Higgs studies at CMS

28/02/2013 - XXVIe Rencontres de Physique de La vallée d'Aoste, La Thuile

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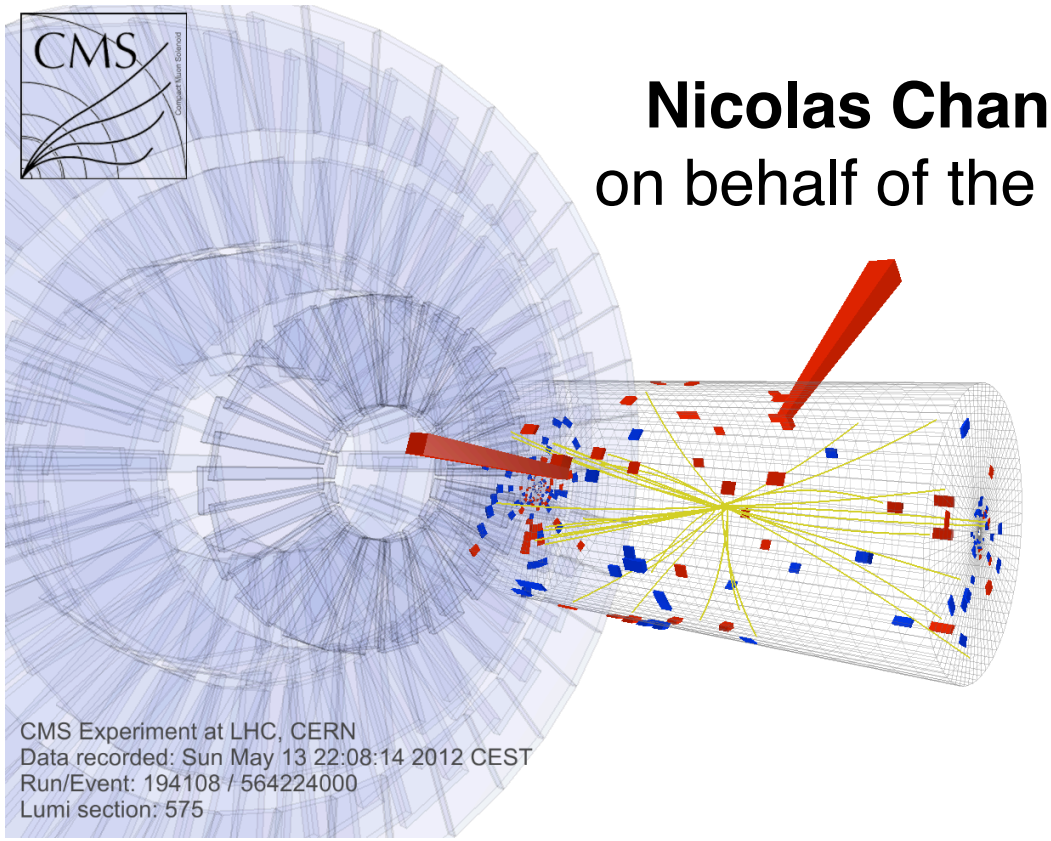
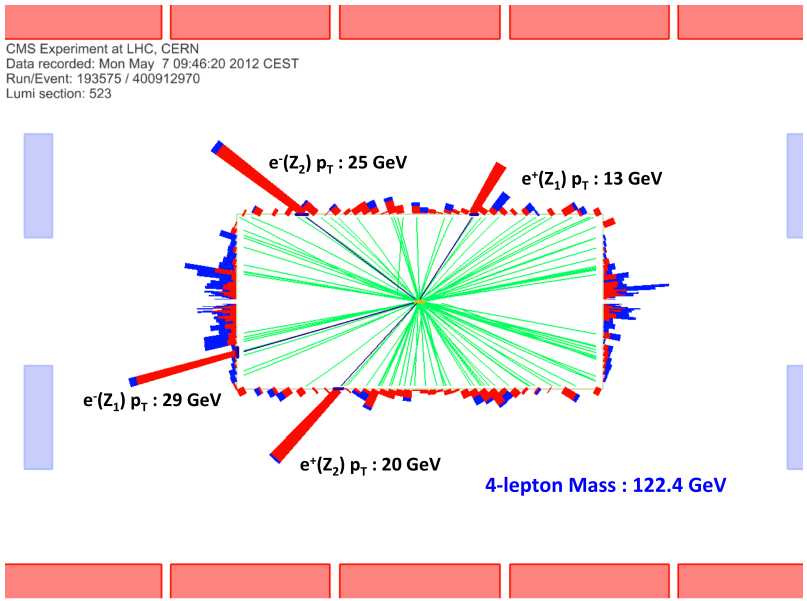
on behalf of the CMS collaboration

ETH Institute for Particle Physics





Outline

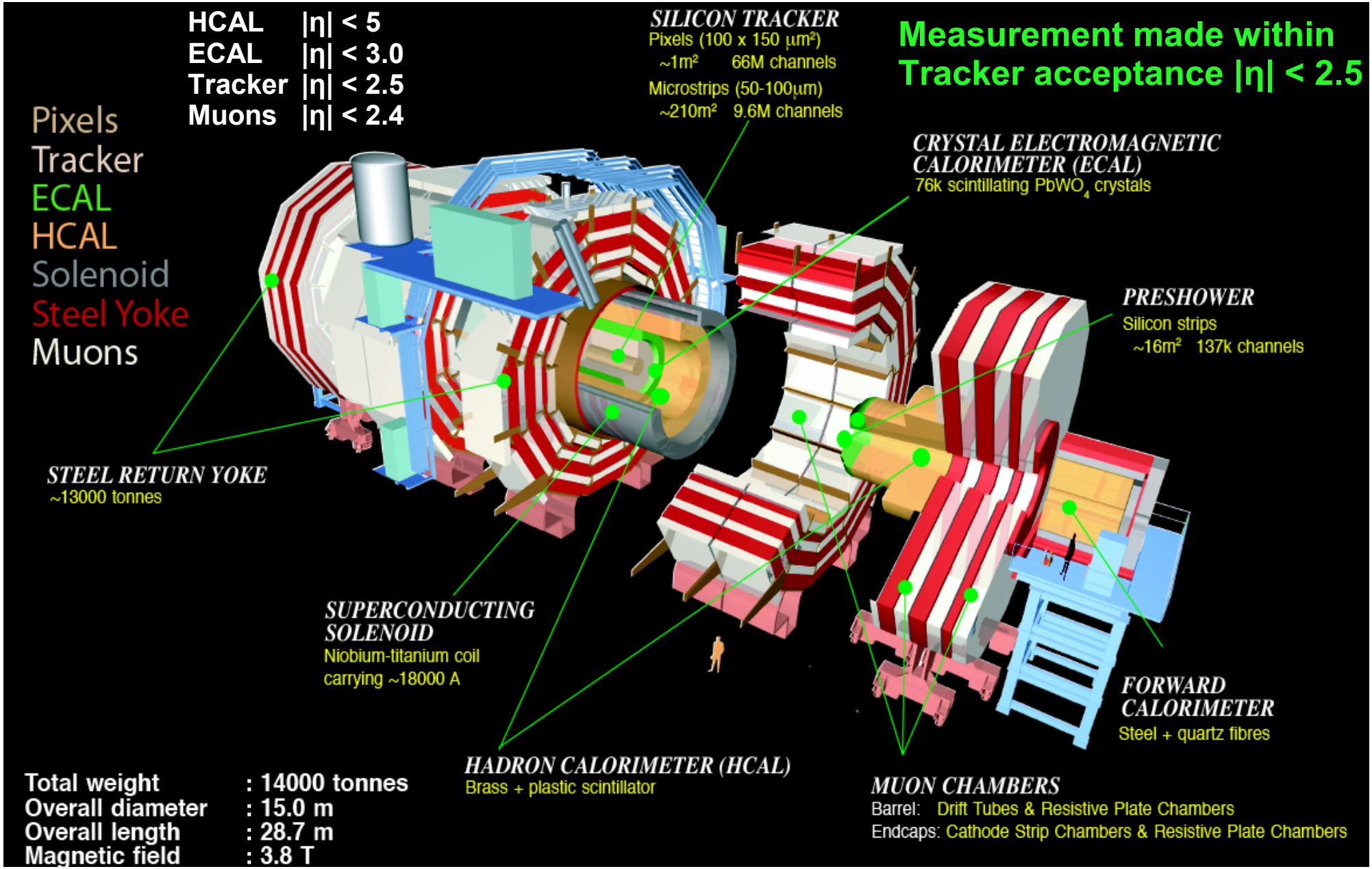
Overview of CMS detector

Higgs analyses:

- **$H \to ZZ \to 4l$** - PAS-12-041
- **$H \to \gamma\gamma$** - PAS-12-016
- **$H \to W^+W^- \to 2l2\nu$** - PAS-12-042
- **$H \to \tau^+\tau^-$** - PAS-12-043
- **$H \to b\bar{b}$** - PAS-12-044
- **Combination** - PAS-12-045

Conclusions

CMS detector

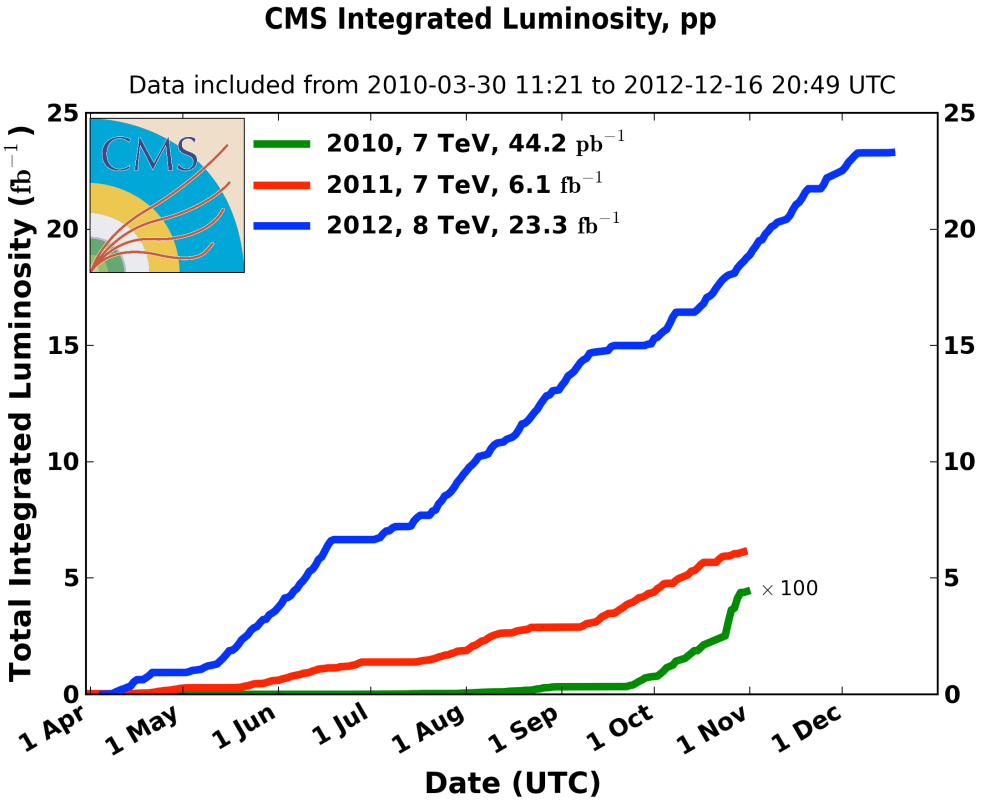


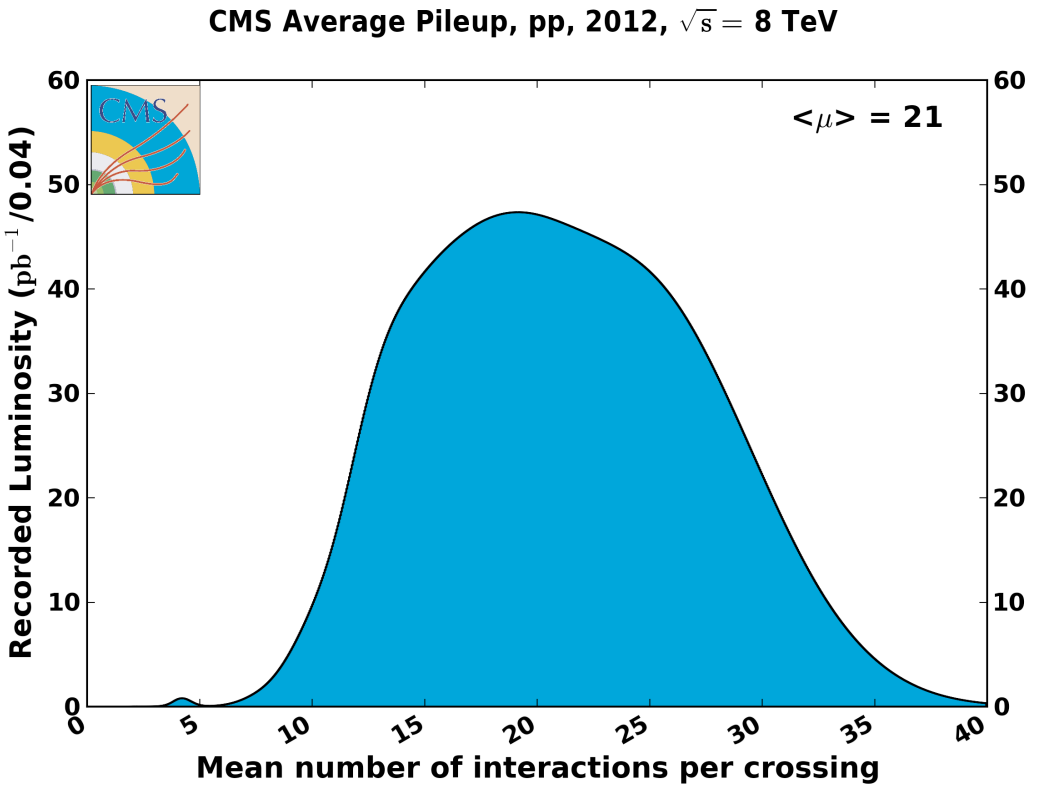
Luminosity conditions

Analyses presented in this talk are using:

- **5.1 fb-1 of 7 TeV data** in 2011
- **Up to 12.2 fb-1 of 8 TeV data in 2012**

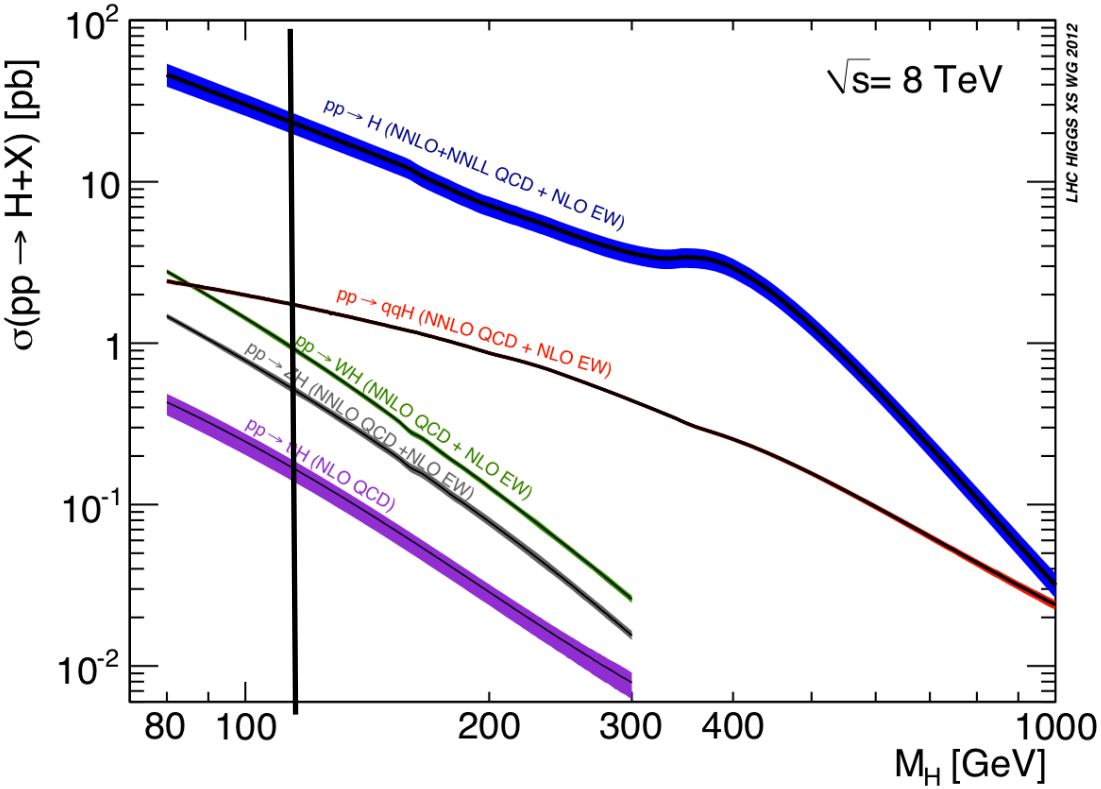
Pileup mean interaction ~21 in 2012 (~10 in 2011)

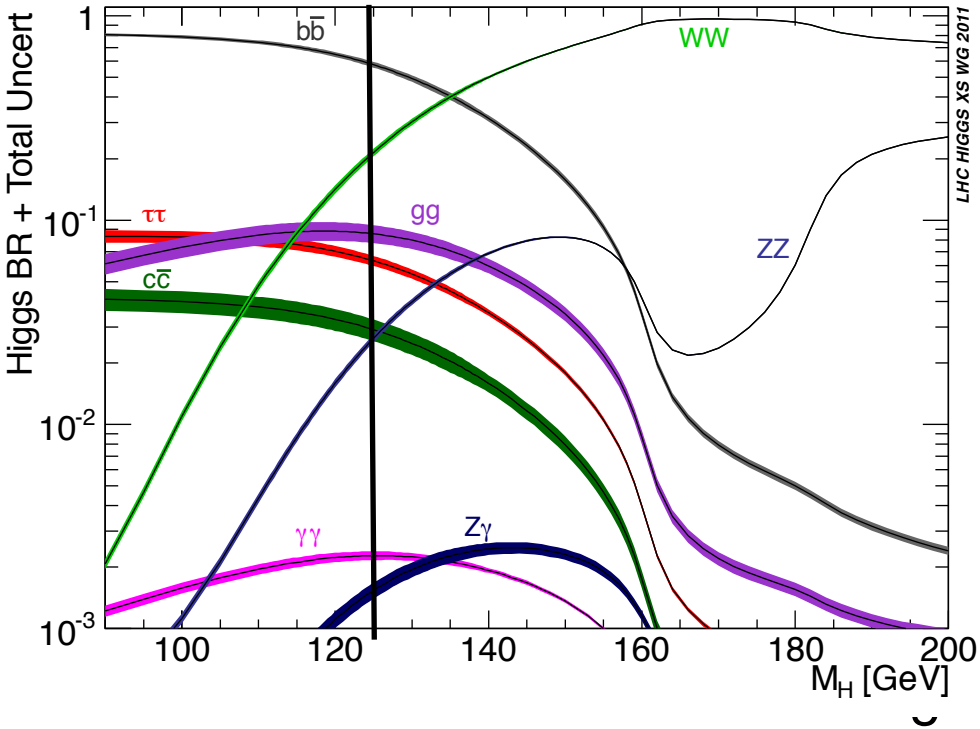




Higgs boson production and decay

- A **new boson** was **discovered in July 2012** in the Higgs boson searches, with a **mass around 125 GeV**
- The main Higgs production mechanism in the SM is gluon fusion followed by VBF
- **Essential to probe boson and fermion decay**: analyses performed in decay channel γγ, ZZ, WW, bb, ττ

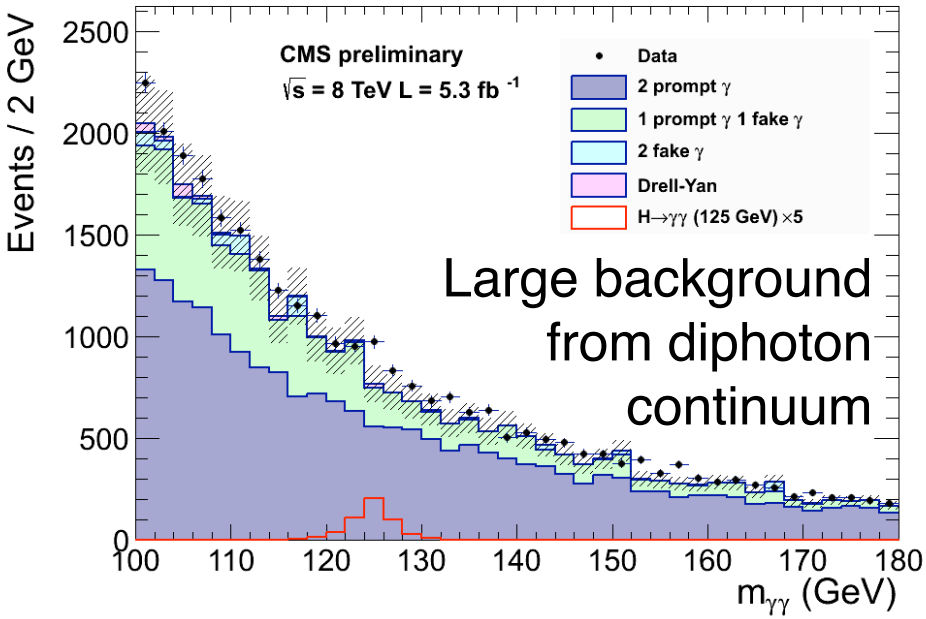


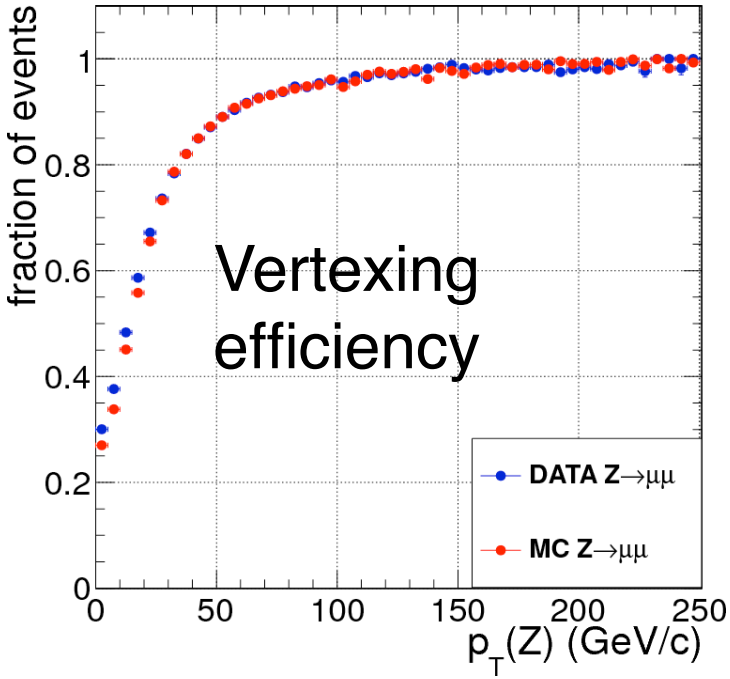


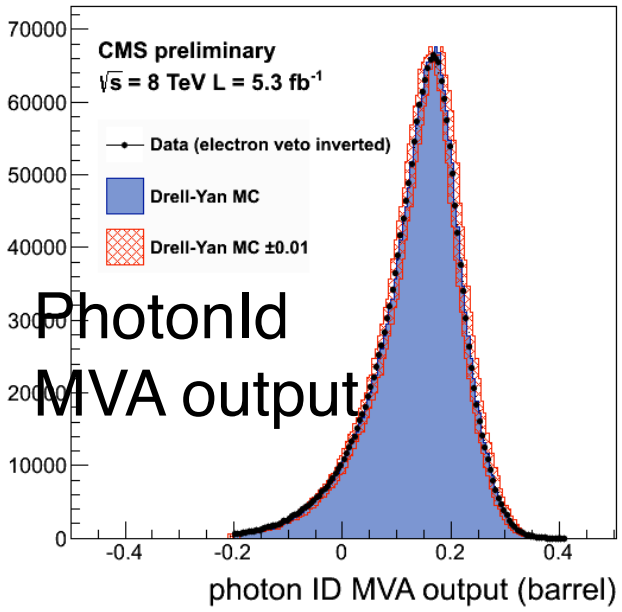
H→γγ analysis (5.1fb-1 at 7 TeV and 5.3fb-1 at 8TeV)

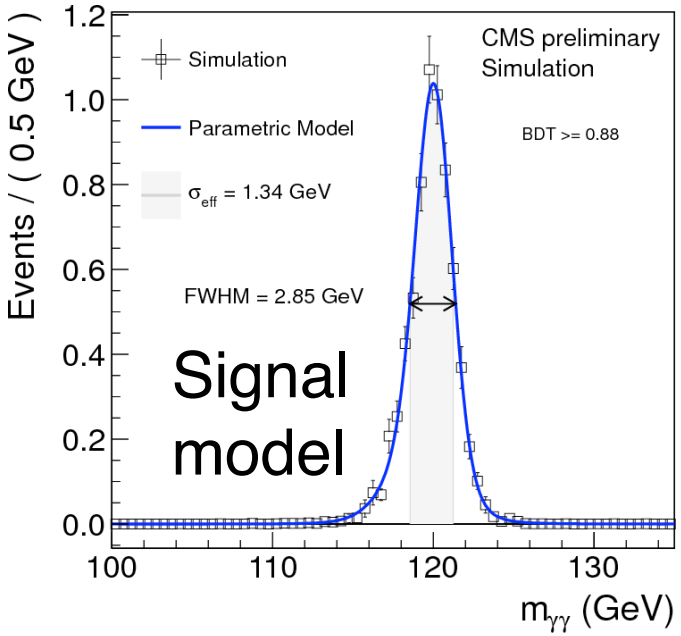
Main analysis is MVA:
Cut-based analysis and 2nd MVA analyses as cross-checks

