

Title: Keynote: What's the latest on the LHC?

Date: Jul 09, 2015 09:00 AM

URL: <http://pirsa.org/15070072>

Abstract: <p>The Large Hadron Collider (LHC) at CERN has already yielded deep insights into nature including the discovery of the Higgs boson. Later this year, it will start operating at its full energy of 14 TeV. What will it be searching for? What might it discover? This talk will explore the LHC in 2015 and its beyond.</p>



# LHC Run II: Which Way to Go?

*Seeking a sign in Europe*



*C.P. Burgess*





# LHC Run II: Which Way to Go?

*Seeking a sign in Europe*



*C.P. Burgess*



# Outline

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- Apparatus
  - *The LHC and how they broke (and fixed) it*
- Theory
  - *The Standard Model and its limitations*
- Experiment
  - *To the Higgs ....and Beyond!*

Einstein Plus 2015

# Apparatus

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- The Machine
- Recent Events



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# Apparatus

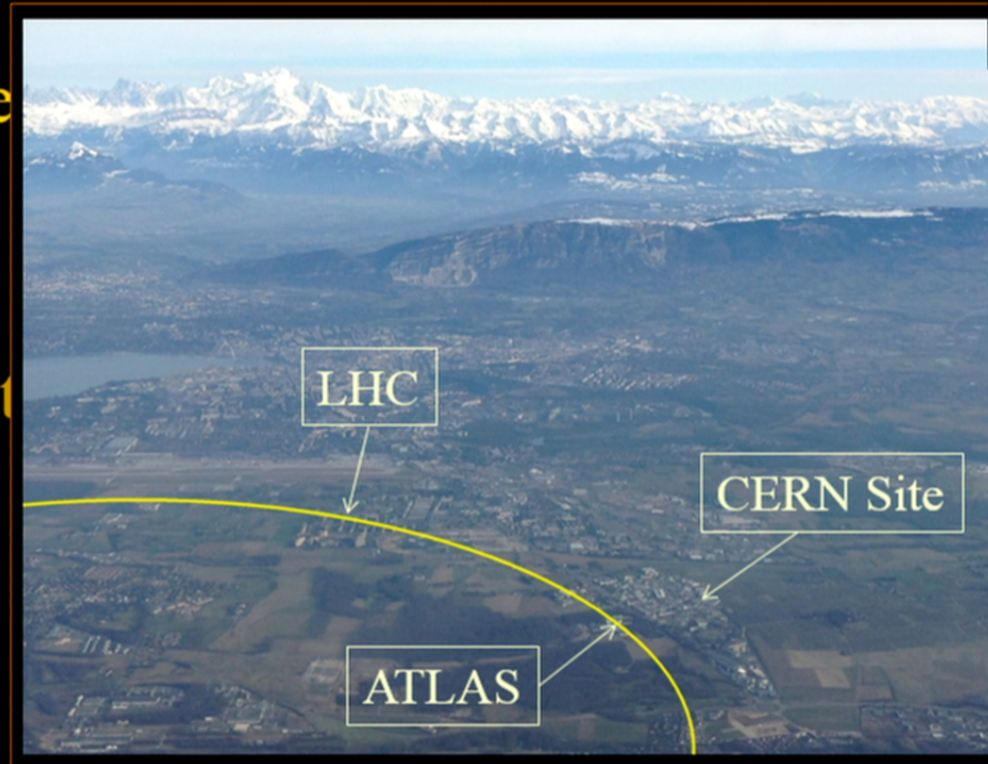
- The Machine
