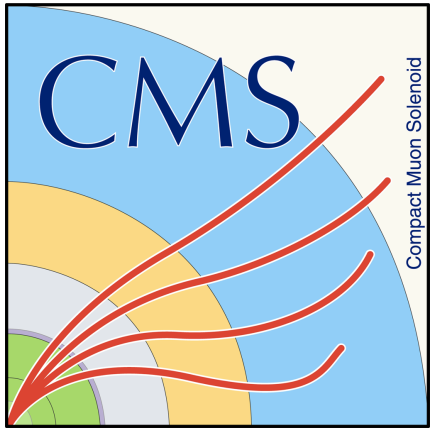


Higgs Flavor Physics at ATLAS and CMS

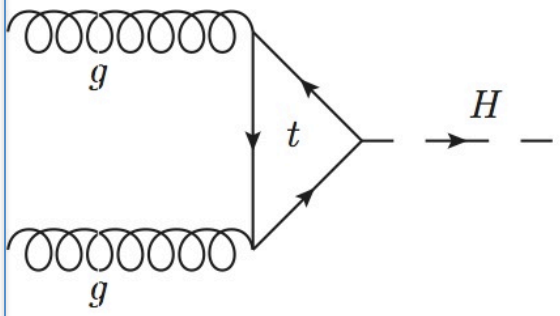
FPCP 2019

May 9, 2019

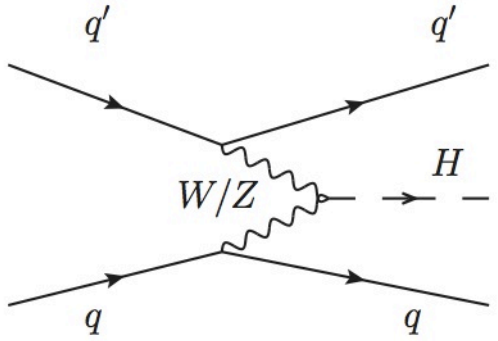
Sarah Demers, Yale University

SM Higgs boson production

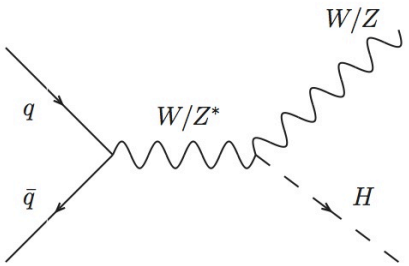
gluon-gluon fusion: ~89%
largest production mode,
challenging for high-background
decay modes



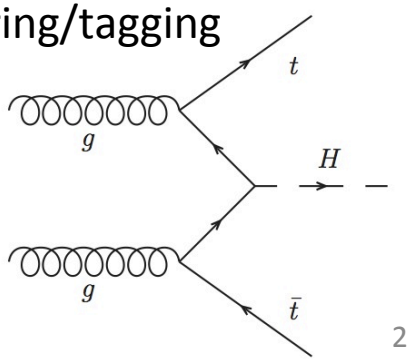
vector boson fusion: ~ 7%
two forward jets enable
event triggering and
background reduction



associated production
with a W/Z boson: ~3%
low cross section,
but excellent options
for triggers and event-
tagging



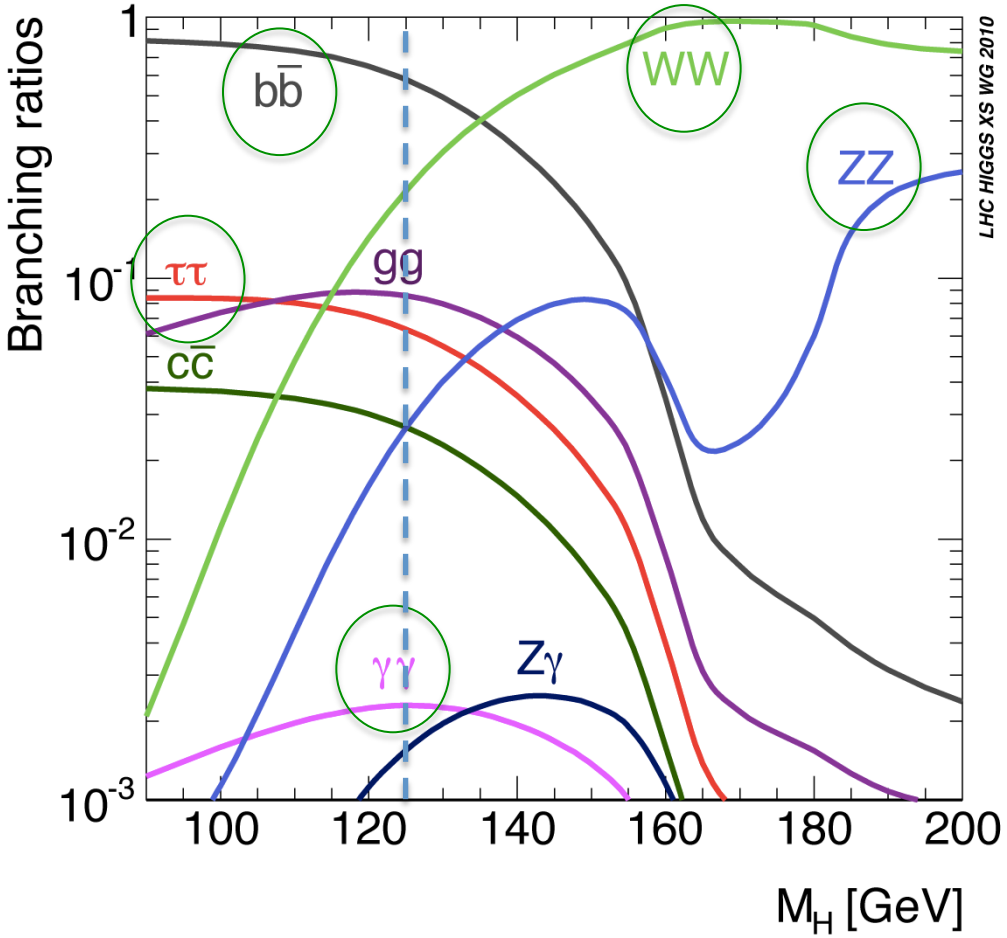
associated production with a pair of top
quarks: (~1%) low cross sections but
excellent triggering/tagging
options



SM Higgs boson decay

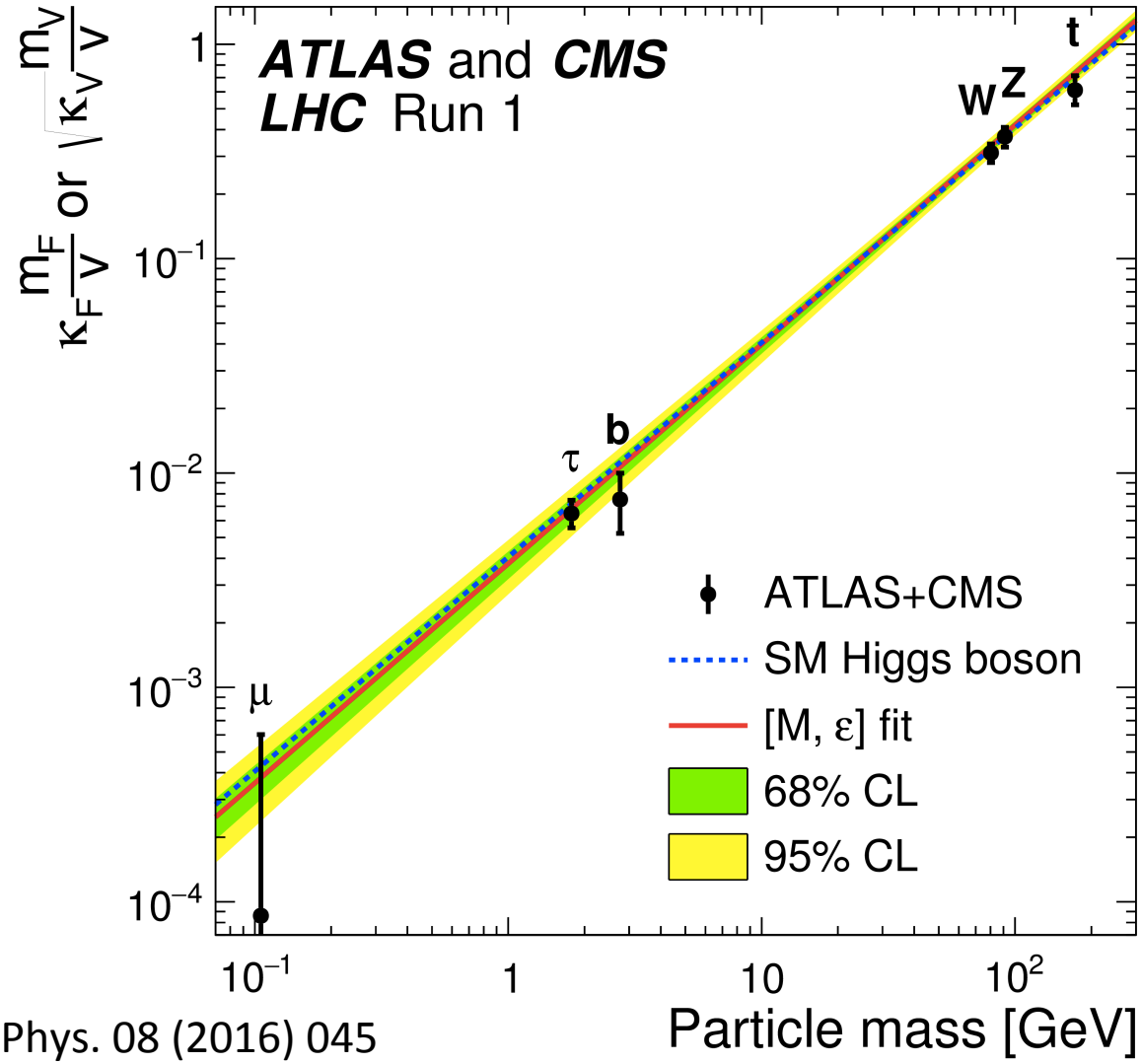
All four production modes and many decay modes have been observed at the LHC (circled below.)

The branching ratios still have large enough uncertainties for new physics to be lurking in the system.



Run 1 ATLAS + CMS Combination

Run 1 ($\sqrt{s}$ = 7 TeV and 8 TeV) analyses showed the Higgs boson looking very standard model-like…



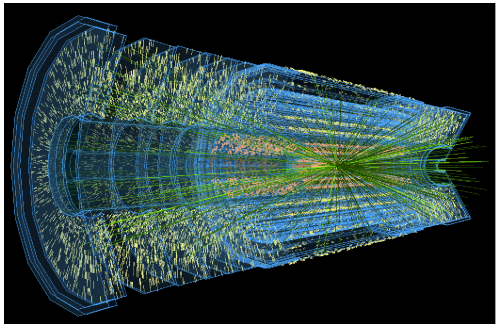
J. High Energy Phys. 08 (2016) 045

Outline

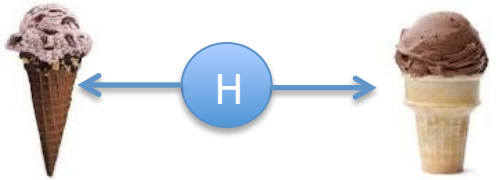
- A tour of Higgs boson coupling measurements to fermions

t, b, and c quarks, taus, and muons

- A glimpse of the future, with the HL-LHC

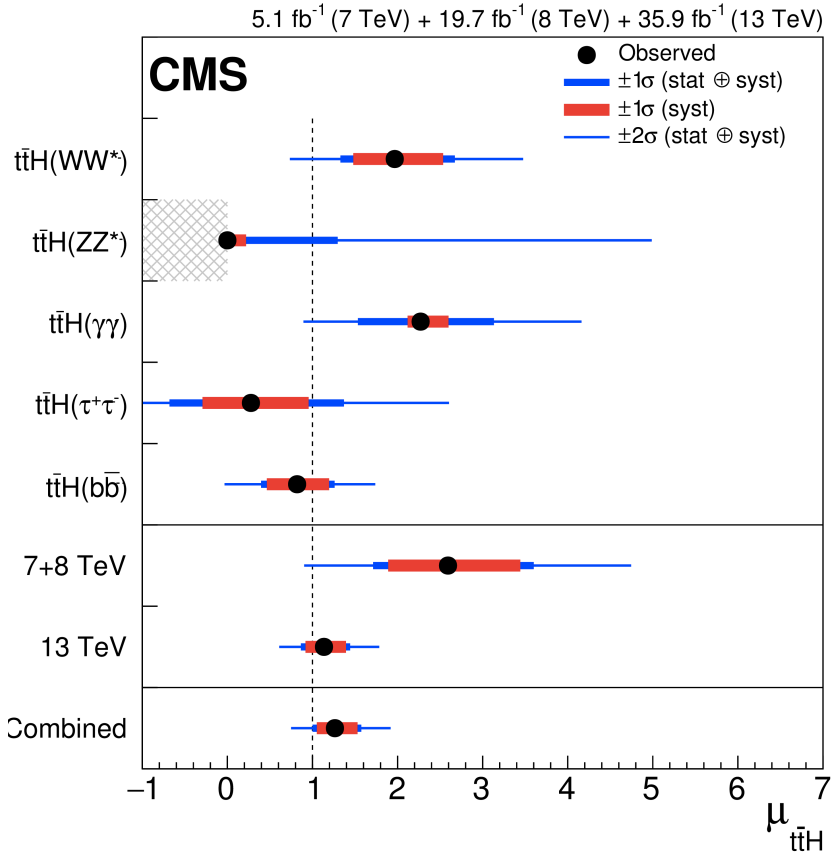


- The hunt for lepton flavor violating Higgs boson decays

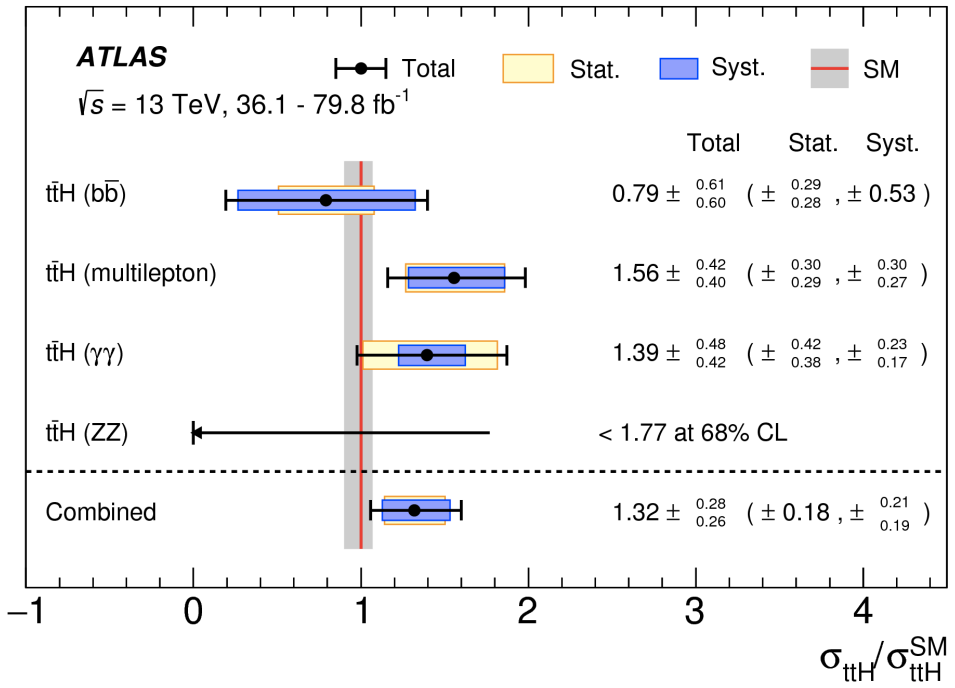


Coupling to top quarks

CMS and ATLAS established the coupling of the Higgs boson to top quarks via the ttH production mode in the spring of 2018.



