ATLAS Higgs Physics (Selected topics)

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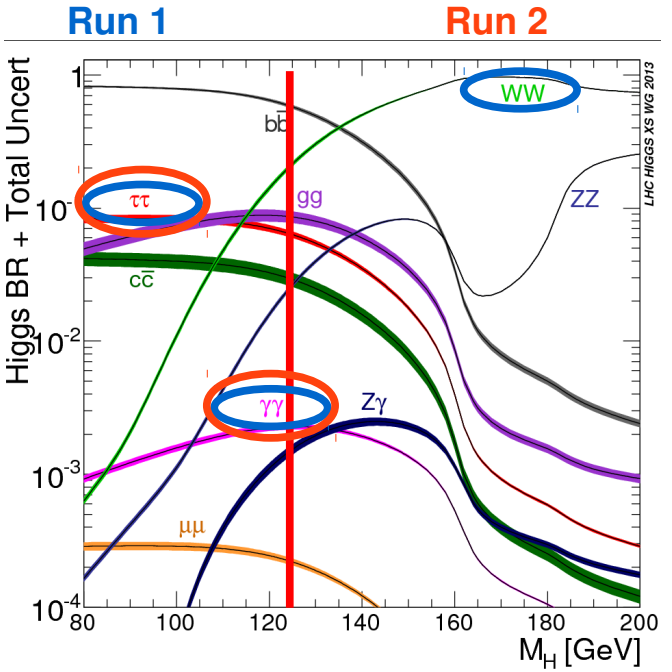
Outline

- A set of Higgs physics results with ATLAS has been selected according to the organizers indications.
- During Run 1, ATLAS-Spain covered all the "big 5" decay modes and some BSM searches. I'm most familiar with H → WW(lνlν), H → γγ, H → ττ and H(125) → τl.
- Current Run 2 Higgs activities: more focus on BSM searches and properties measurements.

- Run 2 H(125) Measurements Results:
  - **H → γγ**
  - **H → ττ**

  } First 13 TeV Higgs results
- Run 2 BSM Searches:
  - **LFV H(125) → τl**
  - **Z',A/H → ττ**
  - **X/H → hh → bbγγ**

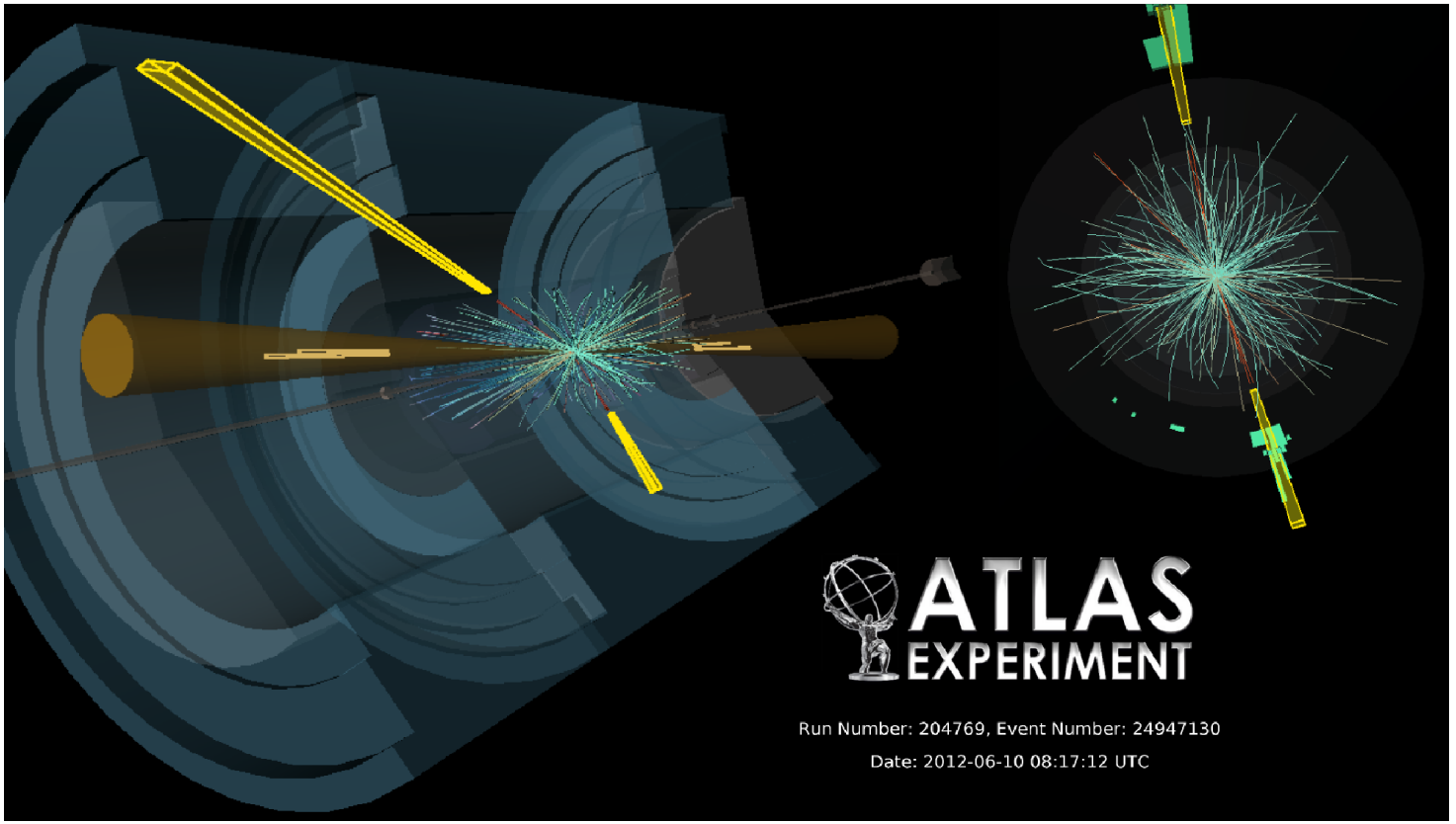
  } First 13 TeV Higgs results

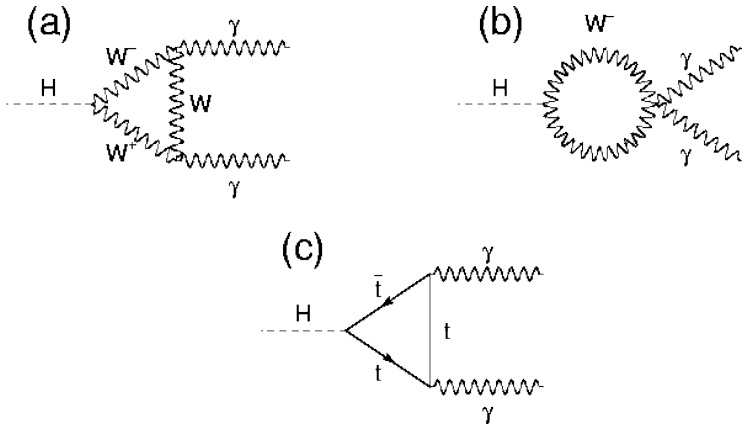


Total Higgs x-section (LHC):
55 pb (55000 evts/fb^{-1}) @13TeV

Only possible to present a short summary of all these analyses in this talk.

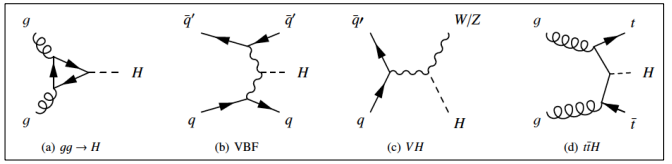
$H \rightarrow \gamma\gamma$



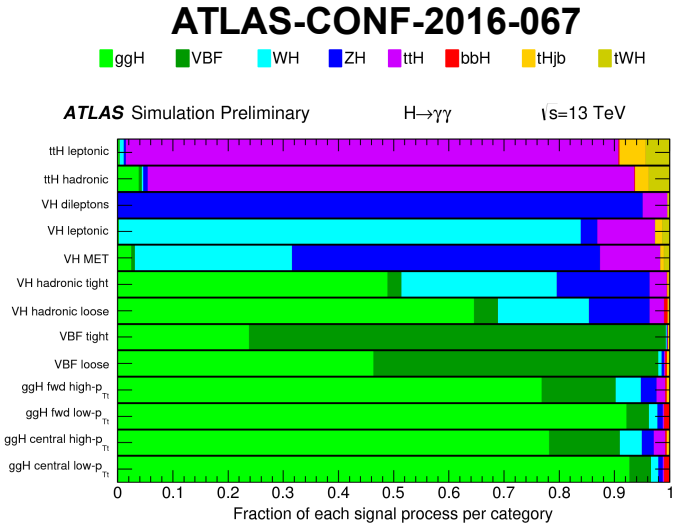


ATLAS $H \rightarrow \gamma\gamma$

- Measurement of the Higgs cross-section @ 13 TeV with ATLAS data (2015 data) and subsequent measurement of couplings and differential cross-sections with 2015+2016 data.



(88%) (7%) (4%) (<1%)

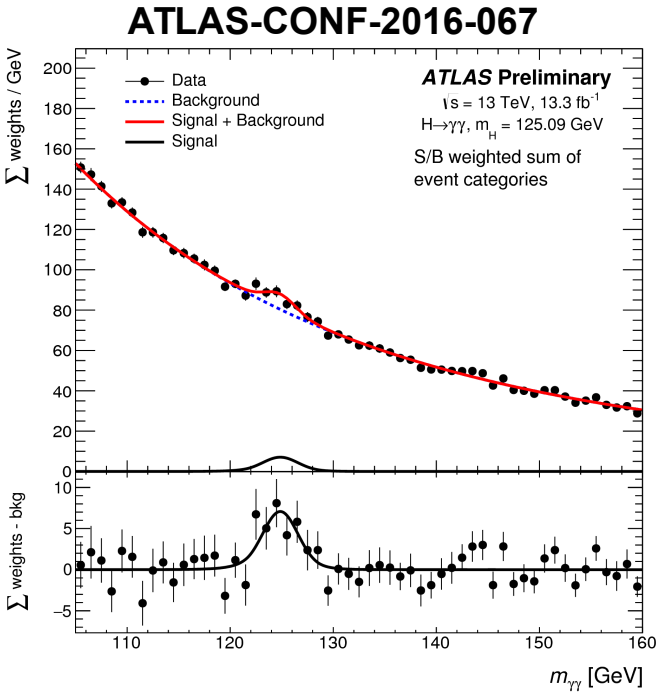


- $H \rightarrow \gamma\gamma$ is a particularly interesting final state given the good mass resolution and fair statistical power.

