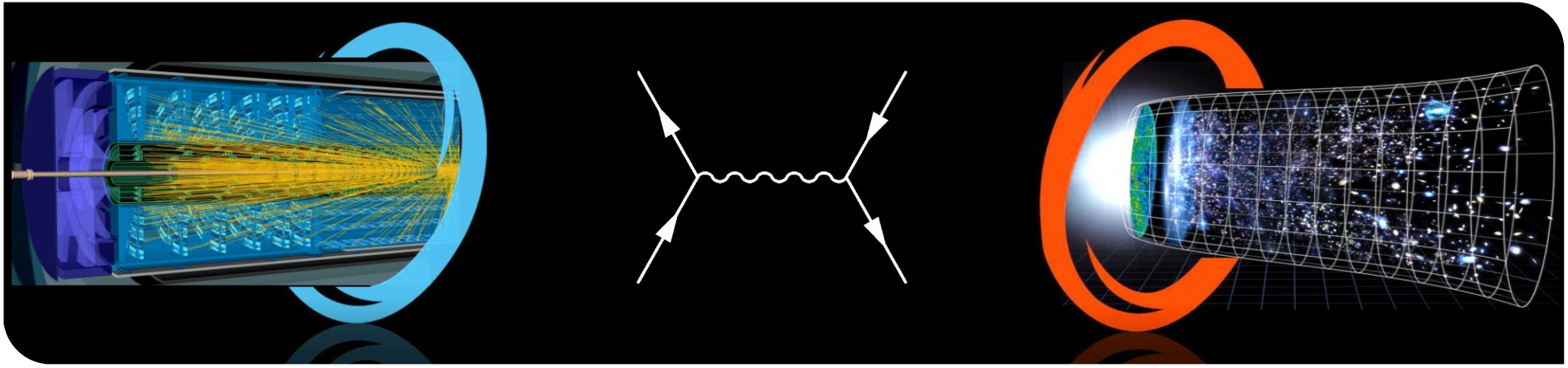
Karlsruhe Institute of Technology

Physics Beyond Colliders

KIT theory plans for PoF V

Felix Kahlhoefer

PoF V MU-FPF Retreat, 20 June 2025



Quick comment: Funding sources

- Theoretical particle physics at KIT funded by
  - **MU-FPF: Felix Kahlhoefer, Monika Blanke + postdoc positions**
  - MU-MRU: Thomas Schwetz + group
  - University: Biekötter, Gieseke, Heinrich, Melnikov, Mühlleitner, Nierste, Steinhauser + postdoc positions and PhD students
- Experimental particle physics at KIT (CMS, Belle II) funded by university
- Experimental astroparticle physics at KIT (KATRIN, …) funded by MU-MRU

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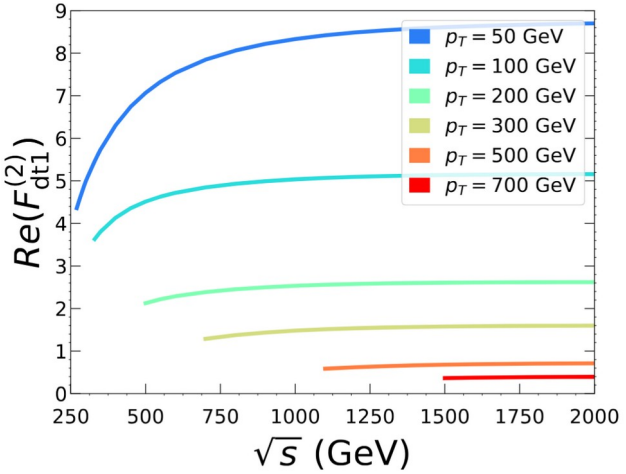
PoF V: Precision physics

Main objectives: Provide the theory predictions needed to determine the properties of the Higgs boson and test the Standard Model with unprecedented precision

- Precision predictions for LHC and flavour experiments
  - Higher-order corrections for Higgs production
  - Fundamental structure of QCD
  - New physics in flavour observables

