

Background determination of the control region of the $R \rightarrow SH \rightarrow 4l + E_T^{miss}$ signal

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January 30, 2020



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□ Introduction

- Motivation
- Event Categorisation
- Signal optimisation

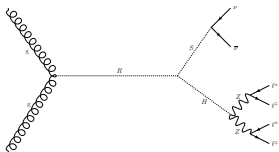
□ Control region

- Jets kinematics
- Lepton-pairs invariant mass kinematics
- $E_{\text{T}}^{\text{miss}}$ significance and $p_{\text{T}}^{4\ell}$ kinematics
- 4-lepton kinematics

□ Signal and background modelling

□ Summary

- Explores the presence of a heavy scalar boson, R ;
- Produced in gluon-gluon fusion in association with Met;
- The resonance decays to lighter scalar H and S bosons;
- H decays into four leptons through ZZ bosons; and
- S decays to a pair of neutrinos.

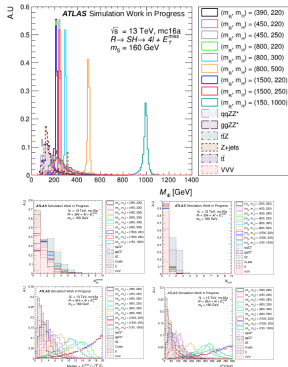


The search looks at the region where the invariant mass of the four leptons greater than 200 GeV ($m_{4\ell} > 200$ GeV), and missing transverse energy. In the phase space of RSH model, we consider the mass of R to be between $(m_S + m_H) < m_R \leq 1500$ GeV.

Objective

Test $R \rightarrow SH$ and $A \rightarrow ZH$ models by scanning H mass from 200 GeV to a TeV level.

- The Met background is very small;
- It can be controlled by varying m_R , m_H ;
- B-veto to reject top related background;
- Lepton selections: $4\mu/4e/2\mu 2e$;
- Events categorized into two categories:
 - $N_{Jets}^{Central} = 0$
 - $N_{Jets}^{Central} \geq 1$

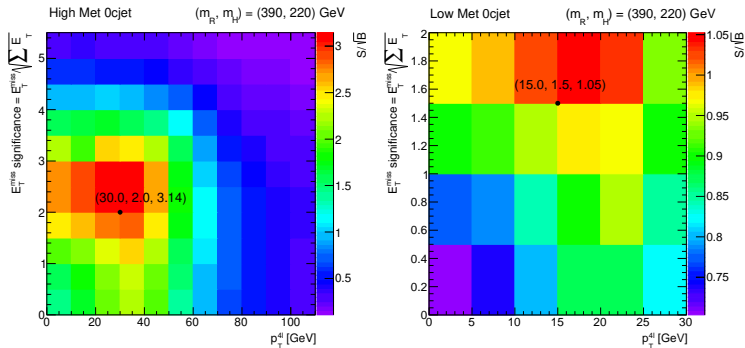


Introduction

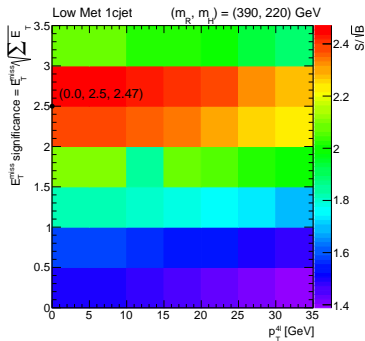
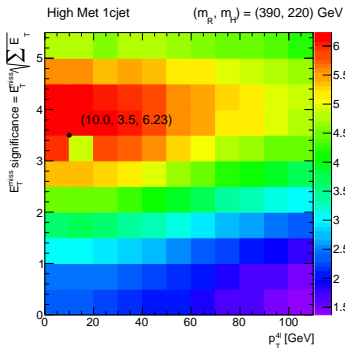
Signal optimisation

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Optimise the signal using a triangle scan over the Met significance and $p_T^{4\ell}$. The significance of the optimal cut is quantified by S/\sqrt{B} .



