AI for the LHC

Tilman Plehn

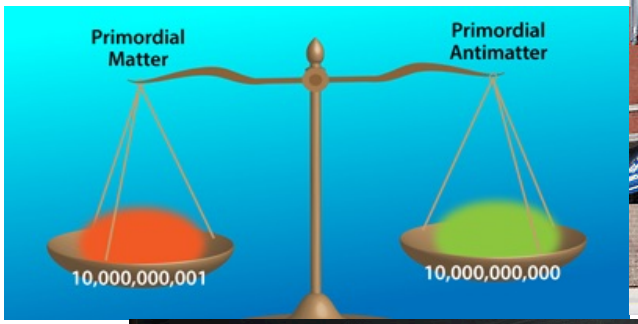
Universität Heidelberg

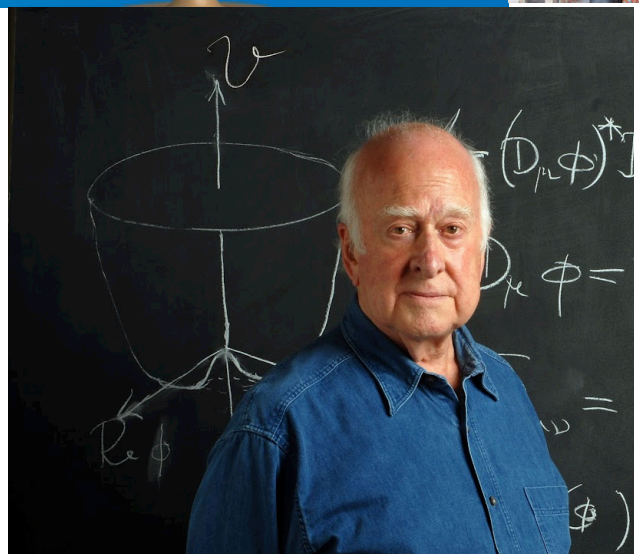
USERN Plovdiv, November 2024

Modern LHC physics

Classic motivation

- dark matter?
- baryogenesis?
- origin of Higgs field?





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- fundamental questions
- first-principle simulations
- huge data set
- uncertainty control

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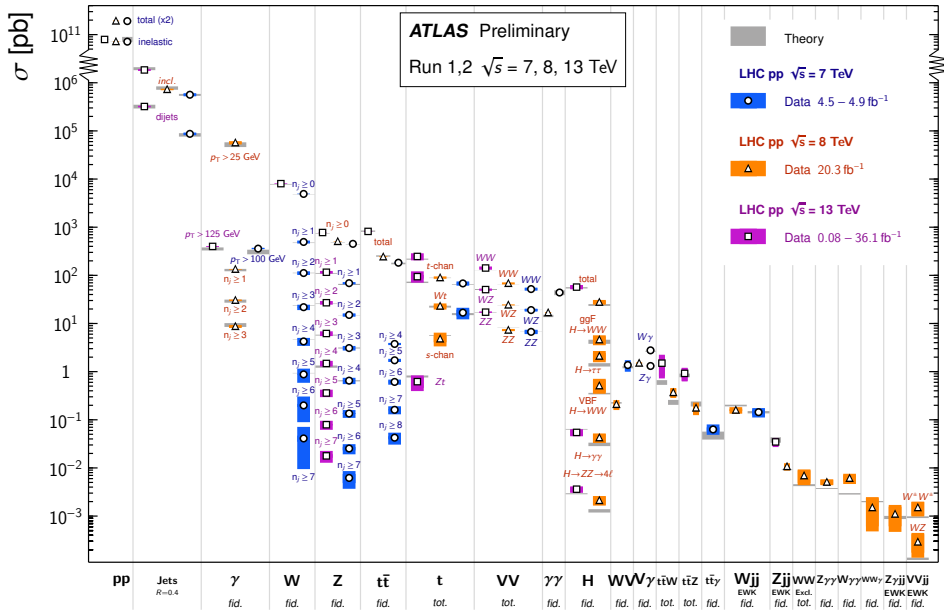
Successful past

- measurements of event counts
- model-driven Higgs discovery
- vast analysis landscape



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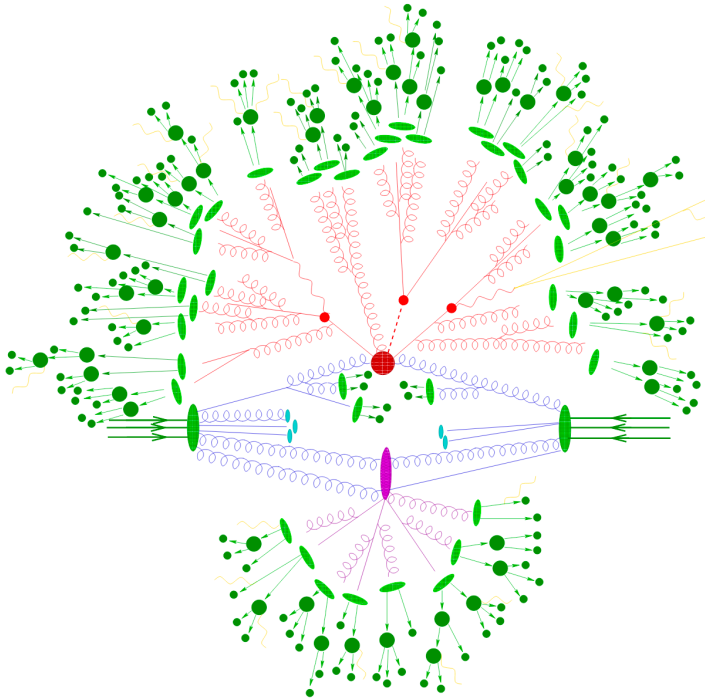
- start with Lagrangian/Hamiltonian
- calculate using quantum field theory
- simulate collisions
- simulate detectors

