# H→bb and H→VV in boosted topologies at CMS

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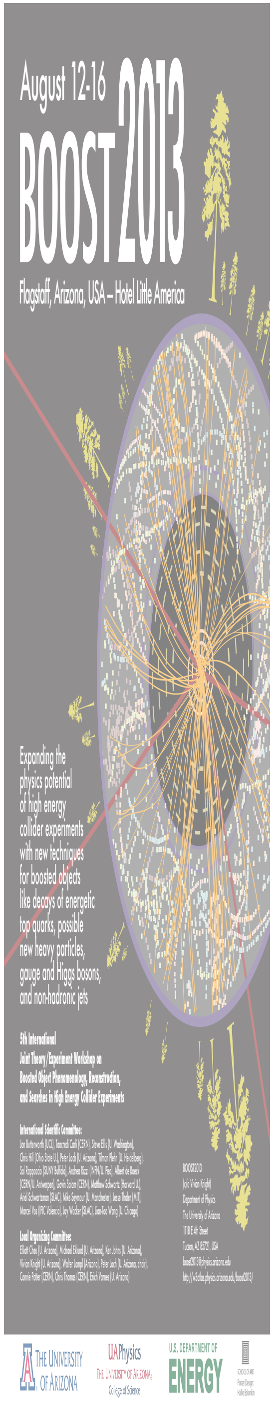
on behalf of the CMS collaboration

August 15th, 2013
BOOST 2013 Workshop



August 12-16
BOOST 2013
Flagstaff, Arizona, USA – Hotel Little America

Expanding the physics potential of high energy collider experiments with new techniques for boosted objects like decays of energetic top quarks, possible new heavy particles, gauge and Higgs bosons, and non-hadronic jets

**5th International**
**Joint Theory/Experiment Workshop on**
**Boosted Object Phenomenology, Reconstruction,**
**and Searches in High Energy Collider Experiments**

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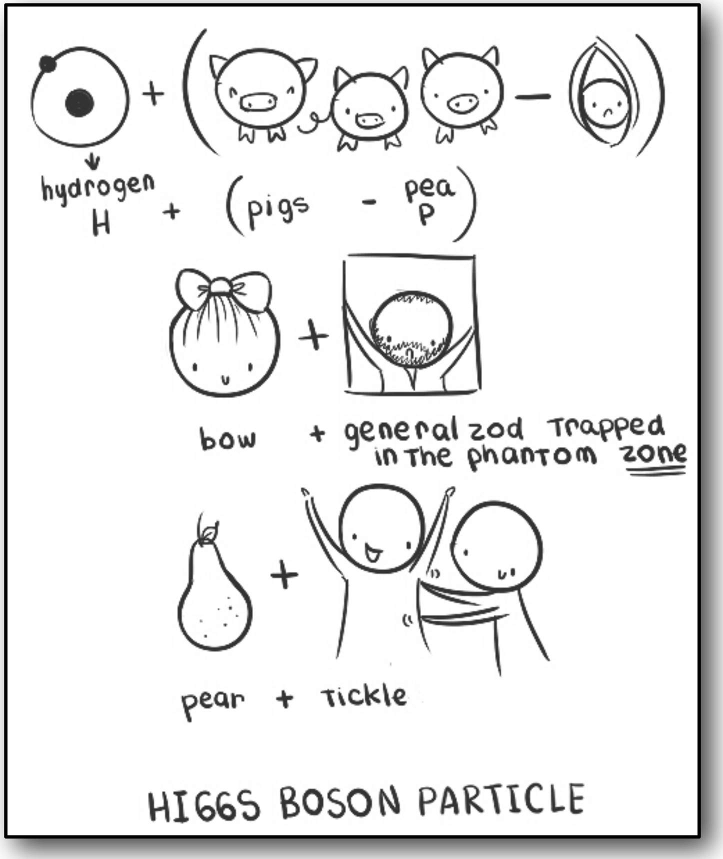
# introduction

- A new boson discovered at 125 GeV
  - *Is it the SM Higgs boson?*
  - *Is it responsible for EW symmetry breaking?*
- Focus on Higgs searches in "boosted topologies"
  - H→bb: No observation yet of direct couplings H(125) to fermions
  - H→VV:
    - At low mass - main discovery channels (ZZ→4l, γγ, WW→lνlν)
    - At high mass - extended Higgs sector? Is H(125) fully responsible for EW symmetry breaking?



# introduction

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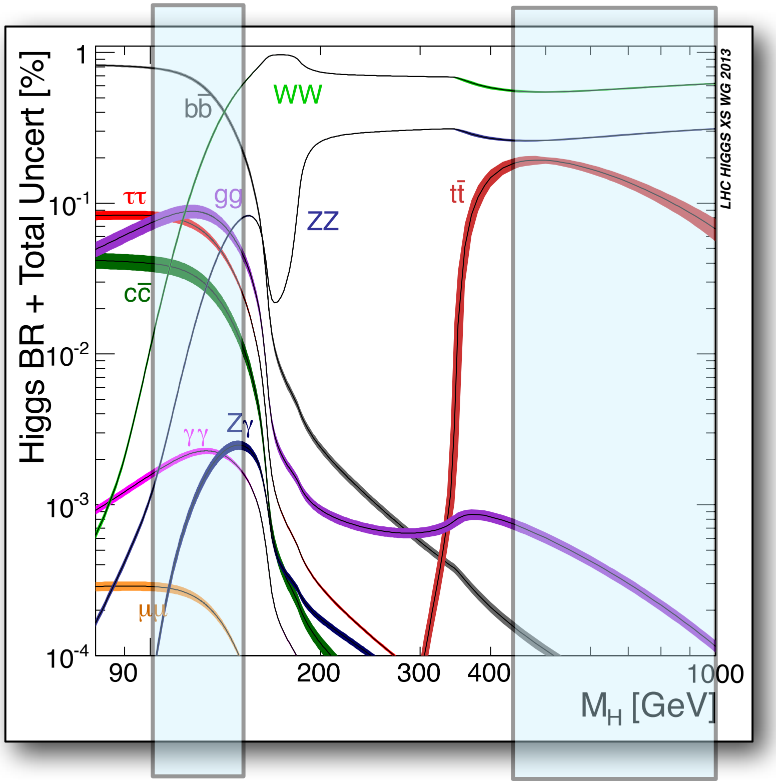


# contents

- Search for SM Higgs boson in VH→Vbb
  - *Moderately* boosted analysis in 6 final states
    - mature analysis -- many generations
  - others: boosted Hττ and VBF Hbb analyses
- Search for Higgs-like boson in H→WW→lνJ
  - *Highly* boosted analysis, both SM and beyond the SM interpretations
  - Jet substructure W-tagging methods
- Future prospects and summary

References
CMS PASes: HIG-13-008, HIG-13-012

# $VH \rightarrow f\bar{f} + b\bar{b}$

ZH→eebb, ZH→μμbb, ZH→ννbb
WH→eνbb, WH→μνbb, WH→τνbb

# VH→ff+bb analysis features

Signal:
VH 115-140 GeV
Backgrounds:
V+jets (0/1/2 b's),
ttbar,
WW/WZ/ZZ

Signature:
VH → V(lν,ll,νν) + b + b

Higgs reconstructed via $m_{jj}$ including b jet energy regression

Kinematics:
boosted V back-to-back with two b jets

Discriminating observables:
Boosted Decision Tree (BDT) or $M_{jj}$ (alternate)

data-driven background extraction using simultaneous fit in multiple control regions

Binned shape limits using BDT or $M_{jj}$ shape

# samples, objects, event selection

CMS √s = 7 TeV dataset, 5 fb$^{-1}$ and √s = 8 TeV dataset, 19 fb$^{-1}$

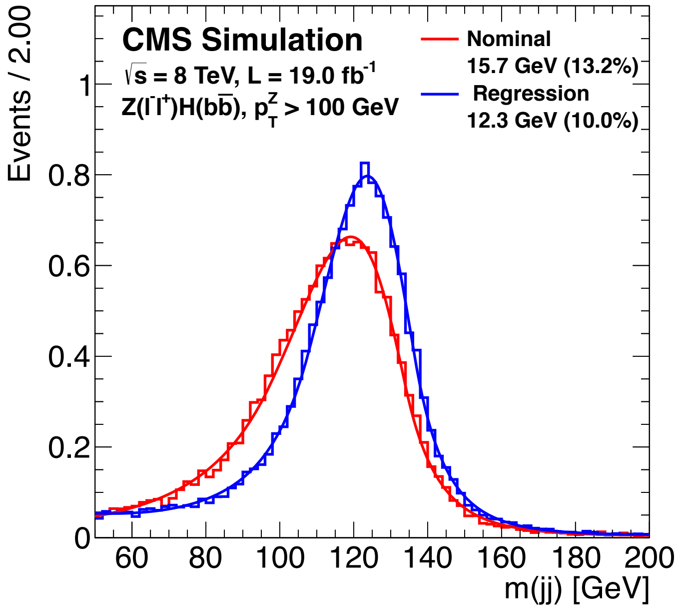
Triggers:
single/double lepton triggers, tau + MET trigger, MET + jet trigger

VH → {l (e,μ) and/or MET} + bb

## Physics Objects - particle flow inputs

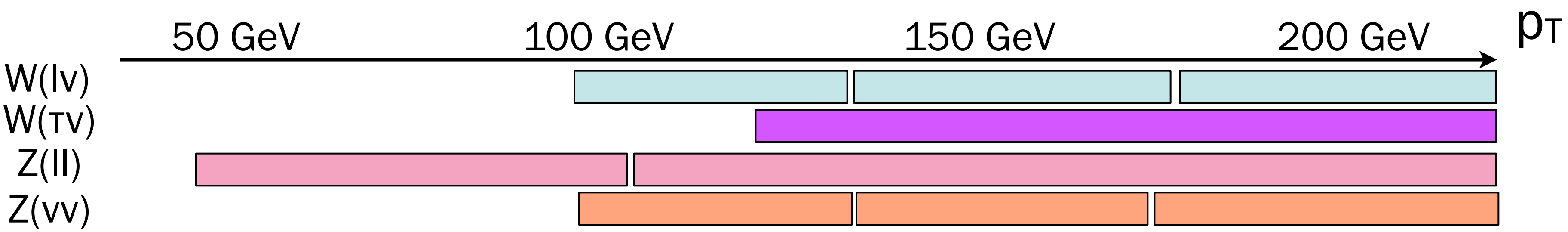
*muons/electrons*: pT(μ,e) > 30 (35) GeV
*taus*: single prong tau, pT(τ) > 40 GeV
*missing transverse energy*: MET(μ,e) > 50 (70) GeV
*jets*: cluster with AK5, Combined secondary vertex discriminant is used to identify b jets, b jet energy regression is applied.

b jet energy regression is validated in data using Z(ll)Z(bb) and top-enriched events



15% improvement in the mass resolution gives 10-20% improvement in expected sensitivity

# event selection



Kinematic observables are combined into a multivariate BDT discriminant

Full set of kinematic cuts for BDT and $m_{jj}$ analyses are defined in the backup

*Boosted Decision Tree inputs*

$pT(j1,j2)$, $m_{jj}$, $pT_{jj}$, $pT_V$

$CSV_{max}$, $CSV_{min}$

$\Delta\varphi(V,H)$, $\Delta\eta_{jj}$, $\Delta R_{jj}$, $N_{aj}$, $\Delta\theta_{pull}$, $\Delta\varphi(MET,j)$

Additional kinematics: $m_{HV}$, $\theta_{ZZ*}$,$\theta_{Zl}$

*VH and jet substructure: sorry, no plots…*

Dedicated studies have been performed to determine the added sensitivity from using substructure quantities

CA12 mass-drop + filtering jets are explored adding the filtered subjets information when existing, $pT_J$, $m_J$, $(m_J - m_{jj})$

Subjet energy regression also is applied indicating improvements in simulation

Ultimately results do not include these developments, LHC Run I data not enough to take advantage of boosted techniques

