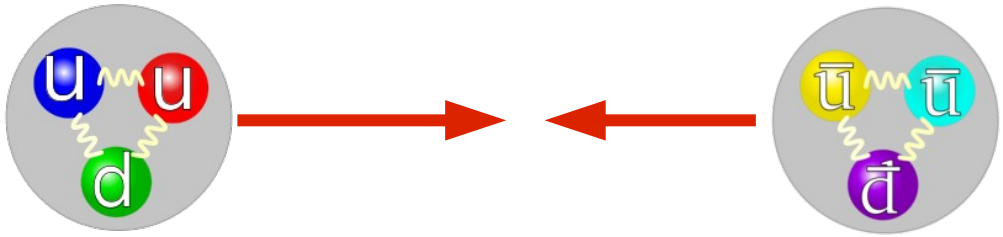
CERN Large Hadron Collider

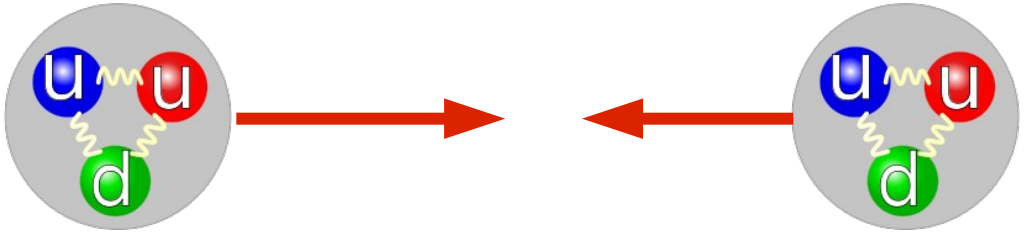
Ref:

Collides Particles to Make Particles

- Earlier colliders collide the particle with the anti-particle.
- LEP and the SLC (Stanford) collided electrons and positrons.
- The Tevatron collided protons with the anti-proton. Difficult to create lots of anti-protons.



- LHC collides the proton with another proton. It is ”easy” to make two intense, good quality proton beams. Particle creation is not so make quark-antiquark, but gluons (that bind the quarks together) are a source of new particles.



From http://press.web.cern.ch/backgrounders/lhc-season-2-stronger-machine.

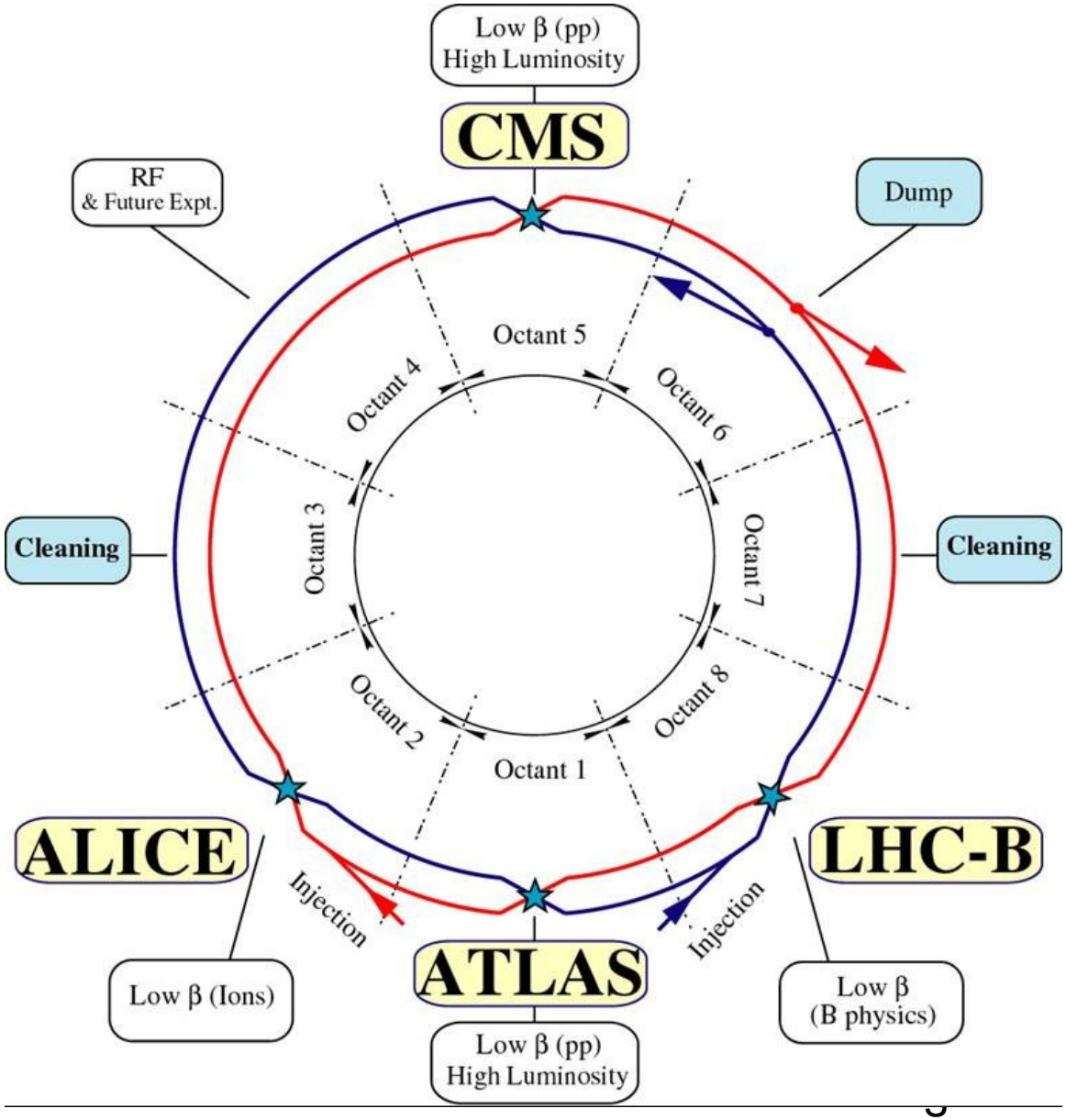
What does/did the LHC do?

