Precision Physics at colliders

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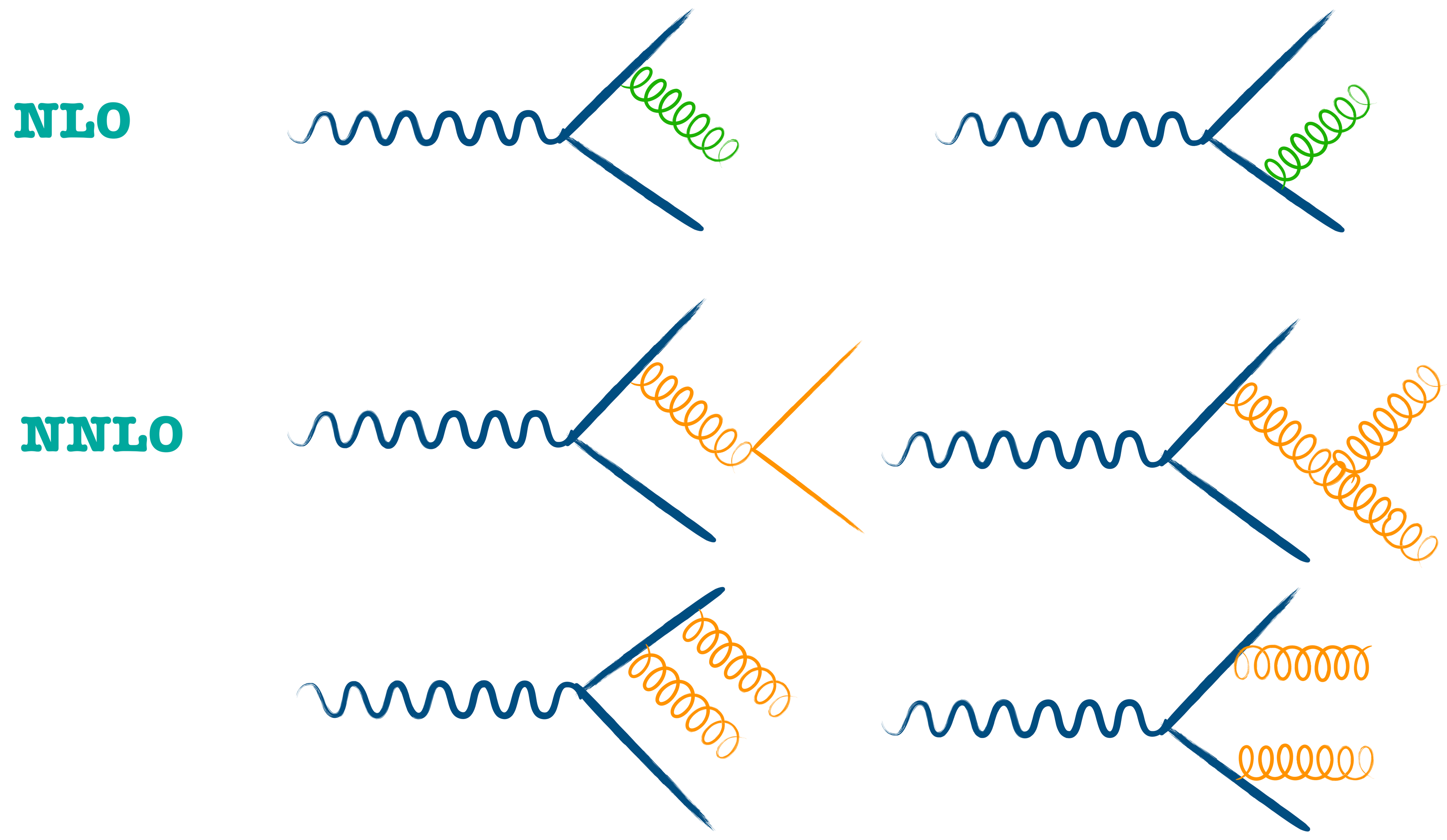
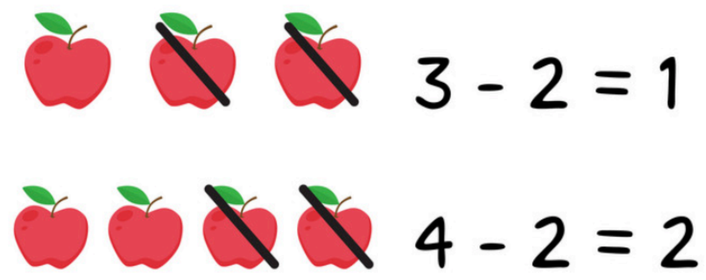
- Experiments performed at CERN Large Hadron Collider (LHC) are collecting a huge amount of data.
- The Standard Model of particle physics and in particular Quantum Chromodynamics (QCD) are the theoretical frameworks that describe LHC physics.
- We need very precise calculations of cross sections to compare theory predictions with experimental data! New physics could manifest as a small deviation from Standard Model predictions.
- Cross sections are computed using perturbation theory, i.e. as a truncated series in the QCD coupling constant α_s: $\sigma = \sigma^{(0)} + \alpha_s \sigma^{(1)} + \alpha_s^2 \sigma^{(2)} + \ldots$, where $\sigma^{(0)}$ is called Leading Order (LO) contribution, $\sigma^{(1)}$ Next-to-Leading Order (NLO), $\sigma^{(2)}$ is called Next-to-Next-to-Leading Order (NNLO).
- The inclusion of higher-order terms is mandatory to improve the accuracy of the theoretical predictions, even if their computation is a very challenging task. Our group works on the formulation of techniques to compute higher-order corrections. We implement our methods in numerical codes to obtain quantitative predictions for the most relevant LHC processes.