Phys. Rev. Lett. 120 (2018) 231801



Phys. Lett. B 784 (2018) 173

b-tagging

Approximately 58% of the 125 GeV SM Higgs boson decays are to b-quarks. But these objects pose challenges for the trigger and in terms of efficiency/purity.

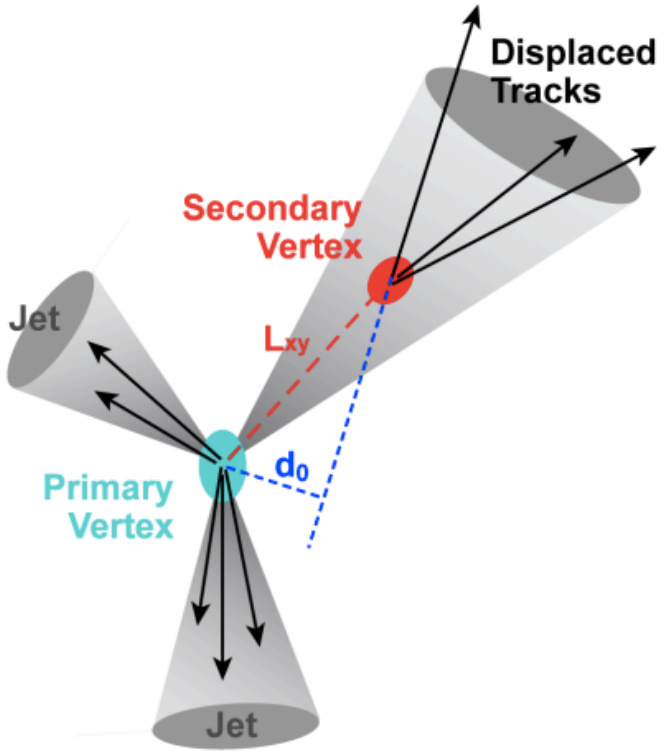


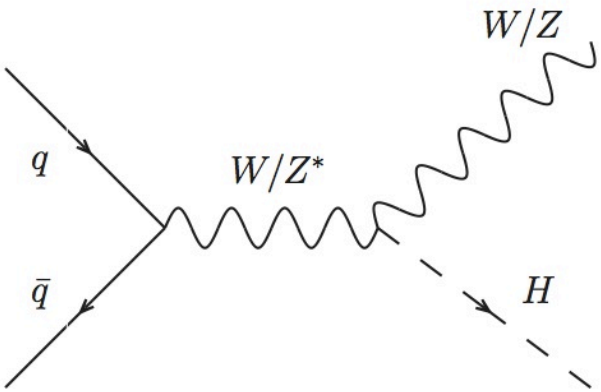
figure from D0 Collaboration

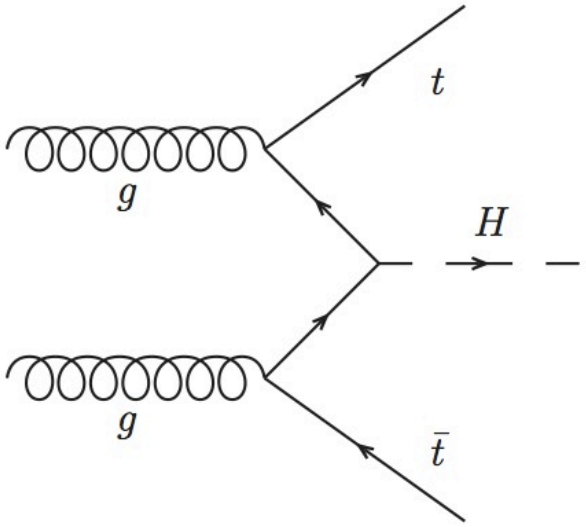
Higgs boson decays to b quarks

Excellent tracking resolution helps identify secondary vertices.

Tracking information is not available in the first level of the trigger decision at ATLAS and CMS, so other event information is needed to get these events.

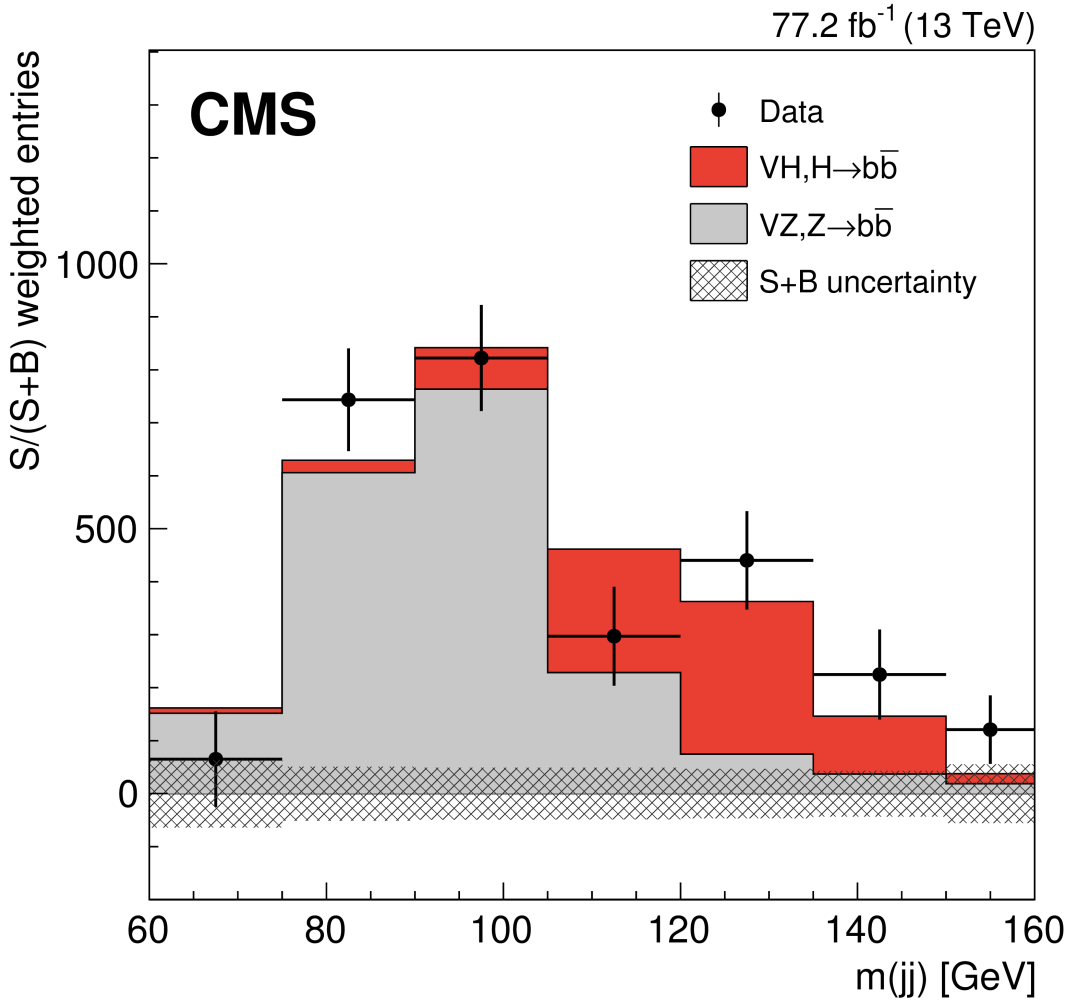
The VH production mechanism provides the W or Z boson for triggering, and can deliver the H->bb events for study. The ttH production, with an even lower cross section, can also provide a clean and efficient trigger.





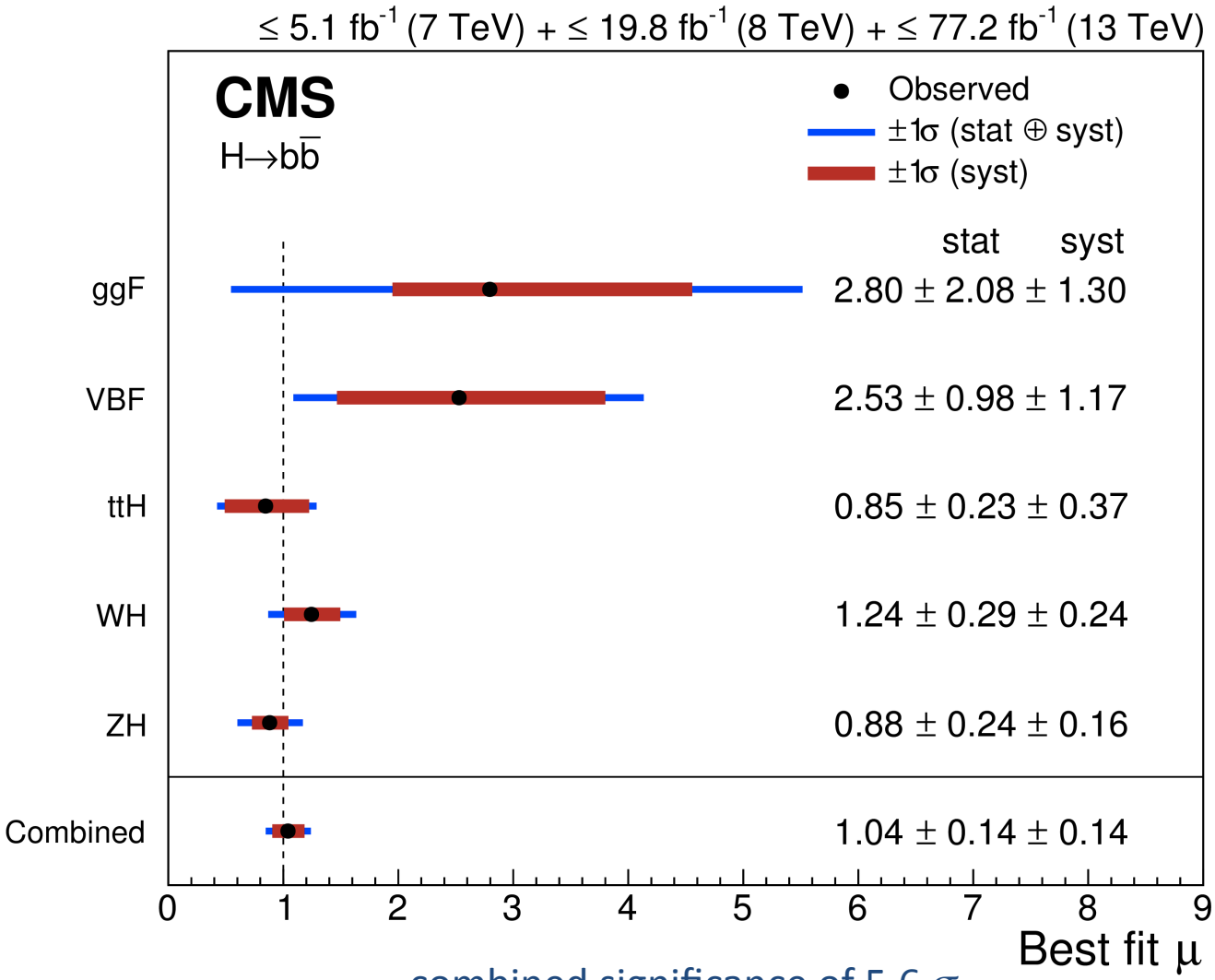
CMS: H->bb

mass separation between VH and VZ



Phys. Rev. Lett. 121 (2018) 121801

CMS: H->bb

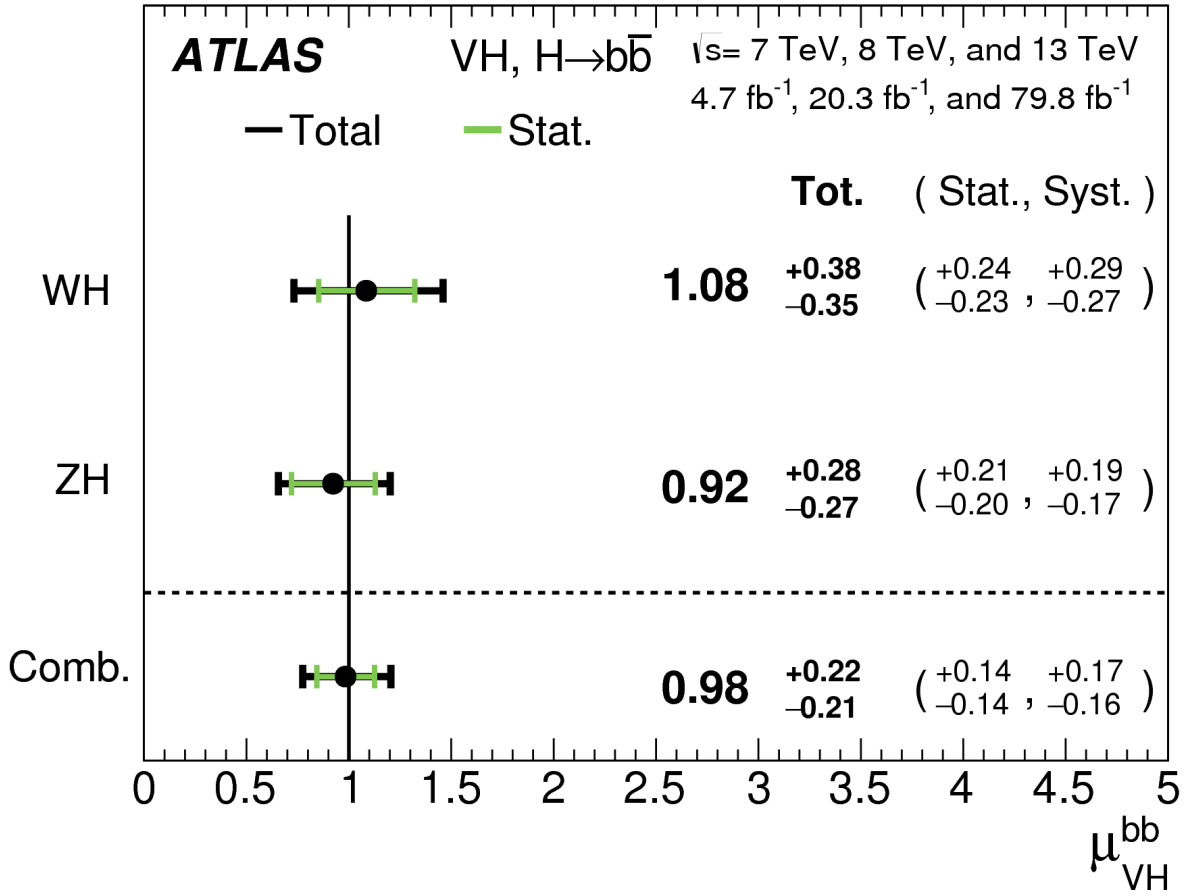


combined significance of 5.6 σ

Phys. Rev. Lett. 121 (2018) 121801

ATLAS: H->bb

See today's talk by Claire David for details!

