

PARTICLE PHYSICS, THE LHC, AND THE SEARCH FOR THE UNKNOWN

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Hubble Ultra Deep Field

Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07a

Modern physics has explained what those small clouds in the sky are, how they are formed and how they evolve.

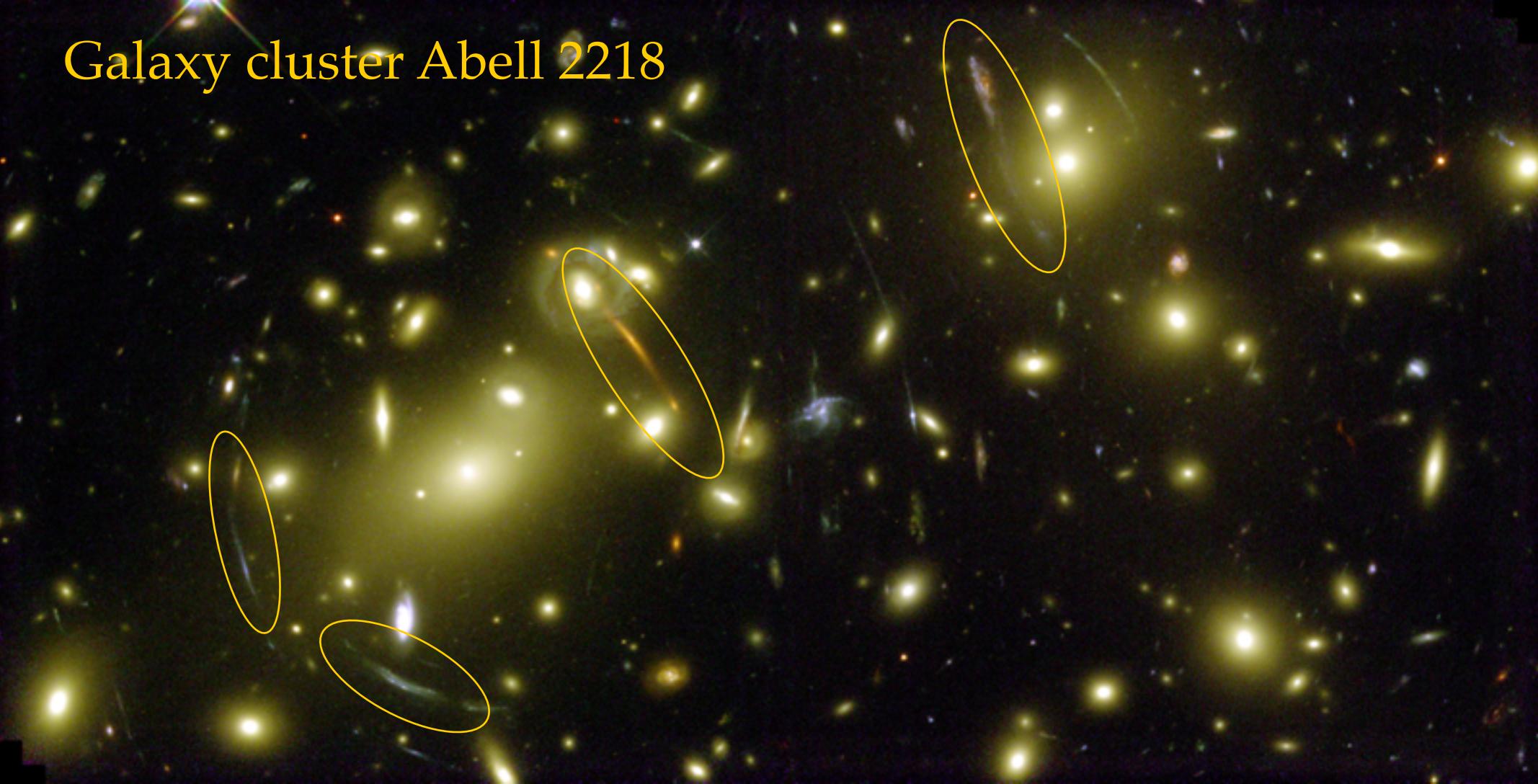
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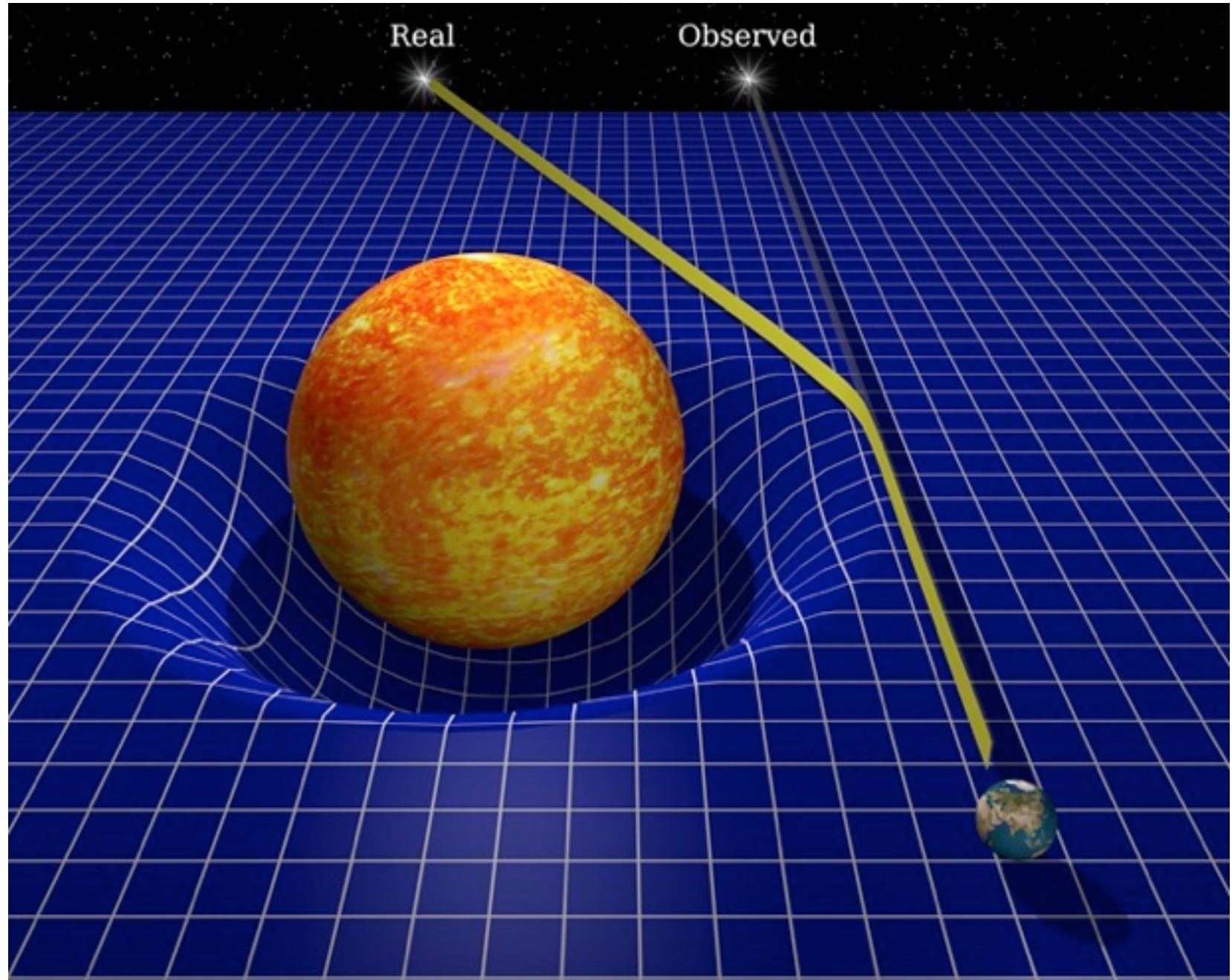
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however

