Dr. Vasily Sotnikov

Curriculum Vitae

January 2025

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Research interests

- High energy particle physics phenomenology
- Perturbative QCD
- Multi-loop scattering amplitudes in quantum field theories
- Mathematical and numerical aspects of Feynman integrals

Education

2015 – 2019 **PhD**, *Physics Institute, Freiburg University, Germany*.
Thesis (summa cum laude):
"Scattering Amplitudes With the Multi-Loop Numerical Unitarity Method" [26].
Supervisors: Harald Ita, Fernando Febres Cordero

2008 – 2014 **Master**, *Physics Department, Lomonosov Moscow State University, Russia*.
Diploma work:
"Study of Time-Dependent Wigner Inequalities for Non-Stationary Quantum Systems"

Career summary

since 2022 **Senior research associate (5 years)**, *Physics Institute, University of Zurich, Switzerland*.

2022 – 2023 One-year research visit, *Michigan State University, East Lansing (MI), USA*

2019 – 2021 **Postdoc**, *Max Planck Institute for Physics, Munich (now Garching), Germany*.

Major research achievements

I have authored over 20 research papers in the leading peer-reviewed journals in my field with over 1100+ total citations. A complete list of publications can be found at the end of this CV. In the following, I summarize my main research achievements, highlighting selected publications.

Pentagon functions

"Pentagon Functions for Scattering of Five Massless Particles",
D. Chicherin and V. Sotnikov, *JHEP 20 167* (2020) (110+ citations) [15]

Before this work, the practical use of two-loop Feynman integrals for five-particle scattering in phenomenological applications was deemed impossible. After completing my PhD, I identified this as the highest-priority issue to address in pushing the frontier of NNLO QCD corrections beyond the simplest scattering processes. To this end, I developed a basis of pentagon functions — special transcendental functions that enable compact representations of scattering amplitudes and their efficient and stable numerical evaluation. This innovative approach bypassed the conventional use of multiple polylogarithms, creating a new framework that is now well-recognized within the community and is employed in all computations of two-loop five-particle scattering amplitudes and their applications for collider phenomenology. The numerical library I designed for these functions has become an essential tool for the field, making previously intractable computations feasible.

In the following years, I extensively refined this pioneering method, leading to the first results beyond completely massless scattering [9, 7]. This breakthrough removed a major obstacle in the computation of NNLO QCD corrections for processes such as $H/Z/W$ boson production in association with two jets at the LHC, thus opening new avenues for precise theoretical predictions and demonstrating the potential to apply these techniques to processes with even more kinematic scales in the future.

First two-loop five-parton amplitudes and α_s measurement

"Analytic Form of the Planar Two-Loop Five-Parton Scattering Amplitudes in QCD",
S. Abreu, J. Dormans, F. Febres Cordero, H. Ita, B. Page, V. Sotnikov,
JHEP 05 084 (2019) (130+ citations) [17]

This paper represents the culmination of methods I developed during my PhD, marking a significant milestone in our understanding of multi-loop scattering. For the first time, the complete set of two-loop five-parton amplitudes in the leading-color approximation was derived analytically. This achievement demonstrated the full potential of analytic reconstruction methods, revolutionizing modern multi-loop computations. Building on this, I developed a numerical code [11] that was employed in the first computation of NNLO QCD corrections for three-jet production at the LHC, facilitating a measurement of the QCD coupling constant at the highest energy scales.
Later in my career, I completed the computation of all remaining contributions [4, 3], lifting the approximations used in the earlier work. By applying a novel approach to minimize the occurrence of unphysical singularities, I achieved remarkably simplified results for these amplitudes, highlighting this approach's potential to tackle even more complex multi-scale amplitudes.

Most precise predictions for triphoton production in hadron collisions

"Triphoton production at hadron colliders in NNLO QCD",
S. Kallweit, V. Sotnikov, M. Wiesemann, *Phys. Lett. B 812* (2021) (90+ citations) [13]

"Leading-Color Two-Loop QCD Corrections for Three-Photon Production at Hadron Colliders",
S. Abreu, B. Page, E. Pascual, V. Sotnikov, *JHEP 01 078* (2021) (60+ citations) [12]

These works presented the first publicly accessible computation of fully differential NNLO QCD corrections for three-photon production in proton collisions, setting a new benchmark in the field. This marked a significant milestone for perturbative QCD, demonstrating for the first time that NNLO corrections for $2 \to 3$ are possible in large-scale phenomenological studies. The work also underscored the importance of NNLO corrections for accurately describing experimental data and their role in searches for anomalous Higgs and gauge couplings. Initially, the computations employed the leading-color approximation, which I later refined by computing all remaining contributions [8].

