GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

ATLAS EXPERIMENT

Machine Learning Activities in Top Quark Physics

Göttingen Group Report

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IDT-UM Collaboration Meeting, KIT
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Overview

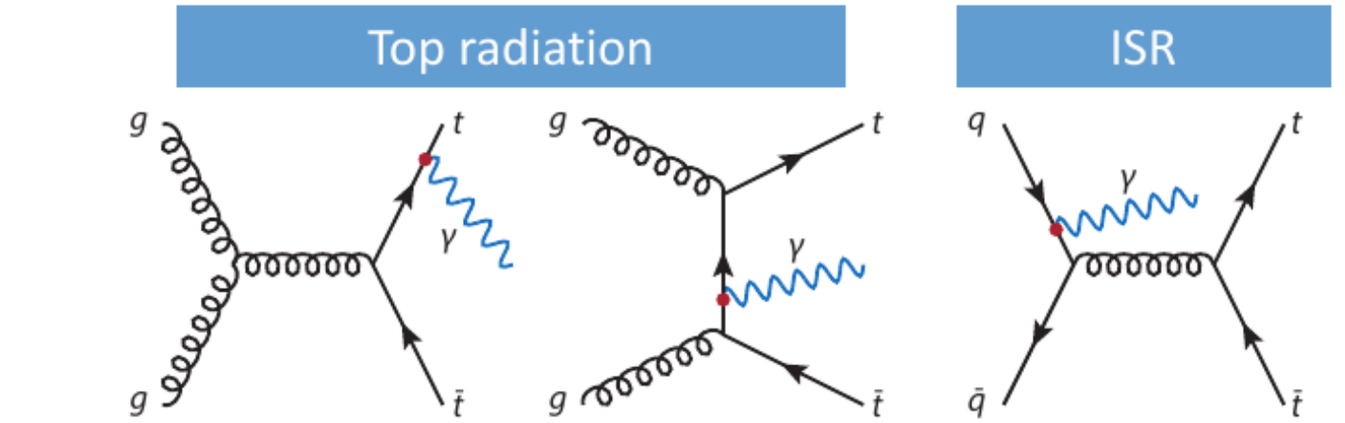
- Our aim: precise measurements of top quark properties

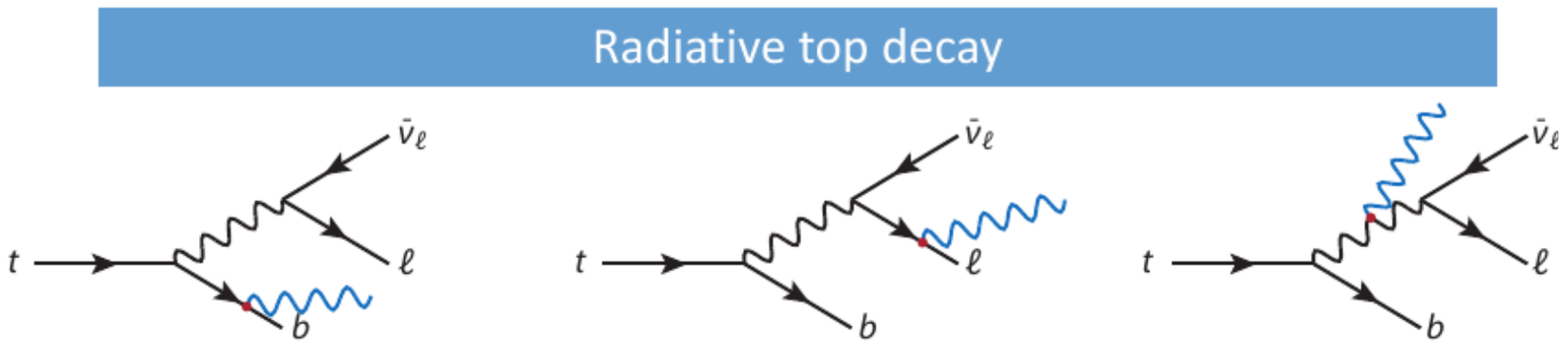
- Broad spectrum of analyses in our group:
  - W helicity
  - $t\bar{t}$+photon
  - $t\bar{t}$+W/Z
  - $t\bar{t}$+Higgs
  - Top quark width
  - $t\bar{t}$ kinematic reconstruction (KLFitter)
  - Effective field theory interpretations

