



Run: 484466

Event: 3913031636

2024-09-13 05:46:24 CEST

Evidence of $H \rightarrow \mu\mu$ from ATLAS experiment

Hongtao Yang (杨洪洮)

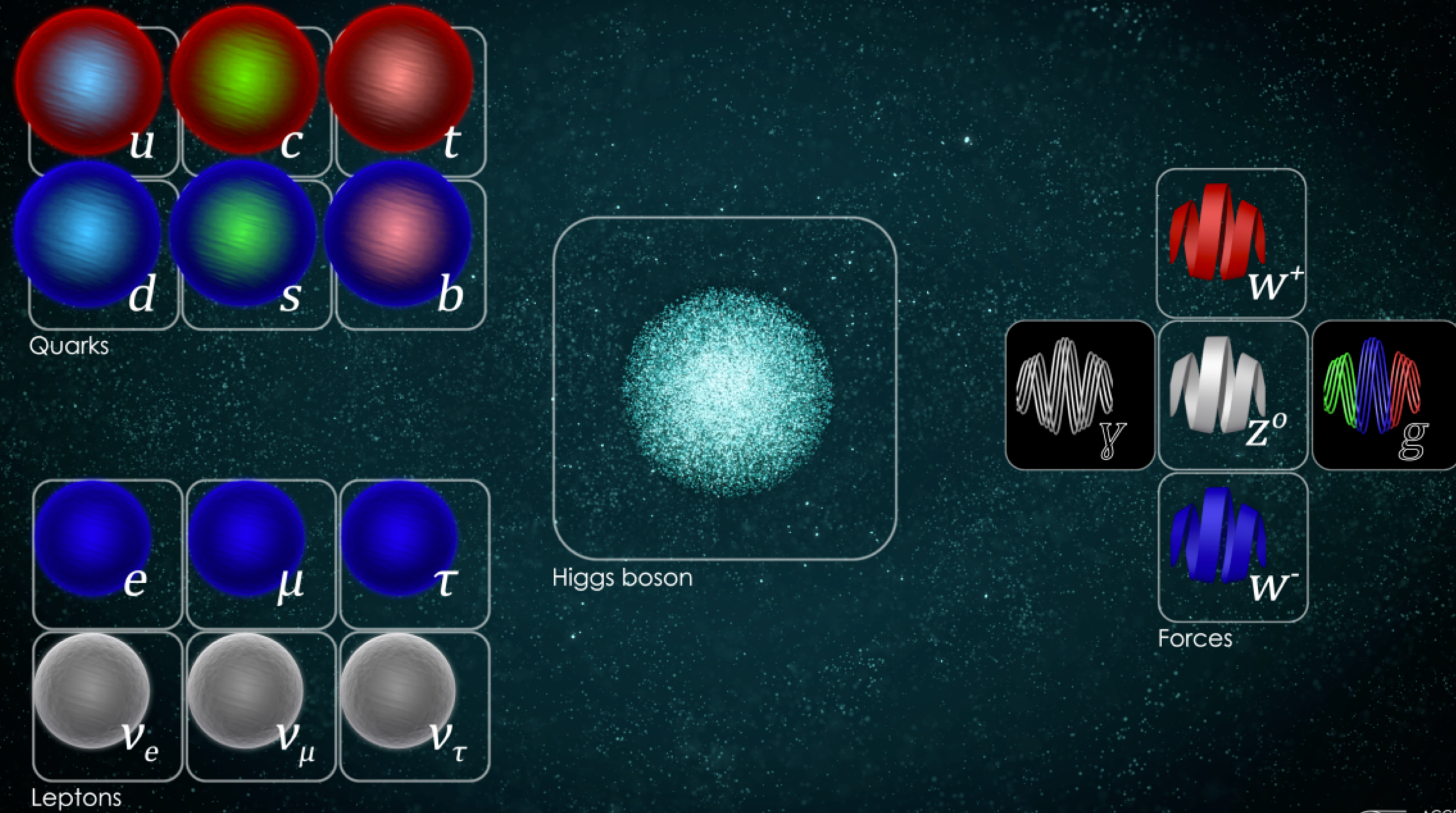
University of Science and Technology of China

Central China Normal University

November 12, 2025

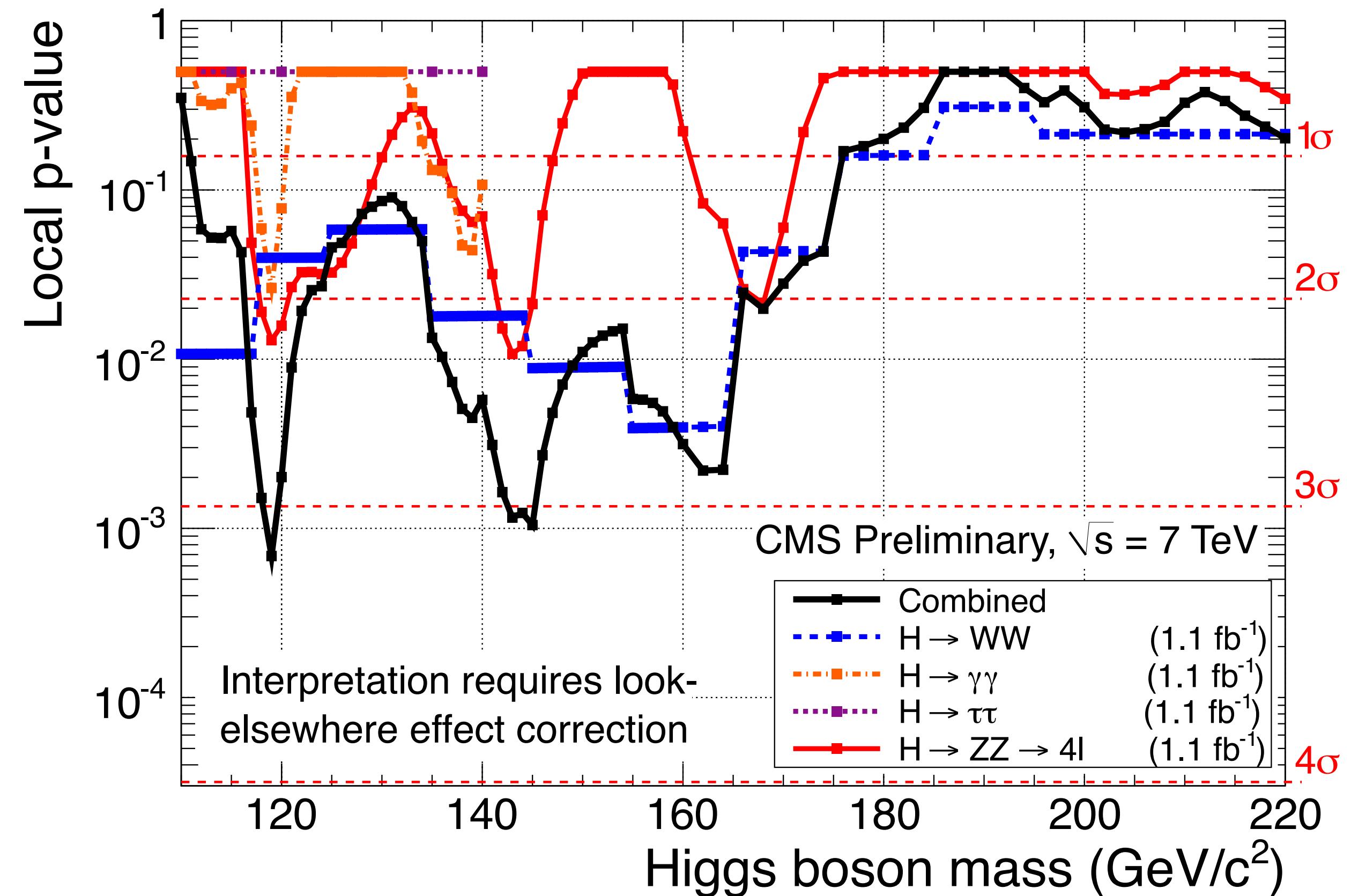
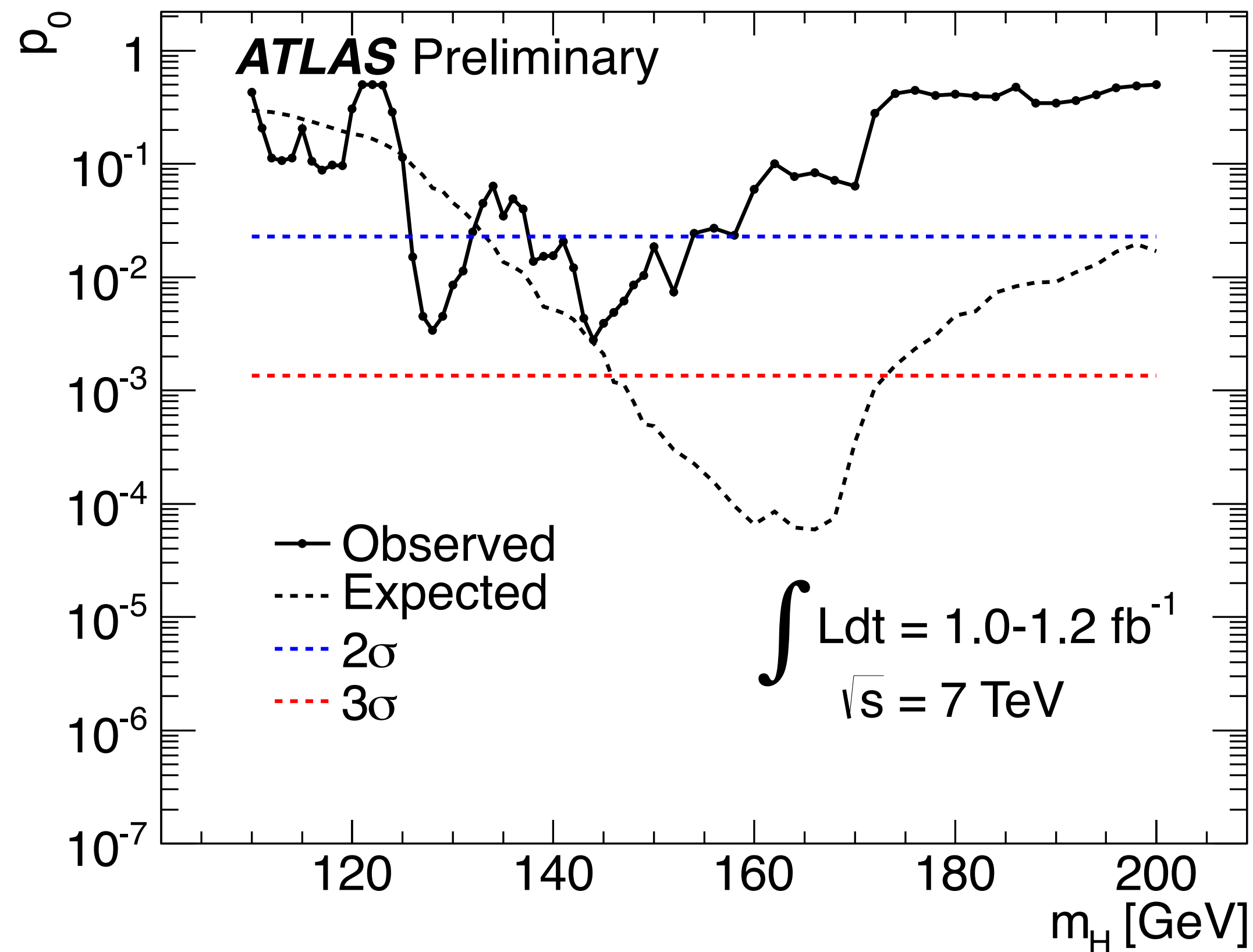


Higgs boson



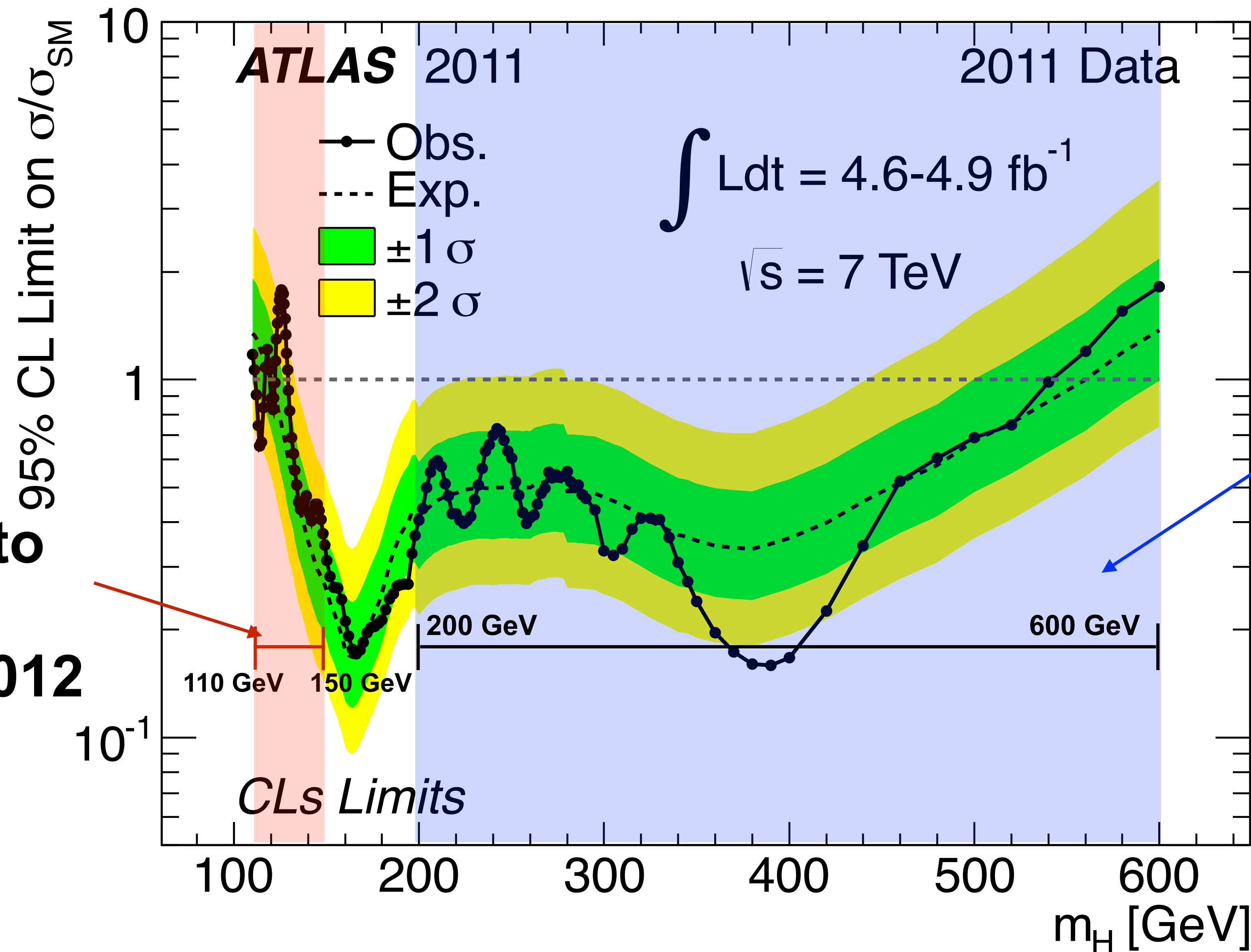


How I got started



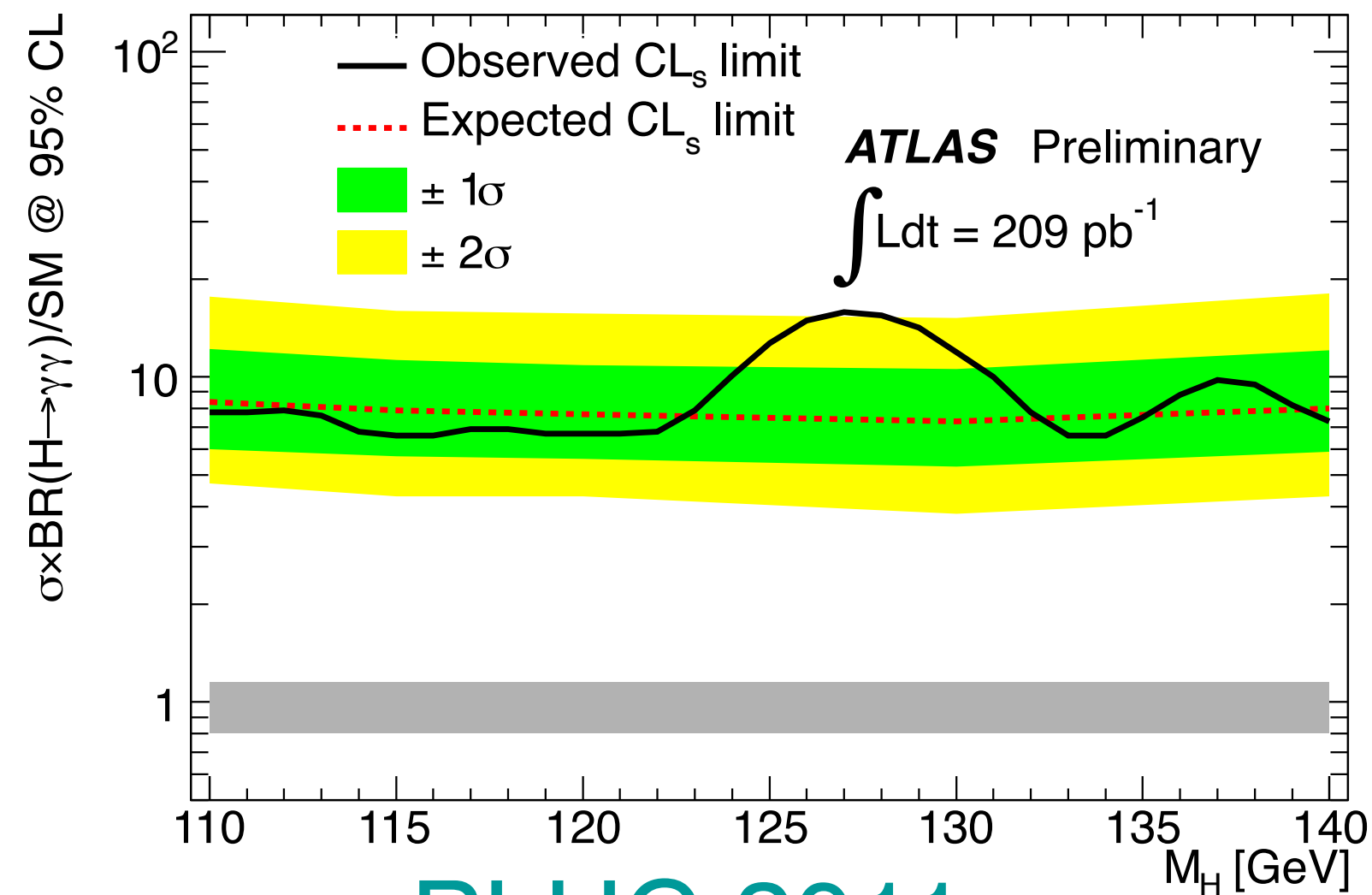
- An excess around 140 GeV in summer 2011: observed in early LHC 7 TeV data by both ATLAS and CMS
- I decided to give up everything at Madison, and start working at CERN full-time. My supervisor supported me
 - However, the excess vanished shortly afterwards...

Moved to
 $H \rightarrow \gamma\gamma$
since 2012

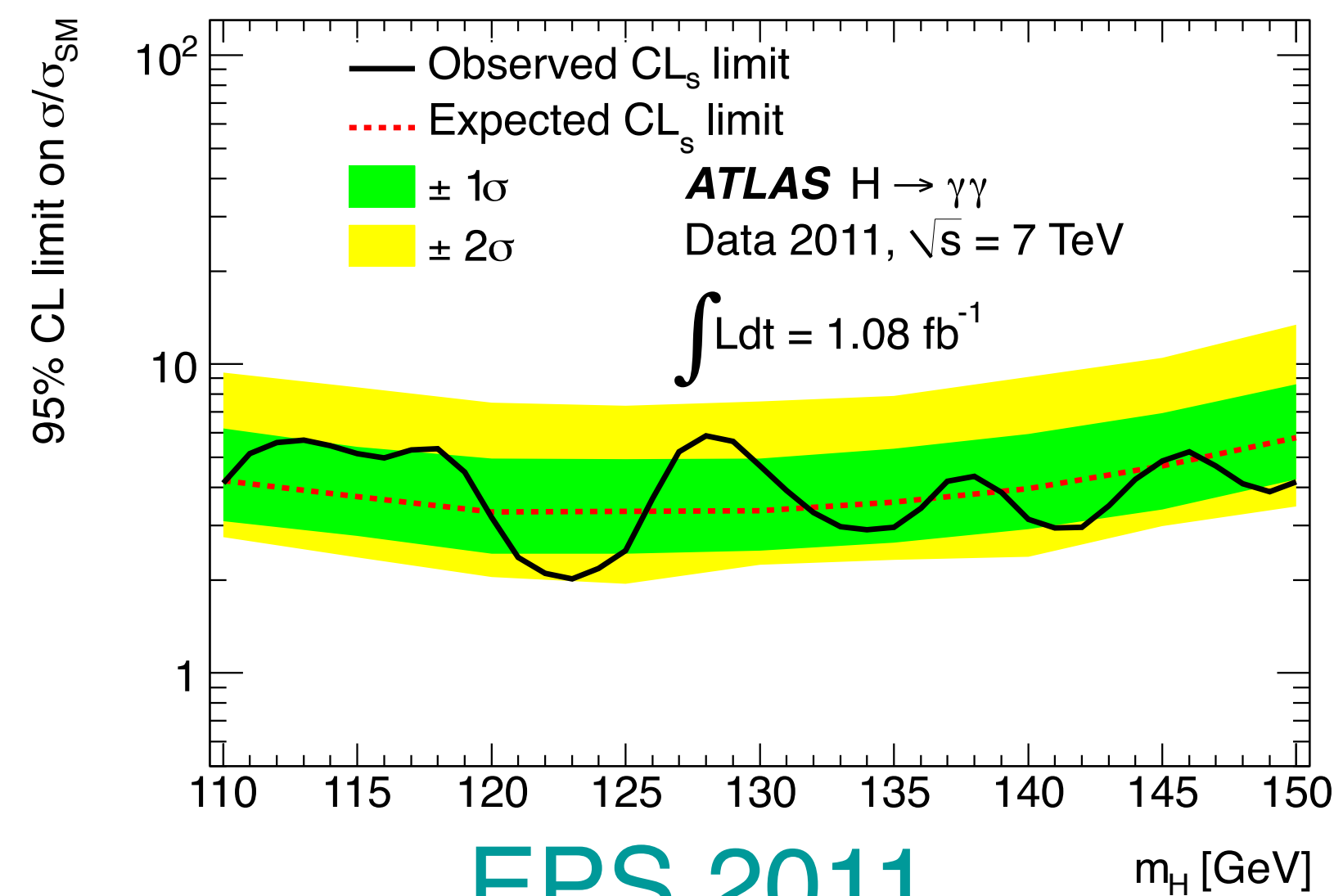


Focused on high mass searches in $H \rightarrow ZZ \rightarrow ll\nu\nu$ and $llqq$ channels, until the high mass range was mostly excluded

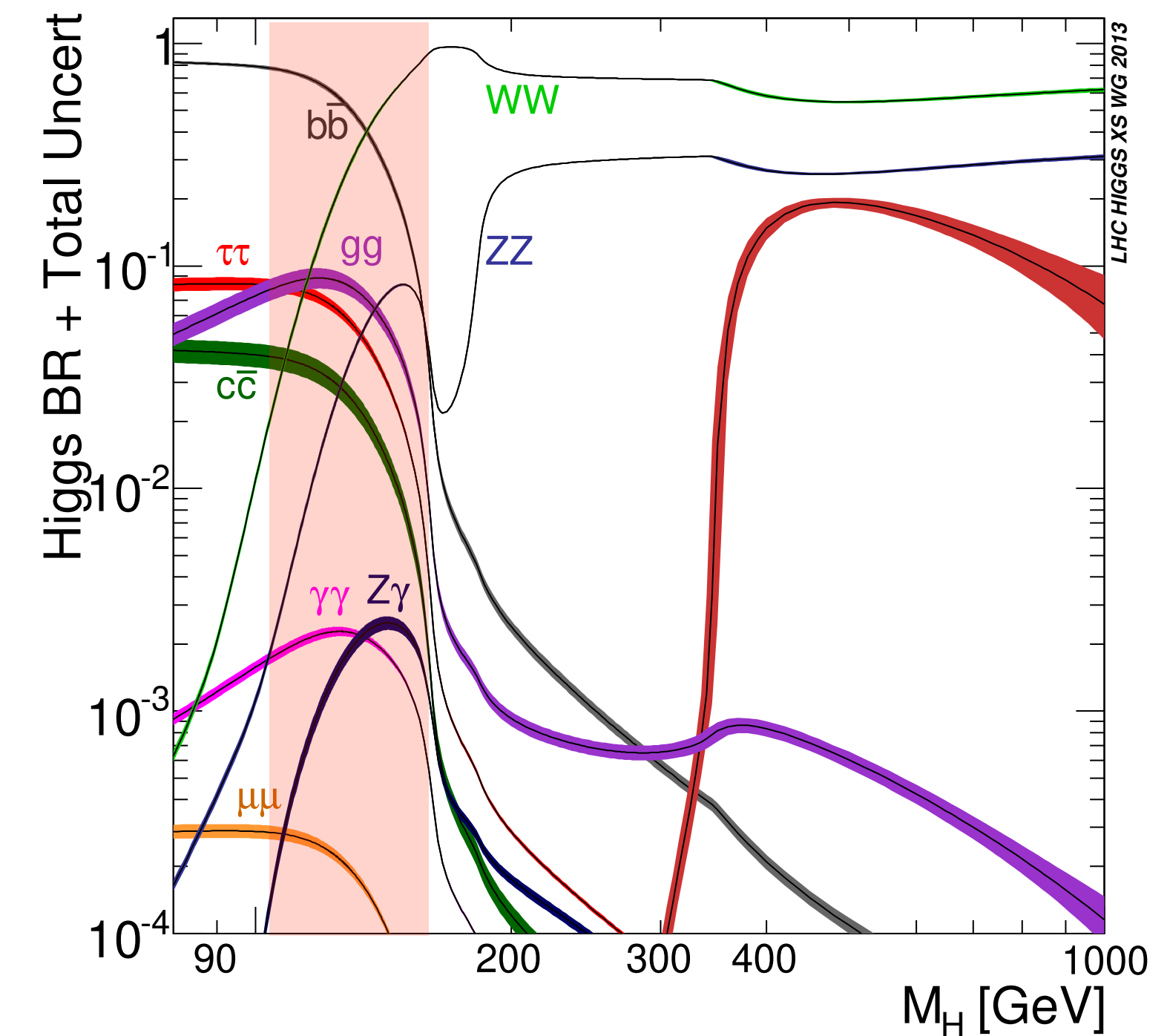
$H \rightarrow \gamma\gamma$ (r)evolution



