EXP18
Top-Quark pairs at the LHC

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Universität Hamburg
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FSP CMS

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GEFÖRDERT VOM
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Top quark pairs at the LHC

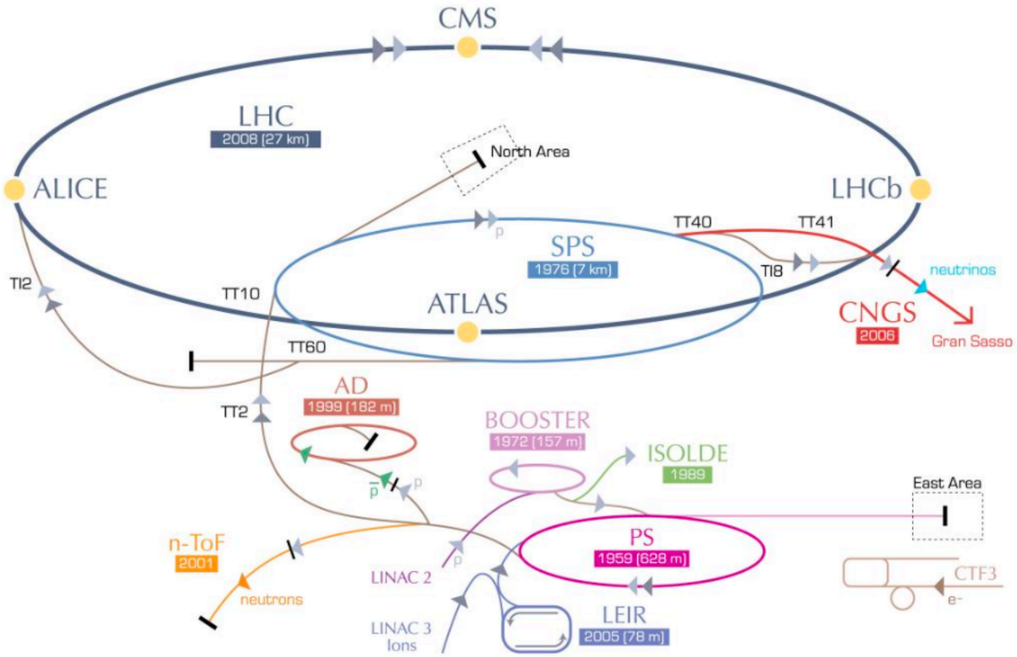
Based on Physics V - Particle Physics

- Introduction to the Large Hadron Collider - Most powerful particle accelerator
- Measure $t\bar{t}$ **production cross section** and the **top quark mass**
  - Highly topical in modern experimental particle physics

Data analysis with the CMS detector

- Real data from the LHC
- Hands-on python programming
- Add experimental view to abstract mechanisms

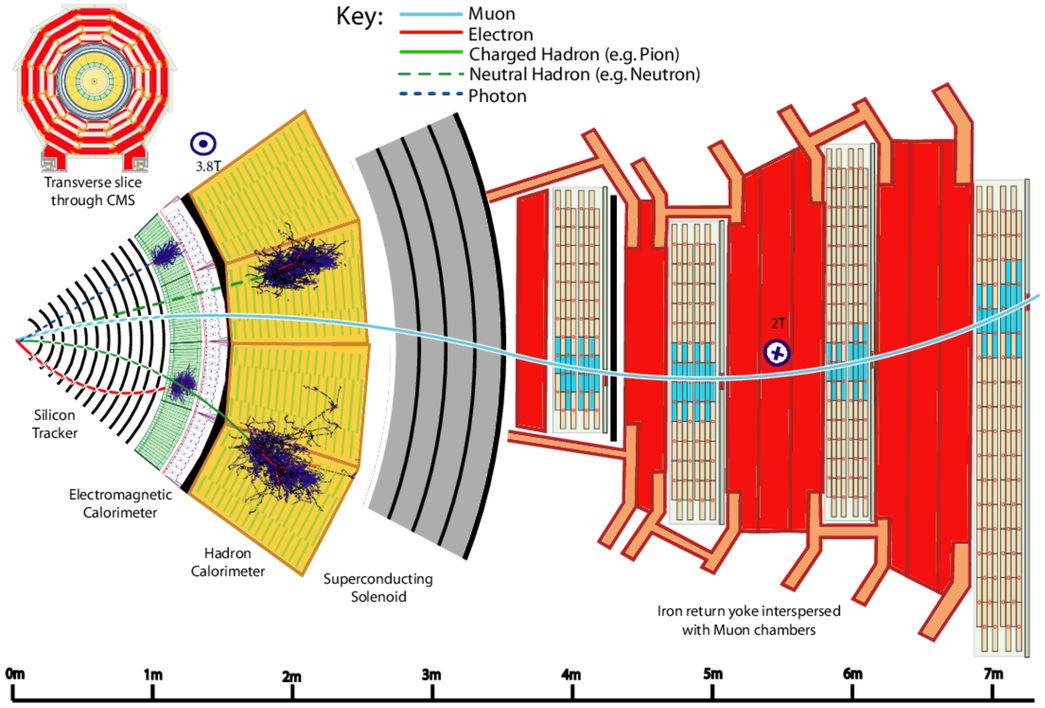
  (e.g. four-momentum, Feynman diagrams, object reconstruction)
- Modern statistical methods for big data analysis
- Duration of **2 - 3 days**



