Study of Higgs boson production in the ZZ and WW decay channels at CMS

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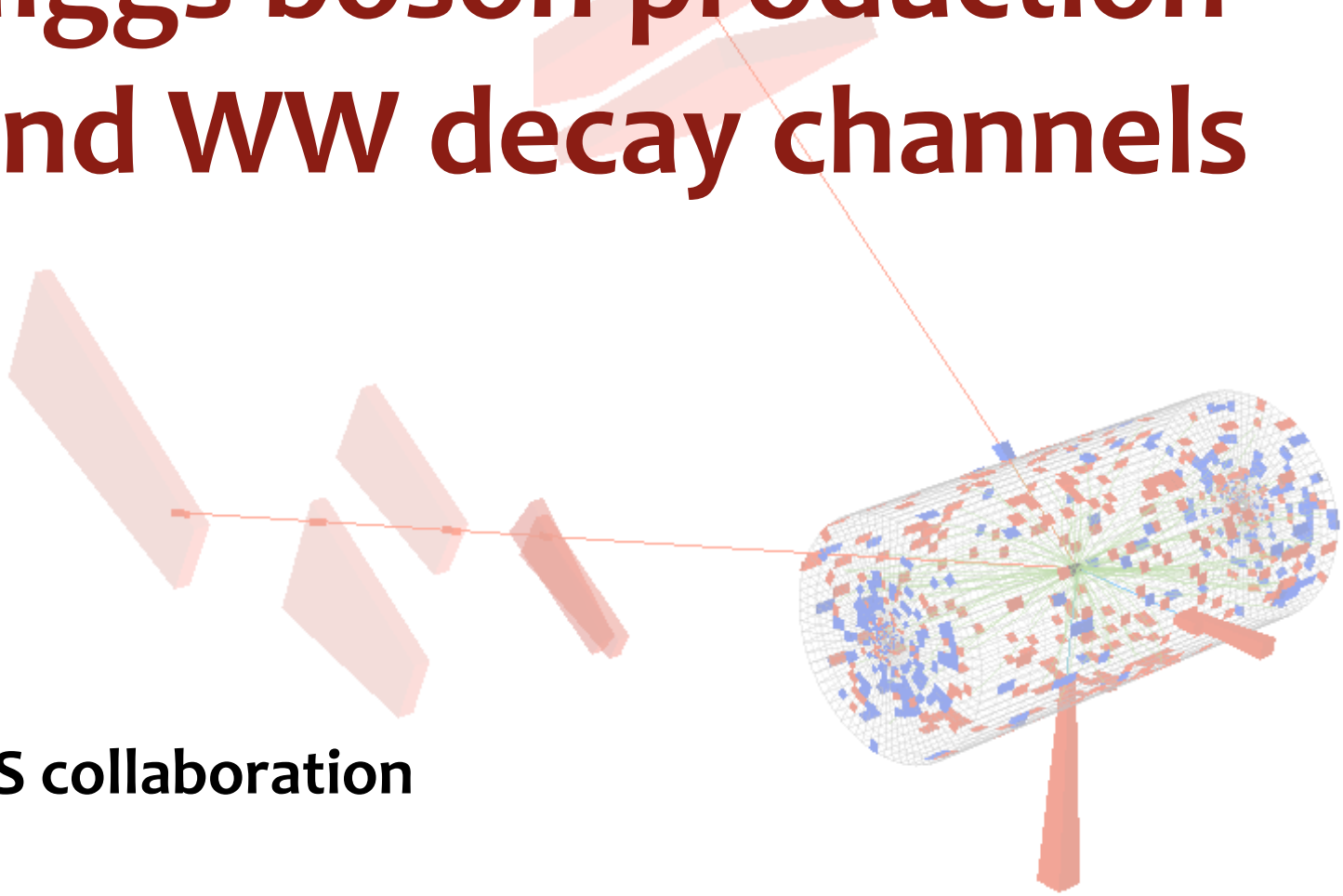
CERN

on behalf of the **CMS collaboration**



The 2013 European Physical Society Conference on High Energy Physics

Stockholm, Sweden. 18-24 July.

In this talk

The analyses which explore the

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ and $H \rightarrow WW^{(*)} \rightarrow 2l2\upsilon$ decays

with enough sensitivity in the low mass Higgs sector

to contribute to the discovery

and properties measurement

of the H(125) boson will be described

+

NEW! Latest news on the combined results of all the

ZZ channels searching for

additional SM higgs-like bosons

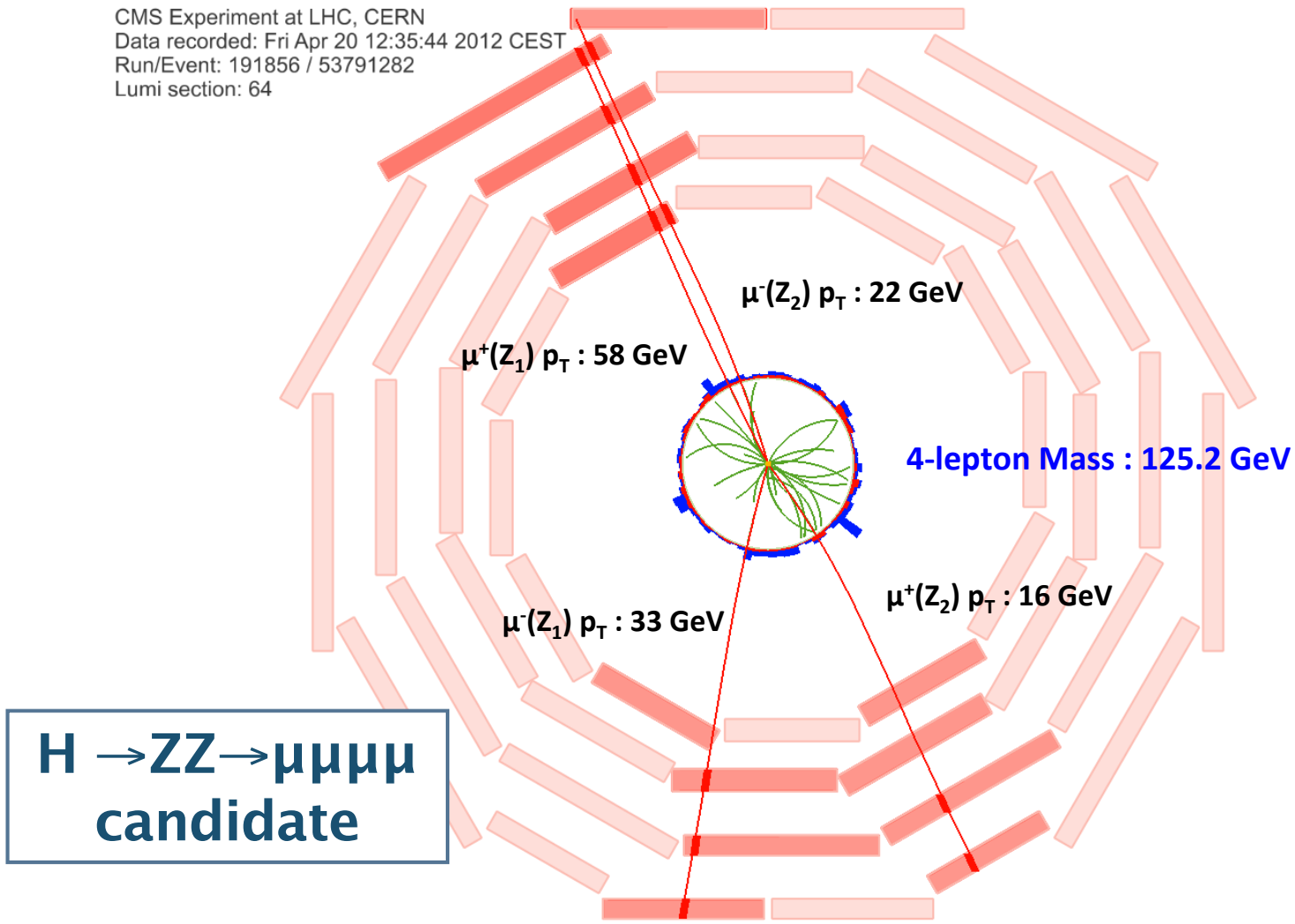
in the high mass region

Contributors

H decay	Prod-Tag	m_H range [GeV]	Lumi (fb^{-1}) [7/8 TeV]
ZZ→4l	**0/1-jets**	110-1000	5.0 / 19.6
	≥2jets	110-1000	5.0 / 19.6
WW→lνlν	**0/1-jets**	110-600	4.9 / 19.6
	VBF-tag	110-600	4.9 / 12.1
	WH-tag	110-200	4.9 / 19.6
	VH-tag	**110-300**	**4.9 / 19.6**

New analysis.
All other results already shown at Moriond 2013

$H \rightarrow ZZ^{(*)} \rightarrow 4l$



H →ZZ→μμμμ candidate

CMS-PAS-HIG-13-002

Analysis Overview

- Search for a **narrow peak in the 4l mass spectrum** on top of a flat and small bkg

- **The must:** high **efficiency** in lepton reco and ID, excellent **precision** in lepton energy-momentum measurement
  - mass resolution @125 GeV **~ 1/2%**

- Events are categorized based on jets multeplicity

- Additional help from **kinematic discriminant** based on angles between leptons

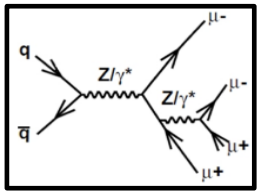
✓ Mass peak from a clean experimental signature

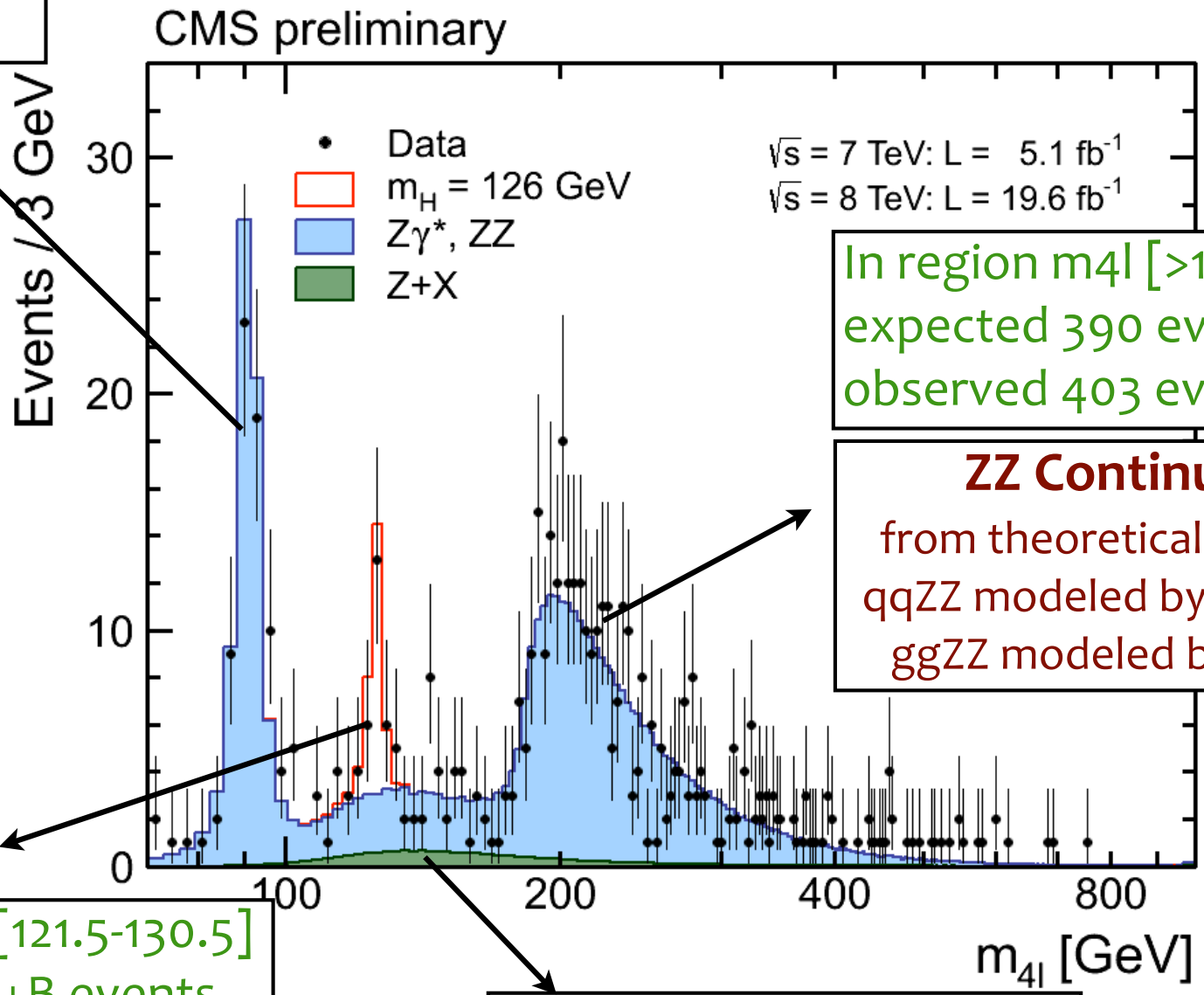
✓ High S/B

✗ Small Rate

m_{4l} Spectrum

Z->4l peak good DATA/MC agreement





In region m4l [>140]
expected 390 events
observed 403 events

ZZ Continuum
from theoretical Xsection
qqZZ modeled by POWHEG
ggZZ modeled by GG2ZZ

H_{125}

In region m4l [121.5-130.5]
expected **28** S+B events
observed **25**

Z+X Background
from data driven estimates
based on fake-rate method

Jet categories

Goal: sensitivity to VVH and ffH couplings (μ_F-μ_V)

events are splitted in two exclusive categories

category I - di-jets

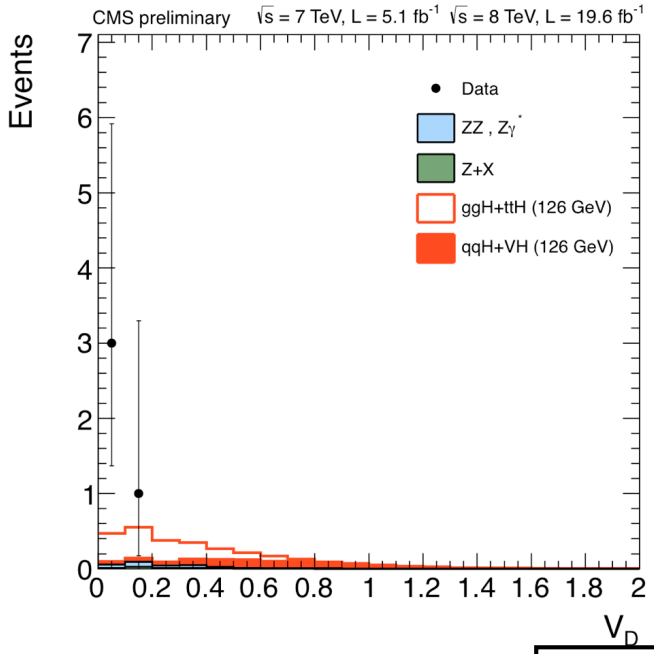
- Events with >= 2 Jets (pT>30)
- ~ 20% of signal events are VBF ones

