Loopfest XXII

Monday, 20 May 2024 - Wednesday, 22 May 2024

Dallas Texas USA

Book of Abstracts

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Heavy Quark Production at High Precision in xFitter

Author: Fred Olness[1]

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We review improvements in precision heavy quark production including updates in the xFitter global analysis framework, and extensions of ACOT using fast grid techniques.

Session 2 / 3

GRIFFIN: A C++ library for higher-order electroweak corrections

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This talk describes a modular framework for the description of electroweak scattering and decay processes, including but not limited to Z-resonance physics. The framework consistently combines a complex-pole expansion near a s-channel resonance with a regular fixed-order perturbative description away from the resonance, in a manifestly gauge-invariant scheme. This framework has been implemented in the publicly available object-oriented C++ library GRIFFIN, with full NNLO and leading higher-order contributions on the Z-resonance, and with NLO corrections off resonance. The library can straightforwardly be extended to include higher-order corrections, should they become available, or predictions for new physics models. It can be interfaced with Monte-Carlo programs to account for QED and QCD initial-state and final-state radiation.

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Five Parton Scattering at Two Loops

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We compute the two-loop helicity amplitudes for the scattering of five partons, including all contributions beyond the leading-color approximation. The analytic expressions are represented as linear combinations of transcendental functions with rational coefficients, which we reconstruct from finite-field samples obtained with the numerical unitarity method. Guided by the requirement of removing unphysical singularities, we find a remarkably compact generating set of rational coefficients, which we are able to display entirely on a few pages. Such results call for further investigations in analytic properties of multi-loop multi-scale scattering amplitudes with the goal to simplify computations and to optimise final results for phenomenological applications.

Session 1 / 5

Top-Bottom Interference Contribution to Fully-Inclusive Higgs Production

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The impact of finite bottom-quark mass effects at next-to-next-to-leading order constitutes one of the leading theory uncertainties of the Higgs production cross section.
In this talk, I will present our evaluation of this contribution. We computed the relevant two-loop master integrals that enter the real-virtual contribution numerically using the method of differential equations. In addition, the Higgs-gluon form factor at three loops in QCD with two different massive quark flavours has been included. Furthermore, I will discuss the impact of the choice of renormalisation scheme.

Session 1 / 6

Combining NNLO QCD corrections with parton showers for Higgs production in bottom-quark fusion

Authors: Aparna Sankar[None]; Christian Biello[1]; Giulia Zanderighi[1]; Marius Wiesemann[1]

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With the growing precision of experimental measurements, combining fixed-order perturbative calculations with parton-shower effects becomes essential for an accurate description of LHC phenomenology. In this talk, we focus on the computation of Higgs production via bottom-quark annihilation ($b\bar{b}H$) at next-to-next-to-leading order (NNLO) in QCD perturbation theory, consistently matched with parton showers (NNLO+PS) using the MiNNLOPS technique. We extend the MiNNLOPS framework to accommodate a scale-dependent Yukawa coupling renormalized in the $\overline{\text{MS}}$ scheme. Given the flexibility in schemes for the $b\bar{b}H$ process calculation, where the bottom quark can be treated as massless or massive at the LHC production scale, we explore both the five-flavour scheme (5FS) with massless bottom quarks and the four-flavour scheme (4FS) incorporating massive bottom quarks. In the 4FS computation, we employ the MiNNLOPS method tailored for the QQF scenario, featuring a heavy quark (Q) and a color singlet final state (F).

Session 1 / 7

A first look at two-loop master integrals for ttH

Author: Manfred Kraus[1]

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I will present our recent computation of the first set of two-loop master integrals for the top-quark pair production in association with a Higgs boson. Exploiting numerical evaluations in modular arithmetic, we construct a basis of master integrals satisfying a system of differential equations in ϵ-factorized form. We discuss the analytical structure of the differential equations and their solutions. Finally, we also discuss the numerical solutions via generalized series expansions of the differential equations. As the first computation of a set of two-loop seven-scale master integrals, our results provide valuable input for the computation of two-loop leading-color ttH scattering amplitudes with a closed light-fermion loop.