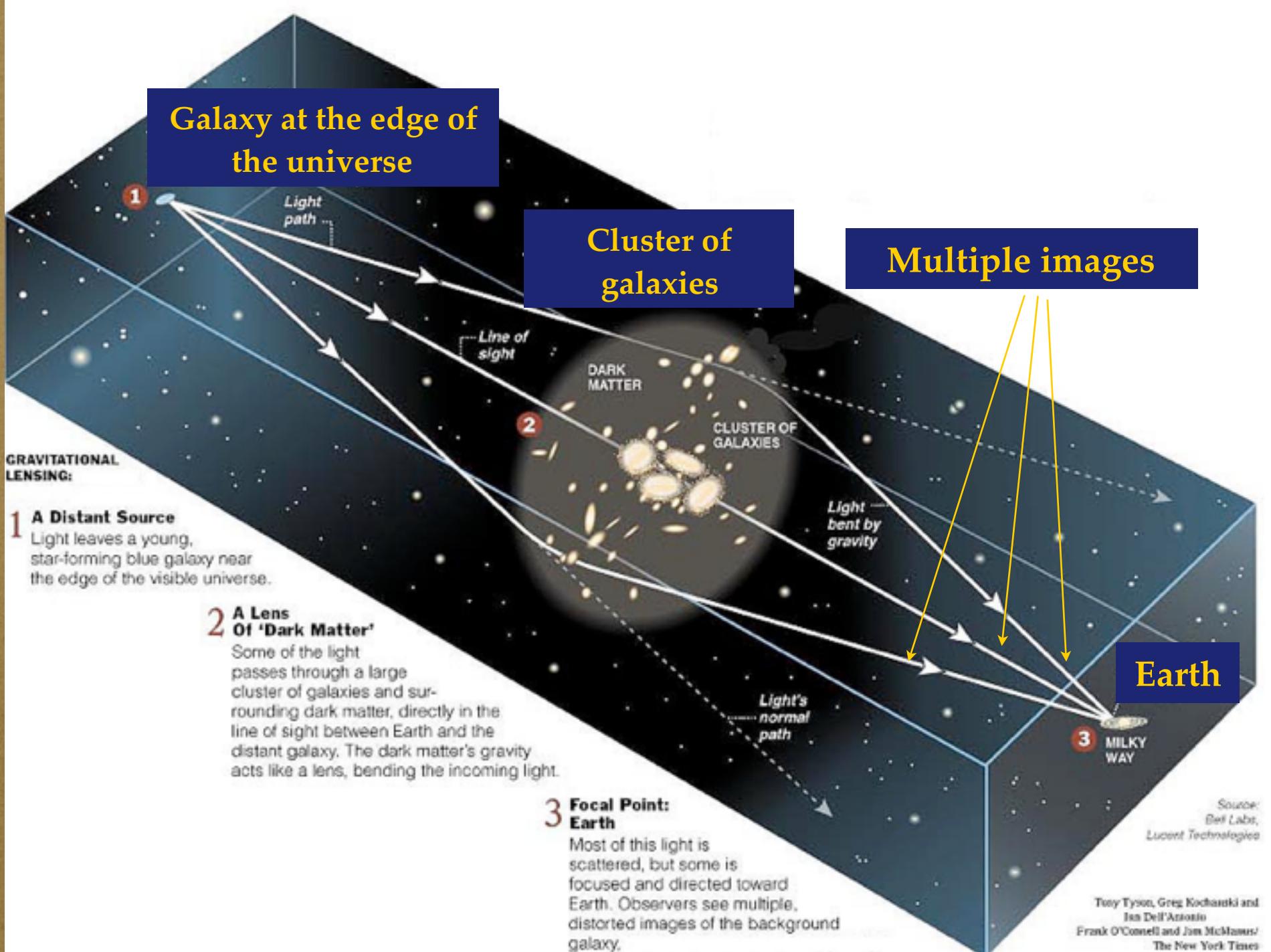
Galaxy cluster Abell 2218



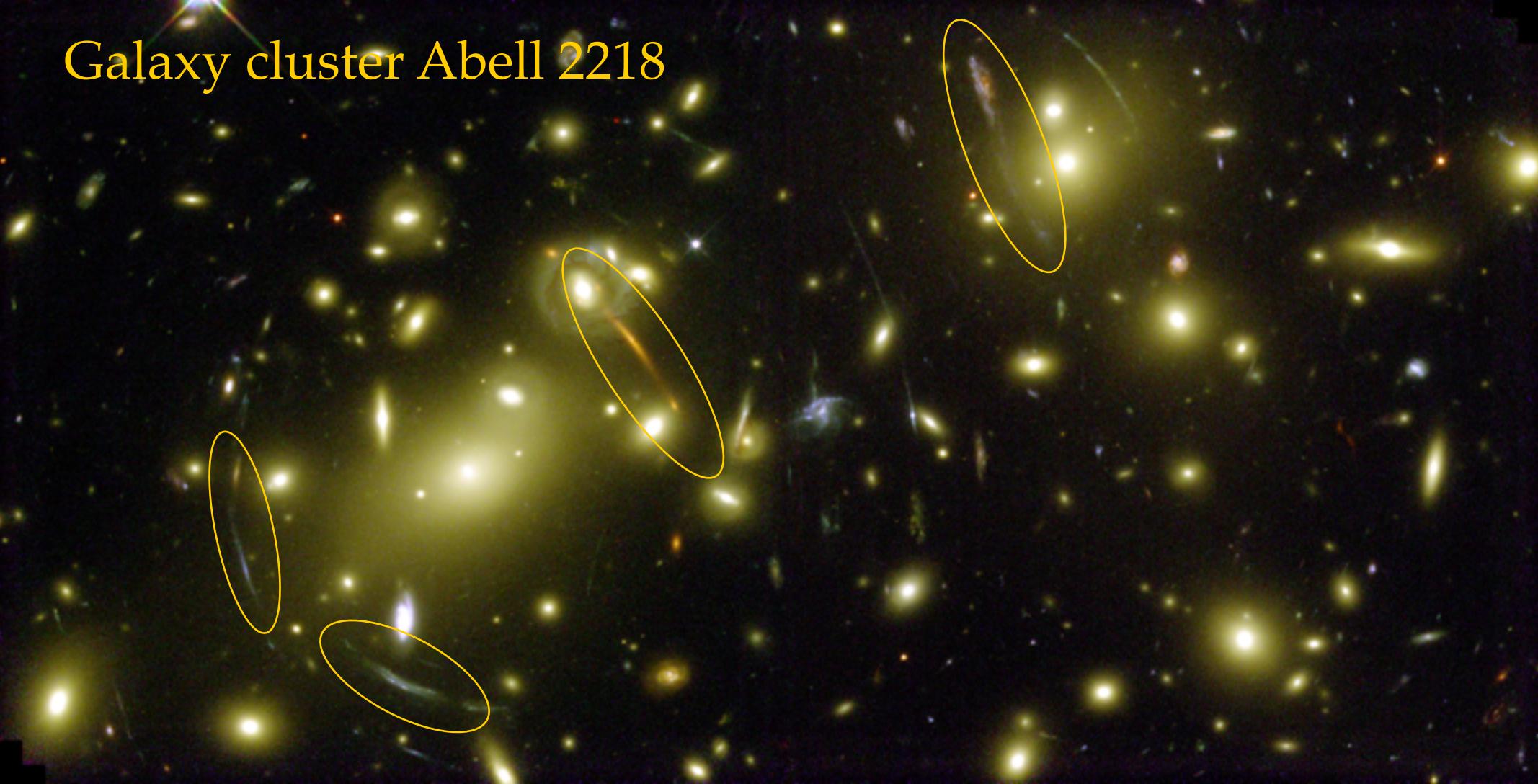
Credits: European Space Agency, NASA, J.-P. Kneib
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Gravitational lensing



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The shape and intensity of lensed images requires the presence of ~5 times more mass than is **visible** in those galaxies !



Invisible dark matter

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So, why is the existence of dark matter interesting? Is its origin known, or is it unknown and puzzling?

What do we reeeeally know about the matter around us and far away in the universe?

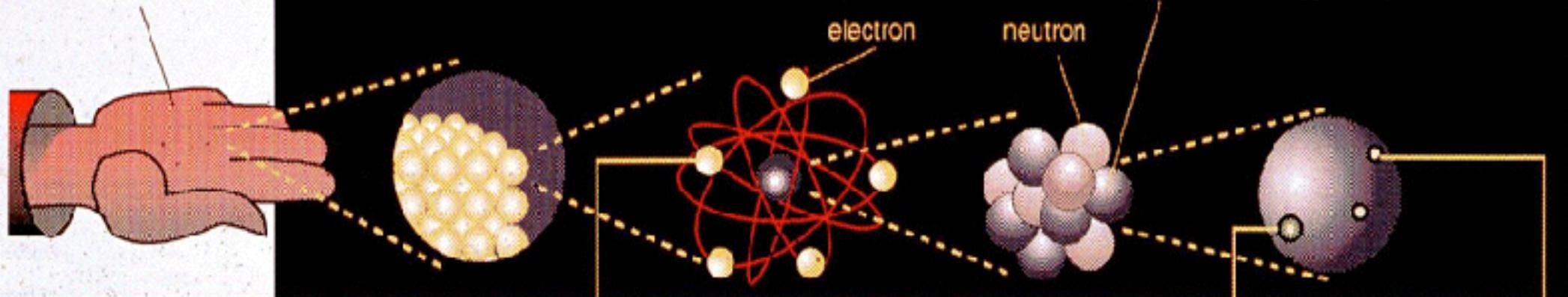


The Standard Model

complete formulation: ~1973

conclusive experimental confirmation: 2012

MATTER



LEPTONS

QUARKS

ALL
