# Searches for exotic decays of the Higgs boson with the ATLAS detector


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on behalf of the **ATLAS** Collaboration


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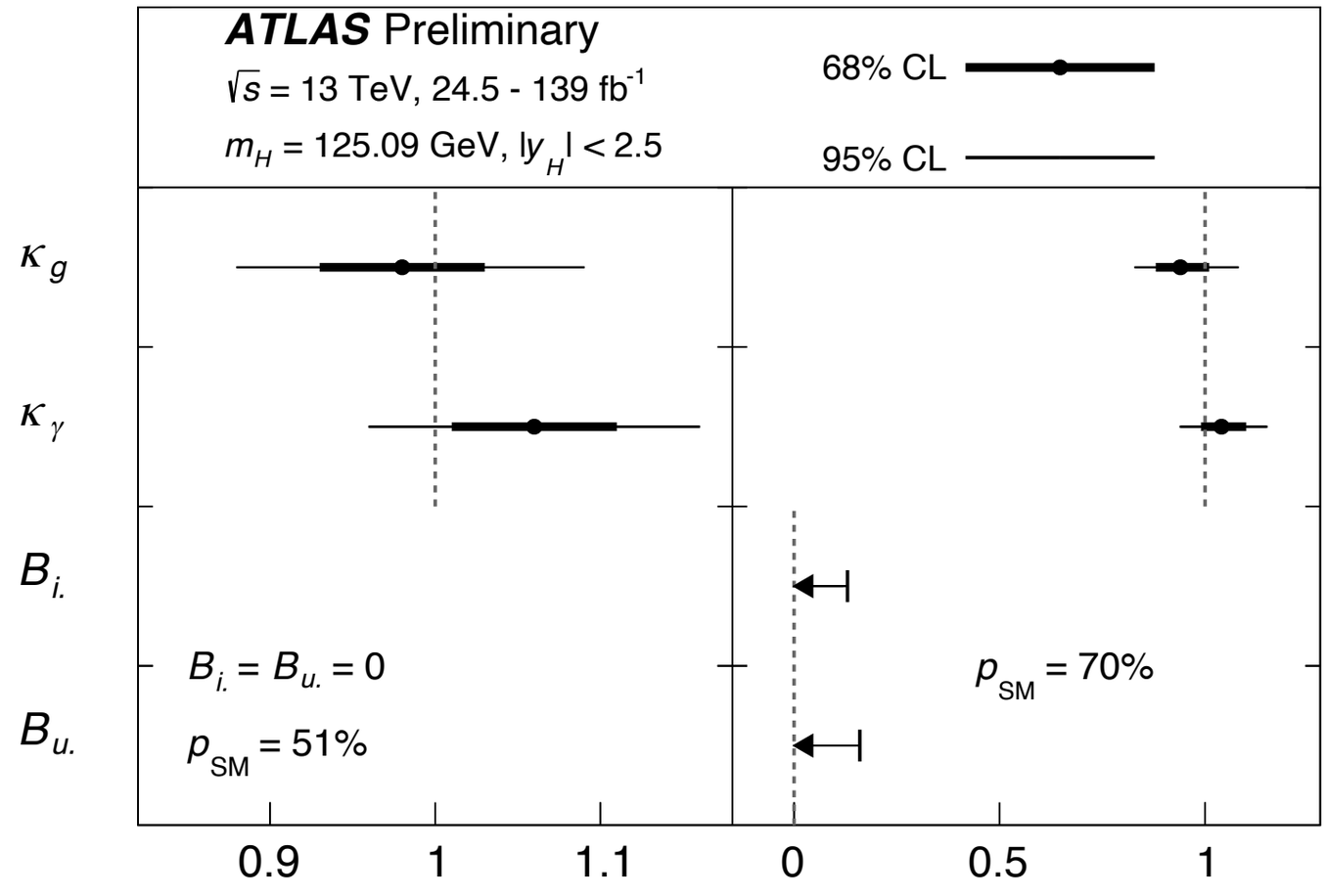
# Motivation



The Higgs Boson exists … does it behave like we expect?

Due to the tiny width of SM Higgs, tiny couplings to BSM can result in observable branching ratios. Current "model independent" limits allow for BRs as large as O(10%).




***Today's talk: exotic, prompt decays of the 125 GeV boson***

ATL-PHYS-PUB-2021-008

# Landscape of Searches

## h → X Y

| | | X | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $e^{\pm}$ | $\mu^{\pm}$ | $\tau^{\pm}$ | $Z$ | $W$ | $\gamma$ | $q/g$ | $c$ | $b$ | Inv. | $\phi,\rho$ | $J/\psi,\Upsilon$ | $\ell^{\pm}\ell^{\mp}$ | $\tau^{\pm}\tau^{\mp}$ | $q\bar{q}/gg$ | $\gamma\gamma$ | $b\bar{b}$ | Other |
| Y | $e^{\mp}$ | [12] | [12] | [13] | | | | | | | | | | | | | | | |
| | $\mu^{\mp}$ | | [14] | [13] | | | | | | | | | | | | | | | |
| | $\tau^{\mp}$ | | | SM | | | | | | | | | | | | | | | |
| | $Z/Z^*$ | | | | SM | | [15] | | | | – | – | [3] | [7] | – | [3] | – | – | – |
| | $W/W^*$ | | | | | SM | | | | | | | | | | | | | – |
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| | $q/g$ | | | | | | | – | – | – | | | | | | | | | |
| | $c$ | | | | | | | | [20] | | | | | | | | | | |
| | $b$ | | | | | | | | | SM | | | | | | | | | |
| | Inv. | | | | | | | | | | [21] | | | – | – | – | – | – | – |
| | $\phi,\rho$ | | | | | | | | | | | – | – | | | | | | |
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| | $q\bar{q}/gg$ | | | | | | | | | | | | | | | – | [6] | – | – |
| | $\gamma\gamma$ | | | | | | | | | | | | | | | | [9] | – | – |
| | $b\bar{b}$ | | | | | | | | | | | | | | | | | [4, 5] | – |
| | Other | | | | | | | | | | | | | | | | | | Many LLP |