- Fiducial and differential cross sections are measured in a variety of phase space regions sensitive to inclusive Higgs boson production and individual production modes.

- Analysis exploits fine separation in categories to enhance the measurement of the sub-dominant production modes.

- Measurement is extracted from the unbinned maximum likelihood fit is performed on the $m_{\gamma\gamma}$ spectrum in each fiducial region or bin of a differential distribution.



ATLAS $H \rightarrow \gamma\gamma$

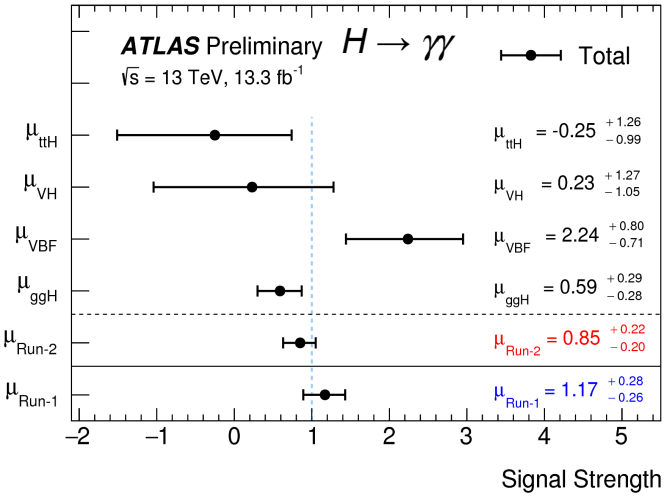
- Signal strength measured in all the analysis categories and x-section measured in 3 fiducial regions: baseline, VBF-enhanced and single lepton.

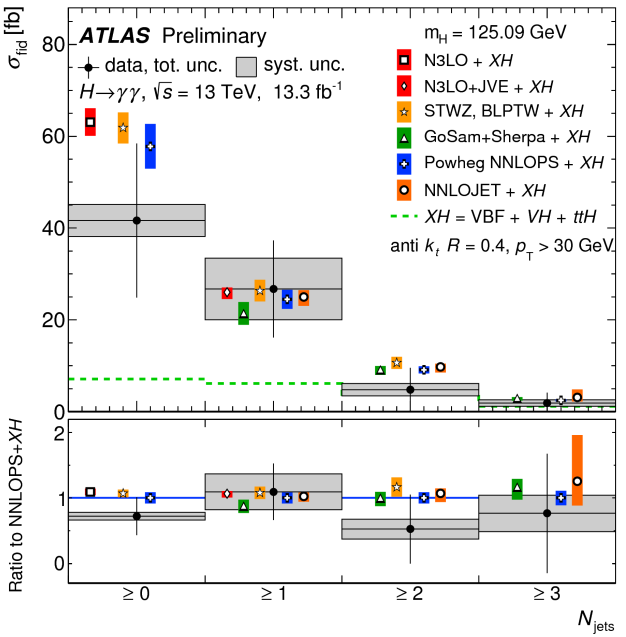
- Differential x-section measured for 7 kinematic variables sensitive to pQCD predictions, Higgs production modes and spin-CP. Variables include $p_T^{\gamma\gamma}$, Njets and $\Delta\phi_{jj}$.

- x-section results limited by statistical uncertainties. Theoretical uncertainties, although non dominant, are not negligible.

- Measurements of the differential and fiducial cross-section in the $H \rightarrow \gamma\gamma$ final state starts to be comparable to Run 1.

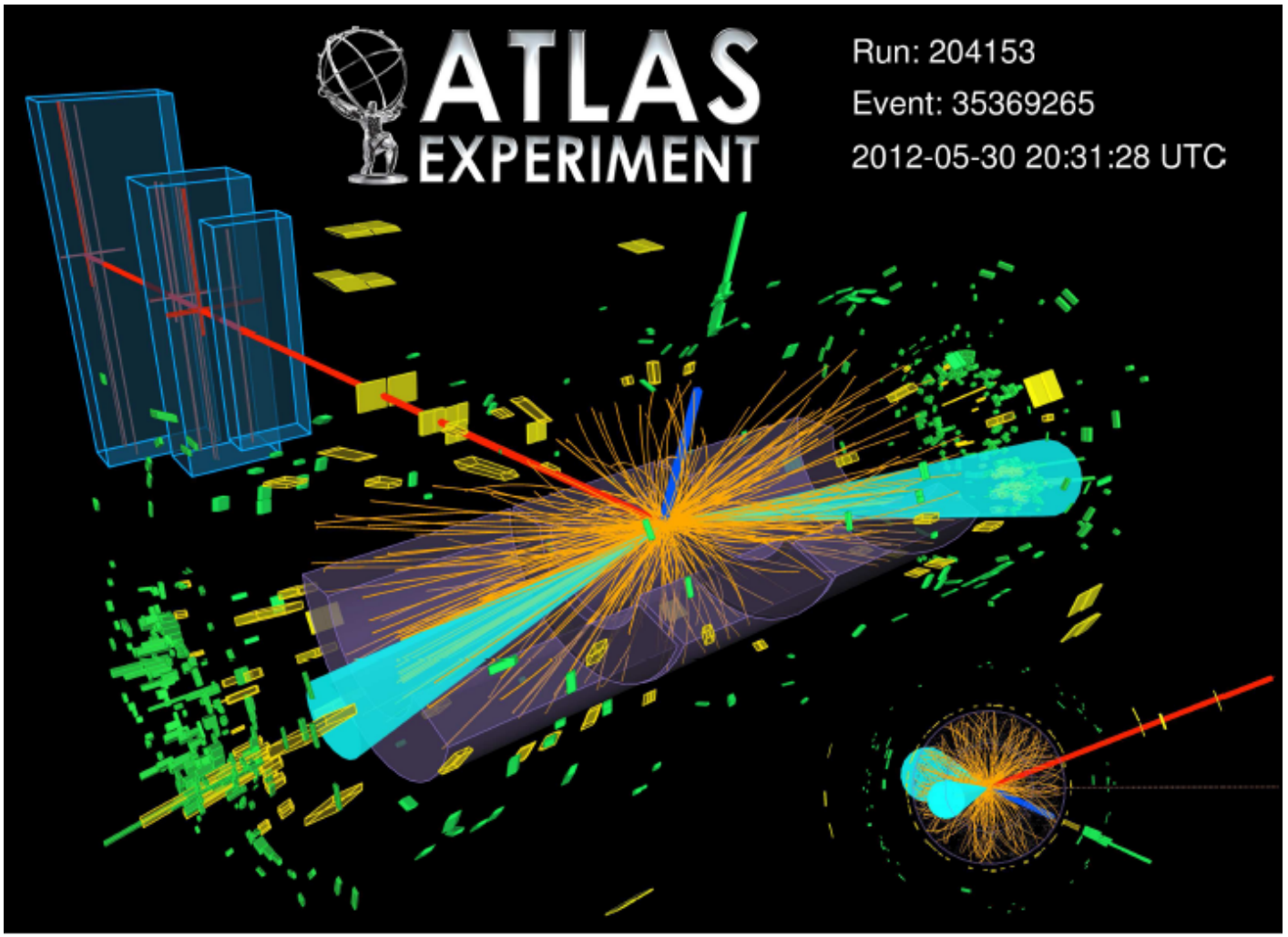
ATLAS-CONF-2016-067





Source	Uncertainty on fiducial cross section (%)		
	Baseline	VBF-enhanced	single-lepton
Fit (stat.)	34.5	35.0	52.9
Fit (syst.)	9.0	11.1	9.3
Photon efficiency	4.4	4.4	4.4
Jet energy scale/resolution	-	9.4	-
Lepton selection	-	-	0.8
Pileup	1.1	2.0	1.4
Theoretical modelling	4.3	9.4	8.4
Luminosity	2.9	2.9	2.9

$\mathcal{H} \rightarrow \tau\tau$



$H \rightarrow \tau\tau$ decays to leptons

- $H \rightarrow \tau\tau$ is important for the determination of the Higgs Yukawa couplings to fermions and measure the VBF production mode.
- ATLAS obtained Evidence of this decay (4.5 σ) and recently Observation was achieved combining with CMS.
- It is still the only leptonic channel accessible for few more years and it is the fermionic channel with the best sensitivity.
- $H \rightarrow \tau\tau$ final state has also strong sensitivity to VBF production mode and Higgs CP.

