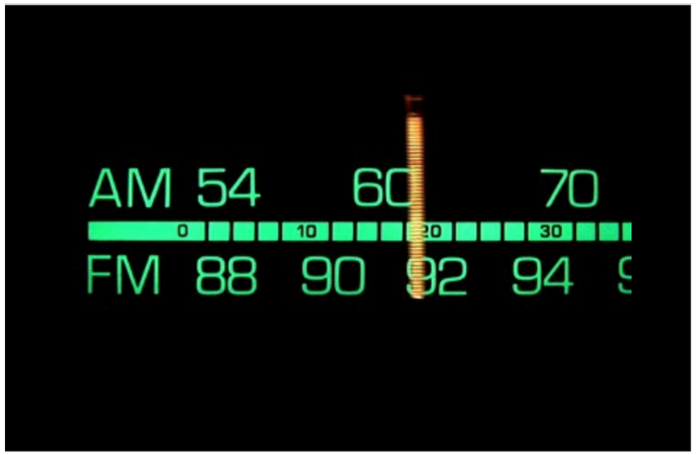
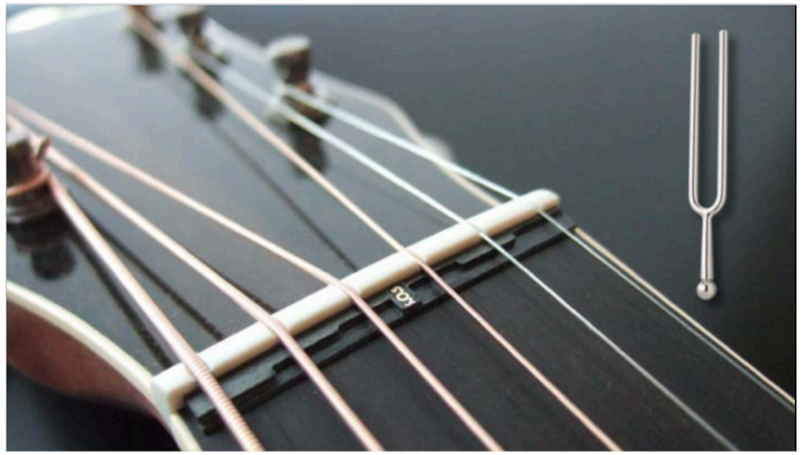
Tuning & Modelling Uncertainties

Input from PYTHIA

Tuning — what do you want it to do?



Physically sensible parameter values, with good universality.



High fidelity (agrees with data)
Reliable Uncertainties
(Depends on quality of physics model!)

The best fit for **your** observable.
➤ universality tests & non-universal tunes

Peter Skands
Monash University

PHENOmenal Meeting with ALICE
April 2021

How to approach tuning systematically? **Universality Tests**

Systematic Approach to Tuning: Universality Tests + characterisation of any deviations.

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Provides a more systematic understanding of what the model can and cannot do simultaneously ➤ phrase conclusions in a more physical way ➤ show non-universalities

- Professor can help automate (recommend adding 5% TH uncertainty to protect against overfitting.)

Some Examples of explicit studies: increasing faith in robustness and universality:

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Modelling Options in Pythia: **Colour Reconnections**

Monash Tune

- Based on "old" colour reconnection model (the QCD CR model was published a year later)
- Contained a mistake in the **D*/D** ratio (thanks to D. Bardhan for alerting us to it!)

StringFlav:mesonCvector = 0.88; should have been 1.25 - 1.5

(Due to taking the D* and D rates from separate, inconsistent, sources)

- "Brute-force" modelling of CR; no explicit flavour dependence

Main effect is on $\langle p_T \rangle$ vs N_{ch} and related momentum-space quantities;

QCD CR Model (ColourReconnection:mode = 2)

Christiansen & Skands *JHEP* 08 (2015) 003 • e-Print: 1505.01681

- First attempt (2015) to model QCD CR effects more faithfully. Good starting point.
- Still acts **purely in colour space**. No explicit flavour dependence.

Can create **colour-epsilon structures in colour space → more baryons**!

No strangeness enhancement (can even go a bit the other way, due to phase-space constraints of occasional very small strings it produces)

Phase-space constraints should probably be revisited esp in context of heavy flavours

What I **think** you have discovered!

