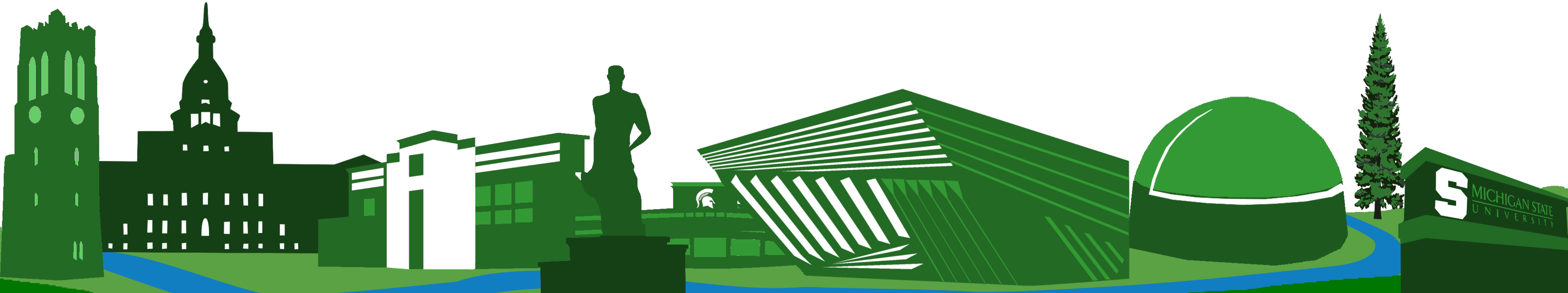
Recent highlights of top-quark properties measurements with the ATLAS detector at the LHC

Jose Enrique García Navarro

on behalf of the ATLAS Collaboration



DIS2023: XXX International Workshop on Deep-Inelastic Scattering and Related Subjects

Heaviest fundamental particle in the Standard Model

Large coupling to SM Higgs + m_{top} is a fundamental parameter in SM

Processes including top are backgrounds for new physics

Good understanding → improvements in searches

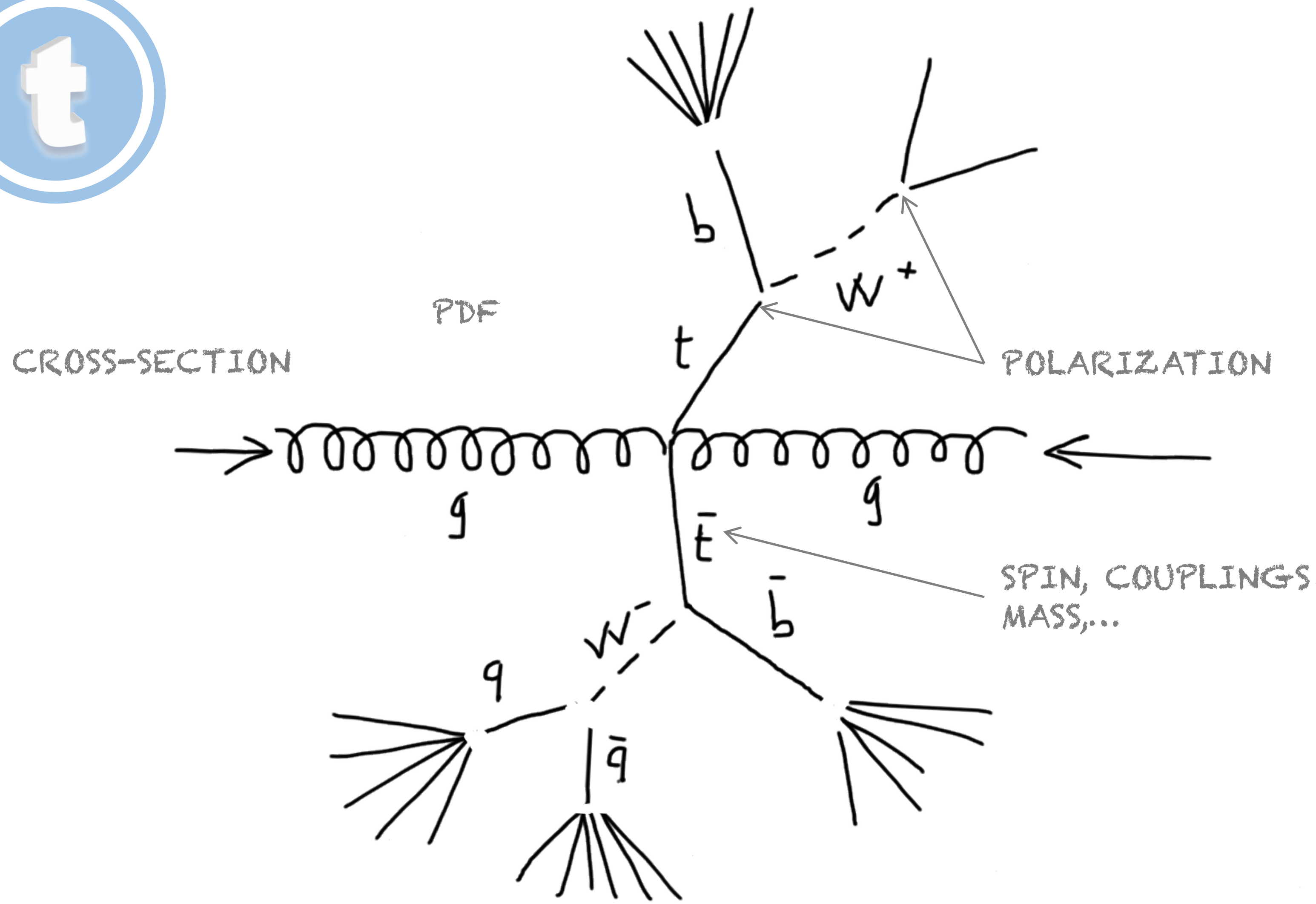
Short lifetime(~10^{-25} s)

Decays before hadronization – Unique among the quarks!

Access to polarization + spin correlations

Hints of new physics?

