3^{+1.2}_{-3.9}$	$254.6 \pm 14.2^{+16.5}_{-22.2}$	$399.0 \pm 17.9^{+13.0}_{-17.2}$	$14.5 \pm 2.8^{+4.6}_{-1.7}$
qqH(1000)	$49.6 \pm 0.2^{+1.2}_{-1.3}$	$3.58 \pm 0.07^{+0.53}_{-0.67}$	$15.3 \pm 0.1^{+0.5}_{-0.5}$	$10.4 \pm 0.1^{+0.6}_{-0.7}$	$2.36 \pm 0.05^{+0.39}_{-0.44}$	$10.7 \pm 0.1^{+0.3}_{-0.4}$	$7.25 \pm 0.09^{+0.47}_{-0.50}$
ggH(2500)	$46.0 \pm 1.7^{+1.0}_{-0.8}$	$7.6 \pm 0.7^{+0.6}_{-0.2}$	$16.9 \pm 0.9^{+0.3}_{-0.5}$	$0.98 \pm 0.22^{+0.24}_{-0.08}$	$6.0 \pm 0.6^{+0.3}_{-0.4}$	$13.9 \pm 0.9^{+0.6}_{-0.3}$	$0.65 \pm 0.15^{+0.09}_{-0.10}$
qqH(2500)	$22.1 \pm 0.1^{+0.6}_{-0.7}$	$2.02 \pm 0.04^{+0.30}_{-0.38}$	$6.66 \pm 0.07^{+0.19}_{-0.18}$	$3.90 \pm 0.06^{+0.30}_{-0.38}$	$1.57 \pm 0.04^{+0.25}_{-0.31}$	$5.09 \pm 0.07^{+0.14}_{-0.13}$	$2.85 \pm 0.05^{+0.25}_{-0.28}$

Apply all the final selection and the data-driven methods.

Signal cross section is scaled to 1pb.

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

Final M_T distribution

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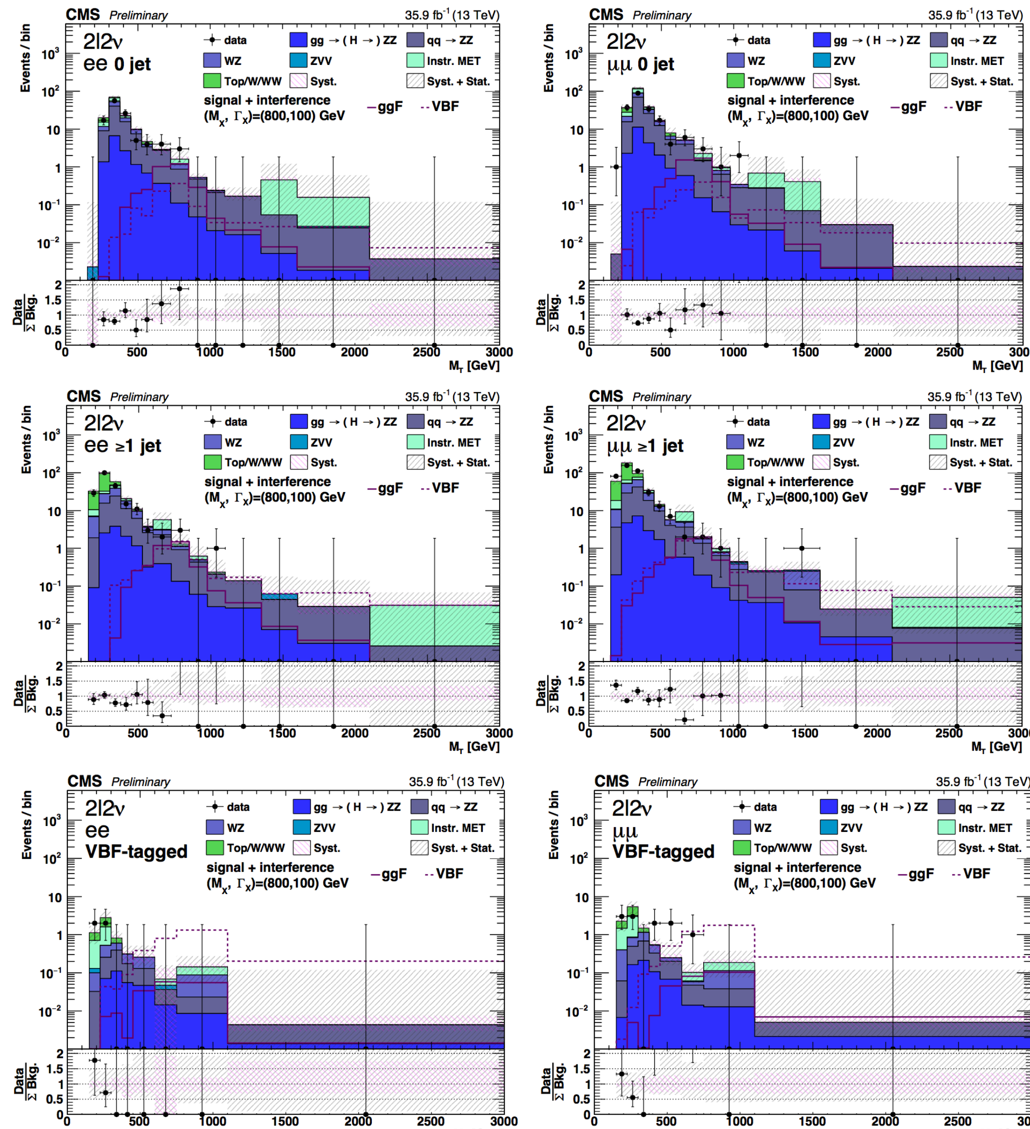
0-jet

