Searching for new symmetries in the Higgs sector at ATLAS Detector

2021 Discrete Symmetry

Y.Y. Fan (IHEP)
On behalf of the ATLAS collaboration

Beyond the standard model

Standard Model (SM):

One Higgs doublet field, only one neutral Higgs boson

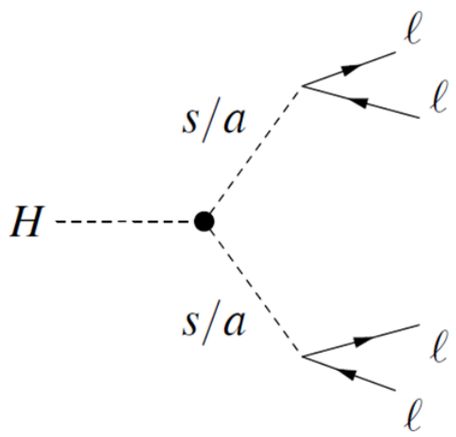
SM needs to be **extended**:

ν mass, dark matter…

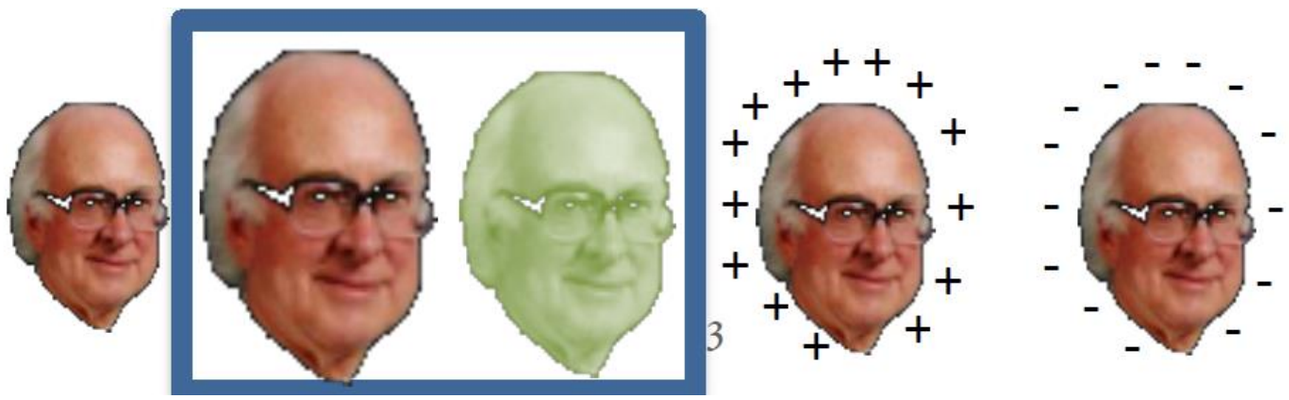
Many **Beyond the Standard Model (BSM) theories predicts:**

✓ **exotic decays of Higgs boson:** exiting precision measurements of the Higgs allow a branching ration of ~30% to exotic decays

✓ **additional Higgs:** Two Higgs Doublet Model (2HDM) + S (singlet)



Higgs exotic decays into light scalar particles



scalar (H), **pseudoscalar (a), heavy scalar**, two charged.

Outline

New results with full data set (139 fb^{-1}) collected by the ATLAS experiment in Run2 from 13 TeV pp collisions

I. H_{125} → new light scalar particles(BSM)

$H \rightarrow aa/Za/ Z_dZ_d \rightarrow 4l$

$H \rightarrow aa \rightarrow bb\mu\mu$

II. Additional low- and high-mass Higgs bosons

$H \rightarrow ZZ \rightarrow llll$ and $llvv$

$H \rightarrow \gamma\gamma$

$H \rightarrow V+\gamma$

I. H_{125} → new light scalar particles(BSM)

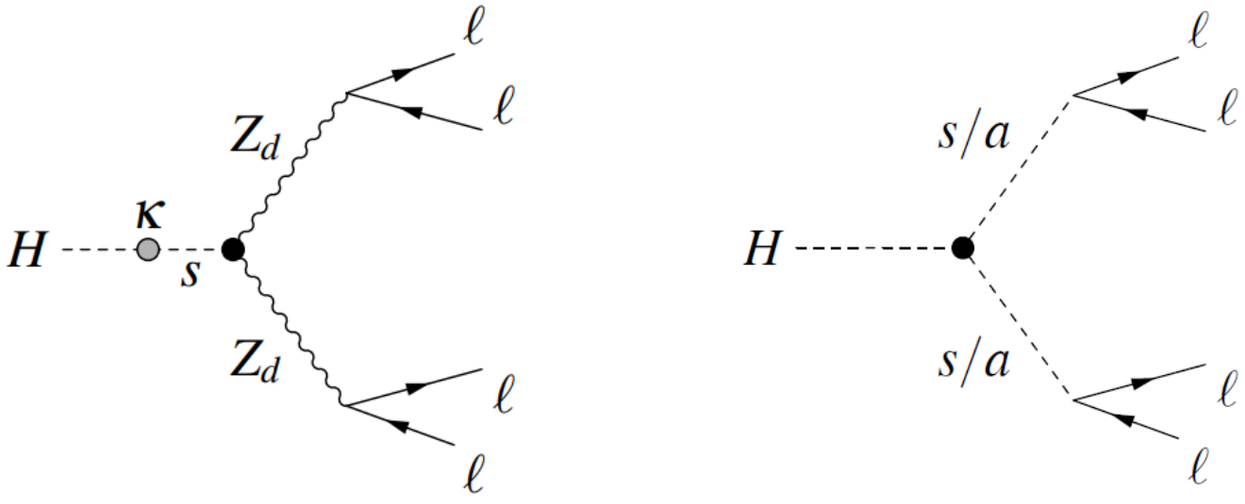
$H \rightarrow aa/Za/ Z_dZ_d \rightarrow 4l$

$H \rightarrow aa \rightarrow bb\mu\mu$

$H \to aa\ /Za\ /Z_dZ_d \to 4l$

arXiv:2110.13673

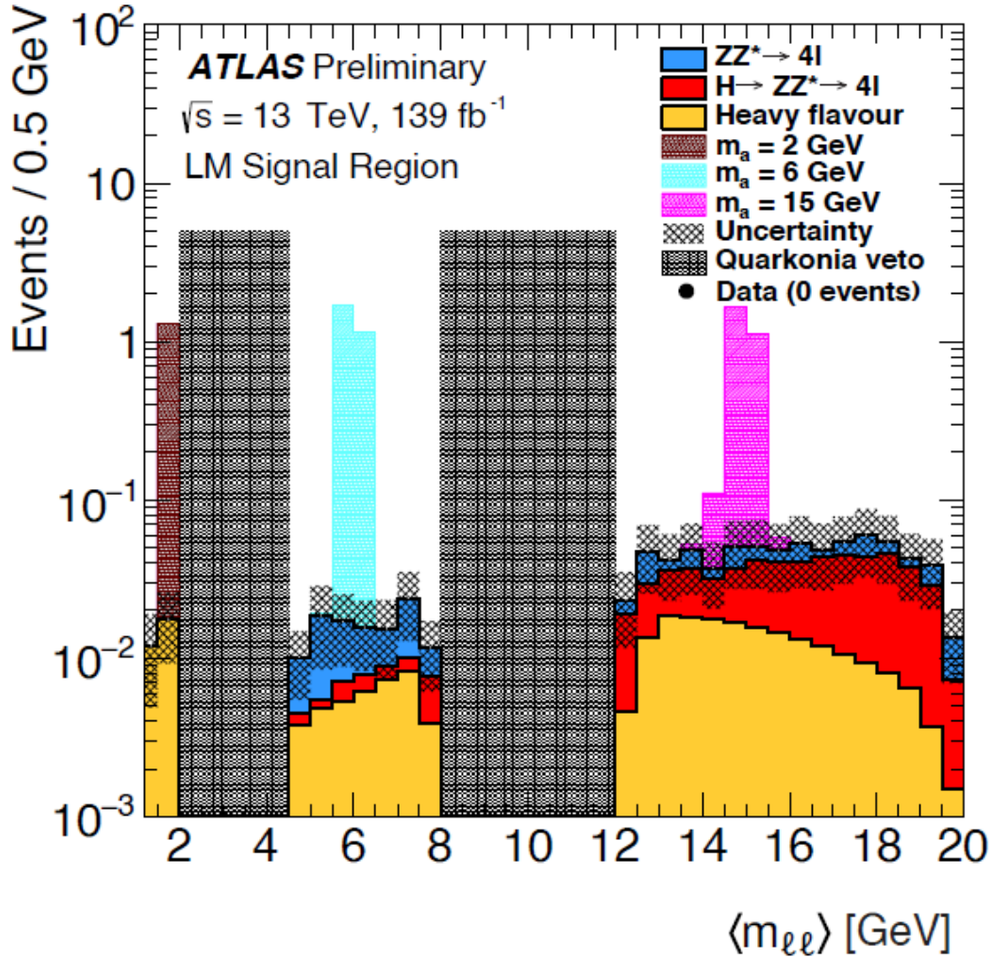
Search for Higgs bosons decaying to new spin-0 or spin-1 particles in four-lepton final states at the ATLAS detector with 139 fb^{-1} of $\boldsymbol{p\,p}$ collision data at $\sqrt{s}$ = 13 TeV



Backgrounds: simulation.

- ZZ* → 4μ: simulation
- H → ZZ* → 4μ: simulation
- Non-prompt leptons from heavy flavour hadrons: data-driven method

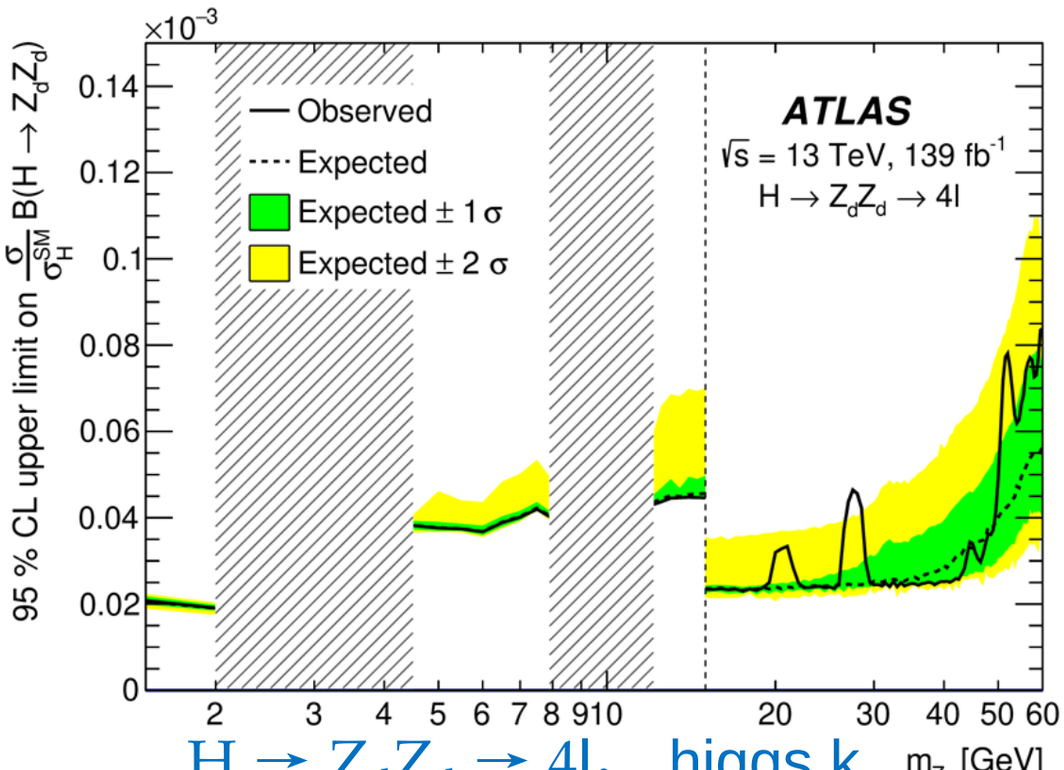
Statistics limited.



