Investigating the Exotic Higgs Boson Decay $pp \rightarrow H \rightarrow Za \rightarrow bb\mu\mu$ with the Large Hadron Collider

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Introduction & Theoretical Motivation

- The Higgs boson gives rise to the Higgs field – the mechanism by which elementary particles acquire mass
- Higgs bosons are known to have many decays with different final states, and we study them to understand the underlying mechanics of this field
- We propose the Higgs decay $pp \rightarrow H \rightarrow Za \rightarrow bb\mu\mu$:

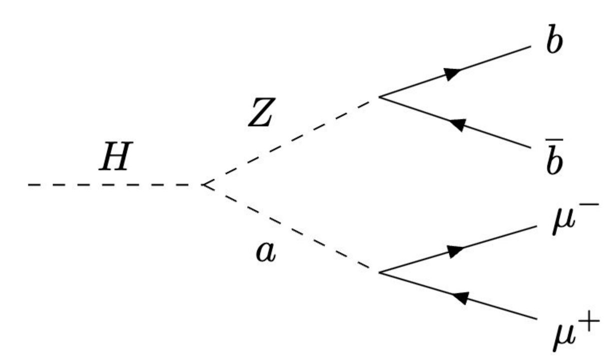

Figure 1. $H \rightarrow Za \rightarrow bb\mu\mu$ Decay

- This decay introduces a new particle 'a', which is a hypothetical pseudoscalar boson predicted to exist by some Beyond the Standard Model (BSM) theories
- Theories that support this decay investigate intriguing topics including the properties of dark matter and the question of baryon (matter-antimatter) asymmetry

Data Collection at the LHC

- Particle beams accelerated to extremely high energies are made to collide at four points around the LHC, which correspond to four particle detectors

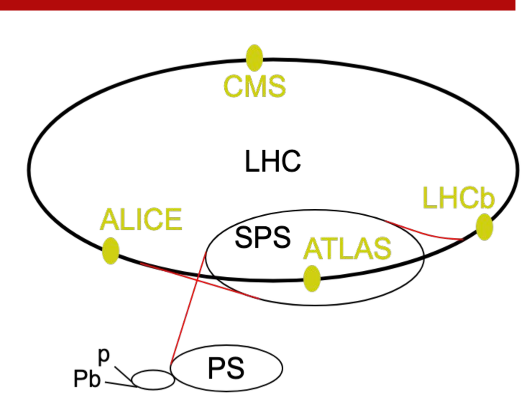

Figure 2. LHC Map [CERN]

- Here, we present proton-proton collision data collected in ATLAS Run 3 at a center-of-mass energy of $\sqrt{s}$ = 13.6 TeV

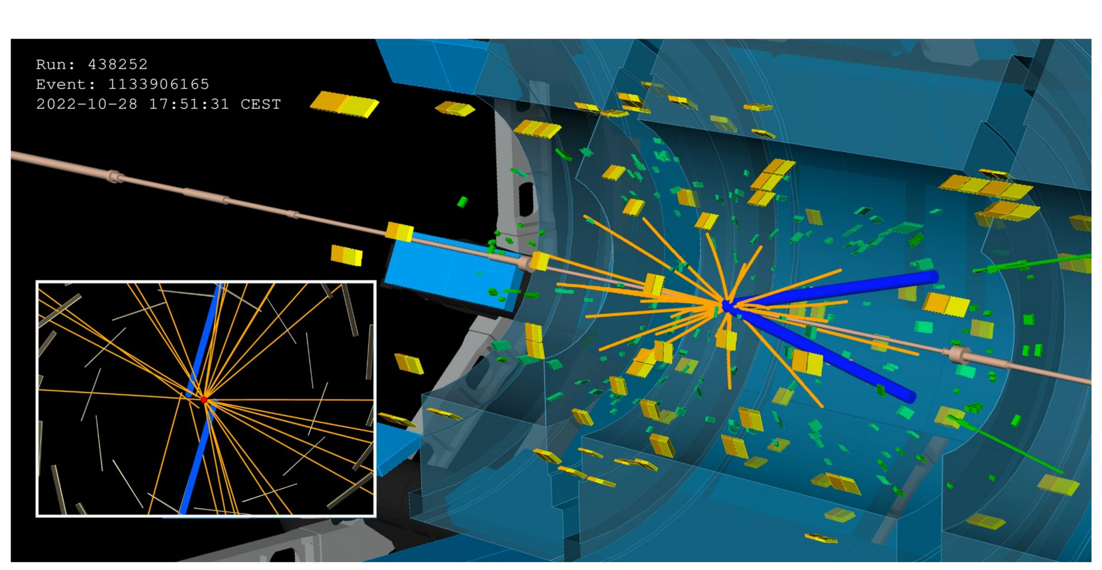

Figure 3. Highest-ever collision energy of 13.6 TeV [ATLAS]