**Uncovered**

**Forbidden/duplicate**

**Run 1**

**Partial Run 2**

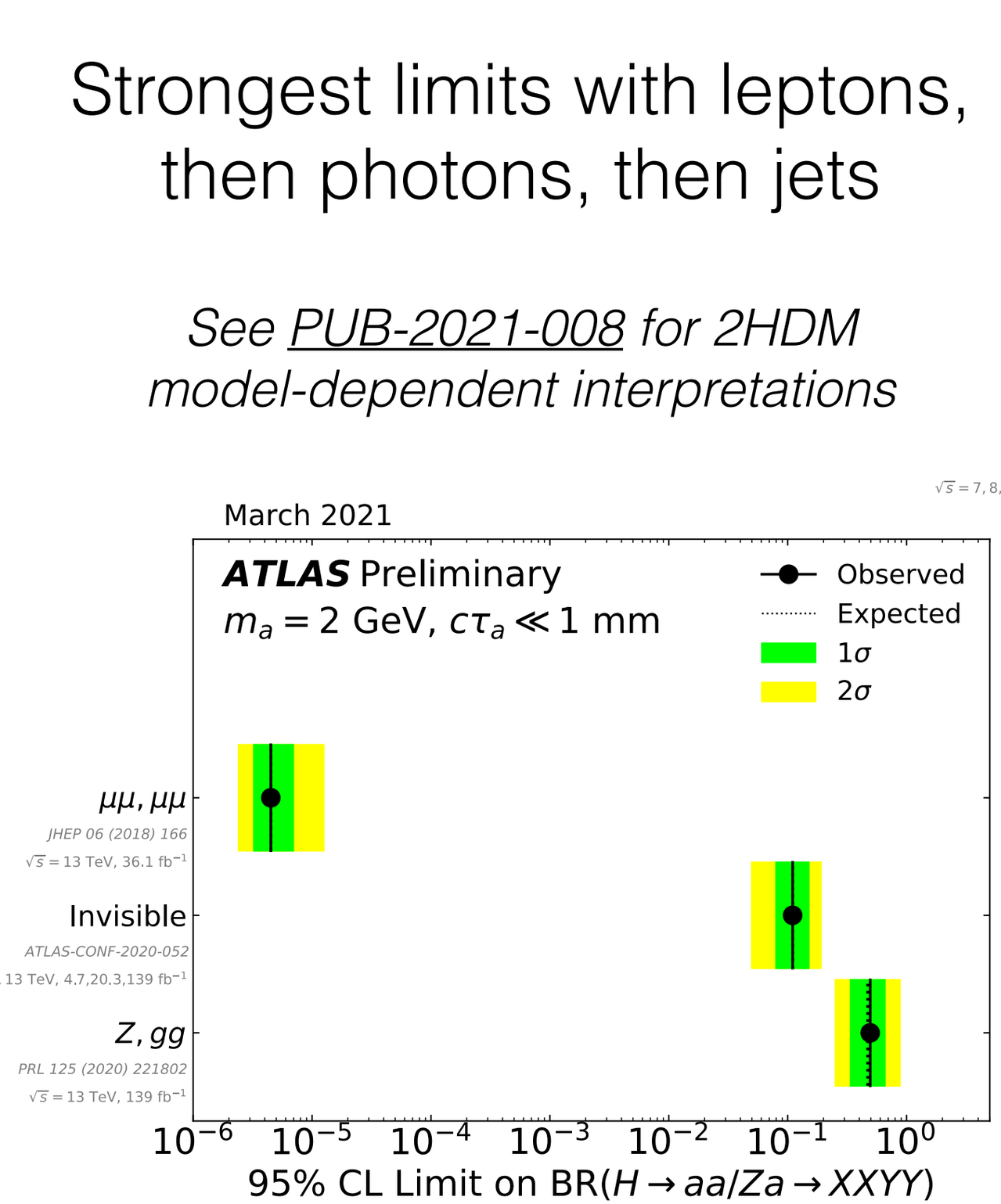
**Full Run 2**

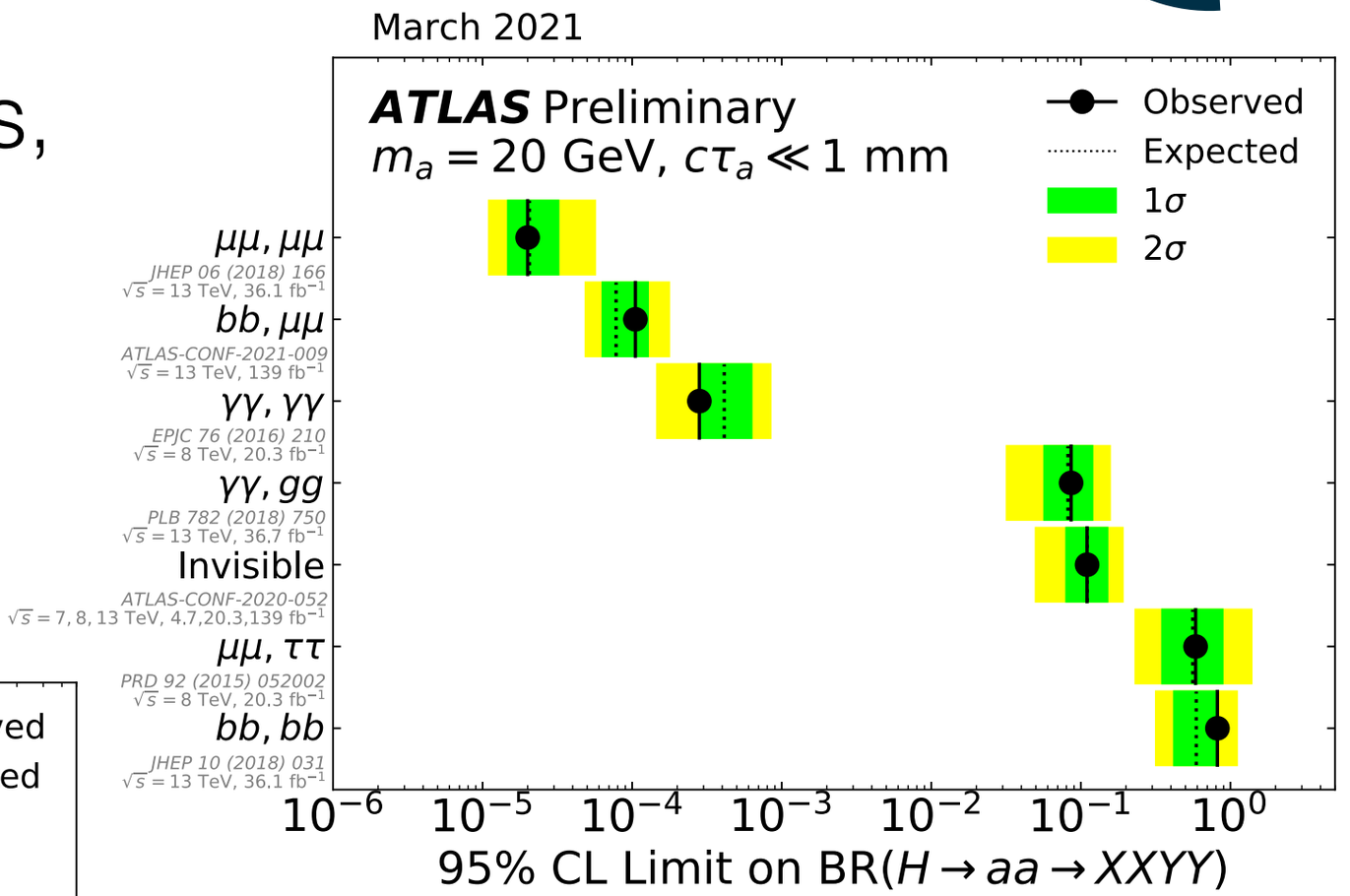
See also https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HDBSPublicResults

# Landscape of Searches

Strongest limits with leptons, then photons, then jets

*See PUB-2021-008 for 2HDM model-dependent interpretations*




Today's highlights:

bb,μμ
bb, invisible
four leptons
lepton flavor violation

ATL-PHYS-PUB-2021-008

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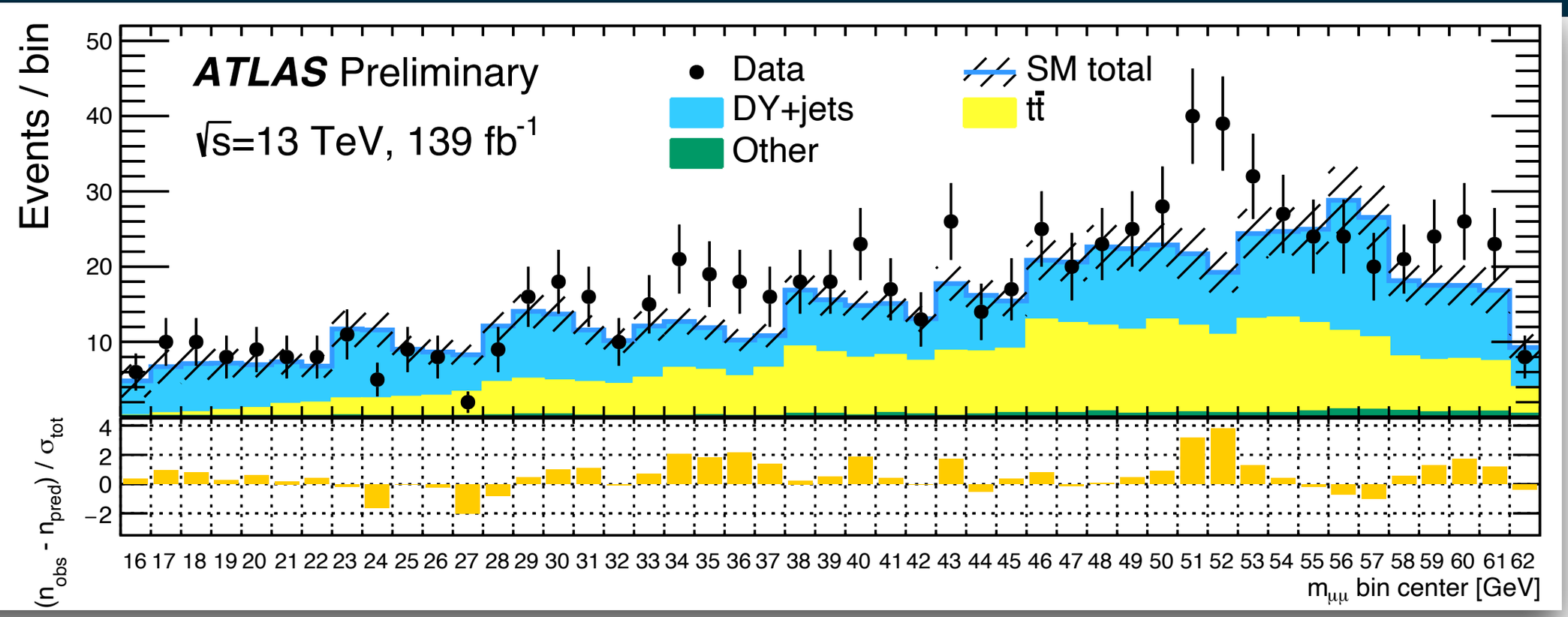
# bb,μμ




