Karlsruhe Institute of Technology

Collaborative Research Center TRR 257

Particle Physics Phenomenology after the Higgs Discovery

MITP Discussion:
Machine Learning for Collider Physics
vs
Traditional Precision Calculations

13.10.2025

“Standard” Workflow to calculate Loop Amplitudes beyond NLO:

Karlsruhe Institute of Technology

automated tools

- Amplitude generation — QGRAF, FeynArts, FeynGraph
- Projection onto form factors or helicity amplitudes — alibrary, Anatar, Feynhelpers, …
- Reduction to master integrals — Reduze, LiteRed, KIRA, Blade, Ampred, …
- Calculation of the master integrals → analytically / semi-numerically / numerically

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construct a foundation model (agent) to employ these tools?

Ingredients to calculate cross sections beyond NLO:

- Loop amplitudes **analytic** expressions or **grid** from numerical evaluation or **neural network**

  Neural Network: need training data

  both, conventional grid interpolation and NN “interpolation” need reliable uncertainty estimates

- Real radiation: construction of IR subtraction terms

- Real-virtual: stable loop amplitude evaluation in IR limits

- Efficient phase space sampling → **ML?**

- Event generation → **ML?**

- Parton showering (matching needed)

ML for precision calculations

amplitudes → integration → event generation → inference

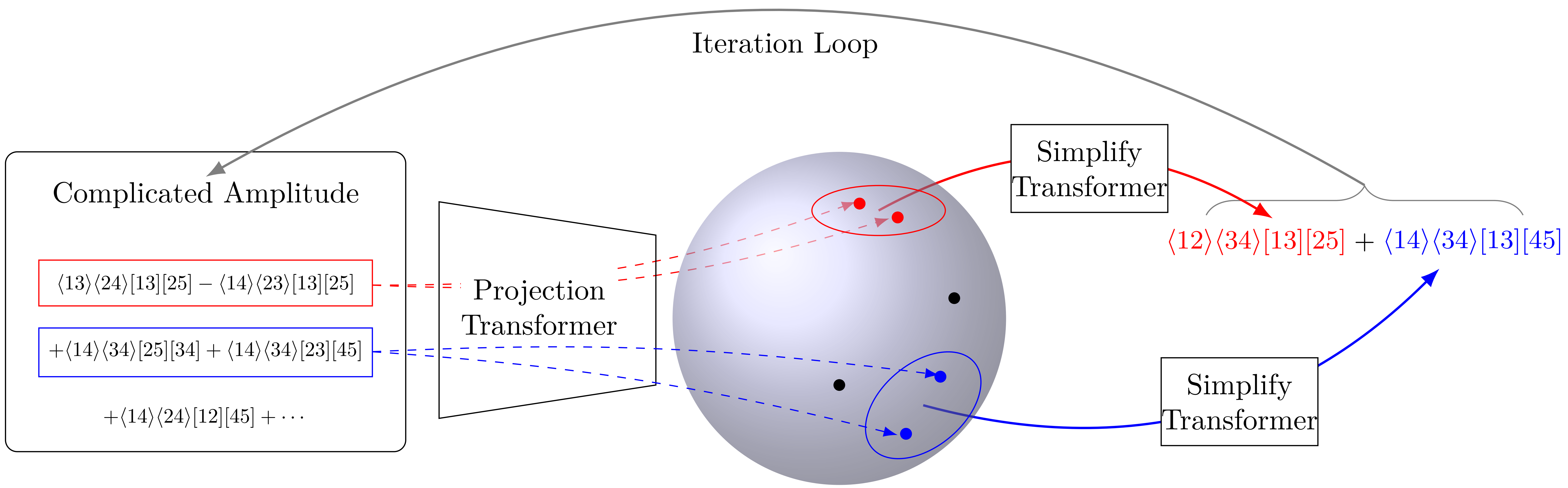
- Symbolic simplification & pattern discovery
- IBP optimisation and reduction
- Feynman-integral evaluation
- Amplitude emulators

