ICHEP 2022
BOLOGNA

ICHEP 2022
XLI
International Conference
on High Energy Physics
Bologna (Italy)

Exotic decays of the Higgs and Z boson

Florencia Castillo
Kirchhoff Institute for Physics, University of Heidelberg
on behalf of the ATLAS collaboration

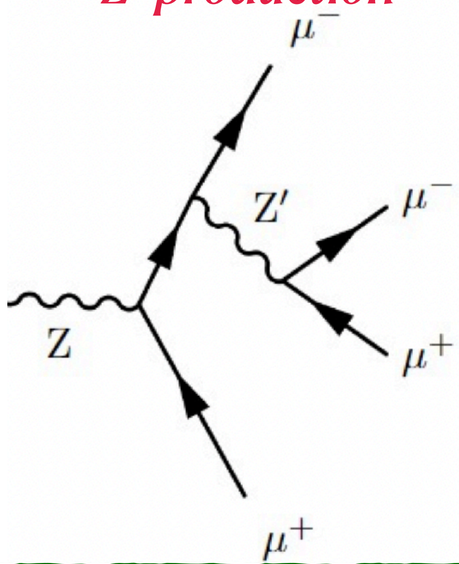
ATLAS
EXPERIMENT

08 July 2022, Bologna (Italy)

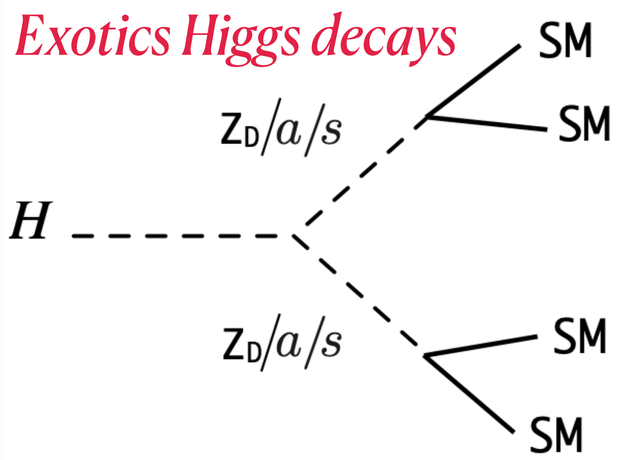
Introduction

- **Beyond Standard Model** (BSM) particles could **couple** to the SM ones only through the **Higgs boson**
  - **Can the** SM 125 GeV Higgs be the bridge between SM and BSM?
  - **Recent constrains** from fits to **SM Higgs couplings**: BR[H—>undetected] < 19% and BR[H—>invisible] < 9% [ATLAS-CONF-2020-027]
  - Today we are going to go though the **latest ATLAS results in Z' searches, exotic decays of the Higgs boson and Higgs and Z bosons LFV measurements** (all full Run-2 dataset results)

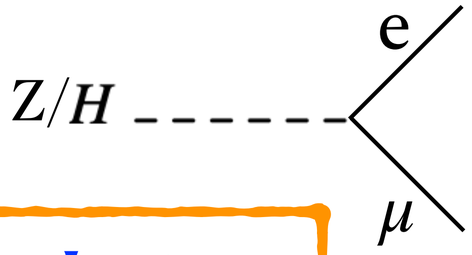
Z' production



Exotics Higgs decays



Lepton flavour violation



Z' production and Higgs to light resonances

- Z' search using 4 μ
- $H \to XX/ZZ \to bb\ell\ell$
- $H \to aa \to bb\mu\mu$
- Summary of 2HDM+S

Lepton flavour violation

- $H \to e\mu$
- $Z \to e\mu$

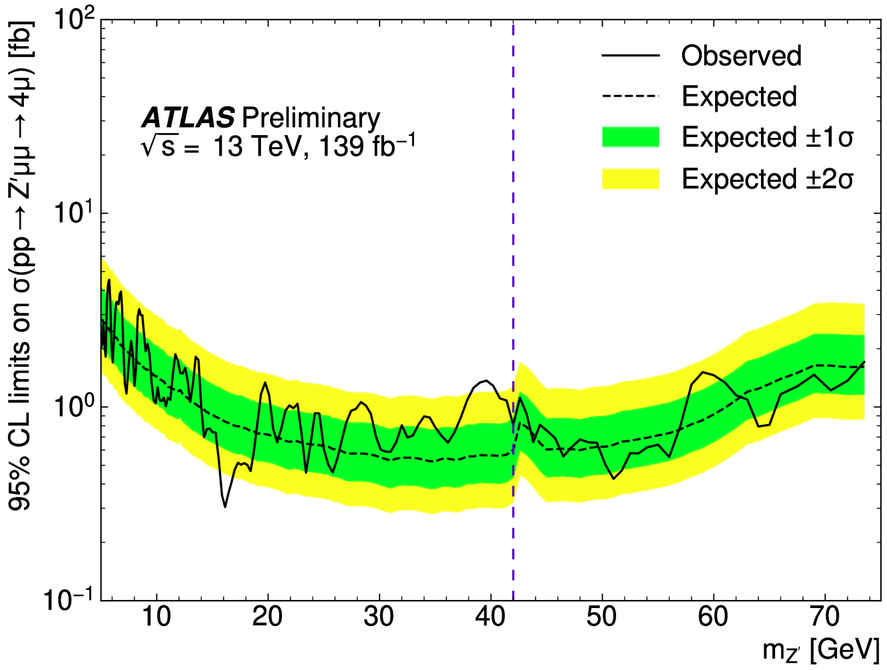
2e2μ event from JHEP 03 (2022) 041

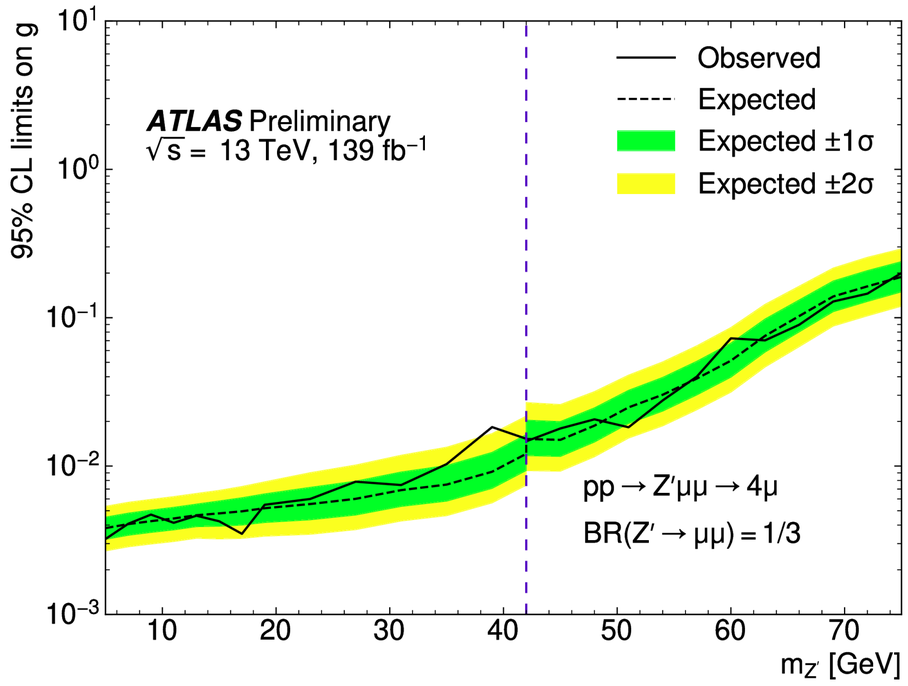
Exotic decays : Z' searches and Higgs to light resonances