(Though maybe not 5σ confidence yet - theoretically!)

Options for **Strangeness** Enhancement

Rope Model

E.g., Bierlich et al *JHEP* 03 (2015) 148 • e-Print: 1412.6259 + several more recent

- First rigorous attempt (in Pythia) to faithfully describe genuine collective effects.

  Elaborate physical model, formulated in spacetime, with explicit differential time evolution.
- Typically starts from QCD CR model.
- Introduces higher effective tensions in multi-string "ropes"

  Explicit strangeness enhancement, increasing with overall activity

  + Further possibility for more diquarks as well (baryons)
- Can also add "Shoving" to generate (repulsive) collective flow

Close Packing

Fischer & Sjostrand *JHEP* 01 (2017) 140 • e-Print: 1610.09818

- Simpler model of "rope-like" behaviour (developed in context of a thermal string-breaking option)

  Formulated in momentum space and less sophisticated than rope model.
- Basic idea: assume strings still fragment ~ independently as usual, but that their vortex cores get "squeezed" by the presence of other strings nearby
- Higher effective tensions ➤ strangeness (and baryon) enhancements (similarly to ropes)
- So far only implemented and available for thermal string breaking model.

  Extend to conventional (Schwinger) model (+ possible to incorporate repulsive flow effects as well?)

D Spectra

Depend on D*/D ratio + feed-down from B

- Possible to measure D* and B feed-down components separately?
- (and hard c vs $g \to c\bar{c}$)

Direct part (not from B) depends on r_c

- Expresses difference between light cone of a **massless** endpoint quark and smaller world sheet of a **massive** one (with v < c)

$$f_{\text{massive}}(z, m_Q) \propto \frac{f(z)}{z^{br_Q m_Q^2}}$$

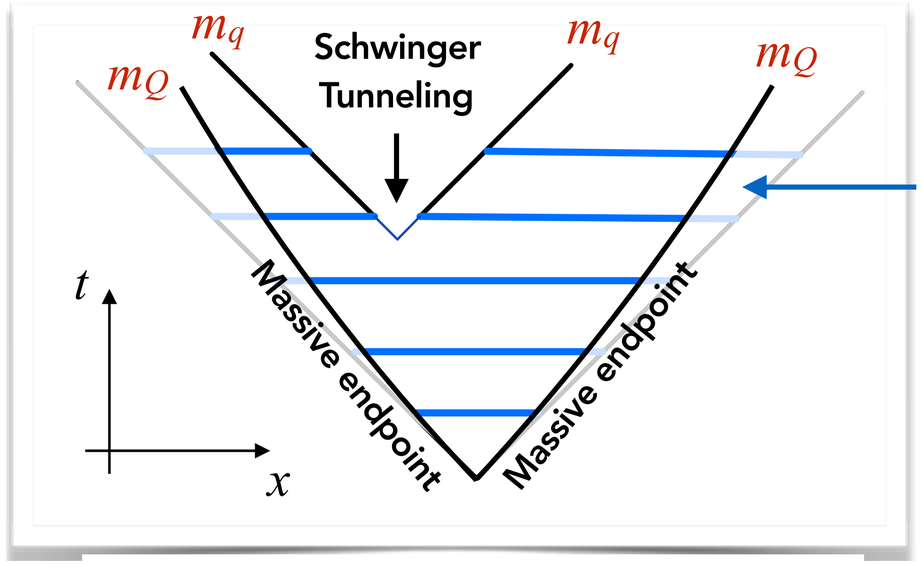
- So far constrained by one LEP D* spectrum

