

Title: TBA

Date: Jul 09, 2014 10:30 AM

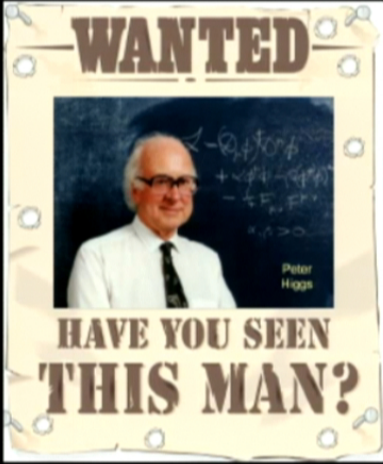
URL: <http://pirsa.org/14070022>

Abstract:

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The Higgs Boson: what is it and what does its discovery mean?



C.P. Burgess

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Outline

- Apparatus
 - *The LHC and how they broke it*
- Theory
 - *The Standard Model and its limitations*
- Experiment
 - *Recent evidence for the Higgs*
- Outlook

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Apparatus

- The Machine
- Recent Events

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Apparatus

- The Machine
- Recent Events



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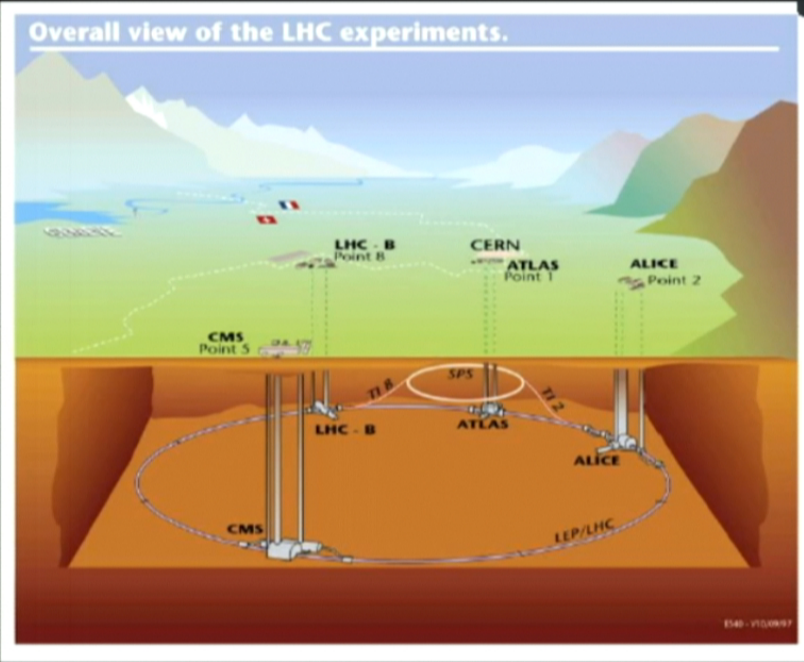
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Apparatus

- The Machine
- Recent Events

Overall view of the LHC experiments.



The diagram illustrates the overall view of the LHC experiments. It shows the LHC ring (LHC-B) and the various experiments (CMS, ATLAS, ALICE, LHC-B) located at different points along the ring. The top part of the diagram shows the LHC ring and the experiments (CMS, ATLAS, ALICE, LHC-B) located at different points along the ring. The bottom part of the diagram shows the LHC ring and the experiments (CMS, ATLAS, ALICE, LHC-B) located at different points along the ring.

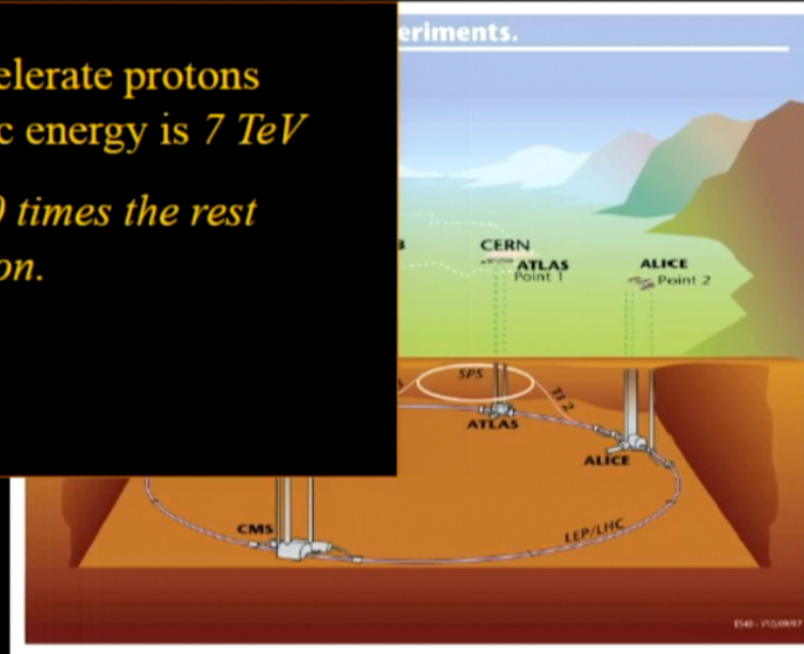
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Apparatus

- Designed to accelerate protons until their kinetic energy is 7 TeV
 0.94 TeV is 1000 times the rest energy of a proton.



The diagram illustrates the LHC tunnel and its experiments. It shows the SPS, ATLAS, ALICE, CMS, and LEP/LHC. The tunnel is labeled 'CERN' and 'ATLAS Point 1'. The experiments are labeled 'ATLAS', 'ALICE', 'CMS', and 'LEP/LHC'. The diagram is credited to 'ES4 - VIGOR7'.

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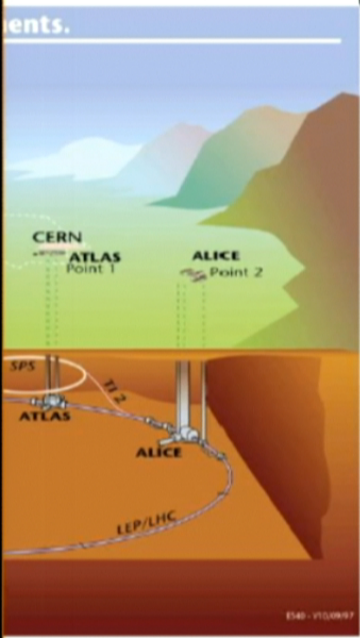
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Apparatus

- The
- Rece



ENTS.

CERN
ATLAS
Point 1

ALICE
Point 2

SPS
ATLAS
ALICE
LEP/LHC

ESD - VISUM7

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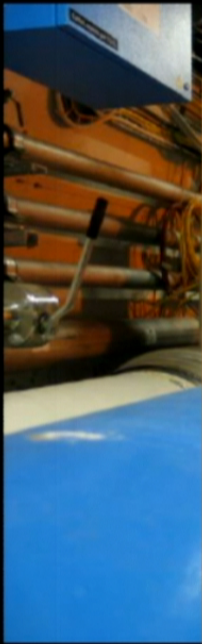
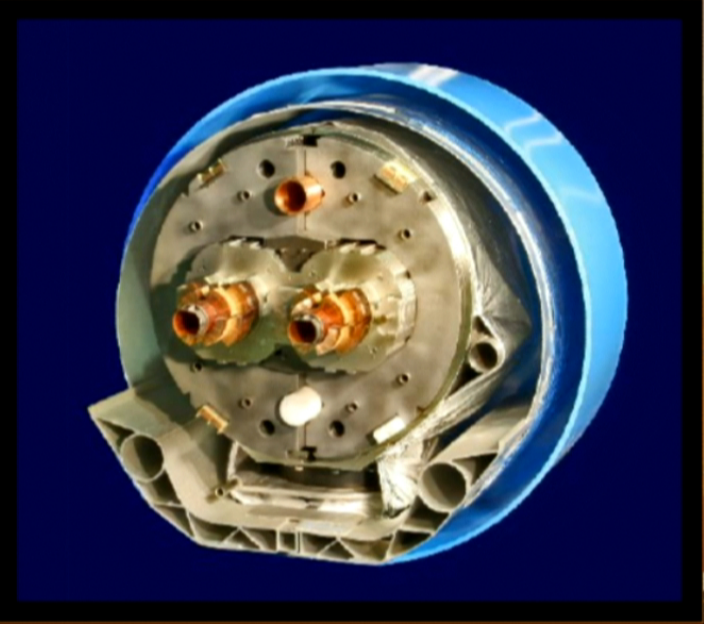
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Apparatus