Exotic particles could decay preferentially to top quarks

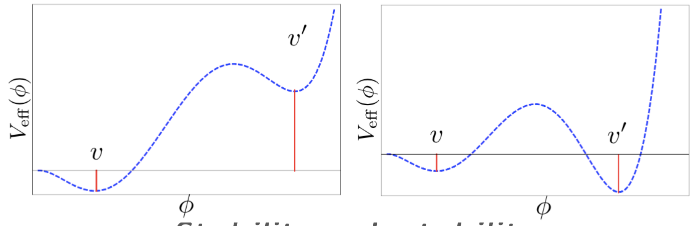


Properties	
Spin	Width
Polarization	Charge
b-fragmentation	CP properties
Mass	Asymmetries

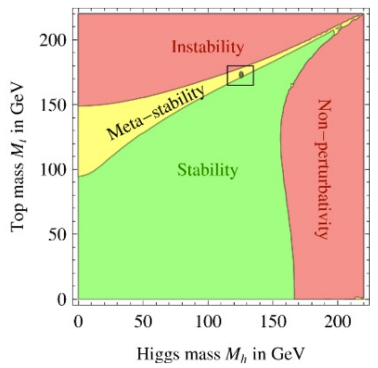
top mass

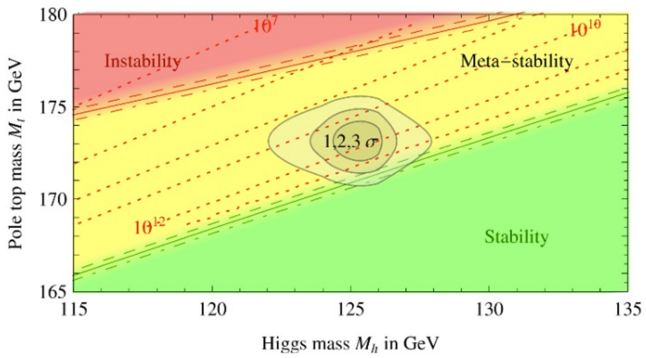
✓ Plays a role in EW vacuum stability

Precise measurements are needed in order to evaluate the vacuum stability



Stability vs Instability





arXiv:1205.6497

top mass measurement

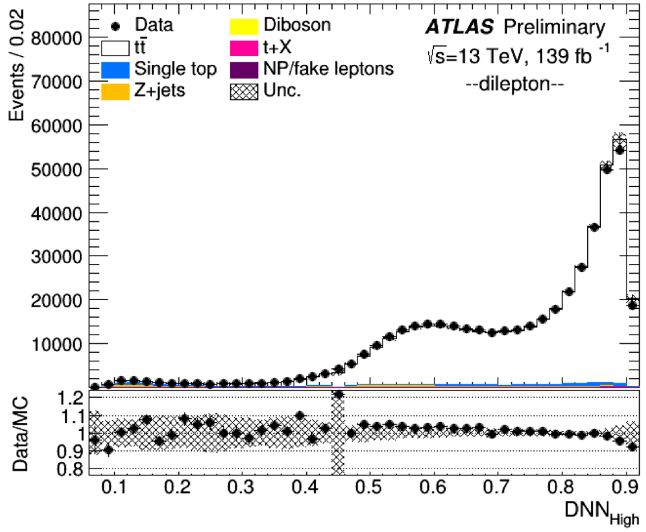
✓ Its mass can be determined through comparison with theoretical calculations:

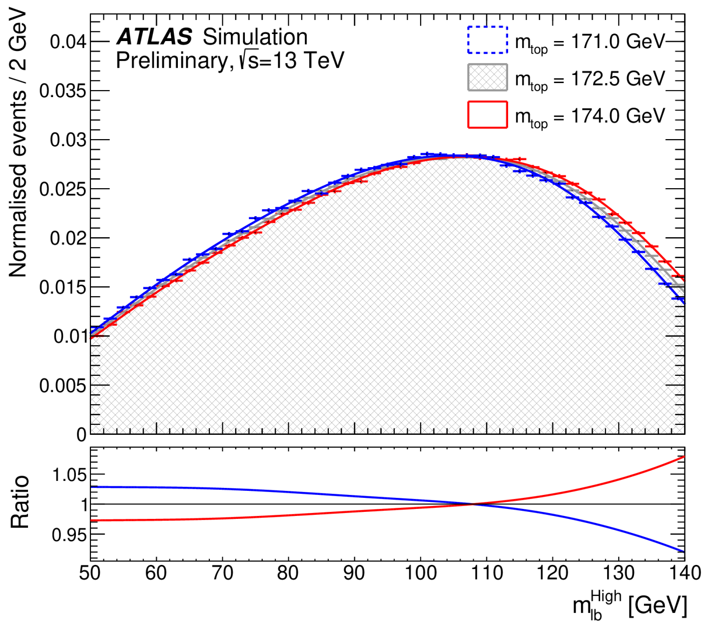
- ✓ "***Direct***" measurements:
  - ✓ Kinematic reconstruction of variables related to the top-quark momentum.
  - ✓ Comparison with MC calculations.
  - ✓ Typically have a high experimental precision.
- ✓ "***Indirect***" measurements:
  - ✓ Measure observable(s) which have a strong dependence on m_t with data unfolding

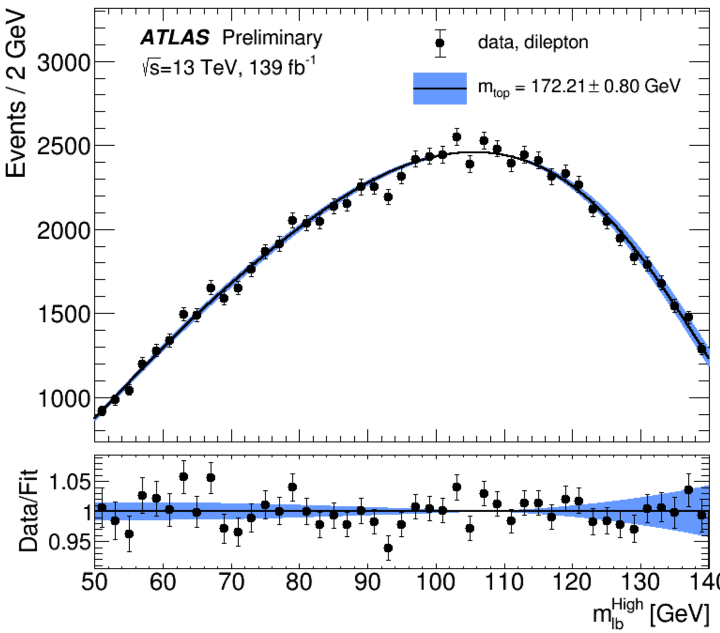
Top quark mass using a dileptonic invariant mass

top mass

- ✓ Select top pairs dilepton channel
- ✓ Generate templates for m_{lb} distribution as a function of m_t
- ✓ DNN for event reconstruction.
- ✓ Likelihood fit to find best value for m_t





