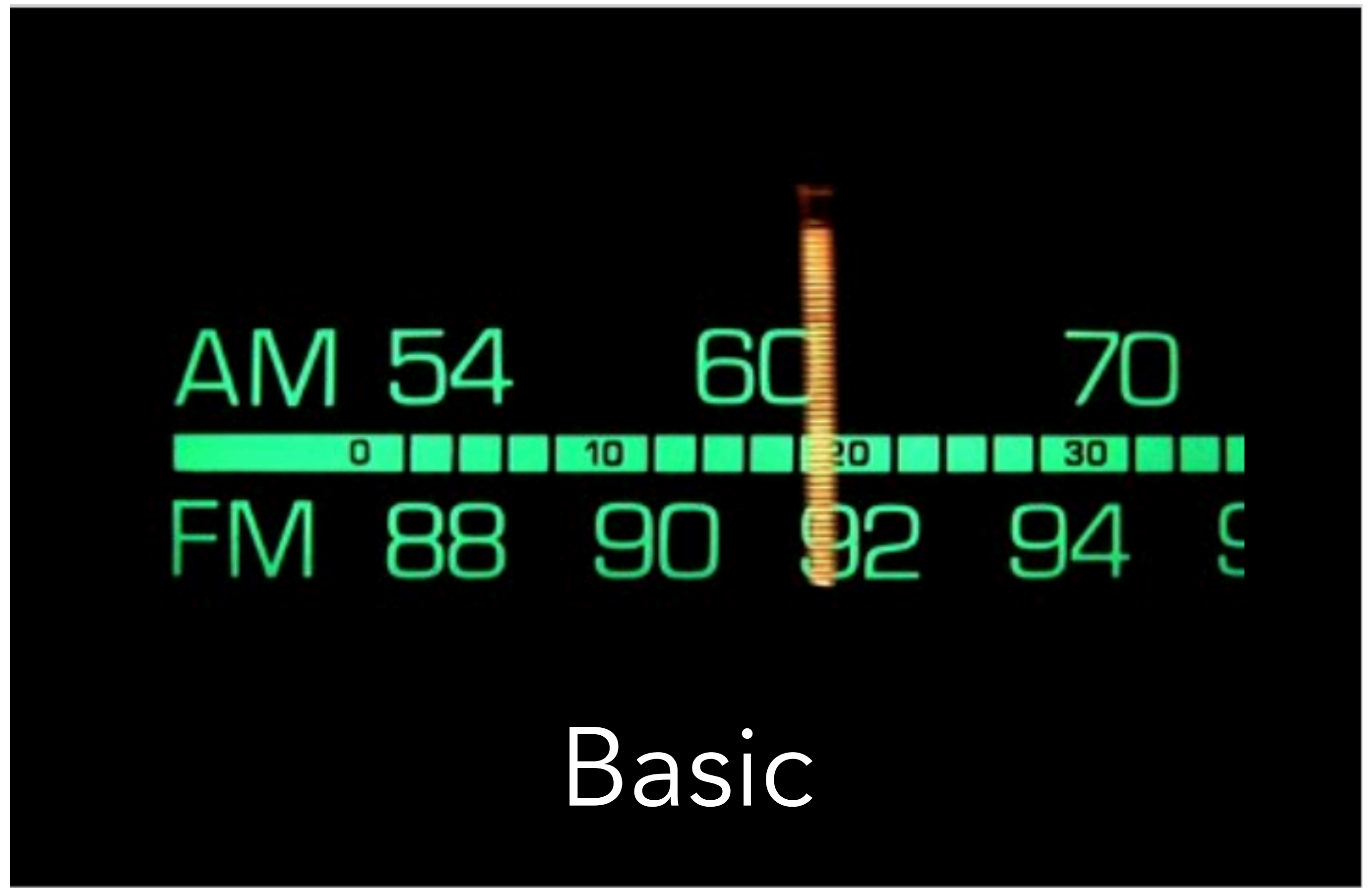
Towards a (new) Pythia 8.3 Tuning

Roles of a Pythia Tune + (My) Wish List

Tuning — what do you want it to do?



Physically sensible parameter values, with good universality.

Reliable Uncertainties
(N)LO Merging
Universal vs Specialised

The best fit we can get
(in standalone mode)
(E.g., Monash Tune and predecessors)

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Standalone Defaults vs State-of-the-Art

Must provide sensible defaults:

- For most processes + beam types
- and most E_{CM} values (of interest)

So far, "default" has been taken to mean "standalone":

- LO Born, with LO MECs (where available), but without (N)LO merging.
- Drives eg choice of large $\alpha_s(m_Z)$ with one-loop running for showers.
- Increasingly an issue that this definition of "default" $\neq$ "state of the art"

+ support at LHC (eg in top) for smaller effective $\alpha_s(m_Z)$ values than at LEP.

Probably at least two "central" options would be useful:

- One for LO applications, starting from best fit standalone (~update of Monash)
- Another for best fit with highest achievable level of NLO merging

Standalone LO/LL vs Merging

One for LO applications, starting from best fit standalone ~ update of Monash.

- Introduce LO merging as cross check on universality, ensuring good all-round performance for LO applications with/without MECs and merging.

Another for best fit with highest achievable level of NLO merging?