Experimental Setup

Unterstand how the CMS detector works

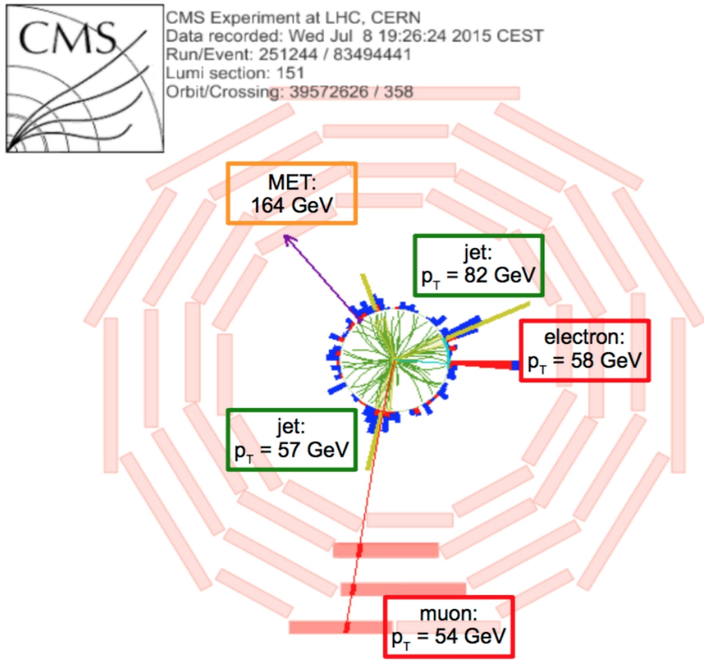
- Modern particle physics detector
- Hands-on data analysis
- Learn the key concepts of the structure
  - Contribution from each sub-detector
  - Each track adds valuable information
- What are potential uncertainty sources
- How to deal with massive amount of data taking

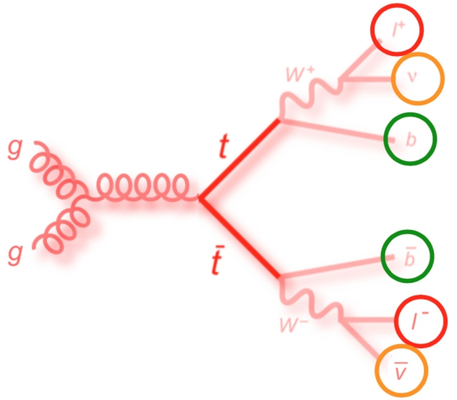


Goal of the experiment

Analyse the top quark, the heaviest known particle

- How to distinguish the signal of interest from other processes
  - Select $t\bar{t}$ events based on top quark properties
- Measure the cross section of the $t\bar{t}$ process
- Measure the top quark mass
  - How to reconstruct objects and processes
  - How to infer parameters of interest using statistical methods (e.g. Gaus fit, error propagation, etc.)

