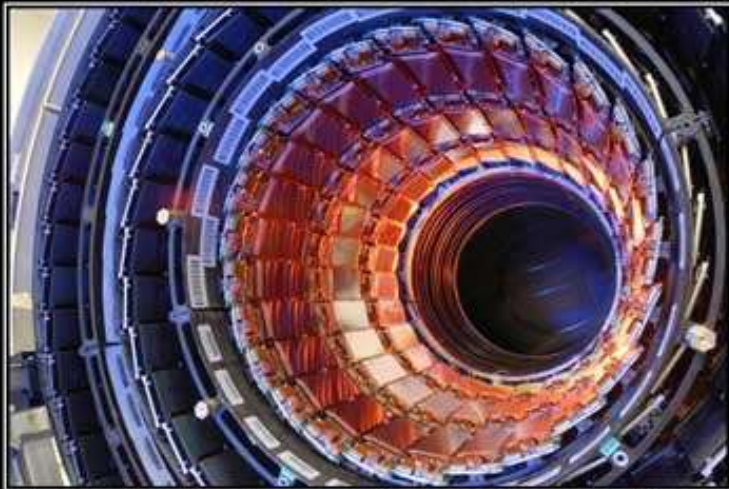


The Large Hadron Collider

*Start of a New Era
or the End of the World?*



LARGE HADRON COLLIDER

It's going to fucking kill you dead. May 2008.

Cliff Burgess



The Large Hadron Collider

*Start of a New Era
or the End of the World?*

Cliff Burgess



Outline

- What is it?
 - *The machine and recent events*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

Outline

- What is it?
 - *The machine and recent events*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

Outline

- What is it?
 - *The machine and recent events*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

Outline

- What is it?
 - *The machine and recent events*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