ML for precision calculations

amplitudes → integration → event generation → inference

- Symbolic simplification & pattern discovery

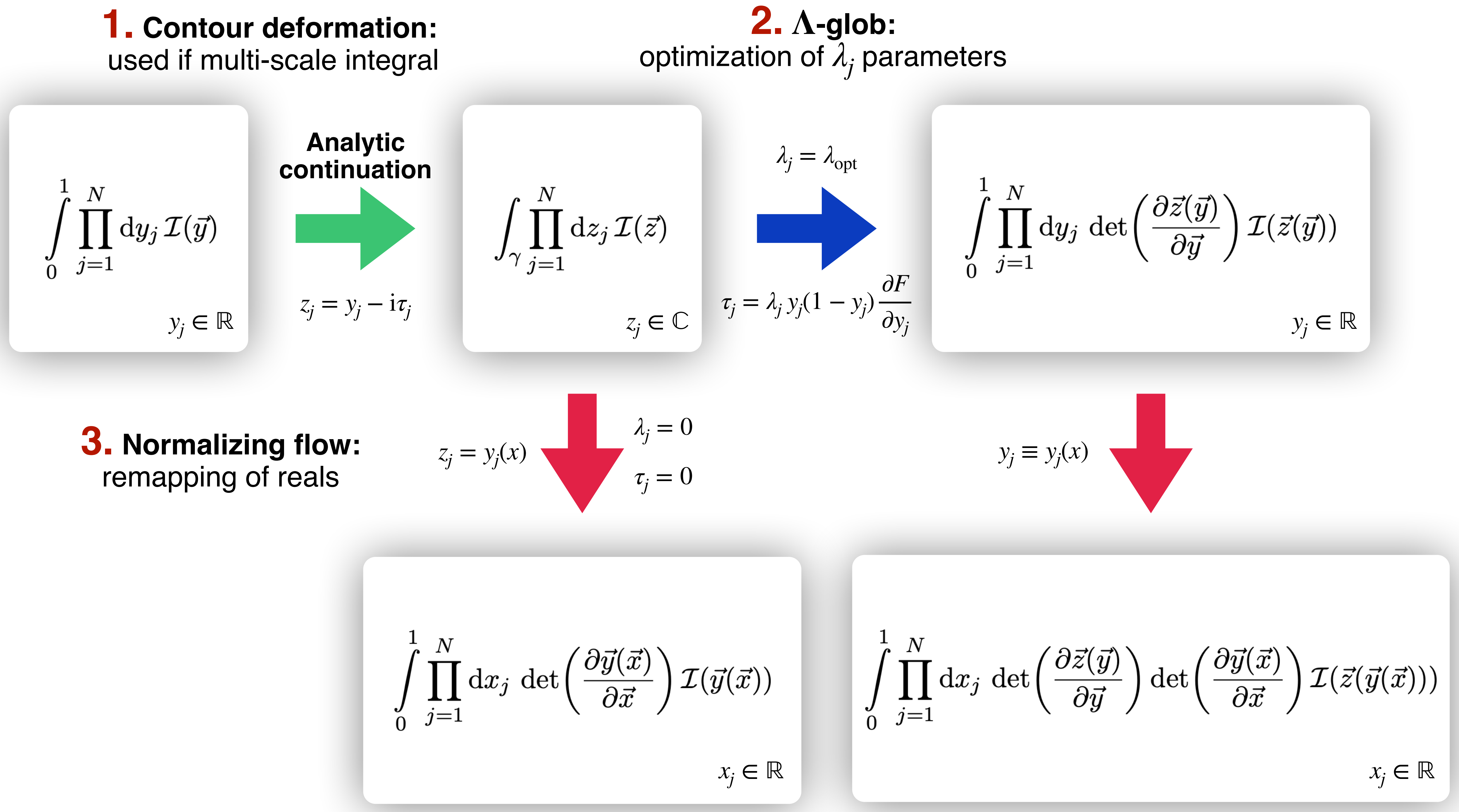
Clifford Cheung, Aurélien Dersy,
Matthew D. Schwartz.,
SciPost Phys. 18, 040 (2025)