- 
- 

ALICE Point 2

ALICE

P/LHC

E50 - VISOR7

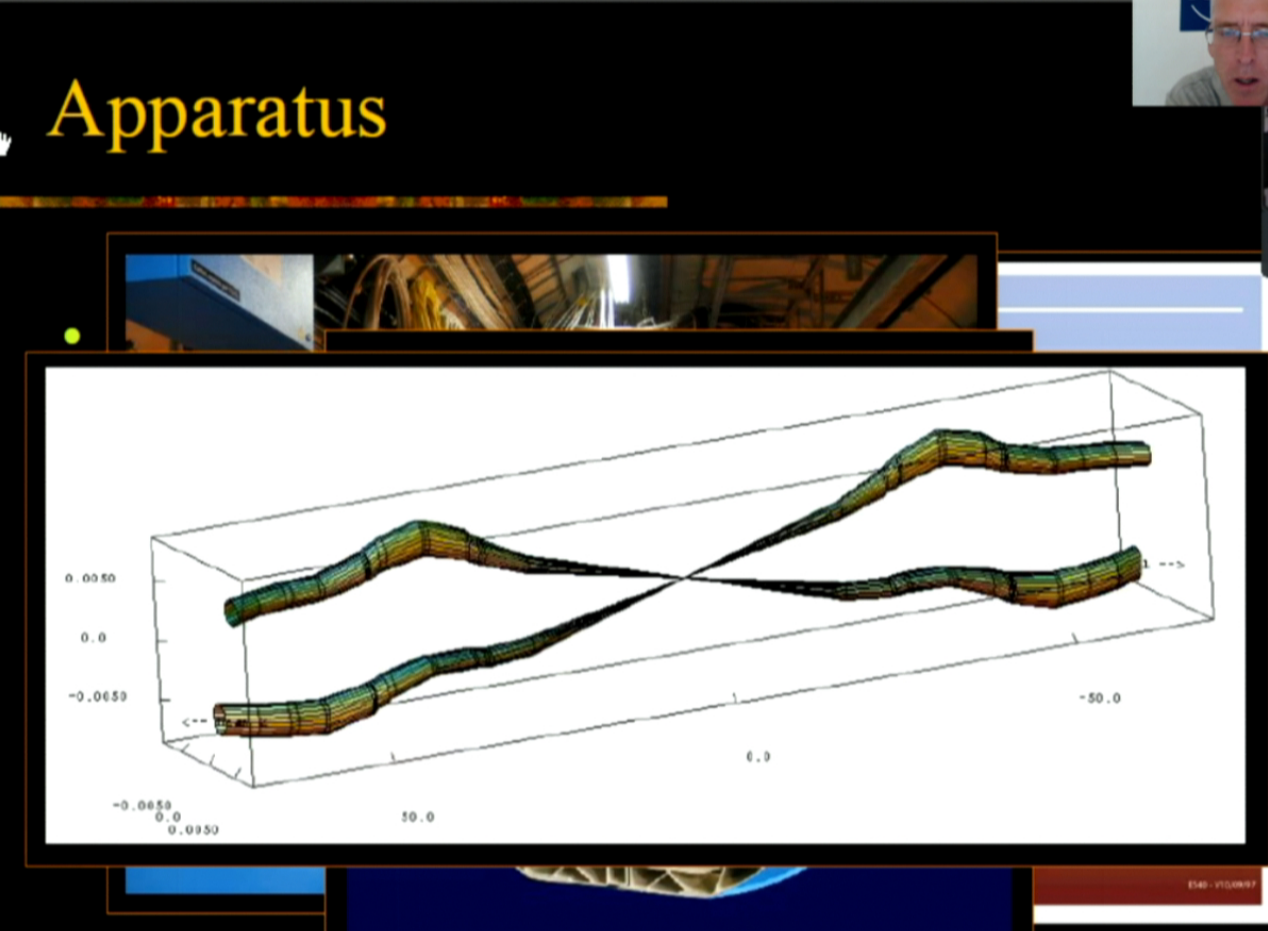
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Apparatus



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Apparatus

- The Machine
- Recent Events



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Apparatus

- The Machine



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Apparatus

- The



Angels & Demons

CERN

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Apparatus

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Angels & Demons

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Angels & Demons

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Apparatus

- The Machine



Angels & Demons

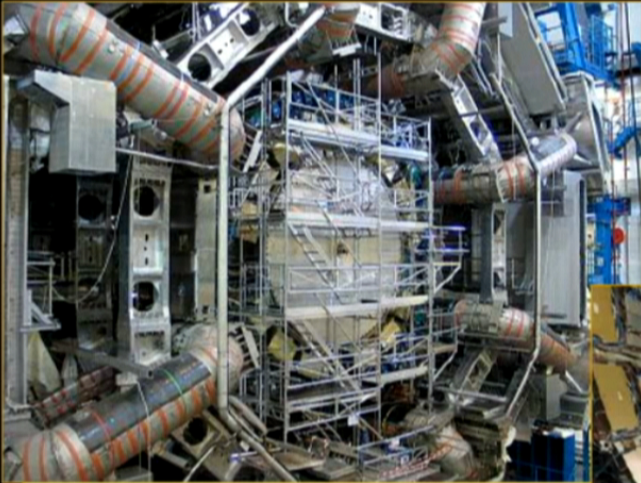
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Apparatus



ATLAS



CMS

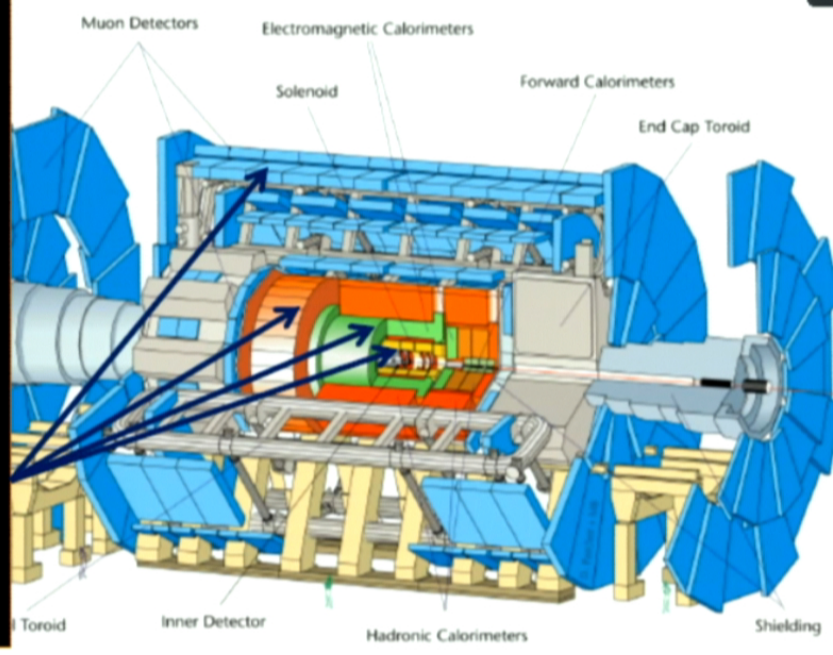
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Apparatus

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

electrons
photons
protons
neutrons
muons show up here



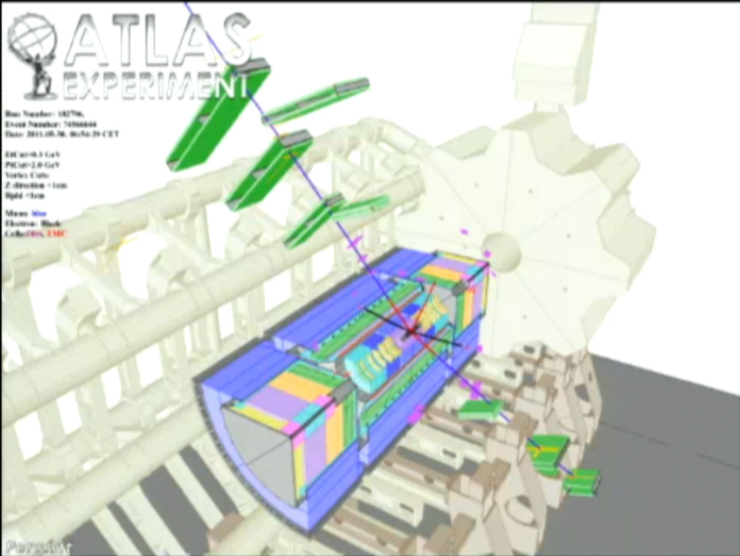
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Apparatus