Production process	Observed 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		
H→ττ	**5.5**	5.0
H→bb	2.6	3.7

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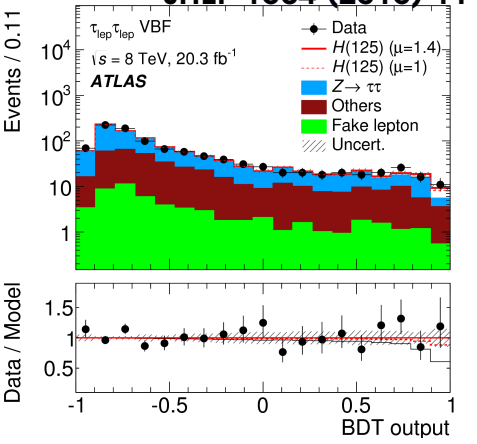

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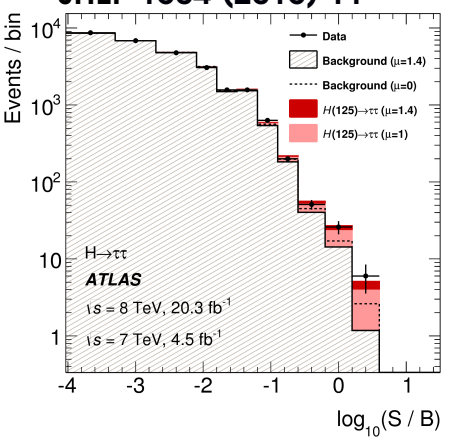

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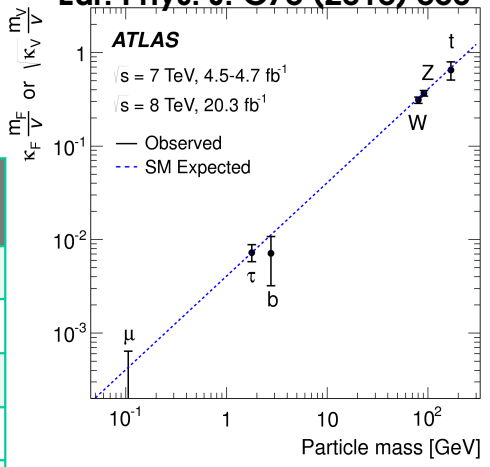

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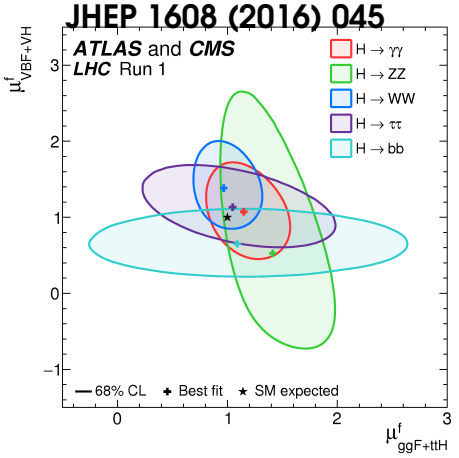
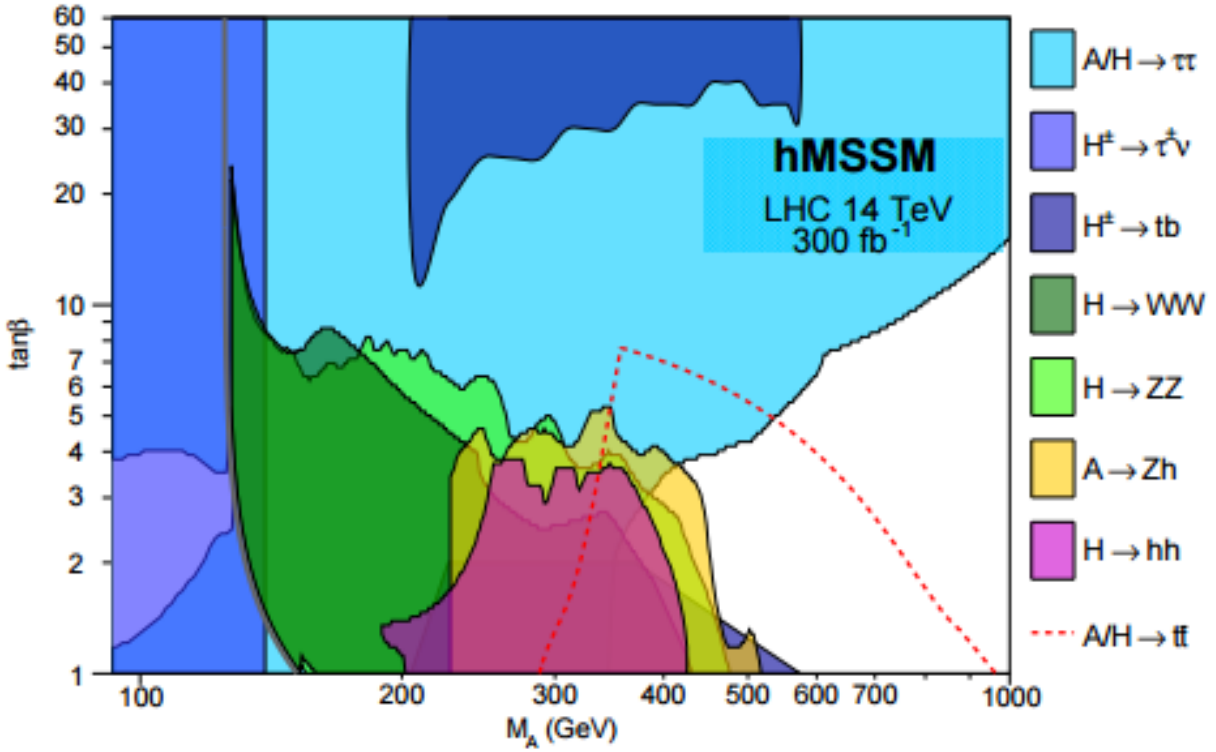


BSM Higgs


hMSSM
LHC 14 TeV
300 fb-1
tanβ
M_A (GeV)
60
50
40
30
20
10
7
6
5
4
3
2
1
100
200
300
400
500
600
700
1000
A/H → ττ
H± → τ±ν
H± → tb
H → WW
H → ZZ
A → Zh
H → hh
A/H → tt

LFV $H \to \tau\mu$ and τe

- The search for LFV decays of the Higgs boson are an interesting door to New Physics, $H \to \tau\mu$, τe.
- ATLAS searches for LFV $H \to \tau l$ decays are in part adapted from the $H \to \tau\tau$ analyses.
- A data-driven method is used for $l\tau_{l'}$ channel, relying on symmetry of the SM bkg processes between $e\mu$ and μe final states.
- Run 1 results:
  - BR($H \to \tau e$) < 1.04%, 95% CL (exp. 1.21%)
  - BR($H \to \tau\mu$) < 1.43%, 95% CL (exp. 1.01%)
- Excellent synergy with $H \to \tau\tau$ measurement.

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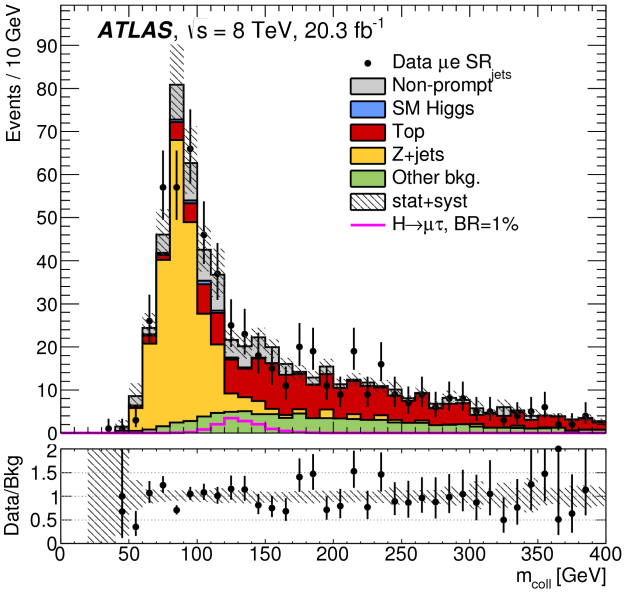

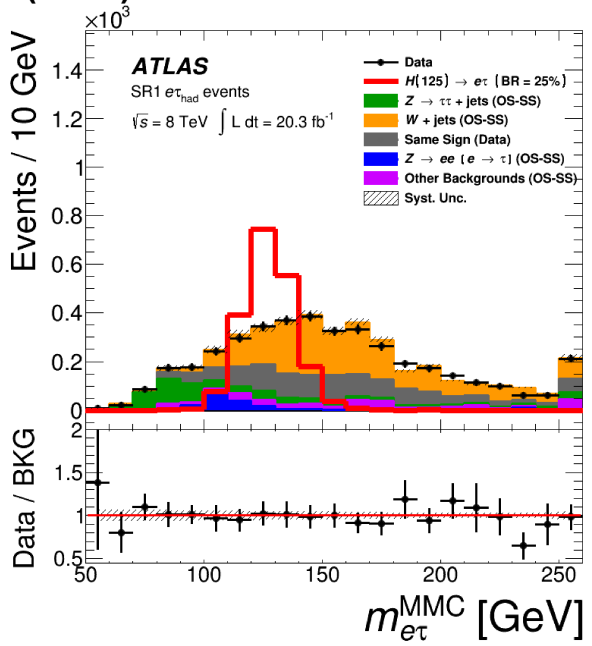

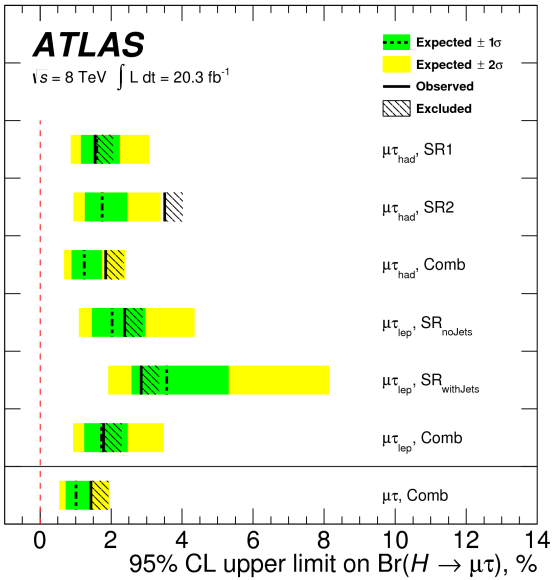

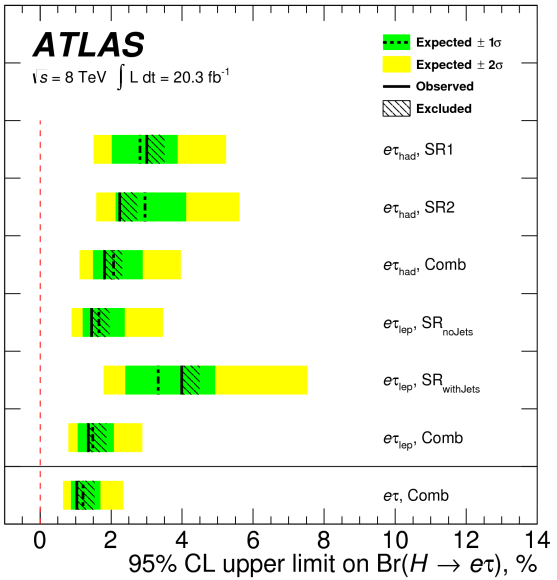

BSM A/H & Z' → ττ

- Focus on early Run 2 searches for Heavy bosons contribution, H/A → ττ and Z' → ττ.
- This final state is very sensitive to a large range of MSSM parameters space and is playing a key role for Run 2 MSSM searches.
- Run 2 analysis focuses on final states with at least one τ_{had}, because they have better sensitivity at high mass.
- Category with b-jets improves sensitivity for MSSM scenarios with large tanβ.
- Main backgrounds are Multi-jet, top-quark production and Z → ττ processes.