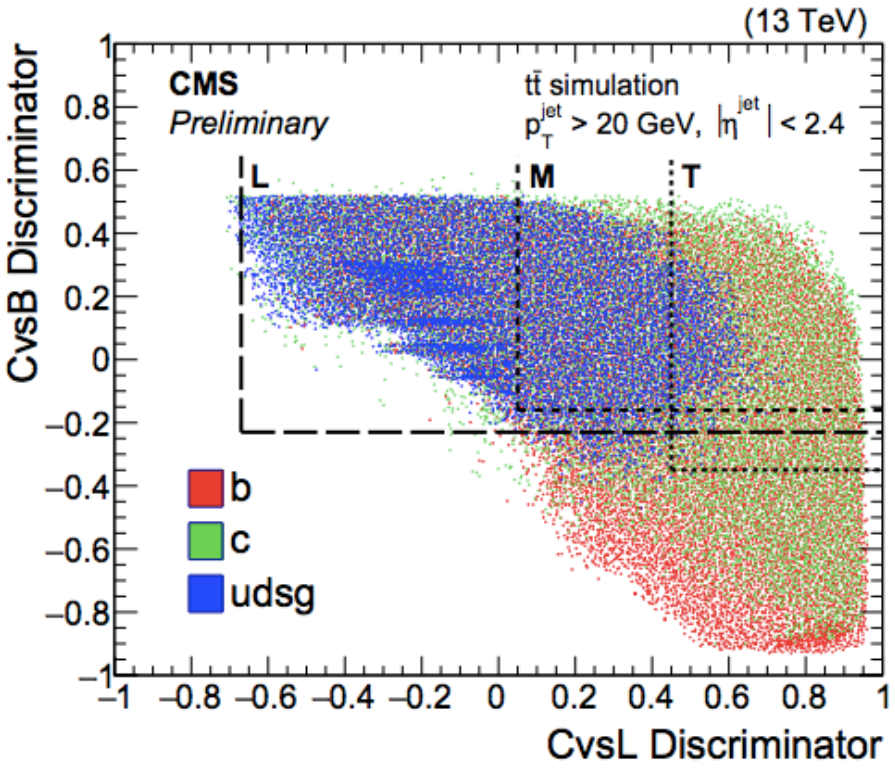


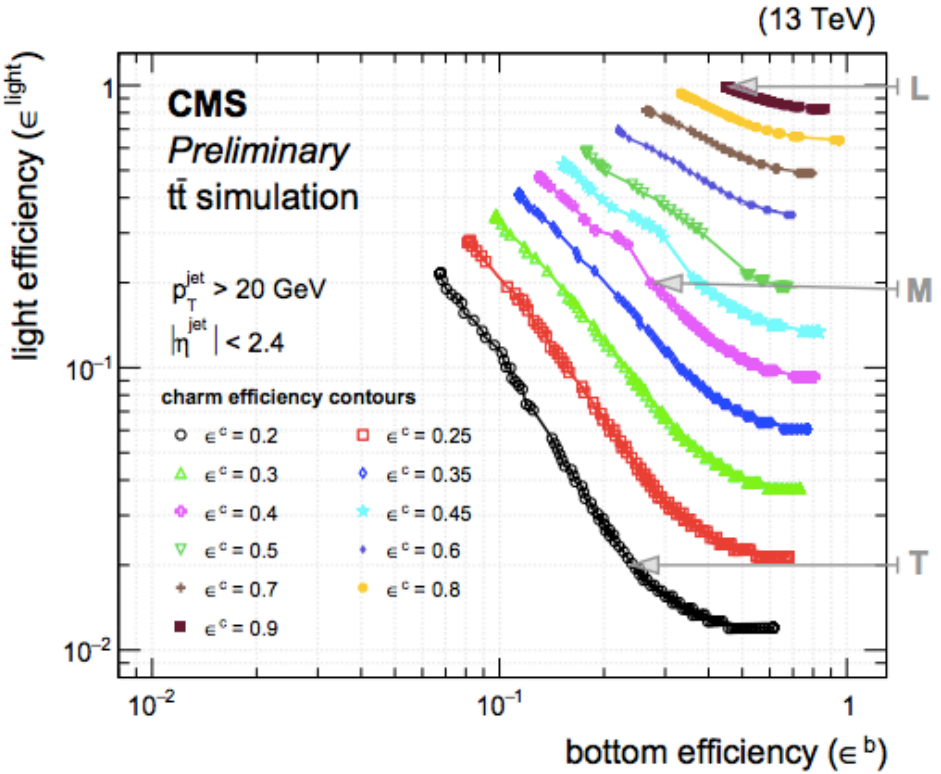
combined significance of 5.4σ for H->bb and 5.3σ for the VH production mode

Phys. Lett. B 786 (2018) 59

charm tagging

charm tagging is more challenging than b-tagging, but significant progress has been made with the help of machine learning.

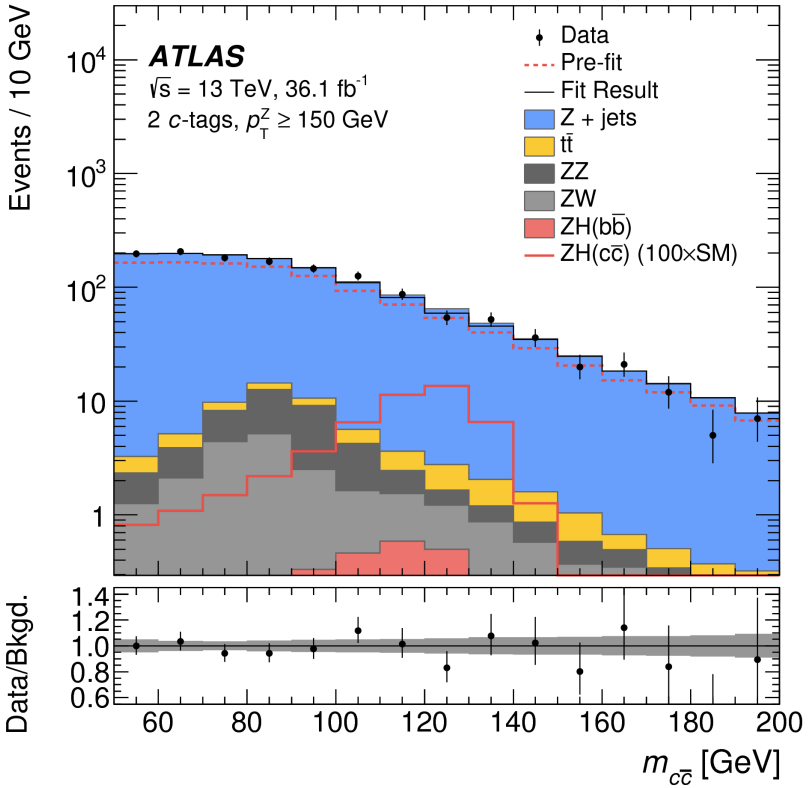


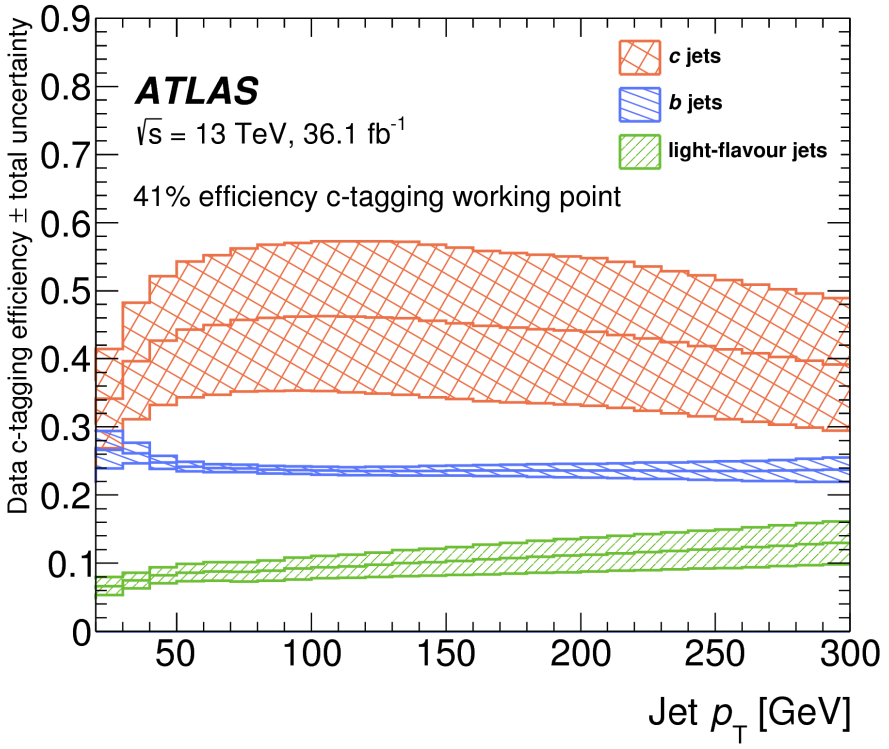


CMS PAS BTV-16-001

Higgs boson decays to c quarks

charm tagging is more challenging than b-tagging, but significant progress has been made with the help of machine learning.





At ATLAS, a 95% CL upper limit on the XS x BR is placed at 110 times the SM prediction

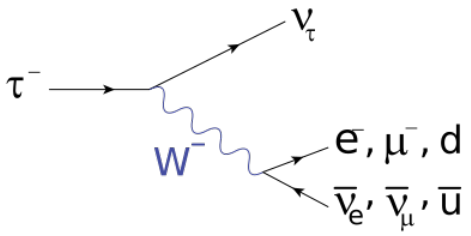
Phys. Rev. Lett. 120 (2018) 211802

See today's talk by Claire David

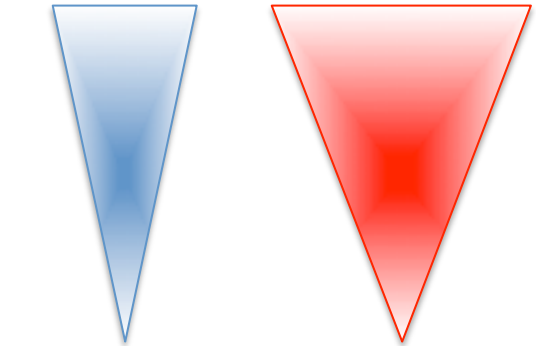
Higgs boson decays to taus

ATLAS and CMS use the both the leptonic and hadronic decays of the taus.

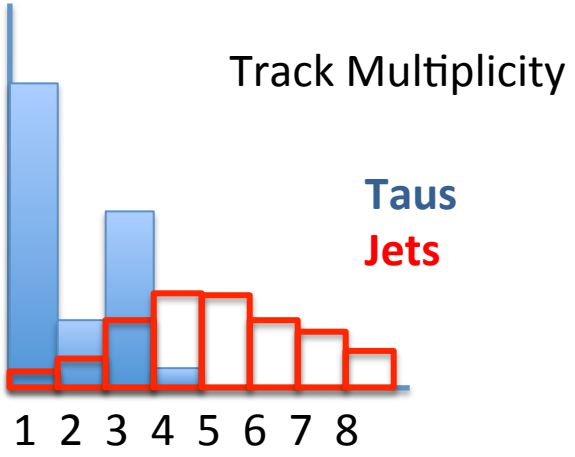
The hadronic tau decays can be faked by quark- or gluon-initiated jets, while the decays to e or μ are difficult to untangle from prompt e and μ.



Both experiments use multi-variable techniques to untangle the taus from jets, using the objects' interactions in the detectors.