Session 3 / **8**

Isolated photon production in association with a jet pair at NNLO QCD

Author: Heribertus Bayu Hartanto[1]

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I will present a calculation of isolated photon production in association with a jet pair at next-to-next-to-leading order precision in massless QCD. The full-colour two-loop scattering amplitude calculation and a selection of phenomenological results will be discussed. In addition, two-loop QED corrections to eˆ+ e- > mu+ mu- gamma process, which is a by-product of pp->photon+dijet scattering amplitude calculation, will be presented together with its relevance to obtain precise predictions for electron-muon scattering, which will be measured in the future MUonE experiment.

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A general mass variable flavor number scheme for Z boson associated with a heavy quark production at hadron colliders

Authors: Marco Guzzi[1]; Pavel Nadolsky[2]; Laura Reina[3]; Doreen Wackeroth[None]; Keping Xie[4]

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The general mass variable flavor number (GMVFN) scheme S-ACOT-MPS will
be discussed for proton-proton collisions. The impact of heavy-flavor
contributions within this factorization scheme will be shown for the production
of a Z boson in association with a charm/bottom quark in pQCD.
An amended version of the QCD factorization formula for proton-proton collisions will
be discussed as well as the role of $Z + c/b$ production at the LHC in constraining
heavy-flavor PDFs. Phenomenological applications will be presented.

Session 2 / 10

A Numerical Implementation of the LASS Subtraction Scheme

Author: Adam Kardos[None]

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NNLO QCD corrections are indispensible for Today's and tomorrow's colliders. Several schemes are available in the literature. The LASS (Local Analytic Subtraction Scheme) as it is developed in Turin gives one more solution to the problem. Its simple analytical integrals make it tempting to generalize even to hadron collisions. Before this crucial step a proof-of-concept numerical implementation is needed for eletron-positron collisions. In my talk I would like to introduce the first numerical implementation of this scheme for NNLO QCD calculations for electron-positron collisions and make detailed comparisons with other methods.

Session 5 / 11

Recent developments in the GENEVA event generator

Author: Matthew Lim[1]

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The GENEVA method provides a means to combine resummed and fixed order calculations at state-of-the-art accuracy with a parton shower program. GENEVA NNLO+PS generators have now been constructed for a range of colour-singlet production processes and using a range of different resolution variables. I will review the GENEVA framework and then describe several recent advancements, such as the use of jet veto resummation at NNLL' accuracy and the ongoing extension to processes including jets in the final state.

Session 3 / 12

Approximate N3LO PDFs with theoretical uncertainties - MSHT20aN3LO Review

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We will review the extension of the MSHT20 PDFs to approximate N3LO order and the consequences for phenomenology. We first describe the inclusion of the known N3LO information and the parameterisation of the remaining missing N3LO contributions, as well as the determination of the theoretical uncertainties from missing pieces and higher orders and their interpretation. We then

examine the impact on the PDFs as well as on predicted cross-sections. We will also comment on updates to the aN3LO PDFs.

Session 4 / 13

Cusp anomalous dimension with massive lines through four loops in QCD

Author: Nikolaos Kidonakis[None]

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I present results for the cusp anomalous dimension in QCD at higher orders. I discuss a general method for determining the massive cusp anomalous dimension to a very high degree of accuracy using its asymptotic behavior at small and large quark velocities, and I present explicit calculations through four loops. Separate results for different values of the number of flavors and for distinct color structures are also given.

