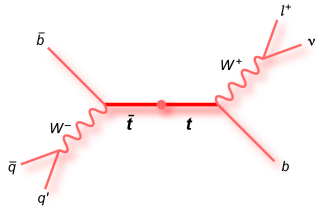
Projektiistai

Hannu Siikonen



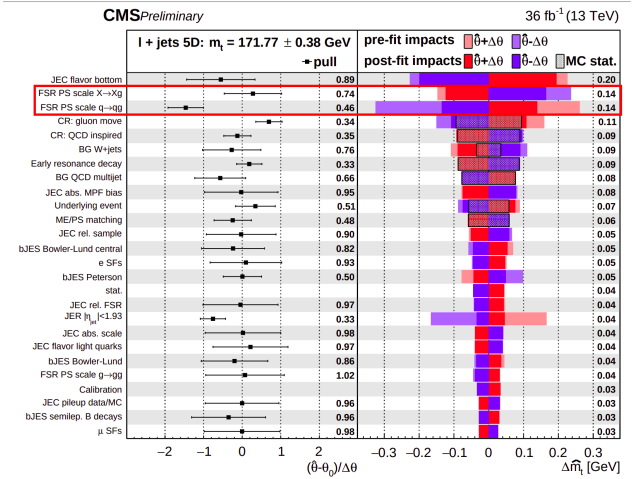
Helsinki Institute of Physics

11th October, 2022

News

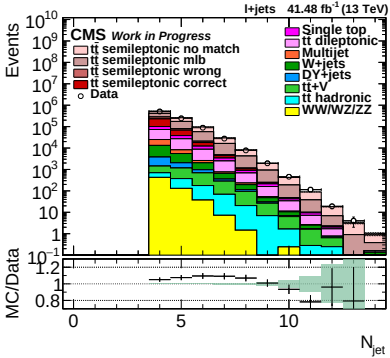
- HIP seminar on the topic of my thesis on 25th October:
  - General information on profile likelihood top quark mass measurements
  - Exact topic and abstract yet to be formulated
  - See https://www.hip.fi/seminars/
- Thesis defense:
  - 22nd November at 1 PM in Chemicum hall A 129
  - More information and Karonkka invitations to be sent later
- Future work plans:
  - (3D CT imaging) Algorithm Specialist position offered at Planmeca
  - Starting date 1st November
  - Yet unconfirmed, but if funding and bureaucracy allows, planning on continuing on the top mass project and Mikael's supervision on a subsidiary 10% contract
- Point of focus in the rest of these slides: FSR tuning in CP5

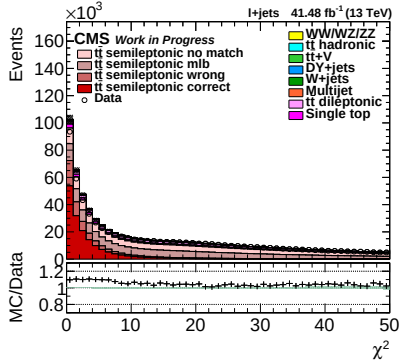
Starting Point



- We are working with the semileptonic UL17-18 m_t analysis
- Point of interest: the Legacy 2016 m_t analysis (PAS and paper draft available)
- From the figure on the left:
  - A significant pull is found only for the qFSR nuisance (around -1.5 $\rightarrow \alpha_S$ up)
  - Different behavior found for the bFSR nuisance (around +0.3 $\rightarrow \alpha_S$ down)

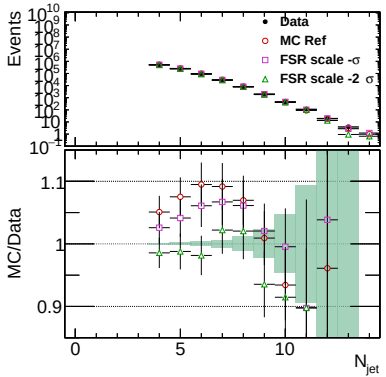
What about UL17(-18)?