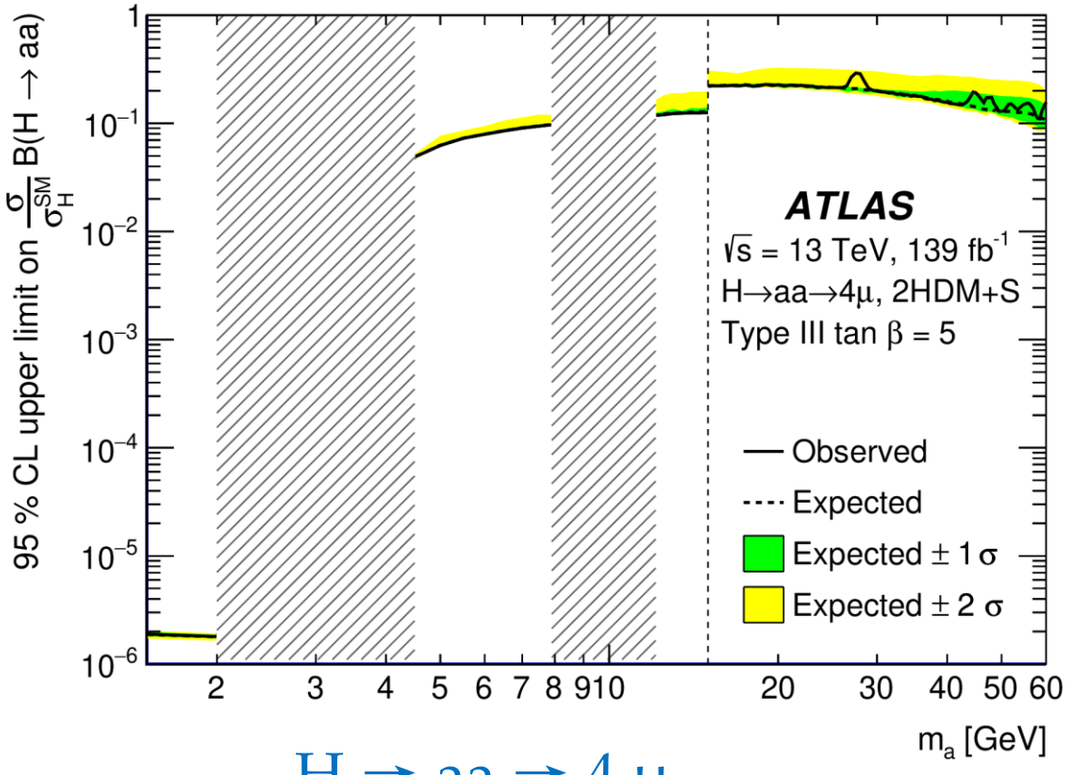
$H \to aa$ /Za /$Z_dZ_d \to 4l$: Limits

- Limits on $\sigma(H \to aa/Za \to 4l)$
- Factor 2-4 improvement from previous results.

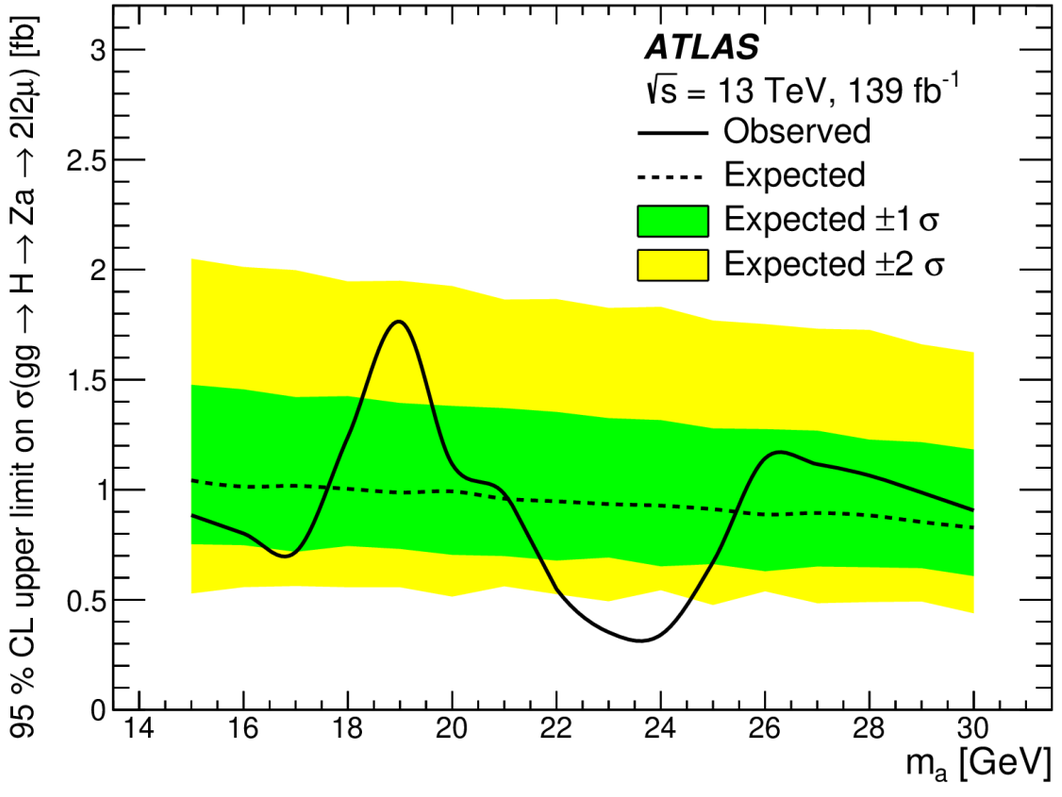
✓ Larger data sample
✓ improved lepton reconstruction and identification
✓ Better optimized event selection



$H \to Z_dZ_d \to 4l$, higgs k



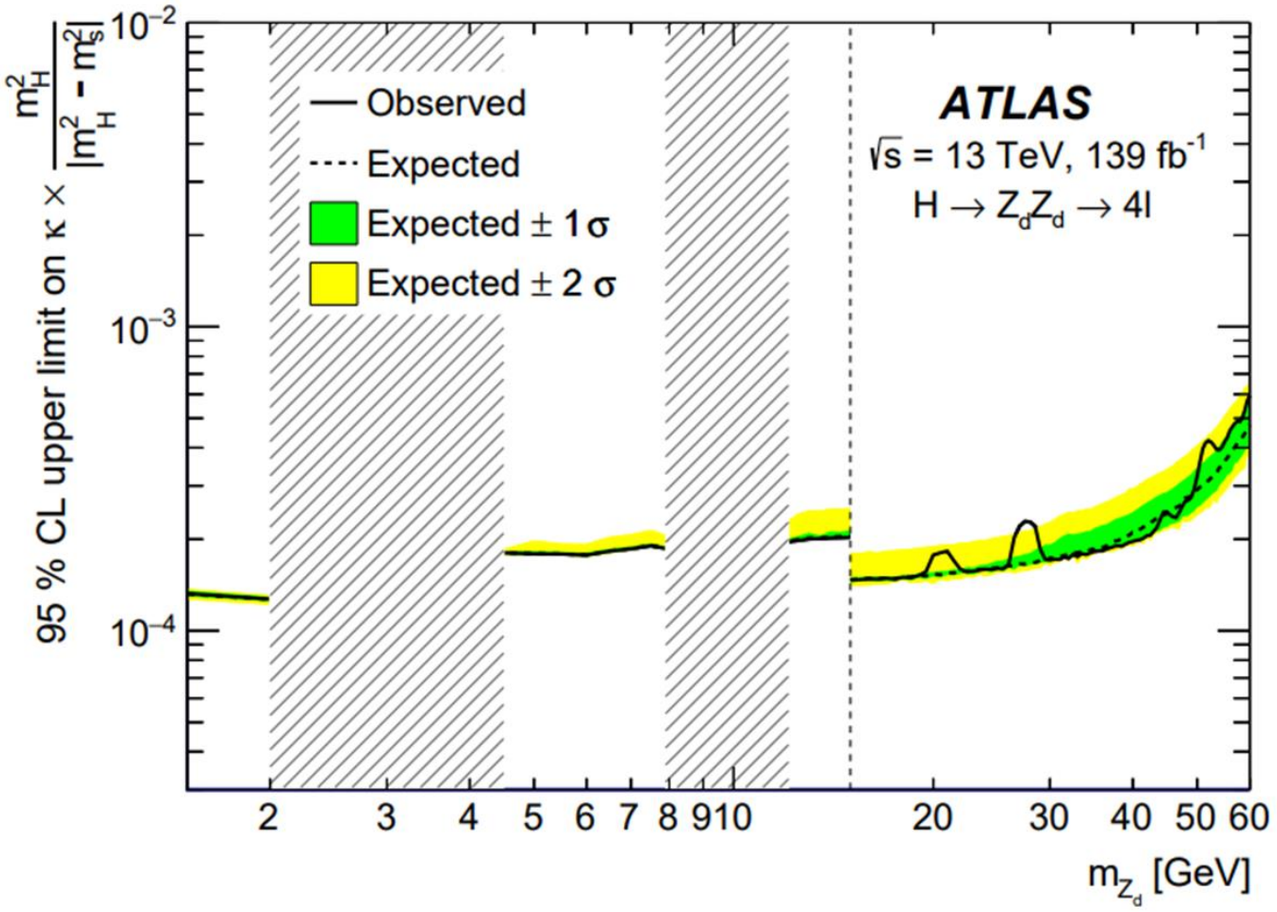
$H \to aa \to 4\,\mu$, 2HDM+S model



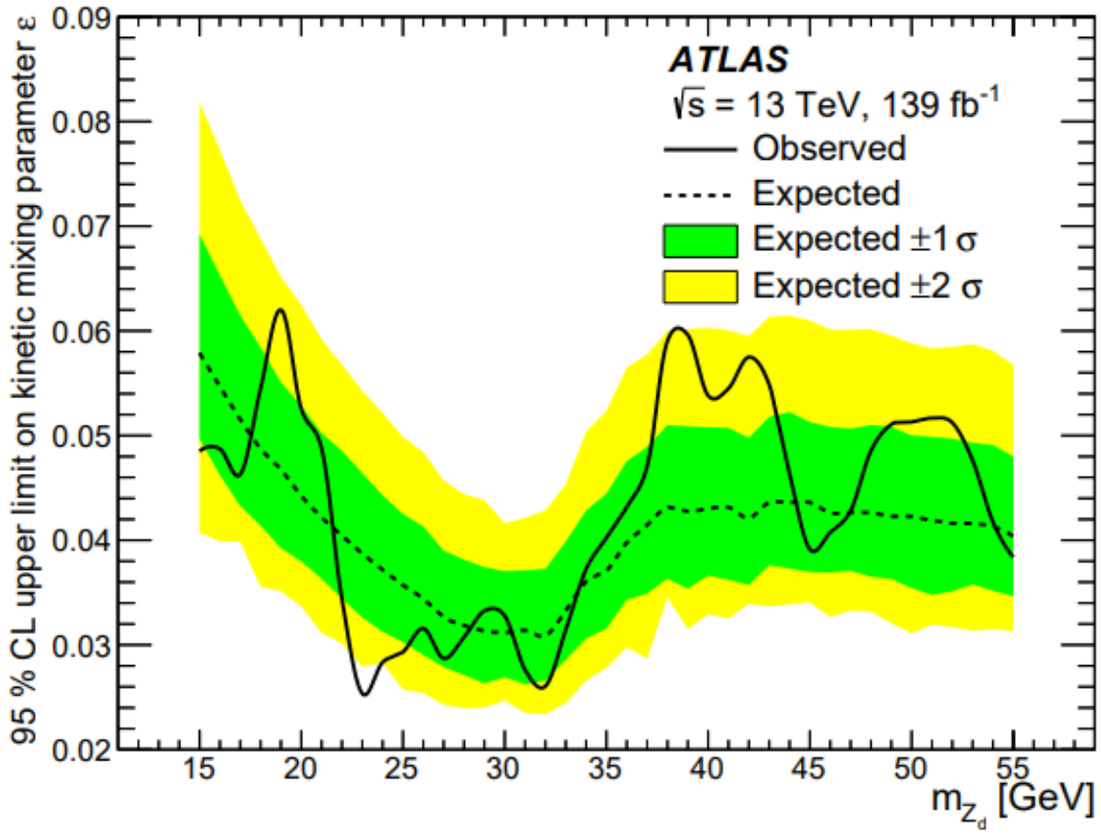
$H \to Za \to 2l2\,\mu$

$H \to aa$ /Za /$Z_dZ_d \to 4l$: Limits

- Used $H \to Z_d\, Z_d$ set upper limit on Higgs mixing parameter
- Used $H \to Z\, Z_d$ set upper limit on Z_d mixing parameter ϵ



