$H + j$ production at NLO QCD

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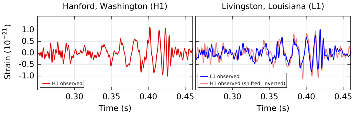
The Niels Bohr International Academy

CARLSBERG FOUNDATION

Theoretical Particle Physics and Cosmology at NBI

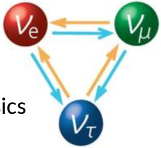
Gravity

Gravitational waves
Black holes
Limits of gravity
Holography/Quantum gravity



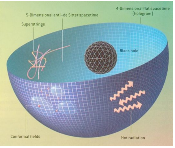
Astroparticle and Cosmology

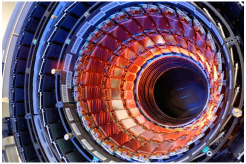
Neutrino physics
Icecube observatory
Transient events
High-energy astrophysics
Astrophysical jets
Cosmic microwave background
Primordial gravitational waves



Particle Physics and Condensed-matter

Modern methods of amplitudes
Particle physics phenomenology
Defect conformal field theory
Strongly coupled matter
Holographic principle
Thermalization
Integrability





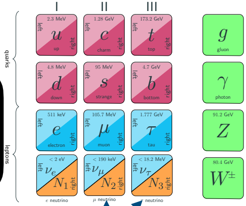
High-energy theory and phenomenology at NBI

Oleg Ruchayskiy, Inar Timiryasov,Kevin Urquía
Blegdamsvej 17, building M

- The group is working on physics beyond the Standard Model with feebly interacting particles
- Theoretical developments (what are they good for) and experimental searches (how to find them at CERN and beyond)

Sterile neutrino dark matter

- Astrophysical searches: X-ray, Lyman-α
- Production mechanisms: Leptogenesis, Einstein-Cartan gravity



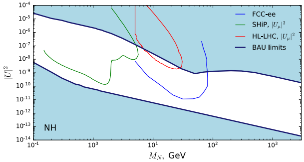
Higgs boson — inflaton

- Higgs inflation in Einstein-Cartan gravity
- Primordial black hole production

Heavy Neutral Leptons

(also known as right-handed neutrinos, heavy sterile neutrinos)

- Phenomenology of direct experimental searches: SHiP, ATLAS
- Indirect searches and EFT
- Baryon asymmetry of the Universe: Leptogenesis



Theoretical Particle Physics and Cosmology at NBI

Permanent members:

- Poul Henrik Damgaard (NBIA director)
- Irene Tamborra
- Niels A. Obers
- Charlotte F. Kristjansen
- Vitor Cardoso (new!)
- Pavel Naselsky
- Konstantin Zarembo
- Troels Harmark
- Emil Bjerrum-Bohr
- Markus Ahlers (tenure track)

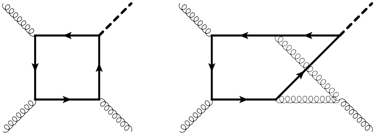
Longterm non-permanent:

- Michael Trott
- Matthias Wilhelm
- Jacob Bourjaily
- Mauricio Bustamante
- Andrés Luna Godoy
- Christian Vergu
- Matt von Hippel

Postdocs: 10
PHD students: 10
MSC students: 15-20
Emeritus professors: 9

Higgs plus jet production at the LHC.

Leading order QCD is one-loop



NLO/two-loop is not yet completely known
with full mass dependence...

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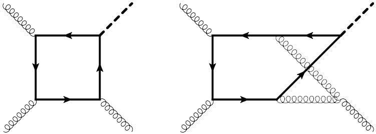

NLO/two-loop is not yet completely known
with full mass dependence...

