Research Overview: Scattering Amplitudes for the LHC

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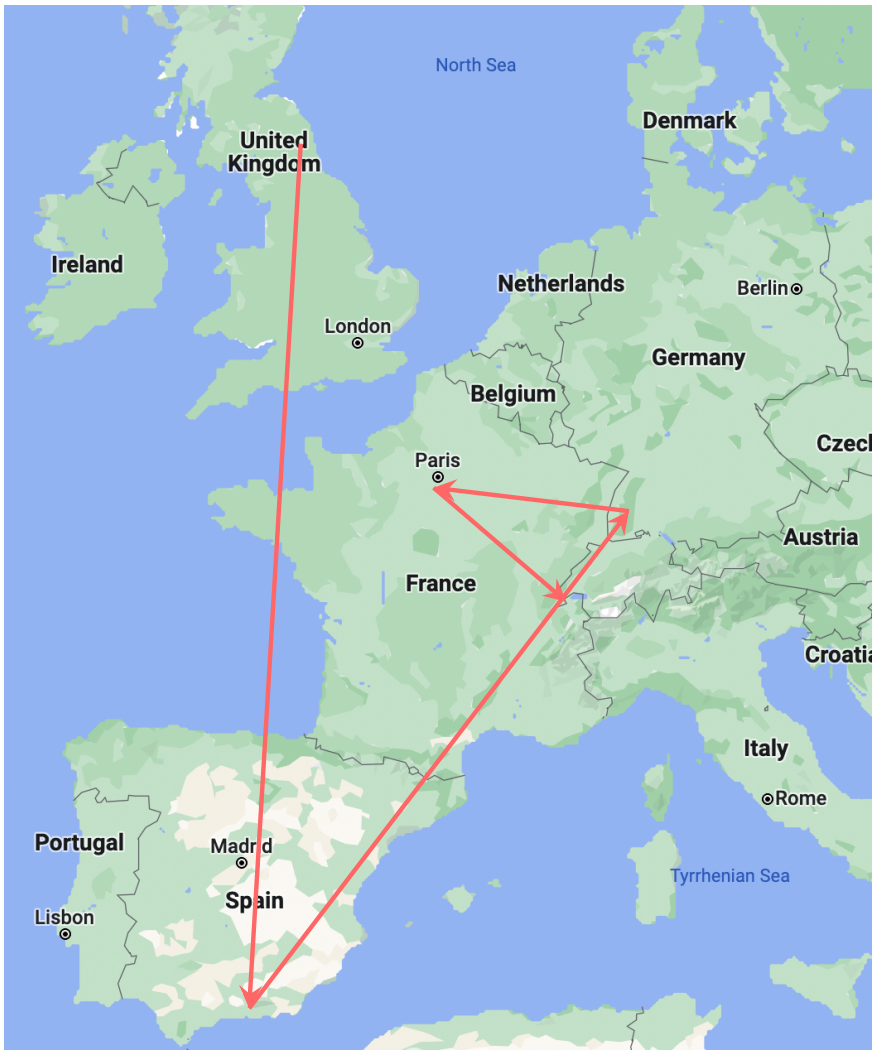
CERN Theoretical Physics Department

Theory Retreat

9th November 2022

Career Path



- ['08–'12] Student: Durham, UK[a].

[a] CERN Summer Student 2011.

- ['12–'15] Masters/PhD student[b]: Granada, Spain.

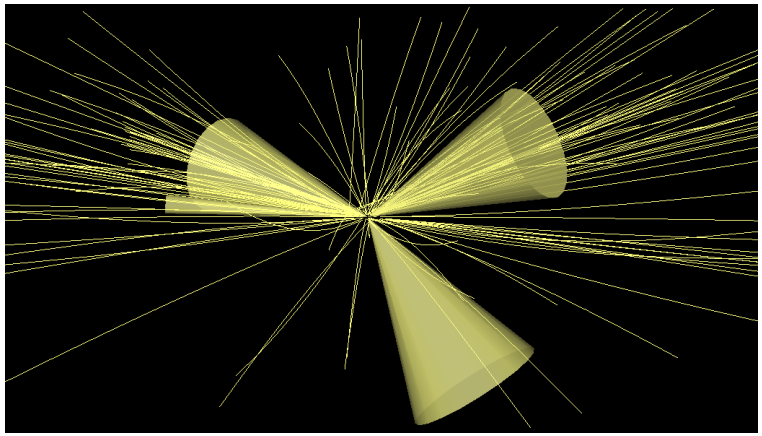
[b] CERN Visitor 2014-2015.