Higgs mixing parameter： κ



Z_d mixing parameter ϵ

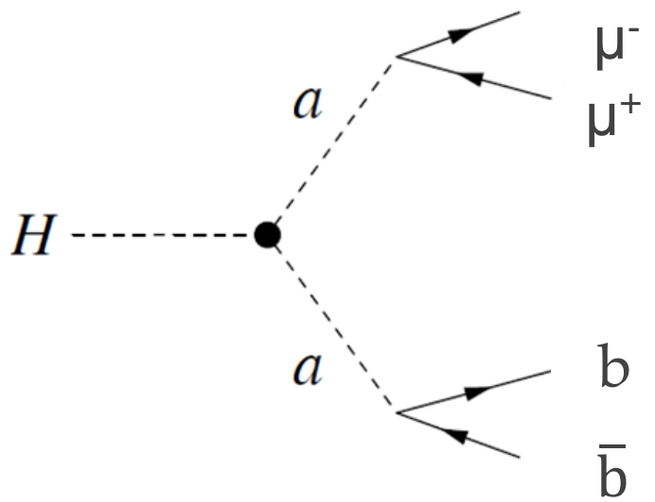
$H \rightarrow aa \rightarrow bb\mu\mu$

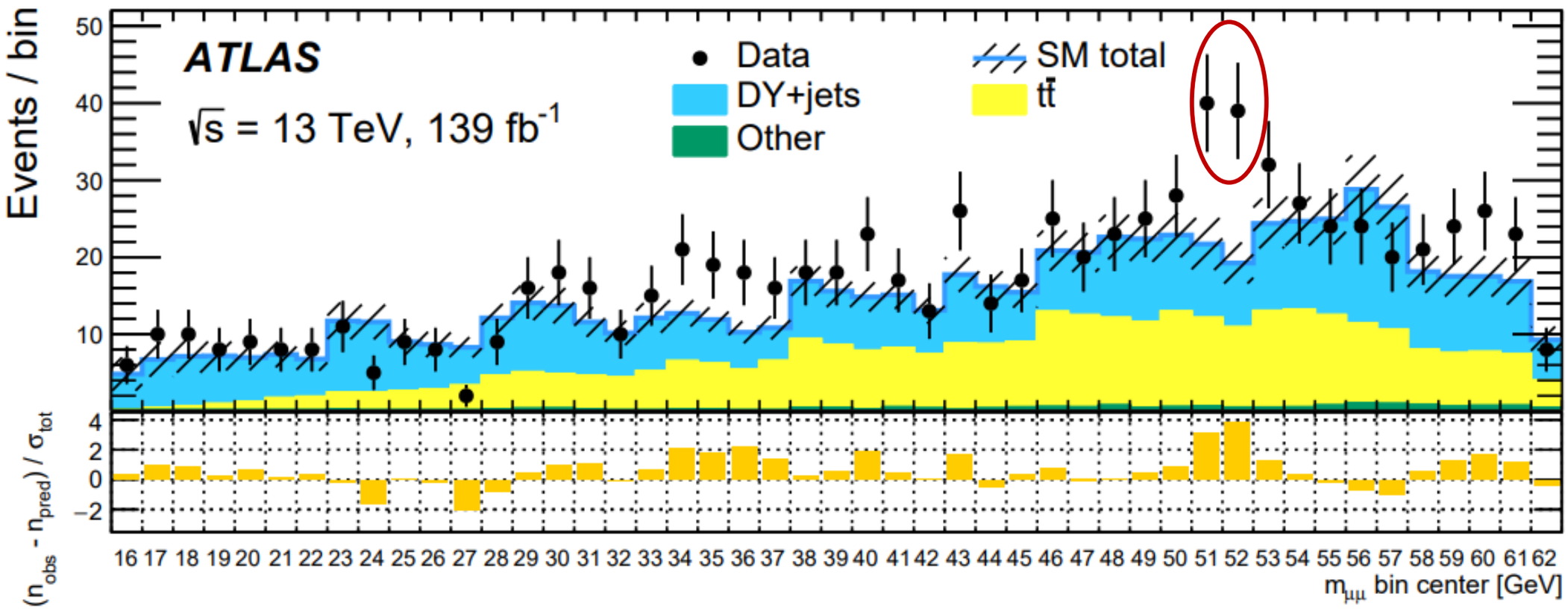
arXiv:2110.00313

Search for Higgs boson decays into a pair of pseudoscalar particles in the bbμμ final state with the ATLAS detector in pp collisions at $\sqrt{s}$ =13 TeV

SM Backgrounds

- **DY (Drell-Yan) dimuon + jets:**
  - bbμμ mass side bands control region.
  - Distribution shapes are from data templates with 0 b-jets
- **ttbar:**
  - High-MET control region
  - Distribution shapes are from simulation.
- **Other (diboson, single-top-quark etc.):**
  - Simulation





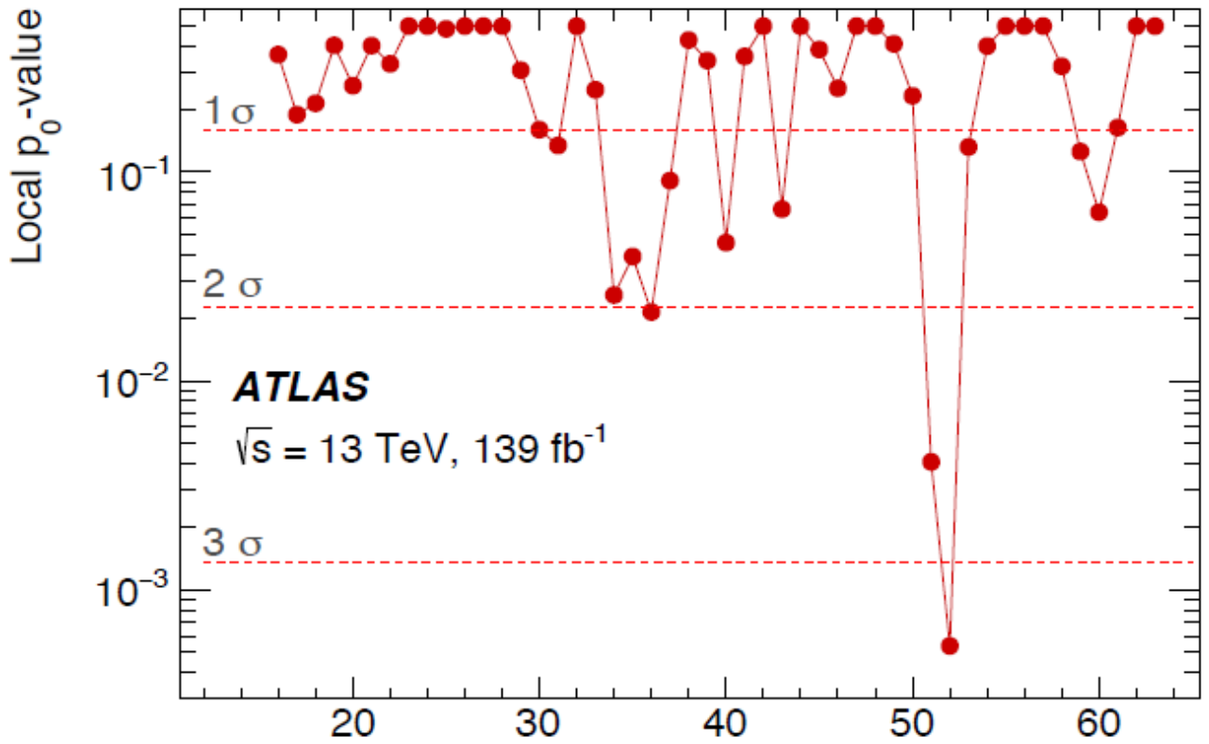
H → aa → bbμμ : Results

✓ **Overall data are compatible with the SM background**

- The largest data excess at 52 GeV is local 3.3 σ (global 1.7 σ)

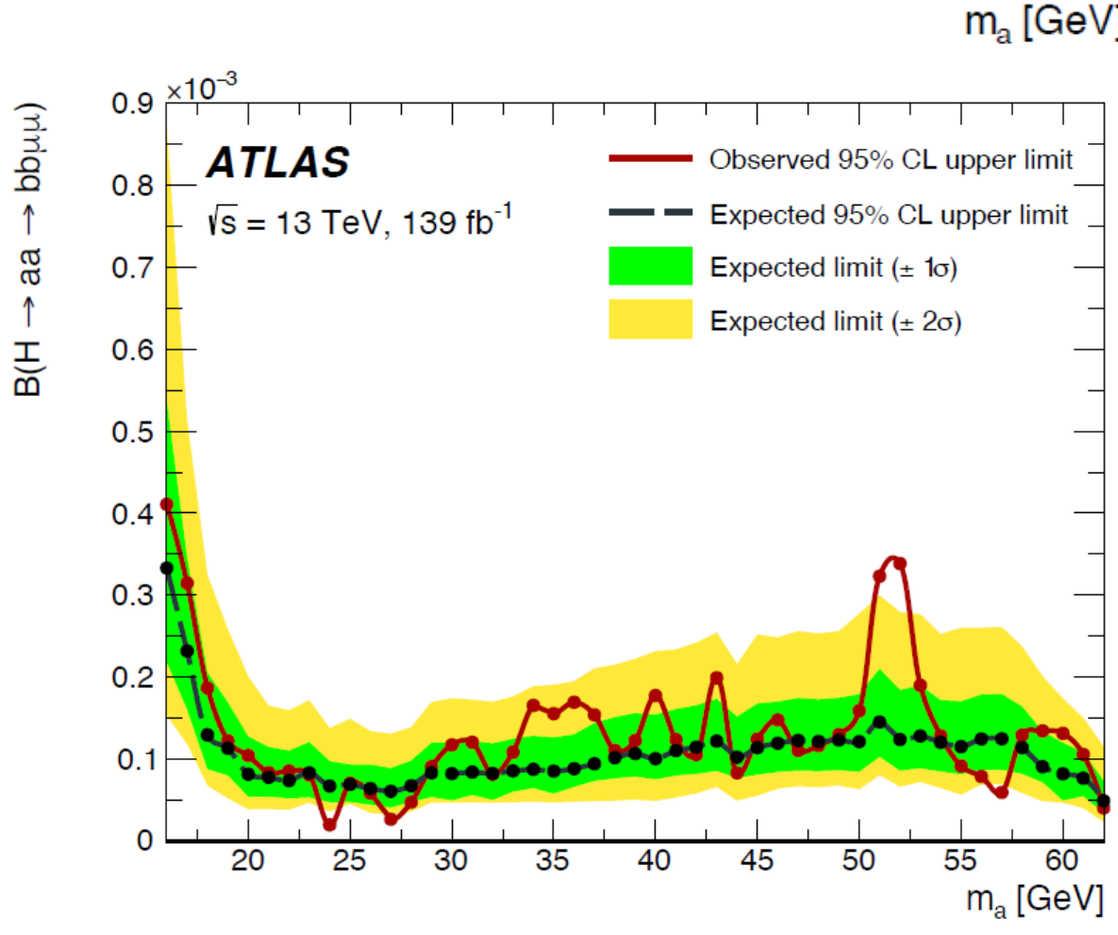
✓ **Dominant systematic uncertainties.**

- DY background: BDT selection and normalization
- Signal : b-tagging and jet energy related uncertainties



✓ **Upper Limits on B(H → aa → bbμμ) range (0.2—4.0)** $\times 10^{-4}$

- **Factor 2 - 5 improvement** from the previous analysis.
- Larger data set (factor ~2).
- Use of BDT (factor ~2).



