The Higgs Boson

Triumph of the Standard Model

Jesse Thaler

Higgs-like Celebration — Oct 11, 2012

Culminating a century of particle physics!

Defining next 25 years of fundamental physics!

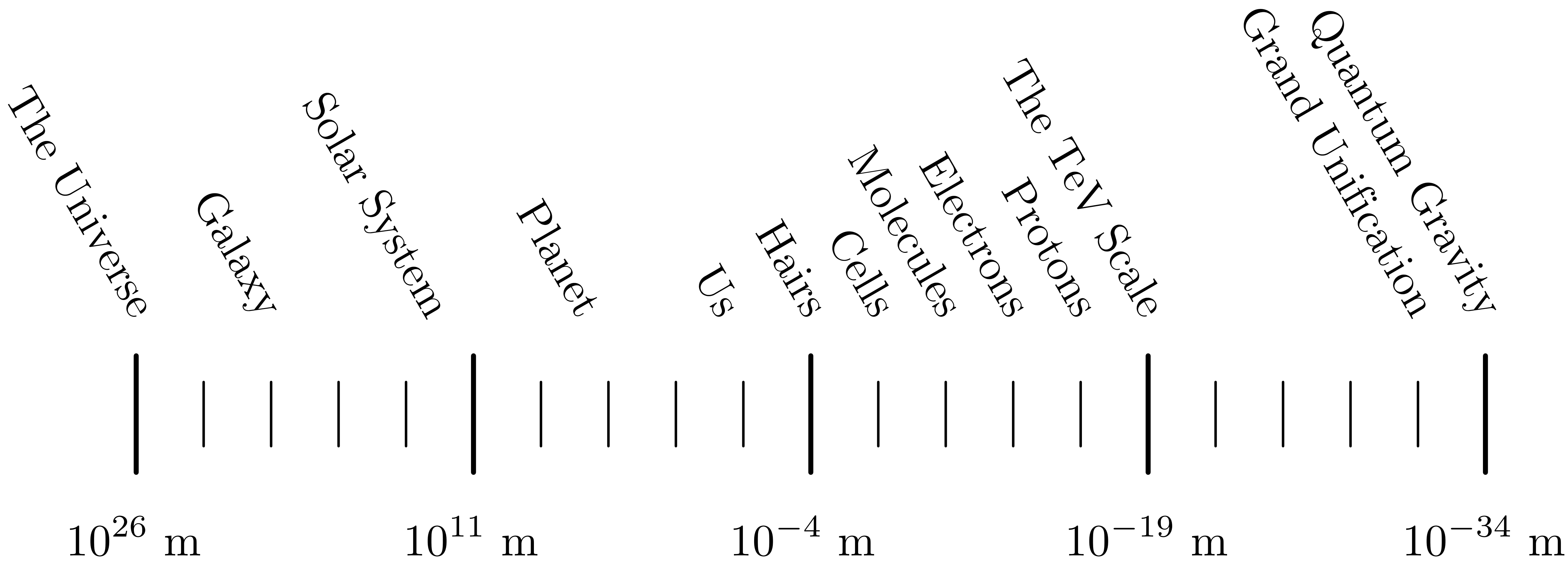
Higgs-like Discovery

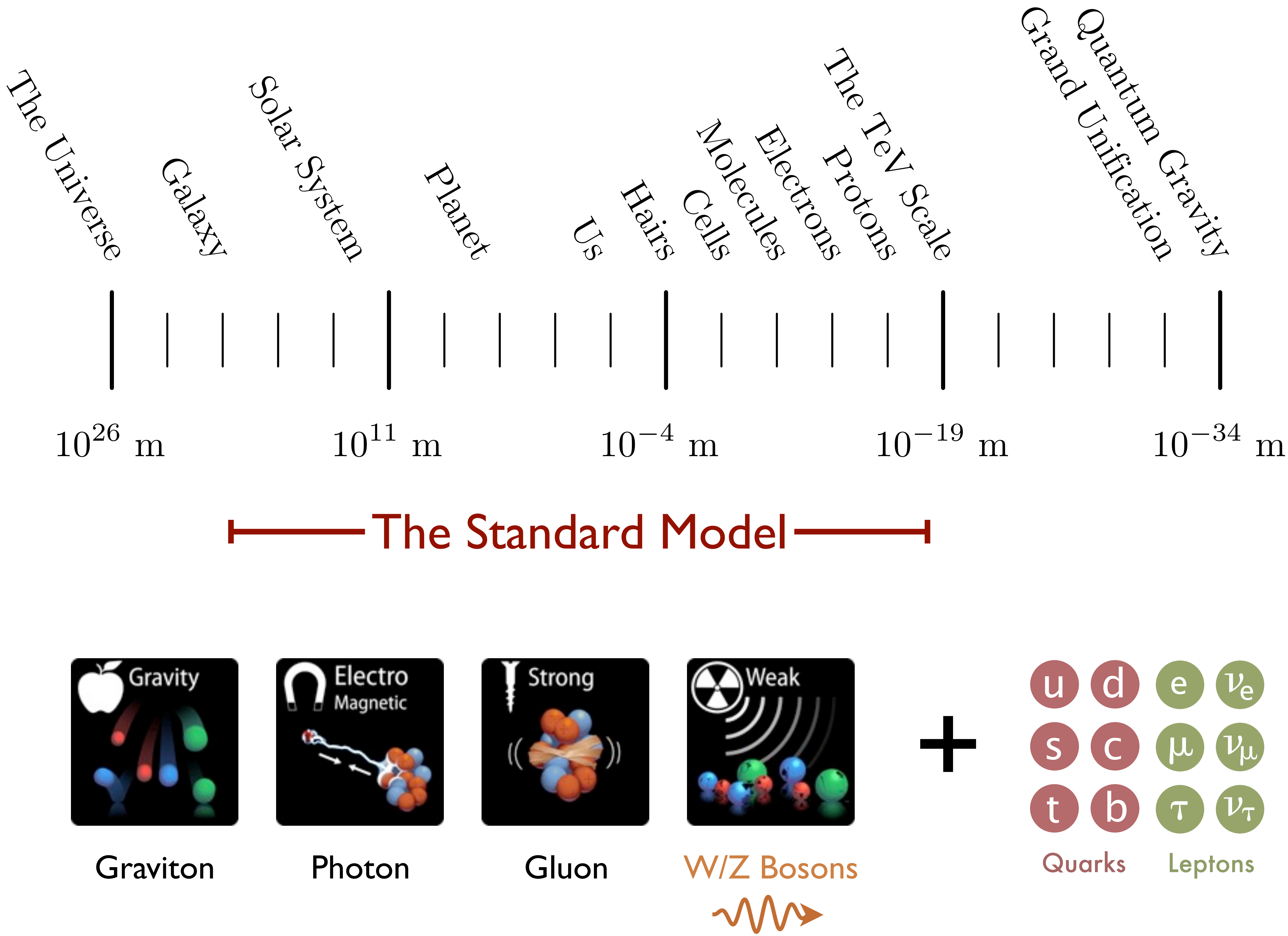
July 4, 2012

This talk: Why the Higgs is such a big deal

MIT = Affiliated (past or present) with MIT

8.05 = Shout out to my recitation students


The Universe
Galaxy
Solar System
Planet
Us
Hairs
Cells
Molecules
Electrons
Protons
The TeV Scale
Grand Unification
Quantum Gravity
10^{26} m
10^{11} m
10^{-4} m
10^{-19} m
10^{-34} m