Dominant Backgrounds: ttbar and Drell-Yan

- Backgrounds are processes or events that mimic the signal of interest by producing the same final state – in this analysis, ttbar ($t\bar{t}$) and Drell-Yan (Z+ jets)
- The analysis program utilizes Monte Carlo analysis methods to evaluate the signal samples against the dominant backgrounds

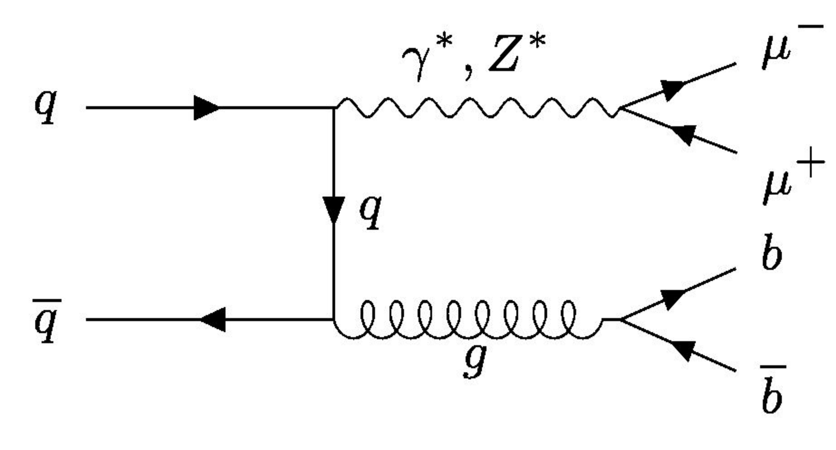

Figure 4. Drell-Yan Process

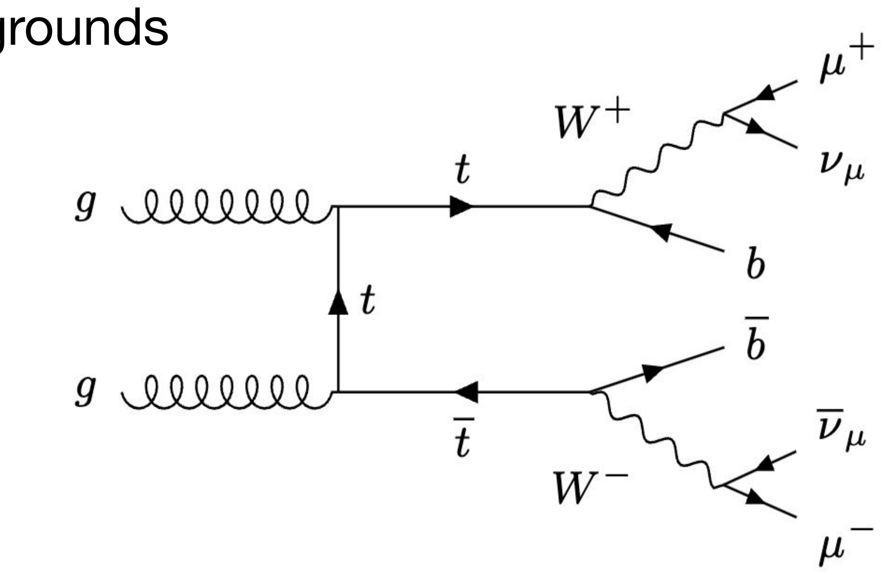

Figure 5. ttbar Process

- Has an identical final state to $H \rightarrow Za$
- Background is greatly reduced with the requirement $10 < m_{\mu\mu} < 65$ GeV

- Has nearly the same final state with the addition of neutrinos
- Expected to have high m_T^{miss} when compared to the sample

