ACCURATE SNAPSHOTS OF COLLIDER EVENTS

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- The Large Hadron Collider (LHC) has not yet found **any direct signal of New Physics** beyond the Standard Model.
- New Physics searches proceed by looking for **tiny deviations** in Standard Model processes, and require **accurate theoretical predictions.**
- Collisions at the LHC are governed by **Quantum Chromodynamics** (**QCD**), the theory of quarks and gluons (partons).
- An accurate description of **collider events** requires a profound understanding of QCD across **a wide range of energy scales and kinematic domains.** We can recognise the following main stages:
  A. **Hard scattering interaction**
  B. **Multi-scale evolution and parton branching**
  C. **Hadronisation and detection**

A.

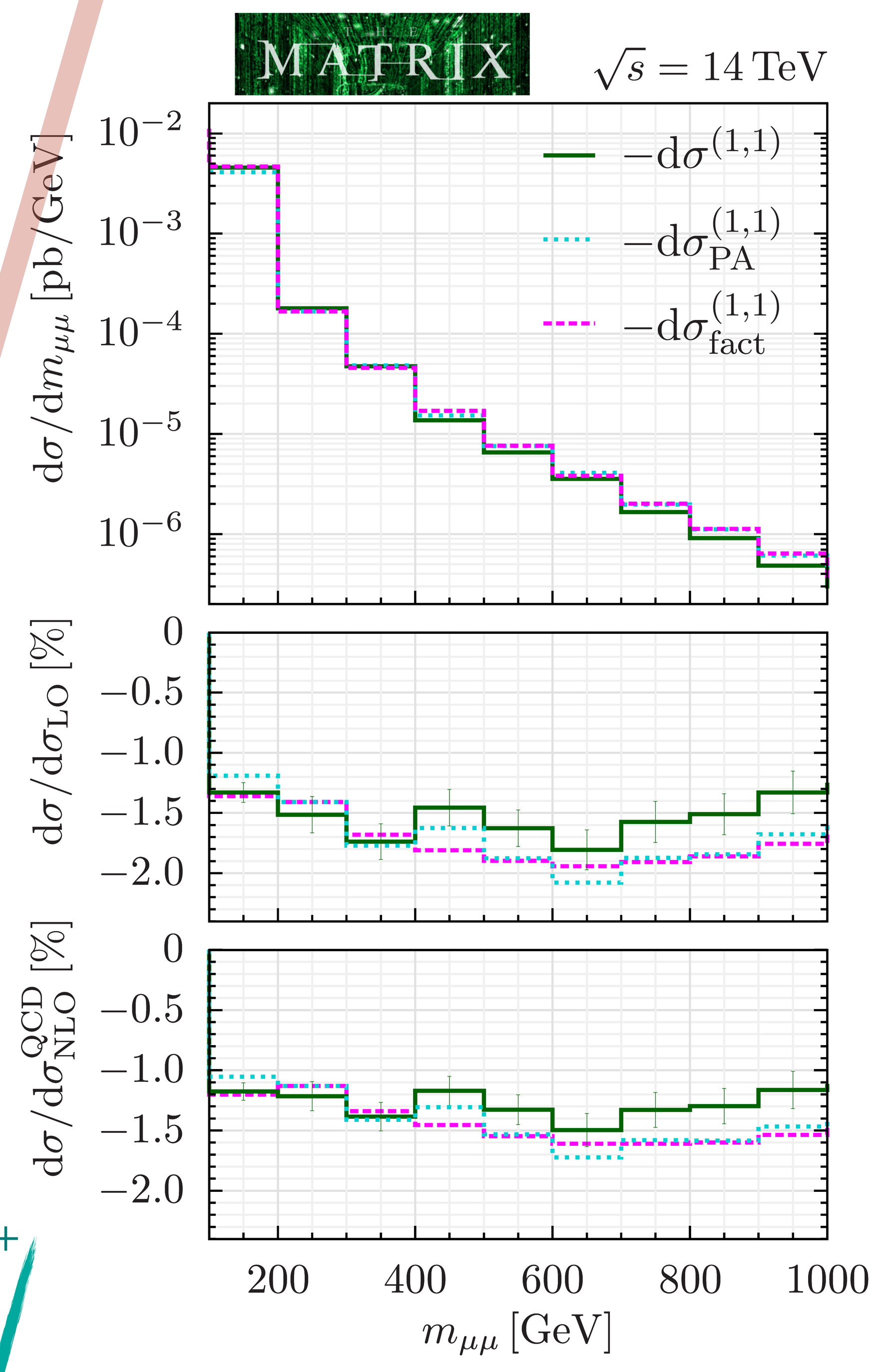
The theoretical modelling of a collider event starts from the **hard collision**, happening at energy scale $Q \sim$ 100-1000 GeV. The hard collision is well described by **fixed-order perturbation theory.** The number of collected events is proportional to the cross section σ, which can be computed as

