Beyond the Standard Model

G.F. Giudice

Lecture 2

CERN Summer Student
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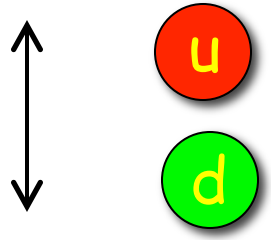
With spontaneously broken symmetry, mass relations implied by exact symmetry can be modified

Equations invariant under exchange



⇒ solutions with $M_u = M_d$

or solutions with $M_u > M_d$ possible,

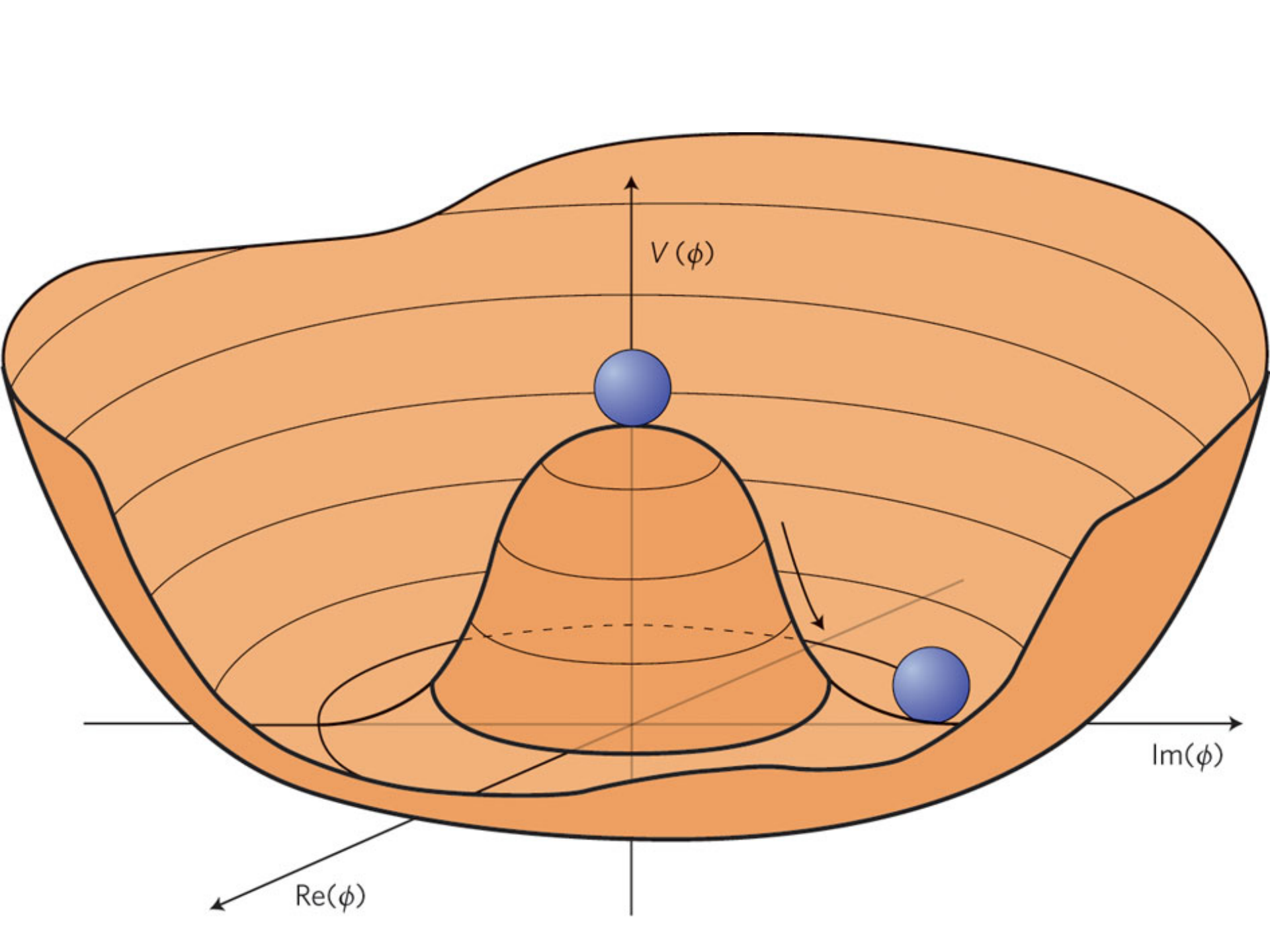
as long as $M_d > M_u$ also exists

Characteristic of SBS ⇒ degeneracy of solutions

Quantum interpretation ⇒ zero-energy excitation ⇒ massless particle

Goldstone 1961

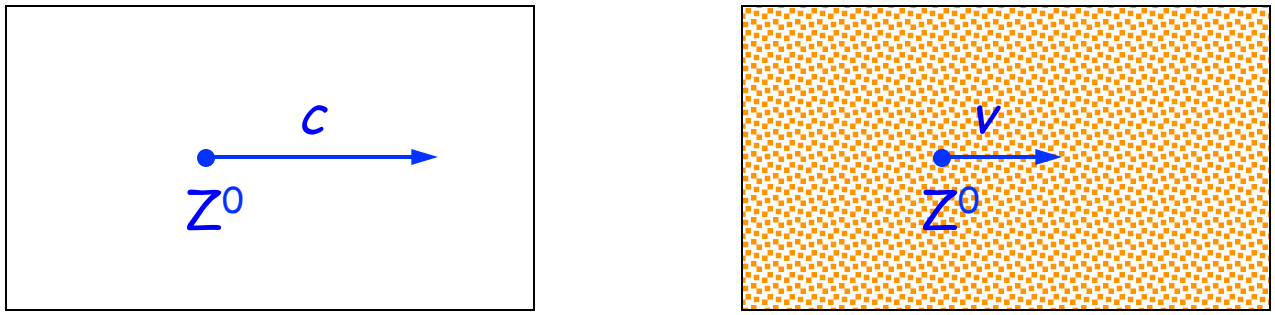
Goldstone boson main obstacle to apply SBS to EW


V (ϕ)
Im(ϕ)
Re(ϕ)

The Higgs mechanism is the solution!!!

