

Higgs boson results

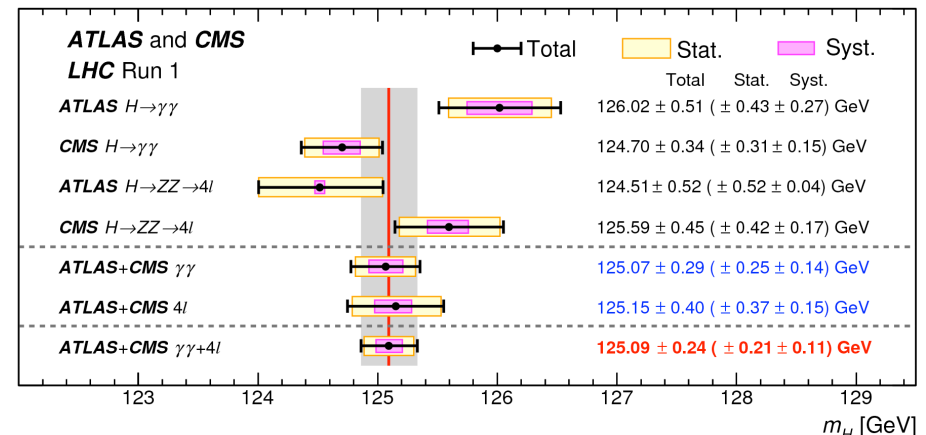
Elisabetta Gallo (DESY and University of Hamburg)
On behalf of the ATLAS and CMS Collaborations

Run 1 selected results:

- Higgs couplings combination
- Differential p_T distribution in WW

Run 2 selected results:

- Higgs in $\gamma\gamma$, $4l$
- $t\bar{t}H$ production
- hh production
- MSSM Higgs in tau channel
- Search for charged Higgs



$m_H = 125.09 \pm 0.24$ GeV (0.2%
precision from Run I ATLAS+CMS)



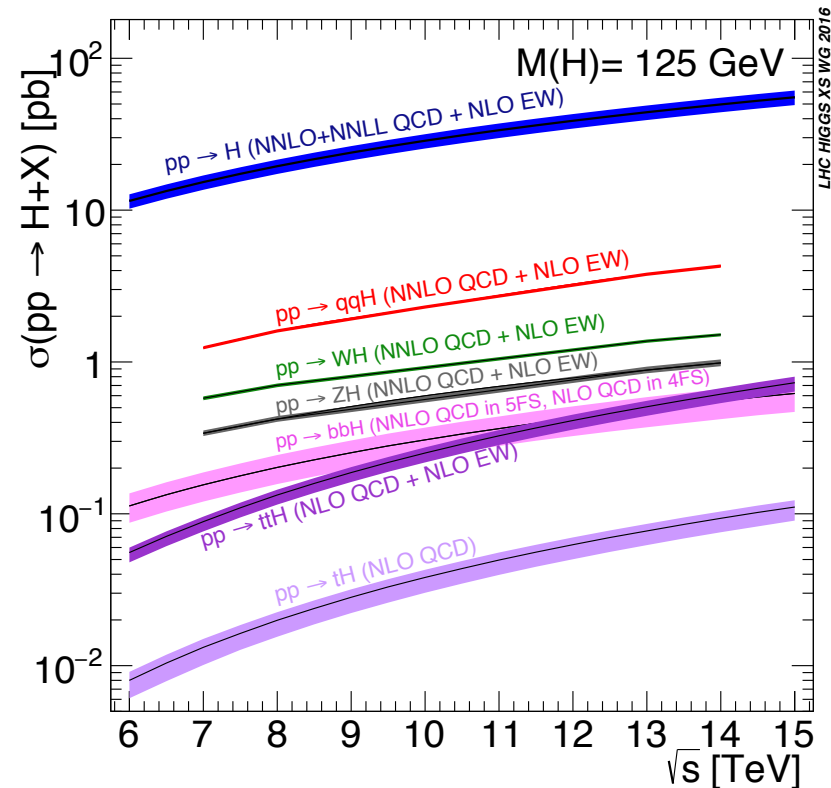
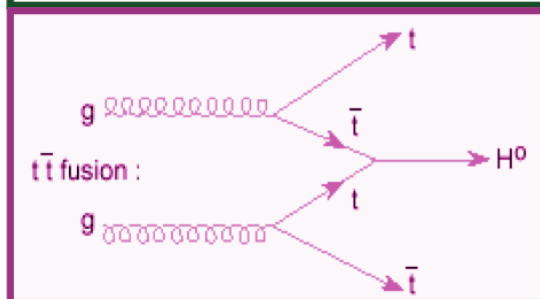
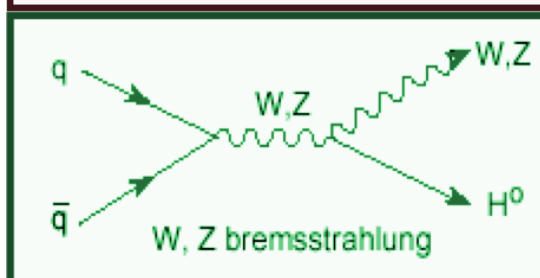
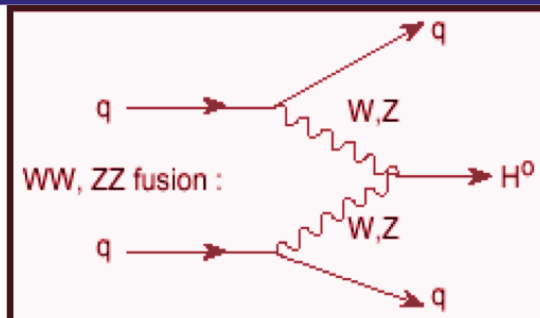
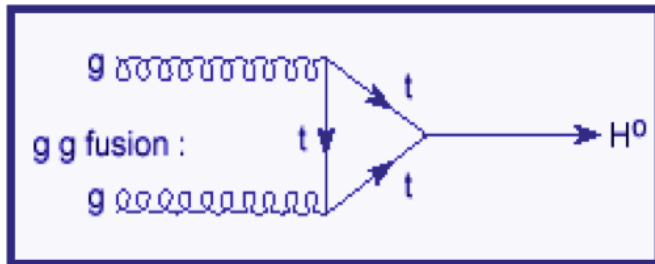
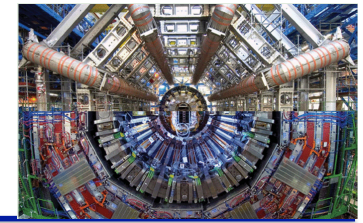
PLANCK 2016
From the Planck Scale to the Electroweak Scale

23-27 May 2016
Valencia, Spain



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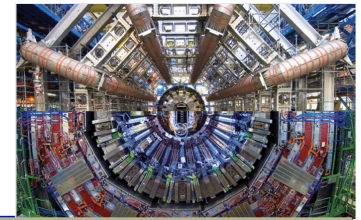
Higgs boson at the LHC



Main 6 decay channels:

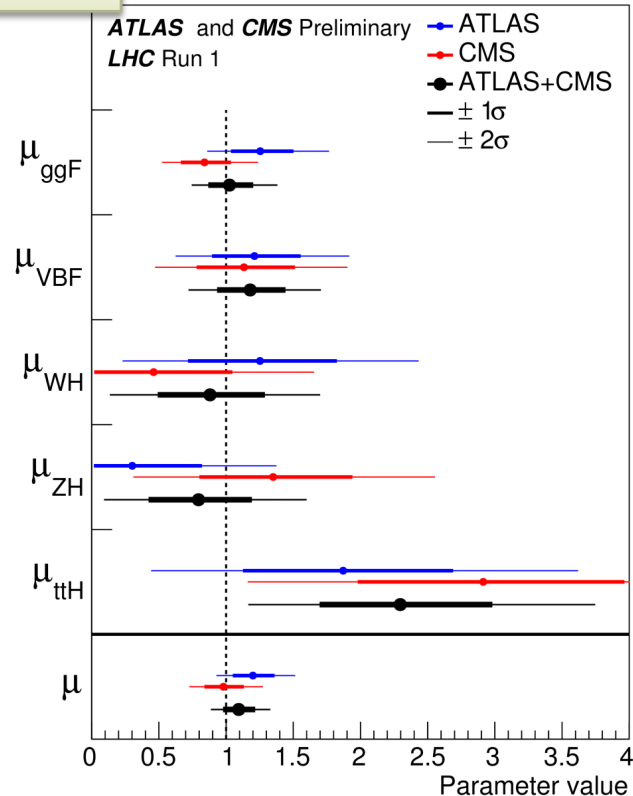
H $\rightarrow$ bb	WW*	ZZ*	$\tau\tau$	$\gamma\gamma$	$\mu\mu$
57.5%	21.6%	2.67%	6.30%	0.23%	0.022%

Higgs Run 1 combination



CMS-PAS-HIG-15-002 and ATLAS-CONF-2015-044

Assume $\mu^f = 1$



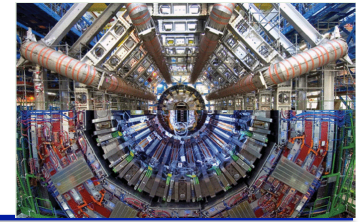
$$\mu_i^f = \frac{\sigma_i \cdot \text{BR}^f}{(\sigma_i)_{\text{SM}} \cdot (\text{BR}^f)_{\text{SM}}} = \mu_i \times \mu^f$$

- Assume 125.09 GeV for m_H value
- More than 600 categories combined
- Delicate combination of correlations of systematics sources between channels and the two experiments
- $\mu(\text{ttH}) = 2.3^{+0.7}_{-0.6}$ excess dominated by multilepton channel in both ATLAS and CMS

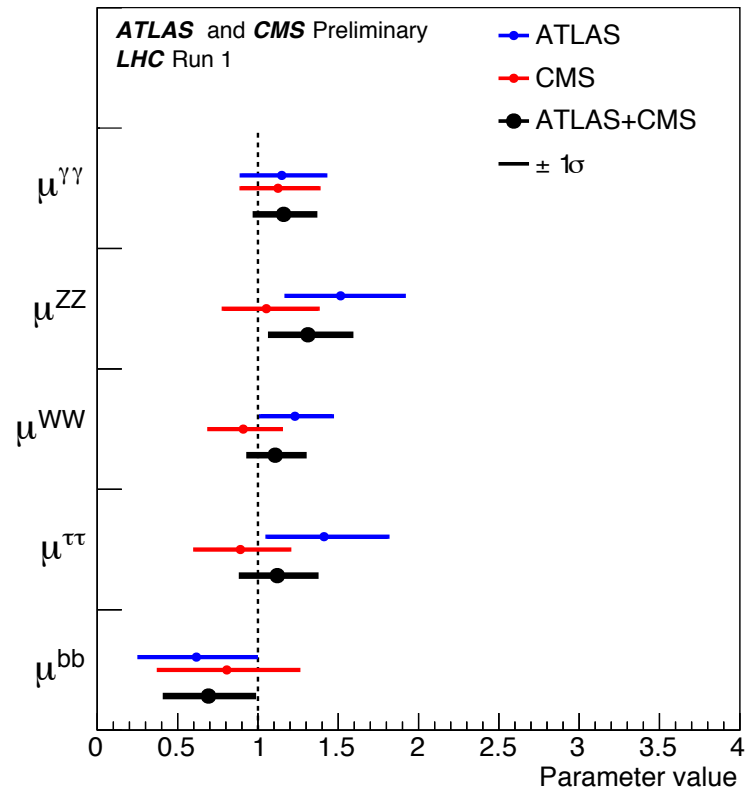
Global:

$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07} (\text{stat})^{+0.04}_{-0.04} (\text{expt})^{+0.03}_{-0.03} (\text{thbgd})^{+0.07}_{-0.06} (\text{thsig})$$

Higgs Run 1 combination



Assume $\mu_i=1$



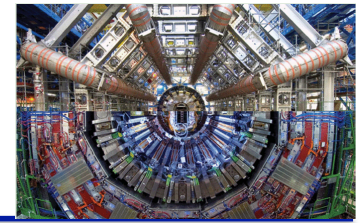
Decay channel	ATLAS+CMS
$\mu^{\gamma\gamma}$	$1.16^{+0.20}_{-0.18}$
μ^{ZZ}	$1.31^{+0.27}_{-0.24}$
μ^{WW}	$1.11^{+0.18}_{-0.17}$
$\mu^{\tau\tau}$	$1.12^{+0.25}_{-0.23}$
μ^{bb}	$0.69^{+0.29}_{-0.27}$

Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.7
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0

