LHCTopWG : theory modeling and challenges

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on behalf of the ATLAS and CMS collaborations

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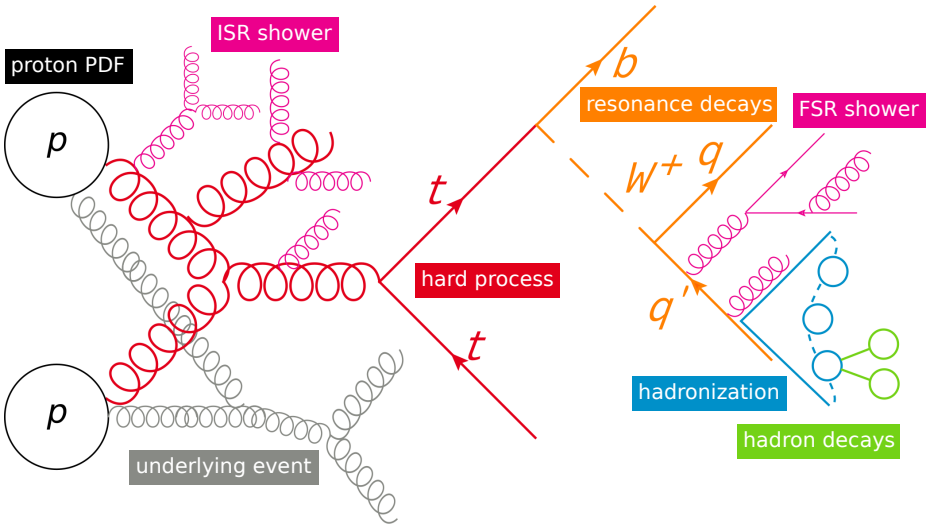
"Radiation and generators" taskforce within LHCTopWG

- ATLAS James Ferrando and Dominic Hirschbühl
- CMS Benedikt Maier and Markus Seidel

- Comparing the definitions of
  - generator settings in the two experiments
  - systematic sources coming from the modelling of radiation in the MC
    `https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TheorySystematics`

- Non-trivial task as there is a variety of...
  - codes: Herwig6/++/7, MG5_aMCatNLO, Powheg, Pythia6/8, Sherpa, ...
  - matching+merging schemes: aMCatNLO, CKKW-L, FxFx, MEPS@NLO, MLM, Powheg, ...
  - tunes: A14, CUETP8M1, EE5C, H7-UE-MMHT, Monash, Perugia11/12, Z2*, ...

Overview of $t\bar{t}$ event generation

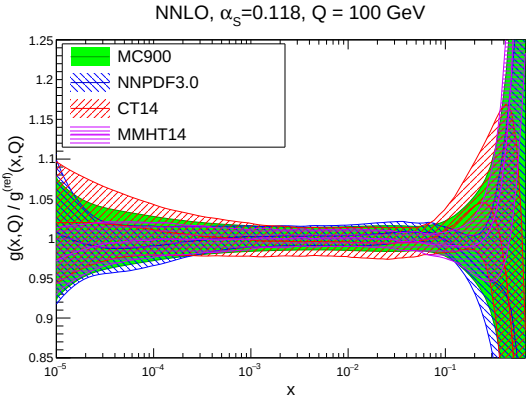


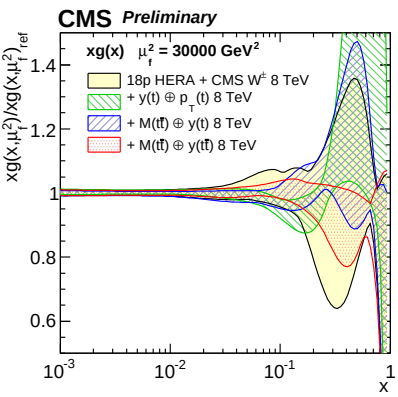
- Each stage contained in multi-purpose generators but there also specialized tools
- In the following: overview of tools and settings used at ATLAS and CMS

PDF

arXiv:1510.03865 | CMS | TOP-14-013

- New PDF4LHC recommendation for precision measurements:
  - evaluate uncertainties of PDF set used for measurement
  - clearly state which PDF set was used (and give result for others if possible)
- Statistical combination of PDF sets available for searches
- High-x region of PDFs can be improved by $t\bar{t}$ data