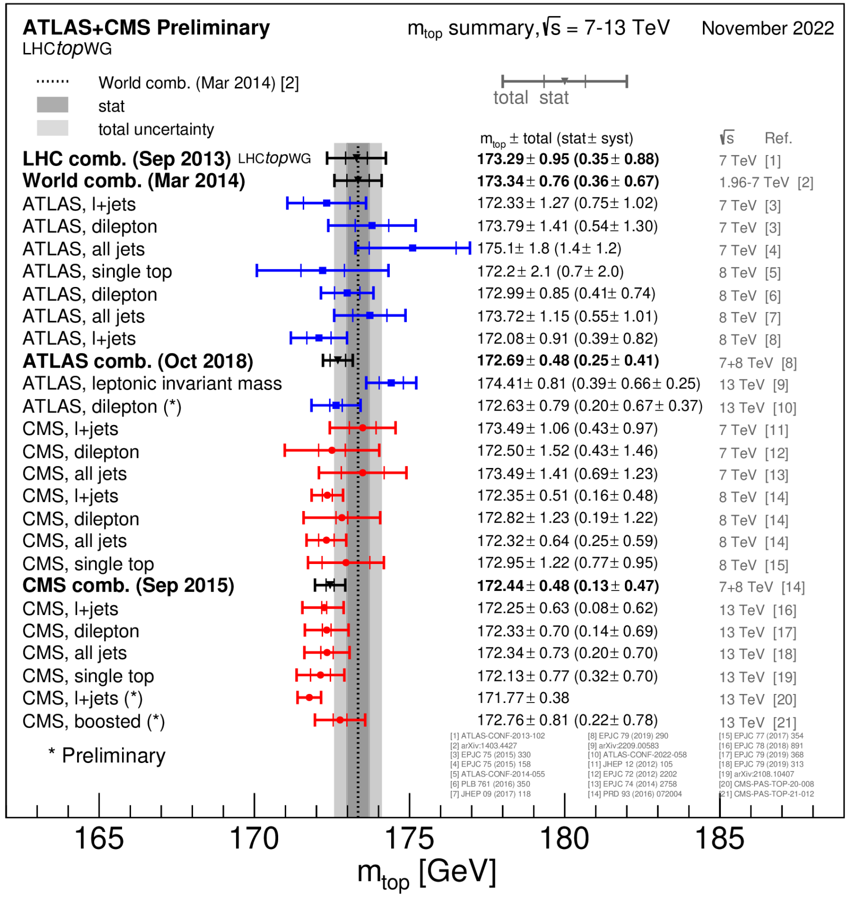


$$m_t = 172.21 \pm 0.20(stat) \pm 0.67(syst) \pm 0.39(recoil)GeV$$

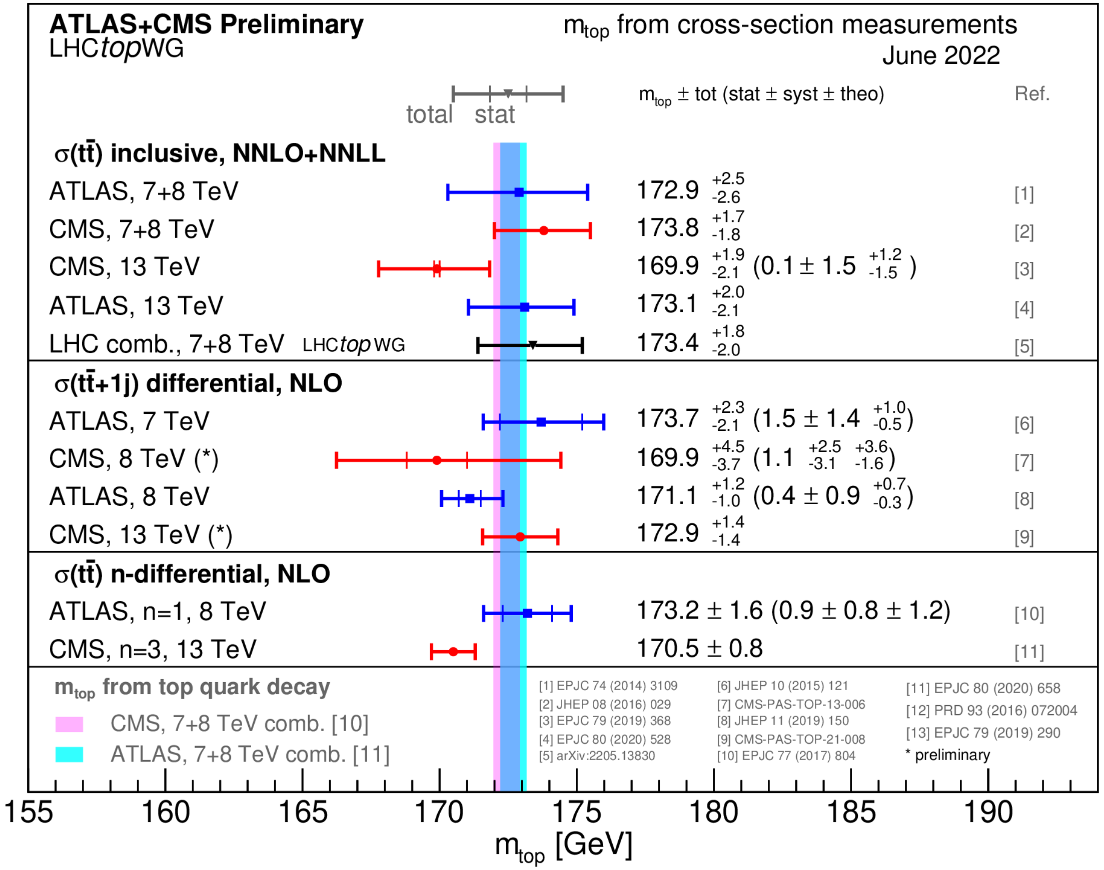
Leading systematic uncertainties: JES, recoil scheme, ME matching, color reconnection

ATLAS-CONF-2022-058

Top quark mass



Summary of the ATLAS and CMS measurements from top quark decay ("direct").