II. Additional low- and high-mass Higgs bosons

$H \rightarrow ZZ \rightarrow llll$ and $ll\nu\nu$

$H \rightarrow \gamma\gamma$

$H \rightarrow V+\gamma$

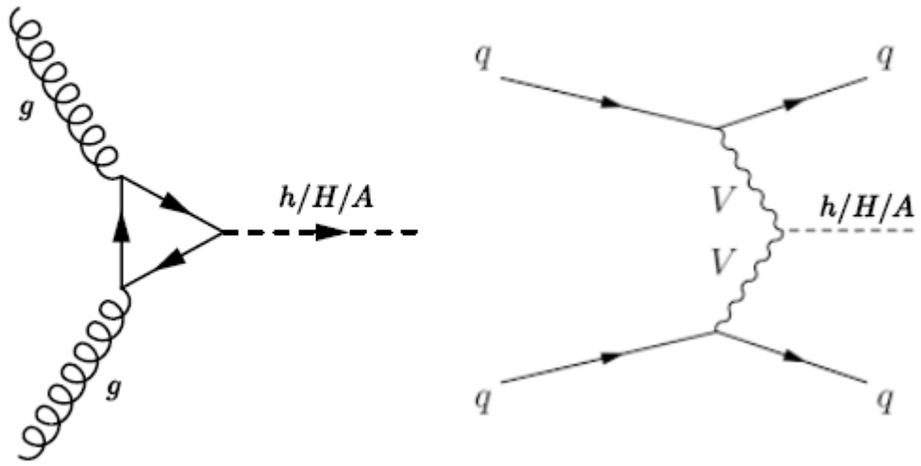
$H \rightarrow ZZ$

Eur. Phys. J. C 81 (2021) 332

Search for heavy resonances decaying into a pair of Z bosons in the llll and llνν final states using 139 fb^{-1} at 13 TeV.

Many channels:

- Productions: gluon-gluon fusion and vector-boson-fusion
- Decays: llll and llνν
- Width assumptions: narrow-width approximation and large-width assumption(only for the ggF channel)



Interpretation:

- Spins: 0 (two-Higgs-doublet model)
- Spins 2 (Randall–Sundrum).

Mass range: 200-2000 GeV.

Discriminating variable:

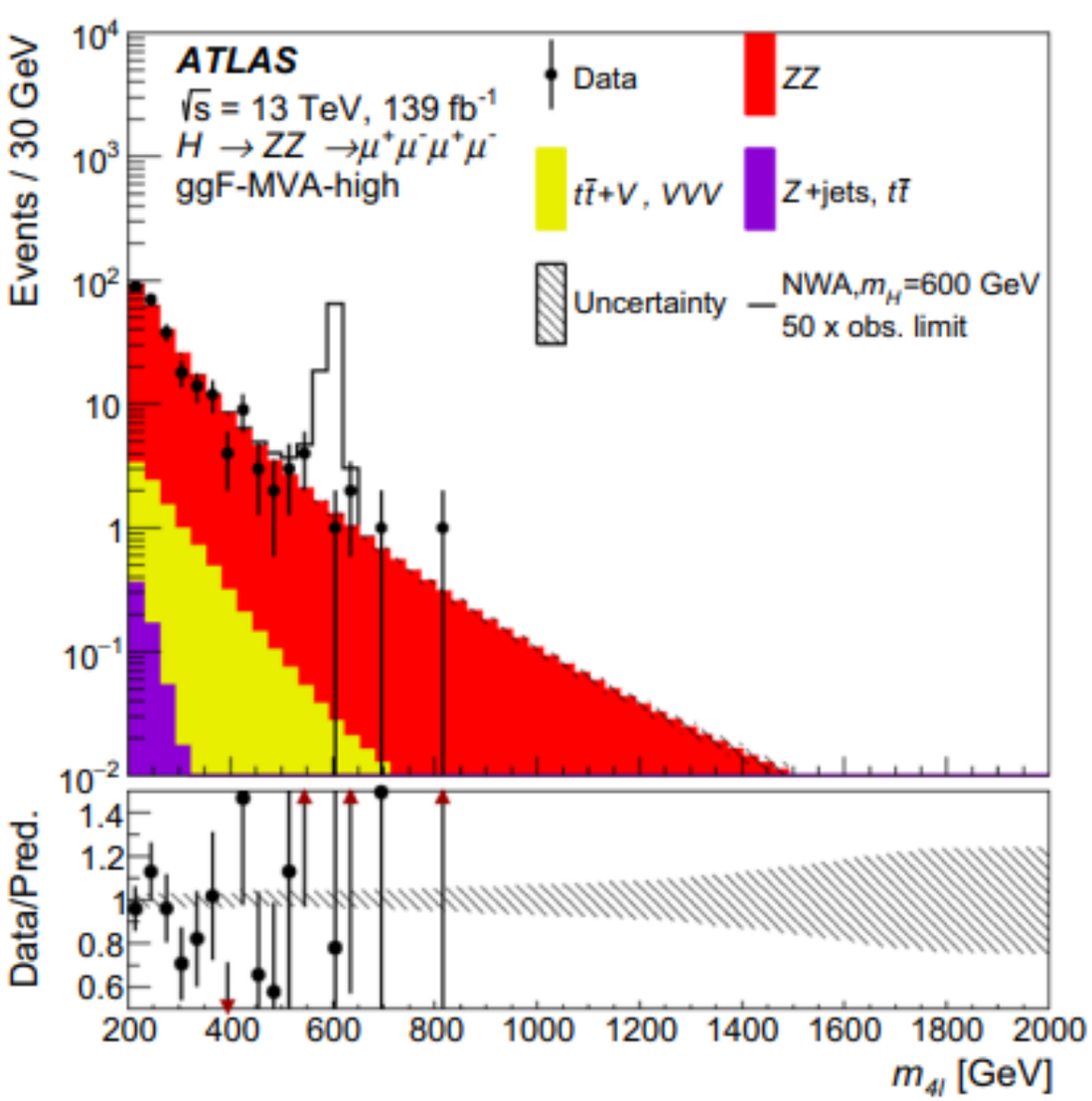
- llll: m4l (four-lepton invariant mass).
- llνν:

$$m_{\mathrm{T}} \equiv \sqrt{\left[\sqrt{m_Z^2 + (p_{\mathrm{T}}^{\ell\ell})^2} + \sqrt{m_Z^2 + (E_{\mathrm{T}}^{\mathrm{miss}})^2}\,\right]^2 - \left|\vec{p}_{\mathrm{T}}{}^{\ell\ell} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}}\right|^2}$$

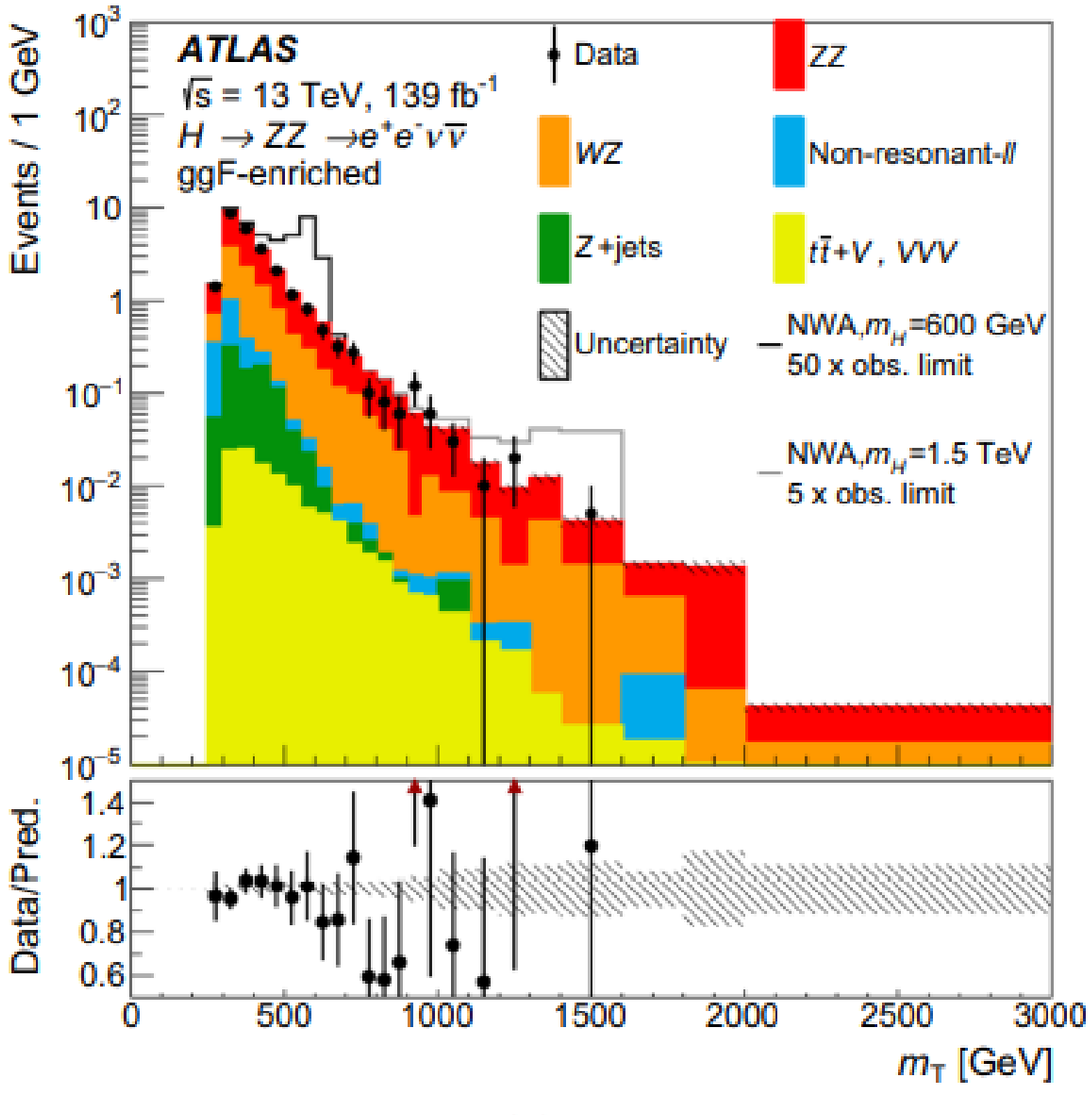
H → ZZ: Background estimation

Background estimation:

- Minor backgrounds – simulated from MC
- Major backgrounds - shape from MC and normalization from data
- llll: dominant non resonant ZZ -using functional form



2HDM

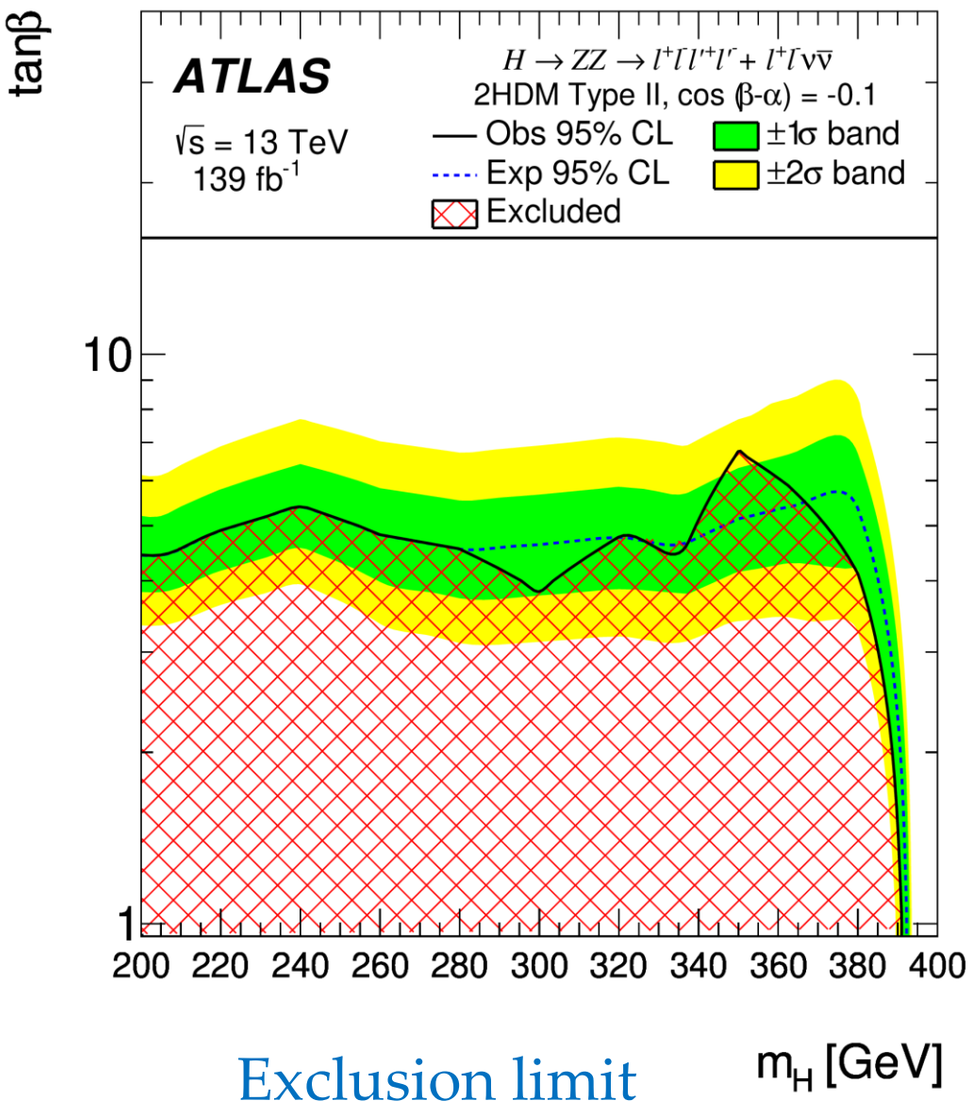


RS(Randall–Sundrum)