Data & Monte Carlo Comparisons

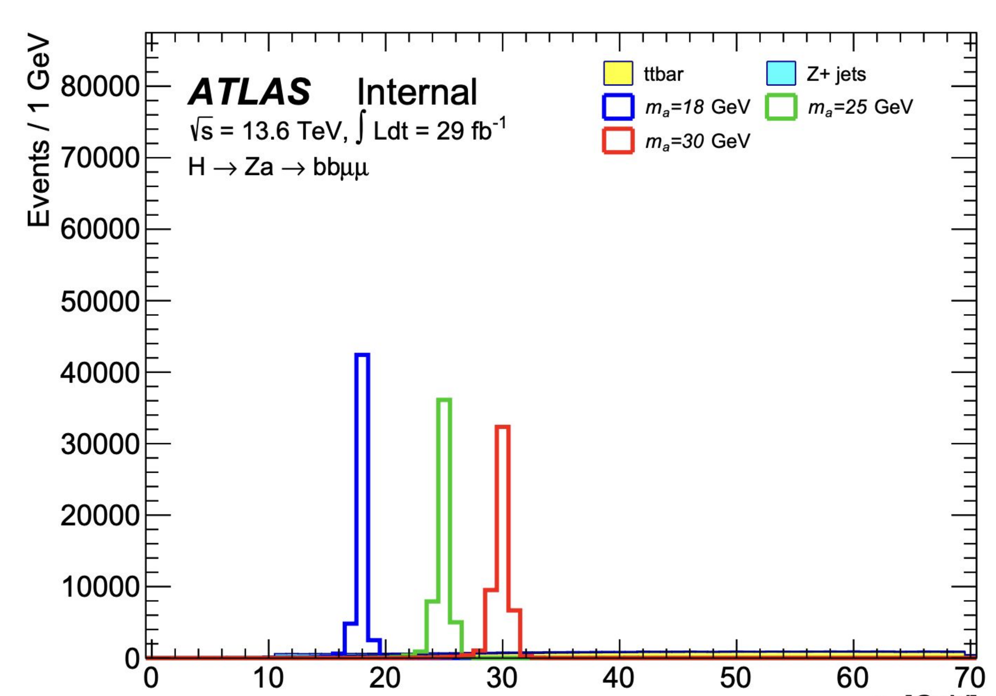

Figure 6. m_{ll} - Cut2BSel

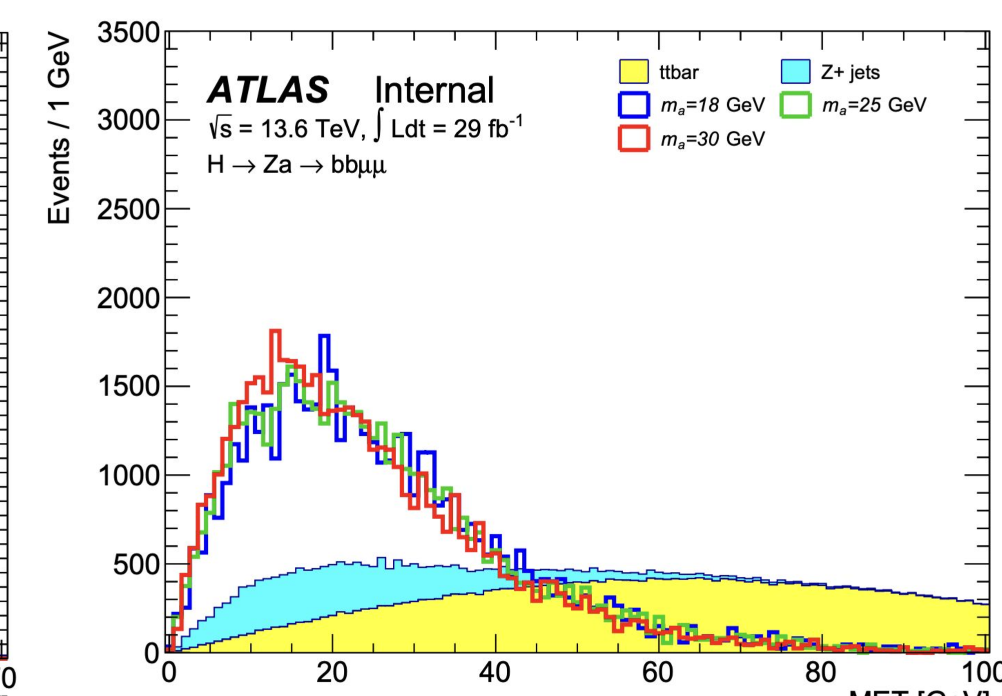

Figure 7. MET - Cut2BSel

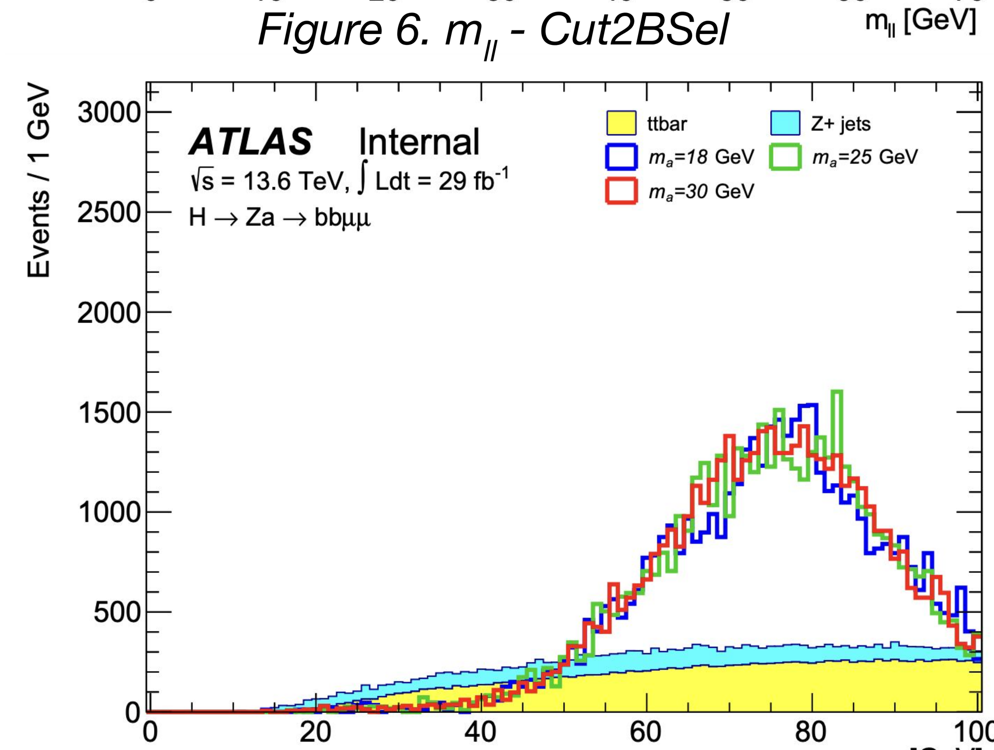

