Dark Matter Detectors

Ed Daw

Office hours: D28 Hicks, Wednesday 12:00, Friday 4pm

Course plan: 8 lectures on dark matter detectors.

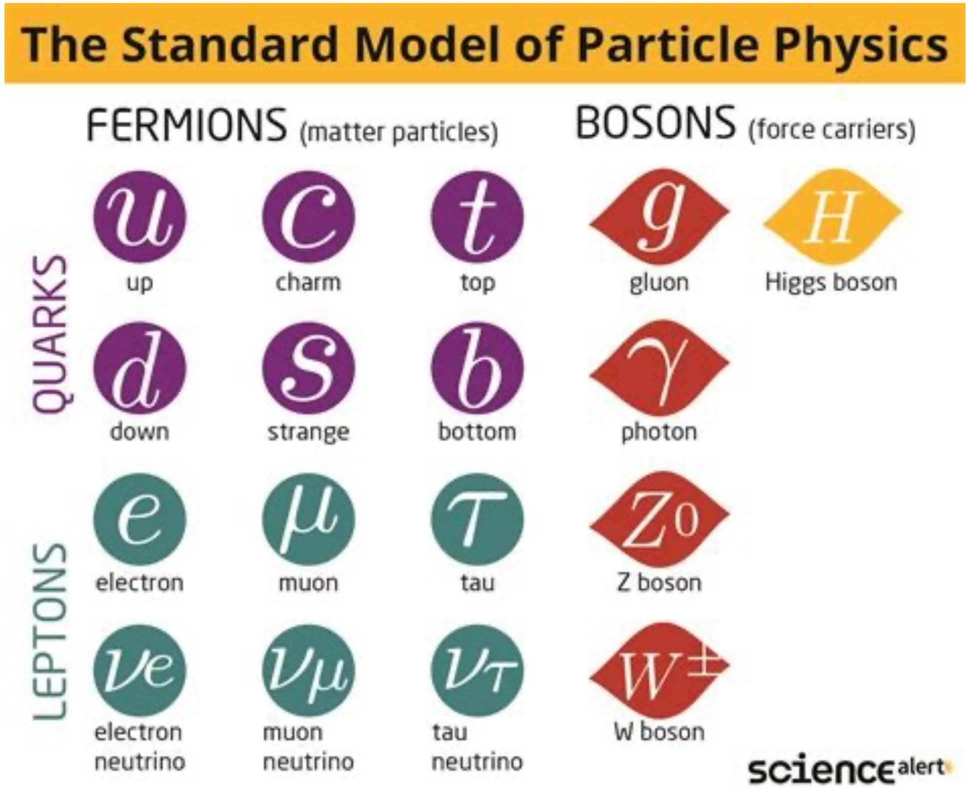
Today: Theory of WIMPs and Axions

Then 3.5 lectures on WIMP detectors

