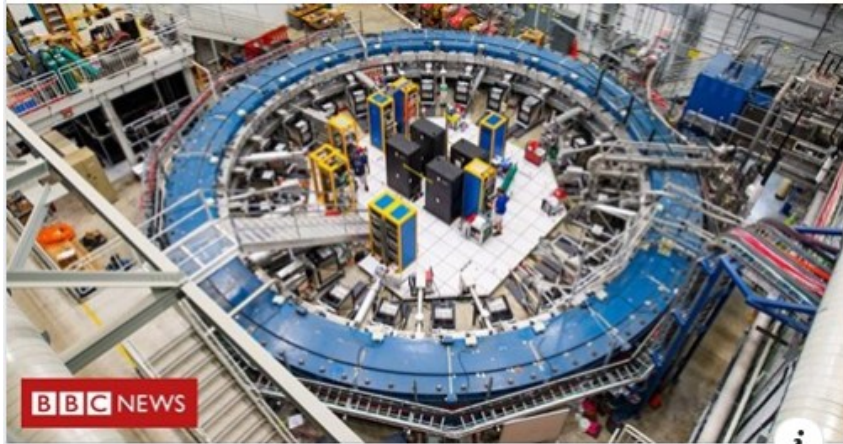


What's all the excitement about muons?

Tim Gershon
University of Warwick
Physics Virtual Offer Holder Open Day
May 5th 2021



BBC.COM

'Strong' evidence found for a new force of nature

Physicists may have just made a major breakthrough in our under...



Mark Hamill 
@HamillHimself

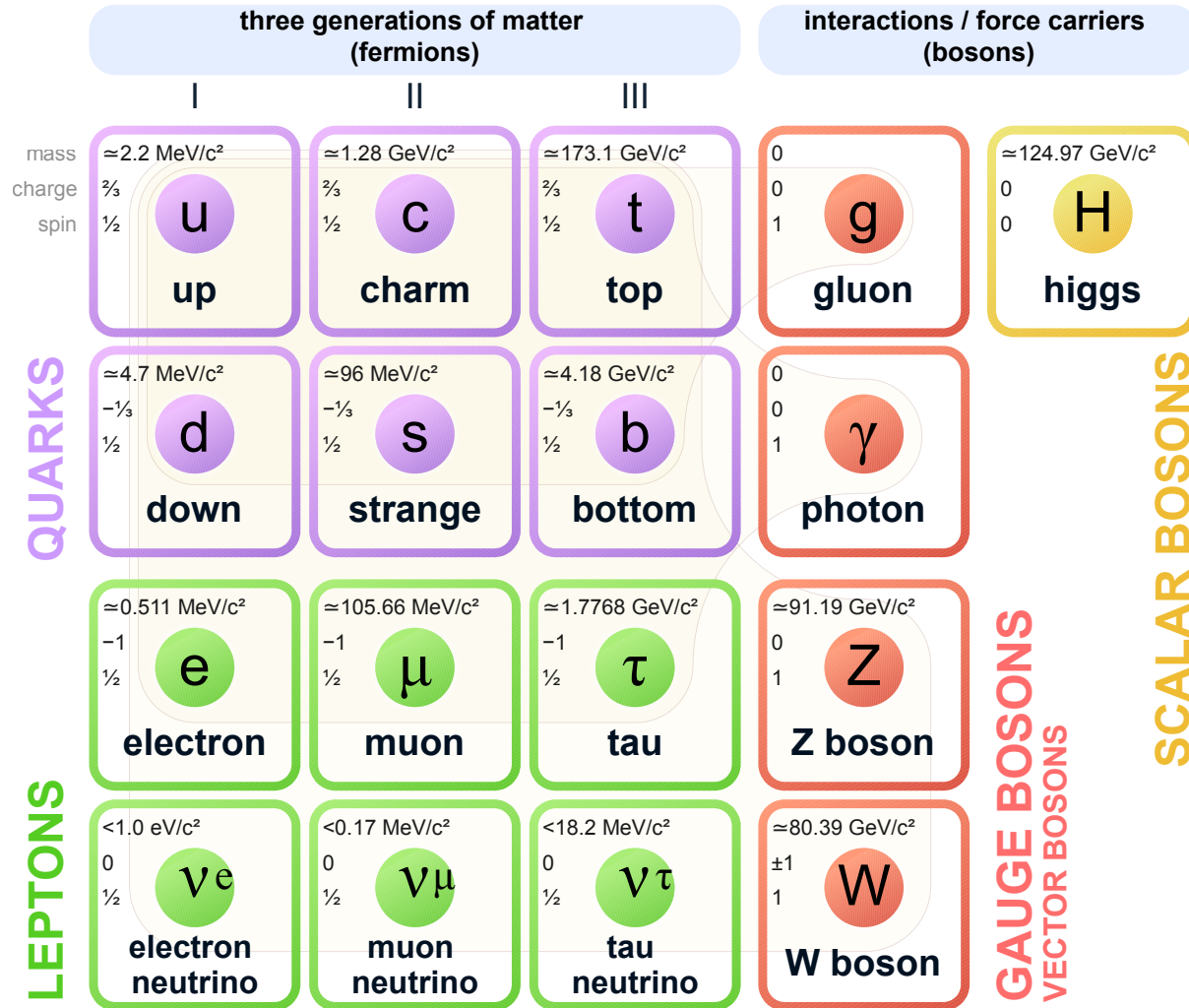
Evidence is mounting that The Force has been with us...
ALWAYS.

 **The New York Times**  @nytimes · 7 Apr

Breaking News: Evidence is mounting that a tiny subatomic particle is being influenced by forms of matter and energy that are not yet known to science but which may nevertheless affect the nature and evolution of the universe. nyti.ms/3uzXOCb

7:37 pm · 7 Apr 2021 · Twitter Web App

Standard Model of Elementary Particles



Standard Model of Elementary Particles

three generations of matter (fermions) interactions / force carriers (bosons)

	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
QUARKS	u up	c charm	t top	g gluon	H higgs
	$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	d down	s strange	b bottom	γ photon	
	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
LEPTONS	e electron	μ muon	τ tau	Z Z boson	
	$< 1.0 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

First generation fermions make up all the visible matter in the Universe

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS

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Force mediators
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 g strong
 W,Z weak

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Origin of mass!