The Machine

- The Accelerator
- The Detectors

The Machine

- The Accelerator
- The Detectors

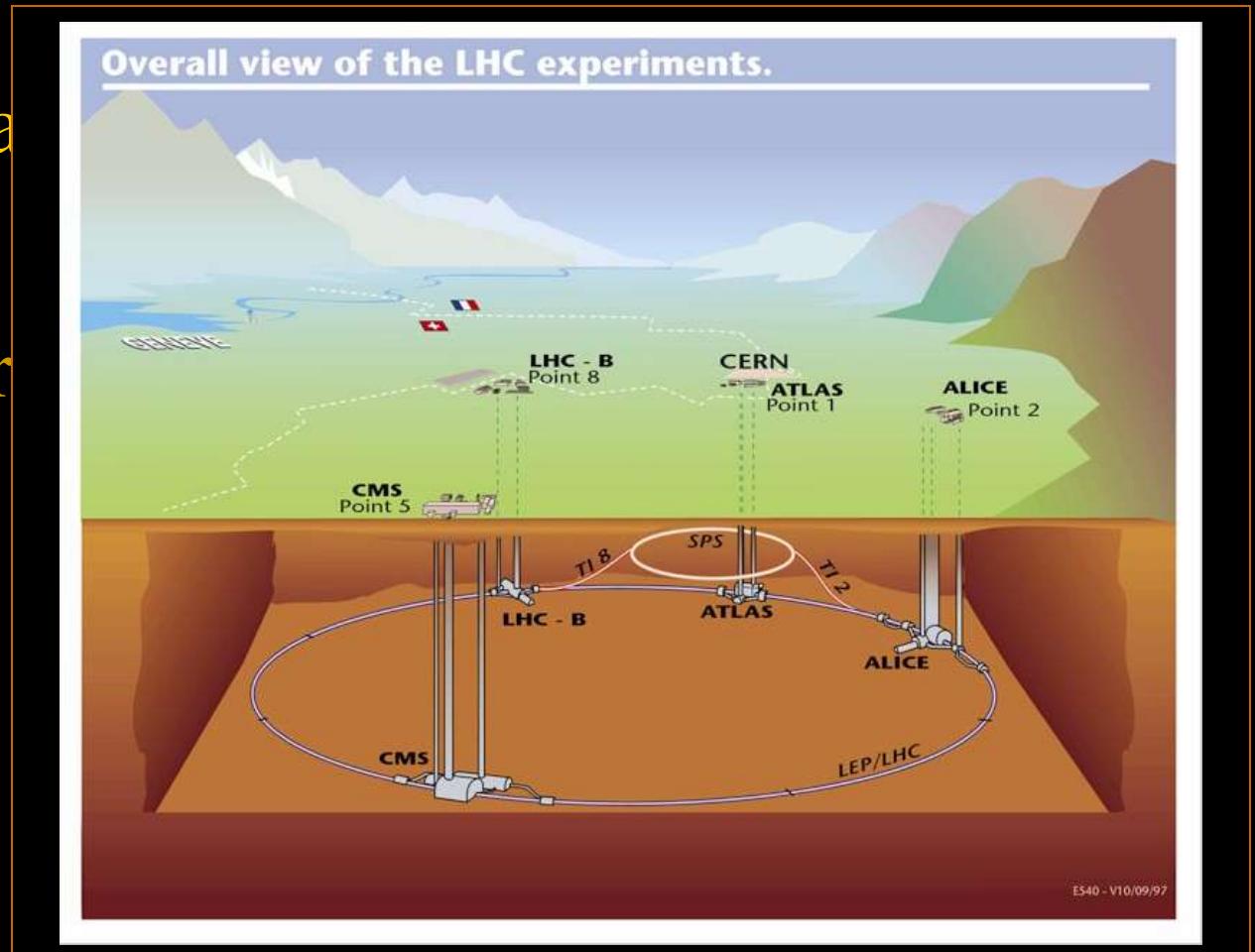
The Machine

- The Accelerator
- The Detector



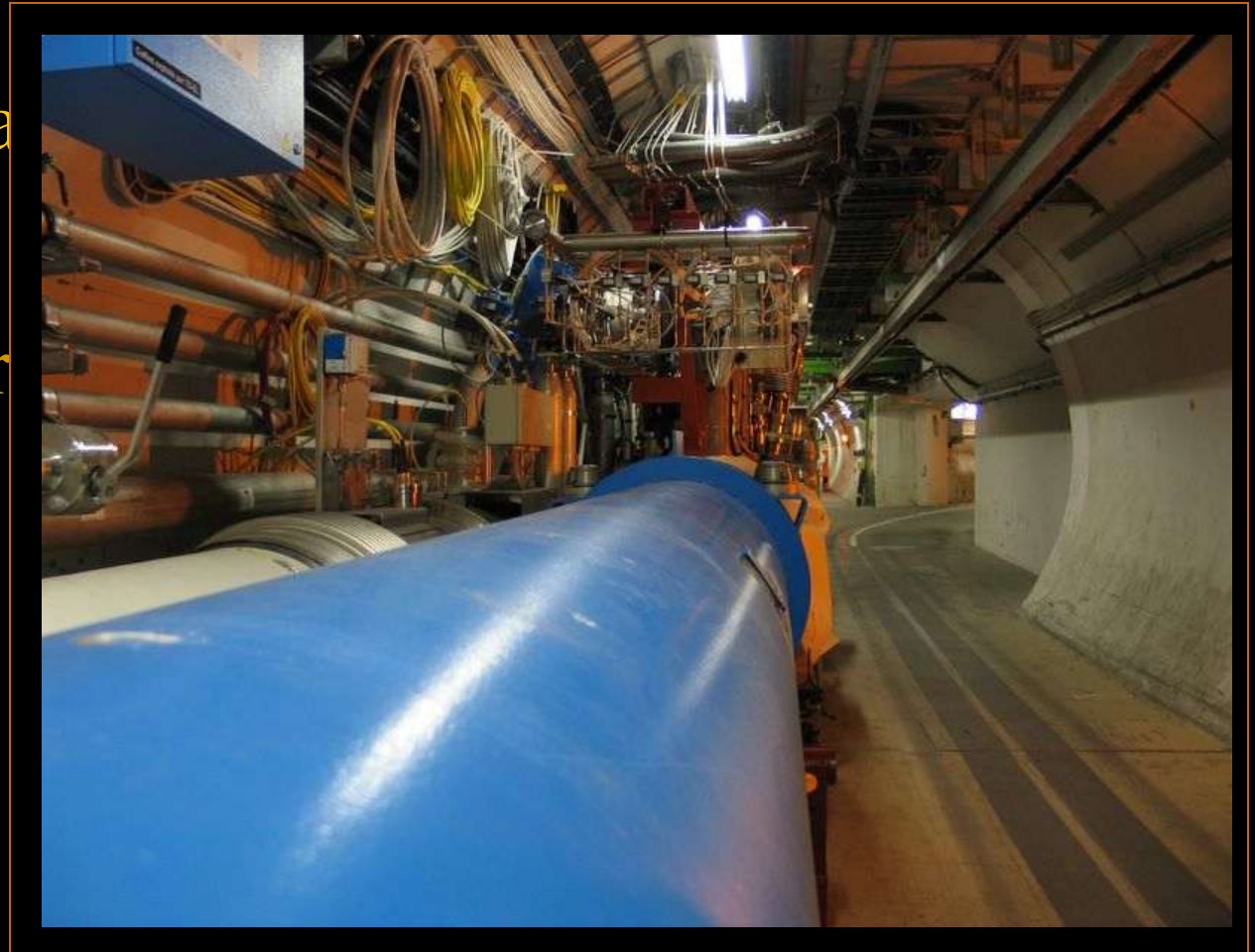
The Machine

- The Accelerator
- The Detectors



The Machine

- The Accelerator
- The Detector



CERN: The Movie

- The Plot



CERN: The Movie

- The

- *Scen*



The Movie

CERN: The Movie

- The



The Movie

CERN

CERN: The Movie

- T
- S



The Movie

CERN: The Movie

- T
- S



The Movie

CERN

CERN: The Movie

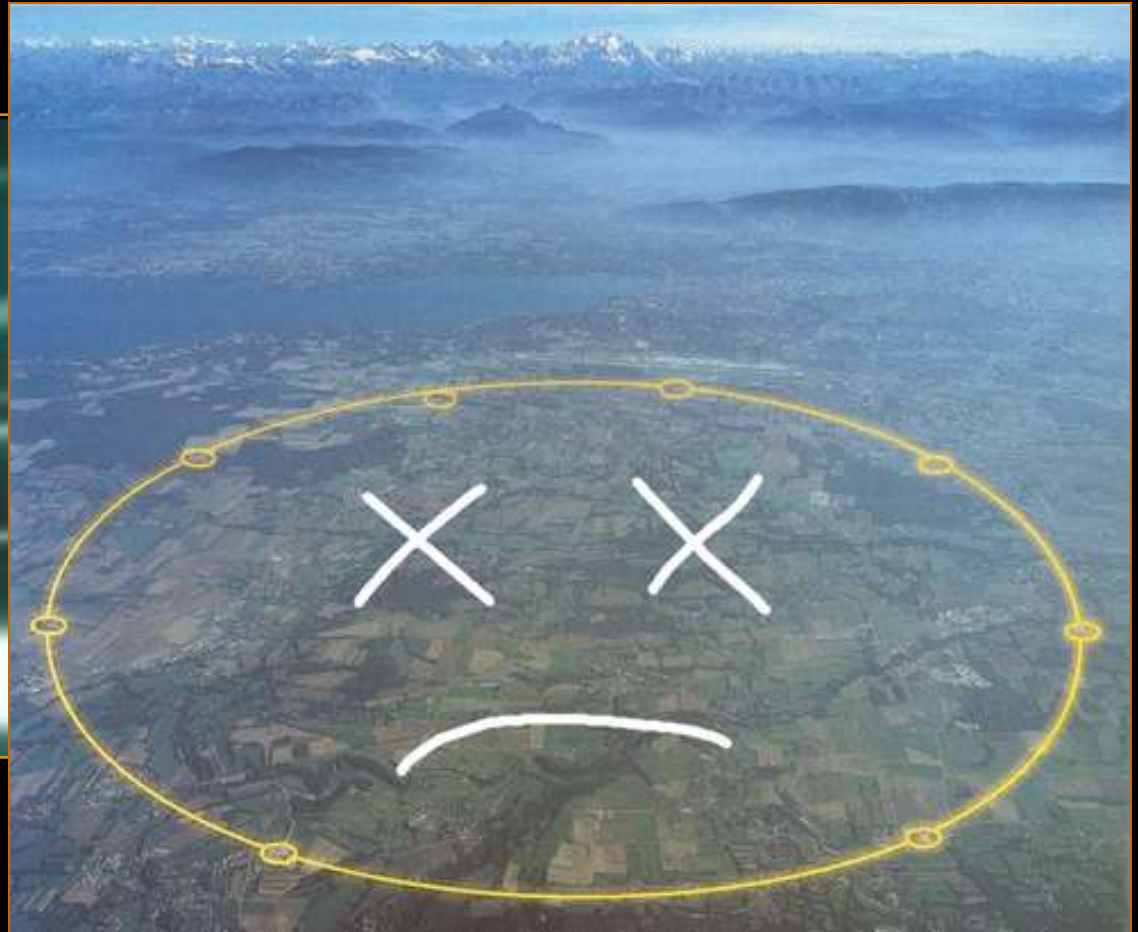
The Plot



The Movie

CERN: The Movie

The Plot



The Machine

W. Trischuk

- The Accelerator
- The Detector



Before repair



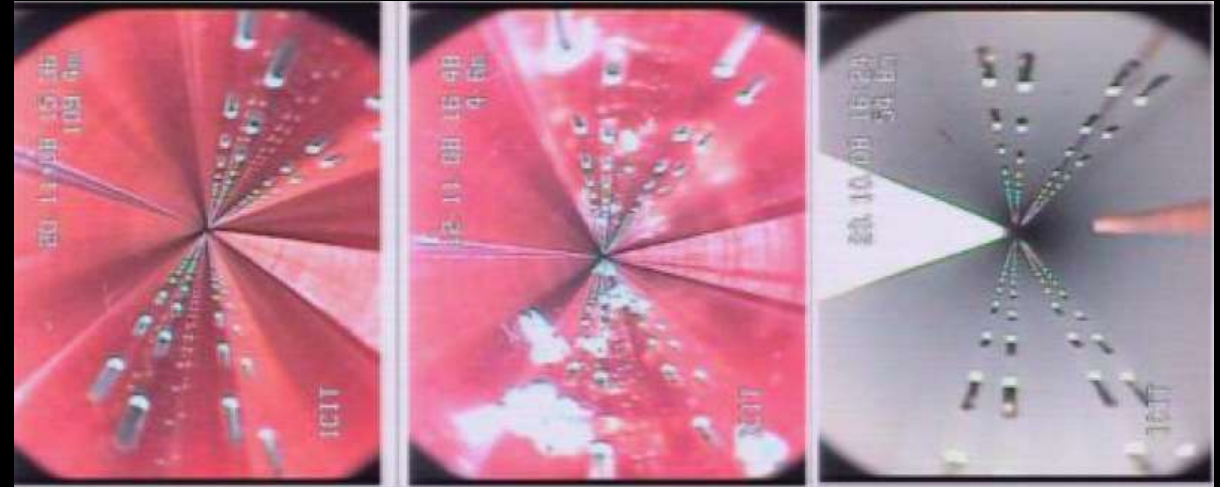
After repair

mechanical damage

The Machine

W. Trischuk

- The Accelerator
- The Detector

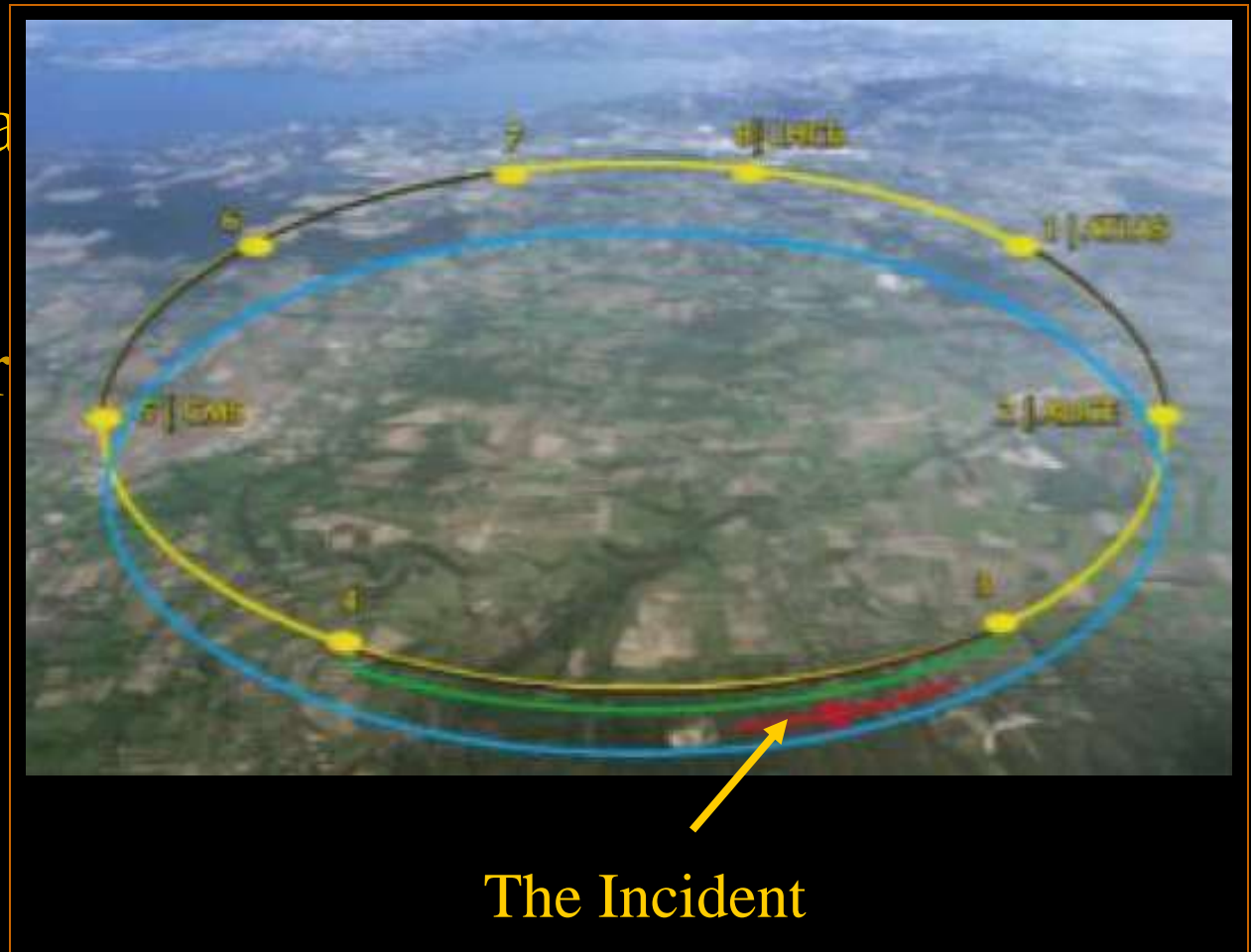


soot in the beam pipe
(normal copper looks red)

