Experimental Particle Physics
AG Prof. K. Jakobs
and
Emmy-Nother-Group Dr. S. Argyropoulos

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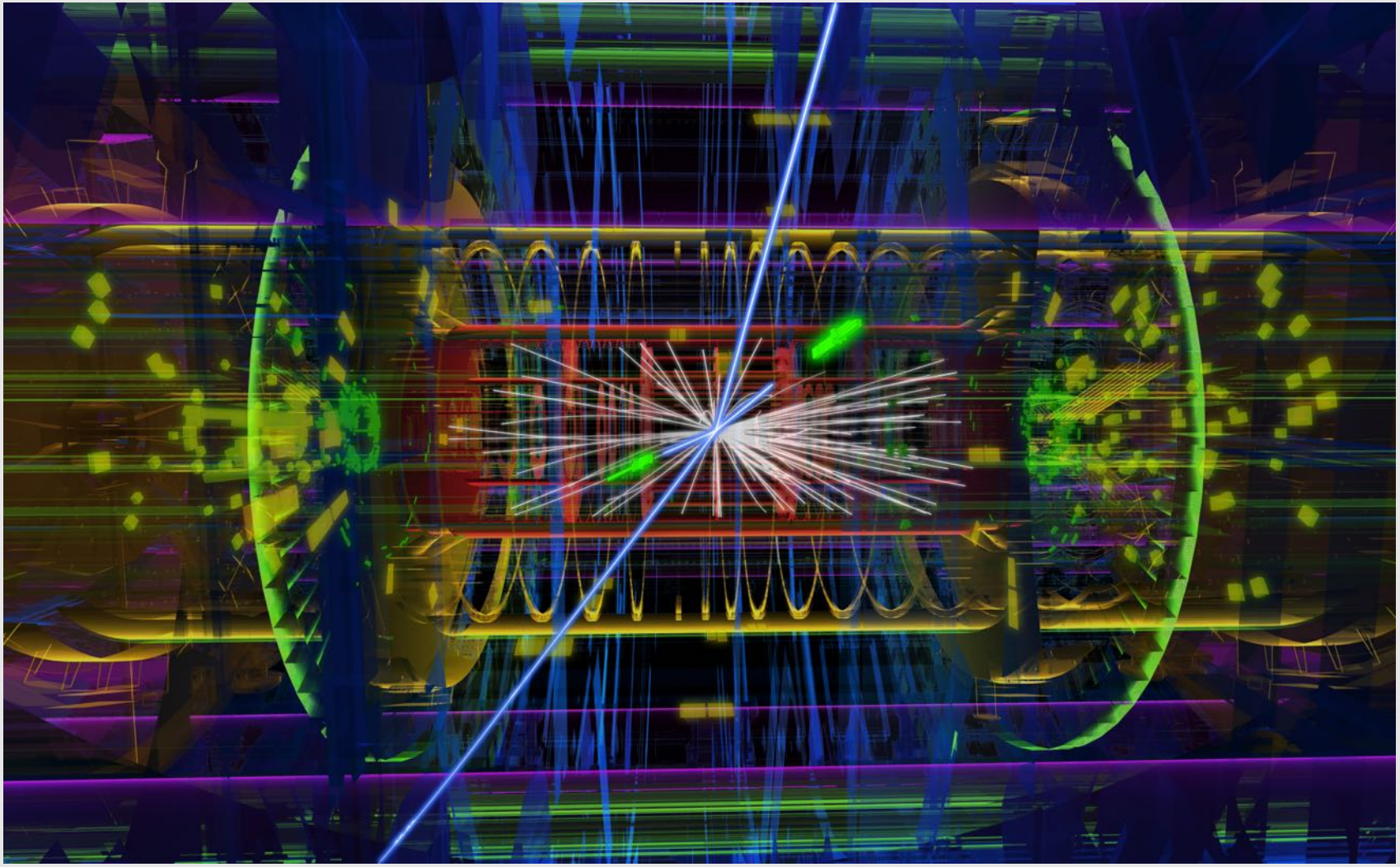
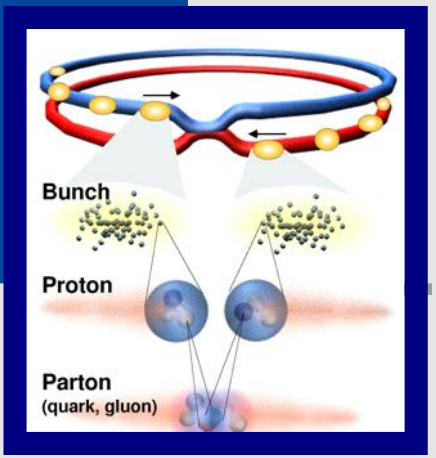
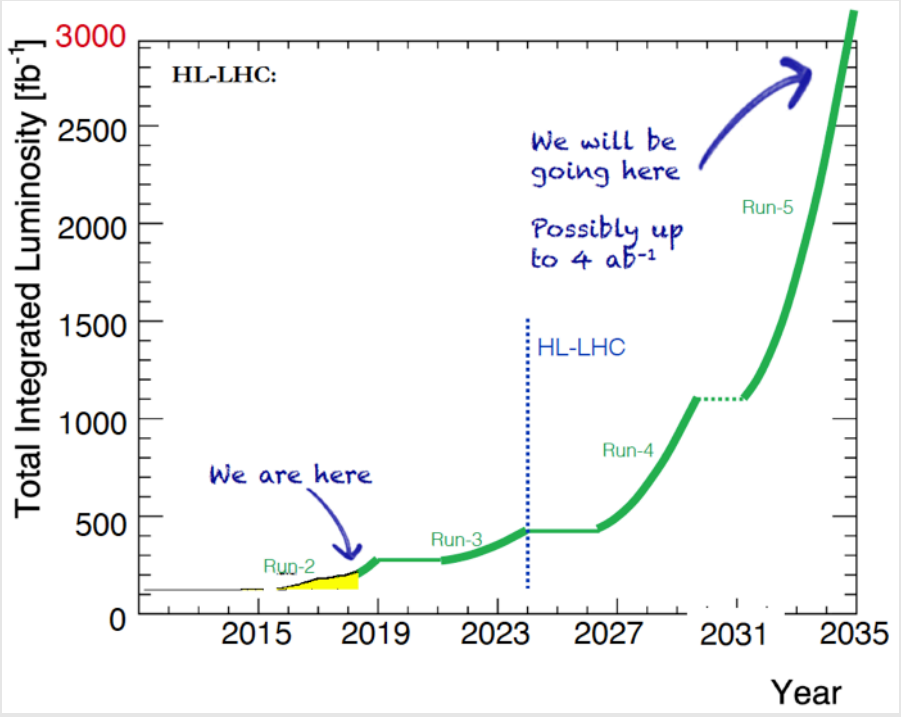


