Jet Flavour summary

Les Houches 2023

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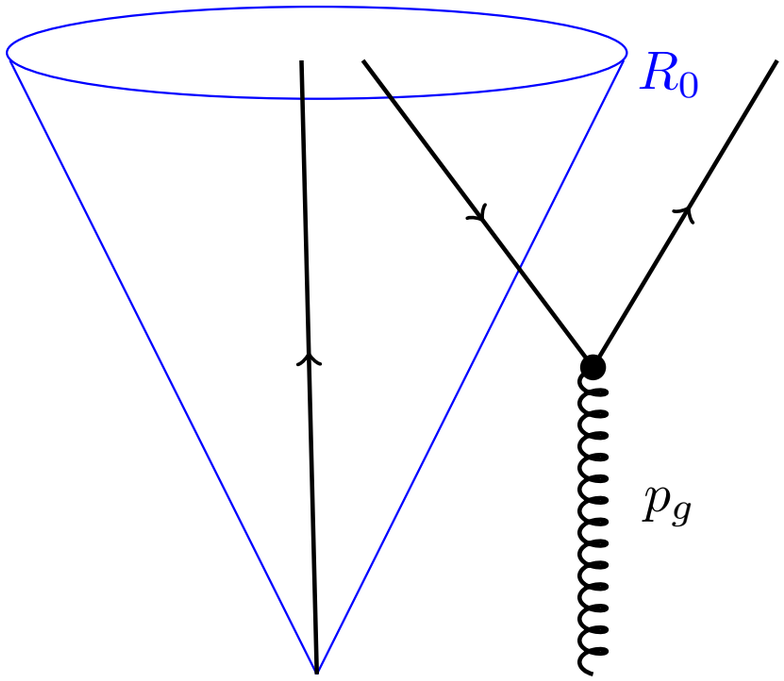
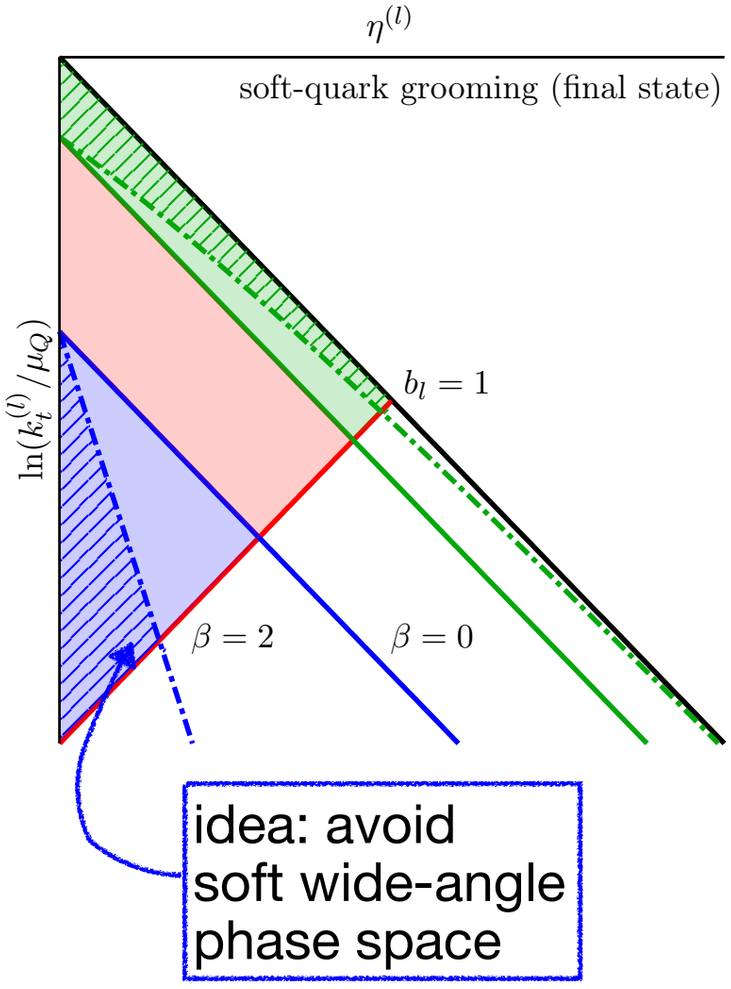
Yeah, but what flavour???
This isn’t working, maybe we should just try ice-cream therapy

Soft Drop Flavour (SDF)

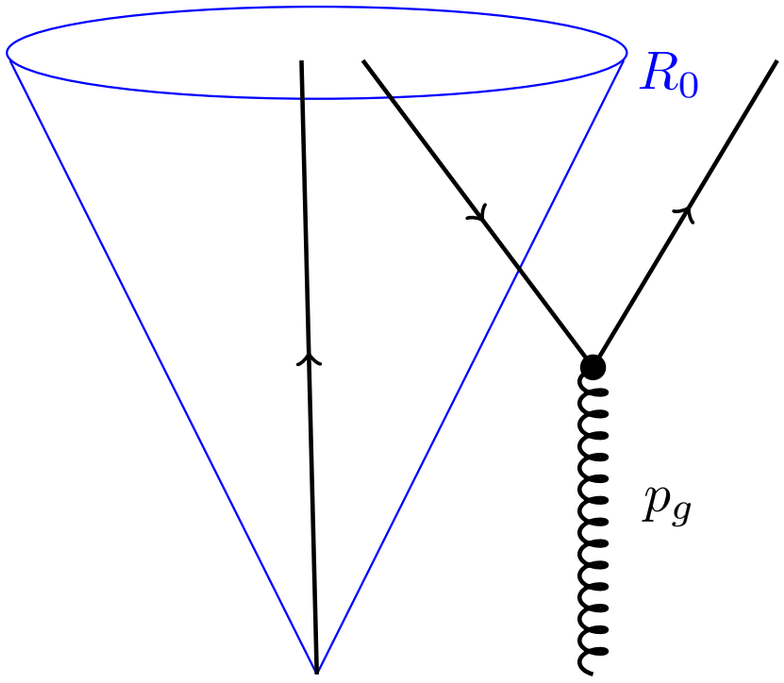




- Safe at NNLO with Jade reclustering (but not beyond)
- Only looks at information in the original anti-k_t jet
- SD only used for flavour determination, no change in the jet kinematics

Caletti, Larkoski, Marzani, Reichelt [arXiv:2205.01109]

Flavour anti-k_t (CMP)