ATLAS EXPERIMENT

Run Number: 361796
Event Number: 7410000
Date: 2015-05-06, Week 29-CTT

1st author: G. Aad
2nd author: J. L. Abad
3rd author: C. Bacci
4th author: A. Ballestrero
5th author: S. Banerjee

6th author: M. Barak
7th author: R. Barlow
8th author: J. Barral

9th author: A. Barzanti
10th author: A. Basso

11th author: A. Belyaev
12th author: A. Belyaev

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96th author: A. Belyaev

97th author: A. Belyaev
98th author: A. Belyaev

99th author: A. Belyaev
100th author: A. Belyaev

A recorded event with 2 electrons and 2 muons

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Apparatus

- The Machine
- Recent Events



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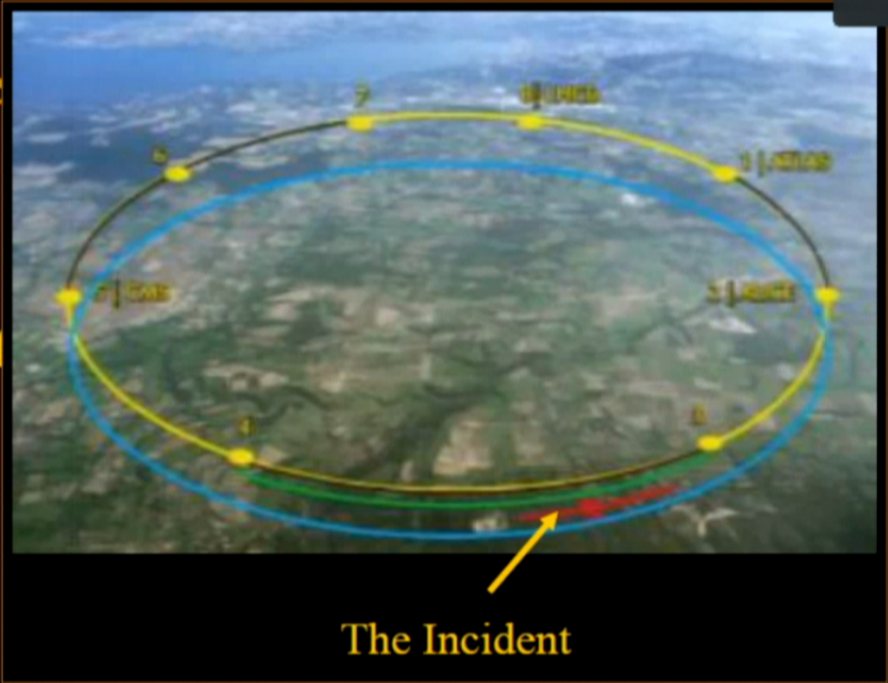
The image shows a presentation slide titled 'Apparatus' with two bullet points: 'The Machine' and 'Recent Events'. To the right of the text is a photograph of the LHC tunnel from an aerial perspective, with a yellow circle and a sad face drawn on it. The slide is part of a PDF document 'LHCHiggs-Eplus2014.pdf' viewed in Adobe Reader. The document is 31 pages long, and the current page is 79% zoomed. In the top right corner, there is a video feed of a man speaking, with an ICTP logo and a 'Stop sharing' button.

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Apparatus

- The Machine
- Recent Events



The diagram shows a top-down view of the LHC particle accelerator, which is a large circular ring. The ring is composed of two concentric paths: an inner blue path and an outer yellow path. Several yellow dots are placed along the ring, representing different experimental areas or detectors. A red arrow points to a specific location on the inner blue path, labeled "The Incident".

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Apparatus

- The Machine
- Recent Events

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LHC 2003



1200 superconducting magnets

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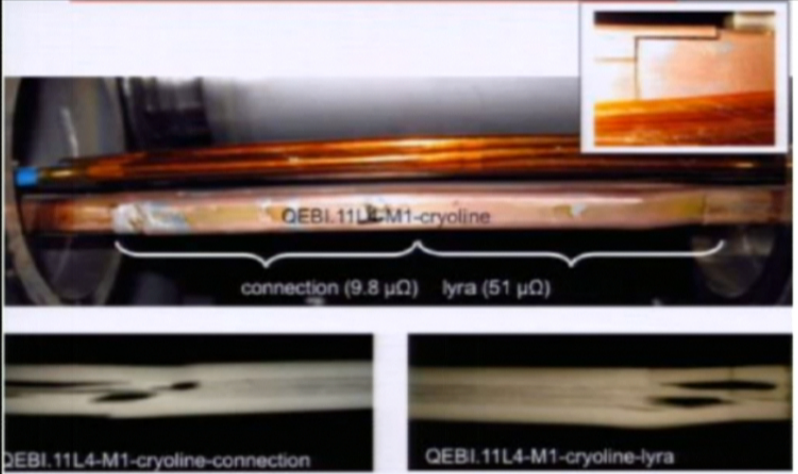
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Apparatus

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- The Machine
- Recent Event



dipole interconnect

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Apparatus

W. Trisch

- The Machine
- Recent Events

Good interconnect normal operation (1.9K)

copper bus bar 280 mm²

interconnection (soldered)

superconducting cable

Must be sure the joint between the sc cables is good.
Measurements of nΩ at 1.9K

schematic connection

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Apparatus

- The Machine
- Recent Events



Before repair After repair



Physical damage; soot in the beam pipe; and so on....

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Apparatus

- The Machine
- Recent Events



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Replaced 14 quadrupoles and 29 dipoles,
34 interconnections fully repaired

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Apparatus

- The Main Magnet
 - What if there are also problems with the other magnets that did not (yet) fail?*
 - * Time-consuming to warm up and fix
 - * Can measure resistance to infer which are bad
- Recent Performance
 - * Ran at half design energy (7 TeV) since 2009,
 - * Slightly higher energy before shutdown (8 TeV)
 - * Fixing magnets until fall this year (2014)
 - * Restart at design energy (14 TeV)

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Apparatus

- The Machine
- Recent Events

LHC sets new world record 30 November 2009



Scenes of joy in the CERN Control Centre more photos »

Geneva, 30 November 2009. CERN's Large Hadron Collider has today become the world's highest energy particle accelerator, having accelerated its twin beams of protons to an energy of 1.18 TeV in the early hours of the morning. This exceeds the previous world record of 0.98 TeV, which had been held by the Tevatron at Fermilab, USA.

Ran for several years at lower energies

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Theory

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A screenshot of a video conference interface. The main window displays a presentation slide with a black background and the word 'Theory' in a large, yellow, serif font. The slide is part of a PDF document titled 'LHCHiggs-Eplus2014.pdf' viewed in Adobe Reader. The Adobe Reader interface includes a top toolbar with various icons and a sidebar on the left. In the bottom right corner of the slide, the text 'Einstein Plus 2014' is visible. Overlaid on the right side of the screen is a video feed of a man speaking, with an ICTP logo in the top left corner of the video. Below the video feed is a dark grey bar with a camera icon and the text 'Stop sharing'.