Session 5 / 14

Physics Potential of a TeV-Scale Muon-Ion Collider

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A TeV muon-ion collider could be established if a high energy muon beam that is appropriately cooled and accelerated to the TeV scale is brought into collision with a high energy hadron beam using facilities such as at Brookhaven National Lab, Fermilab, or CERN. Such a collider opens up a new regime for deep inelastic scattering studies as well as facilitates precision QCD and electroweak measurements and searches for beyond Standard Model physics, in an alternative and complementary way to the proposed LHC-electron collider. It offers a compelling science program as a target for a first TeV scale muon accelerator demonstrator, on the path toward a O(10) TeV muon collider energy frontier machine. We discuss the potential physics program of such a muon-ion collider and some of its experimental challenges.

Session 3 / 15

Progress in the CTEQ-TEA global QCD analysis

Author: Marco Guzzi[1]

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I report on the progress in the precision studies of hadronic parton distributions by the CTEQ-TEA (Tung Et Al.) group.

Session 2 / 17

Feynman integral reduction using Blade

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Feynman integral reduction is very challenging for state-of-the-art calculations. Blade represents the first implementation of the block-triangular form improved Feynman integral reduction method, typically resulting in a remarkable improvement of the IBP reduction efficiency by one to two orders of magnitude. In this talk, I will introduce the key ideas of Blade and present various benchmarks.

Session 3 / 18

Improving alpha_s extractions from collider data

Author: Xiaoyuan Zhang[None]

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Measuring the strong coupling constant from high-energy collider data with precision comparable to the lattice has been a persistent challenge. For e+e- event shapes, a long-standing discrepancy between extractions from thrust and heavy jet mass may be due to physics in the trijet region. In particular, there is Sudakov shoulder in heavy-jet mass but not thrust which we now know how to resum to NNLL accuracy. For hadron colliders, ratios of energy correlators are excellent for alpha_s measurements with good perturbative convergence and small power corrections. I will report on theoretical advances for both of these cases using soft-collinear effective theory and the remaining hurdles that may need to be overcome to get to world-leading precision.

Session 4 / 20

Definitions of fragmentation functions and the implications for sum rules

Author: Ted Rogers[1]

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I will discuss issues that arise from the mismatch between asymptotic states and partonic states in the formal definitions of fragmentation functions. I will show that standard derivations of common sum rules need to be modified for gauge theories, and discuss several possibilities for constructing more precise definitions. Implications for phenomenological applications will also be discussed.

Session 6 / 22

Resummation of small-momentum logarithms for lattice calculation of GPDs in the large momentum effective theory

Author: Rui Zhang[None]

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The generalized parton distributions (GPDs) provide important information for 3D imaging of the proton in the longitudinal momentum fraction x and transverse impact parameter space. Recently, thanks to large-momentum effective theory, they can be directly calculated in lattice QCD from the so-called quasi-GPDs. In the perturbative matching of quasi-GPDs to GPDs, there are logarithms related to three different physical scales, the quark (antiquark) momentum $|x \pm \xi|P_z$ at skewness $\xi = \frac{P_+ - P'_+}{P_+ + P'_+}$, and the momentum of emitted gluon $|x - y|P_z$. When calculating near $x \to \pm \xi$ or $x \to \pm 1$, the contribution of higher-order logarithms become important, thus needs to be resummed. We examine under which conditions these logarithms are becoming important in ERBL and DGLAP region, and propose an approach to resum these logarithms in the two regions. After resummation, we can improving the estimation of perturbation theory uncertainty, and demonstrate which region of x can be reliably calculated from lattice through the large momentum effective theory.

Session 1 / 23

Higgs production at the LHC

Author: Matthew Henry Klein[1]

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Since the discovery of the Higgs boson in 2012, the ATLAS and CMS collaborations at the LHC have made precise measurements of a variety of Higgs boson properties, without significant evidence of any BSM behavior. However, large uncertainties are still present on many properties, and many others still remain unmeasured. In this talk, I will summarize the status of Higgs boson measurements and summarize the prospects looking forward to the High Luminosity LHC.

