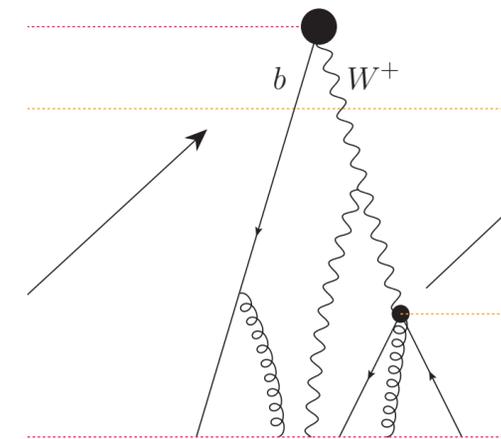
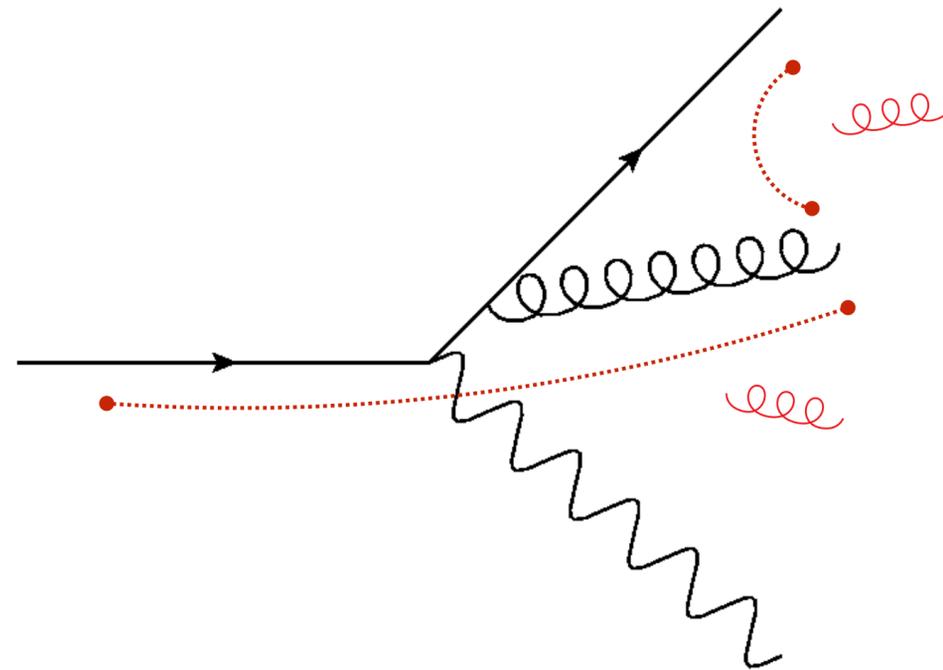
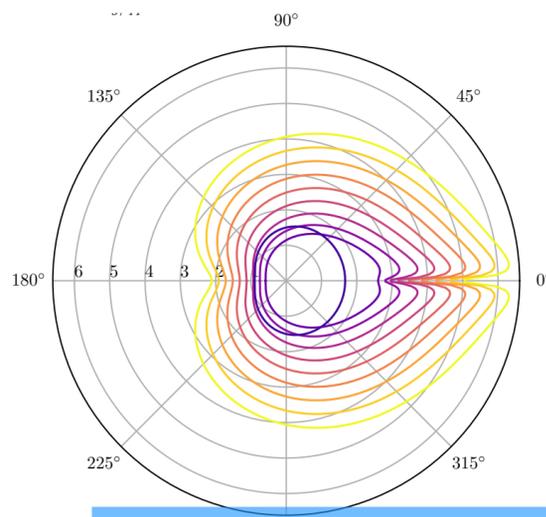


Radiation, recoil, and finite-width effects in top quark decays in PYTHIA



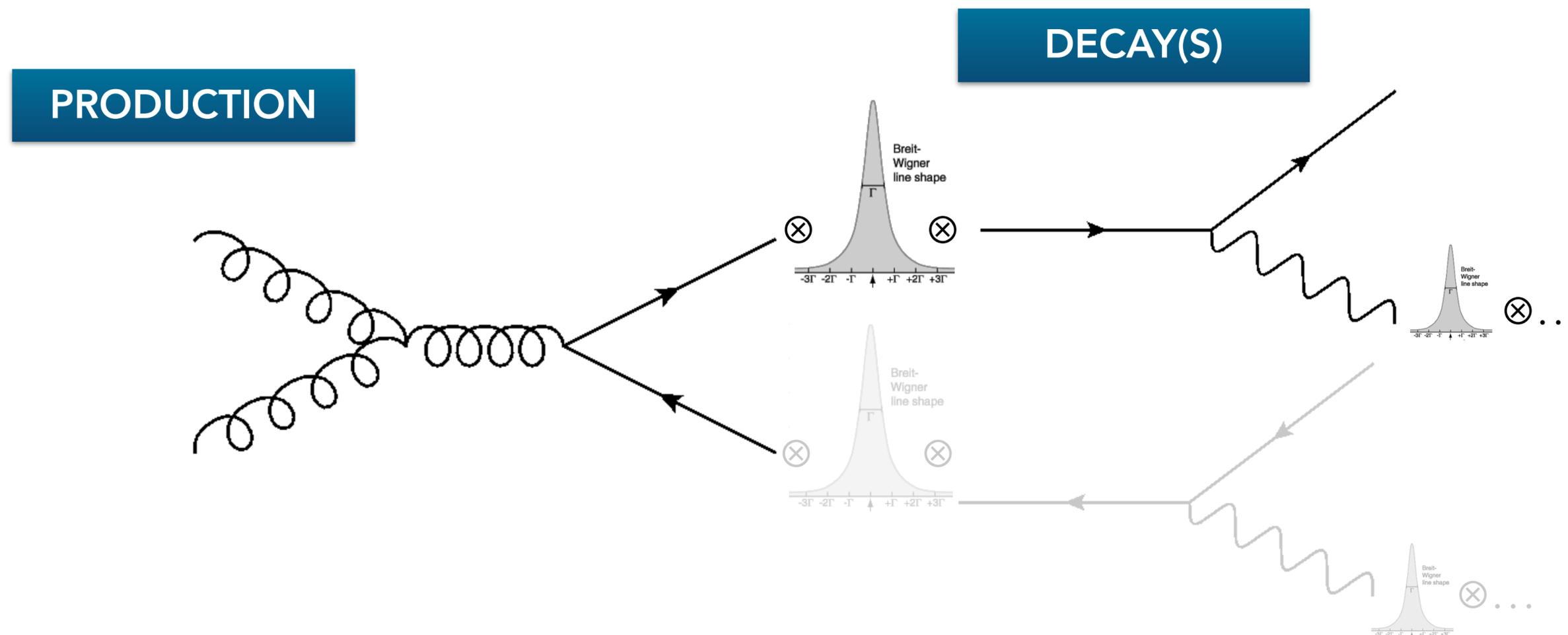
The MC "truth" top-quark mass distribution in PYTHIA