$$\sigma = \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \hat{\sigma}_{ab}(\hat{s}, \mu_R) + \mathcal{O}((\Lambda/Q)^p)$$

f_a and f_b are called **parton distribution functions** and contain information about the structure of the **protons**. $\hat{\sigma}_{ab}$ is the **partonic cross section**, which can be computed perturbatively up to corrections $(\Lambda/Q)^p$, with $\Lambda \sim 1$ GeV.

To match the precision of the experimental data, it is necessary to compute enough terms in the expansion. In the **Drell-Yan lepton pair production**, the precision of the data is so high that it is necessary to take into account also the effect of the **electroweak** (**EW**) interaction and its interplay with QCD.

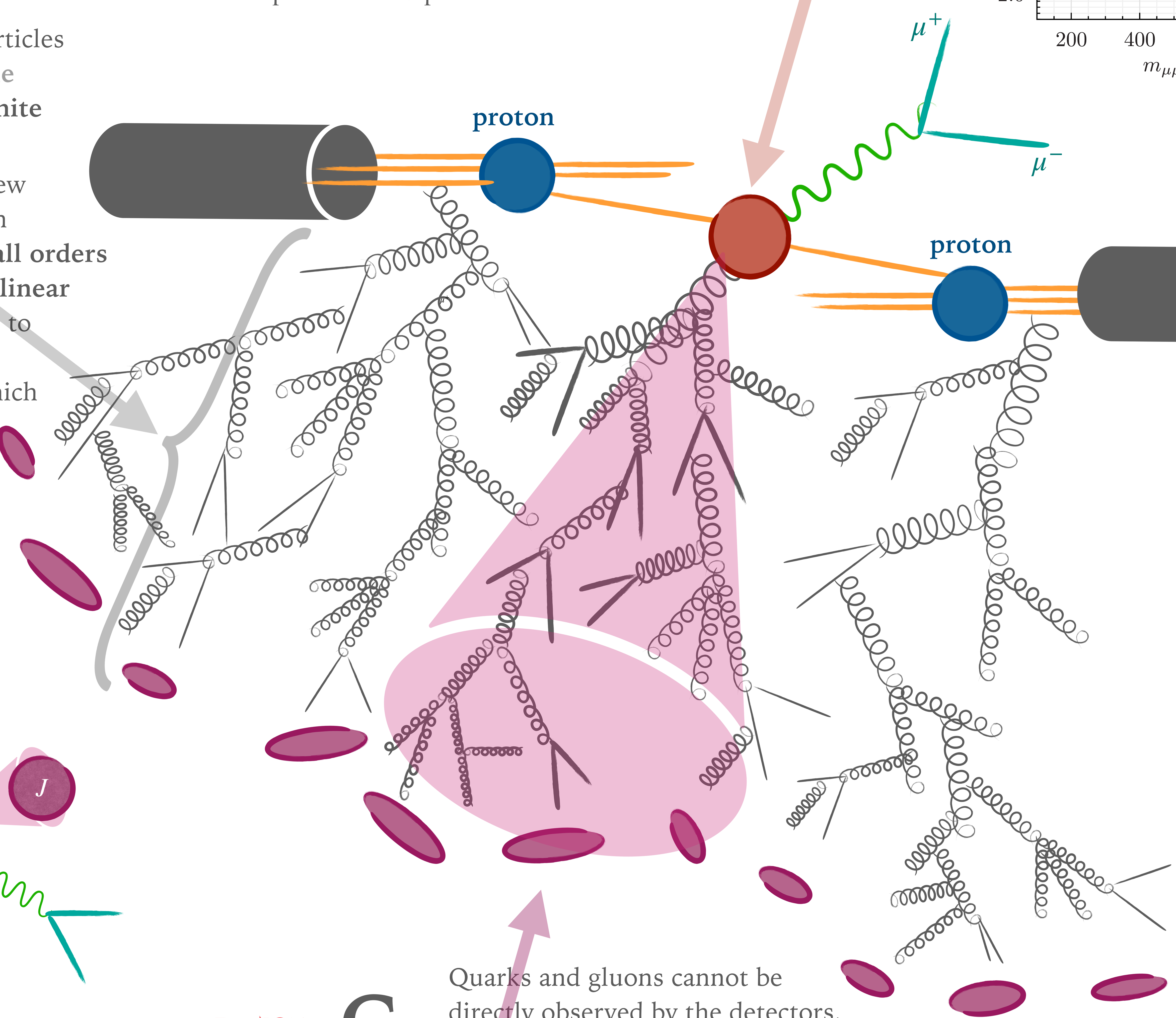
Our group has computed for the first time the **exact mixed QCD-EW corrections** for Drell-Yan production, allowing for a very precise description of various kinematic distributions for this important LHC process.