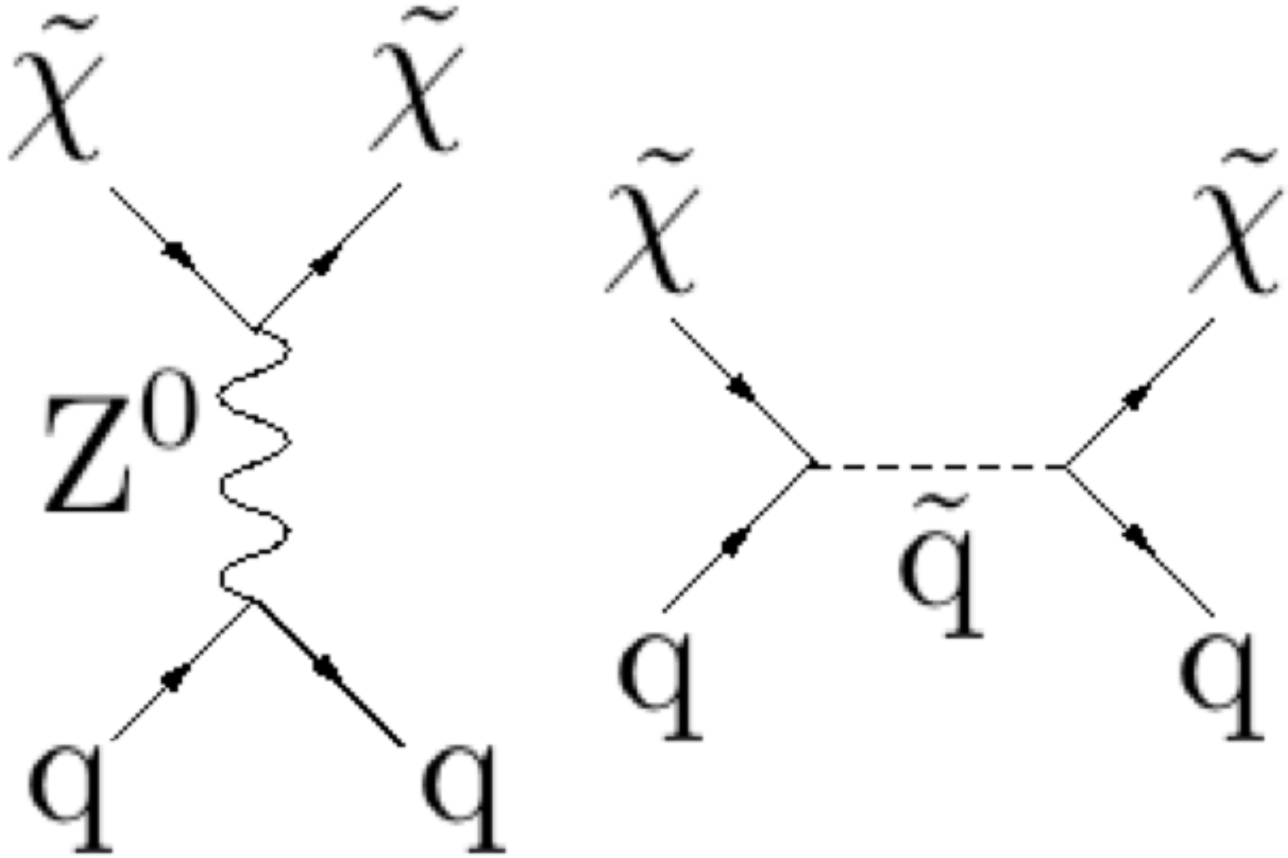
Finally 3.5 lectures on axion detectors

You've had a virtual tour of an underground dark matter lab, used for several WIMP searches. You can have a tour of my axion search experiment, which is on C floor.

