# WG1 Summary:

## Minimum Bias, Underlying Event and MC generators

Matt LeBlanc, Andrzej Siodmok
MPI@LHC 2023

University of Manchester

# Overview

- 3 sessions with 17 talks total: a huge '**thank you!**' to everyone who prepared & presented material in WG1!
  - 'Overview' talks from MC collaborations
  - Experimental talks from LHC & STAR
  - Contributed talks on a variety of more detailed subjects.

- As MPI is all plenary talks, we will try to avoid a rote summary of this material and instead highlight some common themes or action items, leaving time for discussion.

- We apologise in advance for being selective with the topics covered – we did what we could in the time that we had!

**Peter Skands, Peter Meinzinger, Stefan Gieseke**

# General purpose Monte Carlo Generators

## [status & updates on hadronization, colour reconnection MPI]

| Generator |  Pythia | Sherpa  | Herwig |
|---|---|---|---|
| Hadronization | **String** | • **Cluster [default]**<br>• String<br>[interface to old Pythia 6] | • **Cluster [default]**<br>• String<br>[interface to Pythia 8 (PI8)]<br>• MLHAD first tests |
| Colour Reconnection | 3 main options (default, 'qcd-inspired', 'gluon-move')<br>→ 19 total options<br>(different settings) | F. Kraus : *"I will never include CR"*<br>→ now Sherpa has CR :) | • plain CR<br>• bayronic CR<br>• space-time CR |
| MPI | • Interleaved with Parton Shower | • Amisic similar to Pythia's MPI<br>• Shrimp? | • Eikonal Model |

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# Experimental talks

- We did not find many new results targeting UE/MPI understanding since the last MPI…
  - We hope the contributions about jet substructure & hadronisation were interesting!
- Are there measurements that you would like to see performed that aren't being done?
  - **Question:** Are the most useful observables being measured?
  - **Question:** other than at meetings like MPI, how do we ensure there is good communication between MC teams & experiments?

| | $m_{\text{top}}$ [GeV] |
|---|---|
| Result | 172.21 |
| Statistics | 0.20 |
| Method | 0.05 ± 0.04 |
| Matrix-element matching | 0.40 ± 0.06 |
| Parton shower and hadronisation | 0.05 ± 0.05 |
| Initial- and final-state QCD radiation | 0.17 ± 0.02 |
| Underlying event | 0.02 ± 0.10 |
| Colour reconnection | 0.27 ± 0.07 |
| Parton distribution function | 0.03 ± 0.00 |
| Single top modelling | 0.01 ± 0.01 |
| Background normalisation | 0.03 ± 0.02 |
| Jet energy scale | 0.37 ± 0.02 |
| $b$-jet energy scale | 0.12 ± 0.02 |
| Jet energy resolution | 0.13 ± 0.02 |
| Jet vertex tagging | 0.01 ± 0.01 |
| $b$-tagging | 0.04 ± 0.01 |
| Leptons | 0.11 ± 0.02 |
| Pile-up | 0.06 ± 0.01 |
| Recoil effect | 0.39 ± 0.09 |
| Total systematic uncertainty (without recoil) | 0.67 ± 0.05 |
| Total systematic uncertainty (with recoil) | 0.77 ± 0.06 |
| Total uncertainty (without recoil) | 0.70 ± 0.05 |
| Total uncertainty (with recoil) | 0.80 ± 0.06 |

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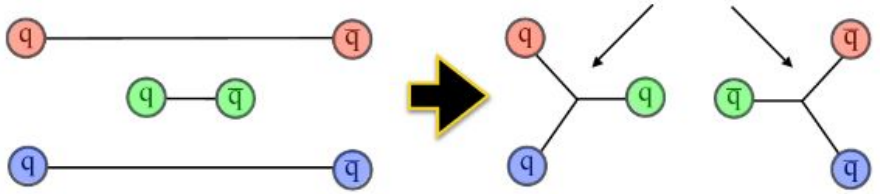
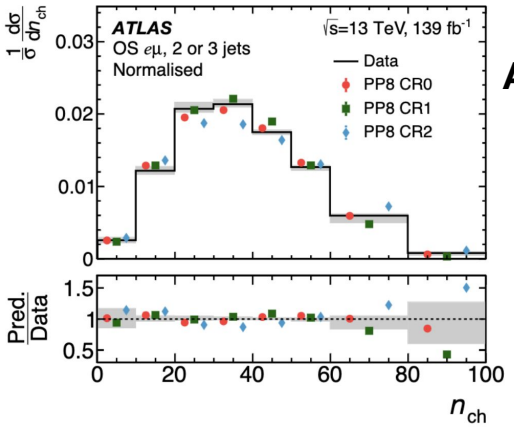
# Connecting to colour reconnection

