

Searches for BSM Higgs and Additional Scalars at ATLAS

Dong Qichen,

University of Oxford

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Why BSM Scalars?

- The SM's single Higgs doublet explains EWSB but leaves key puzzles:
 - naturalness (hierarchy),
 - dark matter,
 - too little CP violation,
 - flavor structure,
- Multi-Higgs sectors are modular ways to tackle these
 - while staying close to current data via alignment/decoupling.
 - Many models were proposed
- Experimentally, we search for Higgs like spin-0 particles

- **hMSSM**

- An effective, data-driven parametrization of the MSSM Higgs sector where $m_h = 125$ GeV is imposed.
- predicting $H, A, H^\pm$ couplings.
- The heavy-Higgs properties are then controlled mainly by $(m_A, \tan\beta)$.

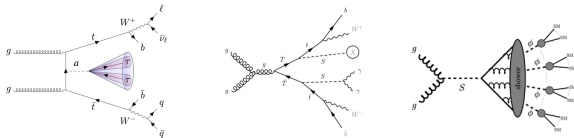
- **2HDM**

- SM + a second $SU(2)_L$ doublet, predicting five scalars: $h, H, A, H^\pm$.
- Key parameters: $\tan\beta = v_2/v_1$, mixing angle α , masses, and m_{12}^2 .
- Can be CP-conserving or CP-violating.

- **2HDM+S**

- Add a gauge-singlet a to the 2HDM.
- Introduces singlet-like neutral state(s), allows a stable DM candidate with a symmetry.
- and opens exotic Higgs decays (e.g. $h \rightarrow aa$)

- **etc.**



Example signal Feynman diagrams predicted by these models

Boosted Light Scalar Search

$$pp \rightarrow t\bar{t} + a, a \rightarrow \tau_{had}\tau_{had}$$

- First LHC analysis looking for boosted exotic low-mass pseudo-scalar associated with top quarks

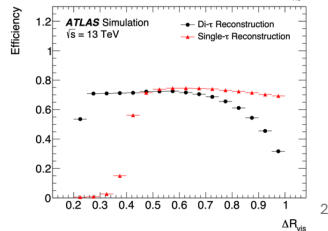
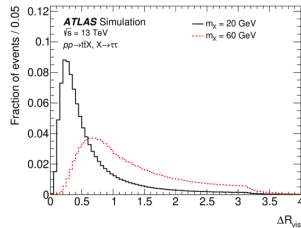
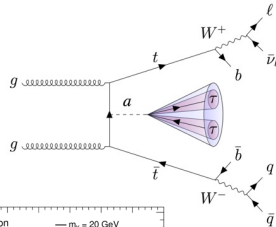
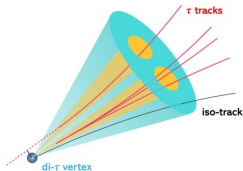
- the large discrepancy in the masses between top quark and the a scalar, results in highly boosted a for very-low masses.

- Angular separation between the di- τ_{had} $\Delta R < 1.0$ for most signal events.
- The decay products of the di- τ_{had} are likely merged:

- Targeting mass window 20 – 85 GeV.

- Using dedicated boosted di- τ_{had} tagger to improve low mass sensitivity ([2411.09357](#))

- recovers sensitivity for events with di- τ_{had} $0.2 < \Delta R < 0.8$



Boosted Light Scalar Search

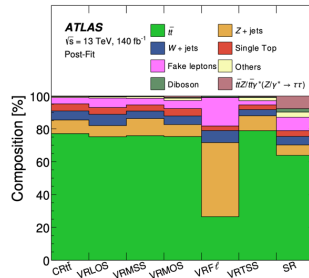
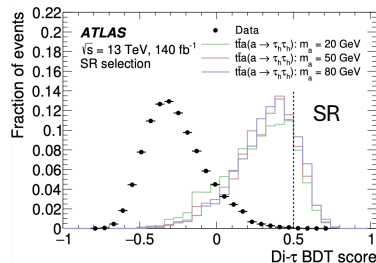
$$pp \rightarrow t\bar{t} + a, a \rightarrow \tau_{had}\tau_{had}$$

