

High energy physics Experiments

Nov. 2025

FYS4505

[A. Read](#)

UiO • University of Oslo

Intro:Simplified anatomy of a typical subatomic experiment

- Create a beam of particles (**what kinds?**), accelerate them, crash them into a target (target may also be another beam: colliders)
- Observe the collisions in a detector, filter/«trigger on» interesting collisions and store them
- Reconstruct the outgoing particles (**typically what?**)
- Filter the data, study statistical patterns in the data
- Monte Carlo-simulate known and potential new processes and compare with the data, check for anomalies, look for excesses above the known processes, measure process rates and particle properties

Plan

- To touch very briefly all the elements of a «typical» HEP experiment (ATLAS at CERN Large Hadron Collider).
- To take a quick look at other detectors

The Large Hadron Collider (LHC)

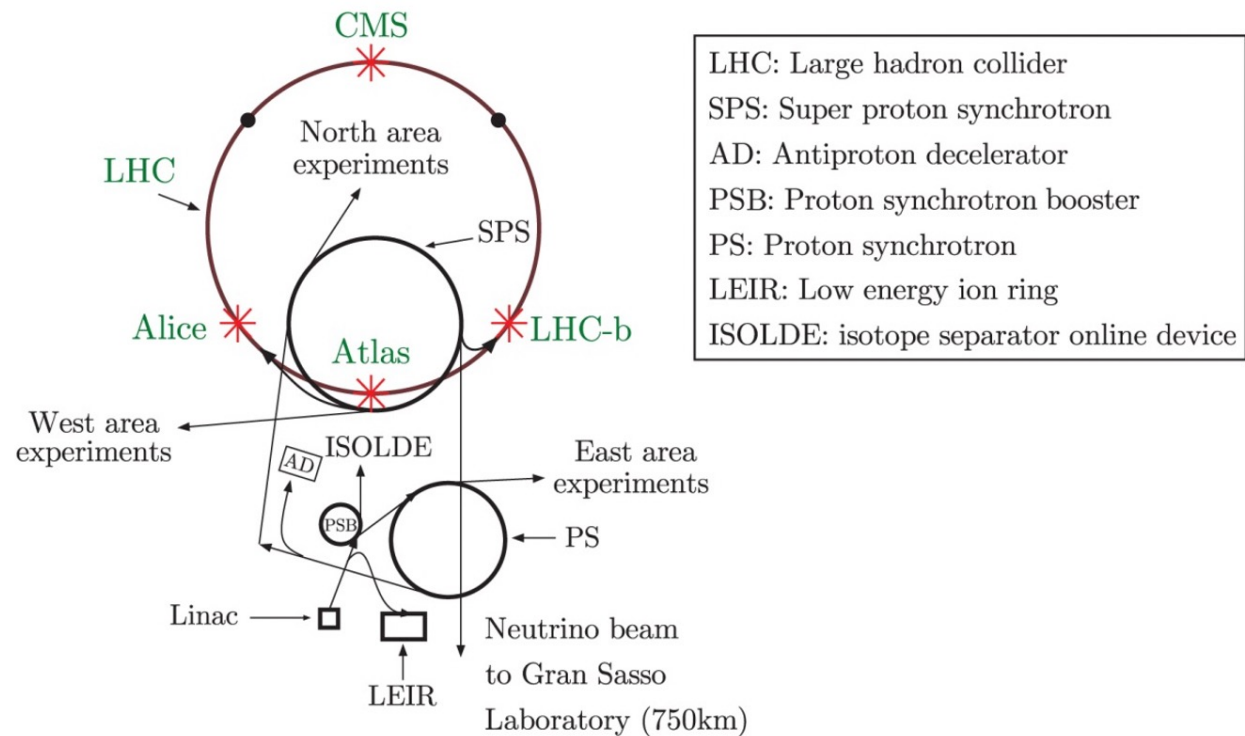


Figure 4.8 A schematic diagram of the CERN site showing the LHC and some of its other accelerators. Source: Reproduced by permission of CERN.

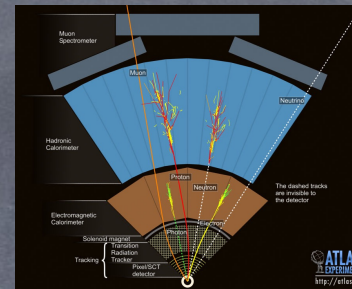




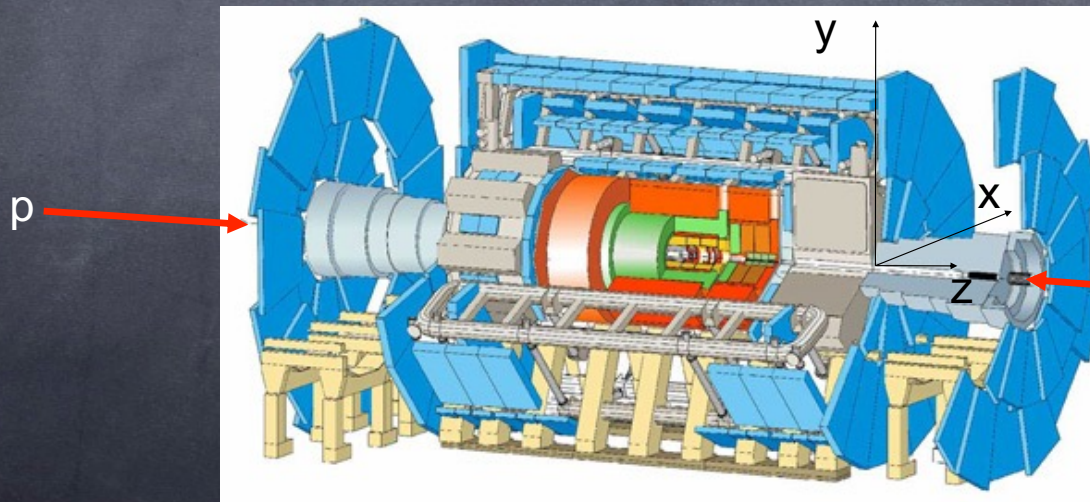
Typical modern HEP experiment

ATLAS-eksperimentet

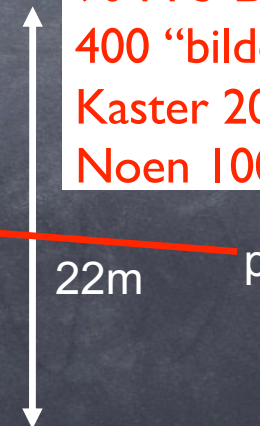
Elektroner (stabile)
Myoner (stabile nok)
Tau-leptoner (fra henfallsprodukter)
Jets (fra kvarker og gluoner)
Manglende transverse bev.mengde
(nøytrinoer, ny fysikk e.g. SUSY)



7000 tonn (~100 tomme Boeing 747er)



90 M 3-D piksler
400 "bilder"/s
Kaster 20 Mbilder/s
Noen 1000 TB/år



High Energy particle interactions

- Electrons above ~ 10 MeV lose energy mainly by radiation

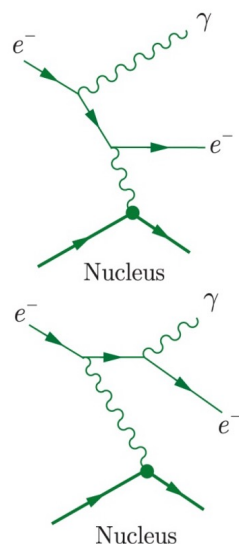


Figure 4.11 Dominant Feynman diagrams for the bremsstrahlung process
 $e^- + (Z, A) \rightarrow e^- + \gamma + (Z, A)$.