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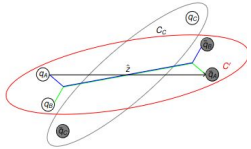
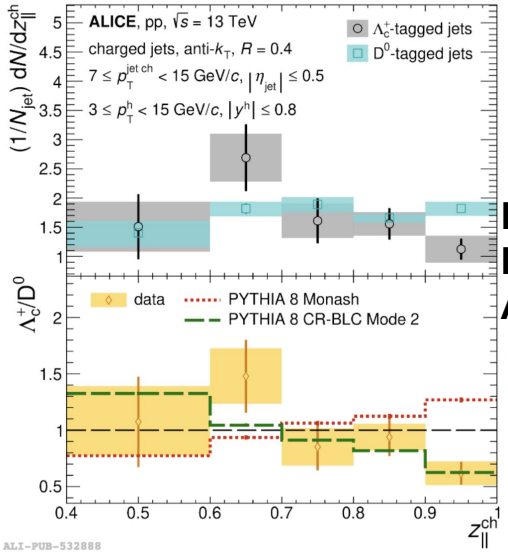
- Many positive comments about junction CR model this week, including suggestions to change default Pythia model …
  - Also in development for H7 – talk to **Stefan Kiebacher!**
  - ATLAS event-wide UE measurement could not really distinguish CR0 and CR1 in ttbar…
  - ALICE measurement of Λ & D-tagged jet fragmentation preferred it!
  - Seen also in Anna's talk: can play an important role in J/ψ Hadroproduction



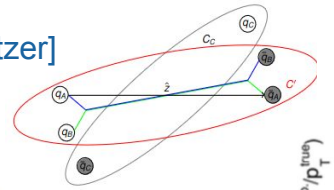
$\Lambda_c$ vs. $D^0$ in jet arXiv:2301.13798



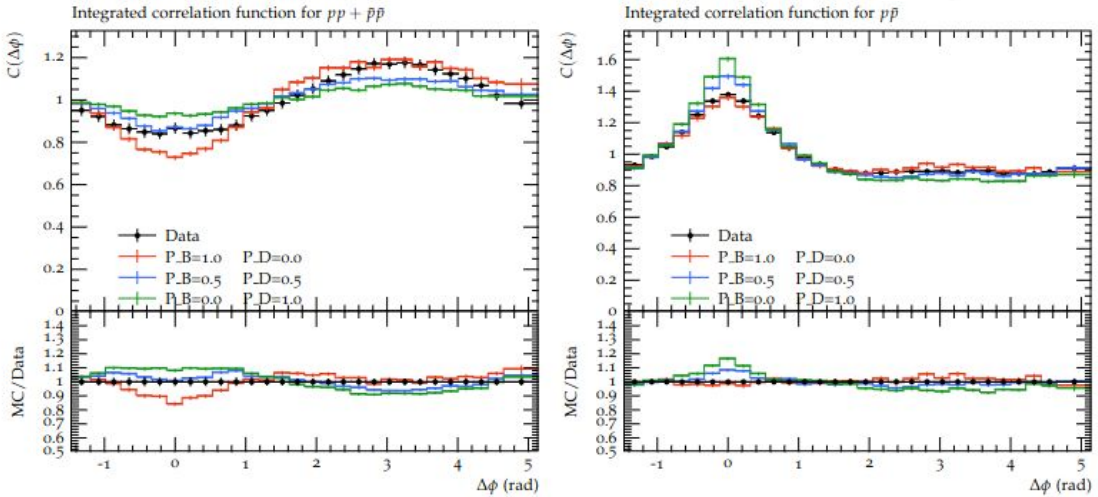

Haidar Masud Alfanda

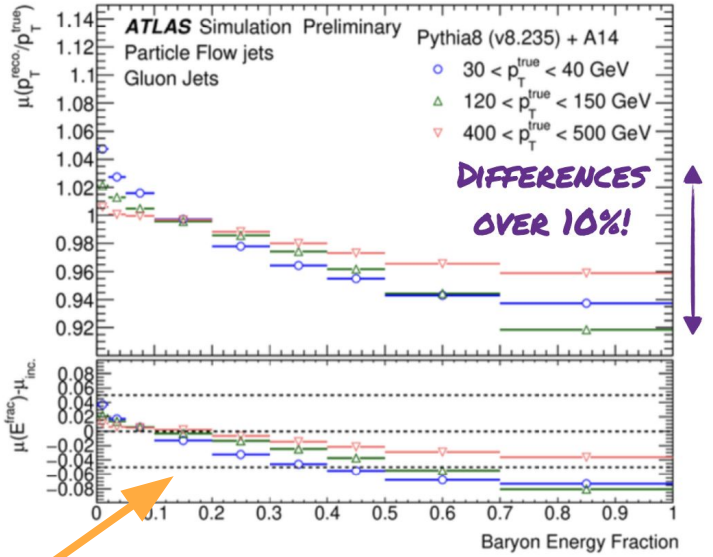
# Diquark Colour Reconnection

[See also “Colour evolution and infrared physics” S. Plätzer]



## Baryon Angular Correlations




- Baryon production is challenging but important: can have a big impact on high-pT physics programme when we get it right!

# Event generator accuracy

## Progress in improving the PS accuracy

- **Assessing the logarithmic accuracy of a shower**
  Herwig [1904.11866, 2107.04051], Deductor [2011.04777], Forshaw, Holguin, Plätzer [2003.06400]
  PanScales [1805.09327, 2002.11114], Alaric [2110.05964], …
- **Triple collinear / double soft splittings**
  Dulat, Höche, Krauss, Gellersen, Prestel [1705.00982, 1705.00742, 1805.03757, 2110.05964]
  Li & Skands [1611.00013], Löschner, Plätzer, Simpson Dore [2112.14454], …
- Matching to fixed-order **see Alexander's talk**
  NLO; i.e. Frixione & Webber [0204244], Nason [0409146], …
  NNLO; i.e. UNNLOPS [1407.3773], MiNNLOps [1908.06987], Vincia [2108.07133], …
  NNNLO; Prestel [2106.03206], Bertone, Prestel [2202.01082]
- Colour (and spin) correlations **see Simon's talk**
  Forshaw, Holguin, Plätzer, Sjödahl [1201.0260, 1808.00332, 1905.08686, 2007.09648, 2011.15087]
  Deductor [0706.0017, 1401.6364, 1501.00778, 1902.02105], Herwig [1807.01955], Plätzer & Ruffa [2012.15215]
  PanScales [2011.10054, 2103.16526, 2111.01161], …
- Electroweak corrections
  Vincia [2002.09248, 2108.10786], Pythia [1401.5238], Herwig [2108.10817], …

C Super-active field of research:
taken from Melissa van Bleekveld's talk at the CERN workshop on parton showers for future colliders.