QUARKS

LEPTONS

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SCALAR BOSONS

GAUGE BOSONS
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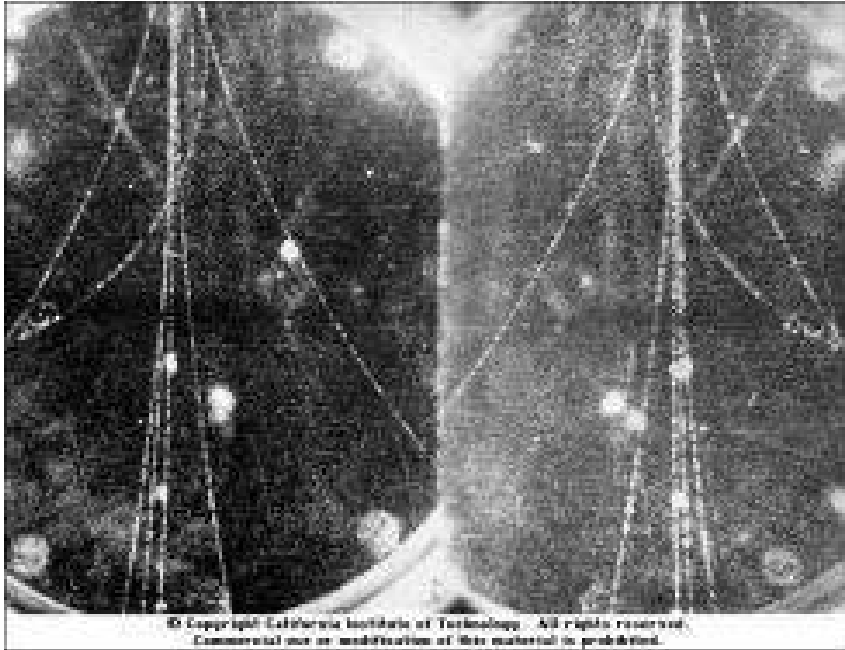
First generation fermions make up all the visible matter in the Universe

Why do we need these?

Force mediators
 γ electromagnetic
g strong
W,Z weak

Origin of mass!

Muons were discovered in 1936 from studies of cosmic radiation



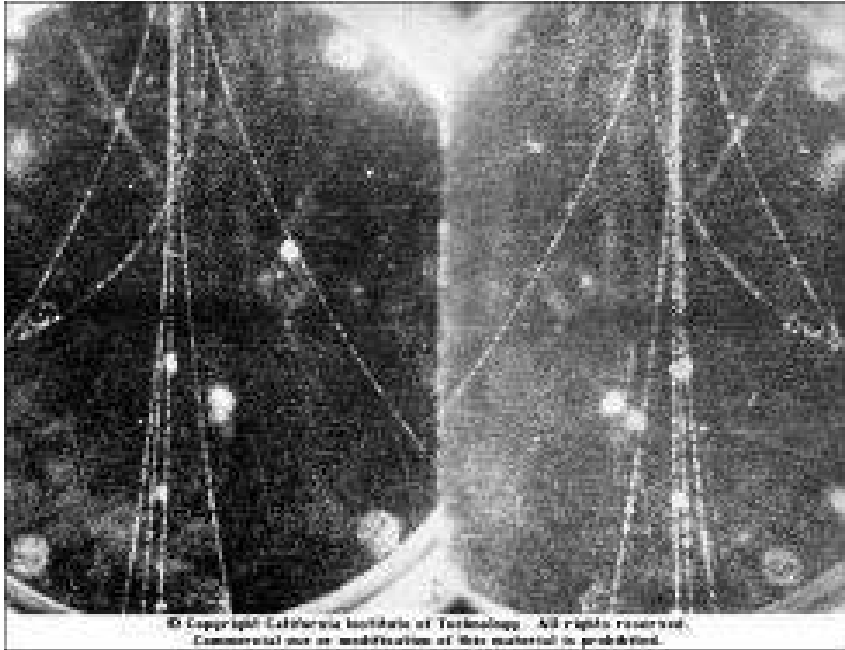
Radius of curvature of charged particle in
magnetic field \propto charge/mass

Who ordered that?



