



LHC^{TOP}WG

24th LHC^{top}WG Open Meeting

November 29 - December 1, 2023

Virtual Edition

Introduction

**Welcome to the second
open session of 2023!**



BERGISCHE
UNIVERSITÄT
WUPPERTAL

UCLouvain



Fabio Maltoni (Louvain/Bologna)
Wolfgang Wagner (Wuppertal)
Maria Aldaya (DESY)

LHCtopWG and its mission

Forum for discussions between experiment and theory on combination and interpretation of top physics measurements at the LHC – since 2012

- Provide combinations of LHC top physics results
 - Reach highest precision and provide a unified experimental answer to the theory community
 - Compare results in a coherent way and understand possible differences
- ⇒ Requires detailed understanding of analysis methodologies, theoretical models used, categories of systematic uncertainties & correlations
- Provide recommendations and guidelines
 - Reference cross sections as common basis for measurements
 - Harmonize prescriptions to facilitate comparisons and combinations
- Provide summary plots of experimental results in comparison to theory predictions
- Ample discussion between experimental and theory communities
 - Open Meetings twice a year and on-demand seminars
 - Monthly closed meetings (conveners + contacts + invited experts on specific topics) to discuss experimental details

Documentation and coordinates

- Integrated in the LPCC structure at CERN:
<http://lpcc.web.cern.ch/lhc-working-groups>
- Public twiki: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCtopWG>
- Public summary plots:
<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCtopWGSummaryPlots>
- Agendas: <https://indico.cern.ch/categoryDisplay.py?categId=4463>
- Main open mailing list: lhc-toplhwcg@cern.ch

Subscribe

LHC^{TOP}WG contacts

- **Theory:** Fabio Maltoni
- **ATLAS:** Wolfgang Wagner
- **CMS:** Maria Aldaya
- **LHCb:** Katharina Mueller



Contacts for ongoing combinations / working groups:

- **Top mass:** Mark Owen (ATLAS), Martijn Mulders & Matteo Defranchis (CMS)
- **EFT:** Baptiste Ravina (ATLAS), Kirill Skovpen (CMS)
- **Common MC:** Michael Fenton, Dominic Hirschi, & Reinhard Schwienhorst (ATLAS), Giulia Negro, Markus Seidel, & Andris Potrebko (CMS)
- **$\Delta\phi$ (II) spin correlation:** Miriam Watson & James Howarth (ATLAS), Andy Jung, Giulia Negro & Afiq Anuar (CMS)
- **Harmonization of modelling uncertainties:** Andrea Knue & Dominic Hirschi (ATLAS), Efe Yazgan & Enrique Palencia (CMS)
- **Global EFT effort within the LHC EFT WG** (<https://lpsc.web.cern.ch/lhc-eft-wg>): Jacob Kempster (ATLAS), Robert Schoefbeck (CMS), Ken Mimasu (Theory)

Also contacts for dedicated topics as needed

(summary plots, theoretical calculations, JES, b-tagging, generators, etc)

Ongoing combinations and other efforts

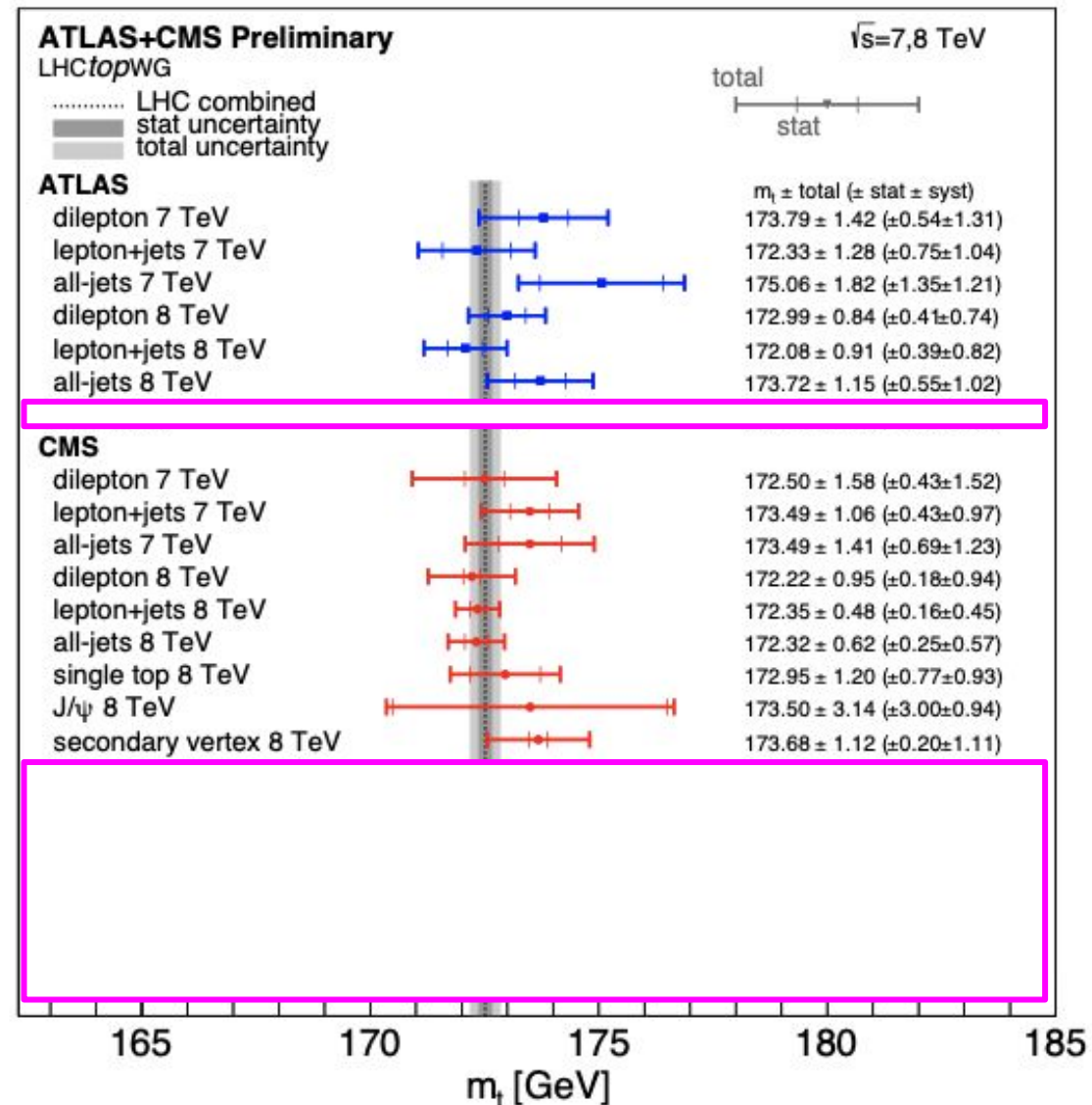
- **Published “Run-1 Legacy”** tt inclusive cross section at 7 & 8 TeV + extraction top pole mass and α_c (Veronique Boisvert (ATLAS), Jan Kieseler (CMS)):
[JHEP 07 \(2023\) 213](#), [arXiv:2205.13830 \[hep-ex\]](#) 
- **“Run-1 legacy” top mass combination:** [preliminary result](#) released for **TOP2023**, 
paper in final stages of review before submission – **next slide**
- Ongoing combinations under review within the collaborations:
 - **EFT combination at 13 TeV** – **update today!**
 - **$\Delta\phi(\text{ll})$ spin correlation combination at 13 TeV:** finalizing writing the documentation
- Other efforts for upcoming Run-2 & Run-3 combinations and comparisons
 - **Common tt MC settings for ATLAS and CMS:** latest studies from June 2023 ([CMS](#), [ATLAS](#))
 - **Harmonization of systematic uncertainties:** started with ME and PS sources in tt
 - **Updating theory reference cross sections:** started with single top and tt, other processes soon to follow