Three processes in one:

$pp \to Hj$	is important in its own right
$H \to 3j$	Higgs decay
$pp \to H$	Real radiation at next order

Previous work on NLO QCD $H + j$ production

Exact LO results:

R. K. Ellis, I. Hinchliffe, M. Soldate, JJ van der Bij. (1988)
U. Baur and E. W. N. Glover. (1990)

HEFT results:

R. Boughezal, F. Caola, K. Melnikov, F. Petriello, M. Schulze. (2013) arXiv:1302.6216
X. Chen, T. Gehrmann, E. W. N. Glover, M. Jaquier. (2015) arXiv:1408.5325
R. Boughezal, F. Caola, K. Melnikov, F. Petriello, M. Schulze. (2015) arXiv:1504.07922
R. Boughezal, C. Focke, W. Giele, X. Liu, F. Petriello. (2015) arXiv:1505.03893

Various other limits and expansions:

R. Harlander, T. Neumann, K. Ozeren, M. Wiesemann. (2012) arXiv:1206.0157
T. Neumann and M. Wiesemann. (2014) arXiv:1408.6836
T. Neumann and C. Williams. (2017) arXiv:1609.00367
R. Mueller and D. Öztürk. (2016) arXiv:1512.08570
K. Melnikov, L. Tancredi, C. Wever. (2016) arXiv:1610.03747
K. Melnikov, L. Tancredi, C. Wever. (2017) arXiv:1702.00426
J. Lindert, K. Melnikov, L. Tancredi, C. Wever. (2017) arXiv:1703.03886
K. Kudashkin, K. Melnikov, C. Wever. (2017) arXiv:1712.06549
J. Lindert, K. Kudashkin, K. Melnikov, C. Wever. (2018) arXiv:1801.08226

Numerical results:

S. Jones, M. Kerner, G. Luisoni. (2018) arXiv:1802.00349
M. Czakon, R. Harlander, J. Klappert, M. Niggetiedt. (2021) arXiv:2105.04436

Feynman integrals:

R. Bonciani, V. Del Duca, HF, J. Henn, F. Moriello, V. Smirnov. (2016) arXiv:1609.06685
R. Bonciani, V. Del Duca, HF, J. Henn, et. al. (2020) arXiv:1907.13156
HF, M. Hidding, L. Maestri, F. Moriello, G. Salvatori. (2020) arXiv:1911.06308

The biggest challenge is the evaluation of the Feynman Integrals.
$\mathcal{O}(10^5)$ integrals $\to$ $\mathcal{O}(10^2)$ "master integrals" (independent basis)
The integrals must be sorted into "integral families"

$$I^f_{a_1,\ldots,a_9} = \iint \frac{\mathrm{d}^d k_1}{i\pi^{d/2}} \frac{\mathrm{d}^d k_2}{i\pi^{d/2}} \frac{P_{f,8}^{-a_8}\; P_{f,9}^{-a_9}}{P_{f,1}^{a_1} P_{f,2}^{a_2} P_{f,3}^{a_3} P_{f,4}^{a_4} P_{f,5}^{a_5} P_{f,6}^{a_6} P_{f,7}^{a_7}}$$