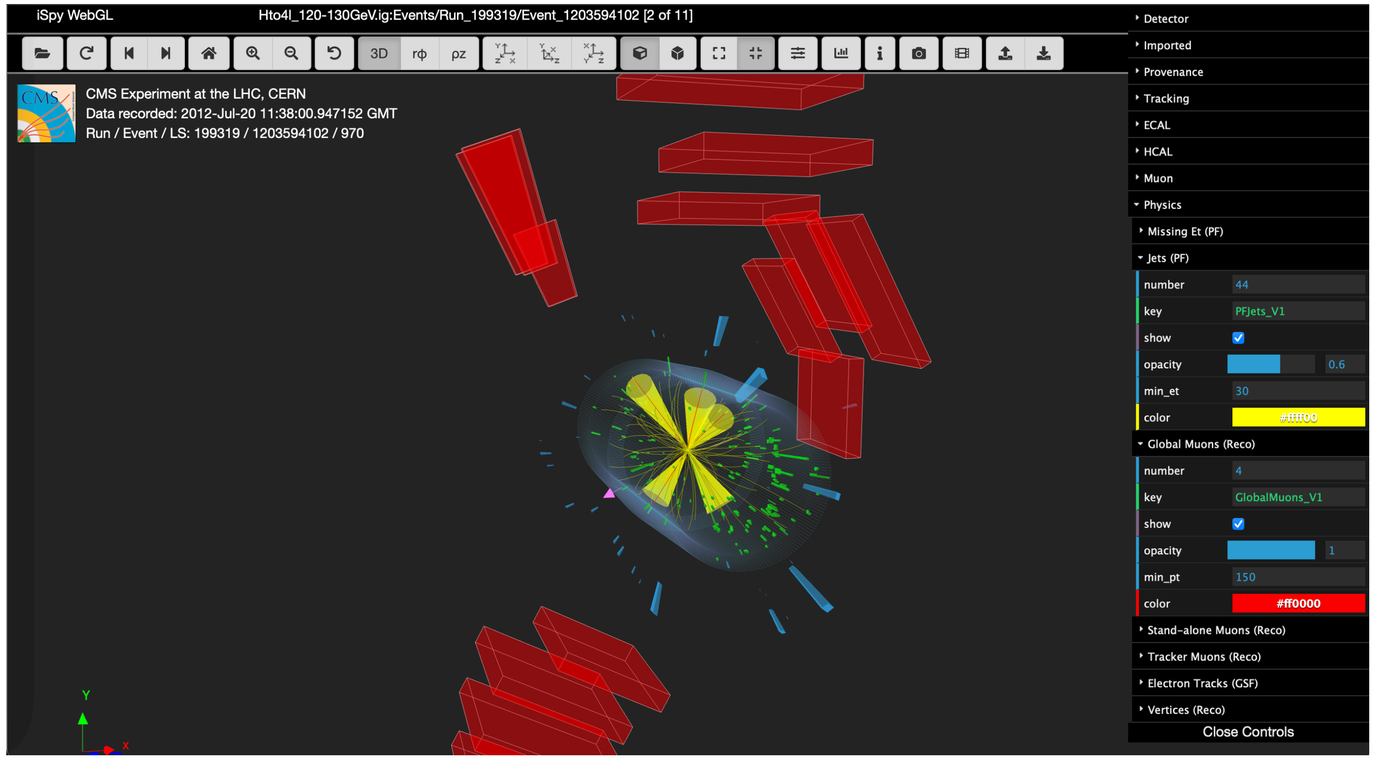




Framework and tools

Event Display with ISpy

- Visualization of measured objects
- Study characteristics of $t\bar{t}$ events and similar processes

