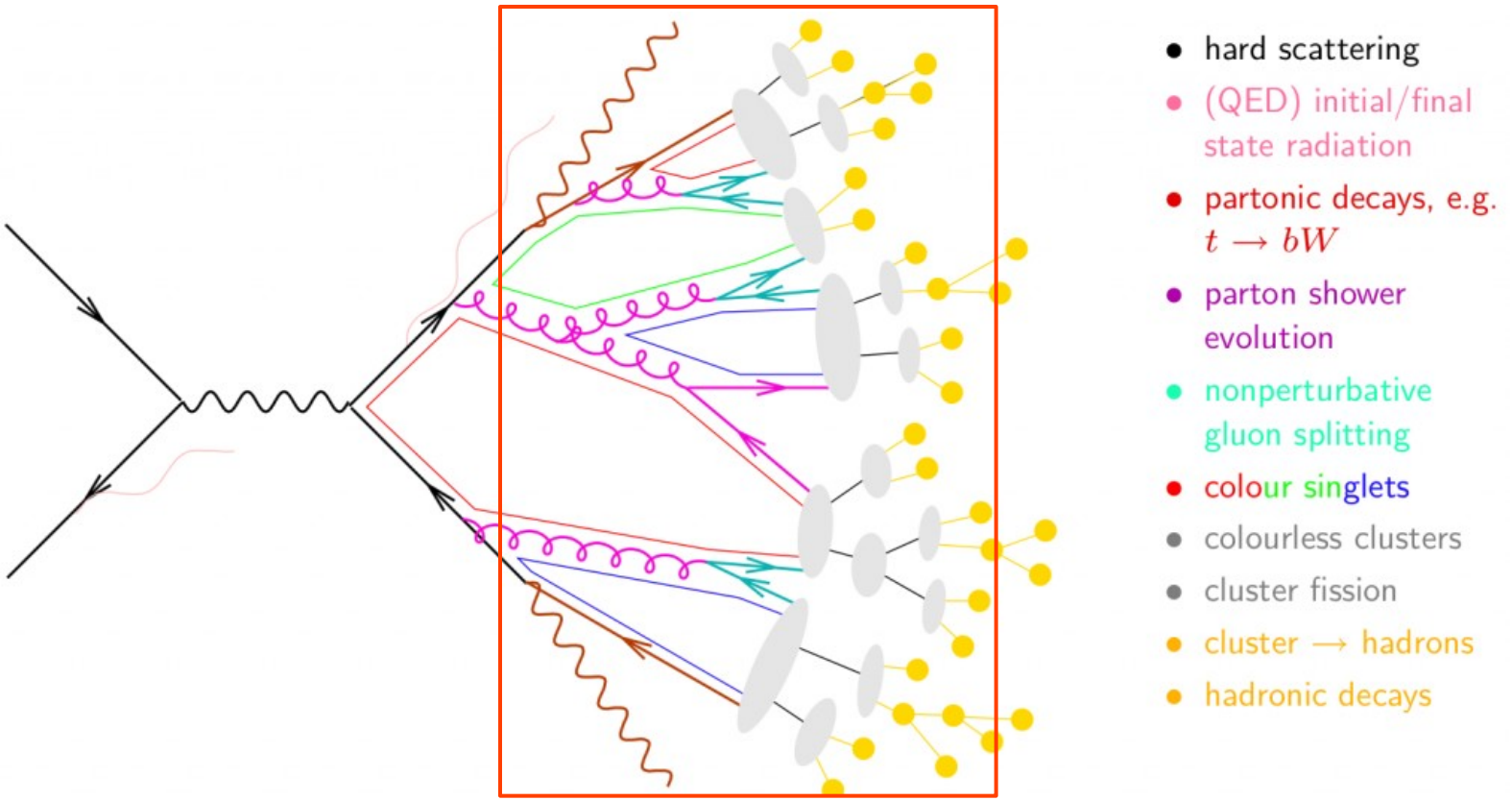
b-quark fragmentation and production of strange particles in $t\bar{t}$ events

TOP2020, 13-18 September 2020

Juan R. González Fernández on behalf of
the ATLAS and CMS Collaborations

Introduction

- Top quark-related measurements deal with non-perturbative QCD from hadronization and fragmentation.



- Top quark results affected by related uncertainties: hadronization, underlying event, color reconnection…
- b-quark fragmentation studied in ee colliders.
- pp collisions: more complex color flow. Can be studied in top quark decays.

Outlook

- K_s^0 and Λ^0 production in $t\bar{t}$ (ATLAS). Eur. Phys. J. C 79 (2019) 1017
  - pp collisions at 7 TeV.
  - Unfolded data compared with several predictions.

- Measurement of the top-quark mass with a J/ψ (CMS).
  - pp collisions at 8 TeV.
  - m(J/ψ+e,μ) sensitive to $t\bar{t}$ modeling. JHEP 12 (2016) 123
  - Comparison with various predictions.

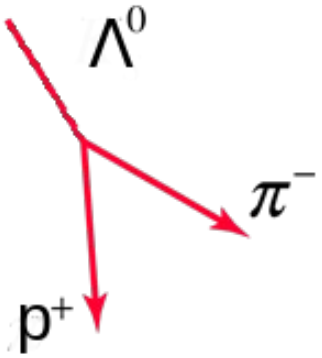
- Study of b-quark fragmentation in $t\bar{t}$ (ATLAS). NEW ATLAS-CONF-2020-050
  - pp collisions at 13 TeV.
  - Observables from b-hadron and b-jet kinematics.
  - Unfolded distributions compared with several predictions.

K_S^0 and Λ^0 production in $t\bar{t}$ (ATLAS)

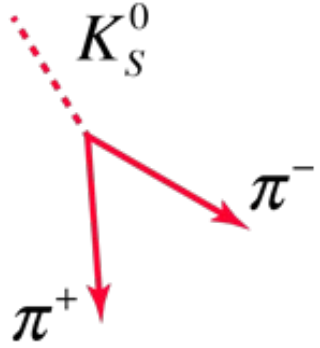
Eur. Phys. J. C 79 (2019) 1017

- Study of neutral strange hadrons in $t\bar{t}$ events.
- Production of strange particles is sensitive to parton shower, fragmentation, multiparton interactions (MPI).
- Decays considered in the analysis:

$\Lambda^0 \rightarrow p^+ + \pi^-$



$K_S^0 \rightarrow \pi^+ + \pi^-$



K_s^0 and Λ^0 production in $t\bar{t}$ (ATLAS)

Eur. Phys. J. C 79 (2019) 1017

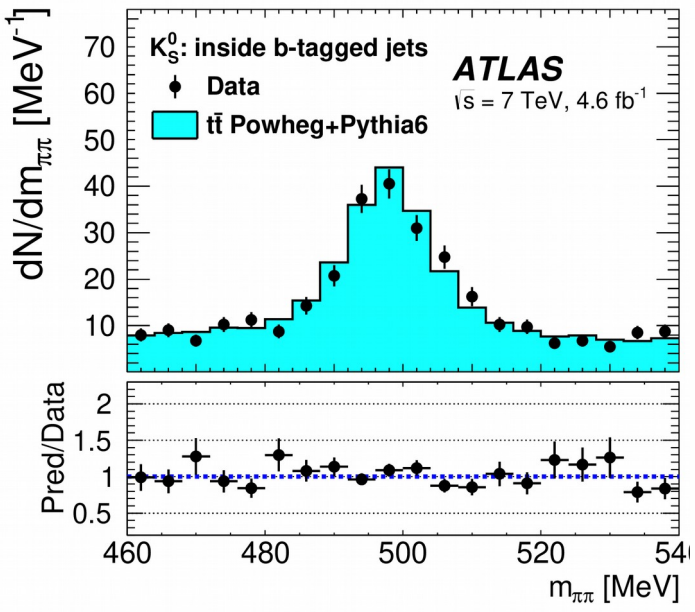
- pp dataset, 4.6 fb^{-1} at 7 TeV.
- $t\bar{t}$ events in the dilepton channel.
- K_s^0 and Λ^0 are reconstructed from charged particles coming from a displaced vertex:

  $K_s^0 \rightarrow \pi^- \pi^+$

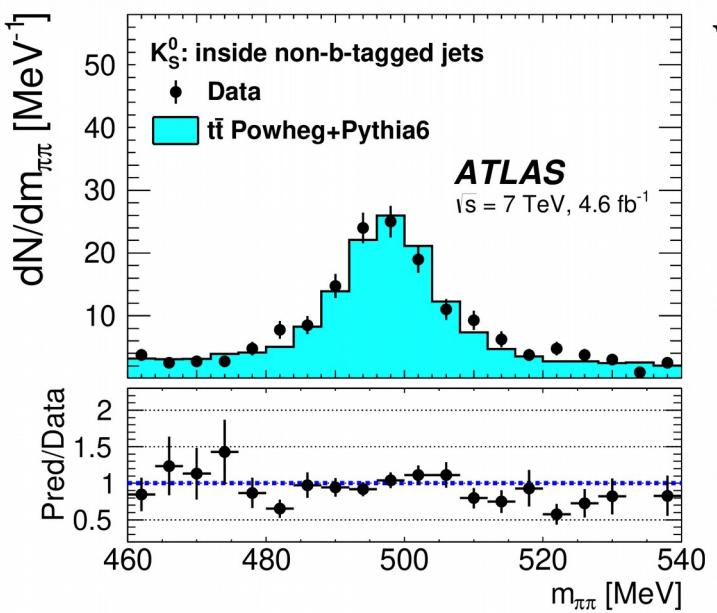
  $\Lambda^0 \rightarrow p\,\pi$

  - Three categories:

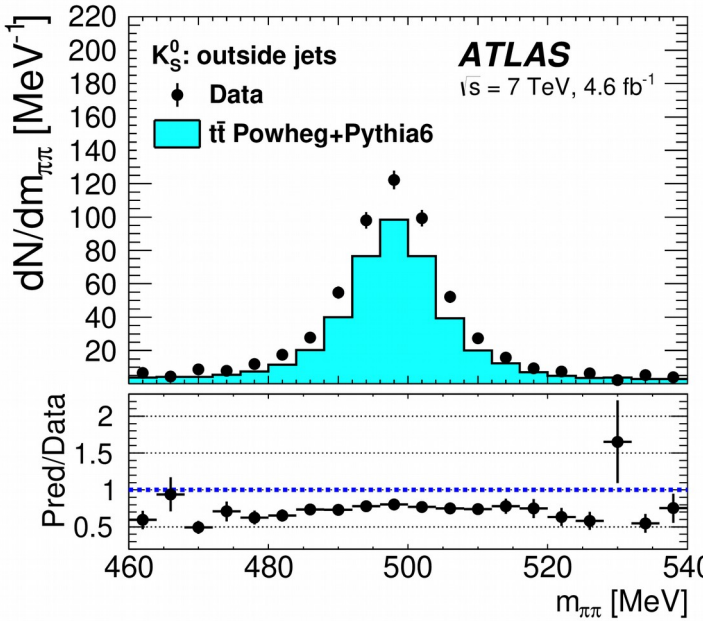
Inside b-tagged jets



Inside non b-tagged jets

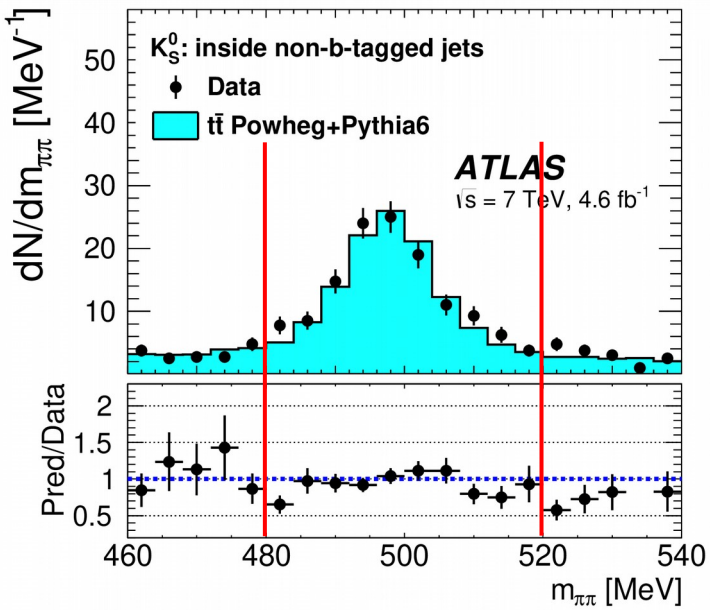


outside jets



Background subtraction

Eur. Phys. J. C 79 (2019) 1017



Background from fake reconstruction is taken from sidebands and subtracted in several kinematic distributions.