$\rightarrow$ LHC collisions in virtual worlds



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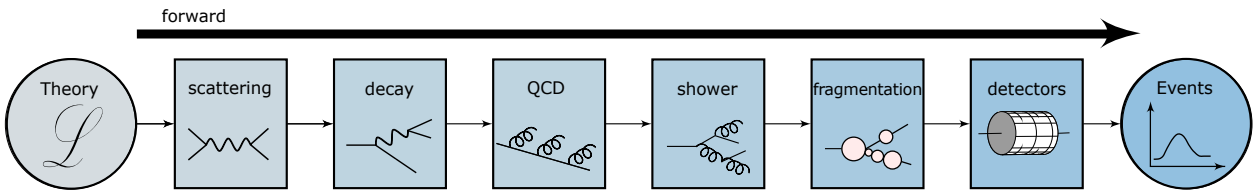
Infer underlying theory

- simulations vs data
- symmetries the key
- phase space interpretable

→ Specific ML



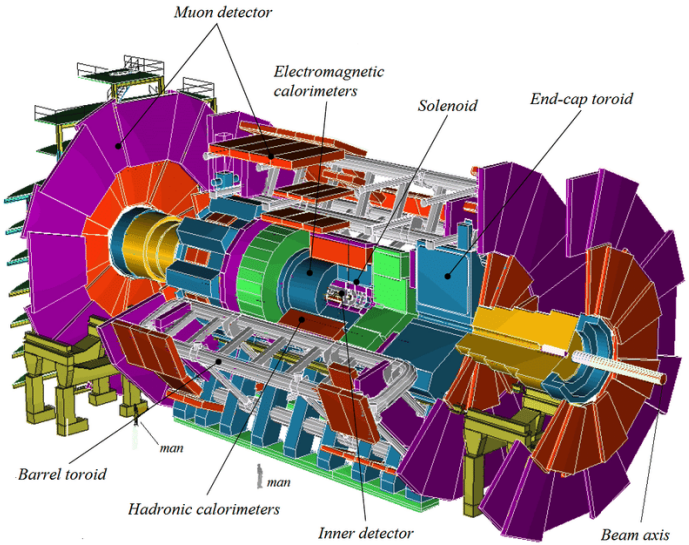
LHC data

Collaborations

- ATLAS & CMS general purpose
  LHCb, ALICE, FASER specialized
- 1000s of scientists per experiment

Detectors

- built around *pp* interaction point
- measuring outgoing particles



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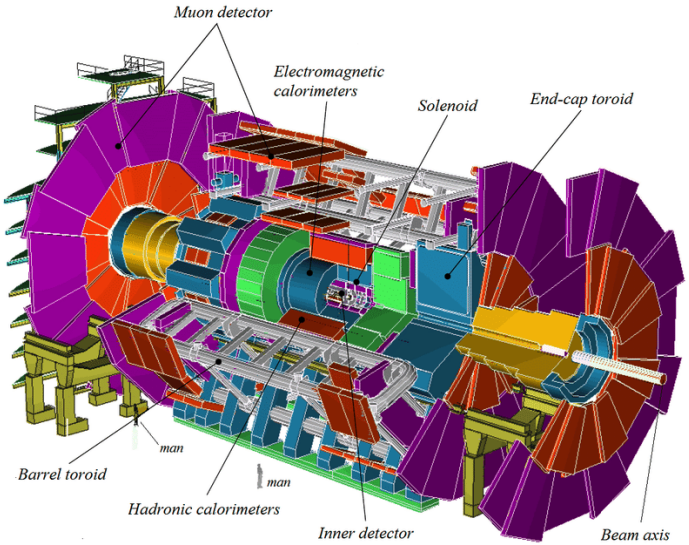
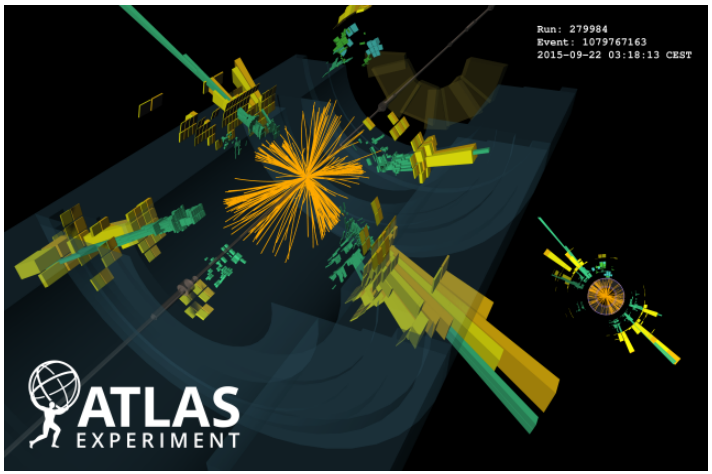