Higgs field fills space with uniform distribution of EW charge

This distribution affects particle propagation



empty space

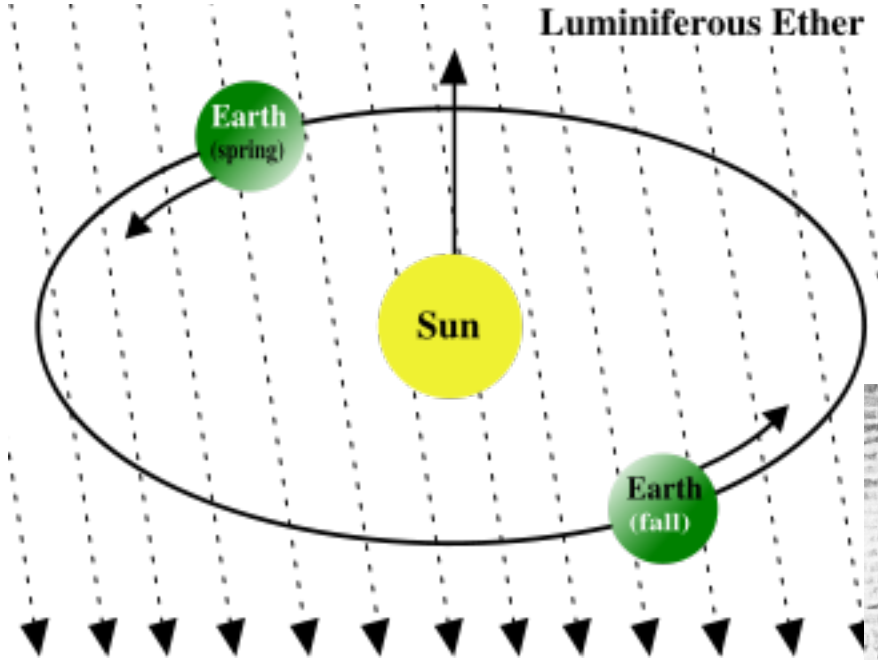
Higgs-filled space

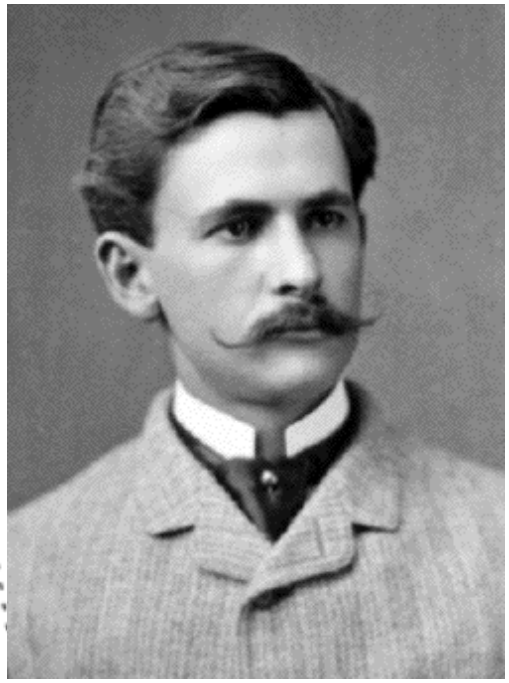
- large distances → mass
- small distances → longitudinal waves are part of the harmless Higgs field → no nonsense

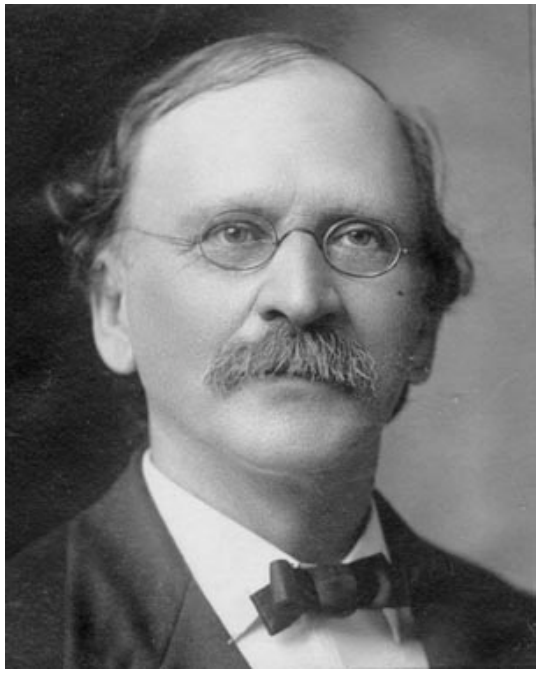
Spontaneous symmetry breaking:
configuration lacks the symmetry of the physical laws

