CMP

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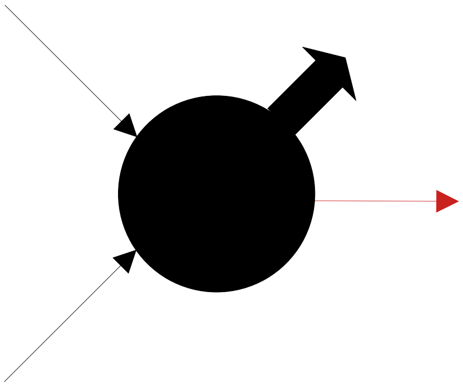
Applications of CMP [2205.11879]:
- Z + bottom [2205.11879]
- Top-pair with decays [2205.11879,2212.06019]
- W + bottom pair [2209.03280]
- W + charm [2212.00467], CMS [2308.02285]

Quick introduction: heavy flavour production (theory perspective)



Process of interest here:
Production of a (massive) quark(s) of fixed flavour
(potentially with high transverse momentum: pT >> m)

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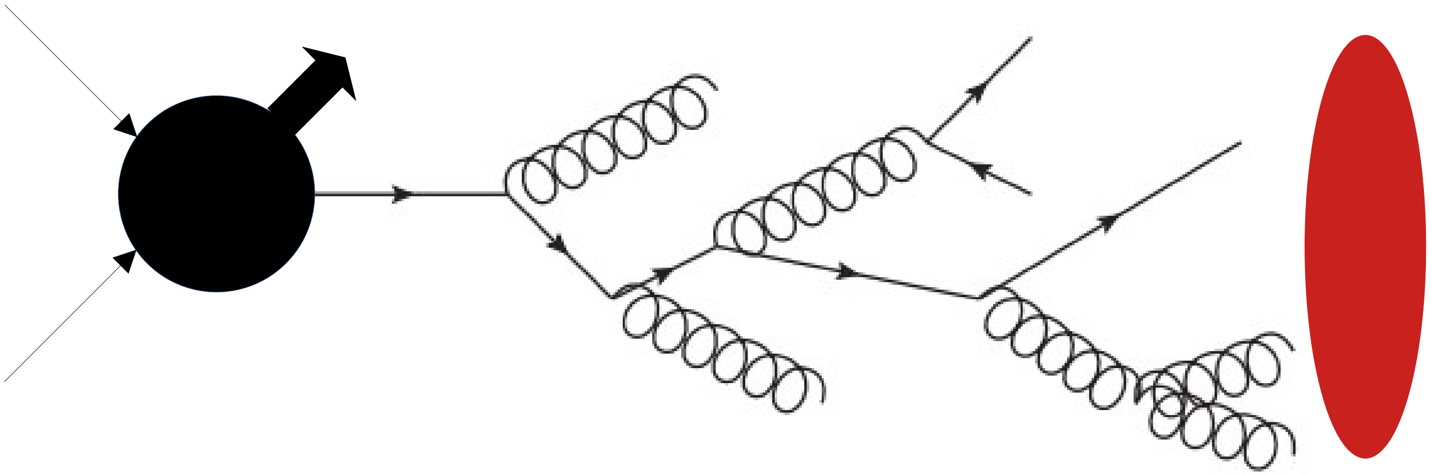
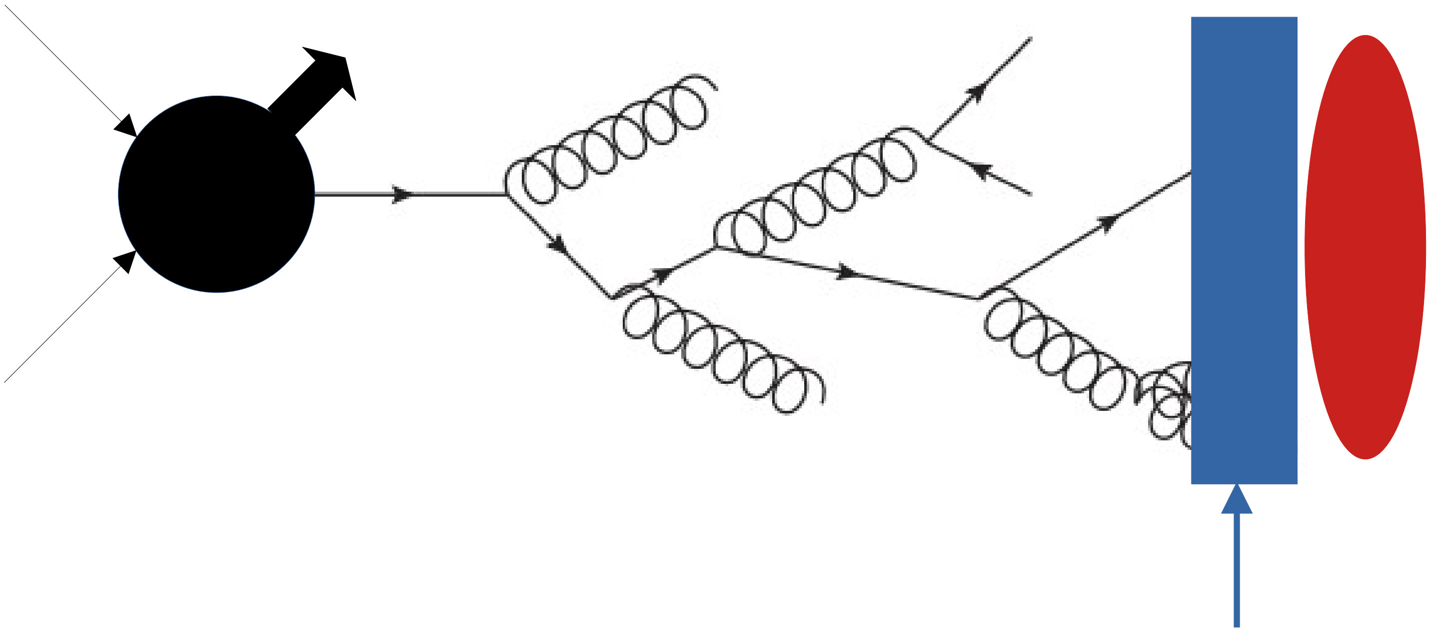