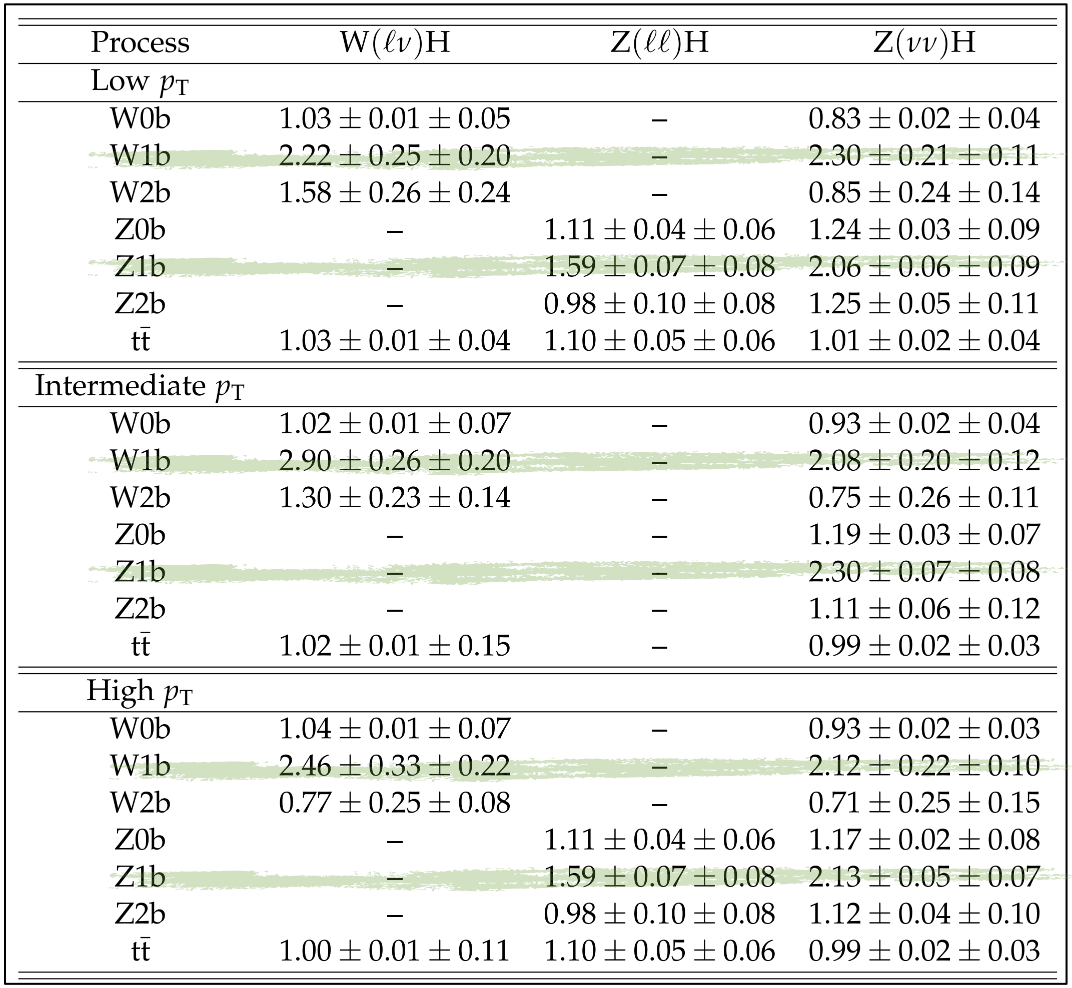
# background scale factors

Strategy is to derive data-driven scale factors for the main backgrounds

Define control samples and perform simultaneous fit of the yields of backgrounds:
V + 0b
V + 1b
V + 2b
tt

Most scale factors are near unity except for V+1b events. Interpretation: mismodeling of g to bb in parton shower modeling

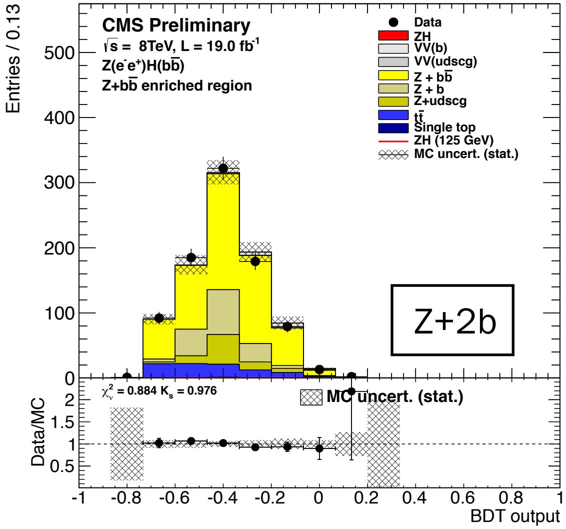
## scale factors across all channels

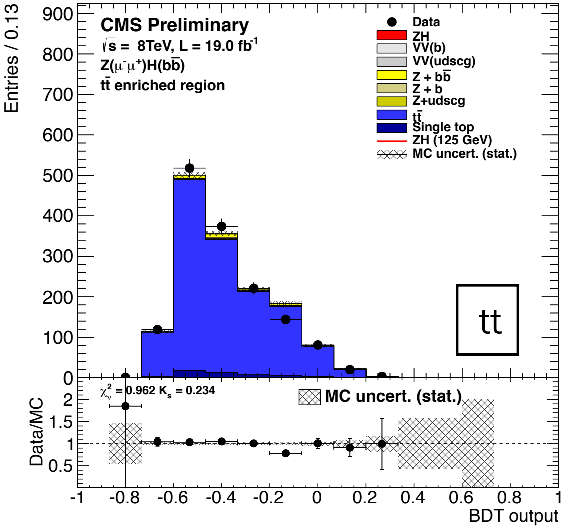


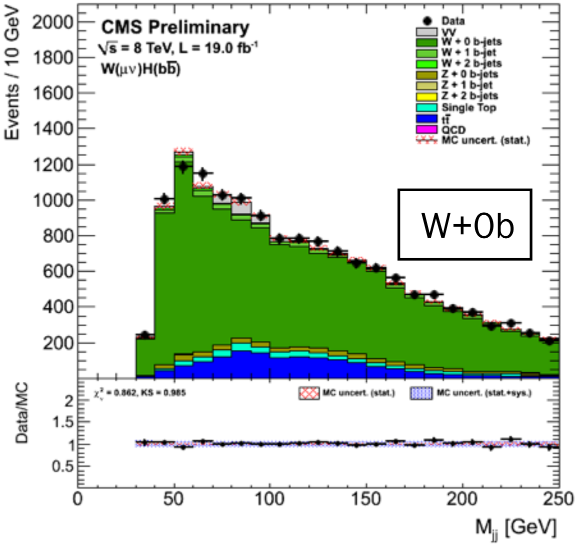
| Process | W($\ell\nu$)H | Z($\ell\ell$)H | Z($\nu\nu$)H |
|---|---|---|---|
| Low $p_T$ | | | |
| W0b | $1.03 \pm 0.01 \pm 0.05$ | – | $0.83 \pm 0.02 \pm 0.04$ |
| W1b | $2.22 \pm 0.25 \pm 0.20$ | – | $2.30 \pm 0.21 \pm 0.11$ |
| W2b | $1.58 \pm 0.26 \pm 0.24$ | – | $0.85 \pm 0.24 \pm 0.14$ |
| Z0b | – | $1.11 \pm 0.04 \pm 0.06$ | $1.24 \pm 0.03 \pm 0.09$ |
| Z1b | – | $1.59 \pm 0.07 \pm 0.08$ | $2.06 \pm 0.06 \pm 0.09$ |
| Z2b | – | $0.98 \pm 0.10 \pm 0.08$ | $1.25 \pm 0.05 \pm 0.11$ |
| $t\bar{t}$ | $1.03 \pm 0.01 \pm 0.04$ | $1.10 \pm 0.05 \pm 0.06$ | $1.01 \pm 0.02 \pm 0.04$ |
| Intermediate $p_T$ | | | |
| W0b | $1.02 \pm 0.01 \pm 0.07$ | – | $0.93 \pm 0.02 \pm 0.04$ |
| W1b | $2.90 \pm 0.26 \pm 0.20$ | – | $2.08 \pm 0.20 \pm 0.12$ |
| W2b | $1.30 \pm 0.23 \pm 0.14$ | – | $0.75 \pm 0.26 \pm 0.11$ |
| Z0b | – | – | $1.19 \pm 0.03 \pm 0.07$ |
| Z1b | – | – | $2.30 \pm 0.07 \pm 0.08$ |
| Z2b | – | – | $1.11 \pm 0.06 \pm 0.12$ |
| $t\bar{t}$ | $1.02 \pm 0.01 \pm 0.15$ | – | $0.99 \pm 0.02 \pm 0.03$ |
| High $p_T$ | | | |
| W0b | $1.04 \pm 0.01 \pm 0.07$ | – | $0.93 \pm 0.02 \pm 0.03$ |
| W1b | $2.46 \pm 0.33 \pm 0.22$ | – | $2.12 \pm 0.22 \pm 0.10$ |
| W2b | $0.77 \pm 0.25 \pm 0.08$ | – | $0.71 \pm 0.25 \pm 0.15$ |
| Z0b | – | $1.11 \pm 0.04 \pm 0.06$ | $1.17 \pm 0.02 \pm 0.08$ |
| Z1b | – | $1.59 \pm 0.07 \pm 0.08$ | $2.13 \pm 0.05 \pm 0.07$ |
| Z2b | – | $0.98 \pm 0.10 \pm 0.08$ | $1.12 \pm 0.04 \pm 0.10$ |
| $t\bar{t}$ | $1.00 \pm 0.01 \pm 0.11$ | $1.10 \pm 0.05 \pm 0.06$ | $0.99 \pm 0.02 \pm 0.03$ |

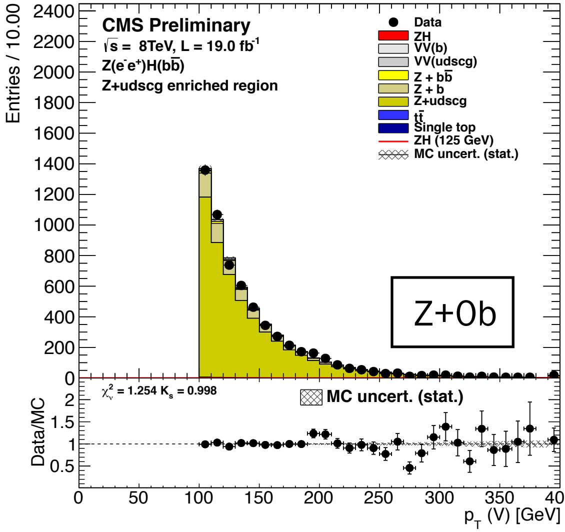
# validation of scale factors, BDT

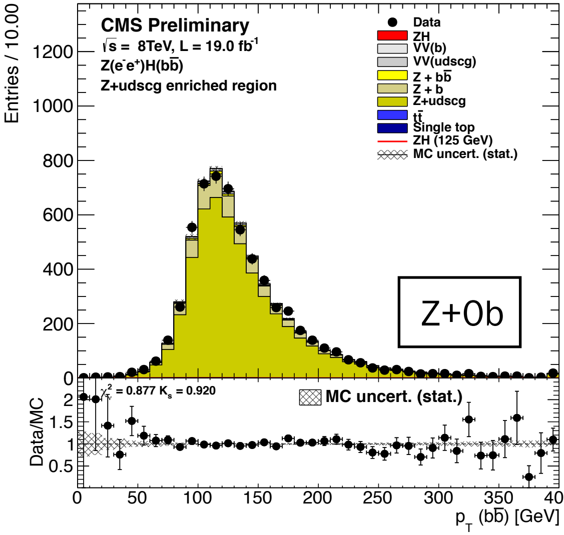
A smattering of validation plots for data/MC distributions in the control regions post-fit.



