Results on Low Mass Higgs Searches with LHC

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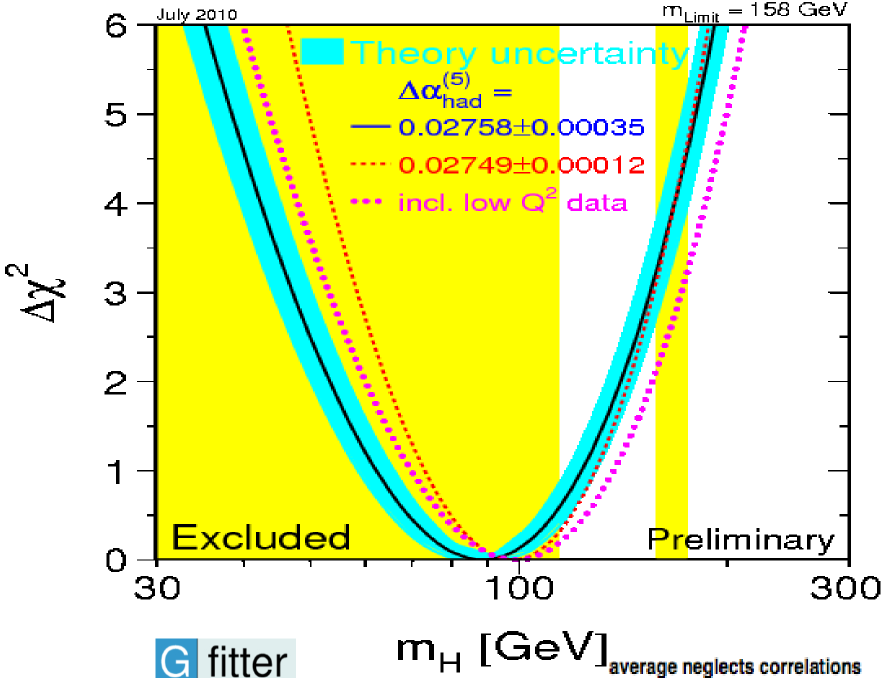
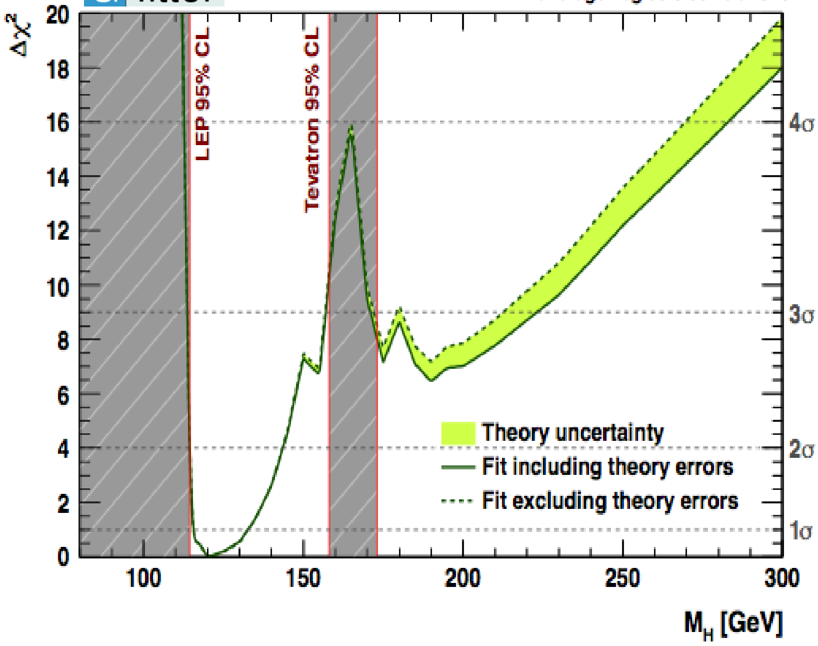
Outline:
- Introduction
- Channel-by-channel results
- Combined result

Introduction

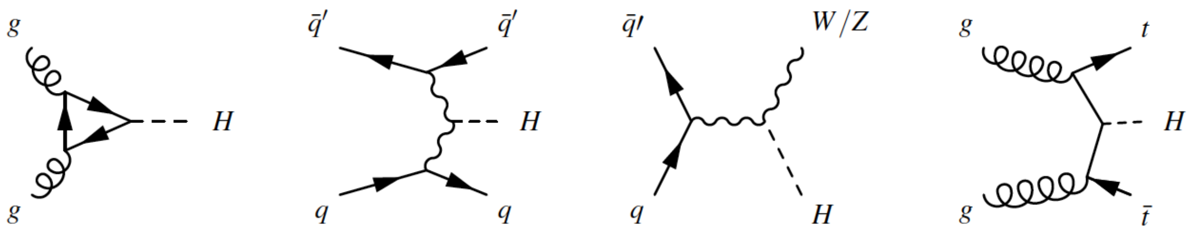
- Light Higgs favoured by precision electroweak tests
  - Light Higgs defined traditionally by m_H<~140 GeV/c^2 (< 2×m_W)
- EW loop correction sensitive on log(m_H)
  - m_H can be obtained from global fit to EW precision measurements
  - m_H of best fit w/o constraints from direct searches: ~**100 GeV/c^2**
  - m_H of best fit w/ constraints from direct searches (LEP&TeV'10): ~**120 GeV/c^2**



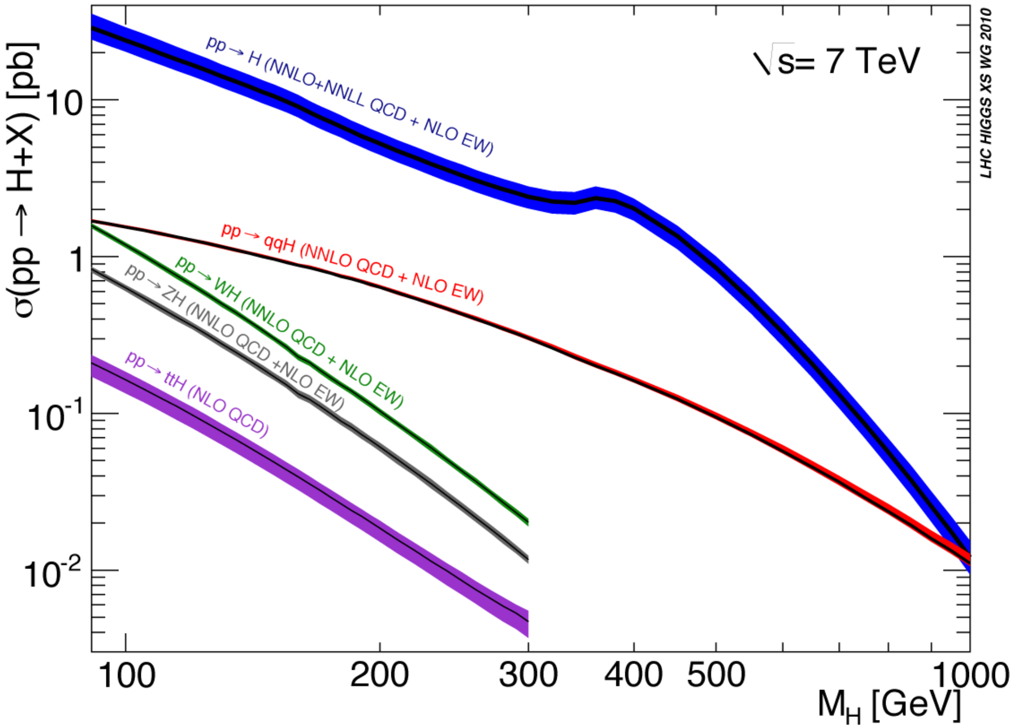


Higgs production at LHC

- Dominant production mode is the gg→H
  - Backgrounds mostly produced in qq annihilation ⇨ usually better S/B ratio than in Tevatron at Fermilab
- VBF and VH production modes
  - Cross-section smaller 10 times than gg→H (VH for light Higgs)
  - Useful thanks to additional signatures (jets, leptons); important, esp. for low mass searches

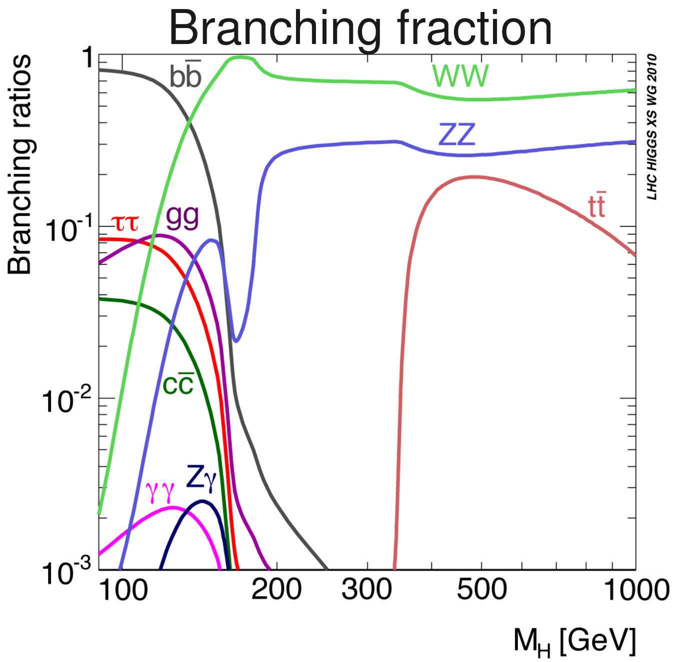


(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$

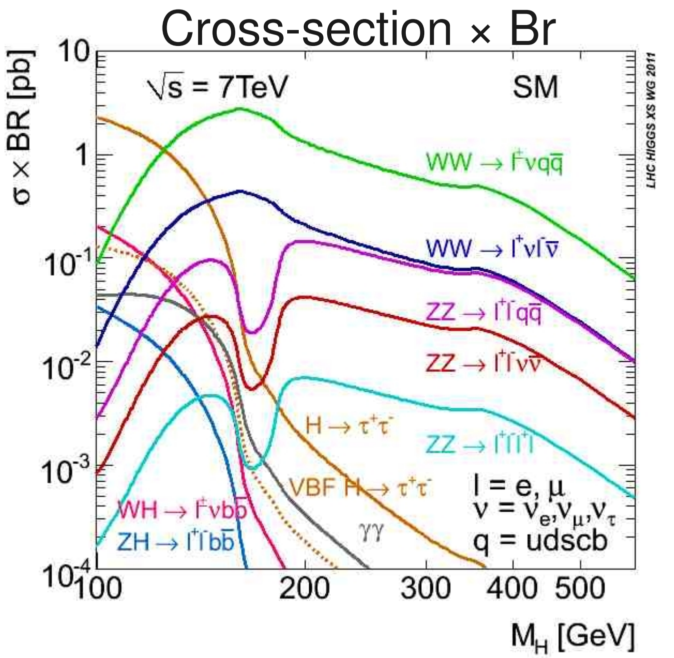


Higgs decay modes

- Decay modes considered in search for Higgs boson determined by σ×Br and S/B
  - S/B disfavours fully-hadronic channels like inclusive H→bb
  - Final states with leptons and providing good mass resolution preferred (e.g. H→γγ/H→4l)
  - Low mass range ($m_H < 2\times m_W \sim 140$ GeV/c^2) more difficult that high mass one

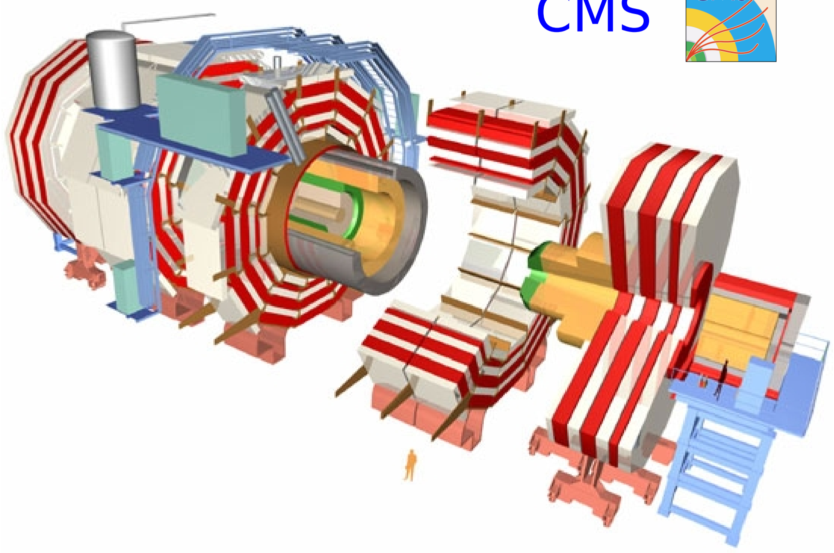


- Several decay modes considered to explore the low mass range
  - The flagship: **H→γγ**
  - The robust: **H→ττ** (both ggF and VBF)
  - The difficult: **V(H→bb)**
  - Others, usually considered for heavy Higgs
    - The powerful: **H→WW→2l2ν**
    - The golden-plated: **H→ZZ→4l**

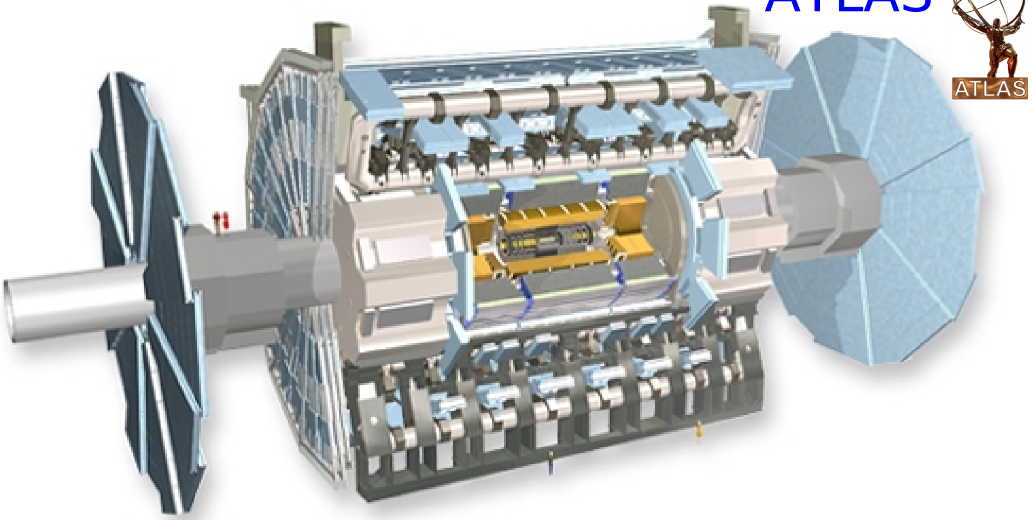


The LHC experiments

CMS



ATLAS



Tracking $|\eta|<2.5$, B=3.8T

- Si pixels and strips

  $\sigma/pT \approx 1.5 \cdot 10\text{-}4pT \oplus 0.005$

Calorimetry $|\eta|^{EM}<2.5$, $|\eta|^{HAD}<5$

- EM: homogeneous $PbWO_4$ crystals

  $\sigma/E \approx 2.8\%/\sqrt{E} \oplus 12\%/E \oplus 0.3\%$
- HAD: Cu-Zn/scint. + Fe/Quartz

  $\sigma/E \approx 100\%/\sqrt{E} \oplus 0.05$

Muon Spectrometer $|\eta|<2.4$

- Solenoid return yoke instrumented (B=2T) DT/RPC + CSC/RPC

Tracking $|\eta|<2.5$, B=2T

- Si pixels and strips
- Transition radiation detector

  $\sigma/pT \approx 5 \cdot 10\text{-}4pT \oplus 0.01$

Calorimetry $|\eta|<5$

- EM: sampling; Pb/LAr accordeon

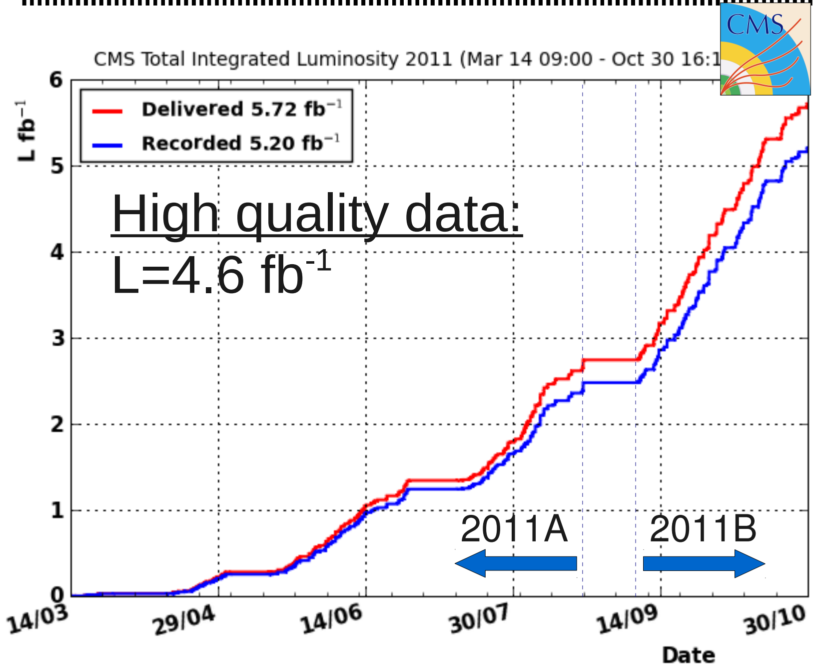
  $\sigma/E \approx 10\%/\sqrt{E} \oplus 0.007$
- HAD: Sampling Fe/scint. + Cu-W/LAr

