Determination of the off-shell Higgs boson coupling to constrain the Higgs total width with ATLAS

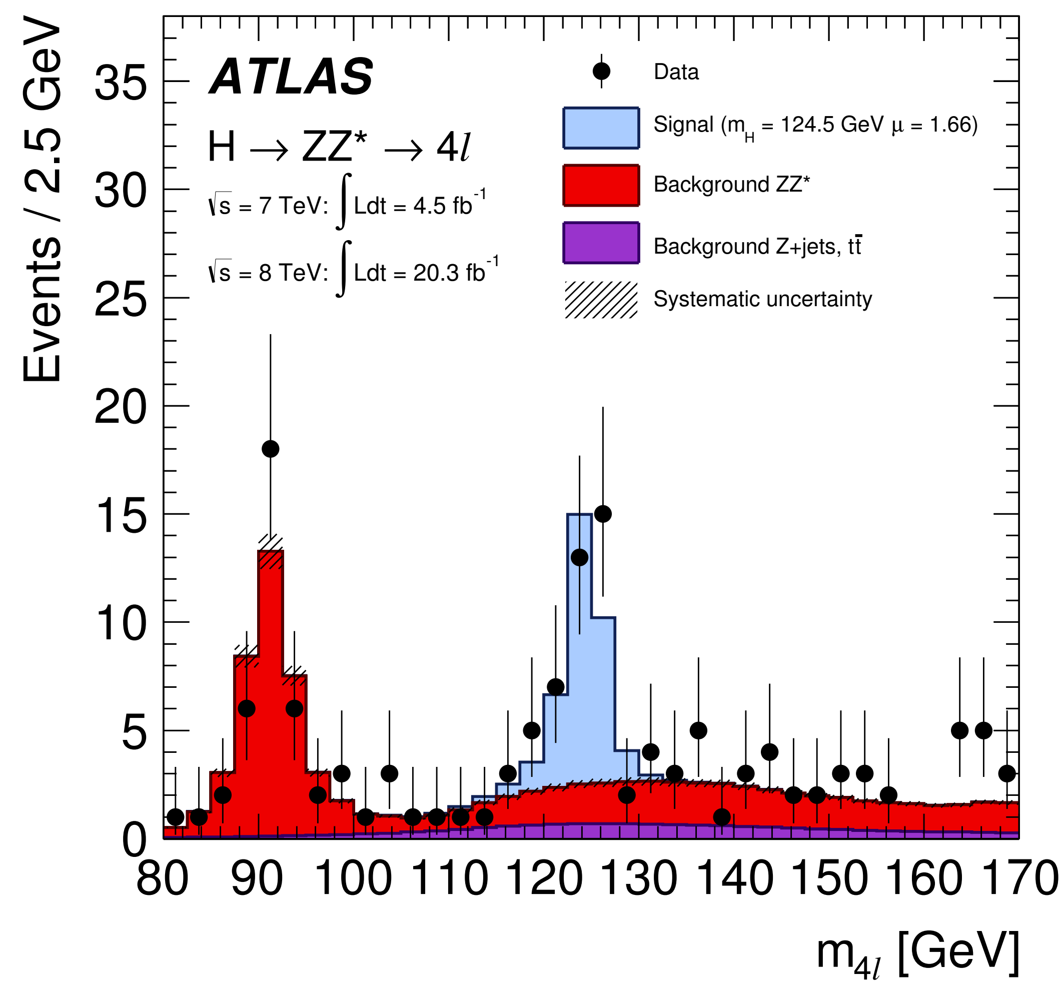
Sebastián on behalf of the D Collaboration

March 15th, 2015

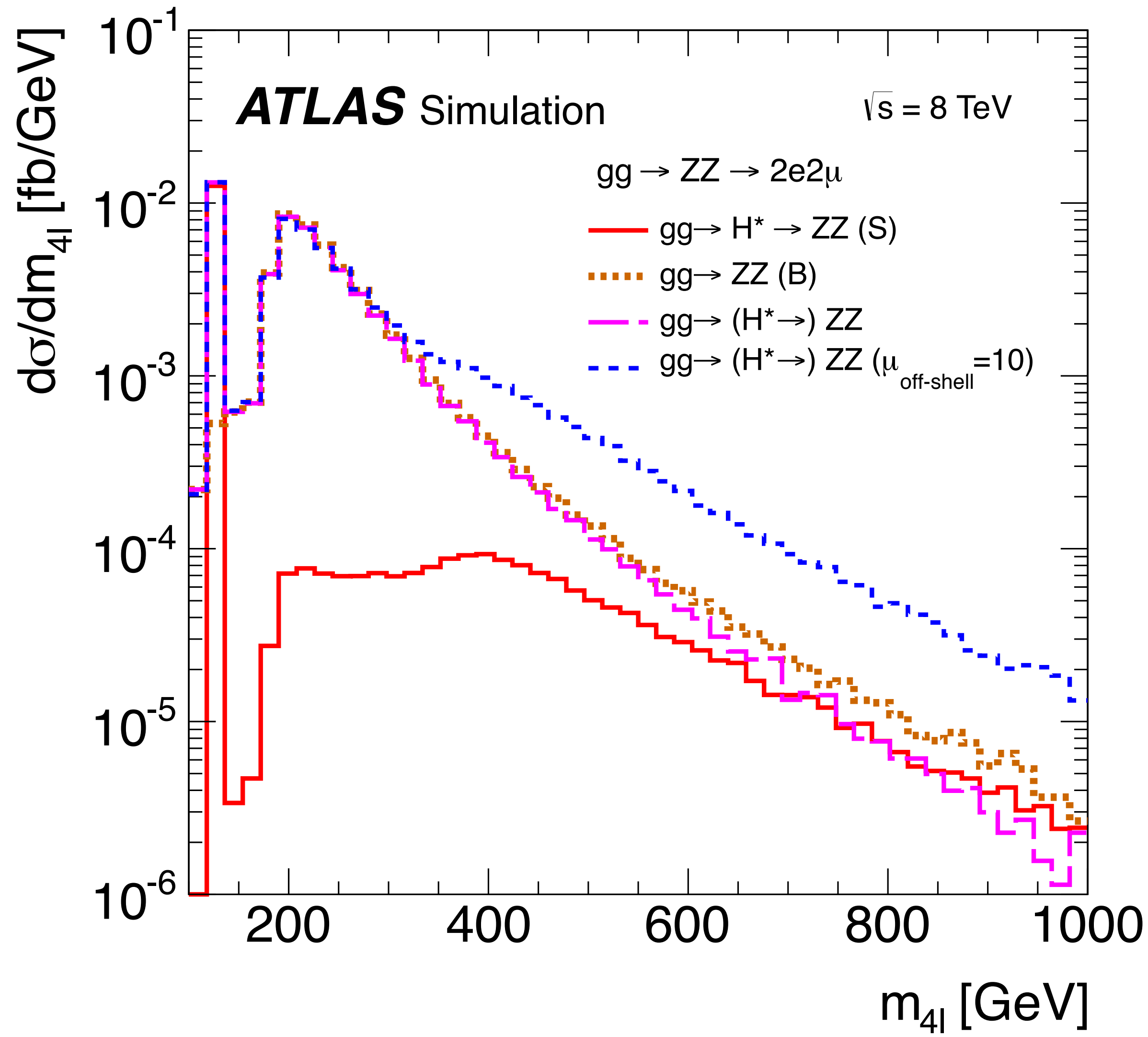
CERN Latin American School of High Energy Physics 2015
Ibarra, Ecuador

Introduction

- A new particle has been observed at the LHC.
- Measuring its properties is necessary to realize which kind of particle it is:
  - Mass
  - Spin/CP
  - Coupling
  - **Width**
- The theoretical SM Higgs boson width is 4.2 MeV, several orders of magnitude smaller than the LHC experimental resolution (~GeV).
- Current ATLAS direct width measurements found an upper limit of: $\Gamma_H < 2.7$ GeV @ 95% CL.
- A direct measurement with a MeV precision is only feasible in future lepton colliders.