Proposed modification:

A soft term designed to modify the distance of flavoured pairs.

$$d_{ij}^{(F)} = d_{ij} \begin{cases} \mathcal{S}_{ij} & \text{i,j is flavoured pair} \\ 1 & \text{else} \end{cases}$$

$$\mathcal{S}_{ij} \equiv 1 - \theta\left(1 - \kappa_{ij}\right) \cos\left(\frac{\pi}{2}\kappa_{ij}\right) \quad \text{with} \quad \kappa_{ij} \equiv \frac{1}{a} \frac{k_{T,i}^2 + k_{T,j}^2}{2k_{T,\max}^2} \,.$$

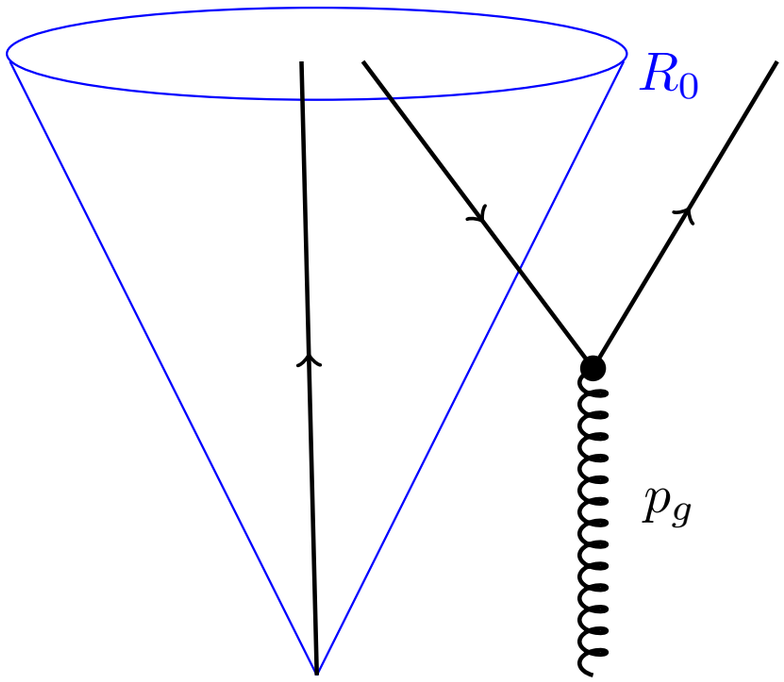
- New jet algorithm to cluster together flavoured pairs first
- Small deviations from anti-k_t kinematics
- IRC sensitivity beyond NNLO can be fixed using a modified metric*

$$\mathcal{S}_{ij} \to \overline{\mathcal{S}}_{ij} = \mathcal{S}_{ij} \frac{\Omega_{ij}^2}{\Delta R_{ij}^2} \qquad \Omega_{ik}^2 \equiv 2\left[\frac{1}{\omega^2}\left(\cosh(\omega \Delta y_{ik}) - 1\right) - \left(\cos \Delta\phi_{ik} - 1\right)\right]$$

* see [2306.07314]

Czakon, Mitov, Poncelet [2205.11879]

Flavour Dressing (GHS)



- start with a set of flavour agnostic jets $\{j_k\}$
- define flavoured clusters in the event $\{f_i\}$
- associate flavour clusters to jet (association criterion)
- determine the total flavour of a jet (accumulation criterion):

- algorithm only used to assign a flavour label, no kinematic modifications
- potential IRC sensitivity with many hard partons and 2 soft emissions*

* see [2306.07314]

Gauld, Huss, Stagnitto [2208.11138]

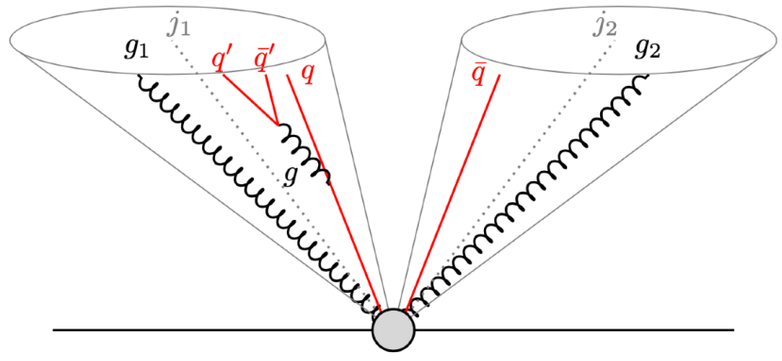
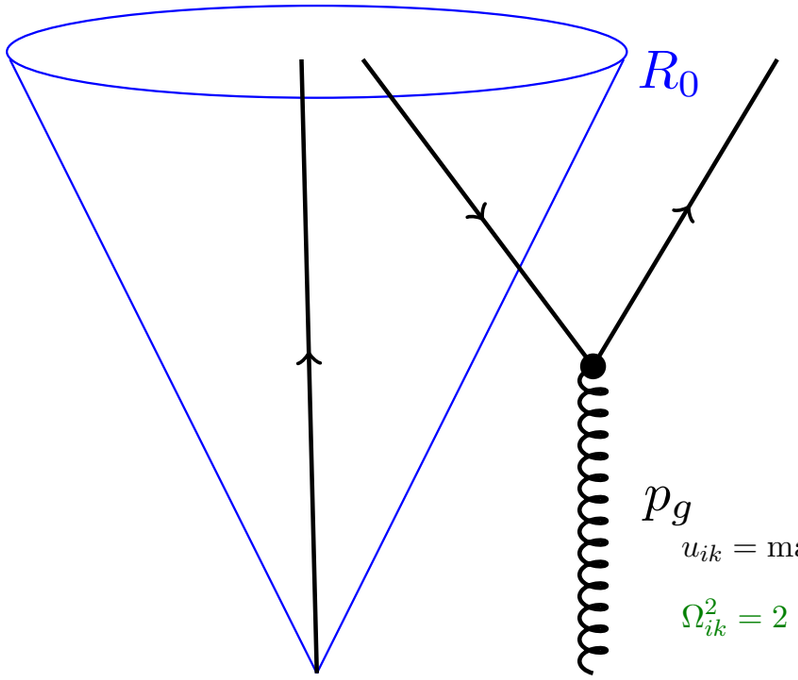
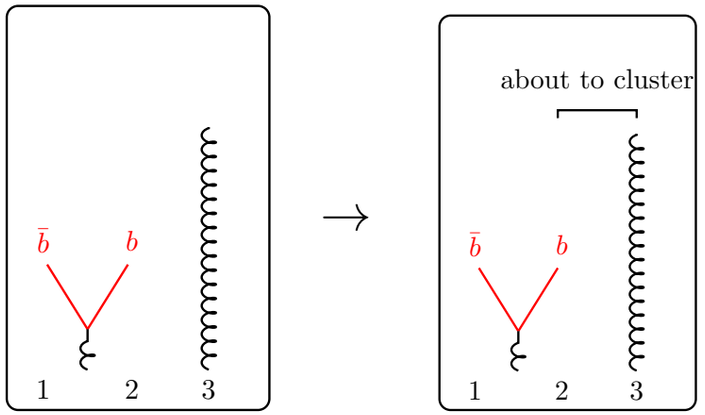