First step: $\frac{\Gamma_t}{m_t} \ll 1 \rightarrow$ **factorise production and decay(s)** ("pole approximation")

+ **Breit-Wigner improved pole approximation** \rightarrow **tops with BW mass distribution**

(skewed by PDF effects: more incoming partons at lower invariant masses.)

NB: if your hard tops are coming from elsewhere (MG5, PowHeg, ...) this distribution *may* be different



Radiative Corrections

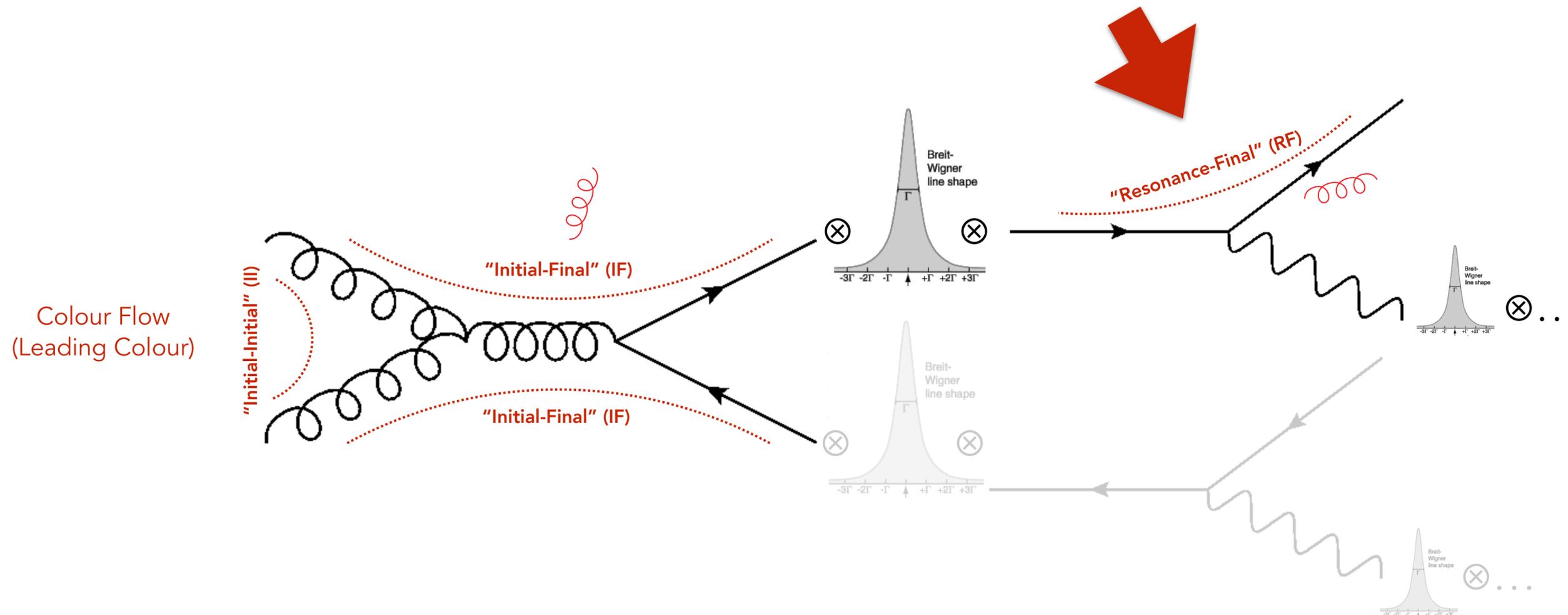
Bremsstrahlung

Colour flow determines coherent (soft-eikonal) radiation patterns

→ VINCIA shower model

[Brooks, Skands, 2019](#)

