An introduction to event generators for pp and AA collisions

PhD TALK 2020 BY TORBJÖRN LUNDBERG
SUPERVISED BY LEIF LÖNNBLAD

LUND
UNIVERSITY
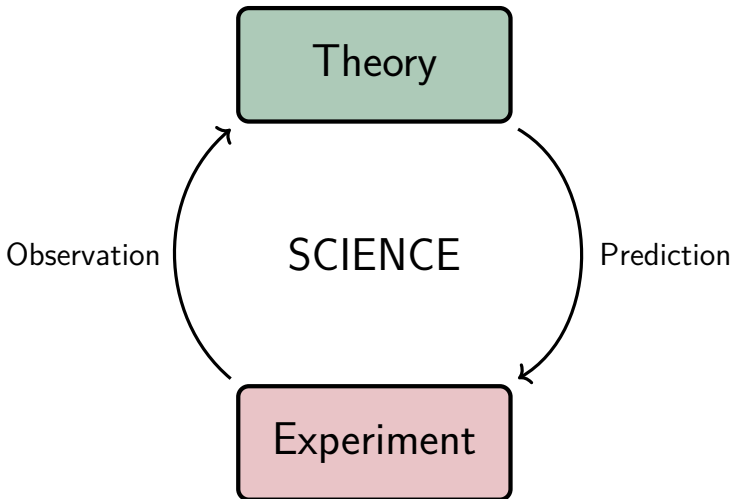
Introduction

Inspiration from figure by Marius Utheim.
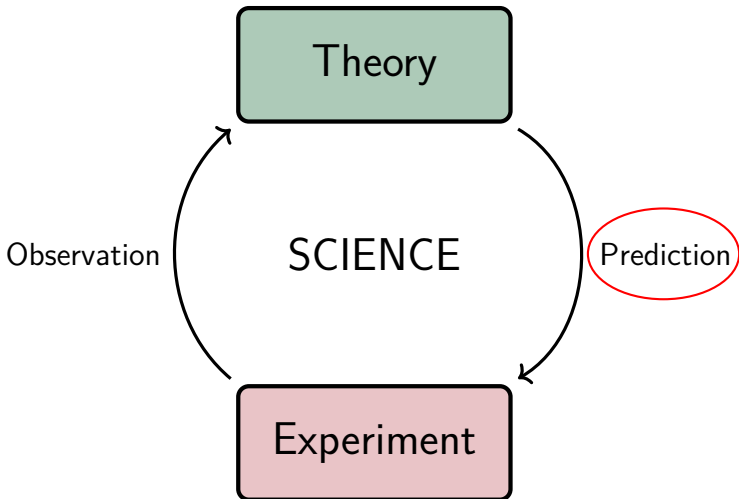
Introduction

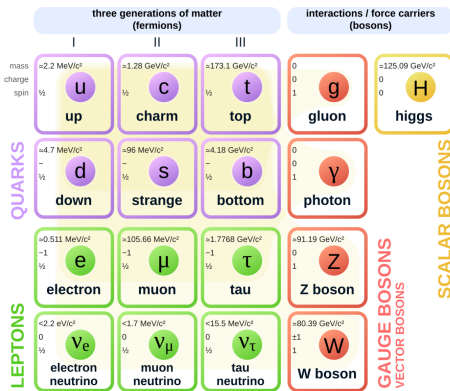Inspiration from figure by Marius Utheim.

Figure from en.wikipedia.org/wiki/Standard_Model

Fundamenal Particles

Fermions (spin 1/2)

- Leptons (EM, weak)
- quarks (EM, weak, strong)

Gauge Boson (spin 1)

- Photon: EM
- W, Z: Weak
- Gluon: Strong (QCD)

Scalar Boson (spin 0)

- Higgs (gives mass)

+ antiparticles

Slide adapted from Andrew Lifson's talk last year which was adapted from Marius' talk the year before.