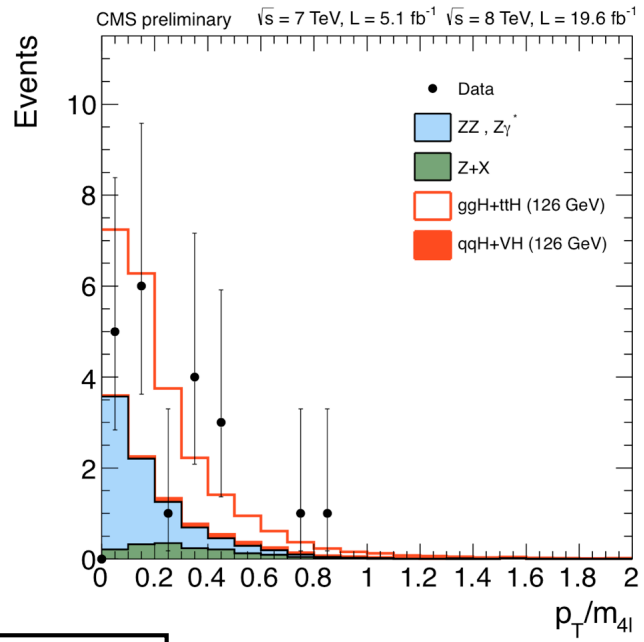
category II - untagged

- All the other events
- < 5% of signal events are VBF

Add an extra-dimension to the analysis to separate the Higgs production mechanisms

- VD (VBF Discriminant): $\alpha \times |\Delta\eta_{jj}| + \beta \times m_{jj}$
- pT(4l)/m(4l) (used only for m_H<180)





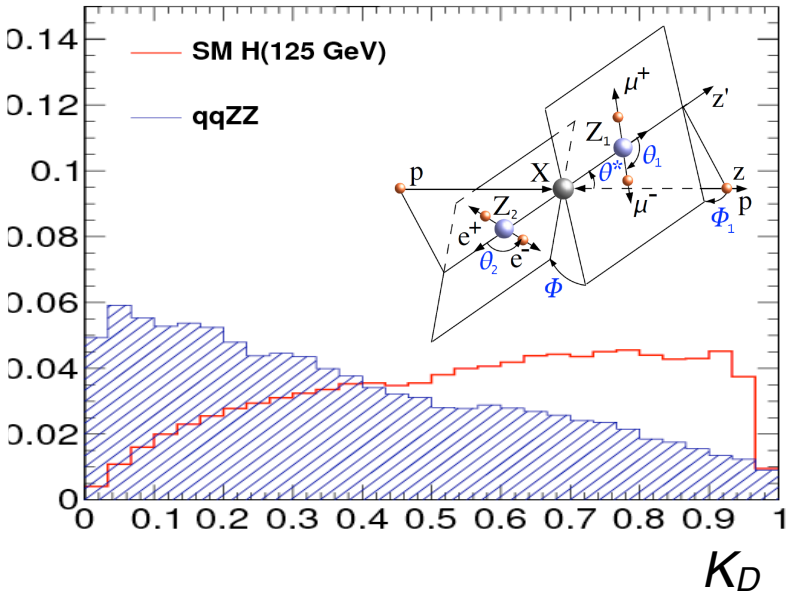
In region m4l [121.5-130.5]

Kinematic discriminant(s)

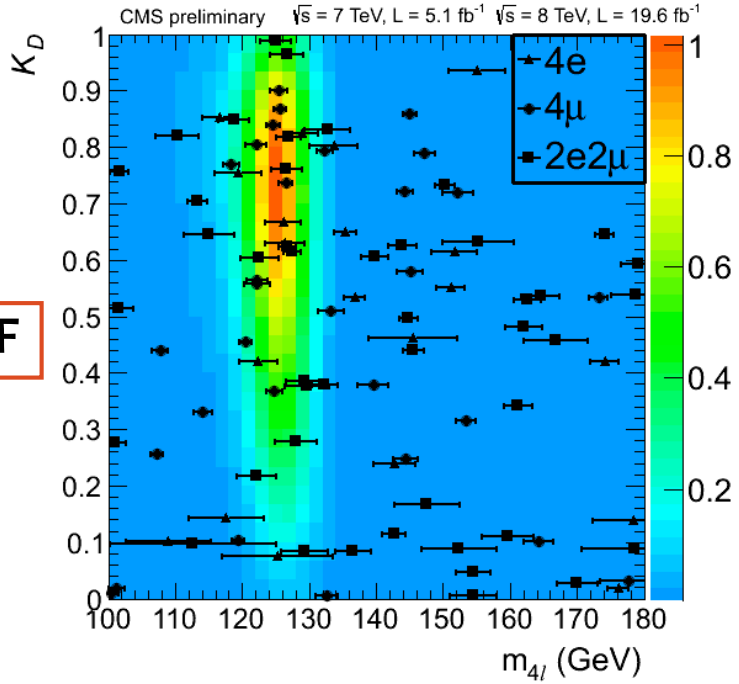
- **Add an extra-dimension** to the analysis to exploit kinematic differences of the Higgs boson decay with respect to the ZZ bkg
  - the **kinematic discriminant (K_D)**

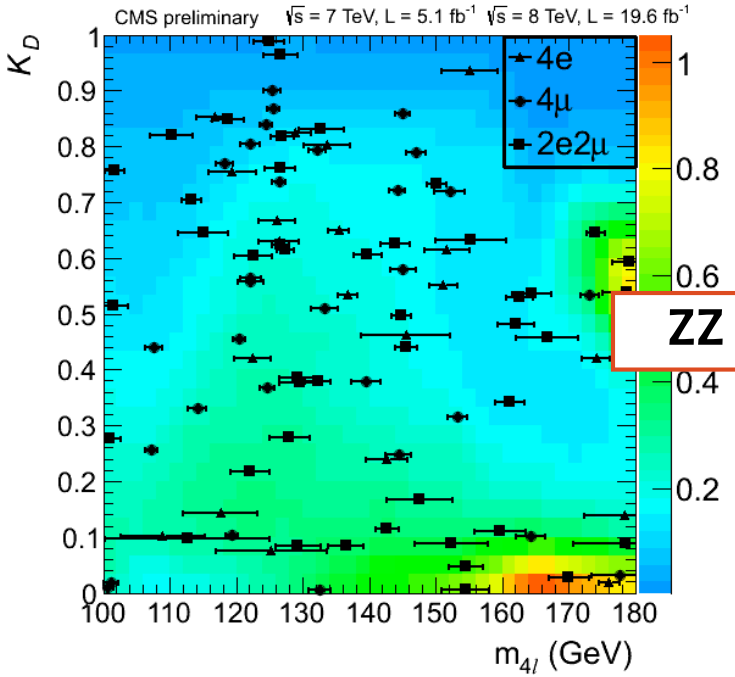
$$\left[1 + \frac{\mathcal{P}_{\rm bkg}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\rm sig}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

- Matrix Element techniques used to build **K_D**



H(126) 2D PDF





ZZ 2D PDF

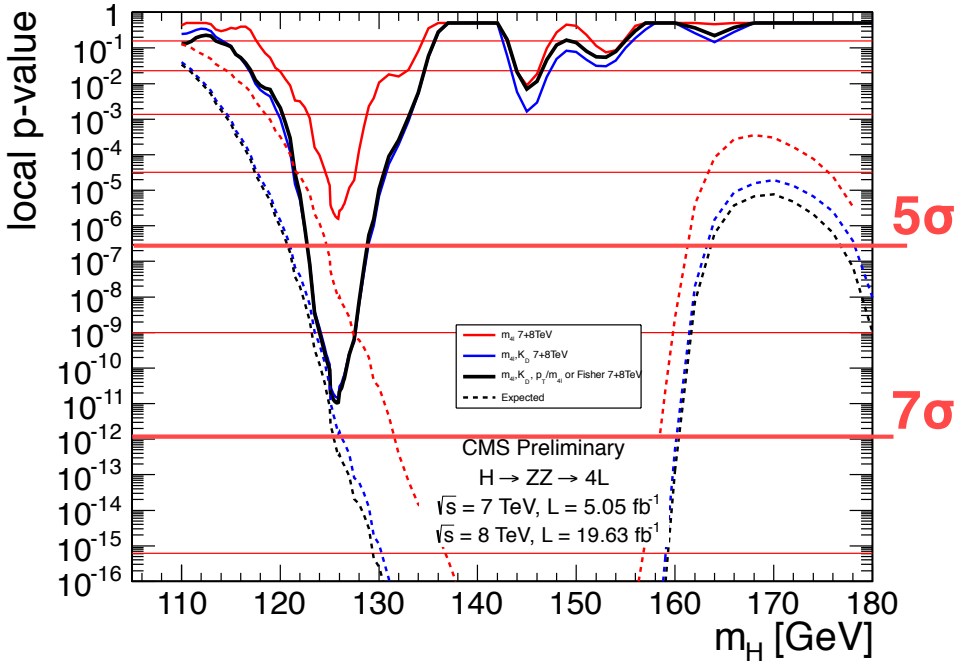
Significance

Factorize 3D model:

category I: $\mathbf{P(m_{4l}, K_D, p_T/m_{4l}) = P(V_D|m_{4l}) \times P(K_D|m_{4l}) \times P(m_{4l})}$

category II: $\mathbf{P(m_{4l}, K_D, p_T/m_{4l}) = P(p_T/m_{4l}|m_{4l}) \times P(K_D|m_{4l}) \times P(m_{4l})}$

Binned 2D MC templates | Unbinned mass model

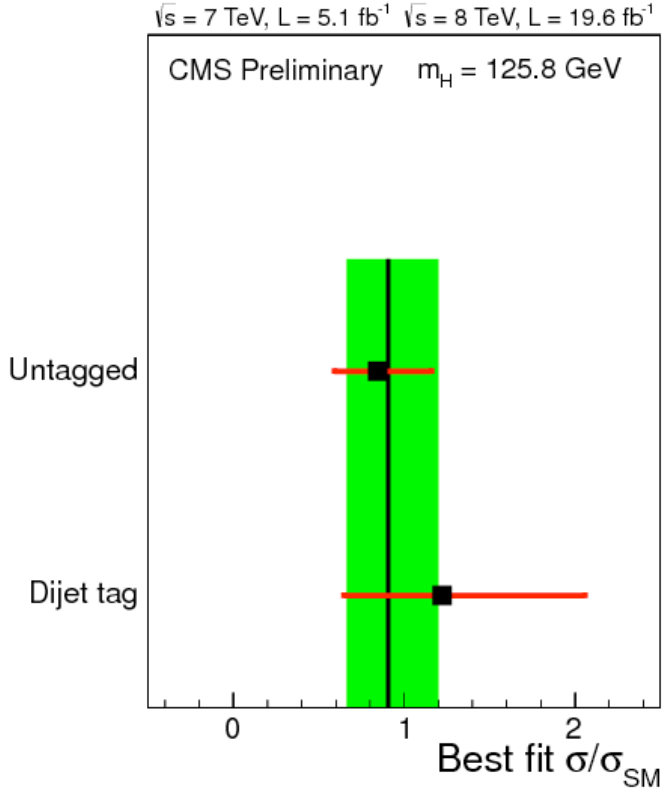


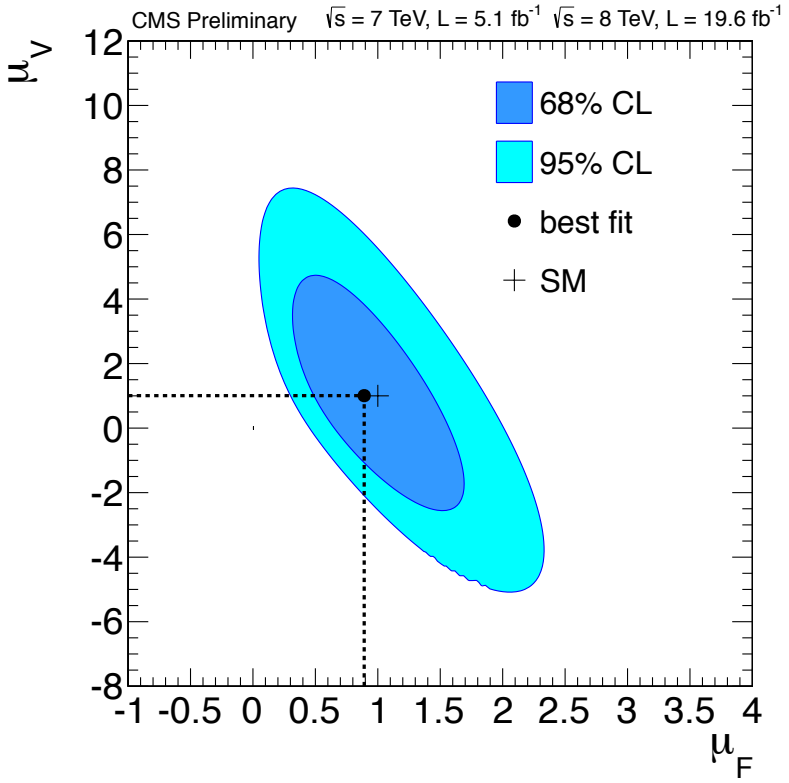
	Expected	Observed
3D (m_{4l}, K_D, V_D or p_T/m_{4l})	7.2 σ	6.7 σ
2D (m_{4l}, K_D)	6.9 σ	6.6 σ
1D(m_{4l})	5.6 σ	4.7 σ

@ m_H=125.8 GeV (minimum of local p-value)

No other excess of events is observed over the full accessible mass range (up to 1 TeV)

σ/σ_{SM}





$\sigma/\sigma_{SM}(\mu) = 0.9\ ^{+0.3}_{-0.2}$

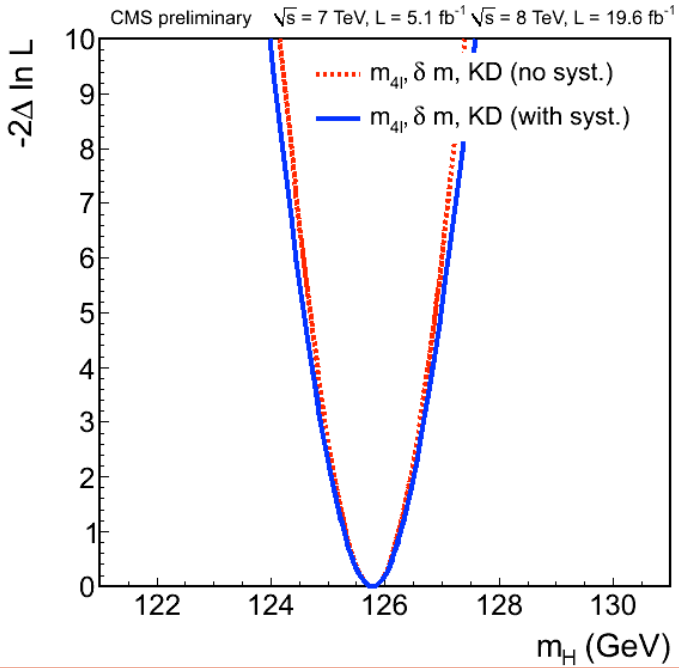
μ_V (qqH, ZH, WH) $= 1.0\ ^{+2.4}_{-2.3}$