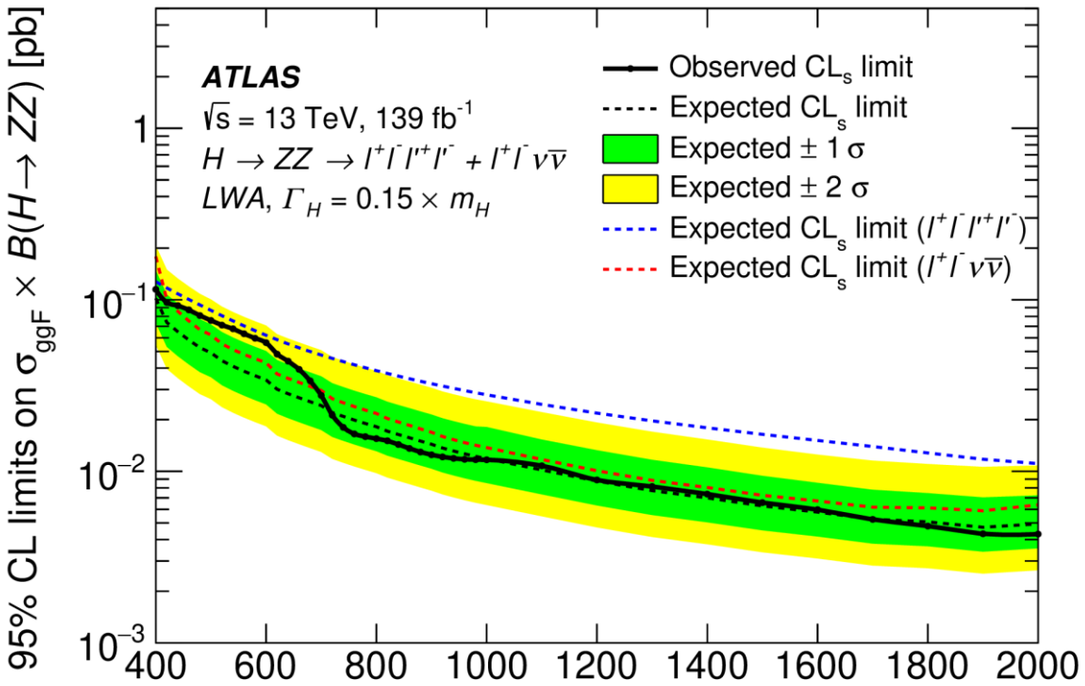
H→ZZ

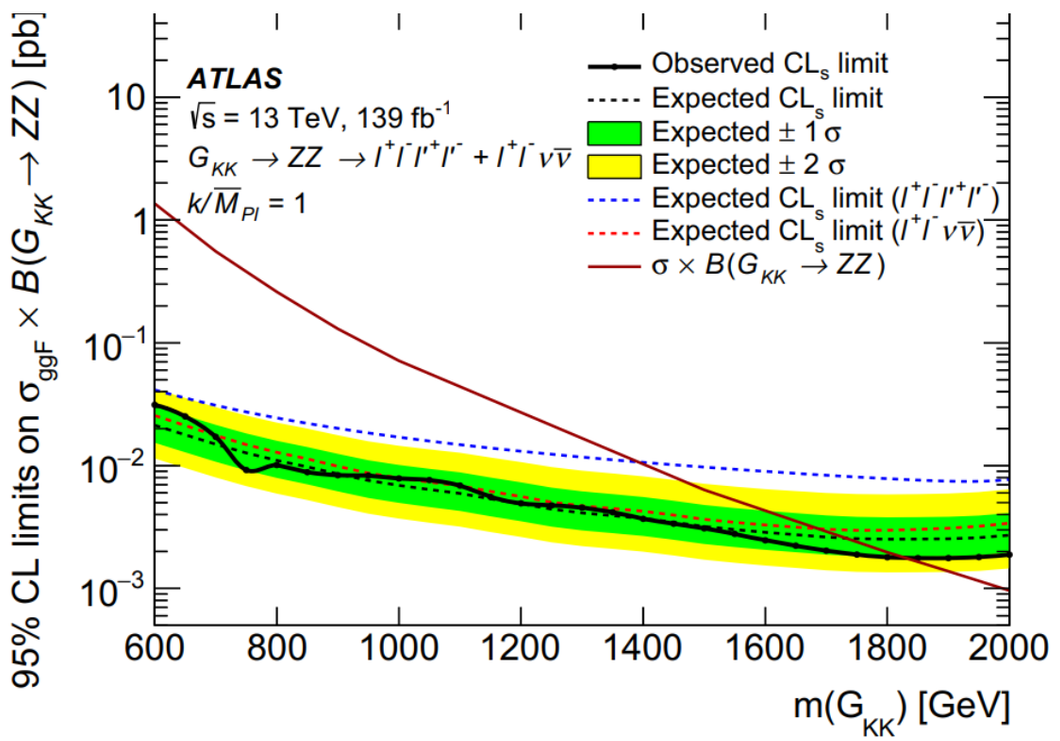
Upper limits are set at the 95% CL:

- NWA improvement of up to ~40% wrt previous results
  - 200–2.6 fb for ggF.
  - 87–1.9 fb for VBF.



Exclusion limit





$H \rightarrow \gamma\gamma$

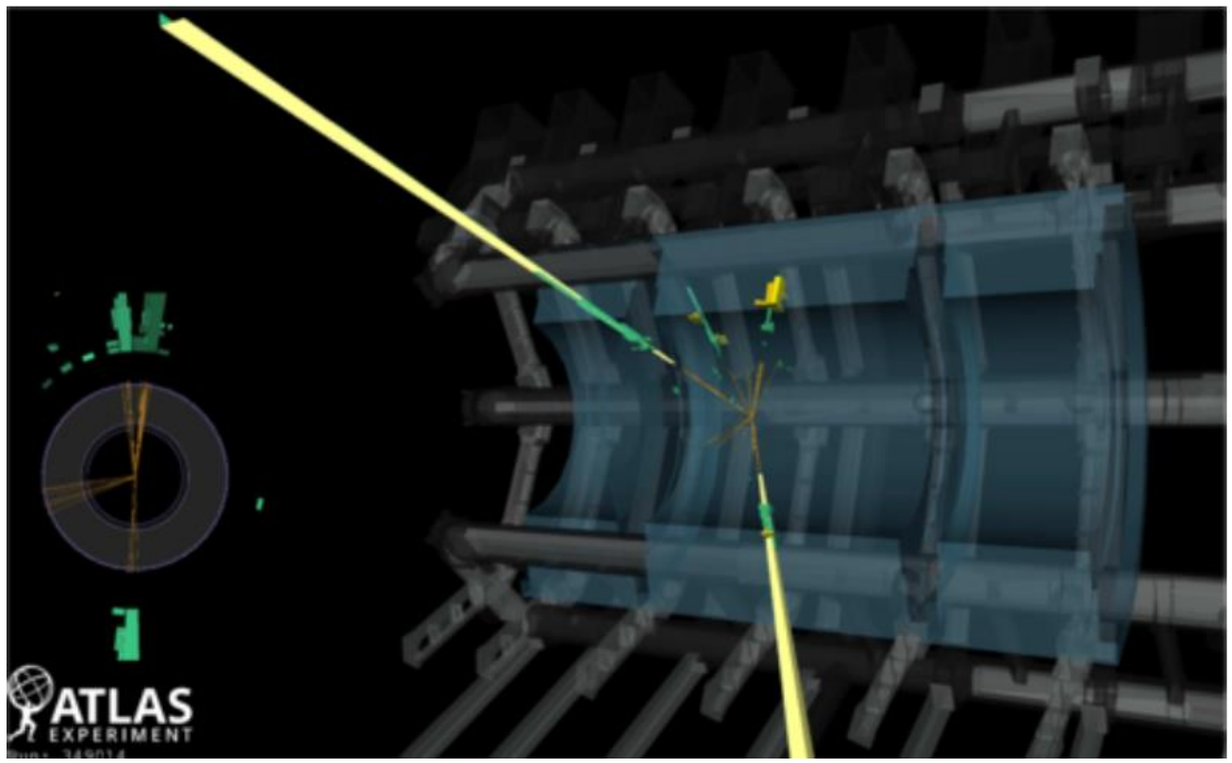
Phys. Lett. B 822 (2021) 136651

Search for heavy resonances decaying into photon pairs using 139 fb-1 at 13 TeV.

Motivation:

- Spin 0 - extended Higgs sector.
- Spin 2 - warped extra-dimension model.

- Require at least two photons with $E_T > 35(25)$ GeV and additional $E_T/m_{\gamma\gamma} > 0.3$ (0.25) for leading (subleading) γ.
- Search range: $m_{\gamma\gamma} > 150$ GeV
- **Signal model:**
  Breit-Wigner
  True lineshape width
  Variety of width hypotheses
  $\Gamma/m_x = [1,10\%]$
  $k/\overline{M_{p1}} = [0.01,0.1]$