ML for precision calculations

amplitudes → integration → event generation → inference

- Feynman-integral evaluation



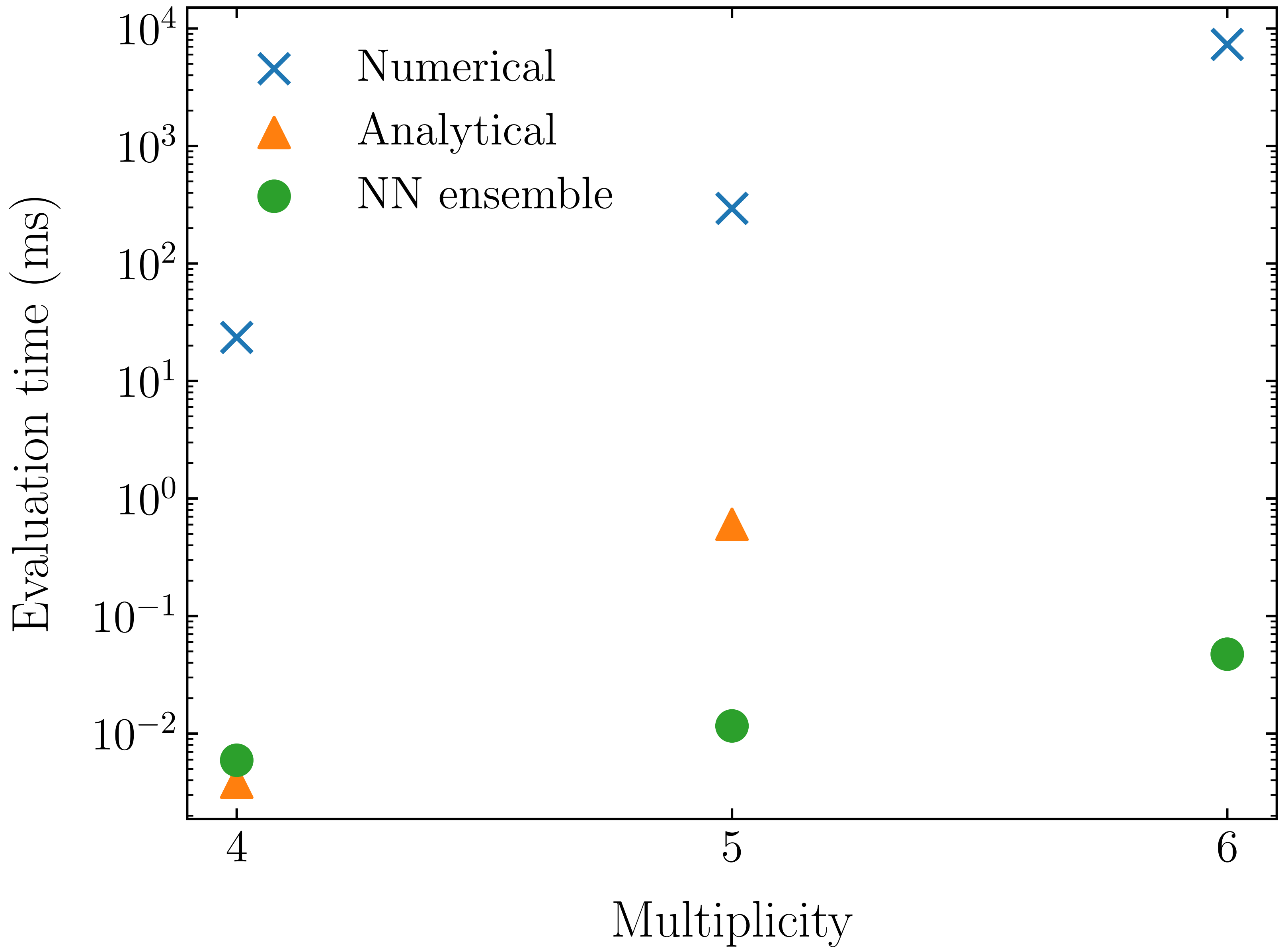
Ramon Winterhalder, Vitaly Magerya, Emilio Villa,
Stephen P. Jones, Matthias Kerner, Anja Butter,
Gudrun Heinrich, Tilman Plehn,
SciPost Phys. 12, 129 (2022)