Reconstruction of jets to “approximate” the hard momentum

Quick introduction: heavy flavour production (theory perspective)



- Fragmentation/Hadronisation
- Partonic jet flavour: Quark-Hadron Duality
- Heavy B/D – hadron have a long life time:
  → experimental signature (displaced vertices)
  → distinguishable from “light” jets

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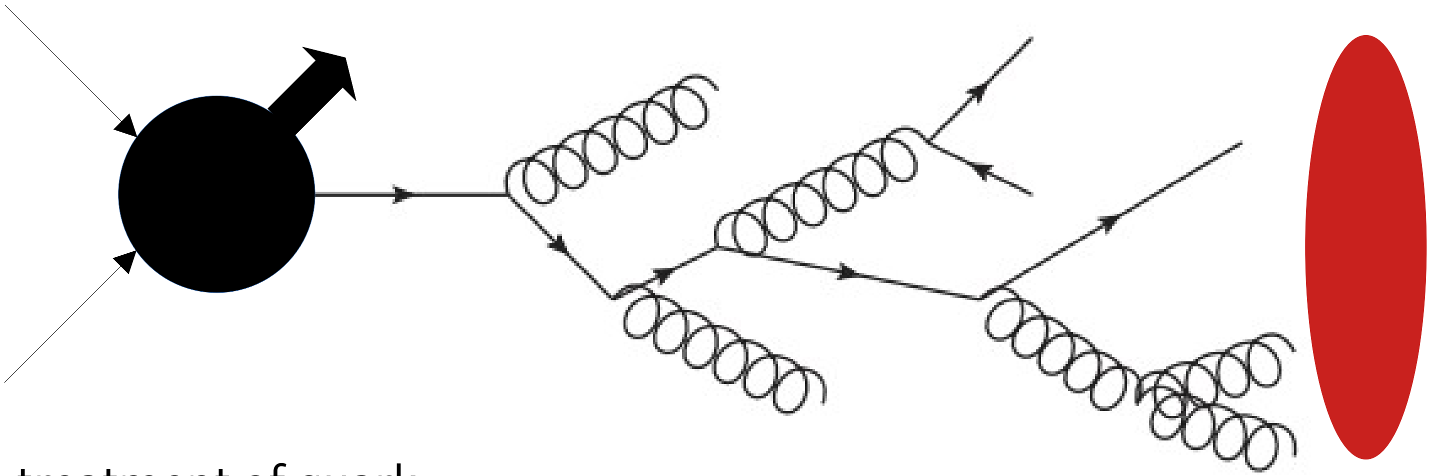
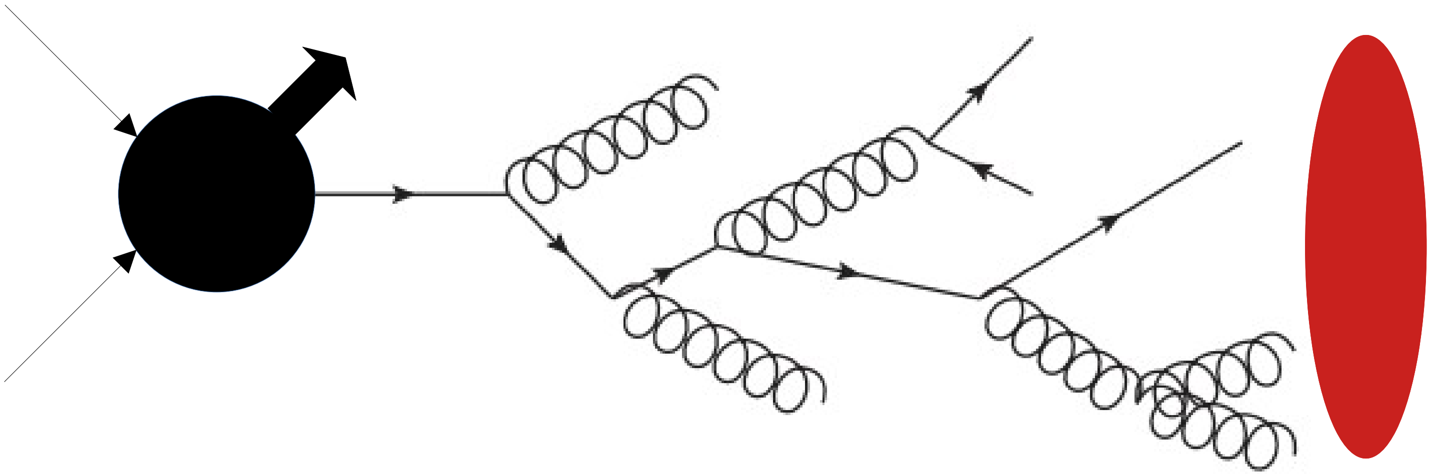