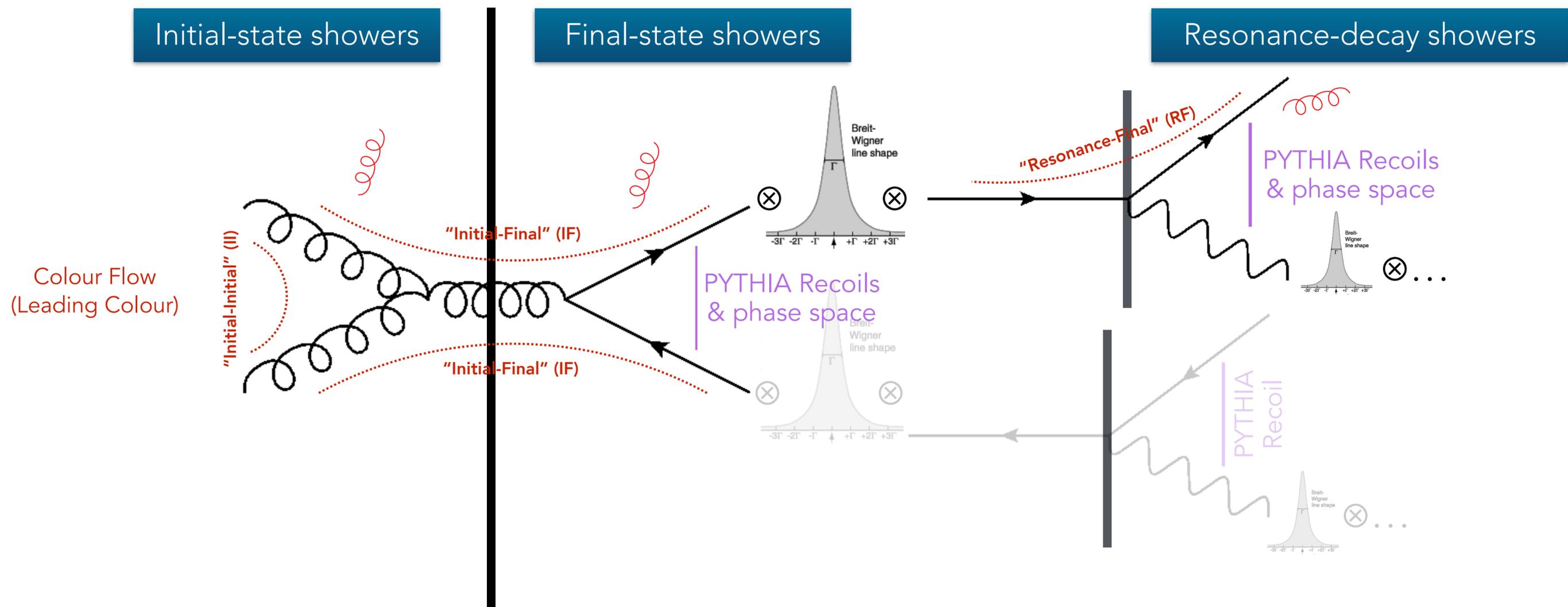
Top decay: unique coherent **"resonance-final"** antenna patterns *and* recoils



Radiative Corrections

PYTHIA's default showers are anchored in collinear (DGLAP) limits

- **Separate** initial-state, final-state, and resonance-decay showers.
- **Coherence for soft radiation across these boundaries is not automatic**
No notion of **resonance-final** recoils; must use **final-final** ones instead.