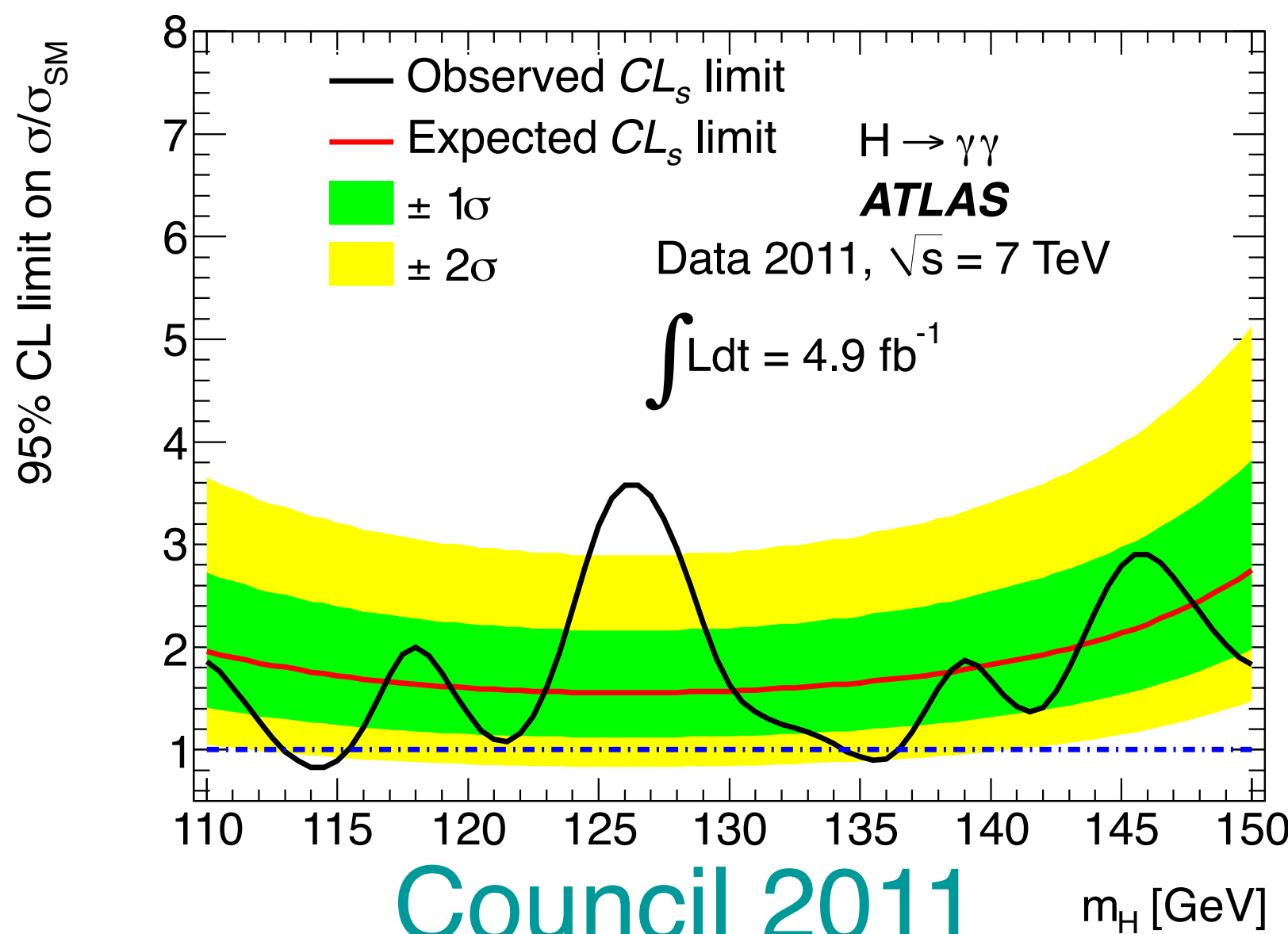
PLHC 2011



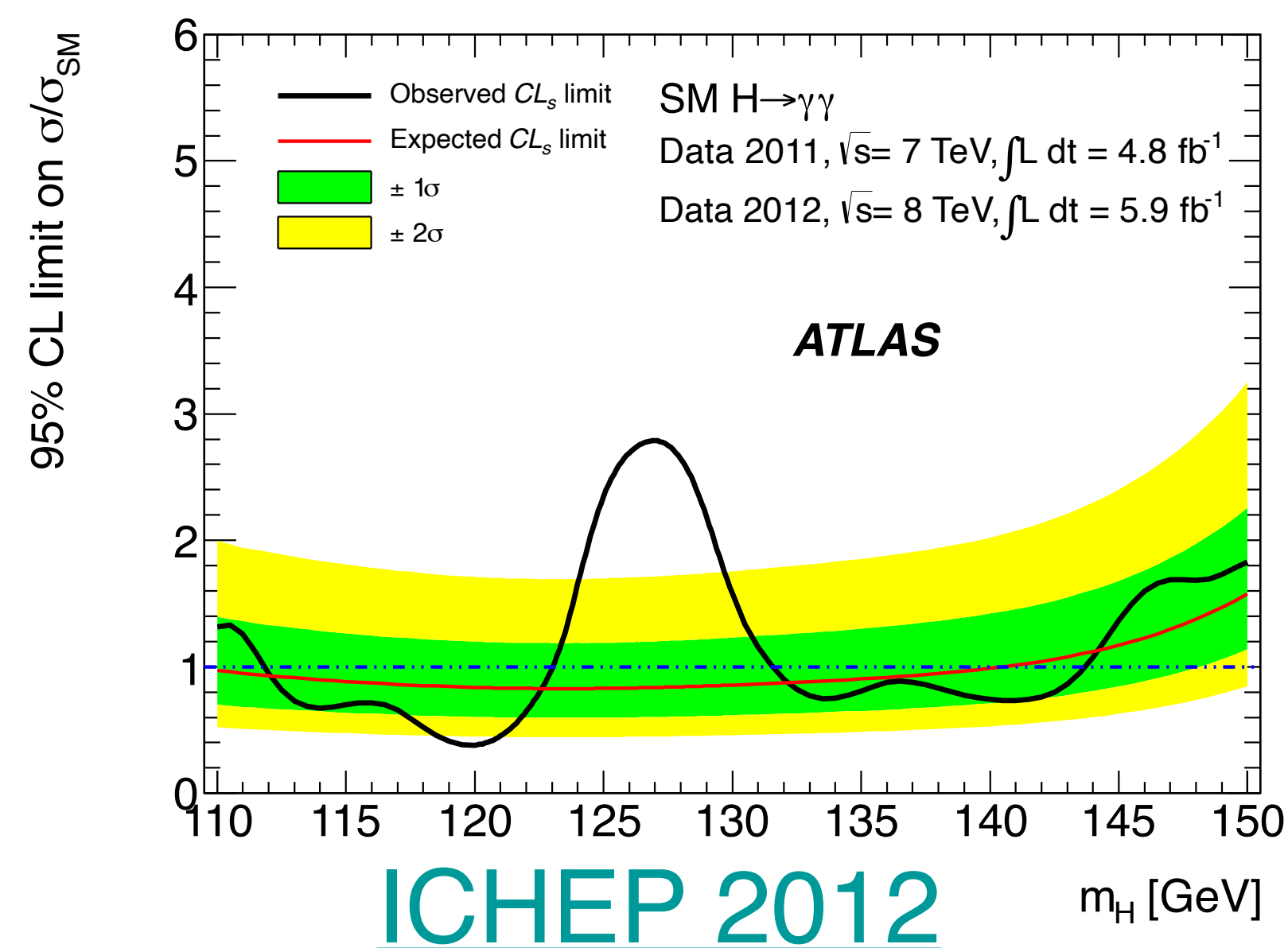
EPS 2011



- Covering the right m_H range

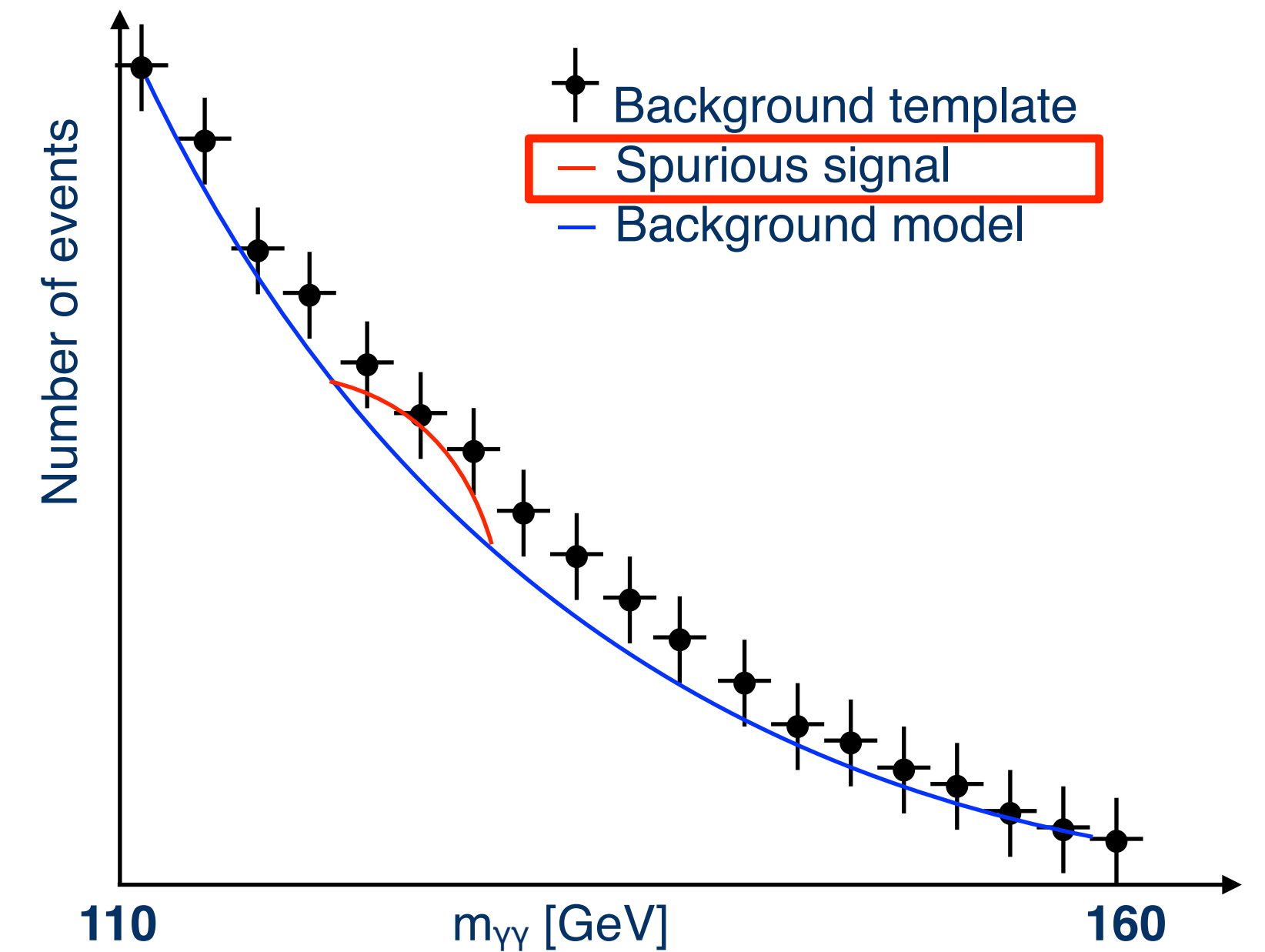
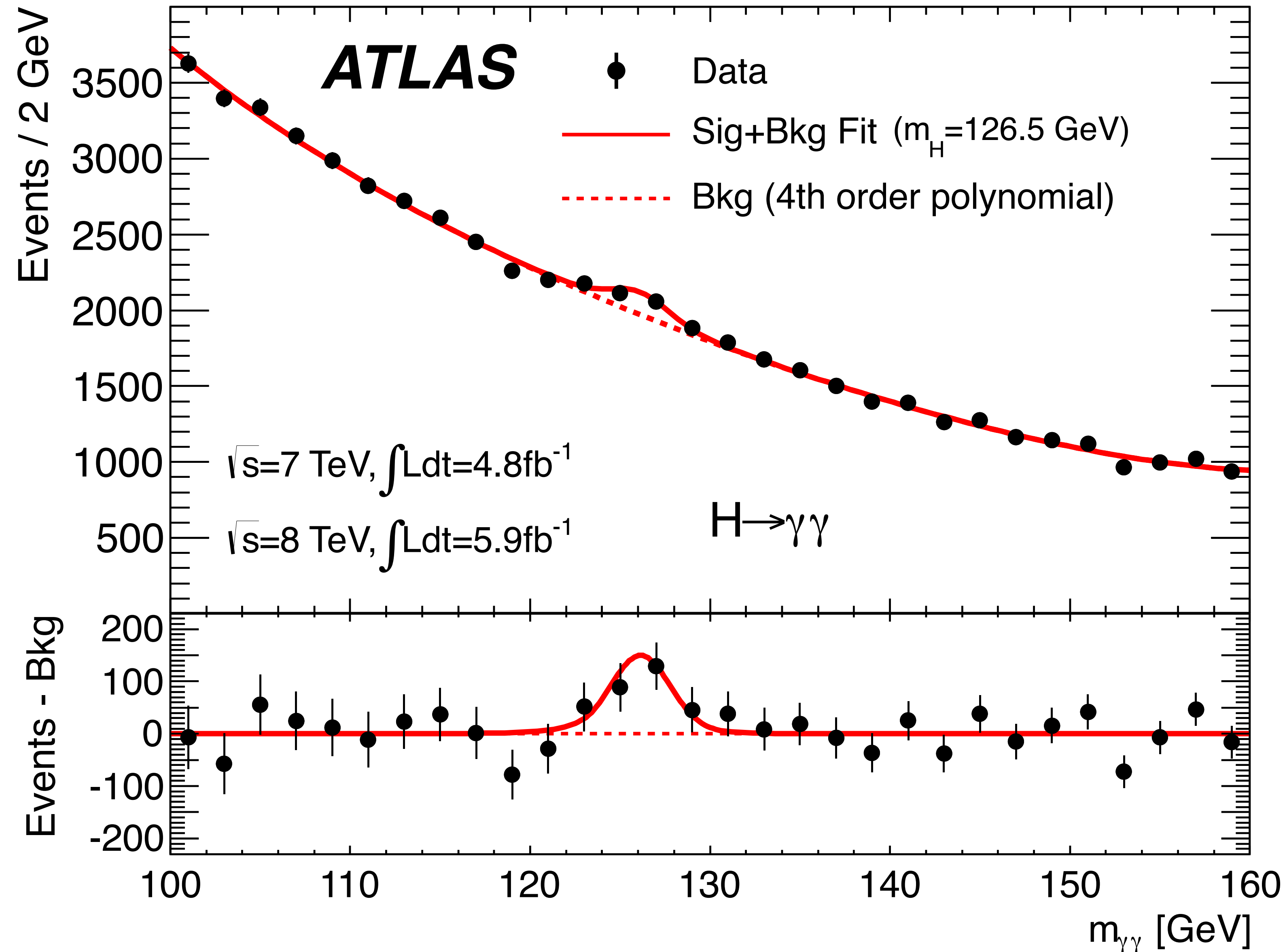


Council 2011

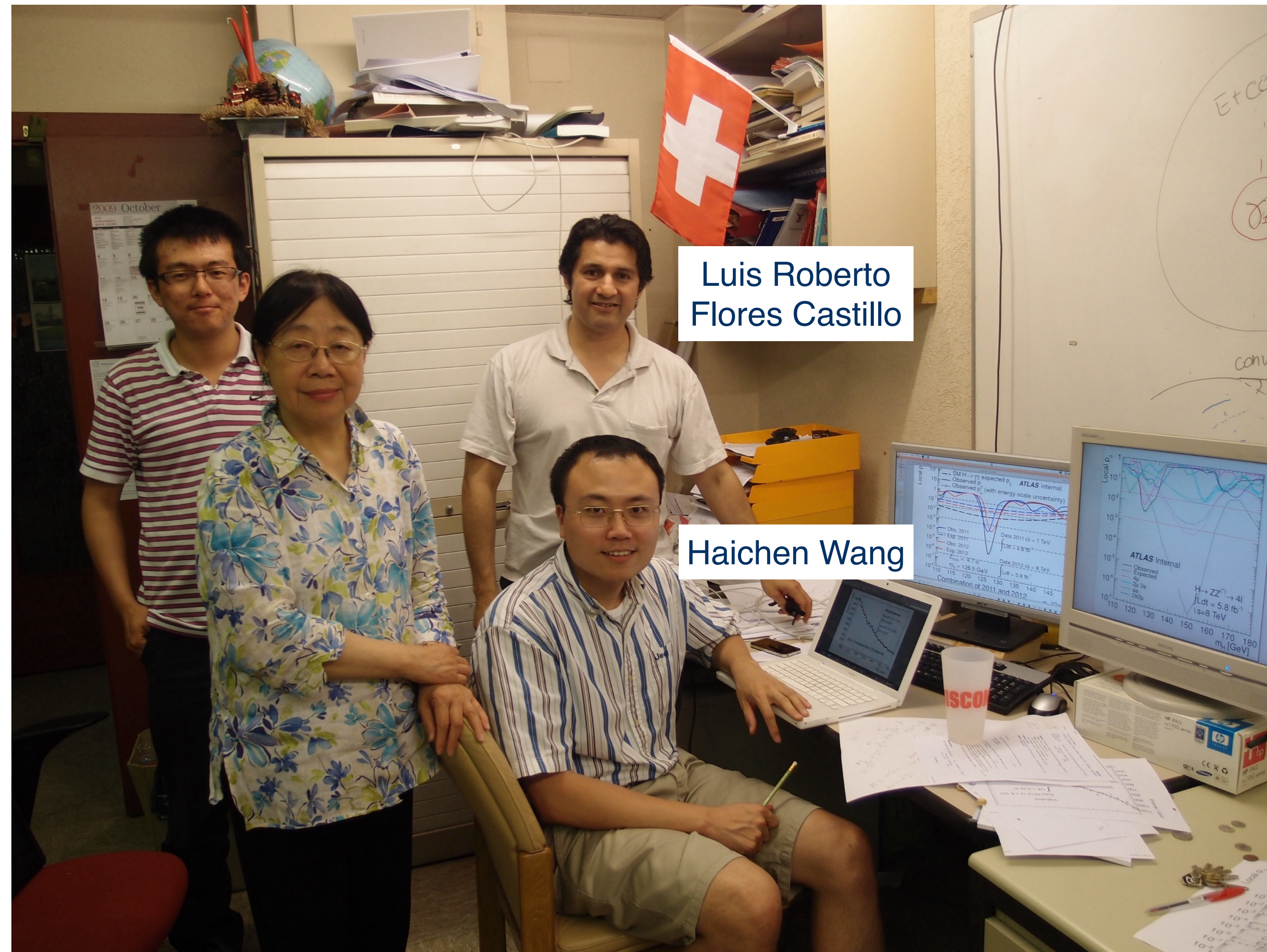


ICHEP 2012

H $\rightarrow\gamma\gamma$ channel

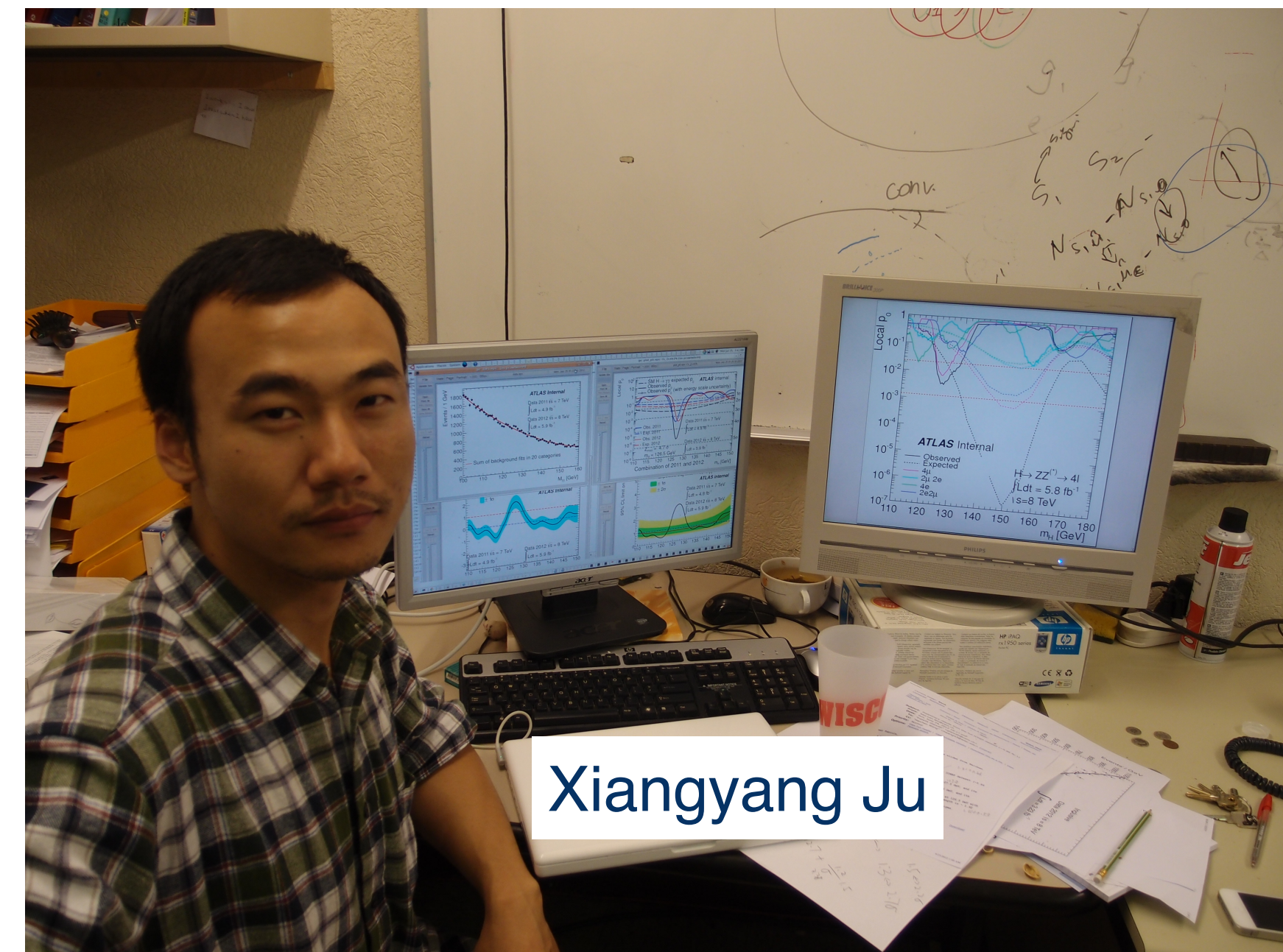


- Search for **resonant peak** on top of **smoothly falling background**
 - Data-driven background estimation preferred
 - Background modeling procedure became a key challenge



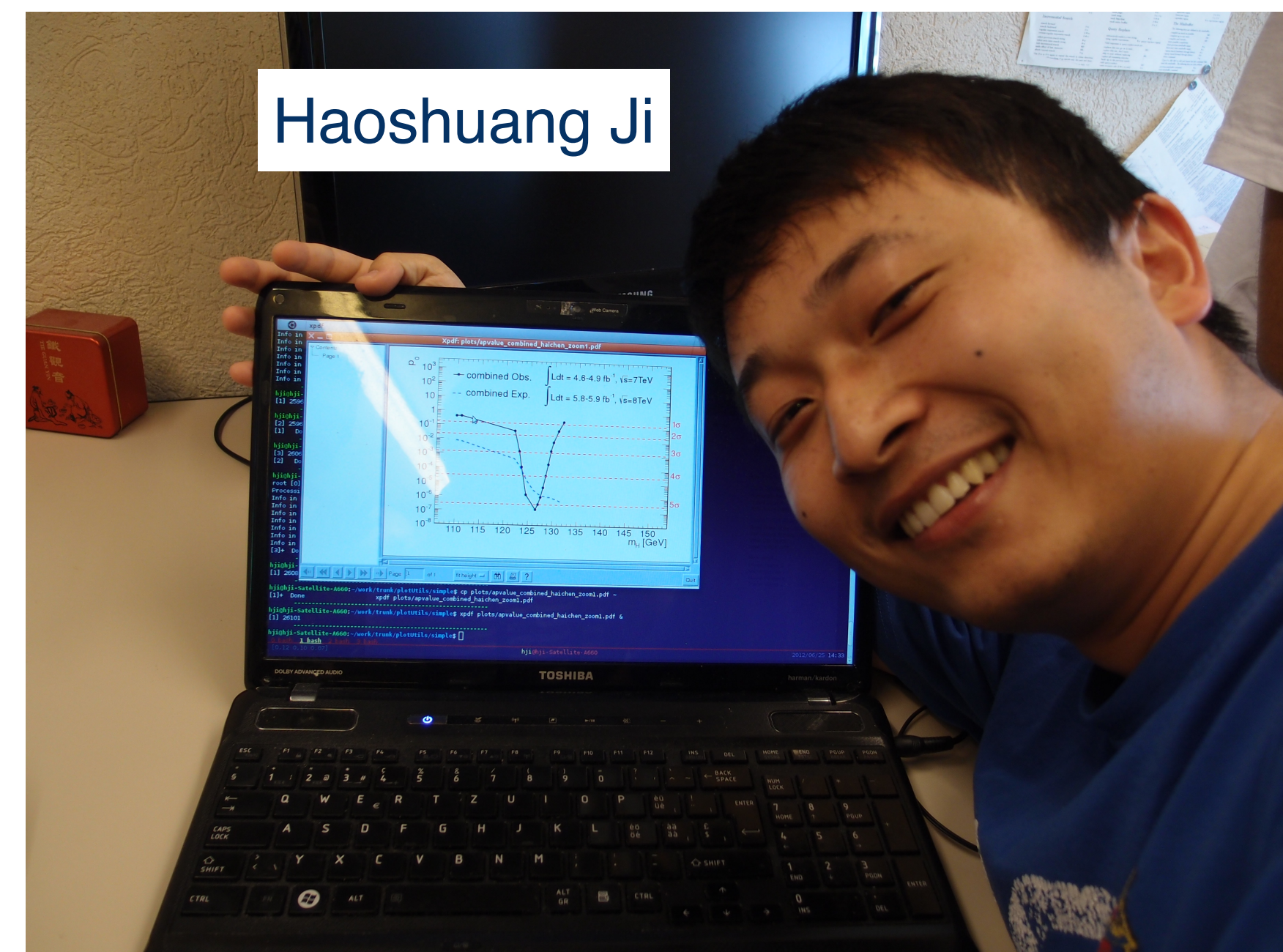
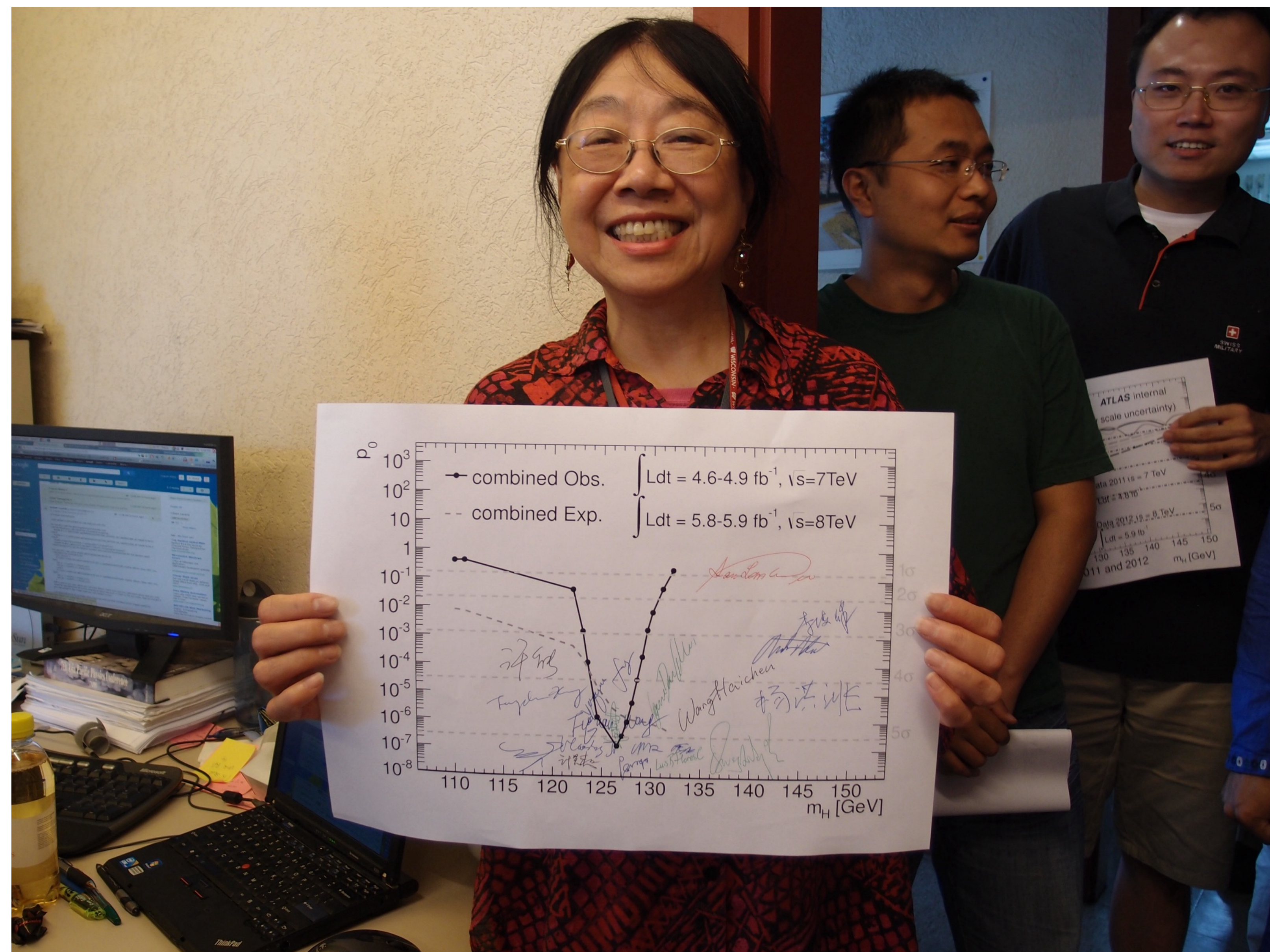
Luis Roberto
Flores Castillo