  $\sigma/E \approx 50\%/\sqrt{E} \oplus 0.03$

Muon Spectrometer $|\eta|<2.7$

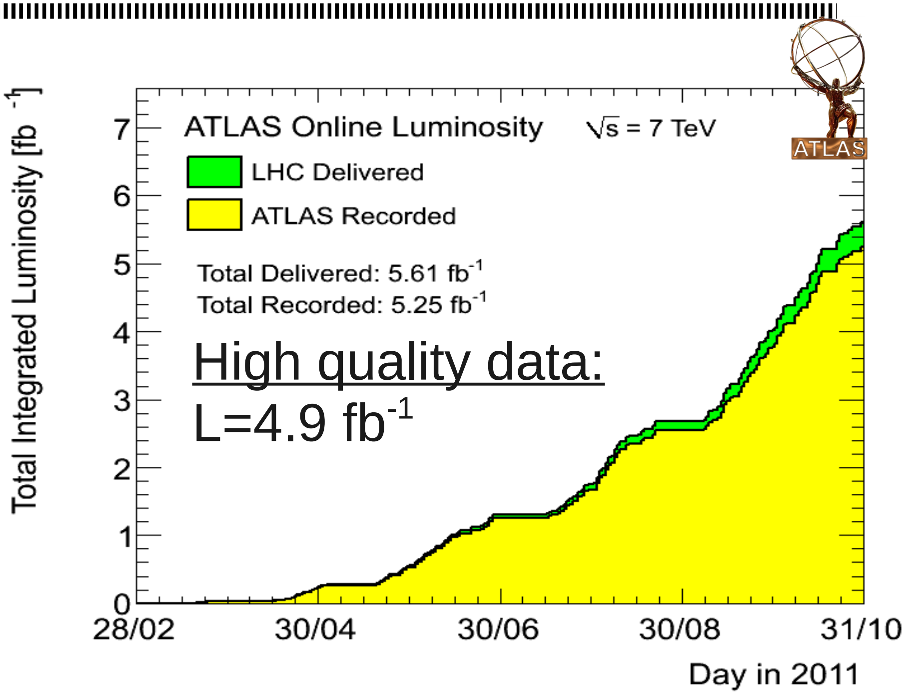
- Air-core toroids with muon chambers

Analysed dataset



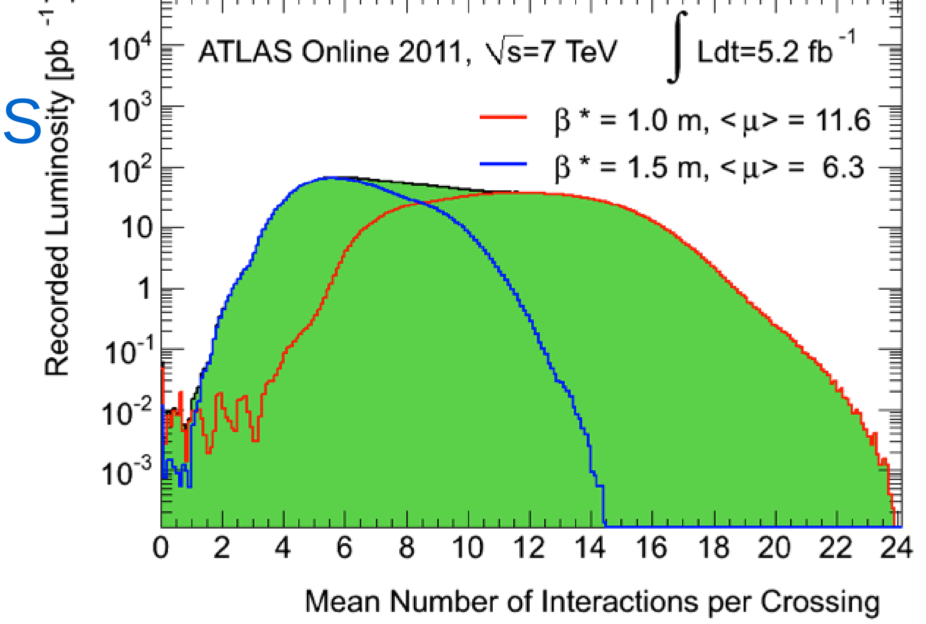
High quality data:
L=4.6 fb^{-1}

2011A
2011B



High quality data:
L=4.9 fb^{-1}

- **L = 4.9 fb^{-1}** of high quality data by ATLAS
  - Not all analysis with full dataset
- **L = 4.7 fb^{-1}** of high quality data by CMS
  - All analyses with all data
- Extreme increase of inst. luminosity
  - $2 \times 10^{32} \Rightarrow 4 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Challenging for trigger system
  - Important pile-up (up to ~20)



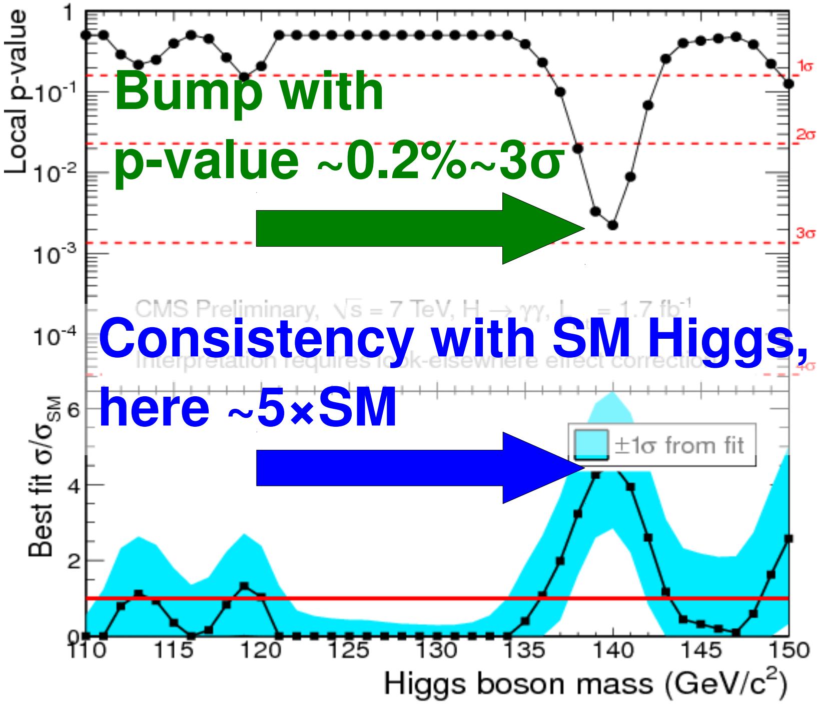
Bumps & LEE

The look-elsewhere effect (LEE) is significant in Higgs searches

- Higgs mass is unknown a priori
- Each channel represents many effective measurements (⇨ trial factor)
- If errors are correctly estimated, ~2% of measurements will fluctuate up by 2σ or more ⇨ bumps are expected!

Resolution is the key parameter

- For a given search window: higher resolution ⇨ larger LEE
- Local p-value plot will show features with frequency driven by resolution
- LEE for channels with high resolution O(10-100)



Bump with p-value ~0.2%~3σ

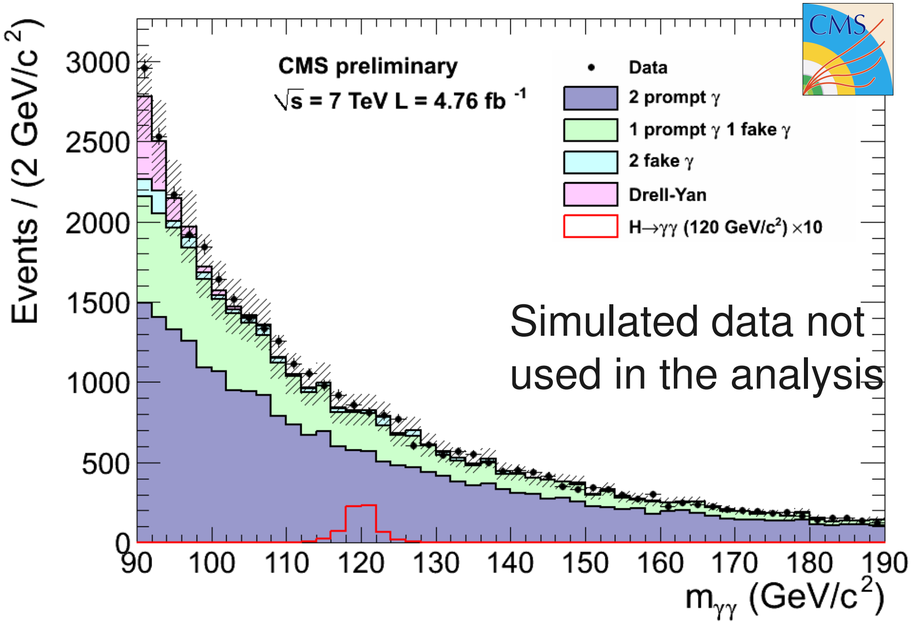
Consistency with SM Higgs, here ~5×SM

- LEE: $p^{global} \sim p^{min} + N_0 \exp(-Z^2_{max}/2)$

where N_0 – no. of crossing of $q_0^{obs}(m_H)$ over low threshold line: $q_0(m_H) = 0$

The flagship: $H\rightarrow\gamma\gamma$

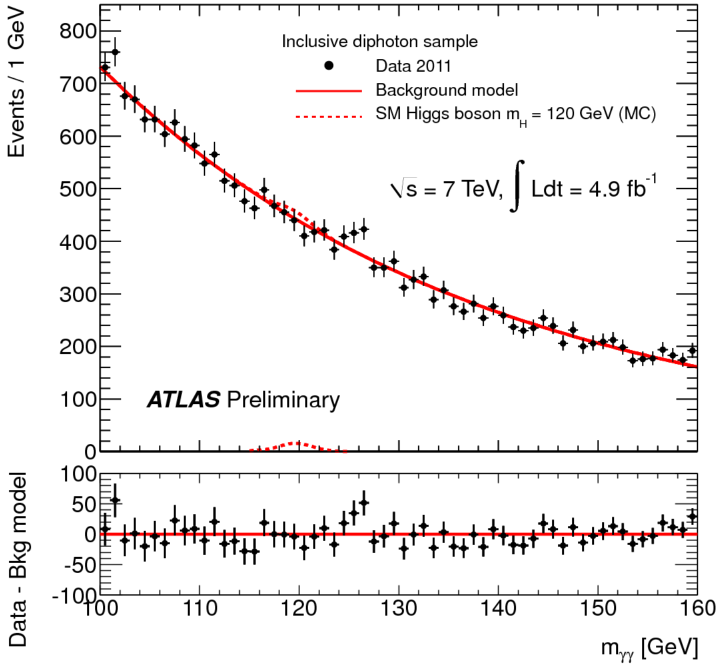
- **The most sensitive channel at low masses despite a small branching fraction** ($1\text{-}2\times10^{-3}$)
  - Signature: narrow peak in distribution of di-photon mass (resolution ~2-3%)
  - **Discovery potential**
- High non-resonant background
  - Background normalisation from m(γγ) sidebands
  - Potential of the channel depends on di-photon mass resolution ⇒ **excellent precision of ECAL crucial** for the search

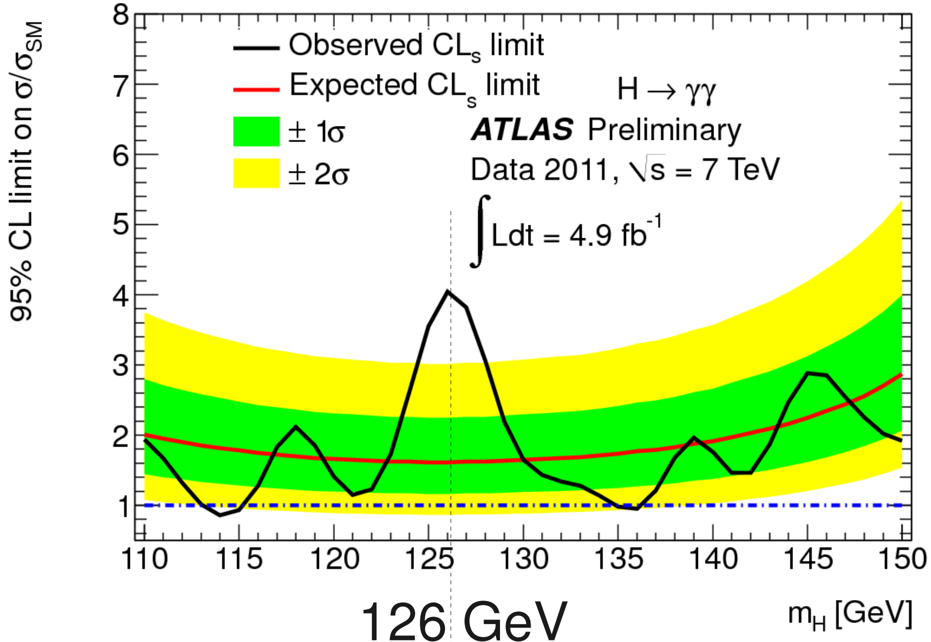


Simulated data not used in the analysis

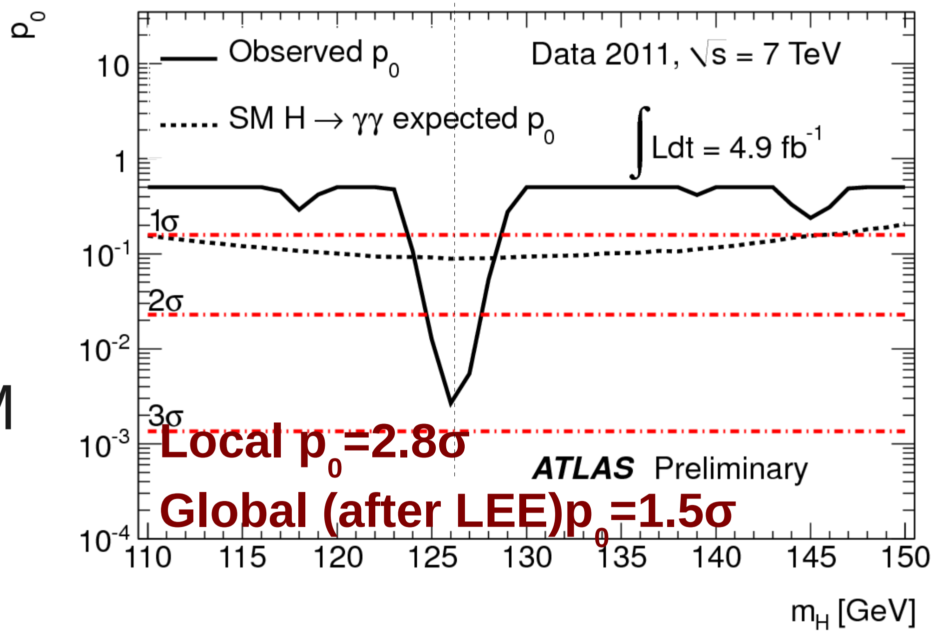
- Sample divided on categories basing on m(γγ) resolution (different photon categories)
  - ATLAS: 9 categories (unconv/conv)x(2 central/rest)x(p_{Tt}(γγ)>40/<40GeV)+(conv&transition)
  - CMS: 4 categories (unconv/conv)x(2 barrel/rest)
- Background: exponential (ATLAS) or 5th order polynomials (CMS)
- Signal: Crystal Ball + Gauss (ATLAS) or 3 Gausses (CMS) resolution determined with Z → ee data

H → γγ: ATLAS results





126 GeV



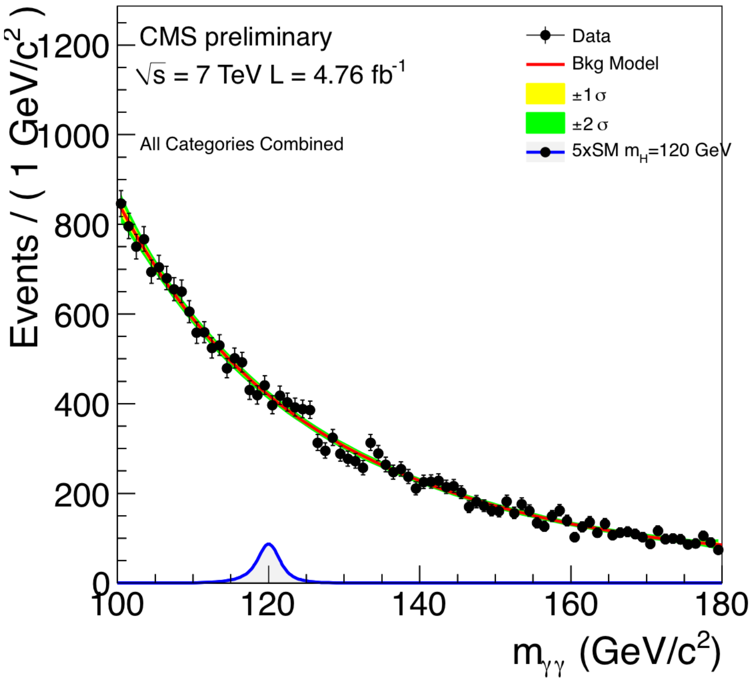
Local p_0=2.8σ

Global (after LEE)p_0=1.5σ

- Distribution of m(γγ) for all categories
- Signal (SM, m_H=120 GeV/c^2) drown to illustrate resolution

◎ **No significant excess is found** (L = 4.9 fb^{-1})
  - Expected exclusion: 1.6-1.8xSM
  - **Observed exclusion between 114-115 and 135-136 GeV/c^2**

H → γγ: CMS results

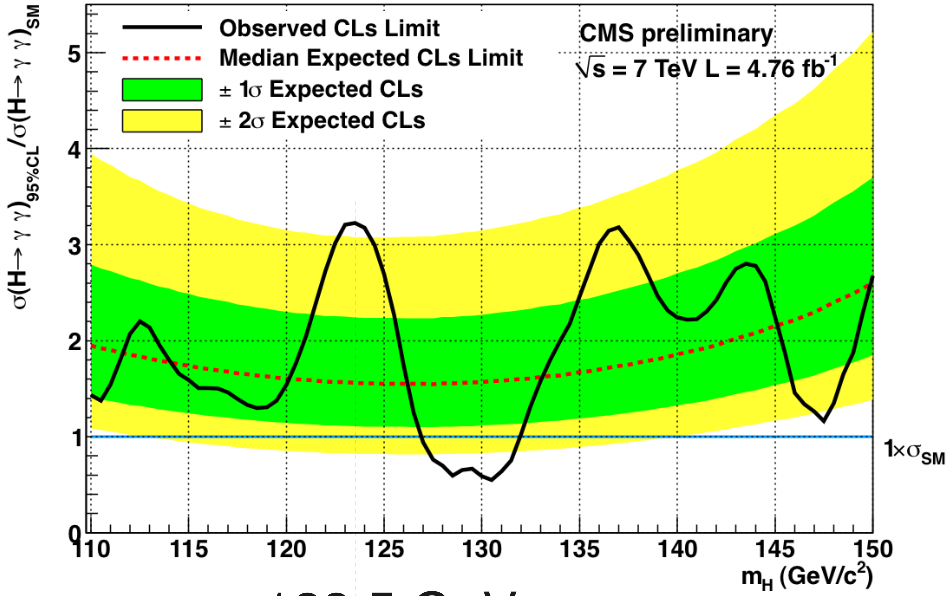


- Distribution of m(γγ) for all categories
- Signal (5×SM, m_H=120 GeV/c^2) drown to illustrate resolution

