GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN IN PUBLICA COMMODA SEIT 1737

ATLAS EXPERIMENT

Alexander von Humboldt Stiftung/Foundation

# Outlook to the ATLAS top physics programme in Run 3 and beyond

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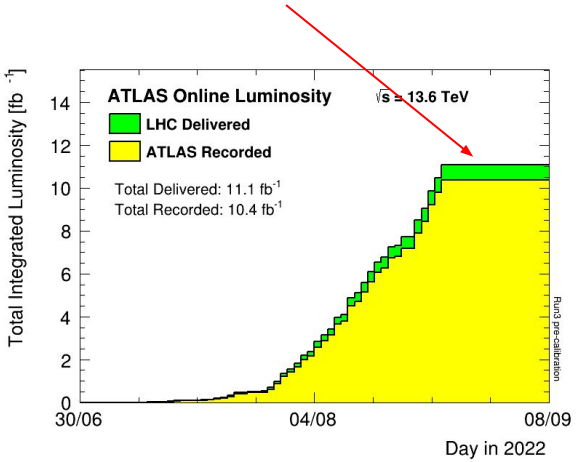
TOP'22 Durham – 8 September 2022

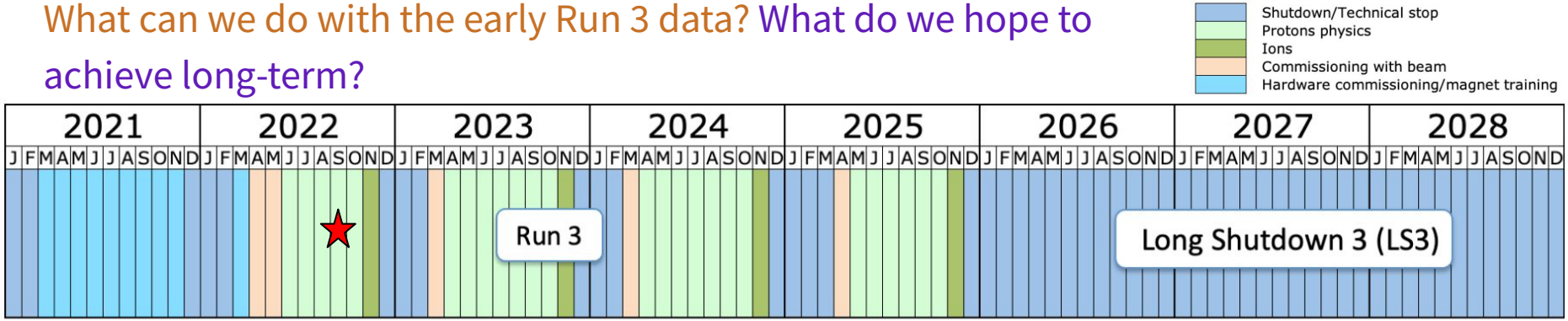
# ATLAS in Run 3

*Issue with cooling tower at LHC P4, RF modules need to be warmed up, cleaned, cooled down again and re-conditioned… ~4 weeks delay*




- ~~**Data-taking is on-going!**~~ will resume in 2 weeks
  - for the first time at √s = 13.6 TeV
  - More than 10 $fb^{-1}$ recorded by ATLAS so far
- Important updates to the detector (e.g. Muon New Small Wheel) and to software (online trigger, object reconstruction, GEANT4 simulation, etc.)

What can we do with the early Run 3 data? What do we hope to achieve long-term?



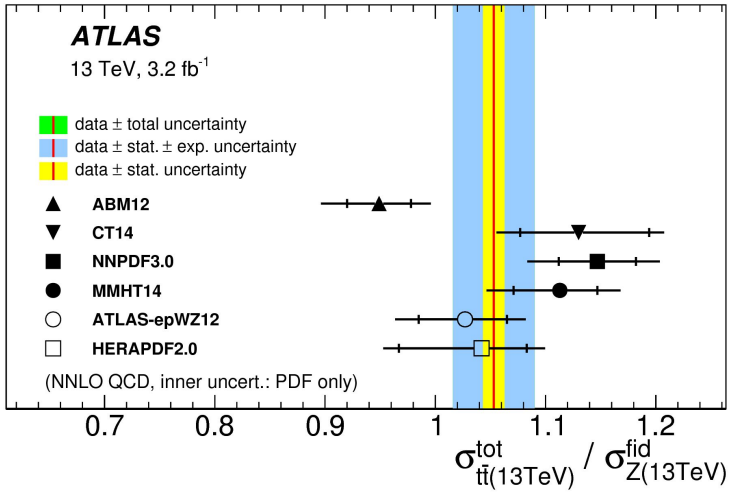
# Luminosity is a limiting factor (for now)