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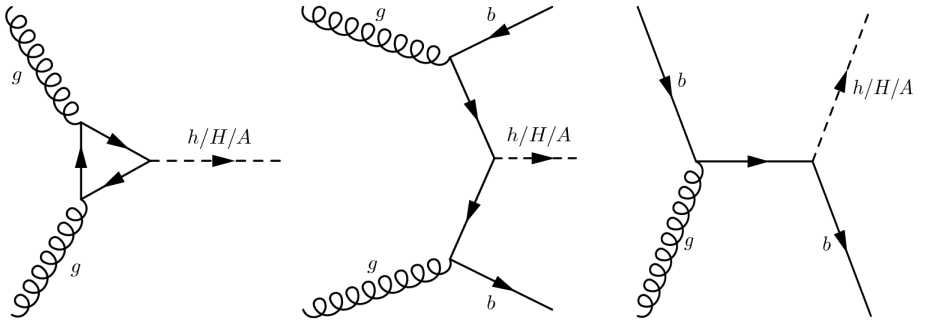
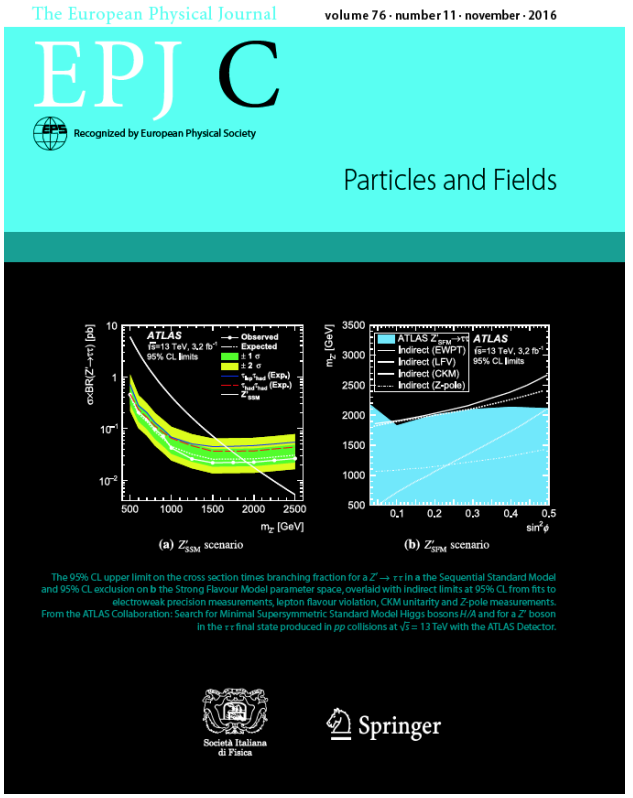
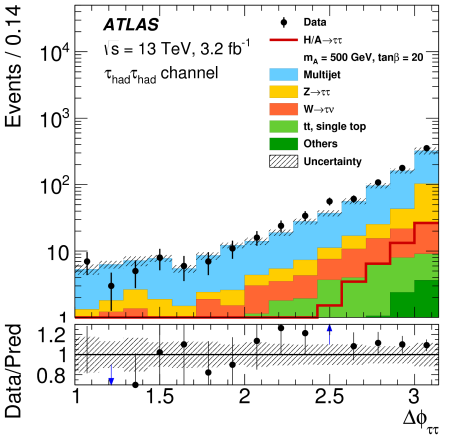
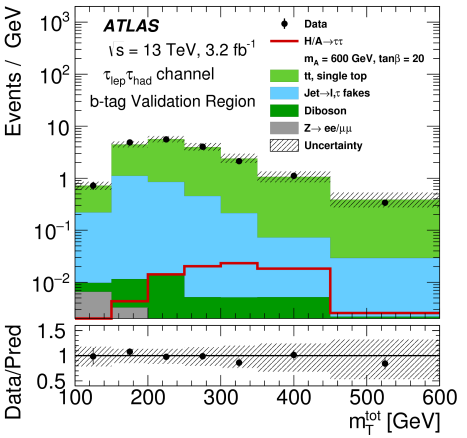






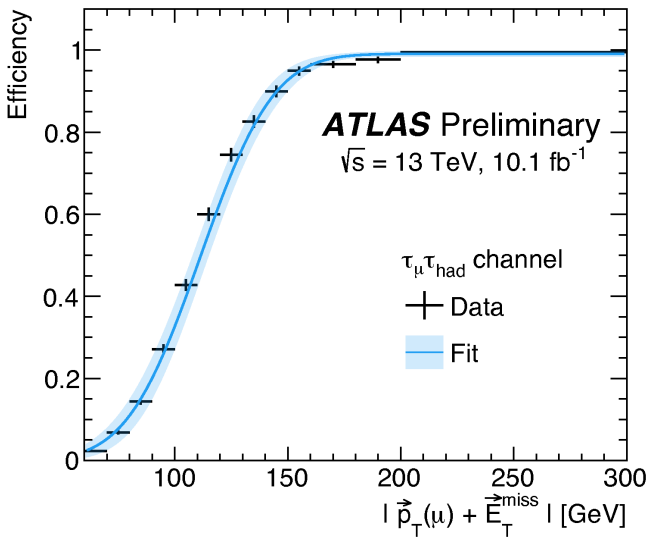


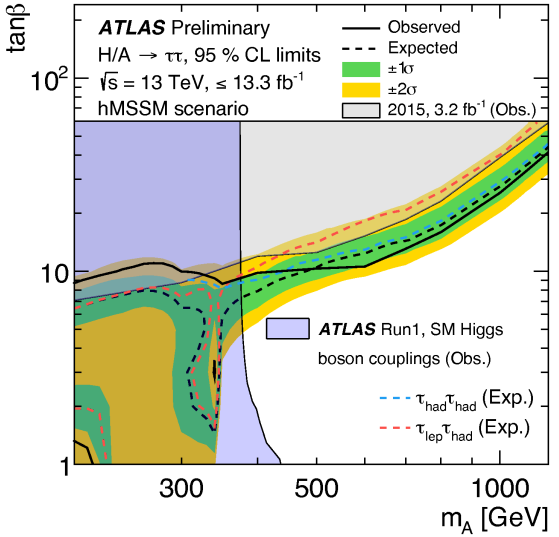
BSM A/H & Z' → ττ

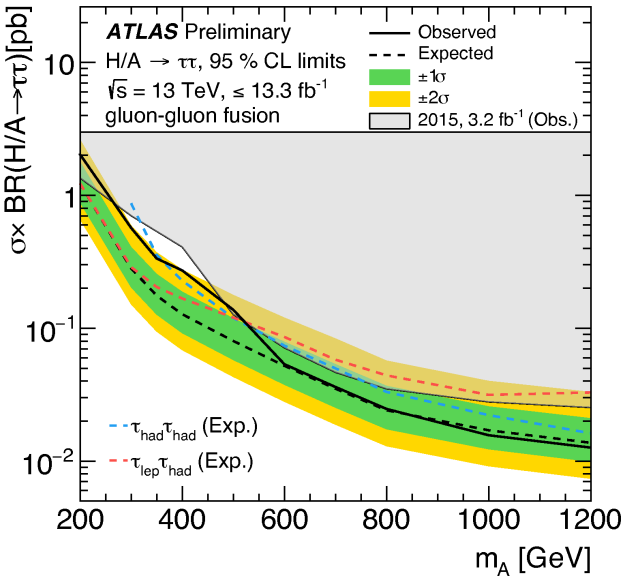
- Search updated to 13.3 fb^{-1} in summer 2016.
- In the $\tau_{lep}\,\tau_{had}$ final state, a category of events selected by E_T^{miss} trigger is used to recover part of the events not selected by lepton triggers.
- Result obtained from a template fit of the m_T^{tot} distribution, a mass observable related to the transverse mass to achieve maximal separation of signal and backgrounds with fake taus.
- Result is interpreted in model-dependent and independent ways, with and without b-jets in the final states. It is interpreted (with small changes) also in terms of Z' → ττ search.

