

Parton shower uncertainties in CMS

Markus Seidel

June 27, 2019



Current status in CMS TOP and HIG groups

2016:

- TOP: ISR up/down + FSR up/down explicit $t\bar{t}$ samples
- HIG: Pythia vs. Herwig comparison for signal and backgrounds (not always), ISR/FSR uncertainties for $t\bar{t}$ backgrounds

2017:

- ISR and FSR weights in all CMS Pythia 8 samples, used for signals and backgrounds
 - included μ_R factors of $\sqrt{2}$ (reduced), 2 (default), and 4 (conservative)

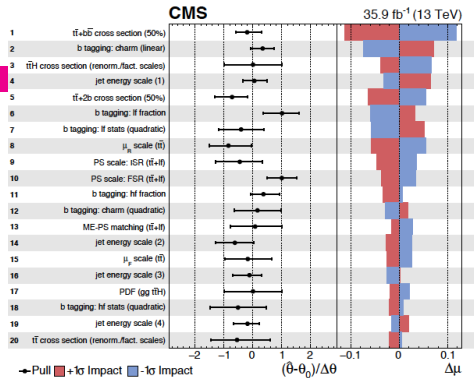
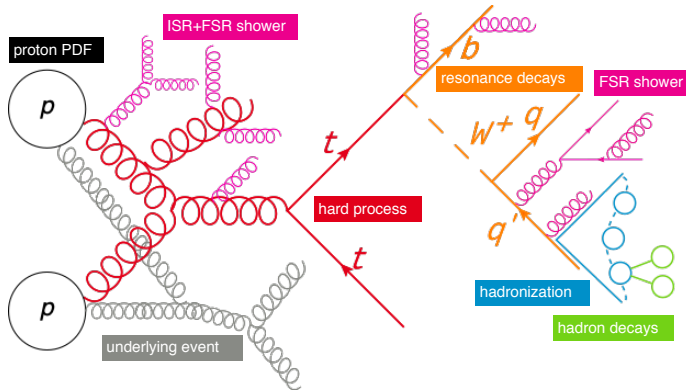
2018:

- “Traditional” and new decorrelated weights scheme in all CMS Pythia 8 samples

2017/2018 schemes based on what's available in Pythia 8 since arXiv:1605.08352

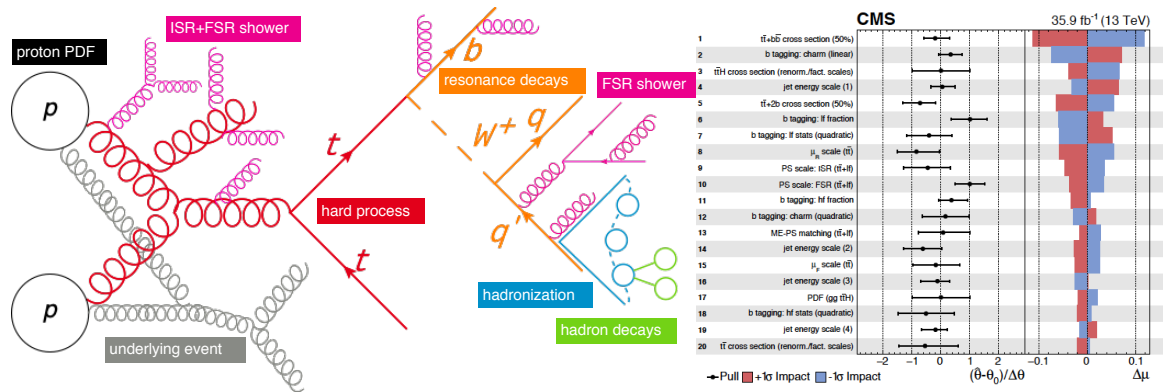
Motivation for new decorrelated weights scheme 1

- Assume top mass measurement or $H \rightarrow b\bar{b}$: how much do the b quarks radiate?
- Initial-state radiation: recoil of the hard system, amount of extra jets
- Final-state radiation: jet broadening, out-of-cone, also for ISR jets



- Combined likelihood fits treat uncertainties as nuisances, powerful with high statistics
- Problem with combined likelihood fit: FSR constrained by ISR jet multiplicity/ p_T

Motivation for new decorrelated weights scheme 2



- Problem with combined likelihood fit: FSR constrained by ISR jet multiplicity/ p_T
- FSR in resonance decays with ME corrections: emissions corrected to LO
- Matrix-element generators for ISR: interference effects, color-octet gluons as emitters
- Different independent renormalization scales (that are educated guesses, after all)
- Or worse: ISR from PS \rightarrow ME-corrected FSR constrained from LL prediction...