LHC Run-1 top quark mass combination

[CMS-PAS-TOP-22-001](#), [ATLAS-CONF-2023-066](#), CERN-LPCC-2023-02

Mark Owen (ATLAS); Steve Wimpenny[†],
Martijn Mulders & Matteo Defranchis (CMS)

- BLUE combination of 15 input top mass measurements from “top quark decays”
- from ATLAS and CMS
 - Profit from most precise results and those with different sensitivity to systematics
- Detailed mapping of systematic uncertainties (25 categories!) and assumed correlations
 - Both intra- and inter-experiment
- Extensive stability checks to test effect of correlation assumptions



LHC Run-1 top quark mass combination

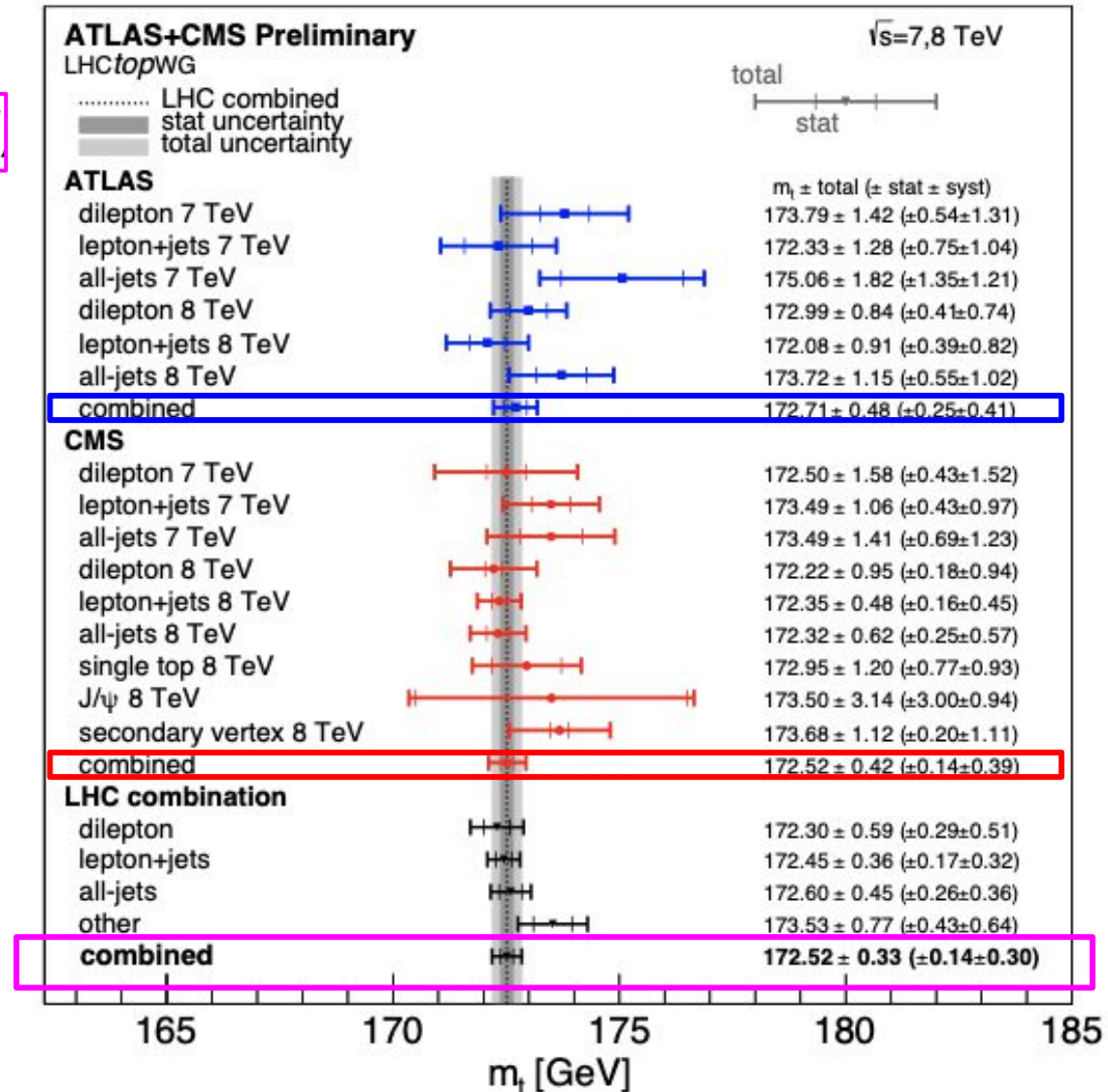
[CMS-PAS-TOP-22-001](#), [ATLAS-CONF-2023-066](#), CERN-LPCC-2023-02

Mark Owen (ATLAS); Steve Wimpenny[†],
Martijn Mulders & Matteo Defranchis (CMS)

- Combination:

$$m_t = 172.52 \pm 0.14 \text{ (stat)} \pm 0.30 \text{ (syst)} \text{ GeV}$$

- Total uncertainty of 0.33 GeV
 - Most precise result to-date
- 30% improvement over most precise individual result
- Excellent compatibility among inputs
- Limited sensitivity to correlation assumptions
- Main systematics: JES, b-tagging, top modelling

