

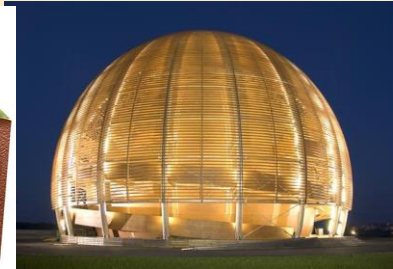
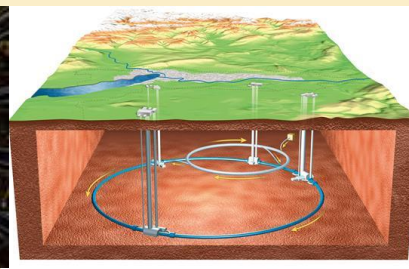
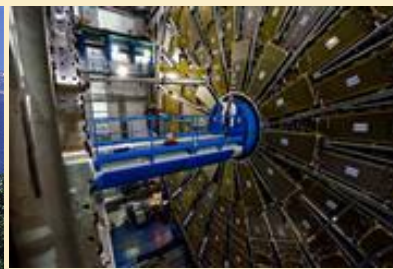
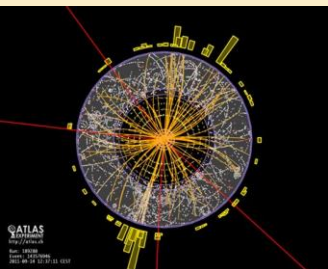
What does a Higgs boson eat during the winter ...and other essential details



**Pauline Gagnon, CERN et Indiana University
Physicist on ATLAS experiment and communicator**

CERN

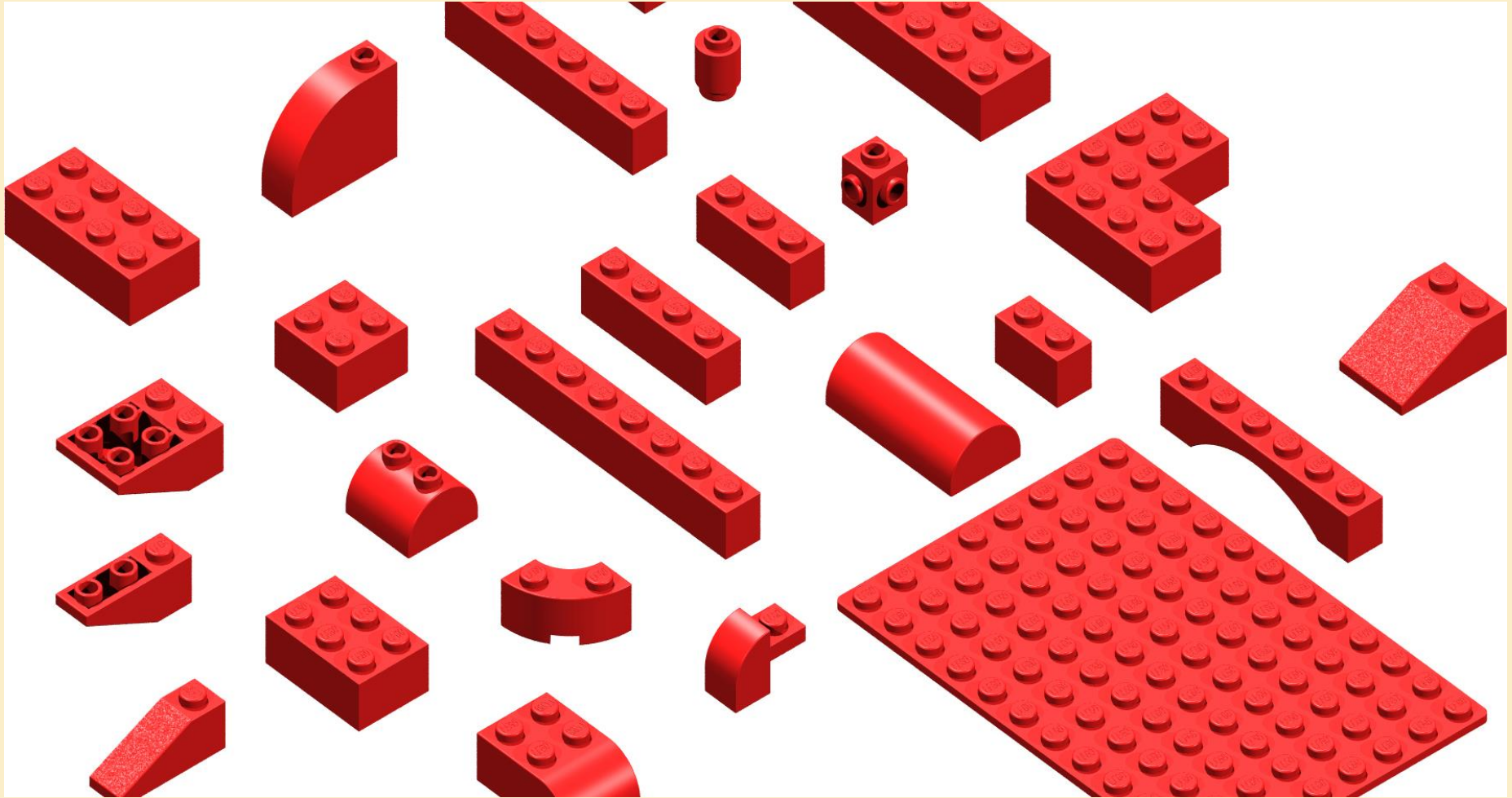
- # **European Laboratory for Particle Physics**
 - # 12000 scientists of 99 different nationalities
 - # Financed by European countries
 - # Many other countries participate in various projects
Canada, United States, Japan, Israel, India, Pakistan etc.
- # **Common goal: find out what matter is made of**



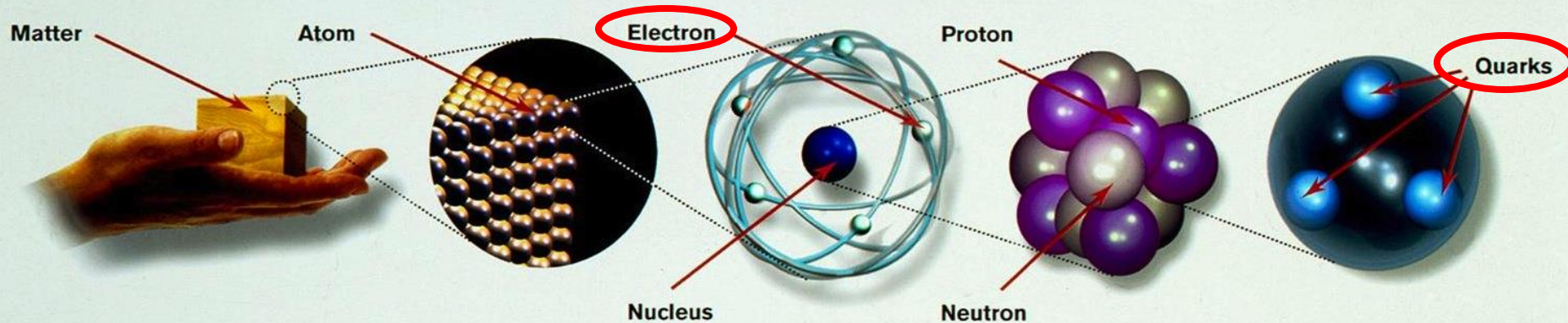
The Legoland version of Copenhagen



At Legoland, here is what fundamental particles look like



What are the smallest building blocks of matter?