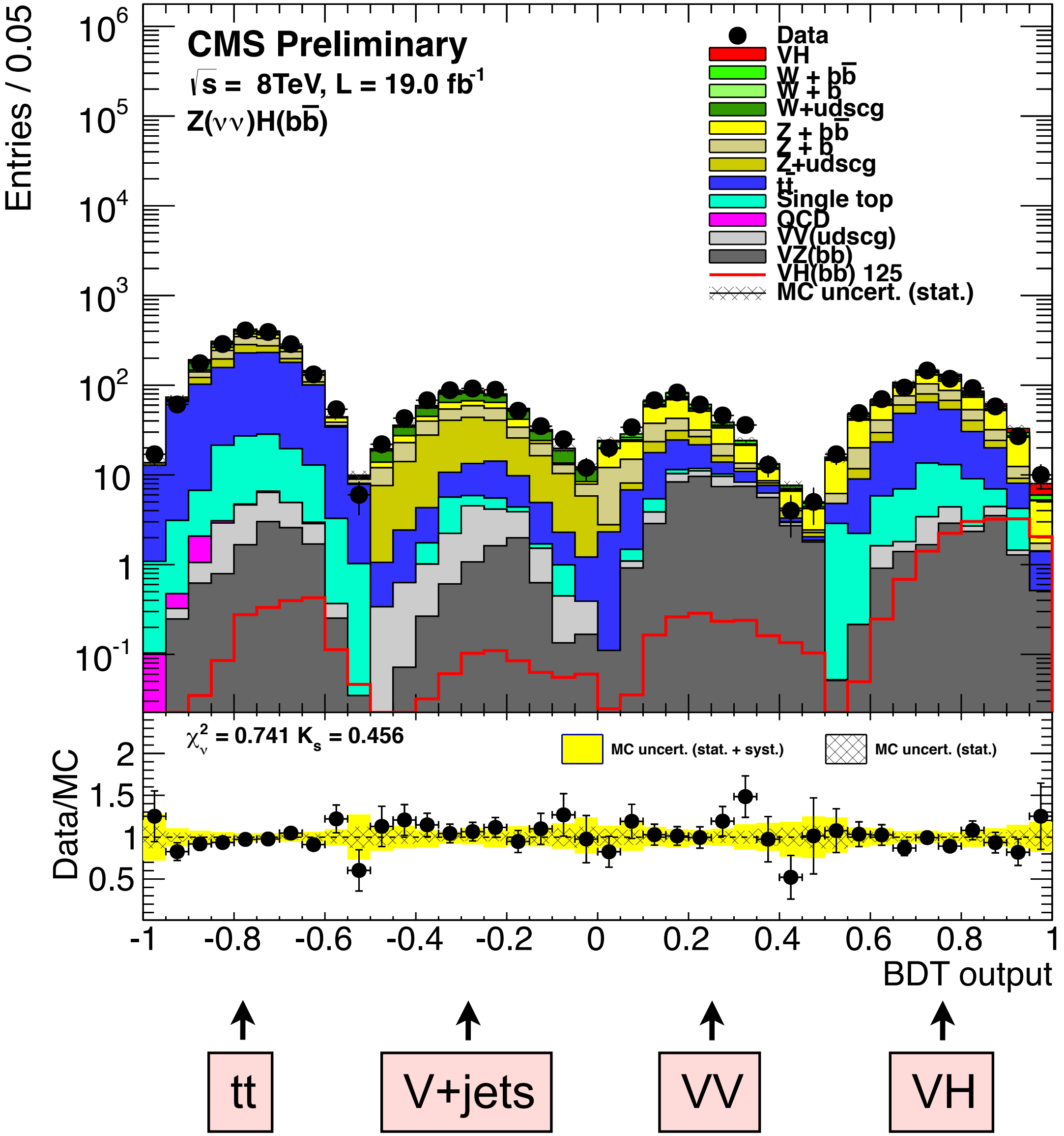








# multi-BDT approach



For channels with multiple significant background contributions, WH/Z(νν)H.

Train in multiple BDT in different categories on different background contributions.

Shows 5-10% improvement in expected limits

Z(ll)H and W(τν) use a single BDT discriminant

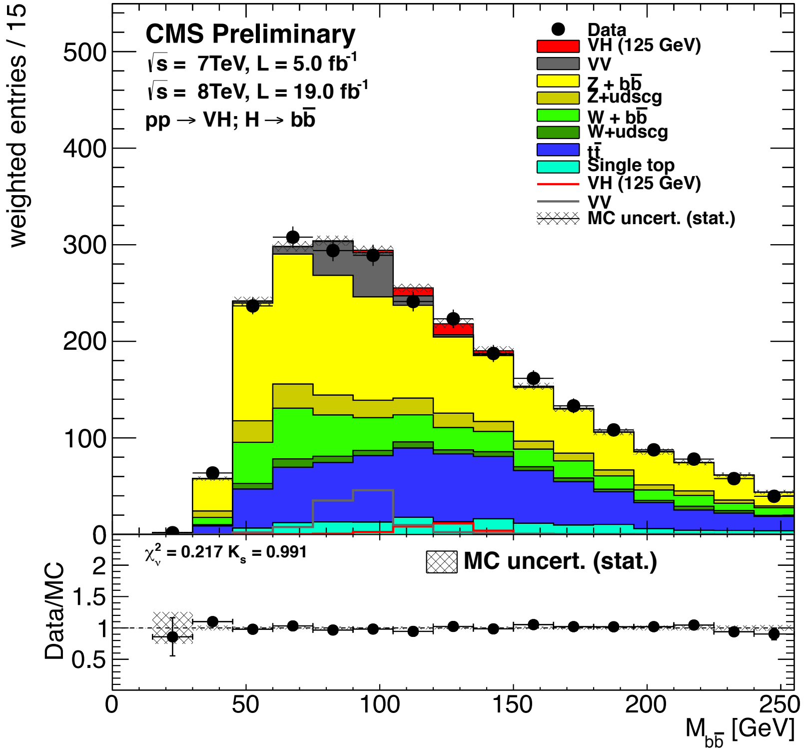
# systematics

| Source | Type | Yield uncertainty (%) range | Contribution to uncertainty (%) | Removal effect on total uncertainty (%) |
|---|---|---|---|---|
| Luminosity | normalization | 2.2-4.4 | $< 2$ | $< 0.1$ |
| Lepton efficiency and trigger (per lepton) | normalization | 3 | $< 2$ | $< 0.1$ |
| Z($\nu\nu$)H triggers | shape | 3 | $< 2$ | $< 0.1$ |
| Jet energy scale | shape | 2–3 | 5.0 | 0.5 |
| Jet energy resolution | shape | 3–6 | 5.9 | 0.7 |
| Missing transverse energy | shape | 3 | 3.2 | 0.2 |
| b-tagging | shape | 3–15 | 10.2 | 2.1 |
| Signal cross section (scale and PDF) | normalization | 4 | 3.9 | 0.3 |
| Signal cross section ($p_T$ boost, EWK/QCD) | normalization | 2/5 | 3.9 | 0.3 |
| Signal Monte Carlo statistics | shape | 1–5 | 13.3 | 3.6 |
| Backgrounds (data estimate) | normlization | 10 | 15.9 | 5.2 |
| Single-top (simulation estimate) | normalization | 15 | 5.0 | 0.5 |
| Dibosons (simulation estimate) | normalization | 15 | 5.0 | 0.5 |
| MC modeling (V+jets and $t\bar{t}$) | shape | 10 | 7.4 | 1.1 |

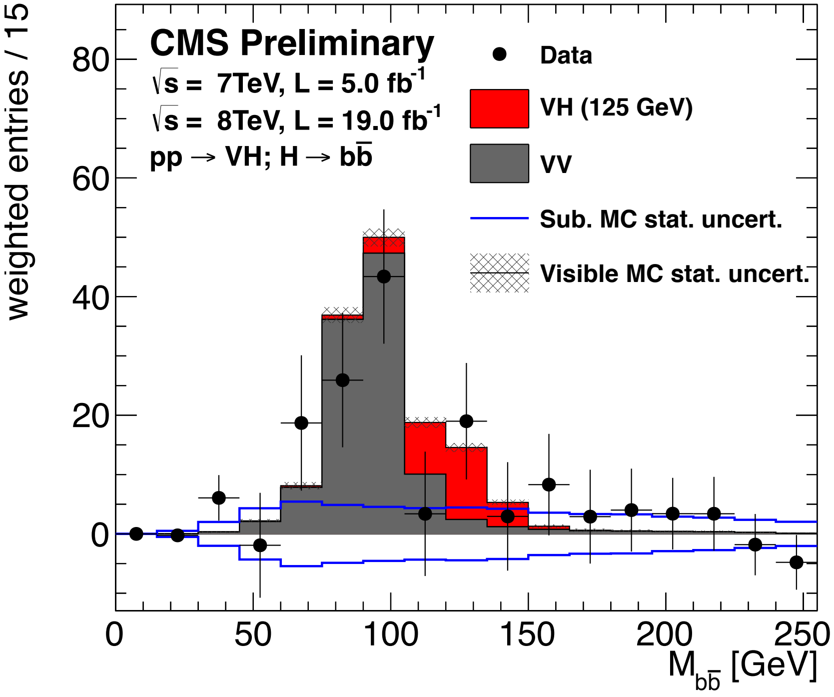
- Shape uncertainties
    - b tagging, JER/JES, trigger, generator modeling, bin-by-bin statistics
- Normalization uncertainties
    - scale factors, signal cross-section
- Uncertainties total ~15%

# $m_{jj}$ results

events weighted by expected signal yield for SM Higgs



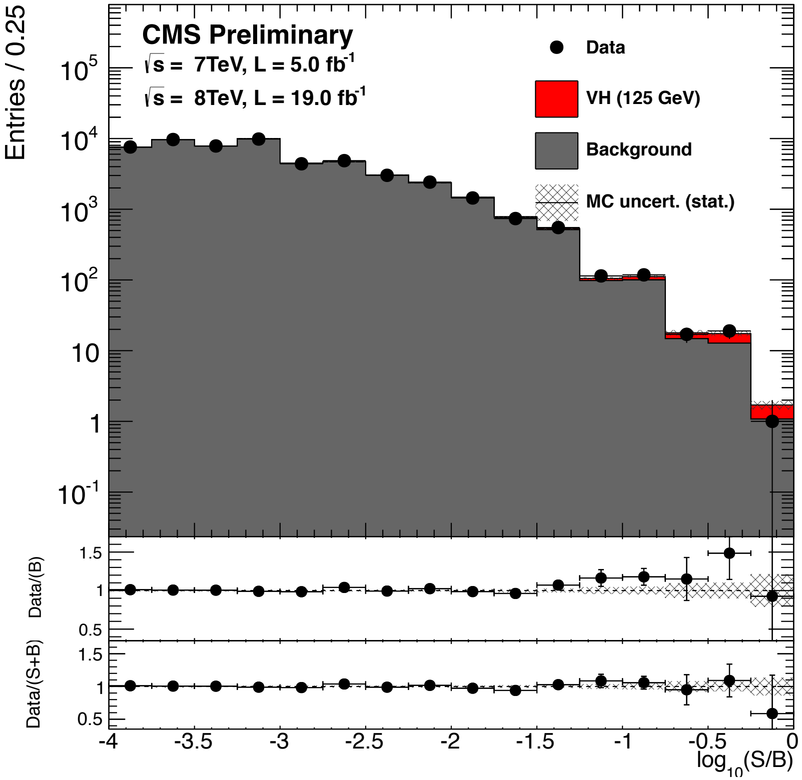
background subtracted version of left hand plot