Particle Physics at the Large Hadron Collider (LHC) with the ATLAS experiment



LHC: - the largest and most powerful particle accelerator ever built:
- proton-proton-collisions at a centre-of-mass energy of 13 TeV

Goal: Answer some of the most important questions of particle physics (the origin of mass, existence of *Dark Matter*, ...)
Discovery (and subsequent measurements) of a Higgs boson



N = L x σ (N: Event rate, L: Luminosity, σ: Cross section)

Excellent Data Taking in *Runs 1 and 2* (until 2018):

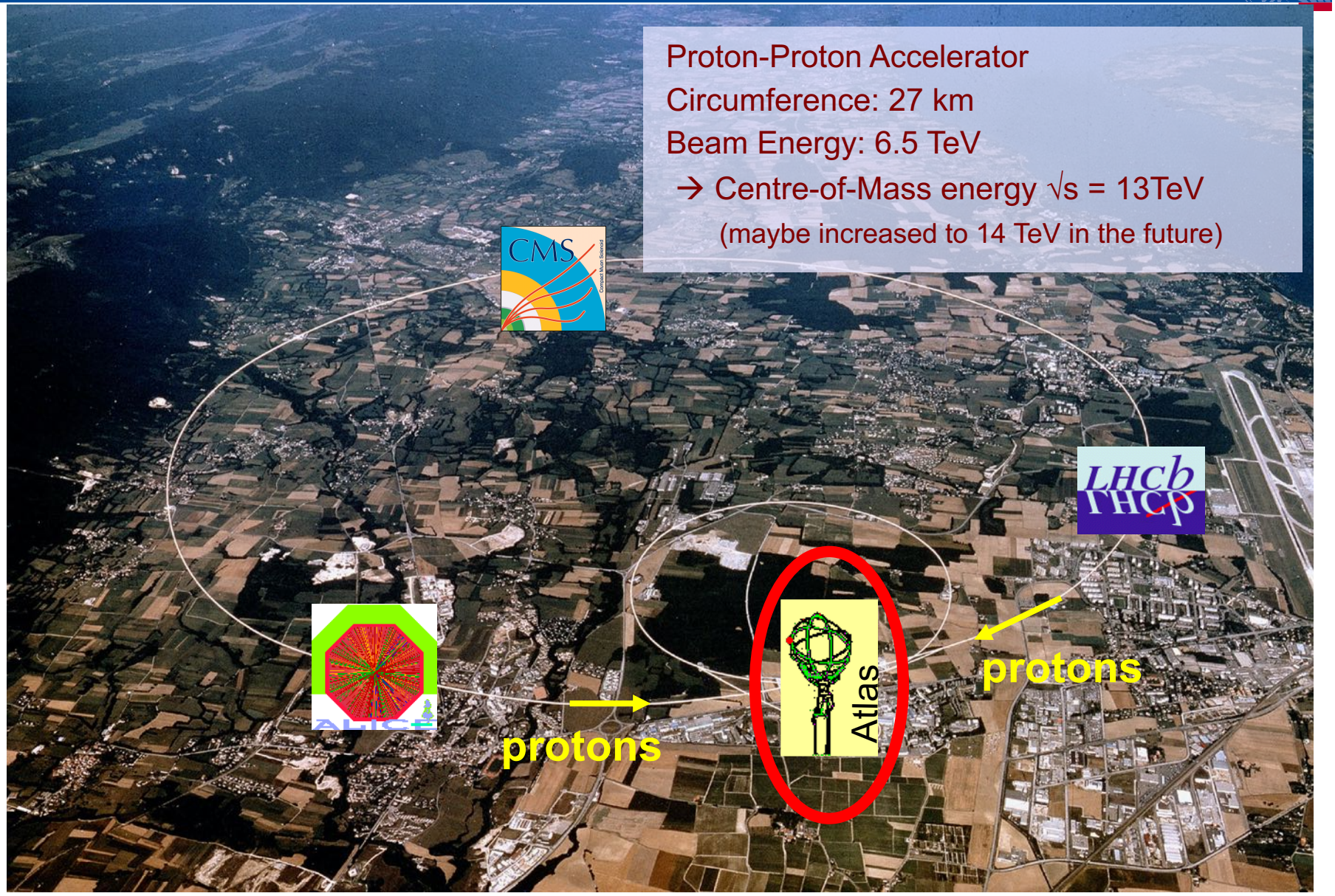
~120 million top-antitop-pairs produced
~ 8 million Higgs bosons produced

