Pre-Lecture 01

Particle Physics and AI

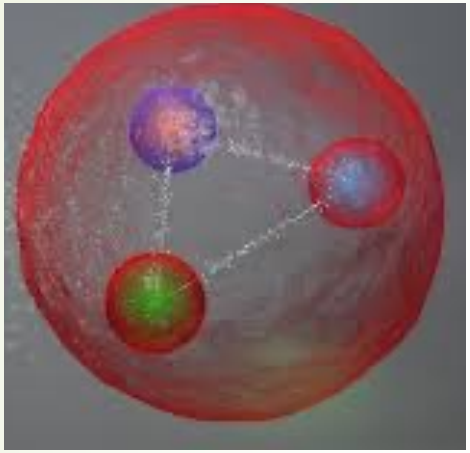
Lecture

Machine Learning in Particle Physics

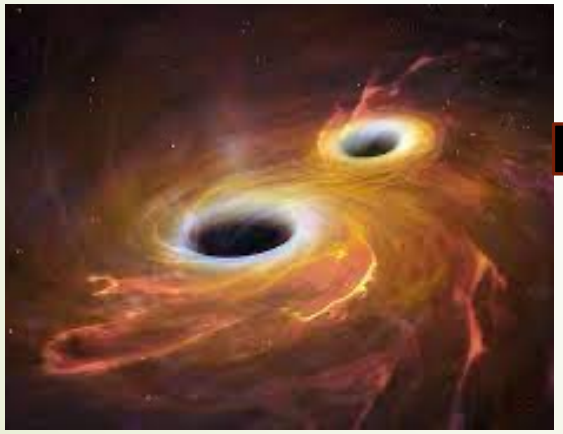
- Particle Physics Introduction
- Forecasting
- Translation
- Reconstruction
- Anomaly Detection

Length Scale

Quark & Gluons

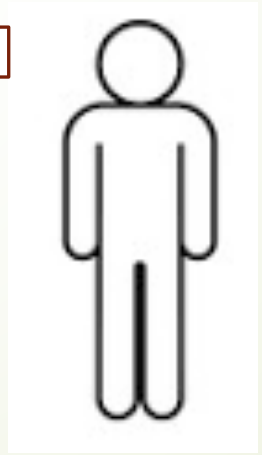


Binary Black Hole



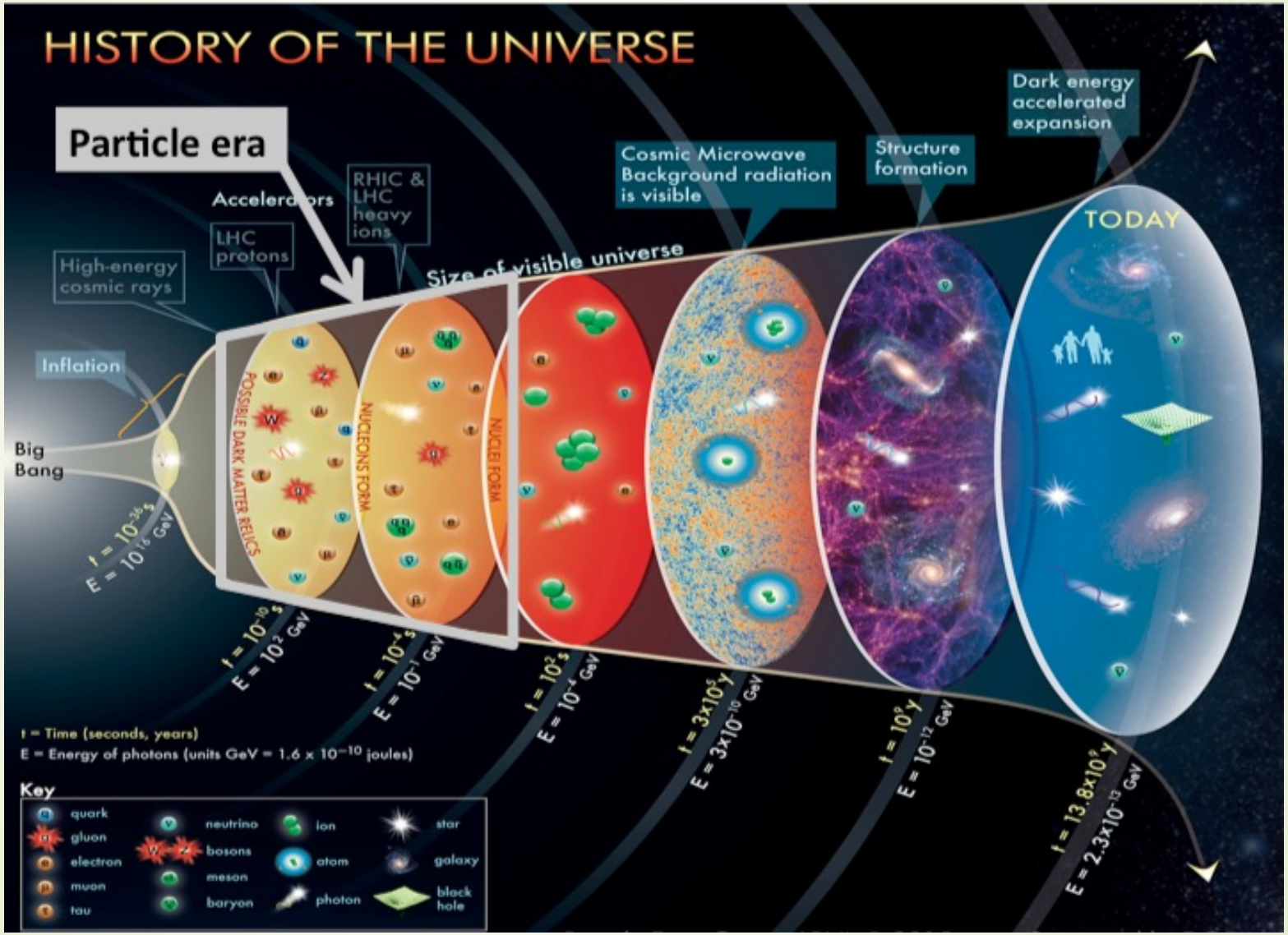
10^{-34}
10^{-30}
10^{-26}
10^{-22}
10^{-18}
10^{-14}
10^{-10}
10^{-6}
1m
10^{6}
10^{10}
10^{14}
10^{18}
10^{22}
10^{26}

Neuron



Human Being

Time Scale


HISTORY OF THE UNIVERSE
Particle era
Accelerators
RHIC & LHC heavy ions
LHC protons
High-energy cosmic rays
Inflation
Big Bang
Size of visible universe
Cosmic Microwave Background radiation is visible
Structure formation
Dark energy accelerated expansion
TODAY
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10⁻³⁶ s
E = 10¹⁶ GeV
t = 10⁻¹⁰ s
E = 10² GeV
t = 10⁻⁴ s
E = 10⁻¹ GeV
t = 10² s
E = 10⁻⁴ GeV
t = 3x10⁵ y
E = 3x10⁻¹⁰ GeV
t = 10⁹ y
E = 10⁻¹² GeV
t = 13.8x10⁹ y
E = 2.3x10⁻¹³ GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10⁻¹⁰ joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole

Particle Physics

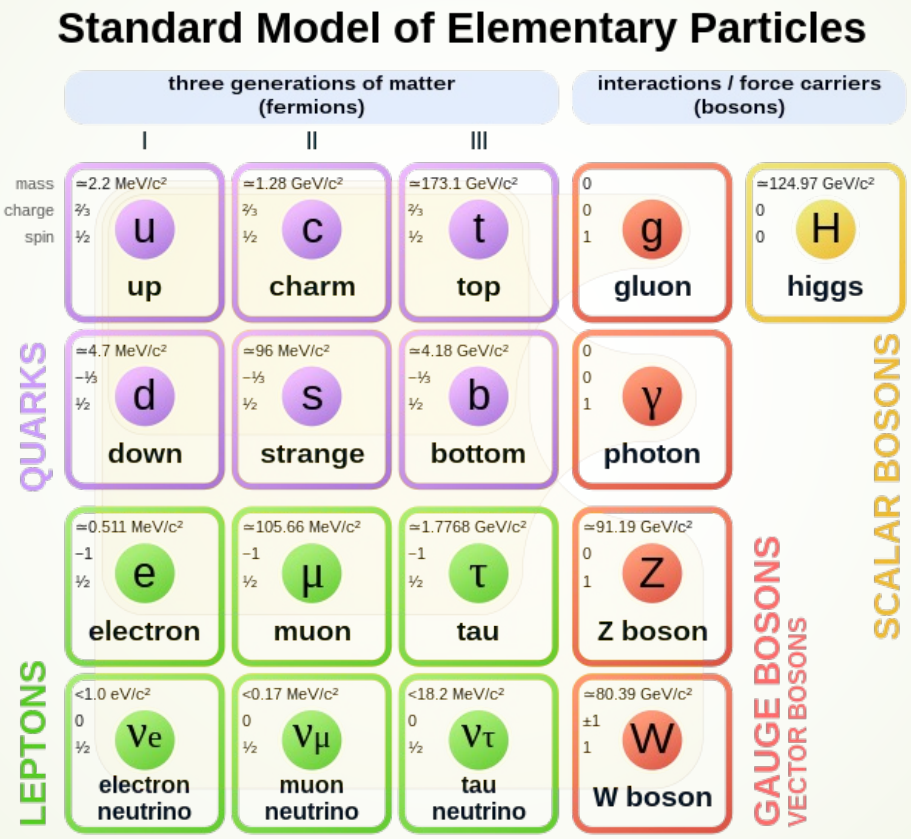
Elementary Particle Physics studies the fundamental building blocks of nature.

- Fundamental means objects that are simple and structureless, not made of anything smaller

Particles and high energy physics try to answer to these questions:

- What is fundamental?
- What is the world made of?
- What holds it together?

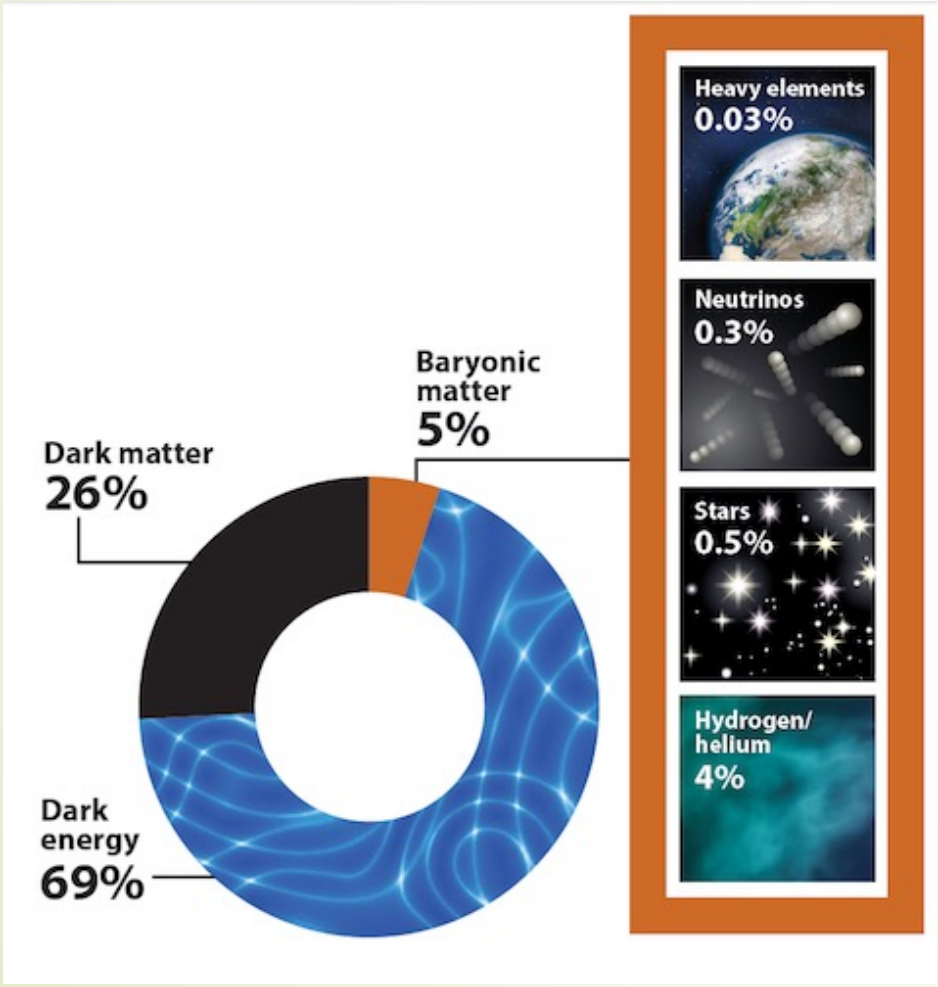
The Standard Model



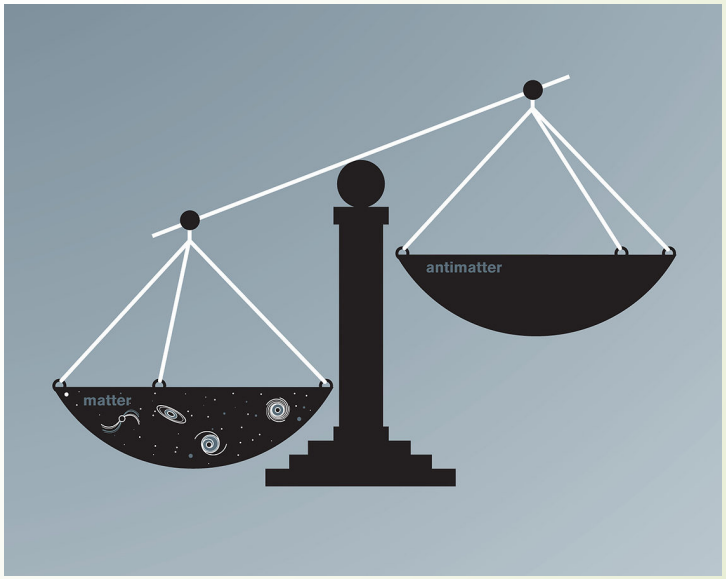
A theory of almost everything you can see!

