HIGGS 2020

Online conference

October 26-30

Higgs boson to charms, taus, and muons

Andrea Carlo Marini

on behalf of the
ATLAS and CMS Collaborations

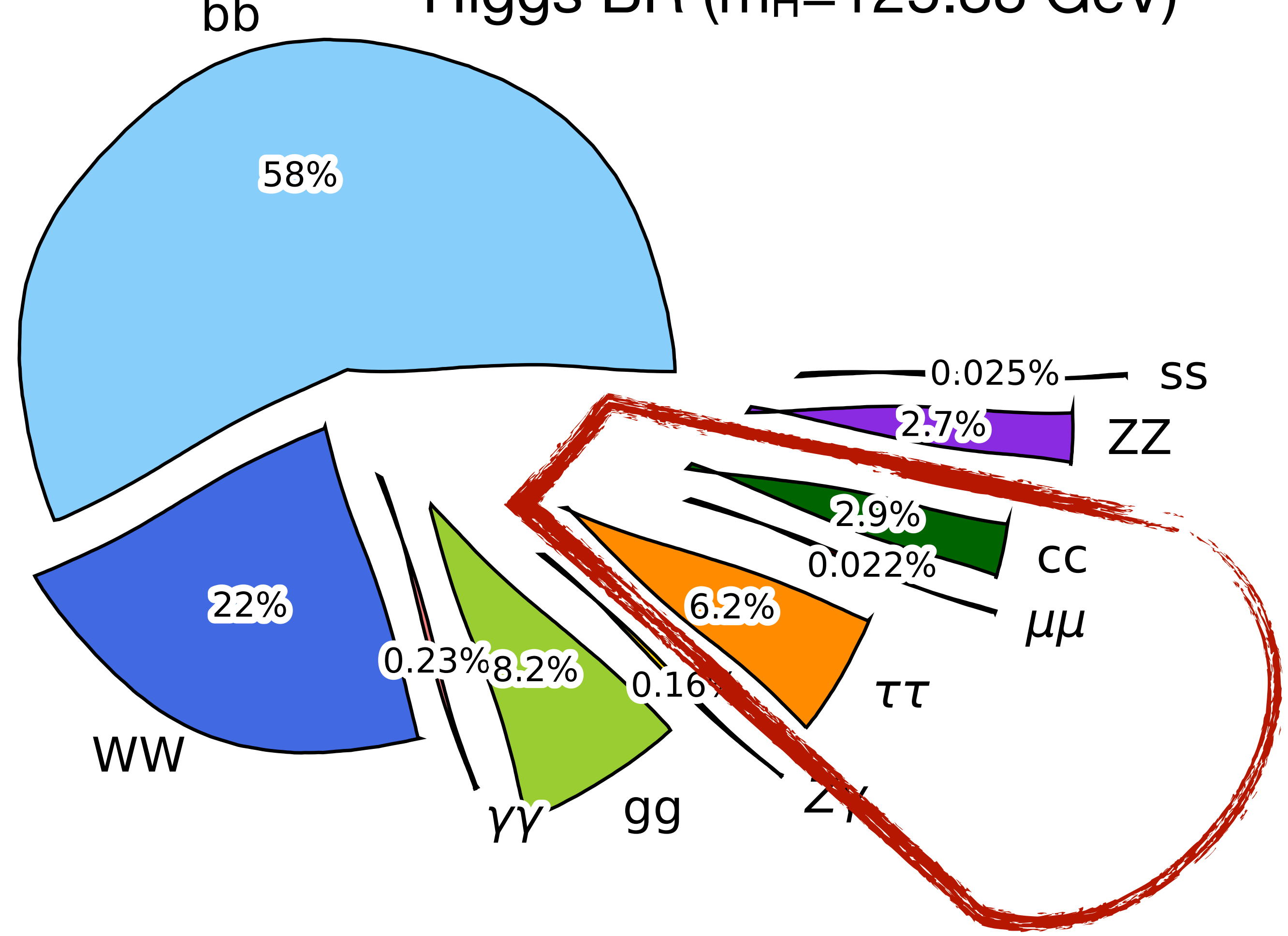
Introduction

Higgs decay to lepton and second fermion generation

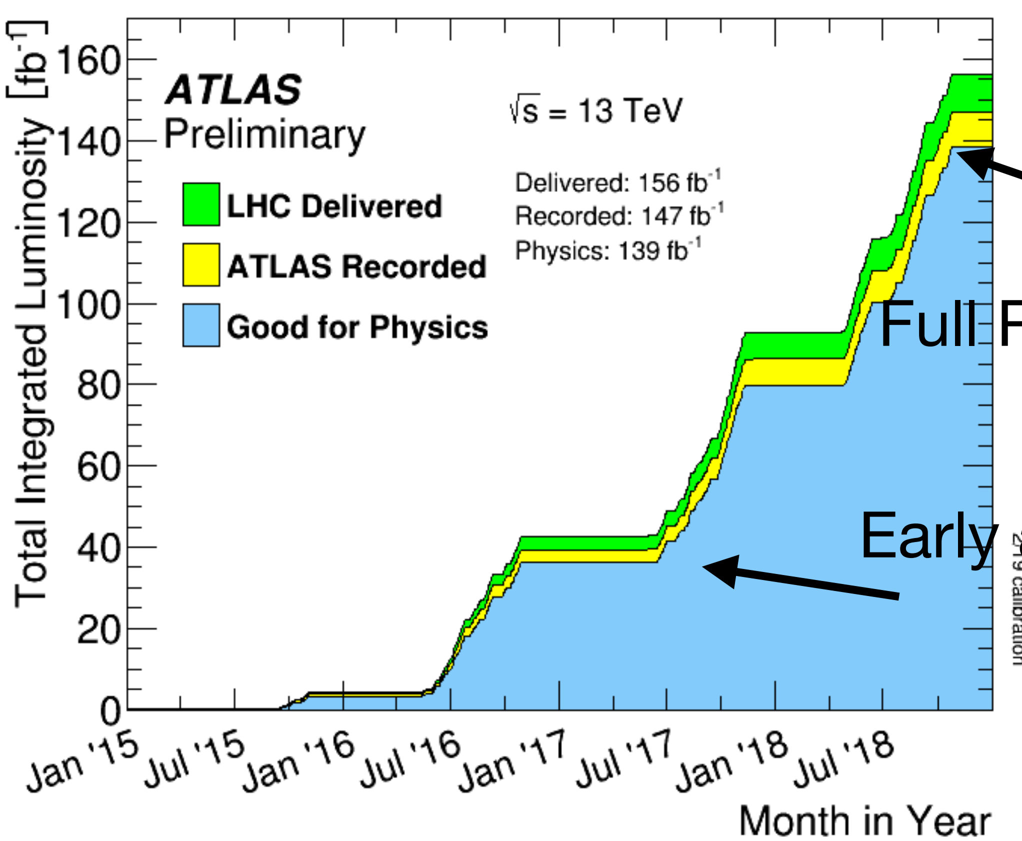
- Higgs to $\tau\tau$
- Higgs to μμ
- Higgs to cc

ATLAS & CMS are upgrading the analysis
To the full Run 2 luminosity

Higgs BR (m_H=125.38 GeV)



Full Run 2



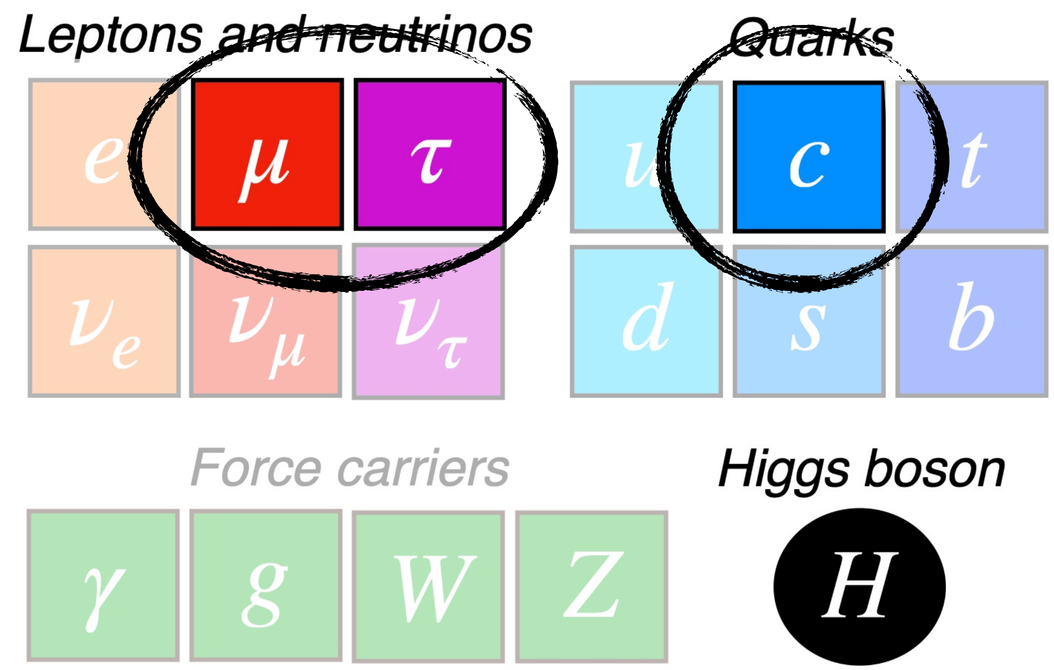
Full Run2 ~140 fb^{-1}

Early analysis ~36 fb^{-1}

The fermionic sector

- The fermionic sector is characterised by Yukawa couplings to the Higgs boson
  - Proportional to the fermion mass!

- New physics may modify the fermionic sector differently from the boson one.
  - Precision mapping of the couplings is key to understand the nature of the Higgs boson
  - Asymmetries in the leptonic vs the quark sector
  - Asymmetries across the fermionic generations



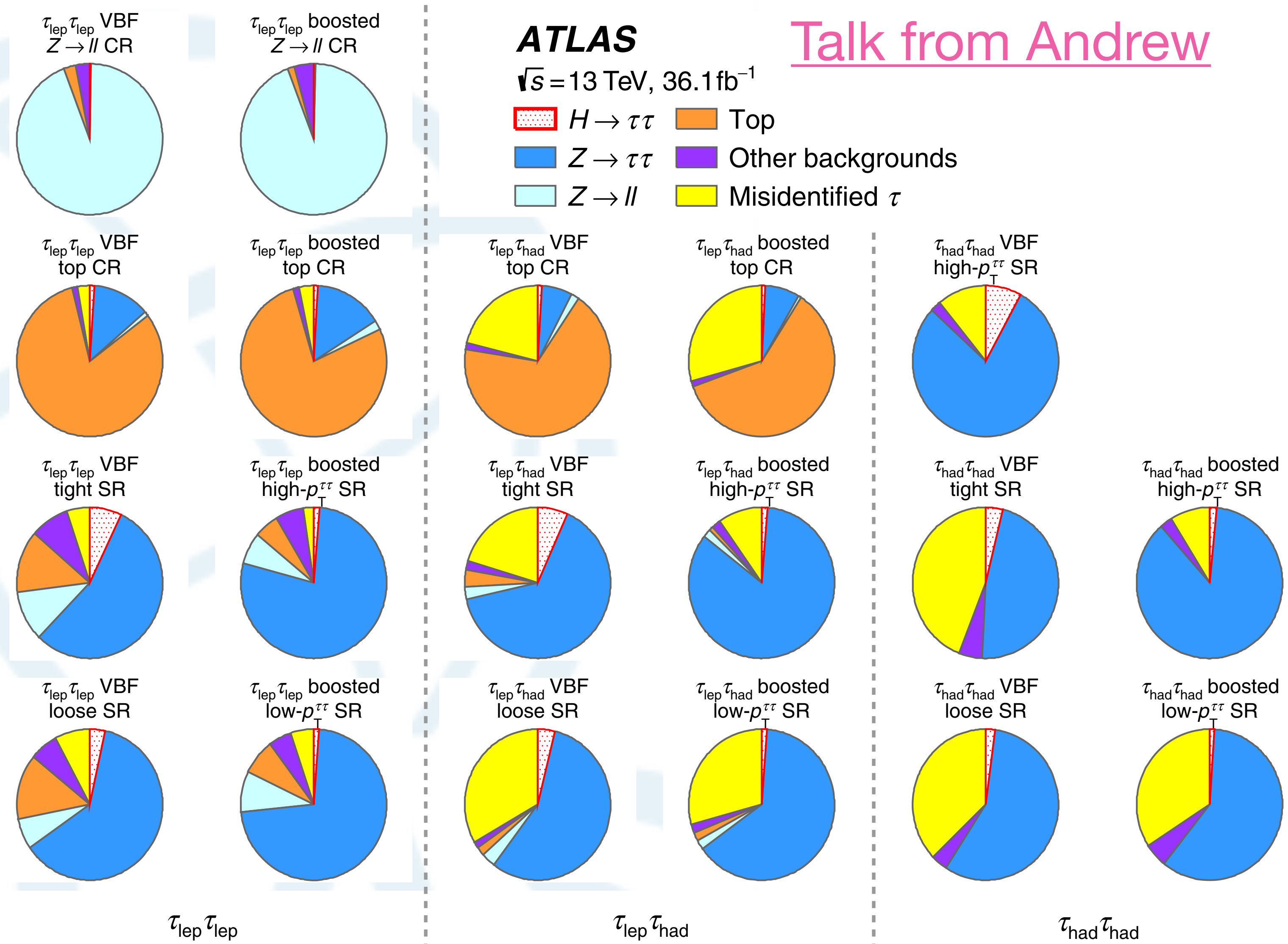
Exploring the couplings to the leptons (taus, muons) and to the second fermion generation (muons, charms)

$H \rightarrow \tau\tau$ — ATLAS

PRD 99 (2019) 072001

- Challenges:
  - Trigger and identification
- Analyzed all final states in τ^{had} and τ^{let}
- Targeting **STXS Stage 0**
- Dominant background:
  - Misidentified taus and DY$\rightarrow\tau\tau$
  - DY estimated from MC simulation misided taus from fake factors
- Events categorized to target the different production modes
- DY MC validated in dedicated regions

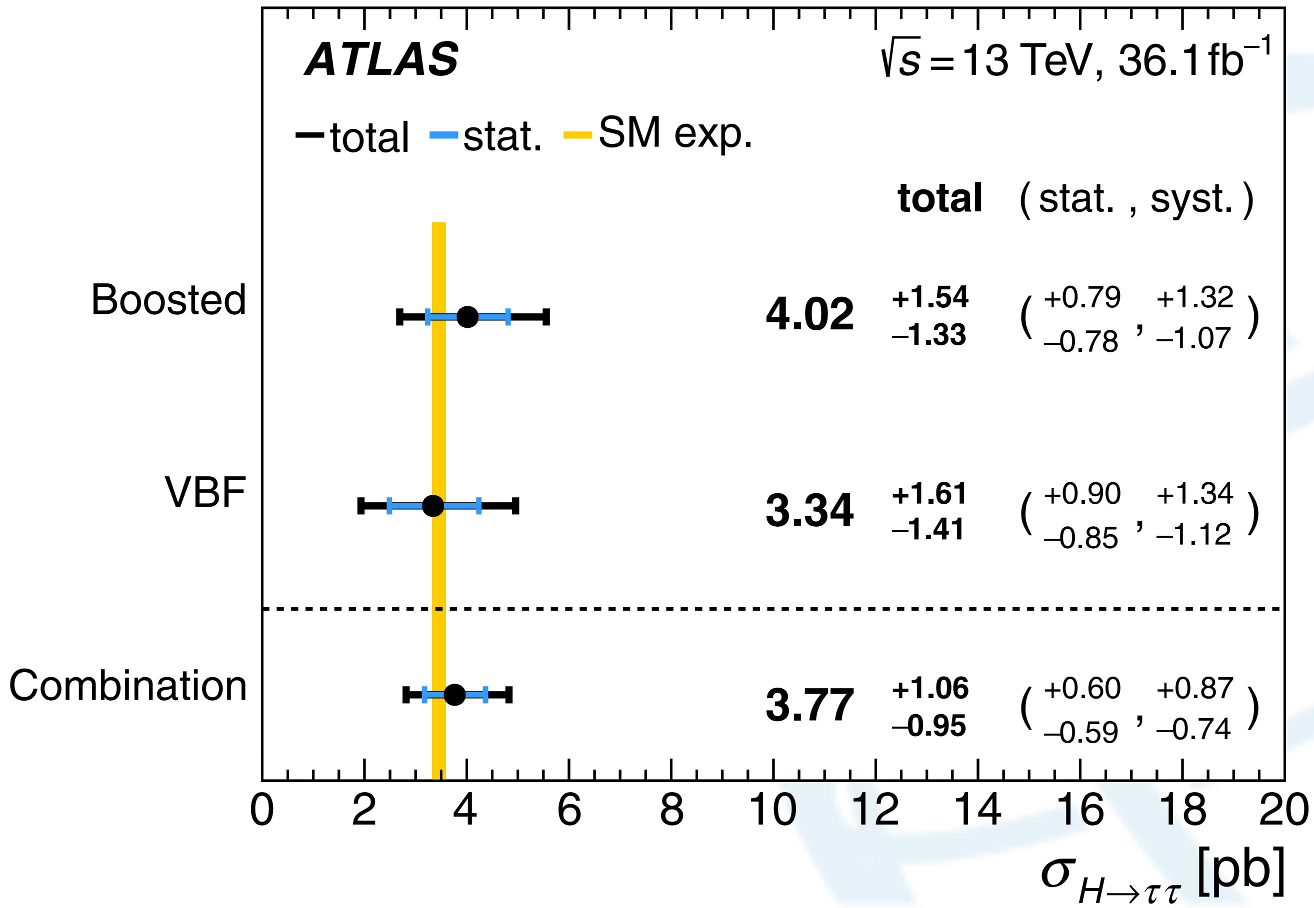
Talk from Andrew



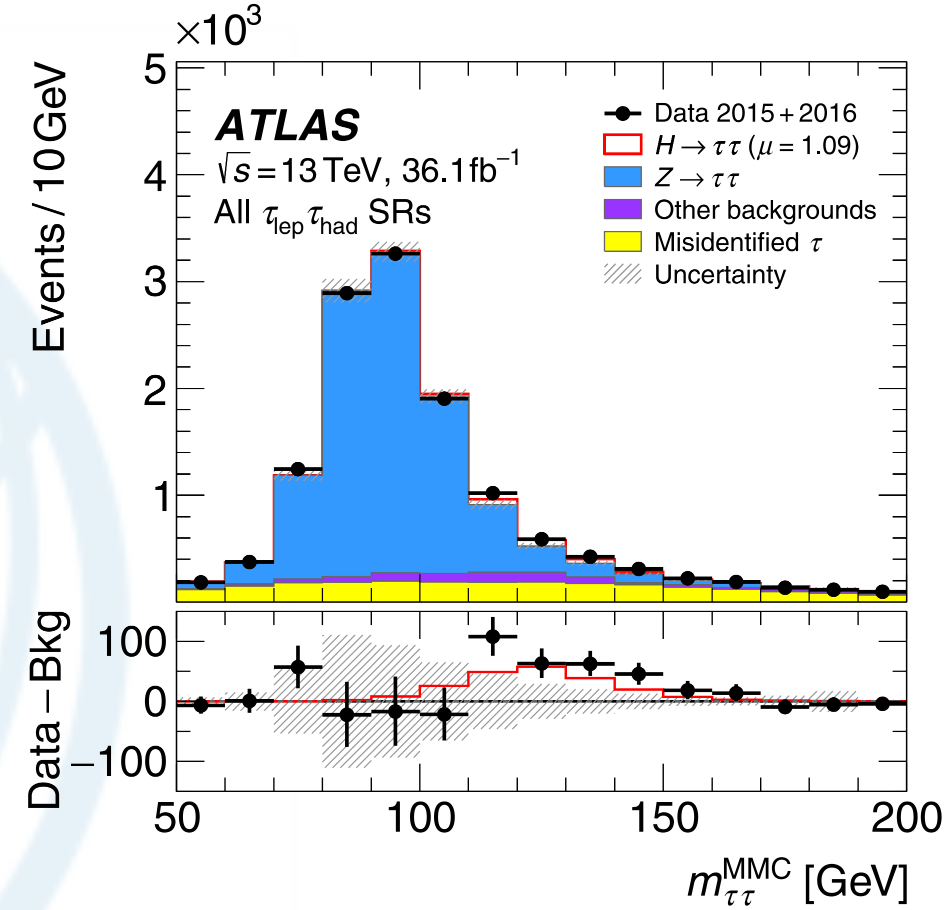
Analysis channel	Trigger	Analysis p_T requirement [GeV] 2015	2016
$\tau_{lep}\tau_{lep}$ & $\tau_{lep}\tau_{had}$	Single electron	25	27
	Single muon	21	27
$\tau_{lep}\tau_{lep}$	Dielectron	15/15	18/18
	Dimuon	19/10	24/10
	Electron+muon	18/15	18/15
$\tau_{had}\tau_{had}$	Di-$\tau_{had\text{-}vis}$	40/30	40/30