μ_F (gg->H, ttH) $= 0.9\ ^{+0.5}_{-0.4}$

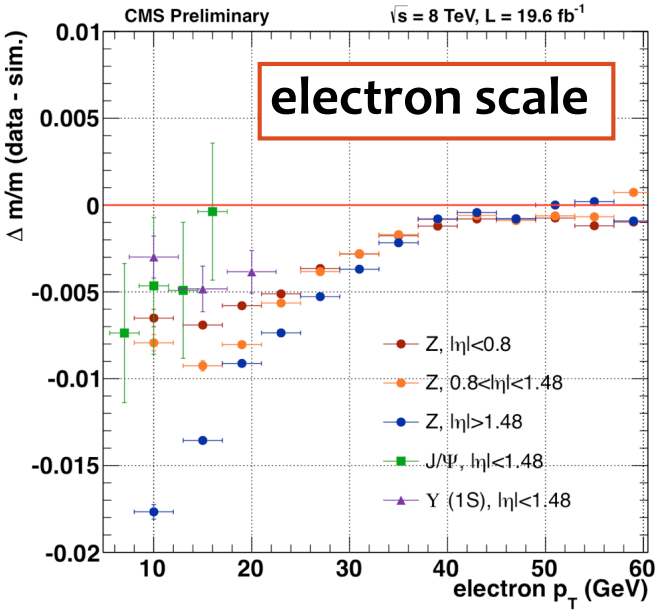
@ m_H=125.8 GeV
(best measured mass - see next slides)

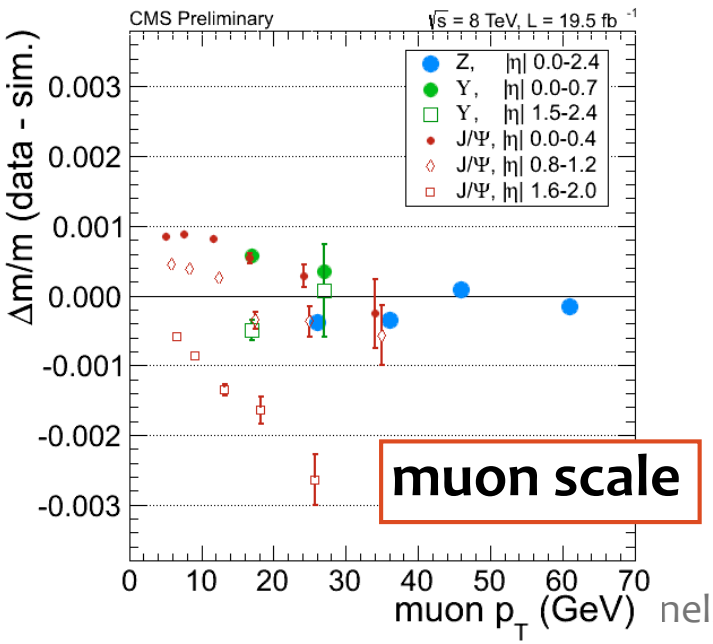
Mass measurement

- Measurement performed with a 3-dimensional fit using for each event:
  - **m4l, associated per-event mass error, K_D**
- The usage of events with individually determined mass resolutions brings **8% improvement**
- Scale and resolution calibrated and validated with Z/Jpsi→ll, Z→4l events
  - **0.1-0.3% uncert. on the 4l mass scale**
  - **20% uncert. on the 4l mass resolution**

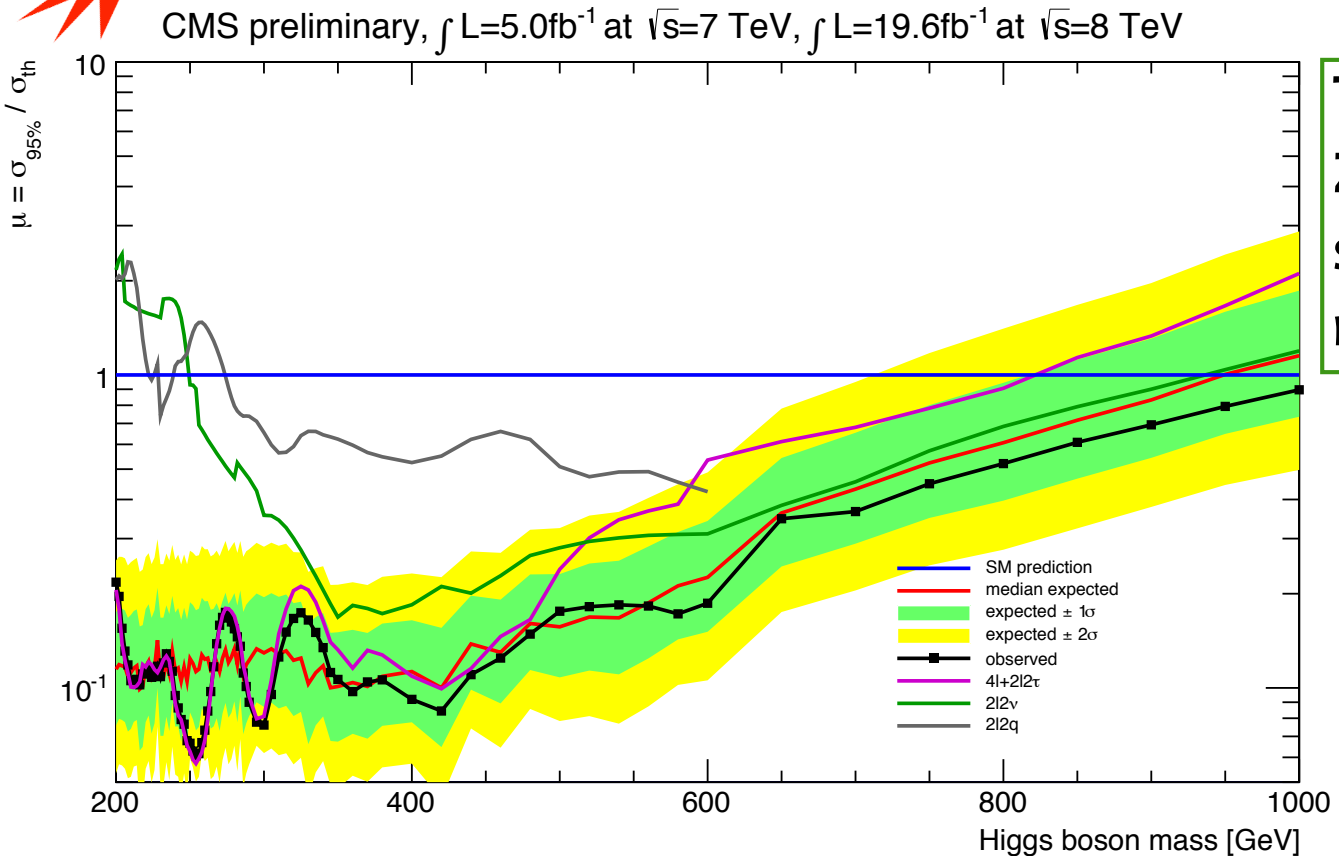


m_H =125.8 ± 0.5 (stat.) ± 0.2 (syst) GeV





News from the high mass search



The global effort of all the ZZ channels completed the search in the high-mass region [200-1000] GeV

Exclusion ranges

ZZ->4l + ZZ->2l2τ : **130-827** (113.5-778) obs (exp) [Moriond results]

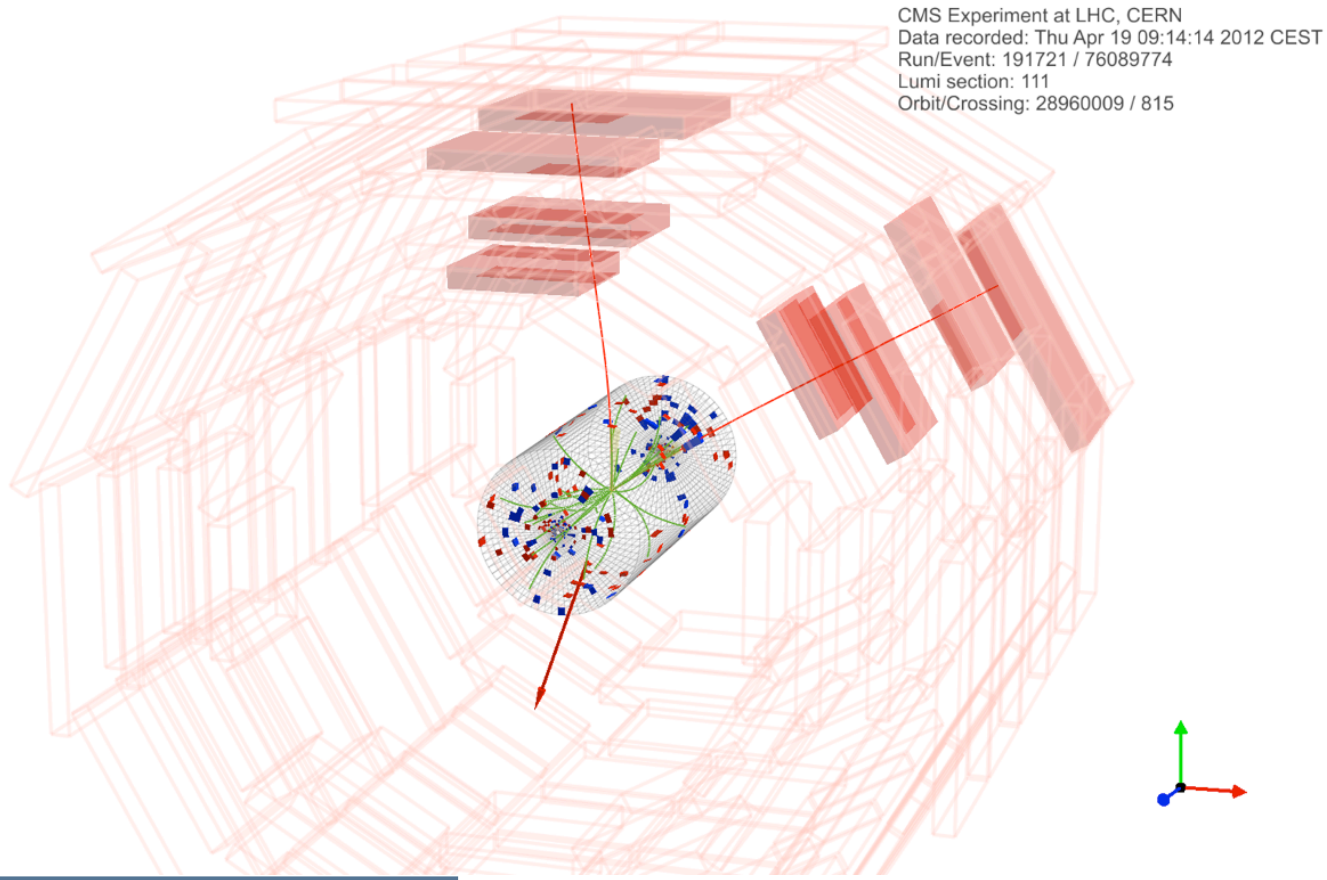
ZZ->2l2υ : **248-930** (254-898) [**new** update - full 7+8 TeV dataset]

ZZ->2l2q : **290-600** (266-600) [**new** update - full 7+8 TeV dataset]

COMBINED: 200-1000 (200-950) obs (exp)

CMS-PAS-HIG-13-014
CMS-PAS-HIG-12-024

$H \rightarrow WW^{(*)} \rightarrow 2l2\upsilon$, 0/1 jets



$H \rightarrow WW \rightarrow \nu\mu\nu\mu$ candidate

CMS-PAS-HIG-13-003

Analysis Overview

- Search for an excess of events **with two opposite sign isolated leptons (e, μ) and large missing energy.** Events split in categories
  - According to the exclusive **jet multiplicity: 0, 1**
  - And further separated in **SF and DF** in each jet multiplicity

✓ Large BR and clean final state

- The analysis challenge: understanding the backgrounds
  - DATA DRIVEN methods for reducible bkg: **tt/tW, W+jets, Z/Υ*->ll, Z/γ*->ττ**
  - **WZ/ZZ, V+γ(*)** from MC
  - **WW** fit to data in sidebands

✗ No mass peak

Analysis Strategy

Almost common **preselection** for all the events based on background rejection cuts:
mll cut, pT(ll), Z-peak veto, extra-lepton veto, B-veto, Z/Y* rejection MVA (MET)

Signal extraction: for SF categories

cut-based approach: m_H dependent cuts common to 0, 1 jets categories

variables: **$\Delta\varphi(ll)$, $p_T(l_{max})$, $p_T(l_{min})$, m_{ll}, m_T**

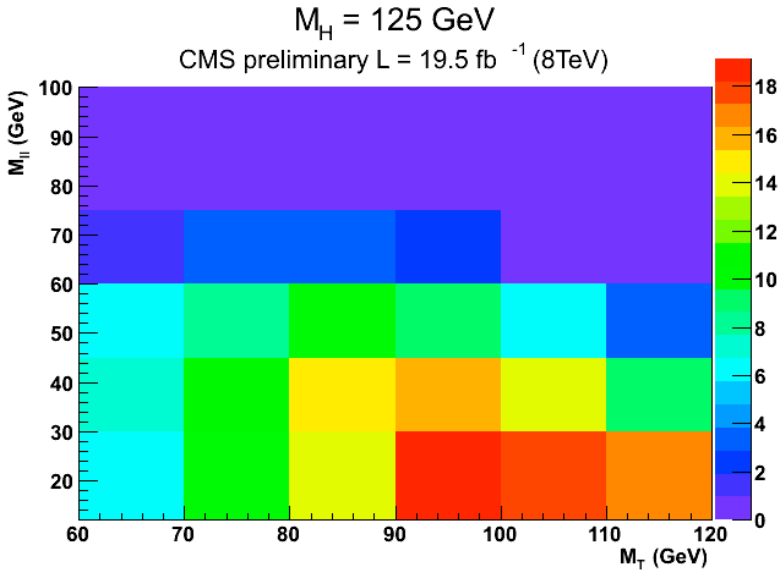
$$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{\text{miss}} \left(1 - \cos \Delta\phi_{E_T^{\text{miss}}\ell\ell}\right)}$$