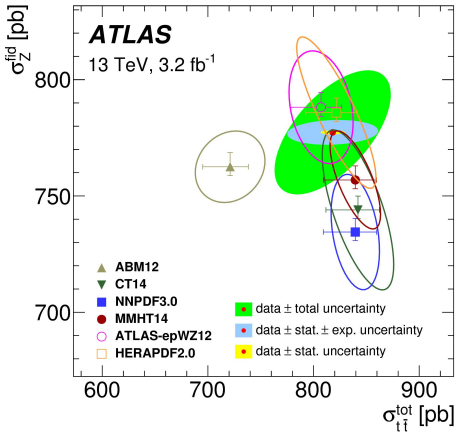
- **Precise estimation of luminosity is a crucial component of cross section measurements**
- ATLAS relies on multiple sub/detectors: LUCID, calorimeters, forward detectors, MBTS, etc.
- **van de Meer scans originally planned for late October / November (+delay!)**
  - until then, early measurements will suffer from large luminosity uncertainties
  - expecting ~30 $fb^{-1}$ of data by the end of the year
- Early ttbar measurements are important!
  - well-known process (standard candle), depends on all sub-detectors
  - validate object reconstruction and software, catch any potential issues early
  - large cross section = small statistical uncertainty
  - dilepton selection offers high purity
  - but how to deal with large luminosity uncertainty?

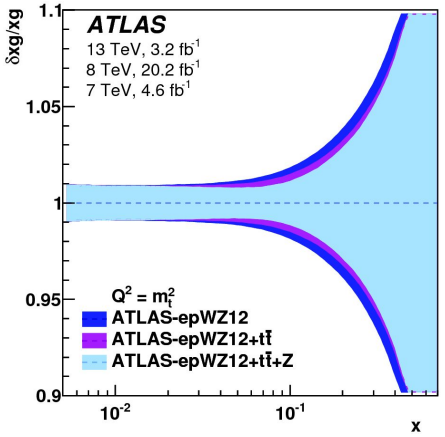
# Analysis strategy

- **Dilepton eμ channel:** small background, no need for data-driven fake estimation
- Use the well-established “b-tag counting” method
  - low dependence on jet systematics
  - provides in-situ b-tagging efficiency calibration
  - now in profile likelihood formalism
- Luminosity uncertainty expected to be large (up to ~10%)
  - **solution: measure the ratio of ttbar to Z+jets production!**
  - luminosity uncertainty cancels out
  - also becomes a probe of the gluon-to-quark ratio in the PDF