Big Puzzles

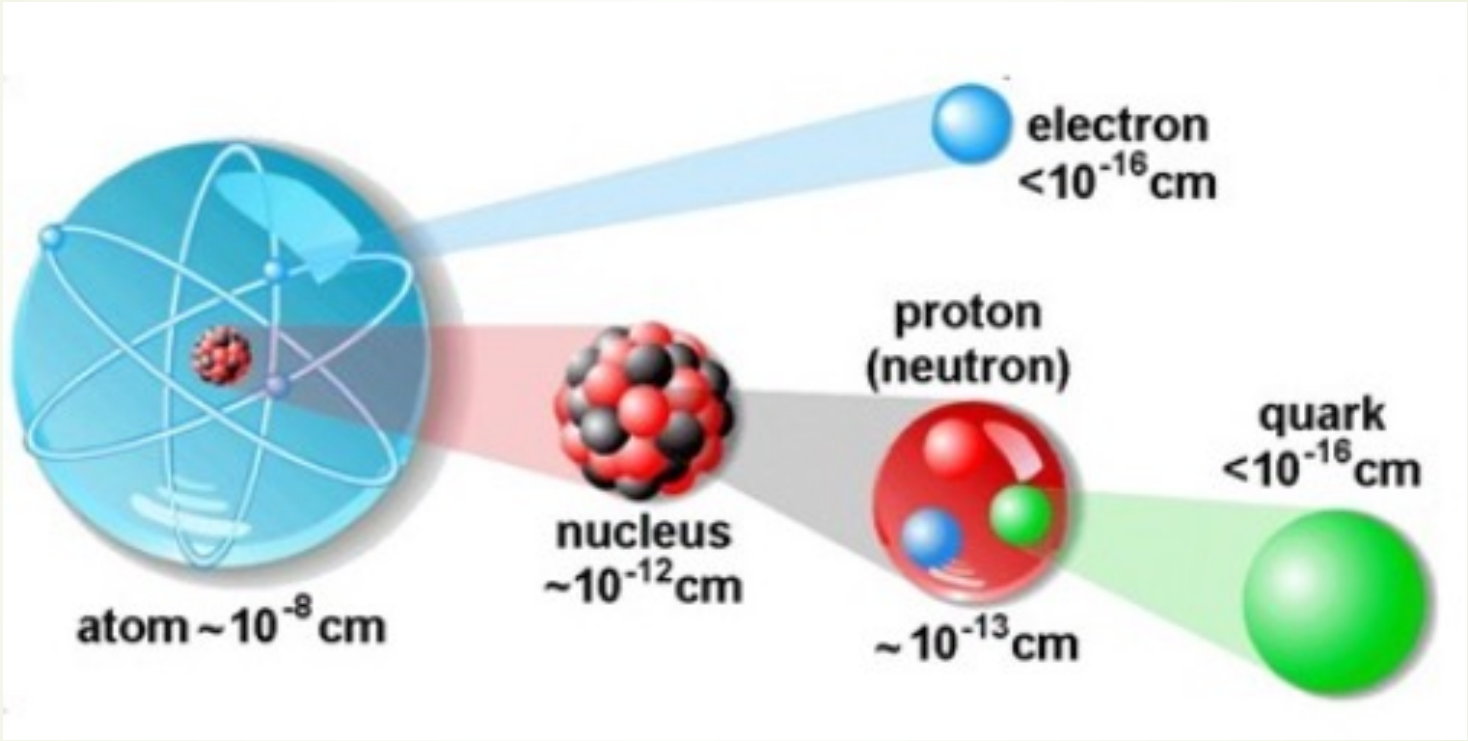
The Standard Model can only explain less than 5% of the Universe!



The Standard Model can not explain matter-anti-matter asymmetry.