FIG. 20. Example $\mathcal{O}(\alpha_s^2)$ configuration that yields an issue for the GHS algorithm. There are four hard particles (that one can imagine recoiling against a hard gluon or electroweak system on the other side of the event), a collinear emission of a hard gluon g from one of the flavoured particles (the q), which then splits collinearly to a flavoured pair $q'\bar{q}'$.

e.g. $Zb\bar{b}$ @ N4LO

Interleaved Flavour Neutralisation (IFN)



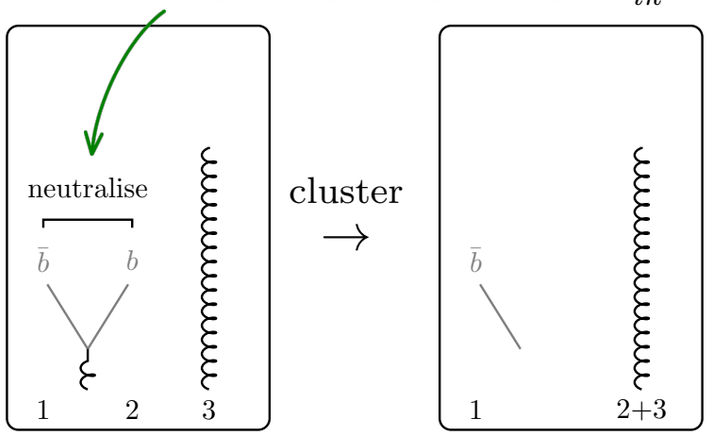


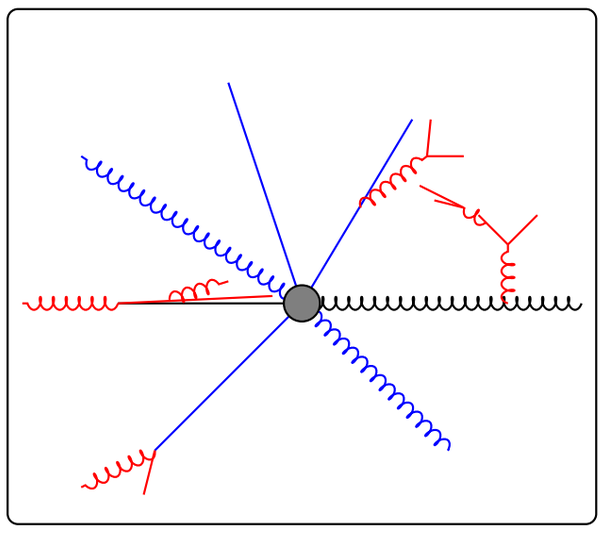
neutralise = remove the (opposite) flavour of both 1 & 2 while maintaining kinematics

based on a neutralisation distance u_{ik}

$$u_{ik} = \max\left(p_{ti}, p_{tk}\right)^{\alpha} \min\left(p_{ti}, p_{tk}\right)^{2-\alpha} \cdot \Omega_{ik}^2$$

$$\Omega_{ik}^2 = 2\left[\frac{1}{\omega^2}\left(\cosh(\omega\Delta y_{ik}) - 1\right) - \left(\cos\Delta\phi_{ik} - 1\right)\right]$$





- BONUS: framework to numerically determine IRC sensitivities at higher orders

Caola, Grabarczyk, Hutt, Salam, Scyboz, Thaler [2306.07314]

Flavours at Les Houches

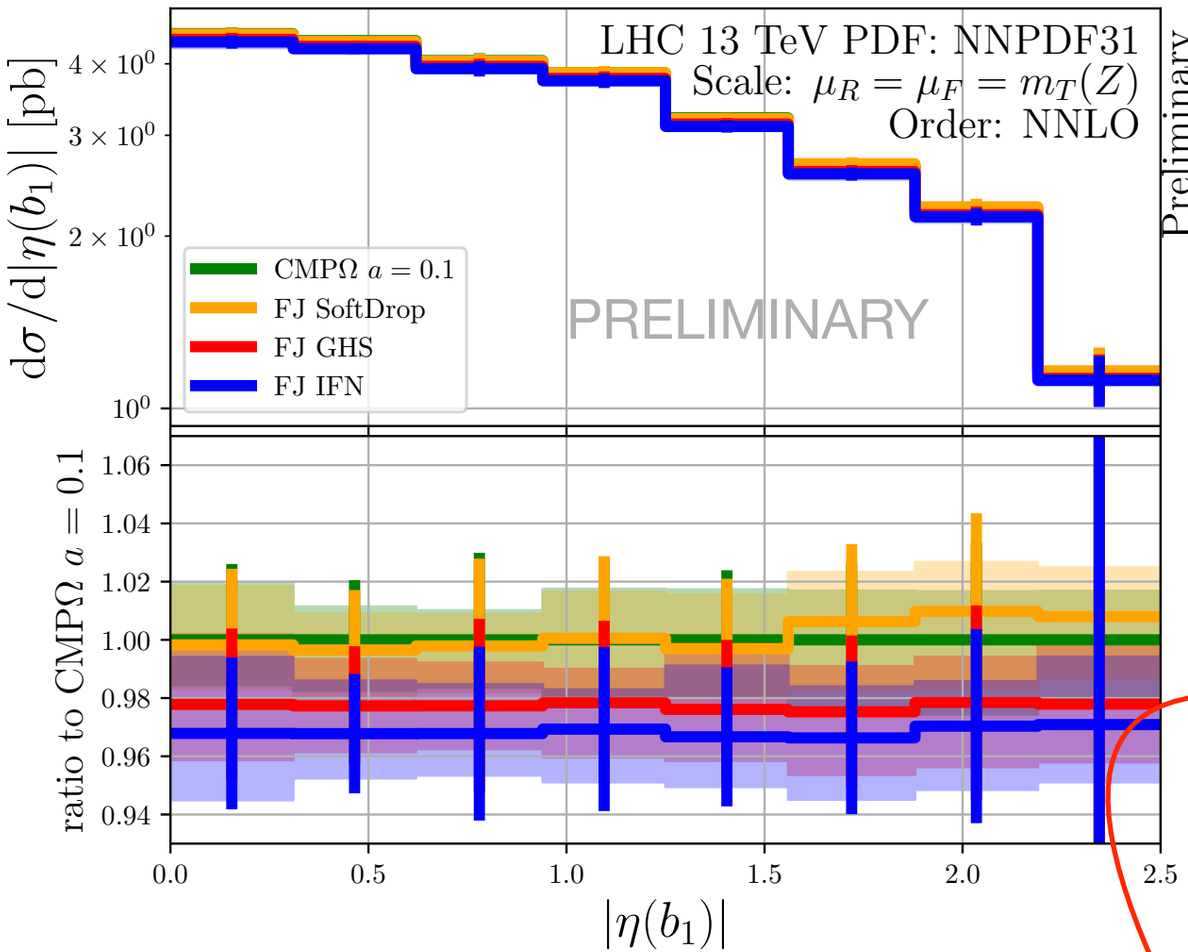
- A common framework for the 4 algorithms was created and made public https://github.com/jetflav
- First stepping stone towards detailed comparisons

