Recoil uncertainty in top mass measurement

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Summer Student Sessions, August 11, 2023

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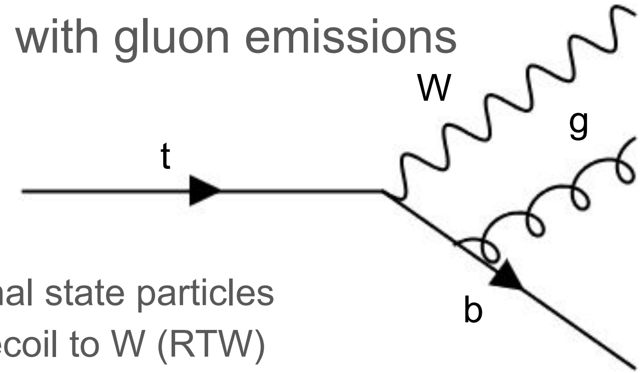
Introduction

- Studying simulation of top quark decays with gluon emissions

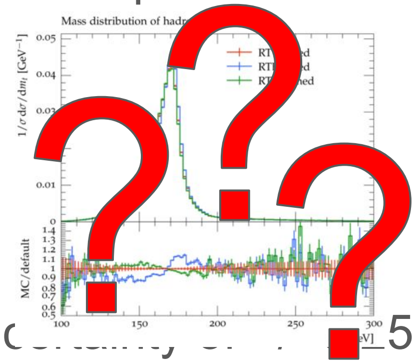


- $t \rightarrow bW$
  - Need to assign 'recoil' from gluons to other final state particles
  - Recoil to bottom (RTB), recoil to top (RTT), recoil to W (RTW)
  - Recoil uncertainty = how much does change in recoiler assignment impact extracted top mass
- Expectations in RTT and RTW observables:
  - b-jet energy reduced
  - b-hadron momenta hardened
  - W p_t *mildly* impacted

[1] H. Brooks, P. Skands, "Coherent Showers in Decays of Colored Resonances", February 2020
[2] P. Skands, "Notes on Top Quark Modelling in Pythia 8 and Vincia", March 2021
[3] P. Skands, "Note on RecoilToColoured", November 2020
[4] ATLAS Collaboration, "Measurement of the top-quark mass using a leptonic invariant mass in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector", September 2022

Objective

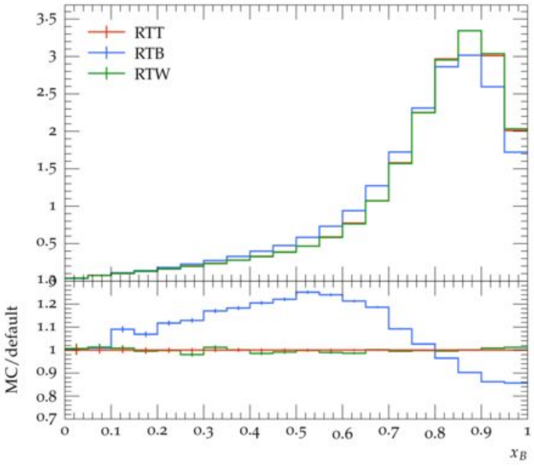
- Evaluate effect of new recoilToTop option on generator level top mass measurements in CMS
    - L + jets hadronic top mass (L+jet)
    - Lepton + soft muon mass (L+SMT)
    - Boosted top decay normalized jet mass (Boosted)
- Integrate RTT into CMSSW Pythia8Interface and Rivet
- 2022 ATLAS paper uses this in their analysis, reports unc[...]5 GeV from recoil [4]
    - We want to cross check this on different top mass measuring methods!

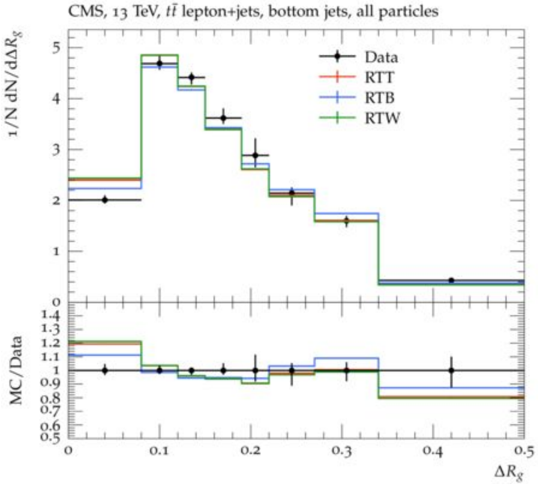


[4] ATLAS Collaboration, "Measurement of the top-quark mass using a leptonic invariant mass in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector", September 2022