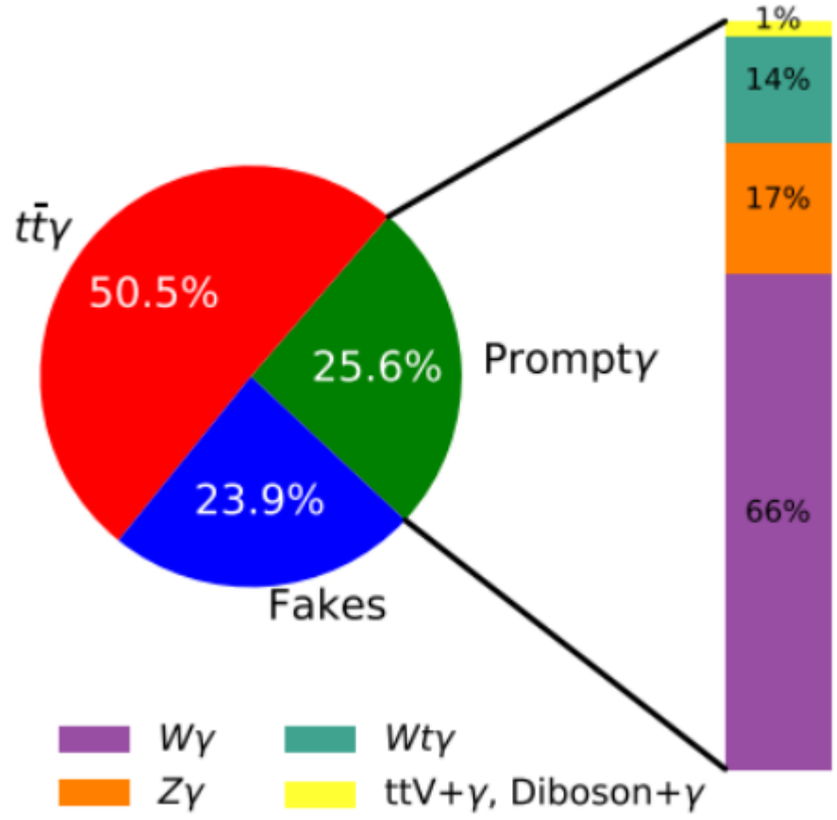
- Machine learning used to squeeze out most information from data
- Involved in several new developments of machine learning applications
- Machine learning important part of lectures/teaching