- Select two high pt photons
- Vertexing MVA
- Photon identification MVA to reject fake photons
- Energy regression to improve mass resolution: 1-2%
- Mass fit in categories defined from diphoton MVA



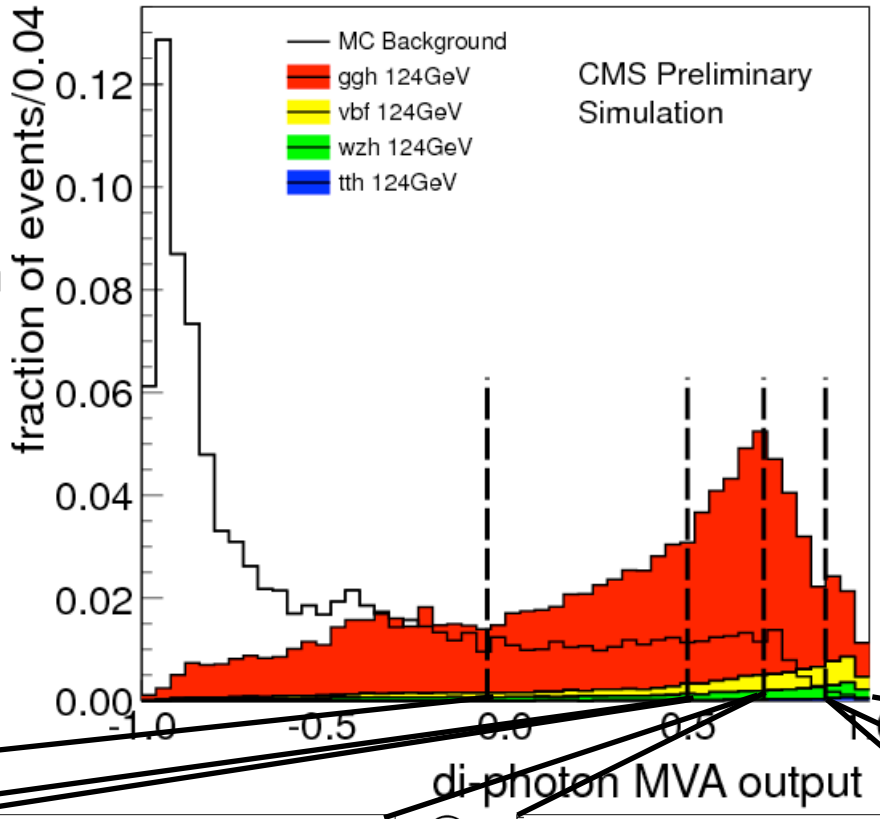


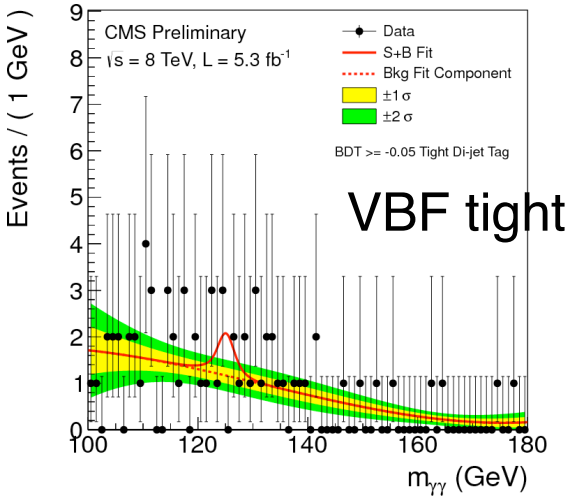


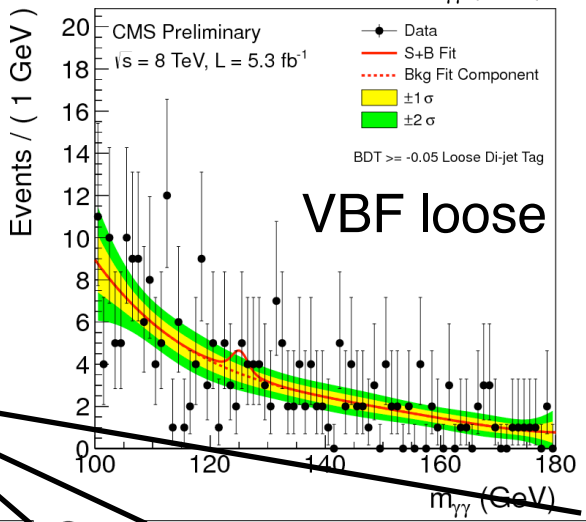


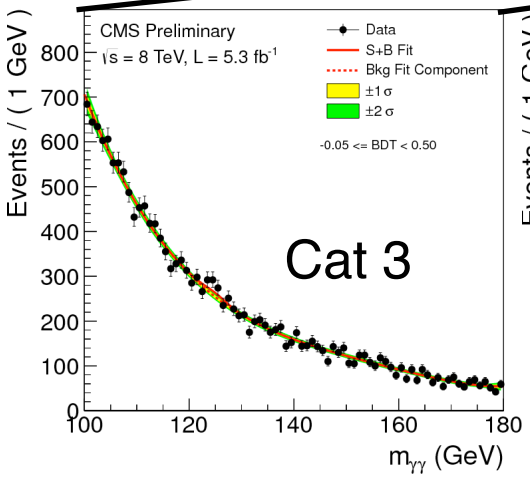
H→γγ: categories

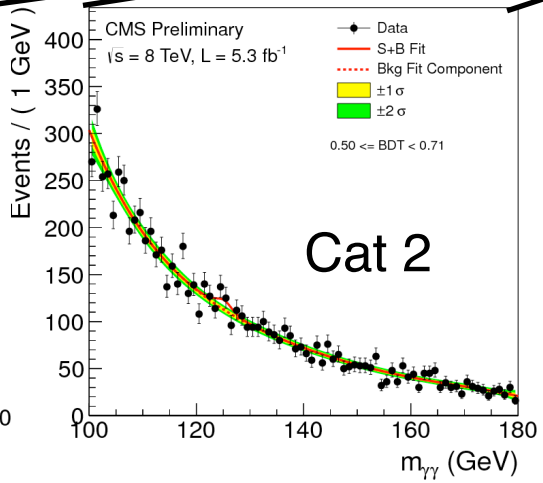
- Feed **Diphoton MVA** with kinematics, vertexing, PhotonId output, energy resolution
- Define 4 **diphoton categories** and 2 **VBF categories**
- **Sensitivity from mass fit.** Bkgd: Bernstein polynomial (bias <20% stat uncertainty)

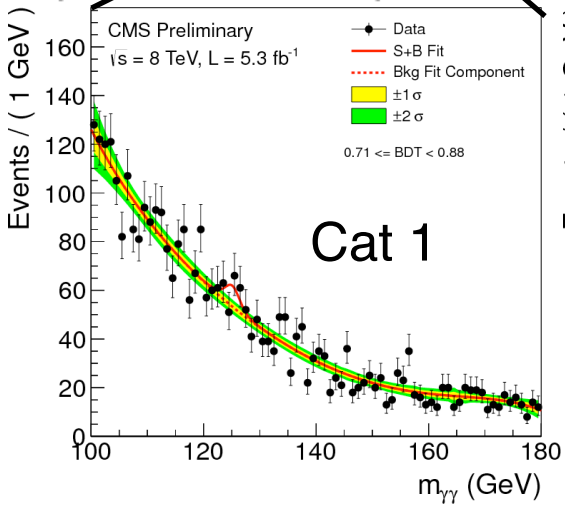


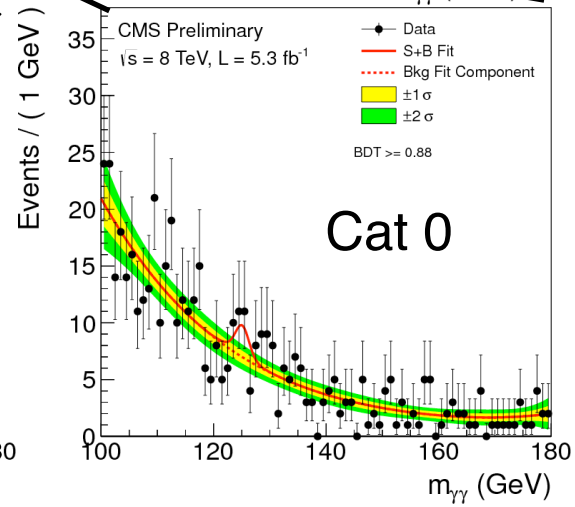




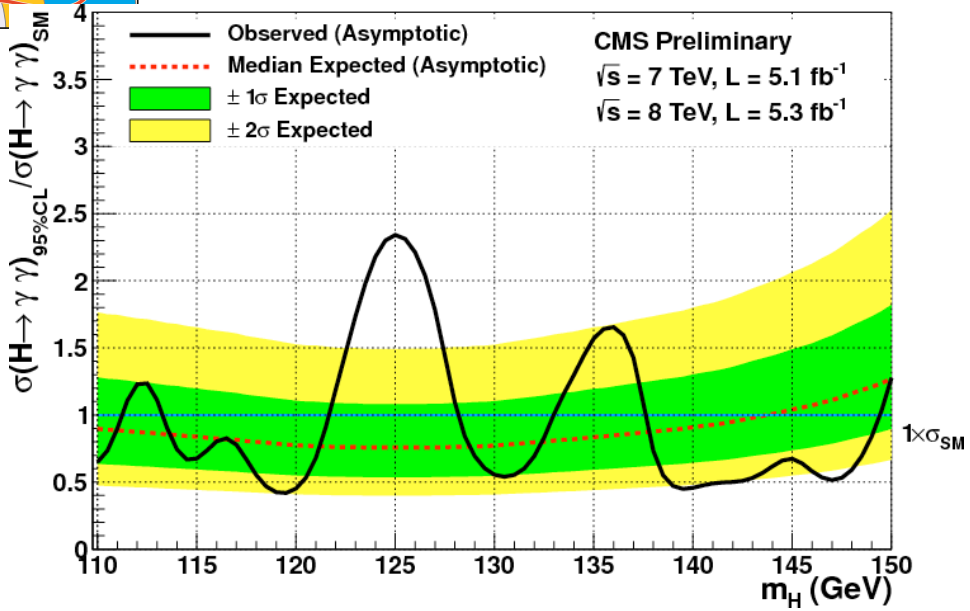


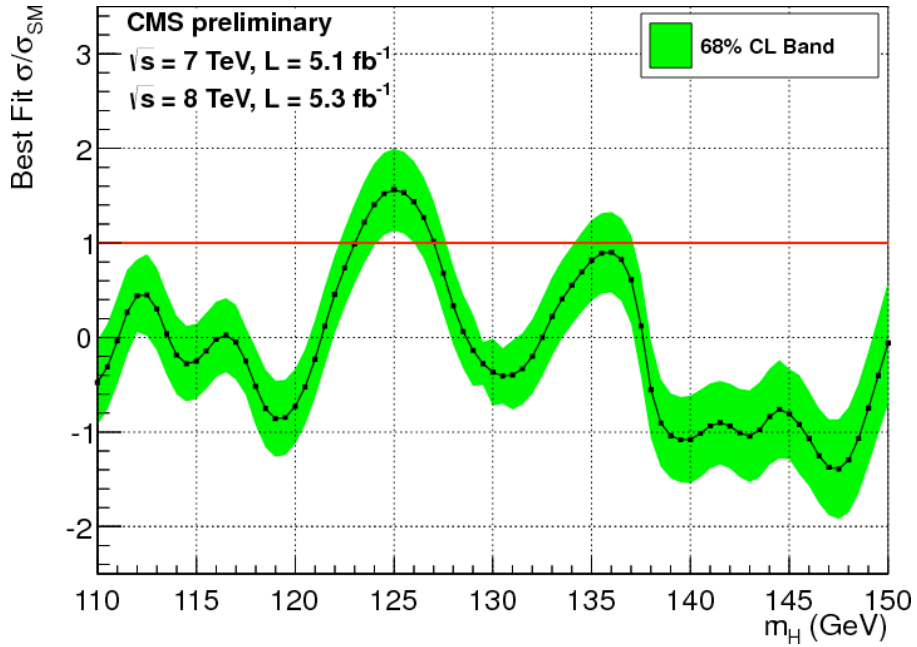




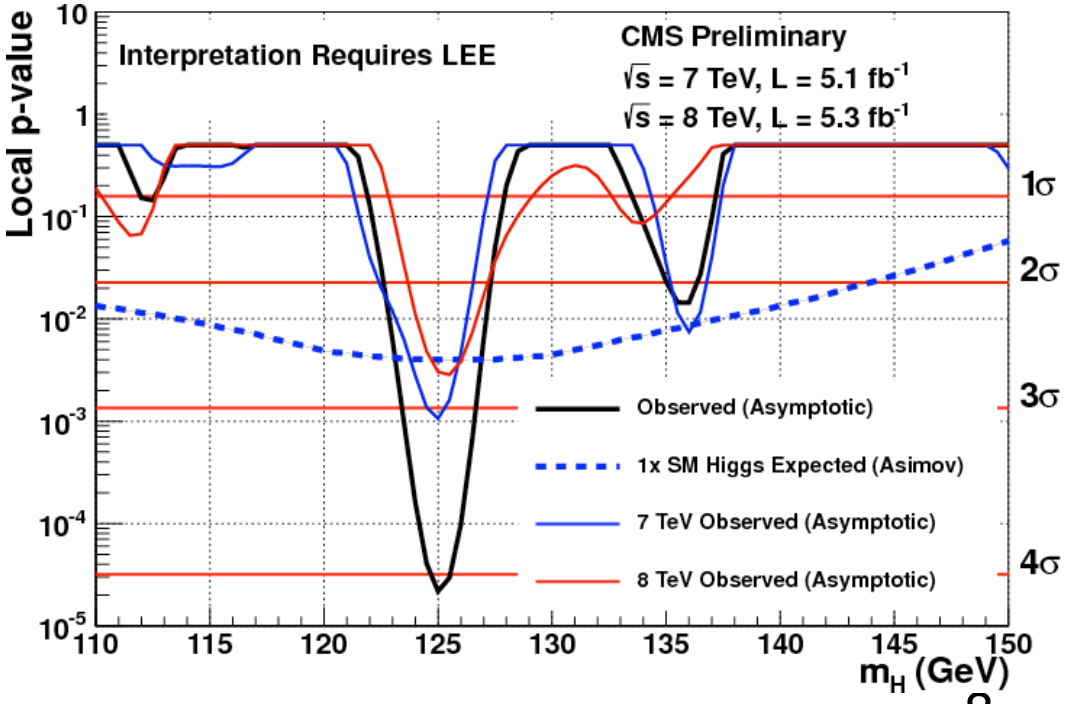


H→γγ results



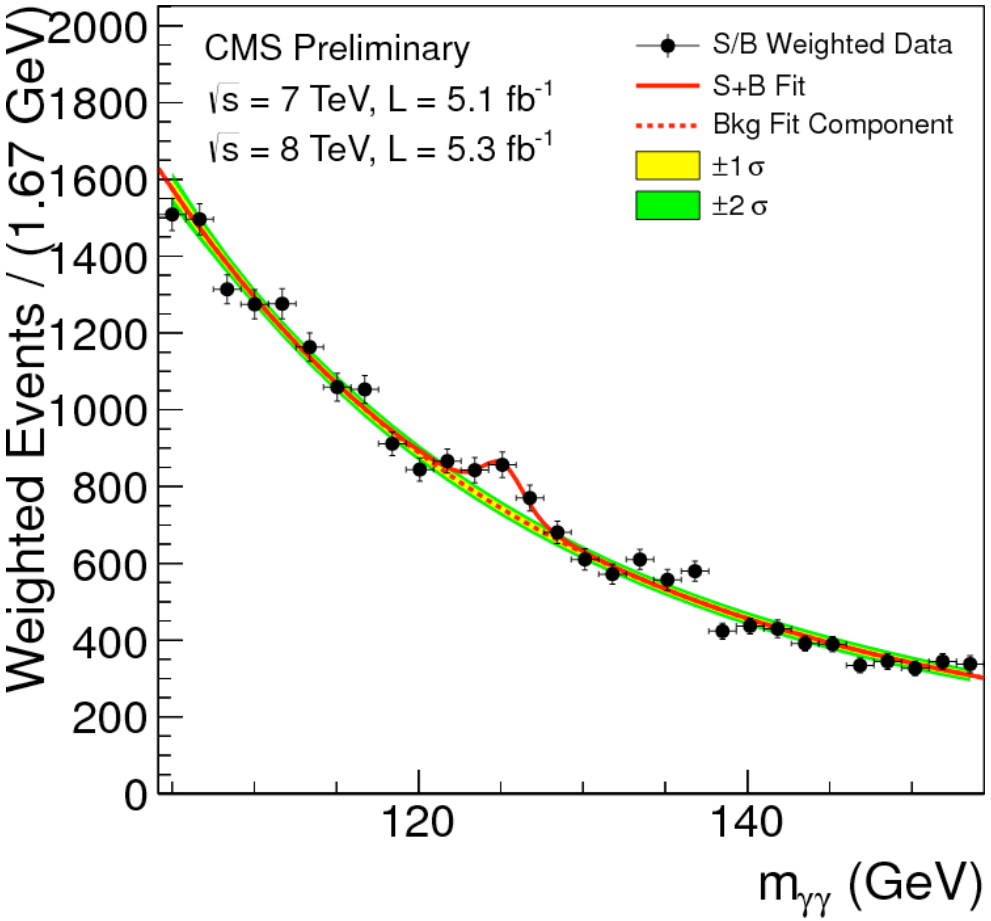


- **Observed local significance above 4.1σ**
- Measure best fit **μ=1.56 ± 0.43 at 125 GeV**

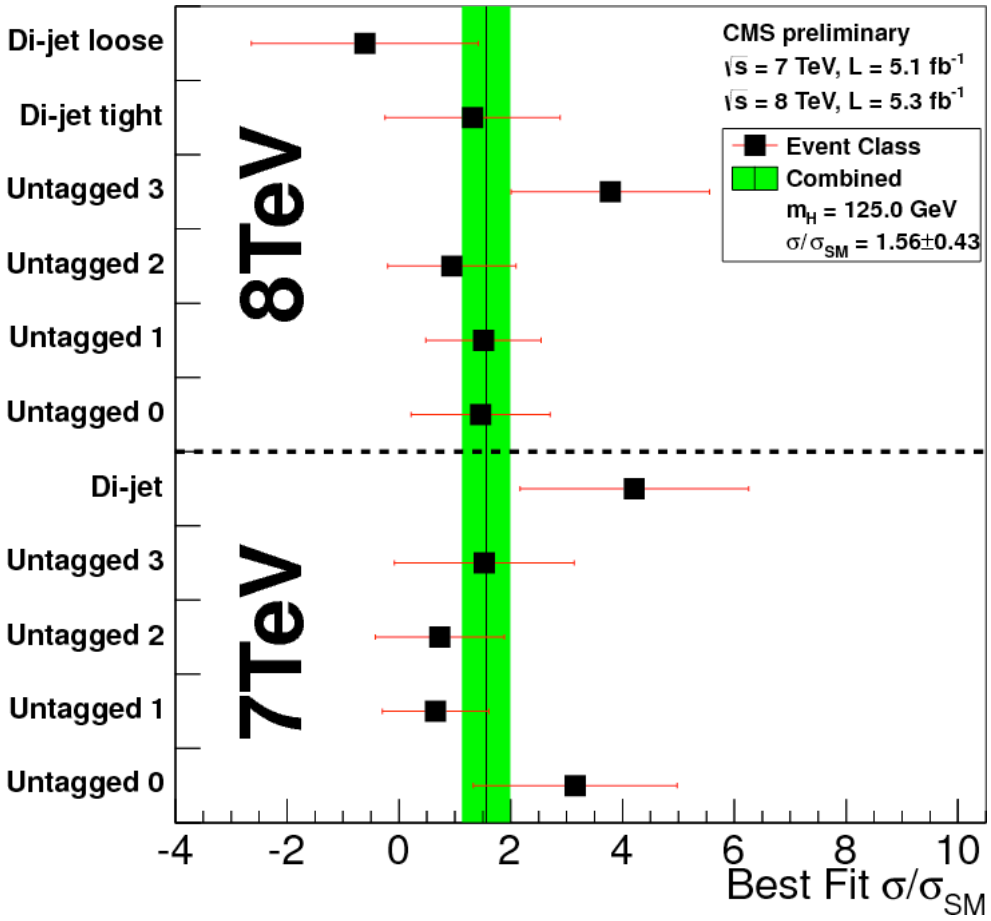


H→γγ results

Weighted mass plot



Channel compatibility

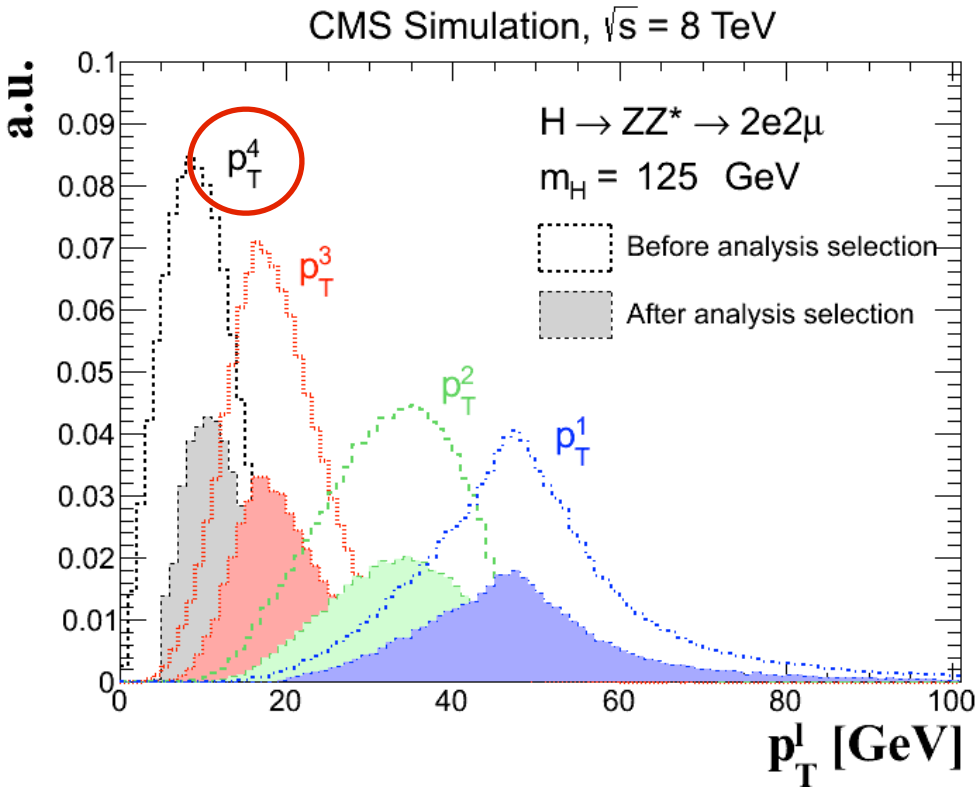


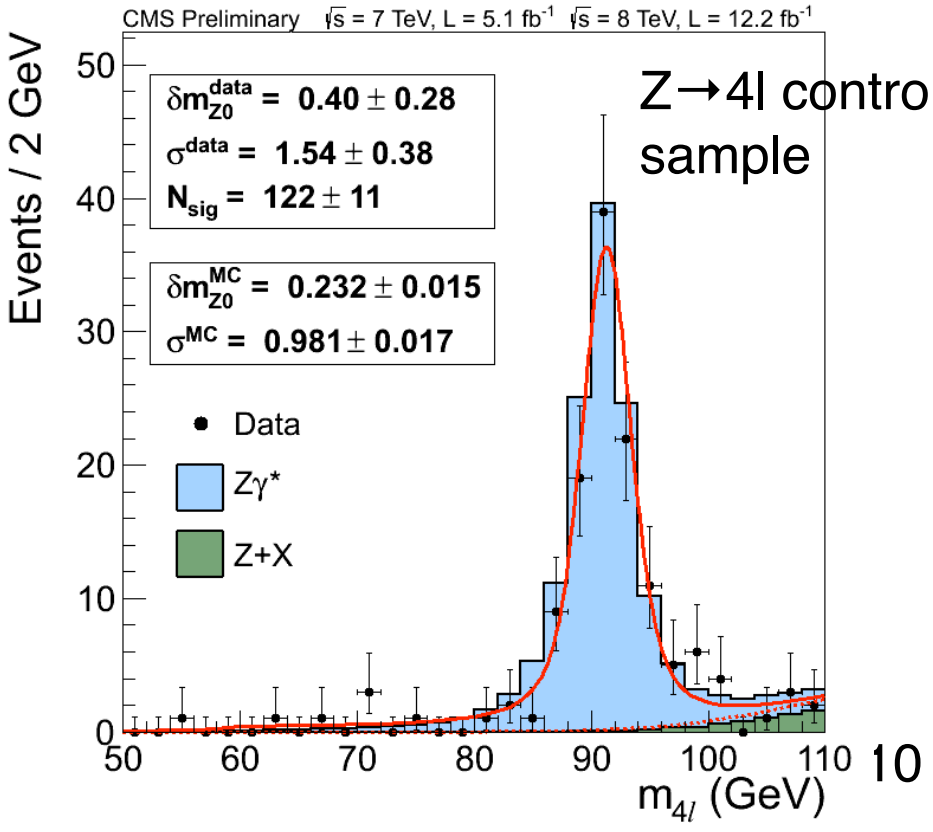
H→ZZ→4l analysis

(5.1fb-1 at 7 TeV and 12.2fb-1 at 8TeV)