Applied to both data and prediction.

Cross check in MC studies and with an alternative method (gaussian + constant fit).

Number of candidates after background subtraction:

Class	N_K	N_Λ
Inside *b*-tagged jets	530 ± 34	115 ± 19
Inside non-*b*-tagged jets	391 ± 25	65 ± 14
Outside any jet	1837 ± 49	183 ± 18
Total sample	2758 ± 69	363 ± 31

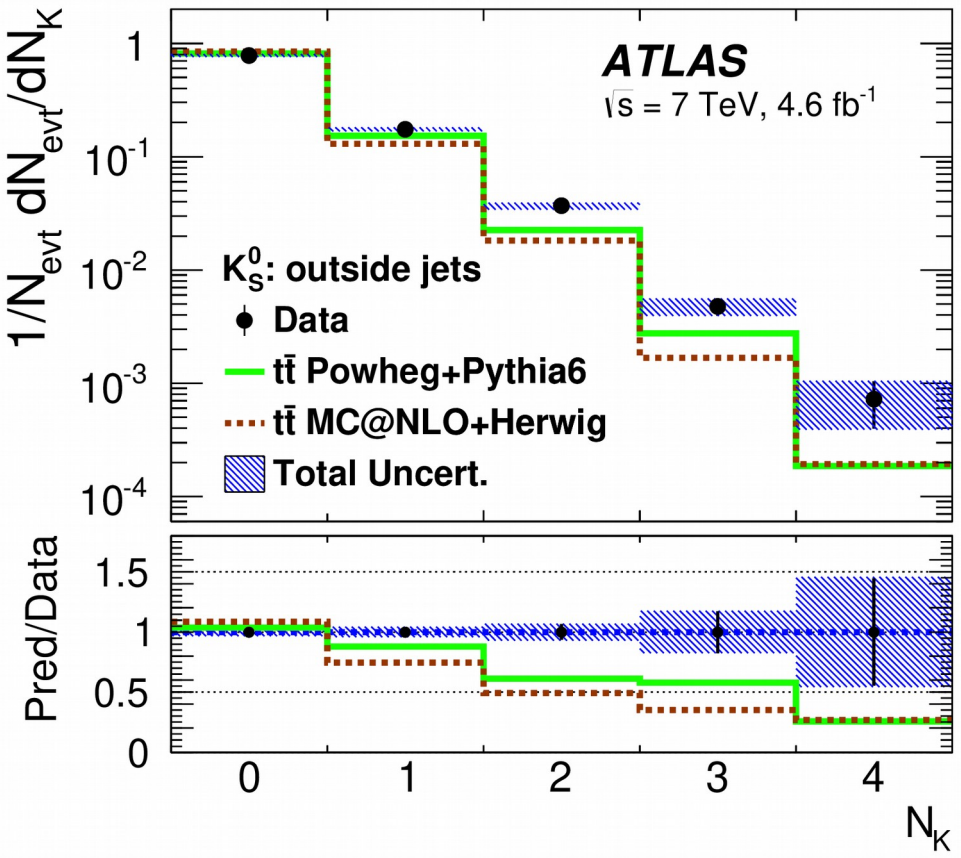
Detector level results

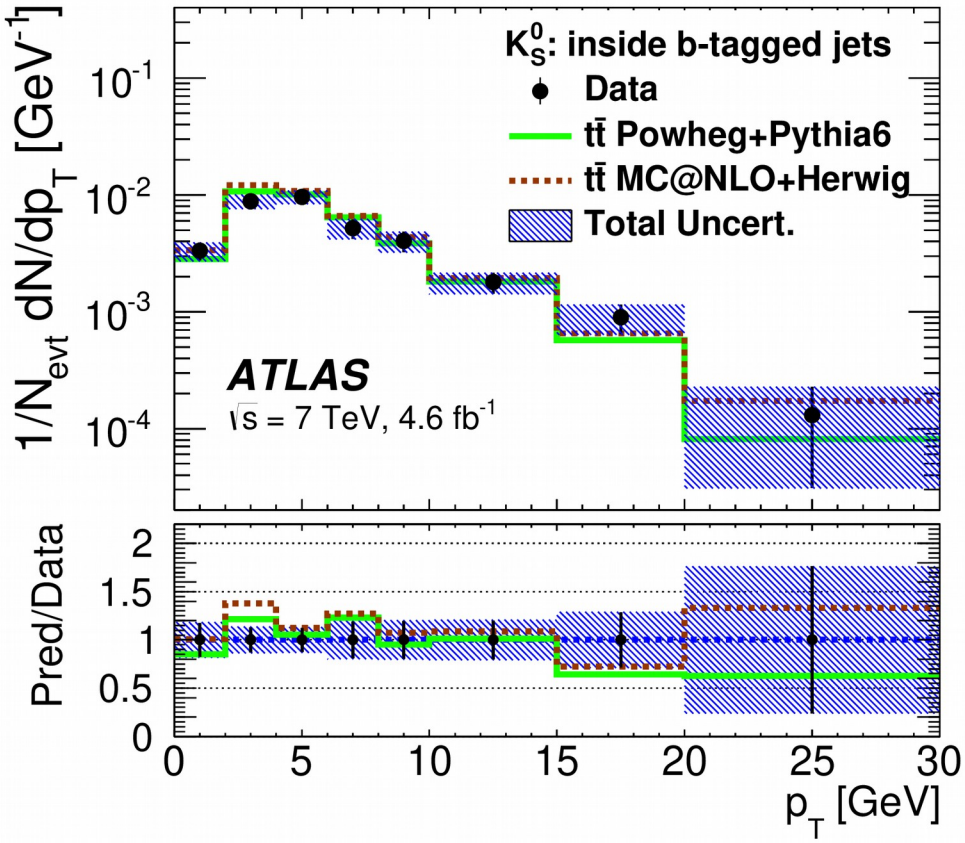
Eur. Phys. J. C 79 (2019) 1017

Explored distributions: p_T, E, η, R_{xy}, N, $x_k = E_k/E_{jet}$.

Normalization: good agreement except for K_S^0 and Λ^0 reconstructed outside jets: MC predictions predict ~30% less events.

Shapes: fair agreement for most of the distributions, with the exception of the multiplicity of Λ^0, K_S^0 .

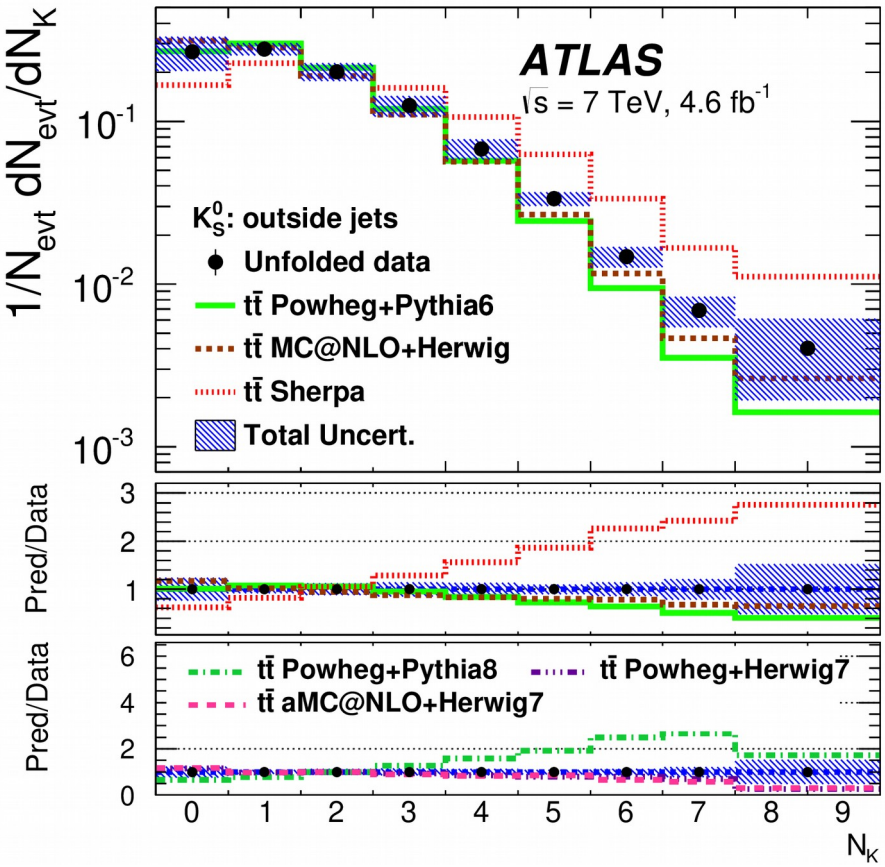


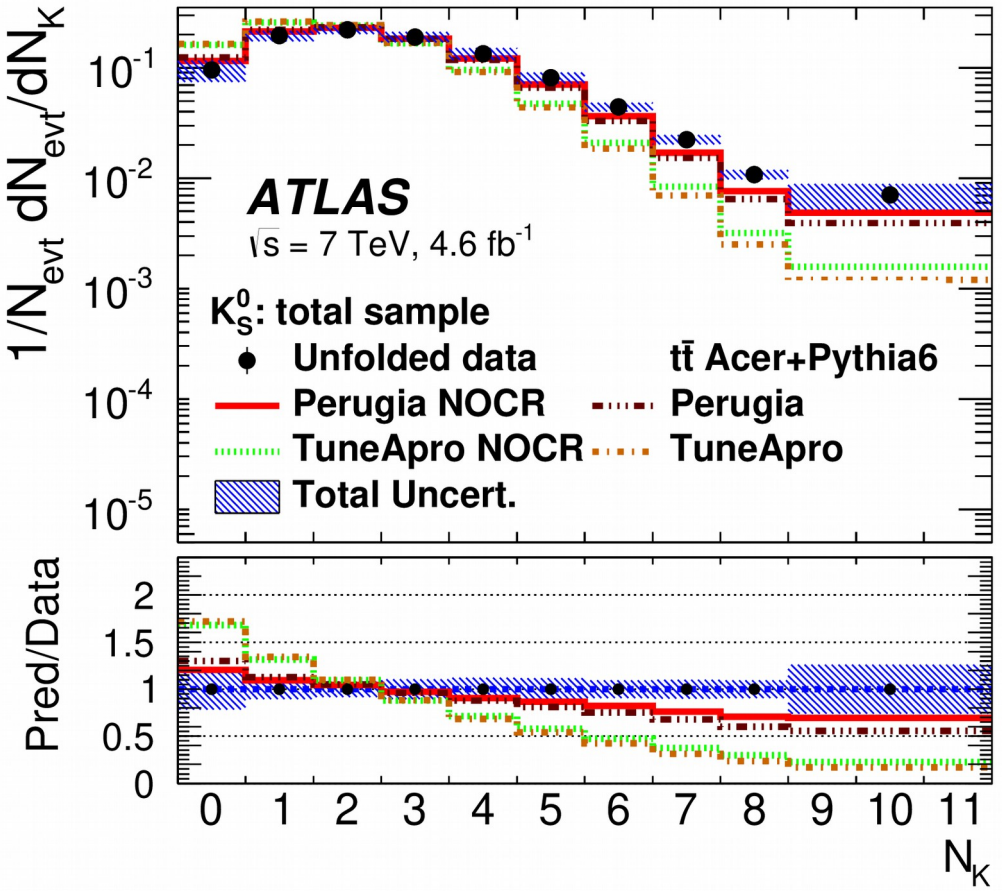


Results for unfolded distributions

Eur. Phys. J. C 79 (2019) 1017

Unfolding to particle level applied to data. Unfolded distributions are compared to several MC generators and different MC tunes.



