PRECISION SIMULATIONS FOR COLLIDER PHYSICS

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The Large Hadron Collider (LHC) has not yet found **any direct signal of New Physics** beyond the Standard Model. Present New Physics searches require **accurate theoretical predictions**. Collisions at the LHC are governed by **Quantum Chromodynamics** (**QCD**), the theory of quarks and gluons.
The theoretical modelling of a collider event starts from the **hard collision,** which is well described by **fixed-order perturbation theory**.
Nowadays, at least 2nd order (NNLO) QCD plus 1st order (NLO) EW is required for most relevant processes to match the (expected) experimental precision.
Our group has recently focused on developing subtraction methods to achieve NNLO accurate predictions and approximations for two-loop amplitudes.

Fighting IR singularities: q_T-subtraction and beyond

Basic idea: split the phase space into a resolved part above a cut on the transverse momentum of the final state and an unresolved part below it.
The final, finite NNLO prediction for the cross section is then constructed from the sum of these two parts, up to power corrections in the cut:

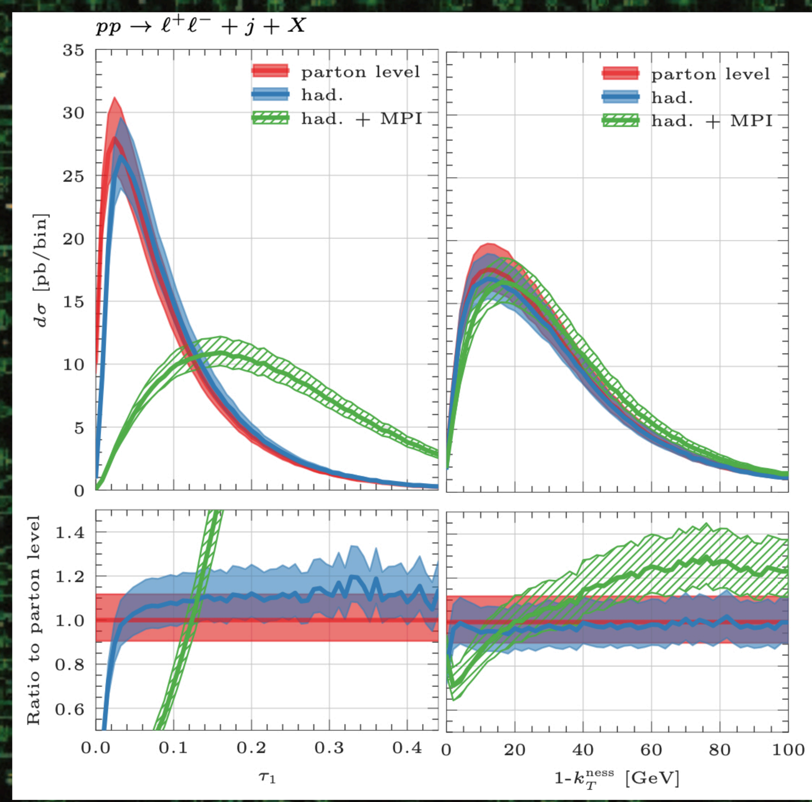
$$d\sigma_{N^kLO} = \mathcal{H}_{N^kLO} \otimes d\sigma_{LO} + \left[d\sigma^R_{N^{k-1}LO} - d\sigma^{CT}_{N^kLO}\right]_{q_T > q_T^{cut}} + \mathcal{O}\left[\left(q_T^{cut}\right)^p\right]$$

Main features of q_T-subtraction:

- Born to deal with colourless final-state systems (see di- and triboson production below)
- Extension to (associated) heavy-quark pair production: only additional soft divergences (see $t\bar{t}H$ below)
- Not restricted to QCD corrections: mixed NNLO QCD-EW corrections to Drell-Yan processes (with massive leptons)

Jets are collimated bunches of hadrons, the fingerprints of the partons produced in the hard scattering and ubiquitous at colliders! A **slicing scheme** for jet processes requires a kinematic variable able to distinguish among configurations with different numbers of jets. Our favorite choice is called k_T^{ness}.

- k_T^{ness} is very stable with respect to hadronization and multiple-parton interactions effects.
- We have developed a **slicing scheme** based on k_T^{ness} for hadronic collisions at NLO, and we are working on its extension towards NNLO, starting with e^+e^- collisions.