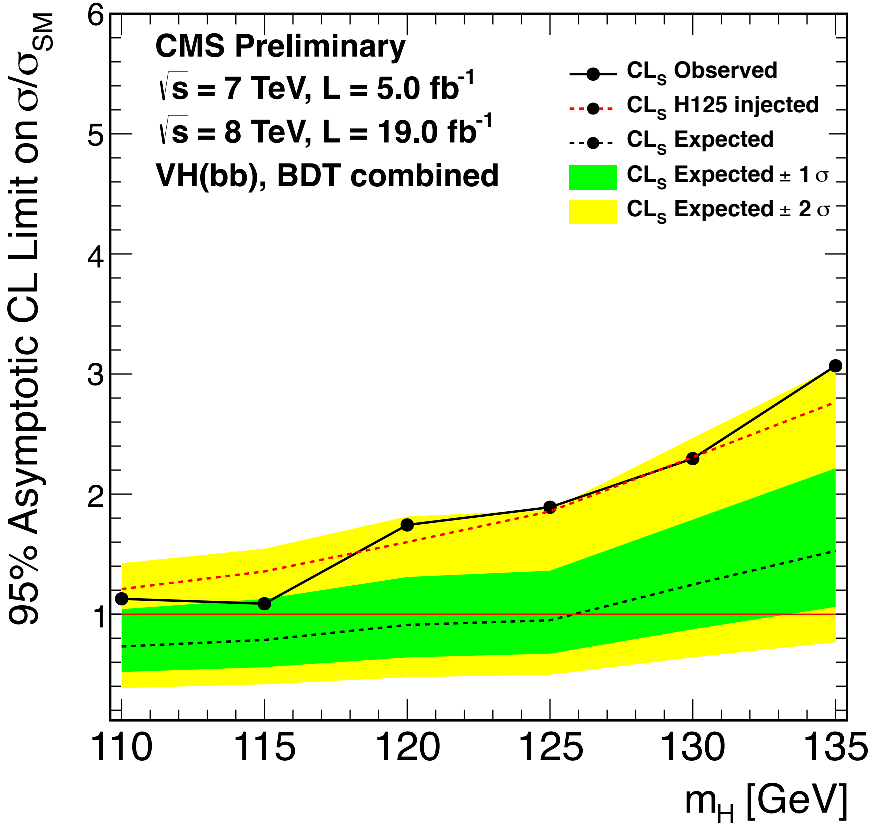


- A complimentary analysis is run using just the $m_{jj}$ mass distribution
- Higgs boson signal strength measured as $0.76^{+0.68}_{-0.66}$
- Validation: re-training the BDT for VZ→Vbb gives a 7.5σ excess (8 TeV only)

# results

events weighted by expected signal yield for SM Higgs

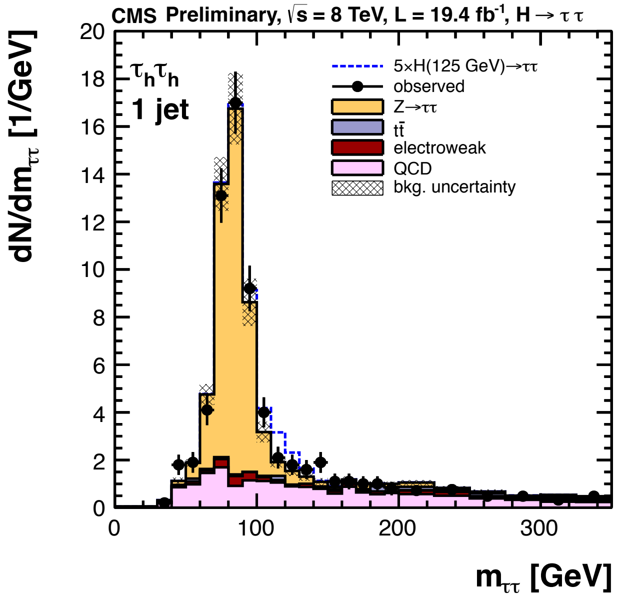


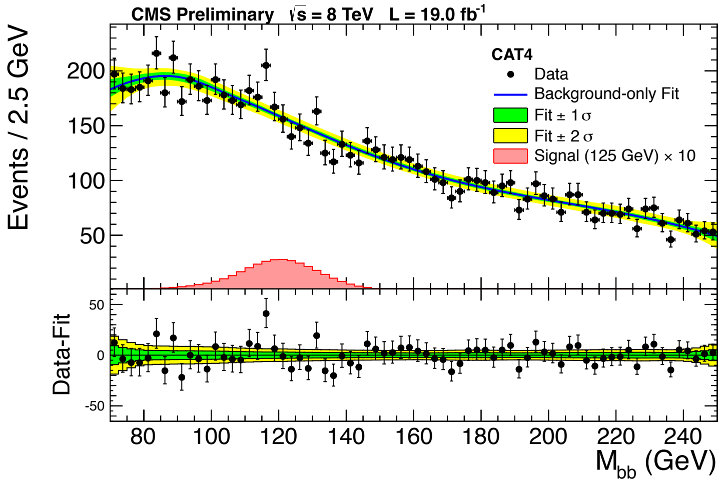


- For visualization, combined BDT distribution
- Observed limits consistent with SM Higgs injected expected limits
- P-value: 2.1σ, Higgs best-fit signal strength: $1.0^{+0.5}_{-0.5}$

# other “boosted” fermionic modes

- $H\to\tau\tau$
  - MVA MET object which takes advantage of PU Jet ID
  - VBF ($p_T$ > 100 GeV) and 1-jet ($p_T$ > 150 GeV) categories for $\tau_H\tau_H$ requires a boosted $H(\tau\tau)$ system
- VBF $H\to bb$
  - quark-gluon discrimination is used to better identify VBF jets
  - moderate boost required of the bb system ($p_T$ > 100 GeV)





References
CMS PASes: HIG-13-004, HIG-13-011

## H⟶WW⟶lvJ

several related analyses:

Exotic high mass WW resonances^

WW scattering

anomalous triple gauge couplings

^ see talk be P. Maksimovic

# H→WW→lvJ analysis features

Signal:

ggH+VBF 600-1000 GeV

Backgrounds:

W+jets (dominant)
ttbar,
single top,
WW/WZ

Signature:
WW → {l + MET} + fat jet

Fat Jet:
Use jet substructure techniques to identify single jets containing decay products of hadronic W

Kinematics:
highly boosted W(lv) back-to-back with fat jet

Discriminating observables:
pruned jet mass, $m_J$, and three-body mass, $m_{lvJ}$

data-driven background extraction of dominant background shape using $m_J$ sideband

Unbinned shape limits using $m_{lvJ}$ shape
[SM and BSM limits]

# samples, objects, event selection

## CMS $\sqrt{s}$ = 8 TeV dataset, 19 $fb^{-1}$

Triggers: single lepton triggers - thresholds at 24 (27) GeV for μ and e channels

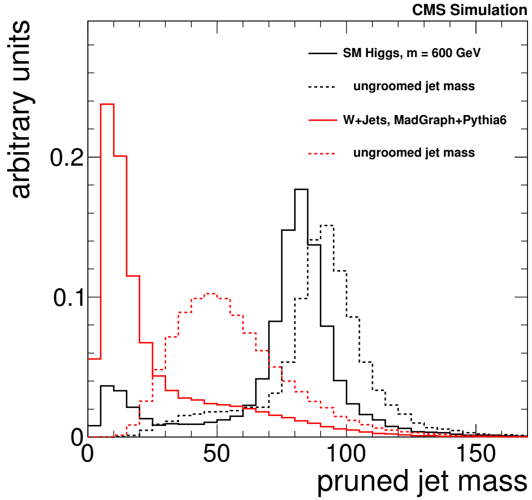
WW ⟶ l (e,μ) + MET + J

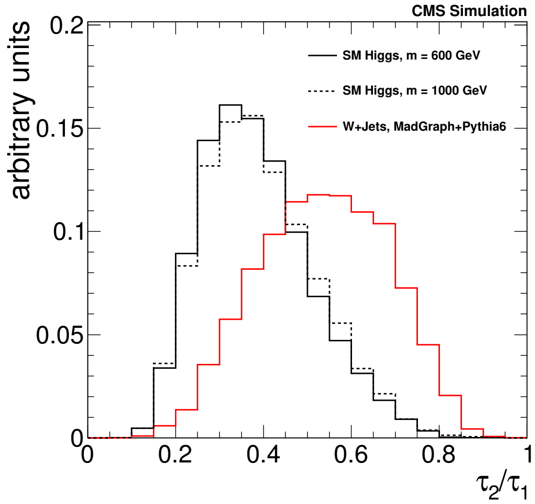
### Physics Objects - particle flow inputs

leptons: pT(μ,e) > 30 (35) GeV; veto presence of 2nd μ or e
missing transverse energy: MET(μ,e) > 50 (70) GeV
jets: cluster with CA8, pruned jet mass = 65-105 GeV, cut on N-subjettiness (one-pass kT) $\tau_2/\tau_1 < 0.5$;

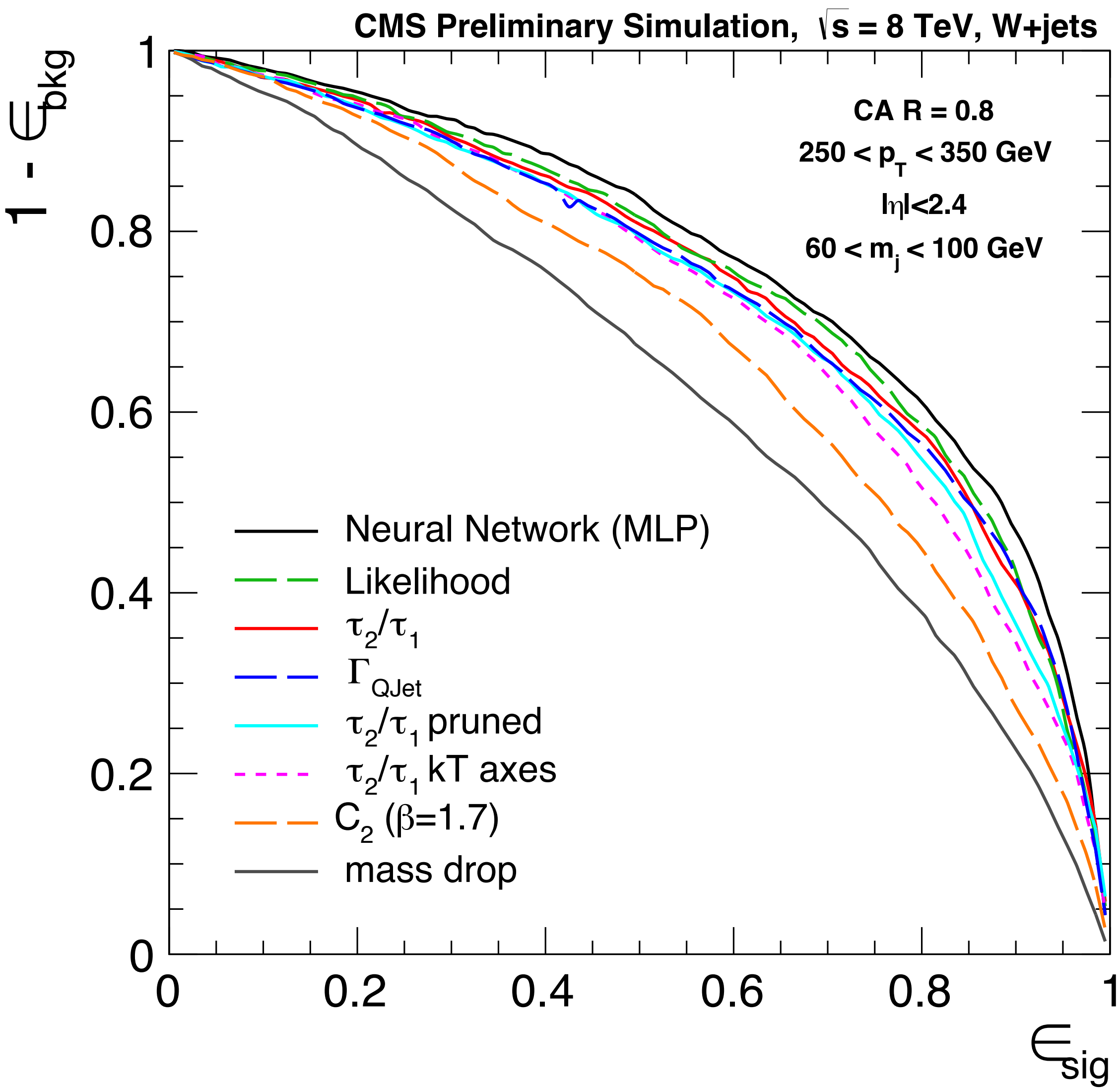
## Event selection:

$pT_J$ and $pT_W$ > 200 GeV
leptonic $mT_W$ > 30 GeV
Topological back-to-back angular cuts
Veto presence of b jets using CMS “standard” AK5 jets





# why $\tau_2/\tau_1$?



## To whet the appetite...

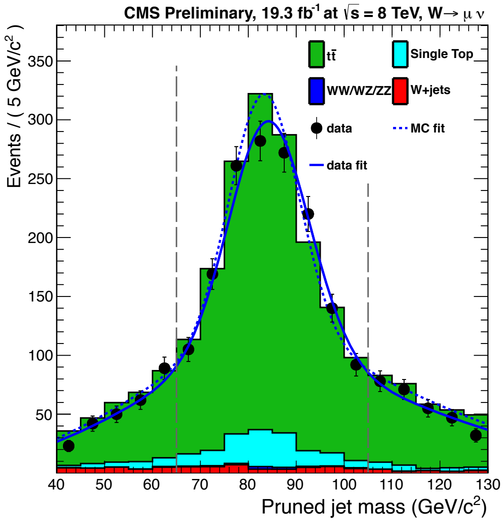
We tried a number of jet substructure observables to determine which would give the best performance.

