

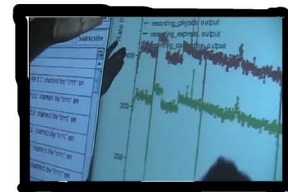
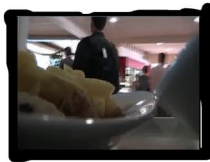
# THE HIGGS BOSON EXPLAINED



TRUE  
TALES



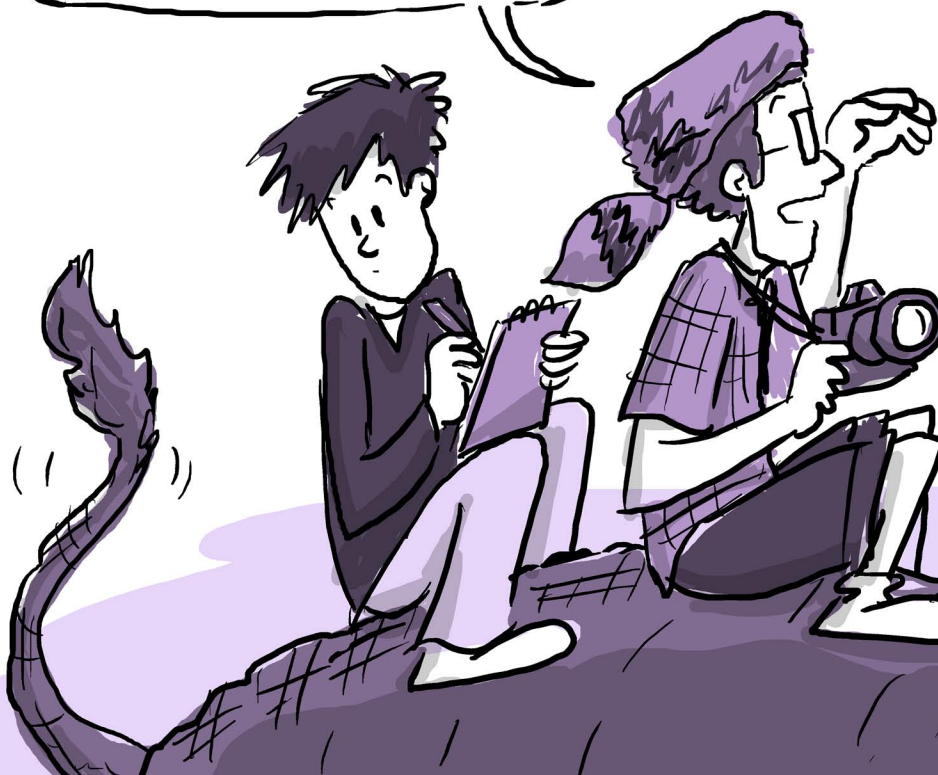
WE VISIT PARTICLE PHYSICIST DANIEL WHITESON AT **CERN**, WHERE HE TALKS TO US ABOUT WHAT THE MYSTERIOUS HIGGS BOSON IS AND HOW THE LHC IS GOING TO FIND IT (IF IT EXISTS).



THE LHC IS REALLY ALL ABOUT  
DISCOVERY AND EXPLORATION.

WE'RE LOOKING FOR  
DIFFERENT KINDS  
OF THINGS.

NEW CRAZY  
THINGS.



TO MAKE UP EVERYDAY  
MATTER, YOU ONLY NEED  
THESE THREE PARTICLES:



electron up quark down quark

WITH THE UP AND  
DOWN QUARKS YOU  
CAN MAKE...

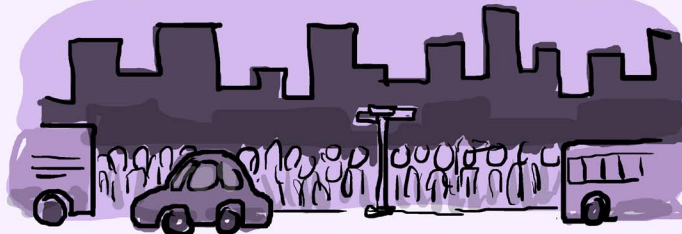
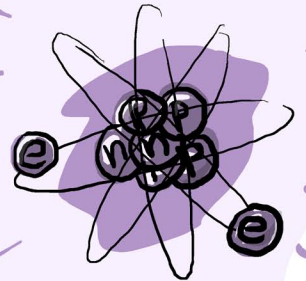