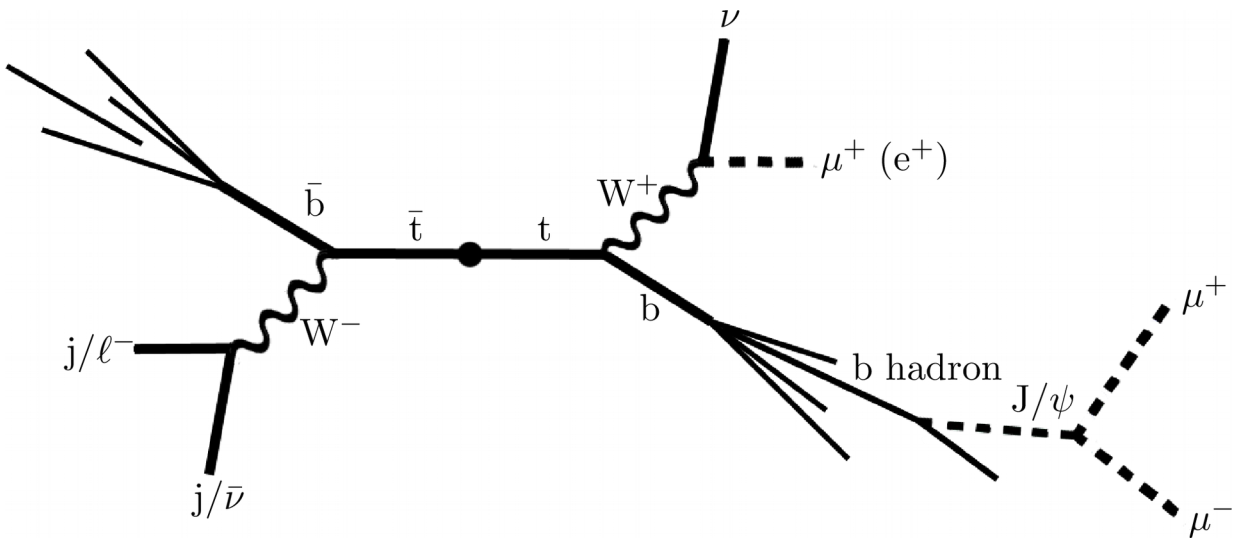


In general, good agreement with predictions. The kaon multiplicity is sensitive to modeling and suggest that the tune of CR and MPI can be improved.

Measurement of the top-quark mass with a J/ψ

JHEP 12 (2016) 123

- The modeling of b-fragmentation effects can be studied in $t\bar{t}$ events with a $b \rightarrow J/\psi$ decay.



Measurement of the top-quark mass:

m(t) is correlated with m(e/μ + J/ψ)

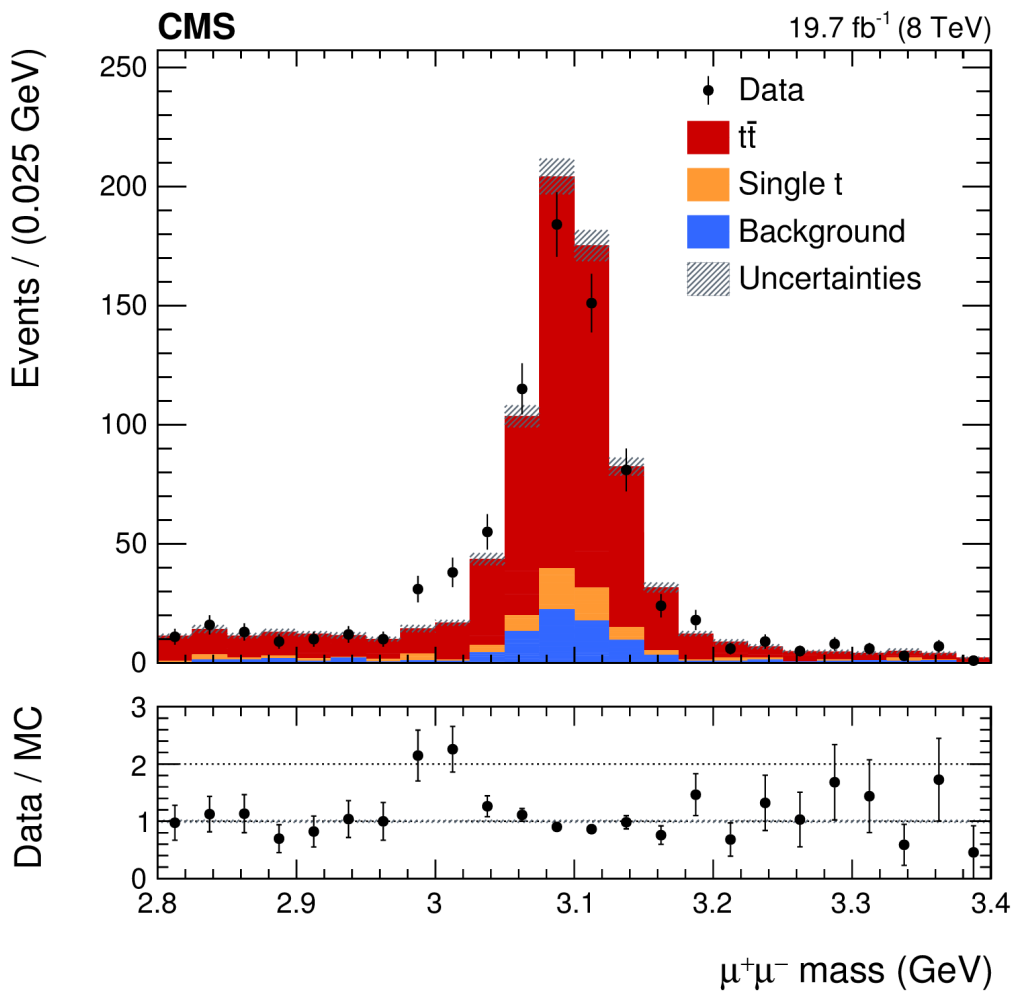
- Clean channel: multilepton final state (3 or 4 leptons).
- Rather small branching fraction: ~1.5×10^{-3}.
- Single-top events are considered signal.

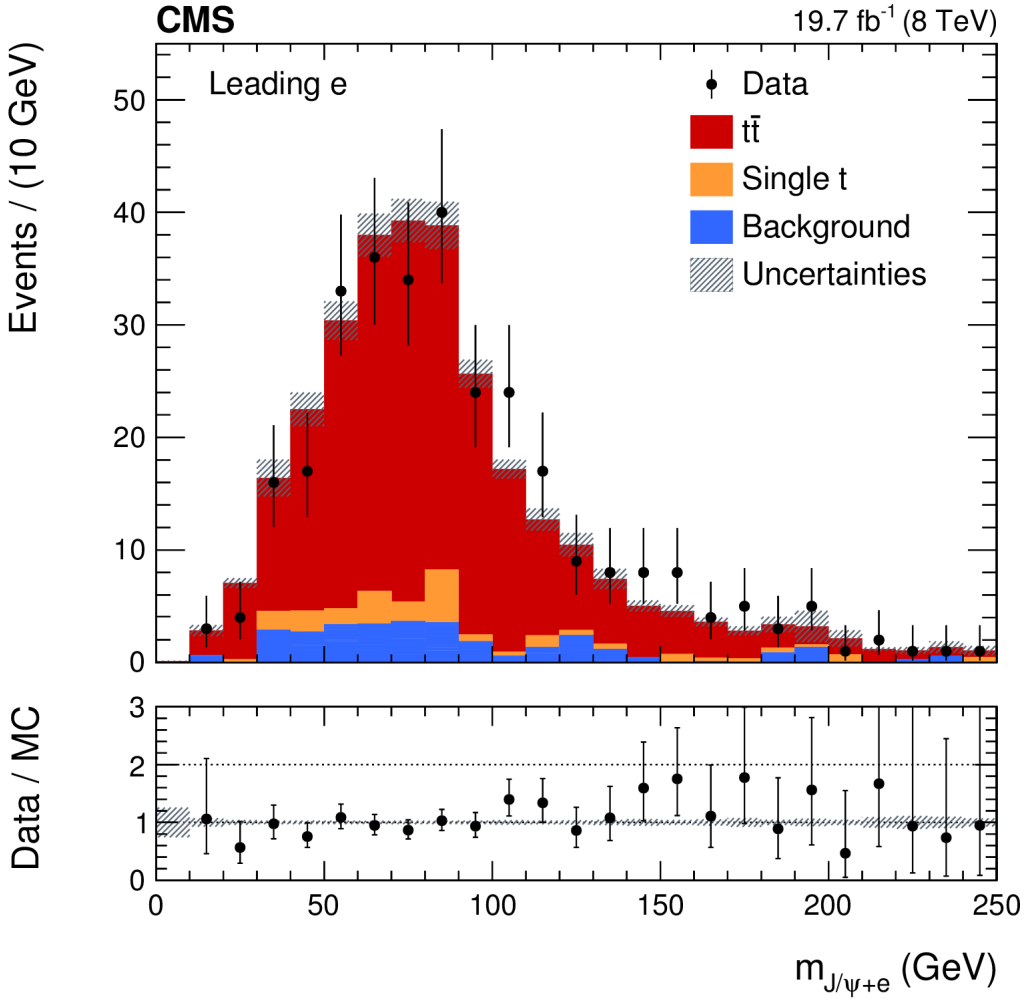
Measurement of the top-quark mass with a J/ψ

JHEP 12 (2016) 123

pp collisions at 8 TeV, 19.7 fb^{-1}.

- Both dileptonic and semileptonic decays are considered.
- Selected events must contain a J/ψ candidate (μμ).