- Recent Event



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# Apparatus

- The Machine
- Recent Events



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# Apparatus

- The Machine



N Site

ATLAS

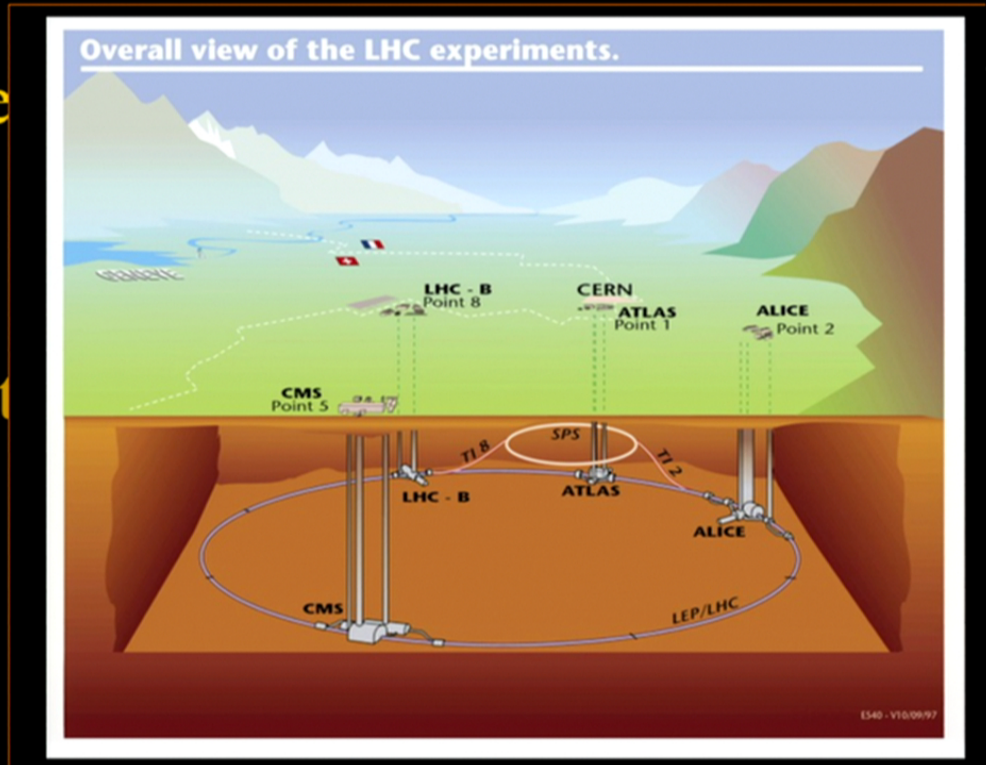
skype



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# Apparatus

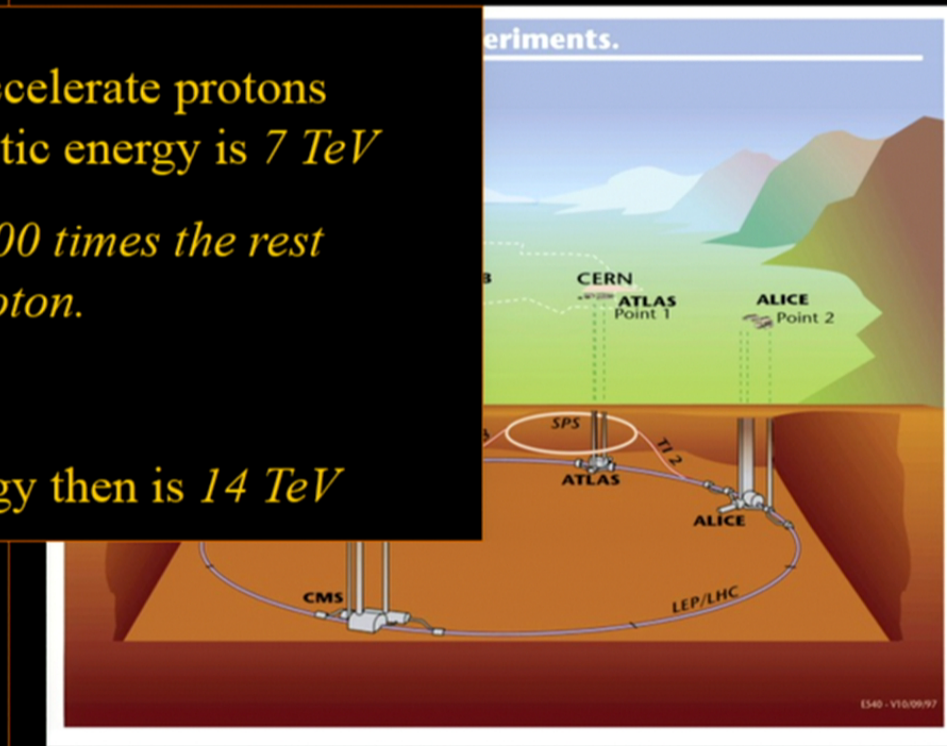
- The Machine
- Recent Events



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# Apparatus

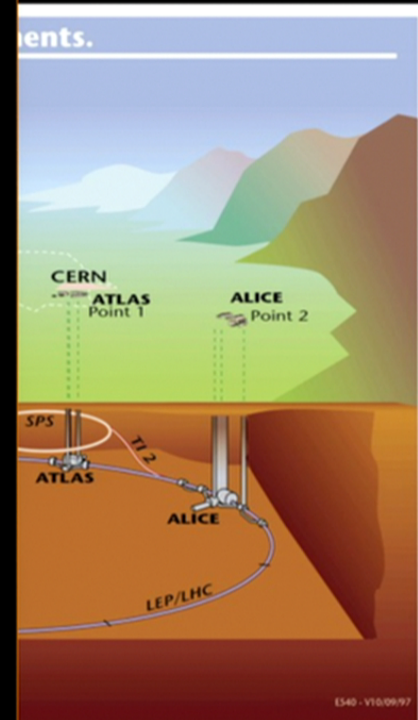
- Designed to accelerate protons until their kinetic energy is  $7 \text{ TeV}$   
 *$0.94 \text{ TeV}$  is 1000 times the rest energy of a proton.*
- Collision energy then is  $14 \text{ TeV}$



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# Apparatus

- The
- Rece



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# Apparatus

- The Machine
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# Apparatus

- The Machine
- Recent Events



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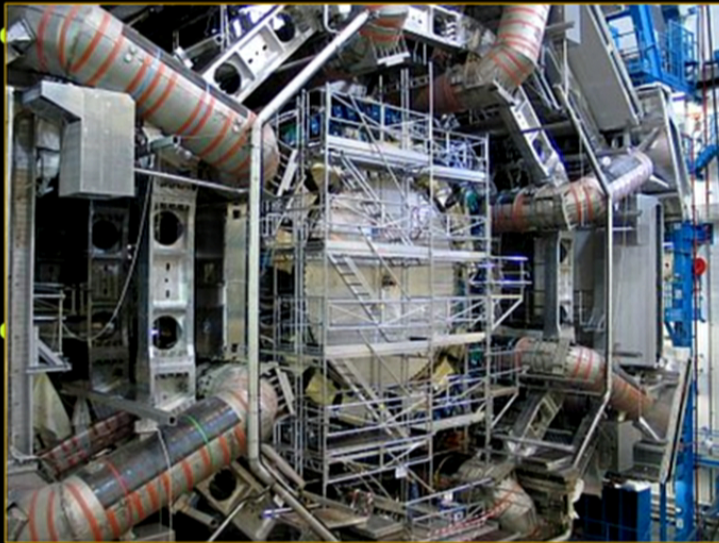
# Apparatus