HDBS-2018-57 Z' searches using 4μ final state

- Low mass Z' from U(1) based on $L_\mu - L\tau$
  - Z' only **couples to muons and taus**
- A Z' boson is radiated from muons
  - **It is explored the SM Z→$\mu\mu$**
- $m_{4\mu}$ in the range [80 GeV, 180 GeV], excluding Higgs region
- Two **pDNN** applied, one for low mass ($m_{Z'} < 42$ GeV) and another for high mass ($m_{Z'} > 42$ GeV) region

Poster: Search for a new gauge boson Z' in 4μ events with the ATLAS experiment **by Zhe Yang**



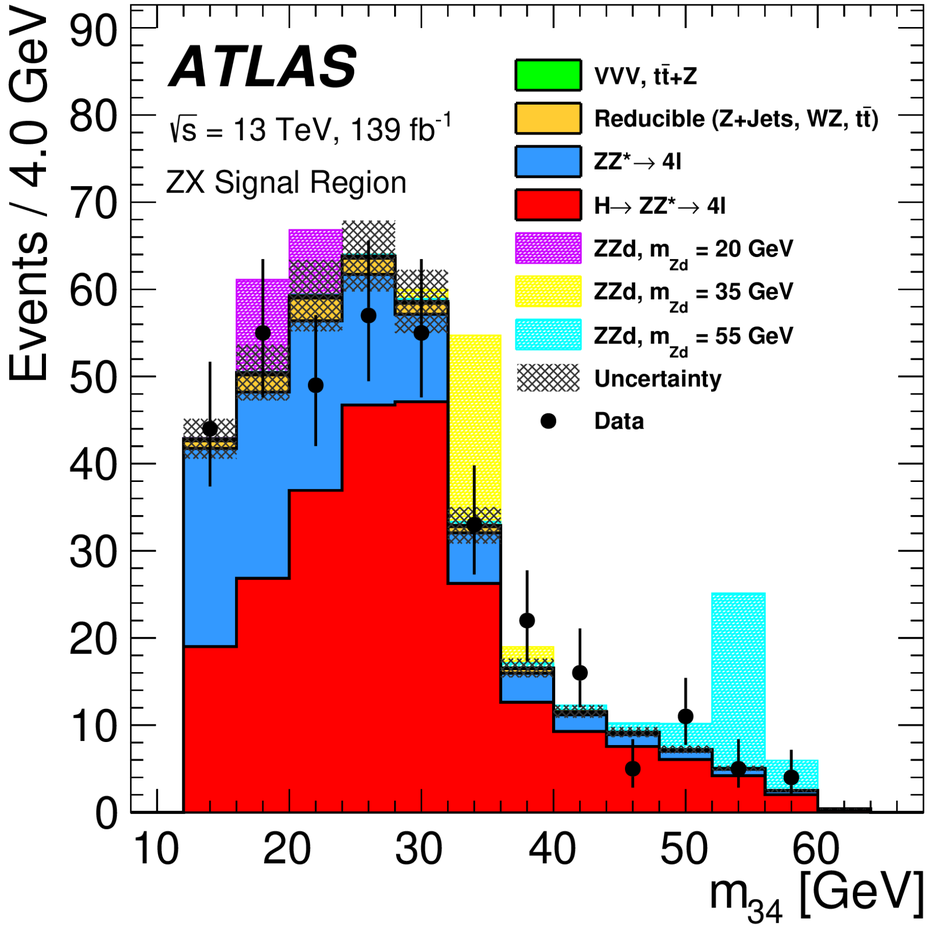


- The **statistic uncertainty is dominant**
- **No significant excess seen** and limits set on several Z' masses [5 GeV, 75 GeV] are calculated
- Coupling limit improved a 30% compared with the **previous result** done by CMS with 77 fb^{-1} (Phys. Lett. B 792 (2019) 345)

$H \to XX/ZX \to 4\ell$

JHEP 03 (2022) 041

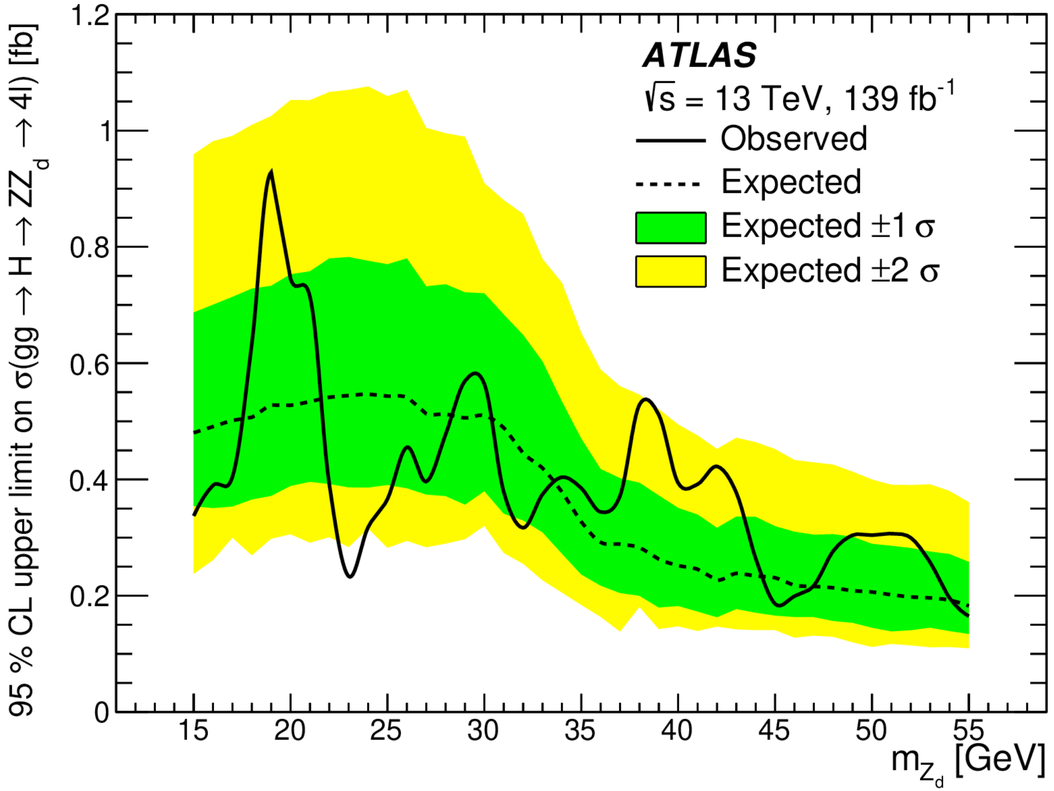
- Search for Higgs bosons **decaying into new spin-0 or spin-1** particles in four-lepton final states (e or μ)
  - **Target separated in 3 channels** (Signal selection)
    - High mass (HM) : $H \to XX \to 4\ell$ 15 GeV $< m_\chi <$ 60 GeV
    - Low mass (LM): $H \to XX \to 4\mu$ 1 GeV $< m_\chi <$ 15 GeV
    - Single Z-boson (ZX): $H \to ZX \to 4\ell$ 15 GeV $< m_\chi <$ 55 GeV
  - $m_{4\ell}$ in the Higgs range (115-130) GeV
- **Main background**
  - Z boson production from Higgs decays
- LM: Require mass compatibility between pairs $m_{34}/m_{12} > 0.85$
- HM and LM:
  - Fit to $< m_{\ell\ell} > = \frac{1}{2}(m_{12} + m_{34})$
- ZX:
  - one pair consistent with m_Z
  - Fit on m_{34}