Haichen Wang



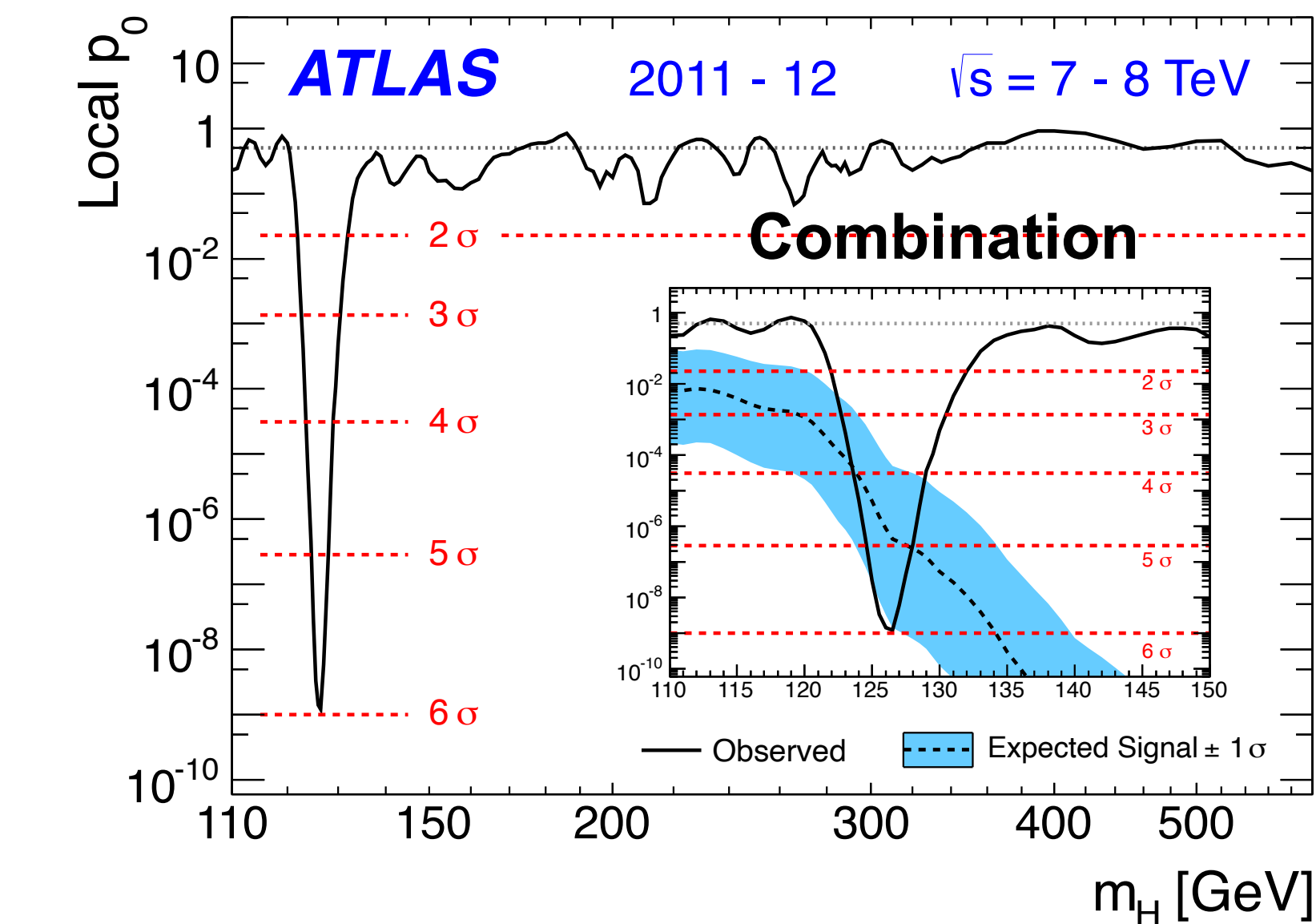
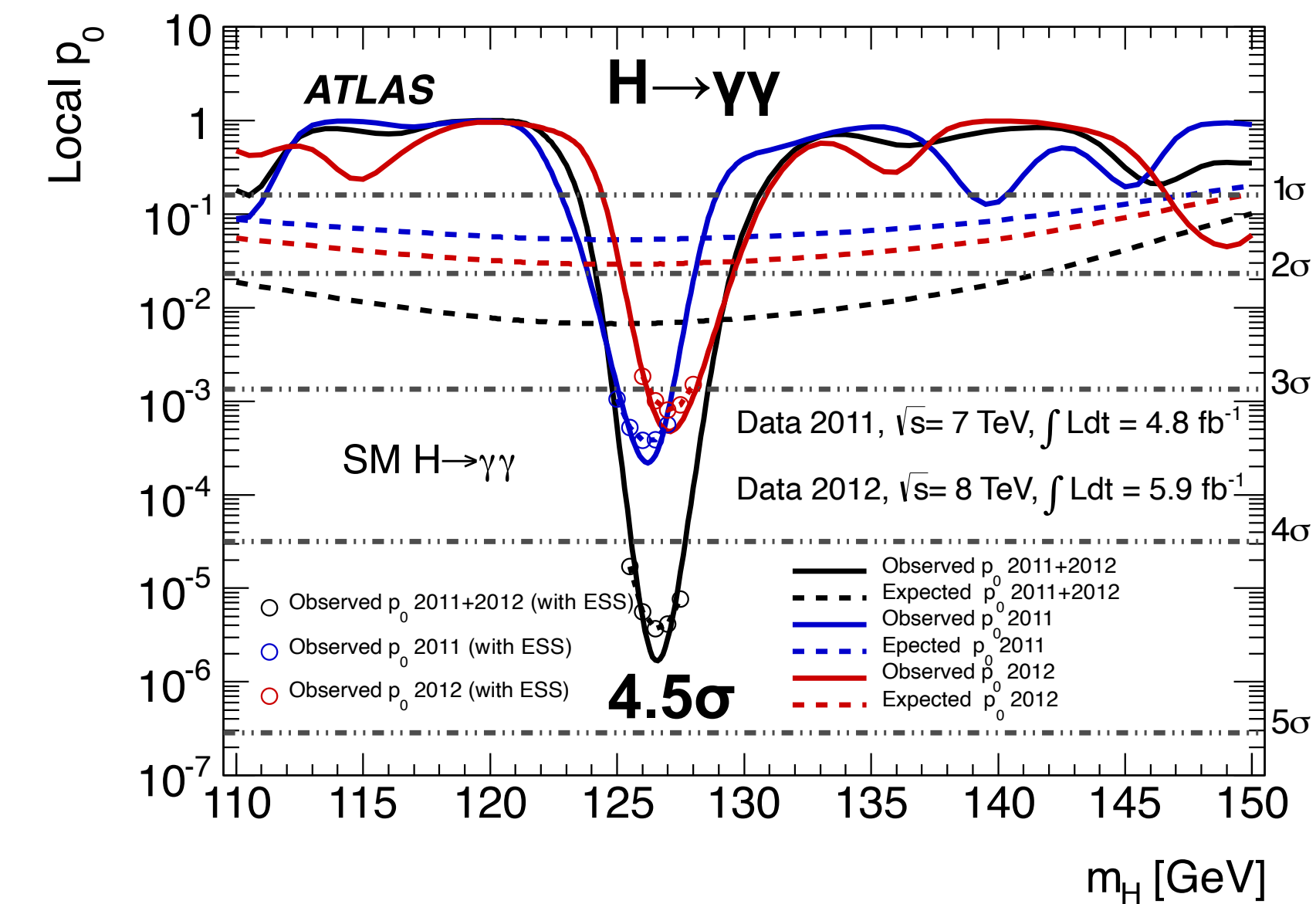
Xiangyang Ju

- With simple square sum, one knows we have a discovery

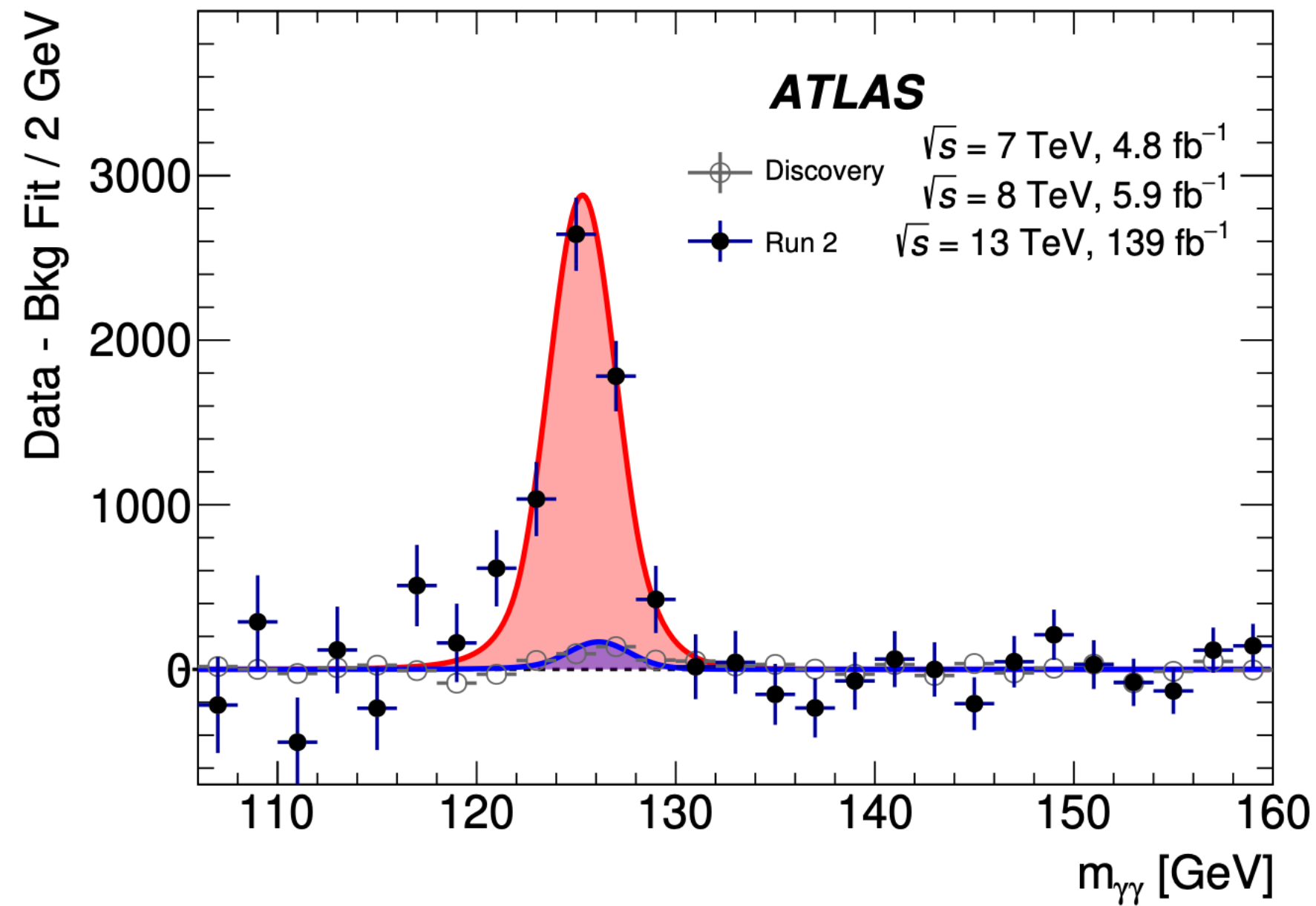


- 5 σ confirmed with rigorous likelihood combination
- Similar celebrations happened everywhere

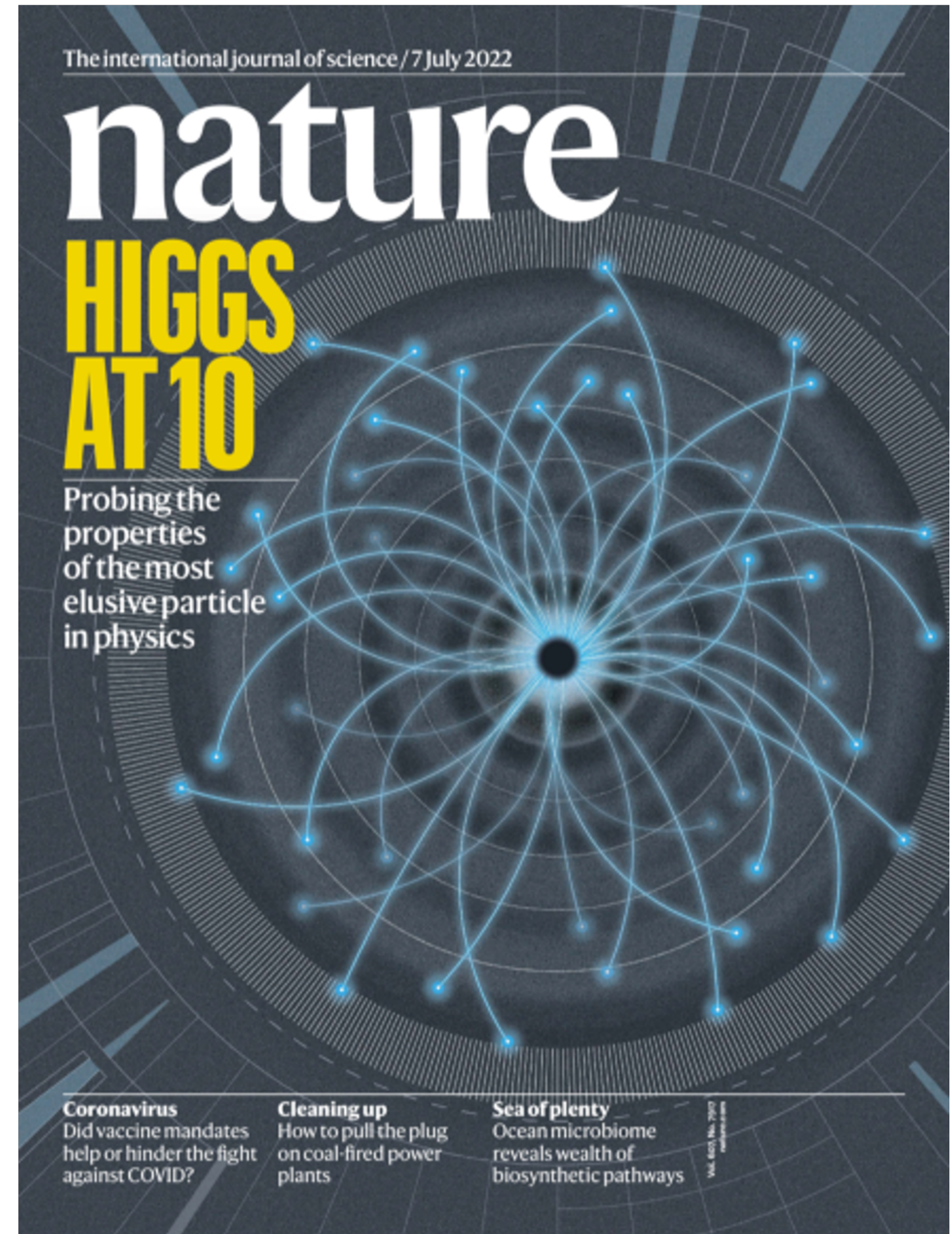
July 4, 2012: announcement of discovery



- Nobel Prize in 2013**, after we checked the couplings & spin of Higgs boson are consistent with SM



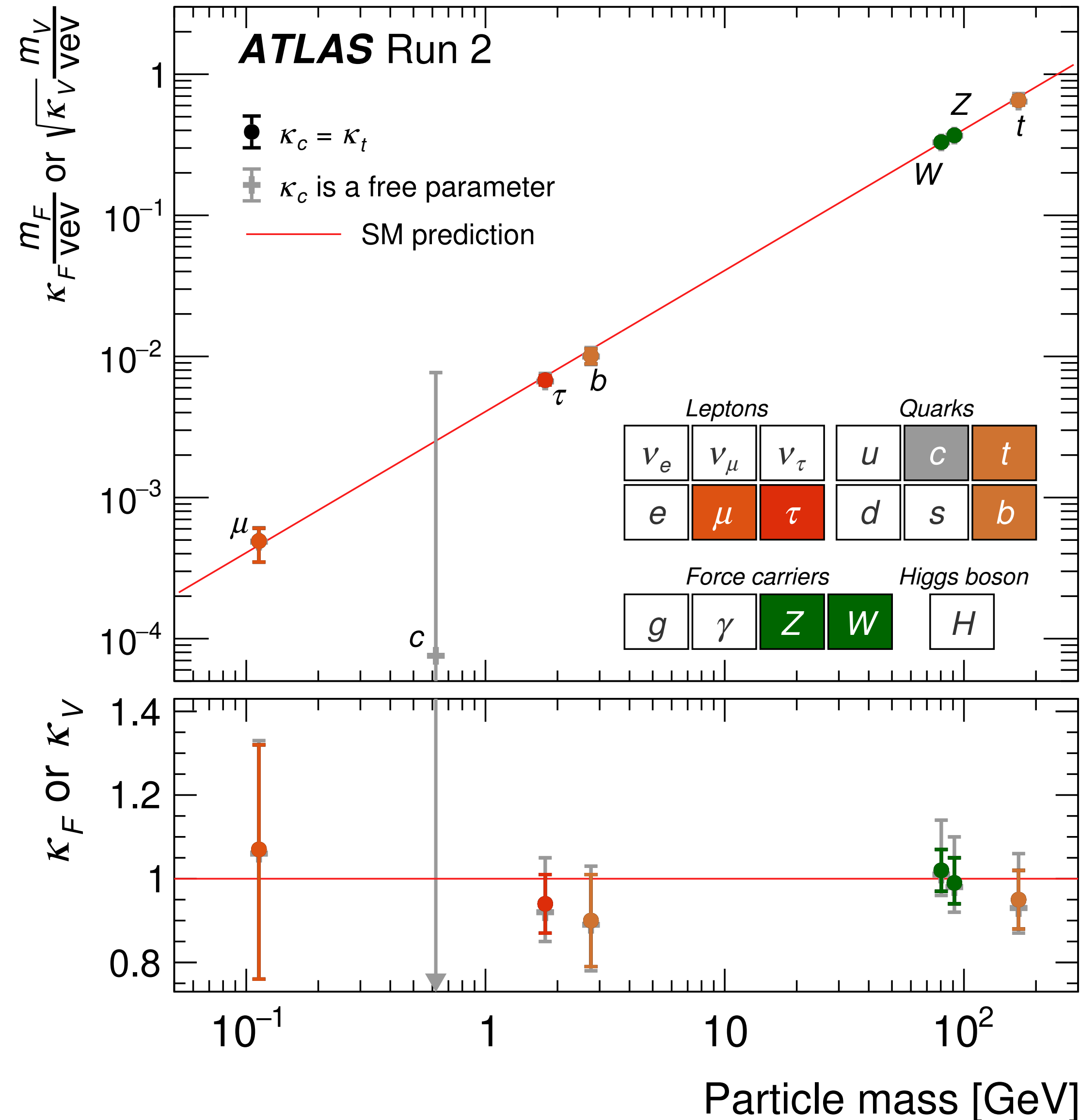
Fish discovered water



Celebration of 10th anniversary of Higgs boson discovery at USTC



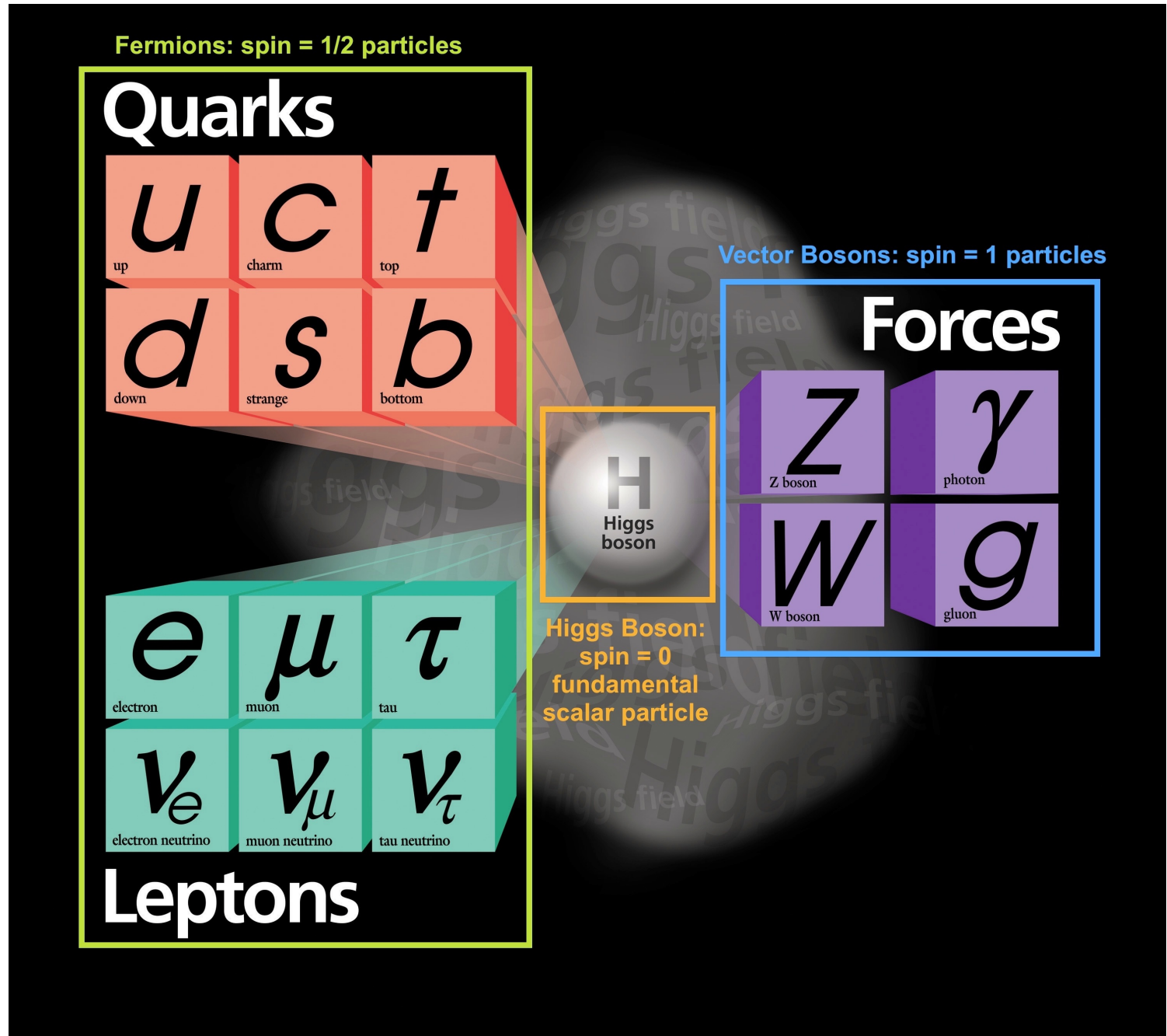
Higgs boson couplings after 10 years



- Higgs boson propagates a **new forces** that gives particle mass
- The heavier a particle is, the stronger it should be interacting with Higgs boson
 - Exactly what we have observed for heaviest particles: W/Z bosons, 3rd generation fermions
- But how about lighter fermions?