ORDINARY MATTER
BELONGS
TO THIS GROUP.



electron

Electric charge -1.

Responsible for electricity
and chemical reactions

electron neutrino

Electric charge 0.

Rarely interacts
with other matter.

up

Electric charge + 2/3.

Protons have 2 up quarks
Neutrons have 1 up quark

down

Electric charge -1/3.

... and one down quark.
... and two down quarks.

THESE PARTICLES
EXISTED JUST
AFTER THE
BIG BANG.



muon

A heavier
relative
of the electron.



muon neutrino

Created with
muons when some
particles decay.

charm

A heavier
relative
of the up.



strange

A heavier
relative
of the down.



tau

Heavier
still.

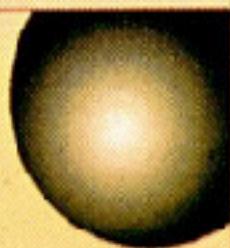


tau neutrino

Not yet observed
directly.

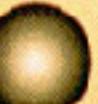
top

Heavier
still,
recently
observed.



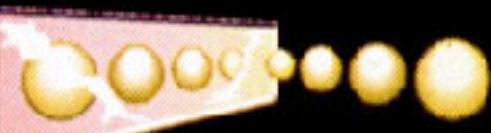
bottom

Heavier
still.