First NNLO-precise study of $Zb\bar{b}$ production at the LHC

"NNLO event generation for Z-boson production in association with a bottom-quark pair",
J. Mazzitelli, V. Sotnikov, M. Wiesemann, *Submitted to Phys. Rev. Lett.* (Apr. 2024) (10+ citations) [2]

In this recent study, I investigated the production of a Z boson decaying into leptons in association with a b-quark pair in proton collisions. This paper represents a significant milestone in perturbative QCD, as it provided the first predictions at NNLO QCD accuracy for this process while simultaneously incorporating all-order radiative corrections from a parton shower. To include the two-loop contributions in the small-b-mass approximation, I utilized analytic two-loop amplitudes derived in my earlier work [10, 9]. The prohibitive complexity of these amplitudes motivated me to design and implement a novel method for their numerical evaluation, ensuring both feasibility and numerical stability. The results of this work revealed that the sizable NNLO QCD corrections resolve long-standing discrepancies between different theoretical descriptions of b-quark. Given the importance of $Z + b$-jet production as a benchmark process for event generators, this work has substantial implications for improving precision phenomenology at the LHC, particularly in measurements involving the b-Yukawa coupling and searches for physics beyond the Standard Model.

Public software

Developed open source software tools which had profound impact on particle physics phenomenology:

Caravel	A C++ framework for computation of analytic multi-loop amplitudes with numerical unitarity method.	[14]
PentagonFunctions++	Efficient numerical evaluation of special functions for five-particle two-loop scattering.	[15, 7, 4]
FivePointAmplitudes++	Efficient numerical evaluation of analytic five-particle two-loop amplitudes for phenomenology.	[8, 11, 3, 12]

Supervision experience

since 2024 **Co-supervising PhD thesis**, *Viktor Kuschke*.
Led planning of PhD project aligned with larger research goals.
Supervisor: Harald Ita (Department of Astrophysics, University of Zurich).

2024 **Co-supervised master's thesis**, *Jingzhi Hu*.
Conceptualized and planned the thesis *"Collinear Expansions of Five-Point Two-Loop Massless Integrals"*, and took full responsibility for its supervision.
Official supervisor: Aude Gehrmann-De Ridder (ETH Zurich).

2024 **Co-supervised semester project**, *Zhexian Ji*.
Planned and supervised a two-month project *"A One-Loop Feynman Integral Alphabet from A-determinants"*.
Official supervisor: Johannes Brödel (ETH Zurich).

2020 – 2022 **Mentored PhD student**, *Maximillian Klinkert*.
Provided advice and guidance for the thesis *"Two-loop five-point amplitudes for bosons and partons in QCD"*.
Supervisor: Harald Ita (Freiburg University).

2019 – 2021 **Co-supervised PhD thesis**, *Evgenij Pascual*.
Initiated and led a project that became the foundation of the thesis *"Two-loop amplitudes for processes involving photons at Hadron Colliders"*.
Supervisor: Fernando Febres Cordero (Freiburg University).

Supervision training

2024 **Project management for research**, *University of Zurich Graduate Campus*.
Completed a two-day intensive course in project management, gaining skills and tools for effectively managing large research projects and teams.

2024 **Supervision training for postdocs**, *University of Zurich Graduate Campus*.
Completed a two-day intensive course on supervision strategy development, gaining knowledge of effective methods and tools for successful PhD student supervision.

Teaching experience

2023 **Lecturer**, *Amplitudes summer school, CERN*.
As an independent lecturer, I developed and delivered a 5-hour lecture course "Modern techniques for multi-loop amplitudes" at a prestigious summer school.

2023 **Lecturer**, *Elliptics summer school, University of Zurich*.
Delivered a lecture "Scattering amplitudes and Feynman integrals", focused on establishing the essential background for the program's advanced topics.

2021 **Discussion leader**, *CERN-Fermilab HCP Summer School*.
Led discussion sessions where students could engage with and ask questions about the school program.

2015 – 2019 **Teaching assistant**, *Freiburg University, Germany*.
Developed and graded exercises and exams for undergraduate courses in Quantum Mechanics, Quantum Field Theory II, and Classical Mechanics.

2013 – 2015 **Private tutor**, *Moscow, Russia*.
Worked part-time as a private tutor of mathematics and physics for high school and undergraduate students.

Service to the scientific community

since 2020 Reviewed 10+ papers (not counting resubmissions) for the top journals in the field: *JHEP*, *Phys. Rev. D*, and *Phys. Rev. Letters*.