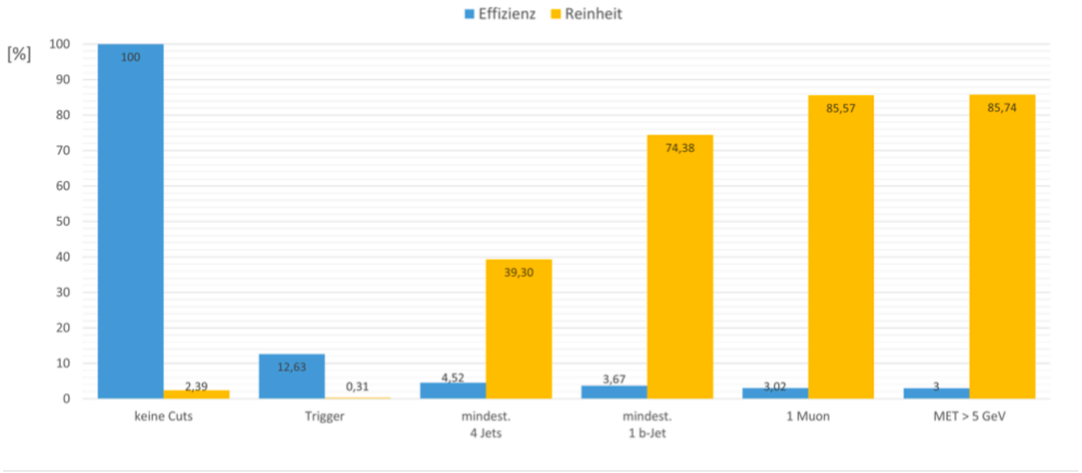


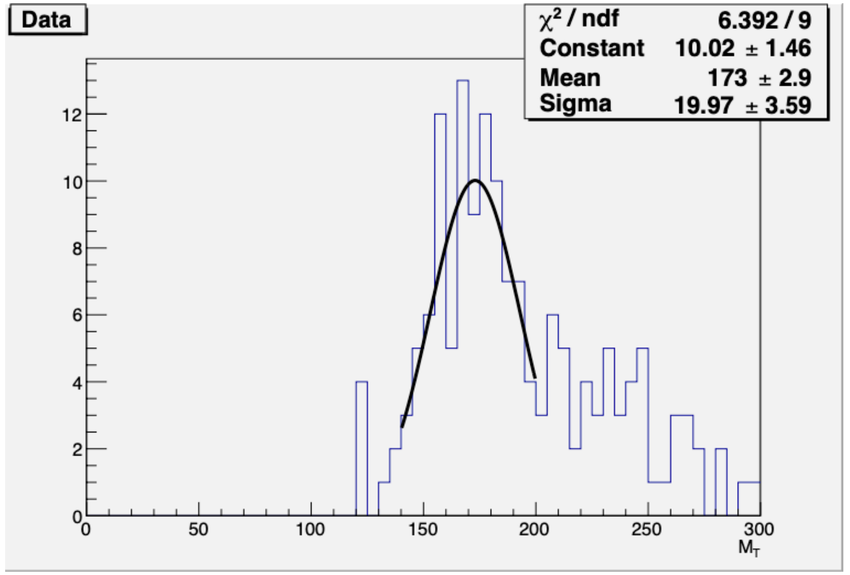
Analysis framework based on Python

- Provided by the organizers
- Students need to complete the code
  - Add code for the selection, data analysis and for tools like the calculation of the four momentum

Statistical and experimental methods

- Derive $t\bar{t}$ selection with simulation
  - Obstacles and advantages of MC simulations
  - Apply selection to data
- Check quality of the selection
  - Efficiency and Purity of each cut
- Calculate the cross-section with measured quantities
  - Error propagation
- Measure top quark mass
  - Perform gaus fit to reconstructed mass spectrum





Precision of main results

- Consider jet energy calibrations as representative example for systematic uncertainties
  - More would blow up the scope of the experiment
- $t\bar{t}$ cross section of 158 pb: ~11% (stat)
  - Literatur*: ~1.3% (stat) and ~6% (syst)
- Top quark mass of 173 GeV: ~2% (stat) and ~5% (syst) GeV
  - Literatur*: ~0.2% (stat) and ~0.6% (syst)

(* Much larger dataset with more sophisticated methods to control uncertainties)

Current activities

- Top quark physics is a central activity of the LHC groups in Hamburg
  - CMS group at the Institut of Experimental Particle Physics (IExp)
  - CMS and ATLAS groups at DESY
  - Quantum Universe Cluster
- Many effort from the University Hamburg
  - World's most precise measurement: $m_t = 171.77 \pm 0.37$ GeV **arxiv:2302.01967**
  - Aiming for new energy regions: $m_t = 172.76 \pm 0.81$ GeV **arXiv:2211.01456**
- Learned methods are key skills for a bachelor and master theses in particle physics

  (e.g. Python skills, data analysis techniques)

Grade your experiment

Theory / preparation	Setup / experimental	Data taking	Analysis	Protokol
3	4	5	1	2

- In order to select the process the students need to many experimental aspects about the CMS detector and the theory
- The setup for the experiment is a prepared framework to analyze data based on Python. The students need to complete the program by adding their idea for the selections
- Key aspect of the experiment is to analyze the data.
- Students need to keep track of many aspect of the analysis and the detector to properly describe their studies
- Excellent preparation for all sorts of big data analysis in the field (bachelor thesis) or beyond