$H \rightarrow ll\gamma$ at ATLAS

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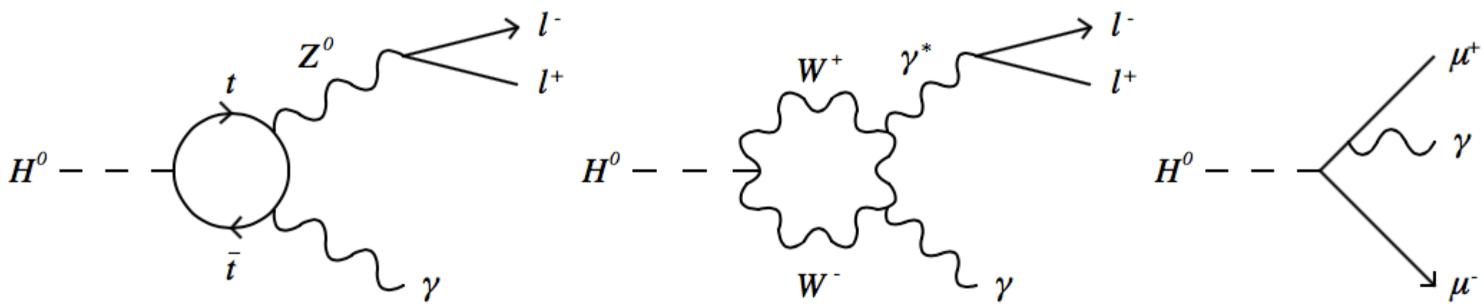
Processes for $H \rightarrow ll\gamma$

- The Standard Model (SM) Higgs boson can decay to the $ll\gamma$ final state in several ways:



$H \rightarrow Z\gamma$	Dalitz decay	Radiative $H \rightarrow \mu\mu$
$m(ll)$ close to Z pole	Small $m(ll)$	Wide range of $m(ll)$

- For more loop mediated examples see arXiv:1302.2159
- For existing analyses we would benefit from accurate estimates and simulation, including interference, of these processes

$H \rightarrow ll\gamma$ processes at ATLAS

- At ATLAS there are several Higgs analyses where $H \rightarrow ll\gamma$ is a relevant process:
  - Resonant and non-resonant signal in the search for $H \rightarrow Z\gamma \rightarrow ll\gamma$ $(l = e, \mu)$
  - Final state radiation in the search for $H \rightarrow ll$ $(l = \mu)$
  - Final state conversion in $H \rightarrow \gamma\gamma$
- The SM branching fractions for these processes are:

Process	$H \rightarrow Z(ll)\gamma$	$H \rightarrow \mu\mu$	$H \rightarrow \gamma\gamma$
Branching fraction	1.0×10^{-4}	2.2×10^{-4}	2.3×10^{-3}

- Comparable to the rare B($H \rightarrow ZZ^* \rightarrow llll$) $= 1.2\times10^{-4}$
  - But with significantly larger backgrounds

http://cds.cern.ch/record/1523683

$H \rightarrow Z(ll)\gamma$ search at ATLAS

- The selections for $H \rightarrow Z(ll)\gamma$ at ATLAS are:

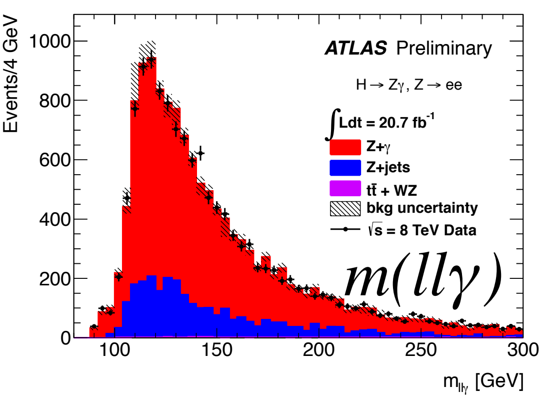
	Electron	Muon	Photon
p_T	> 10 GeV	> 10 GeV	> 15 GeV
Pseudorapidity	$\|\eta\| < 2.47$	$\|\eta\| < 2.7$	$\|\eta\| < 1.37$ or $1.52 < \|\eta\| < 2.37$
Track isolation	$p_T^{iso}/p_T < 0.1$ in $\Delta R < 0.2$	$p_T^{iso}/p_T < 0.1$ in $\Delta R < 0.2$	
Calorimeter isolation	$p_T^{iso}/E_T < 0.2$ in $\Delta R < 0.2$		< 4 GeV in $\Delta R < 0.4$