Event format

- colliding protons at 40 MHz
- ATLAS output 3 PB/s
- measure:
  energy, momentum, charge, etc
- electrons, muons easy
  quarks, gluons as jets [20-50 particles]

→ Event: 100+ ntuples (E, $\vec{p}$, Q...)



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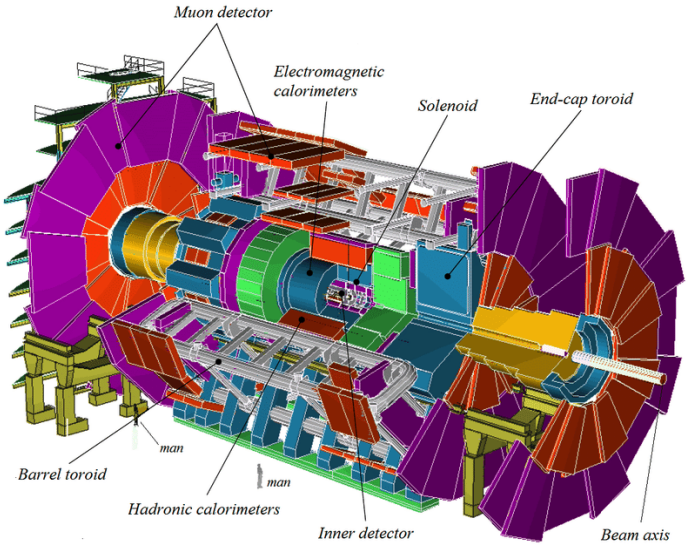

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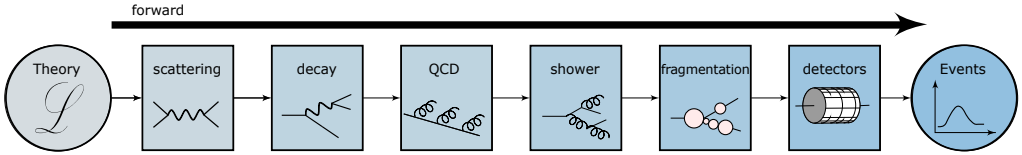
ML applications

- data selection/compression
- object reconstruction
- object classification
- calibration
- analysis preprocessing

$\rightarrow$ Everything, but faster and better

Theory task



Applied quantum field theory

- start with Lagrangian
  generate Feynman diagrams
- compute hard scattering
  compute decays
  compute QCD jet radiation
  compute parton splittings
- describe partons in protons [NNPDF]
  push hadronization towards QCD

$\rightarrow$ Simulations, not modeling

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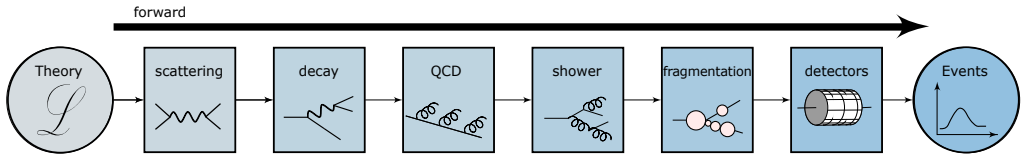

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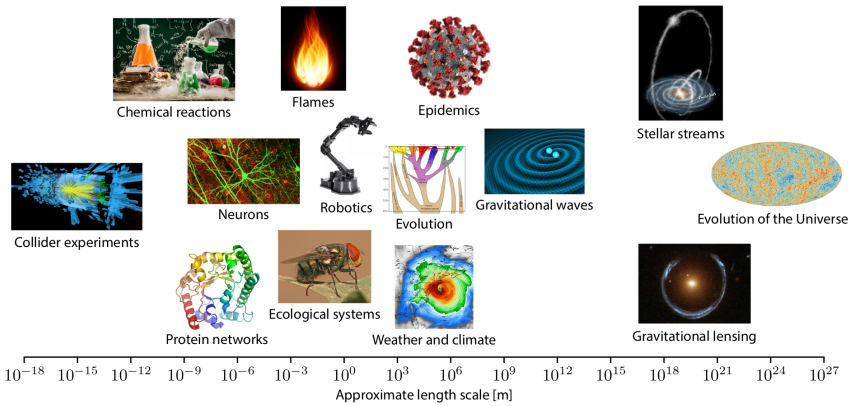
Inference from 20$\times$ more data [HL-LHC]

- SBI starts with Simulations
- statistics scaling with data [$\sqrt{20} = 4.5$]
- theory to follow
- precision $\leftrightarrow$ QFT+speed

$\rightarrow$ Phase space densities to $< 1\%$



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How can we bring this all together?