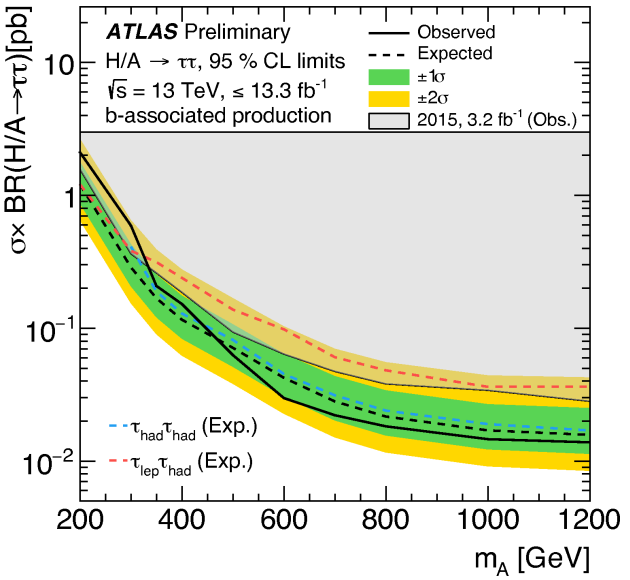
ATLAS-CONF-2016-085

$$m_{\mathrm{T}}^{\mathrm{tot}} = \sqrt{m_T^2(E_{\mathrm{T}}^{\mathrm{miss}}, \tau_1) + m_{\mathrm{T}}^2(E_{\mathrm{T}}^{\mathrm{miss}}, \tau_2) + m_{\mathrm{T}}^2(\tau_1, \tau_2)},$$









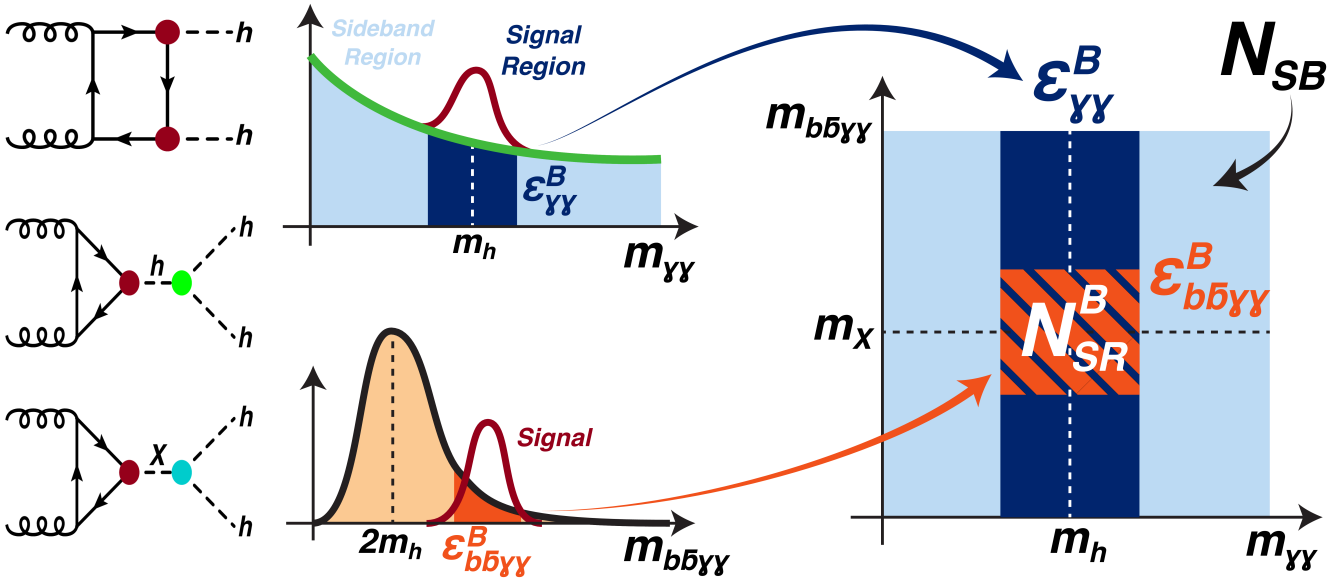
ATLAS $hh \rightarrow bb\gamma\gamma$

- Small excess observed in this final state in Run 1.
- First bbγγ search with 13 TeV data to seek confirmation of the excess performed with 3.2 fb^{-1}.

→ **bbγγ final state:**

- With current luminosity searching for enhancement above SM:
- NP search for heavy resonance decaying to hh
- NP search for non resonant double Higgs production.

ATLAS-CONF-2016-004 $X \rightarrow hh \rightarrow bb\gamma\gamma$

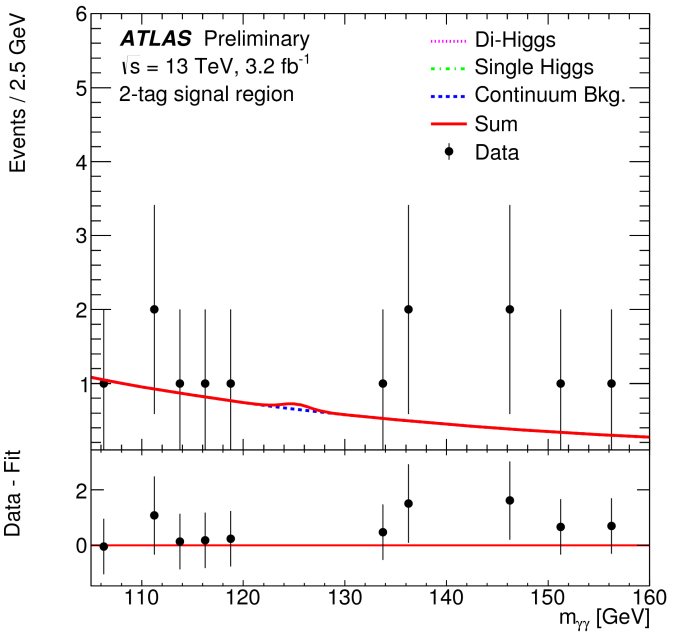


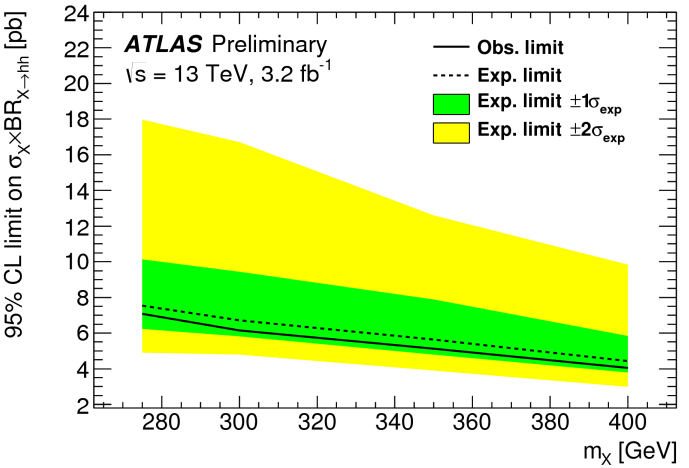
- The search for non-resonant production is performed from the fit of the 2 b-tag region. The 0 b-tag region sidebands is used to determine the background shape.
- The search for a resonant di-Higgs production is a counting measurement requiring selection on the $m_{\gamma\gamma}$ and $m_{bb\gamma\gamma}$ distributions.
- A $m_{\gamma\gamma}$ sidebands CR is used for background estimation. $m_{\gamma\gamma}$ and $m_{bb\gamma\gamma}$ factors are required to extrapolate the background from the sideband to the SR.

ATLAS $hh \rightarrow bb\gamma$

ATLAS-CONF-2016-004

- An upper limit of 3.9 pb on the cross-section for non-resonant production is extracted at the 95% CL (5.4 pb expected).
- The result is completely dominated by statistics.
- Good sensitivity to new physics thanks to possibility to fully reconstruct the mass of the two higgs bosons with good resolution.
- Synergy with $H \rightarrow \gamma\gamma$ measurements.





Process	0-tag	2-tag
Continuum background	35.8 ± 2.1	1.63 ± 0.30
SM single-Higgs	1.8 ± 1.5	0.14 ± 0.05
SM di-Higgs	<0.001	0.027 ± 0.006
Observed	27	0

Summary

- LHC restarted delivering p-p collisions in 2015 with unprecedented center of mass energy:
  - Opportunity for BSM searches in the Higgs sector.
  - Measurement of productions and decays suppressed in the SM.
  - Better measurement of H(125) properties.

- Outstanding performance from the LHC team and experiments is allowing to deliver an impressive amount of results on the Higgs sector during Run 2.

- Participating in several BSM Searches and Higgs boson properties measurements have been updated already with Run 2 data.
  Some results in complex final states have yet to be updated with Run 2 statistics.

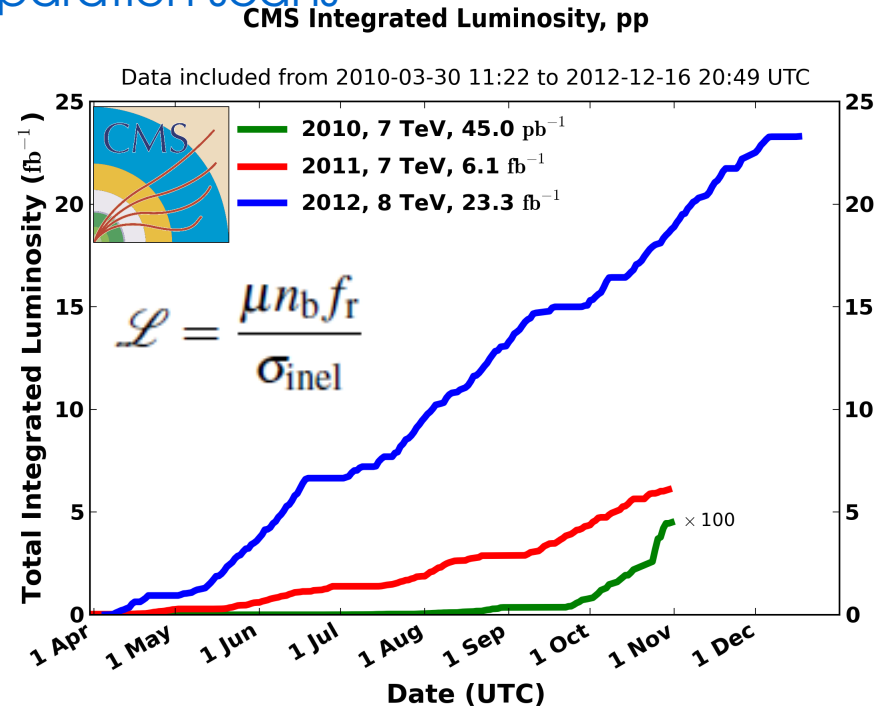
- Many searches and measurements are still statistically limited: increase of luminosity expected by the end of Run 2 allows to further improve their sensitivity.

