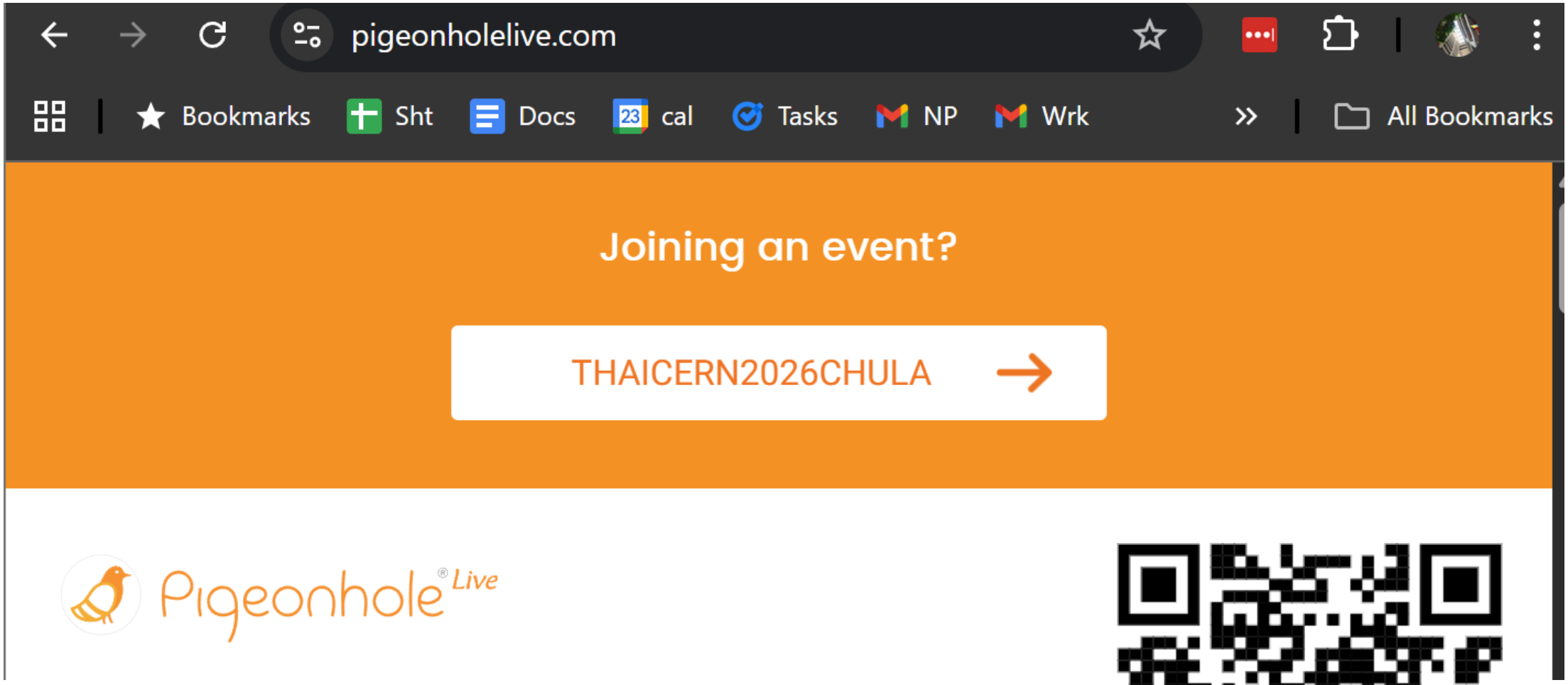
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Joining an event?
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Pigeonhole Live

A THEORIST'S CRASH COURSE IN MODEL BUILDING

Pawin Ittisamai
Department of Physics
Faculty of Science
Chulalongkorn University

Thai-CERN School:
April 25, 2026

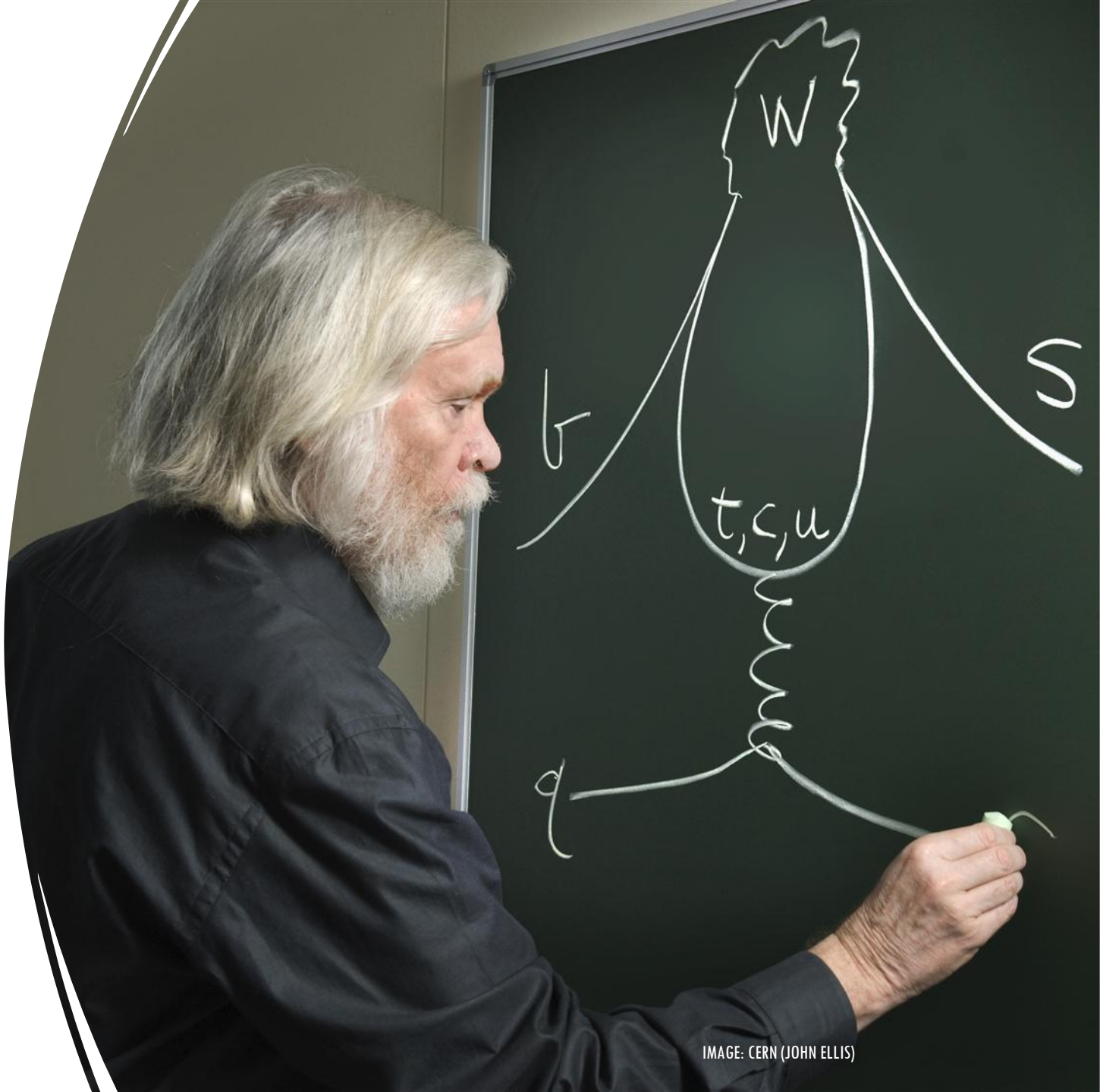

IMAGE: CERN (JOHN ELLIS)

Think of a pencil dot on a paper …

THE STANDARD MODEL OF PARTICLE PHYSICS

OUR BEST THEORY OF NATURE'S FUNDAMENTAL BUILDING PARTICLES

To begin to "see" the following small stuff, magnify that dot to …

Our pencil dot

THE STANDARD MODEL OF PARTICLE PHYSICS

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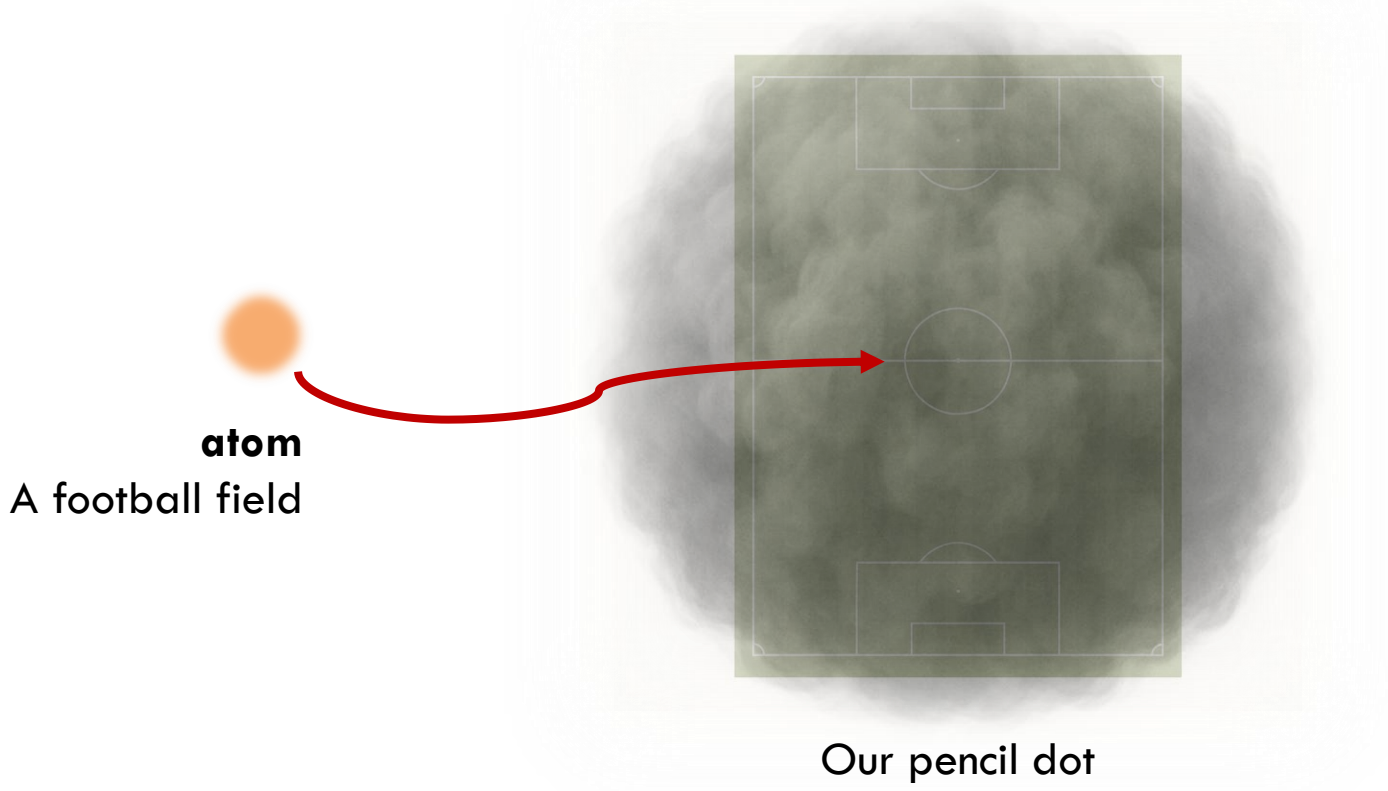


atom
A football field

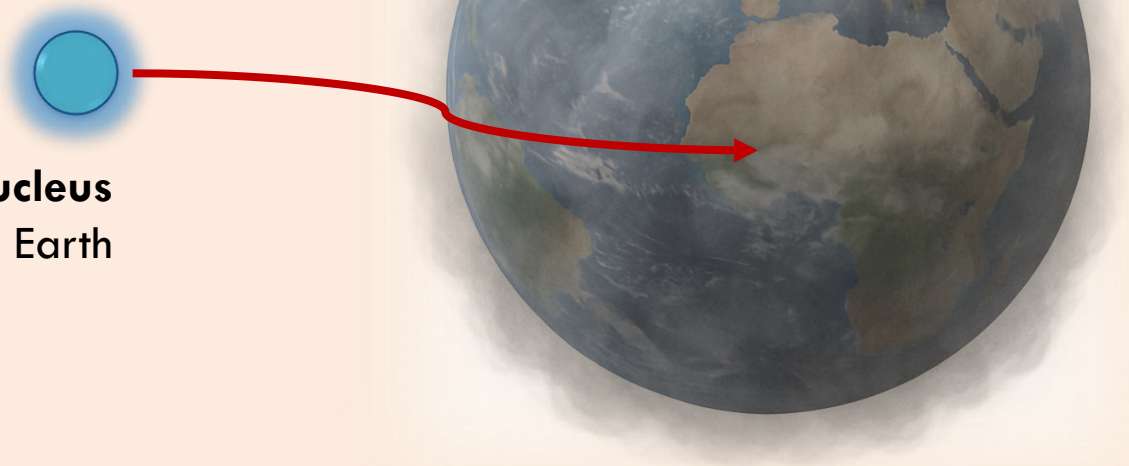
Our pencil dot

IMAGE: CHATGPT

THE STANDARD MODEL OF PARTICLE PHYSICS

OUR BEST THEORY OF NATURE'S FUNDAMENTAL BUILDING PARTICLES

To begin to "see" the following small stuff, magnify that dot to …



nucleus

The size of the Earth

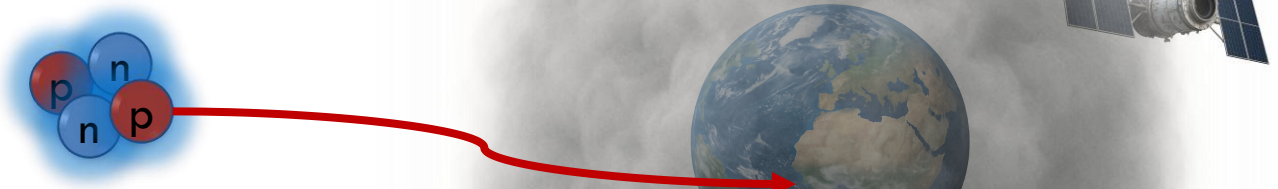
Our pencil dot

IMAGE: CHATGPT

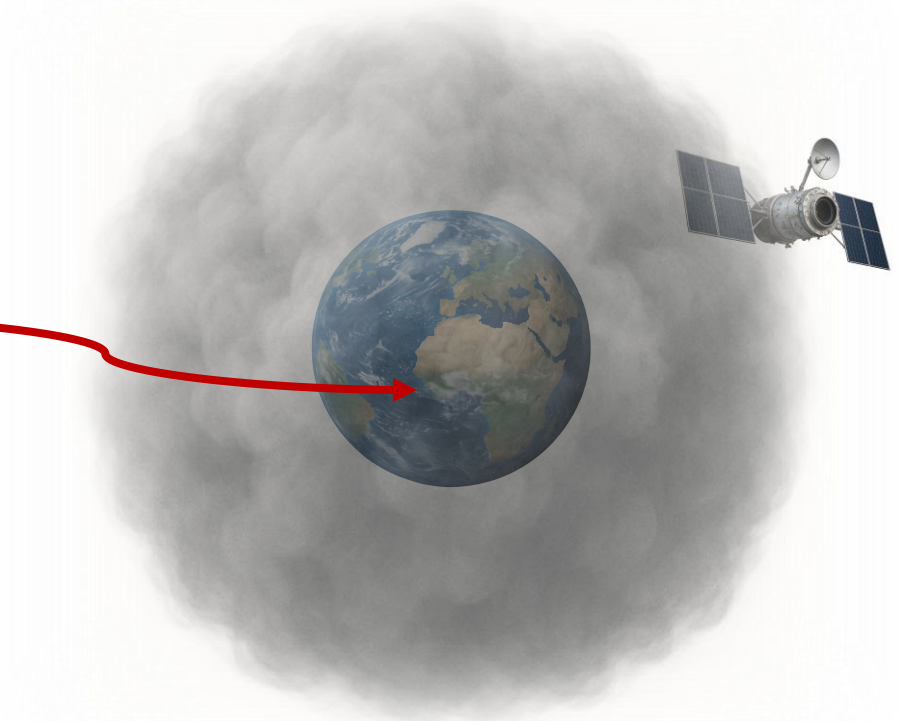
THE STANDARD MODEL OF PARTICLE PHYSICS

OUR BEST THEORY OF NATURE'S FUNDAMENTAL BUILDING PARTICLES

To begin to "see" the following small stuff, magnify that dot to …



protons & neutrons
Beyond where satellites are



Our pencil dot

IMAGE: CHATGPT

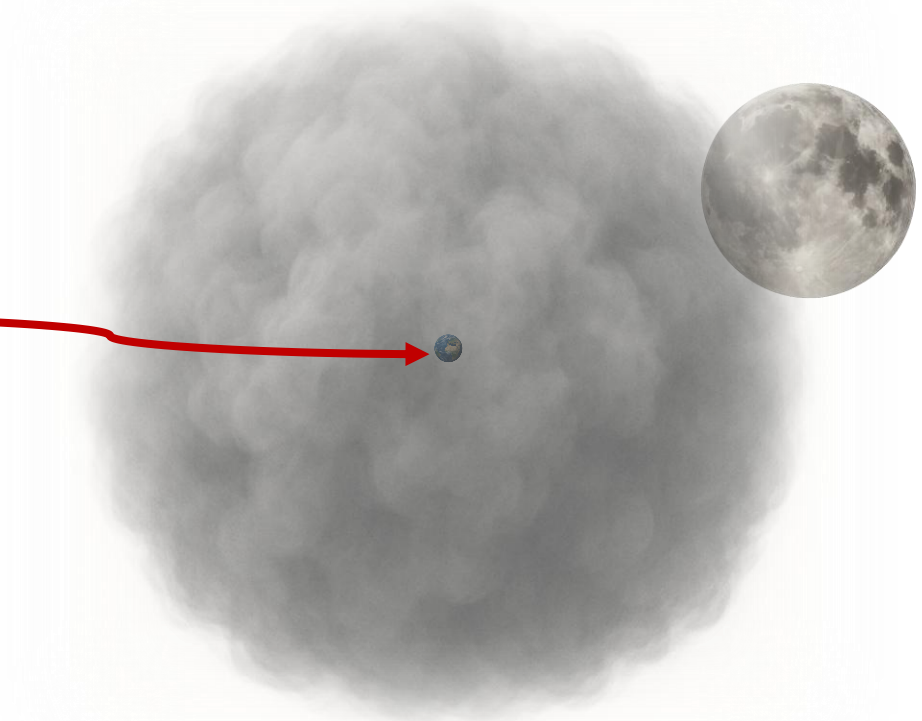
THE STANDARD MODEL OF PARTICLE PHYSICS

OUR BEST THEORY OF NATURE'S FUNDAMENTAL BUILDING PARTICLES

To begin to "see" the following small stuff, magnify <u>that dot</u> to …

3 quarks that made a proton

To the moon!!!



Our pencil dot

The main problem with this picture is …

WE LIED

The Standard Model of *particle physics* does not rely on "**particles**" at all!

IMAGE:

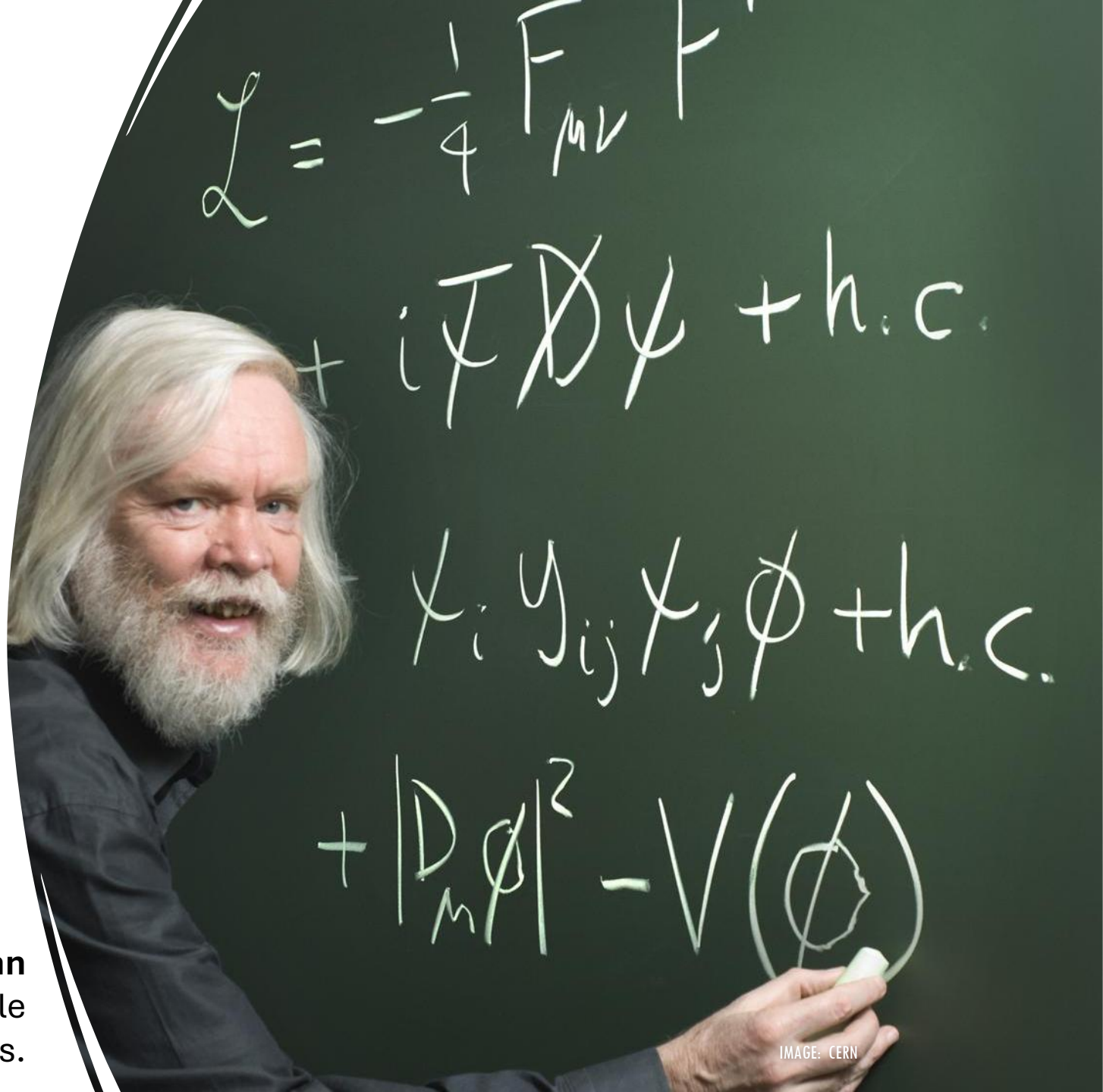
Today's Summary

Fields fill the whole universe.