## Innovations:

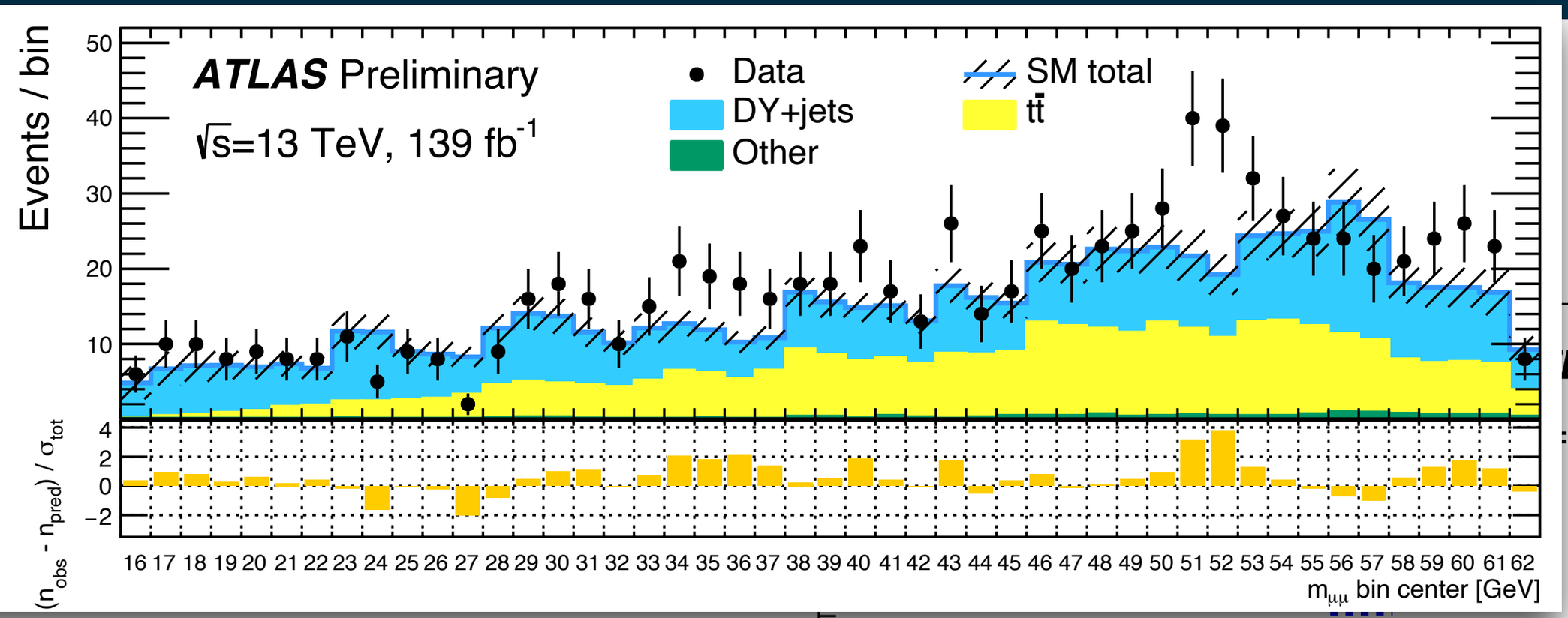
- mass matching
  ($m_{bb} = m_{\mu\mu}$)
- Signal sensitivity:
  - BDT per 8 GeV*
- Background specificity:
  - BDT reweighting

