ATLAS \( ttH \) measurements in \( H \rightarrow \gamma\gamma \) at \( \sqrt{s} = 13 \) TeV

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USLUA Lightning Round

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Higgs production in pp collisions

- ttH production is a direct probe of the Higgs-top coupling
  - Indirect probes include gluon-gluon fusion production and $H \rightarrow \gamma \gamma$ decay loops
- Standard model $\sigma_{ttH}$ is only 0.51 pb at 13 TeV
Why $H \rightarrow \gamma \gamma$ ?

😊 Con: low branching ratio = 0.227%

😊 Pro: manageable background
  – *Low rates* of photons compared to jets
  – *Smoothly falling background* $m_{\gamma \gamma}$ spectrum

😊 Pro: excellent photon energy resolution

😊 Pro: no ambiguity in the origin of final state particles
  – Photons from Higgs, all other objects from tops

😊 Pro: expect big gains with more data
Multivariate analysis

Multiple variables (four-vectors)

Single discriminant (BDT score)

Multiple categories with different S/B

BDT training using XGBoost

Categorization

Sensitivity evaluation

Signal: ttH(γγ) MC
Bkg: continuum diphoton

m_{γγ} spectrum of data in all categories
Multivariate analysis

- Define $ttH$ categories with different S/B by slicing in BDT score
  - Tight BDT categories have lower statistics in data, but higher $ttH$ purity and better S/B ratio

**All-hadronic**

**1+ lepton**
Sensitivity to $ttH(\rightarrow \gamma\gamma)$
with 79.8 fb$^{-1}$

- Perform a combined signal + background fit over all categories to the $m_{\gamma\gamma}$ distribution
- $H \rightarrow \gamma\gamma$ alone is **sensitive to $ttH$ at the level of 4.1\sigma**
- **Statistics limited!**
  Expect further improvement with 2018 data
Top content
in ttH(→ γγ) categories

• Using a dedicated BDT algorithm, *reconstruct top candidates* from sets of three jets

• **Clear peak** in data at $m_{\text{top}}$ in the ttH(→ γγ) categories!

• Fit data to decompose continuum diphoton background into 58% ttγγ and 32% γγ

$m_{\text{top}} = 173$ GeV
We combine the $ttH(\rightarrow \gamma\gamma)$ categories with other Higgs decay channels.

We observe $ttH$ production with a combined significance of $6.3\sigma$.

This is the first observation of direct Higgs-quark coupling!
Discovery of $ttH$

- We measure a 13 TeV $ttH$ cross section of
  \[ \sigma_{ttH} = 670 \pm 90 \text{ (stat)} \pm^{110}_{-100} \text{ (syst)} \text{ fb} \]

- Reasonable agreement with the SM prediction

- We look forward to probing this process further in the full Run-2 dataset!
Thank you!
Backup
Abstract

Higgs production in association with top quarks (ttH) is predicted by the Standard Model at a rate of about 1% of the total Higgs cross section. This process directly probes the Higgs-top coupling, a critical parameter for isolating Beyond the Standard Model contributions to Higgs physics. The ATLAS search for ttH events in conjunction with the decay $H \rightarrow \gamma\gamma$ takes advantage of the high photon detection efficiency and energy resolution of the ATLAS electro-magnetic calorimeter, as well as the relatively low rate of diphoton background processes. The application of sophisticated multivariate techniques to identify ttH $\rightarrow \gamma\gamma$ events improves the sensitivity to ttH compared to past analyses. In combination with other Higgs decay channels, ttH $\rightarrow \gamma\gamma$ contributed to the recent discovery of the ttH production mode.
References

• ATLAS publications

• Other
  – https://twiki.cern.ch/twiki/bin/view/%20LHCPhysics/LHCHXSWG#SM_Higgs
The ATLAS detector
Hadronic channel
BDT Training
in the hadronic channel

• Require ≥3 jets, ≥1 b-jet, 0 leptons
• Signal: ttH(γγ) MC
• Background: data control sample + ggH(γγ) MC
• Training variables:
  – Four momentum and b-tag score of up to six jets
  – Four momentum of the two photons, scaled by $m_{γγ}$ to prevent biasing the $m_{γγ}$ distribution
  – Missing $E_T$ and angle of missing $E_T$
Category Definition in the hadronic channel

- Define four hadronic $ttH$ categories with different S/B by slicing in BDT score
  - Reject events with BDT score < 0.91

- Tight BDT categories have lower statistics, but higher $ttH$ purity and better S/B ratio
  - These are the most powerful categories
Hadronic channel
BDT category 4 (loosest)

Expected $ttH$ yield:
3.00

$S/B$: 0.05

$ttH$ purity ($n_{ttH}/n_{Higgs}$):
48%

Background shape:
Power law

Mass resolution:
1.63 GeV

S/B and purity calculated in the smallest window containing 90% of $ttH$
Hadronic channel
BDT category 3

Expected ttH yield: 4.7

S/B: 0.13

ttH purity ($n_{ttH}/n_{Higgs}$): 70%

Background shape: Power law

Mass resolution: 1.59 GeV

S/B and purity calculated in the smallest window containing 90% of ttH
Hadronic channel

BDT category 2

Expected $ttH$ yield: 3.41

$S/B$: 0.42

$ttH$ purity ($n_{ttH}/n_{Higgs}$): 83%

Background shape: Exponential

Mass resolution: 1.46 GeV

S/B and purity calculated in the smallest window containing 90% of $ttH$
Hadronic channel
BDT category 1 (tightest)

Expected $ttH$ yield:
4.20

$S/B$: 1.87

$ttH$ purity ($n_{ttH}/n_{Higgs}$):
90%

Background shape:
Power law

Mass resolution:
1.32 GeV

$S/B$ and purity calculated in the smallest window containing 90% of $ttH$
Leptonic channel
BDT Training in the leptonic channel

• Require ≥3 jets, ≥1 b-jet, 0 leptons
• Signal: ttH(γγ) MC
• Background: data control sample
• Training variables:
  – Four momentum and b-tag score of up to six jets
  – Four momentum of the two photons, scaled by $m_{γγ}$ to prevent biasing the $m_{γγ}$ distribution
  – Four momentum of up to two leptons
  – Missing $E_T$ and angle of missing $E_T$
Category Definition in the leptonic channel

- Define three leptonic ttH categories with different S/B by slicing in BDT score
  - Reject events with BDT score < 0.70

- Again, tightest BDT category is the most powerful due to high S/B

- Statistics in the leptonic channel are lower
  - Branching ratio of W to $e\nu$ or $\mu\nu$ is only 21.3%
Leptonic channel
BDT category 3 (loosest)

Expected $ttH$ yield:
0.82

$S/B$: 0.17

$ttH$ purity ($n_{ttH}/n_{Higgs}$):
73%

Background shape:
Exponential

Mass resolution:
1.73 GeV

$S/B$ and purity calculated in the smallest window containing 90% of $ttH$
Leptonic channel
BDT category 2

Expected $ttH$ yield: 2.23

$S/B$: 0.46

ttH purity ($n_{ttH}/n_{Higgs}$): 89%

Background shape:
Power law

Mass resolution:
1.68 GeV

S/B and purity calculated in the smallest window containing 90% of ttH
Leptonic channel
BDT category 1 (tightest)

Expected $\ttH$ yield: 4.50

$S/B$: 1.84

ttH purity ($n_{\ttH}/n_{\text{Higgs}}$): 95%

Background shape: Power law

Mass resolution: 1.45 GeV

S/B and purity calculated in the smallest window containing 90% of $\ttH$
Systematics on the combined cross section measurement

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