Search for Dark Higgs at ATLAS and potential to utilize the Xbb tagger

Qibin LIU

[1] TDLI, Shanghai JiaoTong Univ.

[2] Univ. of Washington, Seattle

ATLAS EXPERIMENT

Abstract

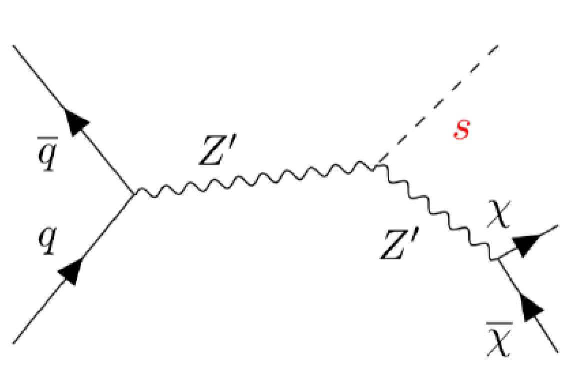
Several extensions of the Standard Model predict the production of dark Matter at the LHC and are widely studied.

Searches of dark matter(DM) produced in association with a **dark Higgs boson** *s* decaying into various final states, including hadronic ZZ/WW and semileptonic WW are performed using 139/fb *pp* collision data recorded by the ATLAS detector at a center-of-mass energy of 13TeV. Reinterpretation of the search of DM produced in association with a Standard Model(SM) Higgs decaying to b-quarks(H→bb) using dark Higgs signal(s→bb) performed using 79.8/fb data and dedicated search is ongoing using 139/fb data.

New analysis techniques are developed and applied in these searches, such as jet reclustering and boosted Xbb tagger *DXbb*, highly improved the signal efficiency and background rejection and achieved better sensitivity. These techniques especially the *DXbb* tagger are promising to be utilized in the future analysis with highly boosted final states.

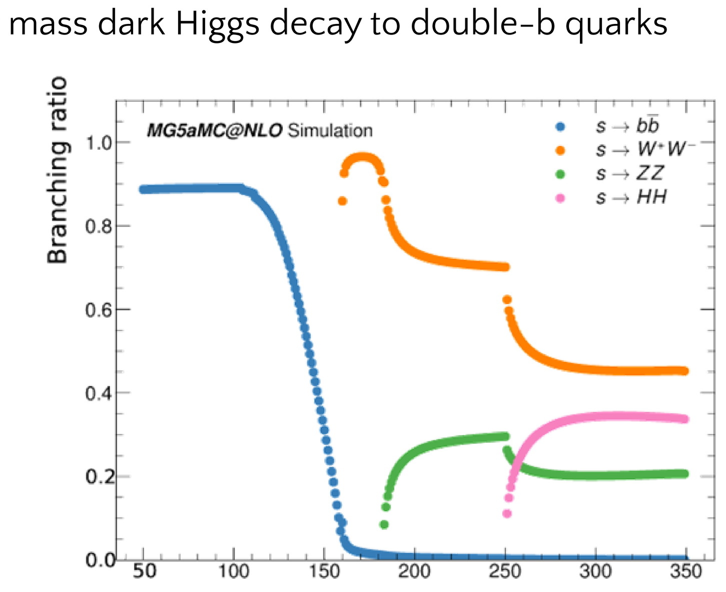
Dark Higgs Model

- New scalar particle s, called dark Higgs boson[1], introduced in the WIMP[2] framework to account for the mass origin of DM
- 2MDM[3] setup with Heavy vector mediator Z' and Majorana DM χ
- New annihilation channel χχ→ss→SM opened up and the constraint of relic abundance from cosmology relaxed : prevent the DM over-production issue
- Main parameters:
  - ➢ Mass: mS, mχ, mZ'
  - ➢ Coupling: gq, gχ, θ