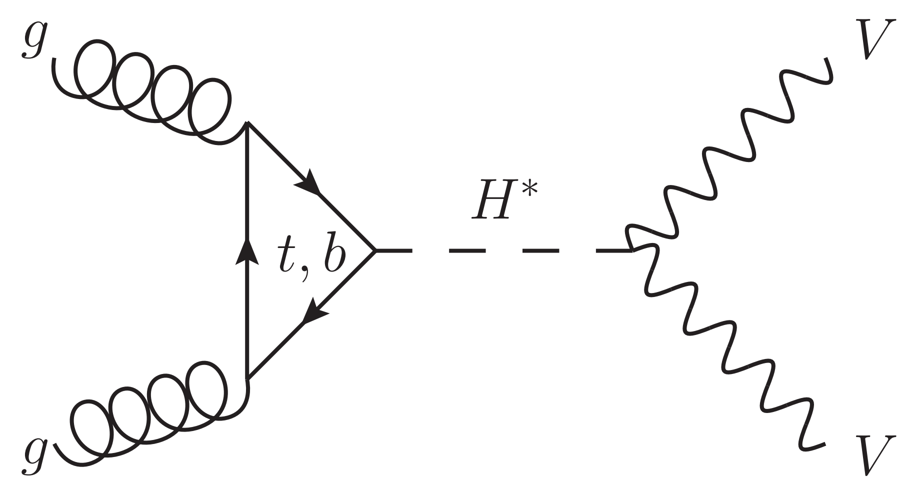
On/off-shell distributions



- There is a novel method that uses the off-shell information to set an indirect limit on the width.
- ~20% of the on-shell contribution is present in the off-shell region.

Off-shell couplings and width constraint

- Differential cross-section:



$$\frac{d\sigma_{gg\to H\to VV}}{dm_{4l}^2} \sim \frac{k_{gg\to H}^2 k_{H\to VV}^2}{(m_{4l}^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}$$

- On/off-shell total cross-sections:

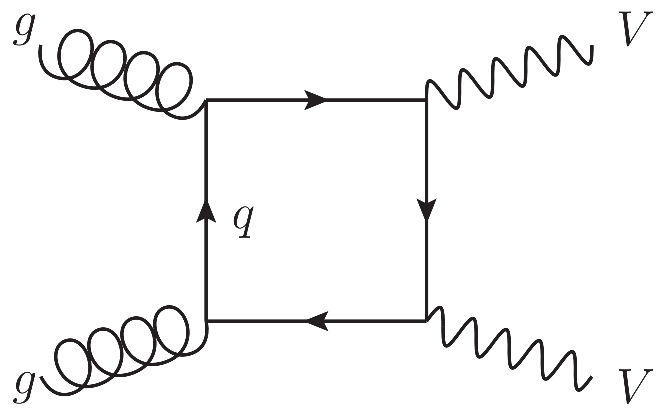
$$\sigma_{on} \sim \frac{k_{g,on}^2 \cdot k_{V,on}^2}{\Gamma_H} = \mu_{on} \qquad \sigma_{off} \sim k_{g,off}^2 \cdot k_{V,off}^2 = \mu_{off} \qquad \mu = \frac{\sigma}{\sigma^{SM}}$$

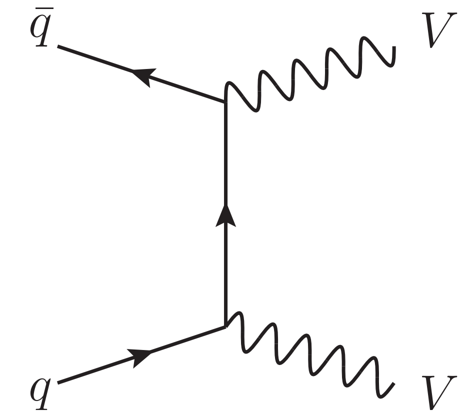
- Assuming on- and off-shell couplings are the same:

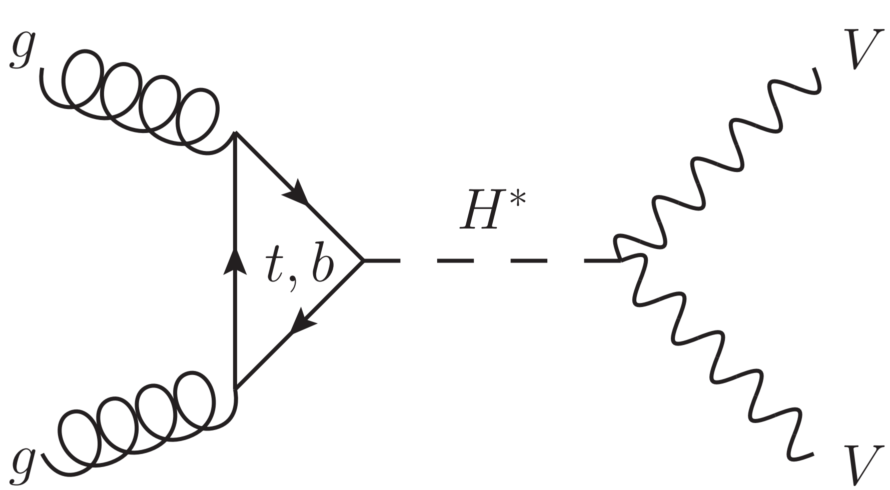
$$\Gamma_H = \frac{\sigma_{off-shell}}{\sigma_{on-shell}}$$

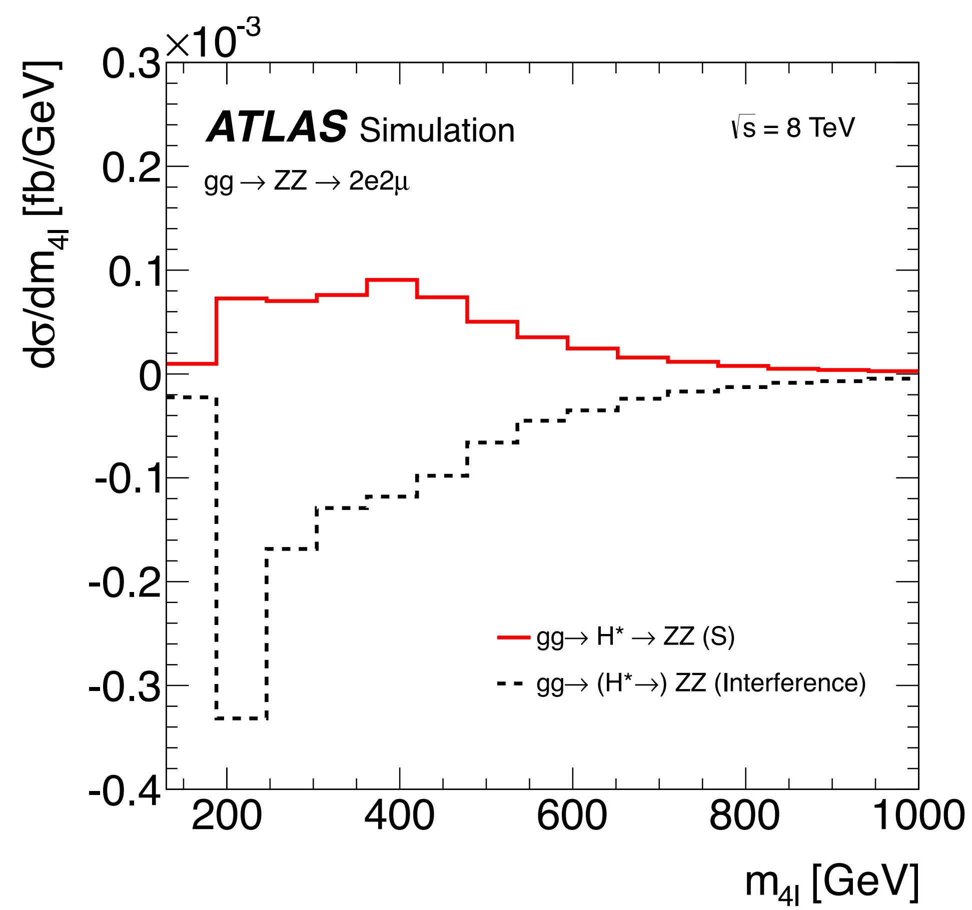
Analysis processes

- The dominant processes contributing to the high-mass (220-1000 GeV) $gg \to VV$ signal region are:
  - $gg \to H^* \to VV$ signal.
  - $gg \to VV$ background continuum.
  - $q\bar{q} \to VV$ background.
  - Interference between signal/bkg.cont.
  - VBF and VH-like production.
  - $t\bar{t}$ and single top $(WW \to e\nu\mu\nu)$