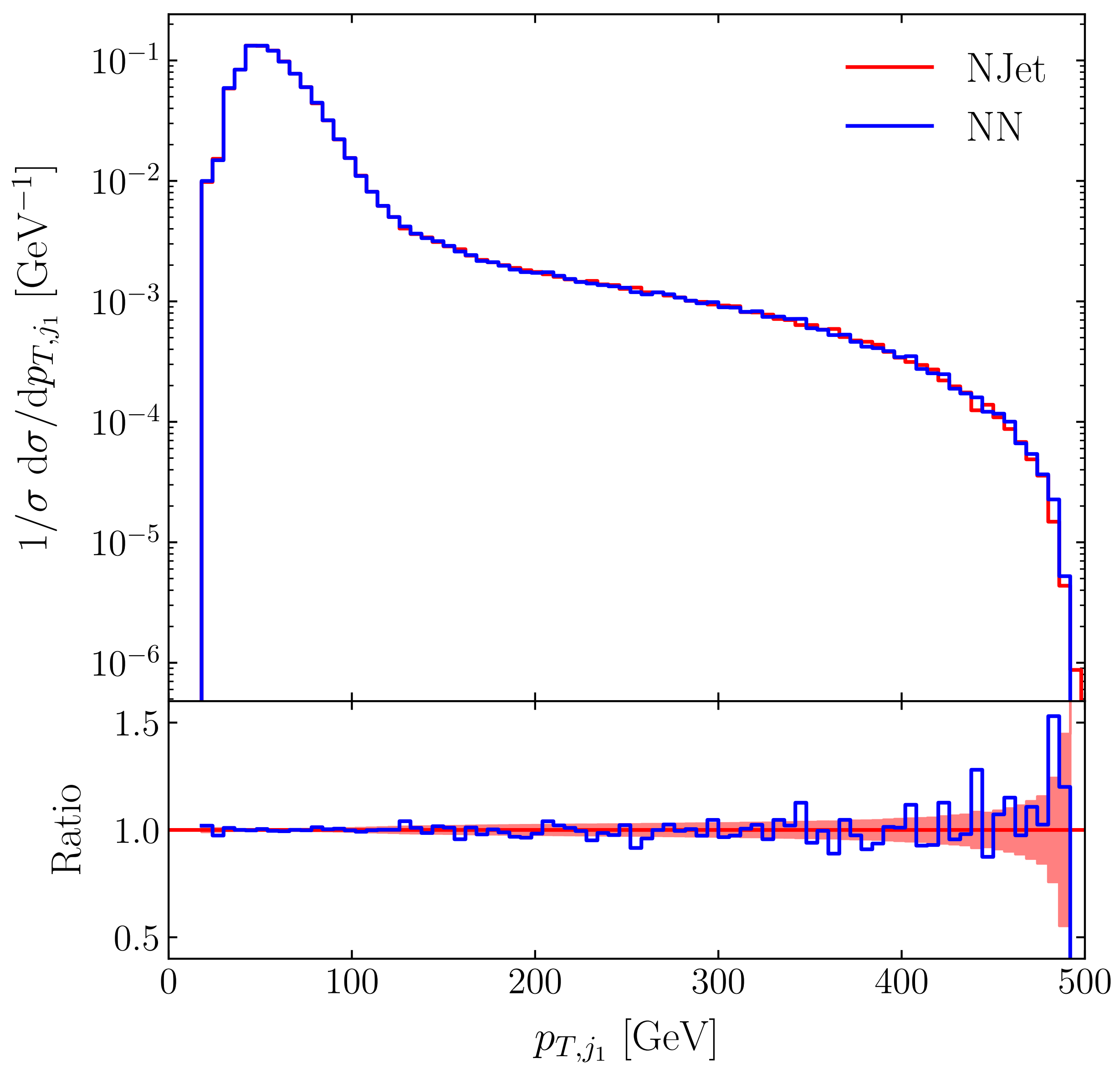
ML for precision calculations

amplitudes → integration → event generation → inference

- Amplitude emulators

Joseph Aylett-Bullock, Simon Badger, Ryan Moodie, JHEP 08 (2021) 066





ML for precision calculations

amplitudes → integration → event generation → inference