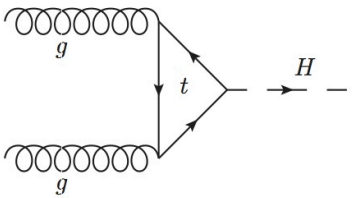


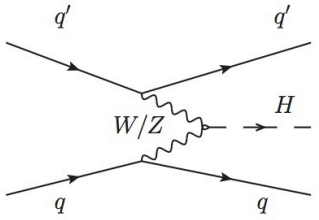
Shape of Energy Deposit in Calorimeter

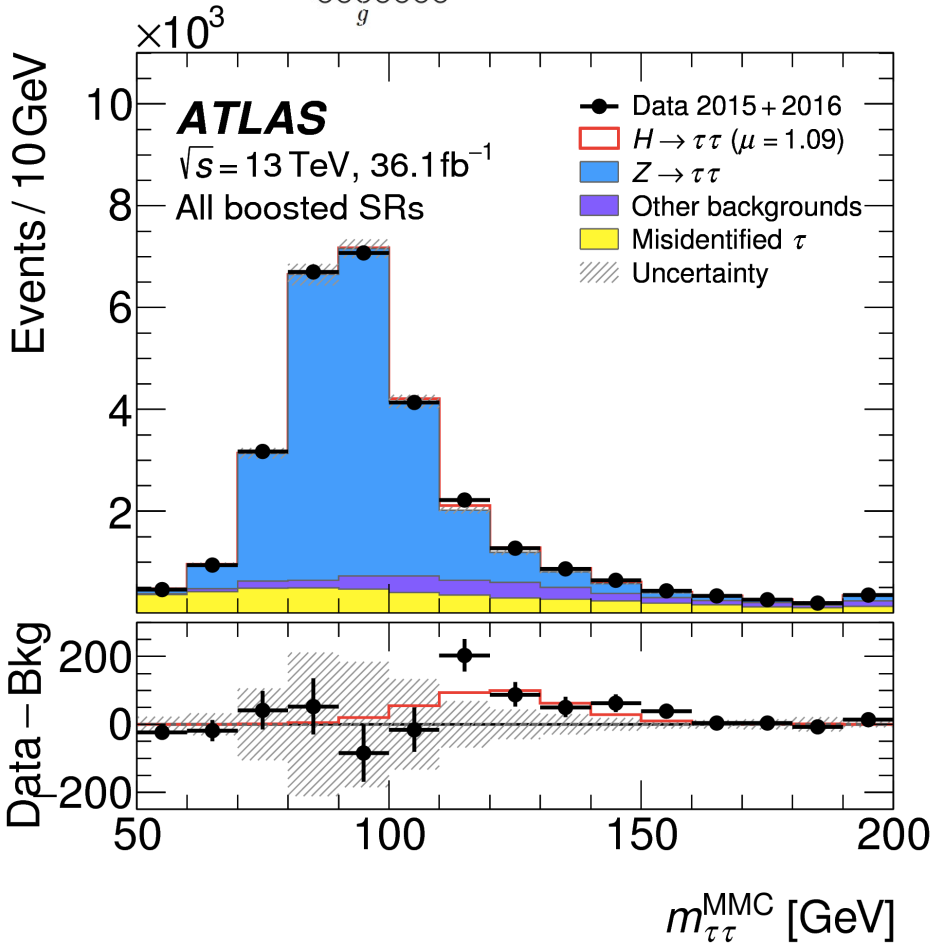


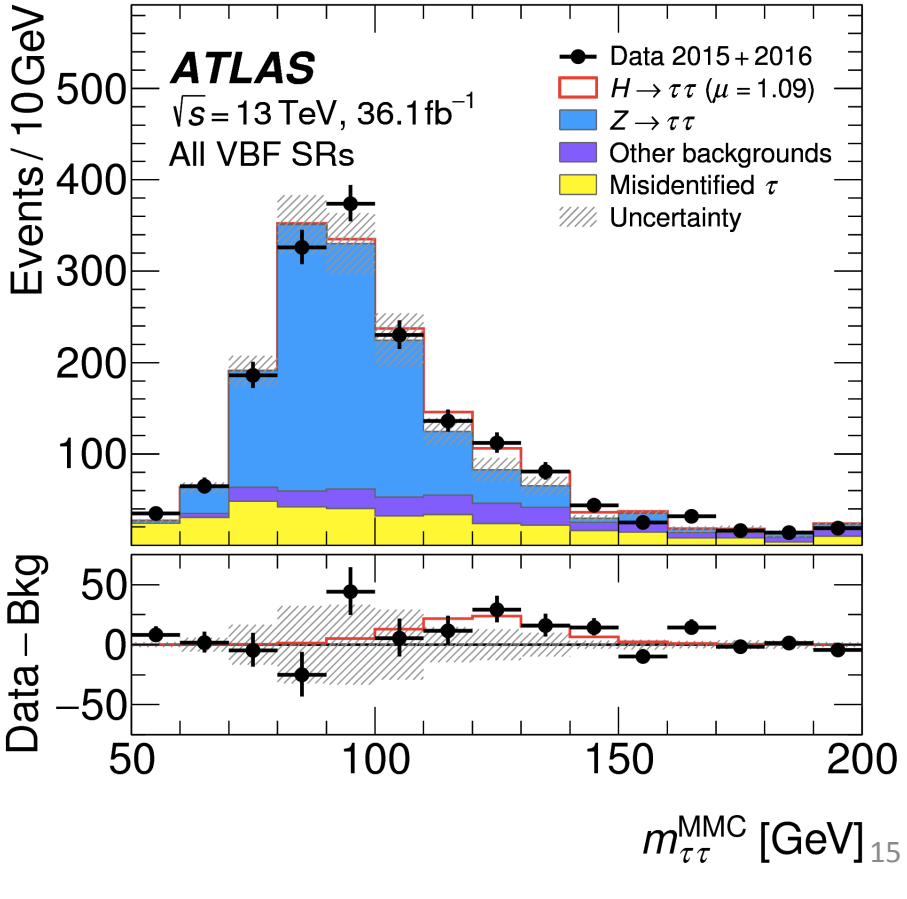
Phys. Rev. D 99 (2019) 072001

The ATLAS analysis takes advantage of the plentiful gluon-gluon fusion events with boosted categories (left) and benefits from the jets in vector boson fusion (VBF) events to define VBF categories (right).

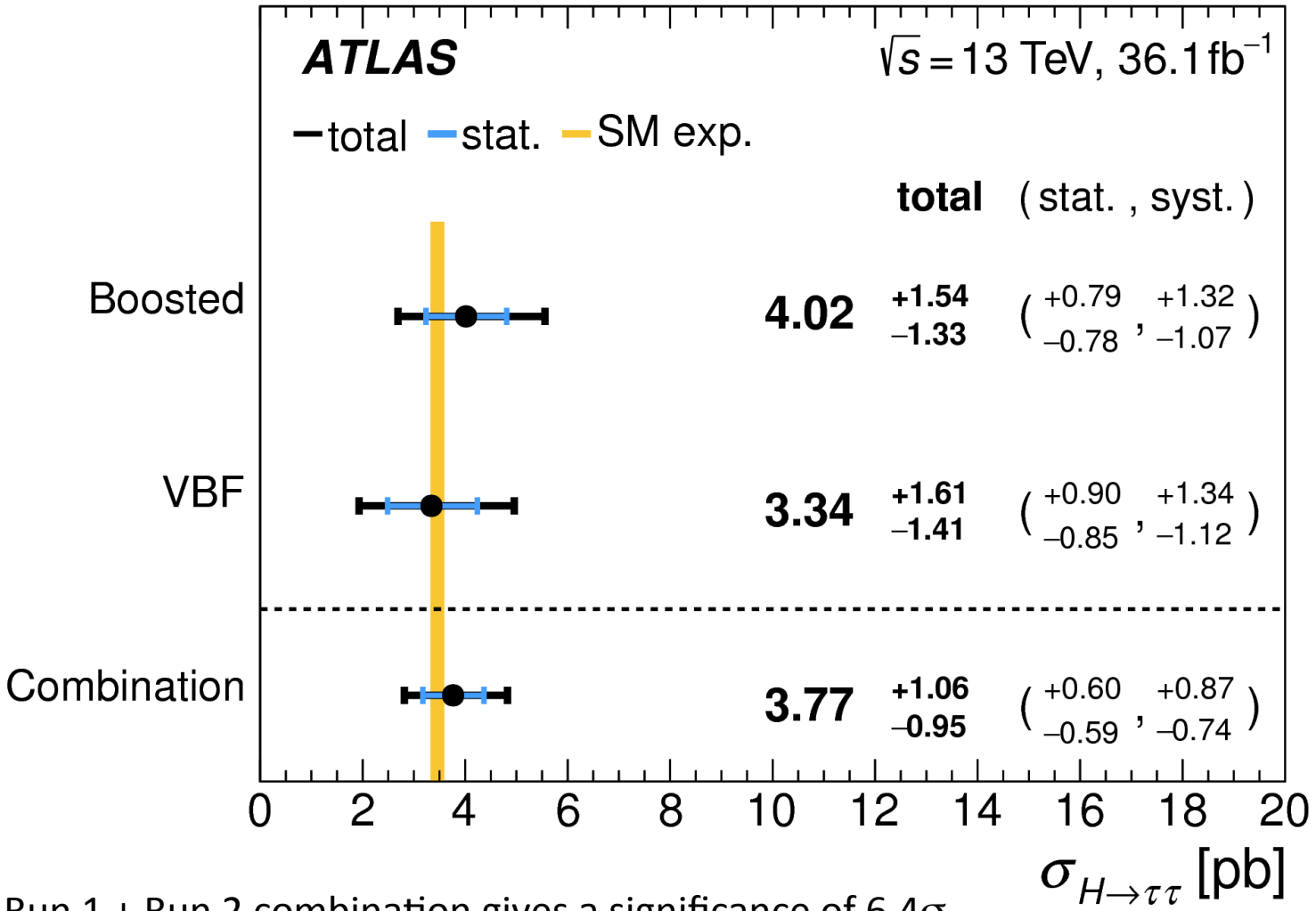








ATLAS and CMS each show results as a function of the production mode (this slide, ATLAS) and decay mode (next slide, CMS)

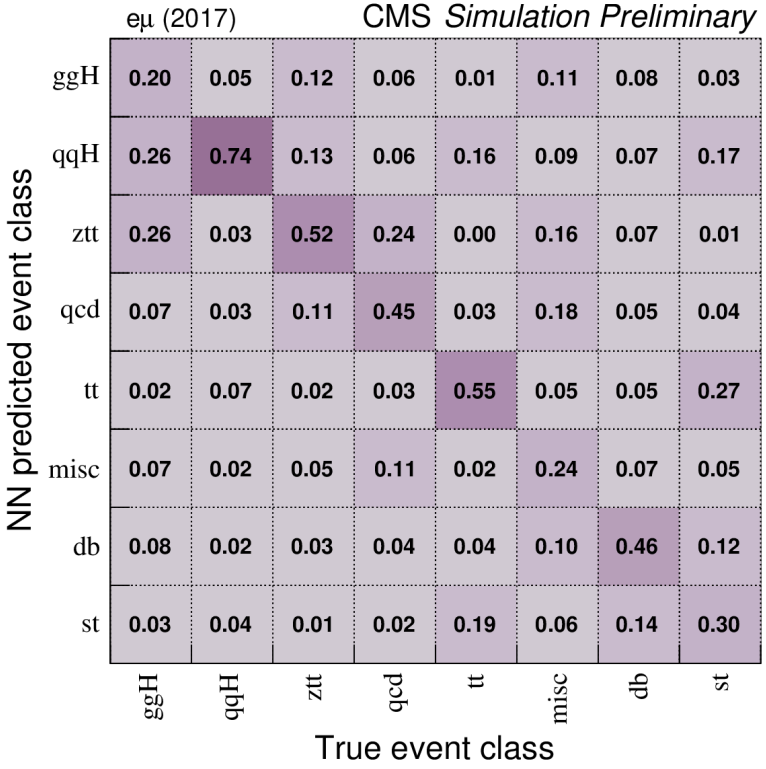


The Run 1 + Run 2 combination gives a significance of 6.4σ

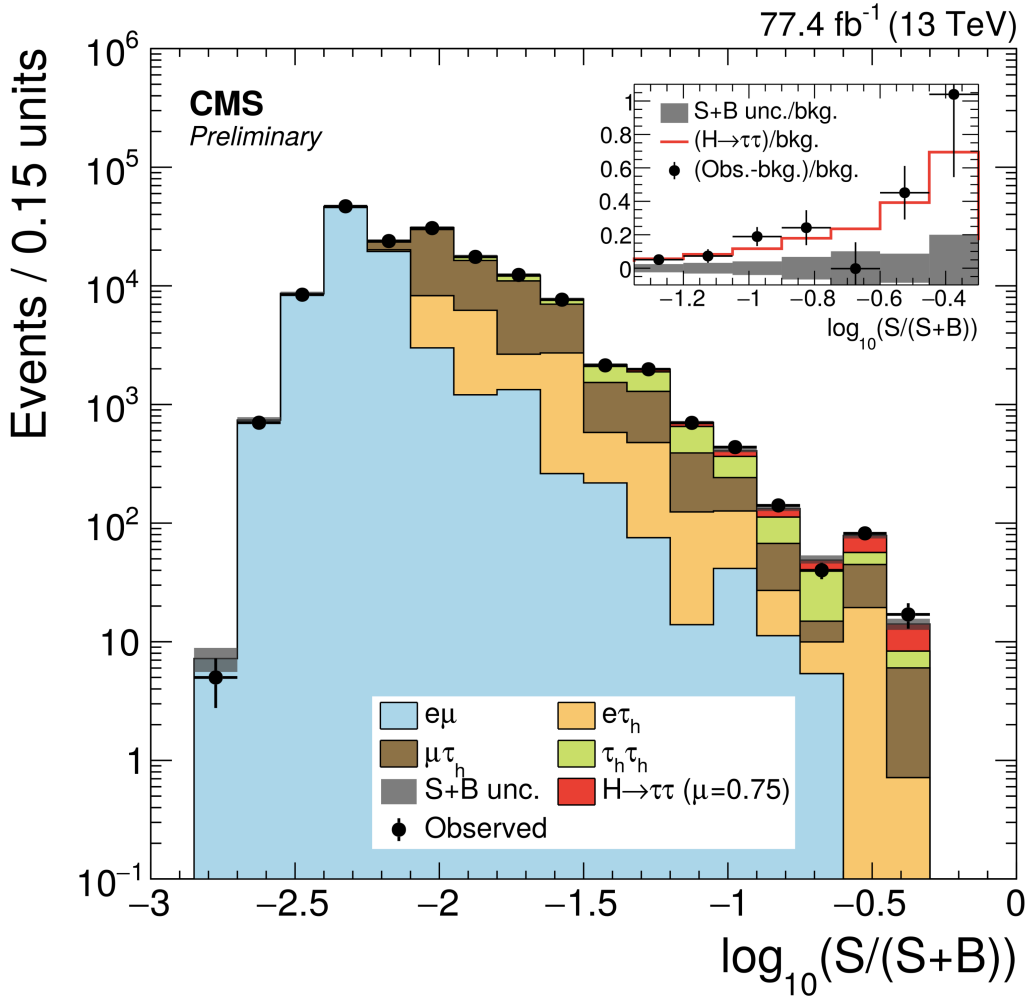
Phys. Rev. D 99 (2019) 072001

Both ATLAS and CMS use many event categories to optimize sensitivity, and rely on multivariate techniques to observe H->ττ beyond 5σ.

