Search for the Higgs boson decaying to a pair of muons in pp collisions at 13 TeV with the ATLAS detector

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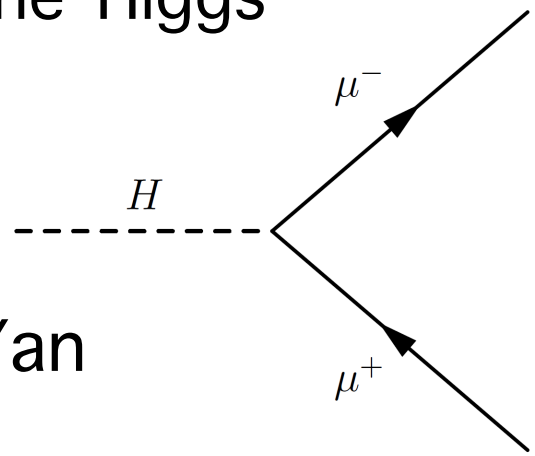
For the ATLAS Collaboration

Higgs 2020, Online

October 27, 2020

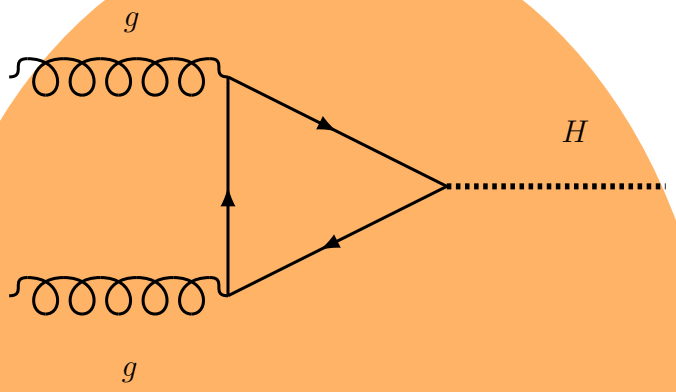
H→$\mu\mu$ @LHC

- The search of H→$\mu\mu$ is very crucial after the Higgs discovery
  - Is the BEH mechanism also responsible for 2nd-generation (1st outside LHC reach) fermion masses?
  - H→$\mu\mu$ provides the best opportunity for probing the Higgs coulping to 2nd-generation fermions
- Rare decay: BR(SM H→$\mu\mu$) = (2.17±0.04)×10^{-4}
- Dominant background in inclusive spectrum: Drell-Yan
  - Typical S/B at 0.1% level
- In this talk, presenting H→$\mu\mu$ search using full run-2 data (139 fb^{-1}) with the ATLAS detector (arXiv:2007.07830)