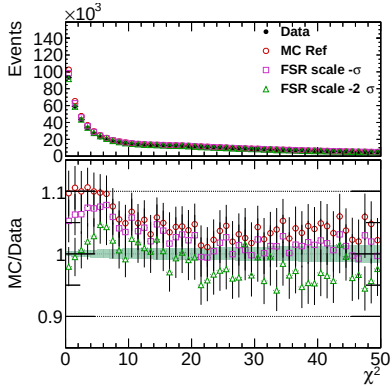




- Event yields have not converged between Data and MC, which is well shown in the number of jets spectrum and in the χ^2 spectrum of the kinematic fit (10% too much MC events in the good fit / low χ^2 region)
- This could be a symptom of a significant pull in some of the systematics

FSR Scale Down Variations for UL17



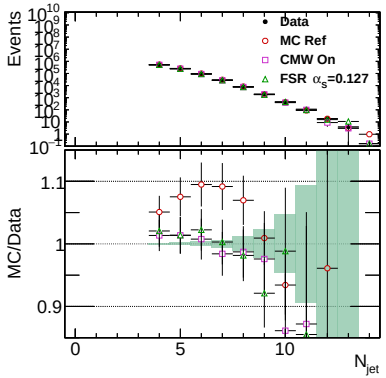


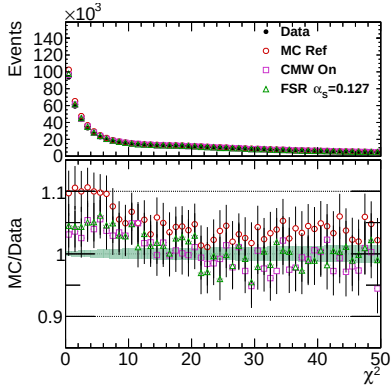
- Above: FSR scale variations $\frac{1}{2}$ and $\frac{1}{4}$ (i.e. α_S^{FSR} up)
- It seems possible that the Data-MC mismatch is explained by FSR: a better match with Data is reached between the $-\sigma$ and -2σ variations

Further Variation Ideas

- The FSR scale variations are abstract, so we could experiment with explicit variations in Pythia8 settings
  - One variant of interest is FSR CMW scaling on (suggested by **Markus Seidel**)
  - According to these slides, increasing α_S^{FSR} by 0.009 has a similar impact
  - In the case of CP5, this means $\alpha_S^{FSR} = 0.118 \rightarrow 0.127$
- The majority of the selected events belong to semileptonic ttbar signal samples, so varying these suffices:
  - The main ttbar (semileptonic) samples have around 300M events, which was infeasible for us
  - $\rightarrow$ but for χ^2 and the number of jets a smaller number suffices!
  - We decide to go with 4M events (2-3 fb^{-1}) on UL17, and (hence UL18 is excluded in the figures above and below - see Backup for UL18 figures)
  - Datasets produced by **Mikael**
- Results given on the next slide

UL17: CMW on and $\alpha_S^{FSR} = 0.127$





- Both with CMW scaling on and at $\alpha_S^{FSR} = 0.127$, Data and Simulation almost agree within the statistical limits

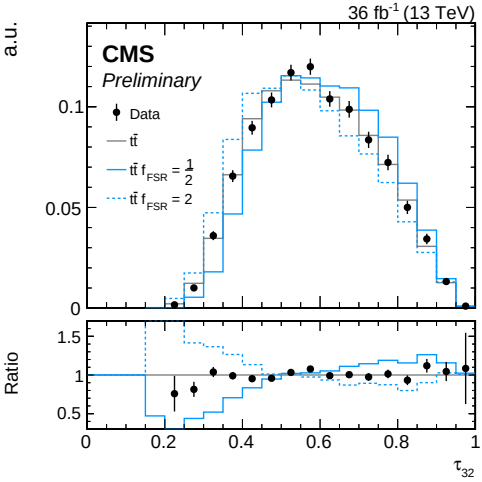
Universality in ttbar Events?