The Machine

W. Trischuk

- The Accelerator
- The Detector



The Machine

W. Trischuk

- The Accelerator
- The Detectors

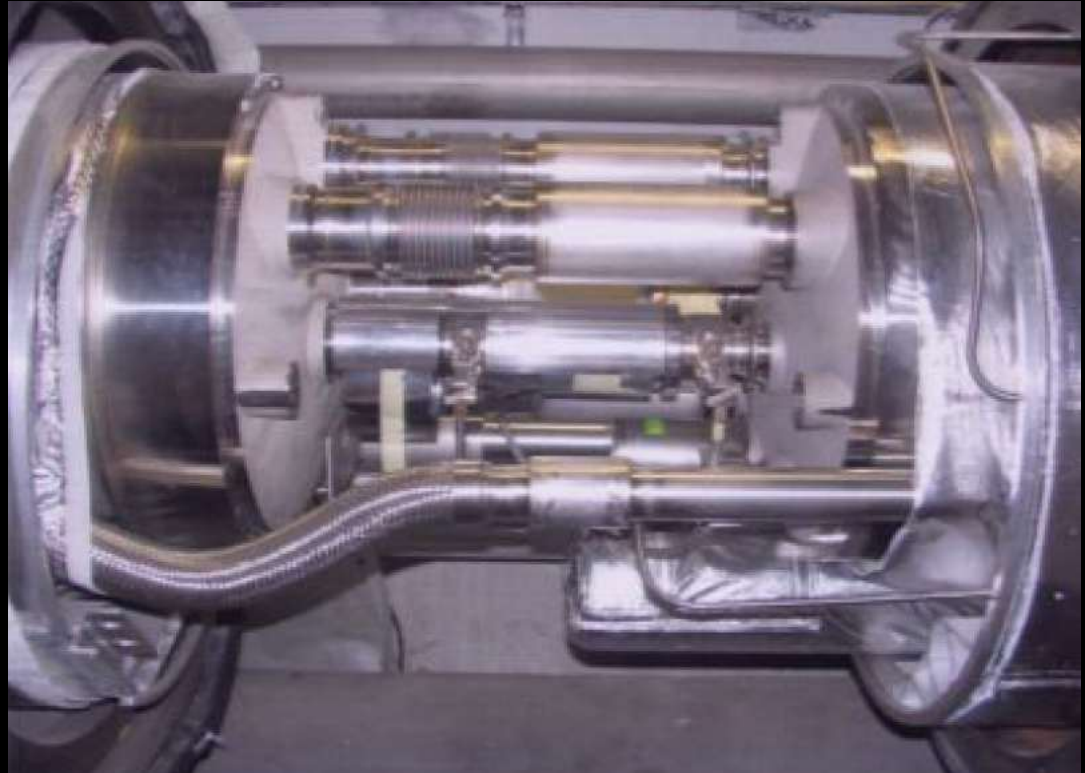


1200 superconducting magnets

The Machine

W. Trischuk

- The Accelerator
- The Detector

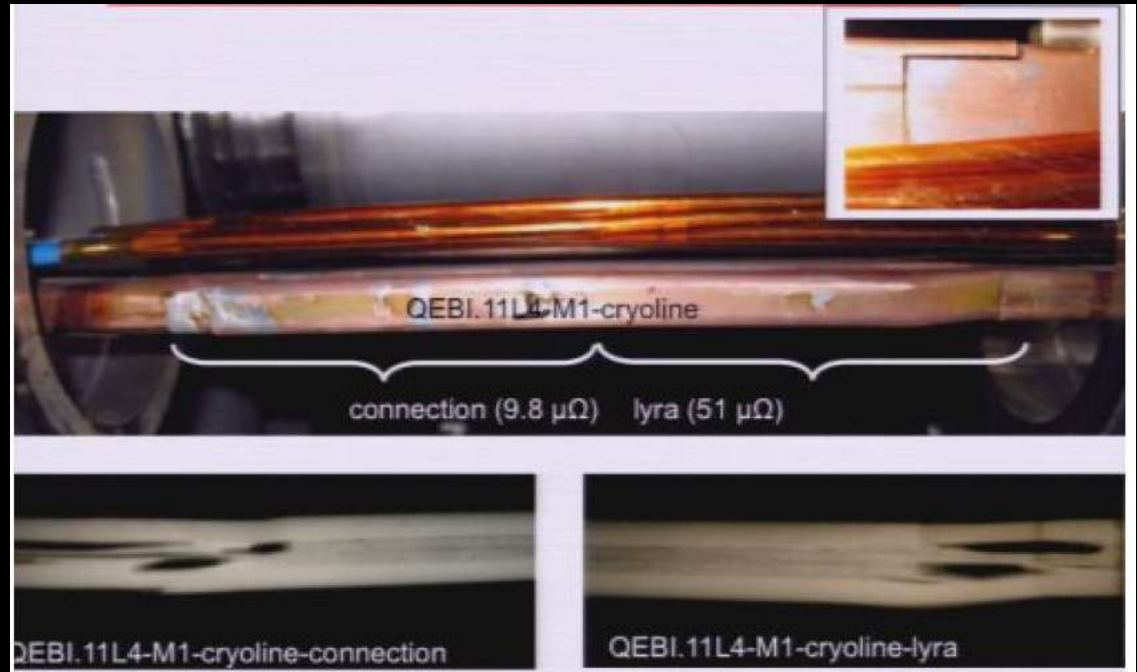


dipole interconnect

The Machine

W. Trischuk

- The Accelerator
- The Detector

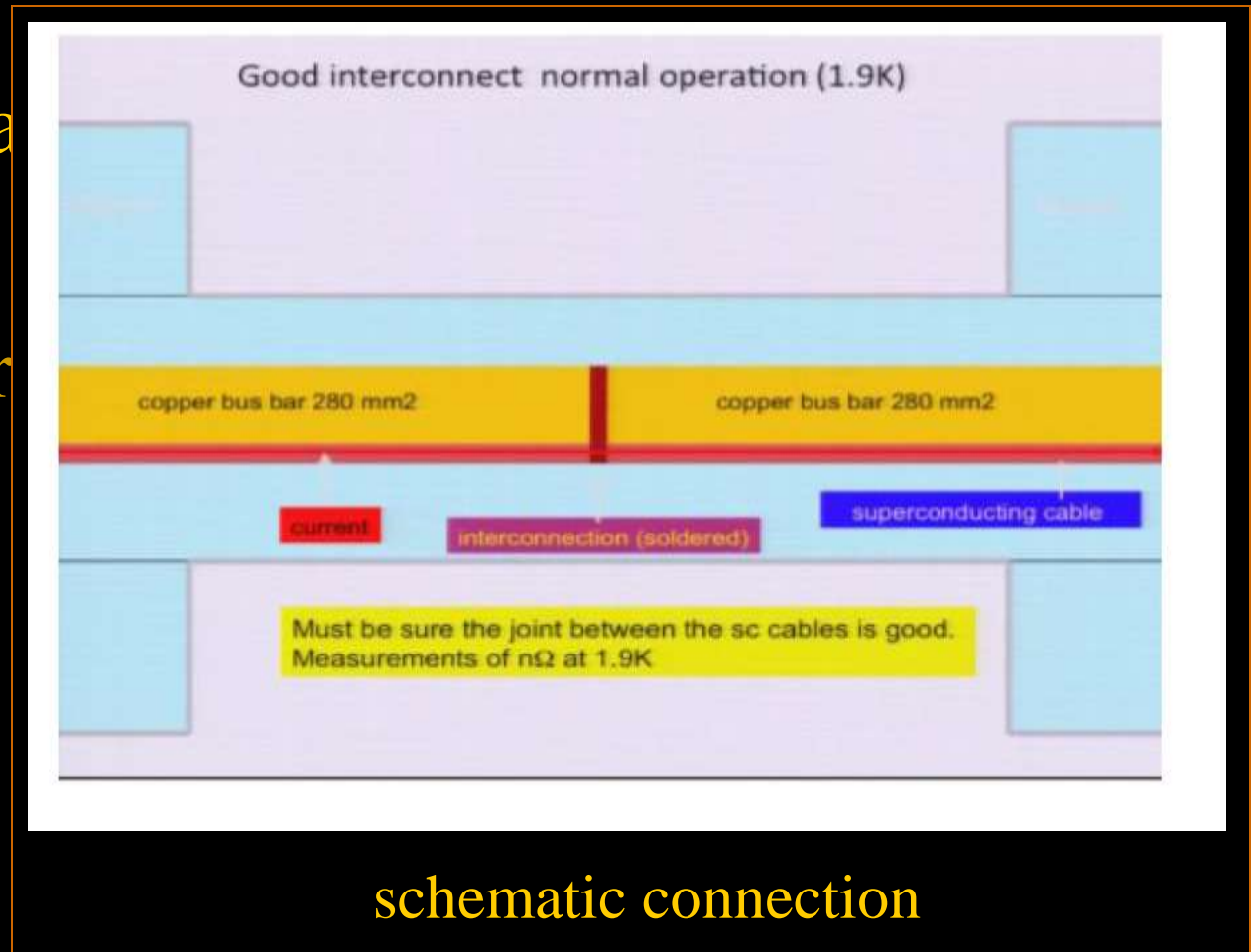


dipole interconnect

The Machine

W. Trischuk

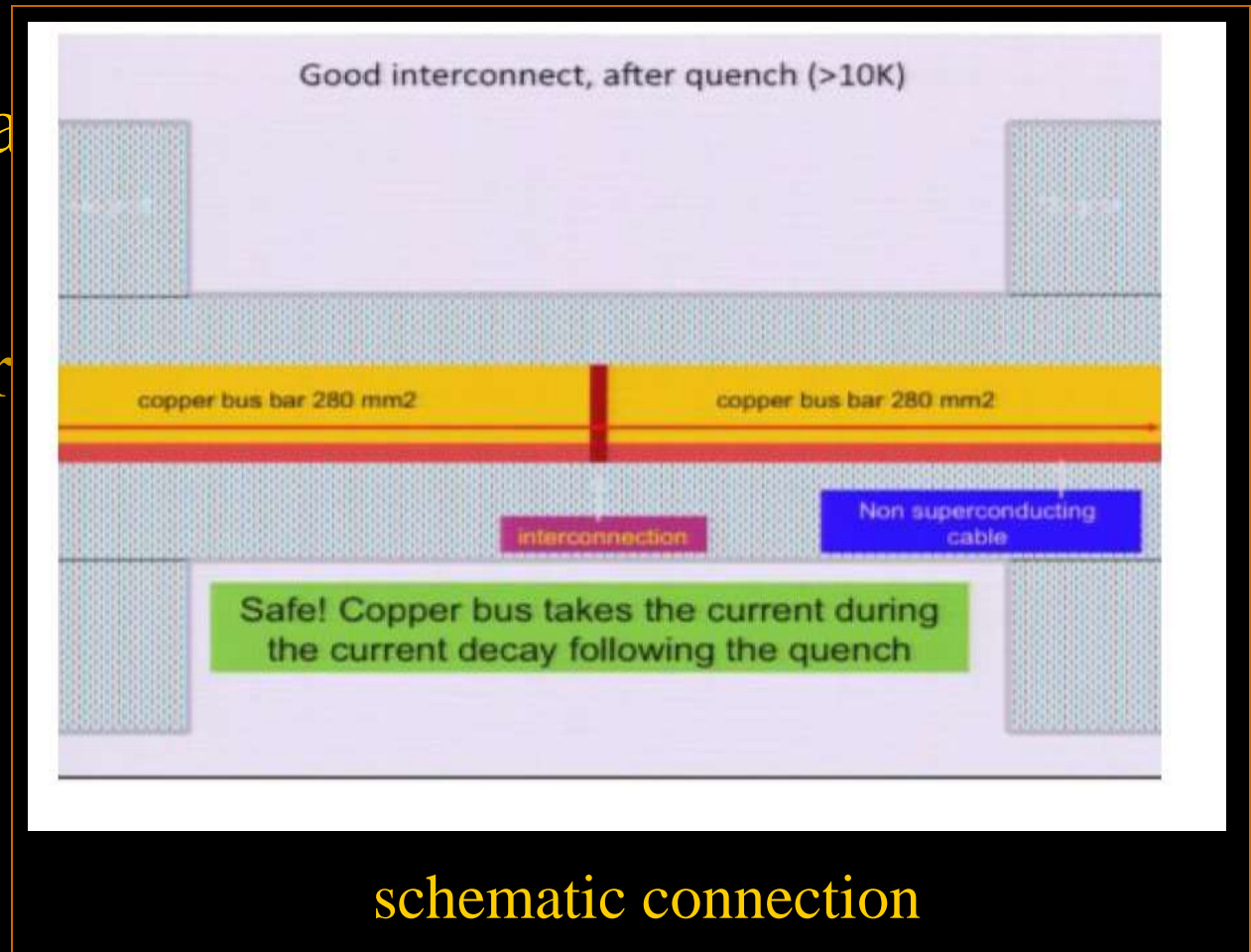
- The Accelerator
- The Detector



The Machine

W. Trischuk

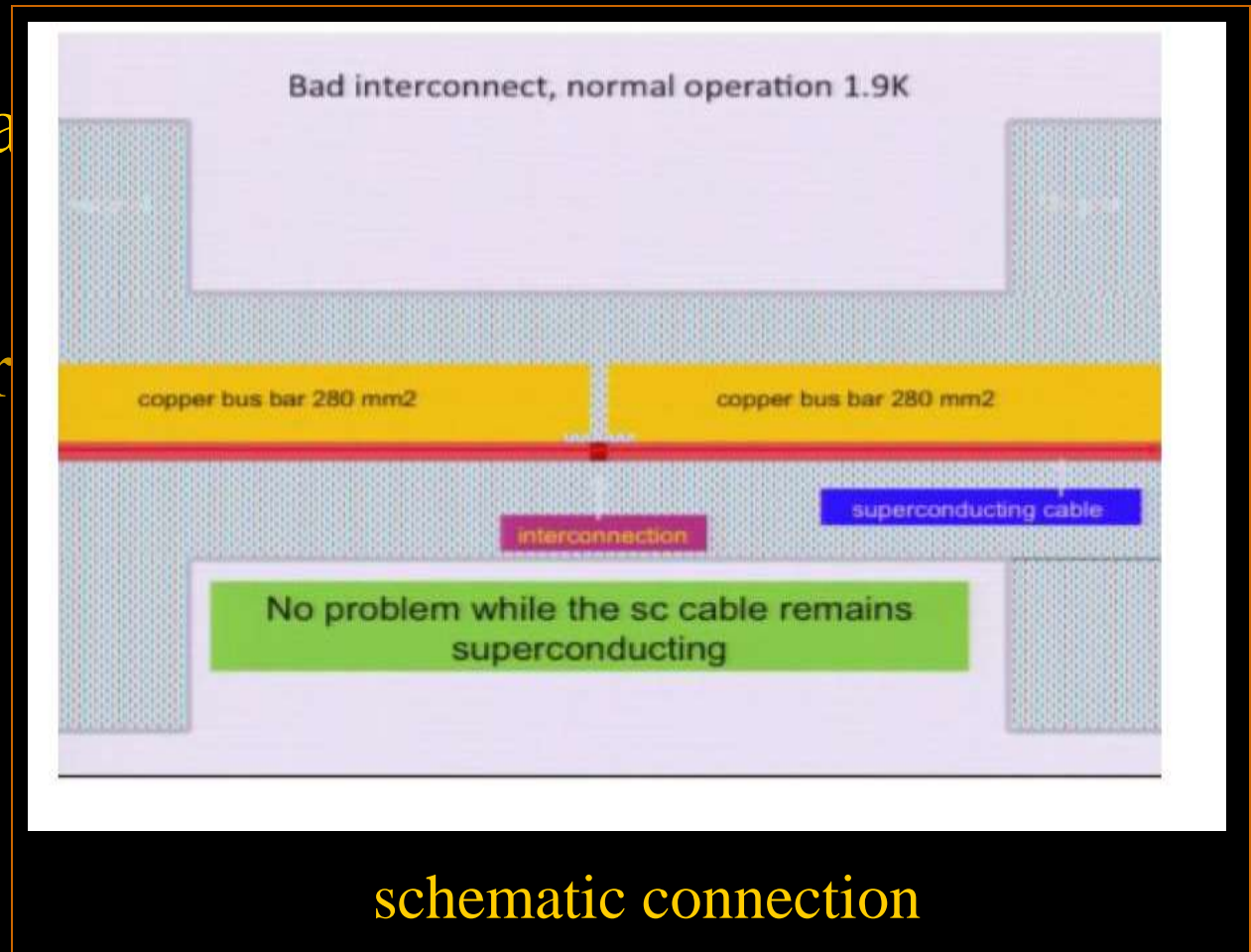
- The Accelerator
- The Detector



The Machine

W. Trischuk

- The Accelerator
- The Detector



The Machine

W. Trischuk

- The Accelerator
- The Detector



Replaced 14 quadrupoles and 29 dipoles,
34 interconnections fully repaired

The Machine

W. Trischuk

- The Accelerator

What if there are also problems with the other magnets that did not (yet) fail?

- The Detector

Can measure resistance of connections to infer which are bad

worst magnet (at 300K): 50 $\mu\Omega$

At 7 TeV believed safe even with 120 $\mu\Omega$

At 10 TeV believed safe even with 70 $\mu\Omega$

The Machine

W. Trischuk

- The Accelerator