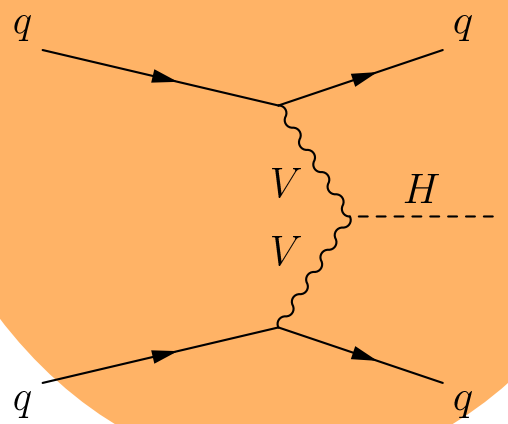


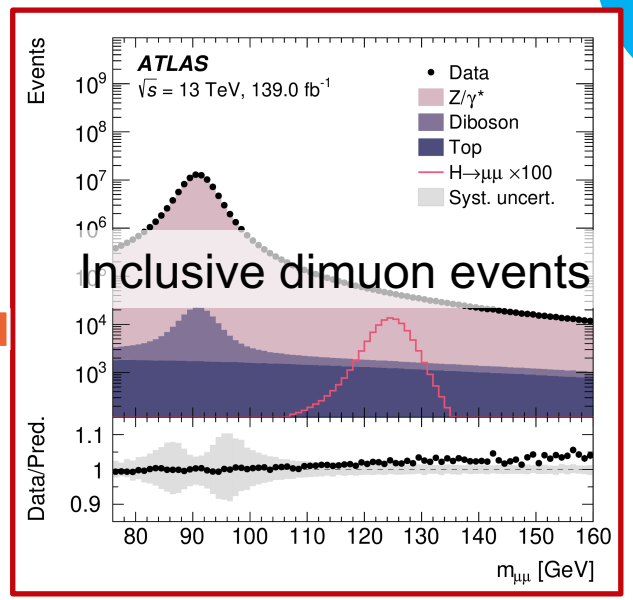
arXiv:2007.07830

Event selection & categorization

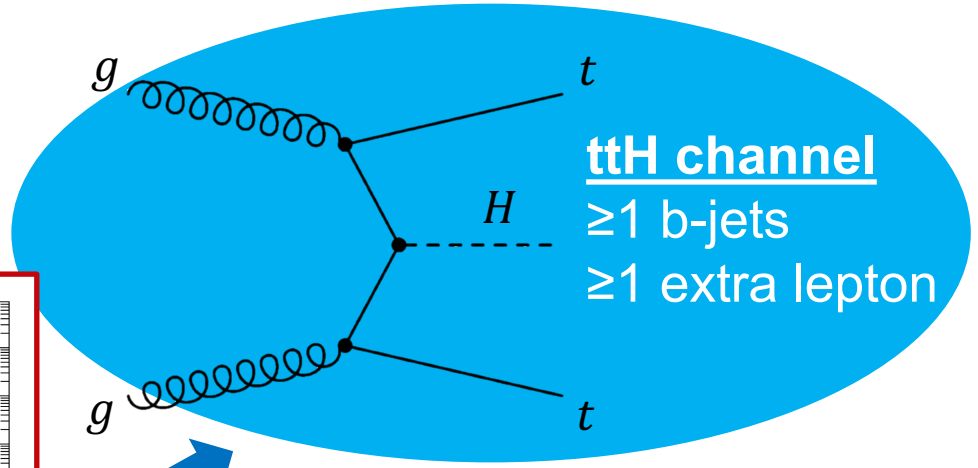


VBF+ggF channel
Rest events



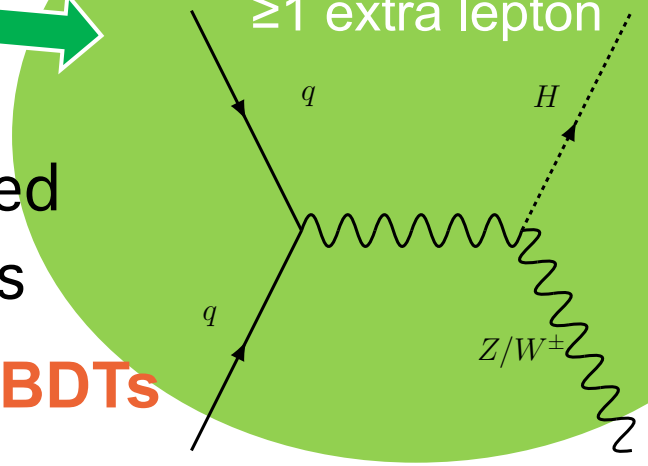


Inclusive dimuon events



ttH channel
≥1 b-jets
≥1 extra lepton

VH channel
0 b-jets
≥1 extra lepton

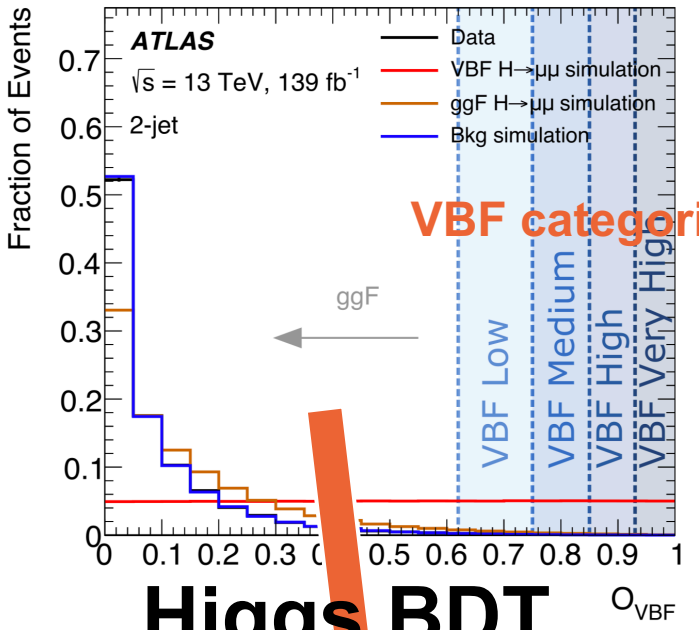


Signal signatures: two isolated muons with opposite charges

➔Further split to 20 categories by BDTs

Categorization for VBF/ggF

arXiv:2007.07830

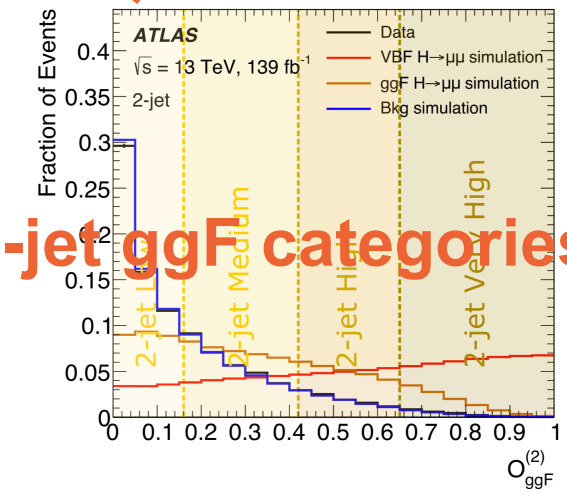


VBF categories

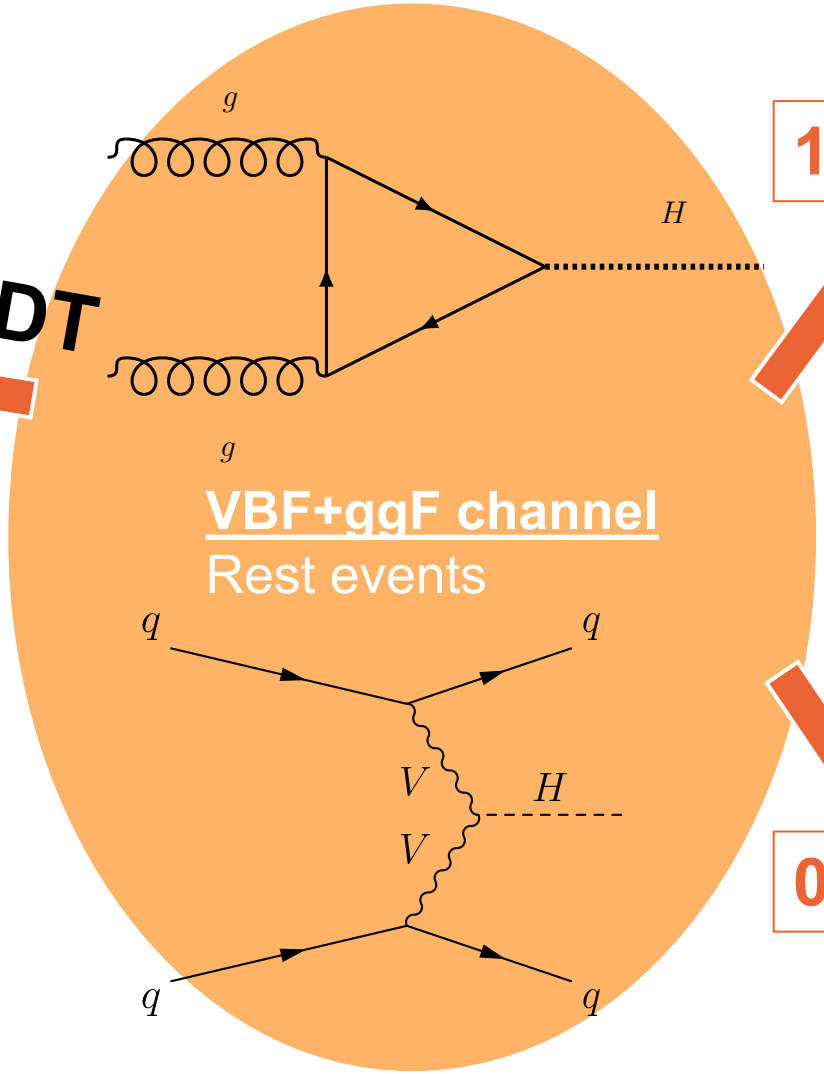