QCD

Contains two very different limits:

Asymptotic Freedom   **Confinement**
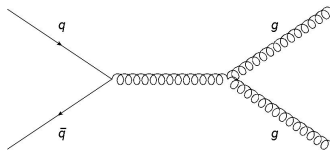
Slide adapted from Andrews' talk.

QCD

Contains two very different limits:

Asymptotic Freedom   **Confinement**

- $r \lesssim 10^{-15}$m ($E \gtrsim 1$ GeV)
- Strong coupling α_S is small (i.e. < 1)
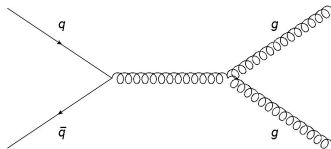- Use Feynman diagrams to calculate scattering probabilities

Slide adapted from Andrews' talk.

QCD

Contains two very different limits:

Asymptotic Freedom

- $r \lesssim 10^{-15}$m ($E \gtrsim 1$ GeV)
- Strong coupling α_S is small (i.e. < 1)
- Use Feynman diagrams to calculate scattering probabilities

Confinement

- $r \gtrsim 10^{-15}$m ($E \lesssim 1$ GeV)
- Strong coupling is large (i.e. > 1)
- Quarks and gluons confined into hadrons
  - Protons
  - Neutrons
  - Pions
  - Kaons
  - . . . and more.

Slide adapted from Andrews' talk.

Purpose of Monte Carlo event generators
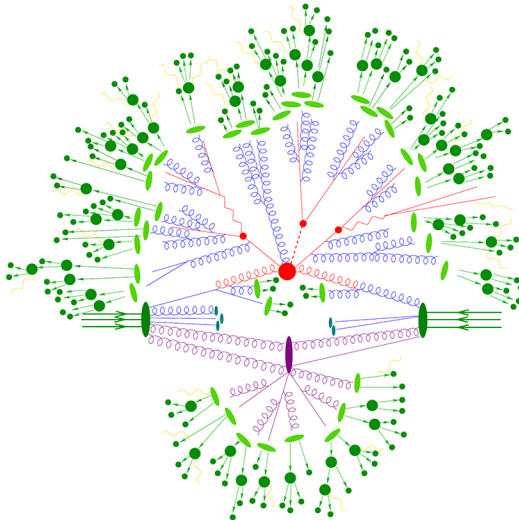
Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- **Hard processes**
  - Hard = highest high-energy…
  - Asymptotic freedom is valid.
  - Resonant decays:
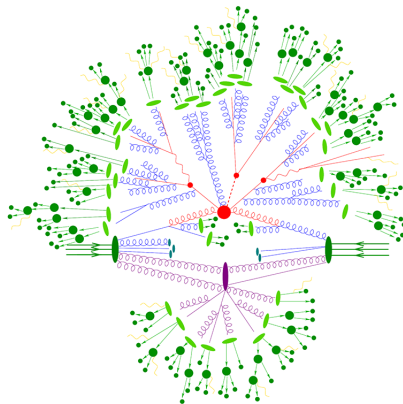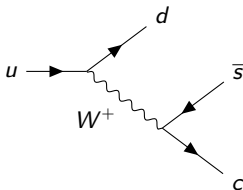
Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- Hard processes
- Parton showers
  - Strong initial- and final-state radiation.
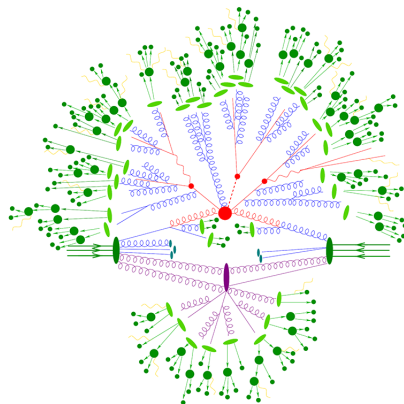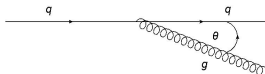
Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- Hard processes
- Parton showers
- Hadronisation
  - Enter confinement (soft physics).
  - Form hadrons from hard partons.
  - Not yet fully understood in QCD
    $\Rightarrow$ model (with strings!)
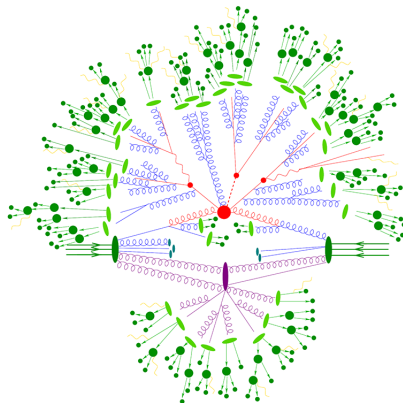 - Hadronisation of individual partons give jets.

Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- Hard processes
- Parton showers
- Hadronisation
- PDFs
  - Parton content depends on probing energy.
  - Characterise parton momentum fraction within the proton.
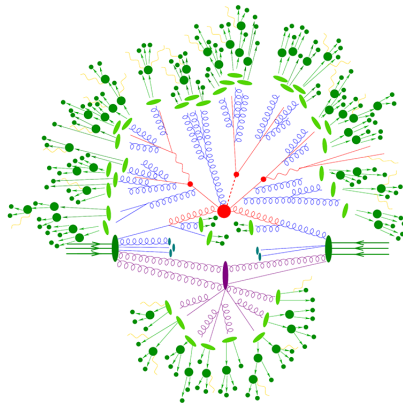 - Not calculable from QCD!
  - Measure.

Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- Hard processes
- Parton showers
- Hadronisation
- PDFs
- Multiparton interactions, MPIs
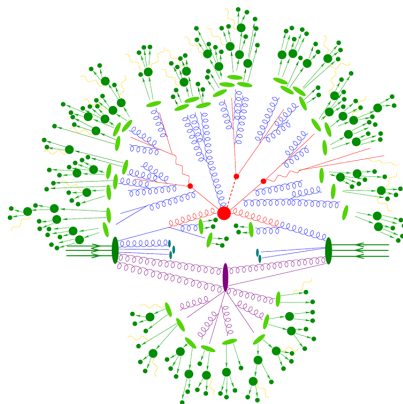 - Pick > 1 parton from each proton in the collision.

Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- Hard processes
- Parton showers
- Hadronisation
- PDFs
- Multiparton interactions, MPIs
- Hadronic rescattering
  - What if the dark green blobs interact?
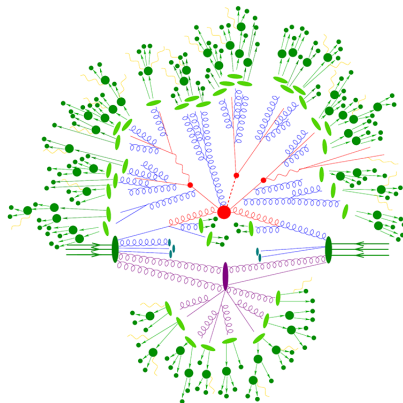 - Listen to Marius.

Figure from Stefan Hoeche, adapted from Andrew's talk.

pp: Aspects of modelling

- Hard processes
- Parton showers
- Hadronisation
- PDFs
- Multiparton interactions, MPIs
- Hadronic rescattering
- Soft photon radiation
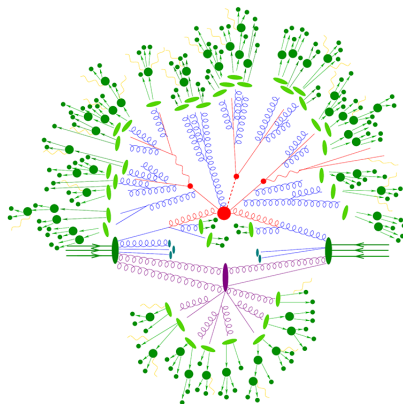 - Bremsstrahlung from charged particles.