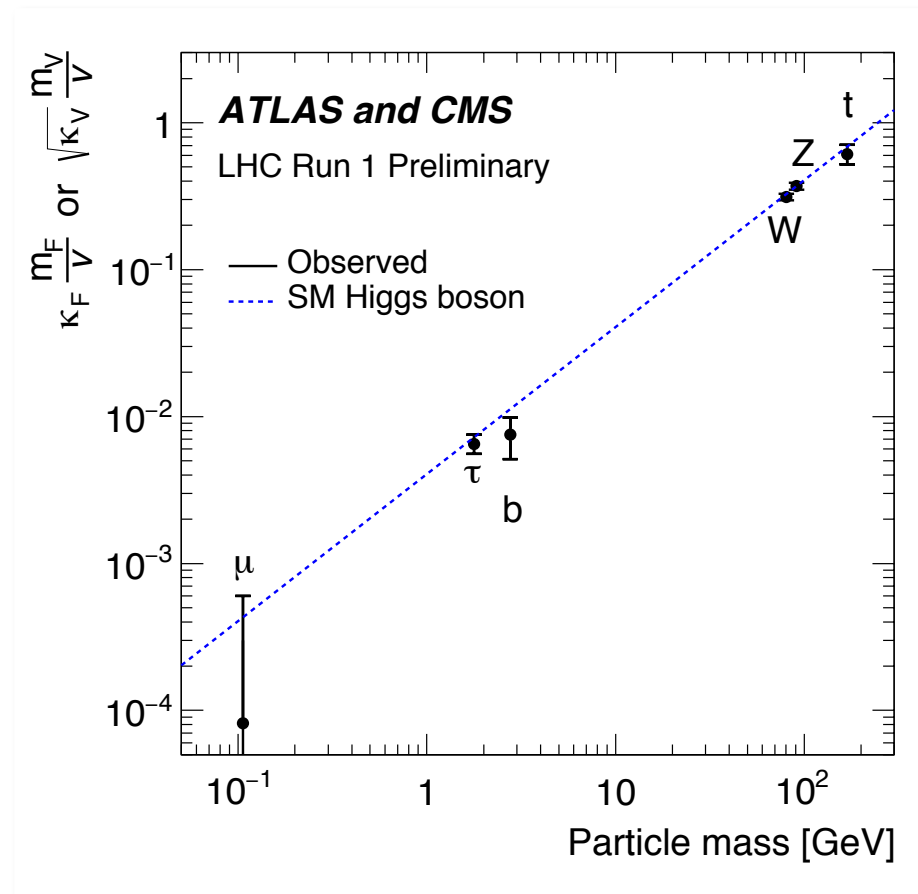
Decay channel	Measured significance (σ)	Expected significance (σ)
$H \rightarrow \tau\tau$	5.5	5.0
$H \rightarrow b\bar{b}$	2.6	3.7

VBF production and $\tau\tau$ decay at 5σ when combining ATLAS+CMS

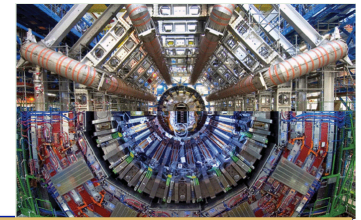
Higgs Run 1 combination



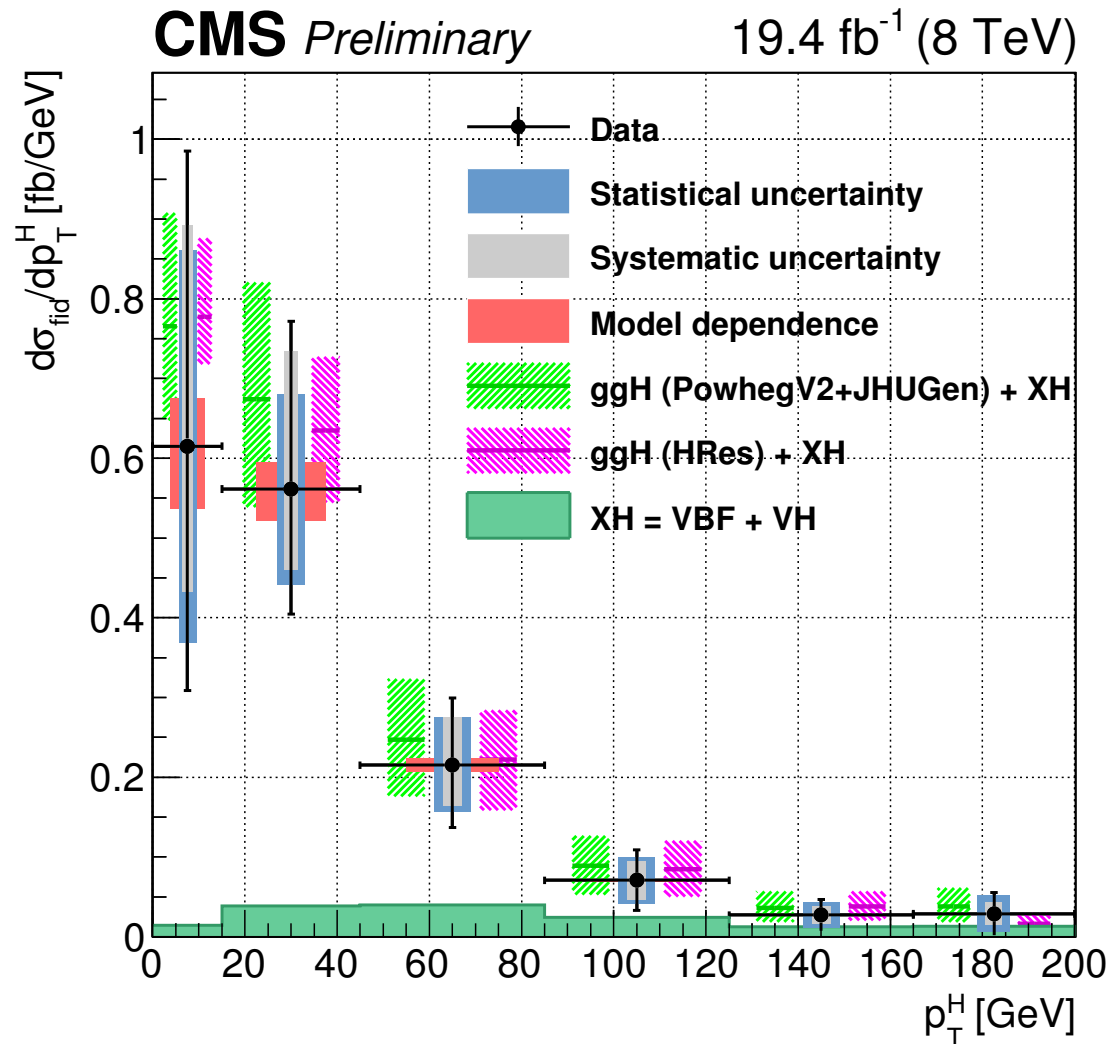
$$y_{F,i} = \kappa_{F,i} \frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i} \frac{m_{F,i}}{v} \quad y_{V,i} = \sqrt{\kappa_{V,i} \frac{g_{V,i}}{2v}} = \sqrt{\kappa_{V,i}} \frac{m_{V,i}}{v}$$



Differential p_T ($H \rightarrow WW$)



CMS-PAS-HIG-15-010

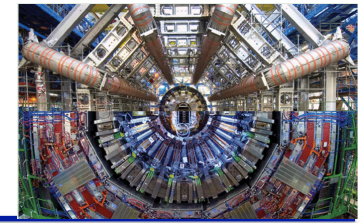


- Differential distributions can give additional information on production mode
- Measured for first time in WW channel in fiducial region of $e\mu$ selected events
- Unfolded spectrum in agreement with Powheg (NLO + Pythia8) and HRES (NNLO + NNLL resummation) predictions

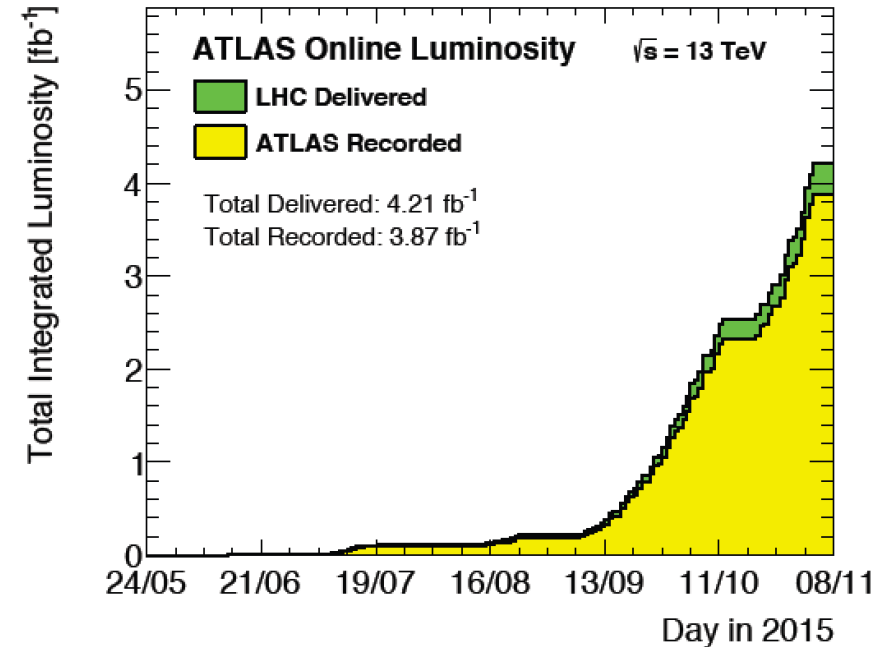
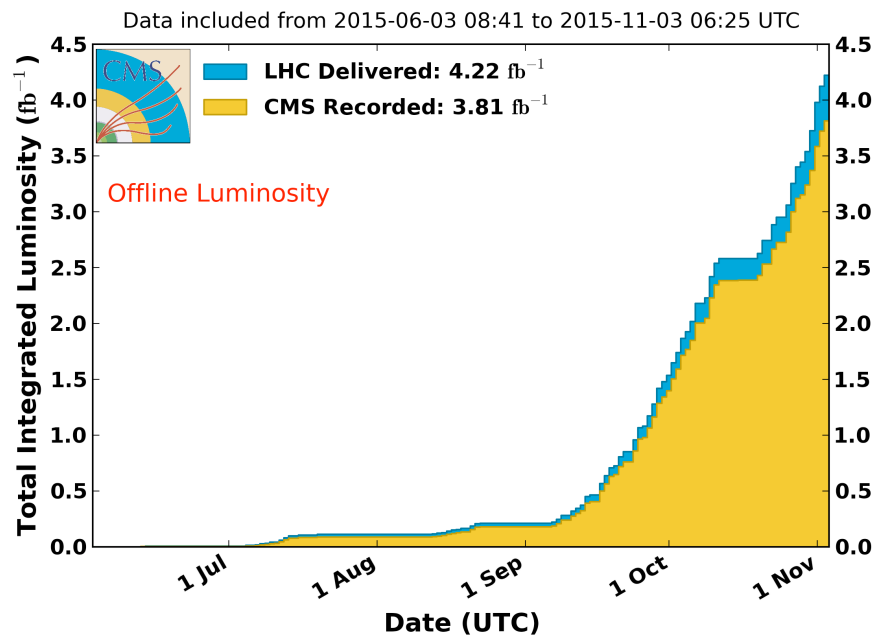
$$\sigma(\text{fid.}) = 39 \pm 8 \text{ (stat.)} \pm 9 \text{ (syst.) fb}$$

Prediction from Powheg 2.0 (ggH + XH): $48 \pm 8 \text{ fb}$

Run 2



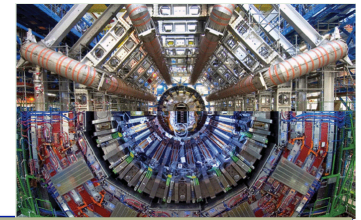
CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV



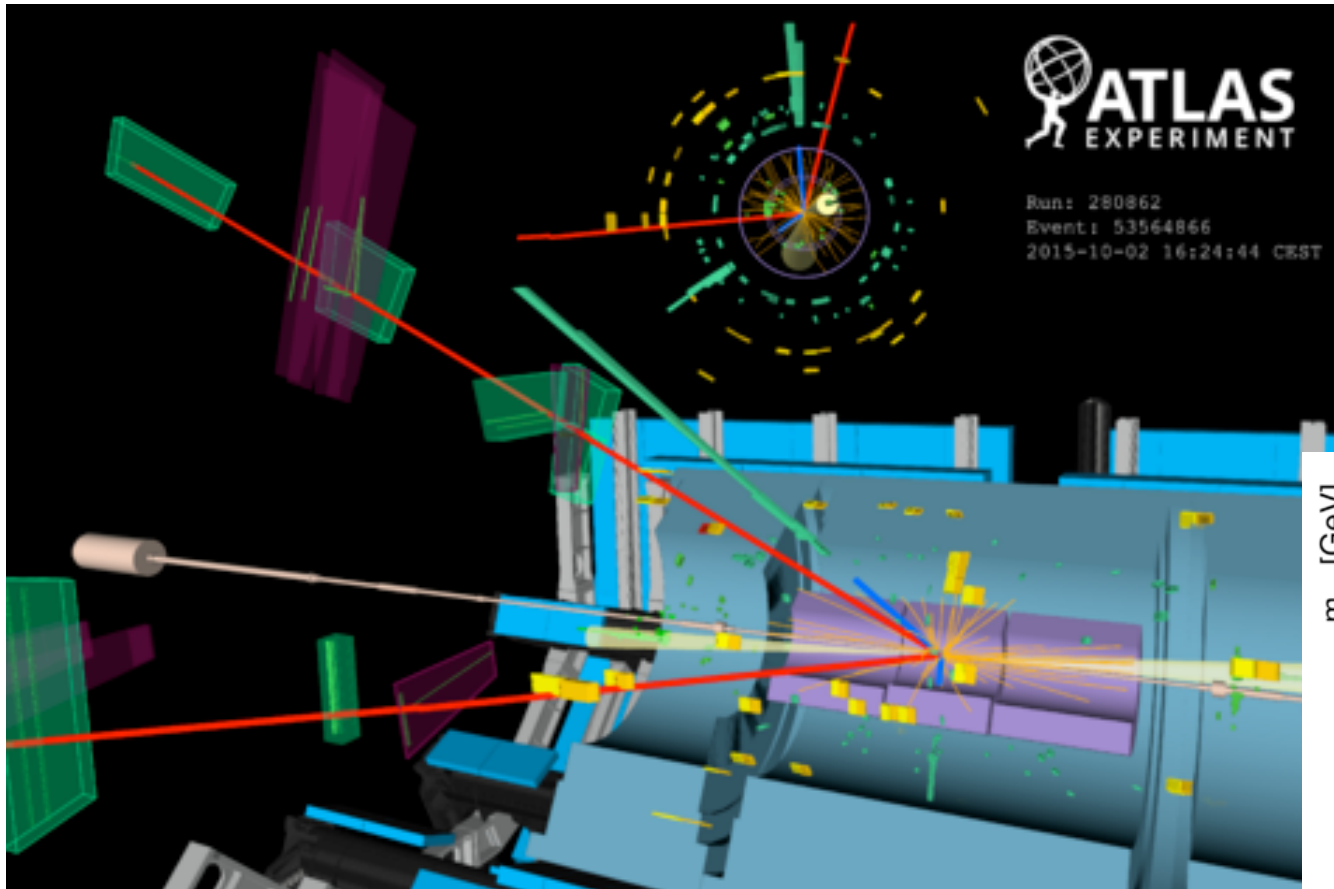
- ~ 2.7 fb⁻¹ used by CMS due to solenoid cold-box problem
- pileup ~ 13
- Increase of Higgs cross sections at 13 TeV compared to 8 TeV

	ggH	VBF	VH	ttH
13TeV/ 8 TeV	2.3	2.4	2.0	3.8

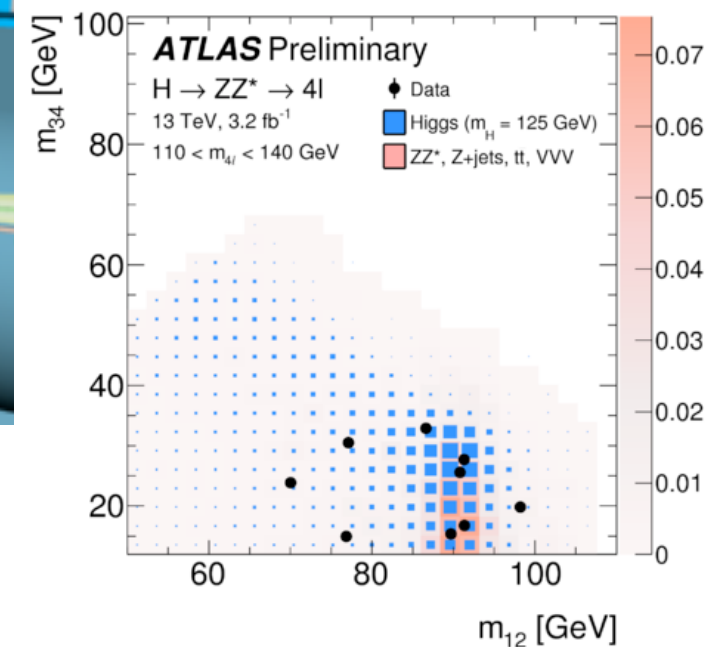
Higgs- $\rightarrow$ $ZZ^* \rightarrow$ 4 leptons



ATLAS-CONF-2015-059

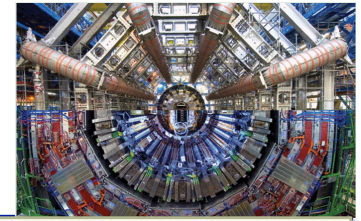


- Better S/B ratio compared to Run I

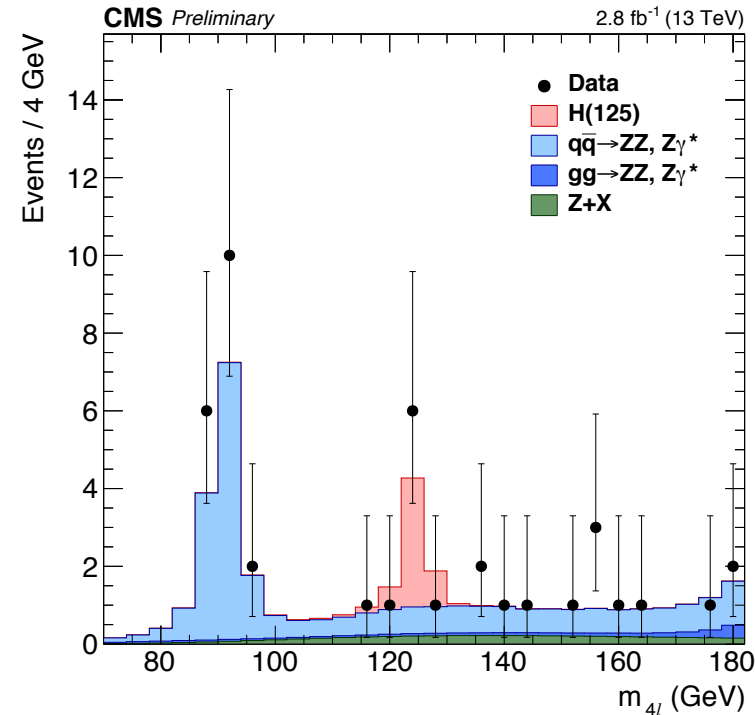
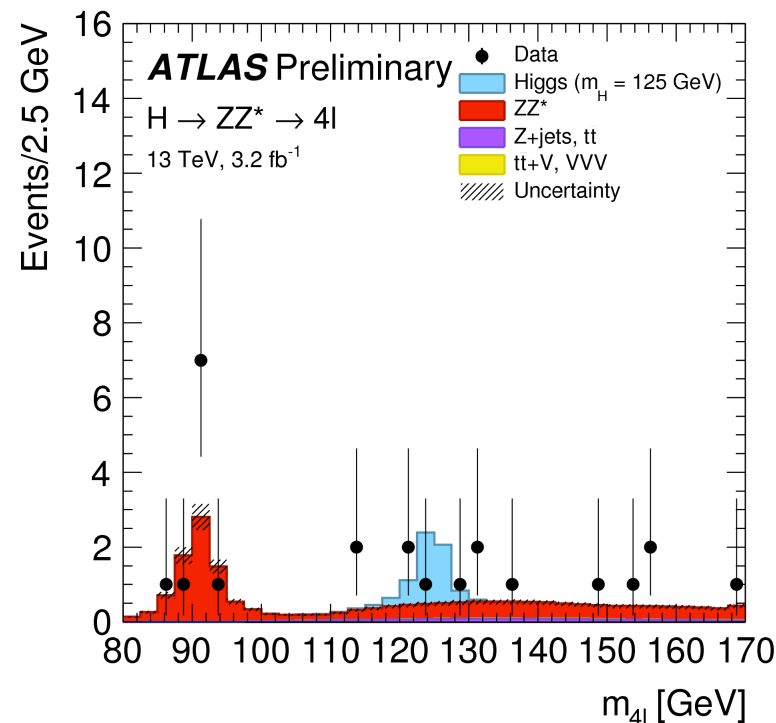


2e2 μ candidate, $m_{4l}=129$ GeV, $m_{jj}=2$ TeV, $\Delta\eta_{jj}=6.4$

Higgs- $\rightarrow$ $ZZ^* \rightarrow 4$ leptons



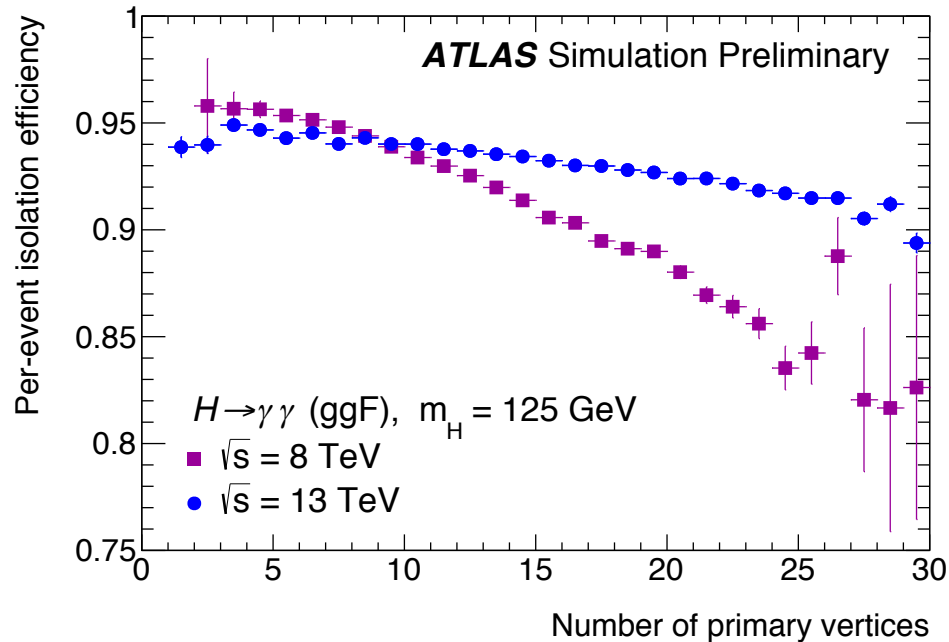
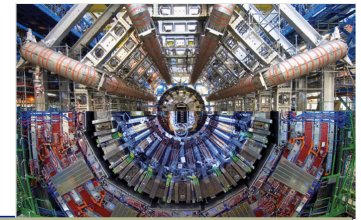
ATLAS-CONF-2015-059 and CMS-PAS-HIG-15-004



$N_S = 1.0^{+2.3}_{-1.5}$ after 1D fit of m_{4l}
SM expected = 4.6 events, observation compatible with SM inside 1.4σ
1 event at $m_{4l} = 129$ GeV consistent with VBF topology

