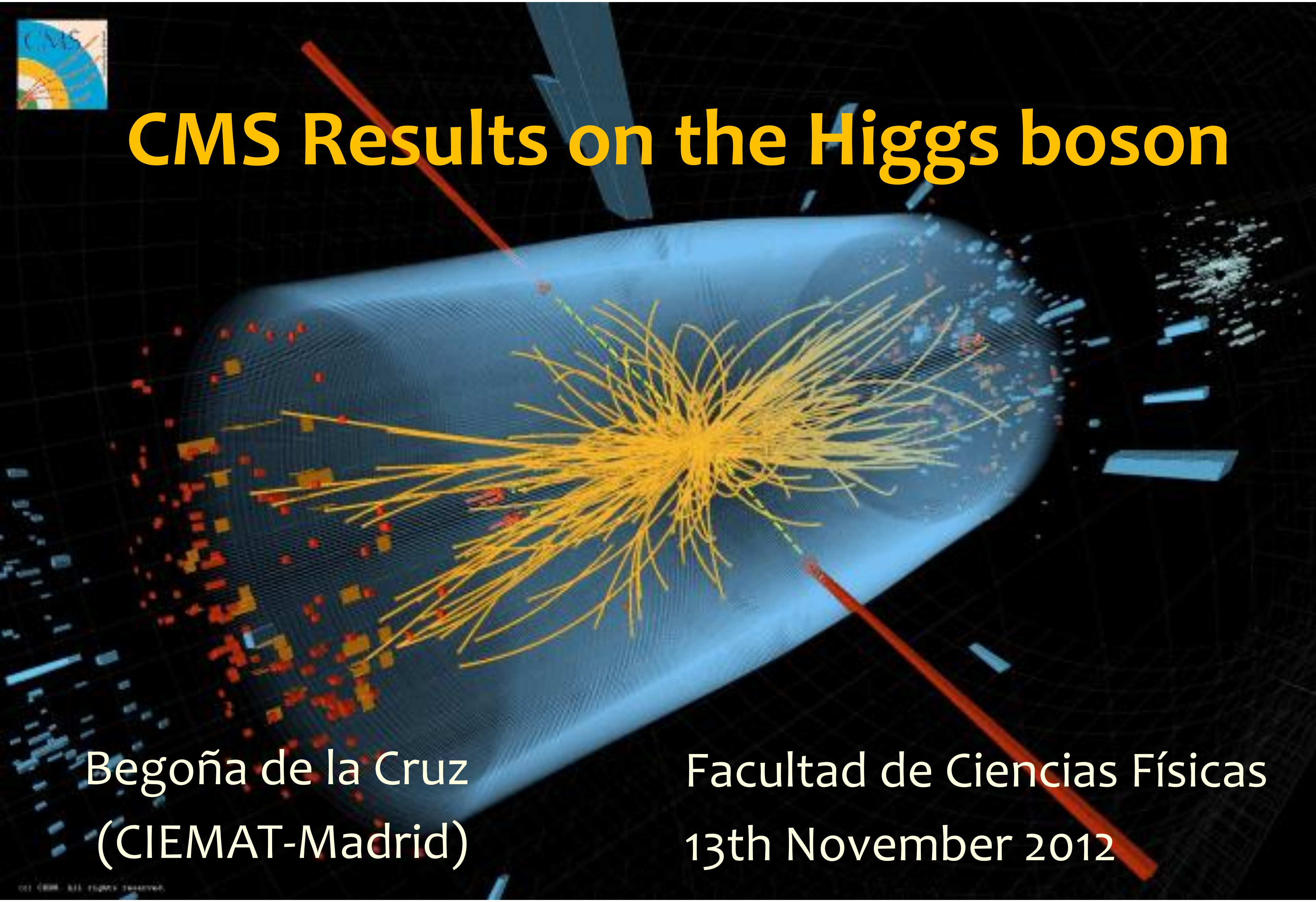
CMS Results on the Higgs boson



Begoña de la Cruz
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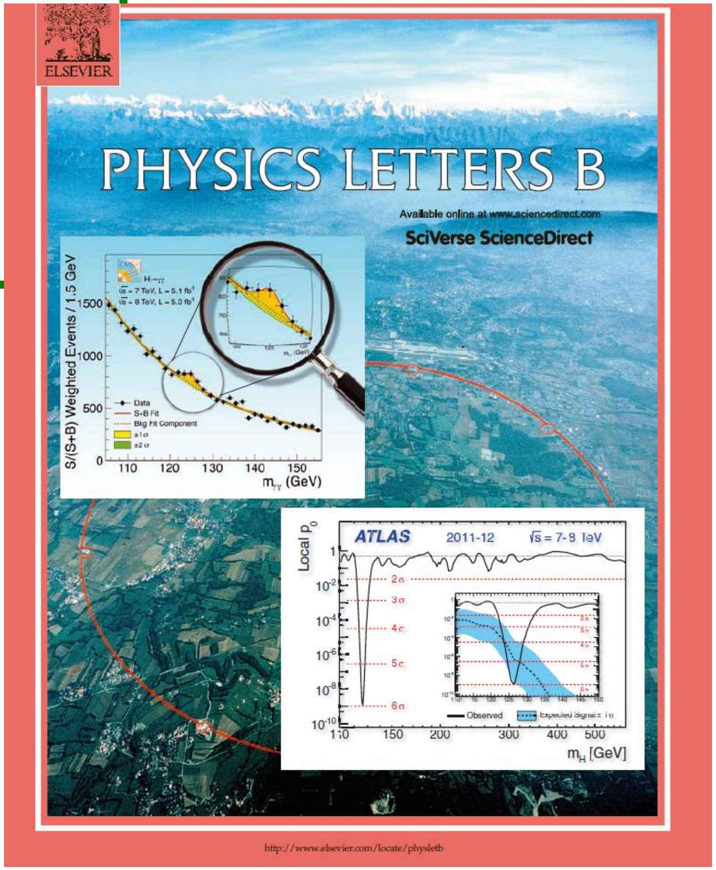
Facultad de Ciencias Físicas
13th November 2012

CMS experiment @ LHC

Index

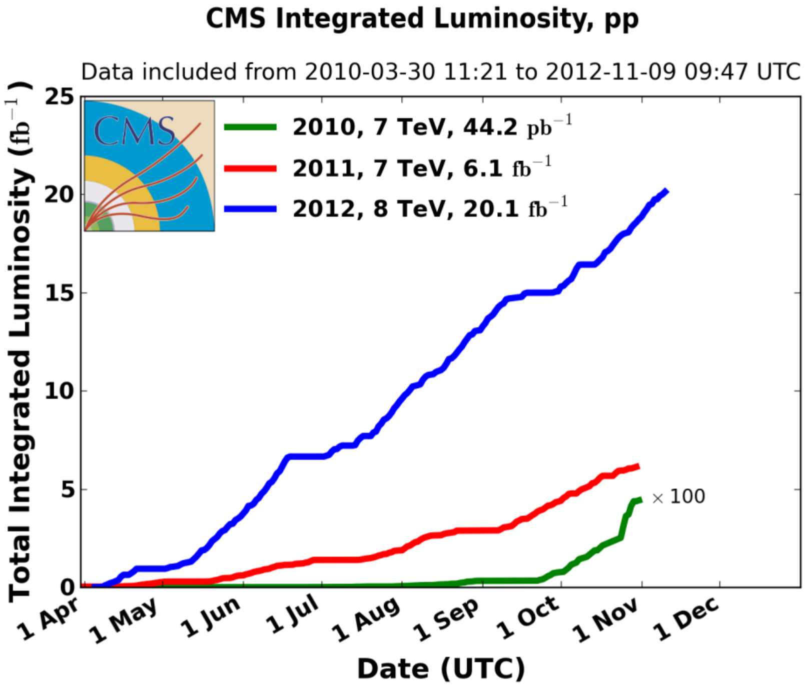
Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

Physics Letters B, Vol.176, Issue1, 17 September 2012, Pages 30-61
arXiv: 1207.7235



- ¿ How did we arrive here ?
- ¿ What have we found ?
- ¿ What next?

LHC Performance

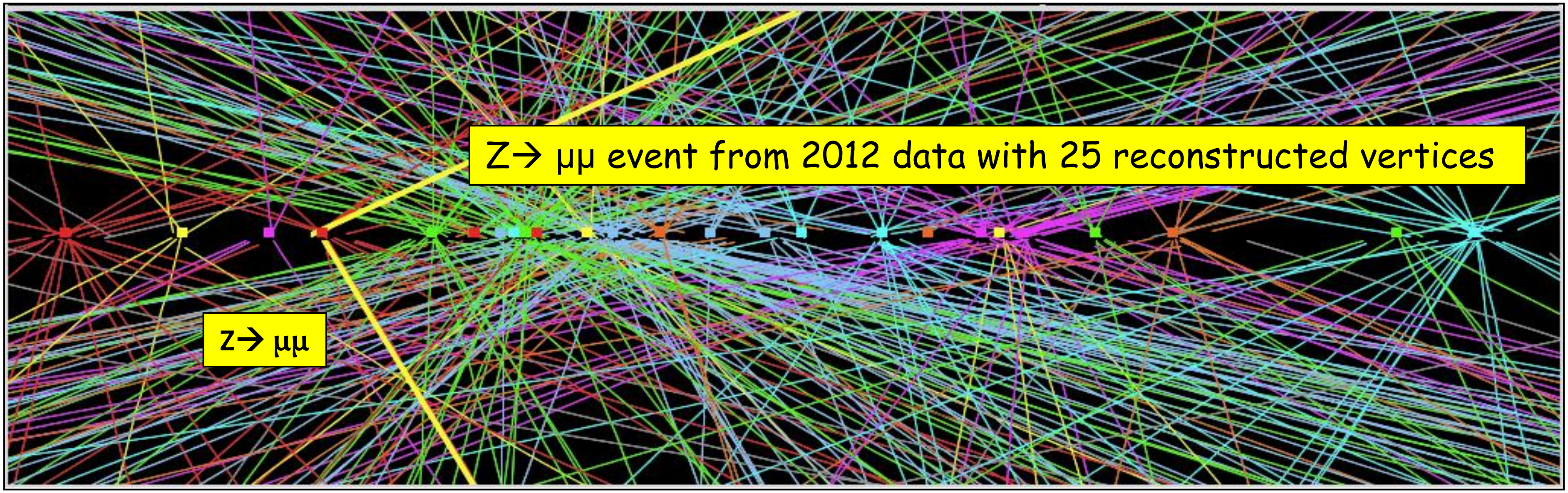


- Excellent performance of LHC. To date, collected luminosity in CMS is ~19fb^{-1} at $\sqrt{s}$= 8 TeV. Additional (previous) ~5fb^{-1} at $\sqrt{s}$= 7 TeV.

- Efficiency for recording (95%) and for good physics (94%) (golden data/behaviour from all subdetectors) in CMS.

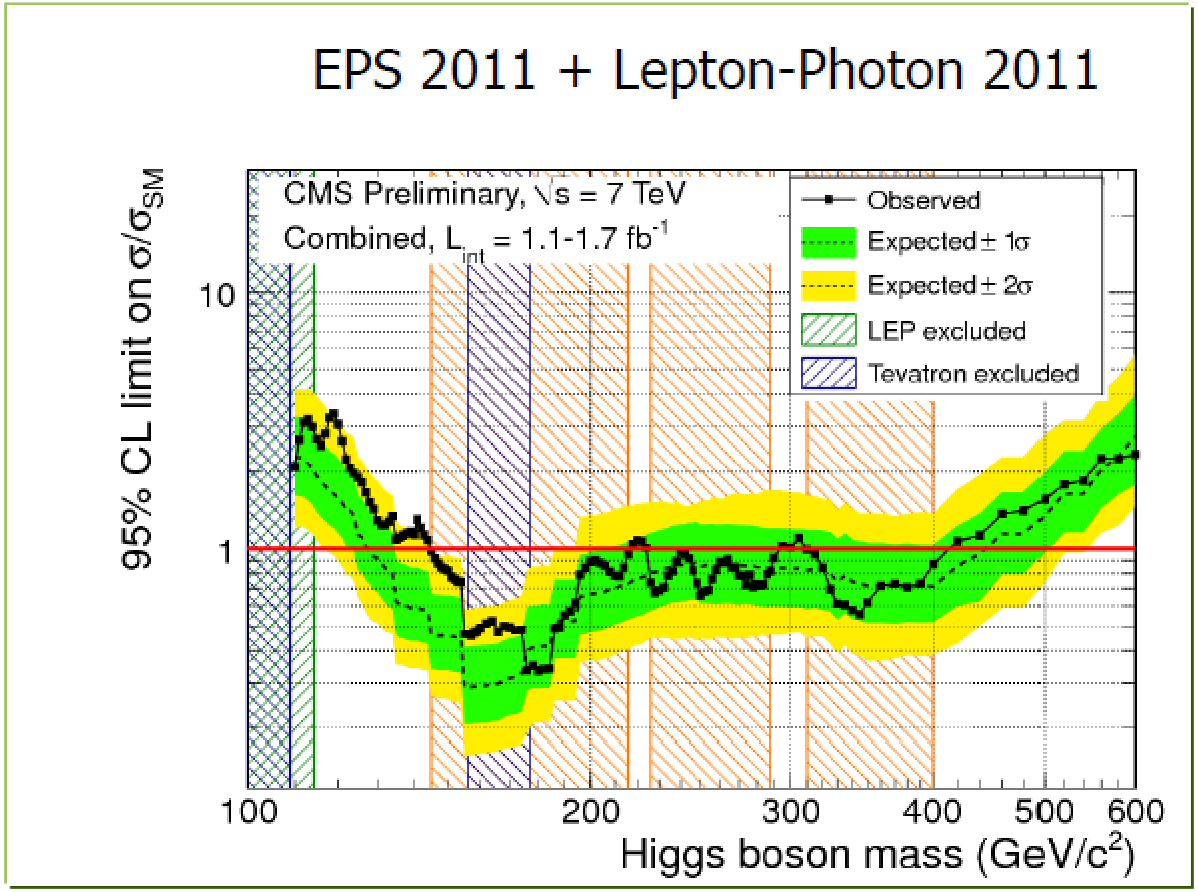
- Main challenge: pile-up (multiple pp interactions in same crossing).

1fb^{-1} of pp collisions @ $\sqrt{s}$= 7 TeV ≈ 60·10^{12} events



CMS Timeline in pursuit of Higgs discovery

- Since LHC start, considerable exclusion ranges for m_H were set



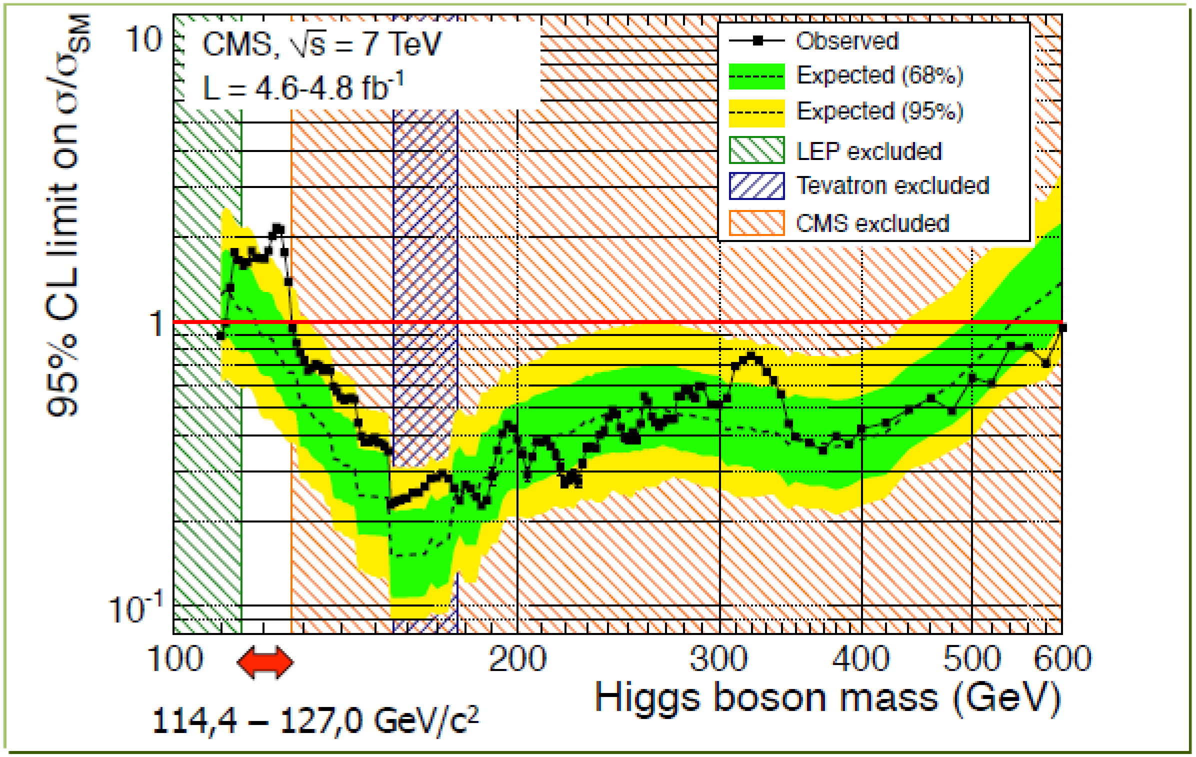
CMS Timeline in pursuit of Higgs discovery

- Since LHC start, considerable exclusion ranges for m_H were set
- Full 2011 dataset ($L \approx 5\ fb^{-1}$ $\sqrt{s}$= 7 TeV) ➔ Seminar at CERN in Dec 2011 ➔ Moriond 2012 (March)

Moriond 2012 (full 2011 dataset)

114.4 – 127.0 GeV/c2
Allowed m_H range for the SM Higgs boson

Small excess at 125 GeV at 2-3 sigmas



CMS Timeline in pursuit of Higgs discovery

July 2012 (ICHEP 2012): L ≈ 5 fb^{-1} $\sqrt{s}$= 7 TeV and ≈ 5 fb^{-1} $\sqrt{s}$= 8 TeV

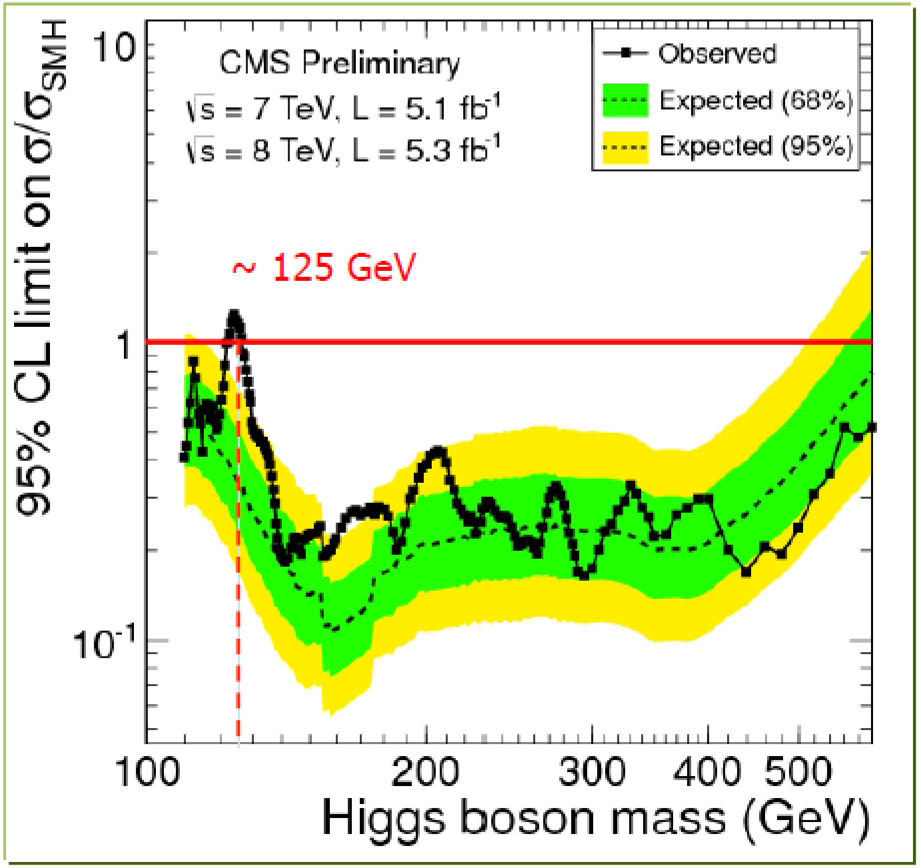
- Studies are performed in a blinded way, not looking at signal region in order not to bias analysis. Once the strategy, selection and methodology is clearly defined, one looks at the whole picture.

- Cannot exclude anymore!! …. Road to discovery!

- July 4th 2012 ➔ ATLAS & CMS new boson discovery announcement at CERN at m ≈125 GeV.

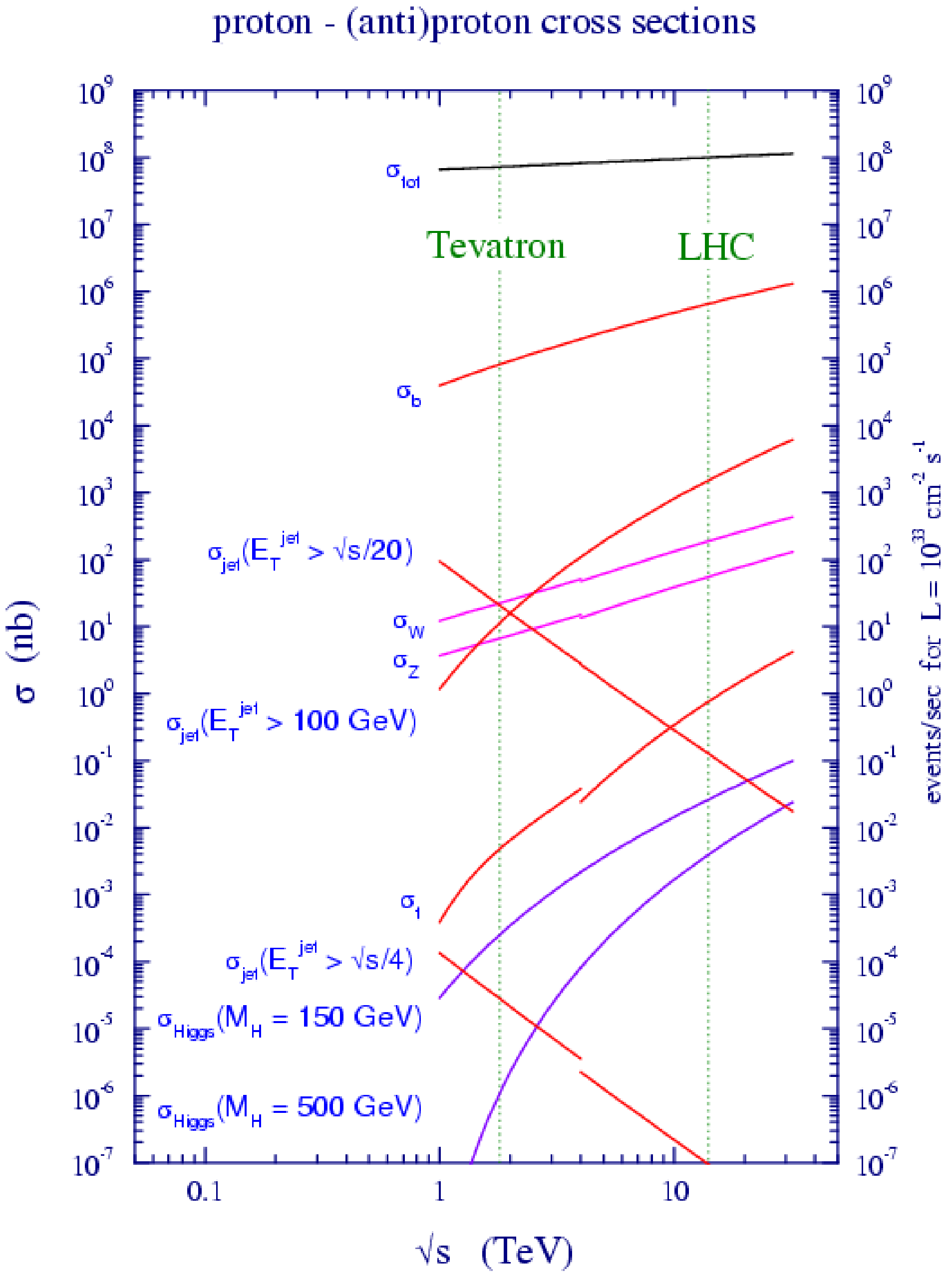
NB: These are basically the results to be shown today

- Just approved an update on Higgs results for HCP Conference with L = 12 fb^{-1} @$\sqrt{s}$= 8 TeV ➔ will also show updated ones .



Higgs production

- Expected SM Higgs cross section for m_H = 125 GeV:
  - ~10-20pb at $\sqrt{s}$ = 7 TeV
  - 25% more at 8 TeV



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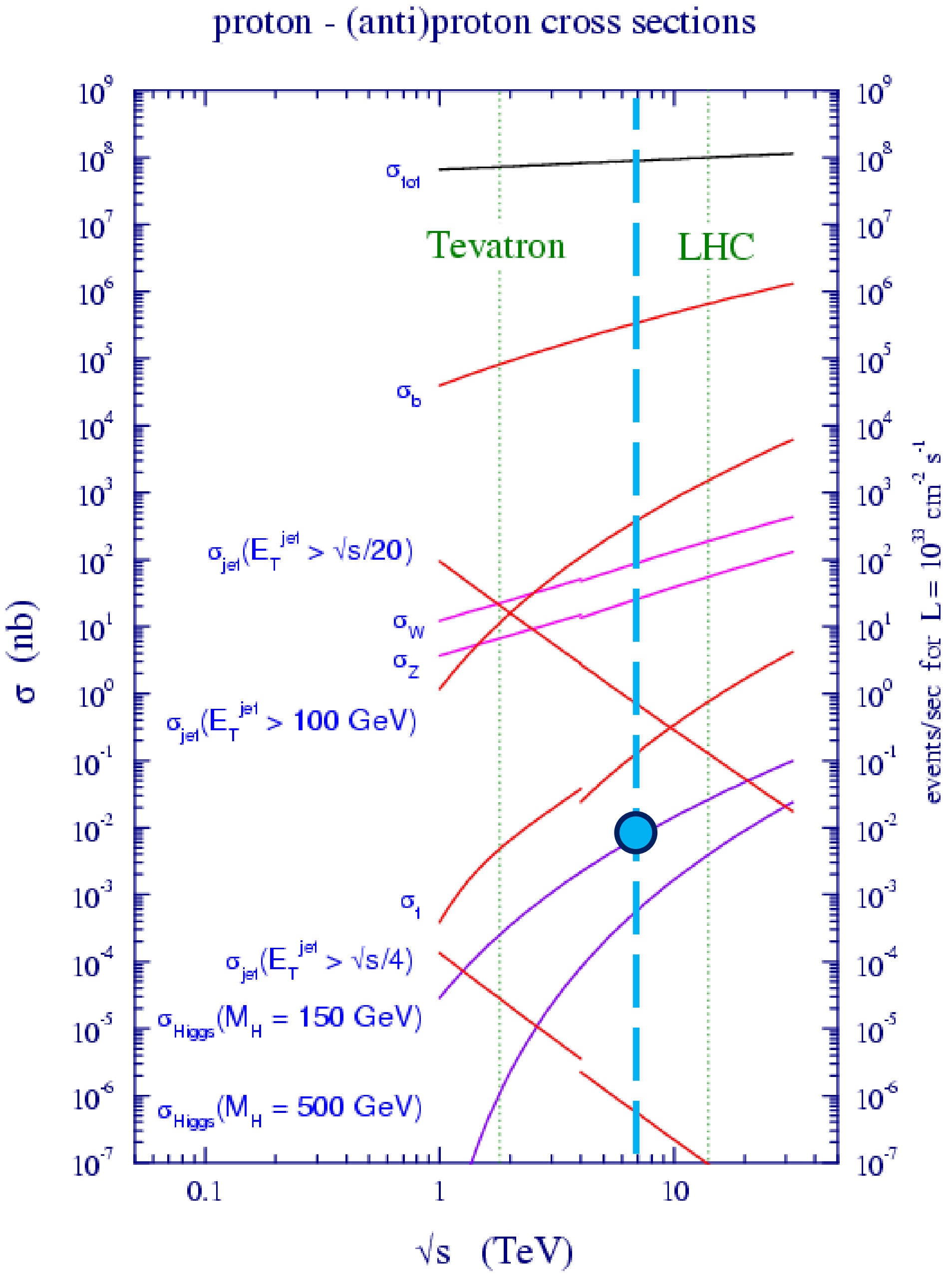


Higgs production

Not all produced Higgs are detected/measured

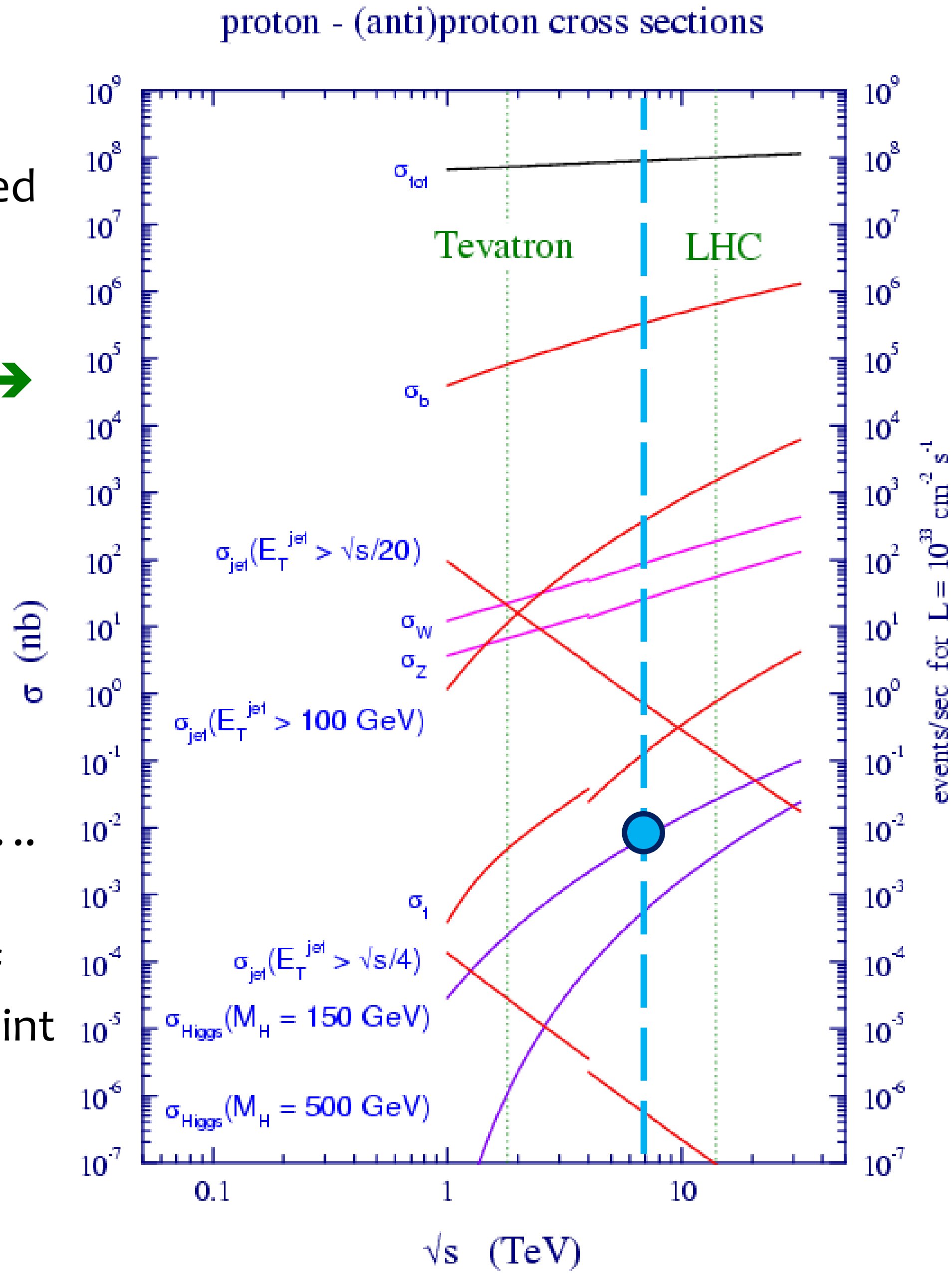
- Phase space (spatial and in particle momentum) ➔ Acceptance
- Reconstruction Identification, Selection ➔ Efficiency
- Tipical A*E in these searches : ~10%