*N.B. assumes H → aa

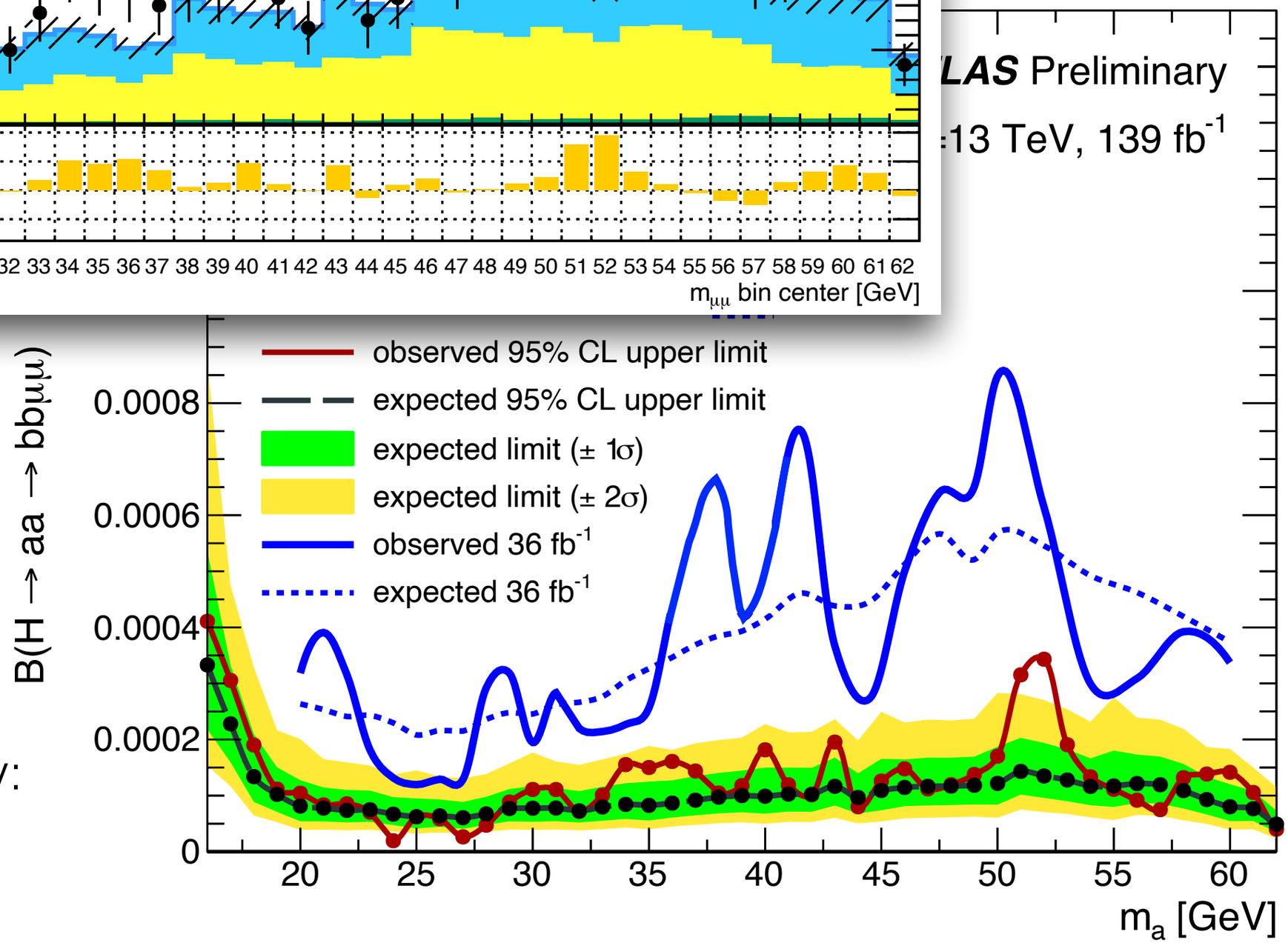
ATLAS-CONF-2021-009



# bb,μμ




*N.B. bins are overlapping (so can't just combine counts)*

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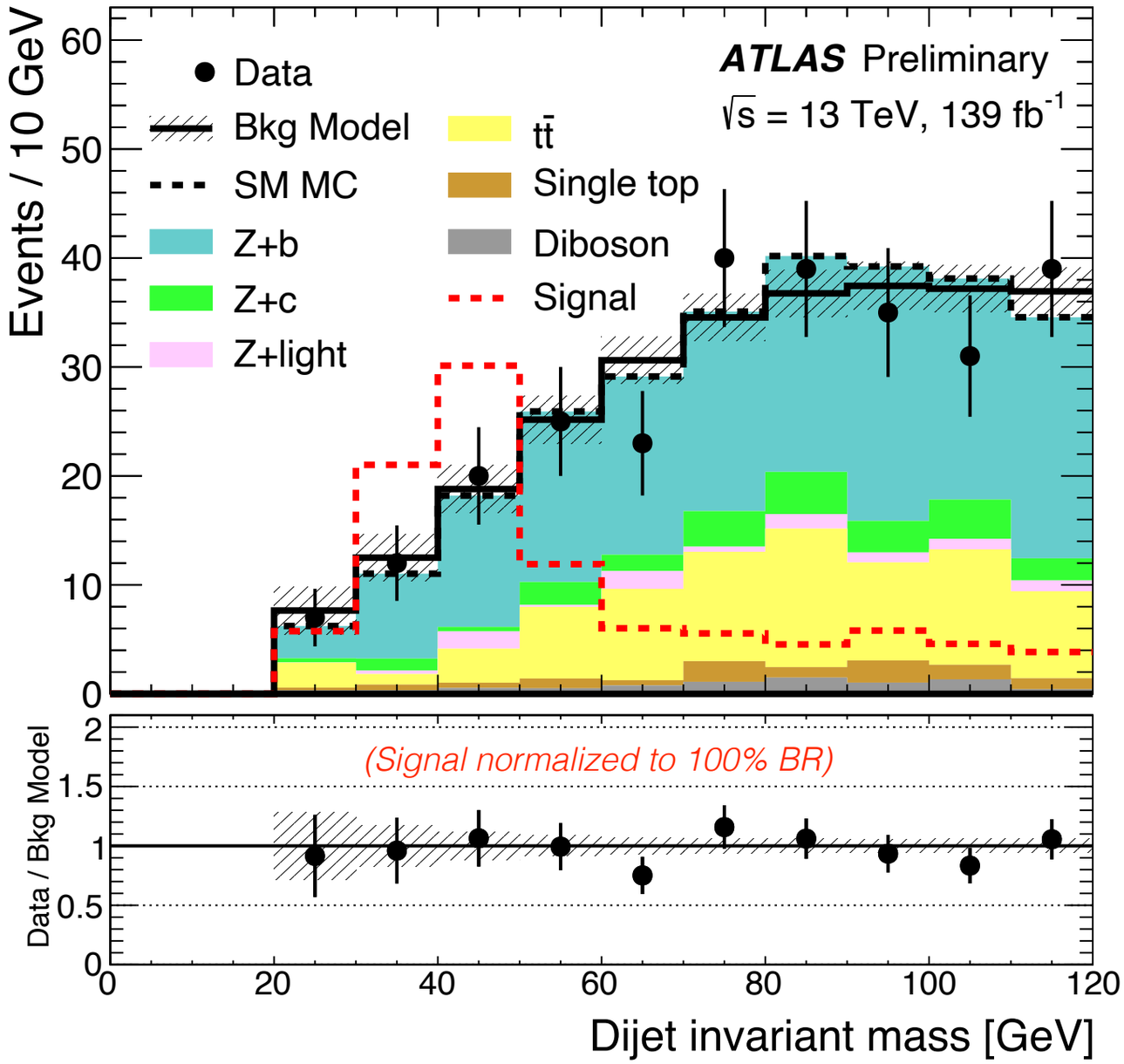
# bb,invisible

$$ZH \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0 \rightarrow a\tilde{\chi}_1^0 \tilde{\chi}_1^0$$

