Future Accelerator Projects

the Future Circular Collider and how it can be used as an engaging context to help achieve school curriculum objectives.

KEY IDEAS

- Compare current accelerator technologies with proposed technologies by applying basic physics principles (eg Lorentz Force and relativistic dilation)
- Understand that new scientific knowledge requires the development of new technologies
- Understand the importance of international collaboration when investing in ‘big science’ projects.

Potential student conceptions and challenges

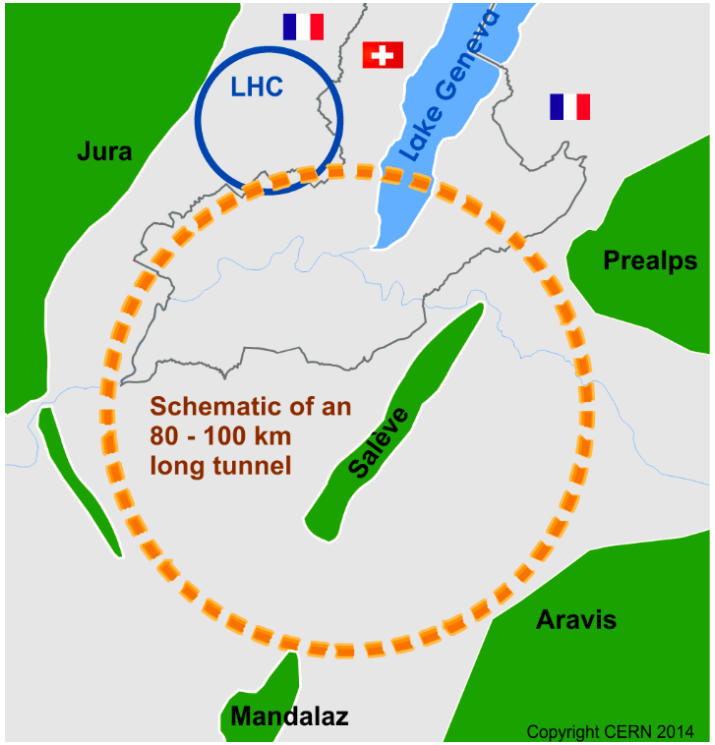
- Particles will be FASTER!

- Science is all about doing lame experiments

Doing the Maths

Comparison table of values for LHC and FCC

	LHC	FCC p-p
energy per proton	$E_{kin}=7\,\text{TeV} \approx E_{ges}=\gamma \cdot E_0$	$E_{kin}=50\,\text{TeV} \approx E_{ges}=\gamma \cdot E_0$
Lorentz factor	$\gamma=\frac{E_{ges}}{E_0}=\frac{7\cdot 10^{12}\,\text{eV}}{938\cdot 10^{6}\,\text{eV}}=7.5\cdot 10^{3}$	$\gamma=\frac{E_{ges}}{E_0}=\frac{50\cdot 10^{12}\,\text{eV}}{938\cdot 10^{6}\,\text{eV}}=53\cdot 10^{3}$
speed of proton	$v=\sqrt{1-\frac{1}{\gamma^2}}\cdot c=99.9999991\,\%\,c \approx c$	$v=\sqrt{1-\frac{1}{\gamma^2}}\cdot c=99.99999998\,\%\,c \approx c$
Time T for completing one cycle	$T=\frac{2\pi r}{c}=\frac{27\,\text{km}}{3.0\cdot 10^{5}\,\text{km}}\,\text{s}=0.090\,\text{ms}$	$T=\frac{2\pi r}{c}=\frac{100\,\text{km}}{3.0\cdot 10^{5}\,\text{km}}\,\text{s}=0.33\,\text{ms}$
relativistic mass of the proton	$m_p=\gamma \cdot m_0=7.5\cdot 10^{3}\cdot 1.67\cdot 10^{-27}\,\text{kg}=1.25\cdot 10^{-23}\,\text{kg}$	$m_p=\gamma \cdot m_0=8.90\cdot 10^{-23}\,\text{kg}$
mean centripetal force F_c	$F_c=m_p\frac{v^2}{r}=2.6\cdot 10^{-10}\,\text{N}$	$F_c=m_p\frac{v^2}{r}=0.5\,\text{nN} \approx 500\,\text{pN}$
mean magnetic flux density B	$F_c=qvB \Rightarrow B=\frac{F_c}{qv}=5.4\,\text{T}$	$B=\frac{5.0\cdot 10^{-10}\,\text{Ns}}{1.6\cdot 10^{-19}\,\text{C}\cdot 2.998\cdot 10^{8}\,\text{m}}=10.5\,\text{T}$



Relativistic proton mass dilation:

- discuss or
- provide the value - depending on the curriculum

Problem example

calculation of centripetal force

calculation of magnetic flux density

optional: discuss shape of FCC in more detail

compare FCC with LHC

discuss technological challenges

Problem example:

a) Calculate the value of the centripetal force which keeps the proton on its trajectory in the FCC (given it is a perfect cycle) and compare with gravity.

solution: $F_C = m_p \frac{v^2}{r} = 0.5\,\mathrm{nN} \approx 500\,\mathrm{pN}$, *gravity of proton on earth: 0.000000000000016 pN*

b) Find out the required value of magnetic flux density in order to achieve this centripetal force:

solution: $F_C = qvB \;\Rightarrow\; B = \frac{F_C}{qv} = \frac{5.0 \cdot 10^{-10}\,\mathrm{Ns}}{1.6 \cdot 10^{-19}\,\mathrm{C} \cdot 2.998 \cdot 10^{8}\,\mathrm{m}} = 10.5\,\mathrm{T}$

c) optional: The FCC project study shows that a magnetic flux density of even 16 T is required. Why do you think that the value calculated above might be too low? Do some research on the internet if the FCC is going to be a perfect circle - or will there be linear parts for acceleration and experiments?

d) The LHC today uses magnets which provide a magnetic flux density of up to 8.3 T. Which challenges do you imagine could arise when aiming to double the value?