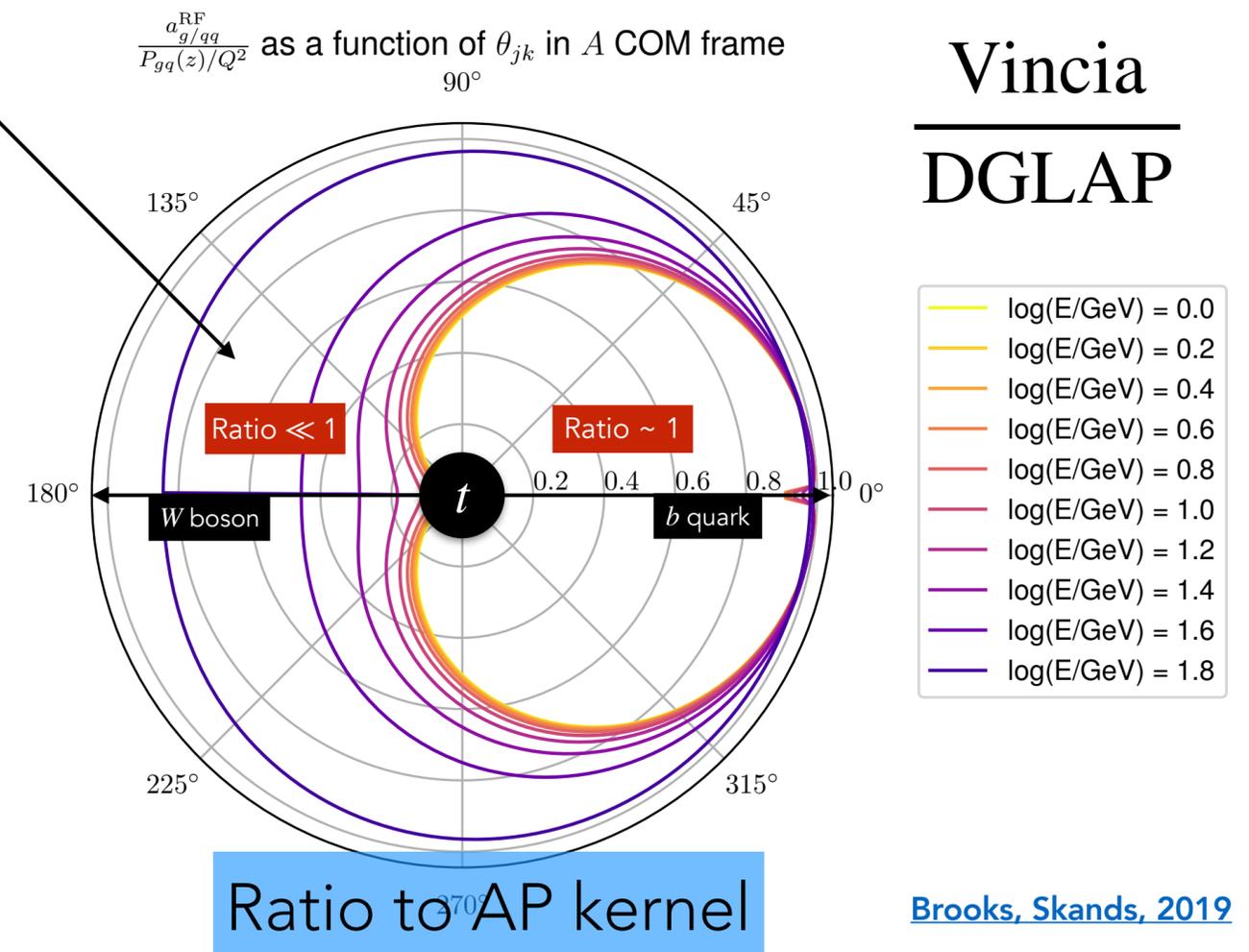
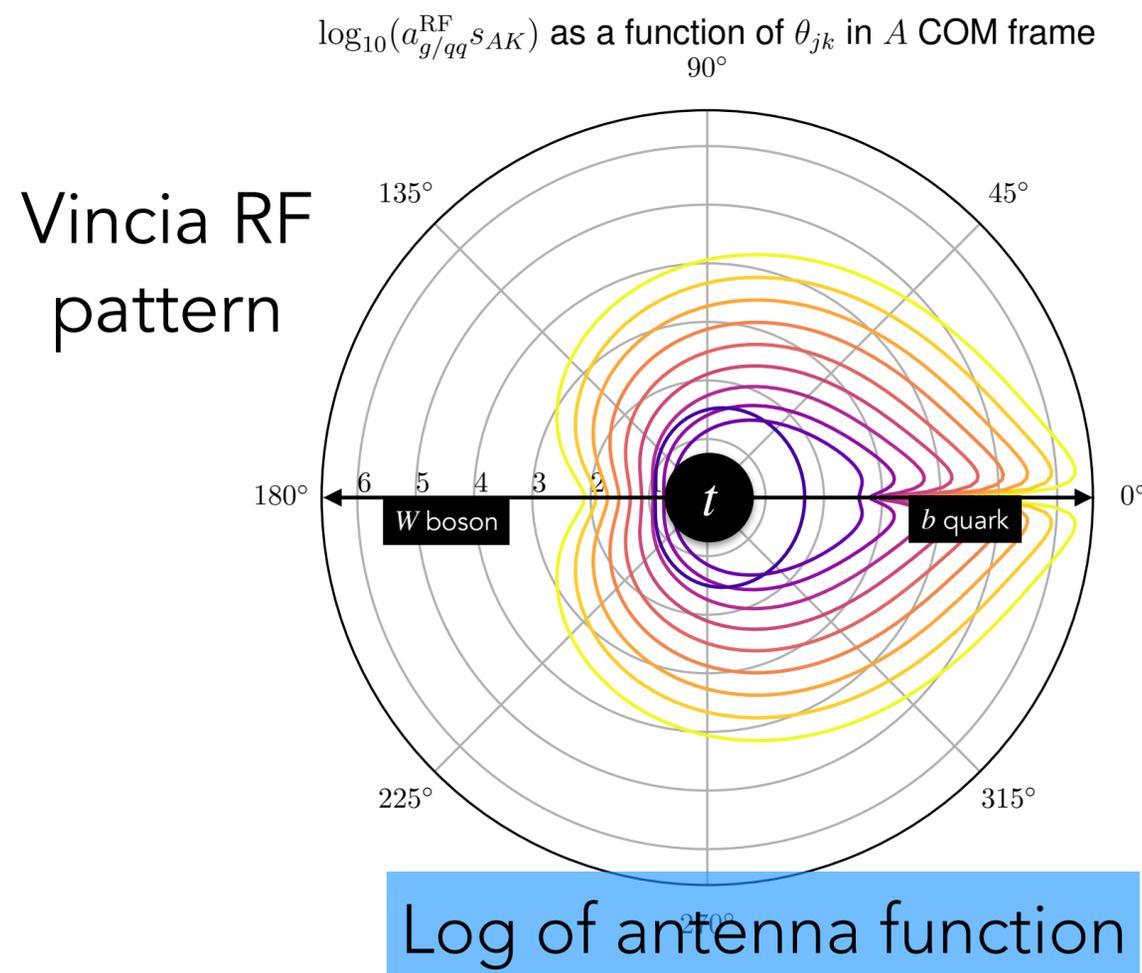
Coherence in Top Decay

First emission: not much difference

Phase space: limit set by $m_t - m_W$ in both cases

Recoils: Vincia RF recoils to $t - b = W \leftrightarrow$ Pythia FF recoils to $W =$ same.

RF pattern suppressed at wide angles compared to DGLAP (but Pythia has **MEC**)



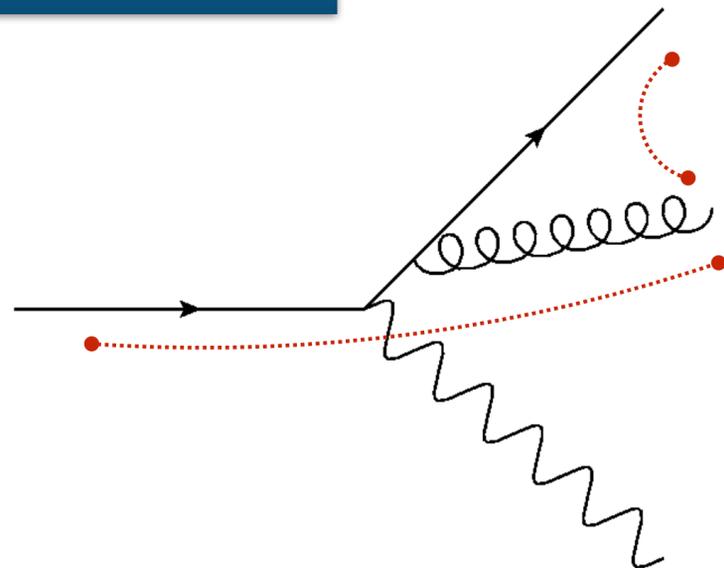
Coherence in Top Decay: 2nd emission

Second emission: big differences

Not controlled by PowHeg, nor by Pythia's MECs.