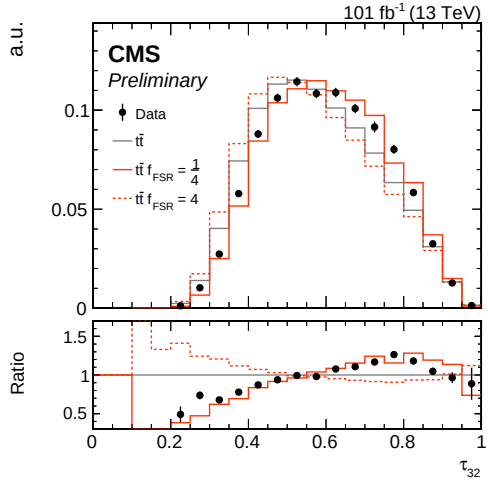
- We have so far observed potential FSR issues in the semileptonic m_t analysis:
  - It seems that α_S^{FSR} should be significantly higher than in CP5
  - Even if there are small differences in the Legacy16 and UL17-18 analyses, these share the same cuts and the same kinematic fitting framework
  - $\rightarrow$ the issues could be an artifact of our analysis chain
- Can we find evidence that the issues are more universal?
- Let's start by looking at other ttbar analyses!

Run2 Jet Mass Analysis I

- The measurement of the jet mass distribution and top quark mass in hadronic boosted top decays provides a phenomenal study of FSR:
  - Here, the P8M1 (non-ttbar) and P8M2T4 (ttbar) tunes are used for 2016 and CP5 for 2017-2018
- A great tension is observed between CP5 and the previous generation tunes
  - In terms of the weight-based FSR nuisances, Data is found to match:
    - **A -0.07 FSR nuisance value for P8M1/P8M2T4**
    - **A -1.59 FSR nuisance value for CP5**
  - For CP5 the offset is non-negligible and suggests the need for a higher α_S^{FSR}, compatibly with the other results
- On the next slide, the distributions of τ_{32} (N-subjettiness metrics) are presented for the different tunes vs. Data
  - These distributions have proved to be sensitive to FSR

Run2 Jet Mass Analysis II

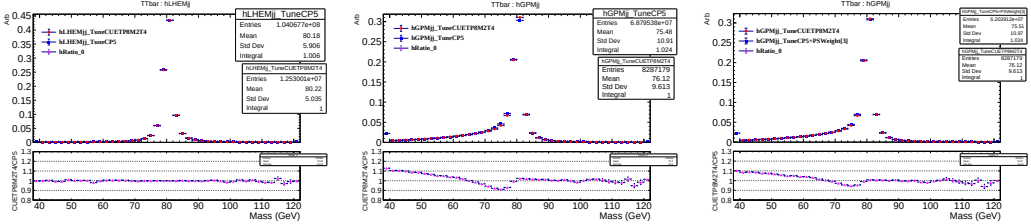




- 2016 (left) with $\pm\sigma$ variations, 2017-2018 (right) with $\pm\mathbf{2}\sigma$ variations

Resonance studies for m_W

- A standalone study compared m_W resonances in ttbar events between P8M2T4 and CP5
- On the LHE/ME level **(left)** the tunes agree
- On the parton level **after FSR (middle)** an inter-tune discrepancy appears
- The discrepancy is mitigated by applying the FSR $-\sigma$ weight variation **(right)**
- A more robust analysis could be performed with GenJets for the two rightmost plots, but the results should be similar



Evidence Outside ttbar Events

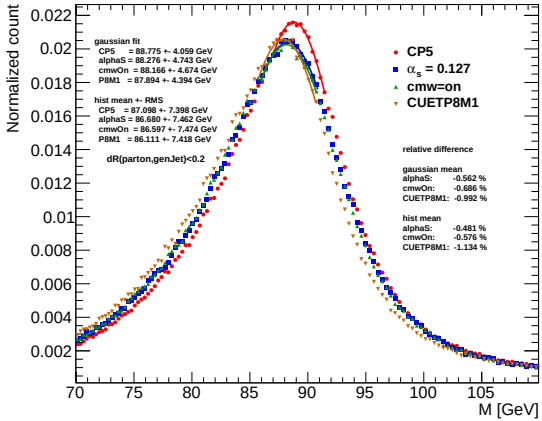
- So far we have found multiple pieces of evidence in ttbar production
- But can we find evidence outside ttbar events?
  - If not, a ttbar-specific sub-tune such as P8M2T4 would suffice for CP5
  - If yes, the issues seem to go onto a deeper level with CP5