ANTIMATTER

Each particle also has an antimatter
counterpart ... sort of a mirror image.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W^-	80.39	-1
W^+	80.39	+1
W bosons		
Z^0 Z boson	91.188	0

Strong (color) spin = 1

Name	Mass GeV/c ²	Electric charge
g gluon	0	0

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at {	10^{-18} m 3×10^{-17} m	10^{-41} 10^{-41}	0.8 10^{-4}	1 1 25 60

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EW symmetry breaking

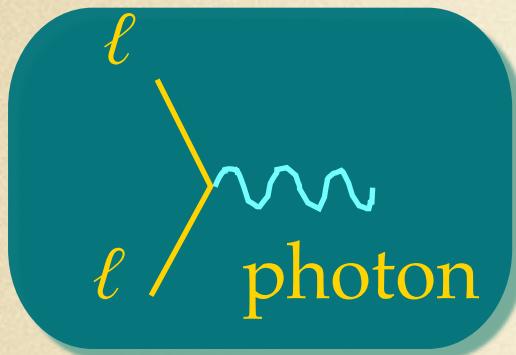
Name	Mass GeV/c ²	Electric charge
H	125	0

Properties of the Interactions

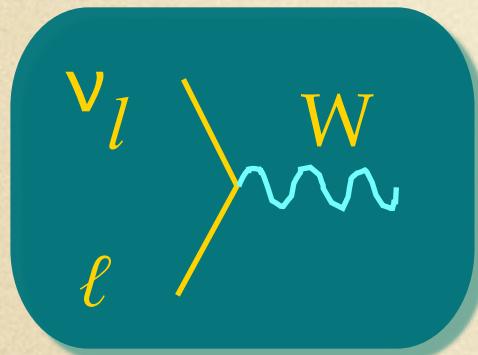
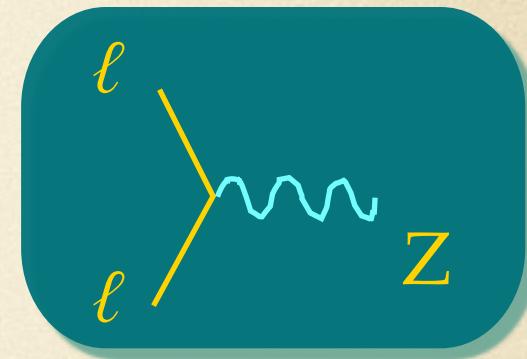
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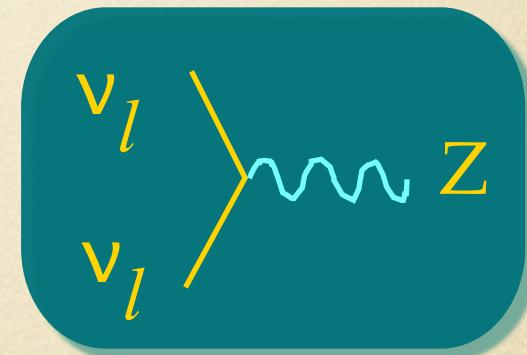
Lepton Interactions ($\ell=e,\mu,\tau$)



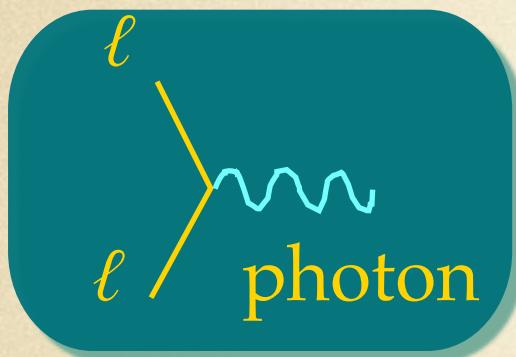
$\propto -e =$ electric charge



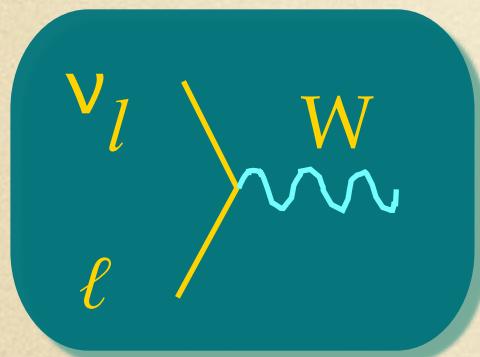
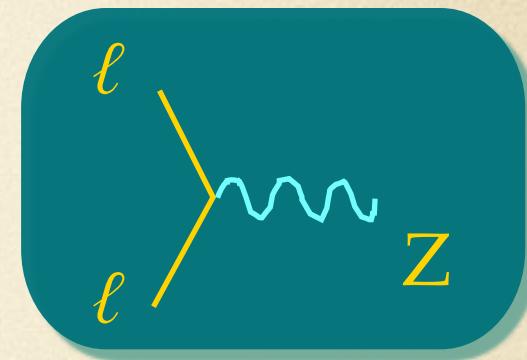
$\propto g_W =$ weak charge