Session 2 / 24

Recent progress in planar two–loop six–point Feynman integrals computation

Author: Antonela Matijašić[None]

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The state-of-the-art in current two-loop QCD amplitude calculations is at five-particle scattering. In contrast, very little is known at present about two–loop six–particle scattering processes. In recent years, the results for one-loop hexagon integrals to higher order in the dimensional regulator become available as well as the results on the maximal cut of the planar two-loop six-point integral families. In this talk, I will show the progress made in computing planar two-loop six-particle Feynman integrals beyond the maximal cut using the differential equations method. In particular, I will discuss the canonical basis for several integral families in four space-time dimensions and their function space.

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Towards Precision Calculations on Modern Computers

Author: Joshua Isaacson[None]

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This talk presents a novel GPU-accelerated framework for efficient tree and one-loop matrix element evaluation. By leveraging the massively parallel architecture of GPUs and the performance-portable Kokkos library, we achieve significant speedups for both tree-level and one-loop calculations. Additionally, we introduce a cutting-edge library for evaluating multiple polylogarithms on the GPU.

Session 4 / 26

Perturbative calculations for first-principle parton distribution functions

Author: Tobias Neumann[1]

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Parton distribution functions (PDFs) are of key interest in both particle and nuclear physics. At the LHC, the limited knowledge of PDFs is currently one of the leading bottlenecks in precise predictions. In nuclear physics, PDFs provide insight into the structure of the nucleon, towards more complicated systems.

In this talk I will first motivate the need for precise PDFs, then explain how the quasi- and pseudo-PDF frameworks provide access to PDFs on the Euclidean lattice from first principles. A crucial ingredient are perturbative calculations of the matching kernel to map Euclideanized PDFs to light-cone PDFs. I will present our one-loop calculation of gluon quasi- and pseudo-PDF matching kernels, which contributes to a more precise gluon distribution and paves the way for higher-order calculations and different schemes.

Session 1 / 27

Pseudoscalar Higgs plus jet production at Next-to-Next-to-Leading Order in QCD

Authors: Ciaran Williams[1]; Youngjin Kim[2]

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We present a calculation of pseudoscalar Higgs production in association with a jet at Next-to-Next-to Leading Order (NNLO) accuracy in QCD. We work in an effective field theory in which $m_t \to \infty$ resulting in effective operators which couple the pseudoscalar to gluons and (massless) quarks. We have calculated all of the relevant amplitudes for the two-loop, one-loop and tree-level contributions. As a cross-check of our calculation we have re-calculated all of the scalar Higgs plus parton

amplitudes and perform a detailed comparison to the literature. In order to regulate the infra-red singularities present at this order we employ the $N-$jettiness slicing method. In addition to a detailed validation of our calculation at this order we investigate LHC phenomenology for a selection of pseudoscalar Higgs masses. Our results are implemented into the parton-level Monte Carlo code MCFM.

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The NNLO soft function for N-jettiness in hadronic collisions

Authors: Bahman Dehnadi[1]; Guido Bell[2]; Rudi Rahn[3]; Tobias Mohrmann[4]

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In this talk I'll present our recent work calculating the N-jettiness soft function, based on an extension of the SoftSERVE framework to the general case of N+2 jets and beams for *a priori* general global observables. I will comment on our approach, present an explicit grid scanning the 2-jettiness soft function, and shed some light on the behaviour of the N-jettiness soft function at the edges of phase space, when two jets/beams become collinear.

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Constraining new physics via improved global fits of the Standard Model Effective Field Theory

Authors: Angelica Goncalves Dos Santos[None]; Jorge de Blas[1]; Laura Reina[2]; Luca Silvestrini[None]; Mauro Valli[3]; Victor Miralles[4]

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We present results from a global fit of dimension-six SMEFT operators that includes electroweak, Higgs-boson, top-quark, and flavor observables. The leading-order scale dependence of the SMEFT Wilson
coefficients is consistently included in the evolution from the UV
scale to the electroweak scale and the low-energy scale of flavor
observables. The global fit is obtained within the HEPfit framework
and is based on the state-of-the-art of both experimental results and
SM theoretical predictions for all the observables considered.