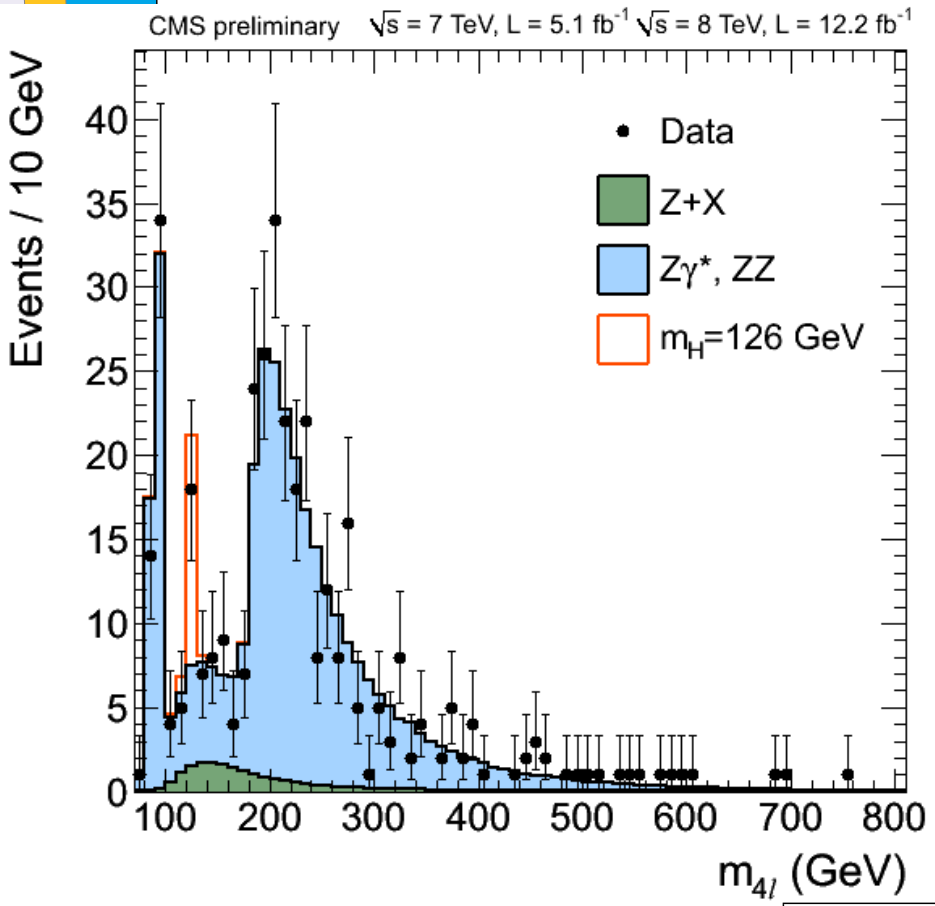
H→ZZ→4l analysis:

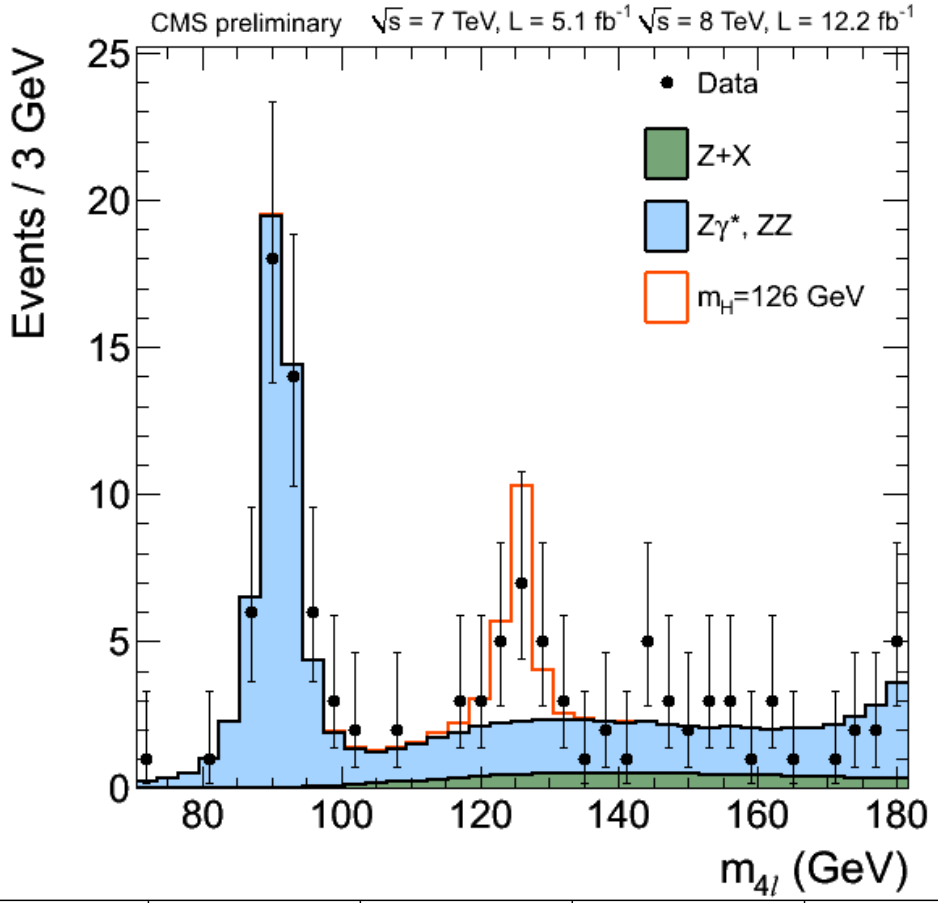
- Main backgrounds: ZZ, Z+jets, ttbar
- Select four isolated leptons from the same vertex
- Need momentum as low as pT>7 GeV (electrons) and pT>5 GeV (muons) to not loose too much efficiency missing the 4th lepton
- Mass resolution is 1-2%
- 2l2τ channel included for higher mass





H→ZZ→4l: mass distribution



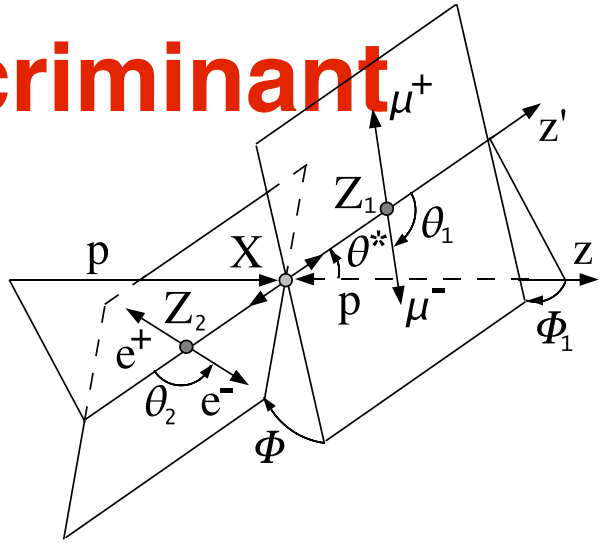


- Small background (s/b~2), almost flat around 125 GeV
- Clear excess observed

In the mass range 110 - 160 GeV:

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	4.7 ± 0.6	9.6 ± 1.0	12.5 ± 1.4	26.8 ± 1.8
Z+ X	$3.4^{+3.0}_{-2.3}$	$1.6^{+1.2}_{-0.9}$	$5.6^{+5.4}_{-3.6}$	$10.6^{+5.3}_{-4.4}$
All backgrounds	$8.0^{+3.1}_{-2.3}$	$11.2^{+1.6}_{-1.4}$	$18.1^{+5.6}_{-3.8}$	$37.3^{+6.6}_{-4.7}$
m_H = 125 GeV	2.4 ± 0.4	4.6 ± 0.5	5.9 ± 0.7	12.9 ± 0.9
m_H = 126 GeV	2.7 ± 0.4	5.1 ± 0.6	6.6 ± 0.8	14.4 ± 1.1
Observed	12	16	19	47

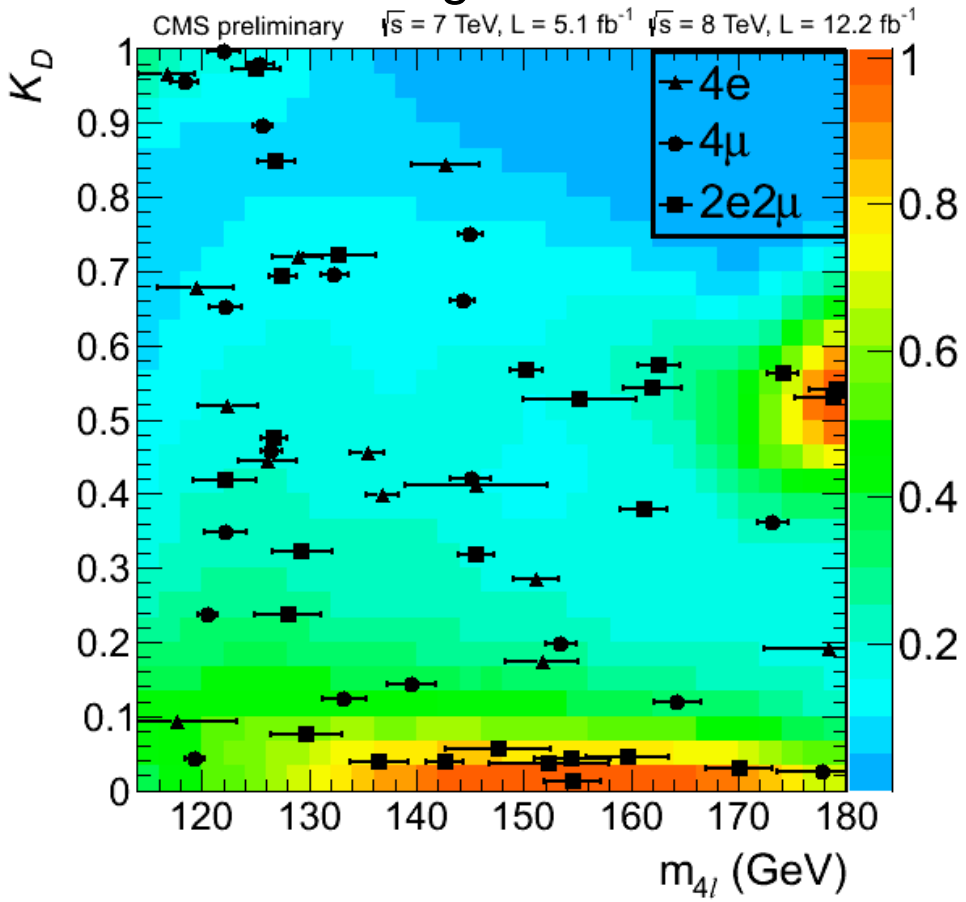
H→ZZ→4l: kinematic discriminant



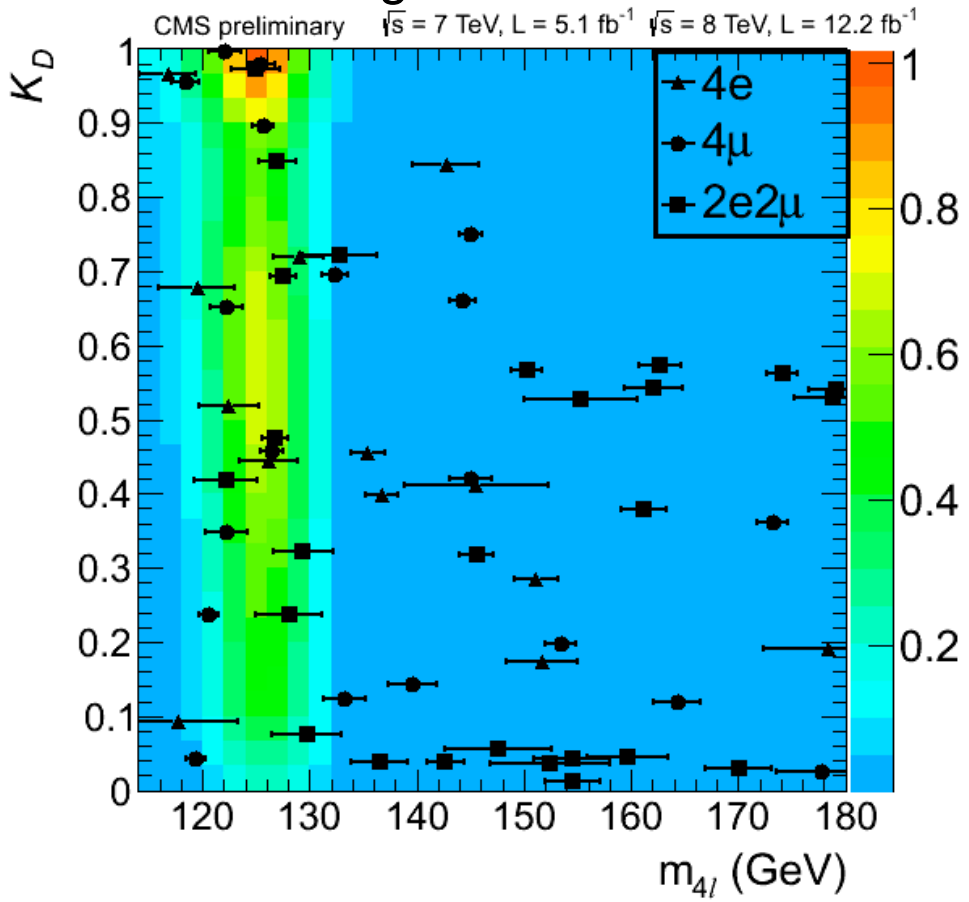
Kinematic discriminant:

- Matrix element method using invariant mass of Z1 and Z2 and 5 angular variables
- Excess near 125 GeV looks compatible with Higgs signal

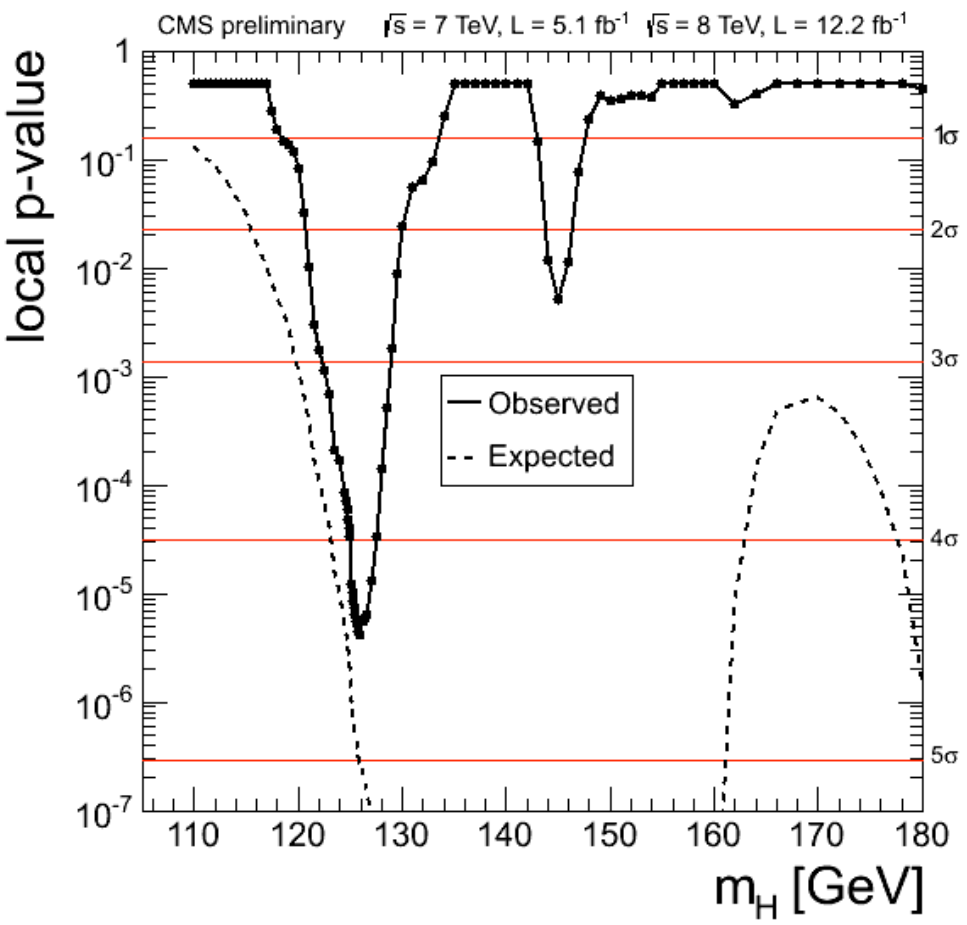
Background MC

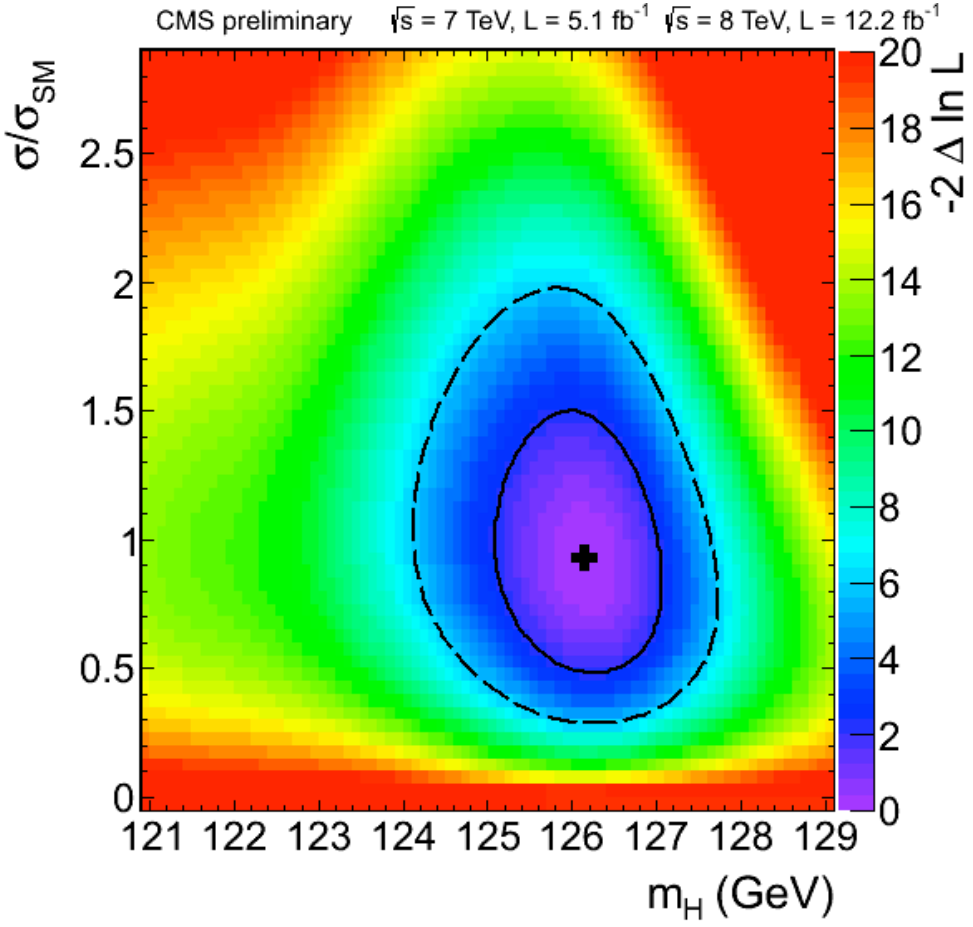


Signal MC



H→ZZ→4l results





- **Observed significance above 4.3σ** for 1D and 2D, **5.0σ** with 3D
- Measure best fit $\mu=0.80^{+0.35}_{-0.28}$ at 126

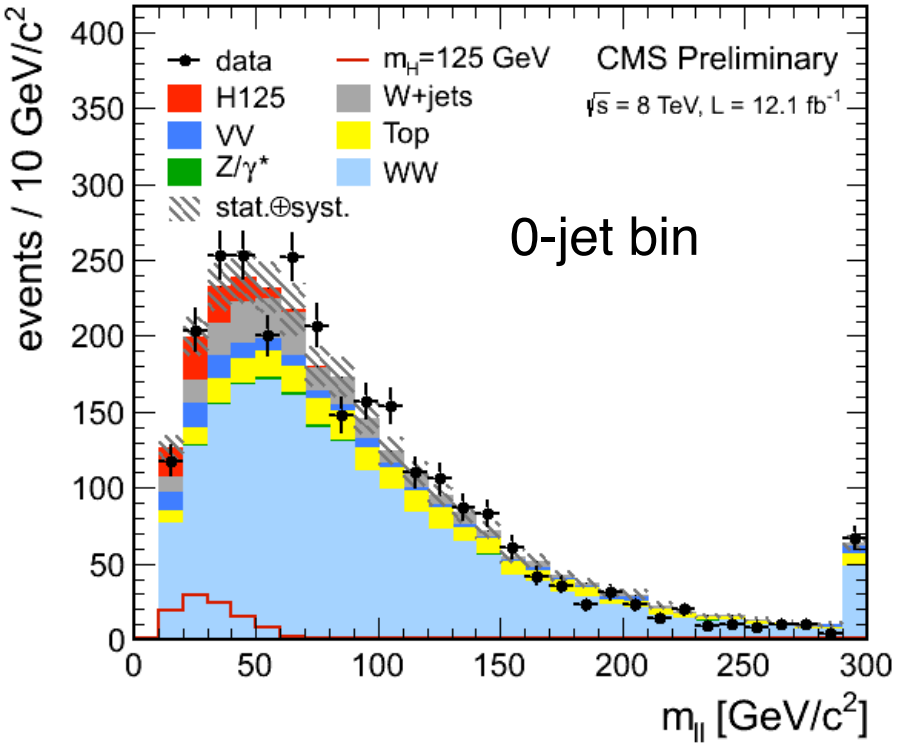
- **Mass measurement** with 3D fit (m_{4l}, δm_{4l},KD)
- **m=126.2 ± 0.6 (stat) ±0.2 (syst) GeV**

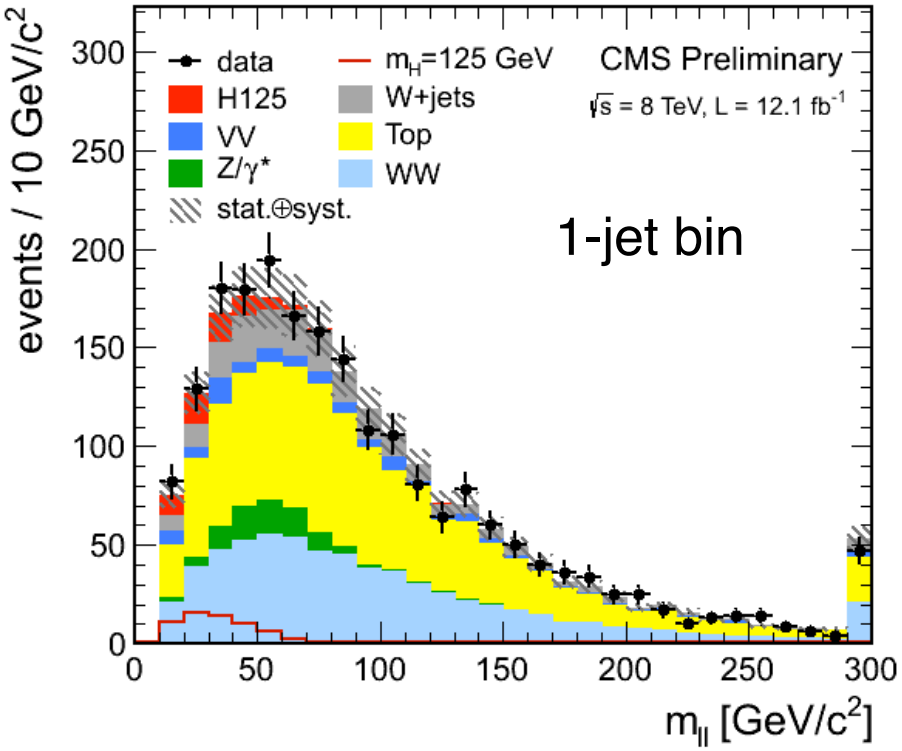
H→W+W- analysis

(4.9fb-1 at 7 TeV and 12.1fb-1 at 8TeV)

H→WW→2l2v analysis:

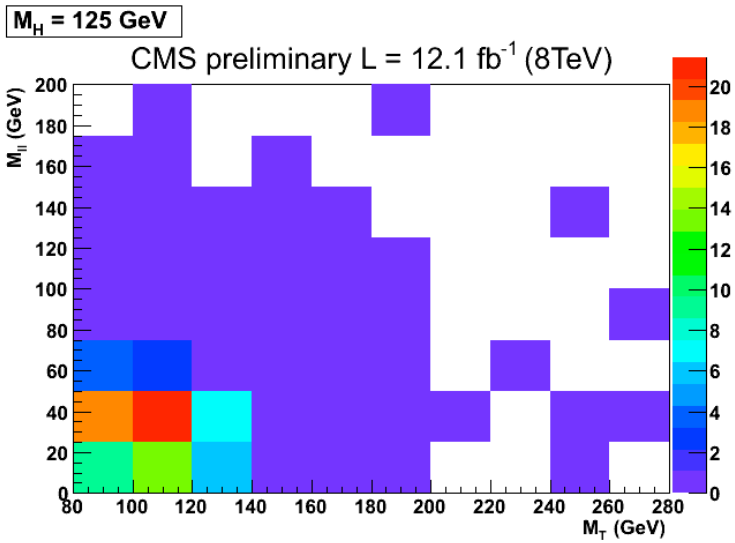
- Main backgrounds: WW, top, W+jets (estimated from control regions in data)
- Select two isolated leptons with pT>20,10 GeV and mET>20 GeV
- Categorize in 0-jet, 1-jet, 2-jet bin (jet pT>30 GeV), then ee,μμ,eμ with opposite charge
- No mass peak
- **0-jet and 1-jet opposite flavour are 2D analyses**, the others are cut and count

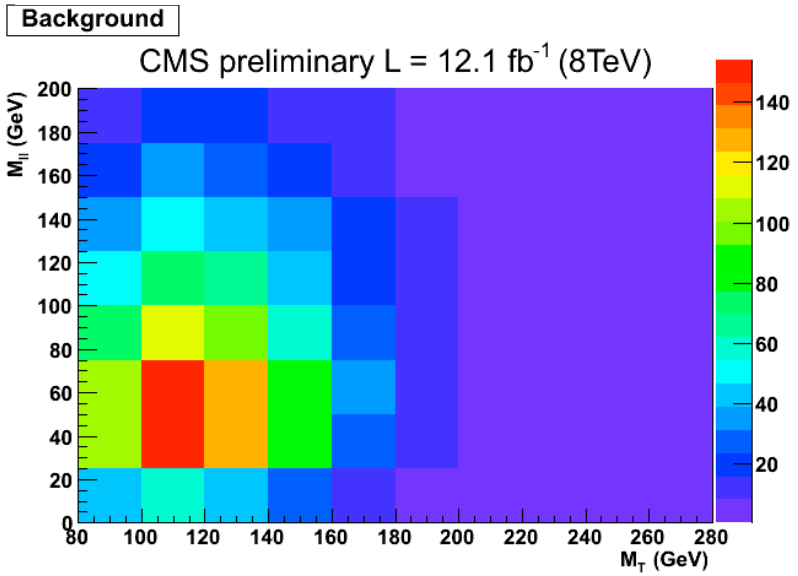


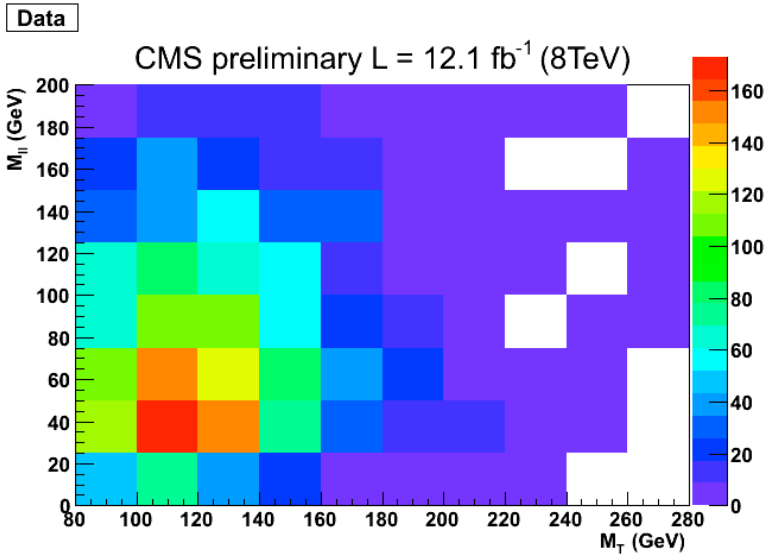


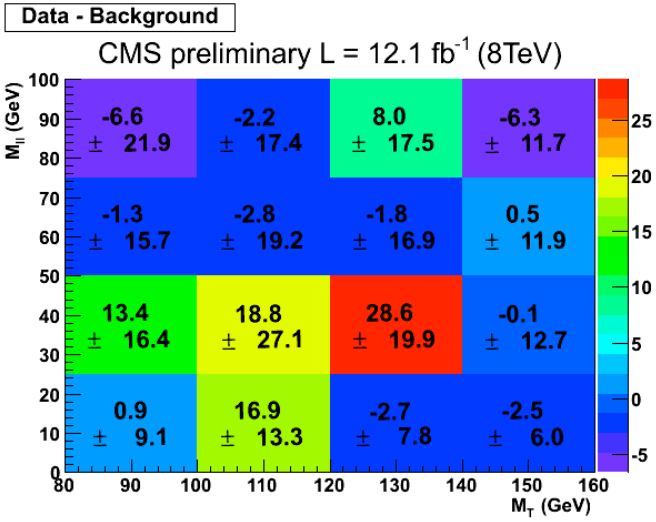
H→W+W-: 2D analyses

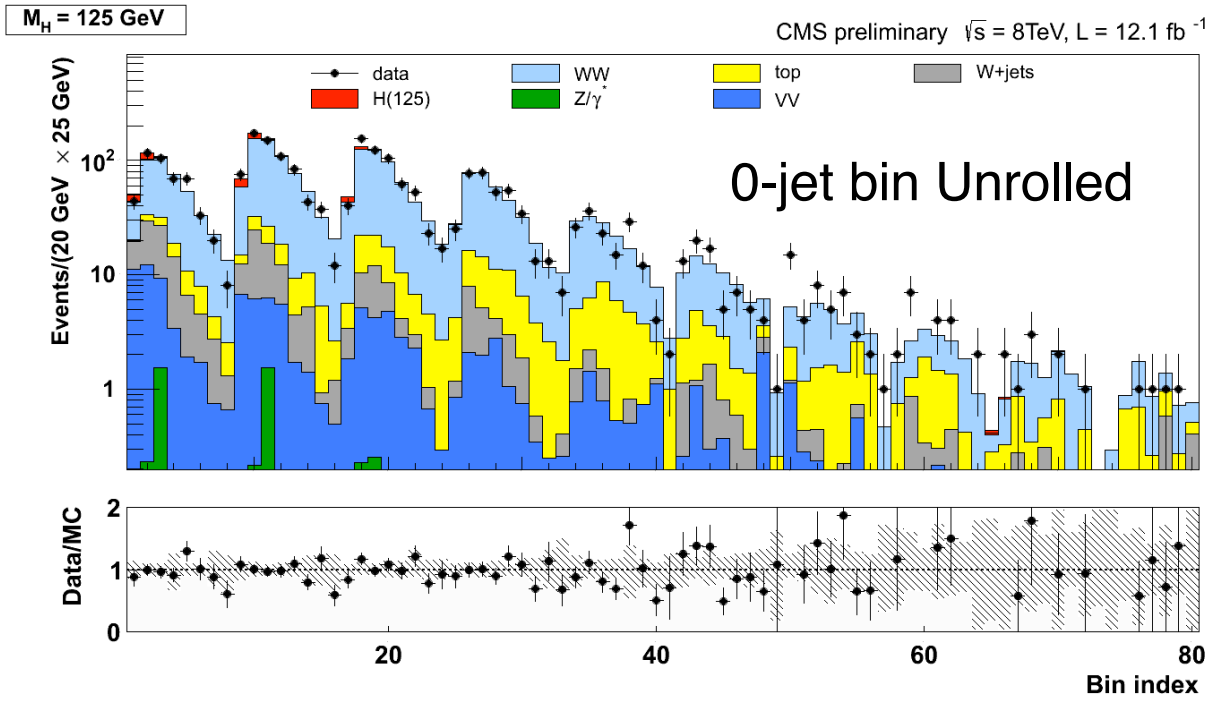
2D shape analysis in (m_T, m_{ll}) for the SF 0-jet and 1-jet bins







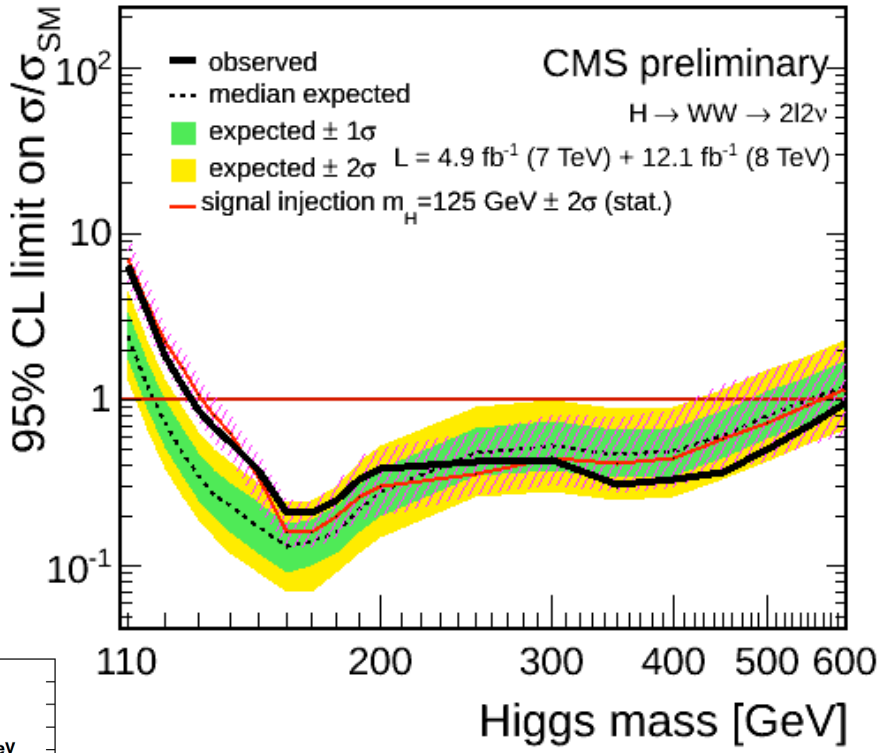


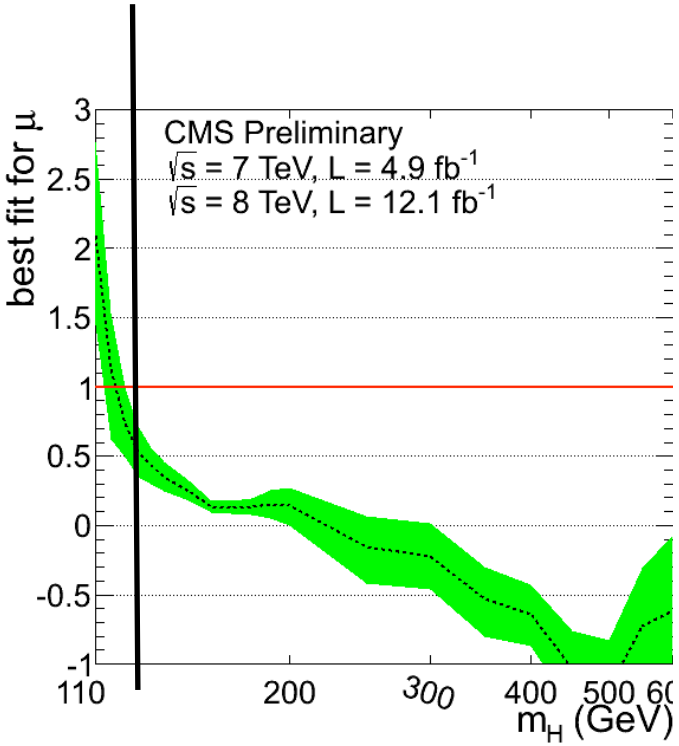


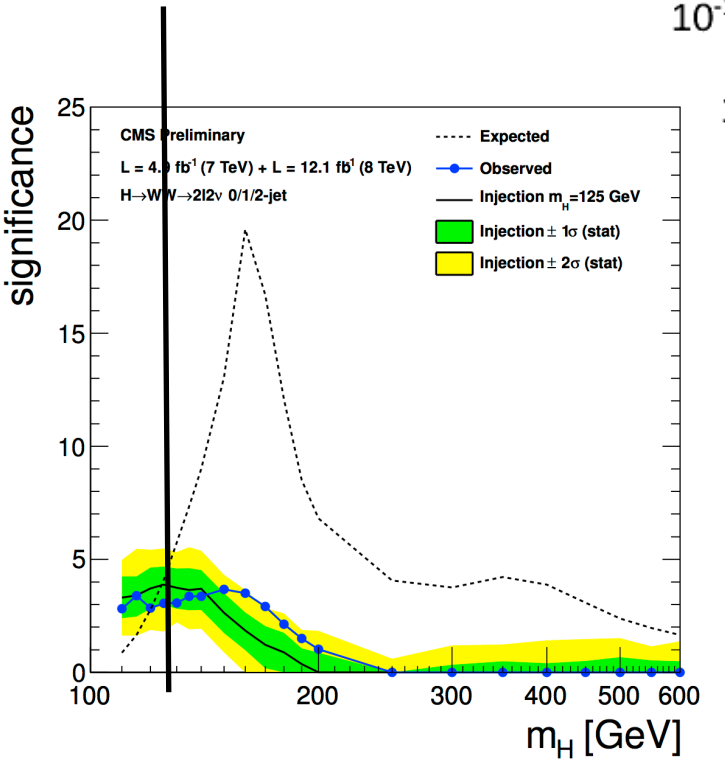
H→W+W- results

Broad excess observed in exclusion limits compatible with presence of signal

- **Best fit** signal strength **μ=0.74±0.25 at 125 GeV**
- **Local significance: expected 4.1σ, observed 3.1σ**





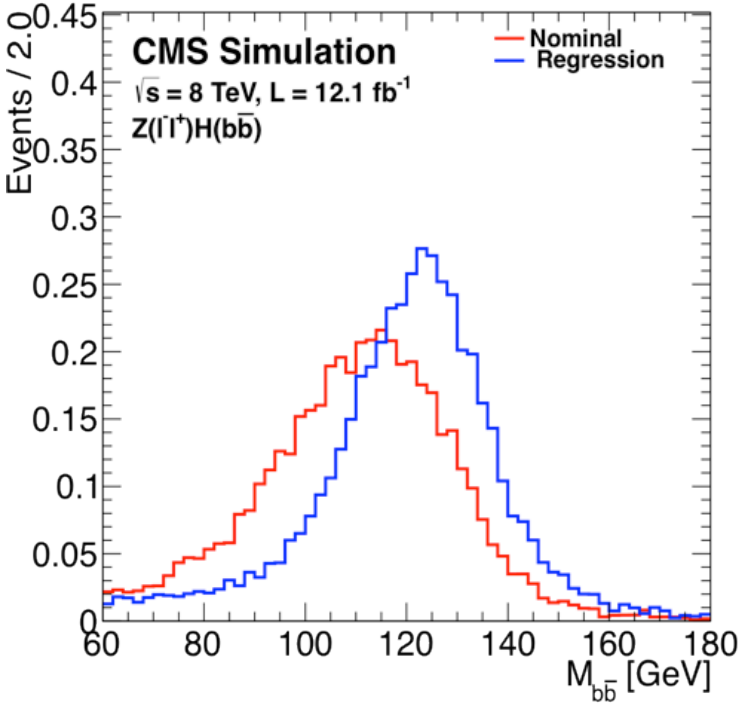


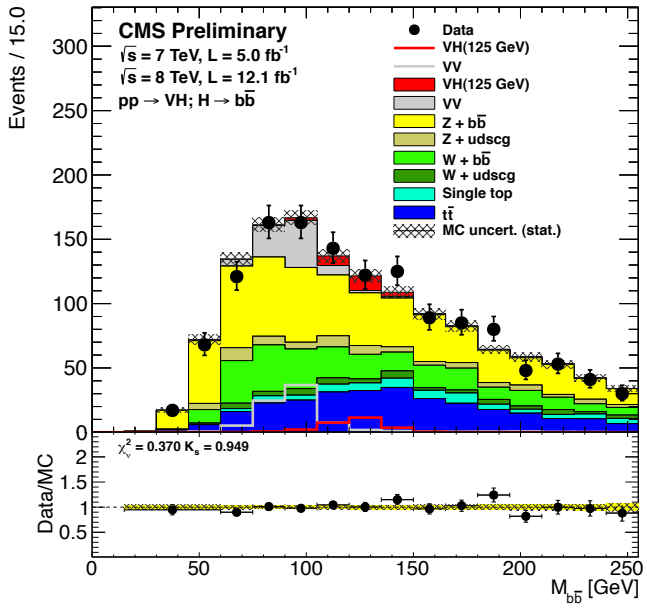
H→bb̄ analysis

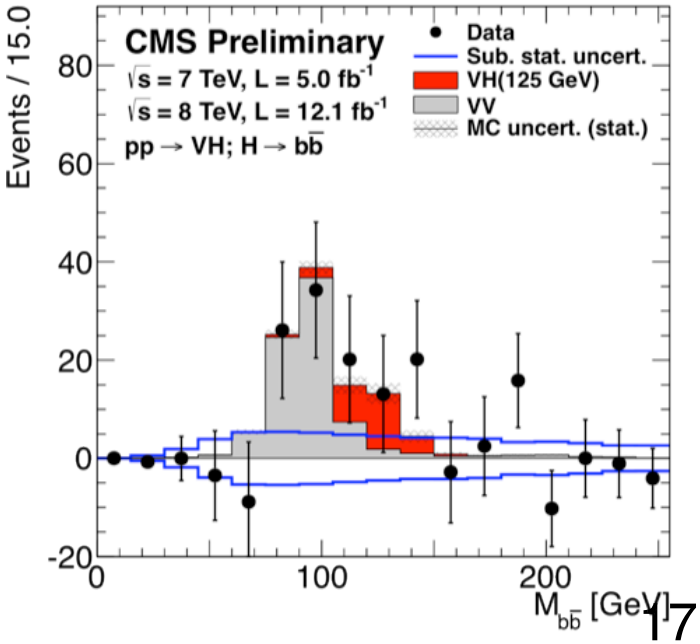
(5.0fb-1 at 7 TeV and 12.2fb-1 at 8TeV)

Associated production VH(bb) with V being W(eν), W(μν), Z(ee), Z(μμ) or Z(νν)

- Background: V+2jets, VV, top
- Trigger on the associated vector boson: single/double lepton, mET(+jets)
- Two categories per channel according to vector boson pT (170 GeV but for Z(ll), 100 GeV)
- Select 2 central b-tagged jets
- b-jet energy regression using 2nd vertex and jet properties, mET direction and soft lepton info inside the jet => improves analysis sensitivity by 15-20%



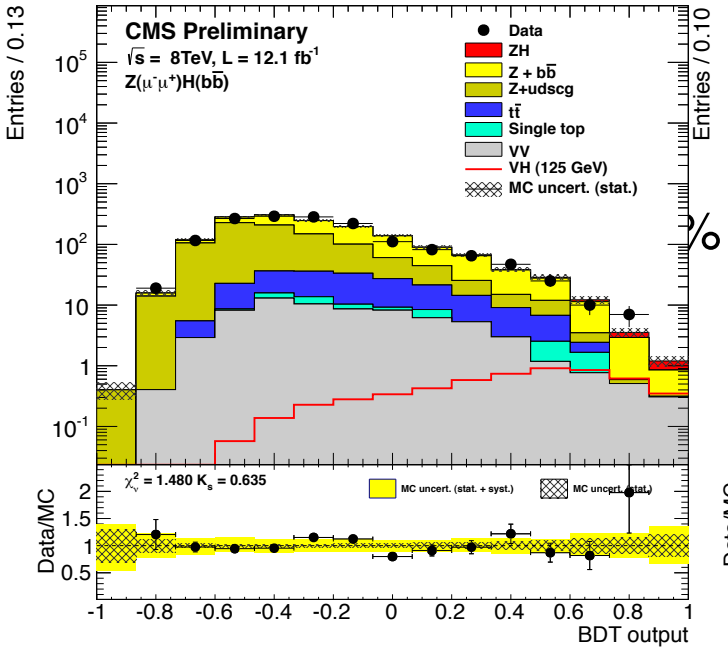


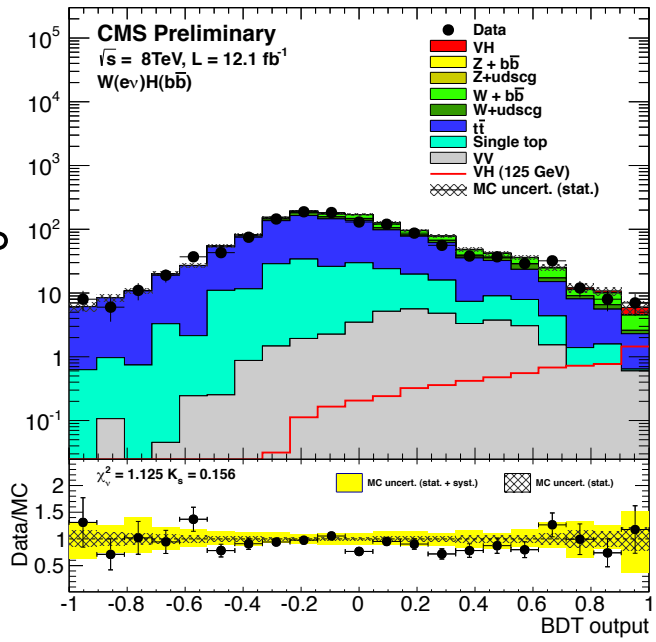


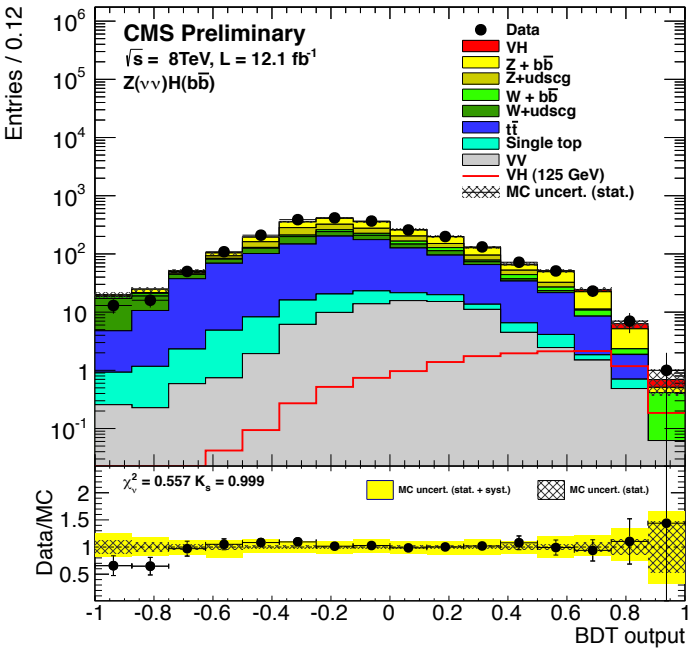
H→bb̄: BDT shape analysis

BDT shape analysis:

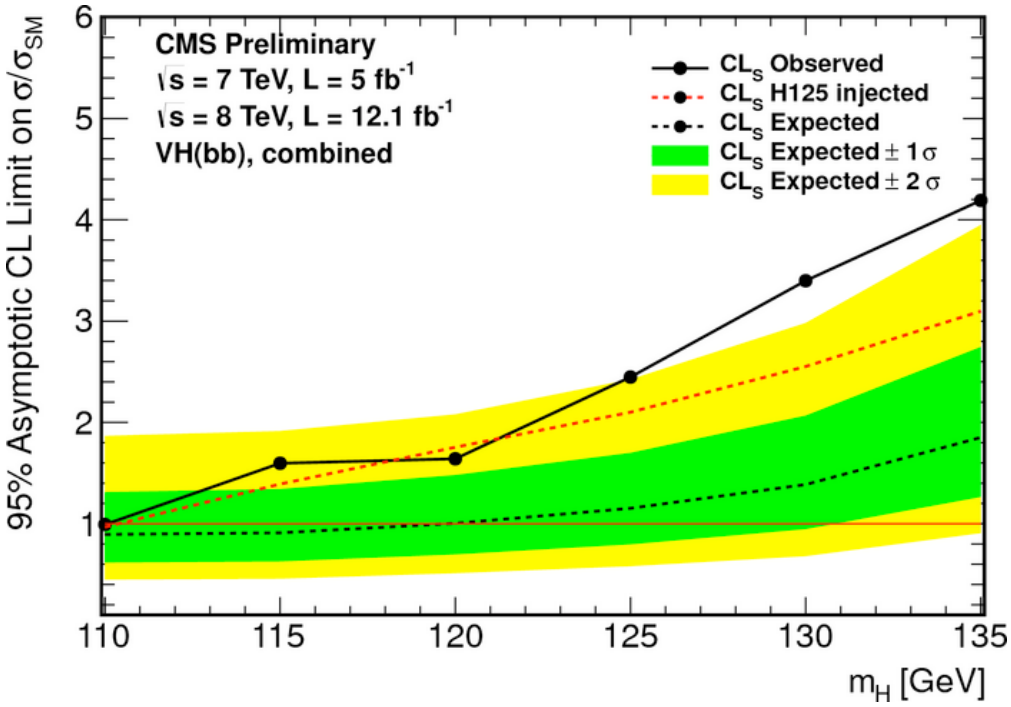
- BDT variables: mainly jets and vector boson kinematics, b-tagging discriminant
- Fit to the BDT shapes in each channel
- 10% improvement using shapes (BDT cut and count used previously)