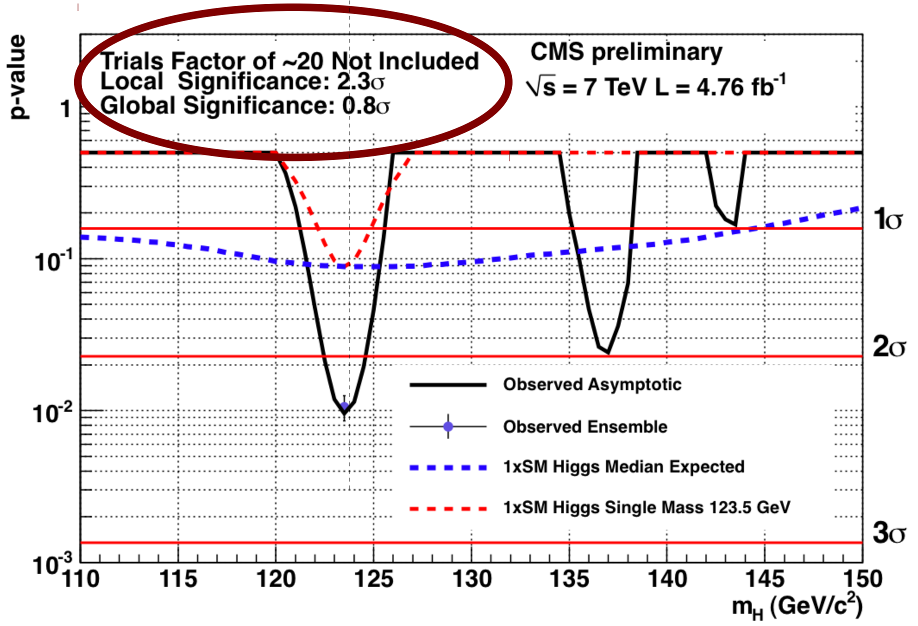
◎ **No significant excess is found** (L = 4.7 fb^{-1})

  ○ Expected exclusion: 1.6-2xSM

  ○ **Observed exclusion between 129-132 GeV/c^2**

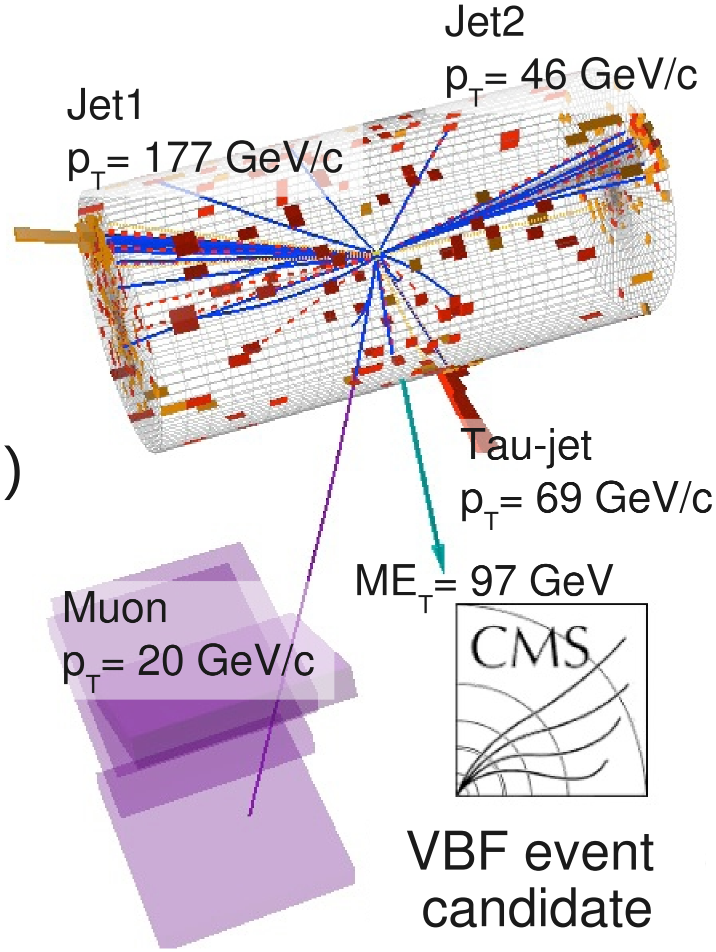


123.5 GeV



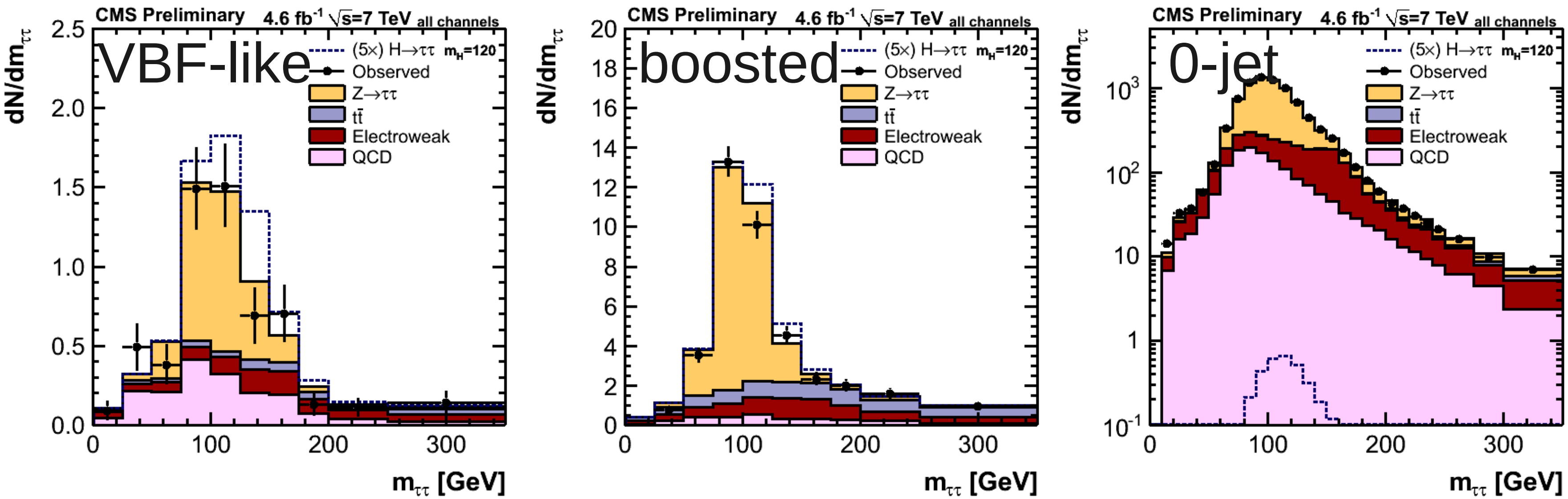
The robust: H → ττ

- **Sensitive** channel at low masses thank to **reasonably high branching fraction** (5-10%)
  - Signature: peak in distribution of di-tau mass (resolution ~20%)
- Many decay modes explored
  - $\mu+\tau_h$: high BR, golden channel
  - $e+\tau_h$: high BR, more background than for $\mu+\tau_h$
  - $e+\mu$: low BR, but very clean
  - ATLAS only: $e+e$ & $\mu+\mu$: quite clean (DY → ll bkg)
- **CMS:** Full mass reco, selection in categories
  - VBF (leads sensitivity of the search):
    - 2 jets $p_T > 30$ GeV/c, $|n| < 4.5$
    - $\eta_{j1} \times \eta_{j2} < 0$, $\Delta\eta_{jj} > 4$, $M_{jj} > 400$ GeV/c^2
  - “Boosted”
    - 1 jet $p_T > 150$ GeV/c, $|n| < 4.5$
  - “0 jet” (complementary to above):
    - Adds some sensitivity, helps to constrain bkg



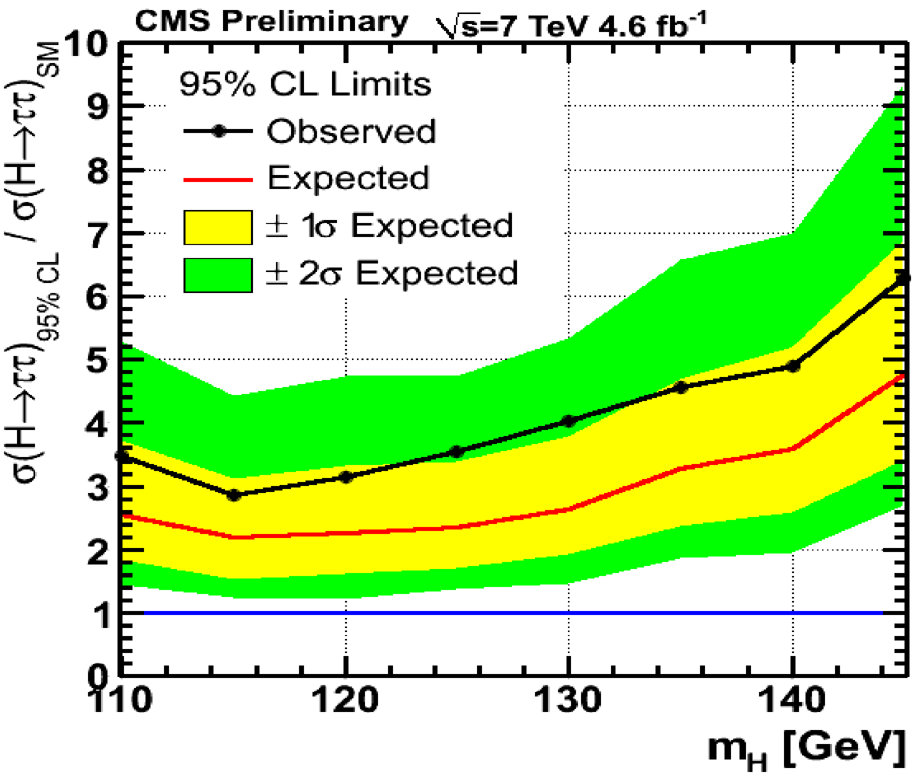
VBF event candidate

H → ττ: CMS results



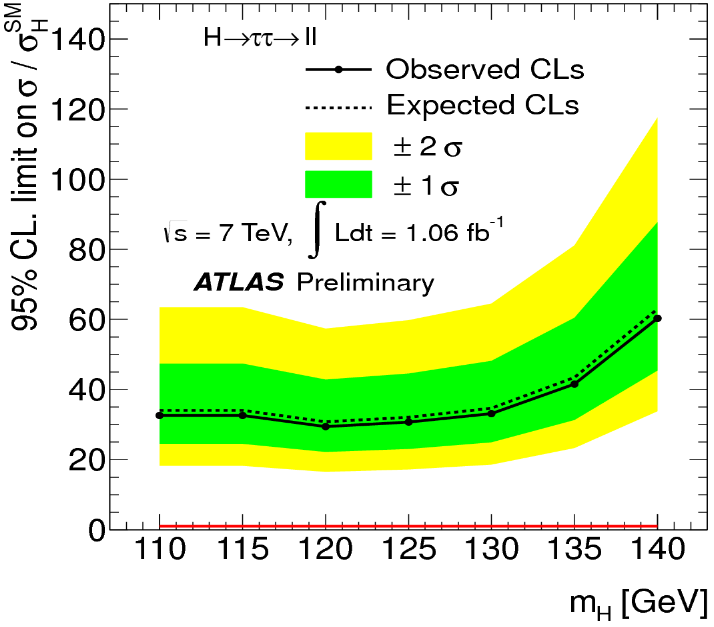
- Distribution of m(ττ) with SVFit algorithm
- Signal (5xSM, m_H=120 GeV/c^2) drown to illustrate resolution

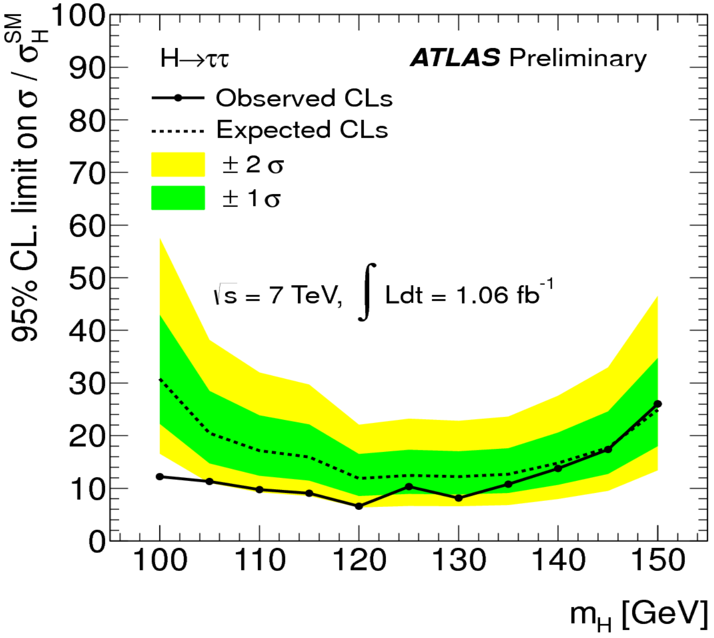
◎ Sensitivity 2.2-4.8×SM with 4.6 fb^{-1}
  - ○ Lead by VBF category
  - ○ No significant excess observed



H → ττ with ATLAS

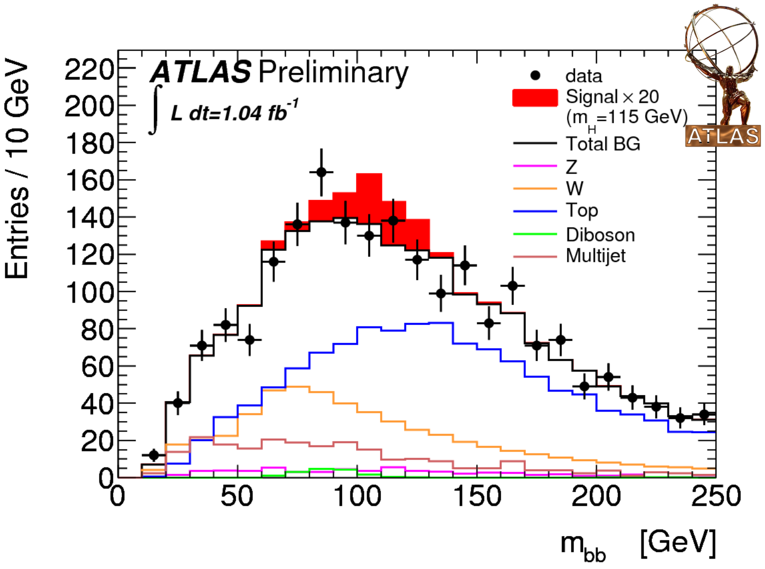
- Channels with two leptonically decaying taus
  - Two leptons
  - MET>20(30) GeV for 2e/2μ (eμ)
  - Jet p_T> 40 GeV 0.5 < |n| < 4.5
  - 30<m_{ll}<75(100) GeV for 2e/2μ (eμ)
  - 0.3<$\Delta\Phi_{ll}$<2.5(2.8) for 2e/2μ (eμ)
  - Mass with collinear approximation
  - Event counting within mass window 100-150 GeV
  - **Exclusion ~30xSM with L=1.1 fb^{-1}**
- Channels with l+τ_h
  - Inclusive l+τ_h selection
  - Mass reconstructed with MMC algorithm
  - Z → ττ background modelled with Z → μμ embedding technique
  - **Exclusion ~10-15xSM with L=1.1 fb^{-1}**