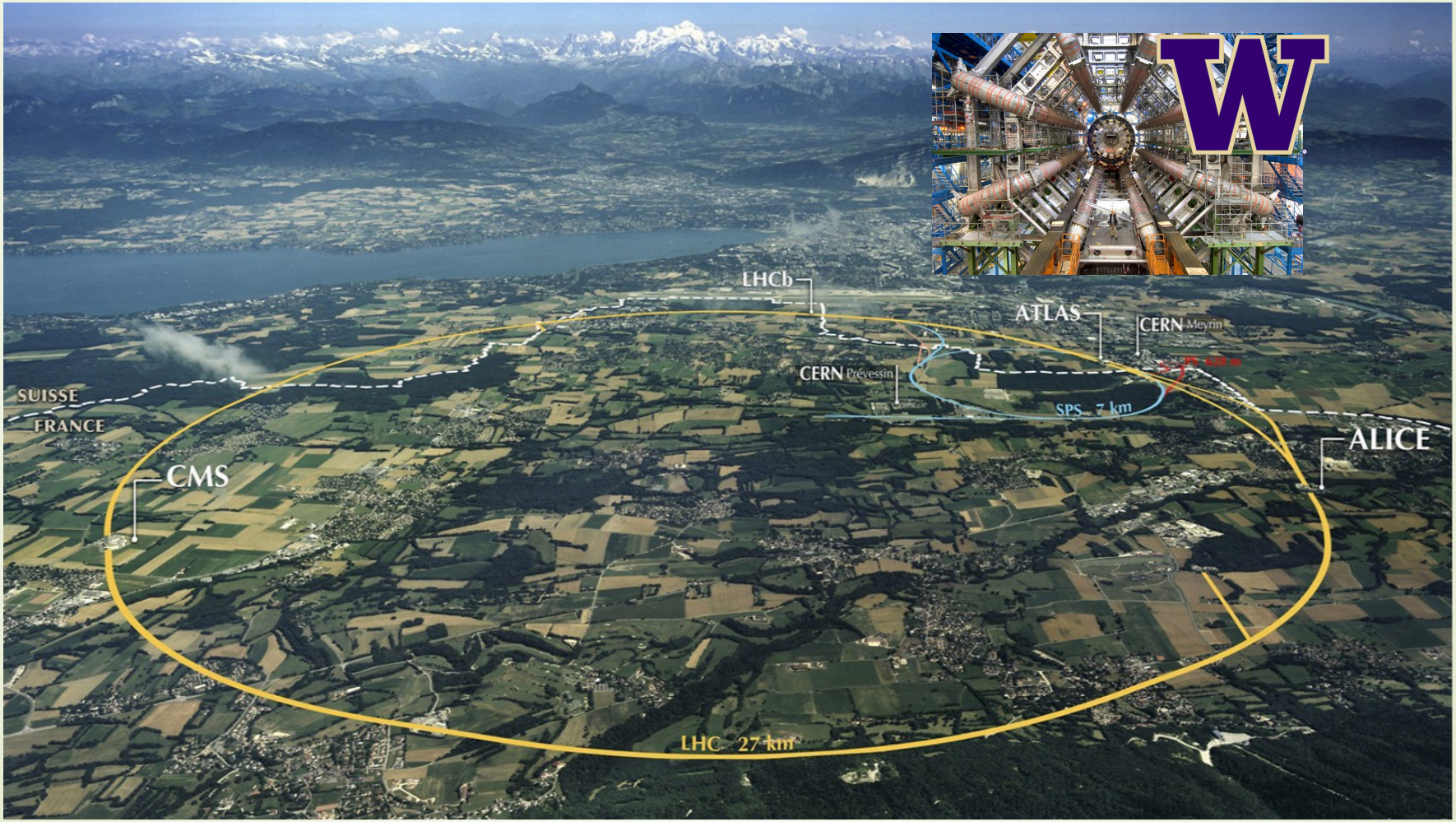
High Energy necessity



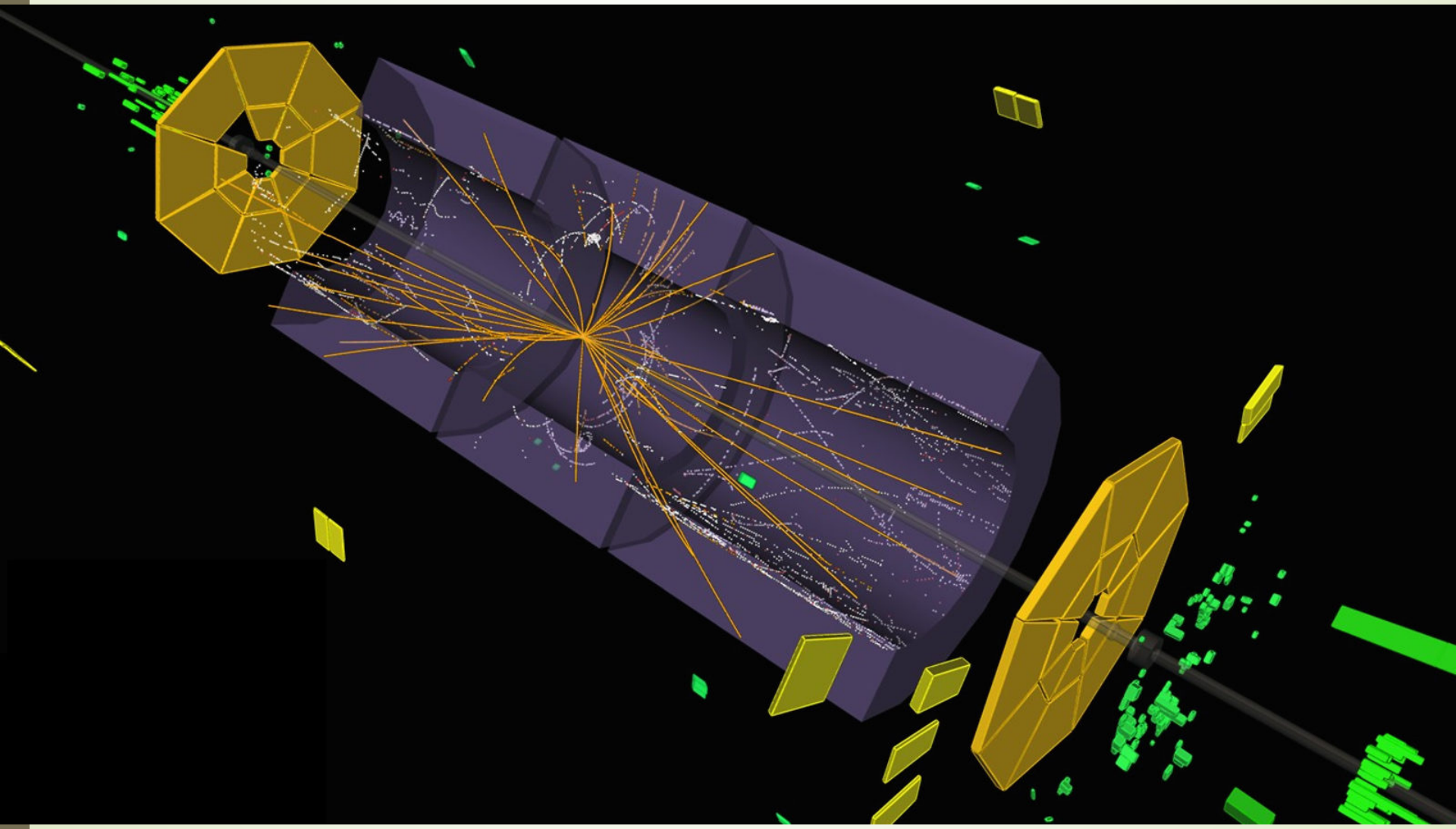
Resolution increases with energy of the probe