SUBTRACTION SCHEME

- When computing NLO and NNLO corrections, in the intermediate steps of the calculation, phase space integrals of scattering amplitudes involving extra real radiation appear. These amplitudes suffer from **infrared (IR) singularities**.



When combining the contributions coming from real and virtual diagrams, the final result is finite in $d = 4$ space-time dimensions. However, each separate integral is still divergent. Since the phase-space integrals are too complicated to be computed analytically, we need a **subtraction scheme** to reorganize IR divergences among all the contributions and obtain finite integrals in 4 dimensions that can be computed using Monte Carlo methods. We work in particular on the development of **slicing methods**:

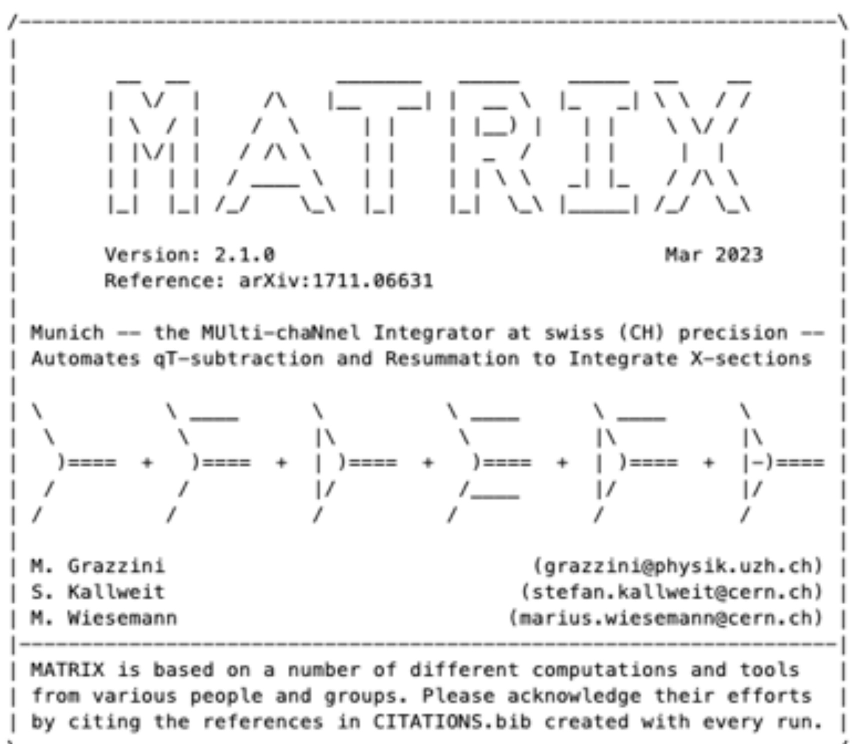
$$\sigma_R = \int_0^{r_{\mathrm{cut}}} d\Phi_R |\mathcal{M}_R|^2 + \int_{r_{\mathrm{cut}}} d\Phi_R |\mathcal{M}_R|^2$$