VBF BDT

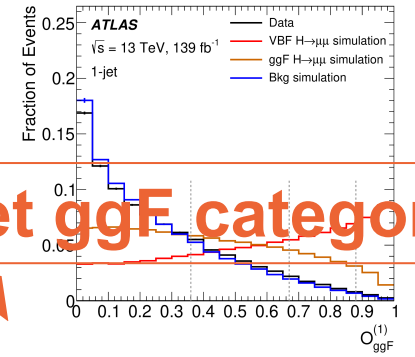
≥2-jet

Higgs BDT



≥2-jet ggF categories

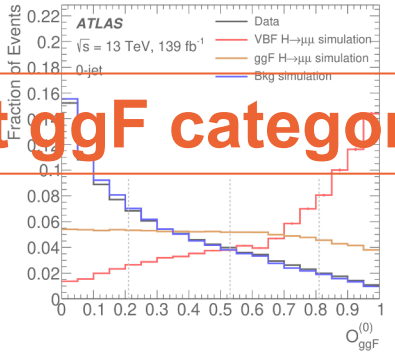




1-jet ggF categories

Higgs BDT

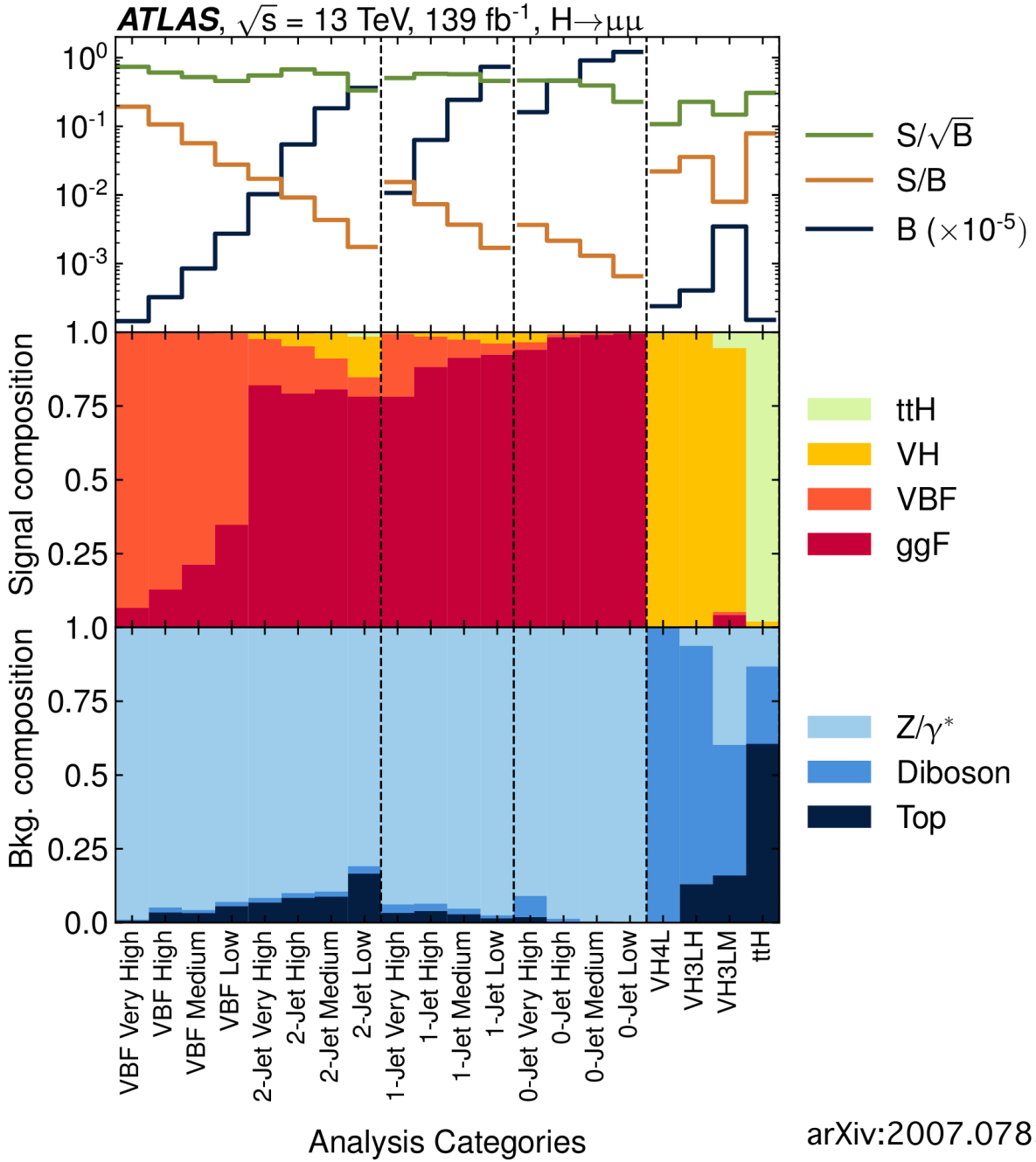
Higgs BDT



0-jet ggF categories

Categorization summary

- 20 categories in total
- Different Higgs production modes are well separated
- Wide range of S/B from 0.1% to 20%
- ~450k events in data
- ~850 signal events expected (ε~52%)



arXiv:2007.07830

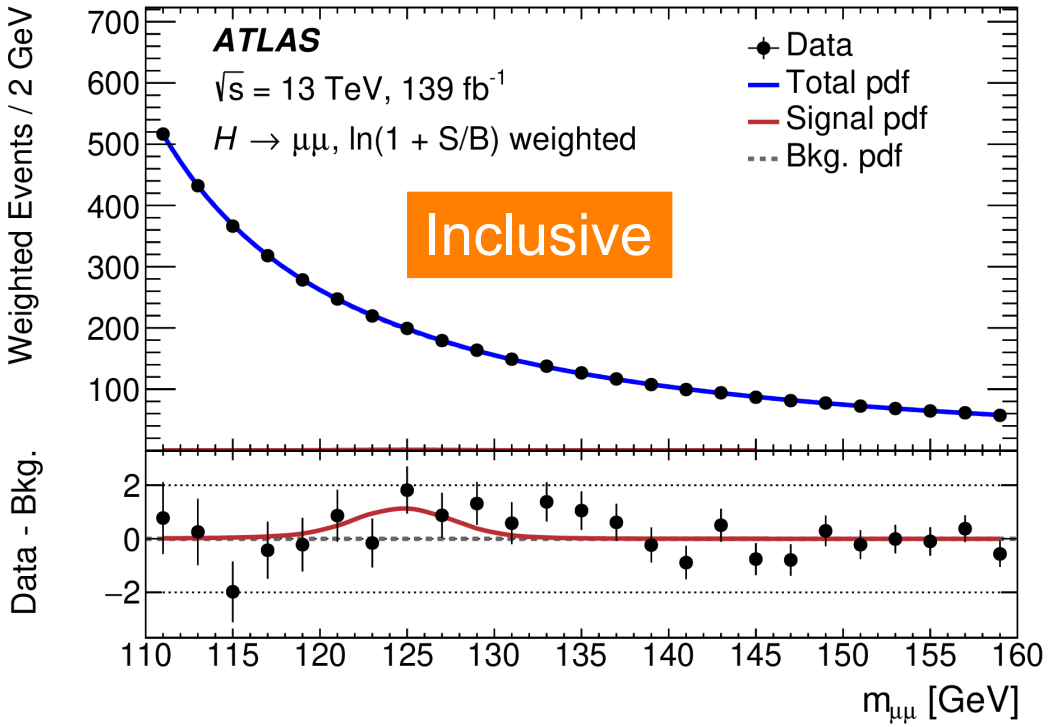
Signal and background modeling

- Signal: A double-sided Crystal Ball function (Gaussian + power-law tails)
- Background: (Core) X (Emperical)
  - Core function: LO DY line-shape convolved with muon resolution (gaussian)
  - Empirical function: Power-law or Epoly functions with free parameters (different in each category)
- Functions selected based on spurious signal procedure using high-stat simulation

Results and summary

- Fitted signal strength: 1.2±0.6 (limited by data statistics: ±0.58)
- Observed (expected) significance: 2.0σ (1.7σ)
- Observed upper limit: 2.2 X SM
- Sensitivity improved by 2.5 (25% from better techniques) wrt previous analysis (arXiv:1705.04582)
- Looking forward to the future results! (CERN press release)

arXiv:2007.07830



Thank you!