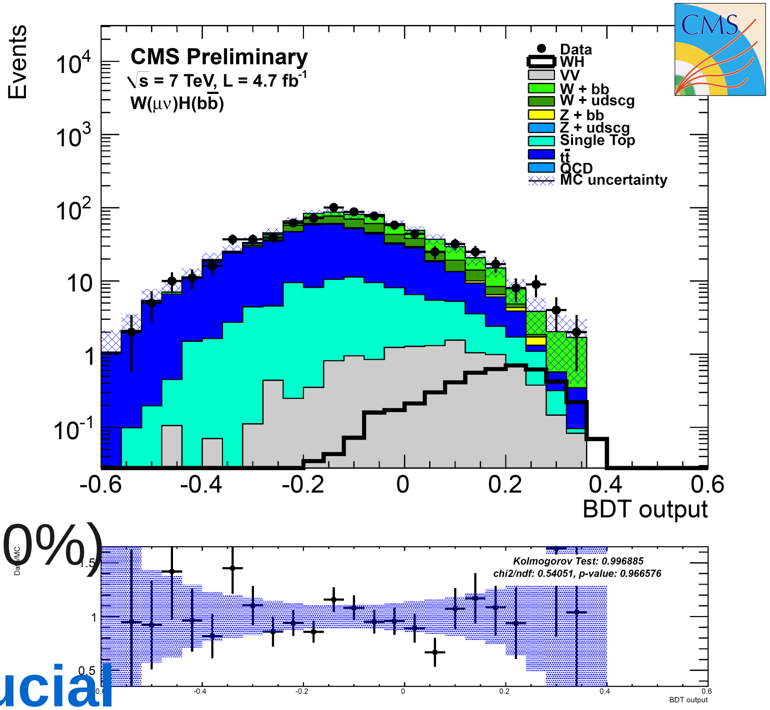




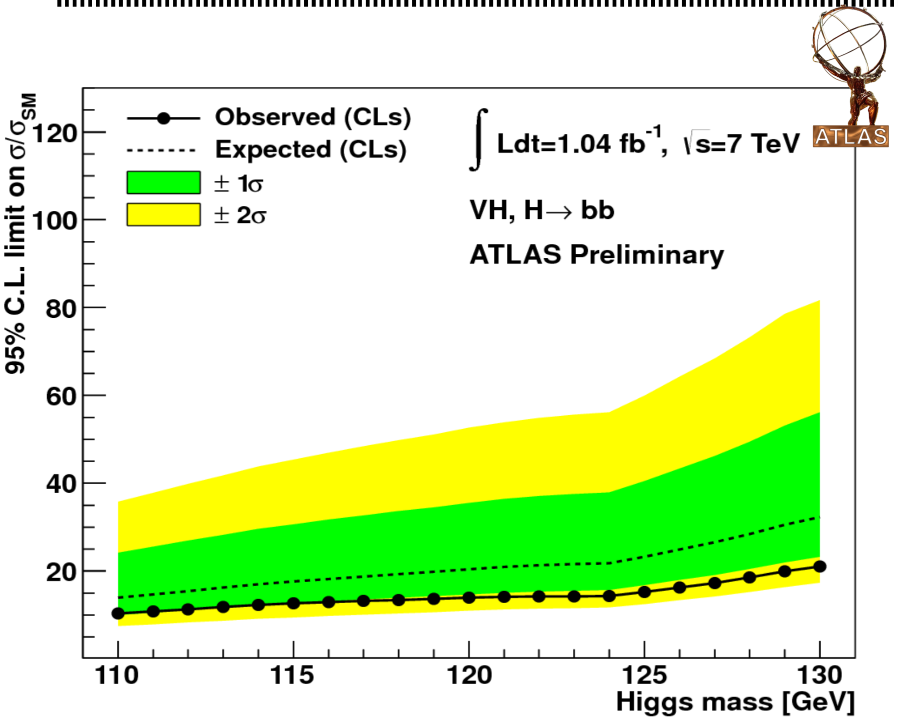
The difficult: $H \to bb$

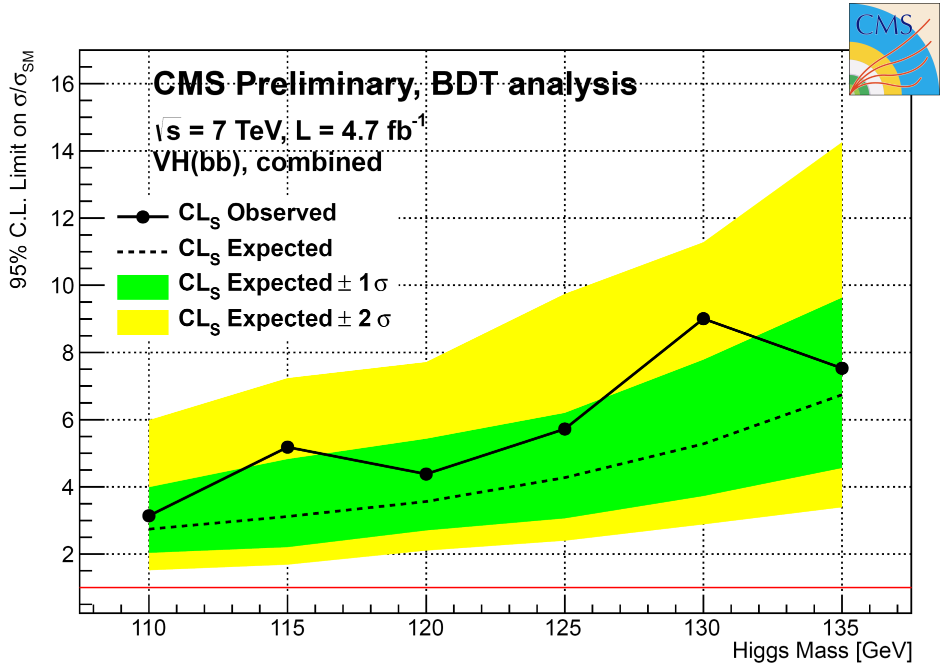
- Dominant production modes ($gg \to H$, VBF) overwhelmed by QCD multi-jet background
  - ⇨ **use $qq \to V(H \to bb)$ process**
  - ○ Decays of V provides handles to cope with background
  - ○ Main backgrounds V+jets, VV, tt
  - ○ $(W \to l\nu)H$, $(Z \to ll)H$, $(Z \to \nu\nu)H$ considered
- **ATLAS**:
  - ○ Require 2 jets with 1 or 2 b-taggs,
  - ○ Search for peak in m(bb) after inclusive selection (resolution ~20%)
- **CMS:**
  - ○ VH topology: $\Delta\varphi(V,H) > 3$
  - ○ Boosted V: $p_T(V) > 100\text{-}160$ GeV/c
  - ○ B-tagging and MET significance
  - ○ Use MVA discriminant (counting, resolution ~20%)
    - Cross checked with m(bb) analysis
- **Background estimated with control data – crucial**





H → bb: results



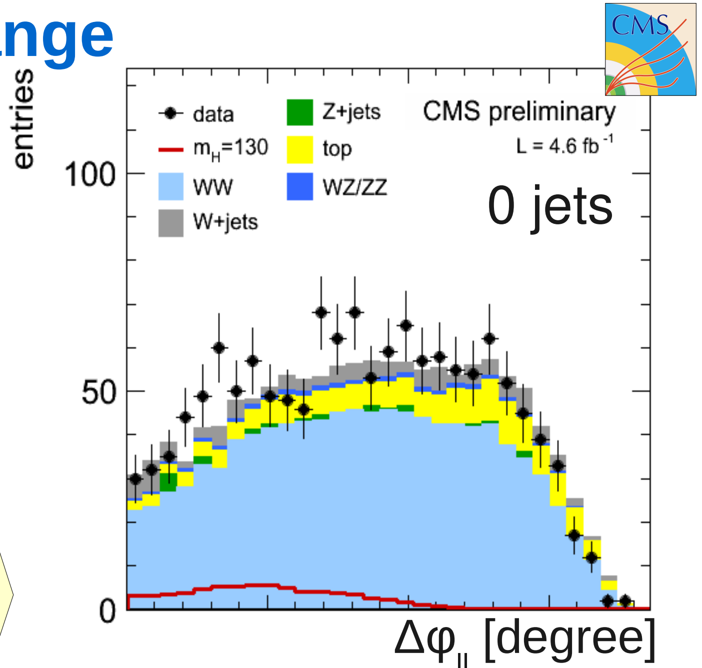


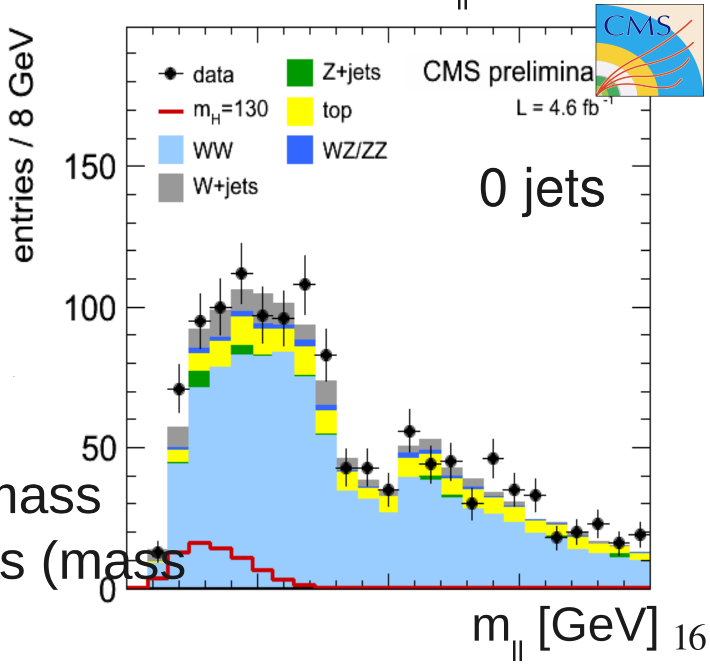
- ATLAS (L=1.04 fb^{-1})
  - Good agreement data-MC
  - **Observed exclusion ~10 – 15 x SM**

- CMS (L=4.7 fb^{-1})
  - No significant excess
  - Expected exclusion: ~3-7xSM
  - **Observed exclusion: 3.1 – 9 x SM**

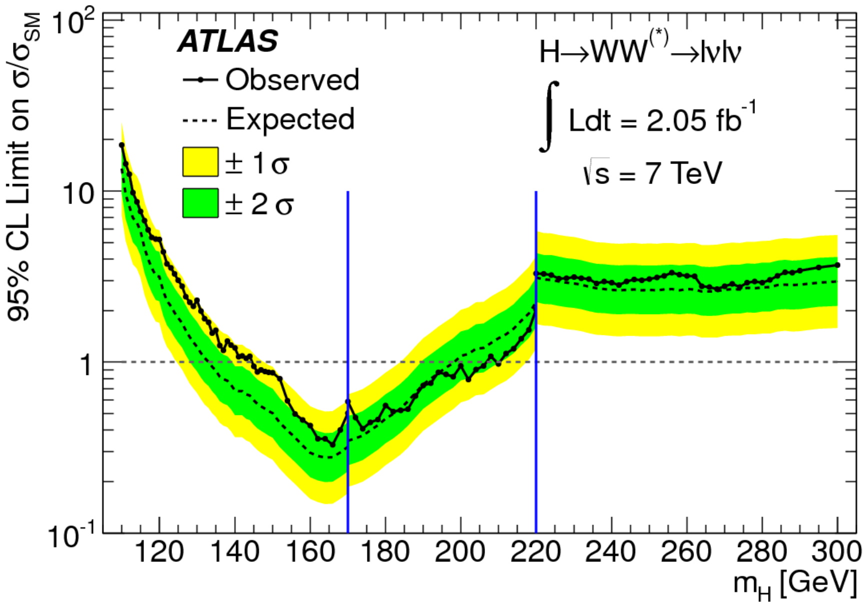
The powerful: H → WW* → 2l2ν

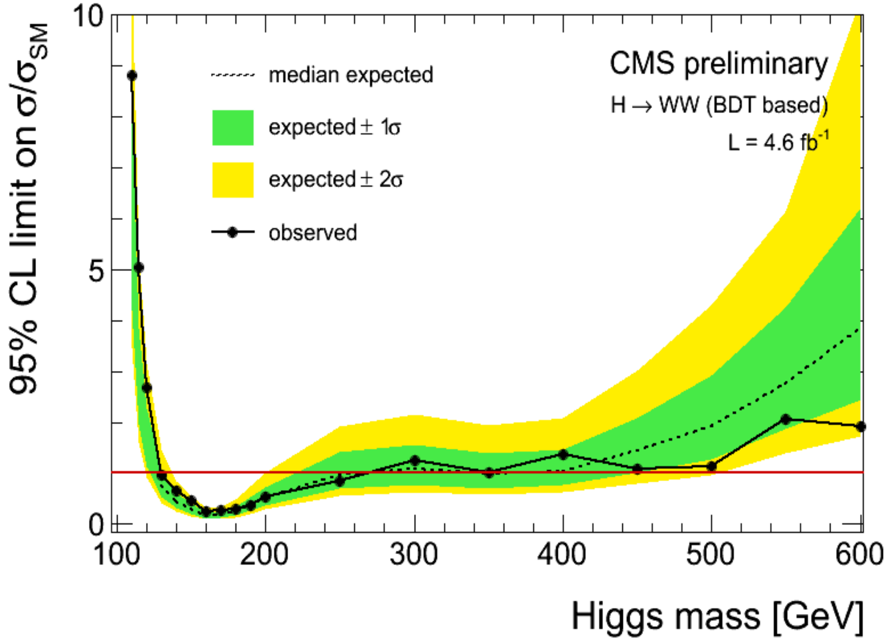
- **The most sensitive in intermediate mass range ($m_H \in 130 - 200$ GeV/c^2)**
  - Signature: exactly 2 opposite sign, isolated leptons, significant MET
  - **No signal mass pick** (presence of 2ν)
    - Poor sensitivity on Higgs mass (20%)
    - Counting experiment
  - Small Δφ(ll) thanks to scalarity of Higgs
- Selection strategy
  - Tight lepton identification and isolation
  - High MET & Z->ee/μμ veto
  - Classes based on jet multiplicity & b-veto
    - 0/1jets (ggF), 2jets (VBF, CMS only)
  - Kinematical cuts: Δφ(ll) and m(ll)
    - To suppress non-resonant WW
  - Selection optimised for m_H
    - **CMS:** shape of output of BDT trained for each mass
    - **ATLAS:** cut based: count events passing all cuts (mass dependent m_T window)





H → WW* → 2l2ν: results





ATLAS (L=2.05 fb^{-1})

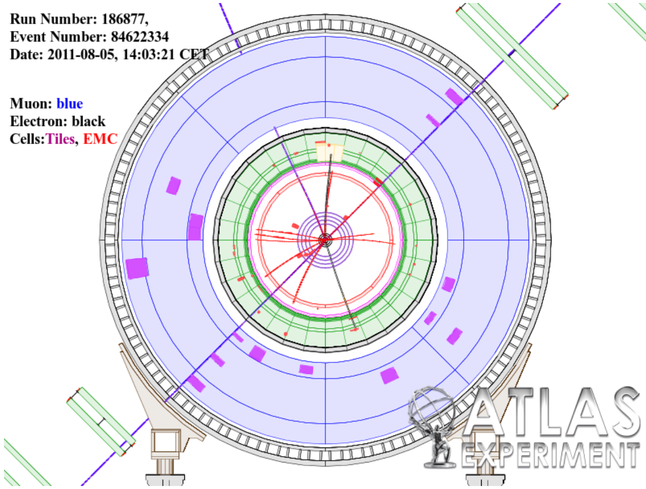
- **SM Higgs boson with $m_H \in$ 145 – 206 GeV/c^2 excluded at 95% C.L.**
- Expected sensitivity $m_H \in$ 134 – 200 GeV/c^2
- Broad ~1σ excess at low masses

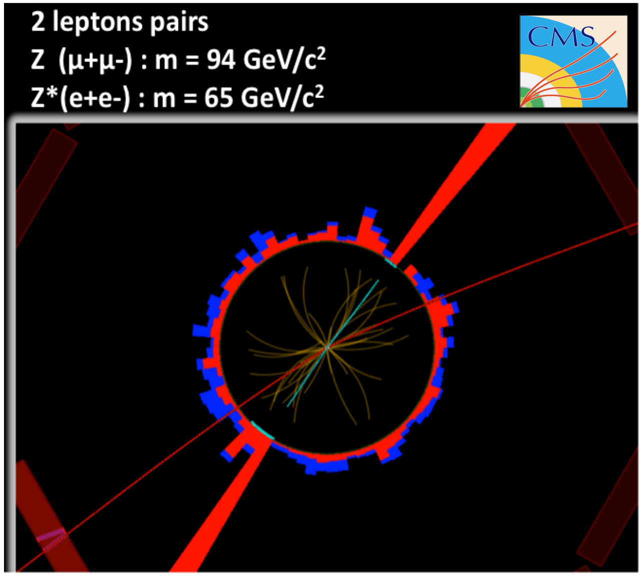
CMS (L=4.8 fb^{-1})

- **SM Higgs boson with $m_H \in$ 129 – 270 GeV/c^2 ruled out at 95% C.L.**
- Expected sensitivity $m_H \in$ 127 – 270 GeV/c^2
- Broad 1σ excess at low masses

The golden-plated: $H \rightarrow ZZ^* \rightarrow 4l$

- **Very sensitive in full mass range**
  $m_H \in 130 - 600$ GeV/c^2
  - **Narrow 4l-mass peak,** resolution 1-2%
  - **Discovery potential**
  - **Low p_T lepton identification crucial**
- **Signature:** 4 isolated leptons from one vertex
- **Reducible backgrounds:**
  - $tt \rightarrow 2l2\nu2b$, Z+bb, Z+jets
  - Removed by lepton isolation & impact parameter
- **Irreducible background:** ZZ*/γ*
  - Shape know at NLO
  - Rate estimated from Z yield in data and ZZ to Z ratio from theory (CMS)
  - Or from theory (ATLAS)
- **Event Selection:** 2 pairs of same flavour, opposite charge leptons





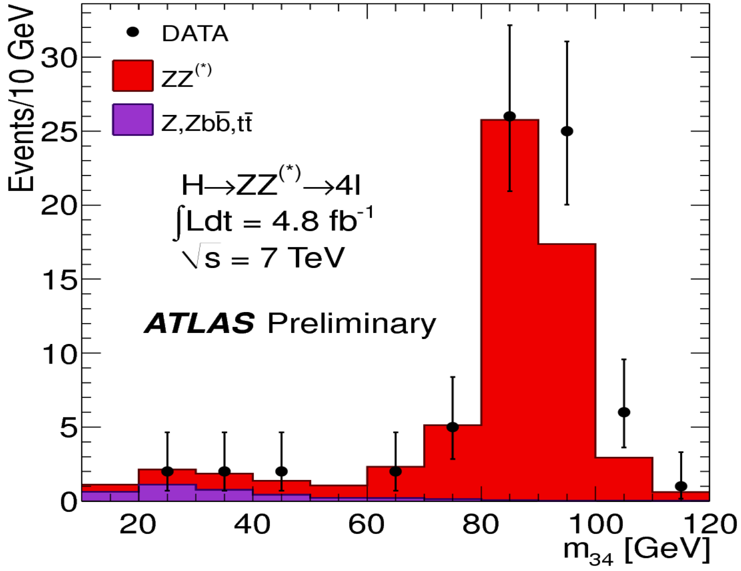
The golden-plated: H → ZZ* → 4l

ATLAS

- 2 leptons p_T>20 GeV
- Mass of better Z candidate m_Z±15 GeV
- Mass of second Z candidate < 115 GeV and higher than m_{4l} depended threshold (>15 GeV)

$m_{4\ell}$ (GeV)	≤120	130	140	150	160	165	180	190	≥200
threshold (GeV)	15	20	25	30	30	35	40	50	60

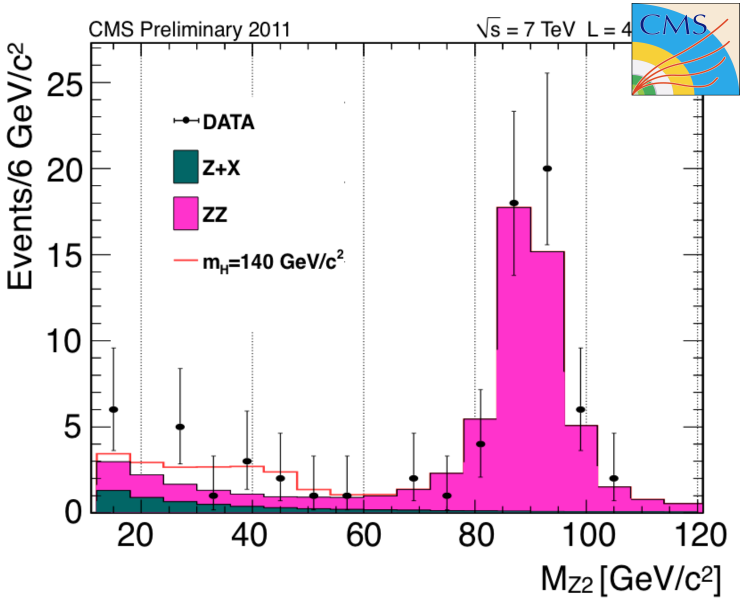
Mass of second Z candidate



CMS

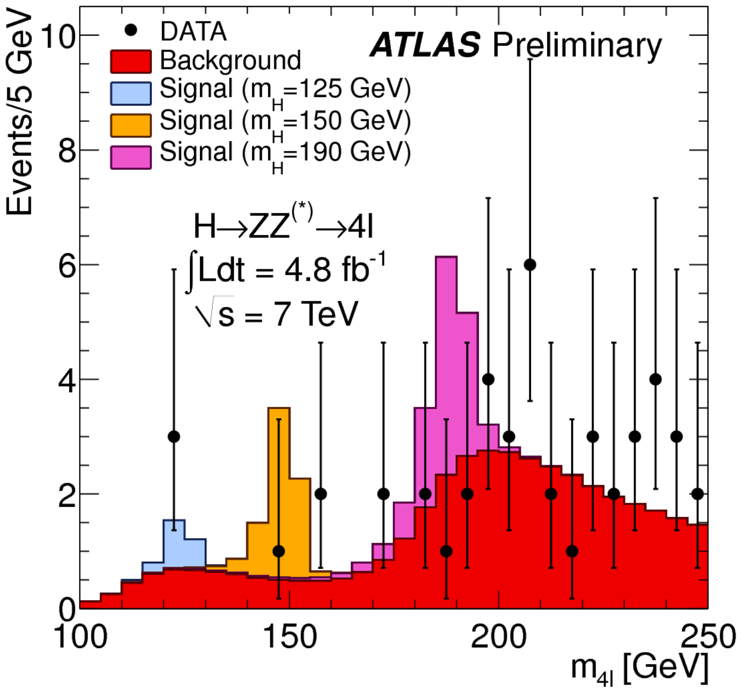
- First ll pair p_T>20,10 GeV, $50 < m_{Z1} < 120$ GeV
- Second ll pair m_{Z2}> 12 GeV
- m_{4l}> 100 GeV
- “Baseline” selection (low m_H):
  - $50 < m_{Z1} < 120$ GeV
  - $12 < m_{Z2} < 120$ GeV