**The only fundamental particles here
are electrons and quarks**





Protons and neutrons are made of quarks

Up :  (charge $+2/3$) and **down quarks:**  (charge $-1/3$)

• **Proton:**

up		up		down		proton
	+		+		=	
$+2/3$		$+2/3$		$-1/3$	=	$+1$

• **Neutron:**

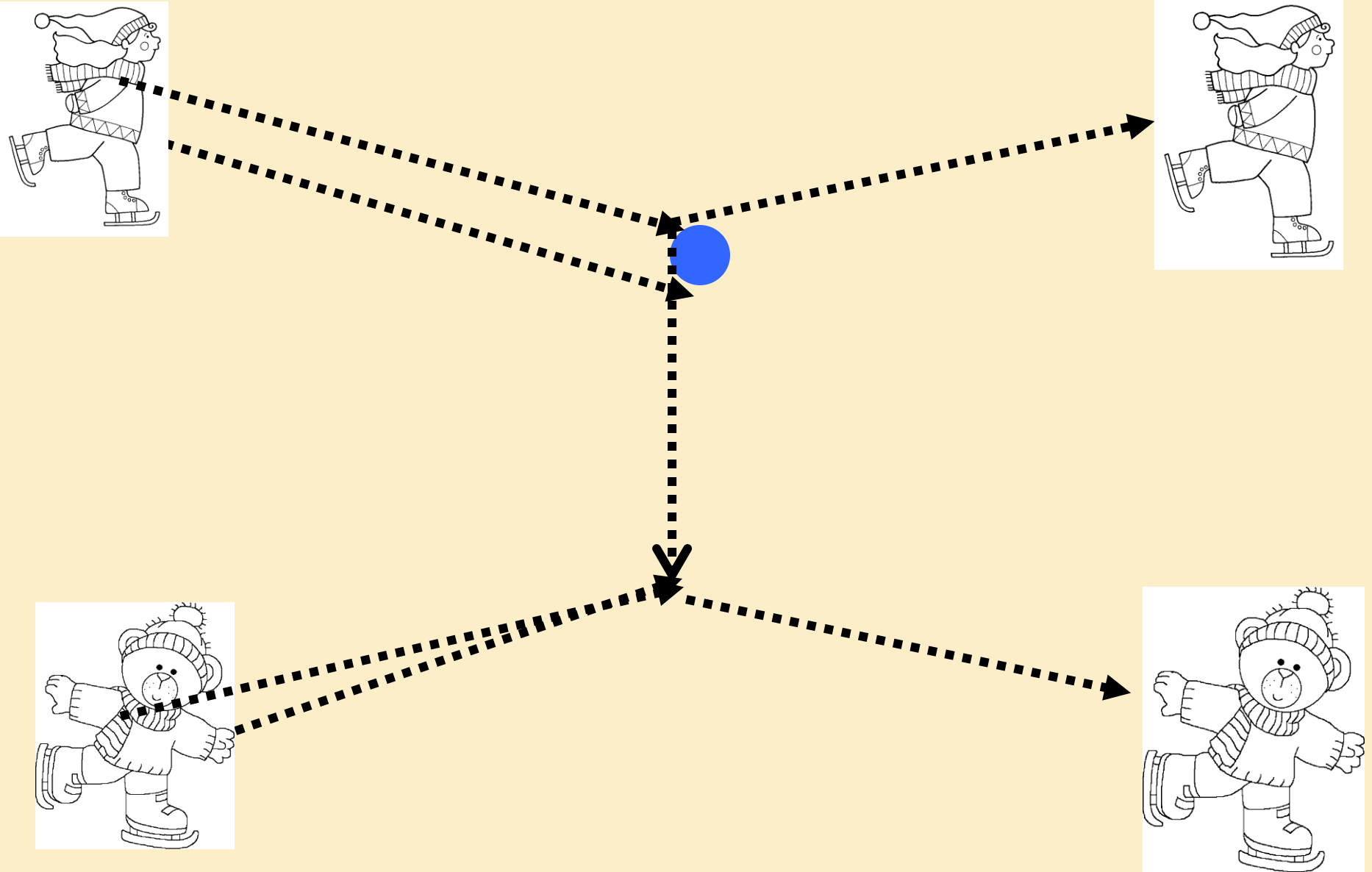
up		down		down		neutron
	+		+		=	
$+2/3$		$-1/3$		$-1/3$	=	0

1 H Hydrogen 1.00794	2 He Helium 4.002602	<div> <div>Atomic #</div> <div>Symbol</div> <div>Name</div> <div>Atomic Mass</div> </div> <div> <div>C Solid</div> <div>Hg Liquid</div> <div>H Gas</div> <div>Rf Unknown</div> </div> <div> <div>Metals</div> <div>Alkali metals</div> <div>Alkaline earth metals</div> <div>Lanthanoids</div> <div>Actinoids</div> <div>Transition metals</div> <div>Poor metals</div> <div>Other nonmetals</div> <div>Noble gases</div> </div>																																																																																					
3 Li Lithium 6.941	4 Be Beryllium 9.012182	5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797	11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050	13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.887	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293	55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	87 Fr Francium (223)	88 Ra Radium (226)	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium (294)	118 Uuo Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.













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Particles interact by exchanging other particles





The Standard Model

1. All matter is made of fundamental particles

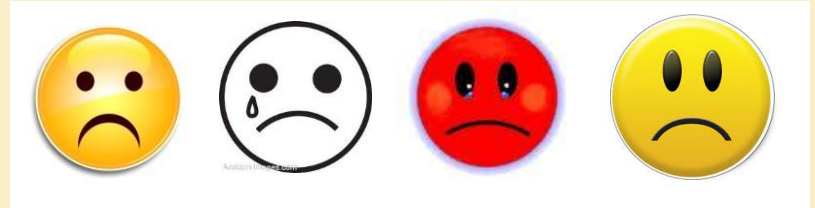
	LEPTONS				QUARKS			
Ordinary matter	ELECTRON		ELECTRON NEUTRINO		UP		DOWN	
	MUON		MUON NEUTRINO		CHARM		STRANGE	
	TAU		TAU NEUTRINO		TOP		BOTTOM	

2. Exchange particles called **bosons** are associated to forces

GLUONS  <i>Strong interaction</i>	PHOTONS  <i>Electromagnetism</i>	W and Z BOSONS  <i>Weak interaction</i>	GRAVITONS  <i>Gravitation</i>	HIGGS  <i>Brout-Englert-Higgs field</i>
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Major problem with the equations

- The Standard Model only predicted massless particles



- But we knew that the W^+ , W^- and Z^0 bosons had a mass



massless photon +



massive bosons

How could the equations of the Standard Model generate massive particles?