Our ZtoQQ Study

- Test planned together by **Mikael**, **Mikko** and me:
  - Idea: the P8M1 tune (and its variants, e.g. P8M2T4) has generally shown a good agreement between Data and simulation
    - Does it agree with CP5 and/or CP5 variations (on FSR)?
    - For the variations, use CMW scaling on and $\alpha_S^{FSR} = 0.127$, as earlier
  - → **Perform a GEN-only study on GenJets (execution by Mikael)**
  - In a GEN-level tune comparison we can safely focus on channels which would be difficult to measure against Data
  - → Choose **ZtoQQ: a non-ttbar topology**, where we can inspect the Z resonance shape, constructed from GenJets
  - Settings taken from: /ZJetsToQQ_HT400to600_qc19_4j_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16MiniAODv3-PUMoriond17_94X_mcRun2_asymptotic_v3-v1/MINIAODSIM
  - Sufficient statistics were reached at around 1M events (results on the next slide)
- Further ideas: make a pure **ZtoBB** variant of the study to show, whether or not the FSR mismatch is similar to b jets and light quark jets

Our ZtoQQ Study: Z resonance

- With CMW scaling on or with the increment $\alpha_S^{FSR} = 0.118 \rightarrow 0.127$ CP5 agrees notably better with P8M1 on the resonance shape and position



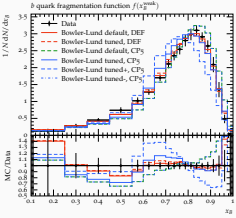
B-Fragmentation in CP5 I

- Most evidence only available for generic FSR; what about qFSR vs. bFSR?
- CP5 bFragmentation study shows a discrepancy that may be linked to bFSR
- A quick reminder:
  - Bowler-Lund fragmentation function is used with $r_b = 0.855$ both in CP5 and P8M*:
$$f(z) = z^{-\left(1+r_b\, b\, m_b^2\right)}(1-z)^a \exp(-b m_T^2/z) \quad (1)$$
  - For b quarks a and b are fixed, **but $\mathbf{r_b}$ can be fit against LEP data**
- Monash (P8M*) tune results:
  - LHC data suggests that $r_b = 0.858 \pm 0.049$
  - From the LEP fit $r_b = 0.895^{+0.184}_{-0.198}$, i.e. the central value is fairly close to the tune default
- For CP5 $r_b = 1.056^{+0.196}_{-0.200}$ from the LEP fit:
  - **I.e. $-\sigma$ variation is at $\mathbf{r_b} = 0.856$, practically equal to the CP5 default**
  - This is visualized on the next slide

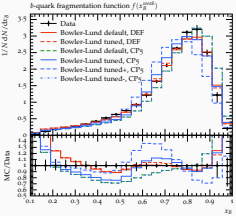
B-Fragmentation in CP5 II

b fragmentation: CP5 UE tune results, Bowler-Lund

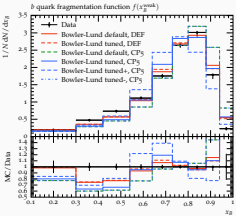
Aleph:



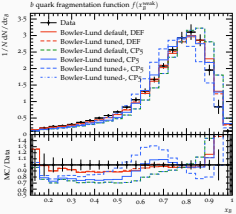
Opal:



Delphi:



SLD:



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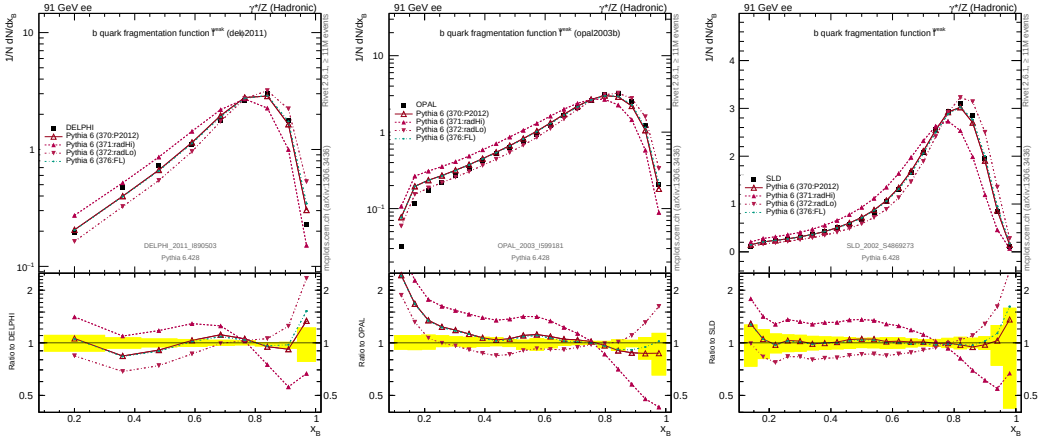
- Visualization: **CP5 default** (green line) almost **agrees with the LEP $-\sigma$ variation** (blue dash-dot line)
- **The CP5 default x_B distributions would move left**, closer to LEP central value **with a greater (b quark) α_S^{FSR}; see the slide next slide!**

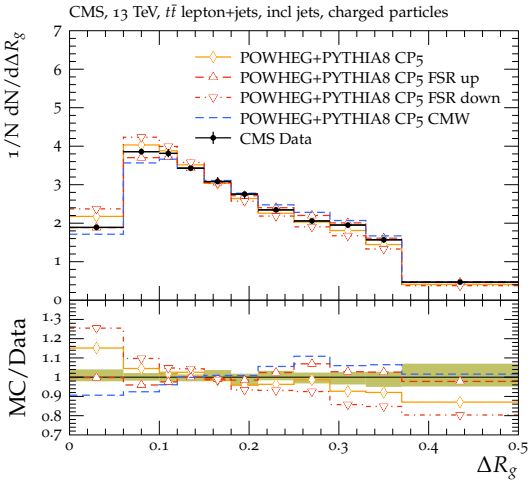
B-Fragmentation in CP5 III

- A greater α_S^{FSR} moves the x_B distributions to the left (radHi in the Delphi/Opal/SLD plots below; thanks for the link to **Markus Seidel**!)



The CPX Paper Reference: FSR

- In the newest version (2) of the CPX flavor tune paper, FSR variations and the CMW scaling on setting are tested on the CP5 tune
- Especially interesting: the separation between two groomed subjets (ΔR_g) in ttbar events (Fig. 20)
- The (plain α_S) FSR up variation agrees best with Data
- CMW rescaling correction also in the correct direction but slightly overshoots



Discussion

- For the tune variants CP3/4/5 the PDF, α_S and α_S running are modified
- Most importantly, $\alpha_S^{FSR} = 0.118$ in CP5 (ref. 0.1365 in P8M1)
- If this change is the origin of FSR issues, **one could expect that the same issues arise in all FSR flavors**:
  - Occam's razor: The CP5 BFragmentation discrepancies could be explained in the simplest manner by the same issues existing both in bFSR and qFSR
  - The Legacy 2016 m_t analysis states that only qFSR (not bFSR) is displaced
    - **Important: correlating qFSR with bFSR adds $+0.43$ GeV to $\mathbf{m_t}$**
    - With what we have so far seen in the same measurement for UL17-18, the measurement is very sensitive to qFSR through the m_W resonance, but it might not be equally good at distinguishing bFSR
    - Most importantly, the bFSR nuisance and m_t variations display similar behavior
    - In a profile likelihood fit this can lead to the fit preferring shifting m_t (no Gaussian constraint) over the bFSR nuisance (with a Gaussian constraint)
  - $\rightarrow$ Further tests (e.g. in the ZtoBB topology) necessary to understand the qFSR-bFSR relationship better