2023 Obtained funding for and co-organized Elliptics Summer School 2023.

2021 Made a short video about theoretical predictions in particle physics for an outreach program.

2020 – 2021 Organized and managed theory seminars at Max Planck Institute for Physics.

Selected talks

I have been invited to deliver **25+ talks** at conferences, workshops, and seminars, including **two plenary overview talks**, demonstrating my recognition as a leading expert in the field.

Conferences and workshops

August 2024 **Frontiers in precision phenomenology: Resummation, Amplitudes, and Subtraction**, *CERN, Switzerland*, "Efficient Numerical Evaluation of Multiscale Two-Loop Amplitudes".

April 2024 **Loops and Legs in Quantum Field Theory**, *Lutherstadt Wittenberg, Germany*, "NNLO+PS predictions for Z boson production in association with b-jets at the LHC".

December 2023 **QCD Meets Gravity**, *CERN, Switzerland*, "Special Functions for Five-Point One-Mass Scattering in QCD".

November 2022 **QCD@LHC**, *Orsay, France*, "Feynman integrals and special functions for Hjj production in NNLO QCD".

June 2022 **Precision calculations for future e^+e^- colliders: targets and tools**, *CERN, Switzerland*, "Modern calculation techniques for multi-scale loop amplitudes".

April 2022 **Loops and Legs in Quantum Field Theory (Plenary Talk)**, *Ettal, Germany*, "Status of double virtual NNLO QCD corrections for high multiplicity processes", proceedings [23].

May 2021 **RADCOR/Loopfest (Plenary Talk)**, *Florida State University, Online*, "Double Virtual Contributions for Massless $2 \to 3$ Scattering in NNLO QCD", proceedings [24].

September 2019 **RADCOR**, *Avignon, France*, "Analytic Two-Loop Five-Parton QCD Amplitudes from Numerical Unitarity".

October 2018 **High Precision for Hard Processes**, *Freiburg, Germany*, "Five-Parton Two-Loop Amplitudes from Numerical Unitarity".

Seminars

November 2025 **Institute for Theoretical Physics, University of Bern**, *Bern, Switzerland*, "Two-Loop Corrections for High-Multiplicity Scattering: Status and Perspectives".

May 2024 **Higgs Centre for Theoretical Physics**, *Edinburgh, UK*, "Pentagon Functions for Five-Point One-Mass Scattering in QCD".

November 2022 **Florida State University**, *Tallahassee (FL), USA*, "NNLO QCD corrections for triphoton production at the LHC in full color".

March 2021 **University of Milano-Bicocca**, *Milan, Italy*, "Pushing the multiplicity frontier of NNLO QCD predictions".

May 2019 **CP3 UCLouvain**, *Louvain-la-Neuve, Belgium*, "Analytic Two-Loop Five-Parton QCD Amplitudes from Numerical Unitarity".

Publications

A complete, up-to-date list of my publications, including the most accurate citation counts, can be found in the INSPIRE database. It is customary in the field to put the authors in alphabetical order.

Research papers

[1] S. Abreu, D. Chicherin, V. Sotnikov, and S. Zoia, "Two-loop five-point two-mass planar integrals and double Lagrangian insertions in a Wilson loop," JHEP **24**, 167 (2024), [2408.05201].

[2] J. Mazzitelli, V. Sotnikov, and M. Wiesemann, "Next-to-next-to-leading order event generation for Z-boson production in association with a bottom-quark pair," Submitted to Phys. Rev. Lett. (2024), [2404.08598].

[3] G. De Laurentis, H. Ita, and V. Sotnikov, "Double-virtual NNLO QCD corrections for five-parton scattering. II. The quark channels," Phys. Rev. D **109**, 094024 (2024), [2311.18752].

[4] G. De Laurentis, H. Ita, M. Klinkert, and V. Sotnikov, "Double-virtual NNLO QCD corrections for five-parton scattering. I. The gluon channel," Phys. Rev. D **109**, 094023 (2024), [2311.10086].

[5] T. Gehrmann, A. von Manteuffel, V. Sotnikov, and T.-Z. Yang, "The NfCF3 contribution to the non-singlet splitting function at four-loop order," Phys. Lett. B **849**, 138427 (2024), [2310.12240].

[6] T. Gehrmann, A. von Manteuffel, V. Sotnikov, and T.-Z. Yang, "Complete N_f^2 contributions to four-loop pure-singlet splitting functions," JHEP **01**, 029 (2024), [2308.07958].