H→ττ — ATLAS

PRD 99 (2019) 072001



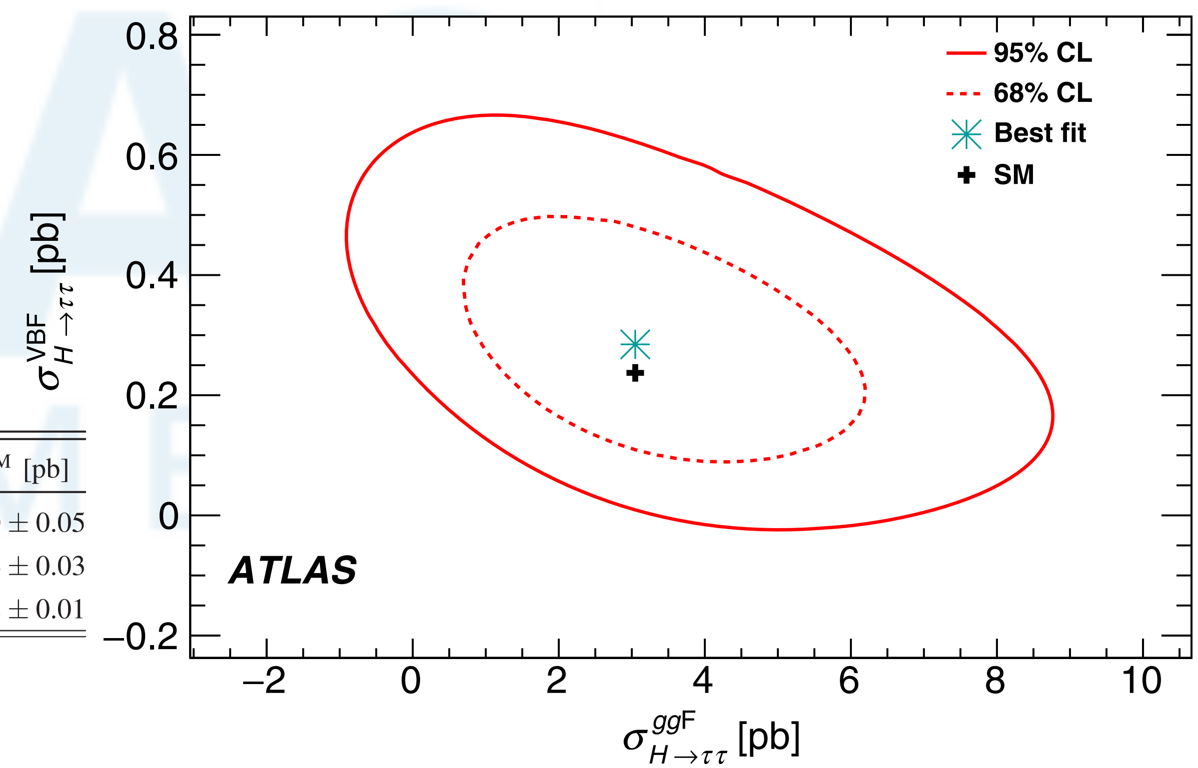
(b)



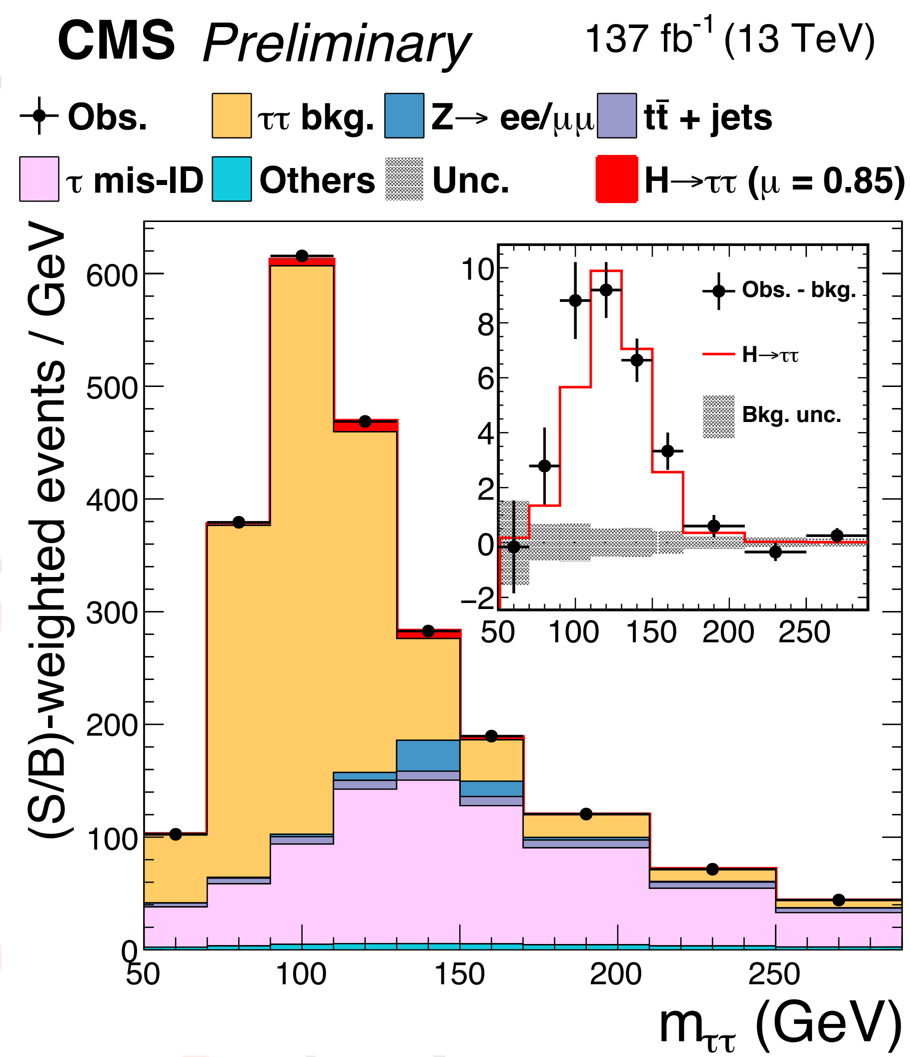
Results compatible with the SM expectations

- Two p_T^H bins provided (60-120-∞ GeV)
- STXS Stage 0 not limited by stat.

Process	Particle-level selection	σ [pb]	σ^{SM} [pb]
ggF	$N_{jets} \geq 1$, $60 < p_T^H < 120$ GeV, $\lvert y_H \rvert < 2.5$	$1.79 \pm 0.53(\text{stat}) \pm 0.74(\text{syst})$	0.40 ± 0.05
ggF	$N_{jets} \geq 1$, $p_T^H > 120$ GeV, $\lvert y_H \rvert < 2.5$	$0.12 \pm 0.05(\text{stat}) \pm 0.05(\text{syst})$	0.14 ± 0.03
VBF	$\lvert y_H \rvert < 2.5$	$0.25 \pm 0.08(\text{stat}) \pm 0.08(\text{syst})$	0.22 ± 0.01



- Cut based analysis targeting STXS production
  - STXS Stage 1.2
  - In $\ell\tau_h$ channels requirement on m_T<50 GeV (ℓ=e,μ)
  - In the eμ channel requirement on D_ζ > -30 GeV
- Sensitivity to ggH high p_T and to VBF topology



Channel	Trigger requirement	Minimal lepton selection		
		p_T (GeV)	η	Isolation
$\tau_h\tau_h$	$\tau_h[35]$ & $\tau_h[35]$ (2016) $\tau_h[40]$ & $\tau_h[40]$ (2017, 2018)	$p_T^{\tau_h} > 40$	$\lvert\eta^{\tau_h}\rvert < 2.1$	DNN τ_h ID
$\mu\tau_h$	$\mu[22]$ (2016) $\mu[19]$ & $\tau_h[21]$ (2016) $\mu[24]$ (2017, 2018) $\mu[20]$ & $\tau_h[27]$ (2017, 2018)	$p_T^{\mu} > 20$ $p_T^{\tau_h} > 30$	$\lvert\eta^{\mu}\rvert < 2.1$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$I^{\mu} < 0.15$ DNN τ_h ID
$e\tau_h$	e[25] (2016) e[27] (2017) e[32] (2018) e[24] & $\tau_h[30]$ (2017, 2018)	$p_T^{e} > 25$ $p_T^{\tau_h} > 30$	$\lvert\eta^{e}\rvert < 2.1$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$I^{e} < 0.15$ DNN τ_h ID
$e\mu$	e[12] & $\mu[23]$ (all years) e[23] & $\mu[8]$ (all years)	$\min(p_T^{e}, p_T^{\mu}) > 15$ $\max(p_T^{e}, p_T^{\mu}) > 24$	$\lvert\eta^{e}\rvert < 2.4$ $\lvert\eta^{\mu}\rvert < 2.4$	$I^{e} < 0.15$ $I^{\mu} < 0.15$

$$m_T \equiv \sqrt{2 p_T^{\ell} p_T^{\text{miss}} [1 - \cos(\Delta\phi)]}$$

$$D_\zeta = p_\zeta - 0.85\, p_\zeta^{\text{vis}}$$

p_ζ : p_T^{miss} bisector of the leps

p_ζ^{vis}: Σp_T^{lep} on the bisector

Full Run 2

CMS-PAS-HIG-19-010

- Categories constructed targeting STXS Stage 0
  - In each category 2D fit, $m_{\tau\tau}$ and an observable discriminating the Stage 1.2 process.

Final state	Category	Selection	Observables
$\ell\tau_h$, $e\mu$	0-jet	0 jet	$m_{\tau\tau}$, τ_h p_T ($\ell\tau_h$) $m_{\tau\tau}$ ($e\mu$)
	VBF low p_T^H	≥ 2 jets, $m_{jj} > 350$ GeV, $p_T^H < 200$ GeV	$m_{\tau\tau}$, m_{jj}
	VBF high p_T^H	≥ 2 jets, $m_{jj} > 350$ GeV, $p_T^H > 200$ GeV	$m_{\tau\tau}$, m_{jj}
	Boosted 1 jet	1 jet	$m_{\tau\tau}$, p_T^H
	Boosted ≥ 2 jets	Not in VBF, ≥ 2 jets	$m_{\tau\tau}$, p_T^H
$\tau_h\tau_h$	0-jet	0 jet	$m_{\tau\tau}$
	VBF low p_T^H	≥ 2 jets, $\Delta\eta_{jj} > 2.5$(2.0 for 2016), $100 < p_T^H < 200$ GeV	$m_{\tau\tau}$, m_{jj}
	VBF high p_T^H	≥ 2 jets, $\Delta\eta_{jj} > 2.5$(2.0 for 2016), $p_T^H > 200$ GeV	$m_{\tau\tau}$, m_{jj}
	Boosted 1 jet	1 jet	$m_{\tau\tau}$, p_T^H
	Boosted ≥ 2 jets	Not in VBF, ≥ 2 jets	$m_{\tau\tau}$, p_T^H

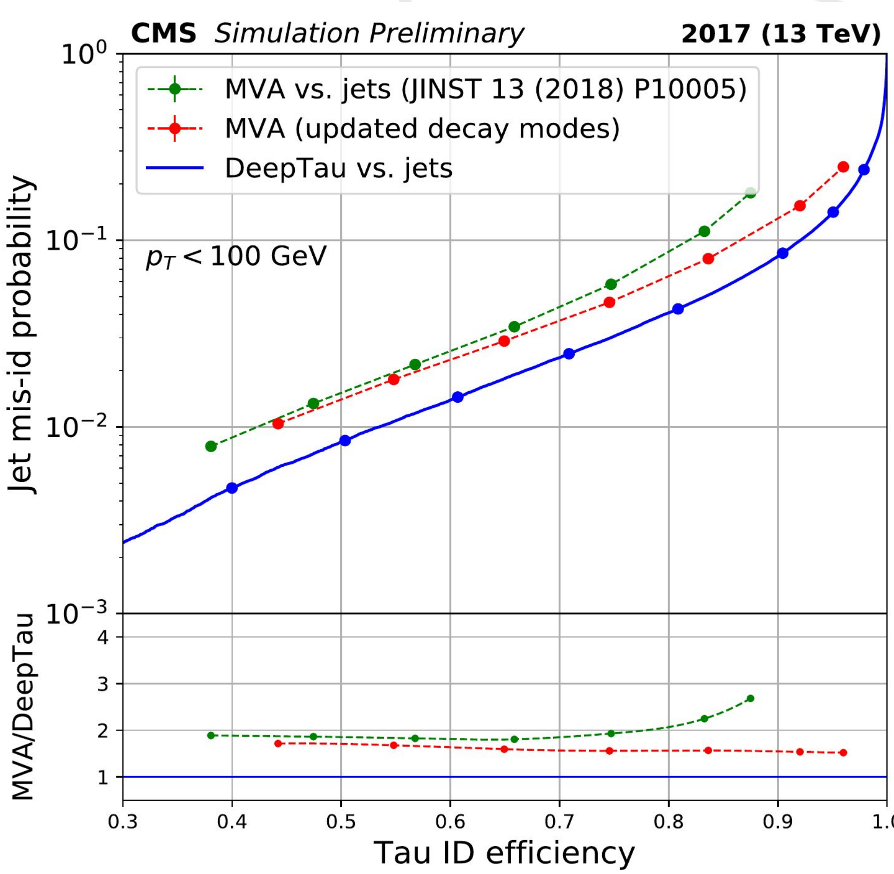
Deep Tau ID:

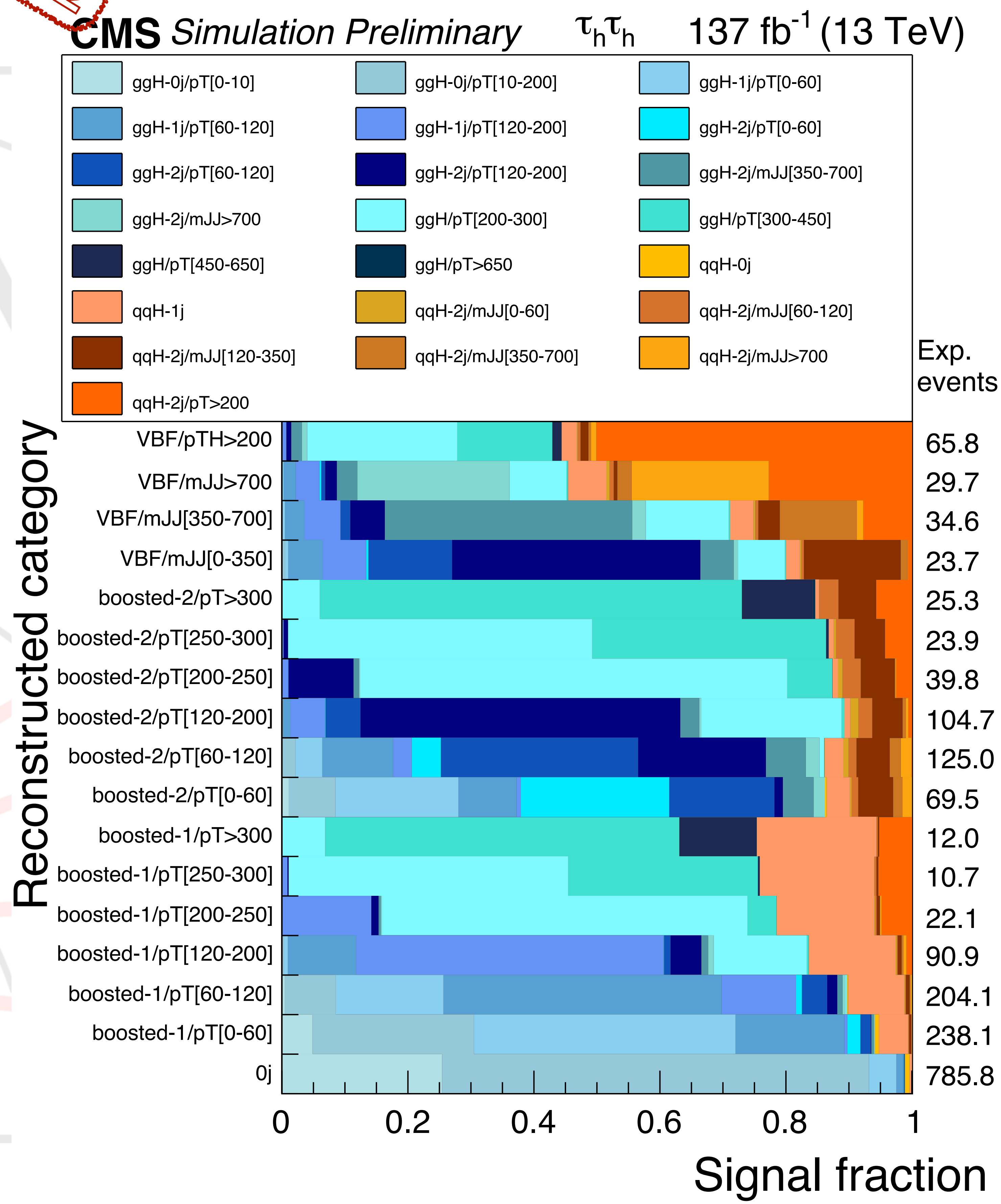
- Deploying DNN for τ-ID
- Increase background rejection

Tau embedding:

- for precise estimate of the Z background

Background from jet$\rightarrow\tau_h$ from fake rate method





H→ττ — CMS

Full Run 2

[CMS-PAS-HIG-19-010]

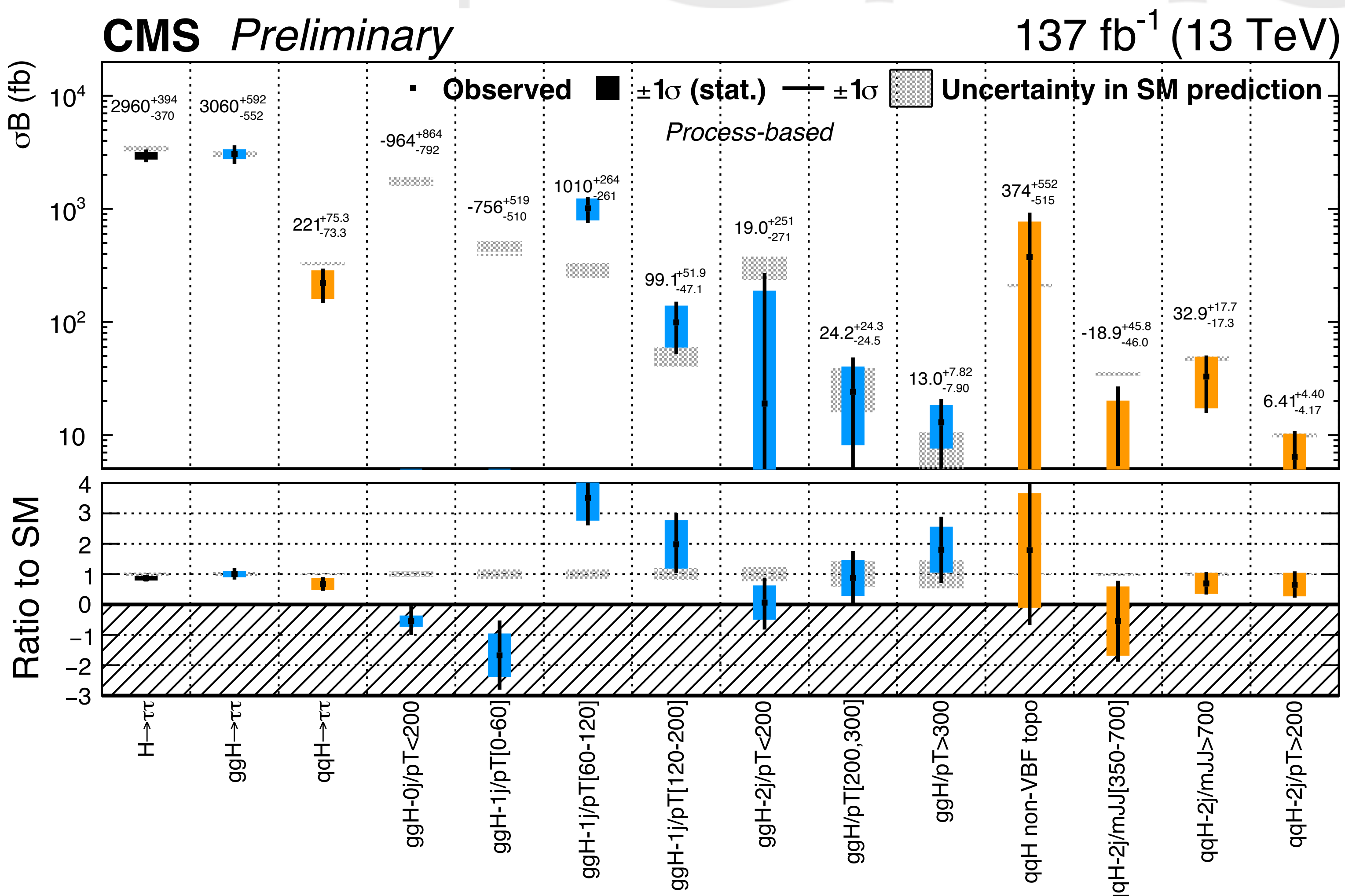
- Results presented in topology based and process based merging