protons

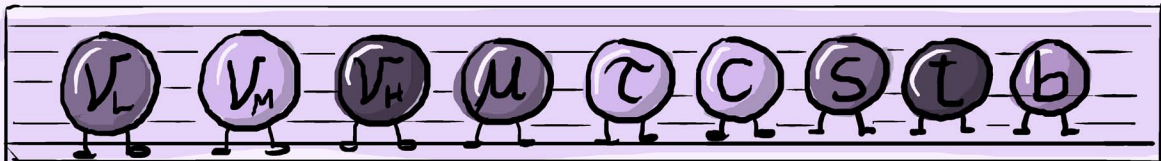


neutrons

WITH ELECTRONS,  
PROTONS AND  
NEUTRONS, YOU  
CAN MAKE  
ANY ATOM.



everyday matter



BUT WE'VE DISCOVERED 12 PARTICLES!

WHY DO WE  
HAVE THEM?

HOW MANY  
ARE THERE?

100?  
1,000,000???  
12?

WE'RE LOOKING  
AT THE TIP OF  
THE ICEBERG AND  
WONDERING...





IS THERE  
SOMETHING  
HUGE UNDER  
THE SURFACE?

OR IS THIS IT?

AND WHAT DOES  
IT MEAN

EITHER  
WAY?



WHAT'S IN  
THE DATA?

THE HIGGS BOSON  
EXPLAINED













A PHD TALES FROM THE ROAD BY JORGE CHAM





SIMILARLY, WE HAVE A

## PERIODIC TABLE OF THE FUNDAMENTAL PARTICLES

charge							
QUARKS	$\frac{2}{3}$	 up	 charm	 top	?	?	
	$-\frac{1}{3}$	 down	 strange	 bottom	?	?	
	-1	 electron	 muon	 tau	?	?	?
LEPTONS	0	 electron neutrino	 muon neutrino	 tau neutrino	?	?	
		→ mass					

IT HAS INTERESTING FEATURES TOO.

PATTERNS THAT SUGGEST THERE MUST BE SOME SORT OF UNDERLYING STRUCTURE THAT WE DON'T UNDERSTAND.

WE HAVEN'T SEEN IT YET.

ARE THERE MORE PARTICLES?

WHAT'S THE SOURCE OF THE PATTERNS?

WE'RE TRYING TO FIGURE OUT CLUES BY SEEING WHAT OTHER KINDS OF PARTICLES ALSO EXIST.

WHAT IS OUT THERE?



THE THING IS, WE HAVE THIS COLLIDER...

THE MAGIC OF A COLLIDER IS THAT YOU CAN MAKE KINDS OF MATTER THAT YOU DON'T HAVE AROUND.

YOU TAKE TWO KINDS OF PARTICLES AND ANNIHILATE THEM...

IT'S A KIND OF QUANTUM MAGIC WHERE IT SORT OF DISAPPEARS INTO PURE ENERGY...\*

WHAT COMES OUT DOESN'T HAVE TO BE A RE-ARRANGEMENT OF WHAT WENT IN.

YOU CAN MAKE ANY SORT OF PARTICLE FOR WHICH YOU HAVE ENOUGH ENERGY.

\* a Force-carrying boson

IT'S LIKE HAVING A MENU...

what can i get in the 500 GeV range?

YOU CAN MAKE ANYTHING THAT COSTS THAT MUCH ENERGY OR LESS.

THAT'S WHY YOU WANT TO HAVE AS MUCH ENERGY AS POSSIBLE.

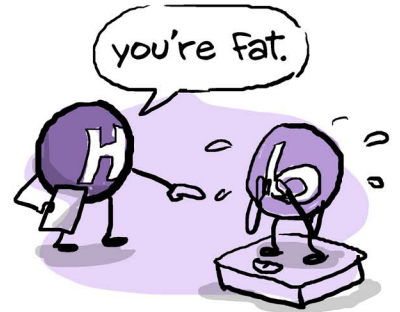
EVERY TIME YOU CRANK UP THE ENERGY, YOU COULD BE EXPLORING A WHOLE NEW REGIME.

ONE OF THE THINGS PEOPLE  
PREDICT WILL COME OUT IS

# THE HIGGS BOSON



THE HIGGS IS THE  
PARTICLE RESPONSIBLE  
FOR GIVING MASS TO  
OTHER PARTICLES.



## WHAT IS MASS?

WHEN YOU THINK OF THINGS  
HAVING MASS, IT MEANS IT  
HAS "STUFF" TO IT, RIGHT?