Search for deviation in *jj* invariant mass from *a* decays. Require at least one *b*-jet and suppress top background:

$$0.8 < \frac{p_{\mathrm{T}}^{jj} + E_{\mathrm{T}}^{\mathrm{miss}}}{p_{\mathrm{T}}^{\ell\ell}} < 1.2$$




*Only leptonic Z decays are considered*

# bb,invisible

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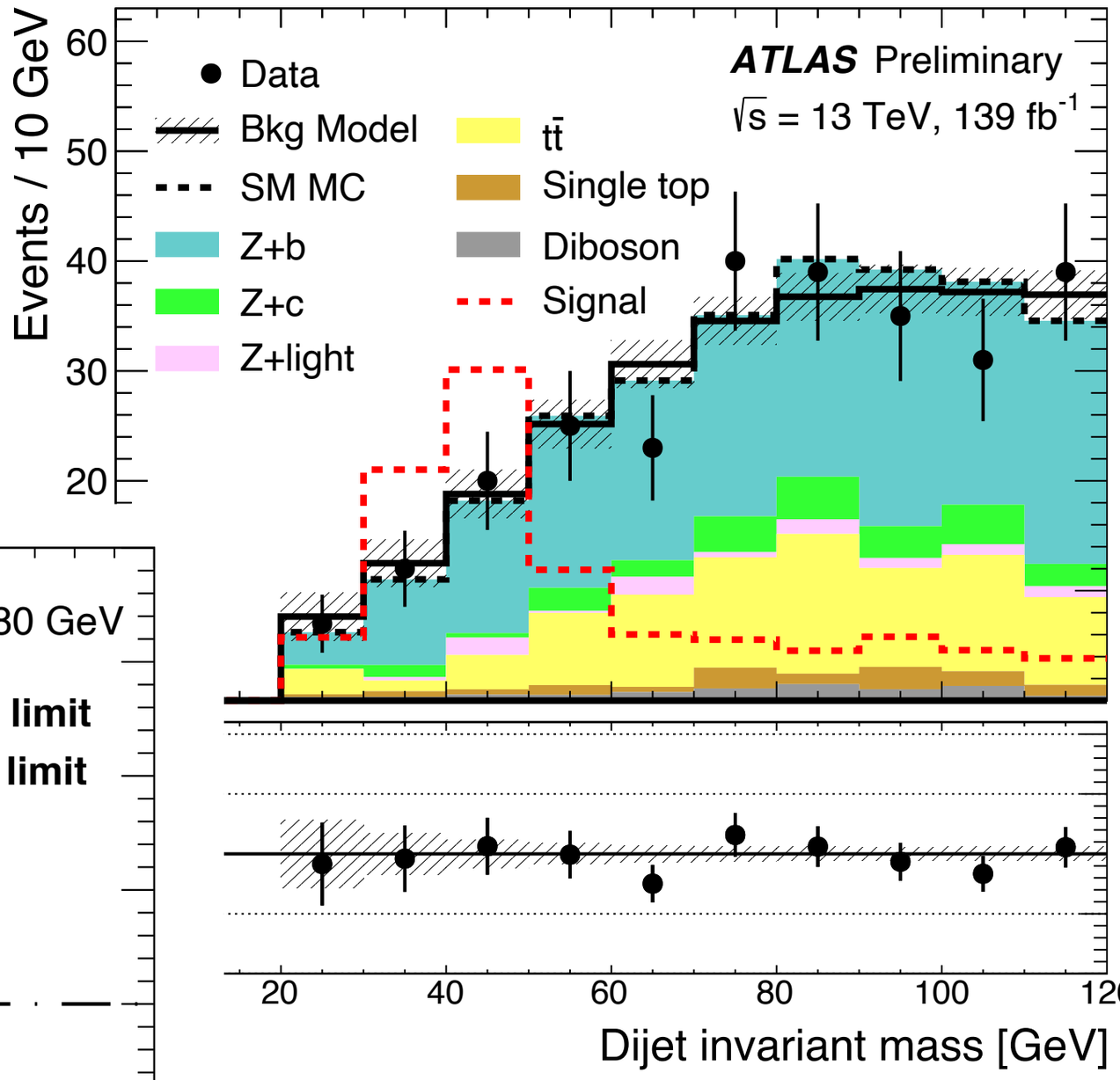
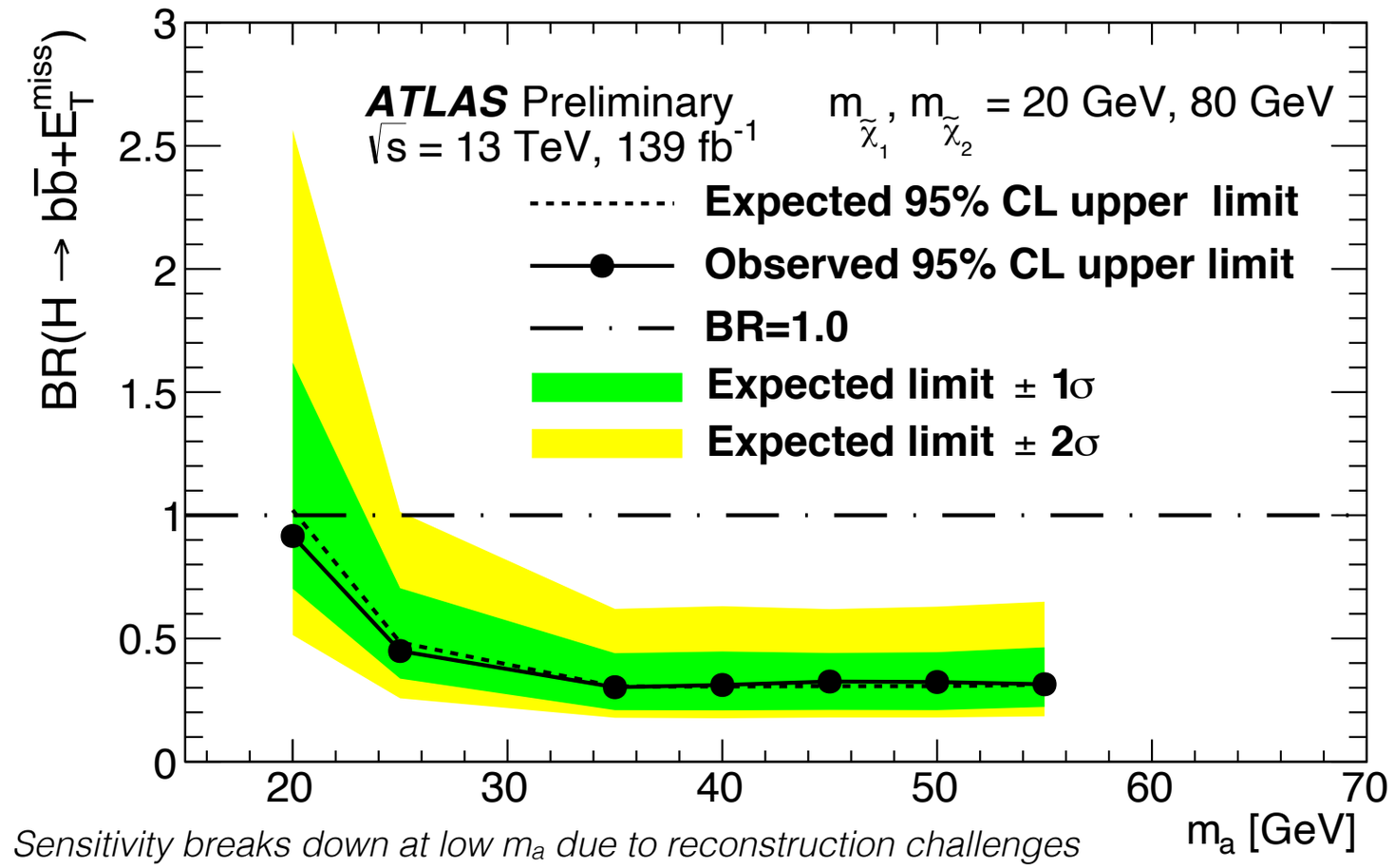


