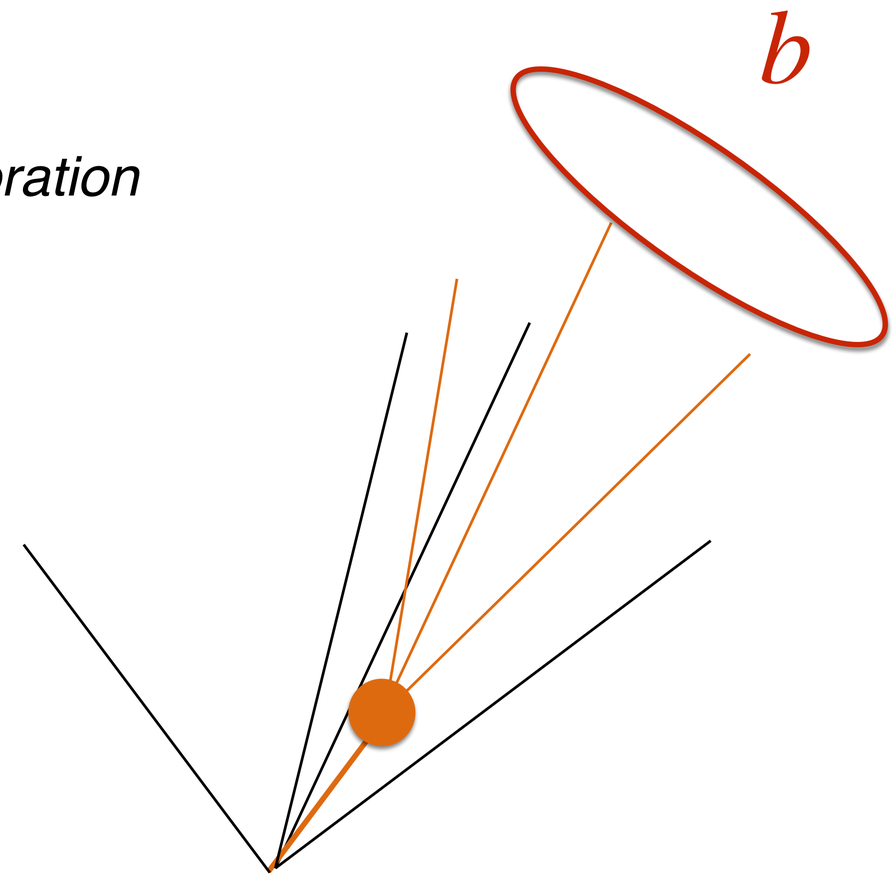
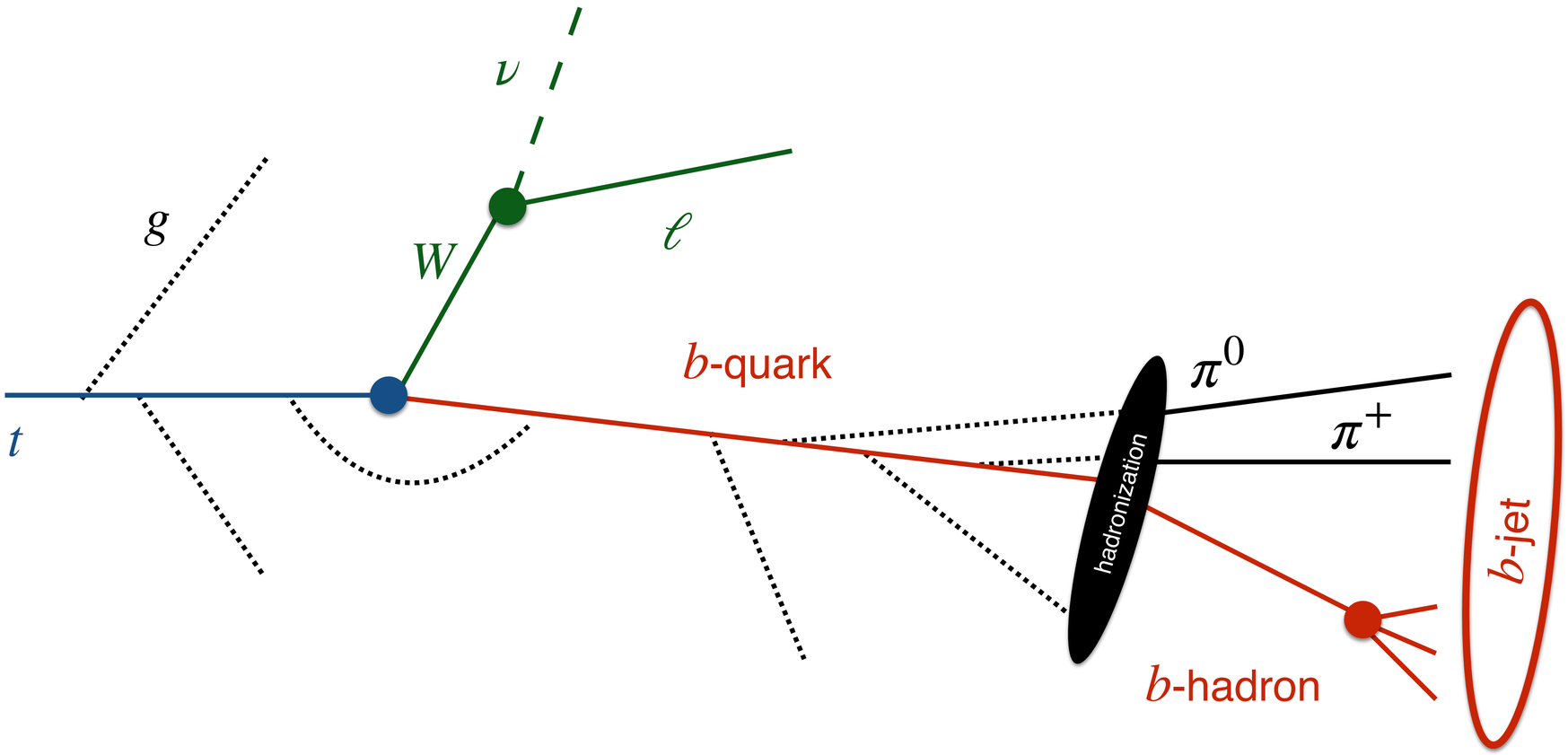
measuring b-fragmentation with ATLAS

Chris Pollard
on b-half of the ATLAS collaboration

ECFA WHF meeting
2022 04 21

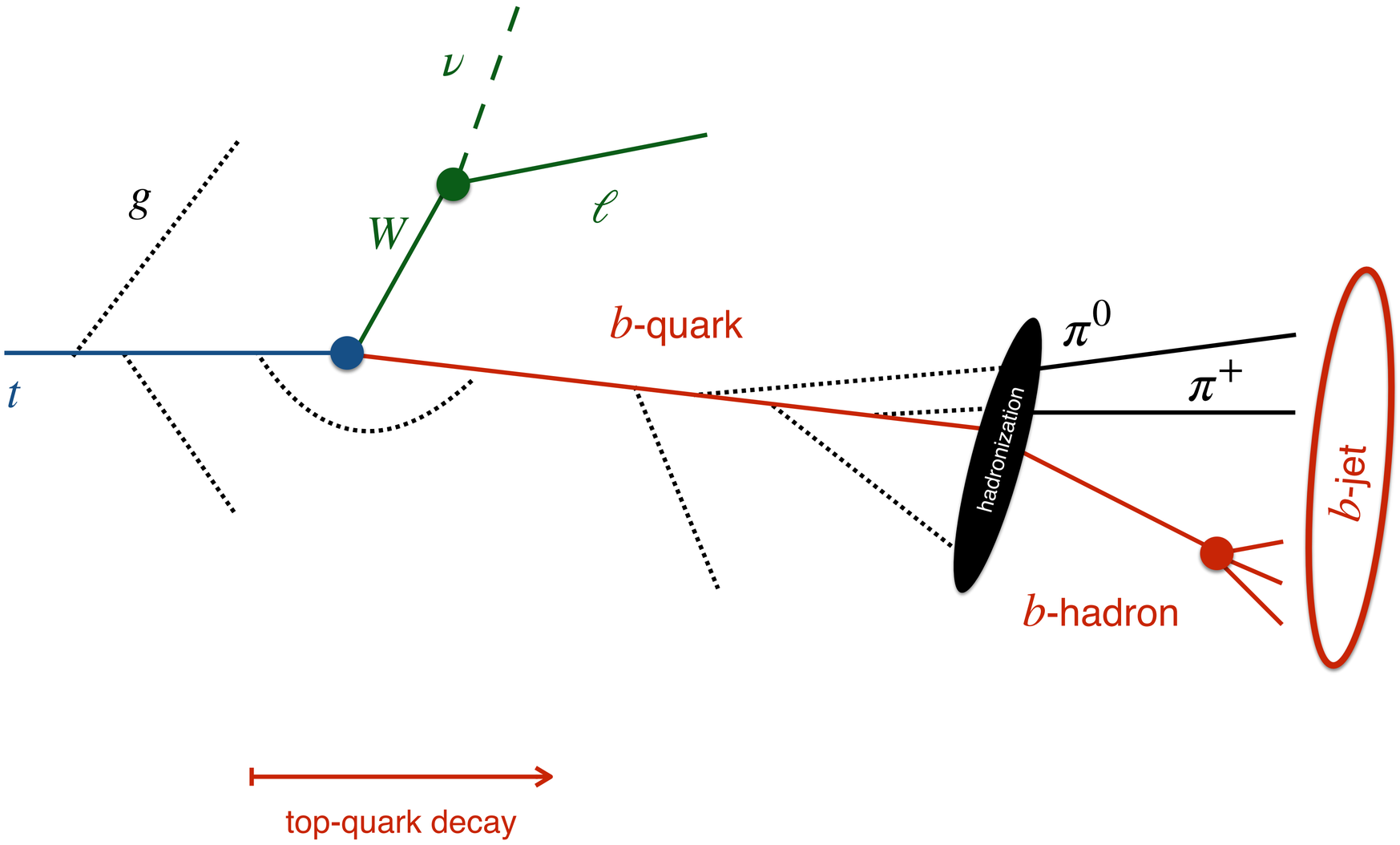


introduction

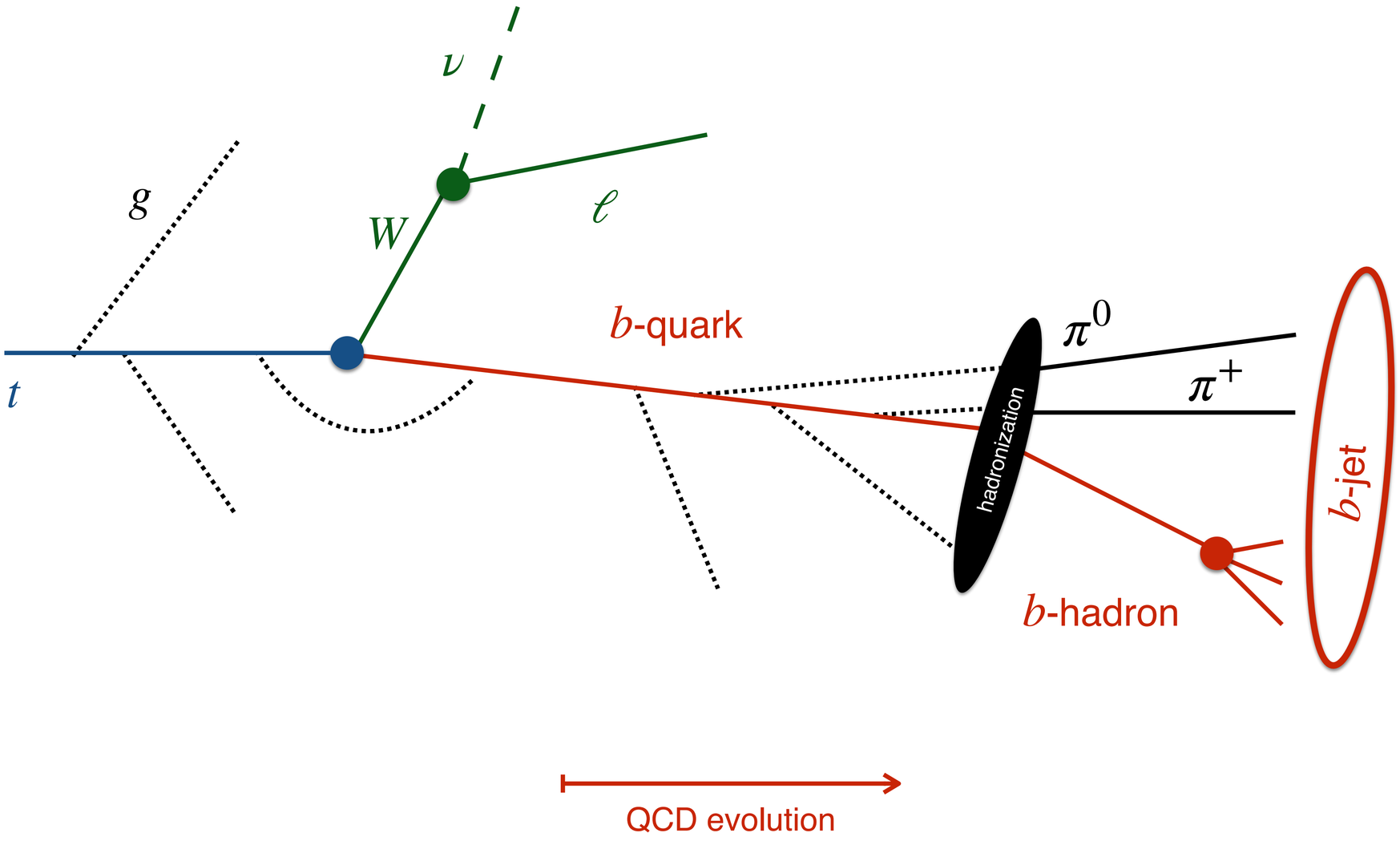


we want a better understanding of this process.

