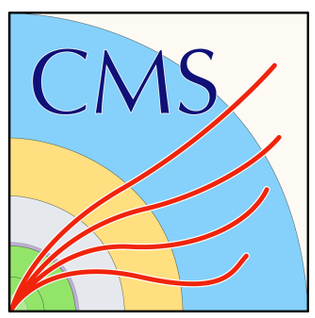
Highlights from ATLAS and CMS measurements

Brookhaven Forum 2021

Kostas Theofilatos
on behalf of ATLAS and CMS



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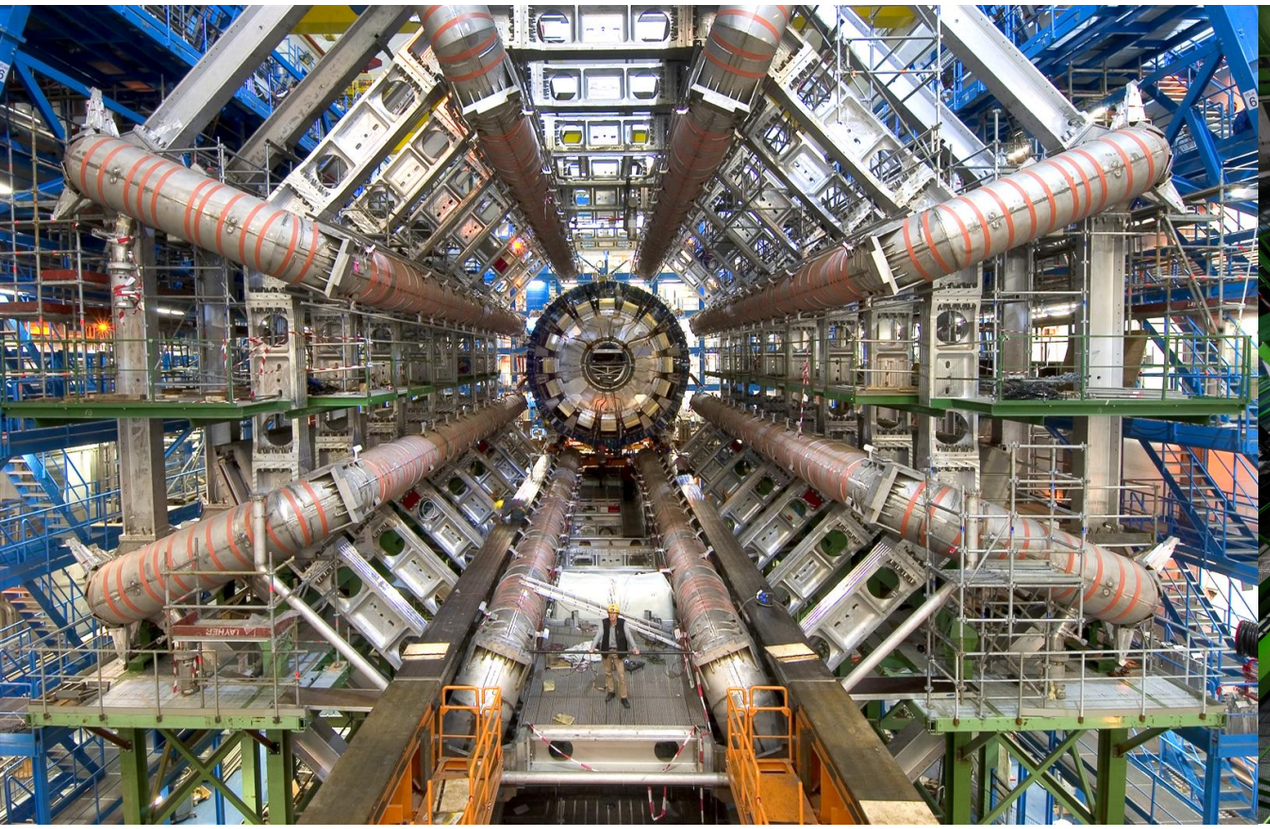
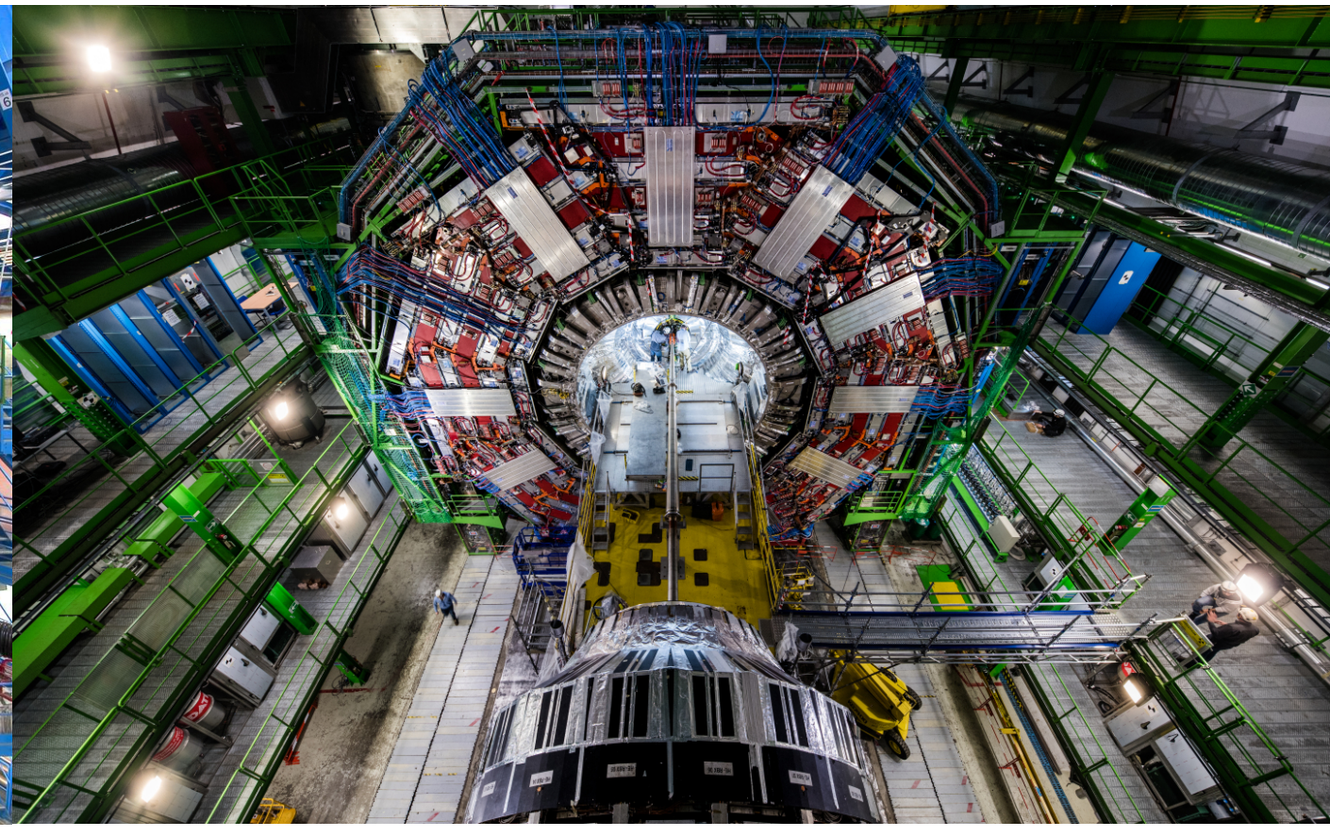
ATLAS



CMS



ATLAS and CMS are particle detectors situated 100m underground recording data from the Large Hadron Collider

an incredible machine

The **LHC** produces* about:

4000 $W^{\pm}$ s / sec

1200 Z^0 s / sec

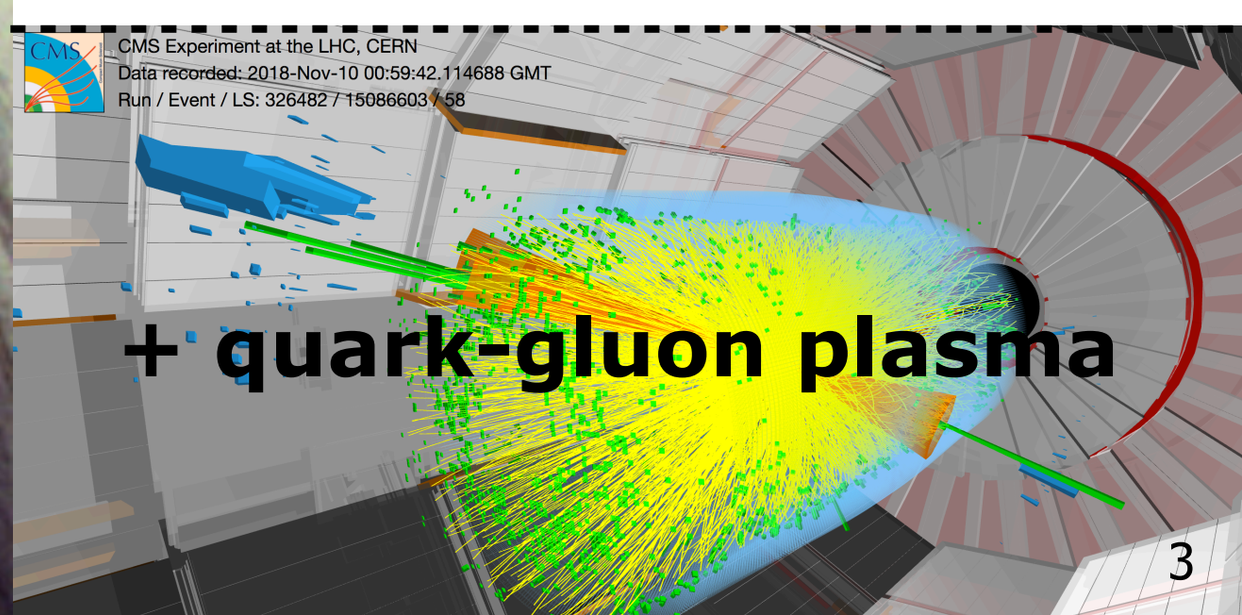
17 $t\bar{t}$ s / sec

1 h^0 s / sec

~0.007 h^0h^0 s / sec

SM prediction

*Run II (20 Hz / nb)



MC simulation

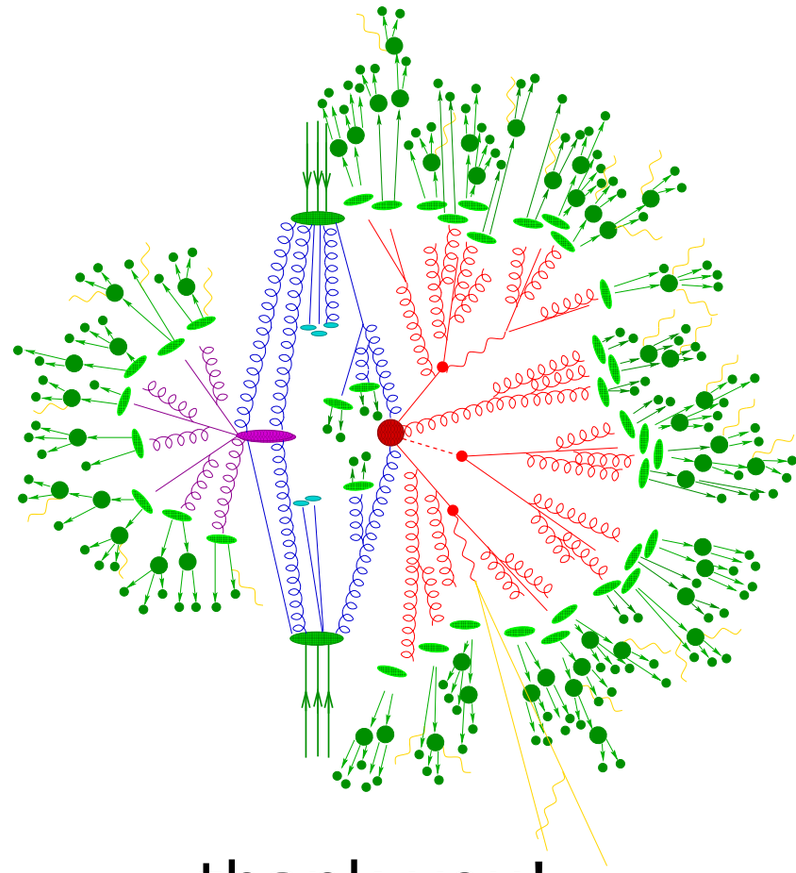
key ingredient for interpreting the LHC data and for designing better (S/B) experimental analyses

entering a new phase 10 y after **NLO** revolution

first **NNLO** simulations available (e.g. **Powheg MiNNLO**):

color singlet first (e.g., **V**, **h⁰**), recently colored particles (**tt**) added, **EW corrections** available from several tools like **Sherpa** or **MG5_aMC@NLO** 3.X

new **PS** beyond **LL** accuracy, devised with weighting techniques allow internal variations avoiding adhoc comparisons, e.g., **Herwig** vs **Pythia** → new understanding of systematic uncertainties



thank you!

the availability of the enormous amount of MC samples needed for the LHC analyses, comes with their own challenges on the computing side

development of **concurrent running**, first tests on **GPUs** e.g. **MG5_aMC@NLO**

S

ATLAS and CMS have produced ~100 new physics results in 2021, in this talk:

	ATLAS	CMS	ATLAS+CMS
SMP	2	3	5
TOP	2	1	3
HIG	4	4	8
BPH	1	1	2
HI	1	1	2
TOTAL	11	10	20

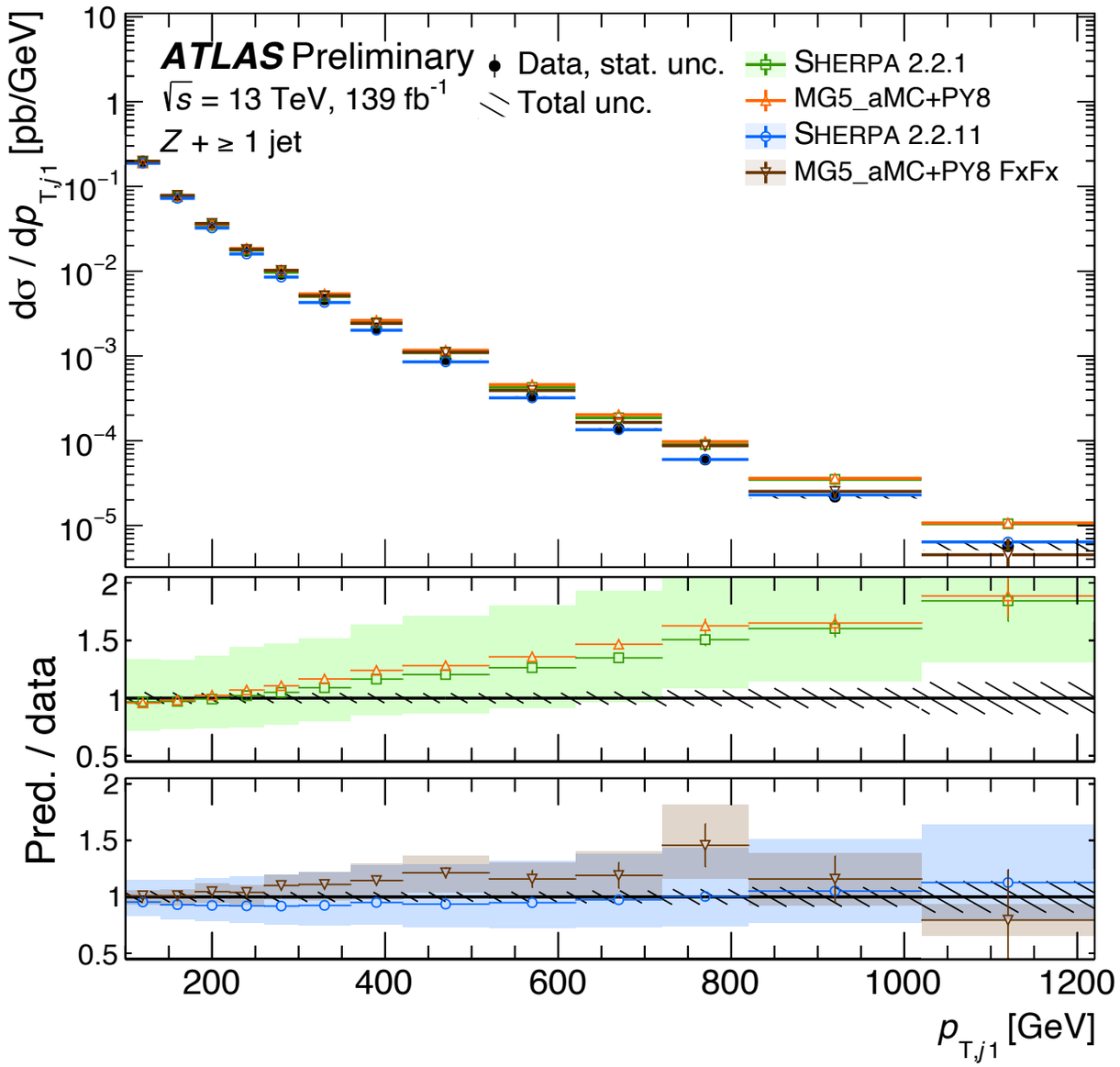
ATLAS physics results

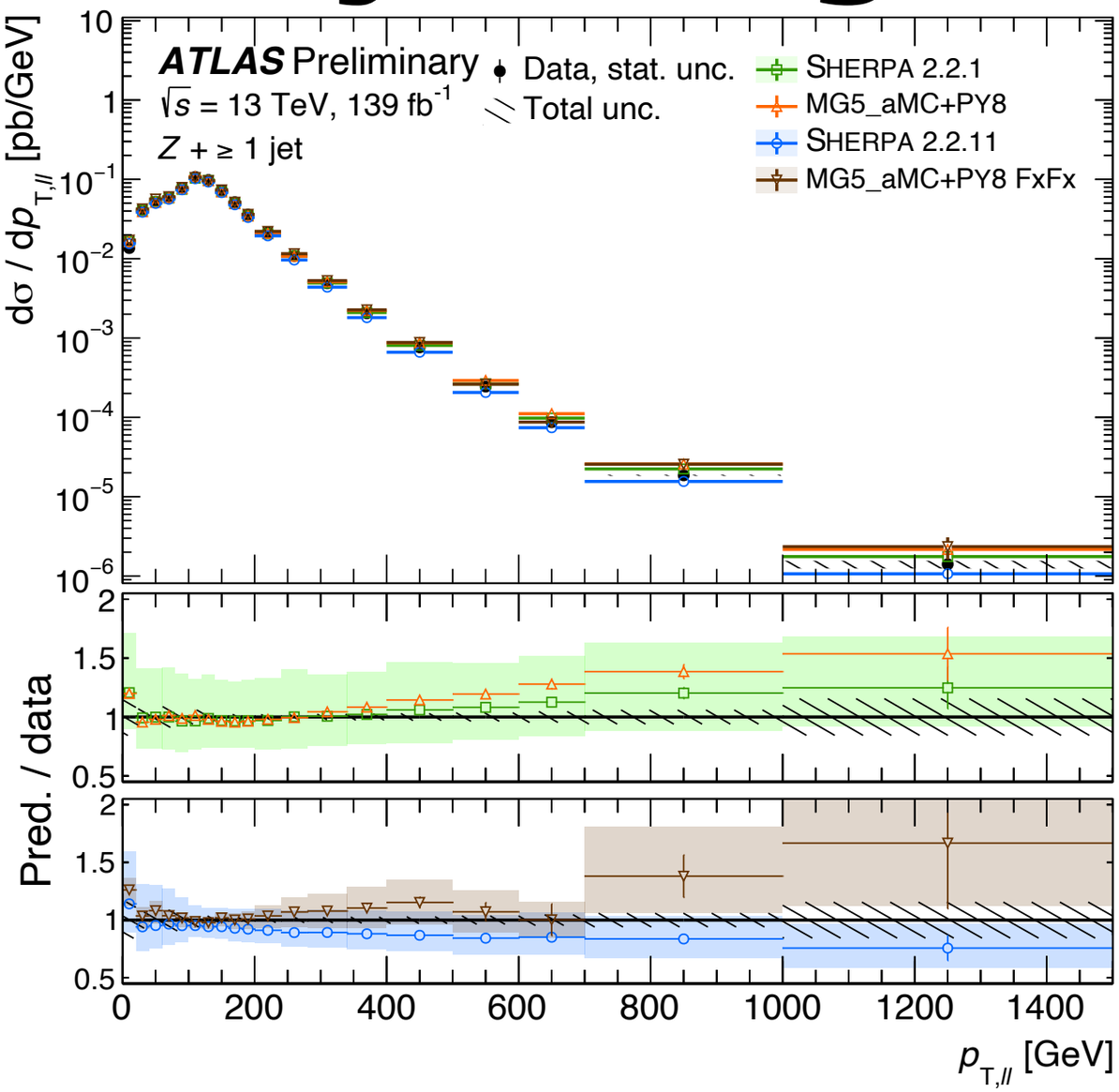
CMS physics results

jets, V, V+jets, VV

ATLAS-CONF-2021-033

Z+jets high P_T





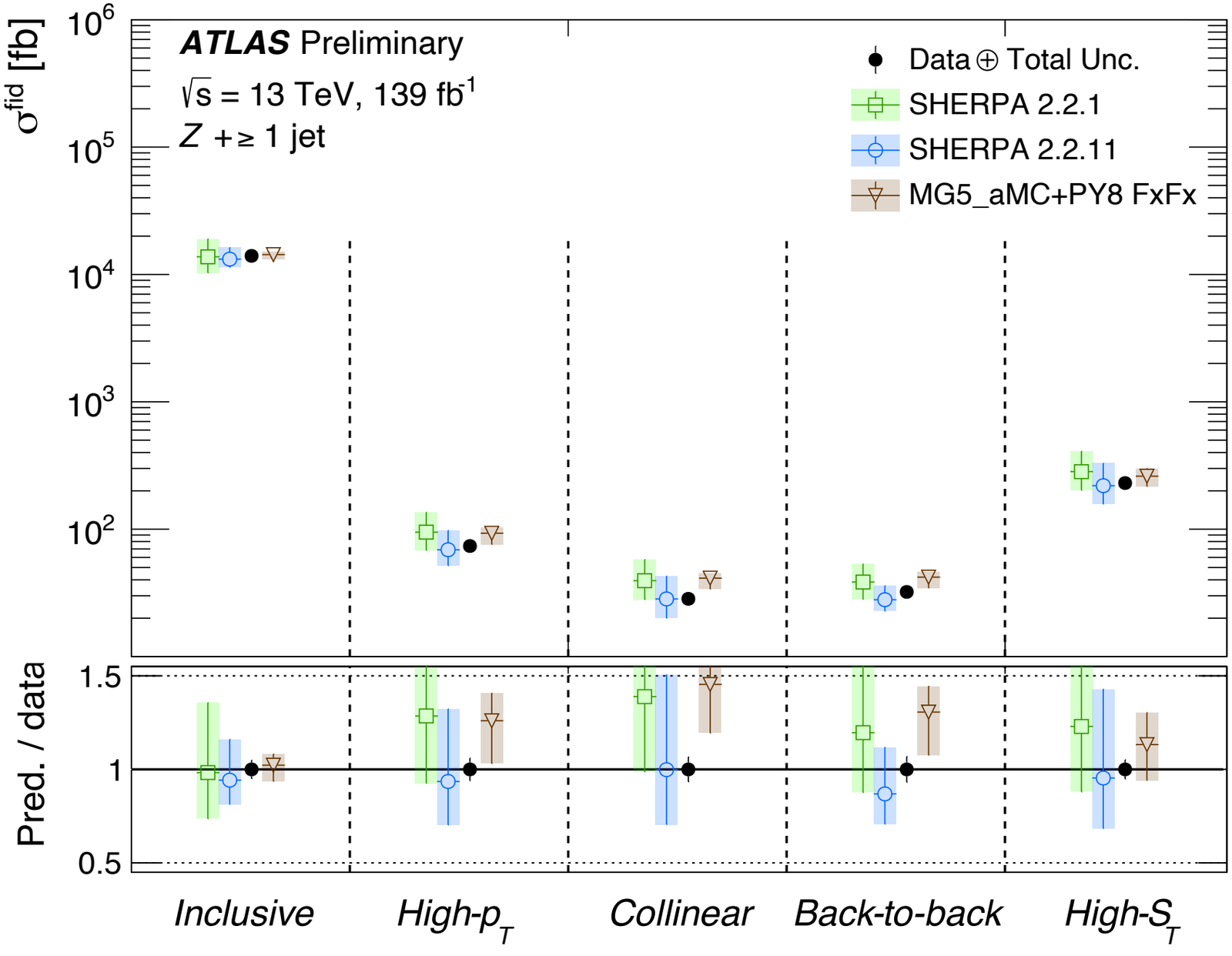
leading jet kinematics nicely captured from NLO MCs, inclusive P_T(ll) is tricker (integrates all additional jets)

exp. uncertainties ~5-14%

ATLAS-CONF-2021-033

Z+jets high P_T

integrated cross sections are also provided (in good agreement with the SM predictions)