Summary of the ATLAS and CMS measurements of the top quark mass from $t\bar{t}$ production observables.

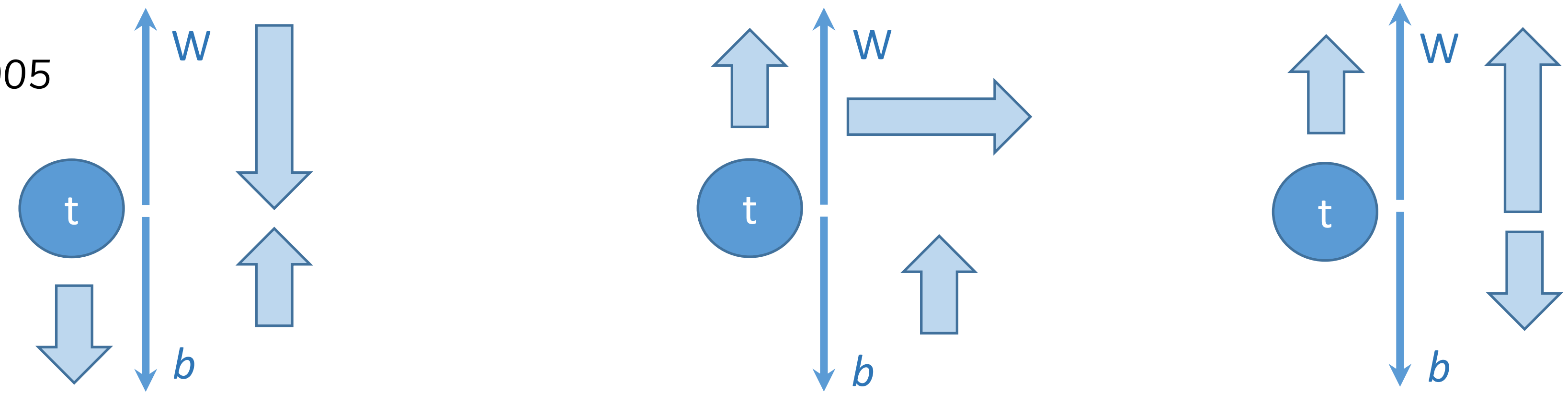
Uncertainty in combinations: ~0.5 GeV (0.3%)

ATL-PHYS-PUB-2022-050

Wtb vertex

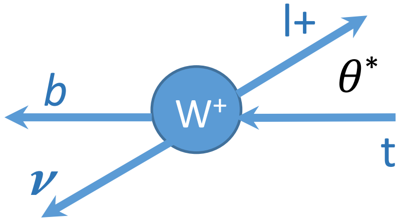
- ✓ Properties of the top quark decay vertex, Wtb are determined by the V-A structure of the weak interaction
- ✓ W helicity factions longitudinal (f_0), left-handed (f_L) and right-handed (f_R) can be extracted from measurements of the angular distributions of decay products of the W boson and top quark:

$f_L = 0.311 \pm 0.005$



$f_0 = 0.687 \pm 0.005$

$f_R = 0.0017 \pm 0.0001$



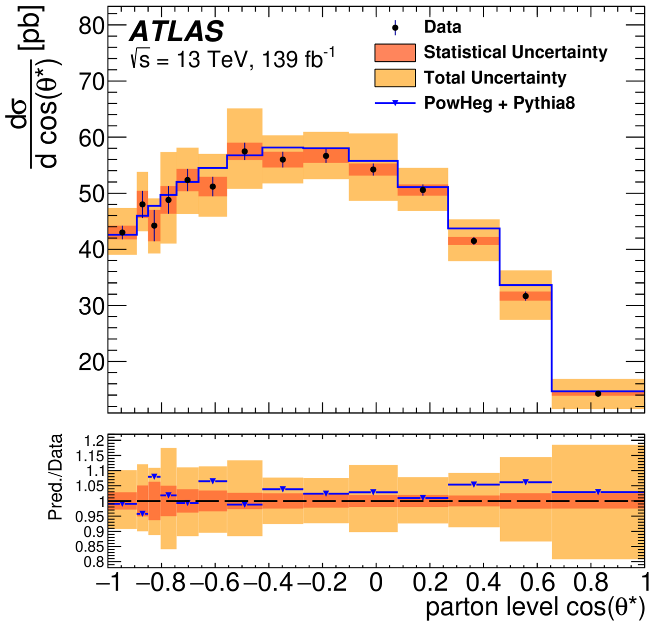
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos\theta^*)^2 f_L + \frac{3}{8}(1+\cos\theta^*)^2 f_R$$

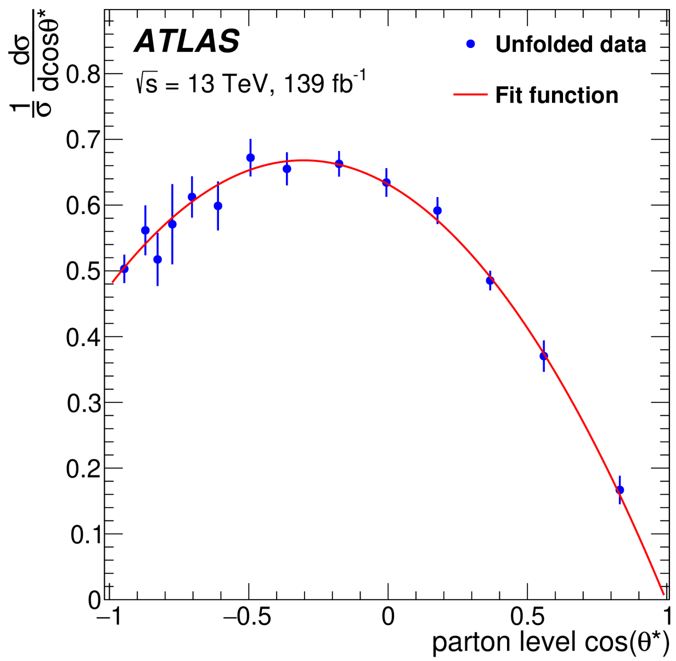
NNLO Calculation: PRD 81 (2010) 111503

arXiv:2209.14903

W-boson *Polarizations*

- ✓ Reconstruction of top pairs (dilepton channel) performed using Neutrino Weighting (NW) method.
- ✓ Unfold detector-level cos θ* to parton level using Iterative Bayesian Unfolding (IBU) technique.
- ✓ Extract helicity fractions from a fit to the normalized differential cross-section distribution.
- ✓ Two parameter fit performed where f_L and f_R extracted from the fit. $f_0 = 1-f_L-f_R$ imposes unitarity of fractions, and f_0 estimated post-fit.