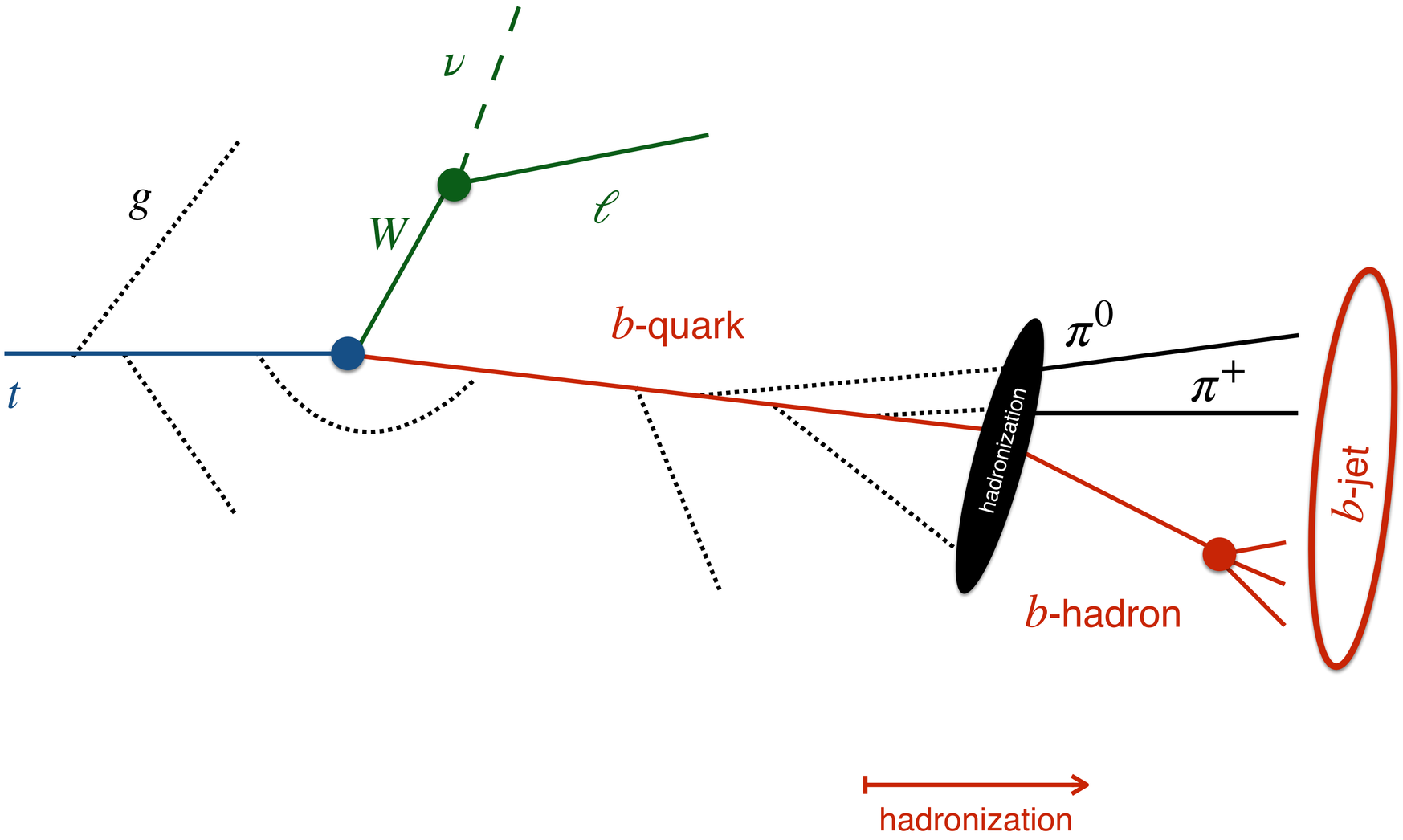
introduction



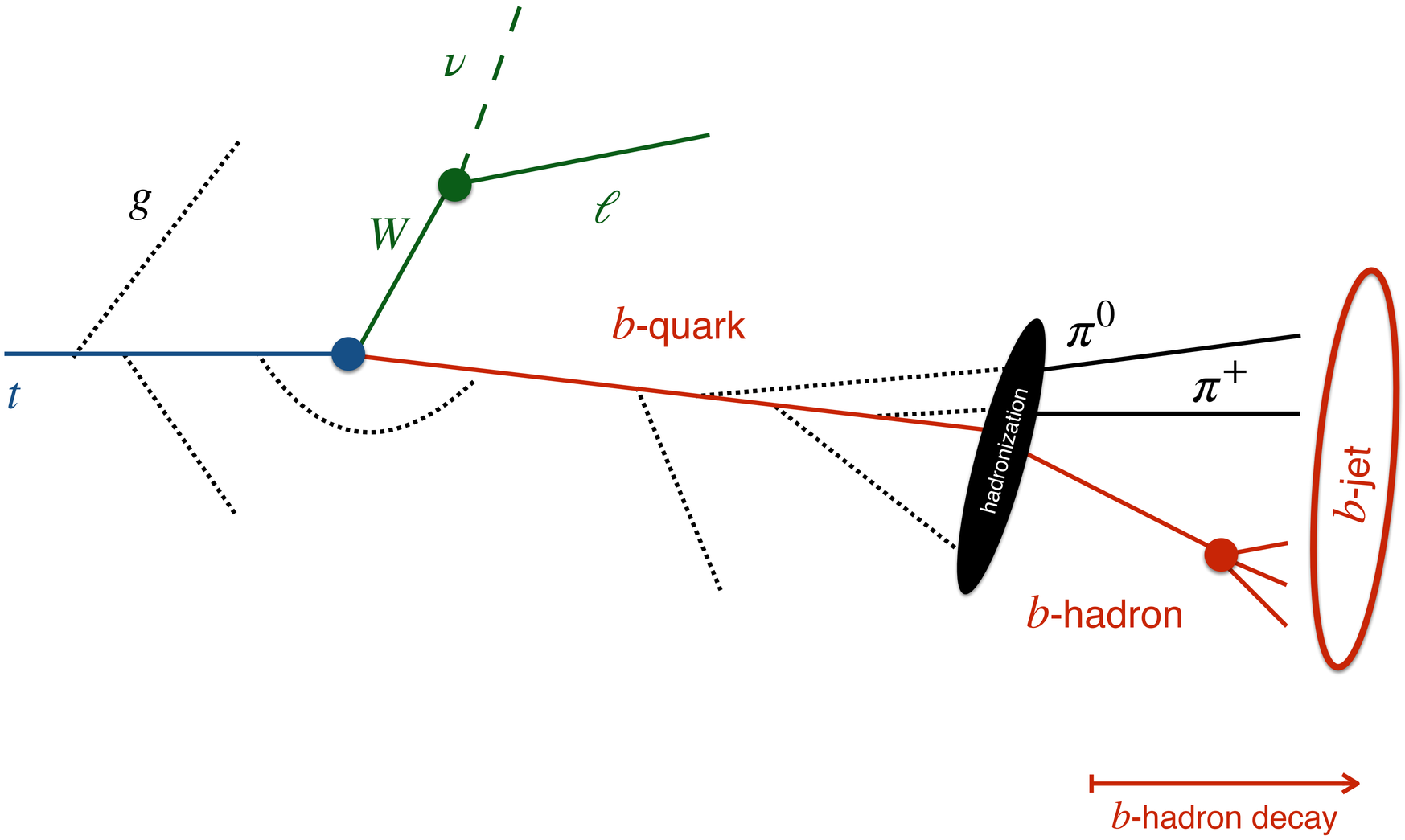
introduction



introduction



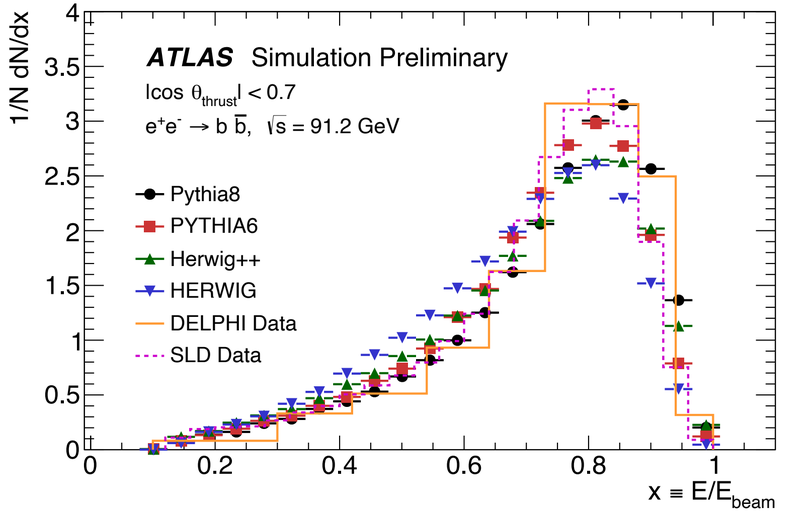
introduction



motivation I

the fragmentation of b-quarks into hadrons is of interest for many reasons.

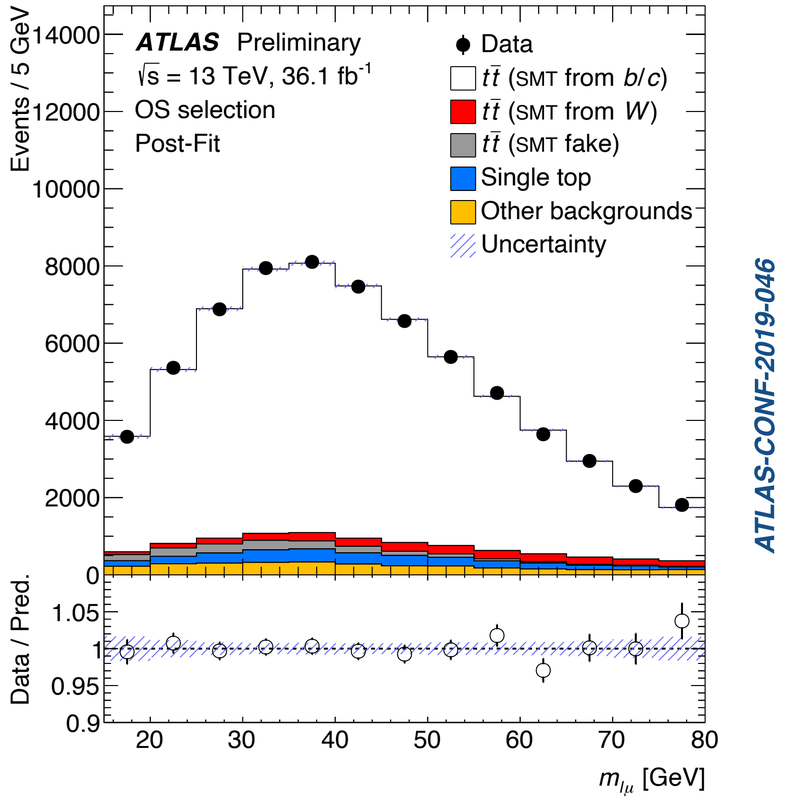
- b-hadrons leave a *striking experimental signature* and…
- there is a *unique correspondence* to the originating b-quarks
  - ergo a *precise probe of QCD*
- b-fragmentation currently *tuned to e^+e^- data* (from $Z \to bb$ decays)
- … then *extrapolated to the LHC* environment
  - to what degree is this correct?



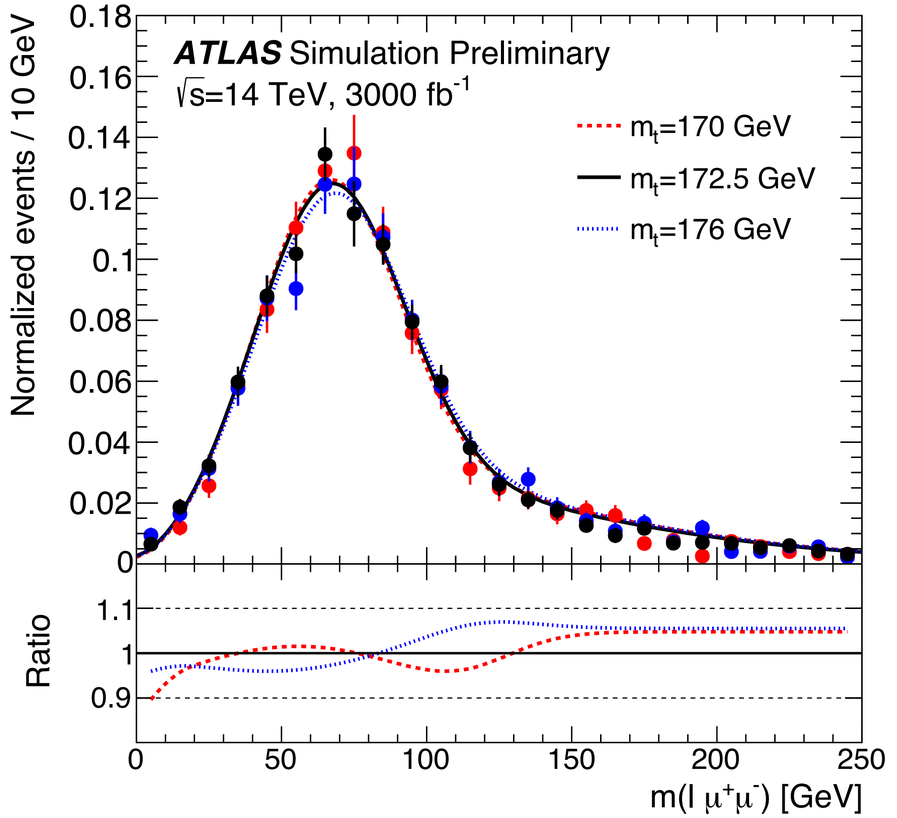
some tension between $e^+e^- \to bb$ measurements of b-fragmentation

parton-shower generators are also *not in good agreement*

motivation II



ATLAS-CONF-2019-046



ATLAS-CONF-2018-042

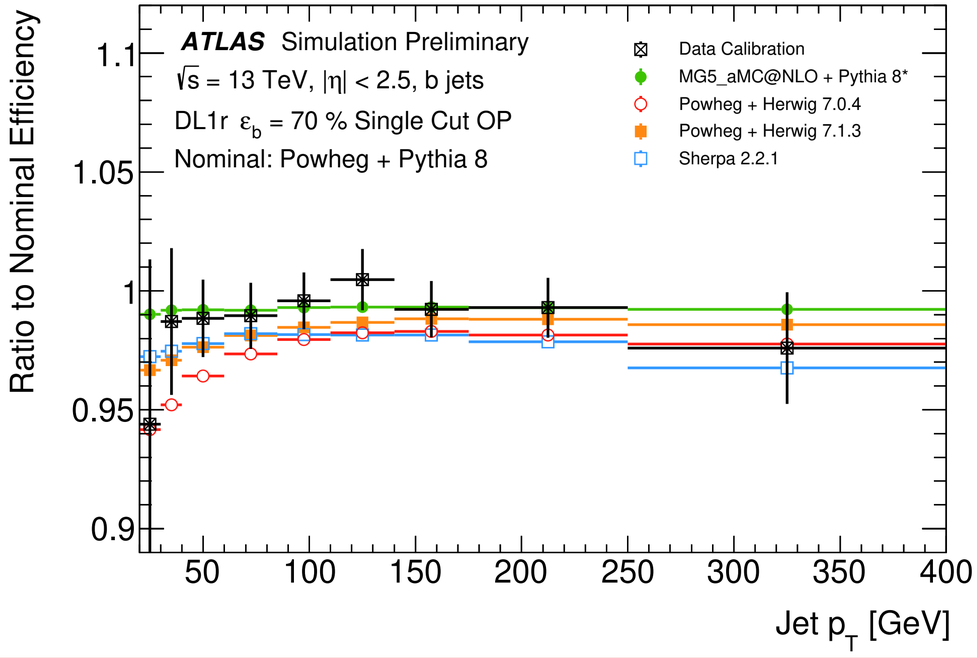
precision *direct top-mass measurements* via $b \rightarrow$ leptons
play a role in the LHC's long-term m_t strategy.