❑ Mandatory excellent reconstruction of different particle species:

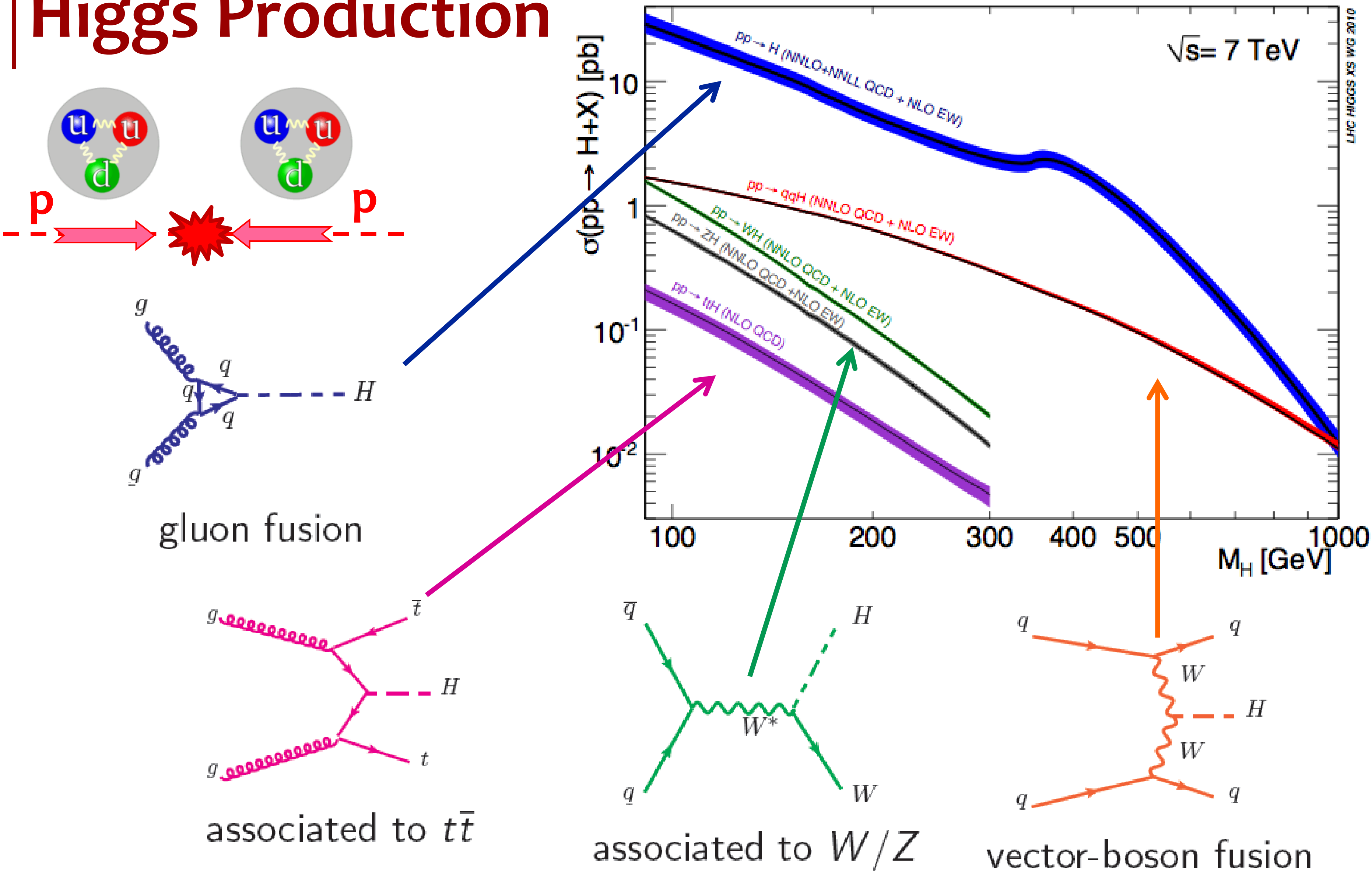
e-/e+, γ, charged hadrons ($\pi^{\pm}$,K), neutral hadrons, π^0, μ, ν (Missing ET) , jets (quarks)…..

❑ Together with precise kinematical reco of events, allow to resolve (up to certain point and statistically) signal from background.

❑ Powerful statistical tools help also.



Higgs Production



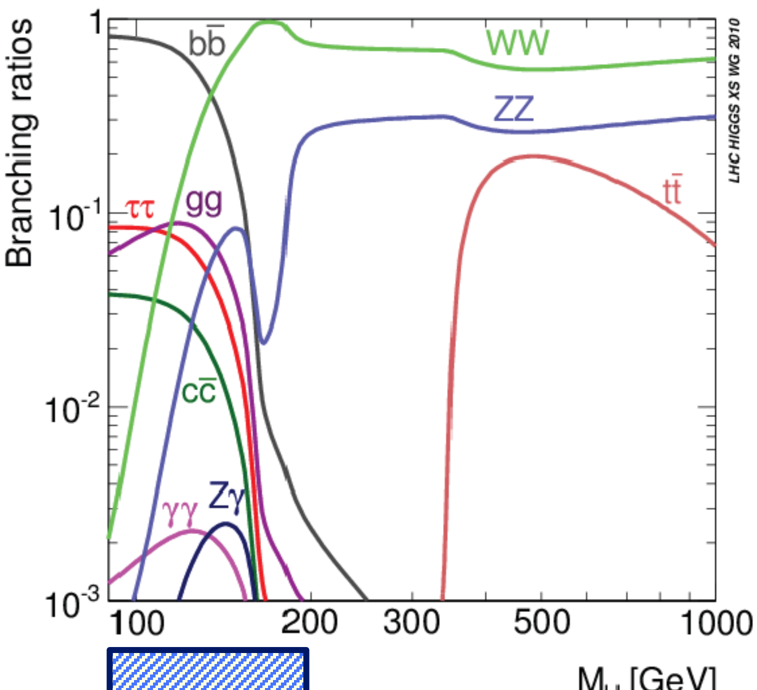
Higgs Decay

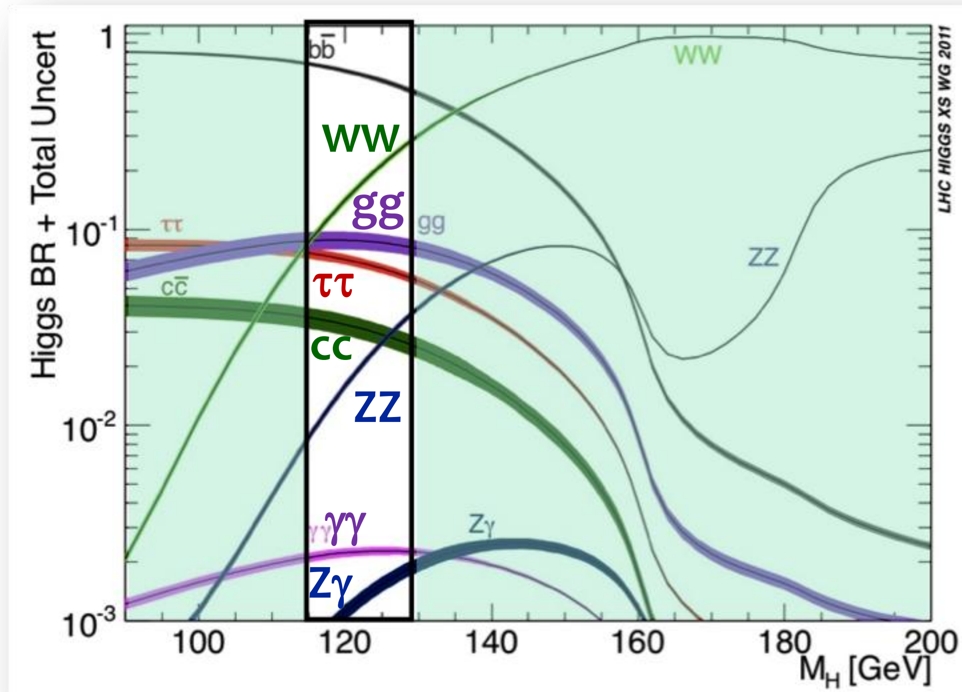
- fermions (quarks & leptons) $\propto m_F^2$
- vectorial bosons (W, Z, γ, g) $\propto m_V^4$

5 main decay modes: ZZ, WW, $\gamma\gamma$, bb, $\tau\tau$

ZZ, WW: $m_H > 135$ GeV — $\gamma\gamma$, bb, $\tau\tau$: $m_H < 120$ GeV

- ❑ Nature is generous, as at $m_H = 125$ GeV many decay channels are open for study
- ❑ Establish optimized analysis for each final topology combining production & decay mode.





Higgs study sensitivity

Given m_H, sensitivity to measure a signal depends on

- Production cross section & decay franching fraction
- Signal selection efficiency (including trigger)
- Mass resolution (intrinsic & instrumental)
- Level of SM background in the same or similar final states

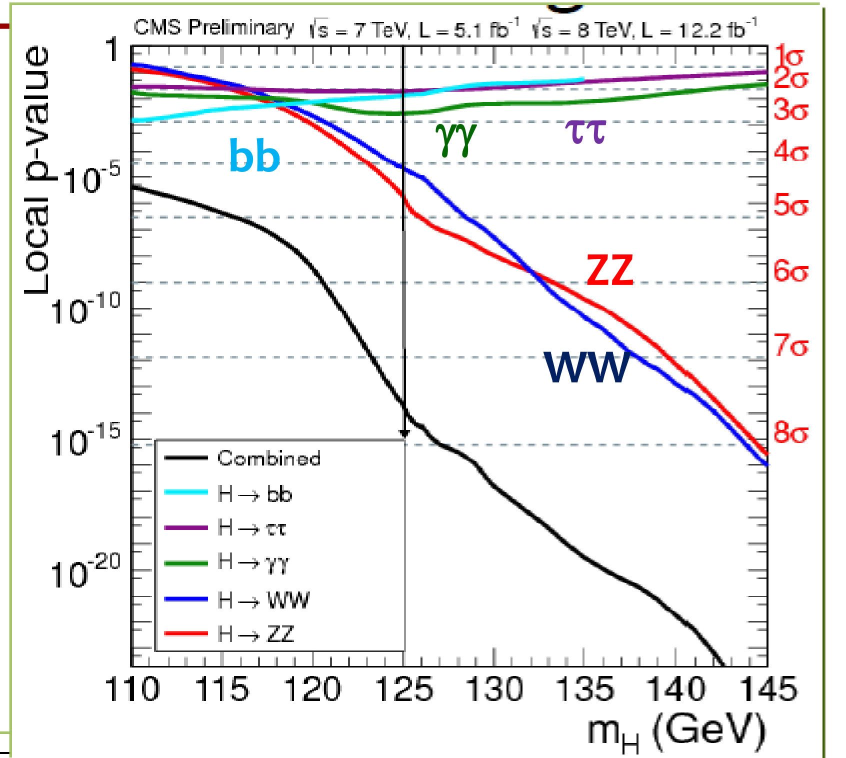
In low mass region:

- $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$ play a special role due to complete reconstruction & excellent photon/lepton reco (Δm = 1-2%)
- $H \rightarrow WW \rightarrow l\nu\ l\nu$ provides high sensitivity but poor mass resolution due to neutrinos.
- $H \rightarrow \tau\tau$ and $H \rightarrow bb$ have reduced sensitivity due to large backgds & poor mass resolution (jets or ν)

In high mass region:

- $H \rightarrow WW$ & $H \rightarrow ZZ$ dominate in sensitivity in various sub-channels

Expected performance

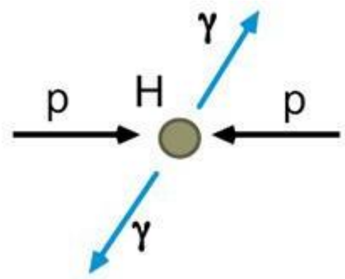


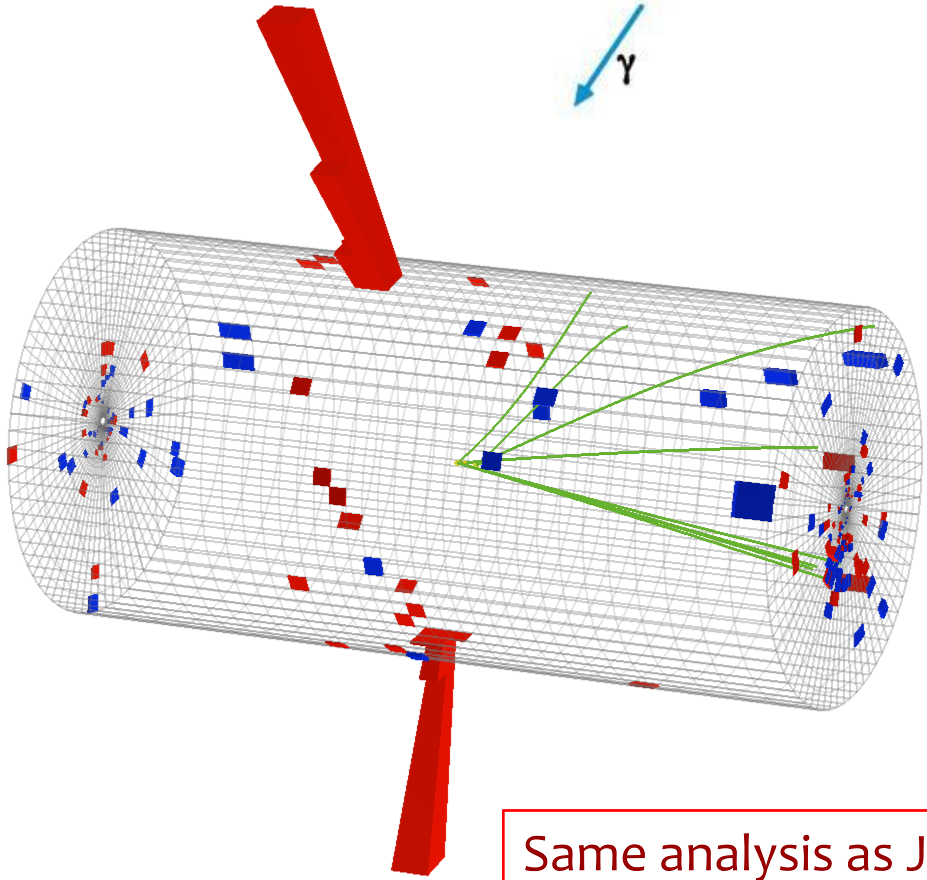
- Sensitivity increased from 5.8σ to 7.8σ (from July to Nov. 2012)
- Most sensitive channels in low mass region: γγ, ZZ, WW; then bb and ττ, more complicated due to background processes.

Channel	m_H range [GeV/c^2]	data set [fb^{-1}]	Data used CMS [fb^{-1}]	m_H resolution
1) H → γγ	110-150	5+5/fb	2011+12	1-2%
2) H → tau tau	110-145	5+12/fb	2011+12	15%
3) H → bb	110-135	5+12/fb	2011+12	10%
4) H → WW → lνlν	110-600	5+12/fb	2011+12	20%
5) H → ZZ → 4l	110-1000	5+12/fb	2011+12	1-2%

H→γγ

Very sensitive channel despite the small BR ~2×10^{-3} (SM Higgs)

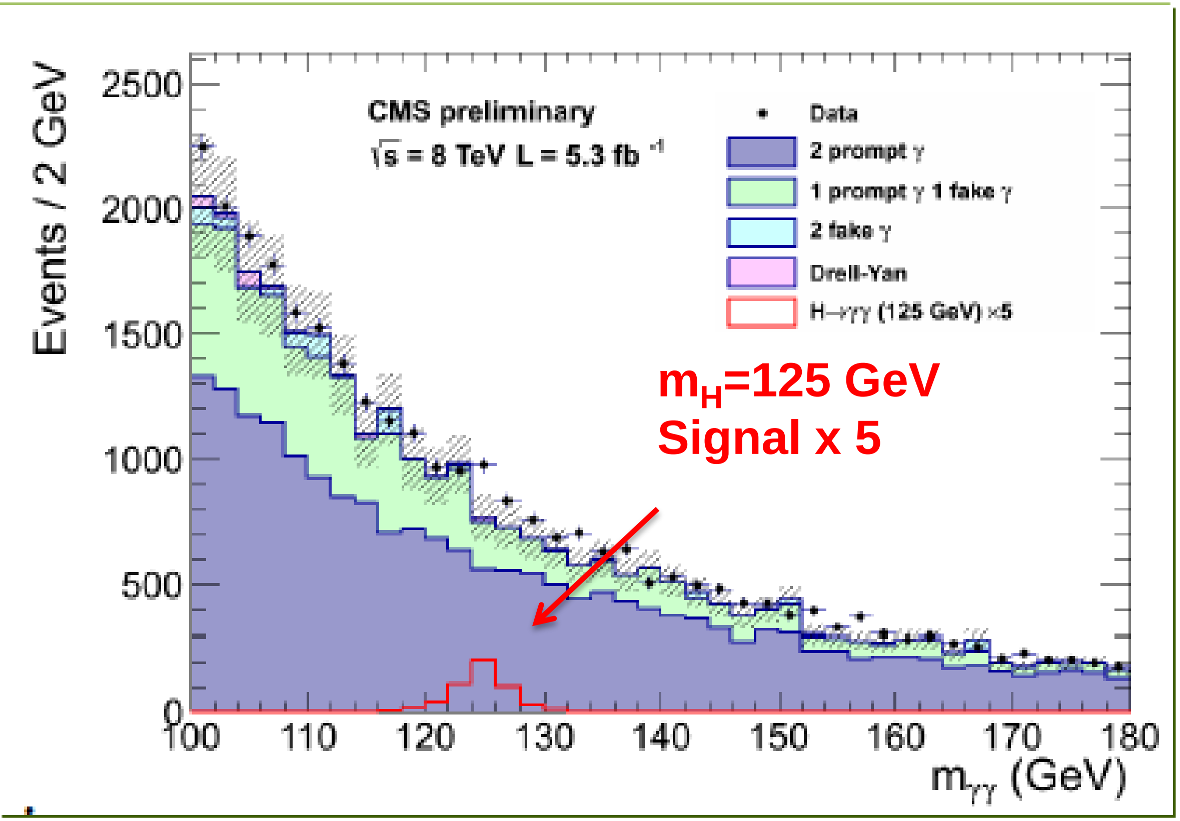




- Search for a narrow mass peak with 2 isolated, very energetic photons on a smoothly falling background
- Excellent resolution measuring photon energy ➔ 1% precision in $m_{\gamma\gamma}$ (in barrel)
- Key element driving the design of CMS electromagnetic calorimeter

Same analysis as July 2012, no update in Nov. 2012

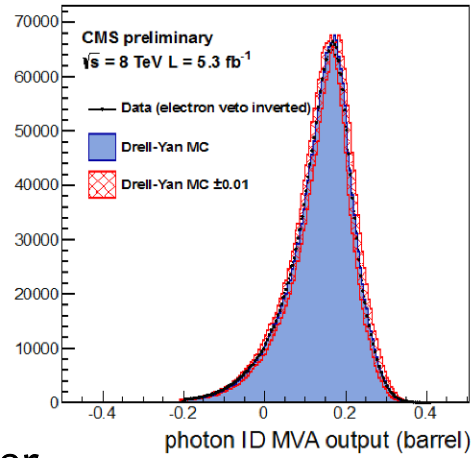
H→γγ

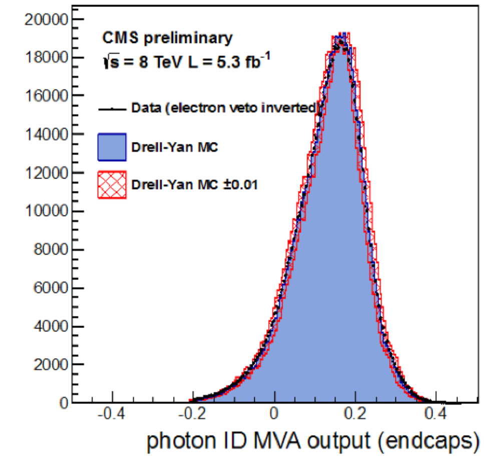


- ❑ Background mainly from QCD processes giving 2 photons in final state.
- ❑ Also,1(2) fake photons from misidentification of jet fragments.
- ❑ Background modelled:
  - polinomial fits of the $m_{\gamma\gamma}$
  - cross-cheked with alternative backgd model extraction (sidebands)

Photons

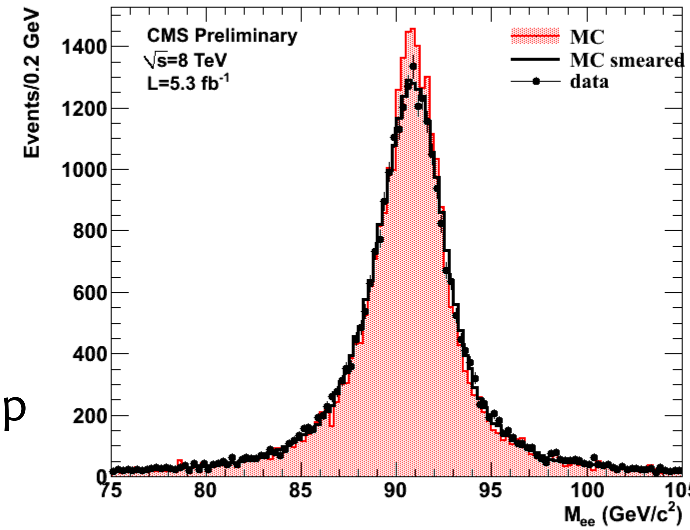
- Photon reconstruction
  - $|\eta|\leq 2.4$, pT> 2GeV
  - Same clustering process as electrons





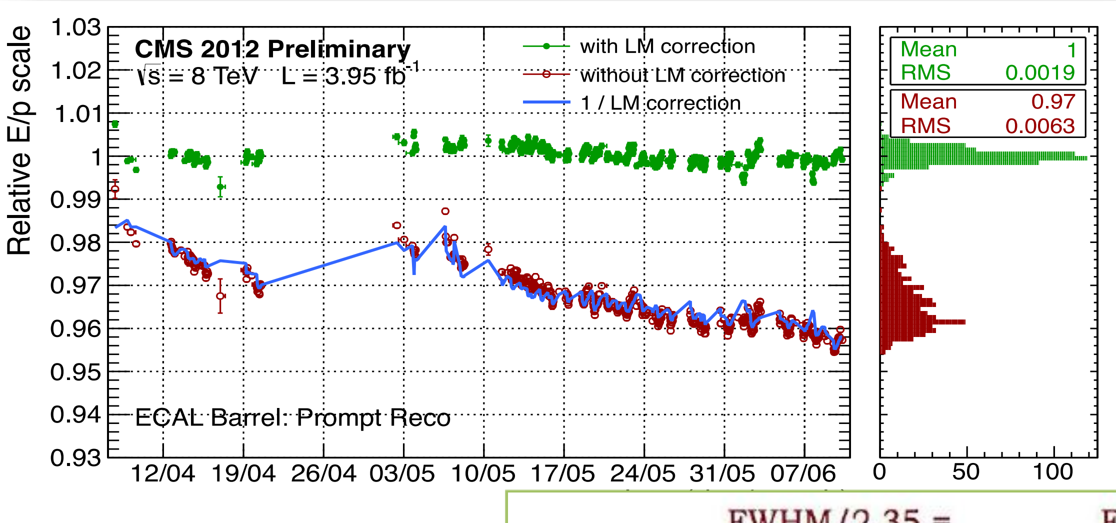
- Photon ID
  - Multivariate: shower shape, preshower, isolation,energy density, η
  - Discriminate prompt photons/ π0 from jets

- Scale and resolution
  - Energy corrected using a MC trained multivariate regression (η, ϕ, shower-shape, local cluster) -> better resolution and flat response of energy scale versus Pile-up
  - Run dependent energy scale and MC smearing
  - Scale, resolution and efficiencies measured with Z->ee events



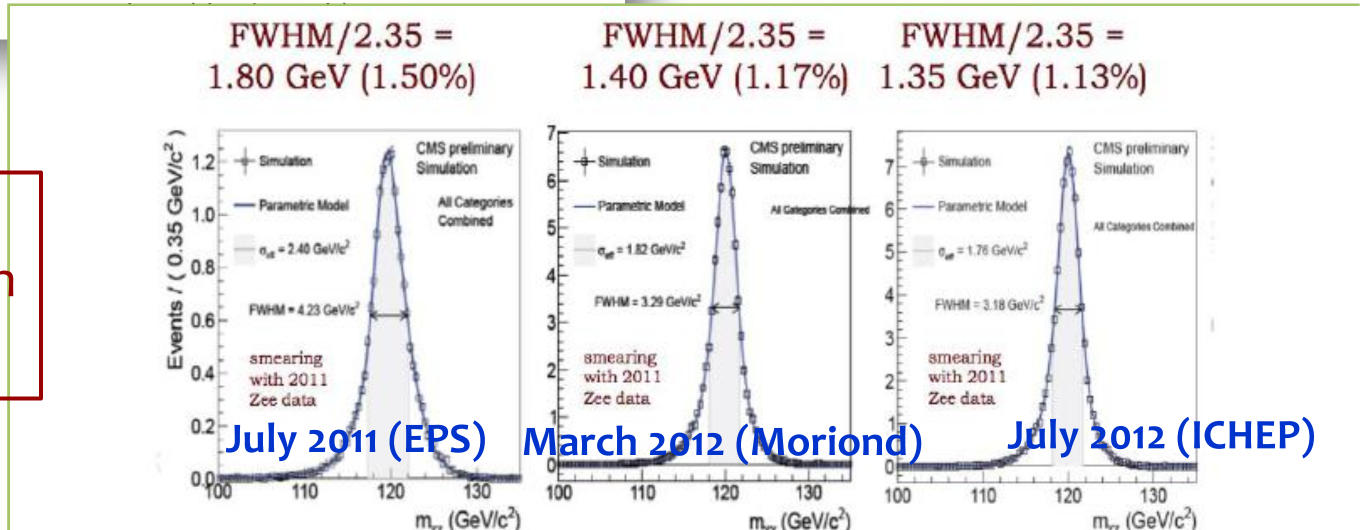
Both electrons in barrel

Progress in ECAL calibration



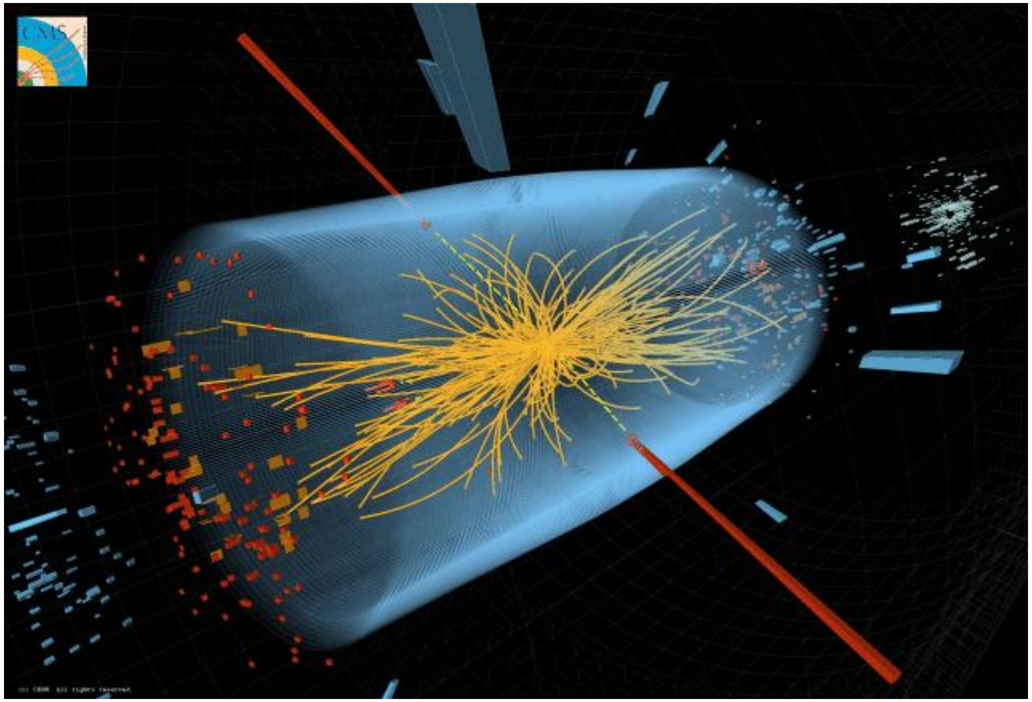
Single electron energy scale (E/p) stability in the ECAL barrel measured using W →eν events

Essential ECAL calibration and photon energy resolution



For the golden categories, both photons in the barrel and no conversions: FWHM/2.35=1.04GeV (0.87%) approaching the nominal value.