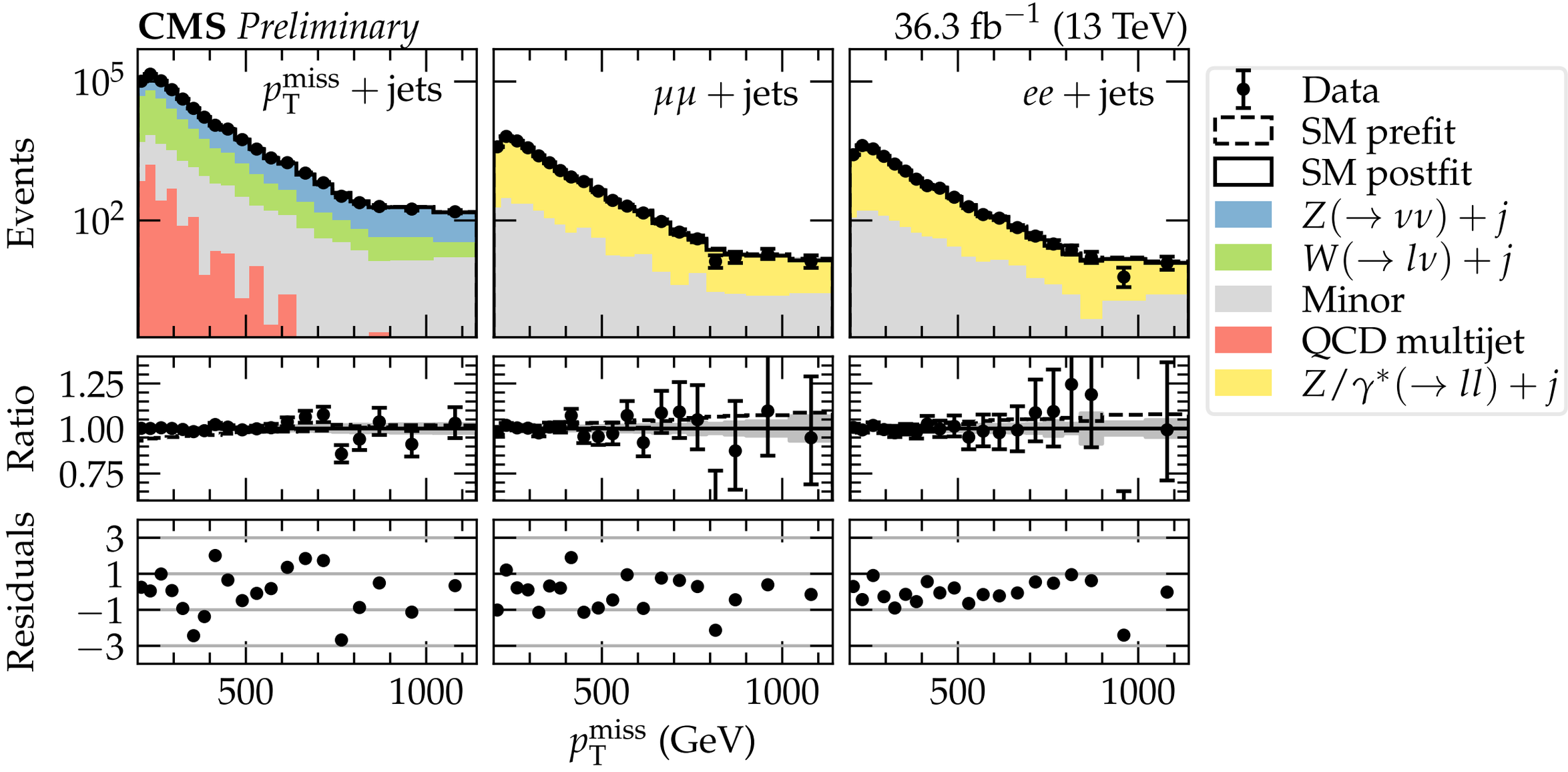


Γ(Z →inv)

1st measurement of the Z invisible width @ hadron collider

$$\Gamma(Z \to \nu\bar{\nu}) = \frac{\sigma(Z+\text{jets})\mathcal{B}(Z \to \nu\bar{\nu})}{\sigma(Z+\text{jets})\mathcal{B}(Z \to \ell\ell)}\Gamma(Z \to \ell\ell)$$

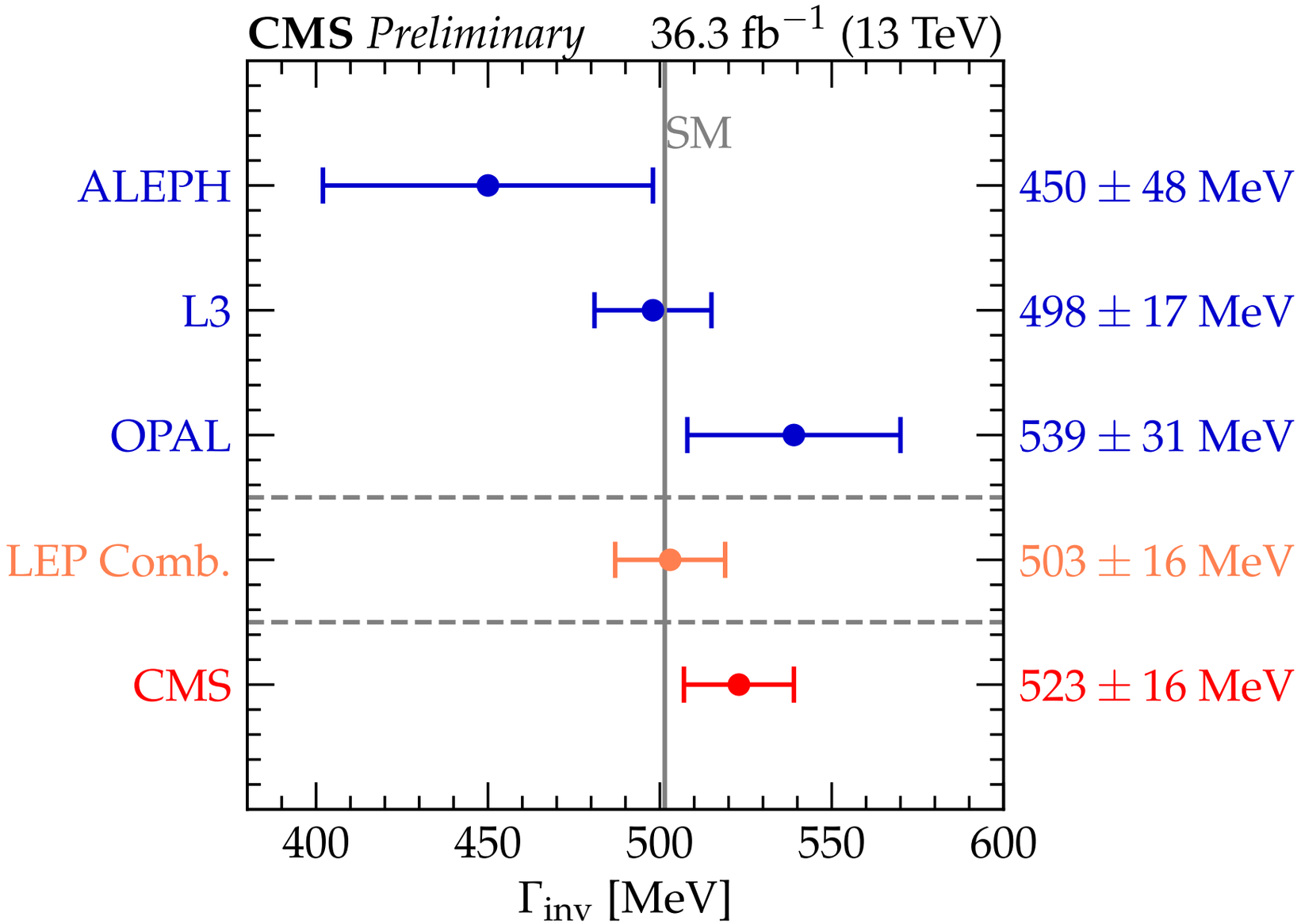
← input from LEP



$\Gamma_{Z \to \nu\nu}$ is extracted as a scaling parameter on the **Z → νν** process, relative to **Z → ll**

Γ(Z →inv)

major systematic uncertainties [1.5-2%] from lepton selection efficiencies and JES

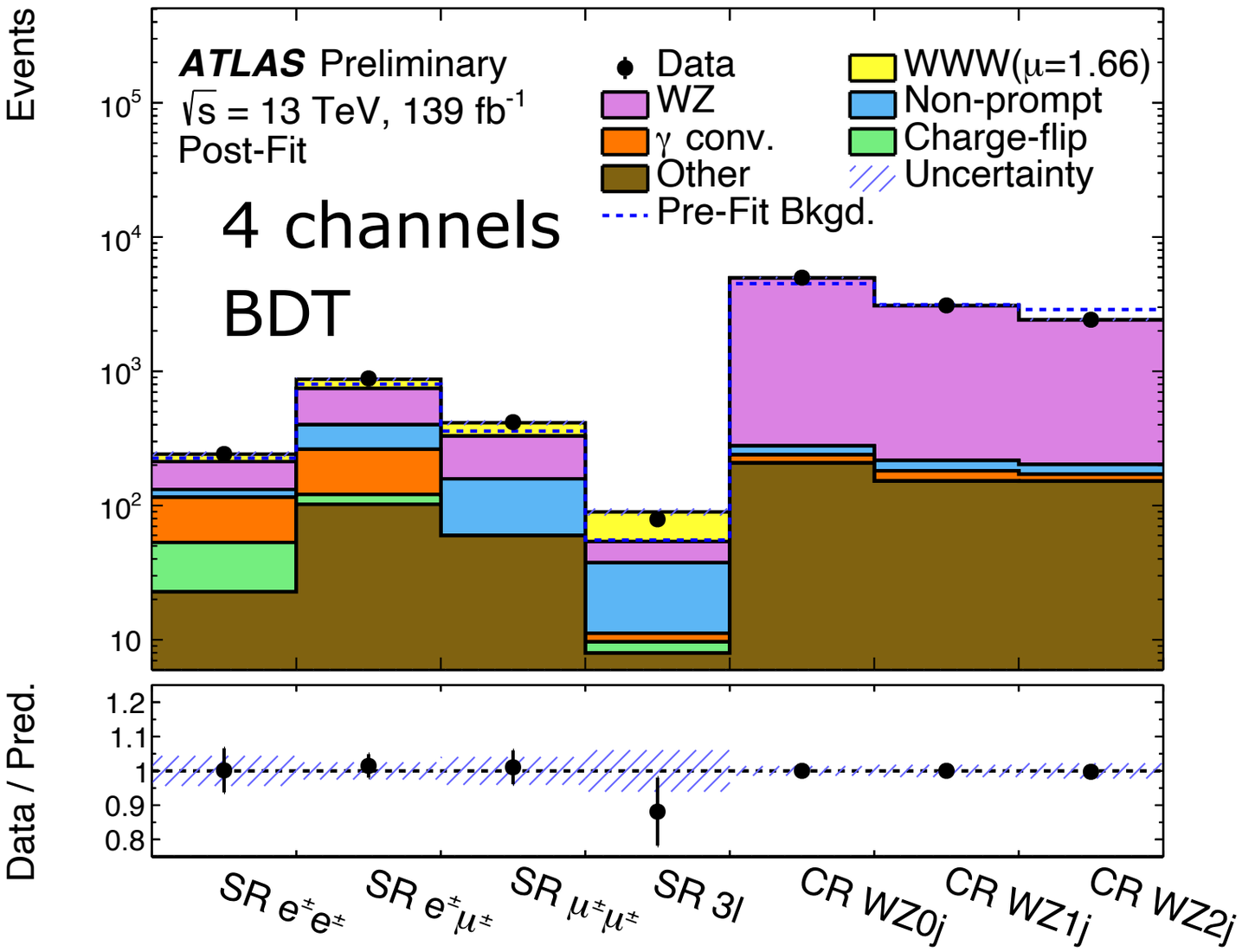


competitive with the *direct* measurement @ LEP

exp. uncertainty ~3%

ATLAS-CONF-2021-039

WWW

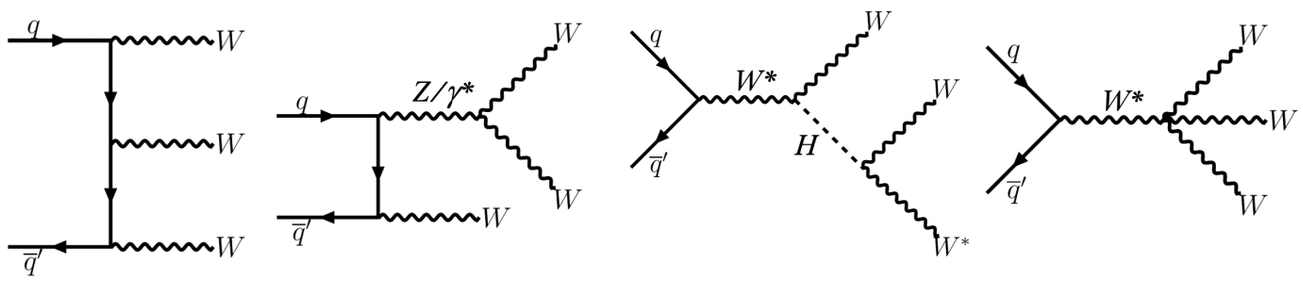


WWW final state sensitive to triple & quartic couplings

SM expectation ~505 fb

with pp→Wh→WWW* accounting for more than the half of the total cross section

$$\sigma(pp \rightarrow WWW) = 850 \pm 100\ (\text{stat.}) \pm 80\ (\text{syst.})\ \text{fb}$$