- The Detector

	Sector 12	Sector 23	Sector 34	Sector 45	Sector 56	Sector 67	Sector 78	Sector 81
Circuit RB	300		300, 300	300, 300	300	300, 300		
Circuit RB		80		80			80	80
Circuit RQ	300		300	300	300	300, 300		
Circuit RQ		80		80			80	80, 80

- Huge effort of dedicated measurement teams
 - About 35000 manual measurements
 - Over 400 kilometers walked in the tunnel

But some sectors remain cold

Takes months to heat and recool and there is not enough storage for the He: $n\Omega$ resistance

The Machine

W. Trischuk

- The Accelerator

	Sector	Sector	Sector	Sector	Sector	Sector	Sector	Sector
Circuit	12	23	34	45	56	67	78	81
RB	300		300, 300	300, 300	300	300, 300		
								80
								0, 80

— Over 400 kilometers walked in the tunnel

- The Design

The Plan: *run at 7 TeV (3.5 on 3.5) until 2012, then shut down and upgrade to the design of 14 TeV.*

But some sectors remain cold

Takes months to heat and recool and there is not enough storage for the He: $n\Omega$ resistance

The Machine

- The Accelerator
- The Detector

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 US Fermi National Accelerator Laboratory's

Up and running again for some time

The Machine

- The Accelerator
- The Detectors (a personal look)