Modify the equations of the Standard Model

In 1964, several theorists proposed a mechanism that would explain how particles could acquire mass



Tom Kibble, Gerald Guralnik, Carl Hagen, François Englert, Robert Brout, Peter Higgs

To generate mass, we need:

1. The Brout-Englert-Higgs mechanism

- A mathematical description

2. The Higgs field

- A real physical entity corresponding to this mechanism

3. The Higgs boson

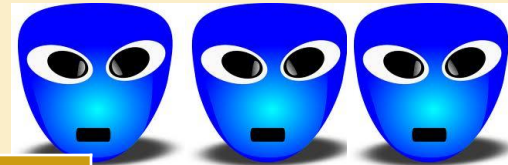
- The materialisation or proof of existence of all that

1. The Brout-Englert-Higgs mechanism

Theory predicted 4 massless bosons



The Brout-Englert-Higgs mechanism breaks this symmetry by remixing everything after injecting 3 fictitious particles



	Mass in GeV	Electric charge
photon	0	0
W^+	80.4 GeV	+1
W^-	80.4 GeV	-1
Z^0	91.2 GeV	0

- Mass

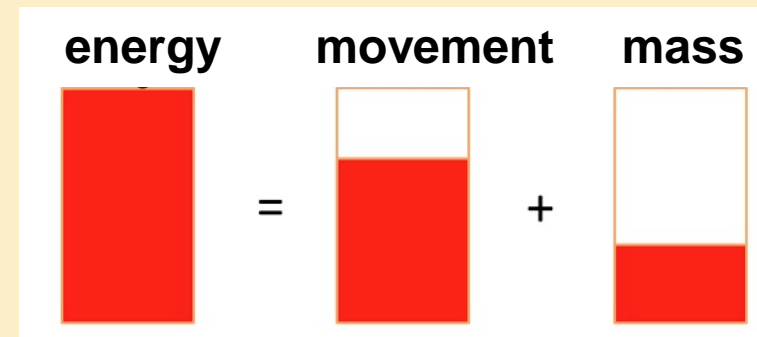
In physics, mass is
resistance to movement

- $E = m c^2$

Energy and Mass are
equivalent

- Energy conservation

Energy can take several forms
but its sum is always conserved



2. The Higgs field

- # Running on the beach, light and free like air
- # Then running in water
- # You get the impression of getting sluggish



With the Higgs field, it is as if the whole space is viscous

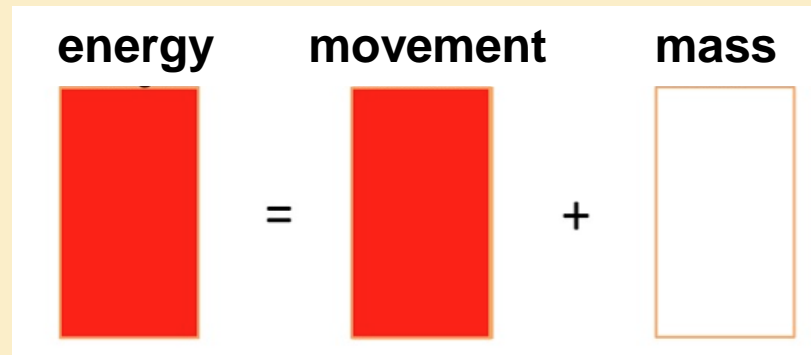
2. How does the Higgs field generate mass

A



Empty space, without a Higgs field

B

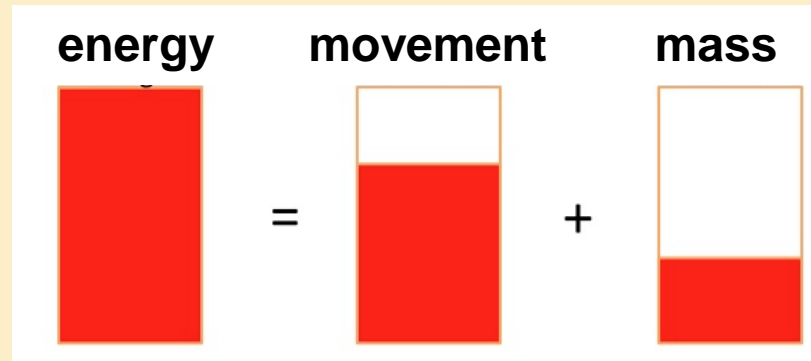


Space with the Higgs field

A



B



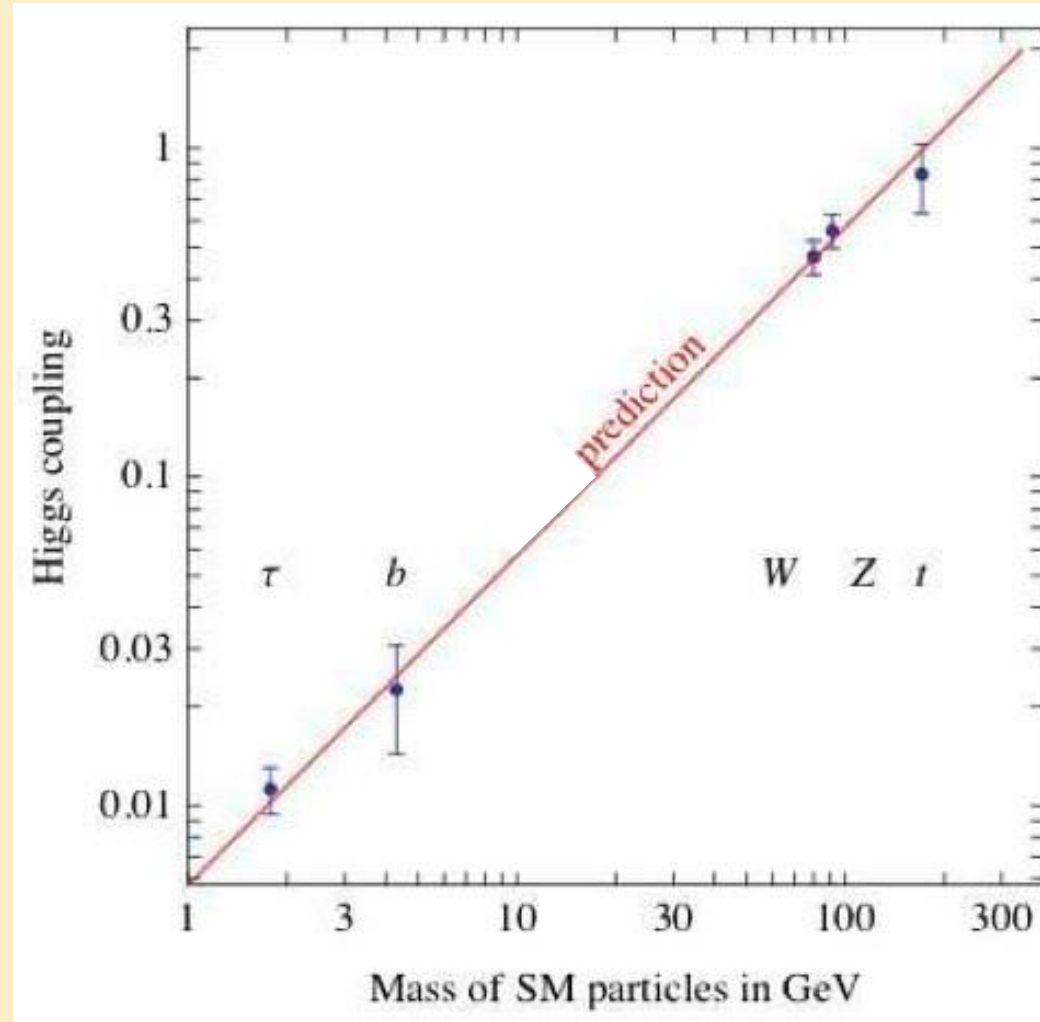
**The Higgs field gives mass without
dissipating energy**

How much mass?