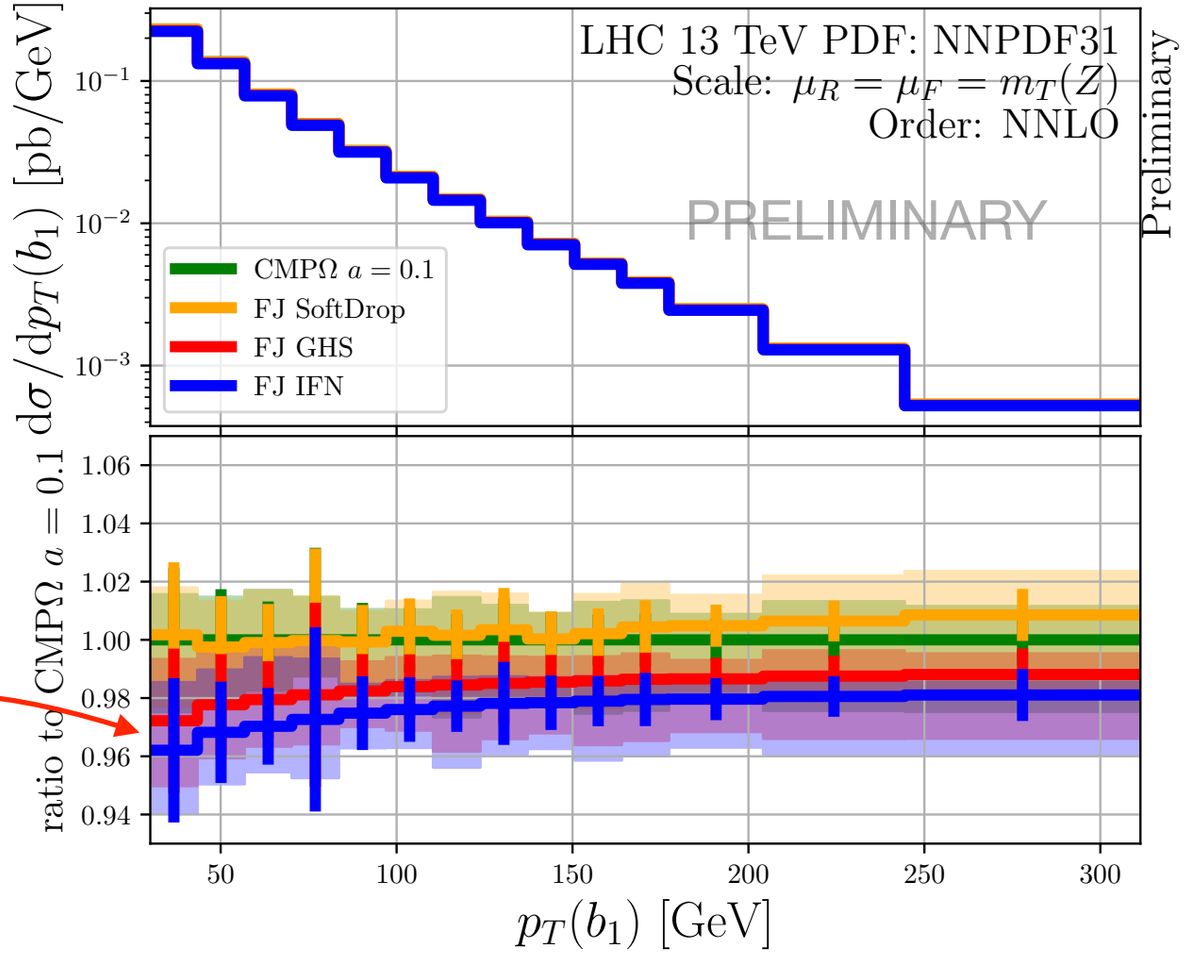
1. Comparisons in NNLO calculations (at parton level)

2. Comparison with LO + parton shower and, eventually, NLO + parton shower, with and without hadronisation corrections

3. Training machine-learning based b-taggers on jets with different b-labels and compare performances with standard anti-k_t

NNLO studies: Z+b jet (R=0.5)