IT'S NOT ACTUALLY  
"STUFF"

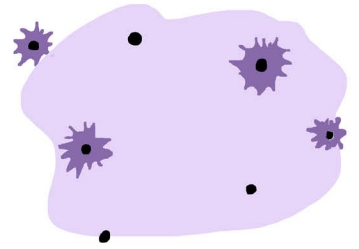
PARTICLES HAVE MASS  
BUT NO VOLUME.



(THEY'RE POINT PARTICLES)

MASS IS A  
CHARACTERISTIC OF A  
PARTICLE, LIKE CHARGE.

SOME HAVE IT,  
SOME DON'T



IT'S JUST A DIFFERENT  
KIND OF CHARGE...

## GRAVITATIONAL CHARGE

WHEN TWO  
THINGS HAVE  
THIS "CHARGE",  
THEY ATTRACT  
EACH OTHER.



INTERESTINGLY, YOU CAN'T  
HAVE NEGATIVE MASS. OR  
REPULSIVE GRAVITY.

GRAVITY IS  
DIFFERENT  
THAN OTHER  
FORCES.



THE HIGGS THEORY STARTS WITH THIS:



IMAGINE A FIELD THAT PERMEATES THE ENTIRE UNIVERSE.

EVERY PARTICLE FEELS THIS FIELD, BUT IS AFFECTED IN DIFFERENT AMOUNTS.

SOME PARTICLES ARE REALLY SLOWED DOWN BY THIS FIELD...

->> "LARGE" MASS

OTHER PARTICLES HARDLY FEEL IT.