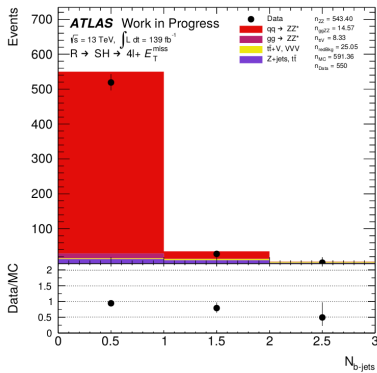
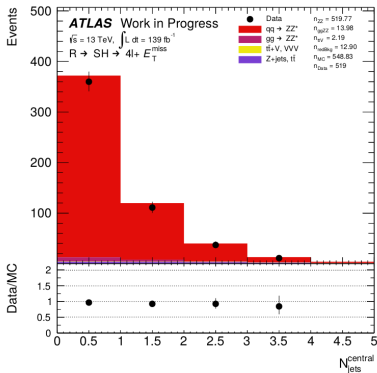
□ $N_{\text{Jets}}^{\text{Central}} = 0: 30/2.0; 15/1.5$



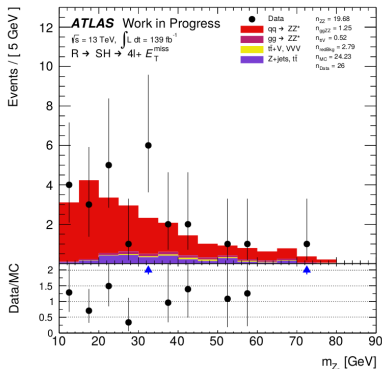
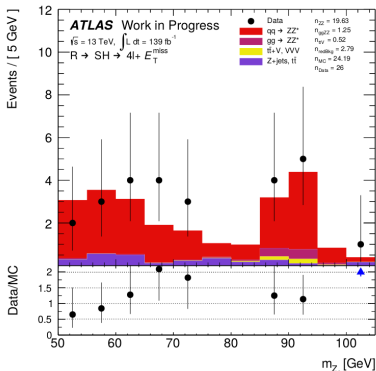
□ $N_{\text{Jets}}^{\text{Central}} = 0: 10/3.5; 0/2.5$

- The signal for $R \rightarrow SH \rightarrow 4\ell + E_T^{miss}$ is for $m_{4\ell}$ above 200 GeV;
- So the data is blinded for $m_{4\ell}$ GeV to test the Data/MC agreement;
- A control region for $m_{4\ell}$ between [80, 110] and [140, 170] GeV;
- Expected yields in this region estimated with the state-of-the-art MC;
- The MC samples used for 2015-2018 data are mc16a, mc16d and mc16e;
- Observed events calculated from 2015-2018 data with an integrated luminosity of 139 fb^{-1} ; and
- All the plots shown here are for the High Met and 0 Central jet category.

Kinematics of the jets on the control region

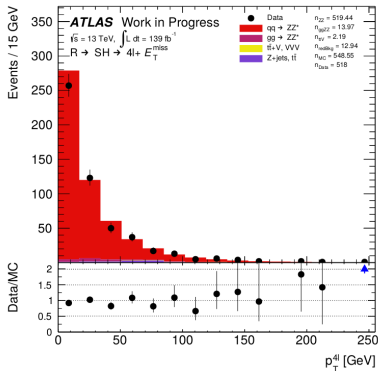
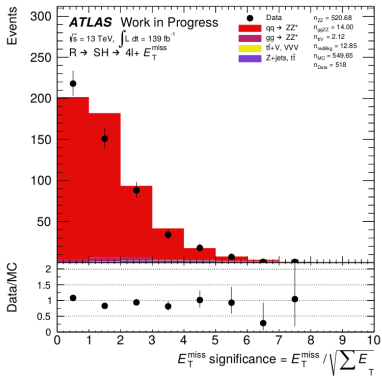