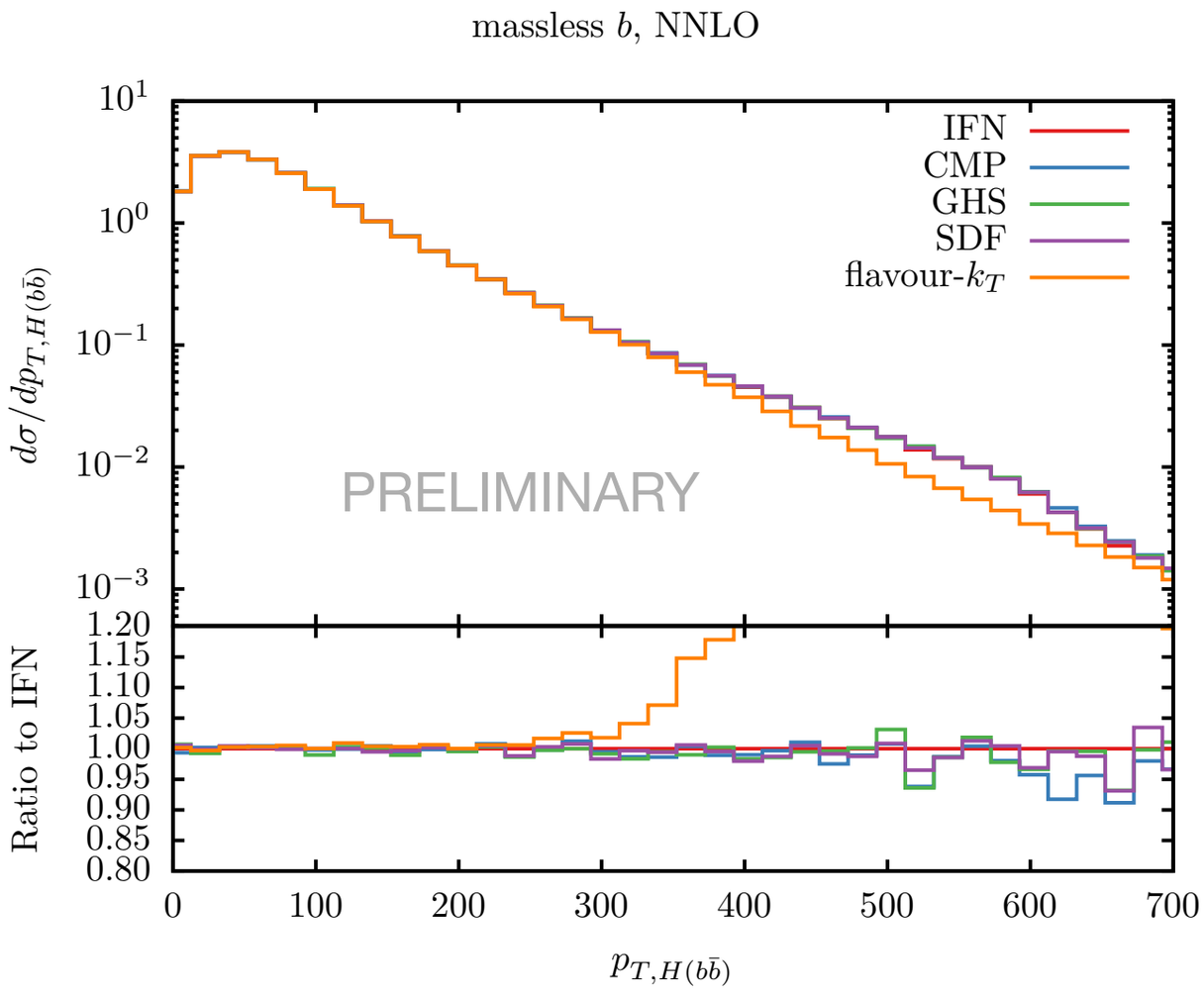


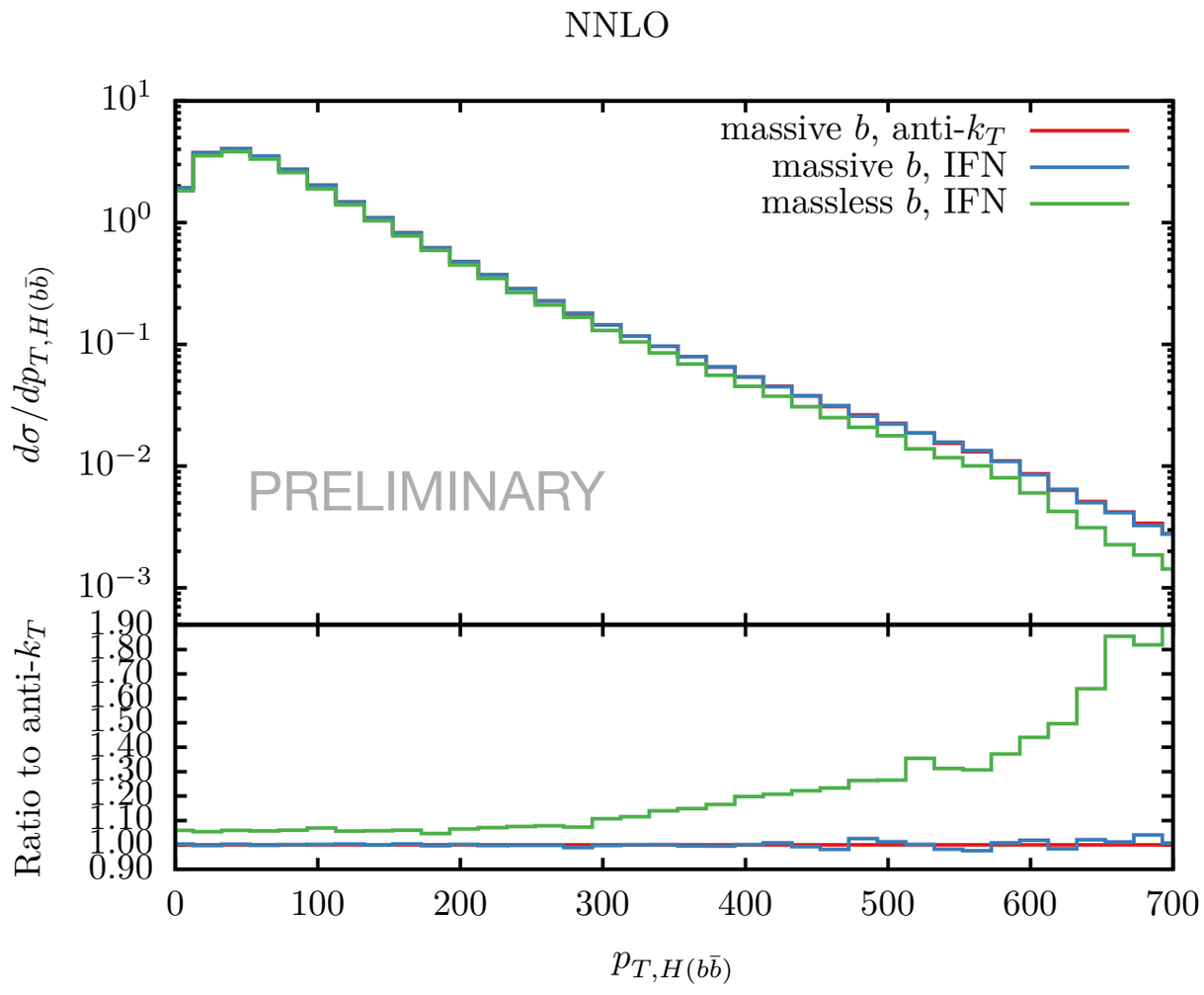
interesting shape difference at low p_t: it deserves further investigation!