We have implemented the ingredients to have all variants of the q_T-subtraction method available in an automated form in the framework

MATRIX

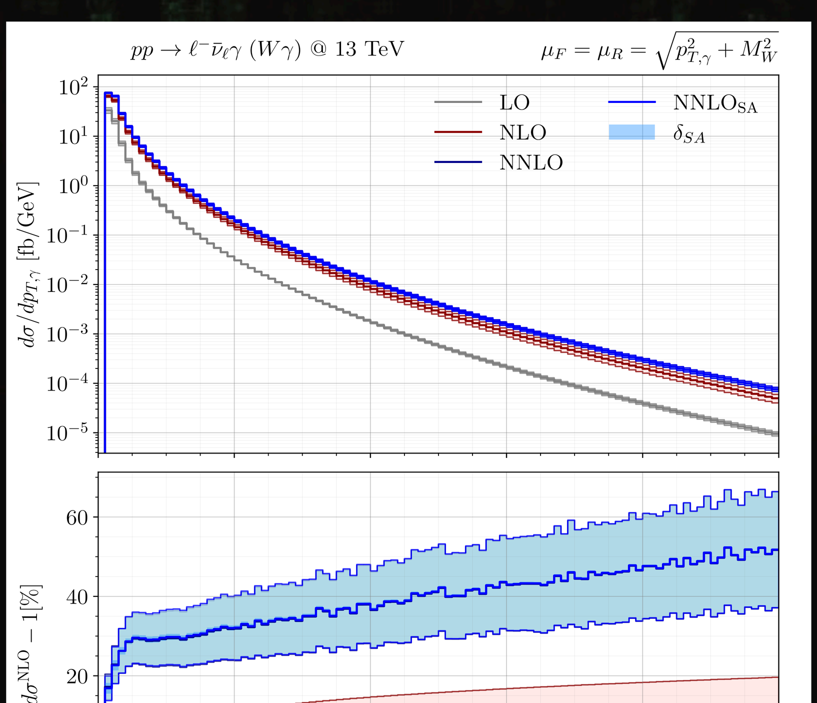
MUlti-chaNnel Integrator at Swiss (CH) precision

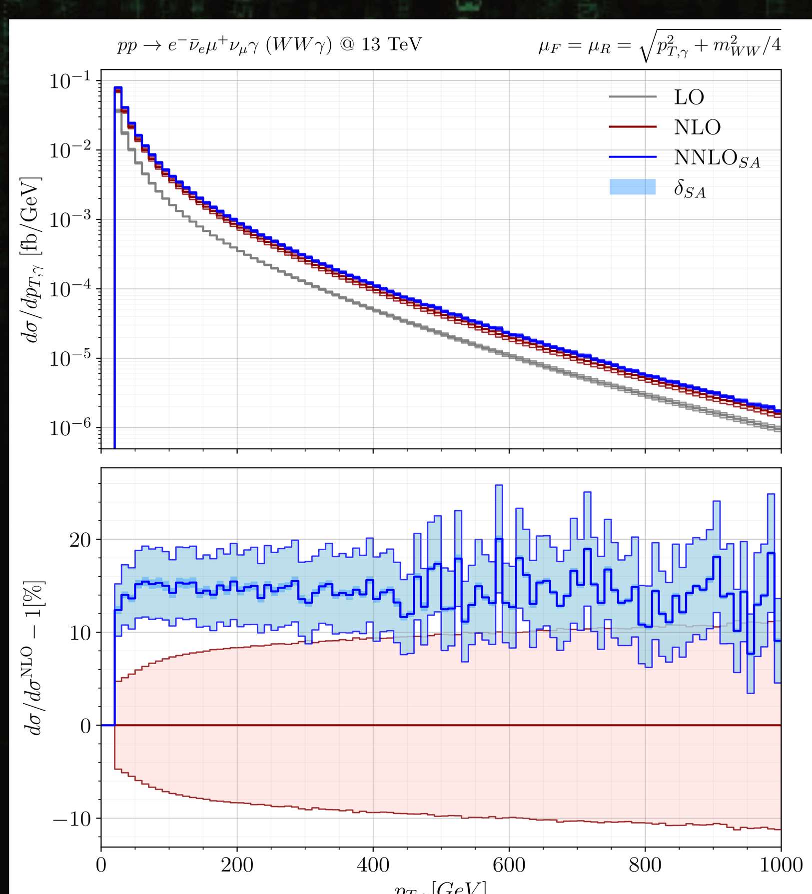
MUNICH Automates qT-subtraction and Resummation to Integrate X-section