Figure from Stefan Hoeche, adapted from Andrew's talk.

Lund strings
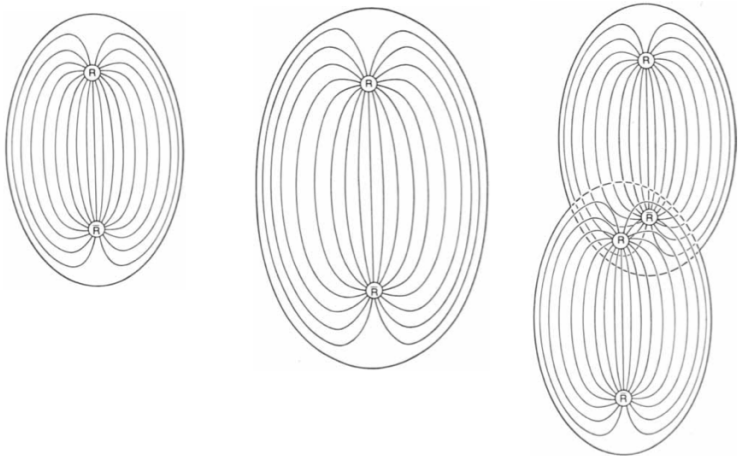
Figure from Johnson, K, The Bag Model of Quark Confinement, 1979.

Lund strings
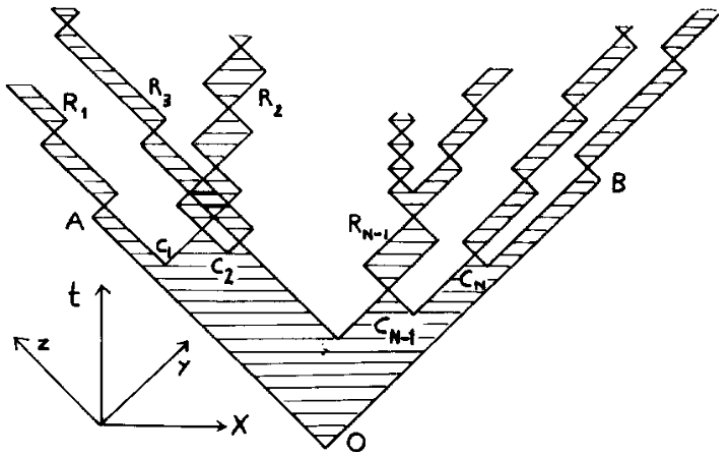
Figure from Artru, X and Mennessier, G, String model and multiproduction, 1973.

HIC: Aspects of modelling

Everything from *pp*-collisions apply + more:

- Nuclei will overlap, use centrality parameter *b*.
- Pick suitable PDFs.
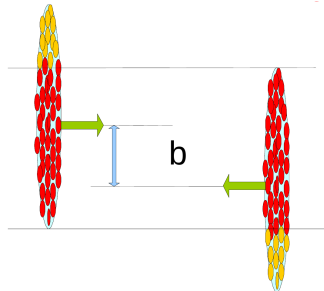- QGP?
- Collective effects?