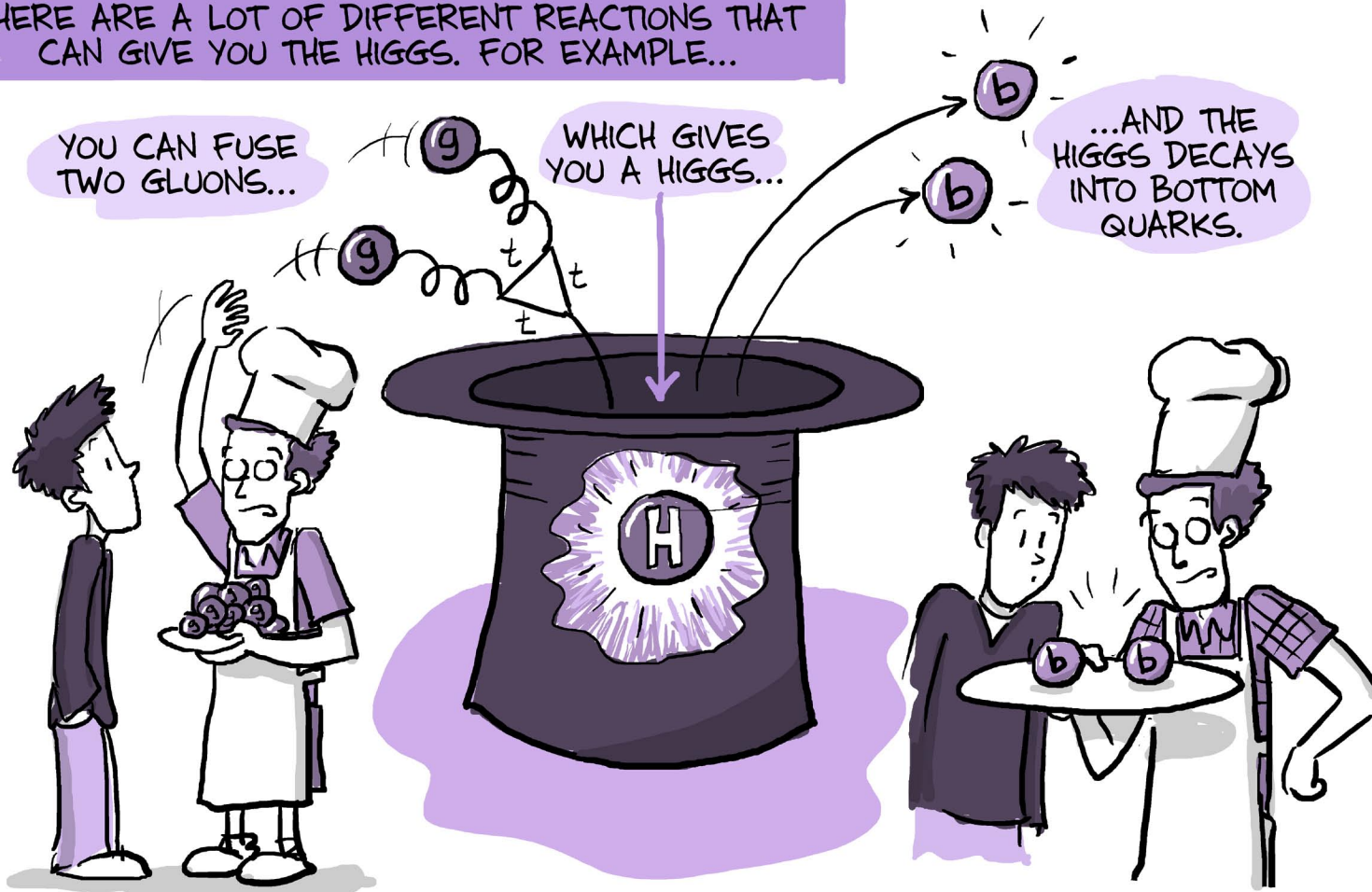
->> "SMALL" MASS

SO YOU TURN THE QUESTION OF WHY PARTICLES HAVE DIFFERENT MASS INTO A DIFFERENT QUESTION:

WHY DO PARTICLES FEEL THE HIGGS FIELD DIFFERENTLY?

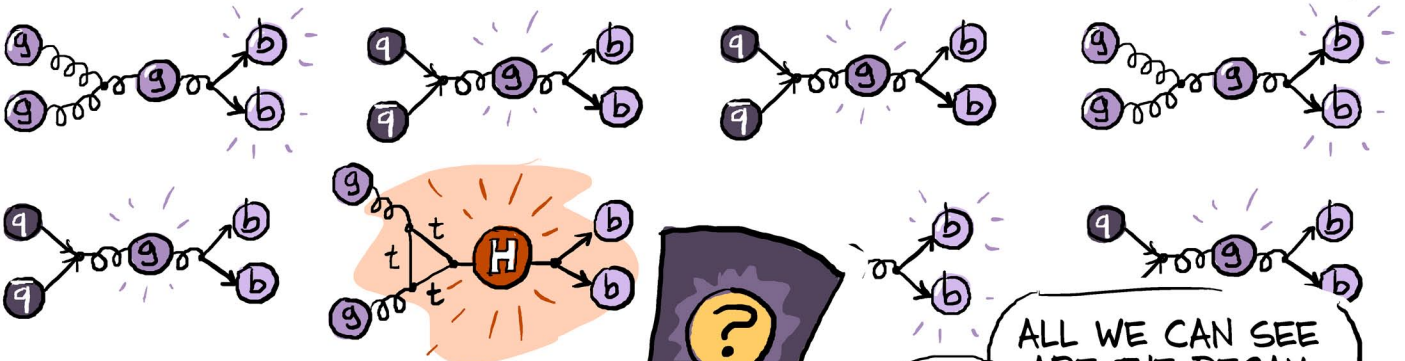
THE HIGGS IS THE MANIFESTATION OF THIS FIELD, THE EVIDENCE FOR ITS EXISTENCE.

THERE ARE A LOT OF DIFFERENT REACTIONS THAT CAN GIVE YOU THE HIGGS. FOR EXAMPLE...



THE PROBLEM IS, THERE'S LOTS OF OTHER WAYS YOU CAN MAKE TWO BOTTOM QUARKS:

IT'S ONE OF THE MOST COMMON THINGS TO MAKE.



THE THING IS, WE CAN'T SEE INSIDE THESE REACTIONS...

ALL WE CAN SEE ARE THE DECAY PRODUCTS.

AND WHAT YOU WANT TO KNOW IS...

DID THE HIGGS EXIST?



# DETECTING THE HIGGS BOSON

FIRST, THE COLLISION HAPPENS...

IT LASTS FOR 0.00000000000000000000000001 SECONDS...

...AND YOU GET ONE MEASUREMENT OF THE (BOTTOM QUARK) DECAY PRODUCTS.