ADVANCES IN ACCELERATOR TECHNOLOGY

- Student groups research different accelerator projects of the past, present and future.
- List of accelerators provided?
- Student predict the beyond!

PAST (1960's – 1990's)

DEVICE	DATE OF FIRST OPERATION	TYPE	PARTICLES COLLIDED	ENERGY PER BEAM (Gev)

TODAY

DEVICE	DATE OF FIRST OPERATION	TYPE	PARTICLES COLLIDED	ENERGY PER BEAM (Gev)

FUTURE (2020's – 2030's)

DEVICE	DATE OF FIRST OPERATION	TYPE	PARTICLES COLLIDED	ENERGY PER BEAM (Gev)

FCC PROJECT PROPOSAL

•Students role play as a team of scientists preparing and delivering an FCC Project Proposal to a board of politicians.

• Guide questions like ‘What fundamental science will the new project be studying? What applications may arise from the project? What are the technical problems that need to be overcome?

•film and edit presentation.

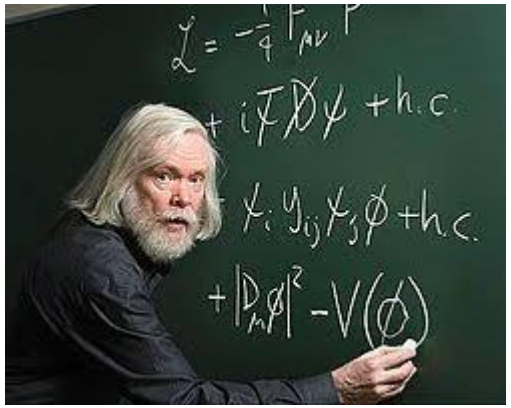
• resource list provided for students.

The Rebel Alliance

A collaboration of different nations coming together to defeat the Dark Side

The CERN Alliance

A collaboration of different nations coming together to discover the Dark Energy



Distribution of All CERN Users by Nationality on 20 January 2017

MEMBER STATES	7714
Austria	109
Belgium	125
Bulgaria	90
Czech Republic	231
Denmark	67
Finland	114
France	867
Germany	1300
Greece	229
Hungary	81
Israel	60
Italy	2027
Netherlands	170
Norway	62
Poland	322
Portugal	118
Romania	128
Slovakia	123
Spain	438
Sweden	91
Switzerland	228
United Kingdom	734

ASSOCIATE MEMBERS	676
India	336
Pakistan	67
Turkey	173
Ukraine	100

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP	70
Cyprus	25
Serbia	45

OBSERVERS	2666
Japan	327
Russia	1141
USA	1198

OTHERS	1803
Albania	4
Algeria	13
Argentina	21
Armenia	25
Australia	32
Azerbaijan	9
Bangladesh	11
Belarus	46
Bolivia	4
Bosnia & Herzegovina	1
Brazil	123
Burundi	1
Cameroon	1
Canada	152
Chile	21
China	439
Colombia	43
Costa Rica	2
Croatia	41
Cuba	16
Ecuador	4
Egypt	31
El Salvador	1
Estonia	13
Georgia	47
Iceland	5
Indonesia	12
Iran	59
Iraq	1
Ireland	16
Jordan	2
Kazakhstan	1
Kenya	3
Korea Rep.	172
Kyrgyzstan	1
Latvia	2
Lebanon	17
Lithuania	32
Luxembourg	1
Madagascar	2
Malaysia	19
Malta	10
Mauritius	2
Mexico	82
Mongolia	2
Montenegro	4
Morocco	18
Nepal	9
New Zealand	6
Nigeria	3
Oman	3
Palestine (O.T.).	7
Paraguay	1
Peru	6
Philippines	3
San Marino	1
Saudi Arabia	1
Senegal	2
Singapore	6
Sint Maarten	1
Slovenia	31
South Africa	39
Sri Lanka	3
Syria	1
Taiwan	54
Thailand	23
T.F.Y.R.O.M.	2
Tunisia	6
Uruguay	1
Uzbekistan	4
Venezuela	10
Viet Nam	11
Zambia	1
Zimbabwe	4

SESAME – Synchrotron Light Source in the Middle East

- **A collaborative organisation that follows the example of CERN**
- **Member states are Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, The Palestinian Authority, and Turkey**

'Apart from providing new scientific knowledge, what do you think is another important aspect of the SESAME collaboration between these countries?'

Just how big is it?

- Students reconstruct a scale diagram of the FCC on a map of their own region.
- Manipulation of the circumference formula and interpreting scales.