

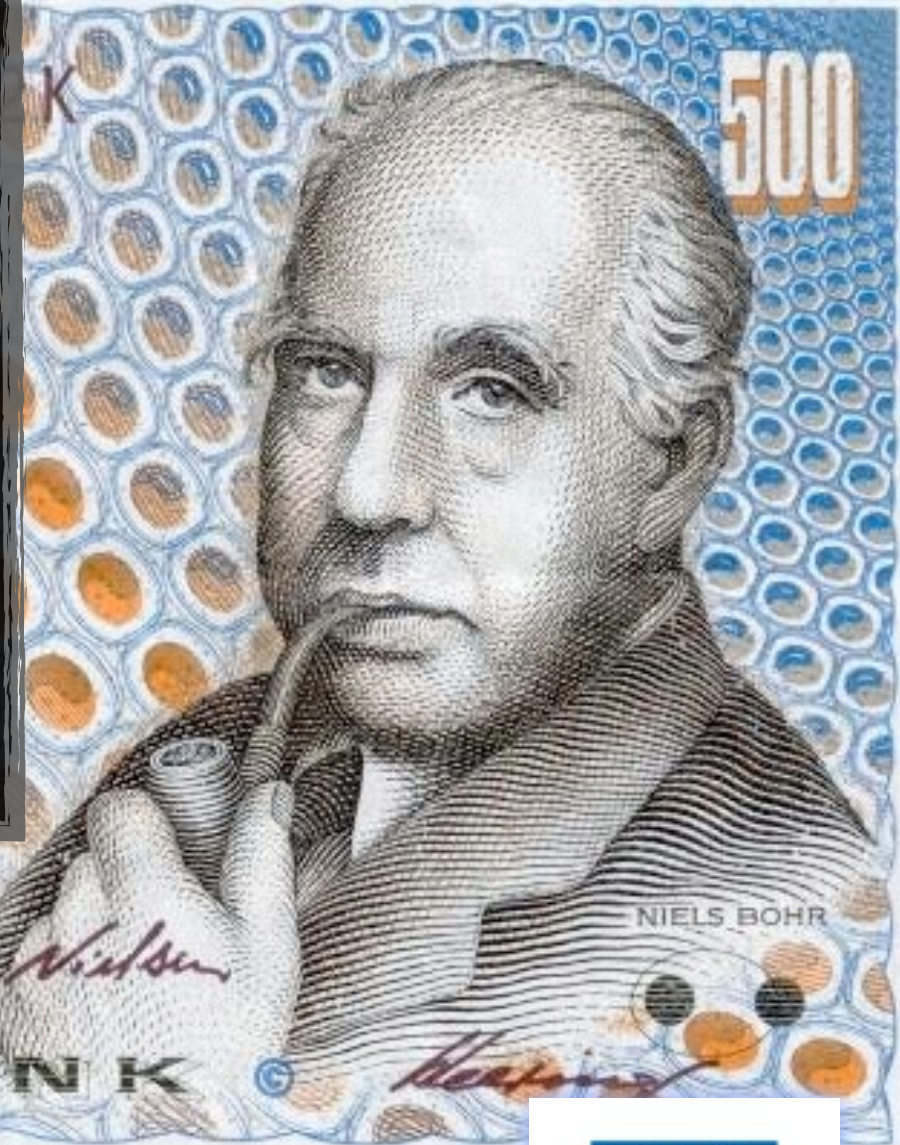
# The Meaning of Fundamental

Dr. Peter Skands, Monash U & ARC Centre of Excellence for Physics at the Terascale

Stockholm, 1922

“The present state of atomic theory is characterised by the fact that we not only believe the existence of atoms to be proved beyond a doubt, but also we even believe that we have an intimate knowledge of the constituents of the individual atoms ...”

*Niels Bohr (1885-1962)*



September 16, 2015  
Monash University





# Voyage to the Heart of Matter

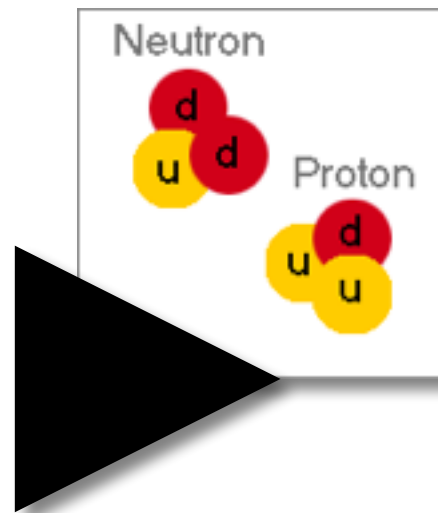
In the ~ 100 years since, all of Mendeleev's periodic table was reduced to just a few ultra-fundamental constituents and the forces that act between them

Periodic Table of the Elements

Legend:

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Semimetal
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

