First Result for a Full Two-Loop Five-Gluon Amplitude

Based on arXiv:1905.03733

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Towards an Era of Precision Measurements at the LHC

A new era of precision measurements is dawning. CERN's Large Hadron Collider (LHC) will start Run 3 in 2021. To fully exploit the machine's potential, accurate theoretical predictions are required. These can be obtained through the computation of higher orders in perturbation theory.

All Feynman Integrals Computed Analytically in the Physical Region

Basis for all QCD amplitudes → pentagon functions

(*https://pentagonfunctions.hepforge.org/*)

Logarithms, dilogarithms, and generalizations thereof (Goncharov polylogarithms)

- Elegant analytic properties
- Fast and accurate numerical evaluation

For Many QCD Processes, Next-to-Leading Order is Insufficient

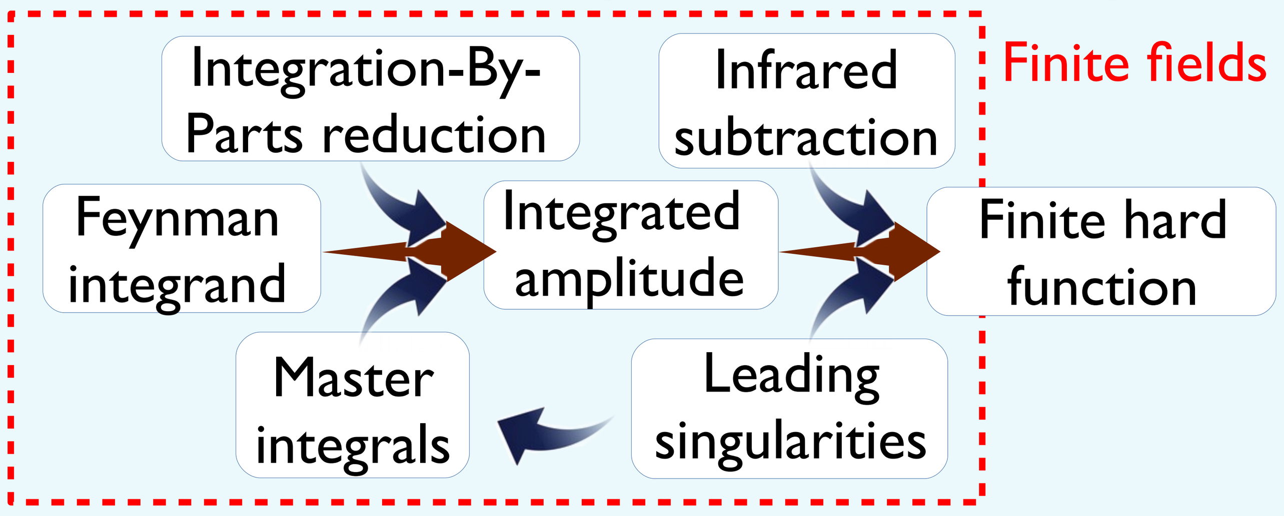
E.g. strong coupling from 3-jet/2-jet ratio [1]:

$$\alpha_s(M_Z) = 0.1148 \underset{\text{(exp.)}}{\pm 0.0014} \underset{\text{(PDF)}}{\pm 0.0018} \underset{\text{(theory)}}{\pm 0.0050}$$

Large theoretical uncertainty!

At present, only observables involving up to four particles are available at next-to-next-to-leading order.

A Refined Amplitude Assembly

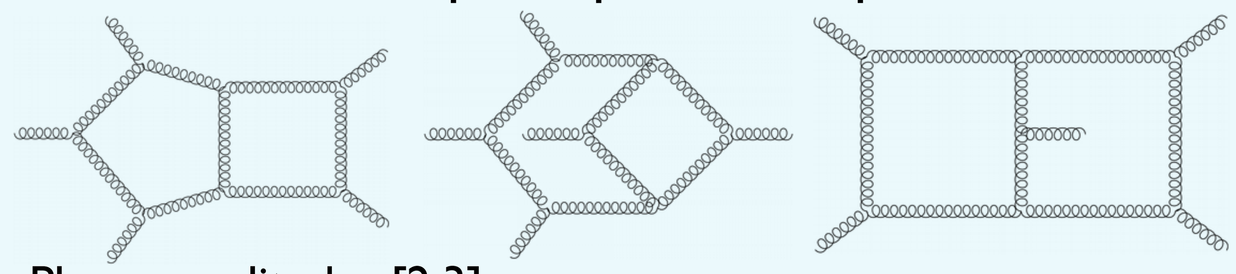


The code can be parallelized, and runs in a few hours using multi-threading on a modern computing node.