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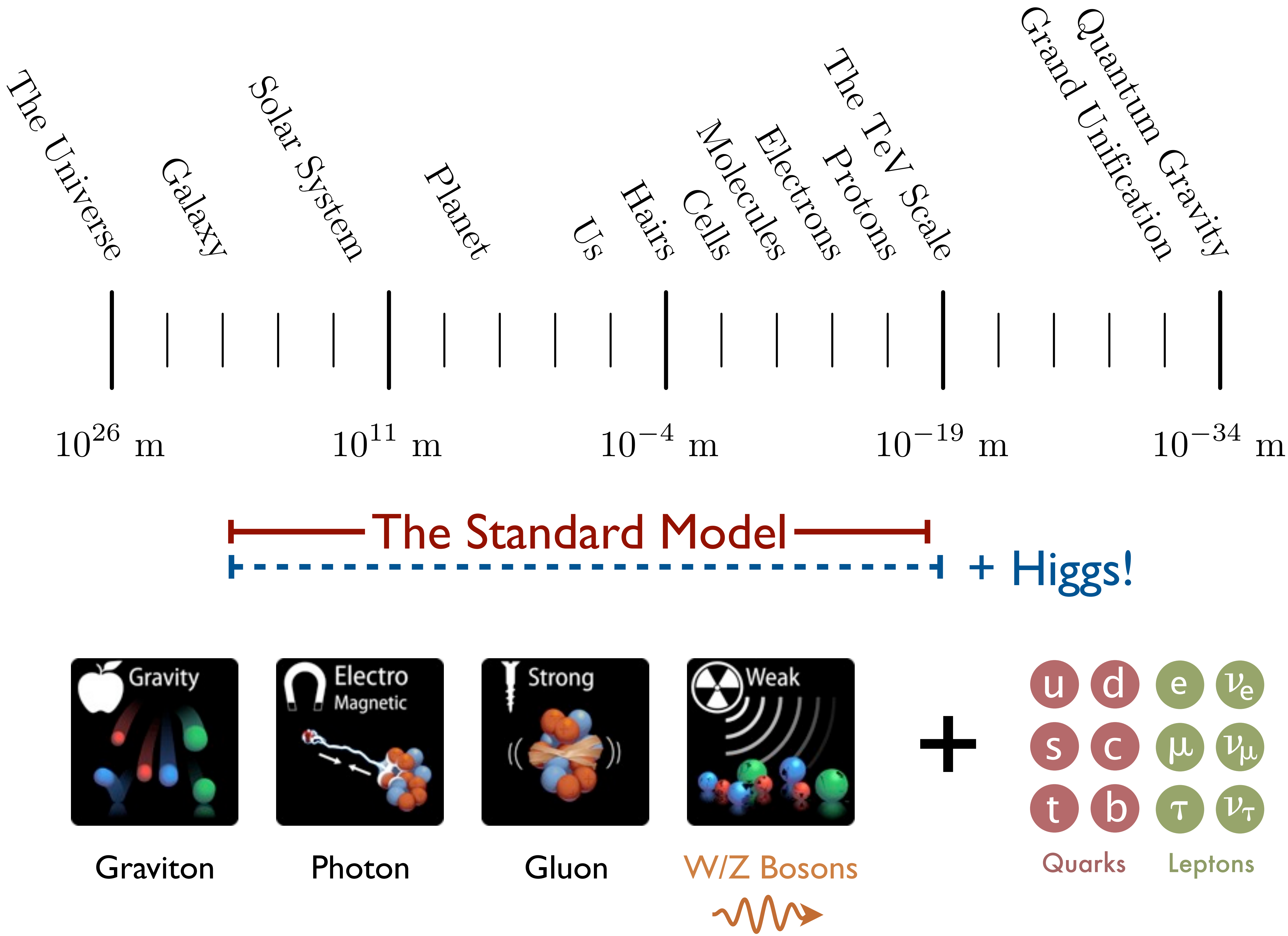
The Standard Model
Gravity
Electro Magnetic
Strong
Weak
Graviton
Photon
Gluon
W/Z Bosons
+
u d s c t b
e ν_e μ ν_μ τ ν_τ
Quarks
Leptons



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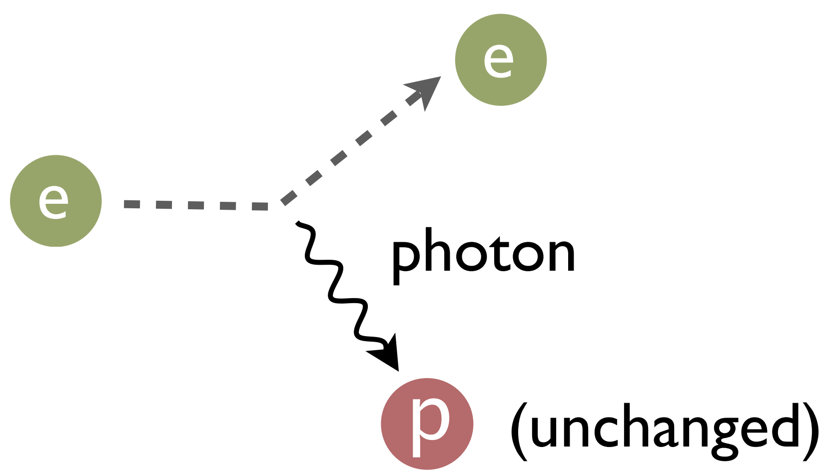
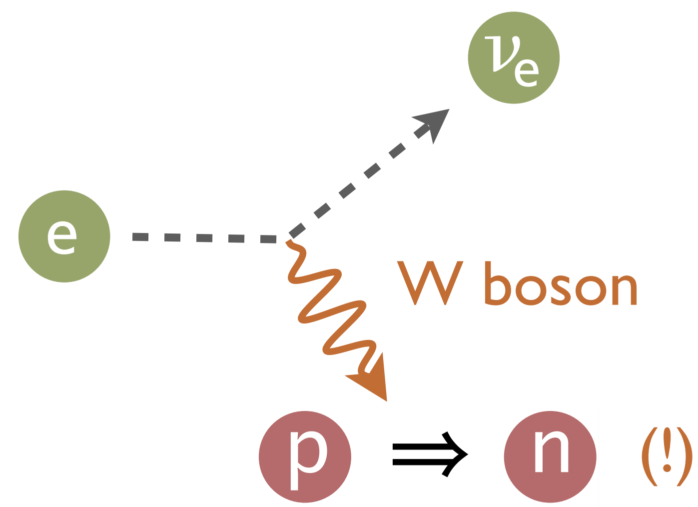
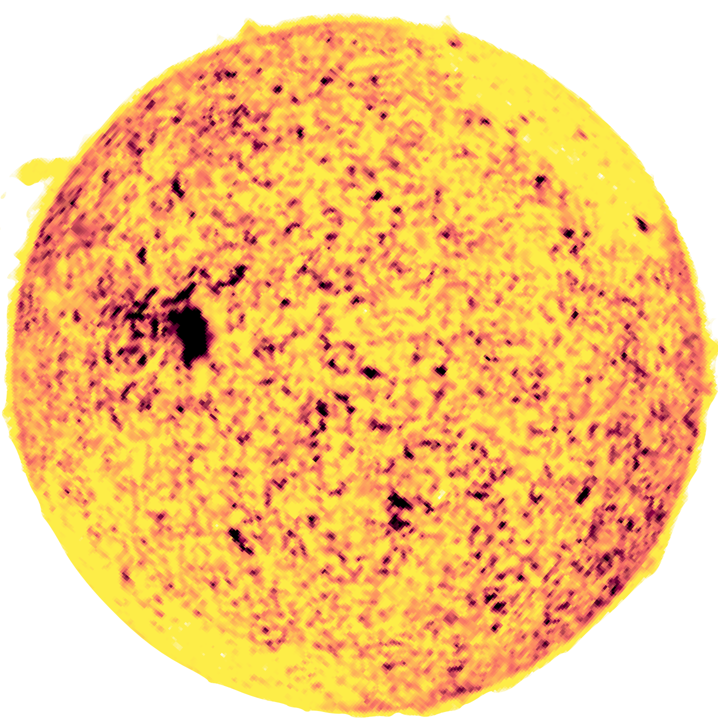
Weak Alchemy