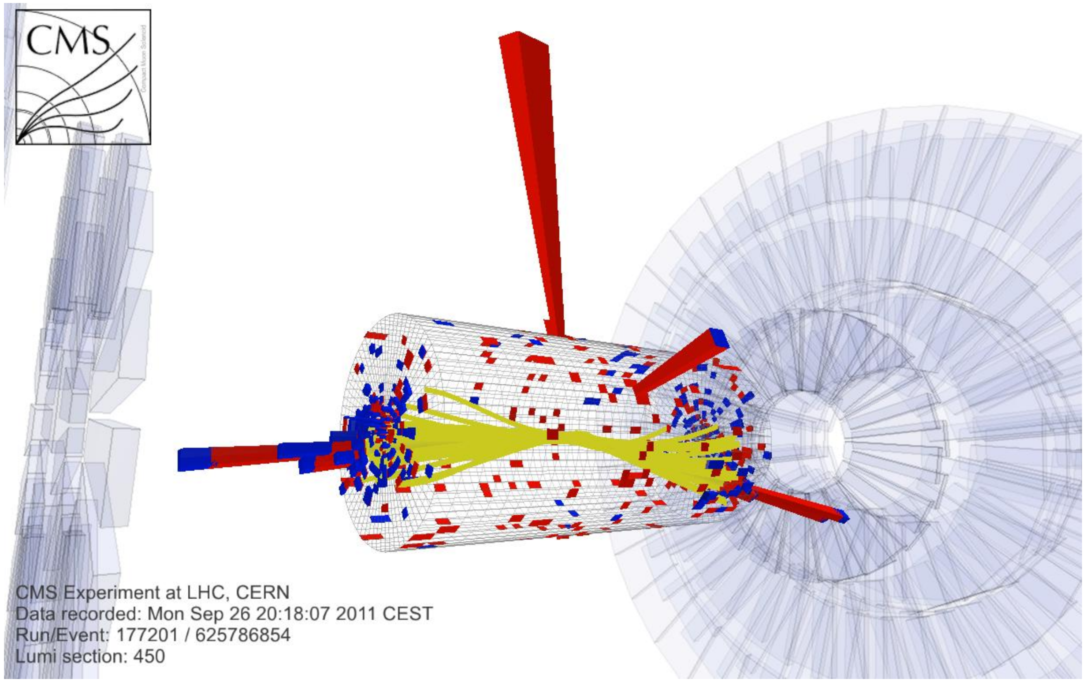
H→γγ analysis



2 type of events:

- ❑ Inclusive 2 photon evts (no jets)

H→γγ analysis

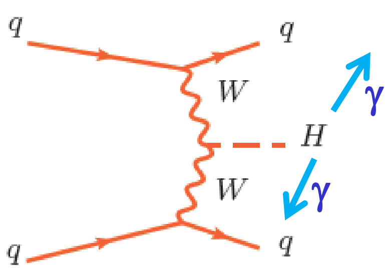


2 type of events:

- ❑ Inclusive 2 photon evts (no jets)
- ❑ those produced accompanied by 2 jets (VBF process)

Analysis optimized dividing selected events in categories according to signal purity and mass resolution

- ❑ using multi-variate technique
- ❑ 6 categories (2 VBF)
- ❑ expected 15% better sensitivity than cut-based (independent) analysis, used as cross-check.

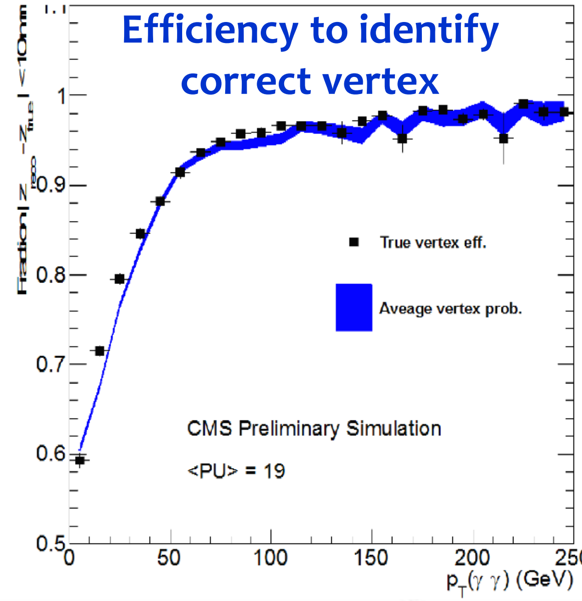


vector-boson fusion

H→γγ analysis

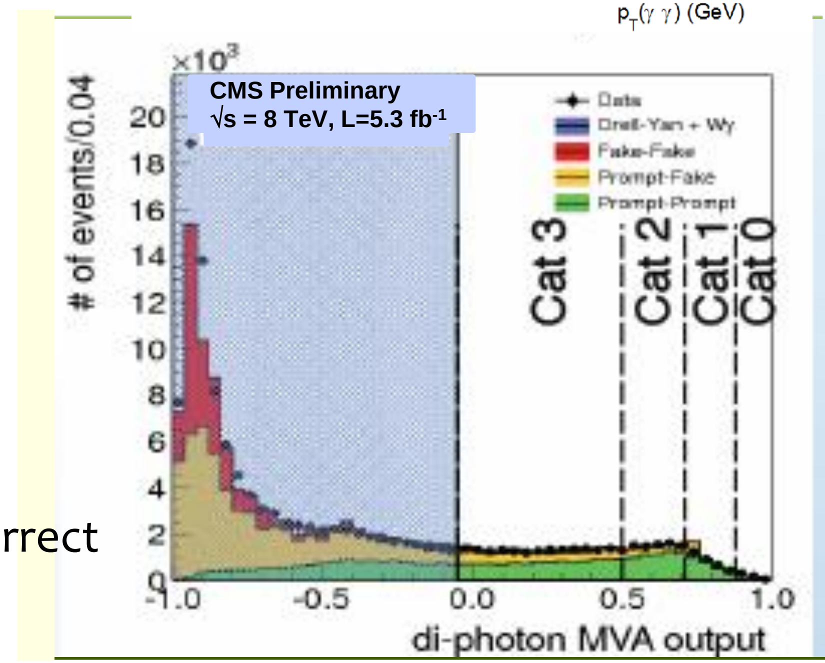
Analysis selection (MultiVariate Analysis MVA)

- ❑ Vertex ID ($m_{\gamma\gamma}$ resol depends on correct choice)
  - ■ Input variables: Σp_T^2(tracks), p_T balance wrt γγ, conversions information
- ❑ ID photons: $p_{T1} > m_{\gamma\gamma}/3$, $p_{T2} > m_{\gamma\gamma}/4$



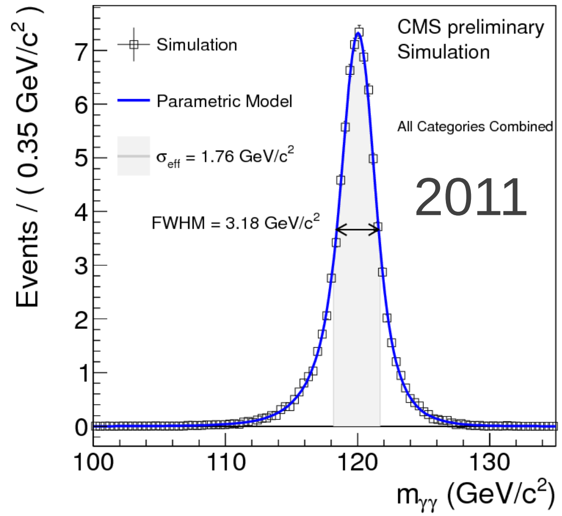
MVA diphoton discriminant ➔ categories

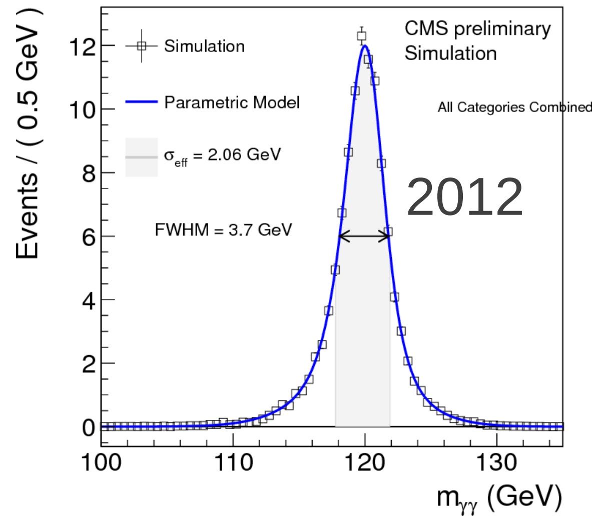
- ❑ High score
  - ■ signal like events
  - ■ good $m_{\gamma\gamma}$ resolution
- ❑ Designed to be $m_{\gamma\gamma}$ independent
- ❑ Trained on signal & backgd MC
- ❑ Input variables:
  - ■ kinematic variables: $p_{T\gamma}/m_{\gamma\gamma}$, η_γ, $\cos(\phi_1 - \phi_2)$
  - ■ photonID
  - ■ per event mass resolution for correct and incorrect choice of vertex



H→γγ analysis

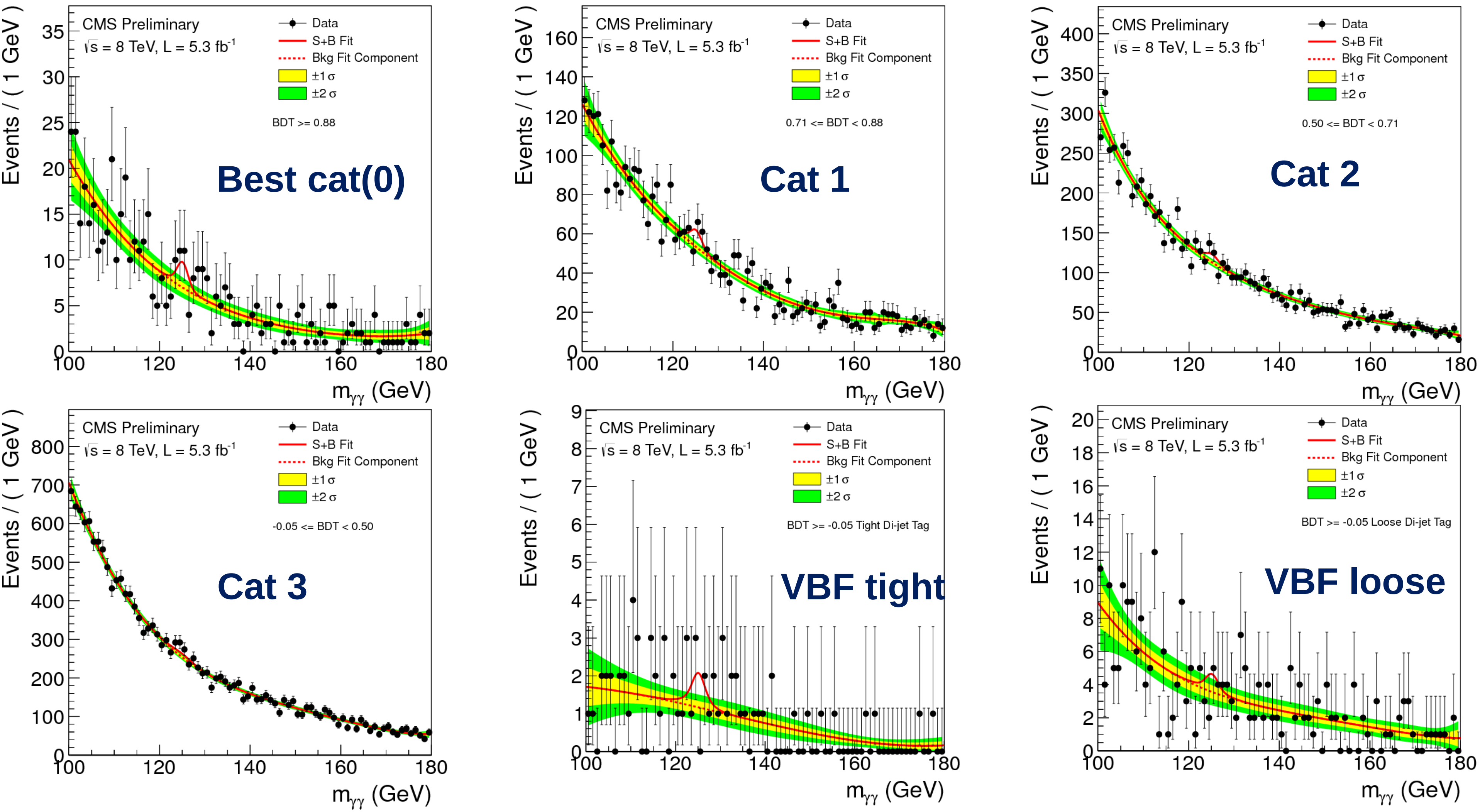
Expected number of events of SM Higgs signal (m_H = 125 GeV) and background at same mass value





	Event classes	SM Higgs boson expected signal (m_H=125 GeV)							Background $m_{\gamma\gamma}$ = 125 GeV (ev./GeV)
		Total	ggH	VBF	VH	ttH	σ_{eff} (GeV)	FWHM/2.35 (GeV)	
7 TeV 5.1 fb^{-1}	Untagged 0	3.2	61%	17%	19%	3%	1.21	1.14	3.3 ± 0.4
	Untagged 1	16.3	88%	6%	6%	1%	1.26	1.08	37.5 ± 1.3
	Untagged 2	21.5	91%	4%	4%	–	1.59	1.32	74.8 ± 1.9
	Untagged 3	32.8	91%	4%	4%	–	2.47	2.07	193.6 ± 3.0
	Dijet tag	2.9	27%	73%	1%	–	1.73	1.37	1.7 ± 0.2
8 TeV 5.3 fb^{-1}	Untagged 0	6.1	68%	12%	16%	4%	1.38	1.23	7.4 ± 0.6
	Untagged 1	21.0	88%	6%	6%	1%	1.53	1.31	54.7 ± 1.5
	Untagged 2	30.2	92%	4%	3%	–	1.94	1.55	115.2 ± 2.3
	Untagged 3	40.0	92%	4%	4%	–	2.86	2.35	256.5 ± 3.4
	Dijet tight	2.6	23%	77%	–	–	2.06	1.57	1.3 ± 0.2
	Dijet loose	3.0	53%	45%	2%	–	1.95	1.48	3.7 ± 0.4

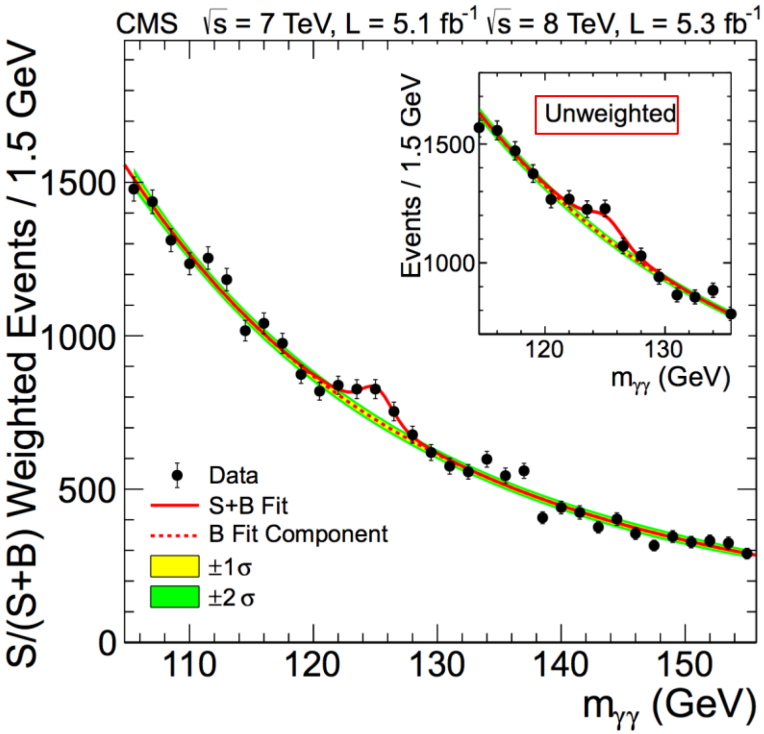
H→γγ : $m_{\gamma\gamma}$ in 6 categories for 8 TeV

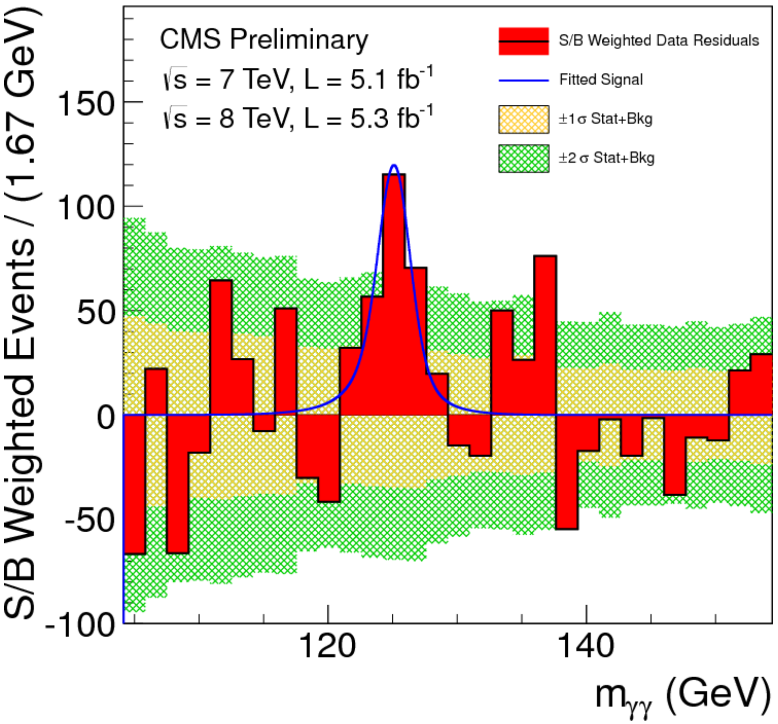


Bckgd: Simultaneous polinomial fits of $m_{\gamma\gamma}$ in all categories

H→γγ : S/(S+B) weighted $m_{\gamma\gamma}$ for 7 + 8 TeV

All 5+6 categories together

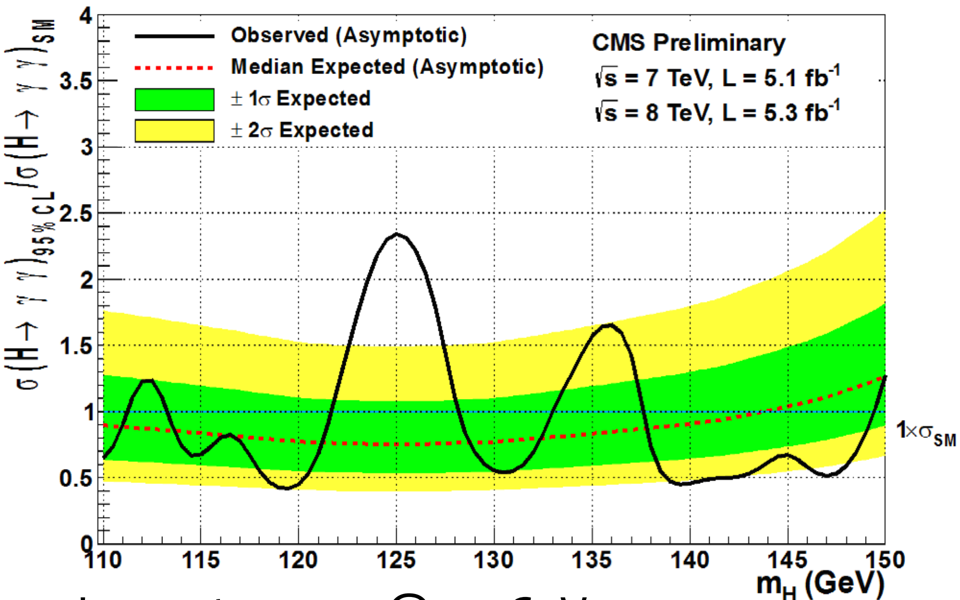


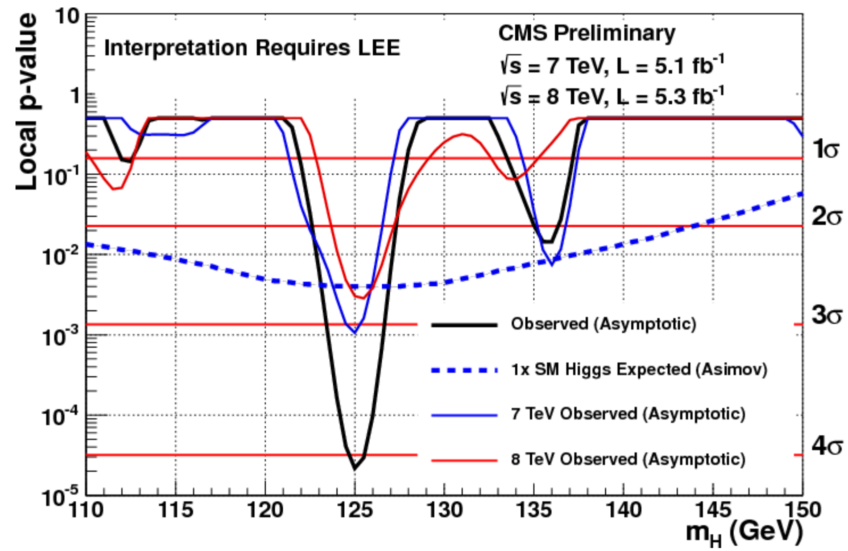


Each event is weighted by S/(S+B) value of its category

Data – Background distribution

H→γγ : Results (July 2012)





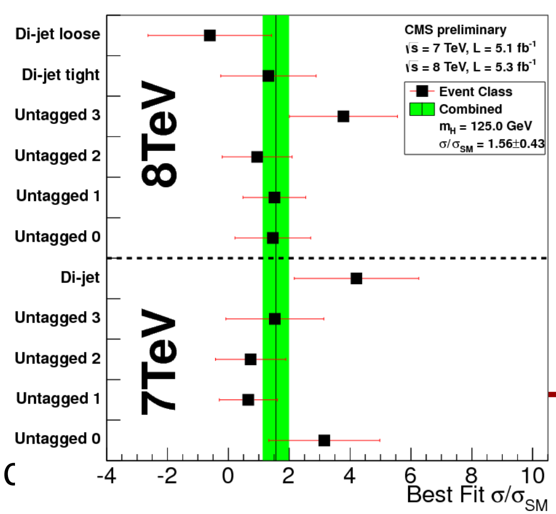
Largest excess @125 GeV

Exp. 95% CL exclusion 0.76xSM

Local p-value significance @ 125 GeV: 4.1 σ

Global significance in full search range (110-150 GeV): 3.2σ

Expected significance: 2.8 σ

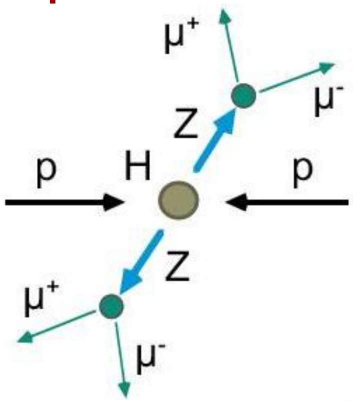


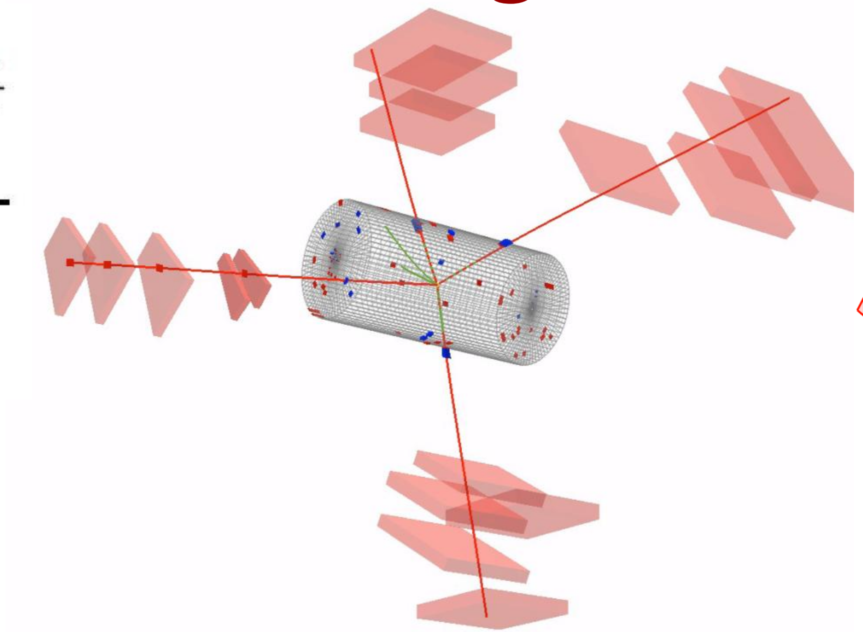
Combined best fit signal strength @125 GeV

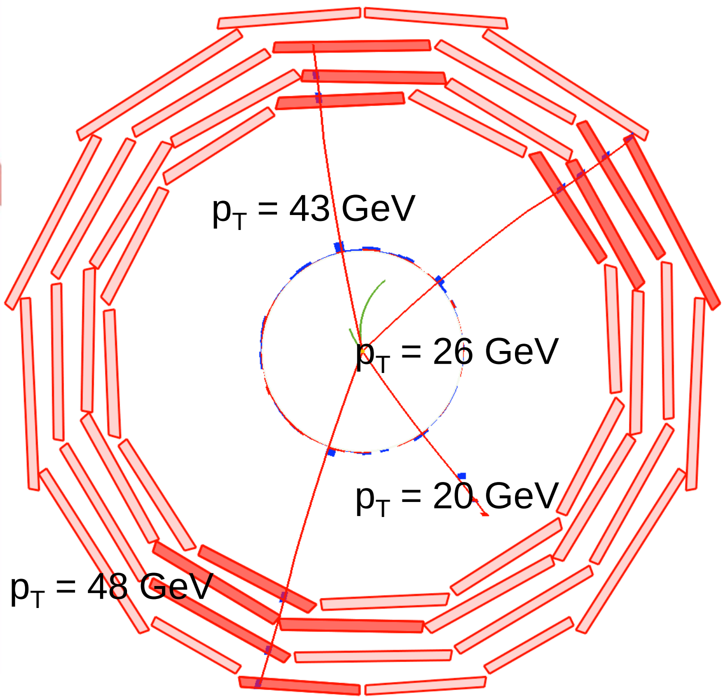
$\sigma/\sigma_{SM} = 1.56 \pm 0.43$

Consistent among different categories

H→ ZZ* → llll : golden channel (l=e,μ)



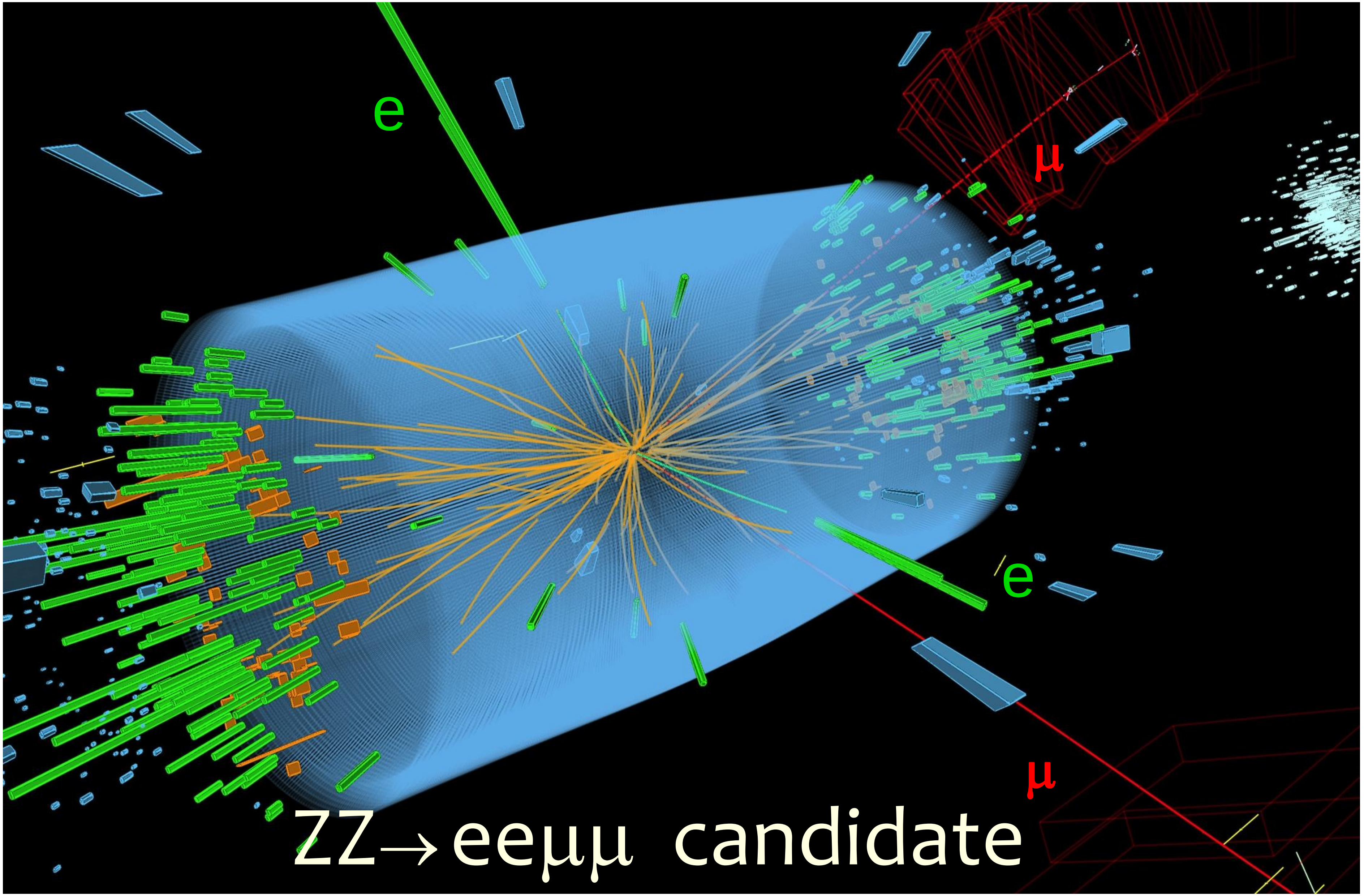




Clean experimental signature:

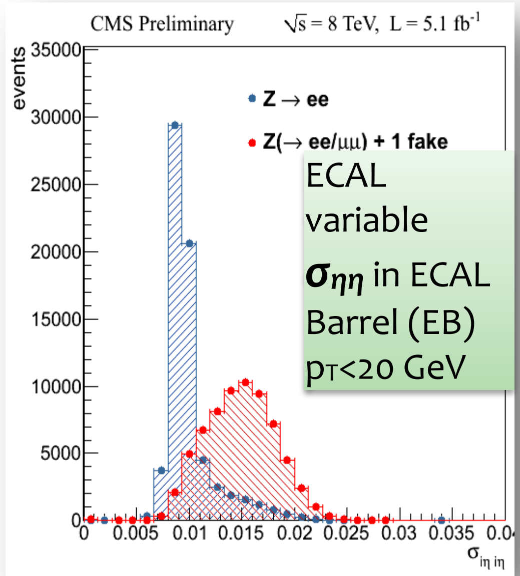
- 4 energetic and isolated leptons (e / μ)
- Coming from the same primary interaction vertex and consistent from originating from 2 Z bosons.
- Narrow peak (resolution 2-3 GeV/c^2) in m_{4l} mass distribution.
- Low background level
- Very demanding for selection and lepton id efficiencies