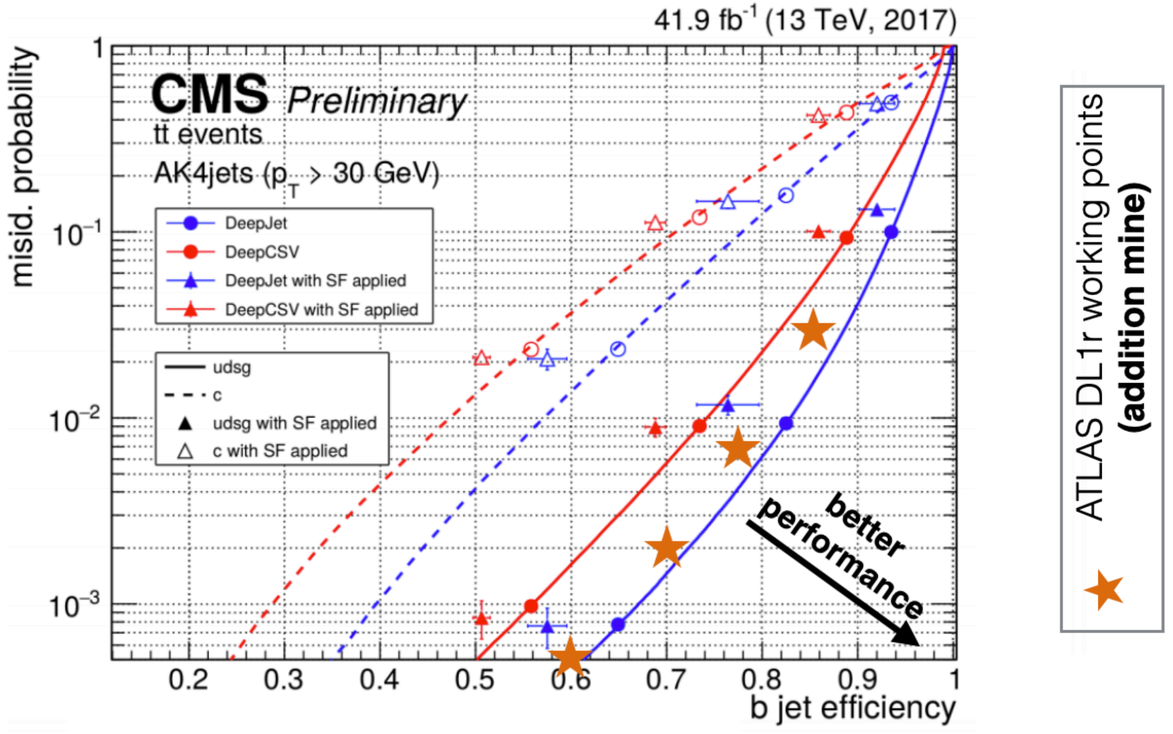
top-quark $\rightarrow b$-hadron momentum transfer is key!

motivation III

critical for delivering the best physics results with b-jets.

b-tagging efficiency and b-jet response are very sensitive to fragmentation.





in the machine-learning era, small mismodeling of b-jet internals has large consequences.

may lose ~10% of signal b-jets in data c.f. simulation.

motivation III

precision top and Higgs physics
require an excellent understanding
of b-fragmentation.

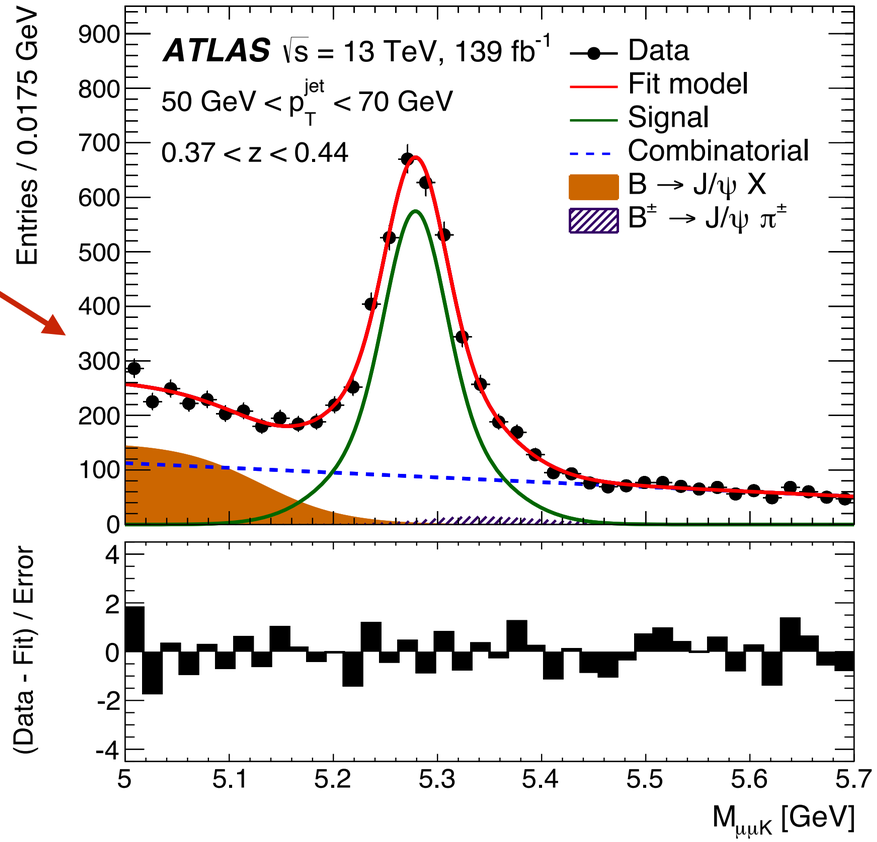
hard to see this going away
at a future collider…

our models tuned to LEP data
do have some “warts”
that we can already see at the LHC.

measurements

two recent measurements at ATLAS in dijet and $t\bar{t}$ final states

Short Title	Journal Reference	Date	√s (TeV)
b fragmentation in ttbar events at 13 TeV	Submitted to PRD	28-FEB-22	13
Exclusive b fragmentation at 13 TeV	JHEP 12 (2021) 131	26-AUG-21	13

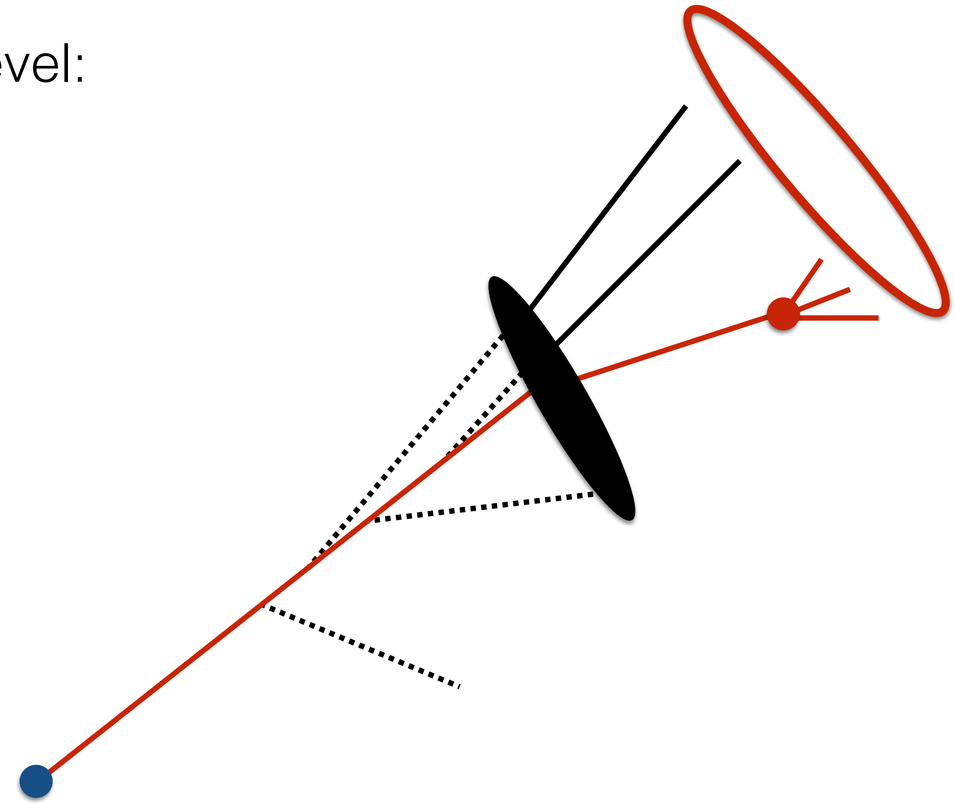


- provide excellent coverage where LEP data can't reach
  - and nicely complementary to each other
- this is the "first generation"
  - many aspects could be improved!

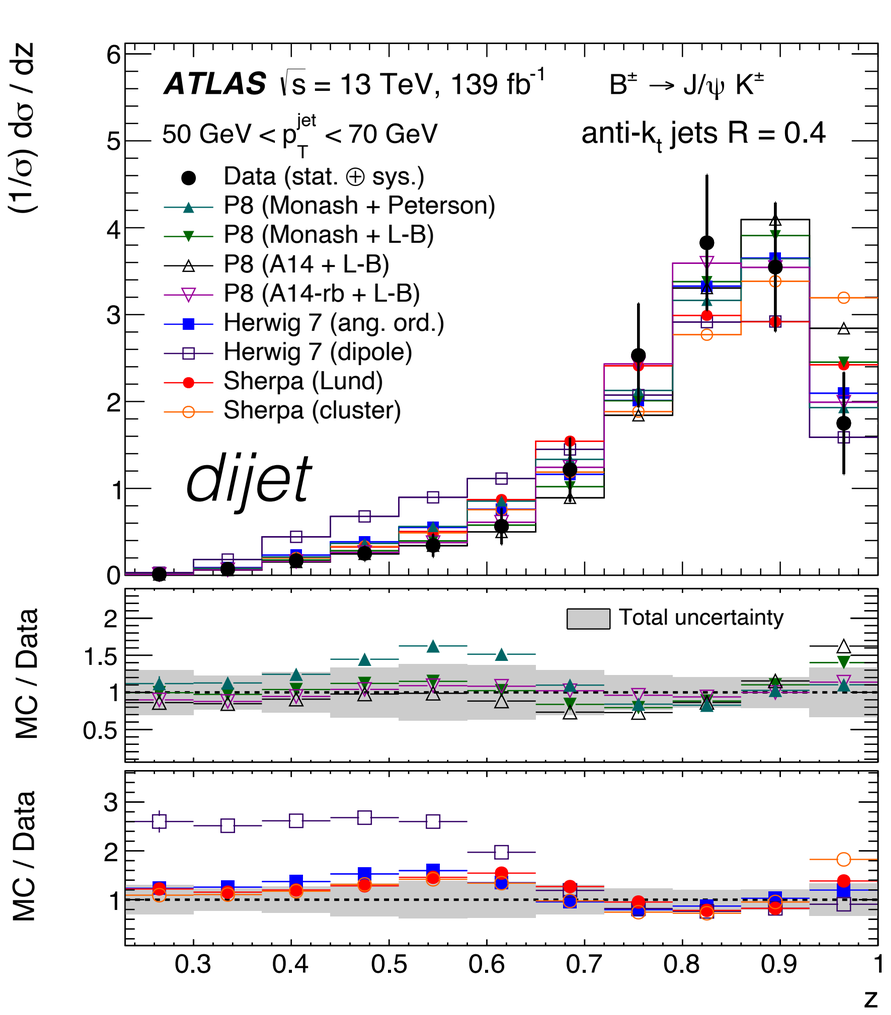
JHEP 12 (2021) 131, arXiv:2202.13901

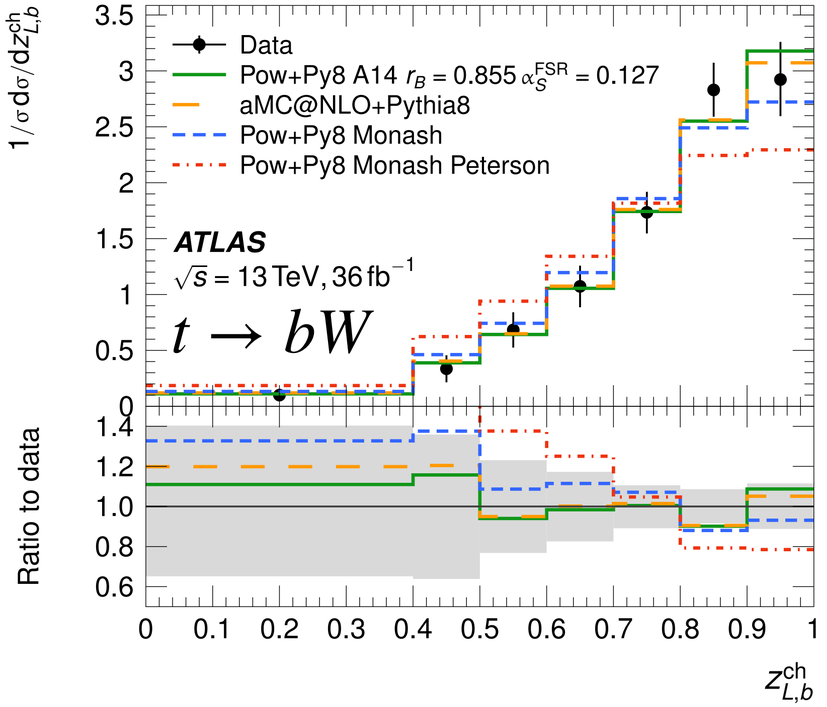
observables

- both measurements unfold related observables to particle level:
  - $z_{(L)} = \vec{p}_B \cdot \vec{p}_{jet} / p_{jet}^2$
  - $p_T^{rel} = |\vec{p}_B \times \vec{p}_{jet}| / |p_{jet}|$ (dijet only)
  - $\rho = p_T^B / \mathrm{avg}(p_T^\ell)$ ($t\bar{t}$ only)
  - charged particle multiplicity, n_{ch}^B ($t\bar{t}$ only)
- dijet: measure full $B \to \mu\mu K$ and full jet momentum
- $t\bar{t}$: only measure “charged momentum” of B and jet