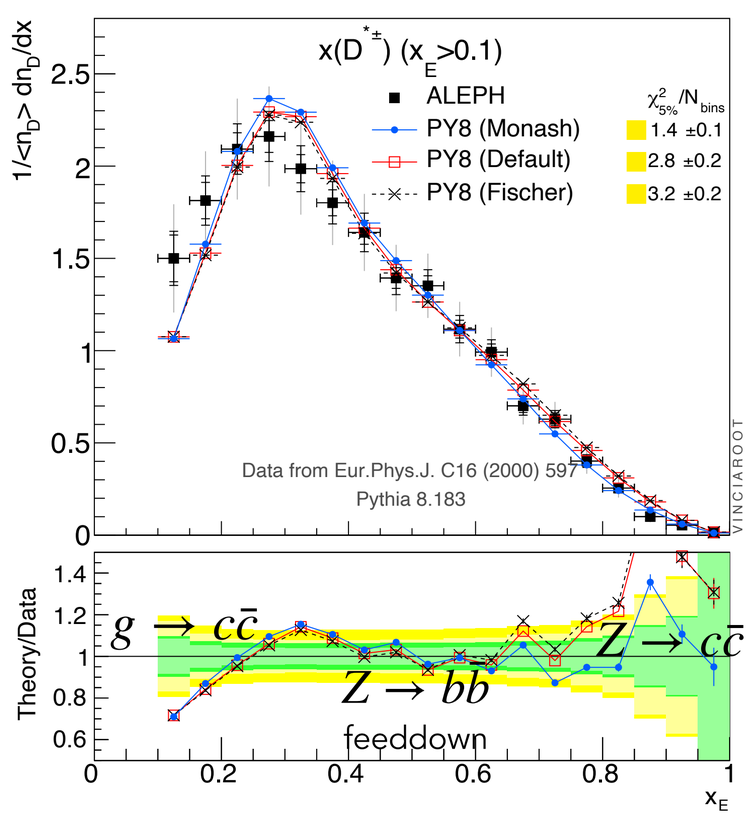
But remember the Monash tune had the wrong D* rate (which affects the mixture)

- Definitely interest for **in-situ constraints** !

Charm fragmentation in (>LEP-style) high-pT jets

~ clean reference without collective effects?





Baryon Spectra — Conventional String Breaks

Conventional string breaks: charm string endpoint picks up a light diquark

- Spectrum sensitive to the aExtraDiquark parameter.
- Normally constrained from proton and Λ spectra at LEP (see eg Monash tune paper)

  But again, **in-situ universality tests** probably a very good idea.
- Relative rates of spin-3/2 vs spin-1/2 states? (And Σ vs Λ)

  ~ProbQQ1toQQ0 = 0.0275 so spin-1 diquarks very heavily suppressed!

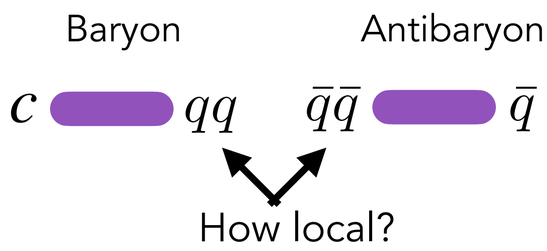
  (Note: no flavour dependence here?)

Local baryon number conservation in string breaks

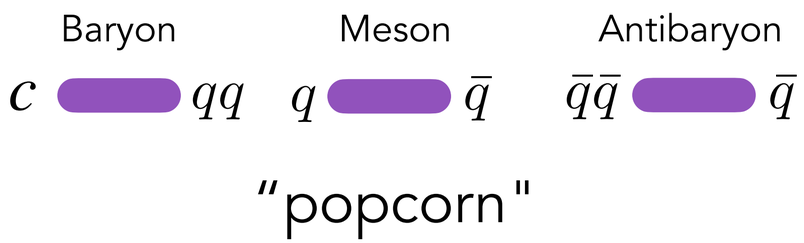
Diquark-antidiquark pair must be close in phase space (modulo popcorn!)

Baryon-antibaryon correlations! (LEP measurements hard to recycle today)

Eg:



vs



Junction Baryons

Junction baryons (e.g, from CR) are expected to be different

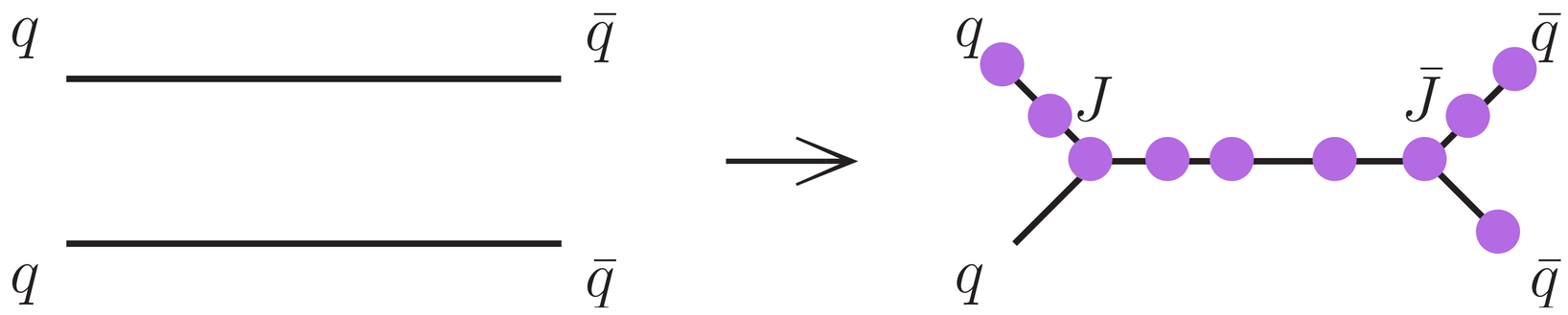
- In junction fragmentation, two junction legs get combined, one of which can be a c quark → charm diquarks + a quark from a string break.
- Radically new possibility.

  ~probQQ1toQQ0join = {0.5,0.7,0.9,1.0} really only **guesses**

  Controls charm baryons

  But note can be vastly different from that of string-breaks (0.0275)
- Also junction baryons should be **less correlated in momentum space**

  Junction and antijunction not necessarily so "close" ➤ **longer-distance correlations?**



(b) Type II: junction-style reconnection

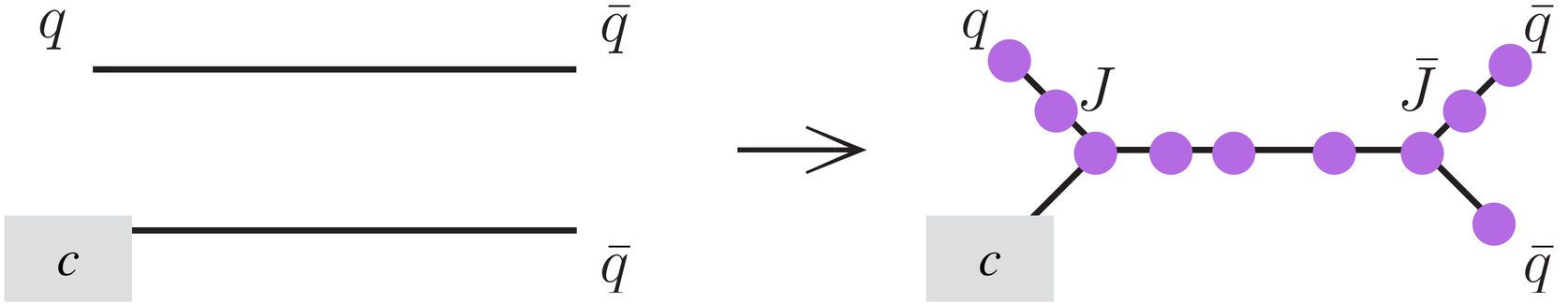
Conclusions

QCD CR probably the most realistic as far as CR goes

- But only works in **colour space**: baryons but no extra strangeness
- Junction baryons have different properties (S=3/2/S=1/2, Σ/Λ) & **correlations**

But theoretical model was not especially formulated for heavy quarks; there is need to look into the effect of phase-space constraints when "free string energy" gets small

Inadvertent suppression of high-mass states? (Some evidence of that in meson sector. Physical or unphysical?) And technical issues like failure to find "Junction Rest Frame"?



(Exacerbated for double-heavy baryons!)

(Also: personally I never was quite happy with the causality structure ➤ want to revisit time dilation)

For strangeness (and flow) expect you need something like ropes

- Also intend to investigate simple "close packing" model (with J. Altmann, V. Zaccolo)

Extra Slide

ALICE measurements mentioned in our last Pythia tuning meeting

Disclaimer: many very recent measurements are of high interest to us; I apologise if this list is not up to date!

- Input from S. Mrenna

https://arxiv.org/abs/1709.08522v1 (no Rivet analysis)
https://arxiv.org/abs/1802.09145v1 (no HepData)
https://arxiv.org/abs/1708.08745v1 (HepData and Rivet available)
https://arxiv.org/abs/1807.11186 (no HepData)
https://arxiv.org/abs/1807.11321 (no HepData)
https://arxiv.org/abs/1811.01535

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