The more a particle interacts with the Higgs field, the more mass it gets



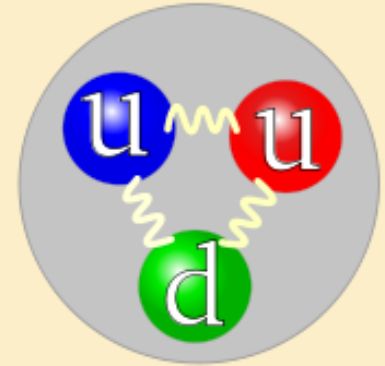
photon



The mass in matter

Quarks mass: 11 MeV

Proton mass: 938 MeV



99% of the proton mass comes from the binding energy given by the gluons

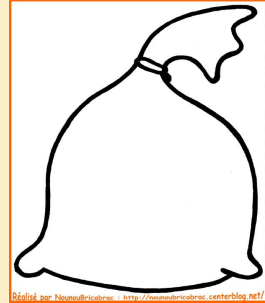


To summarize, there are 3 aspects:

1. A mathematical tool:

The Brout-Englert-Higgs mechanism:

Z^0 and W^\pm get a mass but not photons



2. A physical entity:

The Higgs field filled all space shortly after the Big Bang



3. An excitation of the field:

The Higgs boson



3. The Higgs boson

The Higgs field → the surface of the ocean

The Higgs boson → a wave



Waves are excitations of the ocean surface

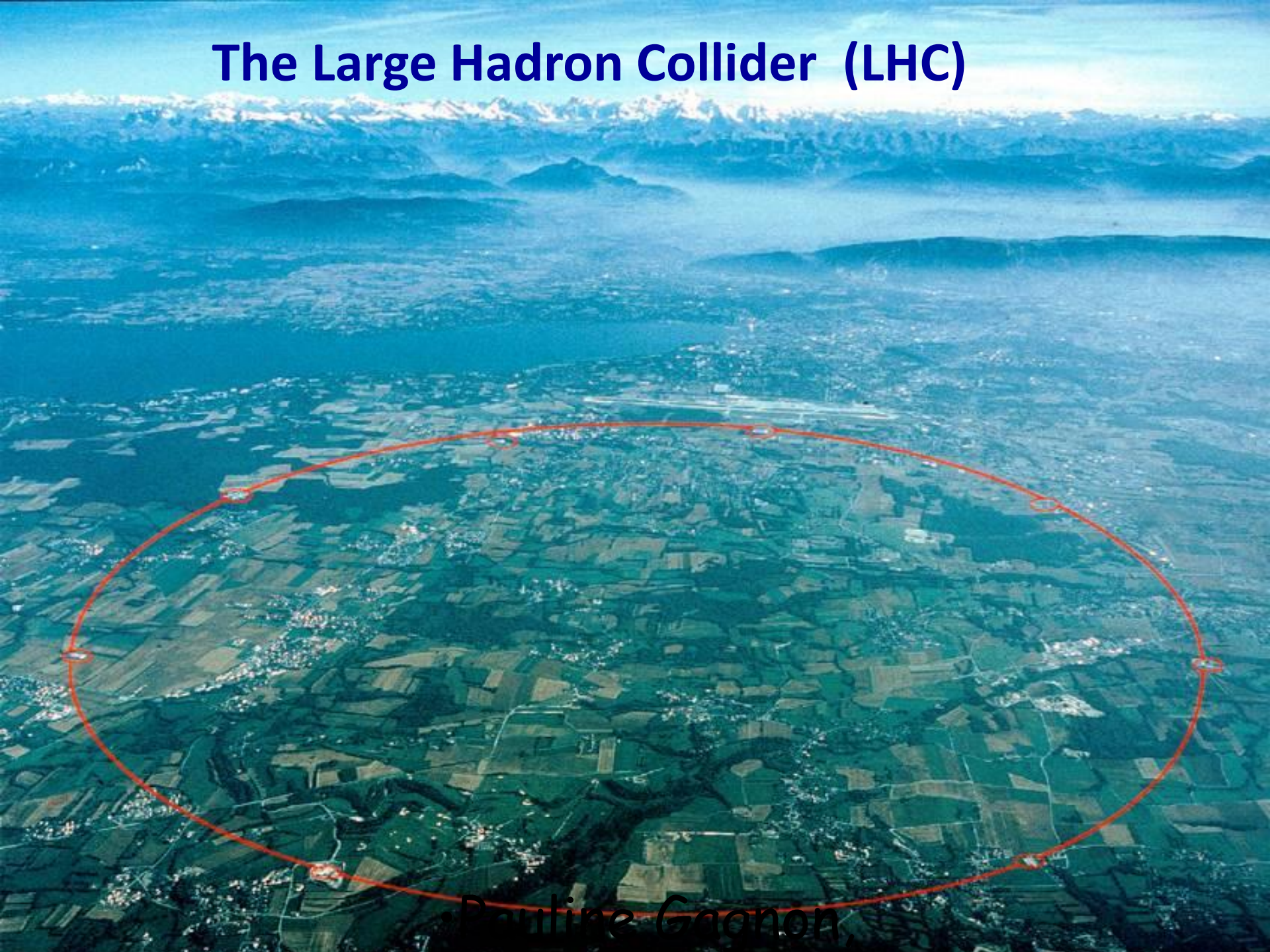
We can create Higgs bosons by exciting the Higgs field

How can we create a Higgs boson?

We need to concentrate a huge amount of energy in a small point in space – that's the role of the LHC



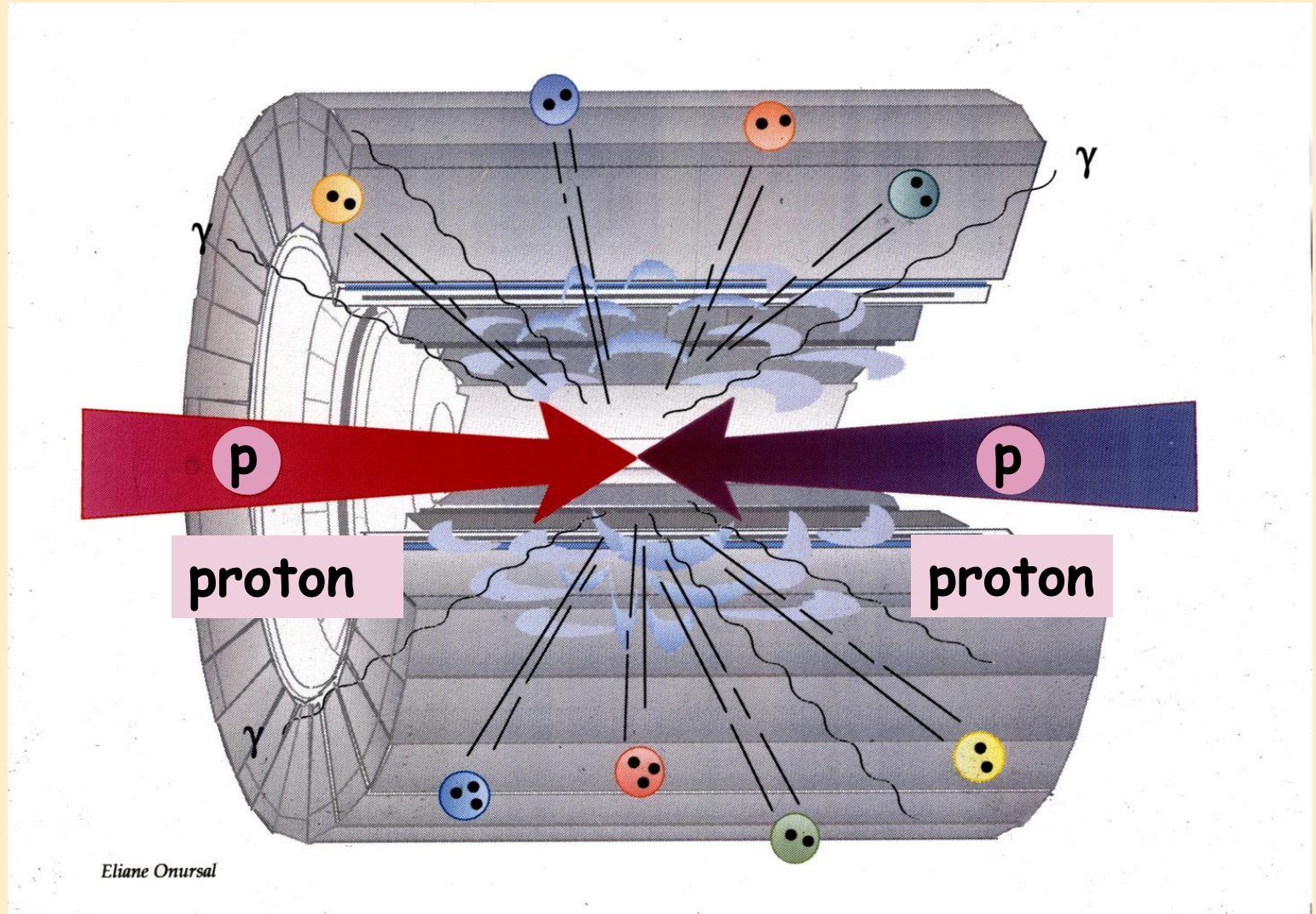
The Large Hadron Collider (LHC)