example confusion matrix for NN classification

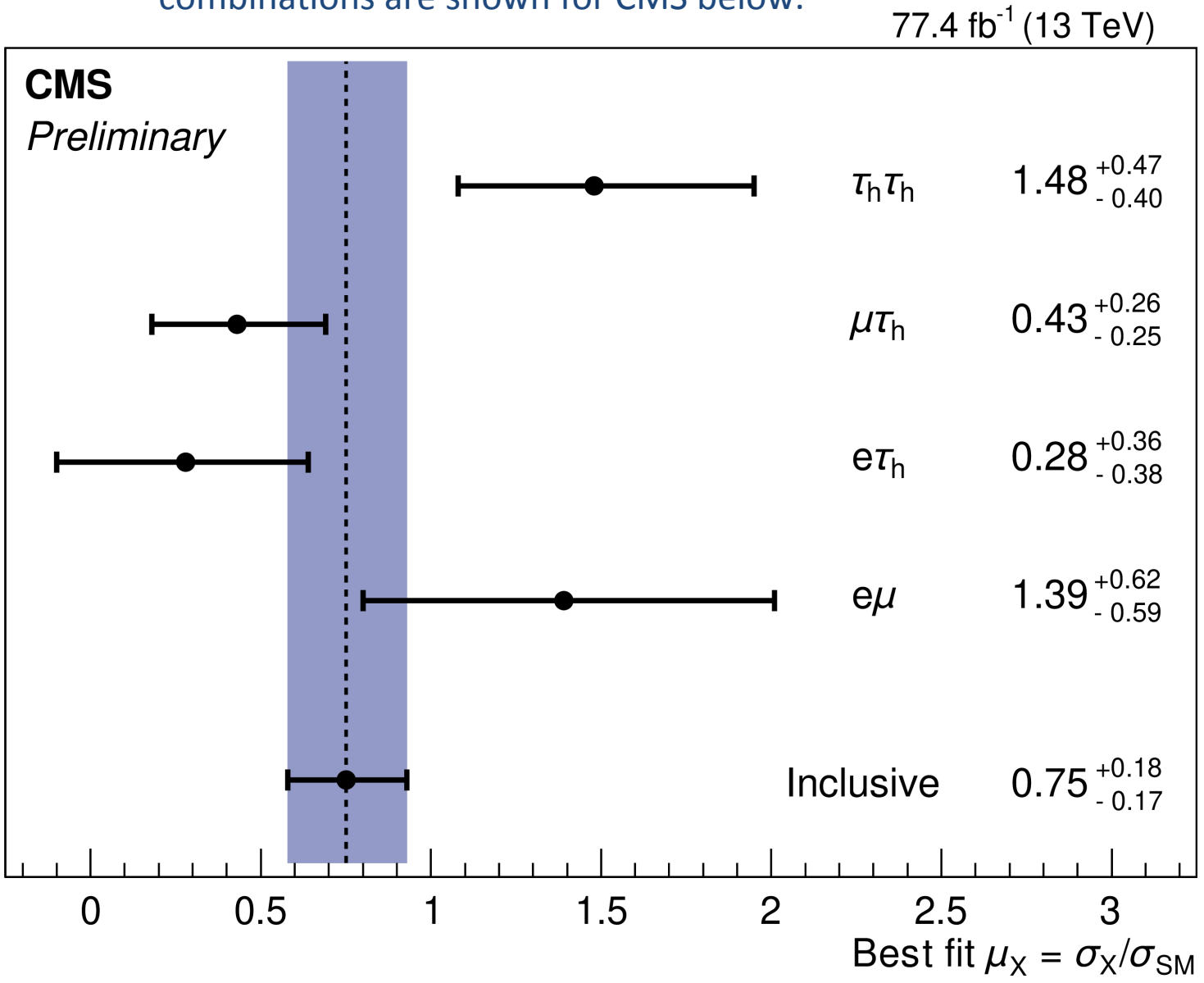


signal purity vs log(S/(S+B))



CMS-PAS-HIG-18-032

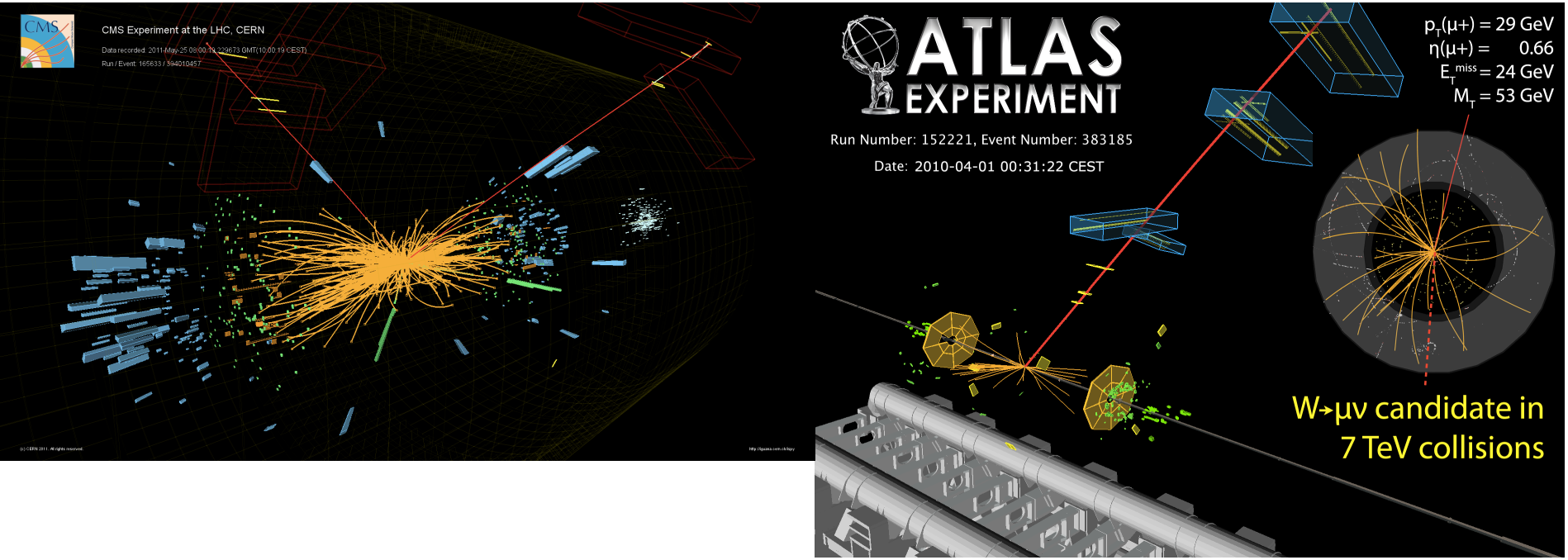
The signal strength measurements for various tau decay combinations are shown for CMS below.



CMS-PAS-HIG-18-032

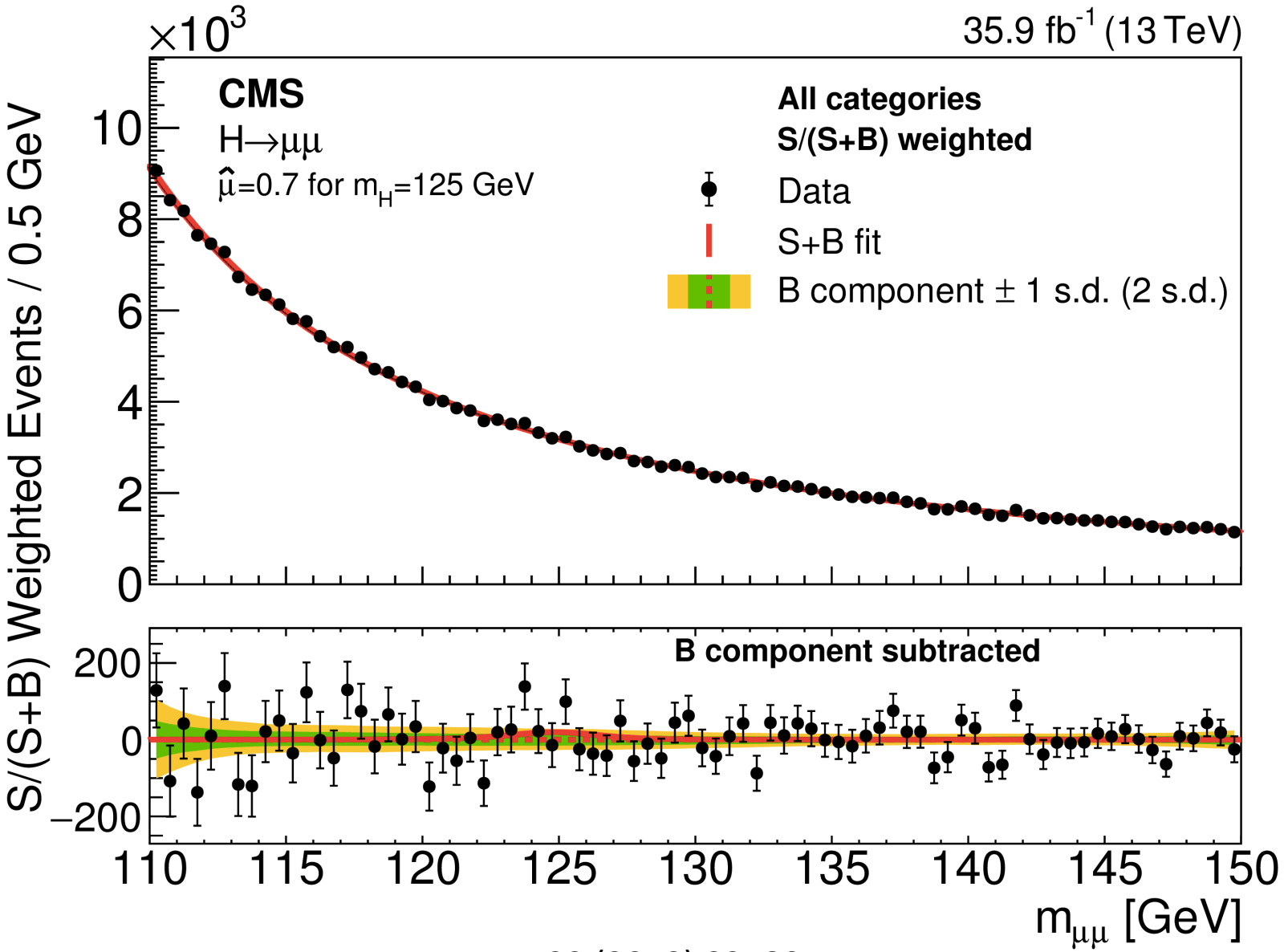
Higgs boson decays to muons

ATLAS and CMS have excellent μ identification and momentum resolution capabilities…



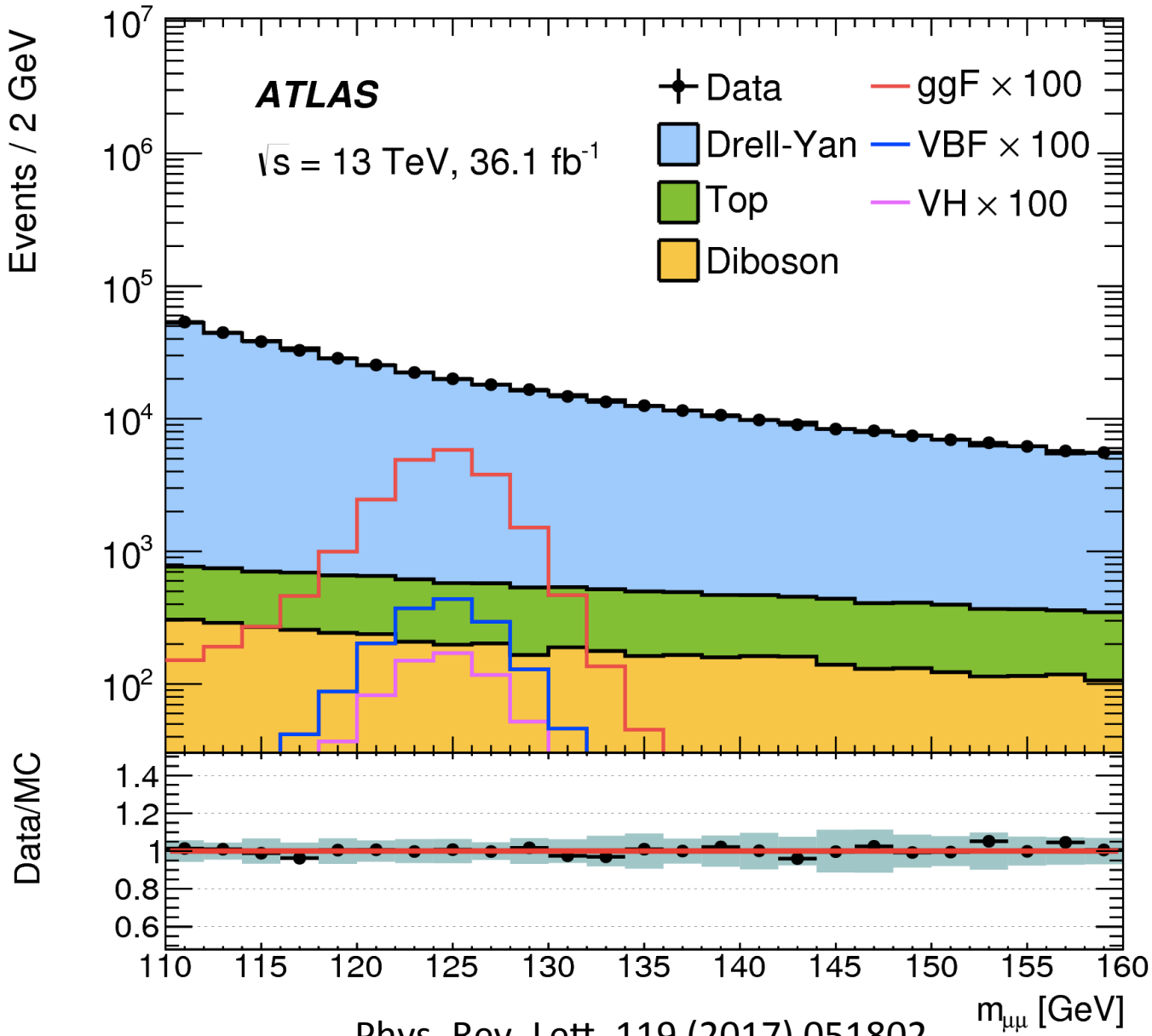
The measurement of the SM Higgs boson branching ratio to muons remains a challenge because the branching ratio is so low! We currently set upper limits.

CMS puts the limit on XS x BR at 2.92 times the SM prediction at the 95% confidence level.



PRL 122 (2019) 021801

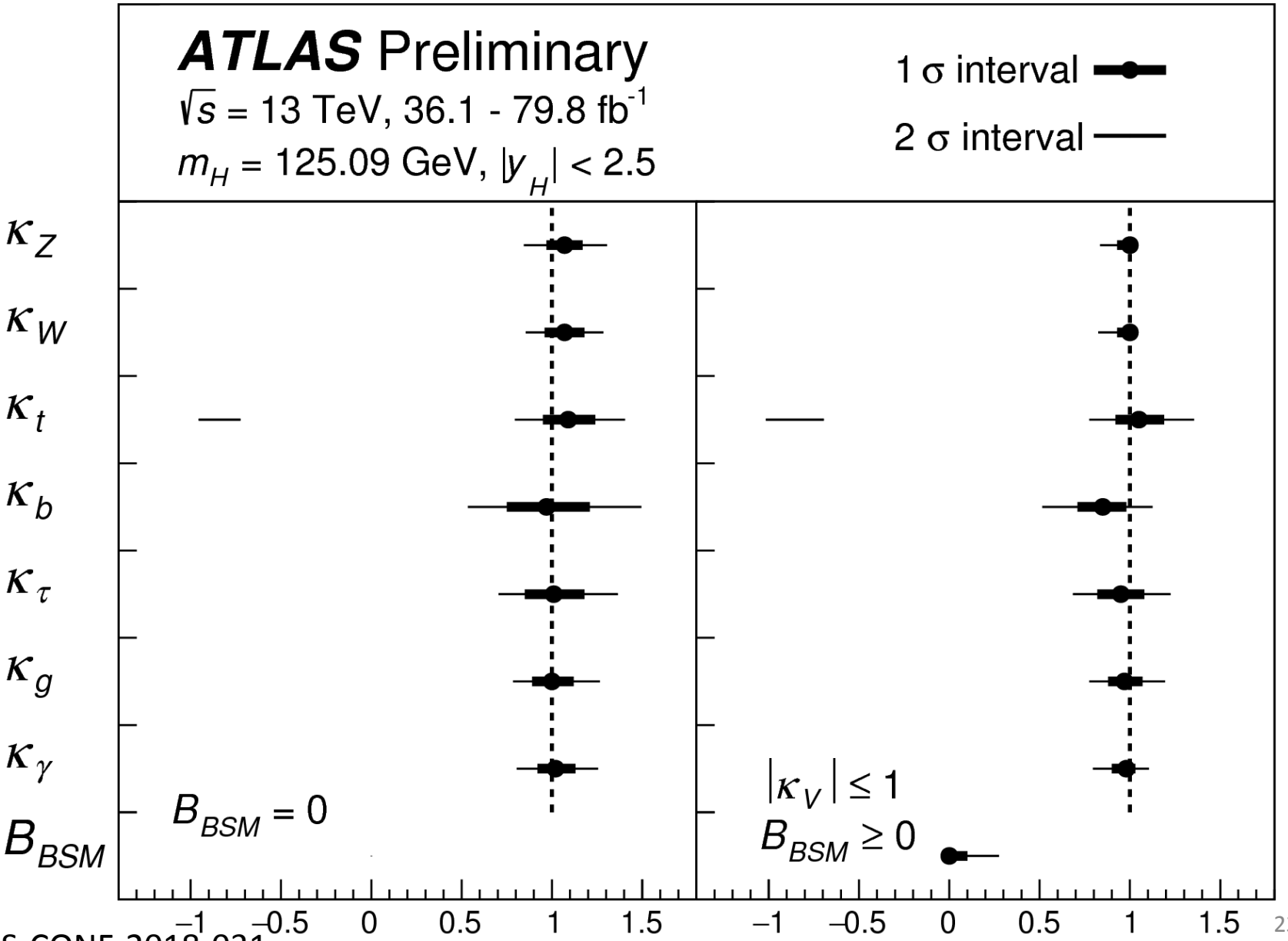
The ATLAS upper limit on XS x BR is at 2.8 times the SM prediction at 95% confidence level.