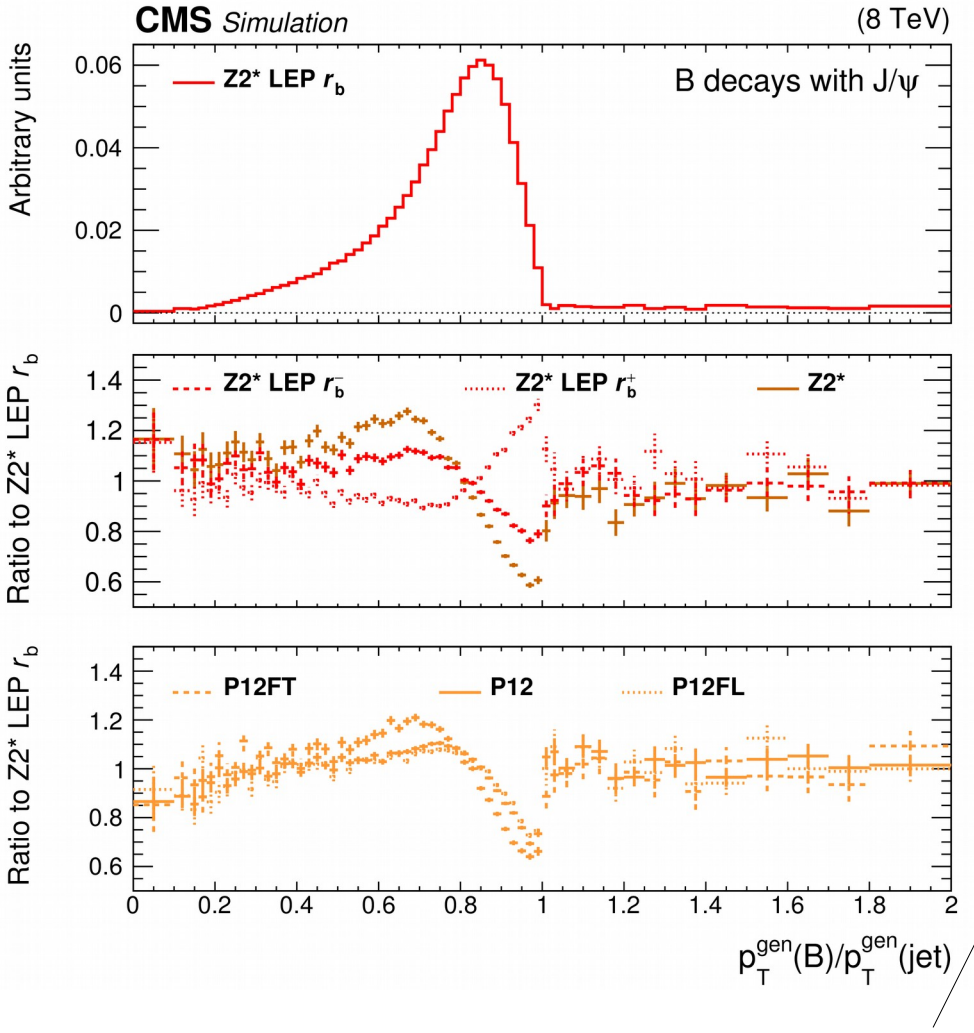


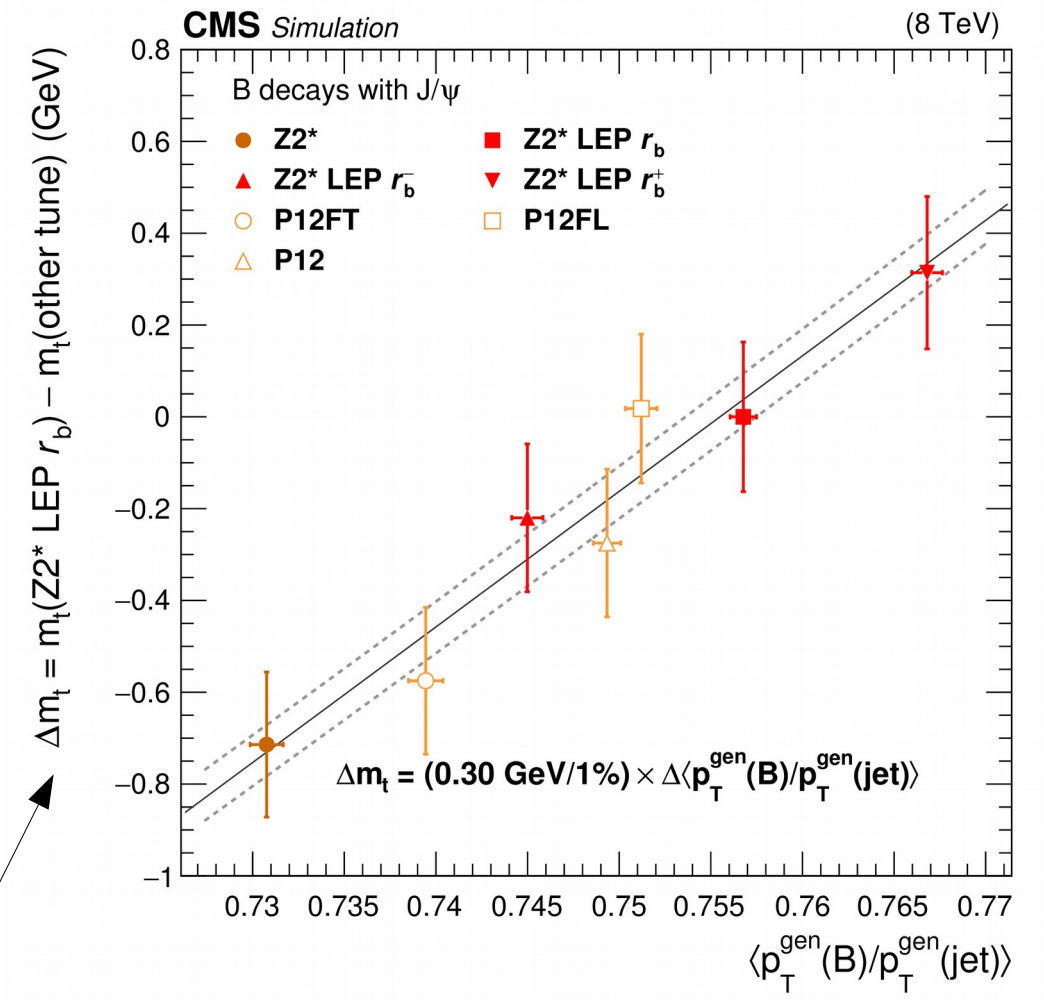


Comparison to different tunes

JHEP 12 (2016) 123

- The b-fragmentation modeling is proven for different MC tunes. The mean of the ratio $p_T^{gen}(B)/p_T^{gen}(jet)$ is tested as a function of the top quark mass.





Top quark mass difference in MC between the reference tune and other tunes.

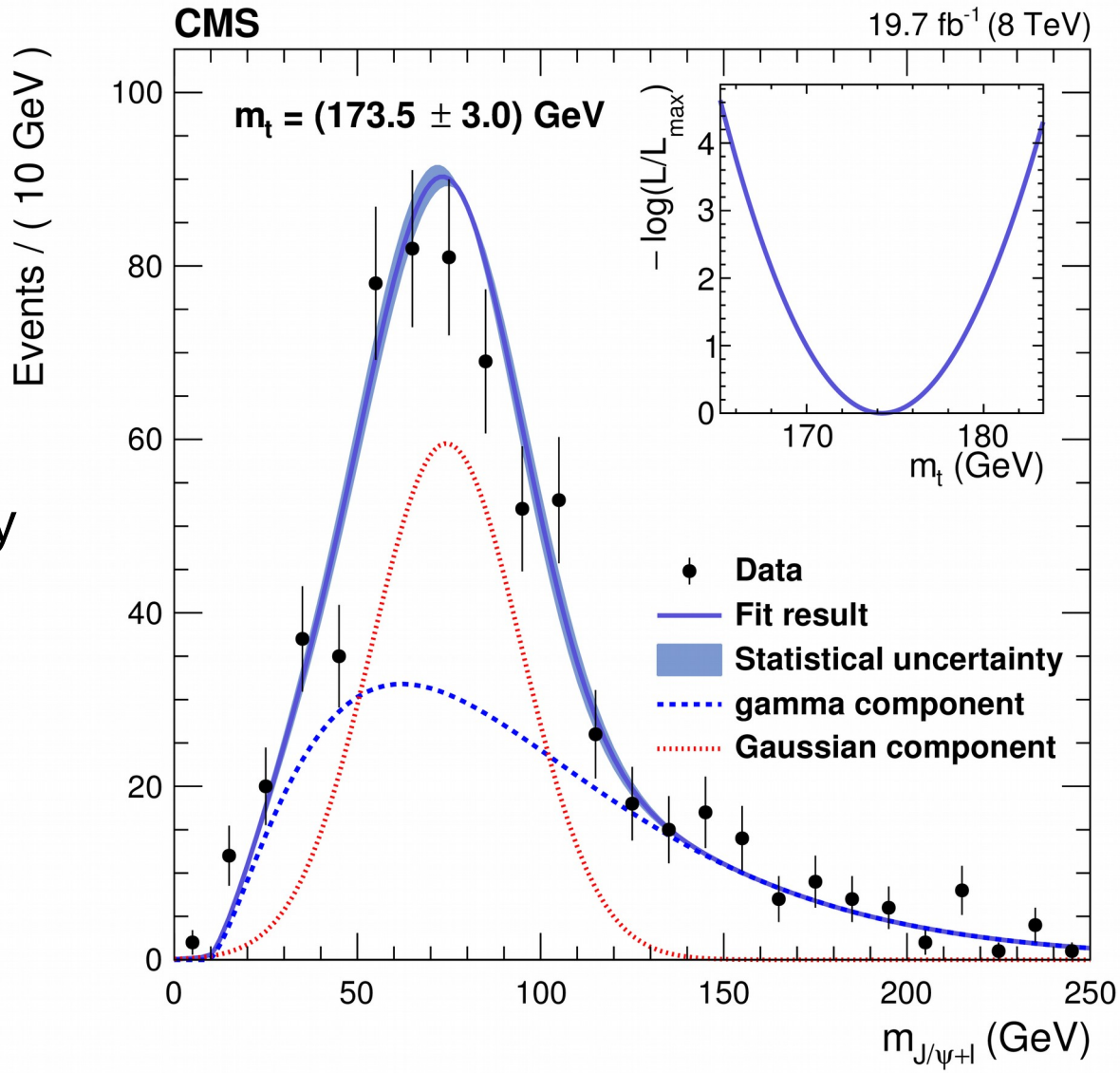
Fit to m(J/ψ+e,μ)

JHEP 12 (2016) 123

- Fit to the m(J/ψ+e,μ) distribution with a gaussian (signal) + gamma (bkg) function.

μ parameter of the gaussian component is shown to be very correlated with the top quark mass.

A value of 173.5 ± 3.0 GeV is measured.



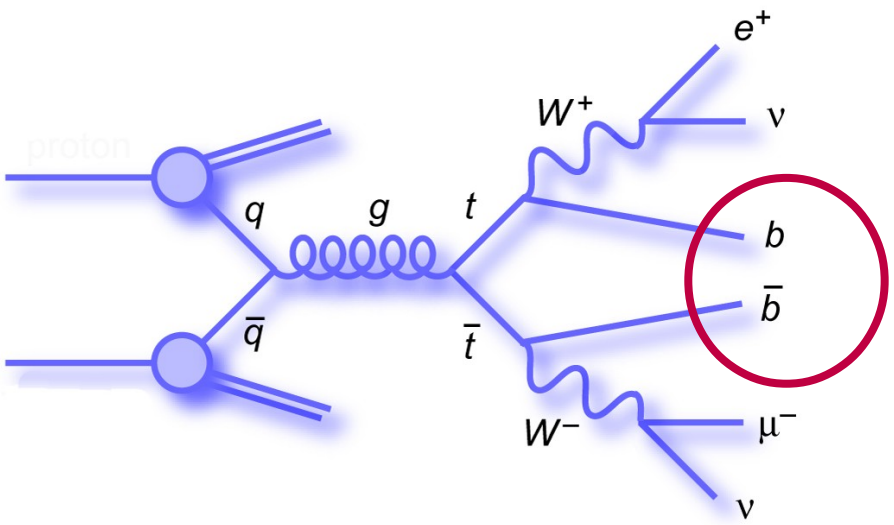
- Uncertainty dominated by statistics.

b-quark fragmentation in $t\bar{t}$ (ATLAS)

ATLAS-CONF-2020-050

Study of observables sensitive to b-fragmentation in $t\bar{t}$ events in the eμ final state.