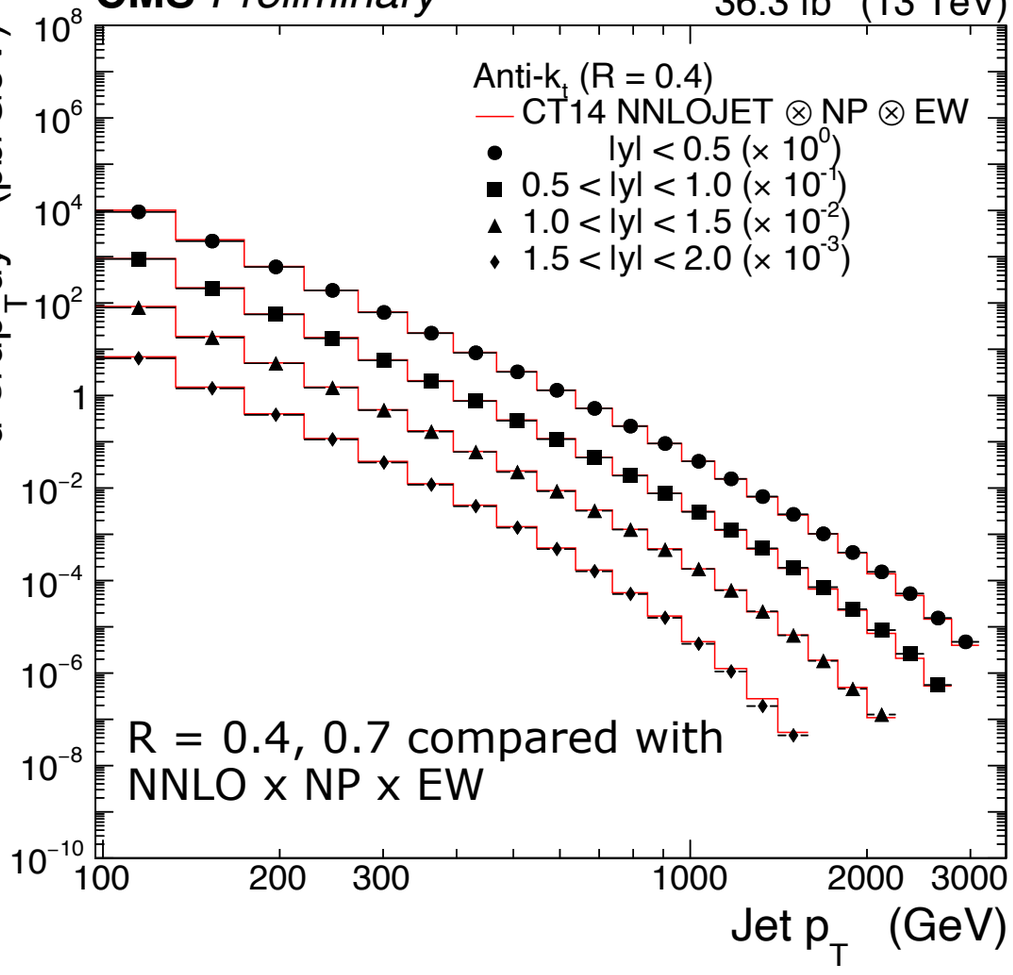
first observation, 8.2σ significance

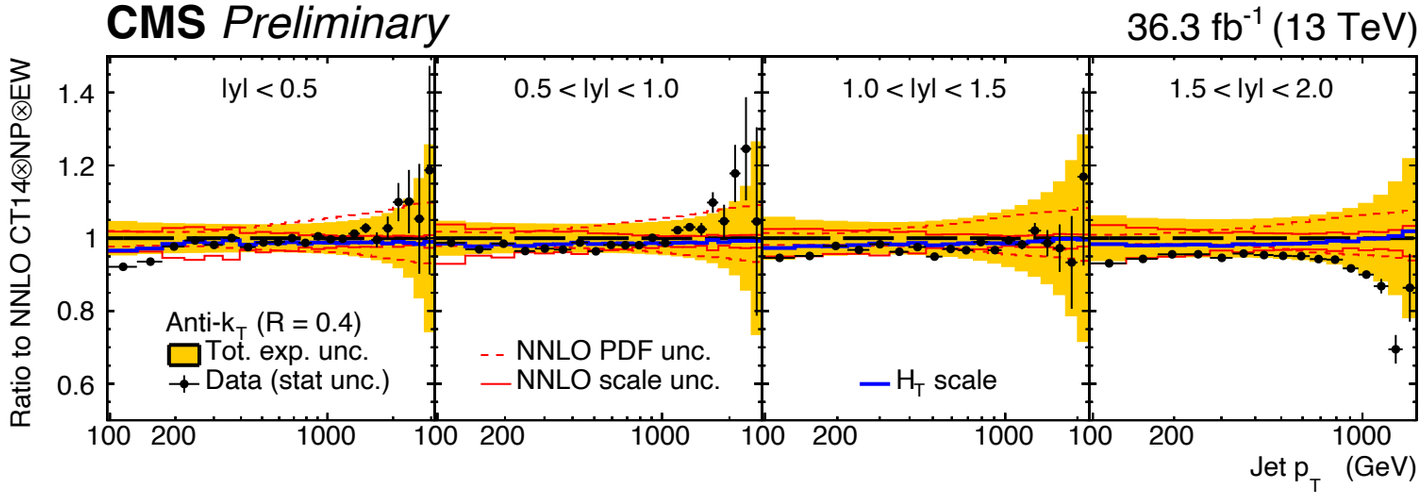
more on VV, see Darien Woods' talk

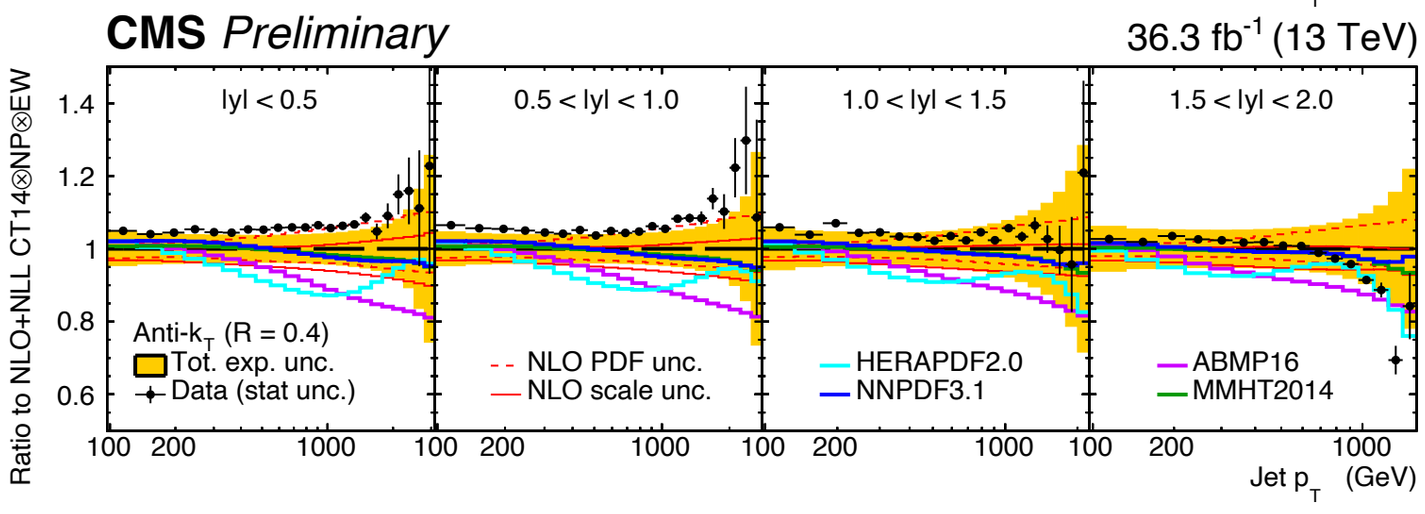
exp. uncertainties ~12%

CMS SMP-20-011

Inclusive Jets @ 13 TeV





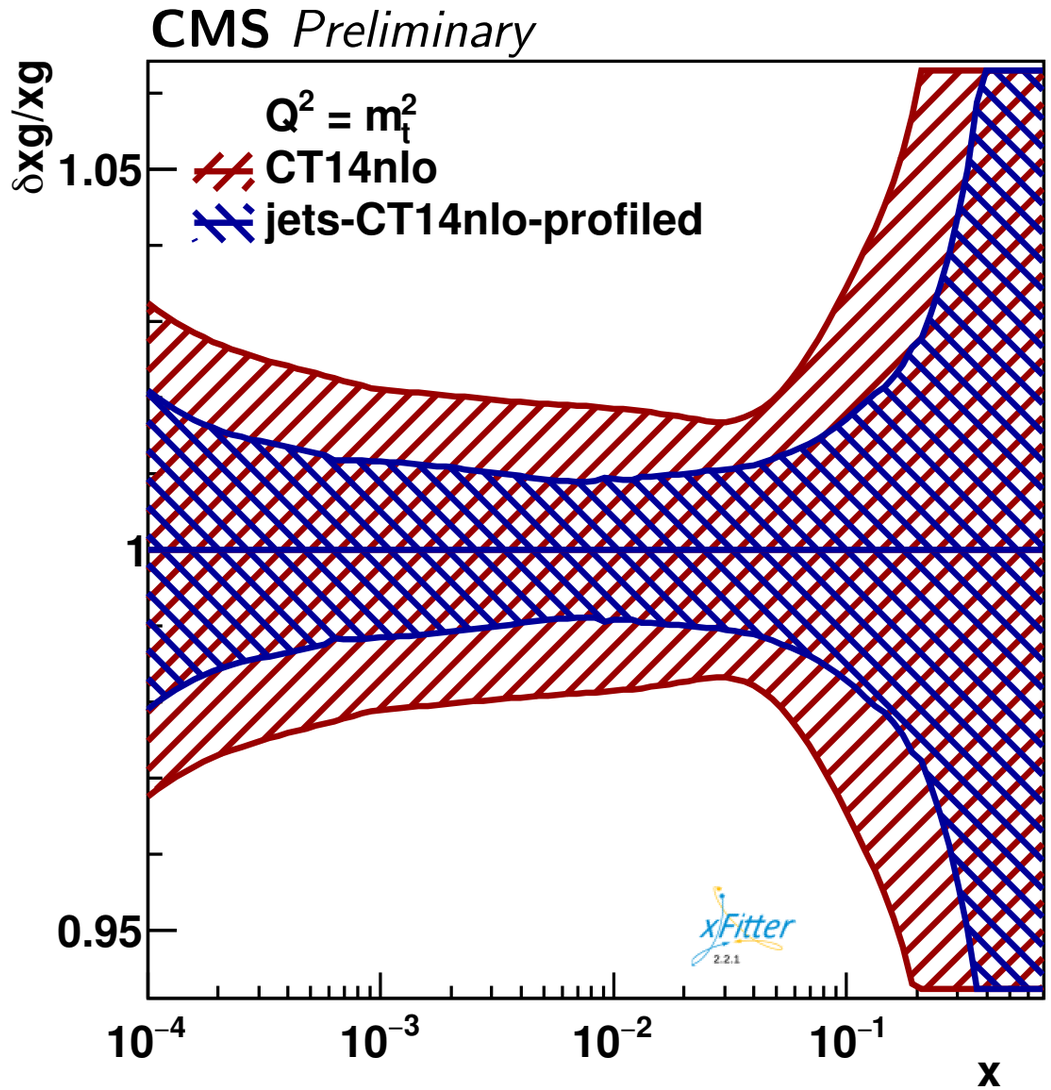


CMS jet data together with the HERA DIS measurements and CMS top pair production cross section are used to constrain **PDFs**, $\mathbf{a_S}$ and $\mathbf{m_{top}}$ simultaneously

exp. uncertainties ~5-20%

Inclusive Jets @ 13 TeV

Relative uncertainties in the gluon distribution



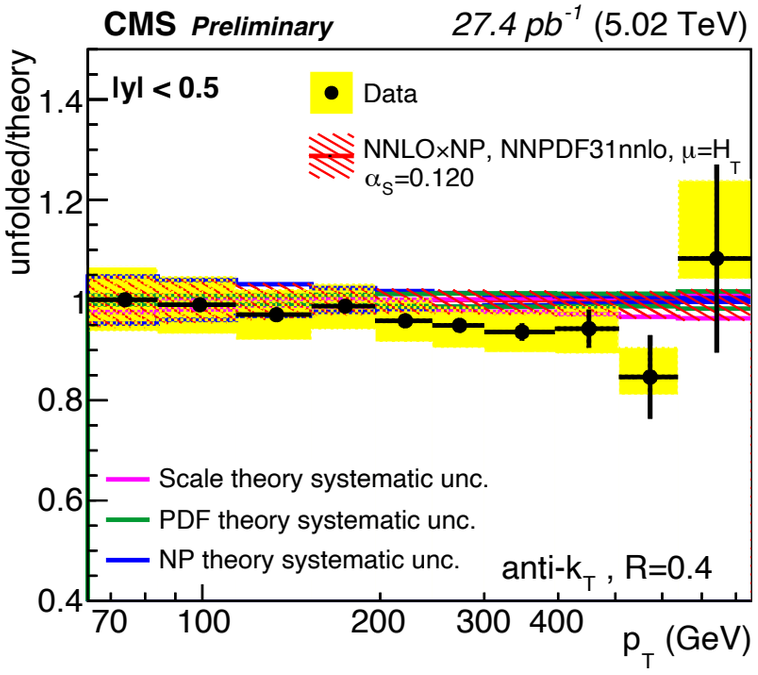
$$\alpha_S(m_Z) = 0.1177 \pm 0.0014(\text{fit}) \pm 0.0022(\text{model and param.}),$$

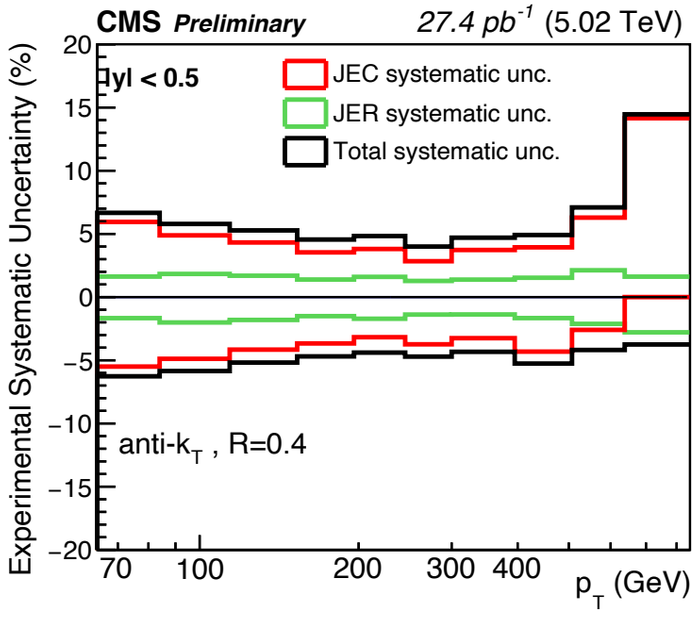
$$m_t^{\text{pole}} = 170.2 \pm 0.6(\text{fit}) \pm 0.1(\text{model and param.})\,\text{GeV}.$$

Although jet data have no direct sensitivity to $\mathbf{m_{top}}$, their influence on the gluon **PDF** and $\mathbf{a_S}$ can be reflected in $\mathbf{m_{top}}$

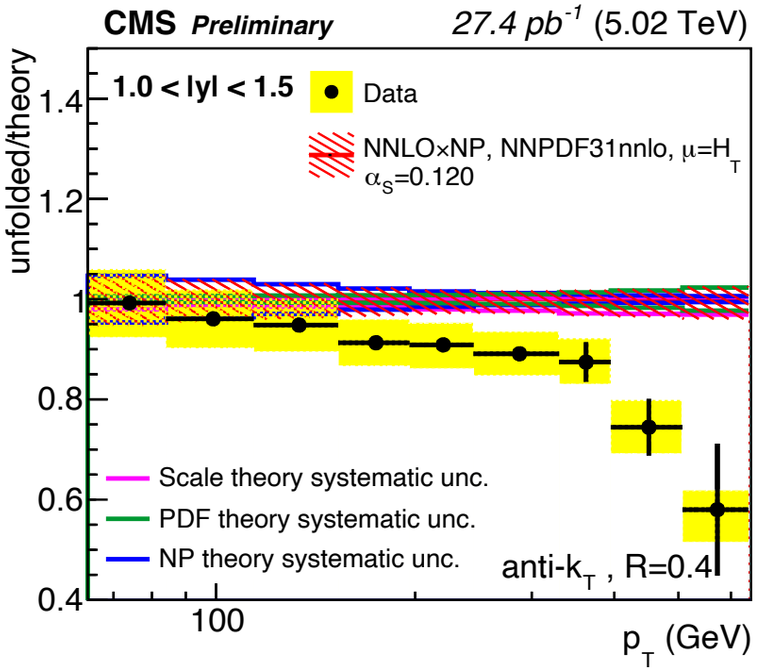
CMS SMP-21-009

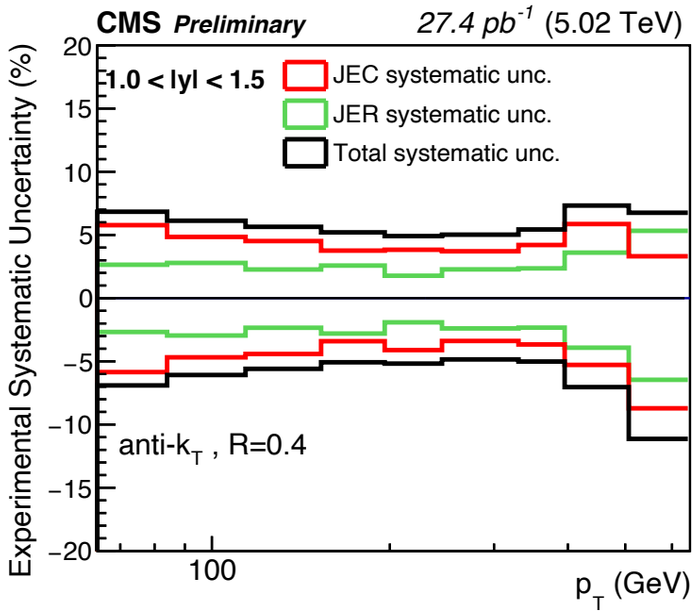
Inclusive Jets @ 5 TeV





comparing with NLO, NNLO & different set of scales/PDFs





measured data are available (Rivet & HepData) for global fits

exp. uncertainties ~5-15%

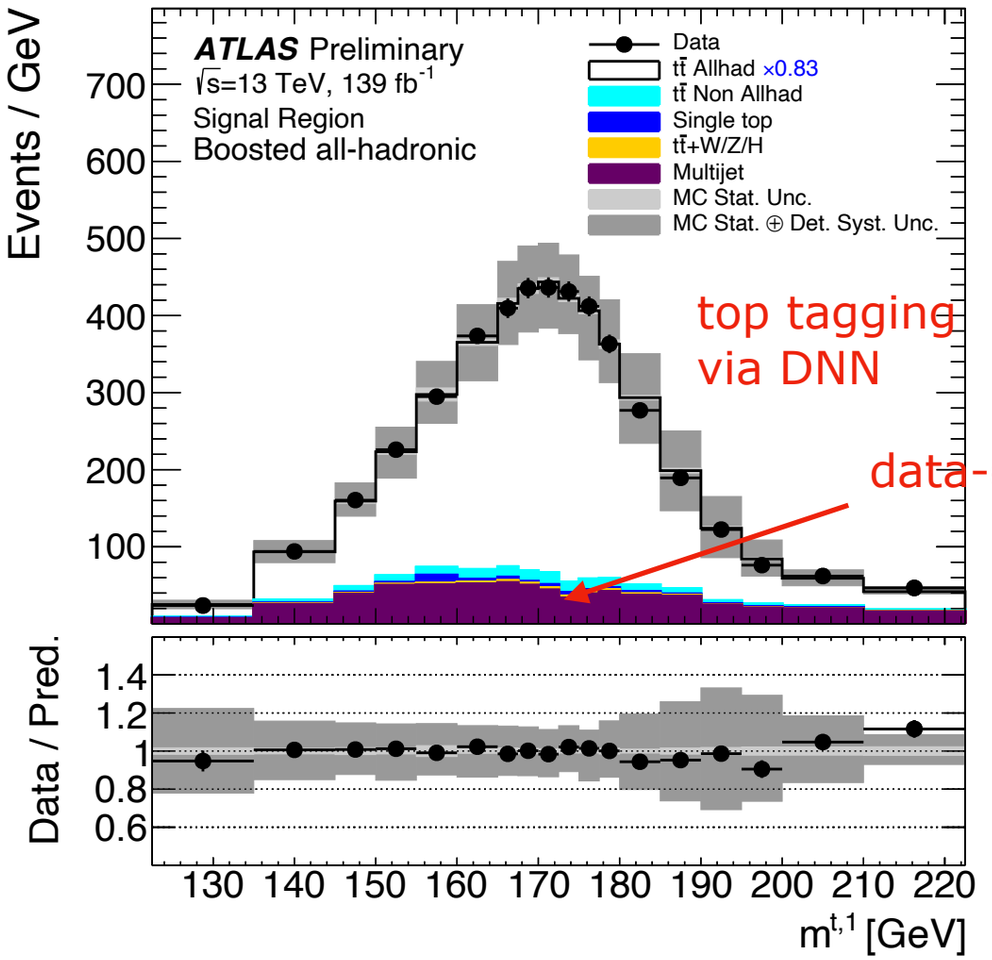
top

ATLAS-CONF-2021-050

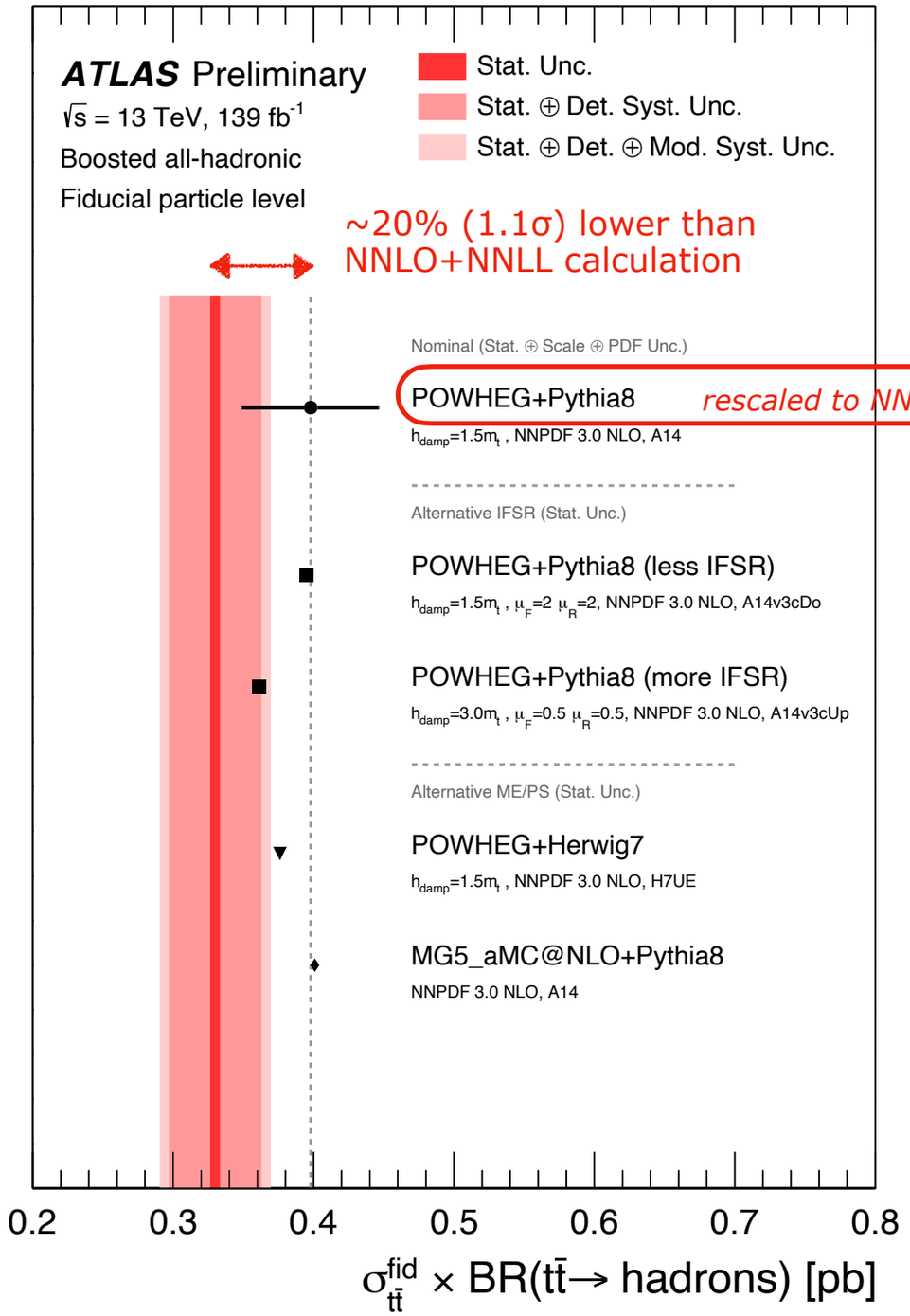
tt (all hadronic)

fiducial space

- $pt(j_1) \geq 500$ GeV
- $pt(j_2) \geq 350$ GeV
- $|\eta(j_i)| < 2.0$
- $122.5 < m(j_i) < 222.5$ GeV
- lepton veto



this analysis is particularly sensitive to 4-quark EFT operators and sets limits on a range of them