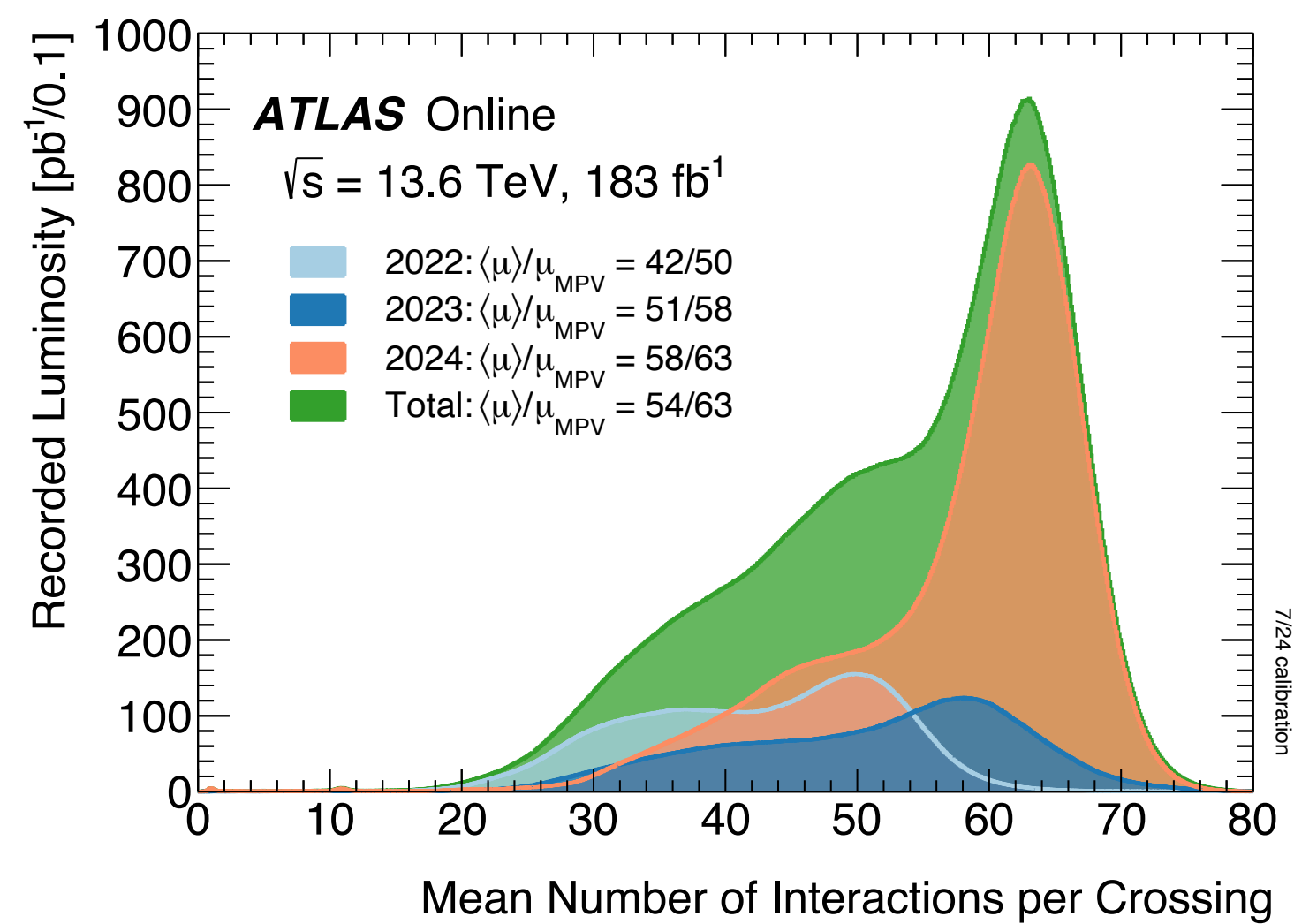
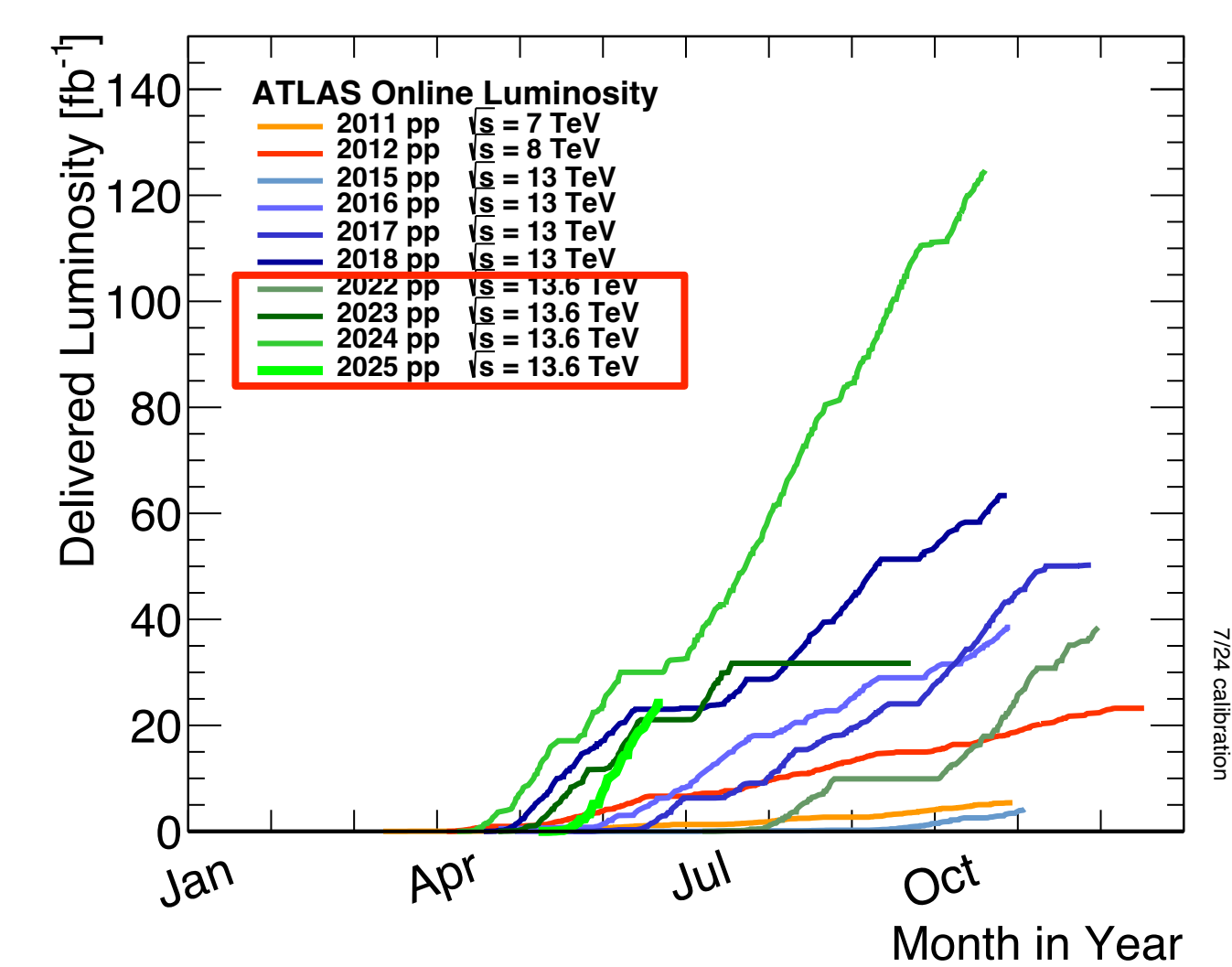
Why $H \rightarrow \mu\mu$?

- $H \rightarrow \mu\mu$ provides an unique opportunity for exploring mass genesis of 2nd generation fermions at LHC
 - Good muon reconstruction efficiency and resolution: much better sensitivity than $H \rightarrow cc$ ($H \rightarrow ss$ unlikely at LHC)
 - Muon mass precisely known: muon Yukawa coupling measurement therefore represents a key test of Higgs mechanism

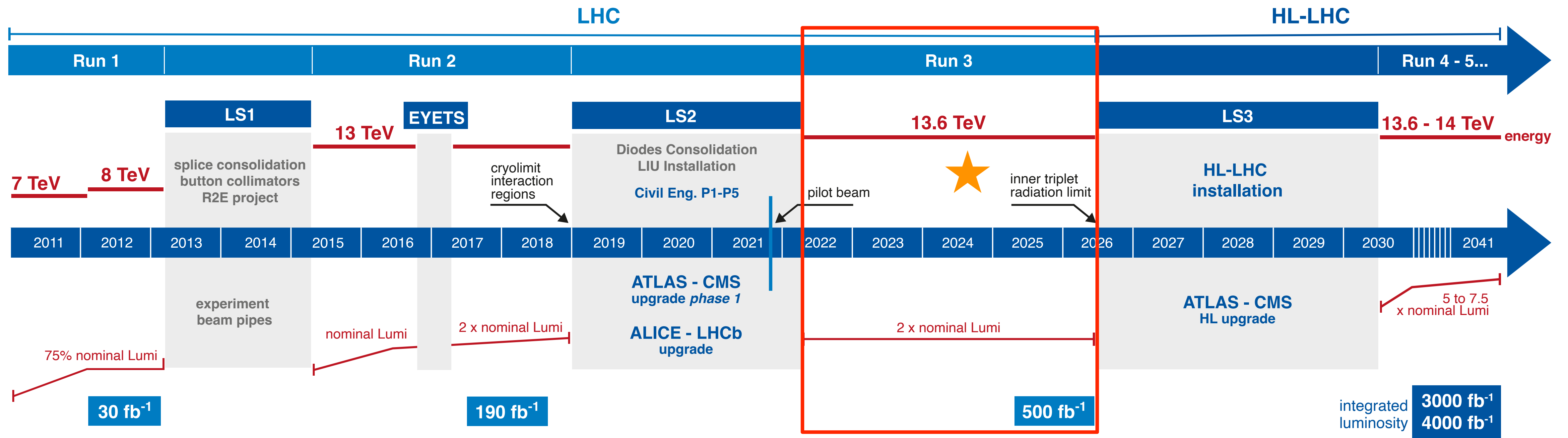


	Mass
μ	$105.6583755 \pm 0.0000023$ MeV
τ	1776.86 ± 0.12 MeV
t	172.69 ± 0.3 GeV
b	4.18 ± 0.03 GeV
c	1.27 ± 0.02 GeV

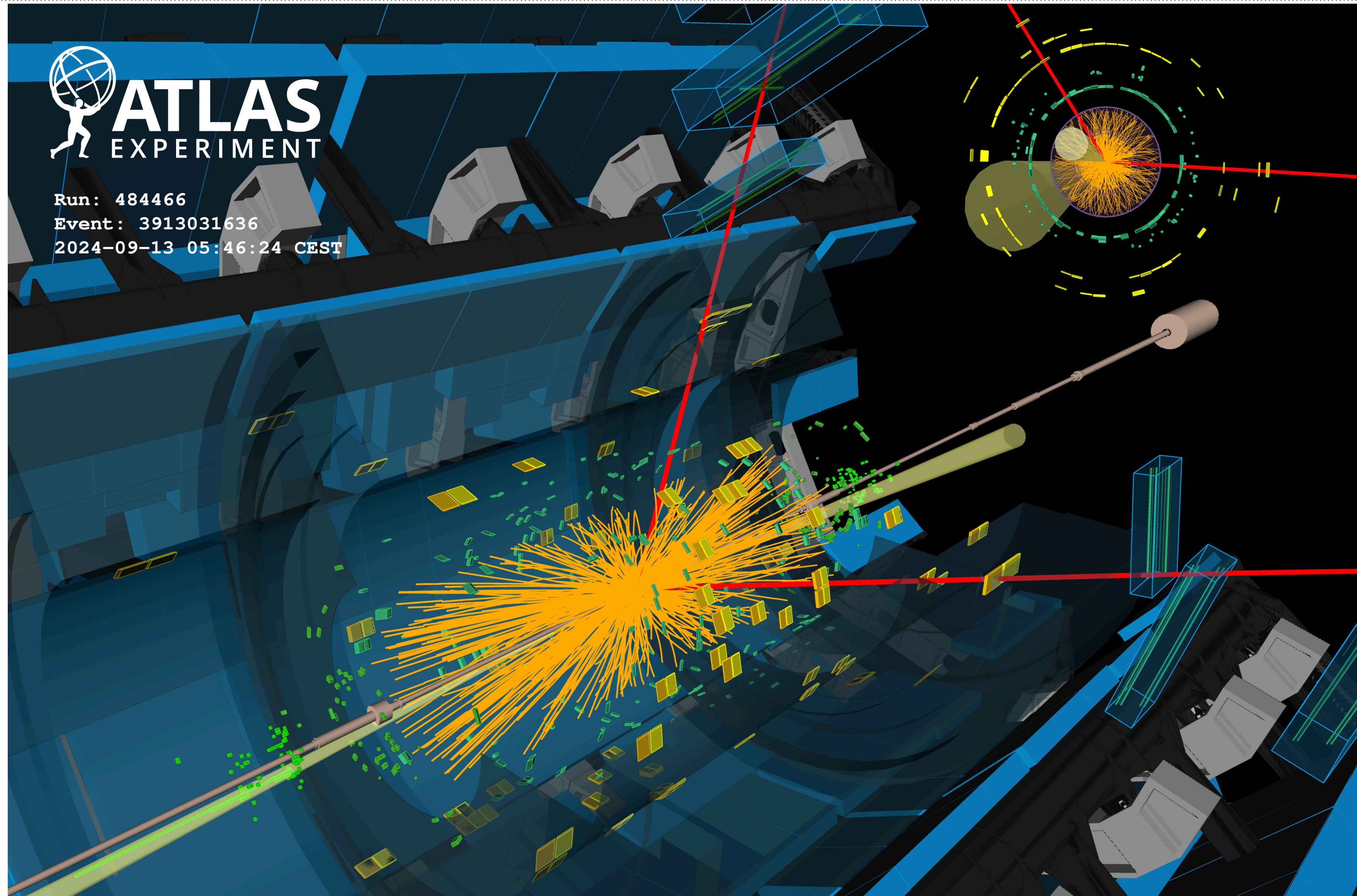
Run 3 data



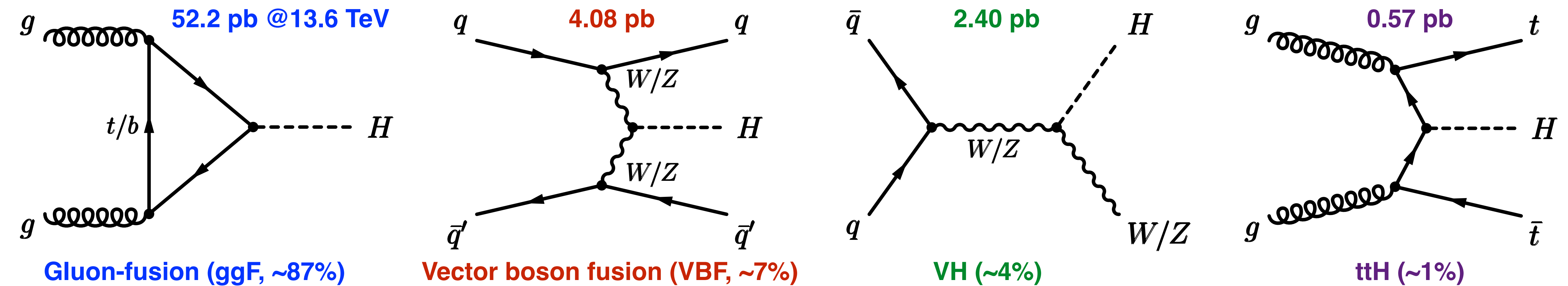
- Successful Run 3 pp collision data taking at $\sqrt{s} = 13.6$ TeV by ATLAS
- 165 fb⁻¹ data collected by end of 2024
- Mean pileup 54
- + 140 fb⁻¹ @13 TeV from Run 2



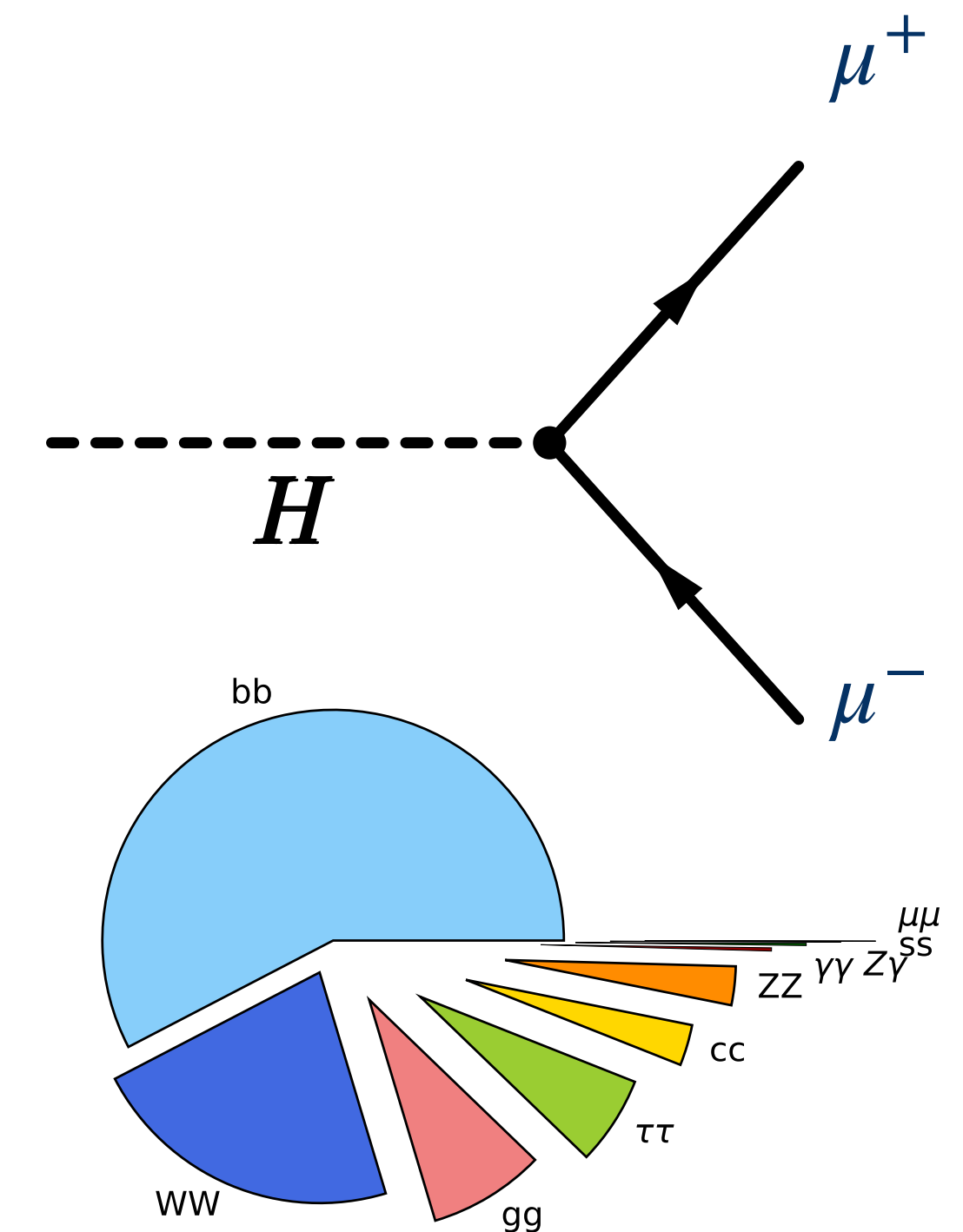
How to search for $H \rightarrow \mu\mu$?



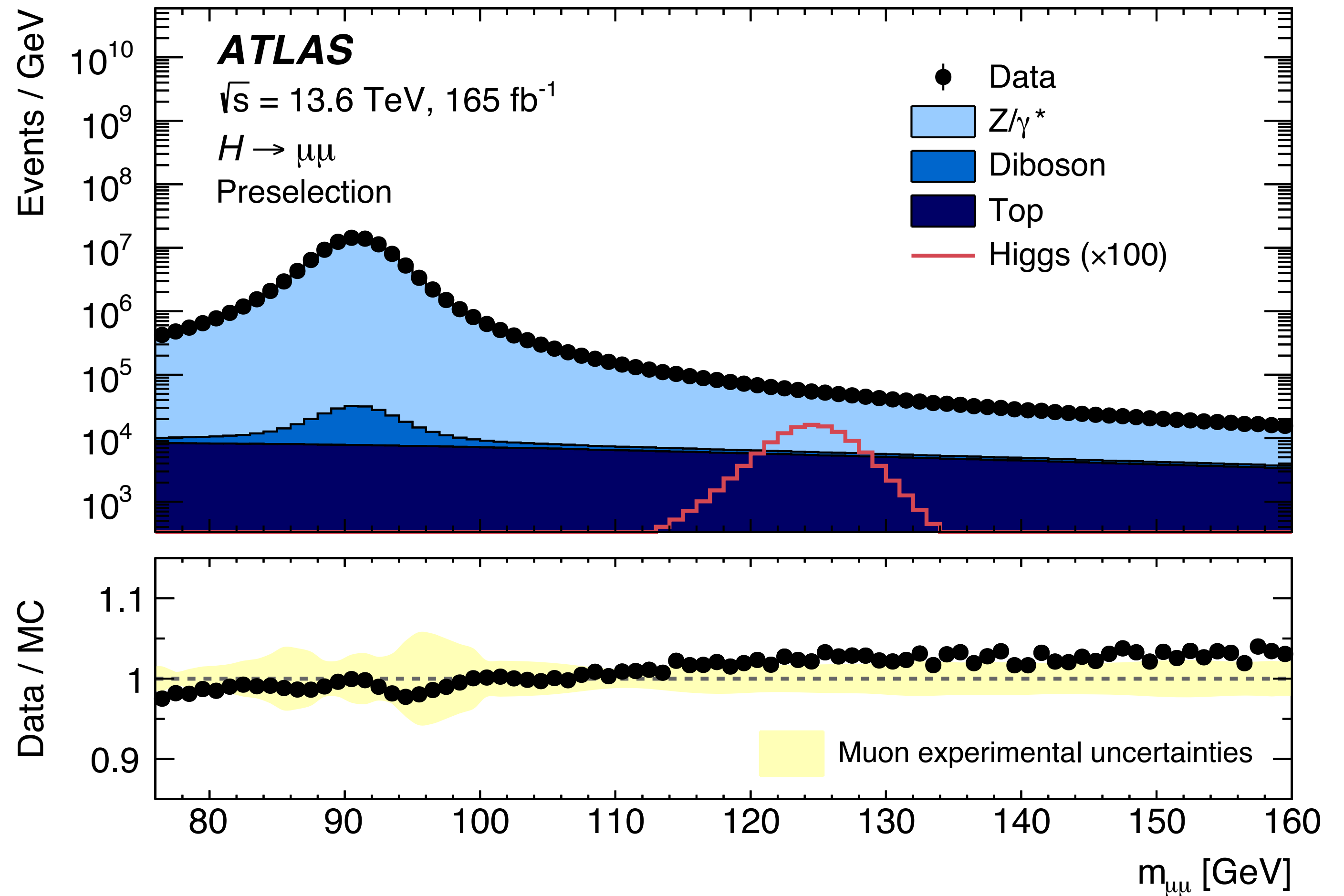
Higgs boson production and decay to dimuon



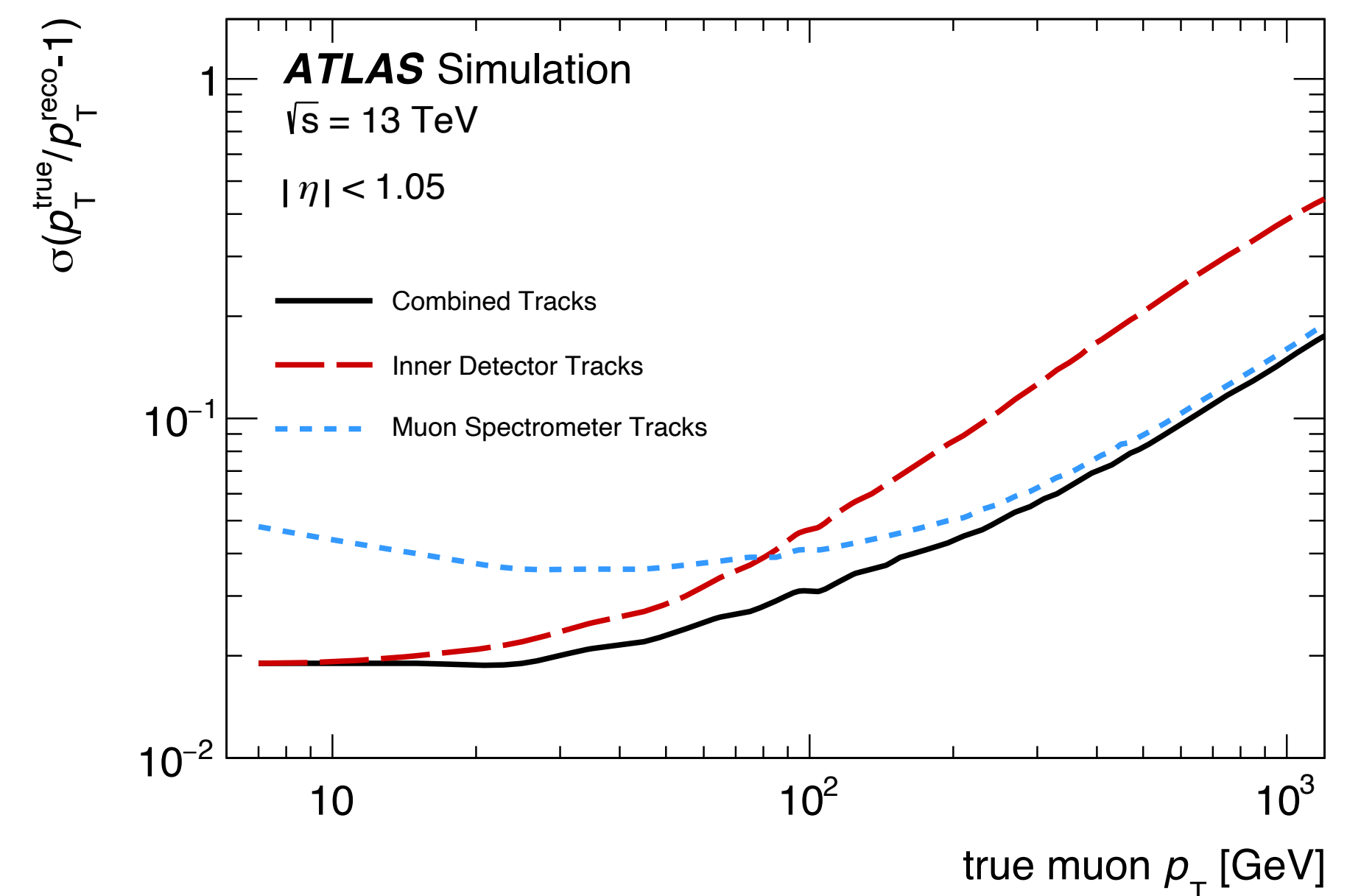
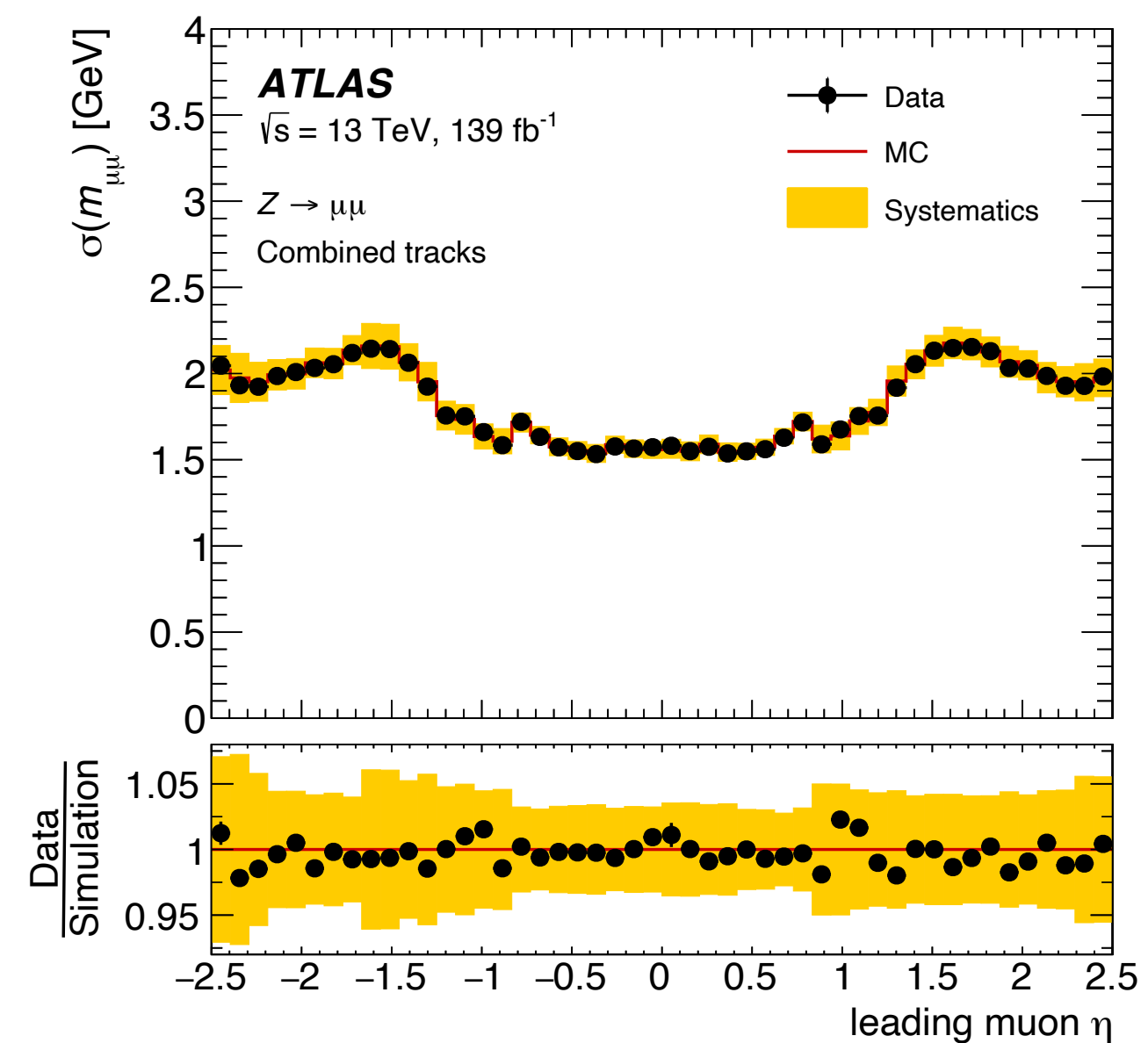
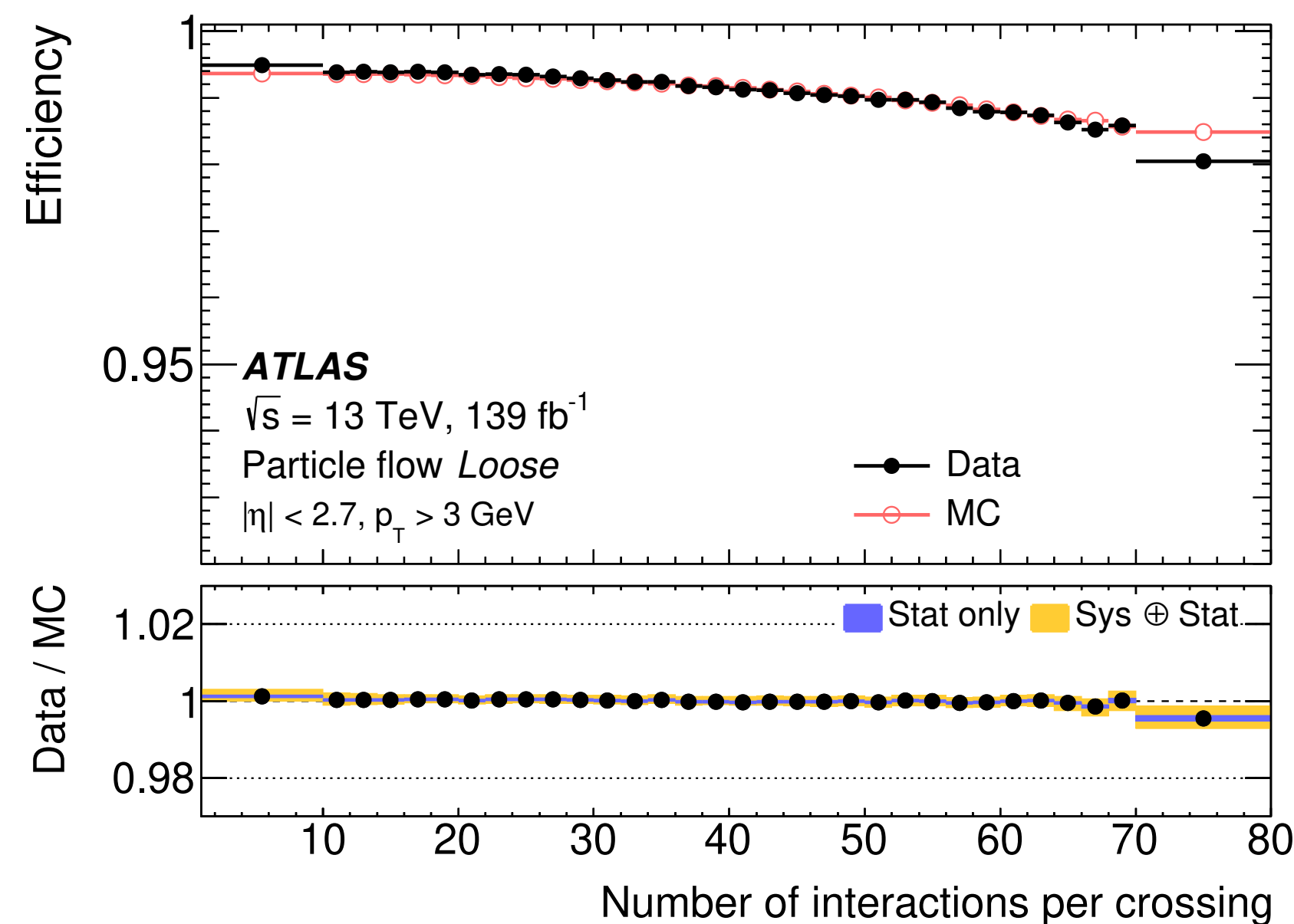
- $H \rightarrow \mu\mu$ branching ratio only **0.02%**!
- Expect **~2100** SM $H \rightarrow \mu\mu$ candidates in 165/fb of Run 3 data
- **~1700** candidates in 140/fb of Run 2 data