JHEP 02 (2017) 117

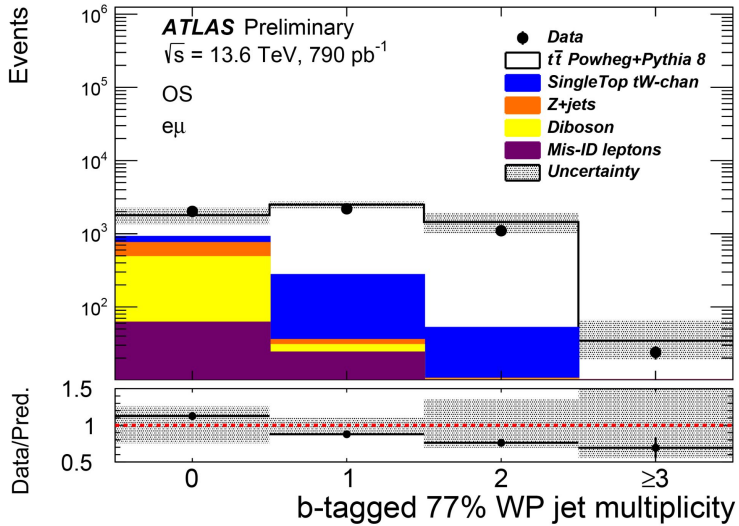


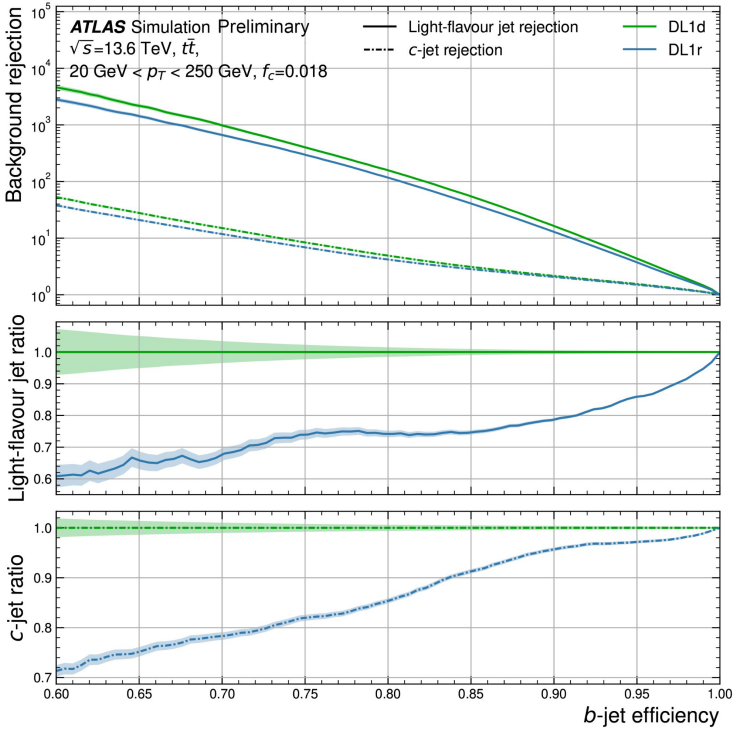



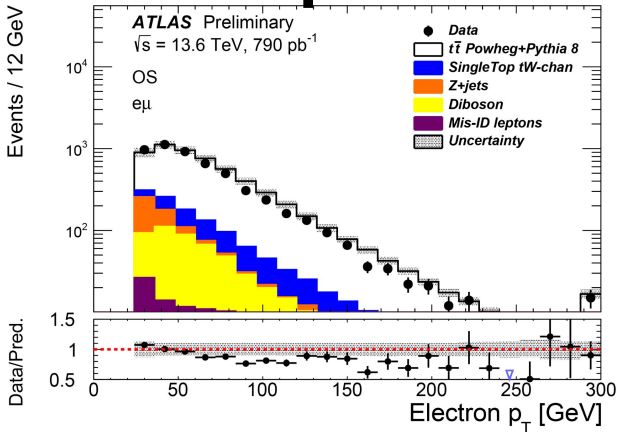
# Analysis selection & b-tagging performance

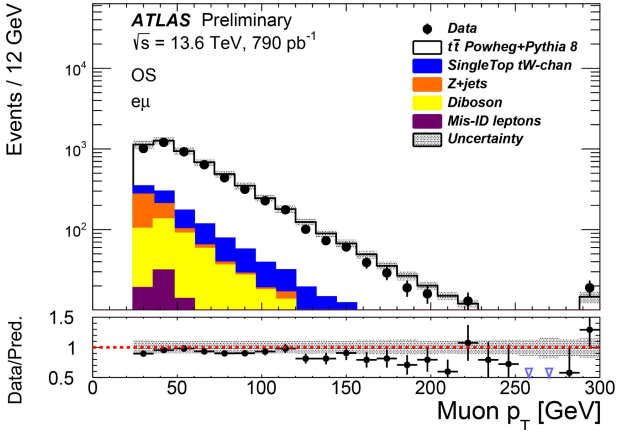
- Exactly one electron and one muon with $p_T$>26 GeV
- Inclusive in anti-$k_t$ R=0.4 jets with $p_T$>25 GeV
- Jets b-tagged with the new DL1d algorithm at 77% efficiency