**CHEMISTRY**



	I	II	III	
Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$	Z
	e	$\mu$	$\tau$	W
Quarks	u	c	t	$\gamma$
	d	s	b	g

Force Carriers

**Three Generations of Matter**  
**PHYSICS**

Called the most precisely tested theory in the history of science

**With great imagination dubbed the “Standard Model” of Particle Physics**

# What *is* a Fundamental Particle?

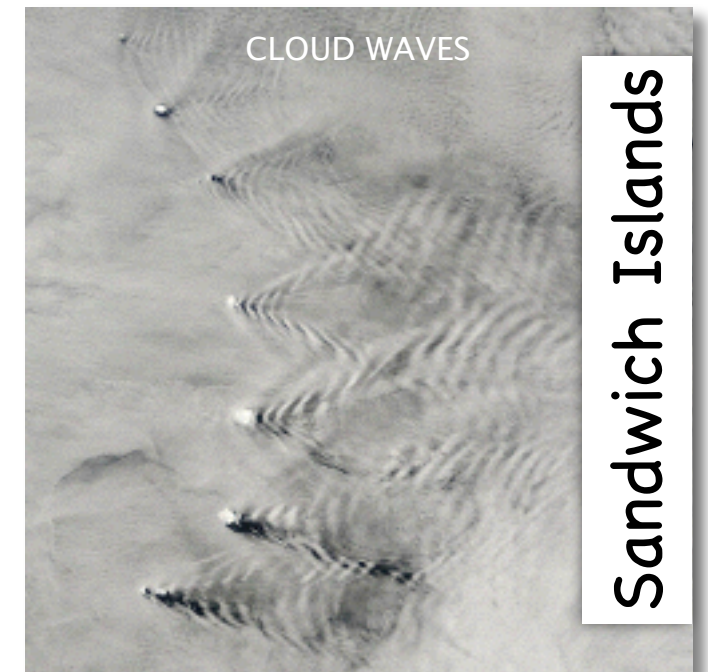
Abstractly, we think of an idealised “pointlike” particle

But could we ever really see “a point”?

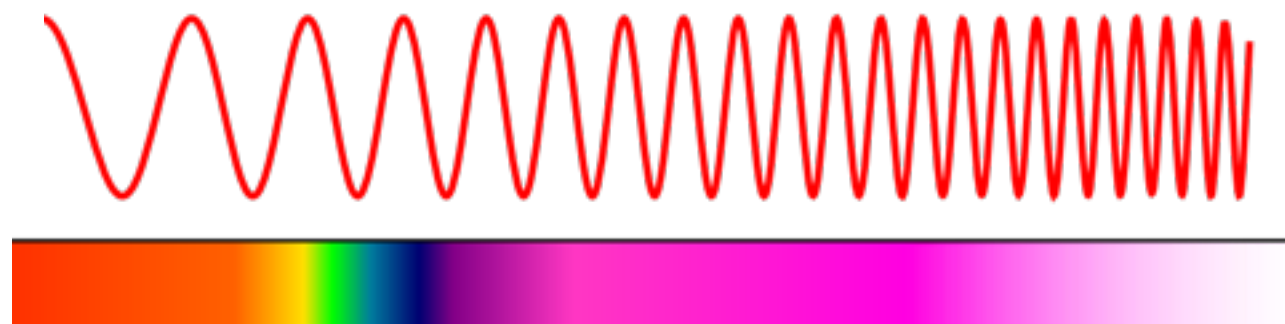
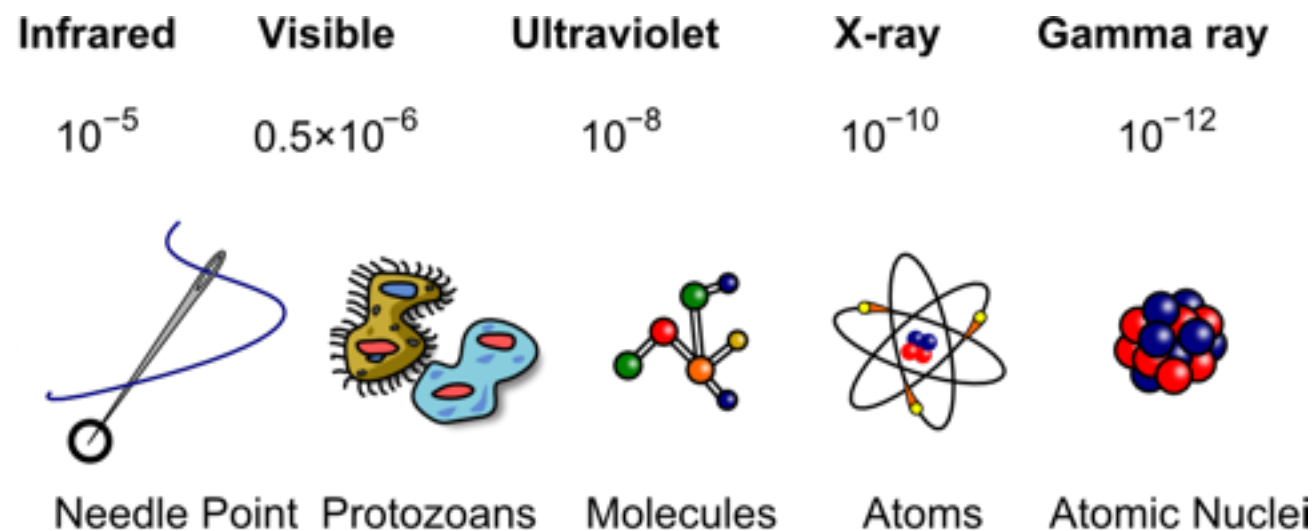
How do we see, in the quantum world?