Example: $t\bar{t}+\gamma$

- tt+photon production sensitive to electroweak coupling of the photon



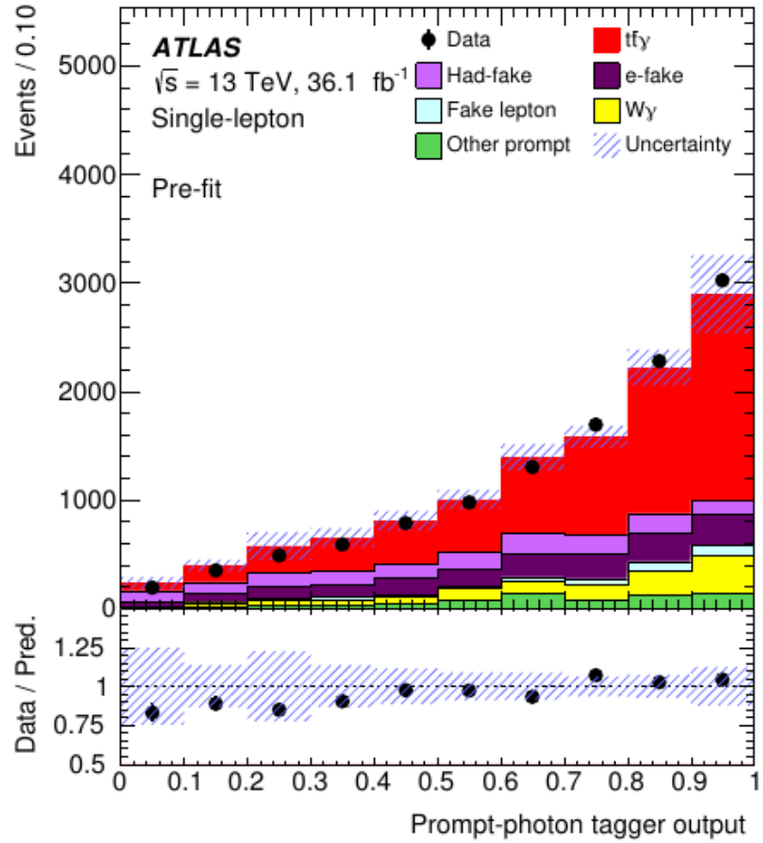


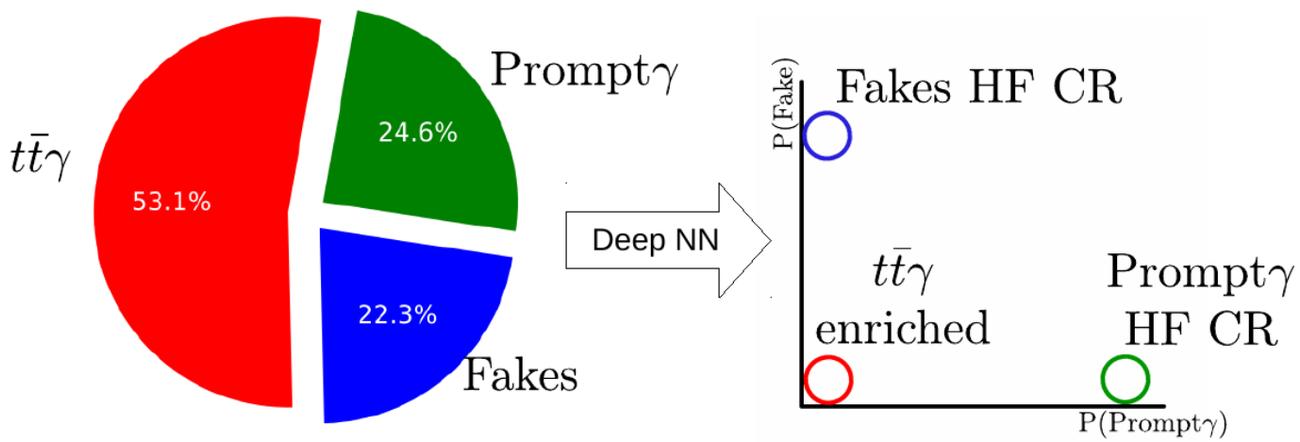


- Application of machine learning:
  - Identification of prompt photons
  - Multi-class classification of signal and background processes
  - Differentiation of photon origin