What appears as particles are **excitations of fields**.

Interactions keep stuff together, or make something happen!

This **Standard Model Lagrangian** describes "everything" from particle contents to interactions.



Richard Feynman
(Physics Nobel 1965)

“One kid says to me, “See that bird? What kind of bird is that?” I said, “I haven’t the slightest idea what kind of a bird it is.” He says, “It’s a brown-throated thrush. Your father doesn’t teach you anything!”

But it was the opposite. He had already taught me: “See that bird?” he says. “It’s a Spencer’s warbler.” (I knew he didn’t know the real name.) “Well, in Italian, it’s a Chutto Lapittida. In Portuguese, it’s a Bom da Peida. In Chinese, it’s a Chung-long-tah, and in Japanese, it’s a Katano Tekeda.

You can know the name of that bird in all the languages of the world, but when you’re finished, you’ll know absolutely nothing whatever about the bird.

You’ll only know about humans in different places, and what they call the bird. So let’s look at the bird and see what it’s doing—that’s what counts.”

I learned very early the difference between knowing the name of something and knowing something.”

IMAGE: CALTECH ARCHIVES, COLORIZED USING AI

You've seen a century of results…not the research.

Most were "right"…until they weren't.

How to make learning about these useful to you?

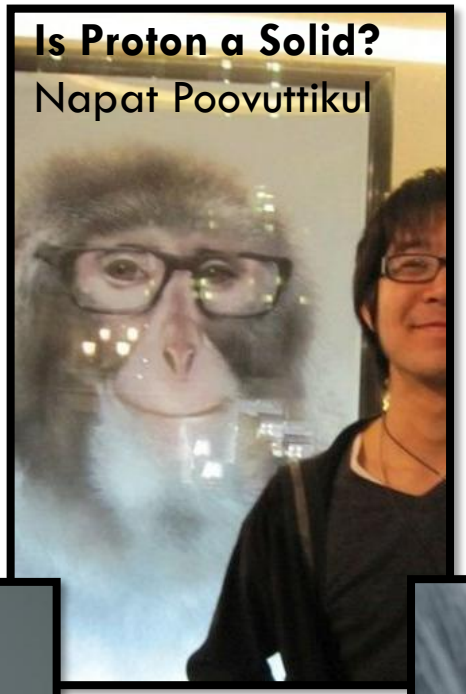
TWO PARTS OF RESEARCH:

RESULTS AND HOW WE FOUND THEM

We'll stick to this more important part.
So, you'll get some ideas on **how to be confused systematically in particle physics.**

Model Building
Pawin Ittisamai

Cloud Chamber
Yossathorn Tawabutr



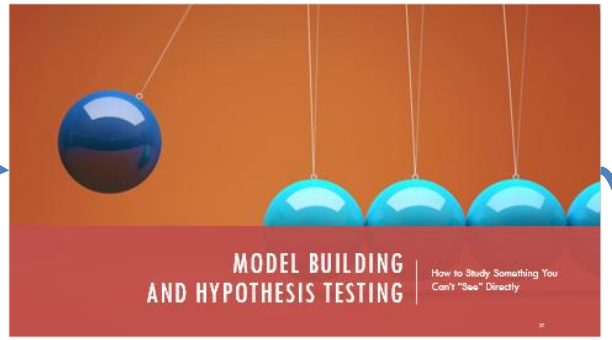
Is Proton a Solid?
Napat Poovuttikul

CERN
Chayanit
Asawatangtrakuldee

Standard Model
Patipan Uttayarat

BSM & Dark Matter
Chakrit
Pongkitivanichkul

OVERVIEW
OF MY TALK



FRAMEWORK & MODEL

A Warm-up Example on What You Know and Love

SCENARIO: A FALLING OBJECT

AND A MODEL PREDICTING ITS MOTION

UNDERLYING FRAMEWORK OF MECHANICS

EQUATION OF MOTION: HOW A STATE CHANGES DURING A SHORT TIME INTERVAL

$$\text{Change in } \textbf{Velocity} = \frac{\text{Force}}{\text{Mass}}$$

How to model the interaction?

IMAGE: BRUCE LEE FOUNDATION (VIA CBS)

SYMMETRY AS A GUIDELINE FOR AN INTERACTION

SYMMETRY = THE SAMENESS UNDER A CERTAIN CHANGE

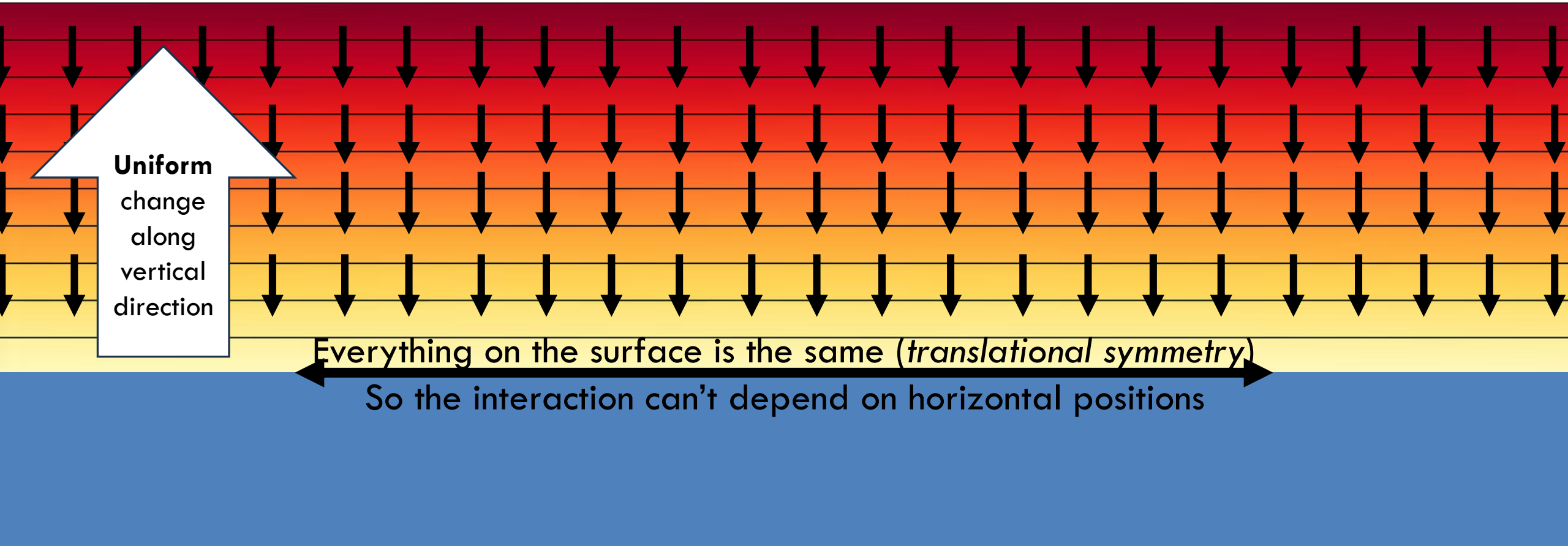
Only the changes (of something) along vertical positions matter.

Everything on the surface is the same (*translational symmetry*)

So the interaction can't depend on horizontal positions

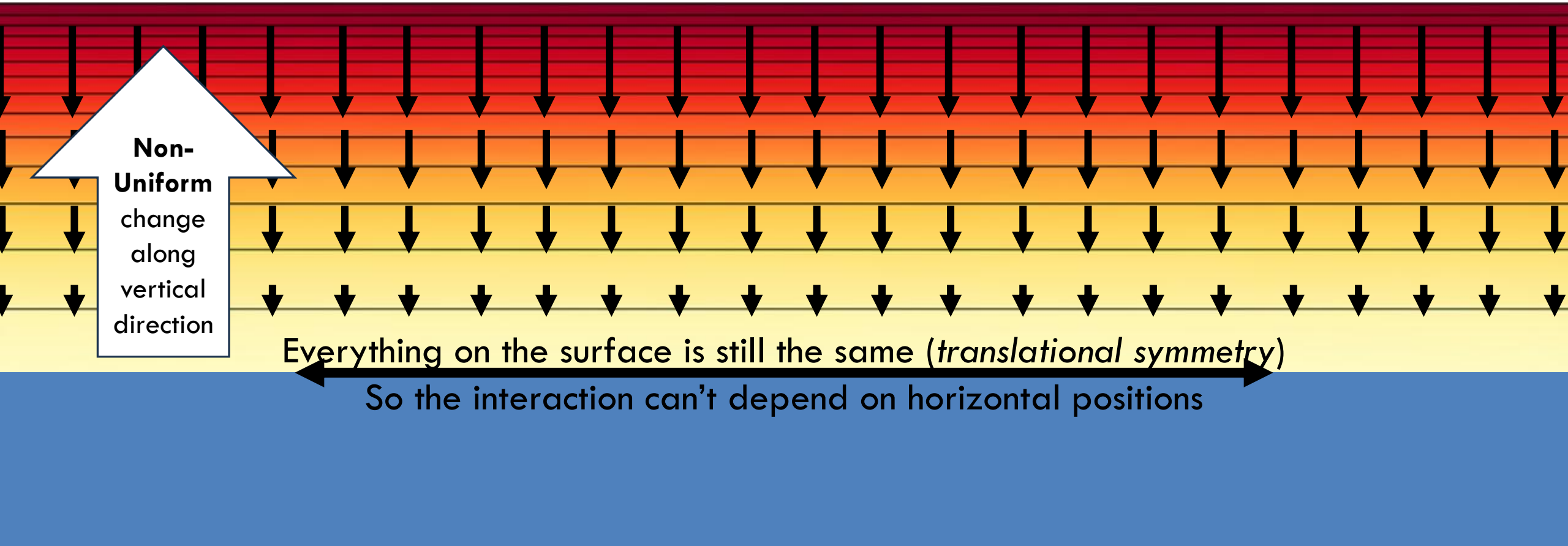
UNIFORM CHANGE = UNIFORM INTERACTION

THIS IS YOUR UNIFORM FORCE $F = mg$



NON-UNIFORM CHANGE = NON-UNIFORM INTERACTION

THERE ARE INFINITE WAYS TO CHANGE THINGS NON-UNIFORMLY. INFINITE POSSIBILITIES?



TWO WAYS TO GET PREDICTIONS

IN LAGRANGE'S FORMALISM, YOU BUILD A MODEL BY BUILDING A LAGRANGIAN!

Newton's Formalism

(lots of vectors)

Framework

$$\frac{\mathrm{d}\vec{\boldsymbol{v}}}{\mathrm{d}t} = \frac{\vec{\boldsymbol{F}}}{m}$$

Model

$$\vec{\boldsymbol{F}} = m\vec{\boldsymbol{g}}$$

Lagrange's Formalism

(scalar function of *building blocks*)

Framework

$$\frac{d}{dt}\left(\frac{\partial \mathcal{L}}{\partial v}\right) = \frac{\partial \mathcal{L}}{\partial z}$$

Model

Lagrangian = A specific function of "building blocks"

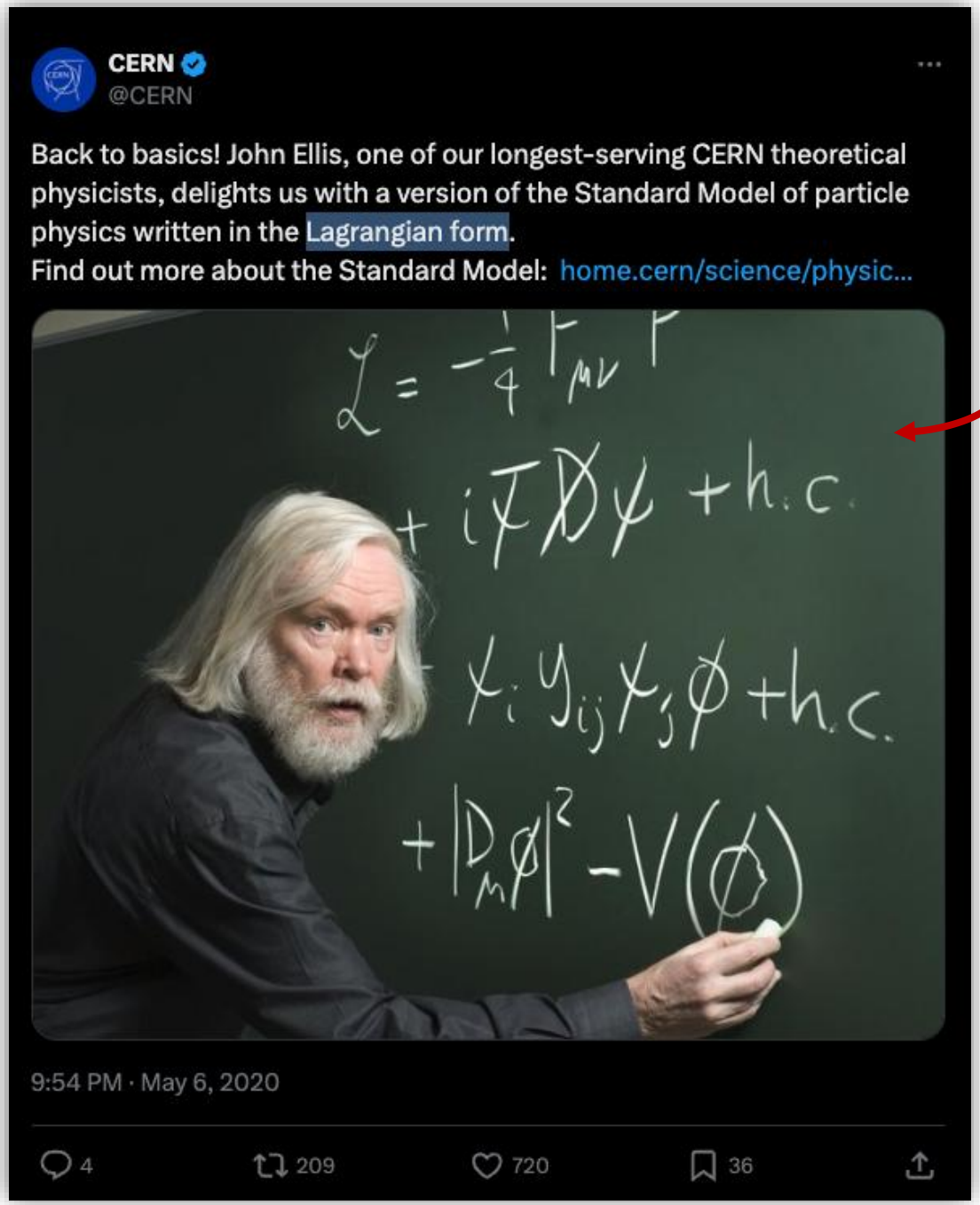
$$\mathcal{L}(z, v) = \frac{1}{2}m\boldsymbol{v}^2 - mgz$$

Much easier to build models!

Measures non-uniformity and mixings

(here, along z)

Same predictions!



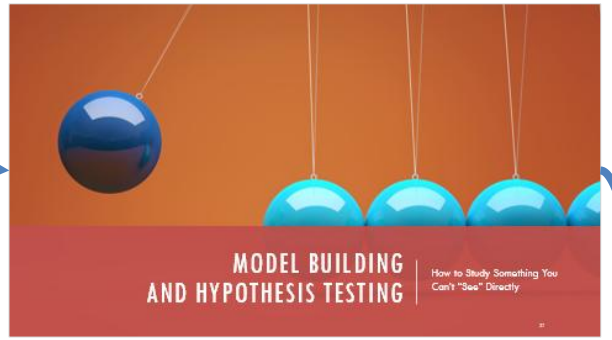
Fields of different kinds ($F_{\mu\nu}, \psi, \phi, \ldots$) are “dynamical variables”

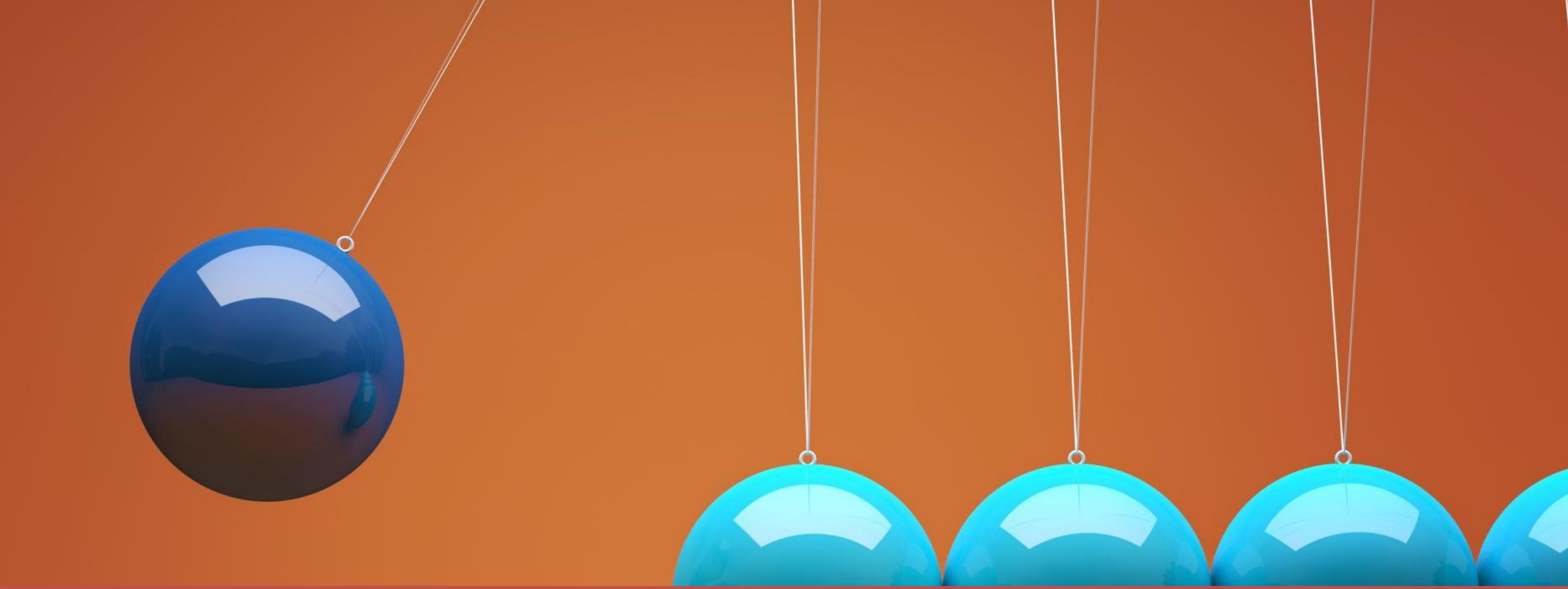
IMAGE: CERN

Wait…

How do you actually build a model!

OVERVIEW
OF MY TALK





MODEL BUILDING AND HYPOTHESIS TESTING

How to Study Something You Can't "See" Directly

WHAT'S INSIDE THE BOX?

AN INTERPLAY BETWEEN MODEL BUILDING AND EXPERIMENTS

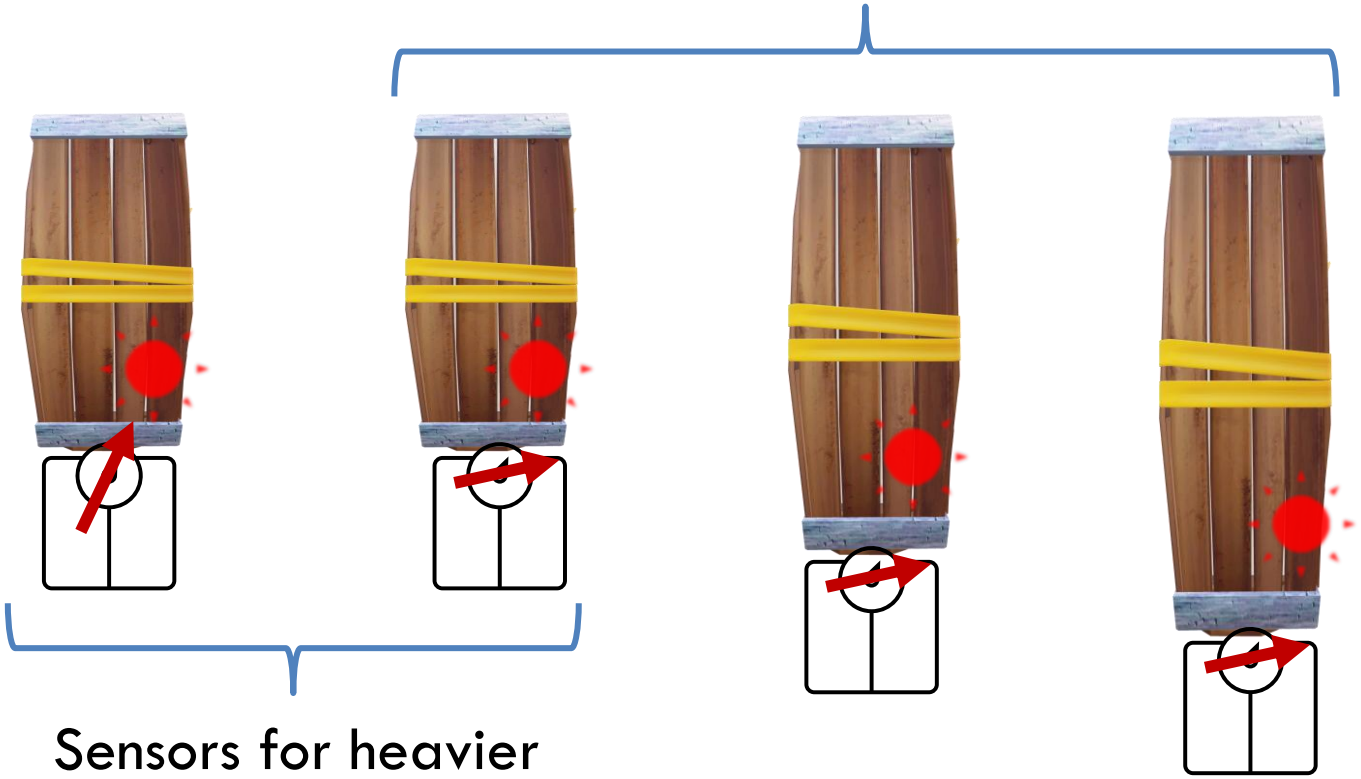
Observation: the sensor flashes with some periods.