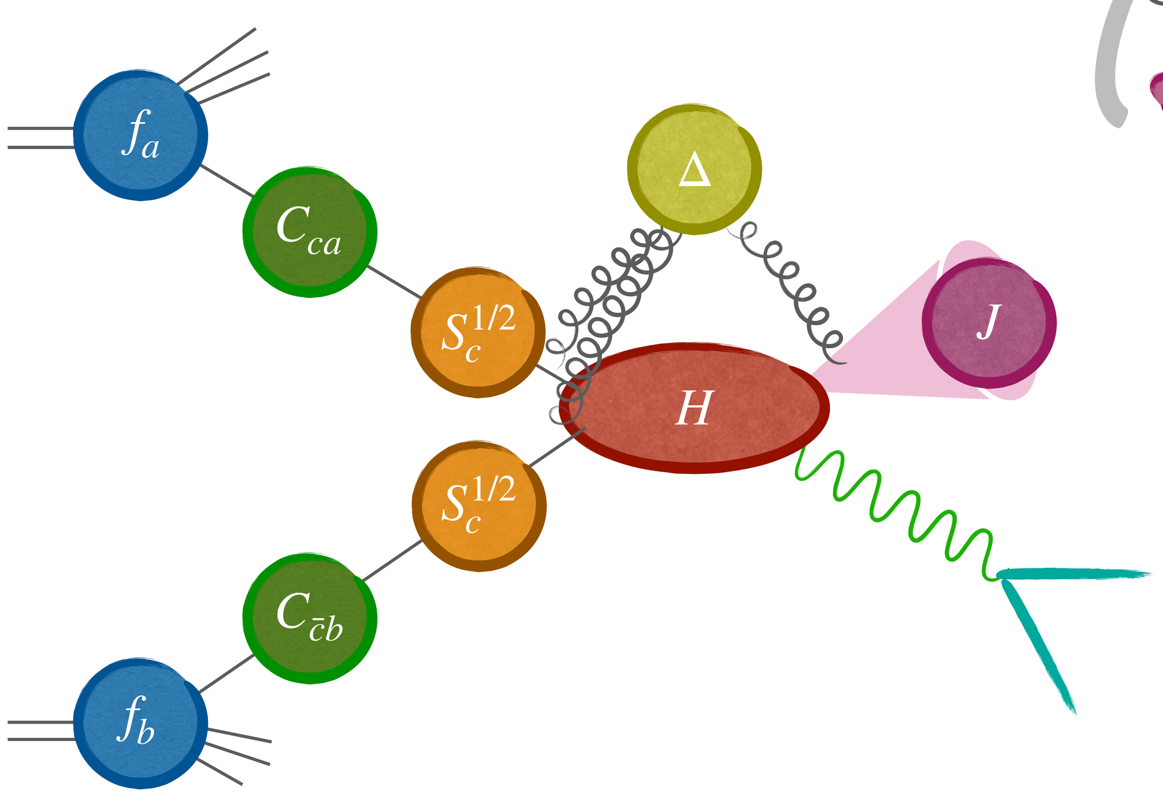


B.

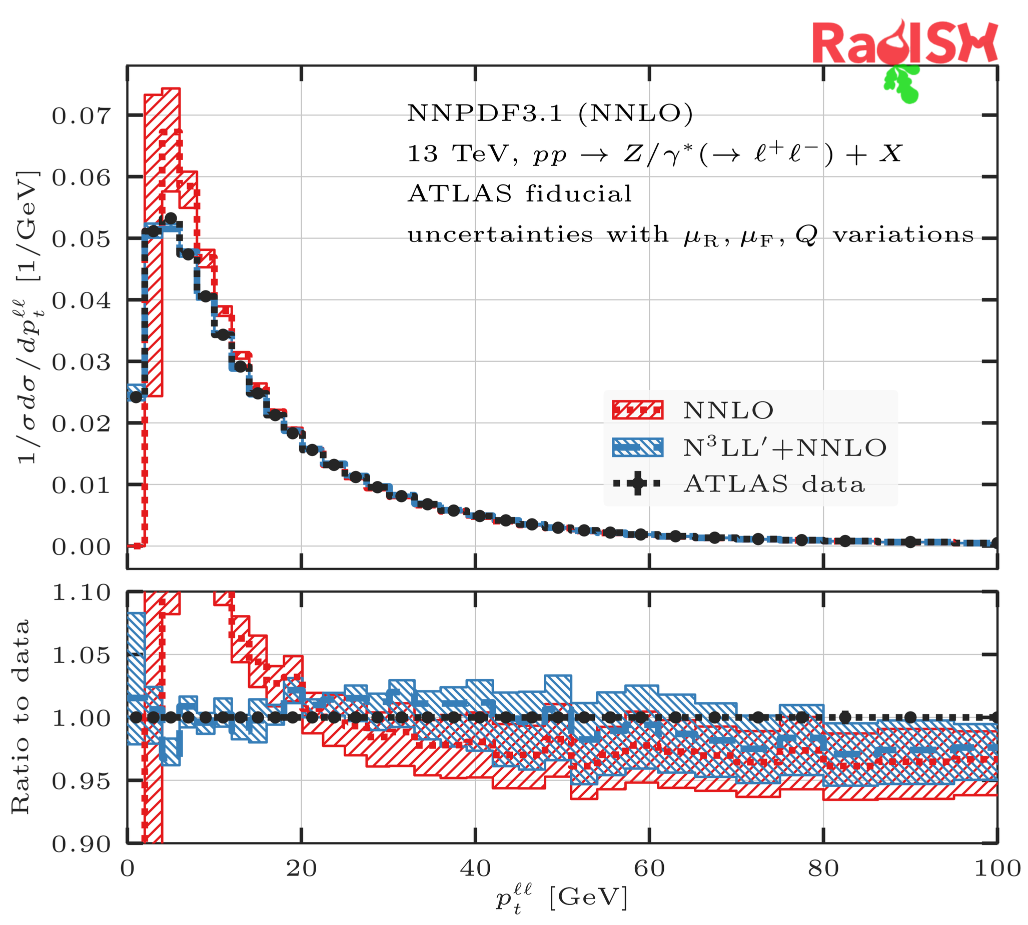
After the hard collision, the particles produced undergo a multi-scale evolution described by an **infinite number of emissions**.