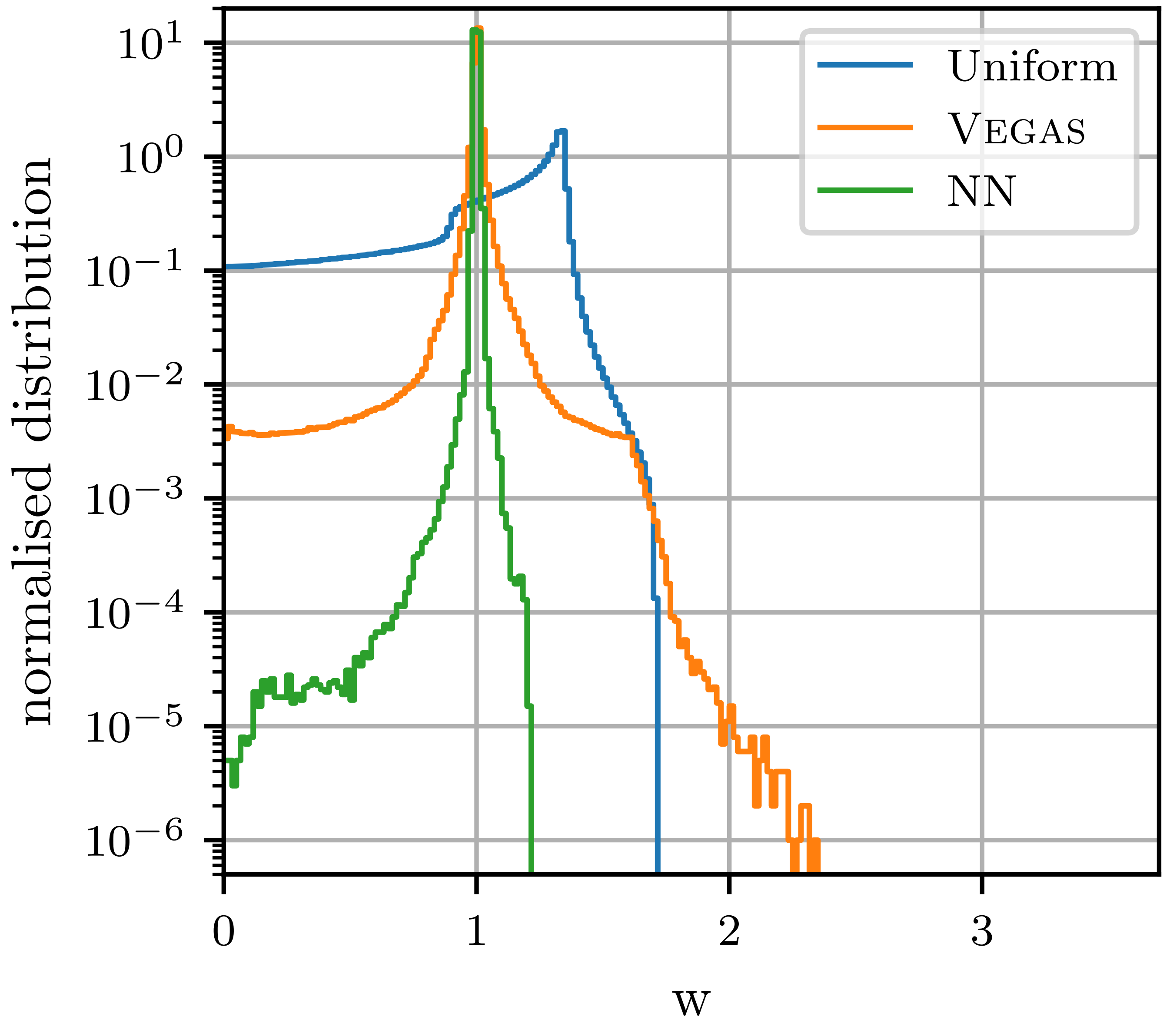
- Phase-space flows
- NNLO real emission integration

ML for precision calculations

amplitudes → integration → event generation → inference

- Phase-space flows

Enrico Bothmann, Timo Janßen, Max Knobbe, Tobias Schmale, Steffen Schumann, SciPost Phys. 8, 069 (2020)