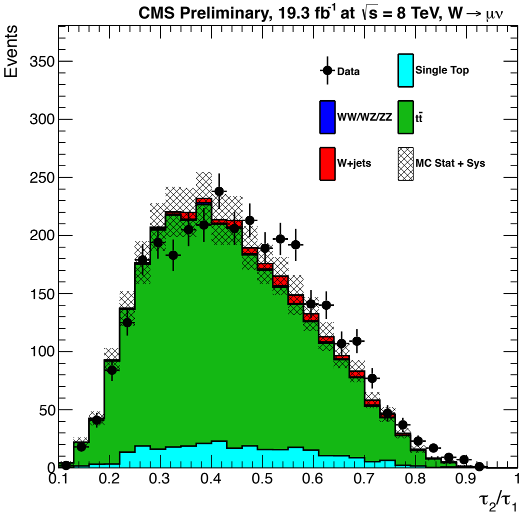
Includes MVA discriminants (8 variables) which show a small improvement in performance

See talk by E. Usai

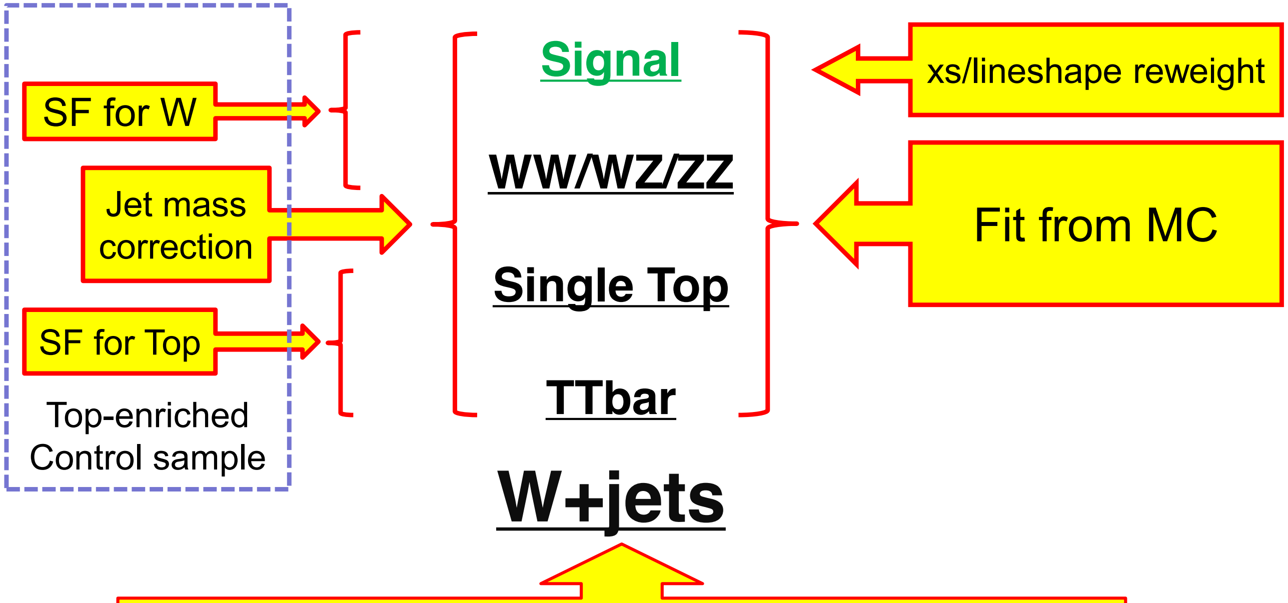
# background estimation

W + jets is dominant background (see next slides)
top and W-jet scale factors are determined from top-enriched control regions





see talk by P. Maksimovic for more details on scale factor extraction

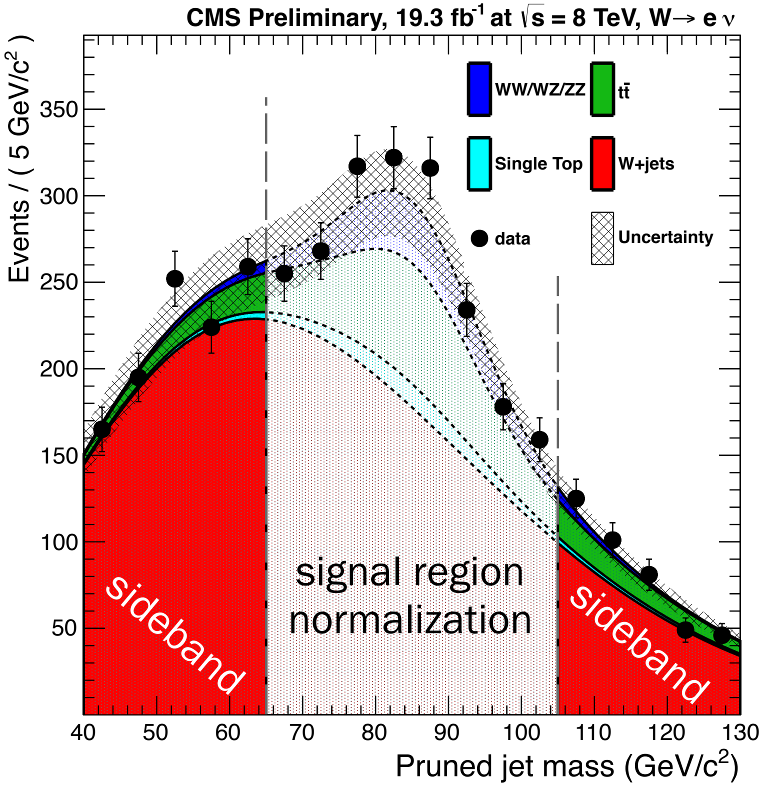


Data-driven for Dominant bkg:

- Normalization: fit mJ sideband
- Shape: $F_{\mathrm{data,SR}}(m_{l\nu j}) = \alpha_{\mathrm{MC}}(m_{l\nu j}) \times F_{\mathrm{data,SB}}(m_{l\nu j})$

$$\alpha_{\mathrm{MC}}(m_{l\nu j}) = \frac{F_{\mathrm{MC,SR}}(m_{l\nu j})}{F_{\mathrm{MC,SB}}(m_{l\nu j})}$$

# W+jets estimation

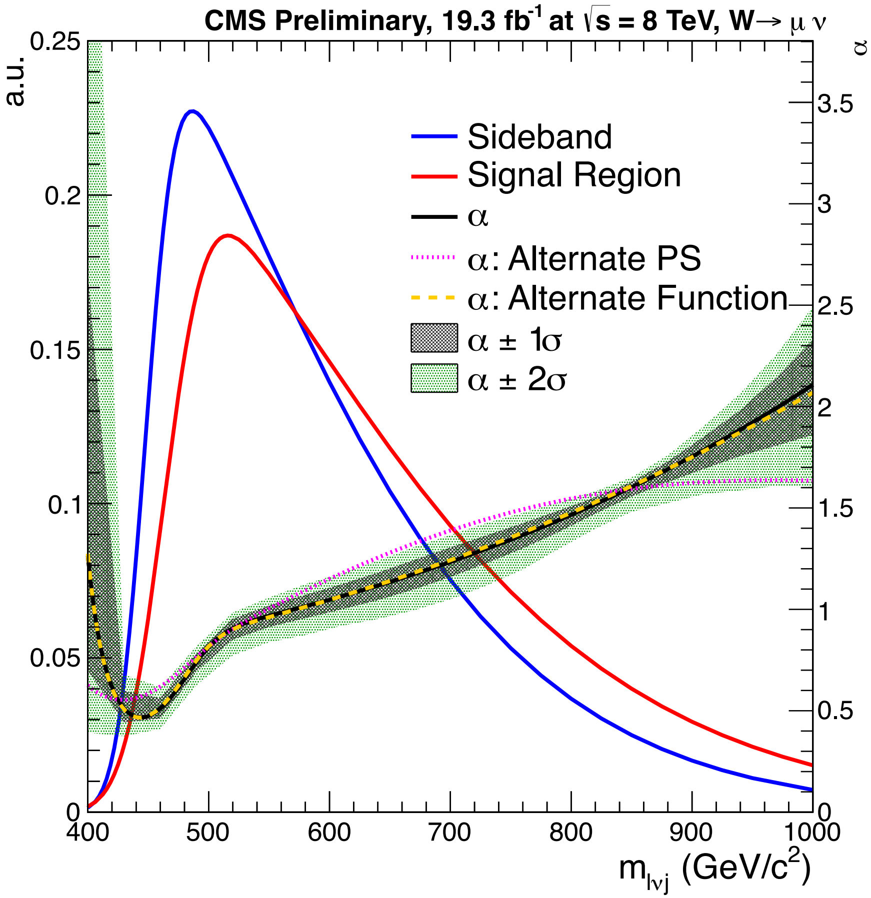


sideband fit to determine W+jets normalization in the signal region

sideband region $m_{l\nu J}$ W+jets shape extrapolated into signal region via α

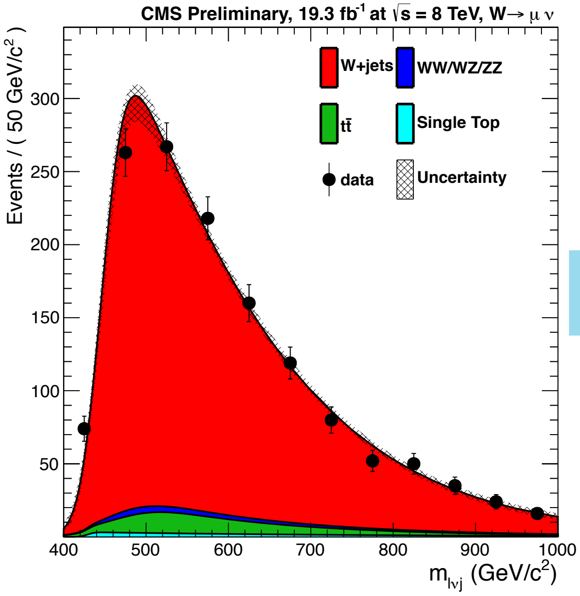
## α function from simulation:

extrapolates W+jets shape in sideband region into the signal region

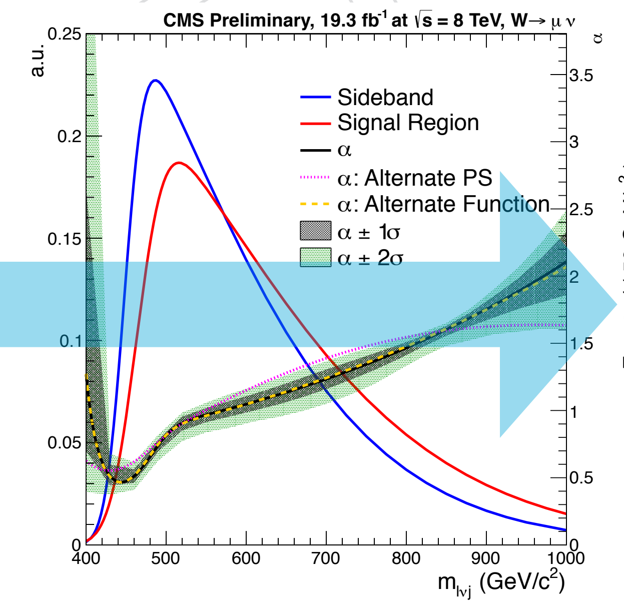


# final $m_{l\nu J}$ distributions

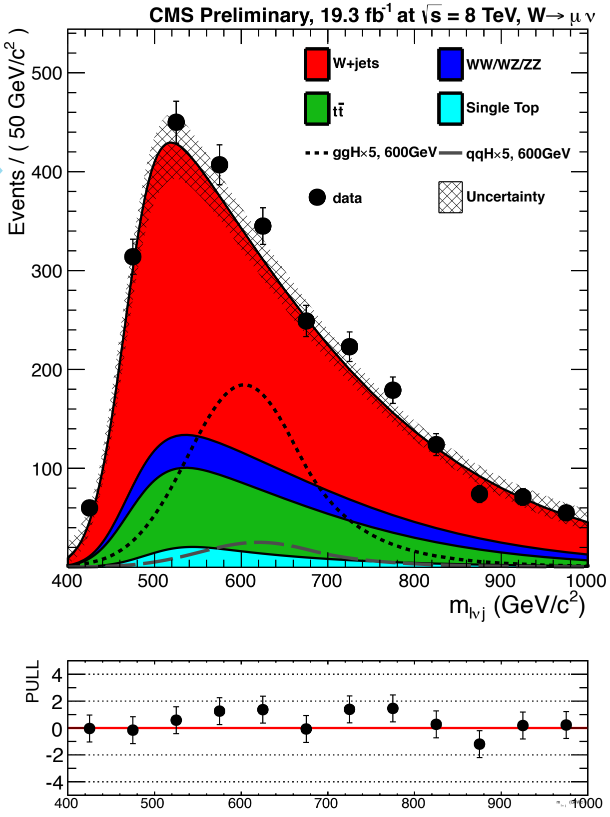
## W+jets sideband



## α function



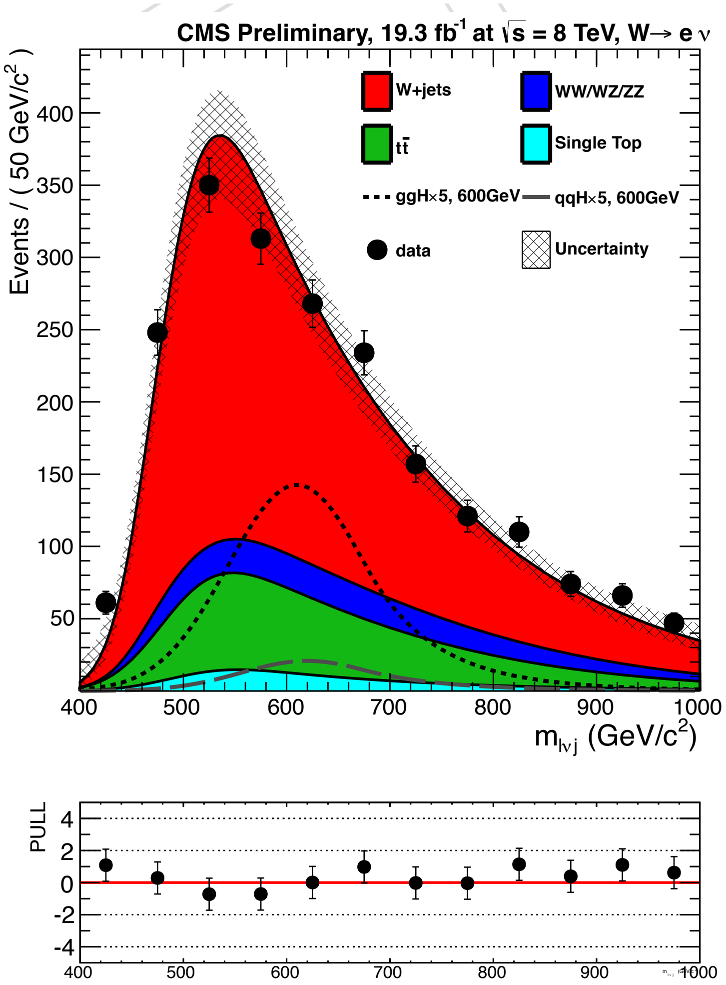
## Putting all together: Final $m_{l\nu J}$ distribution in signal region



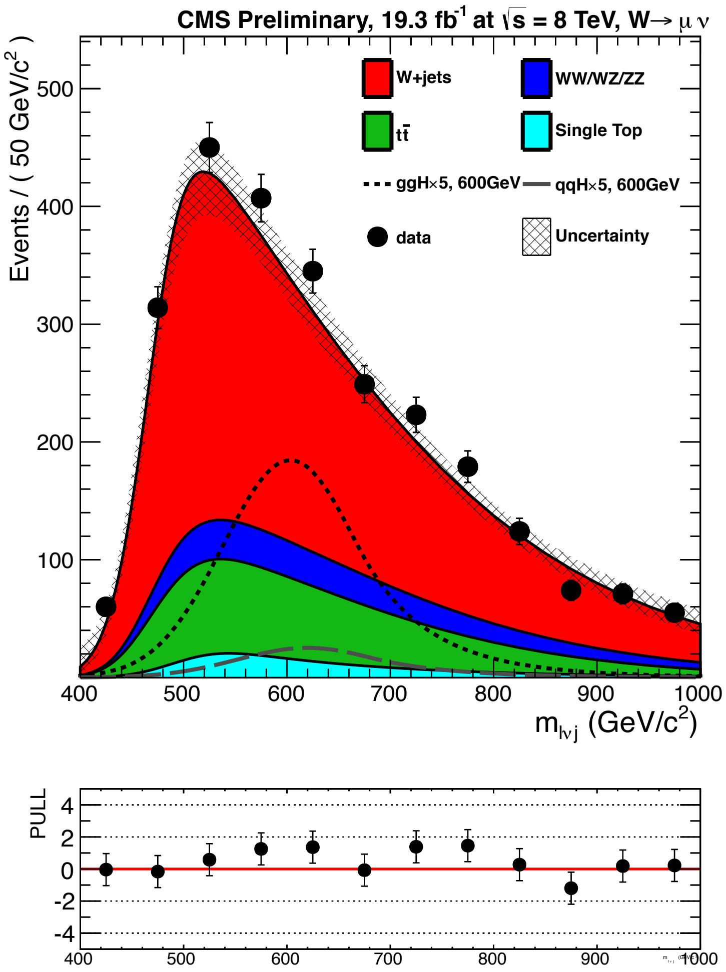
## Uncertainties on W+jets shape come from:

- W+jets sideband fit
- α function fit shape uncertainty
- Shape uncertainty from alternate parton shower and alternate fitting functions