Choice of matrix-element generator

ATLAS PHYS-PUB-2016-004

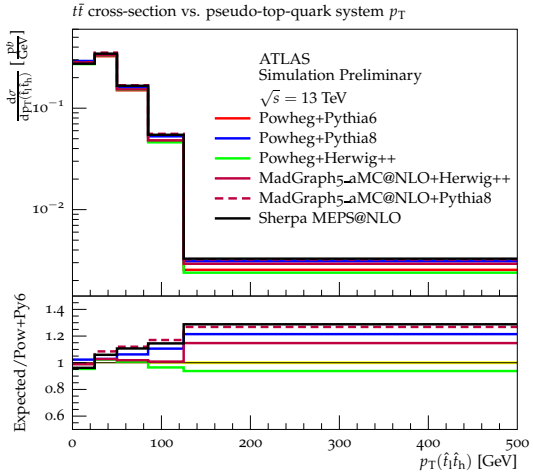
- General guidelines suggest to compare different generators for the ttbar signal

Run1

- ATLAS Powheg vs. aMCatNLO
  - different NLO+PS methods
- CMS MadGraph vs. Powheg
  - LO multileg vs NLO

Run2

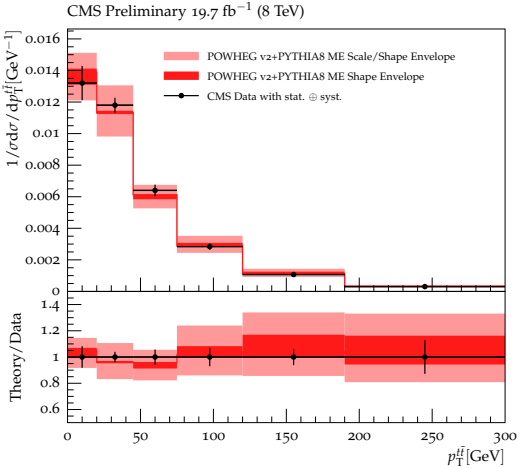
- LO (multileg) generators being phased out
- Quoting Powheg vs. MG5_aMCatNLO
  - MG5_aMCatNLO capable of NLO multileg (FxFx merging)

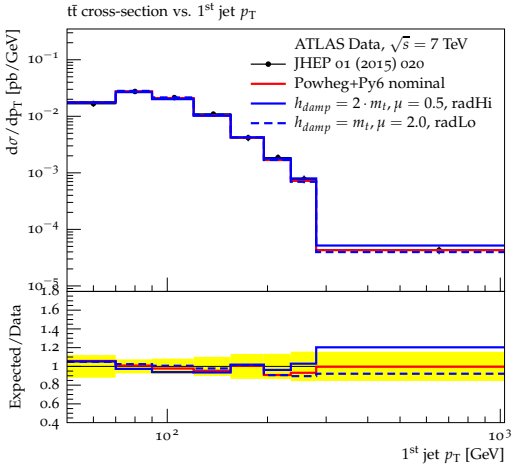


- Is this a well-defined uncertainty? Compare best-tuned/validated setup to sth different
- Sherpa can do NLO multileg but changes all other building blocks (PS, had) as well