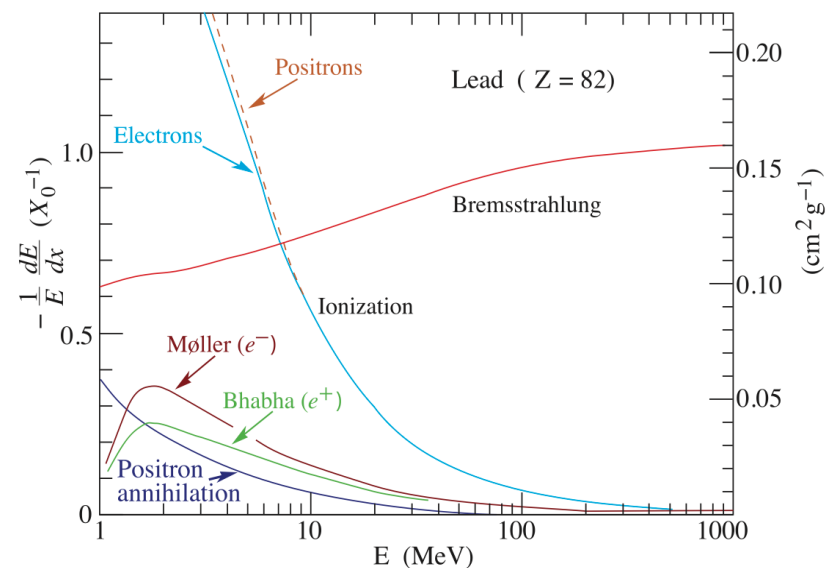


Figure 34.11: Fractional energy loss per radiation length in lead as a function of electron or positron energy. Electron (positron) scattering is considered as ionization when the energy loss per collision is below 0.255 MeV, and as Møller (Bhabha) scattering when it is above. Adapted from Fig. 3.2 from Messel and Crawford, *Electron-Photon Shower Distribution Function Tables for Lead, Copper, and Air Absorbers*, Pergamon Press, 1970. Messel and Crawford use $X_0(\text{Pb}) = 5.82 \text{ g/cm}^2$, but we have modified the figures to reflect the value given in the Table of Atomic and Nuclear Properties of Materials ($X_0(\text{Pb}) = 6.37 \text{ g/cm}^2$).

High Energy particle interactions

- Photons above ~ 1 MeV lose energy mainly by e^+e^- pair creation

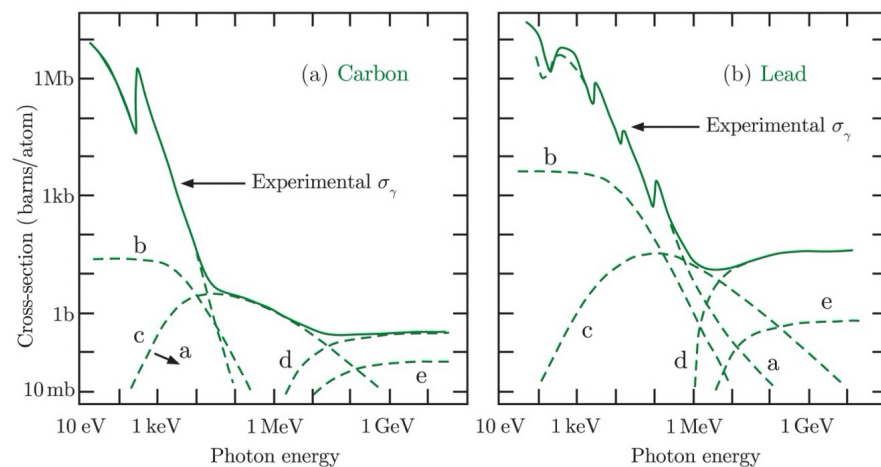


Figure 4.12 Total experimental photon cross-section σ_γ on (a) a carbon atom and (b) a lead atom, together with the contributions from (a) the photoelectric effect, (b) Rayleigh (coherent atomic) scattering, (c) Compton scattering, (d) pair production in the field of the nucleus, and (e) pair production in the field of the atomic electrons. Source: Adapted from Tanabashi et al. (Particle Data Group) (2018).

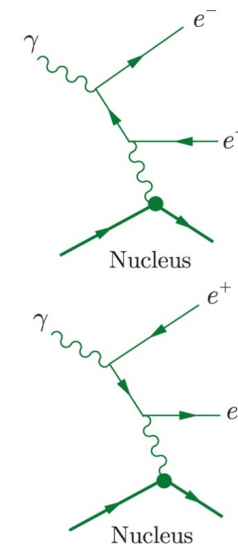
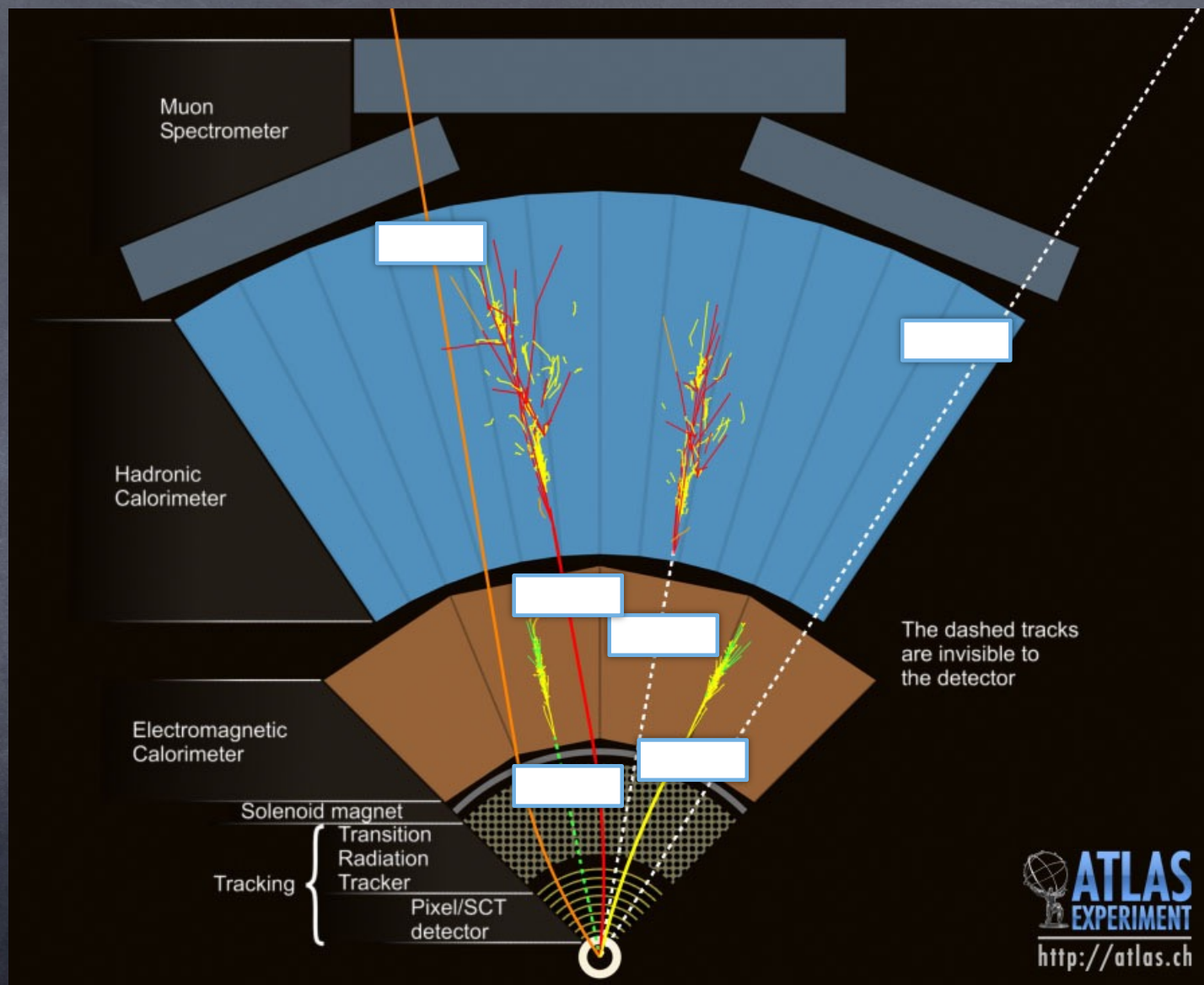