Kinematics of the Z mass on the control region

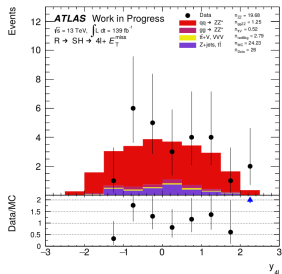
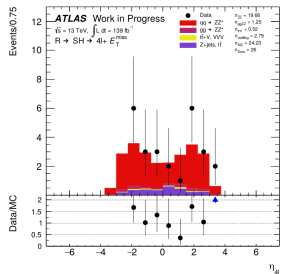
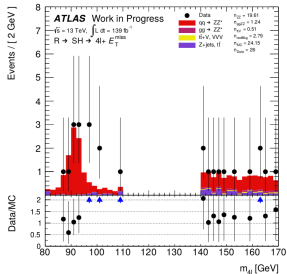


- m_{Z_1} : The first lepton-pairs with invariant mass closest to the Z boson; and
- m_{Z_2} : The second lepton-pairs with invariant mass not matched with the Z boson invariant mass;

Kinematics of the 4-lepton on the control region



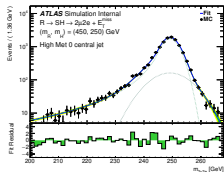
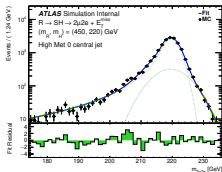
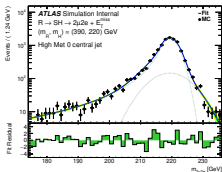
Kinematics of the 4-lepton on the control region



- The Crystal ball, CB, plus Gaussian, G, Pdf has the following form:

$$f(m_{4\ell}) = f_{CB} \cdot CB(m_{4\ell}; \mu, \sigma_{CB}, \alpha_{CB}, n_{CB}) + (1 - f_{CB}) \cdot G(m_{4\ell}; \mu, \sigma_G)$$

- σ_{CB} and σ_G represent the invariant mass resolution;
- μ is the mean value fixed to same parameter for both Pdf;
- n_{CB} and α_{CB} model the shape and position of the non-Gaussian tail;
- Where n_{CB} is the slope of the tail and α_{CB} measures how far from the peak the distribution become non-Gaussian;
- f_{CB} is the relative normalisation of the Pdf.



Signal and background modelling

Background modelling

$$f_{ggZZ/qqZZ}(m_{4\ell}) = (f_1(m_{4\ell}) + f_2(m_{4\ell})) \times H(m_0 - m_{4\ell}) \times C_0 + f_3^{ggZZ/qqZZ}(m_{4\ell}) \times H(m_{4\ell} - m_0),$$

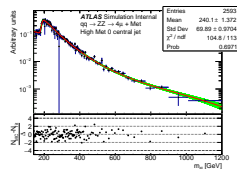
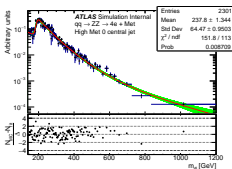
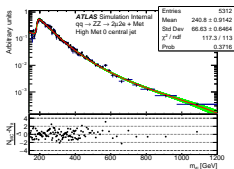
where:

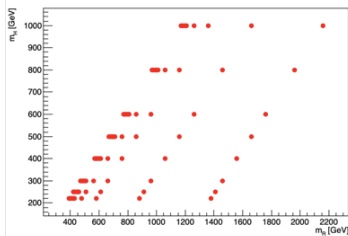
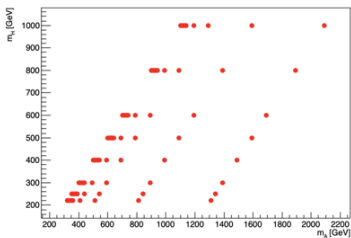
$$f_1(m_{4\ell}) = \exp(a_1 + a_2 \cdot m_{4\ell} + a_3 \cdot m_{4\ell}^2),$$

$$f_2(m_{4\ell}) = \left\{ \frac{1}{2} + \frac{1}{2} \operatorname{erf} \left(\frac{m_{4\ell} - b_1}{b_2} \right) \right\} \times \frac{1}{1 + \exp \left(\frac{m_{4\ell} - b_1}{b_3} \right)},$$

$$f_3^{ggZZ/qqZZ}(m_{4\ell}) = \exp(c_1 + c_2 \cdot m_{4\ell} + c_3 \cdot m_{4\ell}^2 + c_4 \cdot m_{4\ell}^3 + c_5 \cdot m_{4\ell}^4 + c_6 \cdot m_{4\ell}^5),$$

$$C_0 = \frac{f_3(m_0)}{f_1(m_0) + f_2(m_0)}.$$





- The MC sample generated to test different A/R model and setup limit in the 2D mass contour.