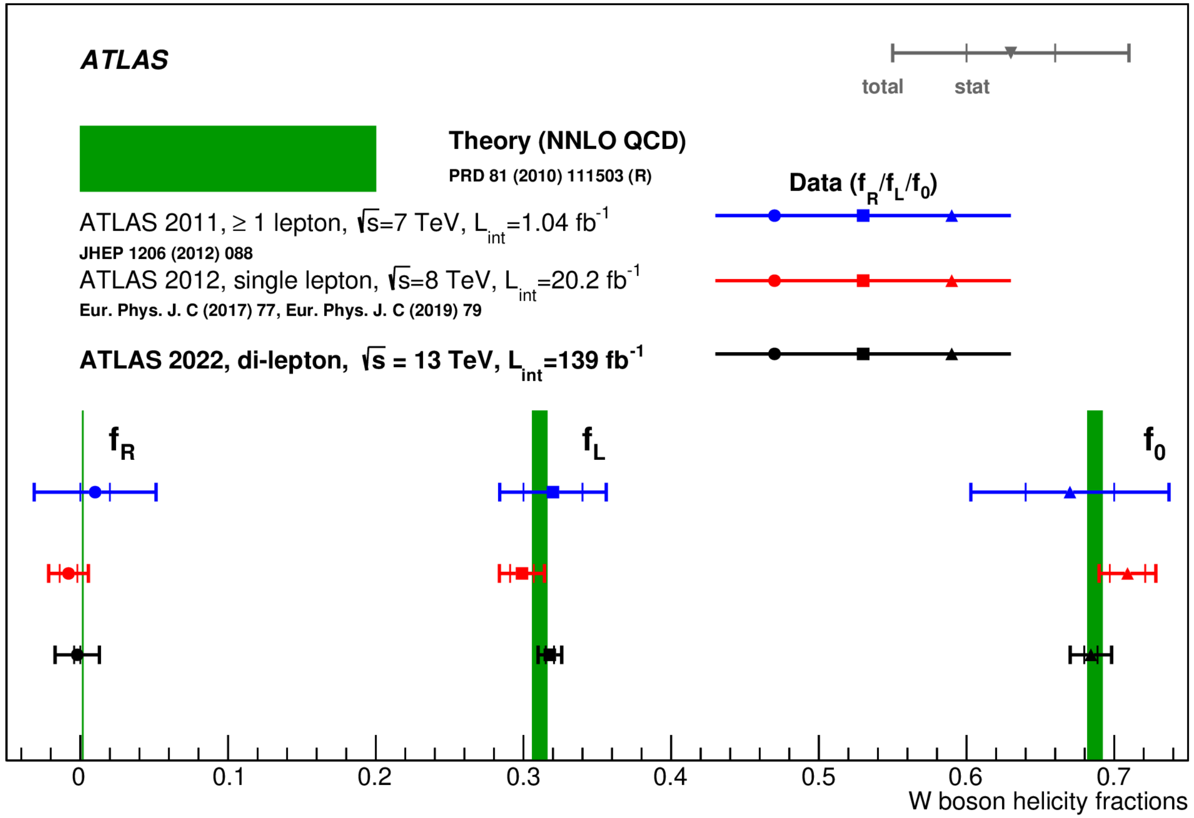
W-boson *Polarization*

- ✓ All values, within uncertainties, agree with SM prediction at NNLO in QCD.
- ✓ Measurement is systematically limited (top pairs modelling and jet reconstruction are the major sources of uncertainties).

$f_L = 0.318 \pm 0.008$

$f_R = -0.002 \pm 0.015$

$f_0 = 0.684 \pm 0.015$



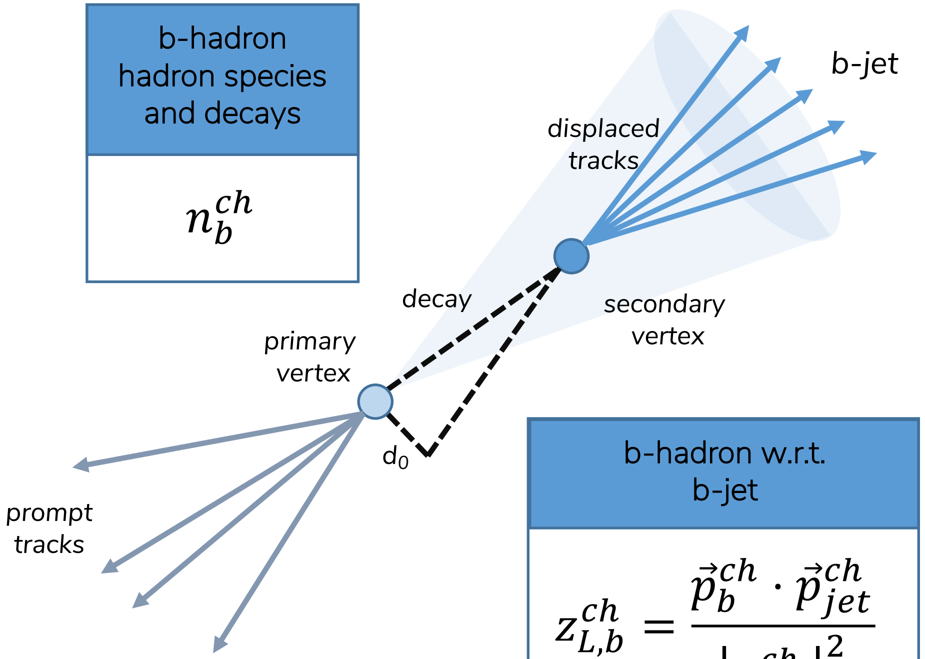
Measurements sensitive to b-quark fragmentation in top pairs

b-quark fragmentation

- ✓ Understanding b-quark fragmentation is important for many processes and physics results.
- ✓ b-jets provide clear experimental signature.
- ✓ top pairs production are great source of b-jets:
  - ✓ Only charged particles or tracks used for b-jets.
  - ✓ Lepton p_T can be used as a proxy for top quark p_T (dileptonic decay).
- ✓ Define different observables that are sensitive to b-fragmentation.