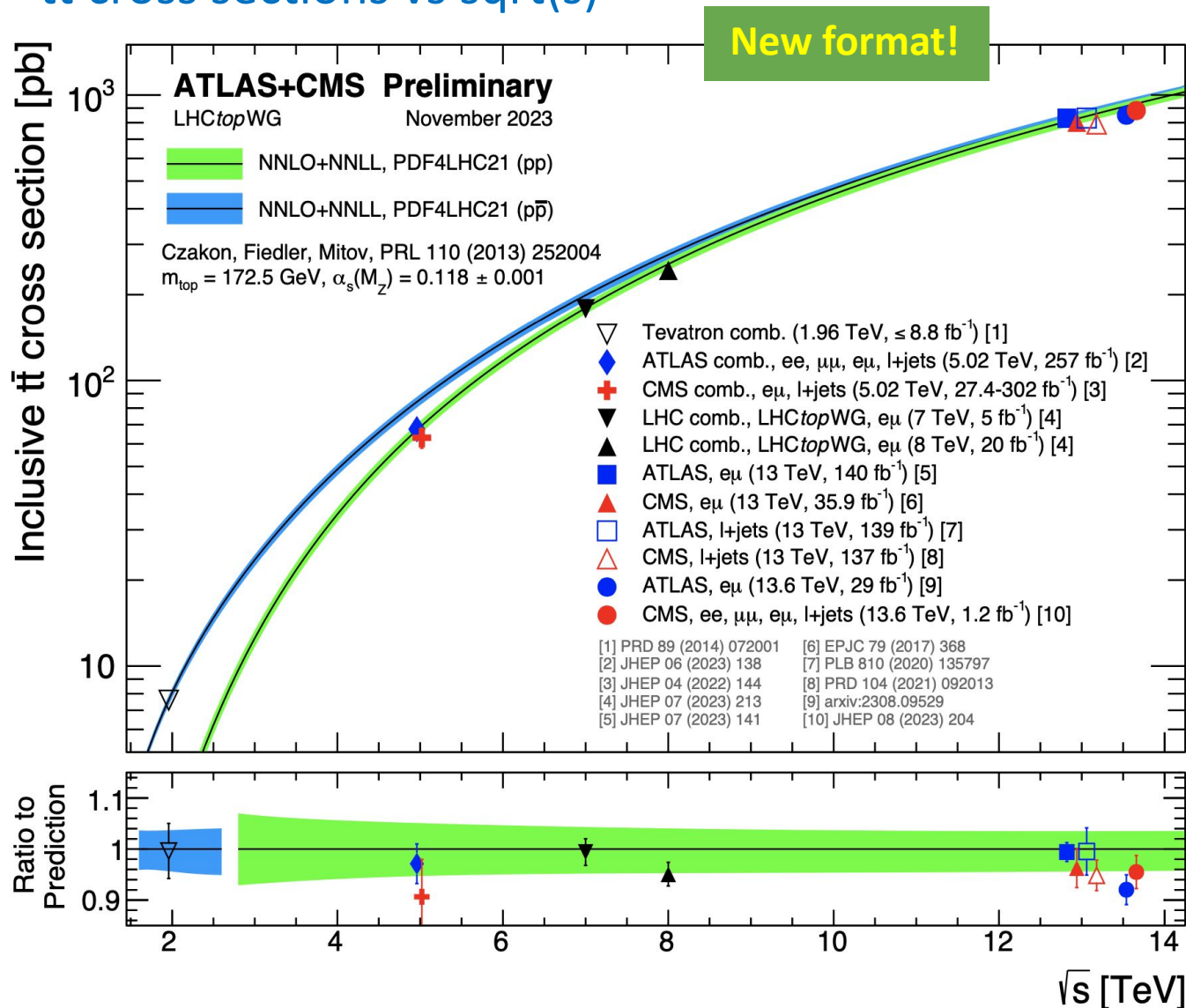


Summary plots

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots> (*)

Newly added/updated results & predictions since last Open Meeting and other updates – more than 30 plots, showcasing some examples only(**):

tt cross sections vs sqrt(s)

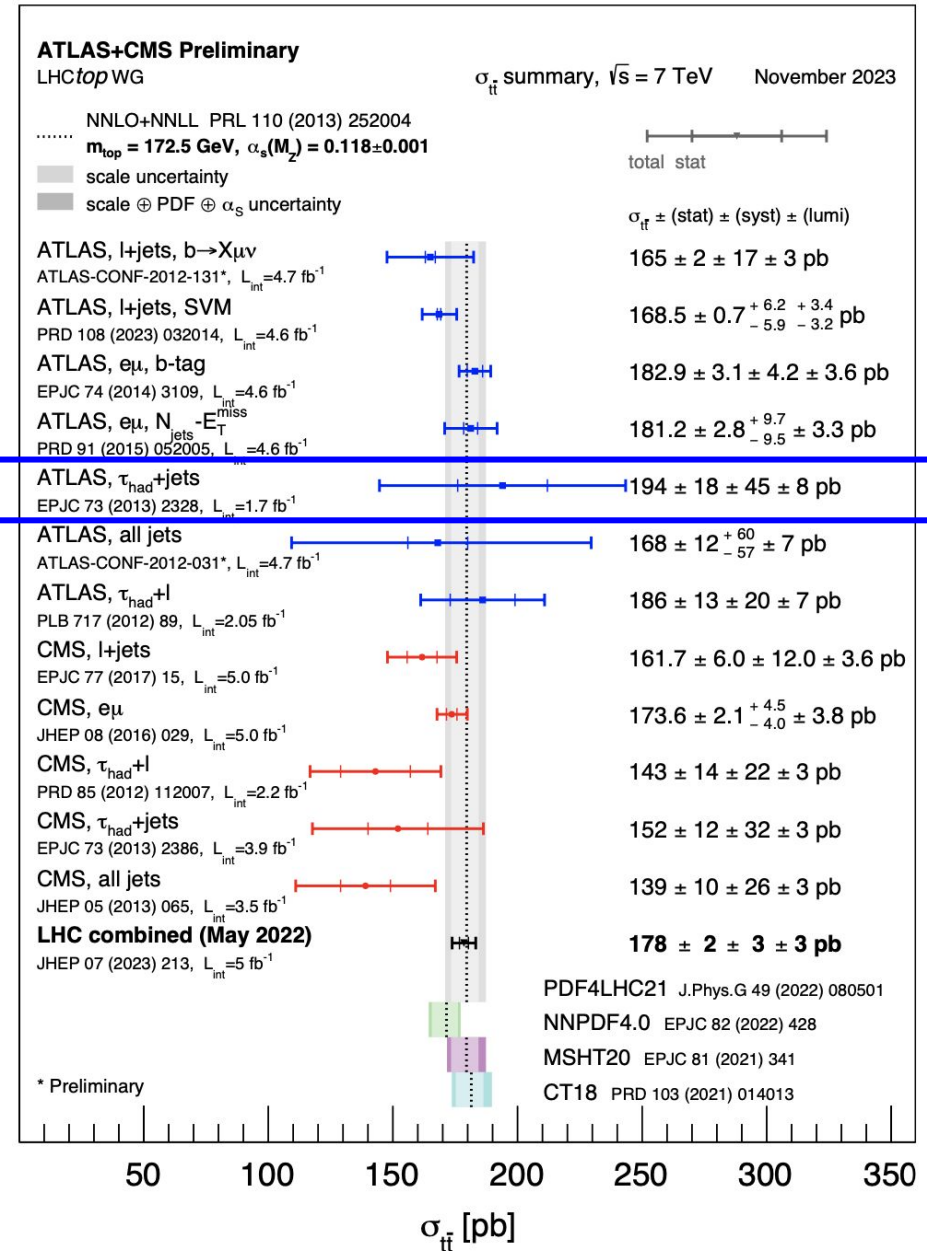
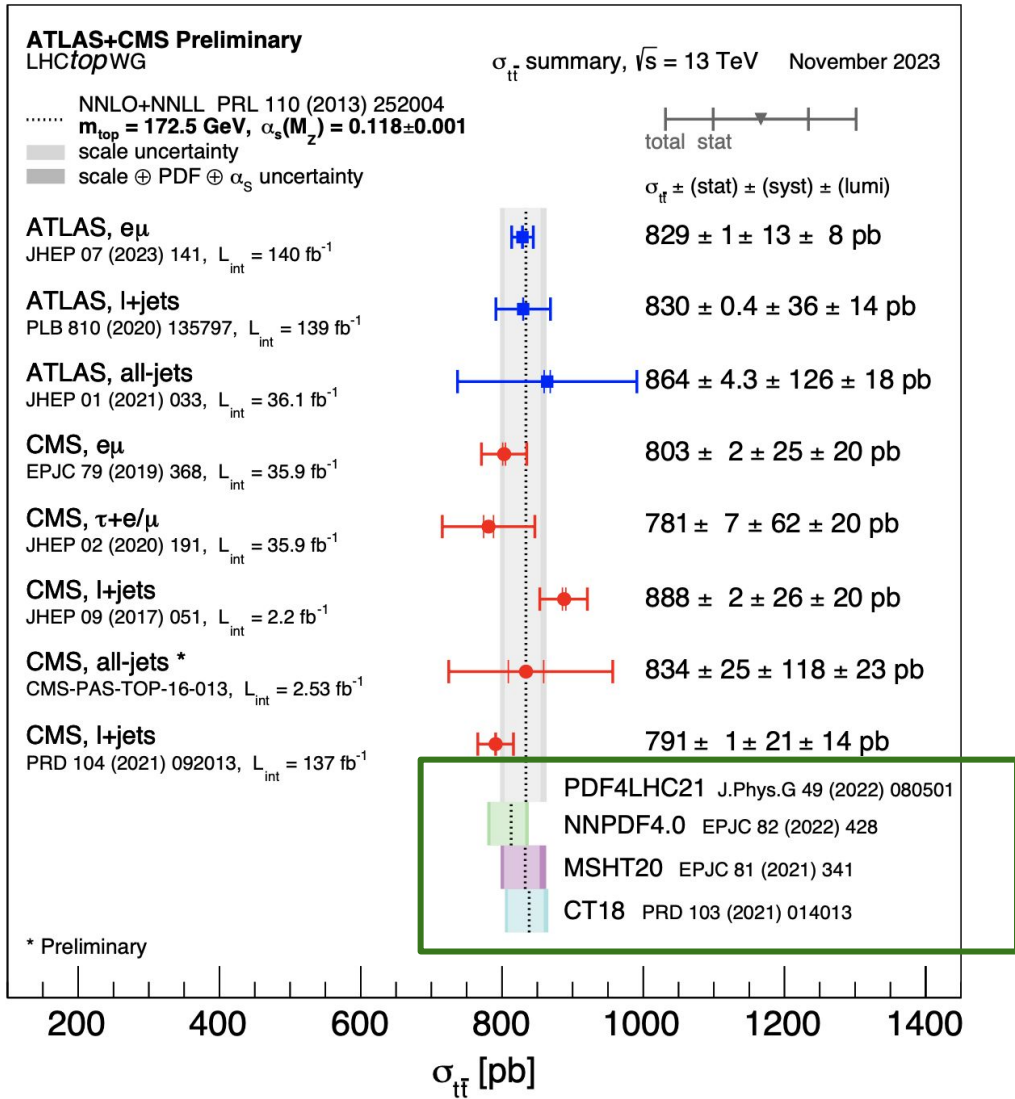