IMAGE: MICROSOFT (STOCK)

BEHAVE LIKE SPRING, BOUNCING WAVES, OR PENDULUM?

DATA GIVE YOU THE CLUES

Sensor for **longer** boxes flash **less frequently!**



Sensors for heavier boxes flash at the same period

IMAGE: MICROSOFT (STOCK)

Richard Feynman

(Physics Nobel 1965)

You guess it!

Image: Joe Munroe / Hulton Archive / Getty

PARAMETERS VS DYNAMICAL VARIABLES

PROPERTIES OF THE SYSTEM VS THOSE REFLECTING STATES OF THE SYSTEM

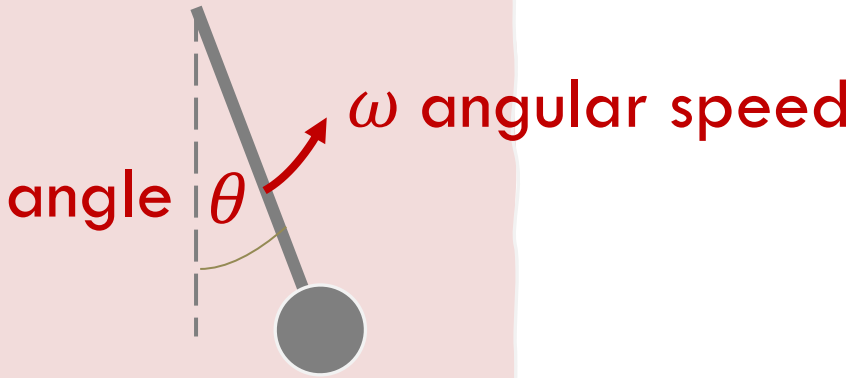
Parameter

Length L of a pendulum

(and mass)

Building Blocks

Something to reflect **states** of the system



A SIMPLE MODEL IS PREDICTIVE

IT'S EASIER TO FALSIFY A MODEL WITH FEWER PARAMETERS

Model 1

"It moves like a spring"

$$\text{Force} = -m\kappa(\text{angle})$$

Dimension

$$\text{Mass} \cdot \frac{\text{Length}}{\text{Time}^2}$$

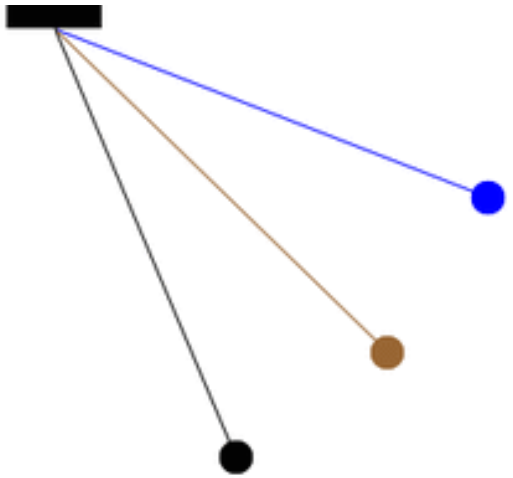
κ = some acceleration parameter that is forced to be introduced.

Underlying Theory (Mechanics)

Predictions

Period $T = 2\pi\sqrt{\frac{L}{\kappa}}$

independent of amplitudes



Lagrangian for Model 1

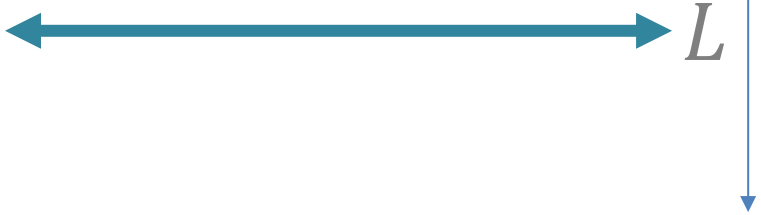
$$\mathcal{L}_1(\theta, \omega) = \frac{1}{2}mL^2\omega^2 - \frac{1}{2}m\kappa L\theta^2$$

WHAT TO MEASURE

NEED MEASUREMENTS THAT ALLOW "HYPOTHESIS TESTING"

Predictions

Period $T = 2\pi\sqrt{L/\kappa}$



L

Experiment

WHAT RELATIONSHIP TO PLOT

A PLOT CAN RELATE WHAT YOU EXPECTED AND WHAT YOU GET

Model predicts

$$T = 2\pi\sqrt{L/\kappa}$$

$$T^2 = \frac{4\pi^2}{\kappa} L$$

If the model (or hypothesis) were "not wrong", the data would align along a straight line in the T^2 vs L plot.

The data don't seem to align along a straight line!

Need more measurements?

What can go wrong!

Samples:
Groups of boxes having the same length.

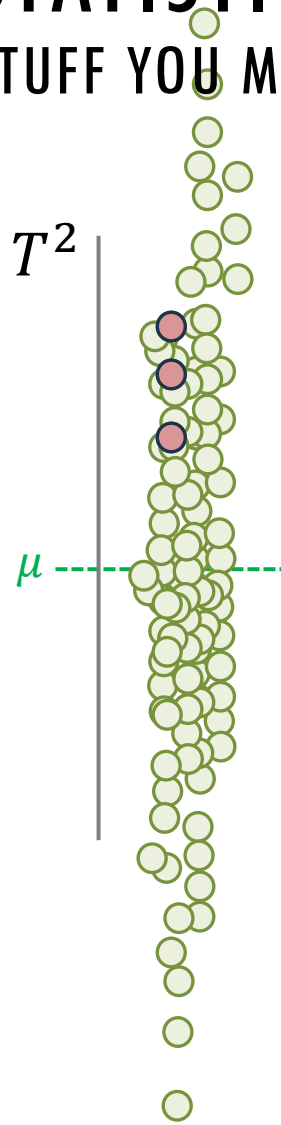
“ANYTHING THAT CAN GO WRONG WILL GO WRONG”

- MURPHY’S LAW

IMAGE: WIKIMEDIA COMMONS

STATISTICS DEALS WITH RANDOM STUFF

STUFF YOU MIGHT NEVER KNOW THE TRUE PROPERTIES



T^2

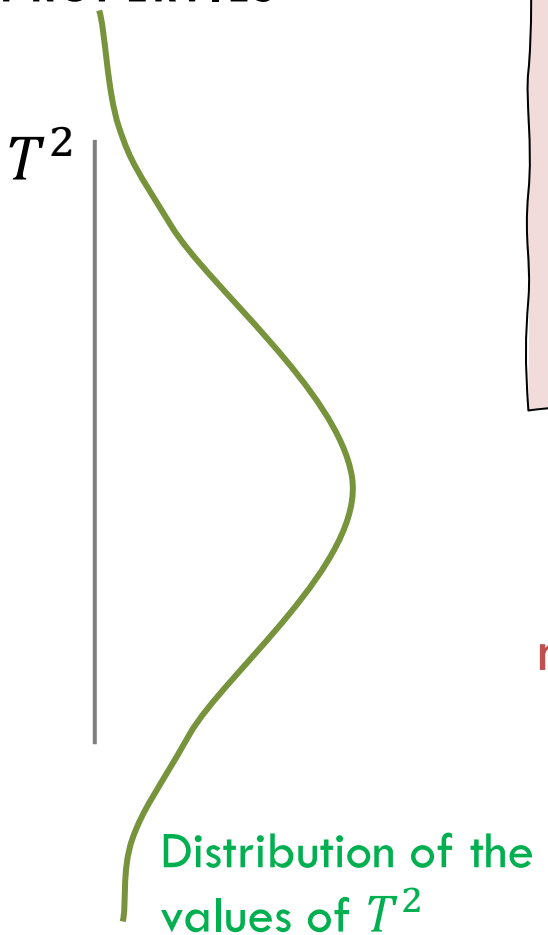
This is the **population** of T^2 from boxes of the same length

The **true** (population) average

μ

$$\mu = \frac{1}{N}[(T_1)^2 + (T_2)^2 + (T_3)^2 + \cdots]$$

Collected numbers from **all possible values** (population)



T^2

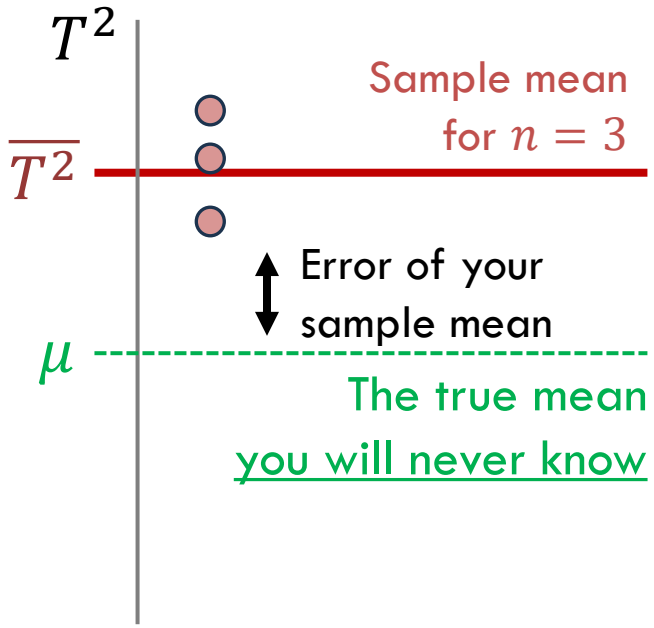
Distribution of the values of T^2

You may **never know** any of the true properties!

So we try to learn about the population by measuring **some samples.**

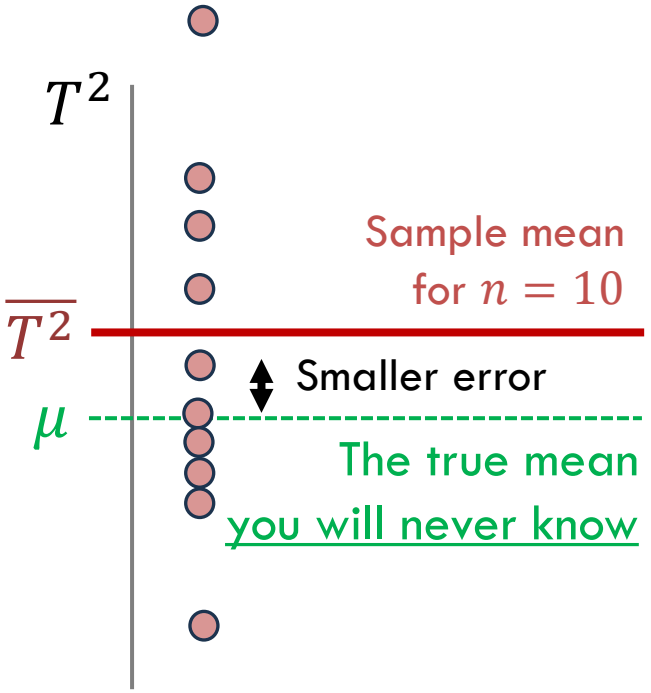
LARGER SAMPLE REPRESENTS THE POPULATION BETTER

ESTIMATES OF LARGER SAMPLE ARE CLOSER TO "TRUE" VALUES



$n = 3$

Sample



$n = 10$

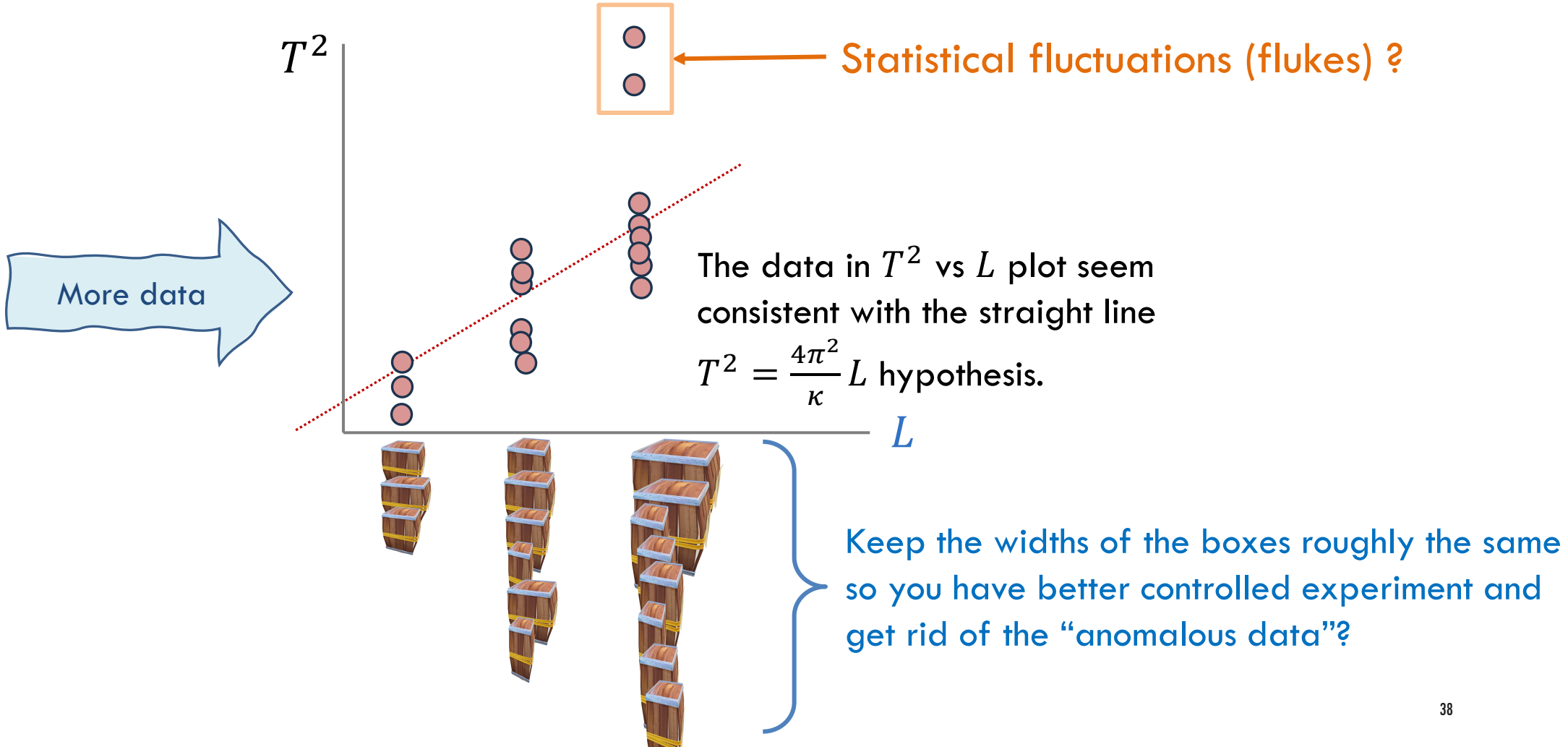
Sample

Error of sample mean

$$\propto \frac{1}{\sqrt{n}}$$

MORE DATA

HELP TEST HYPOTHESIS AND REVEAL FEATURES

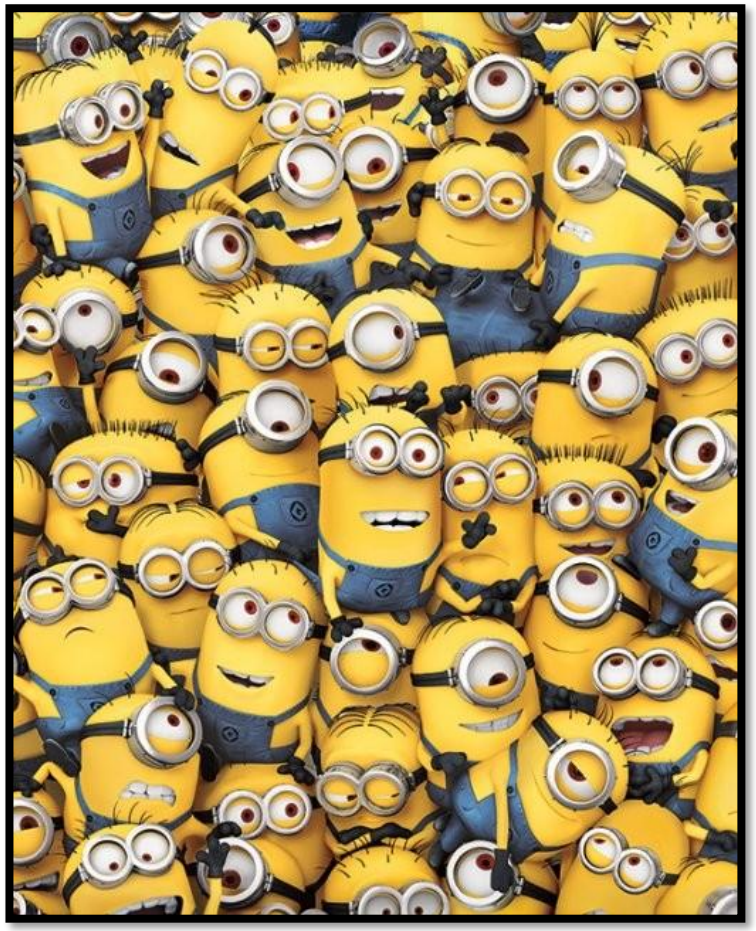


HOW TO IMPROVE YOUR MODEL USING EXPERIMENTS

SPEND TIME, SPEND MONEY, OR THINK VERY HARD

Time & Money

More data,
Better controlled,
Better precision



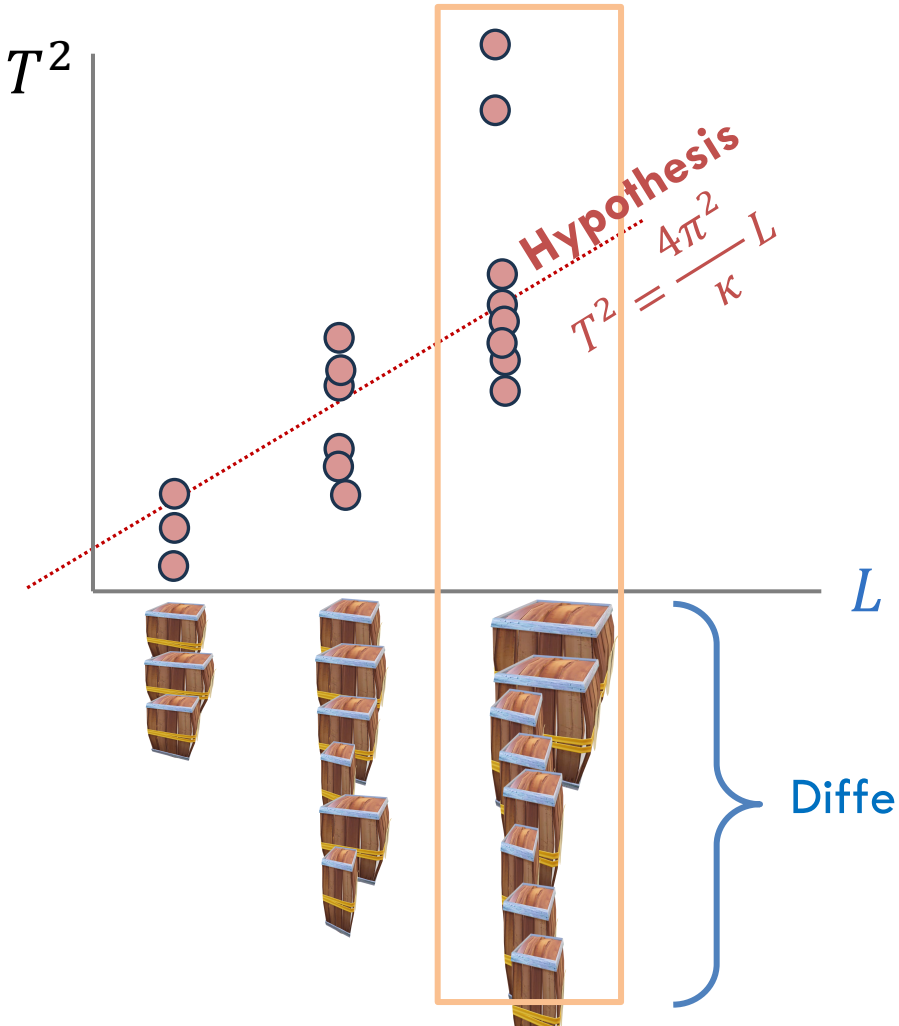
Design different experiments!
Need some "**test statistic**" to be measured and used to test hypothesis.