b-hadron hadron species and decays

$$n_b^{ch}$$



b-hadron w.r.t. top decay

$$\rho = \frac{2p_{T,b}^{ch}}{p_T^e + p_T^\mu}$$

b-hadron w.r.t. b-jet

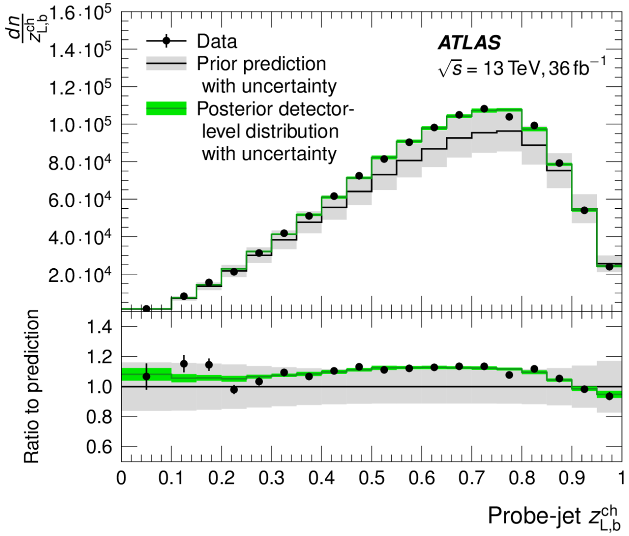
$$z_{L,b}^{ch} = \frac{\vec{p}_b^{\,ch} \cdot \vec{p}_{jet}^{\,ch}}{\left|p_{jet}^{ch}\right|^2}$$

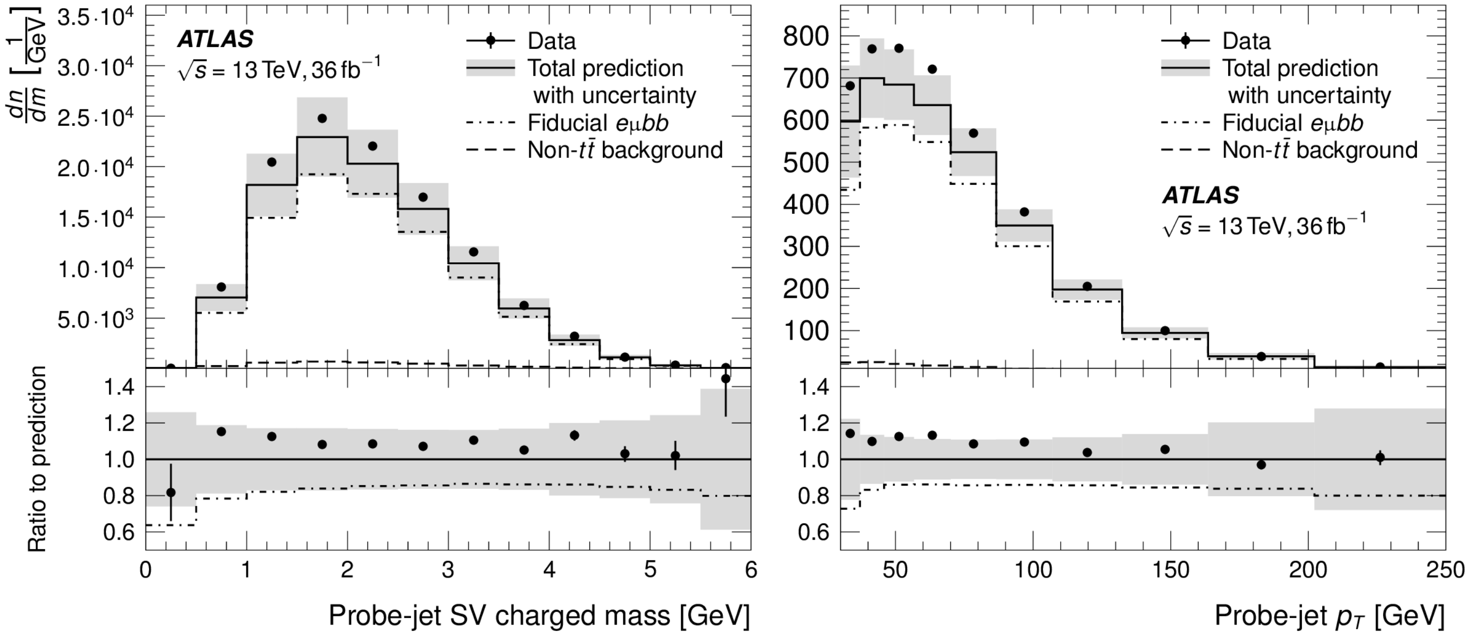
$$z_{T,b}^{ch} = \frac{p_{T,b}^{ch}}{p_{T,jet}^{ch}}$$