- **Drell-Yan $Z/\gamma^* \rightarrow \mu\mu$** is the dominant background
 - EW Zjj, diboson, top also important for studying VBF, VH, and ttH, respectively
- Background spectrum **smoothly falling** after Z-pole
 - Data-driven estimation feasible
- Typical S/B **O(0.1%)**
 - **Accurate background modeling** is the key to search for $H \rightarrow \mu\mu$ signal!
 - **Advanced analysis techniques** i.e. machine learning essential to suppress background



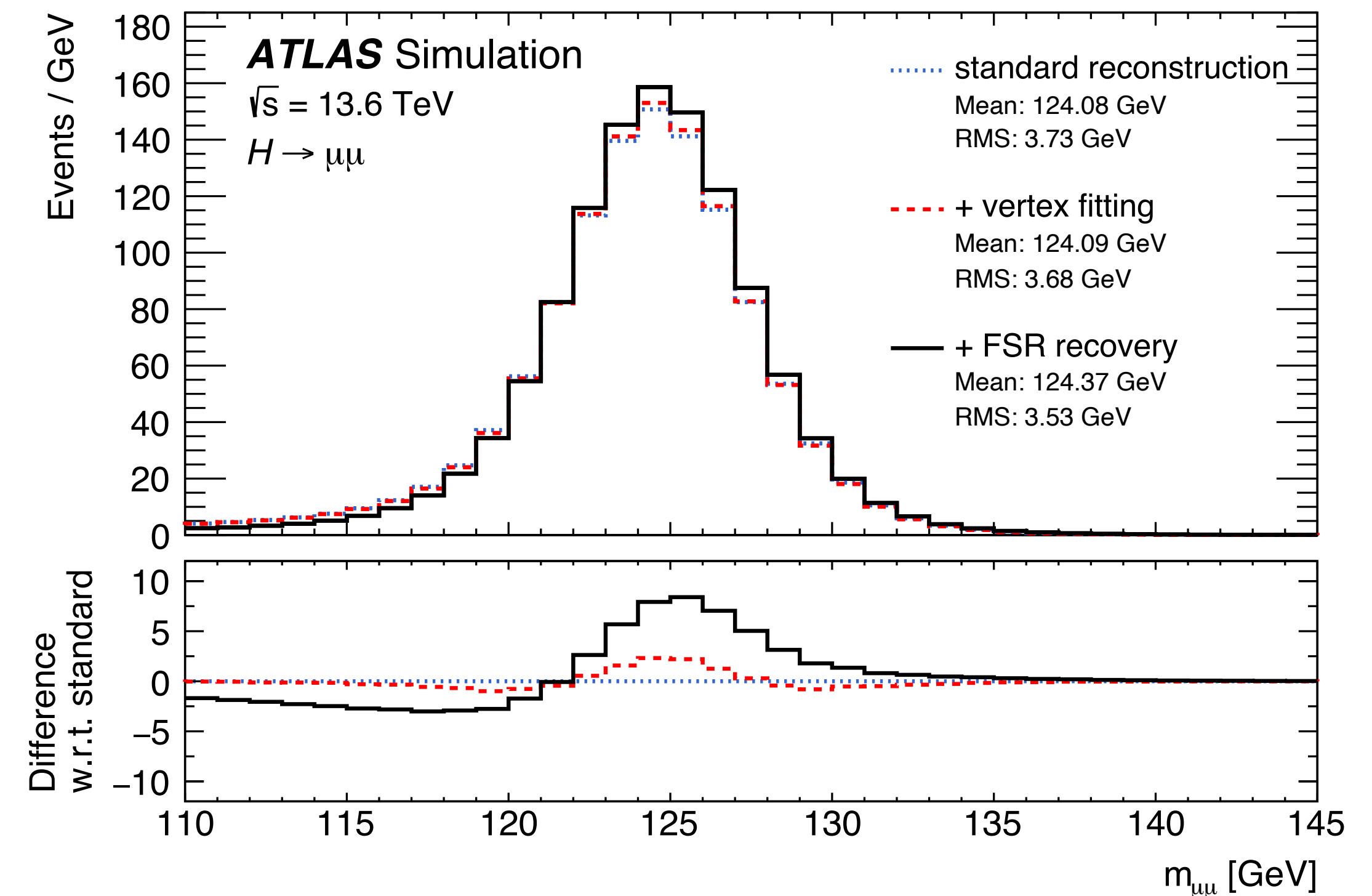
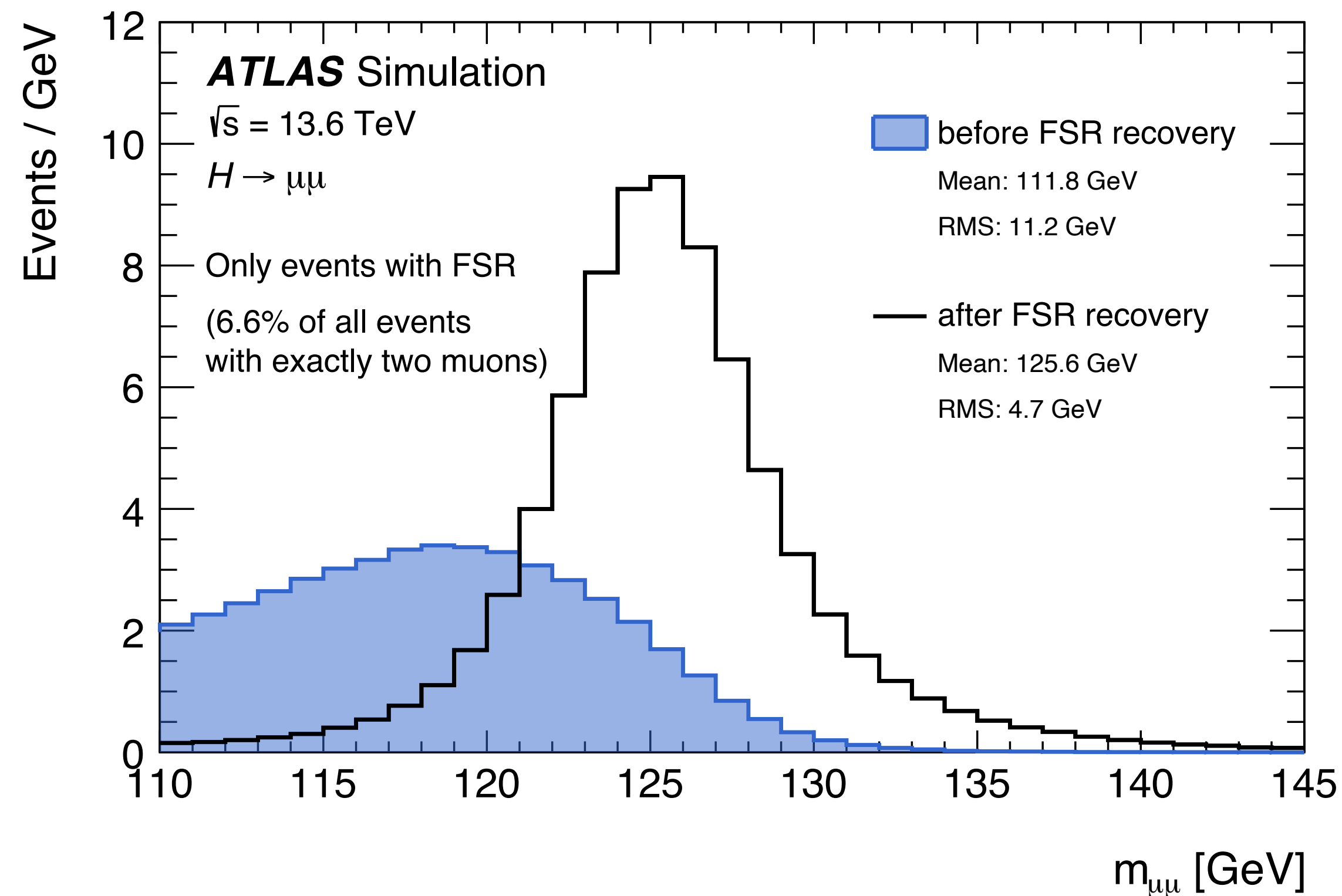
- Muons reconstructed with high efficiency from combining **inner tracker track + muon spectrometer track**
- Using Z as candle (+J/ψ, Y) for calibration
 - Muon momentum resolution largely driven by **inner tracker** precision for O(10 GeV) p_T regime relevant to $H \rightarrow \mu\mu$ search



Event selection

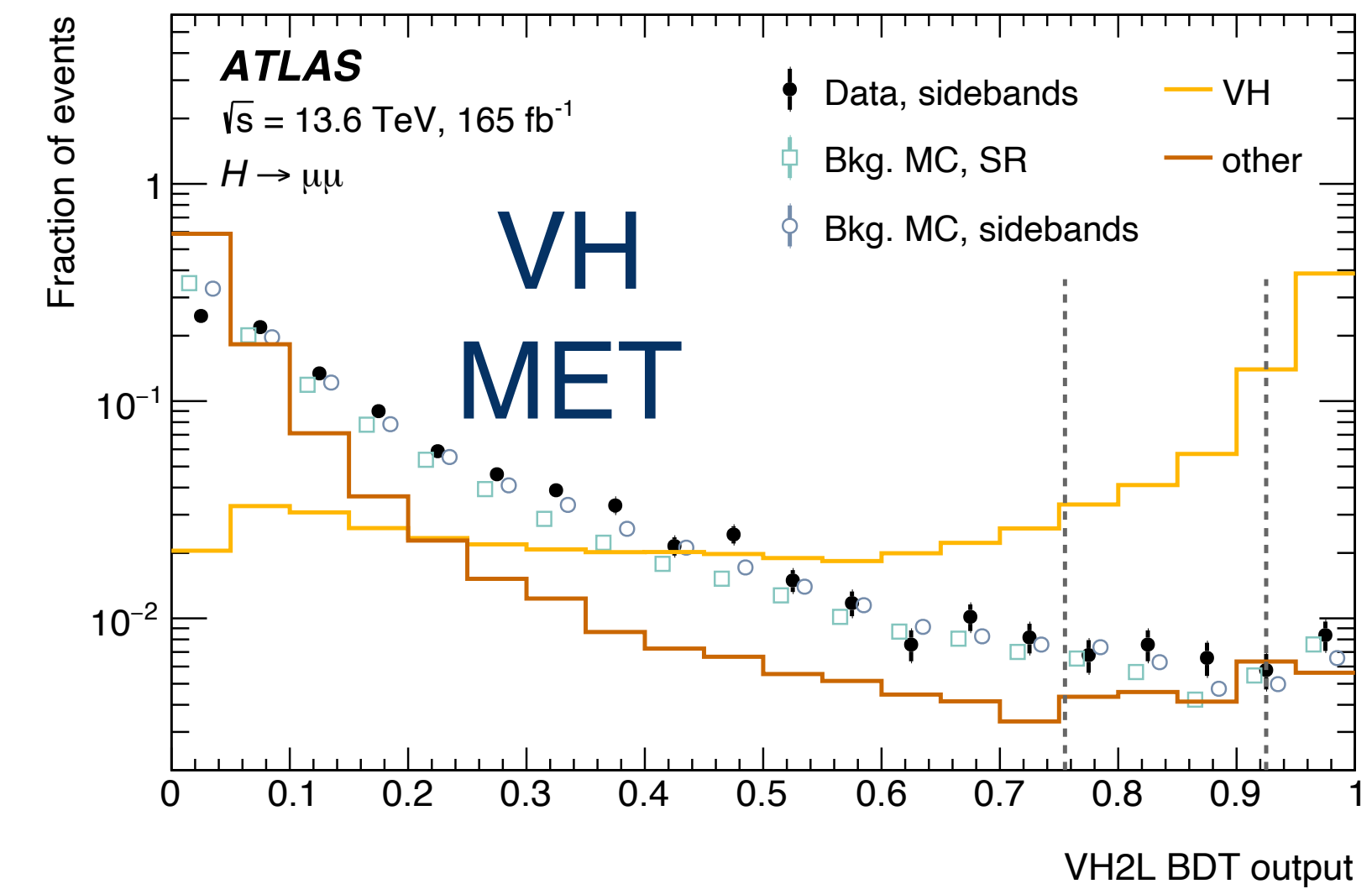
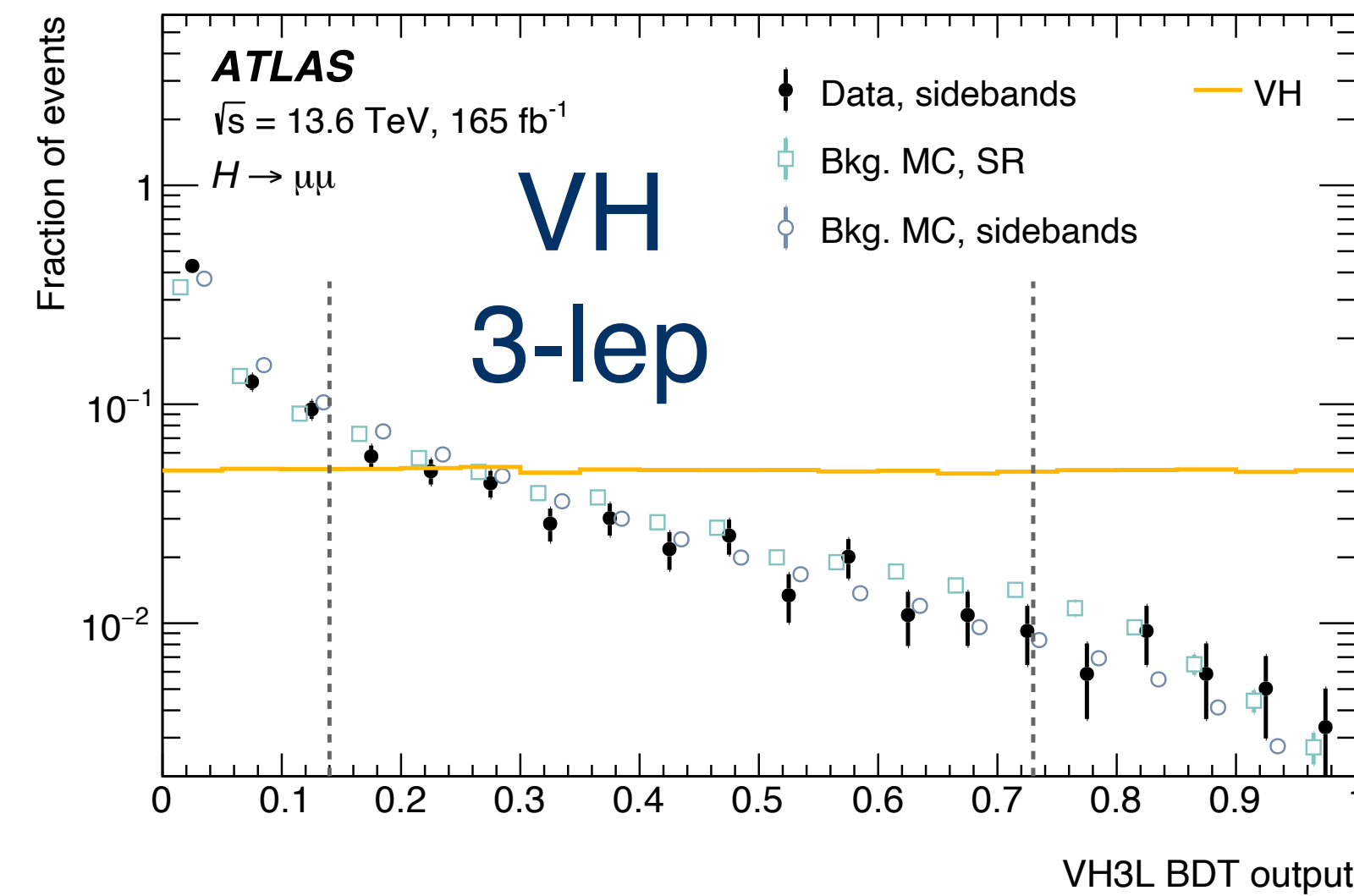
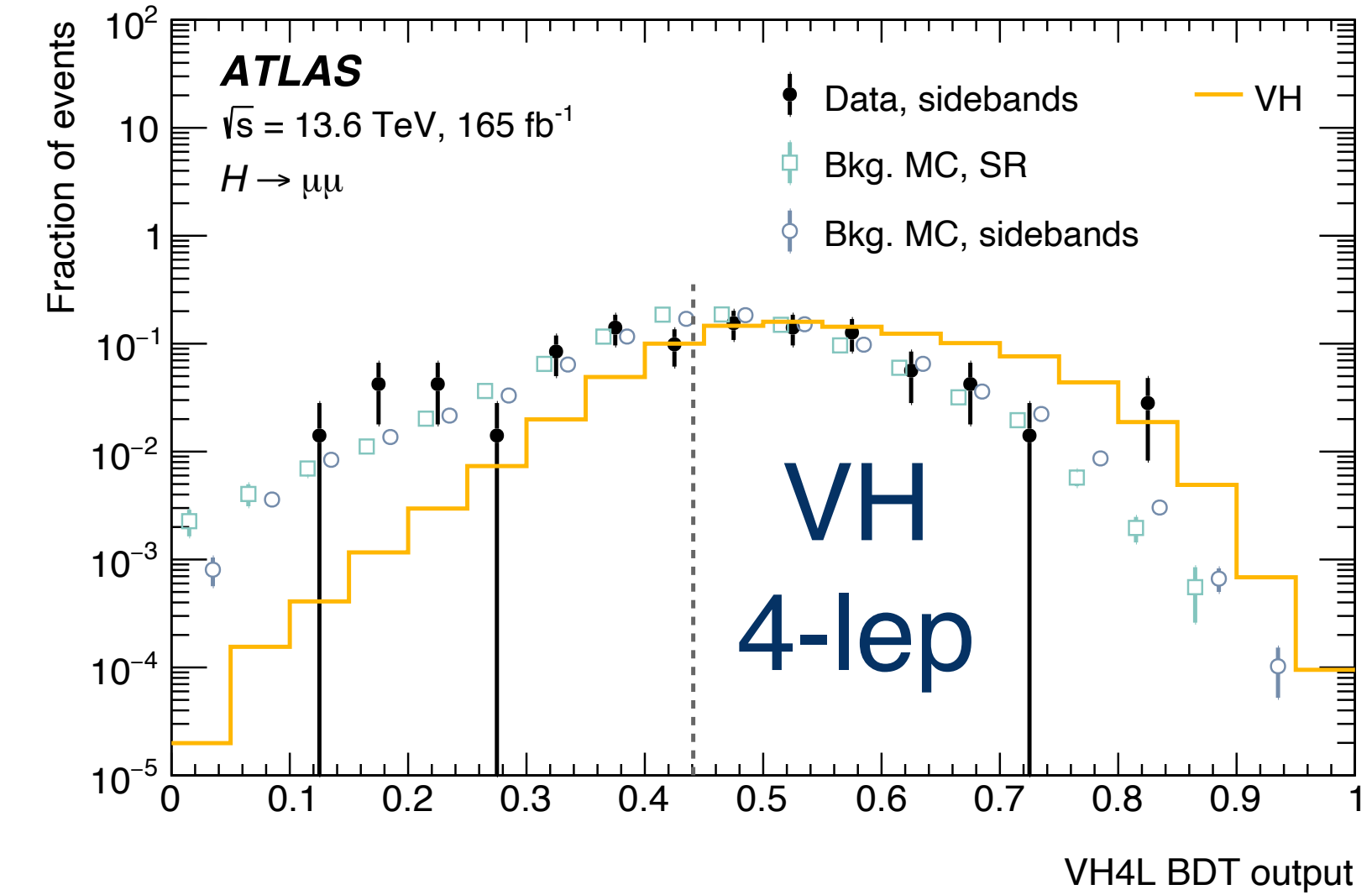
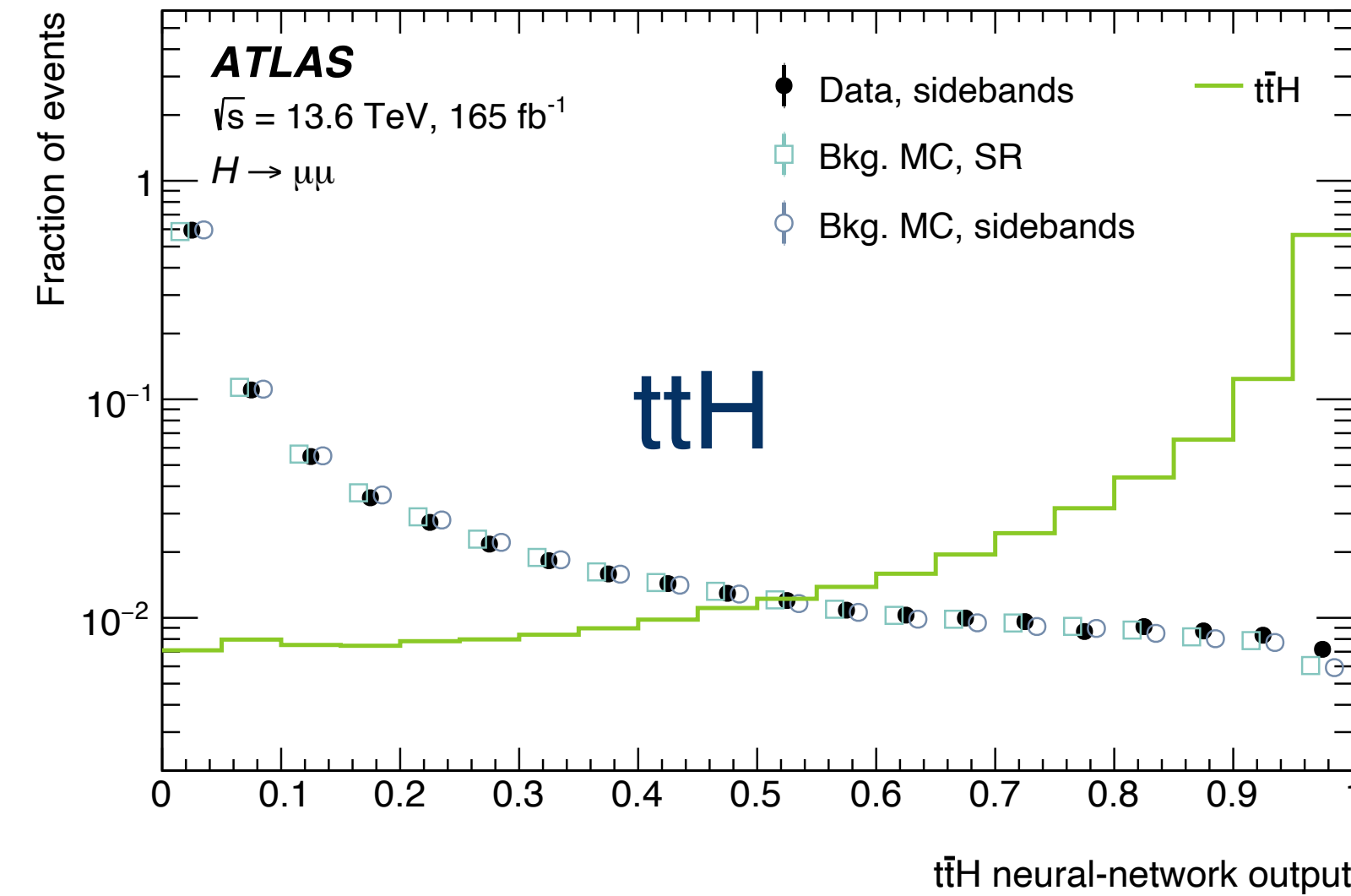
- Select events with two opposite-charge high p_T muons + quality requirements
- FSR recovery (+4%) and dimuon vertex refit (+2%) for better resolution

Trigger	$> 24 \text{ GeV} + \text{iso. or } > 50 \text{ GeV}$
p_T	$> 27 \text{ GeV}$ leading, $> 15 \text{ GeV}$ subleading
$ \eta $	< 2.5
Others	Identification, isolation, impact parameter cuts...