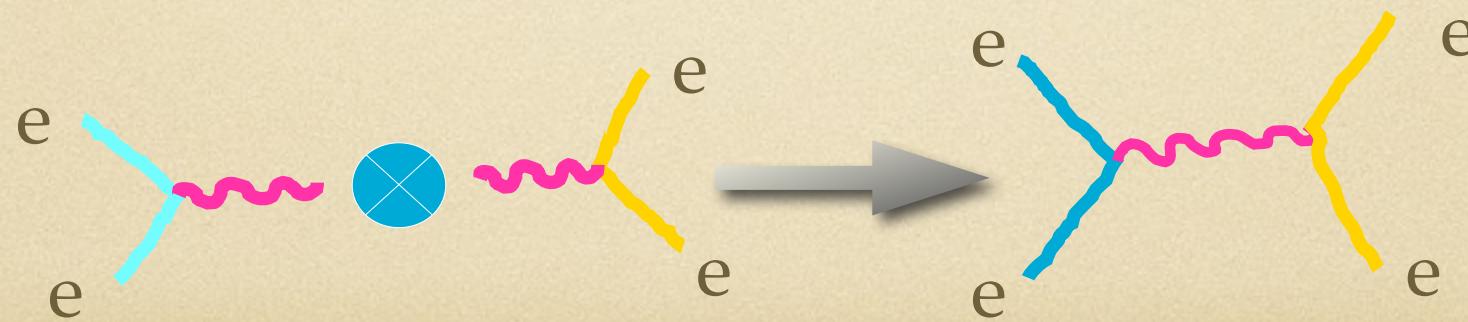
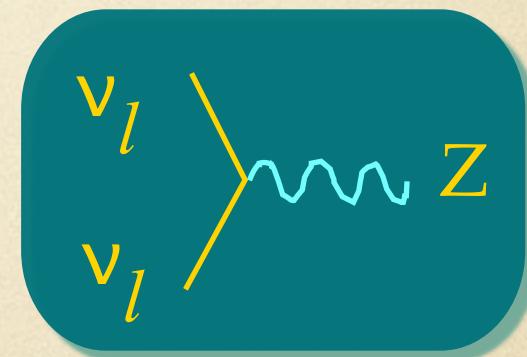
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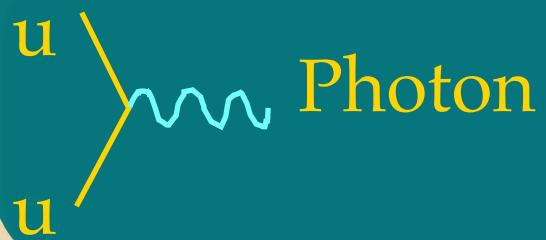
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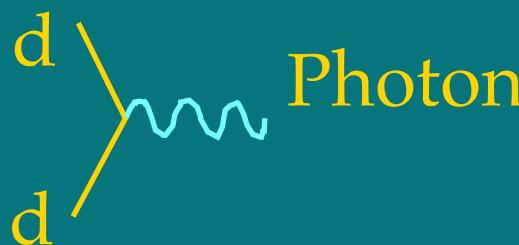
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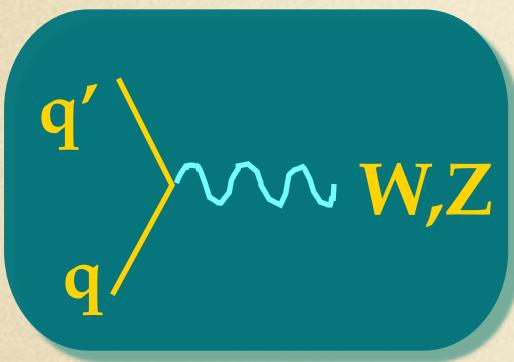
Quark Interactions



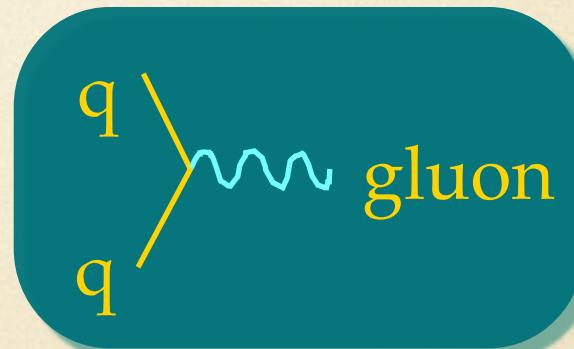
$$\propto 2/3 e$$



$$\propto -1/3 e$$

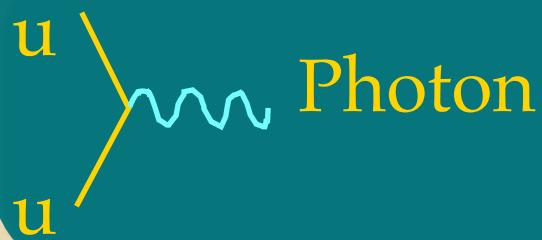


$$\propto g_W$$



$$\propto g_S$$

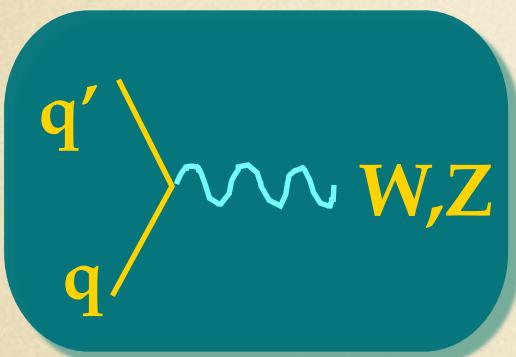
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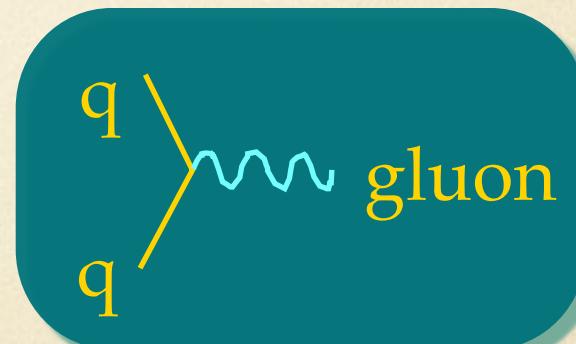
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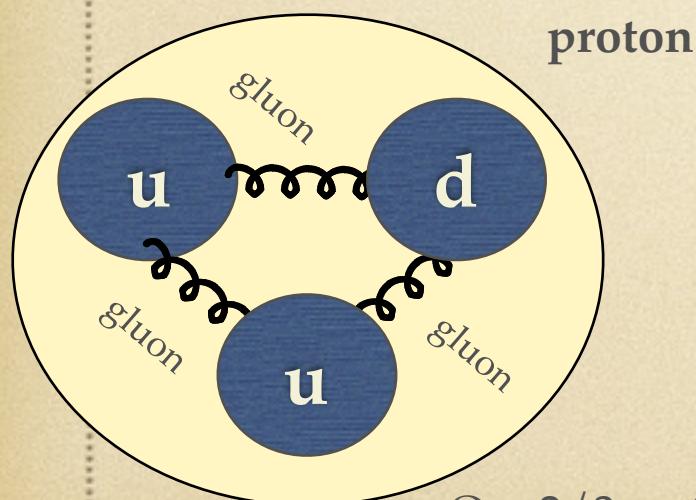
$$\propto -1/3 e$$



