RTG 2994

DFG
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Particle physics at colliders in the LHC precision era

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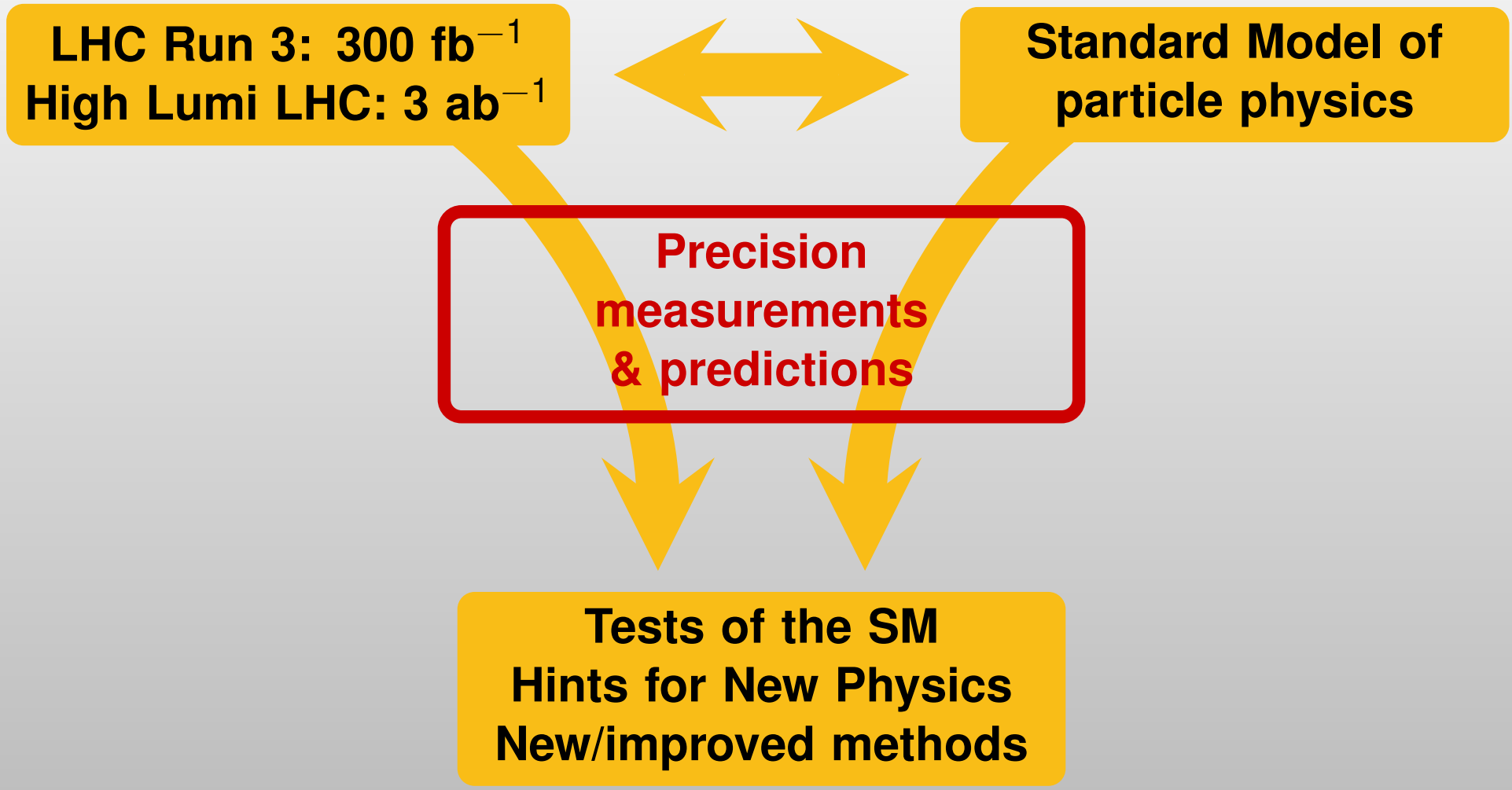
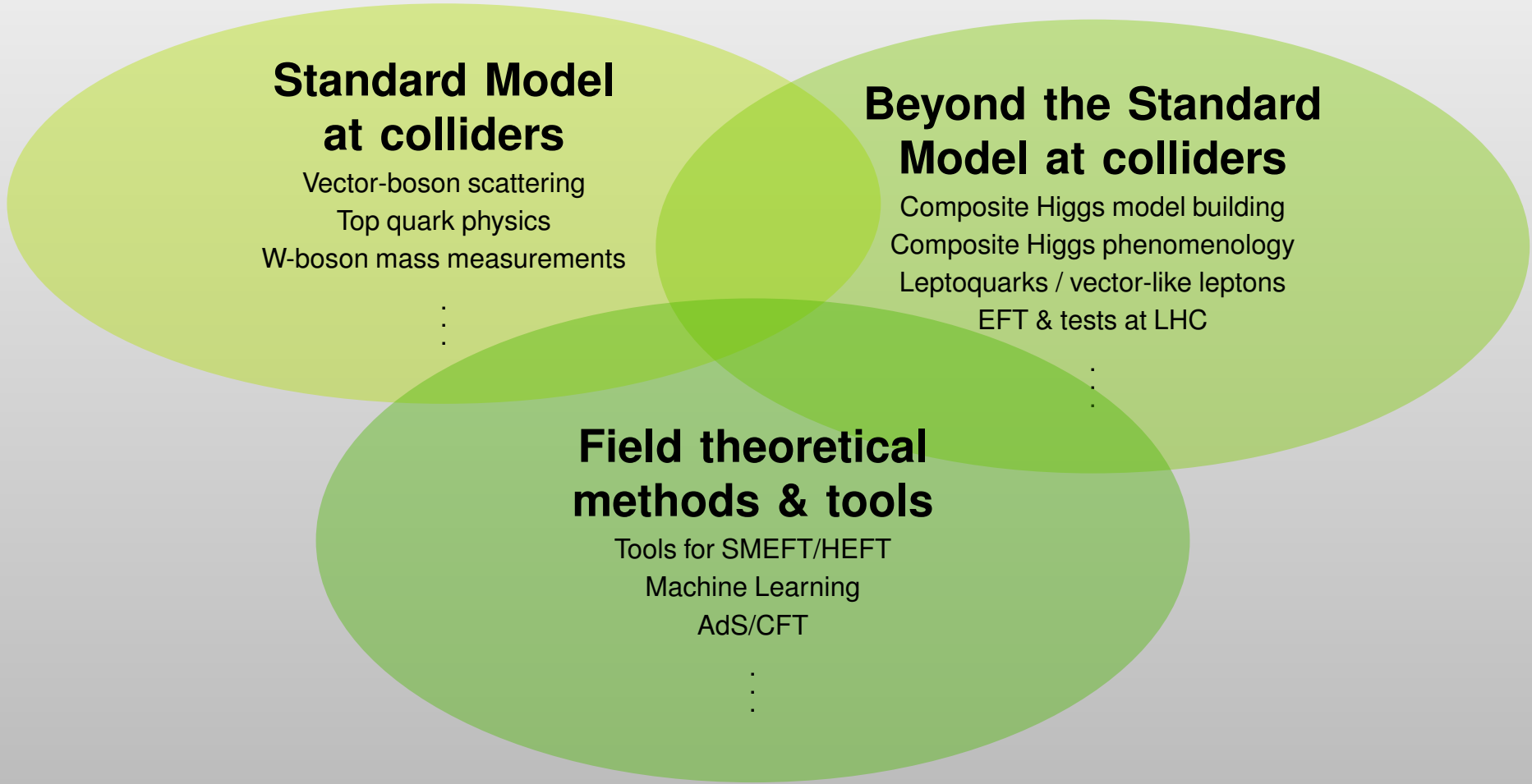
Mainz, DFG priority program roundtable
Theory Hub for Future Circular Collider e^+e^- Physics