[7] S. Abreu, D. Chicherin, H. Ita, B. Page, V. Sotnikov, W. Tschernow, and S. Zoia, "All Two-Loop Feynman Integrals for Five-Point One-Mass Scattering," Phys. Rev. Lett. **132**, 141601 (2024), [2306.15431].

[8] S. Abreu, G. De Laurentis, H. Ita, M. Klinkert, B. Page, and V. Sotnikov, "Two-loop QCD corrections for three-photon production at hadron colliders," SciPost Phys. **15**, 157 (2023), [2305.17056].

[9] D. Chicherin, V. Sotnikov, and S. Zoia, "Pentagon functions for one-mass planar scattering amplitudes," JHEP **01**, 096 (2022), [2110.10111].

[10] S. Abreu, F. Febres Cordero, H. Ita, M. Klinkert, B. Page, and V. Sotnikov, "Leading-color two-loop amplitudes for four partons and a W boson in QCD," JHEP **04**, 042 (2022), [2110.07541].

[11] S. Abreu, F. Febres Cordero, H. Ita, B. Page, and V. Sotnikov, "Leading-color two-loop QCD corrections for three-jet production at hadron colliders," JHEP **07**, 095 (2021), [2102.13609].

[12] S. Abreu, B. Page, E. Pascual, and V. Sotnikov, "Leading-Color Two-Loop QCD Corrections for Three-Photon Production at Hadron Colliders," JHEP **01**, 078 (2021), [2010.15834].

[13] S. Kallweit, V. Sotnikov, and M. Wiesemann, "Triphoton production at hadron colliders in NNLO QCD," Phys. Lett. B **812**, 136013 (2021), [2010.04681].

[14] S. Abreu, J. Dormans, F. Febres Cordero, H. Ita, M. Kraus, B. Page, E. Pascual, M. S. Ruf, and V. Sotnikov, "Caravel: A C++ framework for the computation of multi-loop amplitudes with numerical unitarity," Comput. Phys. Commun. **267**, 108069 (2021), [2009.11957].

[15] D. Chicherin and V. Sotnikov, "Pentagon Functions for Scattering of Five Massless Particles," JHEP **20**, 167 (2020), [2009.07803].

[16] S. Abreu, F. Febres Cordero, H. Ita, M. Jaquier, B. Page, M. S. Ruf, and V. Sotnikov, "Two-Loop Four-Graviton Scattering Amplitudes," Phys. Rev. Lett. **124**, 211601 (2020), [2002.12374].

[17] S. Abreu, J. Dormans, F. Febres Cordero, H. Ita, B. Page, and V. Sotnikov, "Analytic Form of the Planar Two-Loop Five-Parton Scattering Amplitudes in QCD," JHEP **05**, 084 (2019), [1904.00945].

[18] S. Abreu, F. Febres Cordero, H. Ita, B. Page, and V. Sotnikov, "Planar Two-Loop Five-Parton Amplitudes from Numerical Unitarity," JHEP **11**, 116 (2018), [1809.09067].

[19] F. R. Anger and V. Sotnikov, "On the Dimensional Regularization of QCD Helicity Amplitudes With Quarks," (2018), [1803.11127].

[20] F. R. Anger, F. Febres Cordero, H. Ita, and V. Sotnikov, "NLO QCD predictions for $W b\bar{b}$ production in association with up to three light jets at the LHC," Phys. Rev. D **97**, 036018 (2018), [1712.05721].

[21] N. Nikitin, V. Sotnikov, and K. Toms, "Proposal for experimental test of the time-dependent Wigner inequalities for neutral pseudoscalar meson systems," Phys. Rev. D **92**, 016008 (2015), [1503.05332].

[22] N. Nikitin, V. Sotnikov, and K. Toms, "Time-dependent Bell inequalities in a Wigner form," Phys. Rev. A **90**, 042124 (2014), [1408.6023]

Conference proceedings

[23] V. Sotnikov, "Status of double virtual NNLO QCD corrections for high multiplicity processes," PoS **LL2022**, 002 (2022), [2207.12295].

[24] V. Sotnikov, "Double Virtual Contributions for Massless 2 → 3 Scattering in NNLO QCD," SciPost Phys. Proc. **7**, 002 (2022).

[25] S. Abreu, J. Dormans, F. Febres Cordero, H. Ita, B. Page, and V. Sotnikov, "Analytic form of planar two-loop five-patron scattering amplitudes in QCD," in *54th Rencontres de Moriond on QCD and High Energy Interactions* (ARISF, 2019)

PhD thesis

[26] V. Sotnikov, "Scattering amplitudes with the multi-loop numerical unitarity method," PhD thesis, Freiburg U. (2019)