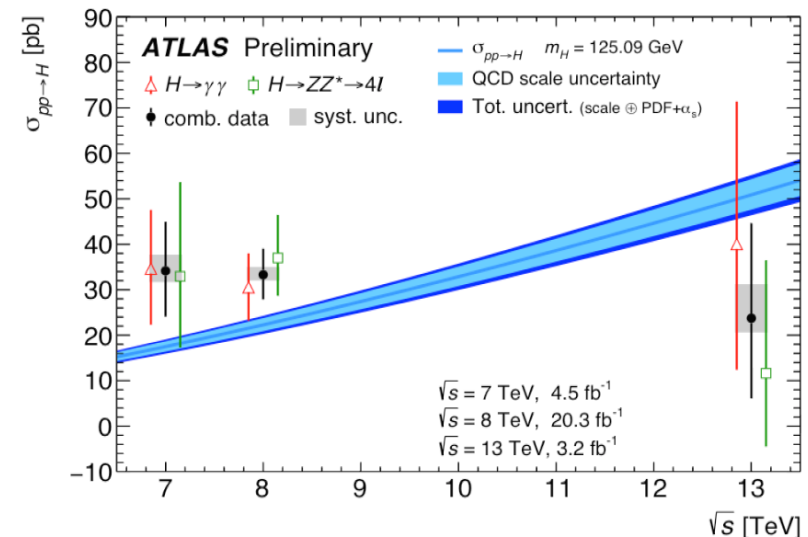
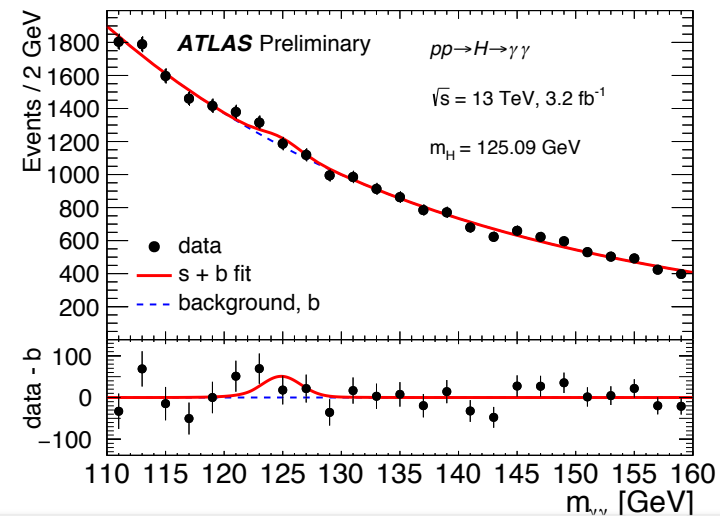
2D fit of m_{4l} and matrix element discriminant to extract the signal strength
 $\mu = 0.82^{+0.57}_{-0.43}$
Observed (expected) significance = 2.5σ (3.4σ)

Higgs- $\rightarrow\gamma\gamma$

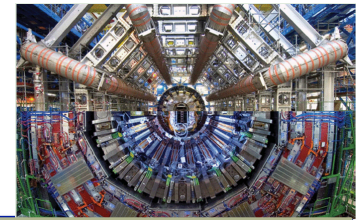


- Improved photon selection vs pileup dependence (i.e. photon isolation), vertex identification with ANN
- Observed (expected) significance = 1.5σ (1.9σ)
- Cross section measured and compared to 7 and 8 TeV (and 4l)

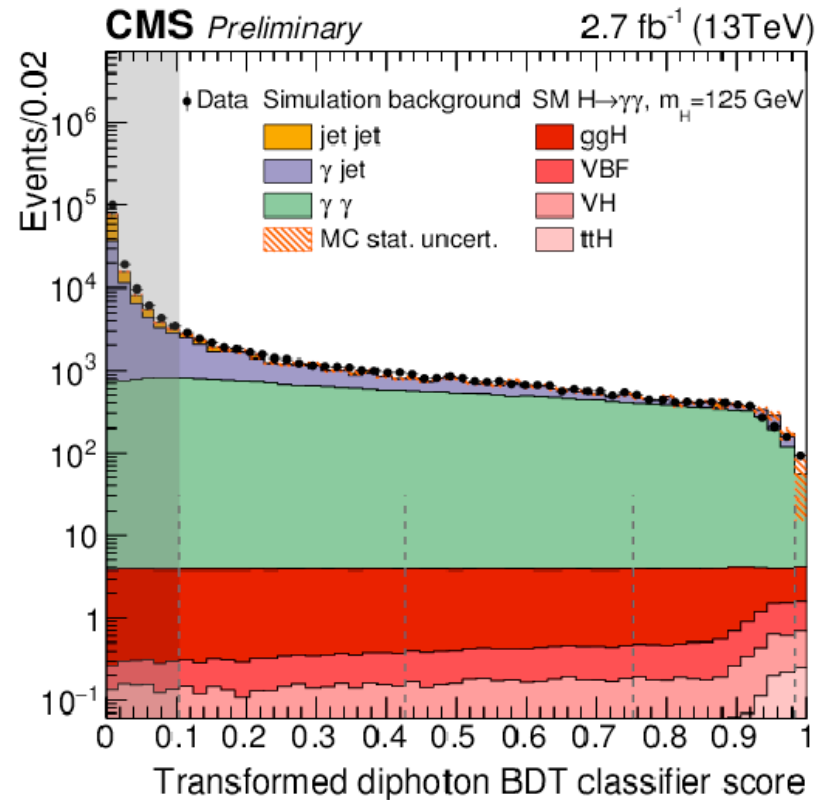
ATLAS-CONF-2015-060, -069



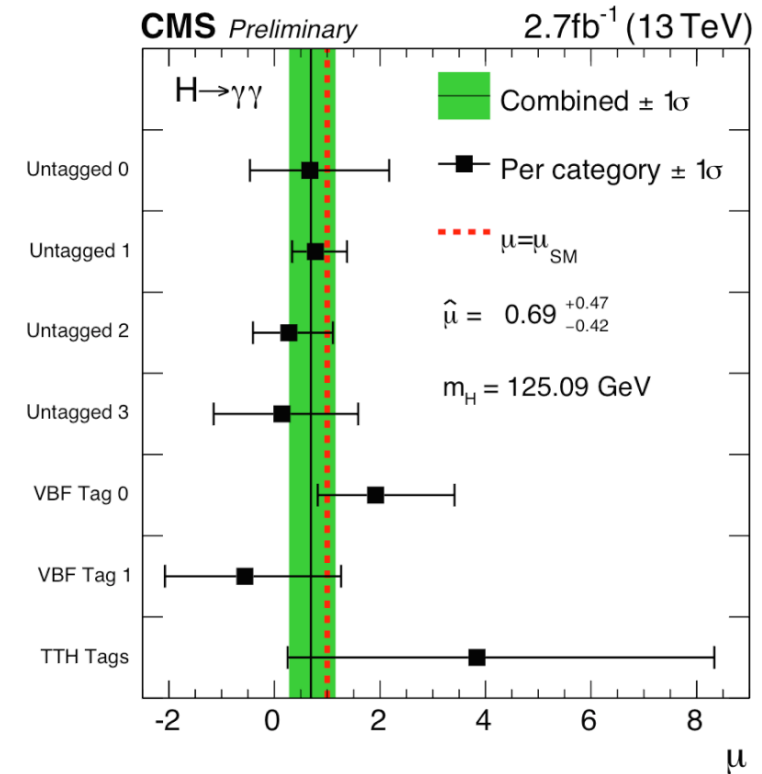
Higgs- $\rightarrow\gamma\gamma$



CMS-PAS-HIG-15-005

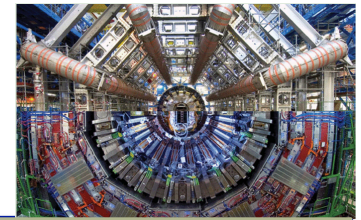


- 8 categories, 4 according to the BDT of the diphoton, 2 VBF, 2 ttH
- BDT to determine vertex of the interaction

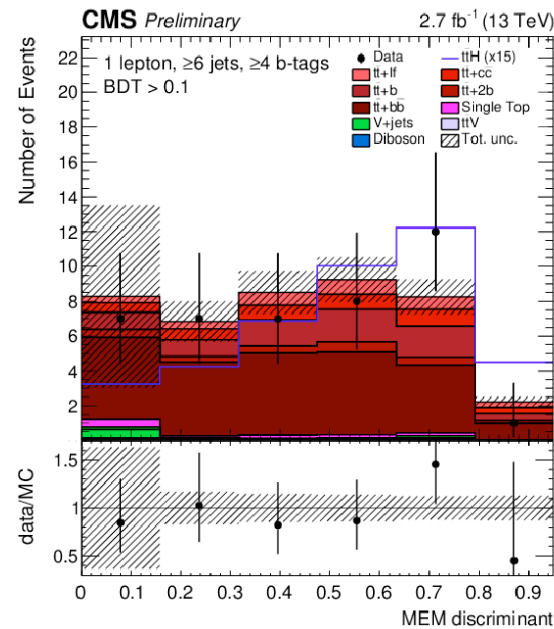
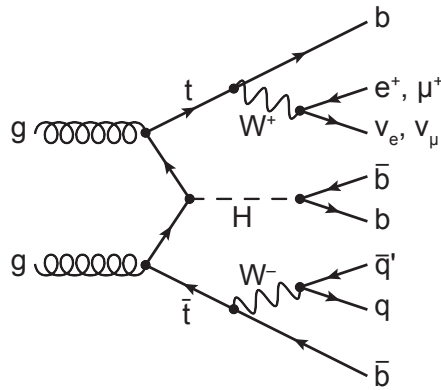


$\mu = 0.69^{+0.47}_{-0.42}$ at $m_H = 125.09$ GeV
 Observed (expected) significance =
 1.7 σ (2.7 σ)

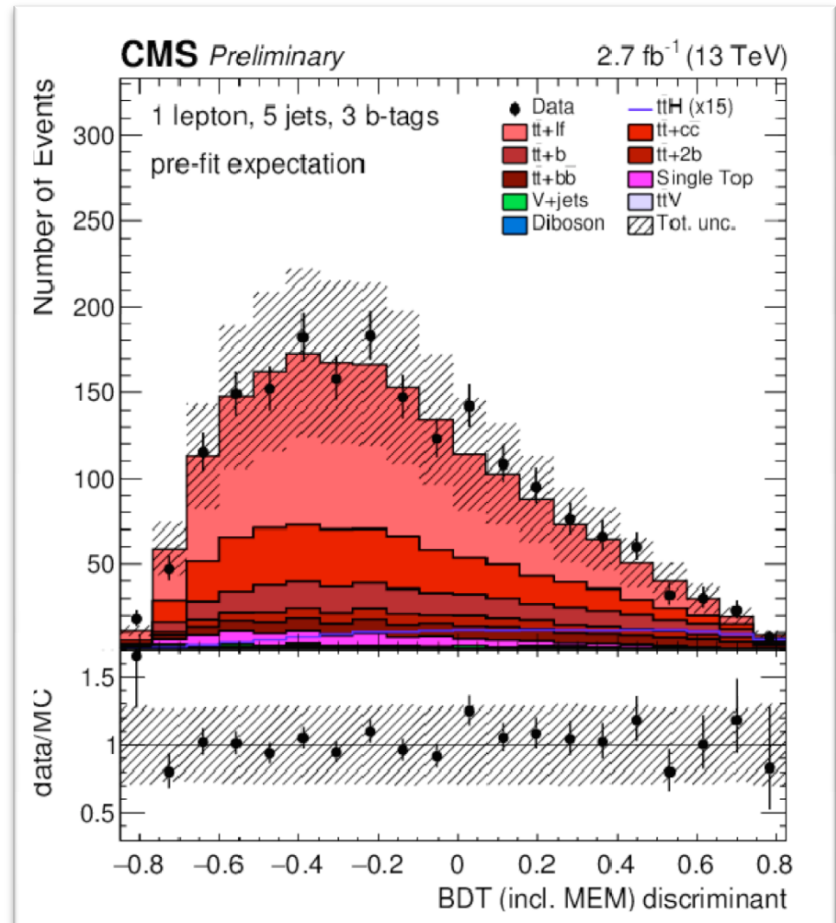
ttH production (H->bb)



CMS-PAS-HIG-16-004

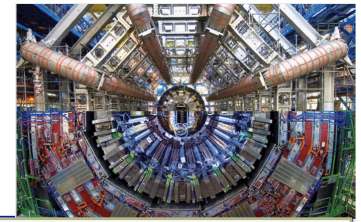


- probe top–Higgs coupling ($Y_t \sim 1$)
- 13 different categories in H->bb according to number of jets and b-jets
- New boosted category for l+jets (fat-jet), for p_T of the top or Higgs $> \sim 200$ GeV
- Exploit Matrix Element Method to separate ttbb from ttH in l+jets

