Notes on Top Quark Modelling in Pythia 8 and Vincia

Meeting with ATLAS Top Group

P Skands (Monash U), March 2021

Recap of comments on LEP x_B tuning

- Monash tune has large $\alpha_s^{\mathrm{FSR}}(m_Z) = 0.1365$, with 1-loop running.
  - Allows to get right (~NLO) 3-jet rate at LEP, while maintaining reasonable value of Λ_{QCD}
  - Monash r_b value then tuned to get right x_B spectrum.
- A14 has lower α_s^{FSR} (desirable at LHC); but this is the input for the entire non-perturbative modelling $\Longrightarrow$ invalidates LEP fragmentation tuning?
  - Not fixed solely by r_b adjustment. Fragmentation tuning will not involve right mixture of 2/3 jets any more. Impacts all IR sensitive quantities such as multiplicities, energy spectra (ratios less sensitive), … so could be **worse** than no adjustment?
  - Consistent precision approach: Merging of NLO $ee \to 2j$ and NLO $ee \to 3j$ samples, with 2-loop running of α_s^{FSR} and CMW scheme translation $\Longrightarrow$ lower α_s^{FSR} preferred **also at LEP** !
    - Poor man's version? **reweight LEP samples to get correct 3-jet rate.**

Some Reference Comparisons of α_s and Λ_{QCD} values

	Monash	CMW	A14	2-Loop			Vincia
$\alpha_s(M_Z)^{Input}$	**0.1365**	**0.127**	**0.127**	**0.127**	**0.118**	**0.118**	**0.118**
CMW	No	**Yes**	No	No	No	**Yes**	**Yes**
k_μ	1	1	1	1	1	1	0.66
$\alpha_s(p_T=m_Z)^{PS}$	0.1365	0.1365	0.127	0.127	0.118	0.127	0.131
Running Order	1	1	1	**2**	**2**	**2**	**2**
$\alpha_s(p_T=1\text{GeV})^{PS}$	0.621	0.699	0.463	0.822	0.481*	0.7*	0.909*
$\Lambda^{(nF=3)}_{MSbar}$	0.325	0.222	0.222	0.485	0.337	0.337	0.337

- Monash (+ many previous tunes) exploits **lucky accident:**
  - 0.1365 with **1L running + LO MECs** ➤ correct (~ NLO) LEP 3-jet rate **and** ~ world-avg $\Lambda^{(3)}_{\overline{MS}}$ ~ 0.33
  - (~ equivalent to inputting 0.127 + CMW scheme translation)
  - But LHC indicates this accident is not universal, prefers lower α_s

- A14: smaller α_s, w/ 1L running
  - α_s change means perturbative part of fragmentation function changes. But nonperturbative part left unchanged.
  - Definitely would not describe LEP out of the box. Reweighted to give same 3-jet rate, would it do so?
  - Switching directly to 2L running would presumably overcompensate in IR region (larger Λ value).

- Vincia: 2L running + CMW
  - 0.118 ➤ "correct" value for $\Lambda^{(3)}_{\overline{MS}}$
  - Attempts to get 3-jet rate ~ right by using $k_\mu p_\perp^2$ with $k_\mu = 0.66$
  - *) Regularises α_s running via $\mu_R^2 = \mu_0^2 + k_\mu p_\perp^2$ with $\mu_0 \sim 1\,\text{GeV}$
  - + own dedicated tune ≠ Monash
  - But **no MECs** until next update.

Recommendations for top analyses

- For analyses that use only the **B hadron** and **not the b jet**:
  - Reasonable to compare A14 (-r_b?) recoilToColoured = on with the new recoilToTop UserHook option.
  - This is based on recoilToTop being the most theoretically consistent option we can offer and the report by ATLAS that A14 (-r_b) achieves a good $\langle x_B \rangle$ in comparison to analytical resummation.
  - These two options also reasonably bracket Pythia's uncertainty on this point:
    - With recoilToColoured = on, the b quark gets more kicks from recoils than it probably should
    - With recoilToTop, the W (and hence the lepton) gets more kicks from recoils than it probably should (but not as many as it does for recoilToColoured = off)
- For analyses that use the **b jet**
  - I believe that recoilToColoured = on mismodels the shape of the b jet, by restricting radiation to a small phase-space region around the b quark direction, with unrealistically little out-of-cone radiation. This produces a too sharp mass peak.
  - The new recoilToTop UserHook option should offer the best overall starting point. Not clear (to me) what the best option to estimate uncertainty is. Perhaps to be further discussed in that context.