NEW



jets containing b-hadrons

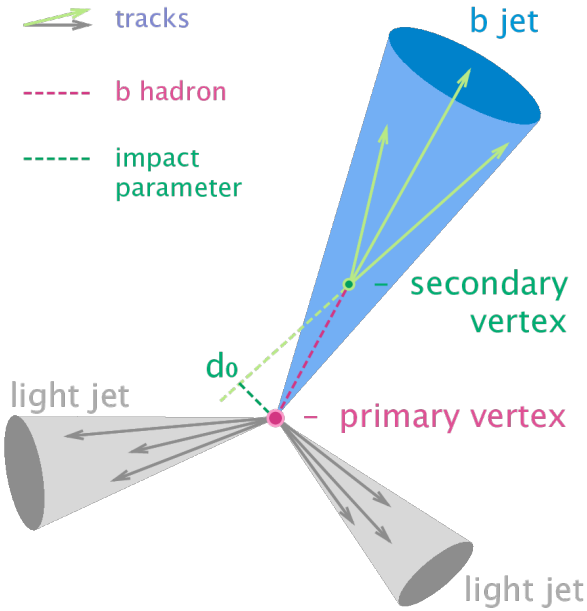
- This process provides a pure sample of b-jets that are used to:
  - Test of heavy-flavor fragmentation modeling at the LHC.
  - Comparison of generators, and different tunes.

b-quark fragmentation in $t\bar{t}$ (ATLAS)

ATLAS-CONF-2020-050

- 36.1 fb^{-1} of pp collisions collected by ATLAS at 13 TeV.
- Event preselection: exactly two leptons (eμ, opposite charge), exactly 2 jets, at least one of which is b-tagged.
- Charged particles are reconstructed as coming from the primary vertex or a secondary vertex.

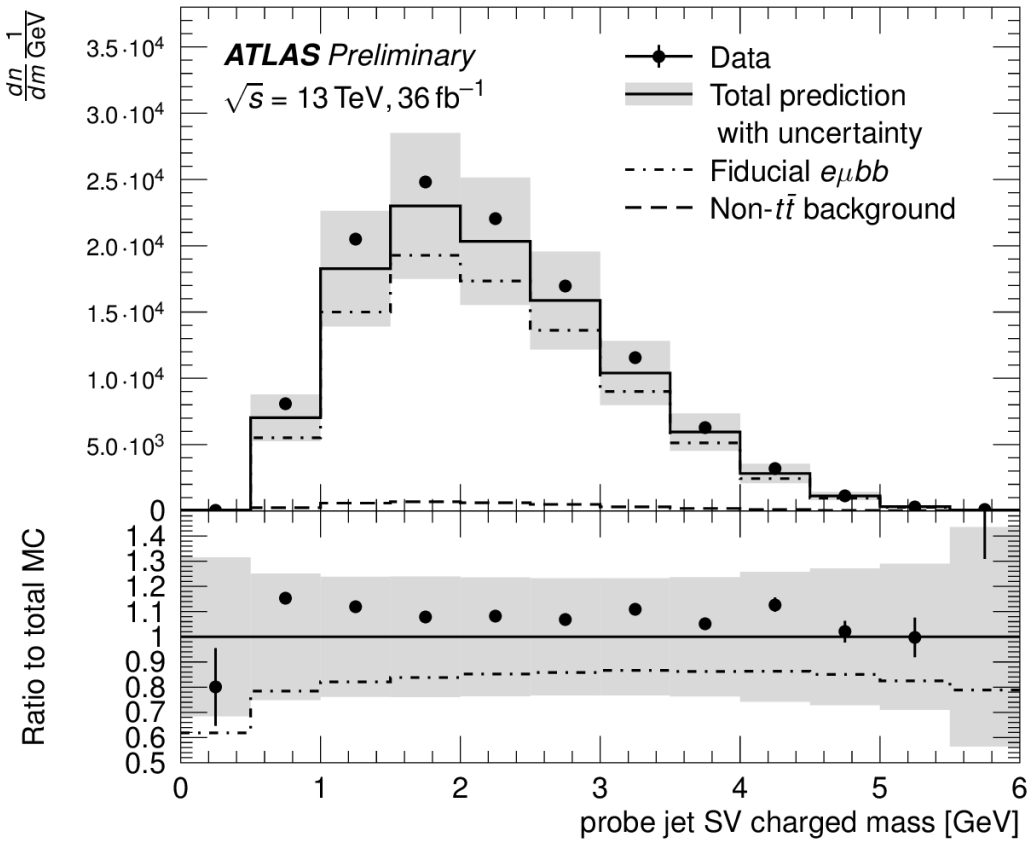
  b-hadrons are reconstructed and several observables are calculated.
- Unfolded data compared to different predictions.



Fiducial definition

- Fiducial object definition:
  - Prompt electrons and muons with p_T>25 GeV, |η| < 2.5
  - Anti-k_T jets with R=0.4, p_T>30 GeV, |η| < 2.5.
    b-jets tagged with the MV2c20 algorithm with 70% efficiency.
  - Charged particles reconstructed from charged tracks with p_T>500 MeV, |η| < 2.5

- To select a pure sample of b-jets and minimize any potential bias: weakly-decaying b-hadrons are reconstructed from charged particles and a tag-and-probe technique is used.



Observables

- The following observables are measured for all the probe-jets passing the selection.

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

momentum sum of all fiducial charged daughters

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

all fiducial charged particles that either are jet constituents or are b-hadron daughters

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

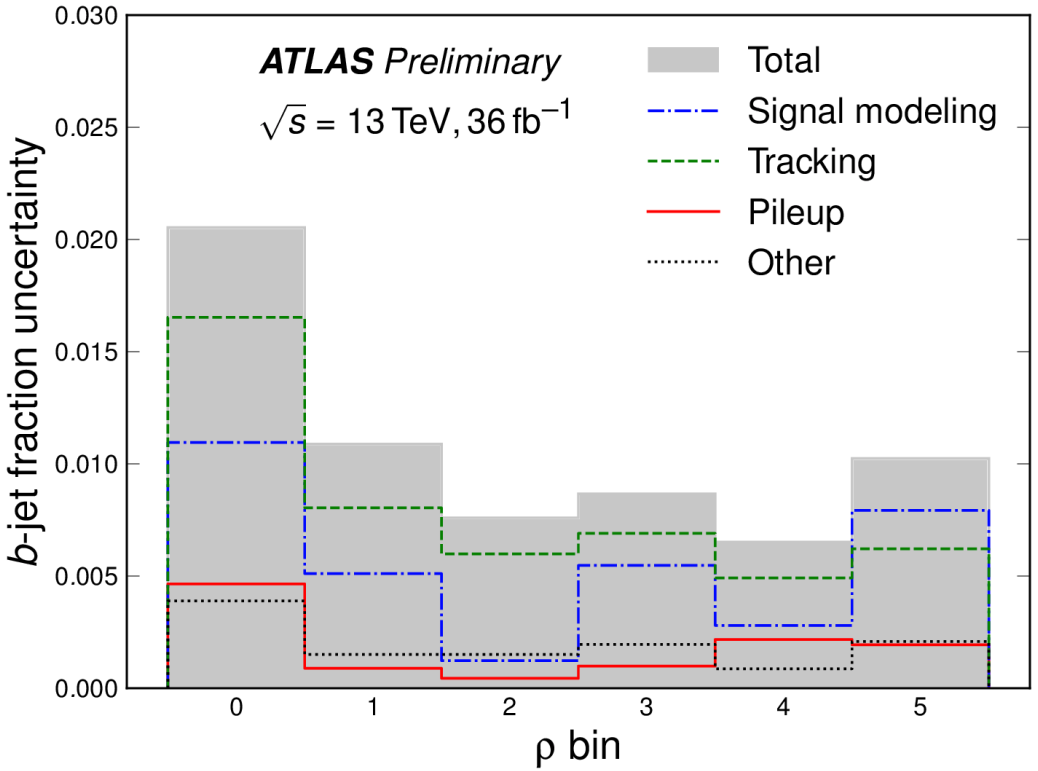
$$n_b^{\mathrm{ch}} = \text{number of fiducial } b\text{-hadron children.}$$

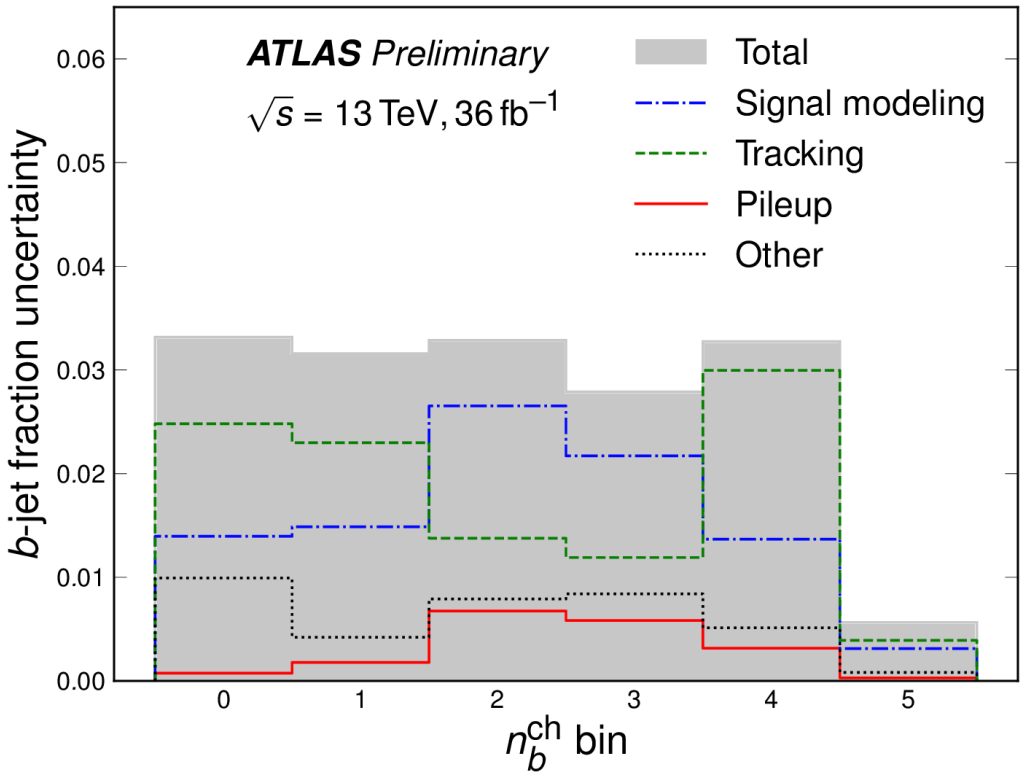
Observed distributions are unfolded using a Full Bayesian Unfolding method to get the particle-level differential cross section.

b-fragmentation uncertainties

ATLAS-CONF-2020-050

- Uncertainties are considered for tt modeling, background prediction and detector. The statistical uncertainty is dominant in a few bins.