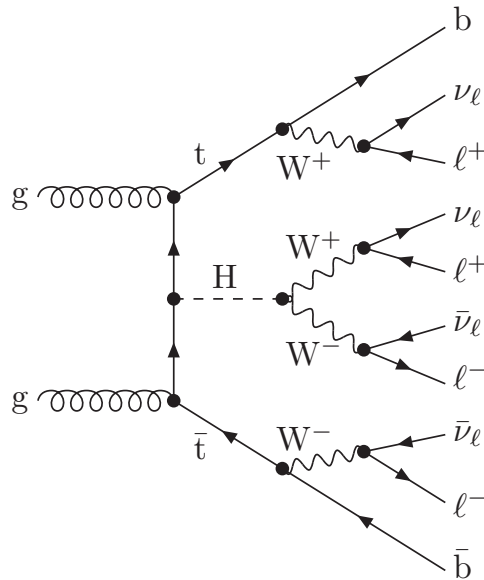


MEM included in discriminator variable
or used in 2D fit together with BDT

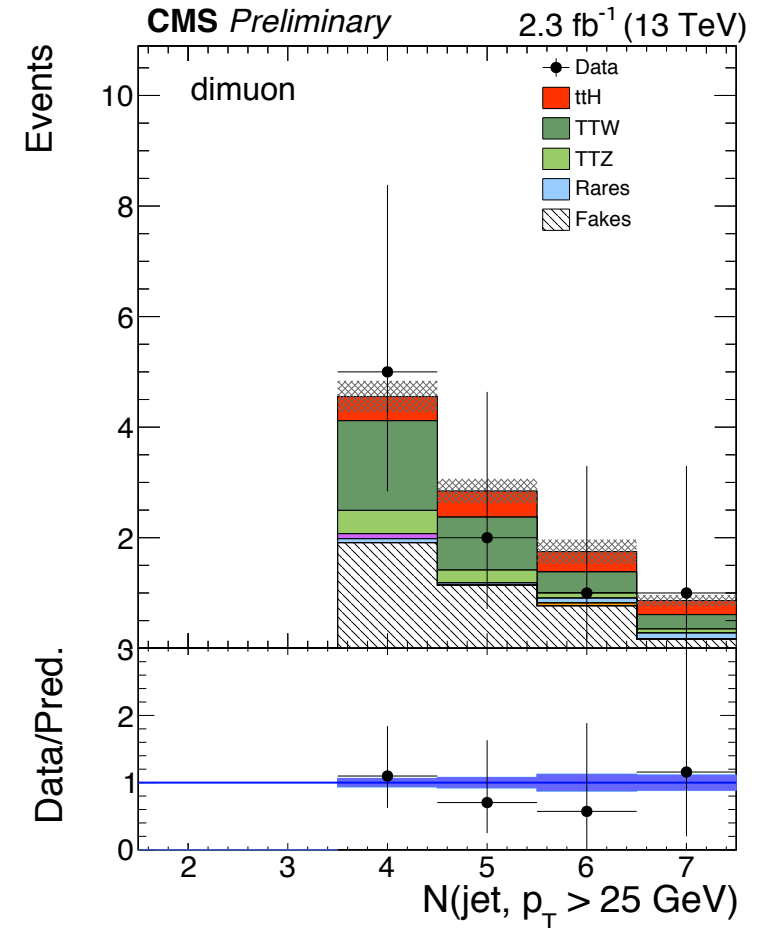
ttH production (multilepton)



CMS-PAS-HIG-15-008

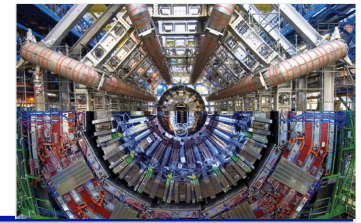


- Targets WW^* , ZZ^* and $\tau\tau$ Higgs decays, excess observed in Run I in same-sign muons
- Signature with ≥ 3 leptons, or two same-sign leptons
- Identification of signal leptons from background leptons using Boosted Decision Trees
- Fake leptons background determined from data in control region

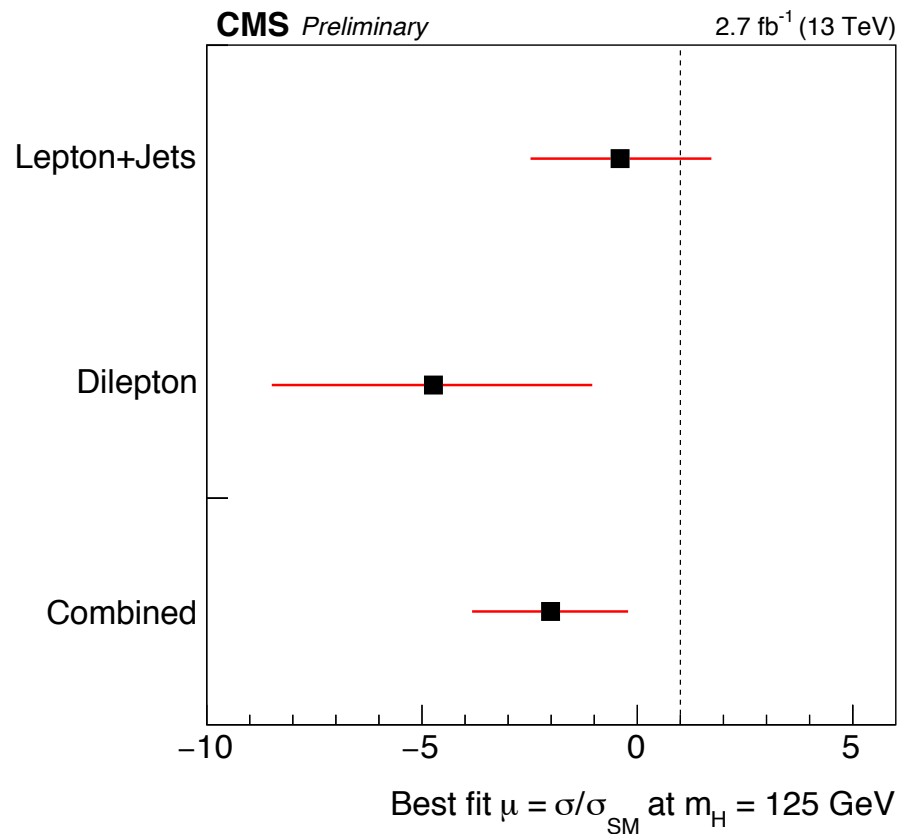


Same-sign dimuon sample

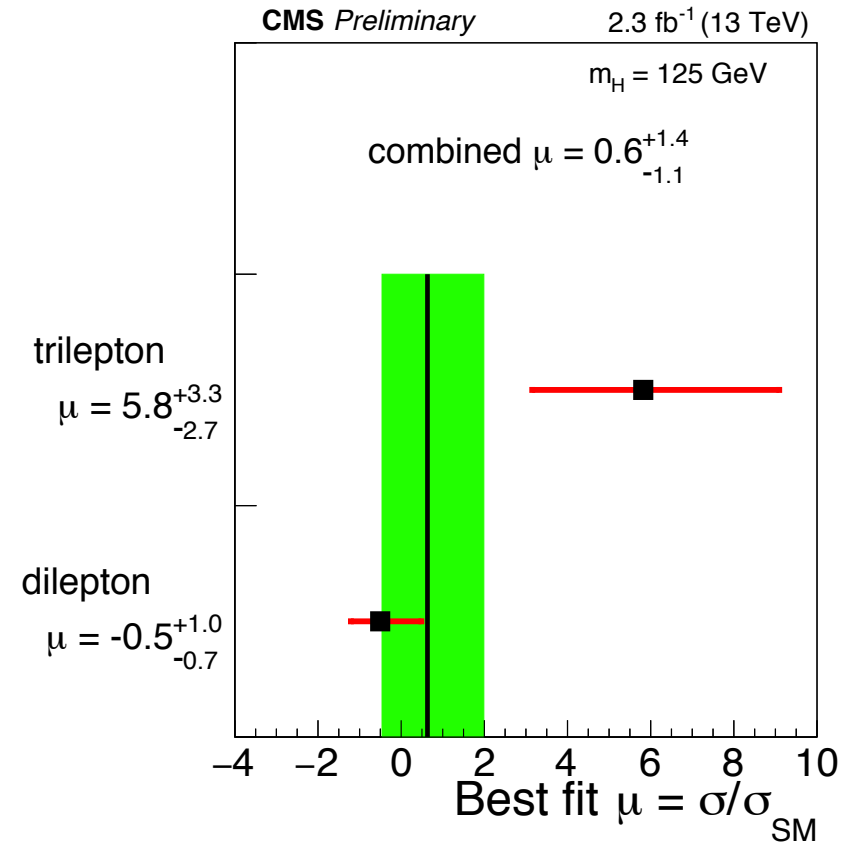
ttH production Run 2 summary



H->bb

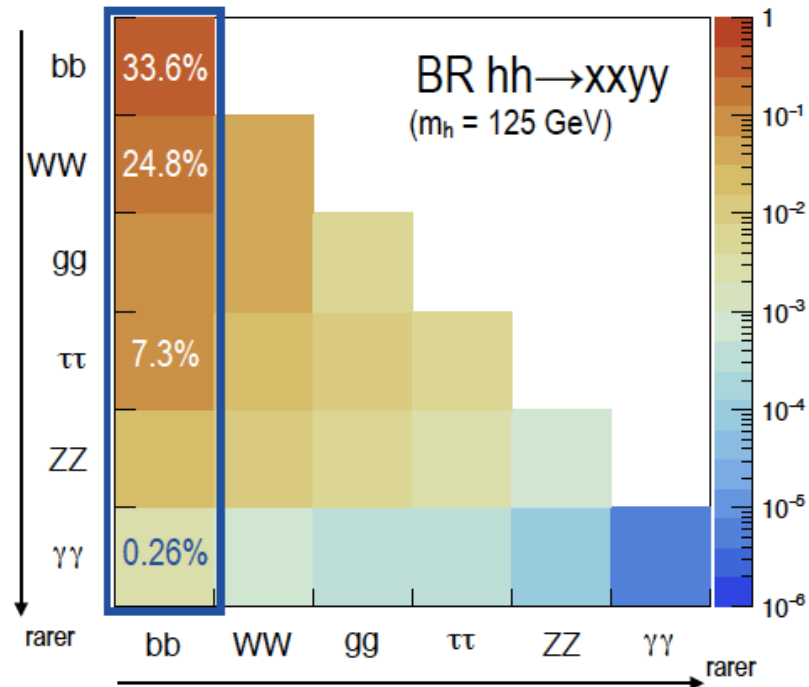
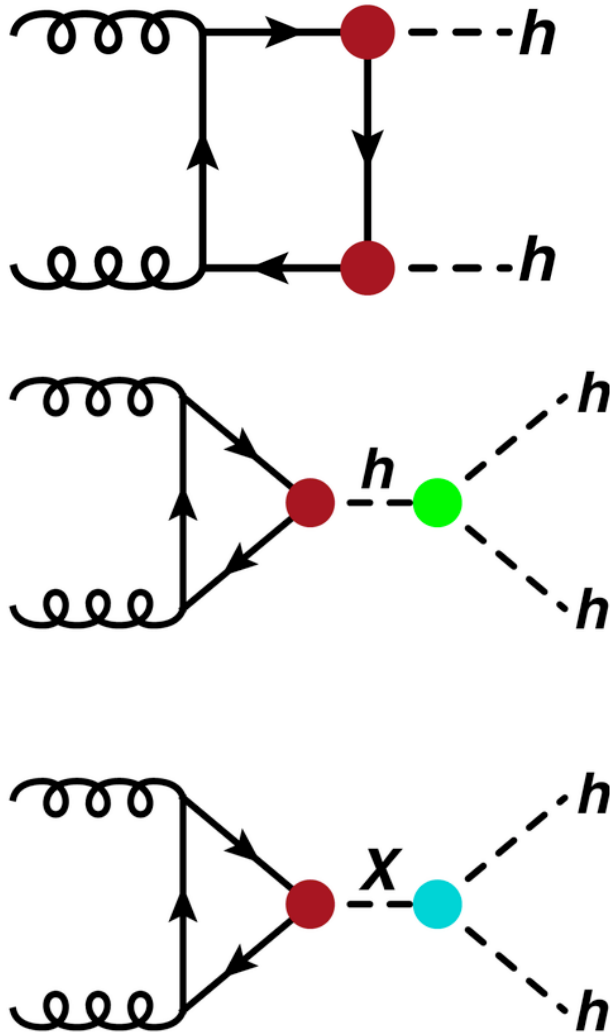
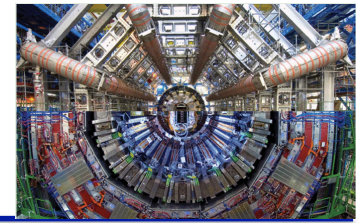


multilepton channel



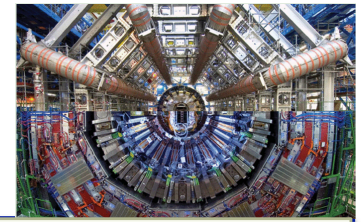
CMS combined ($\gamma\gamma$ +multilepton+bb) Run II: $\mu = 0.15^{+0.95}_{-0.81}$ (obs.), $1.00^{+0.96}_{-0.85}$ (exp.)