Impact on b jet observables

- Difference visible between different recoil options!
  - Observables directly connected to b hadron momentum most impacted
  - Quite literally… b-hadron momentum fraction (x_B), b-jet internal angles



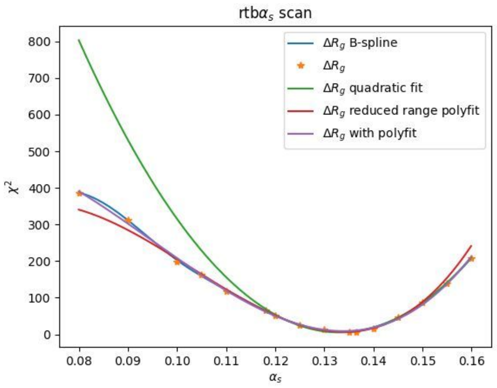


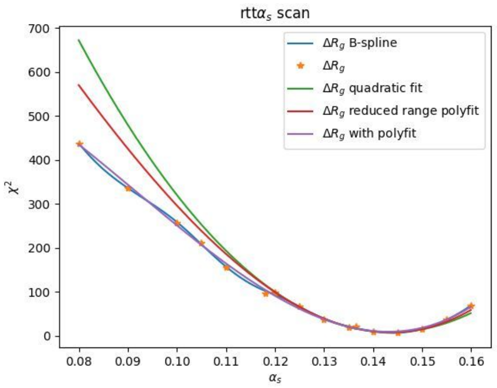
V. Slokenbergs. Summer Student Sessions: August 11 2023. Contact: valdis.roberts.slokenbergs@cern.ch

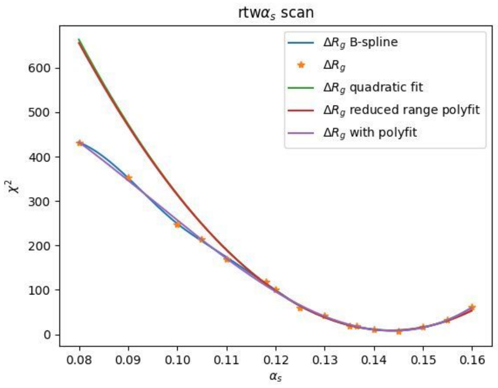
Tuning strong coupling constant α_s

- Perform α_s scan using HEPdata entry from CMS-TOP-17-013 [5]
  - minimize χ^2 on highly correlated observable delta ΔR_g
  - Independent of input top mass

[5] CMS Collaboration, “Measurement of jet substructure observables in ttbar events from proton-proton collisions at √s= 13TeV”, December 2018





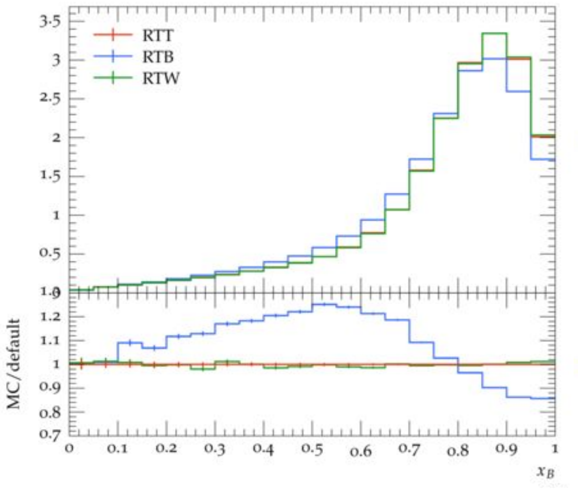


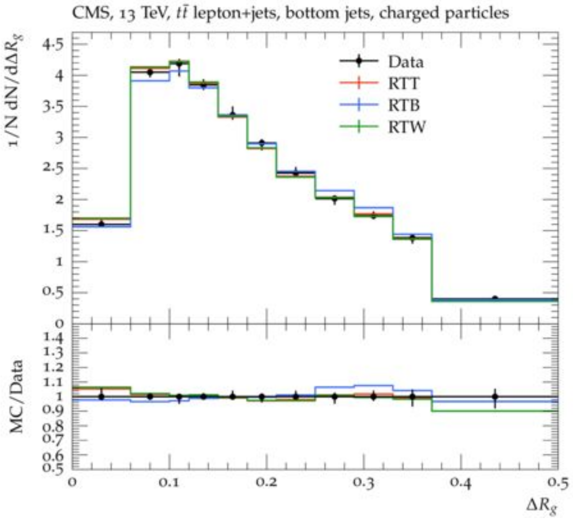
Returned α_s	RTB = 0.1336	RTT = 0.1436	RTW = 0.1437
1σ	0.0004	0.0004	0.0003