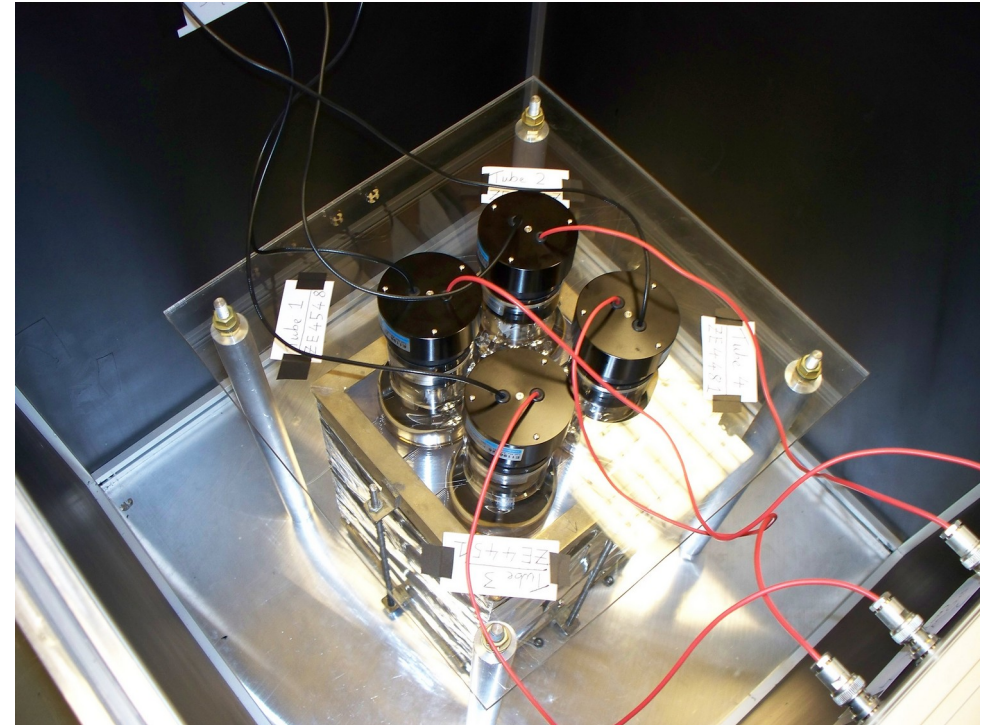
Isidor I Rabi

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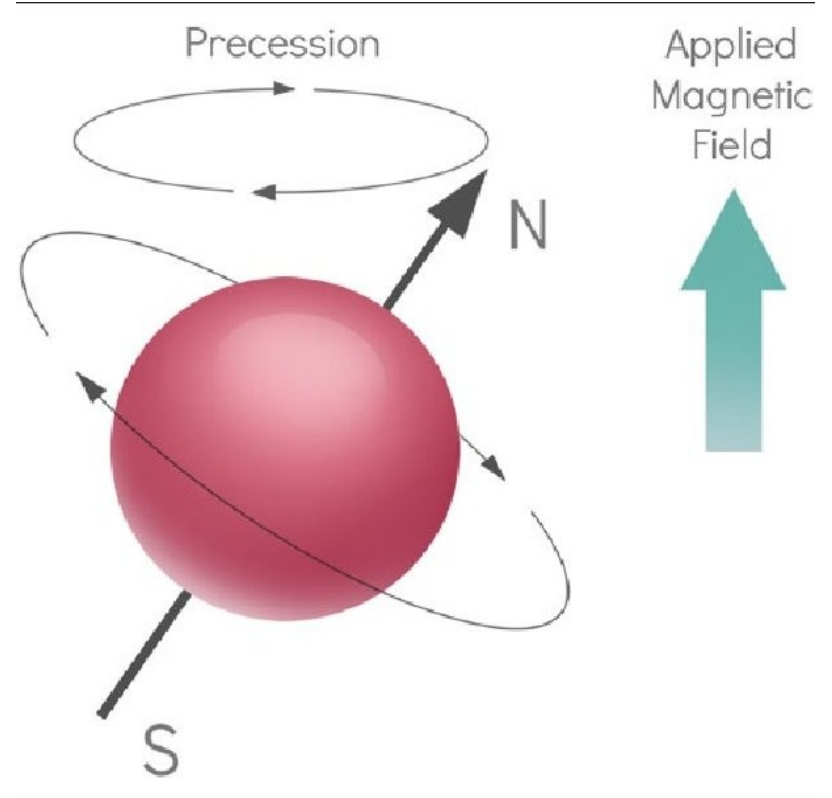
Radius of curvature of charged particle in magnetic field \propto charge/mass

Apparatus used in (non-virtual) Warwick open days to detect cosmic radiation muons



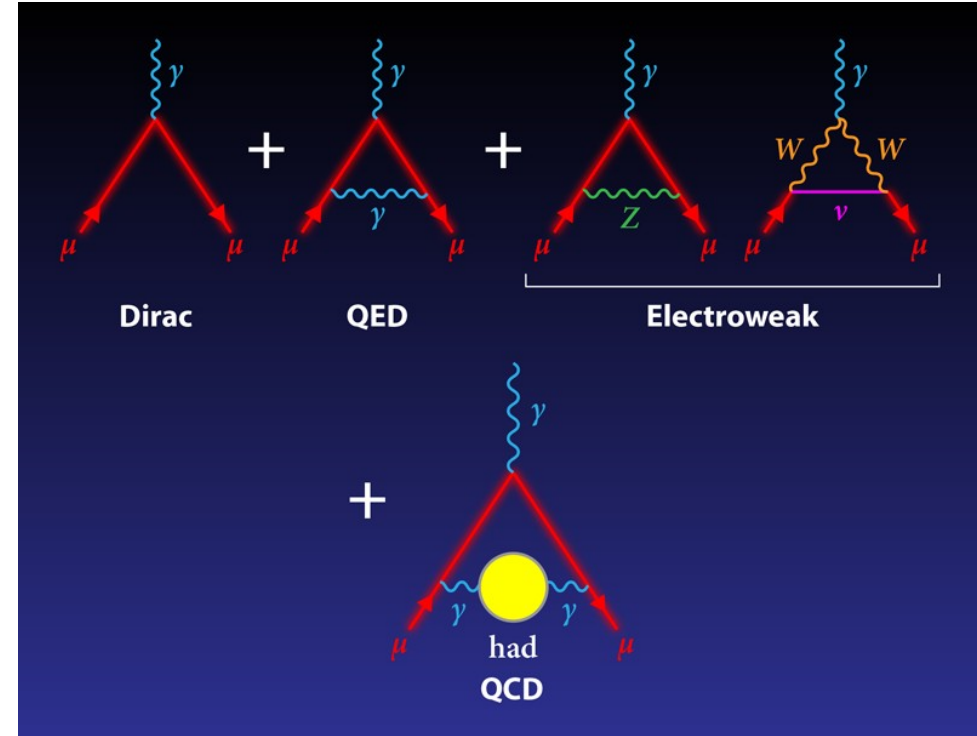
The muon magnetic moment

- The muon (like the electron) has intrinsic angular momentum (“spin”)
- Interaction strength between spin and magnetic field modified by factor denoted g