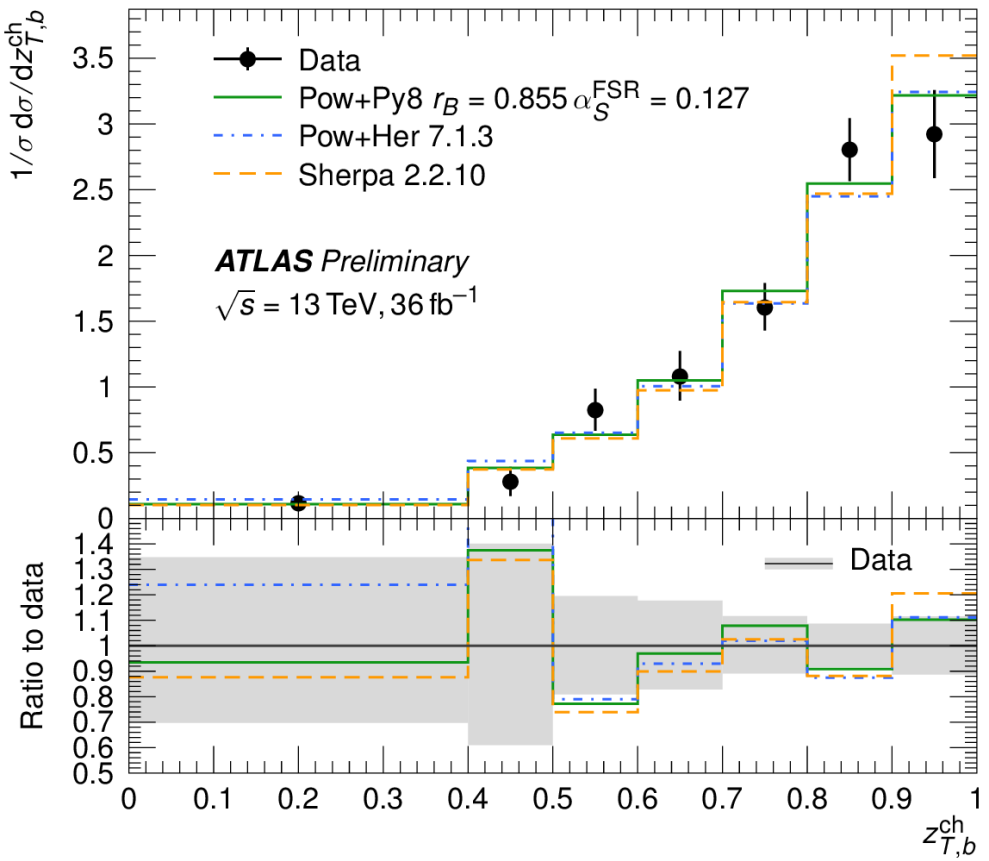


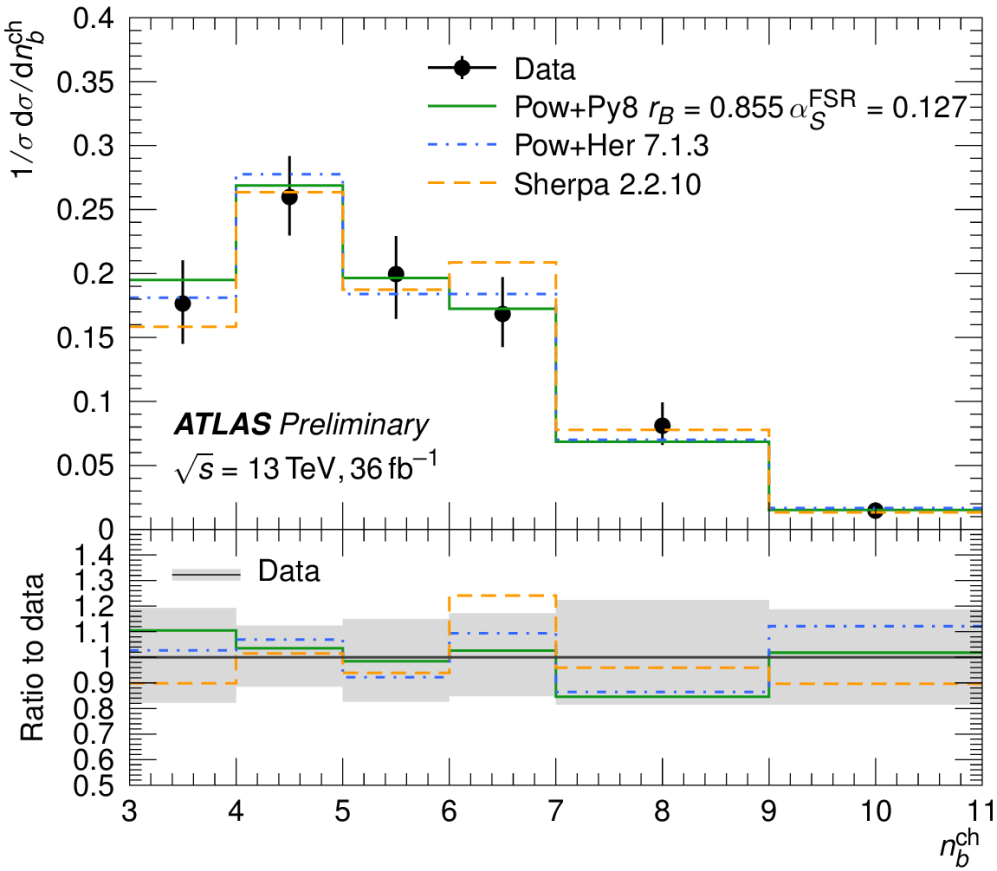


Results – different generators

ATLAS-CONF-2020-050

- The differential cross section is compared with different MC predictions.



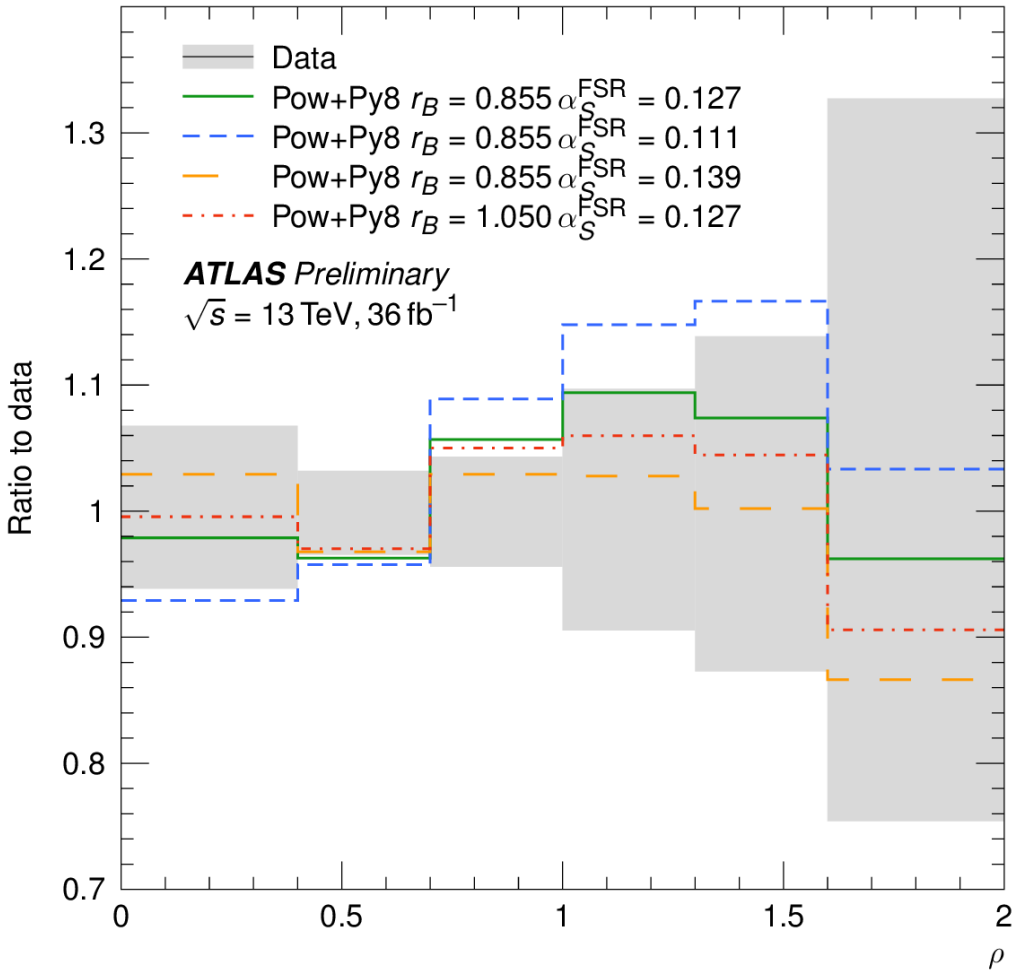


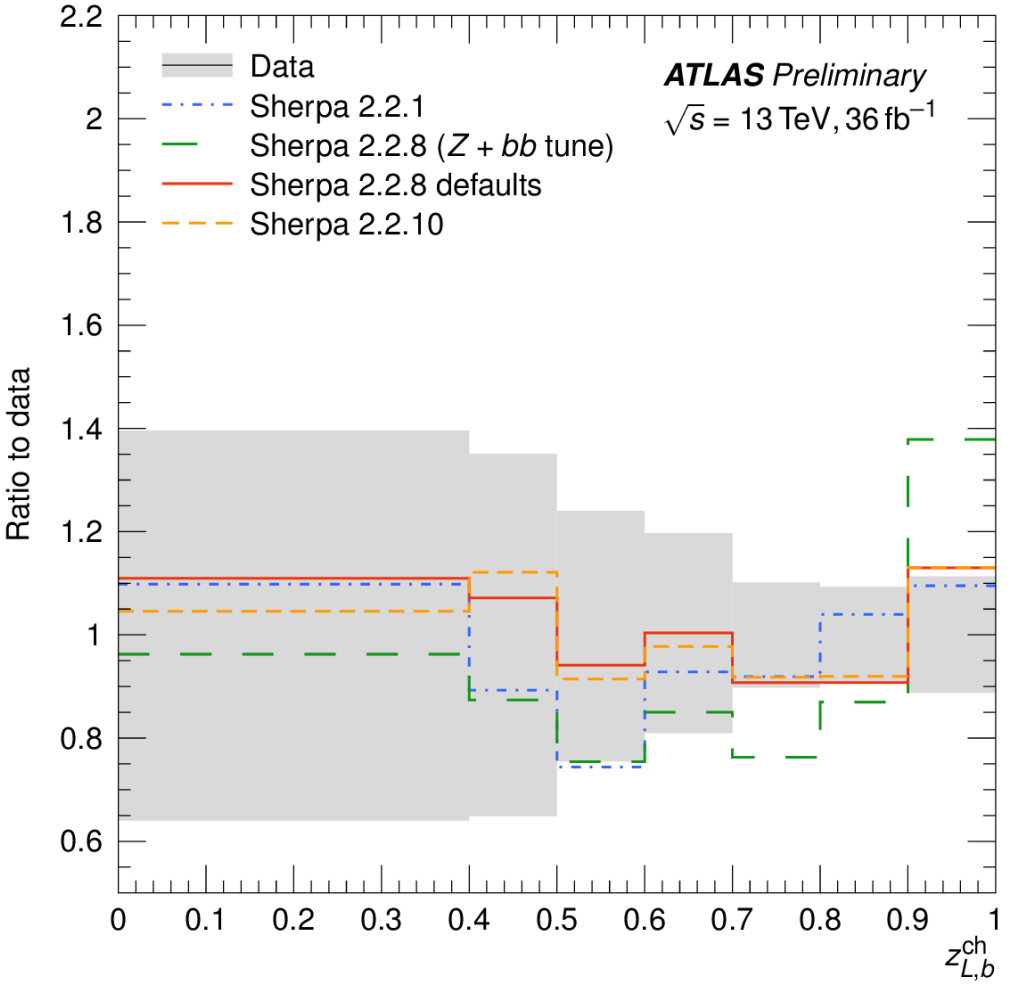
- Predictions are mostly in agreement with the particle-level observed cross section.