To see something small, we scatter waves off it

→ Heisenberg’s uncertainty principle.



NASA - MODIS

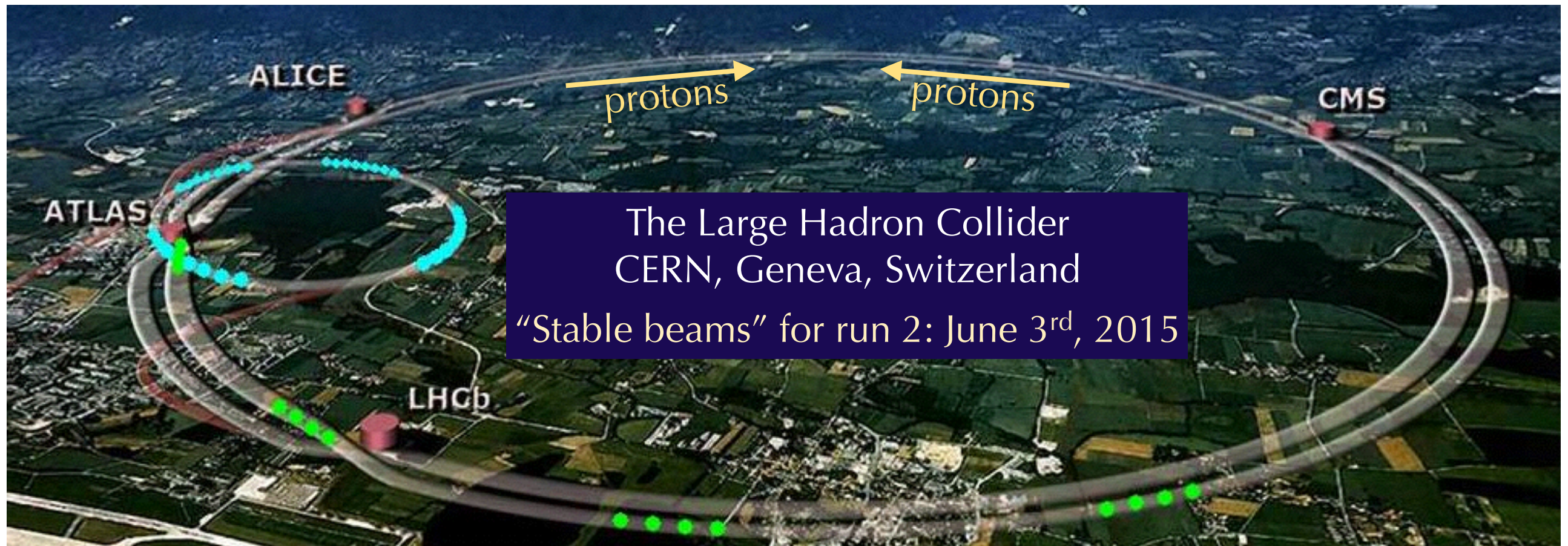


To resolve “a point”, we would need infinitely short wavelengths

Heisenberg would then give it an infinitely hard kick

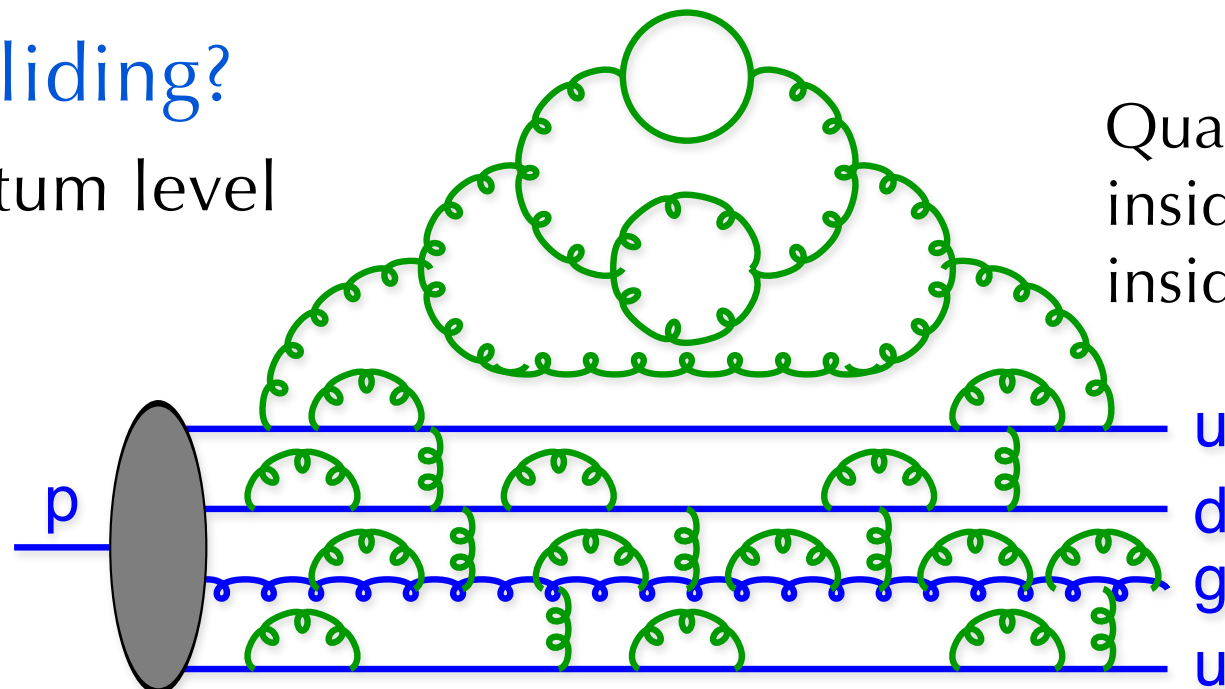
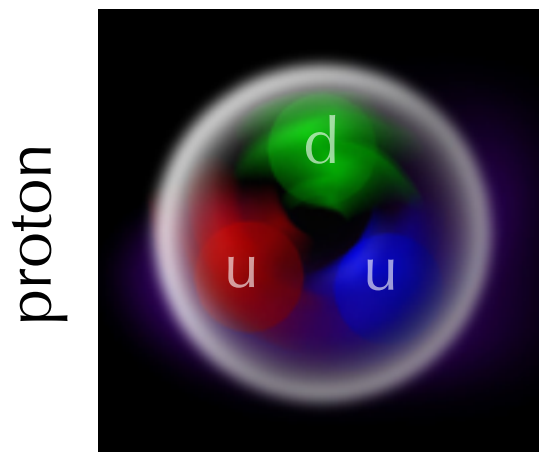