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# Apparatus



*ATLAS*

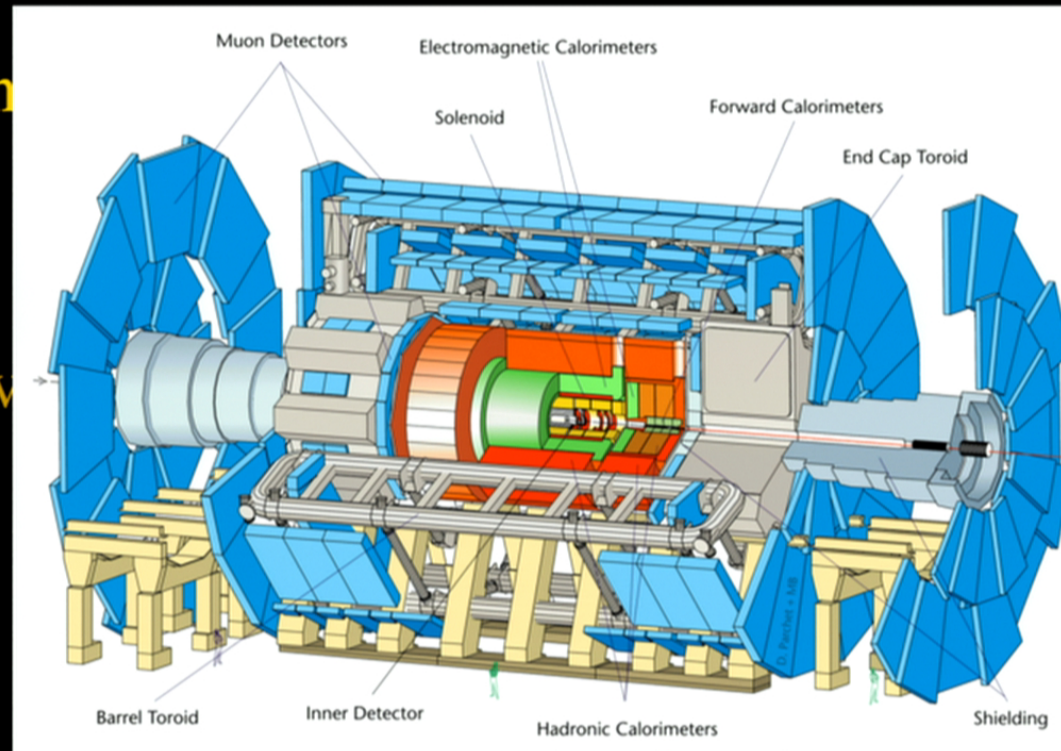


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# Apparatus

- The Machine
- Recent Events

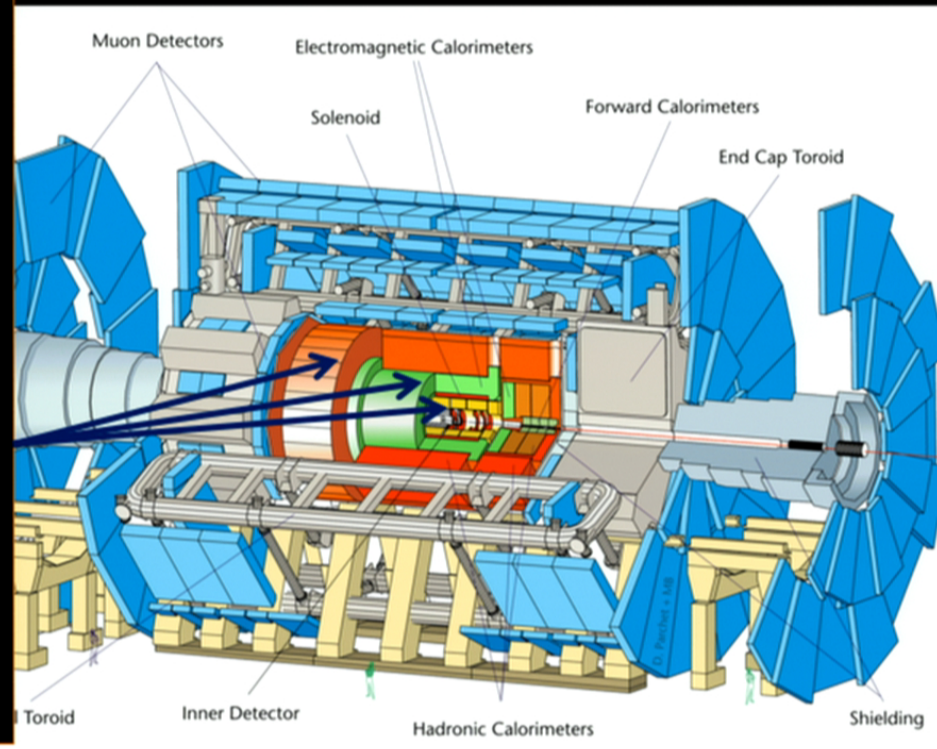


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# Apparatus

Long-lived particles  
that can be seen or  
inferred explicitly:

*electrons*  
*photons*  
*protons* show up here

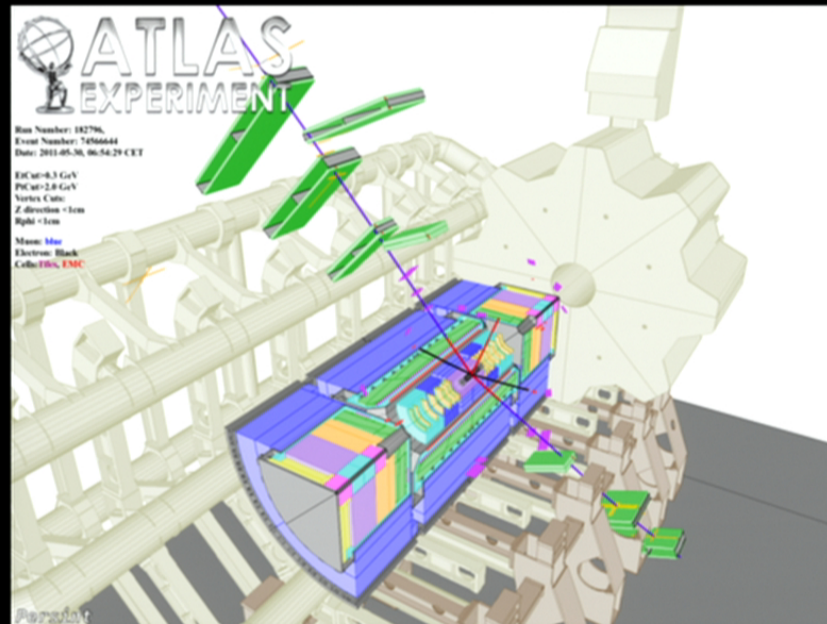


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# Apparatus

- T

- R



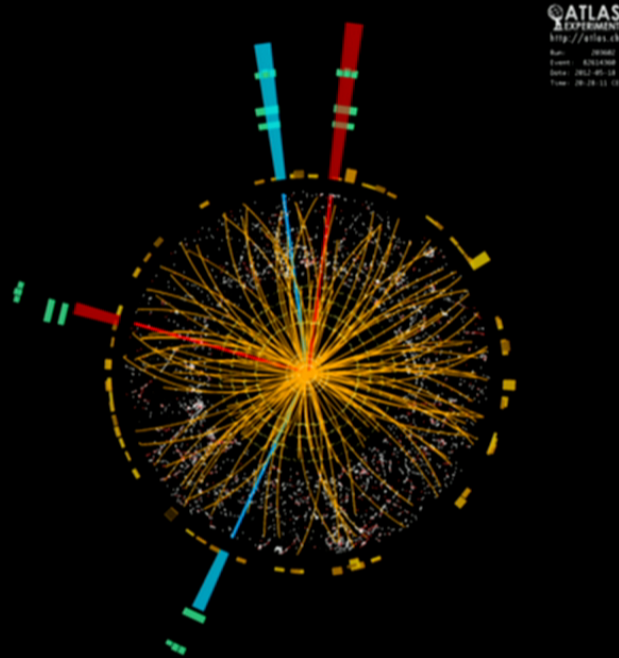
A recorded event with 2 electrons and 2 muons

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# Apparatus

- T

- R



Rarely quite that clean: *eg* a Higgs to 4 muon event

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# Apparatus

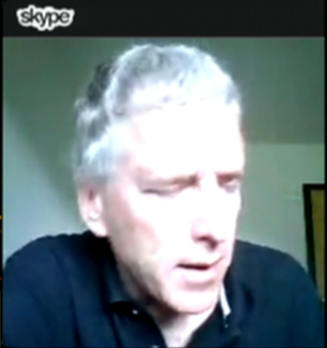
- The Machine
- Recent Events



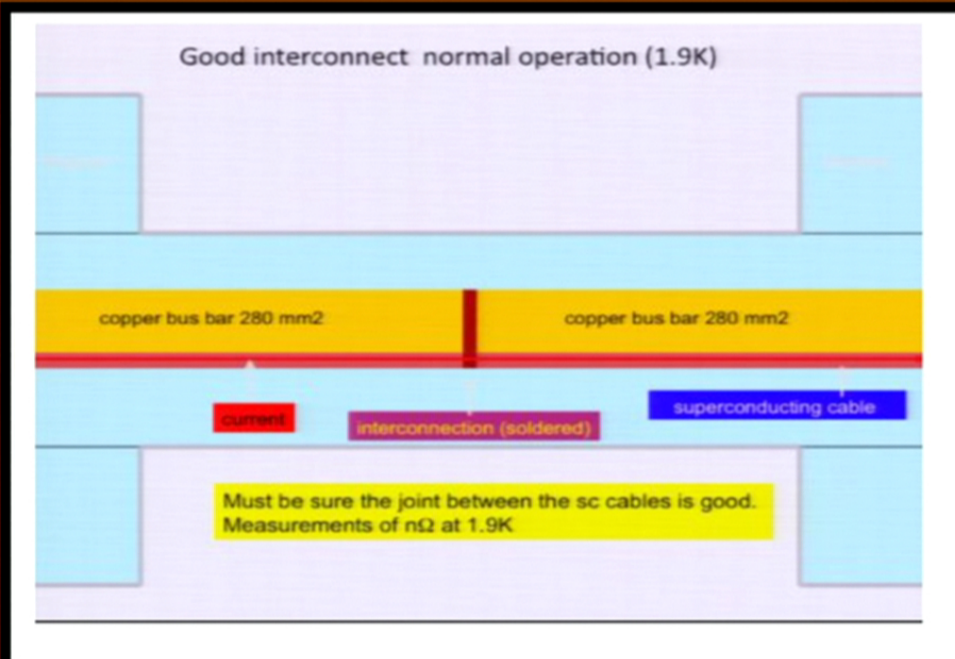
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# Apparatus

W. Trischuk



- The Machine
- Recent Events



schematic connection

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# Apparatus

W. Trischuk



- The Machine
- Recent Events



2009: Replaced 14 quadrupoles and  
29 dipoles and  
34 interconnections repaired

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# Apparatus

skype



- The Ma

*But not all magnet connections were fixed in 2009*

- Recent

- \* Time-consuming to warm up and fix
- \* Can measure resistance to infer which are bad
- \* Ran at half design energy (7 TeV) since 2009,
- \* Slightly higher energy before shutdown
- \* Fixed remaining magnets by fall 2014
- \* Restart in June at near design energy (13 TeV)

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# Appar

- The M

- Recen

From: [Rolf Heuer](#) >

[Hide](#)

To: [cern-personnel \(CERN Personnel - Members and Associate Members\)](#) >

## LHC restart update - Des nouvelles du redémarrage du LHC

March 24, 2015 at 11:07 AM

[tsbox - cliffmacpi@gmail.com](#)

*Version française ci-dessous*

### LHC restart update

LHC run 2 is coming ever closer. Seven of the machine's eight sectors have successfully been commissioned to the 2015 operating energy of 6.5 TeV per beam, and the eighth is not far behind.

There will, however, be no circulating beam in the LHC this week. An intermittent short circuit to ground in one of the machine's magnet circuits was identified on 21 March and is under investigation. It is a well understood issue, but one that could take time to resolve since it is in a cold section of the machine and repair may therefore require warming up and re-cooling after repair. "Any cryogenic machine is a time amplifier," said CERN's Director for Accelerators, Frédérick Bordry, "so what would have taken hours in a warm machine could end up taking us weeks."

Current indications suggest a delay of between a few days and several weeks. A full assessment is on going, and a revised schedule will be announced as soon as it is known. Whatever the case, the impact on LHC operation will be minimal: 2015 is a year for fully understanding the performance of the upgraded machine with a view to full-scale physics running in 2016-2018.