	$q\bar{q} \rightarrow ZZ^*$	$gg \rightarrow ZZ^*$	$Z + jets + t\bar{t}$	$t\bar{t}V$	Expected	Observed
4ℓ	473 ± 28	42 ± 27	11.6 ± 1.3	7.6 ± 0.8	540 ± 40	579

Table: The expected yields of the background process in a control region calculated from the state-of-the-art MC simulation with an integrated luminosity of 139 fb^{-1} . The observed number of events is calculated from Run 2 data at the side-band. The uncertainties included on the table are statistical uncertainty. The table shows the result for the High Met 0 Central jet category

- Data/MC agreement in side-band is shown on the control plots;
- Dominant background is ZZ and it's profiled using an analytical function;
- Signal, RSH, is modeled using a Crystal ball and Gaussian function;

We are going to setup a limit to any resonance decays to 4ℓ in association with missing transverse energy.



Thank you!



Signal samples have already been produced, [JIRA](#), as follows:

- The mass of S is fixed to 160 GeV;
- The masses of R are 390 GeV, 450 GeV, 800 GeV and 1500 GeV:
 - $m_R = 390$ GeV: $m_H = 220$ GeV
 - $m_R = 450$ GeV: $m_H = 220$ GeV and 250 GeV
 - $m_R = 800$ GeV: $m_H = 220$ GeV, 300 GeV and 500 GeV
 - $m_R = 1500$ GeV: $m_H = 220$ GeV, 250 GeV and 1000 GeV
- Requested HIGG2D1 derivation with cache: 21.2.55 and p-tag: p3782. All jobs are finished see [here](#); and
- The mini-tree production is done using [HZZAnalRun2Code](#).

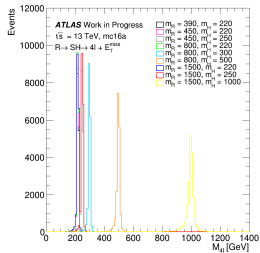
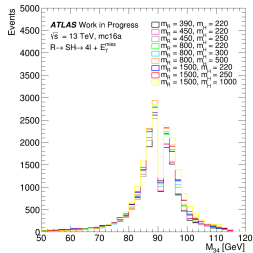
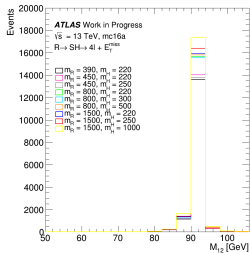
Background samples

- $qqZZ^*$, $ggZZ^*$, $t\bar{t}Z$, $Z + jets$, $t\bar{t}$ and VVV .

Event Selection	
QUADRUPLET SELECTION	<ul style="list-style-type: none"> - Require at least one quadruplet of leptons consisting of two pairs of same-flavour opposite-charge leptons fulfilling the following requirements: - p_T thresholds for three leading leptons in the quadruplet: 20, 15 and 10 GeV - At most 1 calo-tagged, stand-alone or silicon-associated muon per quadruplet - Leading di-lepton mass requirement: $50 < m_{12} < 106$ GeV - Sub-leading di-lepton mass requirement: $m_{\text{threshold}} < m_{34} < 115$ GeV - $\Delta R(\ell, \ell') > 0.10$ for all lepton pairs in the quadruplet - Remove quadruplet if alternative same-flavour opposite-charge di-lepton gives $m_{\ell\ell} < 5$ GeV - Keep all quadruplets passing the above selection
ISOLATION NEEDS UPDATING	<ul style="list-style-type: none"> - Contribution from the other leptons of the quadruplet is subtracted - Muon track isolation ($\Delta R = 0.30$): $\Sigma p_T/p_T < 0.15$ - Muon calorimeter isolation ($\Delta R = 0.20$): $\Sigma E_T/p_T < 0.30$ - Electron track isolation ($\Delta R = 0.20$): $\Sigma E_T/E_T < 0.15$ - Electron calorimeter isolation ($\Delta R = 0.20$): $\Sigma E_T/E_T < 0.20$
IMPACT PARAMETER SIGNIFICANCE	<ul style="list-style-type: none"> - Apply impact parameter significance cut to all leptons of the quadruplet - For electrons: $d_0/\sigma_{d_0} < 5$ - For muons: $d_0/\sigma_{d_0} < 3$
BEST QUADRUPLET	<ul style="list-style-type: none"> - If more than one quadruplet has been selected, choose the quadruplet with highest Higgs decay ME according to channel: $4\mu, 2e2\mu, 2\mu2e$ and $4e$
VERTEX SELECTION	<ul style="list-style-type: none"> - Require a common vertex for the leptons: - $\chi^2/\text{ndof} < 5$ for 4μ and < 9 for others decay channels