**Simon Plaetzer**

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vers

$L \sim 1 \qquad \alpha_s N^2 \sim 1$

# Redefinitions of "bare" operators

How do we consistently hadronize in light of (improved) shower algorithms?
How to do this at subleading N and higher order shower evolution?

$$\sigma = \sum_{n,m} \int\int \mathrm{Tr}_n \left[\mathbf{M}_n \mathbf{U}_{nm}\right] \mathrm{d}\phi_m u(\phi_m)$$

Redefinitions of hard and soft factor **inverse** to each other:

$$\mathbf{Z}_n = \mathbf{X}_n^{-1} \qquad \mathbf{X}_n \mathbf{E}_n^{(s)} \circ \mathbf{E}_n^{(s)\dagger} \mathbf{X}_n^\dagger - \mathbf{F}_n^{(s)} \mathbf{Z}_{n-s} \circ \mathbf{Z}_{n-s}^\dagger \mathbf{F}_n^{(s)\dagger} - \sum_{t=1}^{s-1} \mathbf{F}_n^{(t)} \mathbf{E}_{n-t}^{(s-t)} \circ \mathbf{E}_{n-t}^{(s-t)\dagger} \mathbf{F}_n^{(t)\dagger} = 0$$

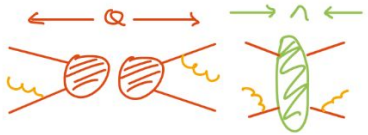

dressing of hard process ~ parton shower

soft evolution ~ measurement and hadronization model

$$\sum_n \int \alpha_S^n \, \mathrm{Tr}\left[\left(\mathbf{A}_n + \mathbf{\Delta}_n\right) \mathbf{S}_n\right] \mathrm{d}\phi(Q) \prod_{i=1}^{n} \mu_R^{2\epsilon} [\mathrm{d}p_i] \tilde{\delta}(p_i)$$

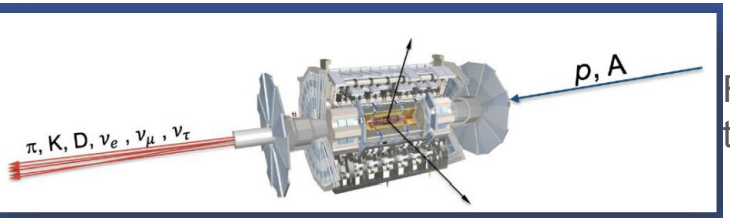
Simon Plaetzer

$\alpha_s$ corrections to tower of logarithms in A —
truncation error of relation of Z factors



# Forward thinking (in space & time)

- Dedicated tuning efforts targeting forward physics (FPF) & other future facilities (Detroit Tune for RHIC → EIC?). Would be great to implement these as Pythia tunes for more distributed validation!




Forward tune

| Full name | Shorthand | Baseline (QCDCR) | Forward Tune | Uncertainty |
|---|---|---|---|---|
| BeamRemnants:dampPopcorn | $d_{\text{pop}}$ | 1 | 0 | |
| BeamRemnants:hardRemnantBaryon | $f_{\text{remn}}$ | off | on | |
| BeamRemnants:aRemnantBaryon | $a_{\text{remn}}$ | - | 0.36 | |
| BeamRemnants:bRemnantBaryon | $b_{\text{remn}}$ | - | 1.69 | |
| BeamRemnants:primordialKTsoft | $\sigma_{\text{soft}}$ | 0.9 | 0.58 | 0.26 . . . 1.27 |
| BeamRemnants:primordialKThard | $\sigma_{\text{hard}}$ | 1.8 | 1.8 | |
| BeamRemnants:halfScaleForKT | $Q_{\text{half}}$ | 1.5 | 10 | |
| BeamRemnants:halfMassForKT | $m_{\text{half}}$ | 1 | 1 | |
| BeamRemnants:primordialKTremnant | $\sigma_{\text{remn}}$ | 0.4 | 0.58 | 0.26 . . . 1.27 |

Detroit tune (STAR)