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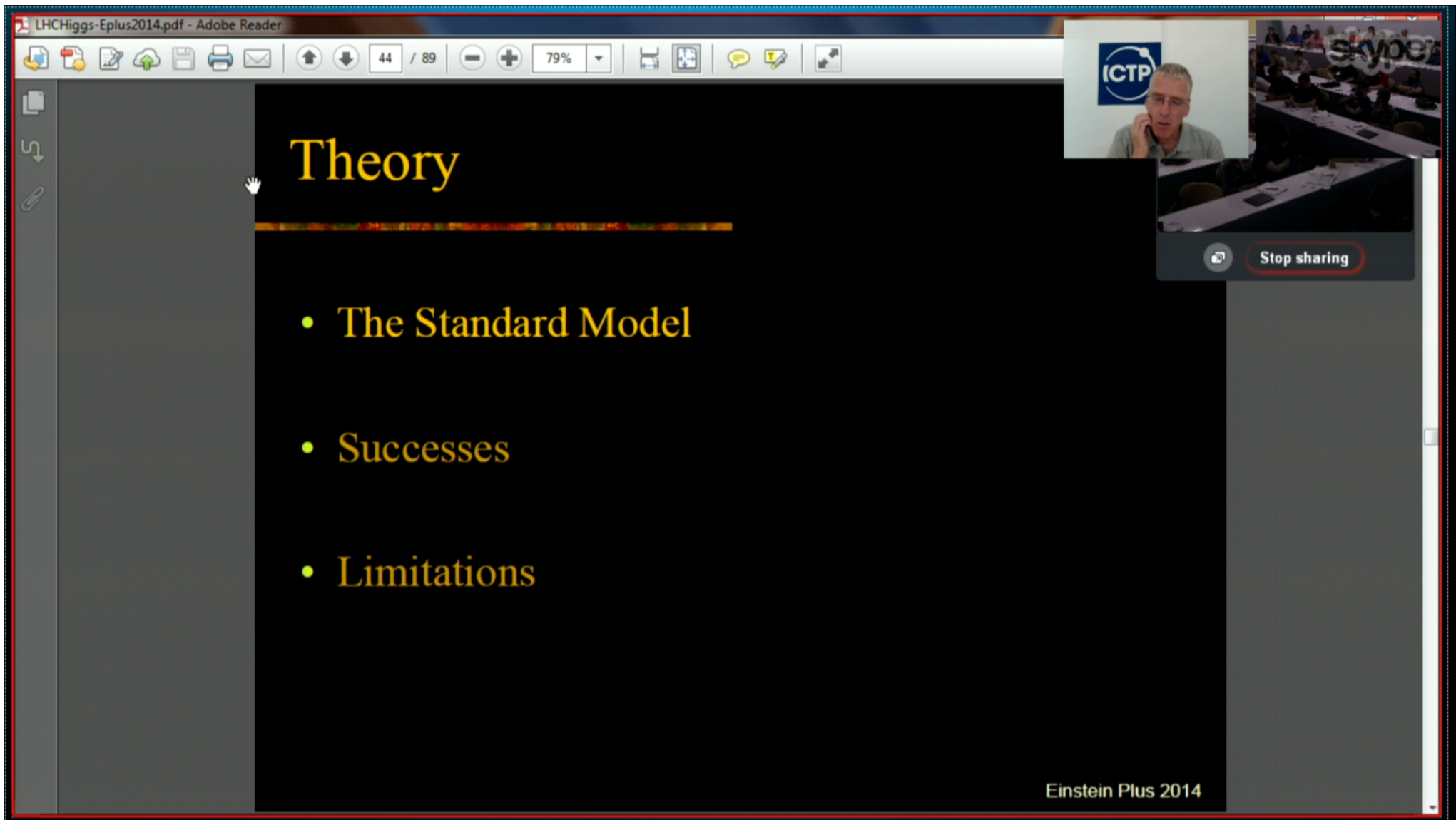
Theory

- The Standard Model
- Successes
- Limitations

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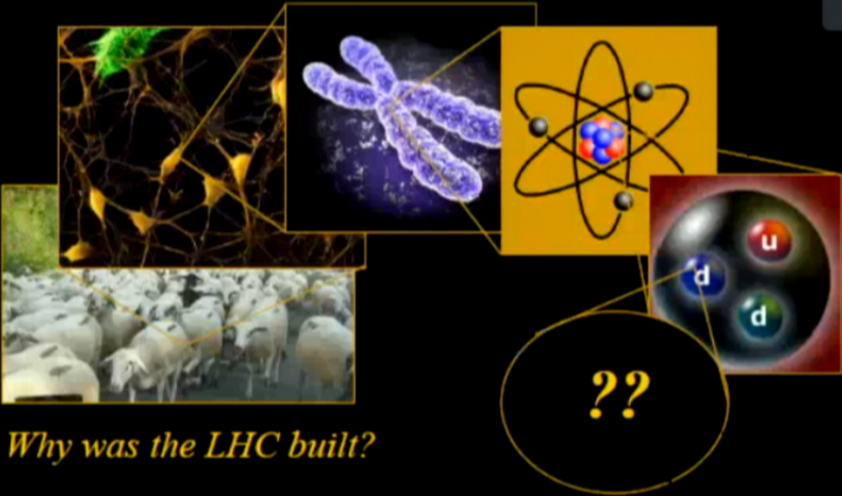


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Theory

- 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.

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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	γ photon
	d down	s strange	b bottom	Z Z boson
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson
	e electron	μ muon	τ tau	g gluon

The 12 known constituents of matter and the 4 fundamental forces

AAAS

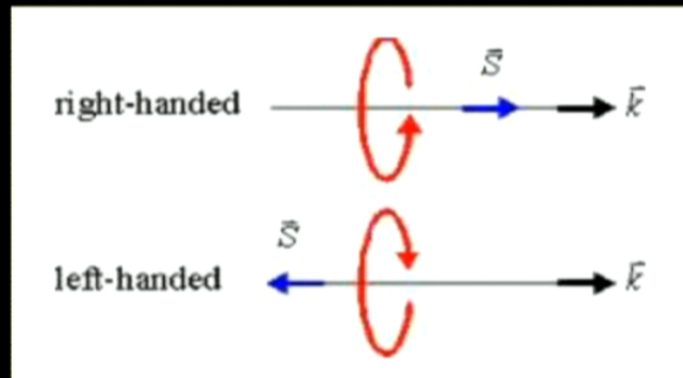
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Theory

- The Standard
- Successes
- Limitations



Matter particles come with two spins: left- or right-handed

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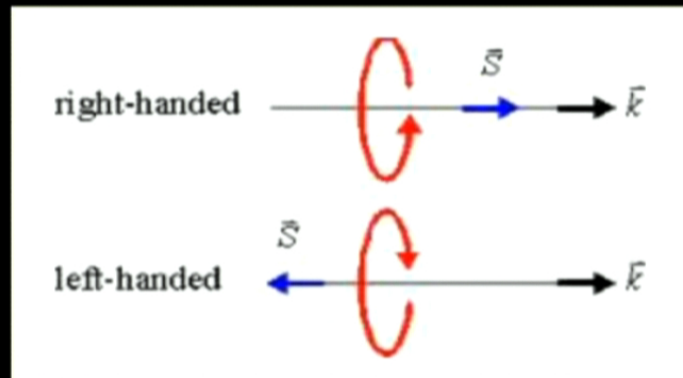
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Theory

- The Standard



Matter particles come with two spins: left- or right-handed (like polarizations of light).

AAAS

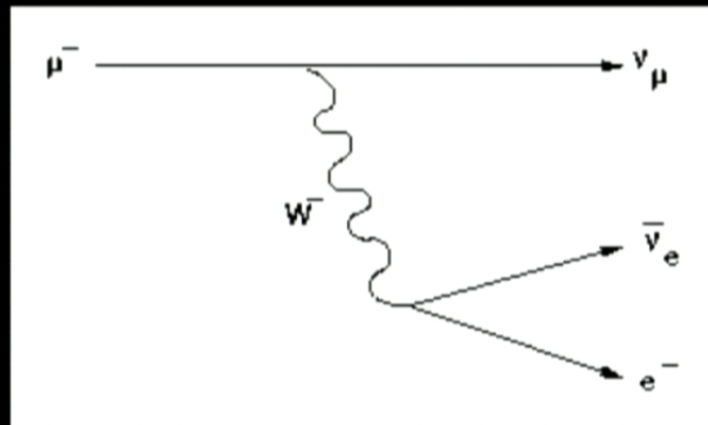
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Theory

- The Standard Model
- Successes
- Limitations



The Standard Model incorporates an experimental fact: only *left-handed* particles participate in the weak interactions

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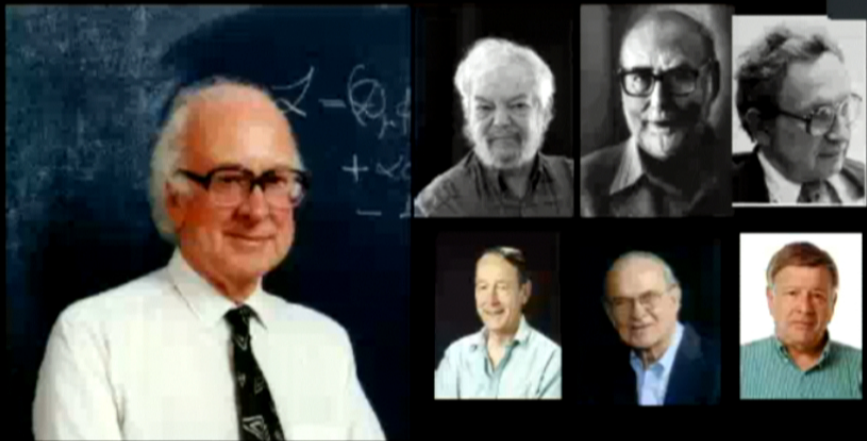
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Theory

- The Standard Model
- Successes
- Limitations



The Higgs boson is inferred theoretically, because it is associated with the *Higgs mechanism*: the reason why all of the SM particles have any mass at all.