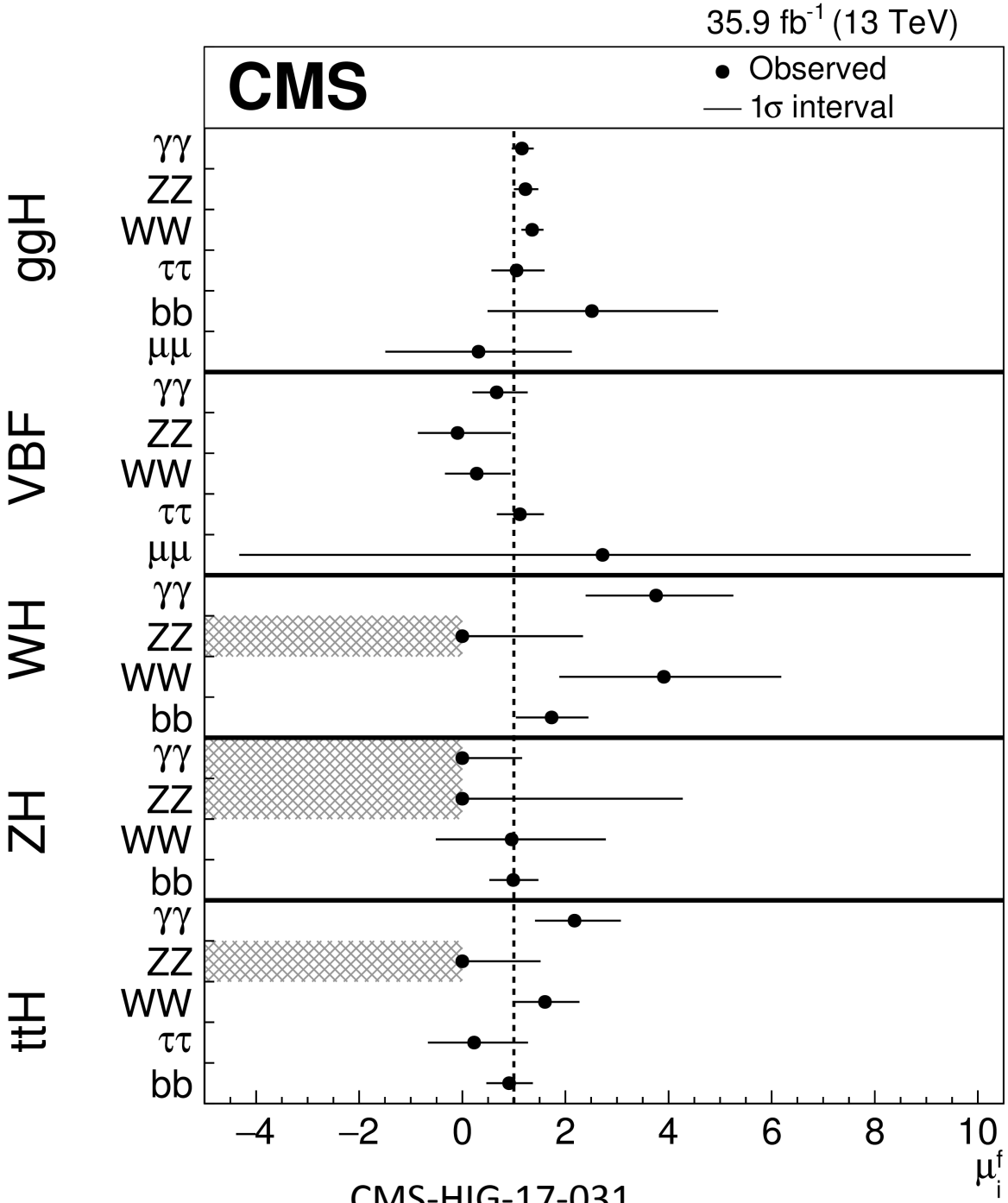
Phys. Rev. Lett. 119 (2017) 051802

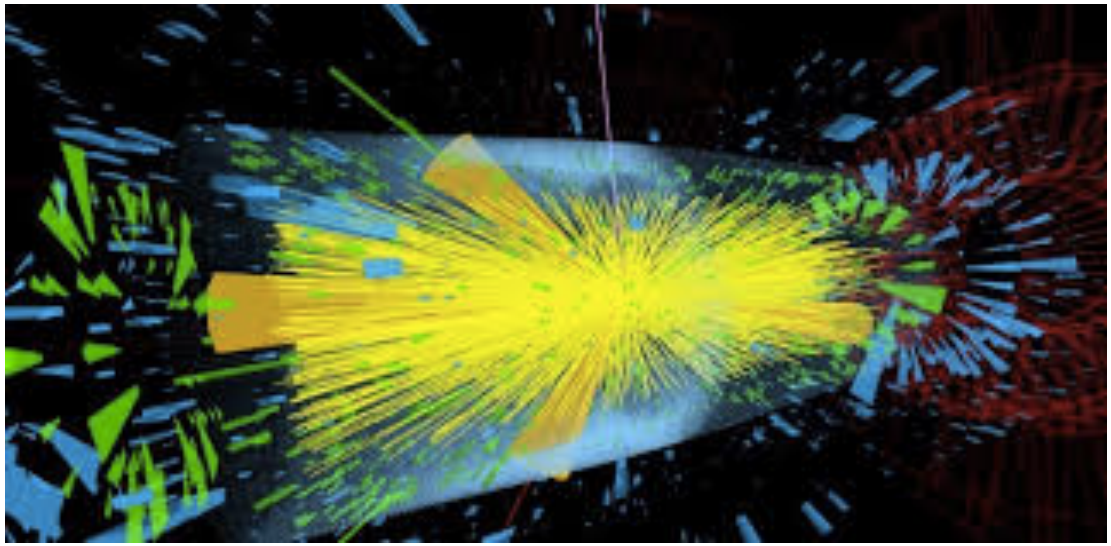
Summary Plots

With Run 2 data, the uncertainties are shrinking, and there are fewer places for new physics to hide.



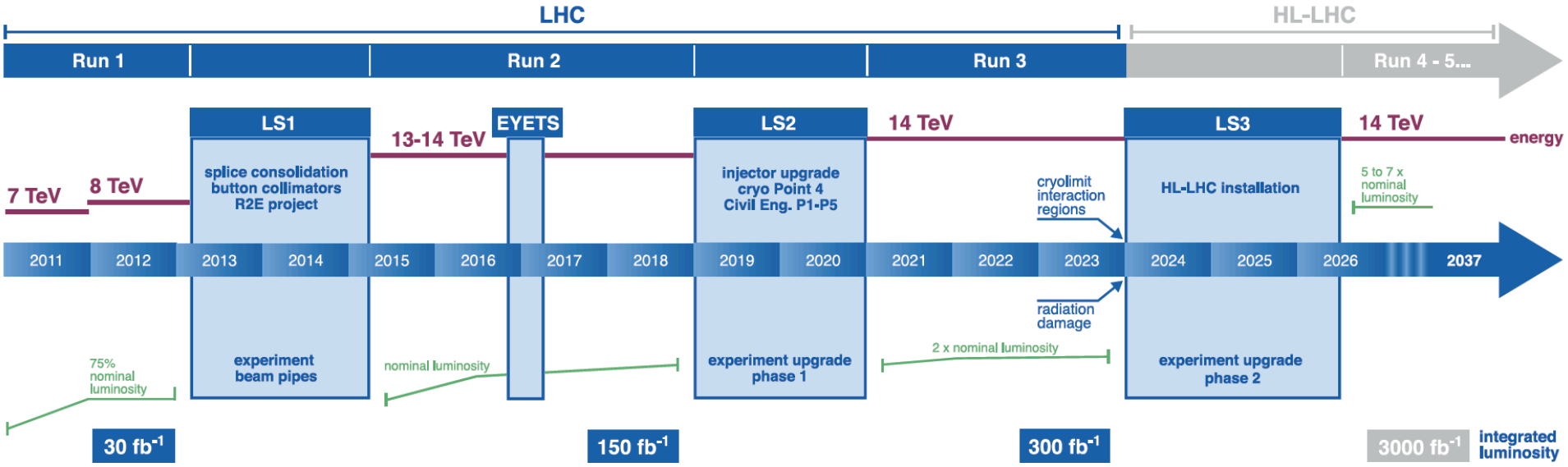
ATLAS-CONF-2018-031


35.9 fb-1 (13 TeV)
CMS
Observed
1σ interval
ggH
VBF
WH
ZH
ttH
γγ
ZZ
WW
ττ
bb
μμ
–4
–2
0
2
4
6
8
10
μ if
CMS-HIG-17-031



High Luminosity LHC (HL-LHC)

LHC / HL-LHC Plan



Detector improvements include:

- new silicon tracking detectors extending to higher eta
- tracking information available in trigger at earlier stage
- increased trigger bandwidth capabilities
- new timing detectors (central for CMS, forward for ATLAS)

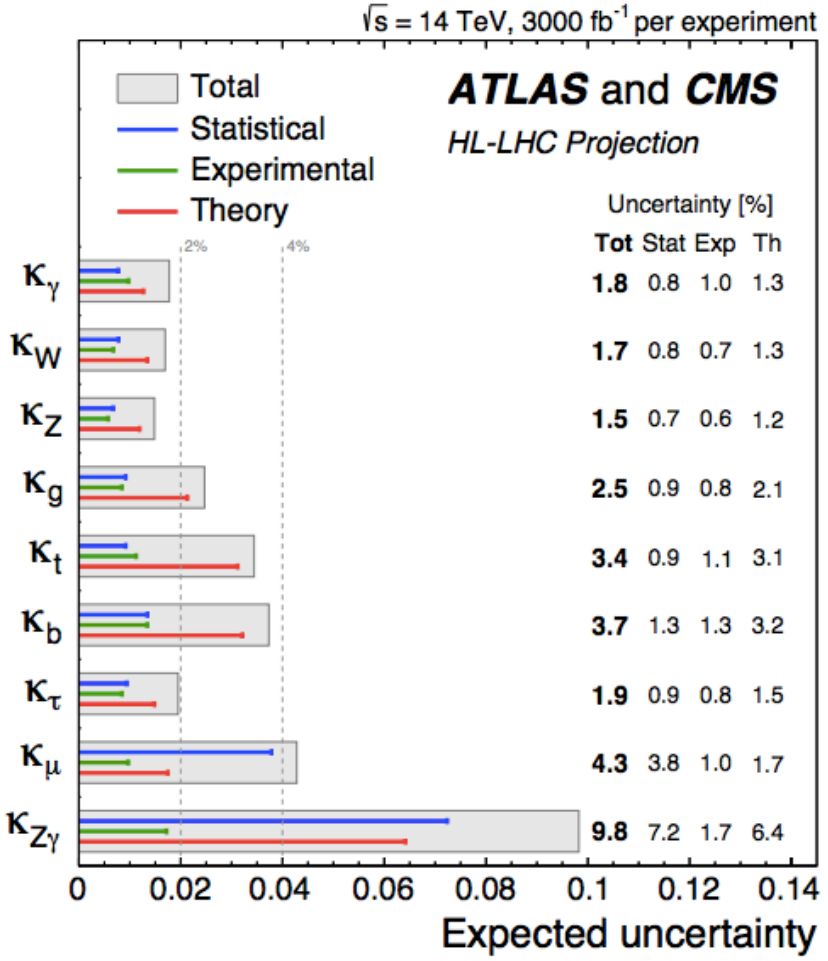
Projections: HL-LHC

A suite of physics projections were carried out as input to the European Strategy process for particle physics, including the predicted sensitivity to Higgs boson coupling measurements.

The benefit of the expected 3000 fb^{-1} and the importance of theory uncertainties can be seen in this ATLAS + CMS Higgs coupling combination.

Full suite of reports can be found here:

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop



Searches for

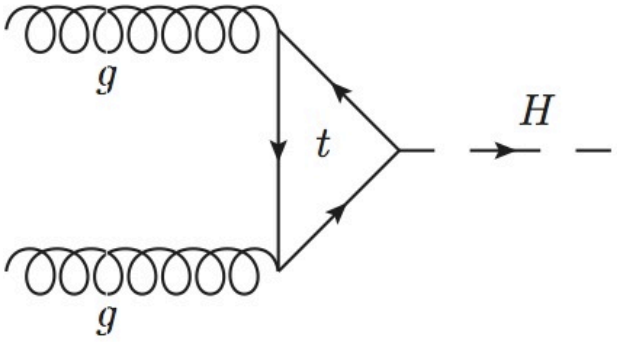
Lepton Flavor Violating

Decays of the Higgs boson

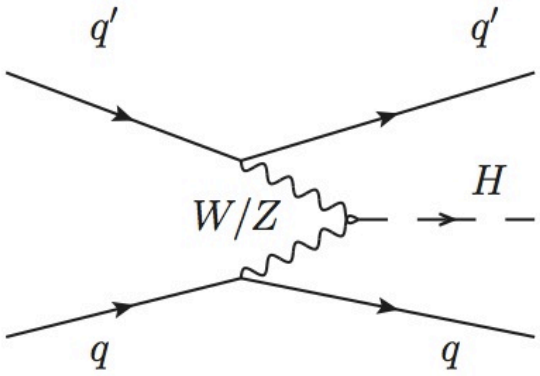
With the Higgs looking so SM-like, there is a suite of searches that uses the Higgs as a probe for new physics. Within in this program are **lepton flavor violating** searches.