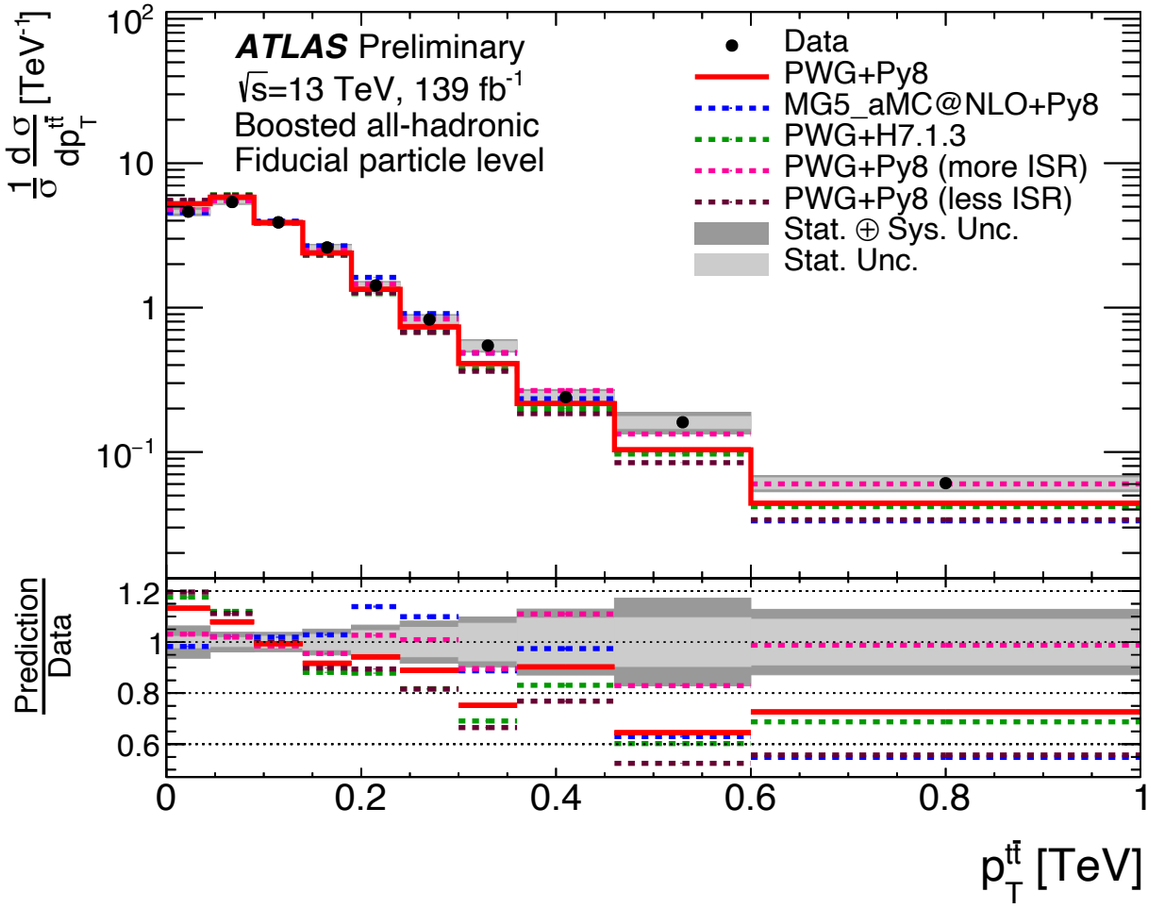


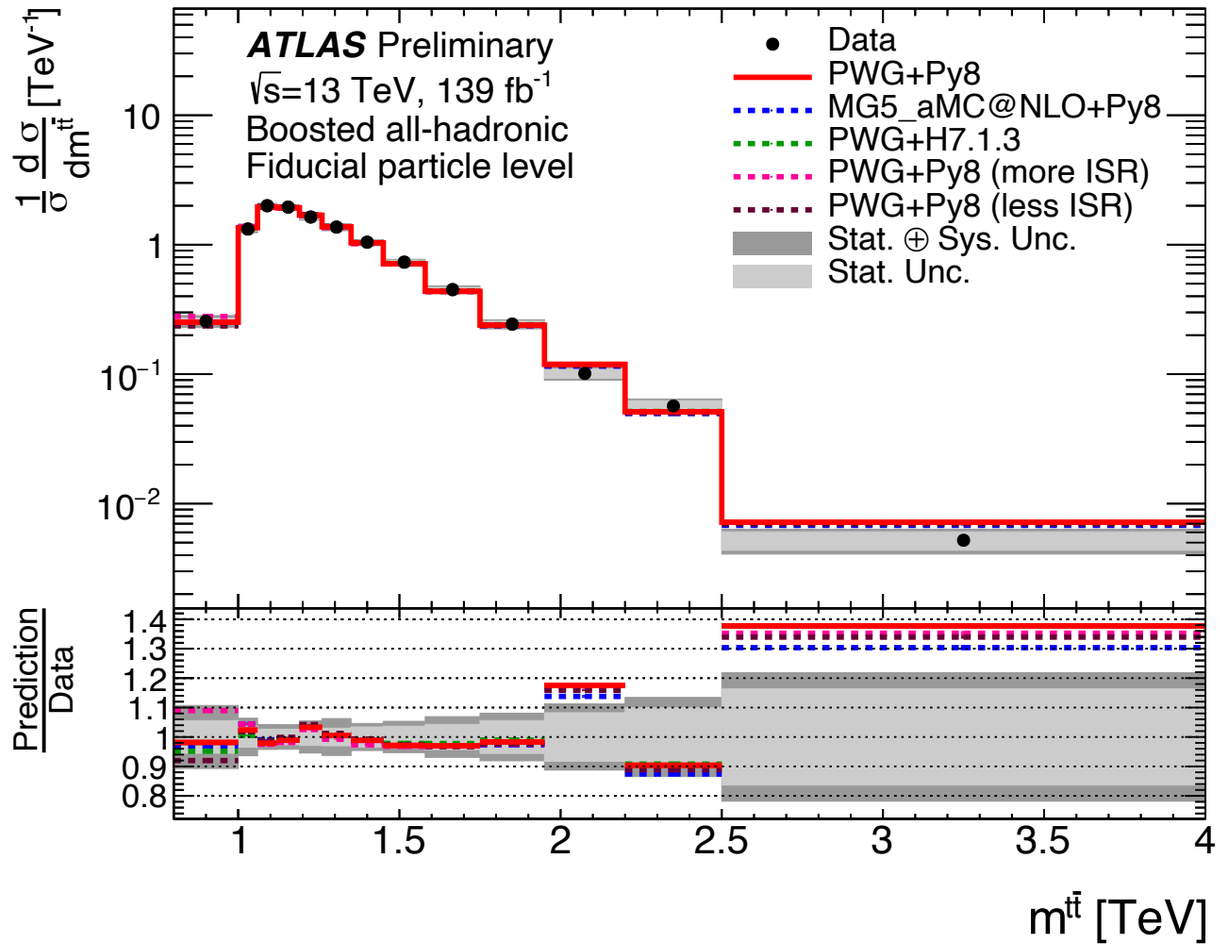
exp. uncertainty ~12%

ATLAS-CONF-2021-050

tt (all hadronic)

normalized differential cross sections



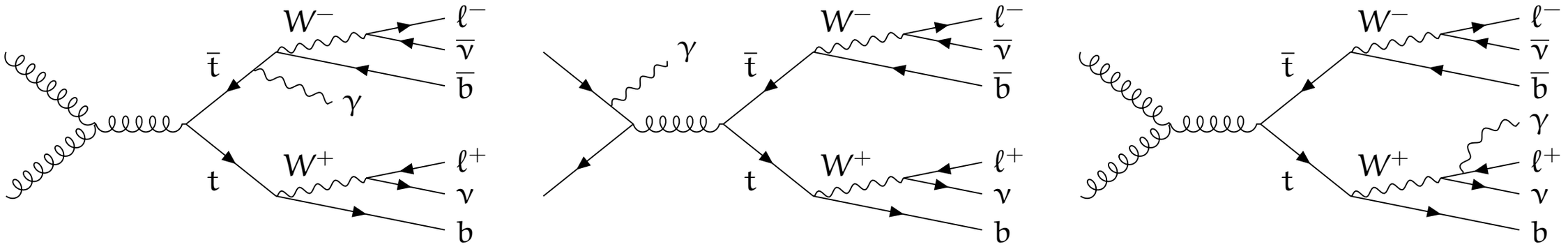


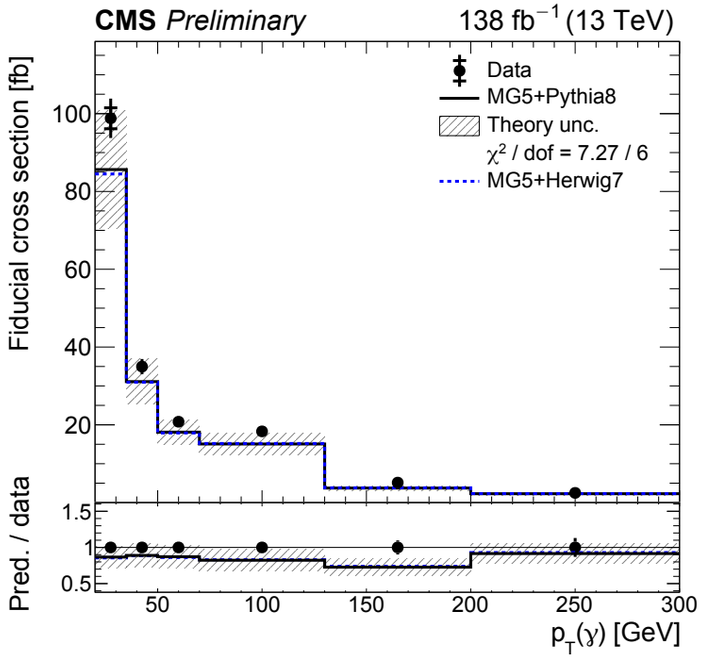
p_T(tt) sensitive to extra radiation, Powheg+Py8 with more ISR describes better the data compared to the nominal Powheg+Py8

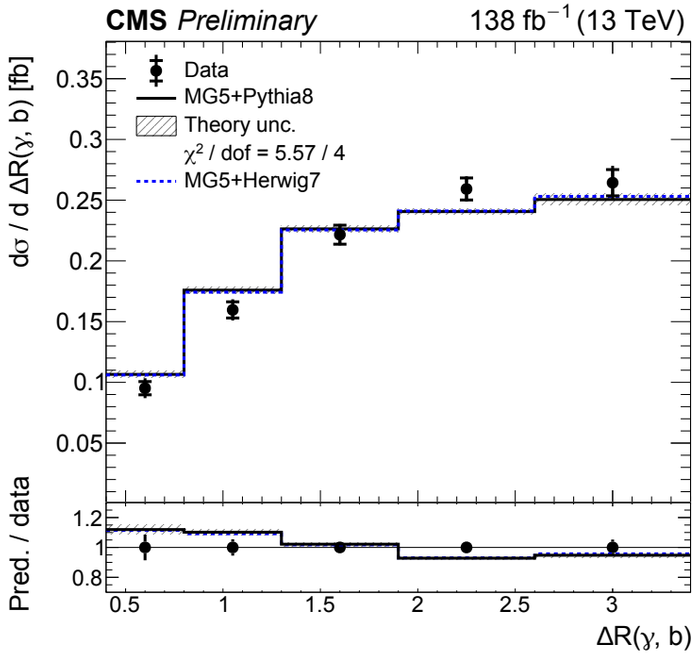
m(tt) > 1 TeV, all predictions have similar level of agreement with the data

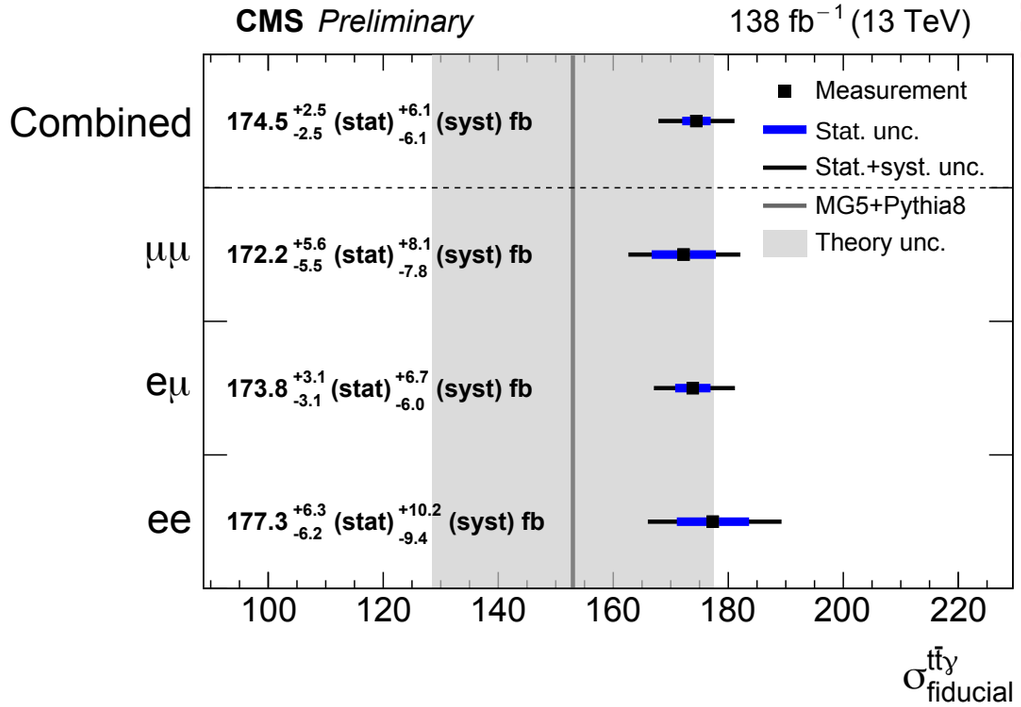
exp. uncertainty ~5-20%

ttγ (dileptonic)







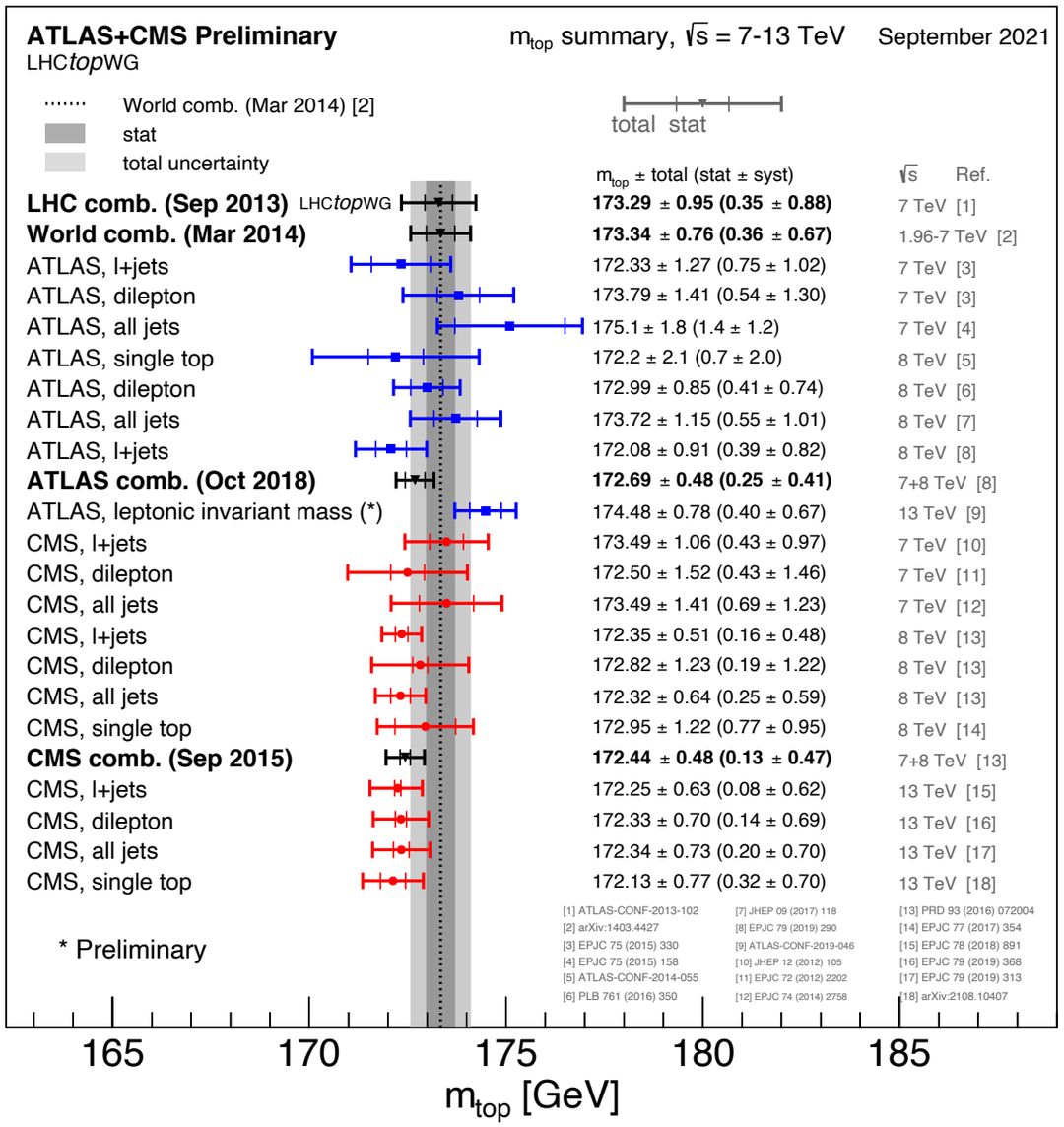


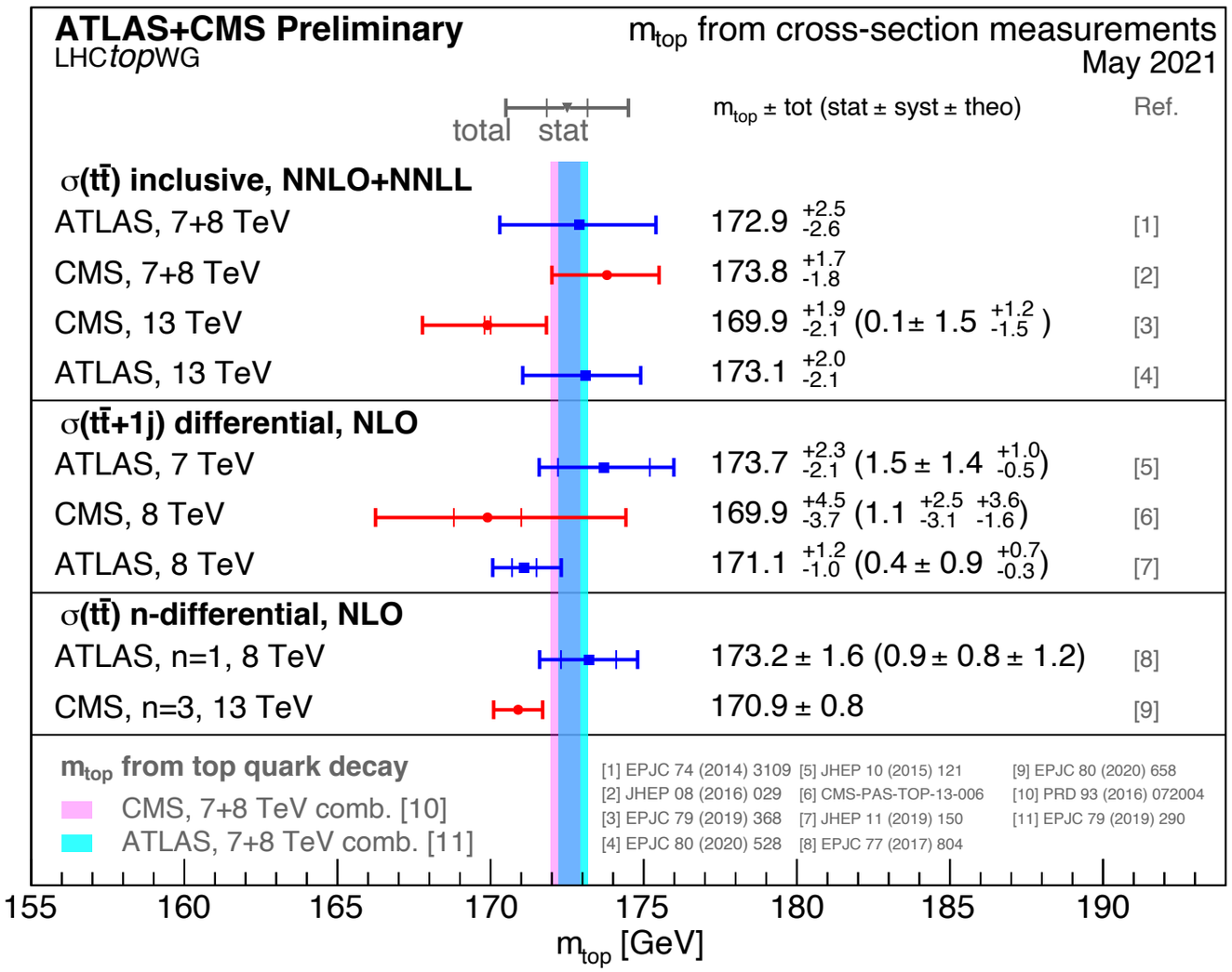
$N_\gamma = 1$, $N_{bjet} \geq 1$, $N_{lep} = 2$, $m_{ll} > 20$ GeV

fiducial phase space

exp. uncertainty ~4-10%

m_{top}





direct

from cross sections

exp. uncertainties ~0.5%

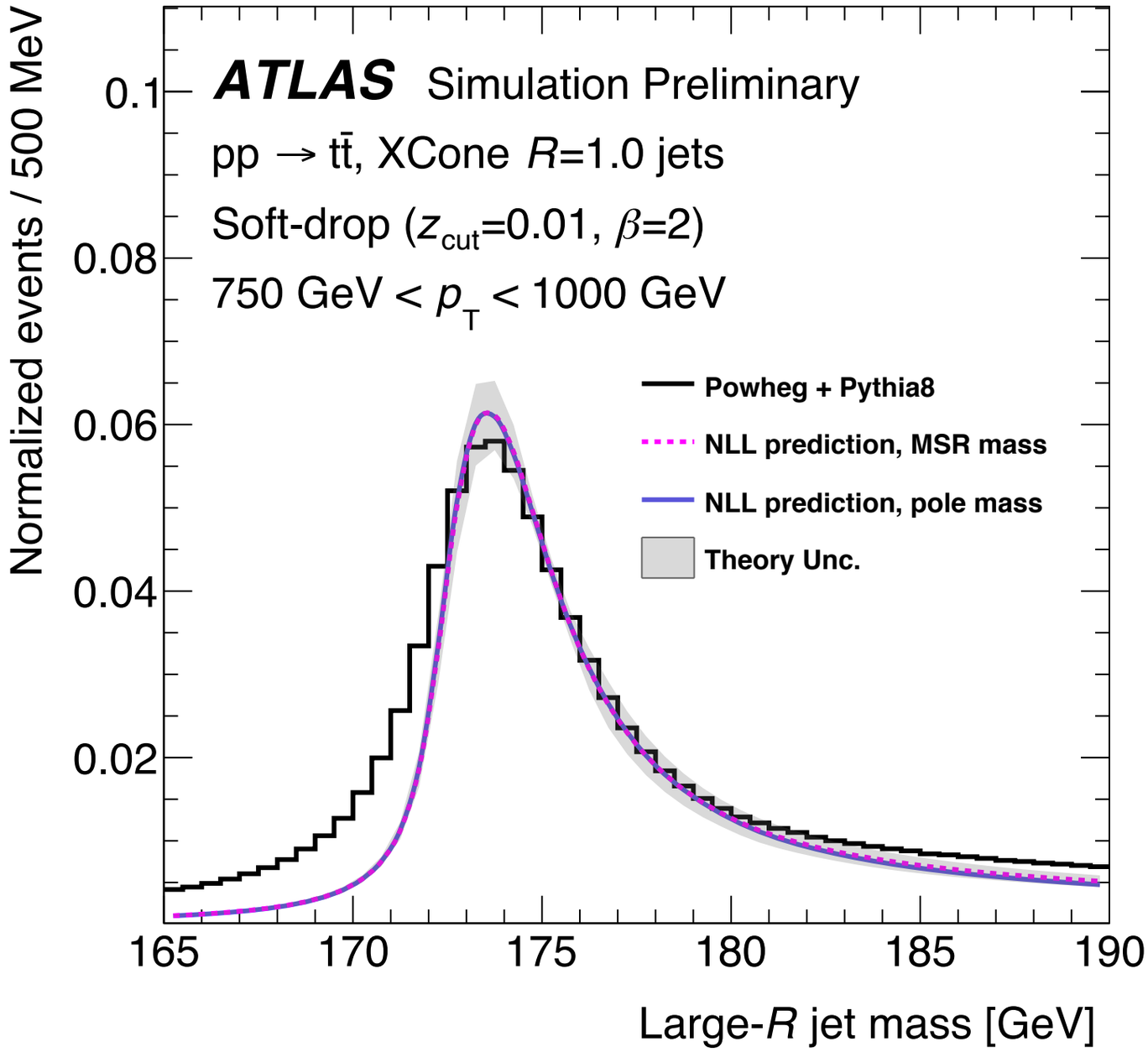
ATL-PHYS-PUB-2021-034

A. Hoang et al. PRL 101 151602

interpreting m_{top}

in direct measurements, data are compared to multiple MCs assuming different values of m_t^{MC}, but m_t^{MC} is not trivially connected to m_t^{pole}