- Improved overall readability:
 - added ratio-to-predictions panel
 - removed inset for 13 and 13.6 TeV
- Added references for all results
- Updated PDF set for ppbar theory prediction

(*) All updated plots will be added to the twiki shortly

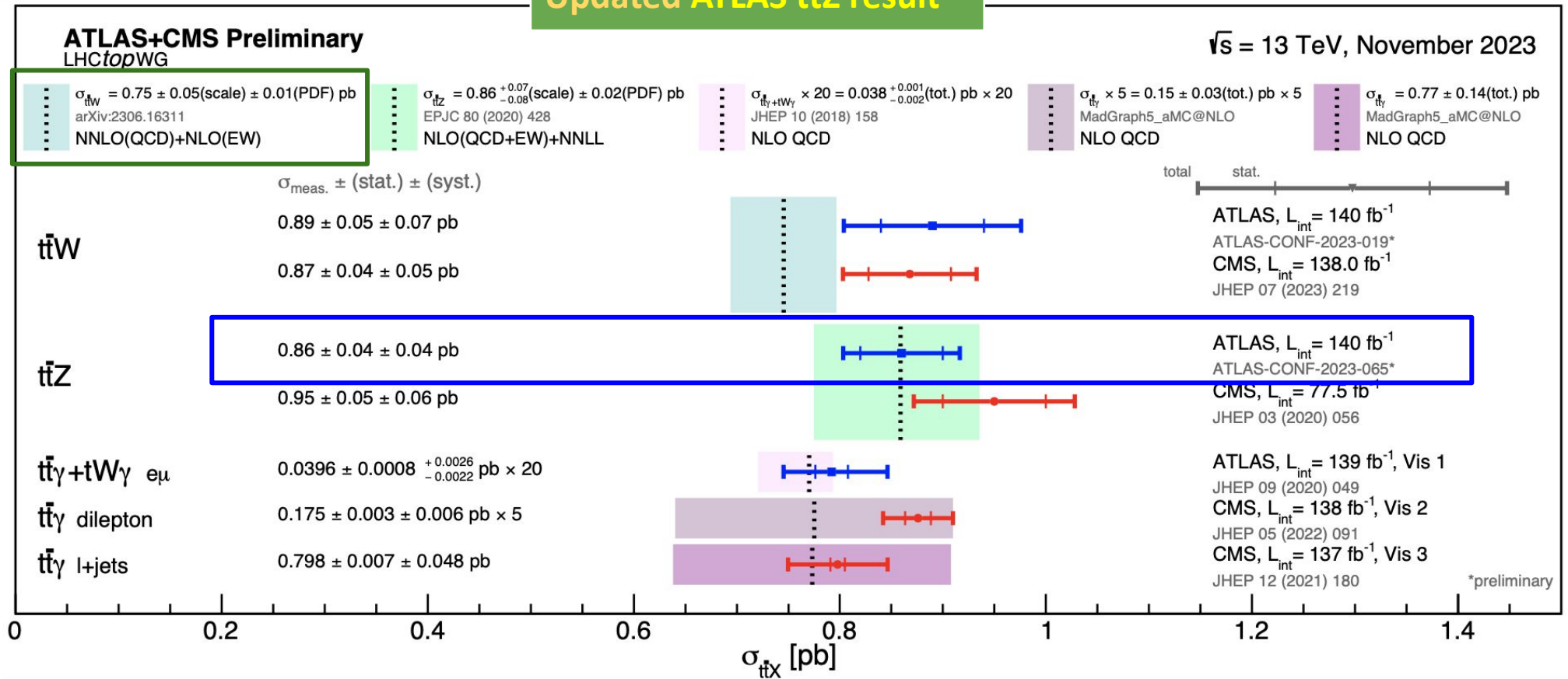
(**) FCNC plots in Daniel's talk today
Top EFT limit plots in Kirill's talk today

tt cross sections



- Added comparison to theory predictions using various recent PDF sets
- Updated references, sync'd format for presenting results where possible
- Similar updates also for plots at 8 and 5.02 TeV