Electromagnetic

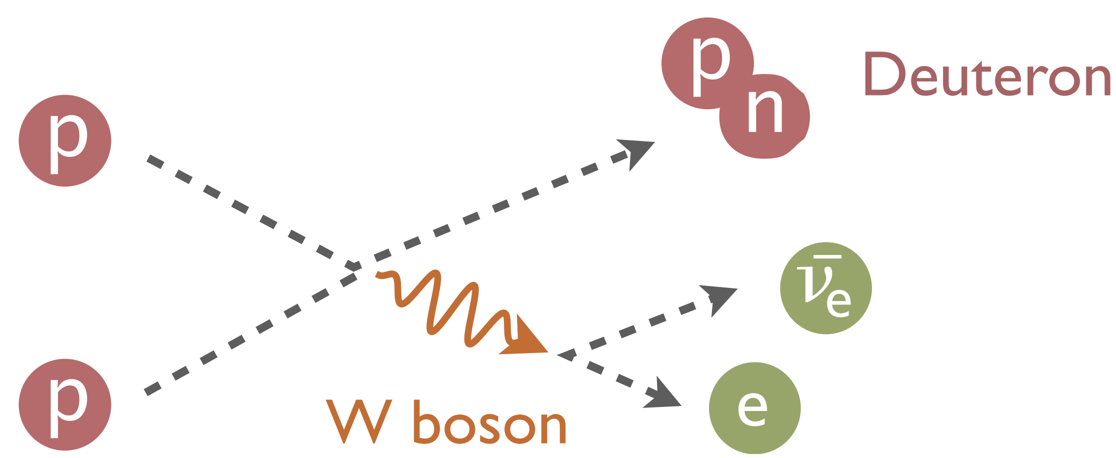


Weak Force



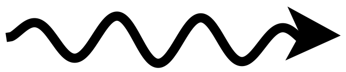


Essential for Stellar Burning



Three Bizarre Properties

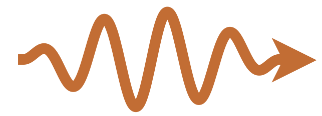
1. Massive Carrier



Massless Photon =

Two Polarizations

vs.



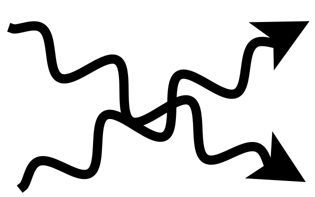
Massive W Boson =

+ ?

Three Polarizations

8.05: spin-1 has m = –1, 0, +1

2. Self-Interacting



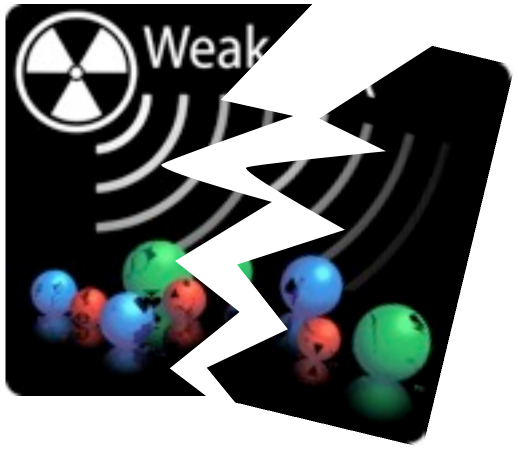
Pass right through

vs.

3. (Parity-Violating)

8.05: x → –x is *not* a symmetry of weak force

Why is Weak Force so Weird?



Because Weak Force is Broken

8.325: "Spontaneous Symmetry Breaking"

8.05: Weak charge is not conserved

Analogy: "Why is ice so weird compared to water?"

Why is Weak Force so Weird?

Because Weak Force is Broken

8.325: “Spontaneous Symmetry Breaking”

8.05: Weak charge is not conserved

Analogy: “Why is ice so weird compared to water?”

Caused by the Higgs!

A Little History

Energy Not Conserved in Weak Decays??

n → p e

Chadwick, et al.

Expt: 1920s

Theory:

A Little History

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Theory: 1930 Pauli | 1933 Fermi

n → p e ν?

A Little History

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Cowan/Reines

1956

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A Little History

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Theory:

1930 Pauli

1933 Fermi

n → p e ν?

Lessons:

- New Particle ⇔ Fundamental Principle
  - Neutrino ⇔ Energy Conservation
- Have to take the long view

A Little History

Energy Not Conserved in Weak Decays??

$n \rightarrow p\ e$

Chadwick, et al.

Expt: 1920s

ν!

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$n \rightarrow p\ e\ \nu$?

A Little History

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Theory:

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n → p e ν?

1967

Weinberg/Salam/Glashow

n → p e ν

via New Weak Force?

Three New Force Carriers:

- W^-? Weak Alchemy
- W^+? (Reverse) Weak Alchemy
- Z? Zomething else...

A Little History

Energy Not Conserved in Weak Decays??

$n \rightarrow p\ e$

Chadwick, et al.

ν!

Cowan/Reines

W/Z!

SPS @ CERN

Rubbia/van der Meer

Expt: 1920s — 1956 — 1983

Theory: 1930 Pauli — 1933 Fermi — 1967 Weinberg/Salam/Glashow

$n \rightarrow p\ e\ \nu$?

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via New Weak Force?

Three New Force Carriers:

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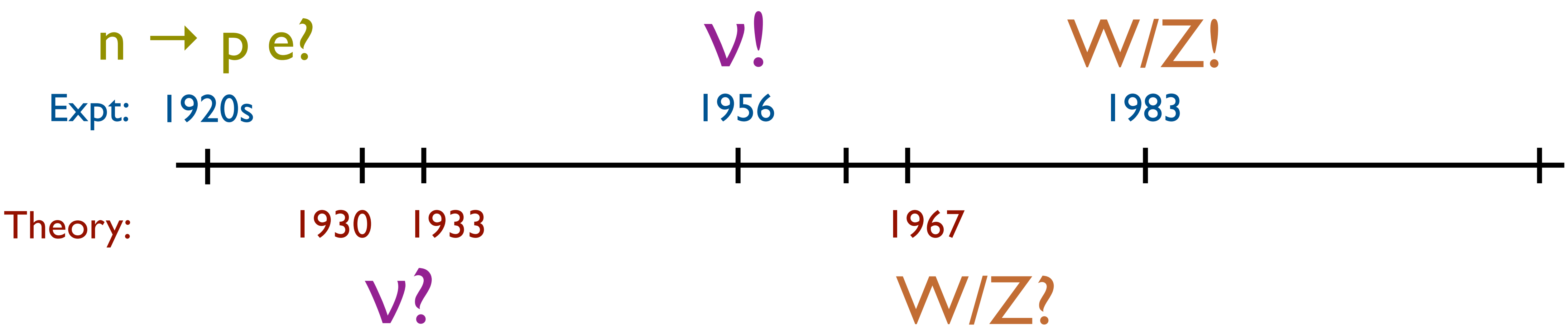
History in the Making?