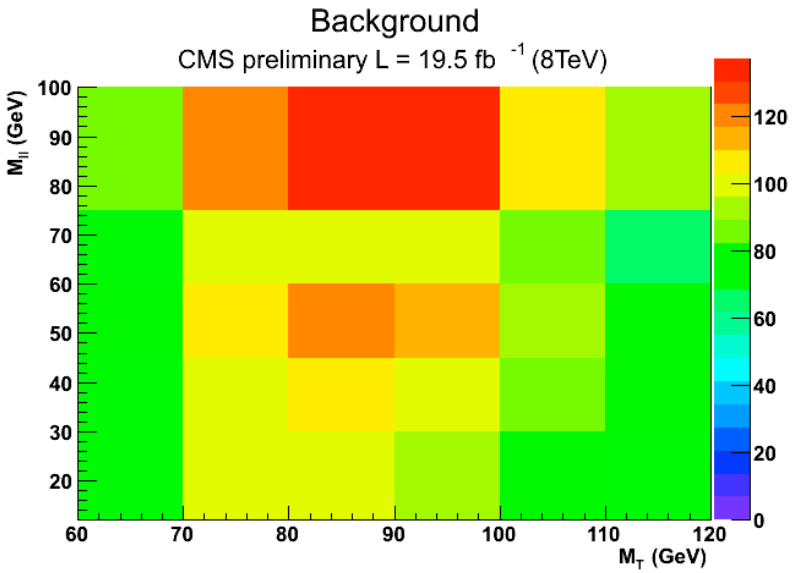
Signal extraction: for DF categories

two-dimensional shape analysis approach:

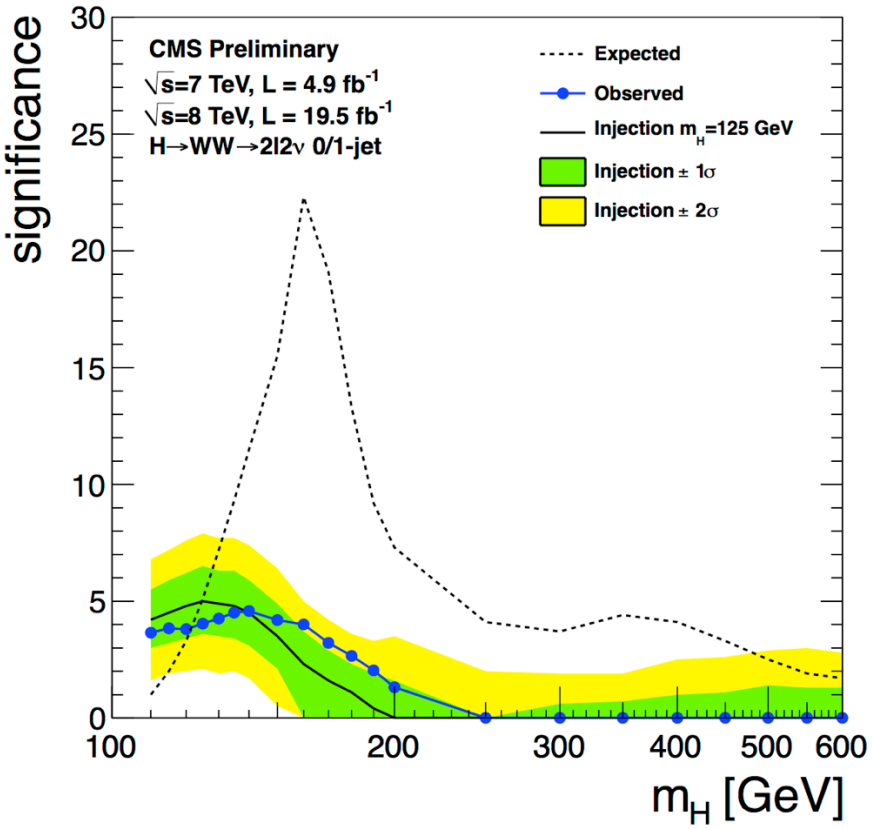
Relaxed selection with respect to cut-based

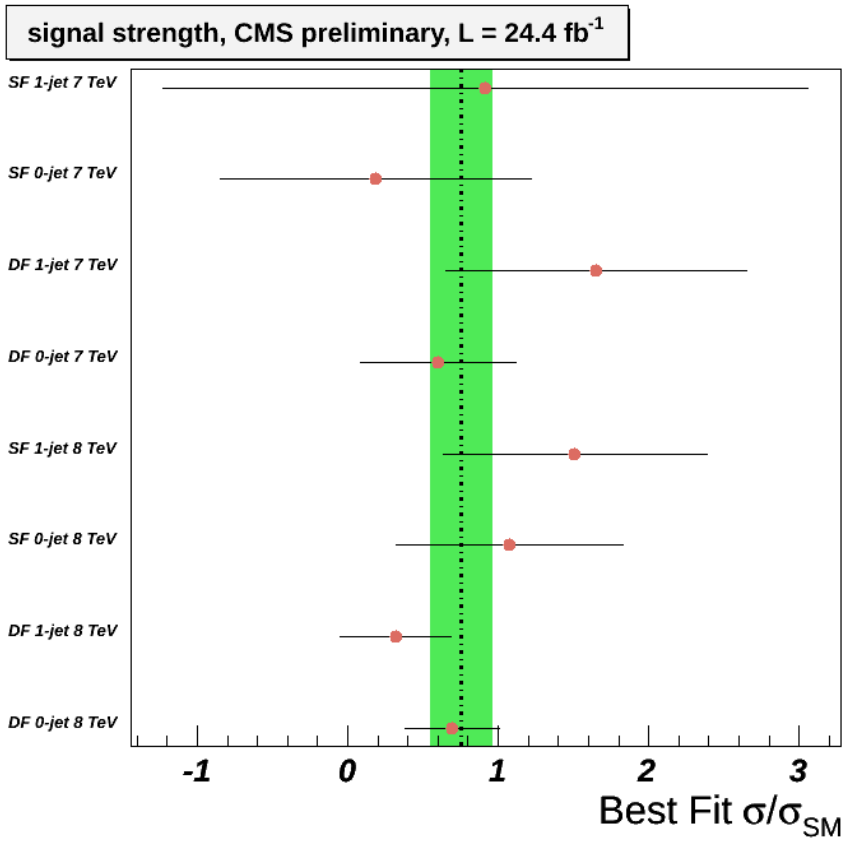
Exploit the 2D correlation of two kinematic variables: m_{ll} and m_T





Significance and σ/σ_{SM}





4.0 (5.1) obs (exp) significance @ m_H = 125 GeV

Poor mass resolution, broad excess

σ/σ_{SM} (μ) = 0.8 ± 0.2

Consistent results among the different exclusive final states

No other excess of events is observed over the full accessible mass range. Additional standard model Higgs-like bosons are excluded in the mass range **128-600 GeV** @ 95% CL.

VH and VBF tags

VH, H->WW->2l2υ + V->jj

NEW!

- Same event preselection as the 0/1 jets analysis plus:
  - **2 additional jets with pT>30 and $|\eta|<2.5$, $\Delta\varphi(ll,jj)<165°$, $65<m(jj)<105$**
  - 30% VH, 60% ggH, 10% VBF @ m_H=125 GeV
- Cut-based approach: m_H dependent cuts on **$\Delta R(ll)$, m_{ll}, m_T** variables
- 95% CL UL on σ/σ_{SM} @ 125 GeV: **5.0 (4.2) obs (exp)**

CMS-PAS-HIG-13-017

WH, H->WW->2l2υ + W->lυ

- Look for 3 isolated leptons (e, μ) and large missing energy
  - two categories according to the presence of an **OSSF pair or not**
- **Z-veto and b-veto** to reject WZ and top backgrounds
- Results extracted with a shape based approach based on **$dR(l^+l'^-)$**
- 95% CL UL on σ/σ_{SM} @ 125 GeV: **3.3 (3.0) obs (exp)**

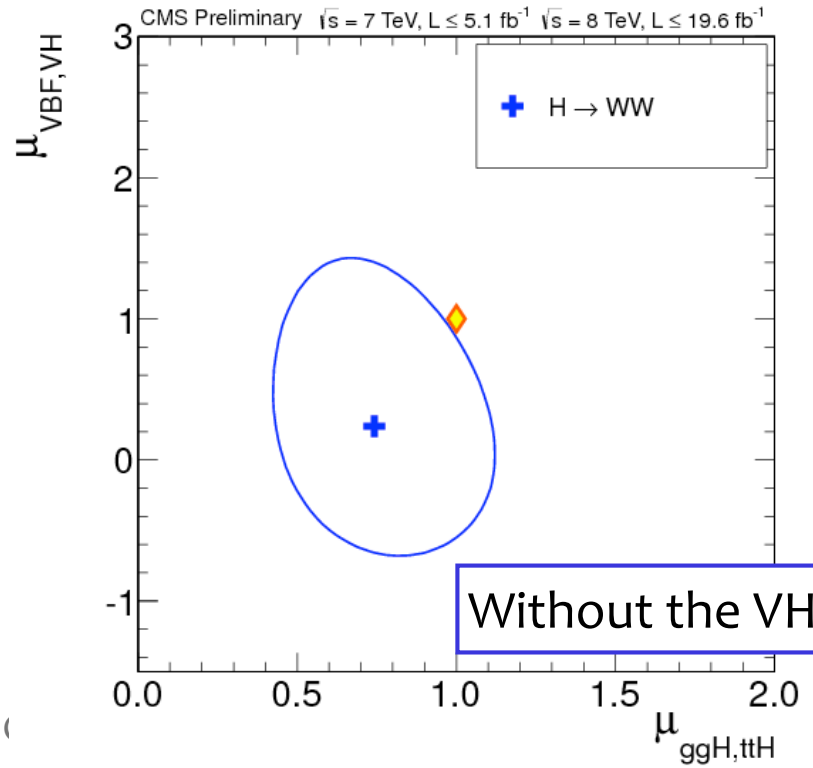
CMS-PAS-HIG-13-009

VH and VBF tags (2)

qqH, H->WW->2l2υ + (jj)$_{VBF}$

- One additional cut-based category of the 0/1 jet analysis with a **VBF tag**
  - **2 (or 3 jets), two leading with pT>30 GeV, no other pT>30 GeV jet in the pseudorapidity region between the two jets, $|\Delta\eta(jj)|>3.5$, $m_{jj}>500$ GeV**
  - 80% VBF, 20% ggH
  - events are split in DF and SF only for the 8 TeV data, only 12.1 fb^{-1} of 8TeV data used

CMS-PAS-HIG-12-042



The VBF-tag (together with the VH-tags) analysis helps to separate the Higgs production mechanisms:

μ_V (qqH, ZH, WH) = **0.2** $^{+0.7}_{-0.6}$

μ_F (gg->H, ttH) = **0.7** $^{+0.2}_{-0.2}$

Without the VH,V→jj analysis

CMS-PAS-HIG-13-005

Conclusions

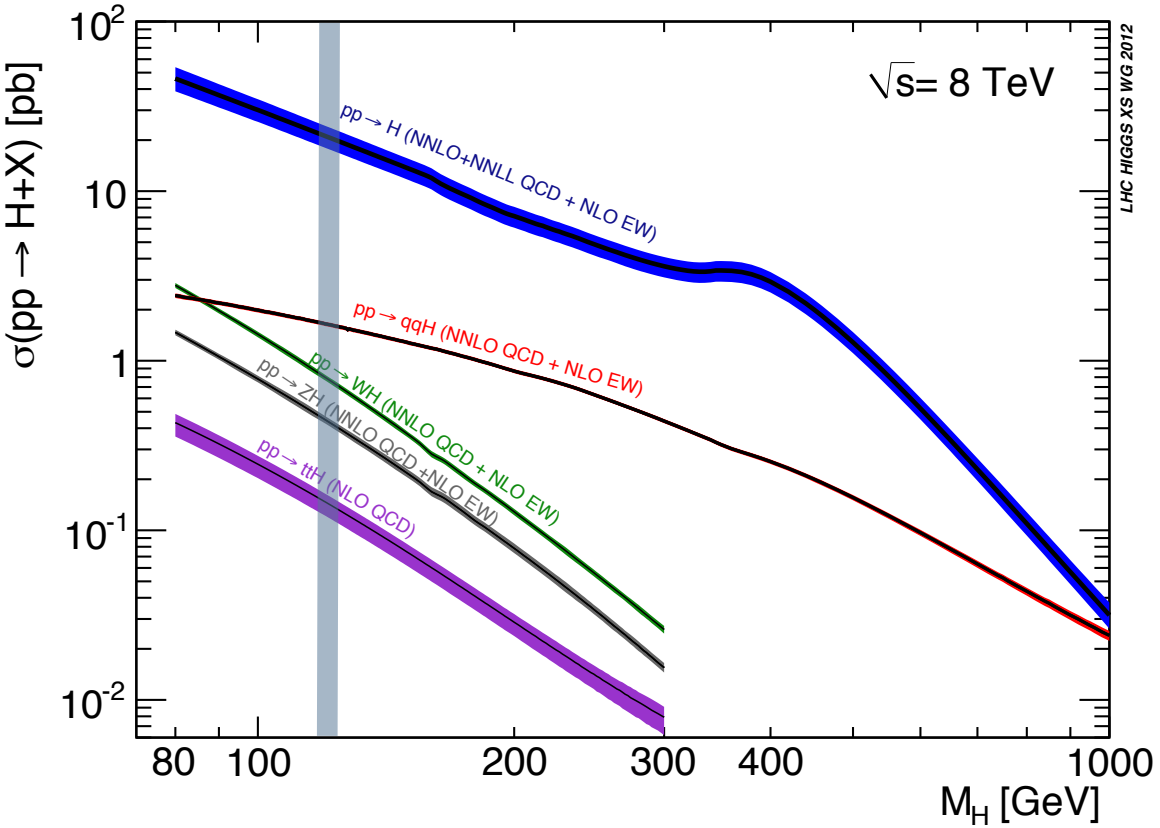
- Results from the **H→ZZ→4l** analysis with full dataset:
  - **6.7 (7.2) s.d. observed (expected) significance**
  - **$\sigma/\sigma_{SM}(\mu) = 0.9\ ^{+0.3}\ _{-0.2}$**
- Results from the **H→WW→2l2υ** analysis with full dataset:
  - **4.0 (5.1) s.d. observed (expected) significance**
  - **$\sigma/\sigma_{SM}(\mu) = 0.8\ ^{+0.2}\ _{-0.2}$**
- H→ZZ→4l **properties measurement:**
  - **m_H =125.8 ± 0.5 (stat.) ± 0.2 (syst) GeV**
  - **$\mu_V = 1.0\ ^{+2.4}\ _{-2.3}$ - $\mu_F = 0.9\ ^{+0.5}\ _{-0.4}$**
- H→WW→2lυ **properties measurement:**
  - **$\mu_V = 0.2\ ^{+0.7}\ _{-0.6}$ - $\mu_F = 0.9\ ^{+0.5}\ _{-0.4}$**