arXiv:2202.13901

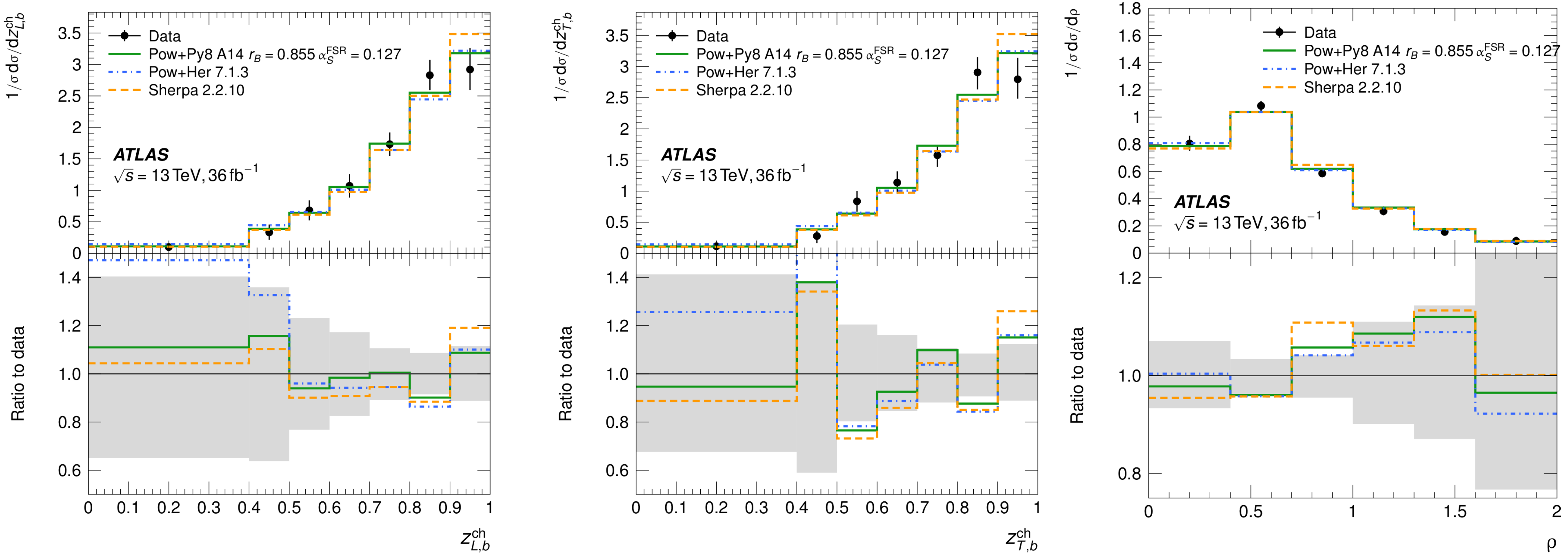
b-quark fragmentation

- ✓ Select top pairs dilepton channel
  - ✓ Events with exactly two jets and at least one b-tagged jet.
- ✓ b-hadron reconstruction:
  - ✓ Use tracks matched to a jet.
  - ✓ Tracks matched to a secondary vertex.
- ✓ Unfolding to stable particle (tracks) level.





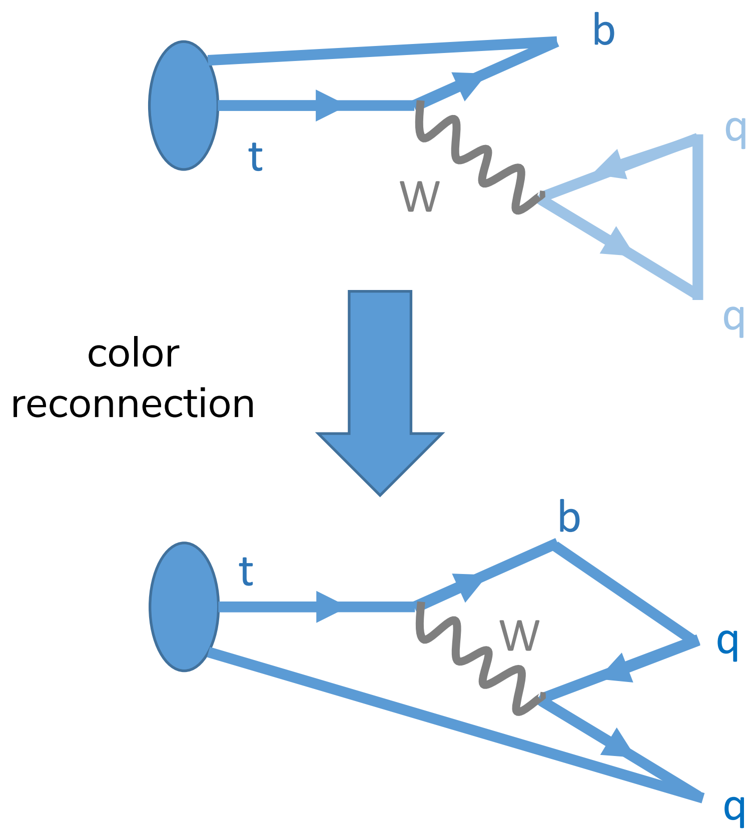
Measurements sensitive to b-quark fragmentation in top pairs



Reasonable agreement between data and prediction

Color reconnection

- ✓ Colour reconnection addresses the problem of how the colour fields rearrange themselves after the collision.
  - ✓ Important phenomenon for Monte-Carlo generators.
  - ✓ Not simulated from first principles.
  - ✓ Generators use leading-color approximation.
- ✓ Different color reconnection models:
  - ✓ Pythia, Herwig and Sherpa have different models, models need to be constrained from data.
- ✓ Color reconnection (CR) is a key ingredient in the quest for precise SM measurements, such as the top quark mass:
  - ✓ top quark decays take place right in the middle of the showering/hadronization region
  - ✓ quarks (and gluons) produced in the decay are subject to the CR