Example: $t\bar{t}+\gamma$

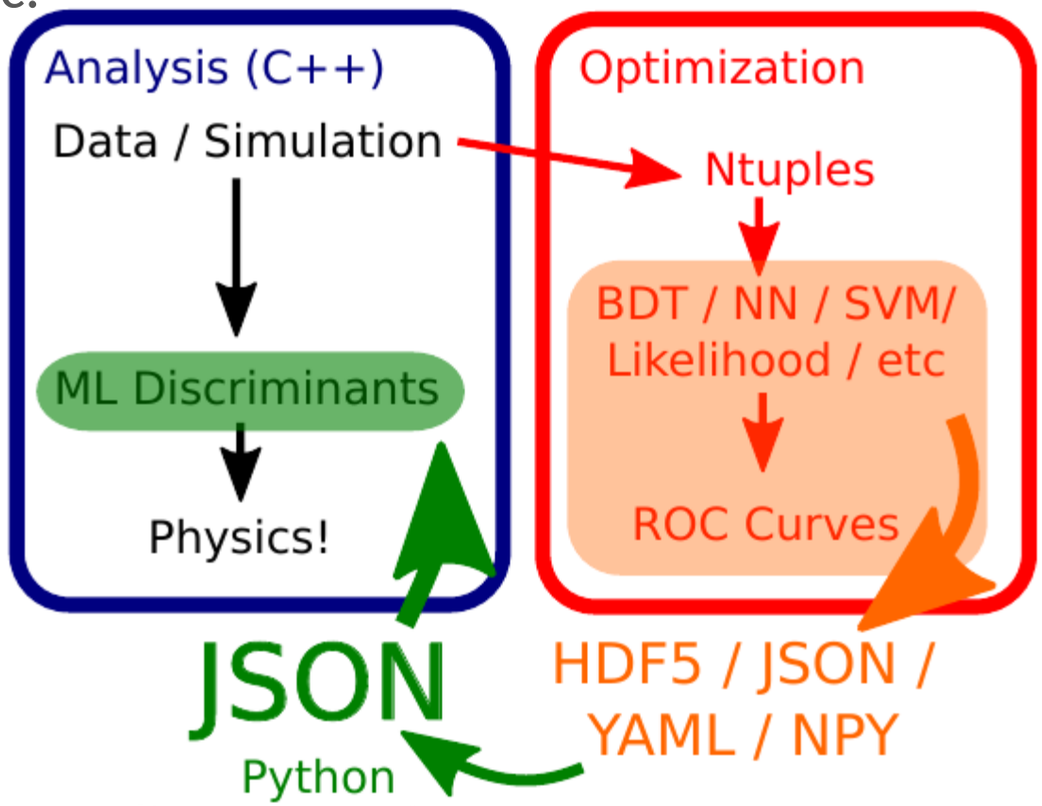
- Developments in our group:
  - Prompt Photon Tagger (PPT) using sower shape variables in a NN to identify prompt photons (master thesis B. Völkel, II.Physik-UniGö-MSc-2017/07)
  - Event-level discriminator: NN to distinguish signal from background (PhD thesis J. Smith, II.Physik-UniGö-Diss-2018/01)
  - Both published in Eur. Phys. J. C 79 (2019) 382
- Recent developments:
  - Differentiate photons radiated from top from initial and final state radiation (master thesis A. Kichhoff, II.Physik-UniGö-MSc-2018/04)
  - New multi-class approach with deep NN to classify backgrounds (master thesis S. Korn, ongoing)





lwtnn

- Software R&D project: developed with contribution from our group (J. Smith)
- Idea: training and testing can be separated:
  - Often: training in complex environment
  - Testing/application: trained network has to be applied to new data, i.e. in new analysis, for many systematics, on trigger level, etc.
  - Application should often run with limited CPU usage