$$p = \frac{h}{\lambda}$$

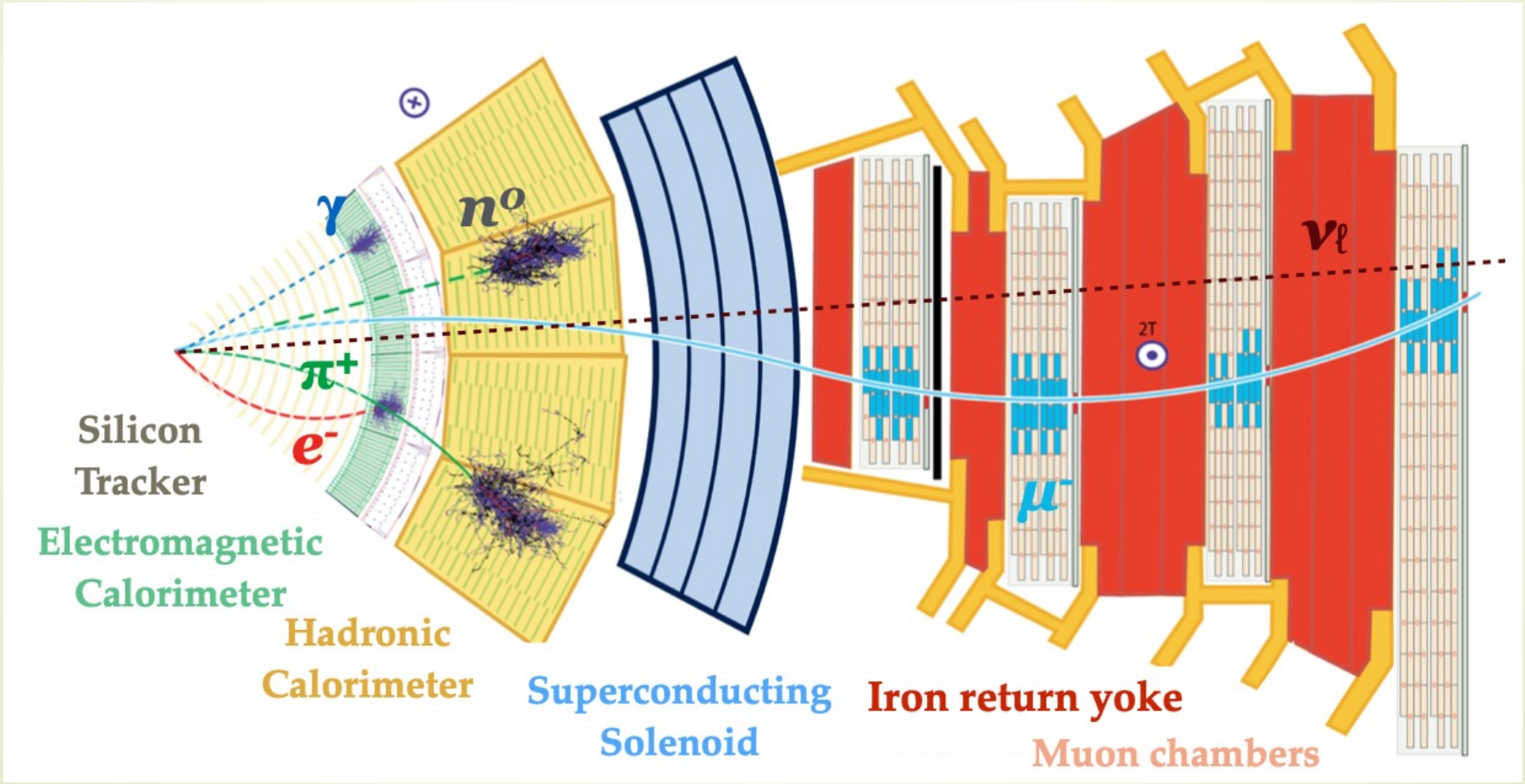
Large Hadron Collider



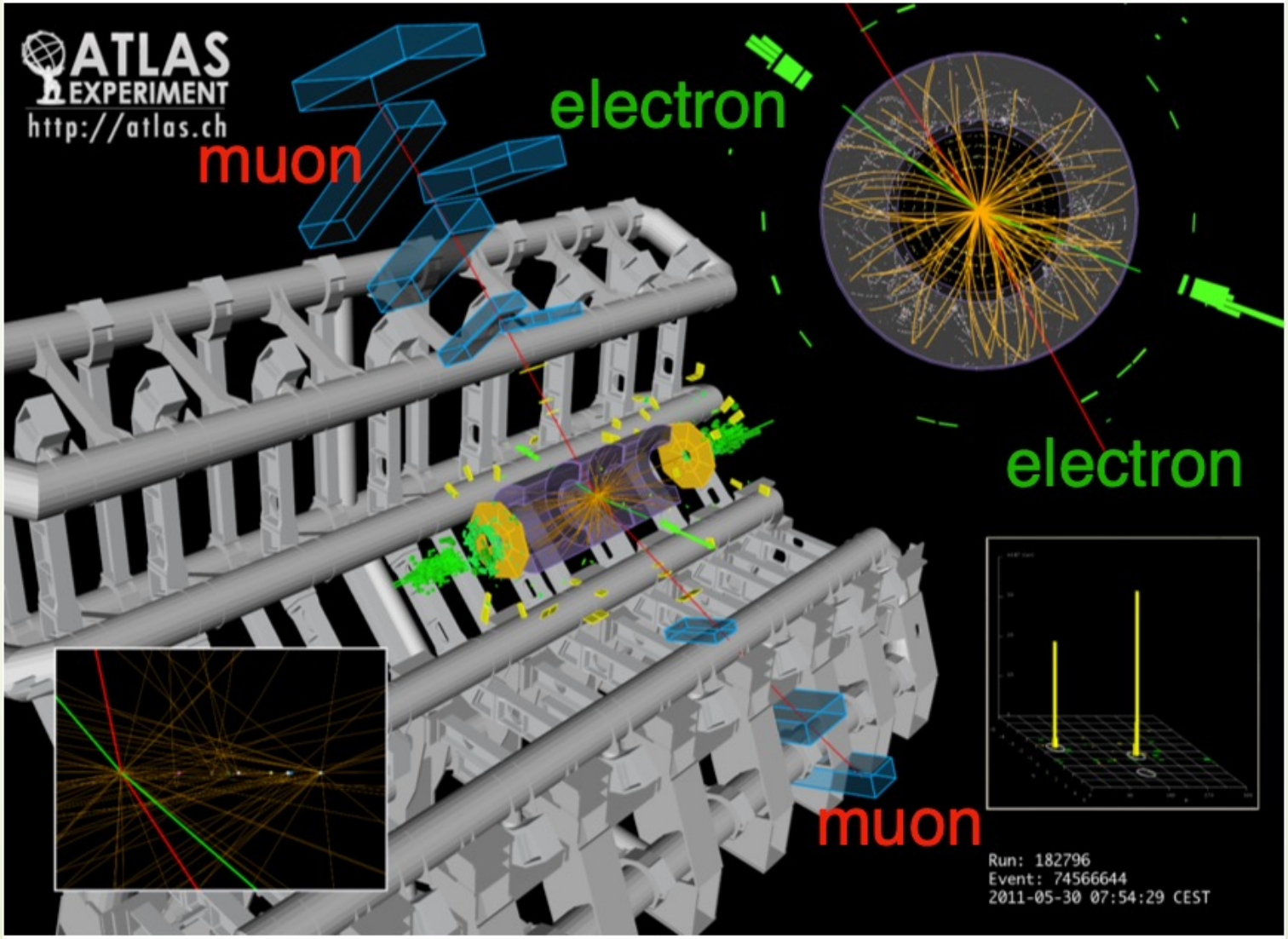
Particle Collisions



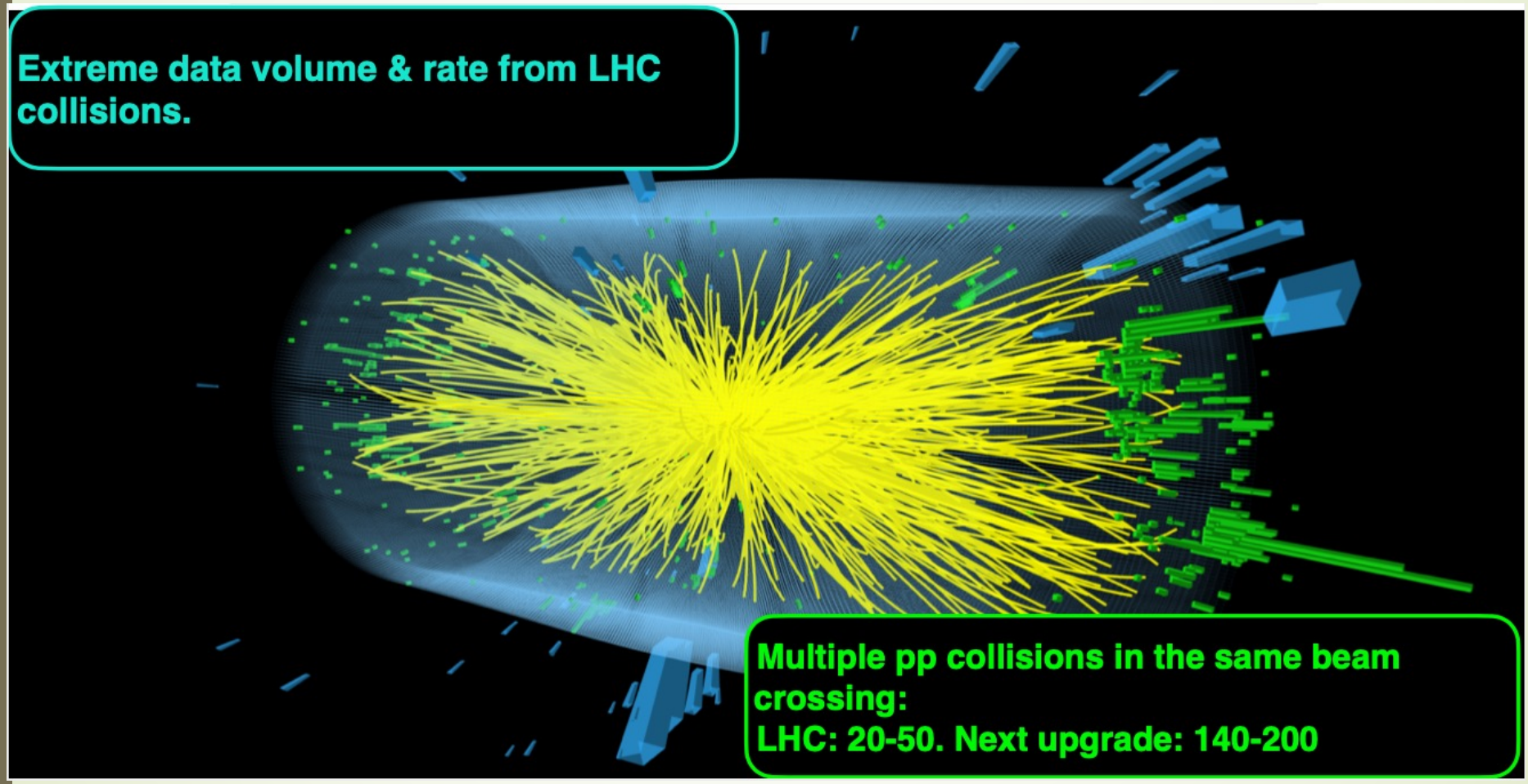
Particle Detection