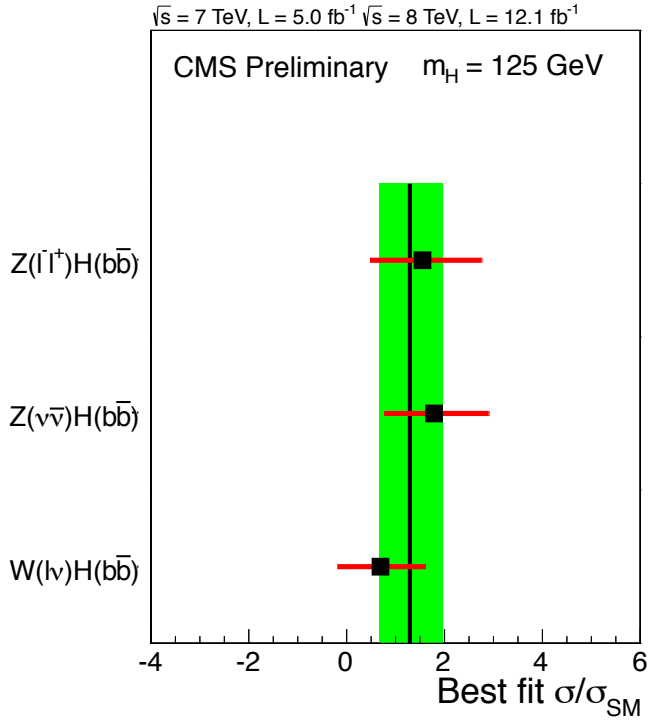


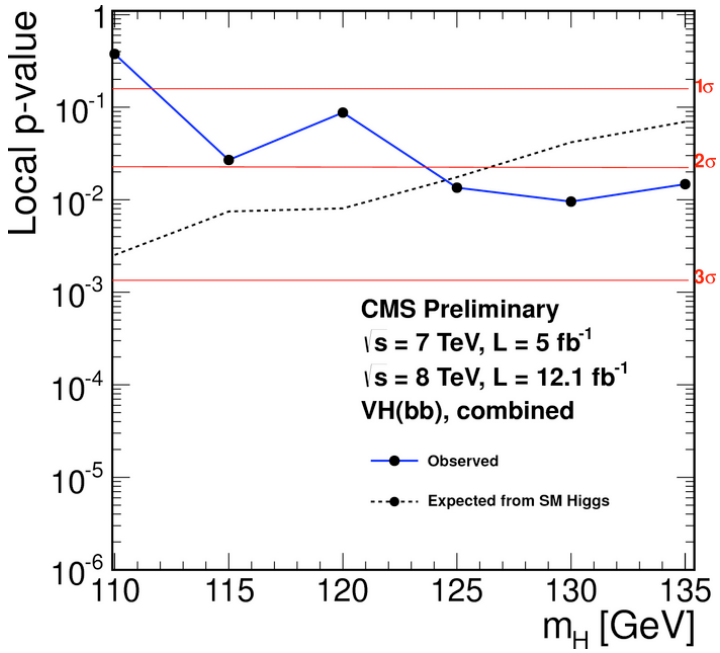




H→bb̄ results







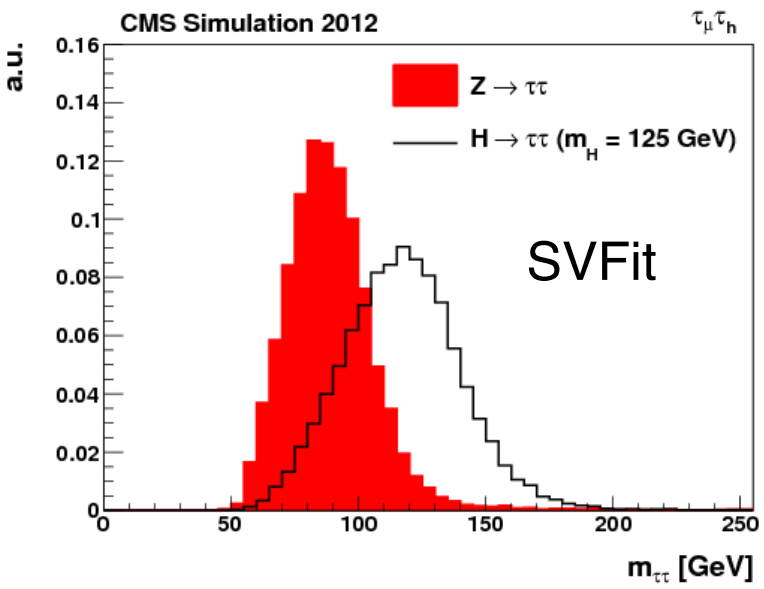
- **Broad excess compatible with SM Higgs injection**
- At 125 GeV, observed **p-value 2.2σ**
  Best fit $\mu = 1.3^{+0.7}_{-0.6}$

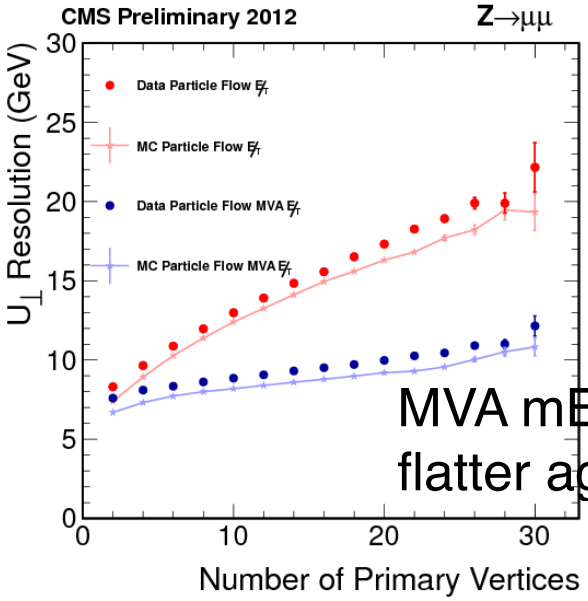
$H \rightarrow \tau^+\tau^-$

(4.9fb-1 at 7 TeV and 12.1fb-1 at 8TeV)

5 final states: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$, also associated production VH($\tau\tau$)

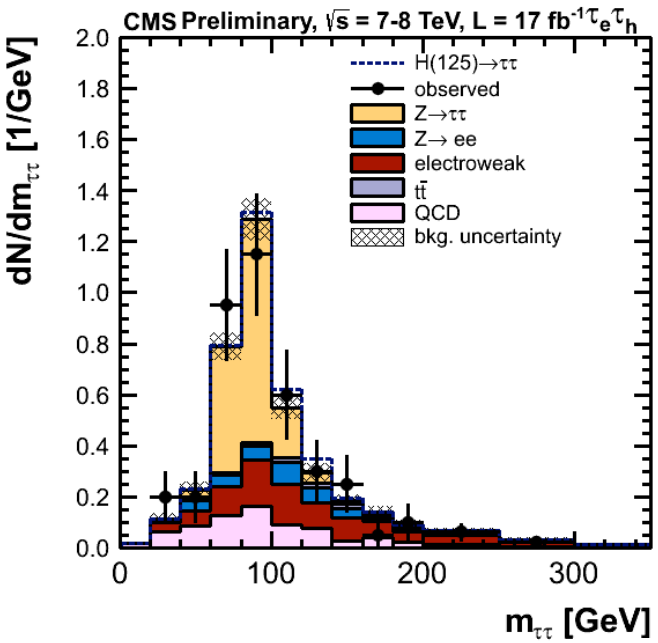
- Main background from QCD, Z($\tau\tau$)+jets
- Tau reconstruction with the particle-flow (PF) algorithm
- MVA τ_h isolation in rings
- Improved PF mET resolution with MVA
- Mass reconstruction with matrix element method (SVFit)
- Categories: 2-jet (VBF tag), 1-jet, 0-jet
- Data-driven method to estimate tau fake rate from control regions

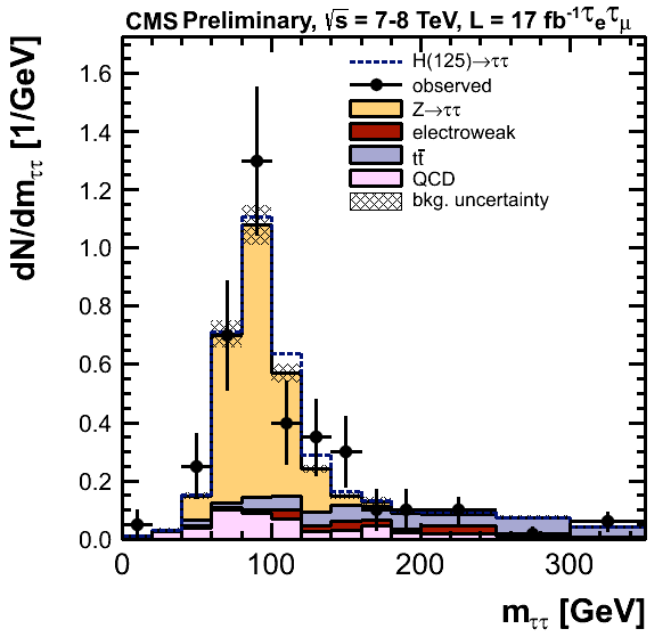


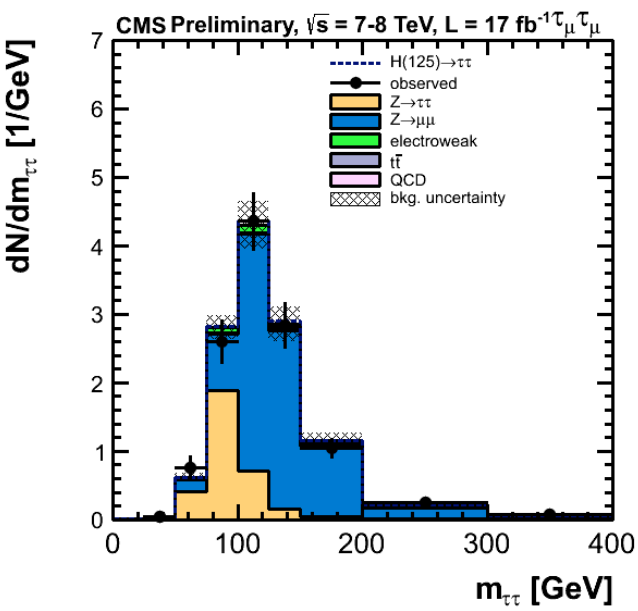


MVA mET resolution flatter against PU

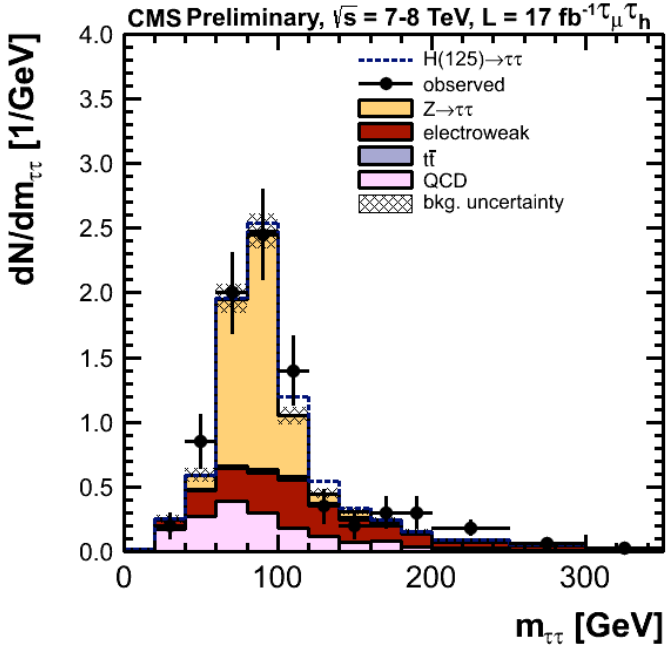
$H \rightarrow \tau^+\tau^-$

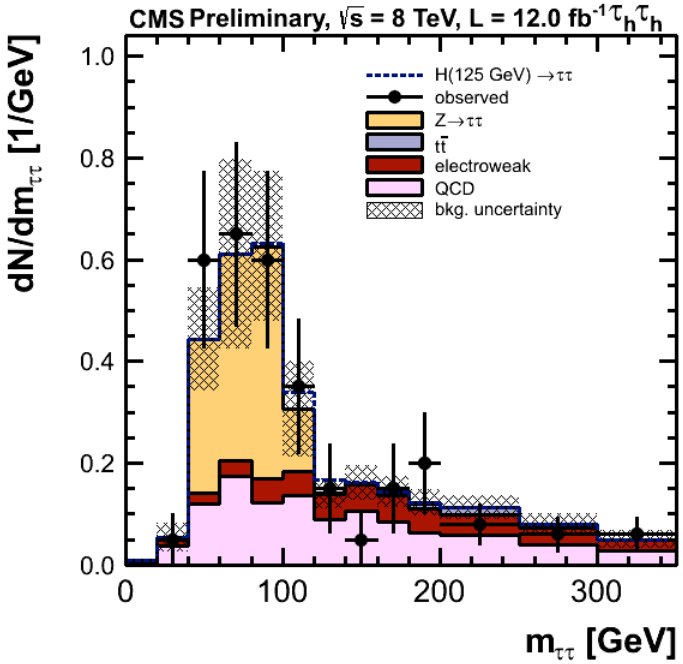




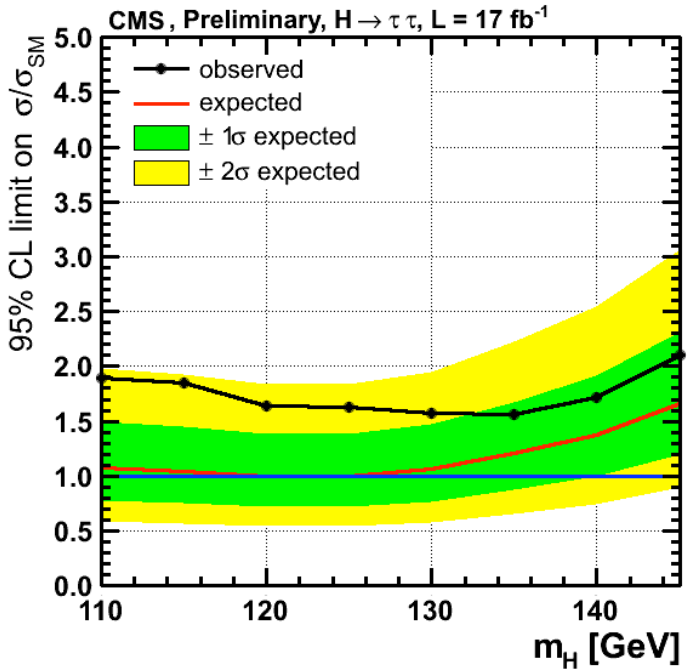


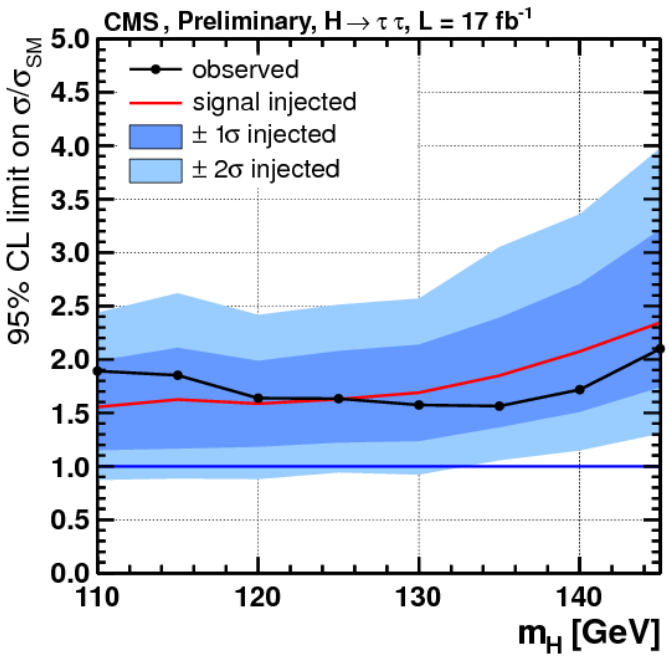
- ditau invariant mass distributions in the VBF channel as an illustration
- 0-jet not used for sensitvity



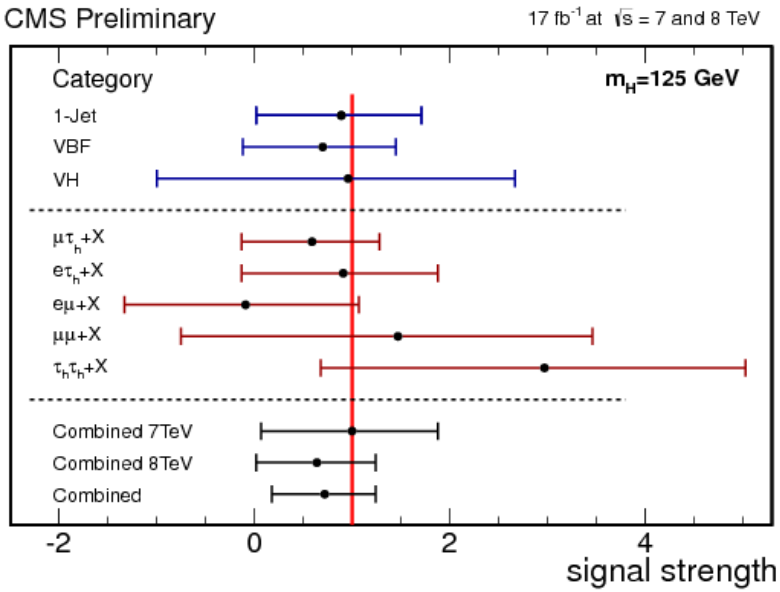


$H \to \tau^+\tau^-$ results





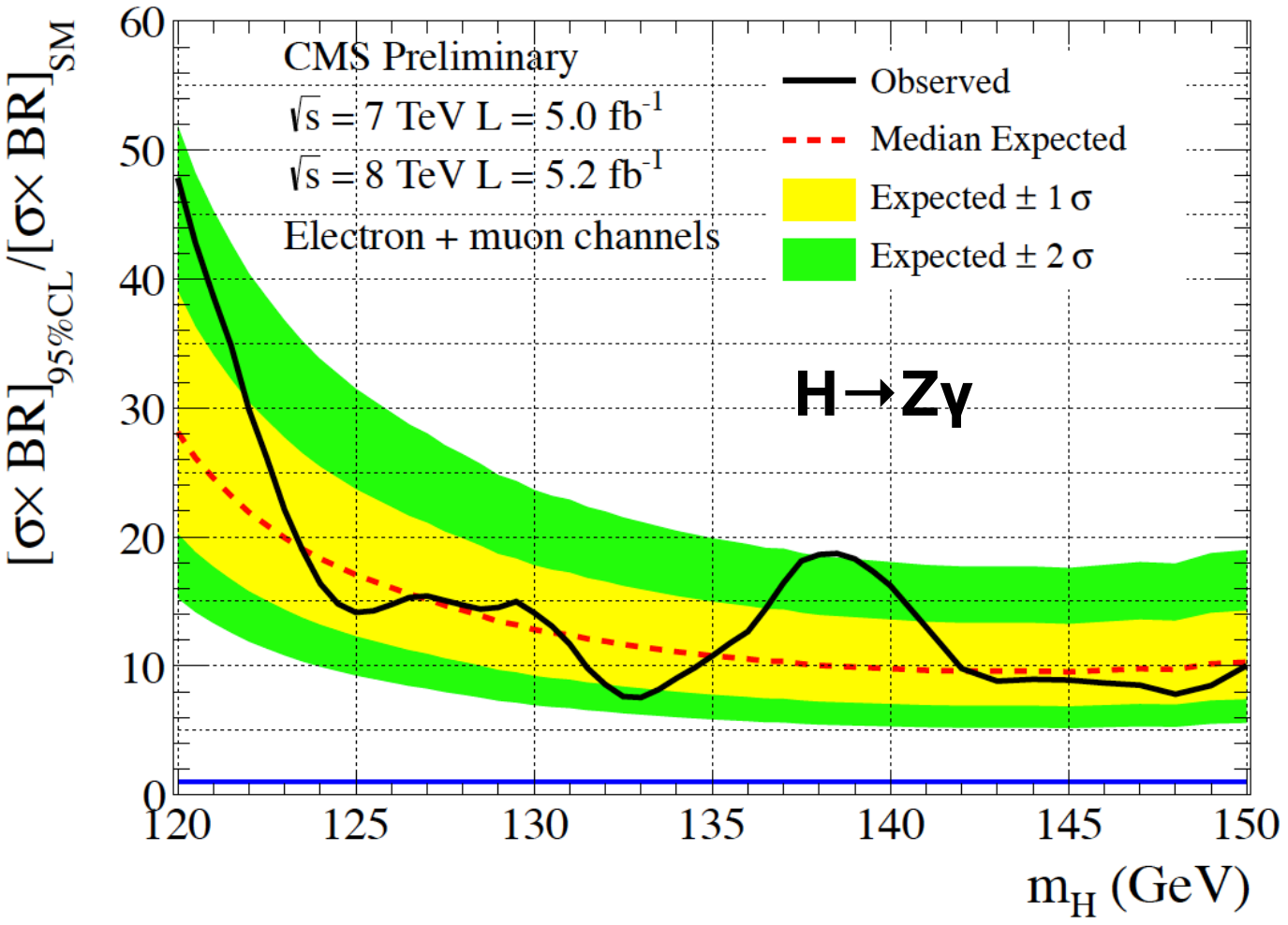
- **Broad excess observed compatible with the signal injection test**
- **Best fit μ=0.7±0.5**



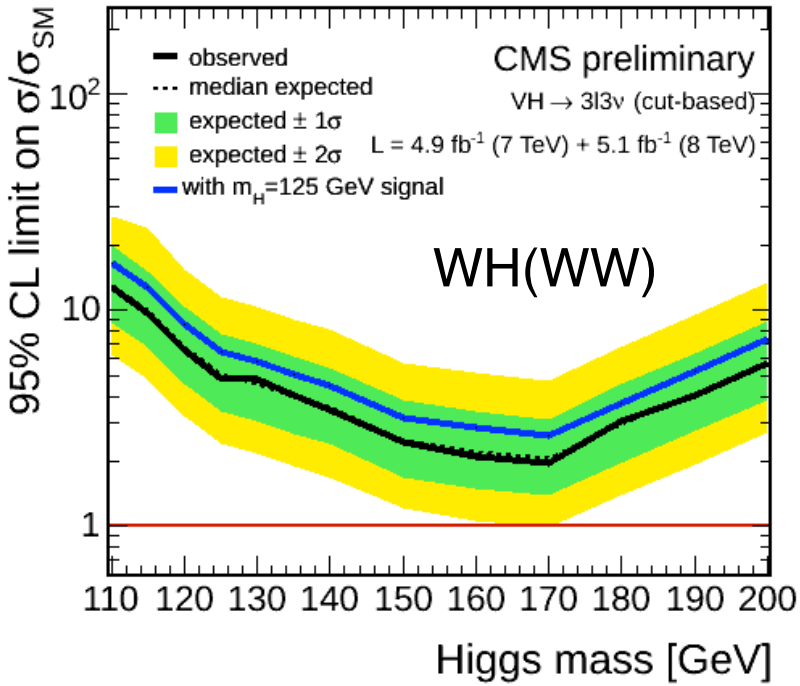
H→Zγ
(5.0fb-1 at 7 TeV and 5.2fb-1 at 8TeV)

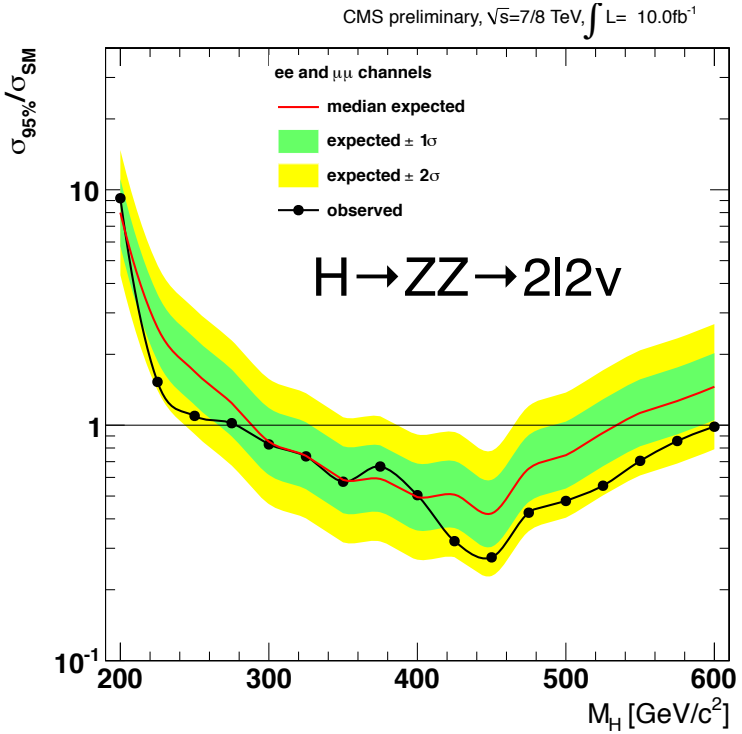
First analysis H→Zγ performed at LHC

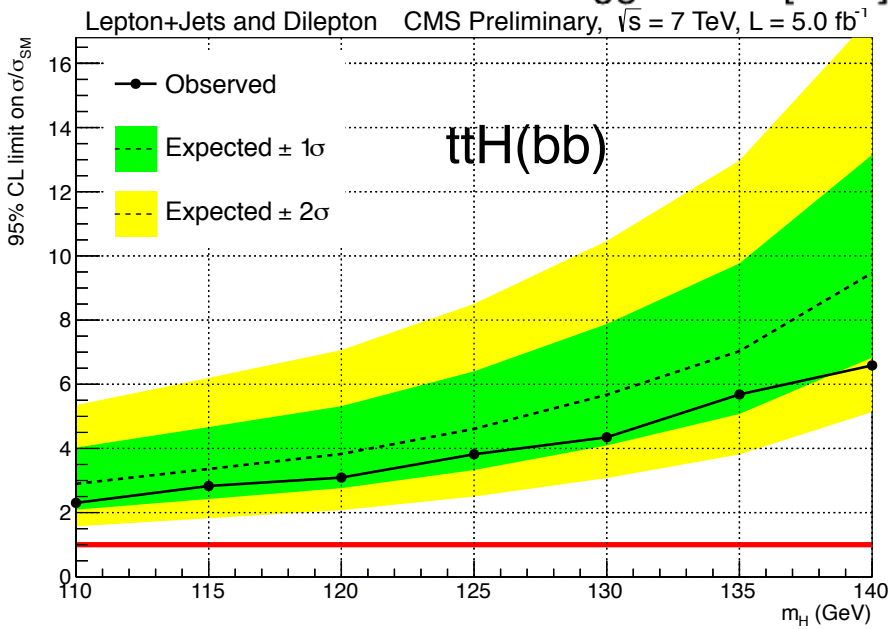
- **PAS-12-049**
- Interesting because probes physics in the loops as γγ
- ee and μμ channels included
- Categorize in lepton η and photon η and converted/ unconverted
- Far from the SM for the moment: at 125 GeV, expect 17xSM and observe 14xSM