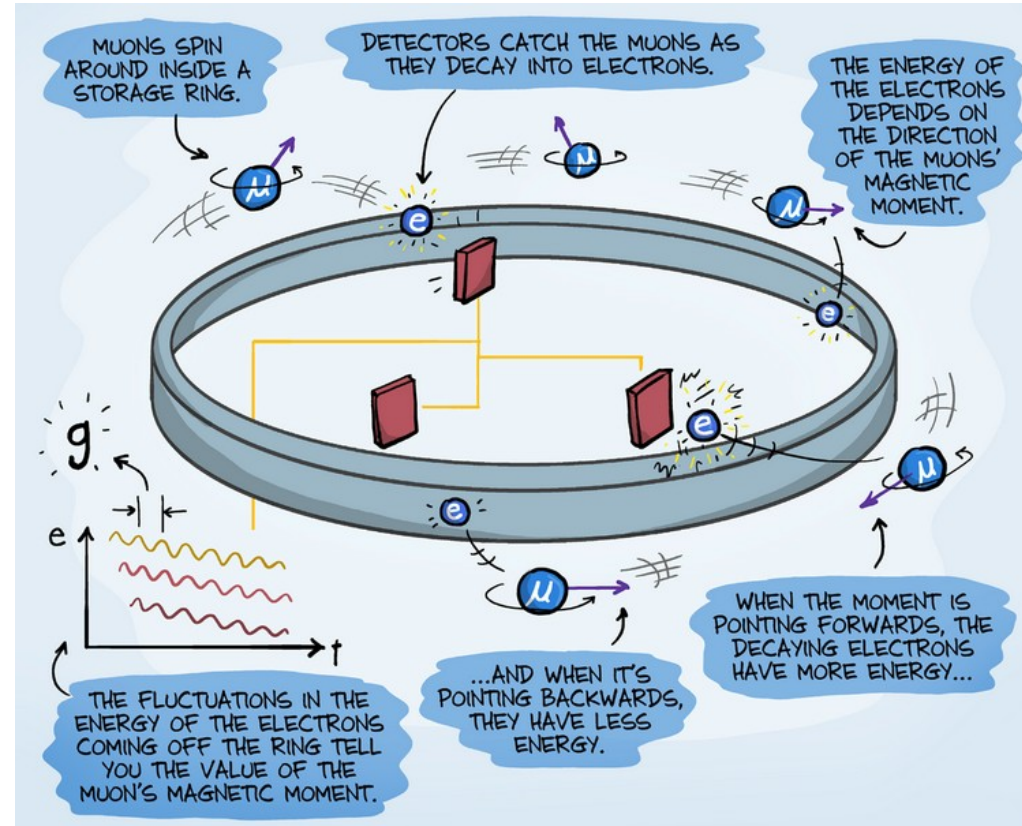
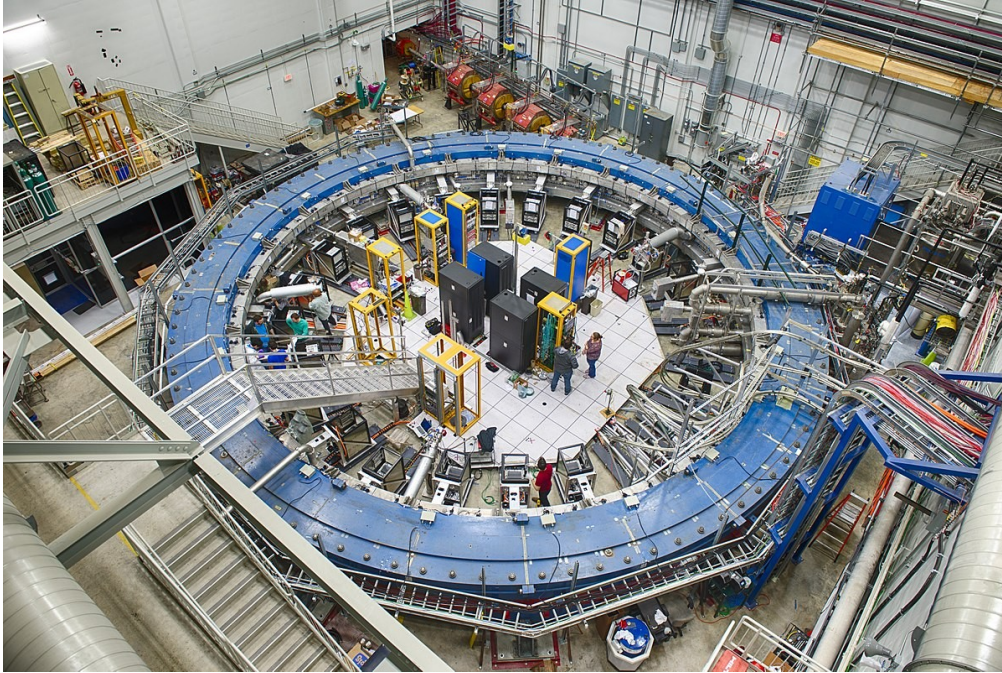