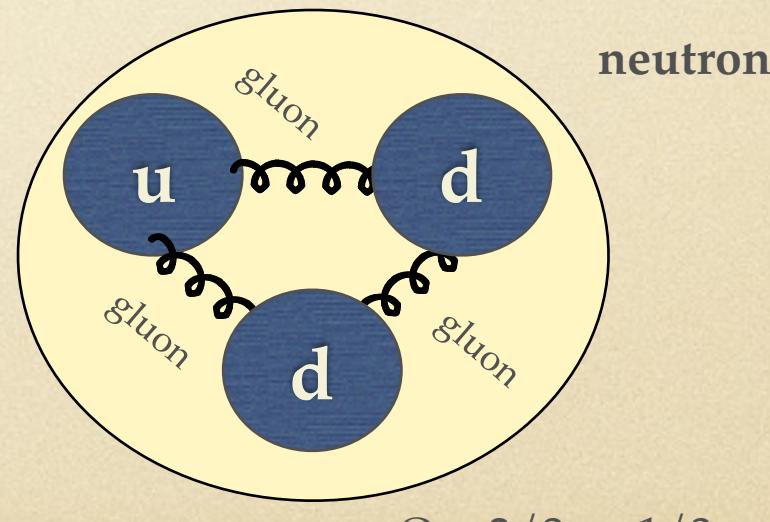
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$$Q = 2/3 e + 2/3 e - 1/3 e = e$$



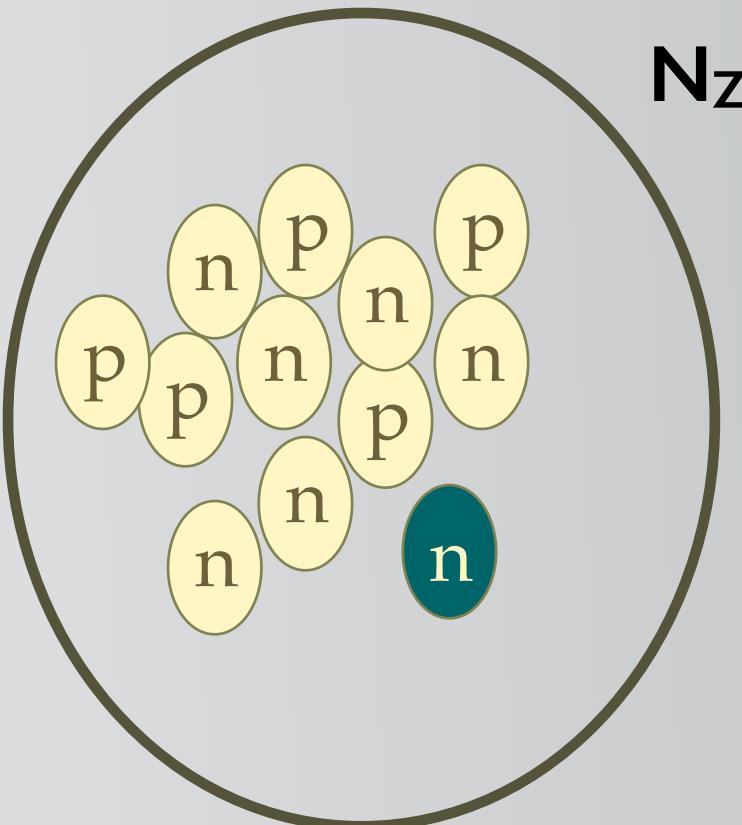
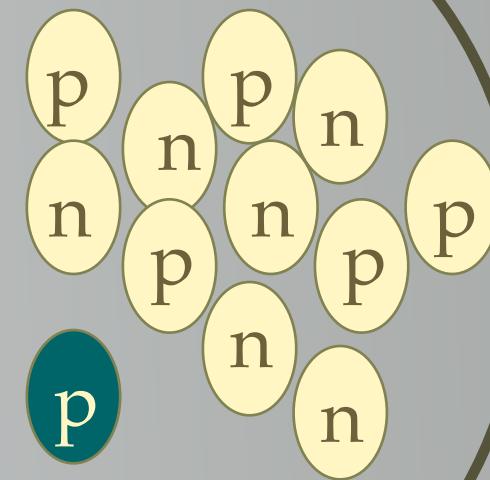
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Example: radioactivity

$N_z \rightarrow N_{z+1} e\nu$

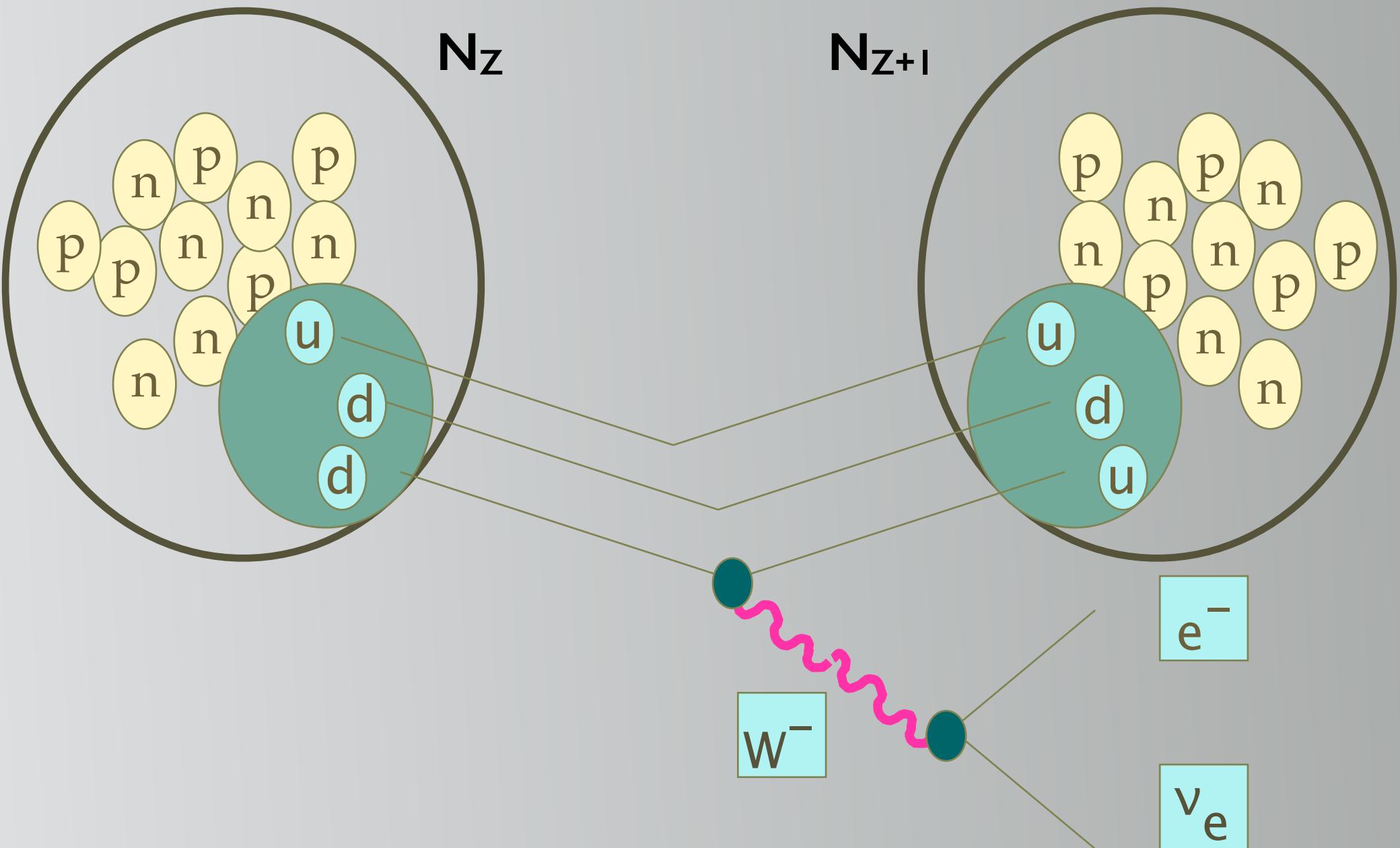
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- **Uniqueness** (of the fundamental laws): independence from place, time and external conditions