Updated ATLAS ttZ result

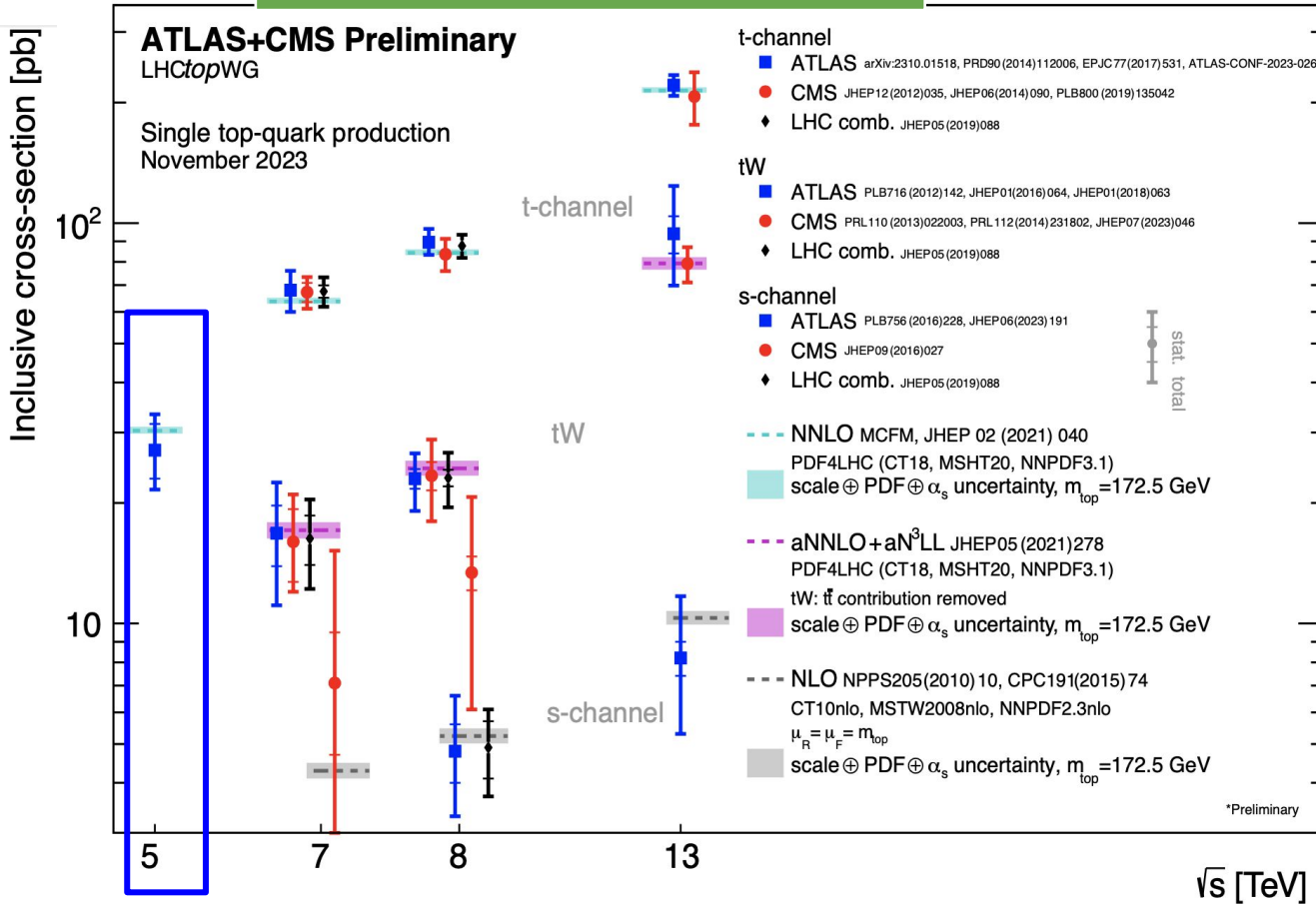


- Updated $t\bar{t}W$ theory prediction to the latest NNLO (QCD) + NLO (EW) from [arXiv:2306.16311 \[hep-ph\]](https://arxiv.org/abs/2306.16311)
- Updated references

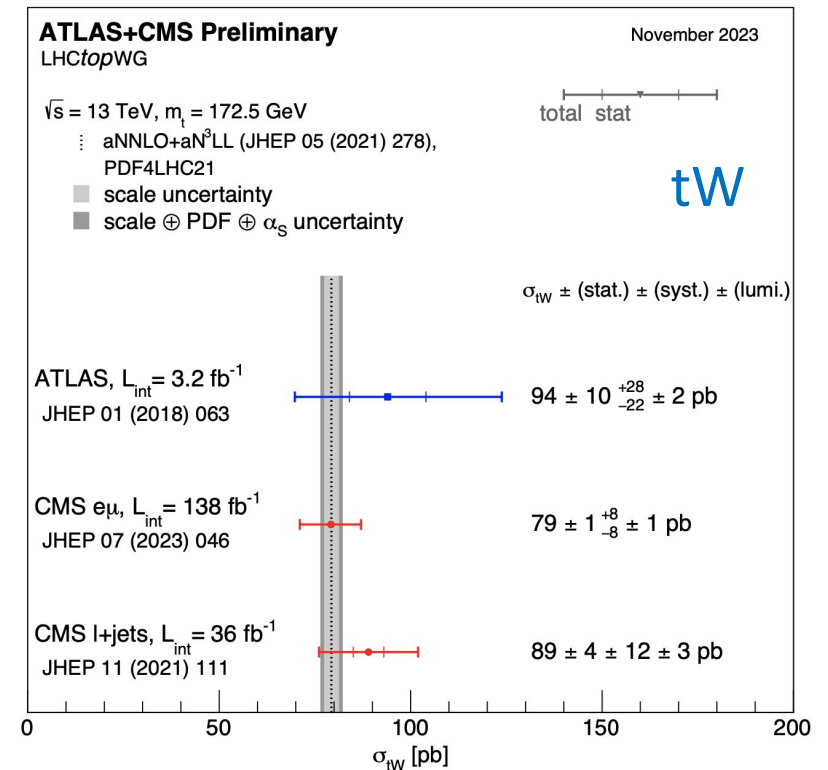
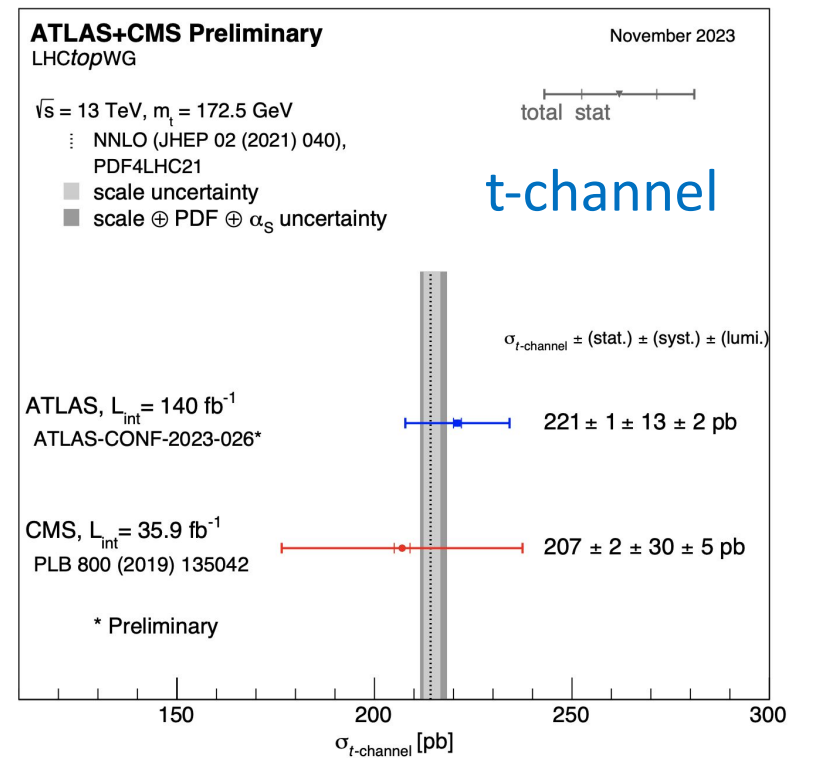
Single top production

All channels and sqrt(s)