# Kick it as hard as we can



## What are we really colliding?

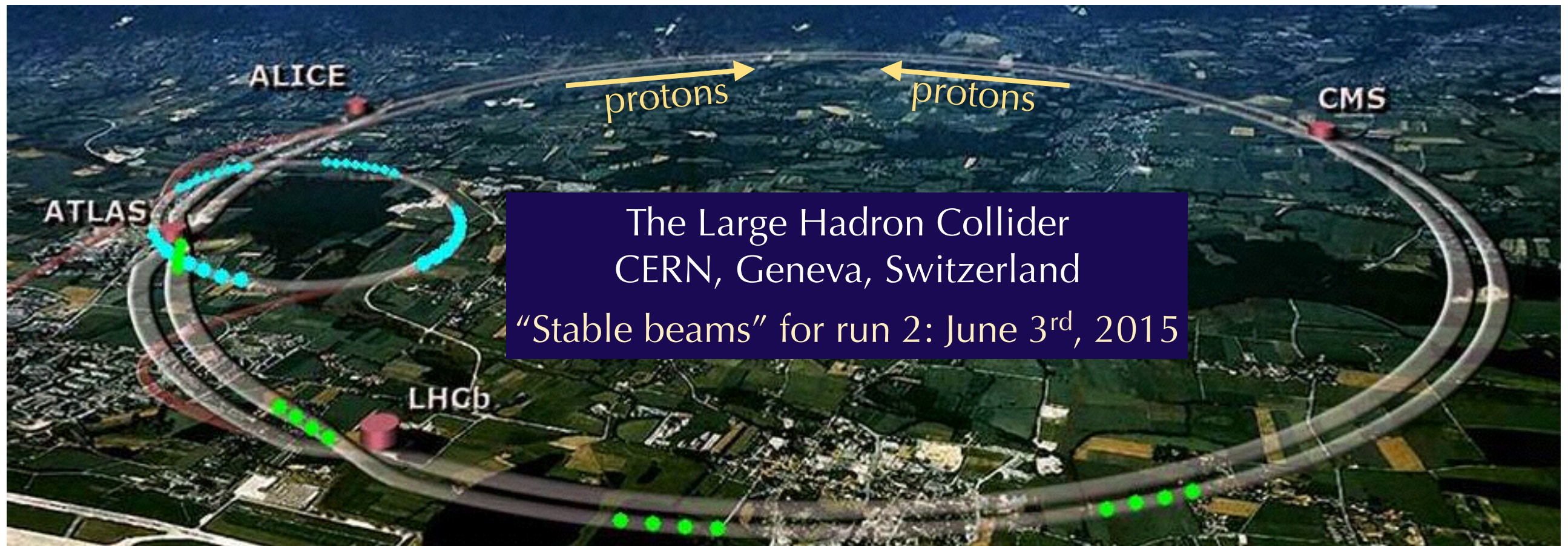
Take a look at the quantum level



Quantum fluctuations  