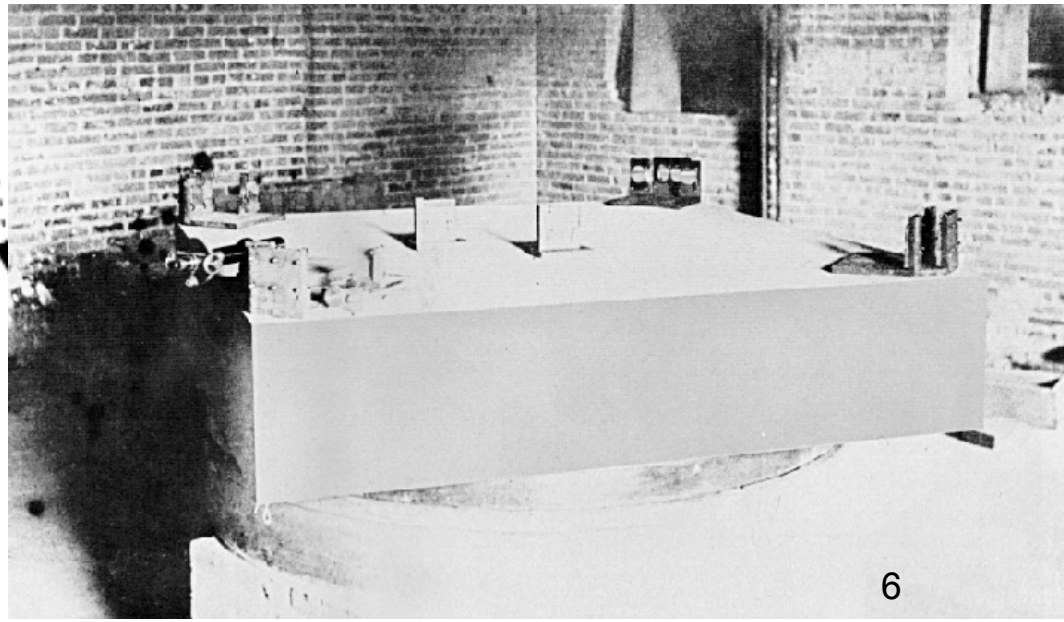
The Higgs mechanism gives a new understanding of the nature of space-time

A new form of aether?



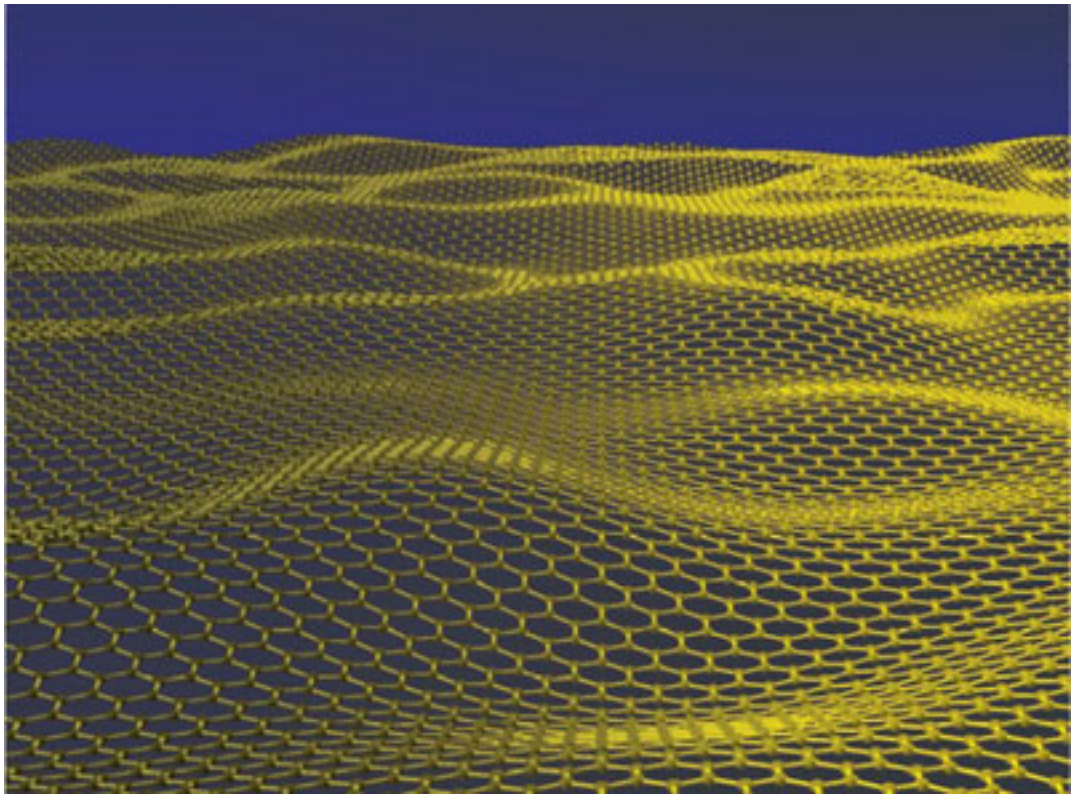






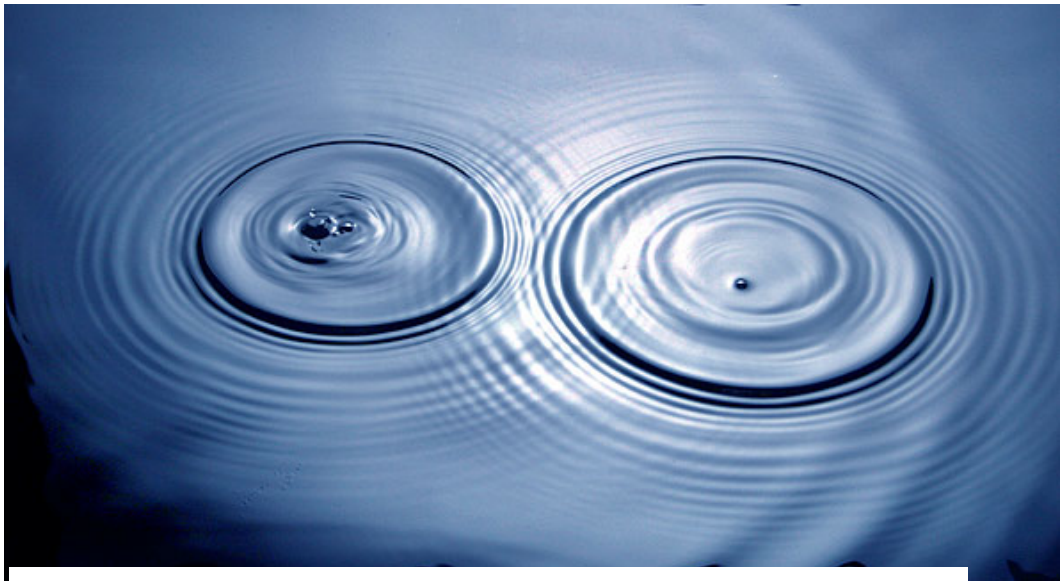
At 10^{-10} seconds after the Big Bang:
Space crystallized into a new form