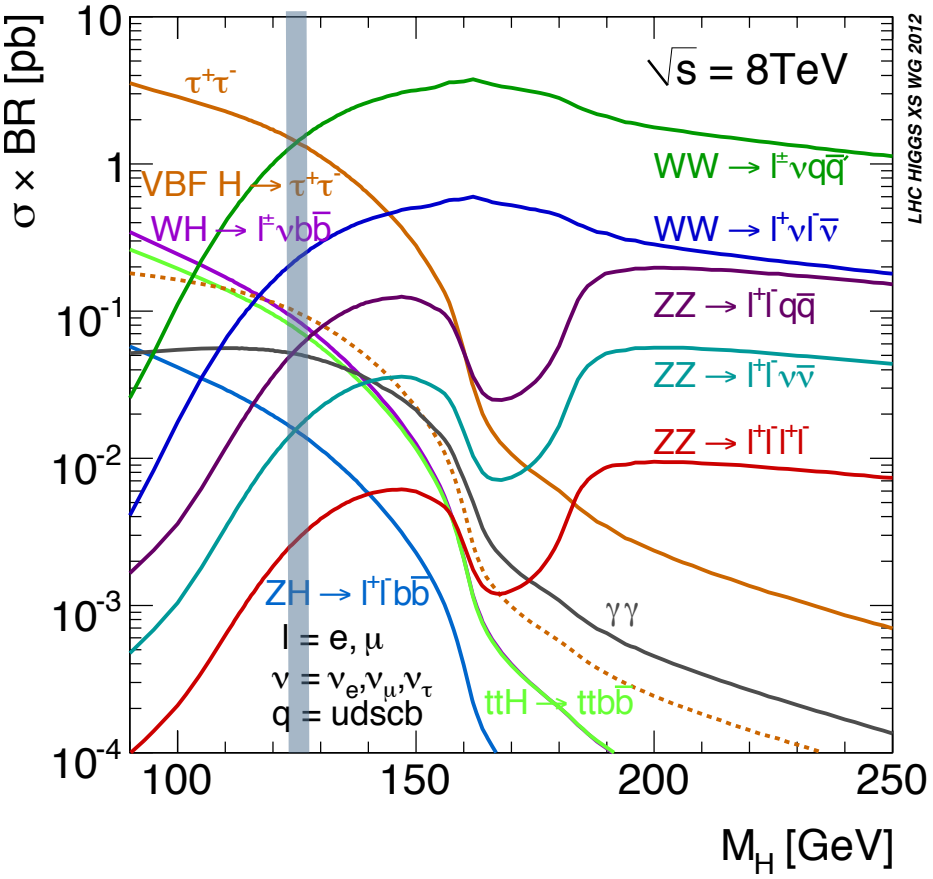
For SPIN separation analyses, both in H→ZZ and H→WW channels, see Josh Bendavid's talk on Friday

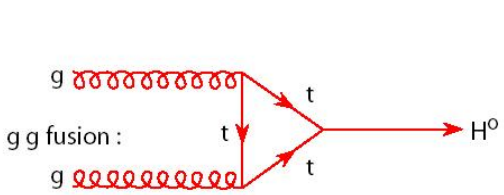
- **So far all the measurements in the ZZ and WW channels of the H(125) boson are consistent with the SM prediction**
- **Additional SM-like higgs boson are excluded up to 1 TeV**

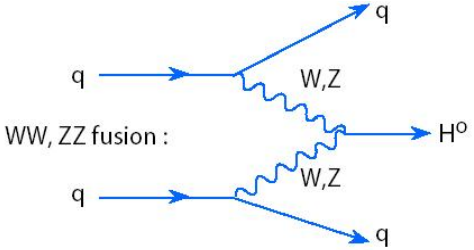
Backup

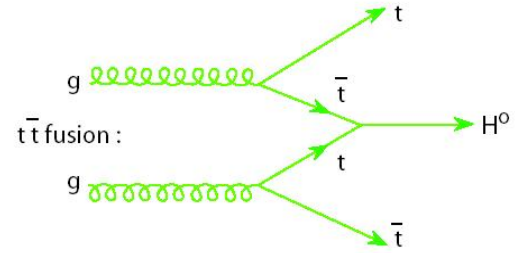
σ and BRs


√s= 8 TeV
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD + NLO EW)
pp → WH (NNLO QCD + NLO EW)
pp → ZH (NNLO QCD +NLO EW)
pp → ttH (NLO QCD)
σ(pp → H+X) [pb]
M_H [GeV]
LHC HIGGS XS WG 2012


√s = 8TeV
τ⁺τ⁻
VBF H → τ⁺τ⁻
WH → l±νbb̄
WW → l±νqq̄
WW → l⁺νl⁻ν̄
ZZ → l⁺l⁻qq̄
ZZ → l⁺l⁻νν̄
ZZ → l⁺l⁻l⁺l⁻
ZH → l⁺l⁻bb̄
l = e, μ
ν = νe,νμ,ντ
q = udscb
γγ
ttH → ttbb̄
σ × BR [pb]
M_H [GeV]
LHC HIGGS XS WG 2012


g
g g fusion :
g
t
t
t
H⁰


q
q
WW, ZZ fusion :
q
q
W,Z
W,Z
H⁰


g
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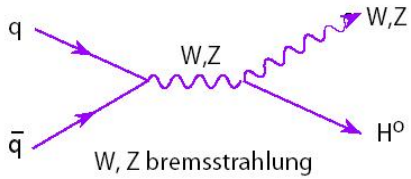

q
q̄
W,Z
W,Z
H⁰
W, Z bremsstrahlung

Contributors: More details

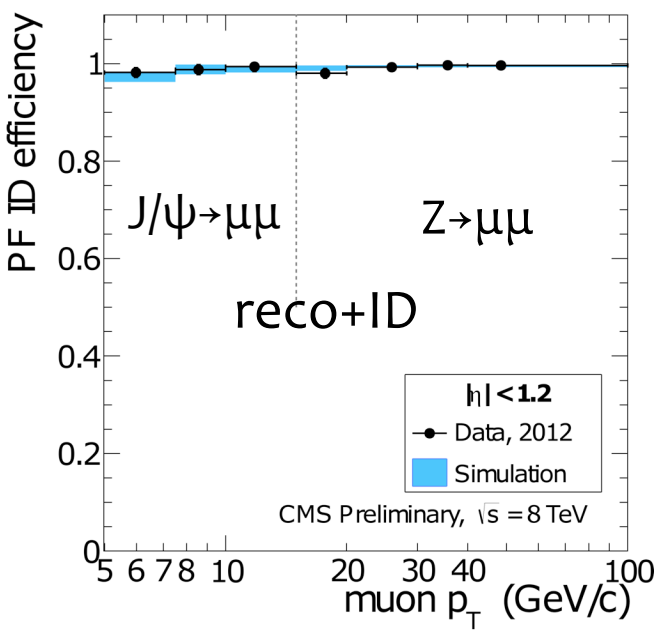
H decay	Prod-Tag	Exclusive Final States	No. chan	m_H range [GeV]	Lumi (fb^{-1}) [7/8 TeV]
H→ZZ→4l	**0/1-jets**	4e, 4μ, 2e2μ	3 + 3	110-1000	5.0 - 19.6
	≥2jets	4e, 4μ, 2e2μ	3 + 3	110-1000	5.0 - 19.6
WW→lνlν	**0/1-jets**	(DF or SF dileptons) ⊗ (0 or 1jets)	4 + 4	110-600	4.9 - 19.6
	VBF-tag	DF or SF dilep for 8TeV	1 + 2	110-600	4.9 - 12.1
	WH-tag	OSSF and otherwise	2 + 2	110-200	4.9 - 19.6
	VH-tag	**DF or SF dileptons**	**2 + 2**	**110-300**	**4.9 - 19.6**

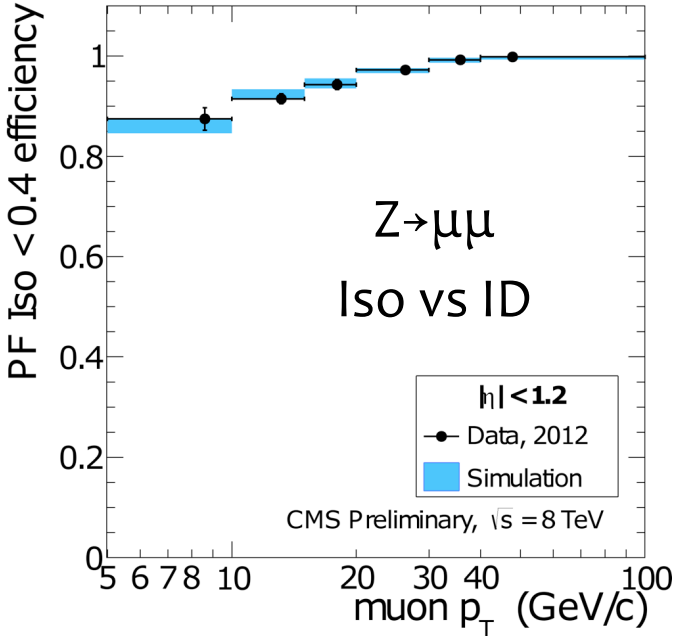
New analysis.
All other results already shown at Moriond 2013

Leptons Identification

Efficiency to select prompt isolated leptons

- reconstruction
- identification
- isolation
- IP requirement





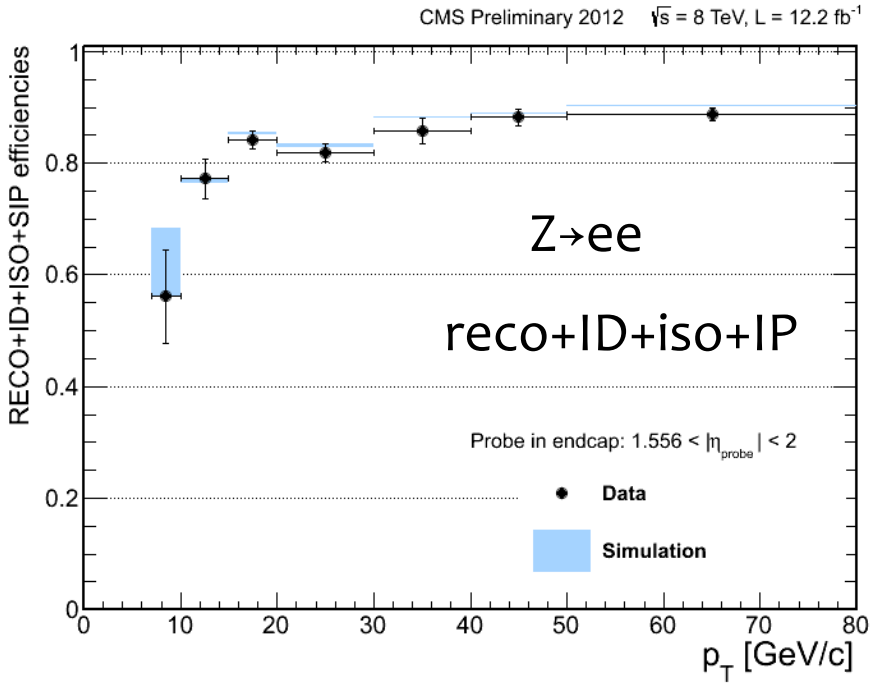
Muons

computed with TnP techniques

efficiency correction factor

muons: 0.98 - 1.03

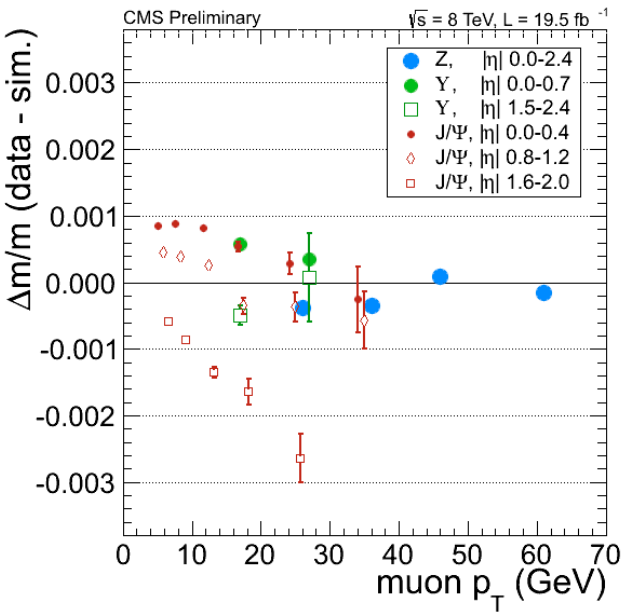
electrons: 0.84 - 1.01

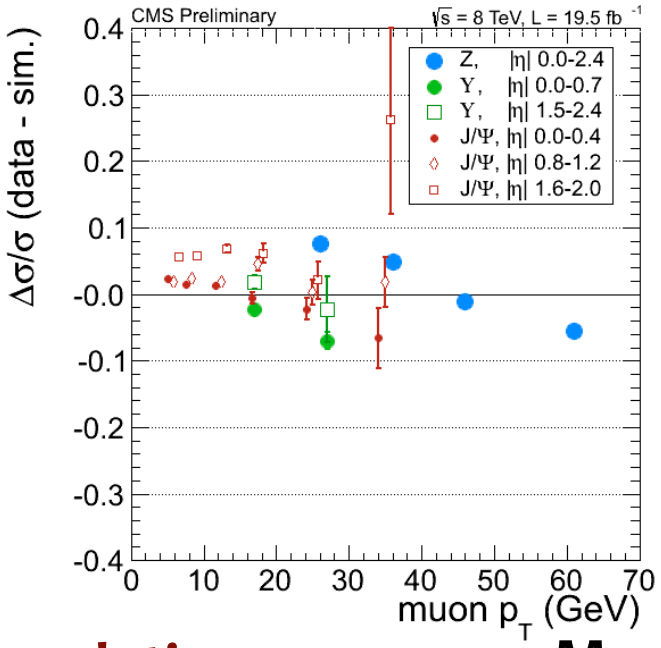


Electrons

Lepton Energy Scale and Resolution

Scale corrections on muon momentum obtained with a calibration procedure on Z->mm / J/psi -> mm events in data are applied MC is **smeared** to match the resolution in data





residual DATA/MC difference: ~ 0.1% in scale, 20% in resolution

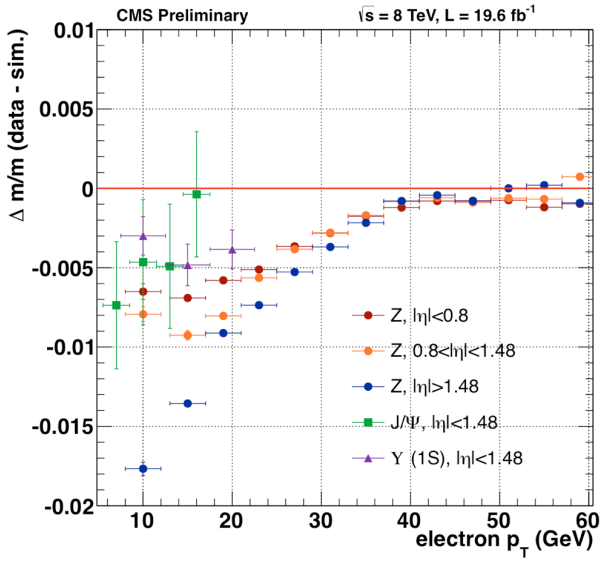
Muons

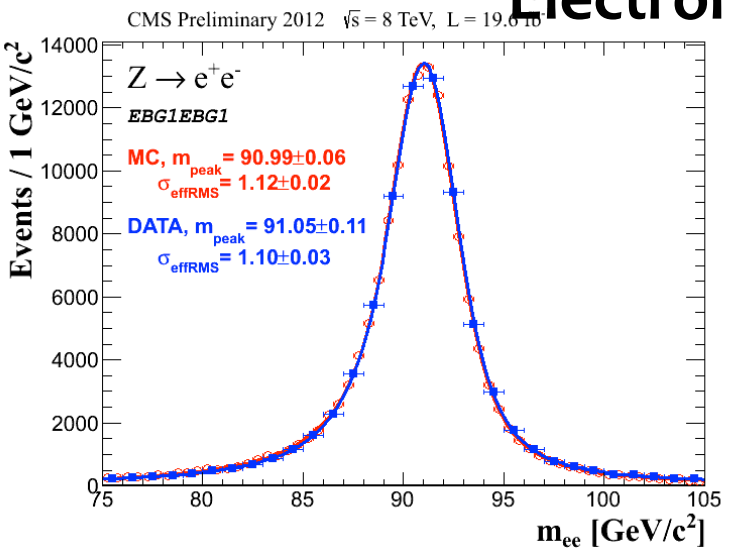
Electrons

The ECAL contribution to the electron momentum and its uncert is from an MVA regression approach:

10-15% improvements on resolution

Energy scale and MC smearing obtained from calibration with Z->ee events are then applied



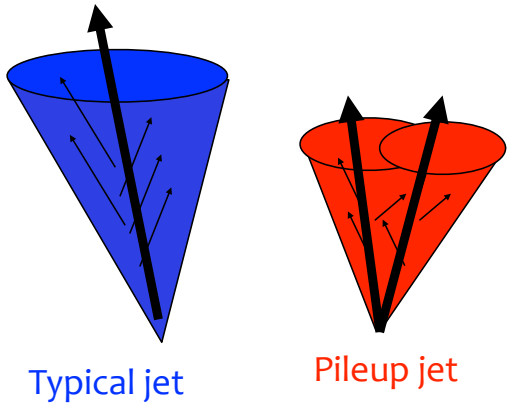


residual DATA/MC difference: ~ 0.4% in scale, 20% in resolution [conservative]

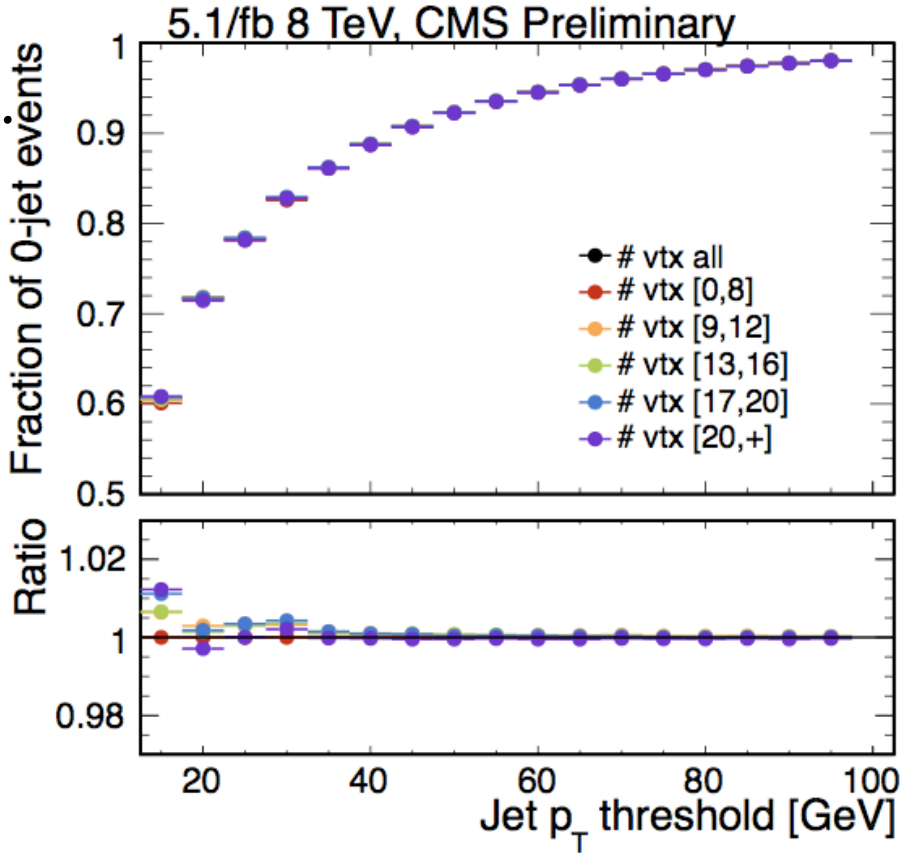
PileUP Jet tagging

PF reconstruction allows to **reject charged particles from PU** in jet building.

Additional: rejection of jets from PU also outside the tracker coverage, relying on jet shape variables.



Important in **VBF searches.**



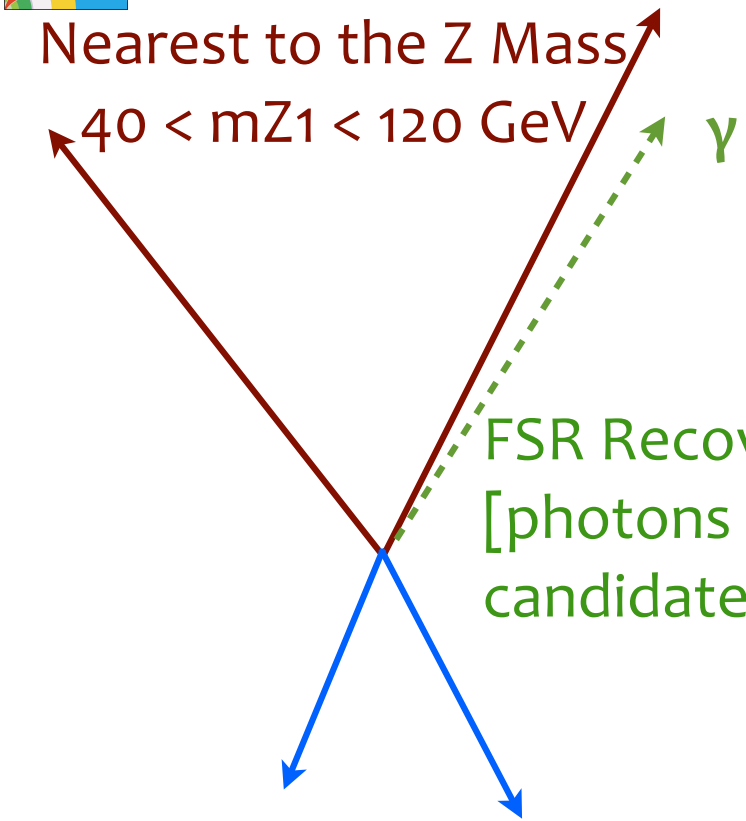
Validation on data:

jet counting in

$Z \rightarrow \mu\mu$ events vs vertex multeplicity.

Stable to <1% for jet p_T > 20 GeV

4l Event Selection



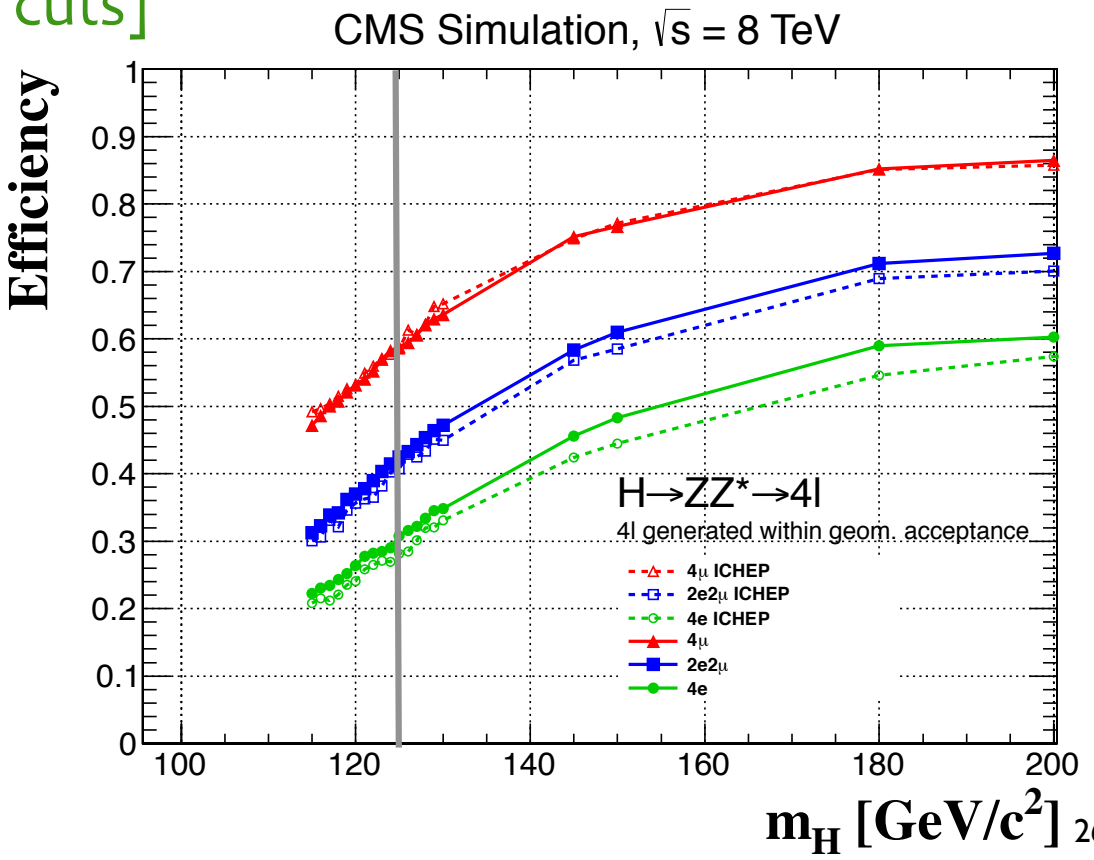
Lepton candidates:

μ pT > 5, η<2.4

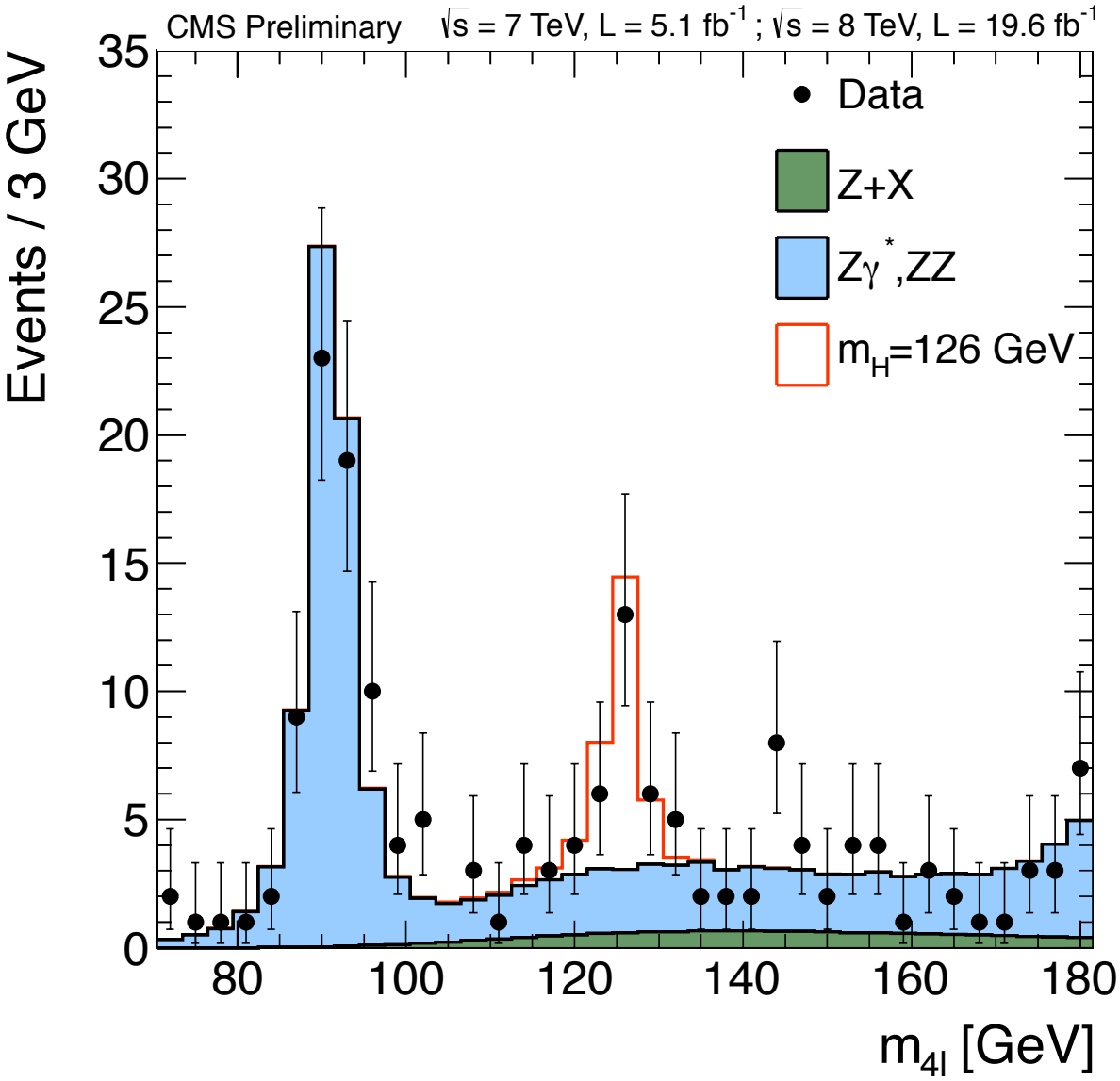
e pT > 7, η<2.5

2 leptons must have pT>20,10 GeV

Isolation and IP cuts applied



m_{4l} - low mass yields

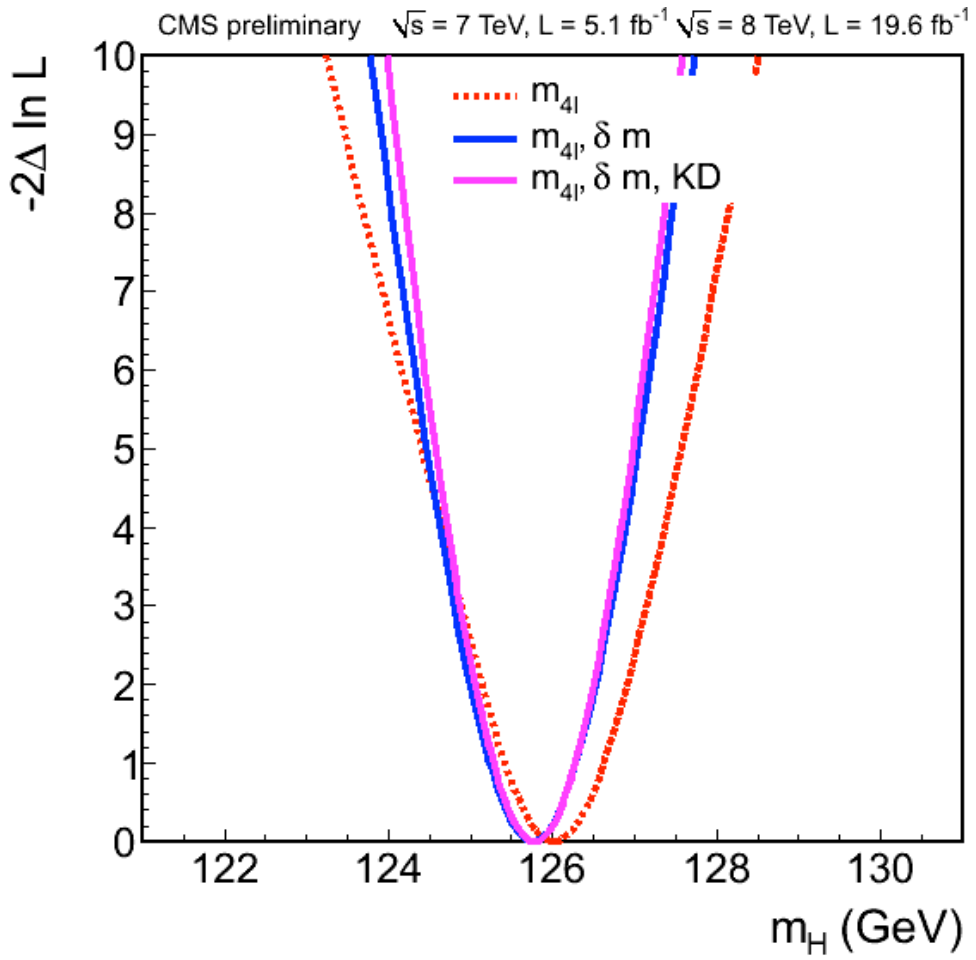


Yields for 7+8 TeV

$121.5 < m_{4l} < 130.5$ GeV

	4e	4μ	2e2μ
H(126)	3.0	6.7	8.9
ZZ	1.2	2.7	3.5
Z+X	0.6	0.5	0.9
Total Bkg.	1.8	3.2	4.4
Data	5	8	12

mass measurement



- $\sigma_{m_{\mathrm{H}}}(1D - m_{4\ell})$: 0.60 GeV
- $\sigma_{m_{\mathrm{H}}}(2D - m_{4\ell}/\delta m_{4\ell})$: 0.53 GeV
- $\sigma_{m_{\mathrm{H}}}(3D - m_{4\ell}/\delta m_{4\ell}/K_D)$: 0.48 GeV

ZZ4l angles

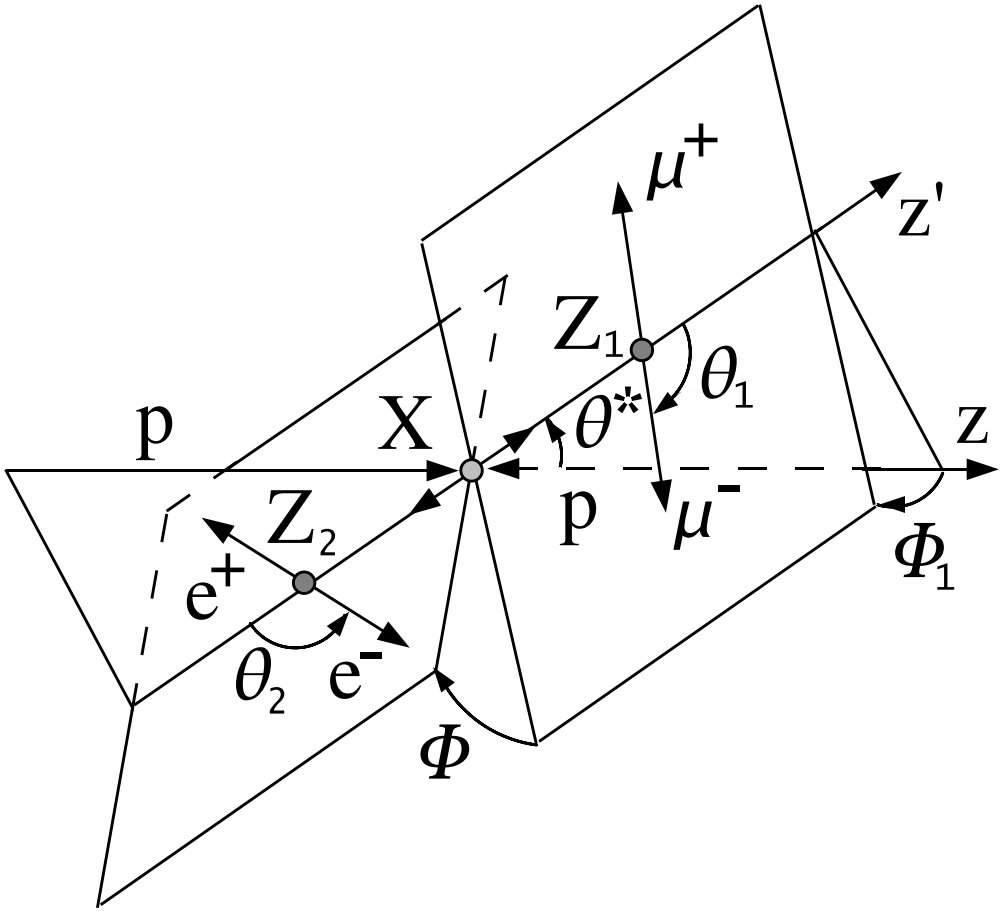
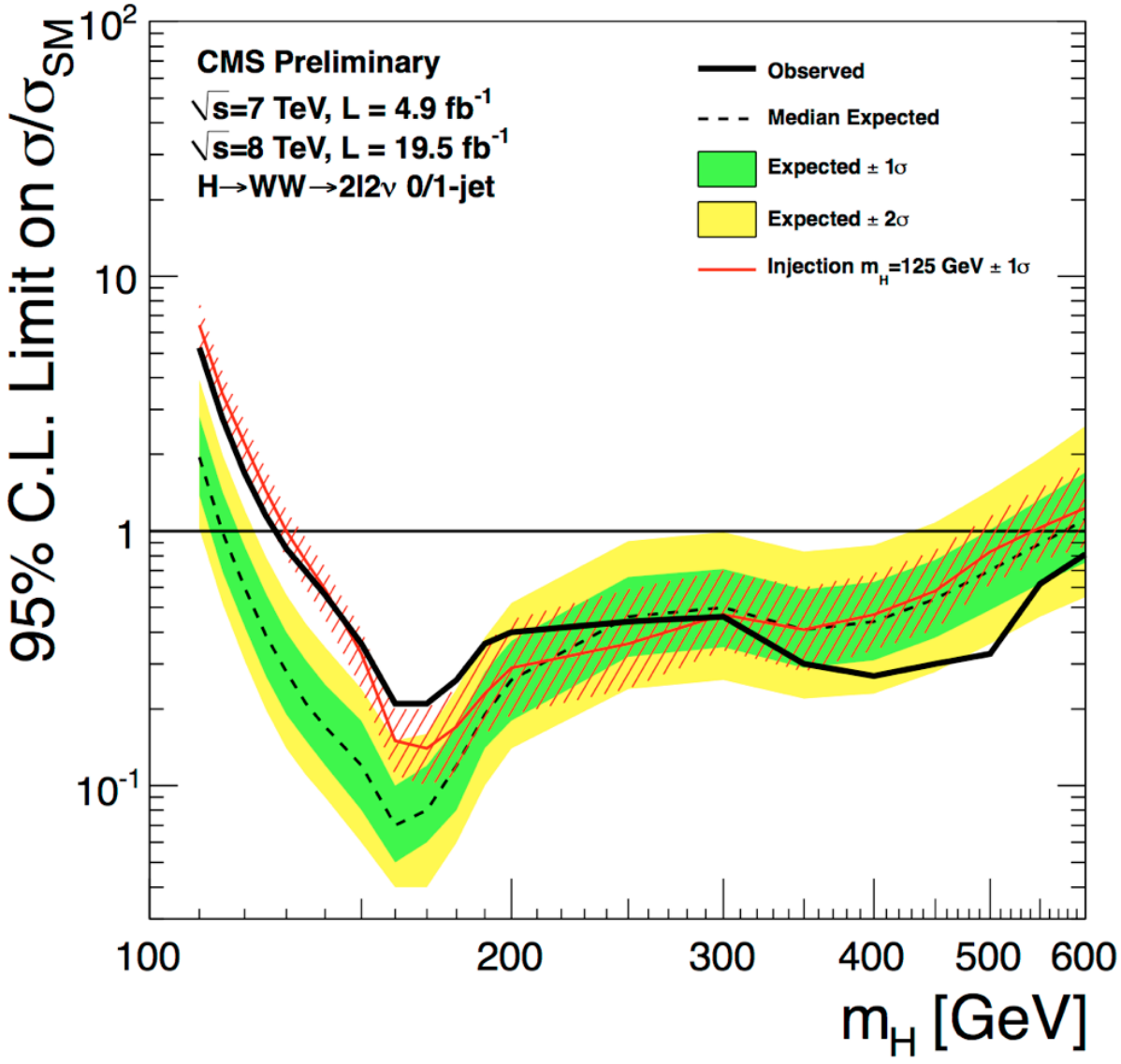
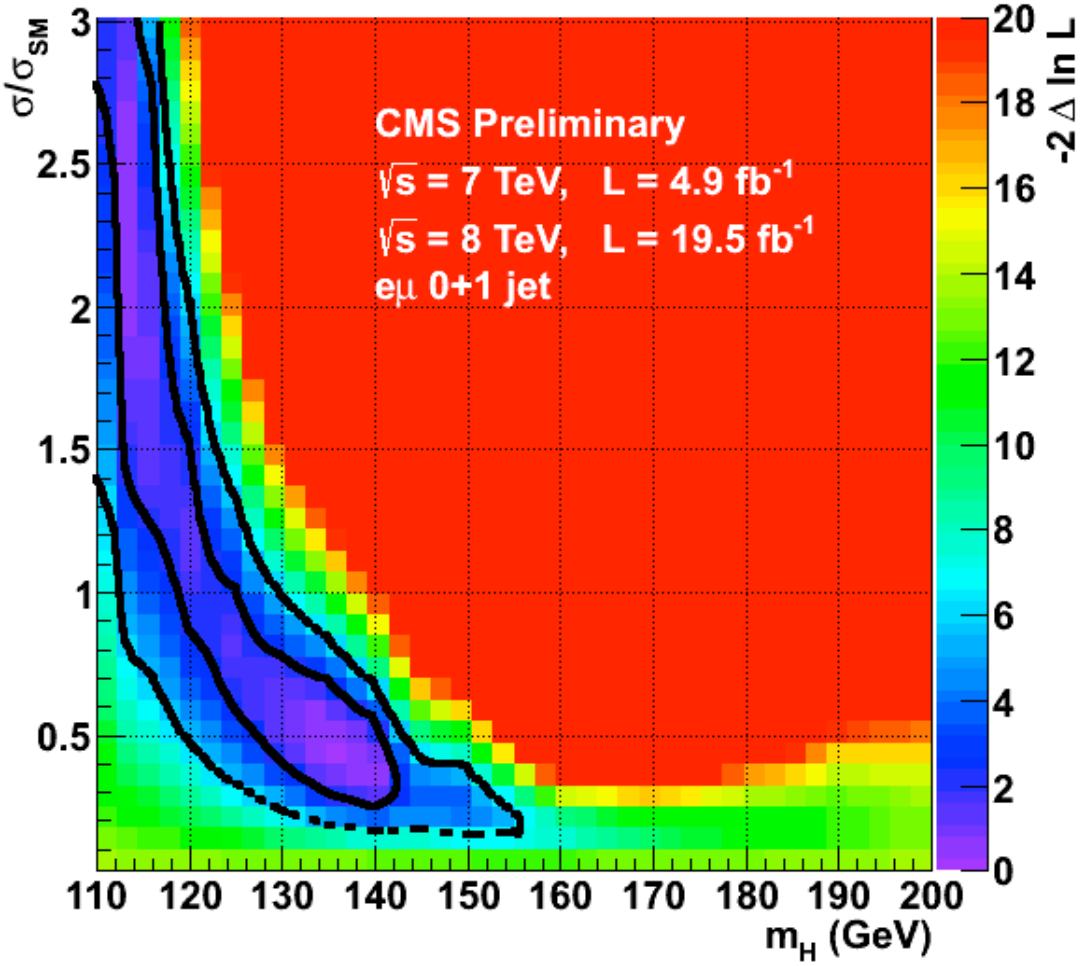


Illustration of a particle X production and decay $ab \to X \to Z_1 Z_2 \to 4\ell$ with the two production angles θ^* and Φ_1 shown in the X rest frame and three decay angles θ_1, θ_2, and Φ shown in the Z_i rest frames