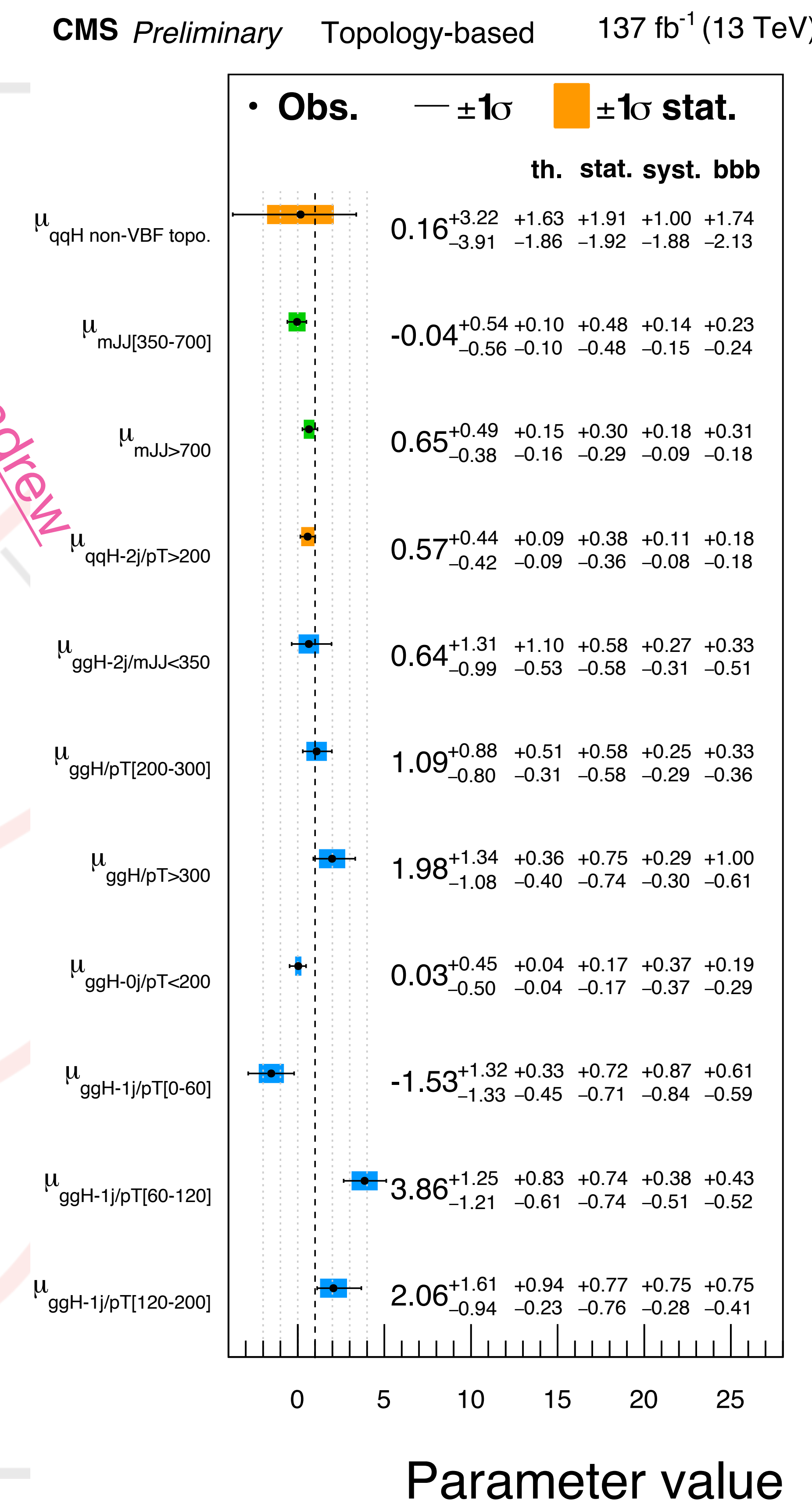
Talk from Andrew

Stage 0

	2016	2017	2018	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$	Combined
μ	$1.13^{+0.23}_{-0.21}$	$0.64^{+0.20}_{-0.19}$	$0.93^{+0.20}_{-0.15}$	$1.29^{+0.51}_{-0.47}$	$0.99^{+0.27}_{-0.24}$	$0.95^{+0.17}_{-0.16}$	$0.76^{+0.19}_{-0.17}$	$0.85^{+0.12}_{-0.11}$
μ_{ggH}	$0.83^{+0.39}_{-0.36}$	$0.72^{+0.35}_{-0.34}$	$1.40^{+0.33}_{-0.29}$	$2.47^{+0.91}_{-0.84}$	$0.42^{+0.53}_{-0.51}$	$0.99^{+0.27}_{-0.25}$	$1.29^{+0.44}_{-0.37}$	$0.98^{+0.20}_{-0.19}$
μ_{qqH}	$1.54^{+0.502}_{-0.47}$	$0.51^{+0.48}_{-0.46}$	$0.36^{+0.30}_{-0.29}$	$-0.17^{+0.98}_{-0.95}$	$1.41^{+0.49}_{-0.46}$	$0.89^{+0.38}_{-0.37}$	$0.09^{+0.39}_{-0.38}$	$0.67^{+0.23}_{-0.22}$

Stage 1.2



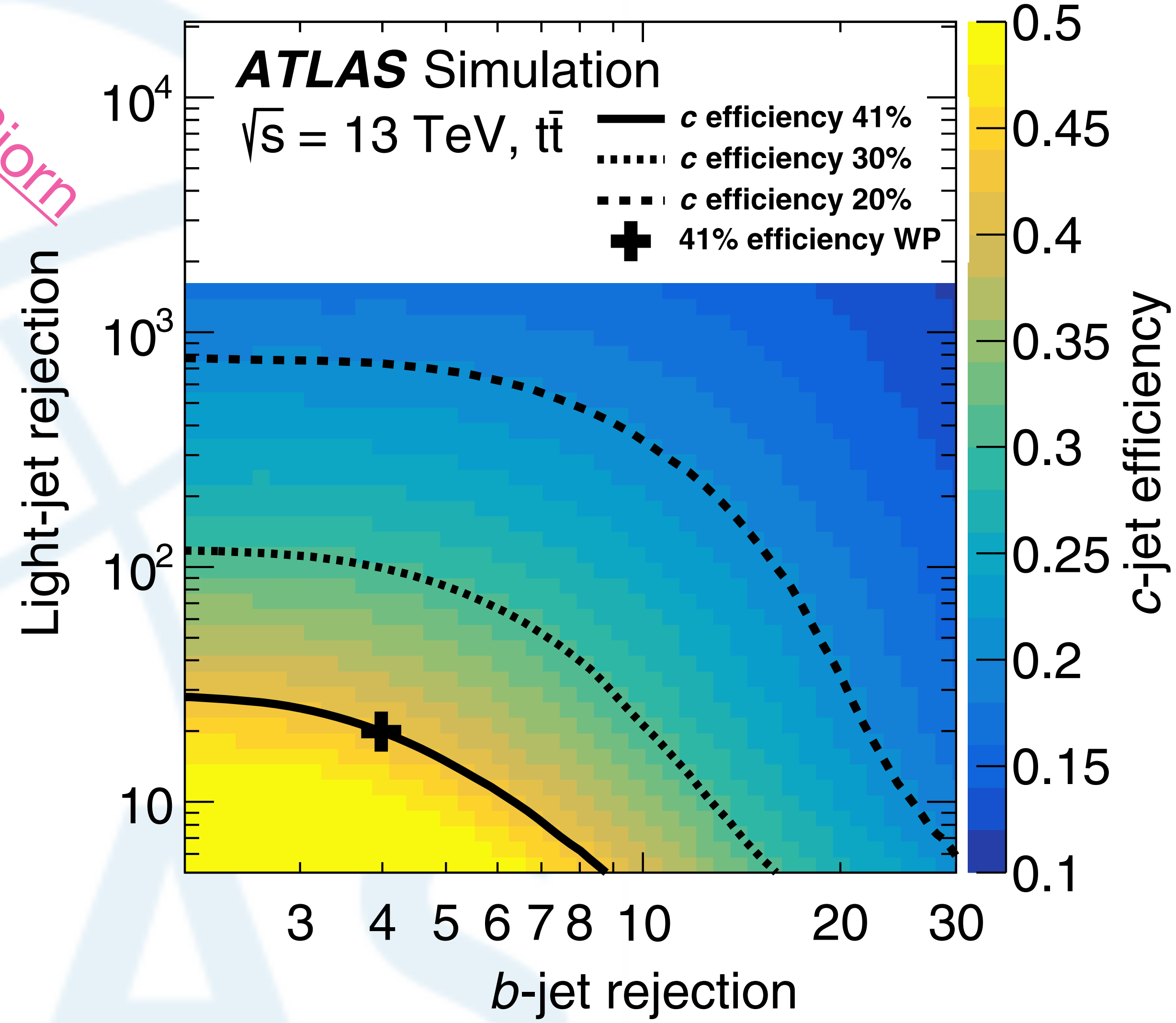


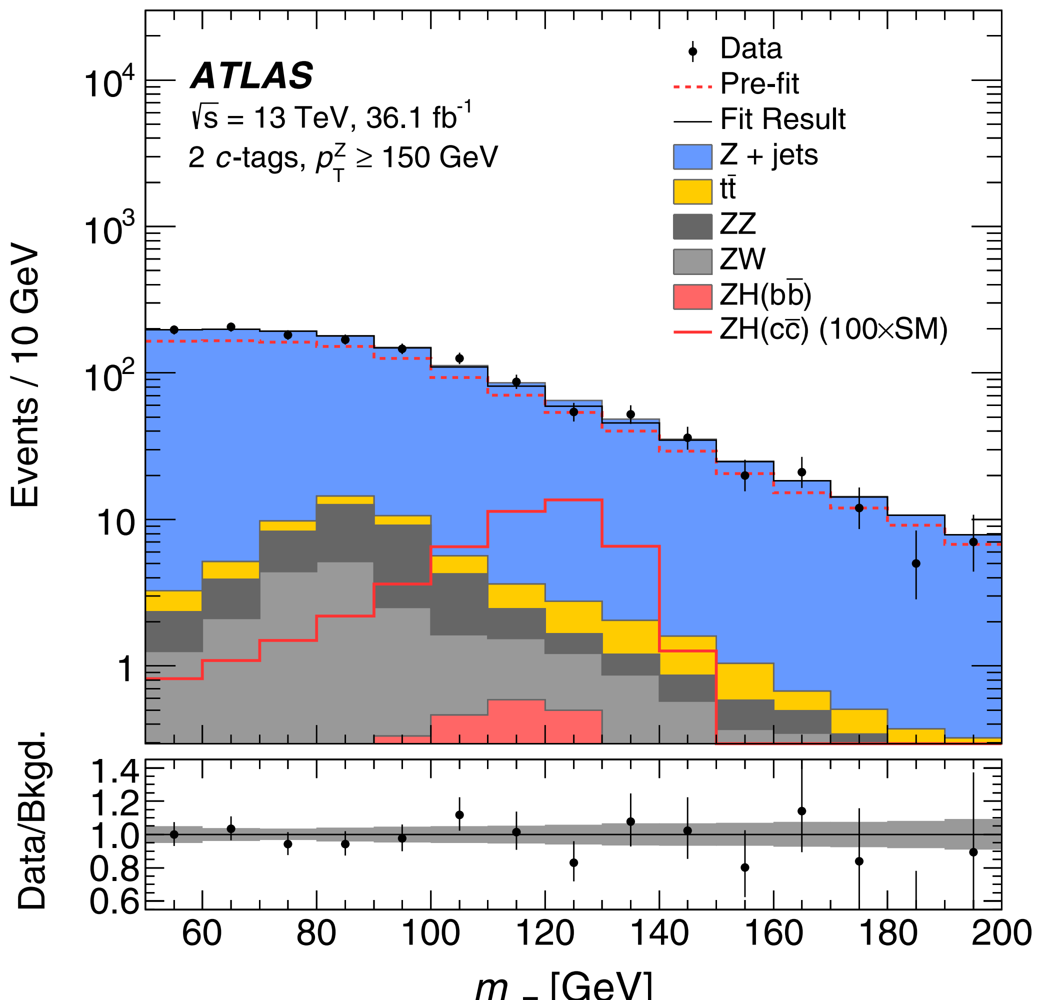
H→cc — ATLAS

PRL 120 (2018) 211802

Talk from Bjorn

- BR (H → cc) 2.9%
- Analysis using 2016 dataset
- Targeting ZH → ℓℓ cc (ℓ=e,μ)
  - 4 categories (c-tagging & p_T^Z)
- Main background from Z+jets production
- Charm tagging:
  - Training 2 BDT to discriminate vs light and b jets





ATLAS

$$\mu_{\mathrm{VH(H\to cc)}} < 110(150^{+80}_{-40})$$

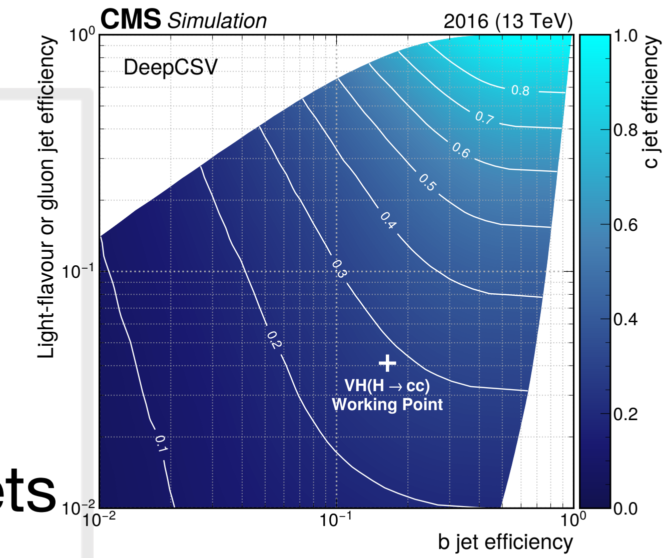
H→cc — CMS

[JHEP 03 (2020) 131]

- Using VH production mode (CMS)

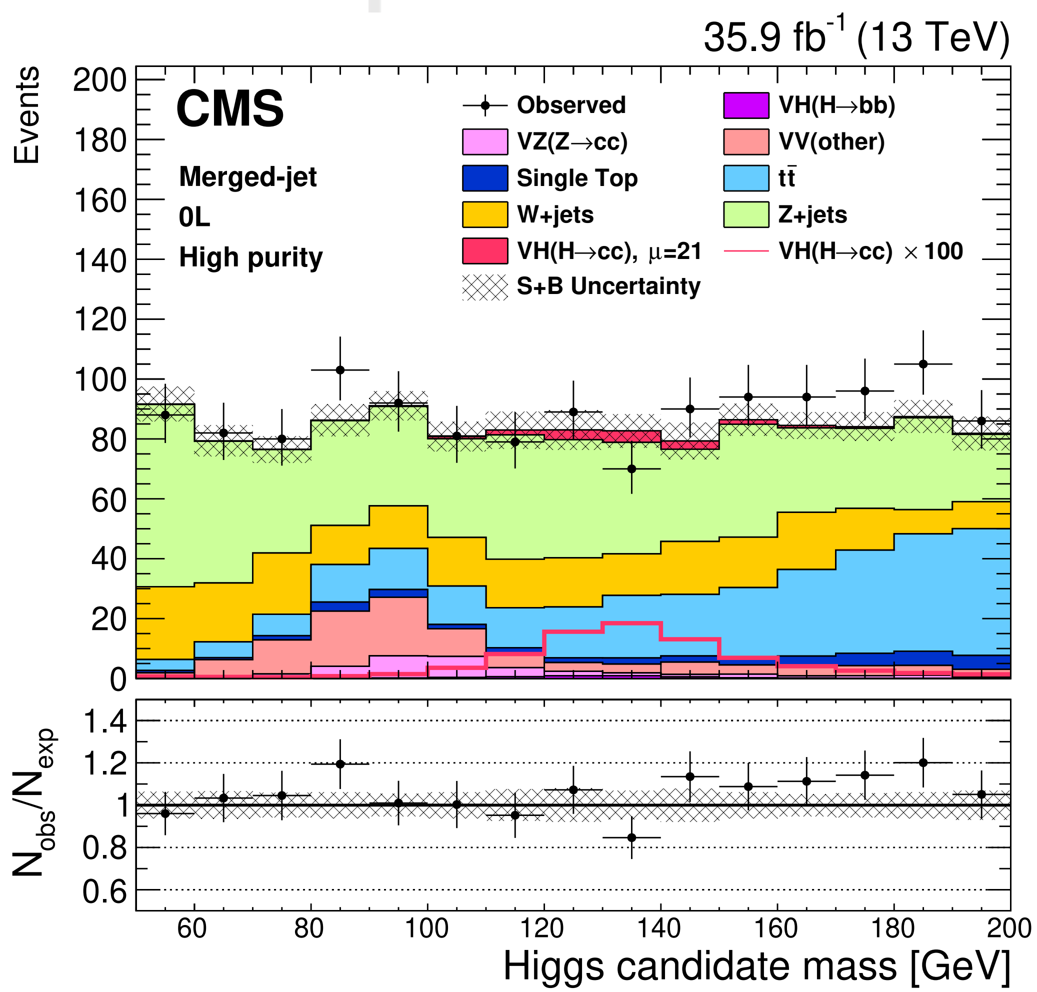
  V=W, Z and leptonic (ℓ=e,μ) or invisible decays (ν)

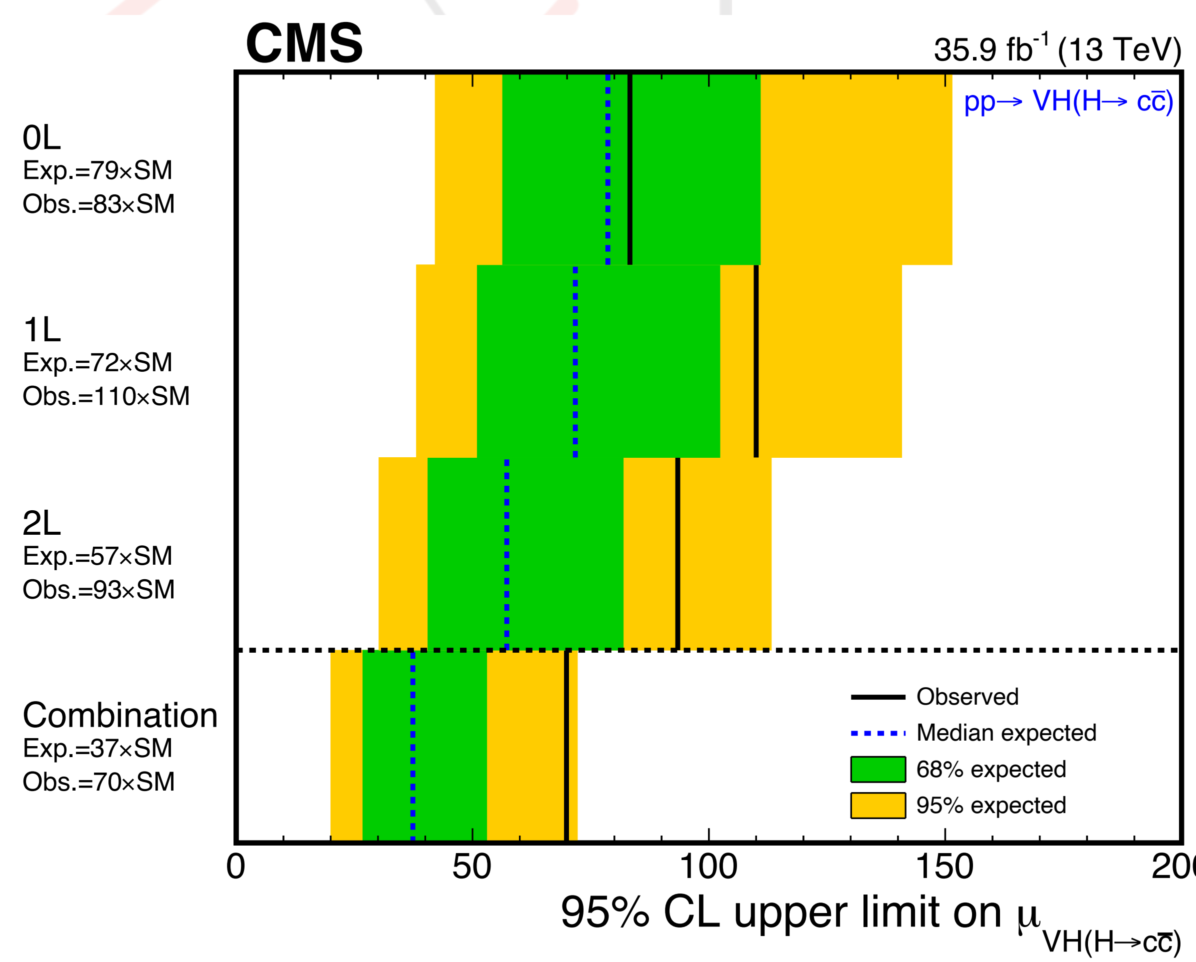
Talk from Biorn



Analysis of the 2016 datasets

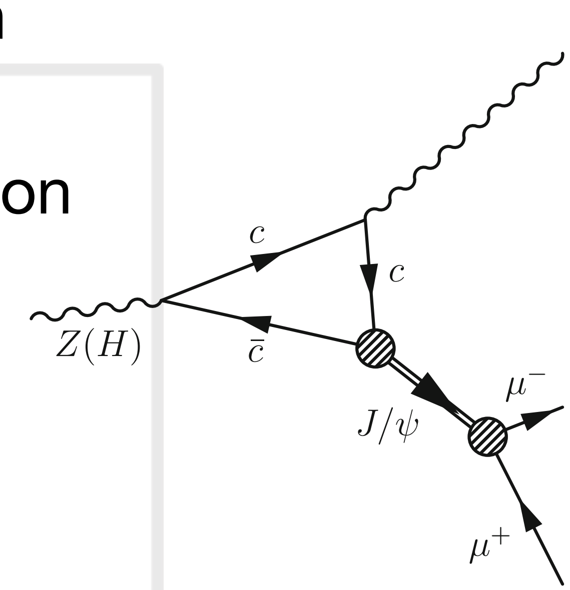
- Higgs to charm reconstructed both in the boosted and resolved regime
- Using deep neural network to gauge rejection vs light quarks and b jets
- Major backgrounds are the corresponding V+jets productions
- Charm tagging: using deep-csv, a multiclass discriminator for jets