→ Excellent datasets for lots of interesting studies

Bright future of the LHC:
- Run 3 to start in 2022
- Further upgrade of the LHC and the experiments for the High-Luminosity-LHC (start planned in 2027)

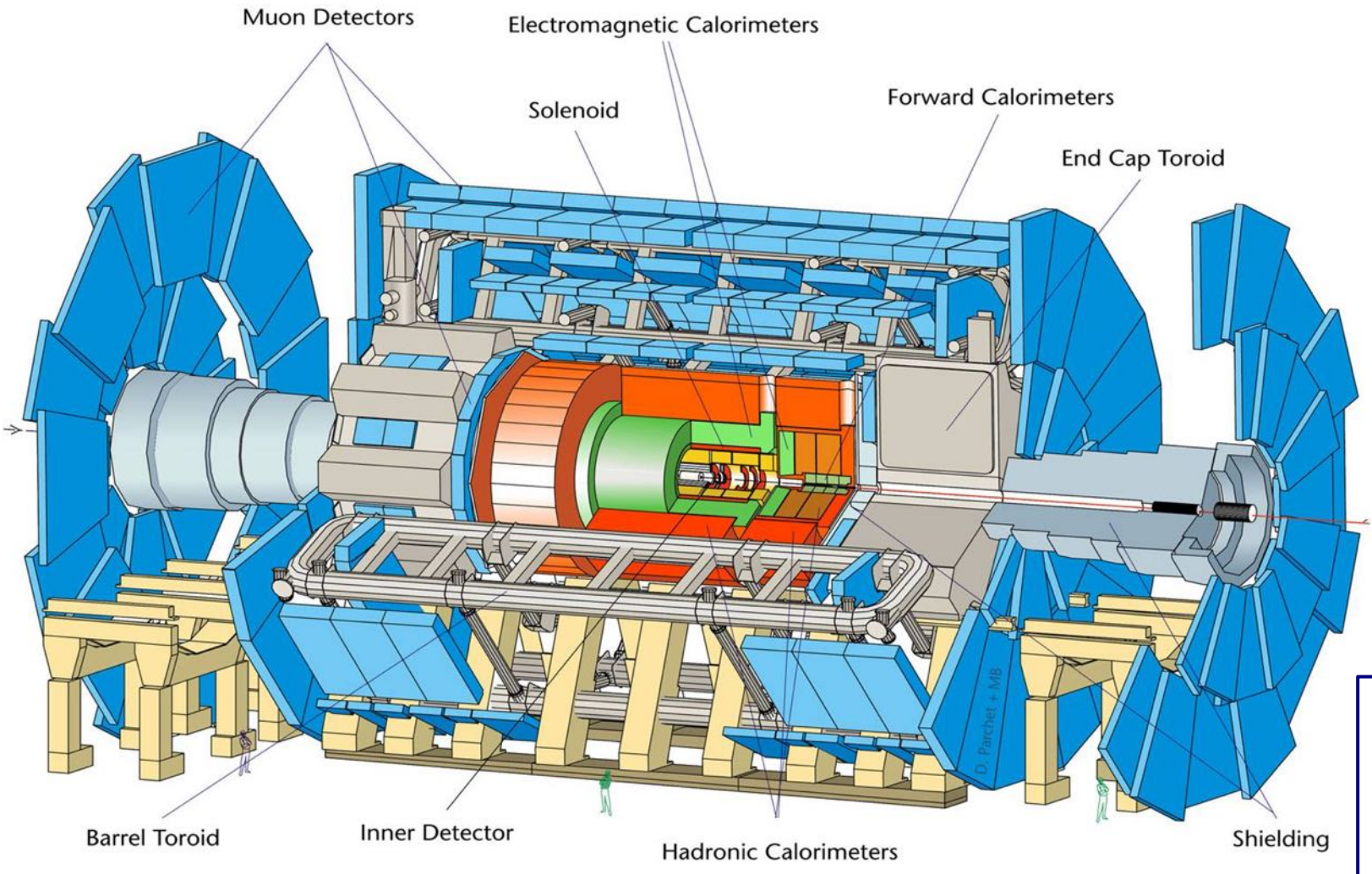
→ A lot more data still to come!