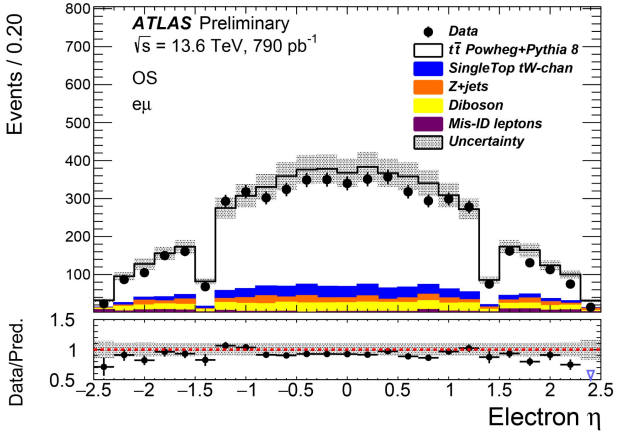


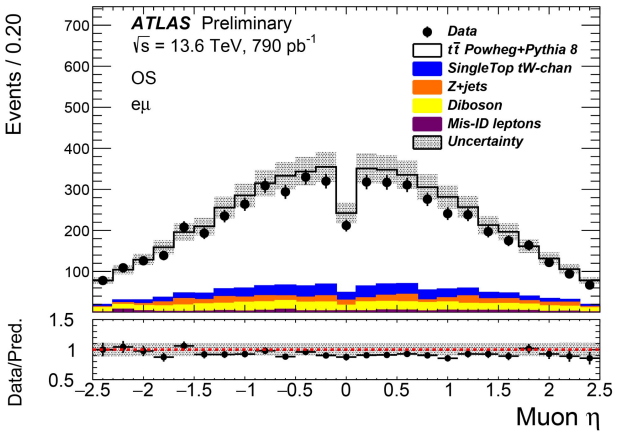



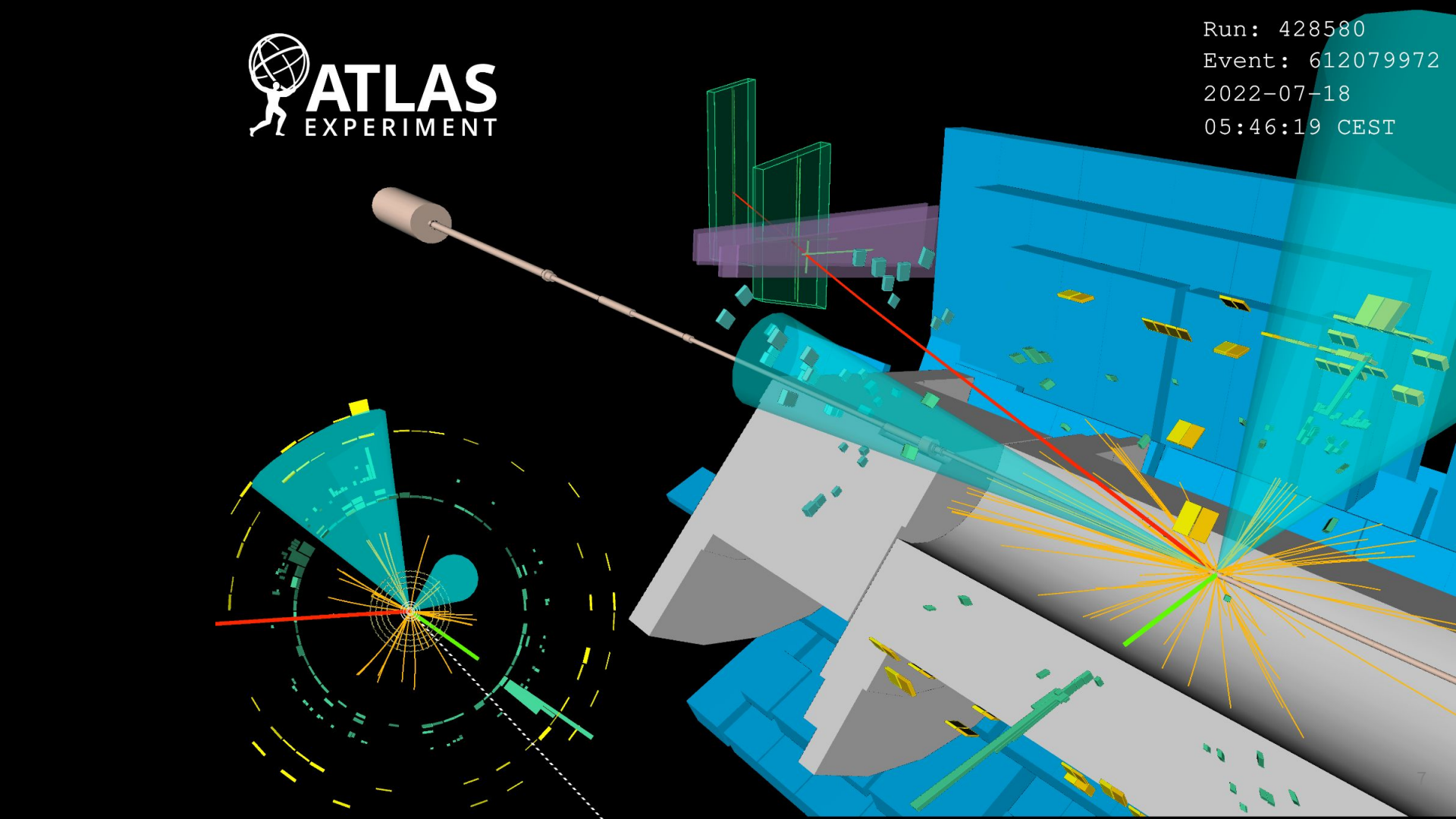
# First data/MC plots – lepton kinematics