The Machine

- The Accelerator
- The Detector



The most important machine at CERN

The Machine

- The Accelerator
- The Detector



next
The most important machine at CERN

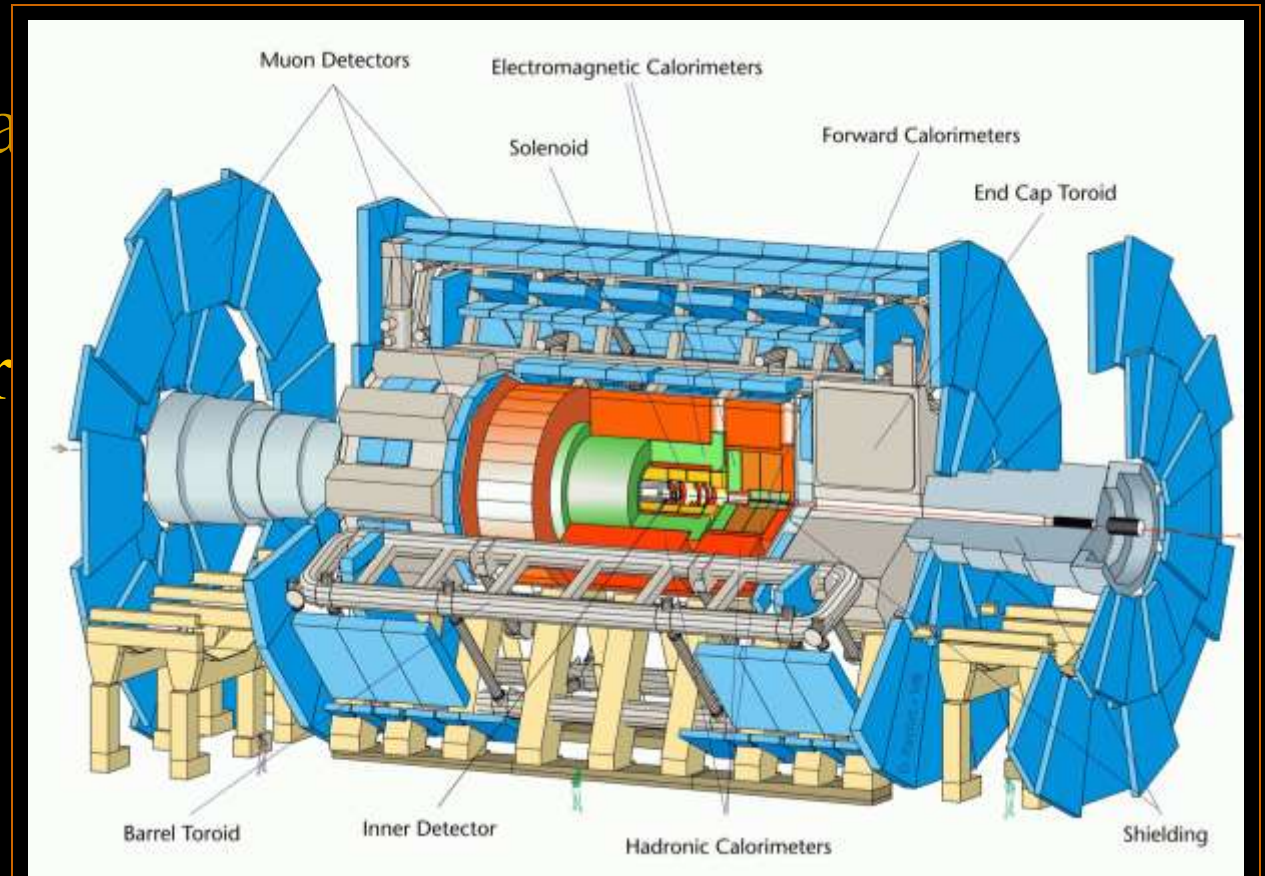
The Machine

- The Accelerator
- The Detector



The Machine

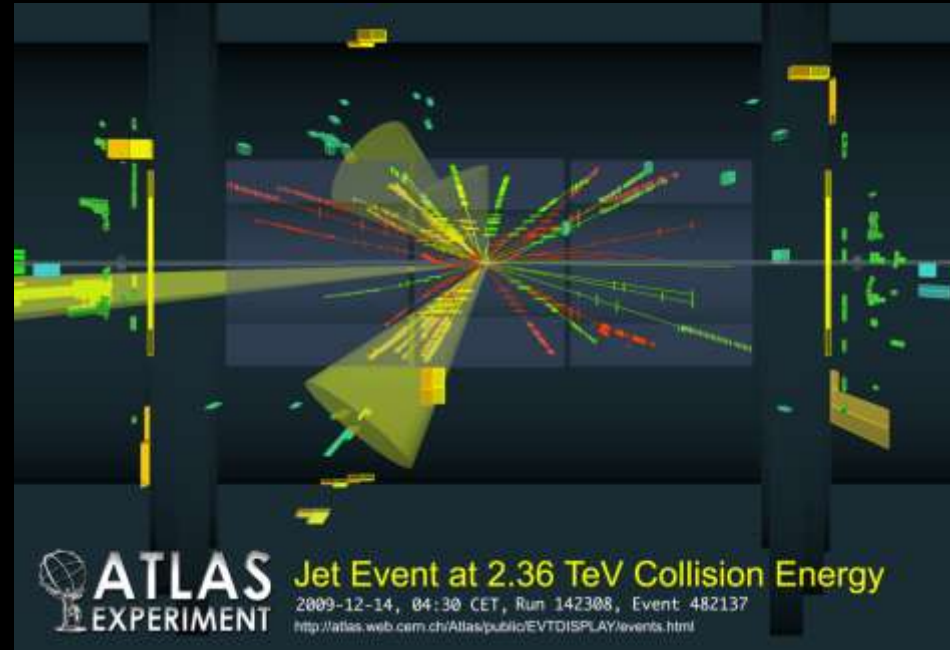
- The Accelerator
- The Detector



The ATLAS Detector

The Machine

- The Accelerator
- The Detector



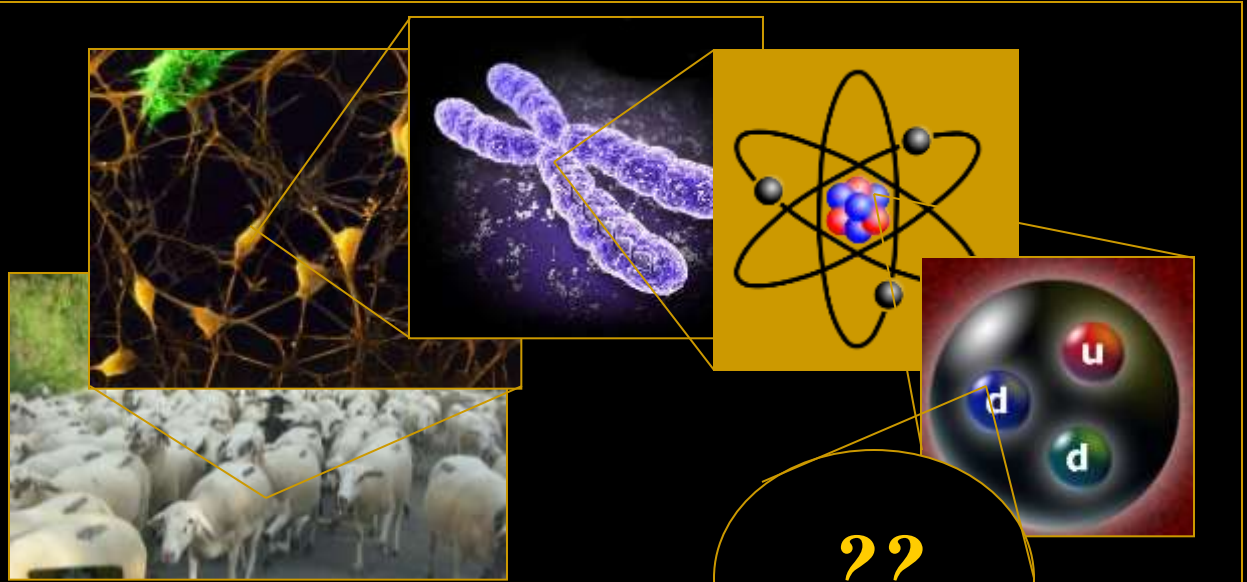
The detectors have been working well

Outline

- What is it?
 - *The machine*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

Outline

- What is it?
 - *The machine*
- Why was it built?
 - *The Standard Model*
- What might it tell us?
 - *Problems*
- Outlook



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.

The Standard Model

- The particles and interactions
- Successes
- Limitations

The Standard Model

- The particles interactions
- Successes
- Limitations

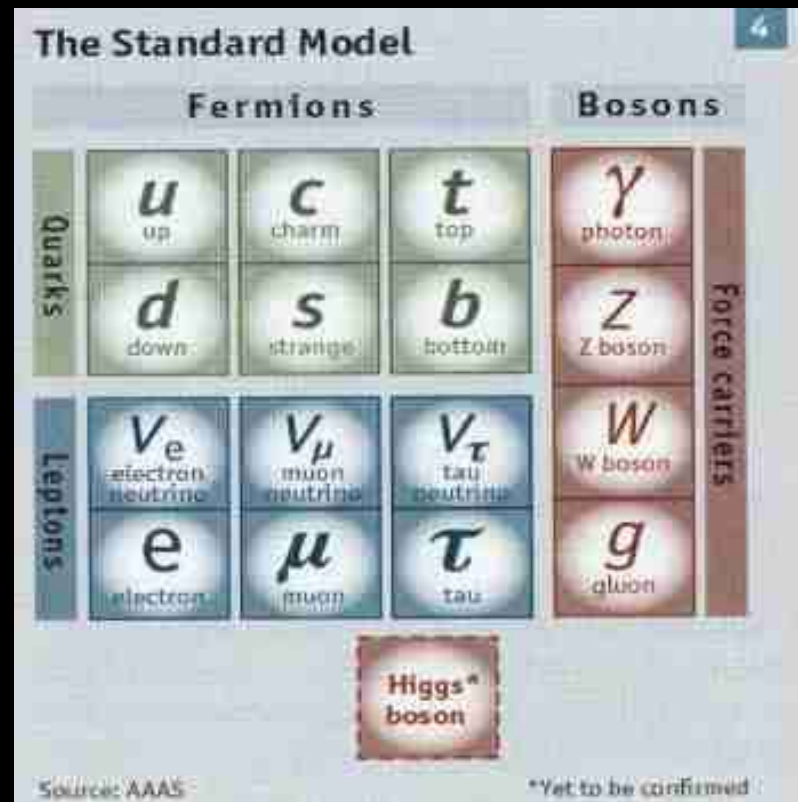
The Standard Model

	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	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

The Standard Model

- The particles interactions
- Successes
- Limitations



One SM particle remains AWOL: the Higgs boson

The Standard Model

- The particles interactions
- Successes
- Limitations



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

The Standard Model

- The particles interactions
- Successes
- Limitations



Particle masses are due to the resistance of moving through the Higgs vacuum.

The Standard Model

- The particles interactions
- Successes
- Limitations



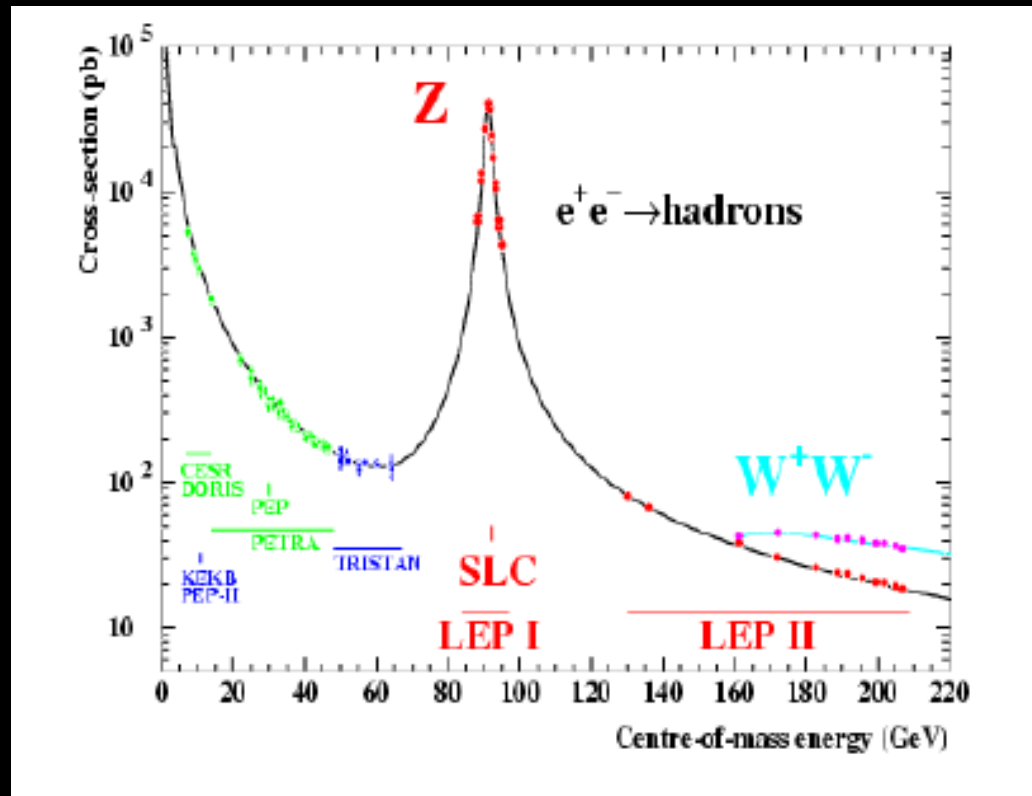
The Higgs *particle* is a wave moving through this Higgs vacuum.