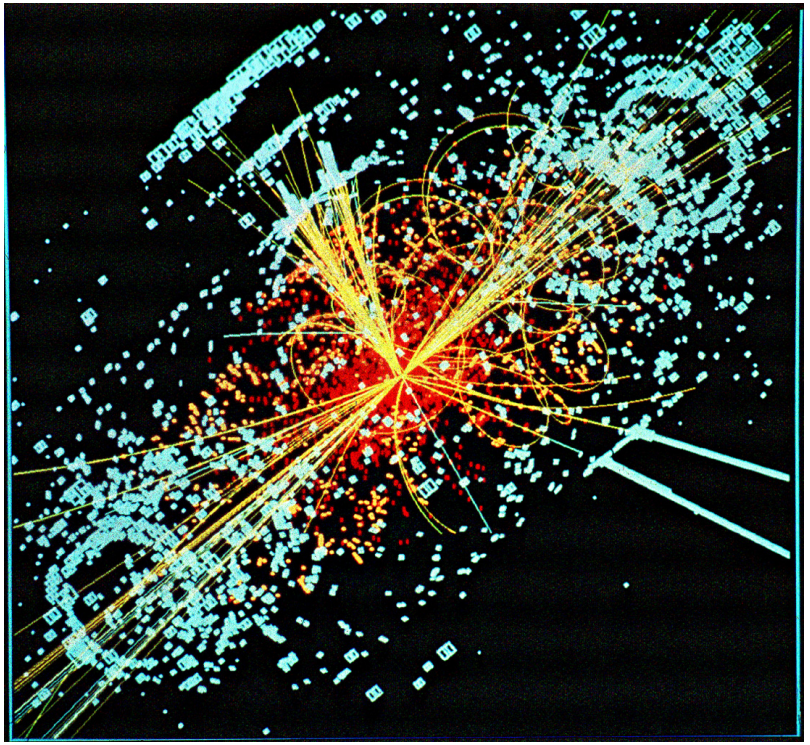
Nature filled space because she saved energy

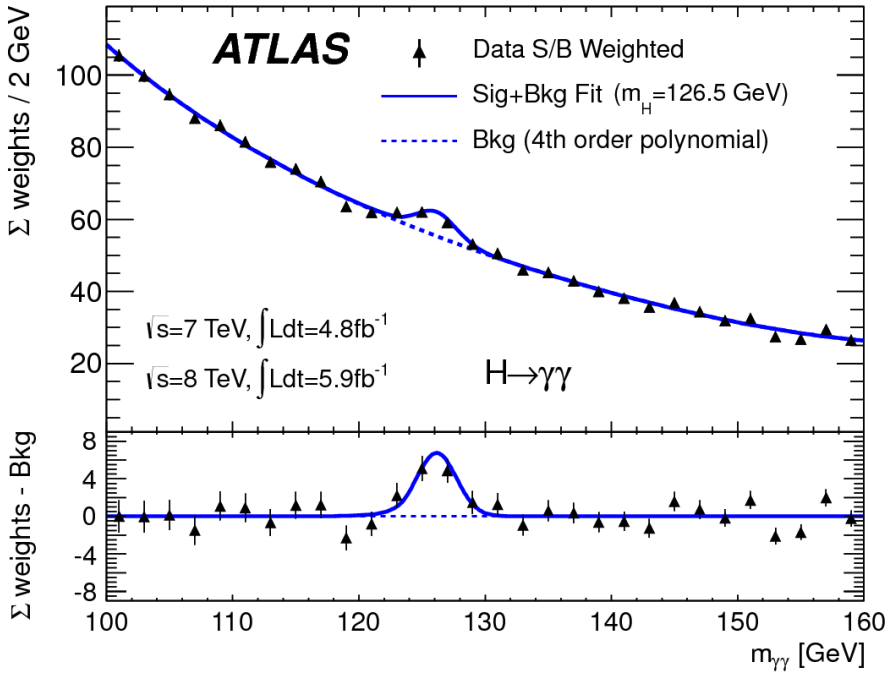


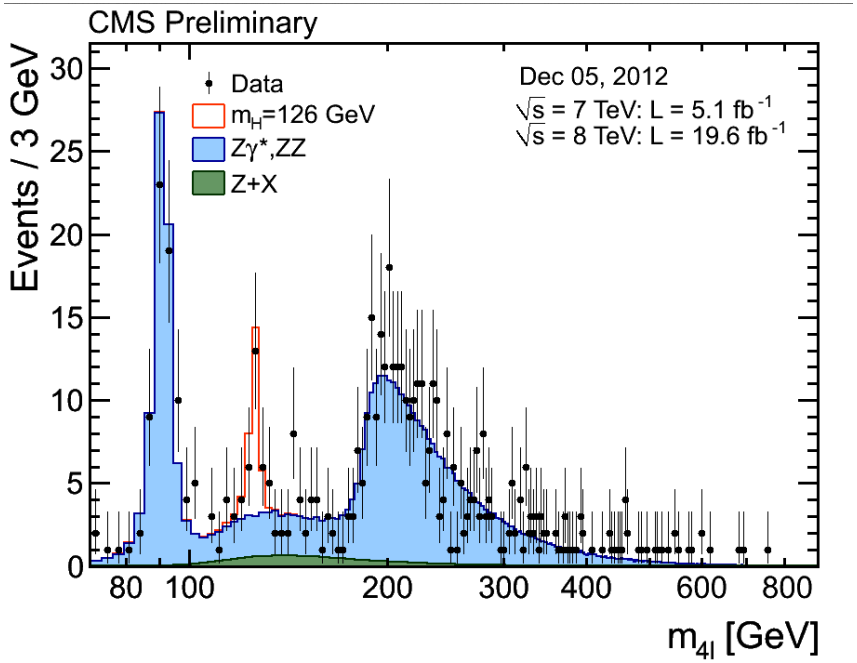
No difference, no matter how you move with respect to this substance