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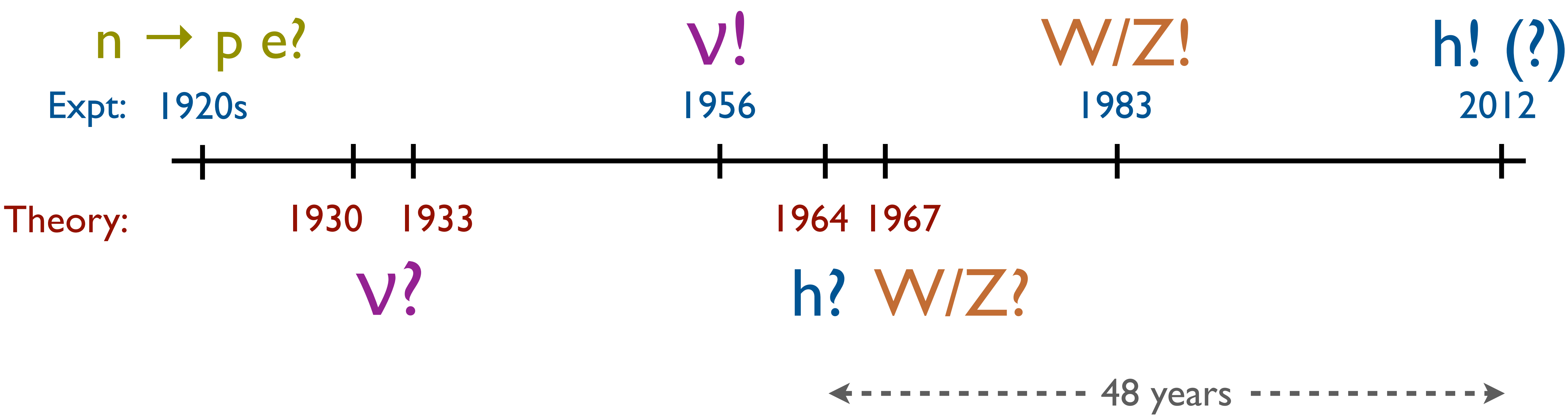


Higgs boson: Last ingredient of Standard Model

Prof. Klute's talk: Higgs or just Higgs-like?

Tale of Two Higgses

Higgs Mechanism

Breaks Weak Force
Gives Mass to
Fundamental Particles

↕

Massive W Boson

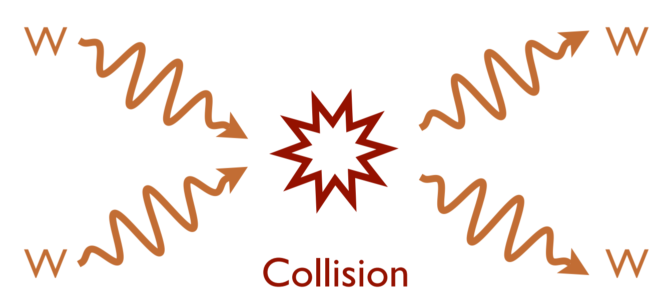
+ ?

Higgs Boson

New Spin-0 Particle
Ensures Consistency of
Quantum Mechanics

↕

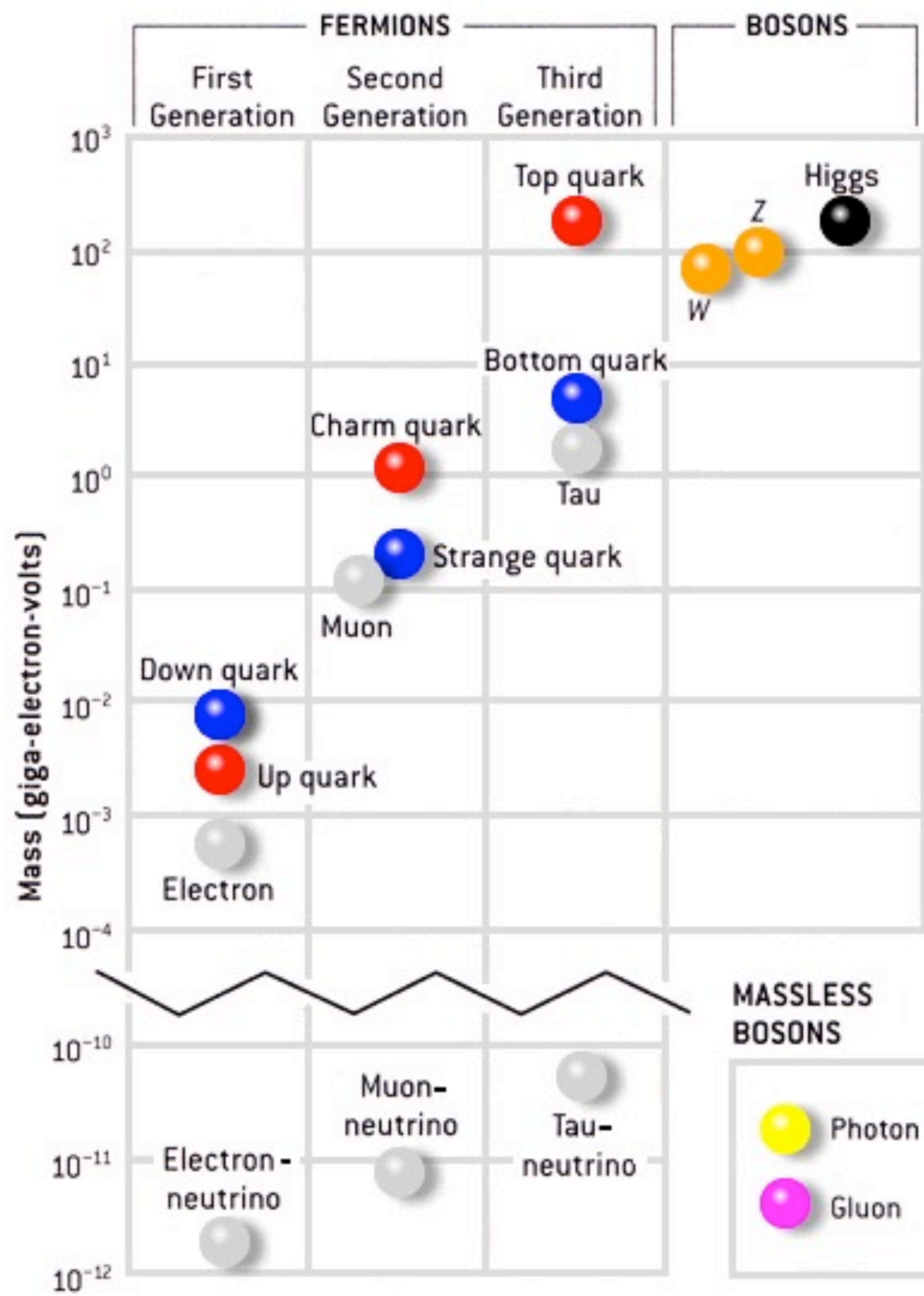
W Self-Collisions



Higgs Mechanism in 2012

Mass for all Fundamental Particles

⇒



For Prof. Klute's talk:

Higgs Couplings

↕

Particle Masses

8.05: Composites (like proton) get most mass from strong force

Higgs Mechanism in 1964

The Anderson, Brout/Englert, Higgs*, (1964)
Guralnik/Hagen/Kibble, 't Hooft Mechanism

+ ?