The muon magnetic moment

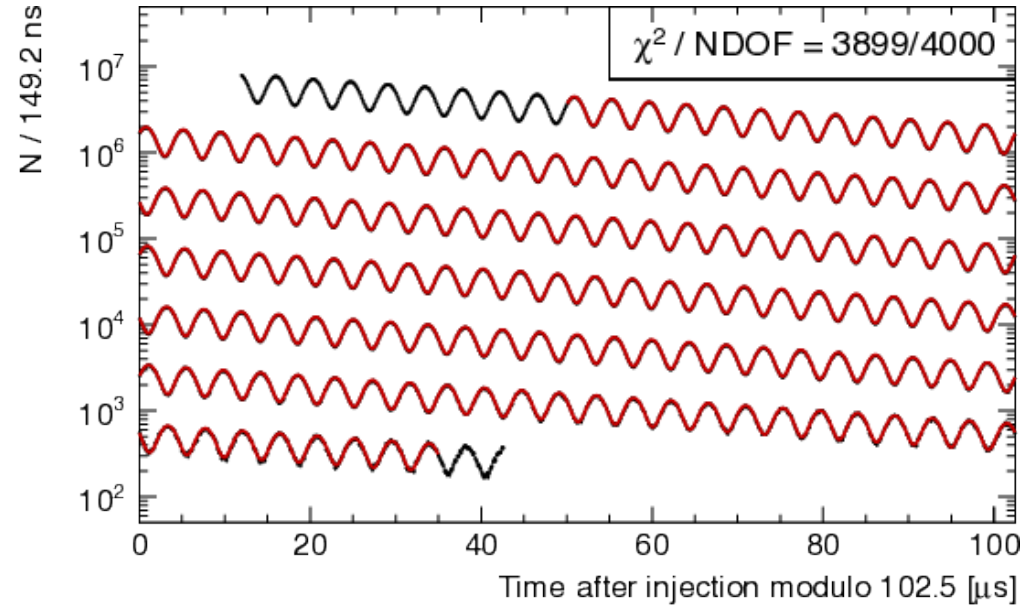
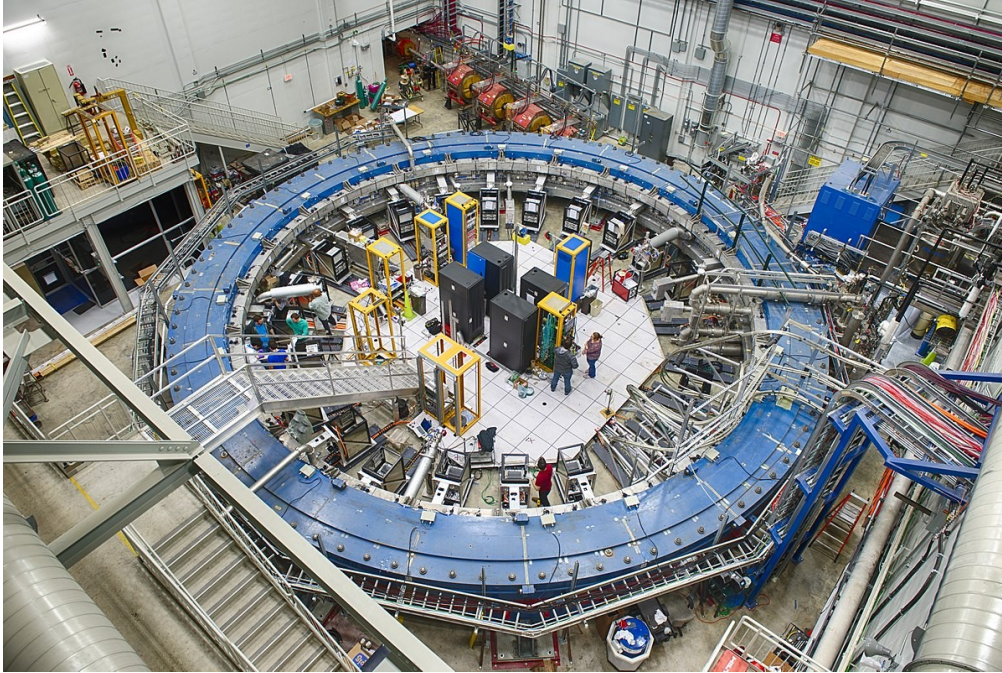
- The muon (like the electron) has intrinsic angular momentum (“spin”)
- Interaction strength between spin and magnetic field modified by factor denoted g
- Dirac (1928) predicted $g=2$
- Schwinger (1948) calculated small QED corrections to this
- Today, we know precisely the corrections due to all Standard Model particles



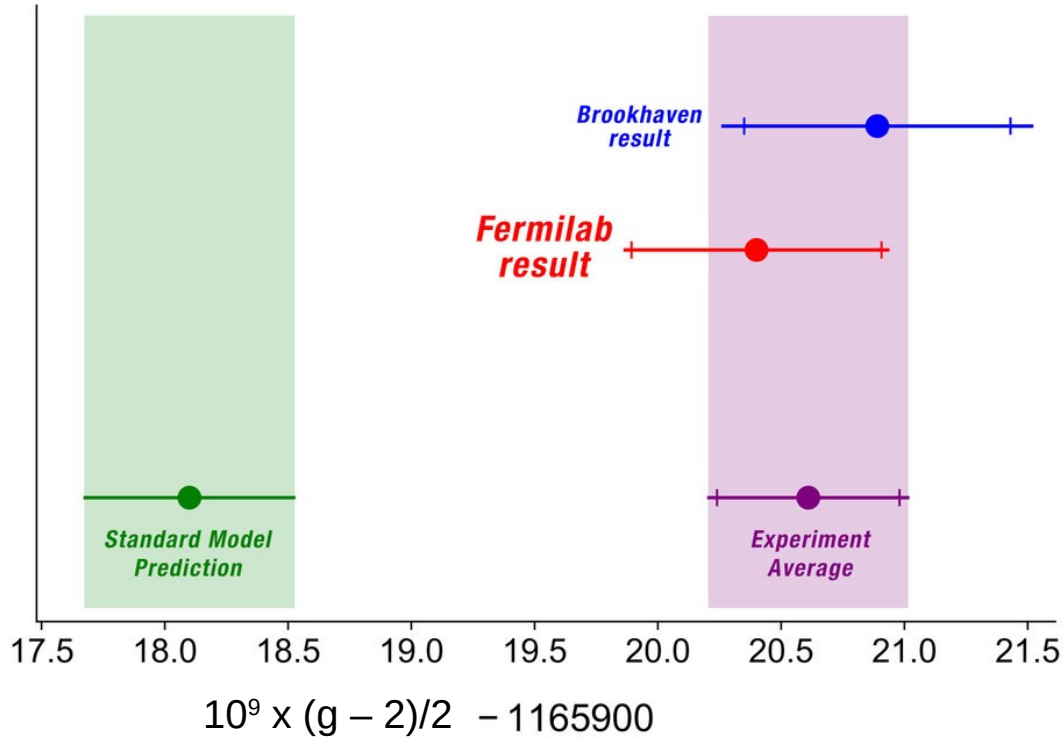
The muon magnetic moment g-2 experiment at Fermilab, USA