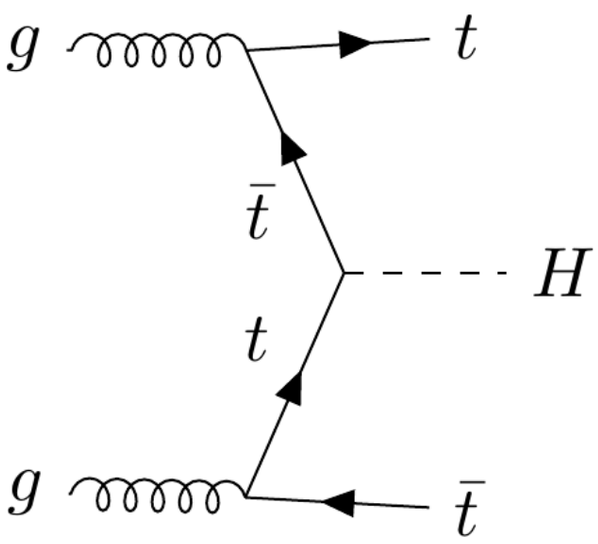


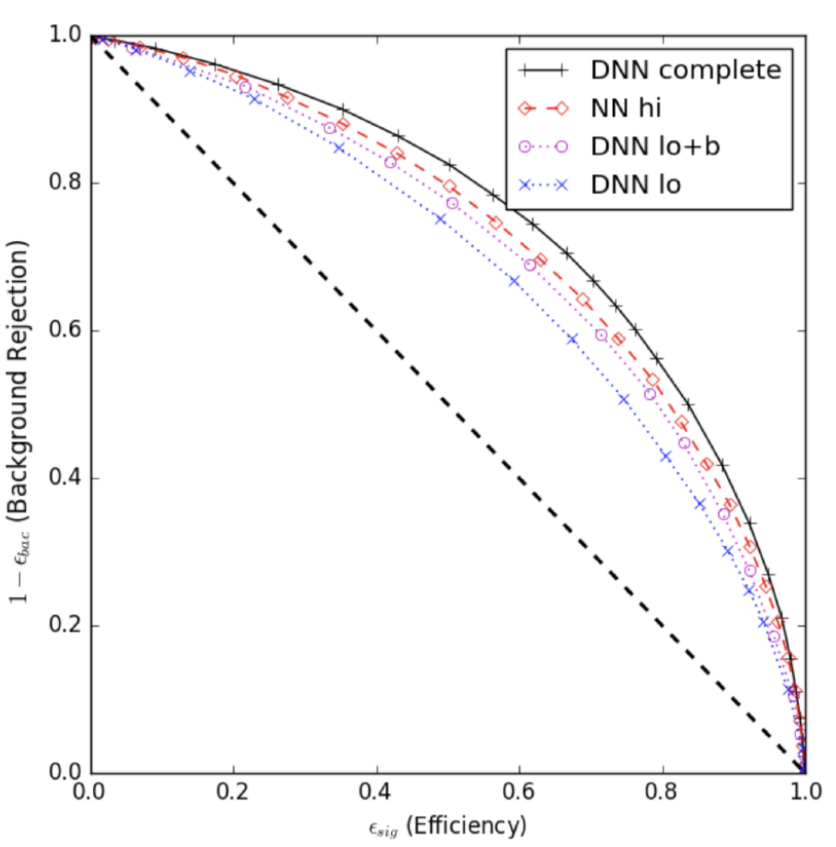
- lwtnn (LightWeight Trained Neural Network):
  - Converts saved NNs to JSON format for several popular formats (Keras, Scikit Learn, etc.)
  - Reconstructs NN from JSON file
  - Run NN in fast/light-weight C++ code

    → reduces CPU time significantly if NNs have to be applied many times
  - Available at: https://github.com/lwtnn/lwtnn
  - experiment independent: can be used in any generic ML application