inside fluctuations  
inside fluctuations ...

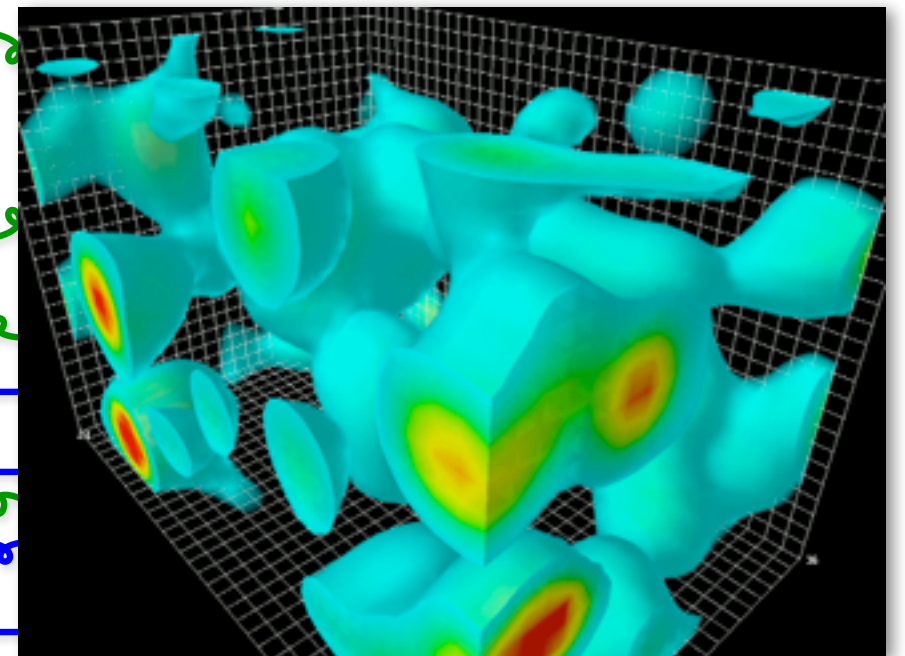
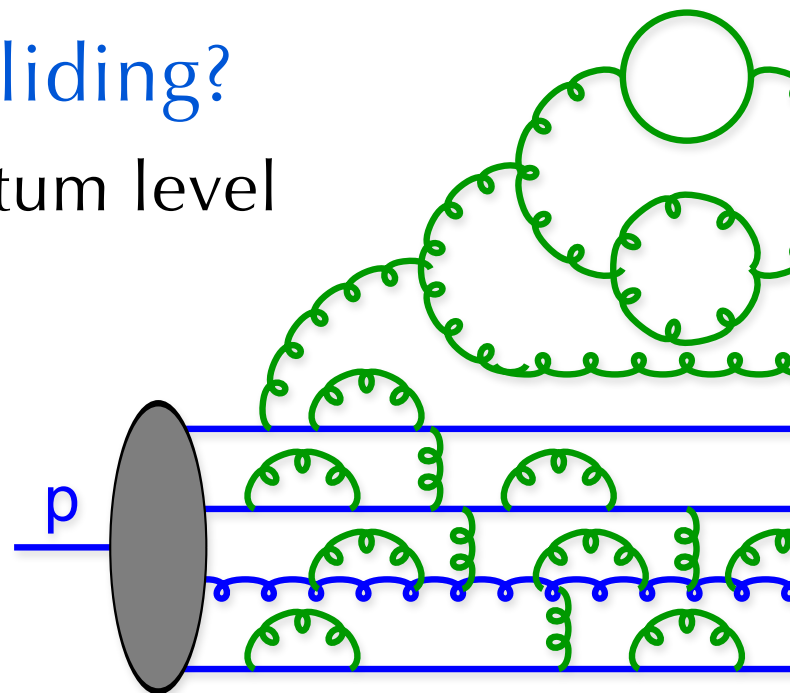
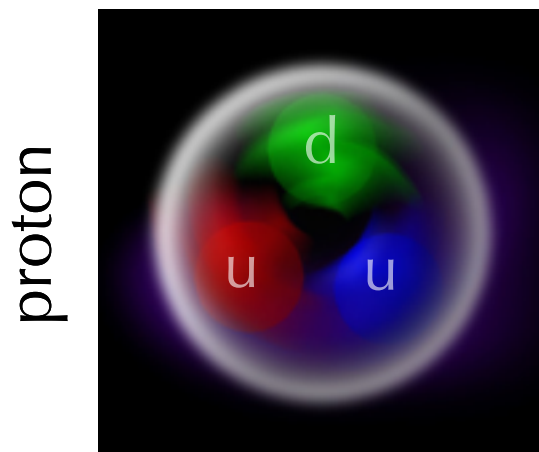