Two
Polarizations

Higgs Mechanism in 1964

The Anderson, Brout/Englert, Higgs*, (1964)
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Two
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Nambu/Goldstone
Boson MIT (1961)

(Necessary consequence
of breaking)

Higgs Mechanism in 1964

The Anderson, Brout/Englert, Higgs*, (1964)
Guralnik/Hagen/Kibble, 't Hooft Mechanism

Two Polarizations

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Nambu/Goldstone Boson MIT (1961)

(Necessary consequence of breaking)

=

Three Polarizations!

Higgs Mechanism in 1964

The Anderson, Brout/Englert, Higgs*, (1964) Guralnik/Hagen/Kibble, 't Hooft Mechanism

Two Polarizations

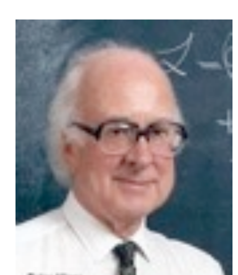
+

Nambu/Goldstone Boson (1961)

(Necessary consequence of breaking)

=

Three Polarizations!

* 

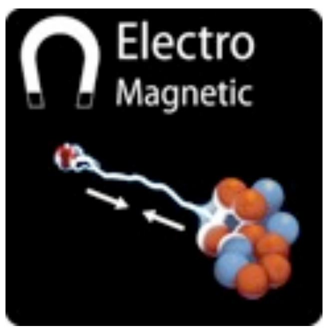
(Optional?) consequence of breaking is extra particle: “Higgs boson”

8.05: Higgs boson is spin-0

Birth of the Standard Model

Killer App for Higgs Mechanism: Electroweak Theory

Weinberg/Salam/Glashow
MIT (1967)



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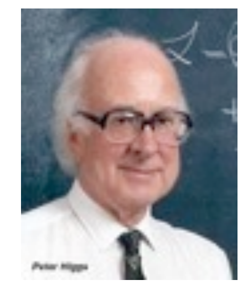


Photon

Unbroken, Massless,
Long Range

W/Z Bosons

Broken, Massive,
Short Range!

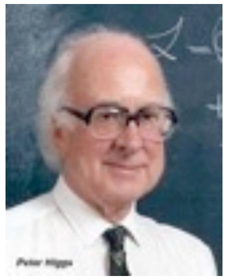
Higgs Boson

+ 

+ 

= Standard Model

Politzer/Gross/Wilczek
MIT (1973)

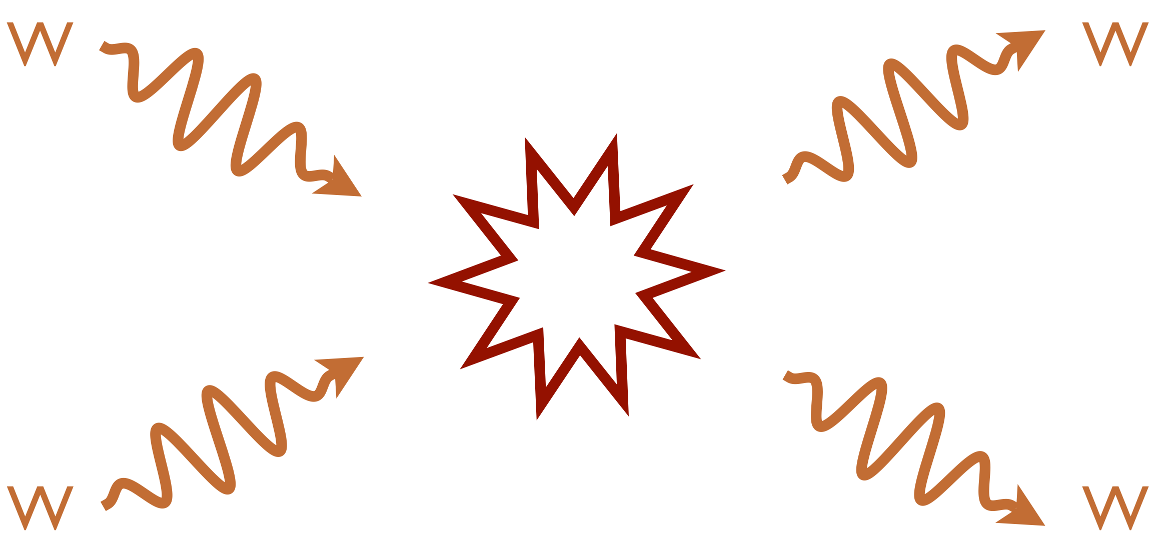


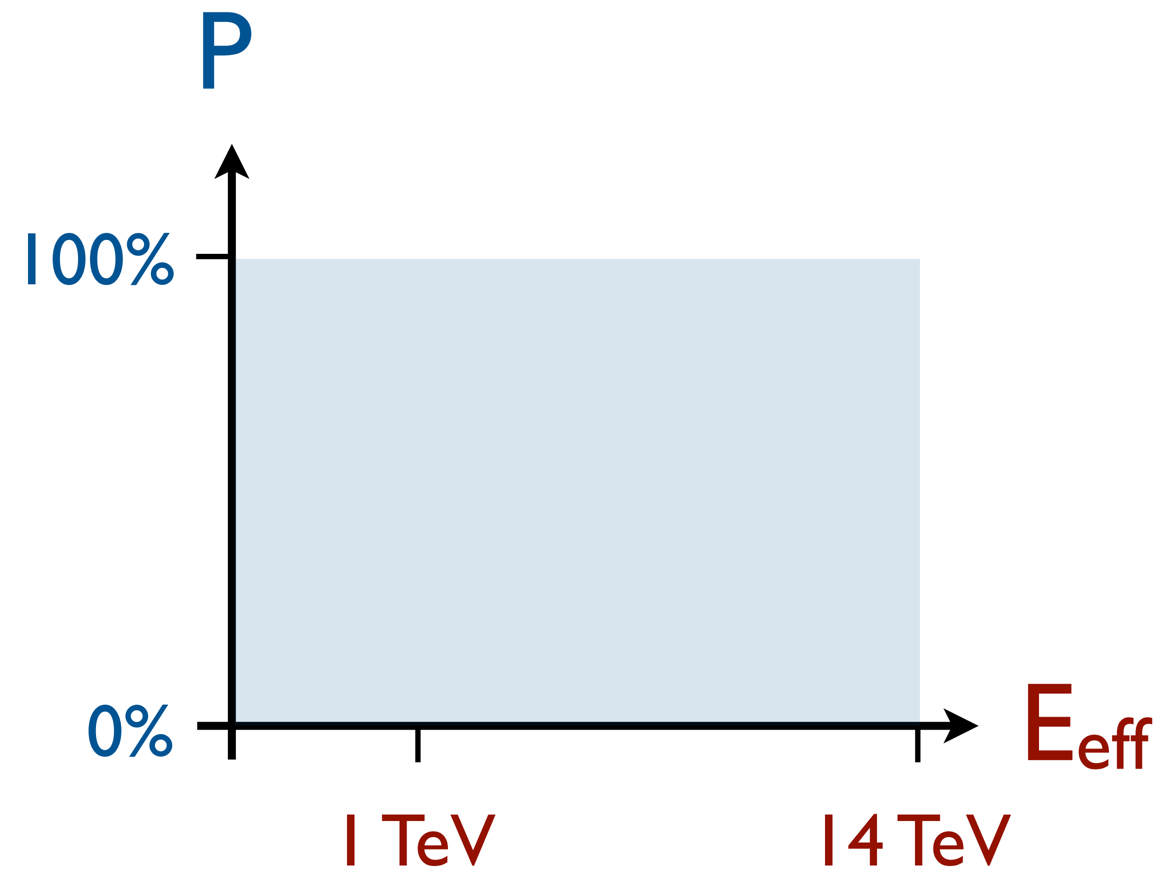
Higgs Boson?