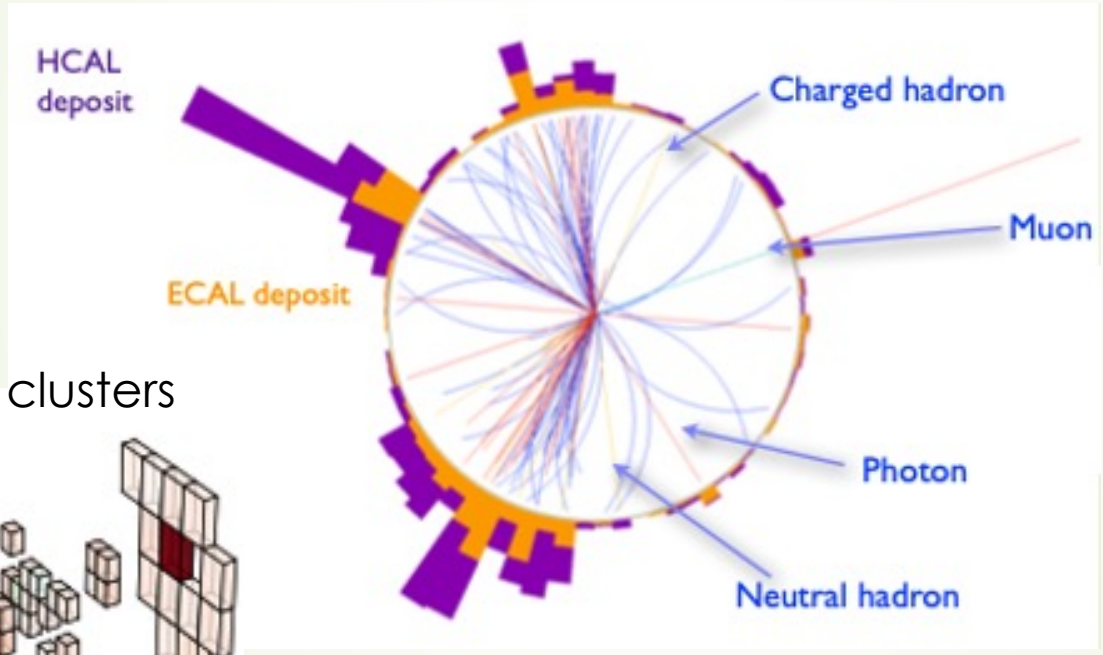
Discovery of the Higgs Boson

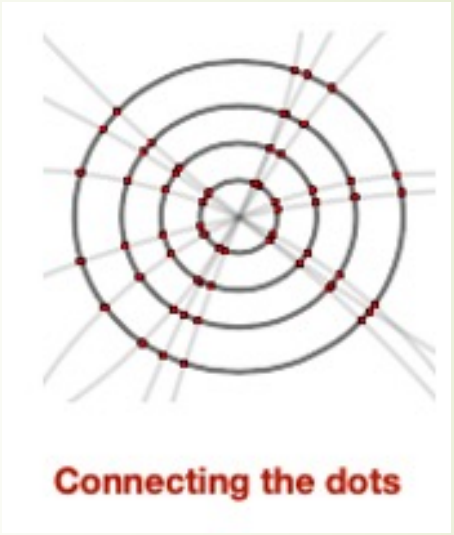


Challenges


Extreme data volume & rate from LHC collisions.
Multiple pp collisions in the same beam crossing:
LHC: 20-50. Next upgrade: 140-200