Computed analytically, using IR limits of matrix elements

Computed numerically, using Monte-Carlo methods

HEAVY-QUARK PAIR PLUS BOSON PRODUCTION

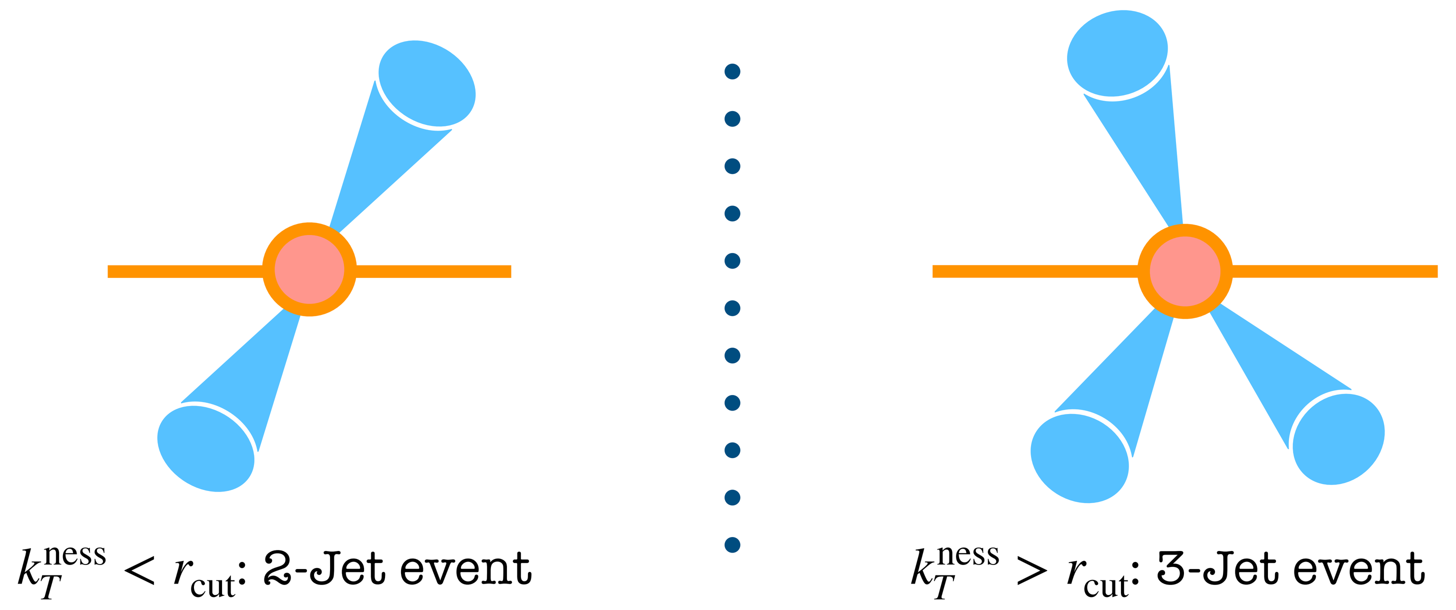
- Among the various scattering processes we are particularly interested in the production of heavy quarks accompanied by vector or Higgs bosons. These calculations are performed using the q_T subtraction formalism.
- One of the most interesting result achieved by our group is given by the **first computation** of NNLO QCD corrections to inclusive cross section for the hadroproduction of $t\bar{t}W$. This high level of precision can be exploited to perform even more rigorous **tests of the Standard Model!**