How empty is the vacuum?

.... introducing the Higgs boson

The Higgs field and particles' masses

Light propagating in a medium is slowed down by its continuous interaction with the medium itself



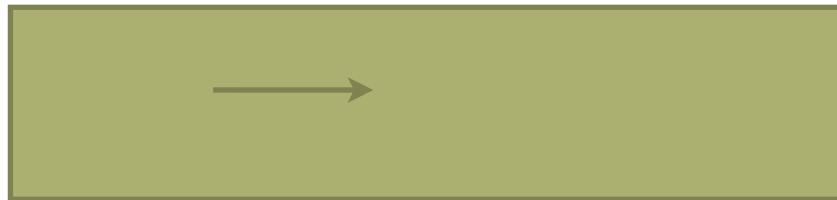
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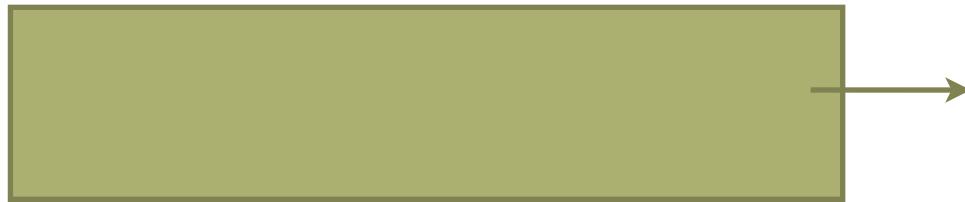
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Think of the Higgs field as being a continuum medium embedding the whole Universe. Particles interacting with it will undergo a similar “slow-down” phenomenon. Rather than “slowing down”, however, the interaction with the Higgs medium gives them “inertia” => mass

Detecting the Higgs boson

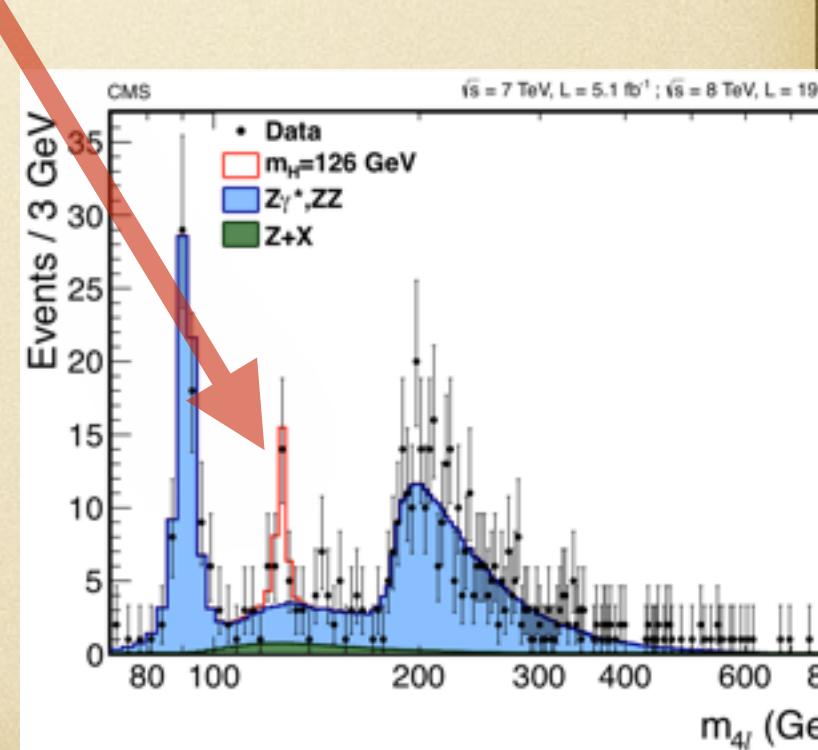
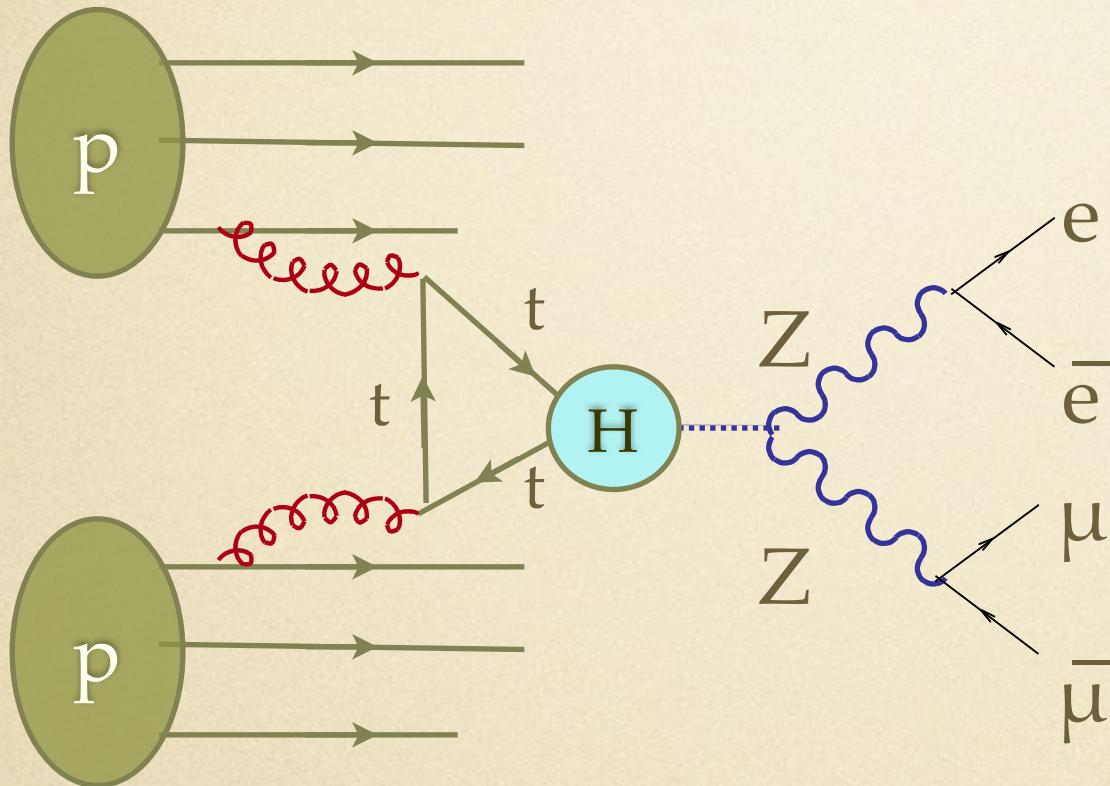
Like any other medium, the Higgs continuum background can be perturbed. Similarly to what happens if we bang on a table, creating sound waves, if we “bang” on the Higgs background (something achieved by concentrating a lot of energy in a small volume) we can stimulate “Higgs waves”. These waves manifest themselves as particles, the **so-called Higgs bosons**