Qualitative tuning results

- Better agreement to observable data and other recoil schemes AFTER tuning

Pre tune

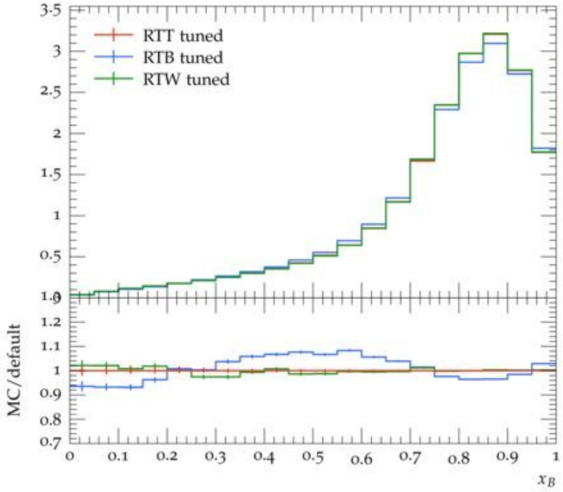


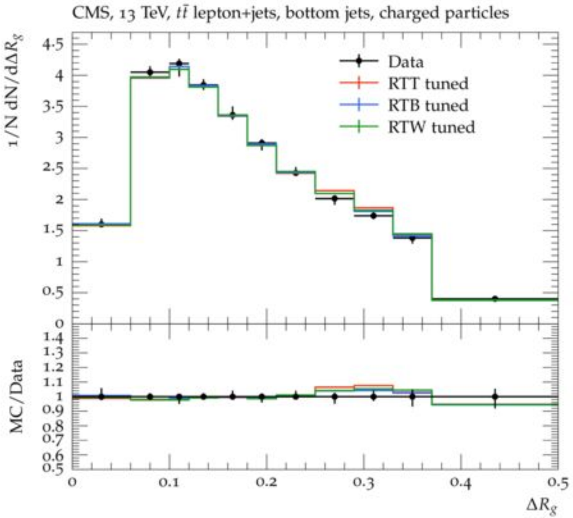


Qualitative tuning results

- Better agreement to observable data and other recoil schemes AFTER tuning

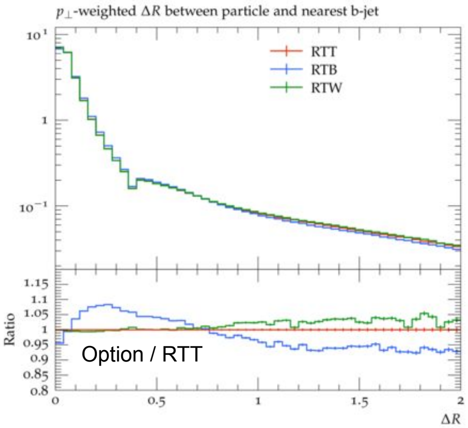
Post tune

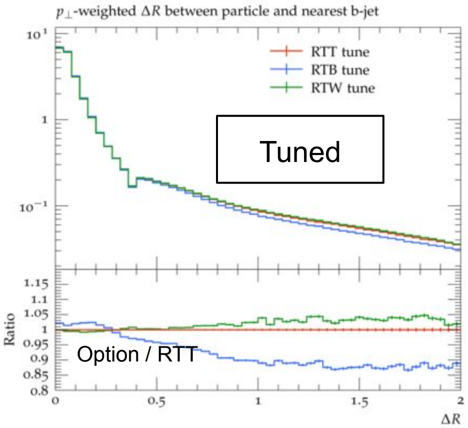


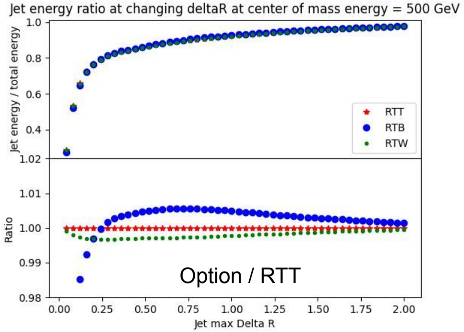


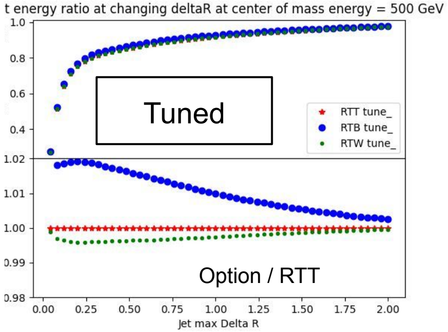
Jet substructure and radiation effects

- Confirmation via study of e+e- at E_{COM}= 500 GeV
  - Behavior between models as expected from theory
    - Much less wide-angle radiation in RTB
    - more energy in RTB jet, jet less focused after tune









