0.1 The Large Hadron Collider

theoretical predictions are tested with experimental data obtained from particle accelerators
world's largest accelerator built by CERN situated on the border of Switzerland and France
has been operating since xxxx
lifetime divided into 3 runs, currently on Run 3 with planned upgrades on the horizon
responsible for a number of discoveries aka Higgs, etc.

0.1.1 Overview

[Basic info: location, size, main working mechanism, main detectors, main physics done]
- 27km circumference, reusing LEP tunnels 175m below ground level
- 7-13-13.6 TeV center of mass energies for pp collisions
- other than pp, also collides pPb, PbPb at 4 points with 4 main detectors: ATLAS, CMS (general purpose detectors), ALICE (heavy ion physics, ion collisions), LHCb (*b*-physics)

0.1.2 LHC operations

- focuses mainly on pp collisions for this thesis - beams split into bunches of 1.1×10^{11} protons with instantaneous luminosity of up to 2×10^{34} cm^{-2}s^{-1}
- beam energies ramp up in other accelerators before injection, full ramp up to 6.5 GeV about 20 minutes
(insert full diagram of accelerator chain)
Linac 4: hydrogen atoms, accelerated up to 160 MeV
PSB: H atoms stripped of electrons before injection, accelerated to 2 GeV
PS: 26 GeV, SPS: 450 GeV
LHC: injection in opposite directions, 6.5 TeV per beam

Run 1: 2010-2012, Run 2: 2015-2018, Run 3: 2022-2025, HL-LHC: 2029-?
COM energies: 7 & 8 TeV, 13 TeV, 13.6 TeV, 13.6 & 14 TeV
inbetween periods: long shutdowns (LS1, LS2, LS3)
(add HL-LHC timeline graph)

(insert LHC SM processes cross sections chart)

Top quark production at the LHC

history (CDF/D0)
LHC as a top factory: show luminosity and cross section for top processes
couples to Higgs as heaviest elementary particle
Higgs produced mainly from ggH (90%) via top loop and from ttH
(Feynman diagram of related processes)

0.2 The ATLAS detector

44m long, 25m diameter inner detector, solenoid/toroid magnet, EM & hadronic calorimeters, muon spectrometer [insert figure]

right-handed cylindrical system, z-axis follows beamline, azimuthal and polar (0 in the beam direction) angles measured with respect to beam axis.
pseudorapidity $\eta = -\ln\tan(\theta/2)$, approaches $\pm\inf$ along and 0 orthogonal to the beamline
distance $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$
transverse energy $E_{\mathrm{T}} = \sqrt{p_{\mathrm{T}}^2 + m^2}$
transverse momentum p_{T} component of momentum orthogonal to the beam axis $p_{\mathrm{T}} = \sqrt{p_x^2 + p_y^2}$

0.2.1 Inner detector

- measures tracks of charged particles with high momentum resolution ($\sigma_{p_{\mathrm{T}}}/p_{\mathrm{T}} = 0.05\% \pm 1\%$
- covers particles with $p_{\mathrm{T}} > 0.5$ GeV, $|\eta| < 2.5$
  pixel detector -¿ semiconductor tracker -¿ transition radiation tracker, innermost to outermost
- pixel detector:
  - innermost, 250 µm silicon pixel layers
  - detects charged particles from electron-hole pair production in silicon
  - measures impact parameter resolution & vertex identification for reconstruction of short-lived particles
  - spatial resolution of 10 µm in the $R-\phi$ plane and 115 µm in the z-direction
  - 80.4m readout channels
- sct:
  - surrounds pixel detector, silicon microstrip layers with 80 µm strip pitch
  - particle tracks cross 8 strip layers
  - measures particle momentum, impact parameters, vertex position
  - spatial resolution of 17 µm in the $R-\phi$ plane and 580 µm in the z-direction
  - 6.3m readout channels.
- trt:
  - outermost, layers of 4 mm diameter gaseous straw tubes with transition radiation material (70% Xe + 27% CO_2 + 3% O_2) & 30 µm gold-plated wire in the center

- tubes 144 cm length in barrel region ($|\eta| < 1$), 37 cm in the endcap region ($1 < |\eta| < 2$), arranged in wheels instead of parallel to beamline)
- gas mixture produces transition radiation when ionized for electron identification
- resolution/accuracty of 130 µm for each straw tube in the $R - \phi$ plane
- 351k readout channels

0.2.2 Calorimeter systems

surrounds the inner detector & solenoid magnet, covers $|\eta| < 4.9$ and full ϕ range. Alternates passive and active material layers. Incoming particles passing through calorimeter produce EM cascades or hadronic showers in passive layer. Energies deposited and convert to electric signals in active layers for readout.