Producing the Higgs boson at the LHC









In relativistic quantum theories field $\Leftrightarrow$ particle $\Rightarrow$ Higgs boson

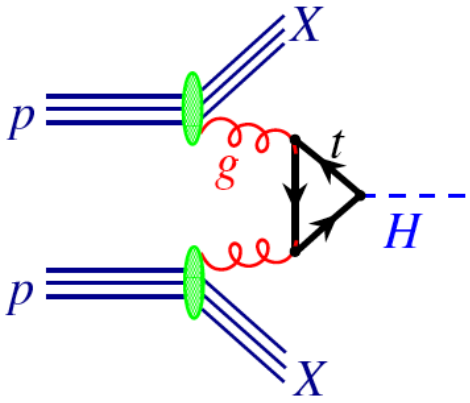
Particle mass $\Rightarrow$ how much it is dragged by Higgs field

Coupling of Higgs to 

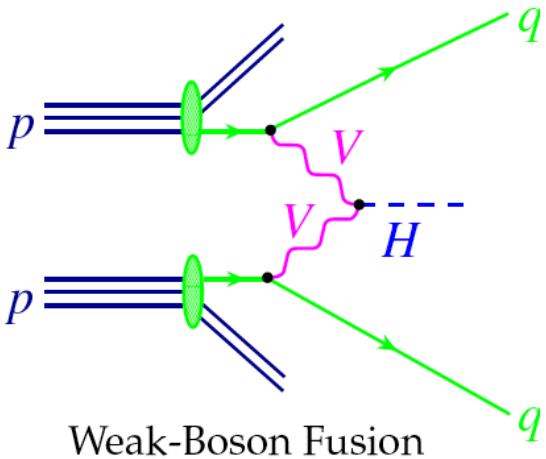
are proportional to M_p

M_H only free parameter: it measures Higgs self-coupling

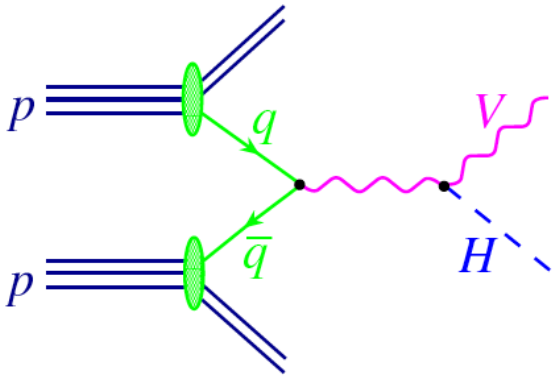
(but Higgs contributes to only 1% of my weight)