- New research directions:
  - Advanced computational methods and machine learning
  - Effective field theories (for SMEFT and light BSM)
  - Precision at future colliders



- Important milestone: Third funding period for Collaborative Research Centre TRR257

Impact: World-leading research of essential importance for the success of ongoing experiments

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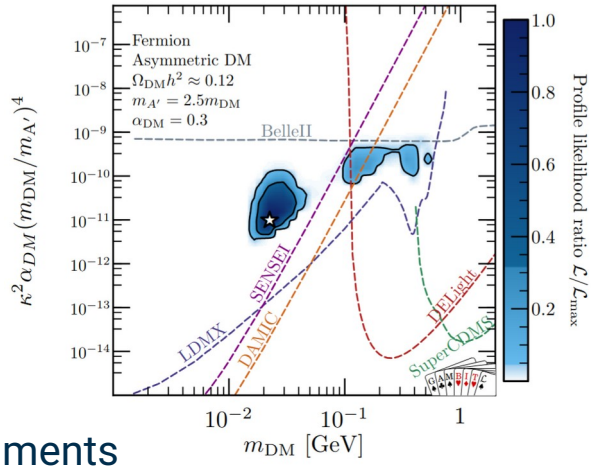
Beyond Standard Model physics

Main objectives: Provide new-physics models for and interpretation of experiments

- Extended Higgs sectors
  - LHC searches
  - Connections to phase transitions and baryogenesis
- Dark matter phenomenology
  - Dark matter at colliders
  - Low-threshold direct detection experiments (DELight)
  - Reinterpretation and global fits
- New research direction: Long-lived particles at beam-dump experiments
  - Production and decay modes of GeV-scale particles (ALPs, dark photons etc.)
  - Models and benchmarks for SHiP, FASER, NA64 (and maybe LUXE-NPOD)



Impact: Develop optimal strategy to maximize the chance of a ground-breaking discovery

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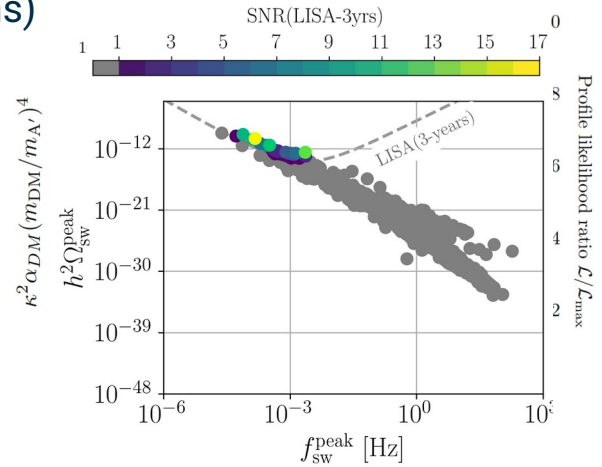
Particle-cosmology connection

Main objectives: Explore implications of dark sector models for astrophysics and cosmology

- Dark sector gravitational waves from phase transitions
  - Computational tools (TransitionListener, BSMPT, lattice simulations)
  - Interpretation of NANOGrav and benchmarks for LISA
- Dark matter nightmare scenario
  - Dark matter evolution beyond thermal equilibrium
  - Astrophysical constraints on dark matter self-interactions
  - Bounds from BBN, spectral distortions, Ly-α forest, 21cm
- Machine-learning applications
  - Neural network emulators for cosmic ray propagation
  - Simulation-based inference for dark matter models



Impact: Build bridges between communities to share and combine complementary information

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Summary

- Theory group at KIT works closely with experiments and observers to provide precision predictions, models of BSM physics and interpretation of results
- Crucial input for HL-LHC (ATLAS, CMS, LHCb), Belle II and SHiP
- World-leading expertise and visibility in Higgs physics, flavour and dark matter
- **New directions:** Machine learning, long-lived particles, gravitational waves
- Many links to MU-FPF@DESY and MU-MRU
- **Central goal: Facilitate discoveries in upcoming experiments**

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