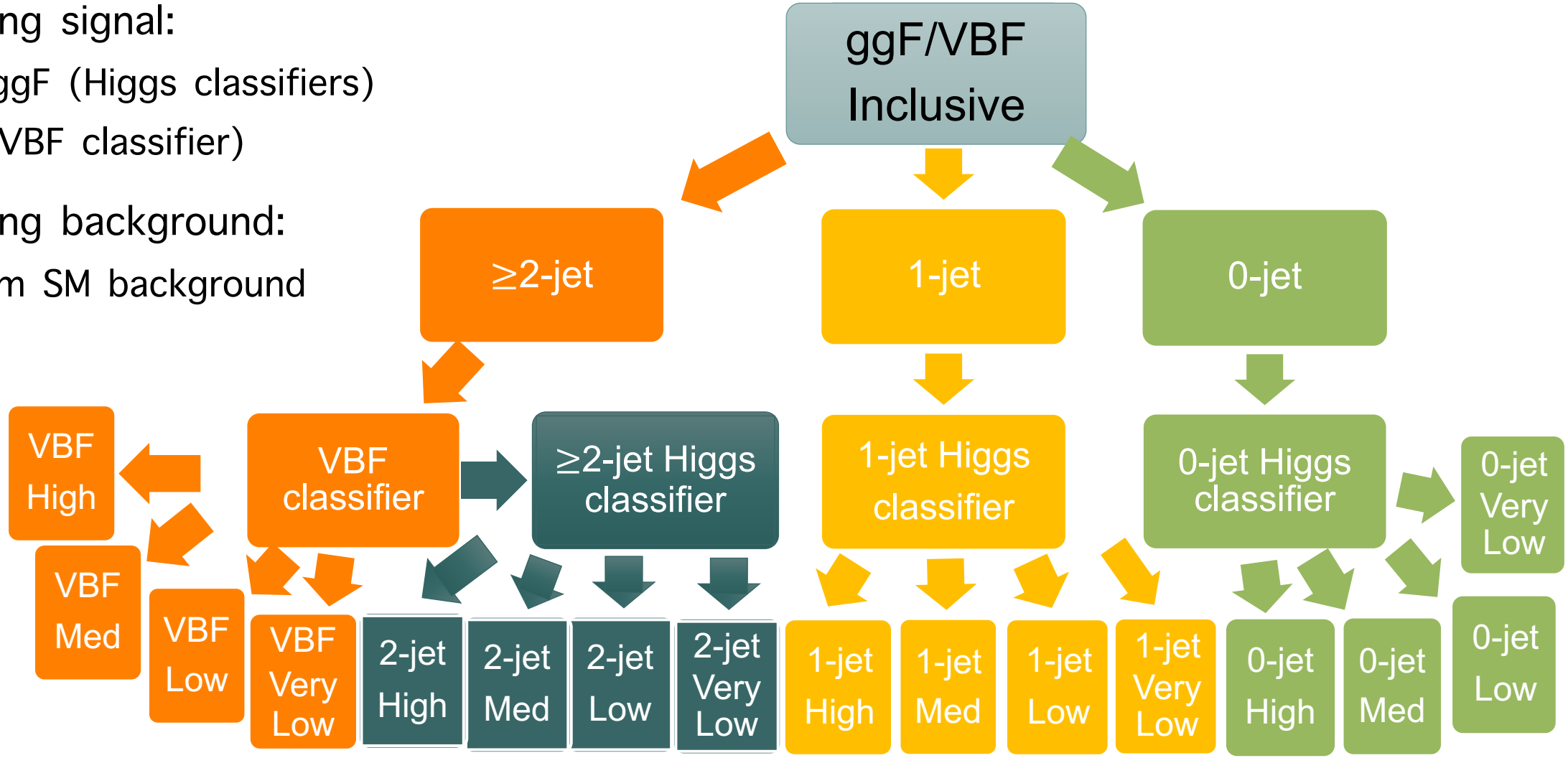
Backup slides

Progress

- Previous ATLAS limits with 36 fb^{-1} of 13 TeV pp collisions: σ*BR < 3.0xSM (Phys. Rev. Lett. **119** (2017) 051802)
- **New** result with full Run2 data (**139 fb^{-1}**) released in ICHEP 2020. (arXiv:2007.07830)
  - 3.8 times more data, as well as refined analysis techniques:
    - Better object definition
    - Optimized BDT-based event categorization
    - Improved background modeling
  - Sensitivity improved by **~2.5** (~2 from higher statistics, ~0.25 from optimization)