(a) $\Gamma_{t\to be^+\nu_e}$

ML for precision calculations

amplitudes → **integration** → event generation → inference

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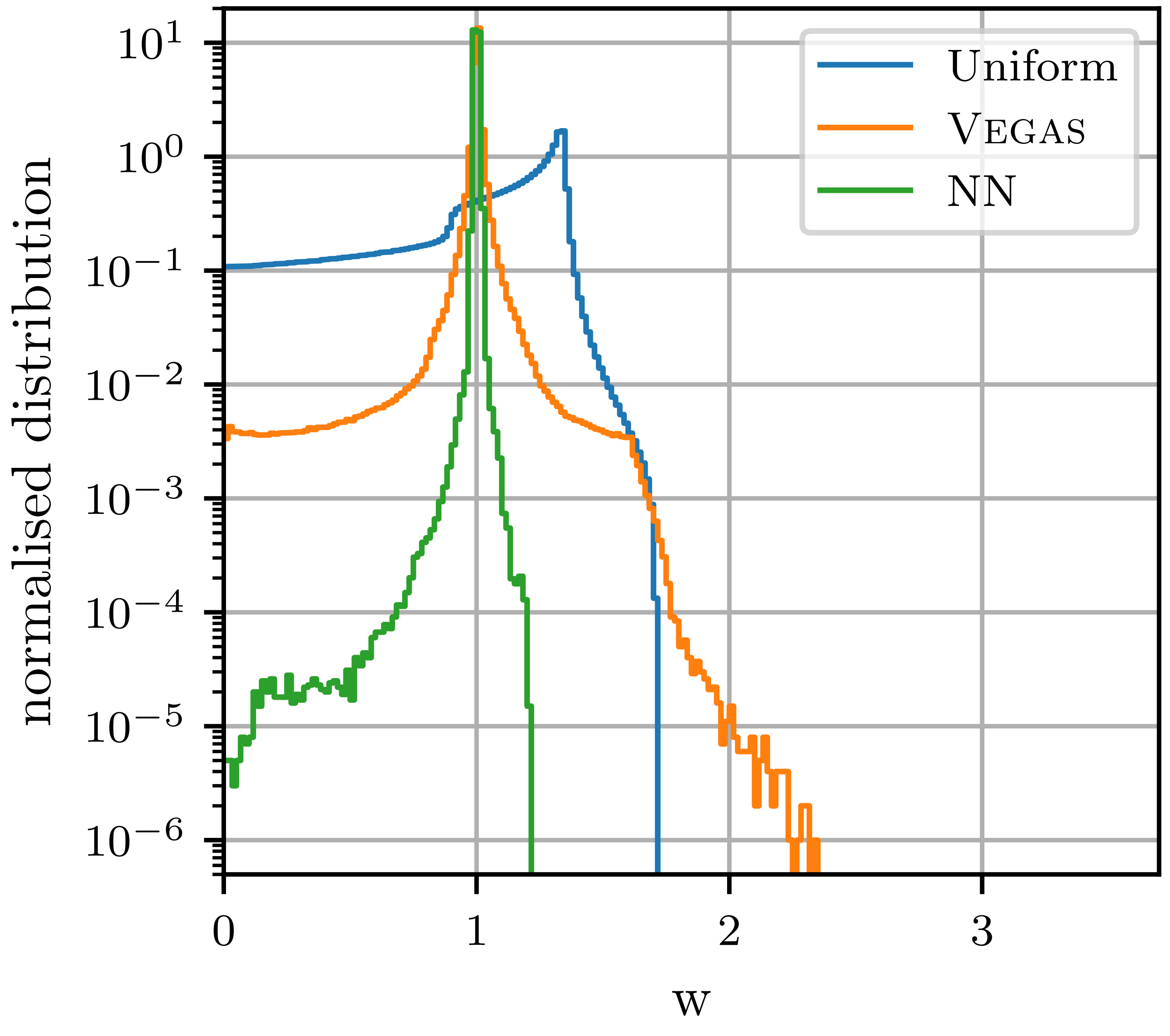
Enrico Bothmann, Timo Janßen, Max Knobbe, Tobias Schmale, Steffen Schumann, SciPost Phys. 8, 069 (2020)

Theo Heimel, Ramon Winterhalder, Anja Butter, Joshua Isaacson, Claudius Krause, Fabio Maltoni, Olivier Mattelaer, Tilman Plehn, SciPost Phys. 15, 141 (2023)