- all new algorithms are IRC safe at this order (anti-kt is not!) and in reasonable agreement
- CMP and SDF behaves very similarly but they differ wrt GHS/IFN by a few percent

amazing work by Rene!

NNLO studies: WH(bb)



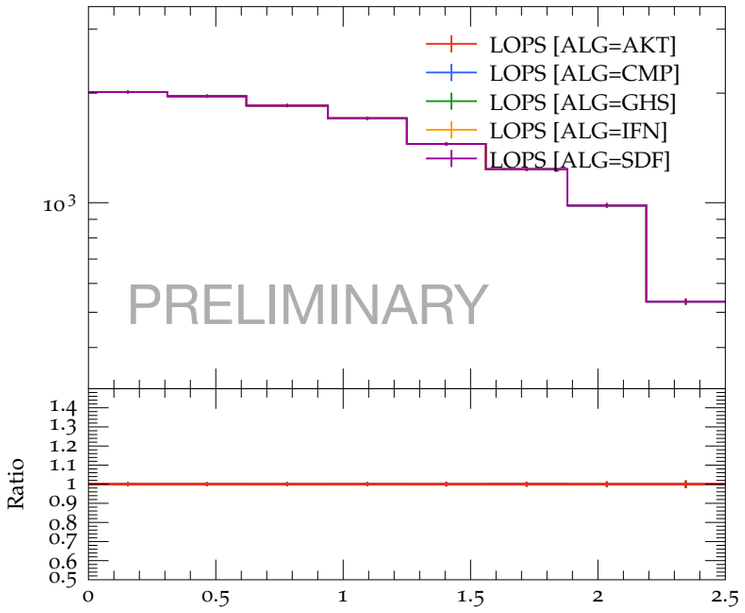


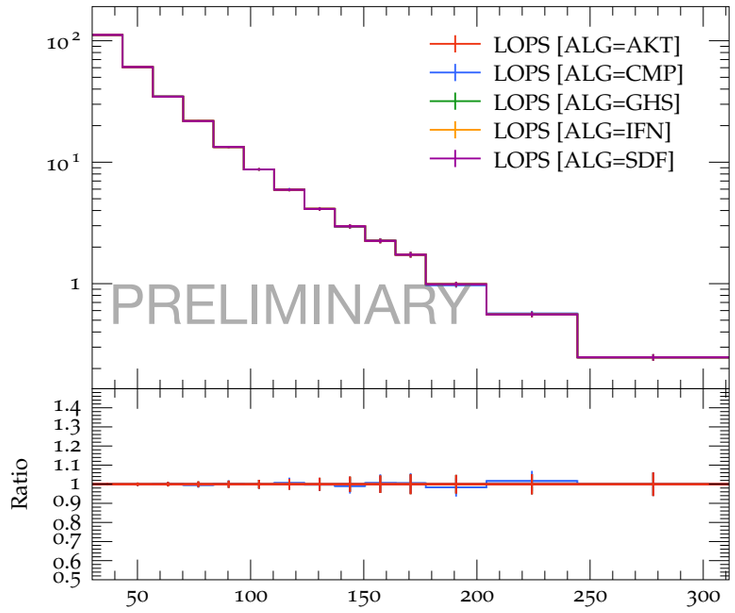
- with both massless and massive b quarks

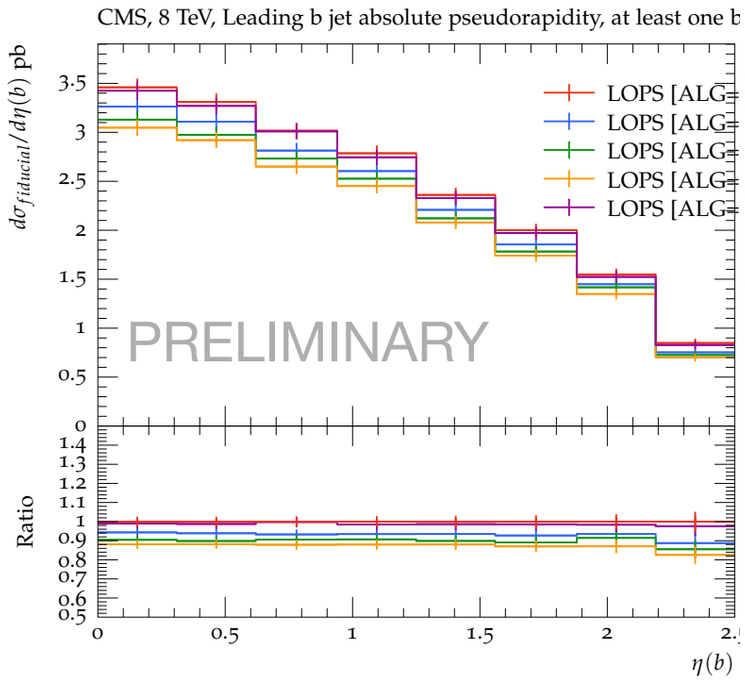
thanks to Arnd and Raoul!