BDT categorization for ggF/VBF categories

- Training signal:
  VBF+ggF (Higgs classifiers)
  VBF (VBF classifier)
- Training background:
  Full-sim SM background

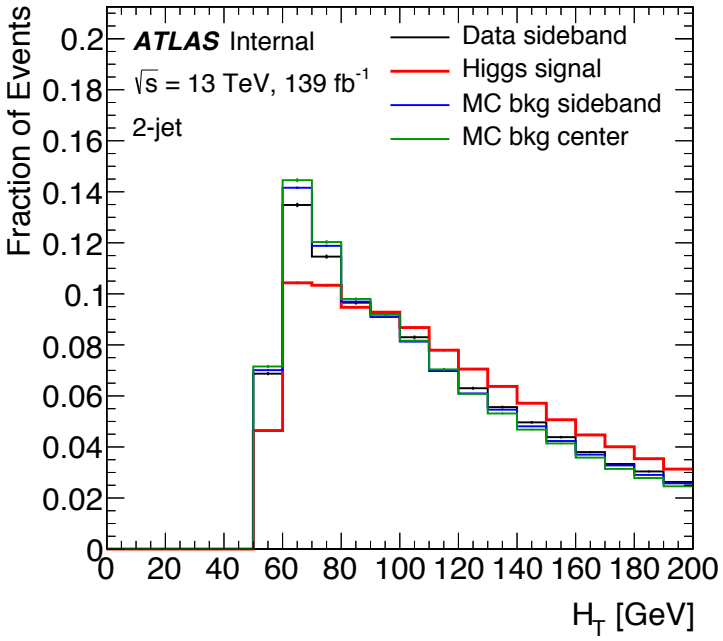


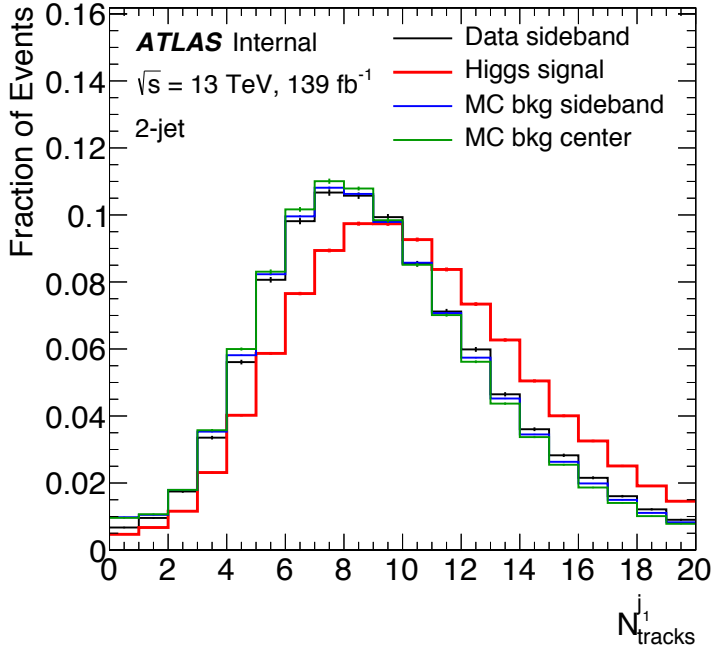
In total **16** ggF+VBF categories **(was 12)**

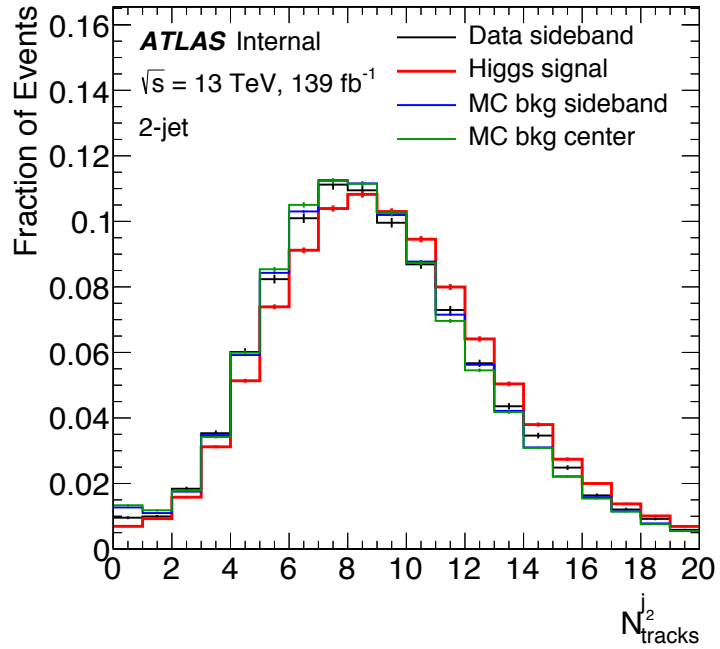
BDT training variables for ggF/VBF classifiers