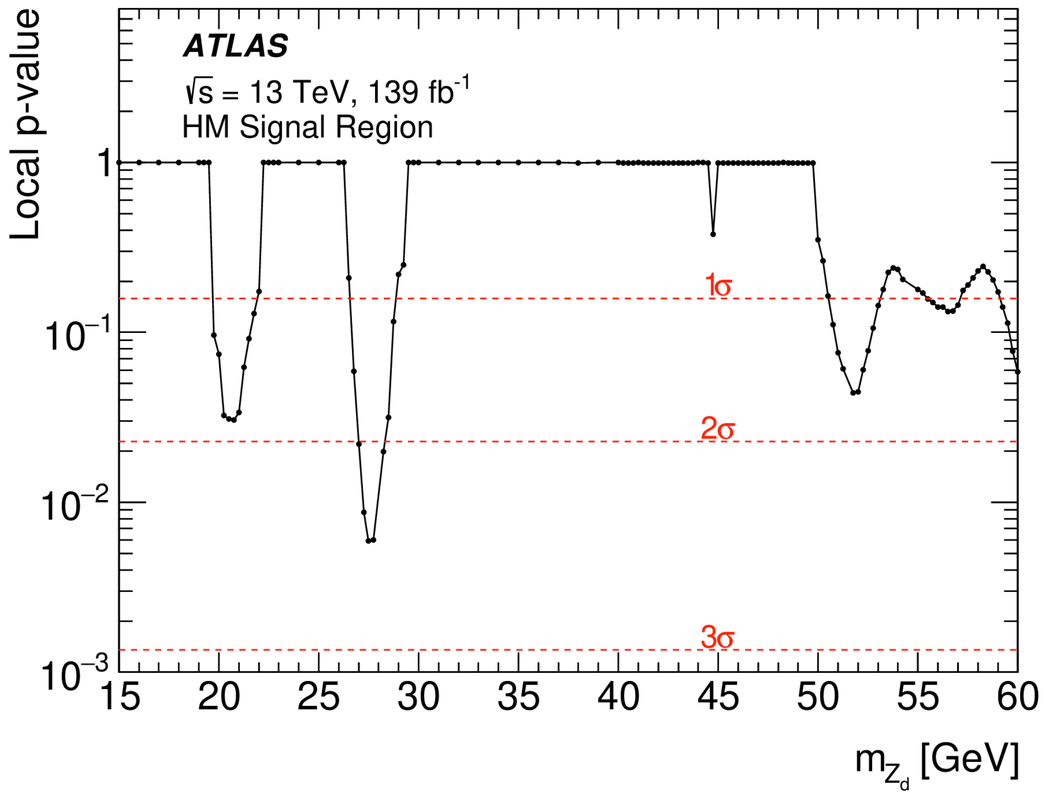
JHEP 03 (2022) 041

$H \rightarrow XX/ZX \rightarrow 4\ell$

- **No significant excess found in all channels**
- Limits set on dark boson (Z_d) or on a pseudo scalar (a)
- Main systematics from modelling, electron identification and muon isolation



- No events observed in low mass signal region.
- Small excess seen around 28 GeV (local significance 2.5σ) in high-mass channel.



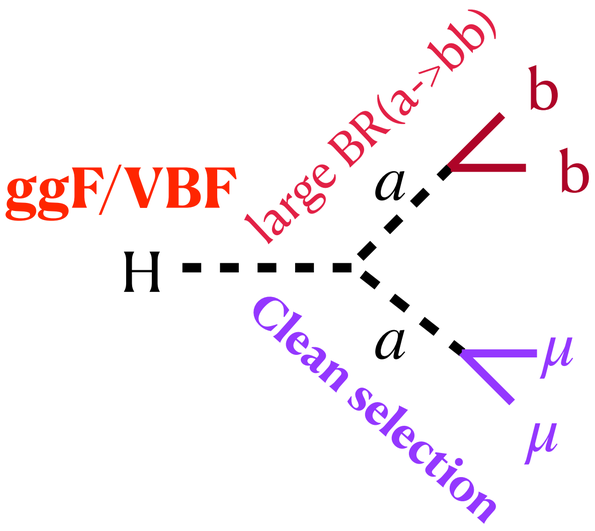
The limits **are improved** on those from the previous ATLAS (JHEP 06 (2018) 166) search by factors between **2 and 4** due to a **larger data sample**, improved lepton reconstruction and identification, and **a better optimised event selection**.

H → aa → bbμμ

Phys. Rev. D 90, 075004 (2014)