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Theory

- The Standard Model
- Successes
- Limitations



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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



Particle masses are due to the energy of interaction with the Higgs vacuum ($m = E/c^2$)

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Theory

- The Standard
- Successes
- Limitations



The Higgs *particle* is a wave moving through the Higgs vacuum itself.

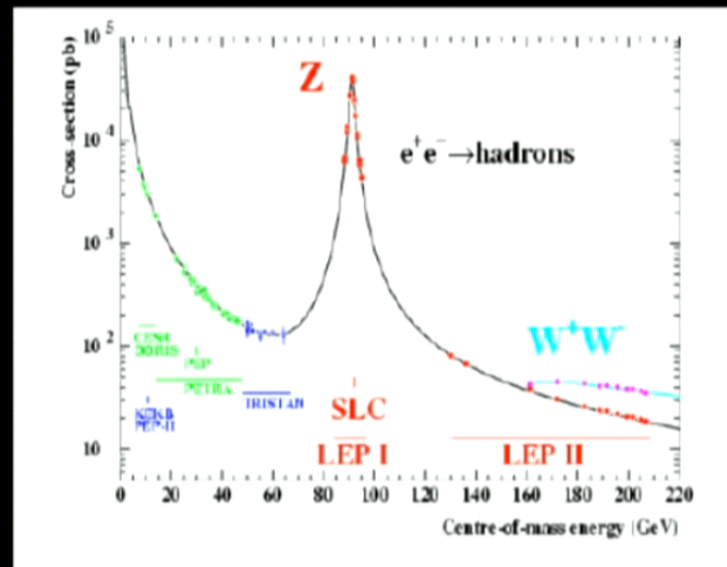
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Theory

- The Standard Model
- Successes
- Limitations



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

A Tonazzo: Moriond 2002

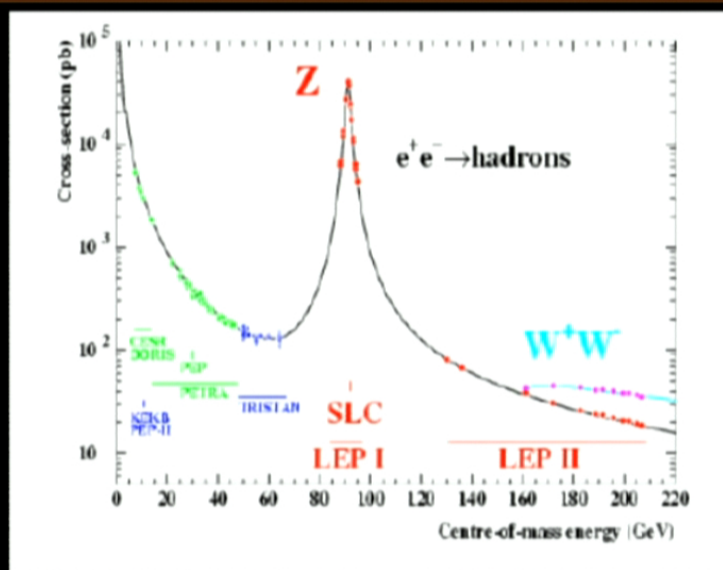
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Theory

- The Standard Model
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- Limitations



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

A Tonazzo: Moriond 2002

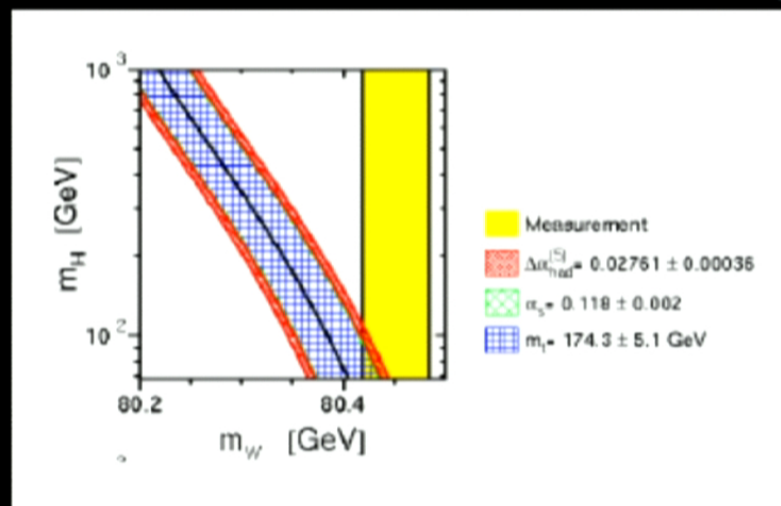
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Theory

- The Standard Model
- Successes
- Limitations



Unknown quantities, like the Higgs mass, are strongly constrained by the accuracy of these tests

A Tonazzo: Moriond 2002

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Theory

- The Standard Model
- Successes
- Limitations

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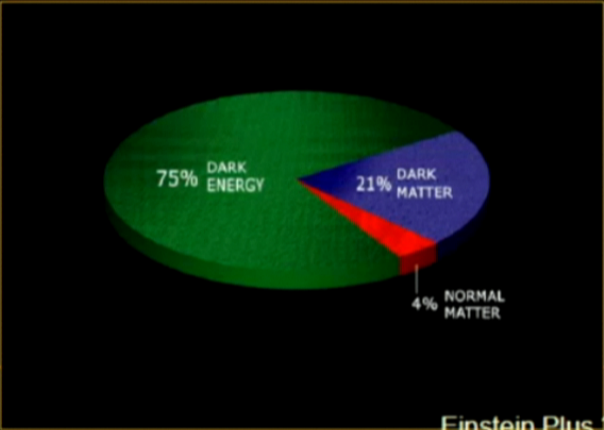
Theory

- 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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*Experiment:
The Higgs - Found?*

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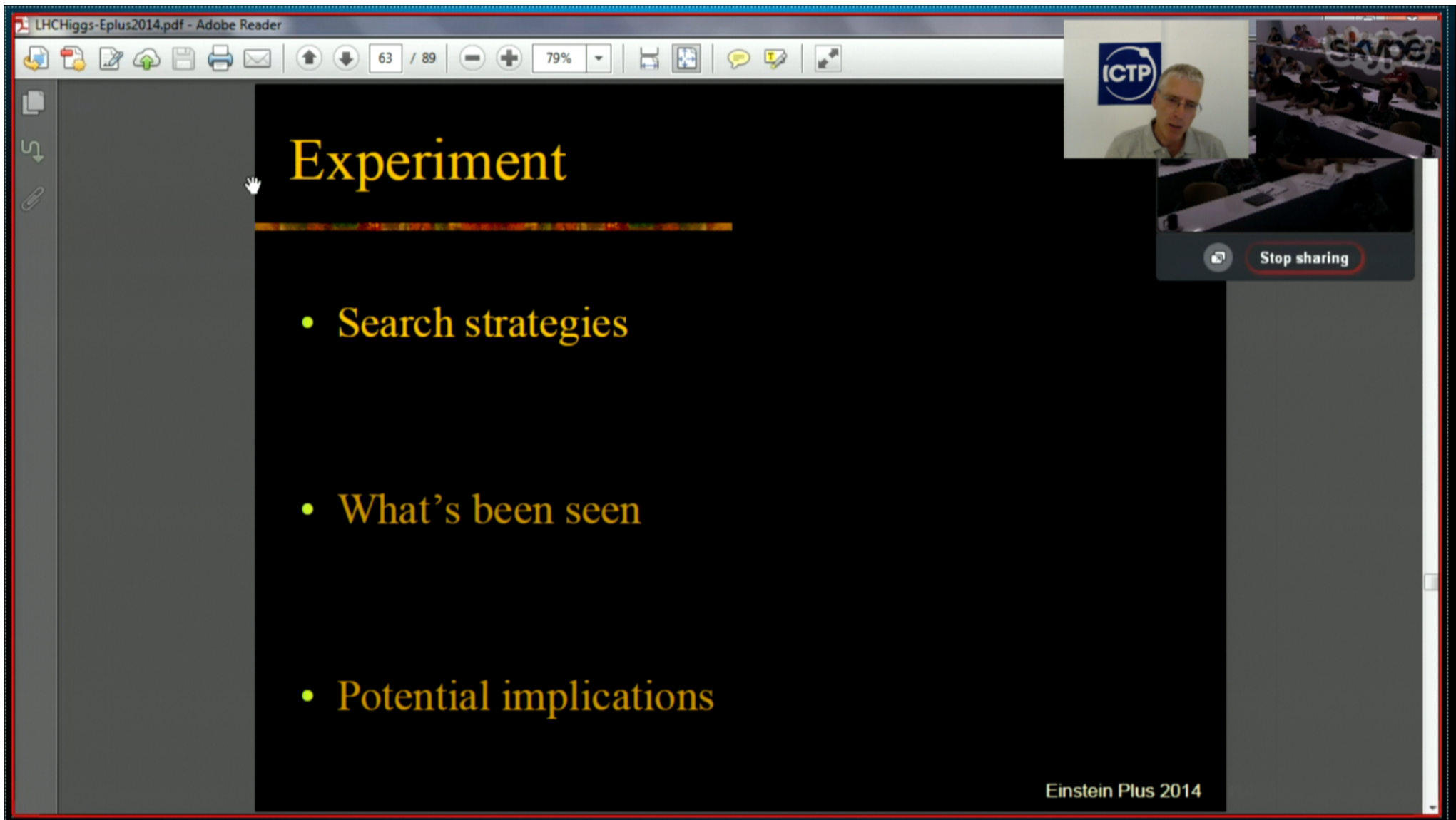
Experiment