"Default" ME+PS scale uncertainties

CMS TOP-15-011 | ATLAS PHYS-PUB-2016-004

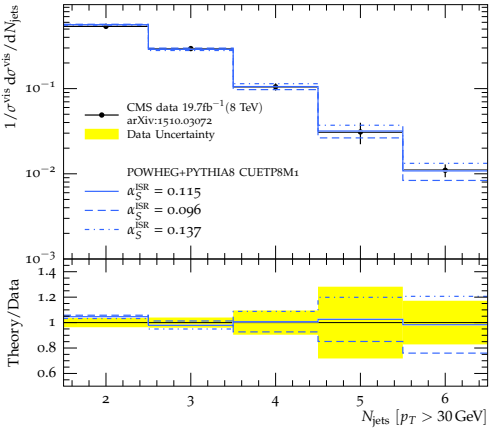


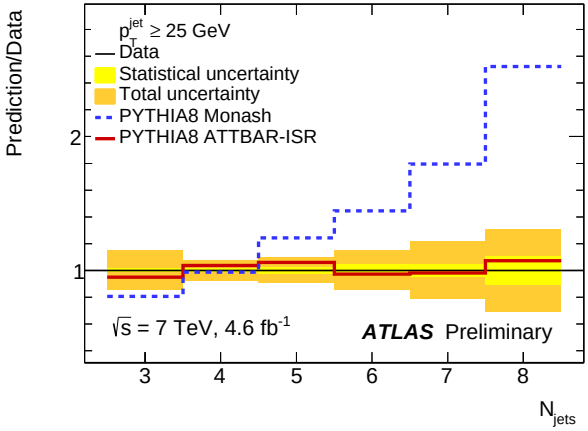


- Different scales to vary in generator setup, example: Powheg+Pythia6/8
  - μ_R, μ_F in ME: usually factors of 2, can be done via weights since Powheg v2
  - h_{damp}: suppresses Powheg real emissions with a factor of $\frac{h^2}{p_{\mathrm{T}}^2+h^2}$, factor of 2
  - μ_R, μ_F in PS: usually factors of 2 (radHi/Lo)
- Which scales are safe to tune?

Tuning radiation using $t\bar{t}$ data

CMS TOP-12-041 | ATLAS PHYS-PUB-2015-007

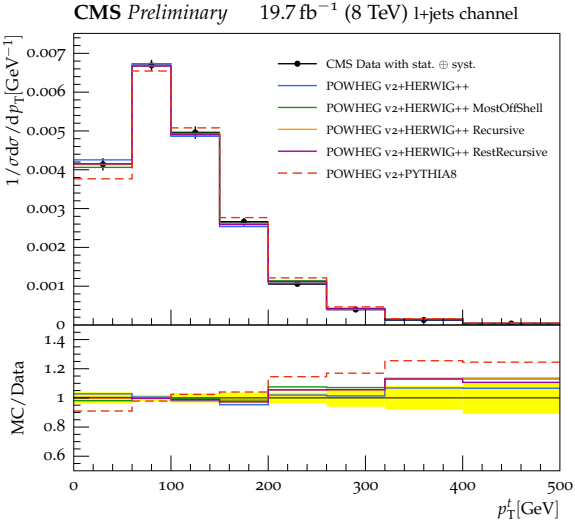


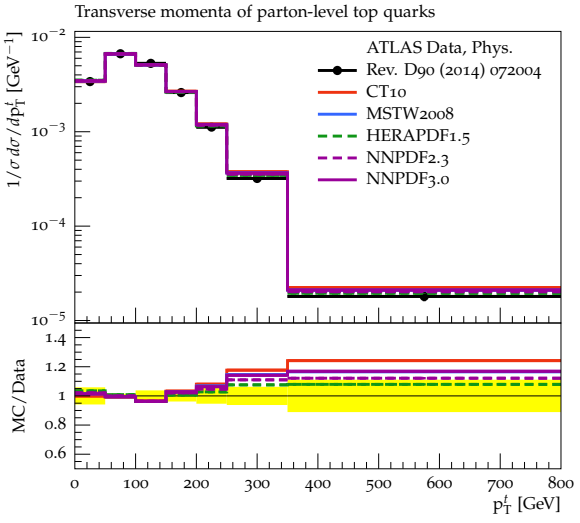


- Jet multiplicity predicted by Pythia8 default/Monash tune is too high
  $\rightarrow$ tune α_s^{ISR} to data, finding significantly lower values
  - default/Monash: $\alpha_s^{ISR} = 0.1365$ CMS $\alpha_s^{ISR} = 0.115$ ATLAS ATTBAR: $\alpha_s^{ISR} = 0.121$

Top quark p_T

CMS TOP-15-011 | ATLAS PHYS-PUB-2015-011 | ATLAS PHYS-PUB-2016-020

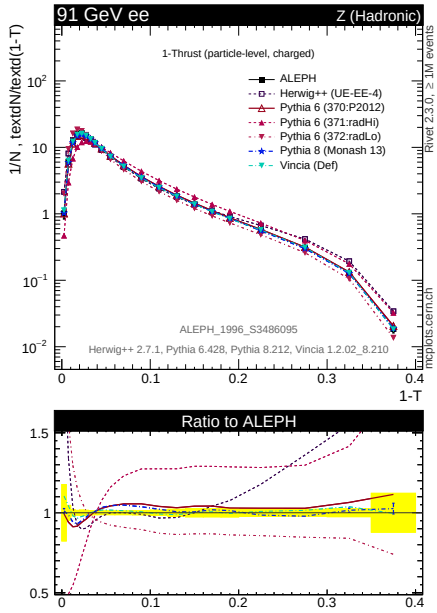




- Disagreement of top p_T data vs. MadGraph/Powheg+Pythia at 7/8 TeV (esp. CMS)
- Compatibility with 13 TeV? Momentum reshuffling? PDFs? NNLO? ($\rightarrow$ David Heymes)
  $\rightarrow$ still not fully understood, work ongoing