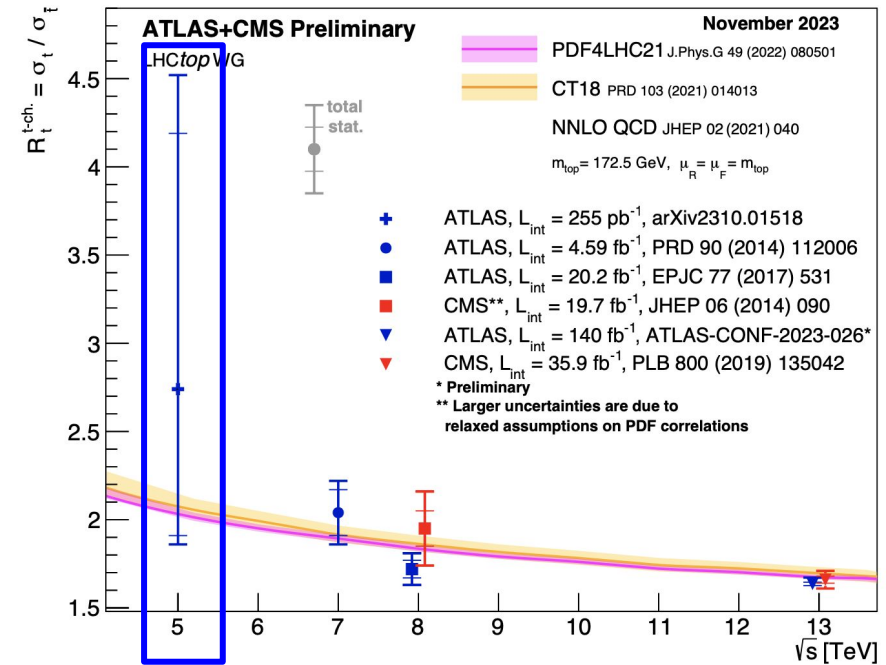
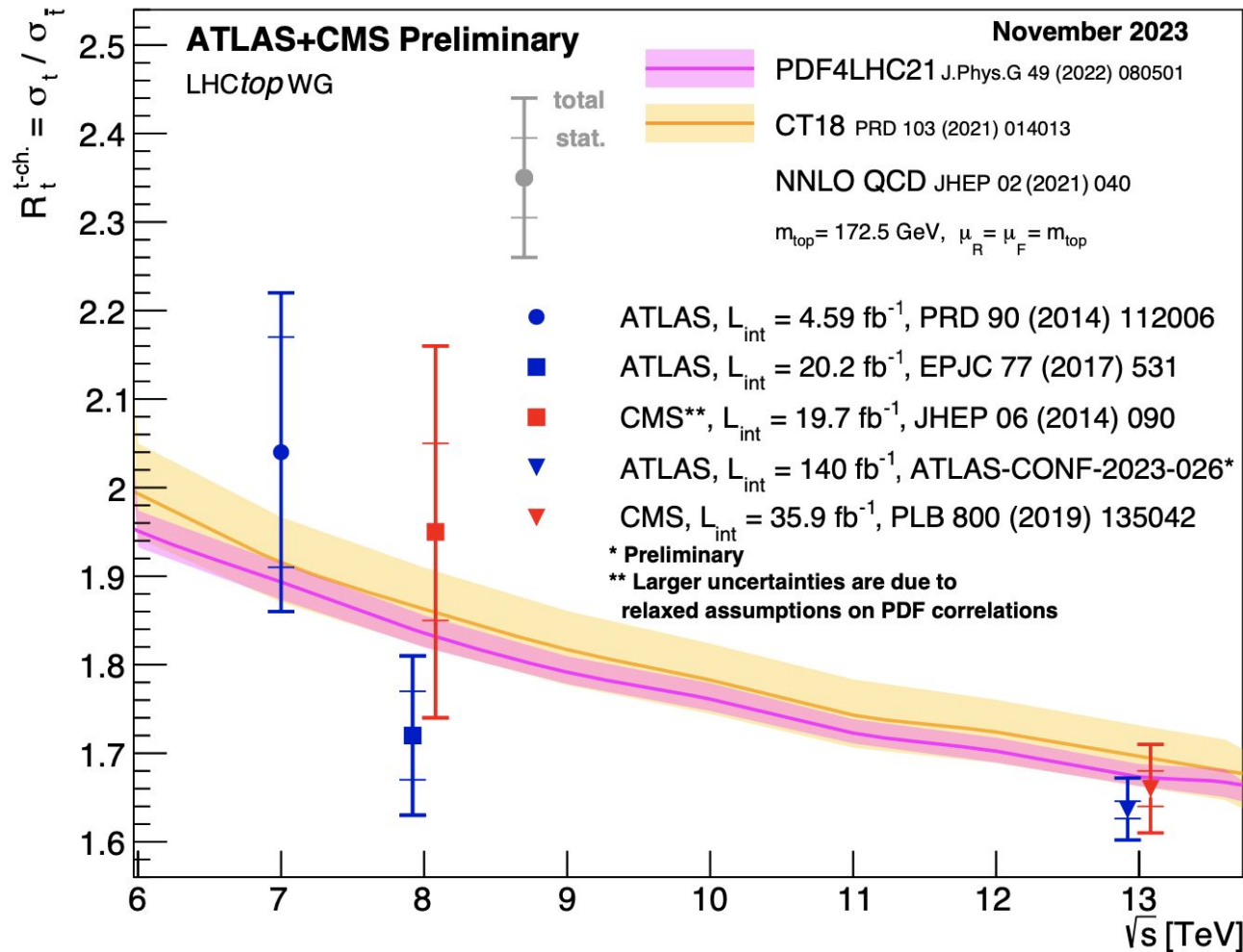
Added ATLAS t-chan. at 5 TeV



- Updated t-channel predictions using PDF4LHC21
- Updated references, sync'd style across channels
- Similar updates for plots at all energies



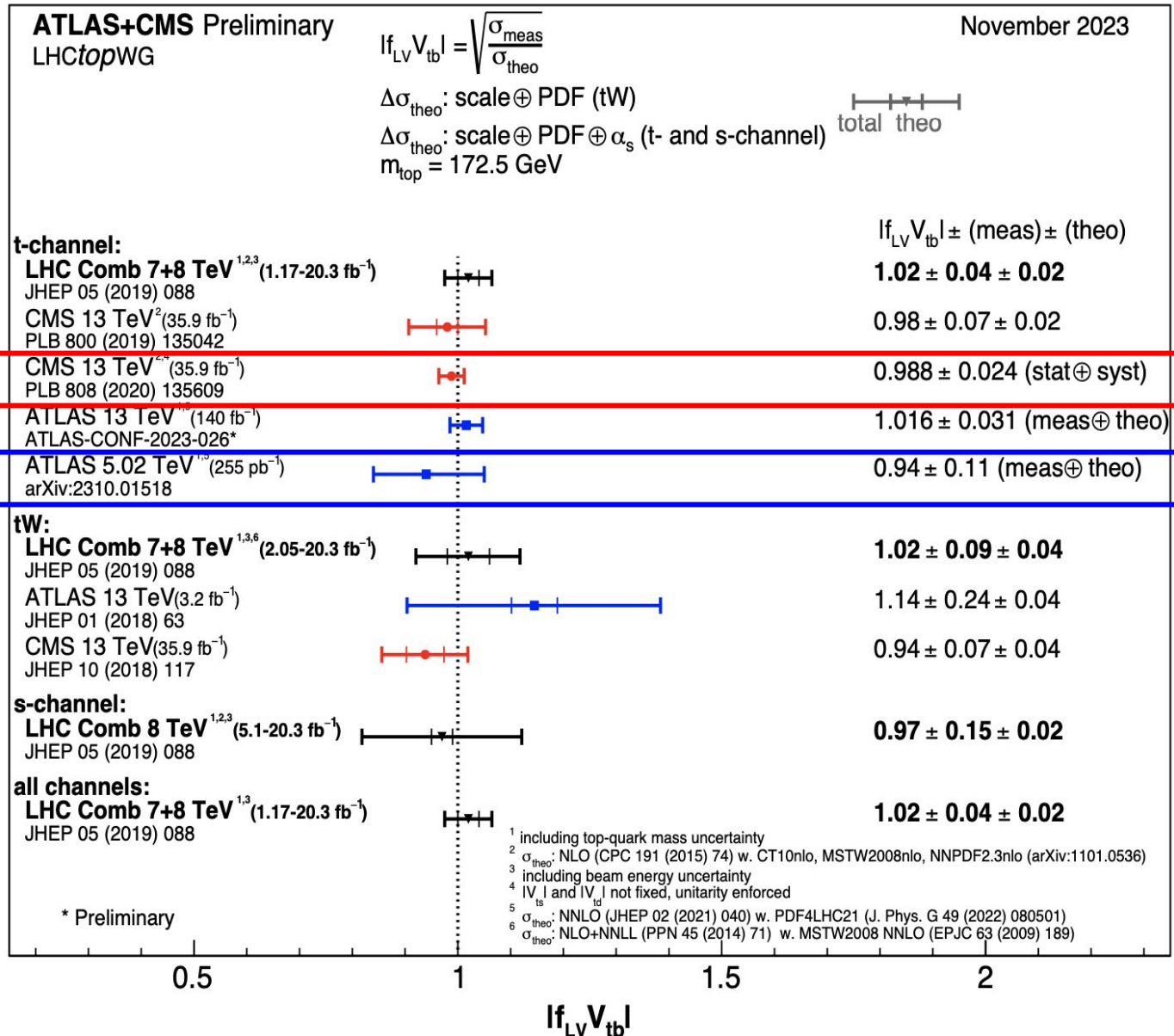
Rt: ratio of $\sigma(\text{top})$ to $\sigma(\text{antitop})$