The Large Hadron Collider: LHC



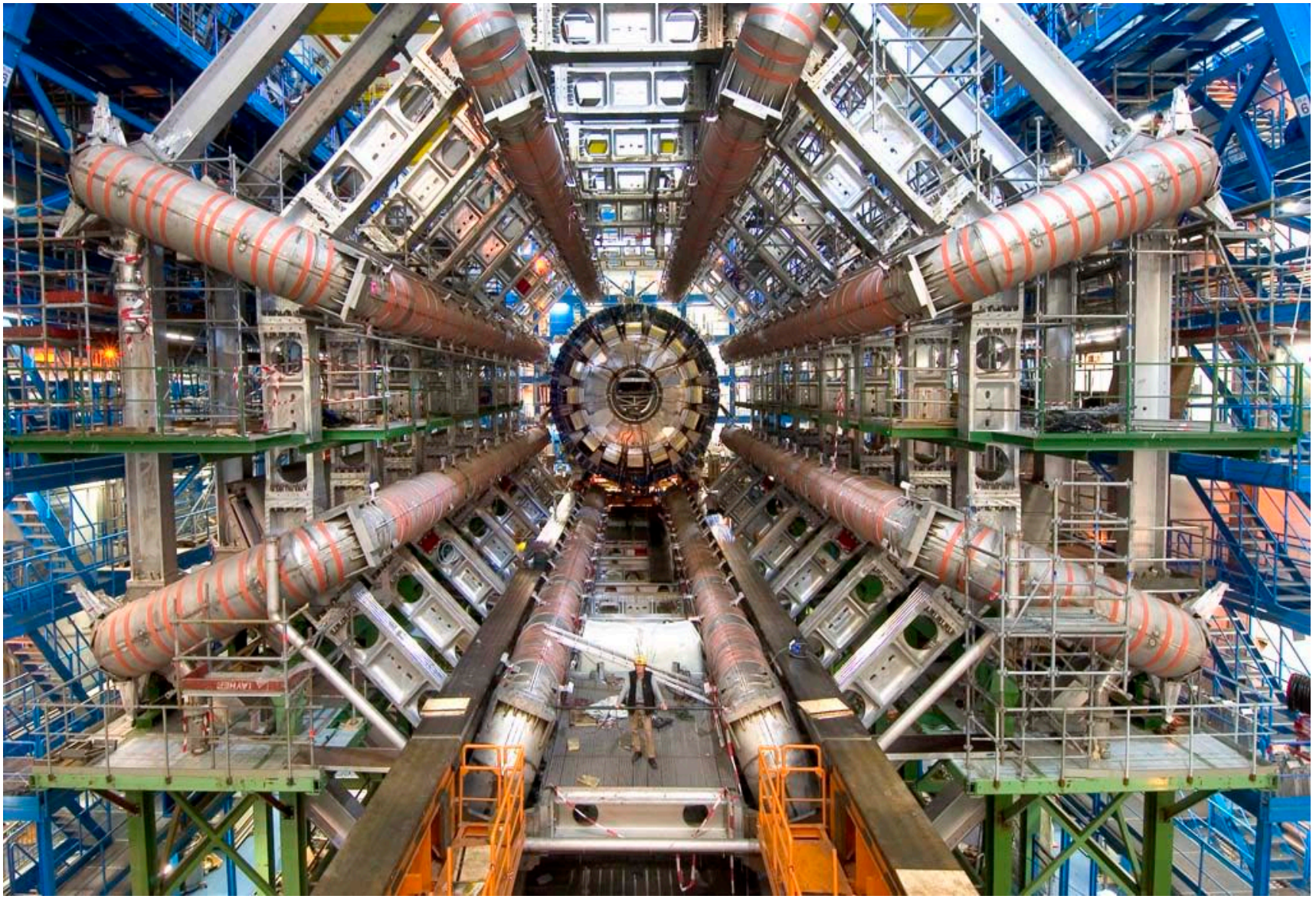
Dipole Magnets in the LHC Tunnel

The ATLAS Experiment



Diameter 25 m
Length 46 m
Weight 7000 t
120 million
readout channels

The ATLAS Experiment

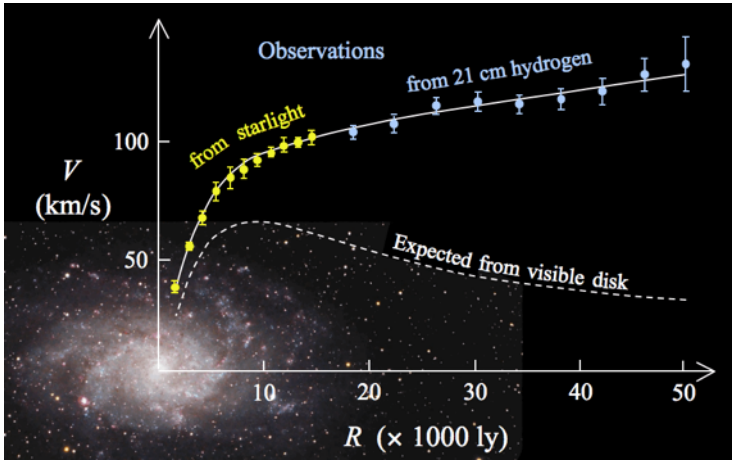


Research Activities

1) Analyses of data taken by ATLAS in the area of

i) Physics of the **Higgs boson**

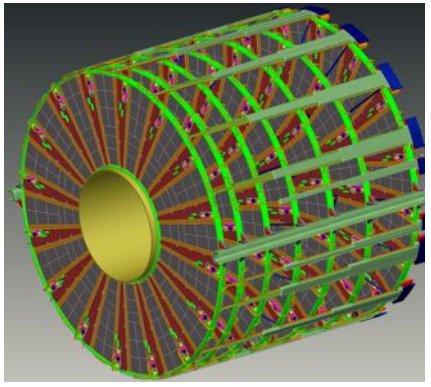
ii) Searches for new physics beyond the Standard Model, especially **Supersymmetry** and **Dark Matter**