Signal + background corrections

- $gg \to H^* \to VV$ (signal) and $gg \to VV$ (background) are calculated at LO.
  - NNLO QCD+EW corrections are included as a NNLO/LO K-factor for $gg \to H^* \to VV$ (signal).
  - Unknown K-factor for $gg \to VV$ (background).
  - Results are presented as a function of the unknown K-factor of the background.

$$\mathrm{R}_{H^*}^{B} = \frac{\mathrm{K}(gg \to VV)}{\mathrm{K}(gg \to H^* \to VV)} = \frac{\mathrm{K}^{\mathrm{B}}(m_{VV})}{\mathrm{K}_{gg}^{H^*}(m_{VV})}$$

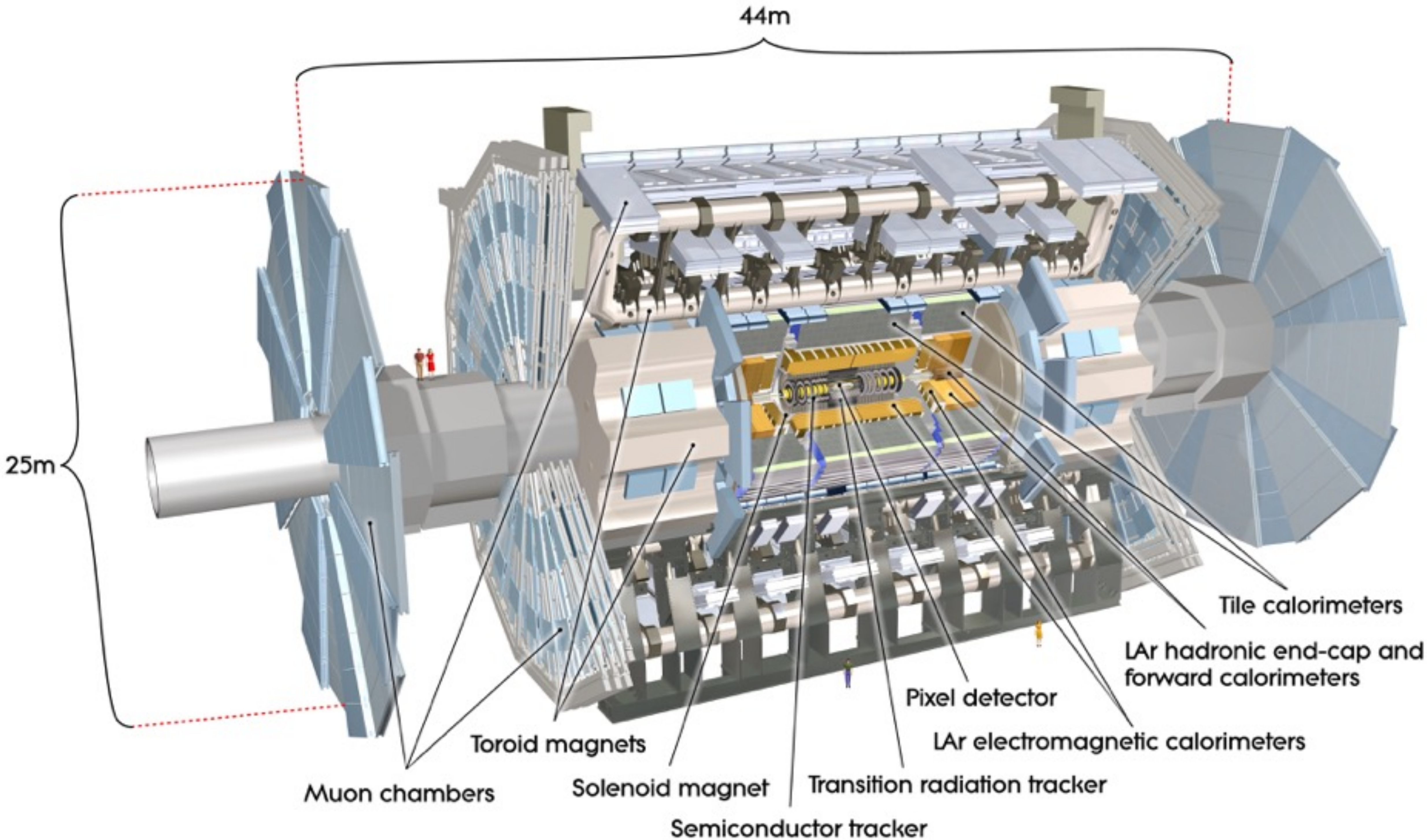
- $q\bar{q} \to VV$ has NNLO/LO QCD+EW corrections.

Signal strength parametrization

- Cross-section for gg→H*→VV process with any off-shell Higgs boson signal strength $\mu_{\text{off-shell}}$

$$
\begin{aligned}
\sigma_{gg\to(H^*\to)VV}(\mu_{\text{off-shell}}) &= \mathrm{K}^{H^*}(m_{VV}) \cdot \mu_{\text{off-shell}} \cdot \sigma^{\text{SM}}_{gg\to H^*\to VV} \\
&+ \sqrt{\mathrm{K}^{H^*}_{gg}(m_{VV}) \cdot \mathrm{K}^{\text{B}}(m_{VV}) \cdot \mu_{\text{off-shell}}} \cdot \sigma^{\text{SM}}_{gg\to VV,\,\text{Interference}} \\
&+ \mathrm{K}^{\text{B}}(m_{VV}) \cdot \sigma_{gg\to VV,\,\text{cont}} \,.
\end{aligned}
$$