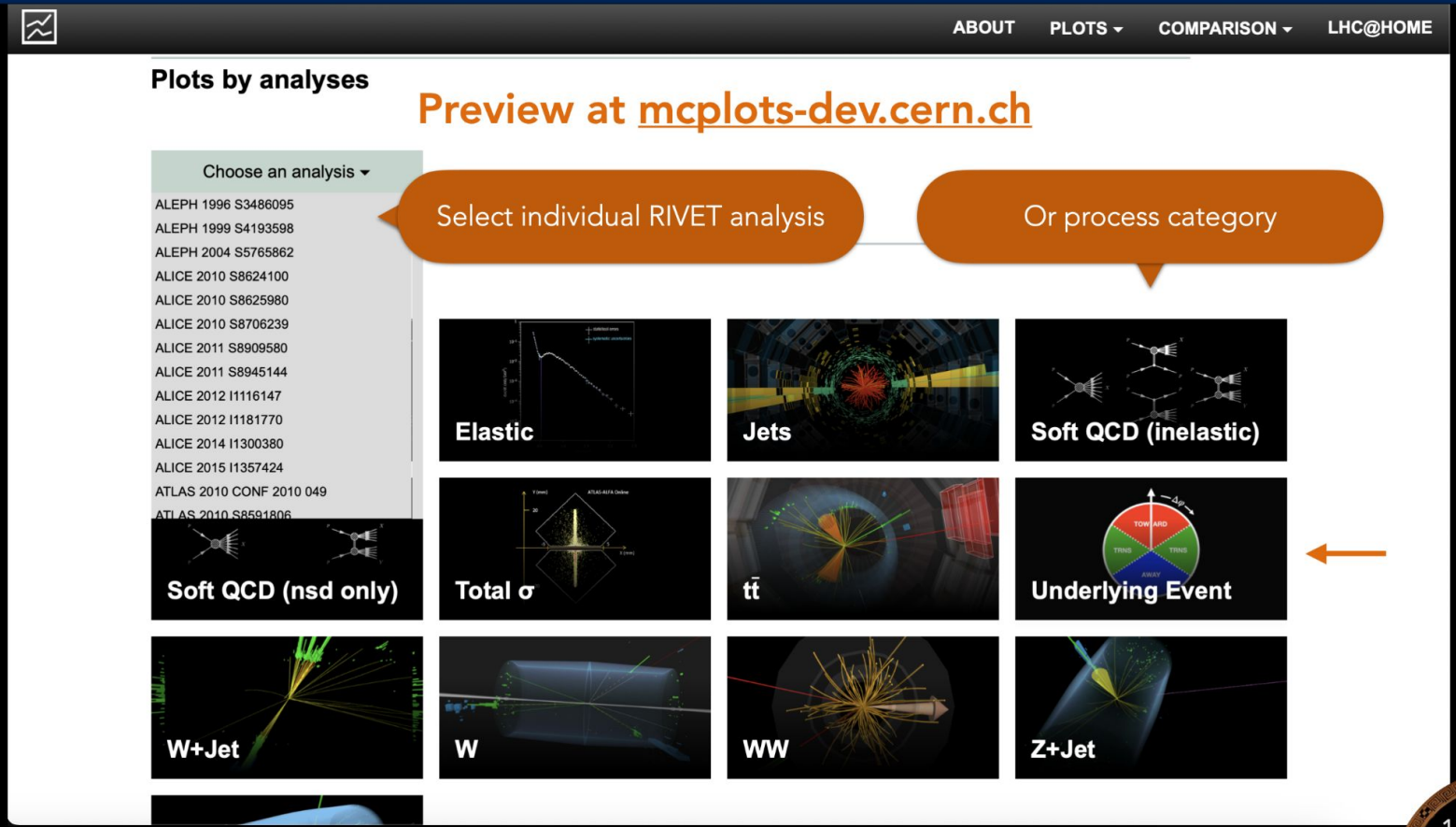
TABLE I. PYTHIA8 settings and tuning parameters.

| Setting | Default | New |
|---|---|---|
| PDF:pSet | 13 | 17 |
| MultipartonInteractions:ecmRef | 7 TeV | 200 GeV |
| MultipartonInteractions:bprofile | 3 | 2 |
| **Tuning Parameter** | **Default** | **Range** |
| MultipartonInteractions:pT0Ref | 2.28 GeV | 0.5–2.5 GeV |
| MultipartonInteractions:ecmPow | 0.215 | 0.0–0.25 |
| MultipartonInteractions:coreRadius | 0.4 | 0.1–1.0 |
| MultipartonInteractions:coreFraction | 0.5 | 0.0–1.0 |
| ColourReconnection:range | 1.8 | .0–9.0 |

- **Raised multiple times:** can/should we improve or change the default Pythia tune?
- Does this actually signal that it's time for **another larger-scale tuning effort**, taking into account lessons learned from these more-focussed studies?

# MCPLOTS — New Look Coming Soon

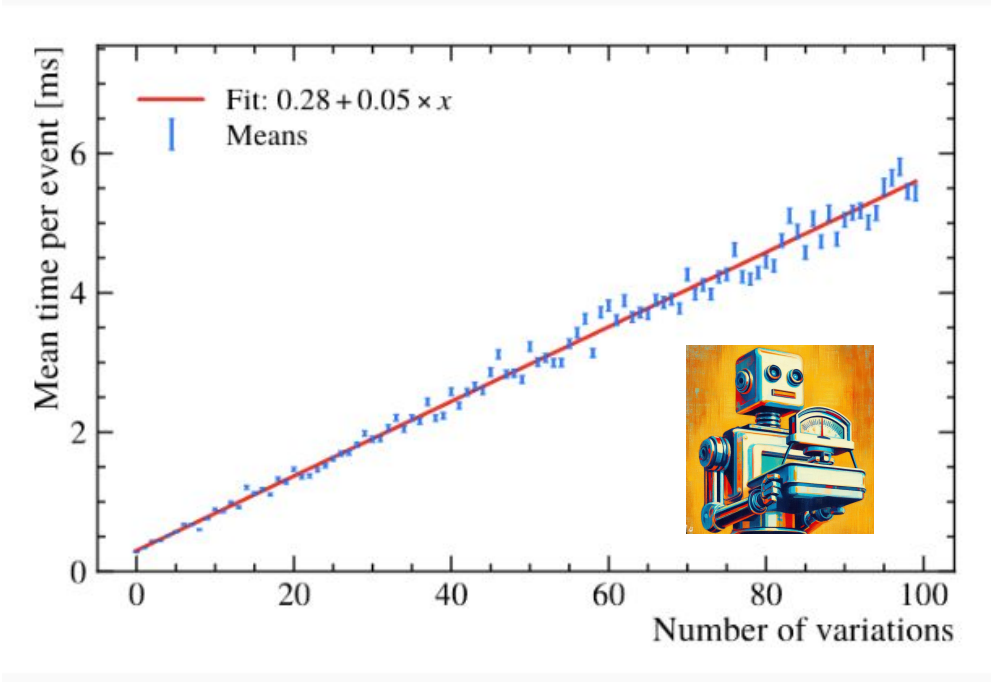
Work in Progress: Korneeva, Karneyeu, PS