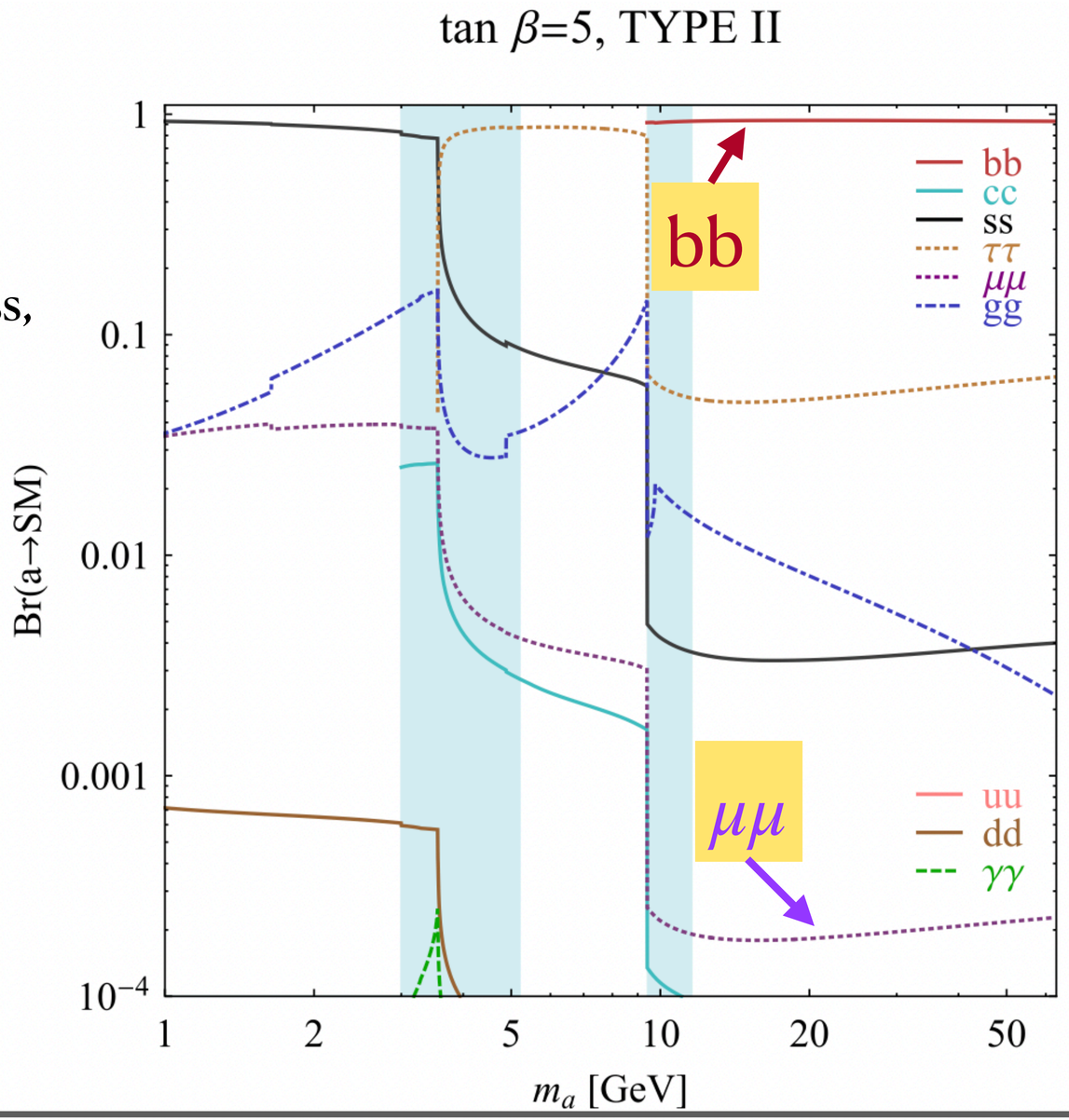
H→aa searches inspired by 2HDM+S —> Mediator is a singlet (pseudo)scalar

- Channels to search and dominant **decay modes change** as a function of mass.
- **New decays to 4-body final** states can come from different (ss, aa, or Za) interactions.



- Taget dominant **ggF** production
- *a*-boson mass hypotheses in 16 GeV < m_a < 62 GeV

tan(β) = ratio of vacuum expectation values of the 2 Higgs-doublets



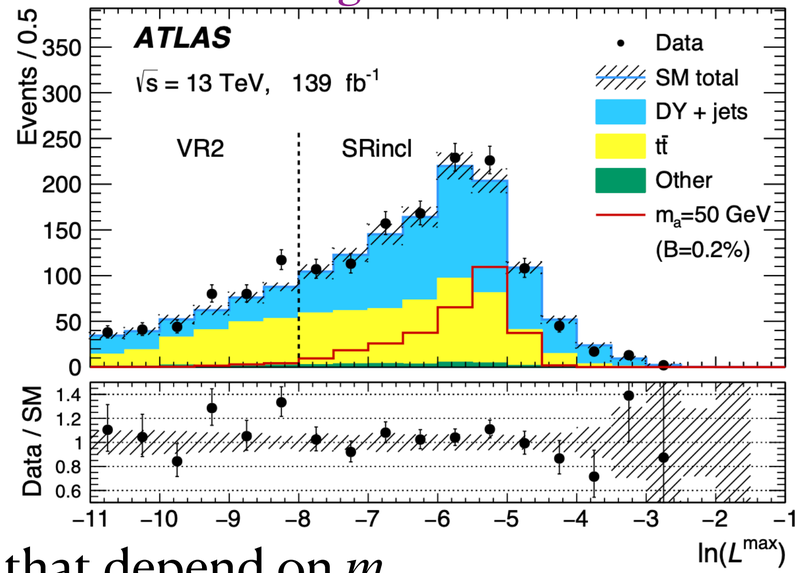
Phys. Rev. D 105 (2022) 012006

H → aa → bbμμ

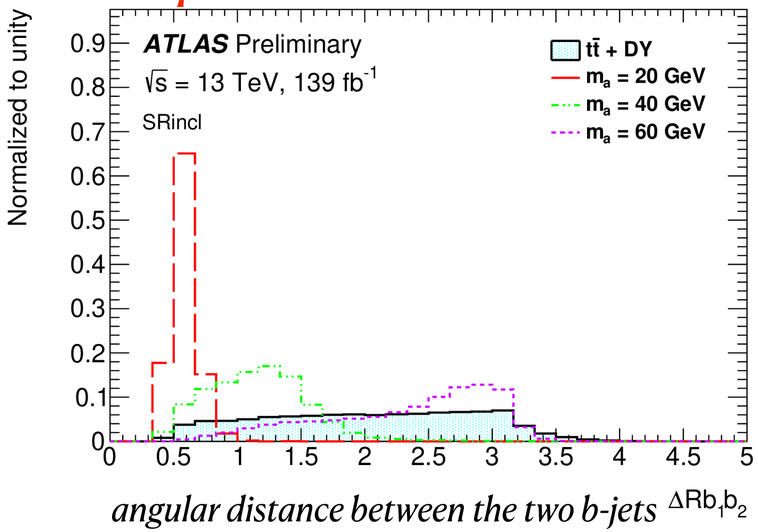
Phys. Rev. D 105 (2022) 012006

- Kinematic likelihood fit used to **improve** $m_{b\bar{b}\mu\mu}$ resolution constraining $m_{b\bar{b}} \simeq m_{\mu\mu}$ in H → aa decays:
  - $m_{\mu\mu}$ has 10 times a better resolution compared with $m_{b\bar{b}}$
- $110 < m_{b\bar{b}\mu\mu} < 140$ GeV
- $E^{T}_{miss} < 60$ GeV
- **Train BDTs** separate signal from $t\bar{t}$ and DY
  - Optimised in a **multiple $m_{\mu\mu}$ windows** to exploit kinematic differences that depend on m_a