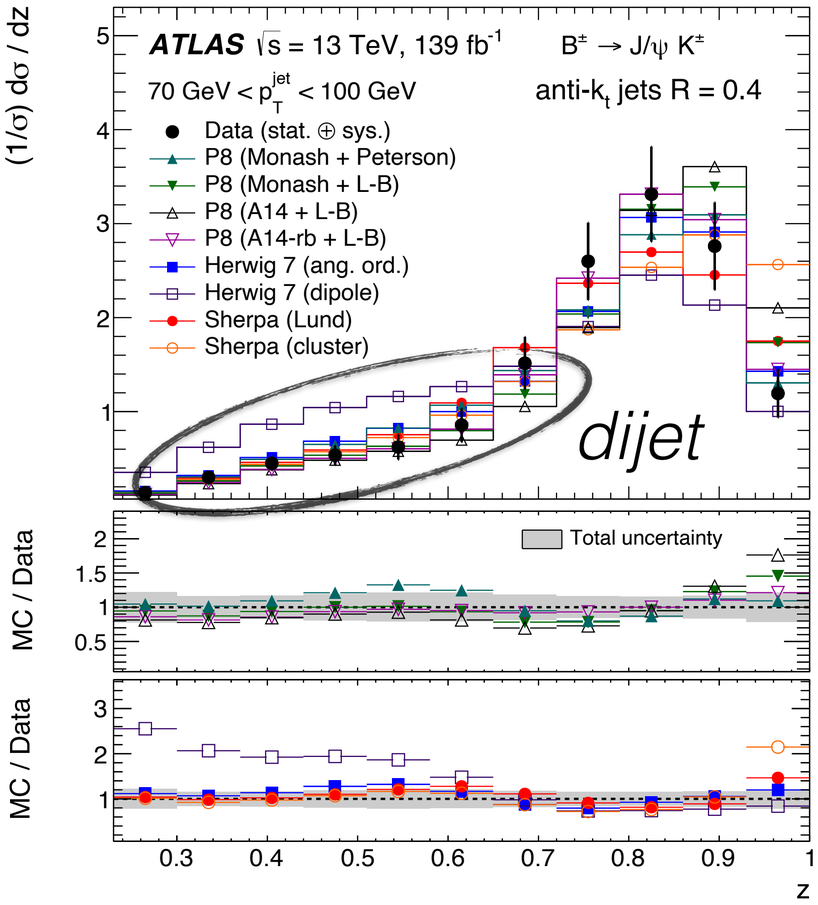
comparisons to data





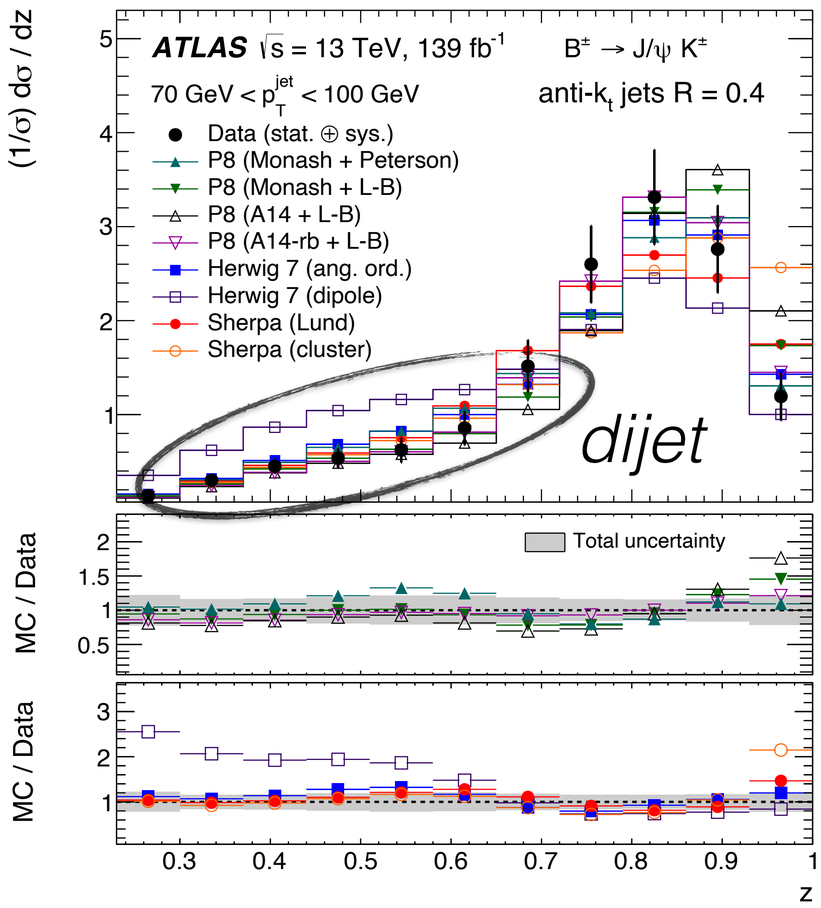
- ATLAS A14 tune + Lund-Bowler fragmentation tuned to A14 α_S^{FSR} performs best
- Peterson model strongly disfavored in both measurements
- Herwig7.0 also disfavored, but improvement in later versions

comparisons to data



clear issues with low-z spectrum for some generators

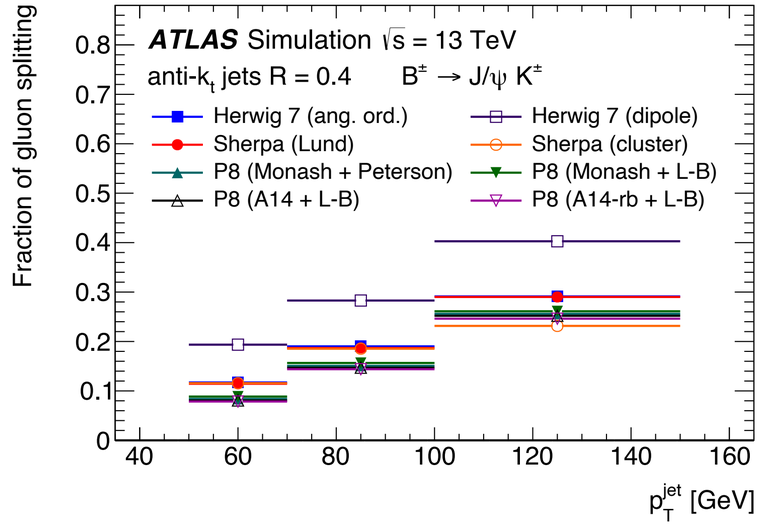
comparisons to data

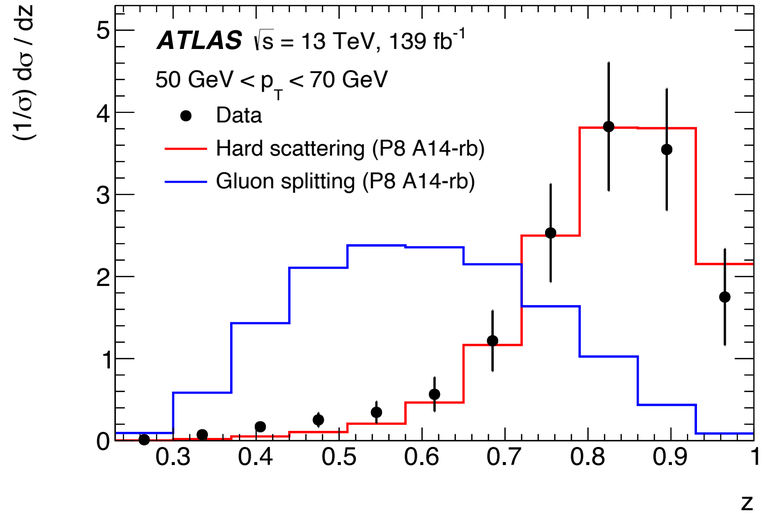


clear issues with low-z spectrum for some generators

likely due to mismodeled $g \to bb$ fractions

$t \to bW$ analysis can help disentangle effects (no $g \to bb$ jets)





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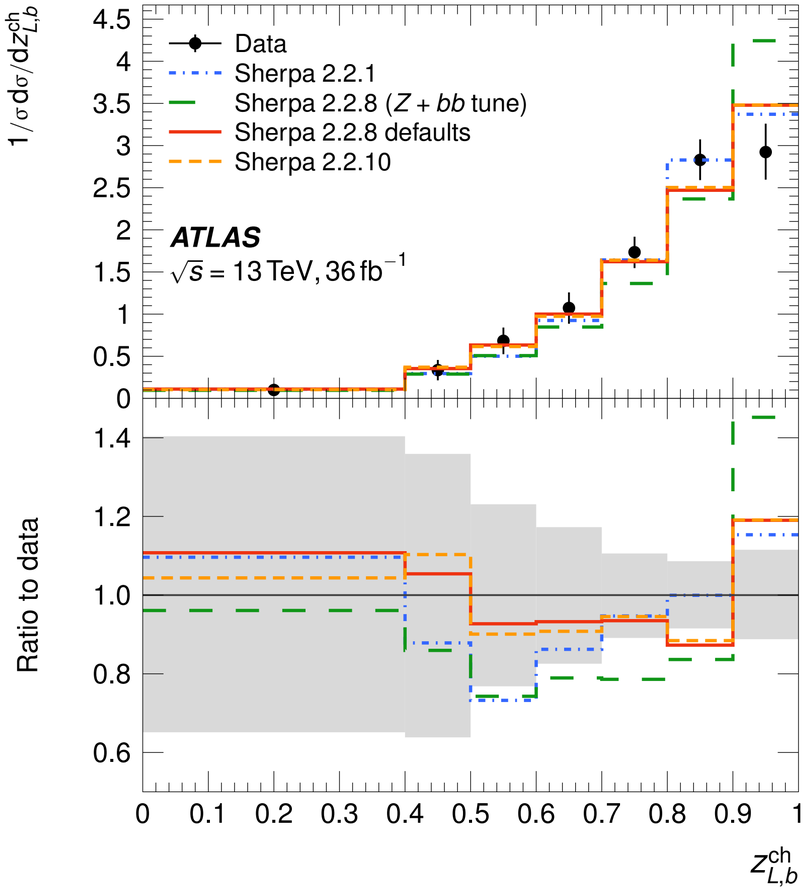
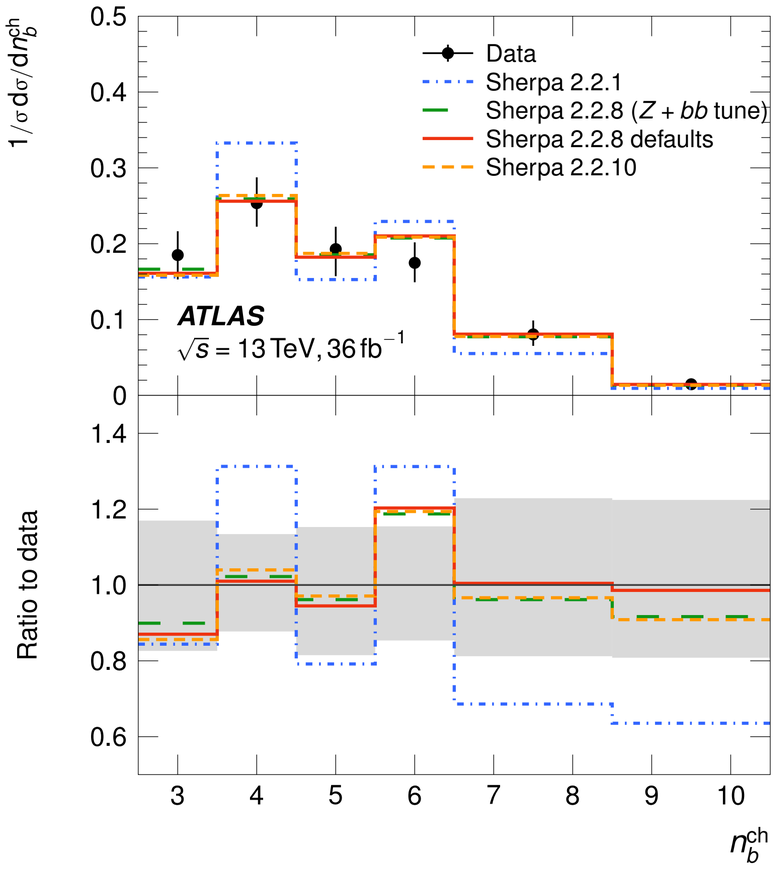


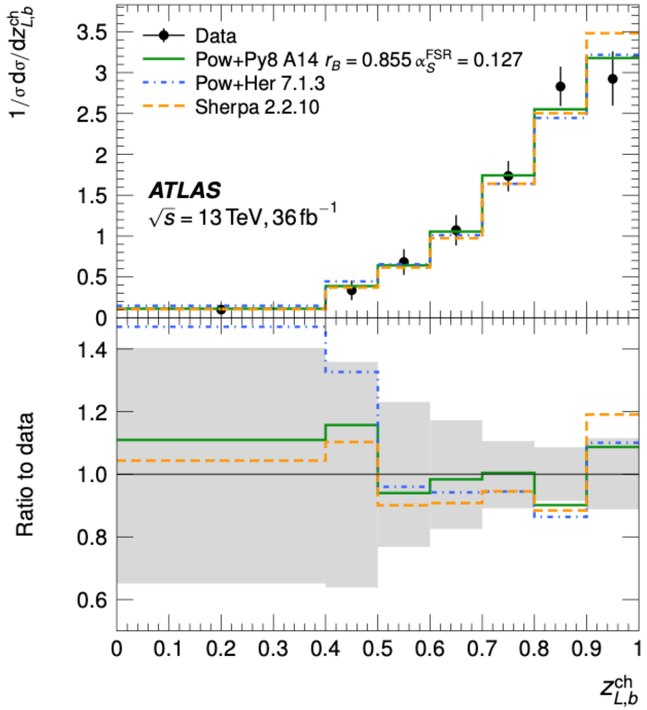
beware!

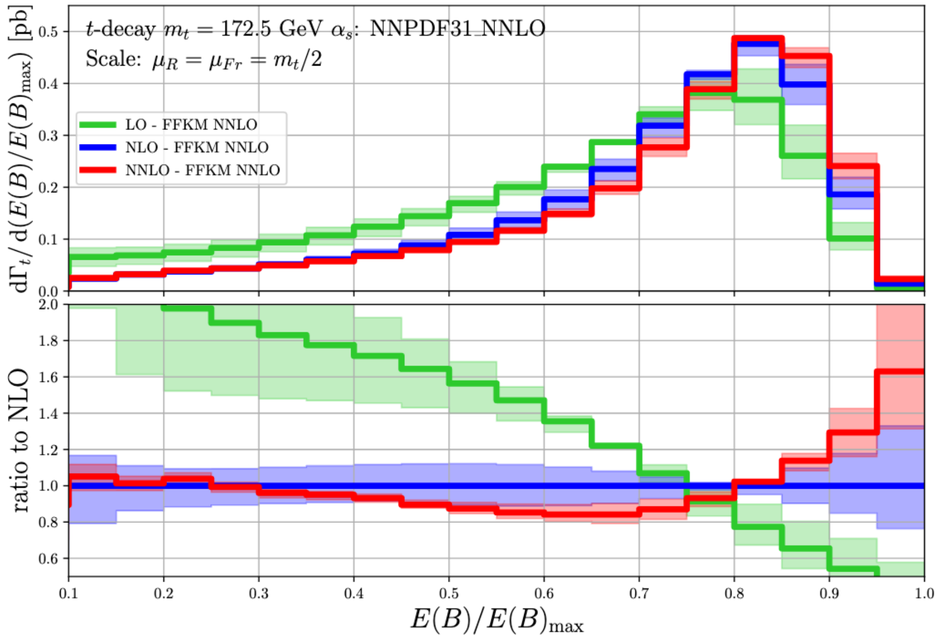
details of top-quark decays depend strongly on parameters that need to be carefully chosen in current MC generators.



comparisons to calculations

- to support more precise direct top-mass measurements, first ~analytic calculations of similar distributions
- substantial interest in comparing unfolded data
- challenging, though: probably needs interface to hadronization MC.





arxiv:2102.08267

measuring charm fragmentation?

- could we measure charm fragmentation in $t \to bW \to b(cq)$ decays?
- could be very interesting (critical?) for studies of $h \to cc$.
- the experimental techniques developed for the $t \to bW$ measurement are fairly general.