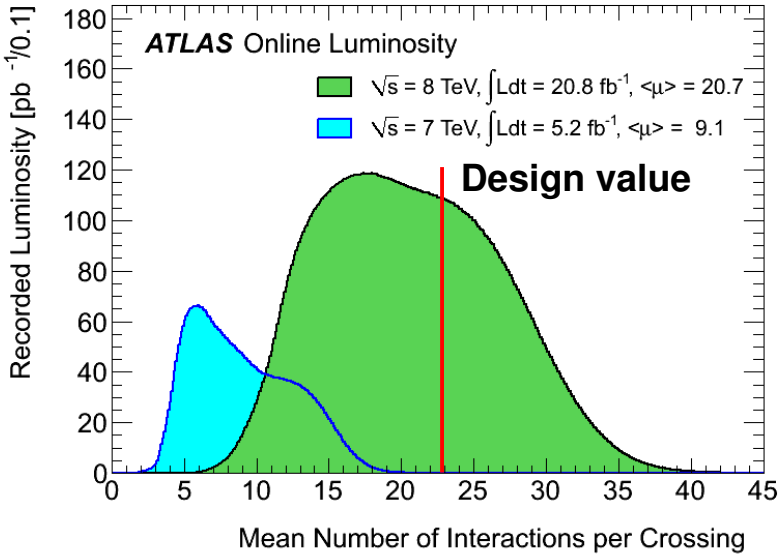
Bonus Slides

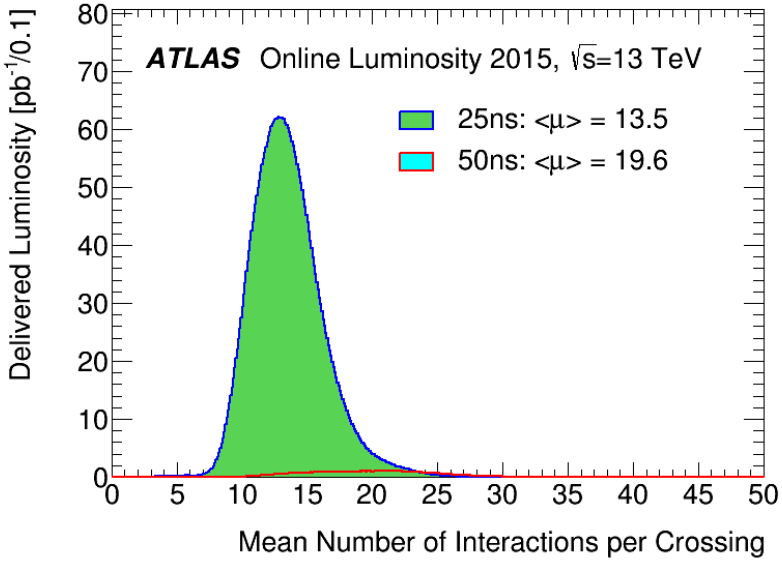
LHC Luminosity and interactions per bunch crossing

Run-1 Results based on 2011+2012 data

Luminosity is measured with forward/tracking detectors and calibrated with beam separation scans







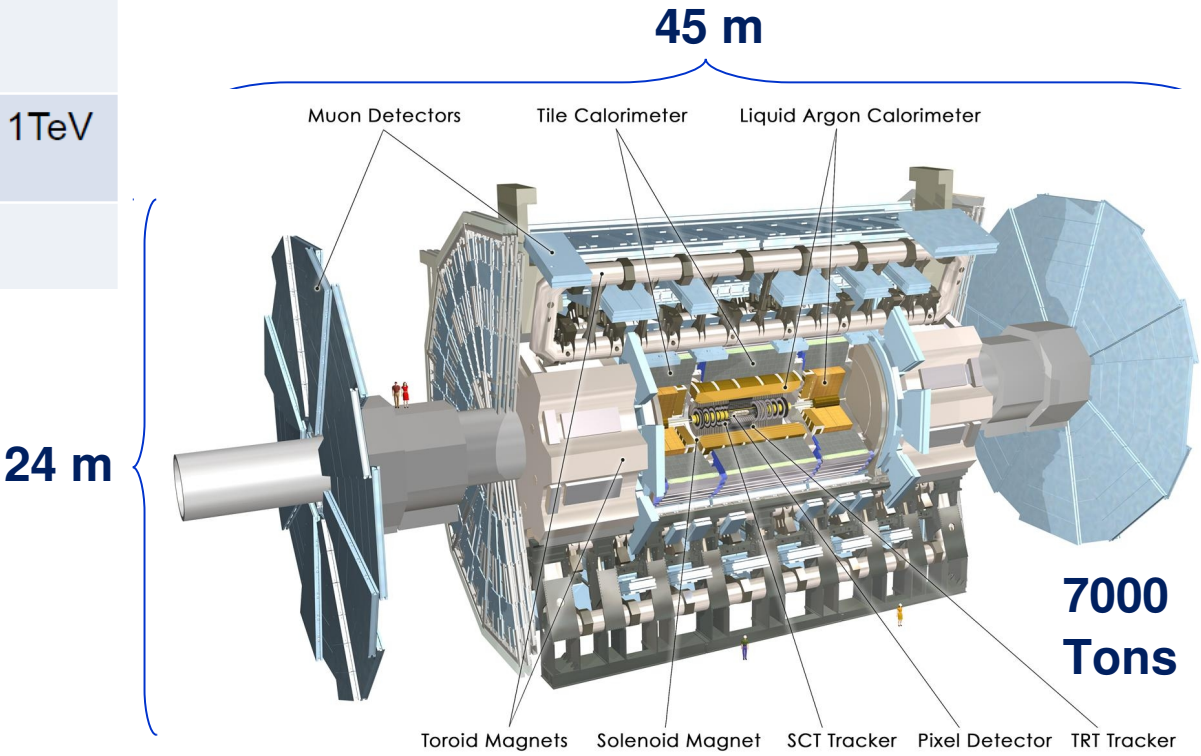
- Pileup already at the design level and above during 2012, thanks to excellent performance of the LHC.
- Peak luminosity (cm^{-2} s^{-1}): 7.7×10^{33} (2012), 5.2×10^{33} (2015).

~29 fb^{-1} of data delivered during Run1and about 4 fb^{-1} during 2015 and up to 25 fb^{-1} expected in 2016.

ATLAS Detector

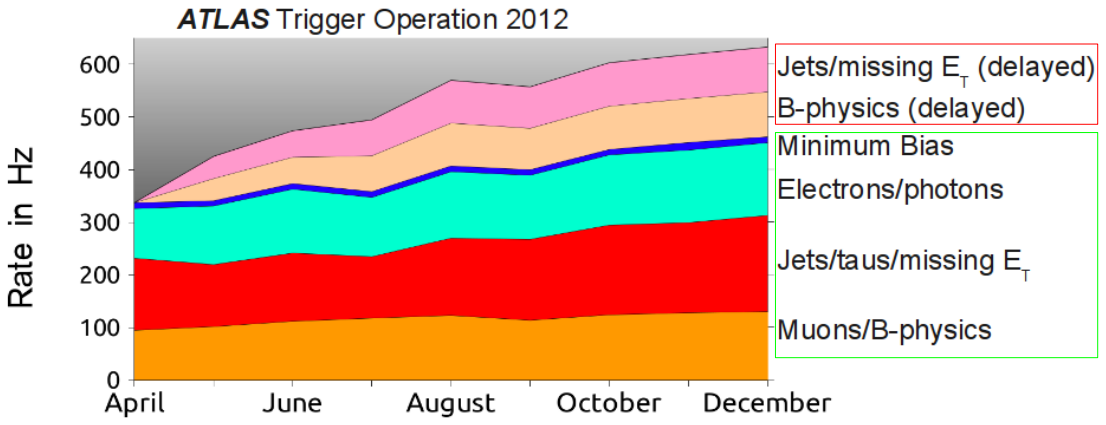
	ATLAS
Magnetic field	2 T solenoid + toroid: 0.5 T (barrel), 1 T (endcap)
Tracker	Silicon pixels and strips + transition radiation tracker $\sigma/p_T \approx 5 \cdot 10^{-4} p_T + 0.01$
EM calorimeter	Liquid argon + Pb absorbers $\sigma/E \approx 10\%/\sqrt{E} + 0.007$
Hadronic calorimeter	Fe + scintillator / Cu+LAr (10λ) $\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV
Muon	$\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV (Inner Tracker + muon system)
Trigger	L1 + HLT (L2+EF)

ATLAS Collaboration
38 Countries
175 Institutions
3000 Scientific Authors total
(~2000 with a PhD)



DAQ and Trigger

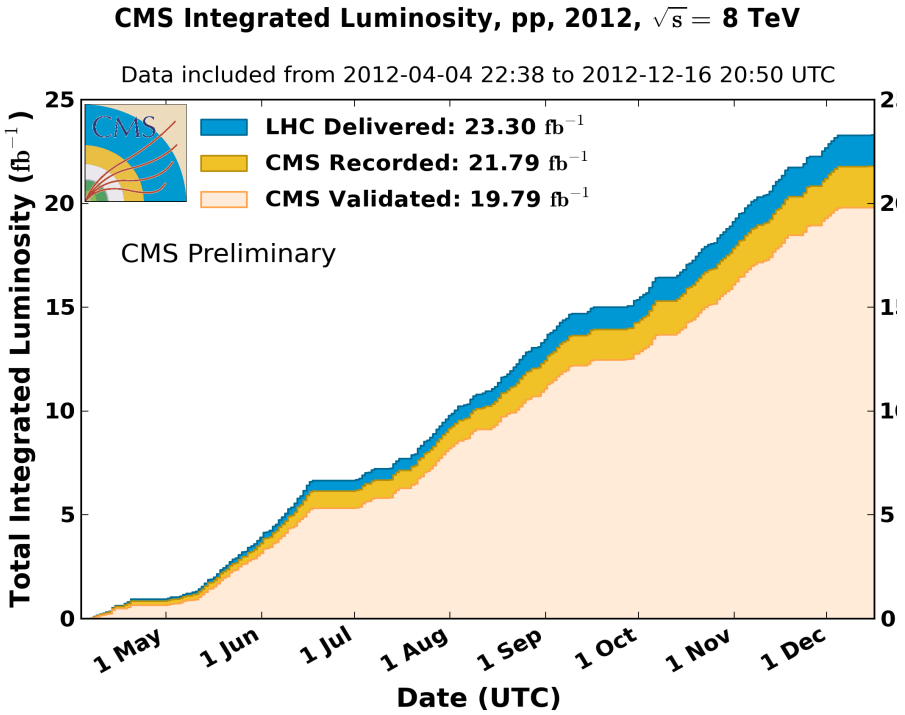
	Trigger No. Levels	Level-0,1,2 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	HLT Out MB/s (Event/s)
ATLAS	3	LV-1 10^5 LV-2 $3x10^3$	$1.5x10^6$	4.5	**600+300** $(4x10^2+2x10^2)$
CMS	2	LV-1 10^5	10^6	100	**O(1000)** (10^3)