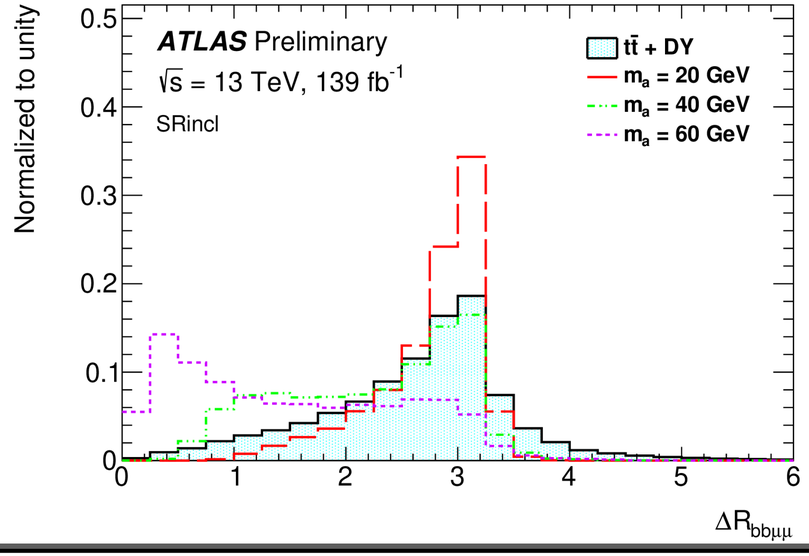
Signal selection



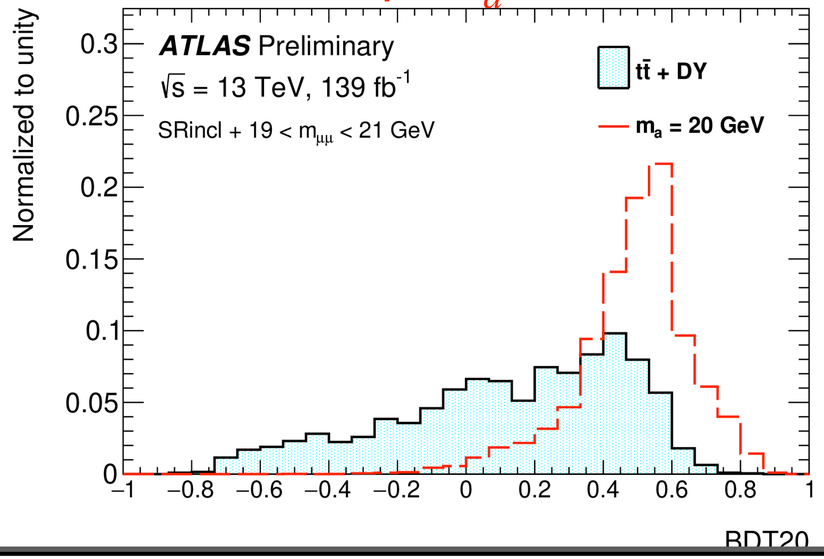
Some input variables



the angular distance between the bb and the μμ systems



BDT trained for m_a=20GeV



H → aa → bbμμ

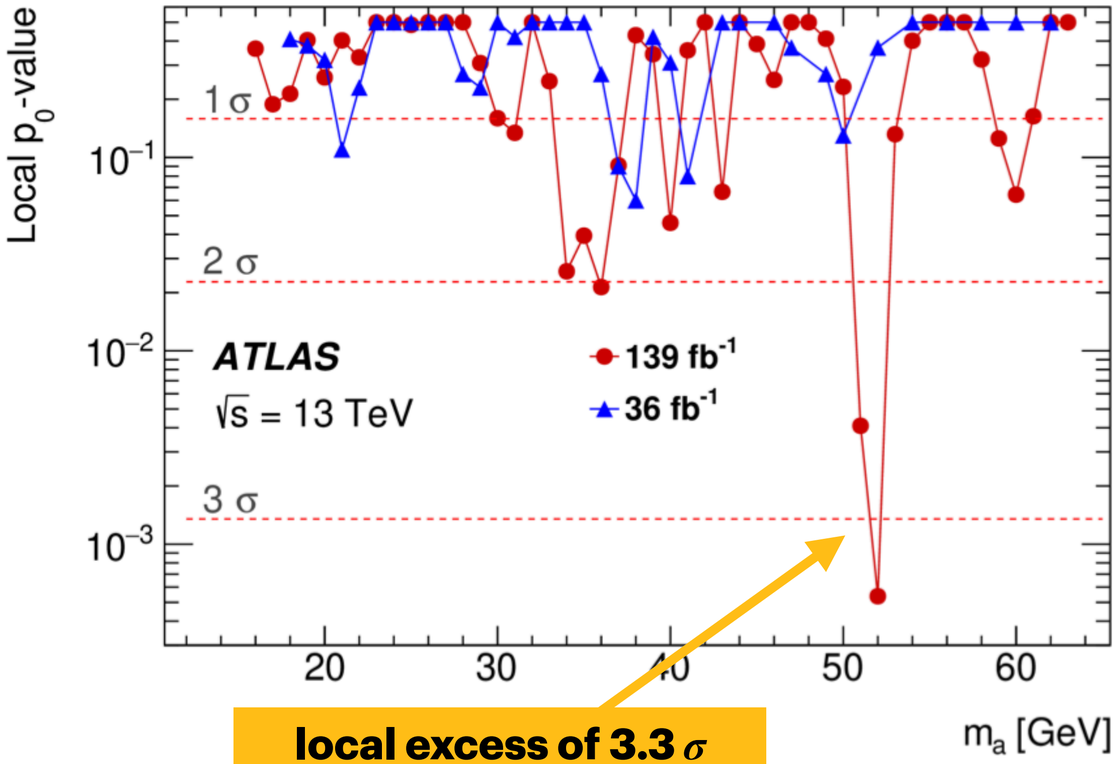
Phys. Rev. D 105 (2022) 012006

- **Statistical uncertainty dominant in this analysis.**
  - Most impacting systematics arise from jet energy calibration and resolution, and b-jet efficiencies

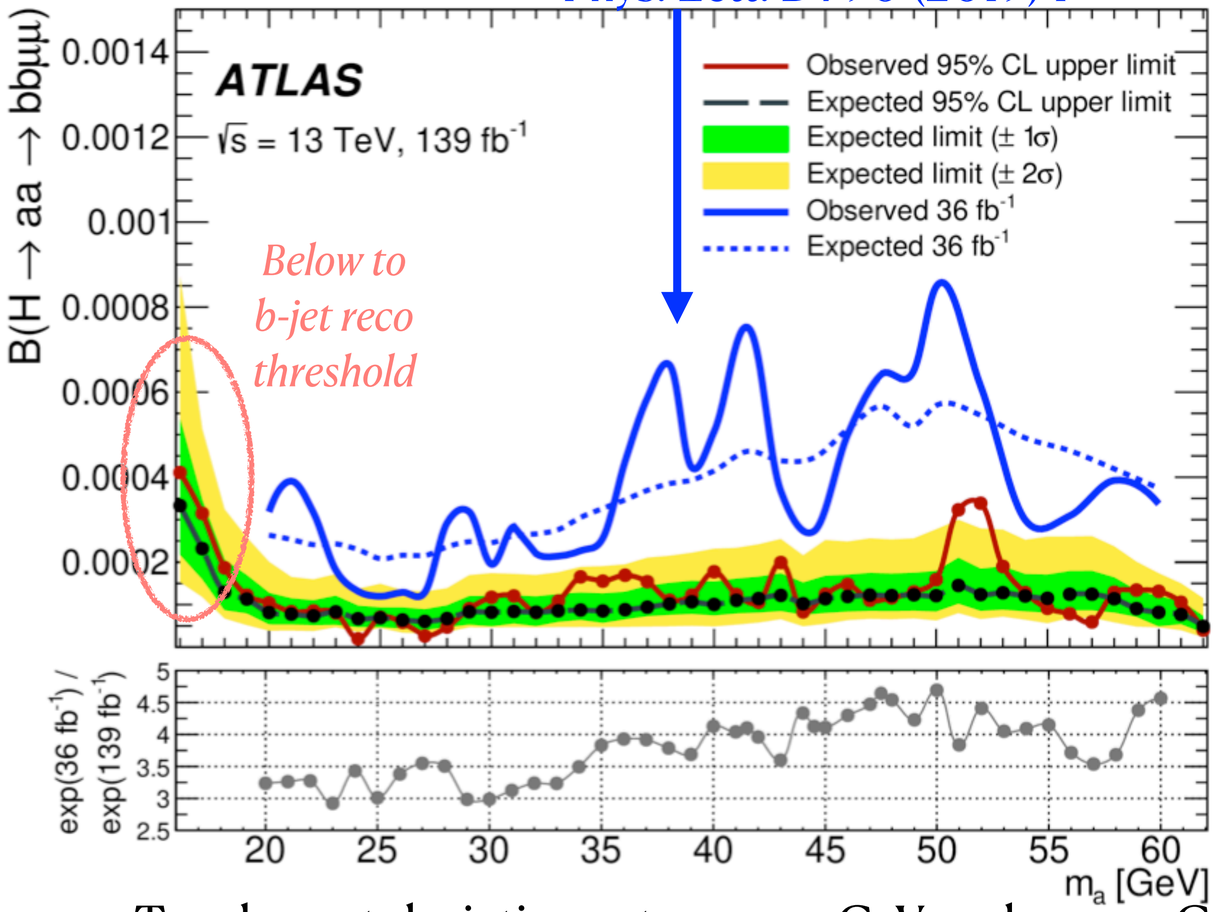
Previous result with 36 fb^{-1} significantly improved by using BDT (factor ~2) and additional data (factor ~2)