- Signal Region selects events with the expected topology:**

- Single isolated and trigger-matched lepton from top decays,
- At least three jets, at least one b -tagged,
- Single $di\text{-}\tau_{had}$ object with opposite charge τ_{had} and BDT ID score > 0.5 .
- $E_T^{miss} > 30$ GeV, loosely aligned with the $di\text{-}\tau_{had}$

- Most SM background events contain mis-identified $di\text{-}\tau_{had}$**

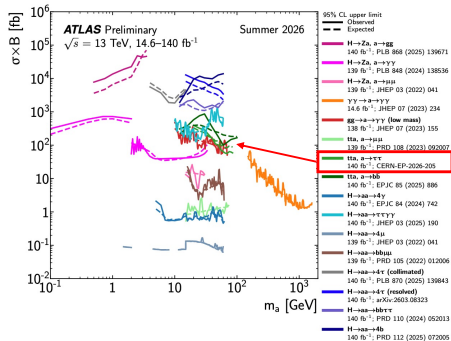
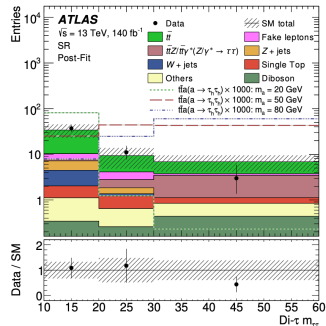
- from quark or gluon-initiated jets, mostly $t\bar{t}$.
 - modelled with MC simulations in control regions, validated with regions outside CR and SR.
- Jets mis-identified as lepton ($Z + \text{jets}$) are modelled with Likelihood based Matrix Method ([2211.16178](#))
- Irreducible background from $t\bar{t} + Z/\gamma^*$ are small, modelled by MC.



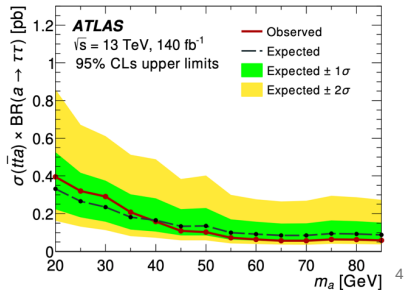
Boosted Light Scalar Search

$$pp \rightarrow t\bar{t} + a, a \rightarrow \tau_{had}\tau_{had}$$

- Profile-likelihood fit on the $m_{\tau\tau}$ distribution are performed
 - To measure signal strength and $t\bar{t}$ normalization
- No excess was found in the signal region.
 - 95% CL limits were set to the production rate.



This work!



Heavy Scalar Search

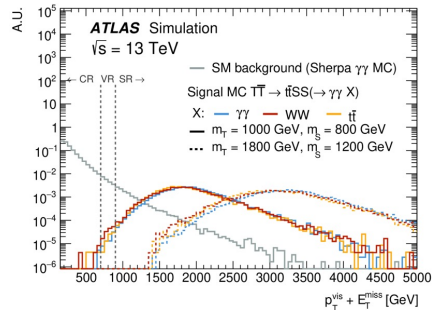
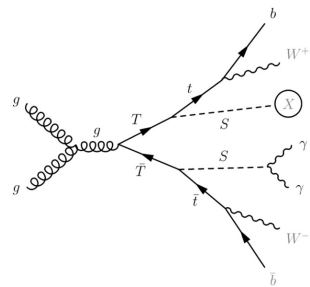
$$T\bar{T} \rightarrow S(\rightarrow \gamma\gamma)t + S(\rightarrow XX)\bar{t}$$

- Search for vector-like quark (VLQ) top partners decaying to additional scalar S and a top quark.