a new ATLAS analysis connects m_t^{MC} with a well defined pQCD calculation at NLL, $m_t^{MSR}(R = 1GeV)$ which is numerically close to m_t^{pole}, by *calibrating* the prediction to different templates of Powheg+Py8 MC



$$m_t^{\mathrm{MC}} = m_t^{\mathrm{MSR}}(1\ \mathrm{GeV}) + 80^{+350}_{-410}\ \mathrm{MeV}$$

more on top, see Rohin Thampilali Narayan's talk

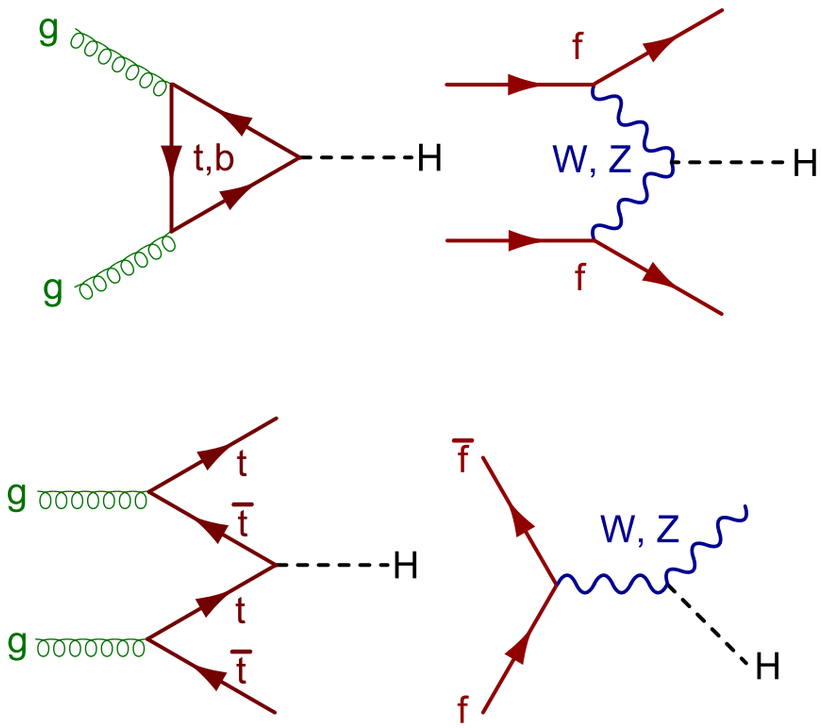
higgs

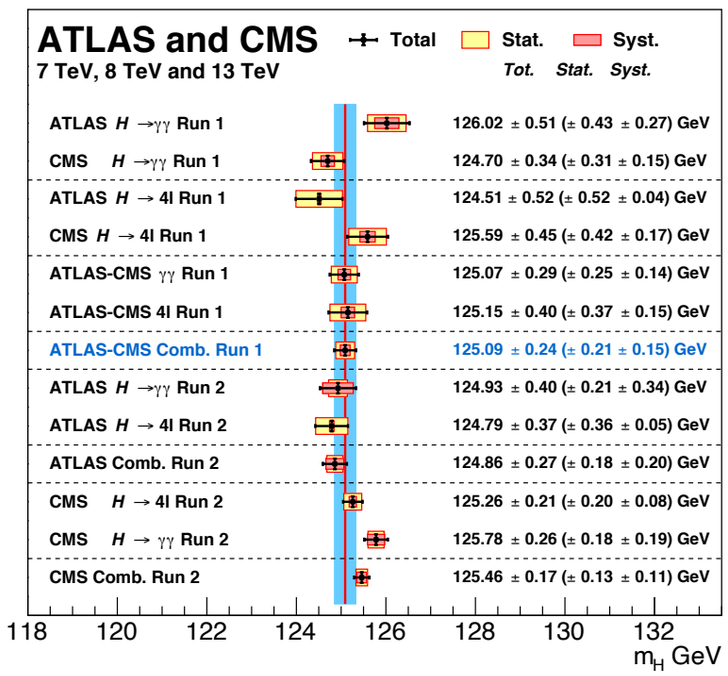
Higgs, so far

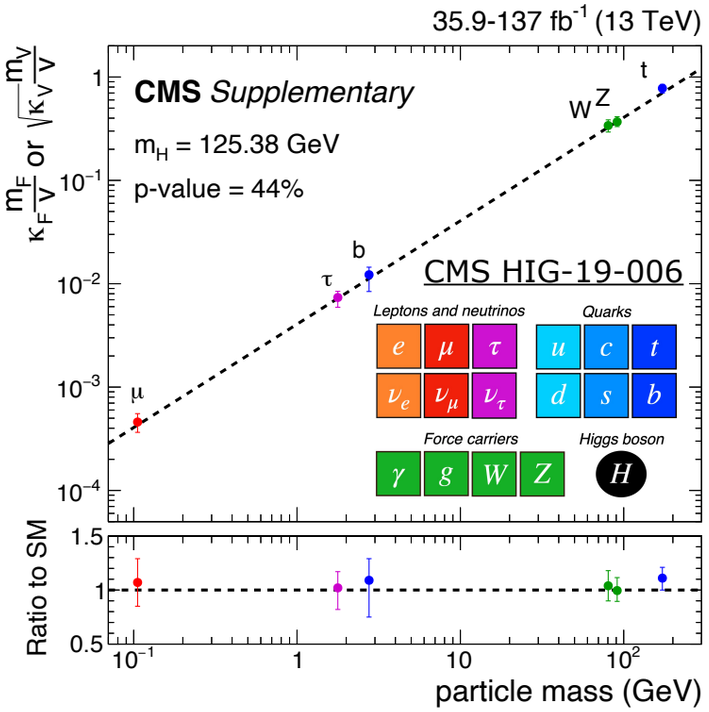
observation of all main:

production modes ggF, qqH, VH, ttH

& **decay modes** γγ, ZZ, WW, ττ, bb and evidence for μμ



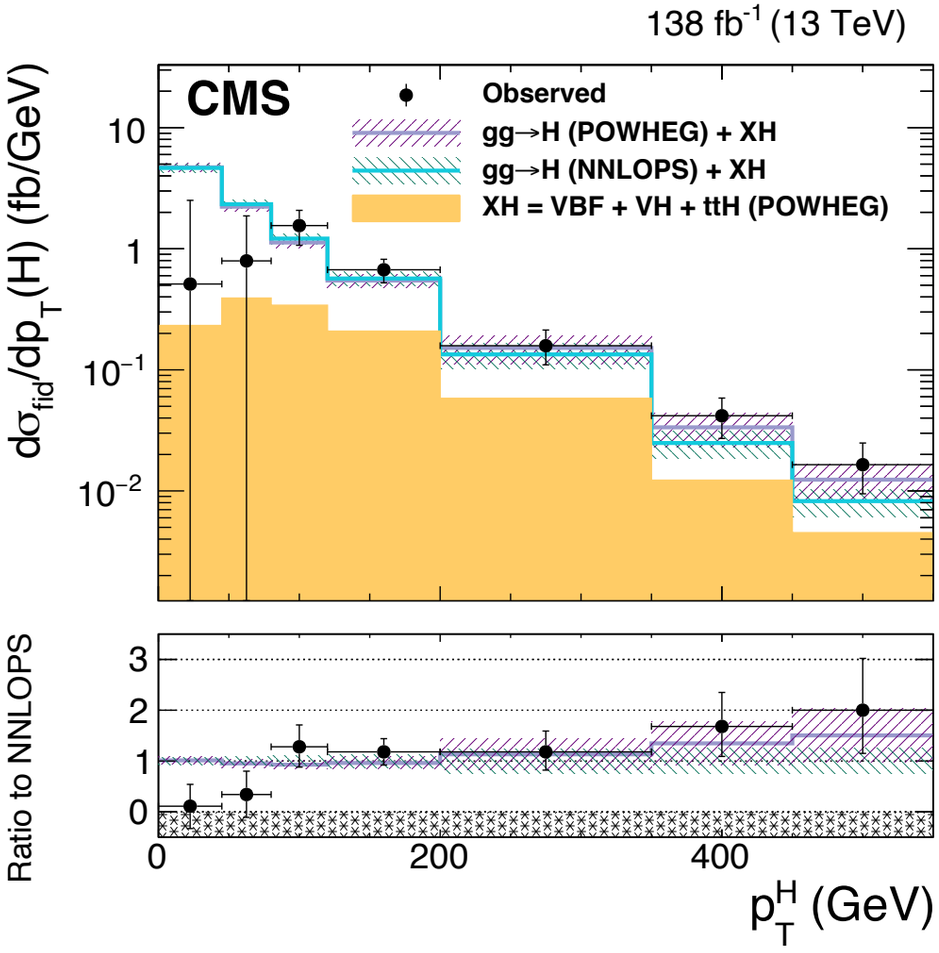


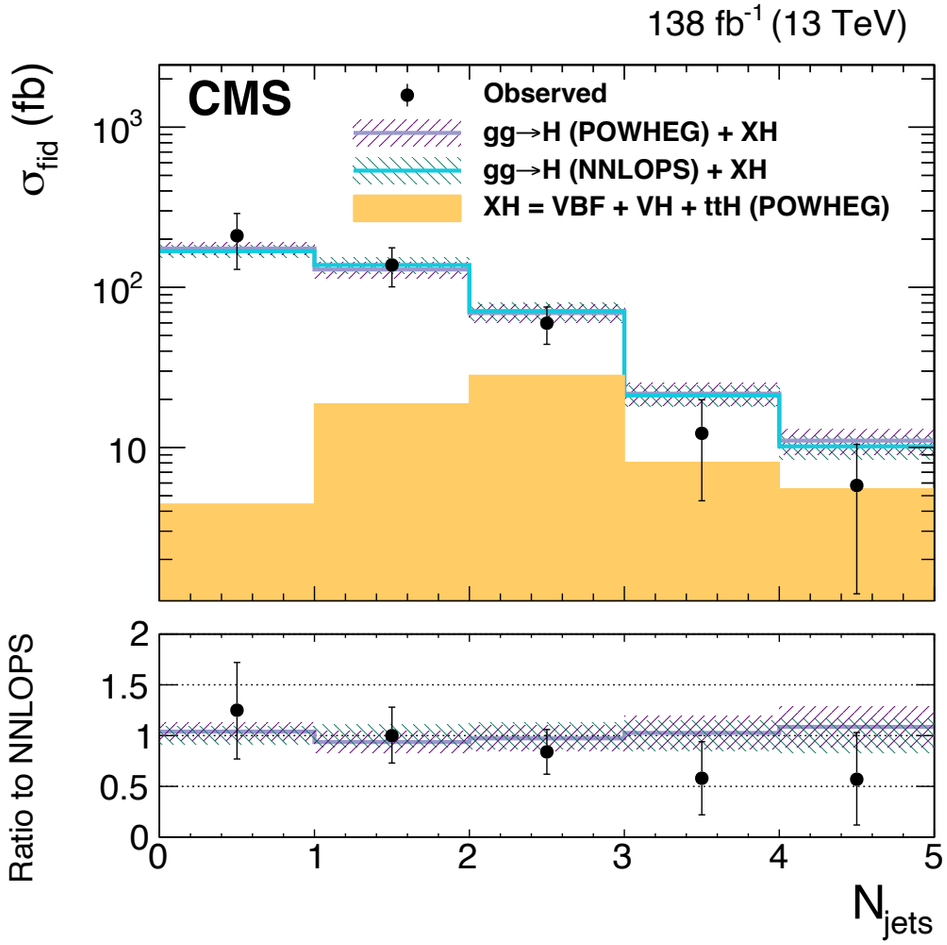


within uncertainties, all measurements consistent (so far) with the hypothesis that the **H** boson is a **CP-even fundamental scalar**

CMS HIG-20-015

H → tau tau (differential)





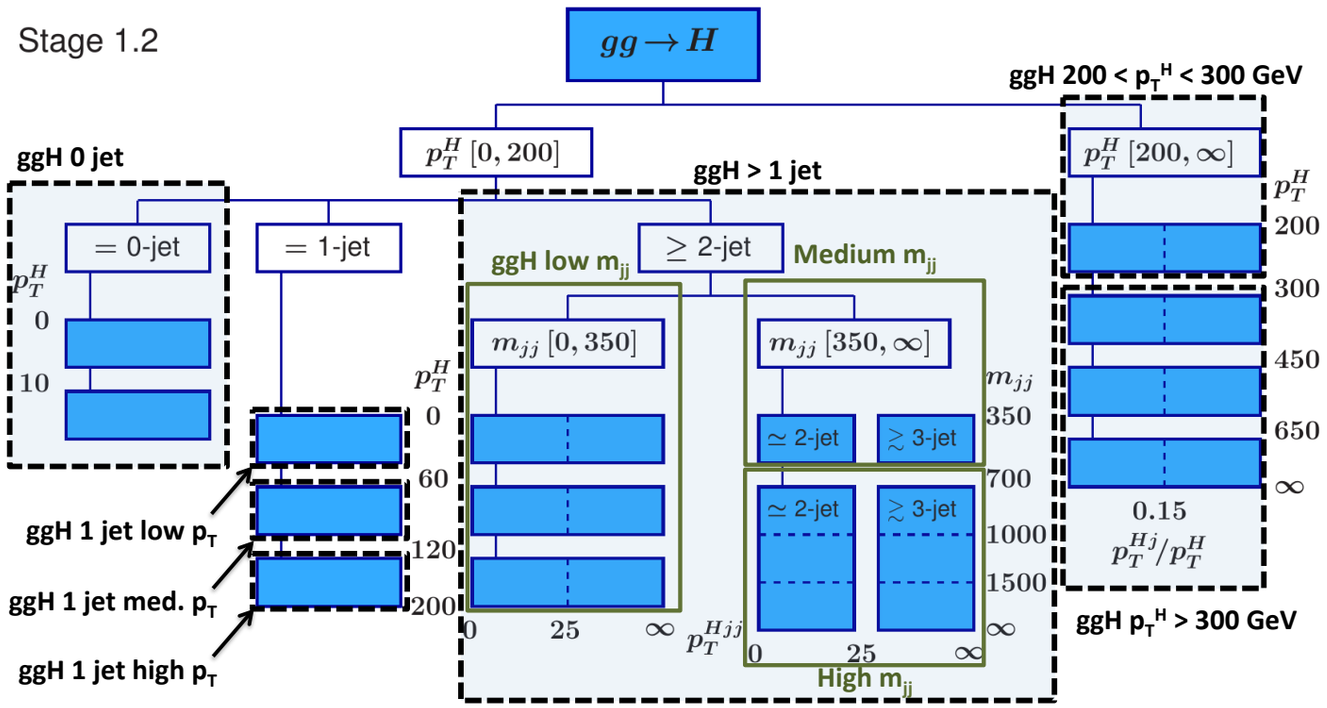
First differential measurement using H → ττ mode

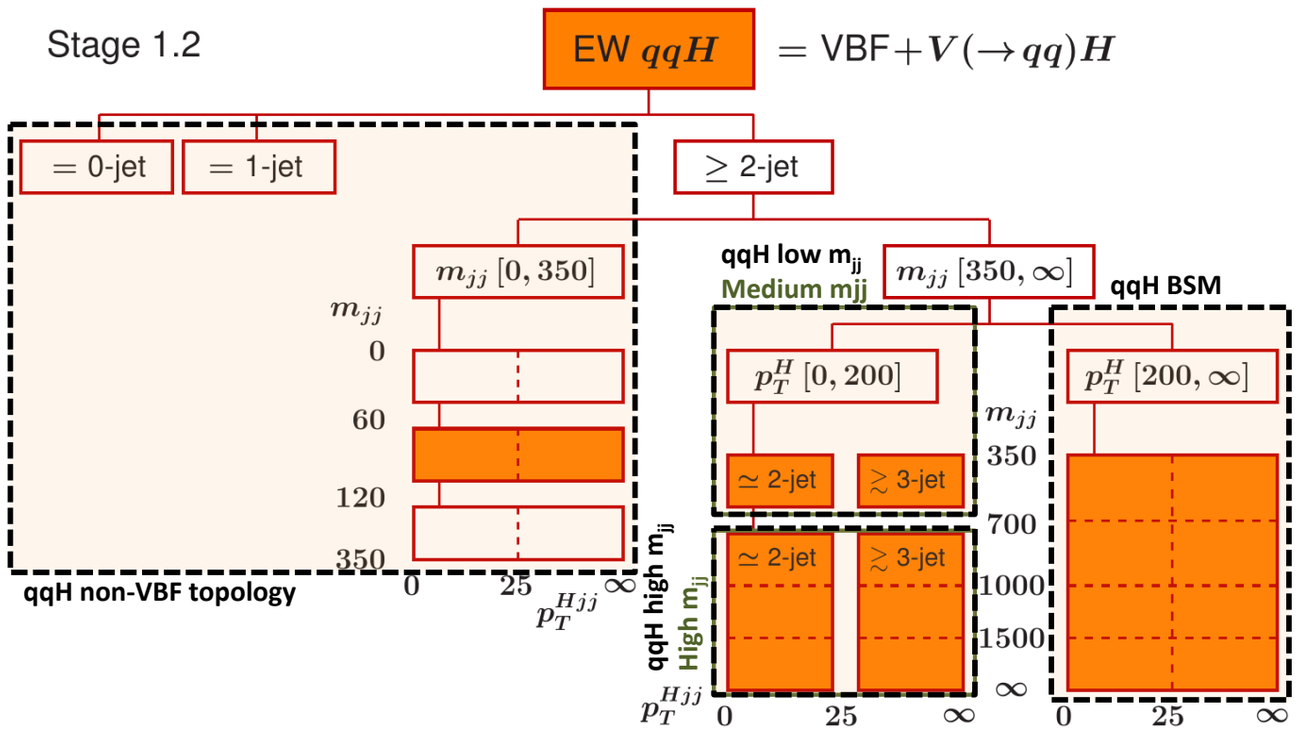
bins of $P_T(H)$, N_{jets}, $P_T(j_1)$

at high p_T, **competitive precision** wrt other final states e.g., **ZZ**, **WW**

CMS HIG-19-010

H → tau tau (STXS)

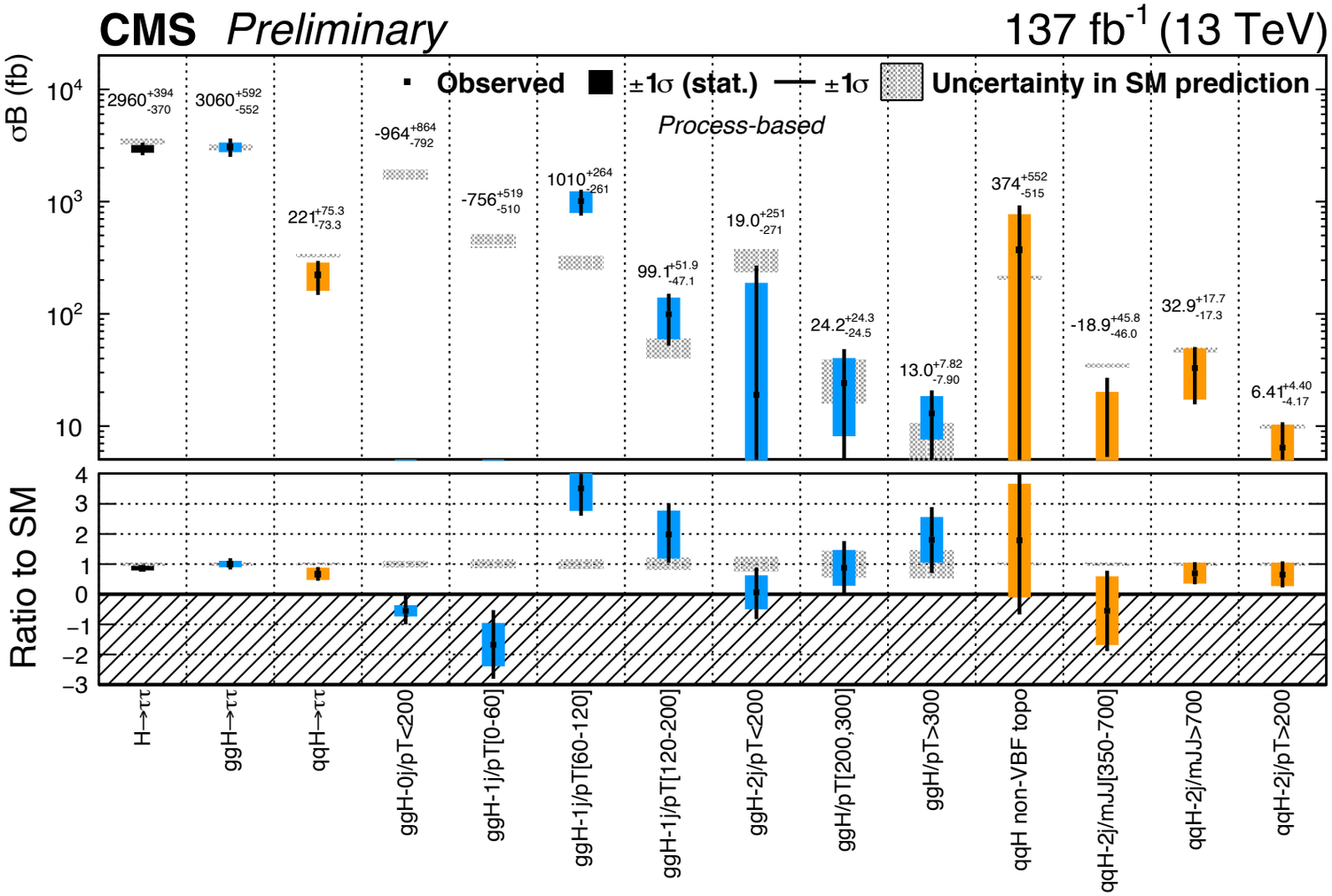




contrary to the fiducial cross section measurements here the xs is measured per production mode in pre-defined mutually exclusive bins, allowing the combination with other decay modes