- Phys. Lett. B 790 (2019) 1

Model independent fit. Global excess of 1.7σ



local excess of 3.3 σ



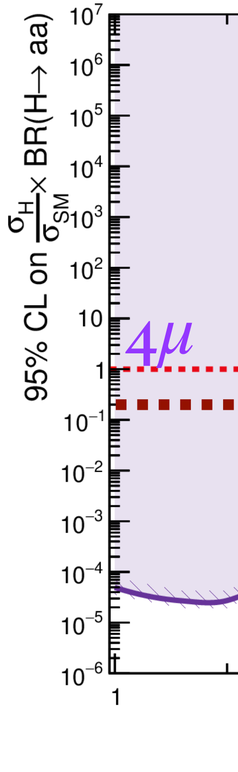
Two largest deviations at: m_a = 35 GeV and m_a = 52GeV

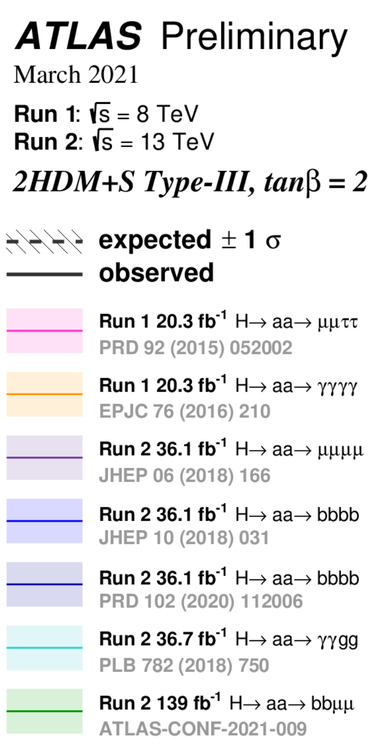
Summary of 2HDM+S

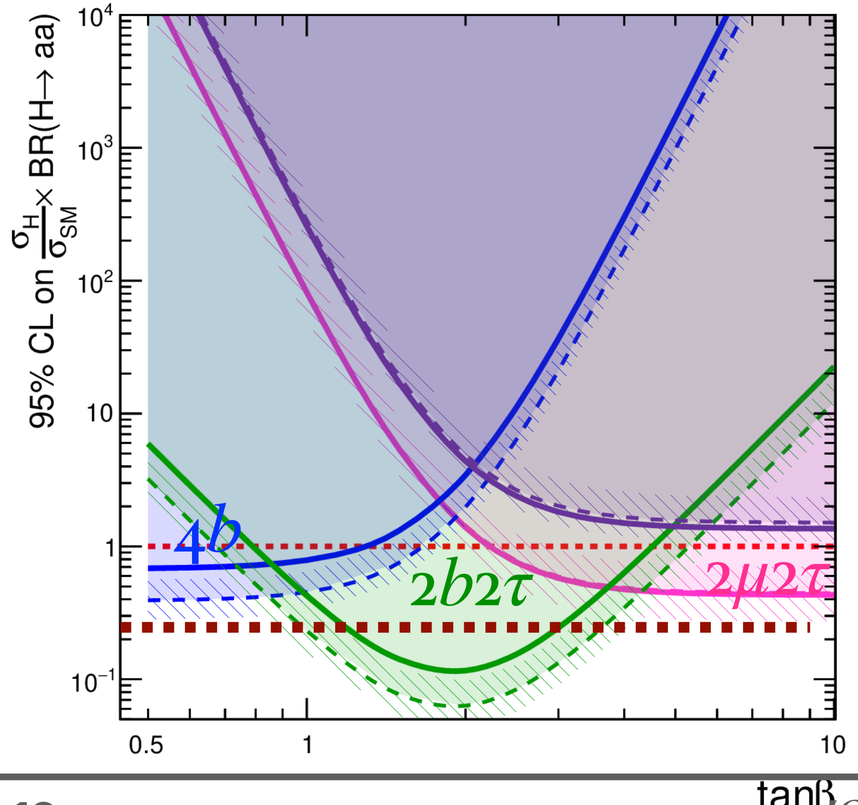
PUB-HDBS-2021-01

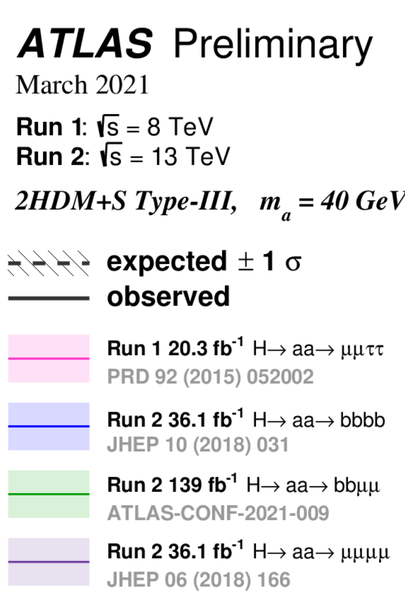
- **Model independent limits** on BR(H→aa→xx yy) translated on limits of **BR(H→aa)** under the assumption of **each particular 2HDM+S scenario** which gives a BR(aa→xx yy)
  - BR(aa→xx yy) are taken from JHEP 03 (2018) 178
- Exclusion limits **differs by channels/analysis** at different tan(β) and m_a values
  - complementary phases