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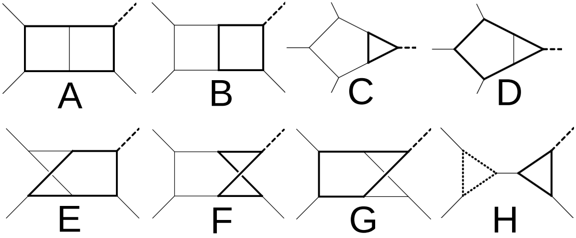
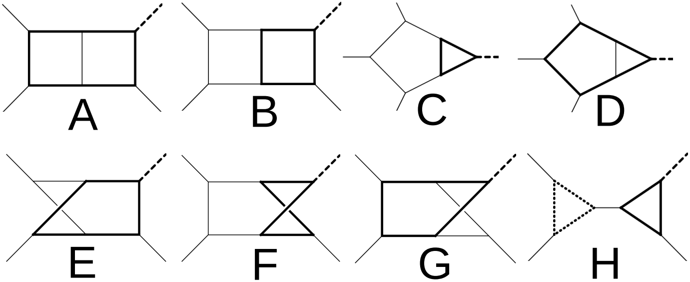
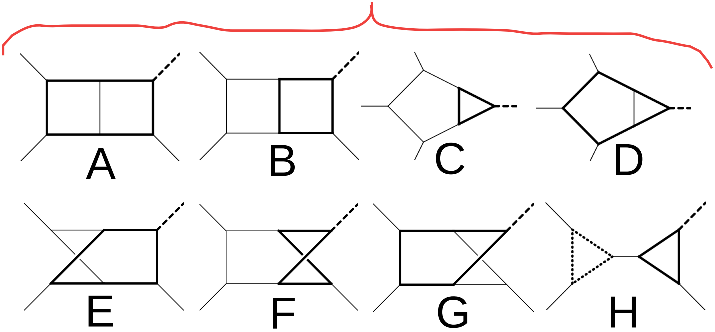
There are eight such integral families:




A
B
C
D
E
F
G
H

Bonciani, Del Duca, HF, Henn, Moriello, Smirnov
JHEP, vol. 12(2016), p. 096 [arXiv:1609.06685]



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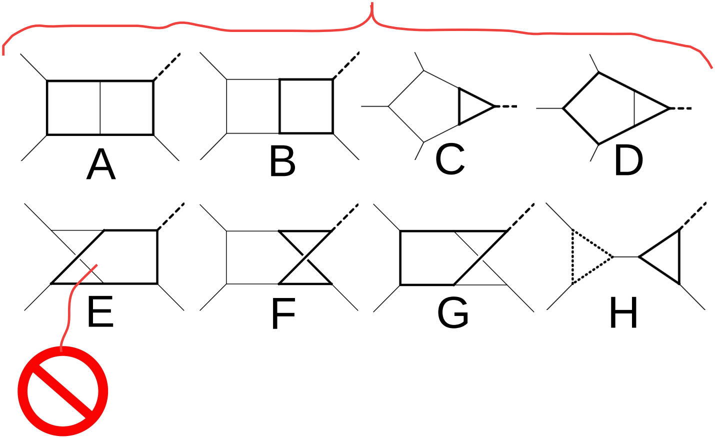

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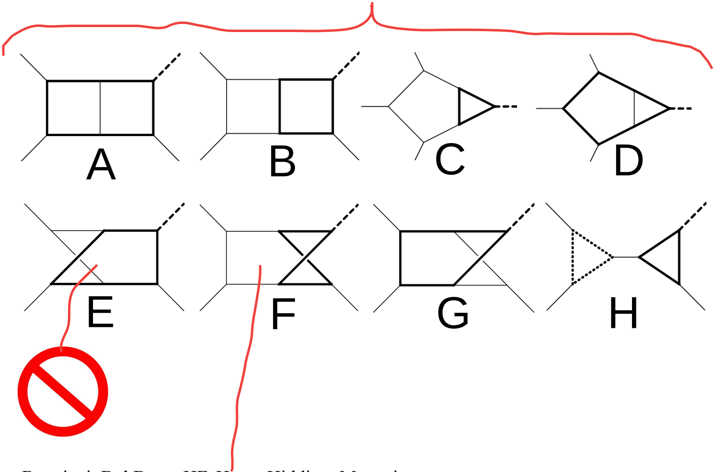