- ['15–'18] Post-doctoral researcher: University of Freiburg, Germany.
- ['18–'21] Post-doctoral researcher: IPhT Saclay, France.
- ['21–'23] Senior Fellow[c]: CERN, Switzerland.

[c] Marie Curie fellowship.

Physics Objective: Enable Precise Predictions

- Entering "precision era". Many processes experimental uncertainty projected to reach 1% level.
- LHC physics program driven by theory/experiment comparison.
- NNLO precision theory prediction demanded to understand data.



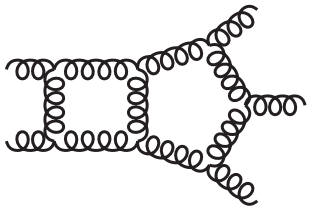
To make the most of LHC physics potential, we need NNLO precise predictions for many complex scattering processes.

Performing Predictions

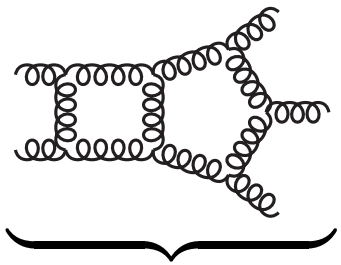
- Theory prediction built from phase space integrals of amplitudes.

$$\text{cross section} \sim \int \underbrace{d\Phi}_{\text{phase space}} \left[\underbrace{|\mathcal{A}|^2}_{\text{amplitude}} \right]$$

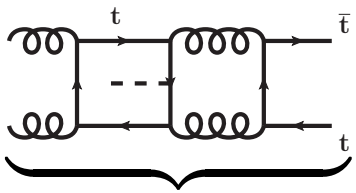
- For NNLO precision, need "two-loop" amplitudes, e.g. for $pp \to 3$ jets.

$\mathcal{A}^{(2)} =$  $+ \cdots \quad =$ 8-fold integral

- Amplitudes are functions of many variables: mass/momentum scales.



5 scales



7 scales

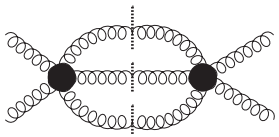
For precise LHC physics involving multiple (heavy) particles, we need two-loop amplitudes depending on many scales.

Past Work

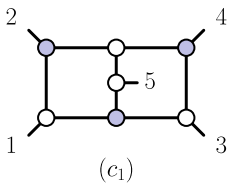
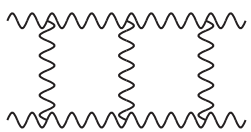
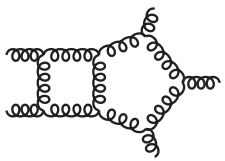
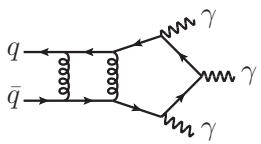
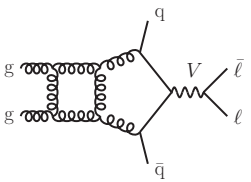
Methods for/Computations of Feynman Integrals/Amplitudes [w/ Abreu].

$$\mathcal{A}^{(2)} = \sum_k \underbrace{\mathcal{C}_k}_{\substack{\text{rational} \\ \text{functions}}} \times \underbrace{\mathcal{I}_k}_{\text{integrals}} .$$

- Methods:

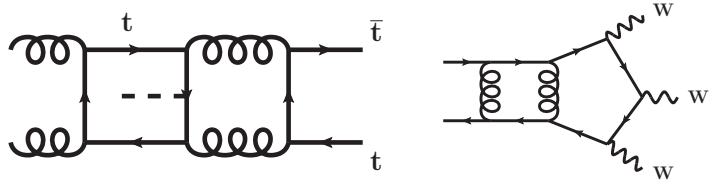
Numerical Unitarity	Differential Equations + Ansatz
$\text{Disc}[A_4] \sim$ 	$d\mathcal{I}_j = \epsilon \mathbf{M}_{jk} \mathcal{I}_k \mod p$

- Integrals: Two-loop five-point massless and one-mass.
- Amplitudes:

$\mathcal{N} = 4 \,/\, \mathcal{N} = 8$	4-graviton	$pp \to 3j$	$pp \to 3\gamma$	$pp \to W + 2j$
				

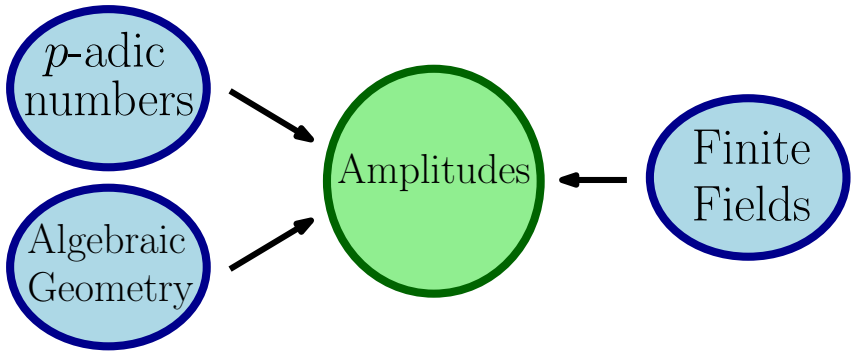
The Next Frontier

Amplitudes with multiple massive particles are currently out of reach.



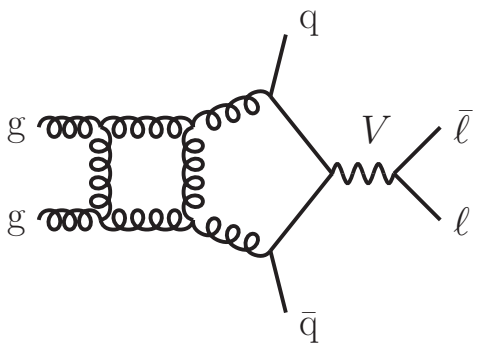
- New problems arising in multi-scale amplitude building blocks:
  1. **Integrals**: $\mathcal{I}_k$ with massive fields involve new special functions.
  2. **Coefficients**: Rational functions becoming gigantic.

What physical/mathematical structures control multi-scale amplitudes?



Research Interest Summary

- Multi-scale amplitudes for precise LHC predictions.



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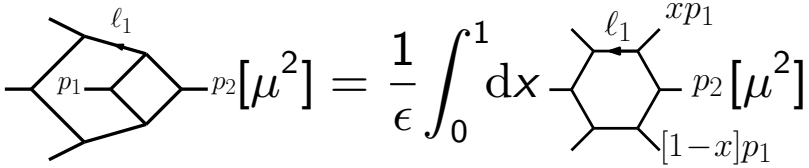
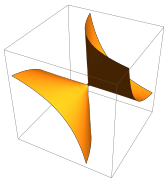
- Understanding of multi-loop integrals/amplitudes.



- Algebraic geometry in pQFT.

$$\mathbb{F}[\lambda_1^\alpha, \tilde{\lambda}_1^{\dot{\alpha}}, \ldots, \lambda_n^\alpha, \tilde{\lambda}_n^{\dot{\alpha}}]/J_{\Lambda_n} \leftrightarrow$$



Ongoing/Future Projects

Two-Loop Amplitudes.

- Feynman Integrals: more scales, more points, masses. [Abreu, Monni]
- LHC scattering: sub-leading color, $Z/H + 2$-jets, ... [Abreu et al].

Structural studies:

- Evanescent integrals from local subtraction. [Georgoudis]
- Algebraic geometry and real radiation. [Kosower]
- Integral relations in four-dimensional limit. [Usovitsch]