The ATLAS detector



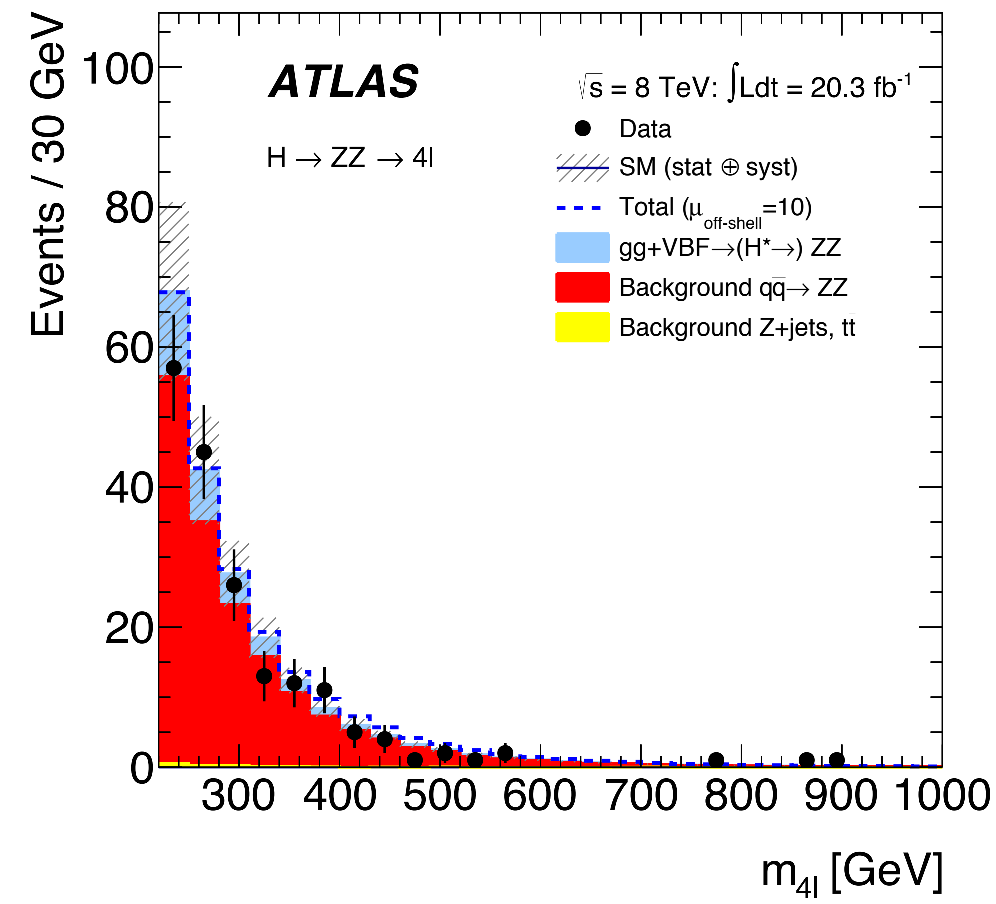
Analysis details and results

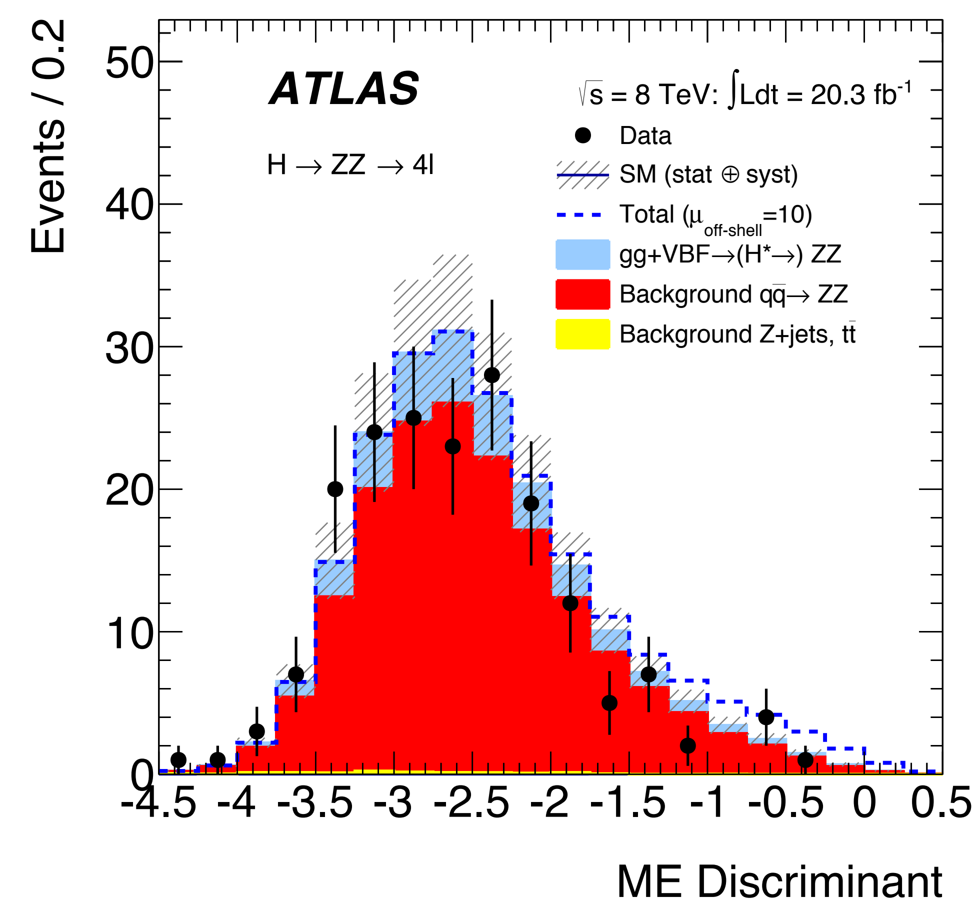
$$H \to ZZ \to 4l$$

- 4 Final states (2e2μ, 2μ2e, 4e, 4μ)
- Main background from $q\bar{q} \to ZZ$
- Selection:
  - Opposite sign, same flavor
  - $220 < m_{4l} < 1000$ GeV
  - m_{12} (leading dilepton pair)
  - $50 < m_{12} < 106$ GeV
  - $50 < m_{34} < 115$ GeV
- Shape based analysis using Matrix element discriminant:

$$ME = \log_{10}\left(\frac{P_H}{P_{gg} + cP_{q\bar{q}}}\right)$$

  - P_H, P_{gg}, P_{qq} are the probability density function for $gg \to H \to ZZ$ (signal), $gg \to ZZ$ (signal+background +interference) and $q\bar{q} \to ZZ$, respectively.





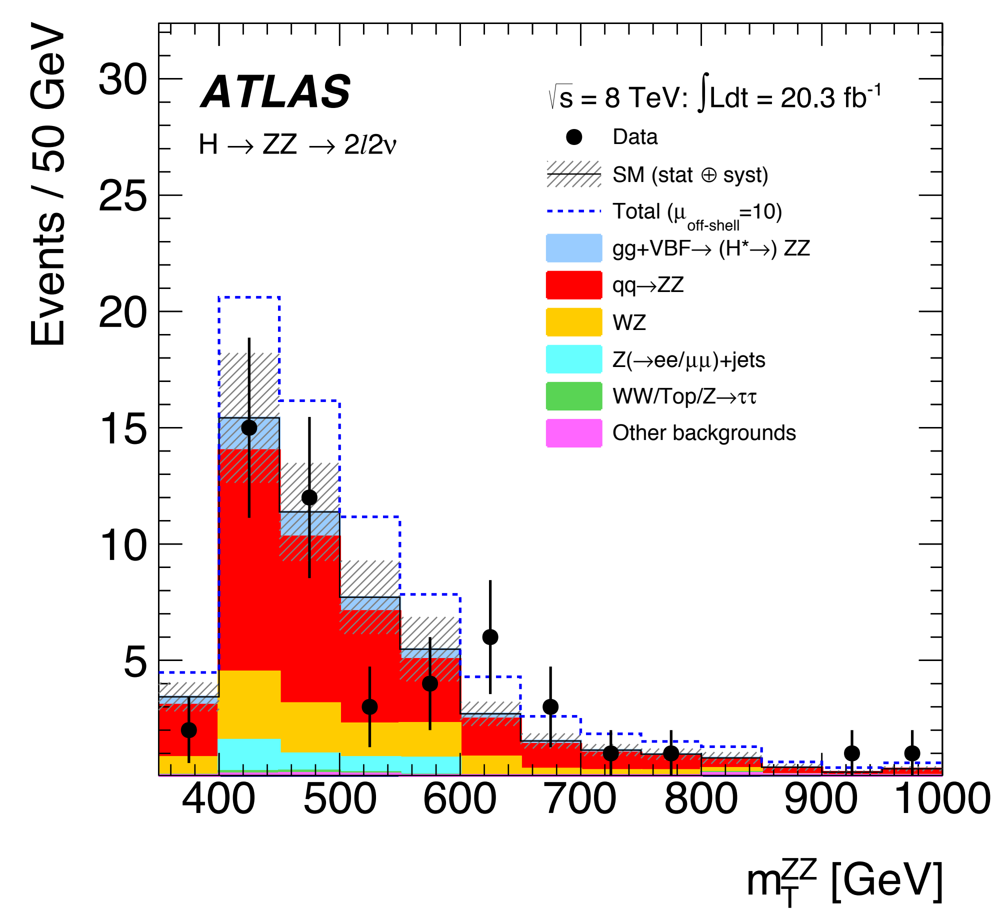
Analysis details and results

$$H \to ZZ \to 2l2\nu$$

- Final states (2e2ν, 2μ2ν)
- The full kinematic reconstruction is not possible, transverse mass (m_T) is employed:

$$m_T^{ZZ} \equiv \sqrt{\left(\sqrt{m_Z^2 + |\mathbf{p}_T^{ll}|^2} + \sqrt{m_Z^2 + |\mathbf{E}_T^{miss}|^2}\right)^2 - |\mathbf{p}_T^{ll} + \mathbf{E}_T^{miss}|^2}$$