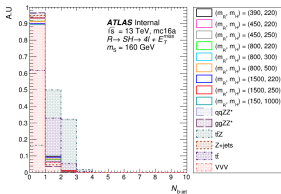
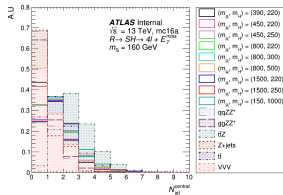
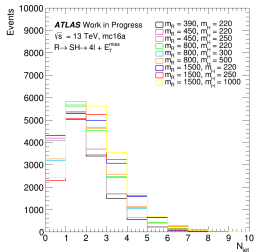
Additional slides

Kinematic distributions for the signal



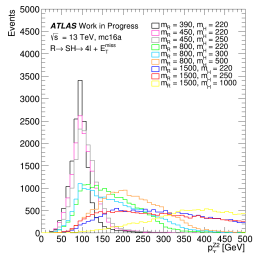
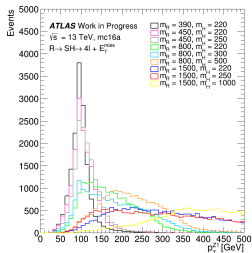
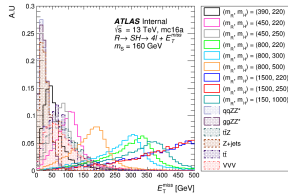
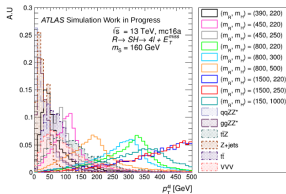
Additional slides

Kinematic distributions for the signal



Additional slides

Kinematic distributions for the signal



Additional slides

Kinematic distributions for signal & background

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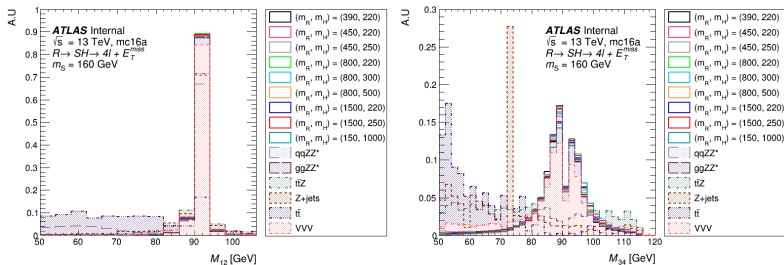


Figure: The invariant mass of the first (left) and the second (right) lepton pairs.

Additional slides

Kinematic distributions

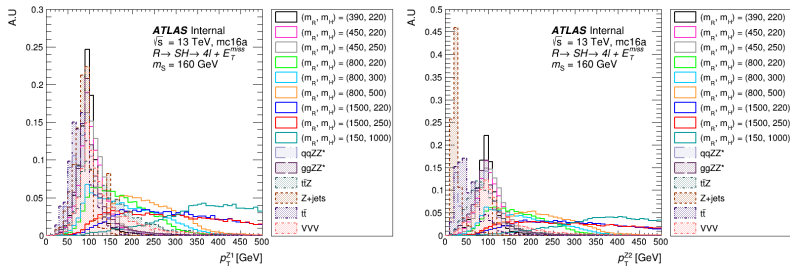


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Additional slides

Kinematic distributions