Ntrack variables are sentive for quark/gluon separation

- 0-jet: $p_{T(\mu\mu)}$, $\eta_{\mu\mu}$, $cos\,\theta^*$
- 1-jet: (0-jet) + $p_{T(j1)}$, η_{j1}, $\Delta\Phi_{j1,\,\mu\mu}$, $N^{j_1}_{\mathrm{track}}$
- 2-jet and VBF classifier: (1-jet) + $p_{T(j2)}$, η_{j2}, $\Delta\Phi_{j2,\,\mu\mu}$, $p_{T(jj)}$, η_{jj}, $\Delta\Phi_{jj,\,\mu\mu}$, m_{jj}, MET, H_T, $N^{j_2}_{\mathrm{track}}$

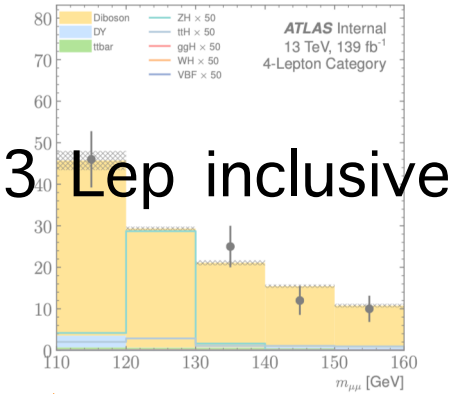




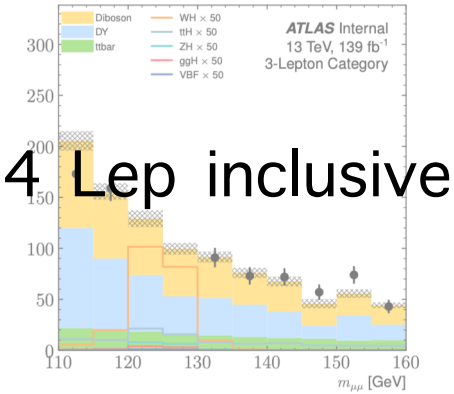


BDT categorization for VH categories

- Training variables:
  - 3-lep: $\Delta\Phi_{MET,\,H}$, $p_{T(l1)}$, $m_{T(MET,\,l1)}$, $\Delta\Phi_{l1,\,H}$, $\Delta\eta_{l1,\,H}$, MET, $p_{T(j1)}$, n_j
  - 4-lep: $p_{T(j1)}$, $p_{T(j2)}$, n_j, $\Delta\Phi_{l1,\,l2}$, $\Delta\Phi_{Z,\,H}$, $\Delta\eta_{Z,\,H}$, m_Z