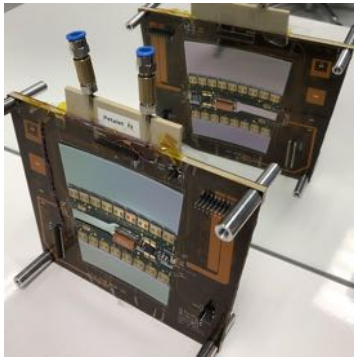


2) Detector developments in the area of silicon detectors

i) Production of a new detector for the High-Luminosity phase of the LHC

ii) Research and Development for radiation hard detectors

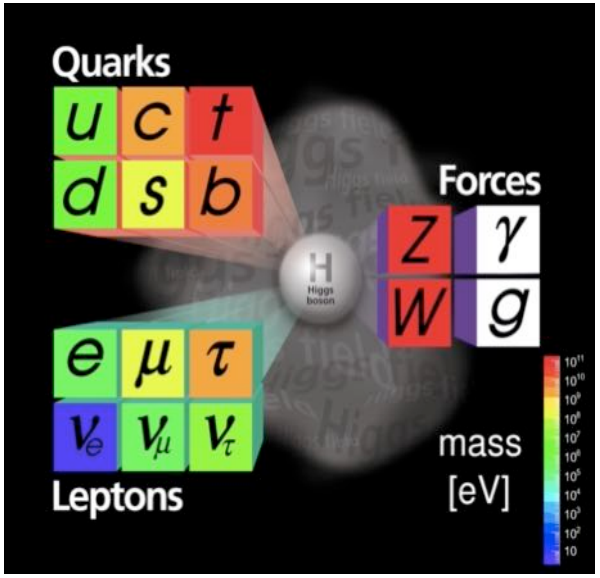




Only a brief overview here, more details in the discussions in the ZOOM rooms and material provided

Physics Analyses

1) Analyses of data taken by ATLAS



The Standard Model (SM)
of Particle Physics

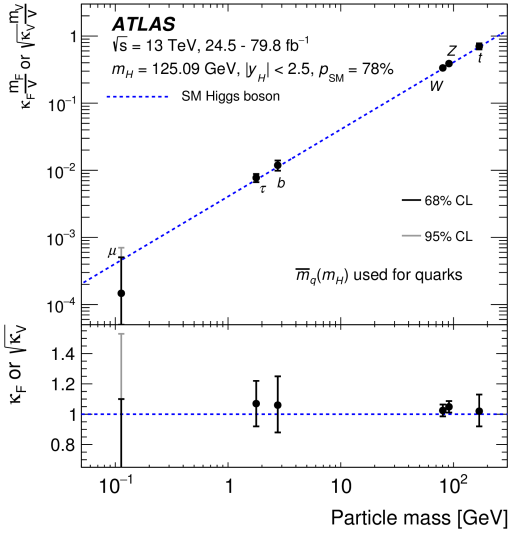
Brout-Englert-Higgs mechanism to explain the masses of fundamental force carrier particles (W, Z bosons; later expanded for leptons and quarks via *Yukawa couplings*)

→ **Existence of the Higgs boson**
(discovered by the ATLAS and CMS experiments in 2012)

Is it THE Higgs boson as predicted in the SM?

→ Determine the properties of the Higgs boson as precisely as possible

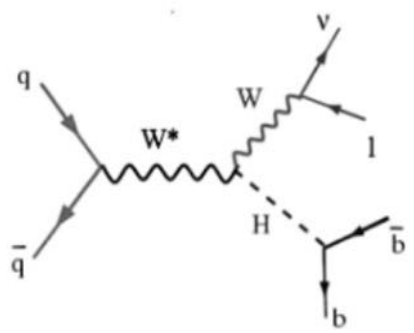
The mass of the Higgs boson is the only unknown parameter
→ once it is known, everything else can be computed, e.g. production and decay properties, coupling strengths to other particles