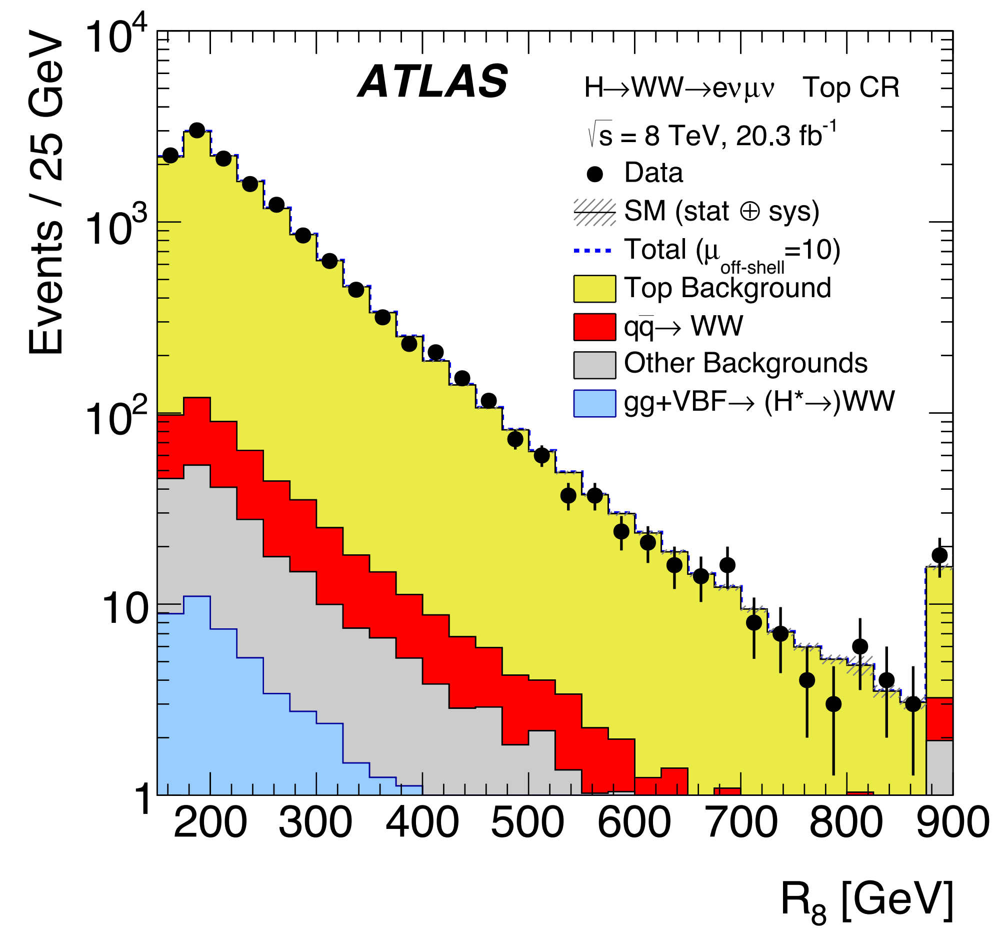
- Selection:
  - $76 < m_{ll} < 106\ GeV$
  - b-jet veto
  - $E_T^{miss} > 180\ GeV$ to suppress DY
  - Optimized kinematic selection
- Background: diboson, top quark and W/Z+jets

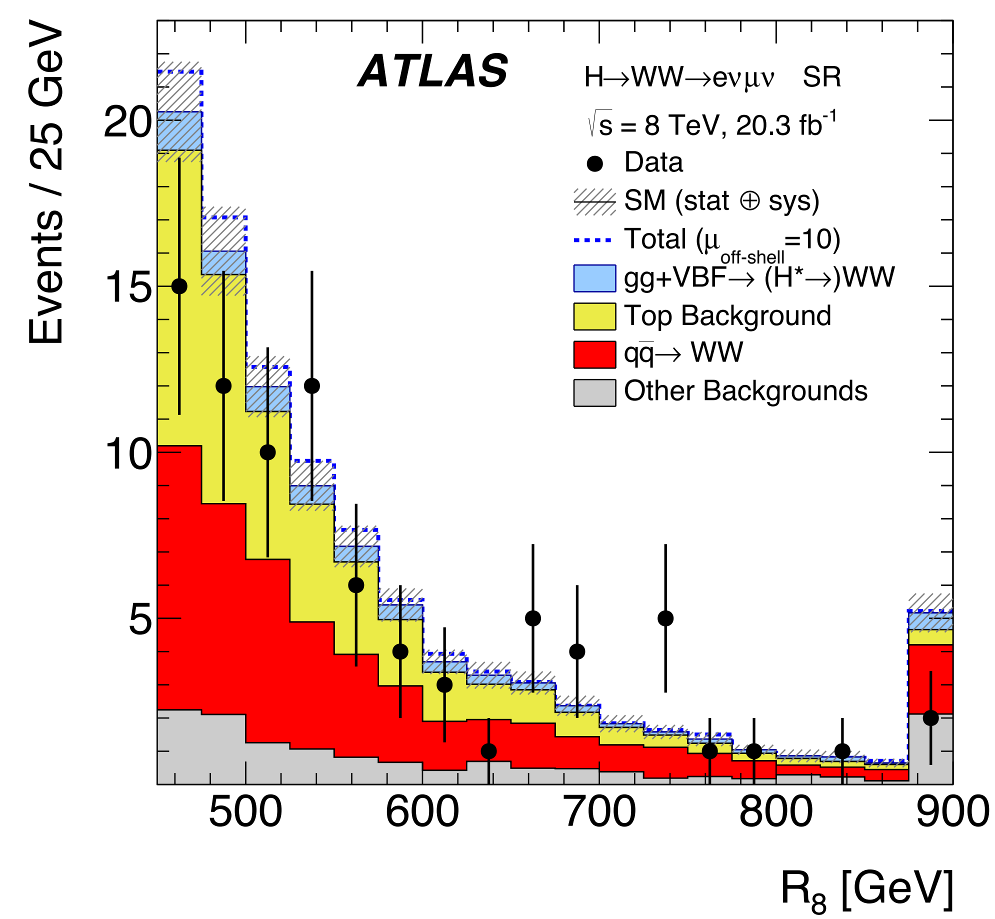


Analysis details and results

$$H \rightarrow WW \rightarrow l\nu l\nu$$

- $m_T^{WW} = \sqrt{\left(E_T^{ll} + \mathbf{p}_T^{\nu\nu}\right)^2 - |\mathbf{p}_T^{ll} + \mathbf{p}_T^{\nu\nu}|^2}$
  where:
  $$E_T^{ll} = \sqrt{(p_T^{ll})^2 + (m_{ll})^2}$$
- To isolate off-shell Higgs
  $$R_8 = \sqrt{m_{ll}^2 + (a \cdot m_T^{WW})^2} \qquad a = 0.8$$
- Selection:
  - $R_8 > 415\ GeV$
  - b-jet veto
  - $\Delta\eta_{ll} < 1.2$ to suppress WW
- Background: W+jets, top and WW
- W+jets and multi-jets are estimated with data driven method.