Massive treatment of quark

- Mass acts as IR regulator → no IR divergences from collinear splitting
- Price to pay: log(pT/m), how to treat PDFs (high Q^2 process due to V-boson)?
  → Resummation for reliable predictions
  → mostly limited to parton-showers (state-of-the-art: NLO+PS) or FONLL (needs also massless)
- Higher order calculations more difficult
- Some applications (like PDF fits) need fixed-order QCD at higher orders

Quick introduction: heavy flavour production (theory perspective)



High transverse momentum → massless quarks

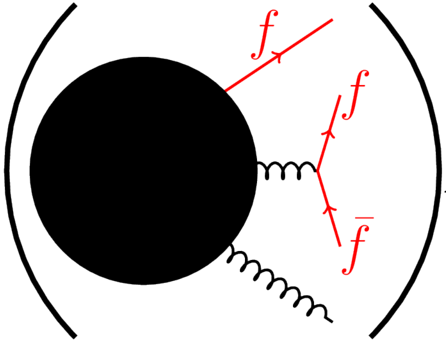
- Consistent treatment with PDFs (high Q^2 → c/b quarks in DGLAP)
- Bonus: higher order calculations easier → NNLO QCD
- BUT: IR-safety more demanding due to collinear and soft flavoured particles
  → here the flavour algorithms come into the game
- This IR-safety issue → IR-sensitivity in massive and showered case

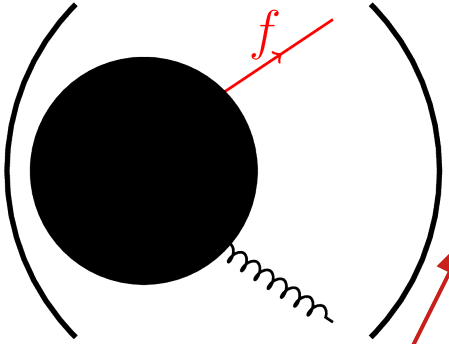
The IR-safety issue

Example NNLO:

Double real matrix element

Double soft subtraction term:
Double soft function * tree ME

$d\sigma \ni d\Phi_{n+2}$ 

$F_{n+2} + \cdots + d\tilde{\Phi}_{n+2}\mathcal{S}_2$ 

F_n

Flavour structure depends on the angular configuration

IR safety:
Have to match in double soft limit

Fixed flavour structure

- If F(n+2) does not treat the flavour pair appropriately:
  → double soft singularity not subtracted

➔ Implies correlated treatment of kinematics and flavour information

Infrared safe definition of jet flavor,
Banfi, Salam, Zanderighi hep-ph/0601139

The CMP algorithm

Infrared-safe flavoured anti-kT jets,
Czakon, Mitov, Poncelet 2205.11879

anti-kT: $d_{ij} = \min(k_{T,i}^{-2}, k_{T,j}^{-2}) R_{ij}^2 \qquad d_i = k_{T,i}^{-2}$

Proposed modification:

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

$$d_{ij}^{(F)} = d_{ij} \begin{cases} \mathcal{S}_{ij} & \text{i,j is flavoured pair} \\ 1 & \text{else} \end{cases} \qquad \text{where} \quad \mathcal{S}_{ij} \to 0 \quad \text{if } i,j \text{ are soft}$$

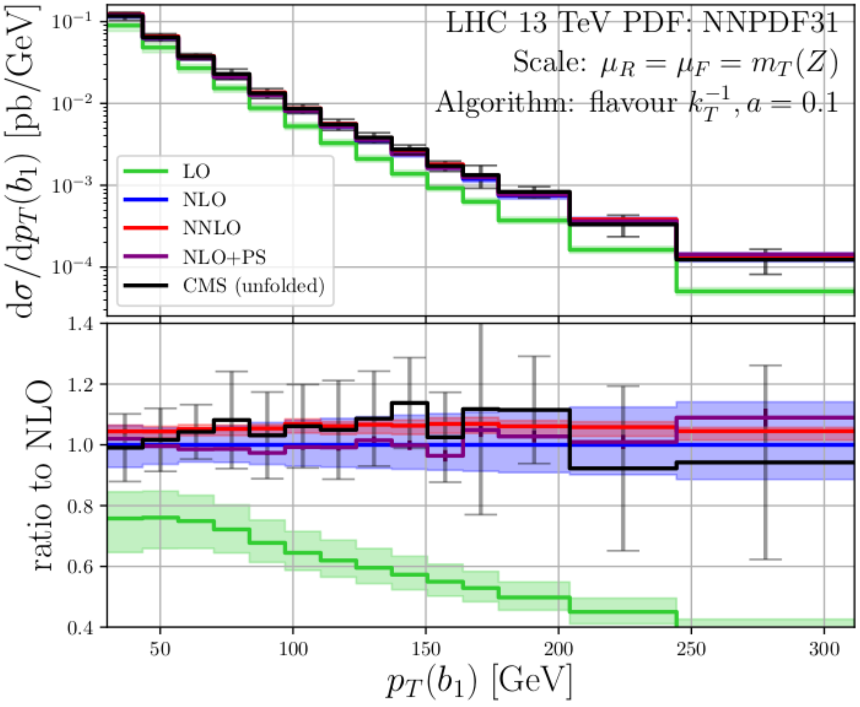
Original proposal: $\mathcal{S}_{ij} \equiv 1 - \theta\left(1 - \kappa_{ij}\right) \cos\left(\frac{\pi}{2}\kappa_{ij}\right) \quad \text{with} \quad \kappa_{ij} \equiv \frac{1}{a} \frac{k_{T,i}^2 + k_{T,j}^2}{2k_{T,\max}^2}\,.$