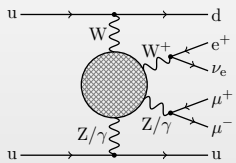
Central Research Idea

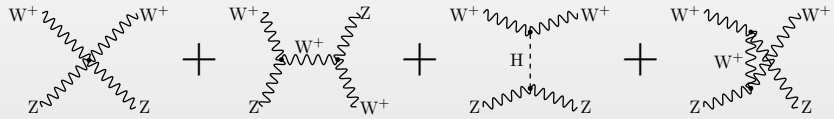


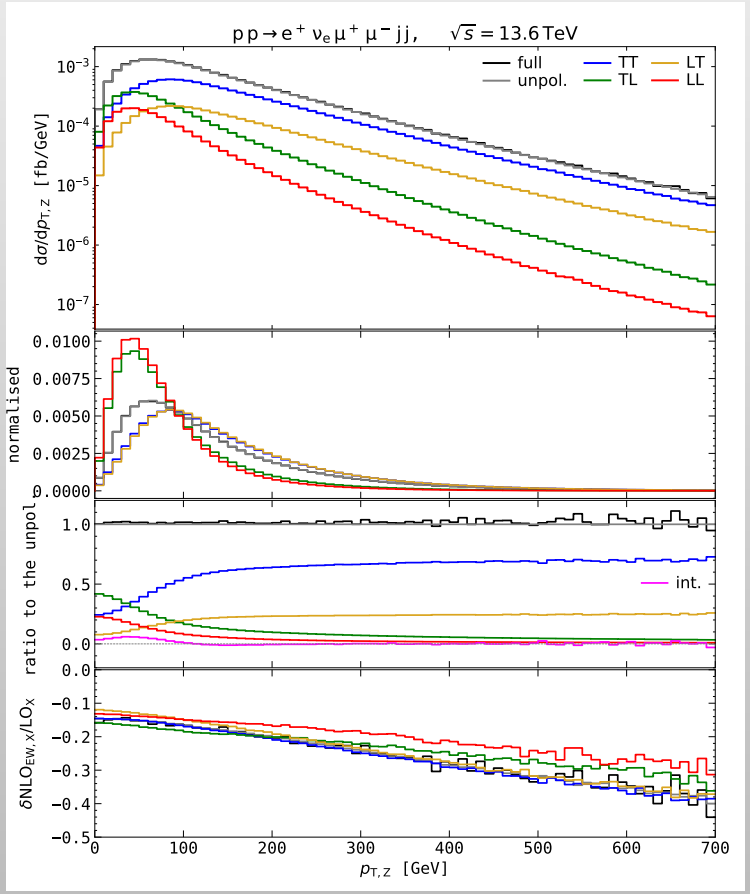
RTG 2994, research lines



Vector-boson scattering

$\mathcal{M}_{\text{VBS@LHC}} =$ 

$+ \ldots$ $\mathcal{M}_{\text{VBS}} =$ 



A. Denner, R. Franken, . . . JHEP 02 (2026) 120

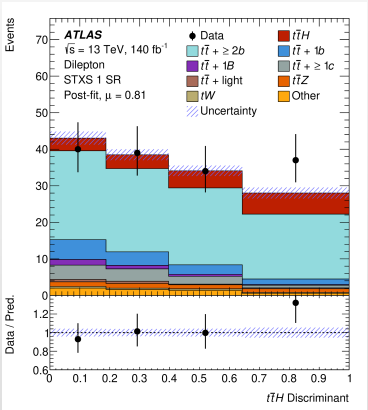
Objectives

- Combined analysis of Run-2 and Run-3 data for Wγjj, WZjj, WWjj
- Measurement of longitudinal polarisation observables of W and Z
- Electroweak corrections for longitudinal polarised vector boson scattering
- Differential correction factors for the re-weighting of events from Monte Carlo event generators

Ongoing projects

- Aryan Borkar: *Polarization studies in semi-leptonic WZ VBS process using the ATLAS Detector*
- Rosy Caliri: *Constraining Composite Higgs models via polarized VBS*