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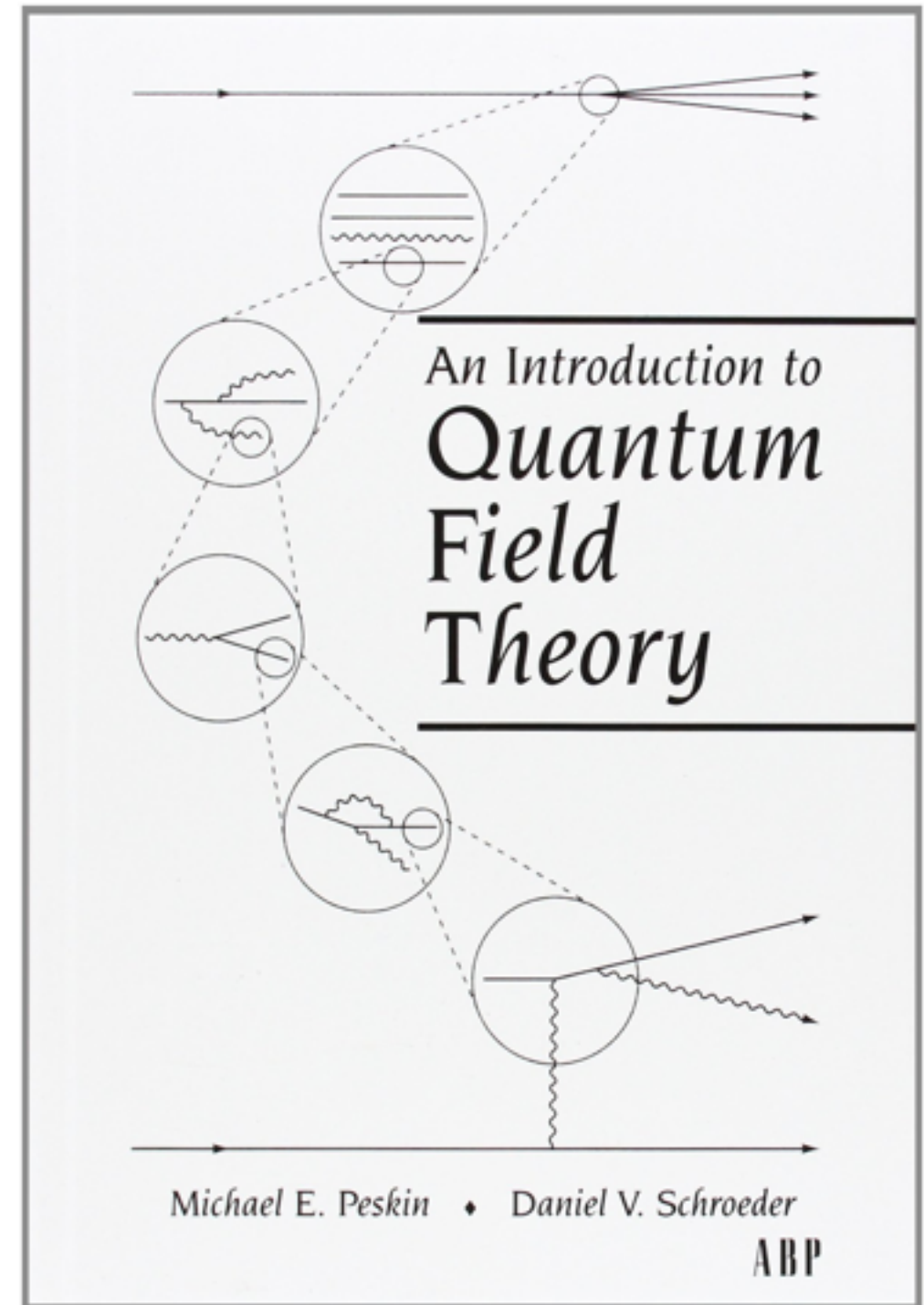
# The Structure of Quantum Fields

What we see when we look at the quarks inside the proton

An ever-repeating self-similar pattern of quantum fluctuations

At increasingly smaller distance scales: *scaling*

To our best knowledge, this is what a fundamental ('elementary') particle really looks like