Issue when $E_i, E_j \gg 1 \quad \text{but} \quad p_{T,i}, p_{T,j} \ll 1$

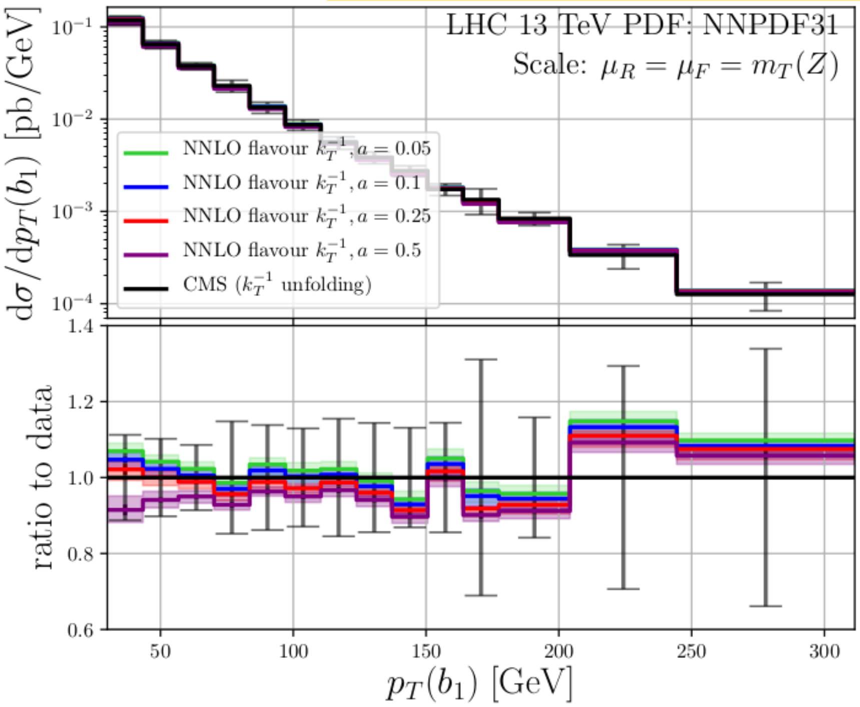
Variant IFN paper [2306.07314]

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

Z + bottom



Infrared-safe flavoured anti-kT jets,
Czakon, Mitov, Poncelet 2205.11879



MC-corrections based on NLO+PS

CMS data [1611.06507]

W + charm: collaboration with CMS

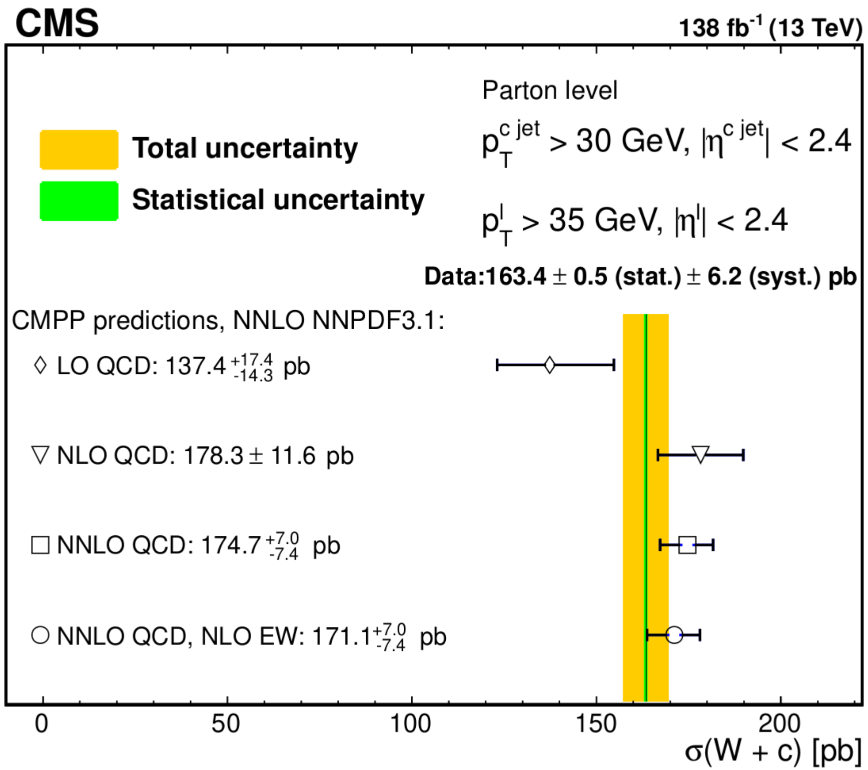
Measurement of the production cross section for a W boson in association with a charm quark in proton-proton collisions at Sqrt(s) = 13 TeV
CMS 2308.02285

Measurement of OS – SS cross-section unfolded to parton-level (anti-kT algorithm)