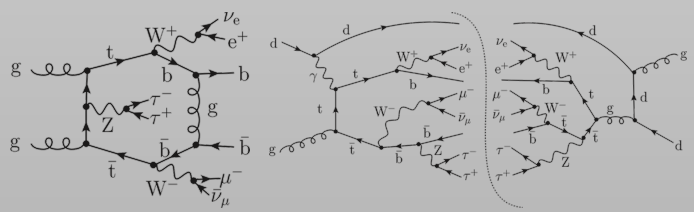
Top quark physics



ATLAS coll. EPJC 2025 85 (2025) 210

	ATLAS + CMS prelim. $\sigma \pm$(stat.)$\pm$(syst.) [pb]	theory pre. $\sigma \pm$(scale)$\pm$(PDF) [pb]
$t\bar{t}W$	$0.88 \pm 0.05 \pm 0.07$	$0.75 \pm 0.05 \pm 0.01$
	$0.87 \pm 0.04 \pm 0.05$	
$t\bar{t}Z$	$0.86 \pm 0.04 \pm 0.04$	$0.86^{+0.07}_{-0.08} \pm 0.02$
	$0.95 \pm 0.05 \pm 0.06$	
$t\bar{t}H$	$0.41 \pm 0.05^{+0.09}_{-0.08}$	$0.51^{+0.03}_{-0.05} \pm 0.02$
$\mu_{t\bar{t}H}$	$0.33^{+0.17}_{-0.16}{}^{+0.20}_{-0.21}$	

Example: fully leptonic off-shell $t\bar{t}Z$ production



Objectives

- Increase sensitivity for searches for physics beyond the Standard Model
  - Improve estimation of $t\bar{t}X$ cross-sections (X=W,Z,H)
  - Measure differential cross-sections for $t\bar{t}$+b-jets
- Investigate non-vanishing entanglement measures for top-quark pairs at the LHC using quantum information theory
- Constrain four-fermion interactions

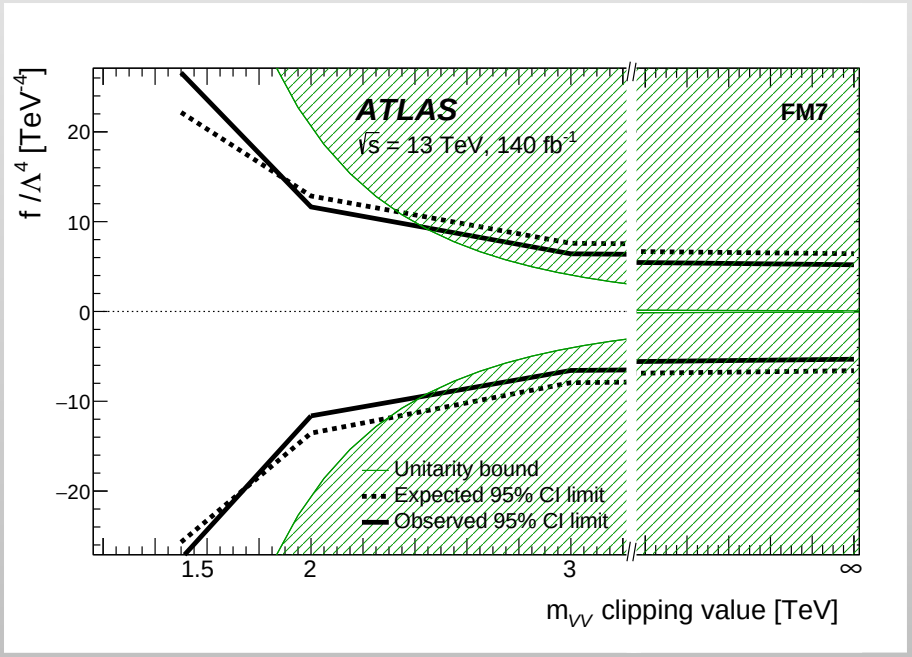
Ongoing projects

- Abderahmane Maiza: *Measurement of $t\bar{t}$ + b-jets production using Run 2 + Run 3 data*
- Philip Fredholm: *Validity of SMEFT in multi-top final states*

BSM: From experiment . . .