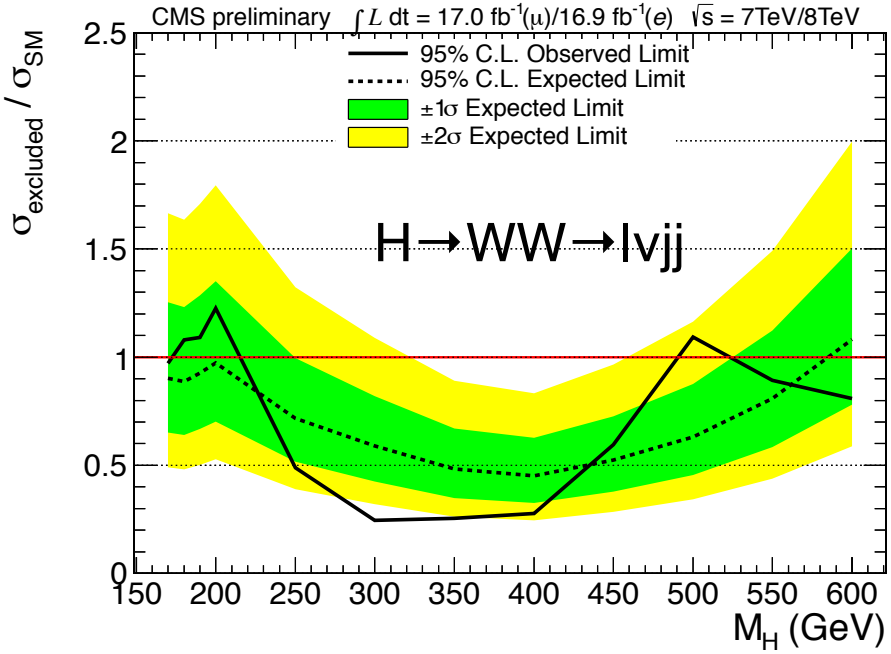


Other channels in the combination



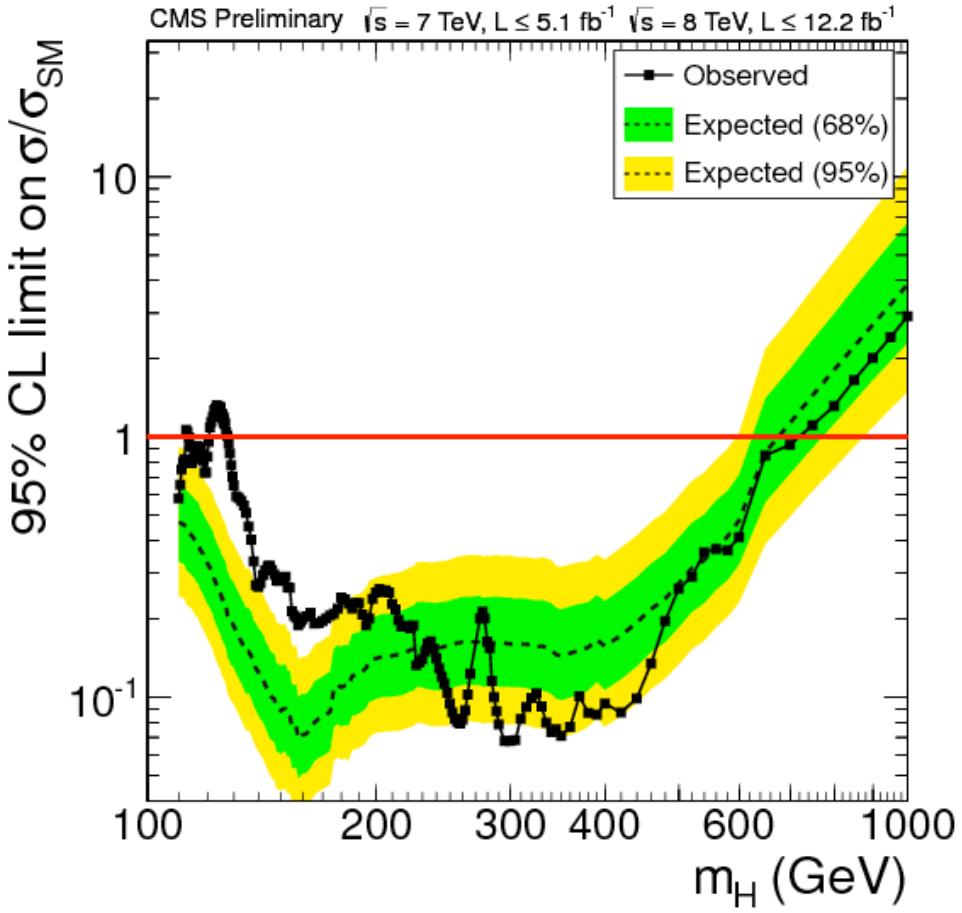


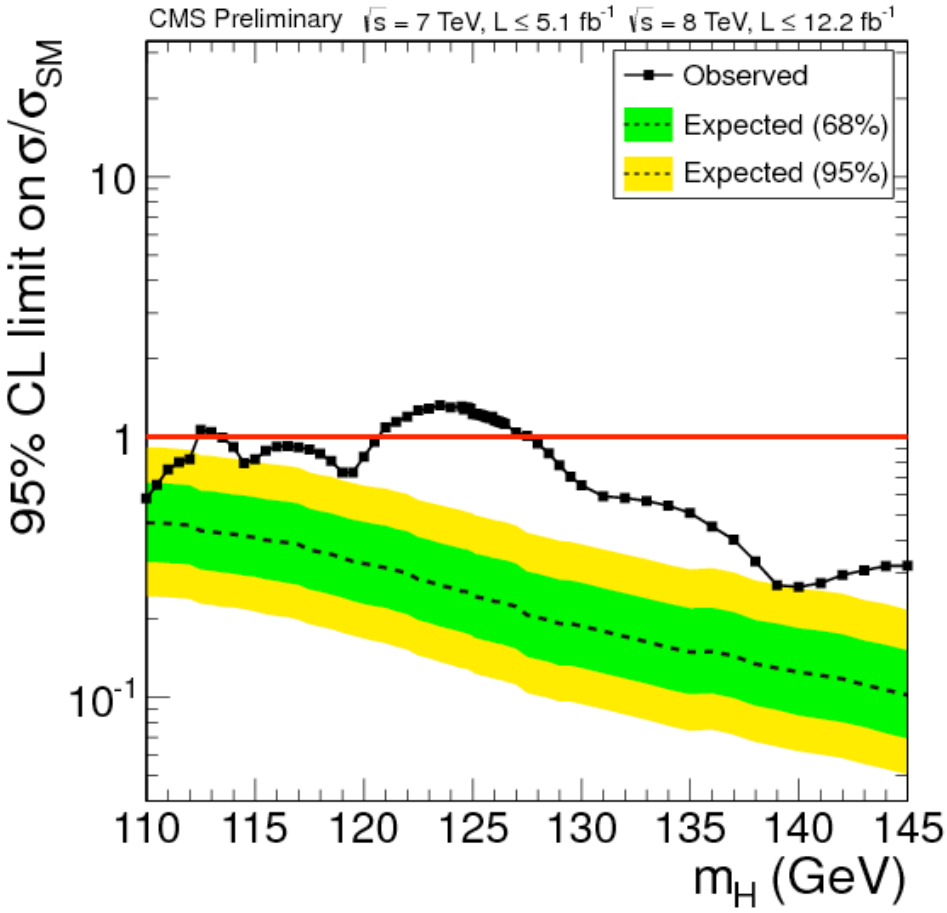




Combination: results

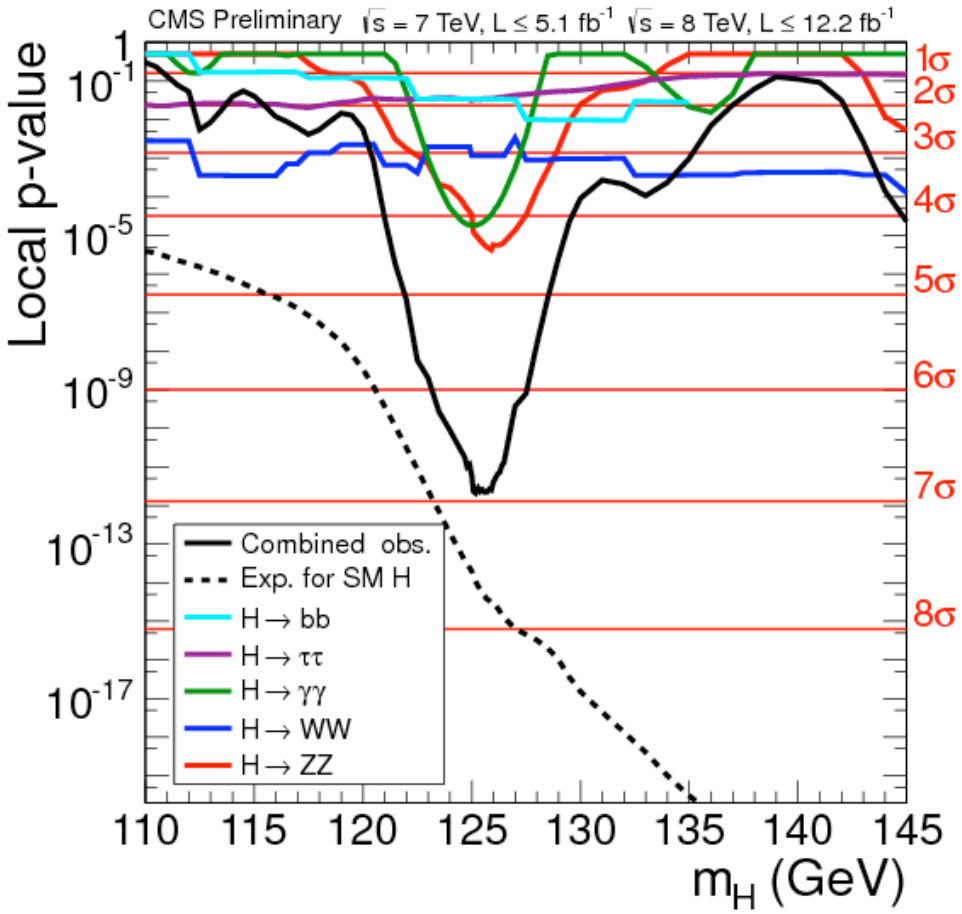
- **Exclude** all mass range at 95% CL **up to 700 GeV** but [120-127] GeV
- **Excess in [120-127] GeV**

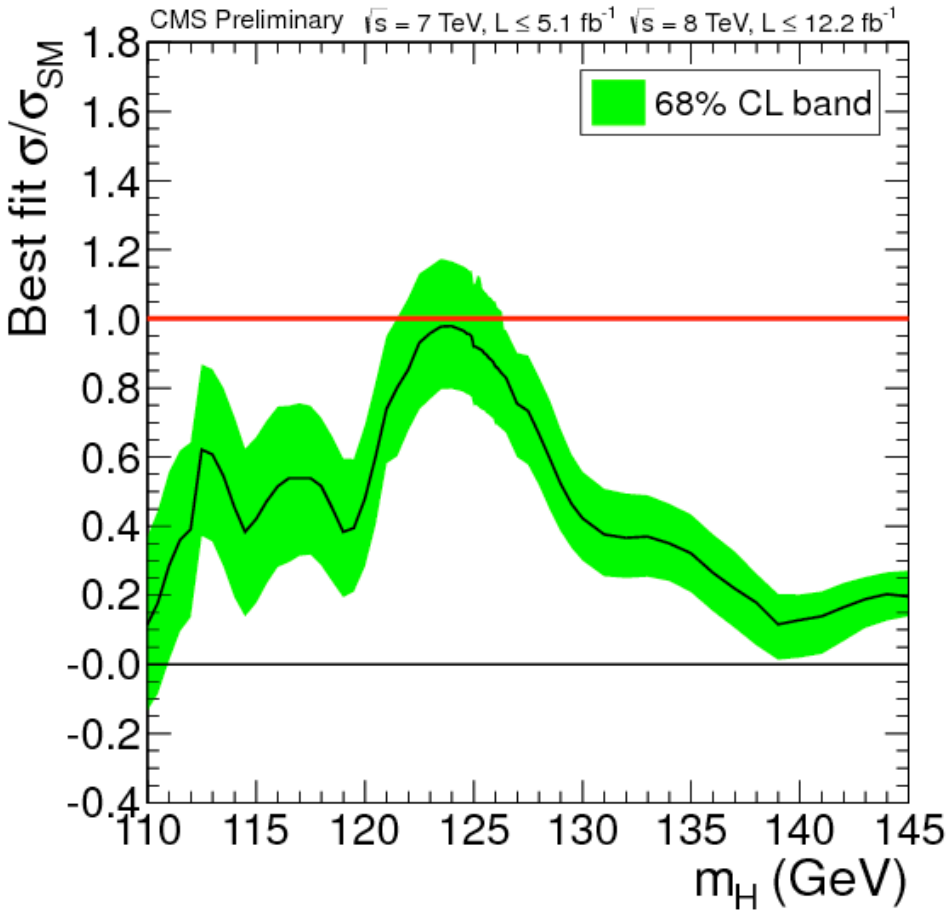




Combination: results

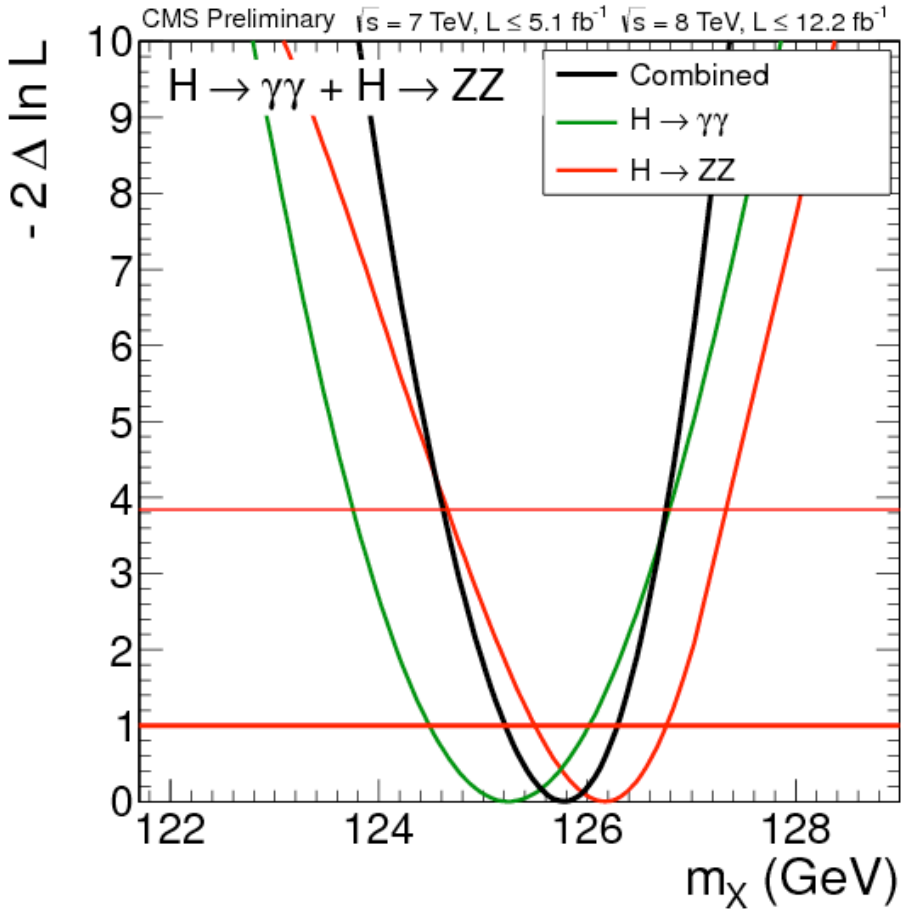
- Combined p-value: **6.9σ observed** (7.8σ expected)
- Combined **best fit μ=88±0.21**

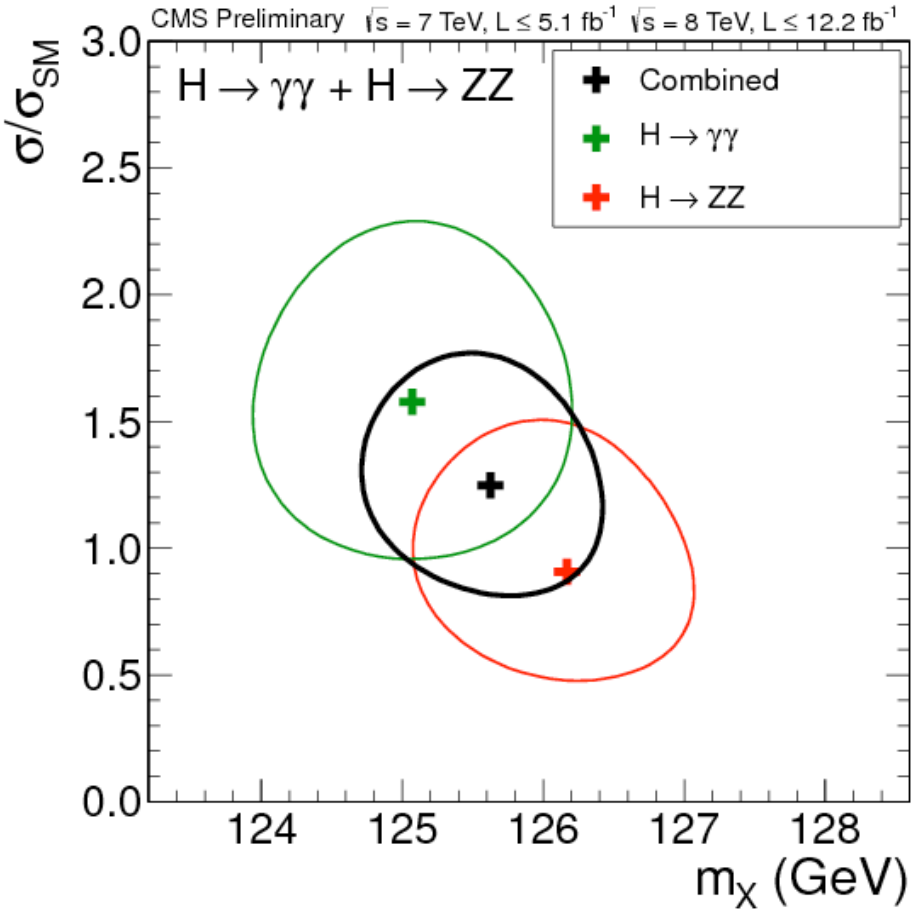




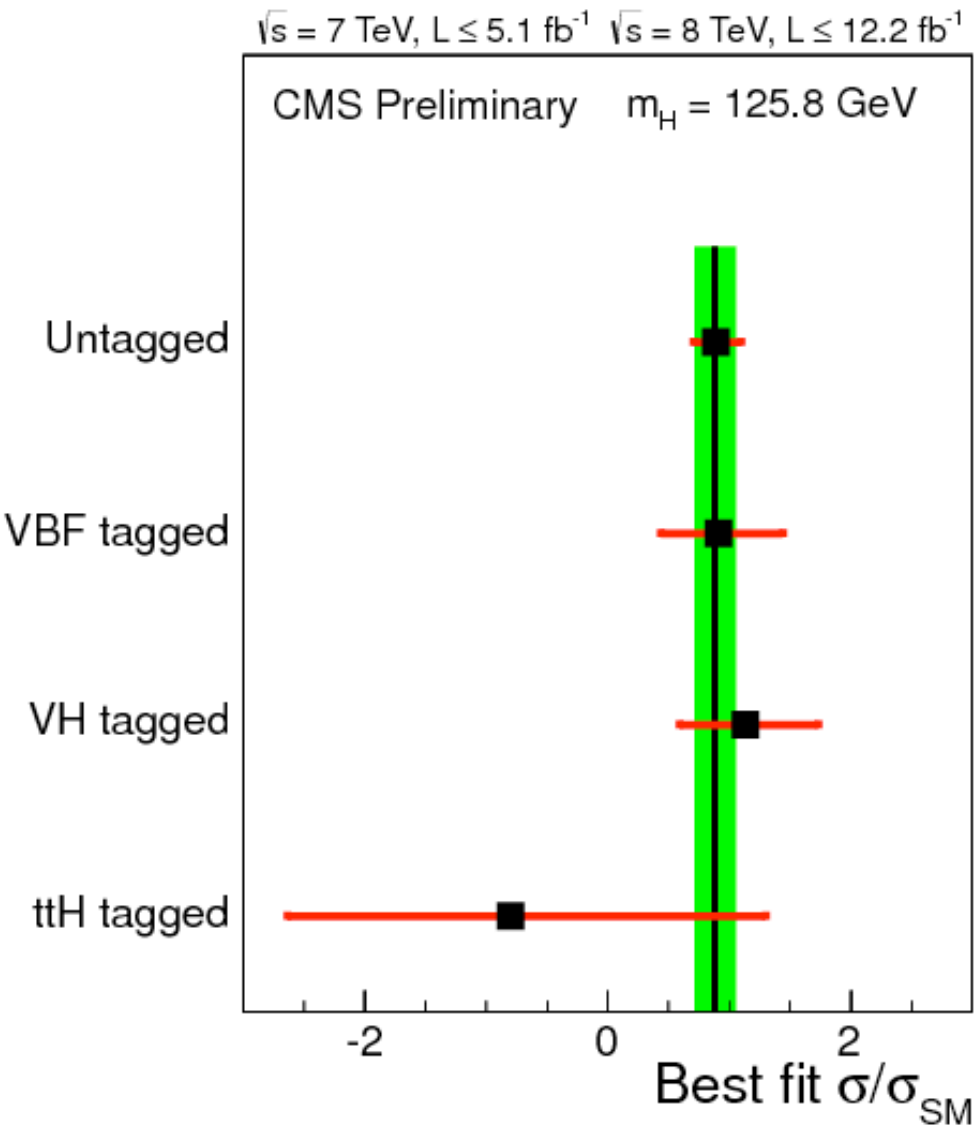
Combination: mass measurement

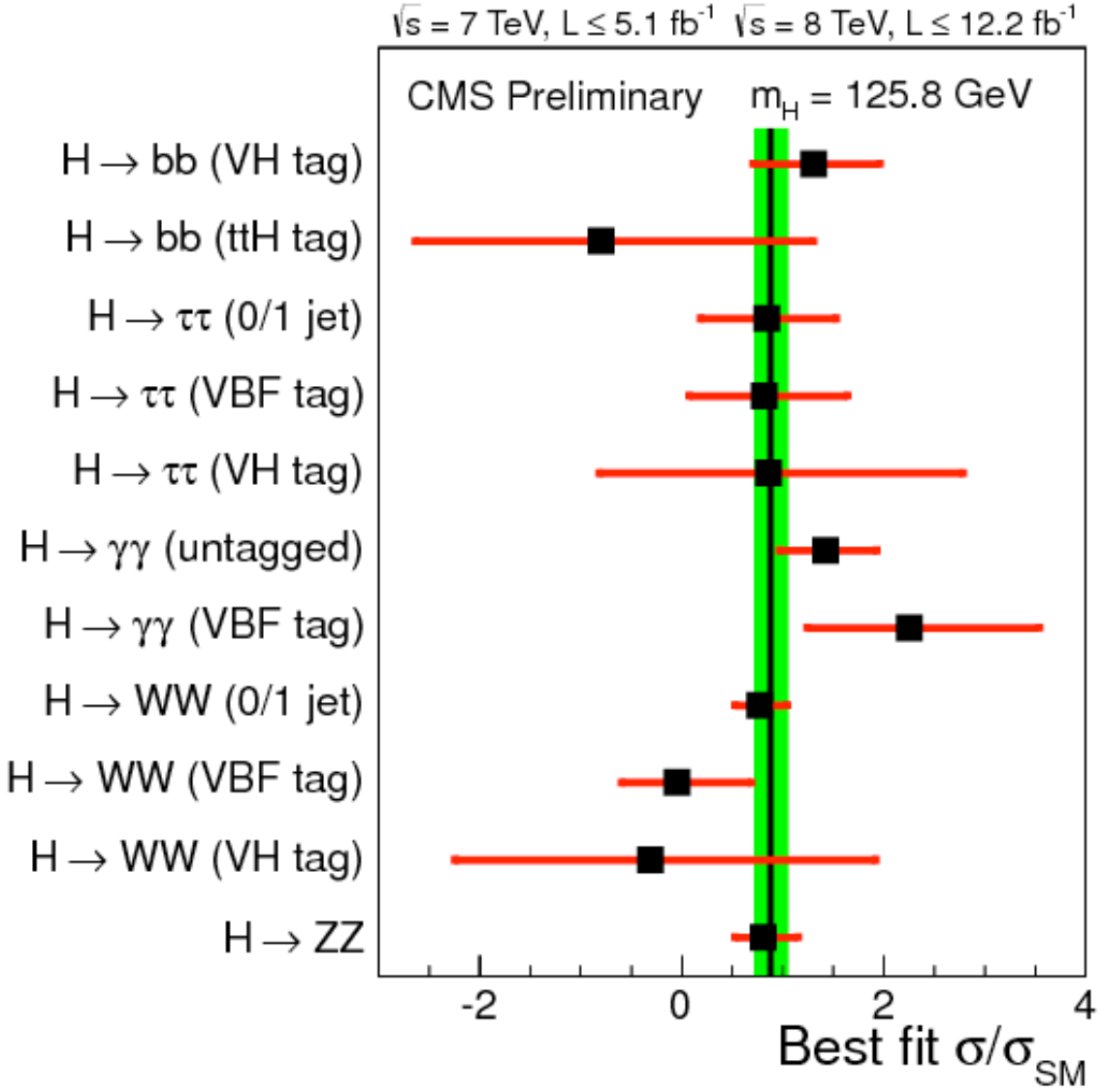
- Fit from γγ and ZZ: measures **125.8 ± 0.4(stat) ± 0.4(syst) GeV**
- Masses from γγ and ZZ are compatible





Combination: results





Conclusions

Higgs searches at CMS

Combined p-value: 6.9σ observed (7.8σ expected)
- Combined best fit μ=88±0.21
- Mass m=125.8 ± 0.4(stat) ± 0.4(syst) GeV

Measurements are compatible with the SM hypothesis so far

Higgs couplings: see talk by Paolo Azzuri tomorrow

Analyses will be updated for Moriond

Thank you!