EM calorimeter:

- innermost, lead-LAr detector (passive-active)
- measures EM cascades (bremsstrahlung & pair production) produced by electrons/photons
- divided into barrel region ($|\eta| < 1.475$) & endcap regions ($1.375 < |\eta| < 3.2$) with transition region ($1.372 < |\eta| < 1.52$) containing extra cooling materials for inner detector
- end-cap divided into outer wheel ($1.372 < |\eta| < 2.5$) & inner wheel ($2.5 < |\eta| < 3.2$)
- higher granularity in ID ($|\eta| < 2.5$) range for electrons/photons & precision physics, coarser elsewhere for jet reconstruction & MET measurements

hadronic calorimeter:

- outermost
- measures hadronic showers from inelastic QCD collisions
- thick enough to prevent most particles showers from reaching muon spectrometer
- split into tile calorimeter in barrel region ($|\eta| < 1.0$) & extended barrel region ($0.8 < |\eta| < 1.7$), LAr hadronic end-cap calorimeter (HEC) in end-cap regions ($1.5 < |\eta| < 3.2$) & LAr forward calorimeters (FCal) in $3.1 < |\eta| < 4.9$ range.
  - tile calorimeters: steel-plastic scintillating tiles, readout via photomultiplier tubes
  - hec: behind tile calorimeters, 2 wheels per end-cap. copper plates-LAr. overlap with other calorimeter systems to cover for gaps between subsystems
  - fcal: 1 copper module & 2 tungsten modules-LAr. copper optimized for EM measurements, tungsten for hadronic.

0.2.3 Muon spectrometer

- ATLAS outermost layer. measures muon momenta & charge in range $|\eta| < 2.7$

- momentum measured by deflection in track from toroid magnets producing magnetic field orthogonal to muon trajectory
  - large barrel toroids in $|\eta| < 1.4$, strength 0.5 T
  - 2 smaller end-cap toroids in $1.6 < |\eta| < 2.7$, strength 1 T
  - transition region $1.4 < |\eta| < 1.6$, deflection provided by a combination of barrel and end-cap magnets
- chambers installed in 3 cylindrical layers, around the beam axis in barrel region & in planes perpendicular to beam axis in the transition and end-cap regions
- split into high-precision tracking chambers (monitored drift tubes & cathode strip chambers) & trigger chambers (resistive plate chambers & thin gap chambers)
- trigger chambers provide fast muon multiplicity & approximate energy range information with L1 trigger logic
  - mdt:
    * range $|\eta| < 2.7$, innermost layer $|\eta| < 2.0$
    * precision momentum measurement
    * layers of 30 mm drift tubes filled with 93% Ar & 7% CO_2, with a 50 µm gold-plated tungsten-rhenium wire at the center
    * muons pass through tube, ionizing gas and providing signals. Combining signals from tubes forms track
    * maximumn drift time from wall to wire 700 ns
    * resolution: 35 µm per chamber, 80 µm per tube
  - csc:
    * forward region $2.0 < |\eta| < 2.7$, highest particle flux and density region
    * multiwire proportional chambers with higher granularity, filled with 80% Ar & 20% CO_2
    * shorter drift time than MDT, plus other features making CSC suitable for high particle densities and consequently able to handle background conditions
    * resolution: 40 µm in bending η-plane, 5 mm in nonbending ϕ-plane due to coarser cathode segmentation, per CSC plane

- rpc:
  - range $|\eta| < 1.05$
  - provide fast meas
- tgc:
  - range $1.05 < |\eta| < 2.7$

0.2.4 Forward detectors

- LUCID (LUminosity measurement using Cherenkov Integrating Detector): ± 17 m from interaction point, measures luminosity using pp scattering in the forward region
- ALFA (Absolute Luminosity for ATLAS): ± 240 m, measures pp scattering at small angles
- ZDC (Zero-Degree Calorimeter): ± 140 m, measures centrality in heavy-ion collisions

0.2.5 Magnetic systems

superconducting solenoid & toroid magnets cooled to 4.5 K with liquid helium
solenoid: 2.56 m diameter, 5.8 m length, 2 T strength, encloses inner detector
toroid = barrel + endcap toroid x2
barrel toroid: 9.2/20.1 m inner/outer diameter, 25.3 m length, 0.5 T strength
endcap toroid: 1.65/10.7 m inner/outer diameter, 5 m length, 1 T strength
(show magnet system diagram)

0.2.6 Trigger & data acquisition

LHC produces large amount of data (40 MHz with 25 ns bunch crossing), necessitates a way to filter out trash from interesting events
handles online processing, selecting and recording interesting events for further offline processing and more in-depth analyses

- Level-1 (L1) trigger: online, fast hardware-based trigger, reduces to 100 kHz
  - L1 calorimeter triggers (L1Calo): selects high energy objects & MET
  - L1 muon triggers (L1Muon): selects using hit information from RPC & TGC
  - L1 topological trigger (L1Topo): select based on topological selection synthesized using information from L1Calo & L1Muon
  - Central Trigger Processor (CTP): uses L1Calo/Muon/Topo for final L1 trigger decision within 2.5 μs latency. Also identify regions of interest in η and ϕ to be processed directly by HLT
- L1 trigger information read out by Front-End (FE) detector electronics then sent to ReadOut Drivers (ROD) for preprocessing and subsequently to ReadOut System (ROS) to buffer

- High-Level Trigger (HLT): offline, software-based trigger, using dedicated algorithms and L1 output as input, reduces to 1 kHz
- Send to storage for analyses after HLT

overall trigger process reduces original collision data rate by a factor of about 10000 after HLT
(show TDAQ diagram)