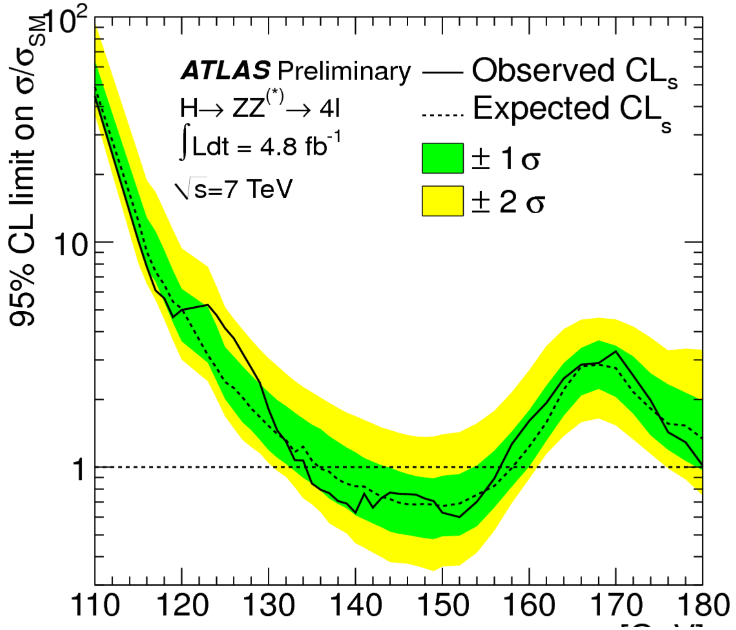
Mass of second Z candidate

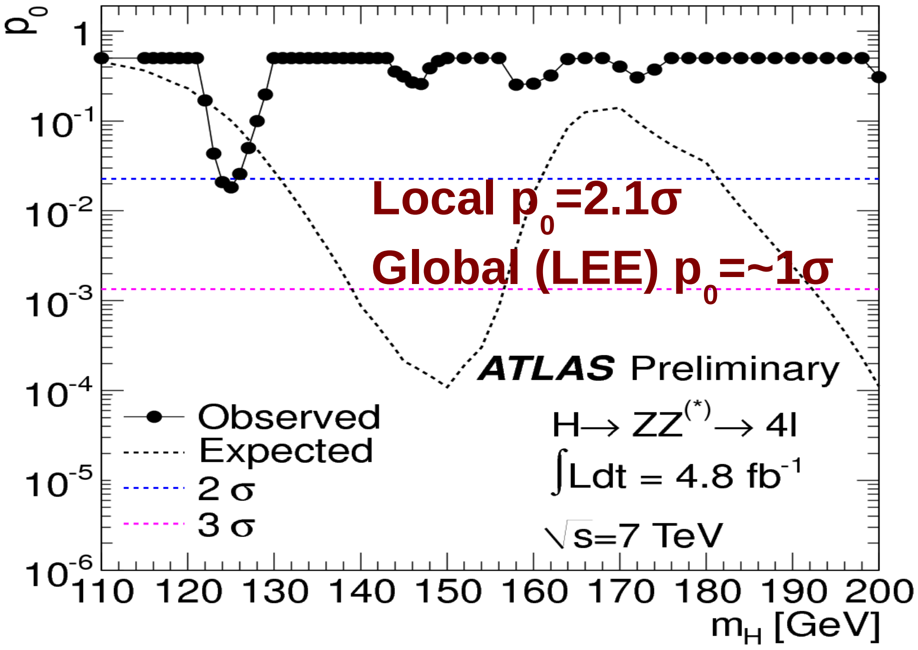


H → ZZ* → 4l: results

Distribution of 4l-mass







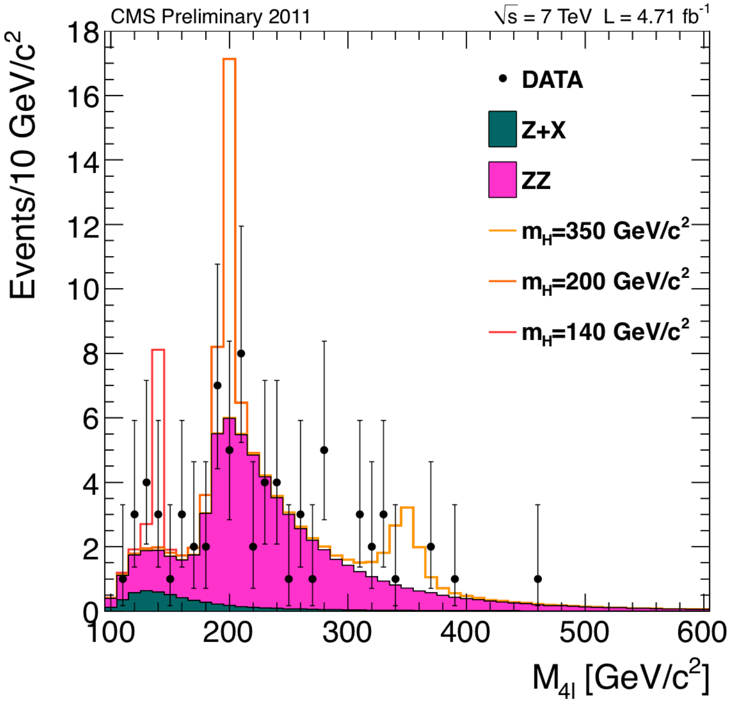
Local p_0=2.1σ

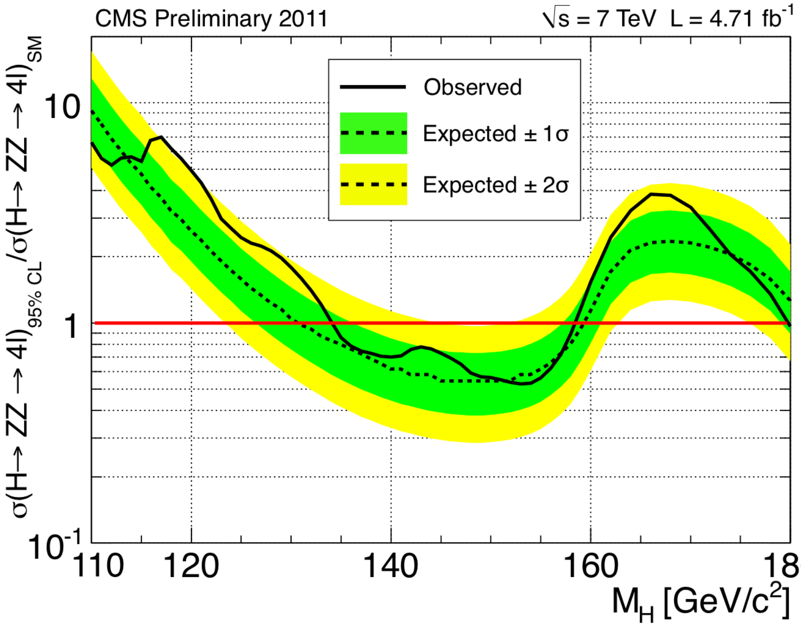
Global (LEE) p_0=~1σ

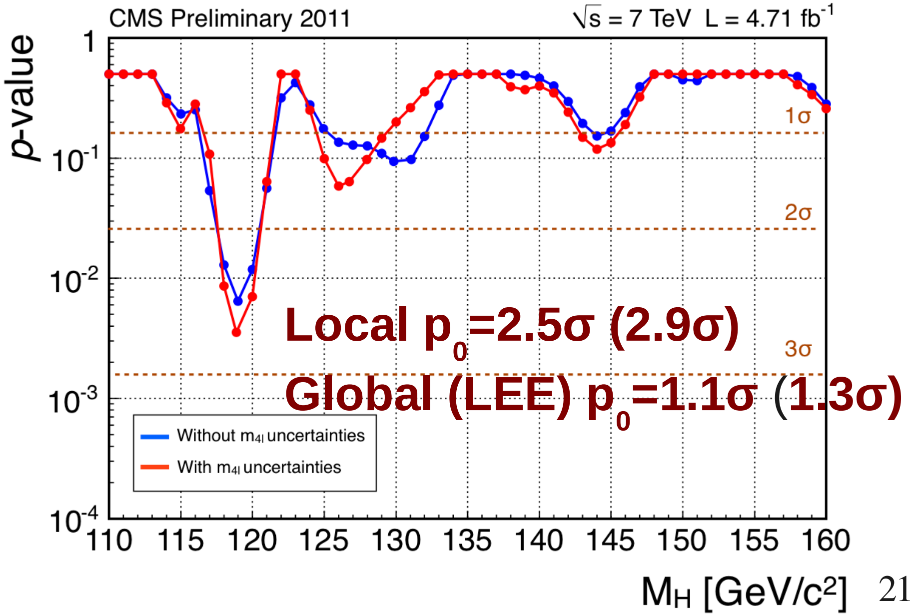
- **71 (8) observed / 62±9 (9.3±1.2) expected (m_{4l}<180 GeV)**
- Excess of events ~125 GeV
- Distribution consistent with ZZ continuum
- **SM Higgs excluded in ranges: 135-156, 181-234 and 255-415 GeV at 95% CL**

H → ZZ* → 4l: CMS results

Distribution of 4l-mass







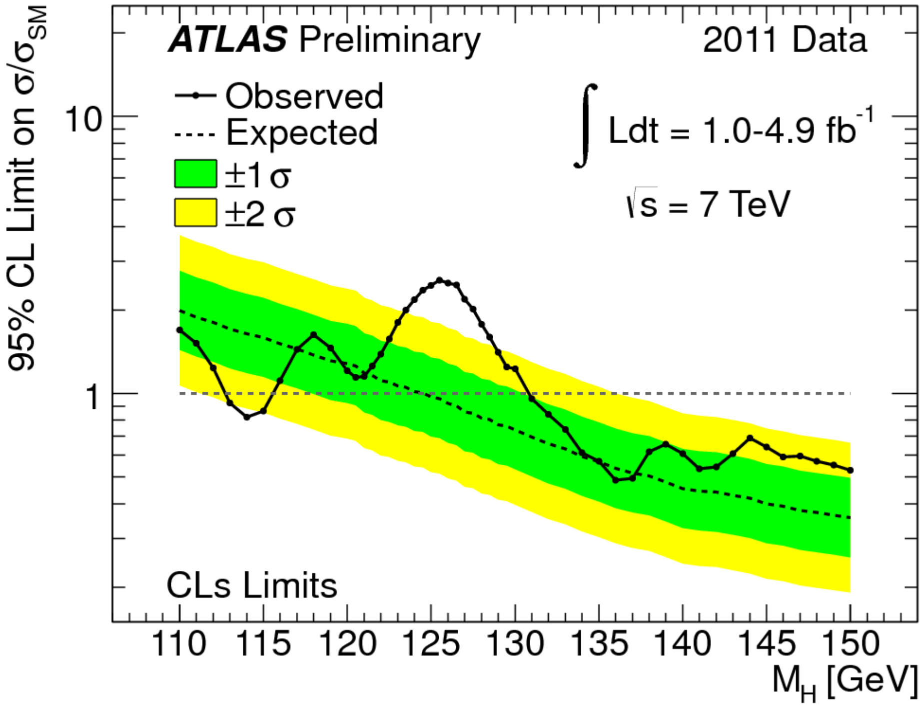
Local p_0=2.5σ (2.9σ)

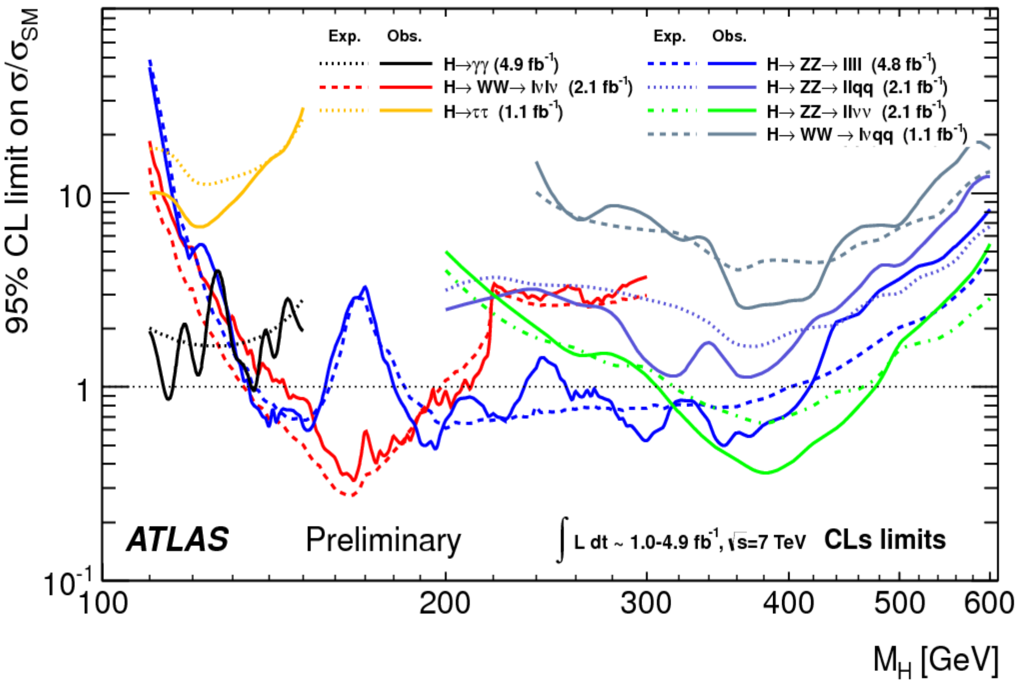
Global (LEE) p_0=1.1σ (1.3σ)

- **72 (13) observed / 67.1±5.5 (9.8±0.8) expected (for m_{4l}<160 GeV)**
- One triplet of events causing big local p-value at m_{4l}~119 GeV
- Distribution consistent with ZZ continuum
- **SM Higgs excluded in ranges: 134-158, 180-305 and 340-460 GeV at 95% CL**

Combined limit: ATLAS

- All channels used together



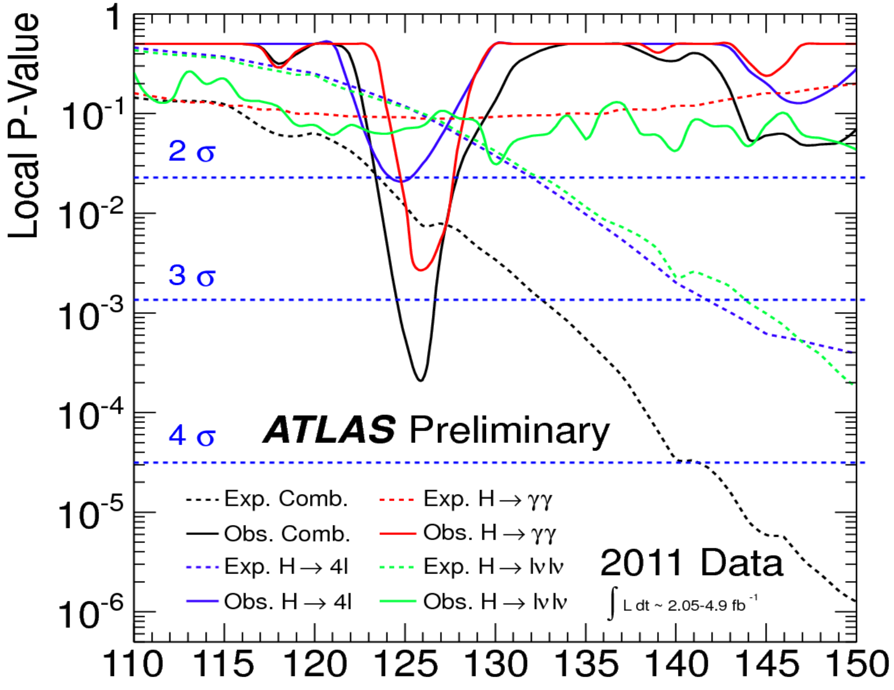


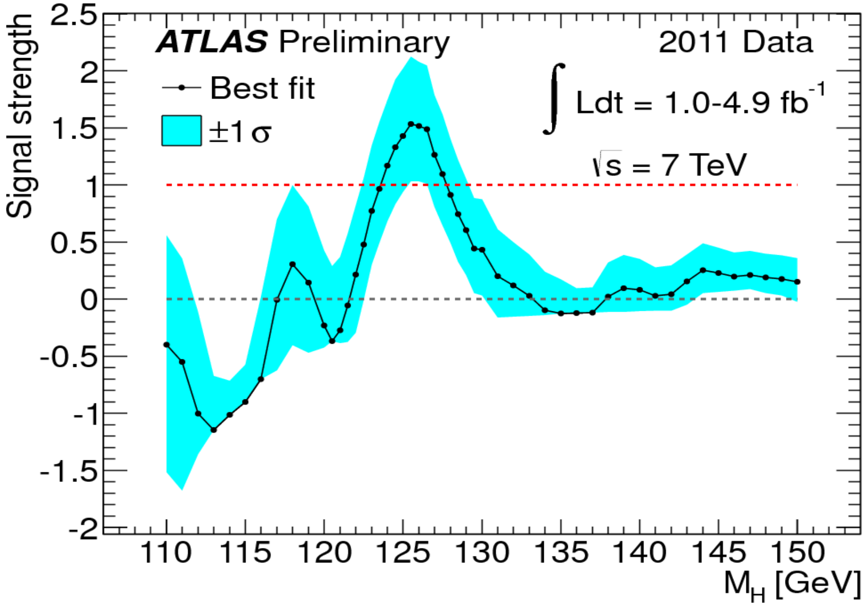
- Combination for low mass Higgs **guided by H → γγ, H → ZZ → 4l and H → WW → 2l2ν**
- There is **not any evidence for a SM Higgs**, but important fluctuation ~125 GeV (due to H → ZZ → 4l and H → γγ).
- **Observed exclusion (95% CL) for m_H=131-237, 251-453 GeV/c^2**