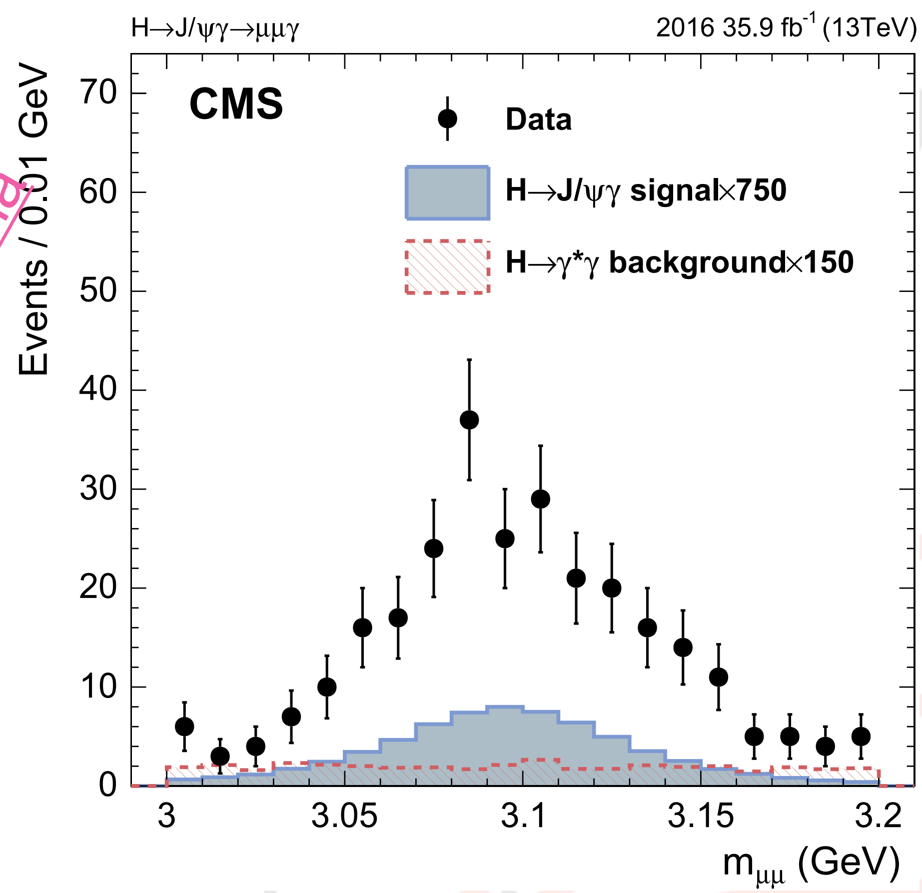


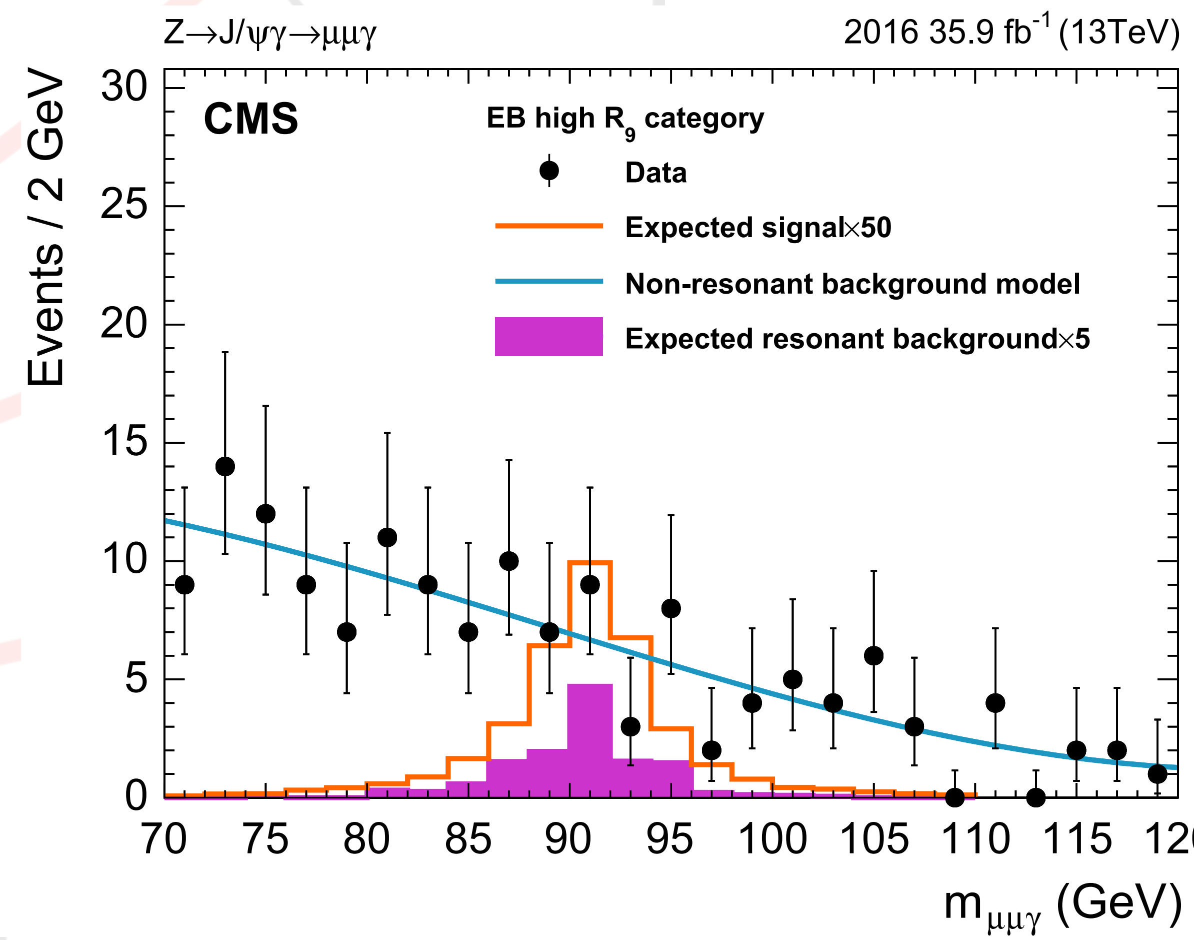


EPJ C79 (2019) 94

- Sensitivity to the coupling of the charm through a loop contribution
  - Many contributions to the loop (W, q)
- Non resonant ($m_{\mu\mu\gamma}$) background estimated with an analytical function
- Resonant background reduced with invariant mass window ($m_{\mu\mu}$) requirements







Talk from Prasanna

95%CL Branching fraction limit

$H \to J/\psi\gamma$	Longitudinal	$1.2\ (1.4^{+0.6}_{-0.4}) \times 10^{-6}$
	Transverse	$7.6\ (5.2^{+2.4}_{-1.6}) \times 10^{-4}$

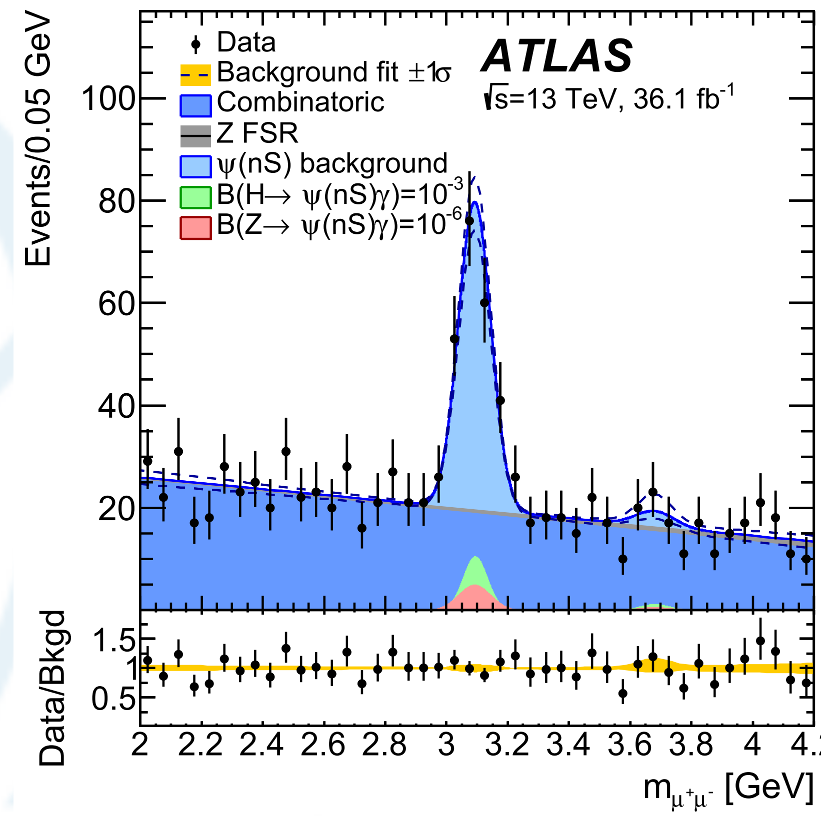
CMS

$H \rightarrow J/\psi\ \gamma,\ \psi(2s)\ \gamma$ — ATLAS

[PLB 786 (2018) 134]

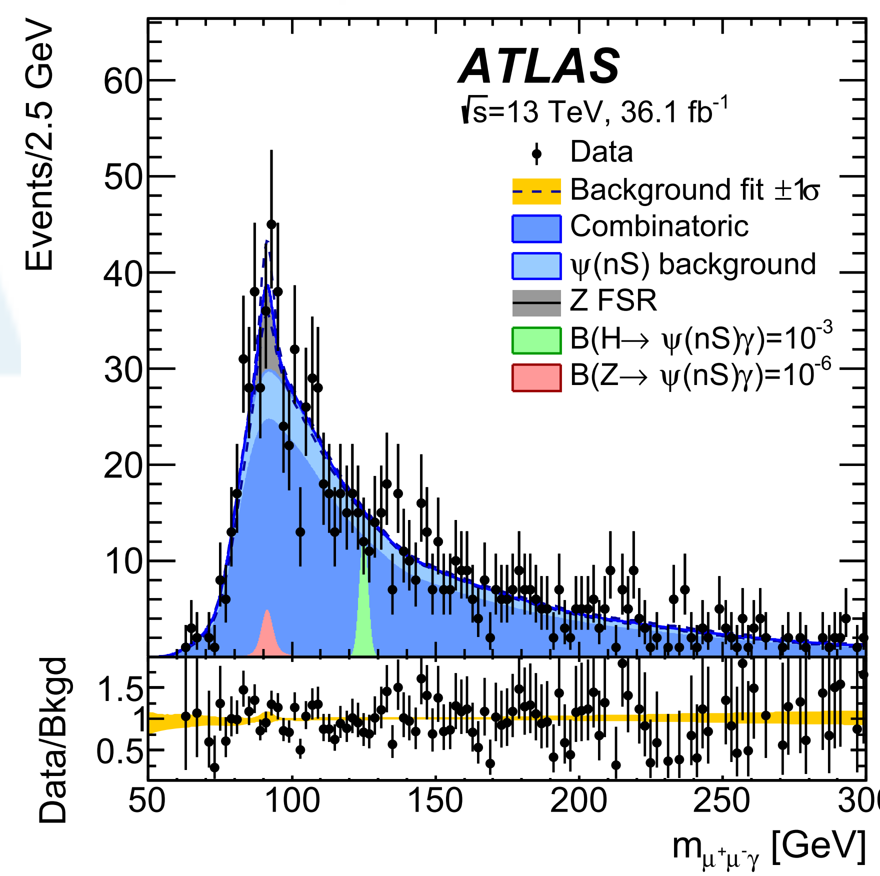
- Sensitivity to the coupling of the charm through a loop contribution
  - Also $\Upsilon\gamma$ presented (sensitivity to the bottom coupling)
  - Kinematic requirements are applied in order to enhance the signal contribution
- Non parametric background model derived from Control regions and validated in dedicated regions
- 2D fit in $m_{\mu\mu}$ and $m_{\mu\mu\gamma}$

Talk from Prasanna



Branching fraction limit (95% CL)	Expected	Observed
$\mathcal{B}(H \rightarrow J/\psi\,\gamma)\,[10^{-4}]$	$3.0^{+1.4}_{-0.8}$	3.5
$\mathcal{B}(H \rightarrow \psi\,(2S)\,\gamma)\,[10^{-4}]$	$15.6^{+7.7}_{-4.4}$	19.8

ATLAS



H→μμ — ATLAS

Full Run 2

arXiv 2007.07830

Tiny BR (H→ μμ) ~ 2.2×10^{-4}

large SM irreducible DY → μμ background
– S/B ~ 0.1% for inclusive events at 125 GeV
Improvements to increase sensitivity:

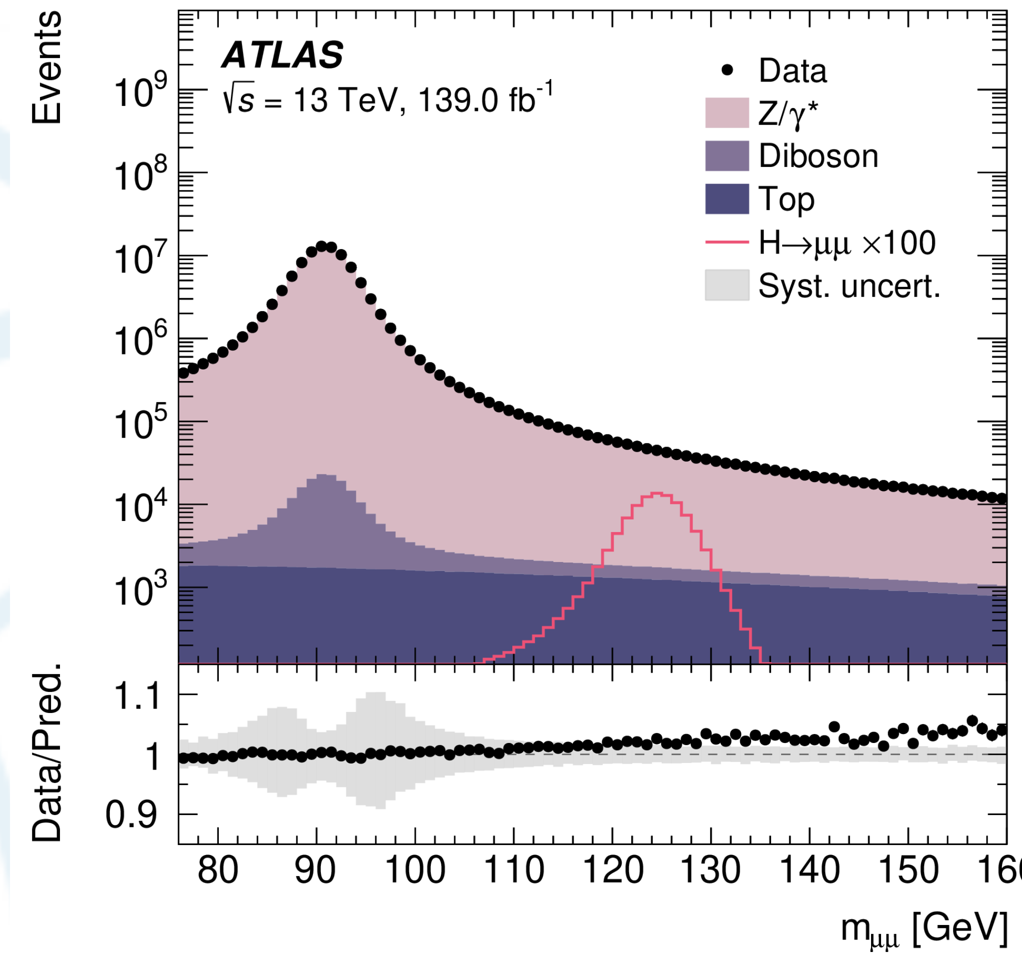
- wrt 36fb[-1] ATLAS result (25%)
- Targeting all production modes
- Improved MVA categorisation to select events at high S/B, e.g. from VBF
- γ-FSR recovery to improve $\sigma(m_{\mu\mu})$
- Improved rejection of jets from pileup
- Background modelling

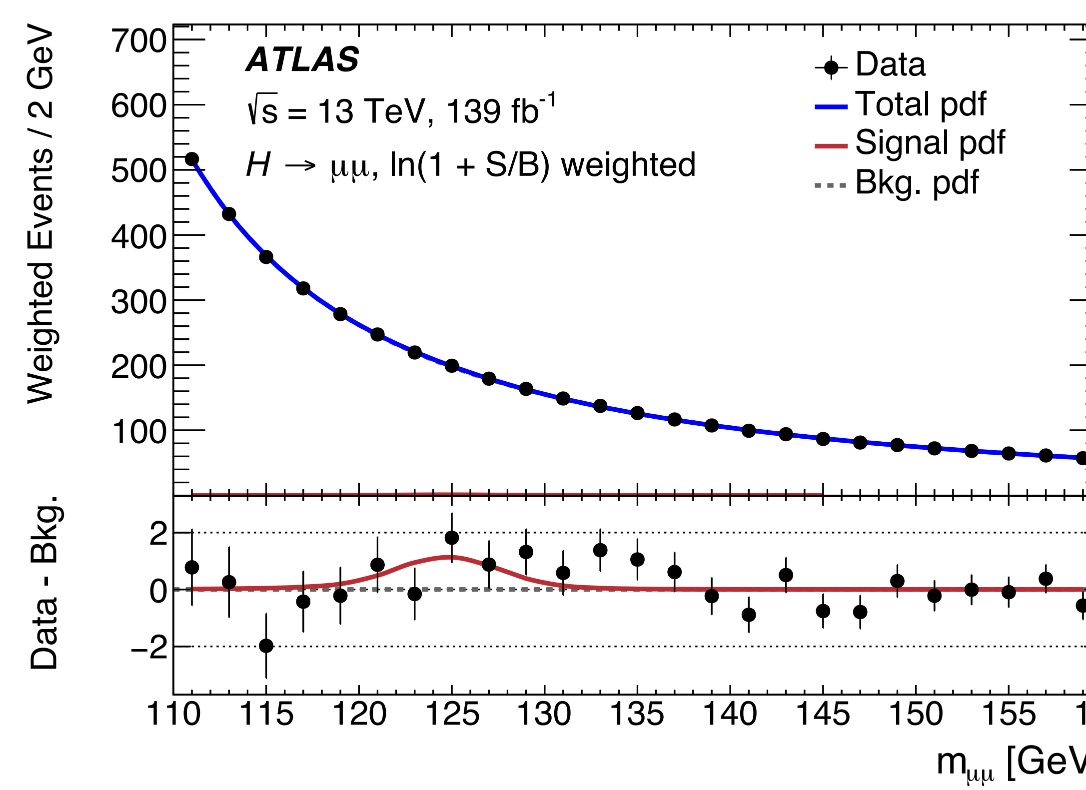
Talk from Miha

Signal extraction from $m_{\mu\mu}$ fit

Background parametrisation:

- inclusive "core" pdf + per-category
  - empirical function





H→μμ — ATLAS

Full Run 2

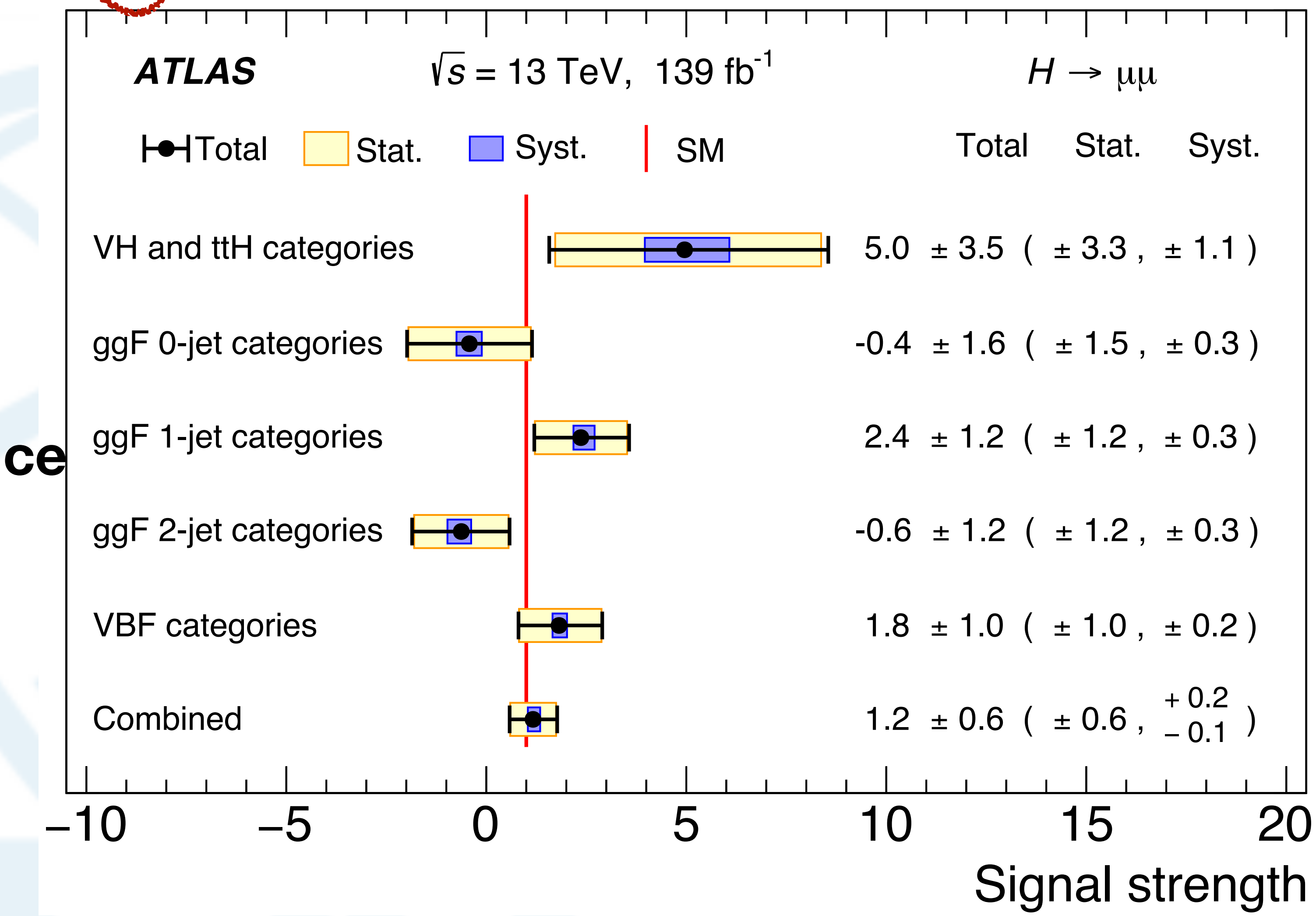
arXiv 2007.07830

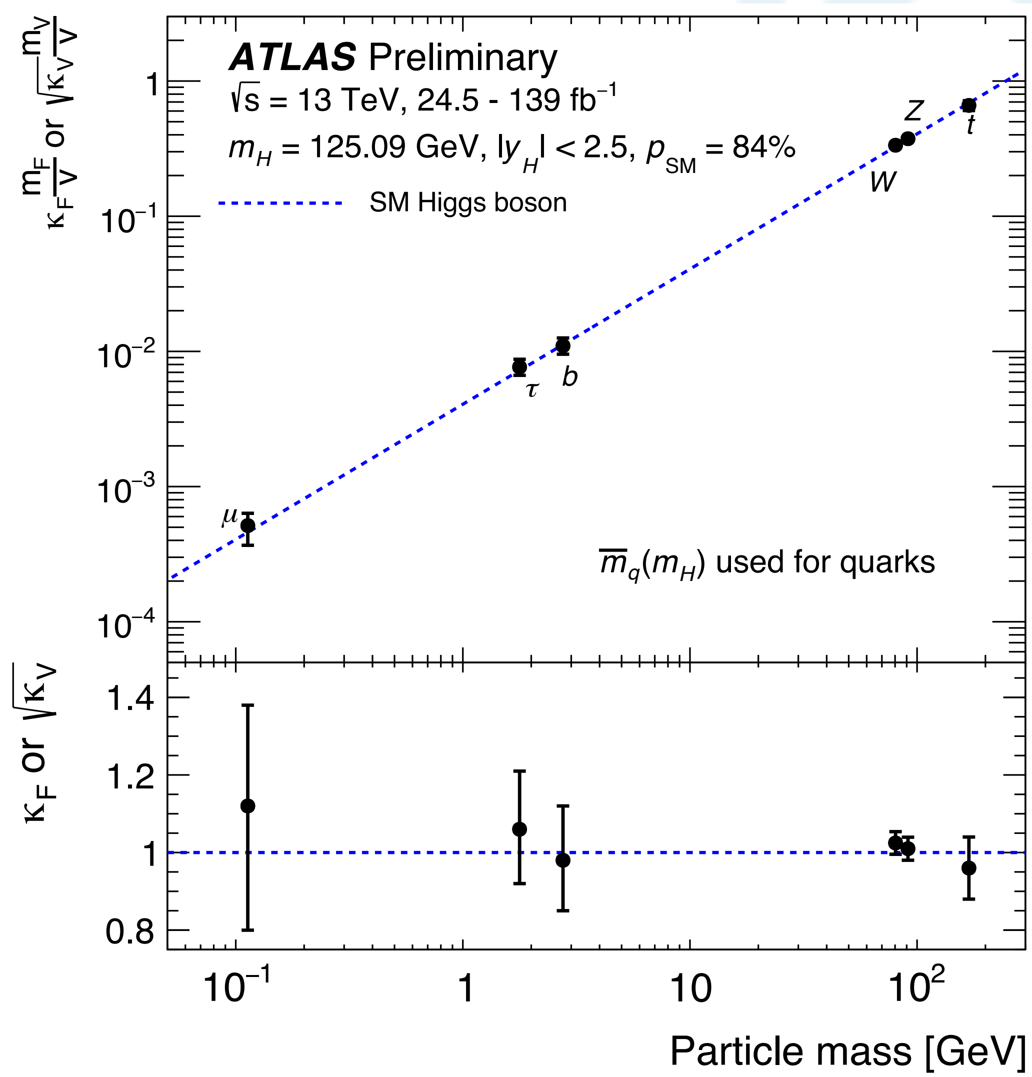
- Reported results at Run I mass measurement, m_H = 125.09 GeV
- Best fit strength

$$\mu = \frac{\sigma\mathcal{B}_{\text{obs}}}{\sigma\mathcal{B}_{\text{SM}}} = 1.2 \pm 0.6$$

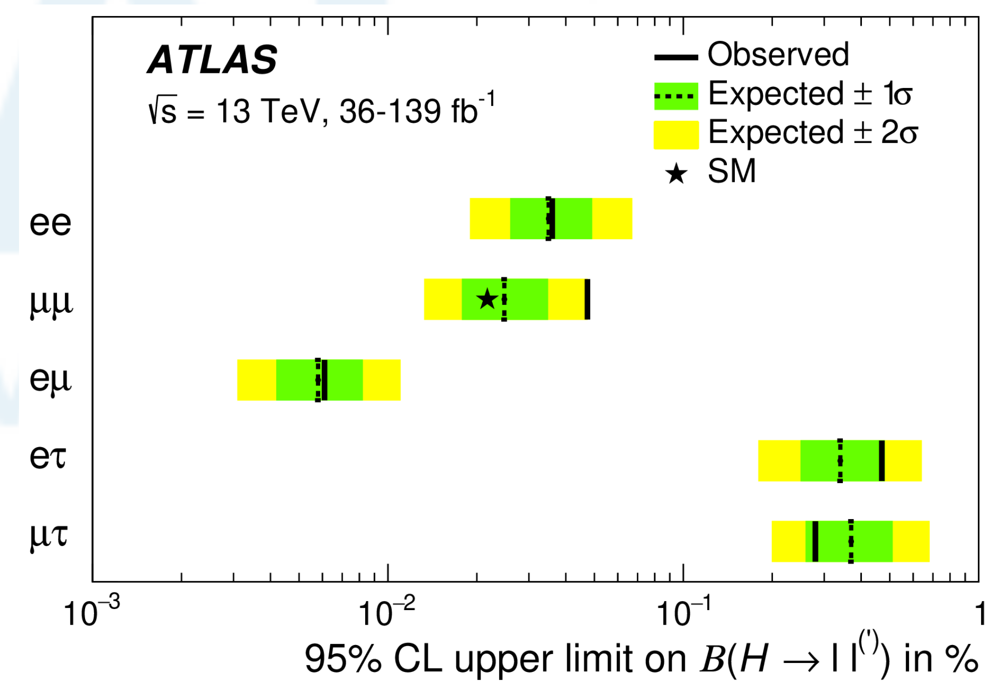
Reported observed (expected) **significance**

$$2.0\sigma\ (1.7\sigma)$$





ATLAS-CONF-2020-027

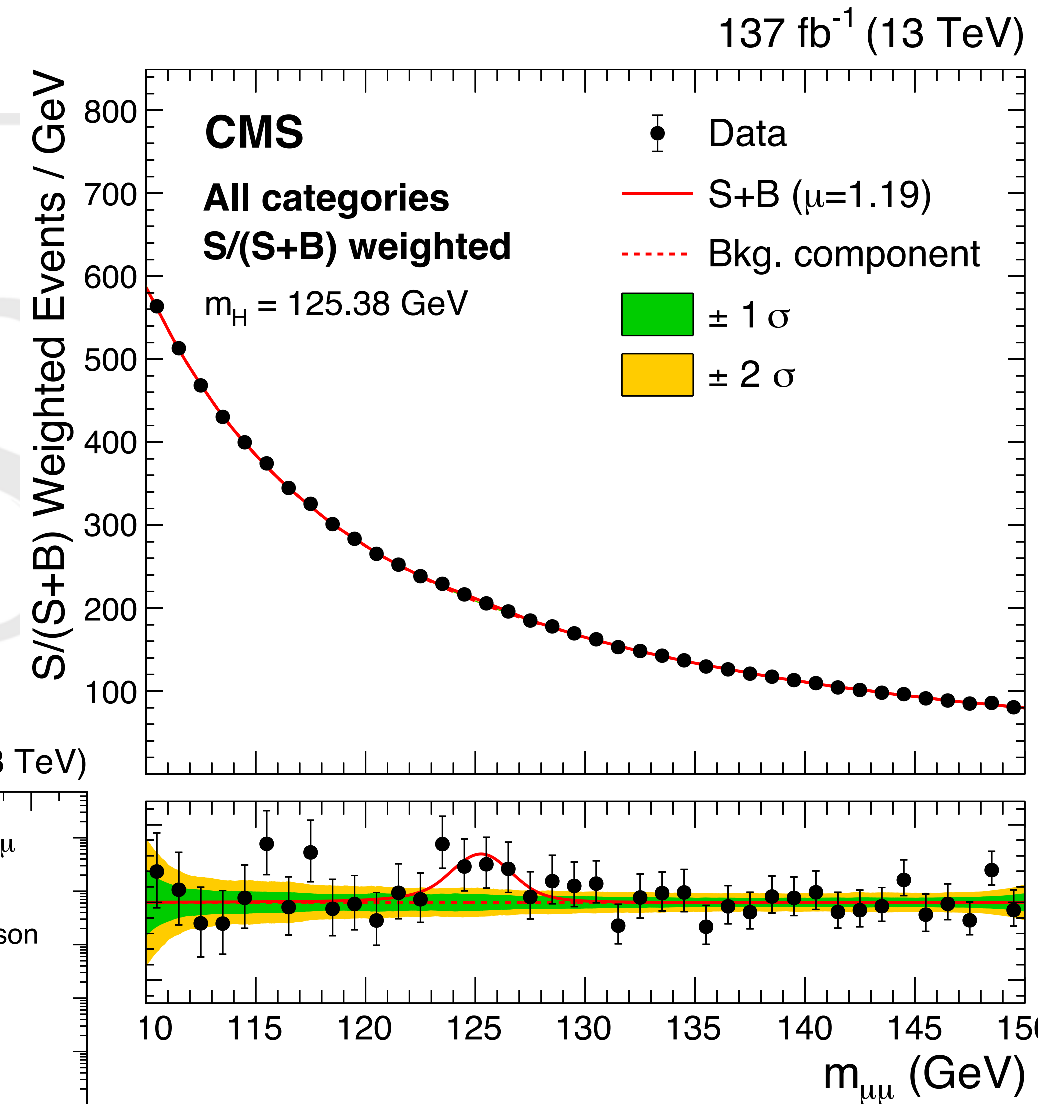


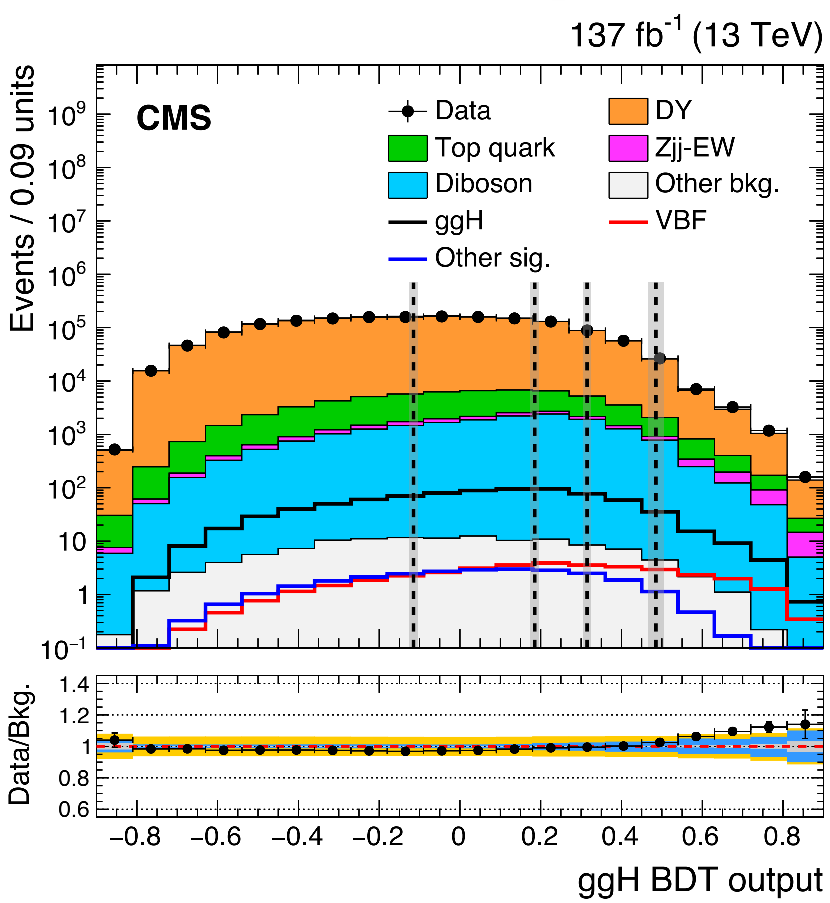
H→μμ — CMS

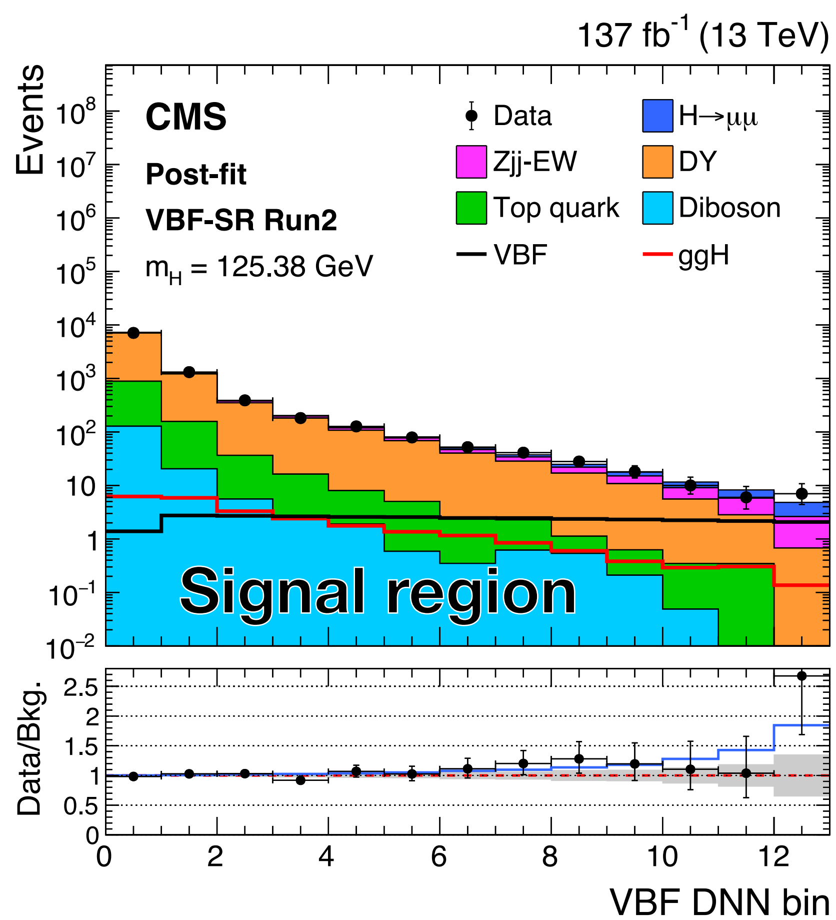
Full Run 2

arXiv 2009.04363

- Target analysis strategy per production mode
- All production modes considered
  - ggH, VBF, ttH, VH
- γ-FSR and in situ Z calibration
- VBF background prediction from MC simulation
  - DNN discriminator with mass as feature
- ggH, ttH, VH analytical fit to the invariant mass
- Isolate signal with BDT/DNN and categorisation