Results – different parameters

ATLAS-CONF-2020-050

- The differential cross section is also compared with different MC tunes for Powheg+Pythia, Powheg+Herwig and Sherpa.





- The observables are found to be sensitive to the MC tunes. In general, good agreement is observed within the data uncertainties.

Conclusions

- The study of b-fragmentation related observables using b-quark J/ decays and K_S^0 and Λ^0 hadrons in events containing top quarks has been presented. These research proves that $t\bar{t}$ events can be used to study b-fragmentation and give insight on improving the modeling of the underlying event or color reconnection.

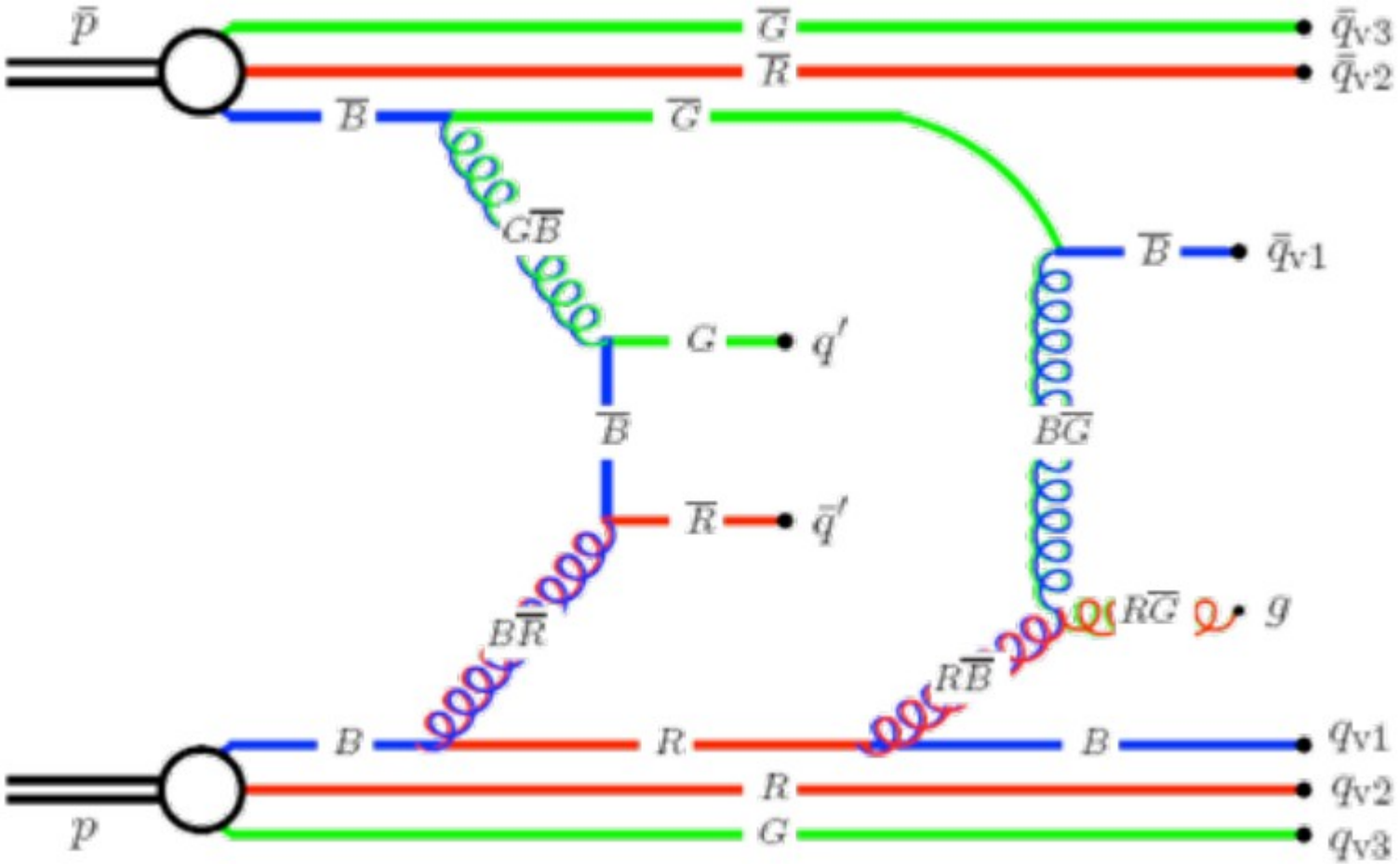
- A new ATLAS analysis has been presented for the first time. This analysis probes b-fragmentation and hadronization modeling using $t\bar{t}$ events.

- Results at detector or particle level are compared with different predictions. Most of the state-of-the-art parton shower generators give predictions in agreement with the SM, with small exceptions.

Thank you!

Backup slides

Color reconnection



K_s^0 and Λ^0 production in $t\bar{t}$ (ATLAS)

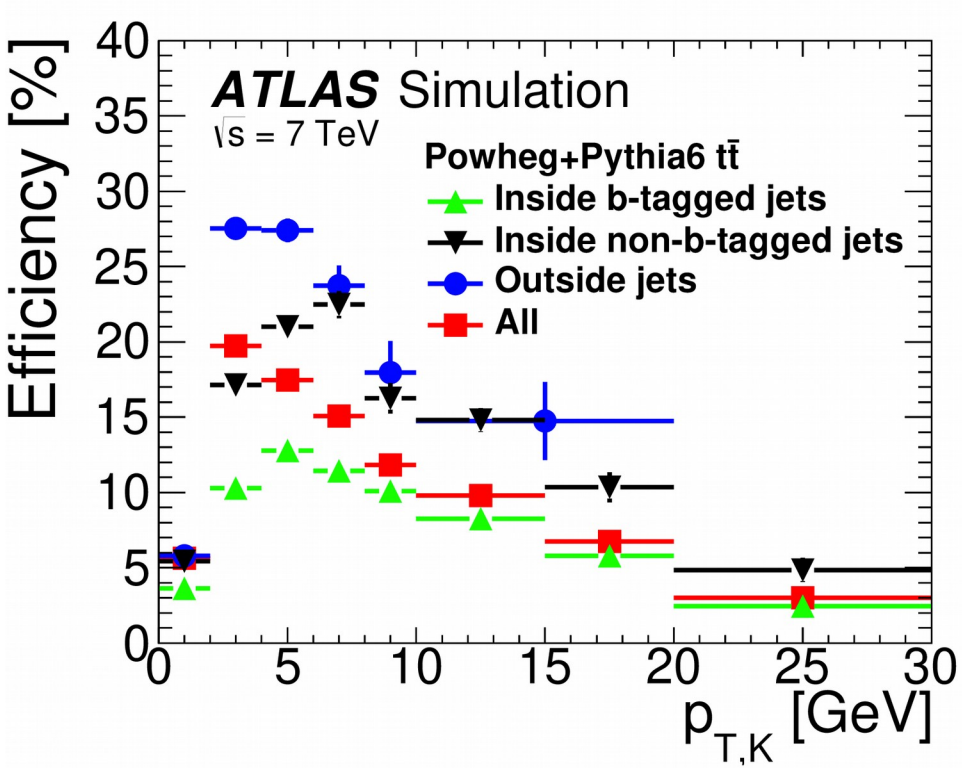
Eur. Phys. J. C 79 (2019) 1017

Main uncertainty: choice of MC to calculate efficiencies – modeling of the parton shower and hadronization.

Systematic uncertainty	MC choice	PU	Tracking	JES	JER	Fiducial	Non-closure
Relative values	< 20–25%	~ 8%	~ 4–5%	< 5%	< 5%	< 5%	< 1 %

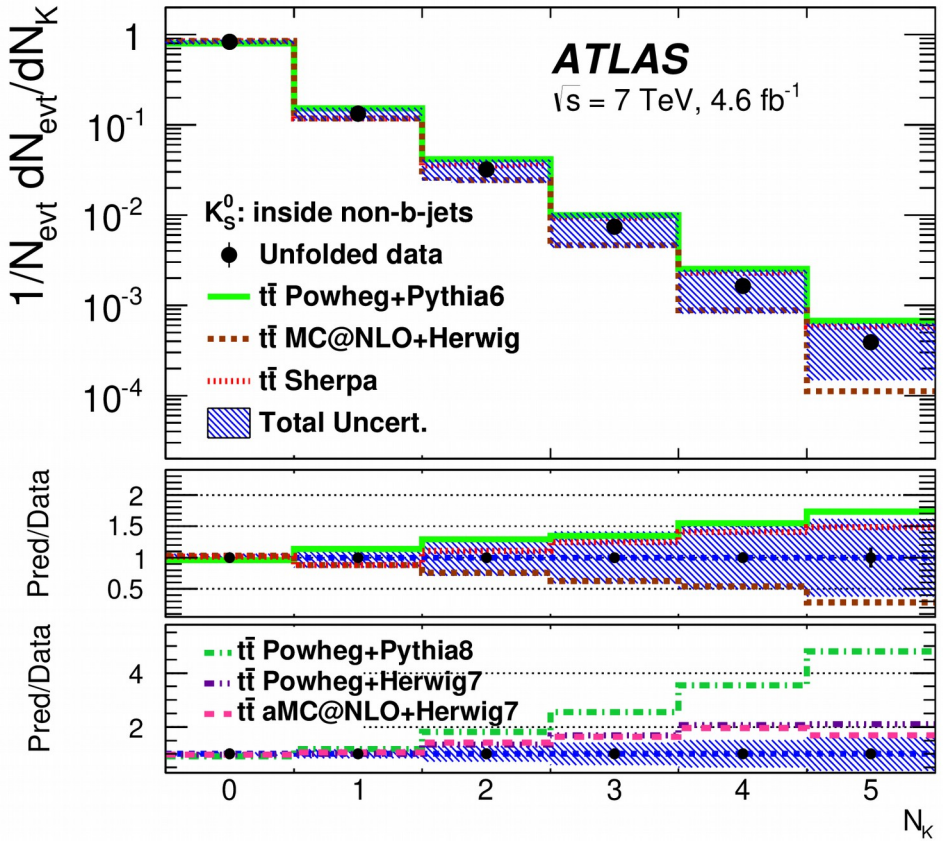
Unfolding to particle level

Eur. Phys. J. C 79 (2019) 1017



For most of the kinematic distributions: efficiencies calculated in a bin-by-bin basis.

Parton multiplicity distributions (migrations might be important): Bayesian unfolding procedure.