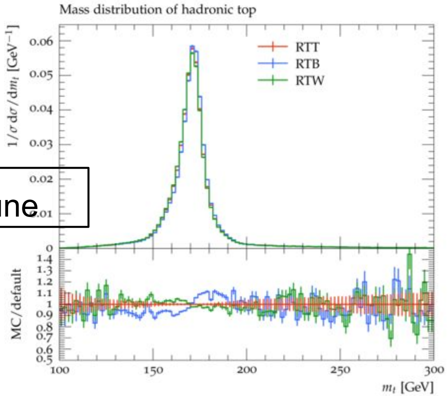
Top mass comparisons

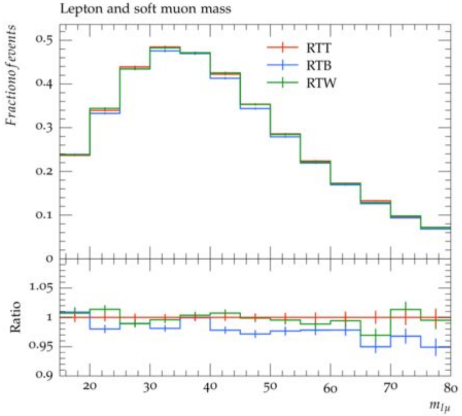
L+jet

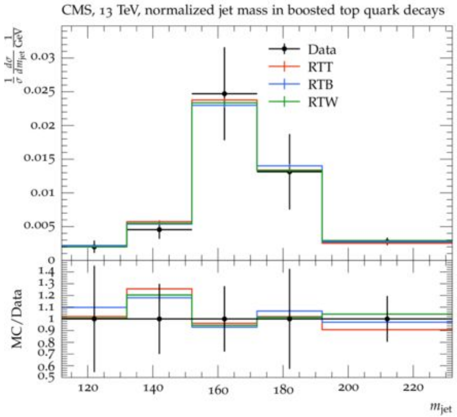
L+SMT

Boosted

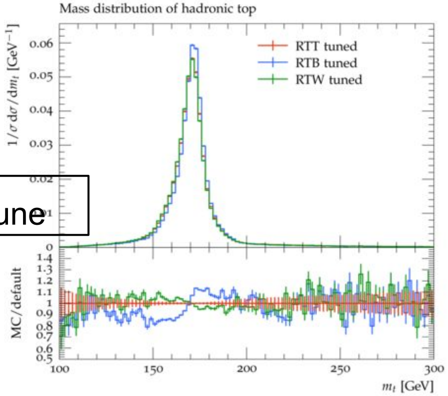
Pre-tune

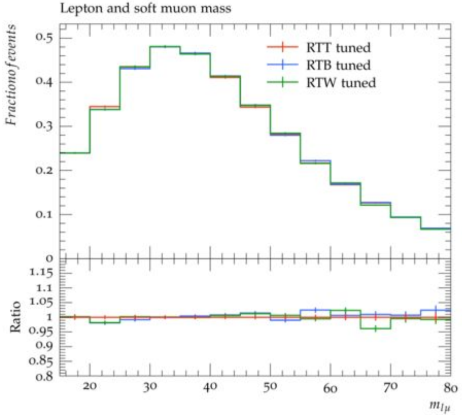


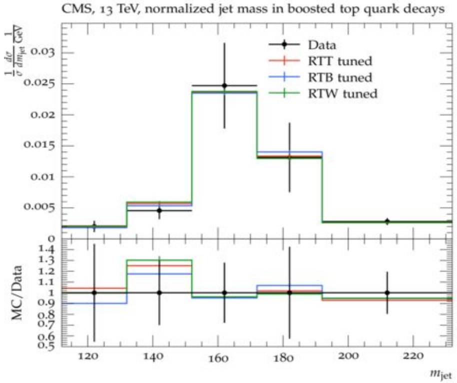




Post-tune



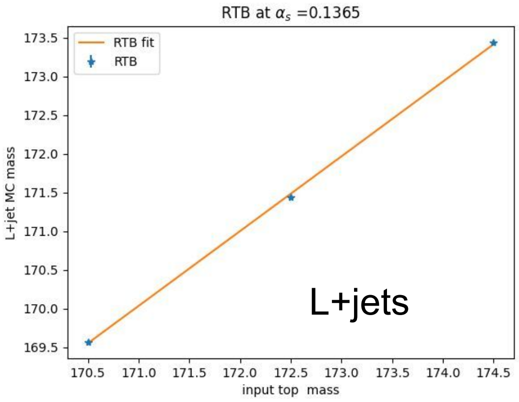


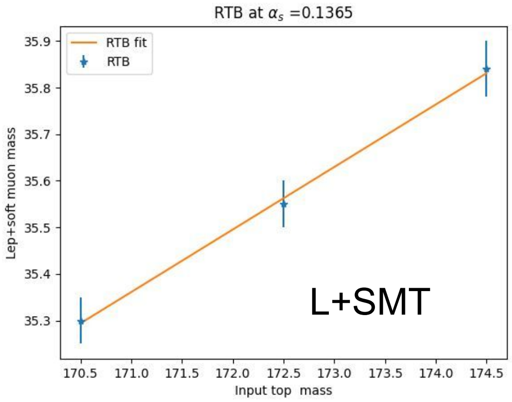


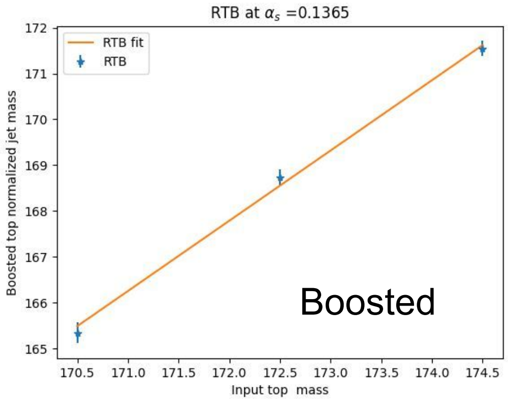
Top mass calibration

- Need to calibrate BEFORE we evaluate top mass shift
- Plot input mass vs. mass plot peak
  - Fit to *y = a*(x-172.5)+b* and use fit parameters *a* and *b* to get extracted masses
- Apply fit from RTB to both RTT and RTW
  - Compare differences!

Example plots







Top mass results

- Notable shifts between recoil models
  - RTT and RTW behave very similarly (expected)
  - RTB to RTT have bigger shift
  - Importance of α_s tuning
    - Big impact on lep + soft muon method
- Technical work:
  - RecoilToTop implemented as Pythia8 plugin [6]