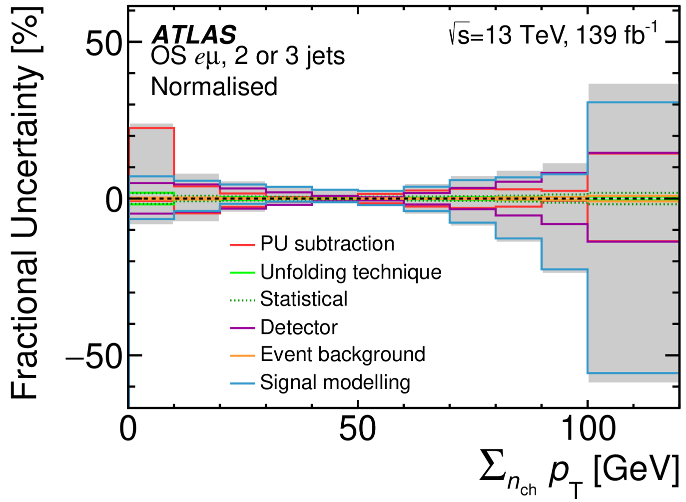


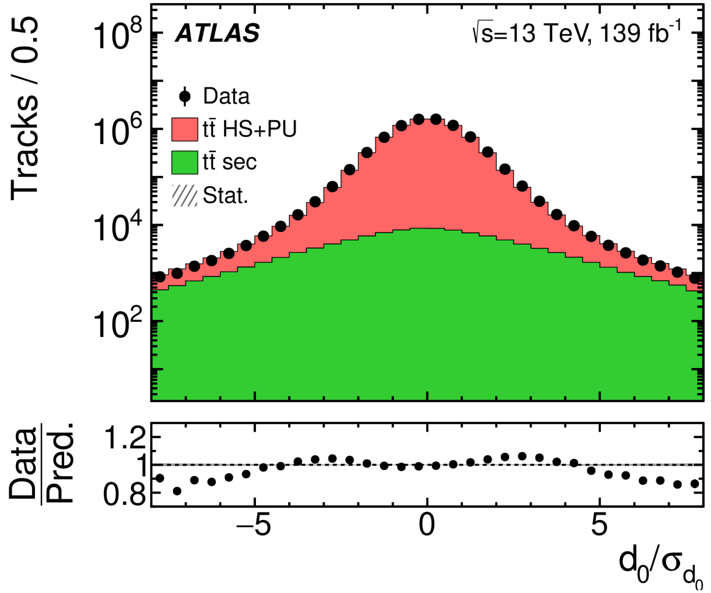
arXiv:2209.07874

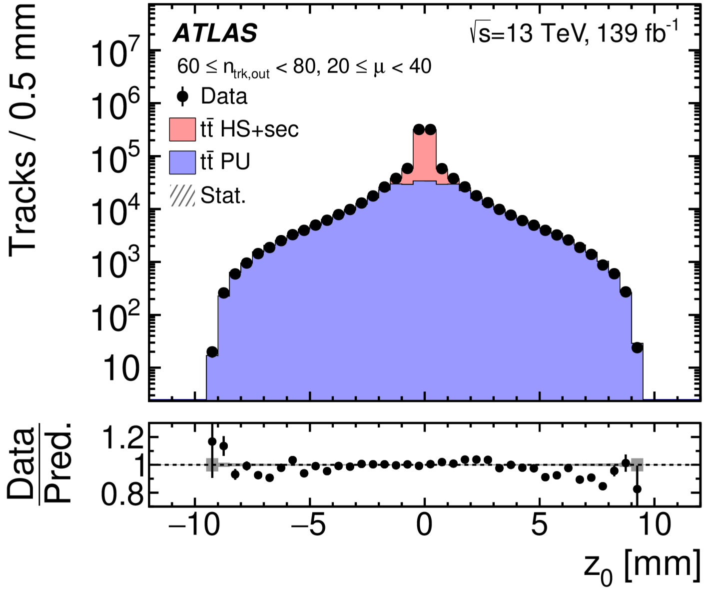
Observables sensitive to color reconnection

Color reconnection

- ✓ Select top pairs dilepton channel
- ✓ Estimate the pile-up and secondary particle tracks contamination
- ✓ Correct for the efficiency in track reconstruction
- ✓ Unfold sensitive observables to particle-level ⟶ compare unfolded data to MC predictions



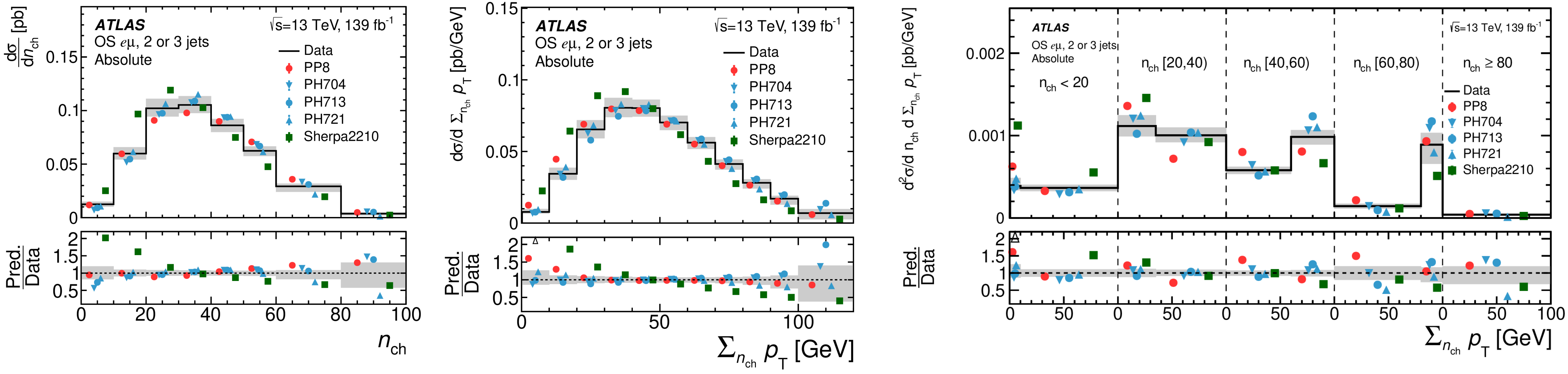




Dominant uncertainties come from pile-up tracks background and signal modeling

more details in [Claire Gwenlan talk]

Observables sensitive to color reconnection



Color reconnection

- None of the generator predictions describe the data in full range:
  - Reasonable agreement for Pythia and Herwig, with Herwig slightly better
  - From the Pythia models, nominal Pythia does better, but not able to exclude any CR models
- Sherpa assumes no color reconnection:
  - Sherpa predicts softer spectrum and more low multiplicities than seen in data

- Precise measurement of the top quark properties are being carried out at ATLAS from mass to polarization.
- Top quarks present are unique environment to test SM and theory predictions.

- ATLAS and LHC combined top mass measurements are getting extremely precise, with a 0.3% uncertainty achieved by the combination.
- W helicity fractions have been measured with high precision.
- Analysis sensitive to b-fragmentation and color reconnection help to a better understanding of the MC generators, which is crucial to reduce MC related uncertainties.

Thank you for your attention!