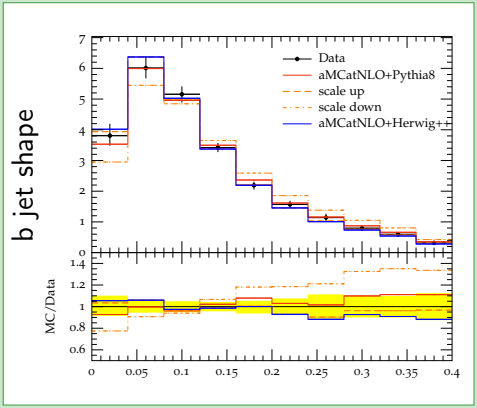
Radiation in decays

Phys. Rept. 294 (1998) 1-165 | ATLAS arXiv:1307.5749 | ATLAS PHYS-PUB-2015-007 | MS



- FSR usually tuned to LEP event shapes
  - ← Thrust $T = 1$ "pencil" event ↔
  - $T = 1/2$ isotropic event ⊛
- Factor 2 scale uncertainty too conservative?

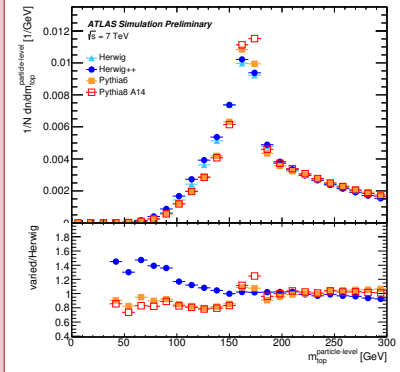
- Constrain radiation from jet shapes in $t\bar{t}$



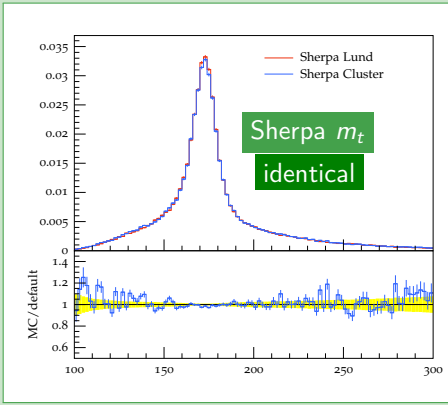
Different hadronization models and parton showers

ATLAS PHYS-PUB-2016-004 MS

Pythia string vs. Herwig cluster



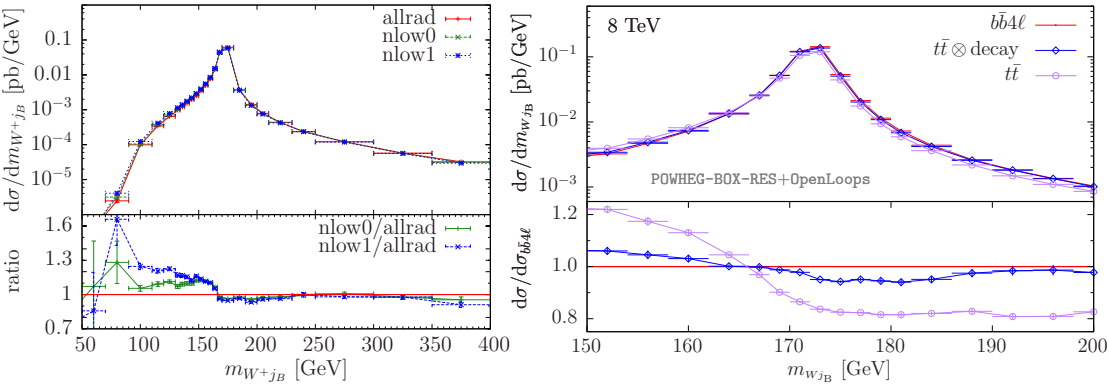
Sherpa string vs. Sherpa cluster



- Hadronization and PS mostly tied together, "building blocks" would help to disentangle
  - Pythia8 can hadronize any parton event. Dire shower for Sherpa and Pythia8 arXiv:1506.05057
- How well are top decays treated in each parton shower? (ME corrections)