A THEORIST'S LESSON 101: TRY TO REJECT A HYPOTHESIS

(YOU CAN'T PROVE ONE ANYWAY)

ANOMALY IN THE DATA MAY LEAD TO A DISCOVERY

OR AT LEAST "CONSTRAINTS" PARAMETERS OF THE MODEL

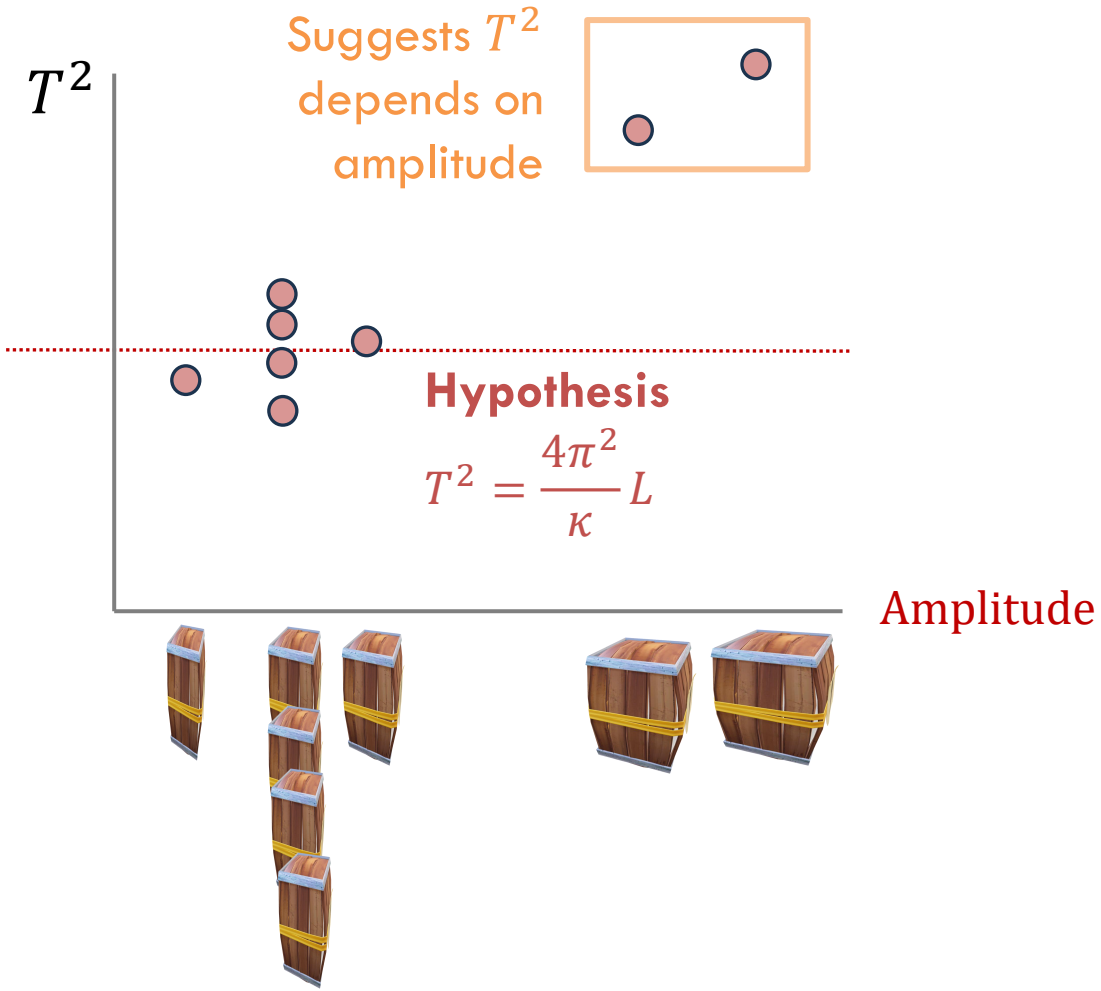


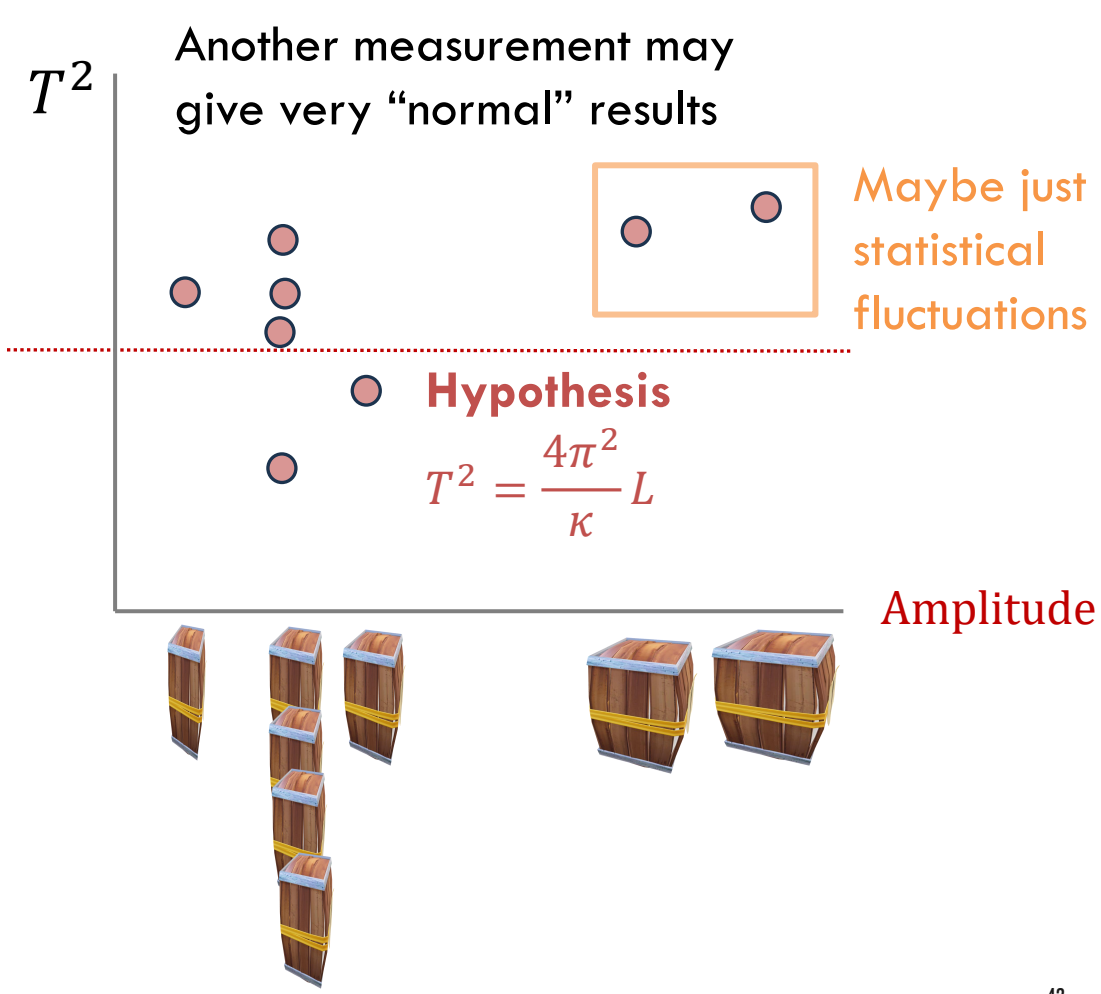
The original Hypothesis implies period does not depend on amplitudes.

Different widths = possibly different amplitudes?

STILL, A DISCOVERY OR JUST A FLUKE?

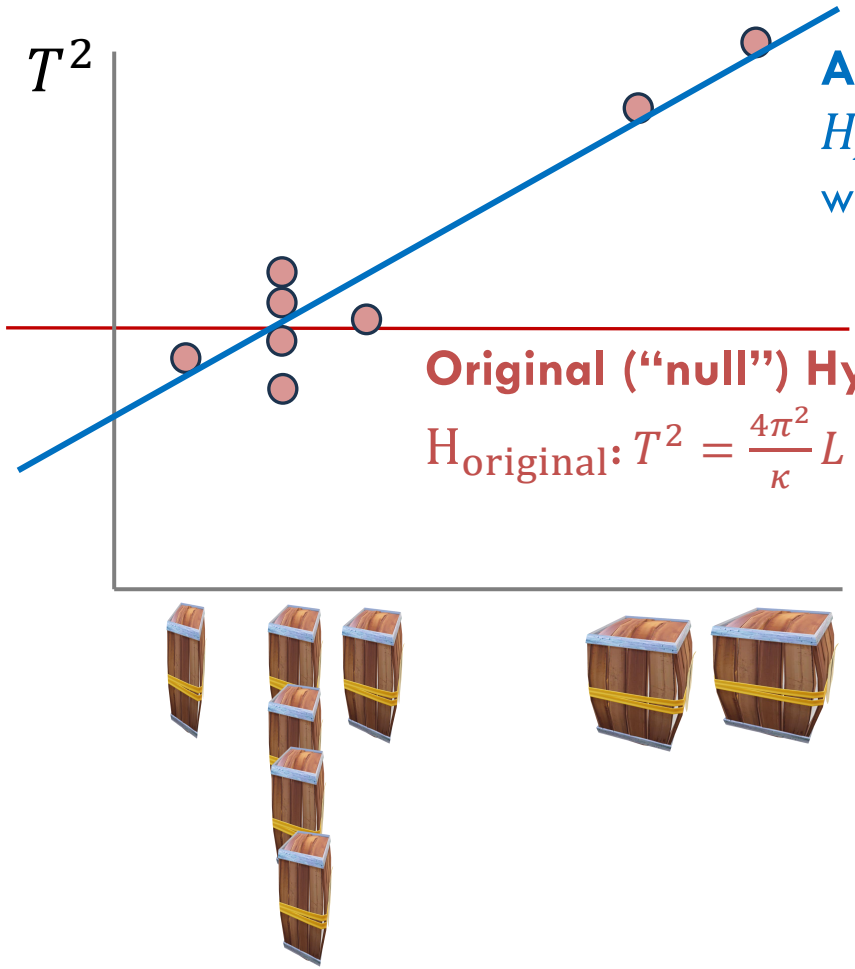
NEED TO QUANTIFY HOW UNLIKELY SOME WEIRD RESULTS ARE



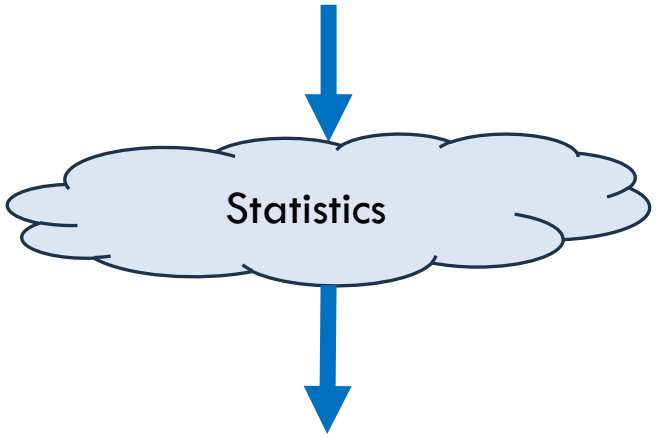


STILL, A DISCOVERY OR JUST A FLUKE?

NEED TO QUANTIFY HOW UNLIKELY SOME WEIRD RESULTS ARE



β (slope): also a random variable



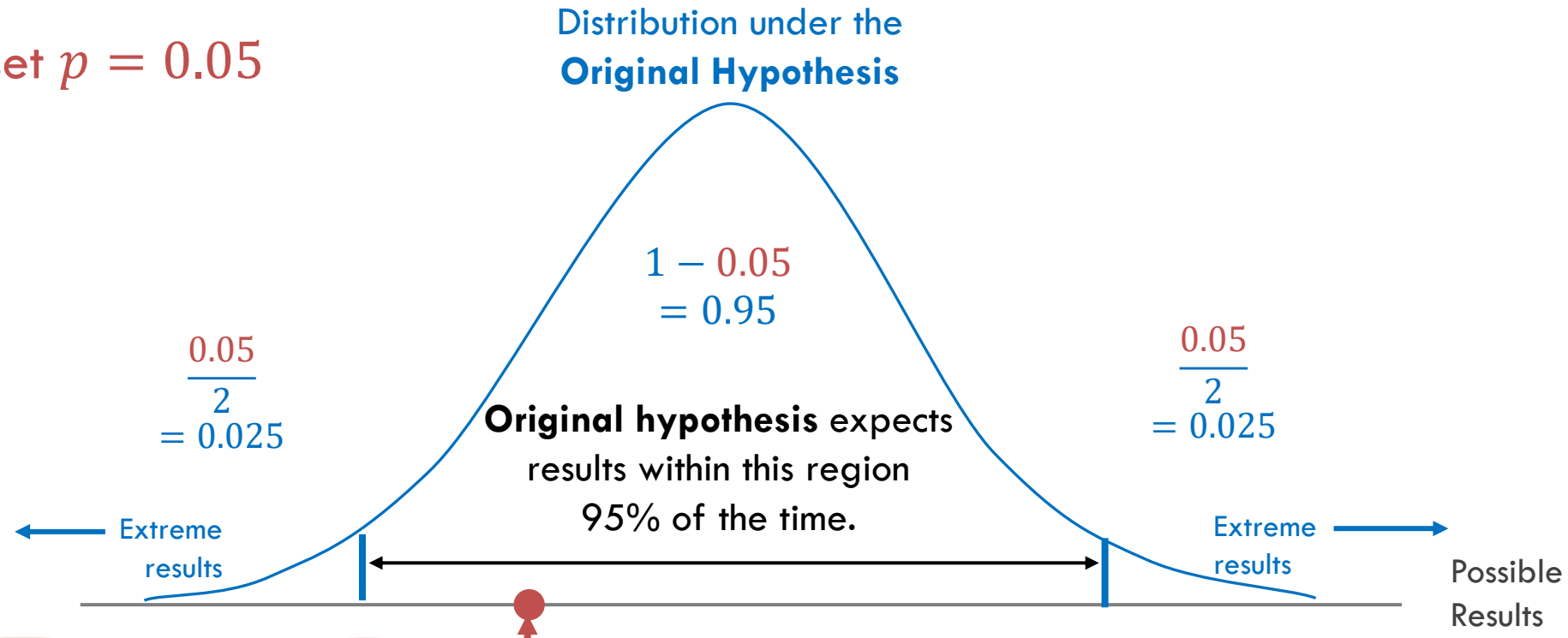
"p-value" for $\beta \neq 0$

tells **how likely** you are to **still observe a relationship** that strong between amplitude and T^2 **even if, in truth, no relationship exists.**

P-VALUE: HOW LIKELY IT IS A FLUKE

YOU KNOW TO WHAT DEGREE YOU CAN REJECT YOUR ORIGINAL HYPOTHESIS

Example: set $p = 0.05$

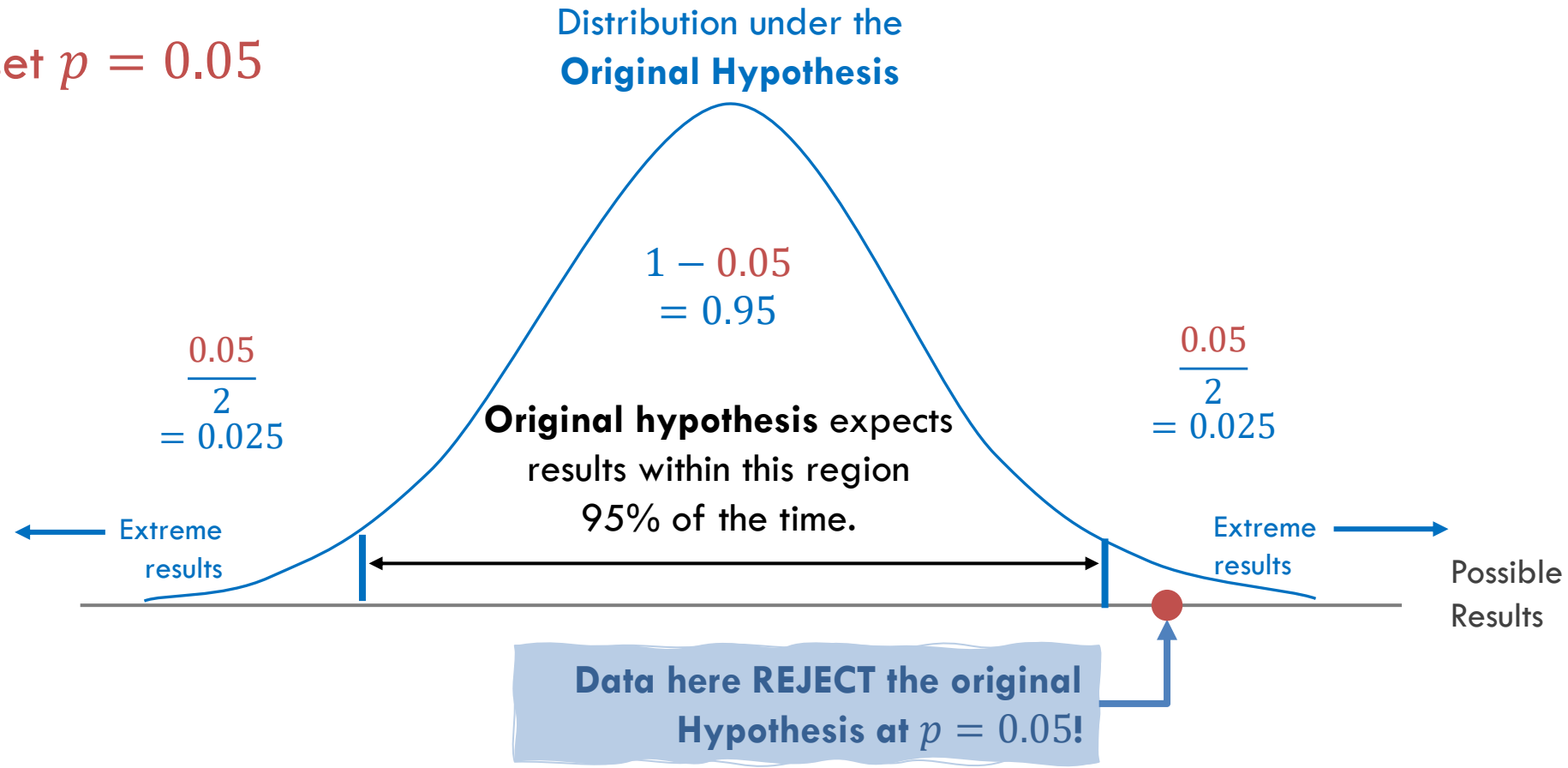


Data here FAILED TO REJECT the original Hypothesis at $p = 0.05$.

P-VALUE: HOW LIKELY IT IS A FLUKE

YOU KNOW TO WHAT DEGREE YOU CAN REJECT YOUR ORIGINAL HYPOTHESIS

Example: set $p = 0.05$



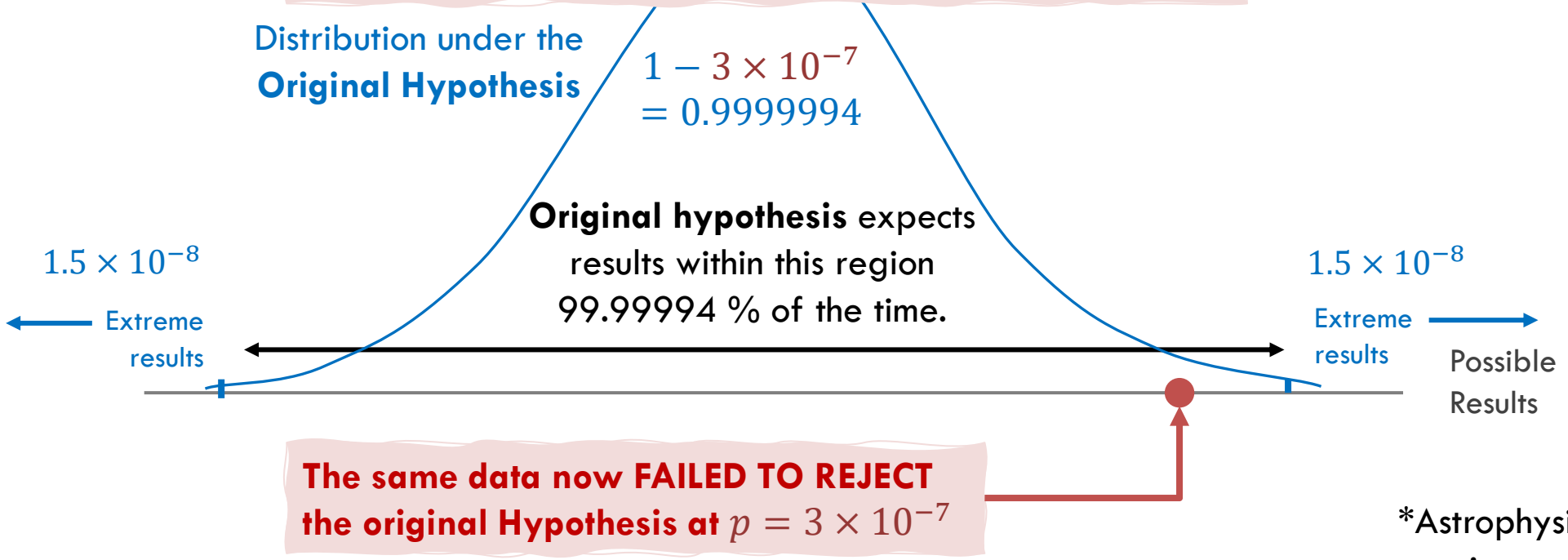
CLAIMING A DISCOVERY IN PARTICLE PHYSICS IS HARD

THE THRESHOLD FOR A "DISCOVERY" DEPENDS ON FIELD OF STUDY

Particle Physics

A **"discovery"** requires $p < 3 \times 10^{-7}$!!!!