Figure 8. m_{bb} - Cut2BSel

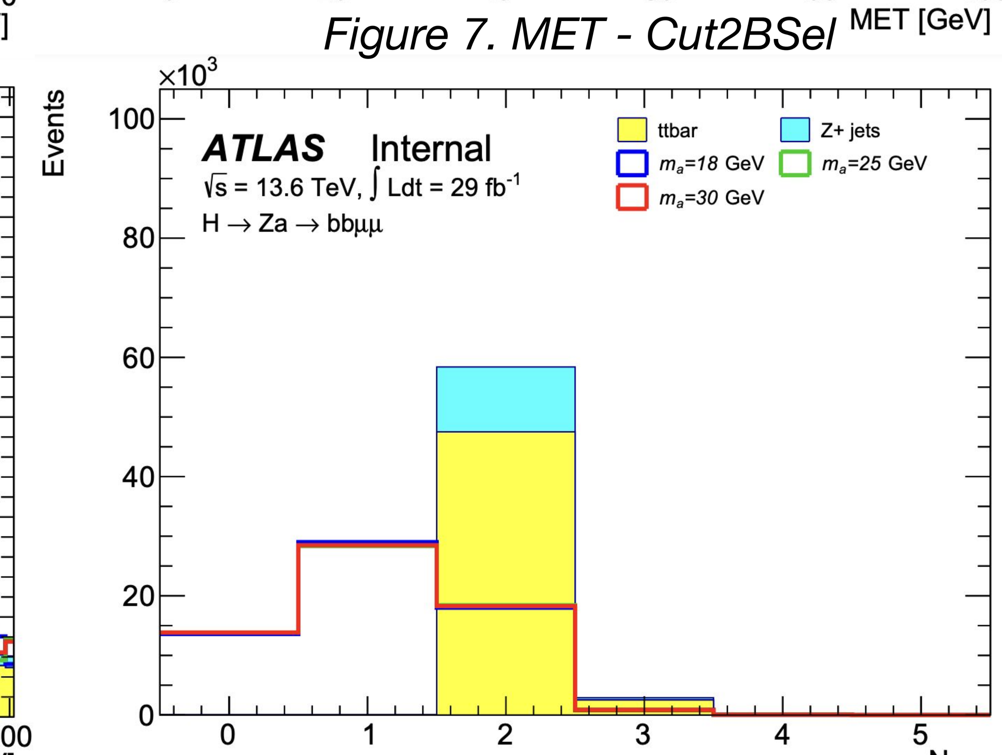

Figure 9. N_{bjets} - CutBase

Note: For illustration purposes, the signal has been normalized to the background and multiplied by 0.1