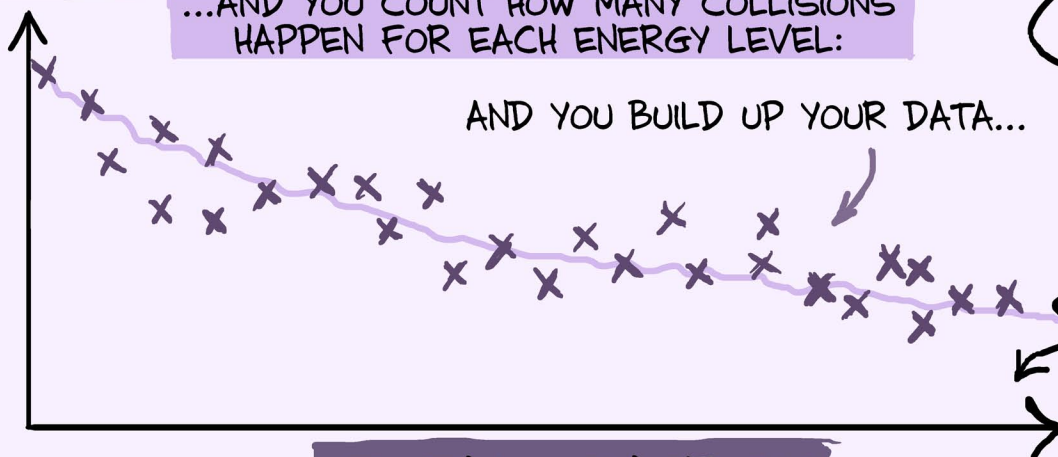
THEN YOU PLOT THE TOTAL ENERGY...



COLLISIONS

...AND YOU COUNT HOW MANY COLLISIONS HAPPEN FOR EACH ENERGY LEVEL:

AND YOU BUILD UP YOUR DATA...

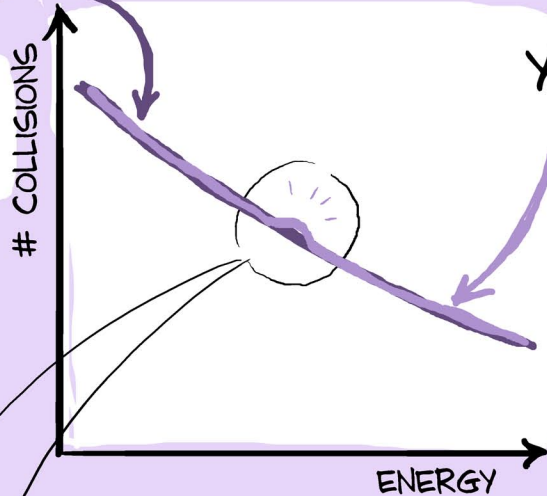


TOTAL ENERGY  
OF THE REACTION

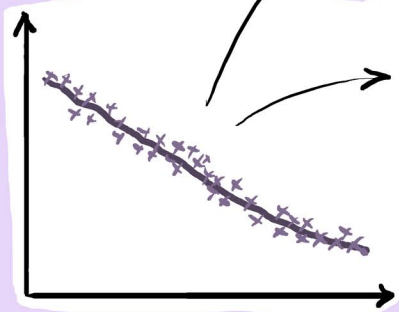
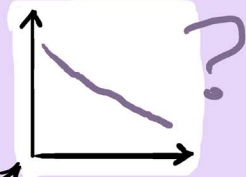
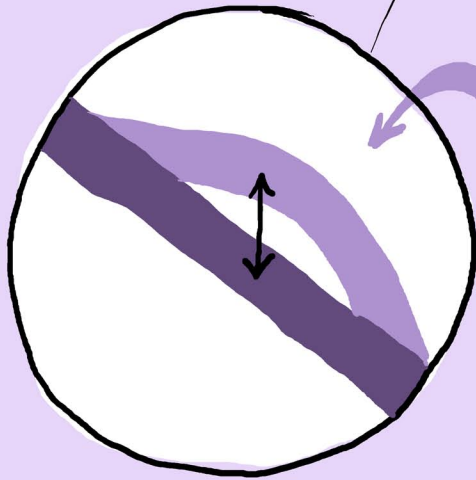
THEN YOU HAVE 2 THEORIES THAT PREDICT THE DATA:

NO HIGGS  
BOSON

YES HIGGS  
BOSON



THE PROBLEM IS THAT  
THE DIFFERENCE  
BETWEEN THE TWO  
IS VERY SMALL



WHAT YOU NEED IS A

**HUGE**

AMOUNT OF DATA.

THAT'S WHY WE RUN  
THIS THING 40 MILLION  
TIMES/SECOND, ALL  
DAY, ALL YEAR.

TO TELL SMALL DIFFERENCES  
BETWEEN THEORIES.

IT'S VERY HARD TO DISTINGUISH  
THESE TWO WITH OUR DATA.

THE PREDICTED EFFECT IS TINY.