"All the signs are good for a great run 2," said CERN Director General Rolf Heuer. "In the grand scheme of things, a few weeks delay in humankind's quest to understand our universe is little more than the blink of an eye."

skype



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# Apparatus

- The M

- Recen

From: [Rolf Heuer](#) > Hide

To: [cern-personnel](#) (CERN Personnel - Members and Associate Members) >

**Start of Run 2 of the LHC - Coup d'envoi à l'exploitation 2 du LHC**

June 3, 2015 at 2:43 AM

Dear Colleagues,

The LHC operators in the CERN Control Centre (CCC) have just declared "Stable Beams". This marks the start of Run 2 of the LHC as the experiments begin to record their first physics data after the long shut down. This important achievement is the result of many months of hard work by all the teams involved, from CERN and the wider community. It is an achievement in which we can all take pride, since it brings the Laboratory into the post-Higgs era, opening up the way, we hope, to new discoveries. Exploring the physics at 13 TeV is a mouth watering prospect for the whole CERN community. A big thank you to all of you, and keep following [cern.ch](http://cern.ch) for live updates from the CCC as the day goes on.

I am enclosing the press release we will shortly be issuing.

Best regards,  
Rolf Heuer

skype



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# Theory

- The Standard Model
- Successes
- Limitations



*Why was the LHC built?*

Our presently successful understanding of elementary particles and the four forces through which they interact must break down at distances just out of reach.



# Theory

- The Standard Model
- Successes
- Limitations



The Standard Model is the theory which describes the known elementary particles and their interactions. It describes well all experiments which have been performed to date, with a few recent exceptions.



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# Theory

- The Standard Model
- Successes
- Limitations

The Standard Model

	Fermions			Bosons	
Quarks	$u$ up	$c$ charm	$t$ top	$\gamma$ photon	Force carriers
	$d$ down	$s$ strange	$b$ bottom	$Z$ Z boson	
Leptons	$\nu_e$ electron neutrino	$\nu_\mu$ muon neutrino	$\nu_\tau$ tau neutrino	$W$ W boson	
	$e$ electron	$\mu$ muon	$\tau$ tau	$g$ gluon	

The 12 known constituents of matter  
and the 4 fundamental forces

AAAS

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# Theory

- The Standard Model
- Successes
- Limitations

The Standard Model

	Fermions			Bosons	
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The 12 known constituents of matter  
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AAAS

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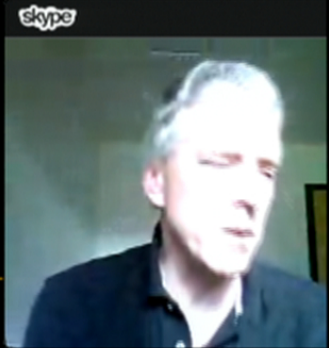


# Theory

- The Standard
- Successes
- Limitations



Although the SM has a symmetry that requires all known particles to be massless, the vacuum has physical properties, which can break this symmetry.



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# Theory

- The Standard
- Successes
- Limitations



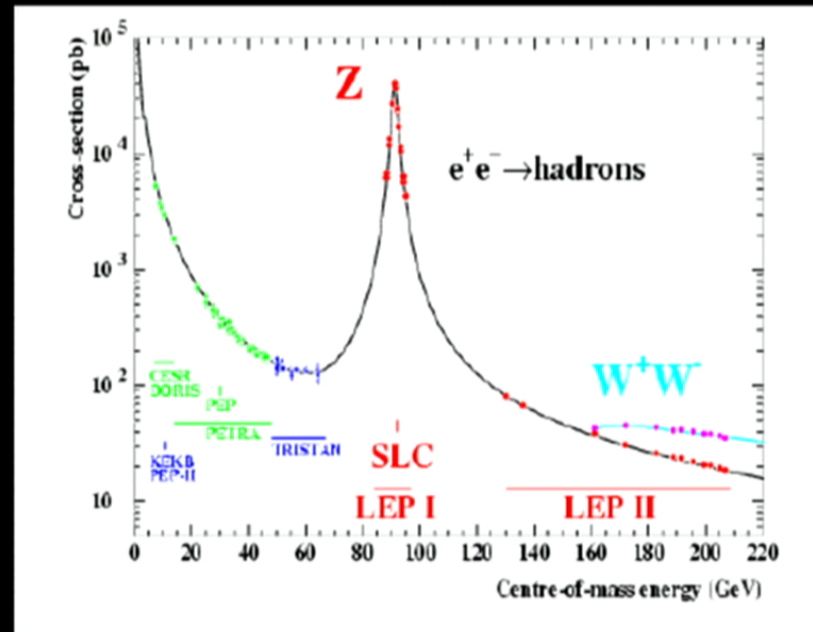
Although the SM has a symmetry that requires all known particles to be massless, the vacuum has physical properties, which can break this symmetry.



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# Theory

- The Standard Model
- Successes
- Limitations



The SM is tested in detail, such as through  $e^+e^-$  collisions

A Tonazzo: Moriond 2002

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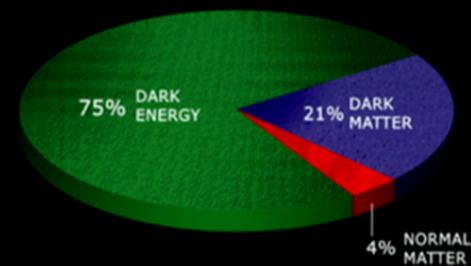
# Theory

- The Standard Model
- Successes

*So what's wrong with the Standard Model?*

*Observational Problems:*

Neutrinos appear to have masses...  
Dark Matter and Dark Energy unexplained..



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# Theory

- The Standard Model
- Successes
- Limitations

*So what's wrong with the Standard Model?*

*Observational Problems:*

Neutrinos appear to have masses...  
Dark Matter and Dark Energy unexplained..

*Theoretical Problems:*

Hierarchy Problem  
Cosmological Constant Problem  
Who ordered all this?  
What about Gravity?

skype



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# Why was it built?

- The Standard Model
- Successes
- Limitations

*So what's wrong with the Standard Model?*

*Observational Problems:*

Neutrinos appear to have masses...

Dark Matter and Dark Energy unexplained..

*Theoretical Problems:*

Hierarchy Problem

Cosmological Constant Problem

Who ordered all this?

What about Gravity?