Pauline Gagnon

The energy released during the collisions
materialises to create particles:

$$E=mc^2$$



Decay of a Higgs boson



Higgs



Z boson + Z boson



muon + muon + muon + muon

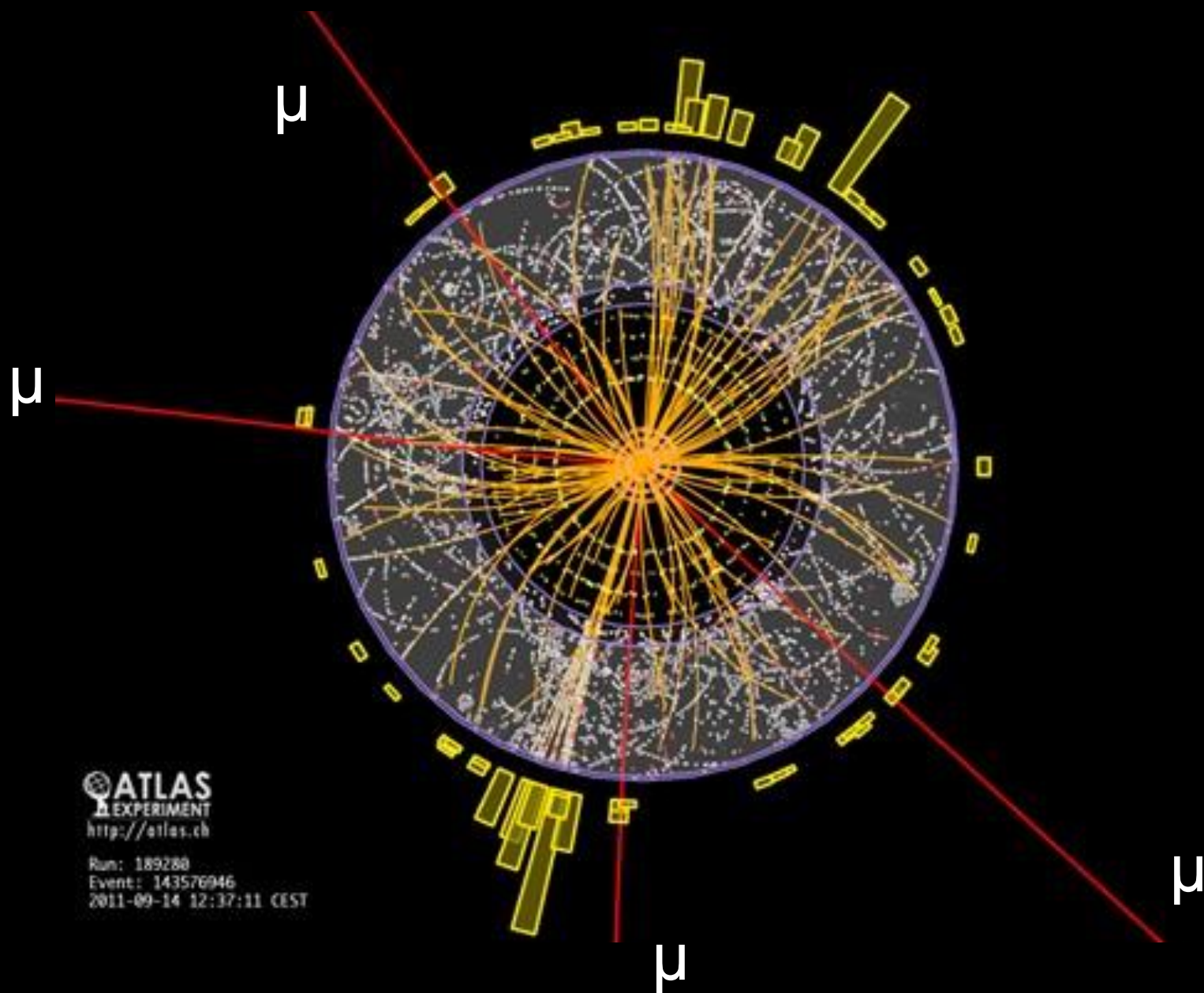


Z boson + Z boson

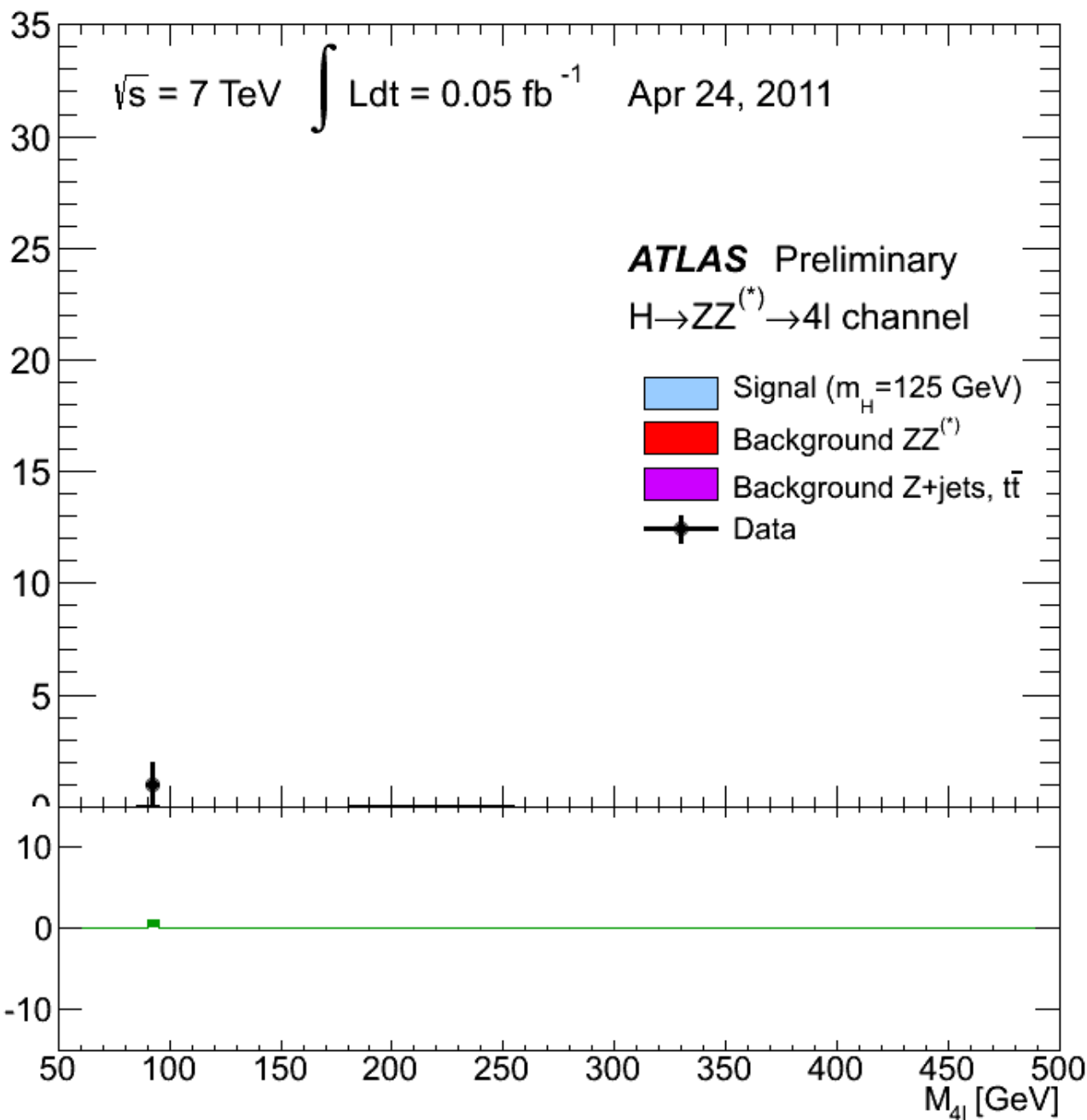


muon + muon + muon + muon

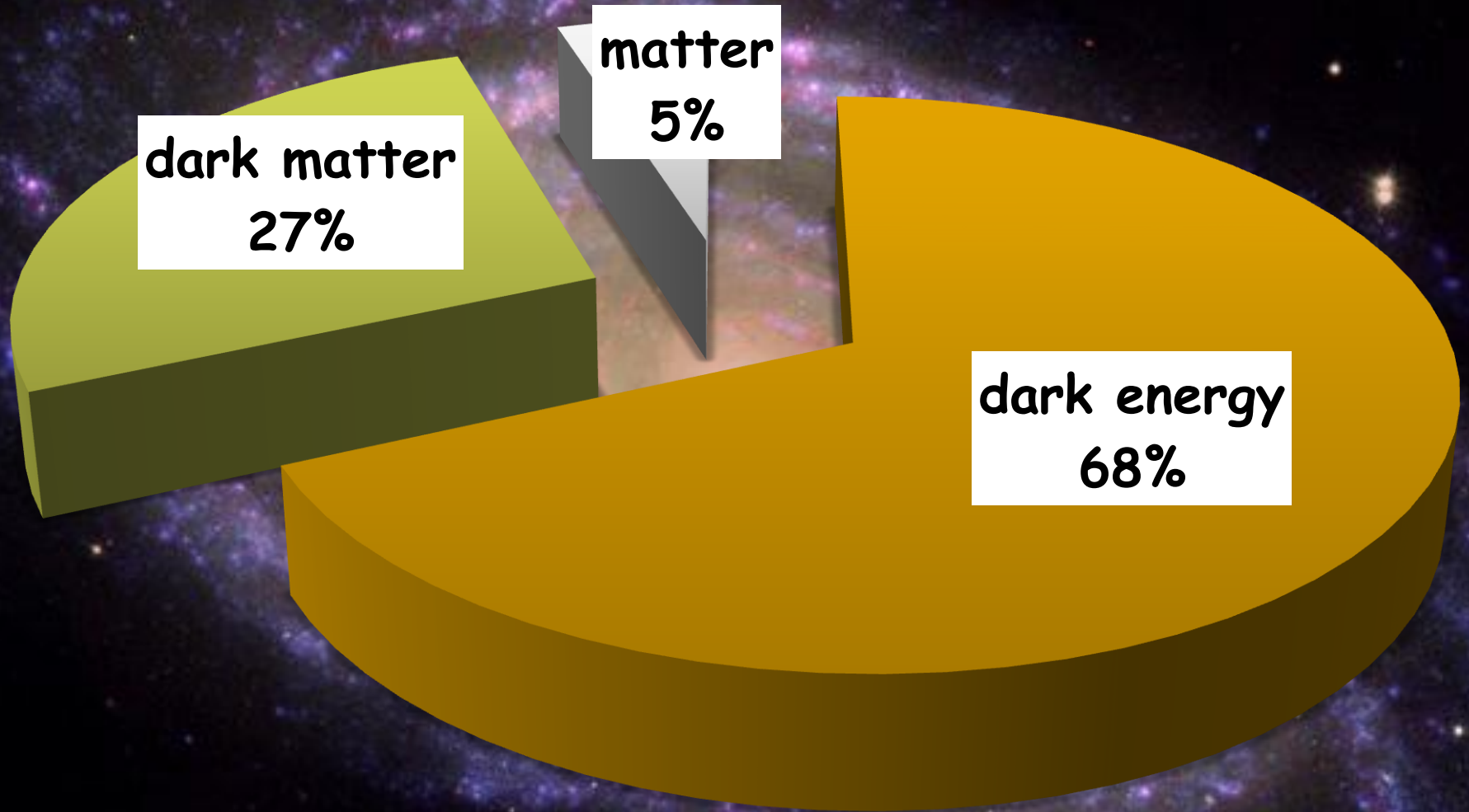
$H \rightarrow ZZ$ or ZZ ? Each $Z \rightarrow \mu\mu$