Top decays at NLO+PS

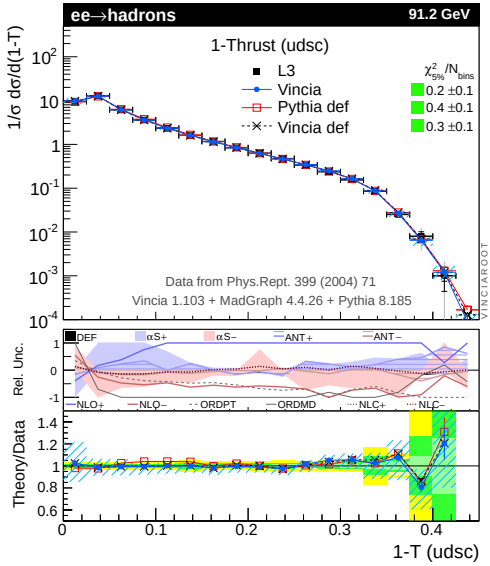
arXiv:1412.1828 arXiv:1607.04538



- NLO top decays implemented in Powheg+Pythia8
  - Approximate off-shell/interference effects for all top decay modes (`ttb_nlo_dec`)
  - Full off-shell/interference effects in `b_bbar_4l` generator
  - 0.5 GeV effect on $m(W + j_b) \sim m_t$ compared to `hvq` (default $t\bar{t}$) generator
  - Currently slow to run and difficult to integrate into experimental frameworks
- MG5_aMCatNLO generates only fixed order so far? How about Sherpa?

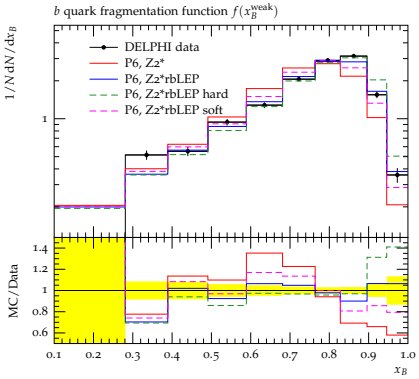
PS weights in newest MC generation

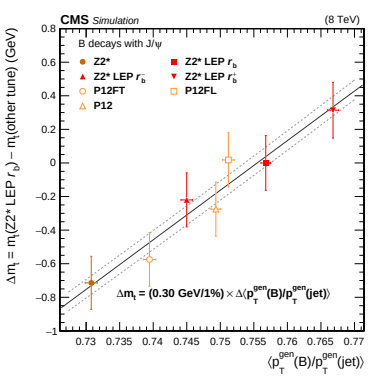
- Weights for variations of scale and other perturbative parameters
- Pioneered in Vincia (no $t\bar{t}$ yet) arXiv:1102.2126
- Recently implemented in
  - Pythia 8.219
  - Herwig 7 arXiv:1605.08256
  - Sherpa 2.2.0 (experimental)
- Saves a lot of CPU ressources!
- Can test different correlation assumptions
  - Vary ISR+FSR coherently
  - or add effects in quadrature
  - or take envelope of all configurations
- To be integrated in experiment and tuning software!