Two-loop amplitudes: exact vs. approximate

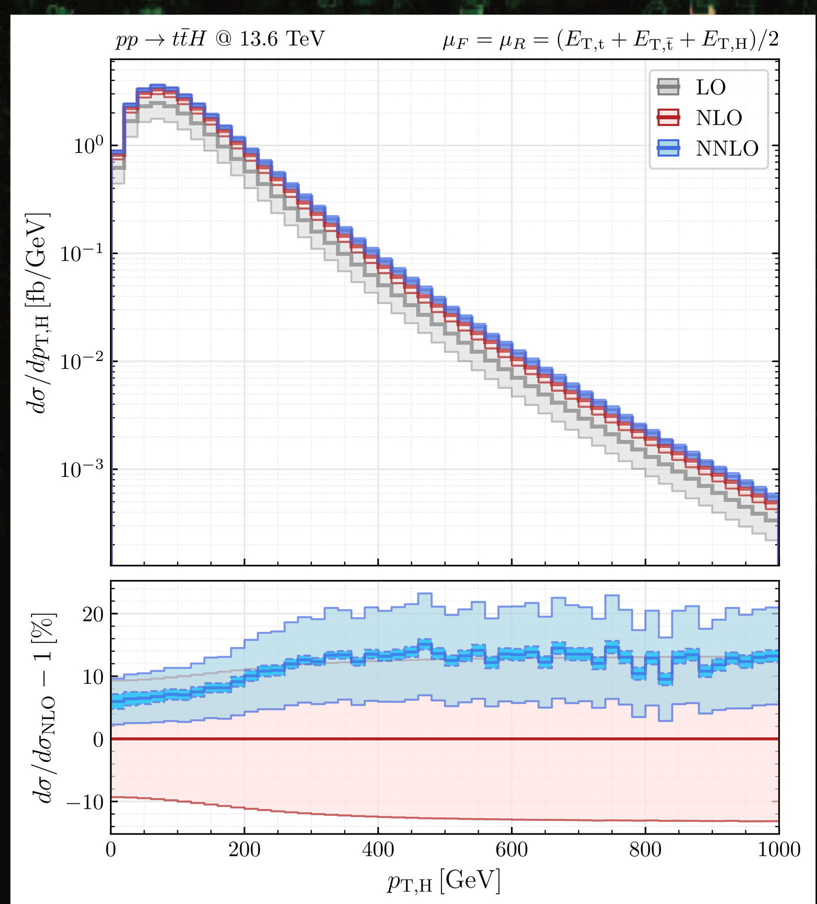
- Soft-photon approximation (SPA): We can approximate the full two-loop amplitudes by those without the photon, restoring it through a soft factor, exact in the soft-photon limit. A re-weighting procedure extends the validity range.

$W\gamma$: exact amplitudes available, used to validate the SPA and to construct a good error estimate of the approximation.

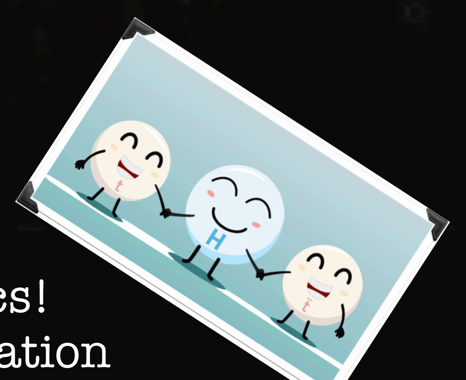




$WW\gamma$: important to study the boson couplings in the EW sector! We rely on the SPA since exact 2-loop amplitudes are unknown. The approximation error is clearly subdominant and under control!

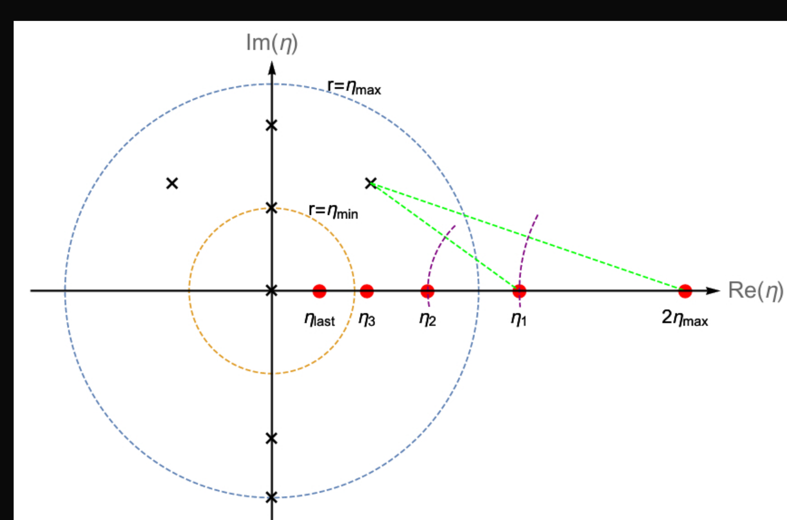


- Soft-boson approximation: same idea as the SPA, but for a massive boson: valid only for a soft (and massless) Higgs!
- Massification approach: valid in the ultra-relativistic limit, where the top mass can be neglected. Also here a re-weighting is applied to extend the validity range.



$t\bar{t}H$: very important to study the top quark, the Higgs sector and New Physics! Soft-Higgs approximation and massification approach give predictions in very good agreement.

What about exact amplitudes? We are now approaching them through a very powerful tool: Auxiliary-Mass-Flow!
This method exploits the property that Feynman Integrals (FIs) simplify to vacuum integrals when the auxiliary mass η introduced in the propagators approaches infinity. This, plus the use of numerical differential equations, reduces the computation of FIs to pure linear algebra, allowing us to potentially probe high-energy Physics at an unprecedented depth!



This is your last chance. After this, there is no turning back. You take the blue pill - the story ends, you wake up in your bed and believe whatever you want to believe. You take the red pill - you stay in Wonderland and I show you how deep the rabbit hole goes.