- First search considering cascade decays, which open new final states
- One scalar decay to $\gamma\gamma$, the other decays to WW , $Z\gamma$, ZZ , or tt
- Targeting m_T [1000, 1800] GeV and m_S [200, 1200] GeV

- Signal candidates selected based on $p_T^{vis} + E_T^{miss}$

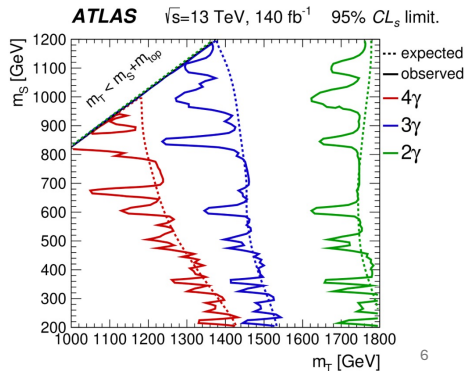
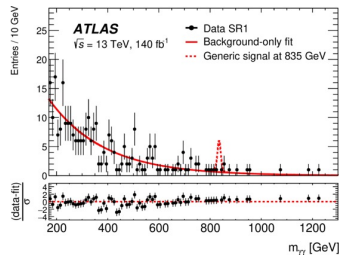
- Main background from SM $\gamma\gamma$ events tends to have low $p_T^{vis} + E_T^{miss}$
- Signal events have high $p_T^{vis} + E_T^{miss}$



Heavy Scalar Search

$$TT \rightarrow t\bar{t} + SS, (SS \rightarrow \gamma\gamma + SM)$$

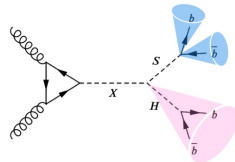
- Signal $m_{\gamma\gamma}$ distribution parameterized with a double-sided crystal ball.
- Background is modelled with a falling exponential function.
- Un-binned maximum likelihood fit performed in the signal regions
 - *No excess was found*
 - *95% CL limits have been set on the $[m_T, m_S]$ plane.*



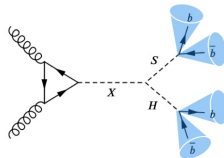
Heavy Scalar Search

$$X \rightarrow SH \rightarrow bbbb$$

Mixed channel

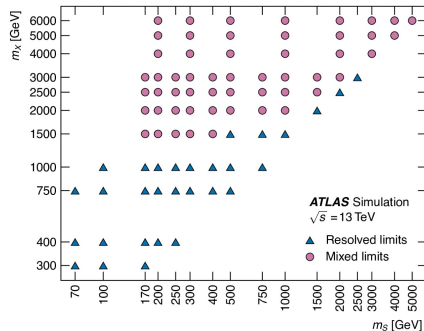


Resolved channel



- First search for $X \rightarrow SH \rightarrow bbbb$ with $m_X \in [0.3, 6.0]$ TeV, $m_S \in [0.07, 5.0]$ TeV

- Resolved channel targeting intermediate m_X .
 - identifying four b-tagged jets
 - Jet pairing relies on Boosted Decision Trees, to form S and H candidates
- Mixed channel targeting high m_X
 - Identifying 2 b-jets (S-candidate) and one large-R jet compatible with Higgs.



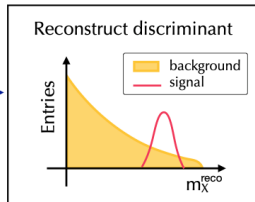
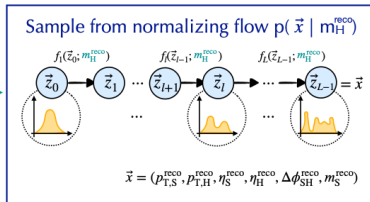
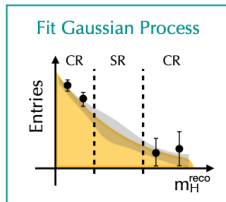
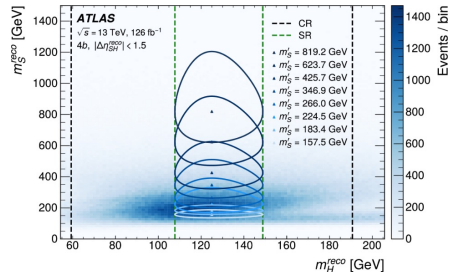
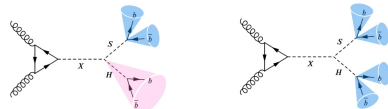
Heavy Scalar Search

$$X \rightarrow SH \rightarrow bbbb$$

- In resolved channels signal regions defined as contours on the m_H, m_S plane
- In mixed channels, signal regions defined with $110 < m_H < 140$ GeV
- Background are estimated with a data-driven method
 - Using ML based gaussian processes and normalizing flows.
 - And validated in control and validation regions.