OPEN 24 HOURS

Over a Bijillion  
Collisions Served





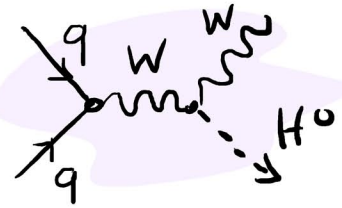
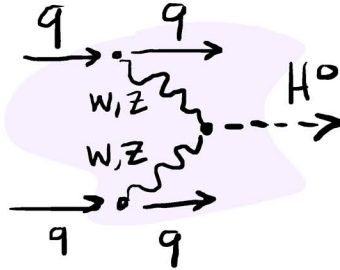
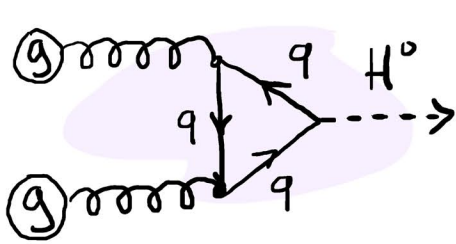
IT'S LIKE TAKING A PICTURE OF THE SKY.

IF YOU JUST TAKE ONE PICTURE,  
YOU WON'T SEE VERY MUCH.

BUT THE LONGER YOU LEAVE  
THE CAMERA ON...

...THE CLEARER THE PICTURE  
BECOMES.

## THERE'S LOTS OF OTHER WAYS TO SEE THE HIGGS BOSON



SOME PEOPLE ARE  
WORKING ON THIS ONE...

SOME ARE WORKING  
ON THAT ONE...



WE WORK IN A COLLABORATION OF THOUSANDS OF PEOPLE AND  
THERE ARE PEOPLE WORKING ON EVERY SINGLE "CHANNEL".

THE IDEA IS TO TRY TO LOOK EVERYWHERE AT THE SAME TIME.

SO THAT A LITTLE EVIDENCE HERE AND THERE  
CAN BE COMBINED INTO SOMETHING CONVINCING.

WE'RE GOING TO LEAVE IT RUNNING FOR A  
LONG TIME AND HOPE SOMETHING POPS OUT.

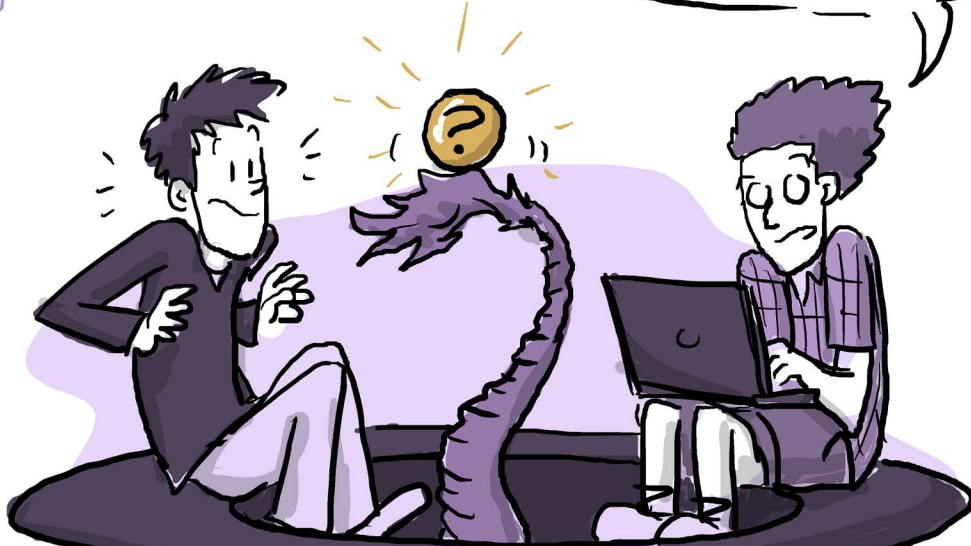


THERE'S STILL THE POSSIBILITY FOR A LOT OF NEW THINGS.

WE HAVEN'T SEEN ANYTHING CRAZY  
YET, BUT THERE COULD STILL BE  
STRANGE PINK ELEPHANTS IN  
THERE, WAITING TO POP OUT.

EVERY TIME YOU OPEN  
YOUR E-MAIL, OR EVERY  
TIME SOMEONE MAKES  
A PLOT...

THAT COULD BE THE  
TIME YOU HEARD  
SOMEONE SAY, "OOH,  
WE SEE SOMETHING..."



WHAT'S IN THE DATA?

WHAT'S IN THE DATA?