ATLAS
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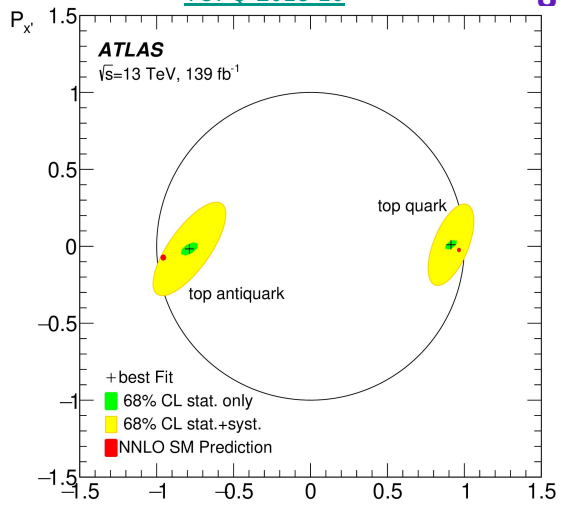
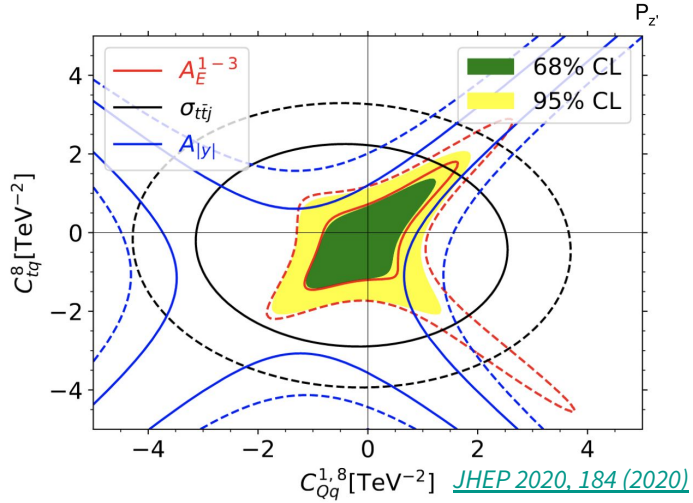
# The picture so far…

- **Run 1** started with the rediscovery of the top quark, followed by the first observations of spin correlations in tops and associated production (ttɣ).
- **Run 2** gave us access to many more properties of the top quark and rare production processes:
  - single-top polarisation [TOPQ-2018-10]
  - energy asymmetry [*Eur. Phys. J. C 82 (2022) 374*]
  - boosted differential ttbar [*JHEP 06 (2022) 063*] [TOPQ-2018-11]
  - comprehensive FCNC programme [TOPQ-2019-17] [TOPQ-2019-19] [*Eur. Phys. J. C 82 (2022) 334*]
  - observation of tqɣ [ATLAS-CONF-2022-013]
  - evidence for s-channel single-top production (3.3σ) [ATLAS-CONF-2022-030]
  - strong evidence for 4tops (4.7σ) [*JHEP 11 (2021) 118*]
  - more and more precise measurements of ttbar+W/Z/H [*Eur. Phys. J. C 81 (2021) 737*] [*JHEP 09 (2020) 049*] [HIGG-2020-16]

TOPQ-2018-10



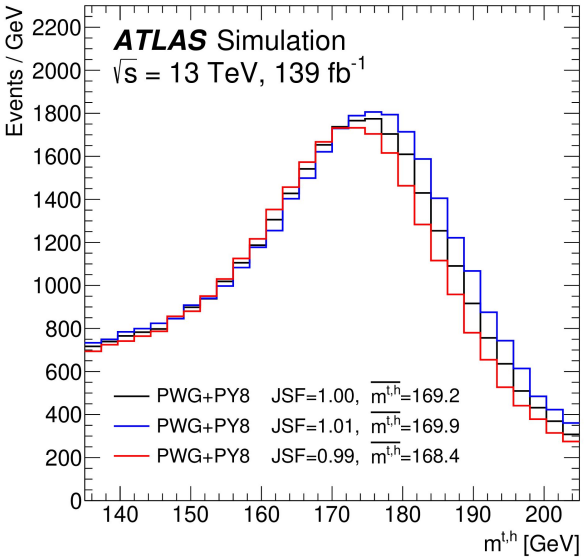

*JHEP 2020, 184 (2020)*

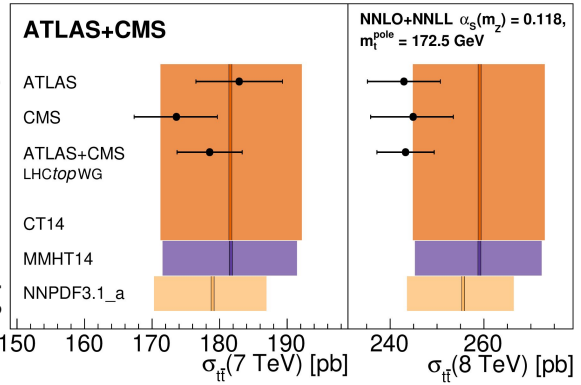
# The picture so far…

- At the end of Run 2, we have a **detailed understanding of our detector**: signal and background modelling uncertainties often become limiting factors.
  - this will take some time to replicate in Run 3
  - in the top+X sector, it is particularly difficult to isolate the signal from other top+X backgrounds
- The most precise results are obtained through combinations or through secondary (in-situ) measurements:
  - Run 1 legacy ATLAS+CMS ttbar cross section ~2.5% [TOPQ-2018-39]
  - Run 1 template top mass measurement relies on JSF and b-JSF to reduce the impact of jet energy scale uncertainties [*Eur. Phys. J. C 79 (2019) 290*]
  - Run 2 boosted l+jets ttbar differential cross section uses a similar technique [*JHEP 06 (2022) 063*]