Peter Skands

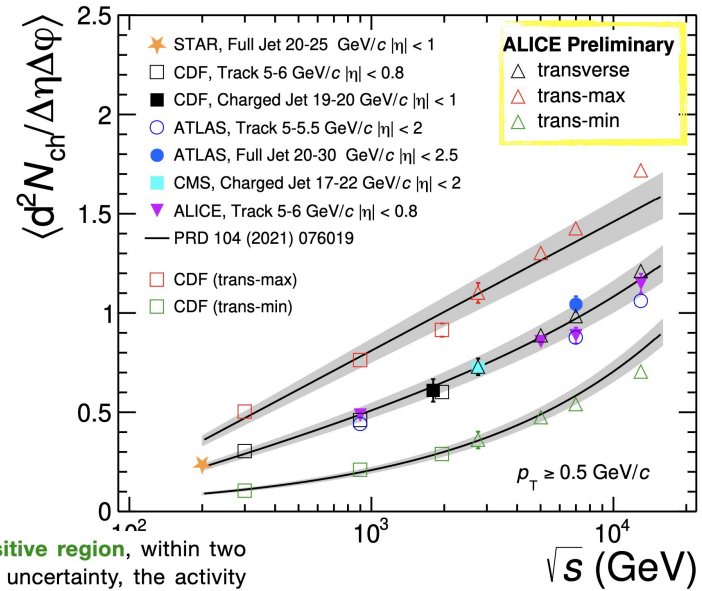
# One more tune!

- **Tuning mentioned several times as a pain point:**
  - Time-consuming
  - Compute-consuming
  - Student-consuming
  - *etc.*
- Likely that there is low-hanging fruit in this area to improve quality-of-life with new techniques (ML/AI?).
- Christian mentioned some interesting ideas about differentiable programming.
  - **Even “simple” reweightings are huge improvements, and save considerable time & compute!**



# Scaling up our understanding

- Re-analysis of Run 1 ALICE data to study multiplicity scaling & MPI effects
  - Great tests for new models: EPOS & PYTHIA consistent with experimental data.

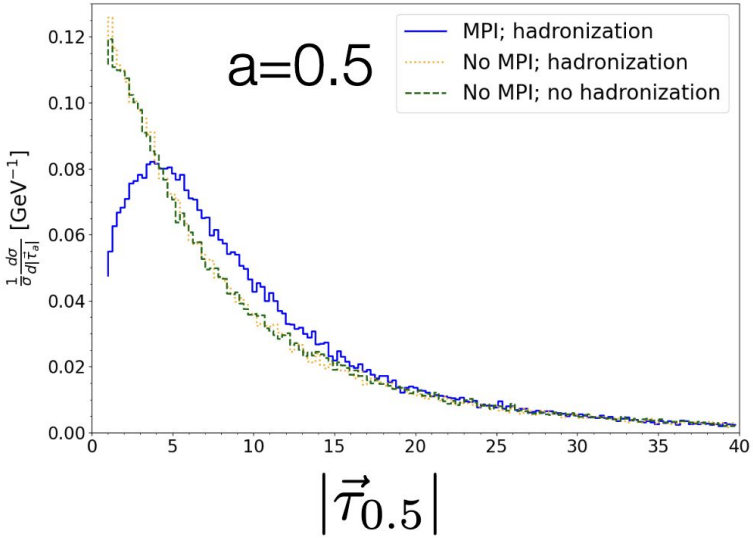



- For the **MPI-sensitive region**, within two sigma systematic uncertainty, the activity inside increases like a power-law with $\sqrt{s}$
- For the **ISR-FSR-sensitive region**, within two sigma systematic uncertainty, the activity inside rises logarithmically with $\sqrt{s}$