Five-Particle Processes at the LHC

- Precision measurements of the strong coupling
- In-depth tests of the Standard Model
- Improved background to new physics searches

Bottleneck: two-loop five-particle amplitudes



Planar amplitudes [2,3]

Cutting-Edge Methods

- Generalized unitarity for Feynman integrands [4]
- Differential equations for Feynman integrals in the canonical form [2,5,6]
- Algorithmic construction of canonical basis using D-dimensional leading singularities [6]
- Computational algebraic geometry [7]
- Finite fields and functional reconstruction [8]

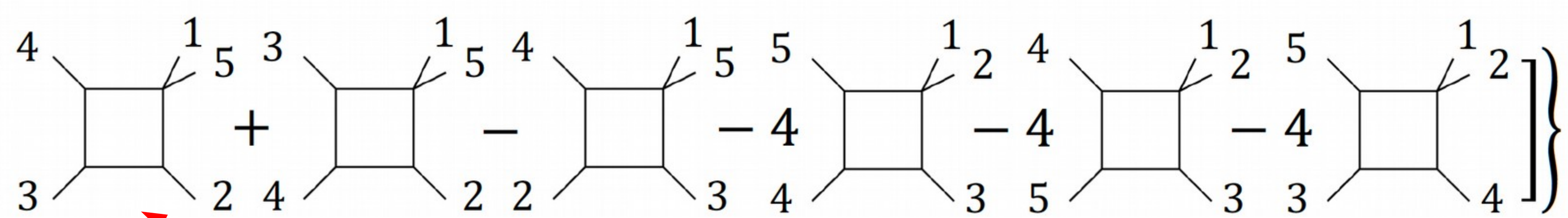
New Result: Full-Color All-Plus Helicity Amplitude

We find a remarkably simple expression for the infrared-subtracted hard function:

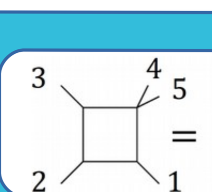
Permutations of the external legs — Color SU(N_c) — Gluon spin dimension — Spinor-helicity variables

$$\mathcal{H}^{(2)}_{\substack{\text{double}\\\text{trace}}} = \sum_{S_5/\Sigma} \mathrm{Tr}(12)[\mathrm{Tr}(345) - \mathrm{Tr}(543)] \sum_{\Sigma} \left\{ 6\,\kappa^2 \left[\frac{\langle 24\rangle[14][23]}{\langle 12\rangle\langle 23\rangle\langle 45\rangle^2} + 9\,\frac{\langle 24\rangle[12][23]}{\langle 12\rangle\langle 34\rangle\langle 45\rangle^2} \right] \right.$$

$$\left. + \kappa\,\frac{[15]^2}{\langle 23\rangle\langle 34\rangle\langle 42\rangle} \left[\ldots \right] \right\}$$



Only logarithms and dilogarithms appear:



$$= \mathrm{Li}_2\left(1 - \frac{s_{12}}{s_{45}}\right) + \mathrm{Li}_2\left(1 - \frac{s_{23}}{s_{45}}\right) + \log^2\left(\frac{s_{12}}{s_{23}}\right) + \frac{\pi^2}{6}$$

Valid in all physical scattering regions $s_{ij} \to s_{ij} + i0$

Surprise: coefficients of box functions are conformally invariant!

References and Acknowledgments

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This research received funding from the Swiss National Science Foundation (Ambizione grant PZ00P2 161341), the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme, Novel structures in scattering amplitudes (grant agreement No 725110), and High precision multi-jet dynamics at the LHC (grant agreement No 772009), under the Marie Skłodowska-Curie grant agreement 746223, from the COST Action CA16201 Particleface, and from the STFC Rutherford Fellowship ST/L004925/1.

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