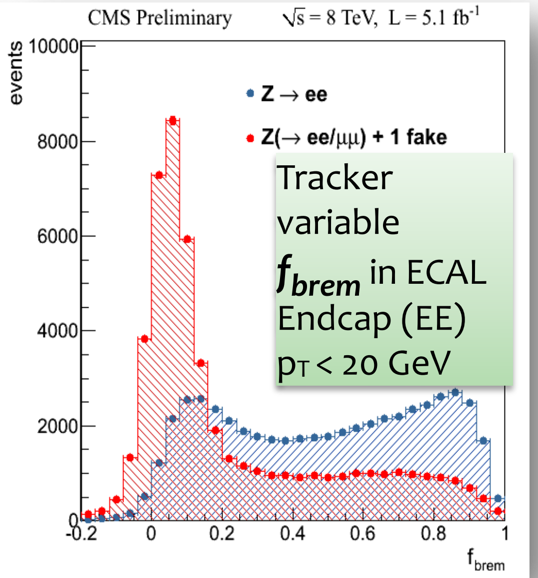
H→ ZZ* → llll : golden channel (l=e,μ)

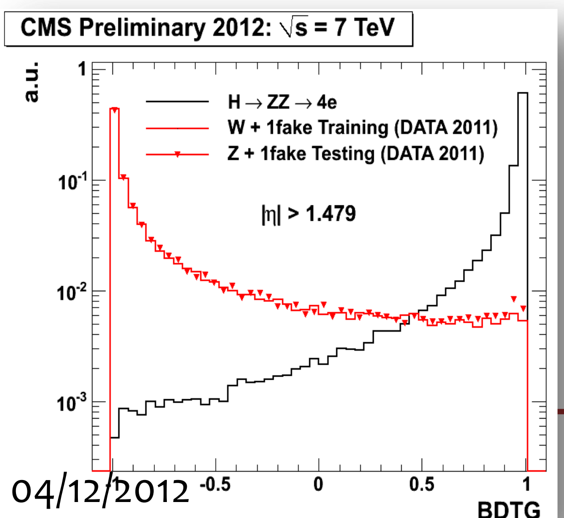


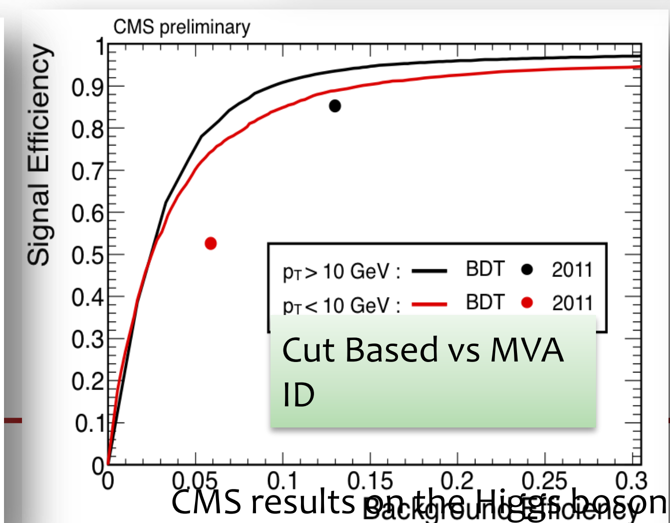
H→ ZZ* → 4l : Electrons

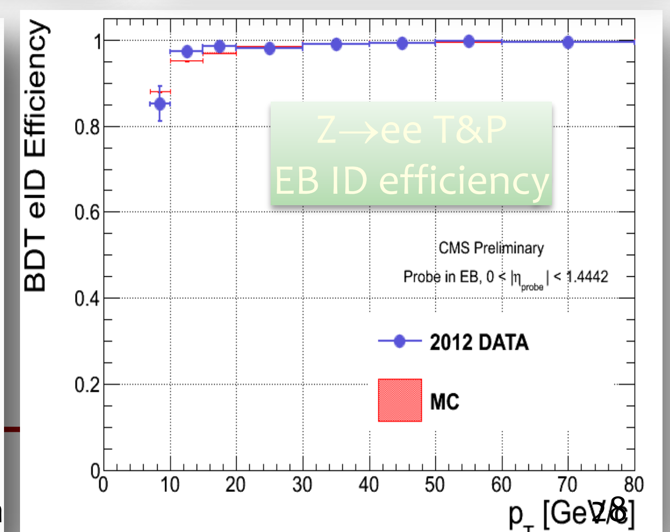
- Multivariate e identification in 2012
  - ECAL, tracker, ECAL-tracker-HCAL matching and impact parameter (IP) observables
- Background from data samples
  - W+jet for training
  - Z+jet for testing
- Performance
  - 30% efficiency improvement in H→ZZ → 4e wrt cut based ID
- Efficiencies
  - Via tag-and-probe at the Z→ee peak





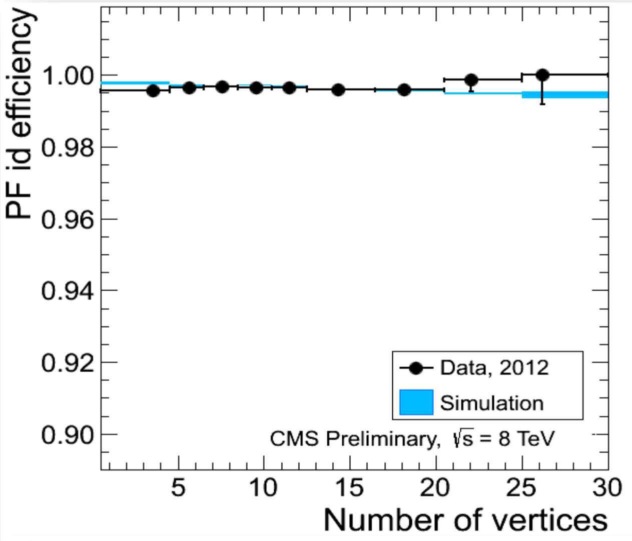




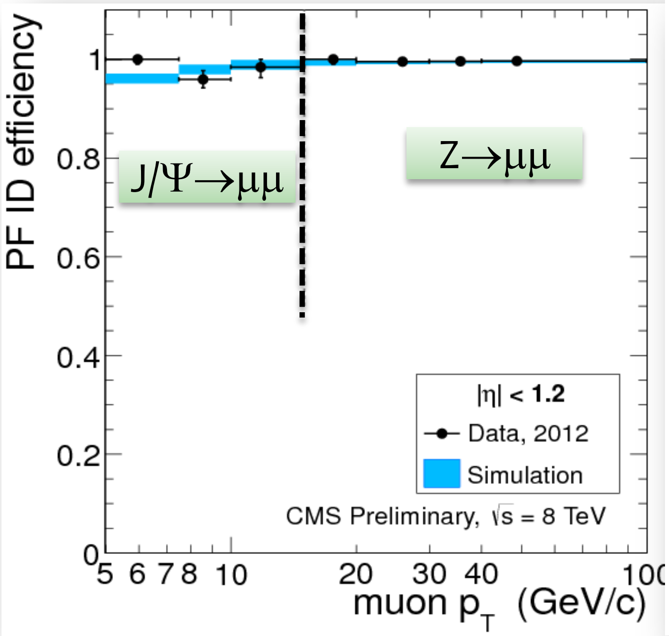


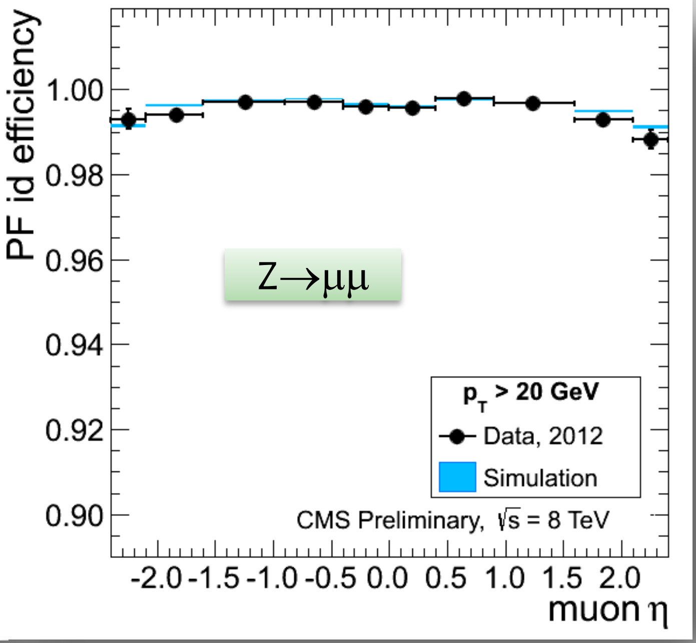
H→ ZZ* → 4l : Muons

- Muons are "clean" particles
- PF Muon Id in 2012: exploit info from all subdetectors
- High efficiency > 96% for p_T≈5 <GeV, > 99% for p_T≥10 GeV
- Efficiency controlled in data with J/ψ and Z T&P



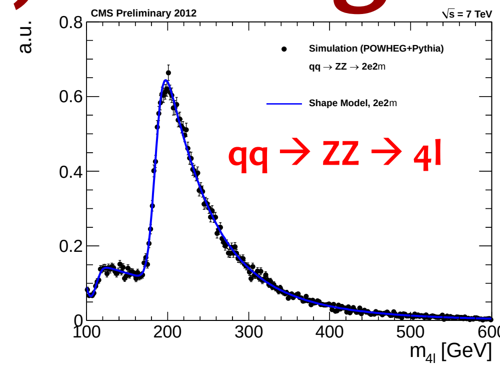
Tighter quality criteria applied in some analyses to further suppress reducible backgrounds

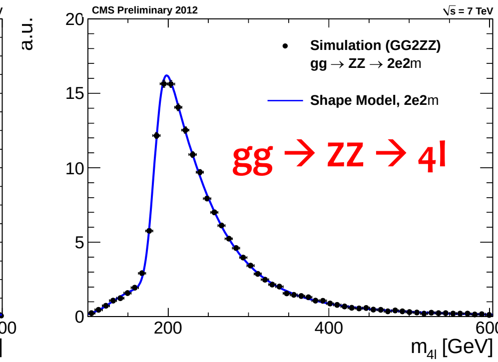




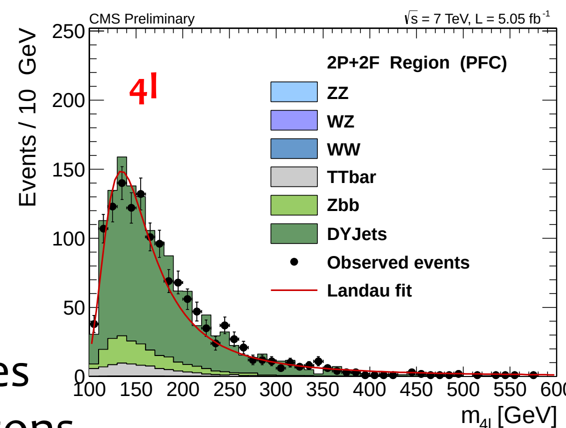
H→ ZZ* → 4l (l=e,μ) : Backgrounds

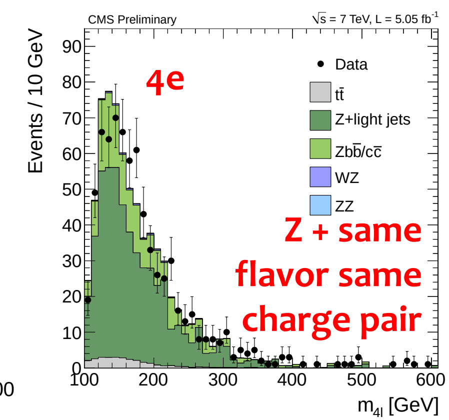
- IrredIrreducible background: ZZ → 4l
  - Estimated **using simulation (theory)**
  - Phenomenological shape models
  - Corrected for data/simulation scale

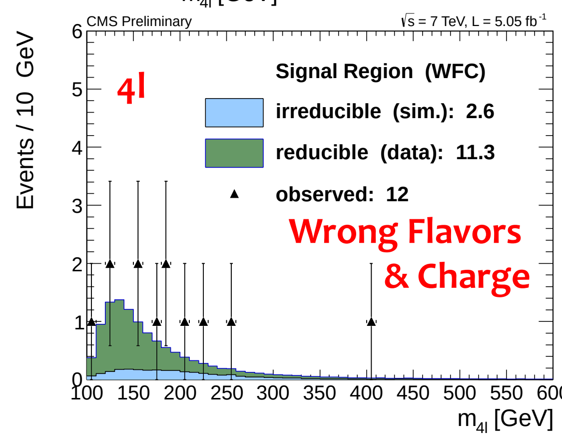




- Reducible bckgd: Z+jets, Zbb, ttbar, WZ
  - Estimated **from data**
    - Measure probabilities for lepton misidentification
    - Extrapolate from control samples enriched with mis-identified leptons
  - **Validation in data** using "wrong flavors & charges" events
  - Total uncertainty ~50%

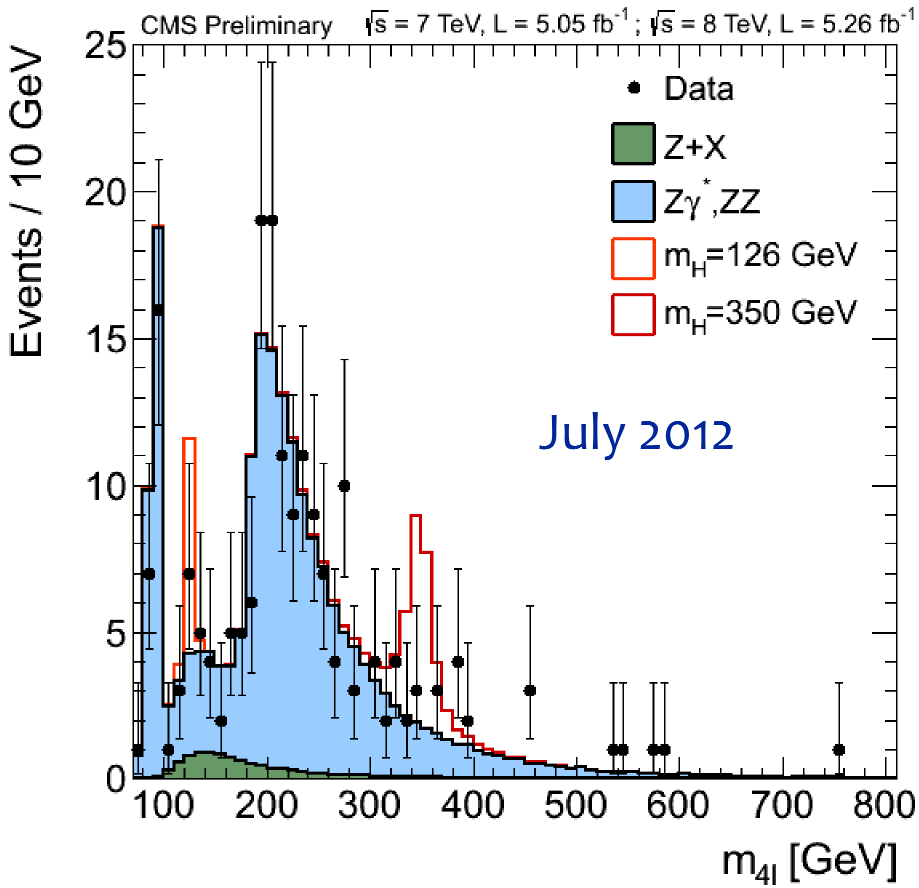






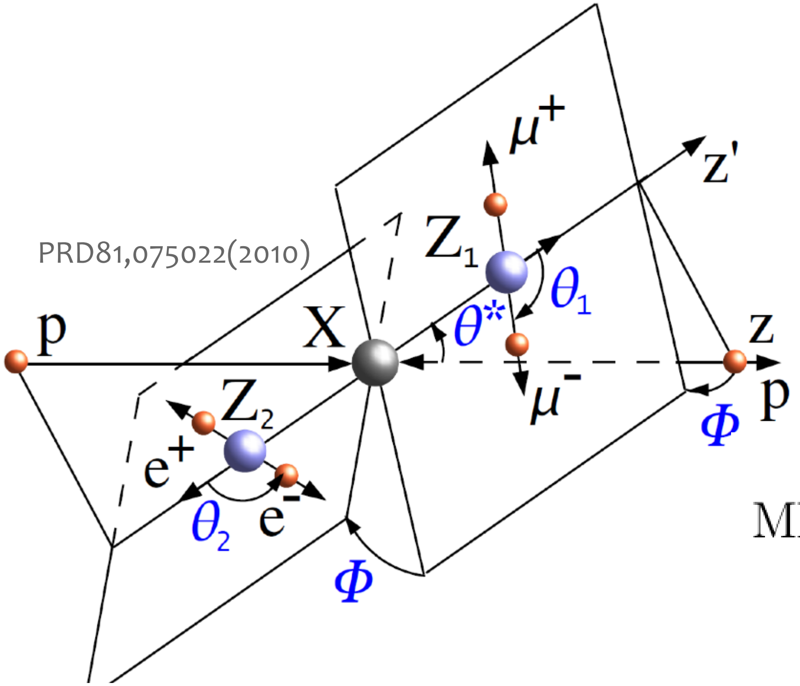
H→ ZZ* → 4l (l=e,μ): Improvements in 2012

- New lepton selection.
- Recovery of photons from final state radiation.
- Exploit angular information to discriminate signal from irreducible ZZ backgd.
- ~20% gain in sensitivity with respect to 2011 analysis.
- Optimization done without looking data at signal region.



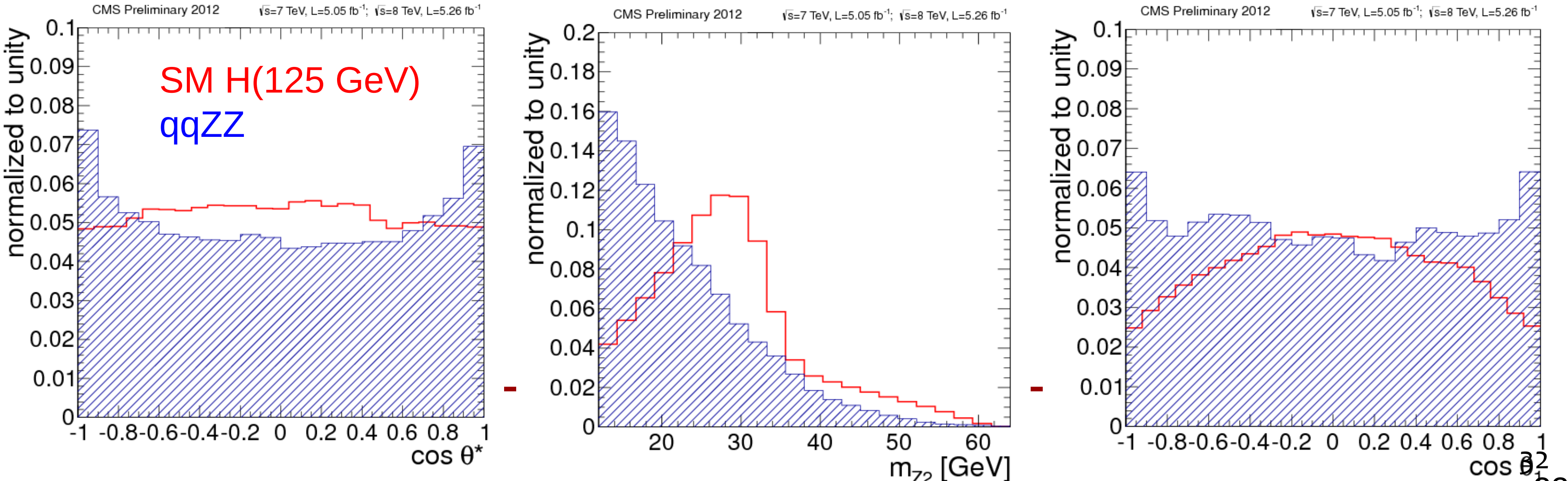
ZZ→eeμμ candidate

H→ ZZ* → 4l (l=e,μ): Angular Analysis



Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

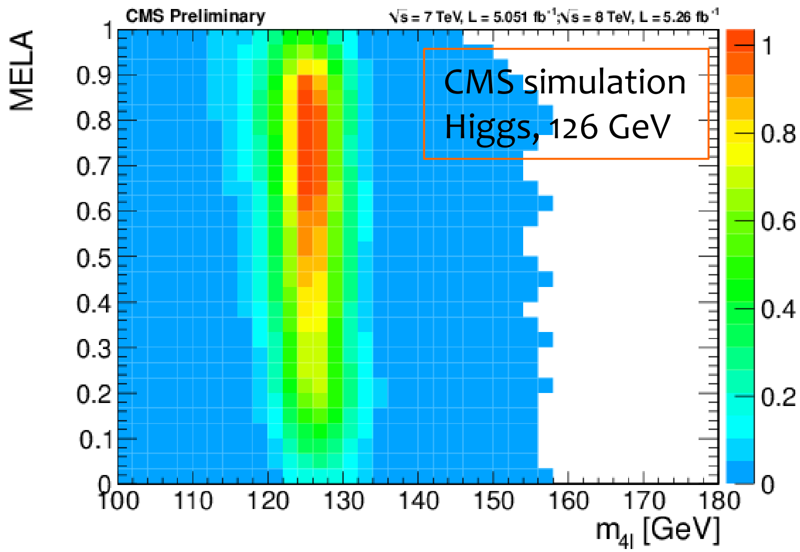
$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$



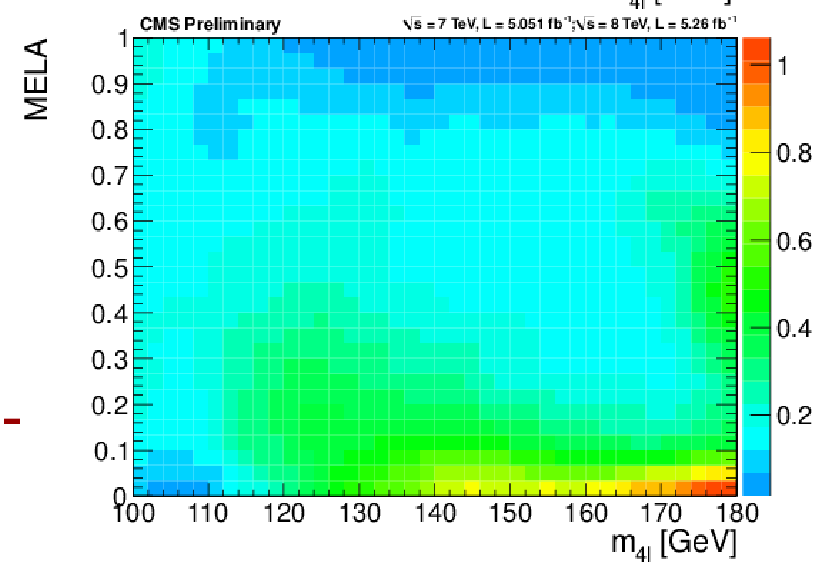
H→ ZZ* → 4l (l=e,μ): Angular Analysis

2D analysis using $\{m_{4l}, \text{MELA}\}$

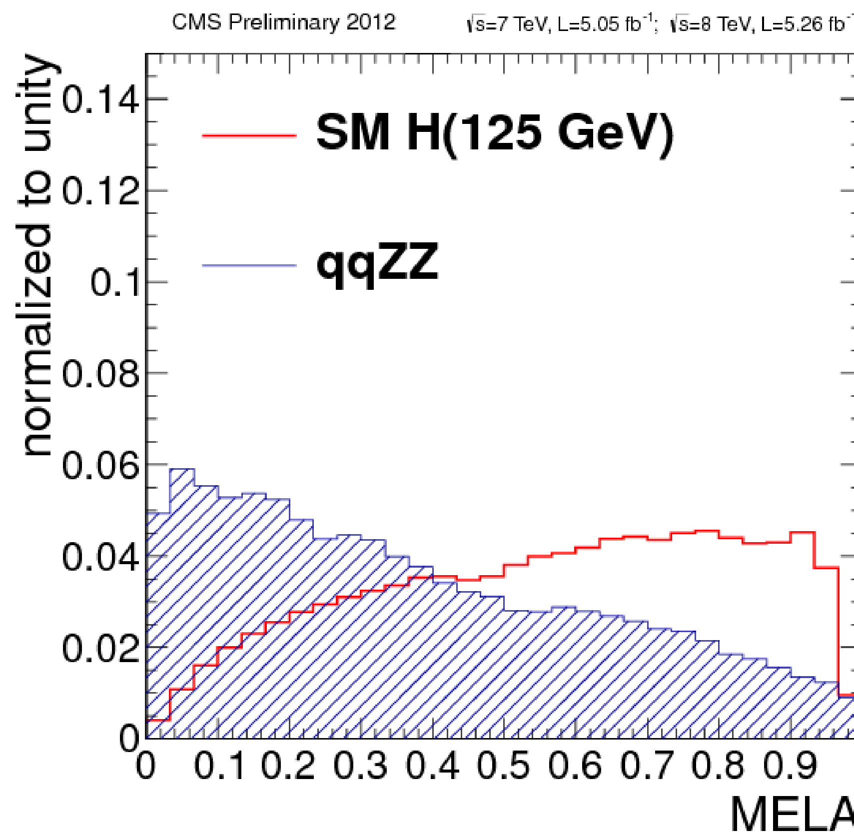
signal



background



MELA offers powerful discrimination of background



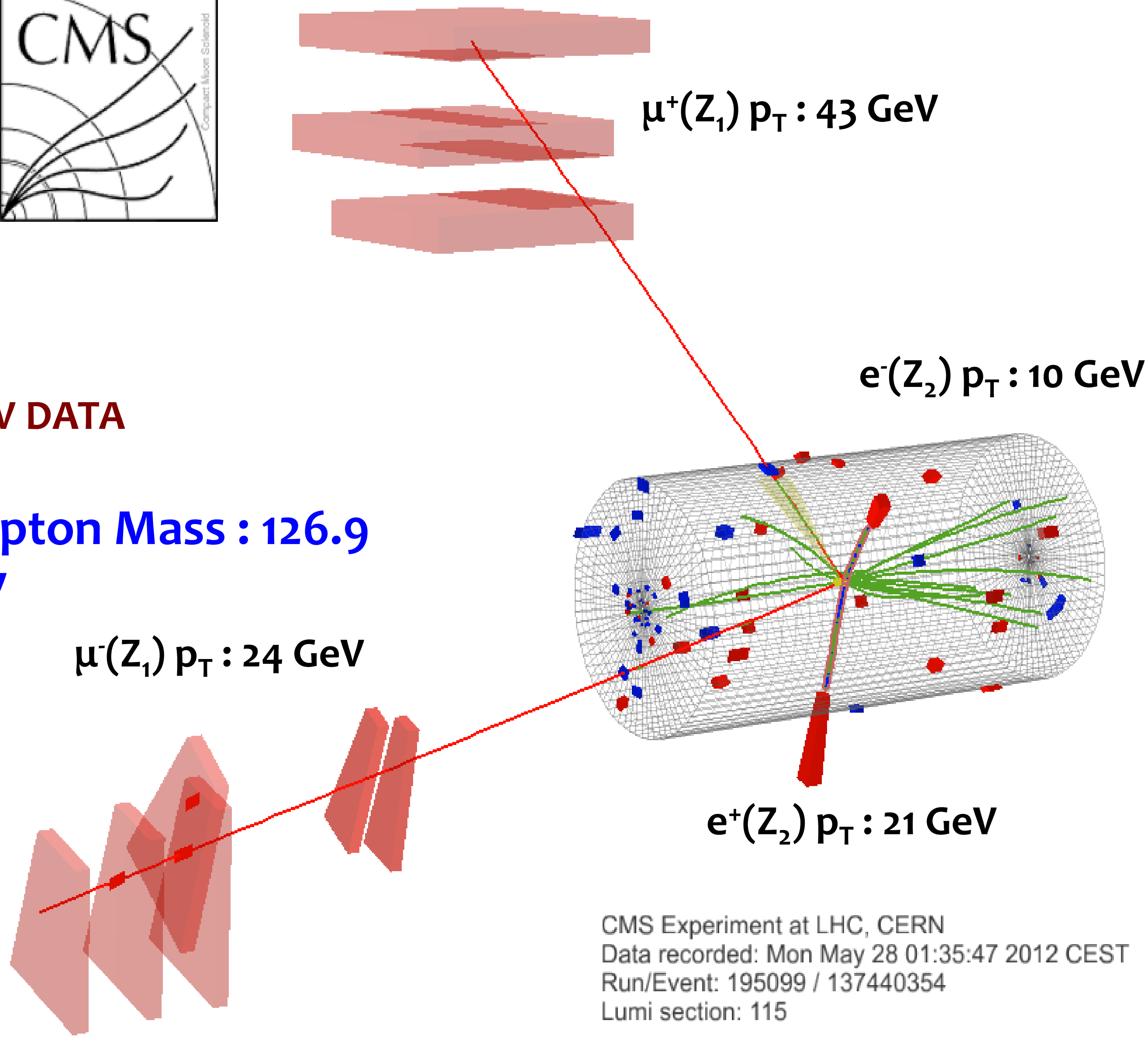
technique applicable for signal hypothesis testing