BR[H—>undetected] < 19%









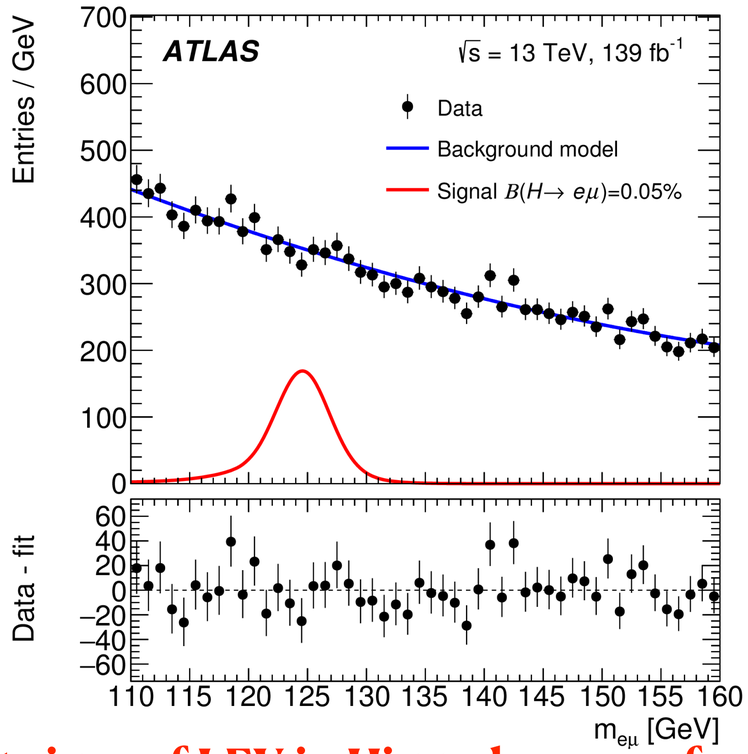
$z \to 2\mu$, event display from twiki page

Higgs/Z → Lepton flavour violation

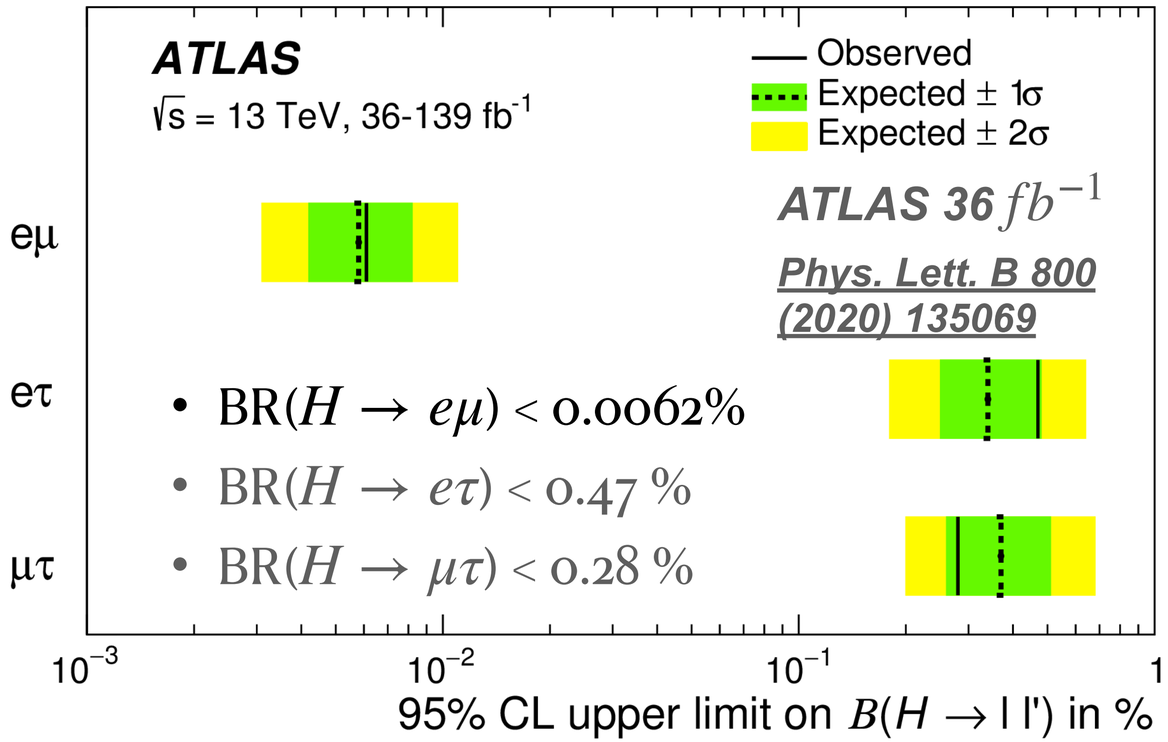
Search for LFV H → eμ

Phys. Lett. B 801 (2020) 135148

- Lepton flavour violating decays of the Higgs boson **are forbidden** in the SM
- Focusing on recent ATLAS result with 139 fb^{-1} (full Run2)
  - Statistically limited



- **Signal**
  - Signal separated from background by requiring $m_{\ell\ell}$ close to 125 GeV (m_H)
  - Eight categories for the eμ channel with different S/B
- **Backgrounds** with top quarks suppressed by bjet-veto and low E^T_{miss} requirements



- BR($H \to e\mu$) < 0.0062%
- BR($H \to e\tau$) < 0.47 %
- BR($H \to \mu\tau$) < 0.28 %