1-jet

VBF



ee　　　　　　*μμ*

Limits

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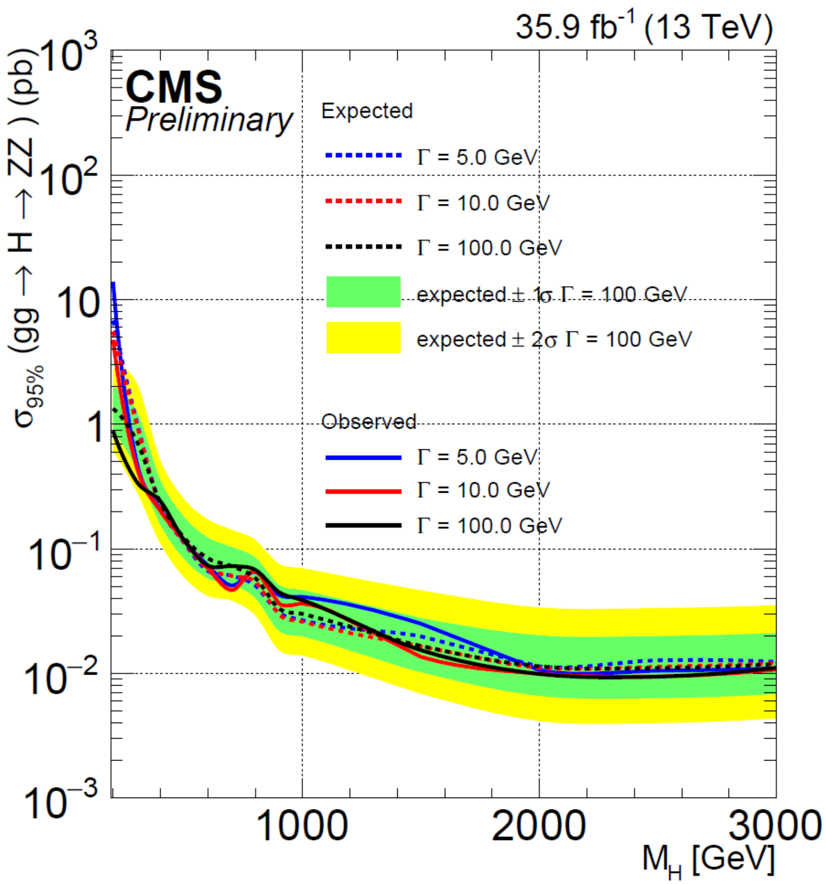

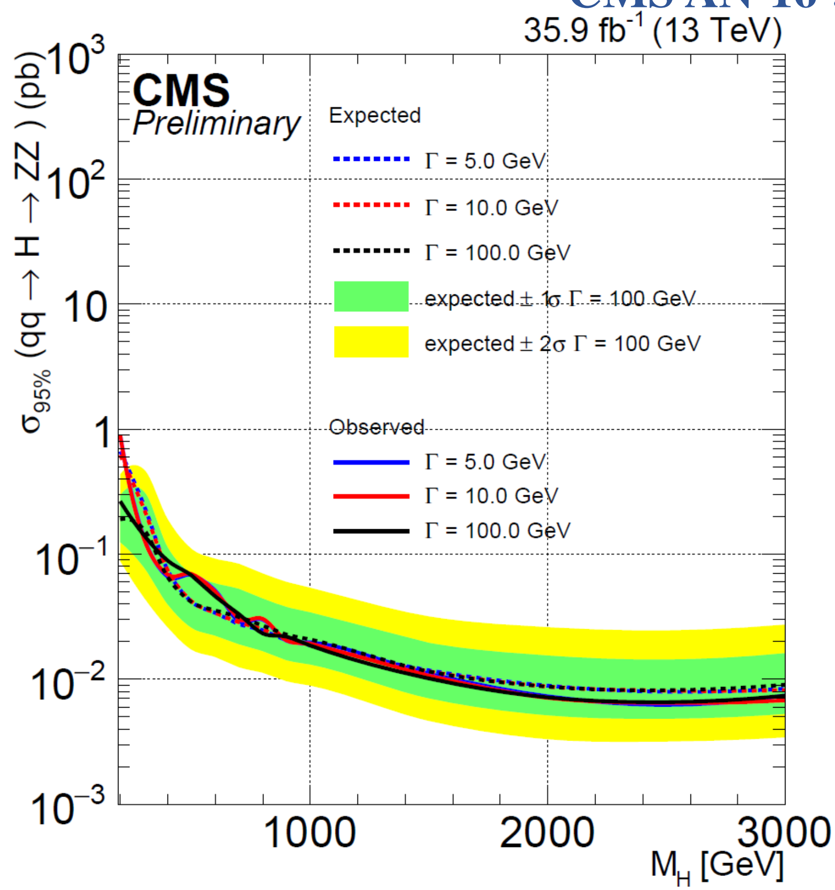

Figure: Upper limits at 95% CL set on the ggH (left) and qqH (right) cross section of a scalar boson as function of its mass for various values of width. Note that these are limits on the absolute cross-section.

Conclusions

- **13TeV data with 35.9 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**
- **Analysis with full 2017 data is on-going**

backup

PAS and AN:

http://cms.cern.ch/iCMS/analysisadmin/cadilines?id=1876&ancode=HIG-17-012&tp=an&line=HIG-17-012