Conclusion

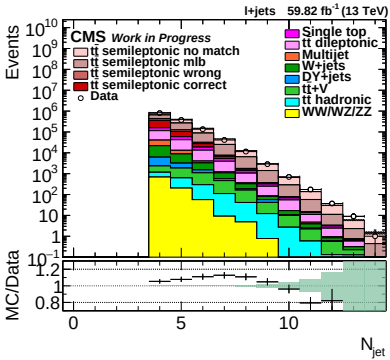
- FSR is closely linked to jet responses, and hence it has a great impact e.g. on mass reconstruction
- Initially, much of the evidence was found in the ttbar topology
  - However, also other event topologies seem to be affected
  - The need for a greater FSR α_S value is indicated
- A majority of the evidence cannot distinguish which FSR flavors are affected
  - There is currently evidence both for and against both bFSR and qFSR being affected
  - If the underlying culprit are the generator settings, full FSR being affected would seem like the more likely scenario

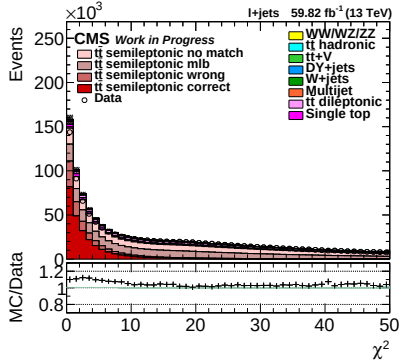
Backup

The CPX Paper Reference: Remarks

- Below, some further comments on the CPX paper
- Philosophically the CPX tunes are UE Tunes, which only fit UE parameters
  - The fits are performed against MinBias TransMin and TransMax observables, measured at different $\sqrt{s}$ values
  - At 13 TeV, for CP3/4/5 both TransMin and TransMax end up preferring charged particle density over p_T sum density, which is underestimated (Fig. 5) - causing trouble for jet calibration (issue does not exist for CP2, see Fig. 4)
- **A potentially fundamental issue for ISR/FSR α_S value choices:**
  - The new choice $\alpha_S = 0.118$ is theoretically motivated, but lacks *a priori* checks
  - Checks are only performed *a posteriori* with the found CP5 tune parameters
  - That is, the CP5 parameters are first fit at $\alpha_S = 0.118$, and then a separate consistency fit is performed for α_S with the CP5 parameters fixed (Appendix A)
  - This check does not answer, whether the α_S choice is the best one *a priori*
  - For studies dependent on jet modeling it would be better to focus **simultaneously on the UE and FSR parameters**, while tuning is performed
  - One could add further FSR checks, e.g. on the LEP BFragmentation Data

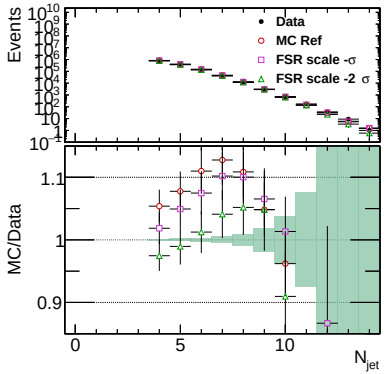
UL18 Event Yields

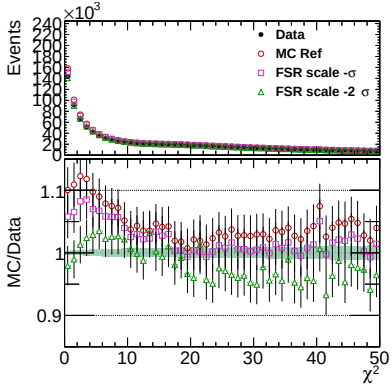




- Event yields have not converged between Data and MC, which is well shown in the number of jets spectrum and in the χ^2 spectrum of the kinematic fit (10% too much MC events in the good fit / low χ^2 region)
- Issues similar as in UL17

FSR Scale Down Variations for UL18





- Above: FSR scale variations $\frac{1}{2}$ and $\frac{1}{4}$ (i.e. α_S^{FSR} up)
- It seems possible that the Data-MC mismatch is (also for UL18) explained by FSR: a better match with Data is reached between the $-\sigma$ and -2σ variations