Energies & Modes:

Proton-Proton
2011 3.5+3.5 TeV
2012 4+4 TeV
1380 on 1380 bunches
1368 on 1262 bunches
2015 6.5+6.5 TeV

Lead-208 (82+)-Lead
2011 1.38+1.38 TeV/u
2012 none (?)
358 on 358 bunches

Proton-Lead
2013 4.0+1.577TeV/u
338 on 338 bunches



What happened to the LHC do?

Restarted in early 2015.

• 18 of 1232 magnets replaced due to wear and tear;
• 10,000 electrical connections have a safety shunt to save magnet interconnect;
• Superconducting magnets have a better ”quench” protection (when they return to normal conducting);
• All that allows for higher energy, 6.5+6.5 TeV;
• Tighter focused beams;
• Closer beams, 25 ns spacing vs 50 ns, allows bunches to have fewer protons, 1.2e11 vs 1.7e11 previously.

• Higher voltages on RF cavities to give the beams higher energy;
• Upgrade and consolidation of the cryogenics to keeping the magnets at 1.9 Kelvin;
• Radiation resistant electronics and electrical systems;
• Vacuum system improvements, like non-evaporable getter and solenoids to mitigate “electron cloud” effect.

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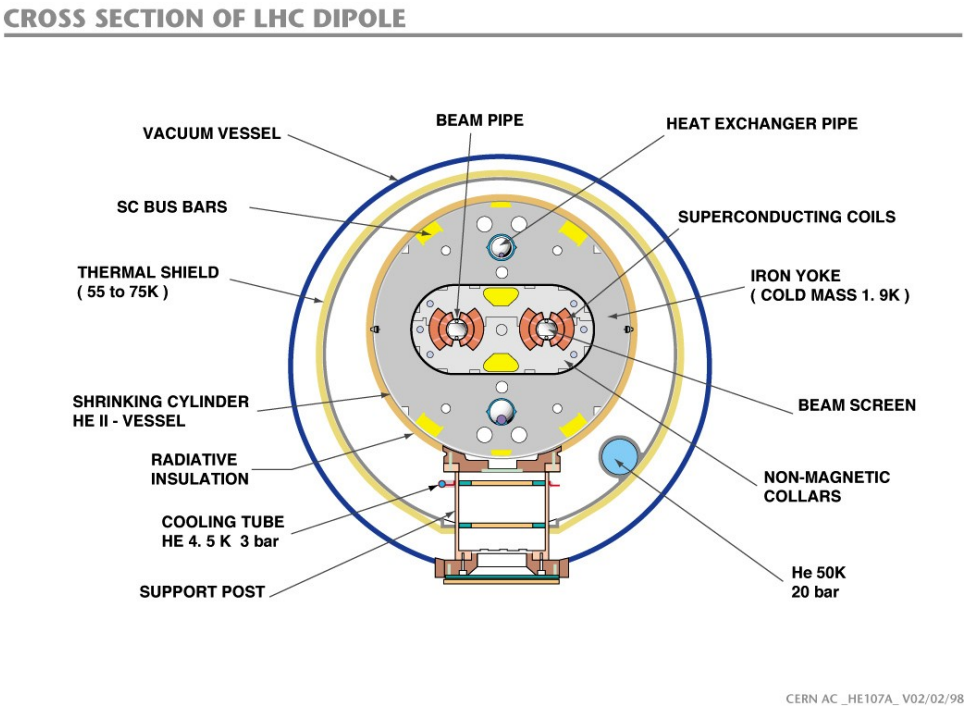
LHC Magnets for your students...