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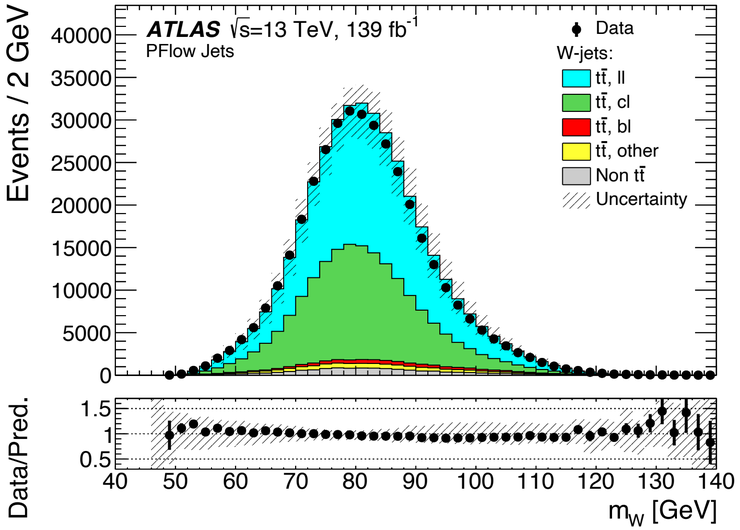

Eur. Phys. J. C 82 (2022) 95

we know how to obtain a reasonably clean sample of charm jets from W decays.

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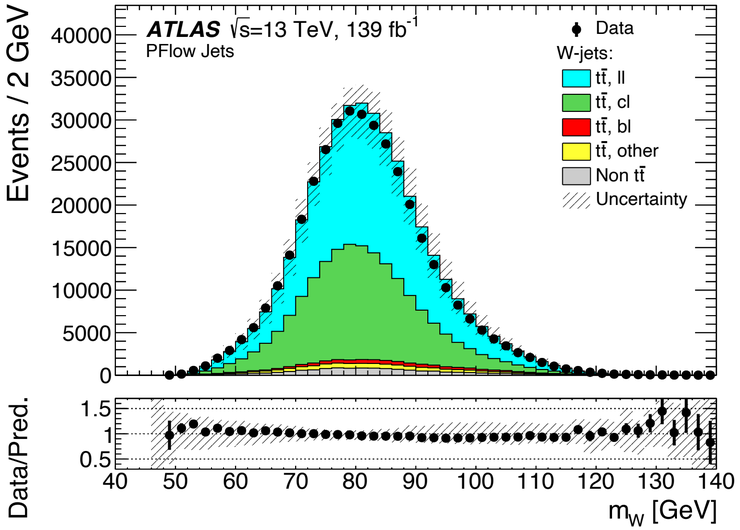
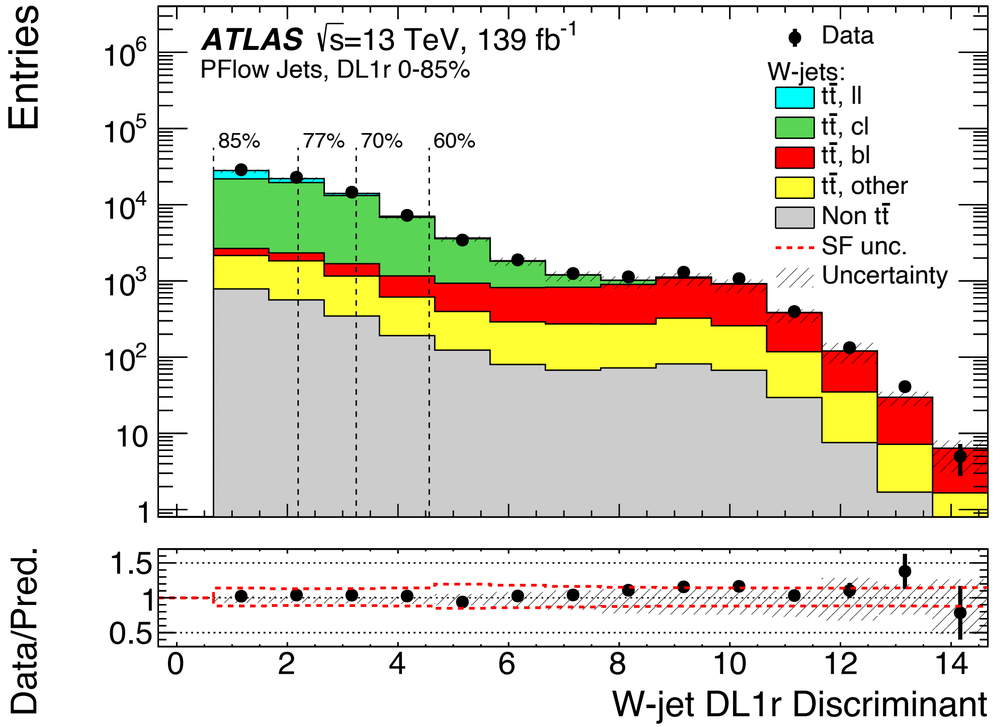


Eur. Phys. J. C 82 (2022) 95



we know how to obtain a reasonably clean sample of charm jets from W decays.

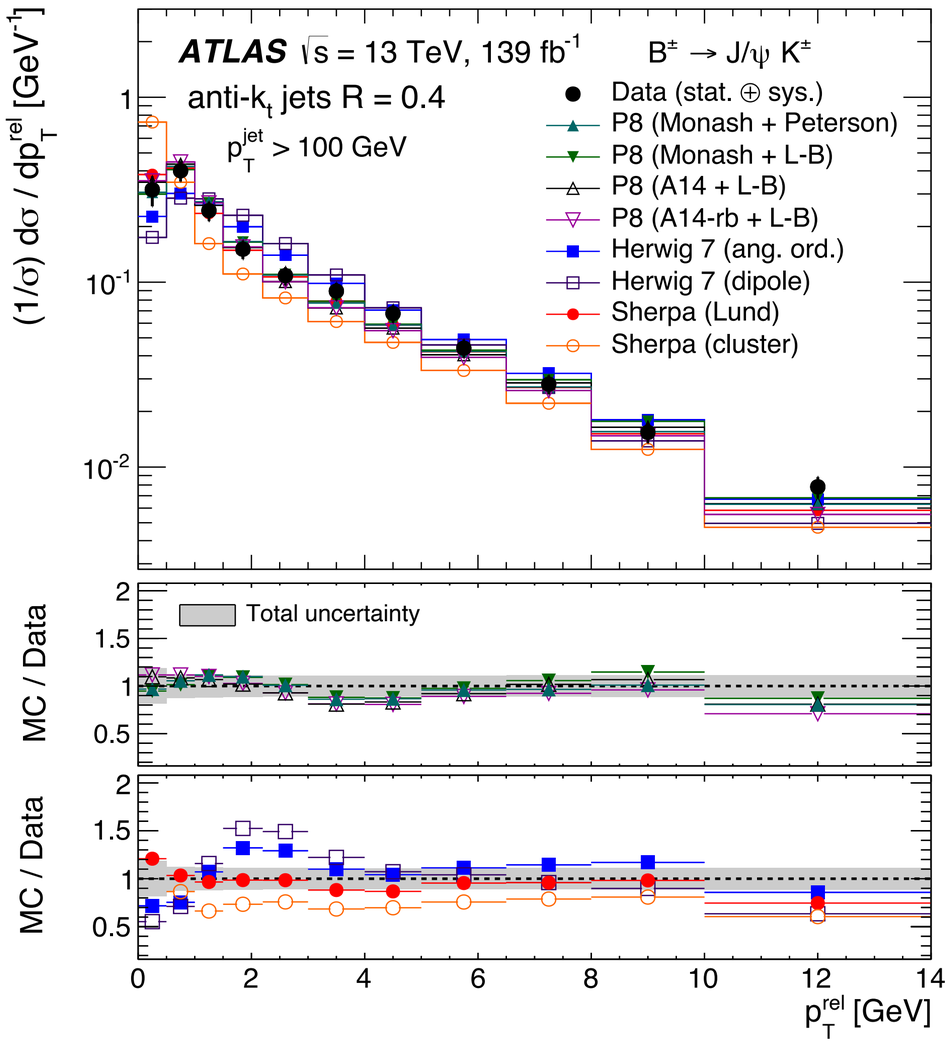
summary and outlook

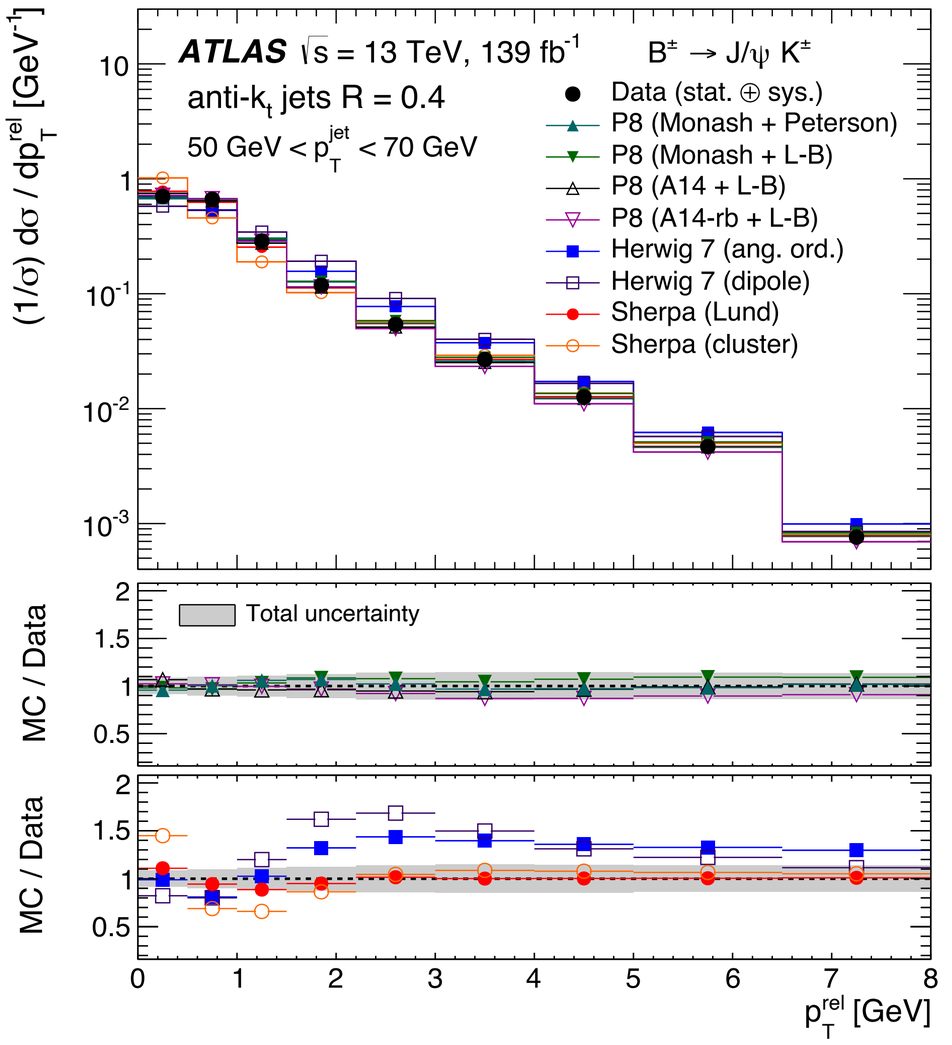
precision top and Higgs physics
require an excellent understanding
of (b-)fragmentation.

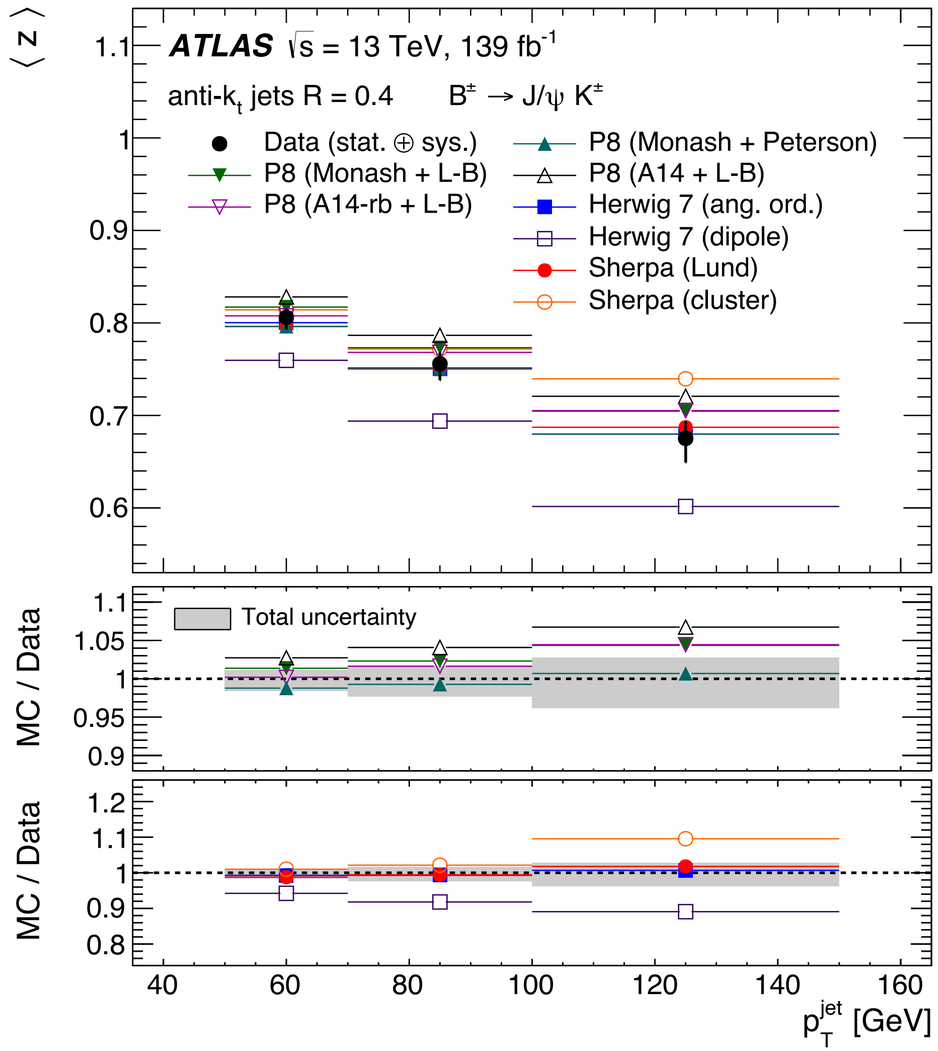
experimental methods have been
recently developed that can
substantially improve this for the future.

there's still enormous room for these to
grow in the coming years.
→ cannot take this for granted.

backup


ATLAS √s = 13 TeV, 139 fb-1
B± → J/ψ K±
anti-kt jets R = 0.4
pjetT > 100 GeV
Data (stat. ⊕ sys.)
P8 (Monash + Peterson)
P8 (Monash + L-B)
P8 (A14 + L-B)
P8 (A14-rb + L-B)
Herwig 7 (ang. ord.)
Herwig 7 (dipole)
Sherpa (Lund)
Sherpa (cluster)
(1/σ) dσ / dprelT [GeV-1]
Total uncertainty
MC / Data
MC / Data
prelT [GeV]