# final $m_{l\nu J}$ distributions

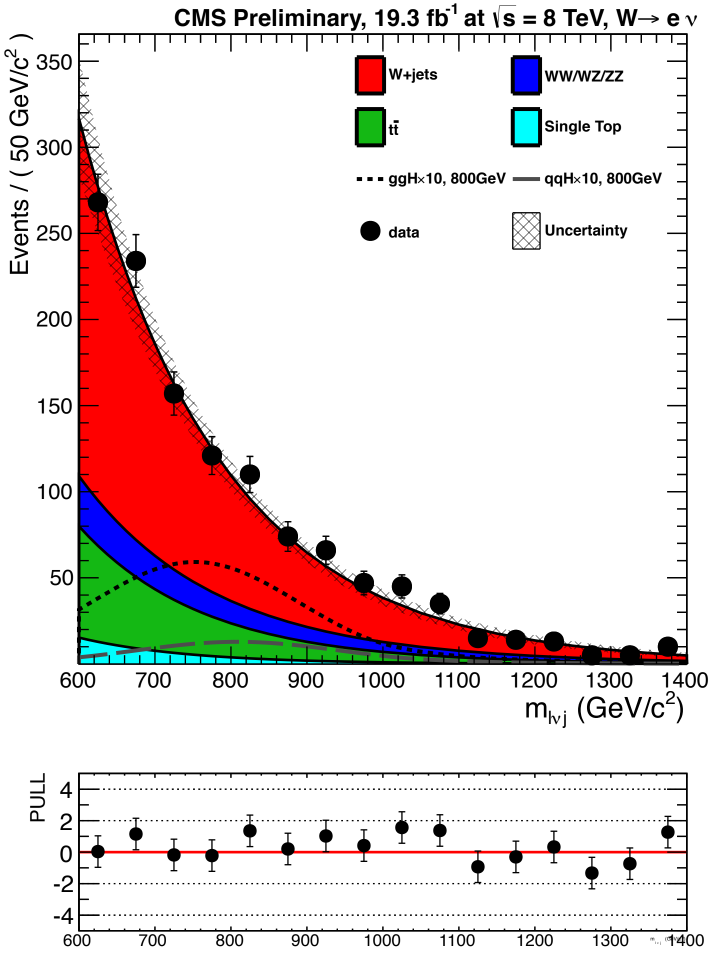


electron channel

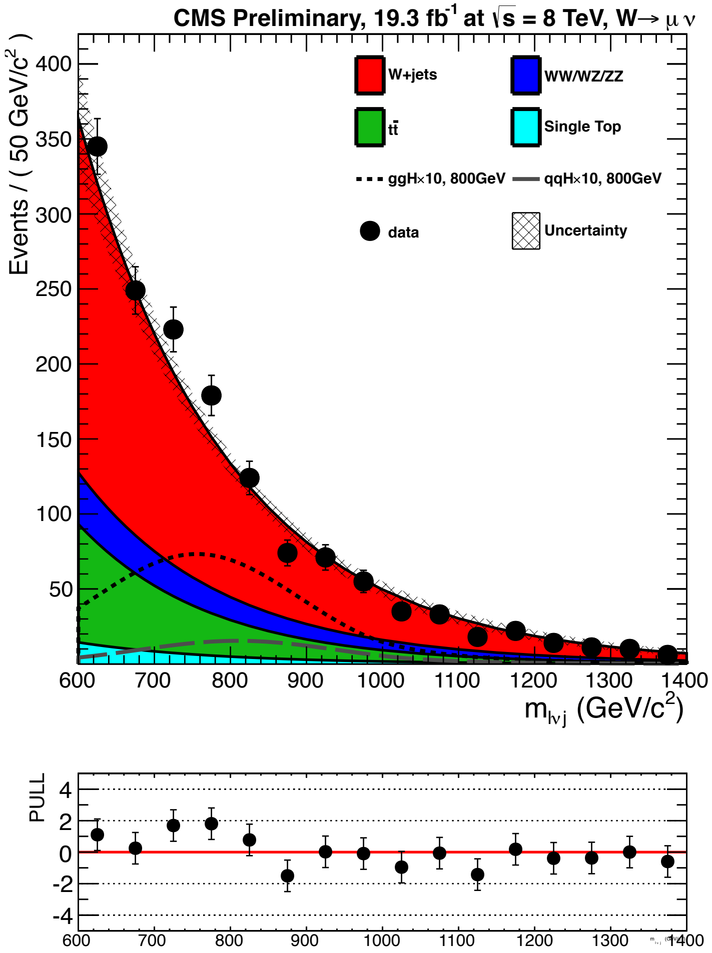


muon channel

# final $m_{l\nu J}$ distributions



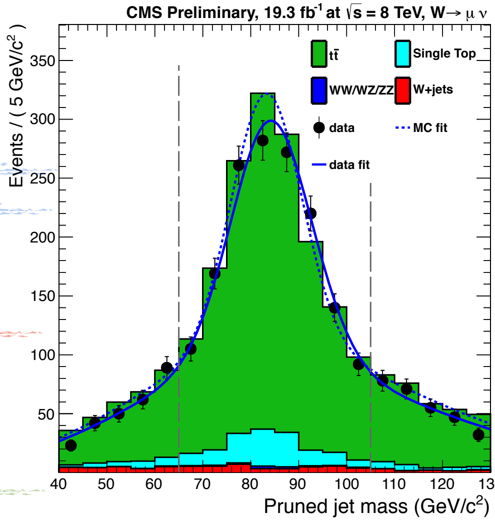
electron channel



muon channel

# systematics

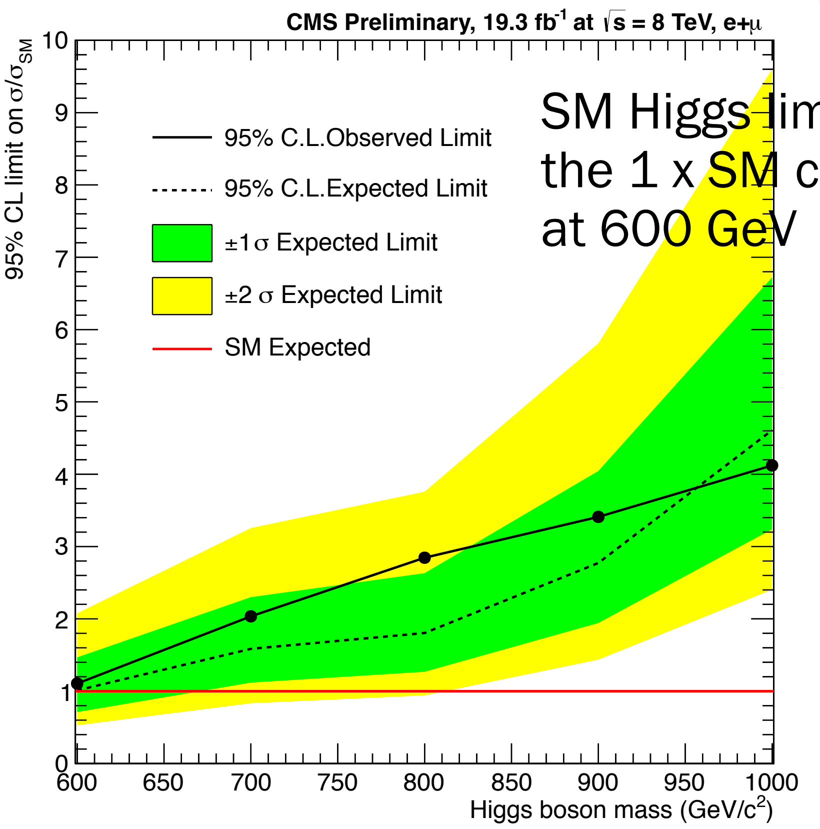
| Syst. uncertainty | sig, $ggH$ | sig, $VBF$ | $W$+jets | $t\bar{t}$ | single $t$ | $WW/WZ$ |
|---|---|---|---|---|---|---|
| lumi | 4.4% | 4.4% | - | 4.4% | 4.4% | 4.4% |
| Higgs QCD scale | 6.5% † | 1.3% † | - | - | - | - |
| Higgs PDF+$\alpha_s$ | 12.1% † | 5.9% † | - | - | - | - |
| Intf (sig/bkg) | 10.0% | 50.0% | - | - | - | - |
| Bkg cross-section | - | - | - | - | 30.0% | 30.0% |
| W+jets norm. | - | - | 8% | - | - | - |
| W-tagging | 10.0% | 10.0% | - | - | - | 10.0% |
| $t\bar{t}$ norm. | - | - | - | 6.0% | 6.0% | - |
| Jet mass/energy scale | 2% | 2% | - | 2% | 2% | 2% |
| W+jets shape | - | - | see Sec. 6 | - | - | - |
| b-tagging | 2.5% | 2.5% | - | - | 2.5% | 2.5% |
| Trigger (e & $\mu$) | 1% | 1% | - | - | 1% | 1% |
| Selection Eff. (e & $\mu$) | 2% | 2% | - | - | 2% | 2% |



data:
<m> = 84.5 ± 0.4 GeV
σ = 8.7 ± 0.6 GeV
MC:
<m> = 83.4 ± 0.4 GeV
σ = 7.4 ± 0.4 GeV

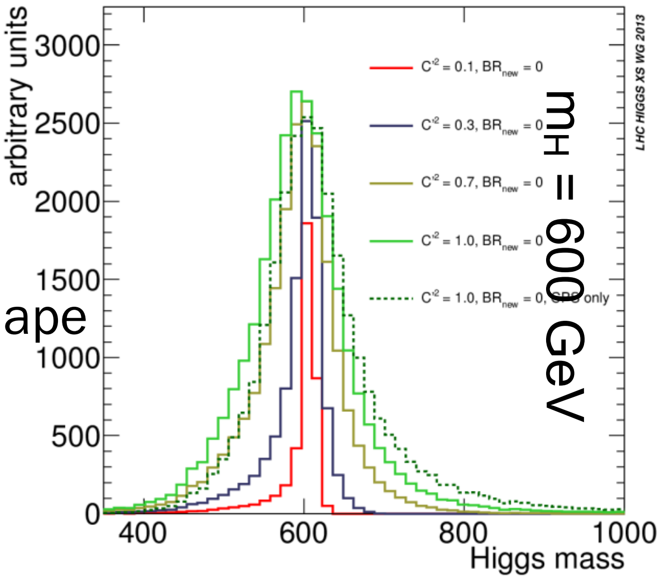
- W+jets shape is one of the larger systematics effects
- W-tagging scale factor estimated in the top-enriched control region to be 0.95 ± 0.10 (0.89 ± 0.10) for the μ (e) channel
- Signal uncertainties are dominated by theoretical uncertainties
    - PDF and $\alpha_s$ and interference effects -- standard within the LHCXSWG

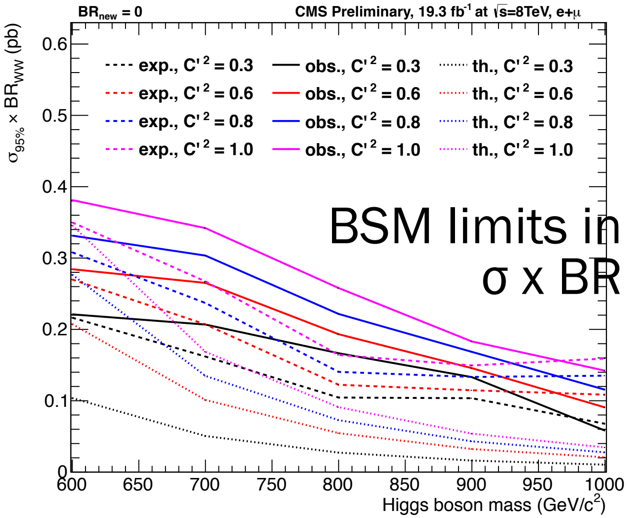
# results



SM Higgs limits are just at the 1 x SM cross-section at 600 GeV

Higgs lineshape reweighting





BSM limits in σ x BR

## BSM models benchmark (LHC XS WG):

Higgs mixes with heavy EWK singlet

Higgs coupling modified -- $C^2 + C'^2 = 1$

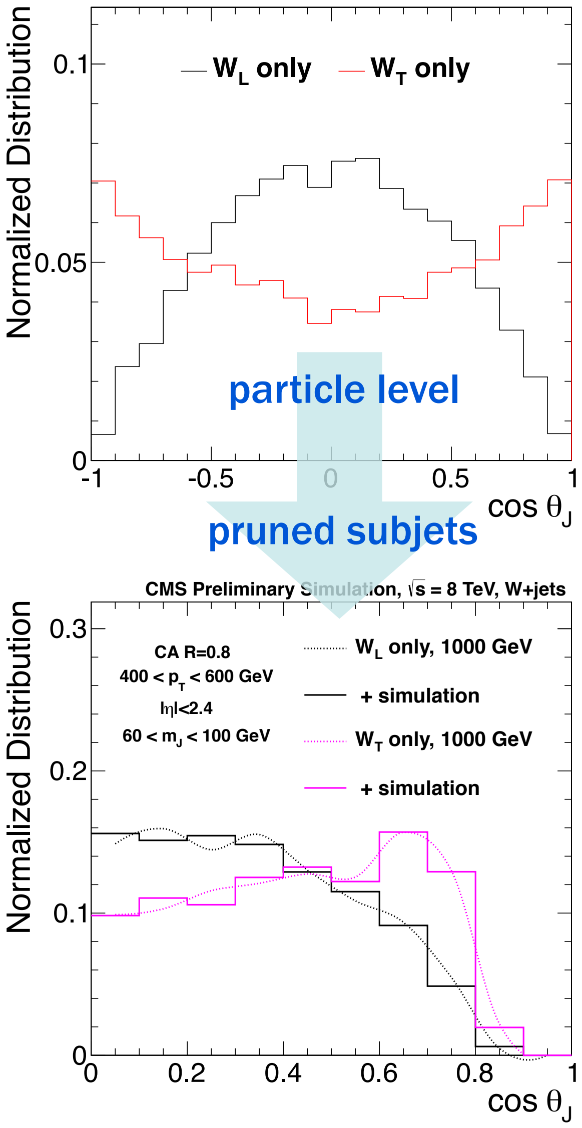
Width and cross-section is modified accordingly

# future prospects and summary

# future prospects

- Subjet b-tagging
  - Large improvements in Higgs tagging by b tagging subjets
  - See talk by I. Marchesini
- Advances in W-jets
  - No longer just bump hunting… angular analysis with substructure
    - Fractions of longitudinal and transversely polarized W’s
  - W$^+$ jets vs W$^-$ jets vs. QCD jets (?)
  - See talk by E. Usai

References
CMS PASes: JME-13-006, BTV-13-001



# summary

- Higgs searches with boosted topologies are presented
  - VH → ff+bb search for SM Higgs boson
    - Observed (expected) limit of 1.85 (0.95) times the SM Higgs cross-section at 125 GeV
    - Consistent with a SM Higgs within errors
    - Substructure methods are studied, do not bring much sensitivity for LHC Run I
  - H → WW → l + ν + qq search for SM and BSM Higgs
    - High mass search including a fat jet tagged as a merged W
    - Limits are set on SM Higgs and also BSM models with modified width and cross-section
- Rich analyses, but this can just the beginning of the story for these modes…

# additional material

# Hbb selections

| Variable | $W(\ell\nu)H$ | $W(\tau\nu)H$ | $Z(\ell\ell)H$ | $Z(\nu\nu)H$ |
|---|---|---|---|---|
| $m_{\ell\ell}$ | – | – | $[75-105]$ | – |
| $p_T(j_1)$ | $> 30$ | $> 30$ | $> 20$ | $> 60$ |
| $p_T(j_2)$ | $> 30$ | $> 30$ | $> 20$ | $> 30$ |
| $p_T(jj)$ | $> 100$ | $> 120$ | – | $> 100$ $(> 130, > 130)$ |
| $m(jj)$ | $< 250$ | $< 250$ | $[40-250]$ $(< 250)$ | $< 250$ |
| $p_T(V)$ | $100-130$ $(130-180, > 180)$ | $> 120$ | $[50-100]$ $(> 100)$ | – |
| $CSV_{max}$ | $> 0.40$ | $> 0.40$ | $> 0.50$ $(> 0.244)$ | $> 0.679$ |
| $CSV_{min}$ | $> 0.40$ | $> 0.40$ | $> 0.244$ | $> 0.244$ |
| $N_{aj}$ | – | – | – | $< 2$ (–,–) |
| $N_{al}$ | $= 0$ | $= 0$ | – | $= 0$ |
| $E_T^{miss}$ | $> 45$ | $> 80$ | – | $[100-130]$ $([130-170], > 170)$ |
| $\Delta\phi(V, H)$ | – | – | – | $> 2.0$ |
| $\Delta\phi(E_T^{miss}, jet)$ | – | – | – | $> 0.7$ $(> 0.7, > 0.5)$ |
| $\Delta\phi(E_T^{miss}, E_T^{miss(trks)})$ | – | – | – | $< 0.5$ |
| $E_T^{miss}$ significance | – | – | – | $> 3$ (–,–) |
| $\Delta\phi(E_T^{miss}, \ell)$ | $< \pi/2$ |  | – | – |
| $p_T(\tau)$ | – | $> 40$ | – | – |
| $p_T(track)$ | – | $> 20$ | – | – |