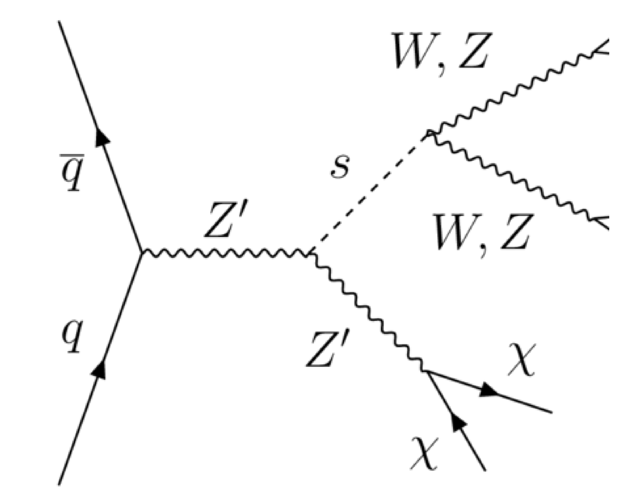
Parameter	Explain
m_s	mass of dark higgs
m_χ	mass of DM
$m_{Z'}$	mass of heavy mediator
g_χ	coupling in dark sector between s, X, Z'
g_q	coupling with SM: q<->Z' fixed 0.25 as benchmark
θ	mixing angle of SM Higgs<->dark Higgs fixed according to [1]

- Dark Higgs boson mixes with SM Higgs and it leads to detectable final states, depending on mass[3]:
  - ➢ High mass dark Higgs decay to two vector bosons or di-Higgs
  - ➢ Low mass dark Higgs decay to double-b quarks

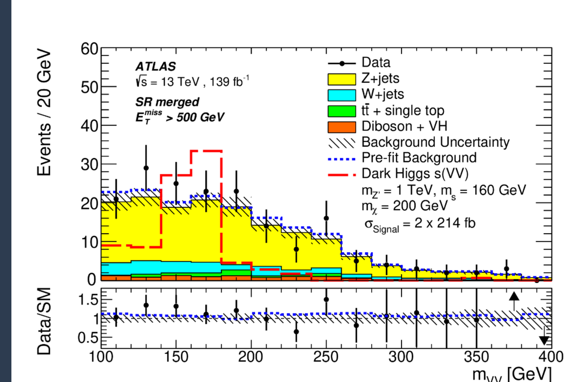


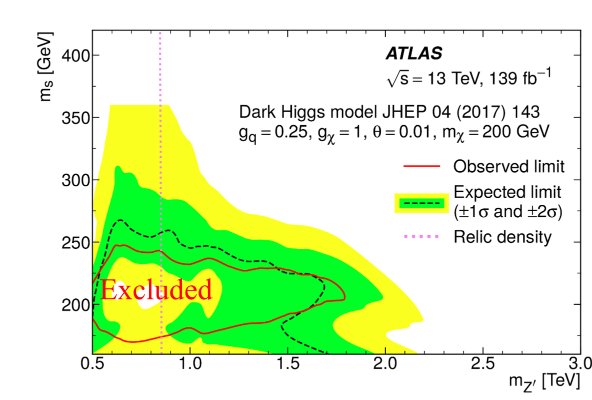
High Mass Dark Higgs Boson (MonoSVV)

Hadronic **MonoS(VV)[4]** and semileptonic **MonoS(WW)[5]** analysis performed to search for high mass dark Higgs boson.