3 Lep inclusive



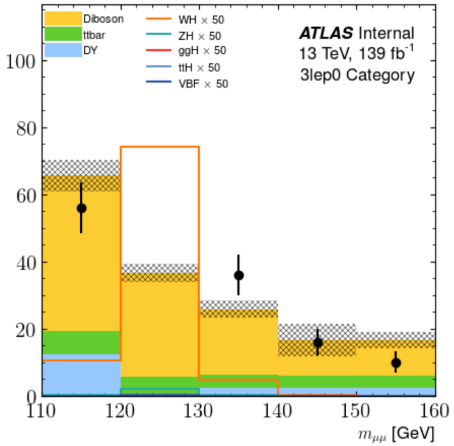
4 Lep inclusive

0.1 < BDT < 0.7

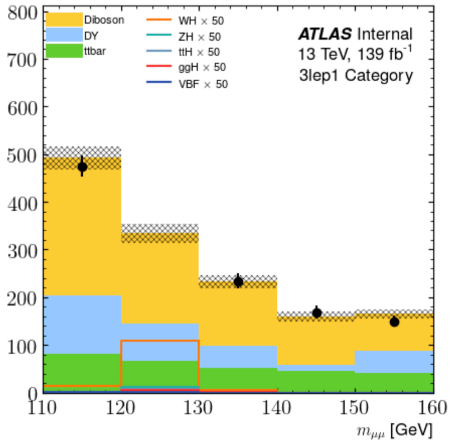
BDT > 0.7

BDT > 0.12

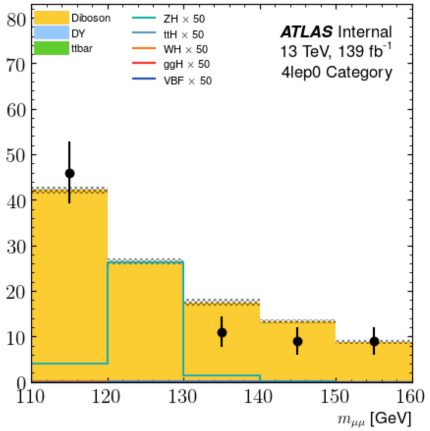
VH-3lep-High



VH-3lep-Low



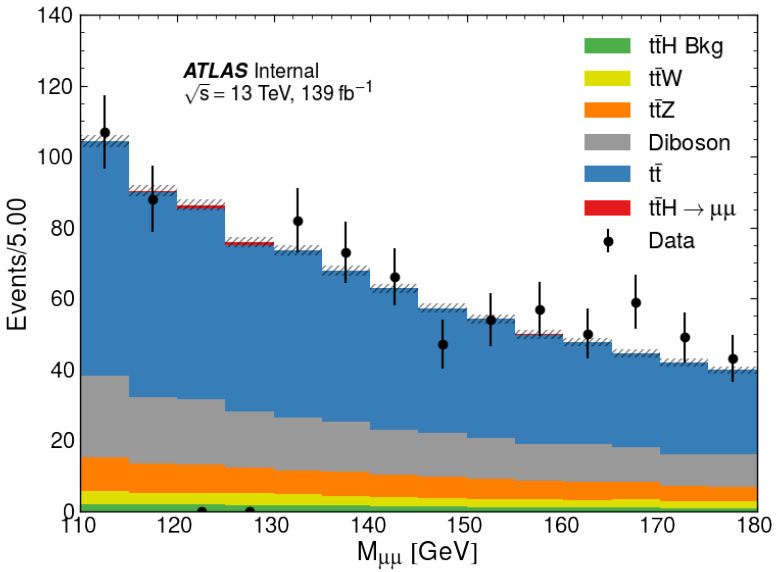
VH-4lep-High



BDT categorization for ttH categories

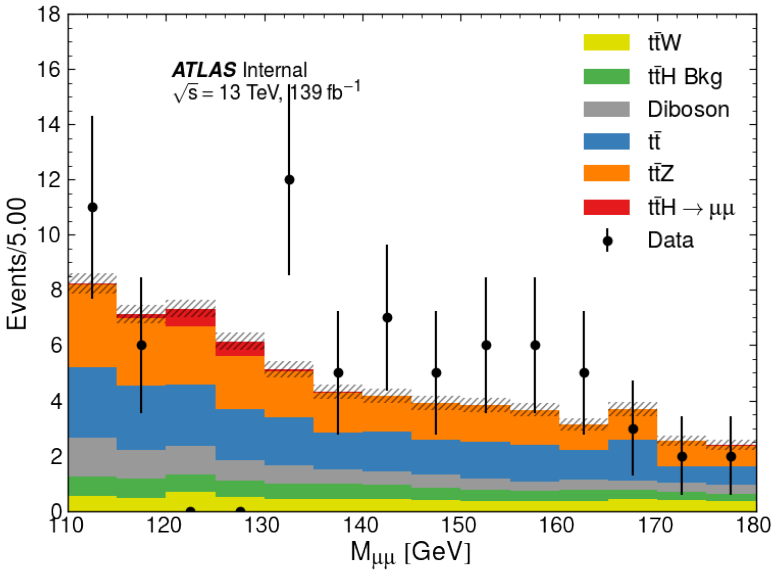
- Training variables:
  - $p_{T(\mu\mu)}$, $p_{T(l3)}$, $p_{T(l4)}$, $m_{\text{leptonic W}}$, $cos\,\theta^*$, $N_{\text{central jet}}$, subleading $m_{\mu\mu}$, $m_{\text{leptonic top}}$, $m_{(l3,\,l4)}$, H_T, $m_{\text{hadronic top}}$, N_{bjet}

Before BDT cut



BDT > 0.35

ttH



Yields in each category

Category	Data	S_{SM}	S	B	$S/\sqrt{B}$	S/B [%]
VBF Very High	15	2.81 ± 0.27	3.3 ± 1.7	14.5 ± 2.1	0.86	22.6
VBF High	39	3.46 ± 0.36	4.0 ± 2.1	32.5 ± 2.9	0.71	12.4
VBF Medium	112	4.8 ± 0.5	5.6 ± 2.8	85 ± 4	0.61	6.6
VBF Low	284	7.5 ± 0.9	9 ± 4	273 ± 8	0.53	3.2
2-jet Very High	1030	17.6 ± 3.3	21 ± 10	1024 ± 22	0.63	2.0
2-jet High	5433	50 ± 8	58 ± 30	5440 ± 50	0.77	1.0
2-jet Medium	18 311	79 ± 15	90 ± 50	$18\,320 \pm 90$	0.66	0.5
2-jet Low	36 409	63 ± 17	70 ± 40	$36\,340 \pm 140$	0.37	0.2
1-jet Very High	1097	16.5 ± 2.4	19 ± 10	1071 ± 22	0.59	1.8
1-jet High	6413	46 ± 7	54 ± 28	6320 ± 50	0.69	0.9
1-jet Medium	24 576	90 ± 11	100 ± 50	$24\,290 \pm 100$	0.67	0.4
1-jet Low	73 459	125 ± 17	150 ± 70	$73\,480 \pm 190$	0.53	0.2
0-jet Very High	15 986	59 ± 11	70 ± 40	$16\,090 \pm 90$	0.55	0.4
0-jet High	46 523	99 ± 13	120 ± 60	$46\,190 \pm 150$	0.54	0.3
0-jet Medium	91 392	119 ± 14	140 ± 70	$91\,310 \pm 210$	0.46	0.2
0-jet Low	121 354	79 ± 10	90 ± 50	$121\,310 \pm 280$	0.26	0.1
VH4L	34	0.53 ± 0.05	0.6 ± 0.3	24 ± 4	0.13	2.6
VH3LH	41	1.45 ± 0.14	1.7 ± 0.9	41 ± 5	0.27	4.2
VH3LM	358	2.76 ± 0.24	3.2 ± 1.6	347 ± 15	0.17	0.9
$t\bar{t}H$	17	1.19 ± 0.13	1.4 ± 0.7	15.1 ± 2.2	0.36	9.2