*require changes  
at low energy*

skype



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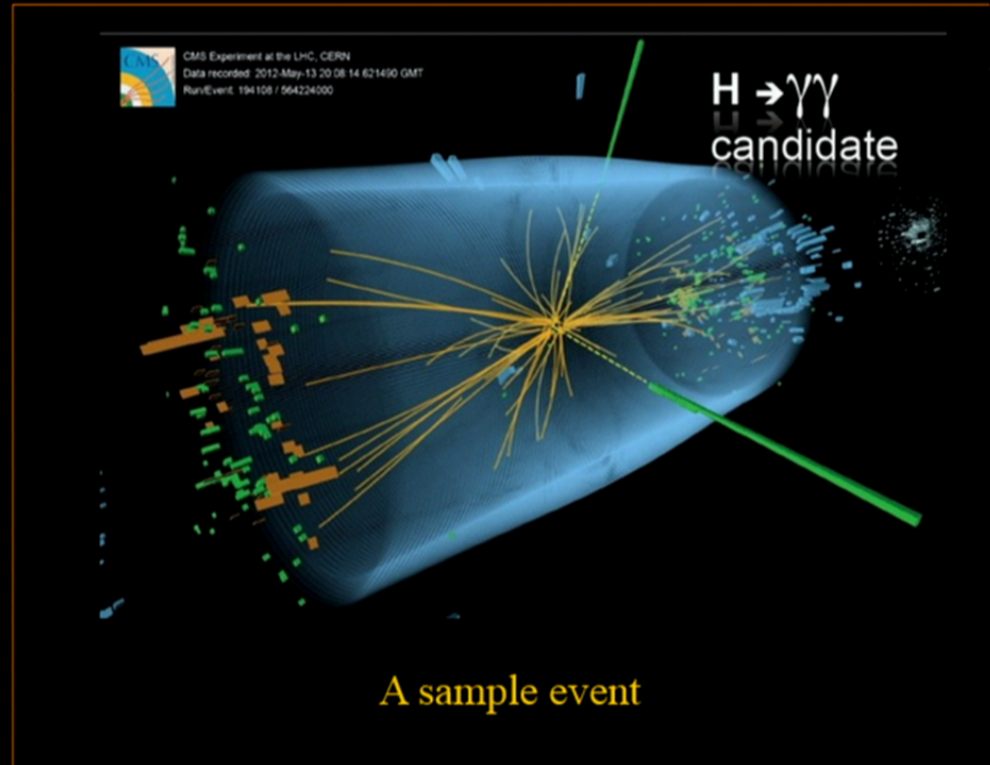


# *Experiment:* *To the Higgs – and Beyond!*

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# Experiment

- The Higgs
- Beyond?



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# Experiment

- The Higgs



Needle in the haystack problem:

*Many other reactions also produce two photons, and much more often*

Really, much worse than that:

*Seek a needle in a haystack, but the needle decays into hay after  $10^{-23}$  seconds!*

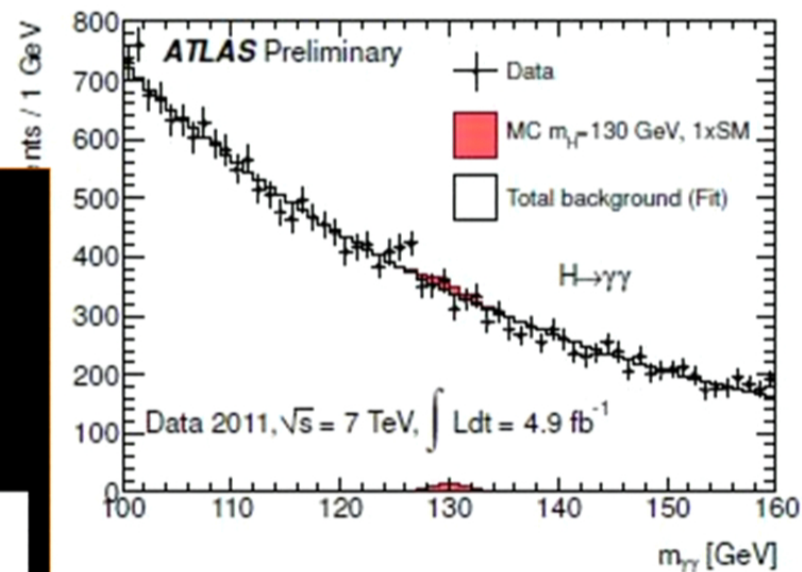


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# Experiment

- The Higgs

Crucial clue: two photons (say) from a Higgs decay always have energies equal to half the Higgs mass in a frame where they move in opposite directions.

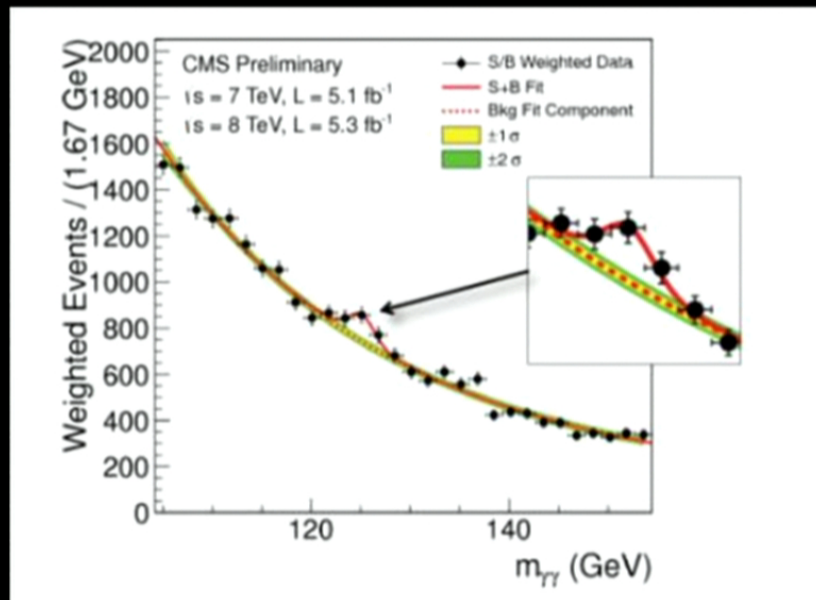


in the haystack problem: *other reactions also produce the same things even more abundantly*

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# Experiment

- The Higgs
- Beyond?