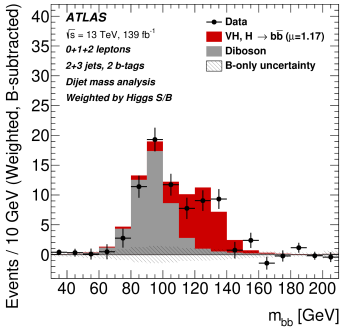


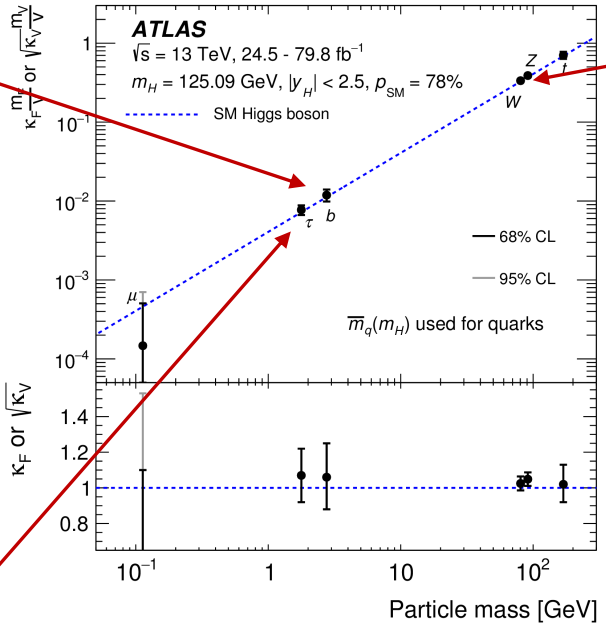
Physics Analyses

Investigation of the decays of the Higgs boson into

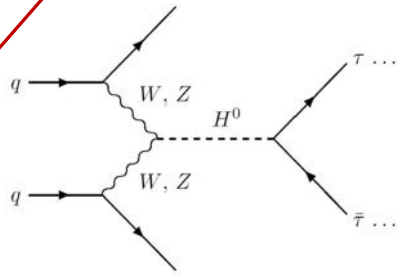
- a pair of b quarks

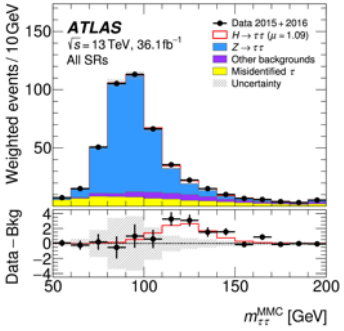




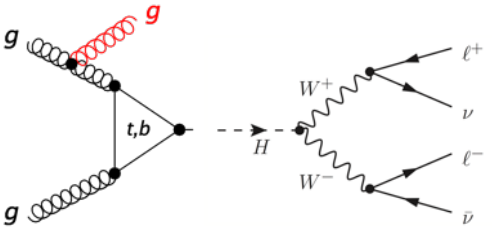


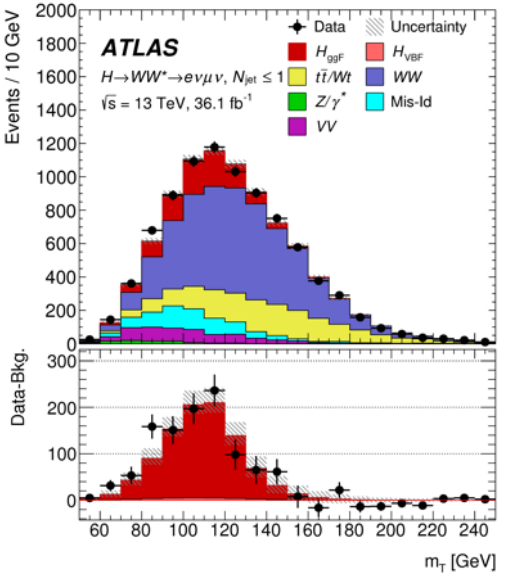
- a pair of τ leptons





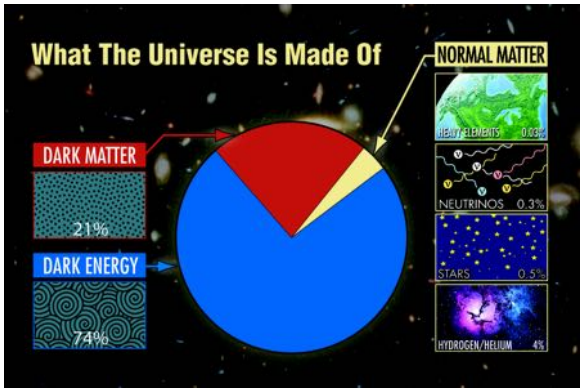
- a pair of W bosons





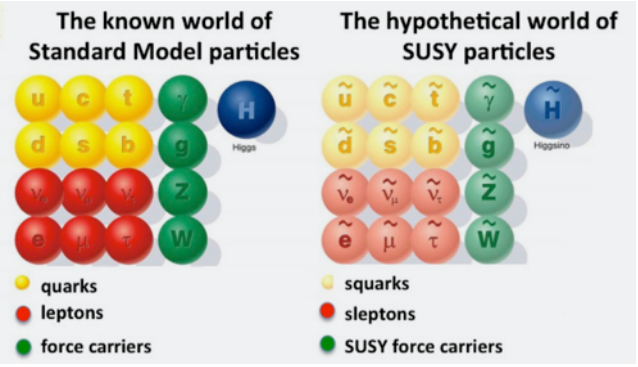
Physics Analyses

Search for new physics beyond the Standard Model:



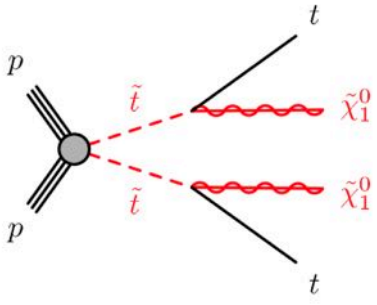
What is the Dark Matter?

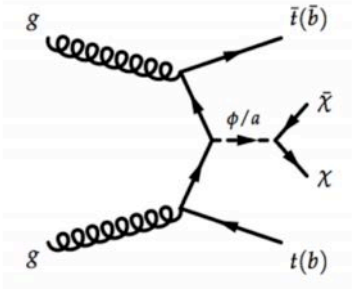
Why is the Higgs so light?