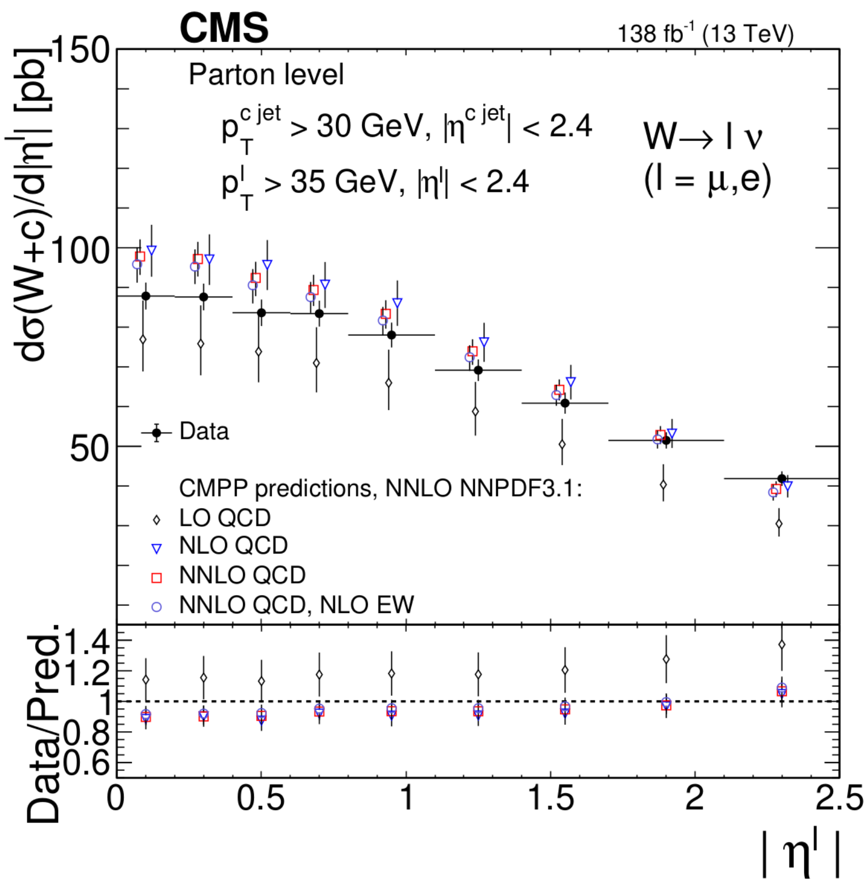
→ hadronisation and fragmentation corr. ~ 10%

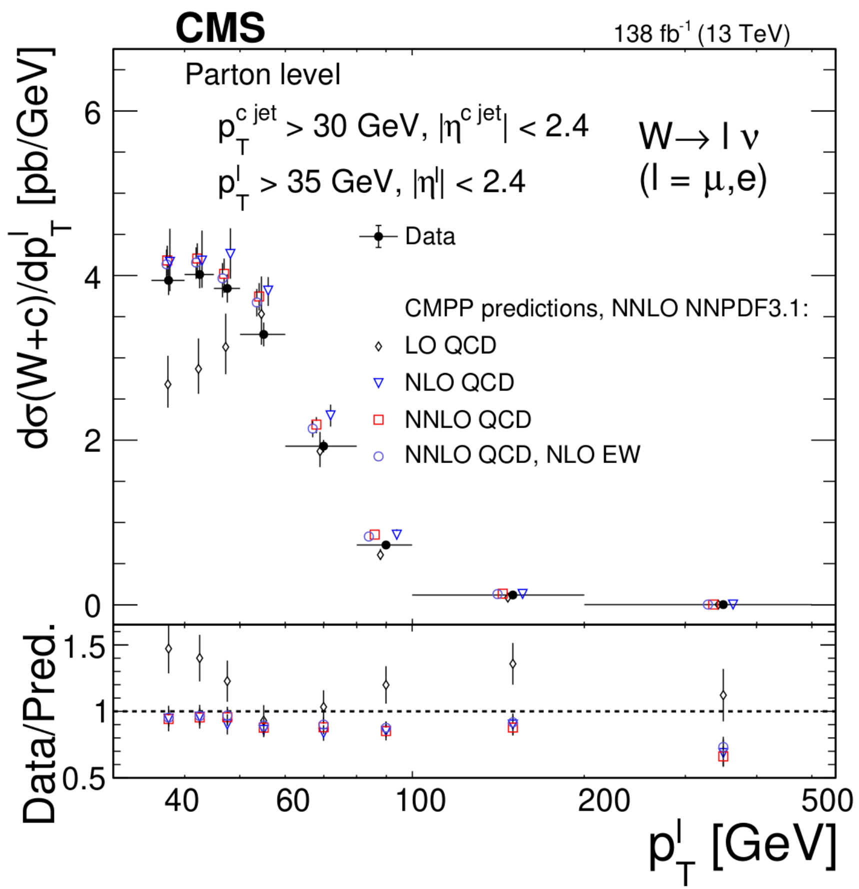
+ anti-kT → flv. Anti-kT correction on fixed-order