Decorrelate scale variations different splitting types

Pythia 8 allows for scale variations independent for different splitting types:

- $g \rightarrow gg$
- $g \rightarrow q\bar{q}$
- $q \rightarrow qg$
- $x \rightarrow xg$, where x is b, t or heavier with `UncertaintyBands:nFlavQ = 4`

Motivation:

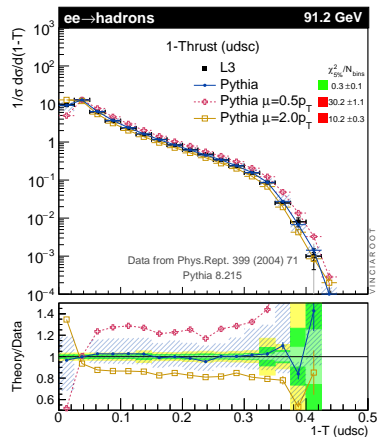
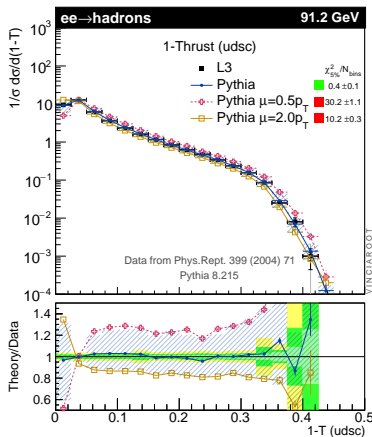
- Different splittings occur at different scales
- Nuisance factor 2 fitted for one splitting does not mean factor 2 is correct for another
- Especially when weak decays with $\mu_R^{def} = m_Z$ are involved

NLO scale-compensation term

flag `UncertaintyBands:muSoftCorr` (default = on)

This flag tells the shower to apply an $O(\alpha_s^2)$ compensation term to the renormalization-scale variations, which reduces their magnitude for soft emissions, as described in [arXiv:1605.08352].

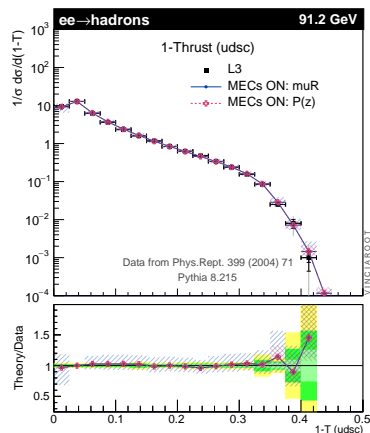
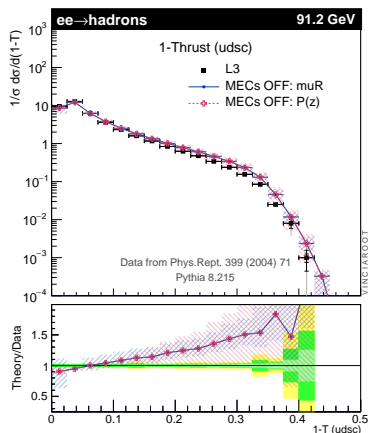
- Dots: explicit variations
- Hashed band: weights
- Left: `muSoftCorr = off`
- Right: `muSoftCorr = on`