    - Backported to older CMSSWs for Run 2 analysis
  - Rivet routine for L+soft muon implemented

RTB - RTT at 172.5 GeV input mass

α_s setting	L+Jet	L+SMT	Boosted
Default α_s	+0.48 GeV	-1.11 GeV	+0.44 GeV
Tuned α_s	+0.65 GeV	+1.02 GeV	+0.34 GeV

[6] PR #42180

Backup!

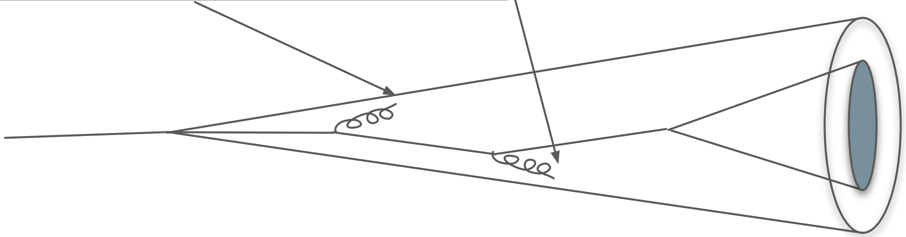
Continuation of work

- Implement Powheg matching
- Perform tunes using current CMS data (CP5 tune), check if shift consistent
- Central production

Additional studies: dead cone effect

- Compare default setting with switching off wide angle suppression via recoilDeadCone
- Comparison on L+jets yields only statistical difference, i.e. no change!
  - Reported statistical uncertainty in L+jets sample of 30 MeV
  - Default tune: Approximately 30 MeV change between sample with and without wide angle suppression
  - Tuned α_s: < 10 MeV less difference between samples with and without dead cone setting

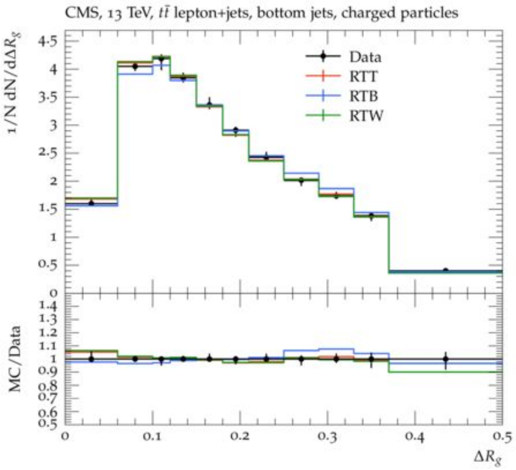
Emissions from these ‘primary’ gluons also respect dead cone