# The Structure of Quantum Fields

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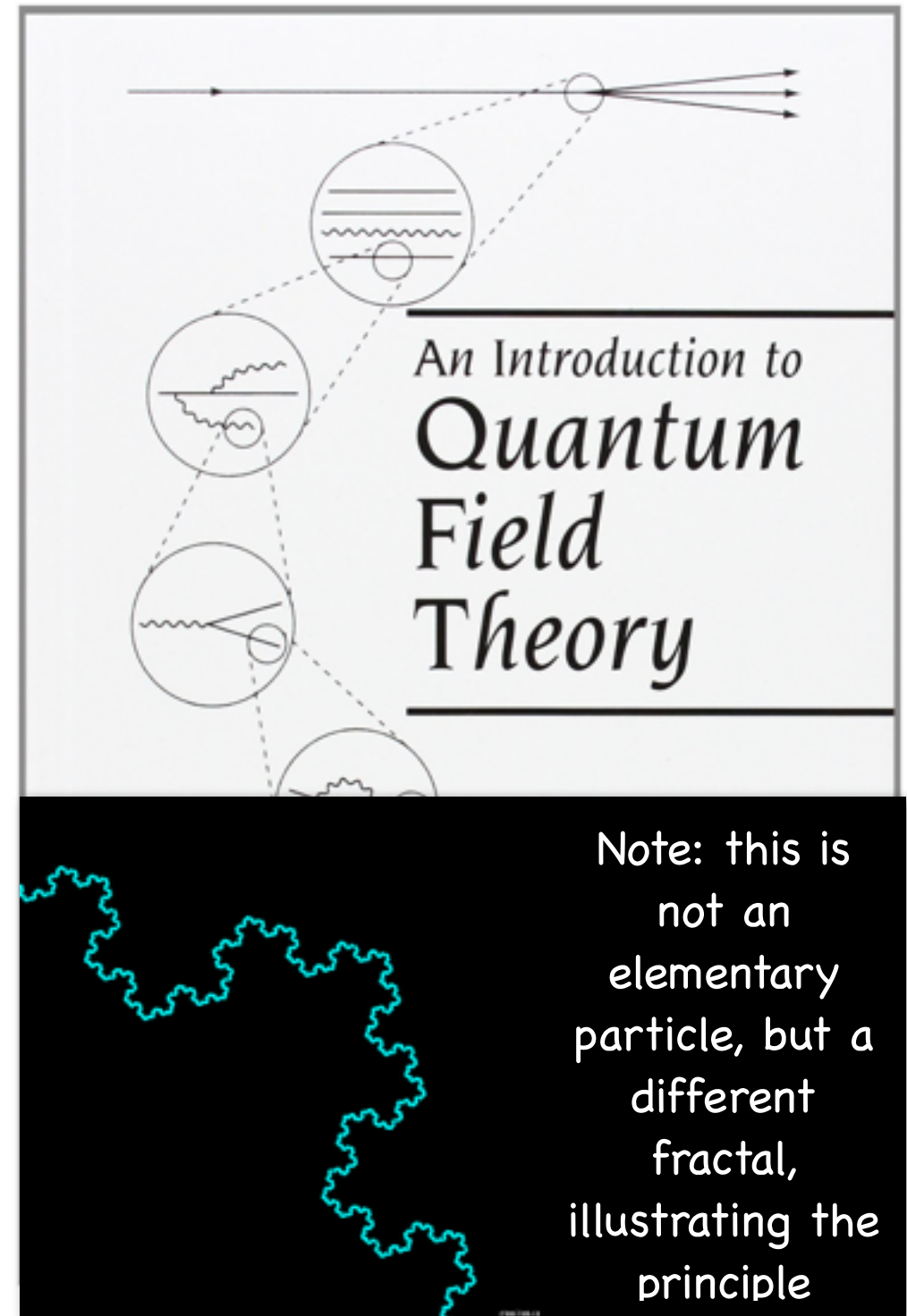
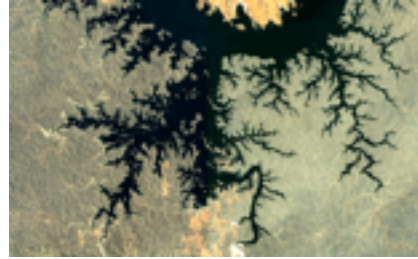
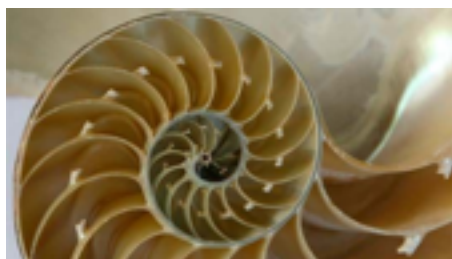
An ever-repeating self-similar pattern of quantum fluctuations

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Nature makes copious use of such structures