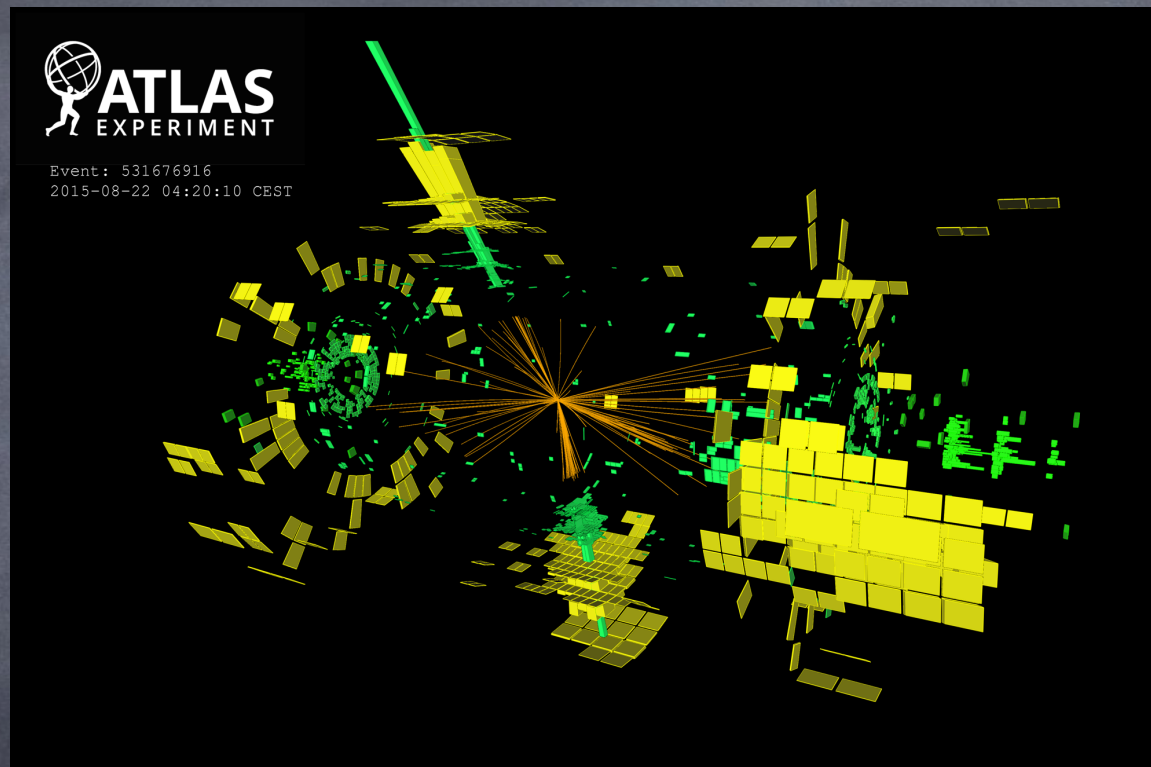
Figure 4.13 The pair production process $\gamma + (Z, A) \rightarrow e^- + e^+ + (Z, A)$.

High Energy particle interactions

- Electrons above ~ 10 MeV lose energy mainly by radiation
- Photons above ~ 1 MeV lose energy mainly by e^+e^- pair creation
- Hadrons above ~ 1 GeV lose energy mainly by strong interactions with nuclei
- Radiation suppressed by $1/m_h^2$
- Interaction lengths tend to be long (with respect to «radiation length» for electrons and photons)
- Muons lose energy mainly by dE/dx
- No strong interactions
- Radiation suppressed by $1/m_\mu^2$



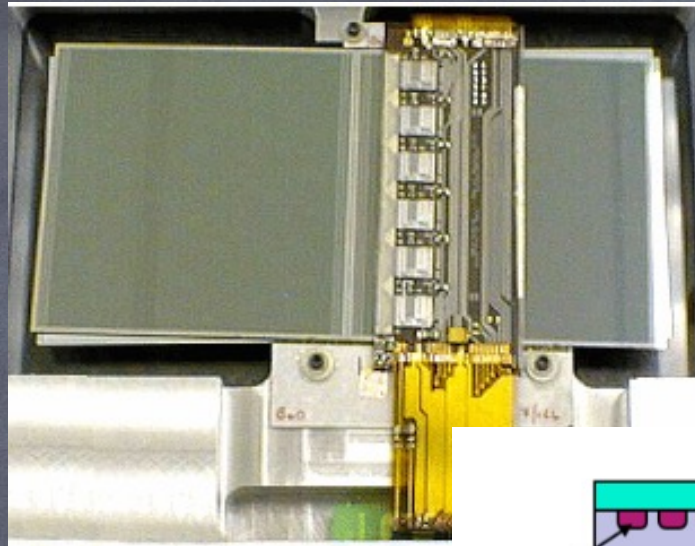
Jets



- High-mass (6.9 TeV) dijet event collected in August 2015.