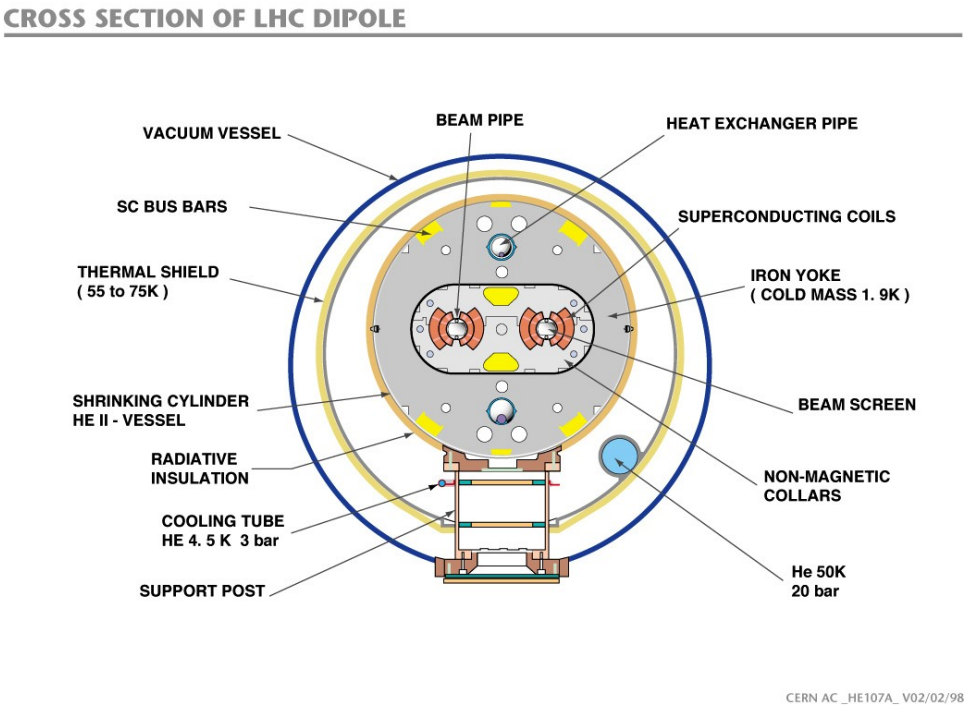
Usual dipole magnet (normally conducting), has a lot of iron and current in its wire coils.

Magnetic field limited, when ”all” the magnetic domains in the iron aligned, about 1.8 Tesla.

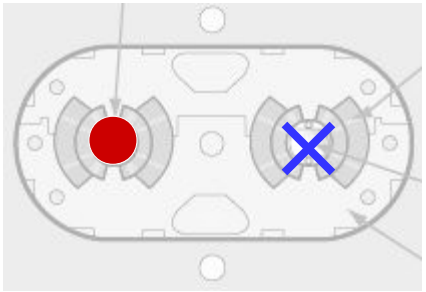
Superconducting dipole magnet has no iron and a lot of current current in its wire coils.

Magnetic field limited by how well you make your supercond. wire and how much current it can carry.

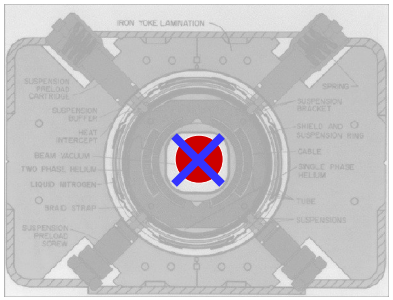
LHC Magnets for your students...



The **LHC** is a Proton-Proton collider at 13 TeV. The two beams have to be in different parts of the magnet, hence different vacuum pipes.