Not as important as 1st. Still highly significant if goal is per-mille precision on m_t

VINCIA RF



tg RF antenna:

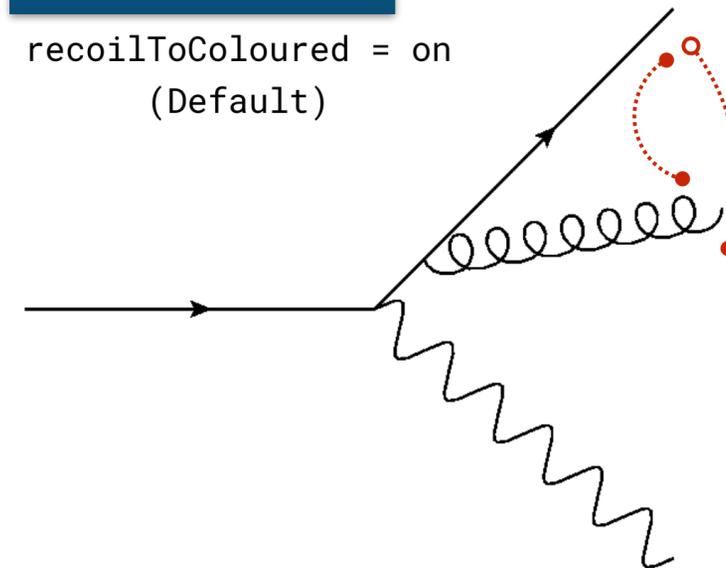
Phase space & recoils set by:

$$t - g = b + W$$

Collective recoil

PYTHIA

recoilToColoured = on
(Default)



$g - t$ dipole treated as $g - b$:

Phase space & recoils set by b

Affects b fragmentation

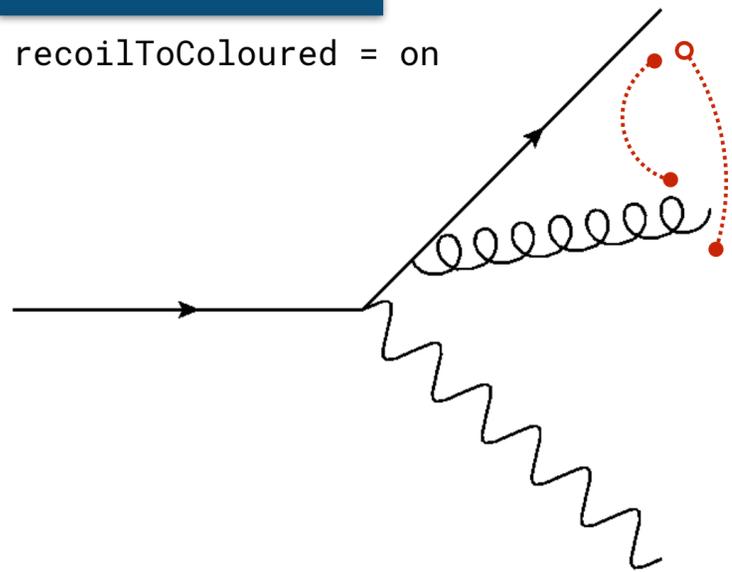
RecoilToTop

PYTHIA allows two different coherence/recoil options

+ recently made a dedicated UserHook "recoilToTop" for use with recToCol = off
Theoretically the least bad option (in absence of RF)? Needs validations & feedback.

PYTHIA

recoilToColoured = on



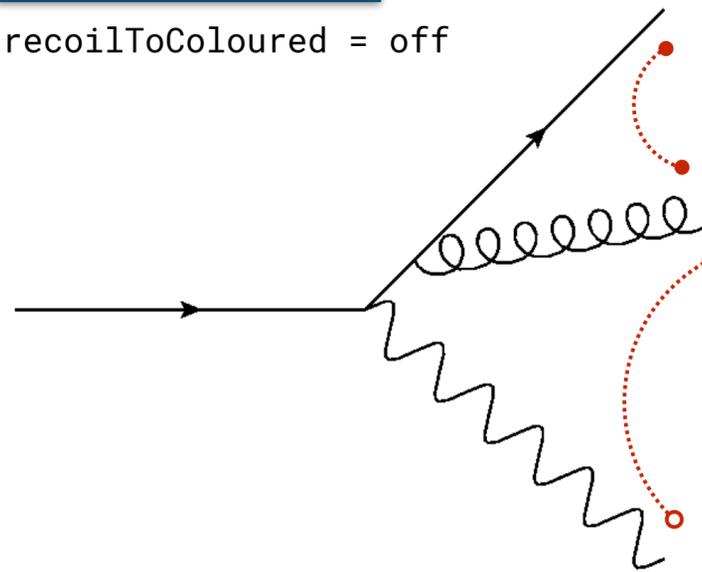
$g - t$ dipole treated as $g - b$:

Phase space & recoils set by b

Affects b fragmentation

PYTHIA

recoilToColoured = off



$g - t$ dipole treated as $g - W$:

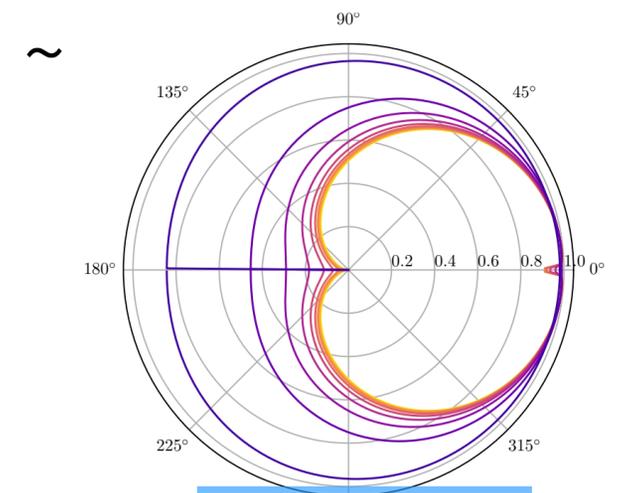
Phase space & recoils set by W

b fragmentation more "normal"?