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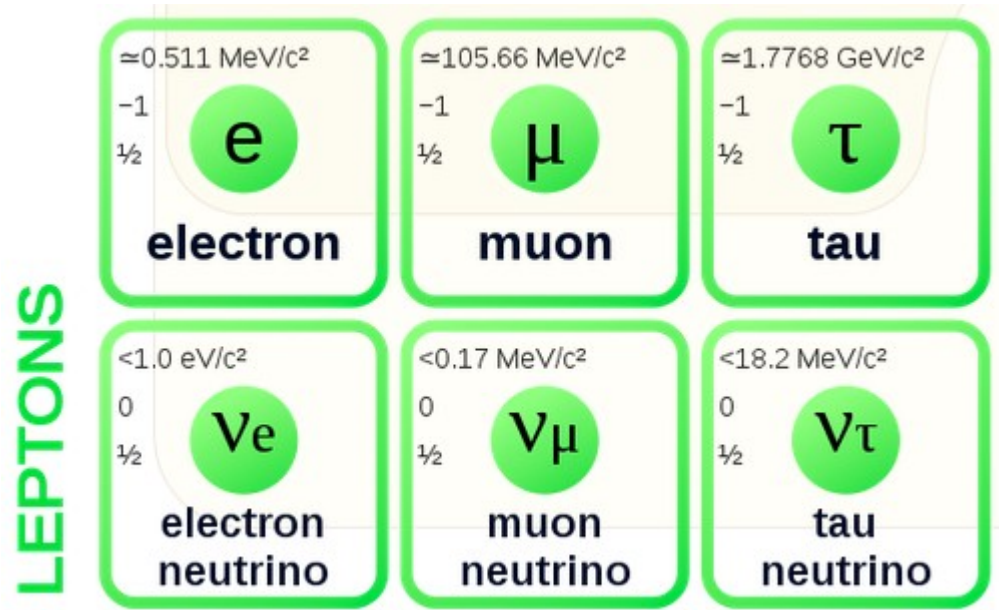


Experiment and theory don't seem to agree!

Could be due to some extra particle(s), not in the Standard Model, causing a small correction to g

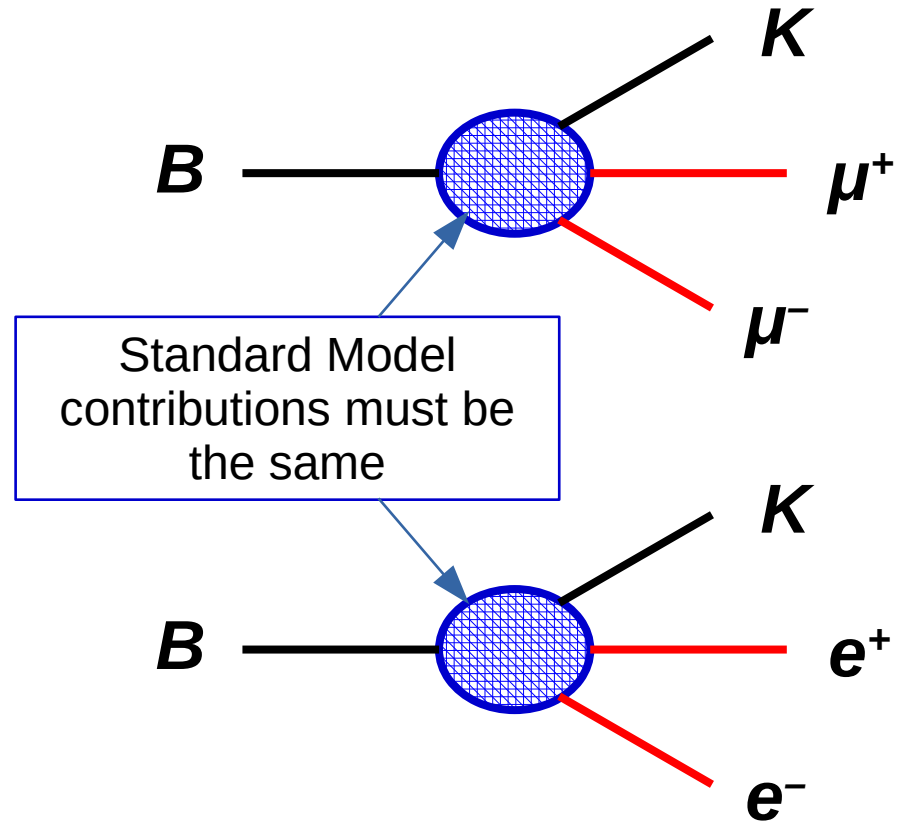
Lepton universality

- Electrons and muons (leptons) have same interaction strength in the Standard Model
 - Only difference between them is their mass
- No fundamental reason for this universality
 - “accidental symmetry”