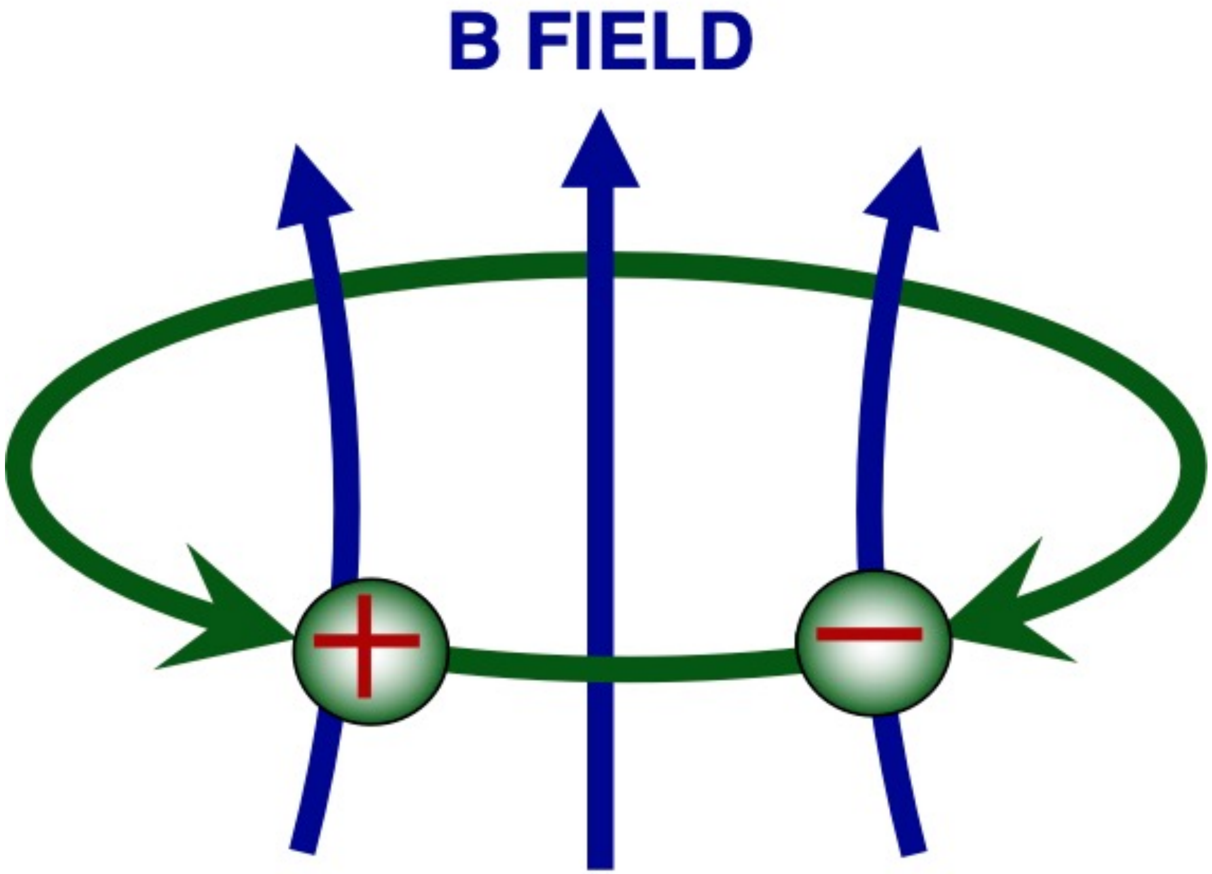
Questions are welcome – raise your hand. Be considerate of other students by not talking loudly otherwise. There will be 1 blackboard homework, and the rest of the assessment is via the exam.