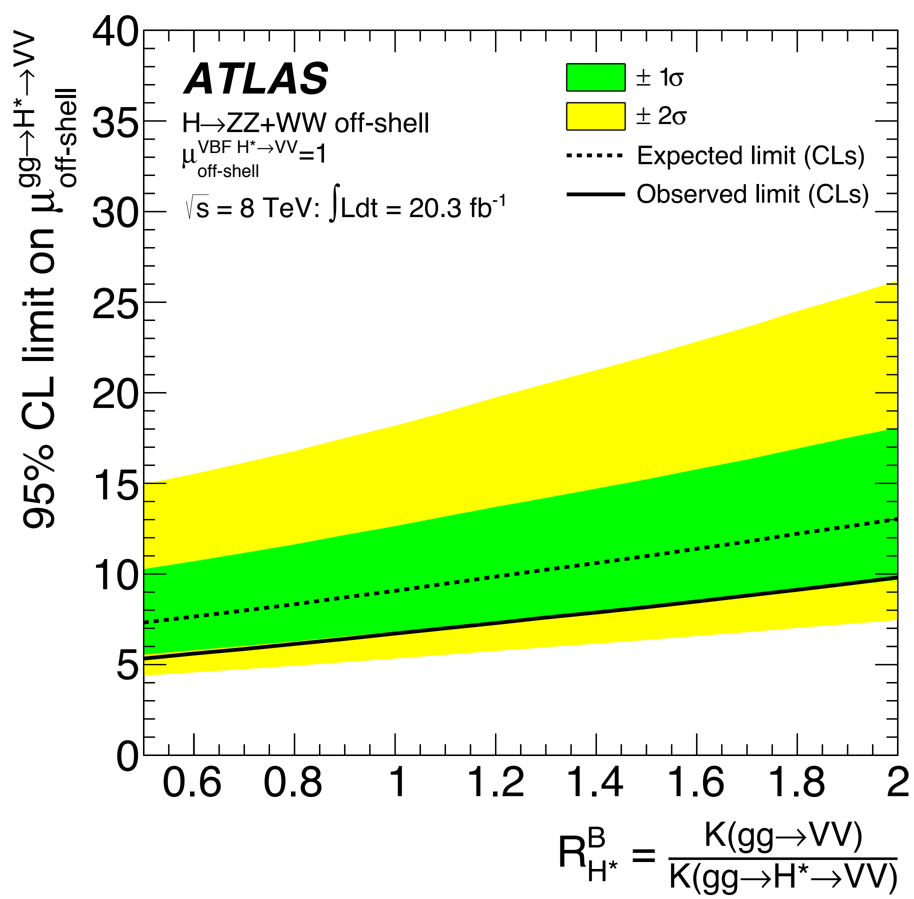




Off-shell signal strength upper limit

- The results are presented as a combination of the three channels: $4l$, $2l2\nu$ and $l\nu l\nu$.
- To obtain an upper limit of μ_{off}, a binned and unbinned maximum-likelihood fit are performed to the $4l$ and $2l2\nu$, $l\nu l\nu$ channels, respectively.
- All 95% confidence level (CL) upper limits are derived using the CLs method.

	Observed			Median expected			Assumption
$\mathrm{R}^{B}_{H^*}$	0.5	**1.0**	2.0	0.5	**1.0**	2.0	
$\mu_{\text{off-shell}}$	5.1	**6.2**	8.6	6.7	**8.1**	11.0	$\mu^{gg\to H^*}_{\text{off-shell}}/\mu^{VBF}_{\text{off-shell}}=1$



Systematic uncertainties

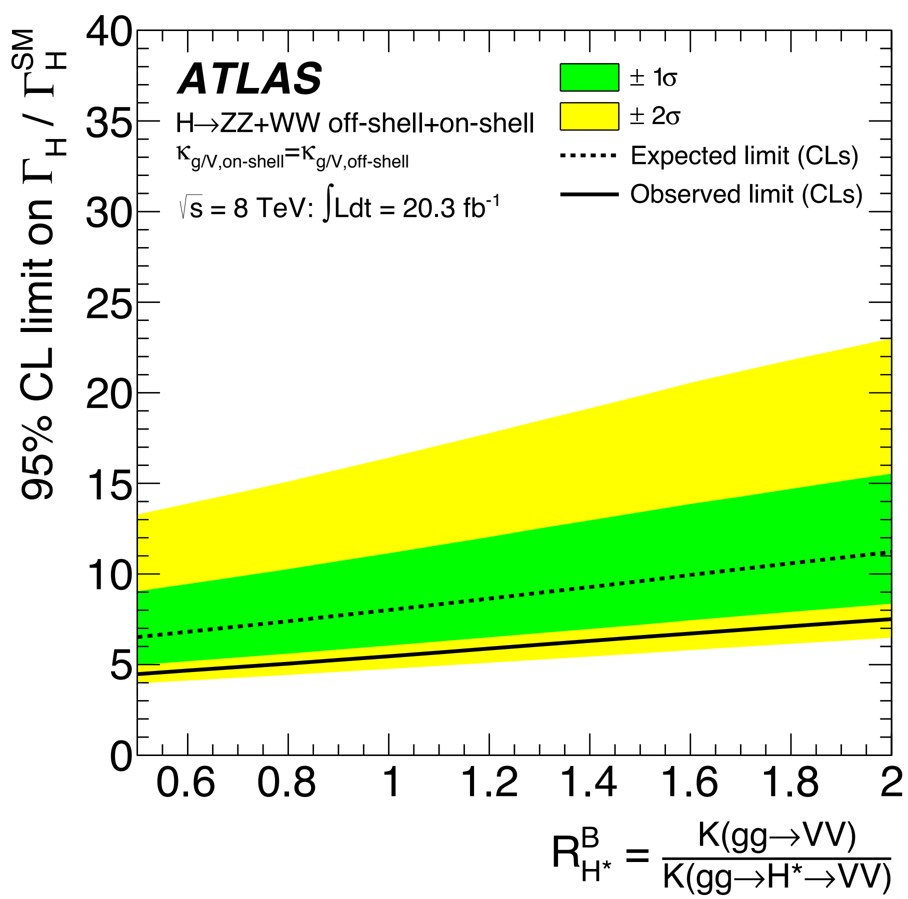
- Main systematics come from theoretical uncertainties:
  - Uncertainty from missing order of QCD and EW to the off-shell signal.
  - Interference uncertainty accounts for 30% approximately.
  - QCD scale and PDF uncertainties applied.
- Experimental systematic uncertainties at few percent level.
- The upper limits are evaluated using the CLs method, assuming $R_{H^*}^{B}=1$.

Systematic uncertainty	95% CL lim. (CL_s) on $\mu_{\text{off-shell}}$
Interference $gg \to (H^* \to)VV$	7.2
QCD scale $K^{H^*}(m_{VV})$ (correlated component)	7.1
PDF $q\bar{q} \to VV$ and $gg \to (H^* \to)VV$	6.7
QCD scale $q\bar{q} \to VV$	6.7
Luminosity	6.6
Drell–Yan background	6.6
QCD scale $K^{H^*}_{gg}(m_{VV})$ (uncorrelated component)	6.5
Remaining systematic uncertainties	6.5
All systematic uncertainties	8.1
No systematic uncertainties	6.5

Total width upper limit

- To obtain an upper limit on Γ_H/Γ_H^{SM} , a binned and unbinned maximum-likelihood fit are performed to the $4l$ and $2l2\nu$, $l\nu l\nu$ channels, respectively.
- All 95% confidence level (CL) upper limits are derived using the CLs method.