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What is required is that the energy available be larger than the Higgs mass \Rightarrow LHC !!!

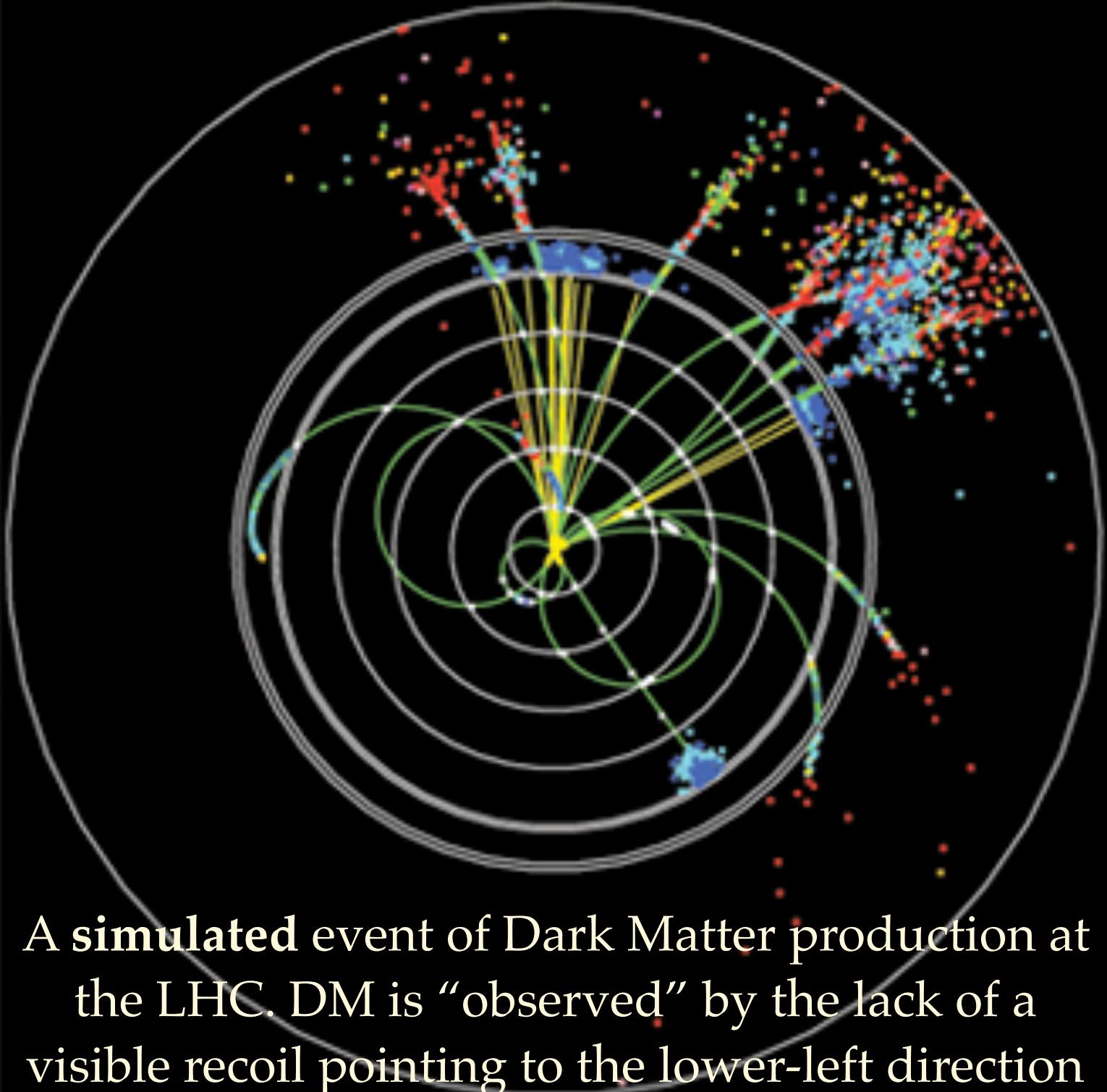
Example of Higgs production process at the LHC



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