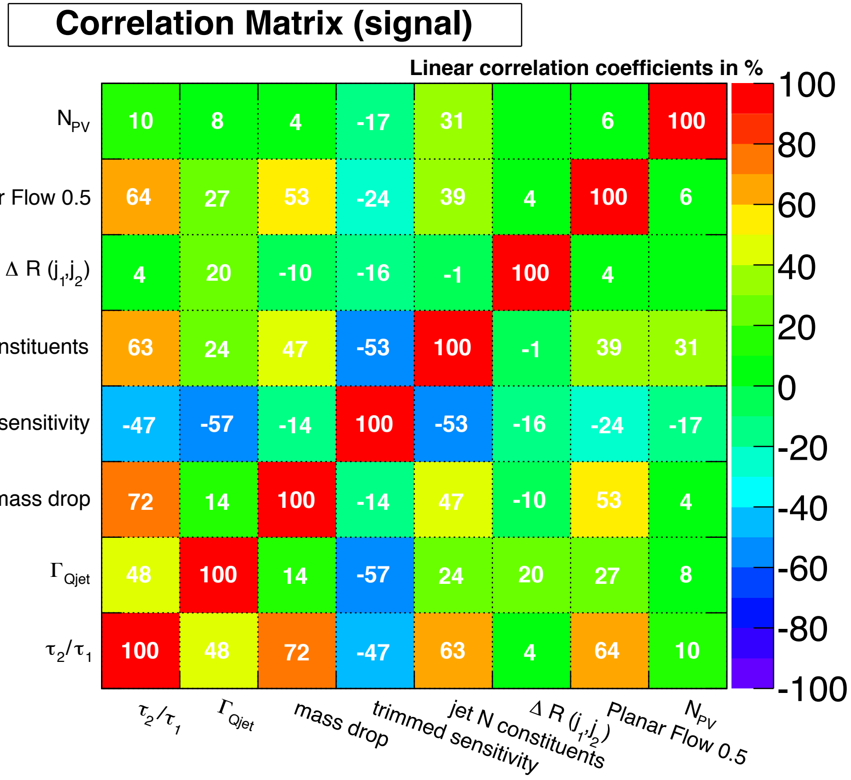
# Hbb control regions

| Variable | W+LF | $t\bar{t}$ | W+HF |
|---|---|---|---|
| $p_T(j_1)$ | $> 30$ | $> 30$ | $> 30$ |
| $p_T(j_2)$ | $> 30$ | $> 30$ | $> 30$ |
| $p_T(jj)$ | $> 120$ | $> 120$ | $> 120$ |
| $p_T(V)$ | $[100-130]$ $([130,180]$ $> 180)$ | $[100-130]$ $([130,180]$ $> 180)$ | $[100-130]$ $([130,180]$ $> 180)$ |
| $CSV_{max}$ | $[0.244-0.898]$ | $> 0.898$ | $> 0.898$ |
| $N_{aj}$ | $< 2$ | $> 1$ | $= 0$ |
| $N_{al}$ | $= 0$ | $= 0$ | $= 0$ |
| $E_T^{miss}$ | $> 45$ | $> 45$ | $> 45$ |
| $E_T^{miss}$ significance | $> 2.0(\mu)$ $> 3.0(e)$ | – | – |
| $m(jj)$ | $< 250$ | $< 250$ | veto $[90-150]$ |

| Variable | Z+jets | $t\bar{t}$ |
|---|---|---|
| $m_{\ell\ell}$ | $[75-105]$ | veto $[75-105]$ |
| $p_T(j_1)$ | $> 20$ | $> 20$ |
| $p_T(j_2)$ | $> 20$ | $> 20$ |
| $p_T(V)$ | $[50-100]$ | $[50-100]$ |
| $CSV_{max}$ | $> 0.244$ | $> 0.244$ |
| $CSV_{min}$ | $> 0.244$ | $> 0.244$ |
| $m(jj)$ | veto $[80-150]$, $< 250$ | veto $[80-150]$, $< 250$ |

| Variable | Z+LF | Z+HF | $t\bar{t}$ | W+LF | W+HF |
|---|---|---|---|---|---|
| $p_T(j_1)$ | $> 60$ | $> 60$ | $> 60$ | $> 60$ | $> 60$ |
| $p_T(j_2)$ | $> 30$ | $> 30$ | $> 30$ | $> 30$ | $> 30$ |
| $p_T(jj)$ | $> 100$ $(> 130, > 130)$ | $> 100$ $(> 130, > 130)$ | $> 100$ $(> 130, > 130)$ | $> 100$ $(> 130, > 130)$ | $> 100$ $(> 130, > 130)$ |
| $m(jj)$ | $< 250$ | $< 250$, veto $[100-140]$ | 250, veto $[100-140]$ | $< 250$ | $< 250$, veto $[100-140]$ |
| $p_T(V)$ | – | – | – | – | – |
| $CSV_{max}$ | $[0.244-0.898]$ | $> 0.679$ | $> 0.898$ | $[0.244-0.898]$ | $> 0.679$ |
| $CSV_{min}$ | – | $> 0.244$ | – | – | $> 0.244$ |
| $N_{aj}$ | $< 2$ (–,–) | $< 2$ (–,–) | $\geq 1$ | $= 0$ | $= 0$ |
| $N_{al}$ | $= 0$ | $= 0$ | $= 1$ | $= 1$ | $= 1$ |
| $E_T^{miss}$ | $[100-130]$ $([130-170], > 170)$ | $[100-130]$ $([130-170], > 170)$ | $[100-130]$ $([130-170], > 170)$ | $[100-130]$ $([130-170], > 170)$ | $[100-130]$ $([130-170], > 170)$ |
| $\Delta\phi(V,H)$ | – | $> 2.0$ | – | – | $> 2.0$ |
| $\Delta\phi(E_T^{miss}, jet)$ | $> 0.7$ $(> 0.7, > 0.5)$ | $> 0.7$ $(> 0.7, > 0.5)$ | $> 0.7$ $(> 0.7, > 0.5)$ | $> 0.7$ $(> 0.7, > 0.5)$ | $> 0.7$ $(> 0.7, > 0.5)$ |
| $\Delta\phi(E_T^{miss}, E_T^{miss^{(trks)}})$ | $< 0.5$ | $< 0.5$ | – | – | – |
| $E_T^{miss}$ significance | $> 3$ (–,–) | $> 3$ (–,–) | $> 3$ (–,–) | $> 3$ (–,–) | $> 3$ (–,–) |

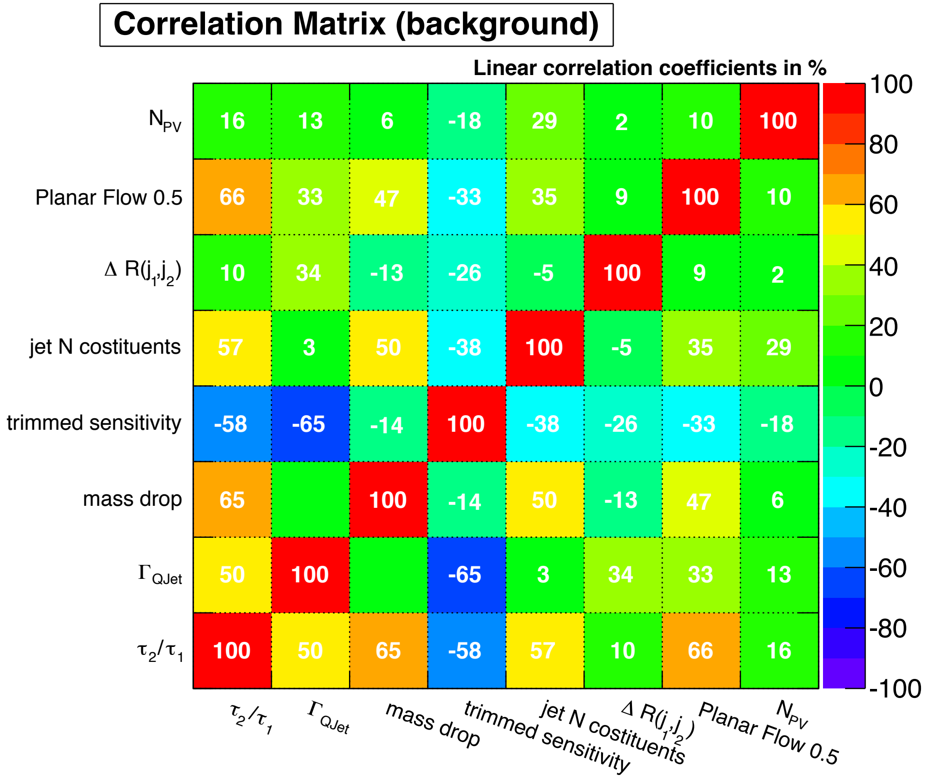
# MVA correlations



**Correlation Matrix (signal)**

Linear correlation coefficients in %

| | $\tau_2/\tau_1$ | $\Gamma_{Qjet}$ | mass drop | trimmed sensitivity | jet N constituents | $\Delta$ R $(j_1,j_2)$ | Planar Flow 0.5 | $N_{PV}$ |
|---|---|---|---|---|---|---|---|---|
| $N_{PV}$ | 10 | 8 | 4 | -17 | 31 | | 6 | 100 |
| Planar Flow 0.5 | 64 | 27 | 53 | -24 | 39 | 4 | 100 | 6 |
| $\Delta$ R $(j_1,j_2)$ | 4 | 20 | -10 | -16 | -1 | 100 | 4 | |
| jet N constituents | 63 | 24 | 47 | -53 | 100 | -1 | 39 | 31 |
| trimmed sensitivity | -47 | -57 | -14 | 100 | -53 | -16 | -24 | -17 |
| mass drop | 72 | 14 | 100 | -14 | 47 | -10 | 53 | 4 |
| $\Gamma_{Qjet}$ | 48 | 100 | 14 | -57 | 24 | 20 | 27 | 8 |
| $\tau_2/\tau_1$ | 100 | 48 | 72 | -47 | 63 | 4 | 64 | 10 |



**Correlation Matrix (background)**

Linear correlation coefficients in %

| | $\tau_2/\tau_1$ | $\Gamma_{QJet}$ | mass drop | trimmed sensitivity | jet N costituents | $\Delta$ R$(j_1,j_2)$ | Planar Flow 0.5 | $N_{PV}$ |
|---|---|---|---|---|---|---|---|---|
| $N_{PV}$ | 16 | 13 | 6 | -18 | 29 | 2 | 10 | 100 |
| Planar Flow 0.5 | 66 | 33 | 47 | -33 | 35 | 9 | 100 | 10 |
| $\Delta$ R$(j_1,j_2)$ | 10 | 34 | -13 | -26 | -5 | 100 | 9 | 2 |
| jet N costituents | 57 | 3 | 50 | -38 | 100 | -5 | 35 | 29 |
| trimmed sensitivity | -58 | -65 | -14 | 100 | -38 | -26 | -33 | -18 |
| mass drop | 65 | | 100 | -14 | 50 | -13 | 47 | 6 |
| $\Gamma_{QJet}$ | 50 | 100 | | -65 | 3 | 34 | 33 | 13 |
| $\tau_2/\tau_1$ | 100 | 50 | 65 | -58 | 57 | 10 | 66 | 16 |