Fermilab's **Tevatron** was a Proton-Antiproton collider at 2 TeV and the two beams can be in the magnet center and the same vacuum pipe.



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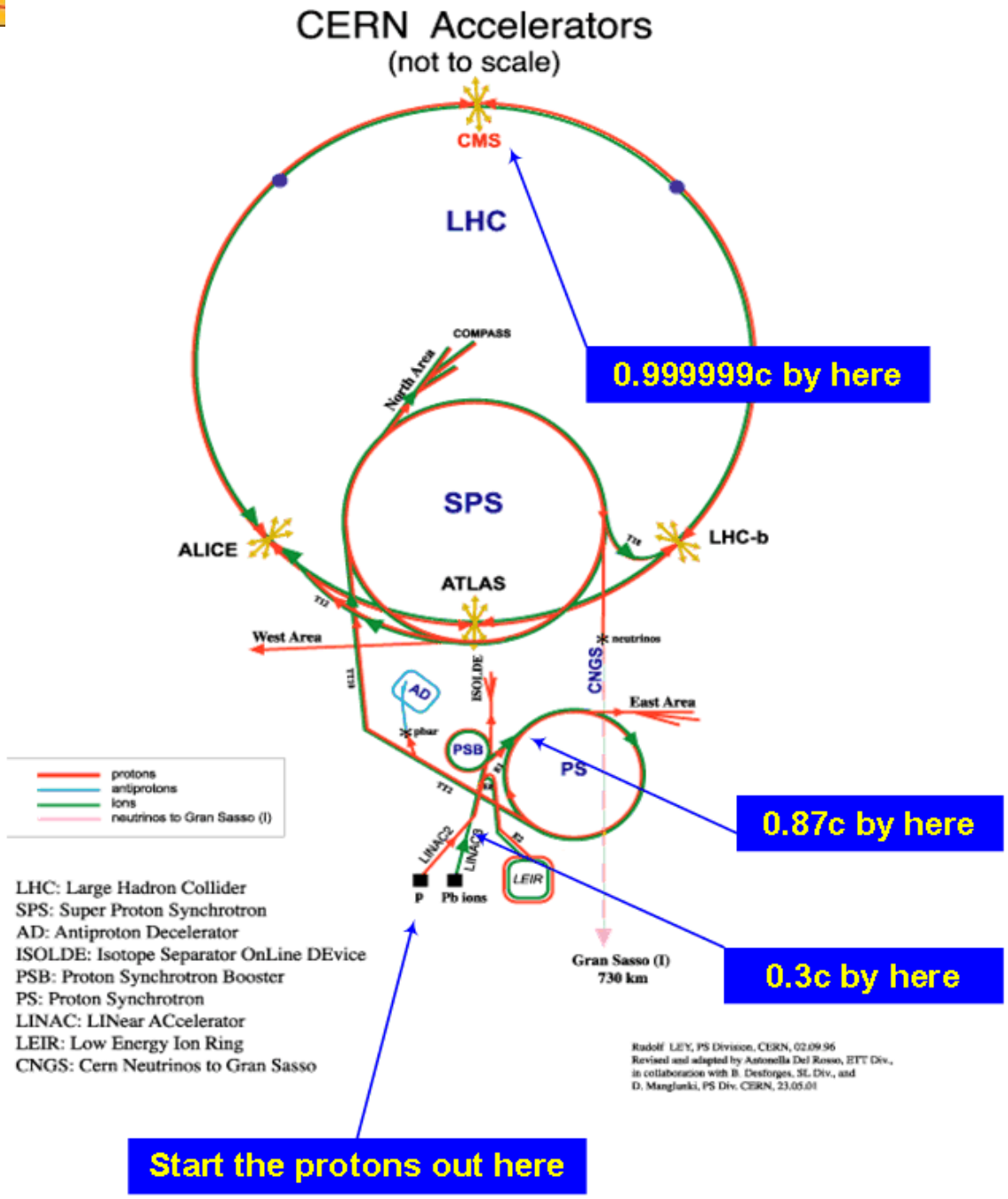
$$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$$

Large Hadron Collider (LHC)



Circumference 27 km
Two beams opposite directions
proton on proton 8 TeV
1380 on 1380 bunches

Energies:

Linac	50 MeV
PSB	1.4 GeV
PS	28 GeV
SPS	450 GeV
LHC	3.5 TeV
	4.0 TeV
(soon)	6.5 TeV