	Observed			Median expected			Assumption
R^B_{H*}	0.5	**1.0**	2.0	0.5	**1.0**	2.0	
Γ_H/Γ_H^{SM}	4.5	**5.5**	7.5	6.5	**8.0**	11.2	$\kappa_{i,\text{on-shell}} = \kappa_{i,\text{off-shell}}$

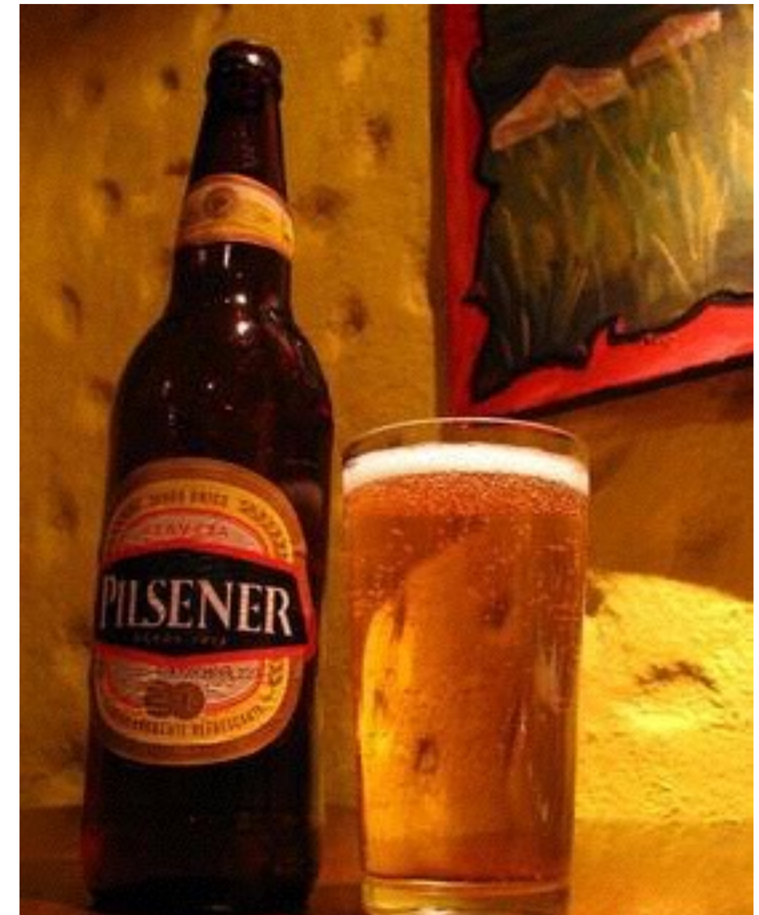


Outlook

- The off-shell $H \to ZZ$ events are used to constrain the off-shell Higgs couplings and the total width.
- The total width of the Higgs is constrained to be ~23 MeV that is better than the direct measurement by a factor of 100.
- K-factor for $gg \to VV$ background (NNLO/LO) is expected from the theory community in order to improve results.
- These results are shown using the assumption that on-shell and off-shell couplings are the same.
  - The VBF production channel can solve this issue, but it has 20 times lower cross section compared to ggF.
  - This could be achieved at the end of the next LHC run.

Special thanks to

MaElena!