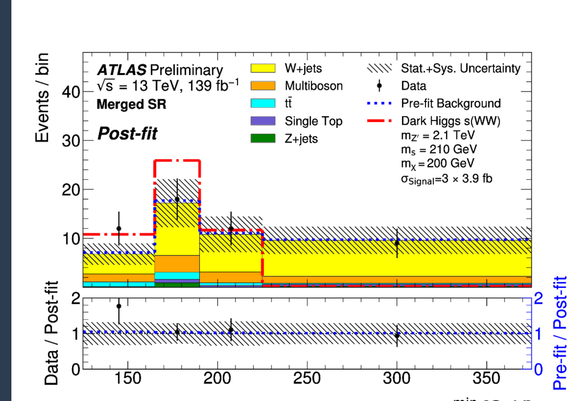


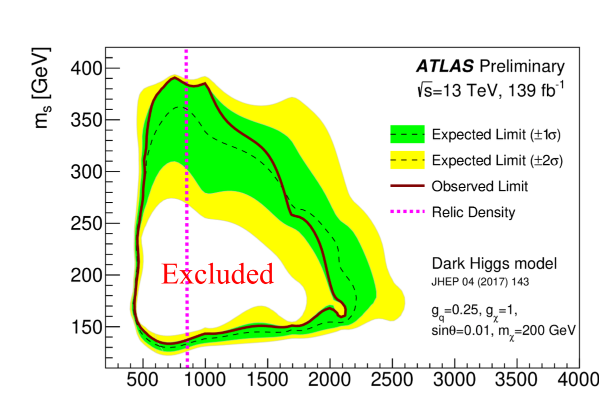
- Hadronic **MonoS(VV)** analysis selects events with 2 large-R jet ("merged") or 1 large-R jet + 2 small-R jet ("intermediate"), zero lepton and MET>200GeV.
- Dominant bkg. from V+jets and controlled in regions allowing additional 1muon(W+jets) or 2lepton(Z+jets)
- Track-assisted reclustering jet (TAR) used, combining the tracking and calorimeter information to improve the multi-prong topology reconstruction and improve the final sensitivity by a factor up to 2.5
- Exclusion curve obtained for mS-mZ' parameter space : mS of [160,250] GeV excluded at fixed coupling constant and DM mass





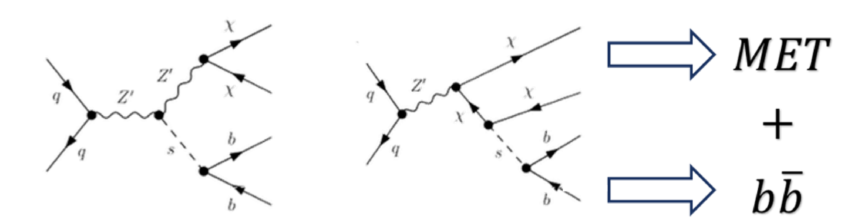
- Semi-leptonic **MonoS(WW)** analysis complement the hadronic search and selects events with lepton, MET and hadronic decay W candidate (*W_had*)
- 2 sets of signal region with different reconstruction of *W_had*
  - ➢ Merged: reconstructed with 1 large-R jet
  - ➢ Resolved: 2 R=0.4 jets whose di-jet mass closet to W mass
- Dominant background from W+jets and tt- controlled by:
  - ➢ CRW: requiring large $\Delta R(W\_had, lep)$
  - ➢ CRTT: requiring >=2 b-jets
- Mass of S candidate reconstructed from *W_had+lep+ν* , minimized by varying $\Delta\theta(lep,\nu)$ and used as fitting discriminant
- Observation agree with SM and mS excluded at [140,390] GeV



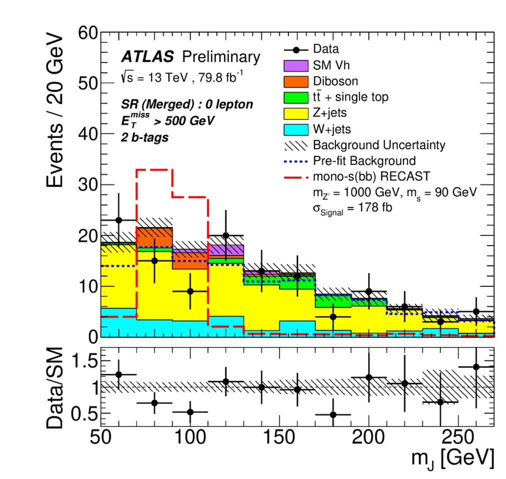


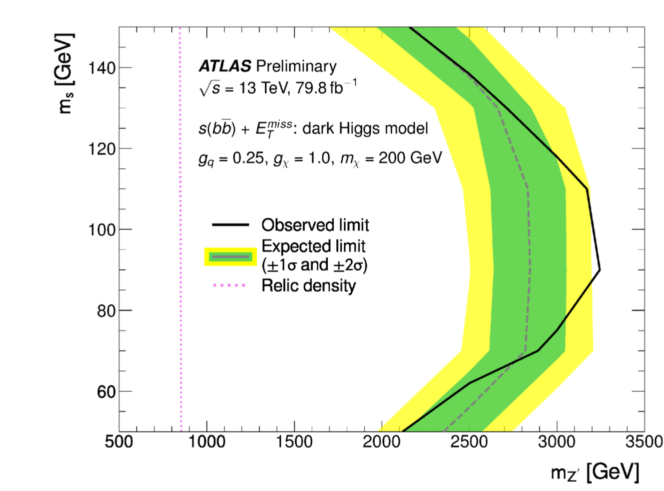
Low Mass Dark Higgs (MonoHbb RECAST)