CMS (and ATLAS): *saw a bump*

skype



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# Experiment

skype



- The Higgs

What do we know?

A new particle decaying into 2 photons:

*A boson (so can mediate a force)*

*Spin zero or two*

*Electrically neutral*

*Mass  $\sim 125$  GeV*

- Beyond?

*Is this 'a Higgs' or 'the Higgs'?*

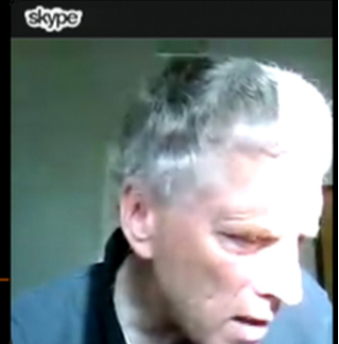
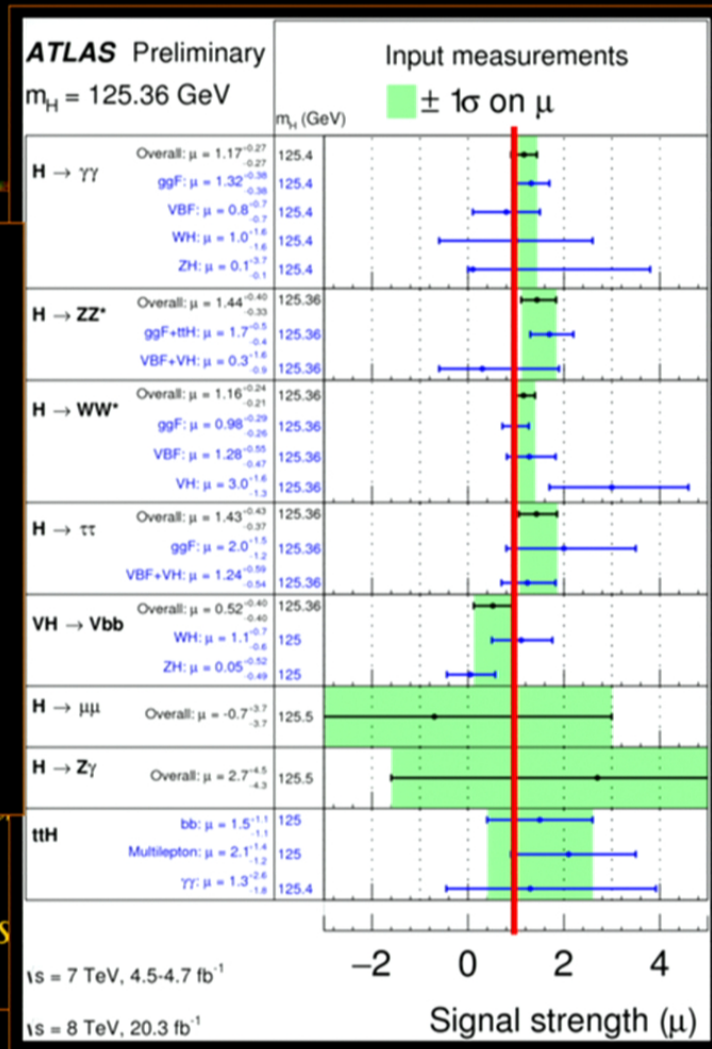
*Is it something else?*

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# Experiment

- The *Experiment divided by SM prediction:*
- Beyond SM prediction should overlap red line

Is it s



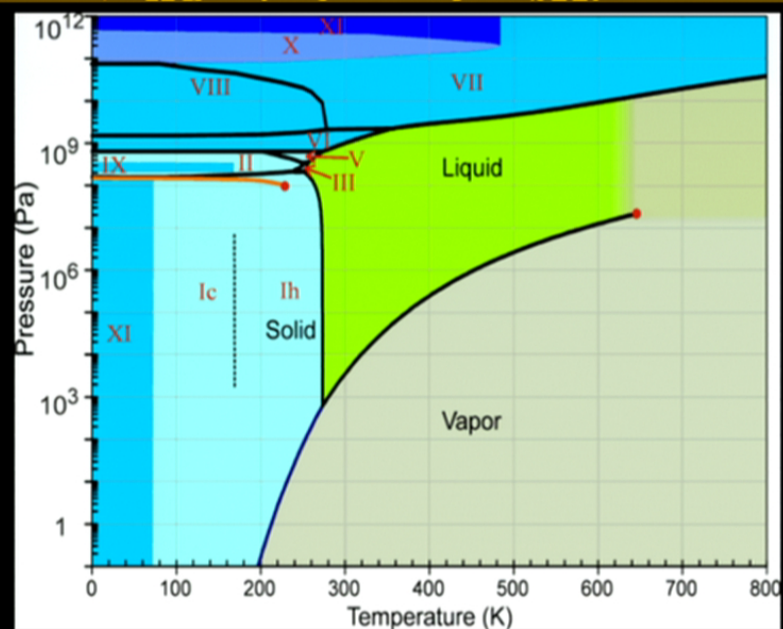
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# Experiment

- The Higgs

- Beyond?

## *The Hierarchy Problem*



metry breaking  
all compared  
s we think

$2 \sim 10^2 \text{ GeV}$

$2 \sim 10^{19} \text{ GeV}$

2  
p

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# Experiment

skype



- The Higgs
- Beyond?

## *The Hierarchy Problem*

Why is gravity so weak?

That is, why is the *scale* of Higgs symmetry breaking (and so all known masses) that sets strength of weak interactions so different than the only other force we know: gravity?