Mixed channel

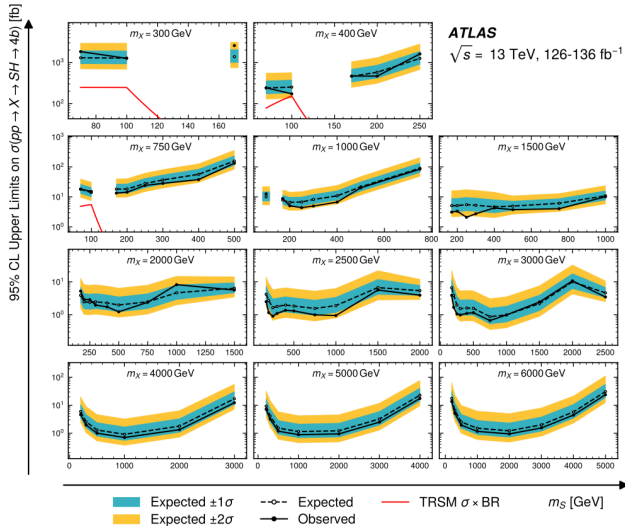
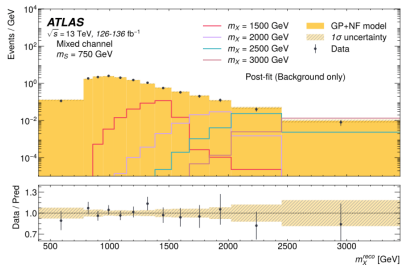
Resolved channel



Heavy Scalar Search

$X \rightarrow SH \rightarrow bbbb$

- No significant excess is observed
 - 95% CL limits set on the production cross-section



Mass-less Dark Vector Boson Search

$$pp \rightarrow H \rightarrow \gamma\gamma_d$$

First search to explore mass-less dark photon in the ggF channel

- The dark photon is predicted as a spin-1 gauge boson of $U(1)_d$ group
- long range mediator between the dark particles
- Higgs decays to $\gamma\gamma_d$ through BSM loop.

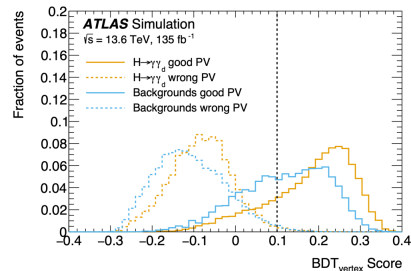
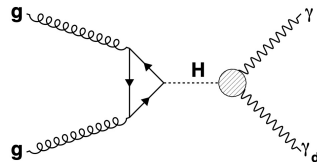
Signal signature is low-track activity in γ +MET final state.

- Triggered by a composite trigger designed for this analysis. Increasing the ggF acceptance by 100%.
- event selection based on a BDT

Background dominated by electron/jet mis-identified as γ ;

- estimated by a novel data driven methods.

Background from genuine γ are estimated by MC



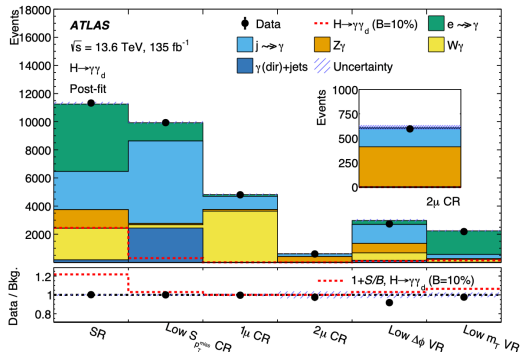
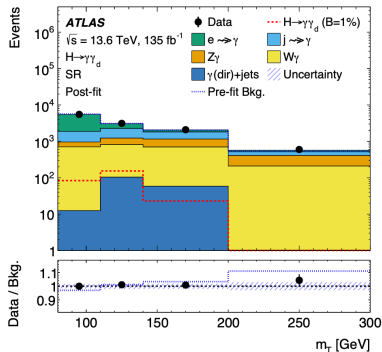
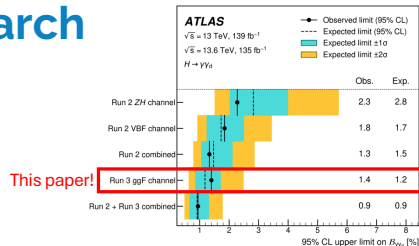
Mass-less Dark Vector Boson Search

$$pp \rightarrow H \rightarrow \gamma\gamma_d$$

Simultaneous fit performed on the $m_T(E_T^{miss}, \gamma)$ distribution.