- Same plot, including the latest ATLAS result at 5 TeV, also available

- Updated theory predictions from NLO to NNLO
- Used newer PDF sets in the predictions
- Updated references

Added CMS t-chan. at 13 TeV
Added ATLAS t-chan. at 5 TeV

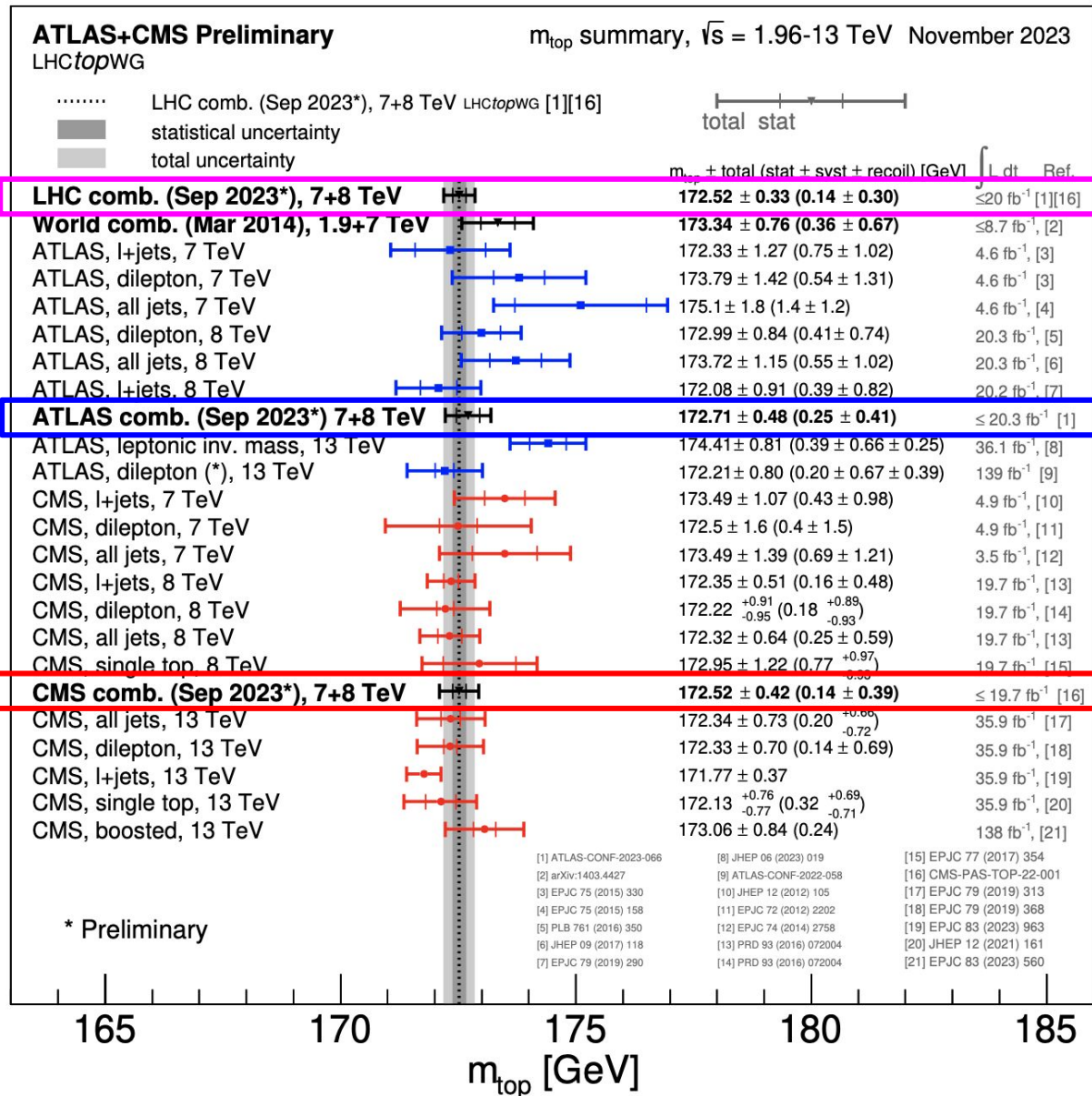


- Updated results as reported in the corresponding publications
- Updated references

Top mass

Top mass from decay

Added new CMS 7+8 TeV combination
 Added new ATLAS 7+8 TeV combination
 Added new LHC 7+8 TeV combination



- Removed all Run-1 results that did not enter the new LHC 7+8 TeV combination
- Added new LHC combination as reference (dotted line and grey bands)
- Updated results as reported in the corresponding publications
- Updated references

Next Open Meeting

- Planned for **May/June 2024**
 - In-person, with the usual zoom connection
 - Sessions will be recorded and uploaded on the agenda after the meeting
- Current scheme: **one in-person** and **one virtual** Open Meeting per year
 - Please let us know if you prefer both in-person
- **Your feedback is important** –let us know if you have suggestions for improving the meetings!