Combined limit: ATLAS

◎ All channels used together

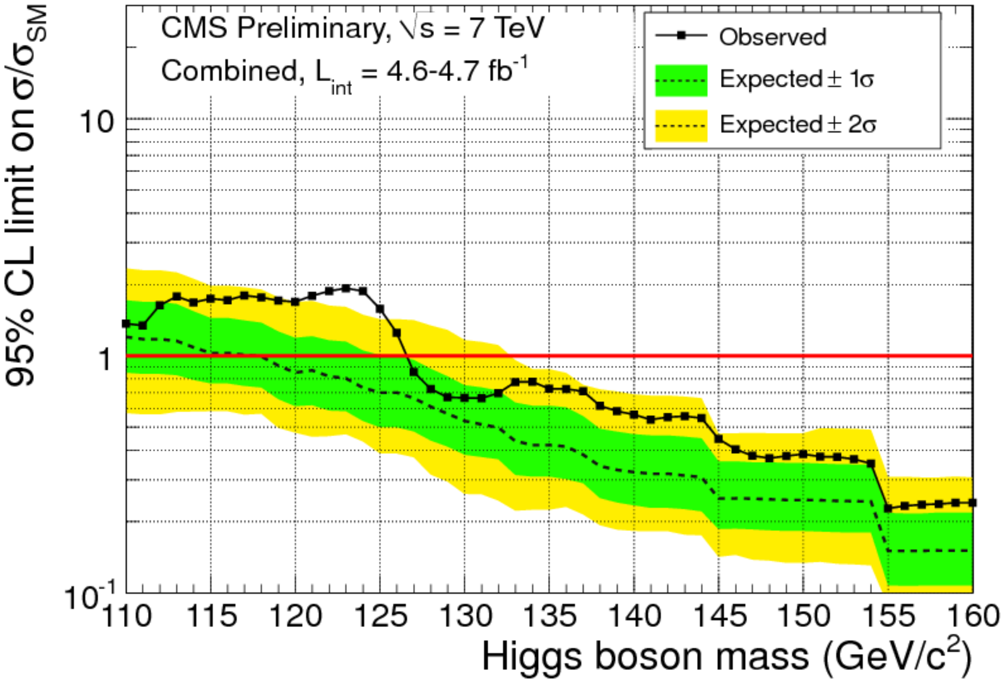
- Fluctuation ~125 GeV due to $H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ enhanced by broad excess of $H \rightarrow WW \rightarrow 2l2\nu$
- Local p-value 3.6σ, global significance ~2.3σ
- The excess requires 1.5 enhancement of SM higgs cross-section, but it is compatible with signal uncertainty (+1σ)
- => observation in agreement with S+B and B only hypotheses => more data needed to derive conclusion

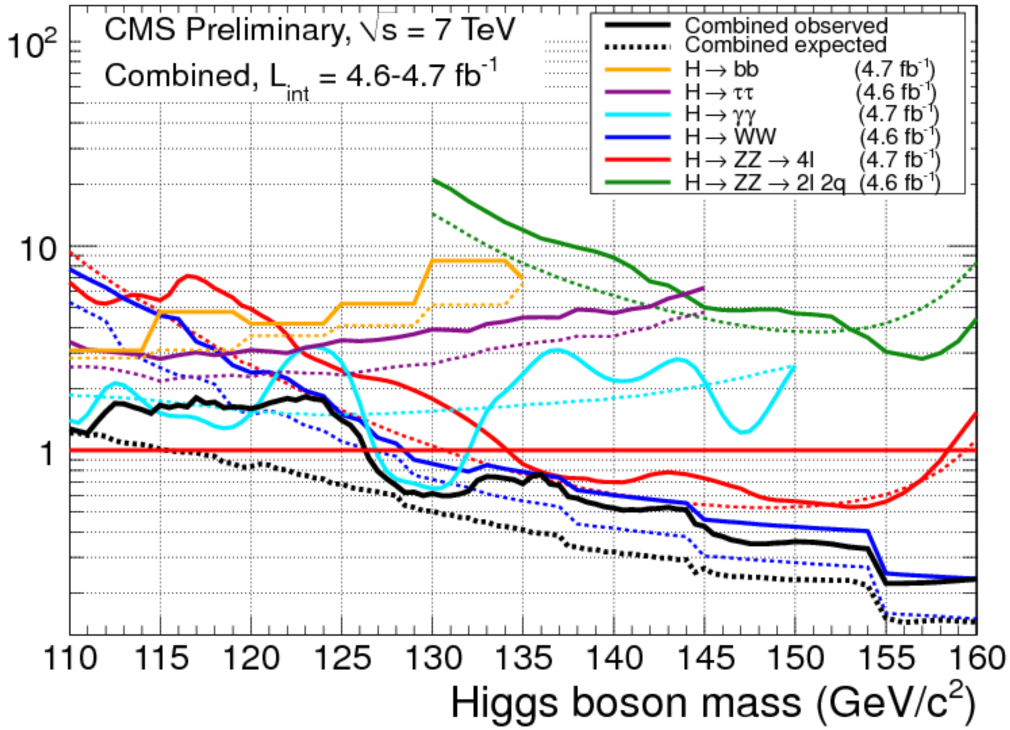




Combined limit: CMS

- All channels used together



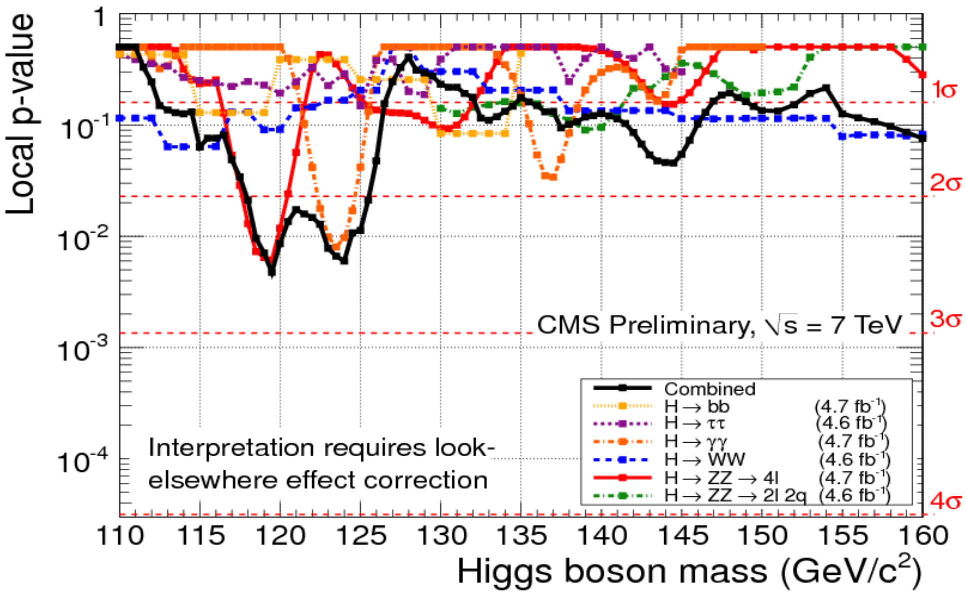


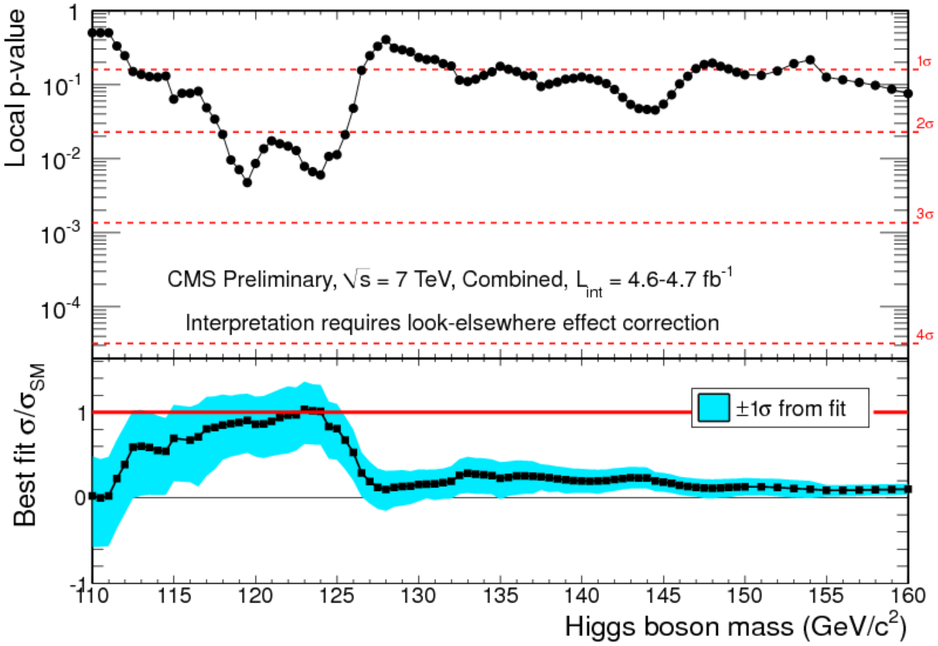
- Combination for low mass Higgs **guided by H→γγ, H→ZZ→4l** and **H→WW→2l2ν** with contribution from **H → ττ** and **H→bb**
- There is **not any evidence for a SM Higgs**, but fluctuations at ~123 GeV due to H→γγ) and ~119 GeV due to H → 4l
- **Observed exclusion (95% CL) for m_H=128-600 GeV/c^2**

Combined limit: CMS

◎ All channels used together

- Fluctuations at ~119 GeV (H → ZZ → 4l) and ~123 GeV (H → γγ) enhanced by broad excesses of H → WW → 2l2ν, H → ττ and H → bb
- Highest local p-value 2.9σ (~123 GeV), with global significance ~1.3σ
- The excess in good agreement with both with S+B and B only hypotheses => more data needed to derive conclusion

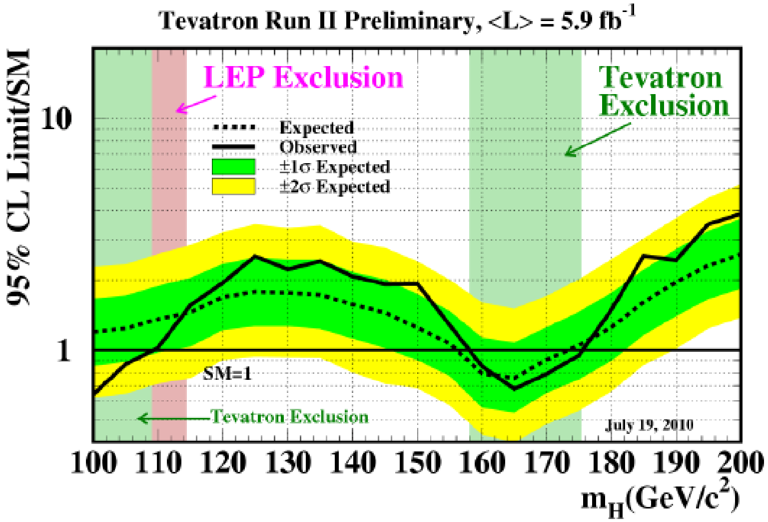




Conclusions

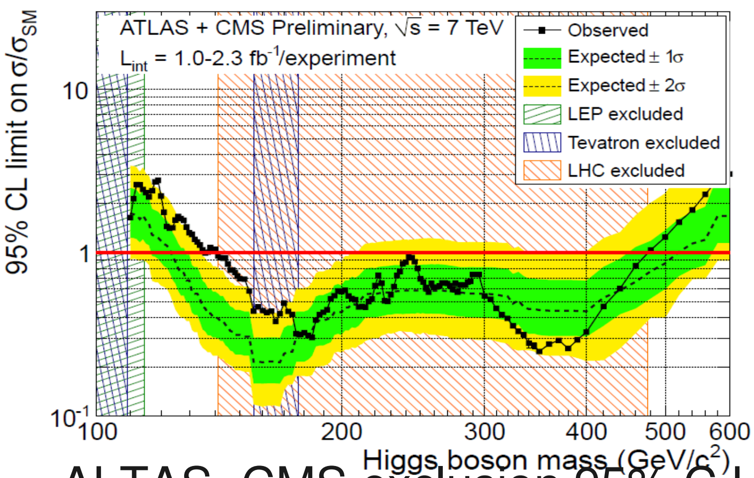
- Search for light Higgs boson with ~5 fb^{-1} data collected by the ATLAS ans CMS detectors was shown
- Several decay modes were used in the search
  - The flagship: **H → γγ**
  - The robust: **H → ττ** (both ggF and VBF)
  - The difficult: **H → bb**
  - Others, usually considered for heavy Higgs
    - **H → WW → 2l2ν**
    - **H → ZZ → 4l**
- **There is an overall good agreement with background only hypothesis**
- Exclusion limits were set for mH>127 GeV (CMS) and 131 GeV (ATLAS)
- Observation in still allowed range between 115 and 127 GeV in agreement with both S+B and B hypotheses
  - Some excesses observed
  - Region preferred by EW tests => next year gonna be really exiting!

Poszukiwanie Higgsa w 2011r. (krótka historia)



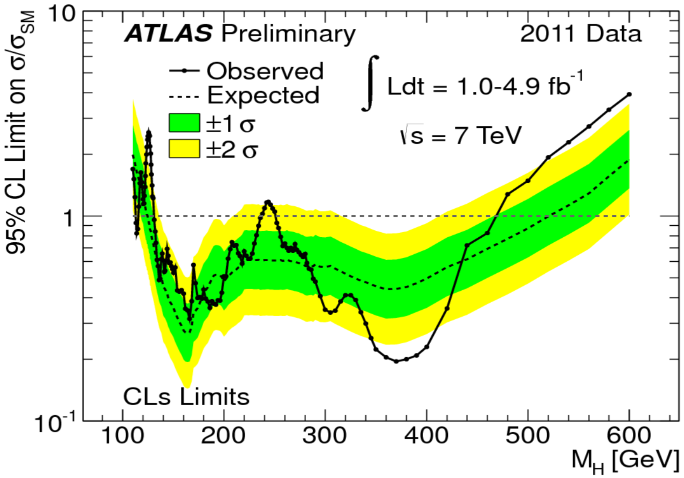
Tevatron exclusion 95% C.L. (Summer'10):

$158 < m_H < 173$ GeV



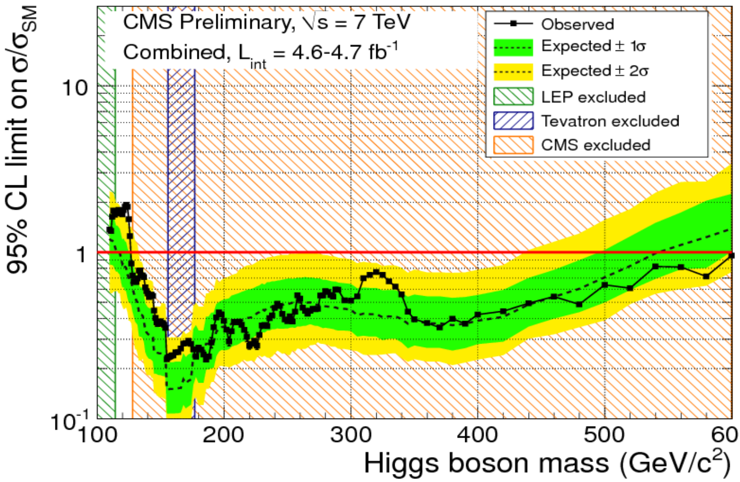
ALTAS+CMS exclusion 95% C.L.
(Summer'11; shown at HCP, Dec'11):

$141 < m_H < 476$ GeV



ATLAS exclusion 95% C.L. (End of 2011):

$131 < m_H < 237$ and **$251 < m_H < 453$ GeV**



CMS exclusion 95% C.L. (End of 2011):

$127 < m_H < 600$ GeV

Standardowy boson Higgsa wykluczony dla $m_H > 127$GeV!