(Keystone or Appendix?)

Colliding Weak Bosons

Quantum Mechanics = Theory of Probability





Colliding Weak Bosons

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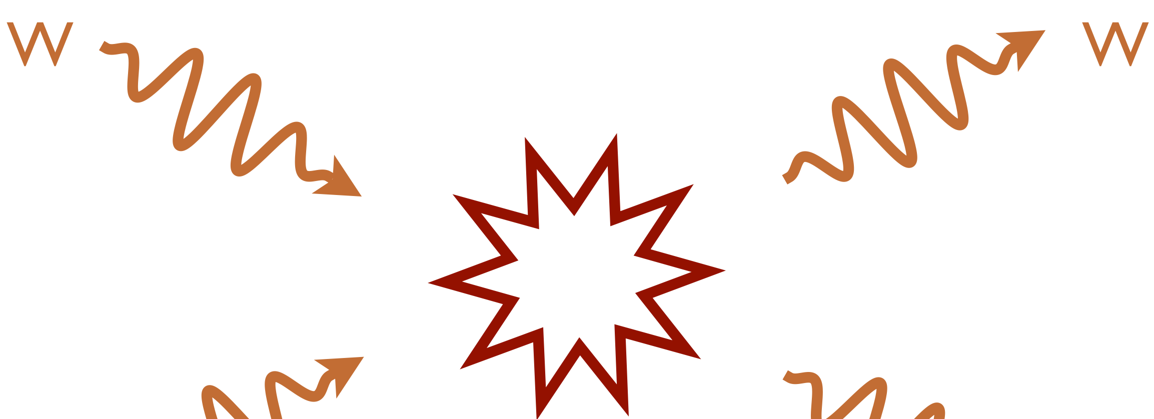
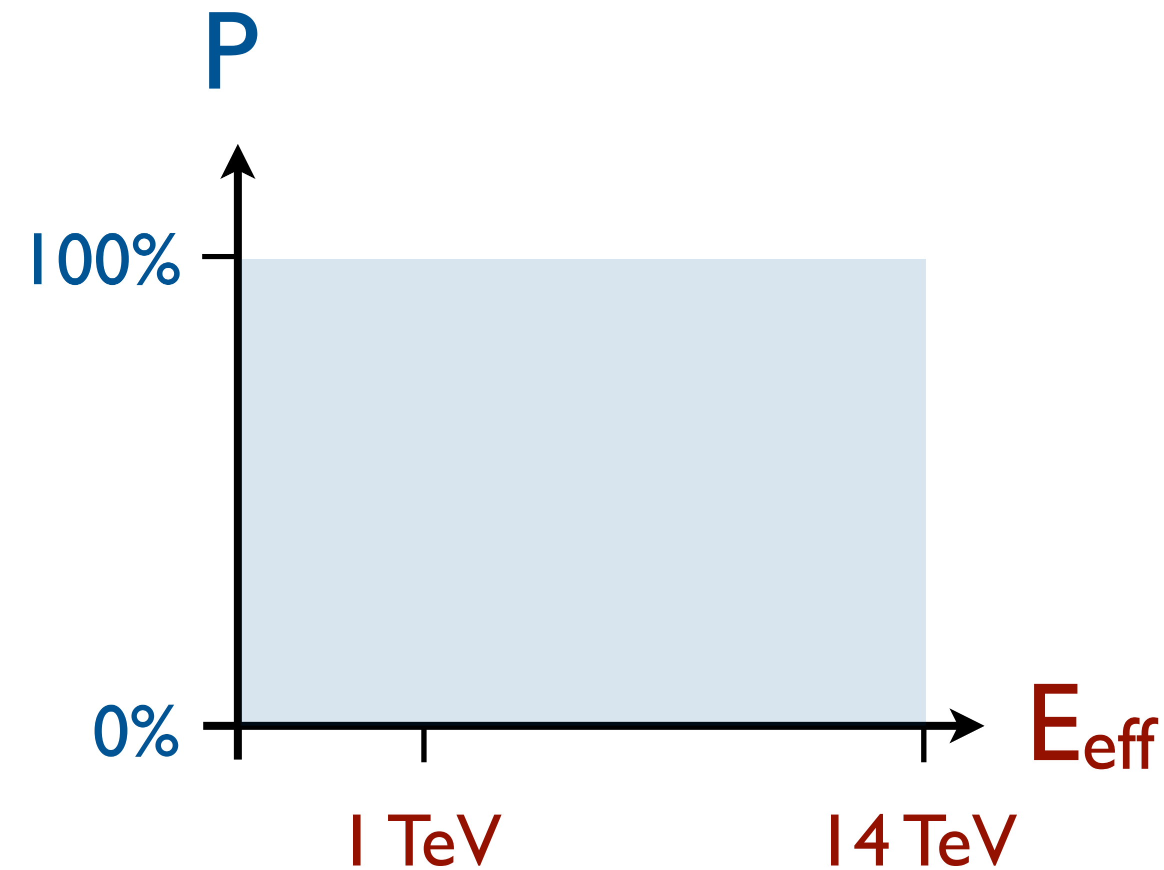