(also known as a "**5-sigma**" level)

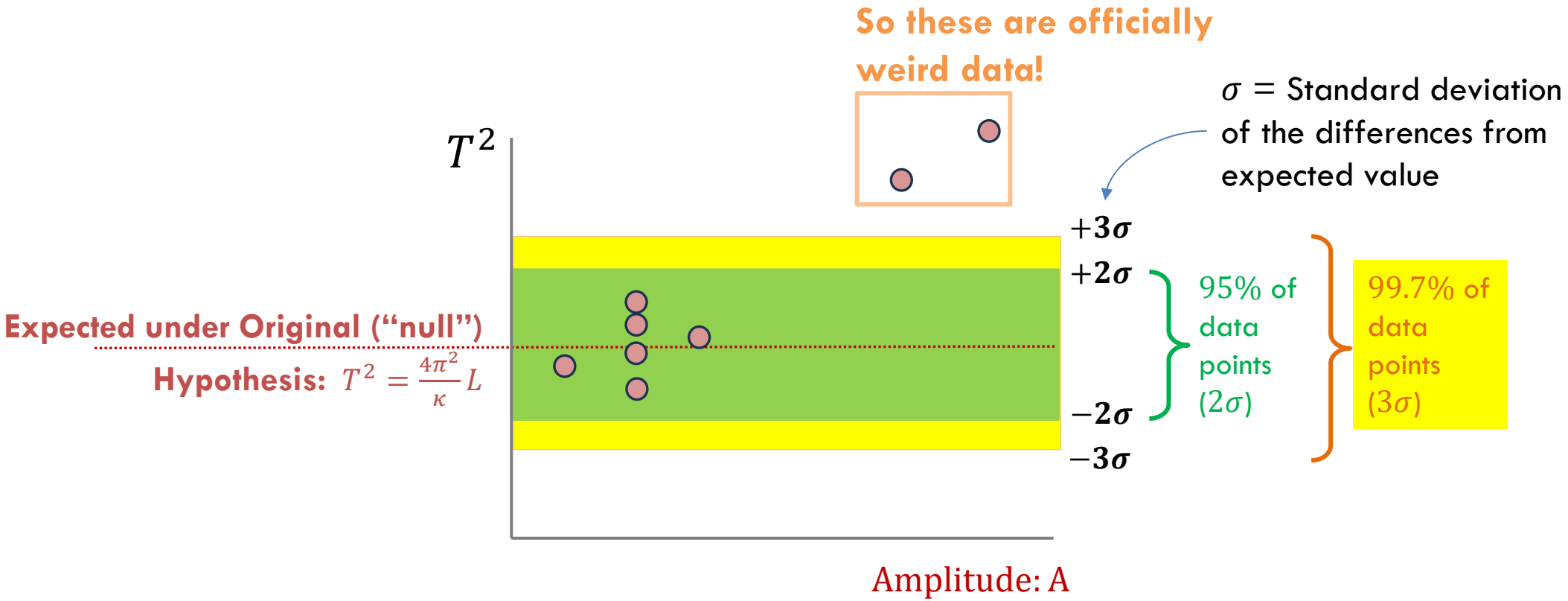


The same data now FAILED TO REJECT the original Hypothesis at $p = 3 \times 10^{-7}$

*Astrophysics, medicines require $p < 0.05$

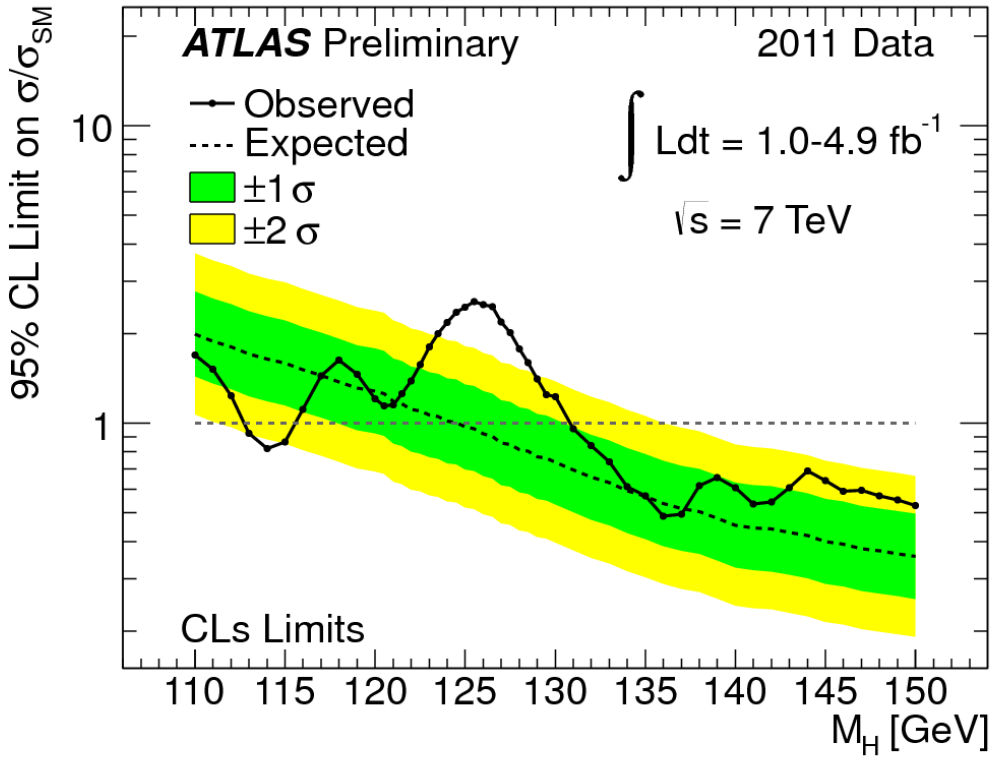
STILL, A DISCOVERY OR A JUST A FLUKE?

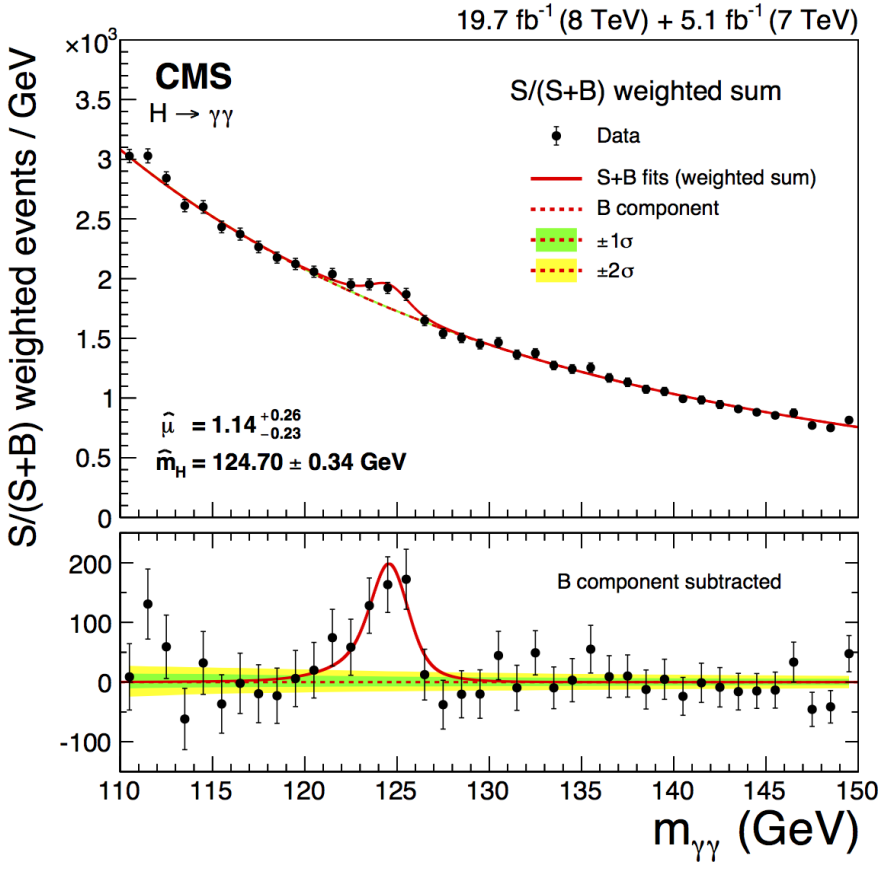
ANOTHER WAY TO ILLUSTRATE: "BRAZILIAN BAND CONFIDENCE INTERVALS"



EXAMPLE OF AN ACTUAL DISCOVERY

ANOTHER WAY: "BRAZILIAN BAND CONFIDENCE INTERVALS"





Statistics involved in these Higgs discovery are way more sophiscitated than what we talked about. But you get some ideas.

Now that we can happily reject the original hypothesis…

How to actually improve your model?

You guess it!

Image: Joe Munroe / Hulton Archive / Getty

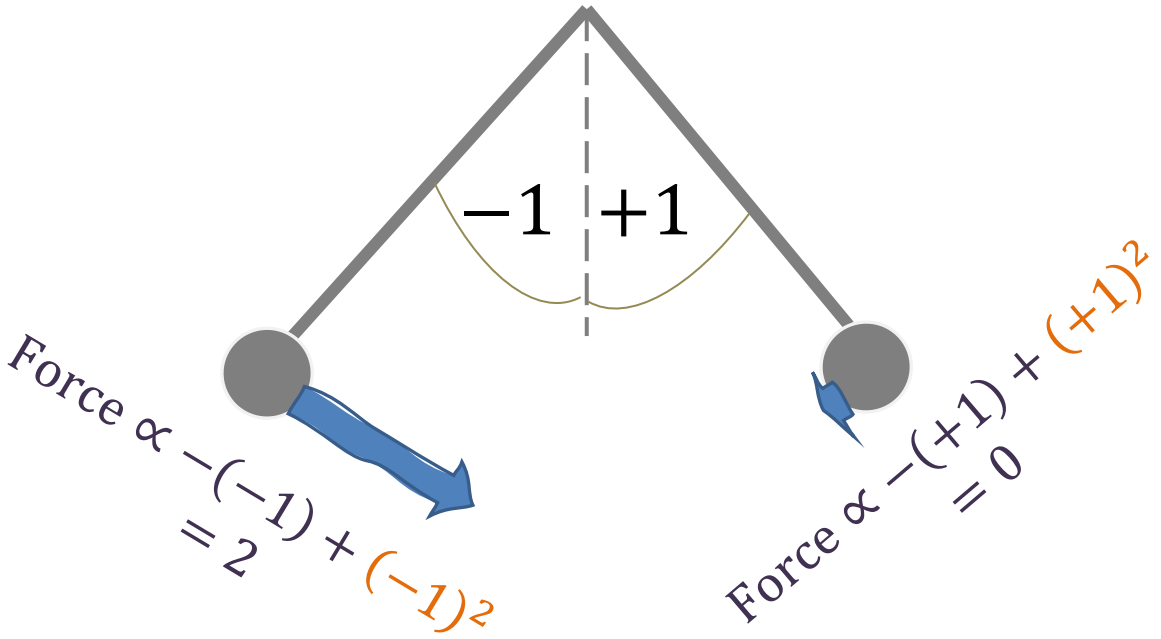
NOT-SO-SMART GUESS

AN INFINITE KINDS OF TERMS ARE POSSIBLE

Model 2

Add funny spring effect

$$F \propto -\theta + \theta^2$$



Predicts different results when swinging left (angle) or right (−angle) !

Lagrangian for Model 2

$$L_2(\theta, \omega) = \frac{1}{2} mL^2\omega^2 - \frac{1}{2} mkL\theta^2 + \gamma\theta^3$$

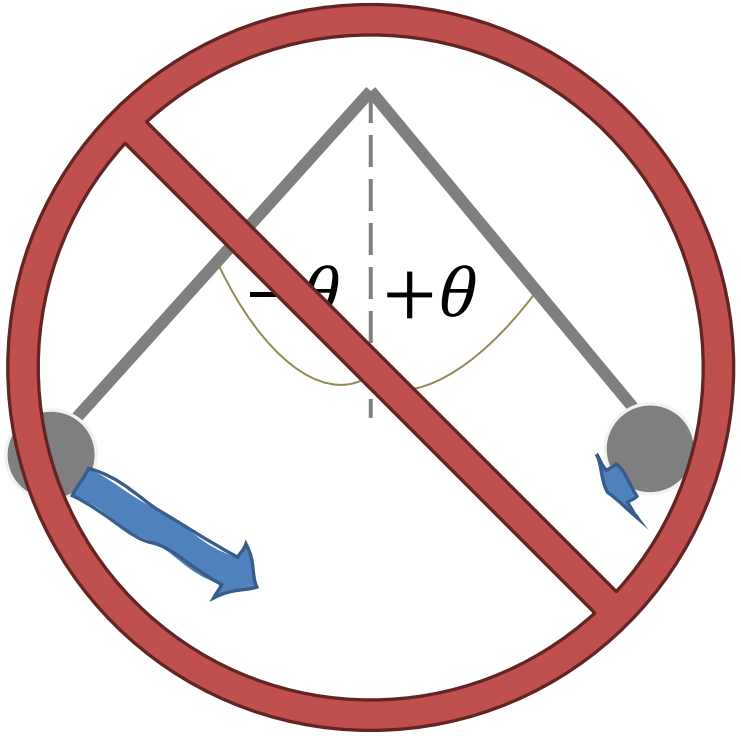
MAKE EDUCATED GUESS WITH SYMMETRY ARGUMENTS

SYMMETRY FORBIDS INTERACTION TERMS VIOLATING THAT SYMMETRY

Symmetry argument:
nature should be "left-right" symmetric

$$F \propto -\theta - \theta^2 + \theta^3 + \theta^4 + \theta^5 + \cdots$$

Our symmetry argument implies
all even powered terms in force disappear!



EXTRA TERMS AS "PERTURBATIONS" TO KNOWN MODEL

EXPLORE SLIGHTLY NEW PROBLEM USING OLD KNOWLEDGE THAT IS KNOWN TO WORK

Model 3

Add another funny spring effect

$$F \propto -\theta + \theta^3$$

Model 1 already did a reasonably good job

So the extra bits can't be too "important"

Model 3α

*Make the extra effect **small***

$$F \propto -\kappa\theta + \alpha\theta^3$$

Need more experiment to determine that **small parameter** α

BETTER MODEL/EXPERIMENTS PROBE MORE STRUCTURES

WHETHER YOU CAN UNDERSTAND THEM IS ANOTHER STORY

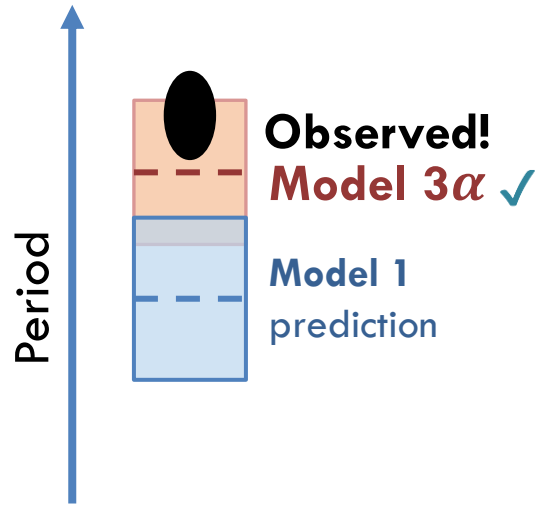
Model 3α

*Add "**small**" funny spring effect*

$$F \propto -\kappa\theta + \alpha\theta^3$$

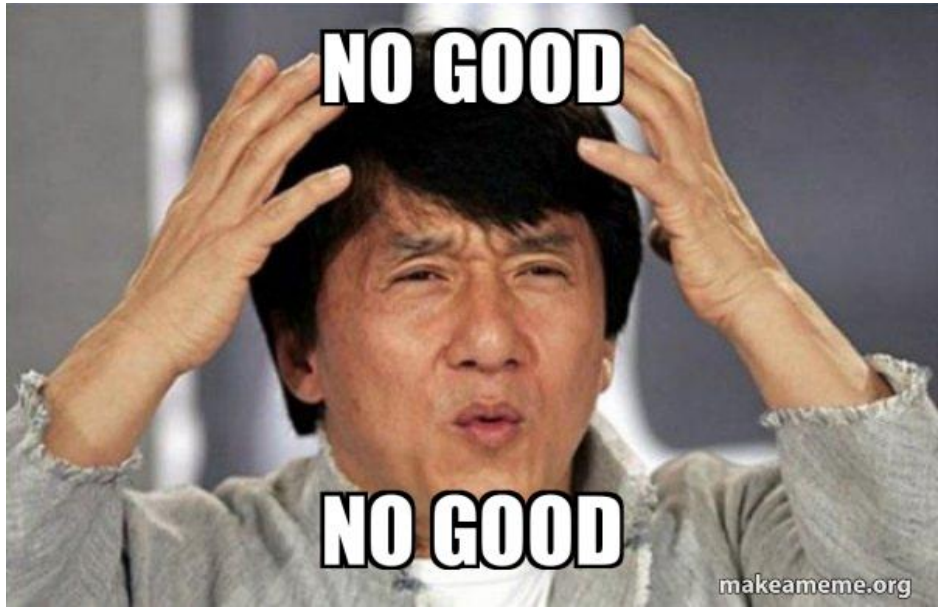
$$T = 2\pi\sqrt{\frac{L}{\kappa}} + 2\pi\sqrt{\frac{L}{\kappa}}\frac{3}{8}\alpha(\text{Amplitude})^2$$

Model 2



Implies a spring with some Length and Amplitude with that mysterious parameter $\alpha \approx \frac{1}{6}$ found from experiments

Improving your model this way definitely
needs lots of parameters!



But sometimes, it's the only way we know …

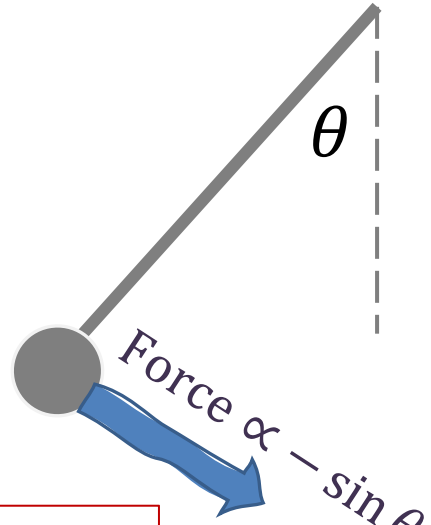
THEORISTS ALSO BUILD MODELS "TOP-DOWN"

BUILDING MORE FUNDAMENTAL INTERACTION MODEL FROM MORE-EDUCATED GUESS

Model S

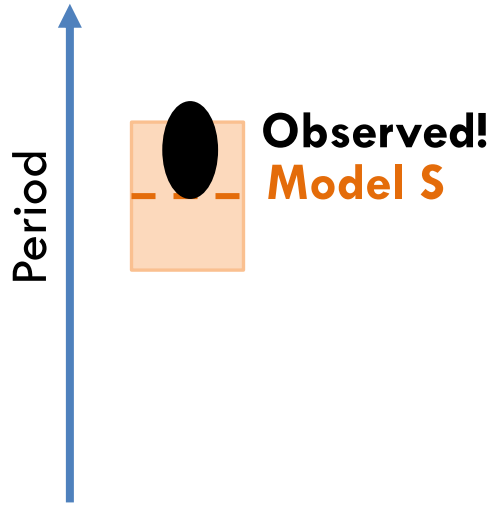
A gift from Trigonometry

$$F = -mg\sin\theta$$



Predicted automatically !

$$T = 2\pi\sqrt{\frac{L}{g}}\left(1 + \frac{1}{16}(\text{Amplitude})^2 + \frac{11}{3072}(\text{Amplitude})^4 + \cdots\right)$$

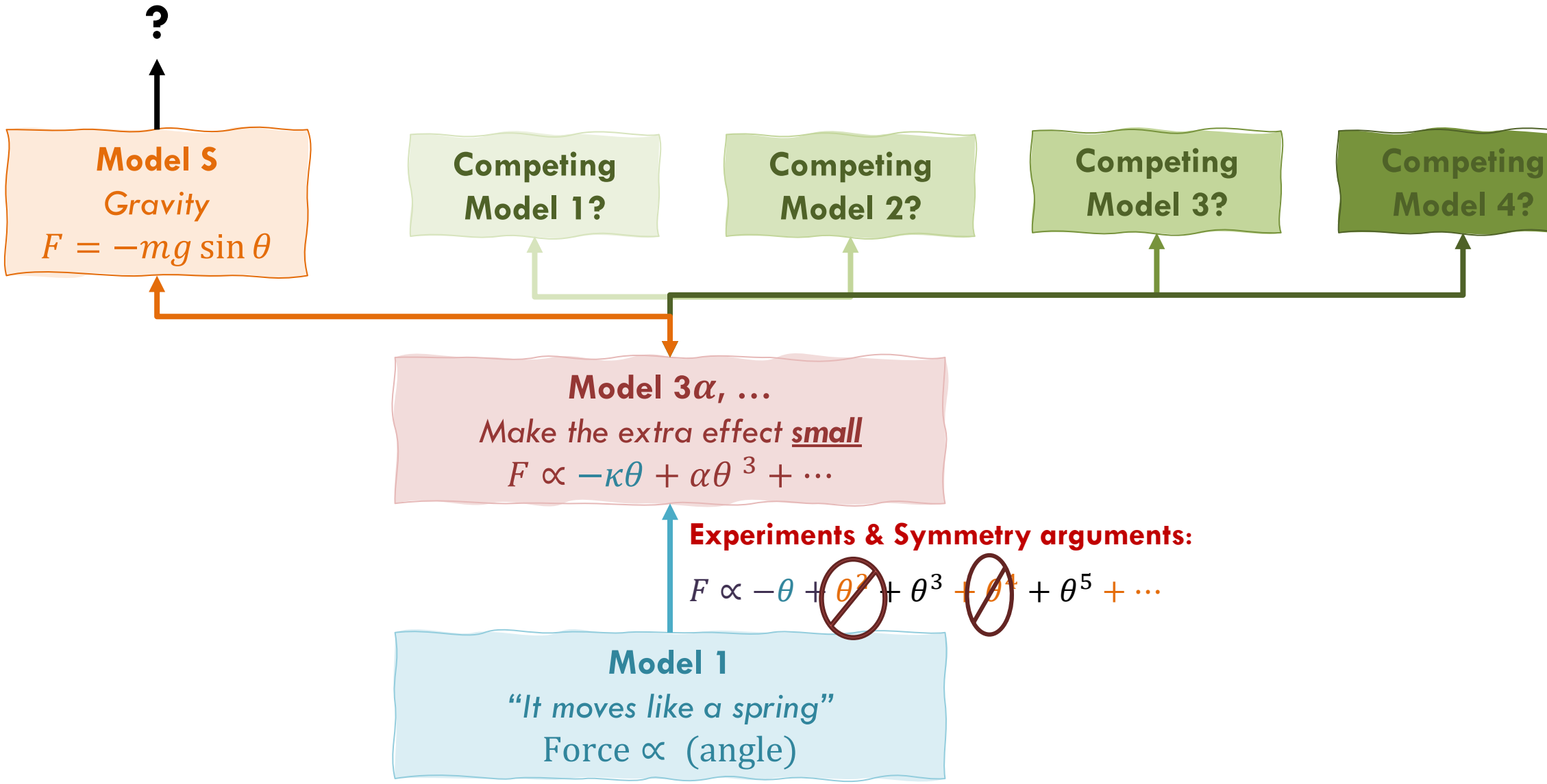


Model S: A pendulum of length L and finite amplitude with **very few parameters**

A MODEL WITH FEWER PARAMETERS IS MORE PREDICTIVE

(EASIER TO FALSIFY)

ROADS CARVED BY "EFFECTIVE THEORY"



"NEW PHYSICS"?

