

To be precise... with ATLAS EXPERIMENT



Precision measurements and studies of ultra-rare processes for testing the Standard Model of particle physics

Hi! My name is Sophie. I'm a physicist working at DESY, on the ATLAS experiment.

Hello Sophie! Say, I have a question. ATLAS hasn't found hints of **physics beyond the Standard Model** so far, right?

Yes, that's right. We haven't seen anything that clearly points to new **fundamental physics**. Although we've observed **many new phenomena of the Standard Model**.

But of course the search is far from over! We do direct searches for new particles. But we also do **precision measurements**: the idea is to measure processes predicted by the Standard Model **very precisely**. Then we can look for disagreement between measurement and prediction. If we see any, it may be new fundamental physics!

So what sorts of things do you measure precisely at DESY?

Well, for example, the mass of the top quark!

The top quark is the heaviest known particle and very special. This picture shows possible Higgs boson and top quark mass values. The ellipse shows where we have so far measured the masses to be. But they lie in the yellow area, where the universe as we know it is only **metastable**. So it could decay after a random, but probably very long, time. To be sure what's going on, we are measuring the top quark mass more precisely.

What's challenging about the top mass measurement?

Many things! Most come from the fact that we can only make **approximate** calculations in practice. The mass value we measure actually **depends** on the approximations. So we try to use clever methods that **minimise the dependence on the calculations**.

...such as "soft muon tagging":

(Example) top quark decay in the detector: We identify the **muon** in the b-jet. We measure the top quark mass from the "invariant mass" of the **electron** and **muon**.

This gives a top quark mass that lies here:

Yup! We'll need to keep on increasing the precision and reducing the possibility of measurement bias.

We also measure other Standard Model parameters, such as the **weak mixing angle**. It relates the masses of the **W** and **Z** bosons:

$$\sin^2(\theta_W) = 1 - (W \text{ mass})^2 / (Z \text{ mass})^2$$

So if we measure **all three** parameters, we can check the **self-consistency** of the Standard Model!

And if you observe inconsistency, that could be a hint of new fundamental physics?

Exactly!

There is a **tension** between past measurements of the weak mixing angle. They used different methods. As you can see, **our measurement** falls pretty much in the middle between the most discrepant ones.

And what method did you use to measure the weak mixing angle?

We analysed 17 million Z boson decays with two electrons or two muons in the final state. The weak mixing angle can be extracted from the angular distribution of these electrons and muons.

Ah. So you measure how often they fly in which direction!

By the way, the biggest **uncertainty** in this measurement comes from our limited knowledge of the **structure of the proton**. The **HERA collider at DESY** was very important to measuring this structure. Up to this day we rely heavily on HERA data to do our LHC measurements. What a cool legacy!

It is.

I heard you also measure **vector boson scattering**. I'm not sure what that is. Can you explain a bit?

Sure! But I'll let my colleague Lisa explain. We're a collaboration, after all. And she's an expert on the topic.

Hi, I'm Lisa!

In vector boson scattering, quarks inside the colliding proton emit W bosons or Z bosons or photons. These interact with each other. The quarks themselves then form characteristic sprays of hadrons. We call those **jets**.

Sounds like a complicated process!

It is! And happens very rarely.

Vector boson scattering

Before collision: quark, quark. After collision: jet, jet, W and/or Z bosons, and/or photons.

Another challenge is the background: other processes look very similar in the detector. To separate signal from background, we use **machine learning**. We teach the computer to classify the events.

Did you find disagreement from the Standard Model predictions?

We tend to observe slightly more vector boson scattering events than predicted, but we still have a large statistical uncertainty.

We'll collect more data soon!

There's also a very special vector boson scattering process that we have first observed recently.

It's called **light-by-light scattering**. That's when two photons "bounce off each other". It's **only possible** thanks to **quantum mechanical effects**.

Juan and Merida have the details.

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Light-by-light scattering was observed in lead ion collisions. An average such collision might look something like this in the detector, producing **thousands of particles**...

... but in a light-by-light scattering event, we only see **two energetic photons** in the detector. Nothing else. Isn't it beautiful?

We hope you learned a lot! To get more information about our fascinating exploration of the universe with ATLAS, visit <http://atlas.cern>, and follow us on **Facebook** and **Twitter (@ATLASexperiment)**.

I will! Thank you!

Meanwhile, 80 metres underground near Geneva, Switzerland...

Hi! We're working on **maintaining and upgrading ATLAS** so that we can record even **more data** from 2021 onwards and make even more **amazing measurements**!

References

Top quark mass measurement using soft muon tagging: ATLAS Collaboration, ATLAS-CONF-2019-046 (<http://cdsweb.cern.ch/record/2693954>)
 Figure of the universe's vacuum stability adapted from: J. R. Espinosa, PoS TOP2015 (2016) 043 (<https://arxiv.org/abs/1512.01222>)
 Weak mixing angle measurement: ATLAS Collaboration, ATLAS-CONF-2018-037 (<http://cdsweb.cern.ch/record/2630340>)
 Latest vector boson scattering measurement with direct DESY involvement: ATLAS Collaboration, Phys. Rev. Lett. 123 (2019) no. 16, 161801 (<https://doi.org/10.1103/PhysRevLett.123.161801>)
 Light-by-light scattering measurement: ATLAS Collaboration, ATLAS-CONF-2019-002 (<http://cdsweb.cern.ch/record/2667214>)
 Note: the figure in panels 5 and 8 refers to the pole mass. In panel 8, the direct measurement is shown as if it had directly measured the pole mass, which is not exactly correct and subject to much current debate.

Poster: Stefan Richter (DESY)