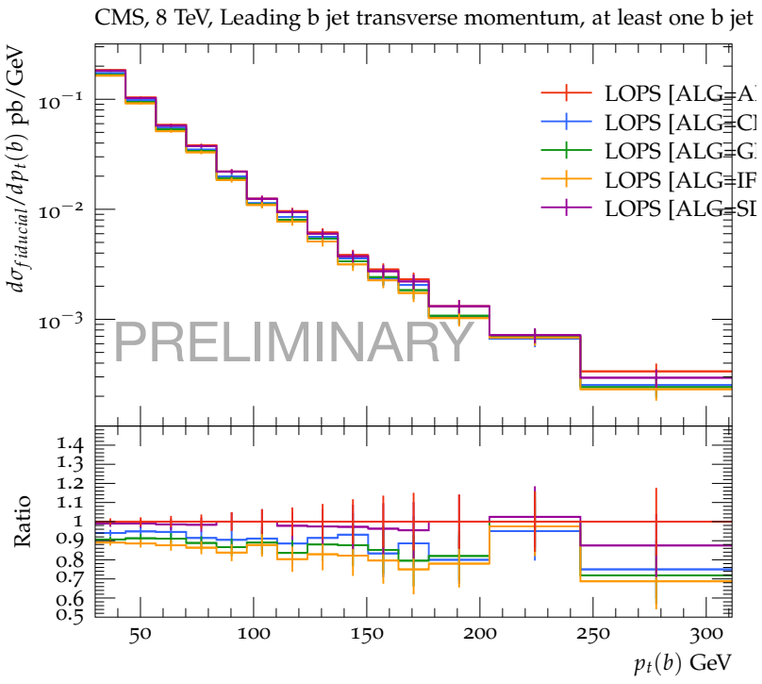
LO-PS (Pythia parton level)

- CMS 8 TeV analysis but identifying **strange quarks** rather than b's to highlight differences