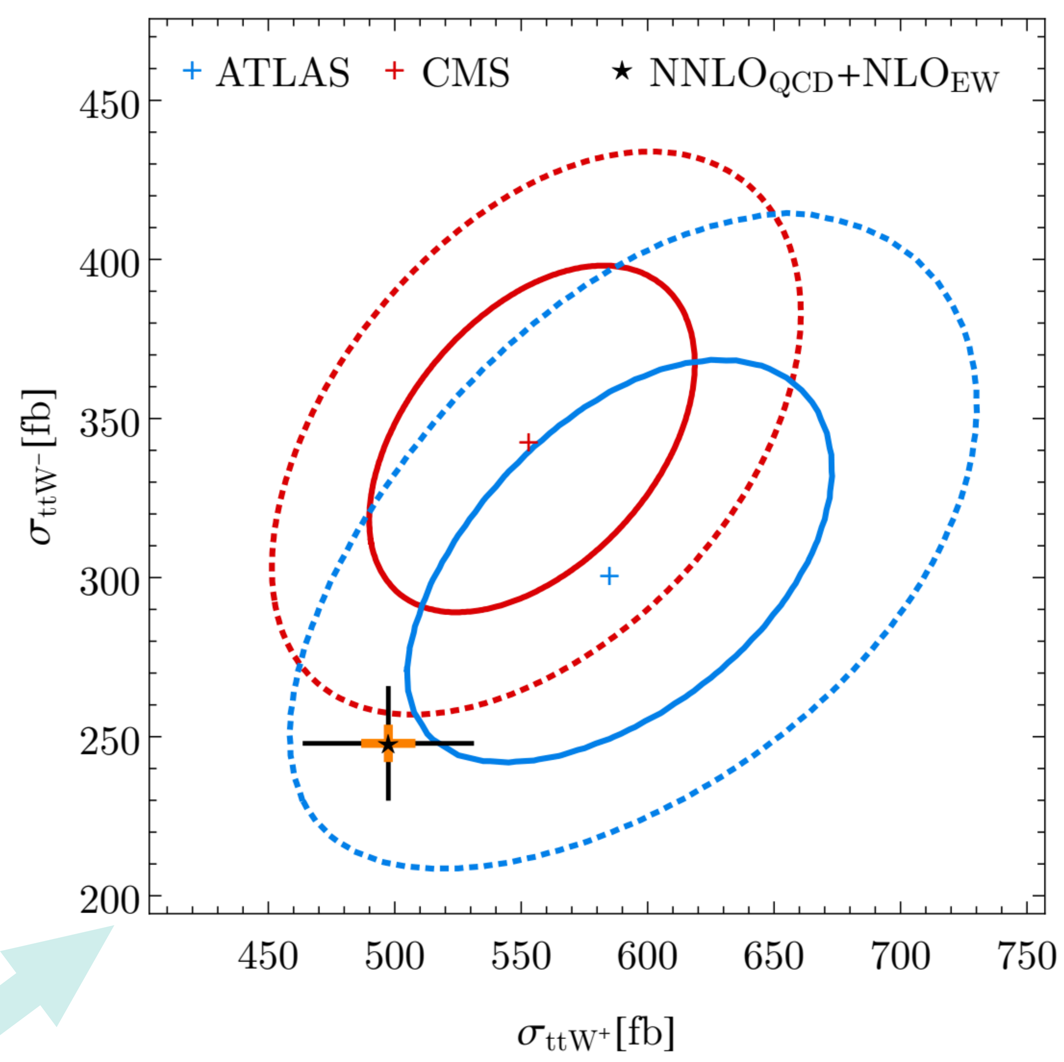
- The main bottleneck is represented by the computation of the two-loop amplitudes contributing to these processes. For this reason, we are developing techniques to approximate this class of amplitudes. These computations are implemented in the MATRIX framework.

JET PHYSICS

- Jets are collimated bunches of hadrons that represent the fingerprints of the partons produced in the hard scattering process. Jets are ubiquitous at colliders! In order to implement a slicing scheme for jet processes, we need to define a **jet resolution variable**, i.e. a kinematic variable able to distinguish among configurations with different numbers of jets. Our favorite variable is called k_T^{ness}!



- We developed a slicing scheme based on k_T^{ness} at NLO and we are working on its extension at NNLO, focusing on e^+e^- collisions.
- k_t^{ness} is a promising variable to be used for Monte Carlo generators, since it is very stable with respect to hadronization and multiple-parton interactions effects. This opens new opportunities for QCD studies in multijet production.



Fixed order calculations are not the end of the story, since a realistic LHC event cannot be described using a finite number of emissions. It is possible to model QCD dynamics at all orders using some approximations in soft and collinear limits. **Analytical resummation** and **parton showers** are very effective frameworks to perform all-order QCD analyses.

Join our group for bachelor and master thesis projects!