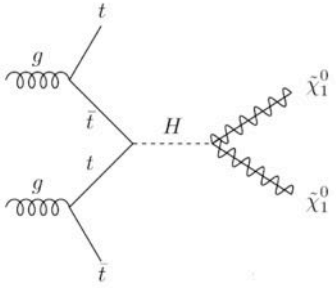


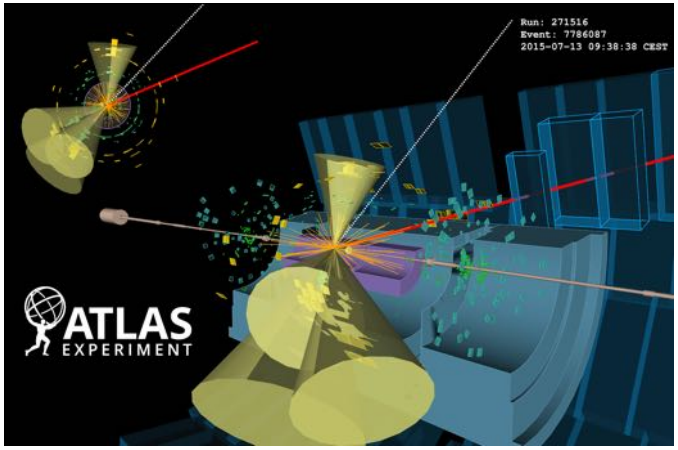
Are there more particles than those we know?

Look for new physics in events with a pair of top quarks:
Exciting opportunity for new discoveries in a wide range of scenarios, including new SUSY and Dark Matter particles







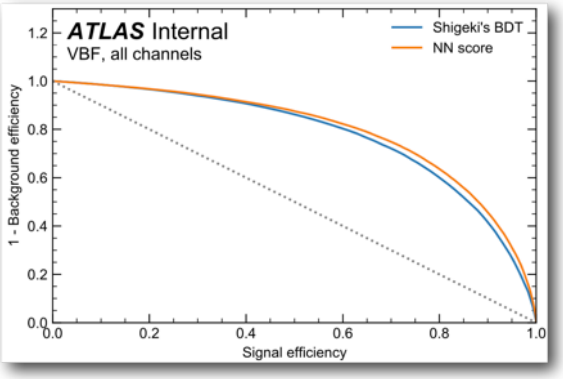


Highly-energetic pair of top quarks decaying into a muon and jets

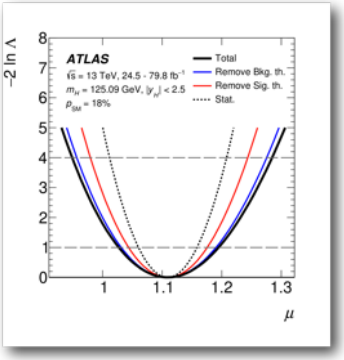
Physics Analyses

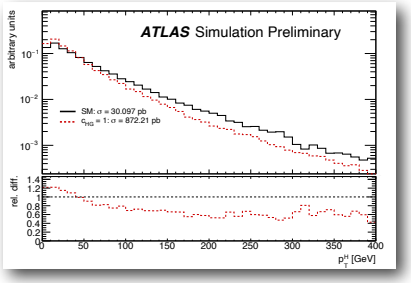
A physics analysis involves many aspects and thus a wide variety of **techniques and tools** is applied, e.g.:

- Application of **Machine Learning** Techniques like **Boosted Decision Trees**, (Deep) **Neural Networks** (applied in many of the analyses we are active)



- **Statistical data analysis:** Hypothesis testing, determination of physical parameters, setting limits on models of new physics, ...





- **Interpretation** of measurements in the framework of **Effective Field Theories**

- **Reconstrution of physics objects** like τ leptons, b jets, Higgs boson, top quarks ...

Several BSc and MSc thesis topics available, in different areas of Higgs boson physics and searches for new physics beyond the Standard Model where typically such techniques are applied

Detector Development

2) Detector Development

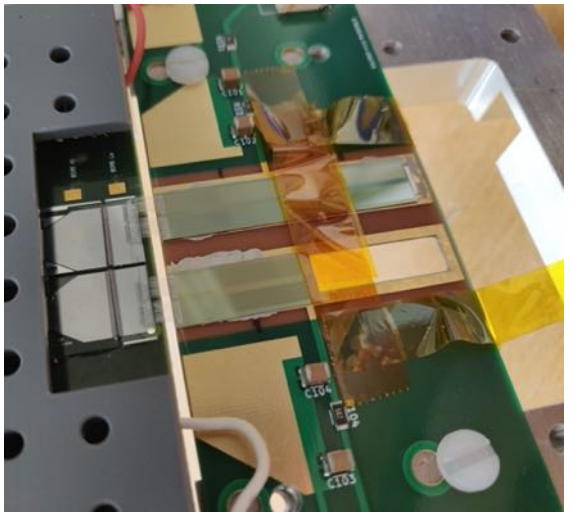
(i) CMOS Silicon Detectors

- Current silicon detectors as e.g used in ATLAS made in an expensive and complicated process