Lepton universality

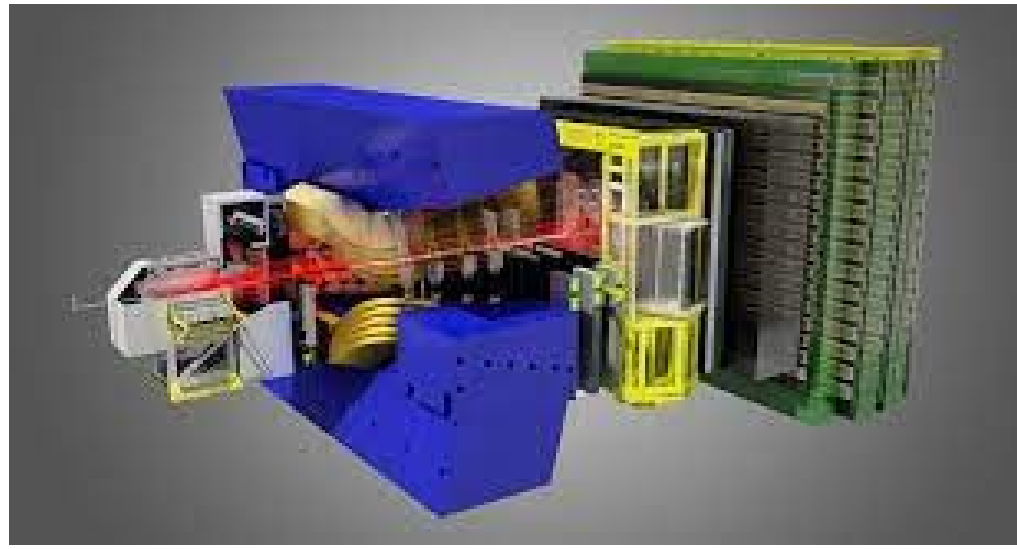
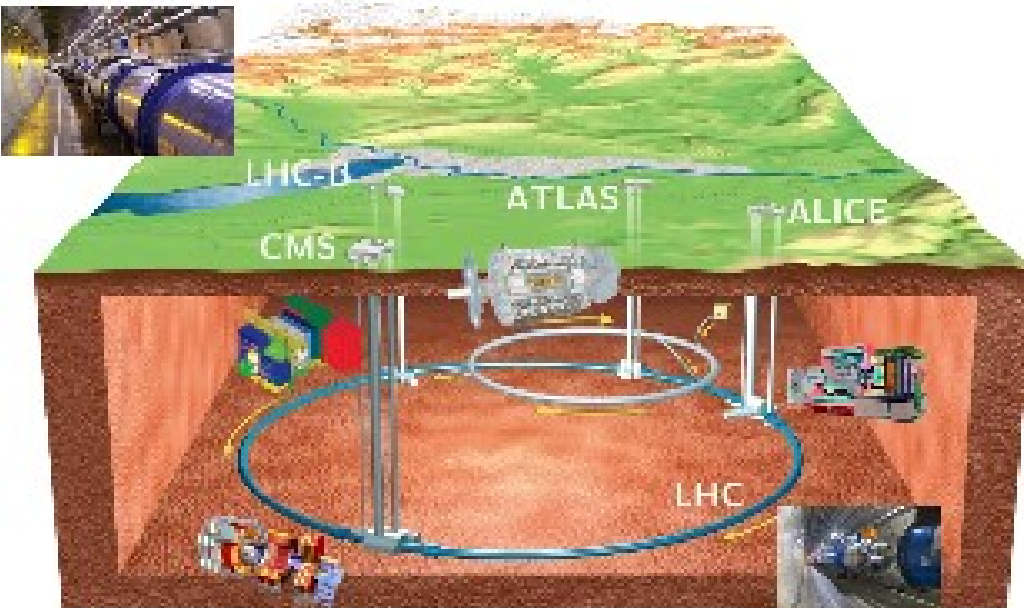
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 - Only difference between them is their mass
- No fundamental reason for this universality
 - “accidental symmetry”
- Can test if they are produced at same rates in various processes





Lepton universality

LHCb experiment at CERN



LHCb collaboration: about 1400 people representing 86 institutes from 18 countries