33

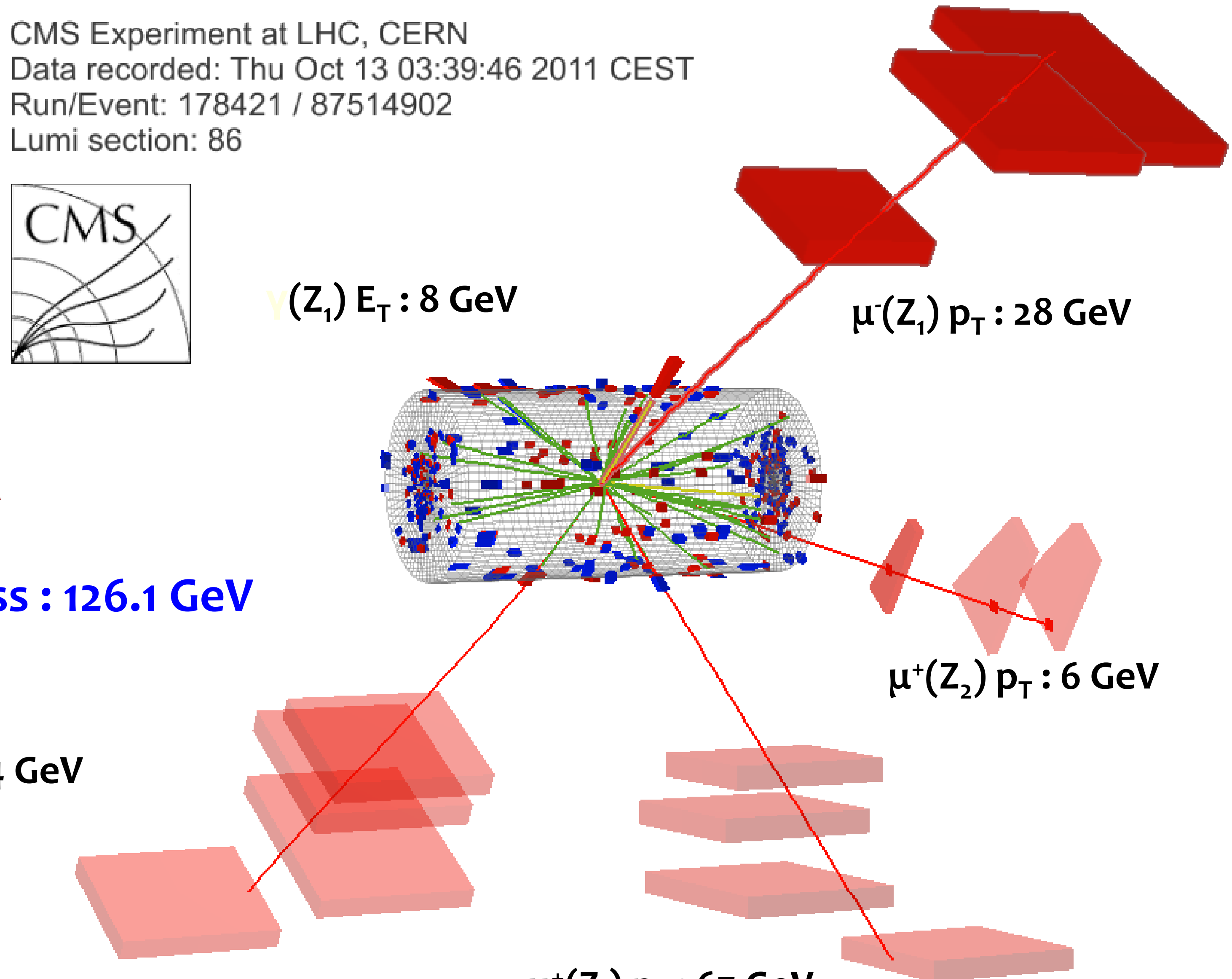
H→ ZZ* → 4l (l=e,μ): Candidate Events

8 TeV DATA

4-lepton Mass : 126.9 GeV



H→ ZZ* → 4l (l=e,μ): Candidate Events



7 TeV DATA

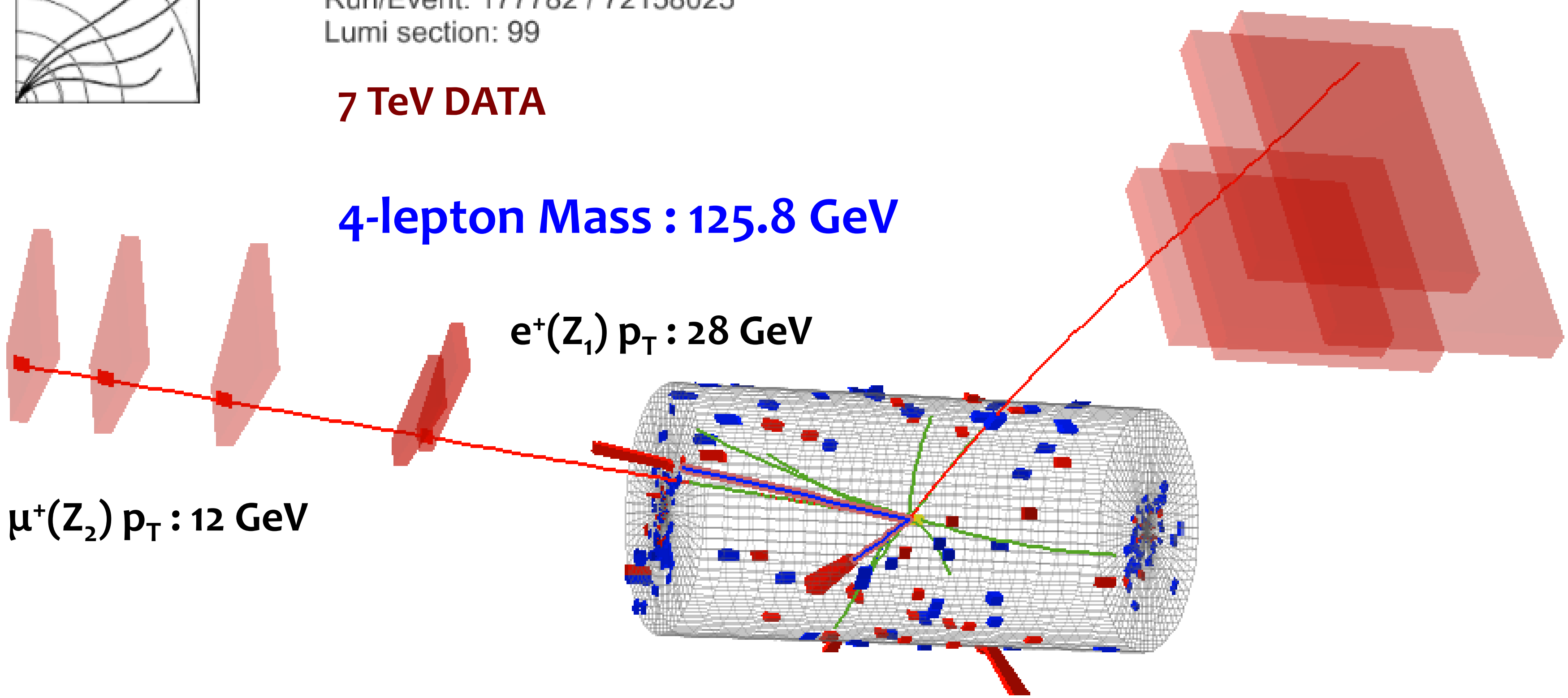
$4\mu+\gamma$ Mass : 126.1 GeV

H→ ZZ* → 4l (l=e,μ): Candidate Events

CMS Experiment at LHC, CERN
Data recorded: Tue Oct 4 00:10:13 2011 CEST
Run/Event: 177782 / 72158025
Lumi section: 99

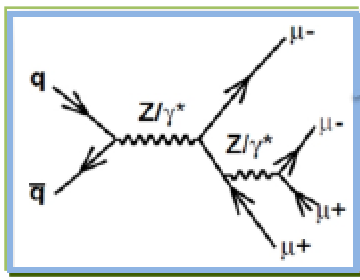
7 TeV DATA

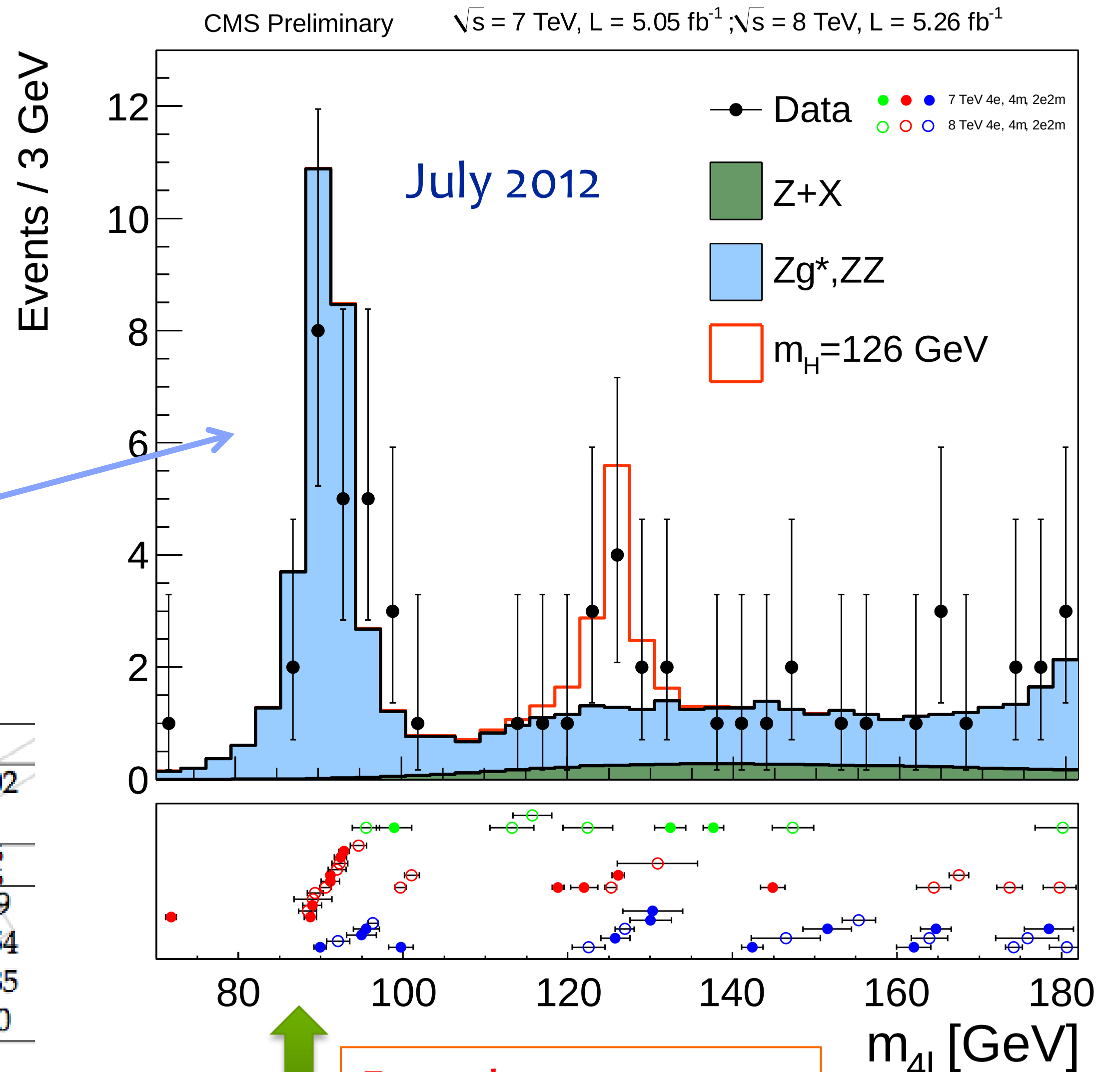
4-lepton Mass : 125.8 GeV



H→ ZZ* → 4l (l=e,μ): Results

Localized excess of events at ~126 GeV





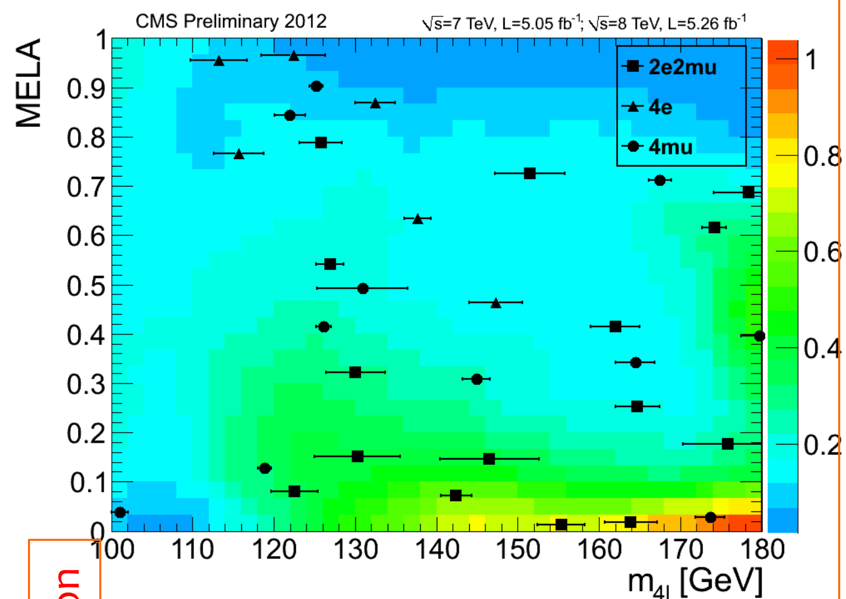
Event-by-event errors

Channel	4e	4μ	2e2μ
ZZ background	29.27 ±3.43	49.01 ±5.08	75.45 ±8.02
Z+X	$3.00^{+2.70}_{-1.94}$	$2.20^{+1.56}_{-1.32}$	$5.00^{+3.96}_{-2.98}$
All backgrounds	$32.27^{+4.37}_{-3.94}$	$51.21^{+5.31}_{-5.25}$	$80.45^{+8.96}_{-8.56}$
$m_H = 126$ GeV	1.51 ±0.48	2.99 ±0.60	3.81 ±0.89
$m_H = 200$ GeV	8.34 ±2.01	13.25 ±2.68	21.63 ±4.54
$m_H = 350$ GeV	4.79 ±1.22	7.46 ±1.63	12.65 ±2.85
$m_H = 500$ GeV	1.68 ±0.79	2.58 ±1.16	4.39 ±2.00
Observed	32	47	93

H→ ZZ* → 4l (l=e,μ): MELA

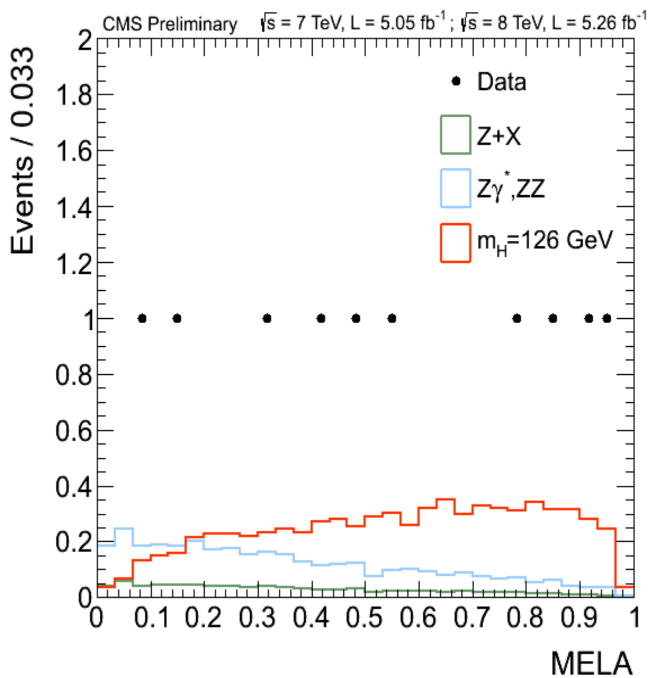
- Analysis performed using a 2D fit of the MELA likelihood discriminant and the 4-lepton mass
- Data points shown with per-event mass uncertainties

Analysis performed using a 2D fit of the MELA likelihood discriminant and the 4-lepton mass
Data points shown with per-event mass uncertainties

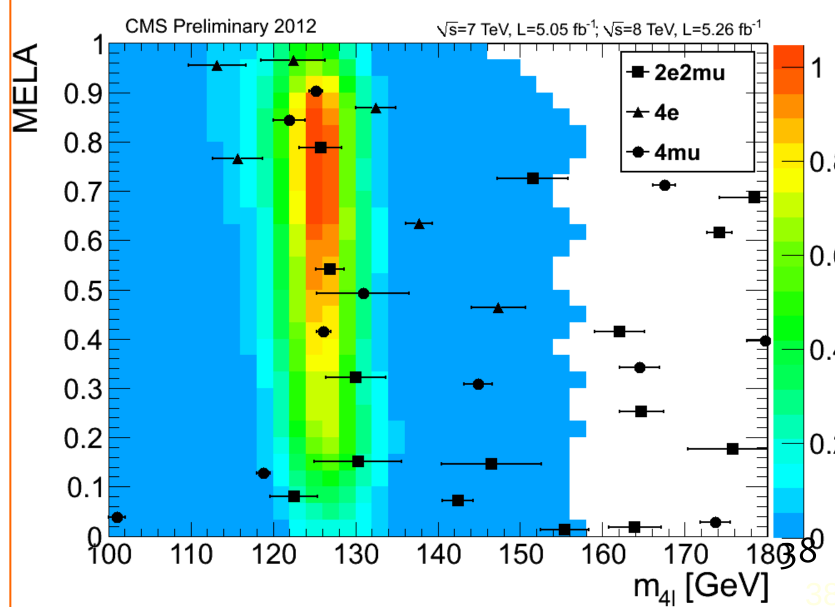


Data w.r.t. background expectation

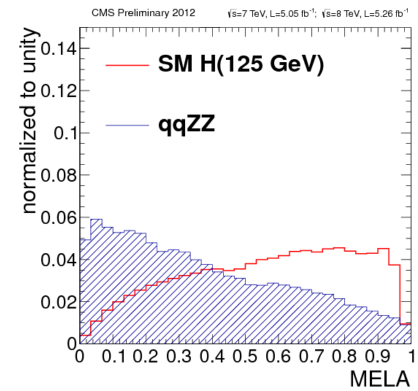
MELA projection in m(4l) slice: 121-131 GeV



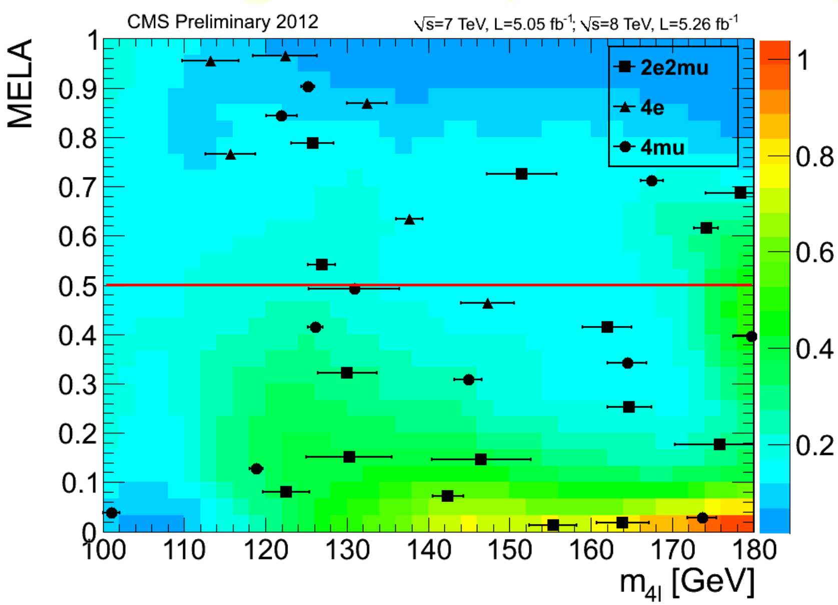
Data w.r.t 126 GeV Higgs Expectation

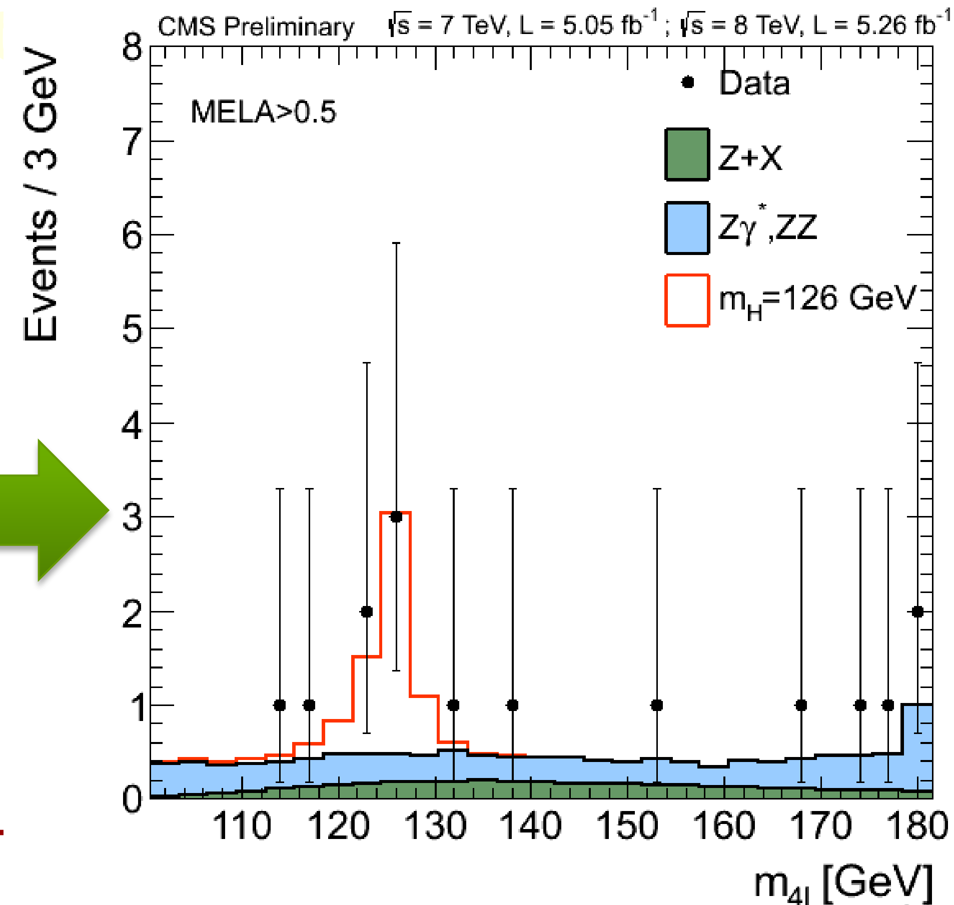


H→ ZZ* → 4l (l=e,μ): MELA

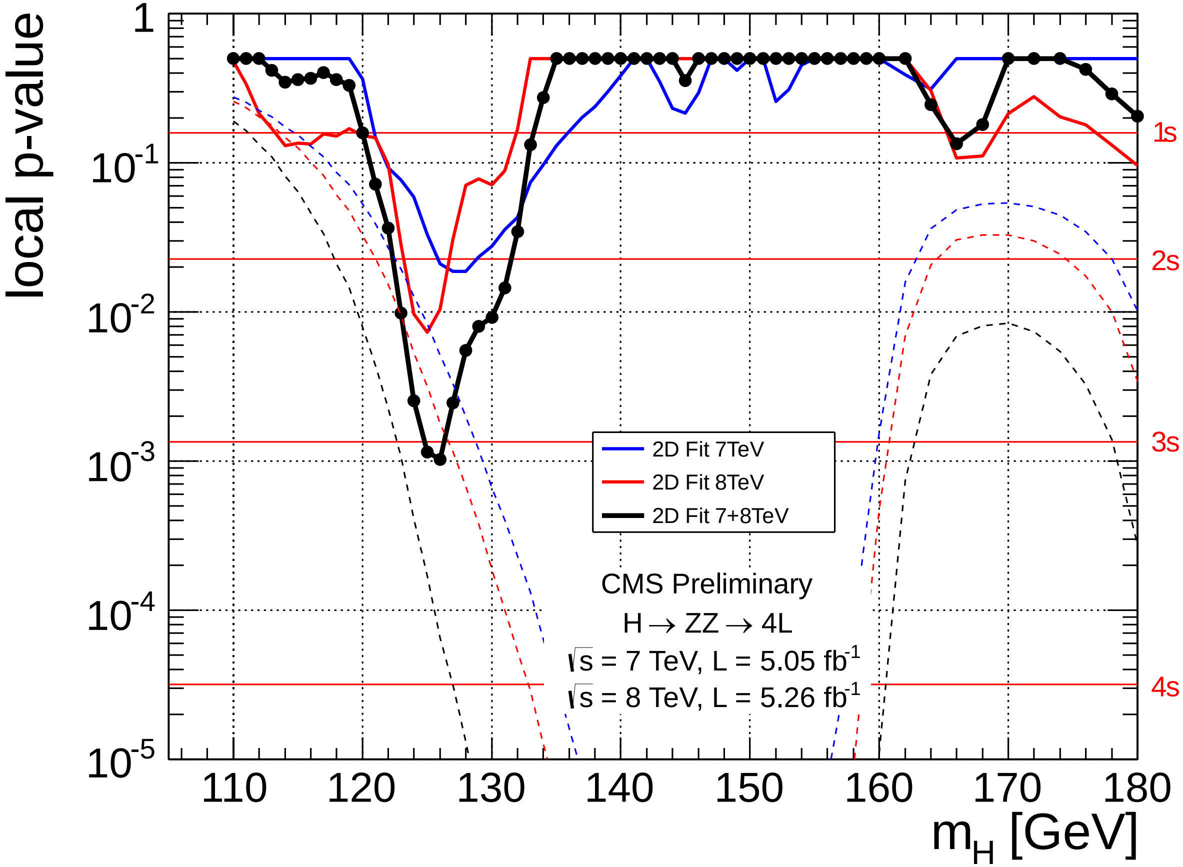


- Choosing a signal-like region in the angular discriminator (MELA>0.5) value chosen such that signal probability > background probability





H→ ZZ* → 4l (l=e,μ): p-values



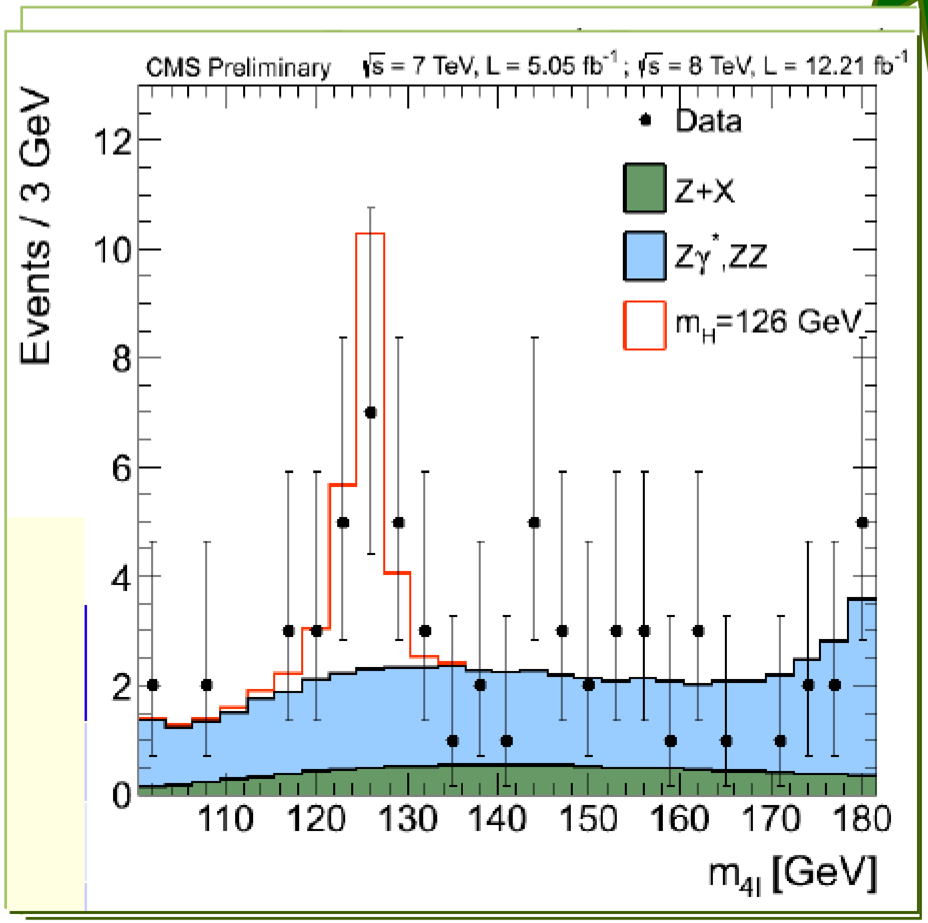
July 2012

Observed significance at 126 GeV: 3.2σ

Expected significance at 126 GeV: 3.8 σ

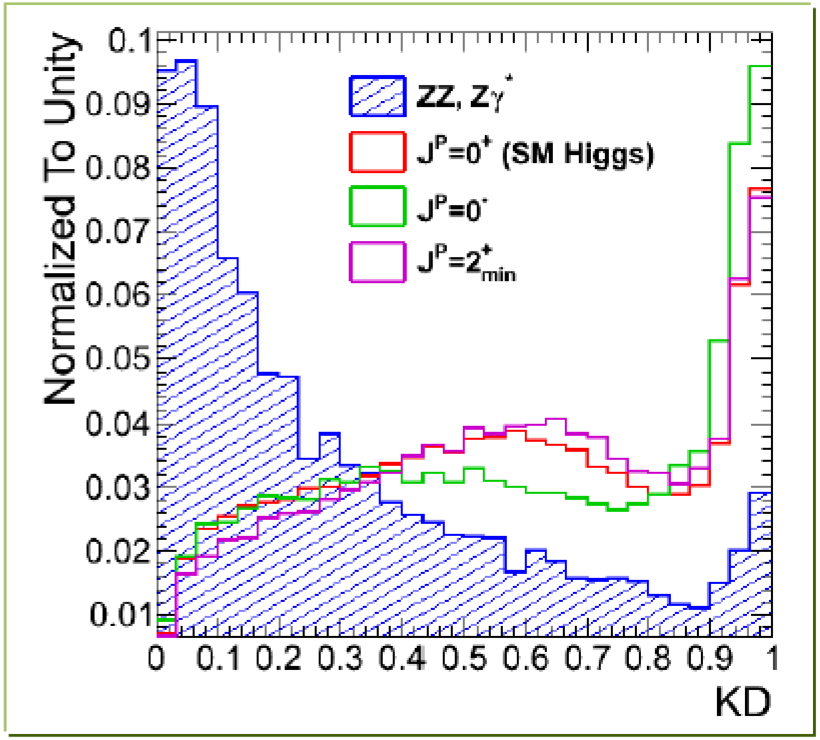
H→ ZZ* → 4l (l=e,μ): Update Nov 2012

NEW



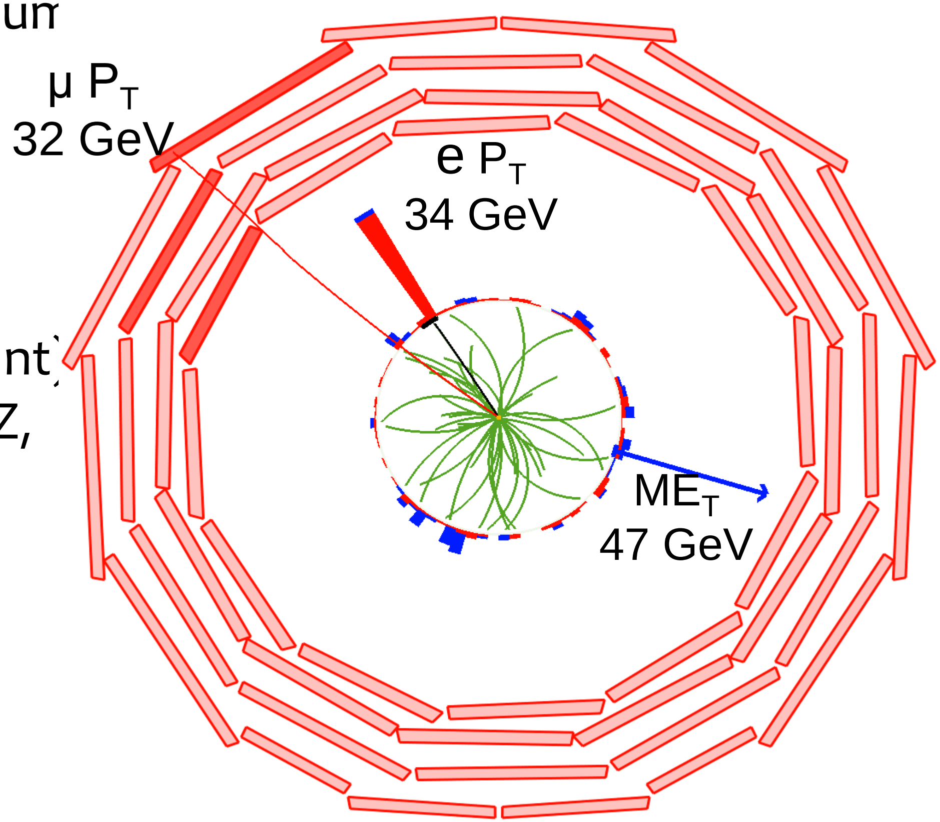
H→ ZZ* → 4l (l=e,μ): Spin & parity

- Define new kinematic discriminants (MELA, m_{4l}, Δm_{4l}) which "distinguish" 0+, 0-, 2+



H→WW→lνlν or lνqq'

- Semileptonic (lνqq) recently addressed (m_H> 170 GeV)
- Better sensitivity from 2l2ν.
- 2 high p_T isolated leptons + momentum imbalance (large missing E_T)
- Not possible full reconstruction of Higgs decay (missing ν) ➔ no mass peak.
- Main backgrounds: WW (non-resonant) top production, also W+jet, Z/γ*, WZ, ZZ, Wγ .