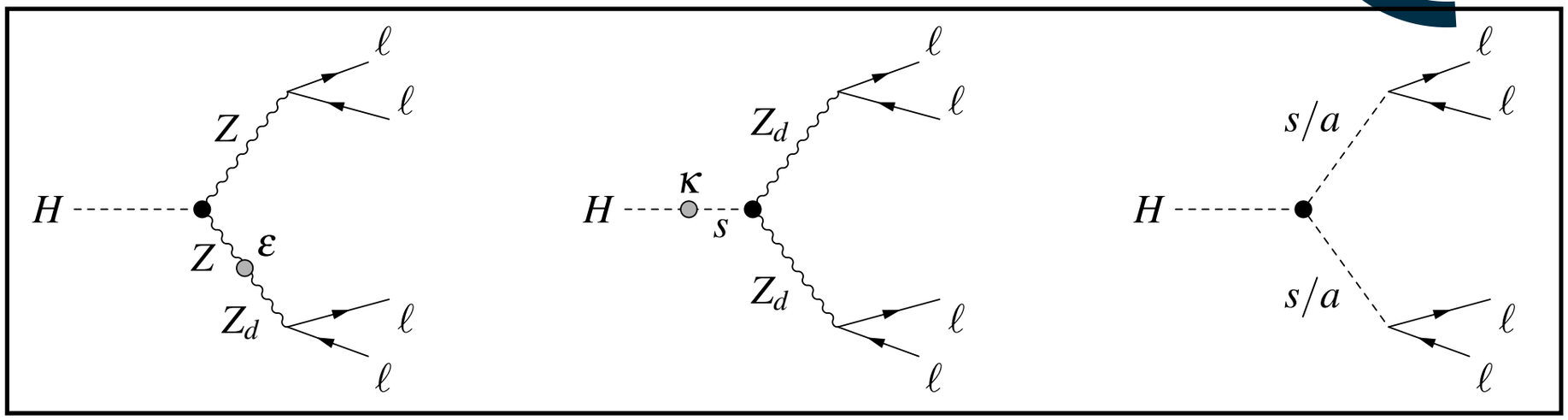



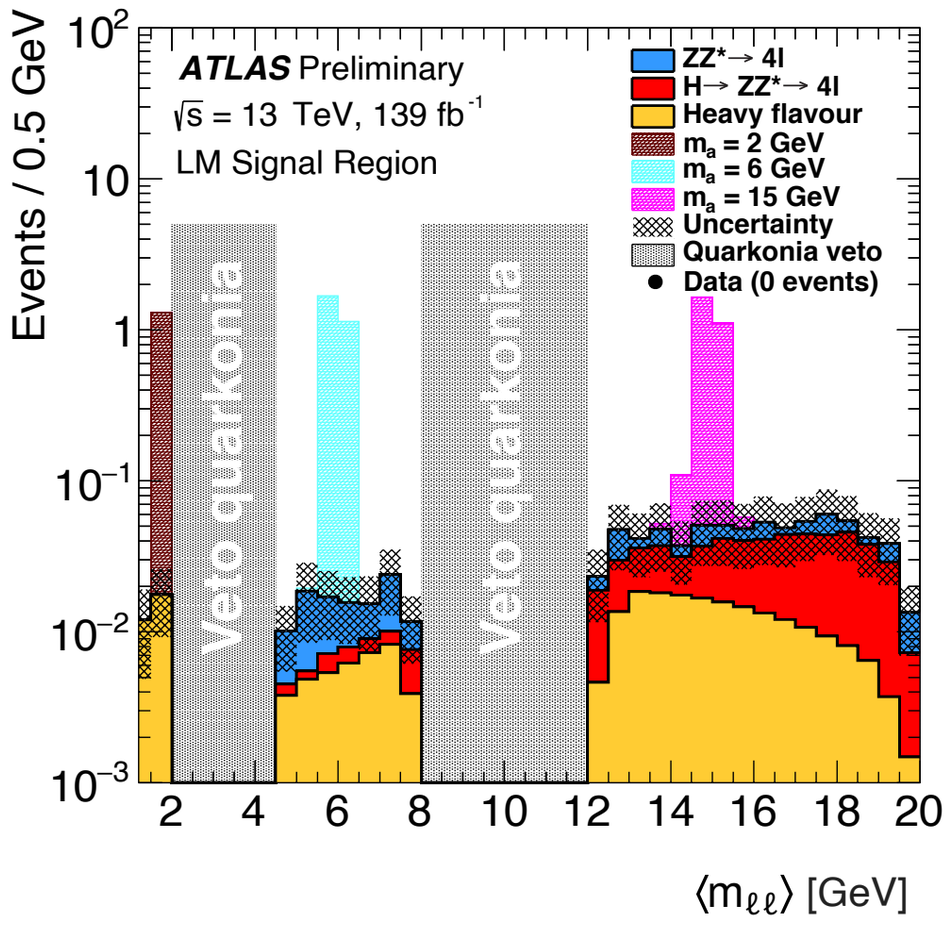

*Sensitivity breaks down at low $m_a$ due to reconstruction challenges*

No excesses - BR sensitivity down to ~30%

# Four leptons

Search for excess in average pair invariant mass




High mass and ZX ([15~60] GeV) with *e* and *μ* and low mass with *μ* only ([1-15] GeV)

*See note for ZX limits*

# Four le

Search for e
in average
invariant m

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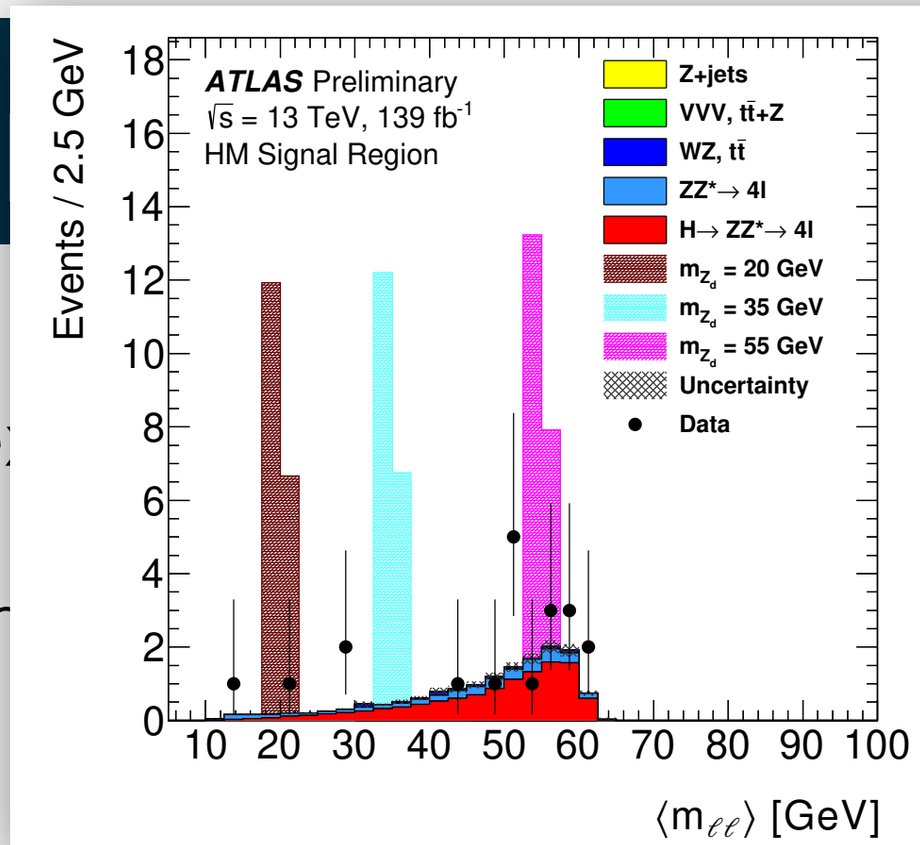