No significant excess is observed

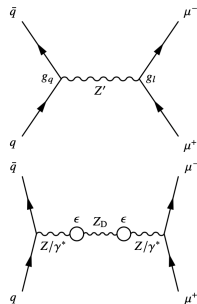
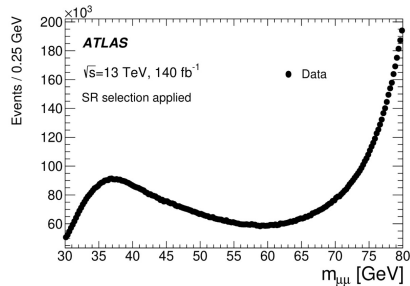
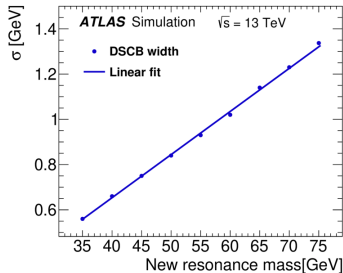
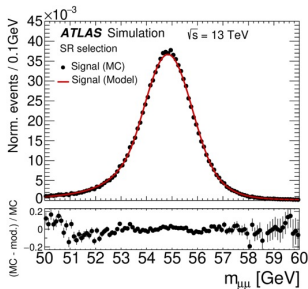
- 95% CL Upper limit set on $BR(H \rightarrow \gamma\gamma_d)$
- better limit compared to combined run 2 search in VBF + ZH channel.



Low-mass resonance Search

$$pp \rightarrow X \rightarrow \mu\mu$$

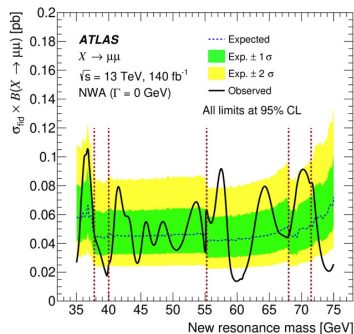
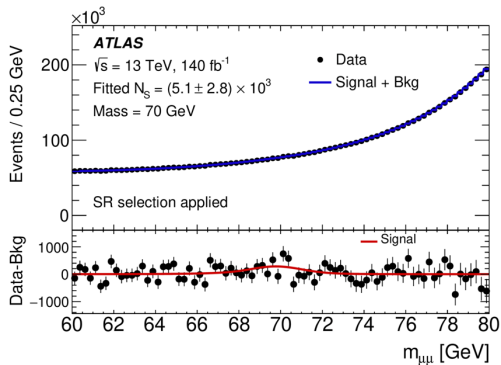
- **ATLAS analysis searching for low mass resonance in the di-muon channel.**
 - Signal mass between 30 and 75 GeV
 - Results interpreted with two dark matter models involving Z' and Z_D
- **Signal modelled with double sided crystal ball from MC.**
 - Masses not simulated by MC are interpolated.
- **Background modelled with Gaussian Process Regression**
 - Instead of analytical functions



Low-mass resonance Search

$$pp \rightarrow X \rightarrow \mu\mu$$

- **No significant excess was found.**
 - 95% CL limit has been set on the production rate of the $\sigma(X \rightarrow \mu\mu)$
 - Largest excess observed at $m_{\mu\mu} = 57.5$ GeV, local significance 2.3σ



Summary

- **Extensive searches for BSM scalars in various channels were performed**
 - *Including many searches in signatures previously un-reached.*
- **no significant deviations observed in these searches.**
- **ATLAS collected more than 300 fb^{-1} during Run 3. It offers exciting opportunities to probe diverse new physics models.**
- **So, stay tuned for future results!**

Thank you for your attention!