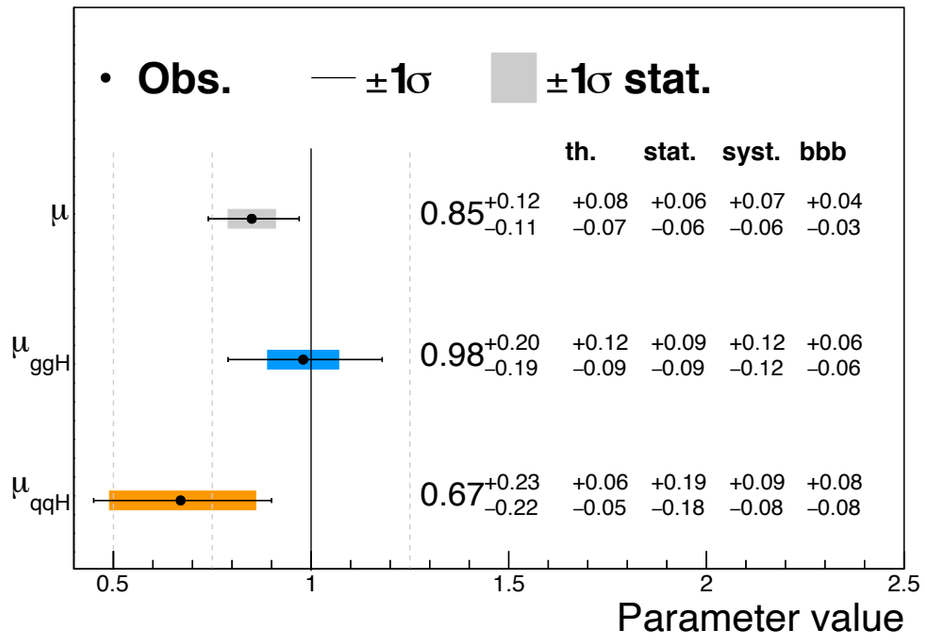
CMS HIG-19-010

H → tau tau (STXS)



process based merging

global signal strength

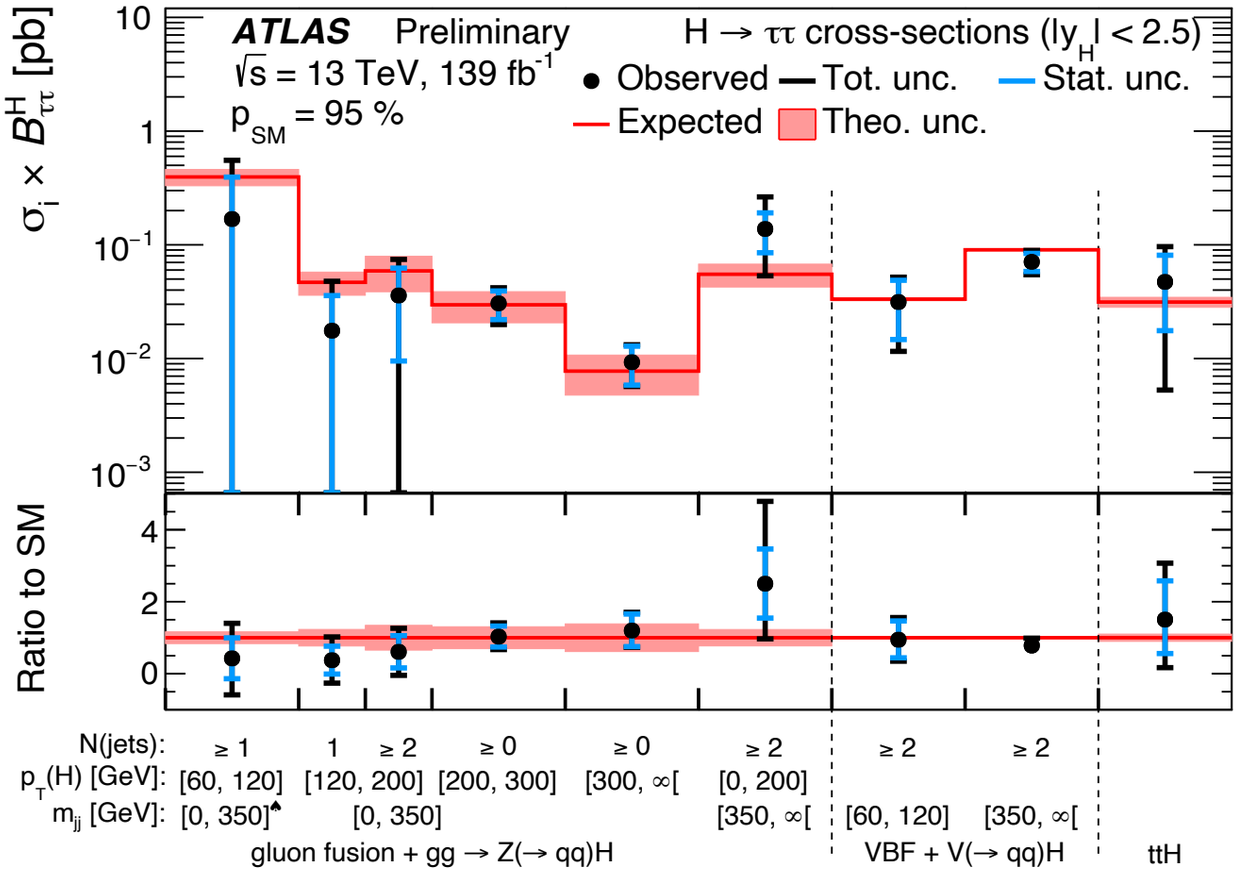


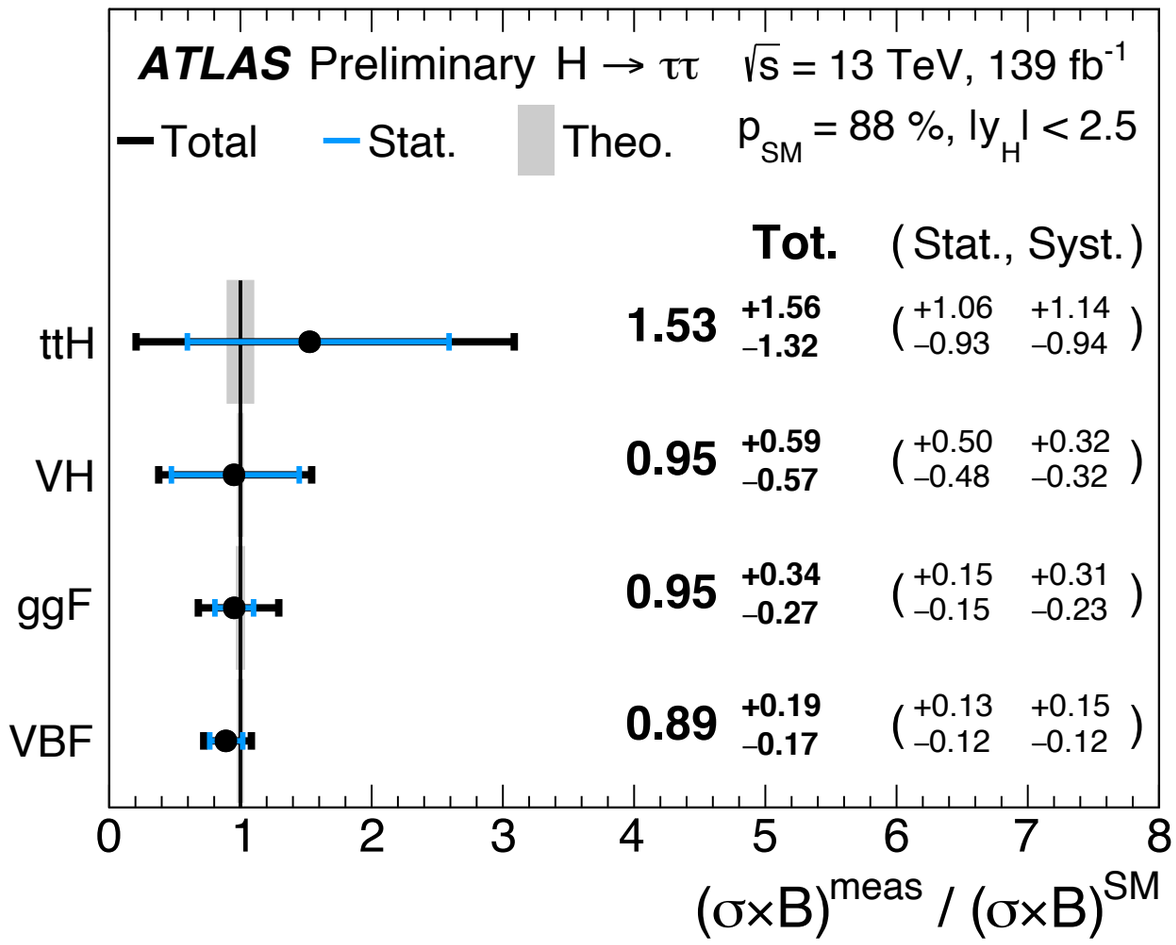
μ_{qqH} statistically limited

Process	$\sigma\mathcal{B}(\mathrm{H} \to \tau\tau)$ (fb) Measured	SM Prediction
Inclusive	2960^{+394}_{-370}	3422^{+172}_{-172}
ggH	3060^{+592}_{-552}	3051^{+160}_{-160}
qqH	$221^{+75.3}_{-73.3}$	$329^{+9.67}_{-9.67}$

ATLAS-CONF-2021-044

H → tau tau (STXS)





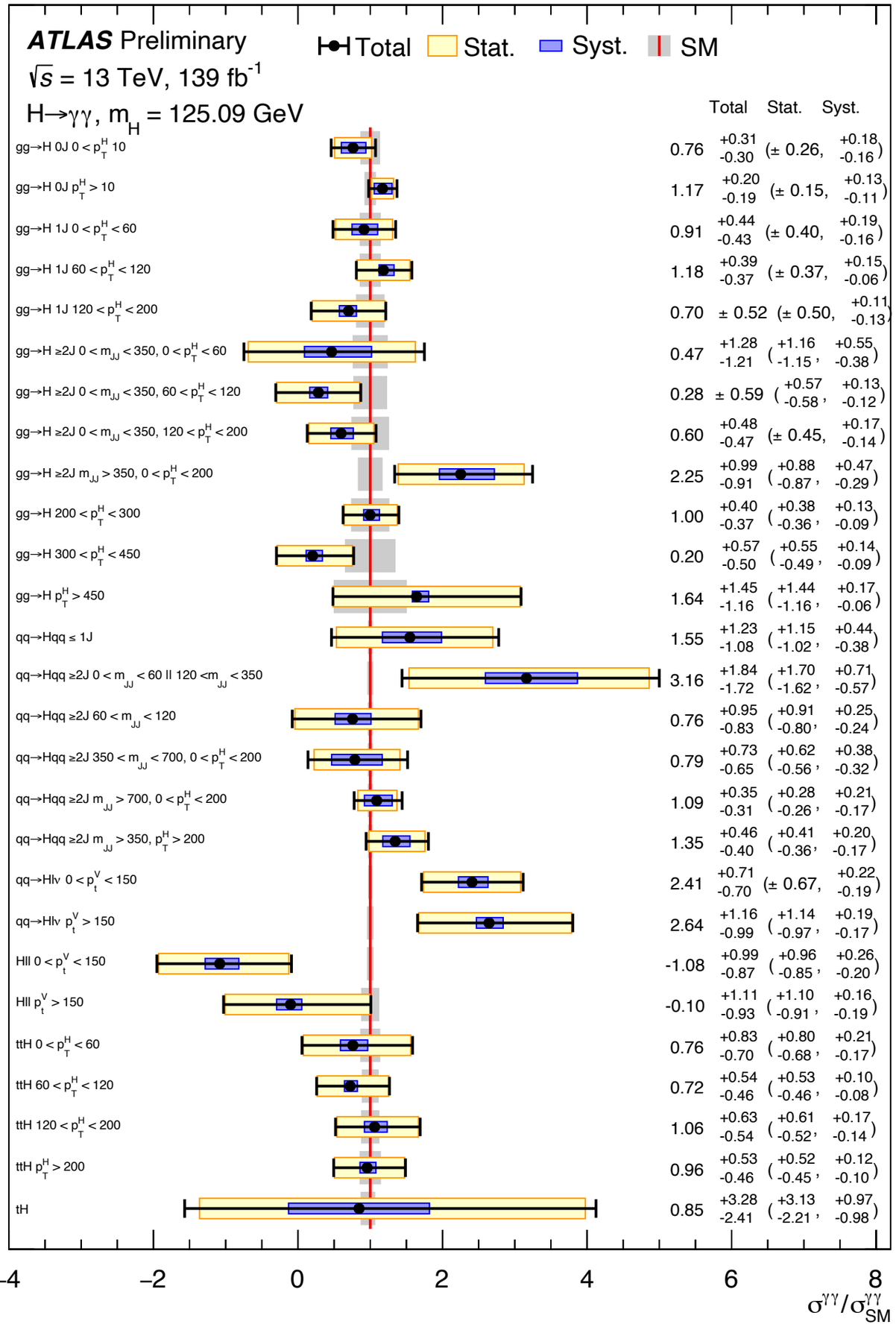
total cross section

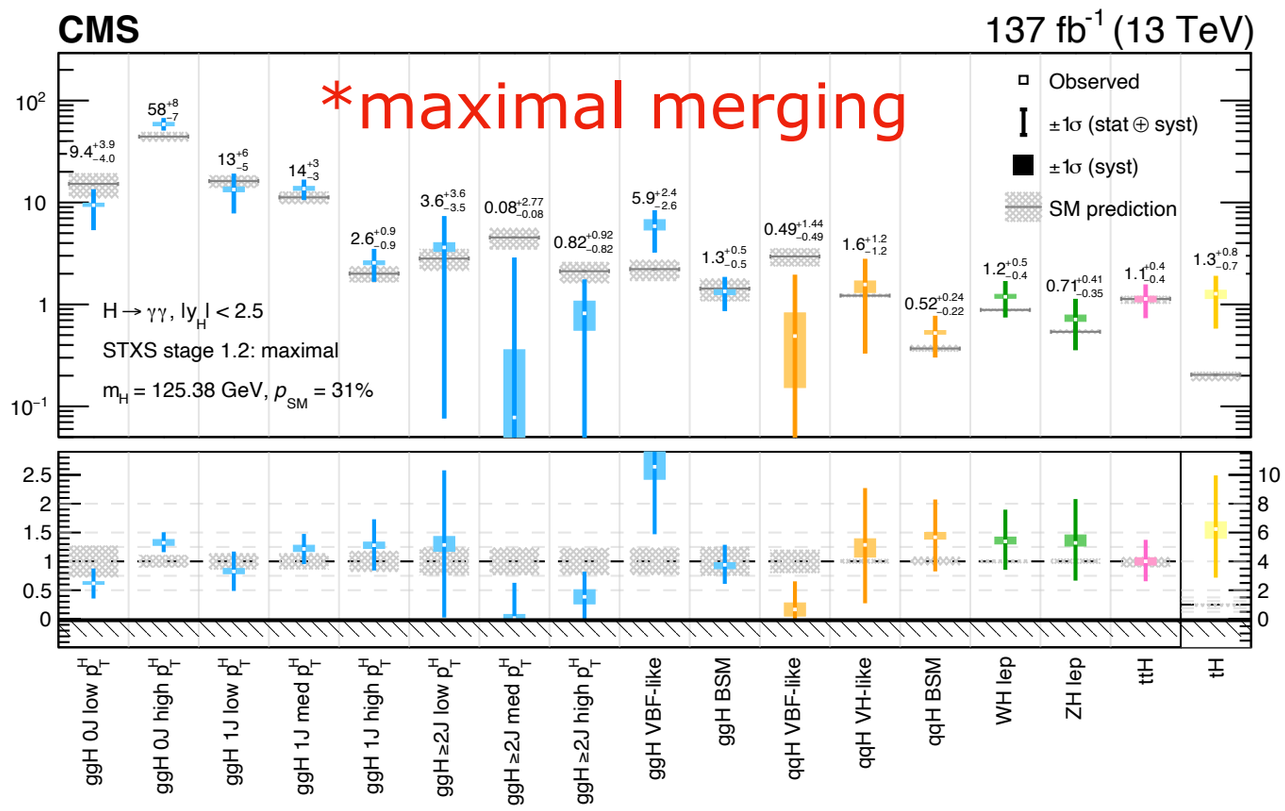
$$\sigma_{H\to\tau\tau} = 2.9 \pm 0.21(\text{stat})^{+0.37}_{-0.32}(\text{sys})\,\text{pb}$$

consistent with the CMS measurement $2960^{+394}_{-370}\,\text{fb}$

H → γγ (STXS)

ATLAS-CONF-2020-026 CMS HIG-19-015



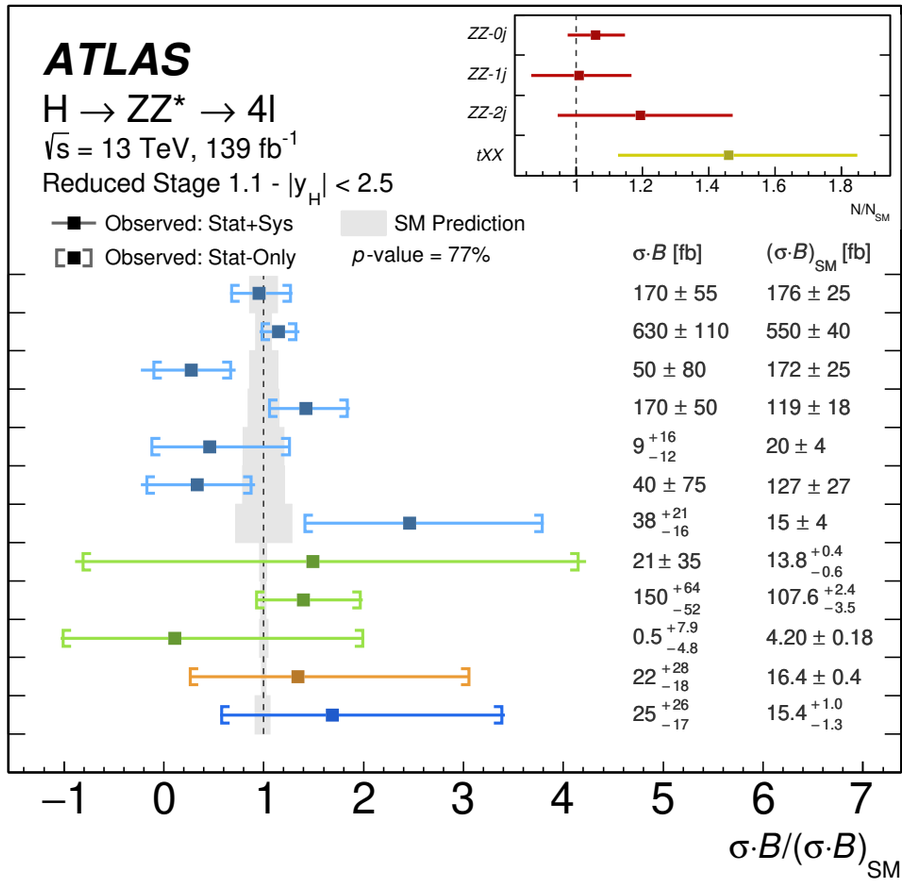


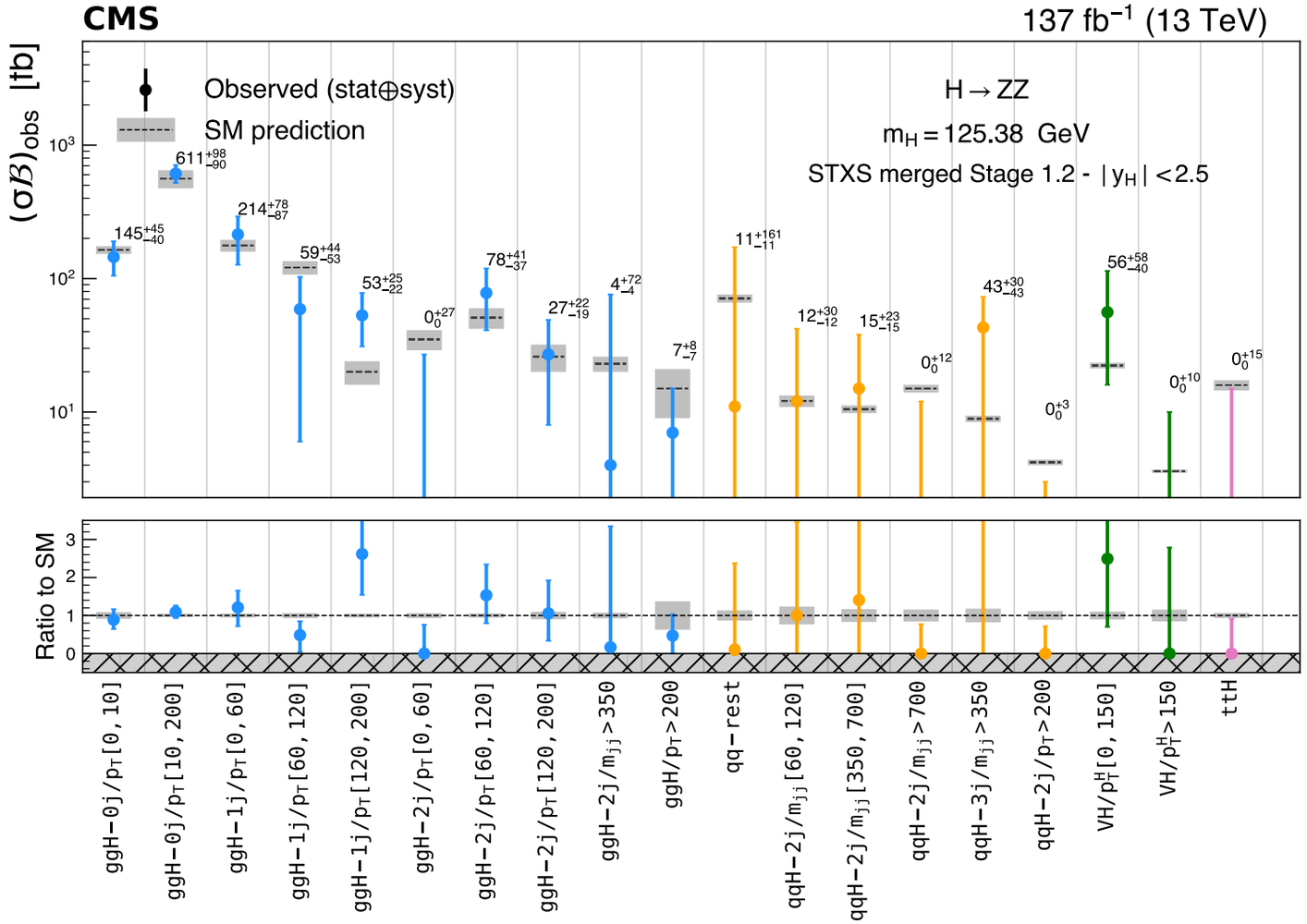
27 regions
measured in total

**bins are merged in 17 regions for this plot, (minimal merging has instead 27 regions)*

HIGG-2018-28 CMS HIG-19-001

H → ZZ (STXS)