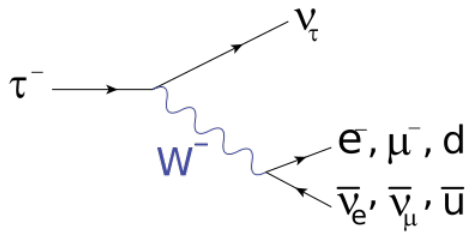
Lepton flavor violating Higgs boson couplings would allow $\tau \to \mu$ and $\tau \to e$ decays via a virtual Higgs boson.

gluon-gluon fusion production provides high statistics and particularly sensitive **boosted** categories.



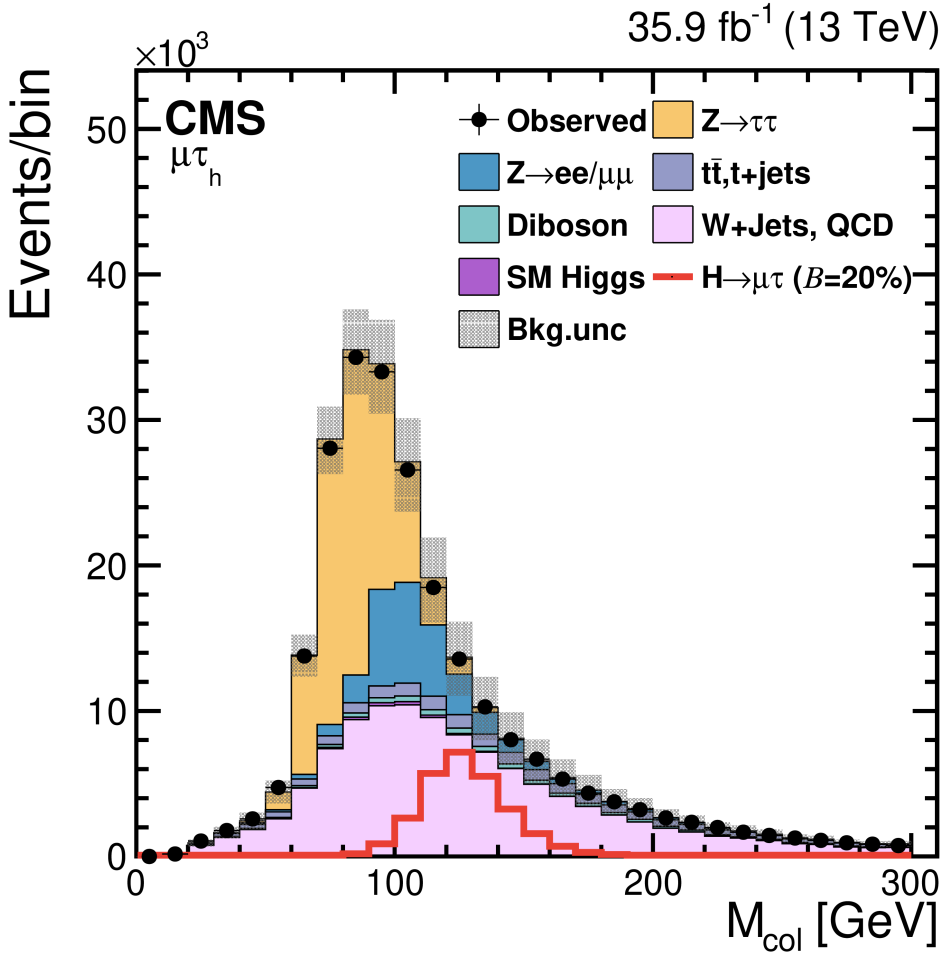
Vector boson fusion signatures are included when the additional **two jets** are present.

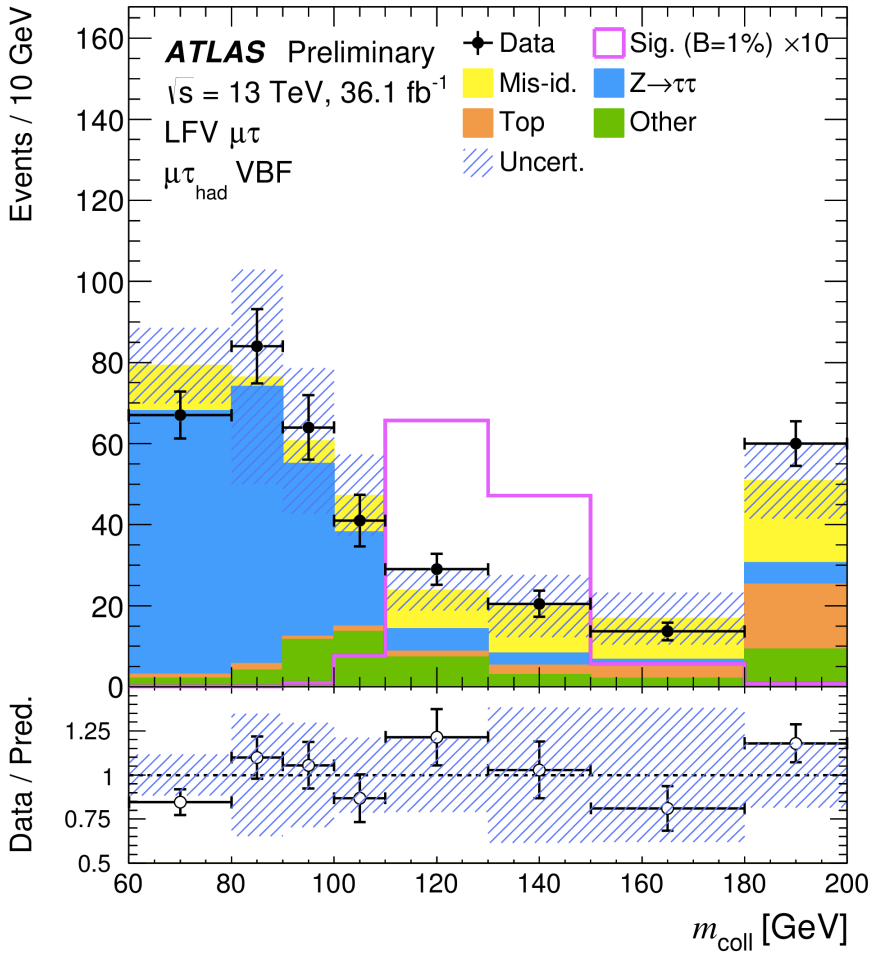




Both the fully-leptonic and semi-hadronic decay modes are used for the searches

Example distribution of signal sample and backgrounds, showing separation in mass of decay products for $\mu\tau_h$.

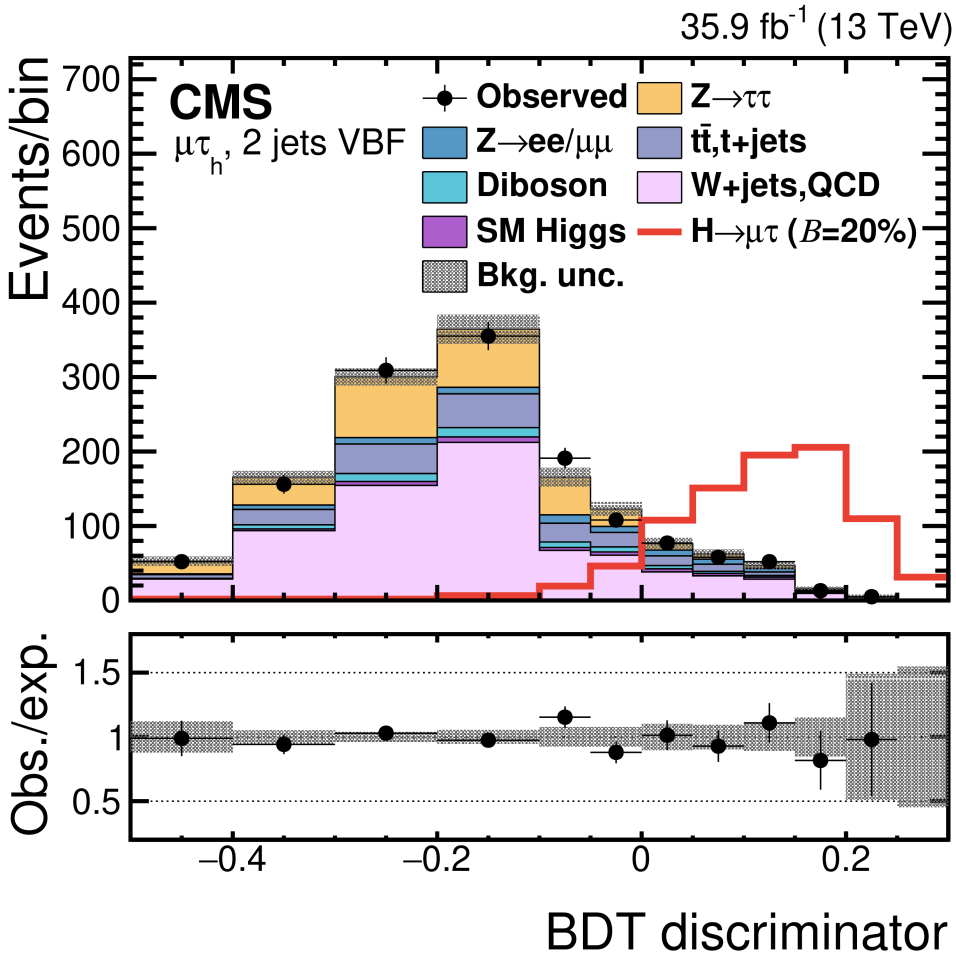


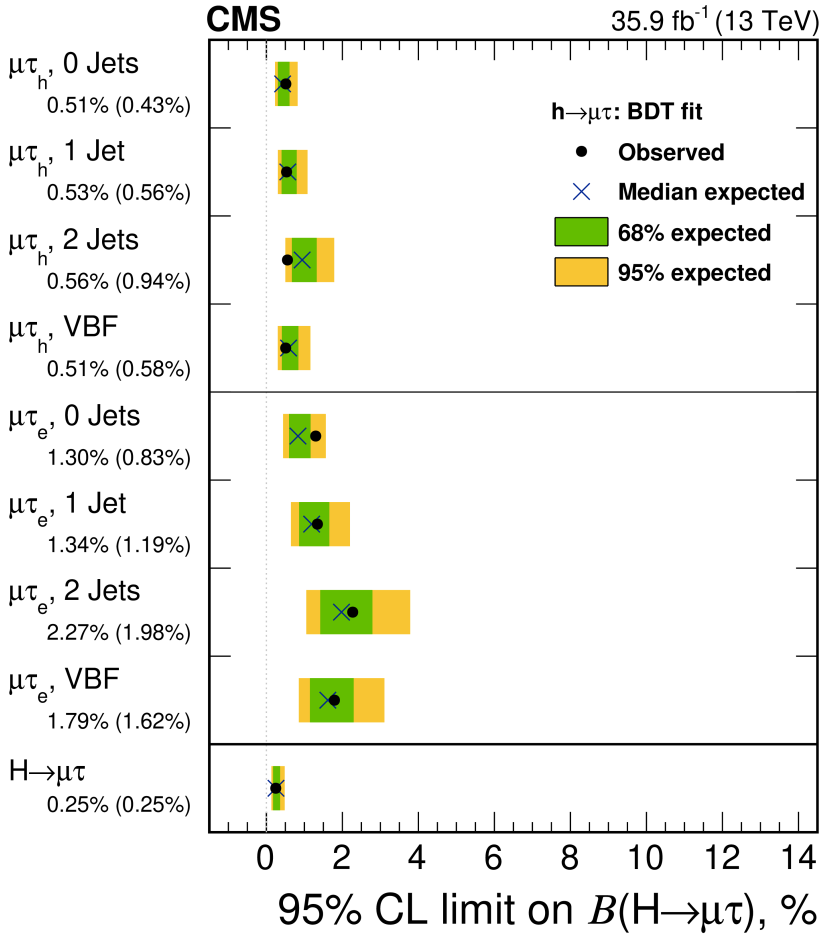


J. High Energ. Phys. (2018) 2018: 1

ATLAS-CONF-2019-013

A BDT discriminator is used in categories defined by ggF (with 0, 1, or 2 jets) and VBF (with 2 jets). The VBF category for for $\mu\tau_e$ is shown below. The 95% confidence limit on the BR for H-> $\mu\tau$ is shown on the right.