- **No significant signs of LFV in Higgs decays so far...**

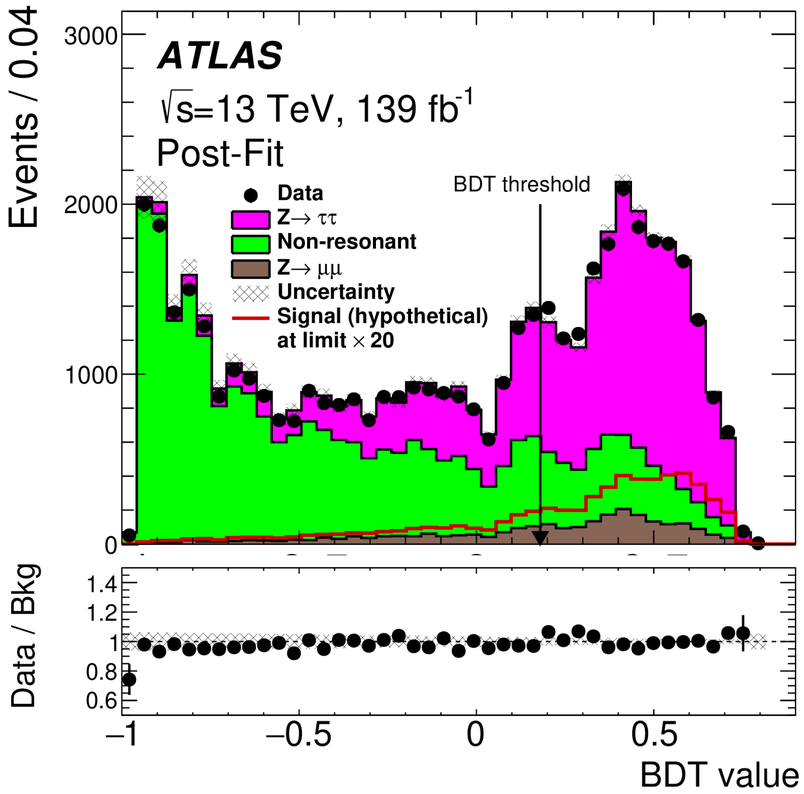
Search for LFV Z→ eμ

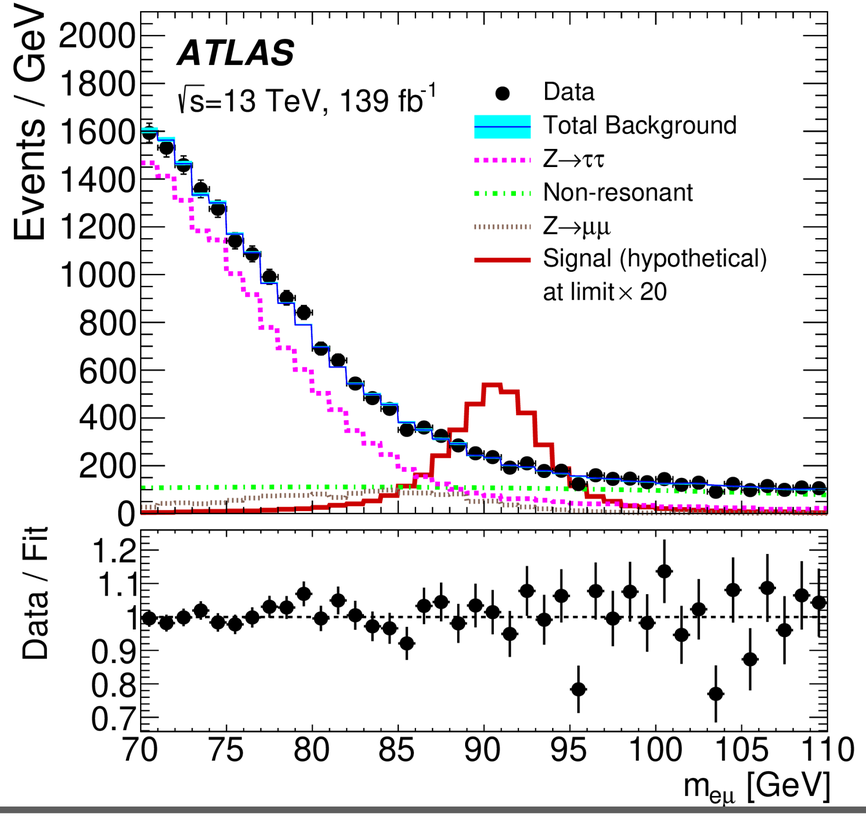
EXOT-2018-35

- LFV only observed in neutrino oscillations, **negligible** for charged leptons in SM
- ~8 $\times 10^9$ Z's produced in ATLAS in Run-2
- $Z \to e\mu$ search based on $m_{\ell\ell}$ w/ reduced uncert. normalising to $Z \to ee, \mu\mu$ observed yields

- **Signal selection**
  - Opposite-sign charged eμ pair
  - 70 GeV < $m_{e\mu}$ < 110 GeV
  - Low E_T^{miss}
  - BDT based (3 vars used)

- **The dominant systematic** uncertainties are due to the statistical uncertainty of the simulated $Z \to \tau\tau/\mu\mu$ backgrounds





Upper Limits @95%CL	ATLAS Full Run 2	ATLAS 2012 data ($20\,fb^{-1}$)	LEP OPAL
BR ($Z \to e\mu$) ($\times 10^{-6}$)	0.26	0.75	1.7

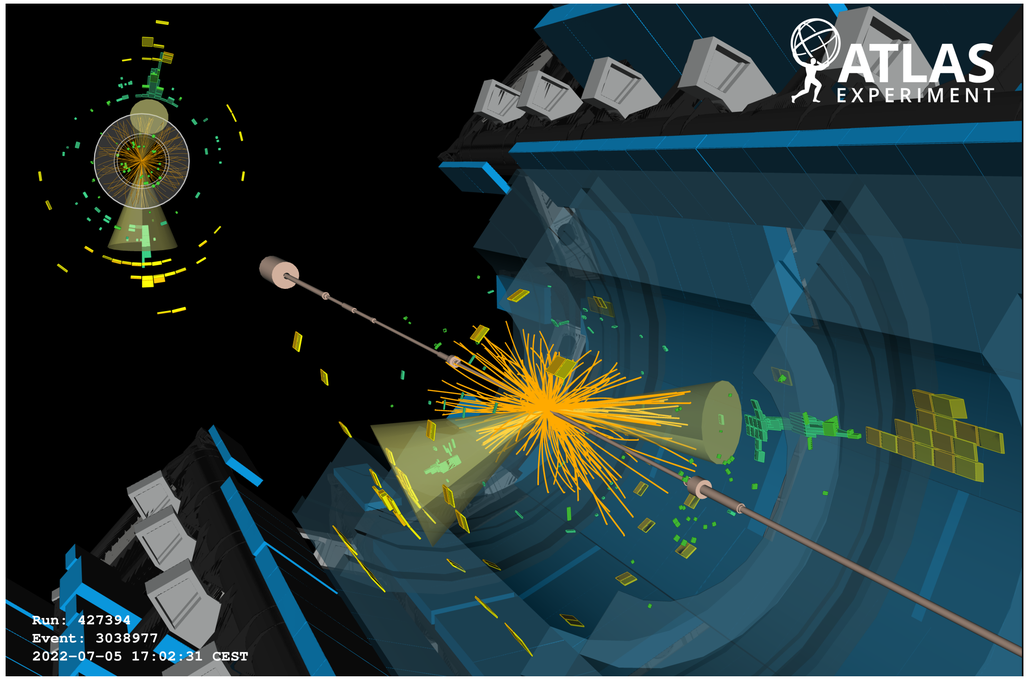
Surpasses LEP limits !

Outlook

- **Latest ATLAS Run 2** published results presented for:
  - Z' searches using 4μ in the final state
    - Coupling limit **improved** a 30% compared with the previous result done by CMS
  - $H \to aa \to bb\mu\mu$ and $H \to XX/ZZ \to bb\ell\ell$
    - **Improve previous result** ATLAS due to better event selection and luminosity increased
  - Summary of $H \to aa$. **Complementary phases!**

- Search for **lepton flavour violation**
  - H→eμ **statistically limited**, waiting for larger dataset (Run-3 and HL-LHC)
  - Z→eμ BR measurement **suppresses by a factor of 6.5 LEP results and a factor of 3 previous ATLAS result!**

First Run3 collisions 5 of July 2022



https://atlas.cern/Updates/Press-Statement/Run3-first-collisions

- **No significant deviation** is observed from the SM background predictions
- New exciting results using the full **Run-2 dataset are going** to be released and future **Run-3 (started in July!) datasets** will give us many new exciting results and the potential for new physics discovery!