H→WW→lνlν

Experimentally analysis is optimized for different categories, according to final states, backgd composition and S/B

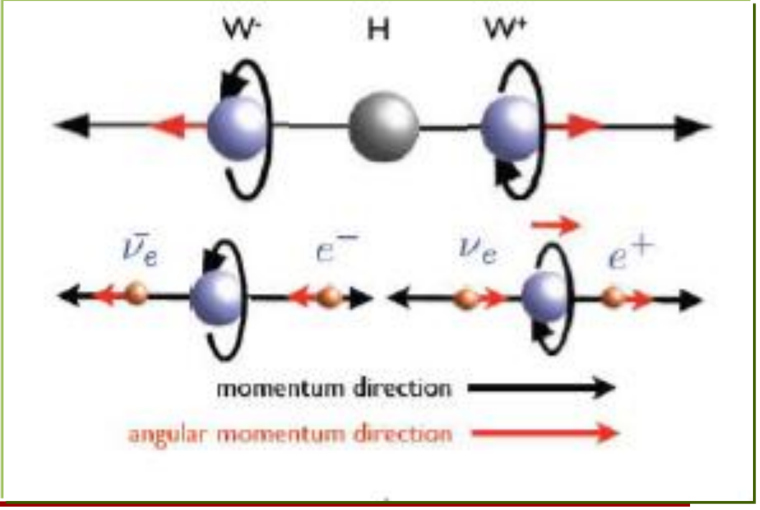
- final state lepton flavour: same flav.–SF (ee,μμ) or different flav.–DF (eμ, μe)
- Jet multiplicity: 0,1 jet (inclusive) or 2 jets (VBF process)

Trigger 1 or 2 leptons > 97 %
p_T^l > 20,10 GeV, iso, ID, from PV
Projected mET > 20 GeV

- Anti-top + p_T^{ll} > 45 GeV
- 3rd lepton veto
- Z veto and mE_T cuts
- Mass dependant: p_T^l, m_{ll}, $\Delta\varphi_{ll}$, m_T

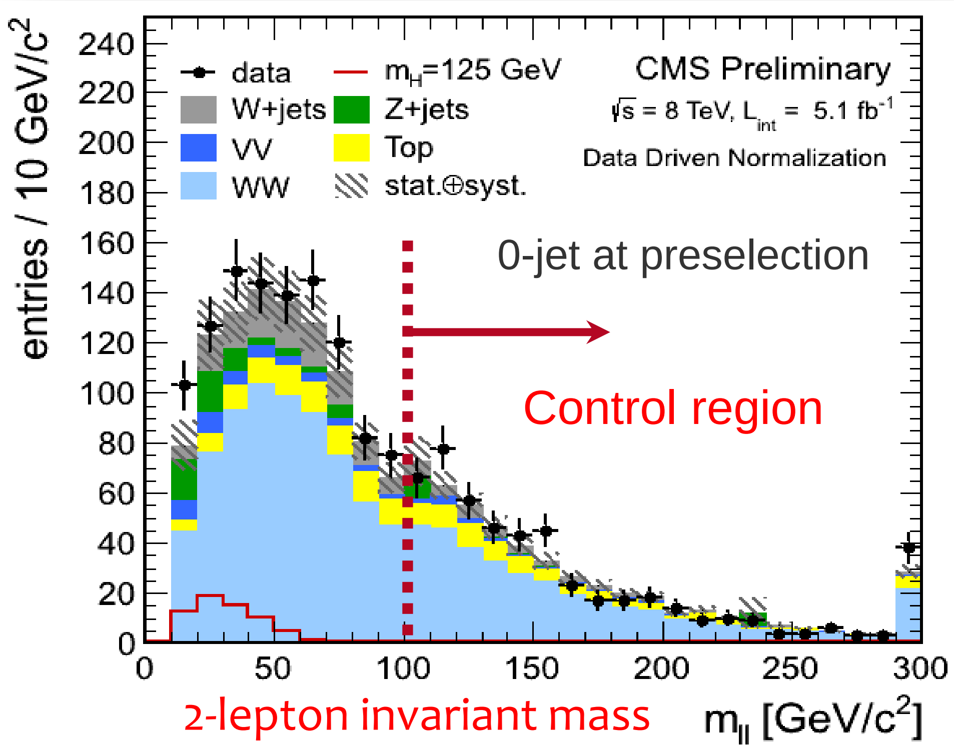
First analysis on 2011+part of 2012 data based on Cut&Count; now, shape analysis, exploiting kinematics of signal and backgrounds:

- Spin correlations
- Scalar boson decay to vector boson and V-A structure of W coupling
- Small di-lepton $\Delta\phi$ and m_{ll} if SM Higgs



H→WW→lνlν

- Main backgrounds estimated from data, in control regions
  - Non-resonant WW
    normal. in m(ll)>100 GeV control region
  - W+jets
    Fake rate measured in QCD enriched data sample
  - Z/γ*
    Normalised in Z mass
  - Top
    b-tagging efficiency measured in top control region in data + soft p_T lepton.
  - WZ, ZZ, Wγ
    from simulation.

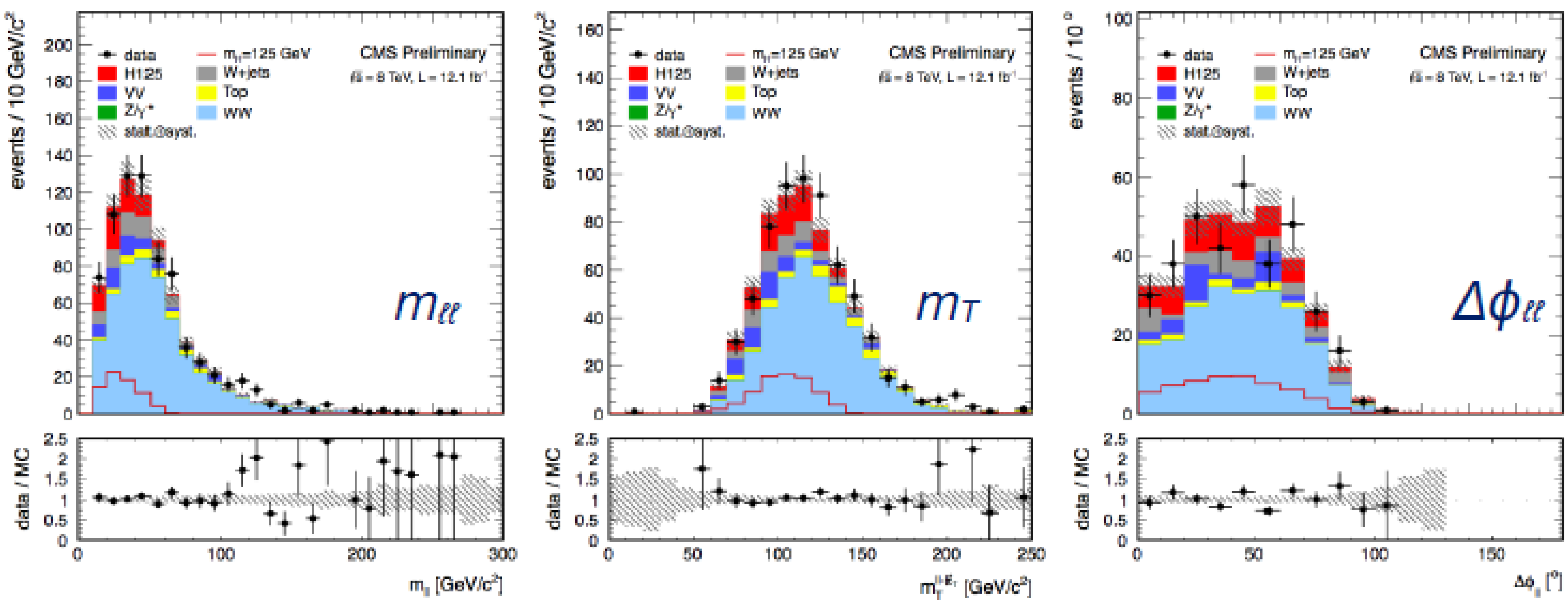


Normalisation of WW background:
Use m(ll) > 100 GeV for low m_H search

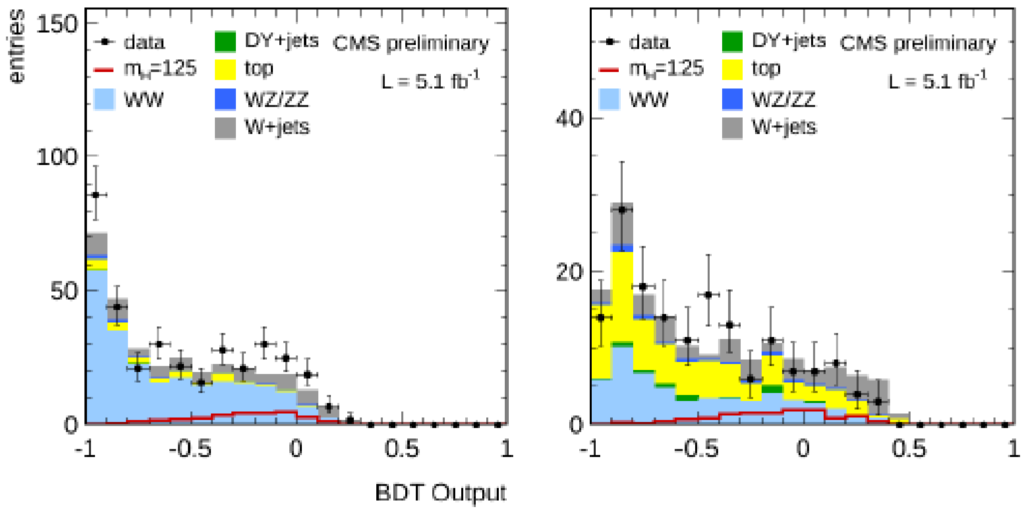
H→WW→lνlν

DF (e,μ), 0 Jets most sensitive category

m_H	$H \to W^+W^-$	$pp \to W^+W^-$	$WZ+ZZ$ $+Z/\gamma^* \to \ell^+\ell^-$	Top	$W+$jets	$W\gamma^{(*)}$	all bkg.	data
0-jet category $e\mu$ final state								
120	34.0 ± 7.3	162.3 ± 15.4	5.3 ± 0.5	8.6 ± 2.0	38.0 ± 14.0	23.1 ± 8.8	237.3 ± 22.7	285
125	57.8 ± 12.5	203.1 ± 19.1	6.6 ± 0.6	11.0 ± 2.5	44.5 ± 16.4	25.6 ± 9.5	290.7 ± 27.0	349
130	86.3 ± 18.4	225.9 ± 21.2	7.1 ± 0.7	12.2 ± 2.8	46.5 ± 17.1	27.1 ± 10.0	318.9 ± 29.2	388
160	237.5 ± 51.0	125.2 ± 11.9	3.7 ± 0.4	13.1 ± 3.1	5.9 ± 2.7	2.6 ± 1.5	160.3 ± 12.6	197
200	95.1 ± 21.1	203.6 ± 19.4	6.3 ± 0.6	28.9 ± 6.4	7.7 ± 3.5	1.3 ± 0.9	277.9 ± 20.7	309
400	39.6 ± 10.7	132.9 ± 14.8	6.2 ± 0.7	49.6 ± 10.7	7.6 ± 3.3	3.5 ± 2.1	199.8 ± 18.7	198
600	6.6 ± 2.3	42.2 ± 4.8	2.5 ± 0.3	16.5 ± 3.8	4.4 ± 2.0	2.4 ± 1.8	67.9 ± 6.7	64



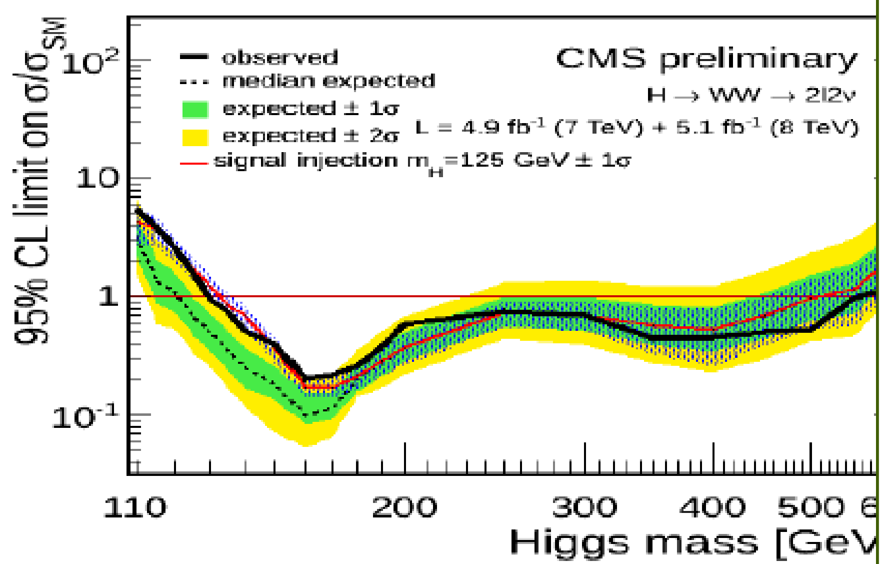
H→WW→lνlν



MultiVariate shape analysis in the eμ final state in the 0 and 1 jet categories: Cut-based variables + ΔR_{ll}, $m_T^{(1,2)}$, $\Delta\phi$(ll, MET), $\Delta\phi$(ll, jet1)

@ mH = 125 GeV
Exp. significance 2.5 σ
Obs. significance 2.2 σ

Signal strength: 0.82 ± 0.38



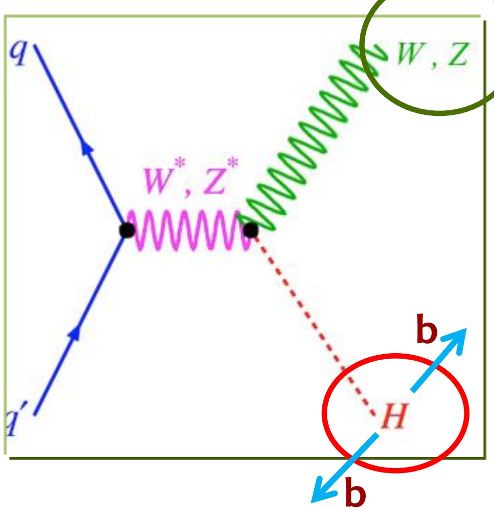
PPC 2012 - KIAS - Nov 5th

What about the fermions?

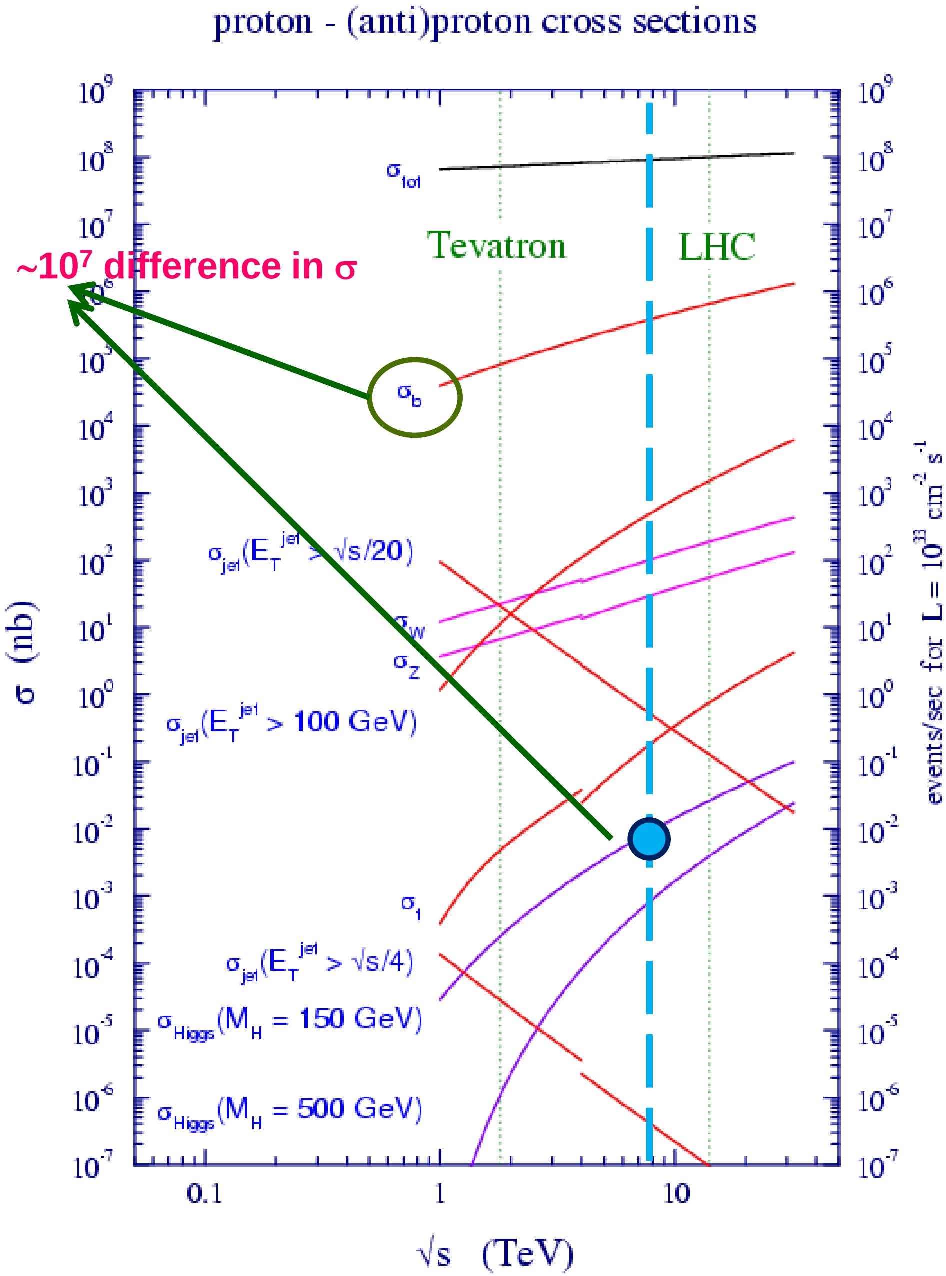
VH, H→ bb

- If SM Higgs → bb has the highest BR
- But very high levels of backgrounds looking for b-pairs alone.
- Look for Associated Production with a Vector Boson (W,Z)

Z→ ll (l = e, μ, ν)
W→ lν (l = e, μ)
5 different final states

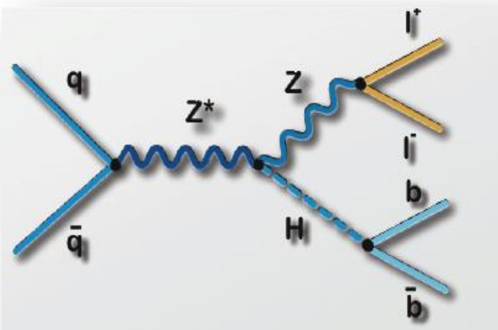


Vector Boson

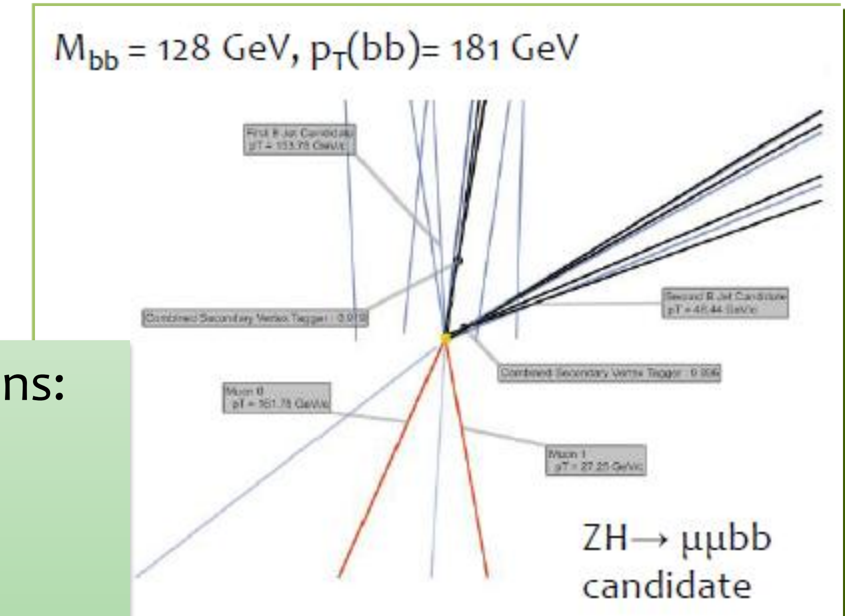


VH, H→ bb

Associated Production
→ final states with leptons, MET and b-jets

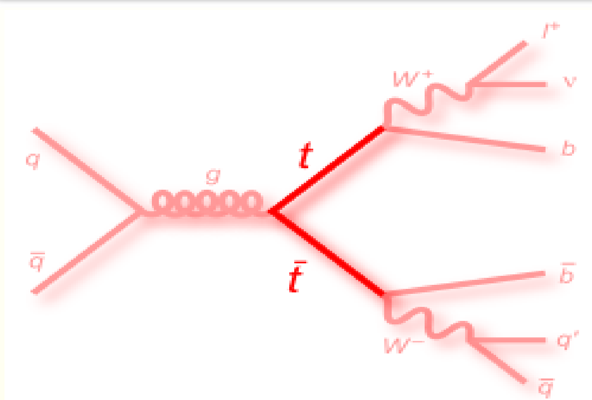


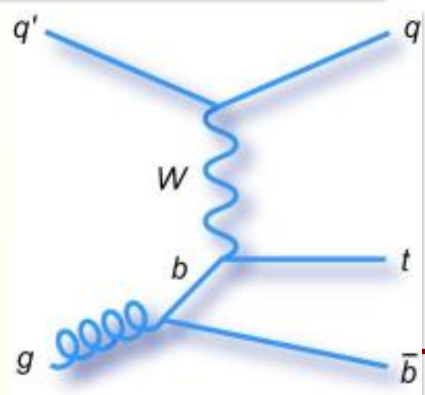
Boosted vector bosons:
- ❑ large $p_T(V)$,
- ❑ 2 b-tagged jets ($H\to bb$)
- ❑ Back-to-back V and H,
- ❑ reconstruct m_{bb}

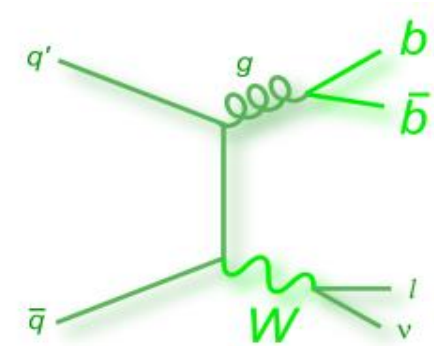


Reducible Backgrounds: QCD, top, W/Z+ light jets
Estimated from data in control regions

Less reducible:
V+bb, ZZ(bb), WZ(bb)



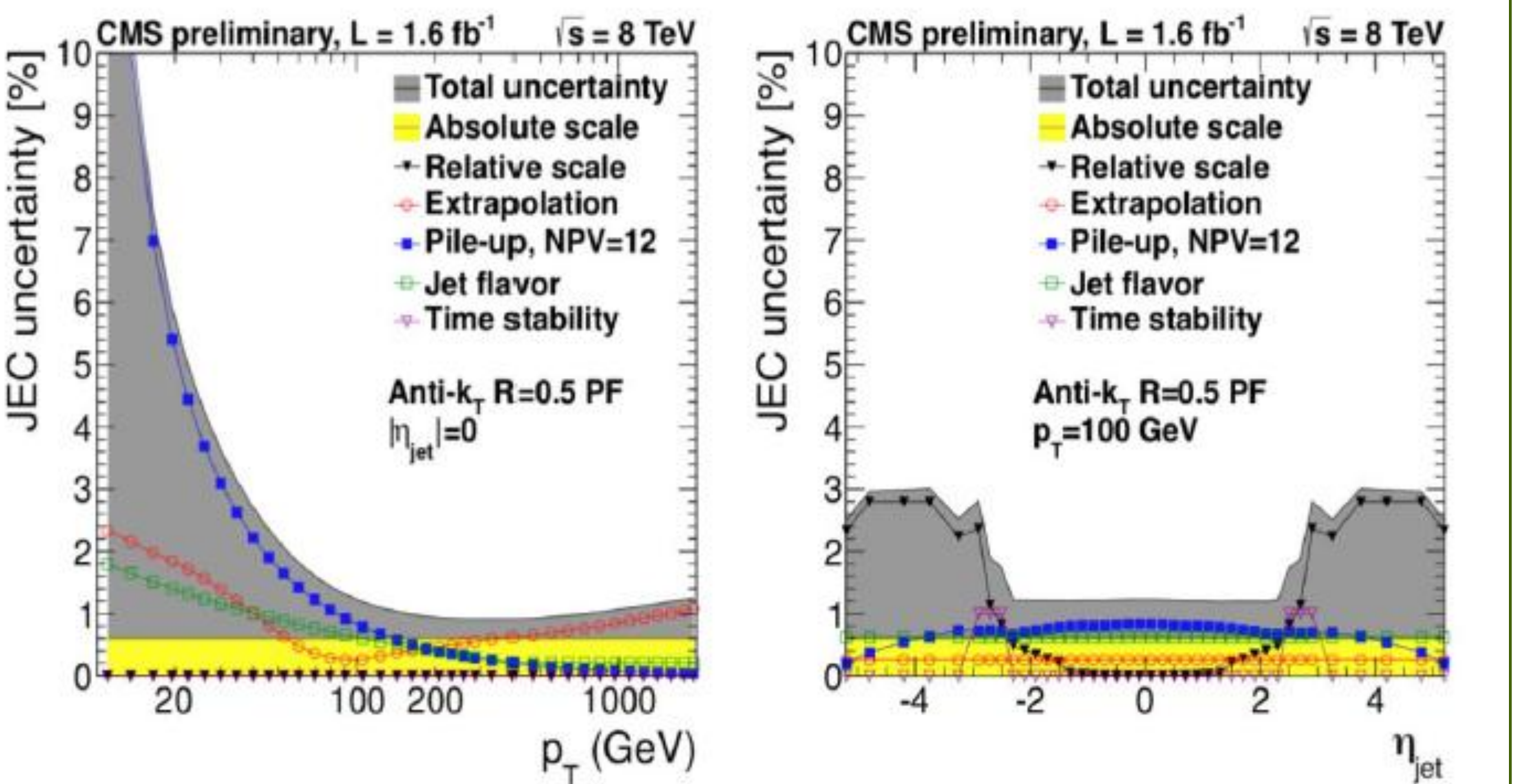




50

VH, H→ bb :Jets

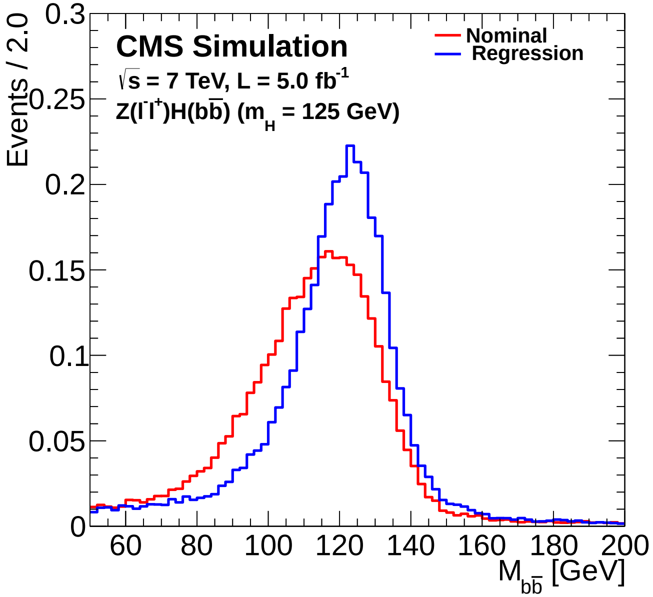
- Jet energy corrections & uncertainties



- the contribution of different uncertainty sources depends on p_T and η
- total uncertainty of the jet energy scale is close to 1% for $|\eta| < 2.4$