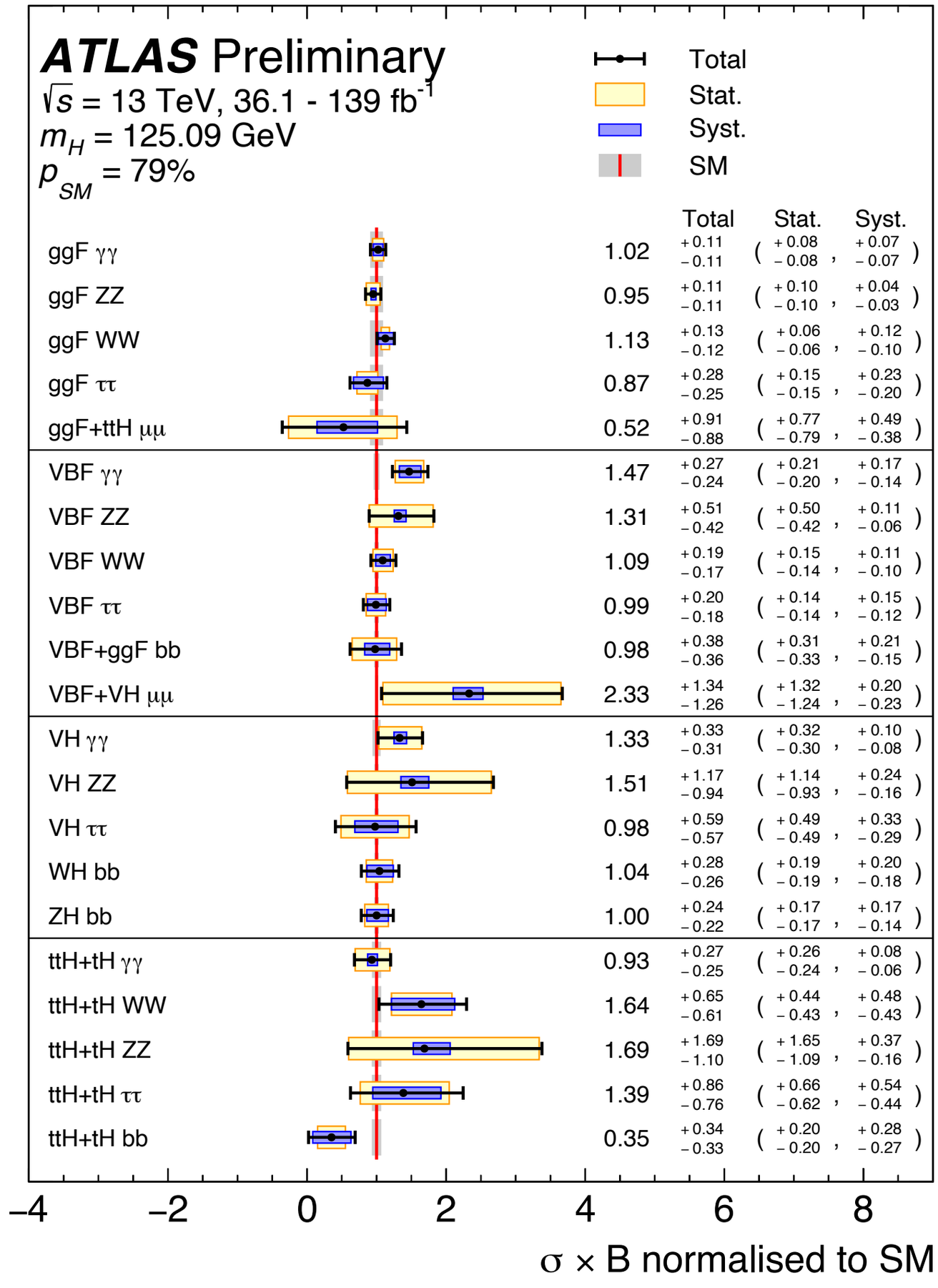




clean and statistically limited, will benefit a lot with more data

ATLAS comb

ATLAS-CONF-2021-053



likelihood level combination of all decay modes

total signal strength

$$\mu = 1.057^{+0.064}_{-0.062}$$

the new ATLAS combination has **decreased uncertainty** wrt the previous one by **~10%**

more about Higgs measurements in Giulia Di Gregorio's talk

beauty

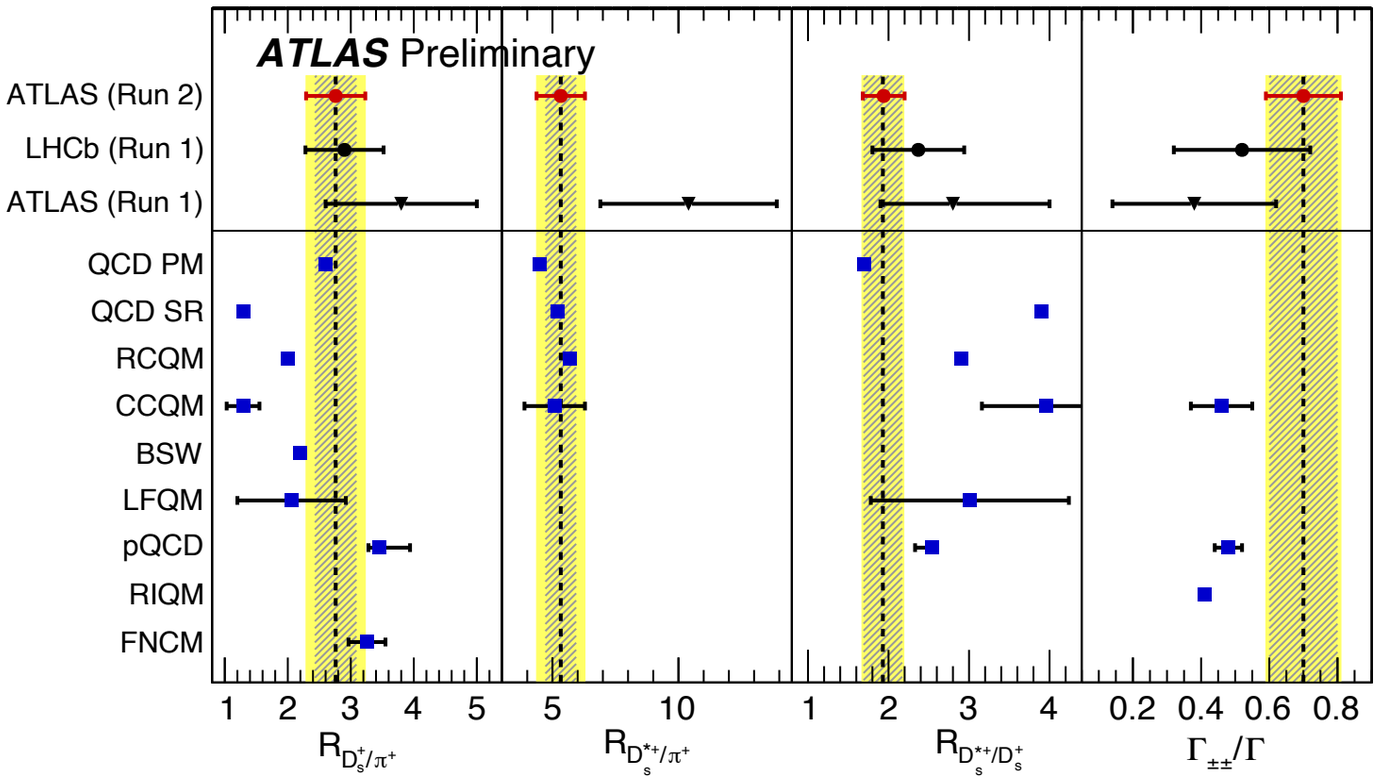
ATLAS-CONF-2021-046

precision charmed beauty

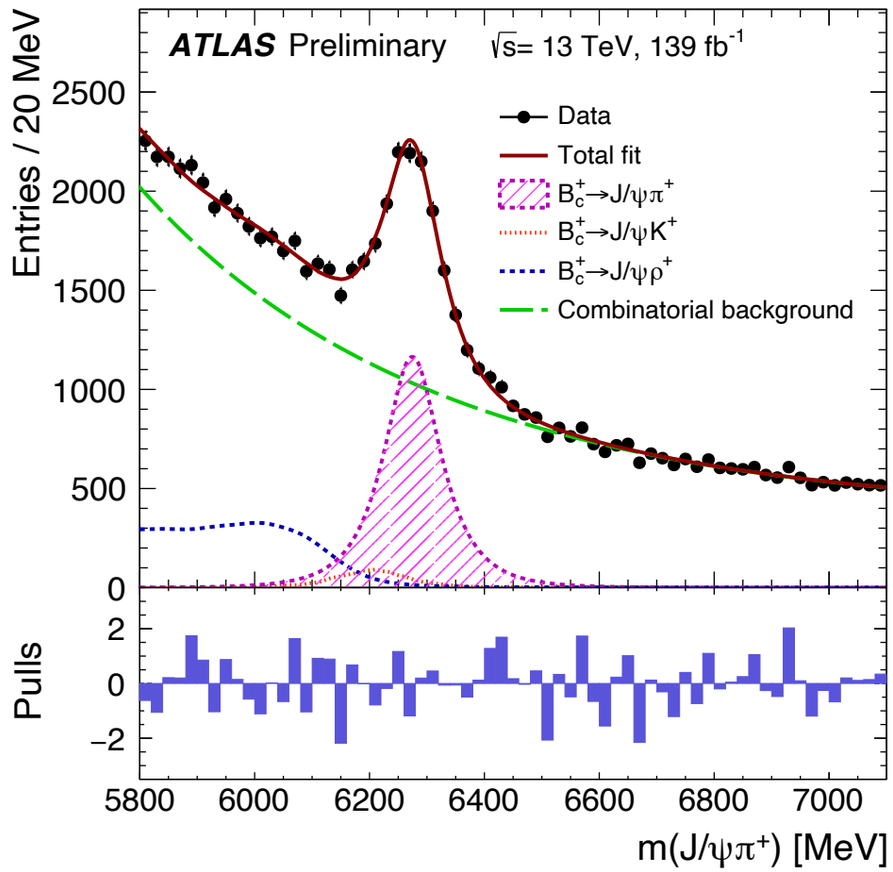
$$R_{D_s^{(*)+}/\pi^+} = \frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{(*)+})}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)}$$

J/ψ used to trigger the decay of interest $B_c^+ \to J/\psi\, D_s^{(*)+}$

$B_c^+ \to J/\psi\, \pi^+$ as reference



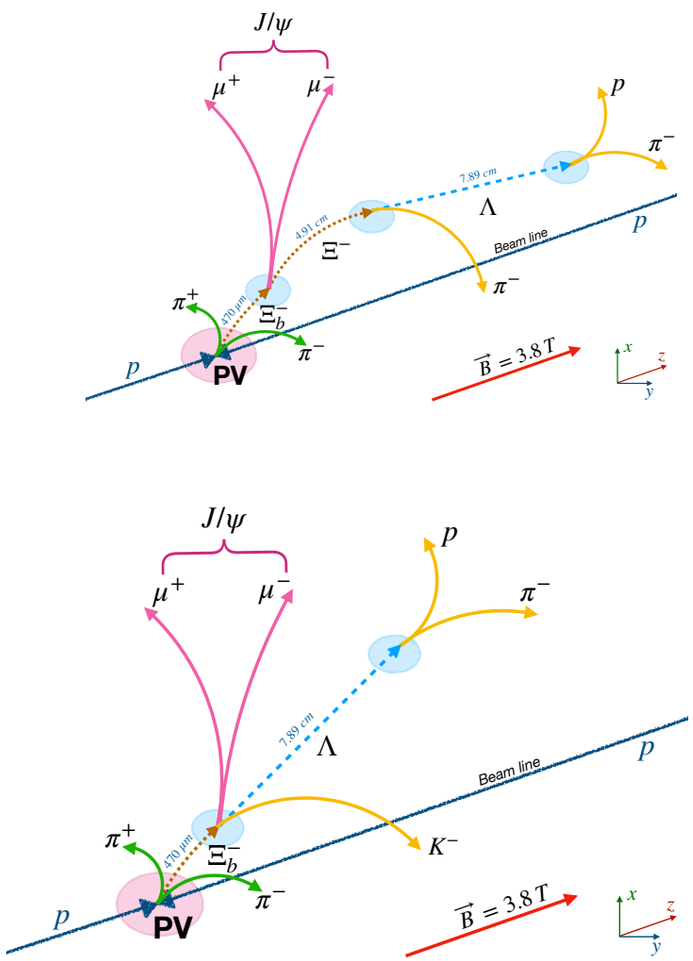
All the ratios of branching fractions are well described by the theoretical predictions



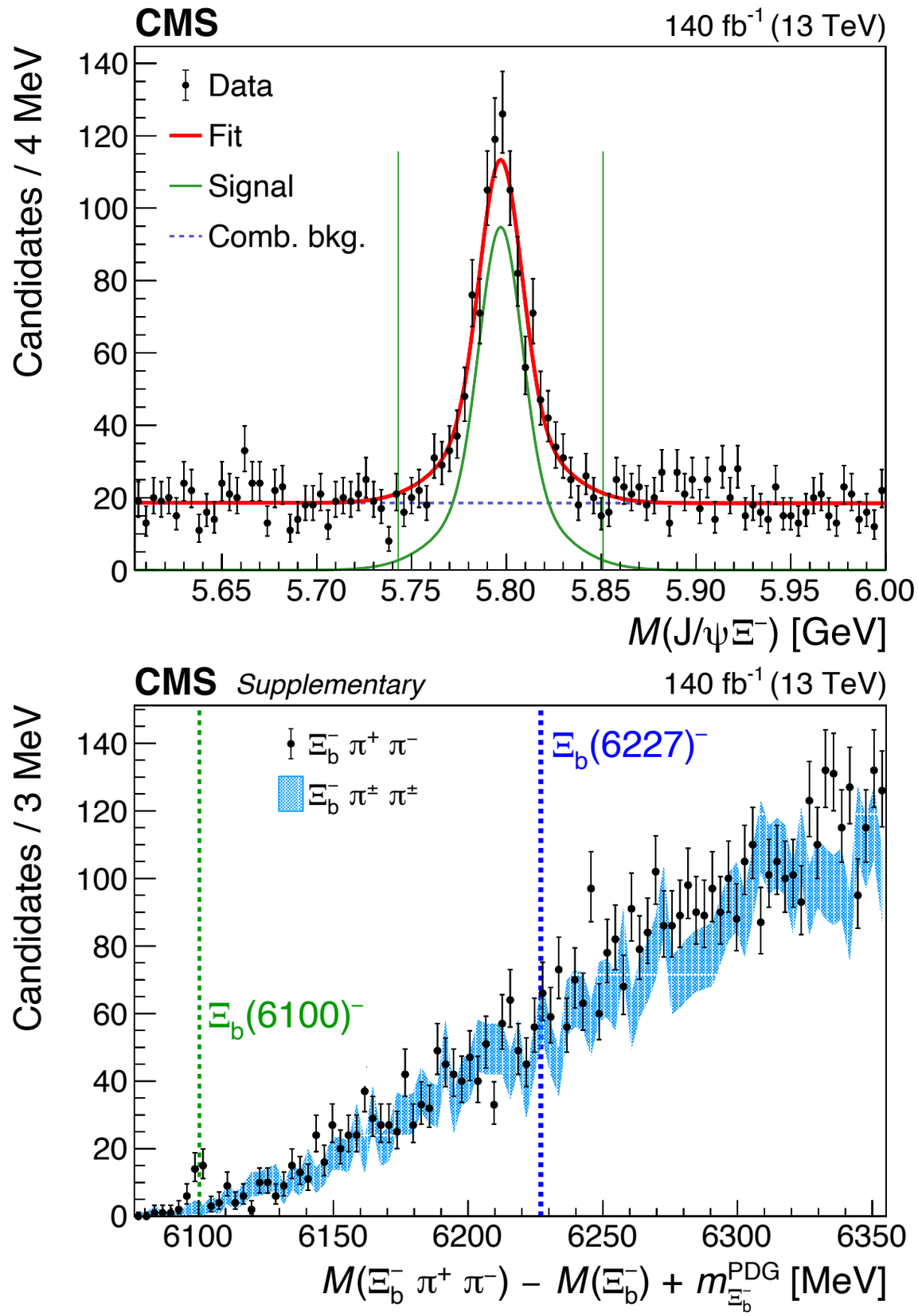
exceeds the precision of all previous measurements

CMS BPH-20-004

new kid on the block



$\Xi_b(6100)^-$



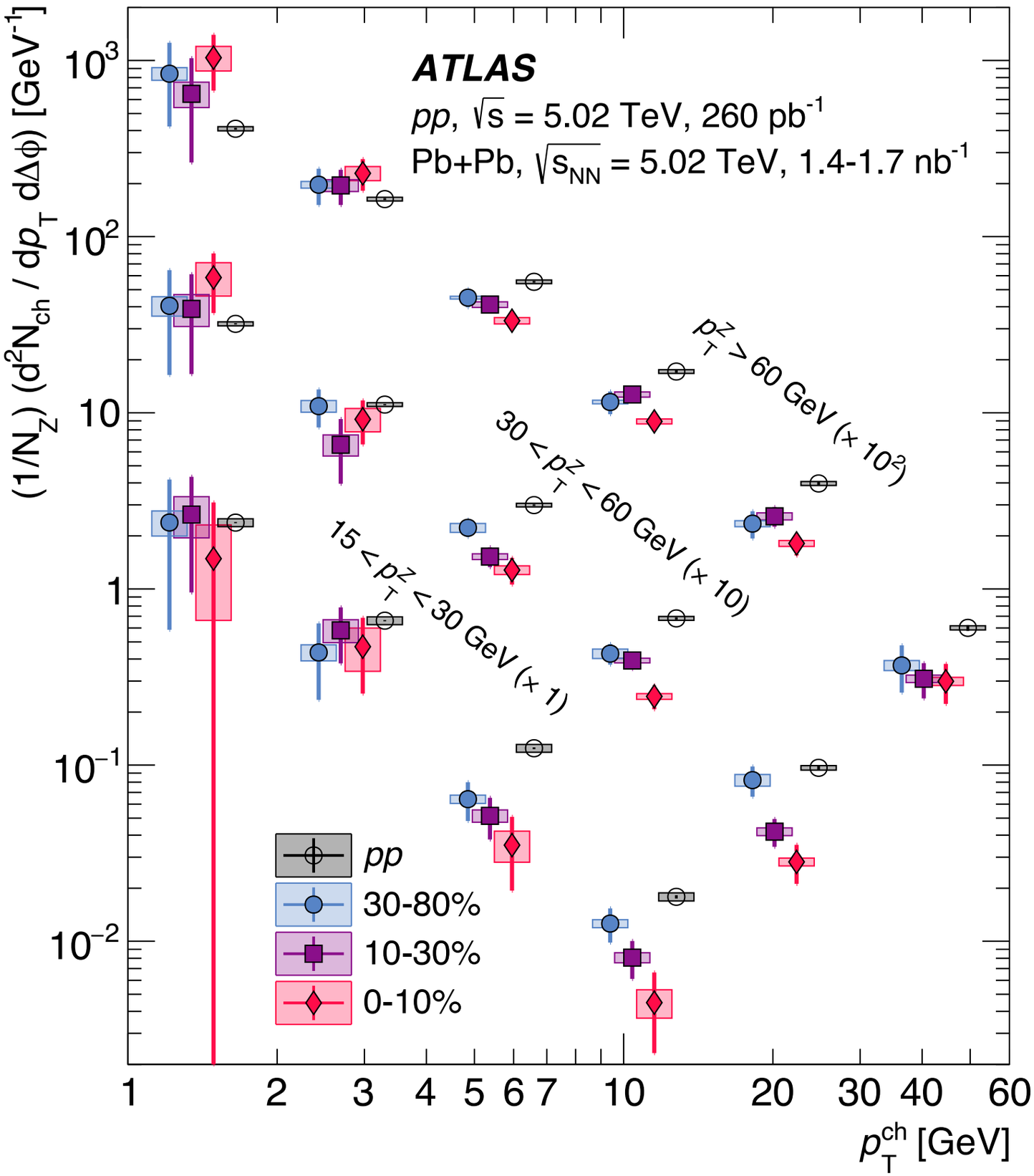
an excited beautiful strange baryon

its existence will help distinguishing among different models predicting the properties of the excited Ξ_b states