- Search strategies
- What's been seen
- Potential implications

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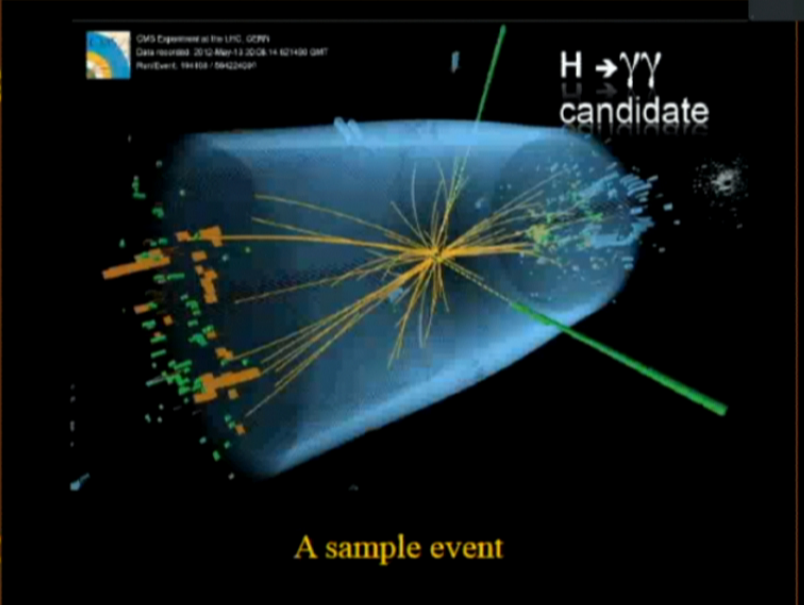
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Experiment

- Search strategy
- What's been
- Potential impact

CMX Experiment at the LHC, CMS
Data recorded: 30.12.2012 14:02:08.14 421430.047
RootEvent: 104.818 / 104224001

$H \rightarrow \gamma\gamma$
candidate



A sample event

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Experiment

- Search strategy

Find it?...

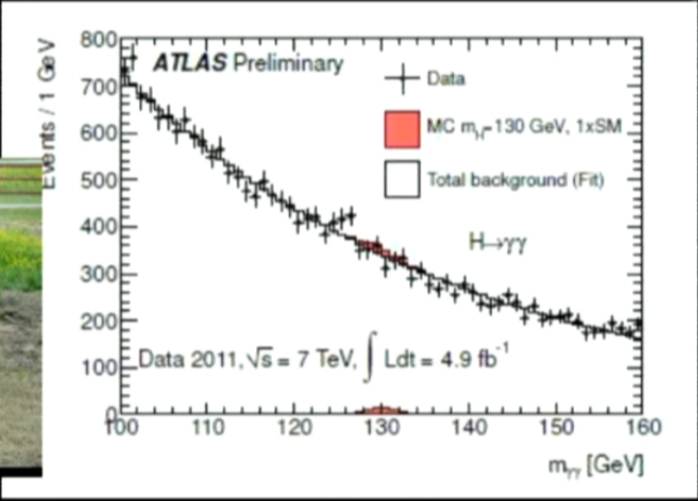
Nope.



• Potential impact

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

ATLAS Preliminary



Events / 1 GeV

$m_{\gamma\gamma}$ [GeV]

Legend:

- +
 Data- MC $m_H = 130$ GeV, 1xSM
- Total background (Fit)

$H \rightarrow \gamma\gamma$

Data 2011, $\sqrt{s} = 7$ TeV, $\int L dt = 4.9 \text{ fb}^{-1}$

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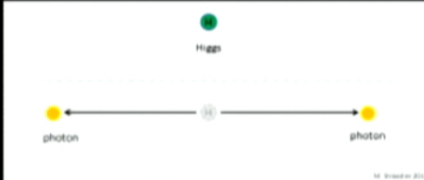
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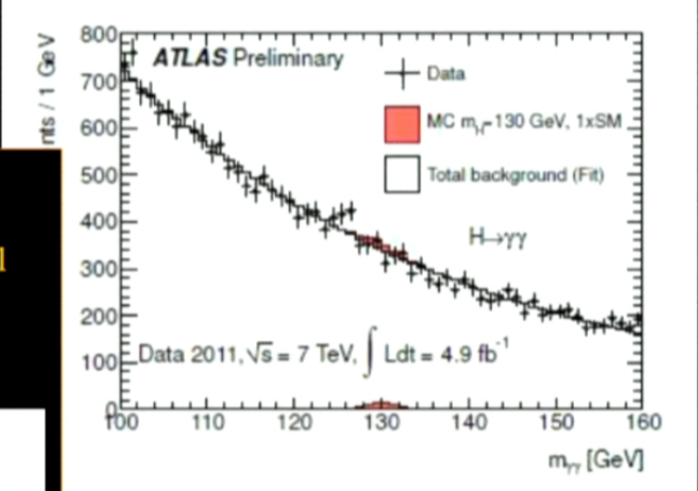
Experiment

- Search strategy

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.



The diagram shows a central green dot labeled 'Higgs' with two arrows pointing outwards to two yellow dots labeled 'photon'.



ATLAS Preliminary

Y-axis: Events / 1 GeV (0 to 800)

X-axis: $m_{\gamma\gamma}$ [GeV] (100 to 160)

Legend:

- + Data
- MC $m_H = 130$ GeV, 1xSM
- Total background (Fit)

Plot label: $H \rightarrow \gamma\gamma$

Data 2011, $\sqrt{s} = 7$ TeV, $\int L dt = 4.9 \text{ fb}^{-1}$

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

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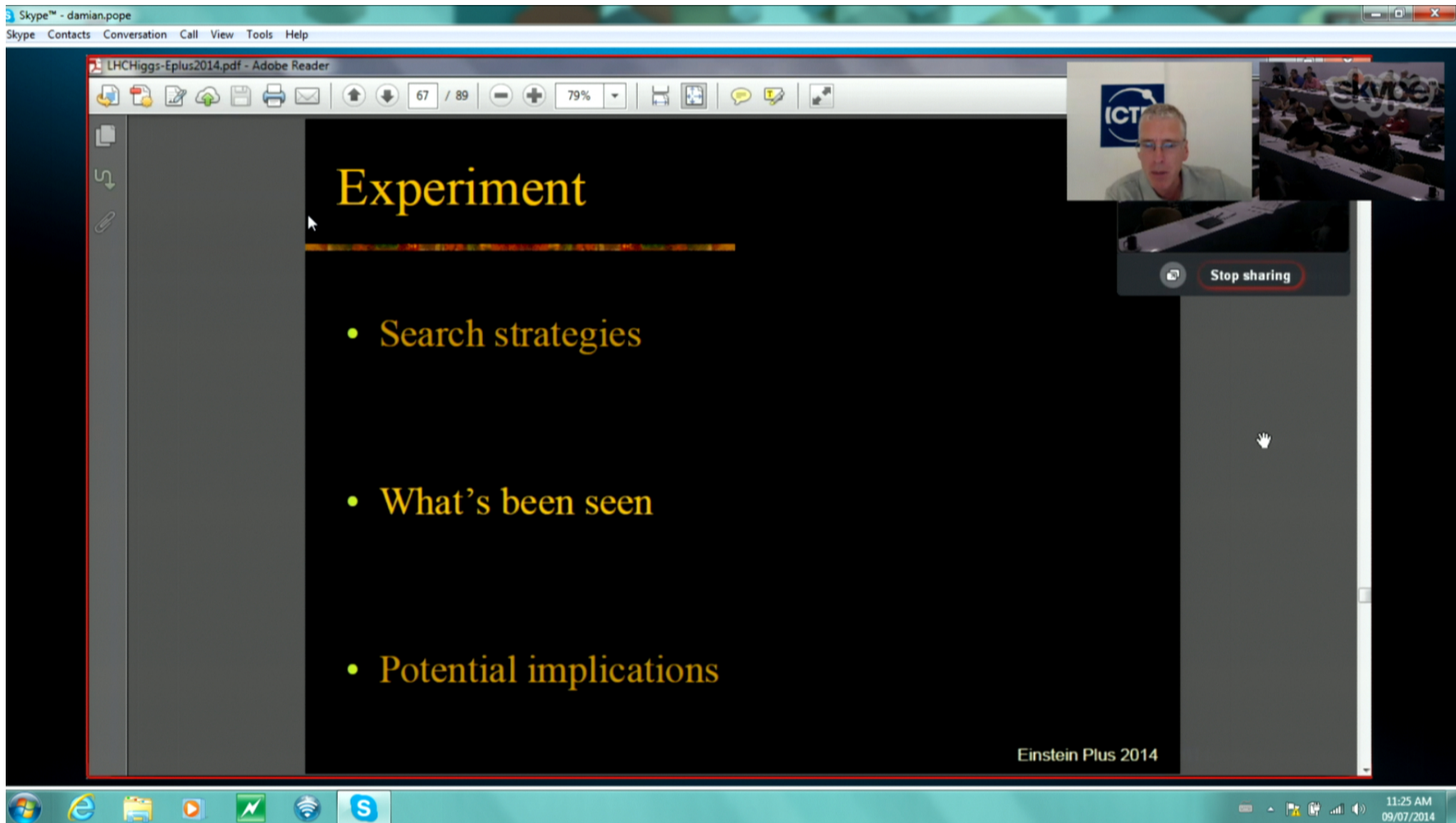
Experiment