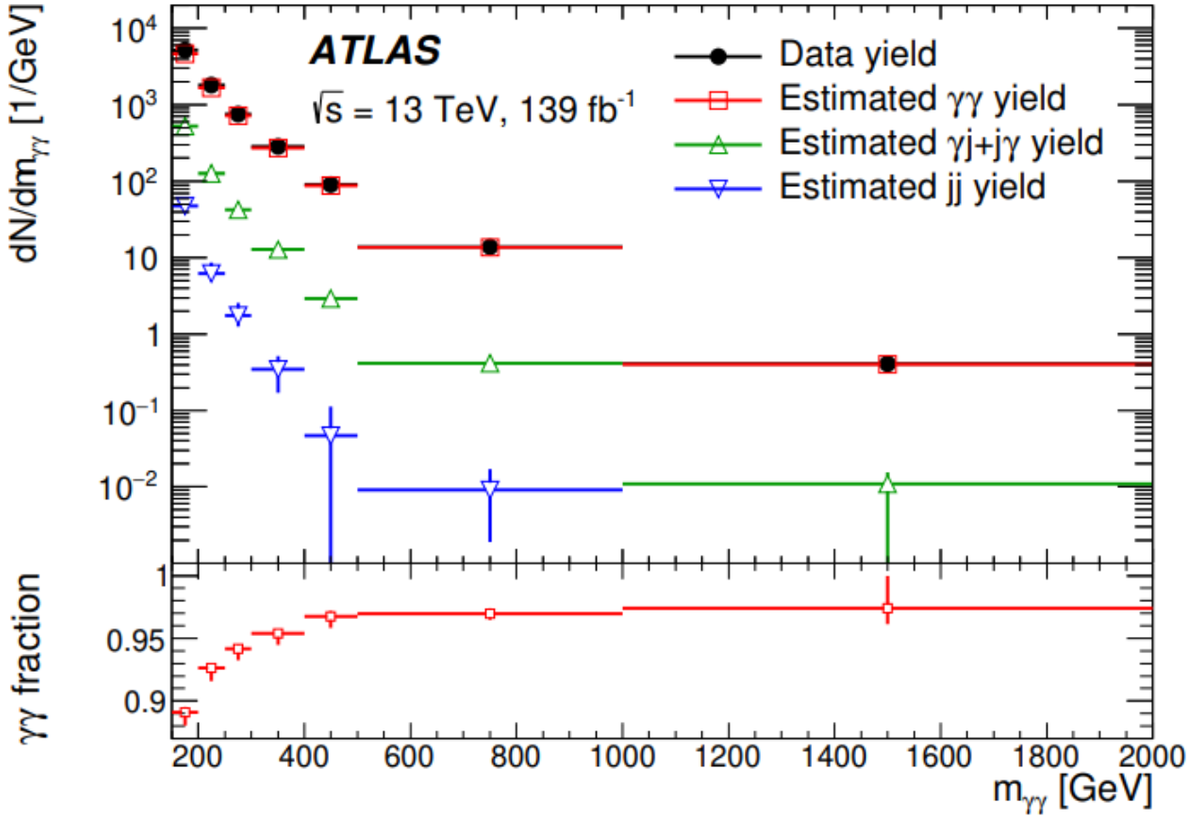


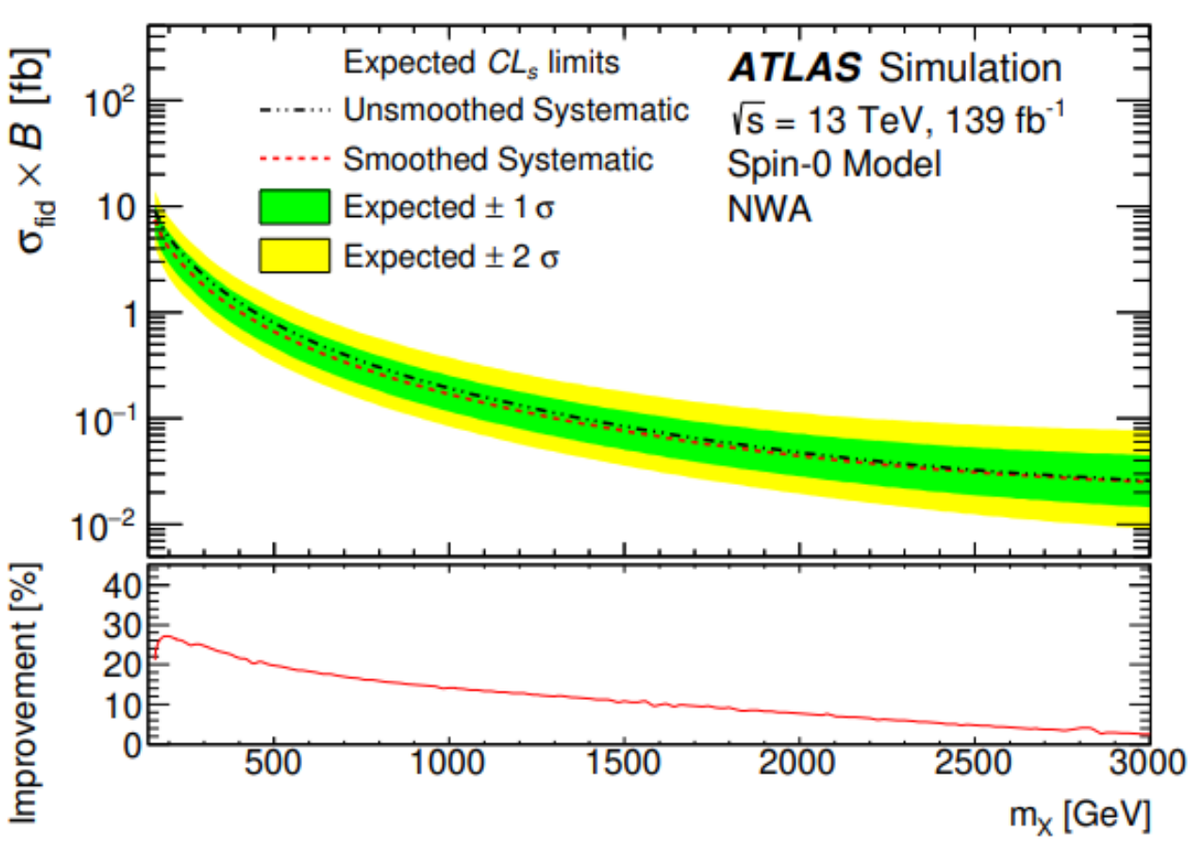
$H \rightarrow \gamma\gamma$

Background estimation:

- Irreducible ($\gamma\gamma$) from MC.
- Reducible (γj,jγ,jj) from data driven methods.
- Mixed according to data-driven purities.
- Fluctuations suppressed using the functional decomposition method.

Up to 25% gain on the limit wrt using the default MC.



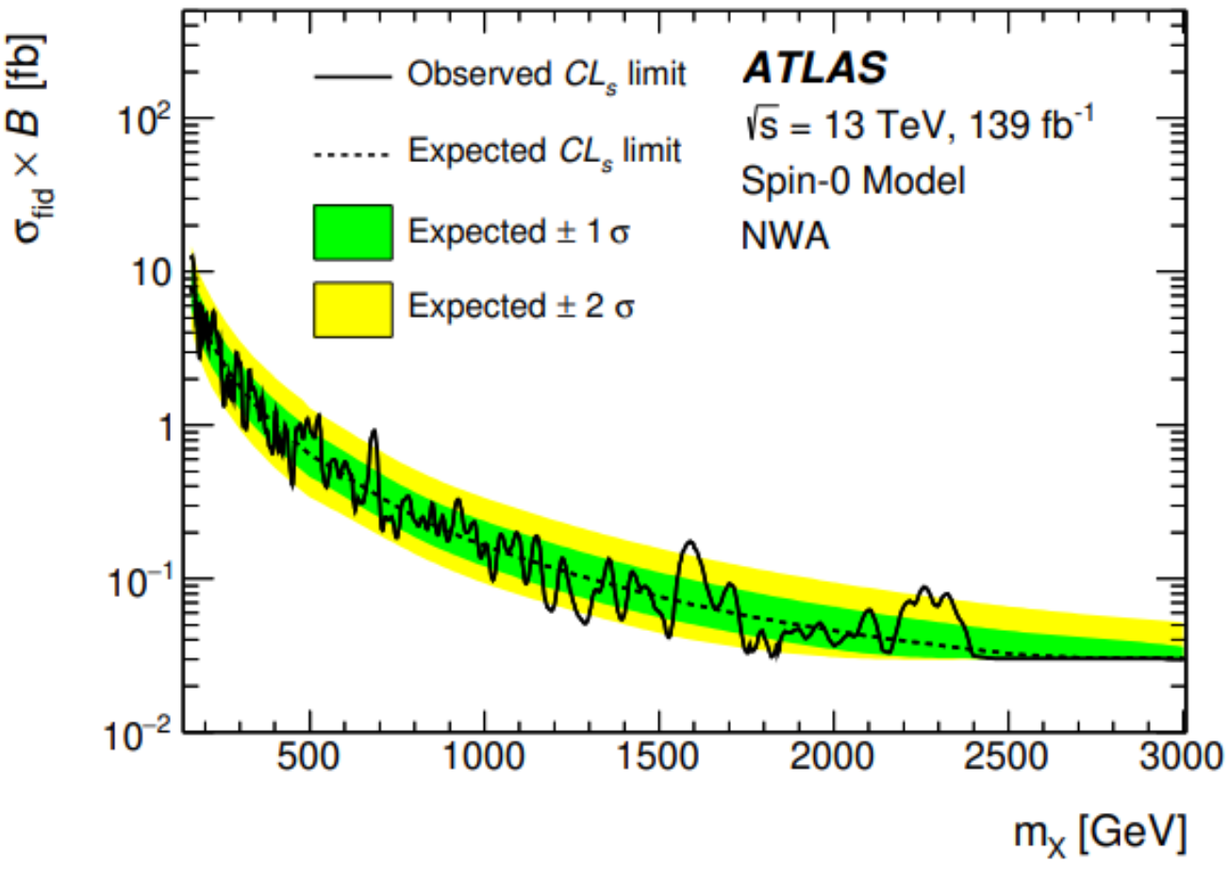


$H \rightarrow \gamma\gamma$

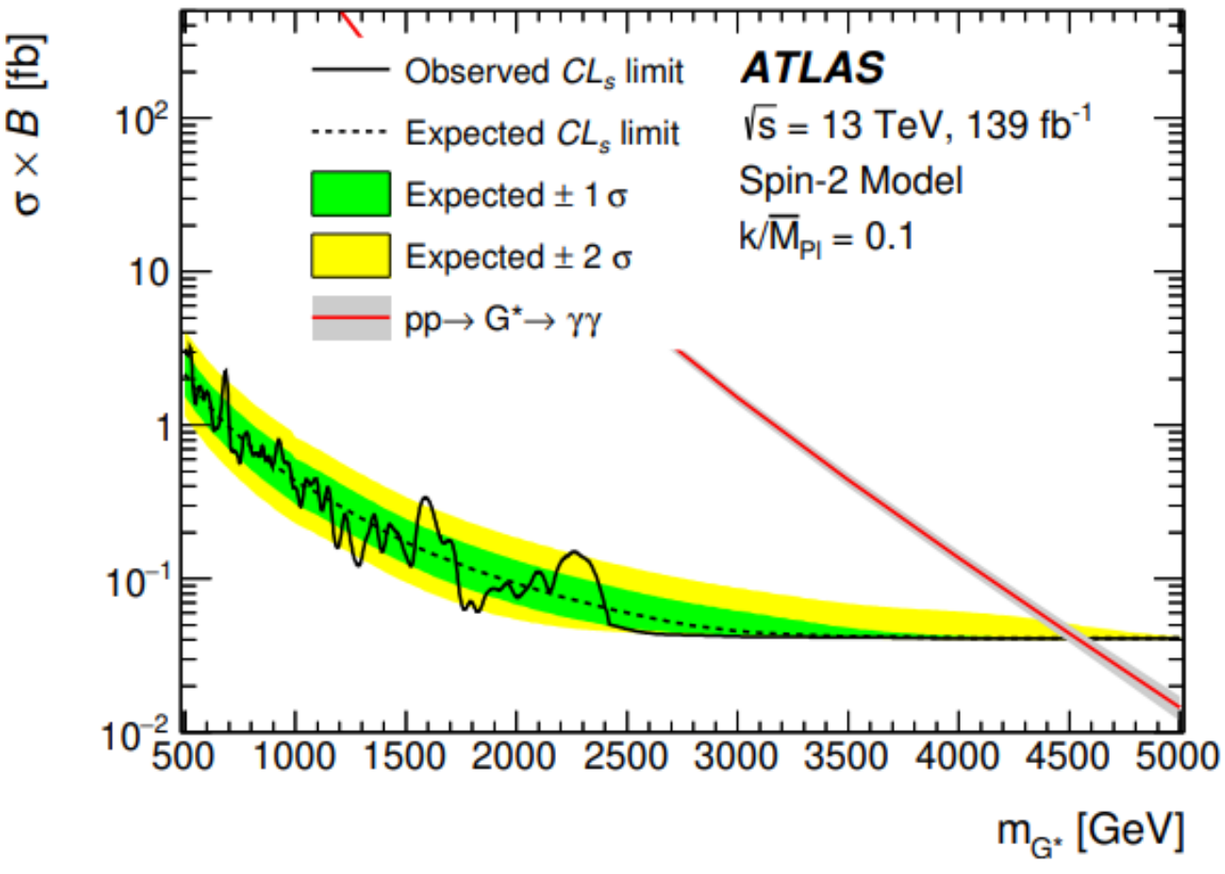
Upper limits on the fiducial XS*BR are set at the 95% CL:

- Spin 0: 12.5–0.03 fb.
- Spin 2: 3.2–0.04 fb.