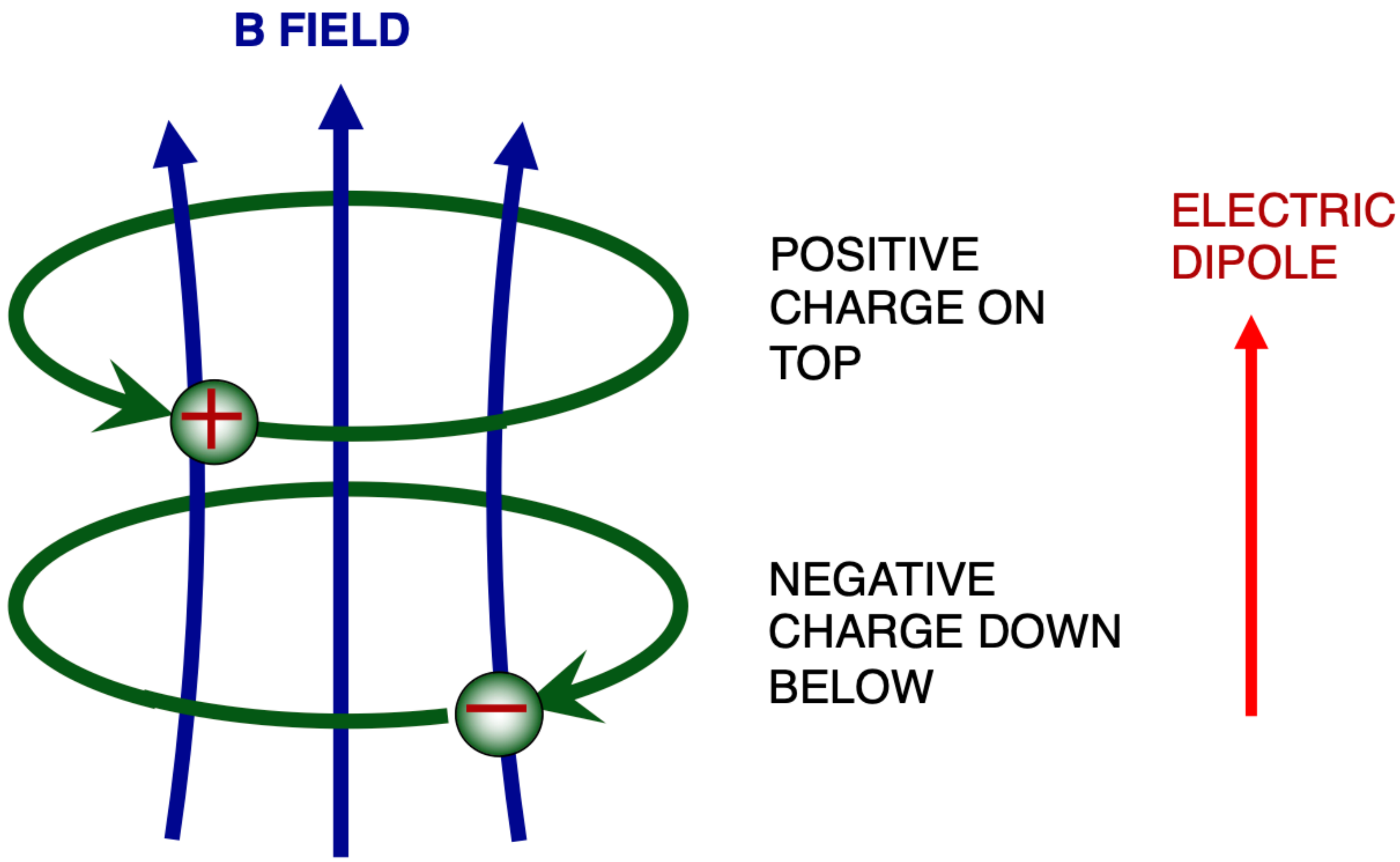


The Standard Model of Particle Physics
FERMIONS (matter particles)
BOSONS (force carriers)
QUARKS
LEPTONS
u
up
c
charm
t
top
g
gluon
H
Higgs boson
d
down
s
strange
b
bottom
γ
photon
e
electron
μ
muon
τ
tau
Z0
Z boson
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
W±
W boson
sciencealert