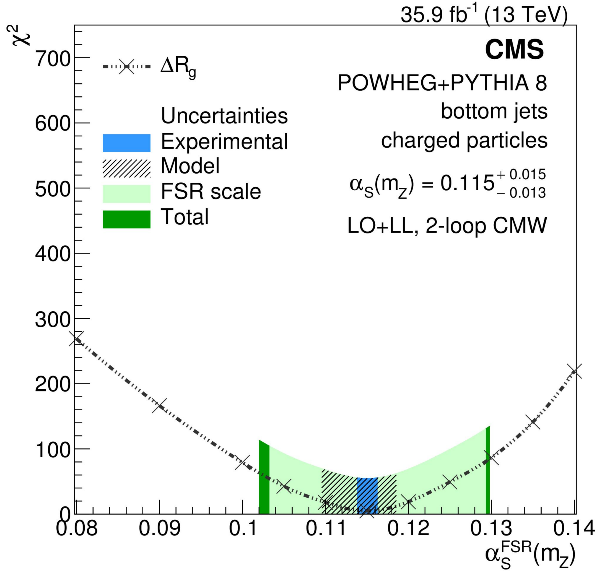


Tuning strong coupling constant α

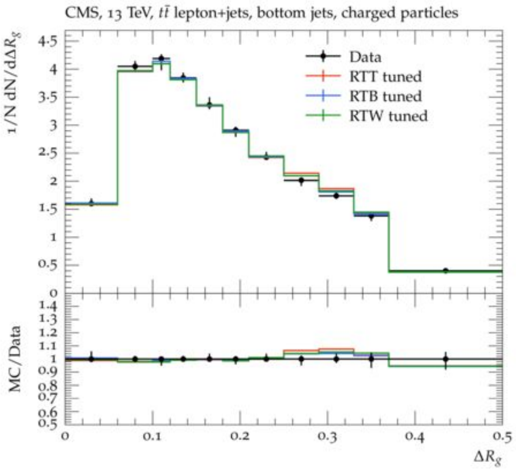
- Mimic procedure used in CMS-TOP-17-013 [5]
  - ΔR_g observable *very* sensitive to α_s AND independent of top mass

Pre-tune





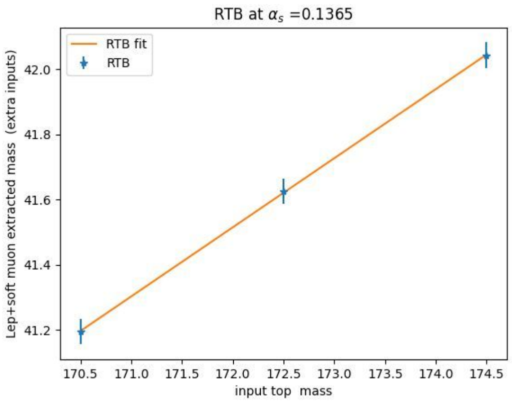
Post tune

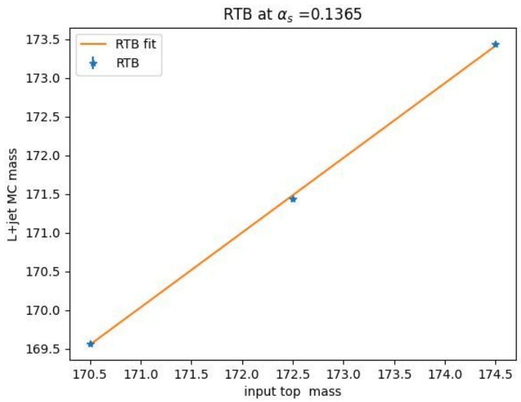


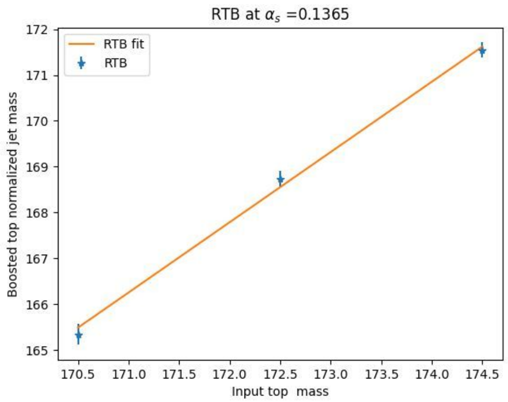
[5] CMS Collaboration, “Measurement of jet substructure observables in ttbar events from proton-proton collisions at s√= 13TeV”, December 2018