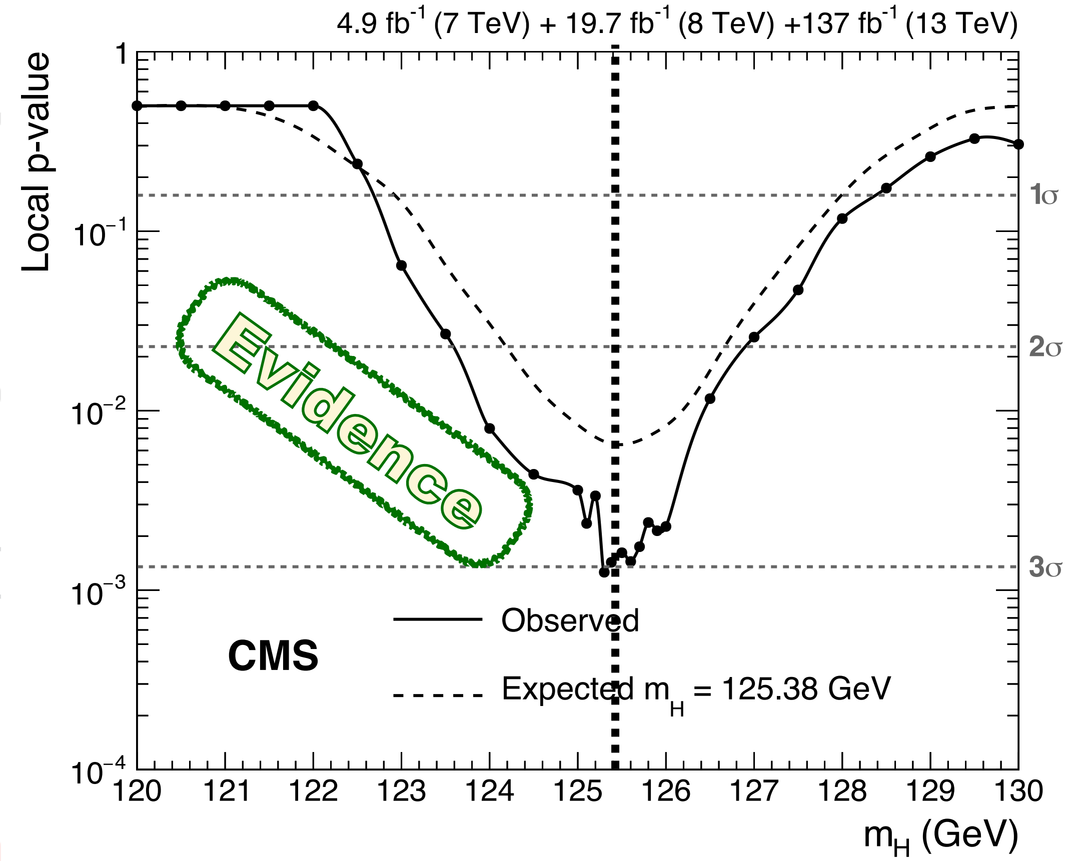
Talk from Oliver

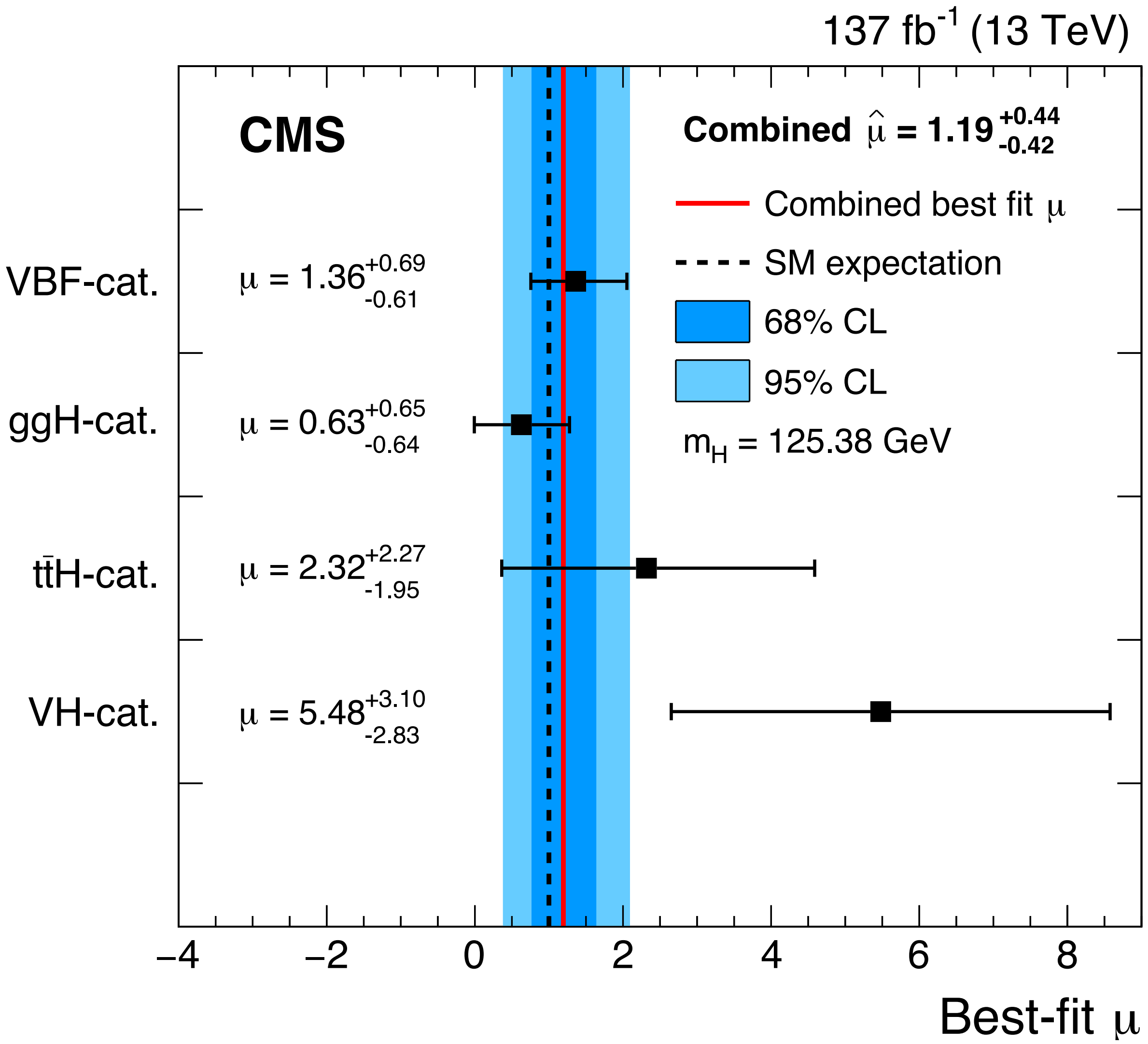
H→μμ — CMS

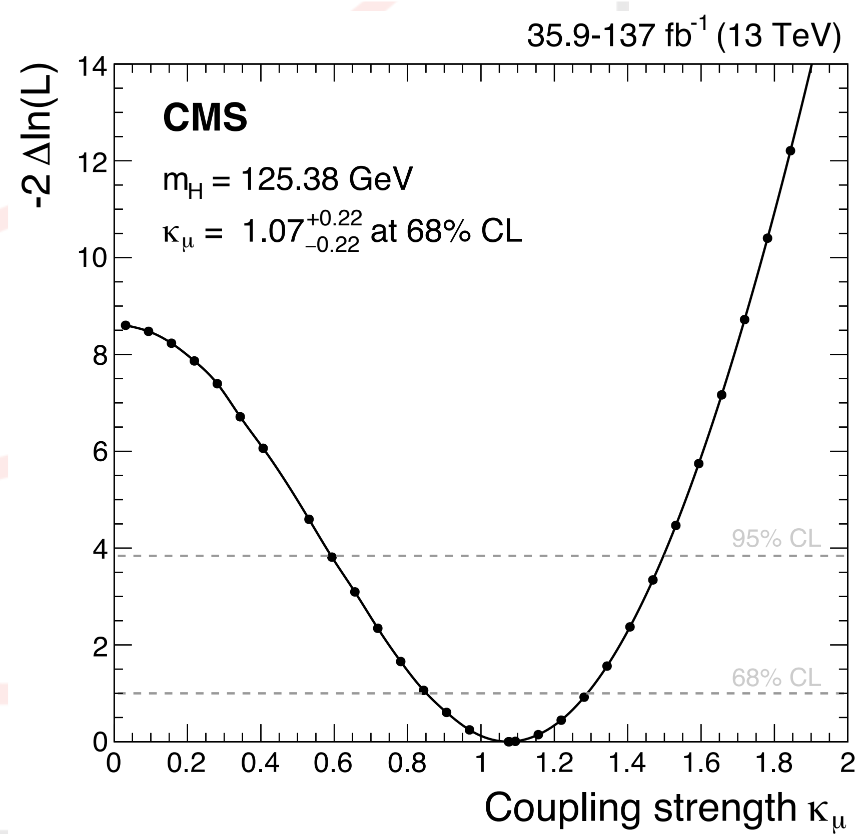
Full Run 2

[arXiv 2009.04363](https://arxiv.org/abs/2009.04363)

- Resulted reported at the best mass measurement m_H=125.38 GeV
- Strength 1.19 $^{+0.44}_{-0.42}$
- **Evidence for H→μμ 3.0σ (2.5σ)**
- Coupling measurement of κ_μ
  - With the inputs from EPJ **C79** (2019) 412







Summary

- CMS and ATLAS have been updating the analyses to the full run 2 luminosity

H$\tau\tau$

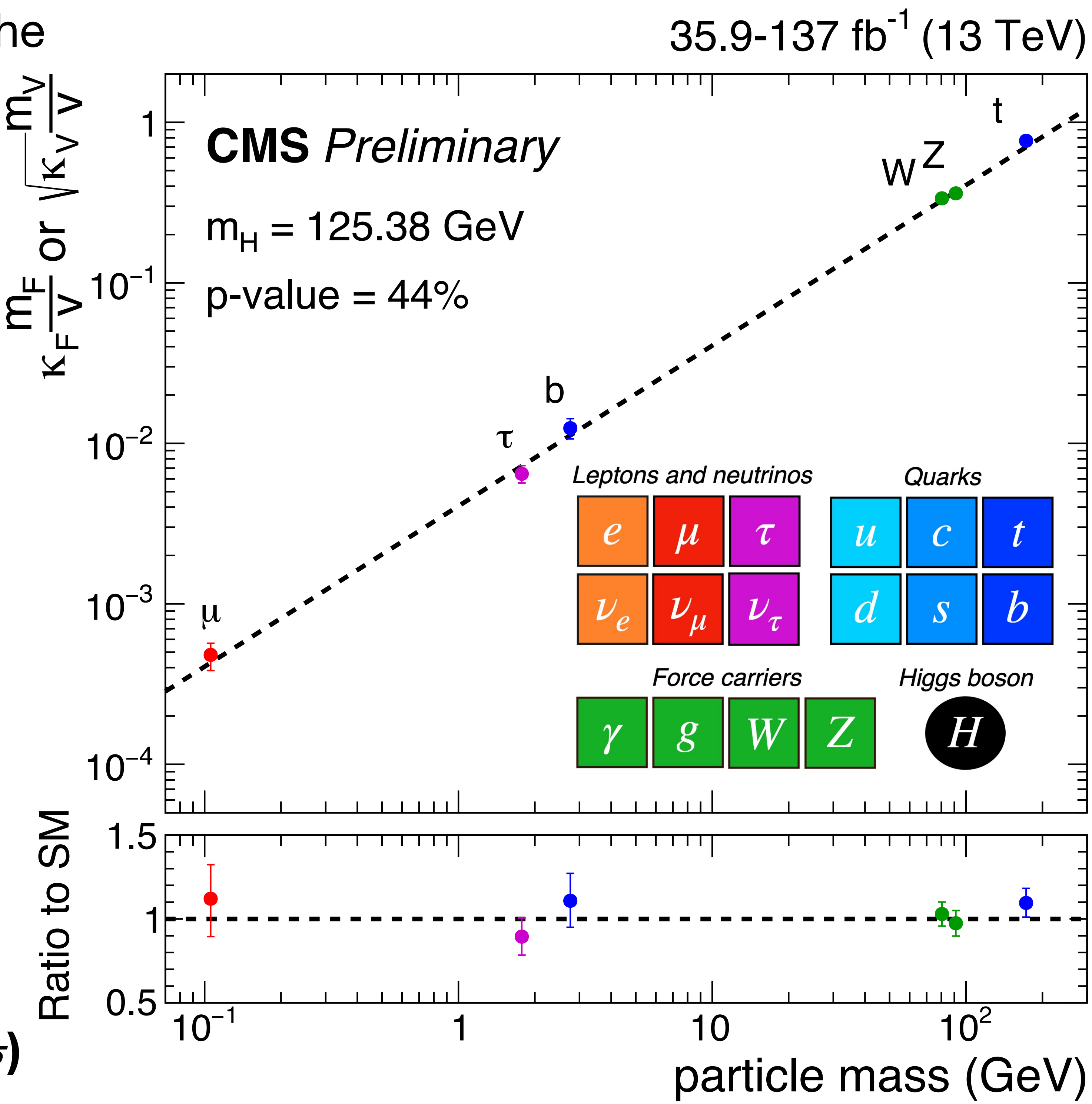
- STXS stage 1.2 by CMS (137 fb^{-1})
- ATLAS 36 fb^{-1} results Stage 0
- Stage 0 not dominated by stat.

Hcc (36 fb^{-1})

- searched in VH associated production
- $\sigma\mathcal{B} < 70$ (37) SM **CMS**
- $\sigma\mathcal{B} < 110$ (150) SM **ATLAS**

Hμμ full Run 2 analyses:

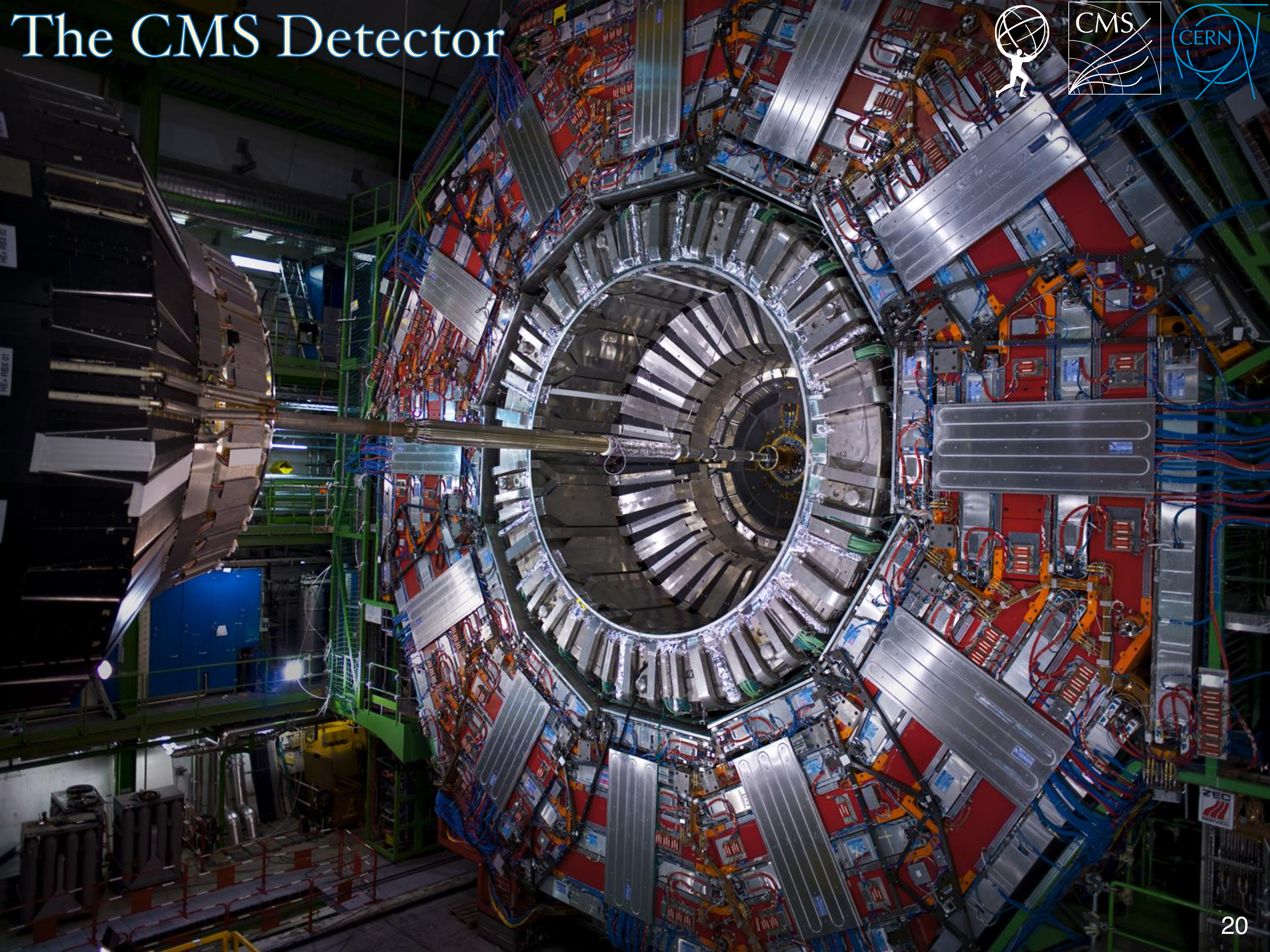
- ATLAS 2.0σ (1.7σ),
- **CMS Evidence for H→μμ 3.0σ (2.5σ)**
- Best fit strength: μ = 1.2 for both