The Standard Model

- The particles and interactions
- Successes
- Limitations

The Standard Model

- The particles interactions
- Successes
- Limitations



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

The Standard Model

- The particles interactions
- Successes
- Limitations



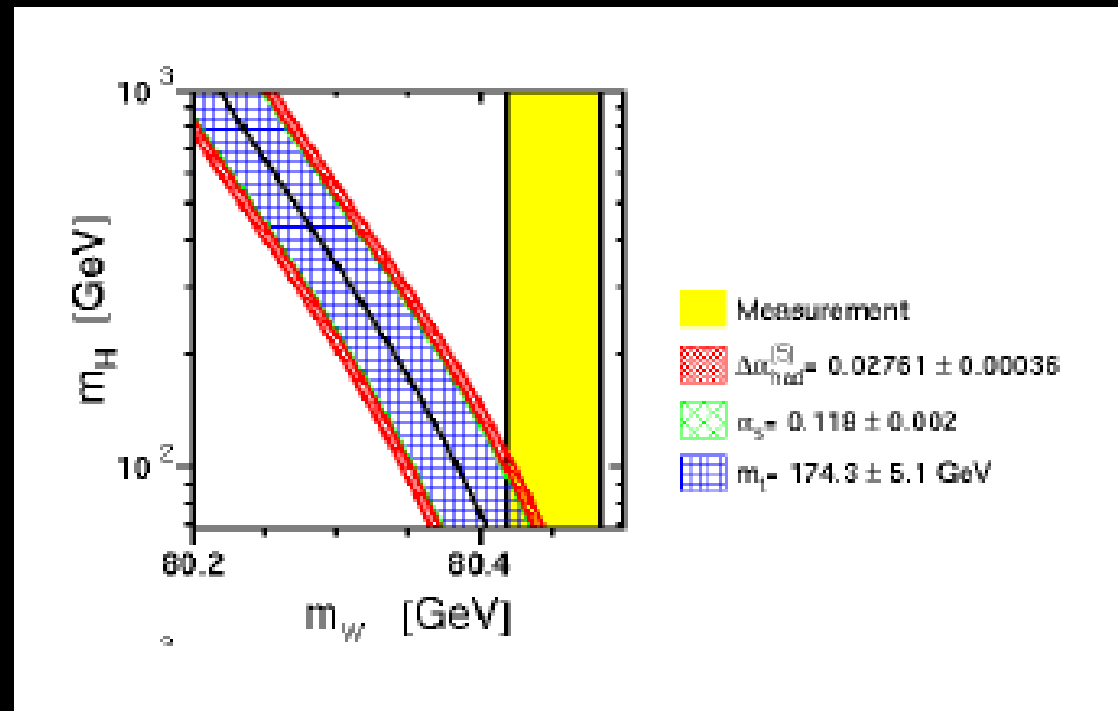
March 2008

The SM

ns

The Standard Model

- The particles interactions
- Successes
- Limitations



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

The Standard Model

- The particles and interactions
- Successes
- Limitations

The Standard Model

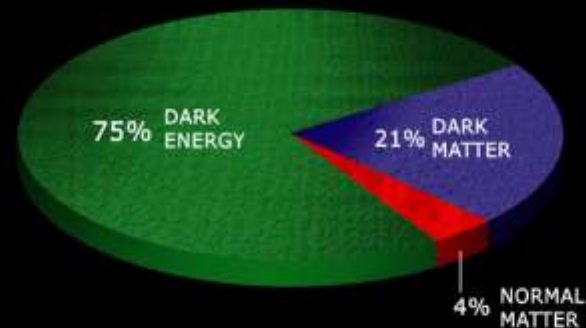
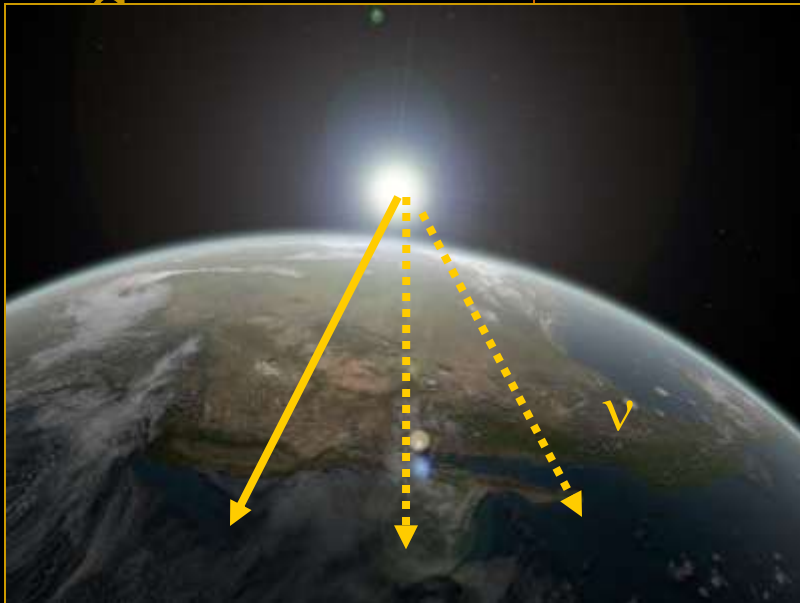
- The particles interactions

So what's wrong with the Standard Model?

Observational Problems:

Neutrinos appear to have masses...

Dark Matter and Dark Energy unexplained..



The Standard Model

- The particles interactions
- 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?

The Standard Model

- The particles interactions
- 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 LHC energy*



The Standard Model

- The particles interactions
- Successes
- Limitations

$$M_{SUN} \approx M_p^3 / m_p^2$$

The Hierarchy Problem

Problem: Why is the *scale* of Higgs symmetry breaking (and so also all known masses) so much smaller than the only other fundamental scales about which we know?

Protons: the nuclear scale

$$m_p \sim 1 \text{ GeV}$$

Higgs: the weak scale

$$M_W = G_F^{-1/2} \sim 10^2 \text{ GeV}$$

Gravity: the Planck mass

$$M_p = G_N^{-1/2} \sim 10^{19} \text{ GeV}$$

The Standard Model

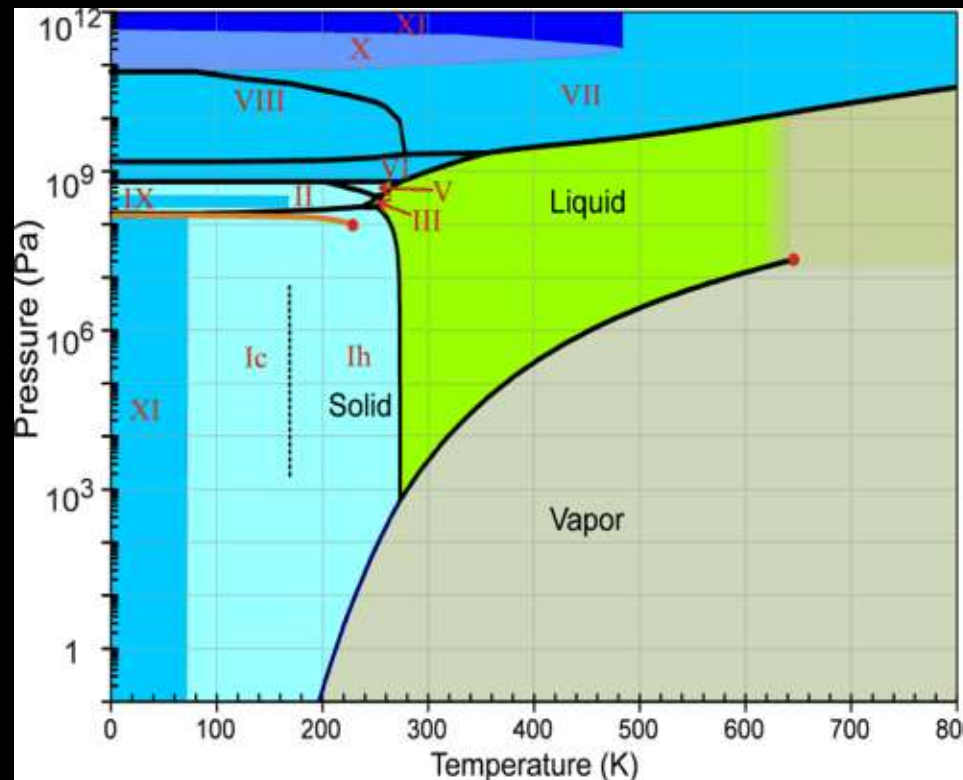
- The particles

$$M_{SUN} \approx M_p^3 / m_p^2$$

interactio

- Successes

- Limitations



mmetry
s) so much
l scales about

$$\begin{aligned} \mu_p &\sim 1 \text{ GeV} \\ \mu_F^{-1/2} &\sim 10^2 \text{ GeV} \\ \mu_N^{-1/2} &\sim 10^{19} \text{ GeV} \end{aligned}$$