Double Higgs production

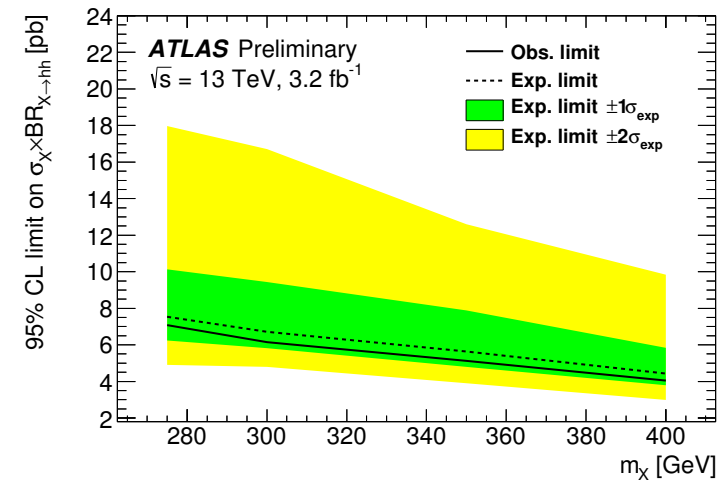
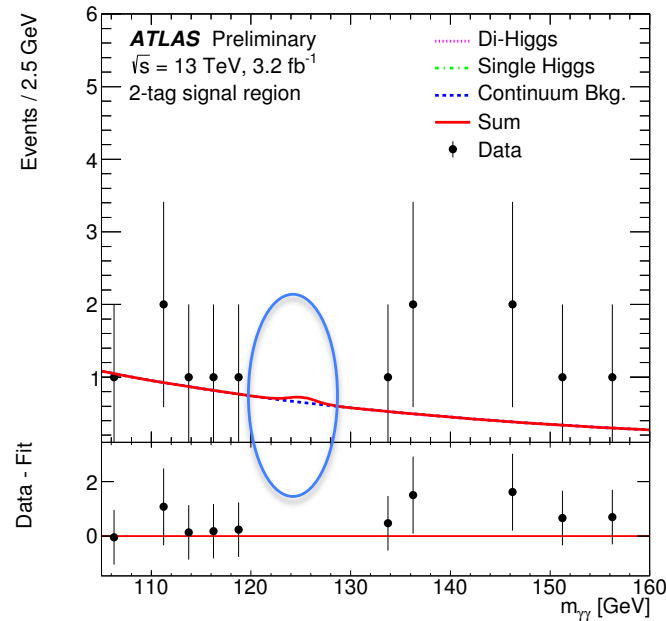


- Process sensitive to self-coupling λ and to possible new physics (X)
- In SM: $\sigma(13 \text{ TeV}) \sim 38 \text{ fb}$, $\sigma(8 \text{ TeV}) \sim 10 \text{ fb}$
- Exploit decay channels with highest branching ratios (need $h \rightarrow bb$)
- Both resonant and non-resonant searches

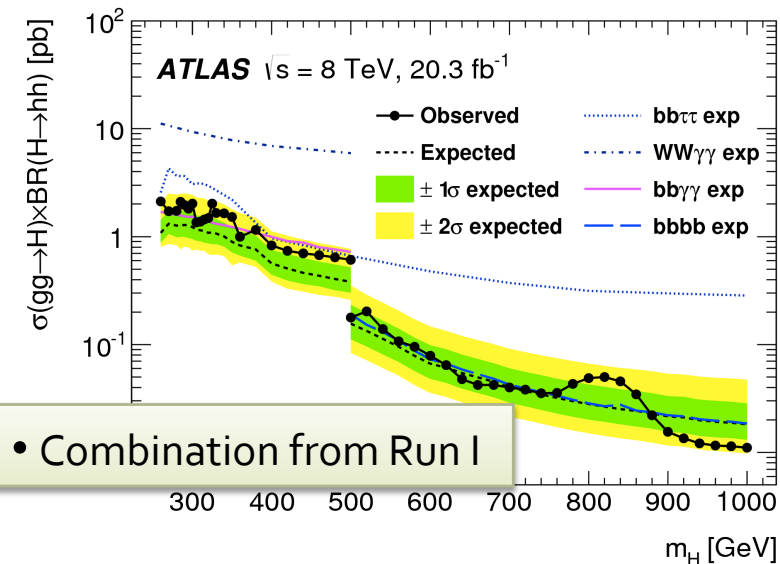
hh->bbγγ



ATLAS-CONF-2016-004



- bbyy final state
- Search for resonant production shown here, where marginal excess (2.4 σ) was reported in Run I, 5 (1.5) events observed (expected) in mass region
- No event observed in mass region in Run II



• Combination from Run I

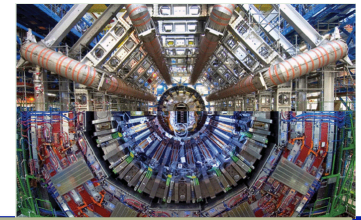


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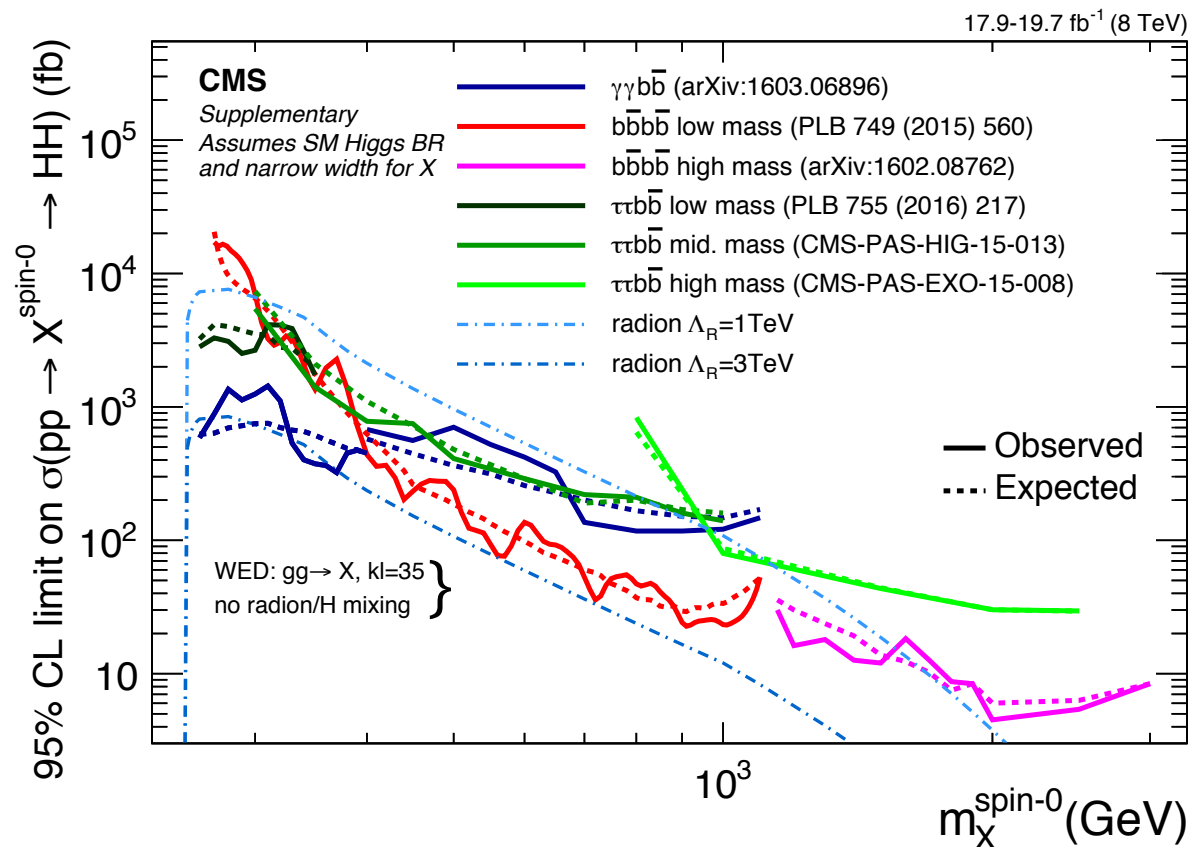
E. Gallo – Higgs Physics

Double Higgs production

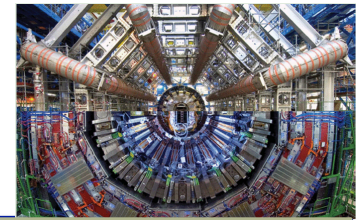


CMS Run I Double Higgs Combination

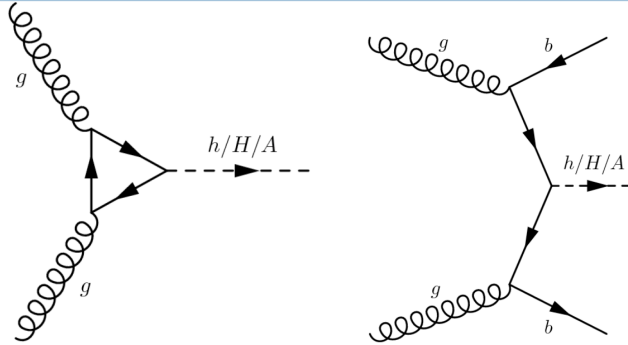
- Compilation of Run I final states from CMS for spin-zero resonant states
- $\gamma\gamma b\bar{b}$ most sensitive channel at low mass, $b\bar{b}b\bar{b}$ at high mass
- Set limits on radion, scalar particles in warped extra-dimensions models



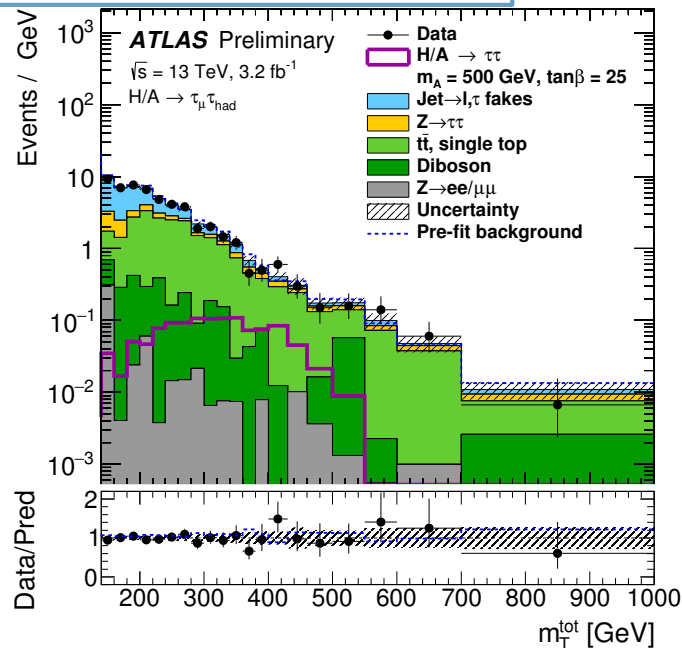
Search for MSSM H/A- $\tau\tau$



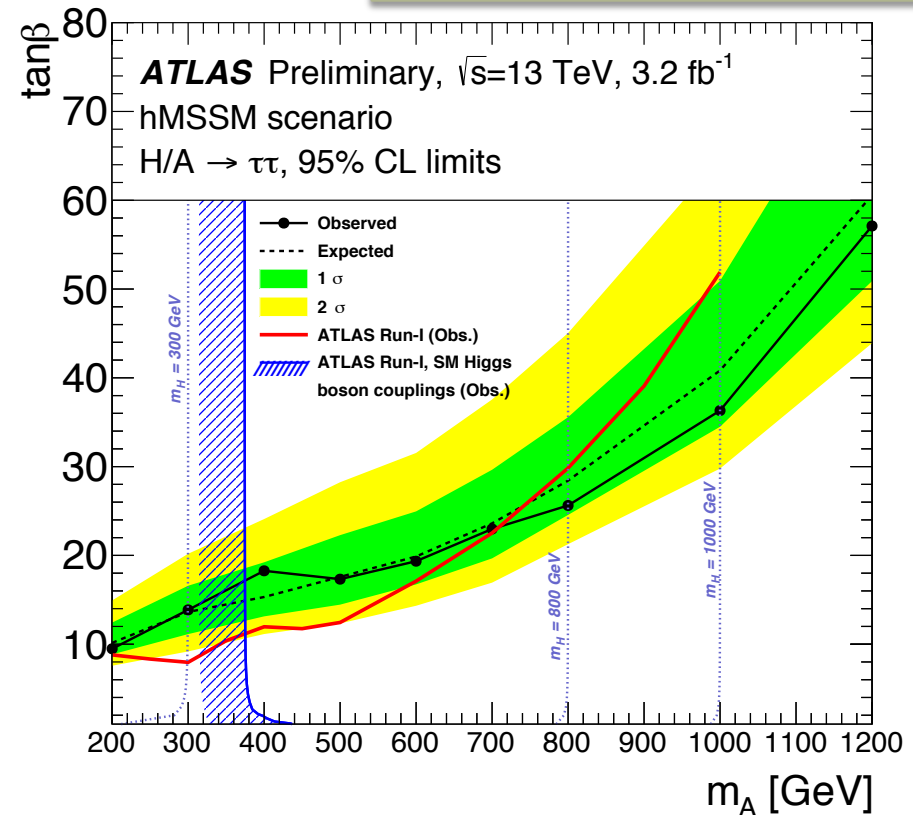
Inclusive search in $\tau_{\text{lep}}\tau_{\text{had}}, \tau_{\text{had}}\tau_{\text{had}}$



$$m_T^{\text{tot}} = \sqrt{m_T^2(E_T^{\text{miss}}, \tau_1) + m_T^2(E_T^{\text{miss}}, \tau_2) + m_T^2(\tau_1, \tau_2)}$$