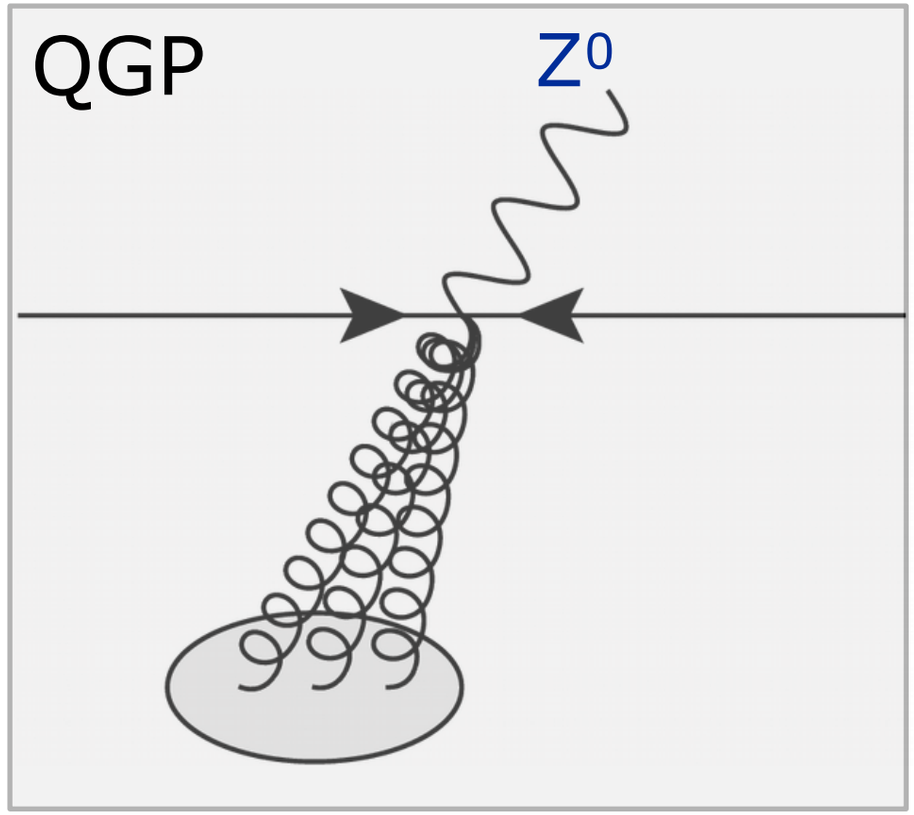
heavy ions

ATLAS PRL 126 (2021) 072301

Z+jet



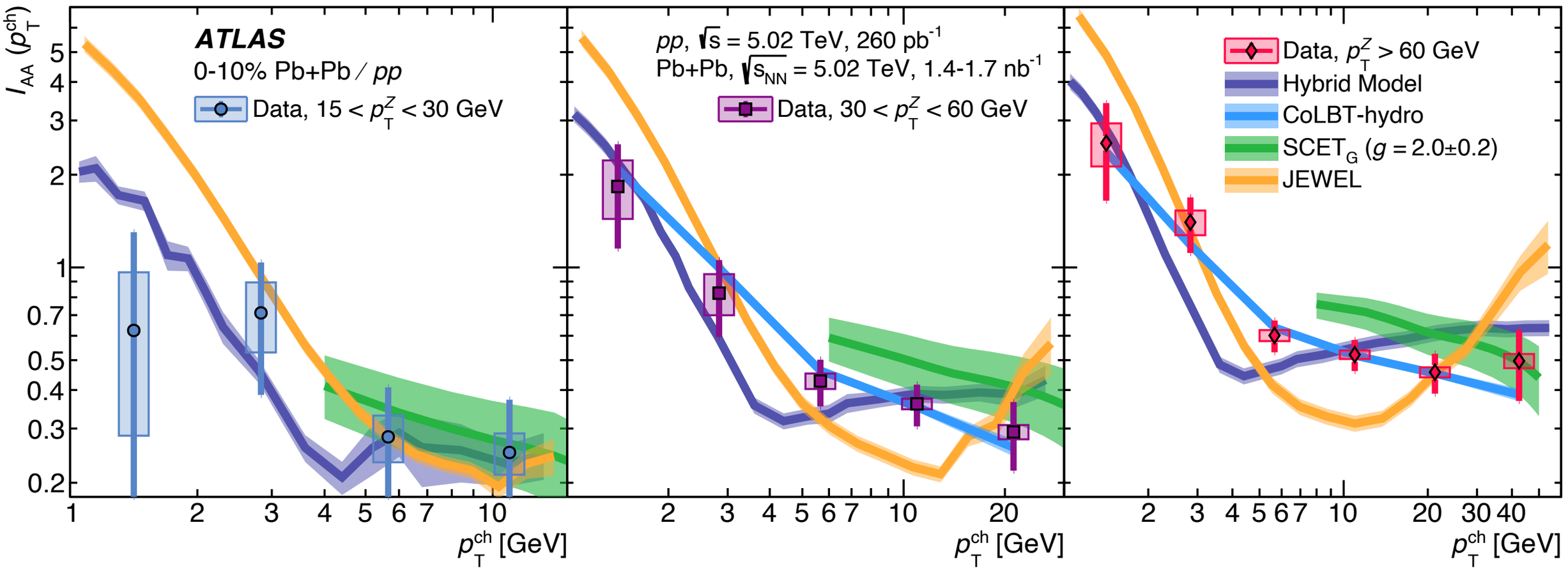
the "medium" is transparent for the colorless Z^0 but not for its hadronic recoil



$p_T(Z^0)$ is unaffected by the medium and informs us about the scale of the hadronic recoil

ATLAS PRL 126 (2021) 072301

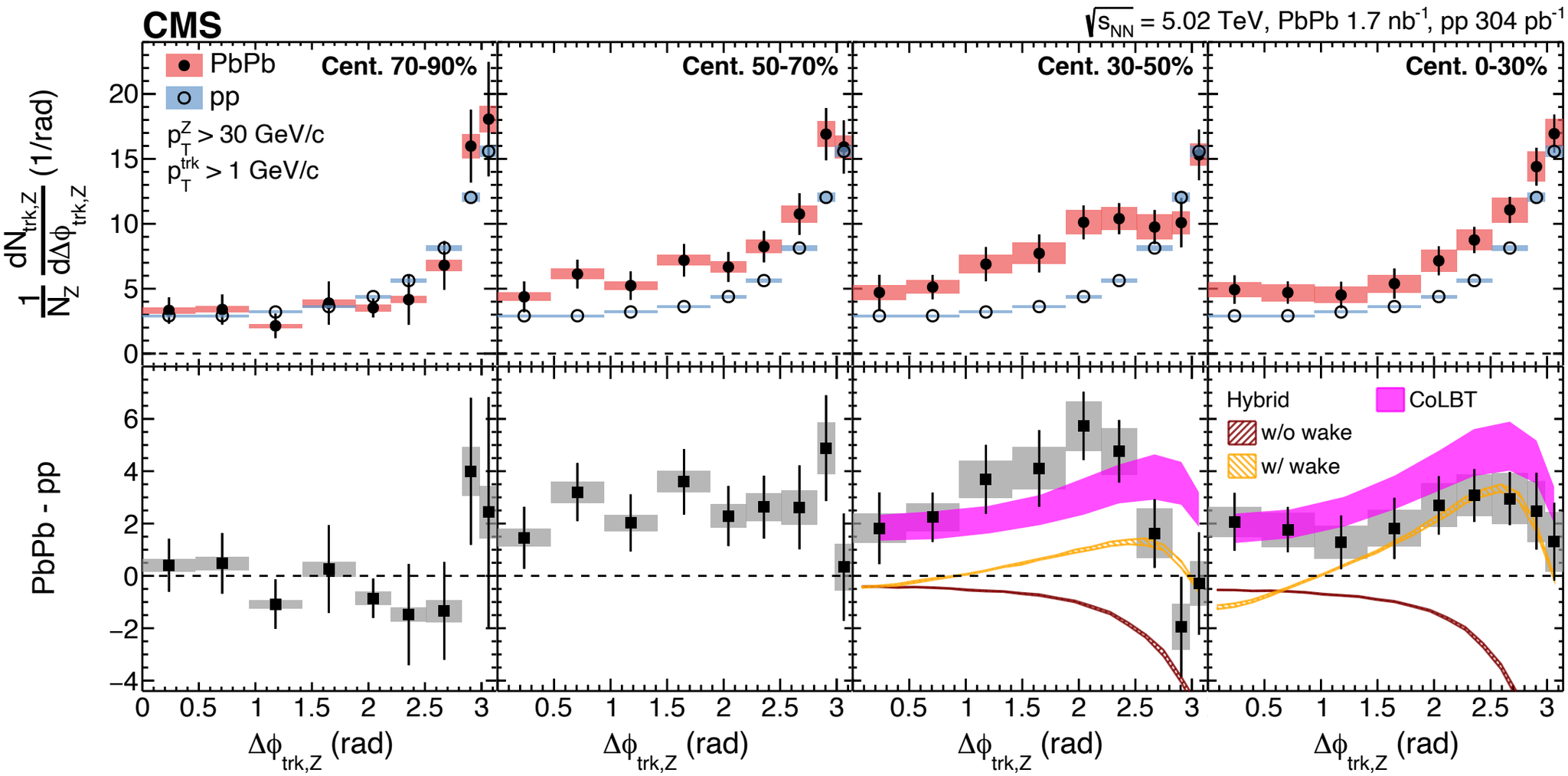
Z+jet



ratio of particle yields between Pb+Pb and pp collisions (I_{AA})

CMS CERN-EP-2021-014 (submitted on 07.03.2021 to PRL)

Z+jet



azimuthal decorrelations and p_T^{trk} losses (not show here) consistent with the hypothesis that the "hard" parton loses energy (i.e., jet quenching) and/or the medium induces modification of the parton shower.

Summary

Interesting physics with **heavy ion data** and decays of **B-hadrons**, from the **two general purpose detectors** @ LHC.

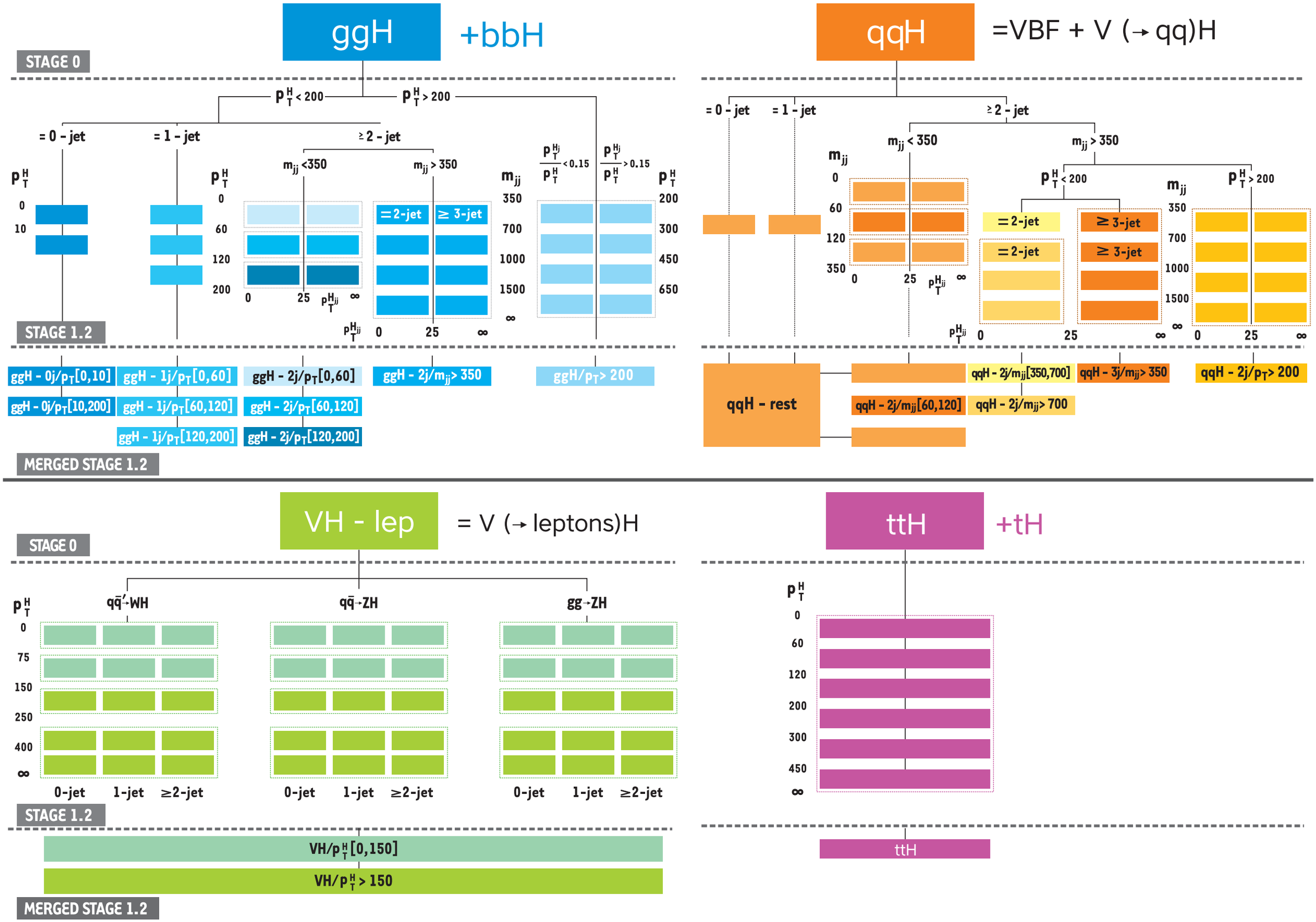
In the realm of the **standard model, top & higgs** many new results in 2021, more precision is desirable.

For each **~10% improvement in precision**, we have to make non trivial advancements in the analyses.

In all shown, the role of **accurate MCs** for designing better analyses (S/B) and for interpreting the results is indispensable.

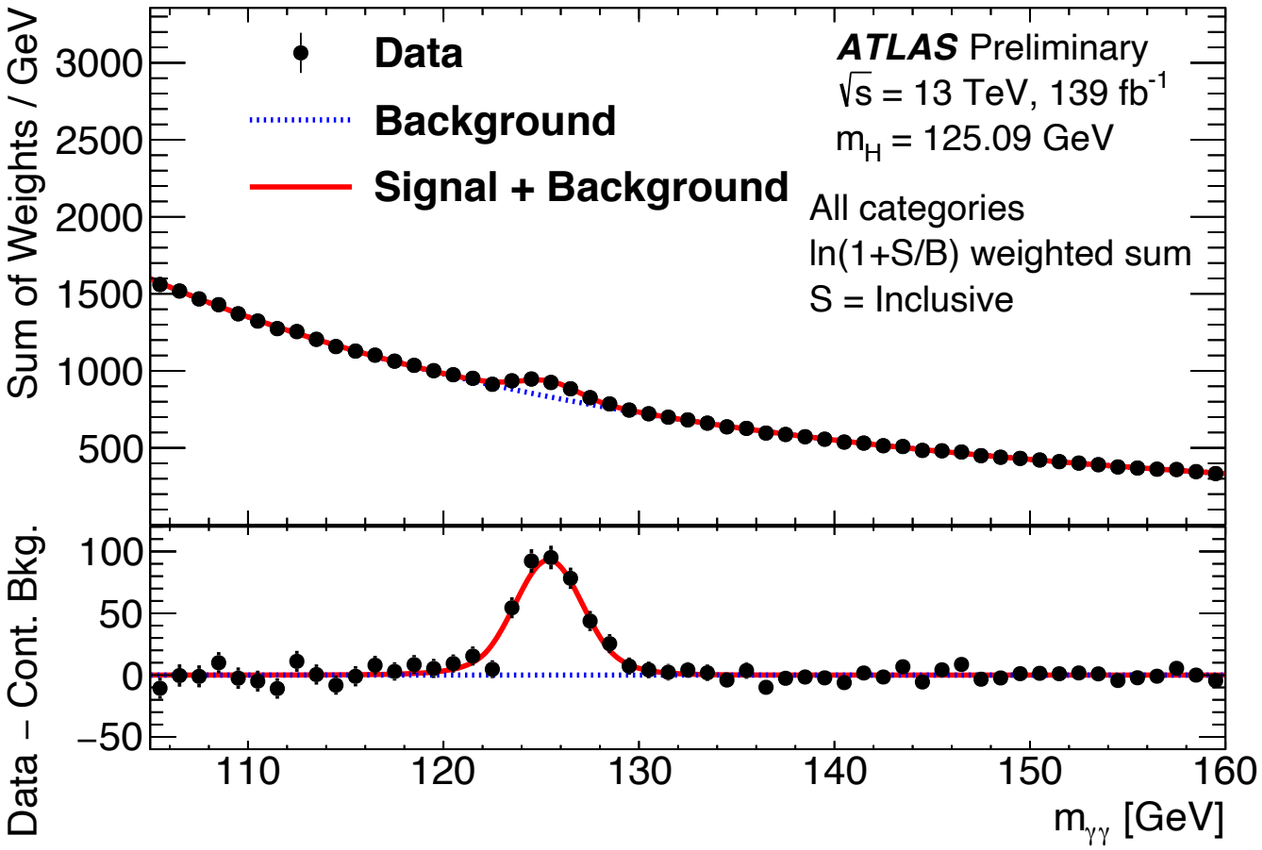
BACKUP

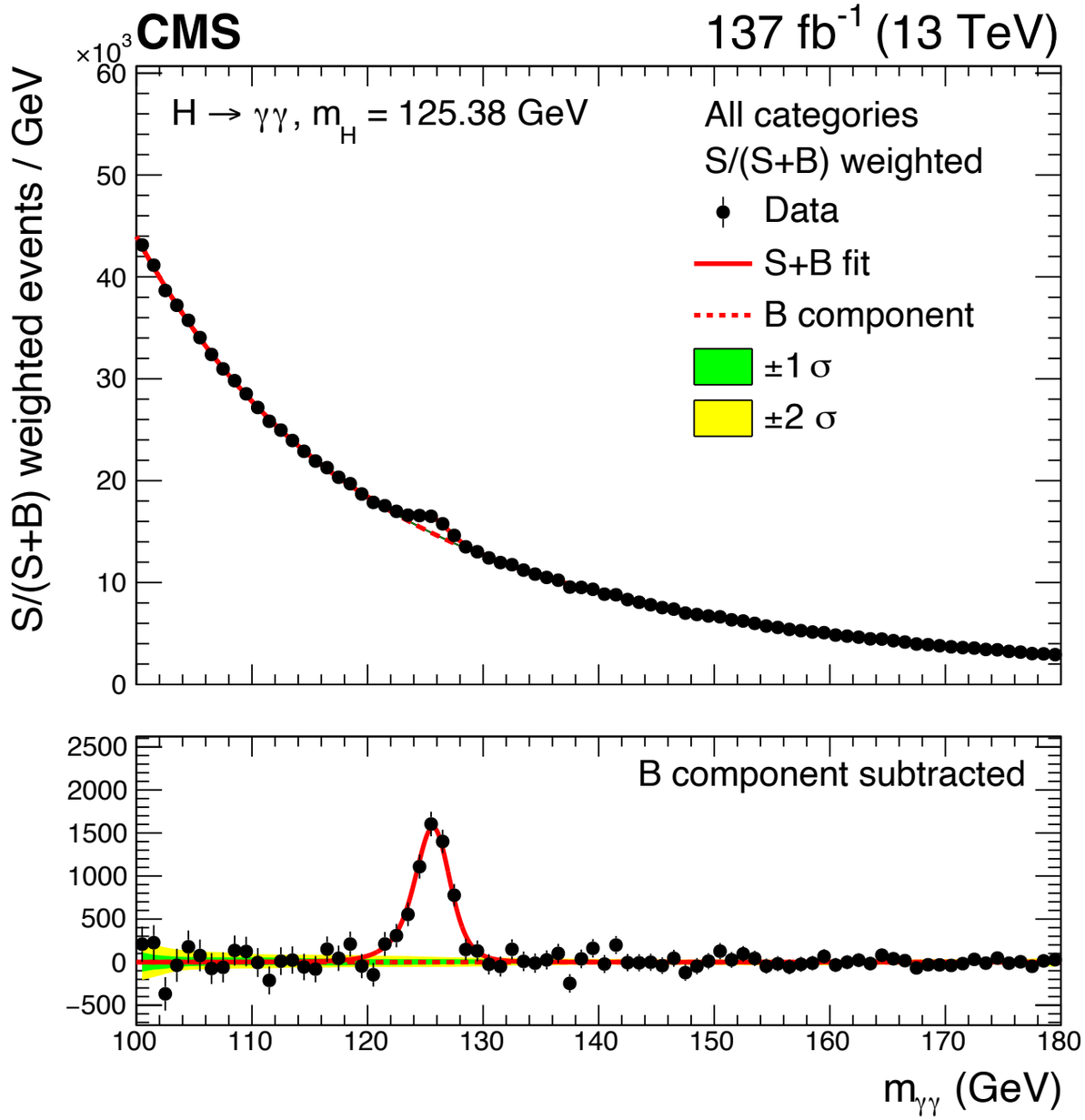
CMS HIG-19-001



ATLAS-CONF-2020-026 CMS HIG-19-015

H → γγ (STXS)





HIGG-2018-28 CMS HIG-19-001

H → ZZ (STXS)