- Search strategies
- What's been seen
- Potential implications

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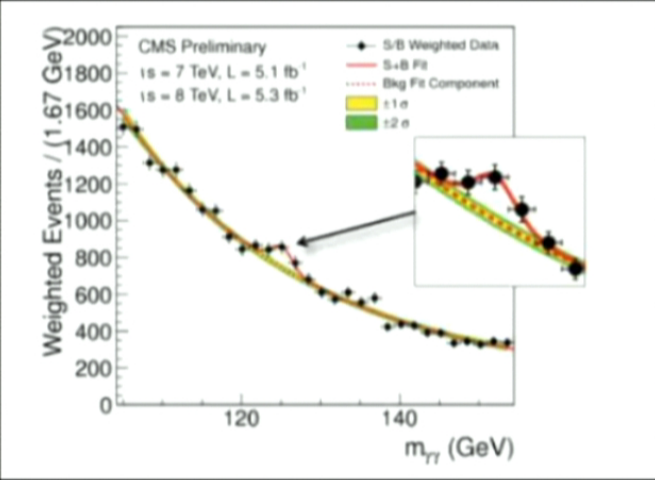


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Experiment

- Search strategy
- What's been
- Potential impact



CMS (and ATLAS): now see a bump

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70 / 89 79%

Experiment

- Search strategy
 - What do we know?
A new particle decaying into 2 photons:
 - A boson*
 - Spin zero or two*
 - Electrically neutral*
 - Mass ~ 125 GeV*
- What's been discovered
 - Is this 'a Higgs' or 'the Higgs'?*
- Potential implications
 - Is it something else?*

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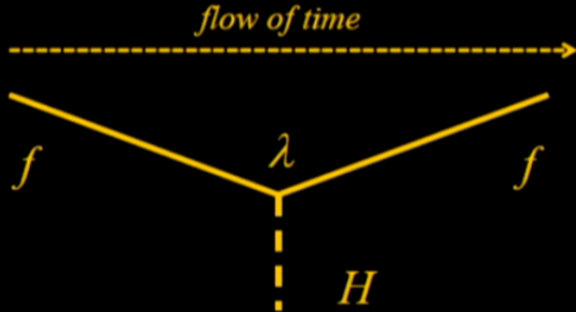
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Experiment

- Search strate
- What's been
- Potential imp



A pictorial representation of the interaction with the vacuum that gives a particle a mass: $m \propto \lambda$

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79%

Experiment

- Search strategy
- What's been achieved
- Potential impact

CMS Preliminary

$\sqrt{s} = 7 \text{ TeV}, L = 5.05 \text{ fb}^{-1}; \sqrt{s} = 8 \text{ TeV}, L = 5.26 \text{ fb}^{-1}$

2011+2012

Events / 3 GeV

● Data

● 7 TeV 4e, 4 μ , 2e2 μ

● 8 TeV 4e, 4 μ , 2e2 μ

■ Z+X

■ Z γ^* , ZZ

□ $m_H = 126 \text{ GeV}$

Also decays into 4 leptons

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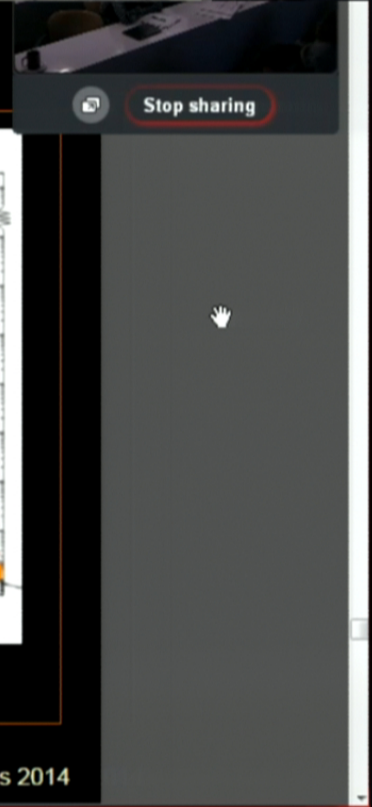
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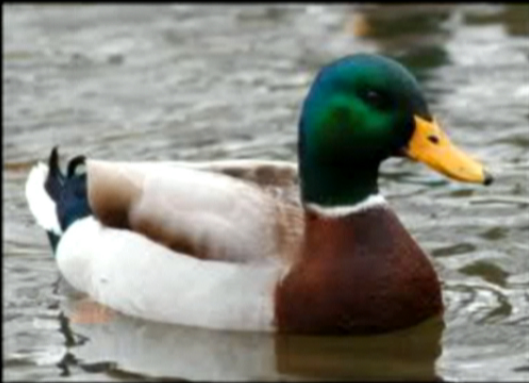
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Experiment

- Search strategy
- What's been
- Potential impact



So far, it is consistent with SM Higgs.

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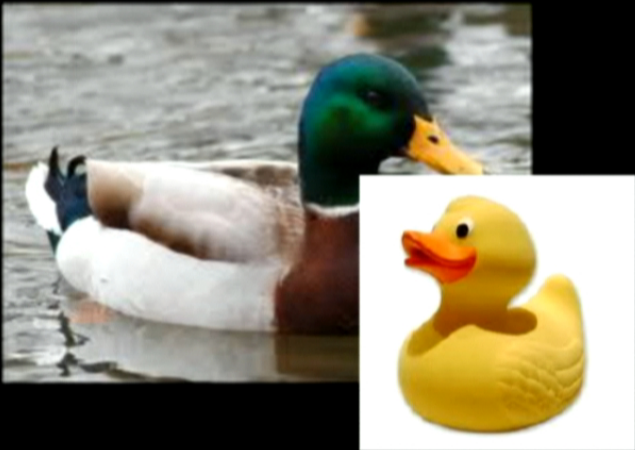
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Experiment

- Search strate
- What's been
- Potential imp



....but stay tuned!