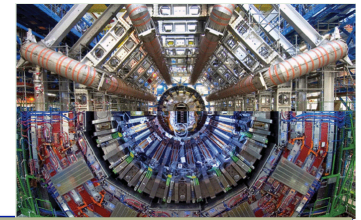


ATLAS-CONF-2015-061

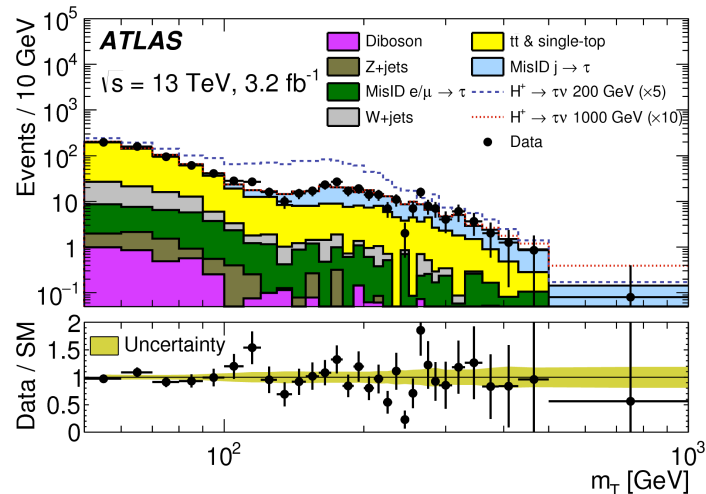
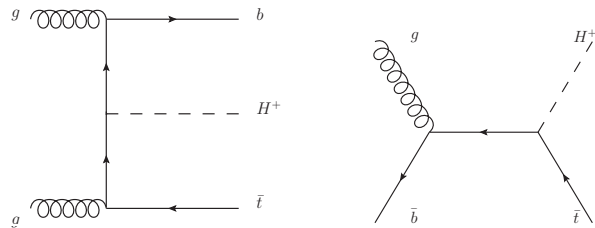


- hMSSM scenario, where the light h has mass=125 GeV
- limits better than Run I for $m_A > \sim 700 \text{ GeV}$ and limits extend up to 1.2 TeV

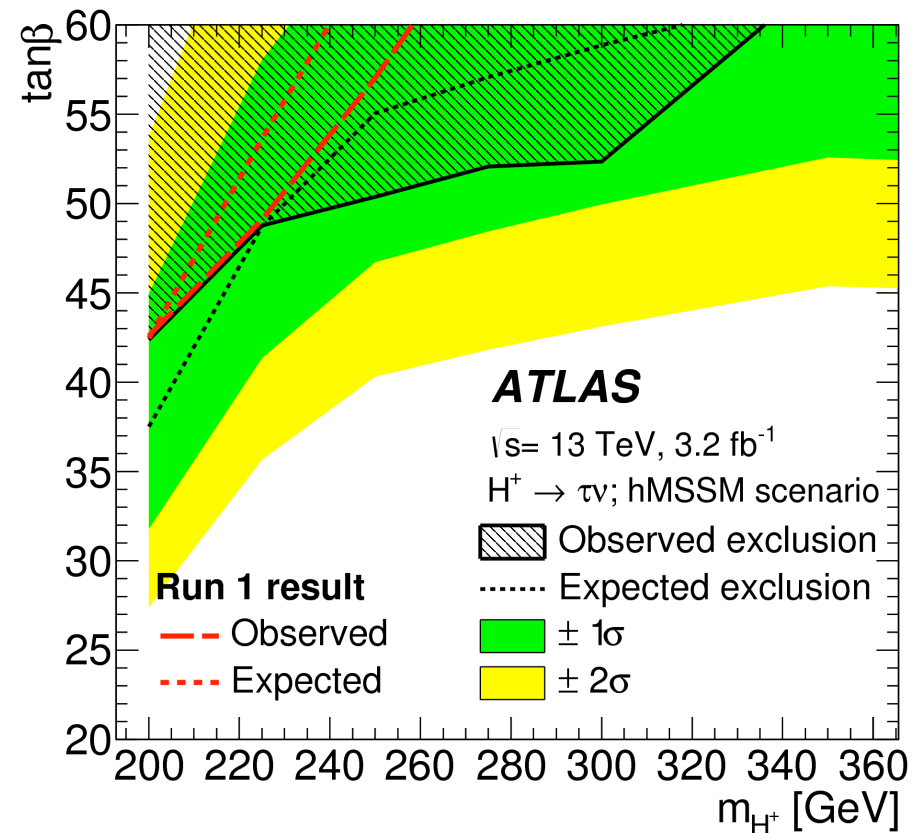
Search for a charged $H^{\pm} \rightarrow \tau \nu$



ATLAS arXiv:1603.09203

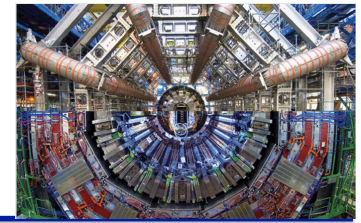


- Search for $H^{\pm}$ with mass greater than m_{top} , associated production with a top
- $H^{\pm} \rightarrow \tau \nu$, and both τ and top decay hadronically (no e, μ in the final state)
- No signal observed in transverse mass

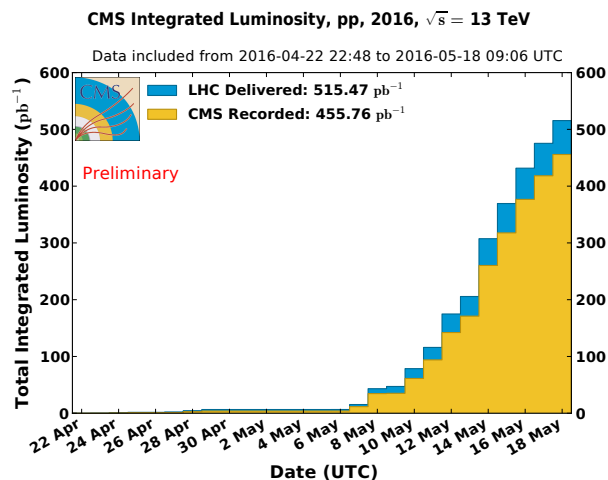


Values of $\tan\beta$ in the range 42-60 are excluded for masses ~ 200 GeV, at $\tan\beta \sim 60$ mass values excluded up to 340 GeV

Summary



- Run 1, combination gives signal strength $\mu = 1.09 \pm 0.07$ (stat.) ± 0.08 (syst.). The VBF production is measured with a measured significance of 5.4σ , $H \rightarrow \tau\tau$ measured with 5.5σ from the combination.
- Run 2, channels 4ℓ leptons and $\gamma\gamma$ measured by ATLAS and CMS at 13 TeV, fiducial cross sections measured. $t\bar{t}H$ measurement from CMS from 3 combined decay channels, $\mu = 0.15^{+0.95}_{-0.81}$ (obs.), $1.00^{+0.96}_{-0.85}$ (exp.)
- Run 2 luminosity still limited but methods for analysis prepared. Fiducial and differential cross sections are part of the analysis now. Some Run 2 limits on new heavy Higgs states already competitive to Run 1



Only a selection of results shown here, more in

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

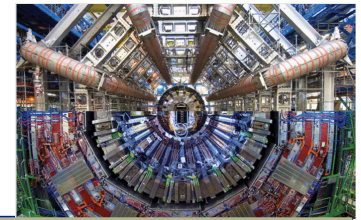
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic>

Run 2016 has started.

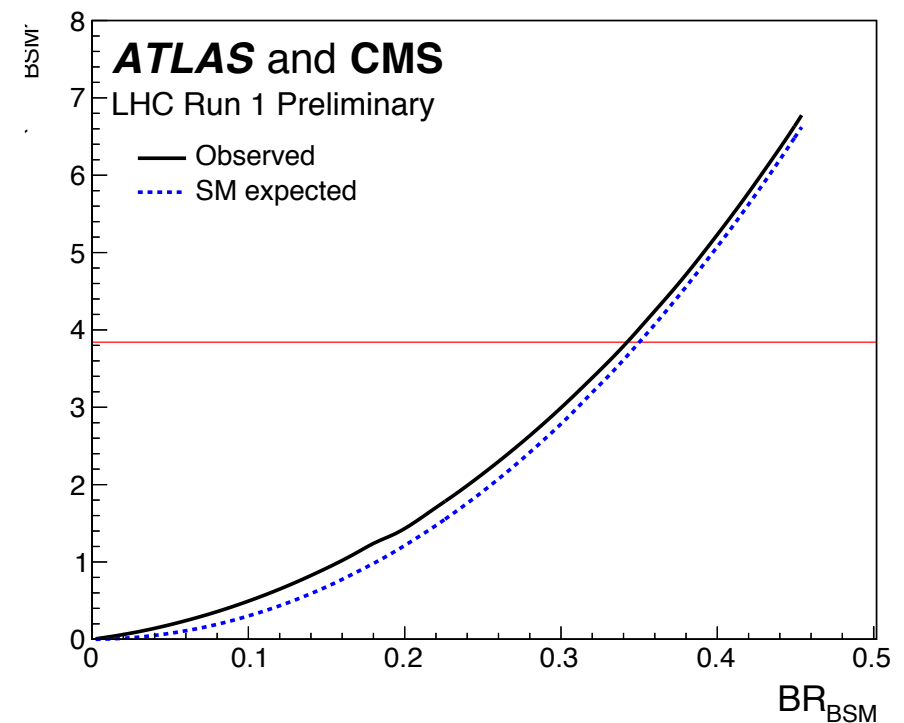
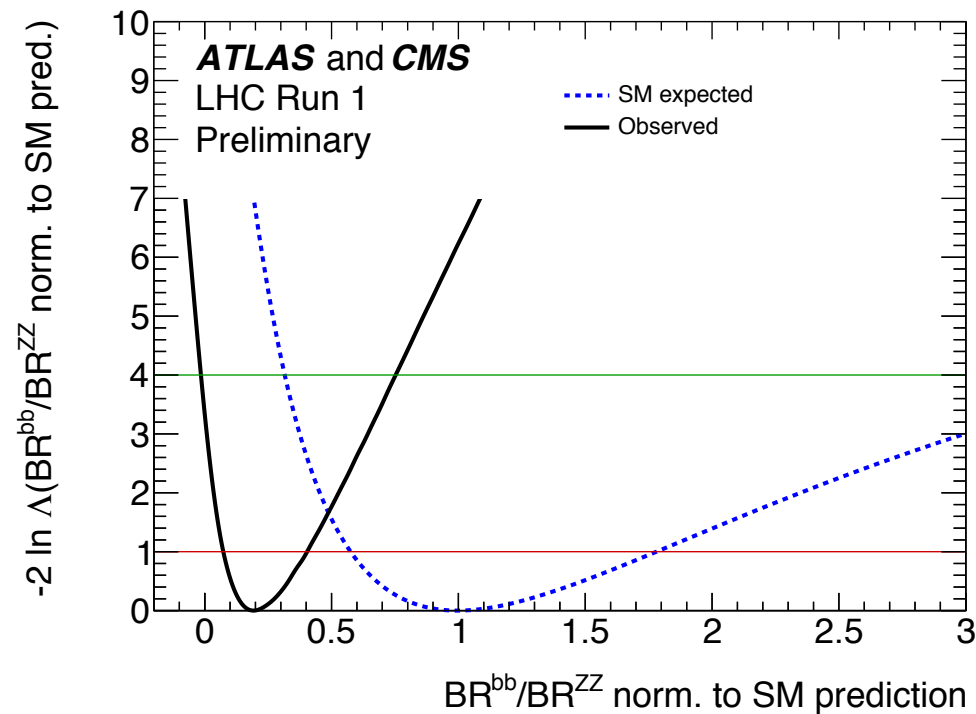
Expect $\sim 25 \text{ fb}^{-1}$ by the end of the year

More results by the summer conferences, still very exciting times ahead for Higgs physics