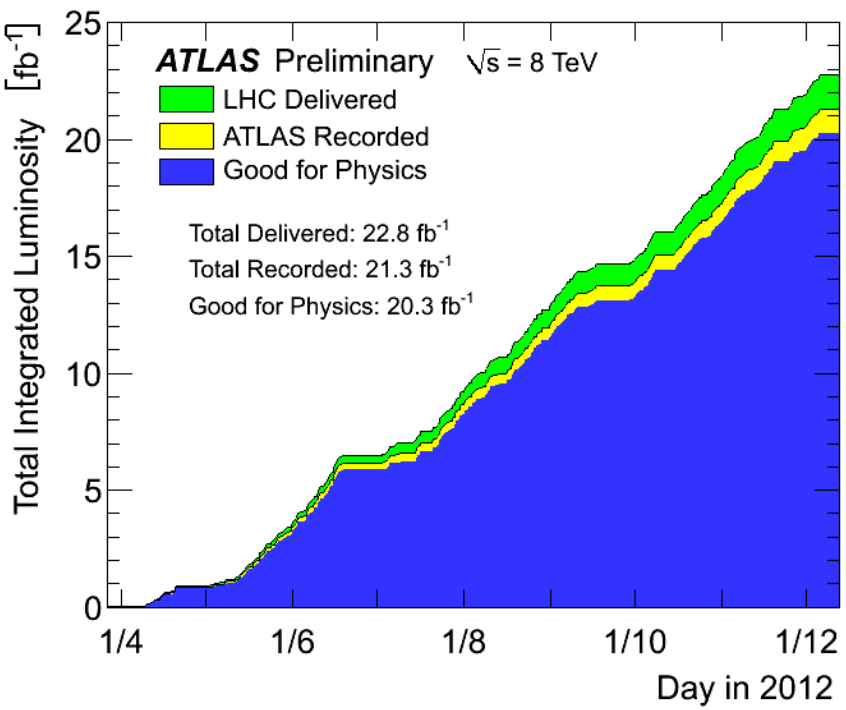


Both experiments have improved their DAQ and trigger systems for Run-2. Current DAQ Performance

- >= 100 kHz at L1
- >= 1 kHz HLT output

Data taking & Quality efficiency



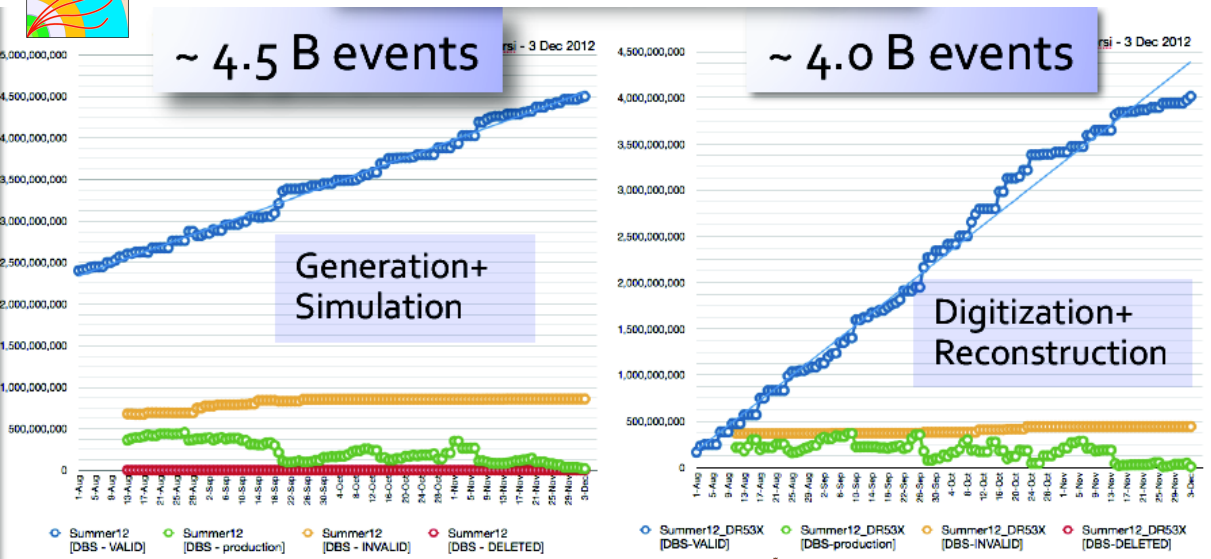


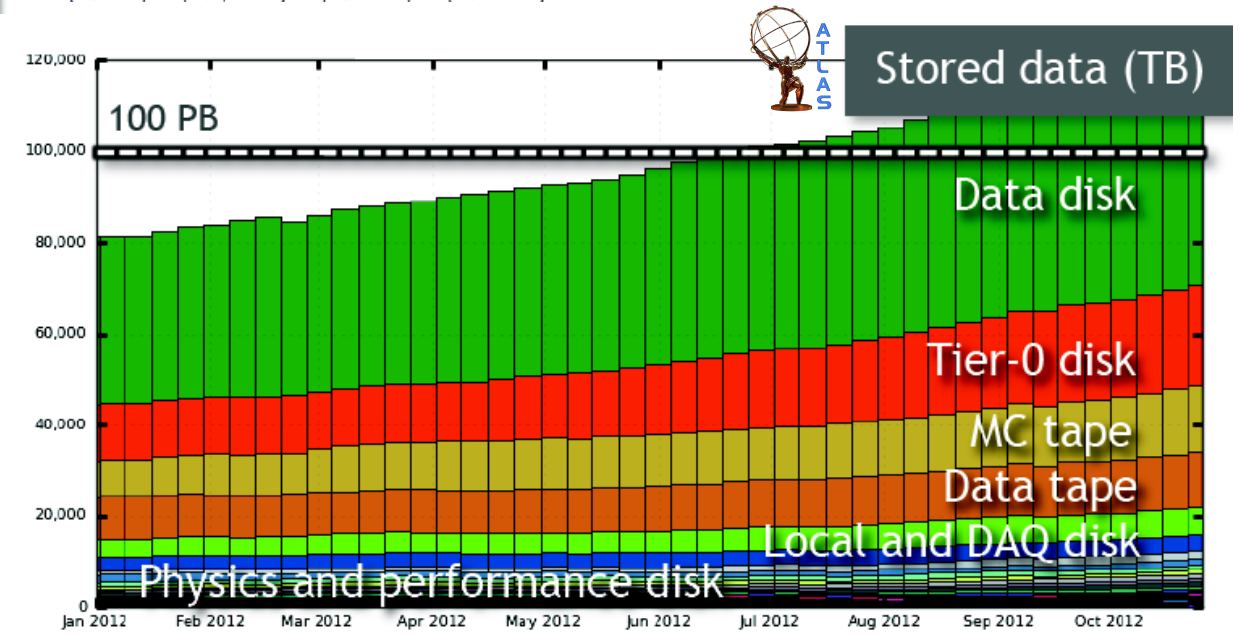
- ATLAS (CMS) data-taking efficiency for 2012 run was 93.1% (93.5%)
- The ATLAS (CMS) good quality data was 95.8% (91%) of the recorded data
  - High DQ also thanks to efficiency recovery from large data reprocessing

Overall ~88% (85%) of delivered luminosity is used for ATLAS and CMS physics analysis.

Computing and Simulation

The fast duty cycle of the LHC analyses is possible thanks to the Tier0 and GRID resources