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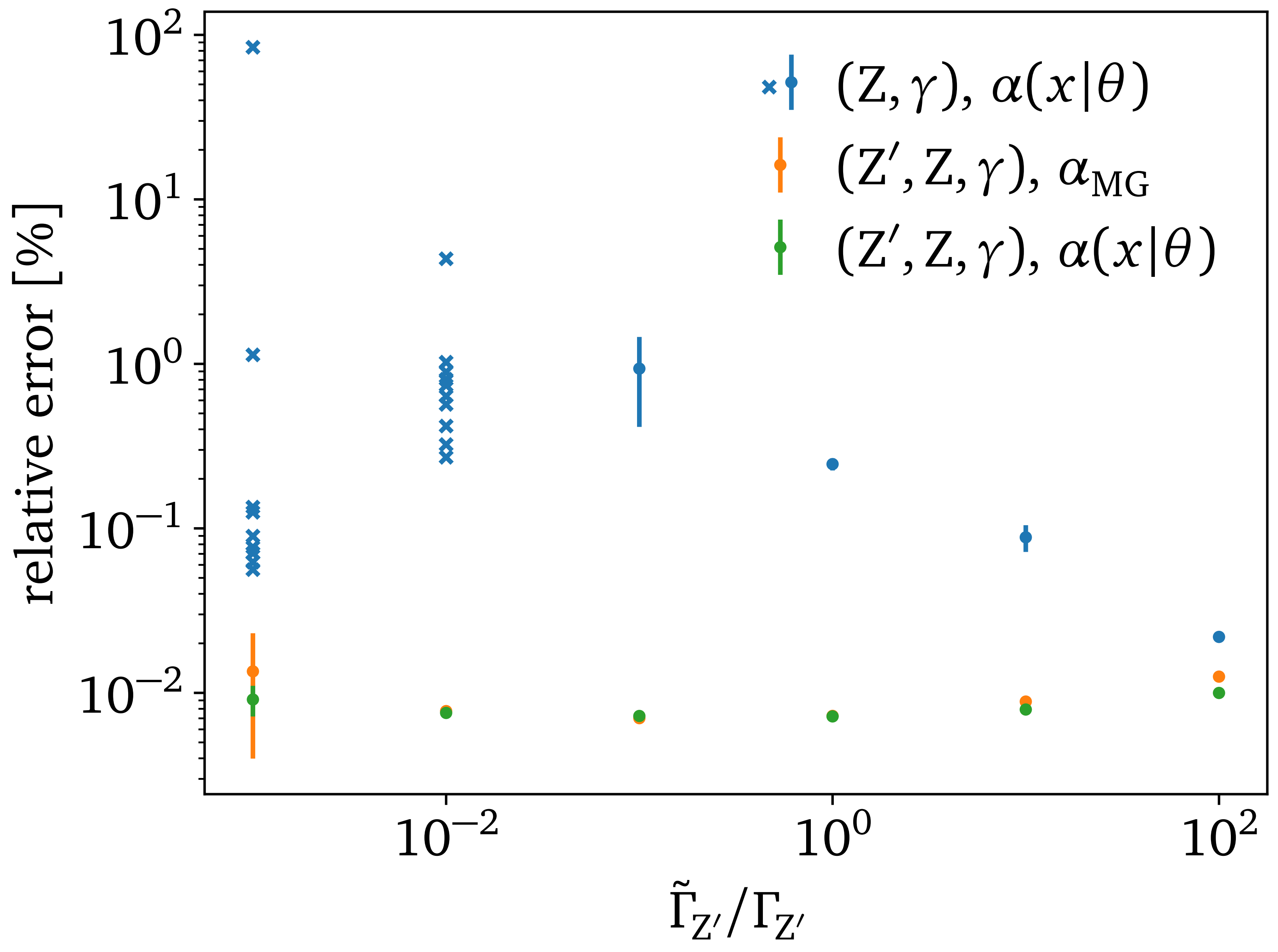