Called **Fractals**



# The Meaning of Fundamental

Similar phenomenon when you kick/hit particles:

Accelerated charges radiate  
→ Self-similar pattern of bremsstrahlung; “jets”

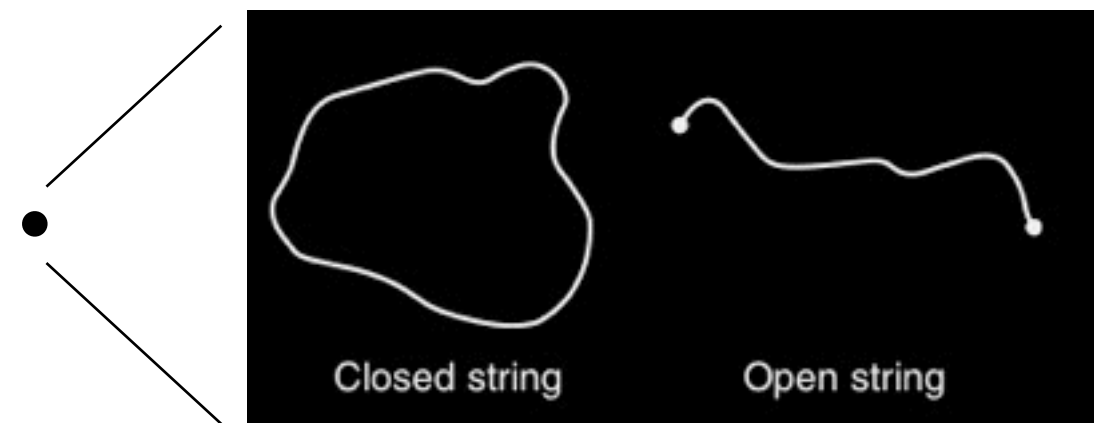
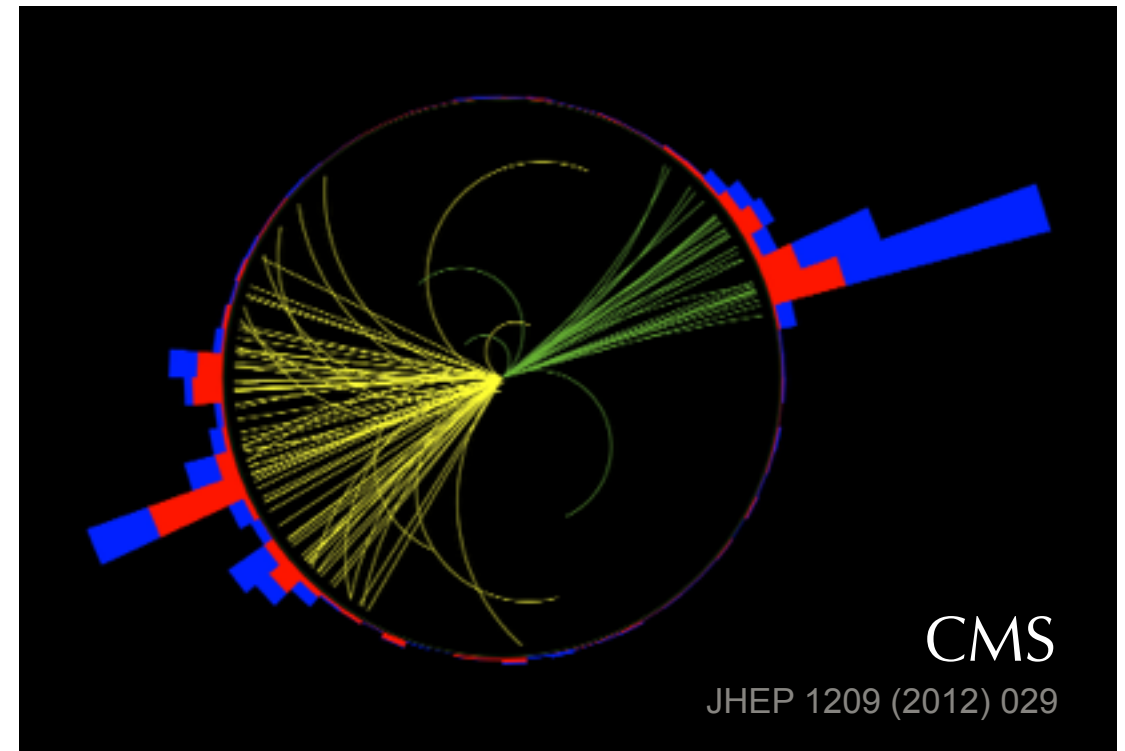
Any deviation from this ever-repeating scaling behaviour

Would indicate “substructure”  
*A new level of fundamental*

Superstring theory?

Probably beyond our reach

Still, the fundamental content of the universe is ...



Expect we could resolve something like this at the “Planck Scale” > billion times LHC energies ...



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