Warwick LHCb group: 5 academics, 7 PDRAs, 10 PhD students



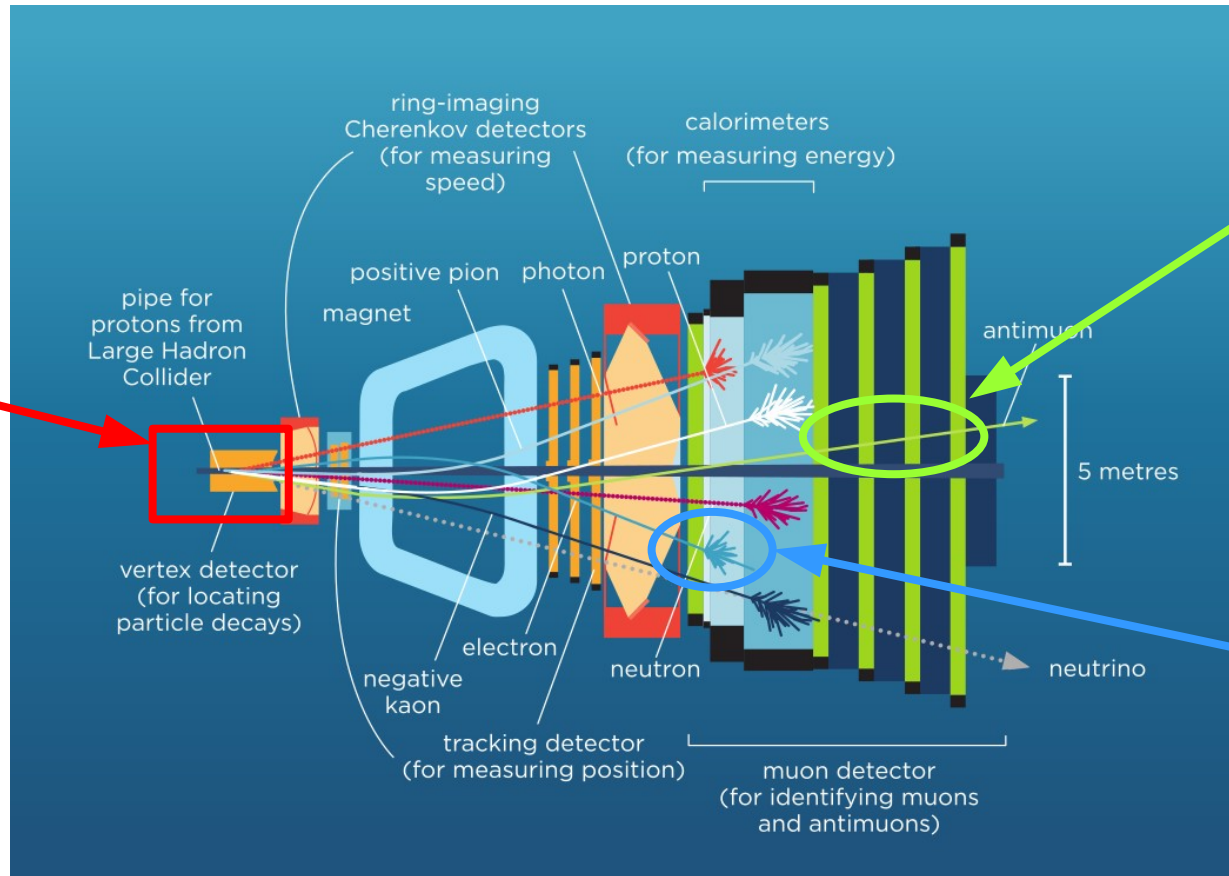
Lepton universality

LHCb experiment at CERN

Proton proton collisions occur inside vertex detector

B particles produced in forward direction

These decay rapidly to particles that traverse the detector



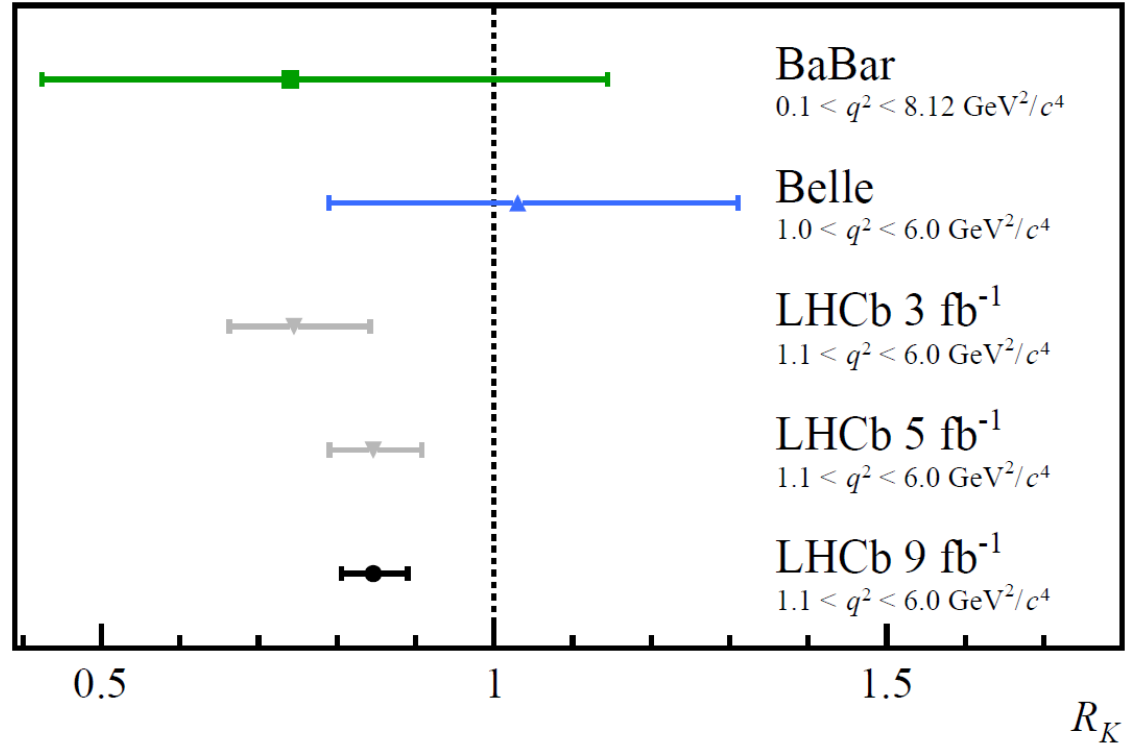
Muons penetrate detector & reach muon counters

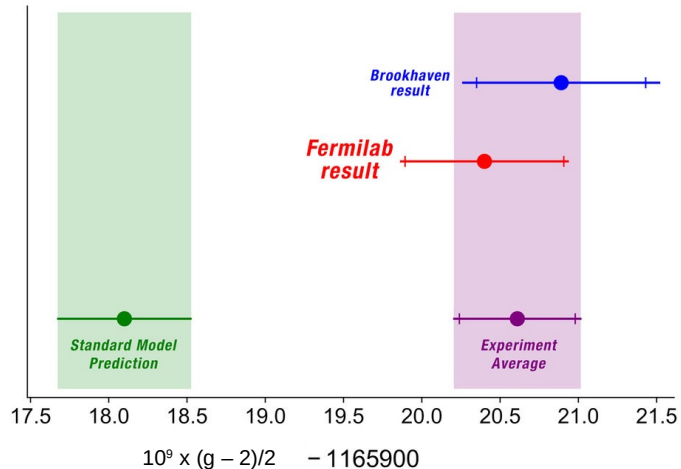
Electrons deposit all their energy in calorimeter

Lepton universality

Experiment and theory don't seem to agree!

Could be due to some extra particle(s), not in the Standard Model, interacting with muons but not electrons



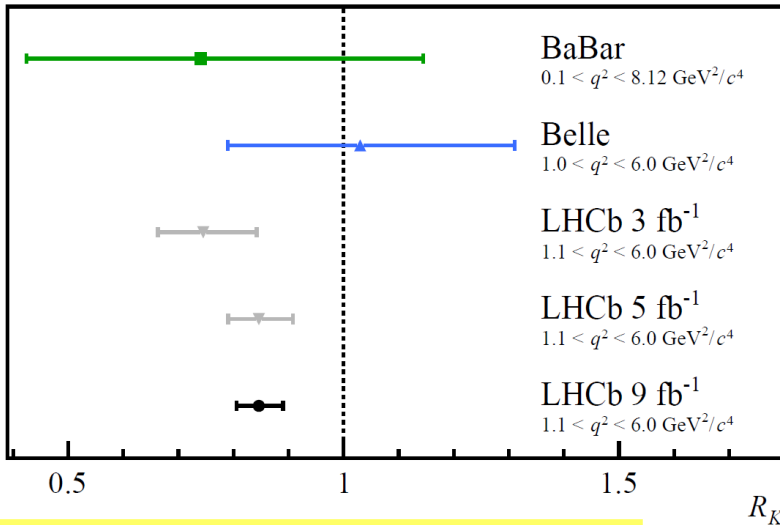


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Could these effects have a common origin?

Yes, potentially. But much more research is needed ...

Particle physics at Warwick

- Year 1
 - Quantum Phenomena + Introduction to Particle Physics
- Year 2
 - Quantum Mechanics and its Applications
- Year 3
 - Quantum Physics of Atoms
 - The Standard Model
- Year 4
 - Advanced Quantum Theory
 - Theoretical Particle Physics
 - Frontiers of Particle Physics

Final year project options
in both 3rd & 4th years (BSc or MPhys)

Opportunities for summer projects

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... and then, if you are really keen,
opportunities for graduate study