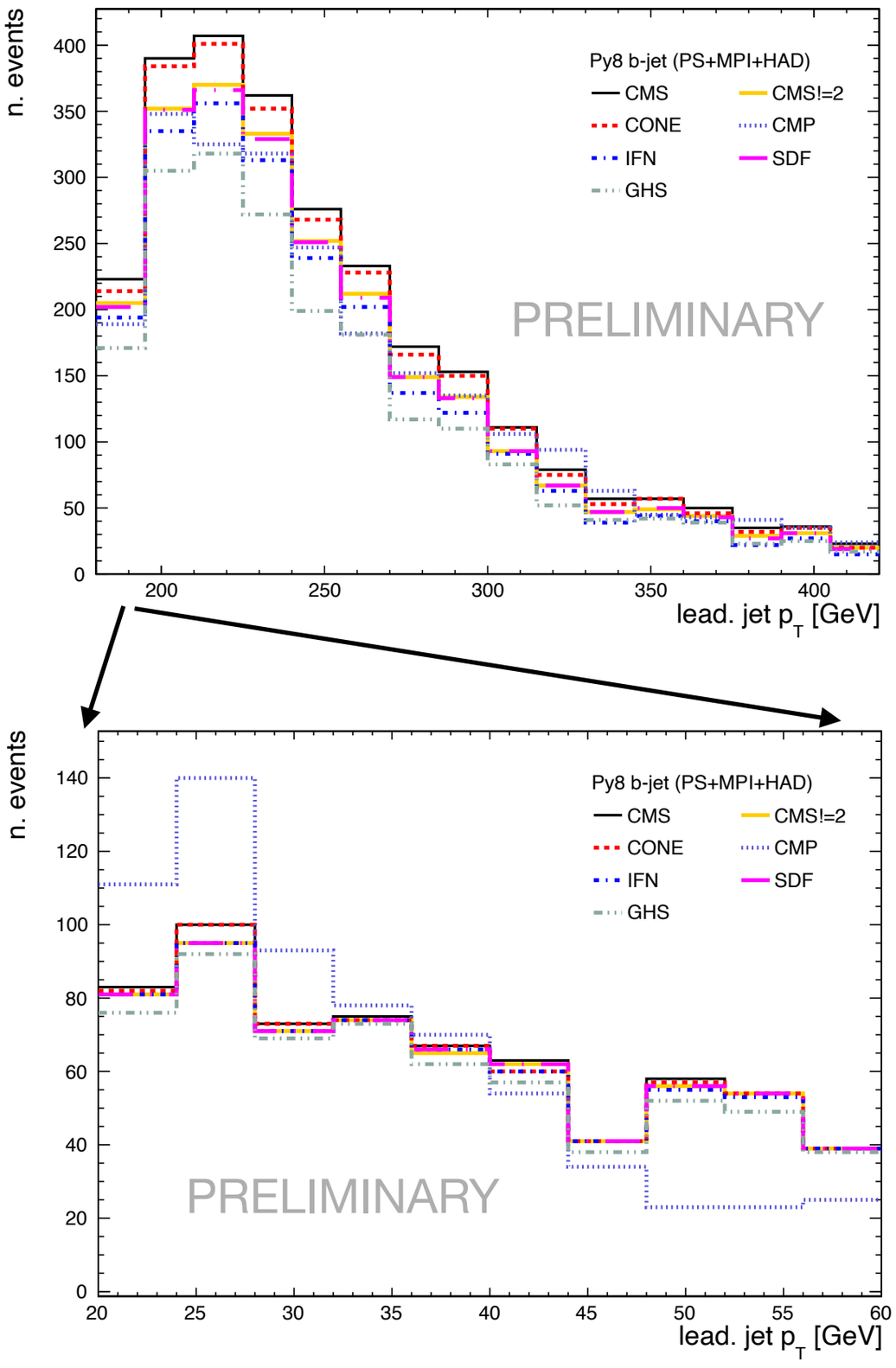


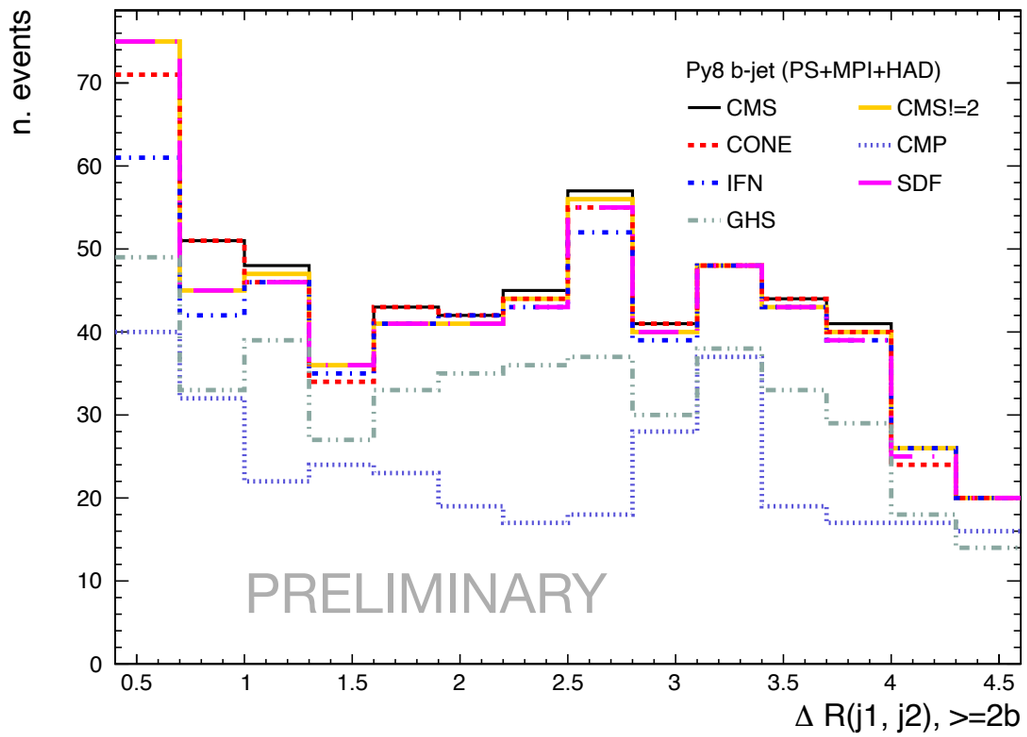


- For inclusive η, p_T distributions only CMP shows a tiny deviation from anti-k_t kinematics (baseline)
- For η_s, p_{Ts} distributions IRC sensitivity of SDF at higher order becomes visibile, while the other 3 algorithms behave similarly
- It would be interesting to see hadronisation corrections to this picture

thanks Silvia! … even if it's not your favourite shower…

LO-PS (Pythia hadron level)

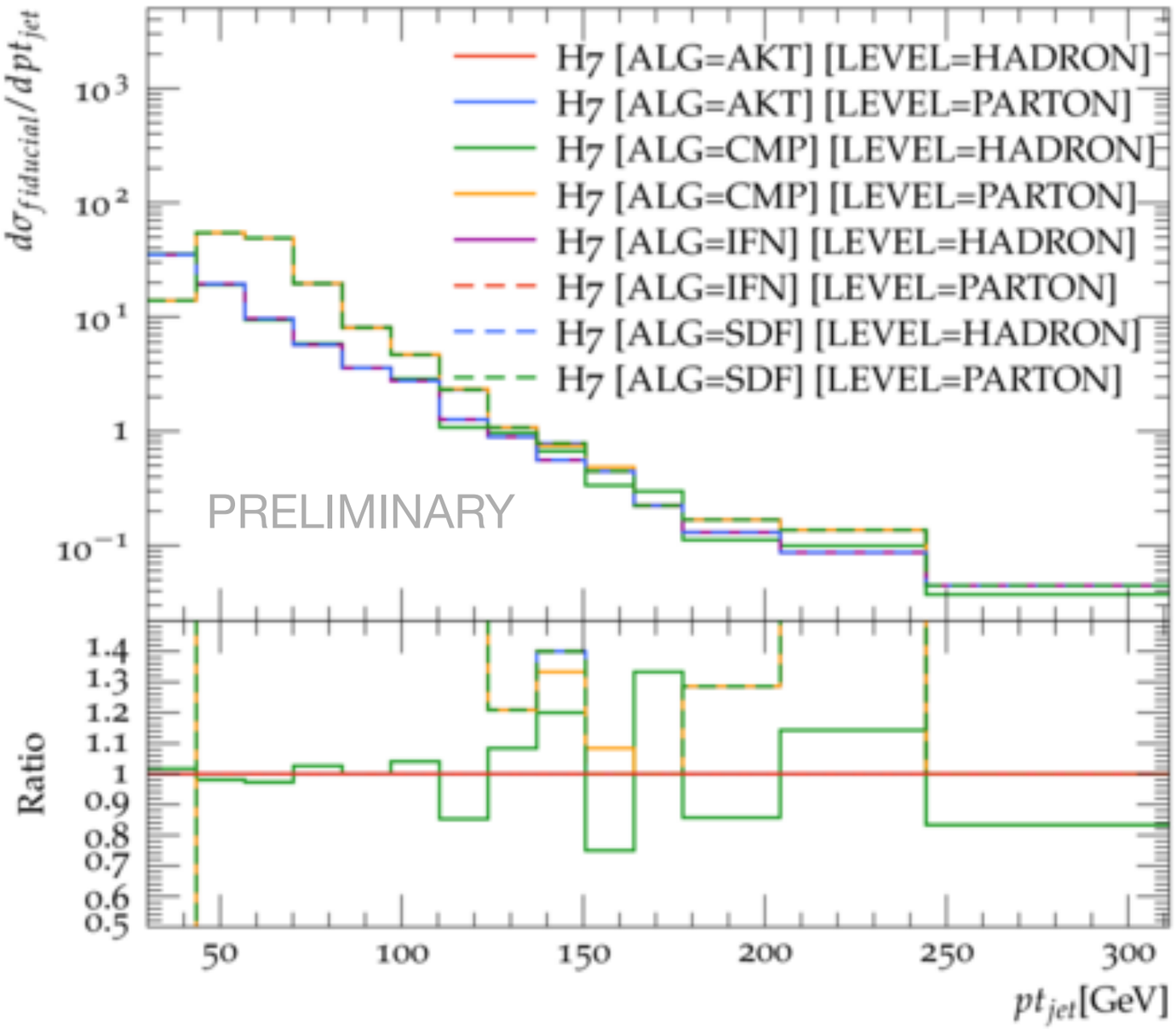




- first hadron-level studies show larger differences… something to investigate further

thanks Federico!

LO-PS (Herwig parton & hadron level)



- First step to understand the behaviour of these algorithms on hadrons
- longer runs are needed to draw conclusions
- it would be interesting to also see correlations plots

thanks to Andrzej & the Herwig team!

Lessons learnt and future plans

- First fixed-order studies here at Les Houches show are reassuring: the algorithms behave as expected
- When we add parton shower and hadronisation the picture changes but we haven't reached a full understanding yet
- It's important to make these comparison more detailed and consistent (all stages of the simulation for each MC generator)
- This will allows us to understand better the use of b-labelled jets as input for ML training and for data/theory comparisons
- We don't always want the same thing (e.g. the discussion we had about double b-tagging) but it's important to record any useful information

- We have an overleaf document https://www.overleaf.com/project/648ab3e1c164ede47c68c368
- We will setup a mailing list for those of you interested in follow-up studies

Thanks everyone for the great work!