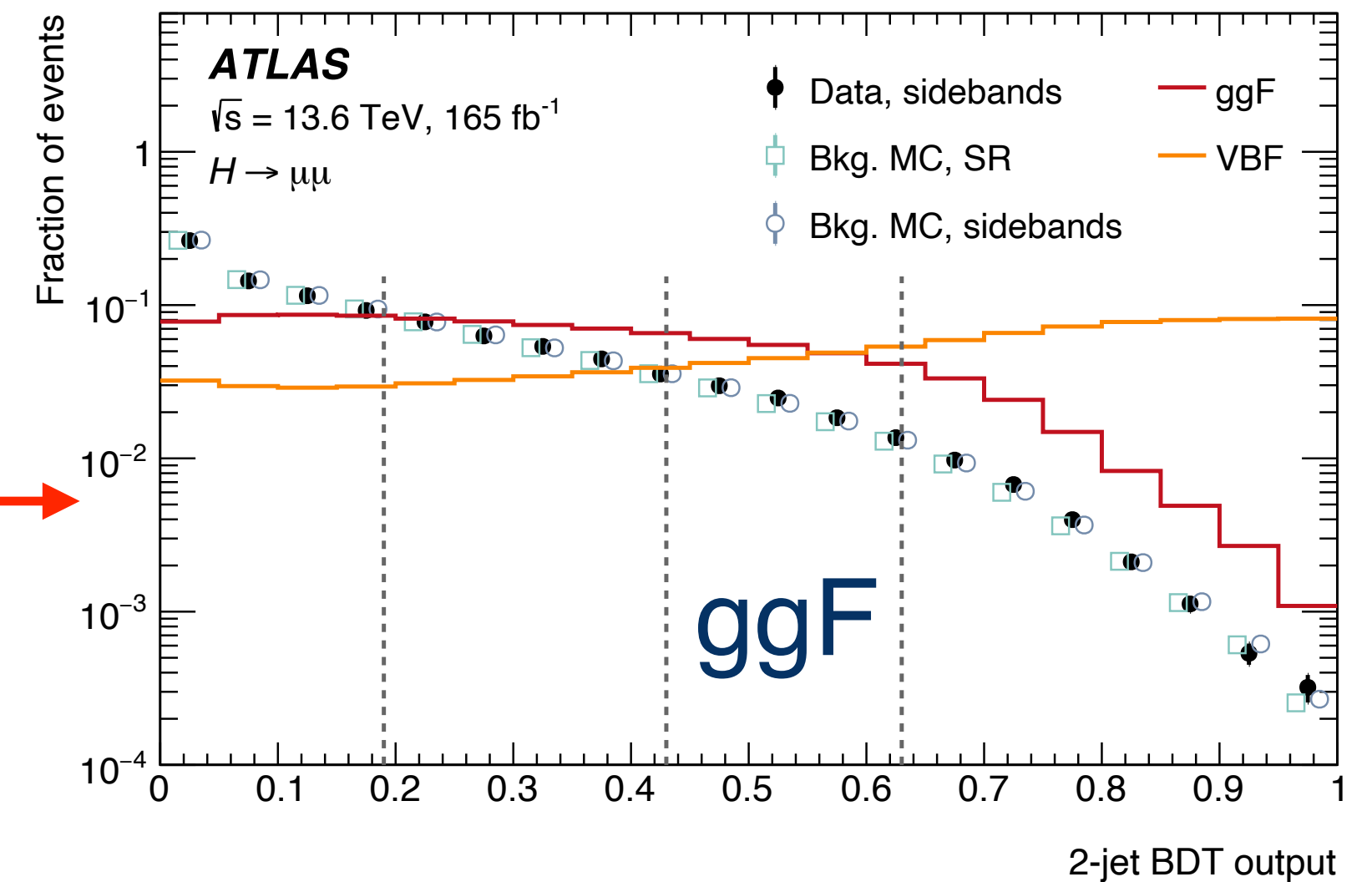
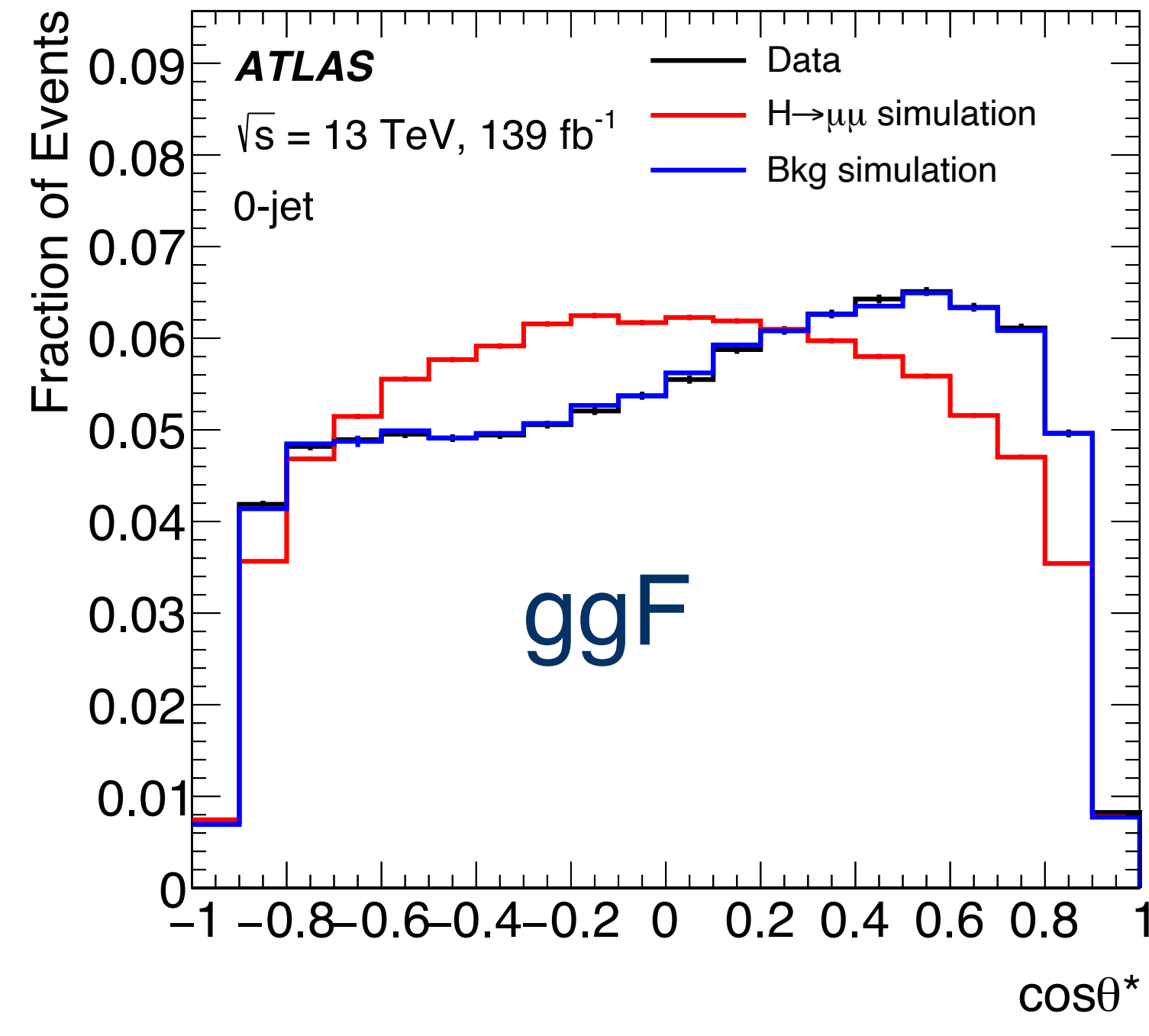
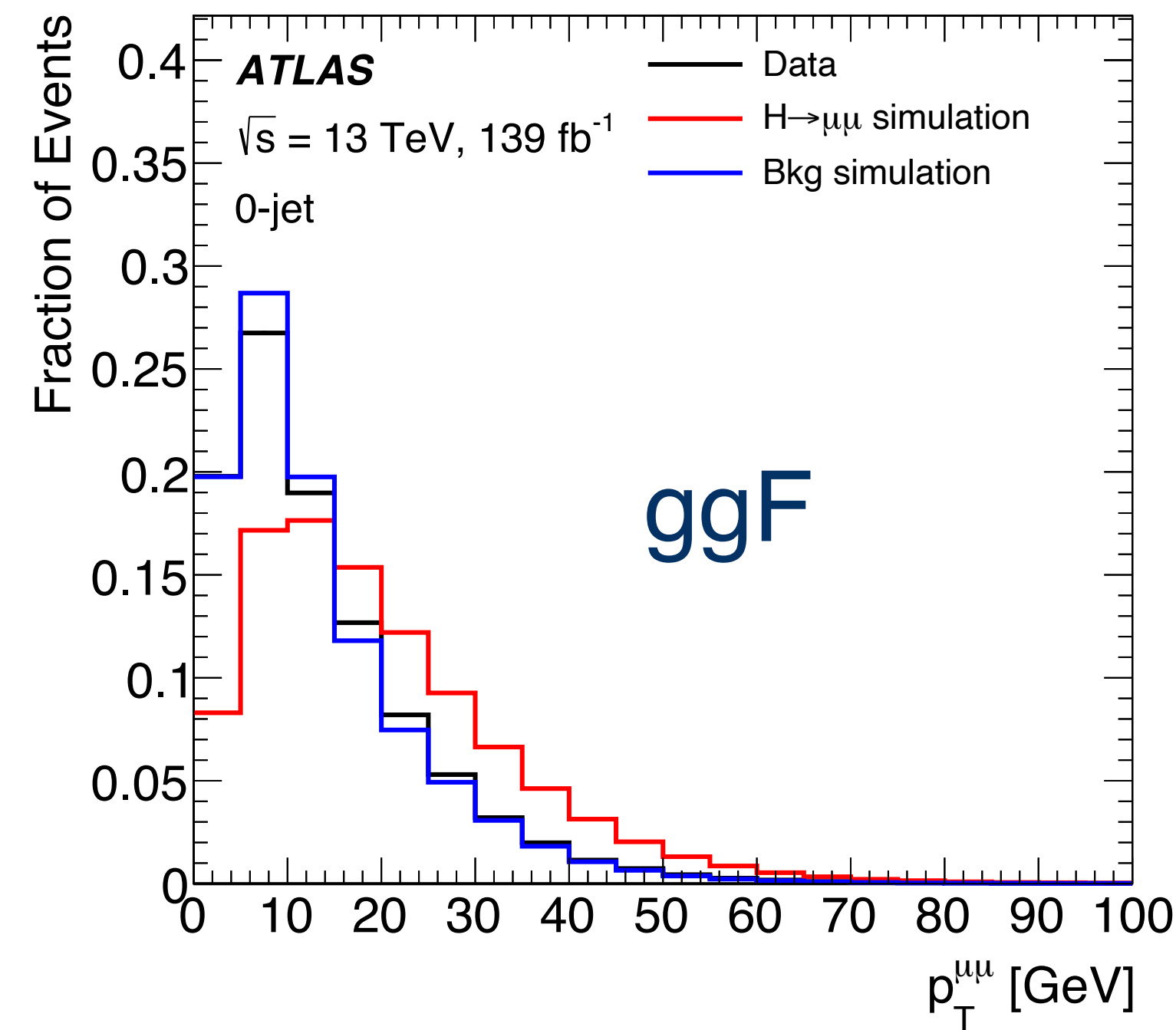
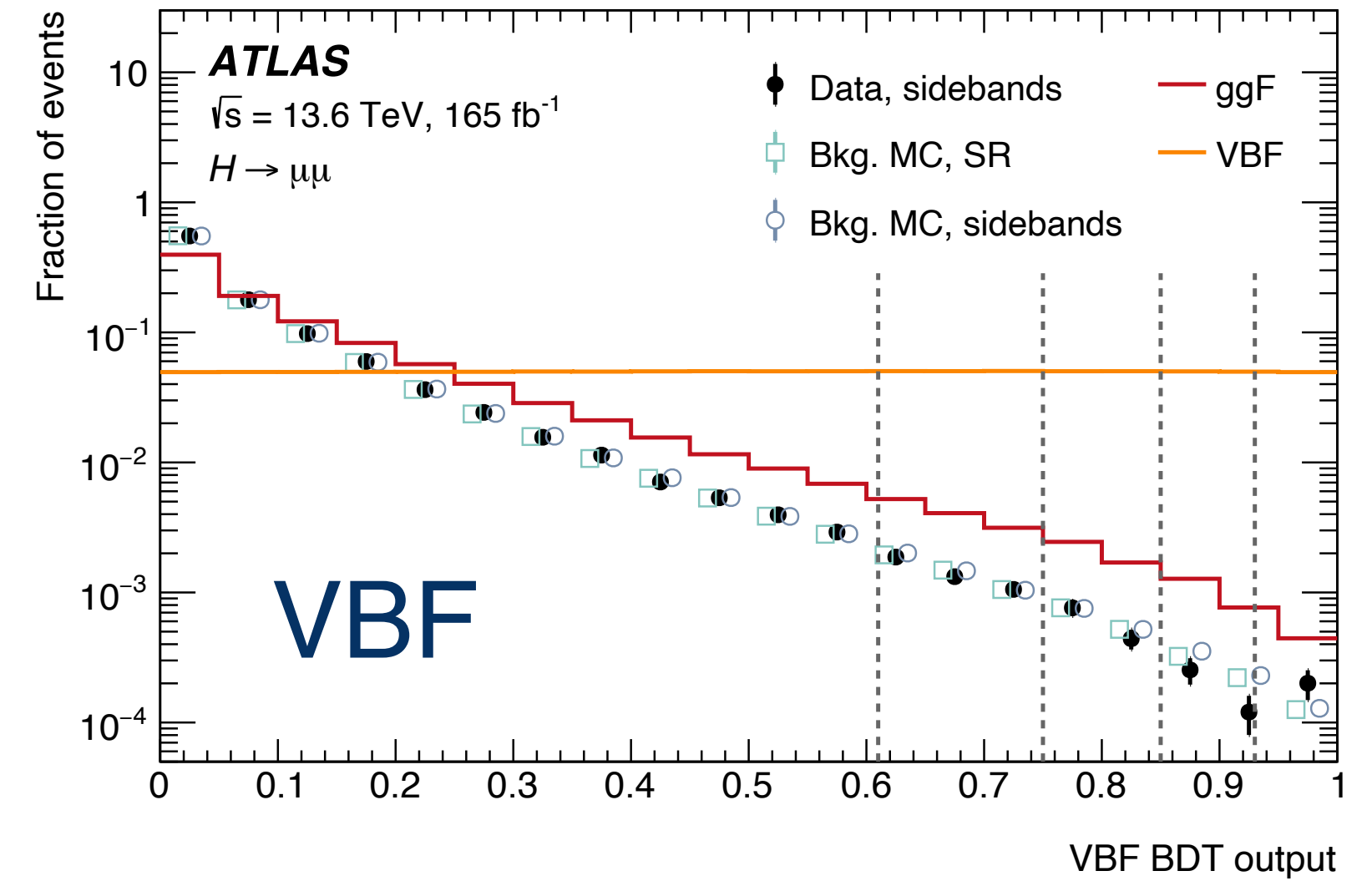
ttH and VH categories

- Use the **decay products** of W/Z/top to tag VH and ttH events
 - ttH: b-jet + jets or leps
 - VH: additional leptons or missing E_T , no b-jet
- Use Boosted Decision Trees (BDT) or Neural Network (NN) to combine all input kinematic variables

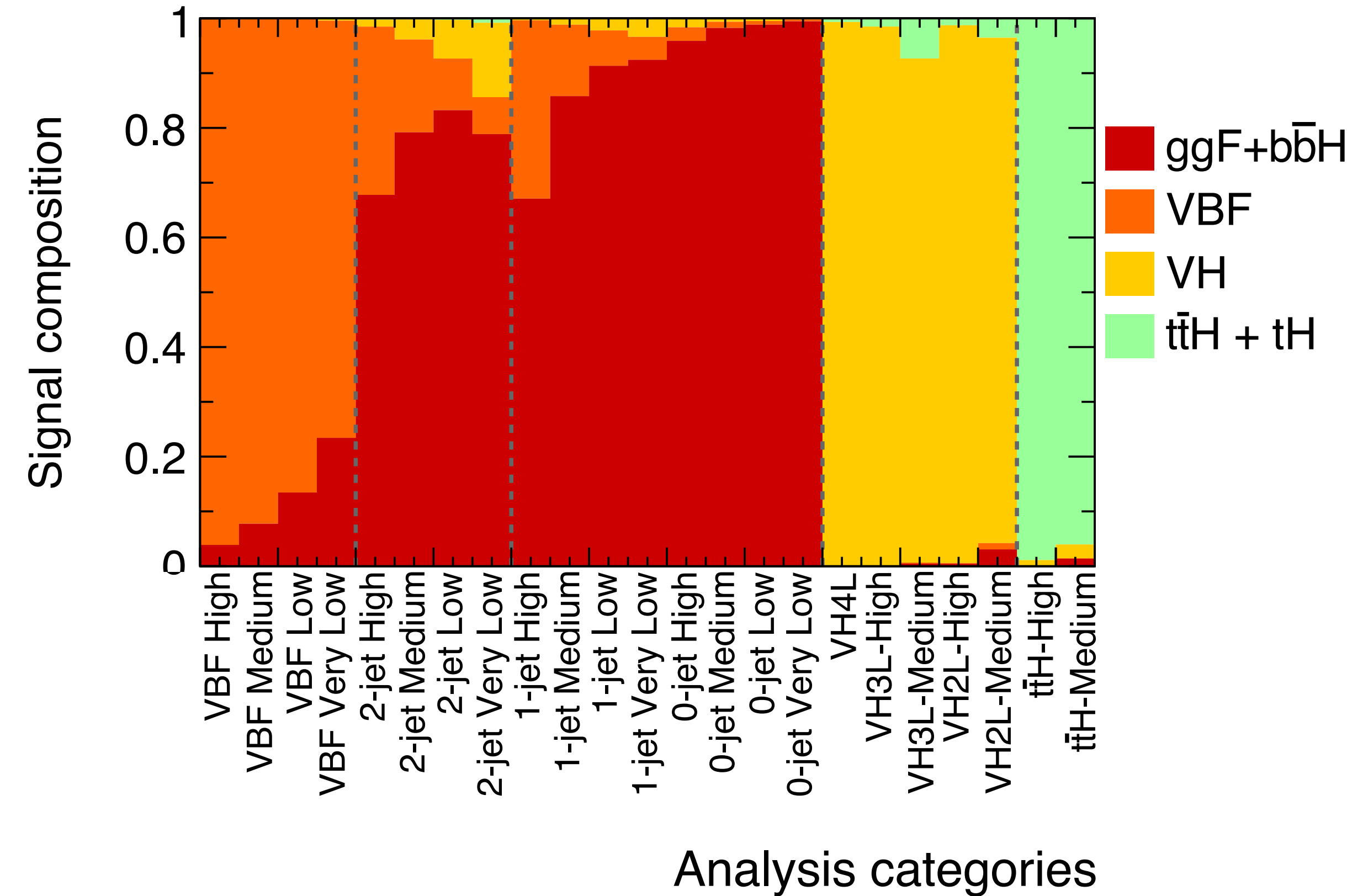
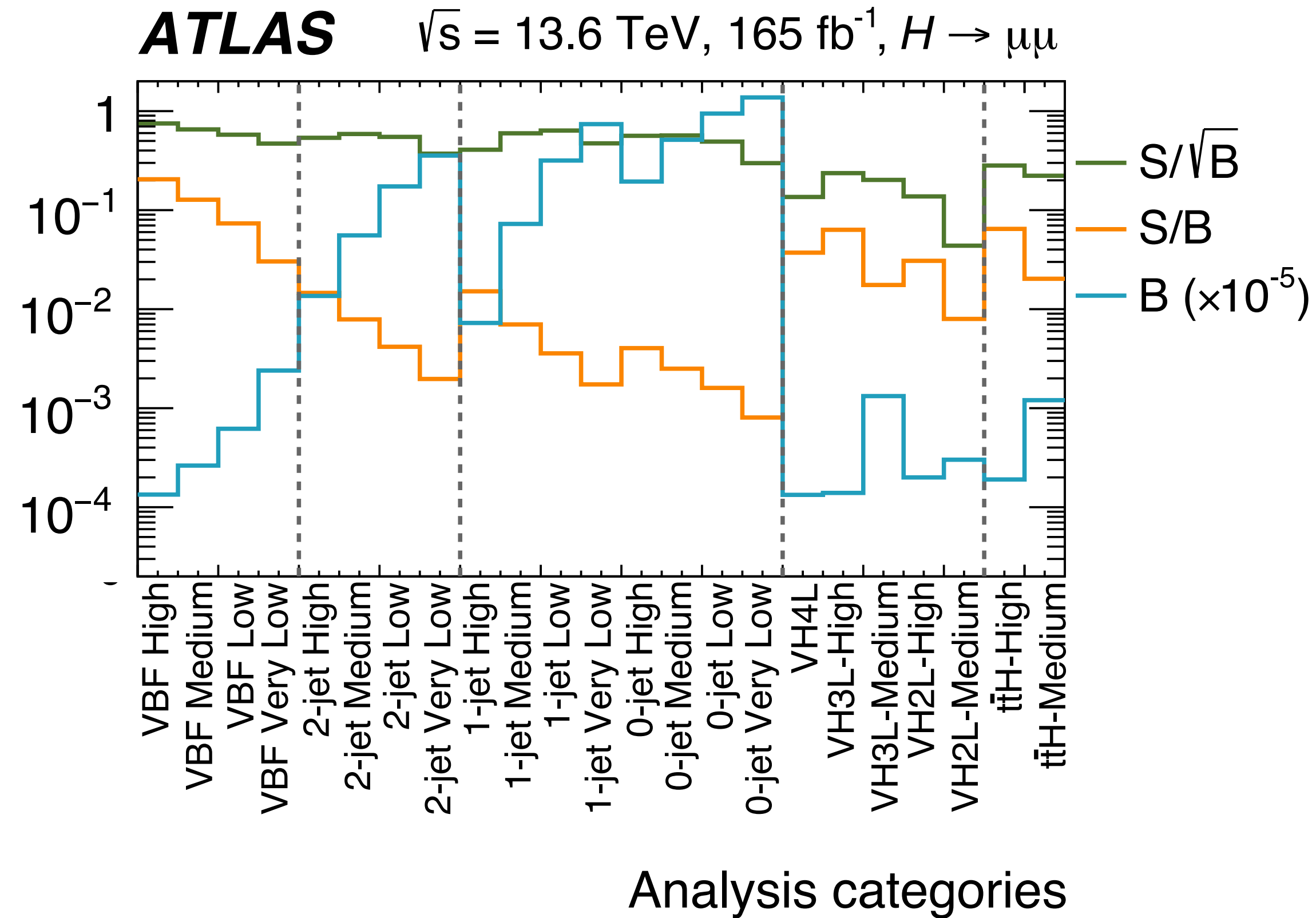


VBF and ggF categories

- VBF: isolate events featuring 2 jets with **large m_{jj}** etc.
- ggF: exploit boost of dimuon p_T , central η etc.
- Veto events with b-tagged jet to suppress $t\bar{t}$. Use BDT to separate signal from background