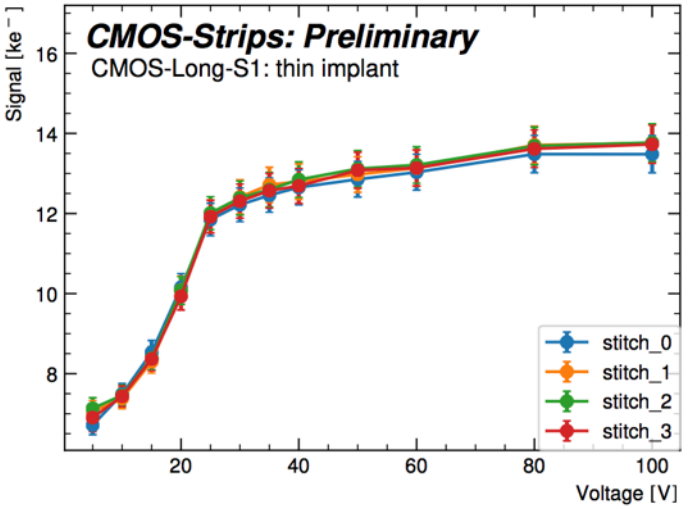
- The chip world market uses much cheaper silicon made in many CMOS foundries, but chips are much smaller than our sensors. Stitching of sensors required.

- Stitched CMOS strip sensors produced in cooperation between Bonn, DESY & Freiburg, available in Freiburg for testing as particle sensors.

Typical BSc/MSc project: Test CMOS sensor performance before and after irradiation.



2 CMOS sensors on test module in our Lab



first results from CMOS test module

Detector Development

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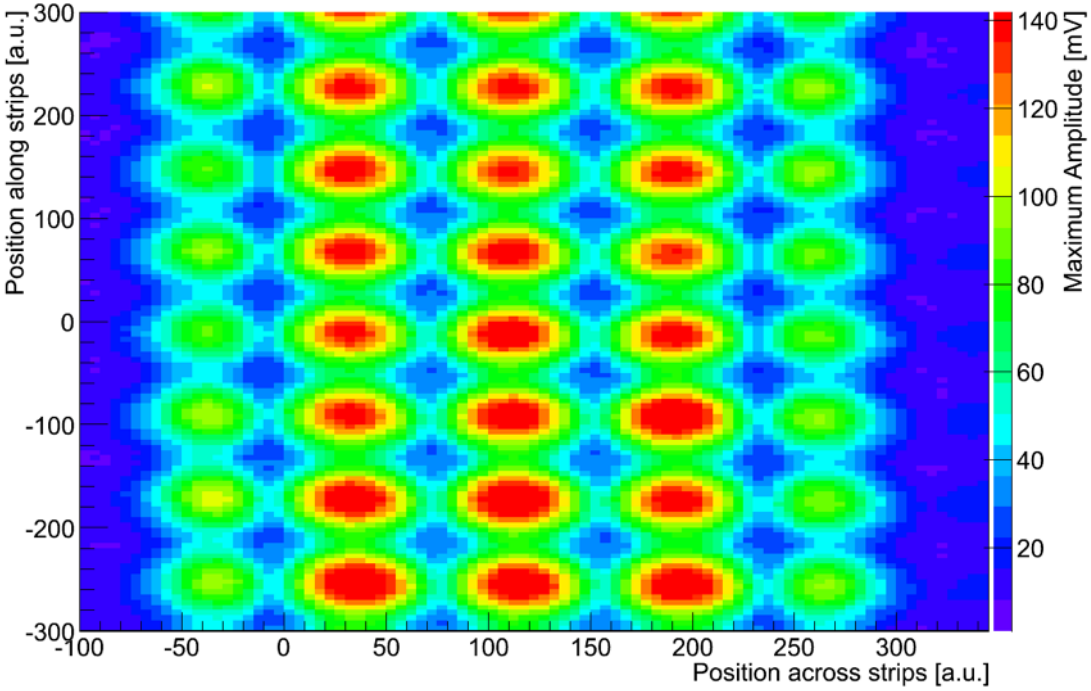
(ii) Ultra Fast Silicon Detectors

- Normal silicon detectors are already fast, forming a signal in about 5 ns

- Reduction to ~ 0.1 ns could give additional, valuable information to reconstruct charged particles

- Launched project with dedicated “fast 3D sensors” to arrive in autumn 2021

Typical BSc/MSc project: Test fast 3D sensor performance before and after irradiation.



Position-resolved signal scan in a 3D sensor. Signal varies strongly with position. The signal is generated by an IR-Laser moved with X-Y stage

BSc and MSC Theses

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For both research lines you should have a basic interest in elementary particle physics

For Physics Analysis a basic interest in analyzing data and programming is needed.
Knowing python (and/or C++) would be beneficial but is not a requirement!

For Detector Development you should have an interest on working *with your hands* in a laboratory

You will

- be embedded in a (international) team of PhD students and Postdocs
- get a taste of working in an international big collaboration
- get a deeper understanding of particle physics, particle detectors, analysis of large data sets, analysis techniques and tools
- get real *hands-on* experience when working on detectors in the laboratory

Learn more on Thursday, 11 March, in our ZOOM rooms!
An updated list of BSc/MSc topics will be provided here: http://www.particles.uni-freiburg.de/bachelor

Interested to join our group? Contact
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