Ref: Introduction to Accelerators, Elena Wildner, CERN

Animation

- Two minute animation of LHC
  https://www.youtube.com/watch?v=pQhbhpU9Wrg

Some Links to Media:

- Motherboard, especially the video on the LHC Startup. https://youtu.be/2wCgpdeQWZA
  - At 8:45 LHC animation. https://youtu.be/2wCgpdeQWZA?t=516
- YouTube and PhotonicsMedia and CERN LHC animation, Nov 23, 2009, https://youtu.be/dw3KuNgD-jE
- Another 2m animation of the LHC, https://www.youtube.com/watch?v=pQhbhpU9Wrg
- And a 5m animation of the data handling, https://www.youtube.com/watch?v=jDC3-QSiLB4
- aa

Links

https://lhc-statistics.web.cern.ch/LHC-Statistics/#

http://www.lhcportal.com/

http://home.web.cern.ch/topics/large-hadron-collider

http://cds.cern.ch/record/1165534/files/CERN-Brochure-2009-003-Eng.pdf

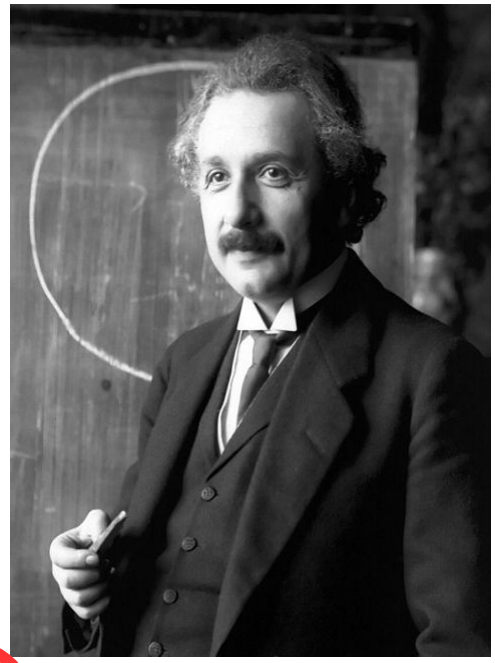
http://home.web.cern.ch/

aa

VANDERBILT UNIVERSITY

Backup

More Magnets...



A little Special Relativity...

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$E = \gamma\, M\, c^2$$

Just like the textbooks, almost... $\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$

And the centripetal force for circular motion, $F = \frac{\gamma M\, v^2}{r}$

All together $\frac{\gamma M\, v^2}{r} = qvB$

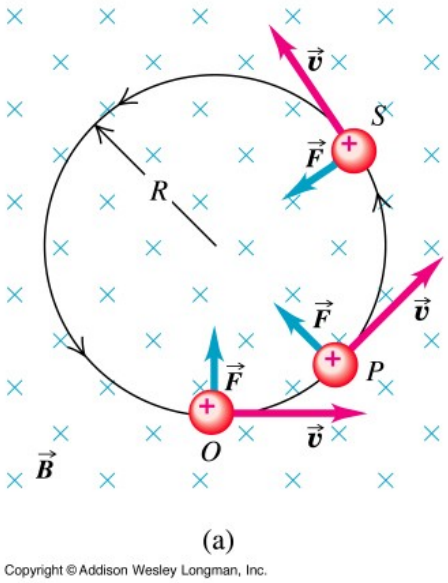
In Accelerator physics it is usually written in the form $B\, r = \frac{\gamma M\, v}{q}$

More Magnets...

$$E = \gamma M c^2$$

What we are doing:

$$B r = \frac{\gamma M v}{q}$$



Some numbers for the LHC:
1232 Dipole Magnets, 15m Length, 27km circumference
7 TeV Design, 11850 Amps, 8.33 Tesla
6.5 TeV Run 2, 11000 Amps, 7.7 Tesla
4 TeV Run 1, 6770 Amps, 4.8 Tesla

The radius of curvature of the orbit at 4.8 Tesla AND 4 TeV is... $r = 2660\,\mathrm{m}$

The radius of curvature of the orbit at 8.33 Tesla AND 7 TeV is...