The Standard Model

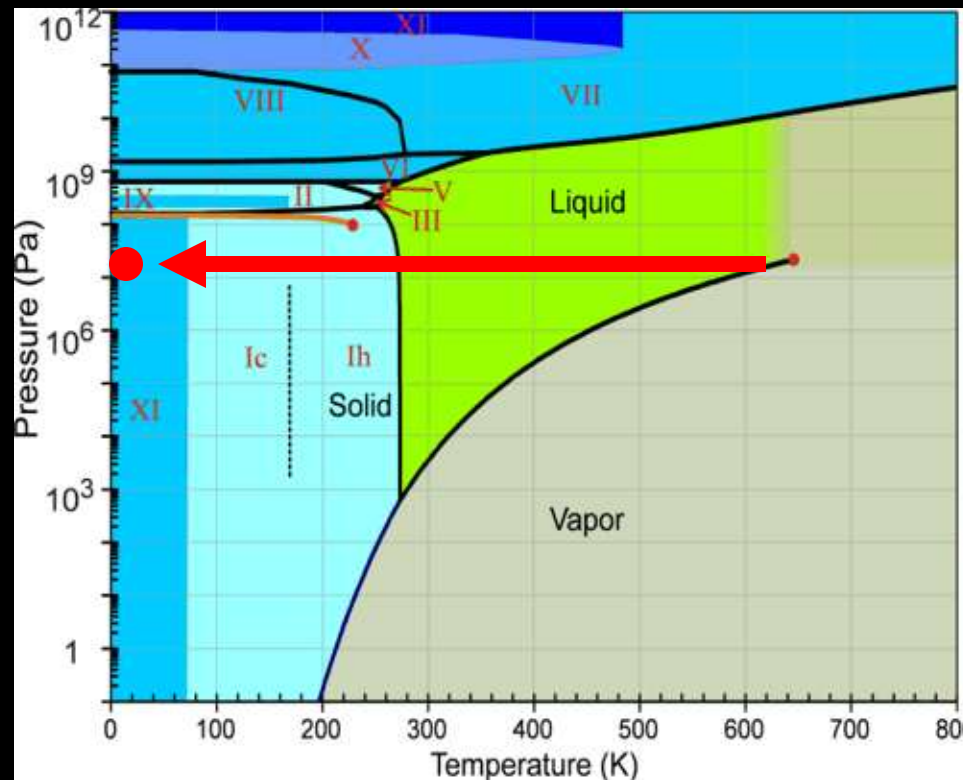
- The particles

$$M_{SUN} \approx M_p^3 / m_p^2$$

interactio

- Successes

- Limitations



mmetry
s) so much
l scales about

$\sim 1 \text{ GeV}$
 $\sim 10^2 \text{ GeV}$
 $\sim 10^{19} \text{ GeV}$

Outline

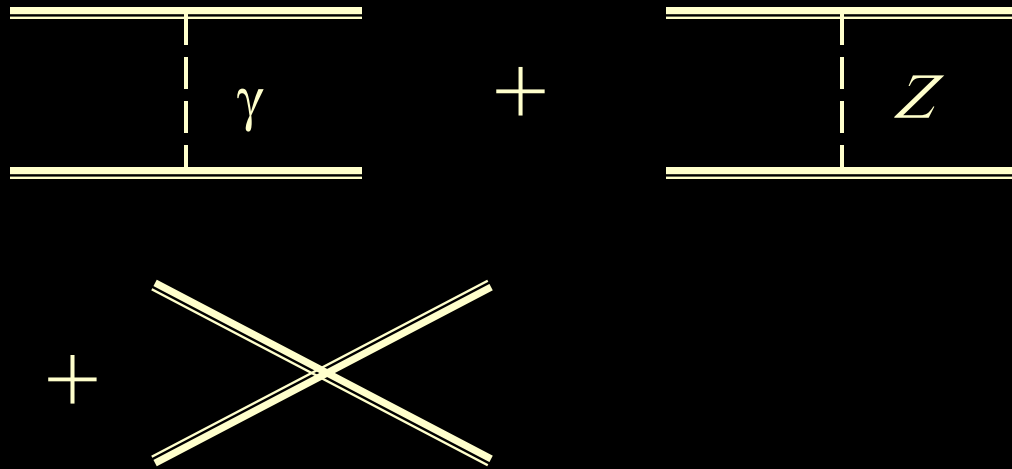
- What is it?
 - *The machine*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

What might be seen

- Nothing?

What might be seen

- Nothing?

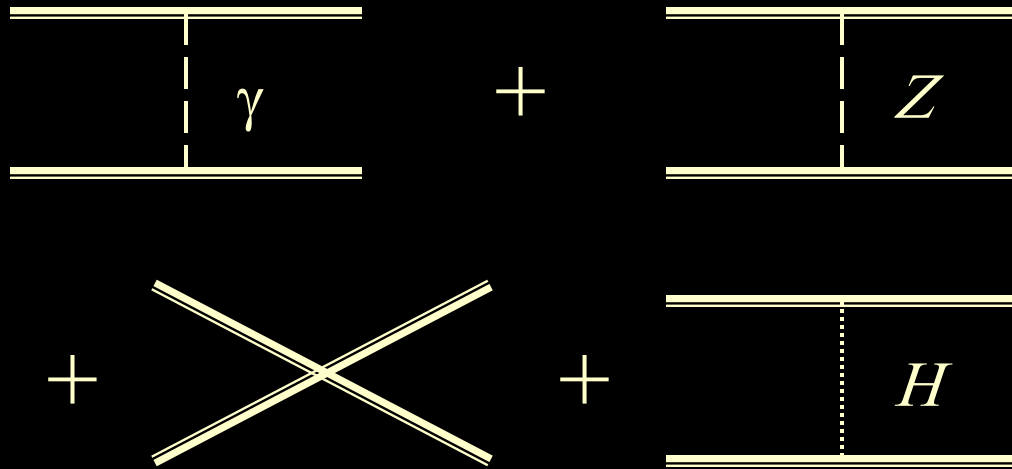


$$W\text{-}W \text{ scattering: } \sigma \sim (\alpha^2 \ln E)/M_W^2$$

The SM without the Higgs boson must break down at energies of order $M_W/\alpha \sim \text{few TeV}$ because $\sigma < 1/E^2$

What might be seen

- Nothing?



W-W scattering: $\sigma \sim \alpha^2/E^2$

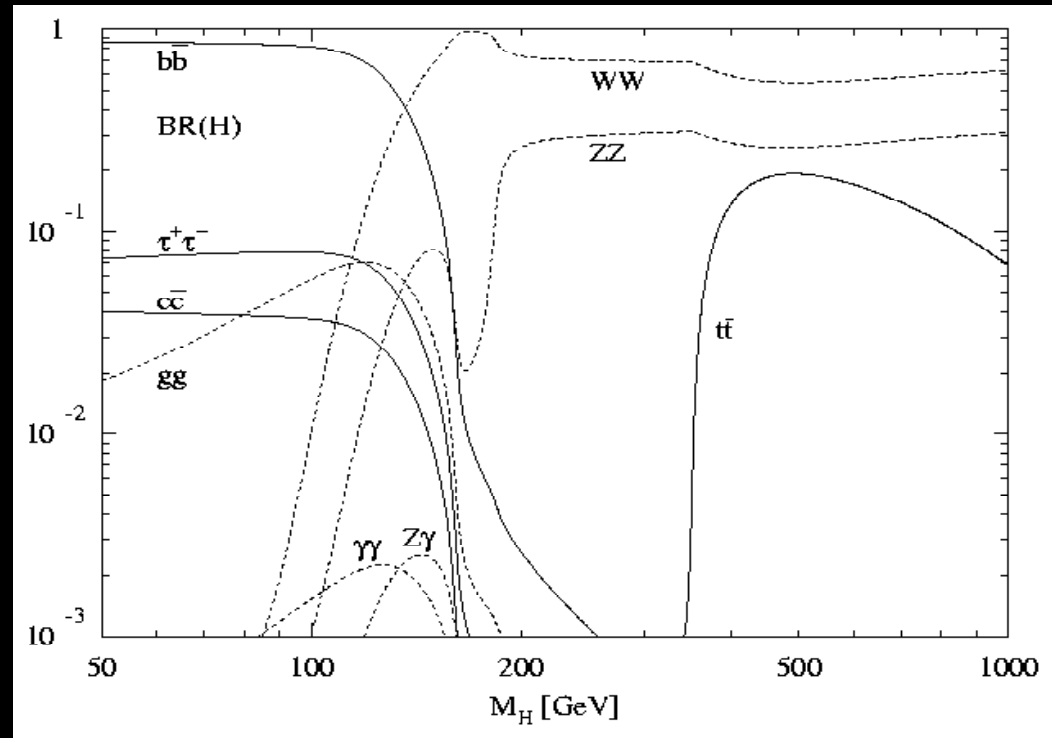
The SM with the Higgs boson can make sense for energies much larger than $M_W/\alpha \sim \text{few TeV}$

What might be seen

- The Higgs Boson?

What might be seen

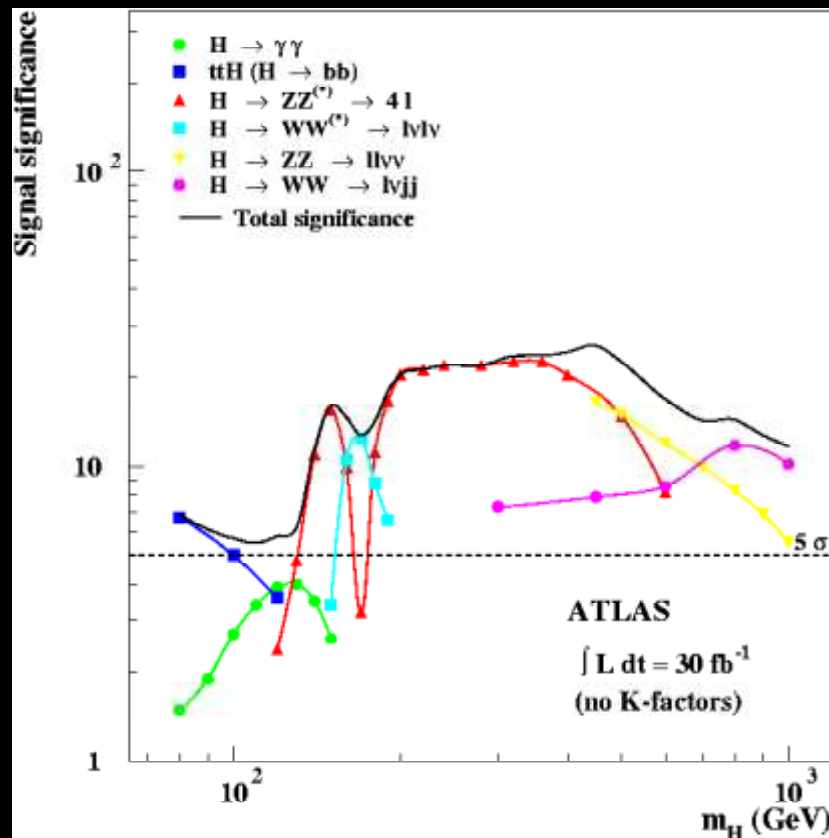
- The Higgs Boson



Search strategies depend on what it decays into,
and this depends on its mass

What might be seen

- The Higgs Boson



Expect it to be visible for the allowed mass range

What might be seen

- Beyond the Standard Model?