ATLAS √s = 13 TeV, 139 fb-1
B± → J/ψ K±
anti-kt jets R = 0.4
50 GeV < pjetT < 70 GeV
Data (stat. ⊕ sys.)
P8 (Monash + Peterson)
P8 (Monash + L-B)
P8 (A14 + L-B)
P8 (A14-rb + L-B)
Herwig 7 (ang. ord.)
Herwig 7 (dipole)
Sherpa (Lund)
Sherpa (cluster)
(1/σ) dσ / dprelT [GeV-1]
Total uncertainty
MC / Data
MC / Data
prelT [GeV]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anti-kt jets R = 0.4
B± → J/ψ K±
Data (stat. ⊕ sys.)
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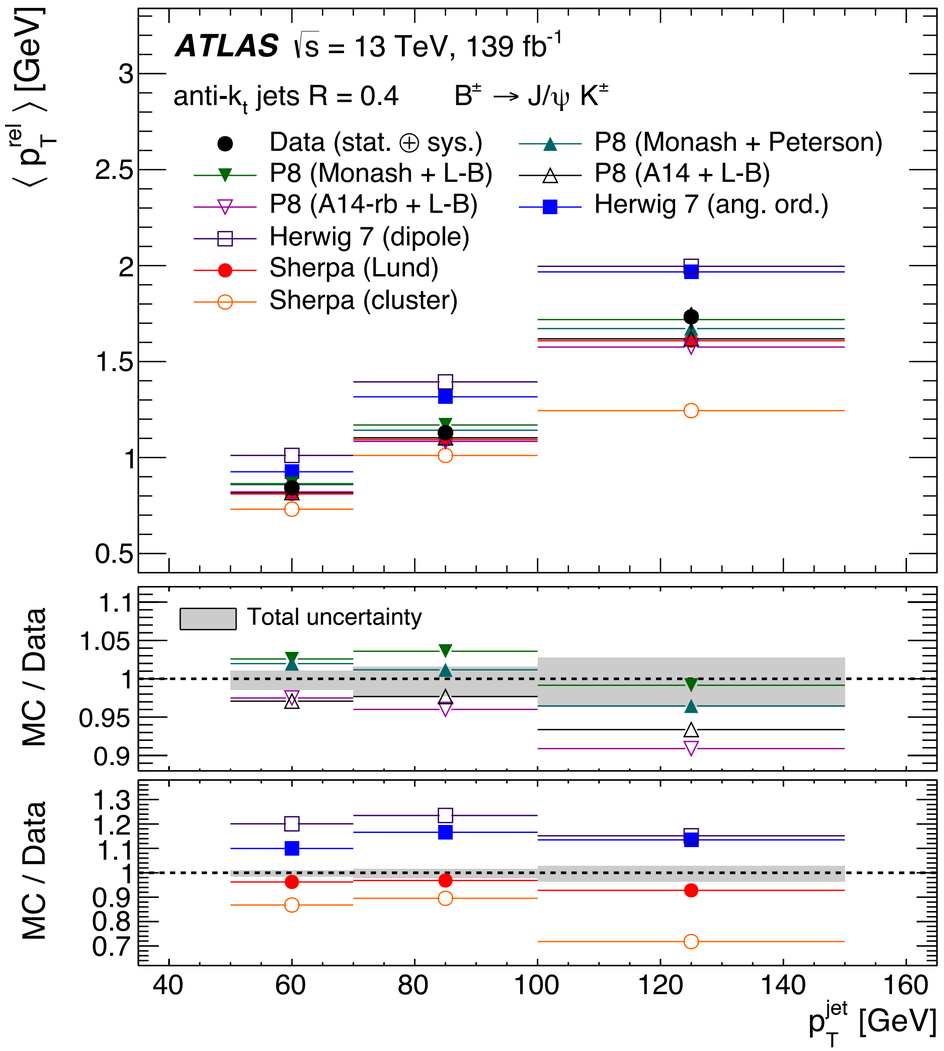
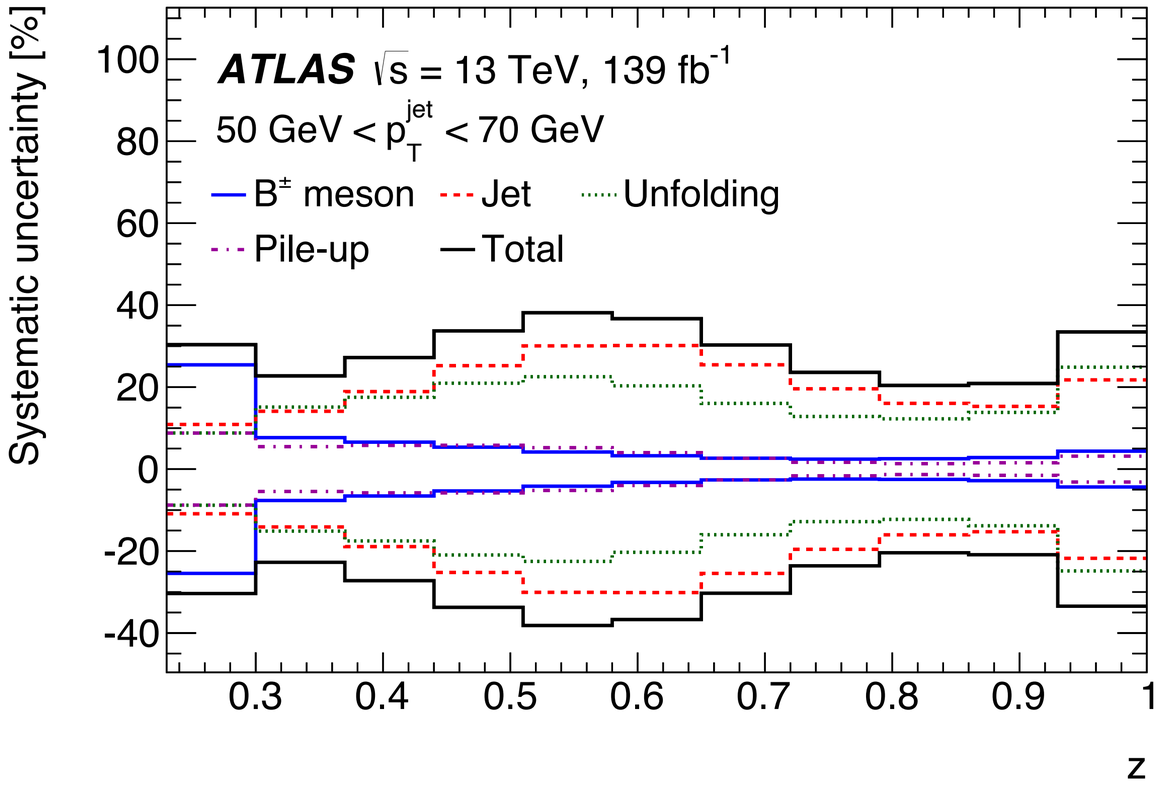
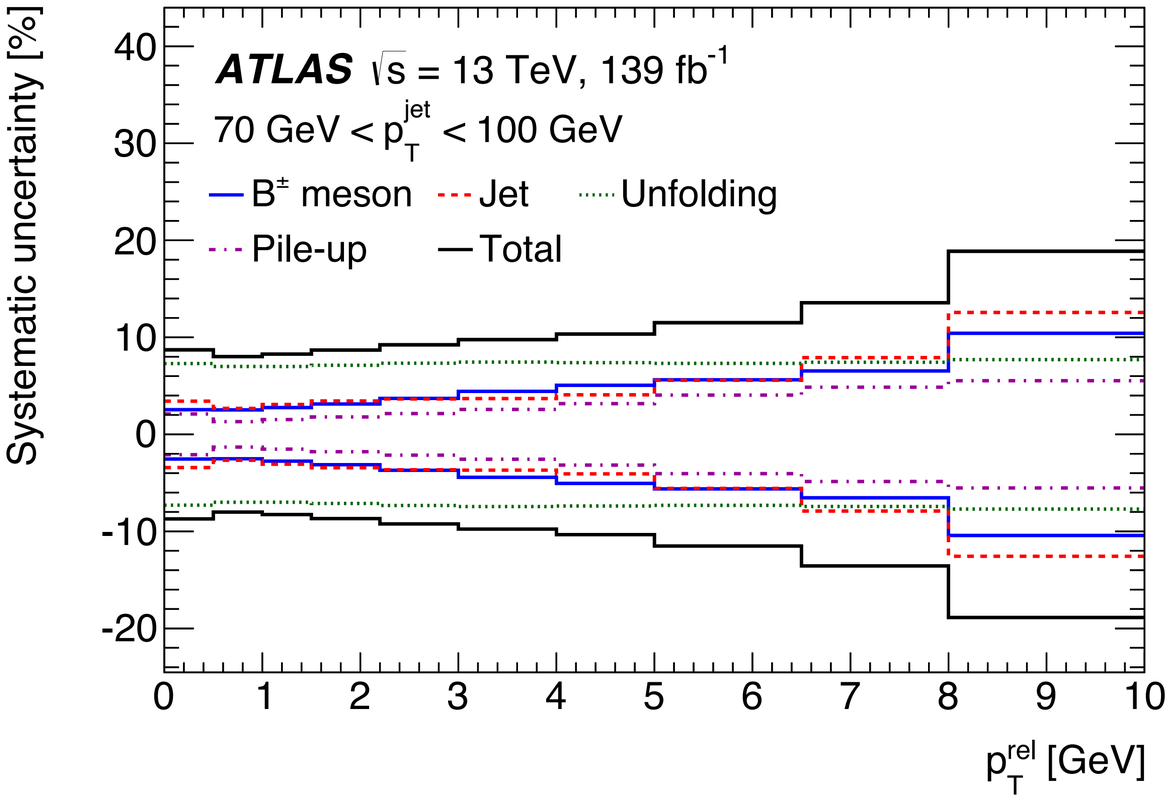
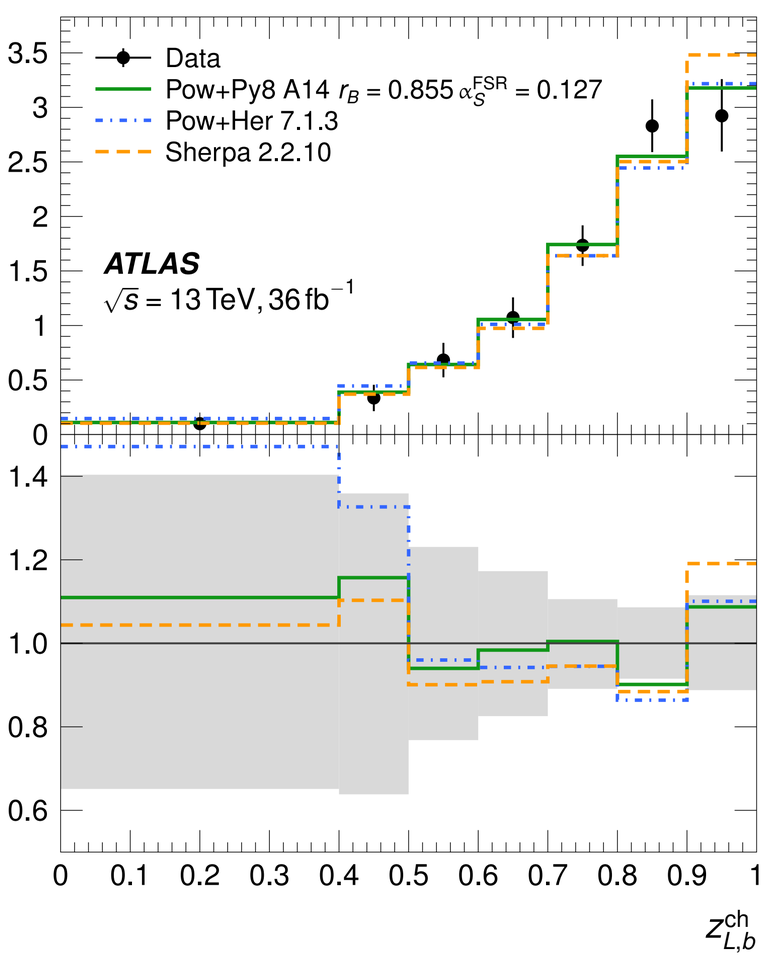
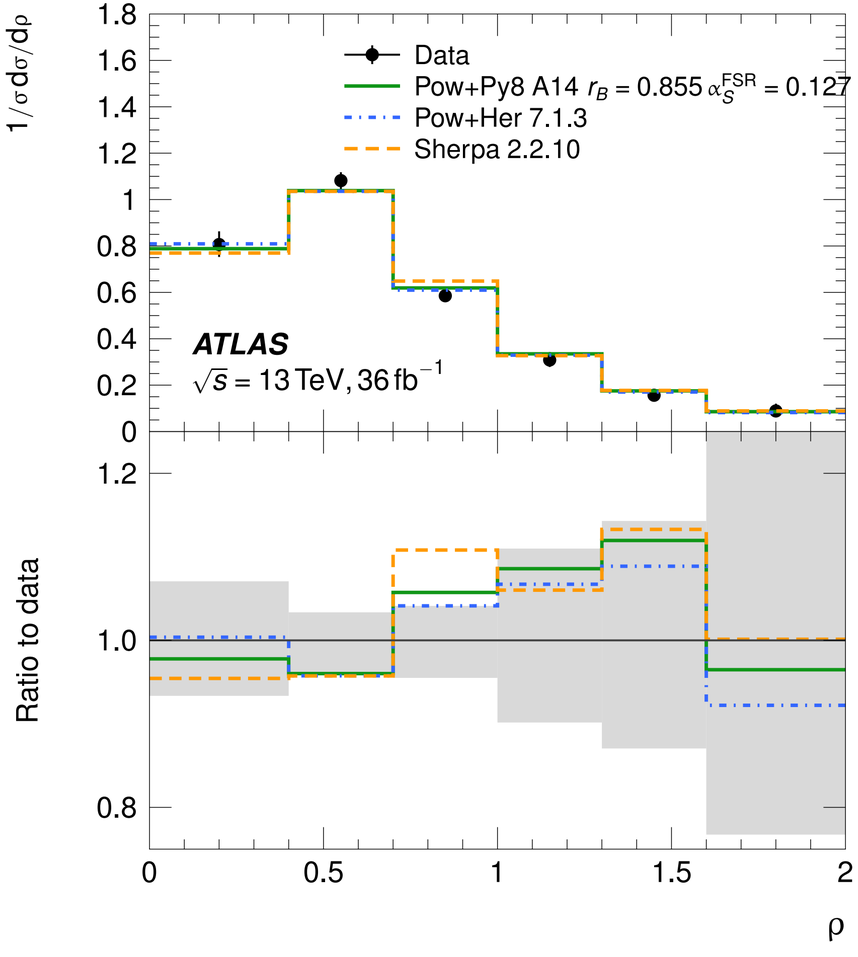
P8 (A14 + L-B)
Herwig 7 (ang. ord.)
Herwig 7 (dipole)
Sherpa (Lund)
Sherpa (cluster)
⟨ z ⟩
Total uncertainty
MC / Data
MC / Data
pjetT [GeV]