**Feng Fan**

**Wouter Waalewijn**

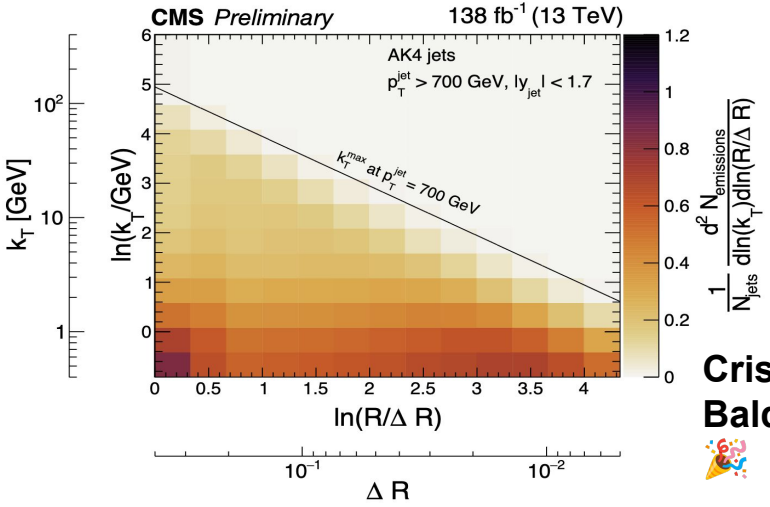
$$\vec{\tau}_a = \sum_i \vec{p}_{T,i}\, e^{-a|y_i|},$$



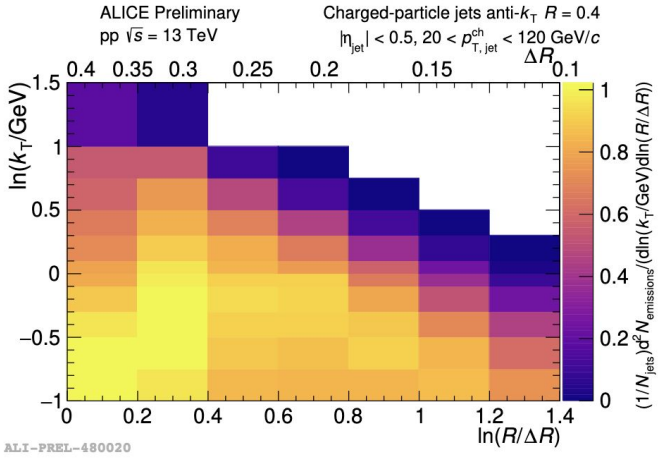

- New vector angularity observables proposed to test factorisation violation and MPI effects

# Boostin' is legit (JSS)

- Jets are a multi-faceted probe of many aspects of QCD.
  - Some observables conflate these : jets are complex!
  - Some observables factorise them : we're getting more clever!
- LJP measurements in high-pT jets are sensitive to radiation at the hadronization scale (tracks down to ~500 MeV)
  - Could we use this approach to learn about npQCD?
- LJP measurements in low-pT jets are dominated by hadronization effects anyway – multiple handles on the same physics.




Cristian Baldenegro 🥳




ALICE

# Aside: Modelling (Les Houches advert)

- No one in this room is happy with two-point model comparisons.
  - Often no consistency between collaborations
    - Somewhat understandable – different setups available, etc.
- Can we do better?
  - Prescriptions, or at least some guidelines, that are developed with input from the whole community would be significant progress.
  - Discussion at LH23 about trying to provide guidance & move towards at least more factorised comparisons as a first step…
    - If you're interested in having input here, get in touch!

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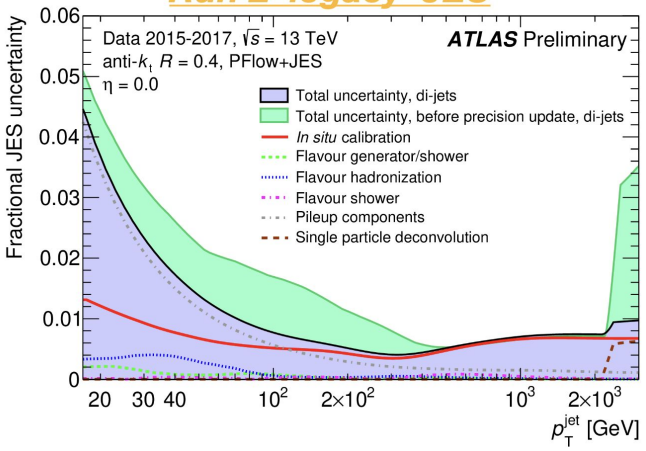
**Run 2 'legacy' JES**




**Flavour generator/shower**

Pythia8 [1] *vs.*
Sherpa v2.2.5 w/ Lund hadronisation (Pythia 6) [2][3]

**Flavour hadronization**

Sherpa v.2.2.11w/ AHADIC cluster hadronisation [2][4] (new tune [5]) *vs.*
Sherpa v2.2.5 w/ Lund hadronisation (Pythia 6)

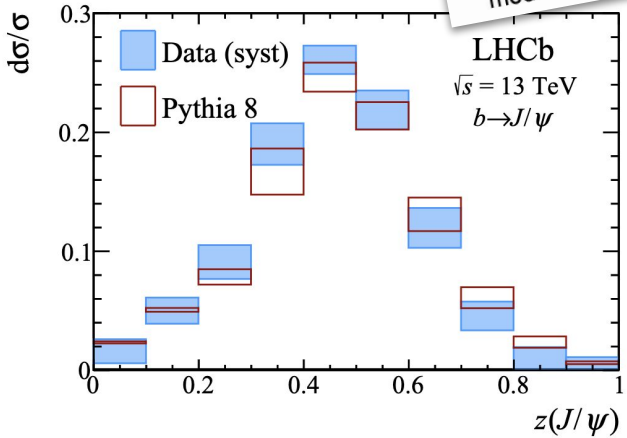
**Flavour shower**

Herwig7 angular parton shower [6][7] *vs.*
Herwig7 dipole parton shower [6][8] shower models