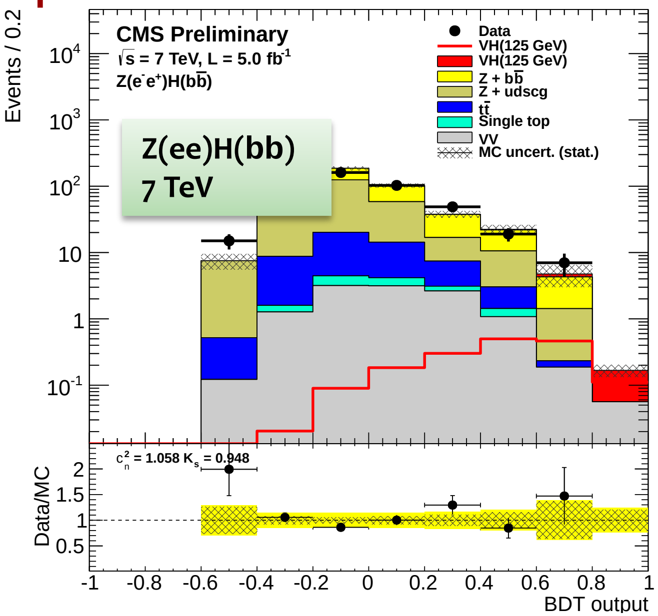
VH, H→ bb : Analyses

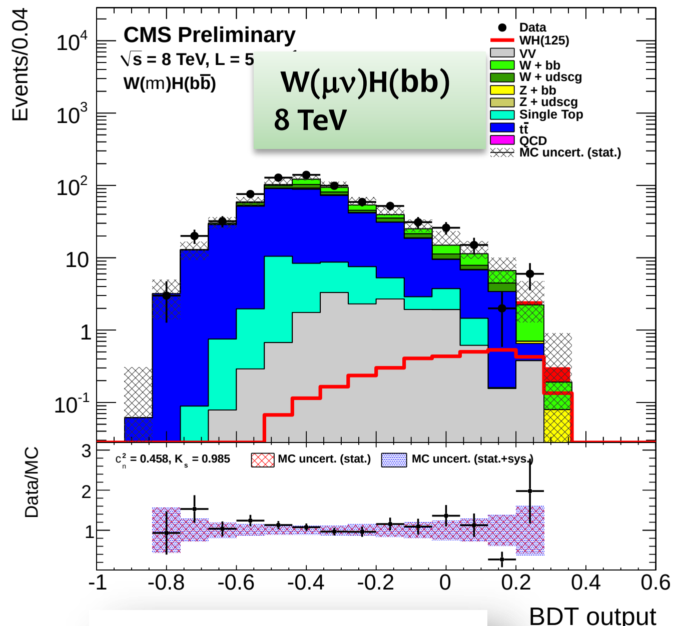
- Analysis with Boosted Decision Tree (BDT) based on multiple variables: M(jj), p_T(jj), p_T(j), p_T(V), b-tag value, |Δϕ(V,H)|, |Δη (jj)|, ΔR(j1,j2)
  - Improvements of ~ 50% in sensitivity:
  - Two Pt(V) bins: "low" and "high"
  - Fit the shape of the BDT output distribution (vs Cut&Count)
  - Improved b-jet energy resolution [MVA regression]

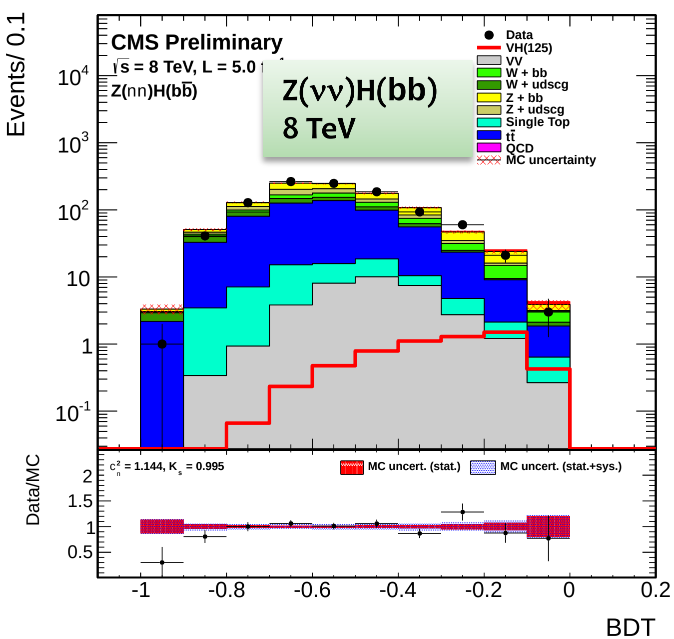


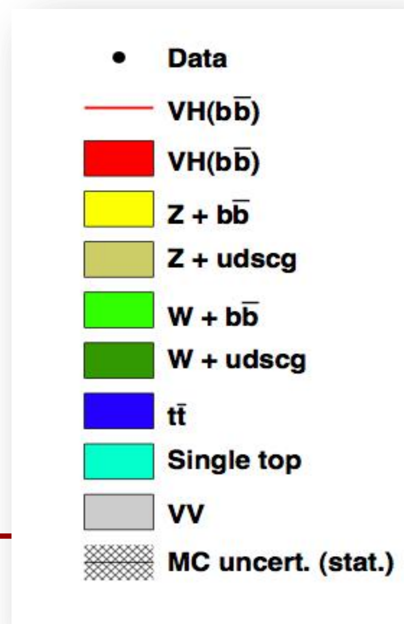
52

VH, H→ bb : Analysis





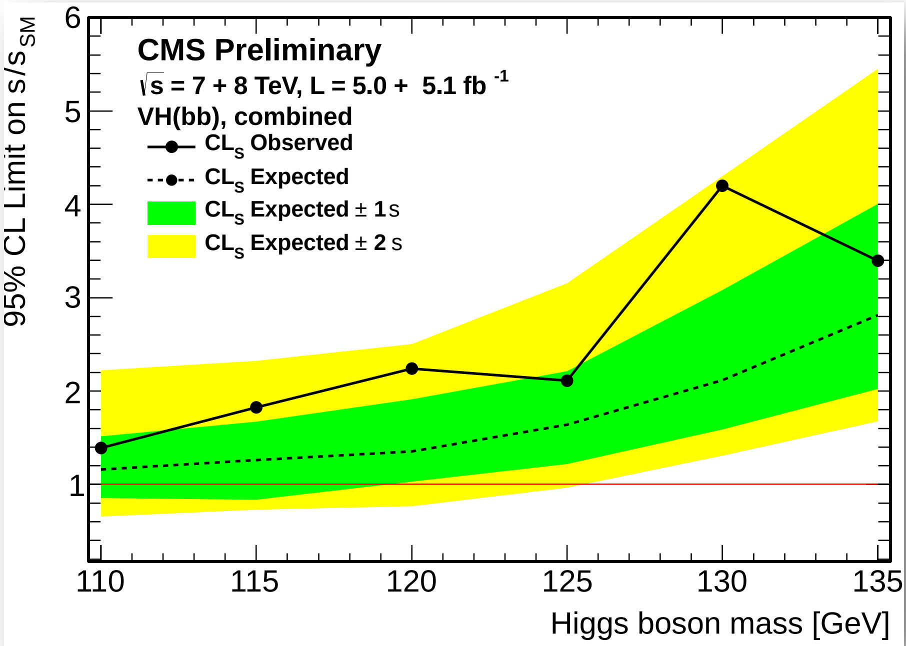


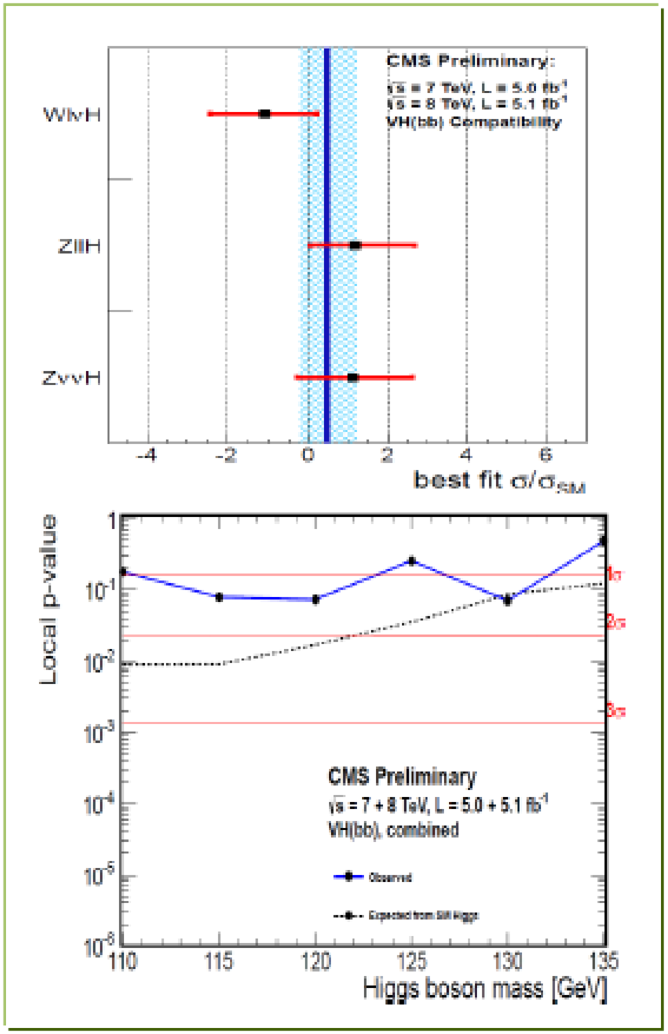


- Examples of final BDT distributions
- Channels dominated by background processes, but shapes well described.
- July 2012: Data compatible either with backgd or signal from a 125 GeV Higgs

53

VH, H→ bb : Results (July 2012)



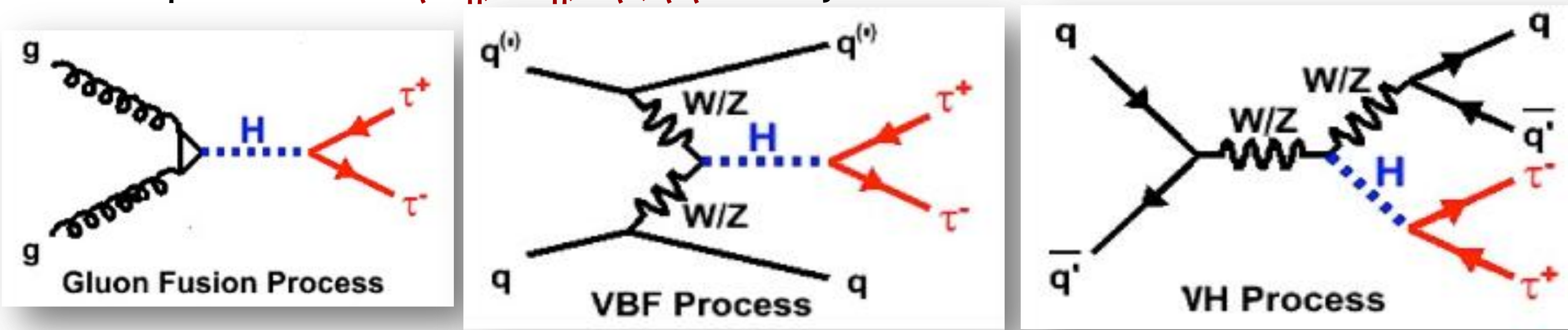


- Data compatible either with backgd or signal from a 125 GeV Higgs

H→ ττ

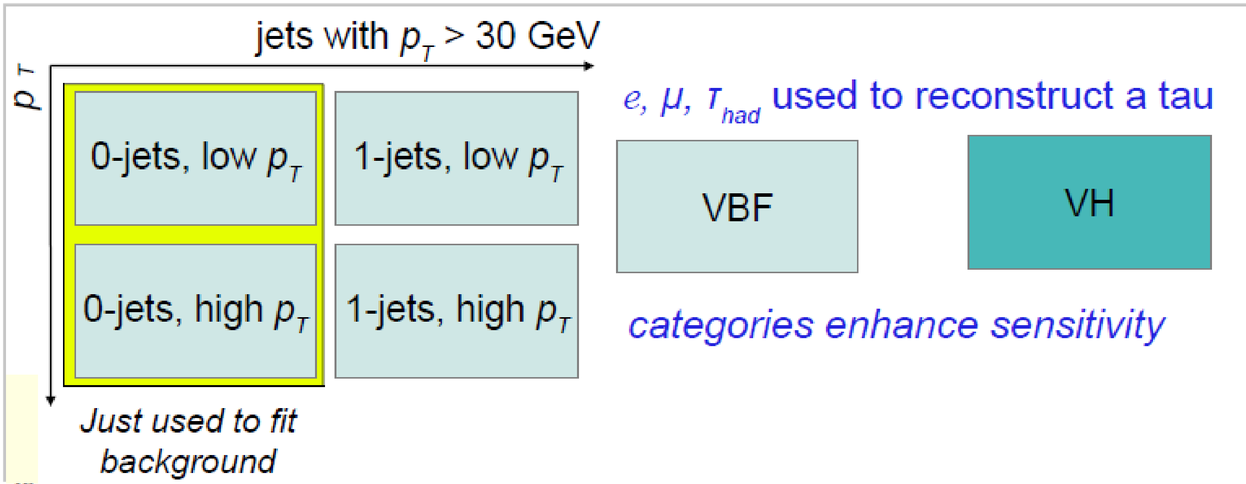
Combination of 3 production mechanisms

Search perfomed in $\mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$ decay modes

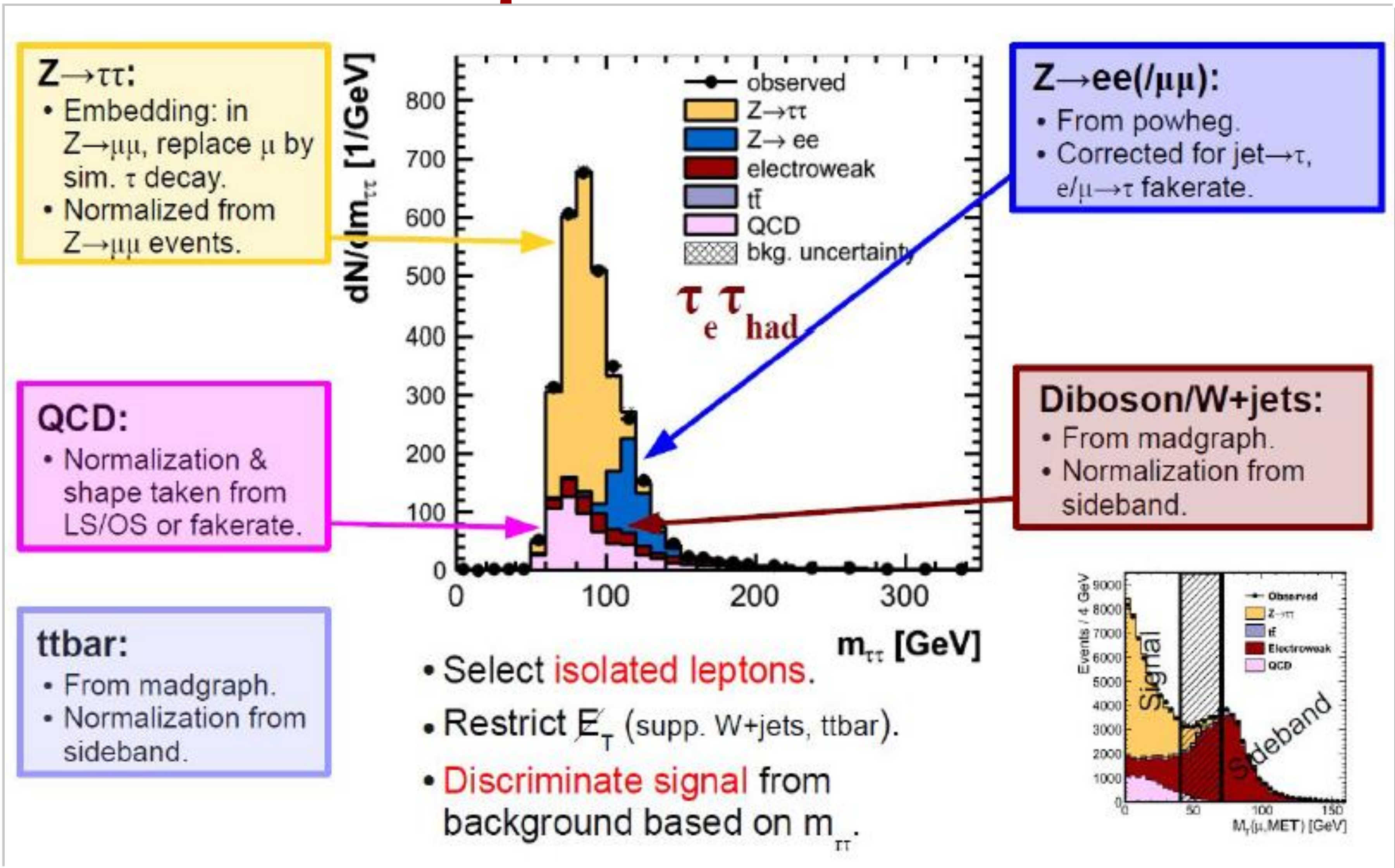


Characteristics

- High σ•BR at low mass
- Sensitive to all production modes
- Probes coupling to leptons
- Enhanced σ x BR in MSSM
- Challenging large bckgds:
  - DY→ττ, W+Jets, QCD



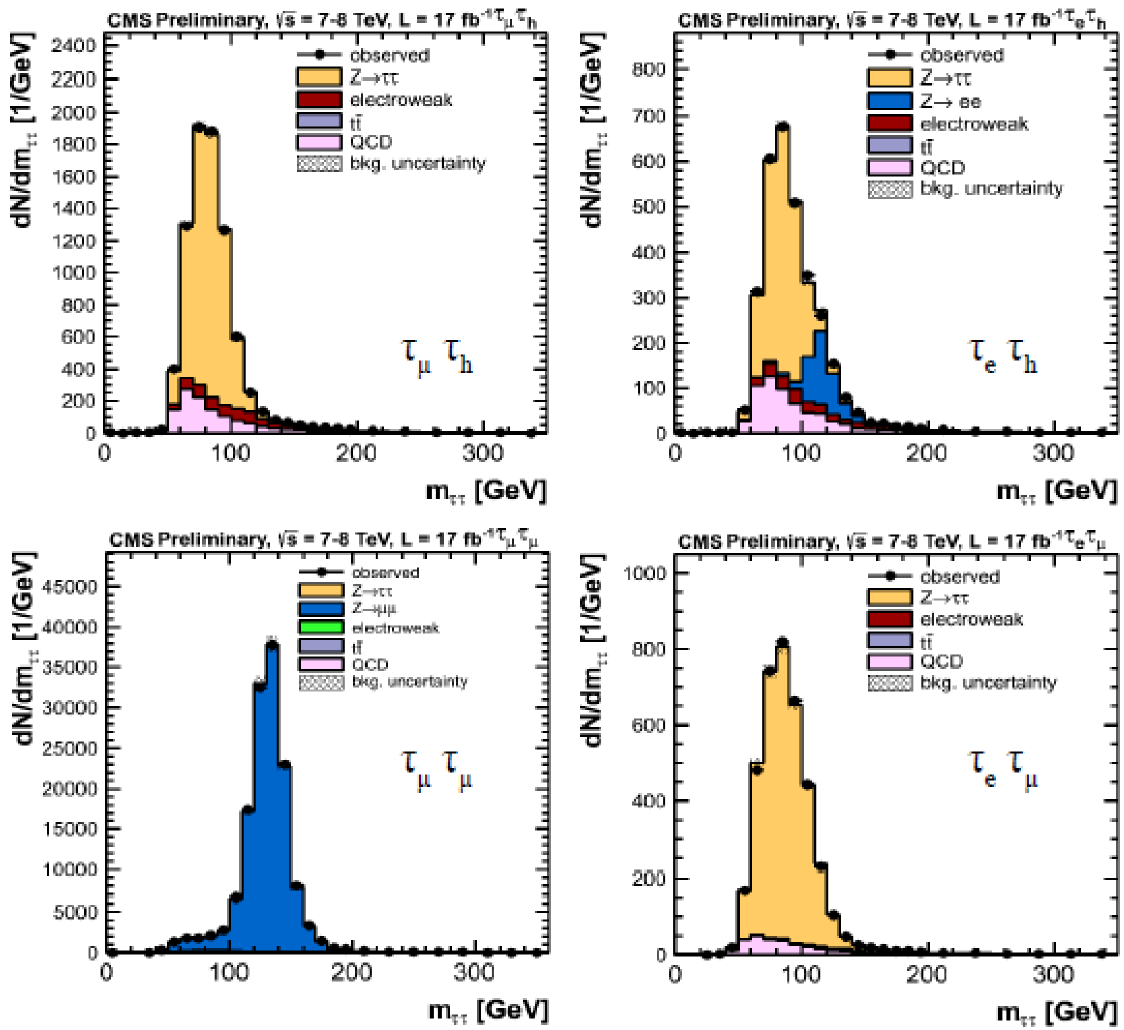
H→ ττ: Components



H→ ττ: 0-jet Category

Summary

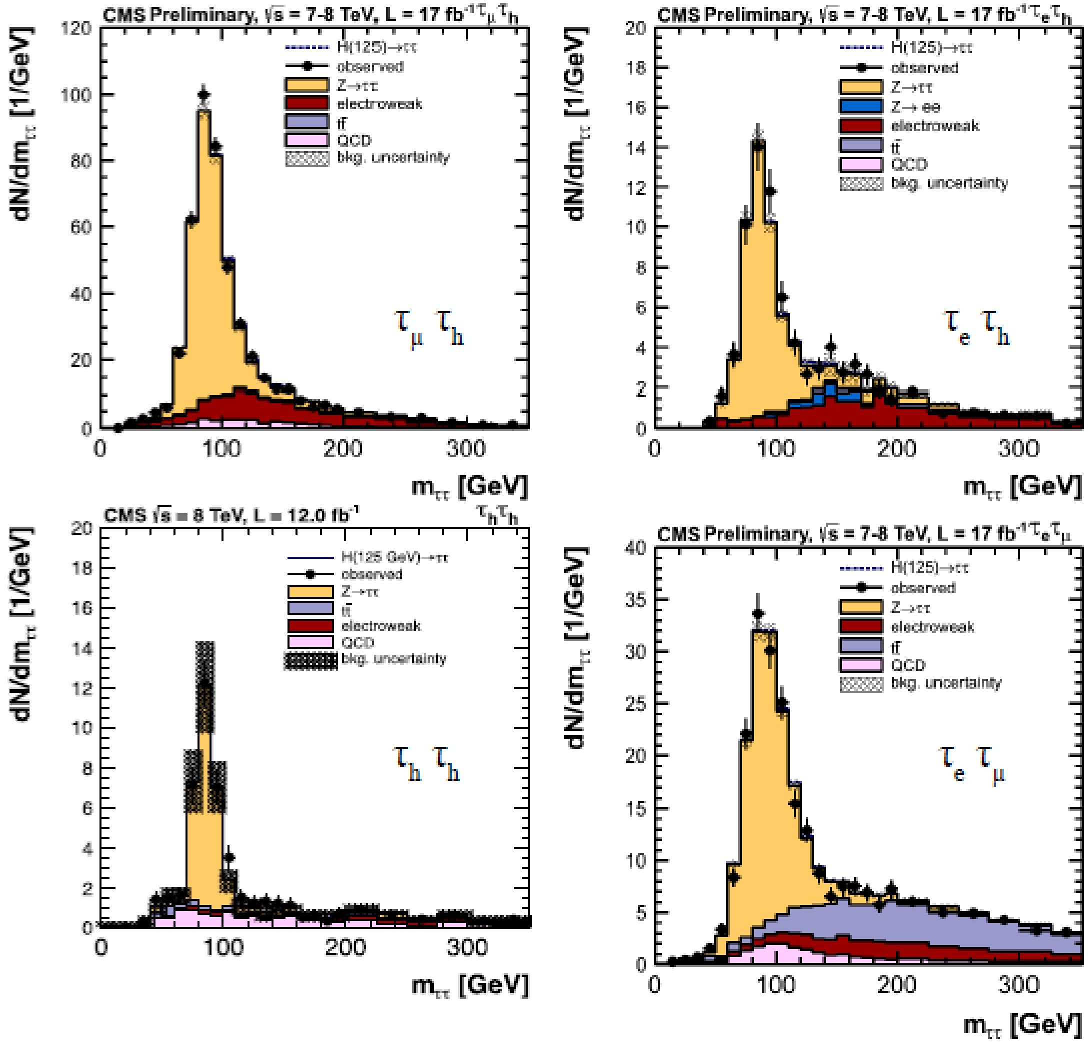
- most events go here
- minimal signal
- background fit only
- constrains background for all categories



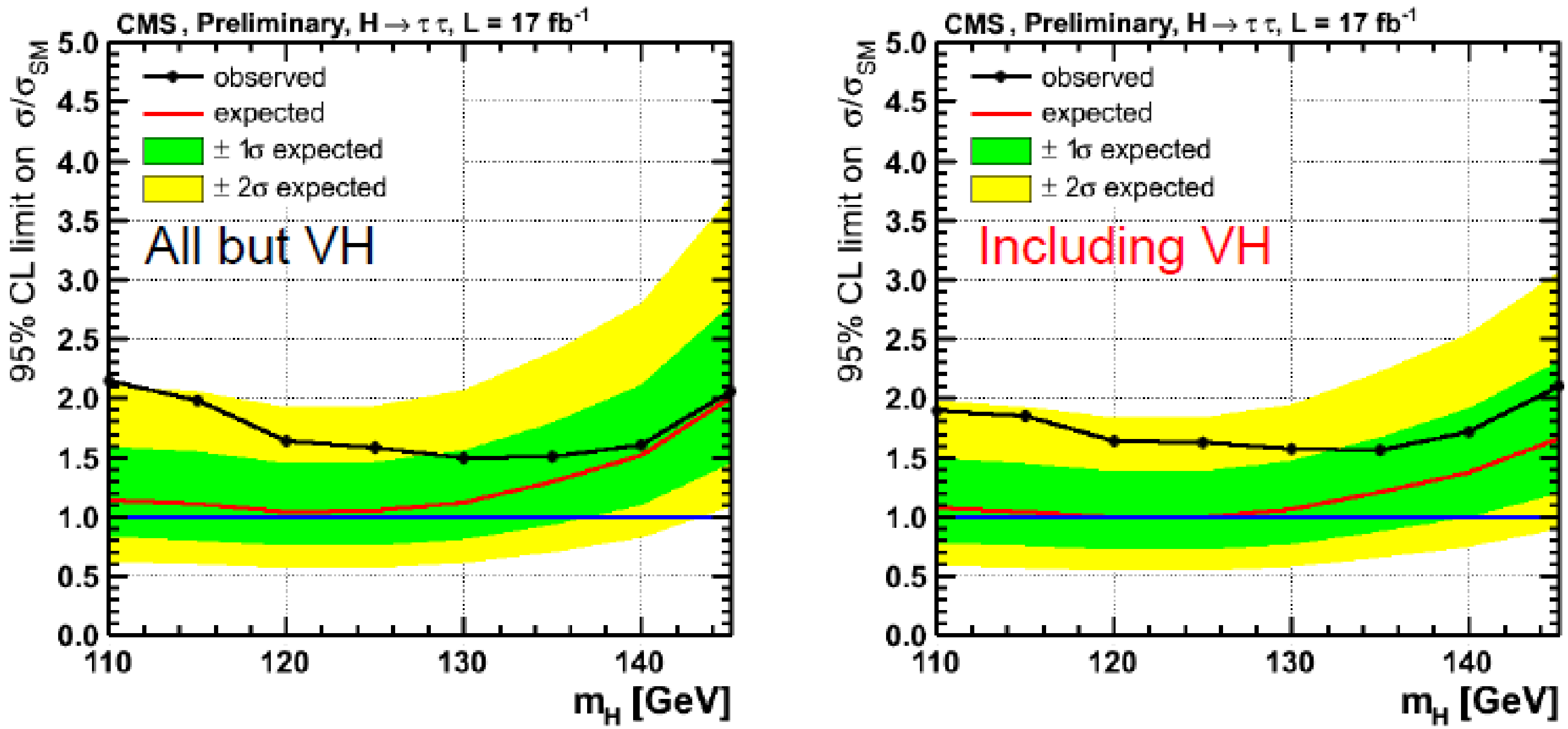
H→ ττ: 1-jet High p_T Category

Summary

- enhanced gluon fusion production
- Improved mass resolution



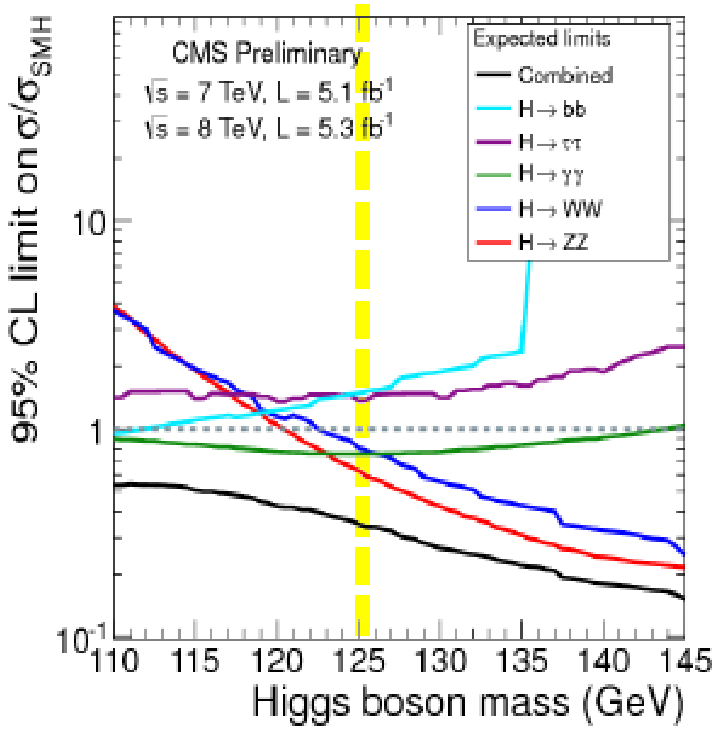
H→ ττ



Summary

- analysis made dramatic improvement – not just added data
- sensitivity ~1 times SM... very mild excess is building at 1.3 std

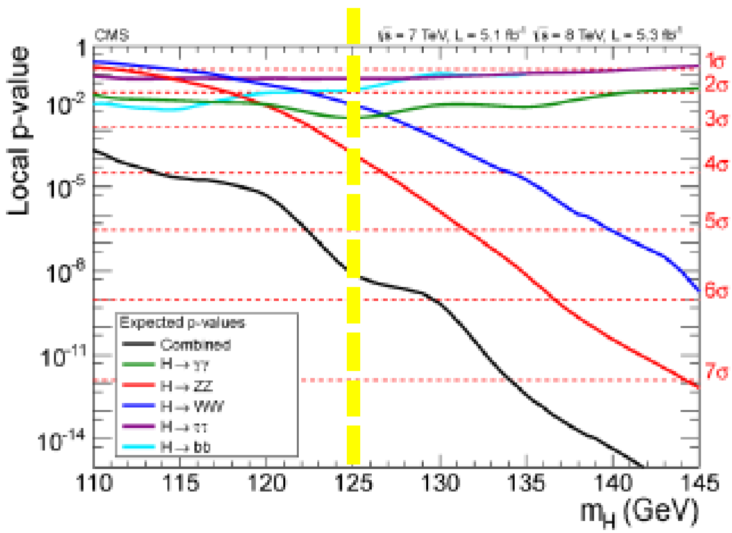
Combined Results



Decay	Prod. Topology	Luminosity
$H \to bb$	WH, ZH	5+5 fb^{-1} at 7+8 TeV
$H \to bb$	ttH	5 at fb^{-1} at 7 TeV
$H \to \tau\tau$	Inclusive + VBF	5+5 fb^{-1} at 7+8 TeV
$H \to \tau\tau$	WH, ZH	5 at fb^{-1} at 7 TeV
$H \to \gamma\gamma$	Inclusive + VBF	5+5 fb^{-1} at 7+8 TeV
$H \to WW$	0/1 jet + VBF	5+5 fb^{-1} at 7+8 TeV
$H \to WW$	WH, ZH	5 at fb^{-1} at 7 TeV
$H \to ZZ$	Inclusive	5+5 fb^{-1} at 7+8 TeV

- Most analyses using 5+5 fb^{-1}, many improved w.r.t. 2011
- Biggest combination done so far at CMS: 95 individual final states contributing at 125 GeV mass hypothesis!