- Need NLO merging for all tuning samples.

  Not totally clear if this is realistically doable.

  + Eg merging in e^+e^- not well developed.

- Could presumably have $\alpha_s(M_Z) \sim 0.12$ while maintaining a good fit.

  Subtlety: interplay between α_s values in shower and in ME.

Or … could they be one and the same?

Happiest if hadronisation parameters were universal

- Possible to settle on a **single choice** of non-perturbative parameters that would give good fits both **with and without** (N)LO merging?
- True for many hadronisation parameters (eg strangeness fractions)

Also eg for MPI: p_{T0} mainly depends on PDF; would use same for MPI here.

- Main differences are # of hard jets and IR limit of shower (Q_{cut} and α_s)

Could address # of hard jets by **reweighting** event samples?

Choose α_s : eg 1-loop for LO, 2-loop for NLO, with **similar** Λ_{QCD}

+ can experiment with smooth dampening (similar to MPI) to make behaviour near cutoff less extreme? (Done in Vincia.)

➜ Could operate with lower cutoffs (though we do still want an absolute cutoff, with $O(\Lambda)$ crinkles absorbed in string).

Possible to get ~ universality by allowing Q_{cut} to float a bit?

- And/or carefully ensure IR limits near cutoff are ~ same.

Universal hadronisation tuning?

- Independent of perturbative order (as discussed) would be a major step
- Would require some dedicated thought. Physics of universality (shower behaviour near boundary) and mathematical formulation.
- Reweighting techniques to bring LO and NLO jet rates into agreement ➜ similar initial conditions for HAD; needed to tackle the many constraints which are sensitive to a mixture of high and low scales.

+ Propose observables (eg hadronisation in exclusive 2-jet events) less sensitive to high-scale corrections?

Universality of MPI under PDF swapping?

- Let the reference value of pT0 be a derived parameter, from a given <nMPI> ~ sigmaQCD(pT0)/sigmaINEL, so that the UE level is more stable against the sometimes huge changes in the low-x gluon.

Ilkka emphasised that NLO evolution is faster, so probably want to do something similar with the energy scaling, eg by looking at <nMPI> at two different ECM values.

New Default Options?

Default options should be fairly "true and tested" and not "under development"

- I'd propose moving to the QCD CR model
- Probably the top coherence hook
- + interleaved resonance decays?

Less explored as yet, but would not very complex and would be thoroughly vetted during tuning

- Other true and tested options that may be ready to become the default choice?
- + Update to a new baseline PDF set?

Systematic Tests of Universality

Systematic Universality Tests + characterisation of any deviations.

- Do independent tunes for different CM energies find universal parameters?
- Do independent tunes for different processes find universal parameters?
- Do independent tunes for different experiments find universal parameters?
- Do independent tunes for different obervables find universal parameters?

I experimented a bit with that so far only in specific contexts, but I would say good experiences, increasing faith in robustness and universality

- E.g., arXiv:1103.3649 tested MB universality across different CM energies; found good universality except for CR strength. Further explored in arXiv:1808.07224.
- arXiv:1812.07424 tuned independently to ALEPH, DELPHI, OPAL, L3, with/without event shapes, and rejected a few extreme "outliers" which were inconsistent with bulk of tunes, defined envelope of uncertainties from rest.
- Another example that has been mentioned: FSR in $t\bar{t}$ at LHC prefers lower $\alpha_s(M_Z)$ than FSR in Z decays

Reliable Uncertainties and Preventing Overfitting

Monash used a 5% flat sanity-limit Theory Uncertainty to prevent overfitting

- Are the automated shower uncertainties useful to prevent overfitting? What else?
- Would like TH uncertainties to get to ~ χ^2_{red} ~ 1. Not well-defined across multiple distributions with unknown correlations. (Monash was done by eye, so this was simply a matter of judgement.)
- Use Pythia to map correlations between observables and incorporate in tuning?

Goes Hand in Hand with Systematic Uncertainty Variations

- Professor's eigentunes are prone to artifacts of overturning

E.g., well-measured peak will dominate, with arbitrarily tiny uncertainties, not spanning range of possibilities elsewhere in distribution at all.

See eg arXiv:1812.07424 for examples (and slightly more elaborate way to address issue but still fundamentally based on the flat 5% sanity limit)

- We should propose reliable uncertainty **variations**, beyond Professor's "eigentunes"
  (Perugia had simple ones, Monash had none)

Ideally also propose ***method*** for how to obtain them, and justify or improve on the 5% approach.

New Observables / Other Constraints?

New observables/constraints to include

- Diffraction was not included in Monash (nor was DIS, or photoproduction, or very low pp energies)
- Merging (as discussed)
- FSR constraints from LHC ↔ interplay with LEP

(Monash included jet shapes, but there are further constraints eg from top)

Impact on hadronisation parameters if we let LHC have a say?

Note: will also need to revisit LEP PID fractions. Many issues highlighted in Monash study.

- The way we impose them.

Professor uses binned histograms; weights are up to you.

For Monash tune, by eye, I probably effectively looked at something more like a few moments (mean + width + getting roughly the right asymptotic slopes); formalise something like that? Boil down the information.

Constraints from comparisons with analytical resummations?

- (A whole new can of tuna - volunteers?)