ATLAS √s = 13 TeV, 139 fb-1
anti-kt jets R = 0.4
B± → J/ψ K±
Data (stat. ⊕ sys.)
P8 (Monash + L-B)
P8 (A14-rb + L-B)
Herwig 7 (dipole)
Sherpa (Lund)
Sherpa (cluster)
P8 (Monash + Peterson)
P8 (A14 + L-B)
Herwig 7 (ang. ord.)
⟨ prelT ⟩ [GeV]
Total uncertainty
MC / Data
MC / Data
pjetT [GeV]


ATLAS √s = 13 TeV, 139 fb-1
50 GeV < p_T^jet < 70 GeV
B± meson
Jet
Unfolding
Pile-up
Total
Systematic uncertainty [%]
z


ATLAS √s = 13 TeV, 139 fb-1
70 GeV < p_T^jet < 100 GeV
B± meson
Jet
Unfolding
Pile-up
Total
Systematic uncertainty [%]
p_T^rel [GeV]


Data
Pow+Py8 A14 $r_B = 0.855$ $\alpha_S^{FSR} = 0.127$
Pow+Her 7.1.3
Sherpa 2.2.10
ATLAS
$\sqrt{s} = 13\,\text{TeV}, 36\,\text{fb}^{-1}$
$1/\sigma\,d\sigma/dz_{L,b}^{ch}$
Ratio to data
$z_{L,b}^{ch}$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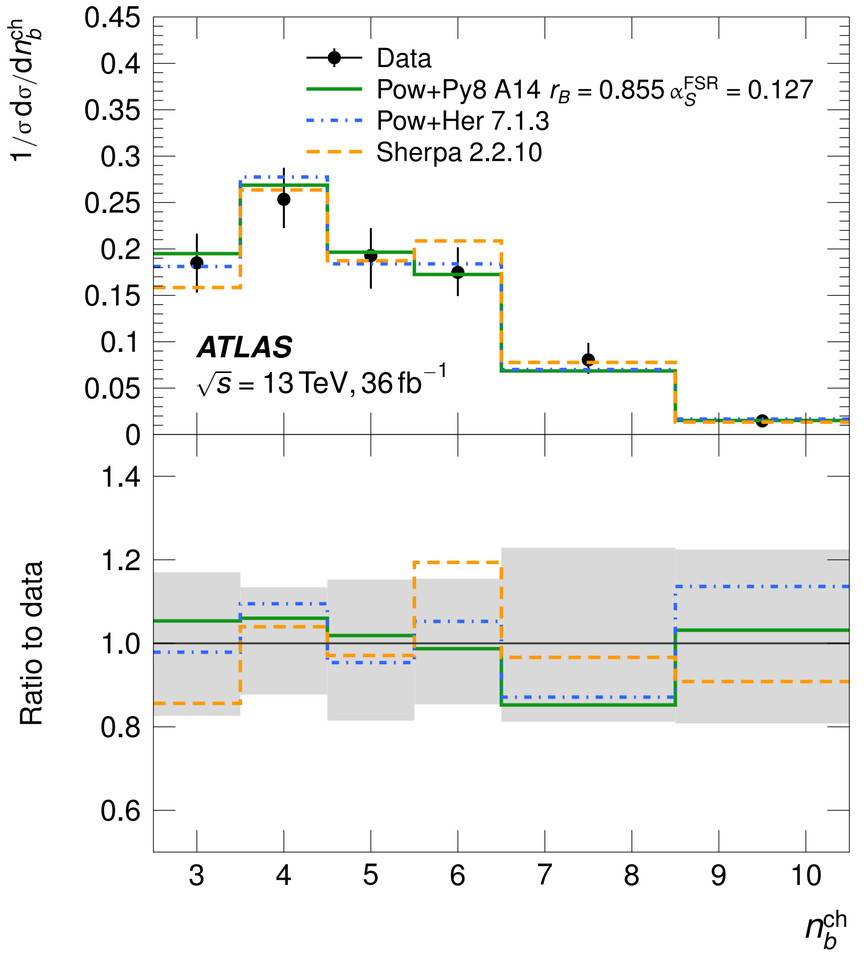
Pow+Her 7.1.3
Sherpa 2.2.10
ATLAS
$\sqrt{s} = 13\,\text{TeV}, 36\,\text{fb}^{-1}$
$1/\sigma\,d\sigma/d\rho$
Ratio to data
ρ


Data
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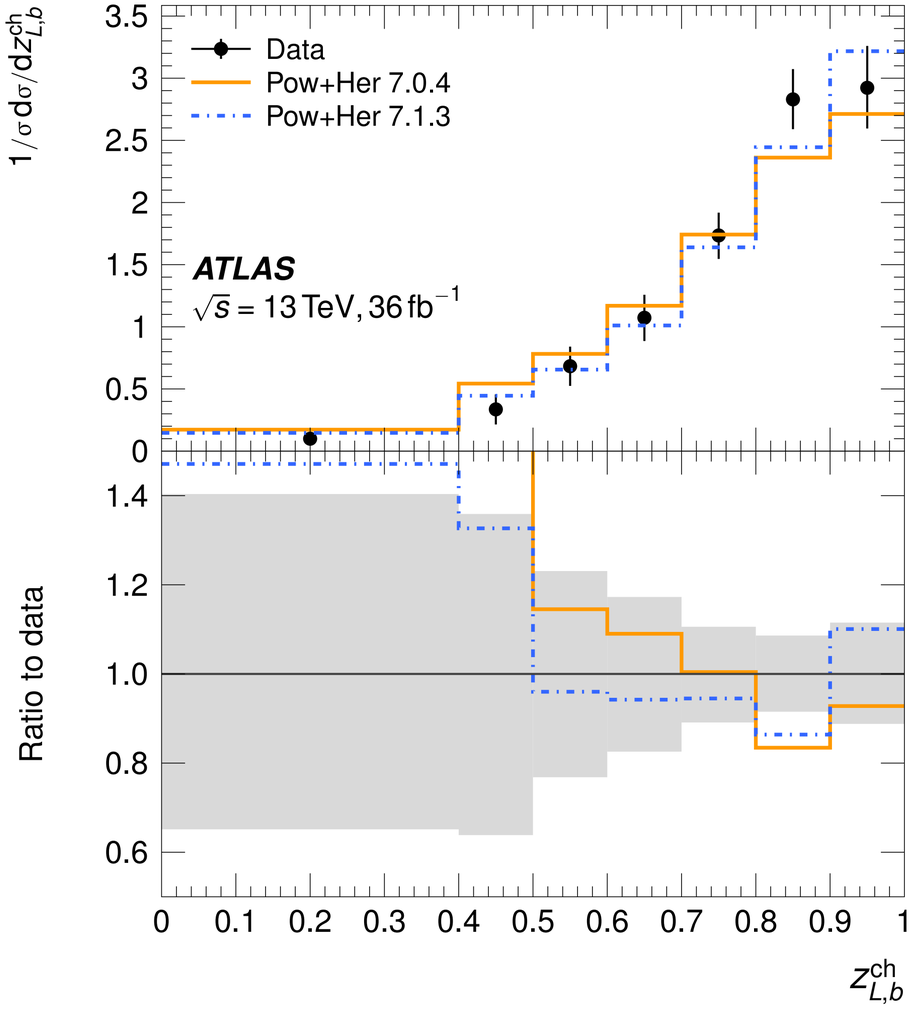
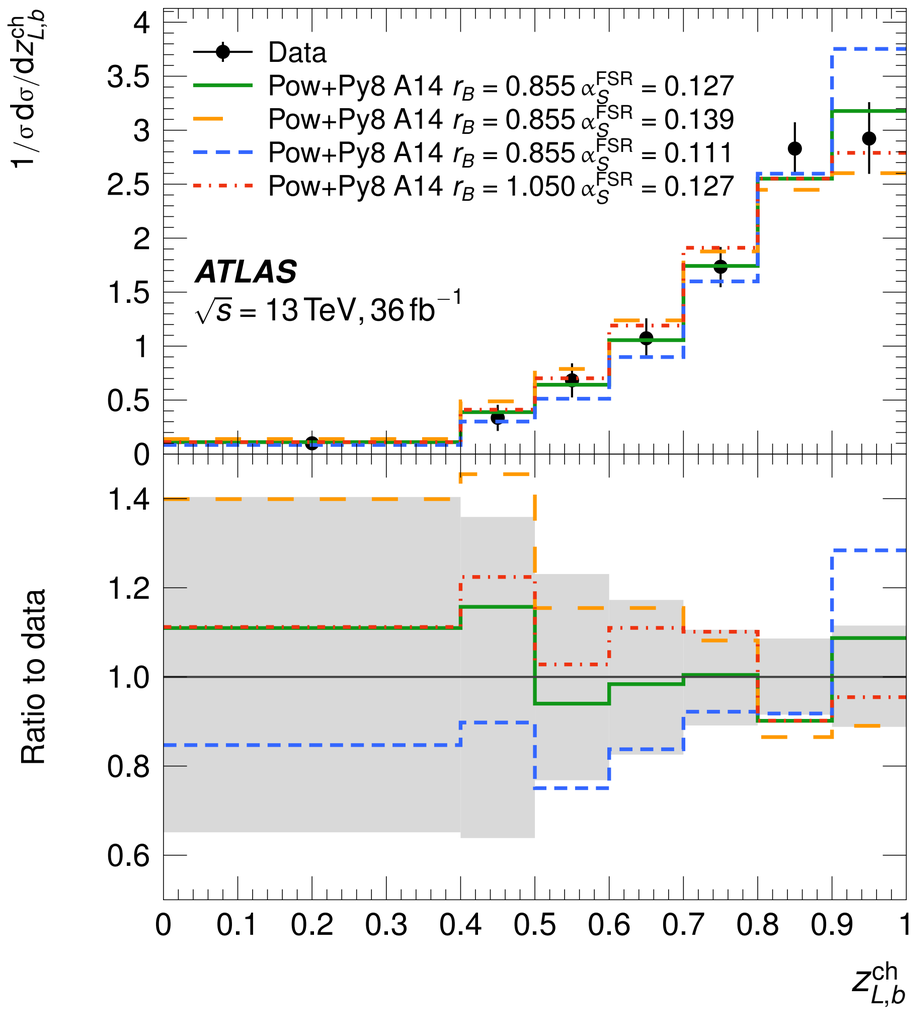
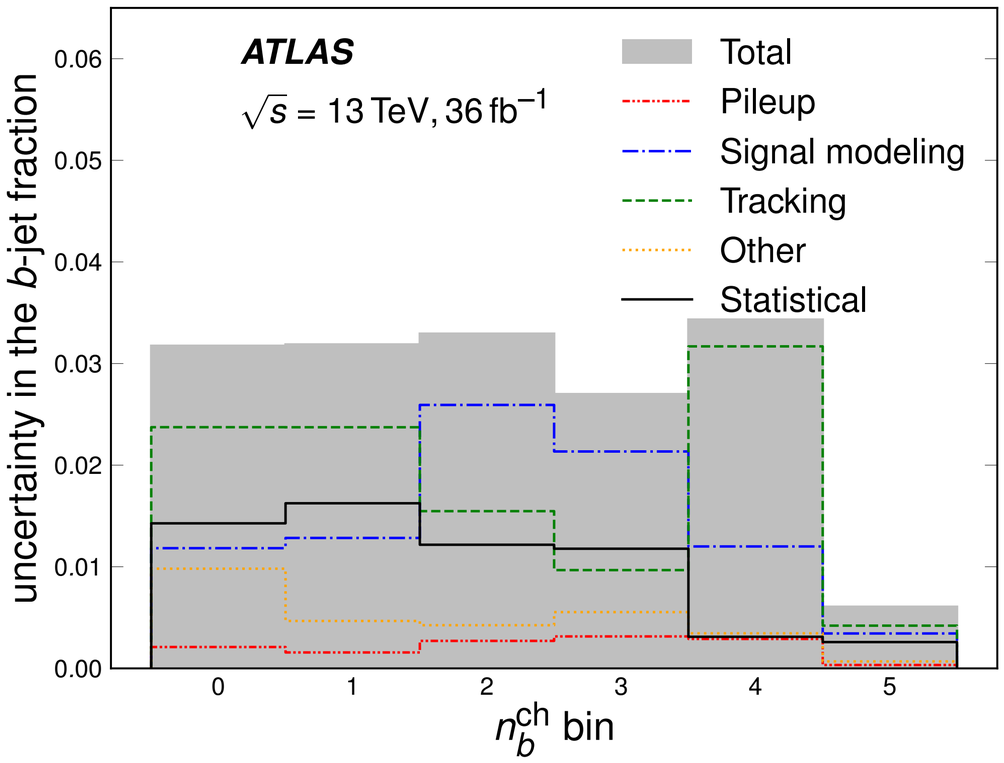
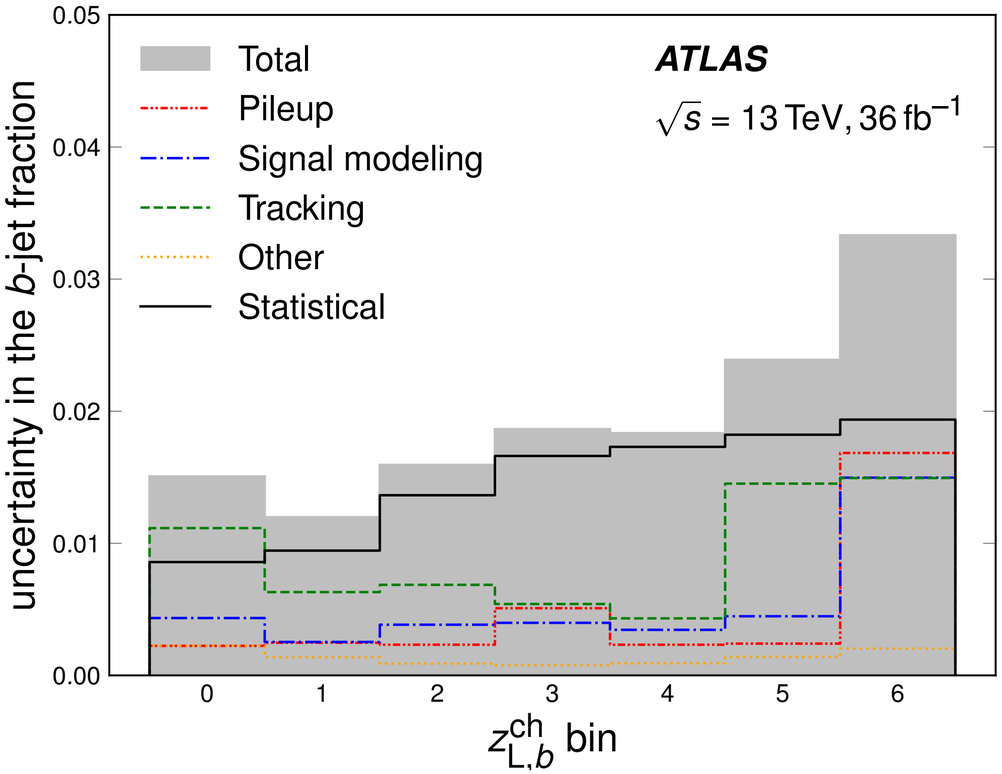
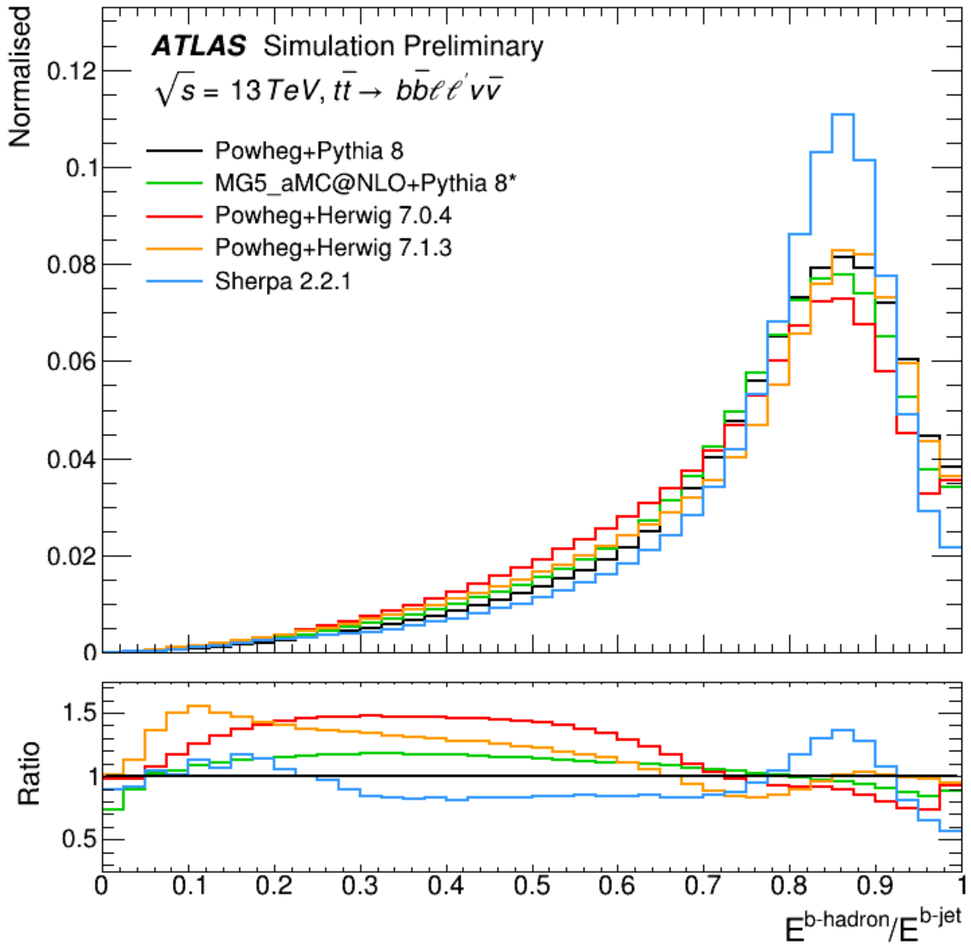
Pow+Her 7.1.3
Sherpa 2.2.10
ATLAS
$\sqrt{s} = 13\,\text{TeV}, 36\,\text{fb}^{-1}$
$1/\sigma\,d\sigma/dn_b^{ch}$
Ratio to data
n_b^{ch}