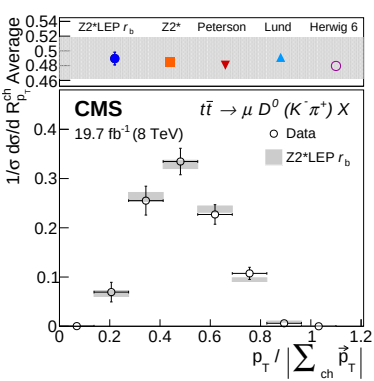


B fragmentation

arXiv:1102.4748 | MS | CMS arXiv:1608.03560 | CMS arXiv:1603.06536



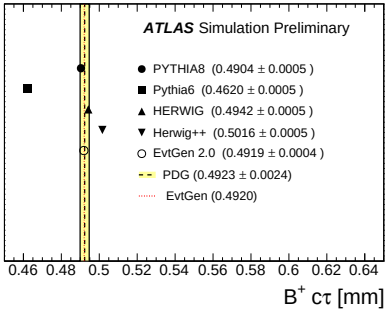


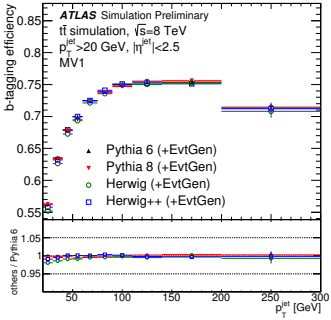


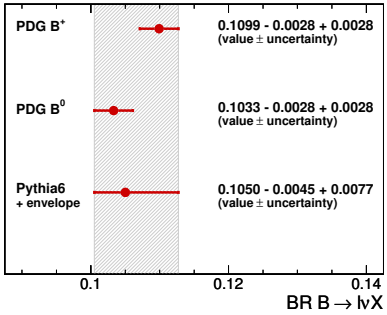
- B fragmentation function tuned to LEP data
- Heavy impact on top mass measurement using $m\left(J/\Psi\left(\to \ell^+\ell^-\right)+\ell\right)$
- LHC data not sensitive enough for adding constraints (yet)

Hadron decays

ATLAS PHYS-PUB-2014-008 | ATLAS PHYS-PUB-2016-004 | CMS arXiv:1607.03663

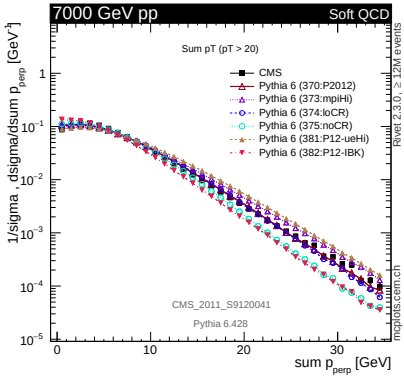


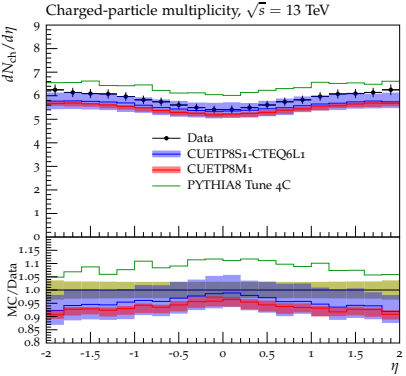


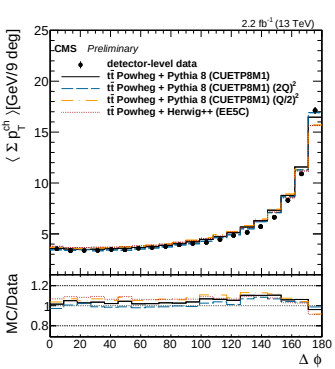


- Lifetime of B hadrons
  - Impact on b-tag efficiencies (constrained from data)
  - Using EvtGen for hadron decays leads to identical b-tag efficiency
    → ATLAS default in Run2!
- Branching ratio $B \to \ell\nu X$
  - Determines neutrino fraction in b jets
  - Direct impact on jet response but would be compensated by b-JES measurement
  - Pythia: same value for B^+, B^0, envelope can be used as uncertainty

Underlying event and color reconnection







- Negligible effects for most analyses. Compared different Pythia6 tunes in the past
  - UE: P11 vs. P11-mpiHi, P12 vs. P12-ueHi/ueLo
  - CR: P11 vs. P11-noCR, P12 vs. P12-noCR/loCR
- New Pythia8 UE tunes include and systematically vary CR strength
  - CUETP8S1/M1 CMS arXiv:1512.00815 A14 ATLAS PHYS-PUB-2014-021
  - Might be beneficial to try new "QCD-inspired" CR model as alternative then? arXiv:1505.01681
- Prospects for including measurements of UE in $t\bar{t}$ CMS TOP-15-017

Summary

- Presented an overview of the tools used for $t\bar{t}$ modeling
  - Including LHC top data in our generator tunes now!
  - Work done in the LHCTopWG
    - Checking configurations, discussing uncertainty prescriptions and new setups
    - Forum for regular interation with theorists
- Experimentalists' tasks:
  - Do particle-level measurements ("pseudo-top") with minimized generator dependence
  - Rivet implementations for all observables
  - Keep up with integrating new generators in our frameworks
- Wishlist to theorists:
  - More guidance for uncertainty estimates, especially when comparing different codes
  - Which parameters can be tuned with predictive power?
    ($\rightarrow$ How much correlation can we assume between observables or even bins?)

  $\rightarrow$ talk by Stefan Prestel
  - Keep on improving all aspects of your valuable simulation tools ☺