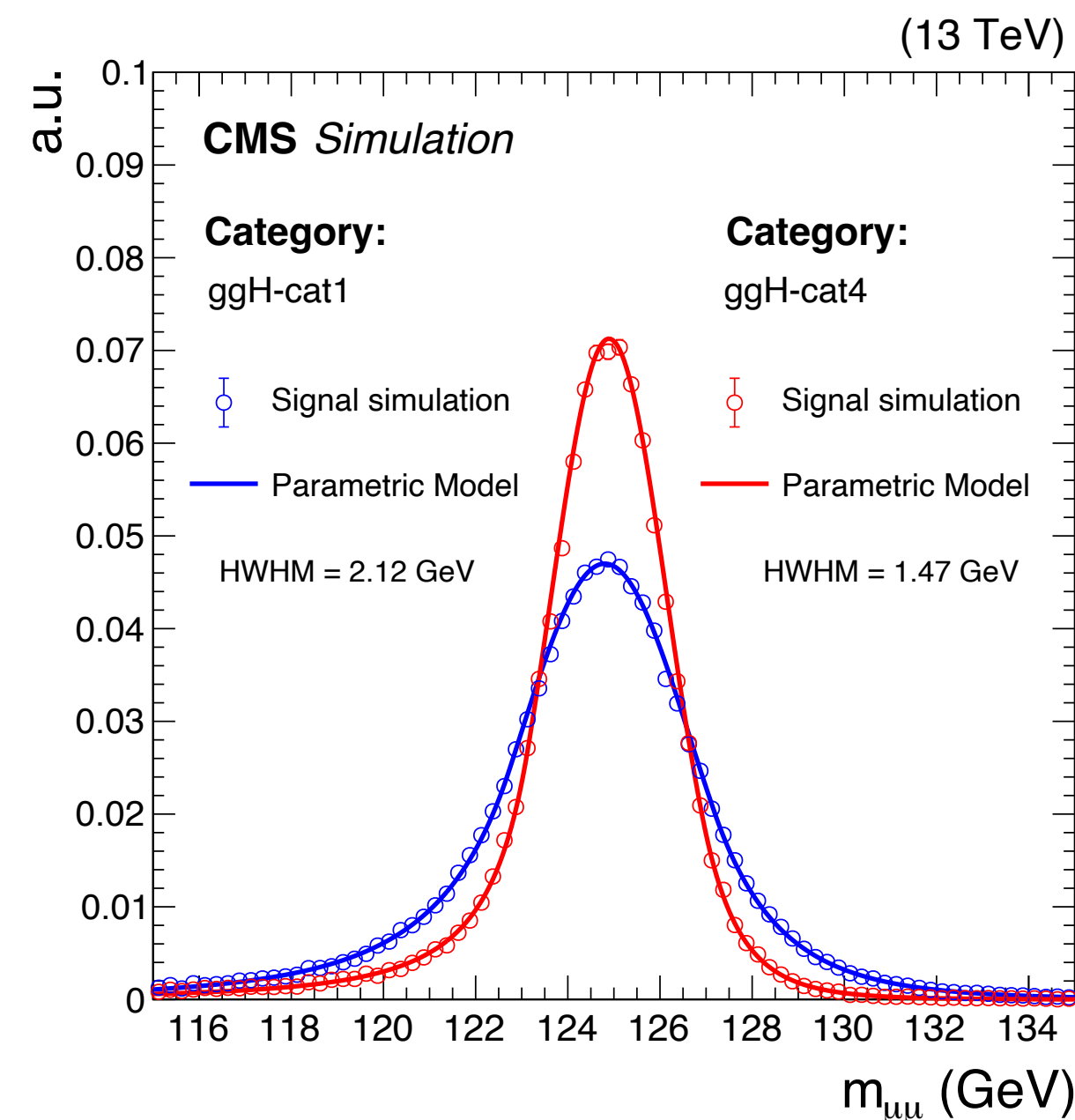
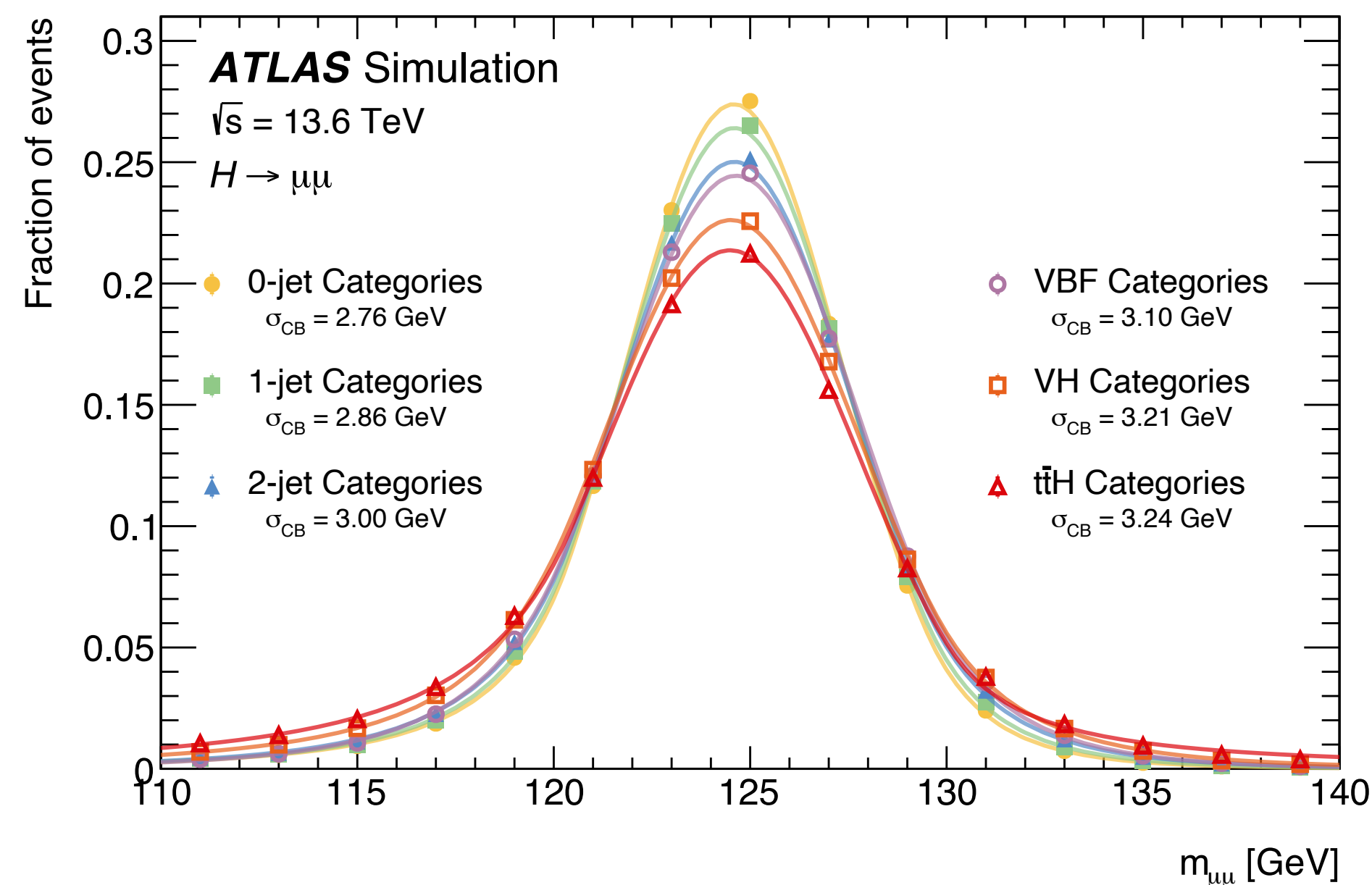


Summary of categorization



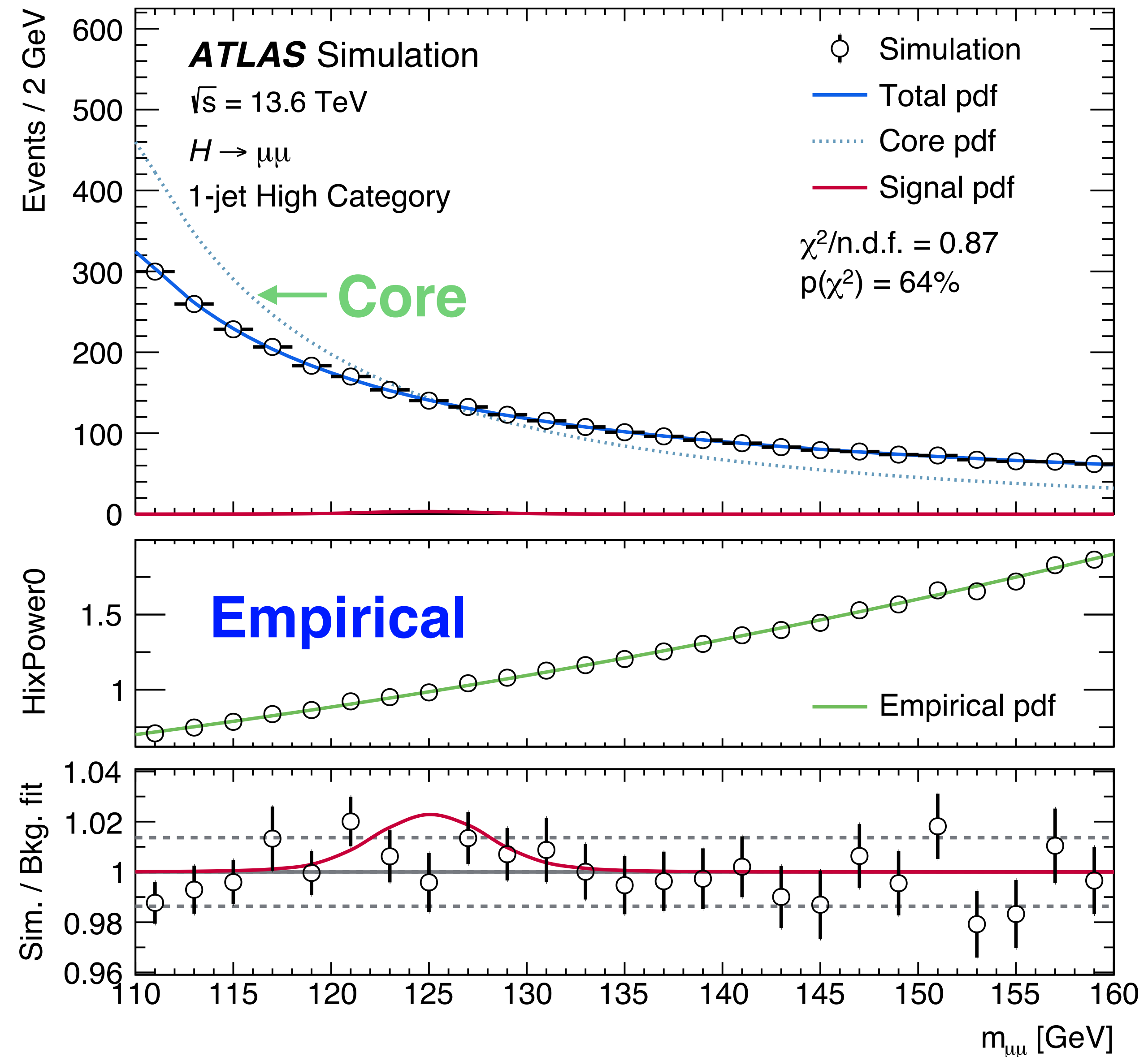
- Sensitivity driven by **VBF** and **ggF** categories
 - S/B close to 20% in best VBF category. Good purity of target signals

- SM Higgs boson width only 4 MeV: signal line-shape fully driven by **detector resolution** (~ 3 GeV)
- CMS signal resolution **up to ~ 2 better** than ATLAS mainly due to **stronger magnetic field in the inner tracker** (ATLAS 2 T vs. CMS 3.8 T)



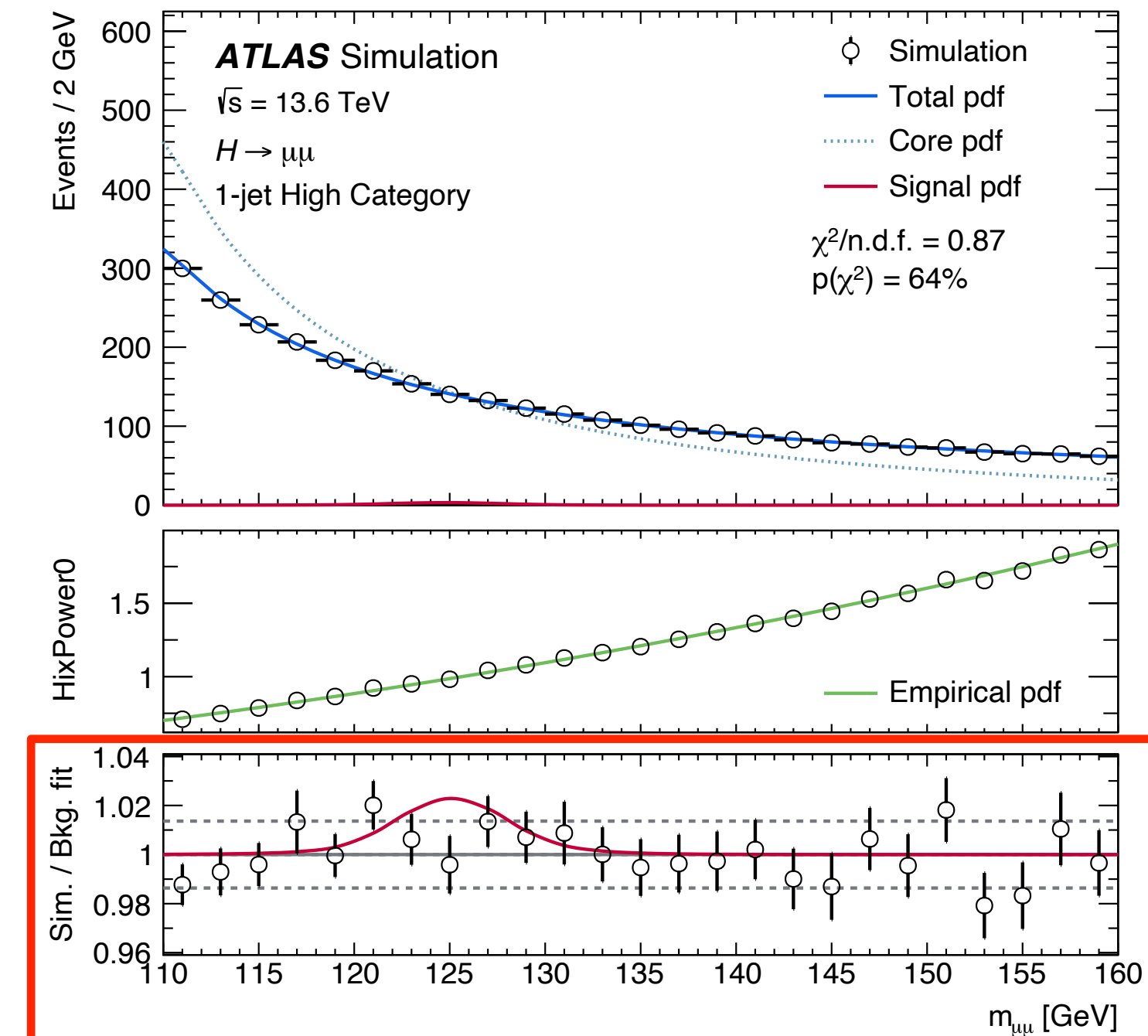
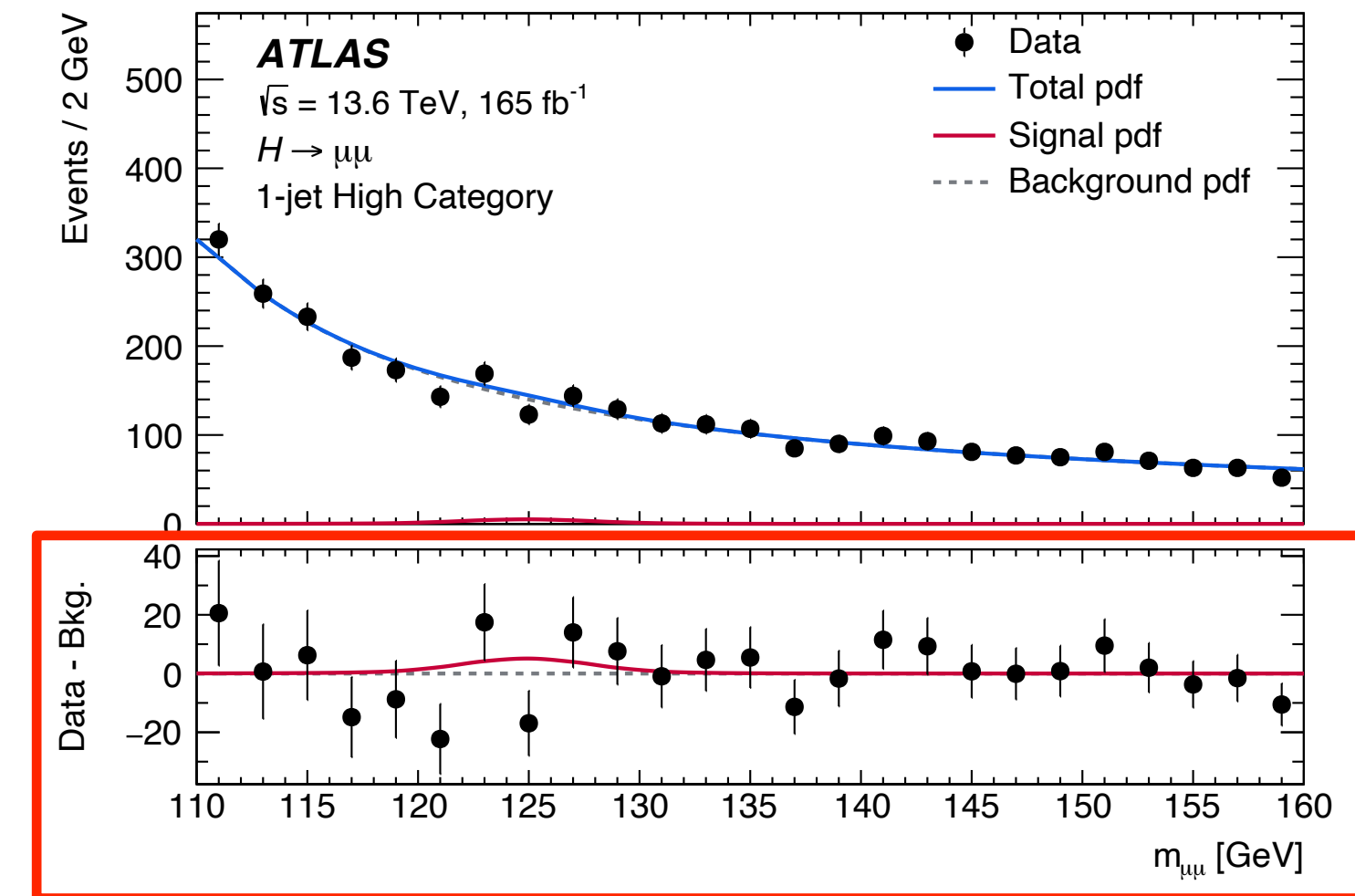
- Muon momentum scale uncertainty: $O(0.1\%)$
- Muon momentum resolution uncertainty: $O(1\%)$
- **Systematics on signal are in general negligible compared to data statistics**

- Drell-Yan shape is very steep and difficult to model
- Use “**core**~~x~~**empirical**” strategy
 - **Core function**: capture the bulk of the spectrum shape
 - LO Drell-Yan line-shape convoluted with detector resolution, fully rigid
 - **Empirical function**: absorb remaining difference

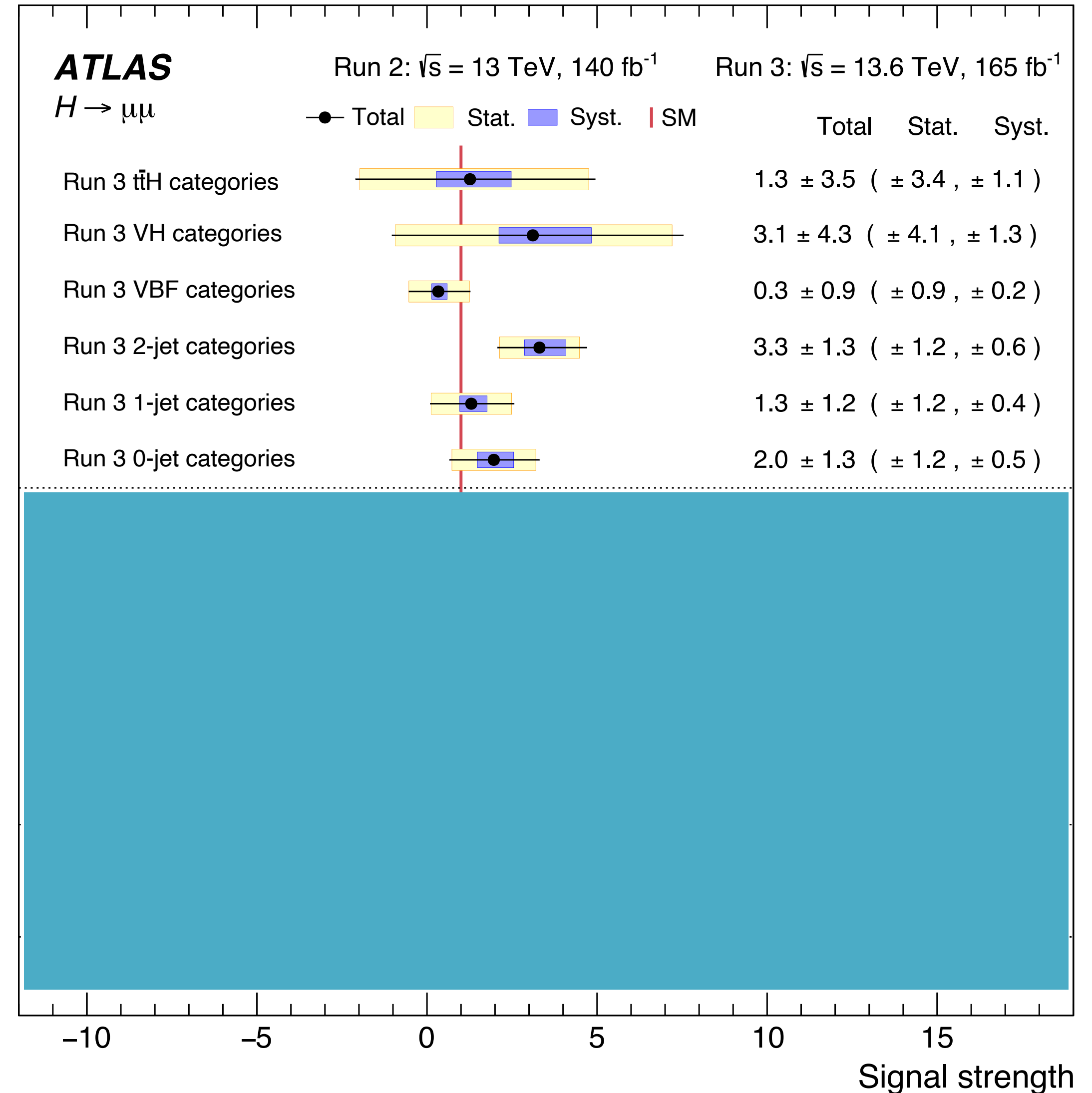
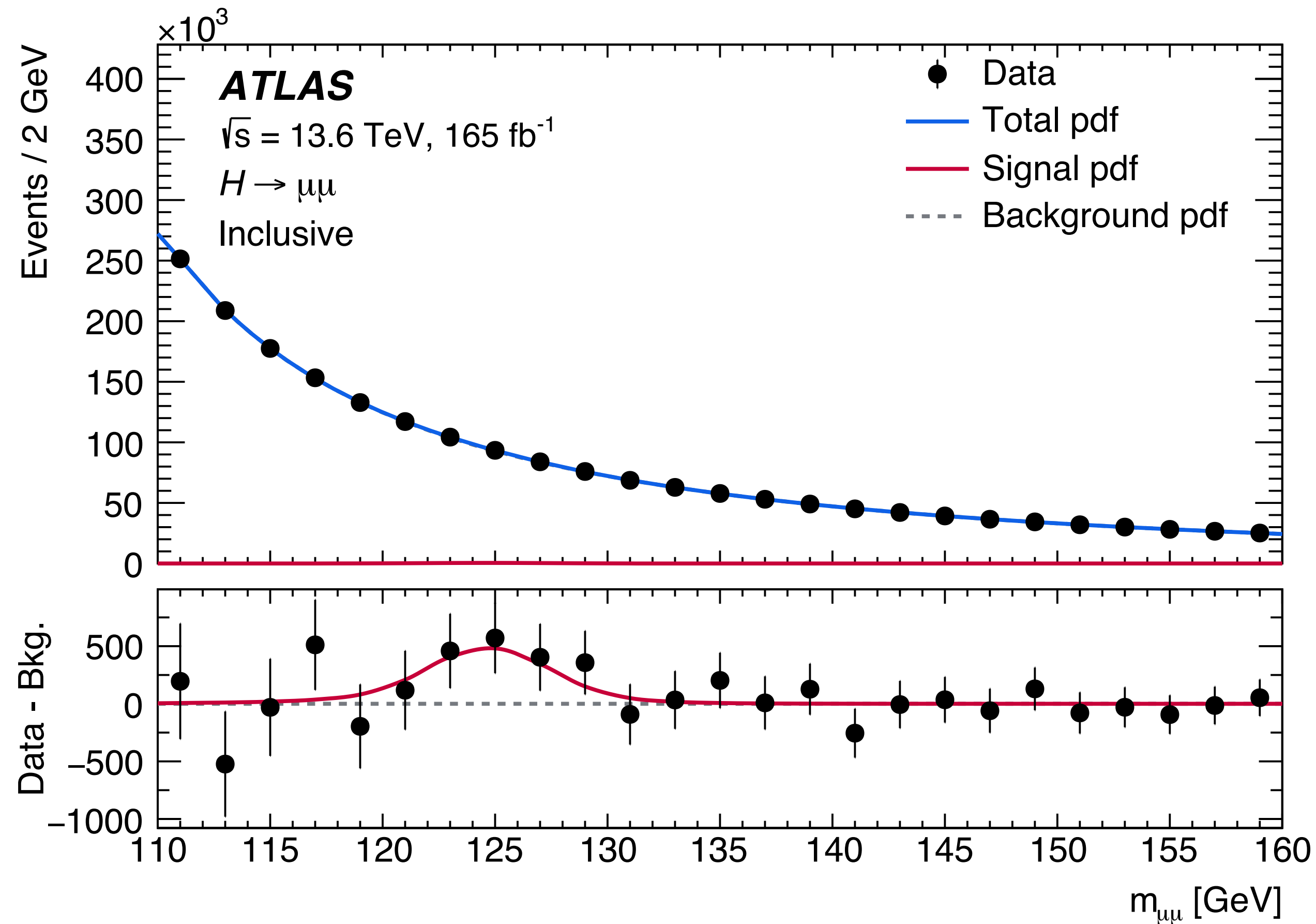


How to decide background parameterization

- Cannot directly use data to decide background model:
fluctuations $\gg$ Higgs signal
- Generate **5 billion NLO Sherpa $Z \rightarrow \mu\mu$ events** to study background model
 - Fluctuations $\sim 20\%$ of data statistical uncertainty
- Selected background model by **spurious signal** test based on high statistics MC background template
 - Fit S+B model to a bkg.-only MC template. Fitted signal yield called “spurious signal” (SS). It is used to
 1. Select bkg. model (SS < 20% of data stat. uncert.)
 2. Assigned as background model systematic