This week's agenda

29 November

30 November

1 December

Intro, highlights (experiment and theory)

ATLAS & CMS comparisons

Top modelling

Top-philic axion festival

EFT

Entanglement

<p>10:00 Session 1 - Maria Aldaya Martin (DESY) Prof. Fabio Maltoni (Universite Catholique de Louvain (UCL) (BE) and Università di Bologna) Wolfgang Wagner (Bergische Universitaet Wuppertal (DE)) (until 13:30) ()</p> <p>10:00 Latest developments in Herwig 7 - Simon Platzer (University of Graz (AT)) ()</p> <p>10:20 --- Discussion ---</p> <p>10:30 Studies on the improvement of the matching uncertainty definition in top-quark processes - Katharina Voss (Universitaet Siegen (DE)) ()</p> <p>10:50 --- Discussion ---</p> <p>11:00 Modeling of tTbar with Powheg bb4l - Laurids Jeppe (Deutsches Elektronen-Synchrotron (DE)) ()</p> <p>11:20 --- Discussion ---</p> <p>11:30 Top quark physics with Pythia - Christian Preuss (University of Wuppertal) ()</p> <p>11:50 --- Discussion ---</p> <p>12:00 Decay matrix element corrections in MC@NLO-type simulations with Pythia8 - Stefano Frixione (INFN) ()</p> <p>12:20 --- Discussion ---</p> <p>13:30 --- Lunch break ---</p> <p>14:00 SUSY searches in tTbar+MET and tc+MET final states with ATLAS - Simran Sunil Gurdasani (Albert Ludwigs Universitaet Freiburg (DE)) ()</p> <p>14:20 --- Discussion ---</p> <p>14:30 Session 2 - Fabio Maltoni (Universite Catholique de Louvain (BE)) (until 15:30) ()</p> <p>14:30 On the coupling of axion-like particles to the top quark - Fabian Esser ()</p> <p>14:45 ALP effects in top-pair production - Vu Phan ()</p> <p>15:00 Phenomenology of an elusive top-philic ALP at the LHC - Alberto Mariotti (Vrije Universiteit Brussel) ()</p> <p>15:15 Distinguishing axion-like particles and CP-odd Higgs bosons in ttbar final states at the LHC - Christian Schwanenberger (Deutsches Elektronen-Synchrotron (DE)) ()</p> <p>15:30 --- Discussion ---</p> <p>15:55 Higgs interference effects in top-quark pair production in the 1HSM - Alexander Lind (Subatech, IMT Atlantique) ()</p> <p>16:15 --- Discussion ---</p> <p>16:25 ATLAS highlight 2: Ttbar+jets in ATLAS and a comparison with the CMS triple differential cross-section measurement, and tTbar in pPb collisions - Miguel Angel Principe Martin (Universidad Autónoma de Madrid) Henriette Aarup Petersen (Deutsches Elektronen-Synchrotron (DE)) ()</p> <p>16:50 --- Discussion ---</p> <p>16:30 Progress report on a combined EFT analysis of ATLAS and CMS results - Baptiste Ravina (Georg August Universitaet Goettingen (DE)) Kirill Skovpen (Ghent University (BE)) ()</p> <p>16:50 --- Discussion ---</p> <p>17:00 Indirect constraints on top quark operators from a global SMEFT analysis - Alfredo Stanzione ()</p> <p>17:20 --- Discussion ---</p>	<p>09:30 Session 1 - Wolfgang Wagner (Bergische Universitaet Wuppertal (DE)) Prof. Fabio Maltoni (Universite Catholique de Louvain (UCL) (BE) and Università di Bologna) Maria Aldaya Martin (DESY) (until 12:30) ()</p> <p>09:30 Summary of the Quantum Observables discussions at GGI - Marcel Vos (IFIC Valencia (ES)) ()</p> <p>09:50 --- Discussion ---</p> <p>10:00 Observation of quantum entanglement in top quark pair production - (University of Glasgow (GB)) ()</p> <p>10:20 --- Discussion ---</p> <p>10:30 xxxxx ()</p> <p>10:50 --- Discussion ---</p> <p>11:00 Quantum Entanglement and Bell Inequality Violation in Semi-Leptonic Top Decays - Arthur Wu (Pitt) ()</p> <p>11:20 --- Discussion ---</p> <p>11:30 --- Close out ---</p>
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Additional information

LHC Run-1 top quark mass combination

[CMS-PAS-TOP-22-001](#), [ATLAS-CONF-2023-066](#), CERN-LPCC-2023-02

Mark Owen (ATLAS); Steve Wimpenny[†],
Martijn Mulders & Matteo Defranchis (CMS)

Systematic correlations

Statistical and other uncorrelated components of JES

Light flavour uncertainties approach different for ATLAS and CMS

Correlation from reliance on MC for flavour composition in the $t\bar{t}$ calibration samples

Uncertainty category	ρ	Scan range	$\Delta m_t/2$ [MeV]	$\Delta \sigma_{m_t}/2$ [MeV]
LHC JES 1	0	—	—	—
LHC JES 2	0	[-0.25, +0.25]	8	7
LHC JES 3	0.5	[+0.25, +0.75]	1	<1
LHC b-JES	0.85	[+0.5, +1]	26	5
LHC g-JES	0.85	[+0.5, +1]	2	<1
LHC l-JES	0	[-0.25, +0.25]	1	<1
CMS JES 1	—	—	—	—
JER	0	[-0.25, +0.25]	5	1
Leptons	0	[-0.25, +0.25]	2	2
b tagging	0.5	[+0.25, +0.75]	1	1
p_T^{miss}	0	[-0.25, +0.25]	<1	<1
Pileup	0.85	[+0.5, +1]	2	<1
Trigger	0	[-0.25, +0.25]	<1	<1
ME generator	0.5	[+0.25, +0.75]	<1	4
LHC radiation	0.5	[+0.25, +0.75]	7	1
LHC hadronization	0.5	[+0.25, +0.75]	1	<1
CMS B hadron BR	—	—	—	—
Color reconnection	0.5	[+0.25, +0.75]	3	1
Underlying event	0.5	[+0.25, +0.75]	1	<1
PDF	0.85	[+0.5, +1]	1	<1
Top quark p_T	—	—	—	—
Background (data)	0	[-0.25, +0.25]	8	2
Background (MC)	0.85	[+0.5, +1]	2	<1
Method	0	—	—	—
Other	0	—	—	—



Different JES calibrations, but sensitive to same MC modelling of radiation

similar MC comparisons (Pythia v Herwig)

No large changes in central value.

15

C. Nellist | Top Mass Combination | TOP2023 | 26/09/2023

Slide from C. Nellist at [TOP2023](#)

LHC Run-1 top quark mass combination

[CMS-PAS-TOP-22-001](#), [ATLAS-CONF-2023-066](#), CERN-LPCC-2023-02

Mark Owen (ATLAS); Steve Wimpenny[†],
Martijn Mulders & Matteo Defranichis (CMS)

Uncertainty category	Uncertainty impact [GeV]		
	LHC	ATLAS	CMS
LHC b-JES	0.18	0.17	0.25
b tagging	0.09	0.16	0.03
ME generator	0.08	0.13	0.14
LHC JES 1	0.08	0.18	0.06
LHC JES 2	0.08	0.11	0.10
Method	0.07	0.06	0.09
CMS B hadron BR	0.07	—	0.12
LHC radiation	0.06	0.07	0.10
Leptons	0.05	0.08	0.07
JER	0.05	0.09	0.02
Top quark p_T	0.05	—	0.07
Background (data)	0.05	0.04	0.06
Color reconnection	0.04	0.08	0.03
Underlying event	0.04	0.03	0.05
LHC g-JES	0.03	0.02	0.04
Background (MC)	0.03	0.07	0.01
Other	0.03	0.06	0.01
LHC l-JES	0.03	0.01	0.05
CMS JES 1	0.03	—	0.04
Pileup	0.03	0.07	0.03
LHC JES 3	0.02	0.07	0.01
LHC hadronization	0.02	0.01	0.01
p_T^{miss}	0.02	0.04	0.01
PDF	0.02	0.06	<0.01
Trigger	0.01	0.01	0.01
Total systematics	0.30	0.41	0.39
Statistical	0.14	0.25	0.14
Total	0.33	0.48	0.42