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Experiment

- Search strategies
- What's been seen
- Potential implications

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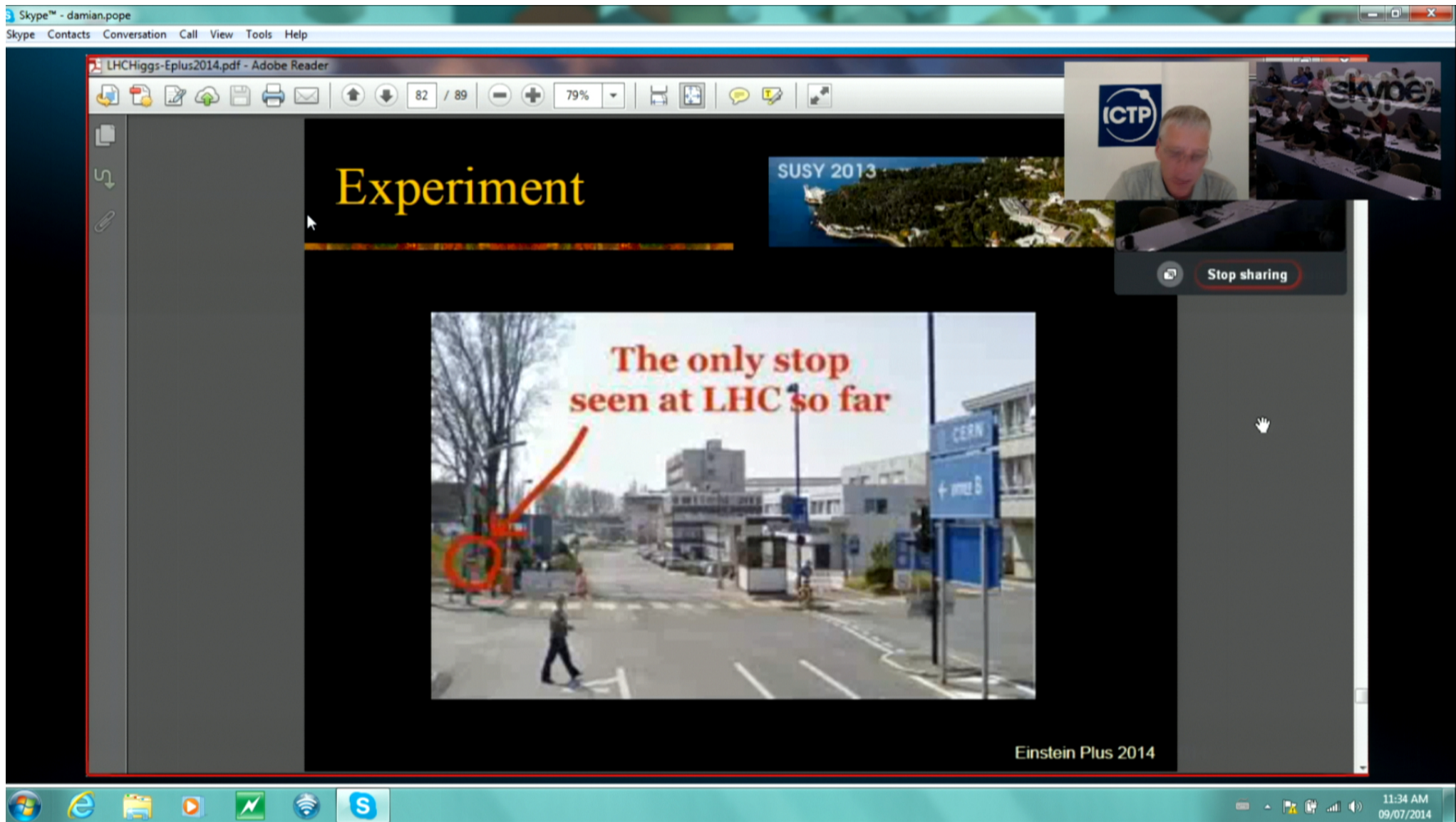
Experiment

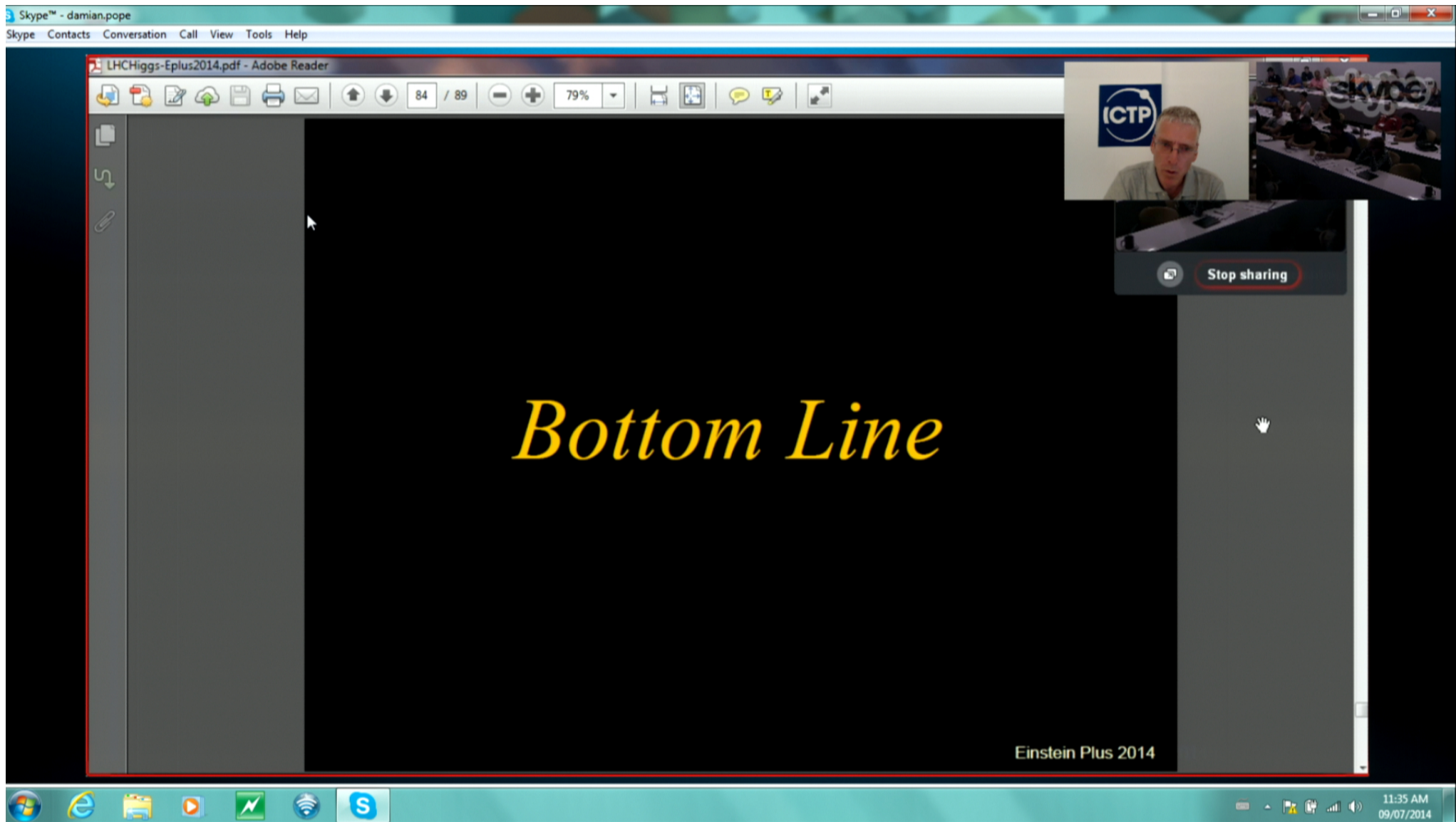
- Search strategy: *If it is a SM Higgs, what does this mean for other theories proposed to replace the SM?*
- What  *eg: Supersymmetric models: all known particles come with new partners having different spin and statistics*
- Potential impact: *These predict several Higgs-like particles, of which the SM-like one likes to be lighter than 125 GeV*

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Outlook

- The LHC is already changing how we think about high energy physics!
 - *Runs at design beam energy should begin early next year.*
- New boson discovered at 125 GeV
 - *So far consistent with a SM Higgs*
- The LHC indicates that the Higgs mechanism is right.
 - *More evidence for consistency/inconsistency with the SM within the year.*

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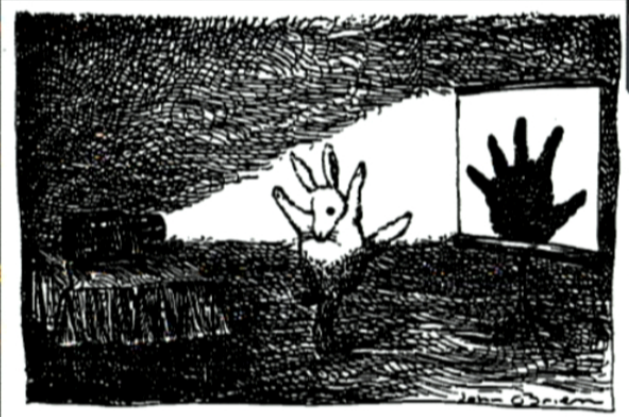
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Outlook

- The LHC is already changing energy physics!
 - *Runs at design beam energy*
- New boson discovered
 - *So far consistent with SM*
- The LHC indicates that the Higgs mechanism is right.
 - *More evidence for consistency/inconsistency with the SM within the year.*
- Watch for surprises



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