- Most significant excess at m_X = 684 GeV with a local （global） signigicance of 3.29σ (1.36σ)



Spin 0： Extended Higgs sector



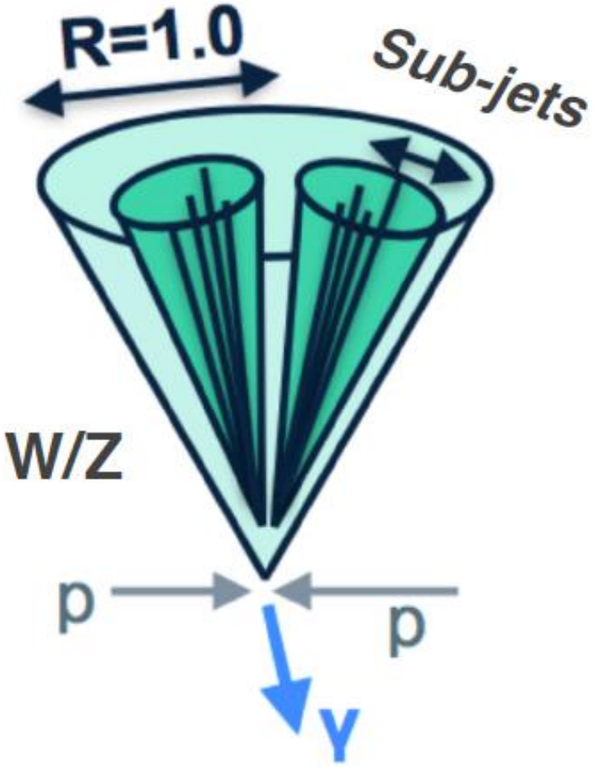
Spin 2 - warped extra-dimension model

H → V+γ

ATLAS-CONF-2021-041

Search BSM heavy Higgs via H γ resonance

p+p->X->V γ(V=W/Z)



Interpretation:

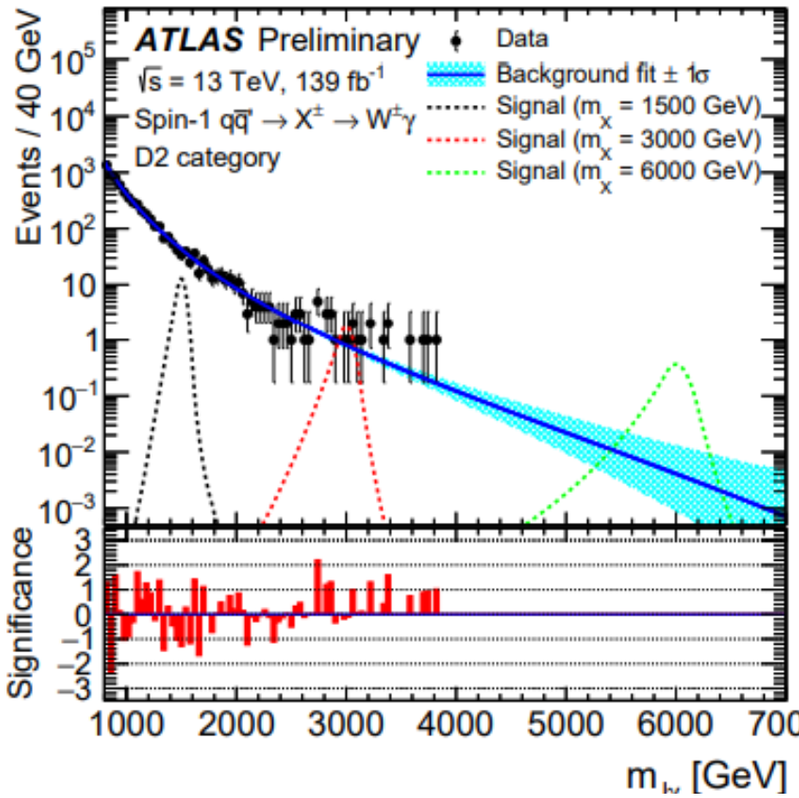
spin-0 $gg \to X^0 \to Z\gamma$
spin-2 $gg \to X^0 \to Z\gamma$
spin-2 $q\bar{q} \to X^0 \to Z\gamma$
spin-1 $q\bar{q}' \to X^{\pm} \to W\gamma$

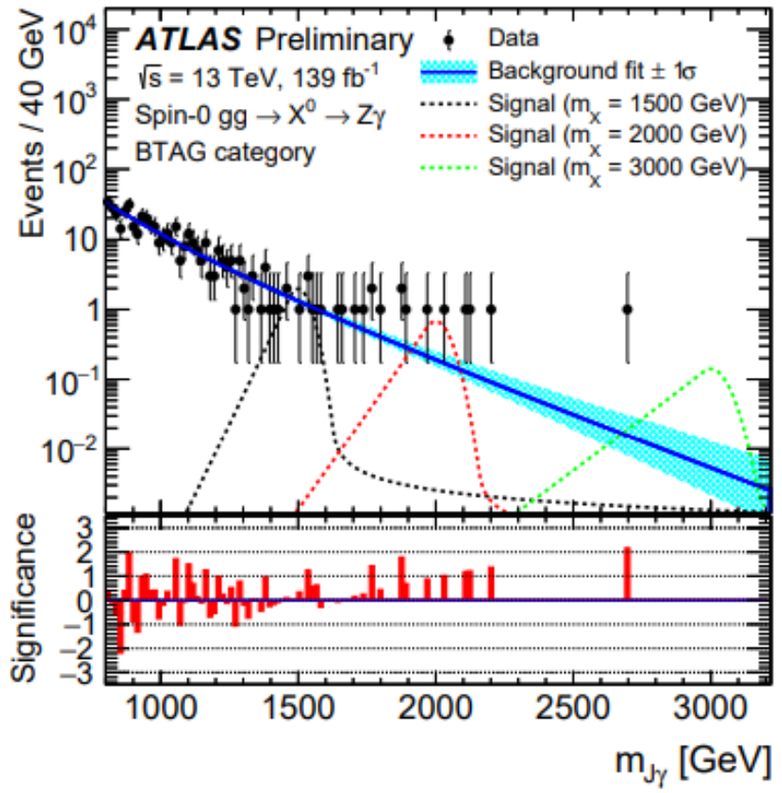
Signal selection:

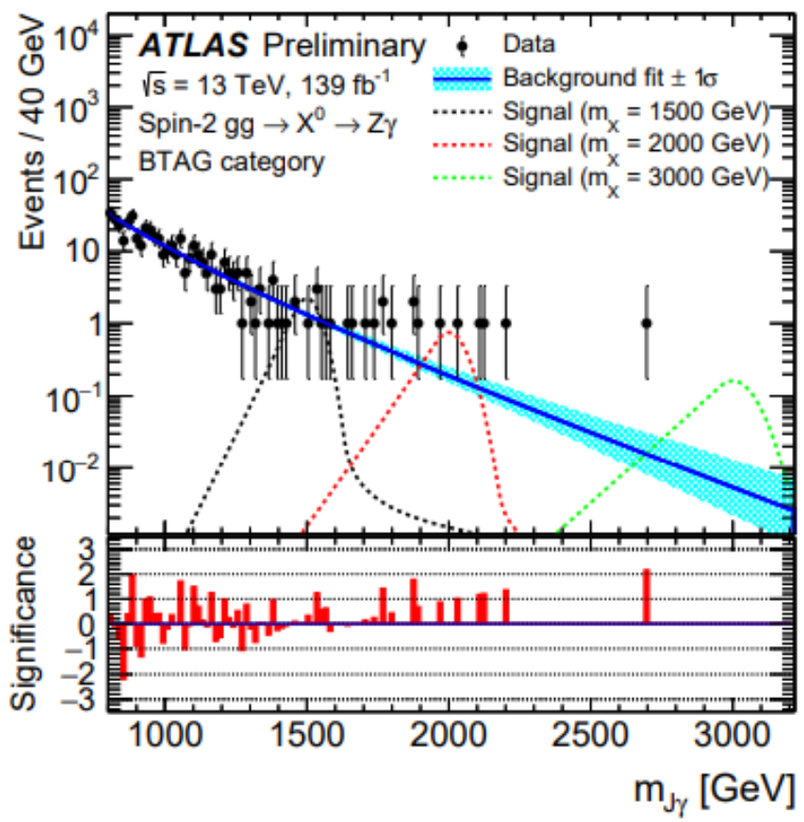
- Photon: P_T>200GeV, |η|<1.37
- jet with large radius : P_T>200GeV, |η|<2.0