Low mass dark Higgs signal has signature of bb+MET which is the same as MonoHbb(79.8/fb) analysis → **Reinterpretation using MonoSbb [3]**



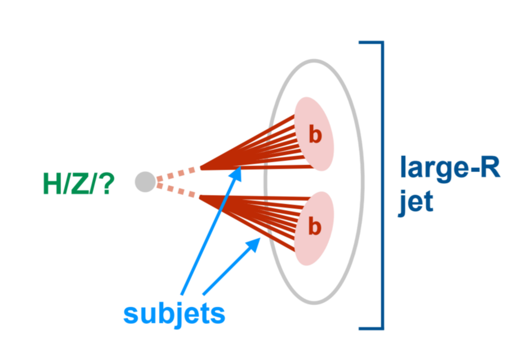
- Resolved and merged regions divided at MET 500GeV
- Higgs candidate recon. and mass used in fitting to separate S/B:
  - ➢ 2 small-R jets used for resolved events where 2 b-jets separated
  - ➢ 1 large-R jet used for merged events in association with 2 b-jets
- Mass window optimized for SM Higgs and best sensitivity for dark Higgs signal mass at [70,120] GeV.

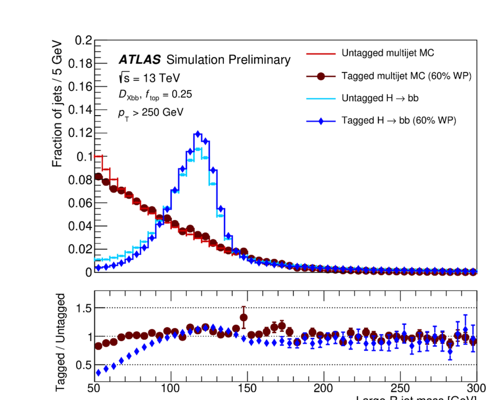




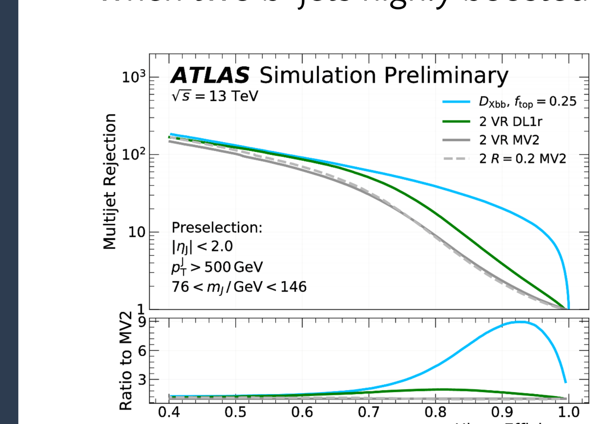
Boosted Tagging – *DXbb* tagger

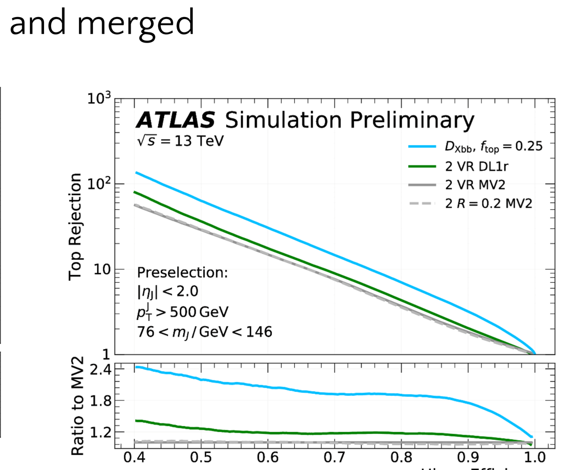
- To further improve the signal efficiency and background rejection of highly boosted double-b jets, deep learning based *DXbb* tagger [6][7] developed and calibrated at ATLAS
- Large-R jet tagged as a whole to be Hbb/QCD/Top jet, combining the information of kinematics and jet constitutes
- Good mass decorrelation property allowing the application to tag the X→bb events with varying mass, e.g. the case of tagging low mass dark Higgs boson decaying to 2 b-quarks