UserHook Illustrations

Two different ways of incorporating wide-angle suppression

Generic dipole (eikonal) soft-gluon density for emission from 2 massive coloured particles
(normalised to be proportional to $(\alpha_s N_C)/(4\pi)$ in Leading-Colour limit)

$$\mathrm{eik}(p_1, p_2, q) = \frac{(p_1 \cdot p_2)}{(p_1 \cdot q)(p_2 \cdot q)} - \frac{m_1^2}{2(p_1 \cdot q)} - \frac{m_2^2}{2(p_2 \cdot q)}$$

Massless eikonal — Mass corrections

- A) with recoilDeadCone = on

For emissions in gluon-W dipole: $$P_{g\to gg}(z) \to P_{g\to gg}(z) \times R_{\mathrm{DC}}(z, m_W) \times \frac{\mathrm{eik}_{\mathrm{massive}}(q, p_t)}{\mathrm{eik}_{\mathrm{massive}}(q, p_W)}$$

recoilDeadCone factor

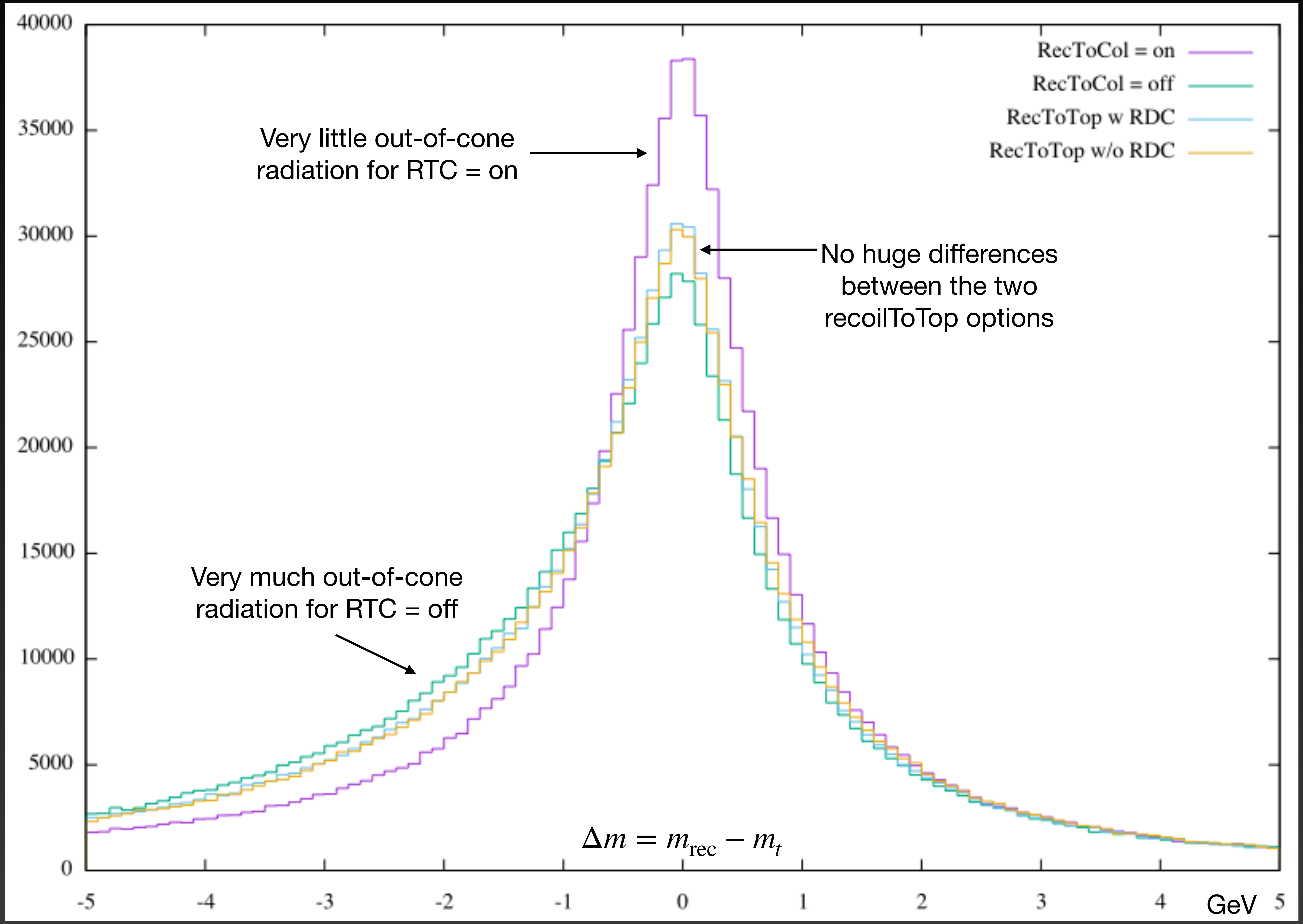
recoilToTop factor for recoilDeadCone = on
= ratio of two massive eikonals