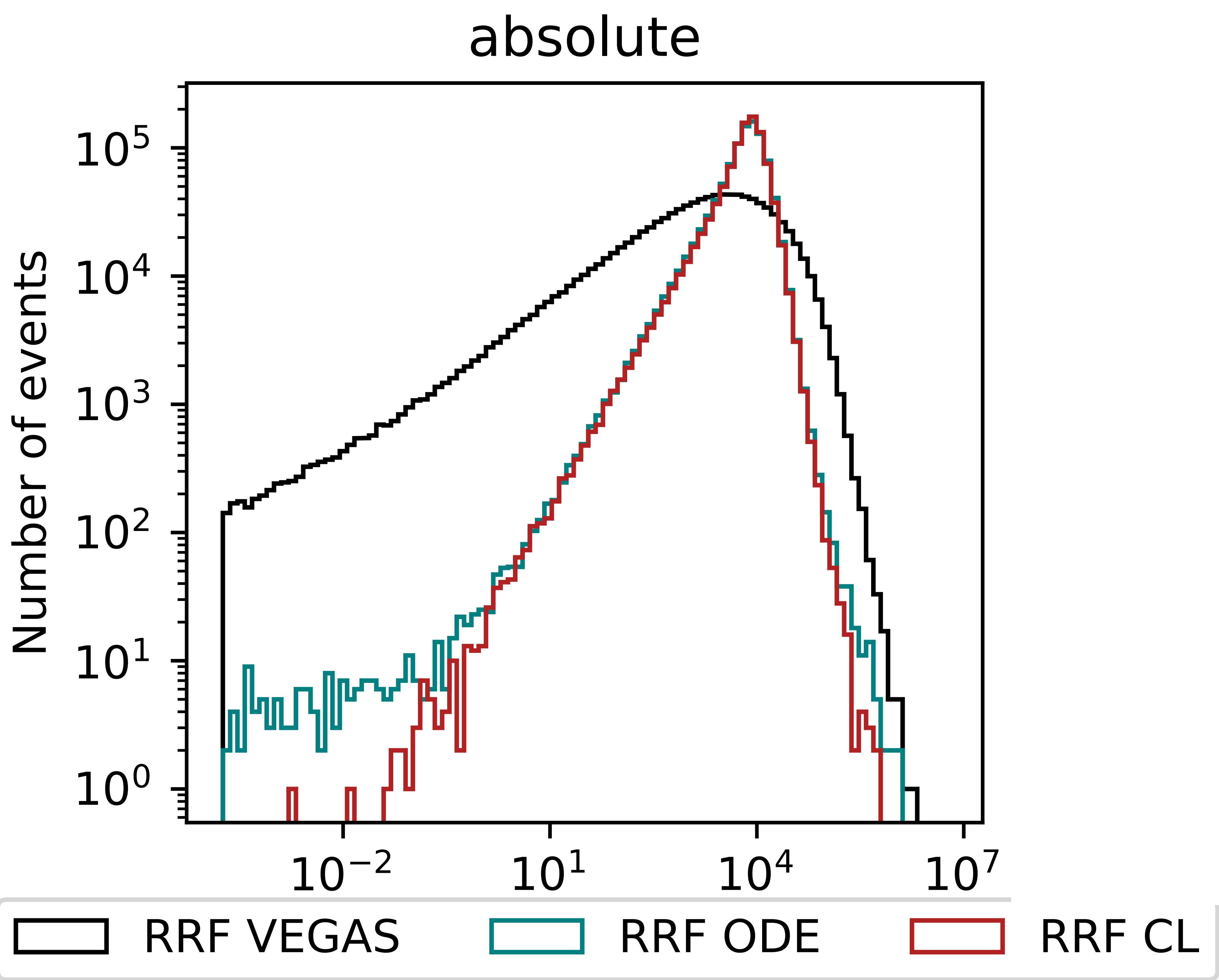
ML for precision calculations

amplitudes → **integration** → event generation → inference

- NNLO real emission integration

Timo Janßen, Rene Poncelet, Steffen Schumann,

arXiv:2505.13608 [hep-ph]



Outlook

Analytic calculations for processes beyond 2 loops and with many mass scales may hit a brick-wall

$\longrightarrow$ ML comes to rescue?

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Analytic calculations for processes beyond 2 loops and with many mass scales may hit a brick-wall

→ ML comes to rescue?

Precision that can be reached with ML methods may also hit a brick-wall

- need reliable methods
- need reliable uncertainty estimates
- physical insight usually helps a lot (e.g. flatten the data by multiplying with singular limits)

→ knowledge about physics will not become obsolete