BACKUP

Limits

CMS uses the CL_s method to set limits on $\mu = \sigma/\sigma_{SM}$

- Frequentist approach including systematic error evaluation

Likelihood function:

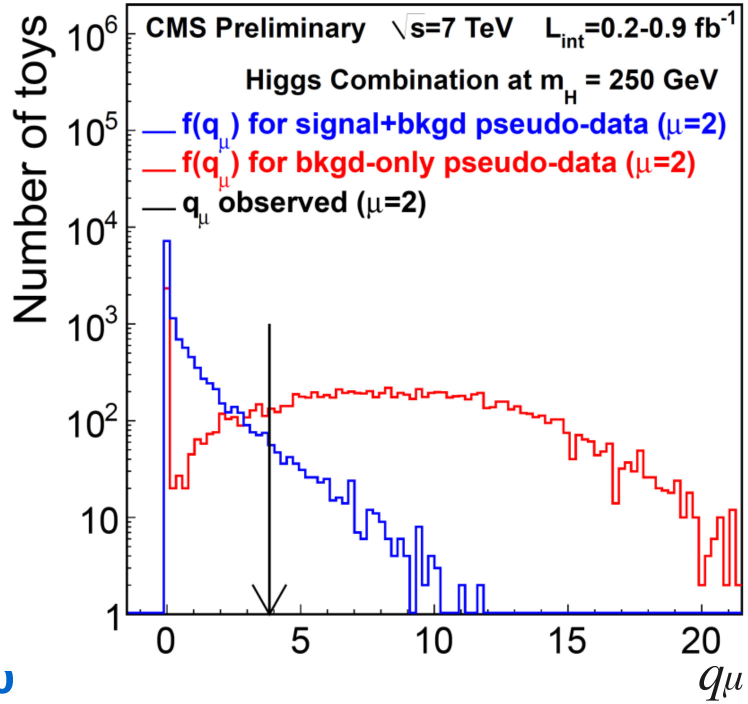
$$\mathcal{L}(data\,|\,\mu,\theta) = \text{Poisson}\left(\overbrace{data}^{\text{Observed}}\,\Big|\,\underbrace{\mu\cdot s(\theta)+b(\theta)}_{\text{Expected S+B}}\right)\cdot\overbrace{p(\tilde{\theta}|\theta)}^{\text{Systematics}}$$

Test statistics:

$$q_\mu = -2\ln\frac{\mathcal{L}(\text{data}|\mu,\hat{\theta}_\mu)}{\mathcal{L}(\text{data}|\hat{\mu},\hat{\theta})}\begin{array}{l}\leftarrow \text{fix } \mu\text{, vary } \hat{\theta}_\mu \\ \leftarrow \text{vary } \hat{\mu} \text{ and } \hat{\theta} \\ \quad 0 \le \hat{\mu} \le \mu\end{array}$$

Finally, calculate CL_s (toy MC):

$$CL_s = \frac{P\left(q_\mu \geq q_\mu^{obs}\,|\,\mu s(\hat{\theta}_\mu^{obs}) + b(\hat{\theta}_\mu^{obs})\right)}{P\left(q_\mu \geq q_\mu^{obs}\,|\,b(\hat{\theta}_0^{obs})\right)}$$



95% C.L. is on μ value giving CL_s = 1 - 95%

Significance

To quantify observed excess (above background only hypothesis)

- Same machinery as on previous slide but to test probability of the null hypothesis

Approximate p-value (probability of the null hypothesis)**:**

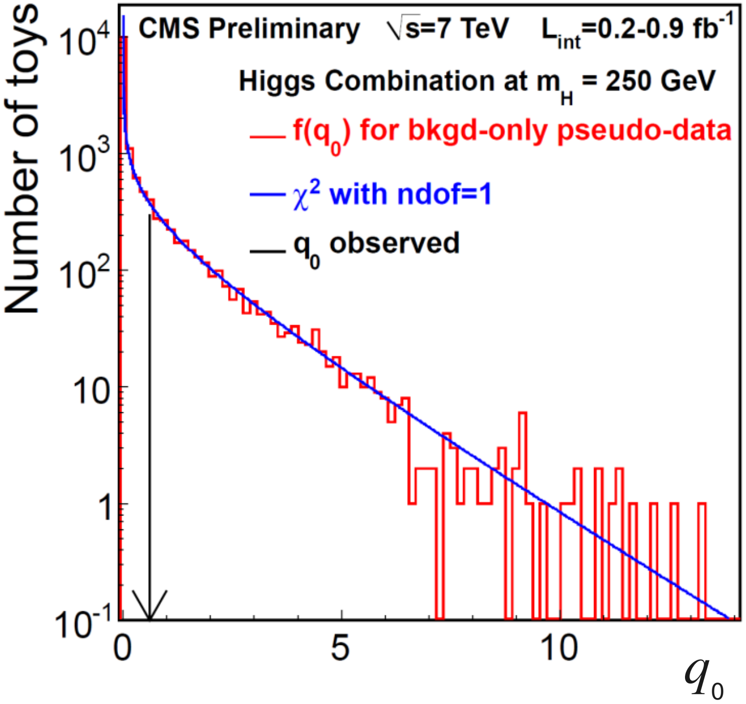
$$\tilde{p} = \frac{1}{2}\left[1 - \mathrm{erf}\left(\sqrt{q_0^{\mathrm{obs}}/2}\right)\right]$$

where q_0^{obs} is the observed q_μ value for the null hypothesis (μ = 0)

Significance (Z) corresponding to p-value

$$p = \int_Z^\infty \frac{1}{\sqrt{2\pi}} \exp(-x^2/2)\, dx$$

Probability expressed in σ's of one-sided normal distribution.



The flagship: $H \to \gamma\gamma$

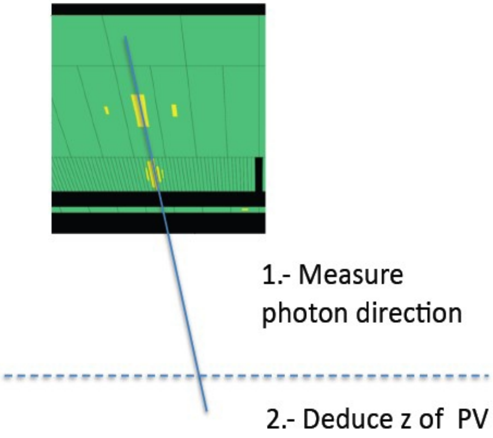
- The **most sensitive** channel at low masses **despite a small branching fraction, discovery potential**
  - Signature: narrow peak in distribution of di-photon mass
    - $p_T > 40,30$ GeV/c (ATLAS); $p_T/m_{\gamma\gamma} > 1/3, 1/4$ (CMS)
    - Id based on shower shape, isolation
    - Electron veto (to suppress DY → ee)
- High non-resonant background
  - $m^2 = 2E_1E_2(1\text{-}\cos\theta) \Rightarrow$

    $\delta m/m = 1/2\ (\delta E_1/E_1 \oplus \delta E_2/E_2 \oplus \delta\theta/\tan(\theta/2)\ )$
  - Potential of the channel depends on di-photon mass

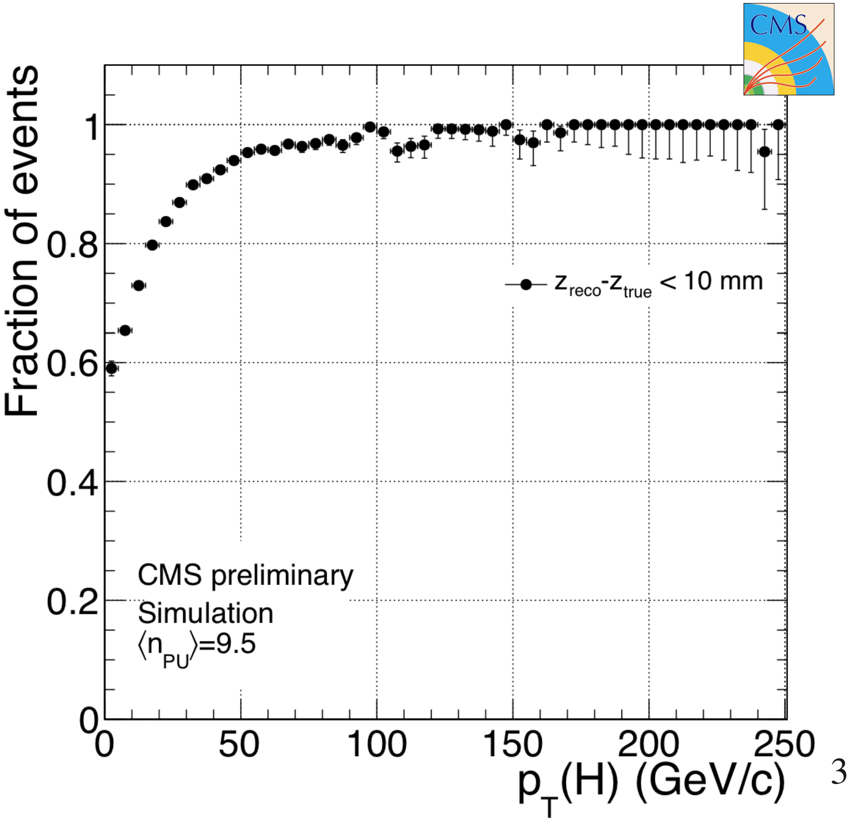
    resolution ⇒ **excellent precision of ECAL crucial** for the search
    - Energy calibration in situ: $\pi^0 \to \gamma\gamma$, $Z \to ee$, E_e/p_e
    - CMS: Monitoring of transparency loss due to radiative damages ⇒ time depended corrections for the effect
  - Direction of photons (vertex finding) important
- Signal extraction: fit of Signal+Background model to the di-photon mass distribution
  - Background estimation fully data-driven

H→γγ: vertex determination

- **ATLAS:**
  - Direction of photons using shower position in two first layers of ECAL extrapolated to beam-line (pointing)
    - σ(z)~15 mm
  - Conversion track finding and projection on beam-line

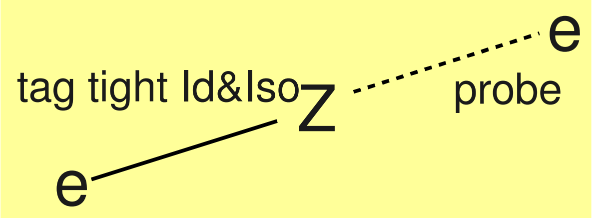


- **CMS:** Vertex determination based on
  - Kinematics of tracks belonging to the vertex Σp_T^2
  - p_T balance between tracks in vertex and photon-pair
  - Conversion track finding and projection on beam-line
  - BTD multivariate technique used
- Performance tested with Z→μμ after removing muon tracks

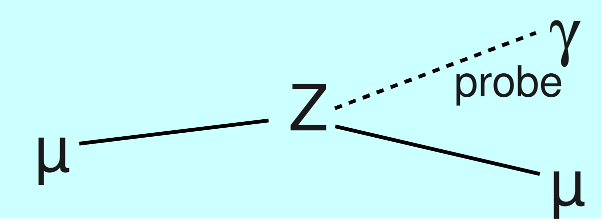


H→γγ: measurement of efficiency

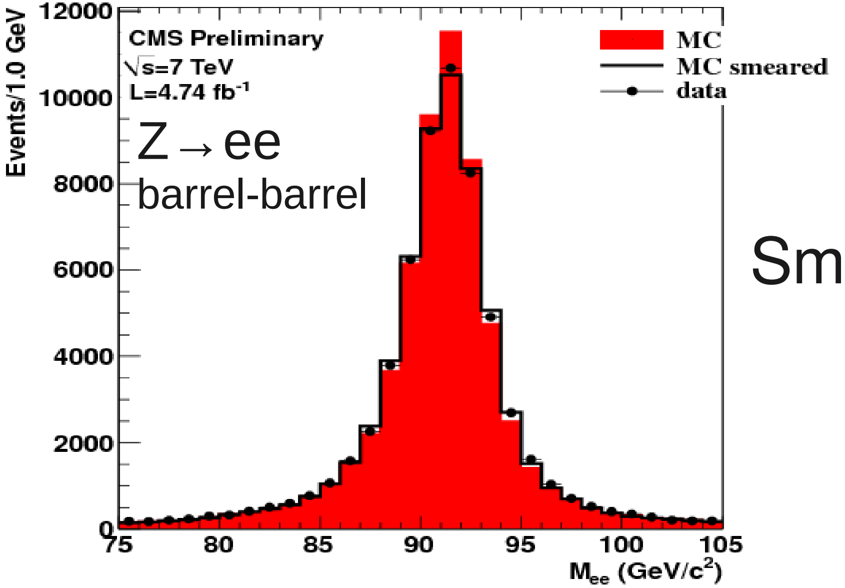
- Trigger and photon-Id & isolation controlled with Z→ee using tag-and-probe method



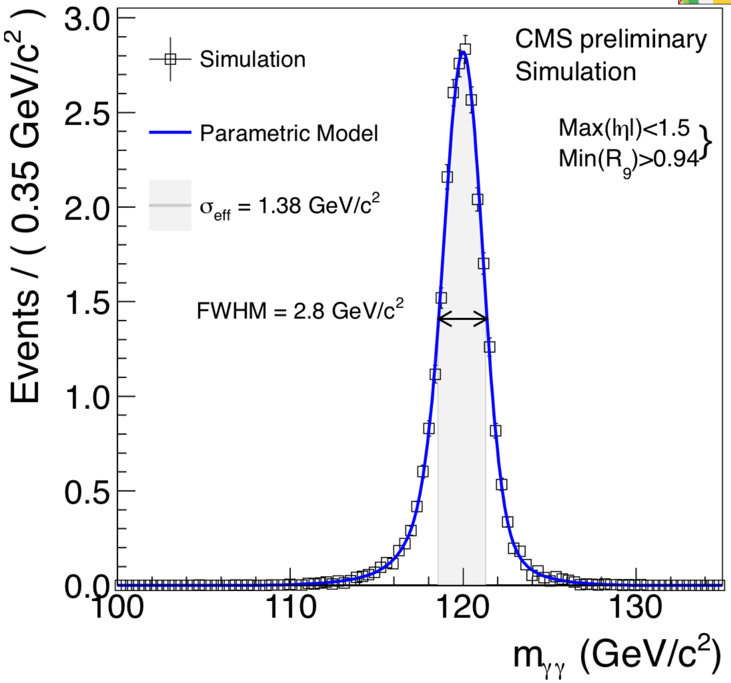
- Electron veto efficiency with Z→μμ+γ



- Energy scale and resolution obtained using mass of Z→ee
  - Performed separately for each event category (next slide)
  - MC reweighted (smeared) to match data



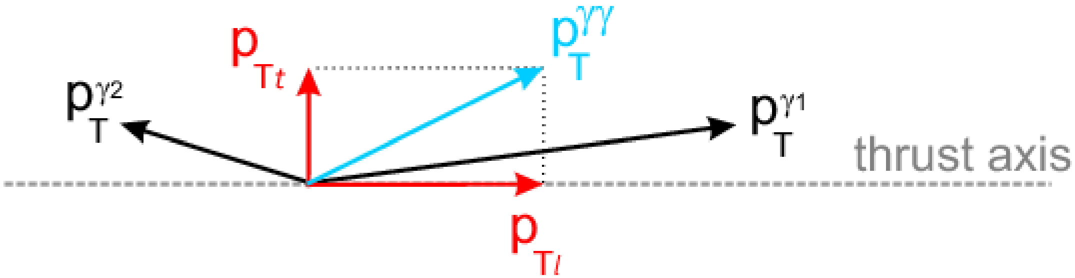
Smearing applied



H → γγ: categorisation

- Events divided onto categories
  - To optimally explore differences between signal and background
    - Different resolutions and S/B
  - CMS: 4 categories
    - [2 unconverted/rest (R9*)] × [2 in barrel/rest (|η|~1.5)]
  - ATLAS: 9 categories
    - { [2 unconverted/rest] × [2 central/rest (|η|<0.75)] × [p_{Tt}> 40 GeV / < 40 GeV] } + [≥1 converted & (1.3<|η|<1.75)]

      p_{Tt}: transverse momentum of di-photon wrt thrust axis



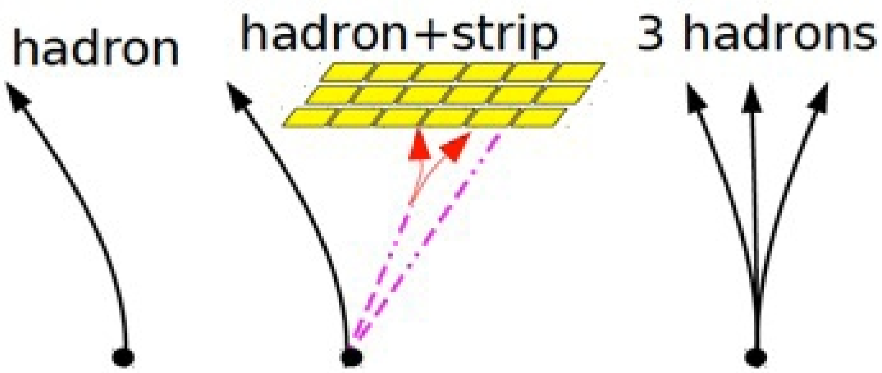
* R9: Energy of central 3x3 crystals to full energy of photon (super cluster), separates converted and unconverted (R9 > 0.94) photons.

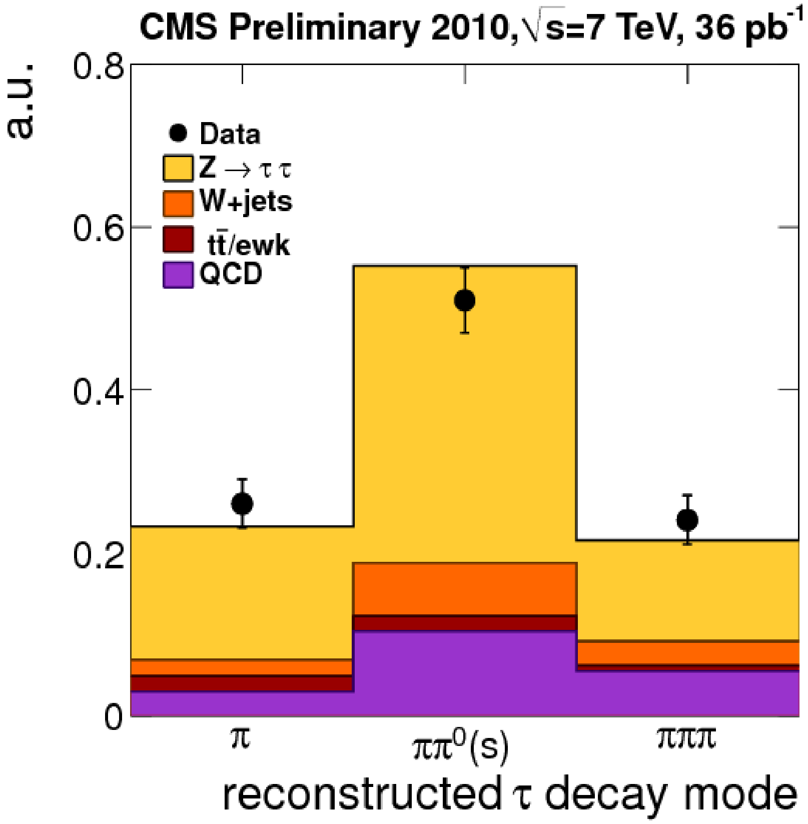
H → γγ: systematics

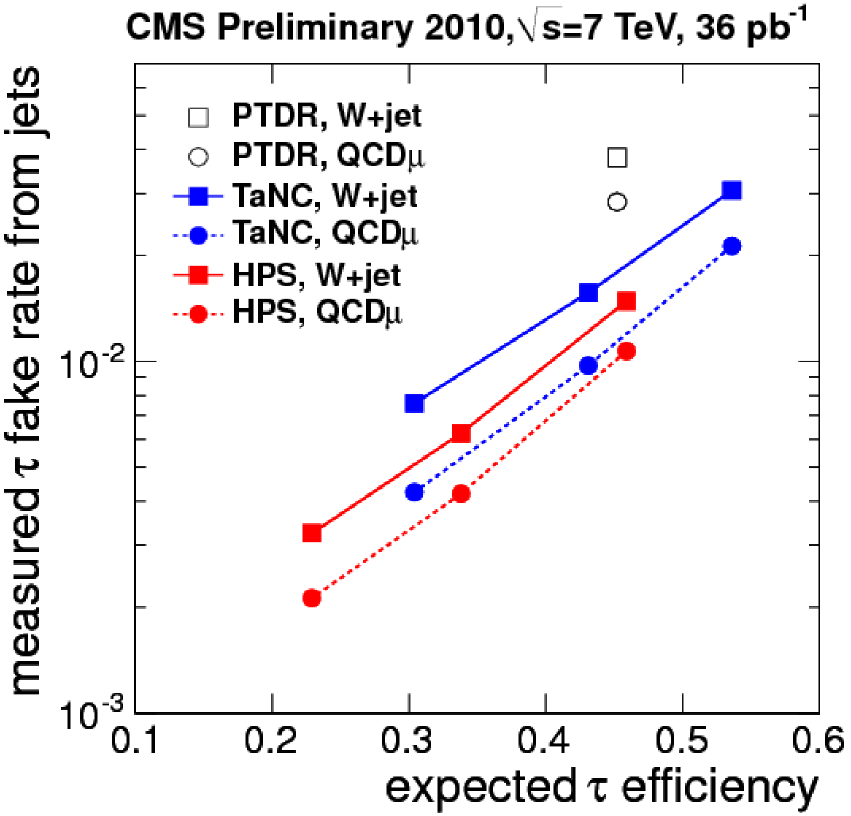
Source of uncertainty	Uncertainty
Applicable to individual photons	
Identification and isolation efficiency	1.0% - 4.0%
R9 cut efficiency	4.0% - 6.5%
Energy resolution	0.2% - 0.5%
Energy scale	0.05% - 0.34%
Applicable to di-photons	
Integrated luminosity	6%
Trigger efficiency	1.0%
Vertex finding efficiency	0.5%
p_T> 40 GeV/c cut efficiency	6.0%
Cross-section and branching fraction	
Gluon fusion cross-section	12.5%(scale), 7.9%(PDF)
Fermiophobic: scale	0.5%(VBF), 0.8%(WH), 1.6%(ZH)
Fermiophobic: PDF	3.1%
Fermiophobic: BR	5.0%