**Run 3** should be an opportunity for complex measurements aiming at a **more global picture of the top sector**.

*JHEP 06 (2022) 063*



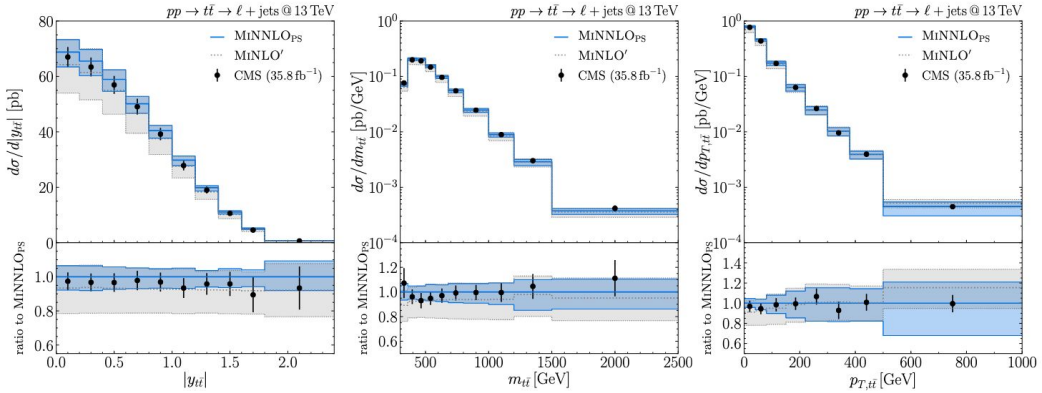




TOPQ-2018-39

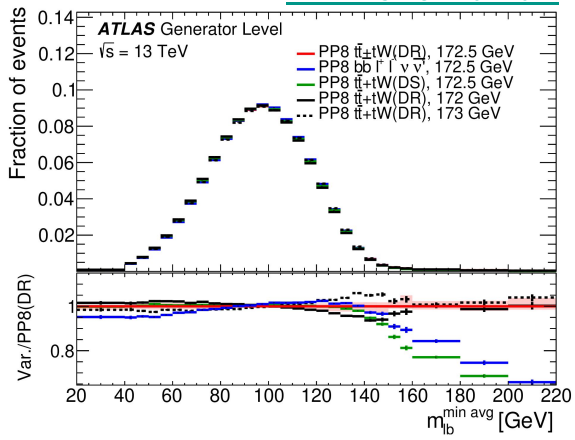
# Improvements in Monte Carlo

- First consistent treatment of single- and double-resonant WbWb production: **“bb4l”**
  - clear differences with previous diagram removal (DR) and subtraction (DS) schemes [ATL-PHYS-PUB-2021-042]
  - ATLAS measurement of ttγ+tWγ [*JHEP 09 (2020) 049*]
  - search for tWZ is statistically dominated, but differential ttZ is in some places limited by tWZ modelling
- **MiNNLO$_{PS}$** interfaces NNLO matrix elements to the parton shower [*JHEP 04 (2022) 079*]
- Moving PS uncertainties from 2-point comparisons to more comprehensive internal variations