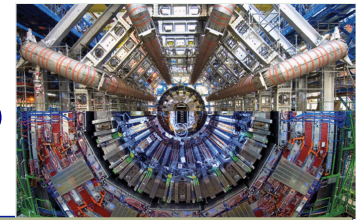
Backup: Run 1 combination



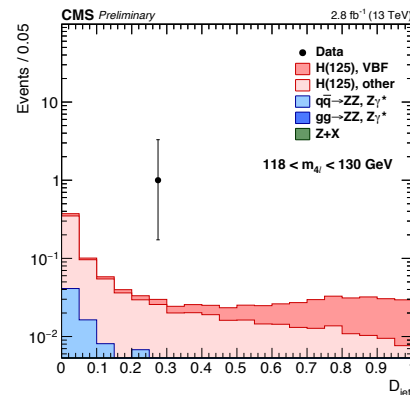
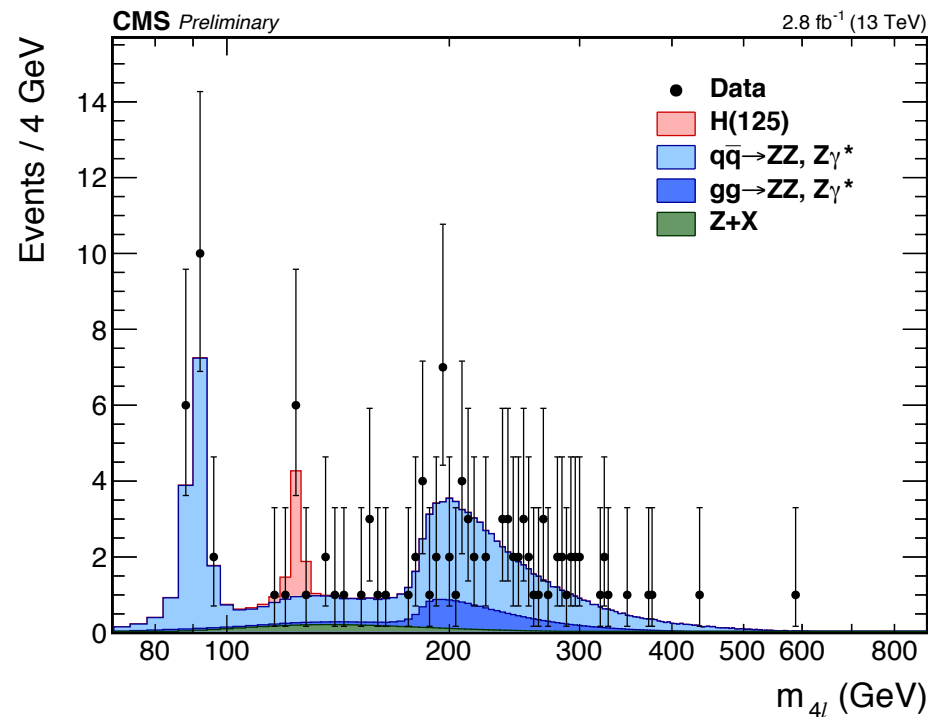
CMS-PAS-HIG-15-002 and ATLAS-CONF-2015-044



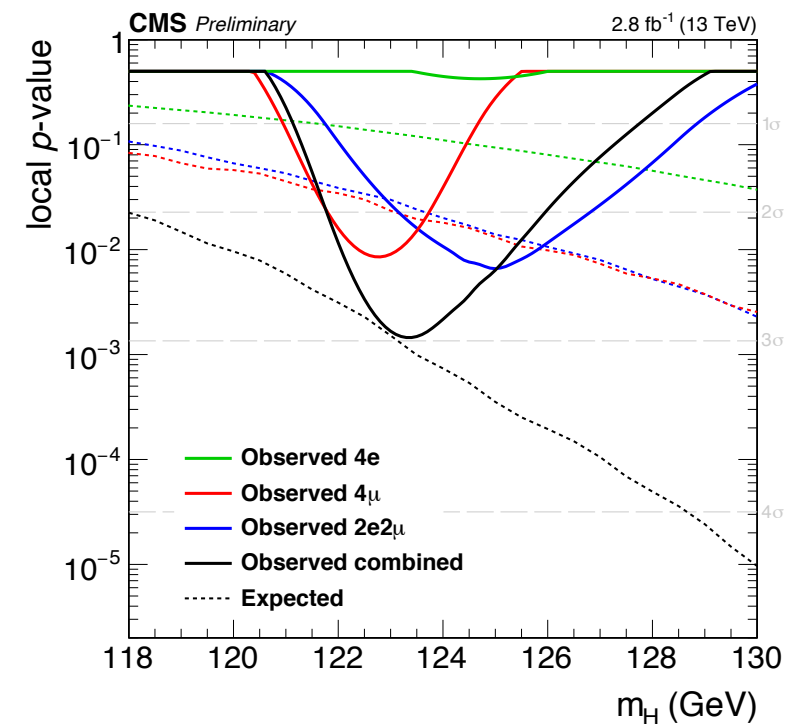
Backup: Higgs-> ZZ*-> 4 leptons



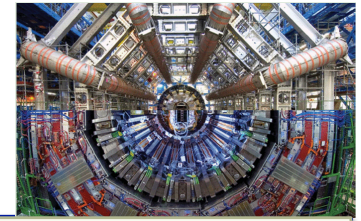
CMS-PAS-HIG-15-004



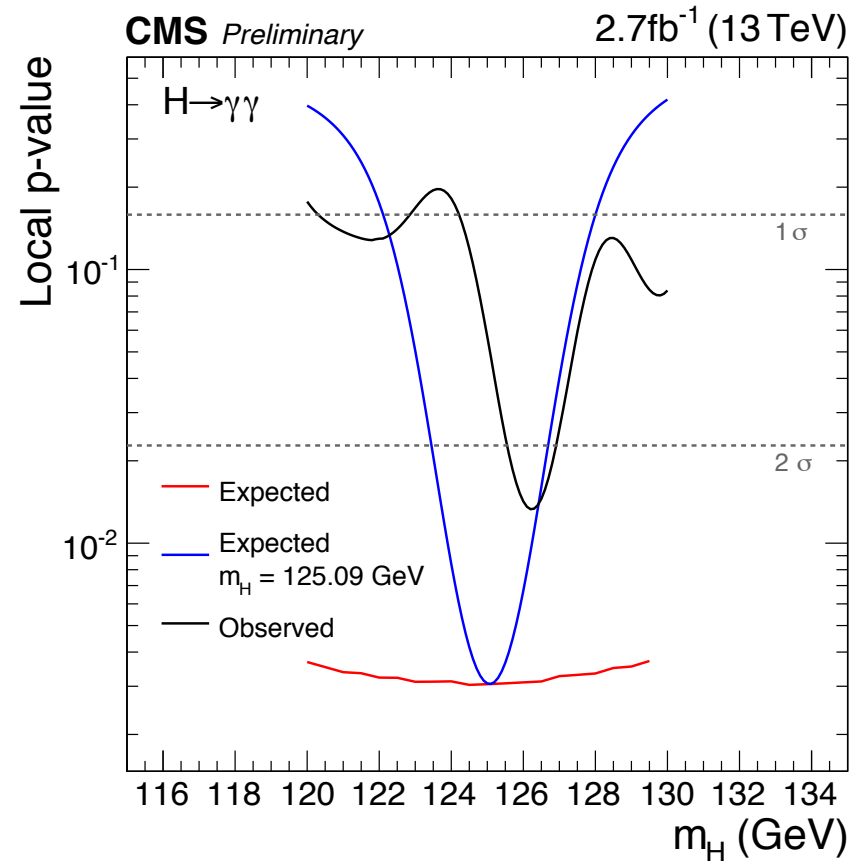
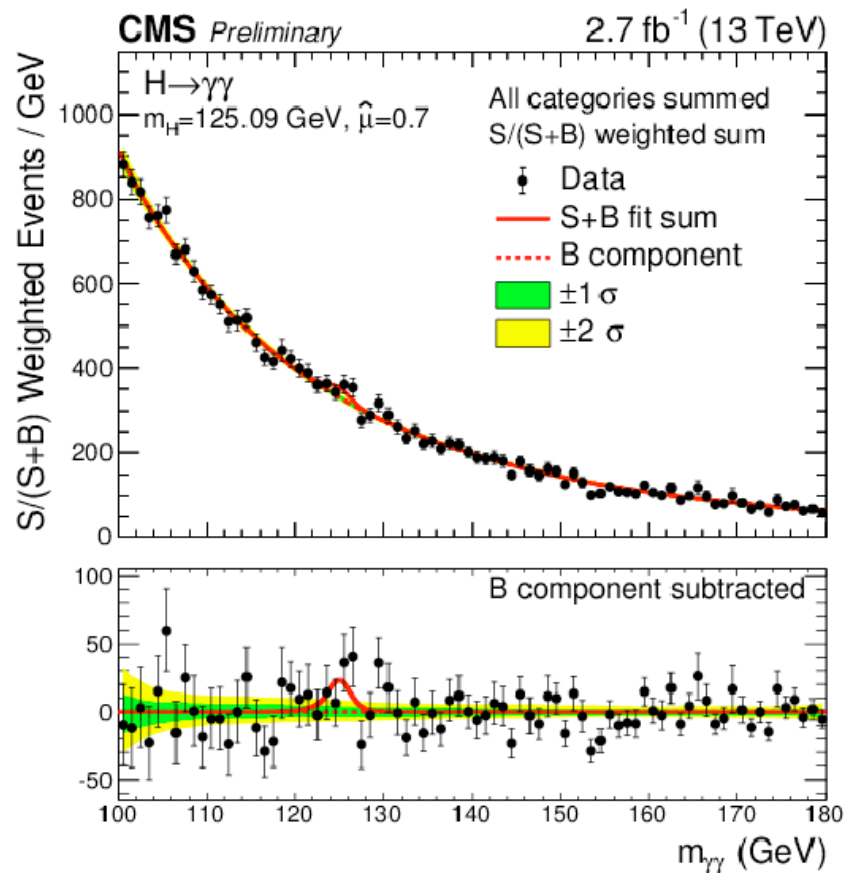
Events with 2 jets



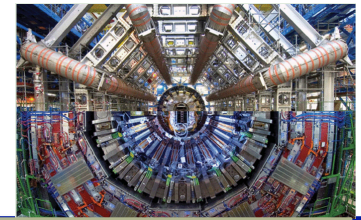
Backup: Higgs- $\rightarrow\gamma\gamma$



CMS-PAS-HIG-15-005

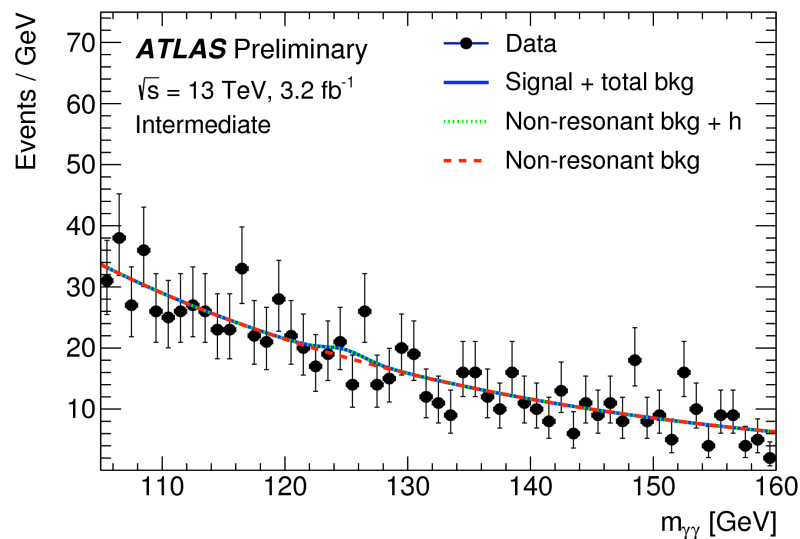
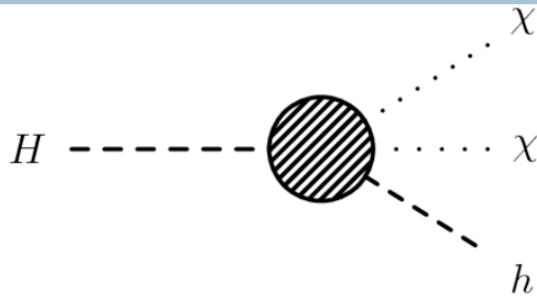


Backup: $\gamma\gamma$ +MET



ATLAS-CONF-2016-011

Search for new physics in diphoton+MET i.e. heavy scalar Higgs decaying in Dark Matter candidates + h



Diphoton mass for intermediate MET, no signal found