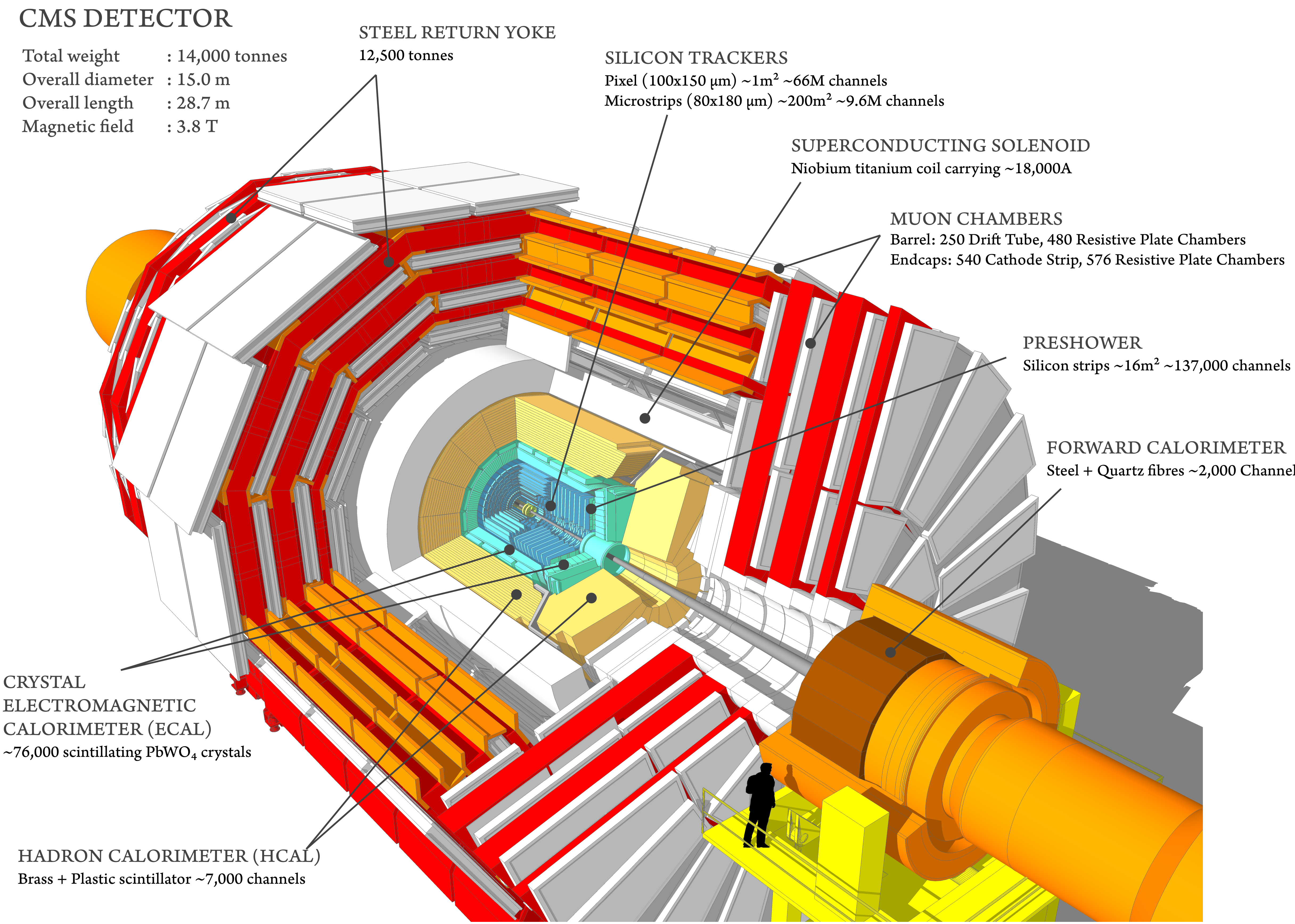
Thank you

Online conference
HIGGS 2020
October 26-30

The CMS Detector

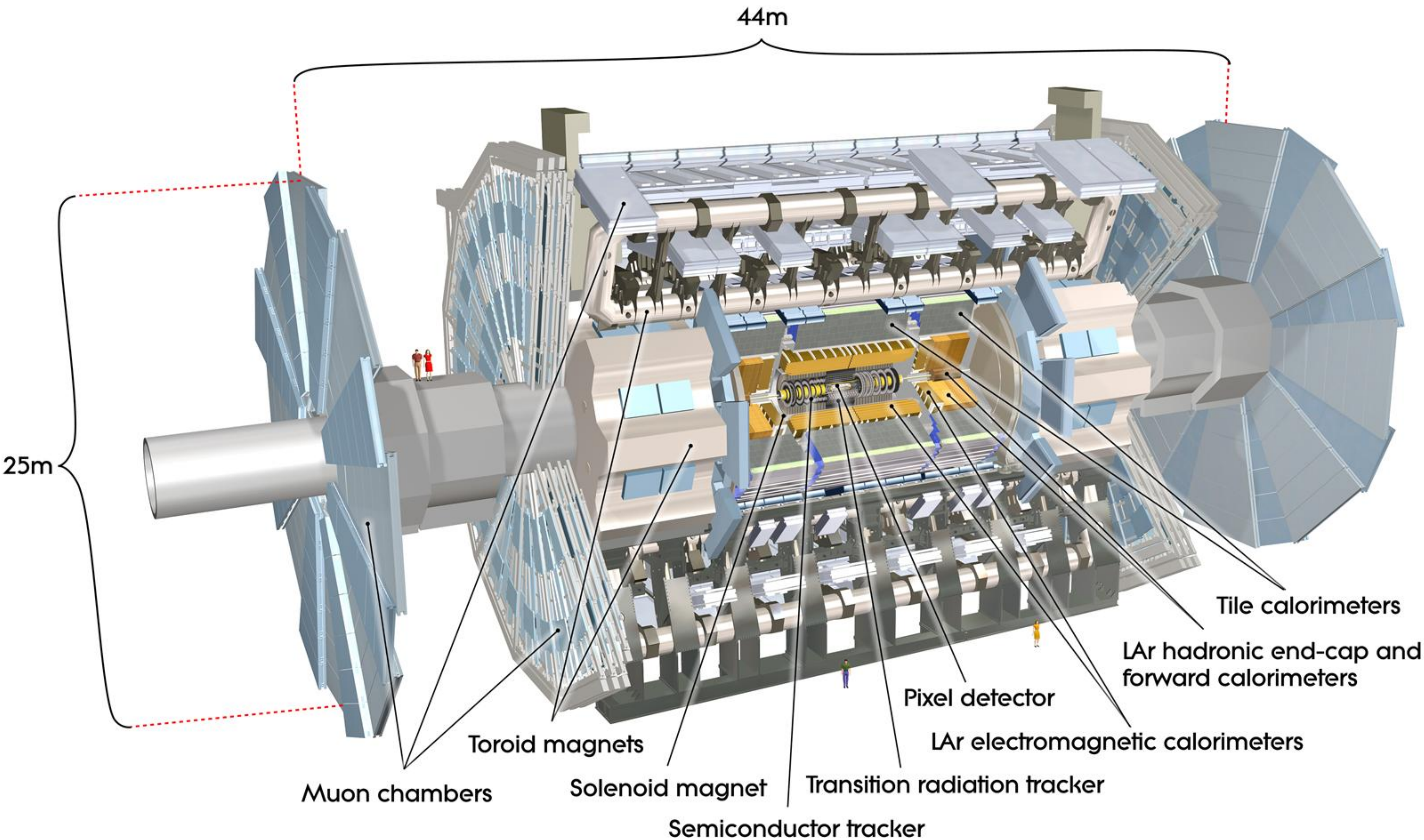


The CMS Detector



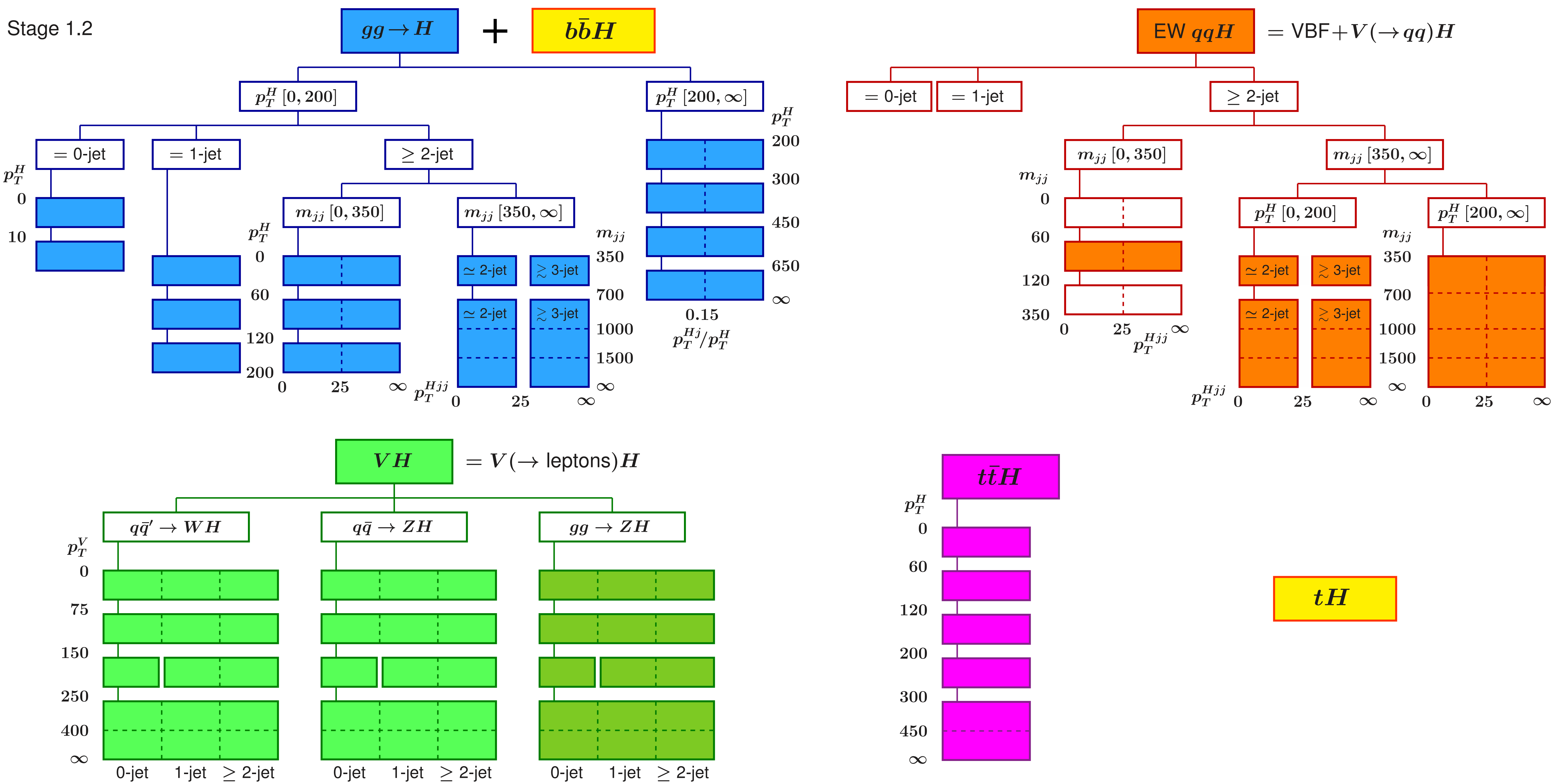
The ATLAS detector

The ATLAS detector



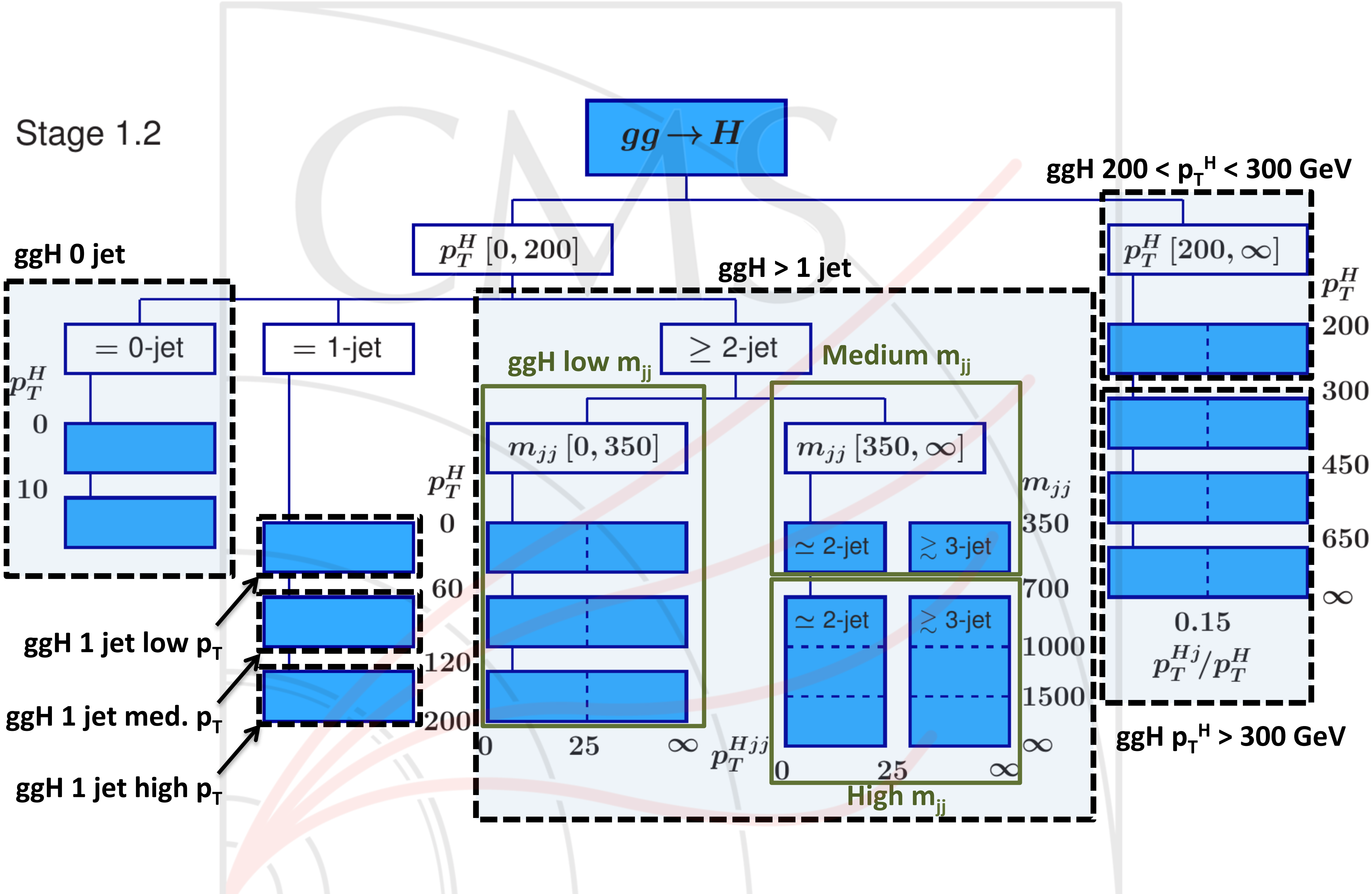
STXS

- A compromize between theory and experiments

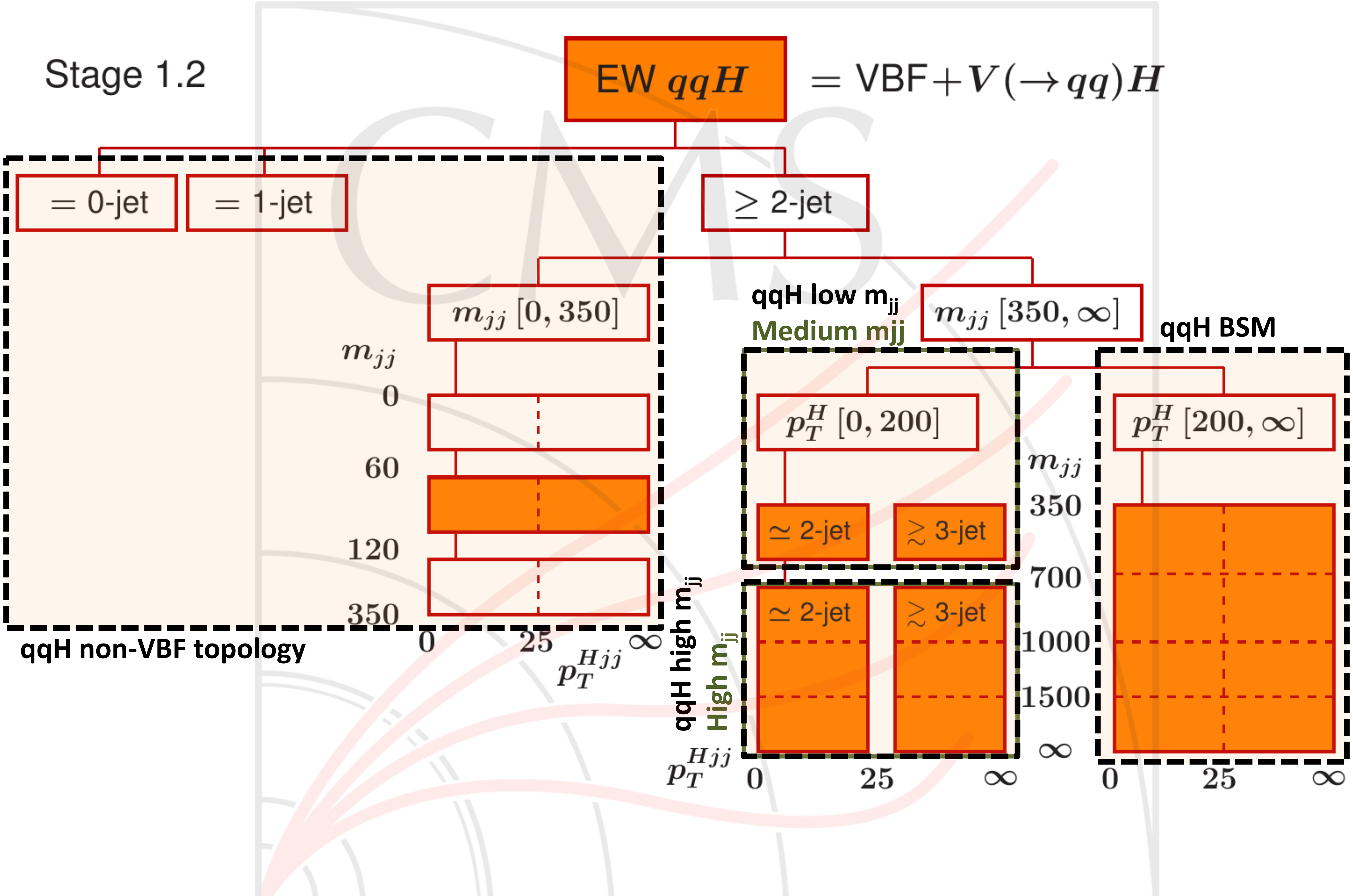


$H \to \tau\tau$ — CMS

- Merging criteria in STXS Stage 1.2



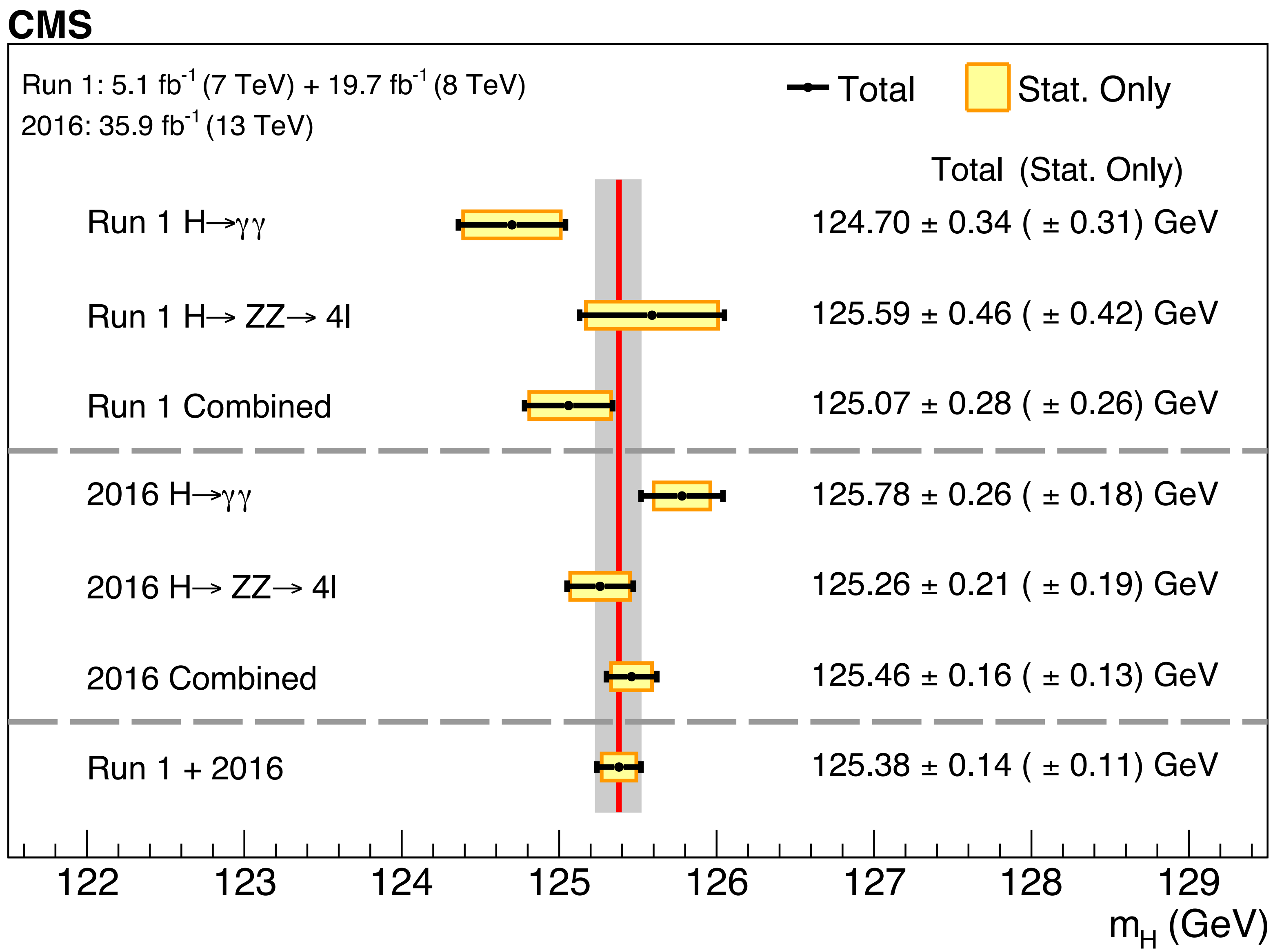
- Merging criteria in STXS Stage 1.2



The Higgs boson mass

Precise measurement of the Higgs boson mass using the diphoton and ZZ (4-leptons) decay channels

m_H = 125.38 ± 0.14 GeV



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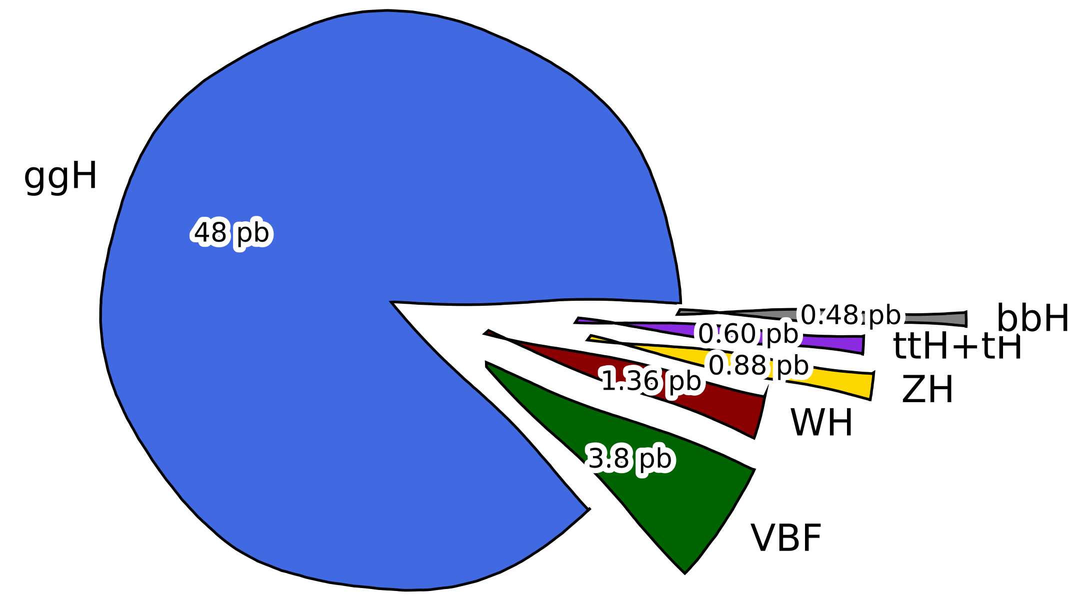
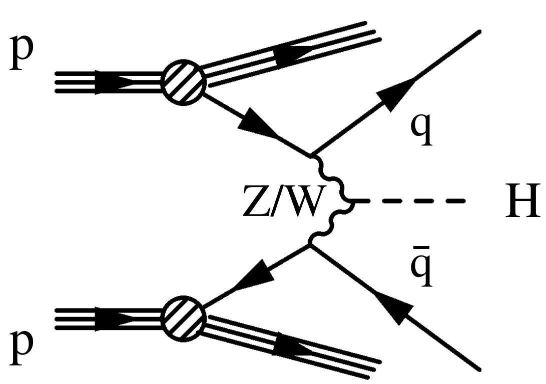
Higgs production

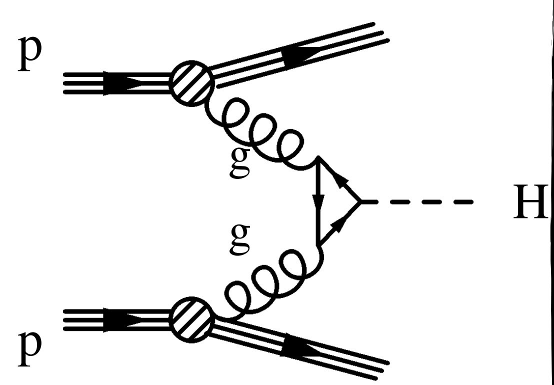
- Different production mode of the Higgs boson



