Structure of the Proton

Name of your Institution: Technische Universitaet Dresden

Title of the educational scenario template: Inquiry-based teaching

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Version: 2.0

Educational problem:

In nuclear physics students learn about the structure and constituents of matter. Textbook teaching of this subject is inherently limited and lacks the possibility of active investigations by the students. By analyzing real data from the Large Hadron Collider at CERN students can themselves examine and understand the structure of a proton at a subatomic level as well as the radioactive beta decay.

Educational scenario objectives:

During this scenario, students will:

1. Learn about fundamental subatomic particles and interactions
2. Learn about particle accelerators and detectors
3. Get acquainted with analyzing particle collisions
4. Perform a measurement with real data from the LHC
5. Gain insight into modern research in particle physics and scientific methods

Characteristics and needs of students:

The scenario helps students understand the structure of the proton at a subatomic level. When protons collide in the LHC at high enough energies, they do not react as a whole, so that only their constituent parts interact with each other. This gives students the possibility to draw a conclusion about the inner structure of the proton by analyzing the products of the collisions.

Students are introduced to the data analysis tool MINERVA that displays real data from the ATLAS experiment at the LHC. The program ATLAS W-PATH guides the students through the exploration of the experimental data, the analysis and the interpretation of their findings. This procedure starts from the initial design of their activity and progresses through the data acquisition to the presentation of their scientific explanation.

The measurement will also allow students to interact (e.g. by working in pairs) and develop social and collaboration skills, allowing them to see that science can be a group activity and not only a solitary one. The experience from working like a real scientist may trigger an increased interest in science in many of them, and possibly a turn to science careers.

Rationale of the Educational approach and Parameters guaranteeing its implementation:

This scenario is structured upon the phases prescribed for inquiry-based learning and allows students to make their own discoveries, albeit in a structured and guided way. During the scenario the students take over the role of a scientist and work with real data from scientific experiments, thus gain a first-hand understanding of scientific inquiry.

For the implementation of this scenario students must have access to PCs, and at least one PC should be connected to the Internet.

Learning activities:

Phase 1: Question Eliciting activities

Exhibit curiosity

The teacher tries to attract the student's attention by presenting:

a) short videos about the LHC, e.g. the LHC@CERN (3 min video)

b) media coverage of the LHC, pictures from special events, e.g. first collisions

c) the LHC as a record machine (energy, temperature, …)

The teacher might also trigger a small conversation with the students by asking what they know about particle physics in general. This is followed by a brief introduction to the different types of elementary particles and forces (standard model) and to colliders and detectors.

Define questions from current knowledge

Then, students are engaged by scientifically oriented questions imposed by the teacher:

a) What will happen when protons at the LHC collide with high enough energy?

b) When particles collide are new particles created or not?

c) How are elementary particles classified?

d) What type of research is performed at the LHC?

Phase 2: Active investigation

Propose preliminary explanations or hypotheses

The LHC was built to enter unknown terrain beyond the standard model. Despite its great success in explaining the building blocks and forces of our universe and its strong experimental confirmation there are still gaps in that same standard model. The experiments at the LHC will provide answers to some open questions like how particles get their masses or why the universe has more matter than antimatter. During the initial phase of LHC operations physicists kept their eyes on every elementary particle of the standard model, which have all been successfully rediscovered within a few weeks. Thus the focus was on particles like the W-boson.

Students will put themselves in the position of a scientist and analyze the structure of the proton by looking on proton-proton-collisions.

The teacher introduces the students to the W-boson and how it can be produced in proton-proton-collisions. Students should come up with an idea how they can deduce the inner structure of the proton by analyzing production and decay of W-bosons at the LHC and performing a measurement (counting W^+ and W^-).

Plan and conduct simple investigation

The teacher prepares students (working in pairs on PCs) for the measurement in 4 steps:

1. Teach how to use the event display http://atlas.physicsmasterclasses.org/en/wpath_teilchenid2.htm … or better, let them discover how the display works.