Search for $t\bar{t}$+Higgs

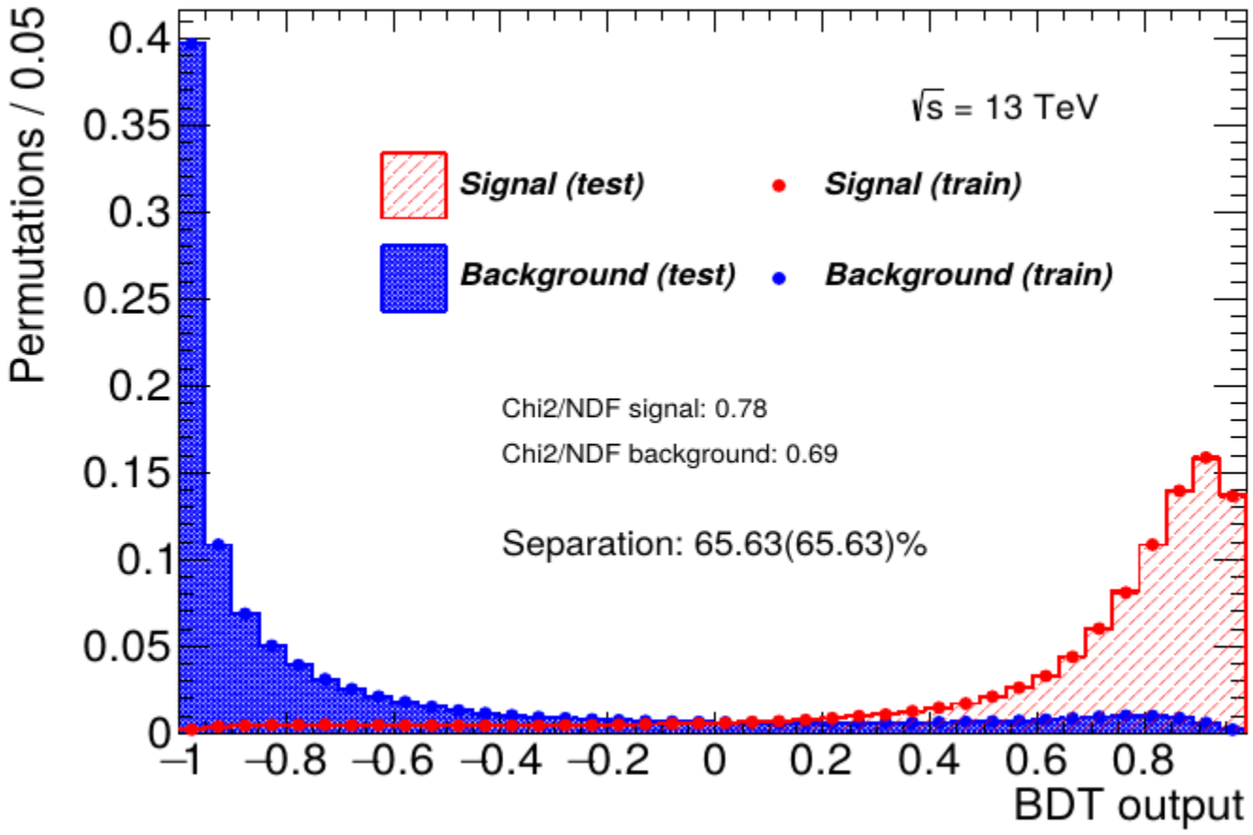
- Multivariate techniques essential to extract small $t\bar{t}H$ signal from background
- Various ML approaches have been studied:
  - BDTs, shallow and deep NNs
  - Various kinds of input variables: low-level, high-level objects, matrix element reconstruction
  - Topic of several PhD thesis (O. Nackenhorst, L. Serkin, M. Mantoani, J. Mellenthin)
  - Finally published $t\bar{t}H$ observation last year:, Phys. Lett. B 784 (2018) 173)





Other Applications

- Multivariate techniques are used/developed in several other analyses in our group:
  - Kinematic reconstruction with a likelihood fit (KLFitter): Choice of correct reconstruction hypothesis can be improved with a BDT (PhD thesis T. Dado, II.Physik-UniGö-Diss-2019/05, used for top-width measurement, ATLAS-CONF-2019-038)



Teaching Activities

- **New lecture** on data analysis and machine learning by Prof. A. Quadt:
  - First given in summer semester 2019
  - More then 80 registered participants
  - Focus on practical exercises with tensorflow and Scikit-learn
  - Tutorials organised by K. Zoch
- Working group on 'machine learning and artificial intelligence' at **Zukunftsakademie Cambridge of the Studienstiftung**:
  - Offered for master and PhD students
  - Fundamentals and applications on relevant topics from society, politics and science
  - Lectures and hands-on tutorials on machine learning and AI by A. Quadt and K. Zoch in collaboration with C. Weisser from department of economics
  - Another summer school in 2020 planned

Summary

- Our group is involved in:
  - Several top-quark related analyses using machine learning
  - Development of new tools like lwtnn for machine learning applications
  - New teaching concepts on machine learning