*JHEP 09 (2020) 049*



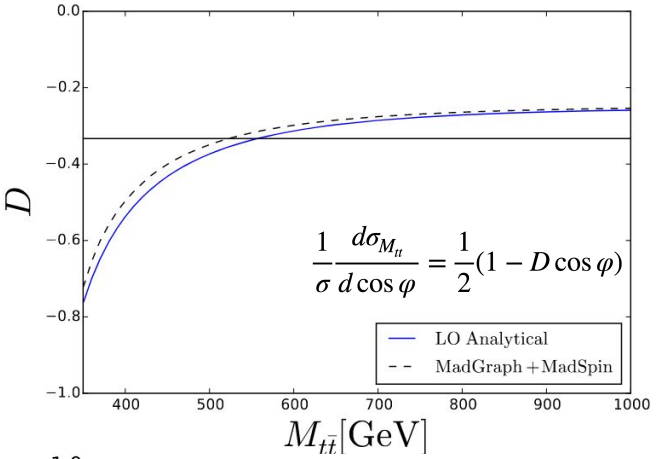

ATL-PHYS-PUB-2021-042

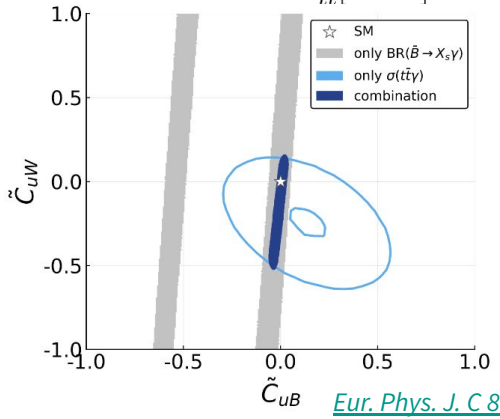


# More subtle properties measurements

- Many approaches to measuring the **top mass**: how to connect them to theory?
  - new phenomenological approaches, e.g. MSR/pole mass from boosted tops [ATL-PHYS-PUB-2021-034]
  - but also new ML-based reconstruction tools: impact of the all-hadronic channel? [*Phys.Rev.D 105 (2022) 112008*]
- **Angular measurements** are powerful probes of new physics
  - W helicity, top polarisation [TOPQ-2018-10], ttbar spin correlations [*Eur. Phys. J. C 80 (2020) 754*]: legacy Run 2 measurements and previous ATLAS+CMS combinations [*JHEP 08 (2020) 51*]
  - SMEFT interpretation of the Wtb vertex & connection to B-physics
  - Open the door to fundamental tests of quantum mechanics: quantum entanglement [*Eur. Phys. J. Plus (2021) 136:907*], Bell's inequalities [*Phys.Rev.Lett. 127 (2021) 16, 161801*]…

*Eur. Phys. J. Plus (2021) 136:907*



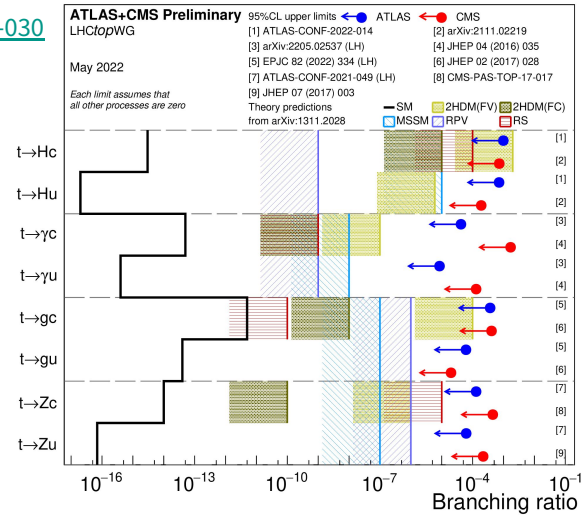



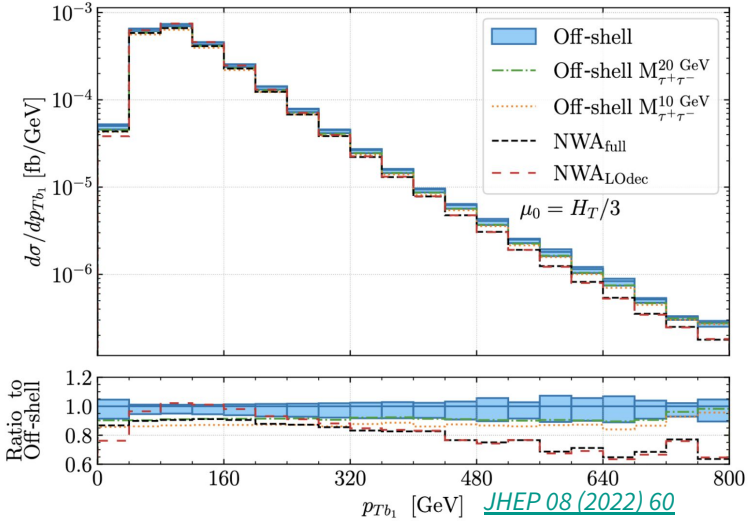

*Eur. Phys. J. C 80, 136 (2020)*

# Top+X: searches & combinations

- Increase in √s can greatly benefit some BSM searches, but for top+X processes the gain is small (<15%)
  - however additional ~300 $fb^{-1}$ of data very welcome for searches (e.g. FCNC, tWZ, 4tops) and expansion of the precision programme (e.g. charge asymmetries, polarisations, spin correlations) [ATL-PHYS-PUB-2022-004]
  - foray beyond NWA into off-shell regime: ttbar+ll (ttZ), tc+ll (tZq), tb+vl (tW) → connections to 4-fermion EFTs, leptoquark models and B-anomalies [D. Marzocca] [*JHEP 08 (2022) 60*]
- Long-standing discrepancy in multi-lepton + b-jets final state (ttW/ttH/4tops)
  - joint top+X measurements: relax assumptions on the backgrounds, extract more information differentially, provide the full EFT picture
  - also valuable inputs to global SMEFT fits
  - **build analysis strategies with combinations in mind**