Scaling procedure fits

Default Pythia8:



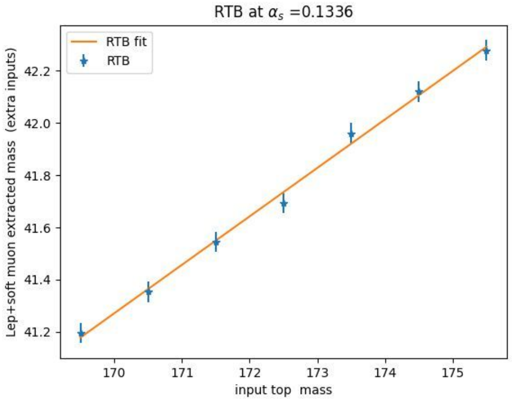


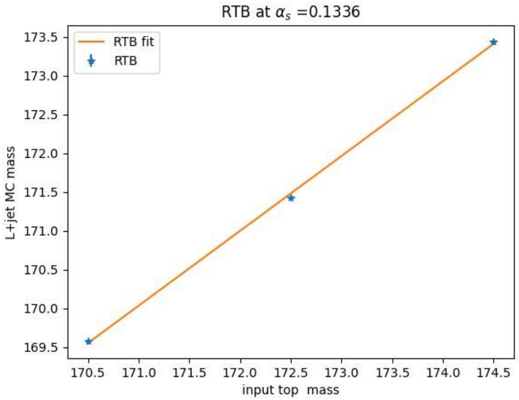


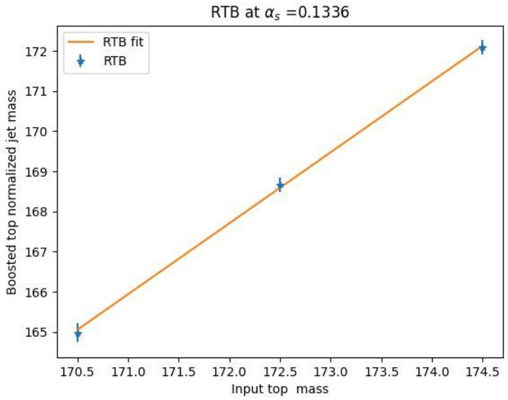
Reco type:	L+soft muon	L+jet	Boosted
Fit params:	a=0.21 +/- 0.01 b=41.62 +/- 0.02	a=0.97 +/- 0.01 b=171.48 +/- 0.01	a=0.86 +/- 0.17 b=183.28 +/- 0.29

Scaling procedure fits

Tuned:







Reco type:	L+soft muon	L+jet	Boosted top jet
Fit params:	a=0.19 +/- 0.01 b=41.73 +/- 0.01	a=0.97 +/- 0.01 b=171.48 +/- 0.01	a=0.67 +/- 0.09 b=183.43 +/- 0.19