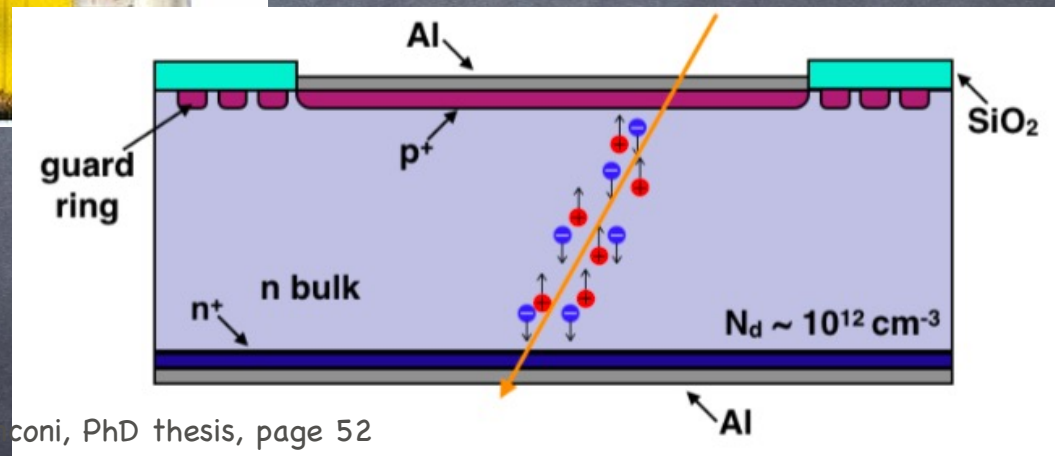
Sub-detector example

Made in Norway (+Uppsala)



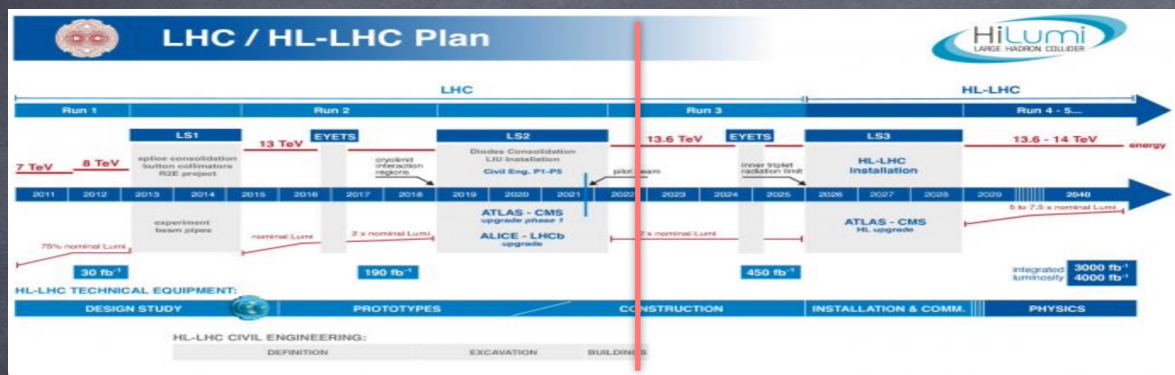
What causes the liberated electrons and holes to move in opposite directions?

Radiation damage makes «trapping centers» in the bulk. Any ideas how radiation damage could be mitigated?



L. Franconi, PhD thesis, page 52

New ATLAS tracker 202?-3?



A new inner tracker for ATLAS

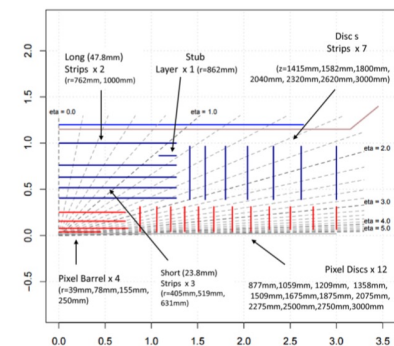
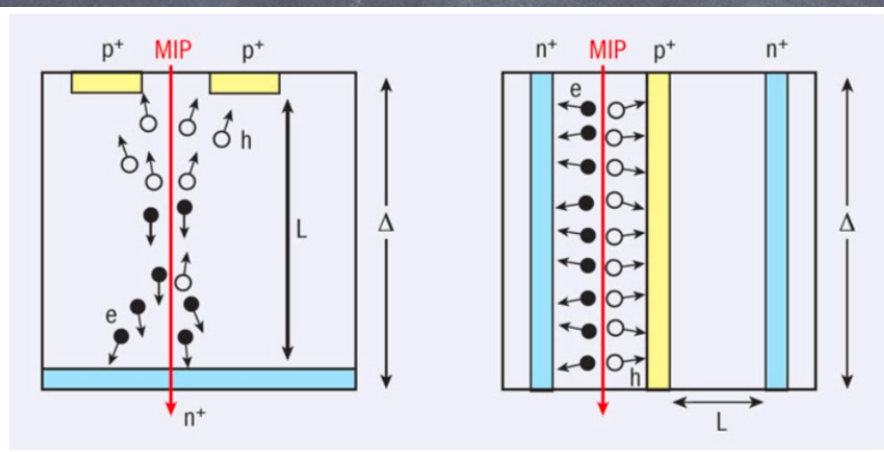


Figure 2: Left: ITk "Reference" layout, axial cross-section installed in the ATLAS IBL. The size corresponds to the size of the ATLAS IBL.



Detector Module Assembly

Department of Physics ELAB – Cleanroom

Cleanroom facility

Class ISO 7 (10,000/m³)

- Constructed during 2015
- Usable area: 35 m²
- Air-lock, transfer cabinets
- 2-3 concurrent activities

Aluminum wire wedge bonding

F&K Delvotec M 175

- Wire diameter: 17.5 – 75.0 μ m
- Bondable area: 254 x 152 mm²
- Repeatability: $\pm$ 3 μ m @ 3 σ
- Pattern recognition: Cognex 8000 Pat Max
- Adaptable bond process control (BPC)
- Fully automatic operation, up to 3 bonds per second

Wire bond quality assurance

F&S Bondtec 5600C

- Universal bonder- and tester platform
- Configured as pull- and shear tester
- Pull head PH100C (100 cN)
- Shear head SE500C (500 cN)
- Destructive- and non-destructive test modes
- Optical pattern recognition
- Automatic operation, report generation

4-axis assembly robot

Zeeco Onyx32

- Working area: 355 x 320 mm²
- Accuracy: $\pm$ 20 μ m @ 3 σ
- SMD pick&place
- De-soldering and soldering
- Heater plate and hot gas
- Liquid dispensing (solder paste, glue)
- Up- and down looking cameras
- Pattern recognition

Assembly- and interconnect technologies

Surface mount soldering	Module assembly	Support facilities
- Solder paste printing - Automatic pick&place - Pos. data from EDA - Vapor-phase solder oven	- Jigs- or robotic placement - Glue stamping - Glue dispensing - Glue printing	- Dry cabinet < 3% RH - Pre-baking oven - Ultrasonic cleaning - Inspection microscopy - Z-axis image stacking