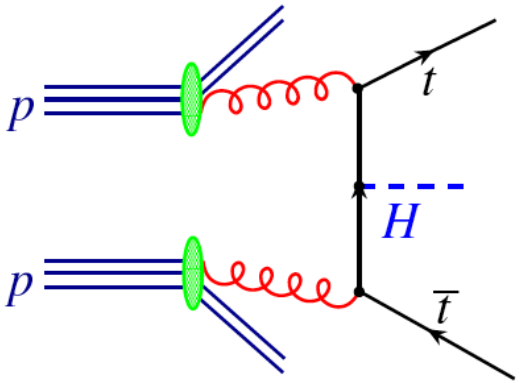
Gluon fusion



Weak-Boson Fusion



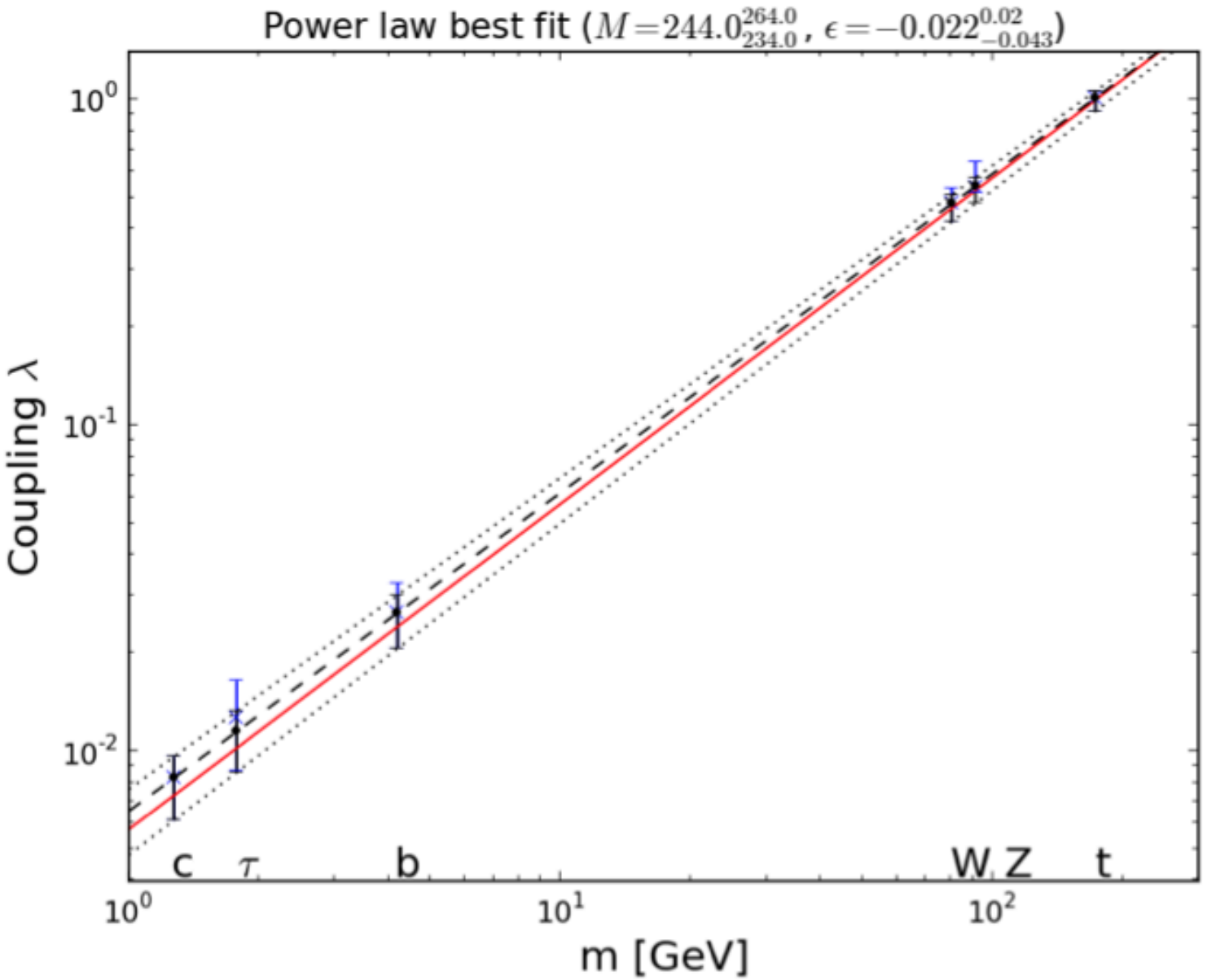
Higgs Strahlung



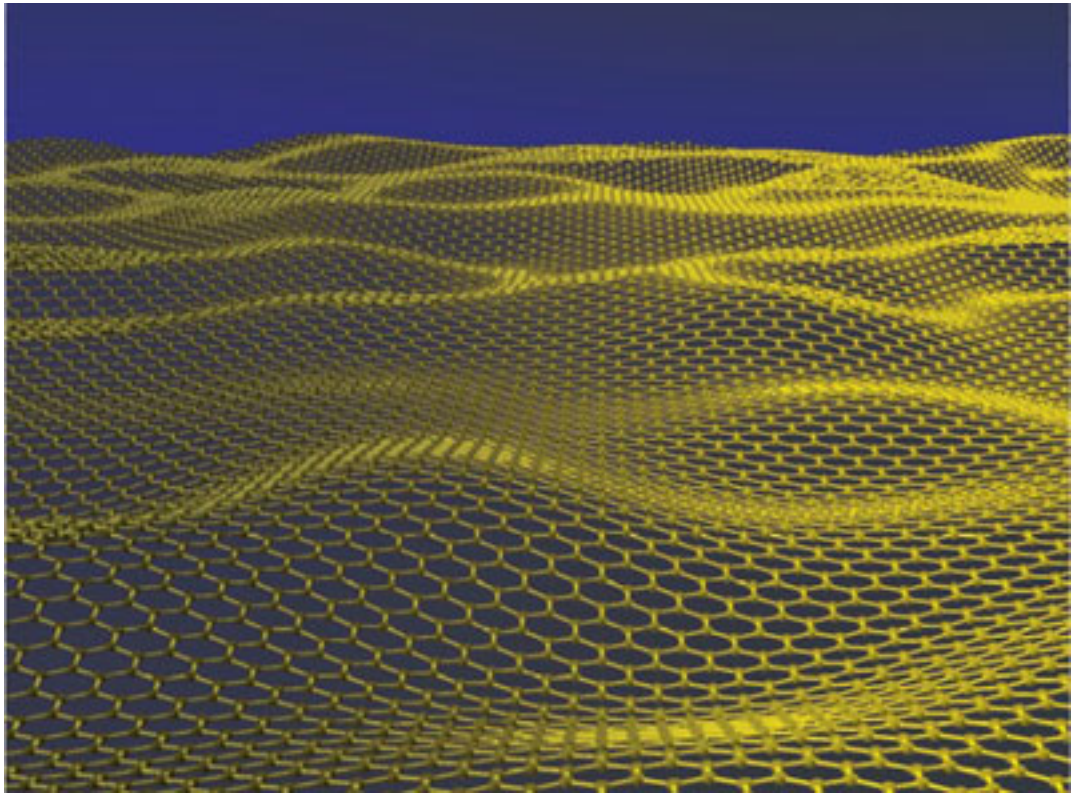
$t\bar{t}H$

Higgs decays in 10^{-22} seconds

Decay	Probability
H ➔ bb	58 %
H ➔ WW	21 %
H ➔ gg	9 %
H ➔ ττ	6 %
H ➔ cc	3 %
H ➔ ZZ	3 %
H ➔ γγ	0.2%
H ➔ Zγ	0.2%
H ➔ μμ	0.02%


Power law best fit ($M = 244.0^{264.0}_{234.0}$, $\epsilon = -0.022^{0.02}_{-0.043}$)
Coupling λ
10^0
10^{-1}
10^{-2}
c
τ
b
W
Z
t
10^0
10^1
10^2
m [GeV]