Events / 5 GeV



Dark matter mystery



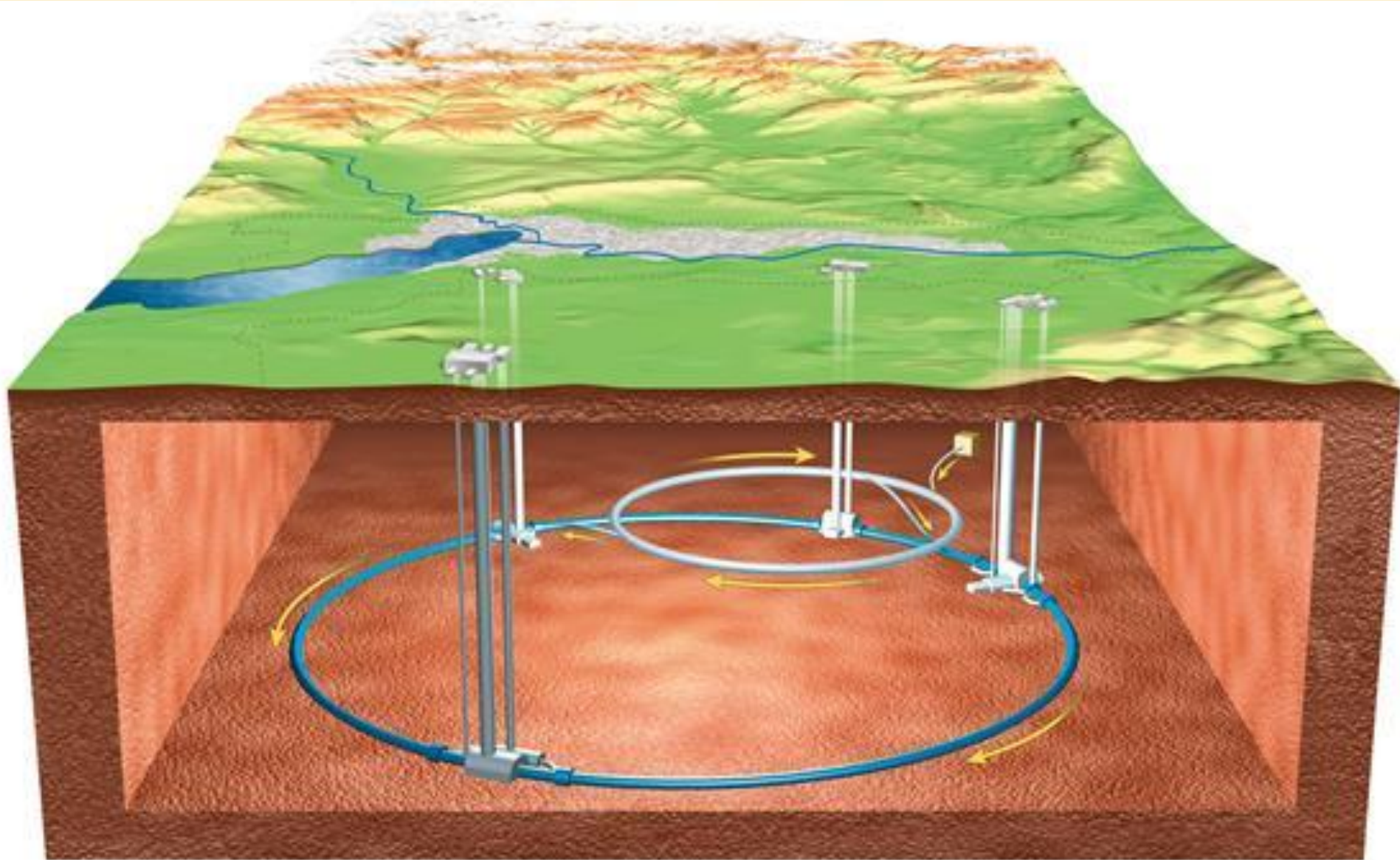


Thank you for your visit

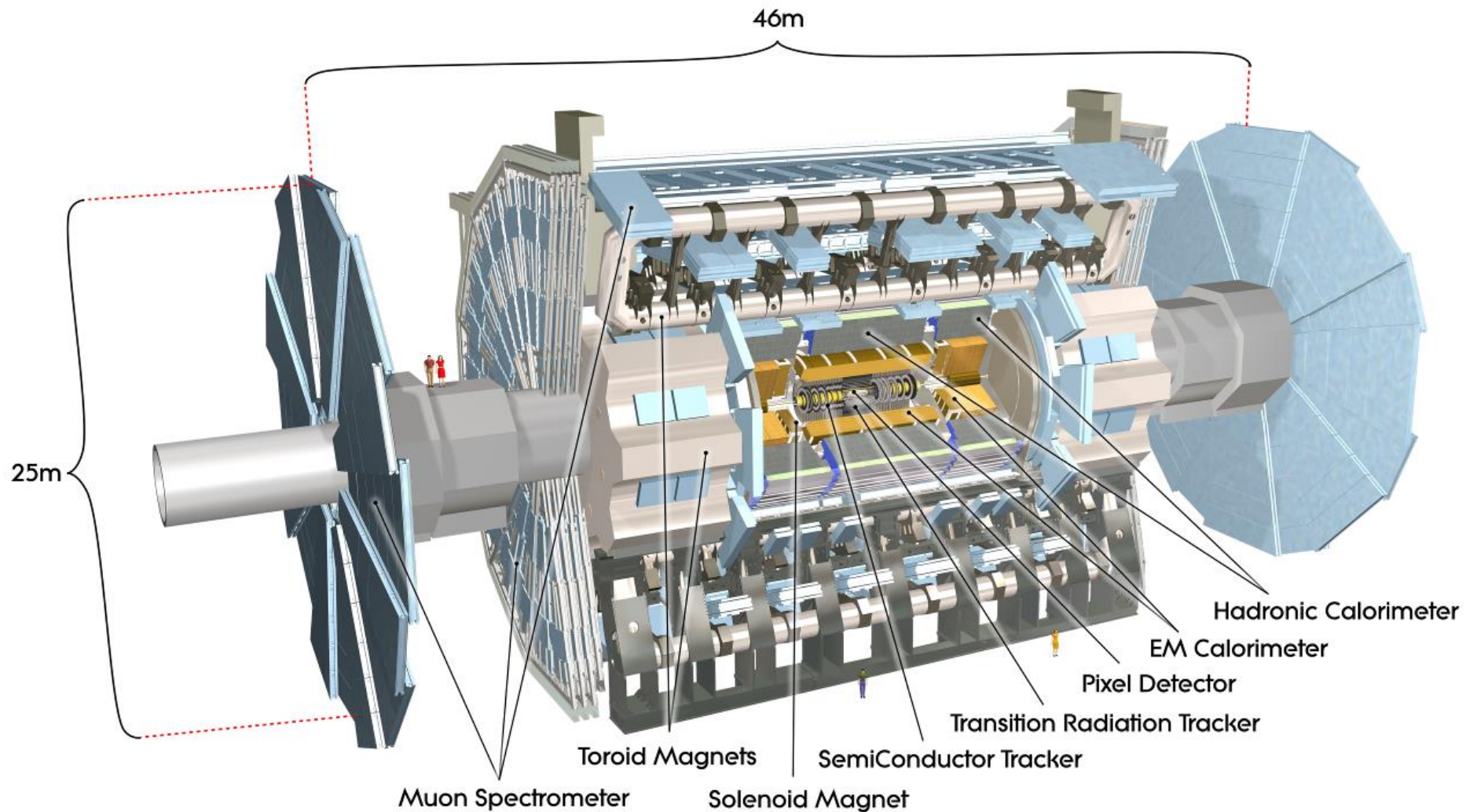


Blogs on Quantum Diaries

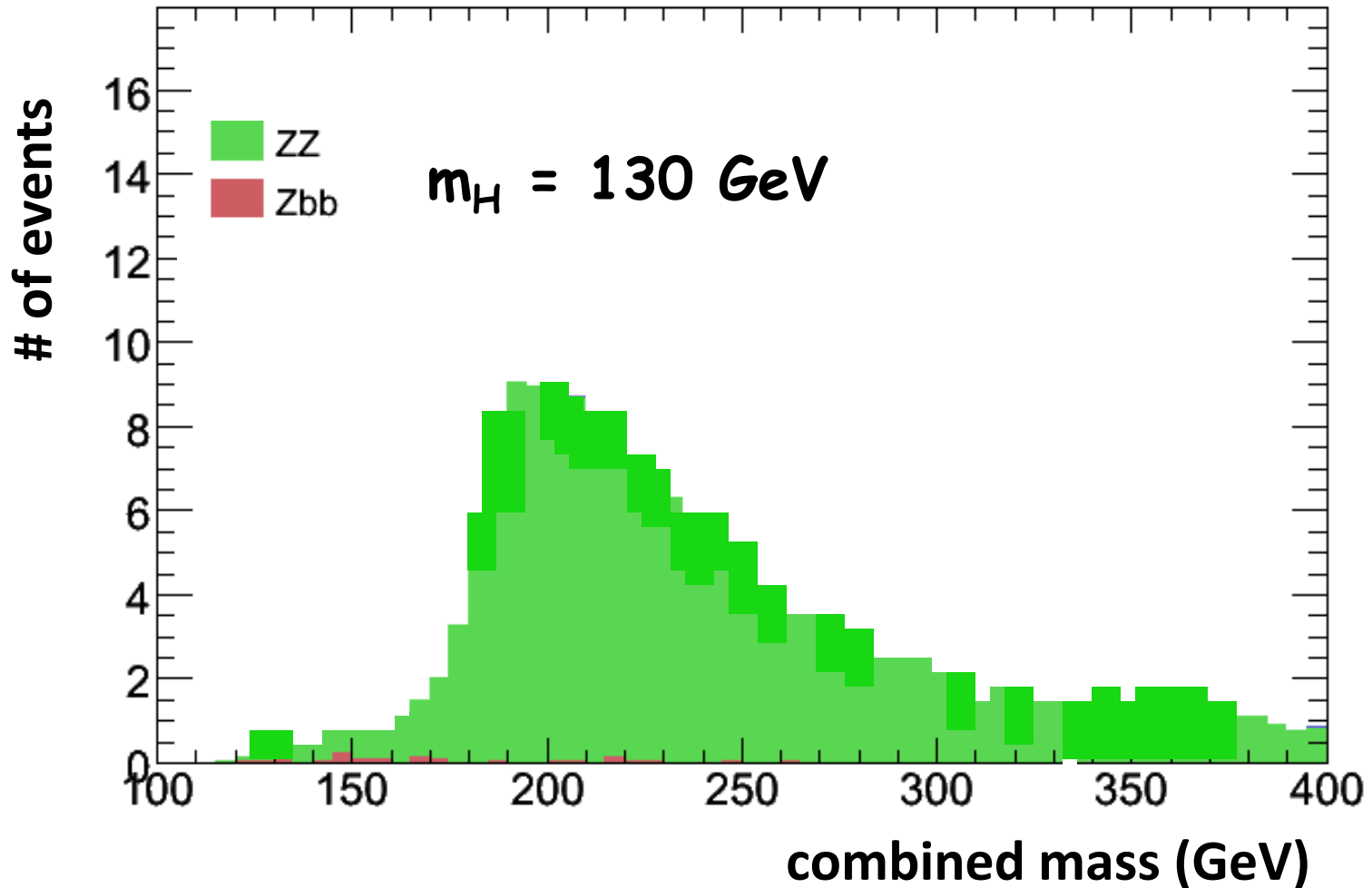
Pauline.Gagnon@cern.ch



The ATLAS detector: a giant camera



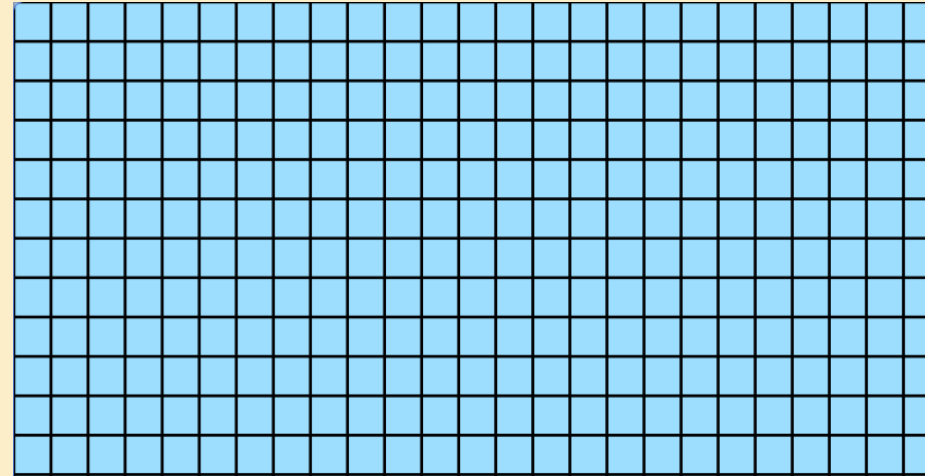
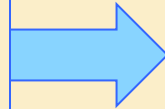
How to distinguish an event containing a Higgs boson from all other events?



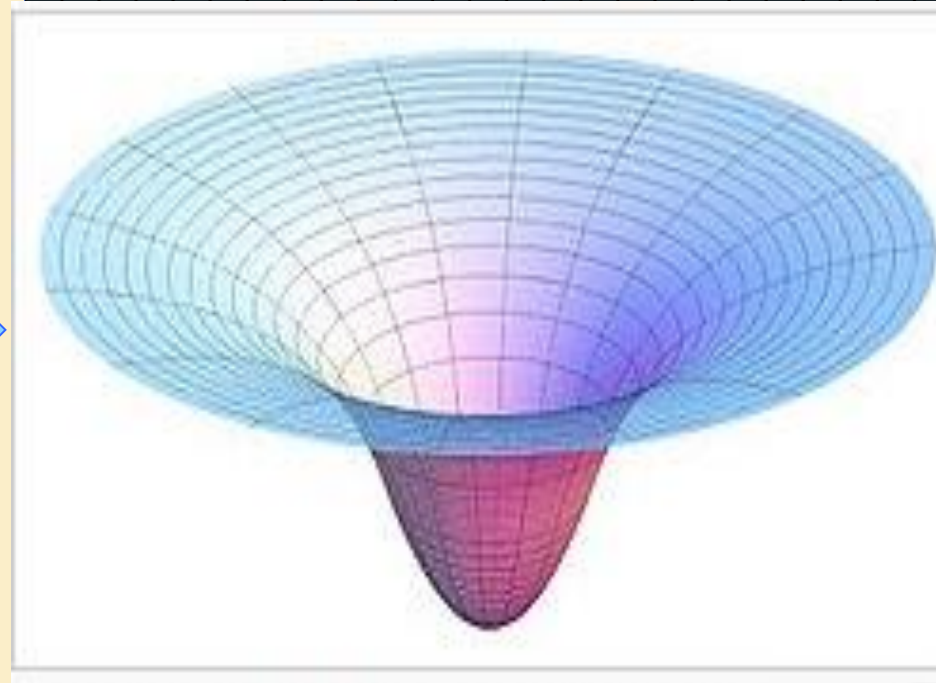
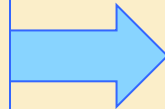
Example: The gravitational field

In empty space:

- space-time is uniform
- light travels on a straight line



We do not see the gravitational field but it affects everything, including light, passing near by



Great discovery

- # Without the Brout-Englert-Higgs mechanism, there was no way to explain the origin of mass
- # Without it, particles would travel at the speed of light
- # There would be no atoms
- # We now have a theory that explains nearly everything