ITk Upgrade NORWAY ATLAS EXPERIMENT

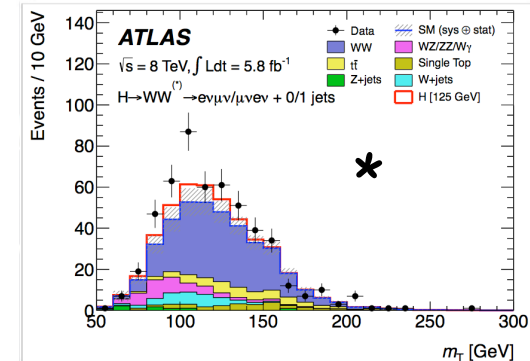
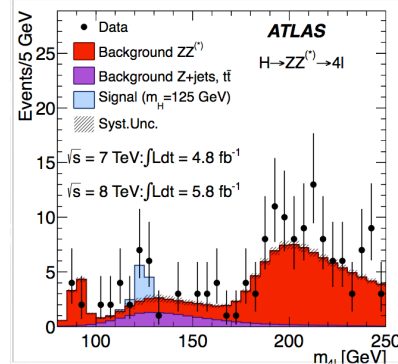
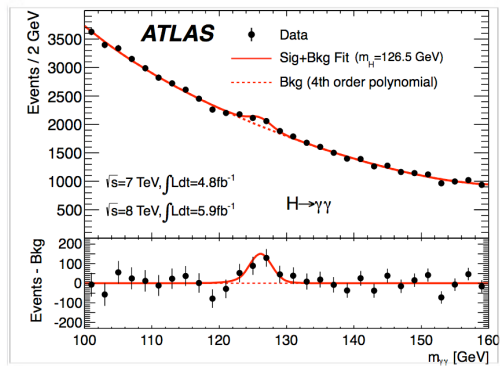
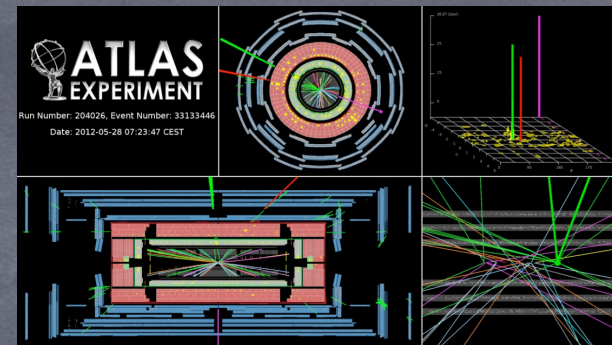
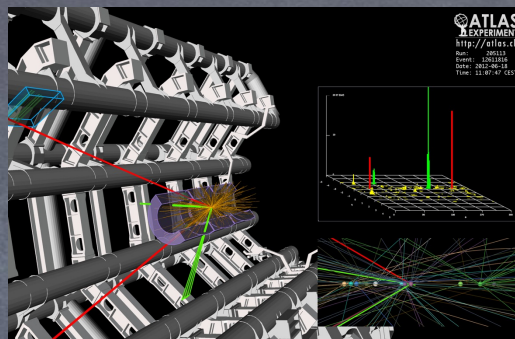
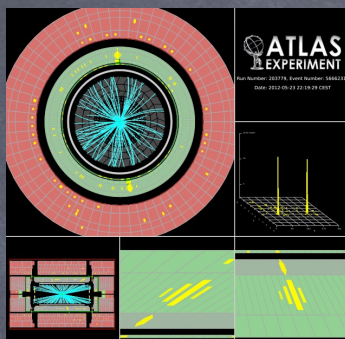
UiO Department of Physics University of Oslo

Higgs boson discovery

- LHC challenge: We looked for about 10,000 Higgs bosons in a million billion proton-proton-collisions