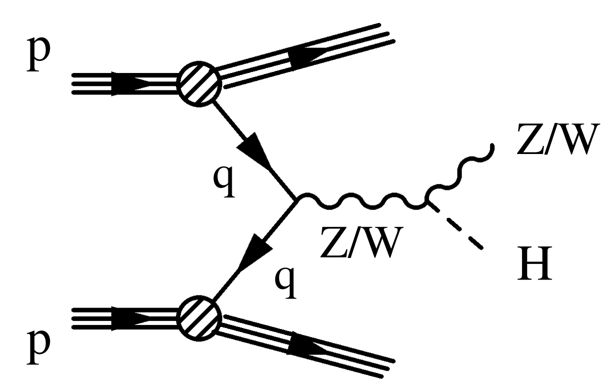
Vector-boson fusion
VBF



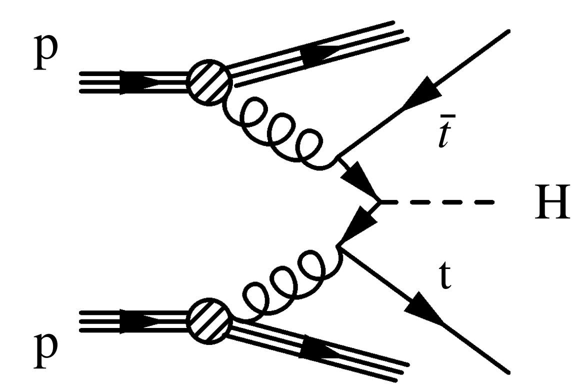
Gluon-gluon fusion
ggH



VH associate production
VH

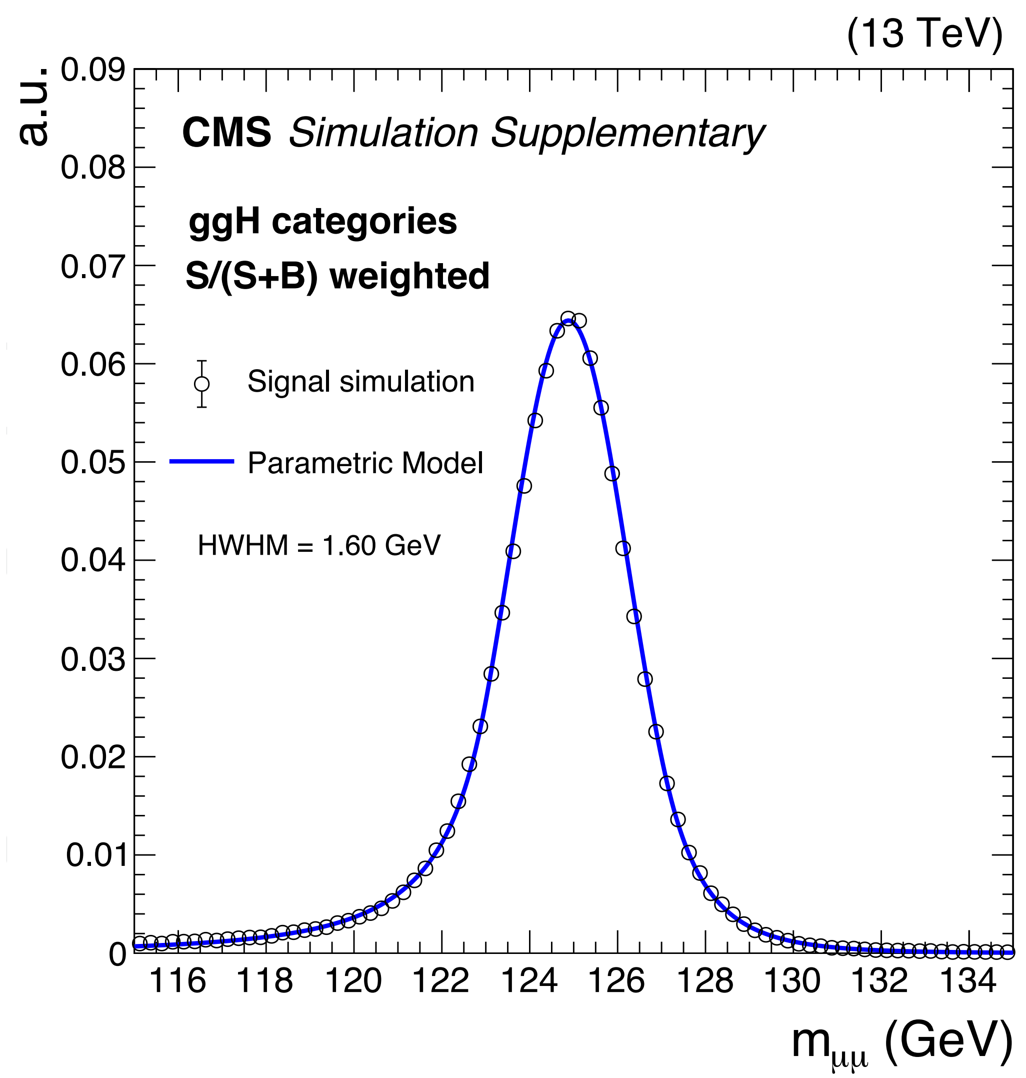


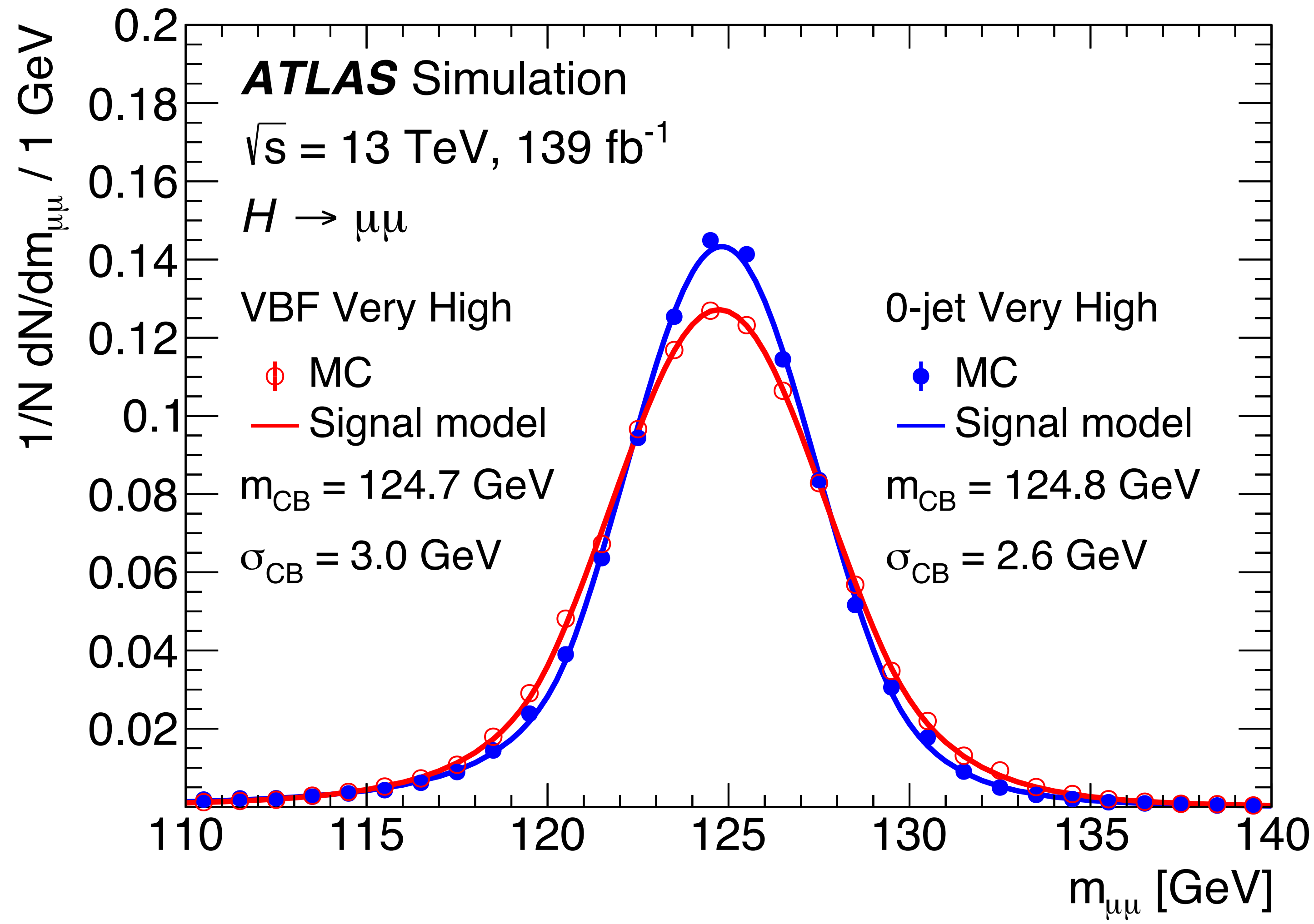
Top quark pair associate production
ttH



Hμμ invariant mass

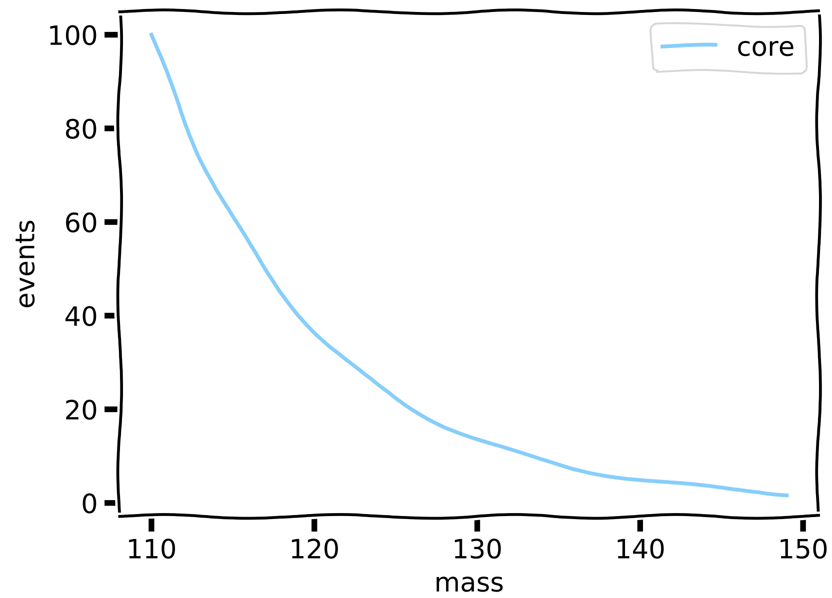
- Invariant mass of the Hμμ peak in MC simulation





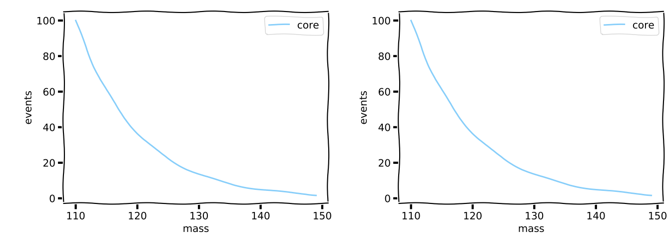
Core PDF — Hμμ CMS

- The background function is designed to minimise possible mismodels due to the choice of the analytical form



Discrete profile

Core: several functional forms used simultaneously on data



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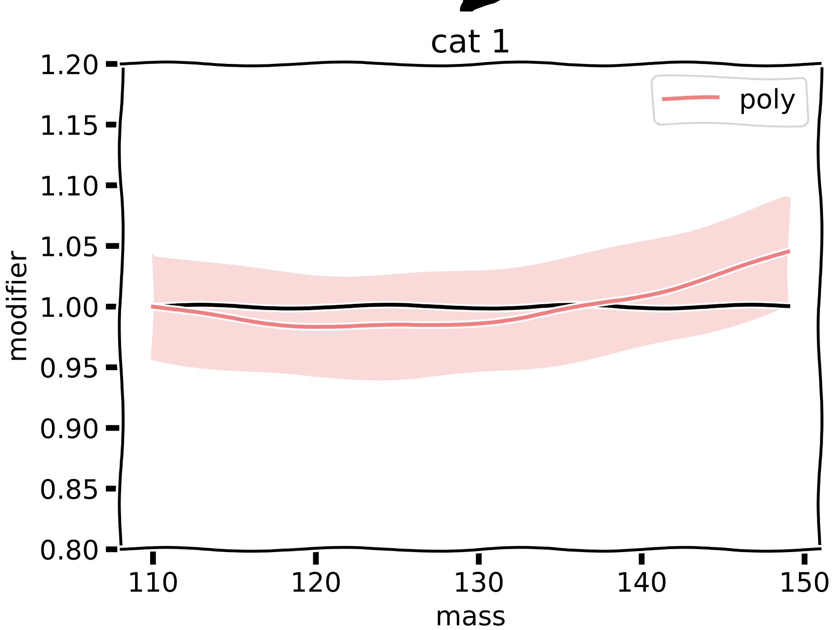

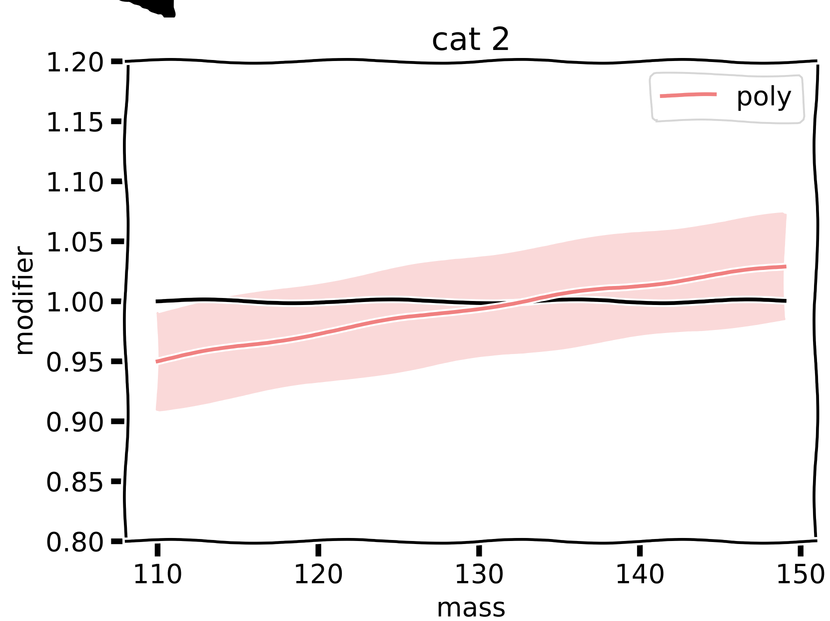

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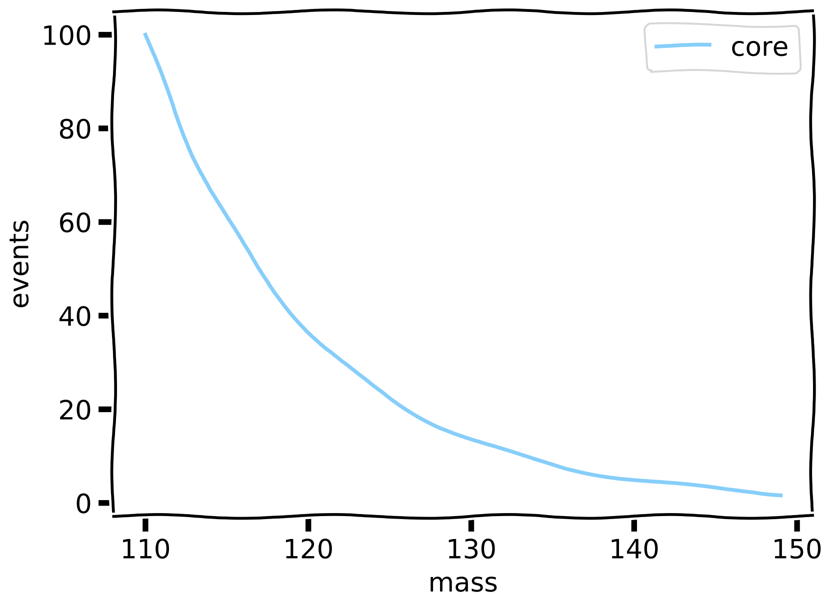
Core PDF — Hμμ CMS

- The background function is designed to minimise possible mismodels due to the choice of the analytical form



Discrete profile

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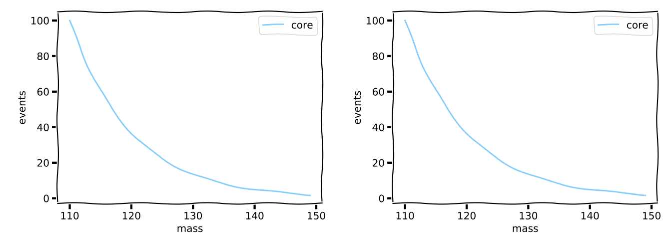

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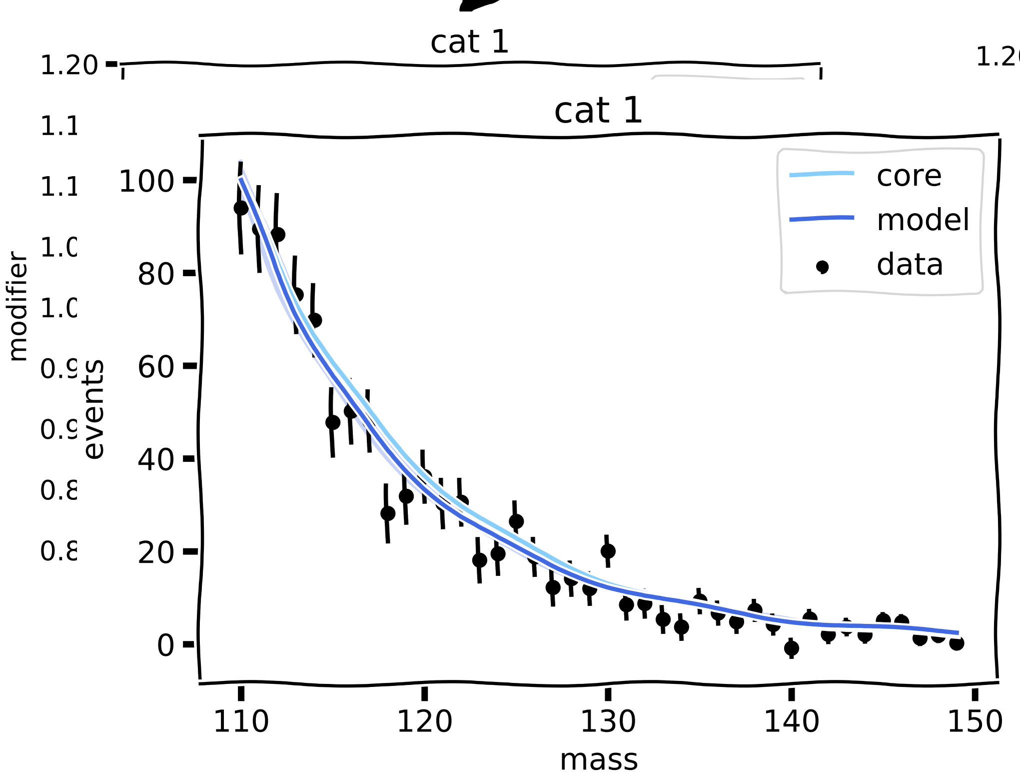

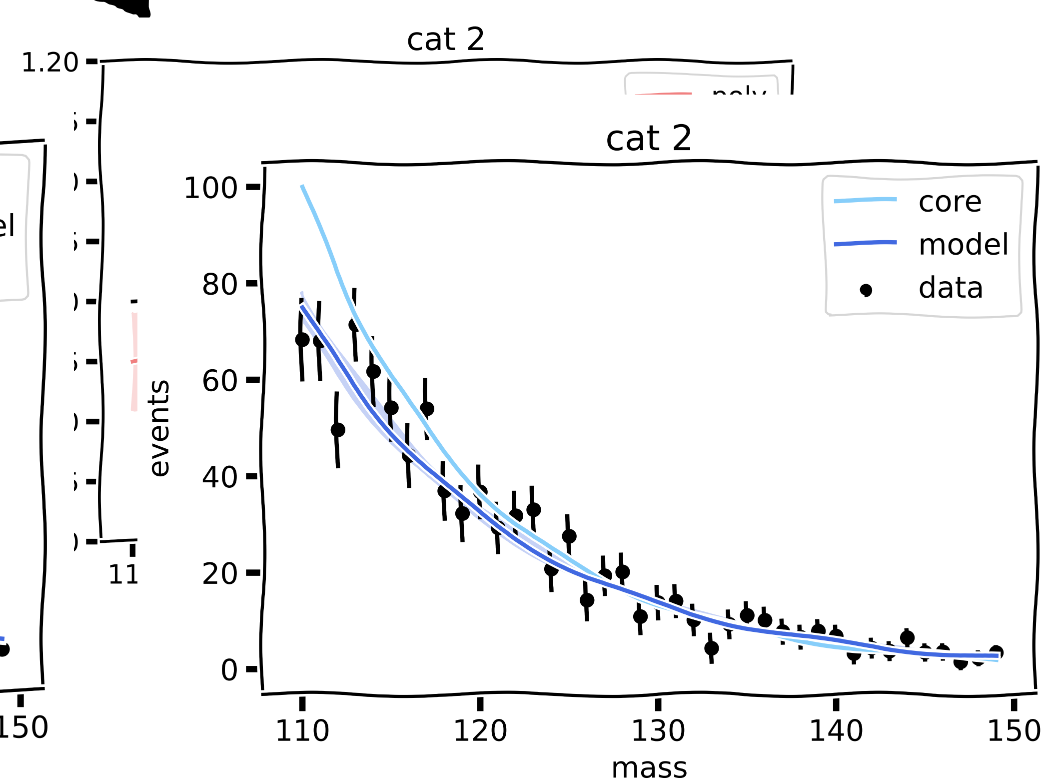

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