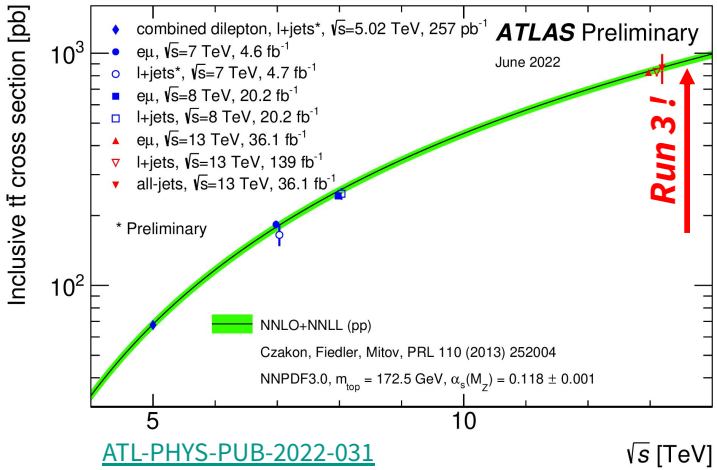
ATL-PHYS-PUB-2022-030




JHEP 08 (2022) 60

# Summary & conclusions

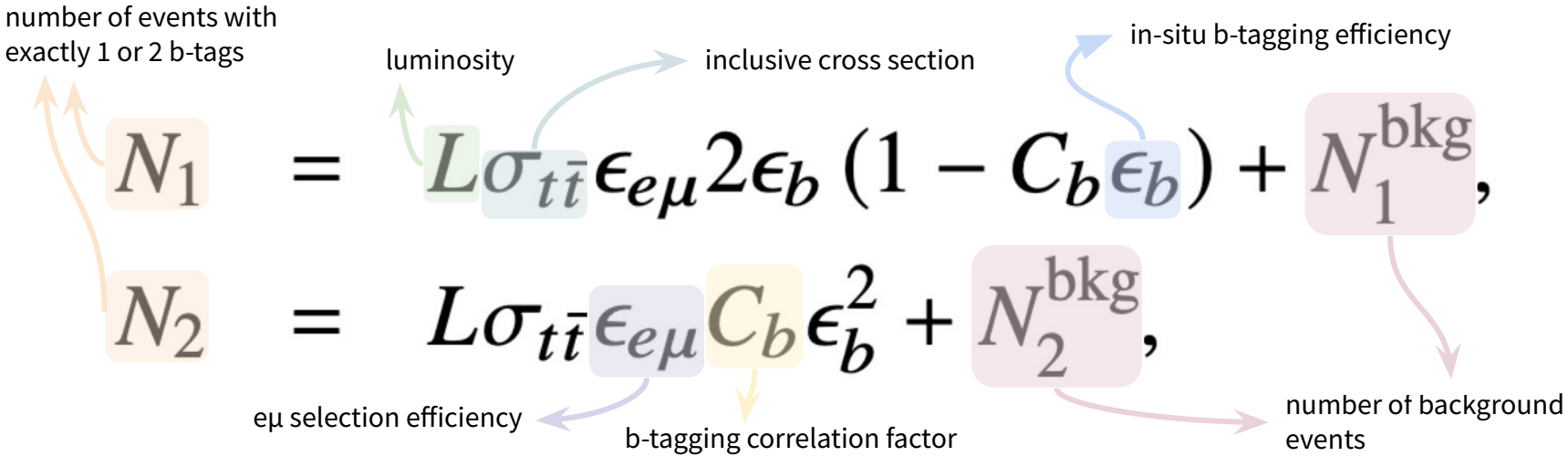



ATL-PHYS-PUB-2022-031

- **First measurement** of $\sigma(tt)/\sigma(Z)$ at $\sqrt{s}$ = 13.6 TeV is **in progress**
- Run 2 results have expanded our experimental toolkit
  - more production processes are accessible
  - refined angular measurements
  - complex measurements in difficult phase-spaces
- Run 3 analyses will leverage this expertise
  - joint measurements, global EFT fits, off-shell topologies, quantum information, top mass, etc.

# Backup.

# The “b-tag counting” method




- Requires only 2 bins to measure the 2 POIs: the cross section and the b-tagging efficiency
  - however also need events with 0 b-tags to measure the b-tagging correlation factor
- This approach can be rewritten as a profile likelihood: allows combination with the l+jets channel and the Z+jets measurement (same-flavour dilepton)