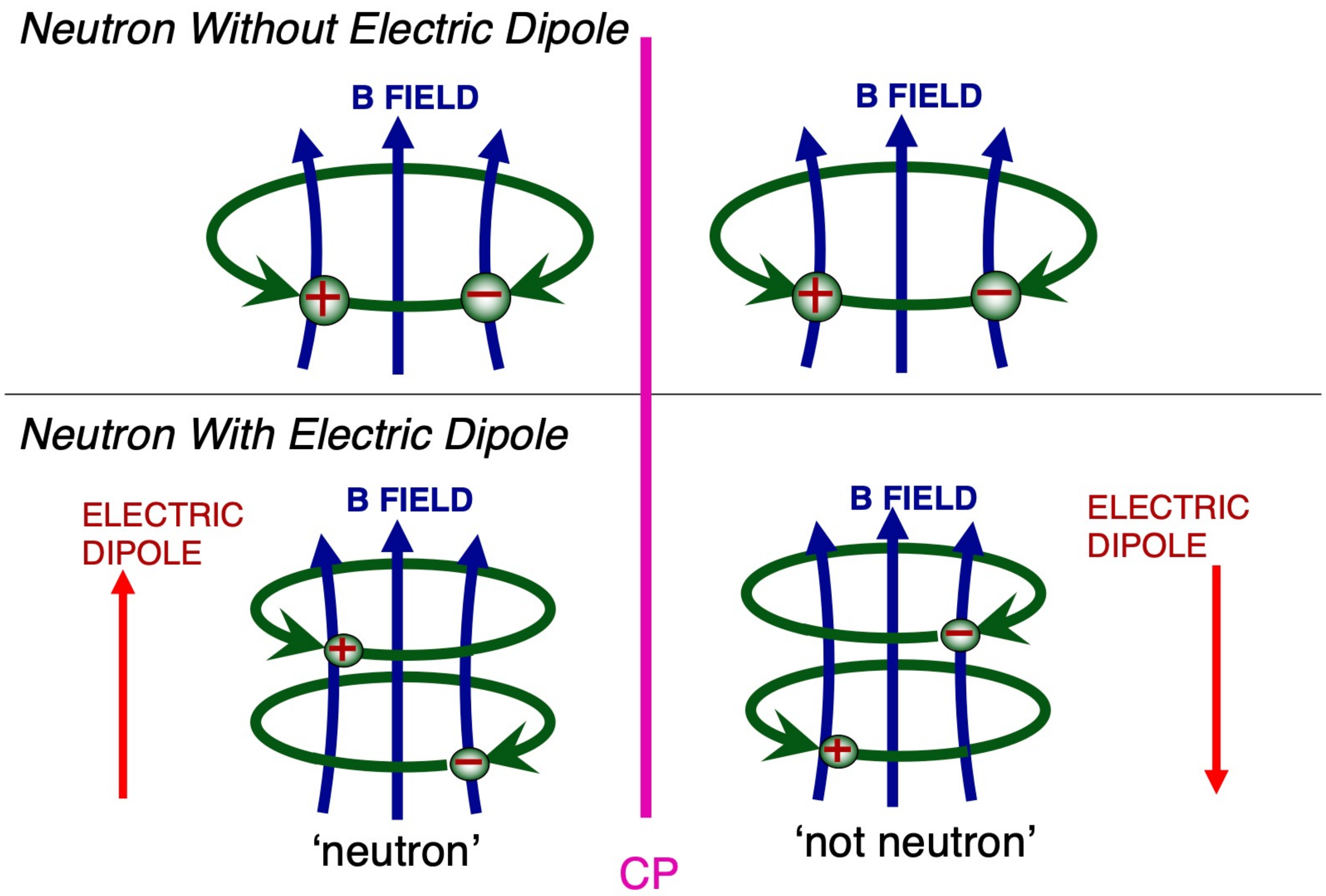


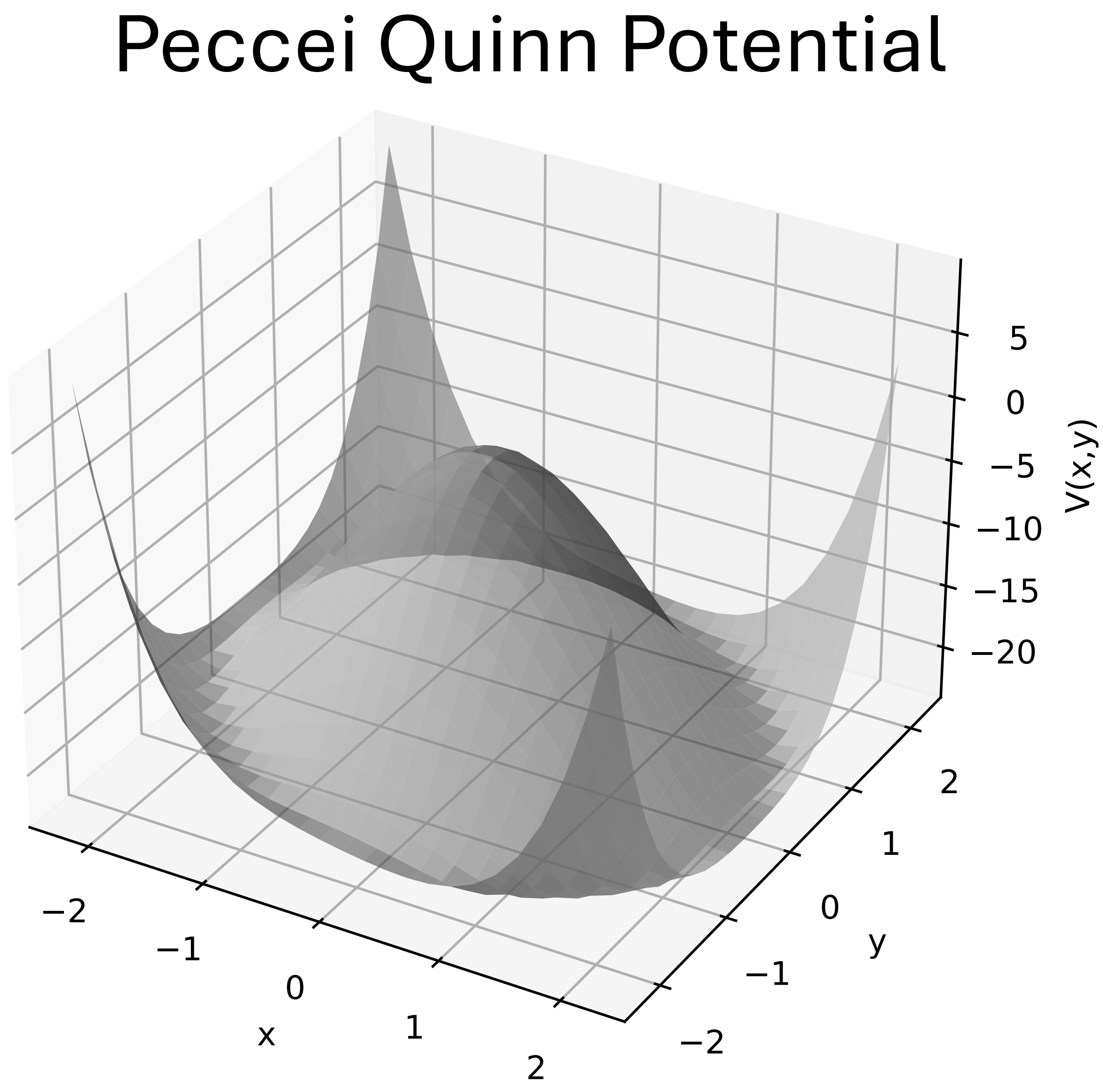
$\tilde{\chi}$
$\tilde{\chi}$
Z^0
q
q
$\tilde{\chi}$
$\tilde{\chi}$
$\tilde{q}$
q
q


B FIELD


B FIELD
POSITIVE CHARGE ON TOP
NEGATIVE CHARGE DOWN BELOW
ELECTRIC DIPOLE

Reflect in Mirror, Reverse the Charges (CP)





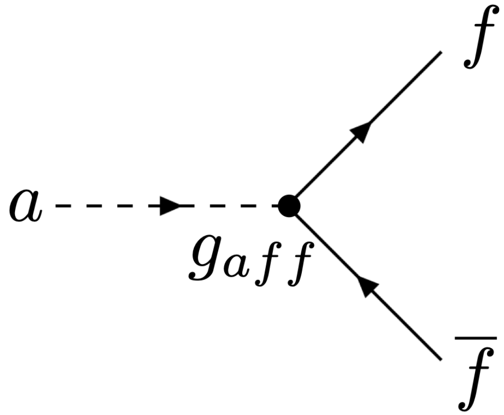
Peccei Quinn Potential
5
0
−5
−10
−15
−20
V(x,y)
−2
−1
0
1
2
x
2
1
0
y
−1
−2