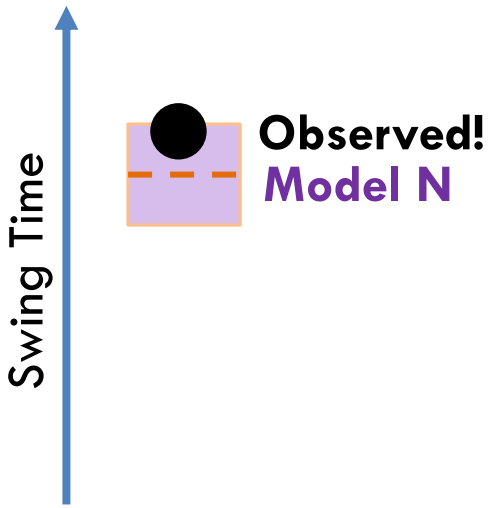
Model N

Contribution from New Physics (Wind, Heat, …?)

$F \propto -\sin\theta + \textbf{New stuff?}$

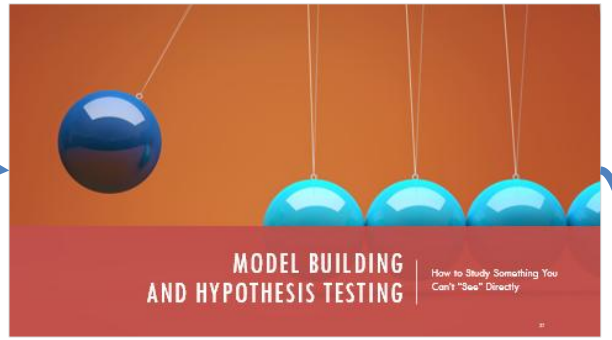
$$T = 2\pi\sqrt{\frac{L}{g}}\left(1 + \frac{1}{16}(\text{Amplitude})^2 + \frac{11}{3072}(\text{Amplitude})^4 + \cdots\right)$$

$$+ \boldsymbol{NP1}\ \textbf{(wind)} \qquad + \boldsymbol{NP2}\ \textbf{(heat)} \qquad + \boldsymbol{NP3}\ \ldots\ (\ldots)$$



Hints for even further discoveries could come from more/better experiments.

OVERVIEW
OF MY TALK



FIELDS AND PARTICLES

or things particle physicists should have told you earlier

SAME ELECTRONS THROUGHOUT THE UNIVERSE?

A SEEMINGLY PHILOSOPHICAL QUESTION IS SOMETIMES USEFUL

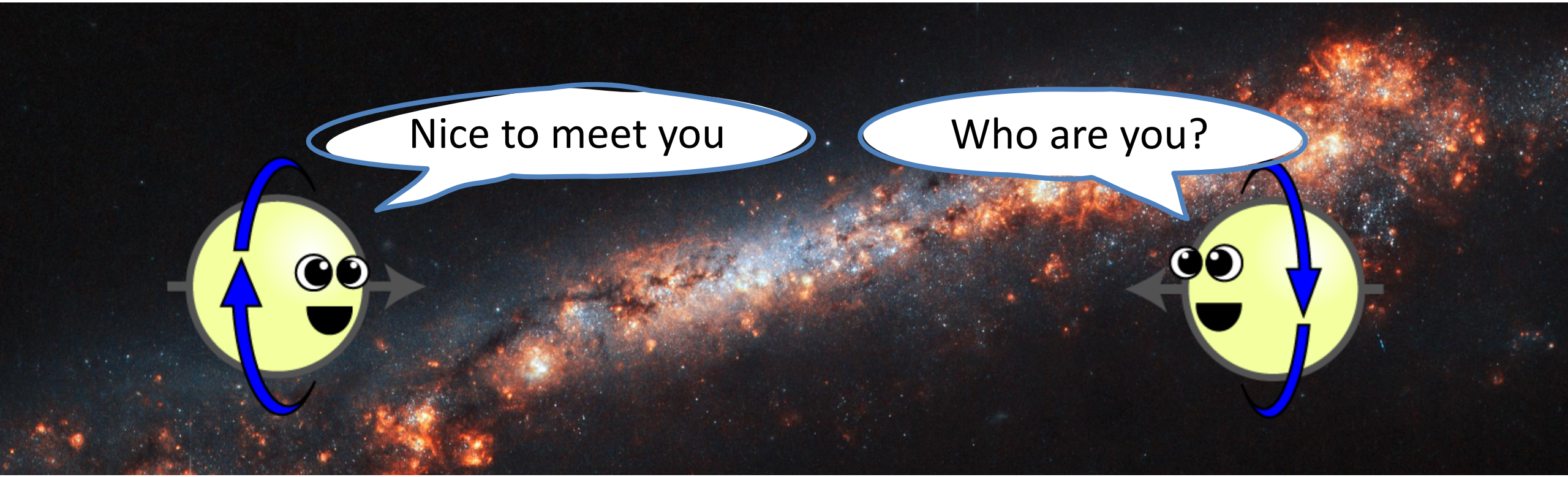


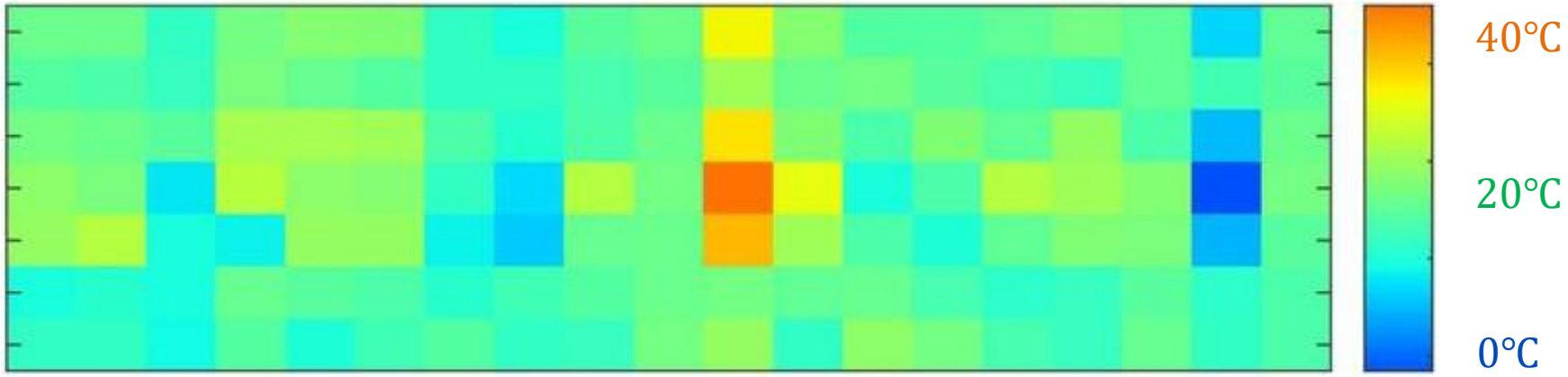
Image: Flip Tanedo / NASA

EVERYTHING IS MADE OF FIELD

WHAT IS A FIELD?

An extended object having different values in different places and times.

Temperature Field



FIELDS IN PARTICLE PHYSICS

EXTREME CARE IS NEEDED TO DESCRIBE PHYSICAL FIELDS

Fields are fundamental and are everywhere.

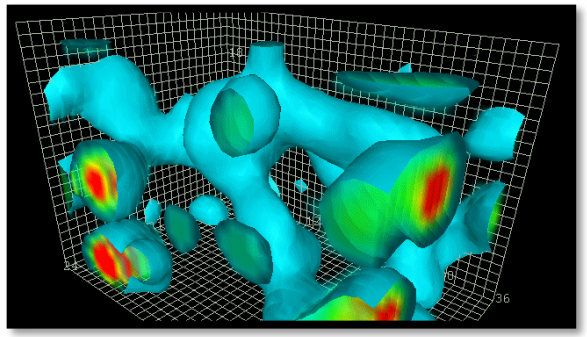
Need to agree with relativity and
quantum principles.

THEN WHAT IS A PARTICLE?

NEED A MATHEMATICAL PRESCRIPTION TO DESCRIBE A PARTICLE OUT OF A FIELD

Quantum Principles:

Nothing sits still: Empty space has residual "quantum fluctuations" of fields



Some fields "vibrate more" in a "chunk" only if there is **minimum energy.**

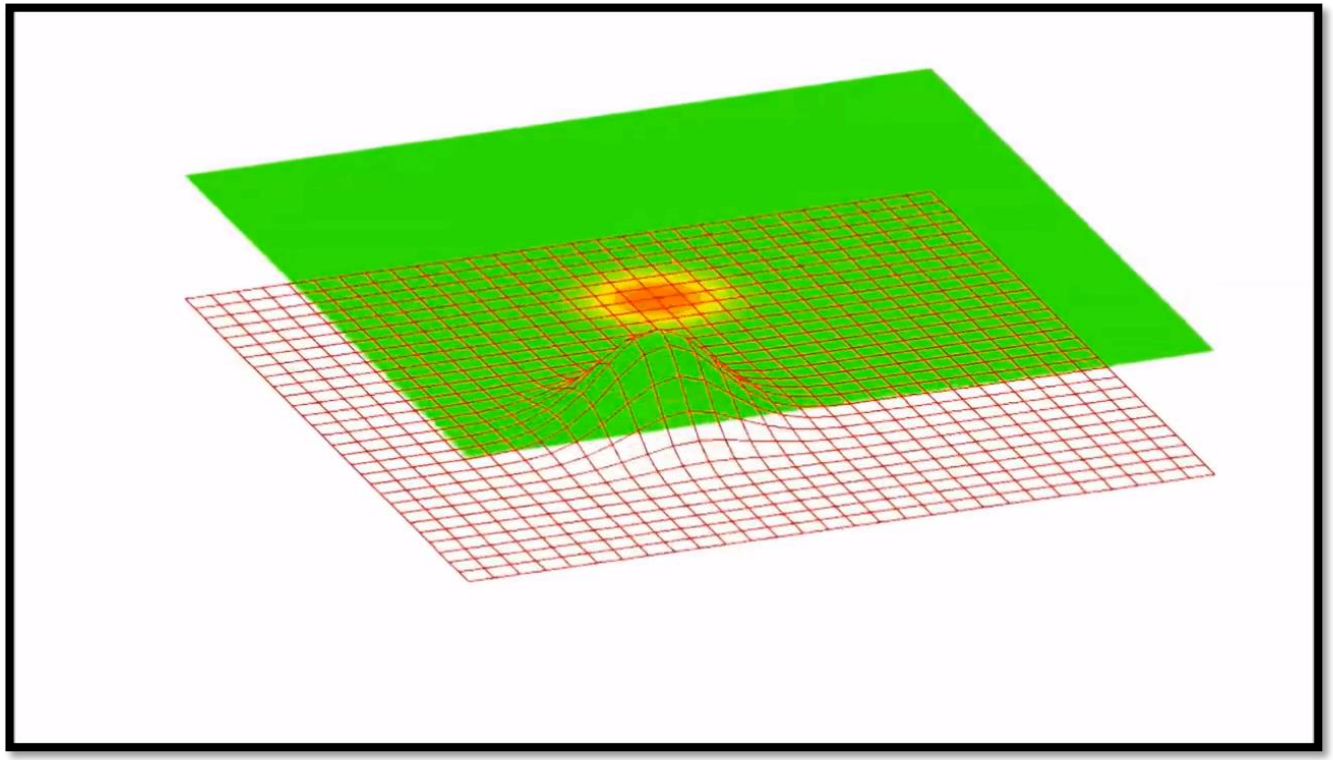
Mass of the "Particle"

Quantum of vibrations (field quantum)

"Particle"

FIELD QUANTUM OF A MASSIVE PARTICLE

EXCITATION PROPAGATES SLOWER THAN SPEED OF LIGHT



* Concepts of mass of field quanta are different in free theory, interacting theory, bound states, etc.

VIDEO: FERMILAB (YOUTUBE)

THINGS WE *OBSERVE AS PARTICLES* ARE LOCAL EXCITATIONS OF FIELDS

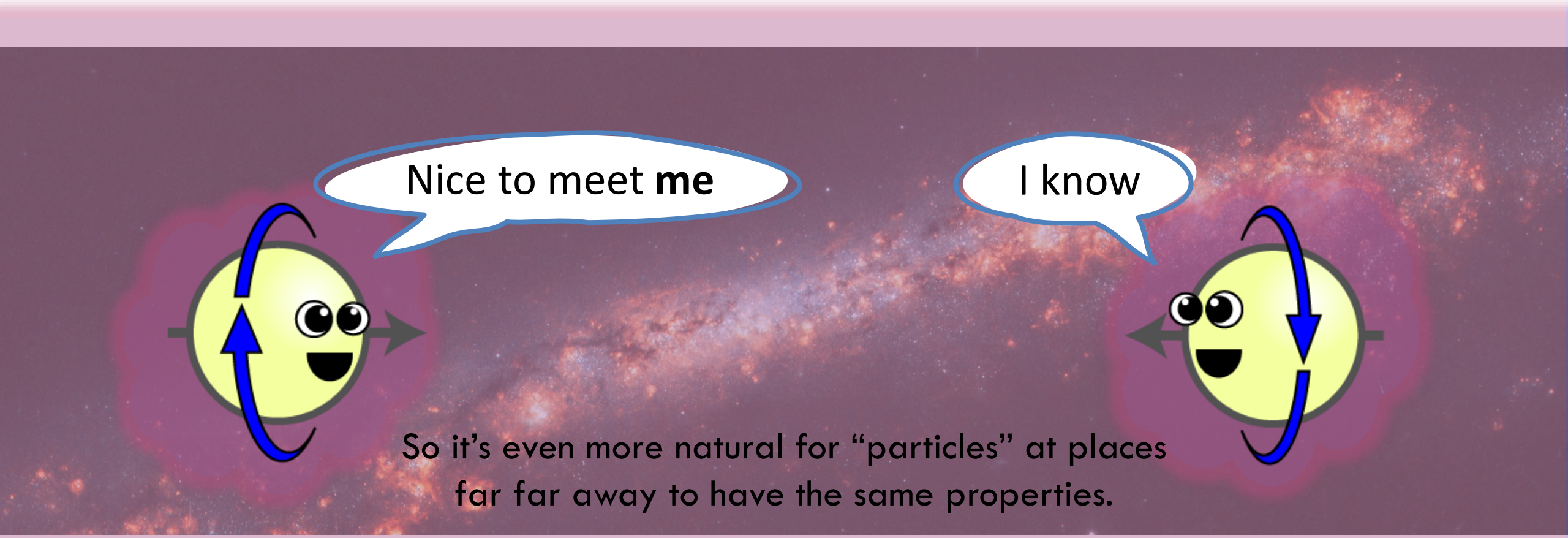
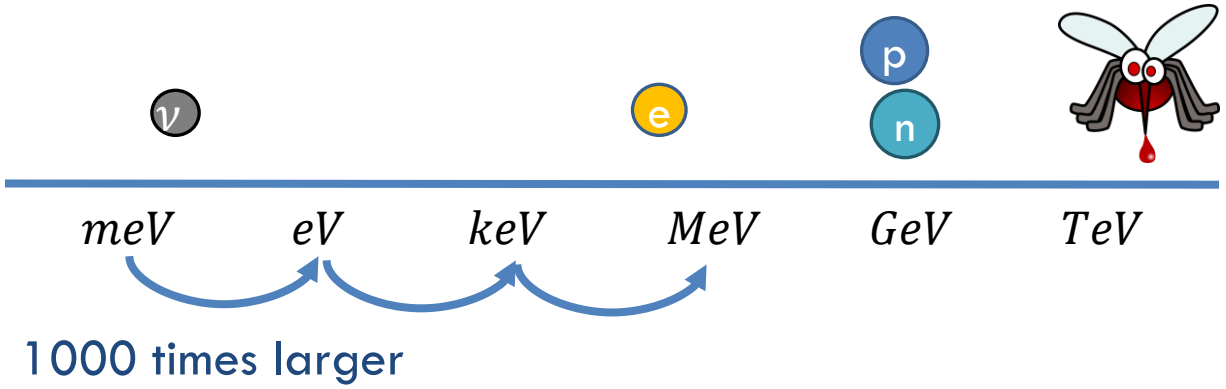


Image: Flip Tanedo / NASA

ENERGY NEEDED TO EXCITE SOME FIELDS YOU KNOW

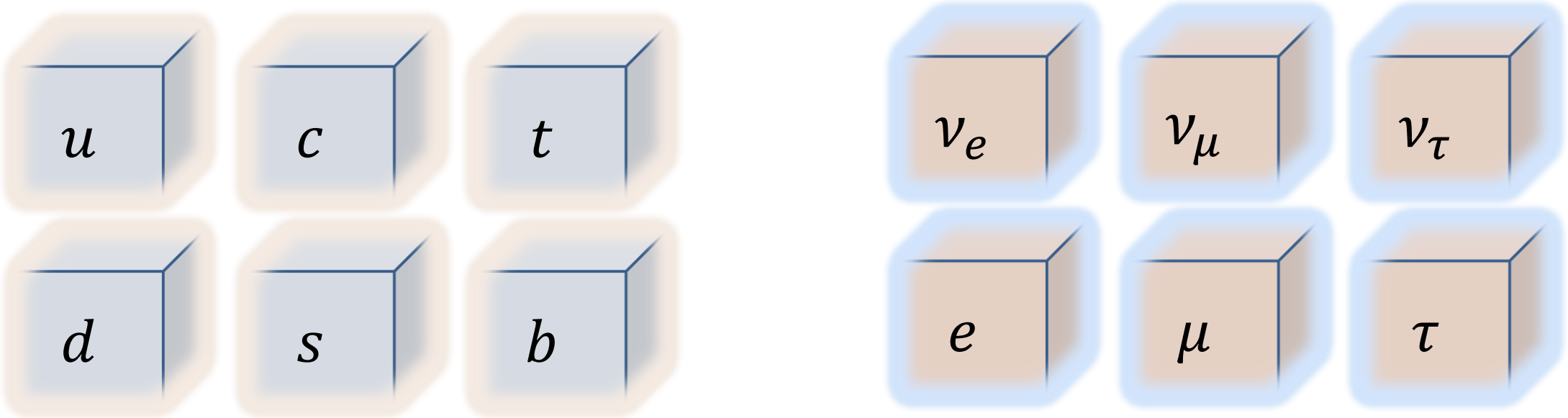
BUT REMEMBER THE ENERGY IS CONDENSED INTO A SUPER SMALL REGION

In a unit called "**electronvolt**"