Session 2 / 30

p-adic reconstruction of rational functions in multi-loop calculations

Author: Herschel Chawdhry[1]

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The calculation and manipulation of large multi-variable rational functions is a key bottleneck in multi-loop calculations. In this talk I will present work using p-adic numbers to reconstruct rational functions in a compact form. I will apply this to examples such as rational functions appearing in cutting-edge 2-loop 5-point amplitudes calculations.

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Welcome from SMU

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3-loop heavy-flavor contributions to deep inelastic scattering

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NLO parton showers

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AI developments at the LHC

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Concluding remarks

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Session 6 / 36

Identifying regions for asymptotic expansions in QCD

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The method of regions, a systematic approach to the asymptotic expansions of Feynman integrals, suggests that a Feynman integral can be reconstructed by summing over integrals expanded in certain regions. This technique not only facilitates the computation of Feynman integrals but also provides valuable insights for formulating an EFT, such as the Soft-Collinear Effective Theory (SCET). However, a fundamental question remains unanswered for most cases: how does one systematically determine the entire list of regions?

This talk aims to address this question by drawing from recent research works. The following results will be presented and demonstrated. 1. For the "on-shell expansion" and the "soft expansion" of massless wide-angle scattering, an all-order result is validated: each region involves only the hard mode, collinear modes, and ultrasoft mode, with their interactions following certain structures. 2. For the heavy-to-light decay processes, more modes are involved as the loop number increases. 3. For the high-energy expansion of two-to-two forward scattering, the Glauber mode is also involved, starting from three loops. Some important implications from these results will be discussed in the talk.

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Amplitude methods for gravitational interactions

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SMEFT probes using LHC Drell-Yan data

Author: Radja Boughezal[None]

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This talk will consider the potential of LHC Drell-Yan measurements to probe several aspects of the SMEFT. We consider the full spectrum of data, including the invariant mass, forward-backward asymmetry, transverse momentum and lepton angular distributions. We demonstrate the importance of higher-order dimension-8 terms in the SMEFT expansion. We also discuss operators that lead to qualitatively new effects and that motivate new analyses with future Drell-Yan data.

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Panel discussion: Theory needs of experiments at the HL-LHC and future colliders

Session 4 / 40

Electroweak physics at very high energies: splitting and showering

Author: Tao Han[None]

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The Standard Model electroweak sector exhibits some novel features at very high energies. For $E \gg v$ (the Higgs vev), the EW gauge symmetry is essentially restored and the massless splitting phenomena dominate the EW physics. Beyond the familiar gauge theory splitting functions, we discuss the emergence of additional "ultra-collinear" splitting phenomena and the violation of the Goldstone-boson Equivalence Theorem. Because the SU(2) quantum numbers are explicit and observable in common physical processes, subtitles of the Bloch-Nordsieck theorem violation are discussed. We implement the EW showering and illustrate its importance by calculating a number of physical processes at high energies within and beyond the SM.

Session 4 / 41

Pushing the NNLO+PS frontier towards new classes of processes with MiNNLO

The MiNNLO framework offers an efficient approach to consistently include NNLO QCD corrections within Monte-Carlo event generators. As the first (and only) NNLO+PS method that was extended beyond colour-singlet production, recent developments of the MiNNLO method will be discussed that tackle new classes of hadron-collider reactions, including heavy quarks, jets, and colour singlets in the final state. The focus of this talk will be the very recent extension of the MiNNLO matching to the production of a heavy-quark pair in association with a colour singlet. As a first application of this approach, NNLO+PS event generation for bbZ production in the 4FS is presented, which yields intriguing results both in comparison to data and in comparison to 5FS predictions.