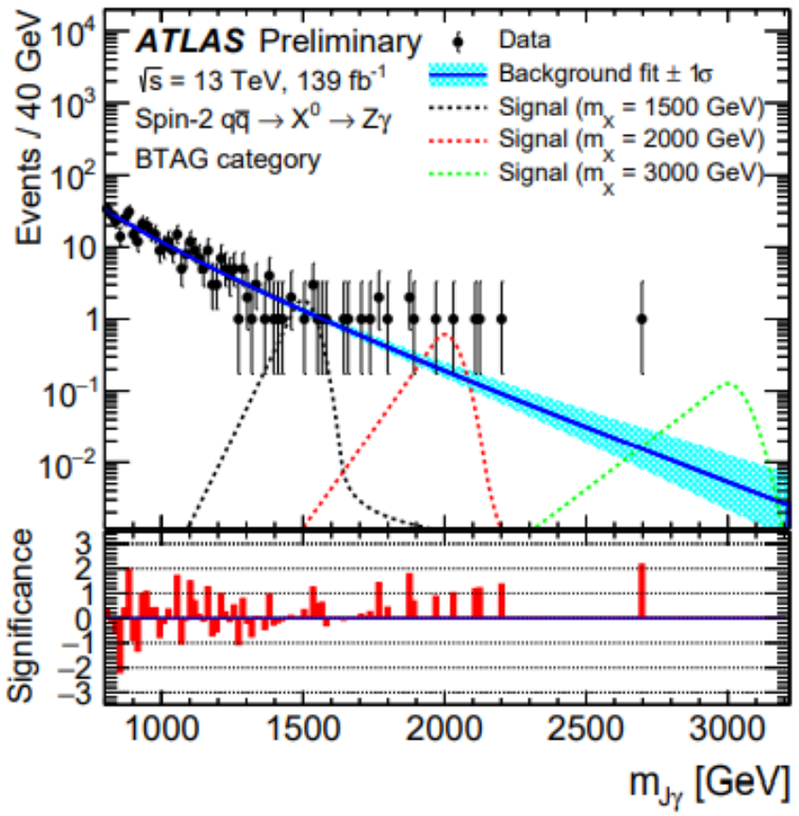
H → V+γ

Background: dominated by γ +jet events， estimated with the analytic function





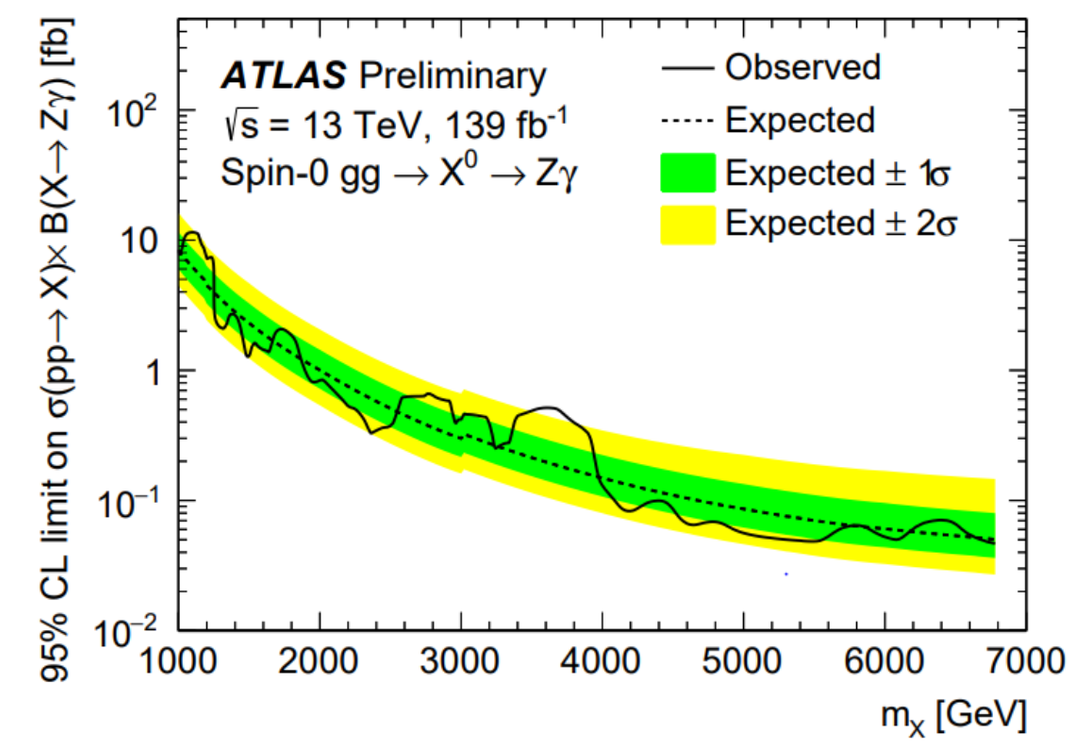


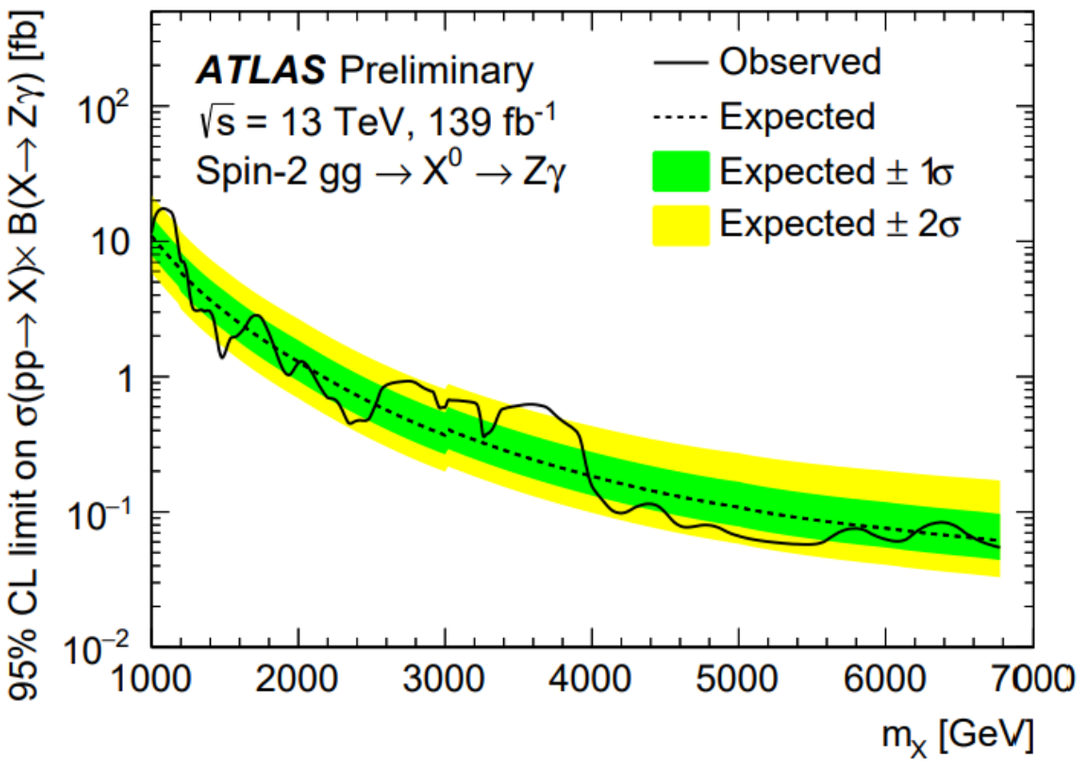


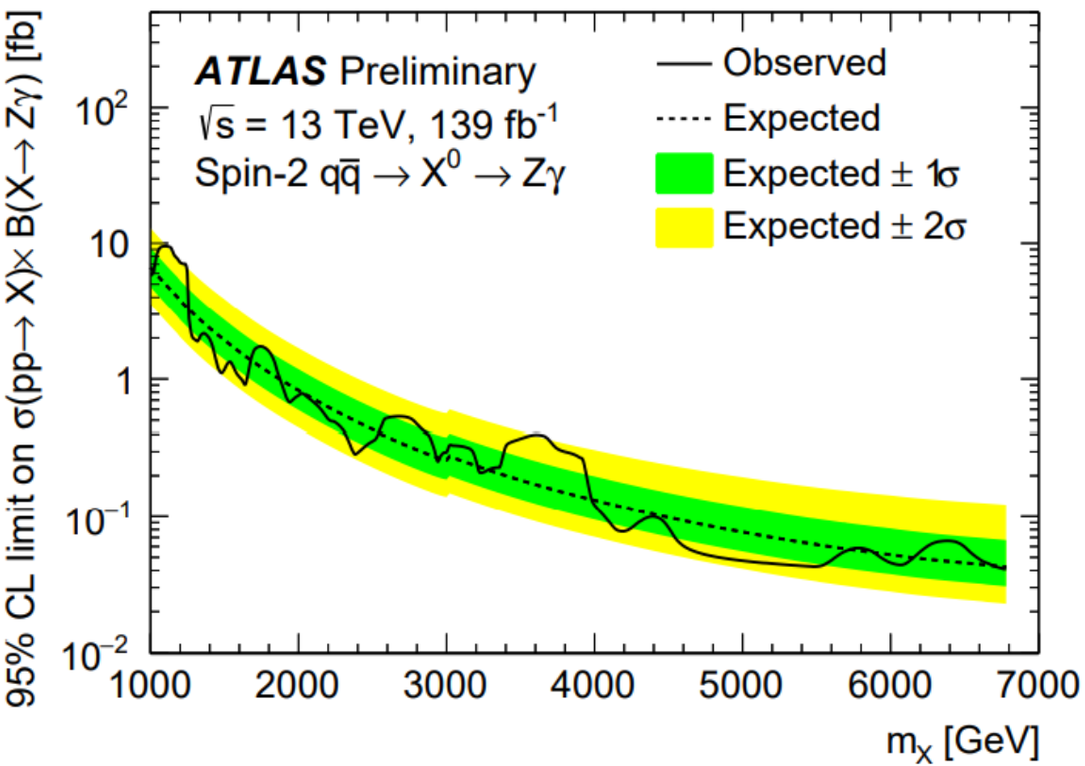
H->V+γ

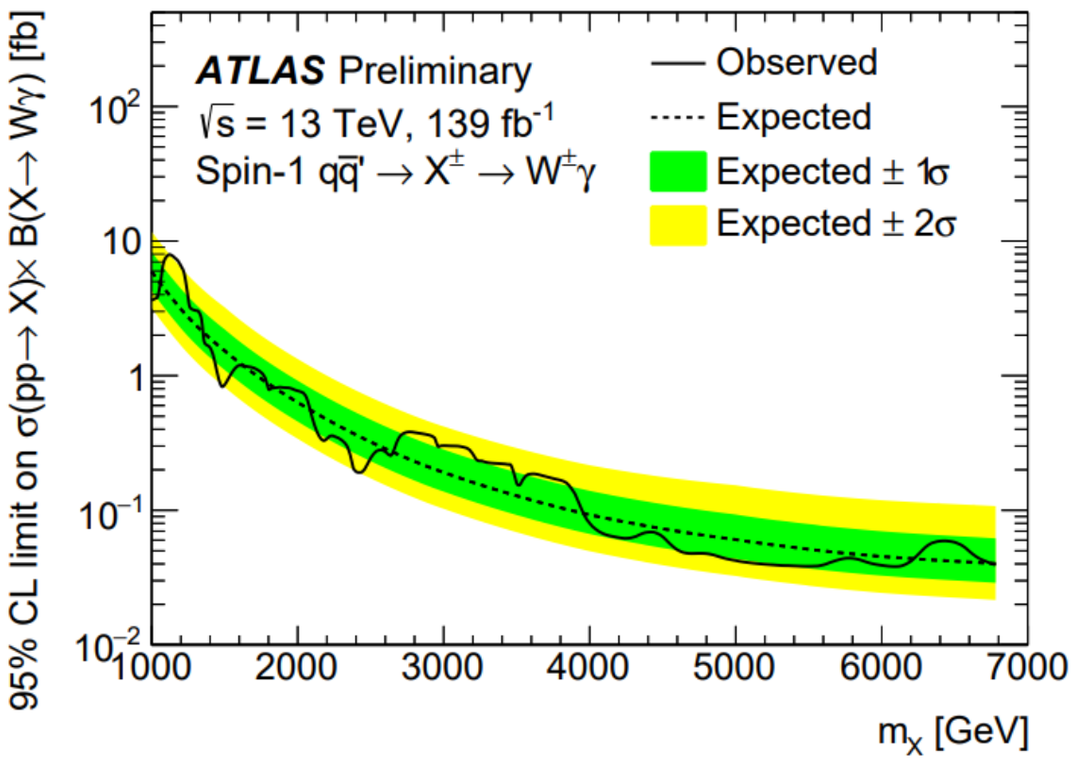
ATLAS-CONF-2021-041

Results: No significant signal found! Set σ×B upper limit at m_x [1TeV,6.8TeV]









Summary

- ATLAS is searching for a new physics in various production and decay modes, under different spin assumptions.
- Unfortunately, no significant deviation from the SM prediction has been observed.
- Many more exciting results to come using the full Run 2 dataset.

Thank you for attention!

Backup

Reference

$pp \to H_{125} \to BSM$

- H→Z(ll)a, Z(ll)hc , Z(ll)J/y, Run 2, √s=13 TeV, L=139 fb-1 , PRL 125, 221802 (2020), submitted Apr., published Nov. 2020
- H→aa→bbμμ, Run 2, √s=13 TeV, L=139 fb-1 , CERN-EP-2021-157, submitted Oct. 2021 to PRD
- H→aa→bbbb, Run 2, √s=13 TeV, L=36 fb-1 , PRD 102, 112006 (2020), submitted May 2020, published Dec. 2020
- Z(ll)H→inv, 2HDM+a, Run 2, √s=13 TeV, L=139 fb-1 , ATLAS-CONF-2021-029, released July 2021 Dark matter combination, Run 2, √s=13 TeV, L=139 fb-1 , ATLAS-CONF-2021-036, released July 2021
- NMSSM, $Z(ll)H(\chi\circledcirc 2\ 0\chi\circledcirc 1\ 0 \to a\ \chi\circledcirc 1\ 0\chi\circledcirc 1\ 0\ )$, Run 2, √s=13 TeV, L=139 fb-1 , CERN-EP-2021-098, submitted Sept. 2021 to JHEP
- H→XX→4l, H→ZX →4l, Run 2, √s=13 TeV, L=139 fb-1 , ATLAS-CONF-2021-034, released August 2021
- H→WW, Run 2, √s=13 TeV, L=36.1 fb-1 , CERN-EP-2021-096, submitted Sept. 2021 to EPJC

Charged Higgs

H±→cb, Run 2, √s=13 TeV, L=139 fb-1 , ATLAS-CONF-2021-037, released Aug. 2021

- H±→tb, Run 2, √s=13 TeV, L=139 fb-1 , JHEP 06, 145 (2021), submitted Feb., published June 202
- H±→W±A→W± (en)μμ, Run 2, √s=13 TeV, L=139 fb-1 , ATLAS-CONF-2021-047, released Sept 2021
- H±± , Run 2, √s=13 TeV, L=139 fb-1 , JHEP 06, 146 (2021), submitted Jan., published June 2021

- **Search for high-mass WγWγ and ZγZγ resonances in the hadronic final state using 139 fb−1−1 of pp collisions at s√s= 13 TeV with the ATLAS Detector**

A search for high-mass charged and neutral bosons decaying to WγWγ and ZγZγ final states is presented in this note. [...] ATLAS-CONF-2021-041. - 2021. - 29 p.

ATLAS Collaboration, Search for Heavy Higgs Bosons Decaying into Two Tau Leptons with the ATLAS Detector Using pp Collisions at √ s = 13 TeV, Phys. Rev. Lett. 125 (2020) 051801, arXiv: 2002.12223 [hep-ex] (cit. on p. 2).

ATLAS Collaboration, Search for heavy neutral Higgs bosons produced in association with -quarks and decaying into 퓛-quarks at √ 푡푡 = 13 TeV with the ATLAS detector, Phys. Rev. D 102 (2020) 032004, arXiv: 1907.02749 [hep-ex] (cit. on p. 2)

A. Djouadi, J. Kalinowski and M. Spira, HDECAY: A Program for Higgs boson decays in the standard model and its supersymmetric extension, Comput. Phys. Commun. 108 (1998) 56, arXiv: hep-ph/9704448 (cit. on pp. 3–6).