Yields

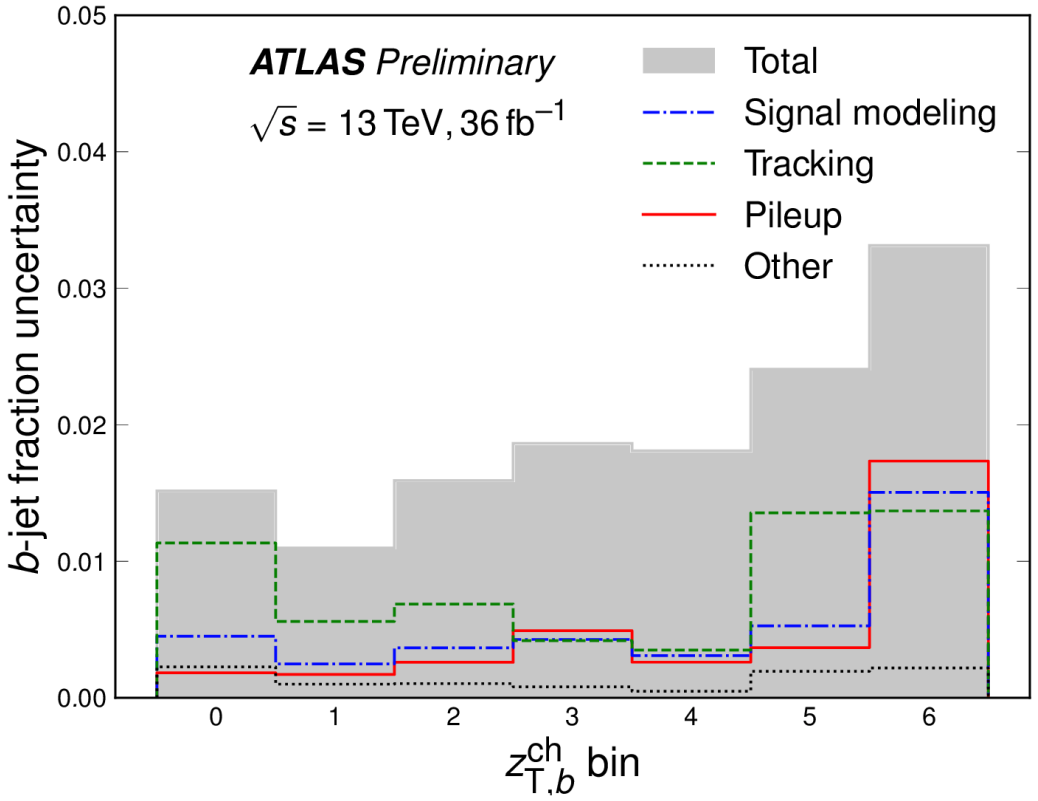
ATLAS-CONF-2020-050

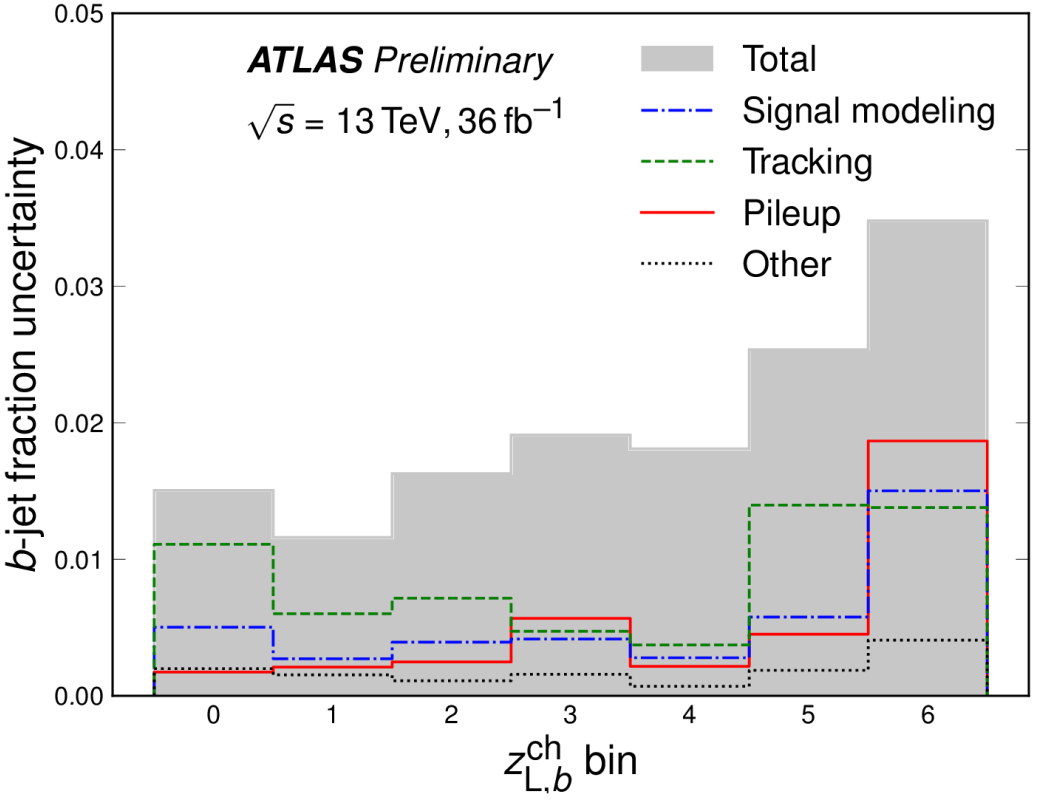
	events with $e\mu jj$ (≥ 1 b-tag)		probe-jets	
process	predicted yields			
fiducial $t\bar{t}$	–		44000	± 12000
non-fiducial $t\bar{t}$	–		6700	± 1900
total $t\bar{t}$	76000	± 18000	51000	± 12000
single top	4400	± 1500	1580	± 600
Z+jets	125	± 45	13.0	± 5.1
diboson	90	± 34	9.7	± 3.9
total non-$t\bar{t}$	4600	± 1600	1600	± 600
b-jets	–		52200	± 12000
c-jets	–		180	± 60
other jets	–		250	± 70
total prediction	81000	± 18000	53000	± 12000
	observed yields			
data	88511		57476	

b-fragmentation uncertainties

ATLAS-CONF-2020-050

- Uncertainties are considered for tt modeling, background prediction and detector. The statistical uncertainty is dominant in a few bins.

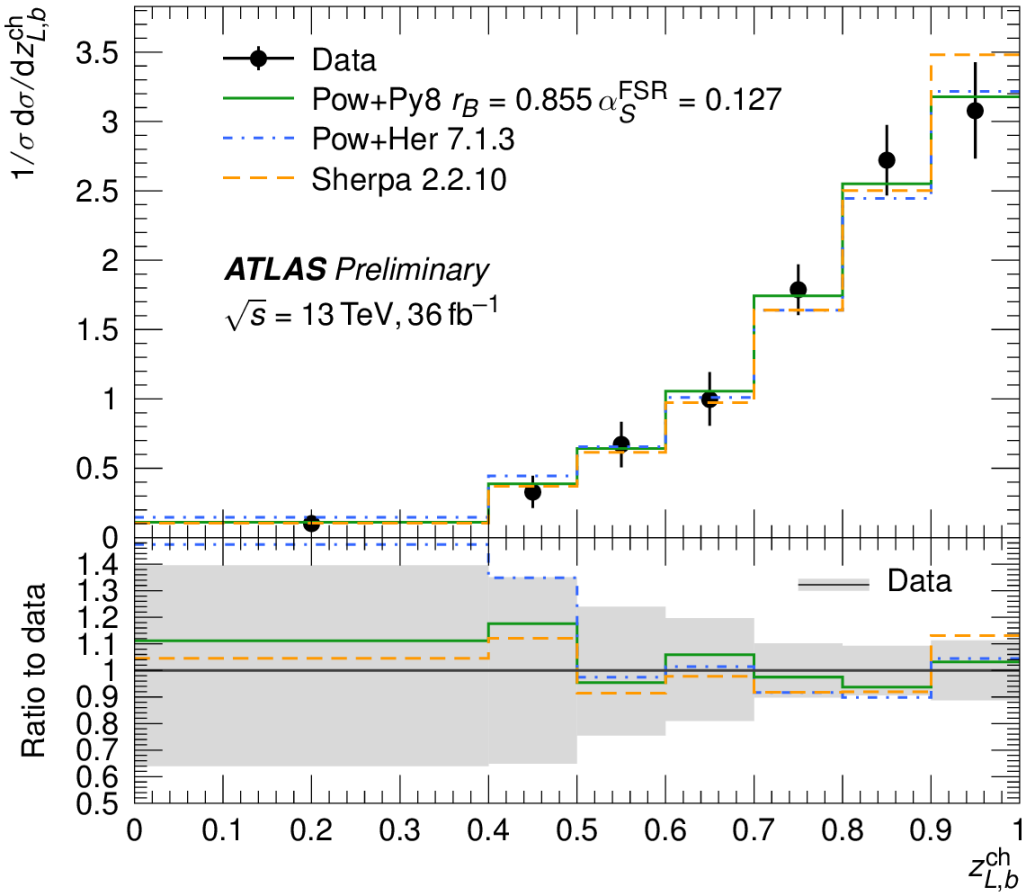


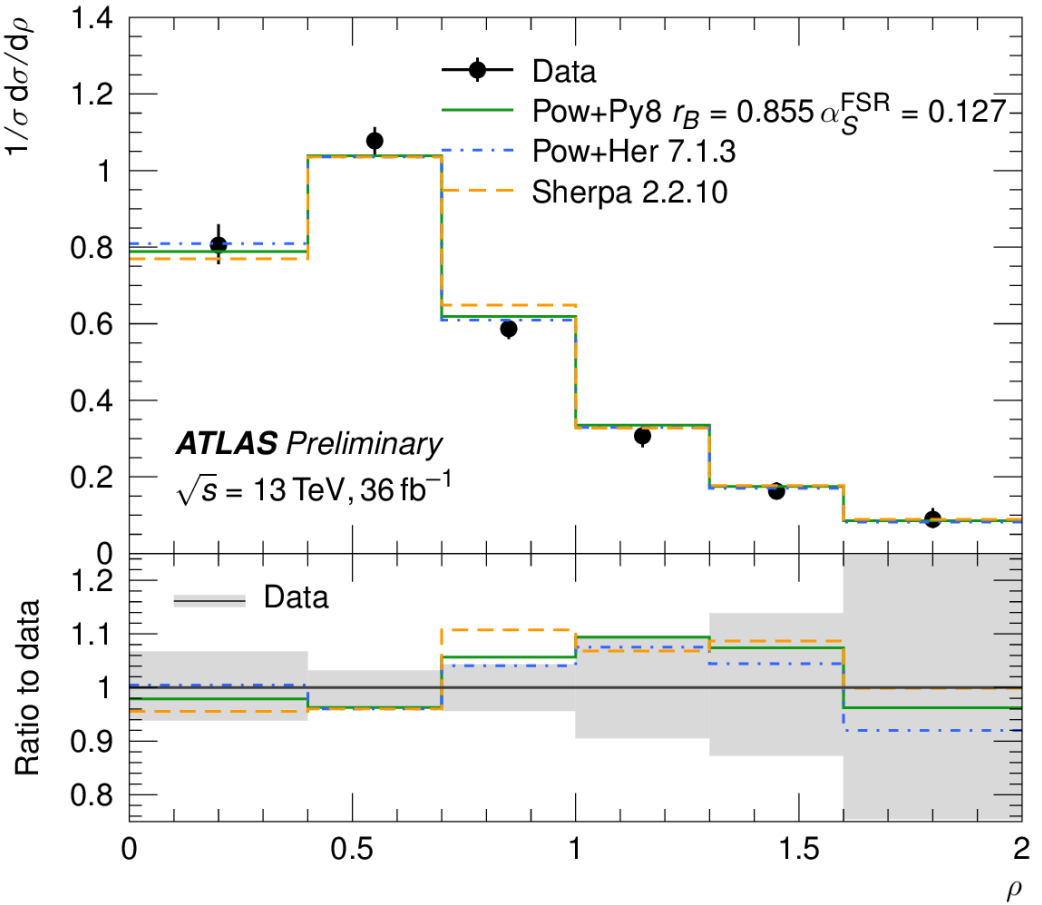


Results – different generators

ATLAS-CONF-2020-050

- The differential cross section is compared with different MC predictions.





- Predictions are mostly in agreement with the particle-level observed cross section.