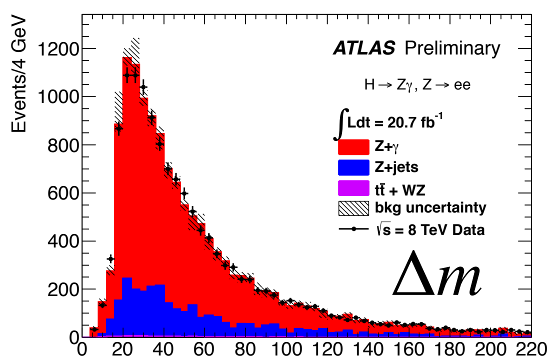
- Trigger on single/double lepton triggers
- Choose Z candidate closest to Z pole (91.18 GeV)
- Choose photon with highest p_T
- Require $m(ll) > 81.18$ GeV

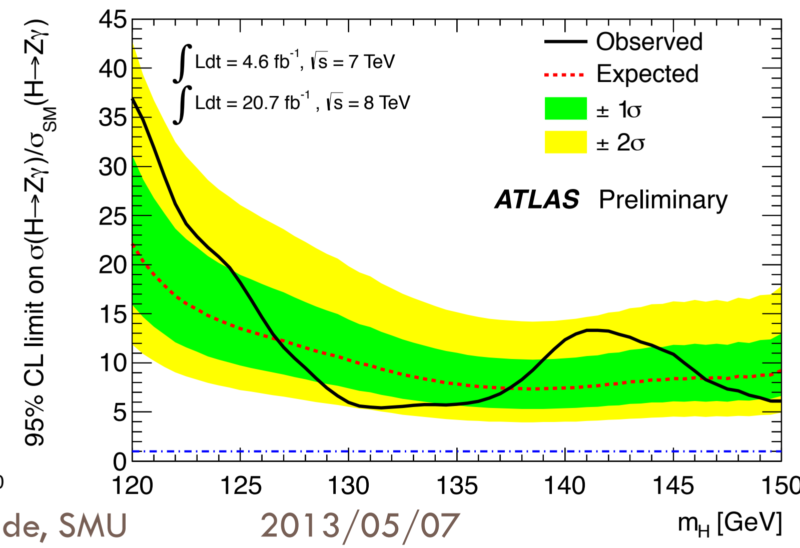
http://cds.cern.ch/record/1523683

$H \rightarrow Z(ll)\gamma$ search at ATLAS

- Two choices of variable:
  - $m(ll\gamma)$: Sensitive to $H \rightarrow Z\gamma \rightarrow ll\gamma$, $H \rightarrow \gamma\gamma^* \rightarrow ll\gamma$ and $H \rightarrow \mu\mu^* \rightarrow \mu\mu\gamma$
  - $\Delta m = m(ll\gamma)$ - $m(ll)$: Only sensitive to $H \rightarrow Z\gamma \rightarrow ll\gamma$
- We use Δm as the discriminating variable
  - Width of Z boson is irreducible
- We are sensitive to ~15×SM cross section at m_H=125 GeV
- Our signal Monte Carlo (MC) samples currently only contain $H \rightarrow Z\gamma$
- Contribution from $H \rightarrow \mu\mu^* \rightarrow \mu\mu\gamma$ estimated to be <10% total signal







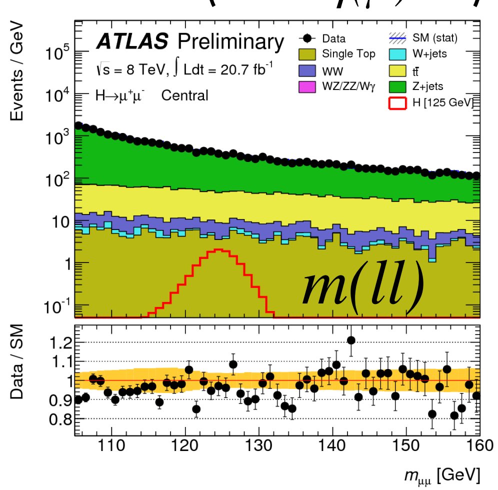
$H \rightarrow \mu\mu$ search at ATLAS

- The selections for $H \rightarrow \mu\mu$ at ATLAS are:

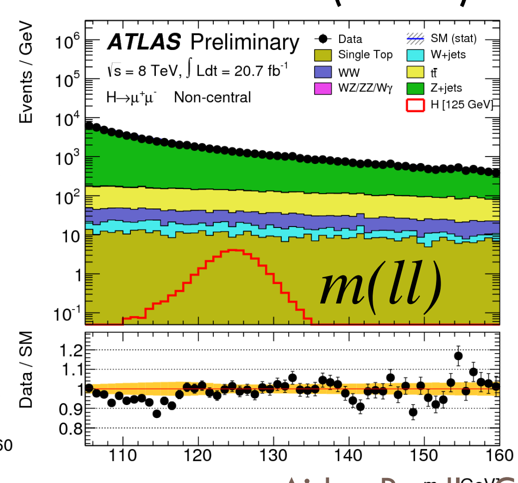
	Muon
Muons p_T, η	$p_T > 25$ GeV (leading muon), $p_T > 15$ GeV (subleading muon), $\lvert\eta\rvert < 2.5$
$p_T(\mu\mu)$	> 15GeV to suppress Drell-Yann backgrounds

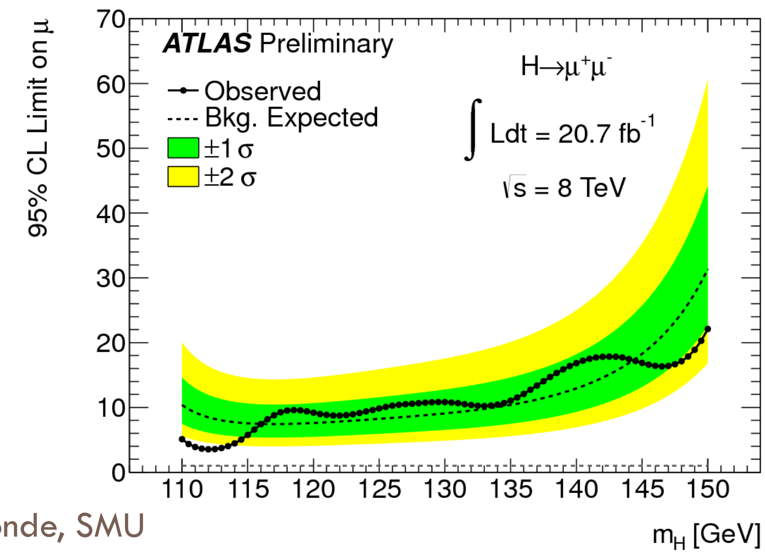
- We define signal region as $m(ll) > 105$ GeV
- We are sensitive to ~10×SM cross section at m_H=125 GeV

Central (both $\lvert\eta(\mu)\rvert<1$)



Non central (others)





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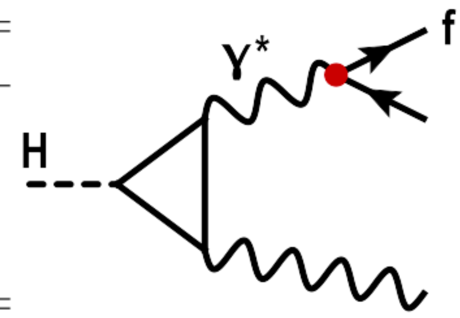
$H \rightarrow \gamma\gamma$ at ATLAS

- Similar situation compared to $H \rightarrow Z\gamma$ analysis
- A fraction of the internal conversions $\gamma^* \rightarrow f\bar{f}$ are picked up by the nominal analysis selection
- Efficiency largest for showers and conversions, albeit much smaller compared to on-shell photons
- This contribution is included in Pythia8 (below are indicative numbers for the fraction, efficiency and conversion fraction for a typical $H \rightarrow\gamma\gamma$ selection and standard generator settings)
- Not included in Pythia6

	Frac.	Effi.	Conv.
Final State Photons	94.3%	41.3%	50.7%
Conversions (e^+e^-)	2.2%	3.8%	97.3%
Quarks and Other Leptons	3.2%	0.4%	62.0%
Showers ($e+\gamma$)	0.4%	8.4%	98.7%



Common issues and questions

- These three analyses are facing similar issues and questions with $H \rightarrow ll\gamma$:
  - We need MC samples that describe the processes well with interference terms
  - Which variables are going to be the most discriminating/most useful?
  - How should the following events be treated?:
    - Interference between $H \rightarrow Z\gamma \rightarrow \mu\mu\gamma$, $H \rightarrow \mu\mu^* \rightarrow \mu\mu\gamma$ near the Z pole
    - $H \rightarrow \mu\mu^* \rightarrow \mu\mu\gamma$ with soft photons
    - $H \rightarrow \gamma\gamma^* \rightarrow ll\gamma$ Dalitz decay events