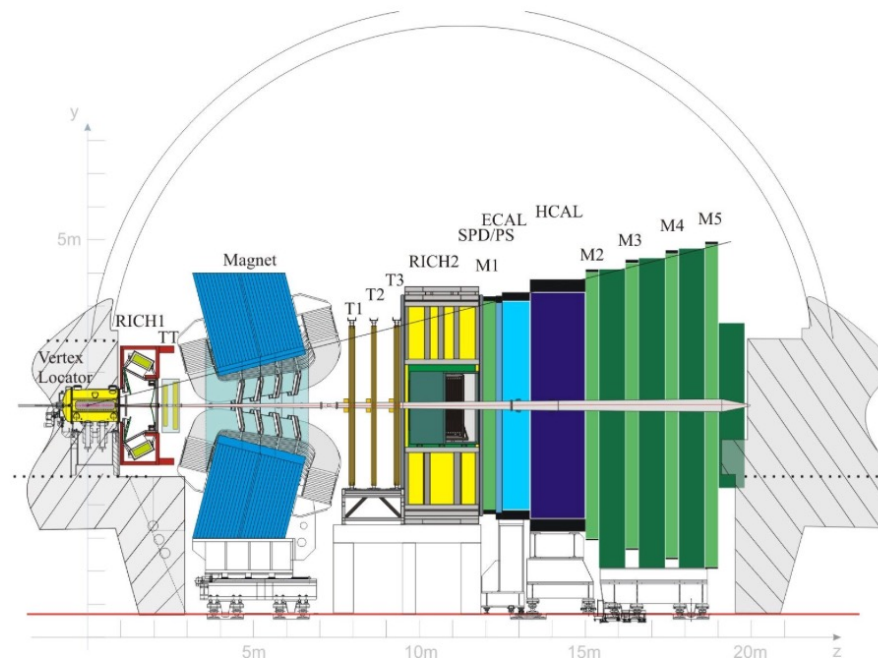
Results 4 July (*), 2012



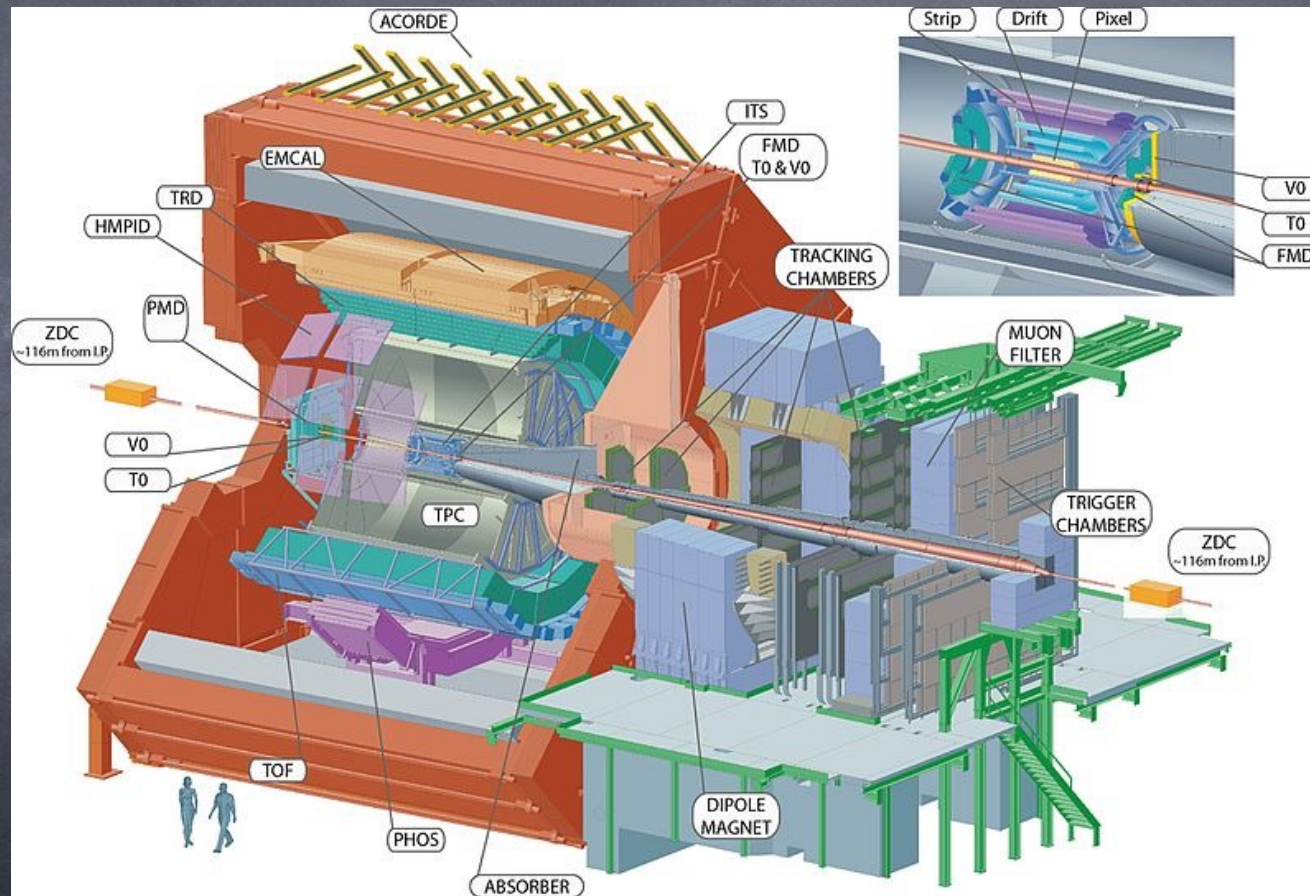
Other experiment types

“Fixed-target”

The LHCb Detector



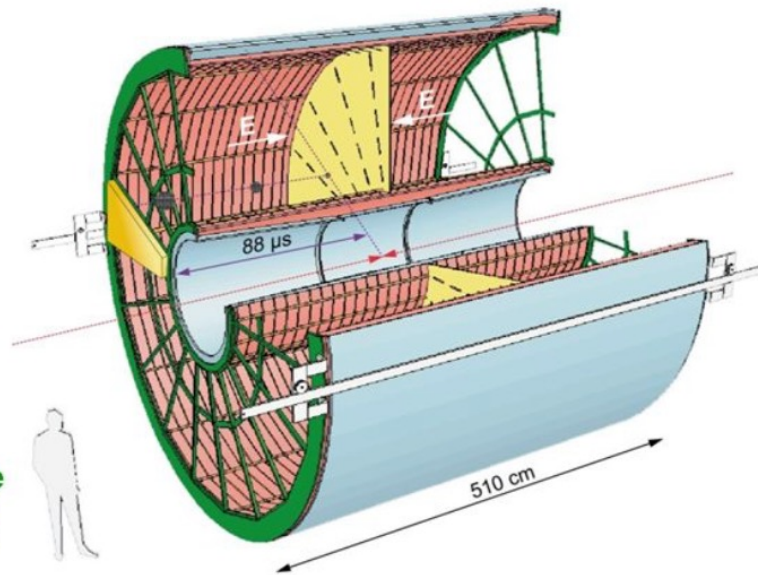
ALICE - heavy ion specialist



ALICE TPC

ALICE TPC: Construction Parameters

- Largest TPC:
 - Length 5m
 - Diameter 5m
 - Volume 88m³
 - Detector area 32m²
 - Channels ~570 000
- High Voltage:
 - Cathode -100kV
- Material X_0
 - Cylinder from composite materials from airplane industry ($X_0 = \sim 3\%$)



ALICE TPC – dE/dx vs p/Z

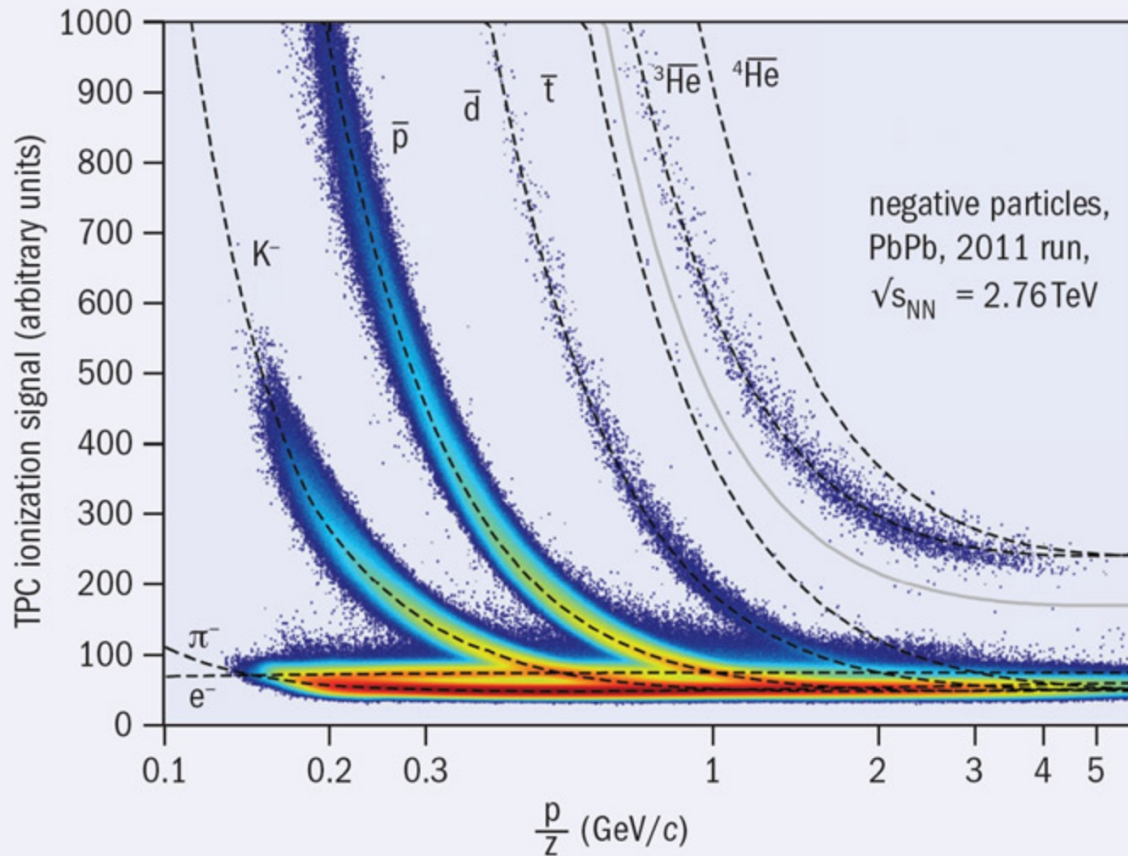
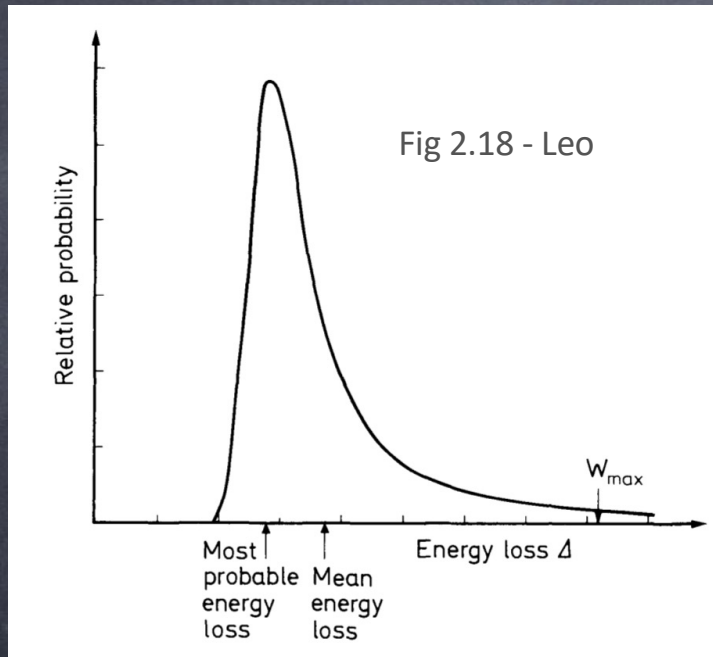