*Higgs: Weak scale*  $M \sim G^{-1/2} \sim 10^2 \text{ GeV}$

*Gravity: Planck mass*  $M_{SUN} = M_p^3 / m_p^2$

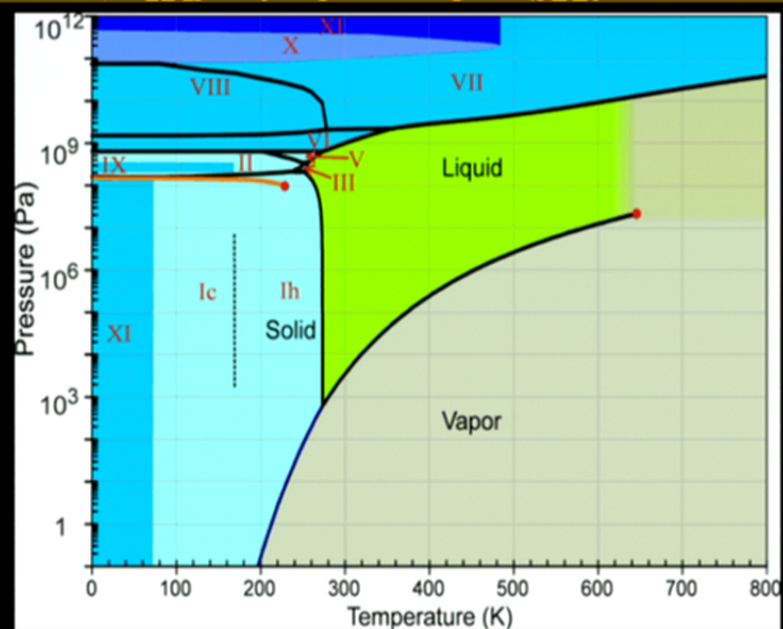
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# Experiment

- The Higgs

- Beyond?

## *The Hierarchy Problem*



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p

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# Experiment

skype



- The Higgs

*Proposals to understand this hierarchy:*

*Composite models: the Higgs is a composite made of smaller constituents*

- Beyond



These tend to predict a light Higgs-like state that can decay into photons, but tend *not* to decay into  $W$ s and  $Z$ s

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# Experiment

- The Higgs

*Proposals to understand this hierarchy:*

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- Beyond



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skype



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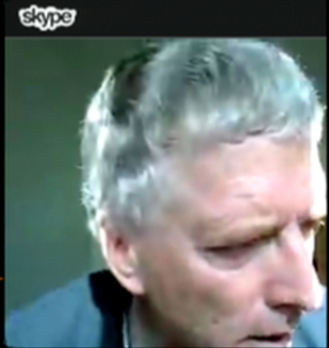
# Experiment

- The Higgs
- Beyond?

*Proposals to understand this hierarchy:*

*Supersymmetric models:* all known particles come with new partners having different spin and statistics

These predict several Higgs-like particles, of which the SM-like one likes to be lighter than 125 GeV



# Experiment

- The Higgs

- Beyond?

*Proposals to understand*

*Supersymmetric models  
particles come with  
different spin and statistics*

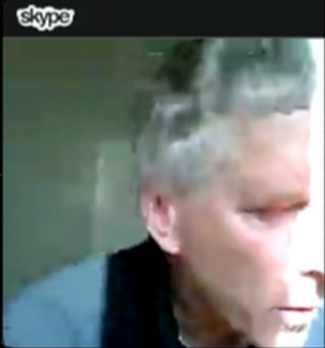
*These predict several new particles  
of which the SM-like Higgs is  
lighter than 125 GeV*

*eg:*

*'selectron' is super partner to the electron*

*'stop' is super partner to the top quark*

*and so on...*



# Experiment

- The Higgs

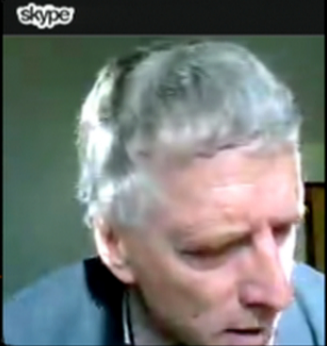
- Beyond



*Proposals to understand this hierarchy:*

*Extra-dimensional models:* there are very large extra dimensions, and gravity becomes strong at LHC energies

These give SM-like Higgs particle, plus energy missing into the extra dimensions (but not expected to be visible at 8 TeV)



# Outlook

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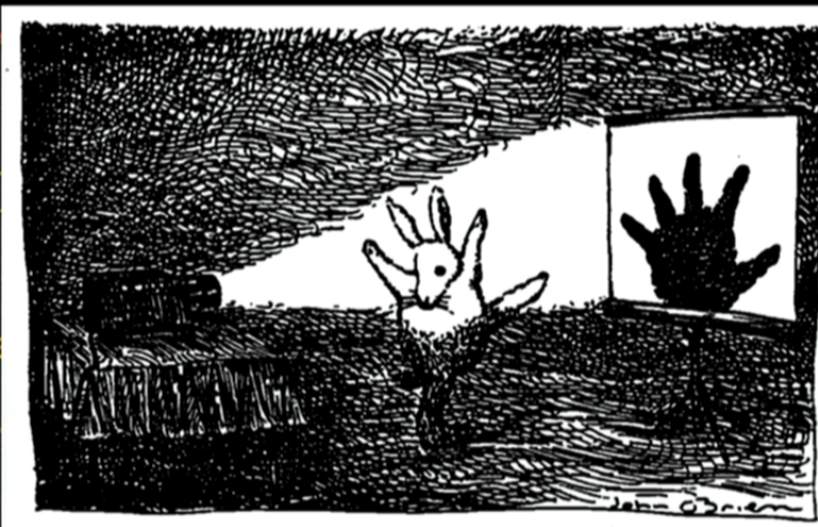
- The LHC is already changing how we think about high energy physics!
  - *Runs at design beam energy even as we speak!*
- New boson discovered at 125 GeV
  - *Seems consistent with a SM Higgs*
  - *More evidence either way within the year*
- *The LHC says the Higgs mechanism is right!*

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# Outlook

- The LHC is already on the edge of new energy physics!
  - *Runs at design beam energy*
- New boson discovered
  - *Seems consistent with the Standard Model*
  - *More evidence either way within the year*
- *The LHC says the Higgs mechanism is right!*
- Higher energy the key to new things:
  - Watch for surprises!

*(cantwaitcantwaitcantwaitcantwaitcantwaitcantwaitcantwait....)*



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