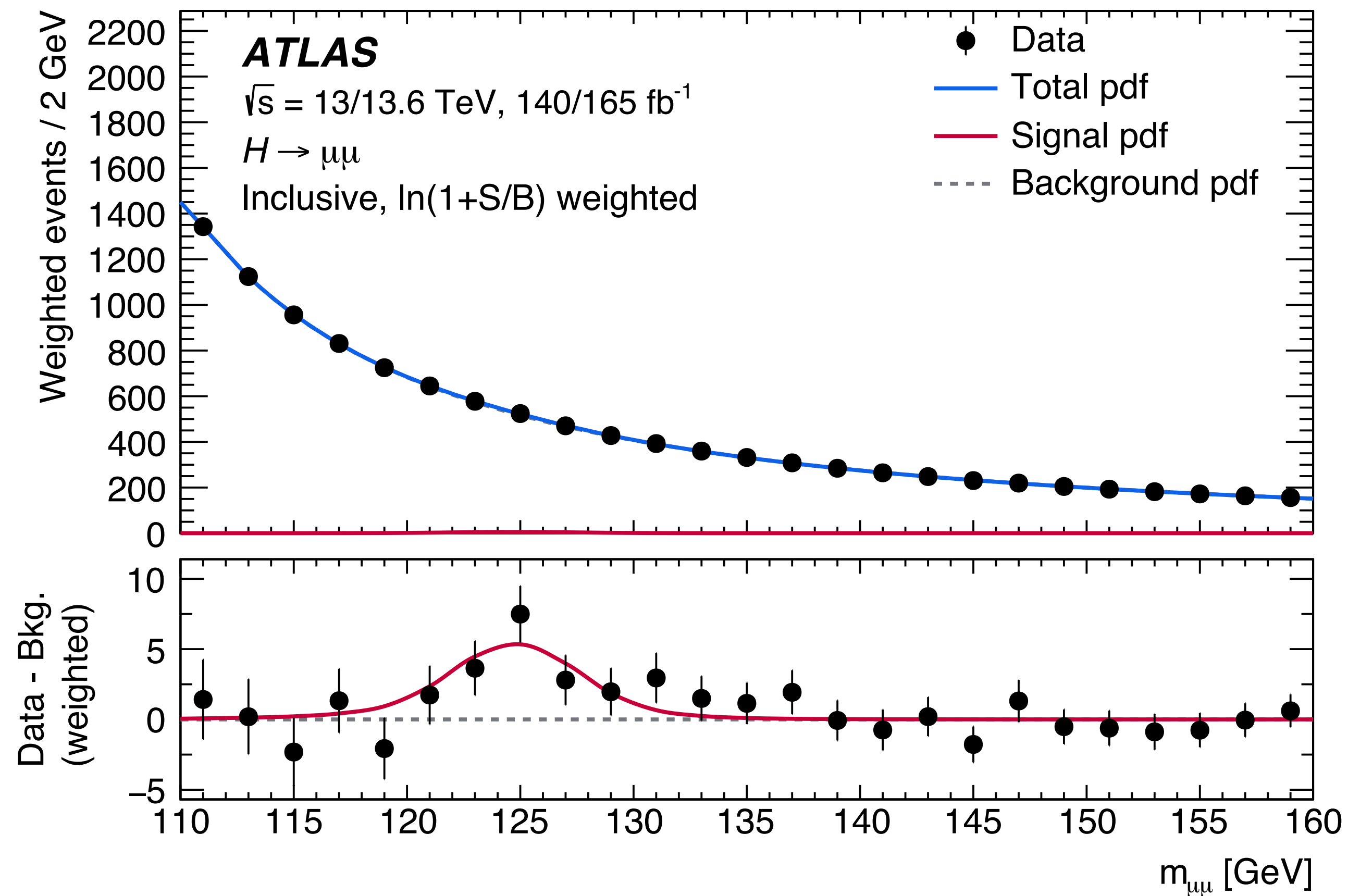


Run 3 results

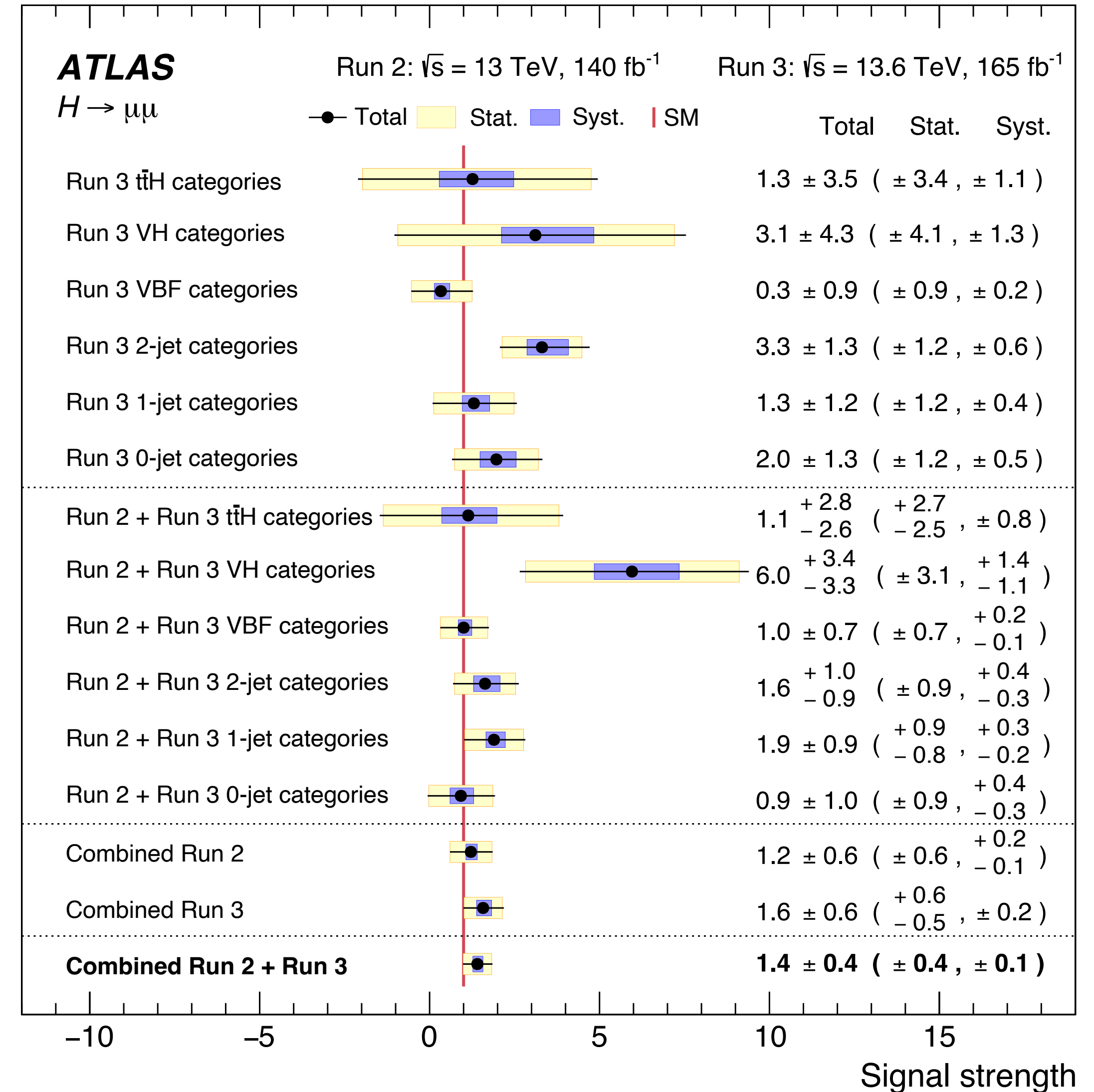


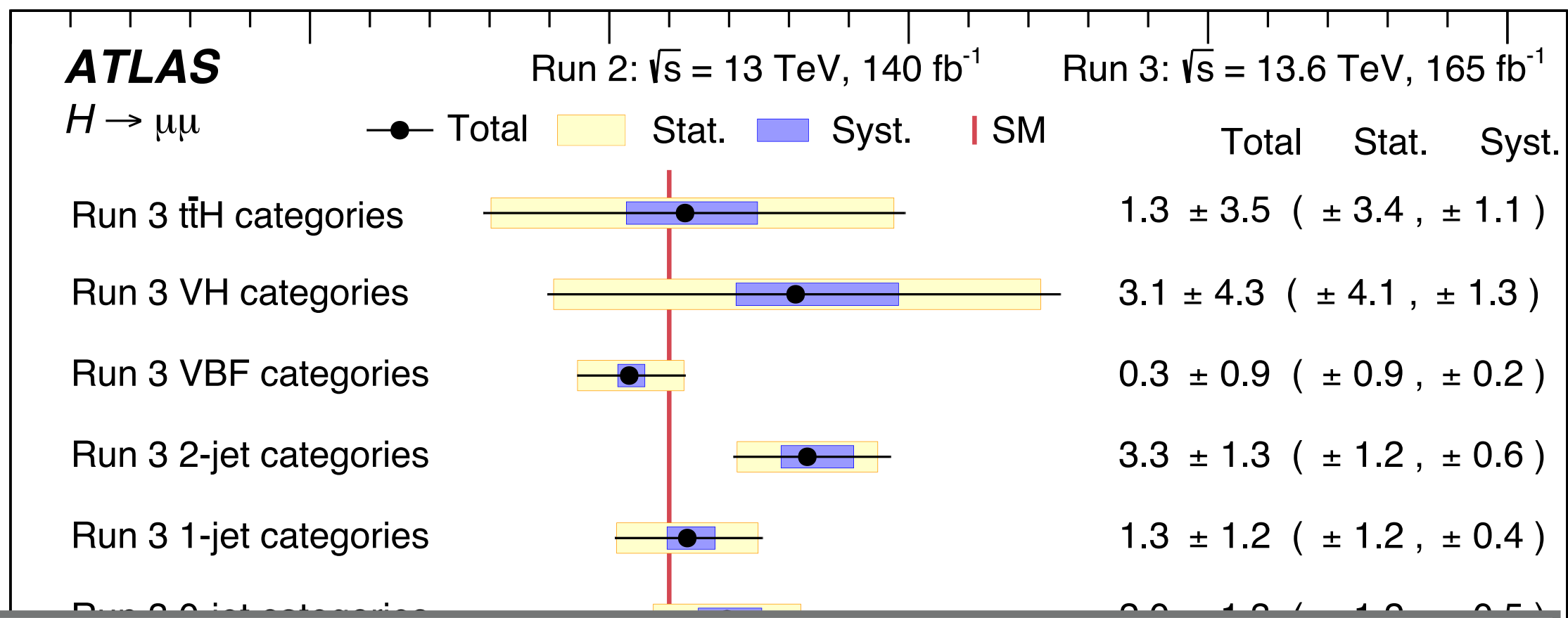
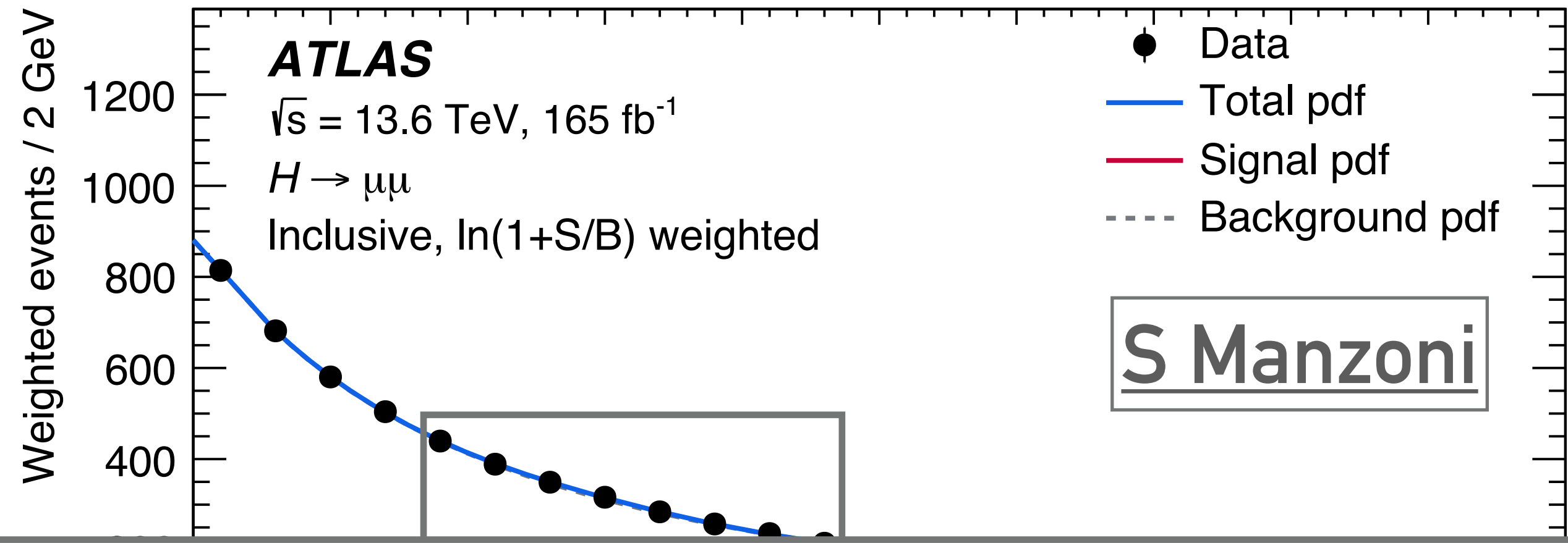
- Exp. significance 1.8σ , **obs. 2.8σ** ($m_H = 125.09 \text{ GeV}$)
- Signal strength $\mu = 1.6_{-0.5}^{+0.6} (\text{stat}) \pm 0.2 (\text{syst})$

Run 3 + Run 2 results

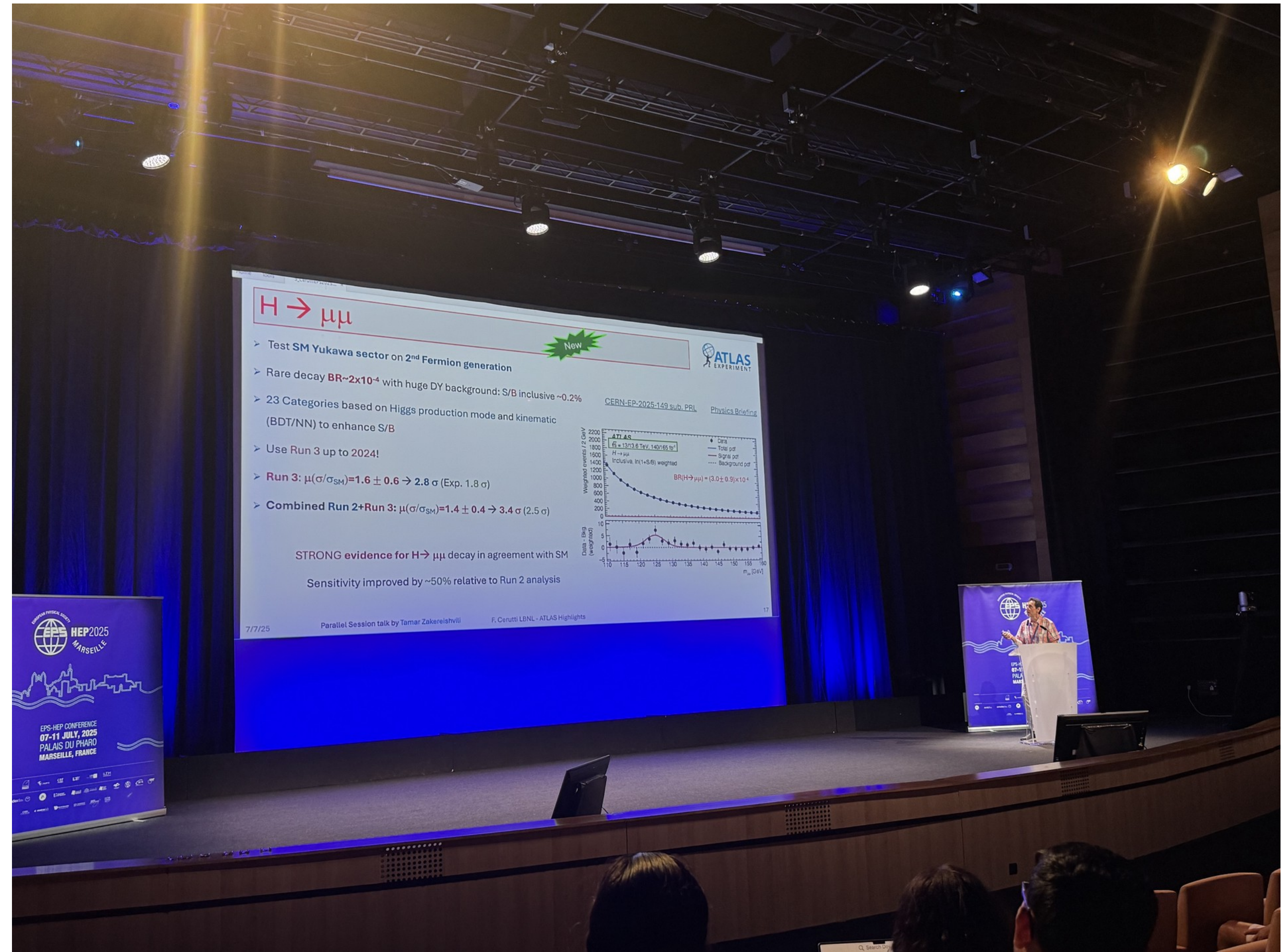
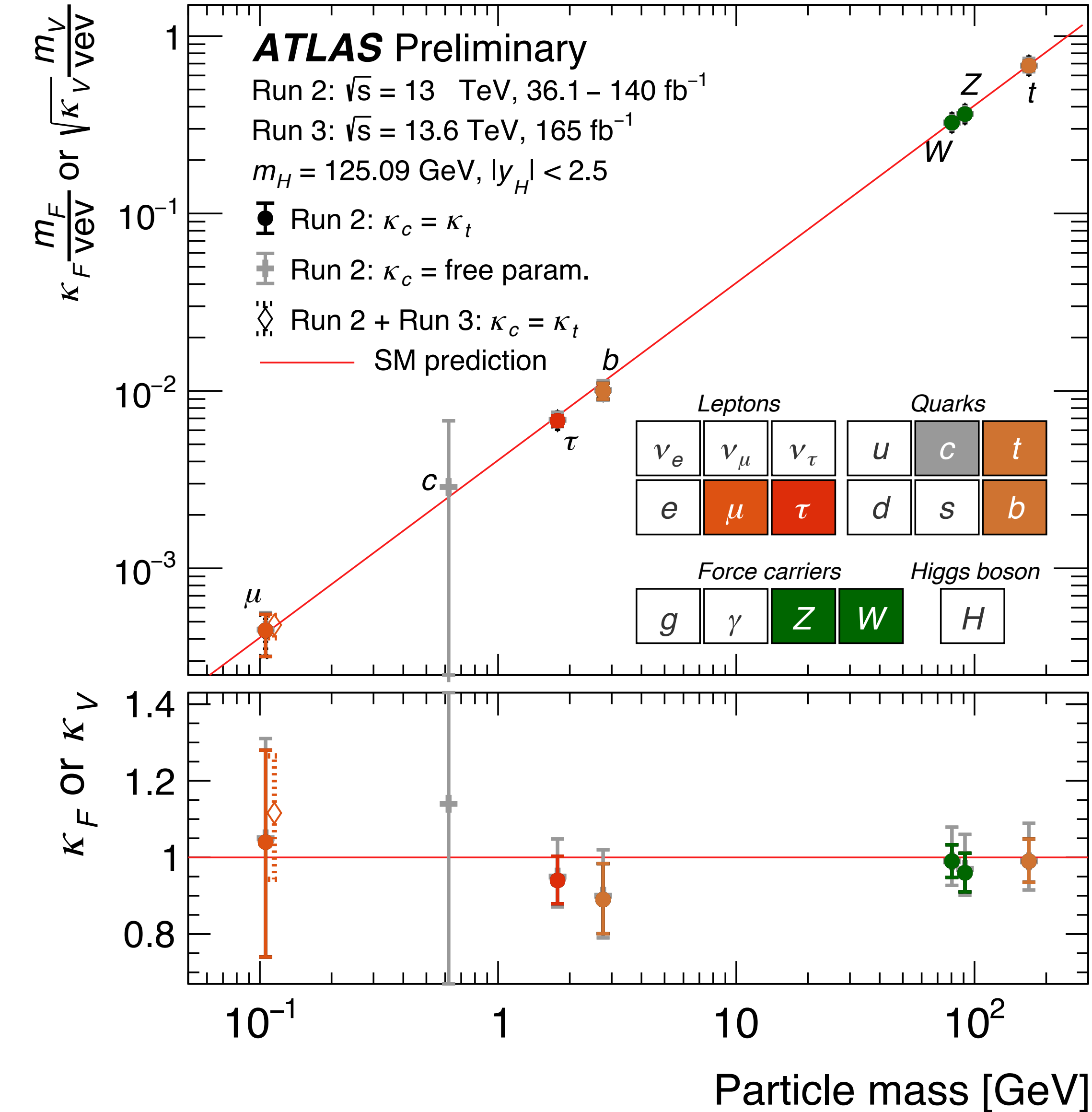


- Exp. significance 2.5σ , **obs. 3.4σ** ($m_H = 125.09$ GeV)
- Signal strength $\mu = 1.4 \pm 0.4$ (stat) ± 0.1 (syst)





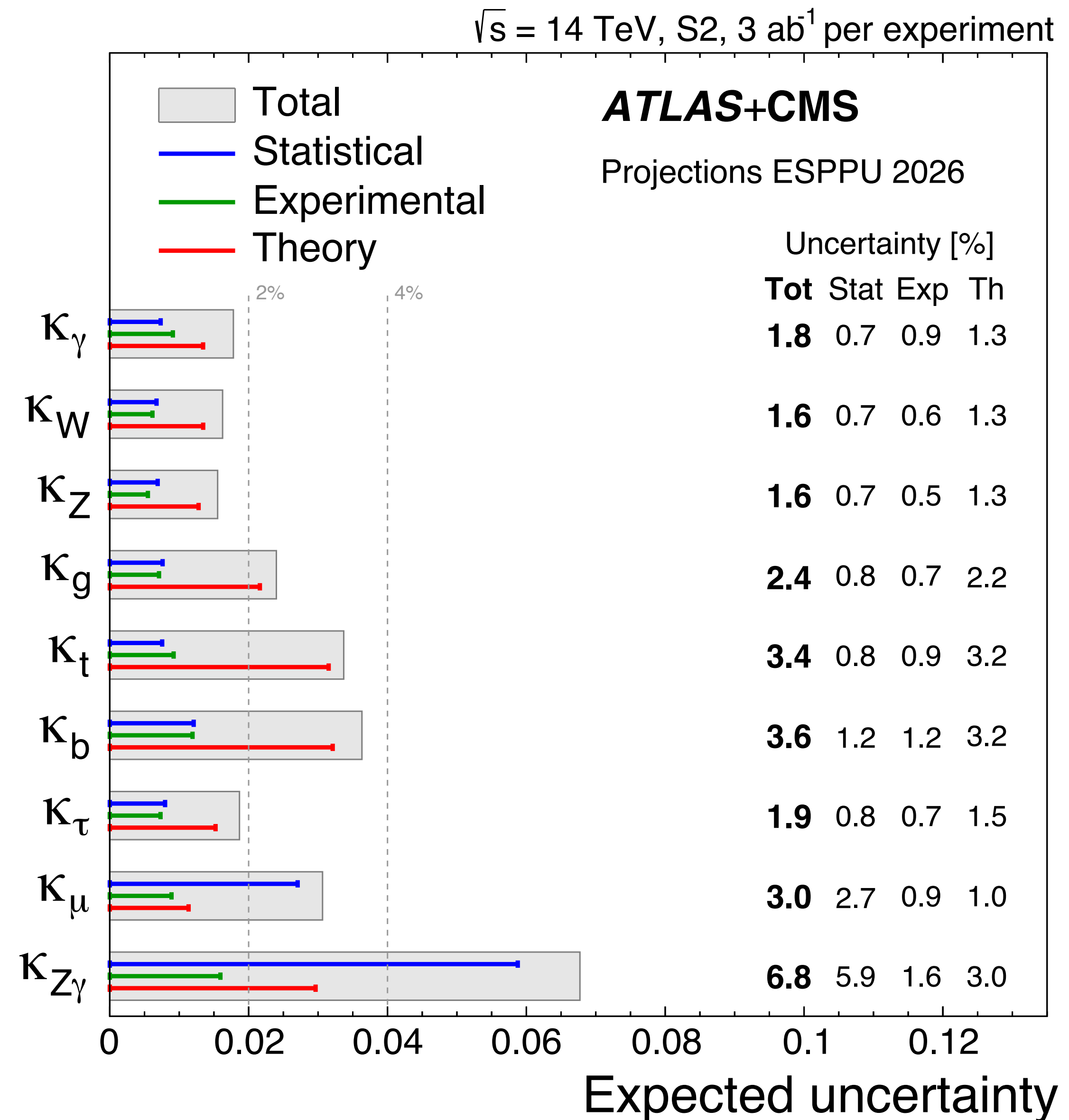
Muon Yukawa coupling strength test



- Results presented for the first time at EPS-HEP conference by Fabio Cerutti (ATLAS Physics Coordinator, LBNL)

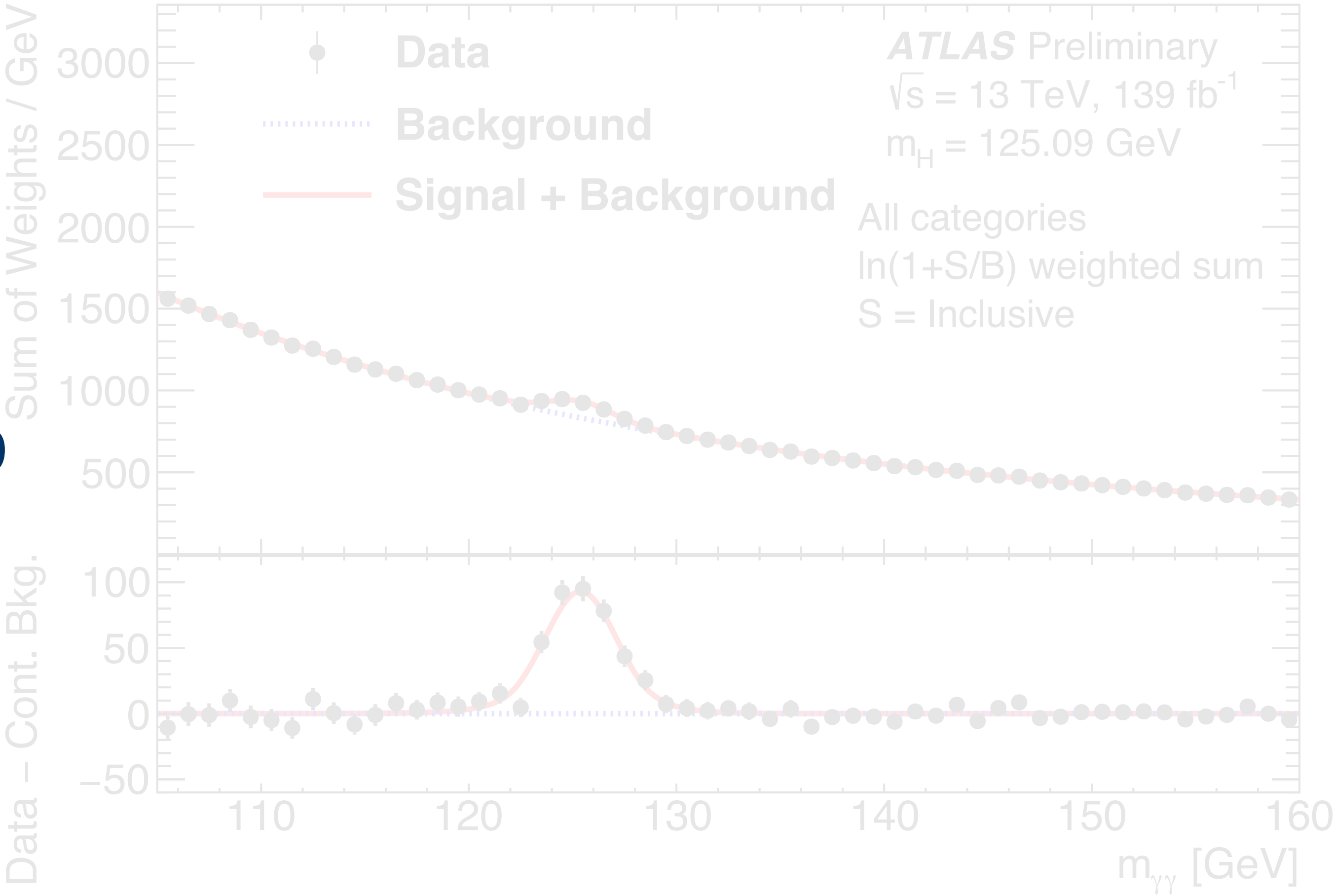
Conclusions

- **First ATLAS evidence of $H \rightarrow \mu\mu$** declared with Run 3+2 data: accepted by PRL ([Paper](#), [ATLAS physics briefing](#), [CERN Courier](#))
- **PRL Editors' Suggestion, APS Viewpoint highlight (top 0.2% of all Phys. Rev. papers)**
- CMS already claimed evidence with Run 2 data ([JHEP 01 \(2021\) 148](#))
- Run 3 data analysis ongoing. Expect $\sim 300 \text{ fb}^{-1}$ @13.6 TeV
- **Observation should be within reach** (but difficult for ATLAS to achieve it by ourselves)
- $H \rightarrow \mu\mu$ will provide very interesting test of SM by the end of LHC lifetime!





Backup



Introduction

Background Modeling Uncertainty Study with MC

For HSG1 Weekly Meeting

Andrew Hard, Yaquan Fang, Fuquan Wang, Haichen Wang,
Hongtao Yang and Sau Lan Wu

Department of Physics, UW Madison

March 22, 2012



- Currently the results of background modeling uncertainty were obtained from residual integration using Resbos diphoton sample.
- Here we will present a new method for estimating background modeling uncertainty, which is more relevant to its nature:
 - S+B PDF to fit the pure MC background for each mass point. The largest fitted $|N_{sig}|$ will be used as uncertainty.
- In this study we use both diphoton and photon-jet samples with high statistics, with many detector effects simulated.

- For those of you with ATLAS internal access, the link of the talk is [here](#)
- We also generated large amount of Sherpa diphoton continuum sample by ourselves. We submitted so many MC generation jobs to the grid, in the end we got a stern warning from ATLAS computing that it must stop