2. Train students to identify particles. Make use of the following:

   a) ATLAS animation on particle identification (ID) on http://atlas.physicsmasterclasses.org/en/wpath_teilchenid1.htm

   b) Explanations on particle ID with MINERVA on http://atlas.physicsmasterclasses.org/en/wpath_teilchenid3.htm

   c) Exercise 1: http://atlas.physicsmasterclasses.org/en/wpath_exercise1.htm

3. Practical guide how to classify events:

   a) Introduce basic ideas of selecting events

   b) Explanations on Event ID with MINERVA on: http://atlas.physicsmasterclasses.org/en/wpath_lhcphysics3.htm

   c) Exercise 2: http://atlas.physicsmasterclasses.org/en/wpath_exercise2.htm

(Here you need the data set “exercise 2” – downloadable at http://atlas.physicsmasterclasses.org/en/downloads.htm (with login MC2012, password ATLAS.is.great)

4. The teacher informs the students about the main task of the measurement: Distinguishing signal from background events and determining the electric charge of the W particle http://atlas.physicsmasterclasses.org/en/wpath_proton.htm

Phase 3: Creation

Gather evidence from observation

Students work in pairs on PCs. They will use the ATLAS W-PATH http://atlas.physicsmasterclasses.org/en/wpath.htm including the event display MINERVA to analyze real data from the LHC.

All material for the measurement can be found here: http://atlas.physicsmasterclasses.org/en/wpath_messung.htm

The students access the data sample 2 from here: http://atlas.physicsmasterclasses.org/en/wpath_data2012.htm (with login MC2012, password ATLAS.is.great). Each pair of students analyzes 50 events (2A – 2T) (each pair analyzes different data!)

The results are first noted on a tally sheet (paper form, download http://atlas.physicsmasterclasses.org/downloads/tallymarks.pdf) and then entered into an online spread sheet http://www.editgrid.com/user/masterclass/Analysis_2012 (tab: data sample 2).

Phase 4: Discussion

Explanation based on evidence / Consider other explanations

Students combine their measurement in the above mentioned online spread sheet. They derive the ratio W^+/W^- and can compare it to the results from the ATLAS collaboration. In addition, it is possible to combine the results with other student groups (tab: combination). Students should answer the following questions:

a) Which ratio W^+/W^- did you expect?

b) Which processes are involved in the production of W-bosons and how does this affect the ratio W^+/W^-? (quark-gluon versus gluon-gluon interactions, see: http://atlas.physicsmasterclasses.org/de/wpath_lhcphysics2.htm)

c) What can you conclude from your result about the structure of the proton?

d) How good is the agreement of your measurement with the ATLAS measurement? Does the number of analyzed events influence the result?

e) How does the combination (in your class / with other student groups) affect the uncertainties of the measurement?

f) Why is it advantageous to collect more data?

Phase 5: Reflection

Communicate explanation

The teacher makes an overview of what has been discussed in the classroom during the measurement. The following issues may be addressed:

a) Did you face any difficulties when classifying the events?

b) Why did you look for electron and muon events only?

c) Why can tracks with low energy or pT be ignored?

d) How does your analysis differ from the way researchers analyse LHC data?

e) What purpose was the LHC built for?

f) Why did the researchers at the LHC measure the $W \rightarrow l\nu$ production cross section?

g) What is a prerequisite to claim a new discovery?

Each classroom/group of students produces a report with the information about the measurement and the results.

Participating roles:

In this scenario students start by talking about CERN, the LHC, and research in particle physics. They are introduced to the subject and the basics of particle physics. Then students get acquainted to the MINERVA event display and learn how to identify particles and events. They perform a measurement on real data from the LHC, record their results, and compare it to their predictions previously made.

The teacher is a facilitator. He/she introduces students to the pertinent concepts and the work carried out at CERN, directs them to the task by asking questions and shows them how to use the MINERVA tool. Then he/she allows them to perform their own measurement and discusses the results with them.

Tools, services and resources:

The scenario requires the use of:

- one PC per 2 students and one for the teacher (Windows, Webbrowser, Java)

- at least one PC must have connection to the Internet

- a projector and projector screen so that the students can view the teacher's desktop

- a minimum of 5 hours is required for this activity

- it might be advantageous to invite a particle physicist to the classroom who could help with the introduction to the subject and the measurement. The activity described is normally carried out in the program "International Masterclasses" (www.physicsmasterclasses.org) , where high school students are invited to research institutes and carry out the measurement under the guidance of scientists.