3D-Printable Things in Particle Physics Education

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slides: cern.ch/go/9WLj
CERN S‘Cool LAB
a hands-on particle physics learning laboratory
6000 students from all around the world

Origin of S‘Cool LAB student groups 2017
Current opportunities

S’Cool LAB Days
A full-day programme of hands-on experiments & CERN tours for high school students aged 16-19 participating in S’Cool LAB’s PER projects.
1030 participants in 2017

Summer CAMP
A two-week residential particle physics summer camp for 30 high school students aged 16-19 from all around the world.
2nd camp in 2018 (24/07 – 04/08)

Cloud Chamber WS
A 90-minute hands-on particle physics workshop for high school students (aged 14 and above) and high-school teachers.
5780 participants in 2017 (4830 students & 950 teachers)
Experiments: high-tech vs. low-cost

In S’Cool LAB: high-tech

- Electrons beams in magnetic fields
- Cloud chamber
- Superconductivity
- Pixel detector
- PET
- X-ray machine
3D printable things & education

- More and more 3D printers & 3D printable things available
- e.g. www.thingiverse.com/education

model of an animal cell
www.thingiverse.com/
thing:689381

model of a caffeine molecule
www.thingiverse.com/
thing:876224

model of ALICE detector
http://cern.ch/alicematters/
?q=ALICE_3D_models
# Experiments: high-tech vs. low-cost

**In S’Cool LAB: high-tech**

<table>
<thead>
<tr>
<th>Superconductivity</th>
<th>Pixel detector</th>
<th>X-ray machine</th>
</tr>
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<tbody>
<tr>
<td>electron beams in magnetic fields</td>
<td>cloud chamber</td>
<td></td>
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</table>

**For the classroom: low-cost**

<table>
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<tr>
<th>ATLAS magnet model</th>
<th>DIY cloud chamber</th>
<th>Bragg peak model</th>
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<tr>
<td>3D compass</td>
<td>particle trap</td>
<td>Rutherford scattering model</td>
</tr>
</tbody>
</table>
Rutherford scattering model

Outreach tool of University of Göttingen
© Ching-Yen Huang
DIY particle trapping

Prof. Klaus Wendt
A 3D printable particle trap

upper electrode
ring electrode
lower electrode

bareconductive.com
LL-304PGC2E-G4-1BC
A 3D printable particle trap
ATLAS – A Toroidal LHC Apparatus
Toroidal magnet system – the T in ATLAS


Designing a 3D printable model

FreeCAD 0.16 scaled 1:100

8x
16x
4x
16x
+500 m copper wire

S’Cool LAB
www.thingiverse.com/thing:1722230
A 3D printable ATLAS magnet model

www.thingiverse.com/
thing:1722286
Comparison between the ATLAS barrel toroid and the functional 3D-printed model

<table>
<thead>
<tr>
<th>Feature</th>
<th>ATLAS toroid</th>
<th>Modell toroid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner diameter</td>
<td>9.4 m</td>
<td>9.3 cm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>20.1 m</td>
<td>20.1 cm</td>
</tr>
<tr>
<td>Length</td>
<td>25.3 m</td>
<td>24.7 cm</td>
</tr>
<tr>
<td>Mass</td>
<td>830 t</td>
<td>860 g</td>
</tr>
<tr>
<td><strong>Coils</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of coils</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Material</td>
<td>Niobium-Titanium</td>
<td>Enamelled copper wire</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>4.5 K</td>
<td>Room temperature</td>
</tr>
<tr>
<td>Turns per coil</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Total length of conductor</td>
<td>56 km</td>
<td>500 m</td>
</tr>
<tr>
<td>Voltage</td>
<td>16 V</td>
<td>12 V</td>
</tr>
<tr>
<td>Nominal current</td>
<td>20.5 kA</td>
<td>0.4 A</td>
</tr>
<tr>
<td>Resistance</td>
<td>0.16 mΩ</td>
<td>31 Ω</td>
</tr>
<tr>
<td>Average magnetic field</td>
<td>0.5 T</td>
<td>0.8 mT</td>
</tr>
</tbody>
</table>

250 eV electron beam & model coils
More about the ATLAS magnet model

Video:
https://cds.cern.ch/record/2255117

Model with straws (German):
https://cds.cern.ch/record/2244917
A 3D printable Bragg peak model
Bragg peak

Dose: increase in energy loss per path length as proton slows down

Dose: peak width determined by range straggling

Dose: includes contributions from primary and secondary protons

https://doi.org/10.1088/978-0-7503-1370-4ch1
Stone skipping

A stone skipping on calm water © Killy Ridols
A 3D printable Bragg peak model
What’s next?

Teacher in Residence

Description

S’Cool LAB is a new Physics Education Research facility at CERN, the European Organization for Nuclear Research in Geneva, Switzerland. S’Cool LAB offers hands-on & minds-on particle physics experiments for high school students and their teachers on-site at CERN. The activities in S’Cool LAB aim to make different aspects of CERN’s research and technologies understandable through hands-on experiments. In addition to watching and learning about the S’Cool LAB.
Thank you for your attention!

S’Cool LAB Website: cern.ch/s-cool-lab
Download the slides: cern.ch/go/9WLj
Contact me: julia.woithe@cern.ch
Range vs. energy

Steel ball range in our model for different inclination angles

Proton range in water for different proton energies (Paganetti, 2017)

\[ y = 19.8x^{0.95} \]

\[ R^2 = 0.96 \]

Bragg Kleeman Rule
- for protons: \( R = a \times E^{1.8} \)
- for alpha: \( R = a \times E - b \)