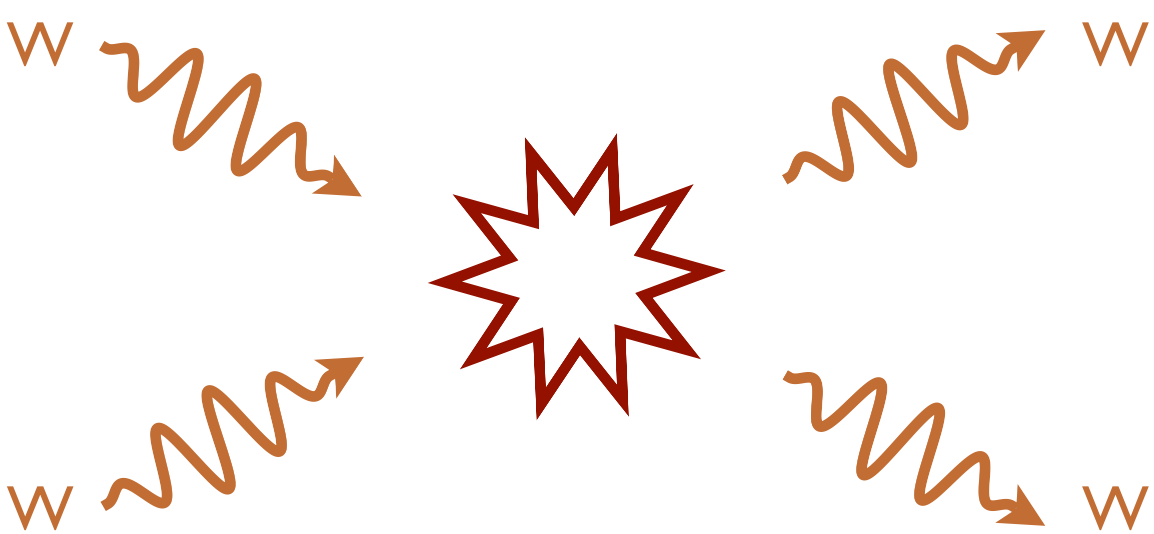


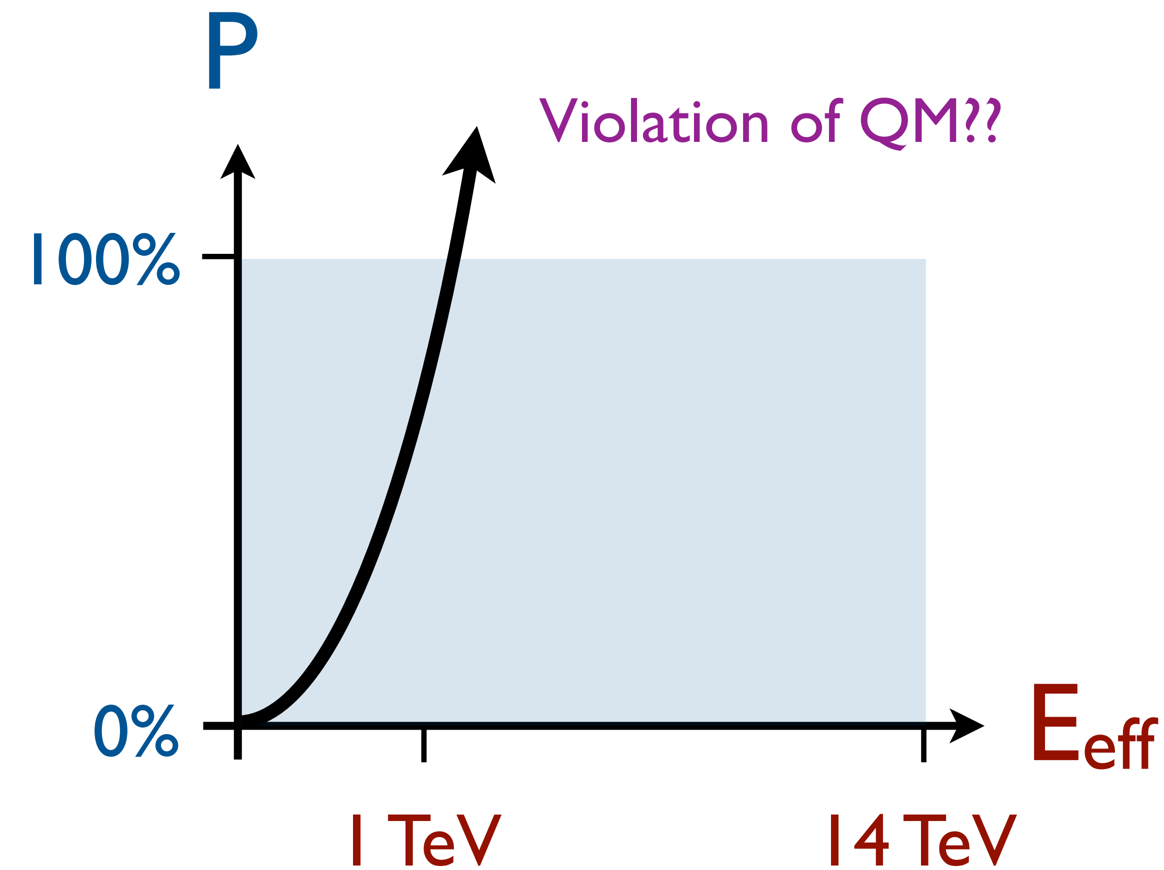
100% chance something will happen

8.05: take 8.06 to learn what "100%" really means

Colliding Weak Bosons

Quantum Mechanics = Theory of Probability





100% chance something will happen

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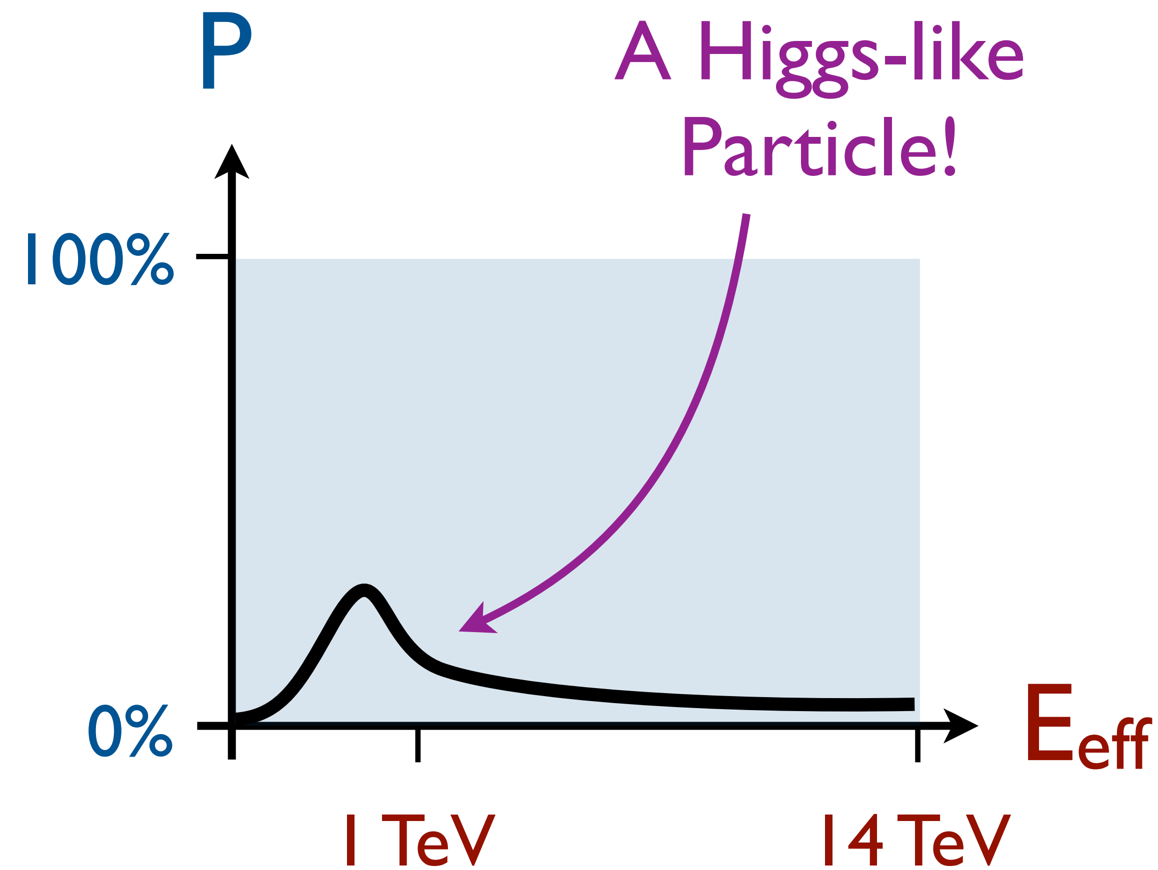
Enter the Higgs Boson

Rescuing Quantum Mechanics

particlezoo.net



Prof Klute's talk: Higgs hunting = "Bump hunting"

The Weak Interaction

A Bizarre Force...