H → ττ: identification of tau-jet

- Reconstruction of individual decay modes (Hadron-plus-strip algorithm HPS)
  - 1-prong, 1-prong+π^0's, 3-prongs
- Several isolation working points
  - Loose, medium, tight
- Additional selection to reject leptons

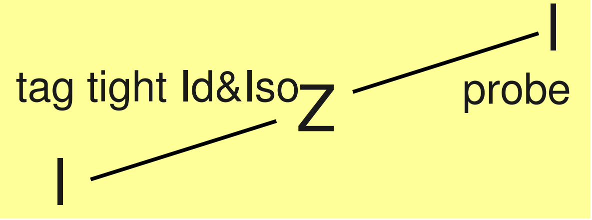


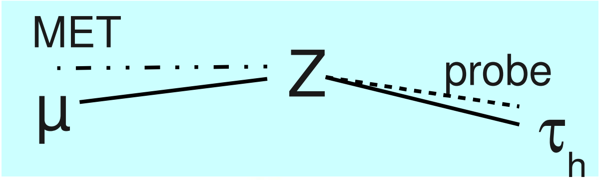


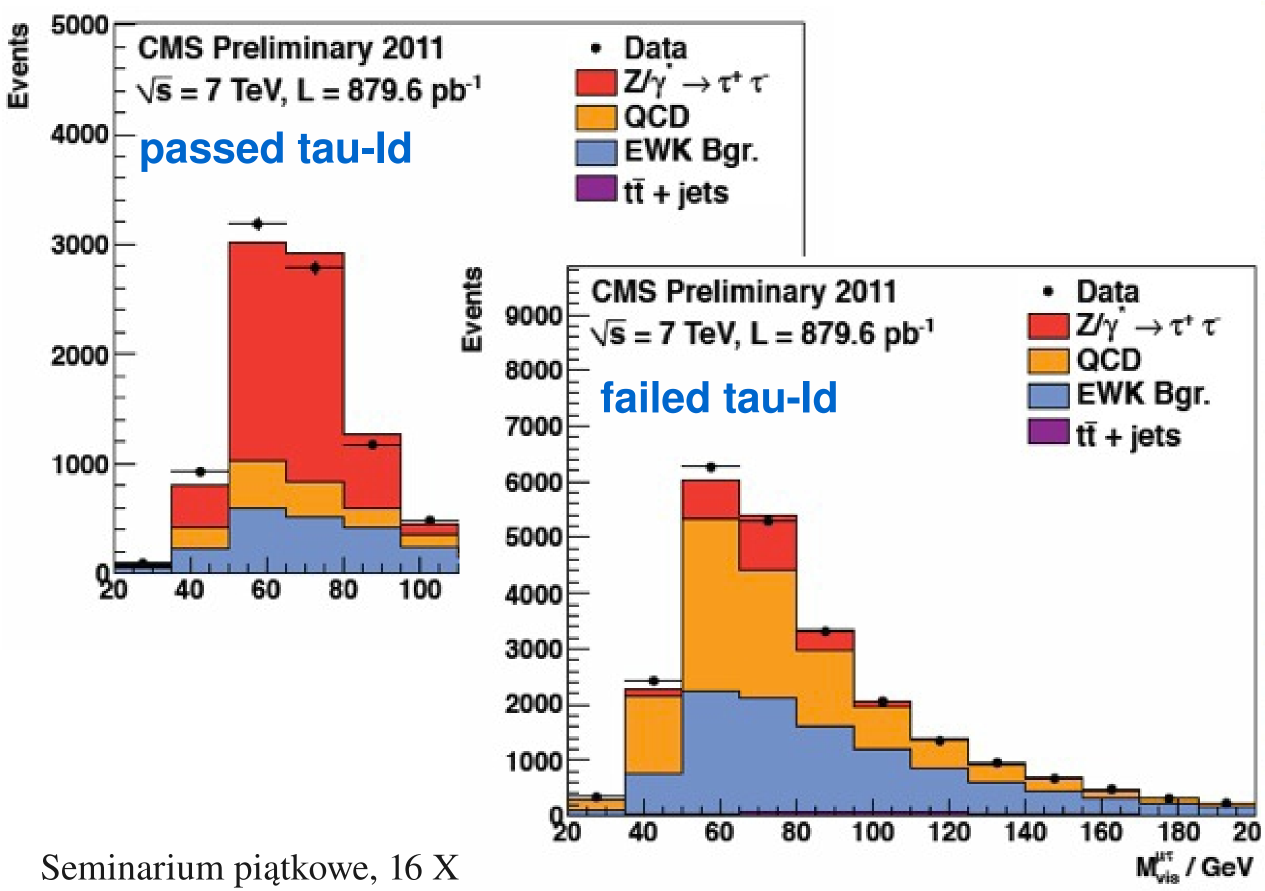


$H \rightarrow \tau\tau$: measurement of efficiency

- Trigger and lepton-Id & isolation controlled with $Z \rightarrow ll$ using tag-and-probe method
- Tau-jet trigger, Id and isolation efficiency with $Z \rightarrow \tau\tau \rightarrow \mu+\tau_h$
  - Not background free: simultaneous fit to signal and background regions





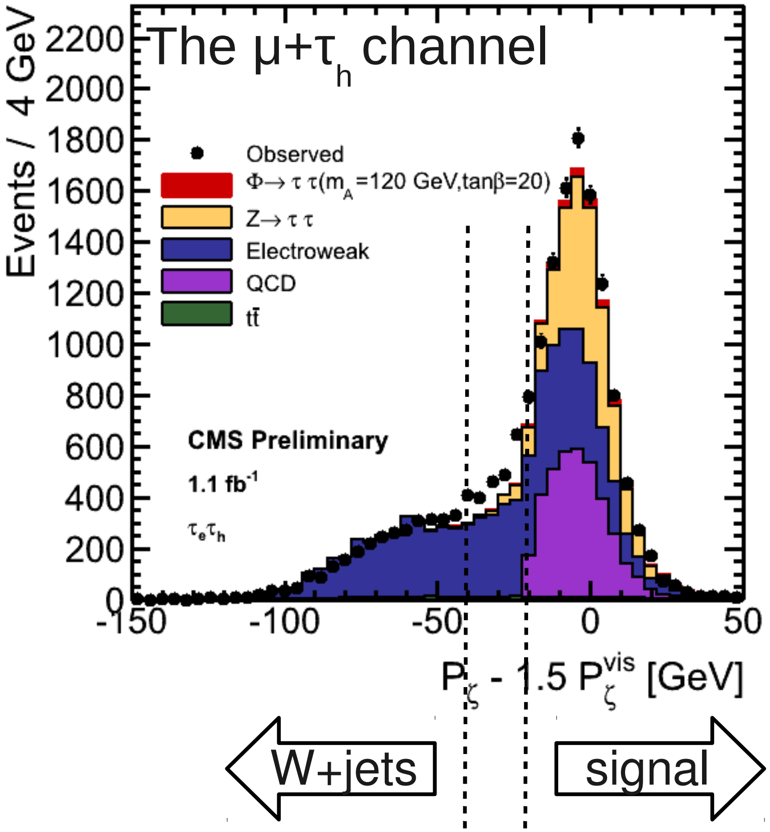


Uncertainty's source	HPS combined loose Δβ
Muon Momentum Scale	<< 1%
τ-Jet Energy Scale	< 1%
Track Reconstruction	3.9%
Track Momentum Scale	< 1%
Lead. Track P_T Cut	1%
Loose Isolation	2.5%
Jet → τ_{had} Fakes	1.2%
Lead. Track Corr. Factor	1.7%
Loose Iso. Corr. Factor	2.1%
Fit (Statistical Uncertainty)	2.6%
Sum	6.0%

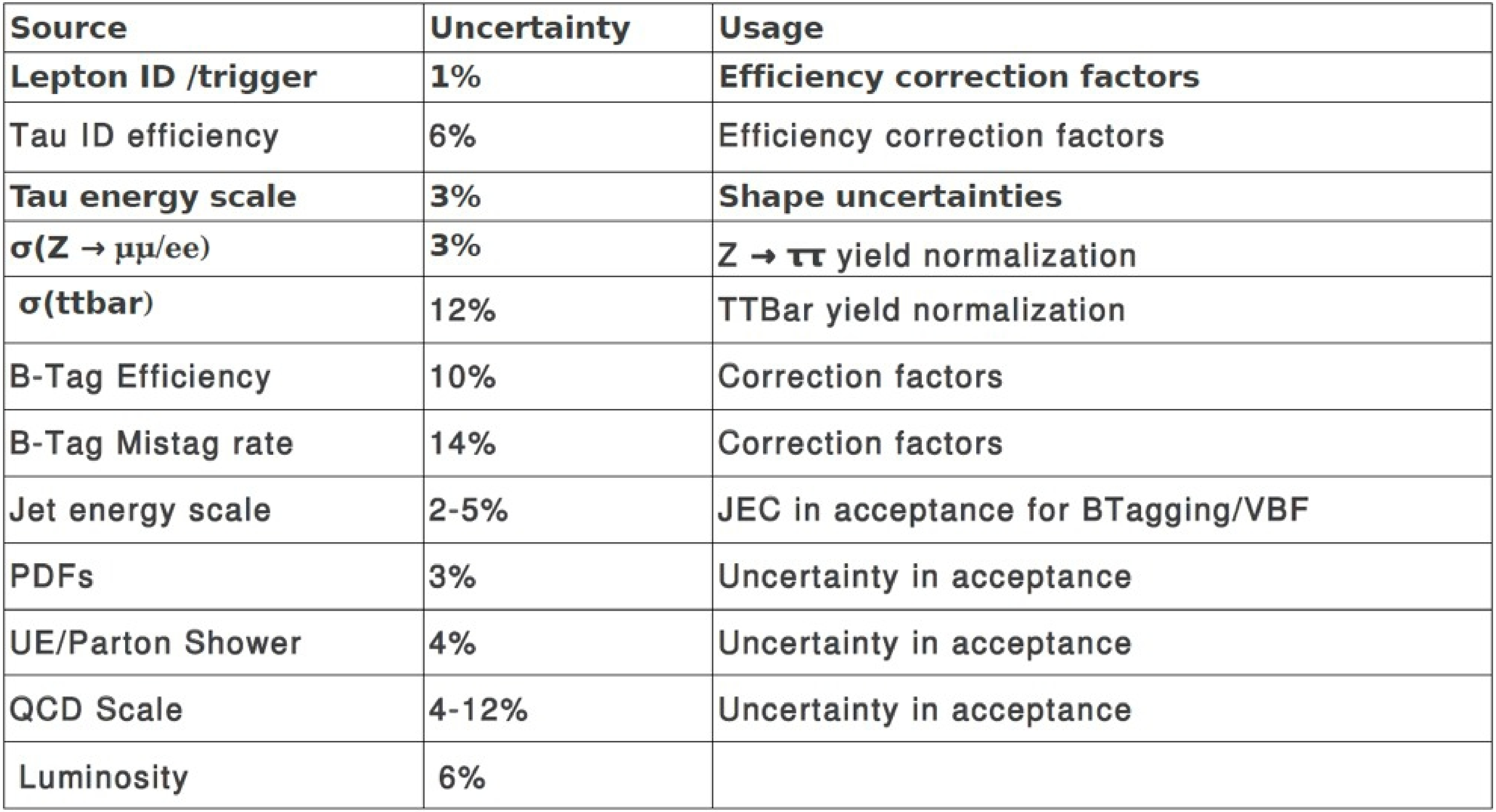
New! In winter was 23%

H → ττ: background estimation

- Irreductible Z → ττ estimated form CMS measured cross-section of Z → ee/μμ
- Main reducible backgrounds estimated with data from side-bands (l+τ_h)
  - W+jets: extrapolated from low P_ζ region
  - QCD: using same-sign control region
- … or using fake-rate method (e+μ)
- Other (smaller) backgrounds taken from simulation
  - tt normalised to cross-section by CMS, multi-boson to NNLO calculation

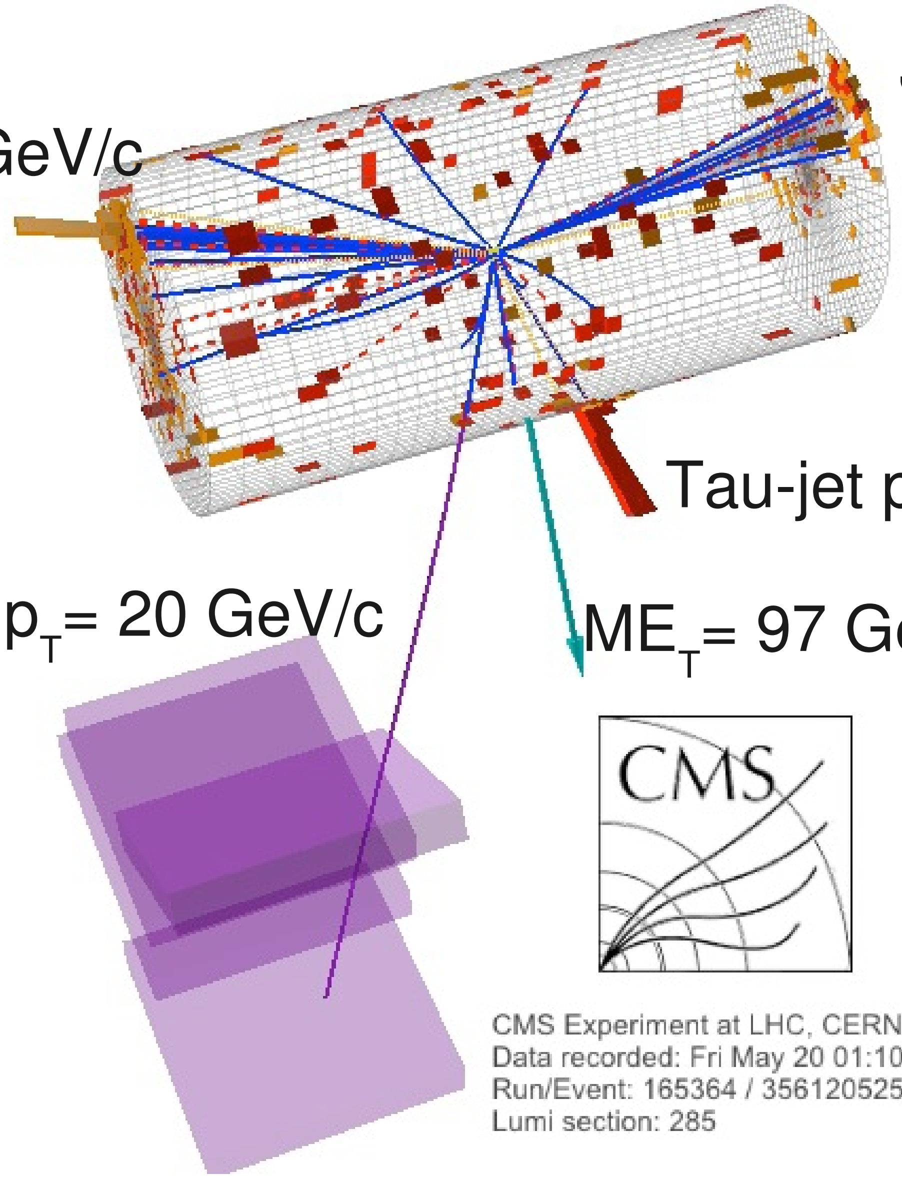


H → ττ: systematics



Source	**Uncertainty**	**Usage**
Lepton ID /trigger	**1%**	**Efficiency correction factors**
Tau ID efficiency	6%	Efficiency correction factors
Tau energy scale	**3%**	**Shape uncertainties**
σ(Z → μμ/ee)	**3%**	Z → ττ yield normalization
σ(ttbar)	12%	TTBar yield normalization
B-Tag Efficiency	10%	Correction factors
B-Tag Mistag rate	14%	Correction factors
Jet energy scale	2-5%	JEC in acceptance for BTagging/VBF
PDFs	3%	Uncertainty in acceptance
UE/Parton Shower	4%	Uncertainty in acceptance
QCD Scale	4-12%	Uncertainty in acceptance
Luminosity	6%	

VBF H → ττ event candidate



Jet 2 p_T= 46 GeV/c

Jet 2 p_T= 46 GeV/c

Tau-jet p_T= 69 GeV/c

Muon p_T= 20 GeV/c

ME_T= 97 GeV

CMS Experiment at LHC, CERN
Data recorded: Fri May 20 01:10:36 2011 CEST
Run/Event: 165364 / 356120525
Lumi section: 285