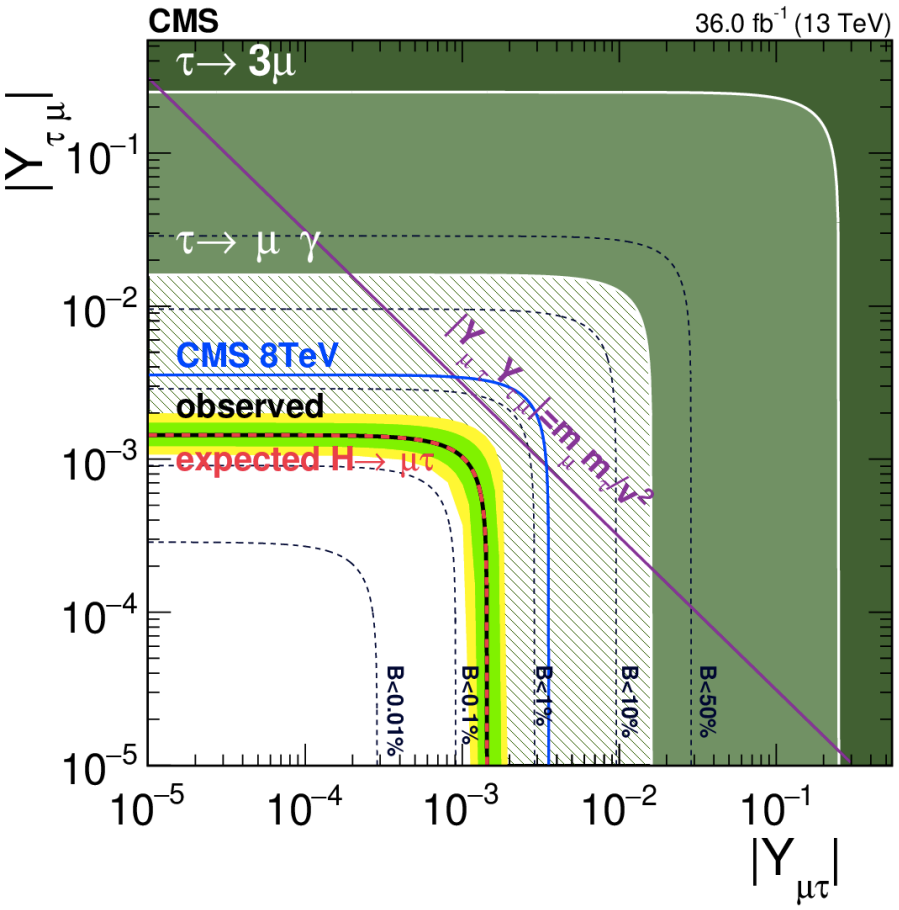


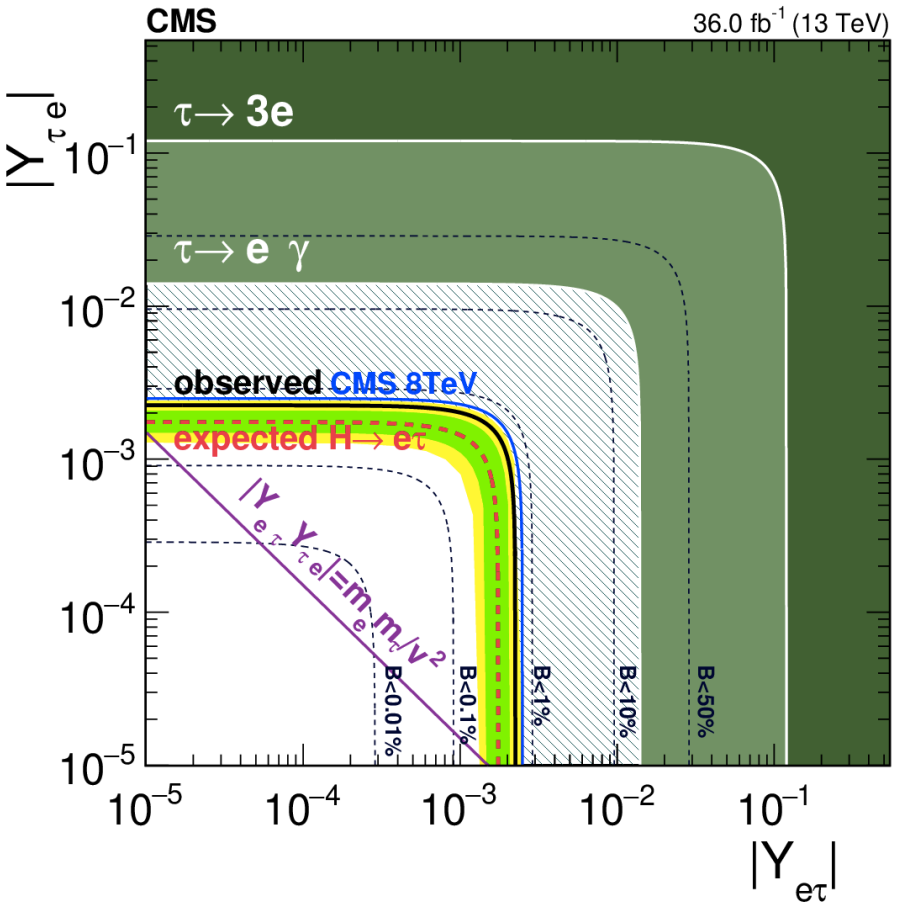


J. High Energ. Phys. (2018) 2018: 1

Results: CMS

Upper limits are placed on the allowed lepton flavor violating decays of the Higgs boson to μτ and eτ at fractions of a percent.





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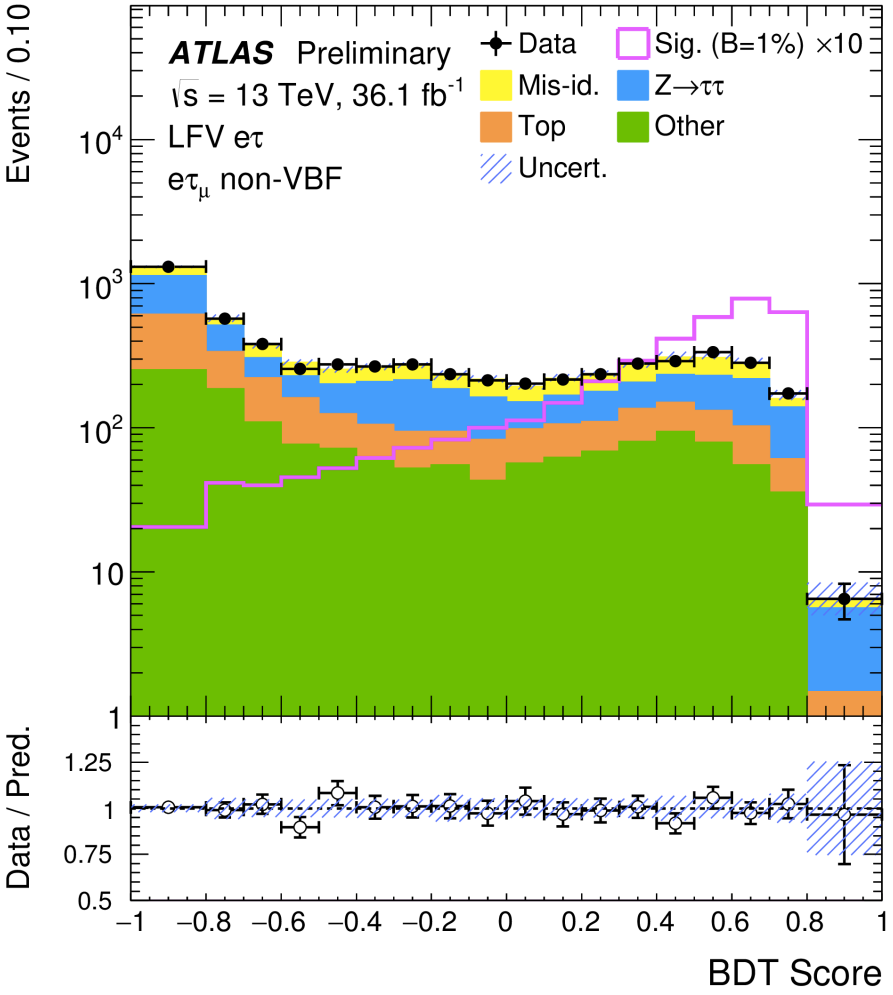
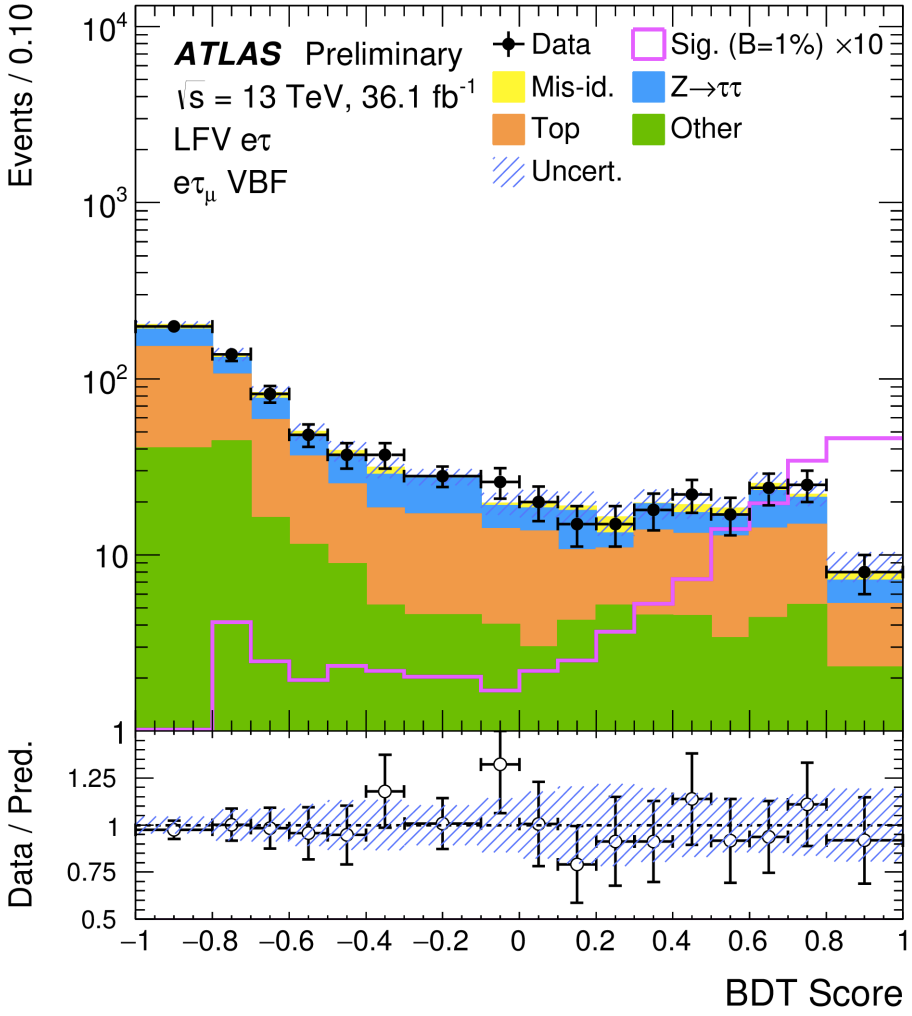
The BDT score for signal and backgrounds are shown in the $e\tau_\mu$ categories of non-VBF (left) and VBF (right).





new this week!

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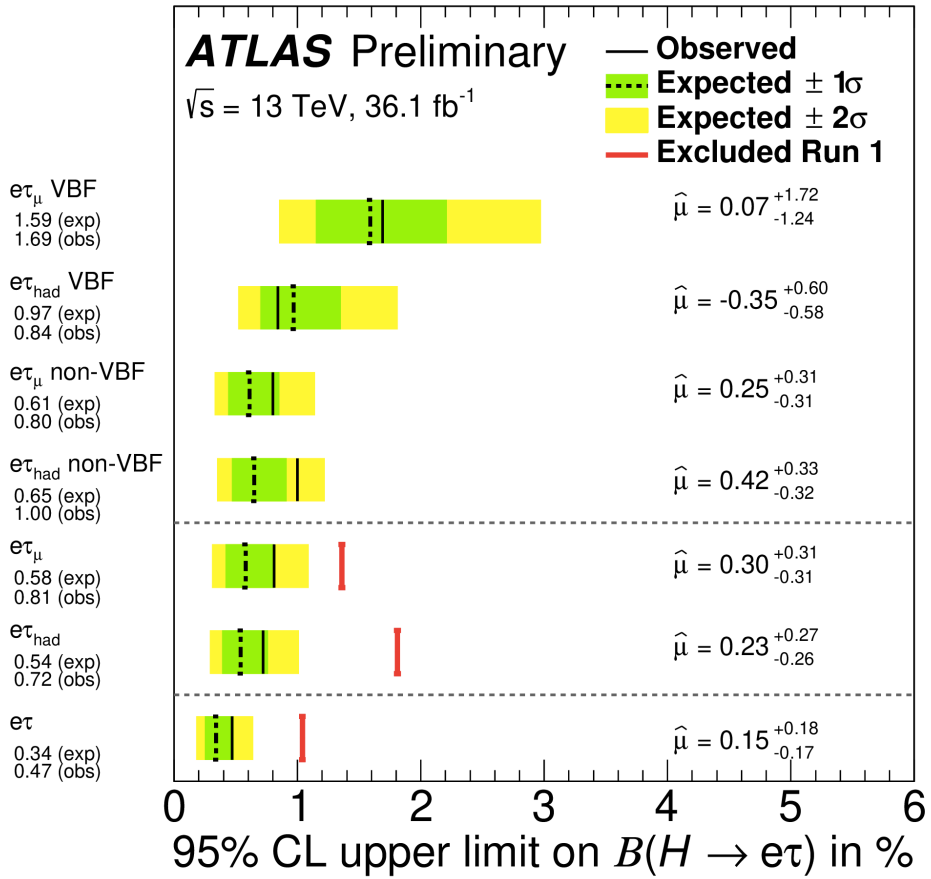
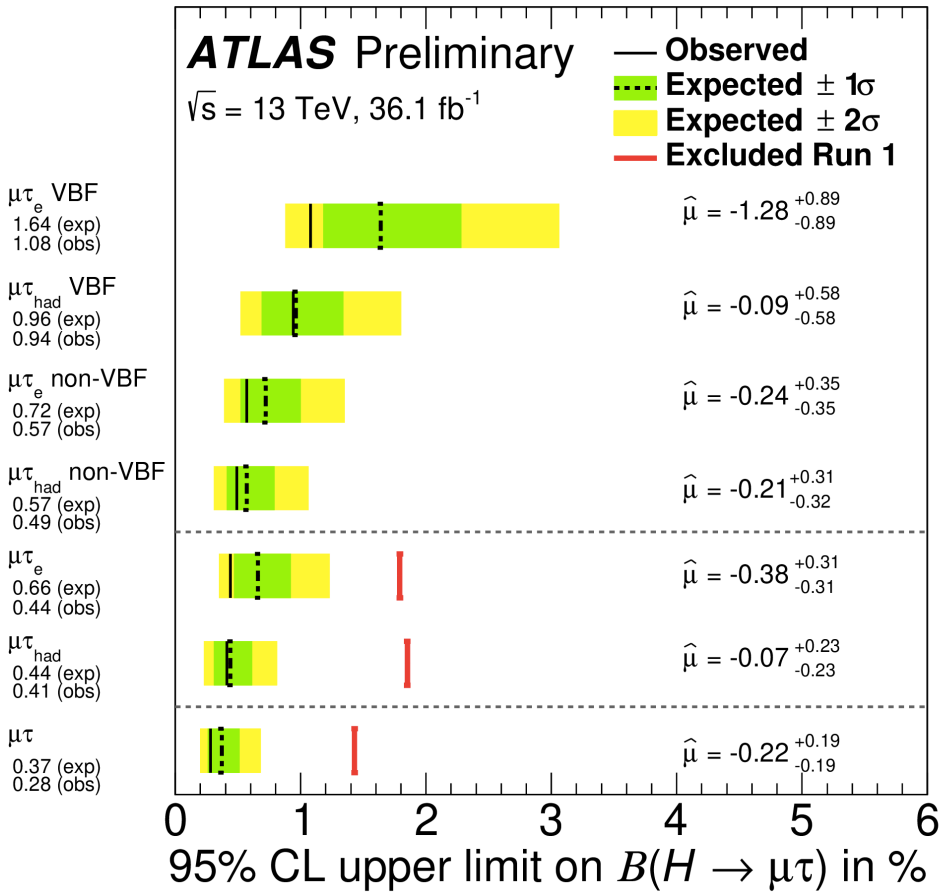
Results: ATLAS





new this week!

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Summary

- ATLAS and CMS continue to improve our understanding of the Higgs boson production and decay mechanisms.
- With the Higgs boson behaving very SM-like, we can use it as a probe for new physics
- Looking ahead, we will have an order of magnitude more data and extremely powerful detectors in the HL-LHC era. Our Higgs boson measurements will be pushing the theory predictions as we better characterize this particle and use it to hunt for new physics.

Thanks for your attention!