recoilToTop UserHook

Suppresses radiation
in W hemisphere

⊗ Correction factor



Radiative Corrections: Finite-Width Effects

Finite-width effects

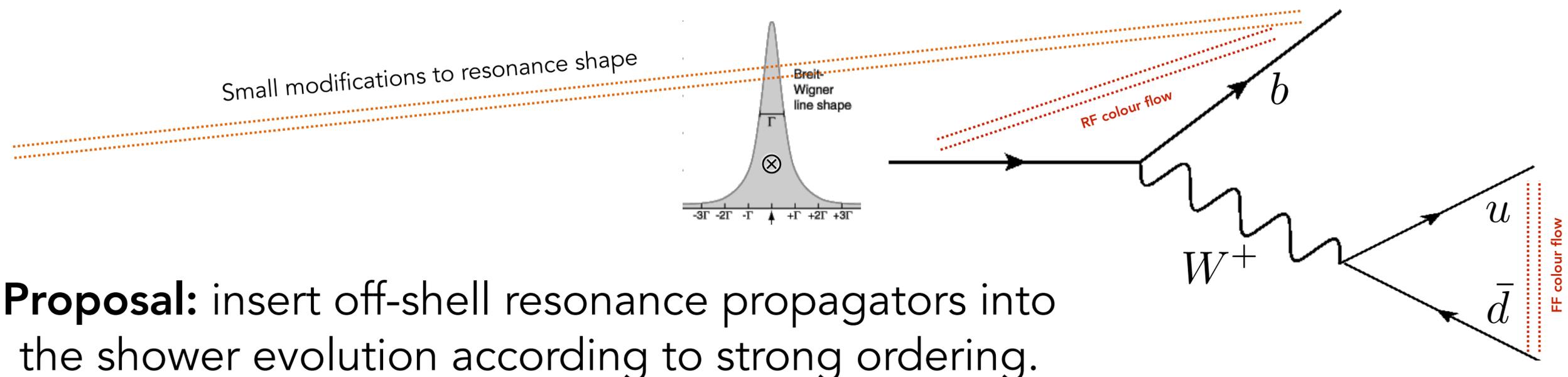
Physically, short-lived fluctuations do not have time to form long-wavelength emissions

In parton showers, this is reflected in the principle of **strong ordering**

However, **resonance decays** are normally treated sequentially, factorised.

No strong ordering.

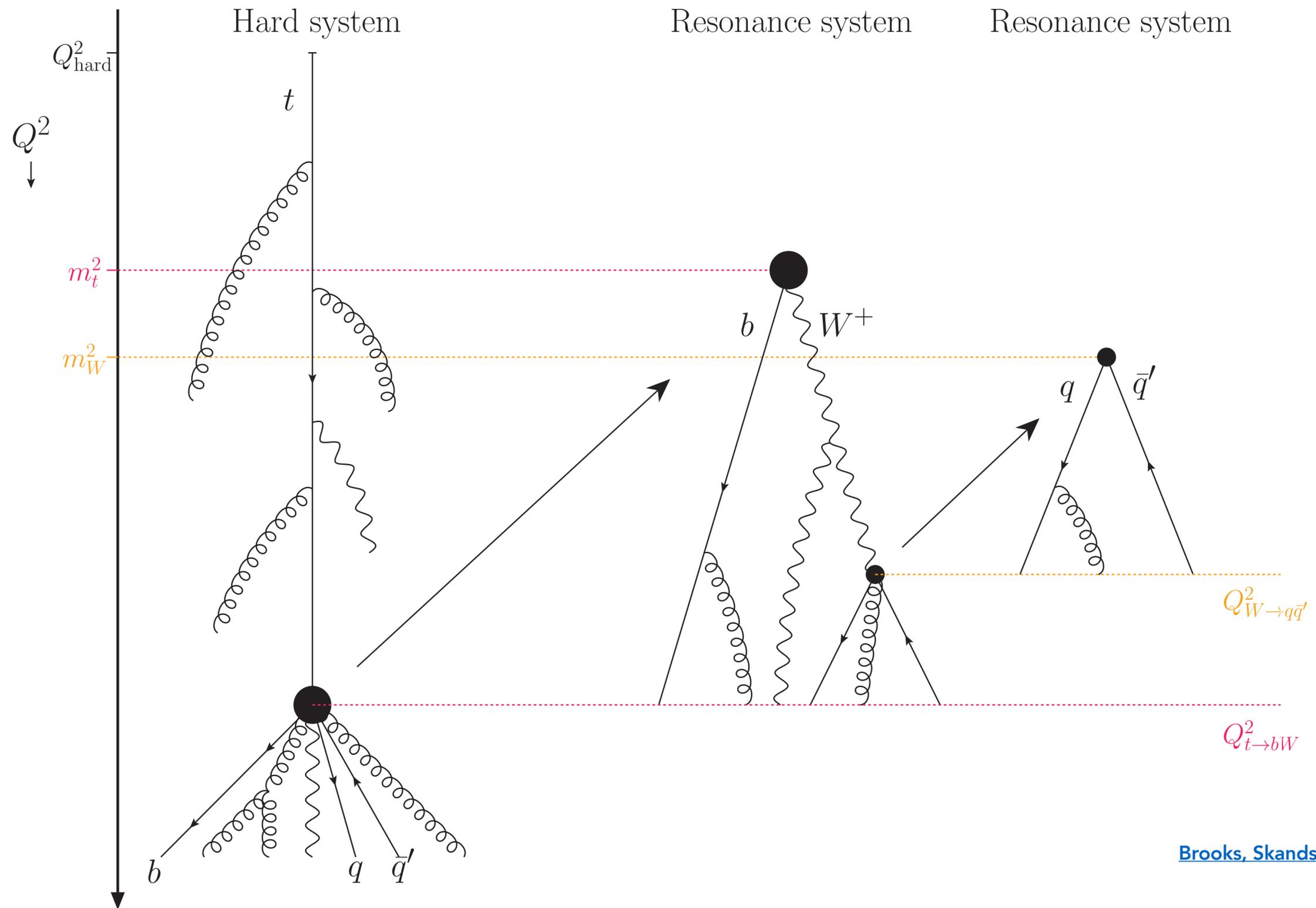
Expect initial-final interference effects at scales below Γ_t



Proposal: insert off-shell resonance propagators into the shower evolution according to strong ordering.