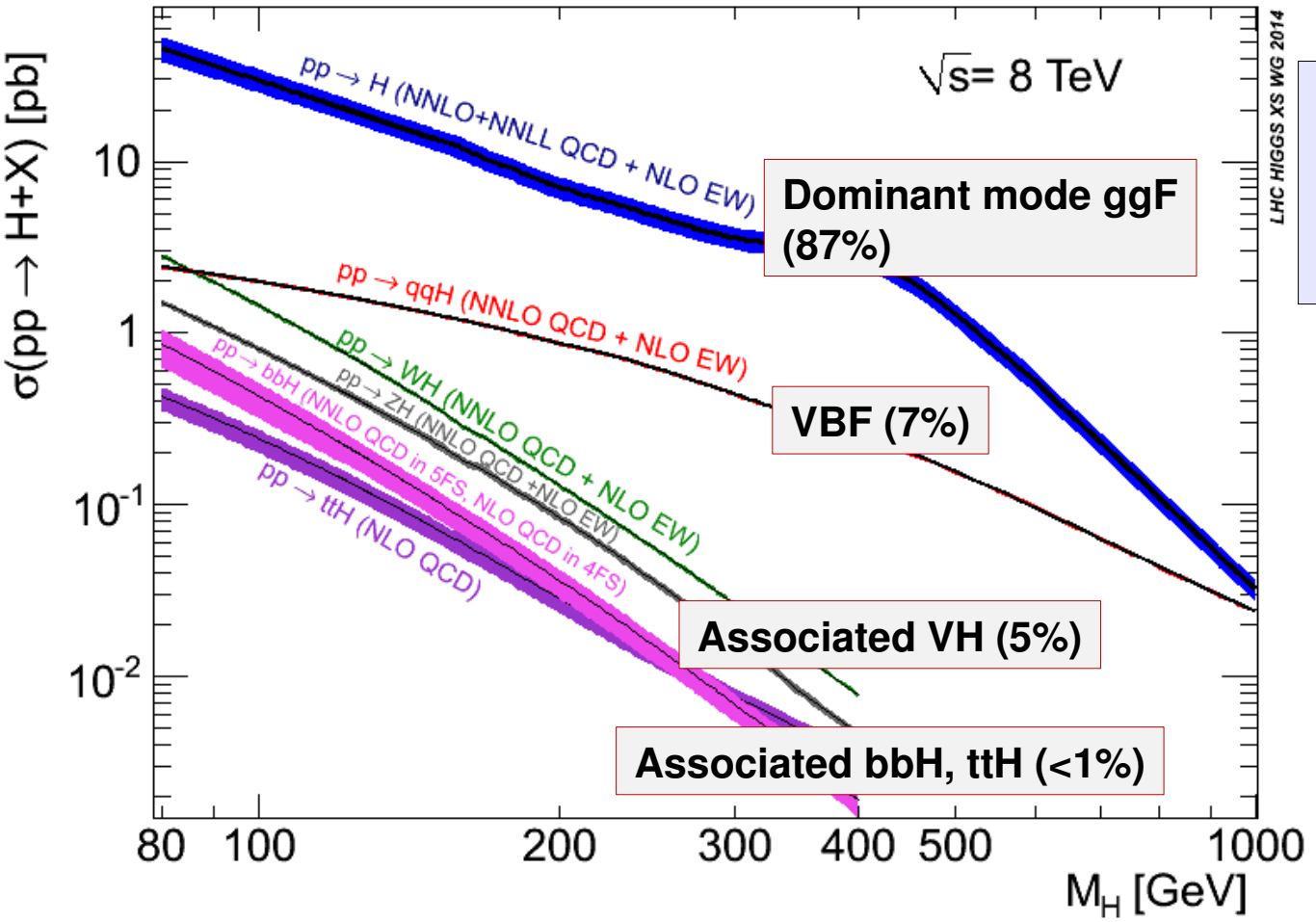


- Just in 2012, both CMS and ATLAS experiments have produced 3-4 billions of MC events on the GRID and processed ~3 billions of data events at Tier0.

- On a single machine, it would require more than 15 thousands years (without considering user and group analyses, calibrations, reprocessings, ...).

- GRID is a crucial asset of the LHC experiments to provide physics results in a timely manner.

Higgs Production Modes at LHC



Dominant mode ggF (87%)

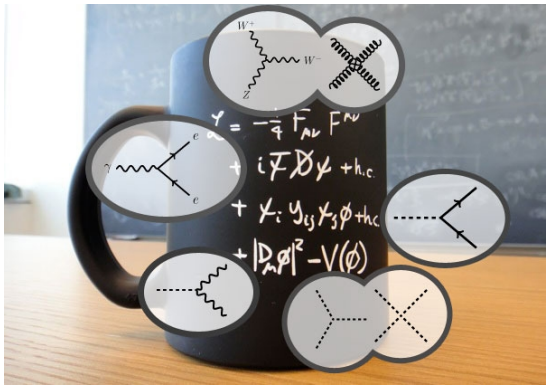
VBF (7%)

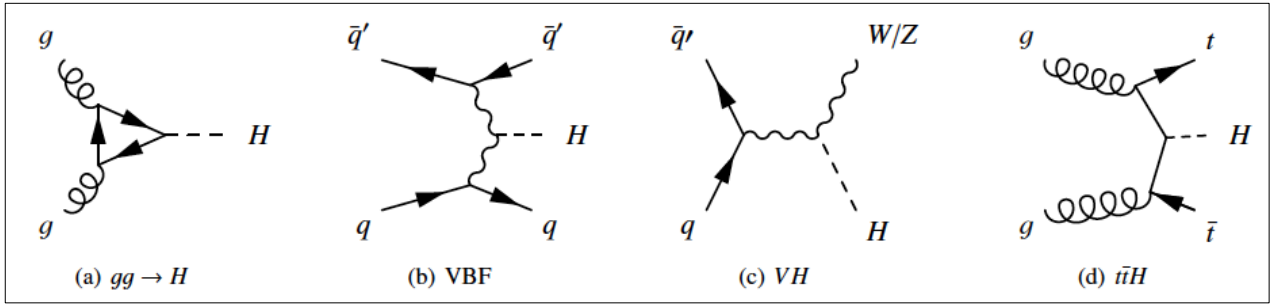
Associated VH (5%)

Associated bbH, ttH (<1%)

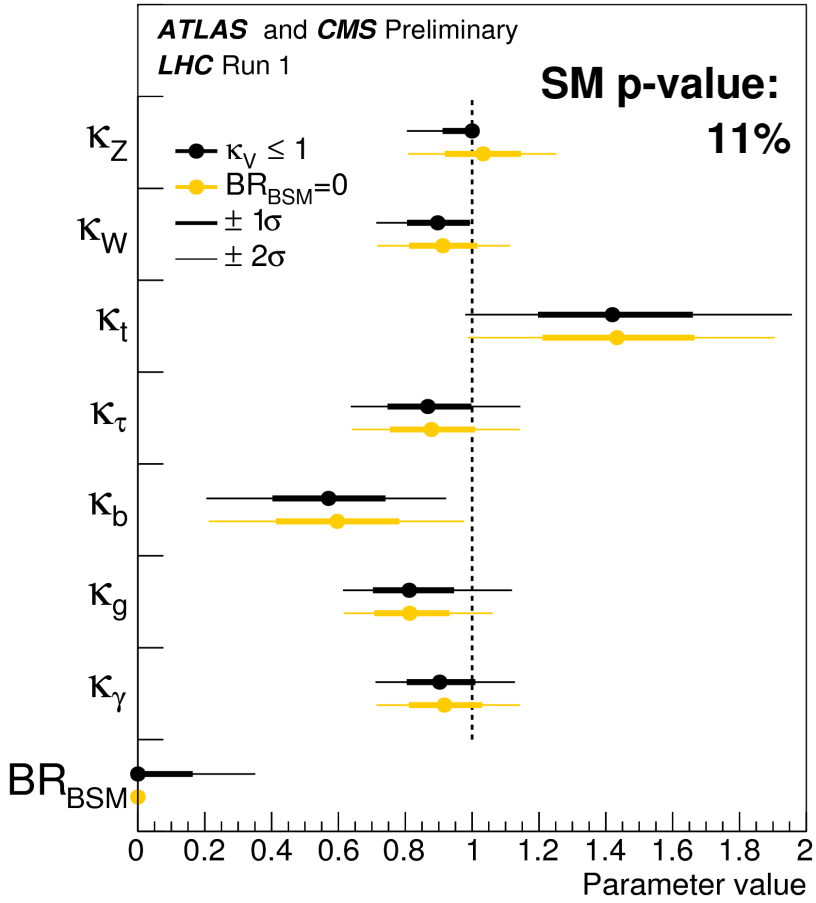
Total x-section:

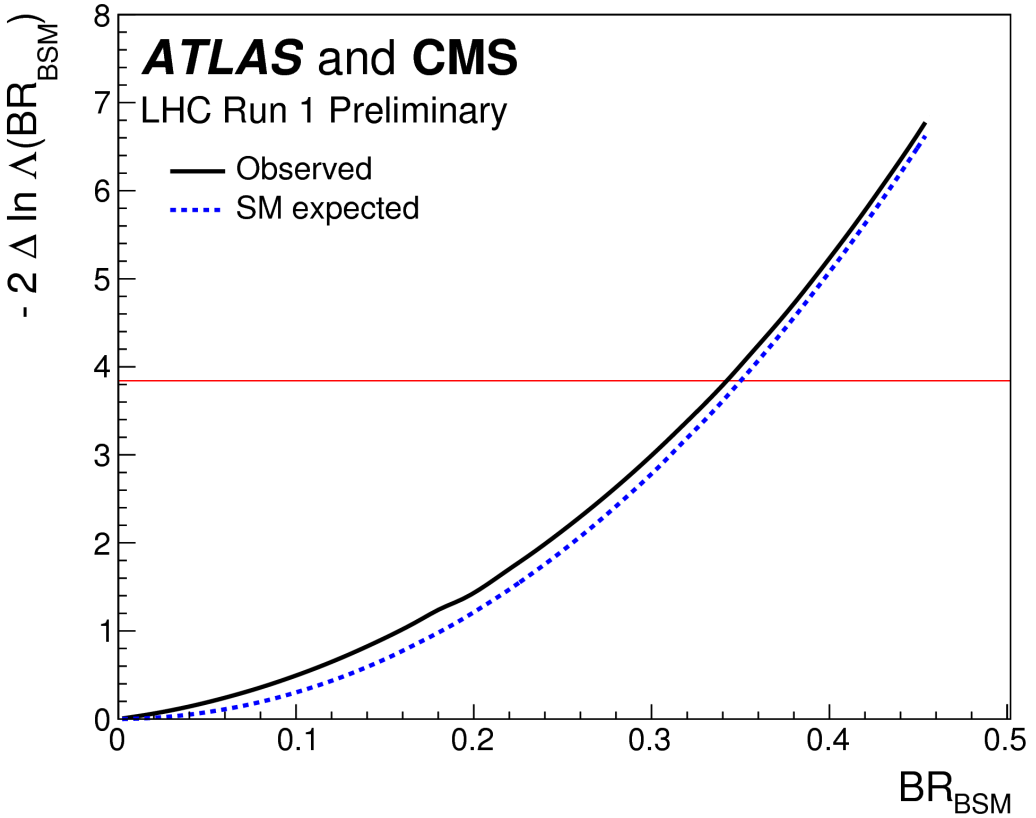
17 pb (17000 evts/fb^{-1}) @7 TeV
22 pb (22000 evts/fb^{-1}) @8 TeV
55 pb (55000 evts/fb^{-1}) @13TeV





Constraints on BSM couplings





- Only σ x BRs can be measured, without further assumptions on the width of the Higgs boson cannot be measured: assume $k_V \leq 1$ (as in 2HDM). H → Dark Matter would contribute to BR_{BSM}
- k_t dominated by ttH process
- $BR_{BSM} < 0.34$ at 95% C.L. (assuming $k_V \leq 1$)

$$\sigma_i \cdot \mathrm{BR}^f = \frac{\sigma_i(\vec{\kappa}) \cdot \Gamma^f(\vec{\kappa})}{\Gamma_H},$$

$$\Gamma_H = \frac{\kappa_H^2 \cdot \Gamma_H^{SM}}{1 - \mathrm{BR}_{BSM}},$$