The D Collaboration

ALVES, Fabio

CALERO DIAZ, Lilet

CHAPARRO SIERRA, Luisa Fernanda

CORREIA ZANOLI, Henrique José

DIAZ DESPOSORIO, Felix Napoleon

KLIMEK, Pawel

LOPEZ LOPEZ, Jorge Andres

MANZANILLAS, Luis

MORALES VALBUENA, Roberto Anibal

NOGUEIRA, Jorge

OLIVARES PINO, Sebastian Andres

RAMIREZ HIDALGO, Gustavo Alonso

ROLDAN GARCIA, Omar Alberto

RONZANI, Manfredi

YAP, Yee Chinn

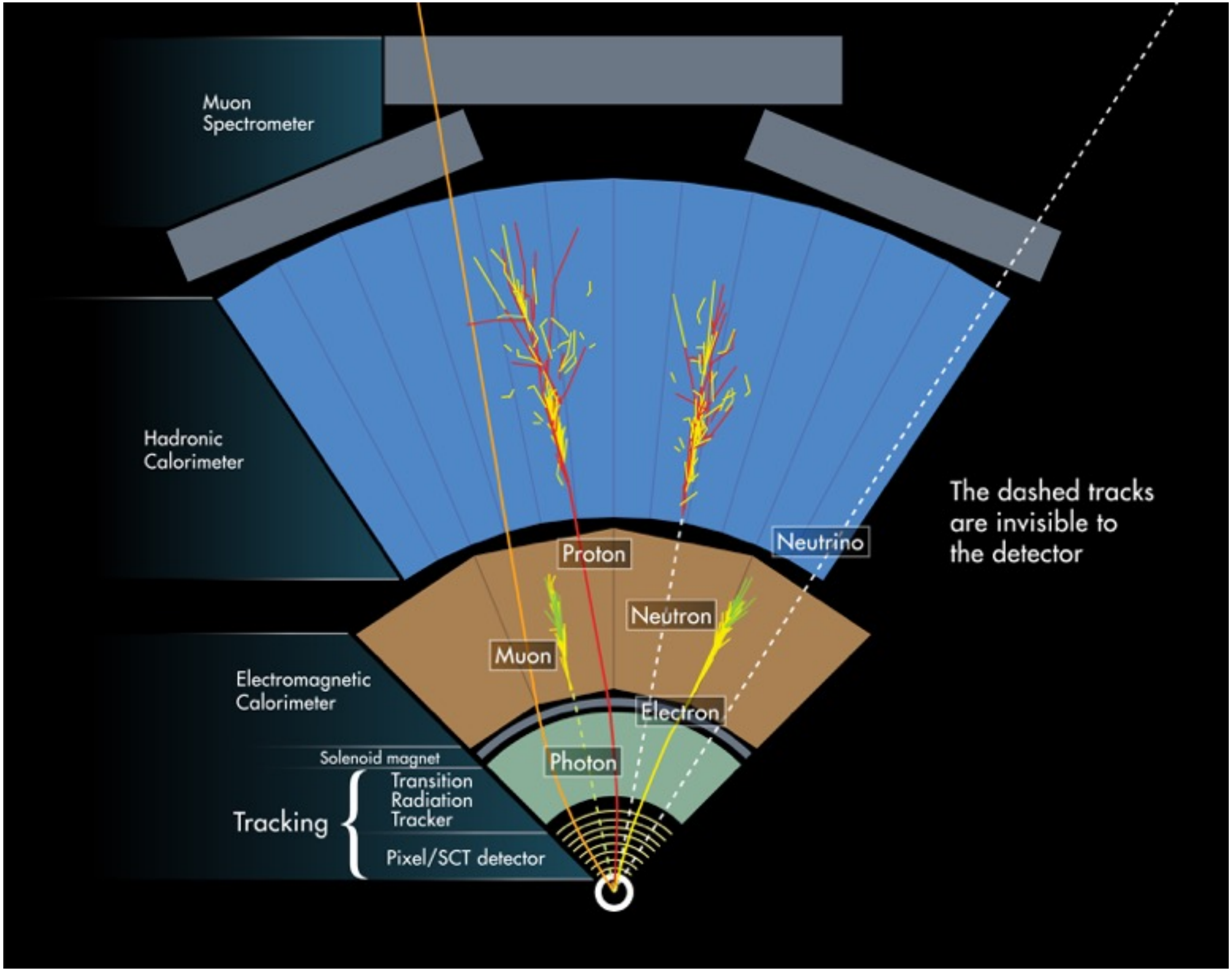
TEJEDA YEOMANS, MaElena

17


31
Hard Rock

Backup

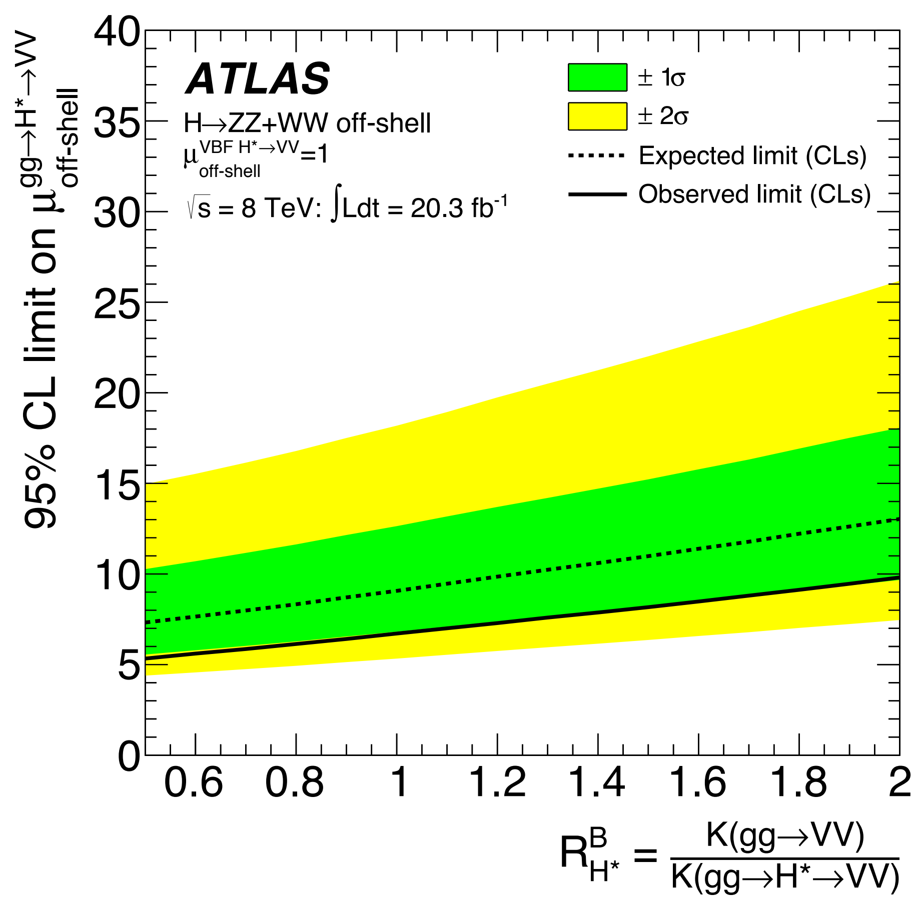
The ATLAS detector

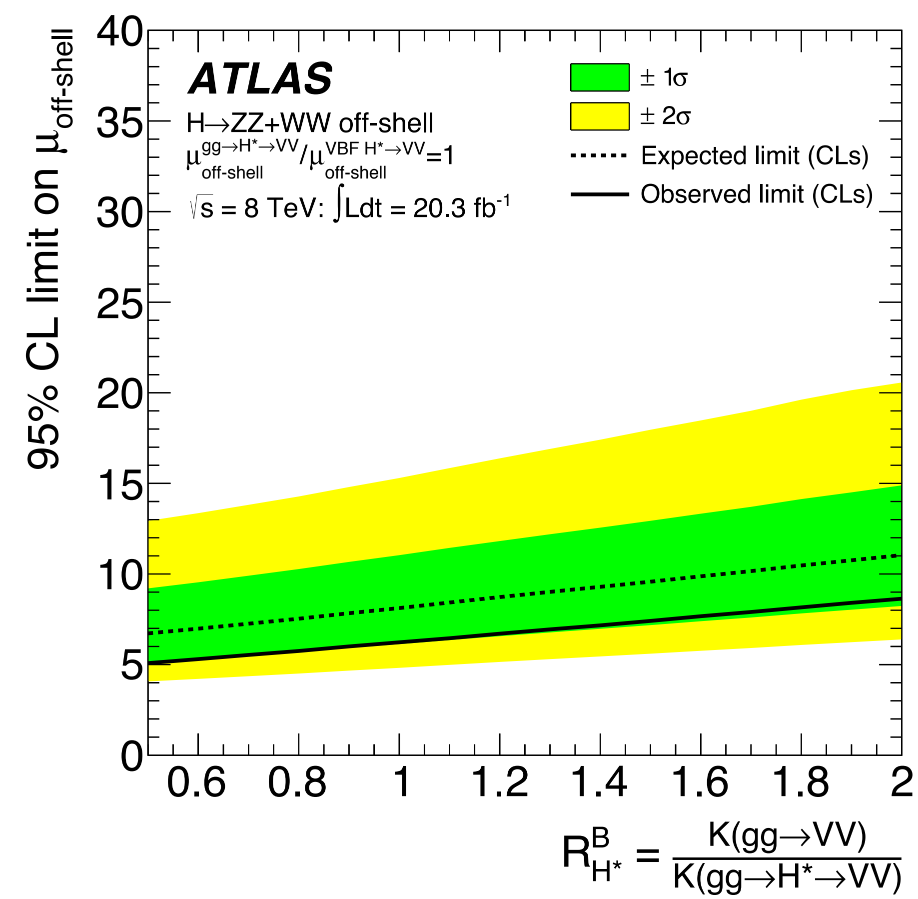


Off-shell signal strength upper limit

- The results are presented as a combination of the three channels: $4l$, $2l2\nu$ and $l\nu l\nu$.
- To obtain an upper limit of μ_{off}, a binned and unbinned maximum-likelihood fit are performed to the $4l$ and $2l2\nu$, $l\nu l\nu$ channels, respectively.
- All 95% confidence level (CL) upper limits are derived using the CLs method.

	Observed			Median expected			Assumption
$R^B_{H^*}$	0.5	**1.0**	2.0	0.5	**1.0**	2.0	
$\mu_{\text{off-shell}}$	5.1	**6.2**	8.6	6.7	**8.1**	11.0	$\mu^{gg\to H^*}_{\text{off-shell}}/\mu^{VBF}_{\text{off-shell}}=1$
$\mu^{gg\to H^*\to VV}_{\text{off-shell}}$	5.3	**6.7**	9.8	7.3	**9.1**	13.0	$\mu^{\text{VBF } H^*\to VV}_{\text{off-shell}}=1$





Total width upper limit

- To obtain an upper limit on Γ_H/Γ_H^{SM} , a binned and unbinned maximum-likelihood fit are performed to the $4l$ and $2l2\nu$, $l\nu l\nu$ channels, respectively.
- All 95% confidence level (CL) upper limits are derived using the CLs method.
- Assuming Γ_H/Γ_H^{SM}=1 and k_V=$k_{V,\text{on}}$=$k_{V,\text{off}}$ associated with the VBF production, the ggF R_{gg}=$k_{g,off}{}^2/k_{g,on}{}^2$ is presented.

	Observed			Median expected			Assumption
R_{H*}^{B}	0.5	**1.0**	2.0	0.5	**1.0**	2.0	
$\Gamma_H/\Gamma_H^{\mathrm{SM}}$	4.5	**5.5**	7.5	6.5	**8.0**	11.2	$\kappa_{i,\text{on-shell}} = \kappa_{i,\text{off-shell}}$
$R_{gg} = \kappa^2_{g,\text{off-shell}}/\kappa^2_{g,\text{on-shell}}$	4.7	**6.0**	8.6	7.1	**9.0**	13.4	$\kappa_{V,\text{on-shell}} = \kappa_{V,\text{off-shell}},\ \Gamma_H/\Gamma_H^{\mathrm{SM}}=1$