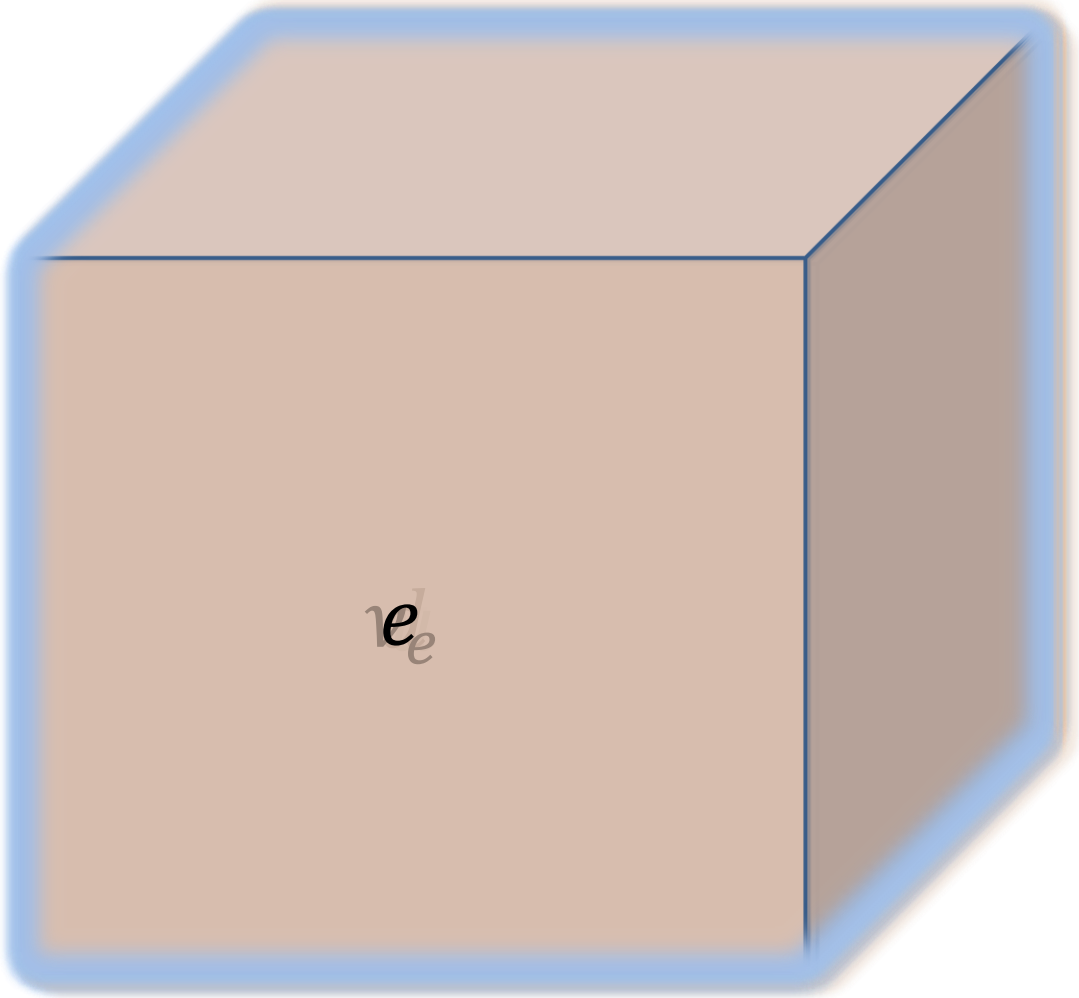
MATTER FIELDS FILL THE UNIVERSE

"FERMIONIC" FIELDS DESCRIBE MATTER



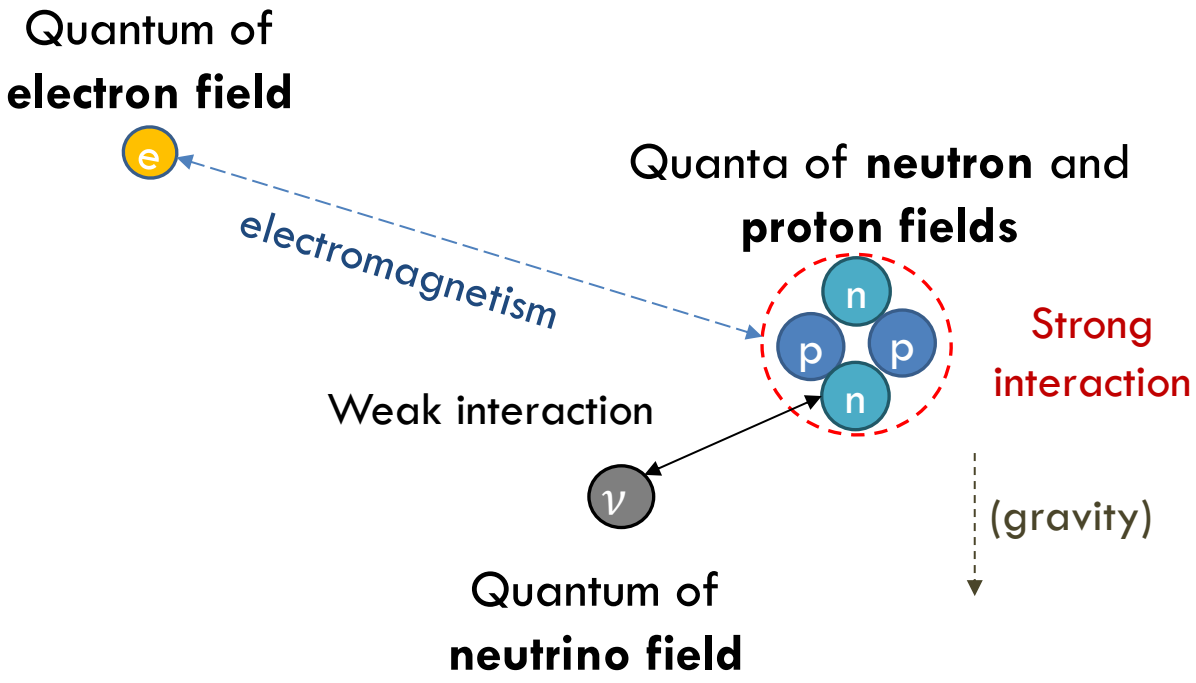
MATTER FIELDS FILL THE UNIVERSE

BUT WITHOUT INTERACTIONS, THEY CAN'T "SEE" ONE ANOTHER



FIELDS ARE THE "TOOLS" TO EXPLAIN PARTICLES

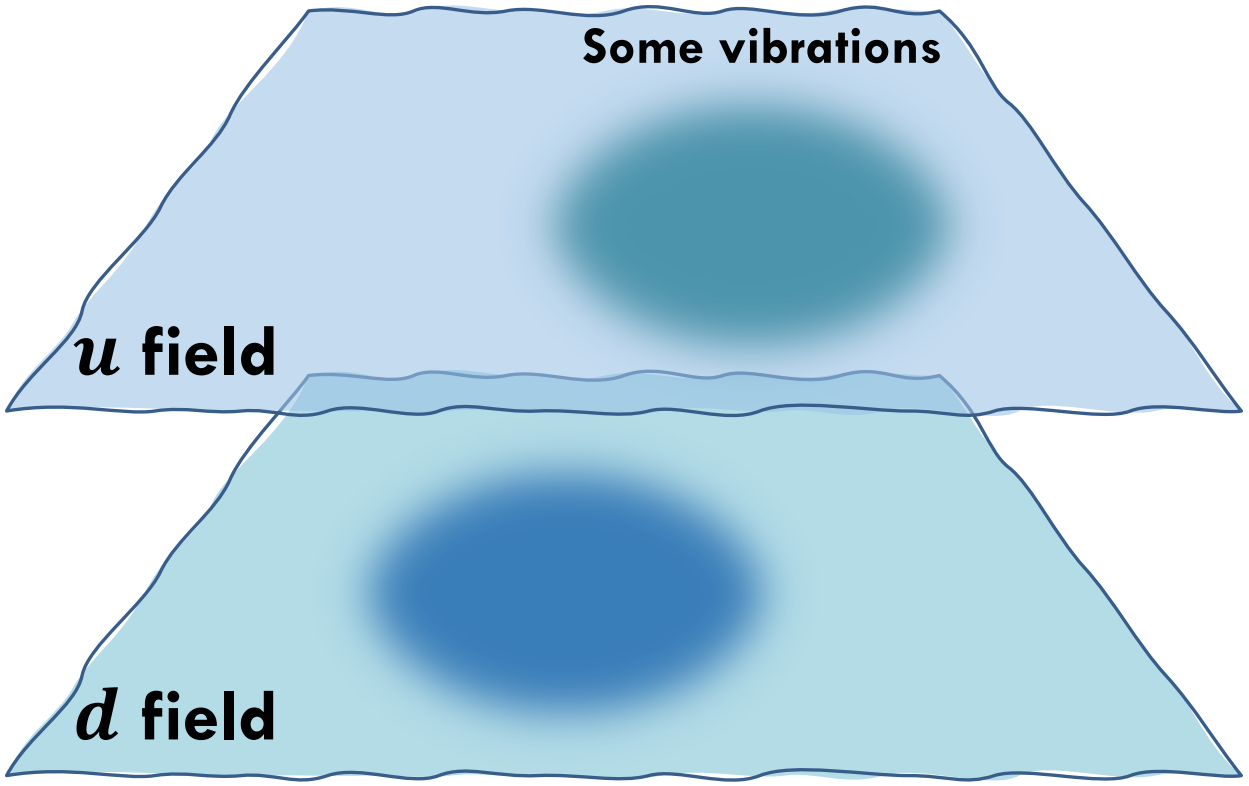
BUT THEY DEFINITELY NEED TO INTERACT



But how do we describe fundamental interactions?

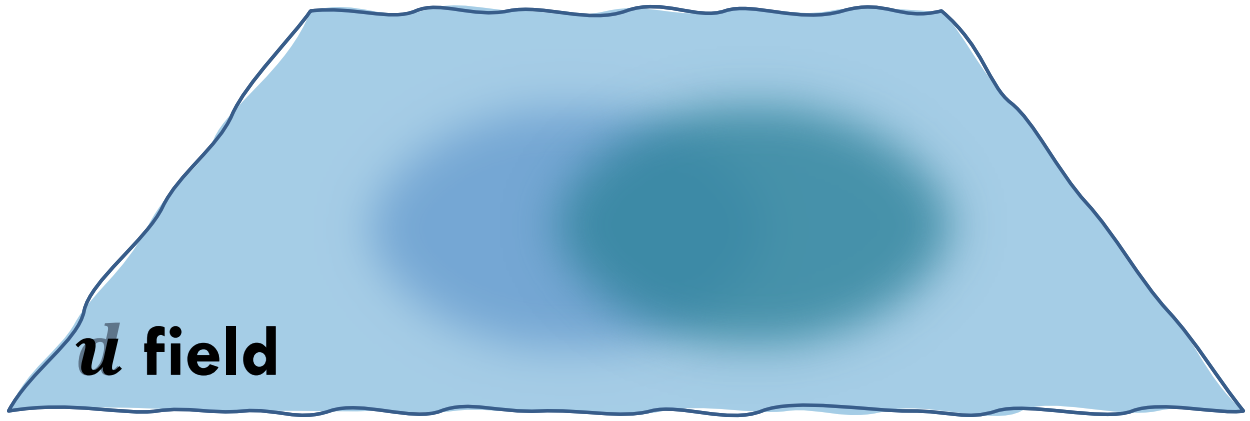
NEED MODELS FOR INTERACTING FIELDS!

MODEL MUST ALLOW VALUE OF ONE FIELD TO AFFECT ANOTHER AT THE SAME POSITION



NEED MODELS FOR INTERACTING FIELDS!

MODEL MUST ALLOW VALUE OF ONE FIELD TO AFFECT ANOTHER AT THE SAME POSITION

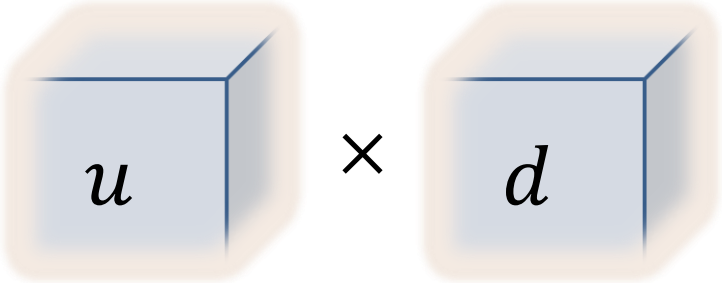


Interactions happen when fields “talk” to each other.

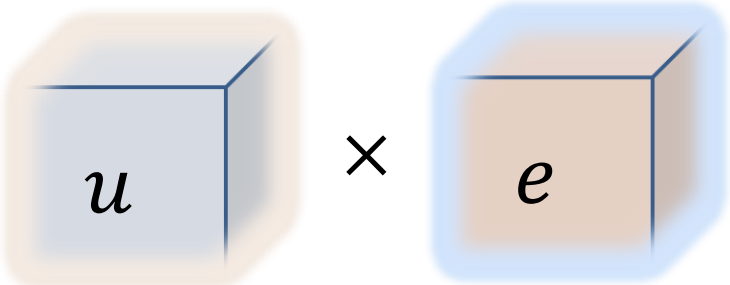
MODEL: HOW TO MAKE FIELDS INTERACT

PRODUCTS OF FIELDS IN THE LAGRANGIAN IMPLY INTERACTIONS

"Interaction terms" in the Lagrangian for fields

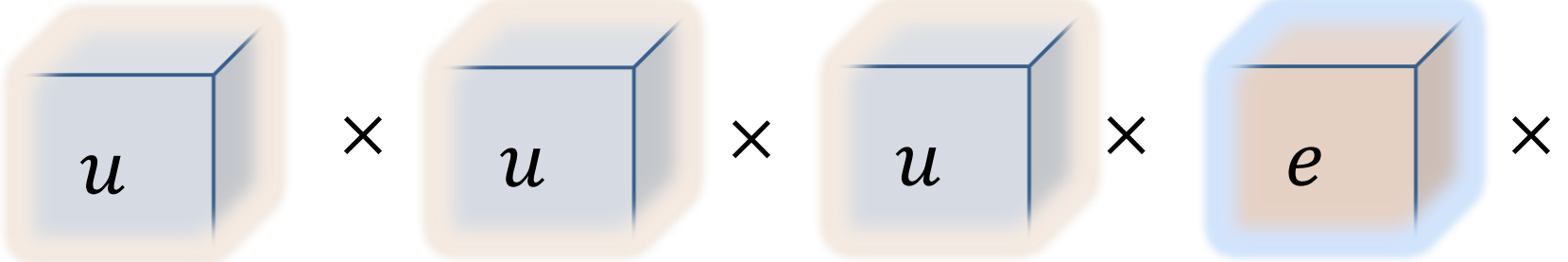


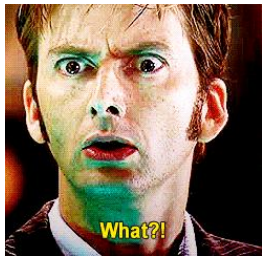
$\bar{\psi}_u(x)\psi_d(x)?$



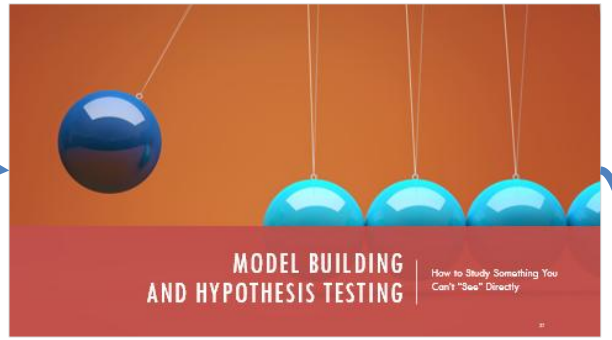
$\bar{\psi}_u(x)\psi_e(x)?$

Rules must not break Quantum Mechanics, Special Relativity… and NATURE!!





OVERVIEW
OF MY TALK

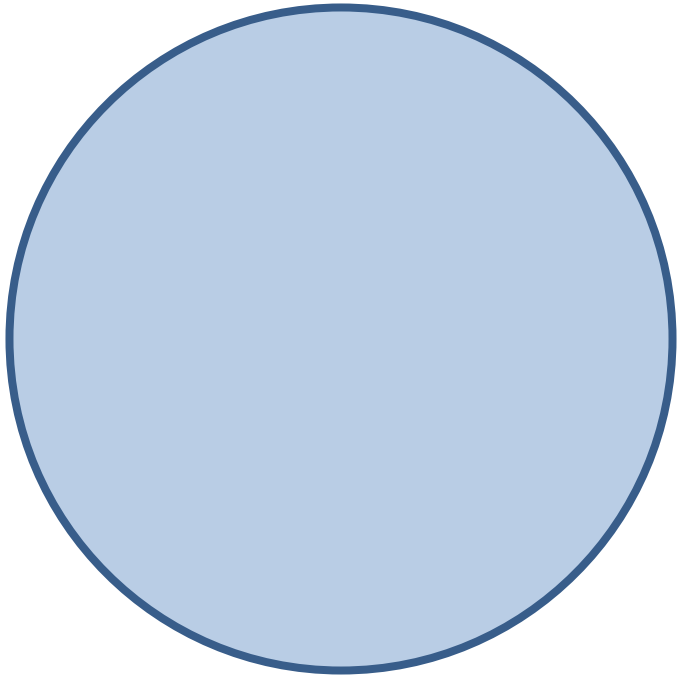


INTERACTIONS BETWEEN FIELDS AND THE STANDARD MODEL LAGRANGIAN

or a set of rules explaining what's going on between fields

SYMMETRY: SAMENESS UNDER A CERTAIN CHANGE

OR INVARIANCE UNDER A CERTAIN MATHEMATICAL TRANSFORMATION



SYMMETRY IN PHYSICAL LAWS

TRANSFORMATIONS DON'T NEED TO BE GEOMETRIC

$$a = \frac{\sum F}{m}$$

Rotation

$$\frac{w}{\sum F} = v$$

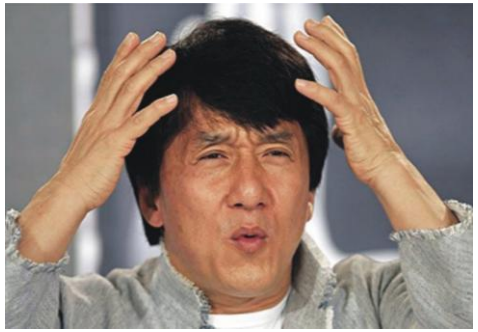
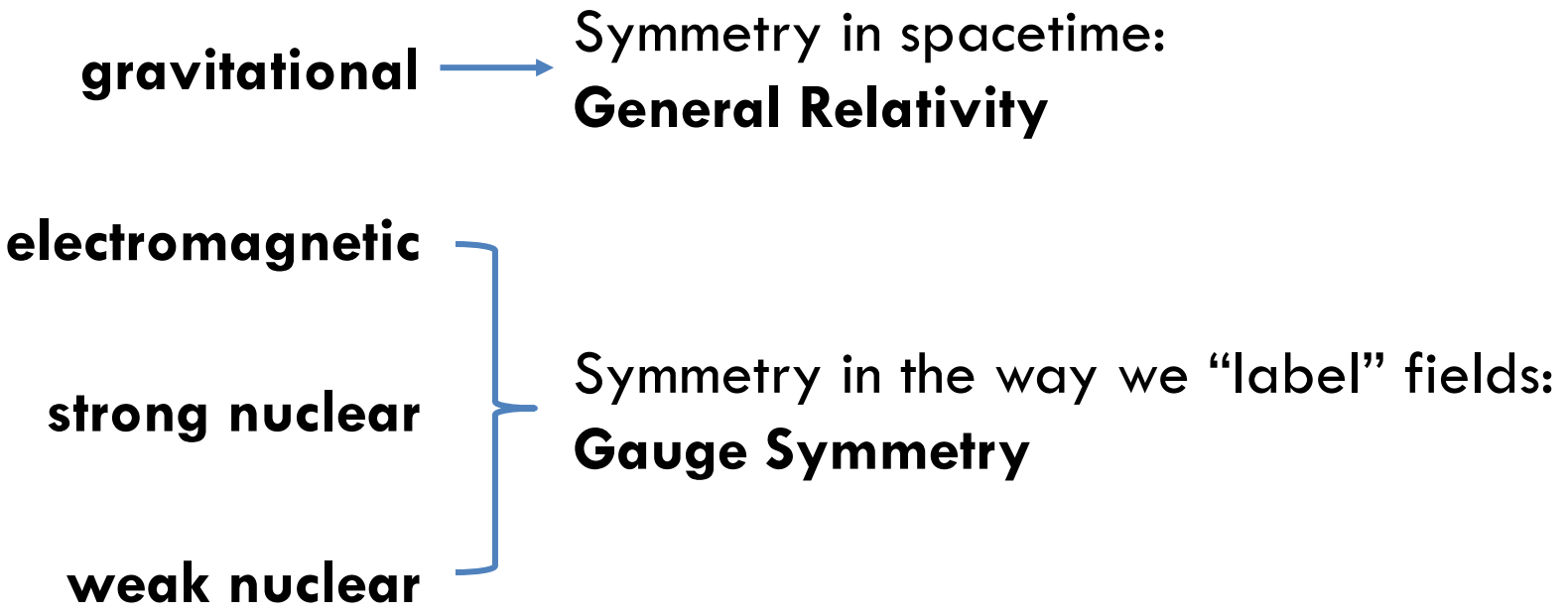


IMAGE: JACKIE CHAN (CREDIT UNKNOWN)

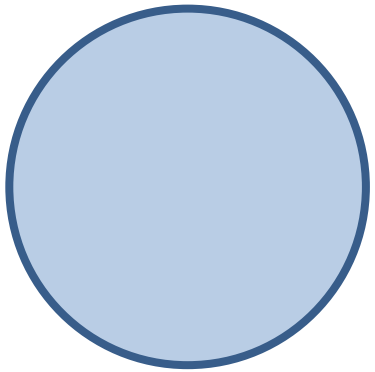
ONE TOOL TO RULE THEM ALL: SYMMETRY!

SYMMETRY IS A TRIED-AND-TRUE GUIDELINE THAT WORKED SO WELL



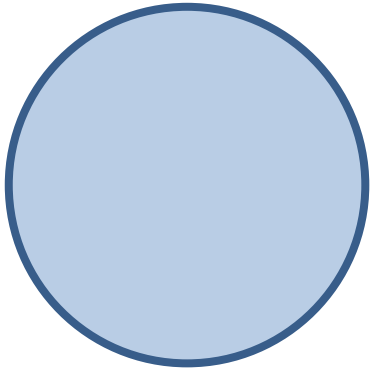
REVERSED LOGIC: NICE TRICK THAT GOES A LONG WAY

WHAT WOULD WE GET IF WE ASSUME A SYMMETRY



Remains the same under any rotation on its plane.

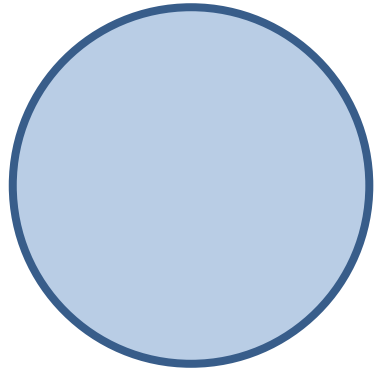
What remains the same under any rotation on its plane?



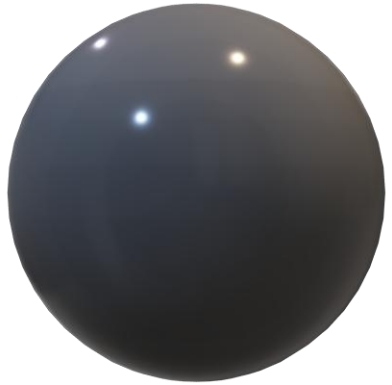
YOU CAN "GENERALIZE" THE SYMMETRY TRANSFORMATION!

A THEORY BASED ON AN ASSUMED SYMMETRY CAN BE EXTENDED EASILY!

What remains the same under any rotation *on its plane*?



What remains the same under any rotation *on <u>any</u> plane*?



A sphere!

MODERN TRICK:
ASSUME A SYMMETRY AND ASK WHAT HAPPENS

Begin building a model by insisting on having a symmetry.

Determine a consistent physical law!