BACK-UP SLIDES

CMS electromagnetic calorimeter (ECAL)

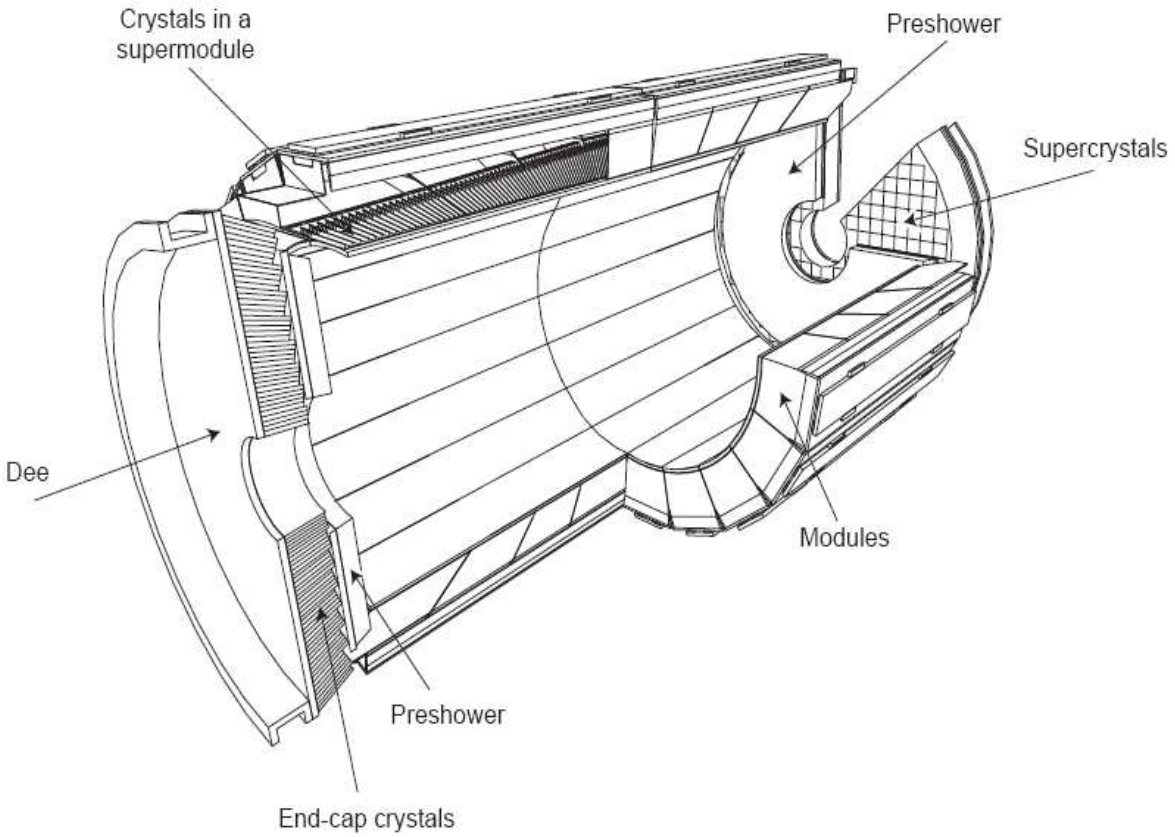
The **ECAL** is made of scintillating crystals of PbWO4 :
- **Barrel** : 36 “supermodules” with 1700 crystals each (coverage $|\eta|<1.48$)
- **Endcaps** : 268 “supercrystals” with 25 crystals each (coverage $1.48<|\eta|<3.0$)

Furthermore, a **preshower** made of silicon strip sensors is located in front of the endcaps ($1.65<|\eta|<2.6$)

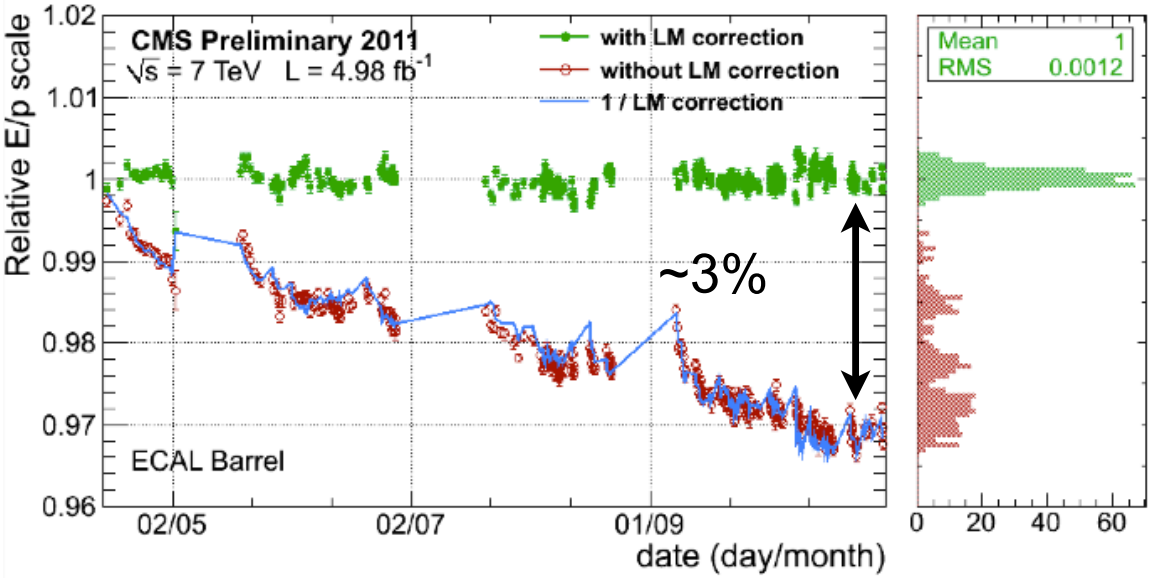
Energy resolution (measured in electron test beam) :

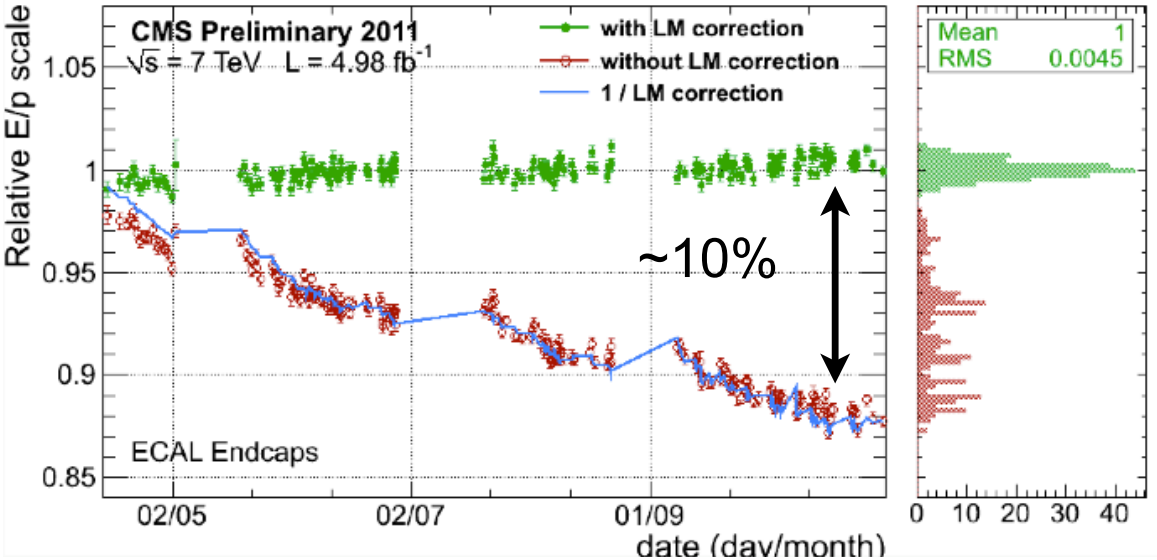
$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E(GeV)}} \oplus \frac{b}{E(GeV)} \oplus c$$