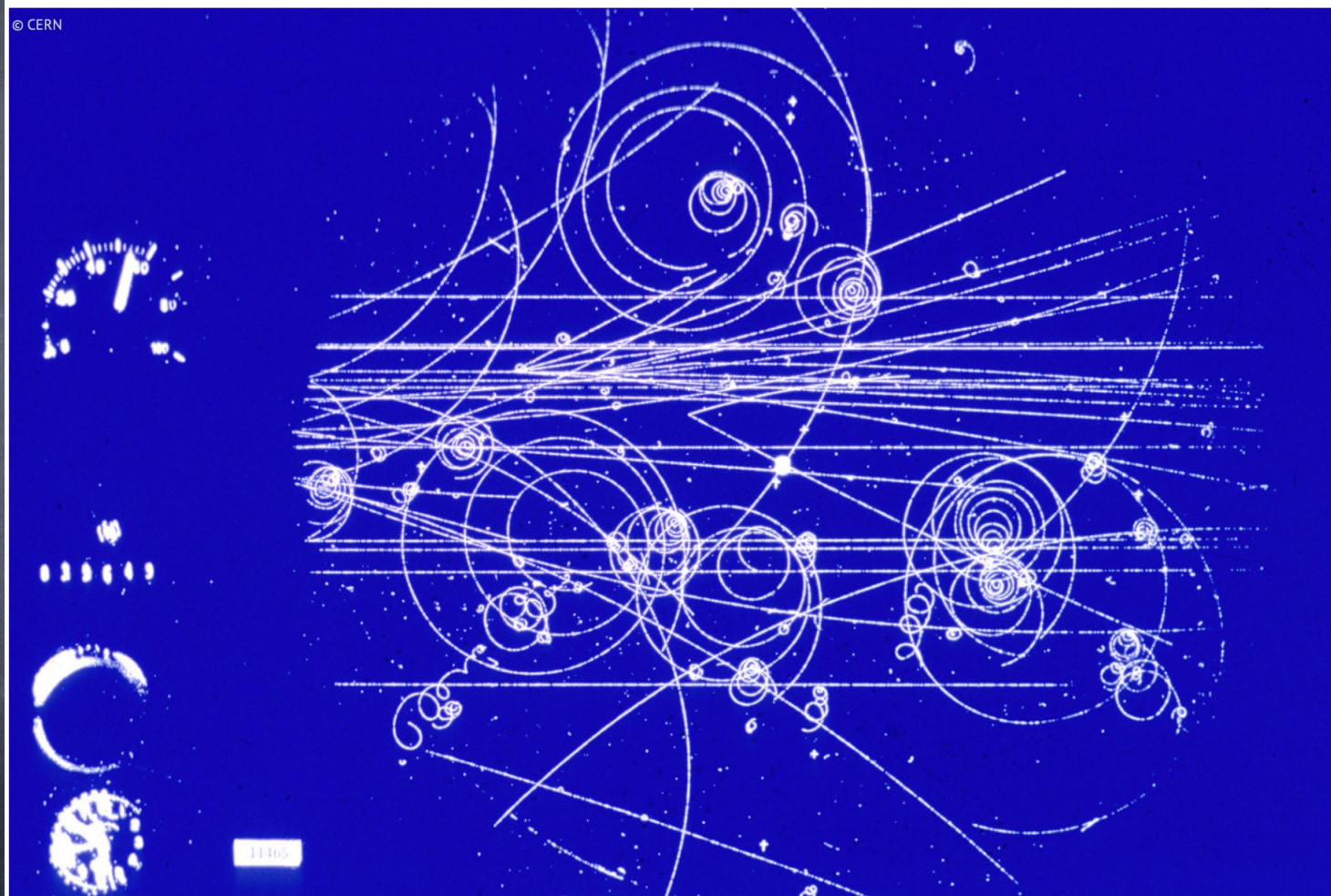
Fig. 2. Ionization signals in the ALICE TPC as a function of the particle momentum for PbPb collisions at $\sqrt{s_{NN}} = 2.76 \text{ TeV}$. An offline trigger was applied to enhance track samples with charges $z < -1$. The charged (anti)hadrons are well separated, in particular at low momentum. Electrons, antideuterons (d^-), antitritons (t^-) and anti- ${}^3\text{He}$ nuclei are visible as well. The dashed lines are parameterizations of the Bethe-Bloch curve.

Landau distribution



- Too few interactions in **thin** absorbers for central limit to hold
- Landau distribution (approximation, but quite good)
- Max energy loss is “infinite”
- Treat electrons as free – ignore small energy transfers from distant collisions
- Particle velocity is constant
- If many dE/dx measurements (a la TPC), cut out the 10% highest

Bubble chamber (1960's, slowwww...)