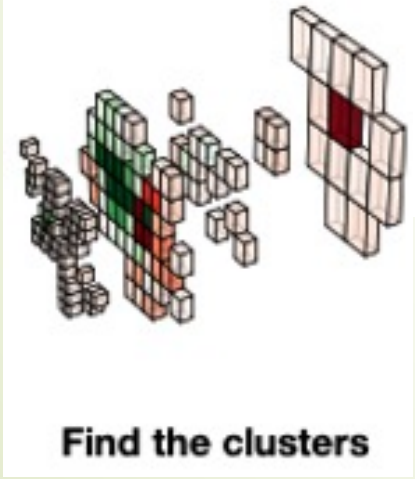
Reconstruction





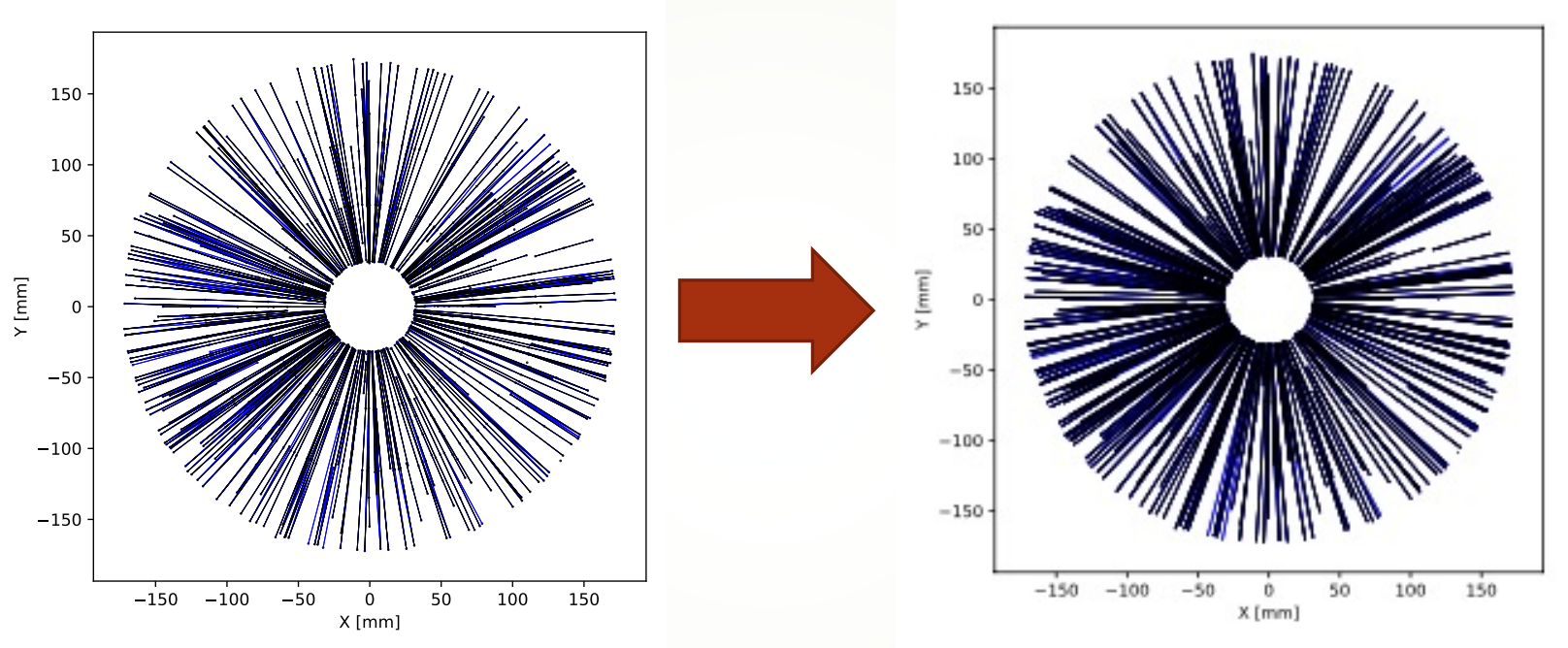
Charged particles

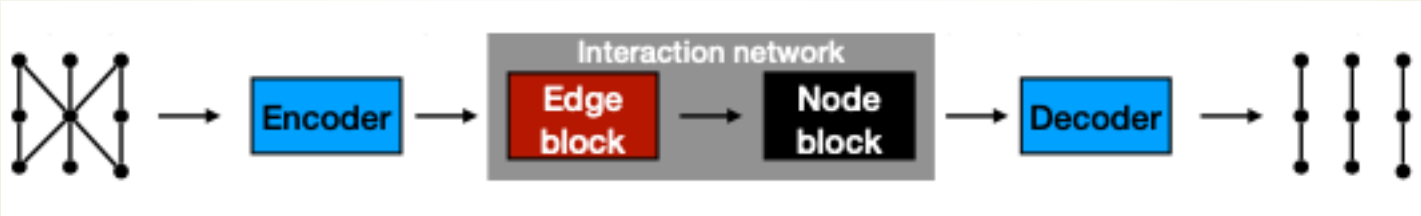
Energy clusters



Track Reconstruction

arxiv:2103.06995

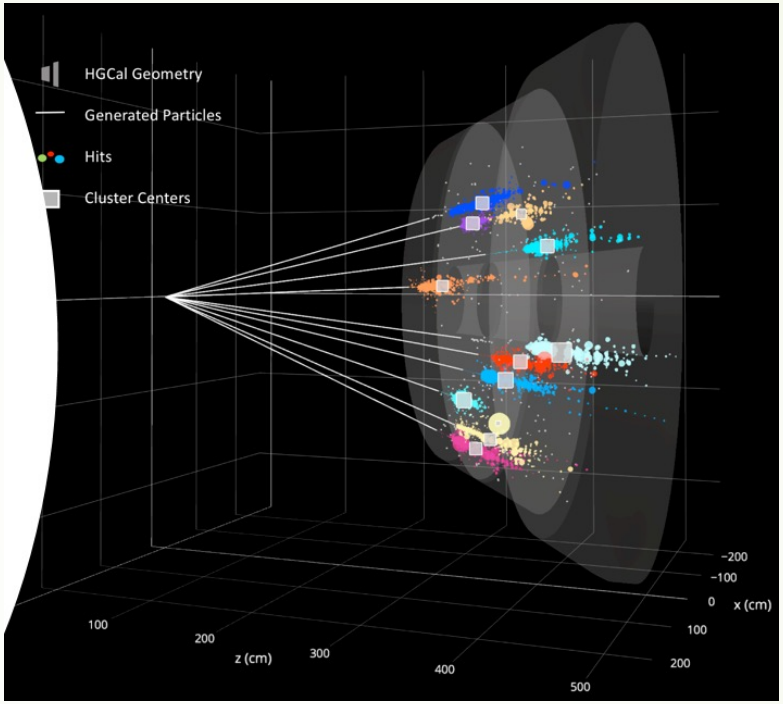


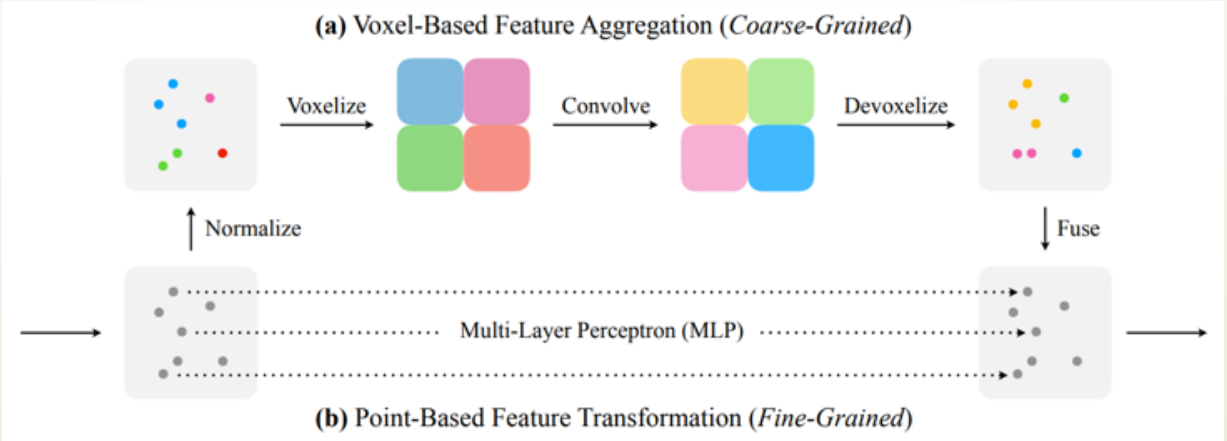


Graph Neural Network to identify correct edge connecting adjacent nodes

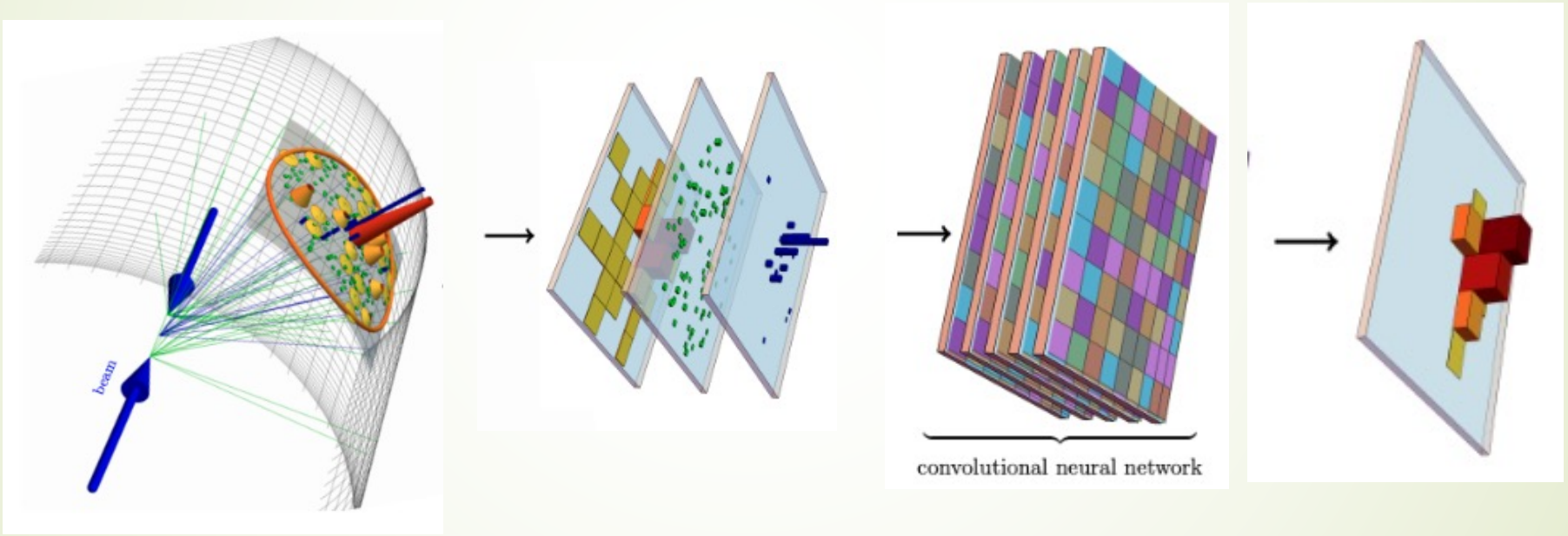
Cluster Reconstruction

A. Schuy [slide]



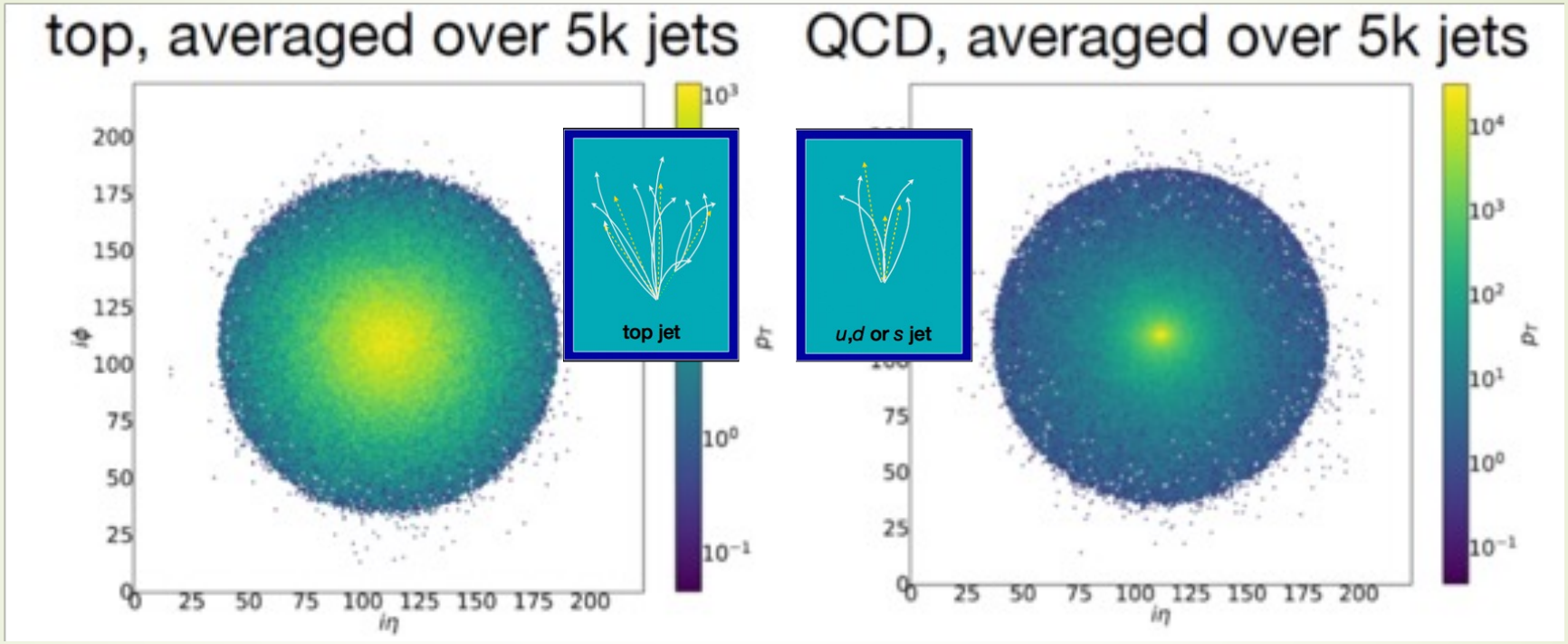


Calorimeter to Image Translation