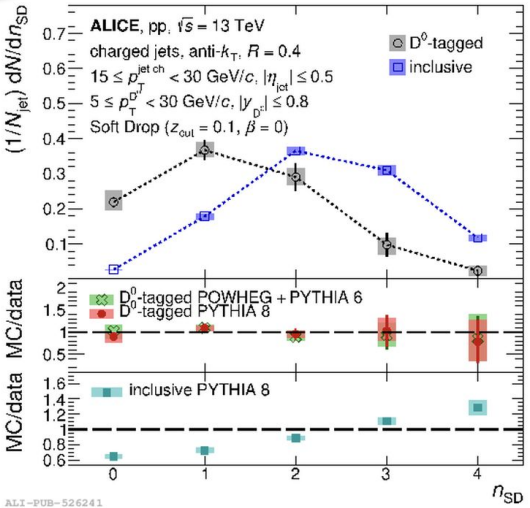
# Flavour

- Some measurements of JSS with heavy-hadron ID have been performed – likely more of these will help provide new insights on npQCD, improve models.
  - We can reconstruct J/Psi, tag D- and B-mesons and then measure fragmentation … what else should be done?

- Convince experimentalists to get more (identified) particle correlation data (also for LEP), since important modelling input

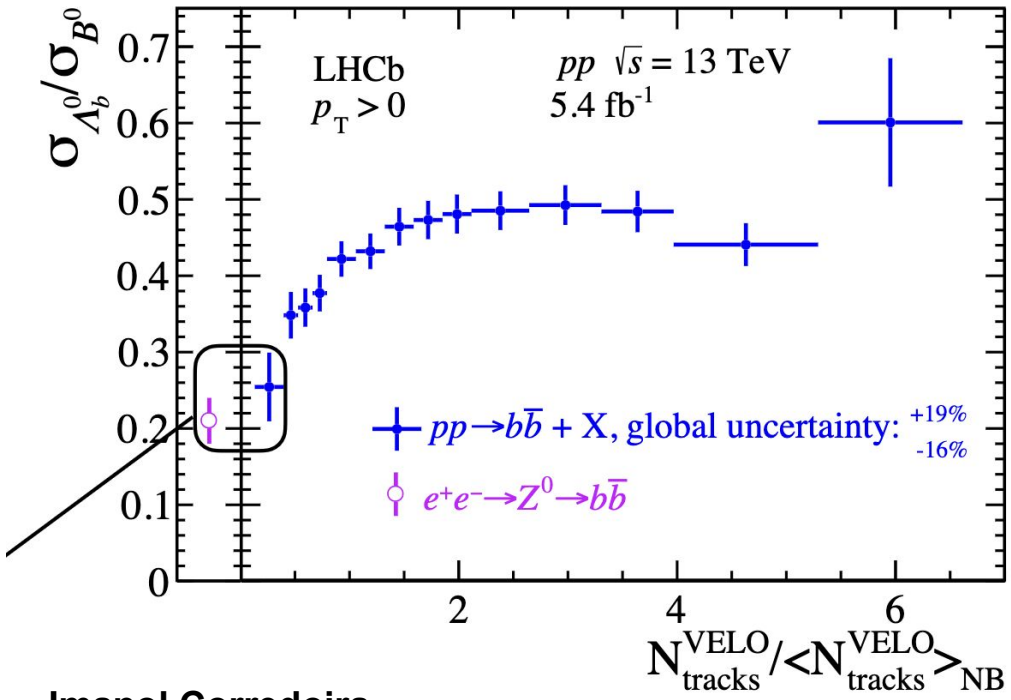



LHCb



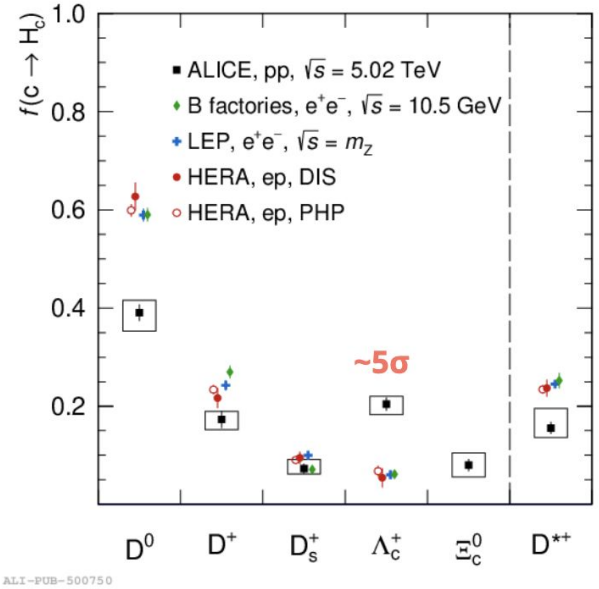

ALICE

# More Flavour




Imanol Corredoira

**ALICE** [2112.08156]




*Charm fragmentation fractions differ significantly from LEP, HERA!*

***... should include LHC data in tuning / validation!***

# https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCJetSubstructureMeasurements

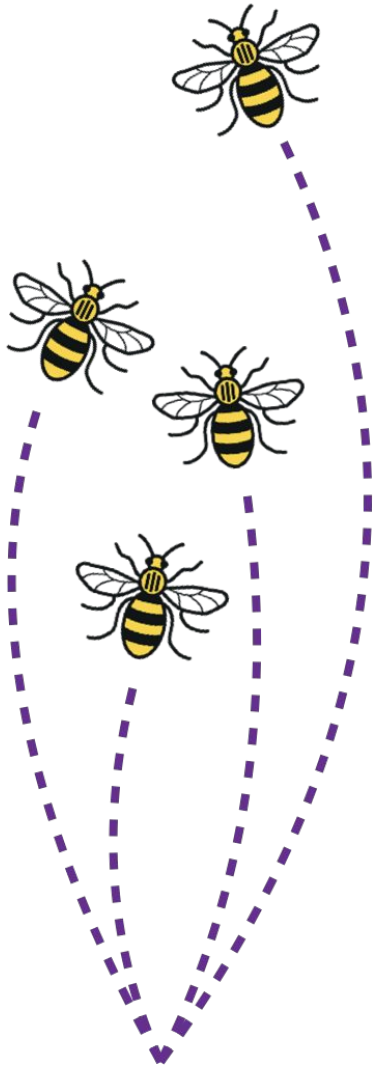
References of recent measurements

- **ATLAS**
  - JSS Observables in boosted ttbar, l+jets and all-had @ 13 TeV, CONF.
  - Properties of b-quark fragmentation @ 13 TeV
  - Substructure of large-radius jets @ 5.02 TeV, prelim.
  - Soft Drop Observables (m, zg, rg; calorimeter- & track-based) @ 13 TeV
  - Lund jet plane @ 13 TeV
  - Mass in Z->(bb)+gamma @ 13 TeV
  - Fragmentation properties @ 13 TeV
  - JSS Observables in multijets & ttbar @ 13 TeV
  - g->bb @ 13 TeV
  - Jet pull @ 13 TeV
  - Jet mass @ 5.02 TeV
  - Jet mass @ 13 TeV
  - Fragmentation properties in photon-jet events @ 5.02 TeV
  - Fragmentation properties II @ 5.02 TeV
  - Fragmentation properties @ 5.02 TeV
  - Collinear W emission @ 8 TeV
  - Charged particles inside jets @ 8 TeV
  - Jet charge @ 8 TeV
  - Jet pull @ 8 TeV
  - Fragmentation properties II @ 2.76 TeV
  - Fragmentation properties I @ 2.76 TeV
  - Jet shapes in ttbar events @ 7 TeV
  - Jet mass and other observables @ 7 TeV
  - Jet mass @ 7 TeV
  - Fragmentation properties @ 7 TeV
  - Fragmentation properties using track jets @ 7 TeV
  - Jet shapes @ 7 TeV
- **CMS**