Splitting-kernel variations

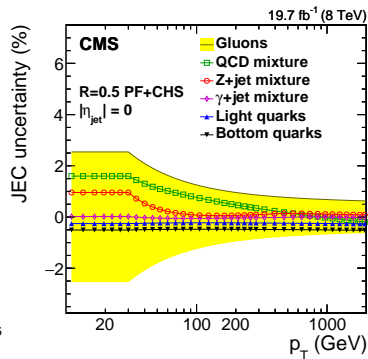
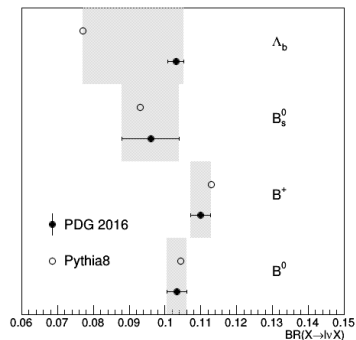
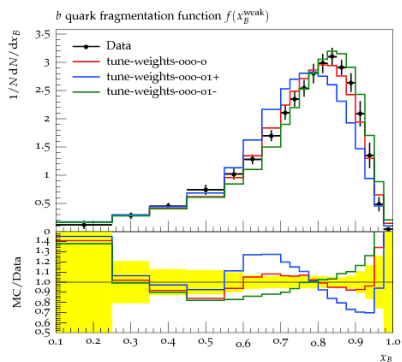
- Splittings with same soft/collinear approximation have different true matrix elements
- MEs contain process-dependent finite terms and may differ a lot from default shower radiation functions
- Pythia 8 allows for variation of non-singular terms (cNS variations)
 - complementary to scale variations (that are proportional to default radiation functions)

- Dots: central prediction
- Blue band /// μ_R variation
- Red band \\\ cNS variation
- Left: MECs = off
 - cNS relevant, tuned to cover MEC=on
- Right: MECs = on
 - cNS negligible



Additional uncertainties used for TOP precision measurements

- b fragmentation: tune to LEP data, take Eigentunes as uncertainty
- Decay tables: envelope of Pythia 8 and PDG for leptonic B hadron decays
- Jet flavor uncertainty: Pythia vs. Herwig response, leading uncertainty in top mass
- Color reconnection: different models, reconnect resonance decays products on/off



Summary

Latest CMS Pythia 8 samples include:

- 12 “traditional” shower scale uncertainties:
(ISR, FSR) \otimes (μ_R [$\sqrt{2}, 2, 4$]) \otimes (up, down)
- 32 decorrelated parton shower variations in all CMS samples \rightarrow 16 nuisance parameters:
(ISR, FSR) \otimes (μ_R [2], cNS) \otimes ($g \rightarrow gg, g \rightarrow q\bar{q}, q \rightarrow qg, b/t \rightarrow b/t + g$) \otimes (up, down)
 - Settings: https://github.com/cms-sw/cmssw/blob/master/Configuration/Generator/python/PSweightsPythia/PythiaPSweightsSettings_cfi.py
- Decorrelated variations give robust nuisance estimates in likelihood fits
 - But be open to surprises, don't follow recipes blindly...
E.g., bins are not necessarily correlated (see top p_T in bonus slides)
- Weights make parton shower uncertainties accessible to every analysis \rightarrow no excuses!

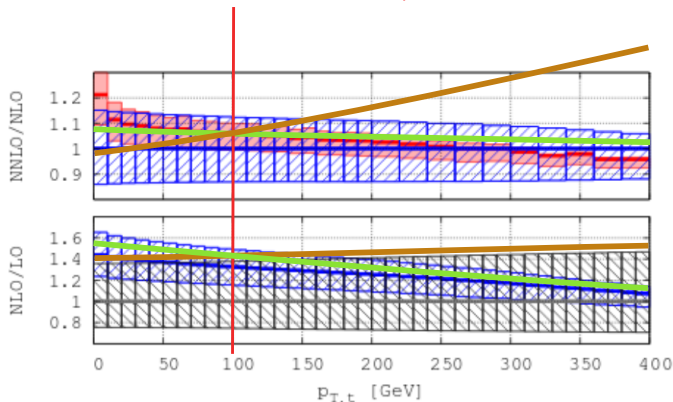
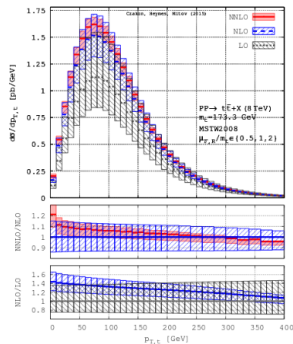
Status of weights from other generators in CMSSW

- Dire and Vincia weights fully supported, like Pythia
- Sherpa weights available but work needed (weight names not stored)
- Herwig7 weights not stored yet (afaik). Needs more work in CMS!

Bonus

Bonus: bin-to-bin correlations

assume NNLO as data, mean ~ 100 GeV



NLO fit
LO fit

- Assuming 100% bin-to-bin correlation leads to wrong results
- Would need to reduce long-range correlations to give the fit flexibility (very difficult to implement)