- B) with recoilDeadCone = off

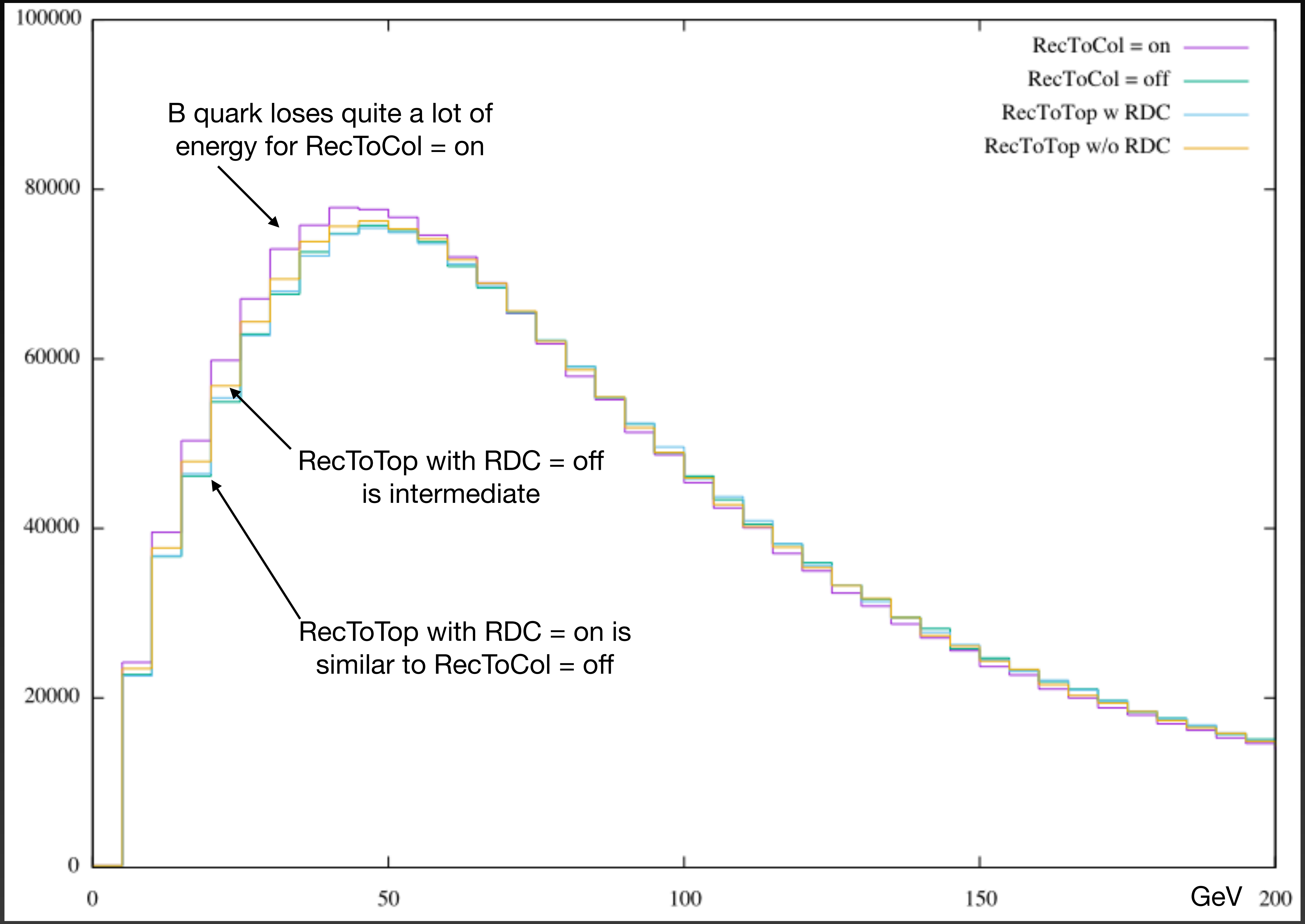
For emissions in gluon-W dipole: $$P_{g\to gg}(z) \to P_{g\to gg}(z) \times \frac{\mathrm{eik}_{\mathrm{massive}}(q, p_t)}{\mathrm{eik}_{\mathrm{massless}}(q, p_W)}$$

recoilToTop factor for recoilDeadCone = off
= ratio of massive to massless eikonal

Results: primitive top mass reconstruction



Results: b quark energy spectrum



(Version History)

- Be aware that version 8.240 accidentally introduced a bug in how the colour flow in top decays was converted to dipoles. It was corrected in **8.245**.
- Unfortunately this overlapped with the period when 8.3 took over from 8.2, so the first few versions of 8.3 also included the bug. It was corrected in **8.303**.

(Inclusive b Jets)

(+ other non-top sources of b-jets)

- In an ideal world, of course useful to constrain same physics!
  - But the `recoilToColoured` ambiguity is specific to resonance decays.
  - At high accuracy (~ 10% ?), must also consider whether ME corrections are relevant for the given observable. If so, and if not implemented in shower $\Longrightarrow$ check with merging.
- Standalone Pythia contains MECs for first emission in top decay ($t \to bWg$)
  - But **not** for $2 \to 2$ processes such as $gg \to b\bar{b}$ ➤ first emission may not be comparably well described unless combined with POWHEG or some other strategy that controls first emission to LO.
- Vincia: currently no MECs but 8.304 $\Longrightarrow$ dedicated Powheg Hooks + merging

  \+ Multi-leg MECs being developed. Expect update during 2021 for both top decay **and** $2 \to 2$ processes