  - Lund jet plane @ 13 TeV
  - Jet mass distribution and top quark mass from boosted top quarks @ 13 TeV
  - Inclusive jet and b-jet shapes in pp and PbPb @ 5.02 TeV
  - Jet angularities in Z+jet and dijet events @ 13 TeV
  - J/psi-in-jet in pp and PbPb @ 5.02 TeV
  - Jet shapes in ttbar events @ 13 TeV
  - Jet mass @ 13 TeV
  - Jet mass of top jets @ 8 TeV
  - Jet charge @ 8 TeV
  - Jet mass in V+jets and dijets @ 7 TeV
  - Color coherence @ 7 TeV
  - Jet shapes @ 7 TeV
  - Medium-induced modifications of jet fragmentation in PbPb @ 5.02 TeV
  - Groomed jet mass in PbPb and pp @ 5.02 TeV
  - Splitting function in pp and PbPb @ 5.02 TeV
  - Jet shapes in PbPb and pp @ 5.02 TeV
  - Jet fragmentation in PbPb and pp @ 2.76 TeV
  - Modification of jet shapes in PbPb @ 2.76 TeV
  - Jet fragmentation in pp and PbPb @ 2.76 TeV
- **LHCb**
  - J/psi inside jets @ 13 TeV
  - Jet fragmentation @ 8 TeV
- **ALICE**
  - Groomed-jet substructure in D0-tagged jets @ 13 TeV (pp)
  - Angle between jet axes @ 5.02 TeV (pp)
  - Lund jet plane @ 13 TeV (pp)
  - Jet angularities @ 5.02 TeV (pp)
  - Soft Drop zg, theta_g @ 5.02 TeV (pp & Pb-Pb)
  - Dead cone in D0-tagged jets @ 13 TeV (pp)
  - N-subjettiness @ 2.76 TeV (Pb-Pb)
  - jt distributions @ 5.02 TeV (pp & p-Pb)
  - zg and nSD @ 7 TeV (pp) & 2.76 TeV (Pb+Pb)
  - D0-tagged jet fragmentation and cross-sections @ 7 TeV (pp)
  - jt distributions @ 7 TeV (pp) & 5.02 TeV (p-Pb)
  - Jet fragmentation and cross-sections @ 7 TeV (pp)
  - Jet shapes @ 7 TeV (pp) & 2.76 TeV (Pb+Pb)
  - Jet mass @ 5.02 TeV (p-Pb) & 2.76 TeV (Pb+Pb)

***Please use LHC Rivet routines!***

# WG1 concluding remarks

- Main themes this year:
  - Colour reconnection
    - QCD junction model!
  - Improved performance
    - Reweighting, connecting hard & soft aspects of shower
  - New observables
    - Vector angularities, JSS
  - Old observables
    - Correlators, multiplicities
  - New tools
    - Angantyr, MCPlots



Thanks for listening!