Combined Results



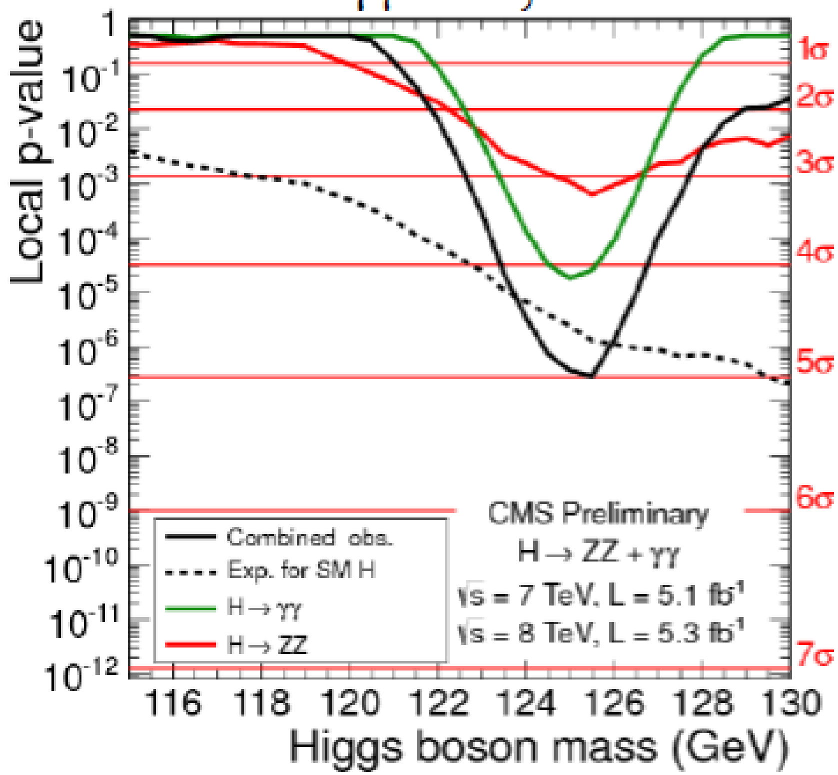
Decay	Prod. Topology	Luminosity
H→bb	WH, ZH	5+5 fb^{-1} at 7+8 TeV
H→bb	ttH	5 at fb^{-1} at 7 TeV
H→ ττ	Inclusive + VBF	5+5 fb^{-1} at 7+8 TeV
H→ ττ	WH, ZH	5 at fb^{-1} at 7 TeV
H → γγ	Inclusive + VBF	5+5 fb^{-1} at 7+8 TeV
H → WW	0/1 jet + VBF	5+5 fb^{-1} at 7+8 TeV
H → WW	WH, ZH	5 at fb^{-1} at 7 TeV
H → ZZ	Inclusive	5+5 fb^{-1} at 7+8 TeV

- Most analyses using 5+5 fb^{-1}, many improved w.r.t. 2011
- Biggest combination done so far at CMS: 95 individual final states contributing at 125 GeV mass hypothesis!

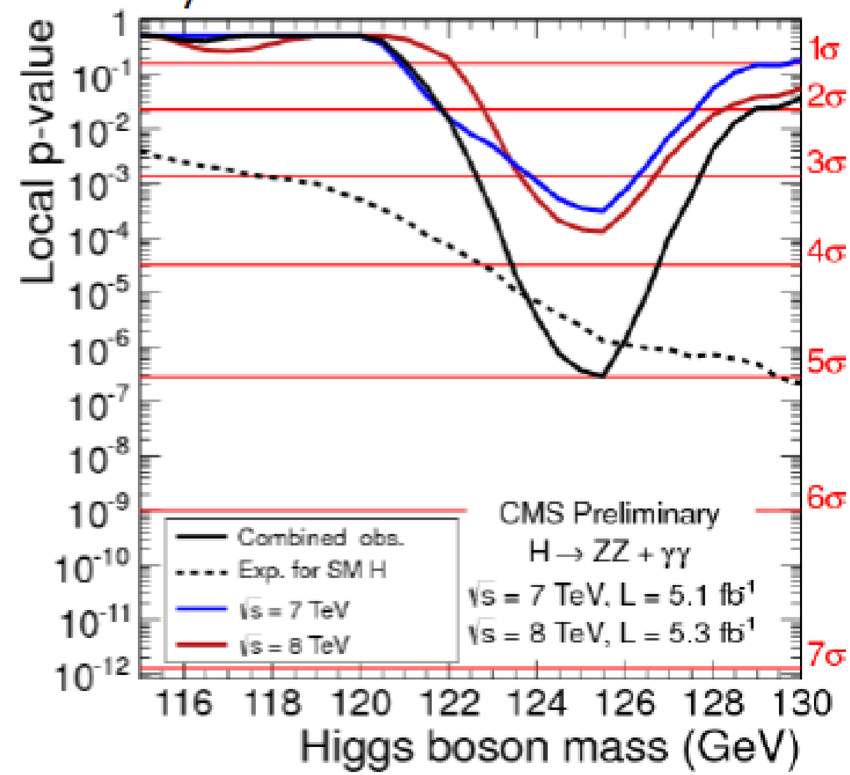
Combined Results ZZ + γγ

In high mass resolution channels, observe an excess with local significance of 5.0σ (expected from SM H: 4.7σ)

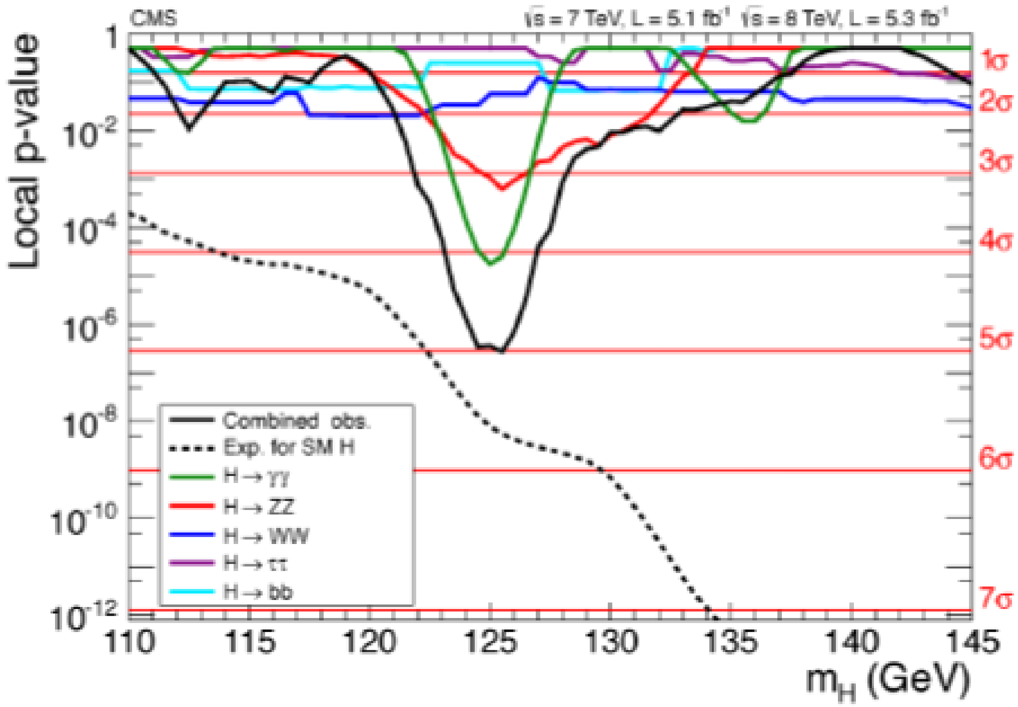
ZZ vs γγ decay mode



7 TeV data vs 8 TeV data



Combined Results all channels



Local significance of excess: **4.9 σ**

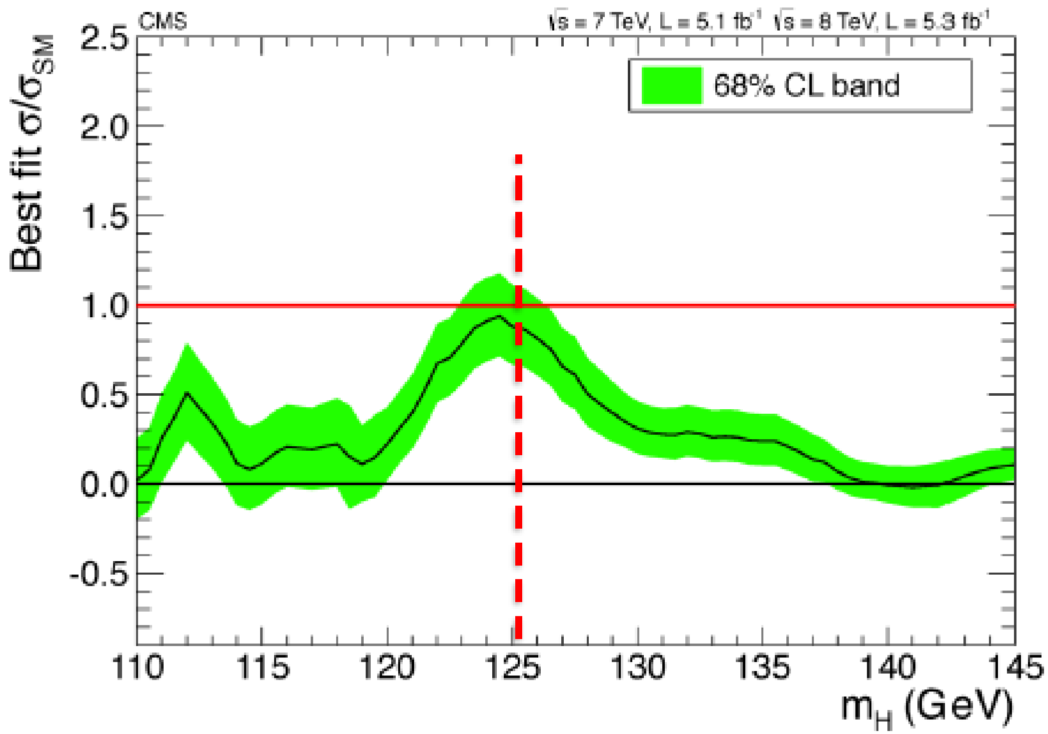
Expected for SM Higgs signal: **5.8 σ**

Global significance > 4σ

Decay mode/combination	Expected (σ)	Observed (σ)
$\gamma\gamma$	2.8	4.1
ZZ	3.6	3.1
$\tau\tau$ + bb	2.4	0.4
$\gamma\gamma$ + ZZ	4.7	5.0
$\gamma\gamma$ + ZZ + WW	5.2	5.1
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	5.8	5.0

We interpret this excess as the observation of a new boson with mass around 125 GeV.

Combined Results all channels

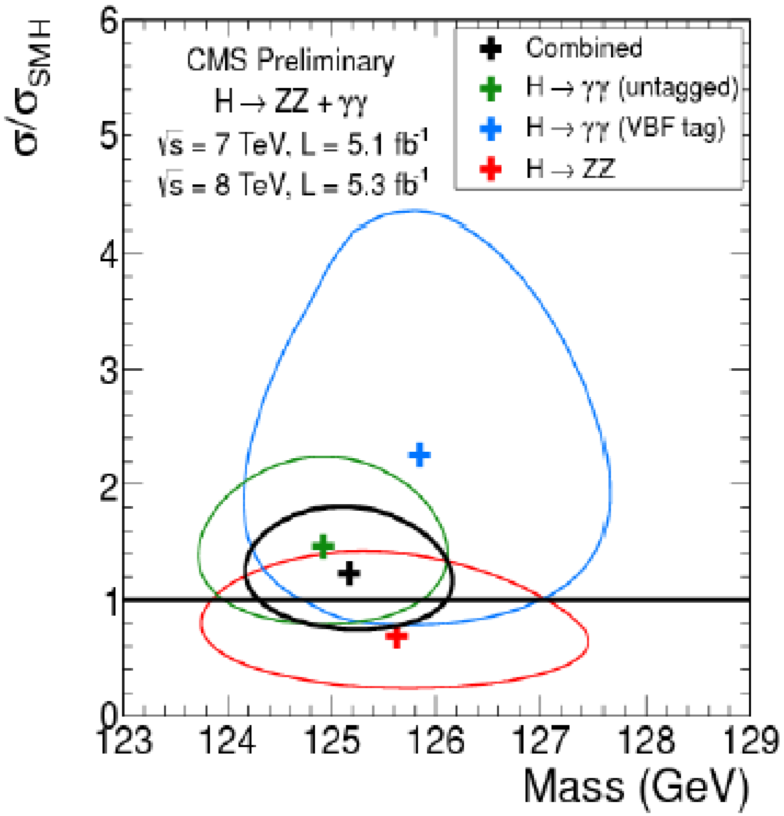


Best fit signal strength at mass 125 GeV:

$(0.87 \pm 0.23) \times \sigma_{SMH}$

Compatible with the expectations from a SM Higgs boson signal!

Mass of observed particle



- Likelihood scan for mass and signal strength in three high mass resolution channels:
  - ZZ 4l
  - γγ untagged
  - γγ with di-jet tag
- Results are compatible within the uncertainties

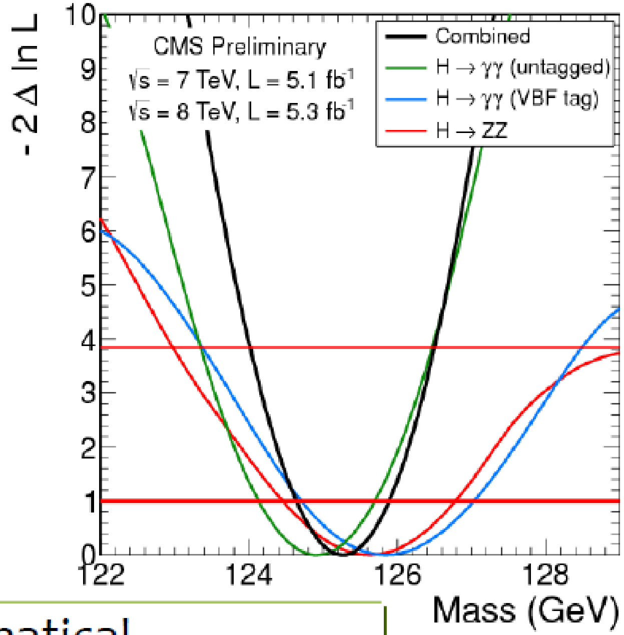
Mass of observed particle

- Perform a fit of the mass with freely floating signal strength for the three final states, to minimize model dependence.

  M = 125.3 ± 0.6

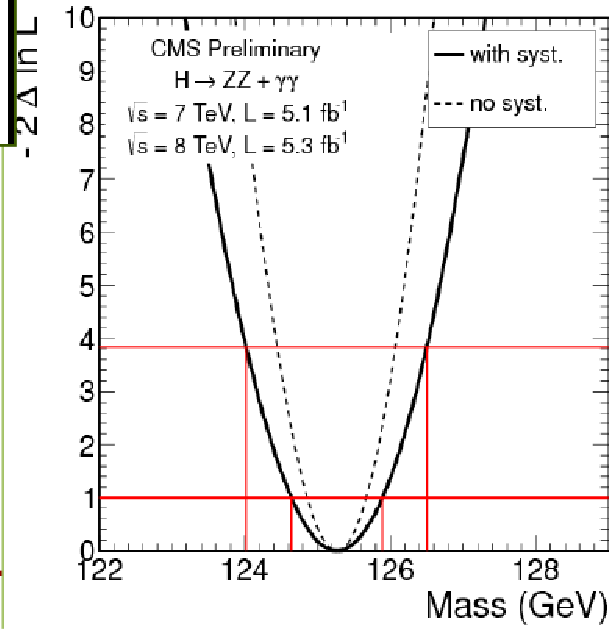
- Ultimate precision:

  σ_m < 100 MeV



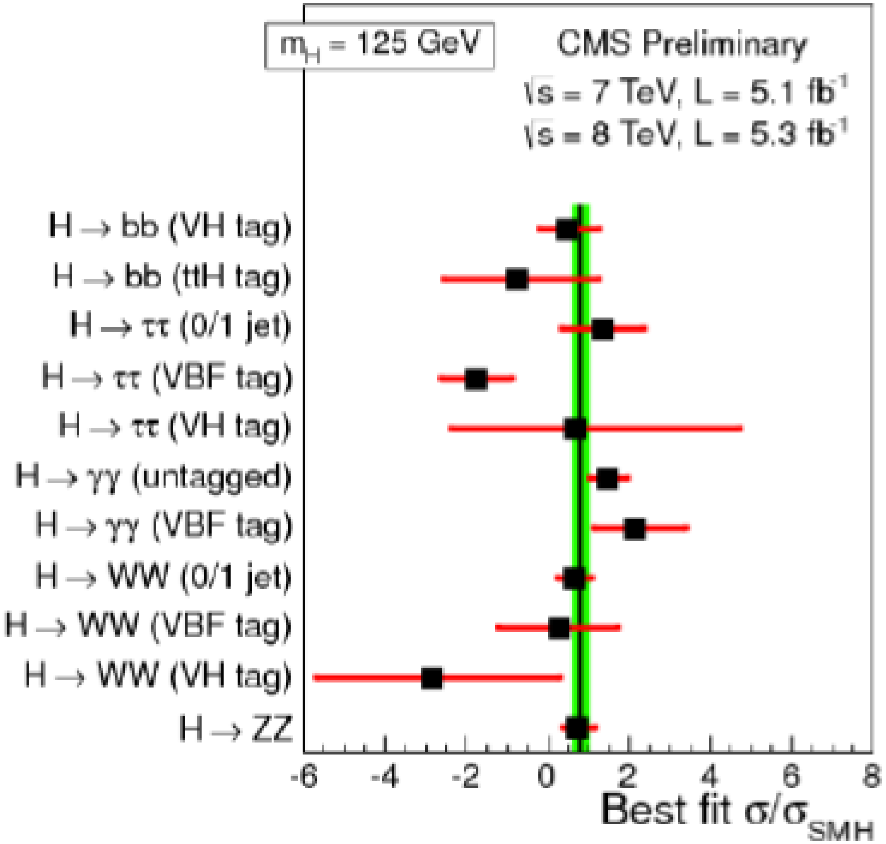
Systematical uncertainty on the mass driven by energy scale uncertainty in γγ: now conservative estimate ~0.5%, will improve in the future.

M = 125.3 ± 0.4 (stat.) ± 0.5 (syst.)



Is it the SM Higgs boson?

- Observed signal stength in the analzyed decay modes and production topologies compatible with a SM Higgs
- However, with the present data sample only few modes have sensitivity to a signal of SM strength.



Is it the SM Higgs boson?

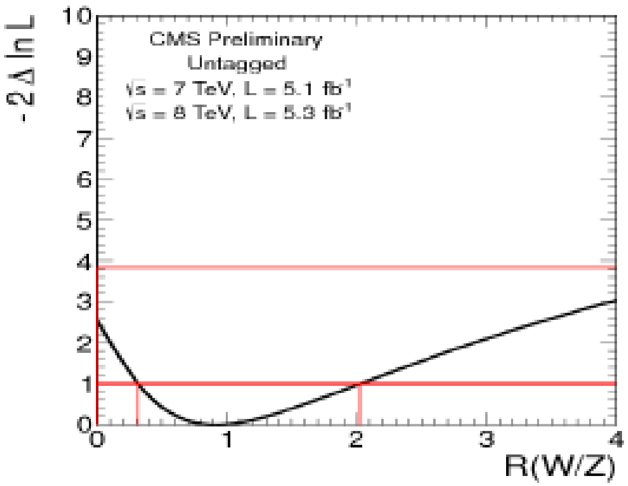
- **Test of custodial symmetry: compare the signal strength observed in WW and ZZ modes.**
- Fit the the ZZ and WW (0/1 jet) data assuming:

$$\sigma\times BR_{H\to ZZ} = \mu_{ZZ} \times [\sigma\times BR_{H\to ZZ}]_{SM\ Higgs}$$

$$\sigma\times BR_{H\to WW} = R_{W/Z} \times \mu_{ZZ} \times [\sigma\times BR_{H\to WW}]_{SM\ Higgs}$$

- Result compatible with SM within the large uncertainties

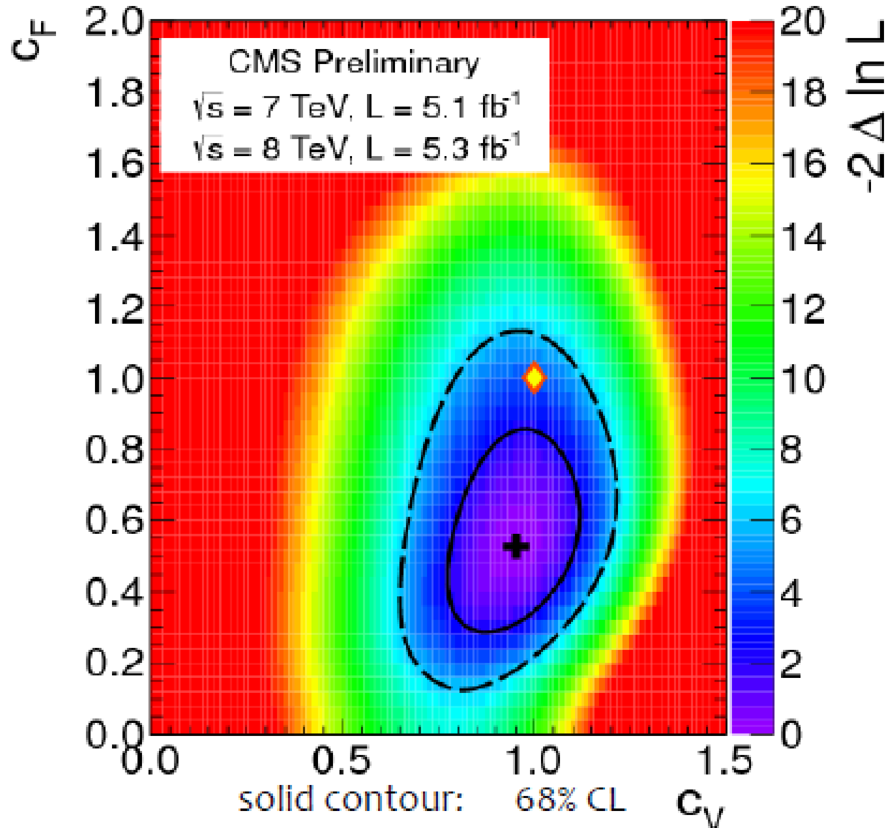
$$R_{W/Z} = 0.9^{+1.1}_{-0.6}$$



Is it the SM Higgs boson?

Test compatibility wrt. to SM predictions by introducing 2 parameters (C_V, C_F), couplings to v. bosons & fermions, and fit to observed results

- **CMS data compatible with SM prediction at 95% C.L.**
- Best fit c_F driven to low values by VBF γγ excess and ττ deficit.
- **More data needed to draw any definite conclusion.**
- LHC Cross Section WG also converging on an improved models for these kinds of fits.

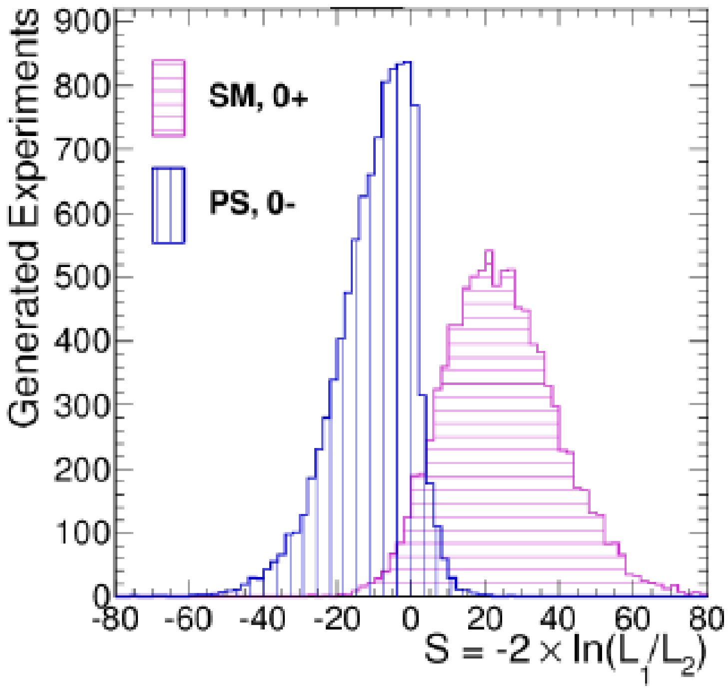


solid contour: 68% CL
dashed contour: 95% CL

Projections for J^{PC} measurements

$H \to ZZ \to 4l$

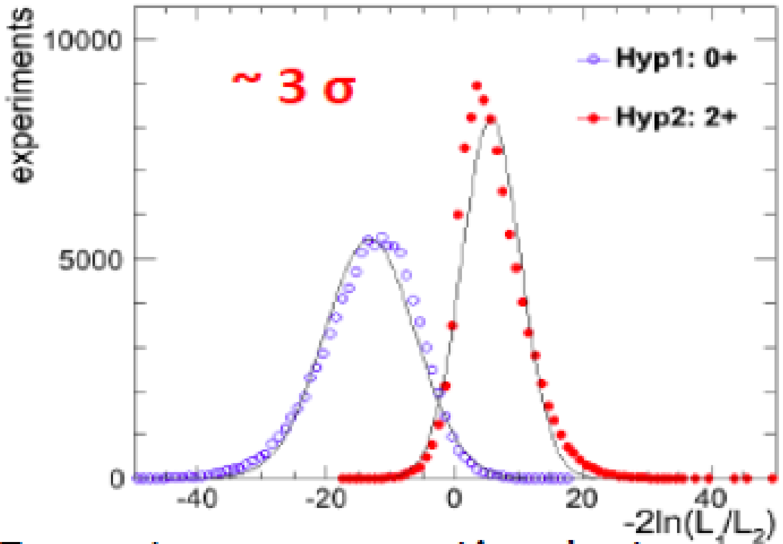
CMS Simulation L = 30 fb⁻¹, √s = 8 TeV



Expect ~3σ separation between scalar and pseudoscalar in 2012

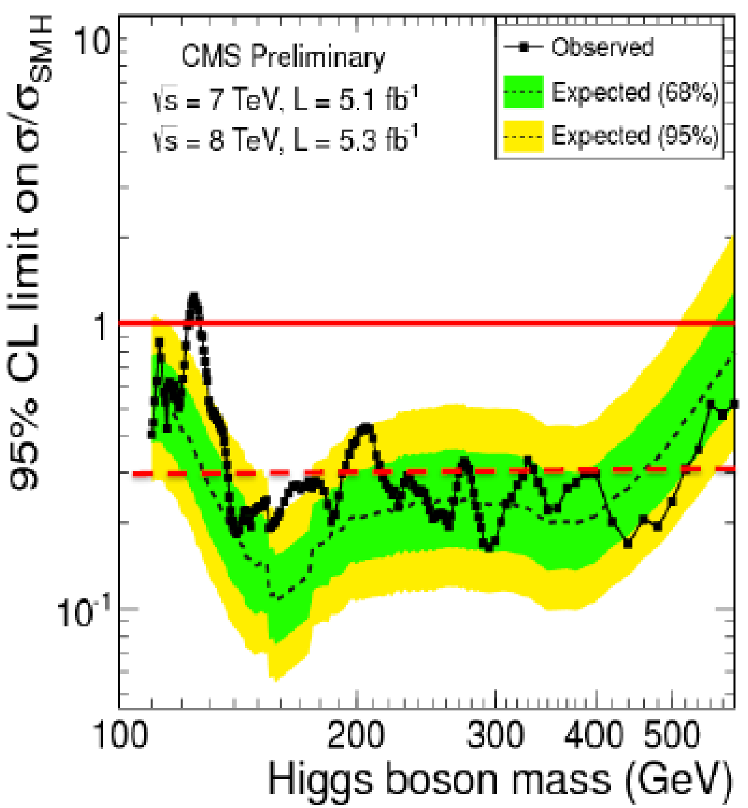
$H \to WW \to 2l2\nu$

JHU Generator level L = 10 fb⁻¹, √s = 8 TeV



Expect ~3σ separation between spin 0, 2 with 10 fb⁻¹ but assuming no systematics and WW as only background

Anything else anywhere?



- Stringent exclusion limits for any heavy Higgs-like boson decaying into WW and ZZ bosons:
- e.g. $\sigma \sim 0.3\times \sigma_{SMH}$ is excluded in most of the 140-500 GeV range.

CONCLUSIONS

- LHC, CMS (and ATLAS) are performing extremely well in their 3rd of running, with a major battle with pile-up.

- A new particle (boson) has been observed, with a significance of 5.0 standard deviations, dominantly in the $\gamma\gamma$ and ZZ(4l) final state.
- Mass of the particle: $m_X = 125.3 \pm 0.6$ GeV
- Within the precision of these data, the observation is compatible with predictions for the SM Higgs boson signal, despite
    - large excess in $\gamma\gamma$ channel
    - deficit in bb and $\tau\tau$ modes

New results are to be presented by the end of this week in HCP Conference!!!

Next update foreseen for Moriond 2013 (March), followed by ~2 years LHC stop to increase collider energy (~14 TeV).

REFERENCES

Further info

- CMS Higgs results twikipage

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

- CMS Seminar at CERN on 4th July

https://cms-docdb.cern.ch/cgi-bin/PublicDocDB/ShowDocument?docid=6125

- CMS talks at HCP 2012 Conference

http://www.icepp.s.u-tokyo.ac.jp/hcp2012/