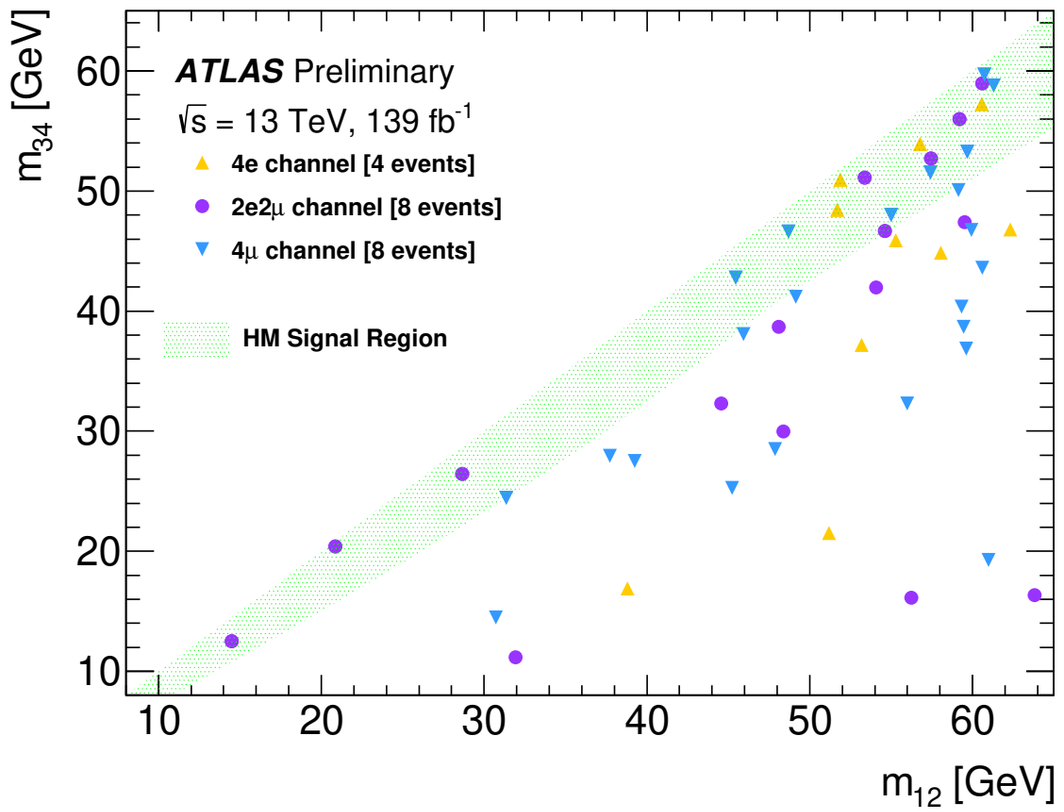


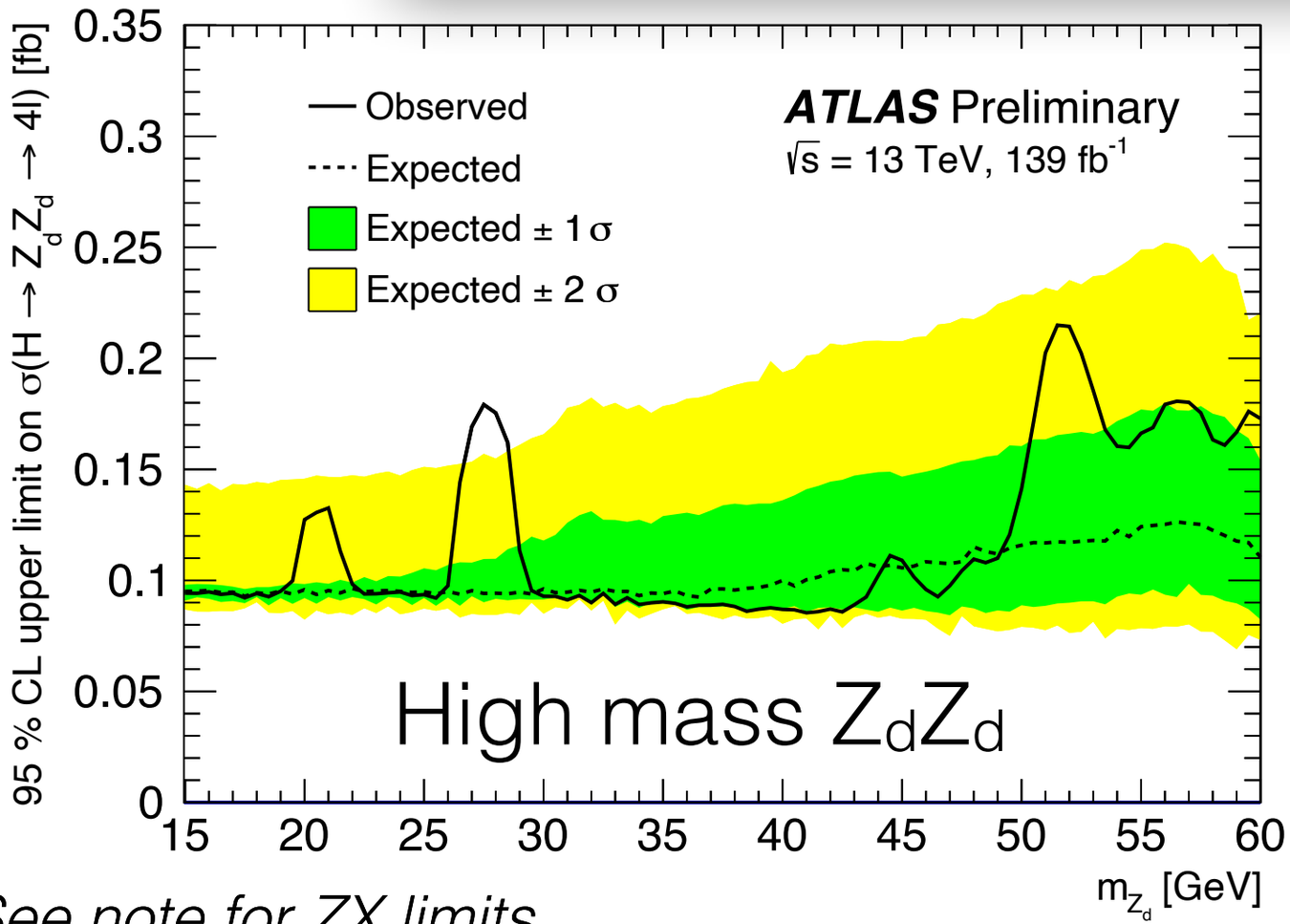


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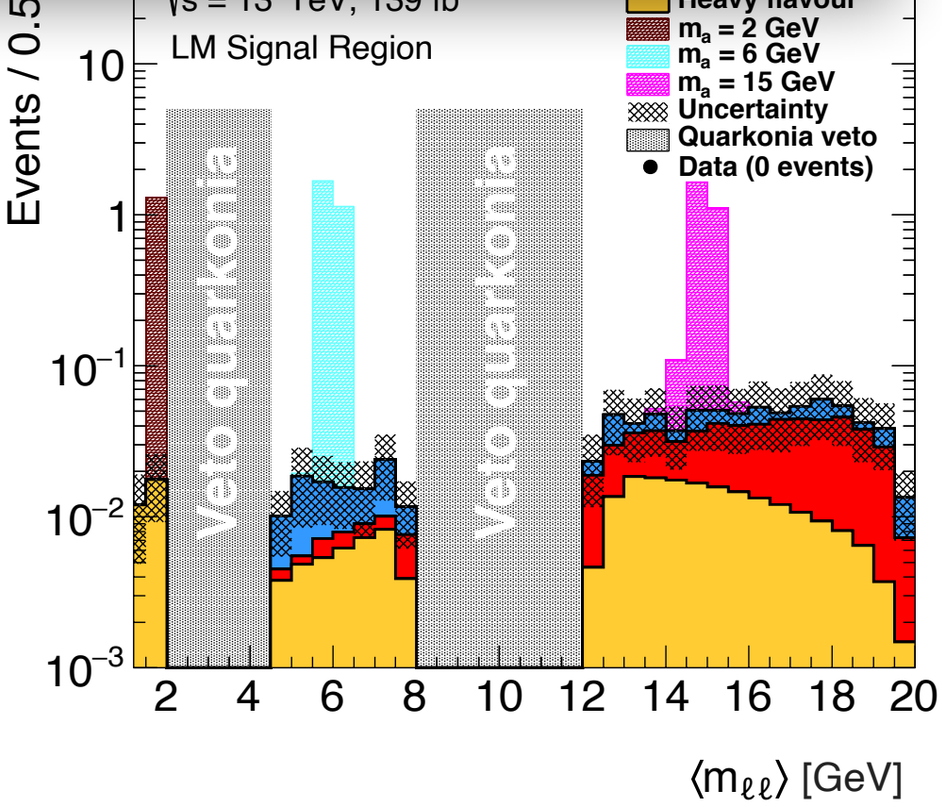


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**Next: SM decay products**

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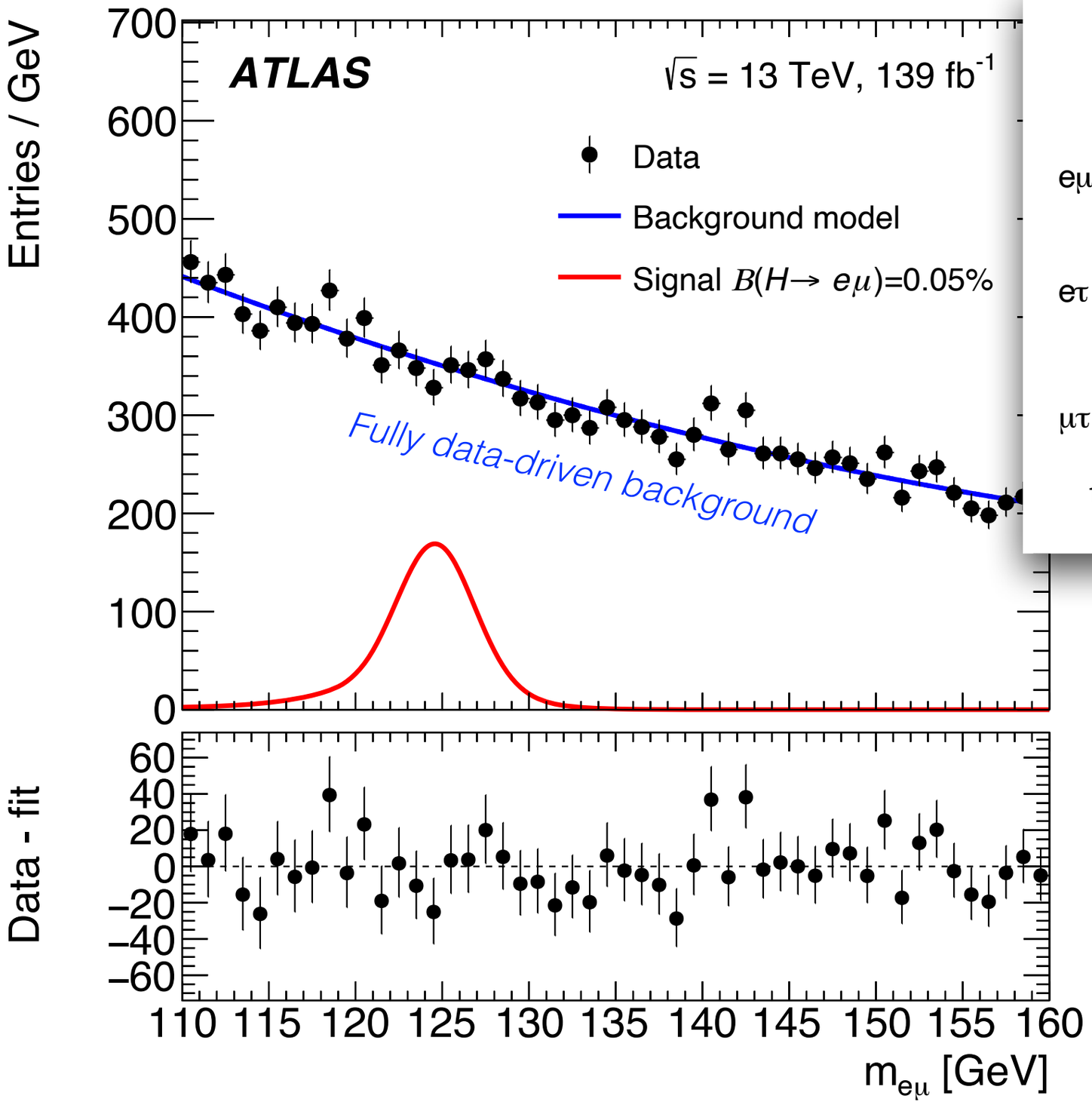
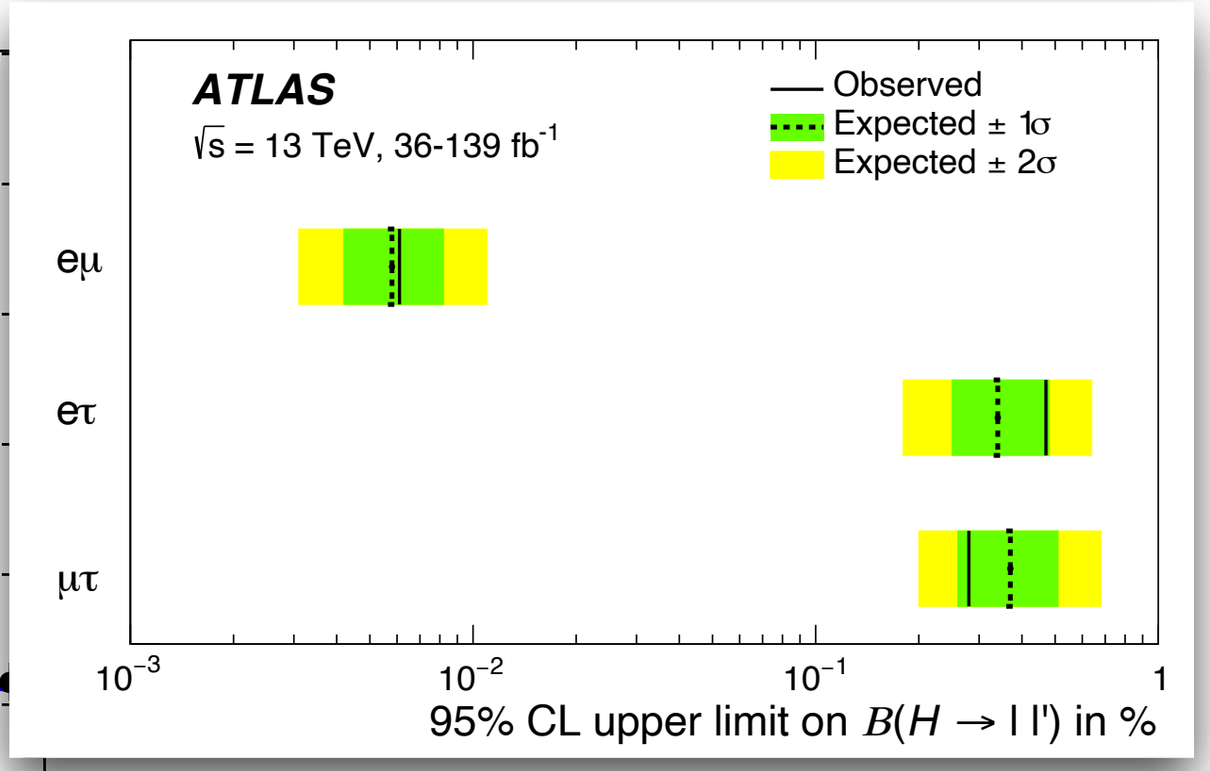
Phys. Lett. B 801 (2020) 135148