a = 2.8% stochastic term
b = 12% noise term
c = 0.3% constant tern

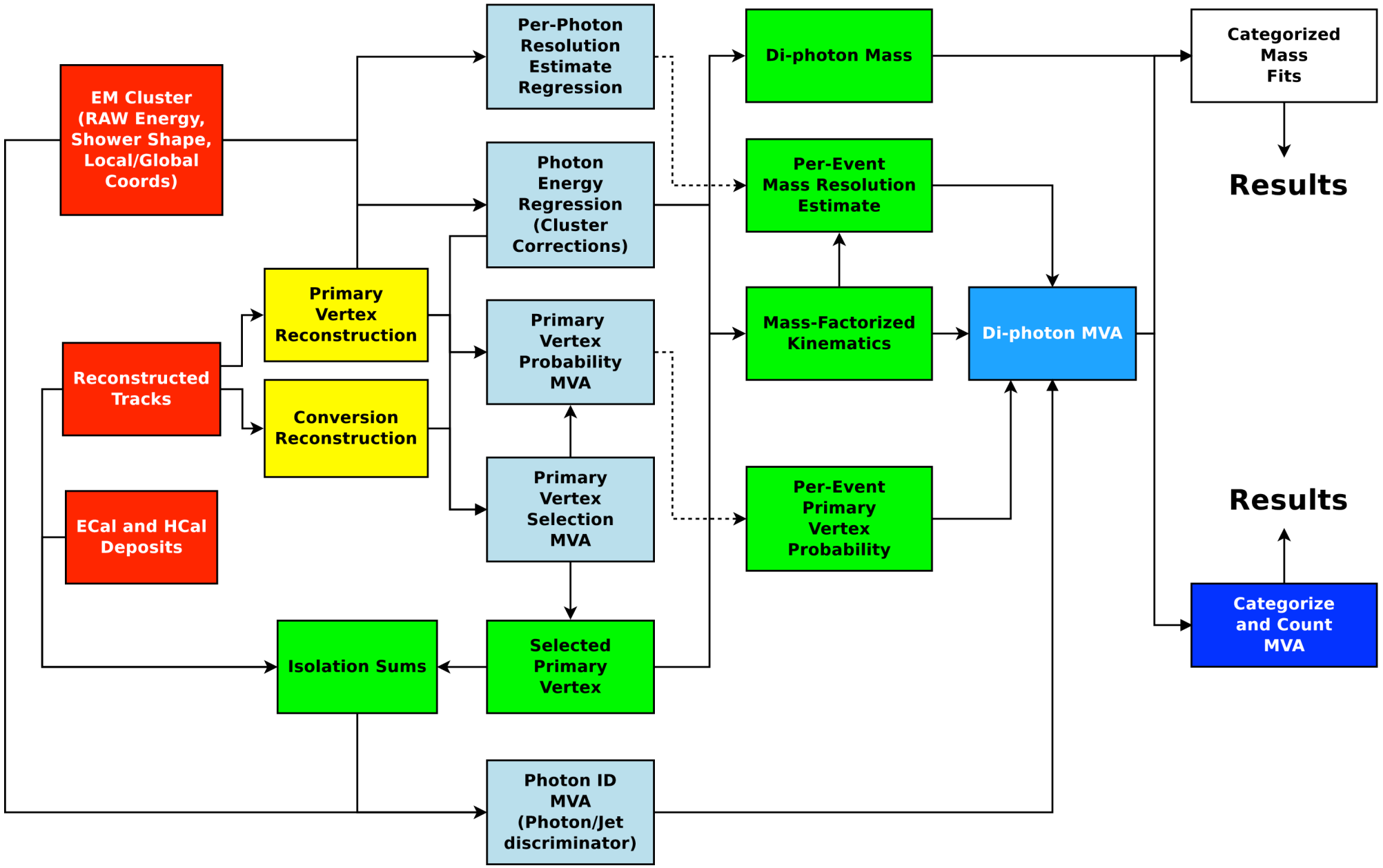


ECAL laser monitoring

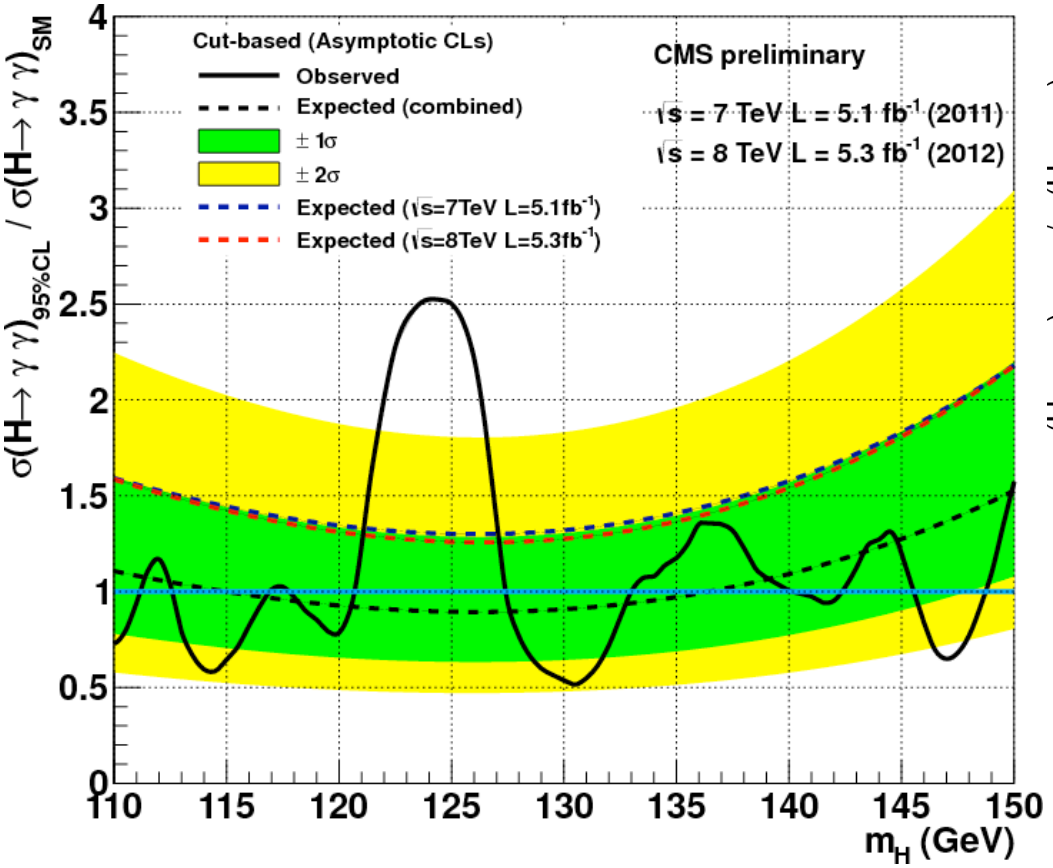


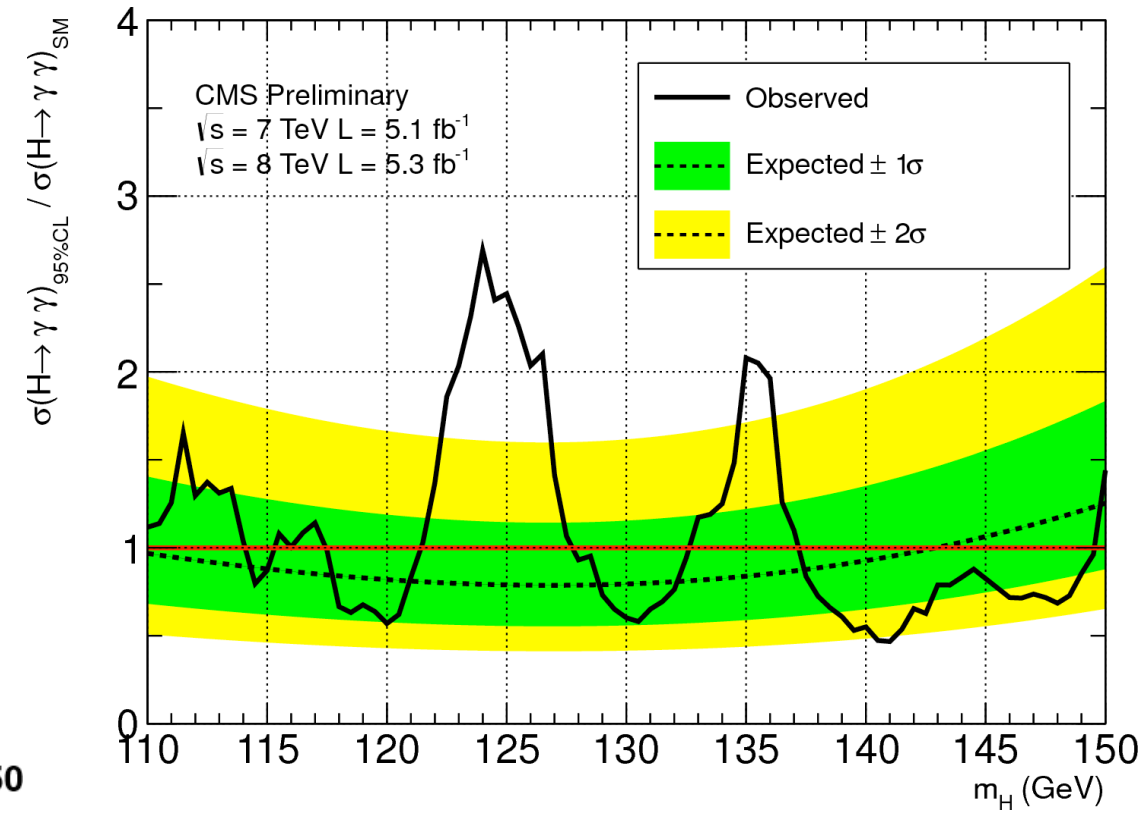


H→γγ flowchart

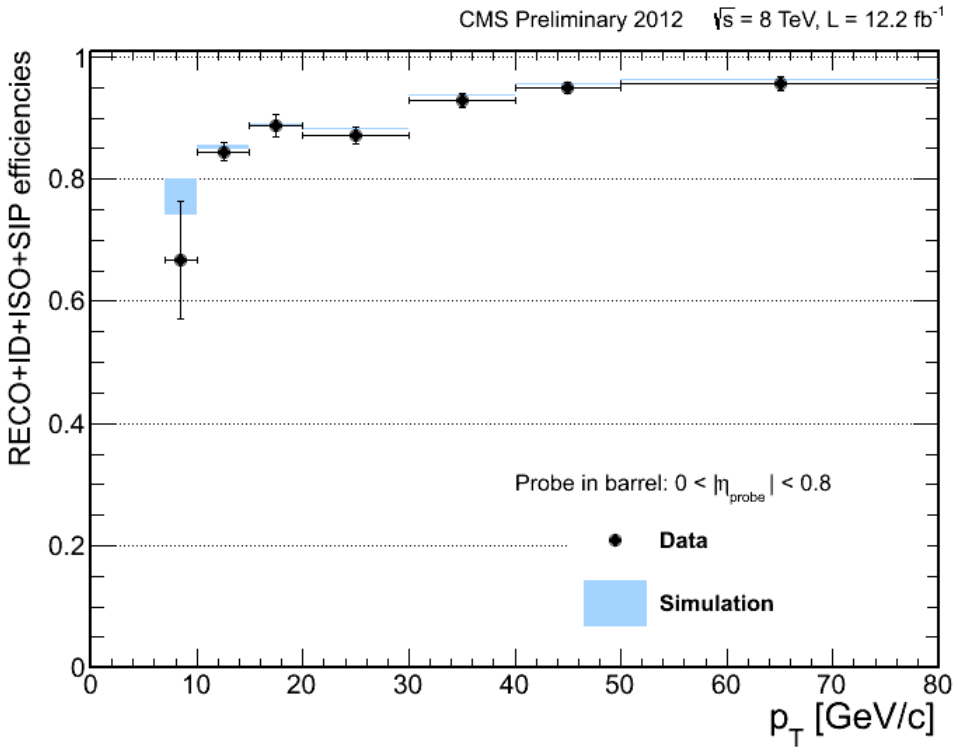


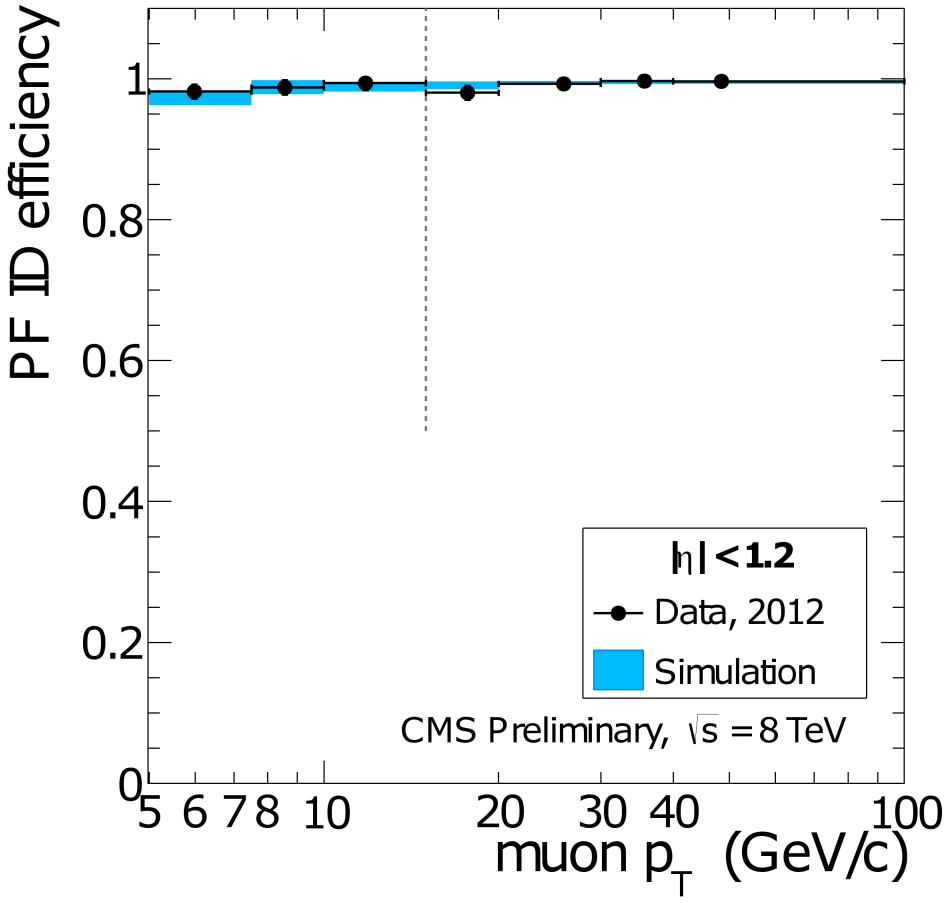
H→γγ cross-checks



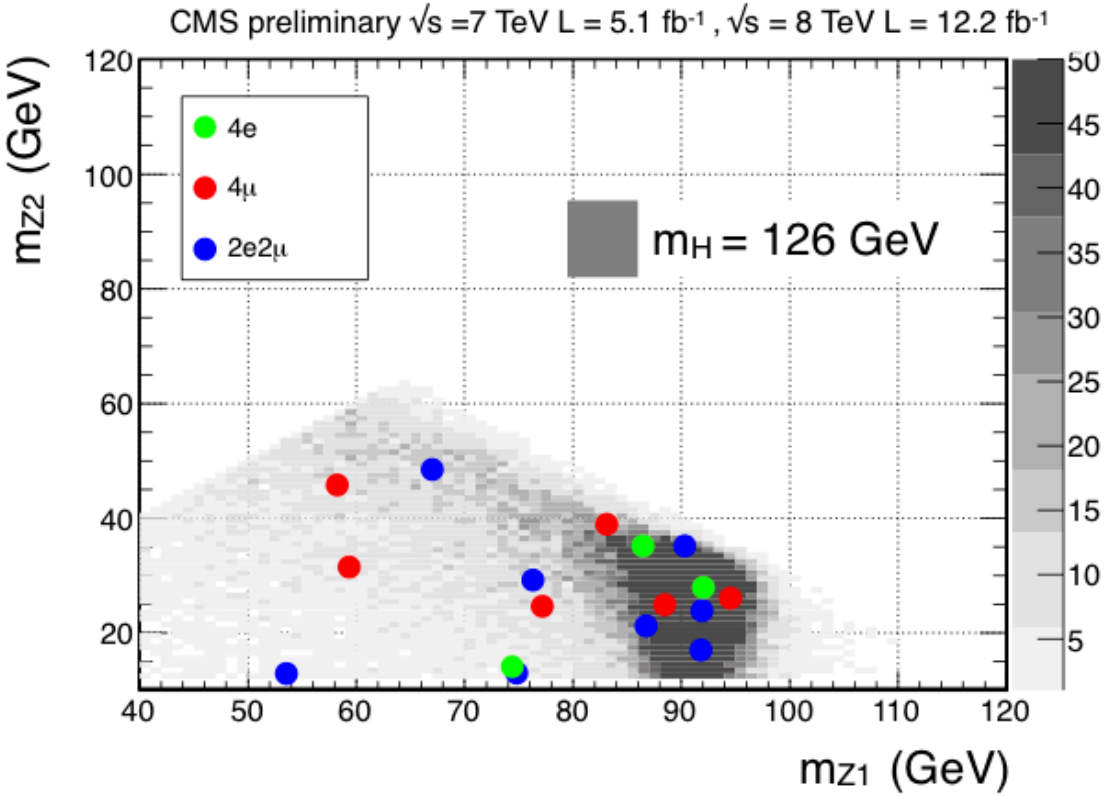


H→ZZ: lepton efficiency

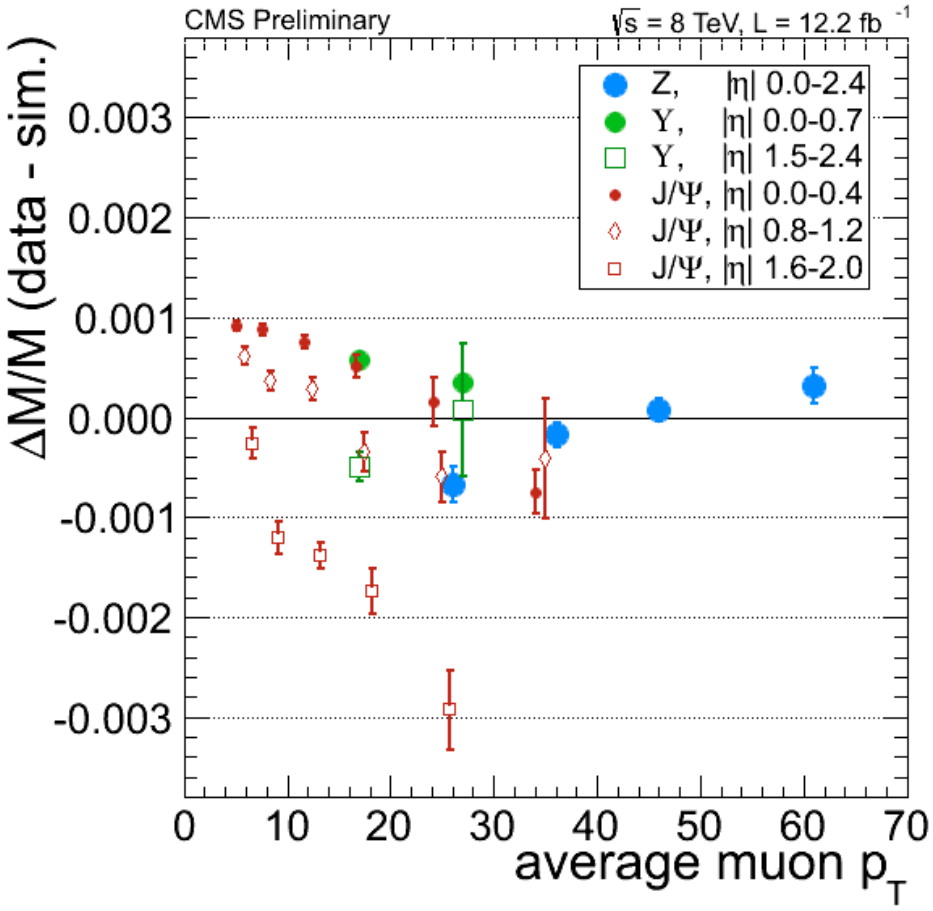


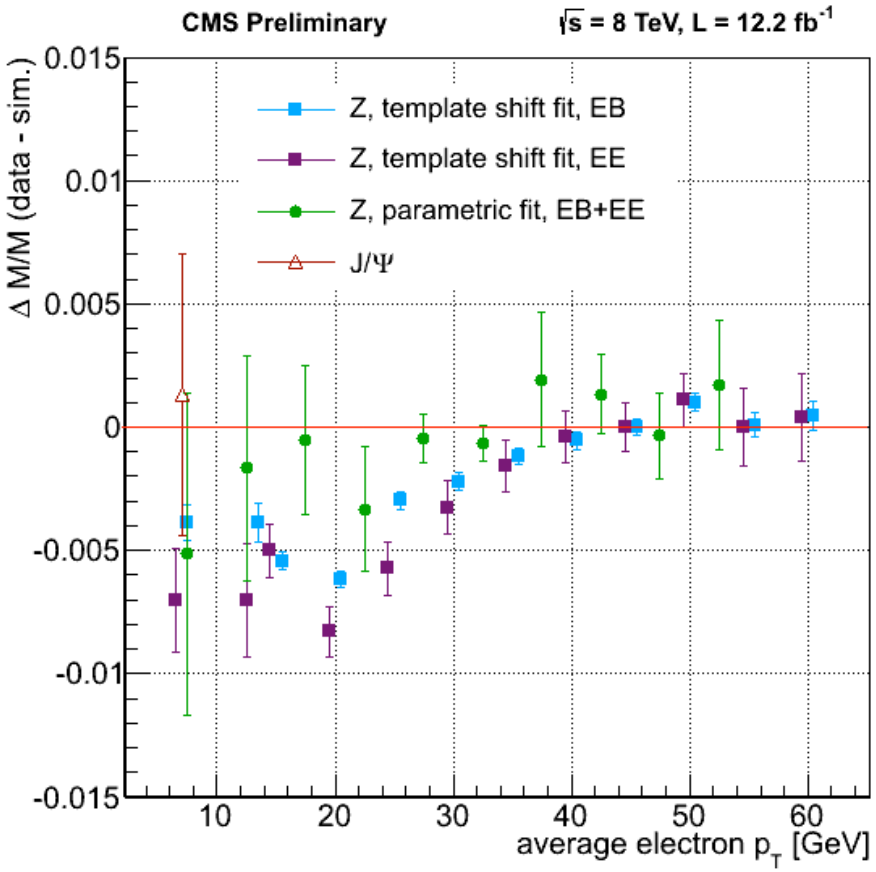


H→ZZ: Z1 and Z2 masses

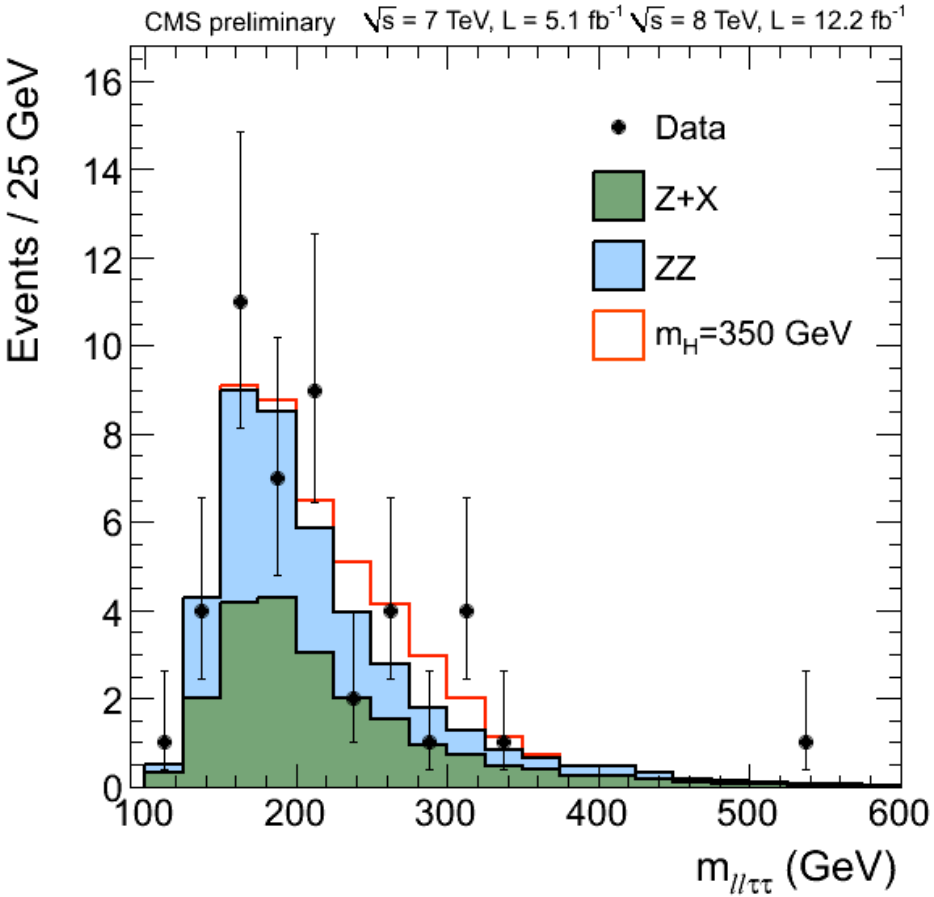


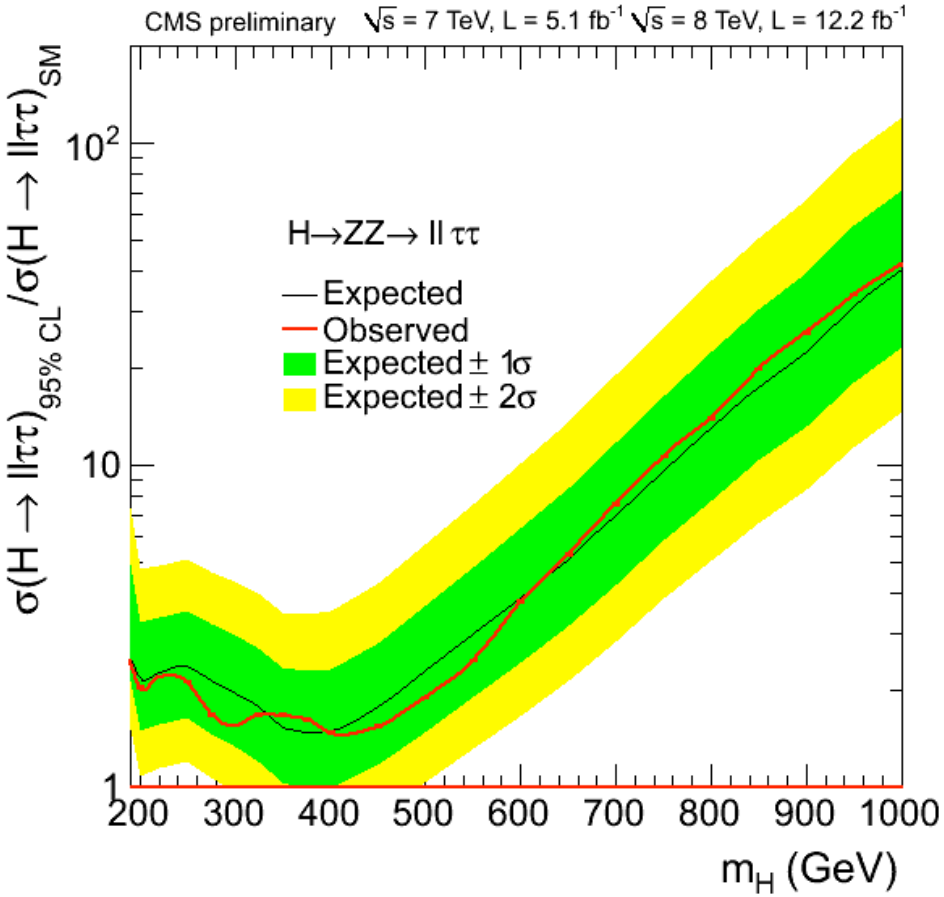
H→ZZ: mass scale



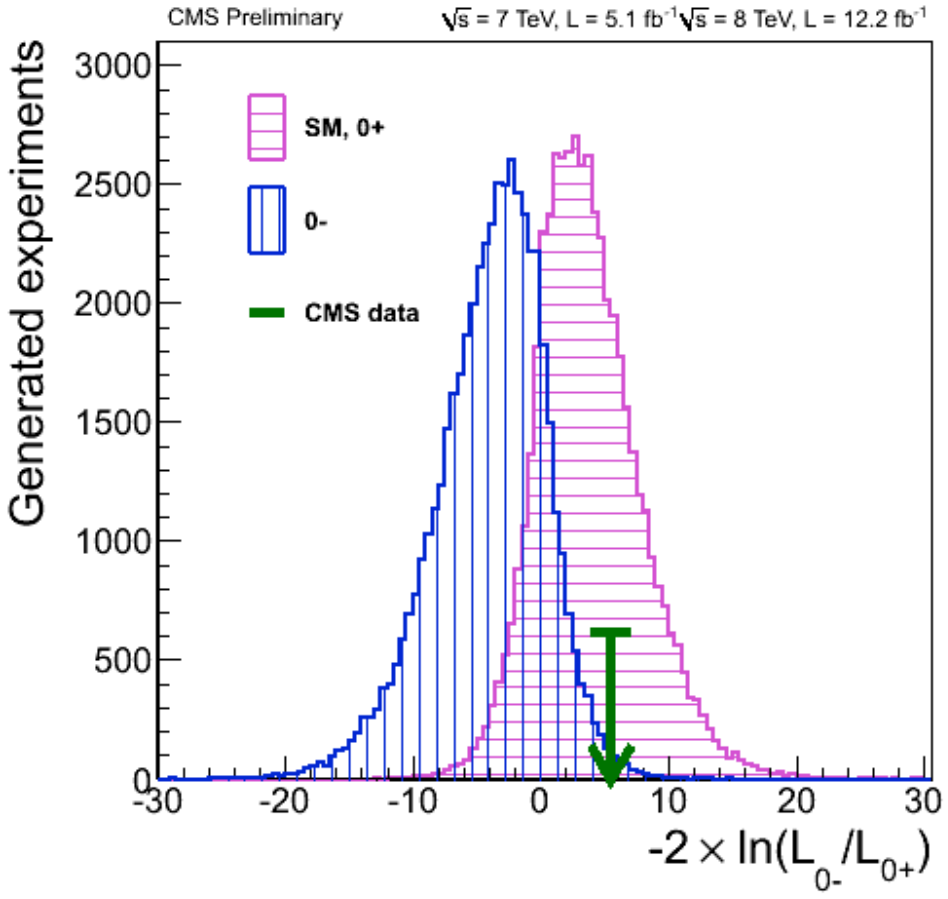


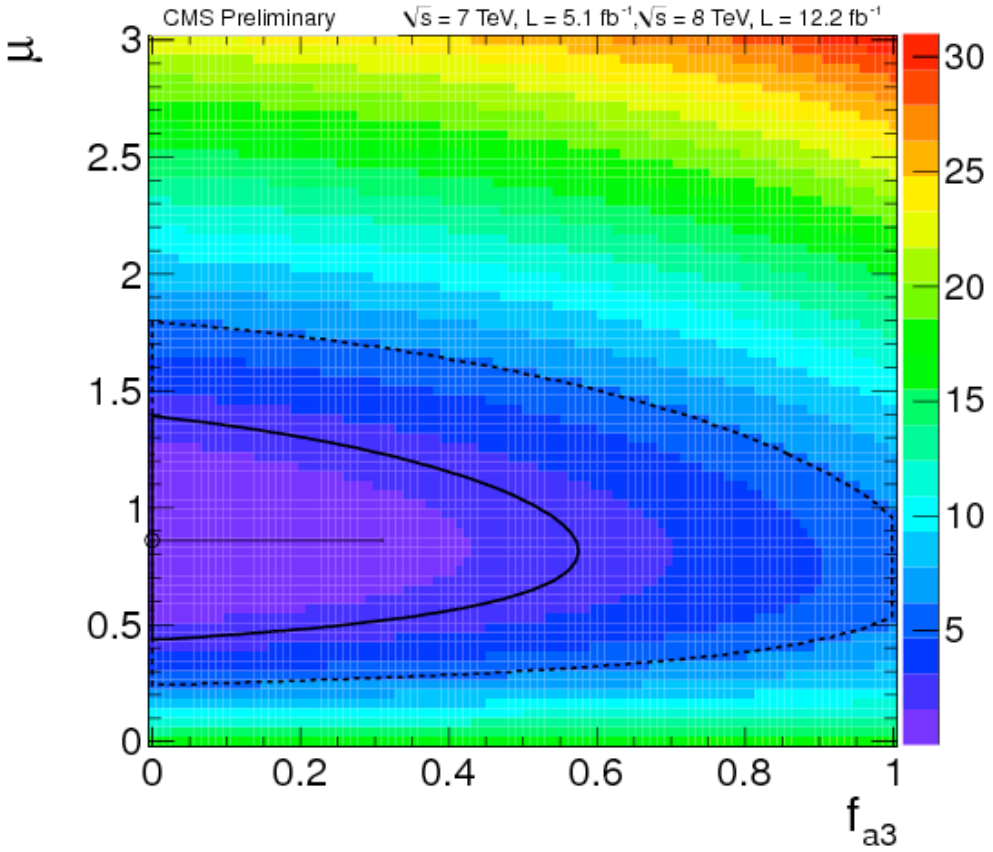
H→ZZ: 2l2tau


CMS preliminary √s = 7 TeV, L = 5.1 fb-1 √s = 8 TeV, L = 12.2 fb-1
Events / 25 GeV
Data
Z+X
ZZ
mH=350 GeV
mllττ (GeV)

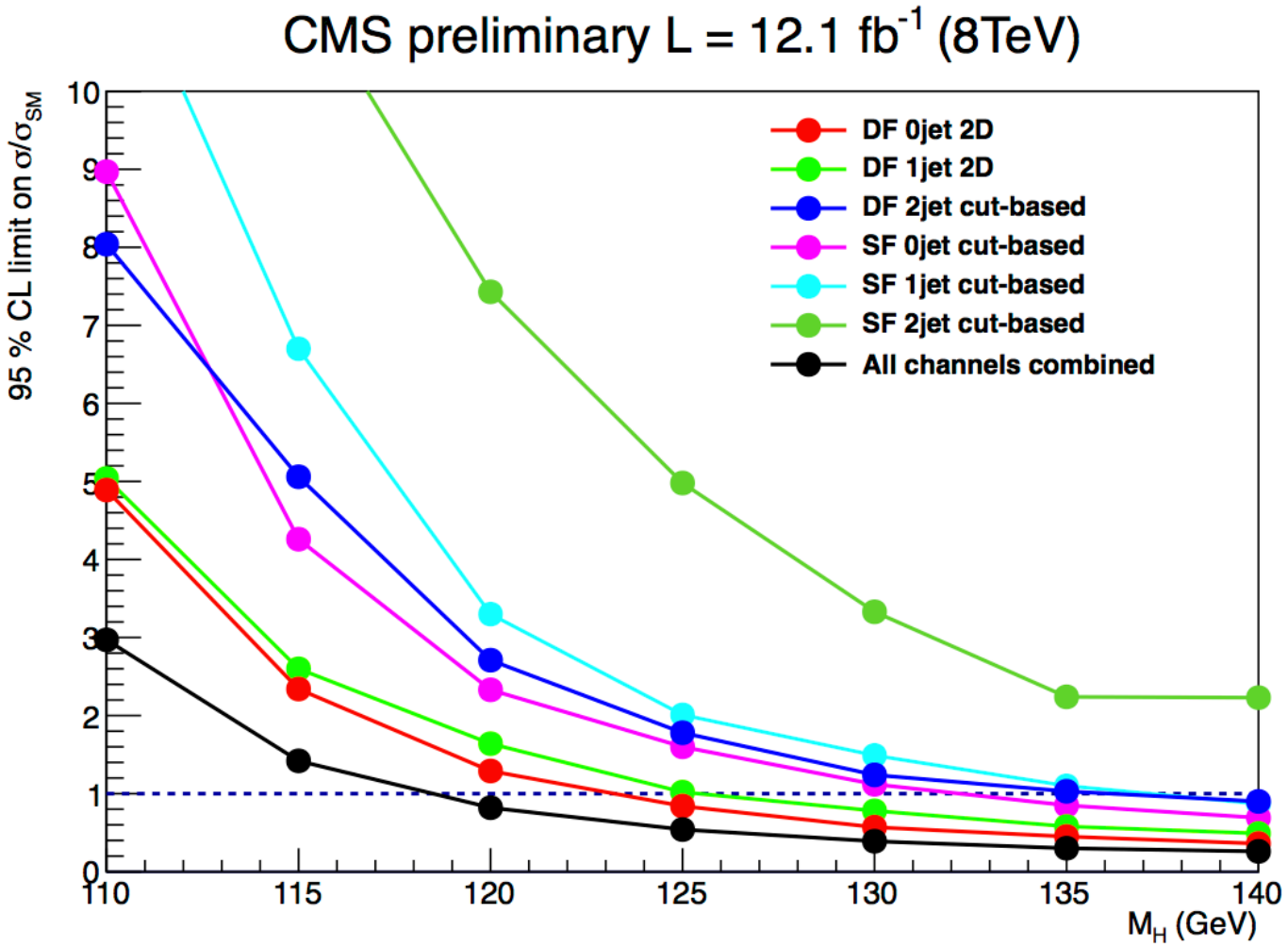

CMS preliminary √s = 7 TeV, L = 5.1 fb-1 √s = 8 TeV, L = 12.2 fb-1
σ(H → llττ)95% CL/σ(H → llττ)SM
H→ZZ→ llττ
Expected
Observed
Expected ± 1σ
Expected ± 2σ
mH (GeV)

H→ZZ: parity measurement

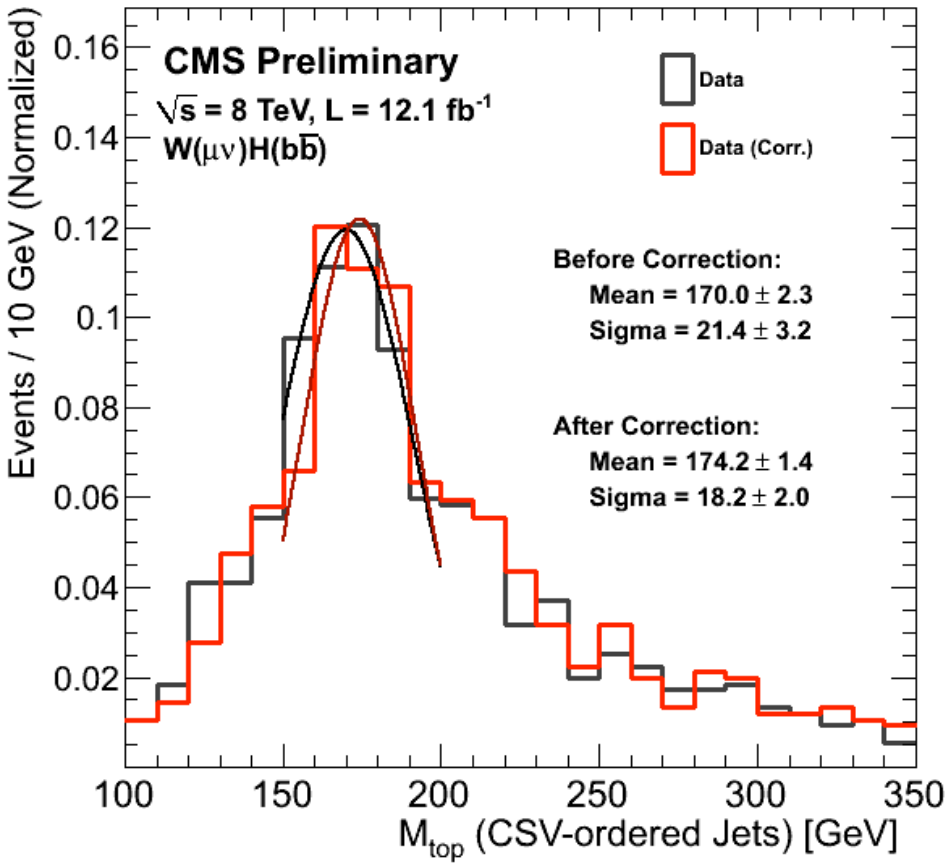




H→WW sensitivity per categories



H→bb energy regression



$H \rightarrow \tau^+\tau^-$ sensitivity