Axion properties

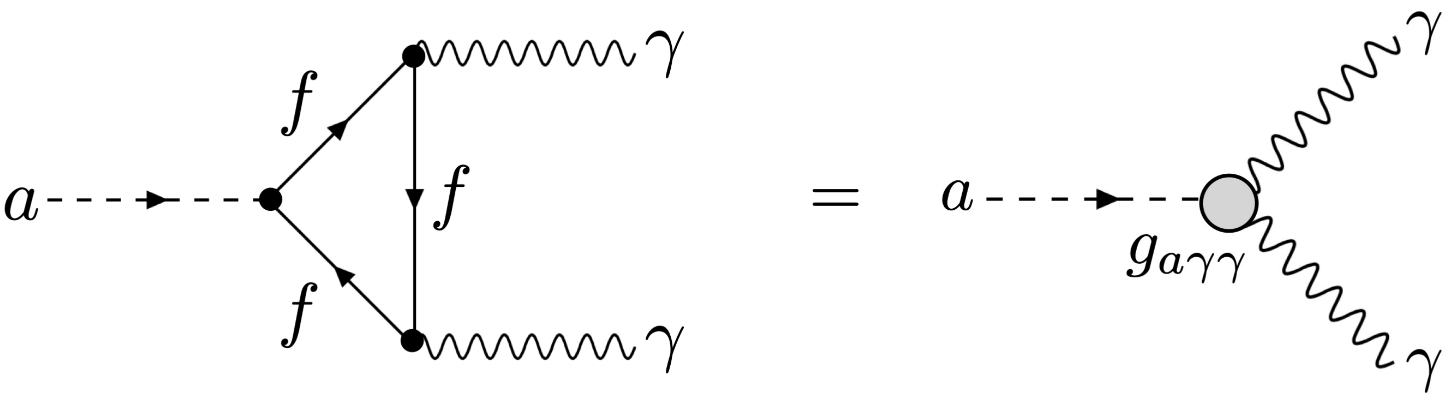
INTERACTIONS [f_{PQ} is the energy scale at the Peccei Quinn phase transition]

The axion has the same quantum numbers as the π^0, therefore there is a scaling rule between axion and pion properties.

$$\frac{m_a}{m_\pi} \simeq \frac{g_{a\gamma\gamma}}{g_{\pi\gamma\gamma}} \simeq \frac{f_{\mathrm{QCD}}(\sim 100\,\mathrm{MeV})}{f_{\mathrm{PQ}}}$$



$$g_{aff} \propto m_a \propto \frac{1}{f_{PQ}}$$



$$g_{a\gamma\gamma} \propto m_a \propto \frac{1}{f_{PQ}}$$

’Easy’ way to work out the De Broglie wavelength from the momentum

$$\lambda = \frac{h}{p} = \frac{2\pi\hbar c}{pc}$$

In the non relativistic limit,

$$p = mv$$

$$pc = mc^2 \left(\frac{v}{c}\right)$$

$$\lambda\,[\mathrm{fm}] = \frac{2\pi(0.2\,\mathrm{GeV\,fm})}{mc^2\,[\mathrm{GeV}] \times \frac{v}{c}}$$

The mc^2 term is the energy of the particle at rest, or its rest mass in GeV/c^2. I’ve used $\hbar c = 0.2\,\mathrm{GeV\,fm}$, a convenient thing to remember that comes in handy a lot. The quantity (v/c) is dimensionless; just make sure the units for v and c match. The answer is in femtometers.

Summary

WIMPs

- Originate in high energy accelerator ‘frontier’ new physics.
- Are associated with the weak interactions, so the WIMP mass is within a couple of orders of magnitude of 100 GeV/c^2.
- Are particle-like, if they are dark matter.
- Have De Broglie wavelengths of order the diameter of a nucleus.

Axions

- Originate as a by-product of the Peccei Quinn mechanism introduced to explain why strongly interacting hadrons are CP-symmetric in the low energy limit.
- Are associated with the strong interactions, so the axion mass is far lower than the WIMP mass, with its mass constrained by astrophysical observations and cosmological arguments. See a later lecture for further disussion
- Are wave-like, if they are dark matter.
- Have De Broglie wavelengths of order a hundred metres.