An exact treatment is possible only for few emissions. We can describe the evolution accurately by considering **emissions at all orders** in some approximation (**soft and/or collinear regimes**). Two main frameworks help us to characterise the multiscale evolution: analytical **resummation techniques**, which guarantee a high level of accuracy in the theoretical predictions, and **parton shower event generators**, all-purpose tools capable to describe in principle every observable.



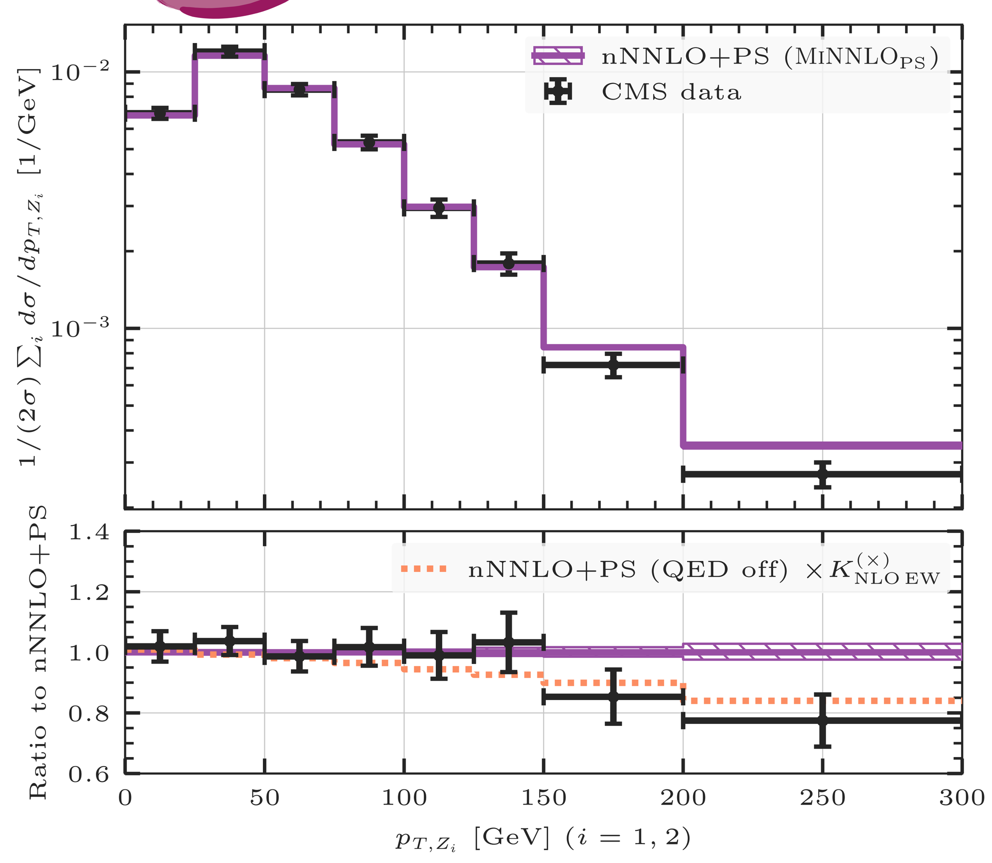


Our group is active in the development of both these frameworks. We have recently produced predictions at the highest available accuracy for the **transverse momentum spectrum** of the Z boson at the LHC, and we are now investigating processes involving **jets** (collimated bunches of quarks and gluons).



C.

Quarks and gluons cannot be directly observed by the detectors. When the multi-scale evolution reaches scales of $\Lambda \sim 1$ GeV, partons form colourless bound states called **hadrons** via the **hadronisation** process. Parton shower event generators are capable to model hadronisation and allow for a complete description of the whole event. In a recent study we considered the production of a pair of Z bosons. We combined the best fixed order predictions available for this process with parton showers and compared our results to LHC data.



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