...with a Profound Prediction

0. Weak Alchemy

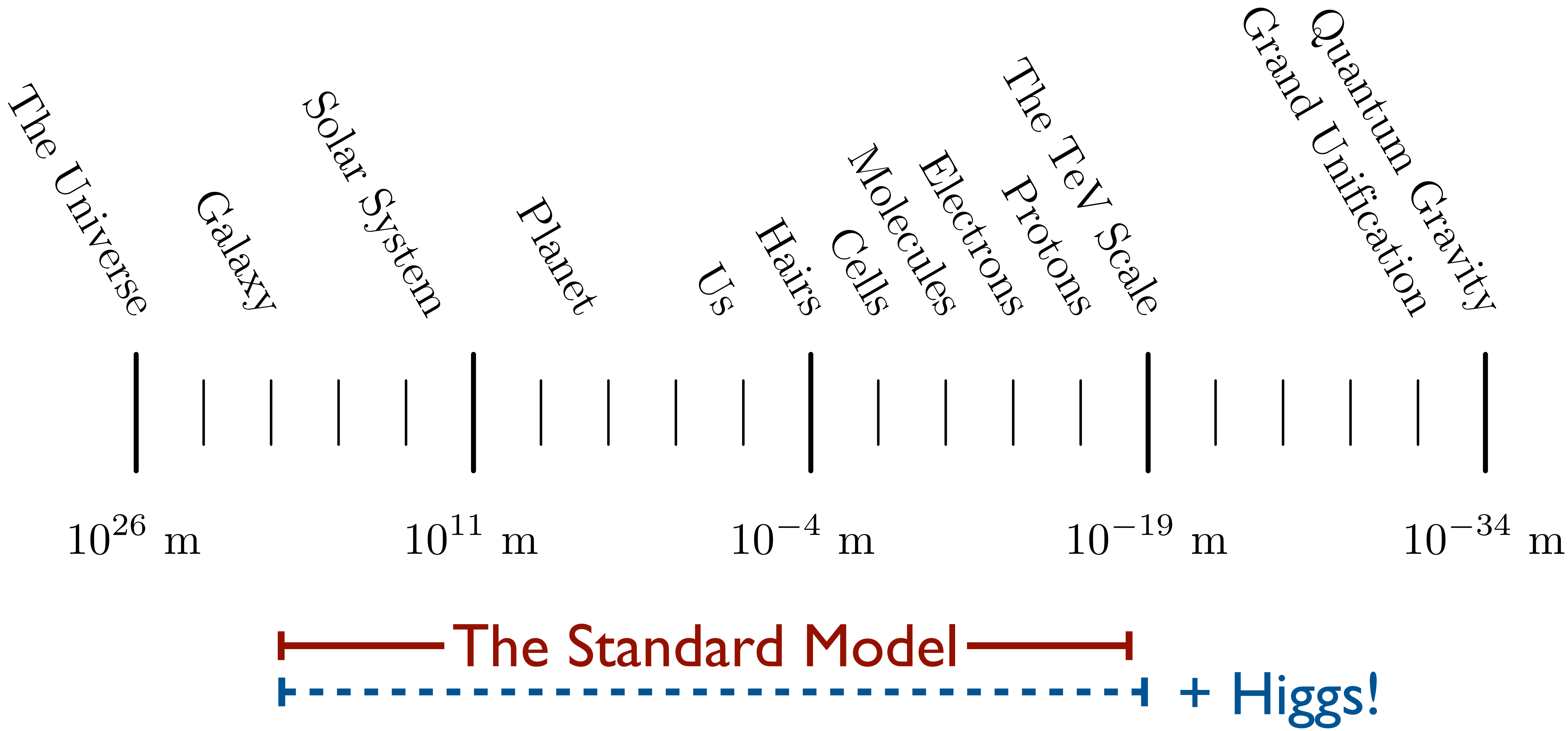
1. Massive Carrier → M **Higgs Mechanism**

Breaks Weak Force
Gives Mass to Fundamental Particles

2. Self-Interacting → % **Higgs Boson**

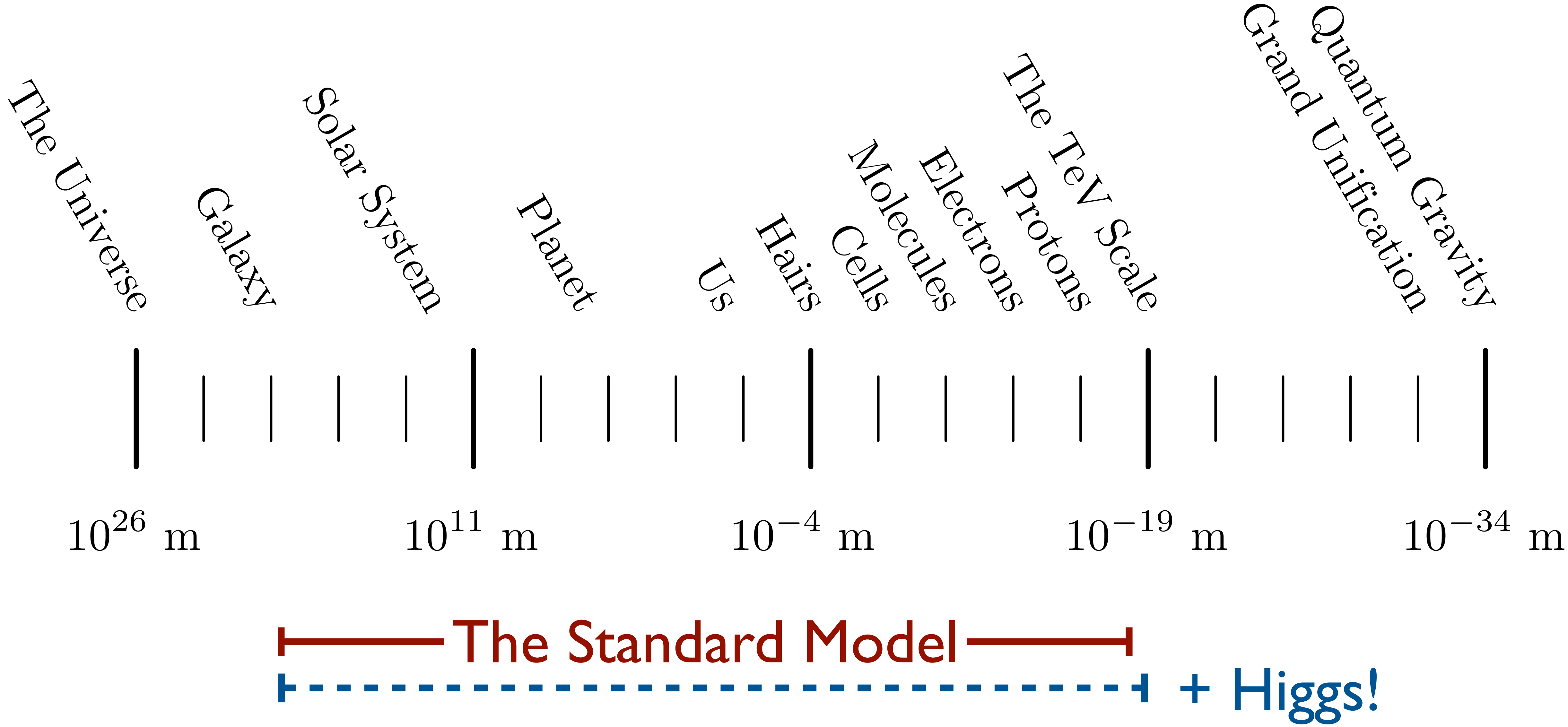
New Spin-0 Particle
Ensures Consistency of Quantum Mechanics

3. (Parity-Violating)



New Particles ⇔ Fundamental Principles

Neutrino	⇔	Energy Conservation
W/Z Bosons	⇔	Essential Similarity of All Forces
Higgs Boson	⇔	Probability Conservation



New Particles	⇔	Fundamental Principles
Neutrino	⇔	Energy Conservation
W/Z Bosons	⇔	Essential Similarity of All Forces
Higgs Boson	⇔	Probability Conservation
Dark Matter?	⇔	??
??	⇔	Supersymmetry?

An exciting future for fundamental physics!