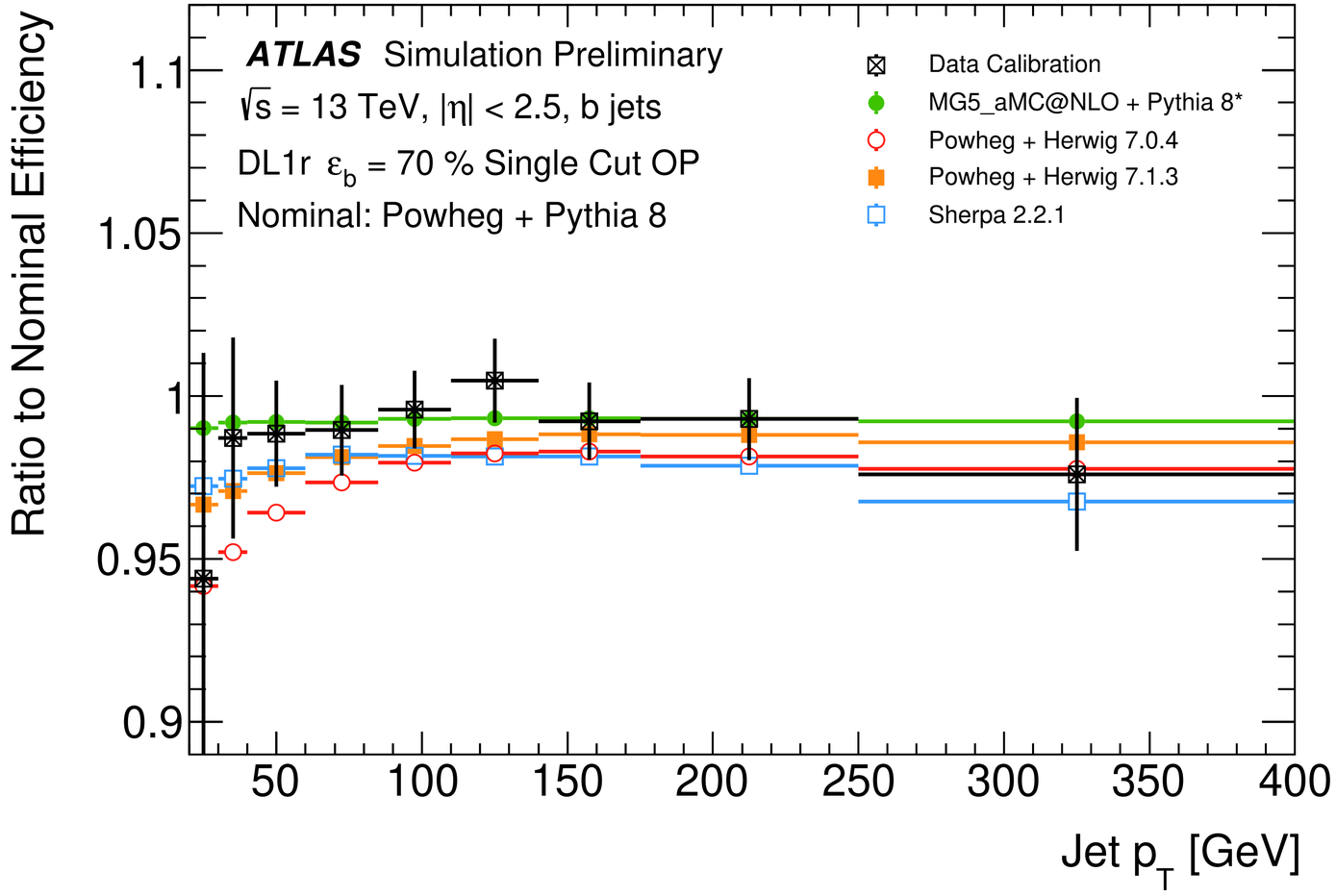

Data
Pow+Her 7.0.4
Pow+Her 7.1.3
ATLAS
√s = 13 TeV, 36 fb−1
1/σ dσ/dz^ch_L,b
Ratio to data
z^ch_L,b

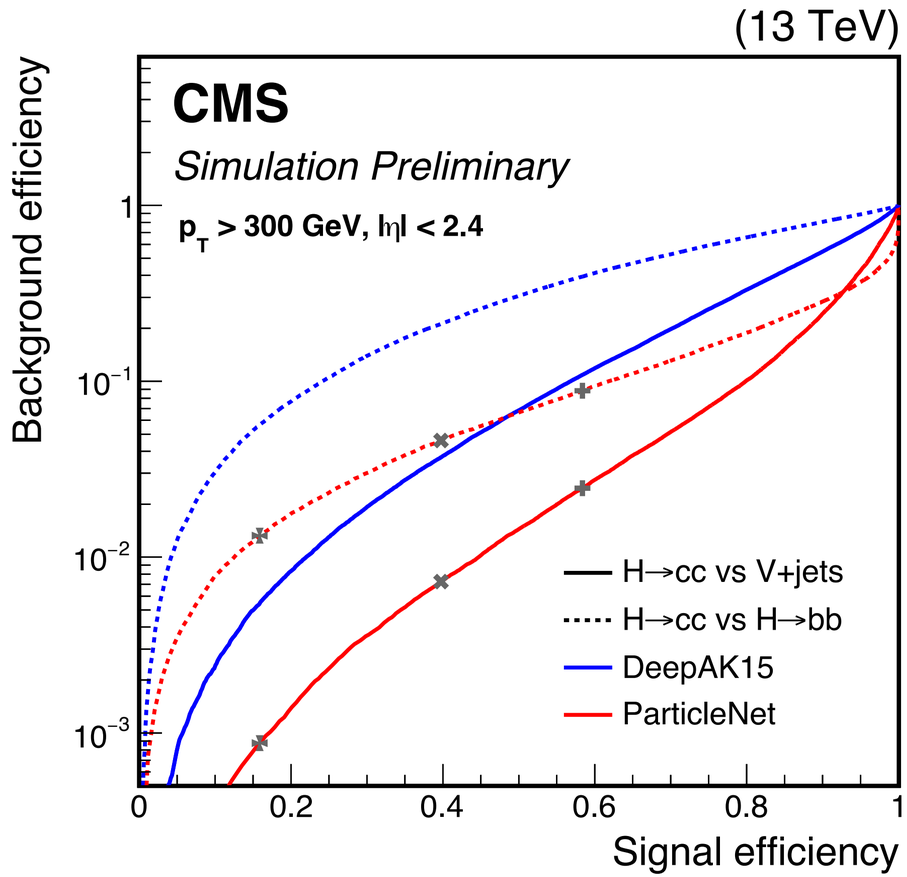

Data
Pow+Py8 A14 r_B = 0.855 α_S^FSR = 0.127
Pow+Py8 A14 r_B = 0.855 α_S^FSR = 0.139
Pow+Py8 A14 r_B = 0.855 α_S^FSR = 0.111
Pow+Py8 A14 r_B = 1.050 α_S^FSR = 0.127
ATLAS
√s = 13 TeV, 36 fb−1
1/σ dσ/dz^ch_L,b
Ratio to data
z^ch_L,b

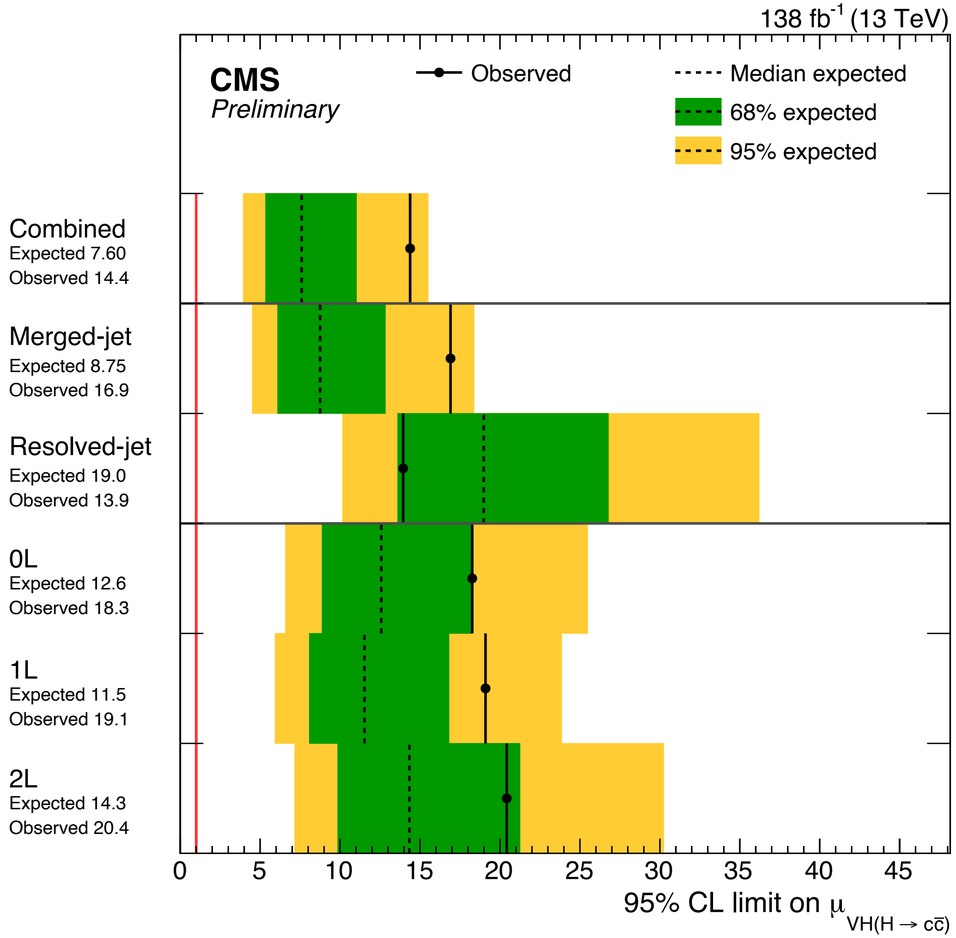

ATLAS
$\sqrt{s}$ = 13 TeV, 36 fb^{-1}
Total
Pileup
Signal modeling
Tracking
Other
Statistical
uncertainty in the b-jet fraction
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0
1
2
3
4
5
n_b^{ch} bin


Total
Pileup
Signal modeling
Tracking
Other
Statistical
ATLAS
$\sqrt{s}$ = 13 TeV, 36 fb^{-1}
uncertainty in the b-jet fraction
0.00
0.01
0.02
0.03
0.04
0.05
0
1
2
3
4
5
6
$z_{\mathrm{L},b}^{\mathrm{ch}}$ bin


ATLAS Simulation Preliminary
$\sqrt{s}$ = 13 TeV, $t\bar{t} \rightarrow b\bar{b}\ell\ell'\nu\bar{\nu}$
Powheg+Pythia 8
MG5_aMC@NLO+Pythia 8*
Powheg+Herwig 7.0.4
Powheg+Herwig 7.1.3
Sherpa 2.2.1
Normalised
Ratio
$E^{b\text{-hadron}}/E^{b\text{-jet}}$


ATLAS Simulation Preliminary
$\sqrt{s}$ = 13 TeV, |η| < 2.5, b jets
DL1r ε_b = 70 % Single Cut OP
Nominal: Powheg + Pythia 8
Data Calibration
MG5_aMC@NLO + Pythia 8*
Powheg + Herwig 7.0.4
Powheg + Herwig 7.1.3
Sherpa 2.2.1
Ratio to Nominal Efficiency
Jet p_T [GeV]


(13 TeV)
CMS
Simulation Preliminary
p_T > 300 GeV, |η| < 2.4
Background efficiency
Signal efficiency
H→cc vs V+jets
H→cc vs H→bb
DeepAK15
ParticleNet


138 fb-1 (13 TeV)
CMS
Preliminary
Observed
Median expected
68% expected
95% expected
Combined
Expected 7.60
Observed 14.4
Merged-jet
Expected 8.75
Observed 16.9
Resolved-jet
Expected 19.0
Observed 13.9
0L
Expected 12.6
Observed 18.3
1L
Expected 11.5
Observed 19.1
2L
Expected 14.3
Observed 20.4
95% CL limit on μ VH(H → cc̄)