Not ideal but a full flv. Anti-kT unfolding was not feasible at that time…



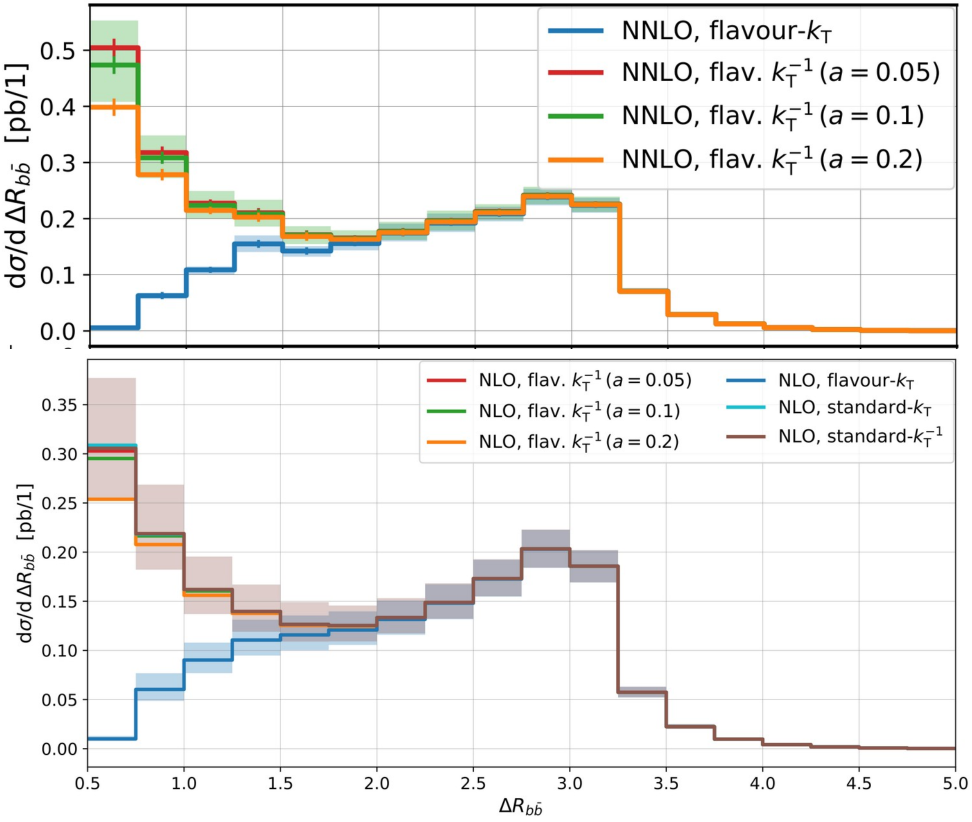
W + charm: collaboration with CMS

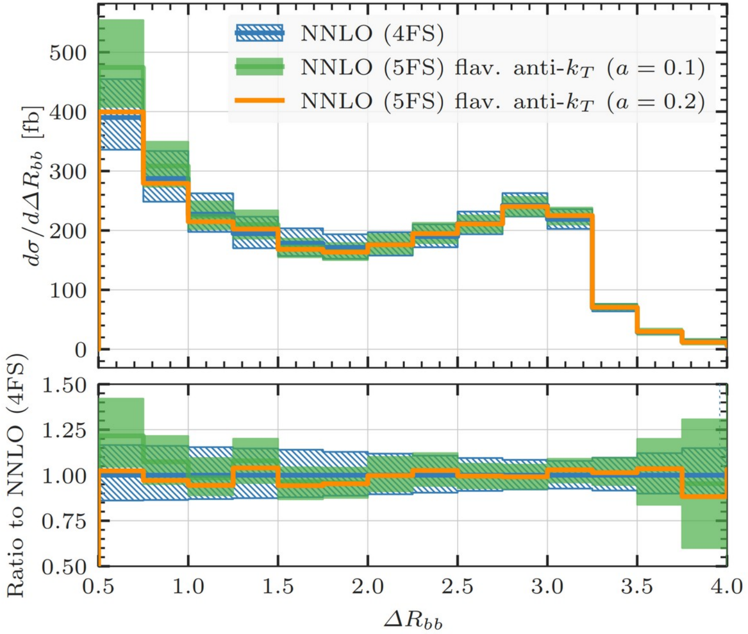




W + bottom pair: $pp \to Wb\bar{b} + X$

Flavour anti-kT algorithm applied to Wbb production at the LHC
Hartanto, **Poncelet**, Popescu, Zoia 2209.03280