CERN-EX-11465-1 - Small, Medium, Large, Original

Bubble and cloud chambers

- Historically important
- How do they work?

Aiming for groundbreaking discoveries



Origin of Matter

Could neutrinos be the reason that the universe is made of matter rather than antimatter? By exploring the phenomenon of neutrino oscillations, DUNE seeks to revolutionize our understanding of neutrinos and their role in the universe.



Unification of Forces

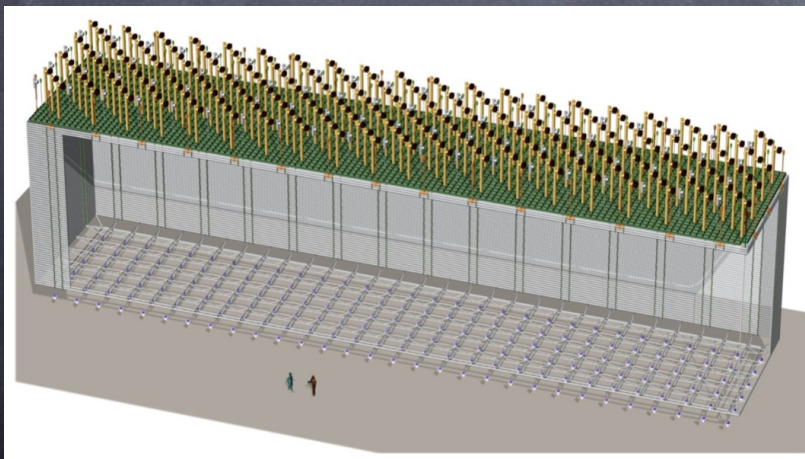
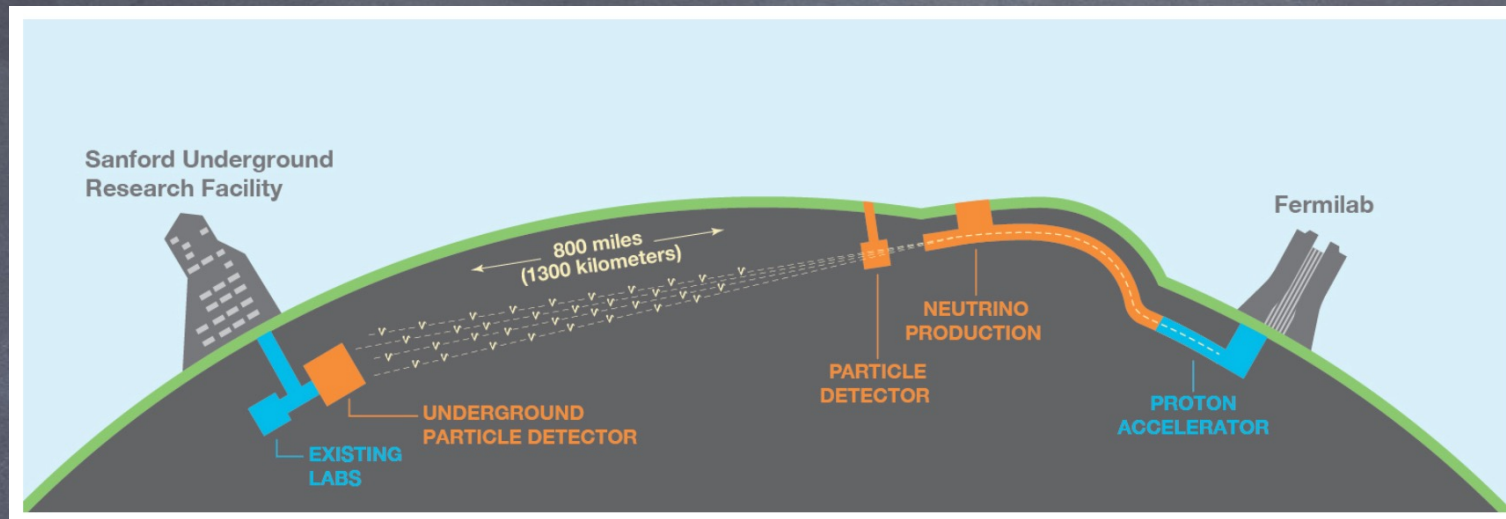
With the world's largest cryogenic particle detector located deep underground, DUNE can search for signs of proton decay. This could reveal a relation between the stability of matter and the Grand Unification of forces, moving us closer to realizing Einstein's dream.



Black Hole Formation

DUNE's observation of thousands of neutrinos from a core-collapse supernova in the Milky Way would allow us to peer inside a newly-formed neutron star and potentially witness the birth of a black hole.

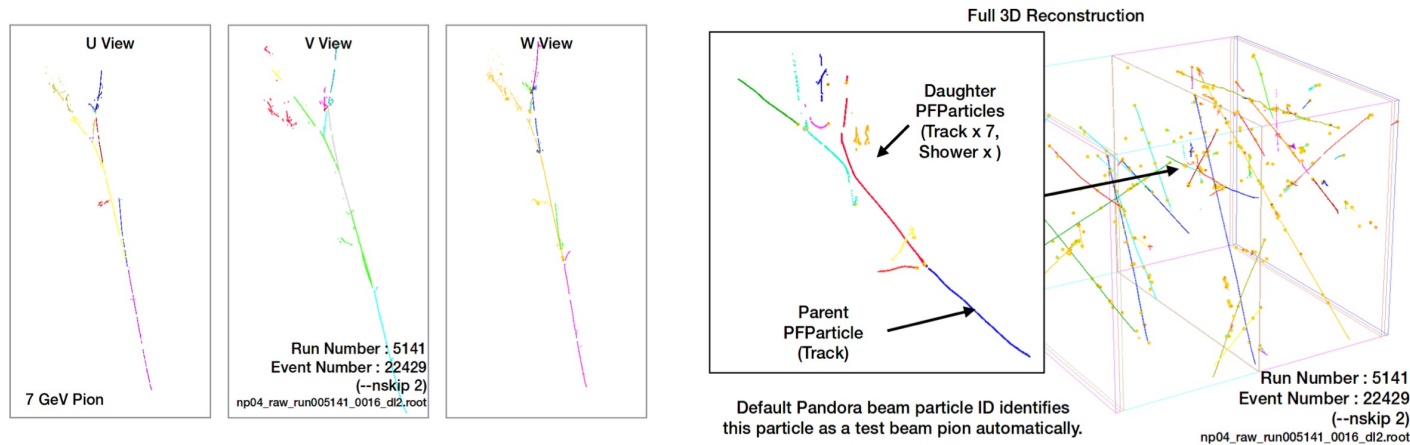
Neutrino detector: DUNE



- Liquid argon (LAr) Time Projection Chamber (TPC) - 3D detection of ionising particles.
- The 10 kton LAr is first target then detector.

Neutrino detector: DUNE

ProtoDUNE SP: data reconstruction



https://indico.in2p3.fr/event/17355/contributions/66894/attachments/50840/65055/gdr_strasbourg.pdf

Incoming 7 GeV pion from test-beam at CERN