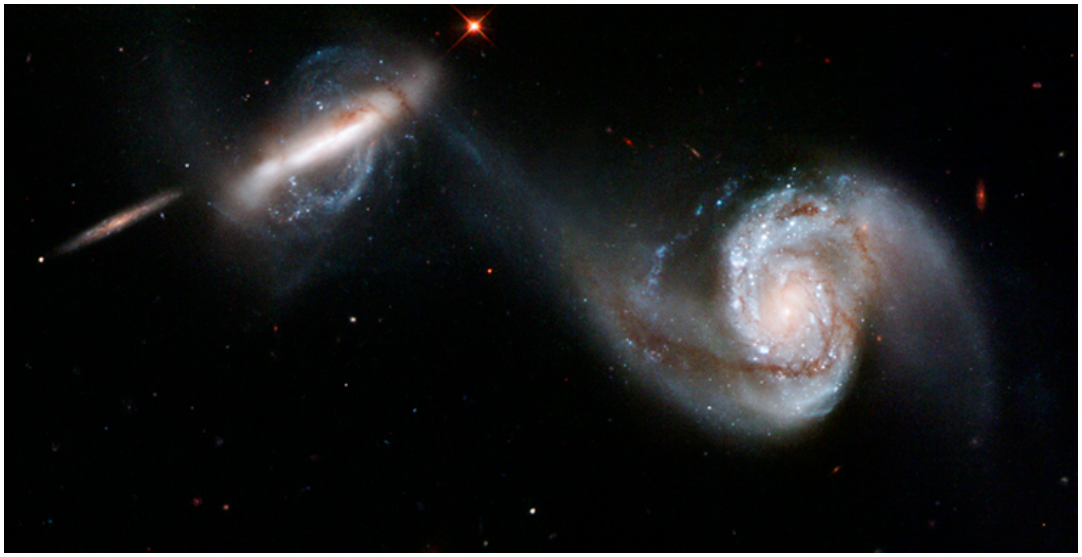
All particles are described by fields, but Higgs field is special



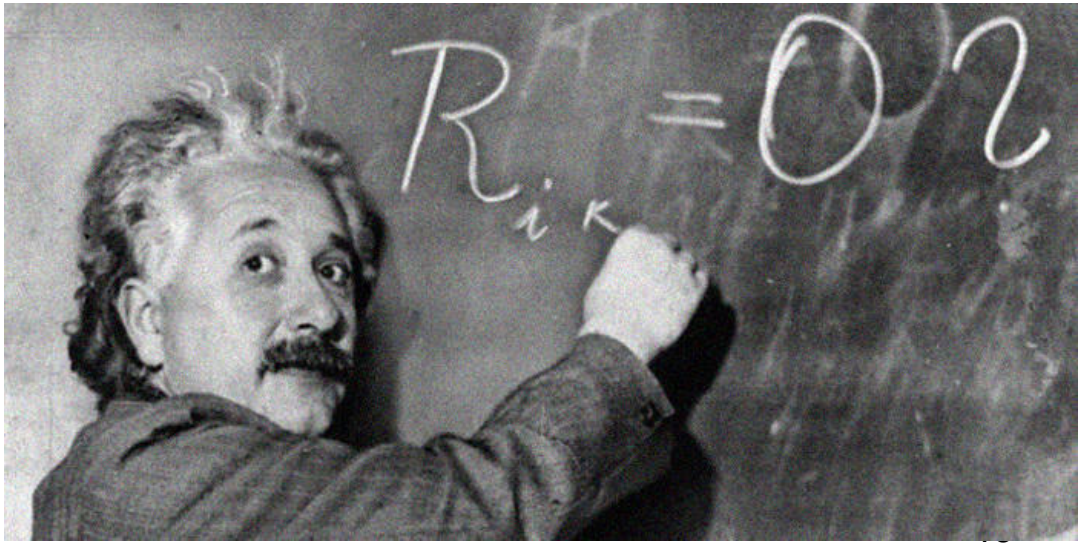
Higgs condensate: special arrangement of Higgs particles such that, in the “vacuum”, the average Higgs field is constant in space-time. ➔ spin zero

What caused the Bang?