Figure from Jean-Philippe Lansberg, adapted from Andrews' talk.
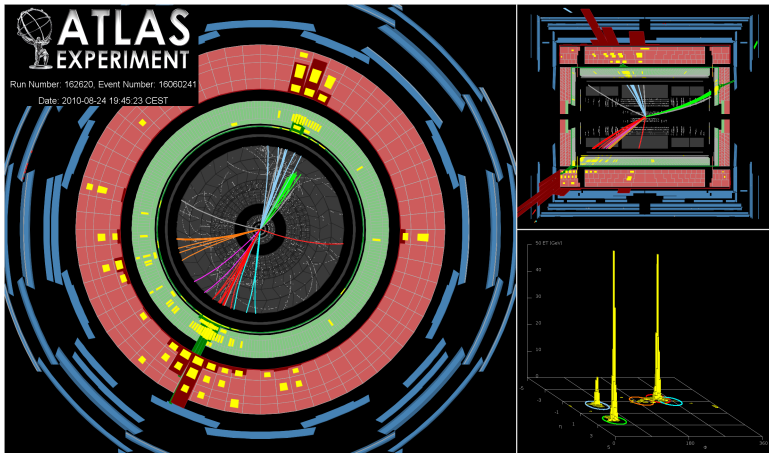
Experiments: boom!

Figure from arxiv:1107.2092

Experiments: collisions in ALICE

pp 7 TeV (June 2010)

Figure from https://cds.cern.ch/record/2034251?ln=en
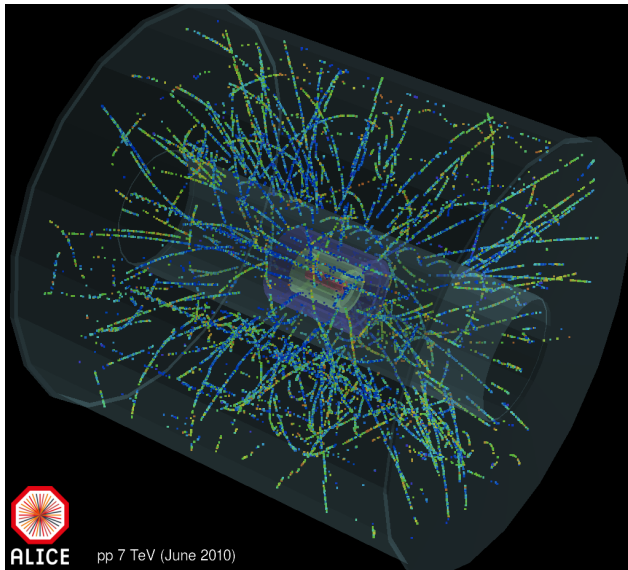
Experiments: Pb-Pb-collision in ALICE

Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:29:52
Fill : 1482
Run : 137124
Event : 0x0000000042B1B693
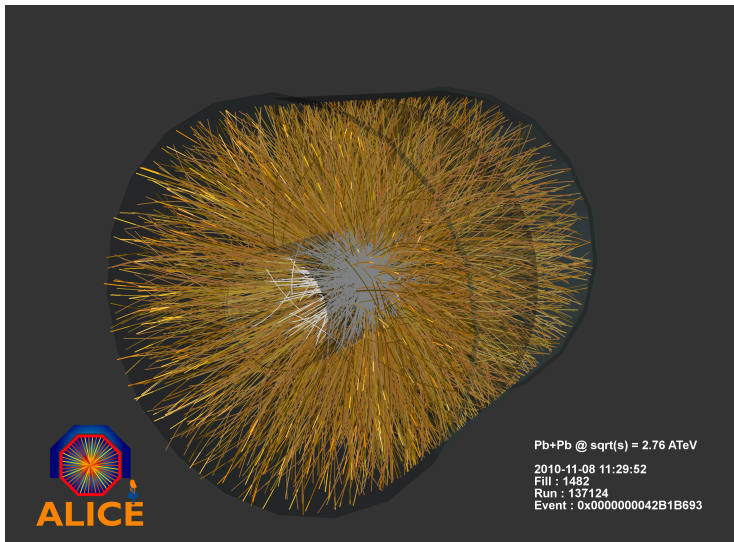
Figure from aliceinfo.cern.ch/Public/Objects/Chapter1/hltmc/results_-1_0x00000000000013E2/real2.png
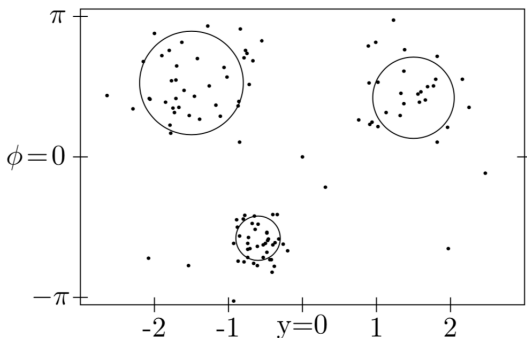
What you get out: observables