WW Upper Limits

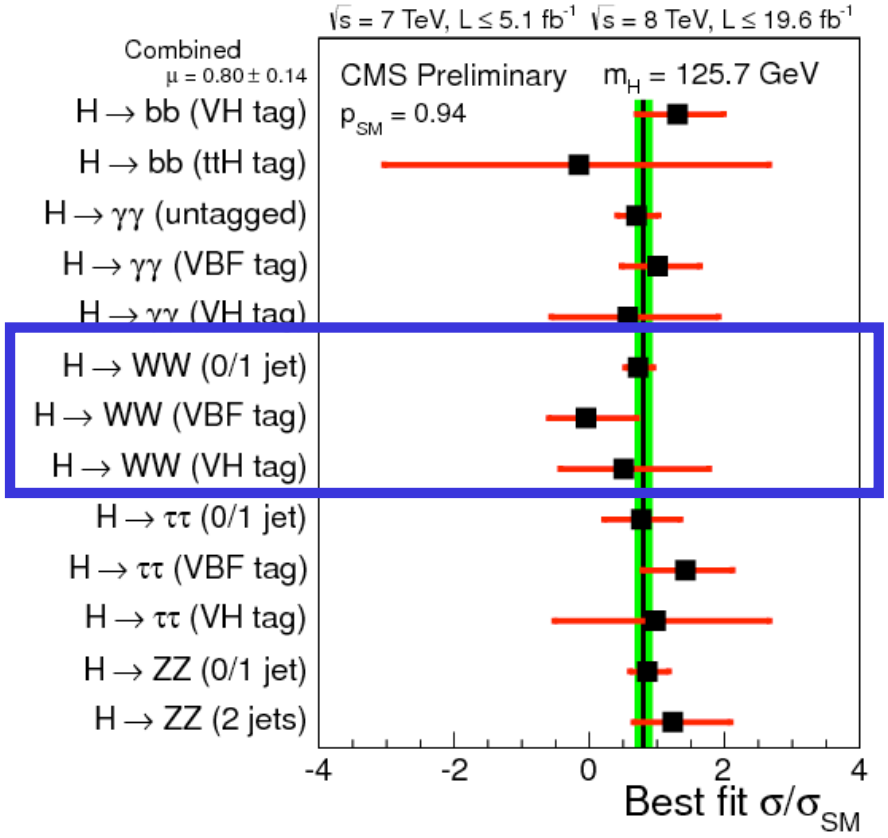


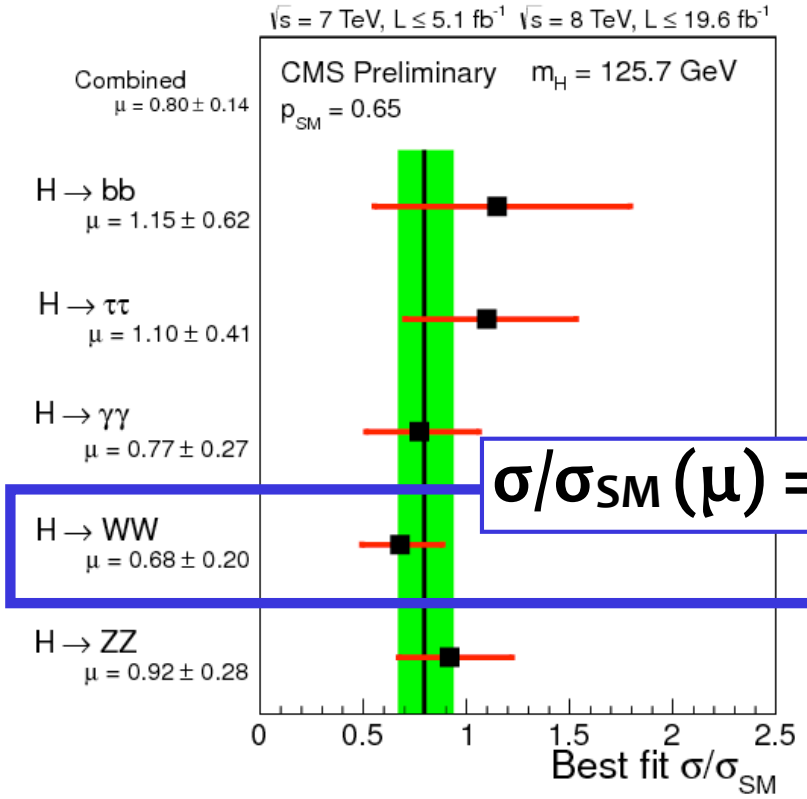
WW σ/σ_{SM} vs M_H



WW combined results

Without the VH,V→jj analysis





$\sigma/\sigma_{SM}(\mu) = 0.68 \pm 0.20$

	Expected significance $m_H = 125.7$ GeV		
	Pre-Fit	Post-Fit	Observed
H->WW	5.6 σ	5.3 σ	3.9 σ

Cut based analysis 0/1 jets

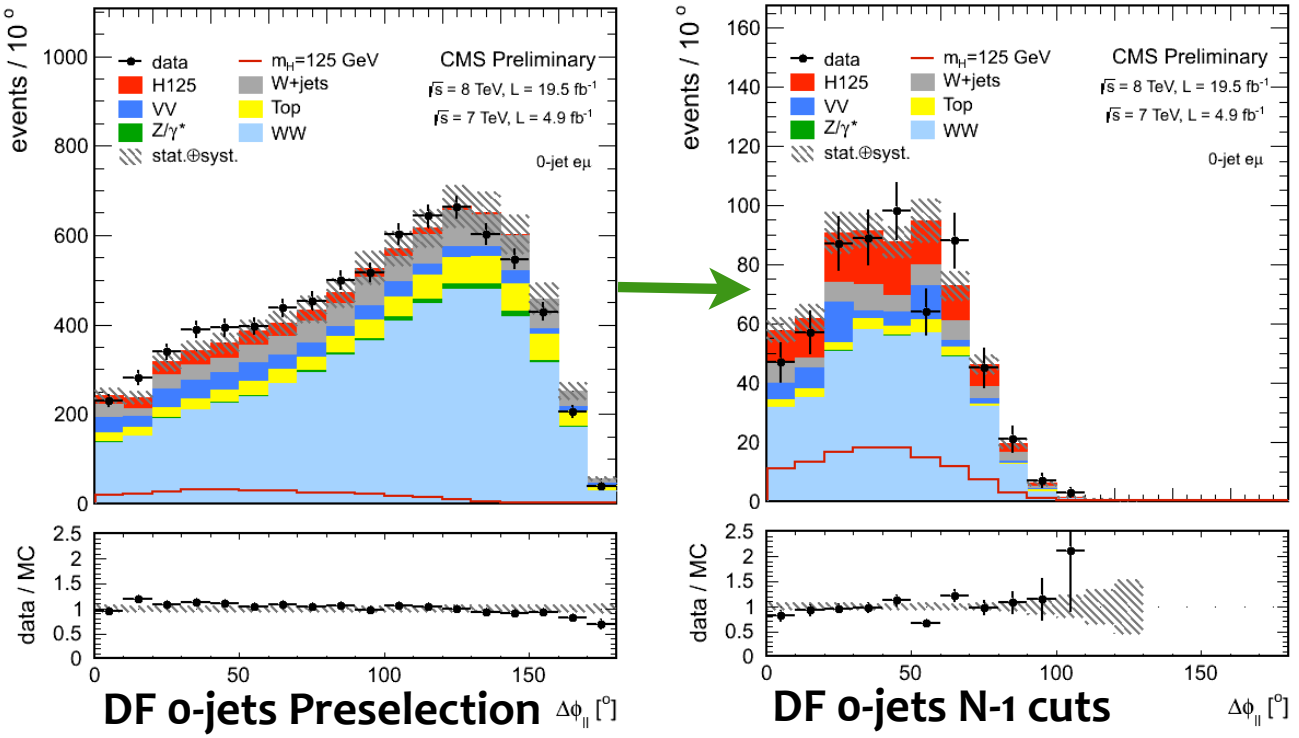
Almost common **preselection** for all the events based on background rejection cuts:
mll cut, pT(ll), Z-peak veto, extra-lepton veto, B-veto, Z/Y* rejection MVA based on MET

Signal extraction (1)

cut-based approach: m_H dependent cuts common to 0, 1 jets categories

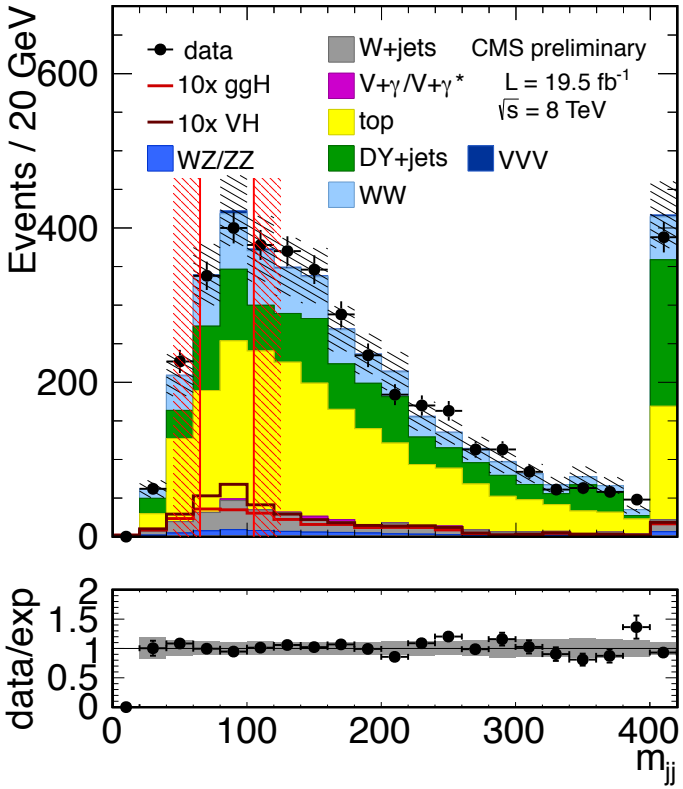
variables: **Δφ(ll), $p_T(l_{max})$, $p_T(l_{min})$, m_{ll}, m_T**

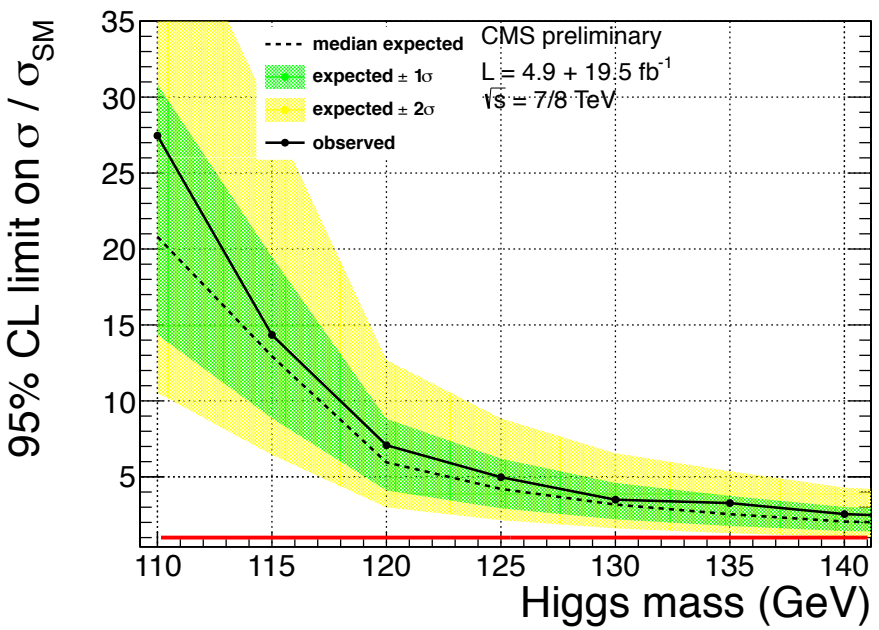
$$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{\mathrm{miss}} \left(1 - \cos \Delta\phi_{E_T^{\mathrm{miss}}\ell\ell}\right)}$$



NEW! $H \rightarrow WW^{(*)} \rightarrow 2l2\upsilon$,VH Tag

- Search for associated Higgs boson production with a V (W/Z) boson decaying hadronically
- Same event **preselection** as the 0/1 jets analysis plus:
  - **2 additional jets with pT>30 and $|\eta|<2.5$, $\Delta\varphi(ll,jj)<165°$, $65<m(jj)<105$**
  - 30% VH, 60% ggH, 10% VBF @ m_H=125 GeV
- **cut-based approach:** m_H dependent cuts on **$\Delta R(ll)$, m_{ll}, m_T** variables





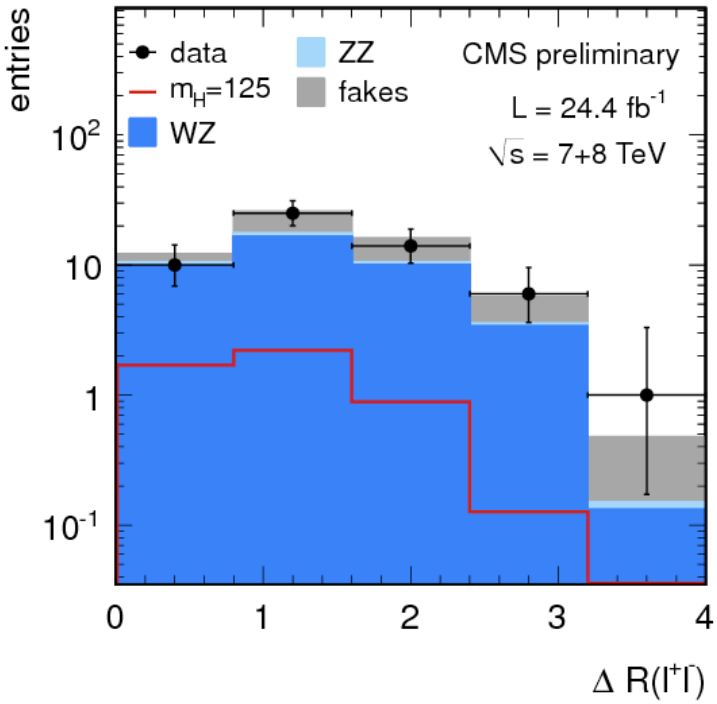
UL @ 95% CL on σ/σ_{SM}:
observed 5.0
expected 4.2
(m_H = 125 GeV)

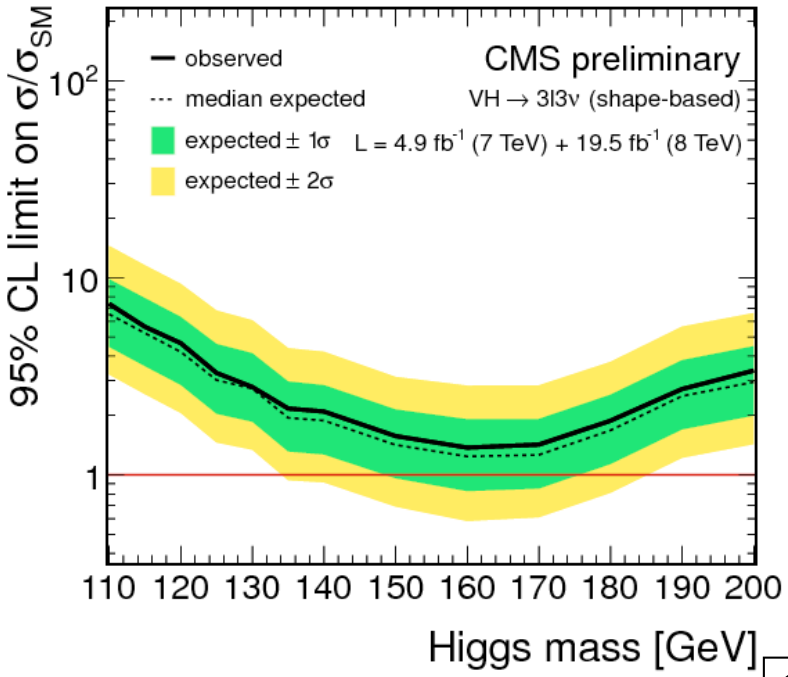
0.5σ excess
μ=1.0±2.0

CMS-PAS-HIG-13-017

H→WW(*)→2l2υ,WH Tag

- Search for associated Higgs boson production with a W boson
- Look for **3 isolated leptons (e, μ) and large missing energy**
  - two categories according to the presence of an **OSSF pair or not**
- **Z-veto and b-veto** to reject WZ and top backgrounds
- Results extracted with a shape based approach based on **dR(l⁺l'⁻)**





UL @ 95% CL on σ/σ_{SM}:
observed 3.3
expected 3.0
(m_H = 125 GeV)

CMS-PAS-HIG-13-009