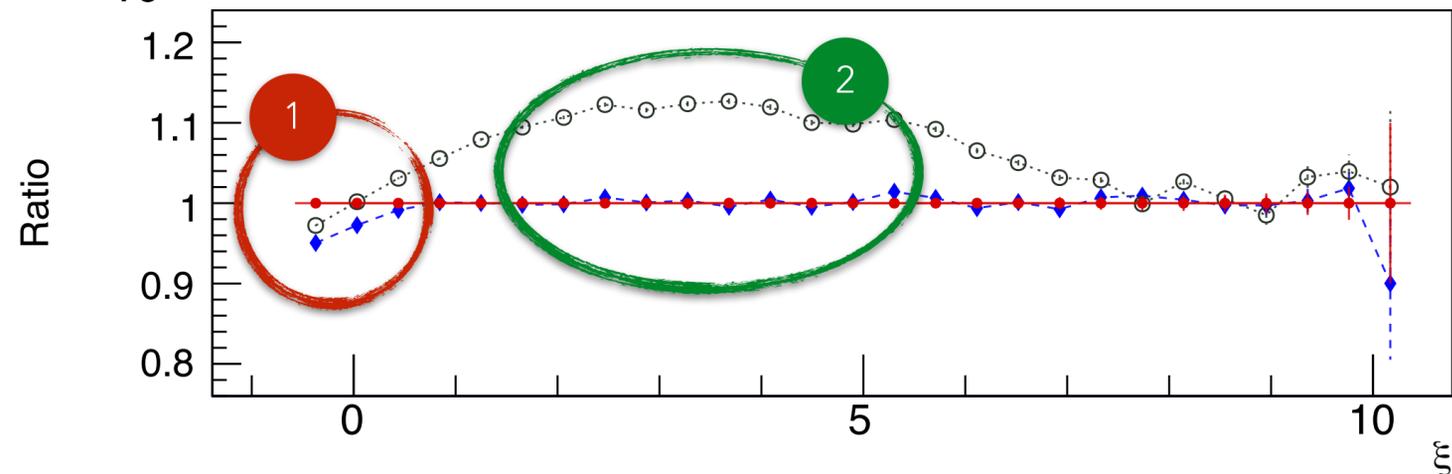
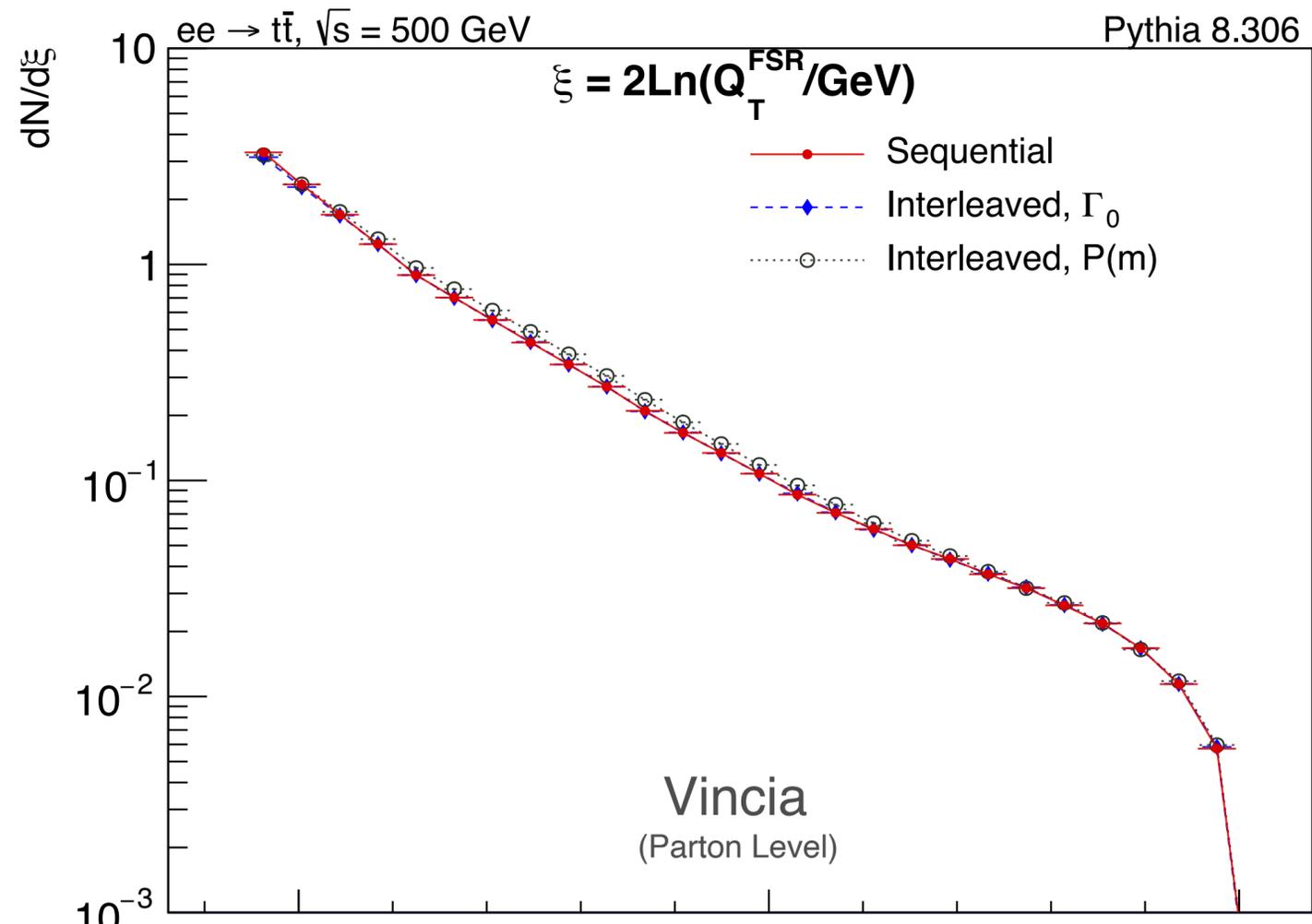
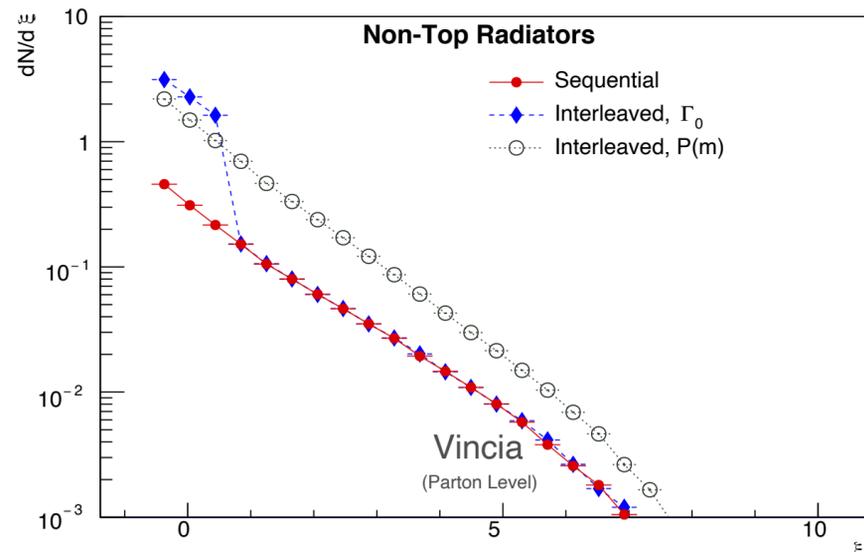
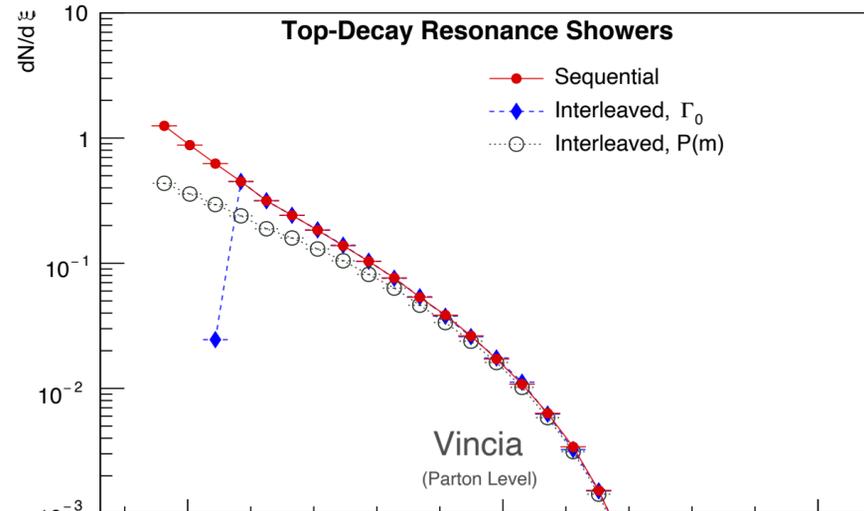
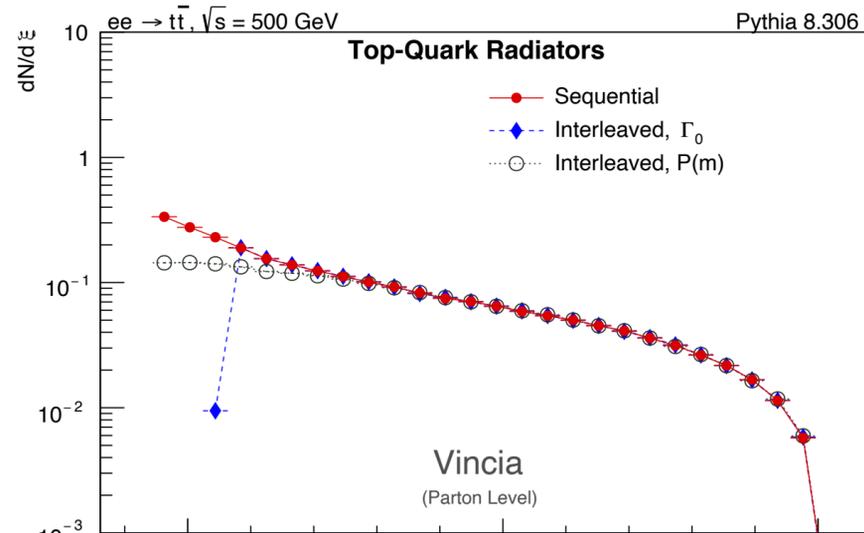
Uniquely treated in VINCIA via "interleaved resonance decays"

Interleaved evolution with resonance decays



Brooks, Skands, Verheyen 2022

Some consequences



Summary

	Coherence $pp \rightarrow t\bar{t}$ shower $t \rightarrow bW$ shower		Mass effects for b (and t)	Finite-Width effects (Γ_t, Γ_W)	Matrix-Element Corrections $pp \rightarrow t\bar{t}$ shower $t \rightarrow bW(\rightarrow q\bar{q})$ showers	
	 Approximate dipole treatment	 Best is recoilToTop?	 Via iterated MECs	 BW + Sequential Decays	 → use PowHeg	1 1 st order MECs for $t \rightarrow bWg$ & $W \rightarrow q\bar{q}g$
	 Coherent Initial-Final and Resonance-Final antennae + global (coherent) resonance-final recoils. (IF and FF recoils still local → ongoing work.)		 Massive eikonals & exact massive antenna phase spaces	 BW + Interleaved Decays. (Still missing a formal proof)	 → 1 Under development. Can also use PowHeg	 → 2 Under development. MECs up to $t \rightarrow bWgg$ & $W \rightarrow q\bar{q}gg$