Event Selection Information

- The two muons will be oppositely charged due to the conservation of lepton charge
- We take $m_a \approx m_{\mu\mu}$ with the dimuon mass $m_{\mu\mu}$ being between 10 and 65 GeV
- b-jets are tagged with the requirement that the PFlow Jet p_T^b is above 20 GeV

Trigger	Unprescaled single or dilepton trigger match
Muons	$N_\mu = 2$ Opposite Sign (OS) $10 < m_{\mu\mu} < 65$ GeV
***b*-jets**	$p_T^b > 20$ GeV $N_b = 2$
Likelihood: $\ln(L^{max})$	> -8

Region	Signal Region	Top Control Region
E_T^{miss} **(GeV)**	< 60	> 60

Figure 10. Event Selection

$\sqrt{s}$=13.6 TeV, L=29 fb^{-1} μμ(2022)	m_a=18 GeV	m_a=25 GeV	m_a=30 GeV	ttbar	Z+ jets
Base cut	47.83 ± 0.25	66.21 ± 0.29	81.45 ± 0.32	50229.25 ± 58.49	11272.15 ± 105.48
Single OR Dilepton Trigger Match	23.52 ± 0.17	29.27 ± 0.19	42.98 ± 0.23	47585.02 ± 56.93	12718.06 ± 87.27
$N_\mu = 2$	22.71 ± 0.17	28.17 ± 0.19	41.73 ± 0.23	47410.63 ± 56.82	12659.28 ± 86.87
OS Muons	22.36 ± 0.17	27.89 ± 0.19	41.57 ± 0.23	46758.69 ± 56.43	12578.88 ± 86.63
Muons η<2.47	22.24 ± 0.17	27.77 ± 0.19	41.38 ± 0.23	46582.58 ± 56.32	12507.77 ± 86.42
Muons Isolation Loose_VarRad	18.43 ± 0.15	22.68 ± 0.17	34.32 ± 0.21	42491.73 ± 53.79	10859.25 ± 81.61
N_b == 2 & p_T^b >= 20 GeV	5.51 ± 0.08	6.93 ± 0.09	10.44 ± 0.11	40298.40 ± 52.38	10479.21 ± 81.00
$10 < m_{\mu\mu} < 65$ GeV	5.51 ± 0.08	6.93 ± 0.09	10.44 ± 0.11	36196.17 ± 49.64	9774.91 ± 78.14
$E_T^{miss} < 60$ GeV	5.26 ± 0.08	6.63 ± 0.09	10.07 ± 0.11	14019.59 ± 30.89	9244.27 ± 77.23
Likelihood > -8	0.01 ± 0.00	0.04 ± 0.01	0.20 ± 0.02	1430.03 ± 9.86	1331.35 ± 33.48
VR: Likelihood ≤ -8	5.25 ± 0.08	6.59 ± 0.09	9.87 ± 0.11	12589.49 ± 29.27	7913.15 ± 69.59
$E_T^{miss} > 60$ GeV	0.25 ± 0.02	0.31 ± 0.02	0.37 ± 0.02	22176.59 ± 38.86	530.65 ± 11.93
Likelihood > -8	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	2234.98 ± 12.32	63.74 ± 5.14

Figure 11. Resulting Cutflow from Analysis

Note: Cross section value used is 1.9×10^{-4} – taken from Run 2 paper (10.1103/PhysRevD.105.012006) for $H \rightarrow aa$ at m_a=52 GeV, applied to $H \rightarrow Za$

Conclusions & Future Work

- The primary conclusion is that signal efficiency drops off after the 2-bjet cut (*Figure 11*)
- At the N_{bjets} cut, m_a = 18, 25, and 30 GeV events drop from 18.43 to 5.51, 22.68 → 6.93, and 34.32 → 10.44 respectively, then remain the same in the following cut
- Analyze over less dominant backgrounds: W jets, diboson processes (VV), and triboson processes (VVV)
- Reoptimize the selection within the analysis to account for the difference in Z- and a-boson mass

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