Gravity is
always attractive

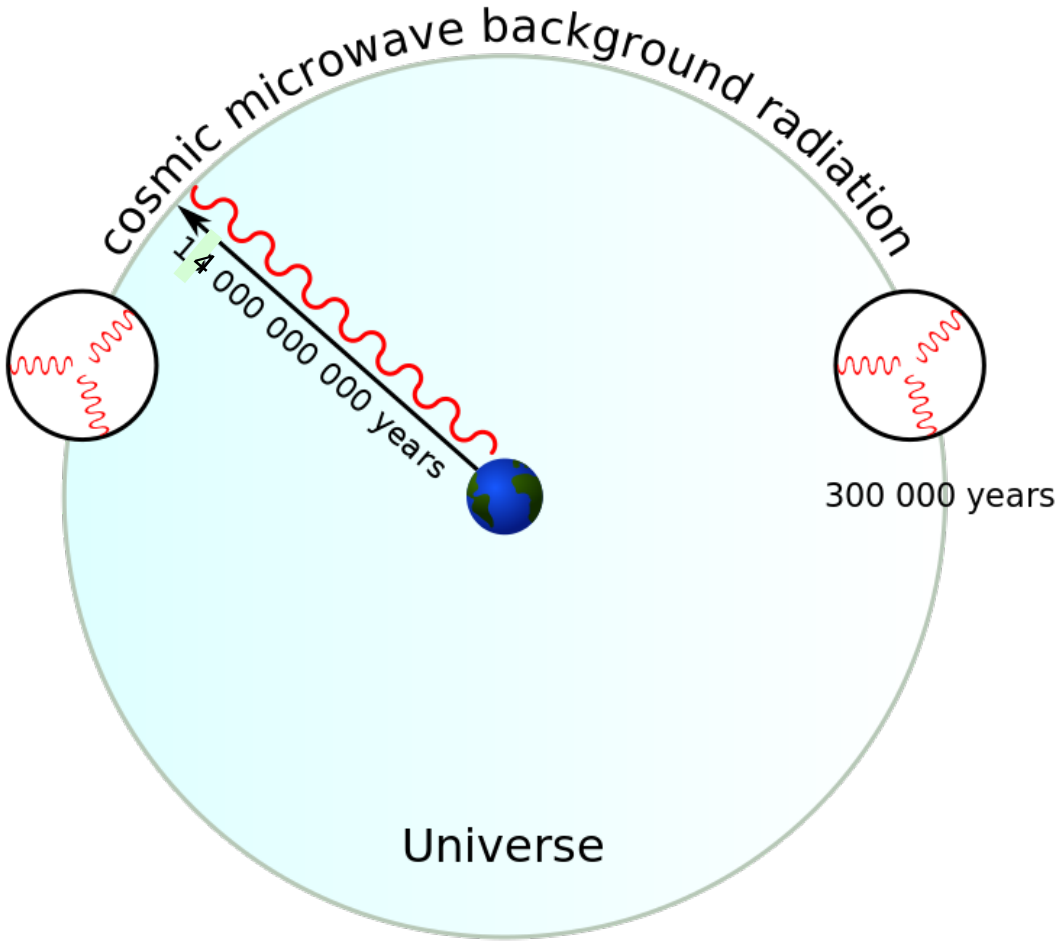


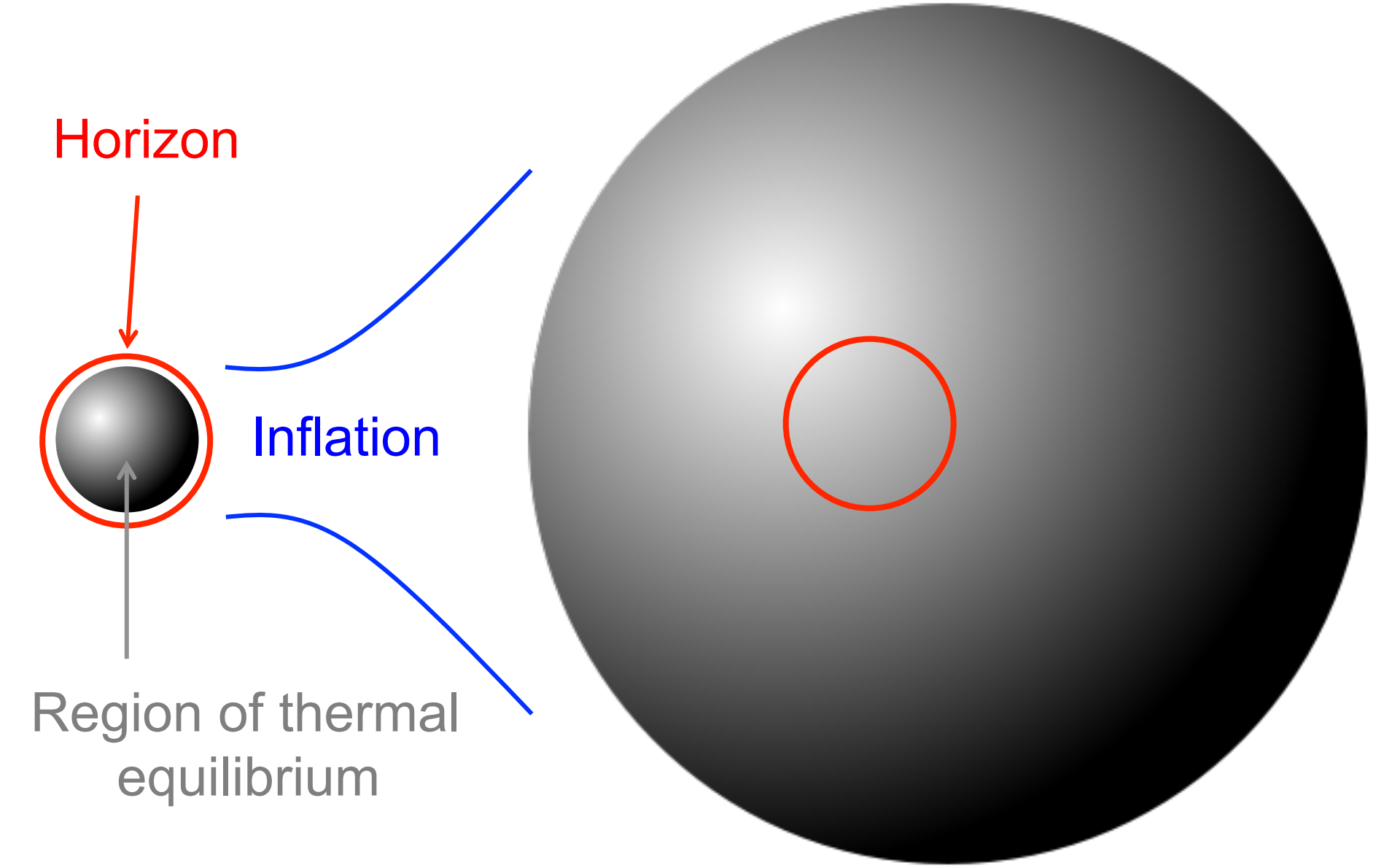
One exception in
General Relativity



Vacuum energy of a scalar field ➔ inflation

Extraordinary space expansion sets the right initial conditions of the universe (uniform, flat, smooth, and expanding)




Horizon
Inflation
Region of thermal equilibrium

Inflation explains the initial conditions of the universe

No bang, but

- Uniform and flat because of superluminal expansion
- Expanding because of initial kick from vacuum energy
- Low entropy
- Hot because, at the end of inflation, vacuum energy is released in the form of thermal energy

A new spin-0 field responsible for inflation?