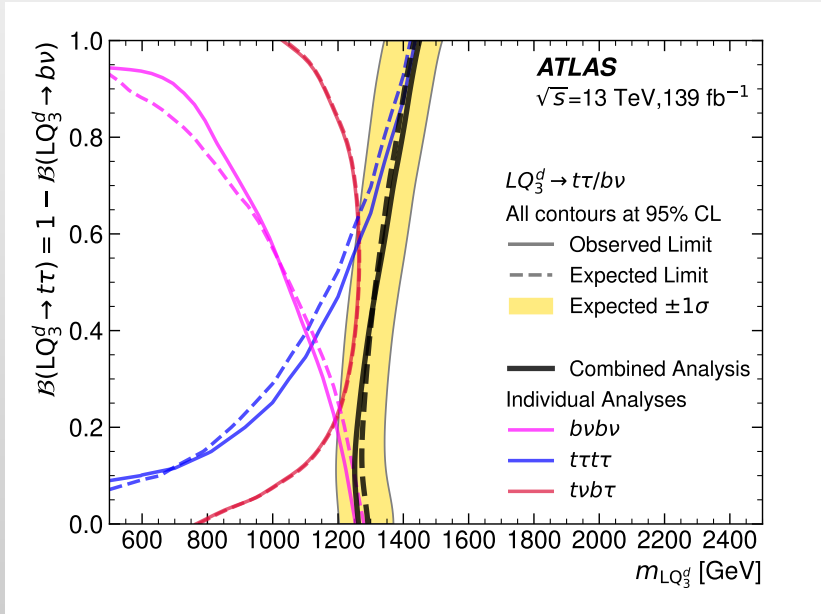
- Precision measurements $\Rightarrow$ bounds on SMEFT operators, e.g.

$$f_{M7}(D^{\mu}\Phi)^{\dagger}W_{\beta\mu}W^{\beta\nu}D_{\nu}\Phi$$



ATLAS coll., EPJC 86, 433 (2026)

- Direct searches, focus on final states with t-quarks, e.g.



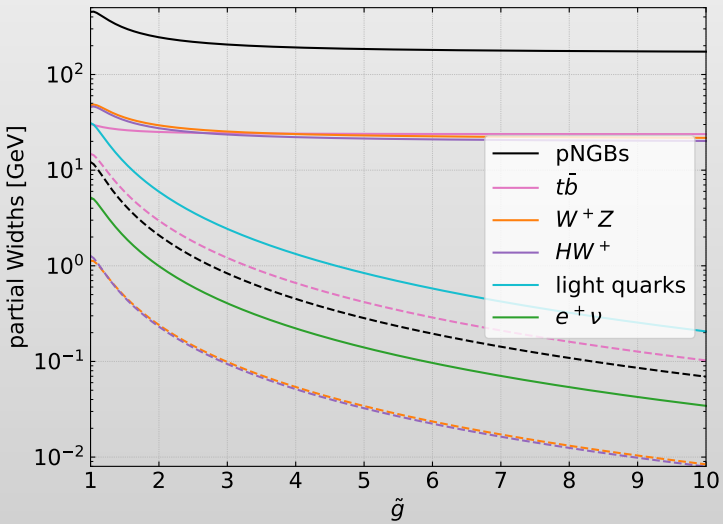
ATLAS coll., Phys. Rep. 1116 (2025) 301-385

- Reinterpretation of searches for further models
- Handling reinterpretation of searches for which ML-techniques have been used

BSM: . . . to theory

Composite Higgs (CH) models:

- Predict unusual signatures, e.g. $V^+ \to S^{++}S^- \to W^+ \bar{b}t\bar{b}t$



R. Caliri, J. Hadlik, M. Kunkel, W.P., Ch.Verollet, JHEP 04 (2025) 160

- Mass hierarchy of bound states
  - Expensive lattice calculation only for few models
  - Gauge/gravity duality applied to simplified CH models, predict e.g. $M_B \lesssim (0.3-0.5)M_V$ if $Y_t \simeq 1$

Objectives

- Phenomenology of realistic CH models with focus on unusual signatures
- Study quantitatively the cross-over region between SMEFT/HEFT and UV completions
- Investigate dark matter in CH model
- Predict mass hierarchies of realistic CH models using gauge/gravity duality
- Explain Standard Model fermion masses within CH models

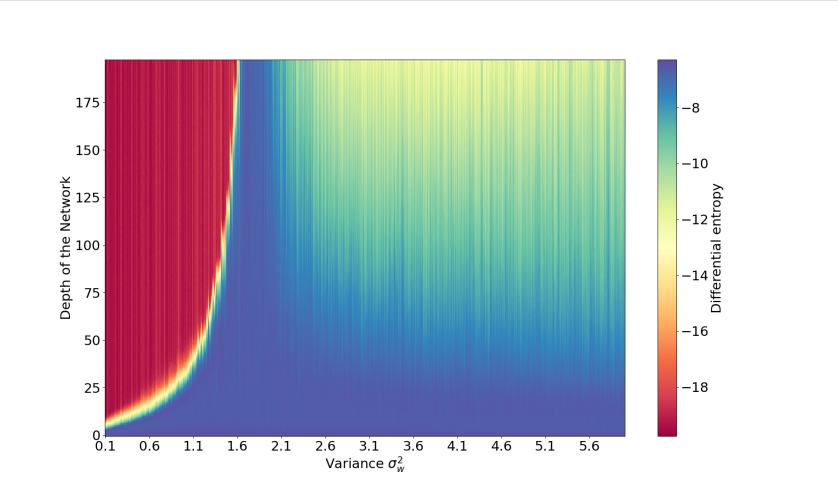
Ongoing projects:

- Konrad Becker: *Non abelian fermionic actions for an AdS/CFT setup*
- Rosy Caliri: Phenomenology of spin-1 resonances at the LHC
- Yu Chen: *Dark matter aspects of Composite Higgs models*
- Jan Hadlik: *Supersymmetric UV completions of Composite Higgs models*

Machine Learning

Use field theoretical methods for quantifying learning of Neural Networks to improve Machine Learning

- Apply renormalisation group inspired measures (e.g. relative entropy) to predict trainability of feedforward neural networks

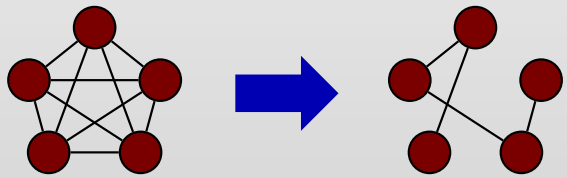


Y. Thurn, J. Erdmenger, R. Jefferson, arXiv:2406.12916

- Use information theoretic measures from AdS/CFT to quantify information propagation in hyperbolic neural networks

Use Machine Learning to improve capabilities of tasks in particle physics

- Investigate use of sparse graph networks and hyperbolic networks for jet tagging



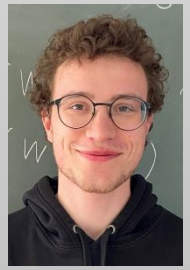
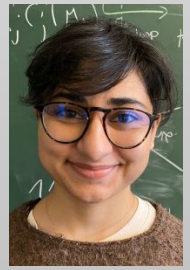
- Use neural networks as universal approximators to construct optimized phase space mappings in Monte Carlo generators

Ongoing projects

- Abderahmane Maiza: *Machine learning based identification of* $\mathfrak{b}$*-jet origin*
- Maximilian Gaschler: *Information geometry techniques for machine learning*

RTG 2994, who we are

Started in January 2025

Main Topics: SM + BSM LHC physics with focus on precision