A TEMPERATURE FIELD

ONE OBJECT WITH VALUES OF TEMPERATURE IN MANY PLACES

A **field** describing temperature is a field of real number

= has magnitude everywhere

Temperature Field

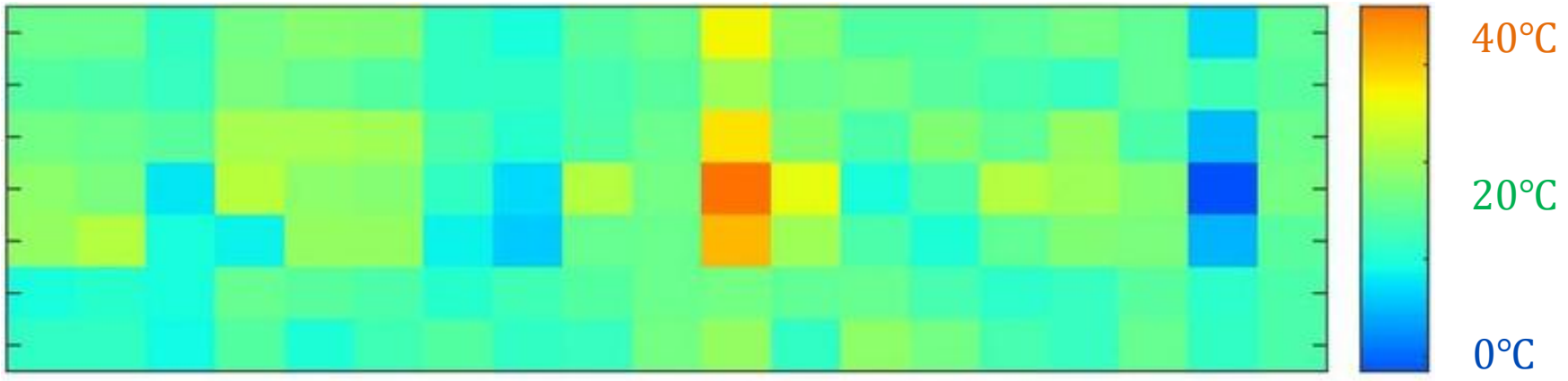


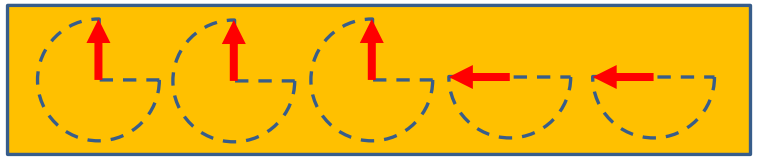
IMAGE: XUEWEI FAN ET AL 2020 ENVIRON. RES. LETT.,

AN ELECTRON FIELD

PHASE OF QUANTUM FIELD IS NOT PHYSICAL

Electron **field** is a field of complex number
(with some special structures)
= has magnitude and phase everywhere

Electron Field



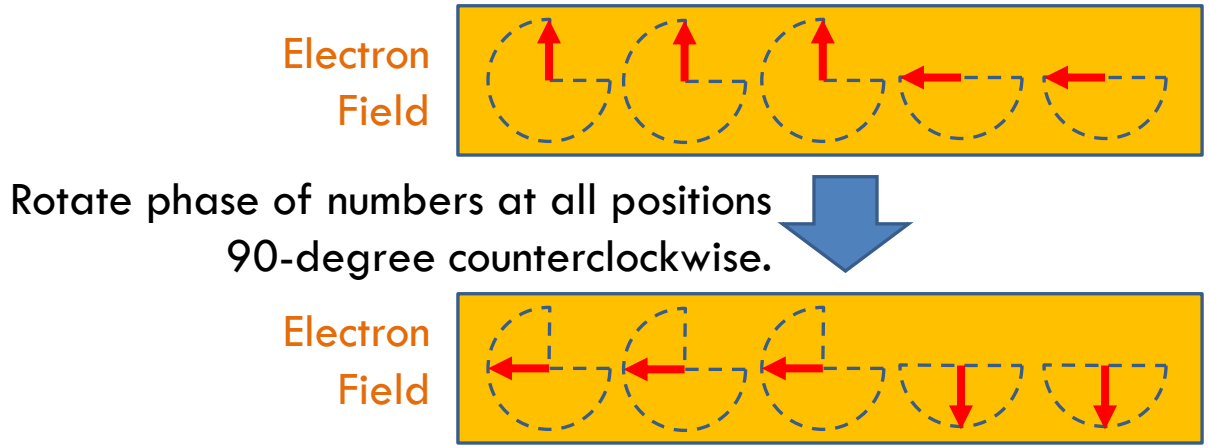
Quantum principle for electron field

Phase at each location doesn't matter.

But ***differences in phases between neighboring points are physical***.

CHANGE PHASE EVERYWHERE BY THE SAME AMOUNT

A GLOBAL SHIFT OF PHASE IS UNPHYSICAL



Physics is symmetric under a global change!

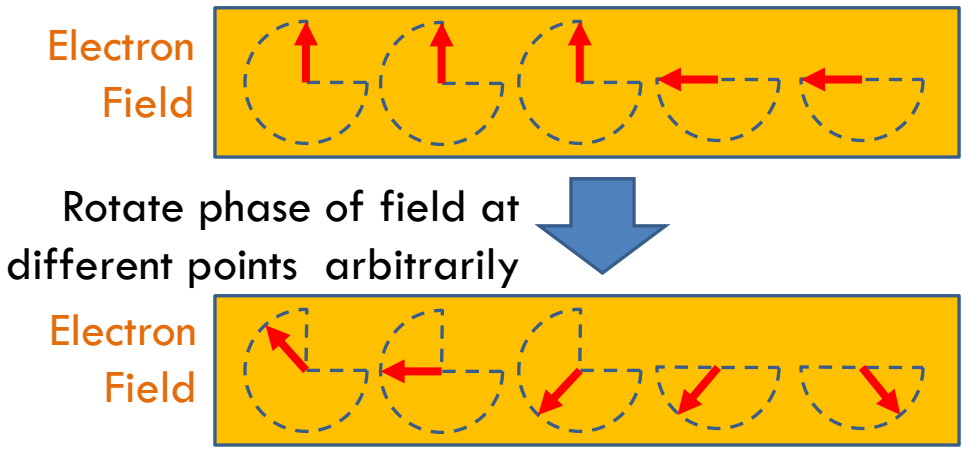
Quantum principle for electron field

Phase at each location doesn't matter.

But ***differences in phases between neighboring points are physical.***

CHANGE PHASE EVERYWHERE BY DIFFERENT AMOUNT

DIFFERENT LOCAL CHANGES ARE PHYSICAL. SYSTEM DEFINITELY CHANGES.

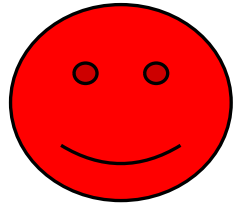


Physics is not symmetric under a local change!

Quantum principle for electron field

Phase at each location doesn't matter.

But difference in phases between neighboring points is physical.

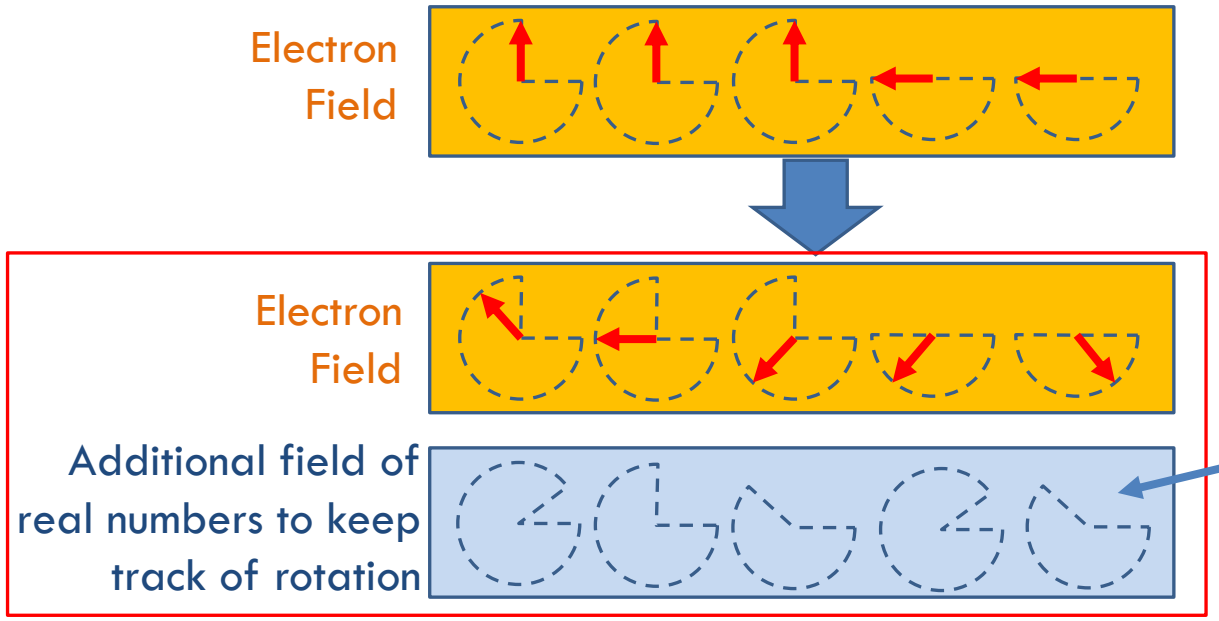


ONE PRINCIPLE TO RULE THEM ALL: INSIST ON HAVING A LOCAL SYMMETRY

and study the consequences.

NEED A FIELD STORING INFO OF LOCAL CHANGE

INSISTING THE SYMMETRY FORCE THE EXISTENCE OF ANOTHER FIELD



Massless **"Gauge field"**

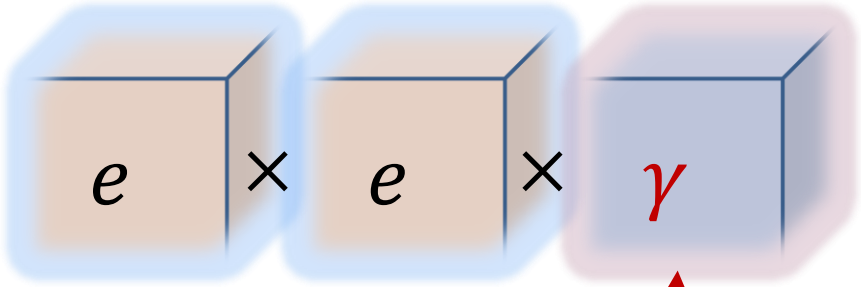
The whole system of electron field and gauge field is symmetric under a local change!

THE ADDED FIELD IS THE ELECTROMAGNETIC FIELD!

GAUGE FIELD UNDER LOCAL PHASE SHIFTS BEHAVES EXACTLY AS PHOTONS

Modern Physics Trick: Assume a symmetry and ask what happens

What **matter-only model** remains the same under local phase change in **matter field**?

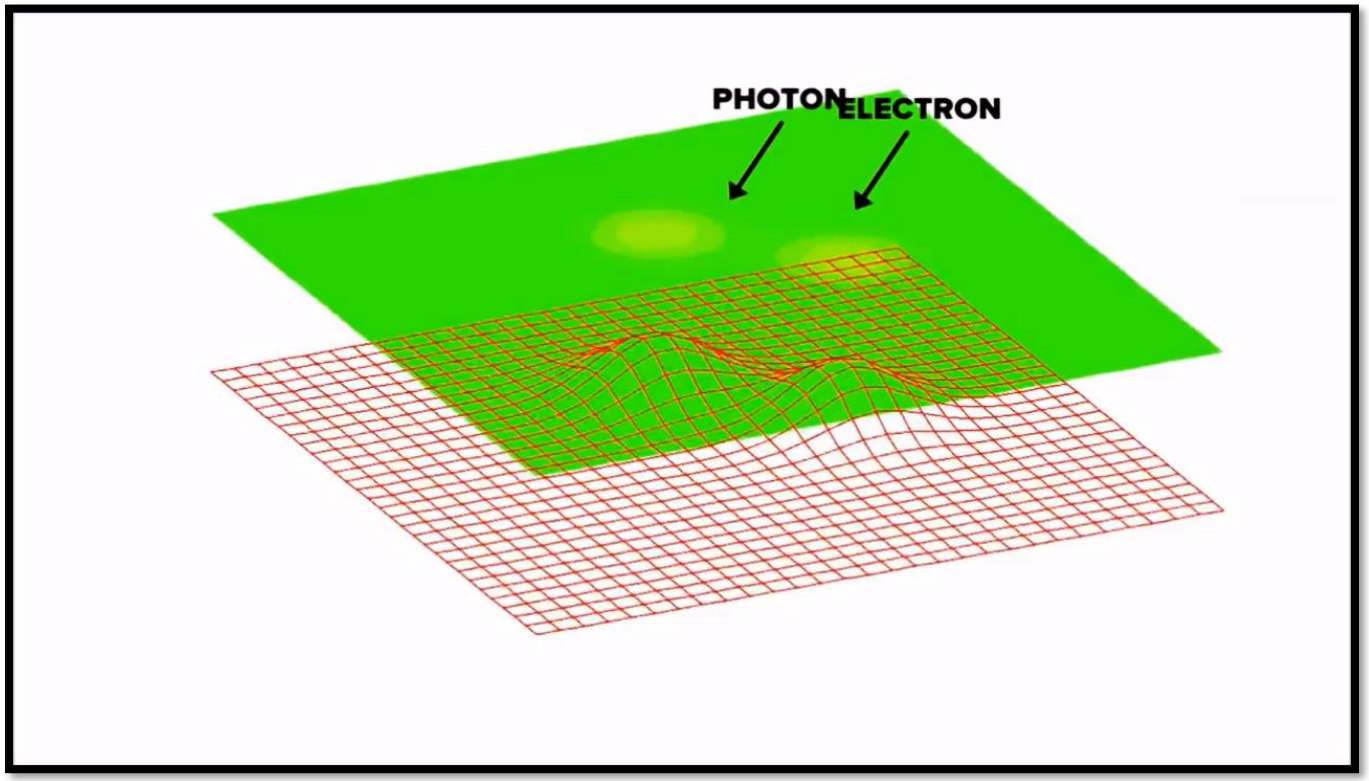


Photon is ***Predicted*** from symmetry!

This is how modern physicists understand Quantum Electrodynamics (QED).

QUANTUM ELECTRODYNAMICS:

GAUGE FIELD THEORY FOR INTERACTIONS BETWEEN LIGHT AND MATTERS



VIDEO: FERMILAB (YOUTUBE)

GROUP THEORY: A SYSTEMATIC TOOLKIT FOR STUDYING SYMMETRY

Gauge Symmetry
The sameness under a set of independent local changes.

"Group theory" tells what changes are possible.

Experiments tell what groups are feasible.

STANDARD WORKFLOW FOR MODERN PHYSICS

Guess a change and insist a <u>gauge symmetry</u>
under that changes

↓

Predicts <u>gauge fields</u>
to preserve the symmetry

↓

Mathematical model describing interaction

↓

Explains the mystery?
Yes?

Agrees with other observed phenomena?
Yes?

Other predictions?
Yes?
Found?

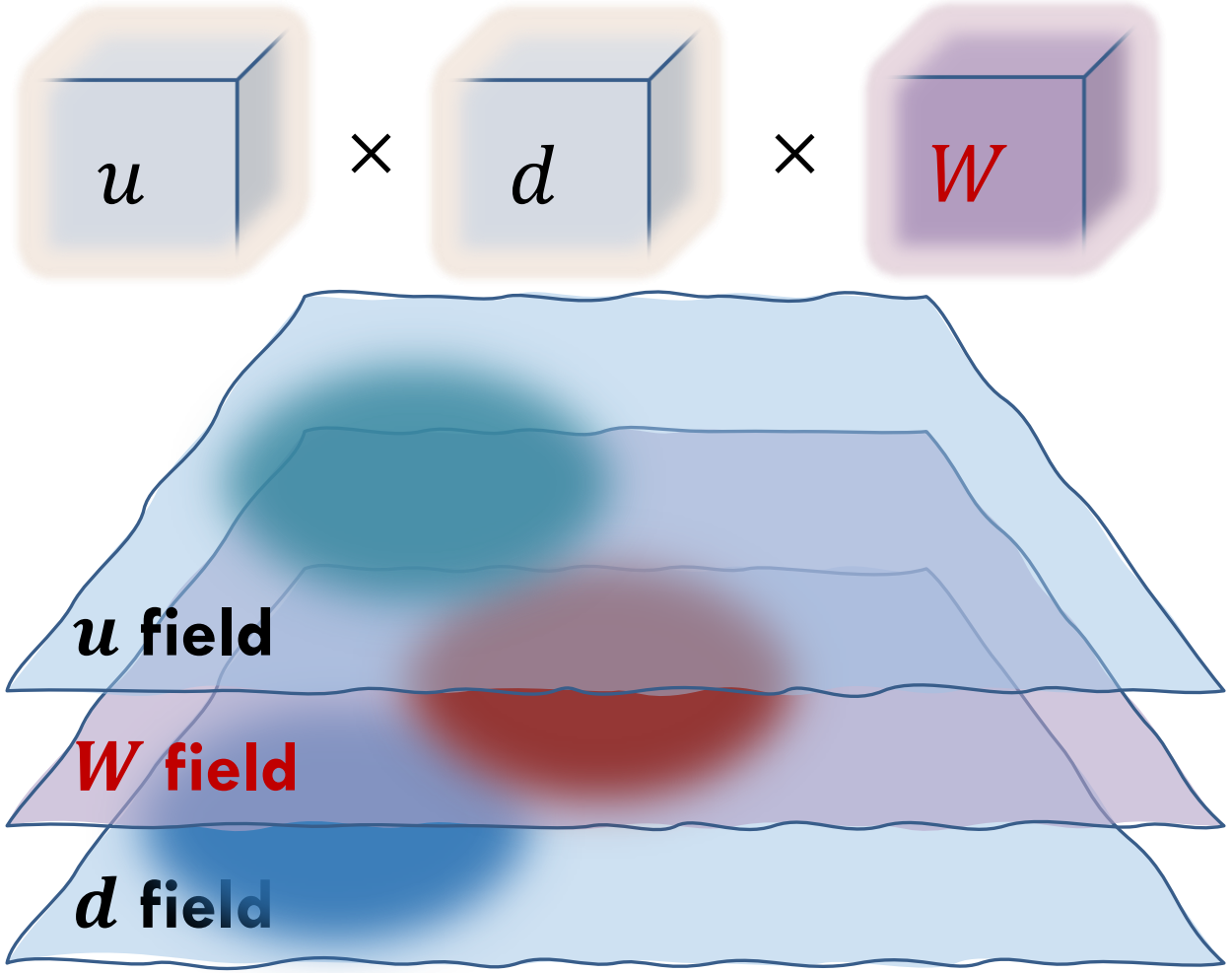
Images: Nobel.se

NO?

Most of gauge theories live here.

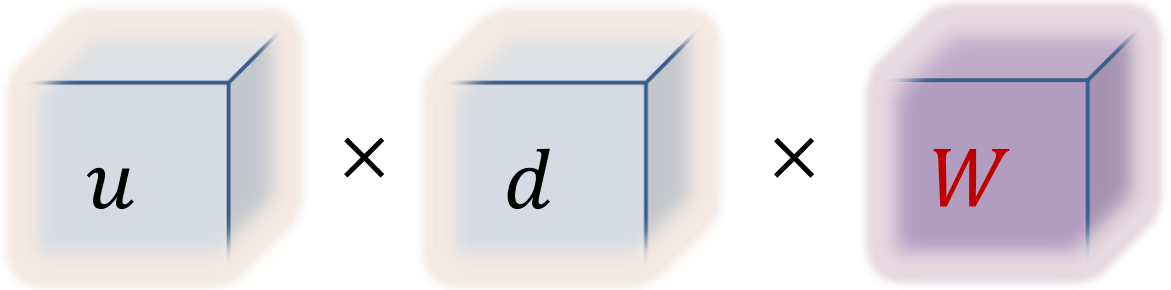
“W BOSON” OF WEAK INTERACTION

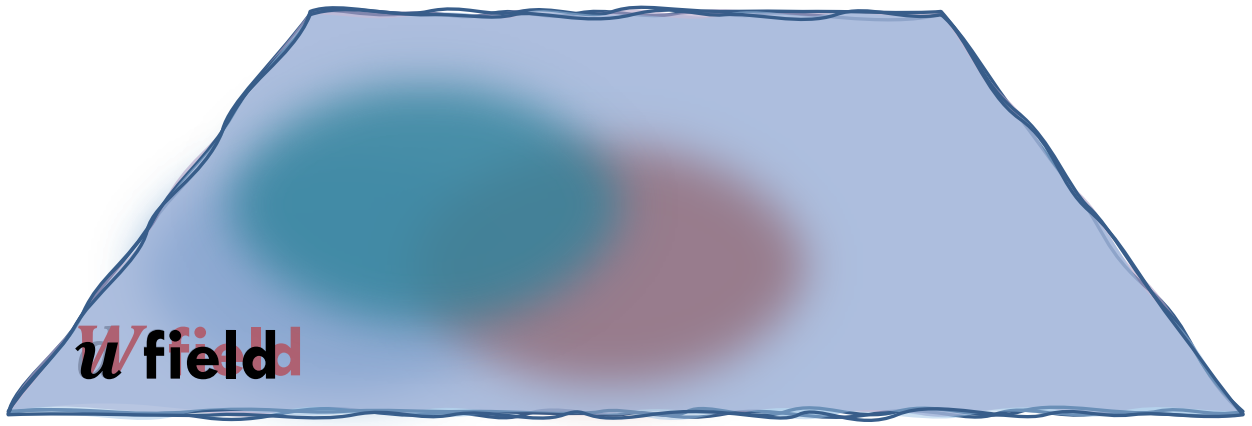
ALSO PREDICTED BY (MORE COMPLICATED) GAUGE SYMMETRY



“W BOSON” OF WEAK INTERACTION

ALSO PREDICTED BY (MORE COMPLICATED) SYMMETRY





One massive problem is …
fields created by gauge symmetry force their corresponding particles to be massless!

Nature doesn't care about <u>our model</u>

*"**If it disagrees with experiment, it's wrong.** In that simple statement is the key to science. It doesn't make any difference how beautiful your guess is, it doesn't matter how smart you are who made the guess, or what his name is… **If it disagrees with experiment, it's wrong.** That's all there is to it."*
-- Richard P. Feynman

Image: Caltech Archives

LHC Experimentalist

BSM Theorist

Advances in experiments and theories are crucial for understandings of the fundamental building blocks of nature.

“IF IT DISAGREES WITH EXPERIMENTS, IT’S WRONG!!!”

RICHARD FEYNMAN

TWO PARTS OF RESEARCH:

RESULTS AND HOW WE FOUND THEM

Hope you're convinced this matters just as much.
Knowledge lives within in disciplines,
skills for **systematic confusion** cut across them.