JHEP12 (2017) 051

Jet Classification as Images



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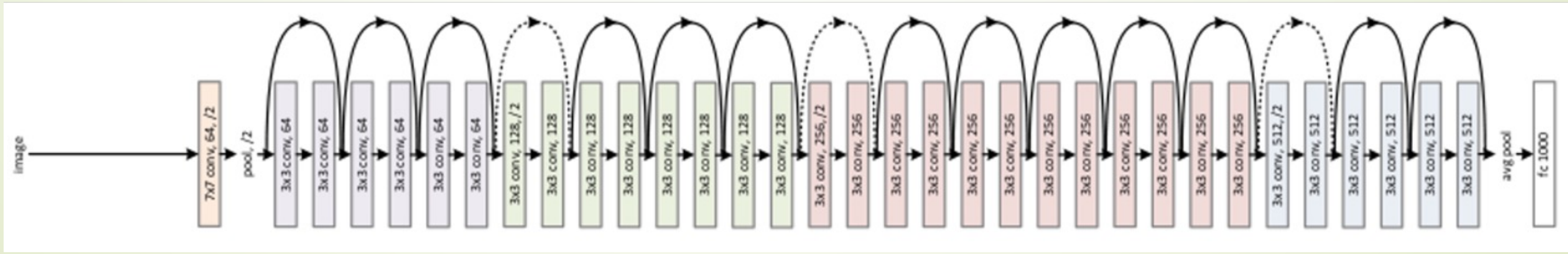
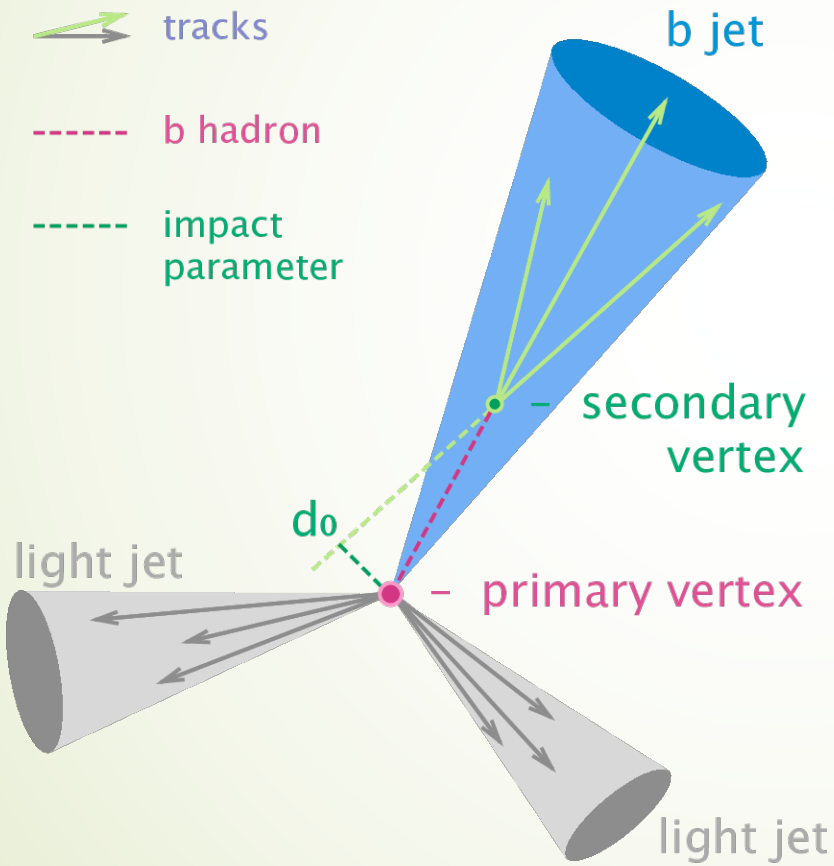
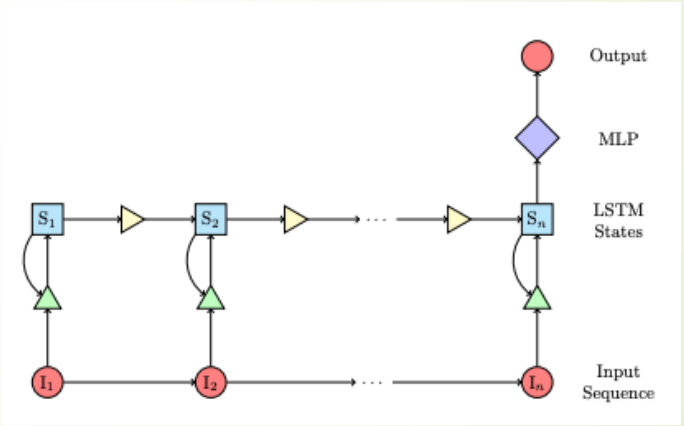


Flavor Identification as Natural Language Processing



LSTM Phys. Rev. D 94, 112002 (2016)



Summary

- Particle Physics studying fundamental building block of the Universe and their interactions
- Deep Learning critical to Particle Physics
  - Reconstruction
  - Classification
  - … many more, e.g., anomaly detection, regression,