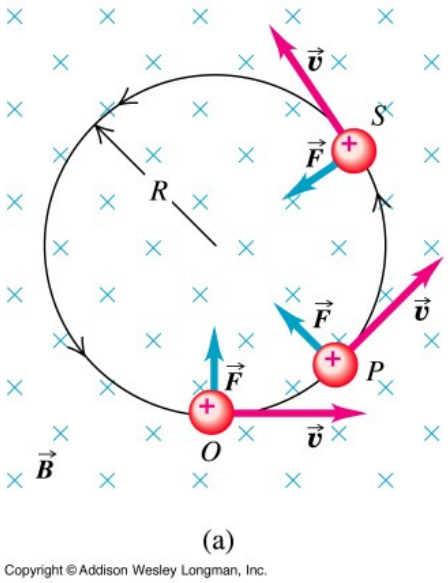
Any guesses?

More Magnets...

$$E = \gamma M c^2$$

What we are doing:

$$B r = \frac{\gamma M v}{q}$$



(a)

Some numbers for the LHC:
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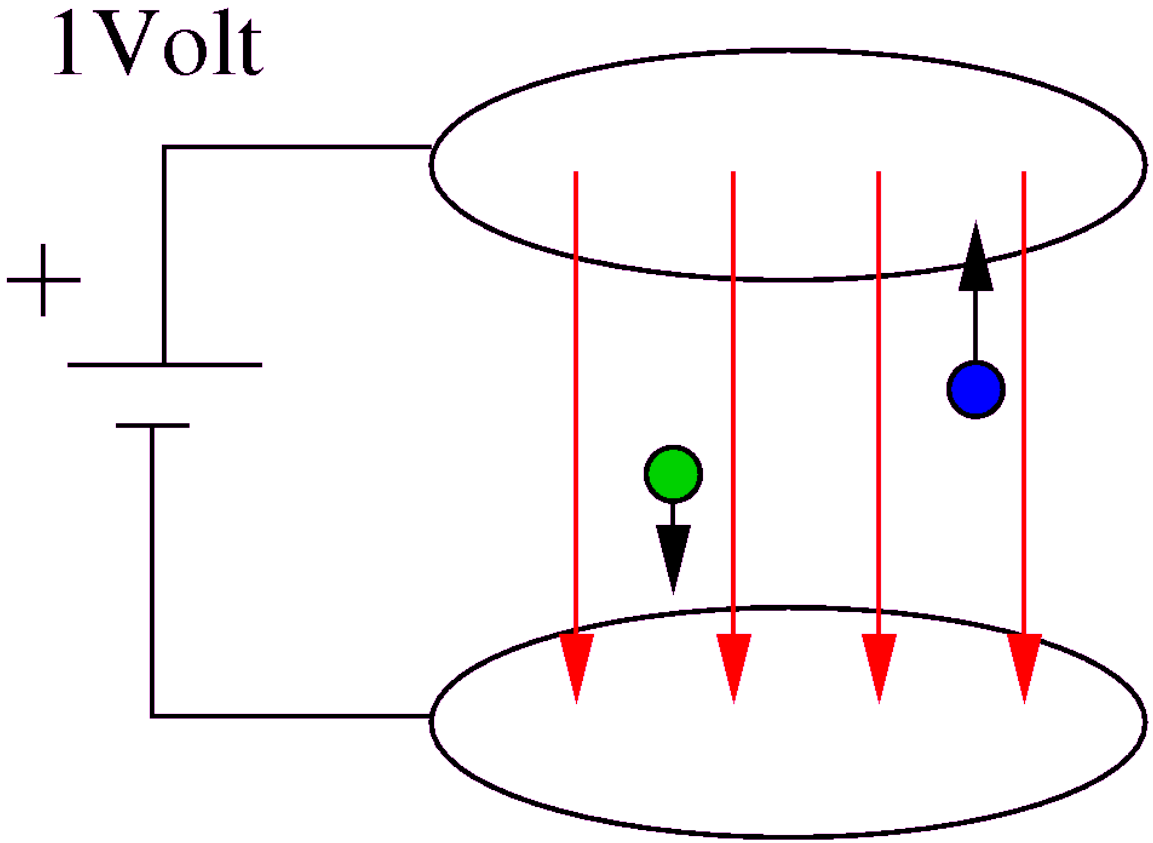
4 TeV actual, 6770 Amps, 4.8 Tesla

The radius of curvature of the orbit at 4.8 Tesla AND 4 TeV is... $r = 2660\,\mathrm{m}$

The radius of curvature of the orbit at 8.33 Tesla AND 7 Tev is... $r = 2680\,\mathrm{m}$

The LHC ring does not change here. Its size is fixed, r is fixed.

Units?



- Proton, heavy, +e
- Electron, light, –e