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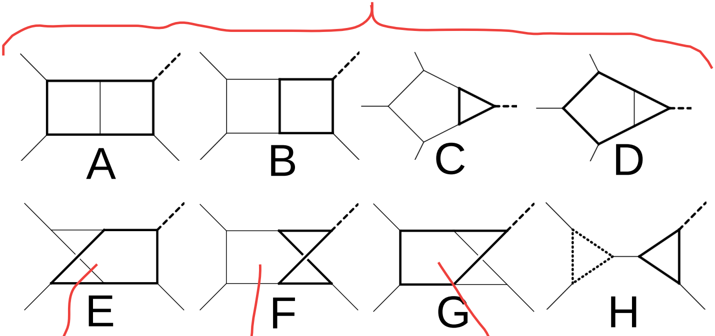
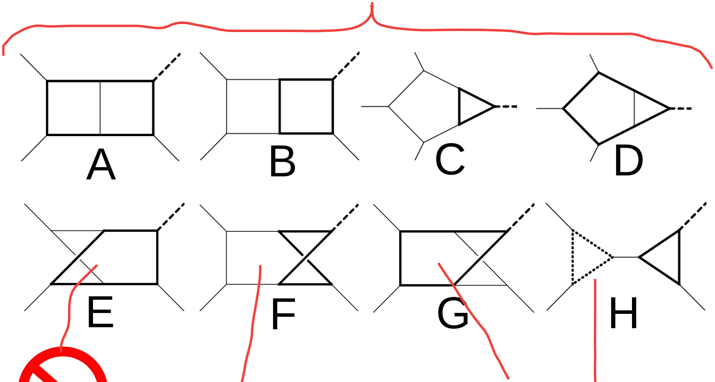


HF, Hidding, Maestri, Moriello, Salvatori
JHEP, vol. 06(2020), p. 093 [arXiv:1911.06308]

Bonciani, Del Duca, HF, Henn, Hidding, Maestri,
Moriello, Salvatori, Smirnov
JHEP, vol. 11(2020), p. 132 [arXiv:1907.13156]

Integrals

Bonciani, Del Duca, HF, Henn, Moriello, Smirnov
JHEP, vol. 12(2016), p. 096 [arXiv:1609.06685]



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$$1 \times 1$$

The computational approach is the method of differential equations

$$\partial_s f = \epsilon A f$$

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Three different "complexity classes":

1) Result given in terms of *polylogarithms* such as $\mathrm{Li}_n(x) = \int_0^x \frac{\mathrm{d}y}{y} \mathrm{Li}_{n-1}(y)$.

2) Result *looks polylogarithmic* but no closed expression can be found.

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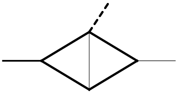
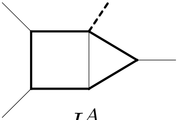
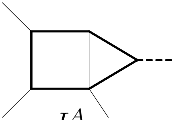
All cases present in family A



I^A_{32}



I^A_{64}



I^A_{66}

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What we actually do, is solve the diff-eqs numerically.

We use the Frobenius method: sequential series expansions near critical points
Moriello [2020], Hidding [2020]

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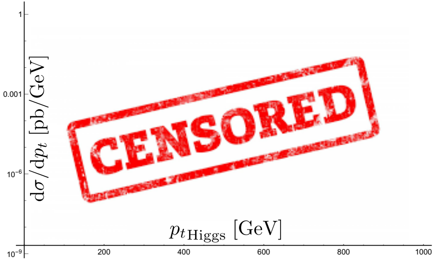

Plots for the final NLO cross section will be published this year!

What else do I work on?

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Main project: Intersection Theory and Feynman Integrals

$$J_i = \int_{\mathcal{C}} u\phi_i = \langle \phi_i | \mathcal{C}] \qquad\qquad I = \sum_i c_i J_i \Leftrightarrow c_i = \langle \phi_I | \phi_i \rangle$$

$\langle \phi_I | \phi_i \rangle$ is the *intersection number* - a pairing between differential forms

We can extract the coefficients with a direct projection!

Mastrolia, Mizera [2019]; HF, Gasparotto, Laporta, Mandal, Mastrolia, Mattiazzi, Mizera [2019,19,21]

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as well as other projects

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Thank you for inviting me,
and thank you for listening!

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