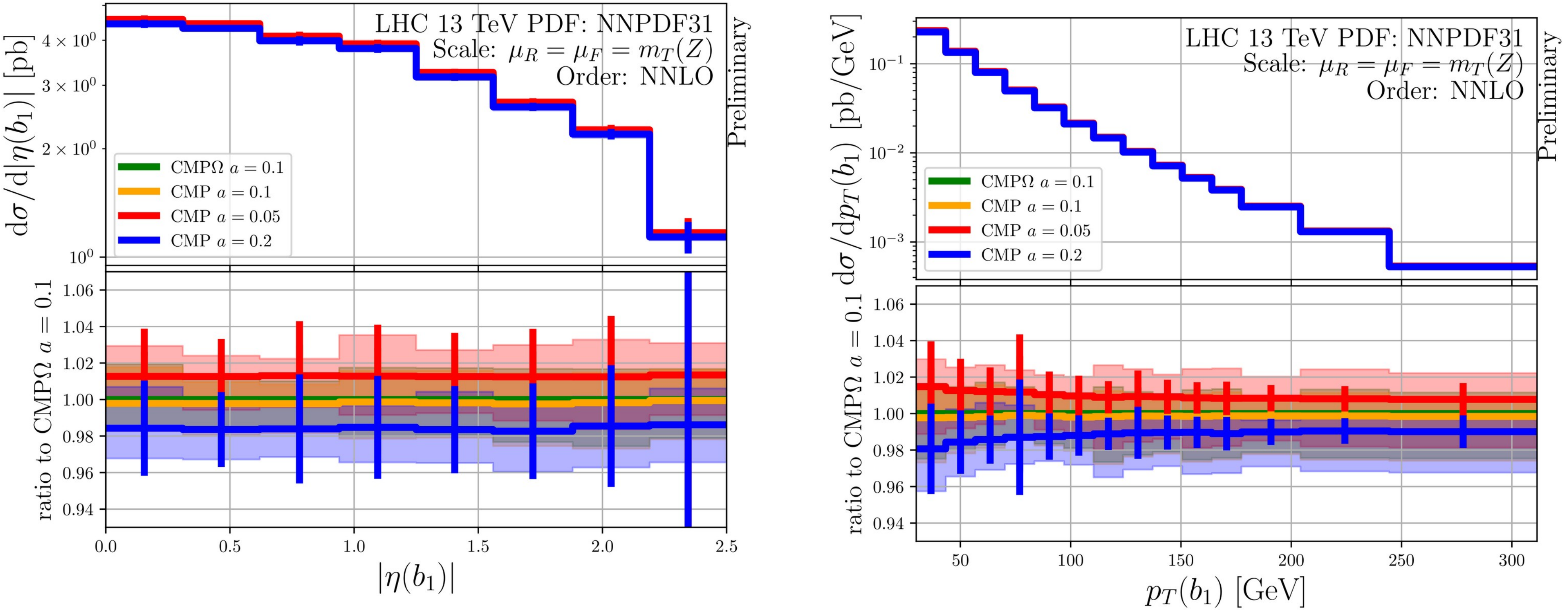


4 FS vs. 5 FS [Buonocore 2212.04954]
→ CMP and anti-kT close

Differences to CMPΩ

Calculations performed with sector-improved residue subtraction scheme
1408.2500 & 1907.12911

Les Houches Jet Flavour WG



Negligible difference between CMPΩ and CMP at NNLO

Take home message

- What we want: define an observable (a flavoured jet definition) that
  → can be predicted in an accurate and precise way (needed for interpretation)
  → well behaving under higher-order corrections, i.e. multiple emissions
  → can be implemented in a experimental analysis and is measurable

- Theory solutions to IR-safety/sensitivity rely on “flavoured” algorithms
  → Need detailed flavour information, difficult to implement them directly in exp.
  → My view: some sort of Monte Carlo based correction needed
  → Les Houches effort to systematise the study of these effects

- CMP(Ω) provides a solution in terms of a modified clustering sequence
  → logically a simple extension of the anti-kT
  → small kinematic differences to anti-kT