# Lepton Flavor Violation






Reject events with b-jets and significant MET

See HDBS and Higgs group public pages for additional SM decay analyses

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| Y \ X | $e^{\pm}$ | $\mu^{\pm}$ | $\tau^{\pm}$ | $Z$ | $W$ | $\gamma$ | $q/g$ | $c$ | $b$ | Inv. | $\phi,\rho$ | $J/\psi,\Upsilon$ | $\ell^{\pm}\ell^{\mp}$ | $\tau^{\pm}\tau^{\mp}$ | $q\bar{q}/gg$ | $\gamma\gamma$ | $b\bar{b}$ | Other |
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**The future**

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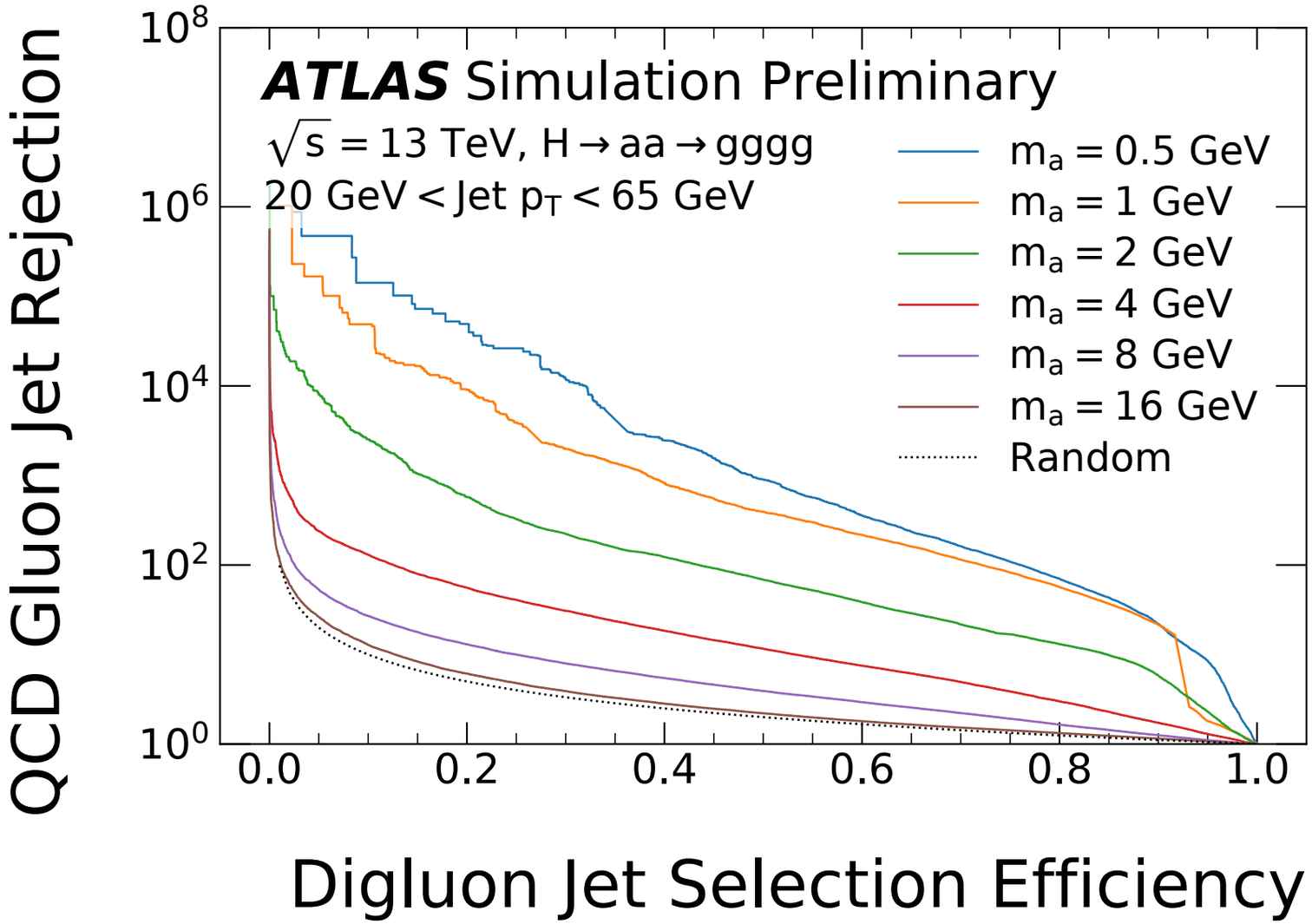
# Sneak peak: custom tagging

Low-mass Higgs decay products have significant Lorentz-boost and thus the SM children are collimated, H → XX →(ff) (ff)



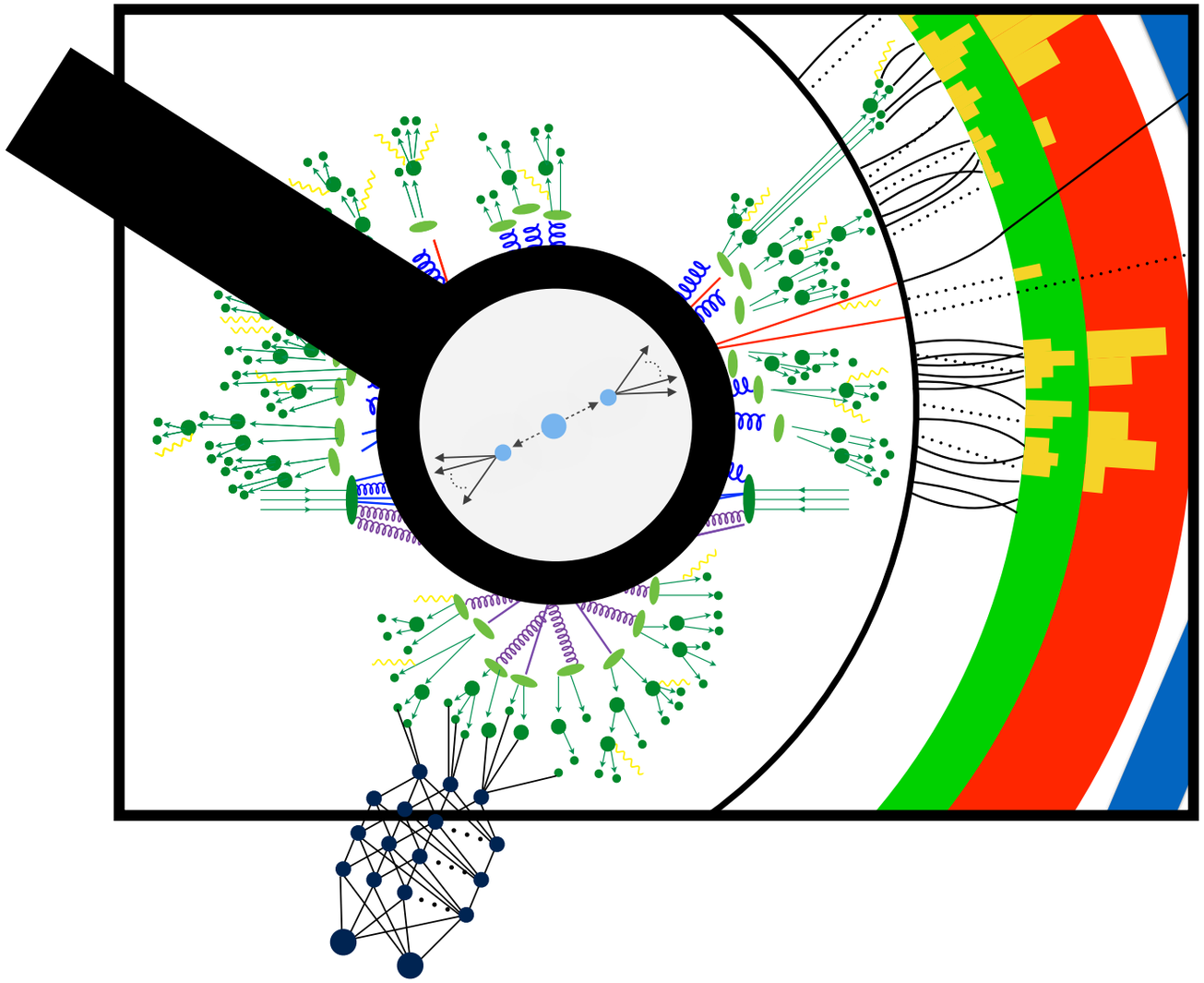

*We can define custom di-object taggers to push down to lower mass for bb, cc, $\gamma\,\gamma$, $\tau\,\tau$*

← *Deep sets-based tagger using all tracks inside jets*

# Conclusions and outlook



Today, I have presented the status of exotic decays of the 125 GeV Higgs Boson



*I have focused on new results given the limited time - please see the ATLAS HDBS public webpage for further details.*

There are still many uncovered possibilities - stay tuned for updates in this exciting research program!

# Backup