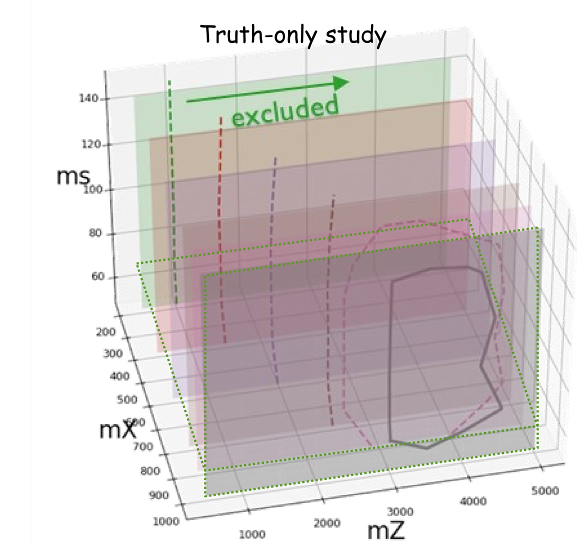
- Better performance than the doubly b-tagging algorithms on separate associated jets which typically suffer from low efficiency when two b-jets highly boosted and merged



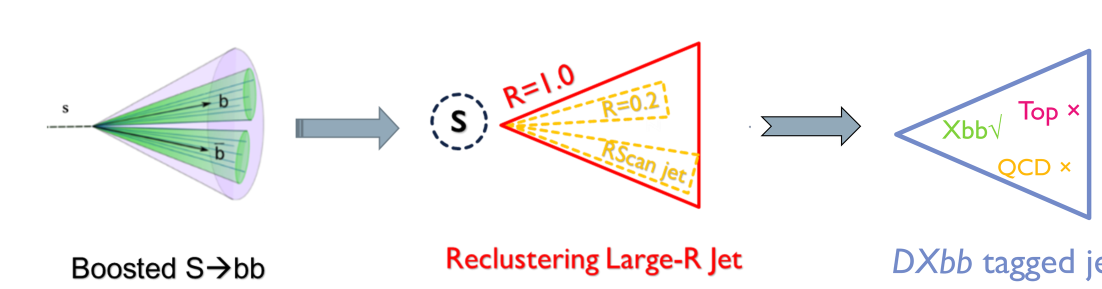


Low Mass Dark Higgs (MonoSbb Full Run2)

- **Dedicated MonoS(bb) analysis** is actively ongoing : focus on the search for low mass dark Higgs with ATLAS full Run2 data
- 4-D parameter space probed : gχ, mS, mχ, and mZ' with constraint from relic abundance $\Omega h^2 \cong 0.12$ [8] considered



- Analysis techniques optimized for dark Higgs signal especially for low mass and highly boosted topology
  - ➢ Reclustering jet supports reconstruction of mJ down to 20GeV
  - ➢ *DXbb* tagger applied and achieved better S/B for highly boosted jets than separately double-b tagging



Summary and Outlook

- Three analyses searching for dark Higgs boson at ATLAS presented:
  - ➢ Hadronic MonoS(VV)
  - ➢ Semi-leptonic MonoS(WW)
  - ➢ Recast of MonoH(bb)(79.8/fb)
- Limit set for dark Higgs model mass from 50GeV to 390GeV, with fixed coupling and dark matter mass (200GeV)
- Dedicated MonoS(bb) analysis exploring wider parameter space for low mass dark Higgs is ongoing with new reclustering technique and ML-based boosted Xbb tagger -- *DXbb*
- Good performance of *DXbb* shown and promising for future analyses

References

[1] arXiv:1701.08780

[2] arXiv:hep-ph/9303253

[3] ATL-PHYS-PUB-2019-032

[4] PRL 126(2021)121802

[5] ATLAS-CONF-2022-029

[6] ATL-PHYS-PUB-2020-019

[7] ATL-PHYS-PUB-2021-035

[8] Planck2018