Summary and outlook

- $H \rightarrow ll\gamma$ is an important final state for ATLAS searches:
  - Non-resonant signal in search for $H \rightarrow Z\gamma$
  - Final state correction to $H \rightarrow \mu\mu$
  - Final state conversion for $H \rightarrow \gamma\gamma$
- The various contributions interfere with each other, making estimation non-trivial
- We need well understood simulation of these processes
- There are open questions about how to treat and classify the events
- Feedback and input greatly appreciated

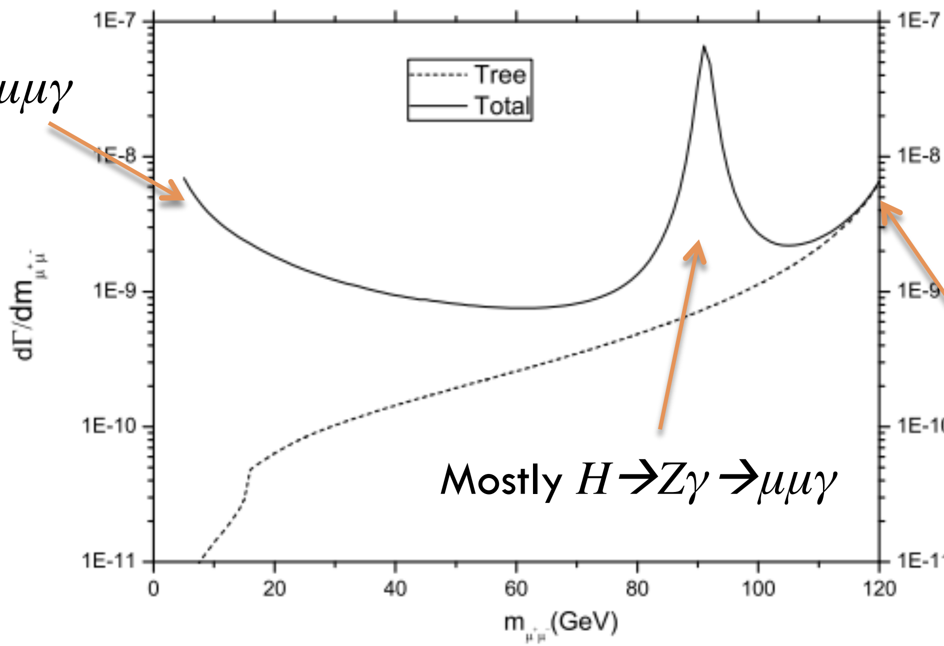
Backup slides

- Illustrative $m(ll)$ spectrum
- Higgs branching fraction uncertainties

Illustrative $m(ll)$ spectrum

- In arXiv:1211.6058 [hep-ph] Gainer et al present a simulation of $H \rightarrow \mu\mu\gamma$ events
- They provide the $m(\mu\mu)$ spectrum, which shows the various contributions:

	$(m^2_{\ell\bar{\ell}})_{\rm cut}$	$(m^2_{\bar{\ell}\gamma})_{\rm cut}$	$(m^2_{\ell\gamma})_{\rm cut}$	$(E_\ell)_{\rm cut}$ (GeV)	$(E_{\bar{\ell}})_{\rm cut}$ (GeV)	$(E_\gamma)_{\rm cut}$ (GeV)
cut I	$25m^2_\mu$	$25m^2_\mu$	$25m^2_\mu$	1	1	1



Uncertainties in $B(H \rightarrow ll\gamma)$

- The theoretical uncertainties for $B(H \rightarrow ll\gamma)$ are:

Process	Uncertainty	
$gg \rightarrow H$	15.3% @ m_H = 110 GeV	14.4% @ m_H = 150 GeV
Vector boson fusion $\rightarrow H$	3.0% @ m_H = 110 GeV	2.9% @ m_H = 150 GeV
$H \rightarrow Z\gamma \rightarrow ll\gamma$	9.4% @ m_H = 120 GeV	6.2% @ m_H = 120 GeV
$H \rightarrow \mu\mu$	7.0% @ m_H = 110 GeV	3.2% @ m_H = 150 GeV
$H \rightarrow \gamma\gamma$	5%	