- $\mathrm{d}\Omega^2 = \mathrm{d}\theta^2 + \sin^2\theta \mathrm{d}\phi^2 = \frac{1}{\cosh y}\left(\mathrm{d}y^2 + \mathrm{d}\phi^2\right)$
  $\Rightarrow \quad (E, \mathbf{p}) \to (p_\mathrm{T}, y, \phi, m)$.

- Good coordinates since both p_T and Δ_y are invariant under boosts in beam direction.

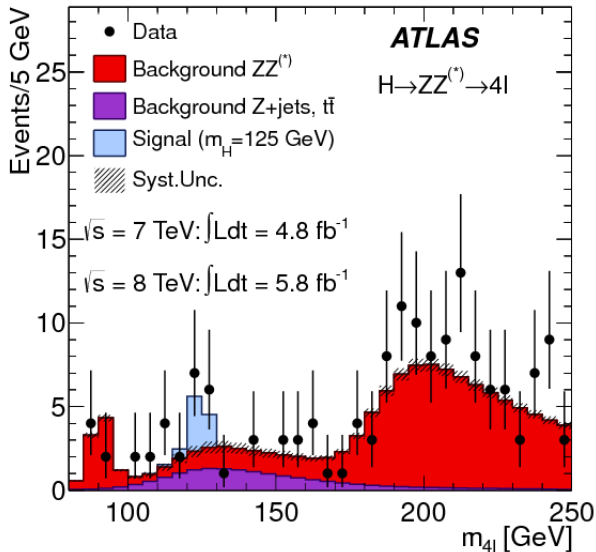- High p_T means large momentum transfer: hard stuff

Discovery

Introduction

The Model

Event generators

Colliders

Observations

Summary

Summary

- The Standard Model (SM) is great!

- Event generators are indispensable tools for particle physics phenomenology at hadron colliders.

- Hard physics $\rightarrow$ measurable hadrons.

- They simulate a lot of physics.

- Popular: PYTHIA 6.4 manual has been cited 10770 times.

My project

Introduction
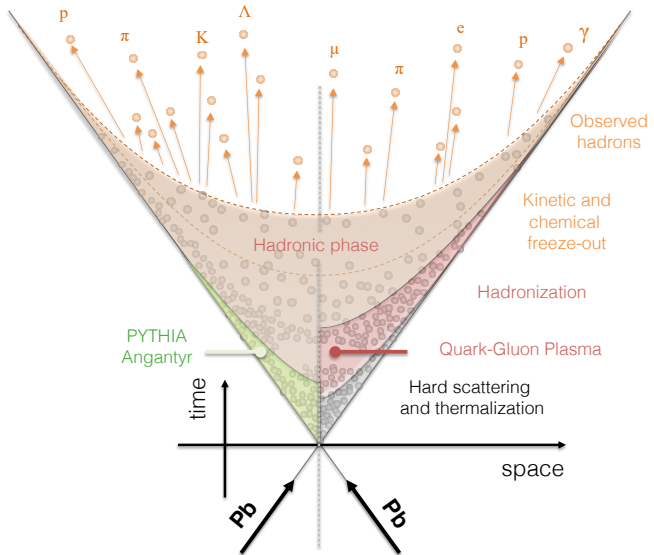
The Model

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Figure by courtesy of David Chinellato.