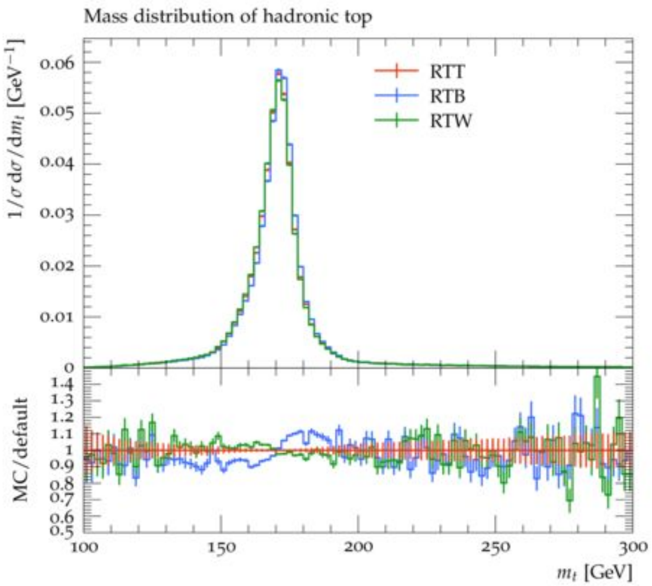
Differences between recoil models

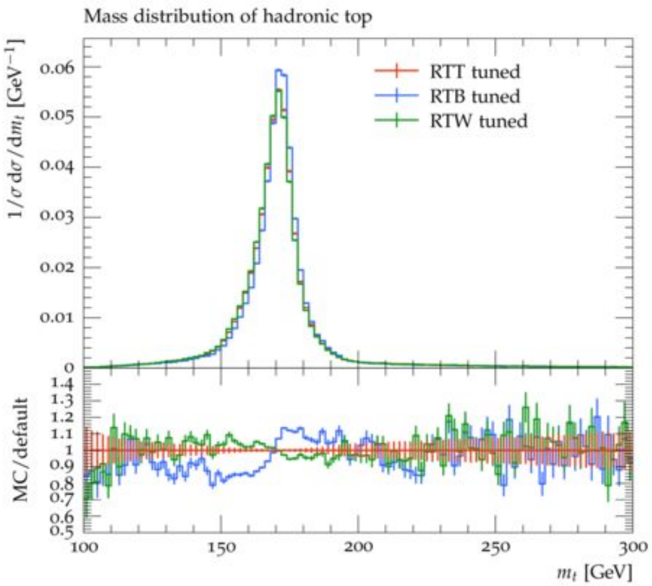
- RTB - RTT: correction for Run 2 measurements to RTT scheme
- RTB - RTW: correction for Run 2 measurements to Run 1 setup
- RTW - RTT: correction for Run 1 measurements to RTT scheme

Table 2: Recoil model difference with top input mass at 172.5 GeV

Comparison mode	α_s setting	L+jet	L+soft muon	Boosted
RTB-RTT	Default α_s	+0.48	-1.11	+0.44
	Tuned α_s	+0.65	+1.02	+0.34
RTW-RTT	Default α_s	-0.18	-0.42	+0.12
	Tuned α_s	-0.24	+0.12	-0.23
RTB-RTW	Default α_s	+0.65	-0.69	+0.32
	Tuned α_s	+0.89	+0.91	+0.57

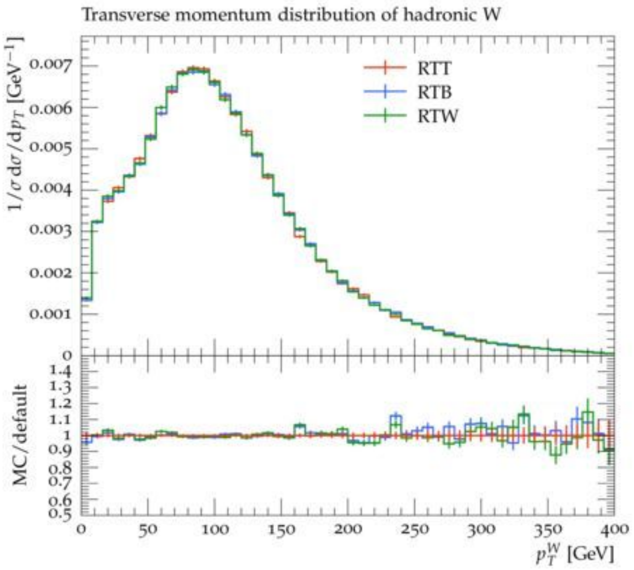
Important plots not otherwise shown

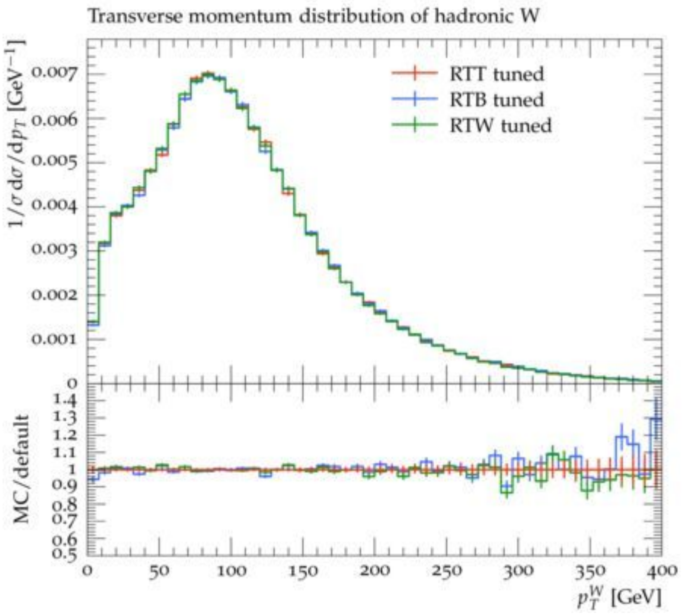




Important plots not otherwise shown

- Note minimal difference, so b momenta is primary factor in xB





Tuning effect on light jets

- Tune might have negative effect on light jets
  - Need independent alpha_s tunes for light and bottom jets?