What might be seen

- Beyond the S
- *Beyond the SM: the Hierarchy problem provides clues as to what else might be found, since any explanation of what allows $M_w \ll M_p$ must change physics at energies just above M_w*

What might be seen

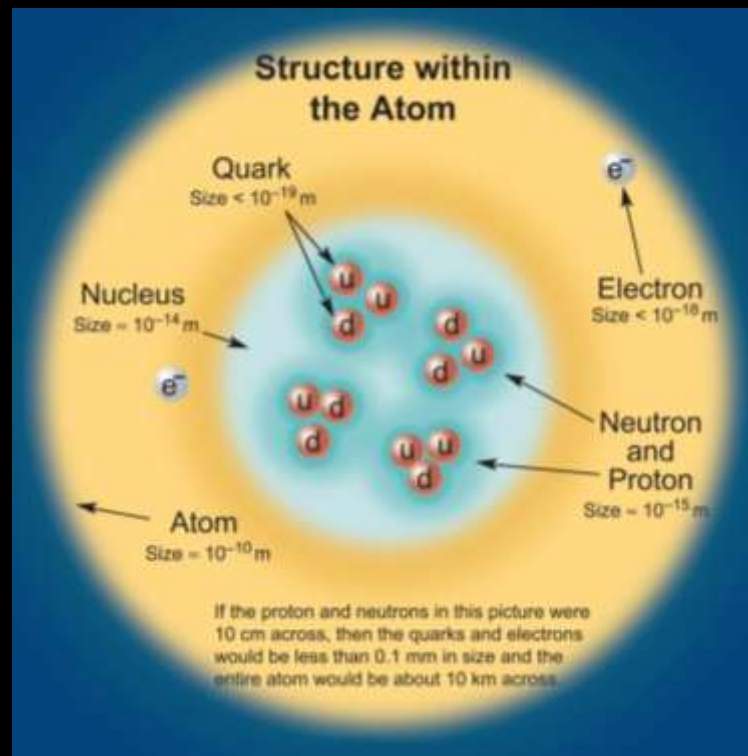
- Beyond the S
- *Beyond the SM*: basically three options:

What might be seen

- Beyond the SM
- *Beyond the SM*: basically three options:
 - No elementary Higgs:
 - *Composite models*

What might be seen

- Beyond the S



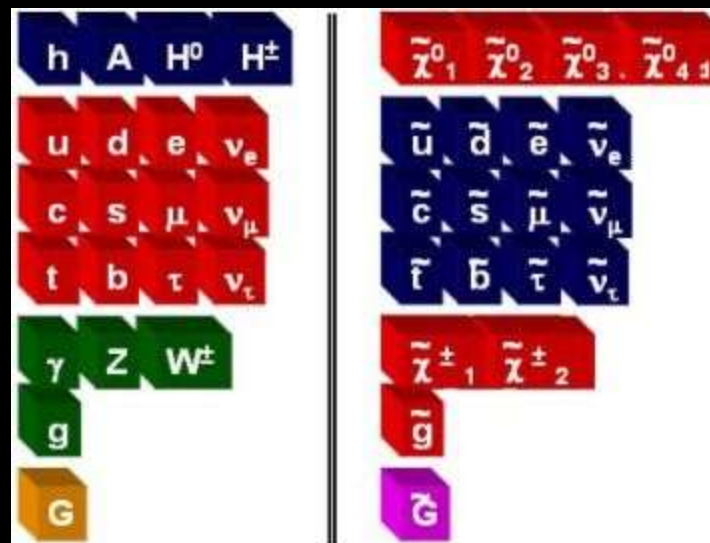
- Another level of substructure is historically the most conservative guess

What might be seen

- Beyond the S
- *Beyond the SM*: basically three options:
 - No elementary Higgs:
 - *Composite models*
 - New symmetry alleviating fine tuning:
 - *Supersymmetry*

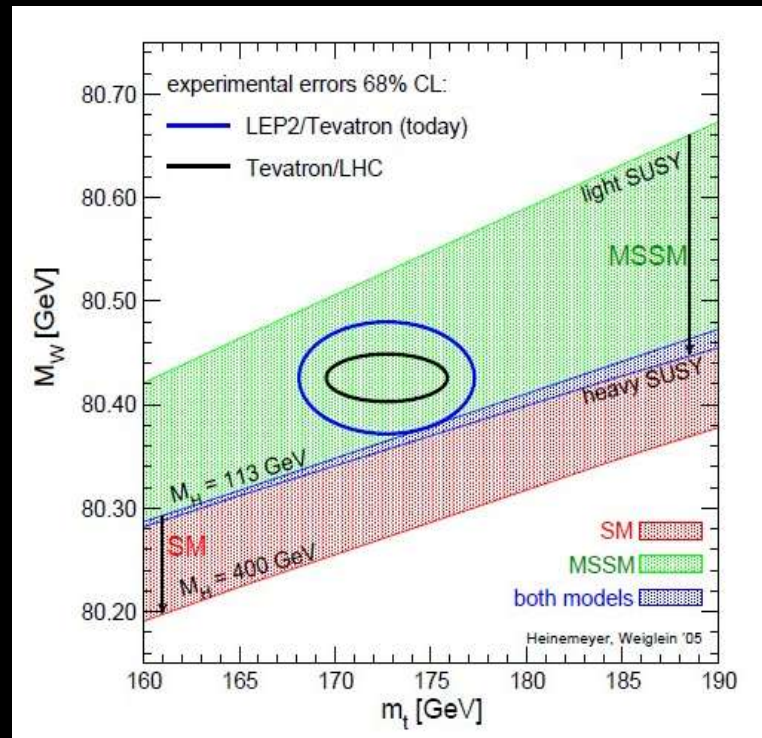
What might be seen

- Beyond the S
- Usually implies ‘superpartners’ for each kind of known particle
- lightest superpartner is usually a good dark matter candidate



What might be seen

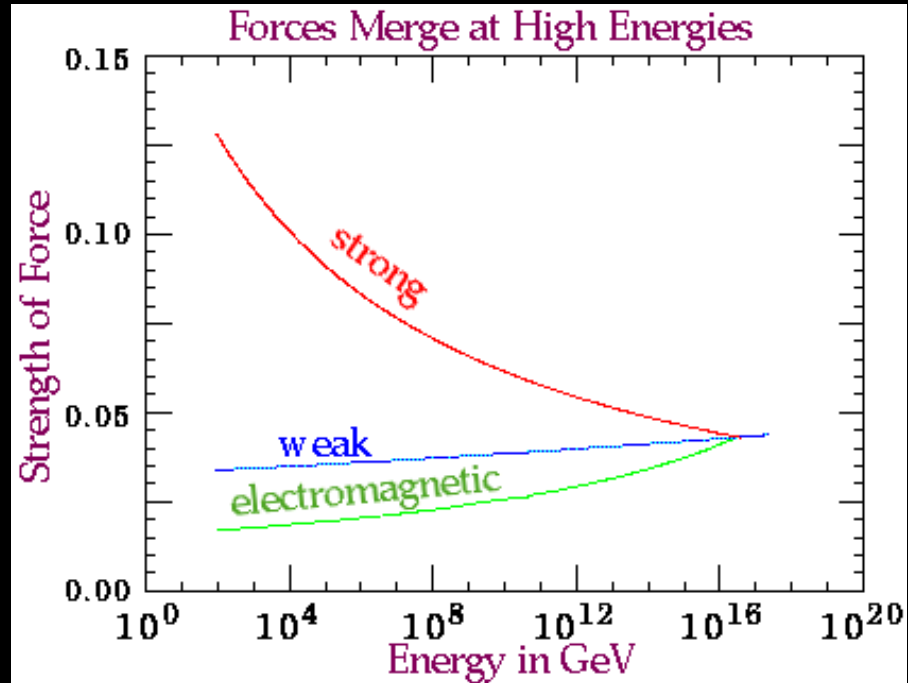
- Beyond the S



- Hint for supersymmetry: in the preference for light Higgs in precision measurements

What might be seen

- Beyond the S



- Hints for supersymmetry: apparent unification of SM couplings

What might be seen

- Beyond the S
- *Beyond the SM*: basically three options:
 - No elementary Higgs:
 - *Composite models*
 - New symmetry alleviating fine tuning:
 - *Supersymmetry*
 - Gravity scale is not really M_p
 - *Extra dimensions*

What might be seen

- The Higgs Boson
- Beyond the Standard Model
- If there are extra dimensions and they are large, then the gravity scale could be much lower than we think....



What might be seen

- Beyond the S *This is the scenario that potentially leads to black hole production...*



Wh

B
3TE

I'VE INVENTED A QUANTUM COMPUTER, CAPABLE OF INTERACTING WITH MATTER FROM OTHER UNIVERSES TO SOLVE COMPLEX EQUATIONS.



www.unitedmedia.com

S. Adams

ACCORDING TO CHAOS THEORY, YOUR TINY CHANGE TO ANOTHER UNIVERSE WILL SHIFT ITS DESTINY, POSSIBLY KILLING EVERY INHABITANT.



3/24/97 © 1997 United Feature Syndicate, Inc.

SHIFT HAPPENS.

FIRE IT UP.



Copyright © 1997 United Feature Syndicate, Inc.
Redistribution in whole or in part prohibited



UNIVERSAL
© 2000 Universal Pictures



What might be seen

- Beyond the S *This is the scenario that potentially leads to black hole production...*



What might be seen

- Bey

has the lhc destroyed the world yet - Google Search - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.google.ca/#hl=en&source=hp&q=has+the+lhc+destroyed+the+world+y

arXiv SPIRES PI PI Mac Me@Mac Gmail Hotmail Google CERN Seminars Not That Dave Matthews PDG

has the lhc destroyed the ...

Web Images Videos Maps News Books Gmail more

Web History | Search settings | Sign in

Google has the lhc destroyed the world yet Search Advanced Search

Search: the web pages from Canada

Web [show options...](#) Results 1 - 10 of about 12,100 for **has the lhc destroyed the world yet.** (0.28 seconds)

[Has the Large Hadron Collider destroyed the world yet?](#)

[has the large hadron collider destroyed the world yet.com](#) - Cached - Similar

[Has the Large Hadron Collider destroyed the earth yet?](#)
NO ?
[www.has the lhc destroyed the earth.com/](#) - Cached - Similar

[Has the Large Hadron Collider destroyed the world yet?](#) | Ed ...
11 Sep 2008 ... Nope. That's the answer you'll get from [has the large hadron collider destroyed the world yet.com](#) today, despite the **LHC's** successful startup tests ...
[blogs.zdnet.com/Burnette/?p=653](#) - Cached - Similar

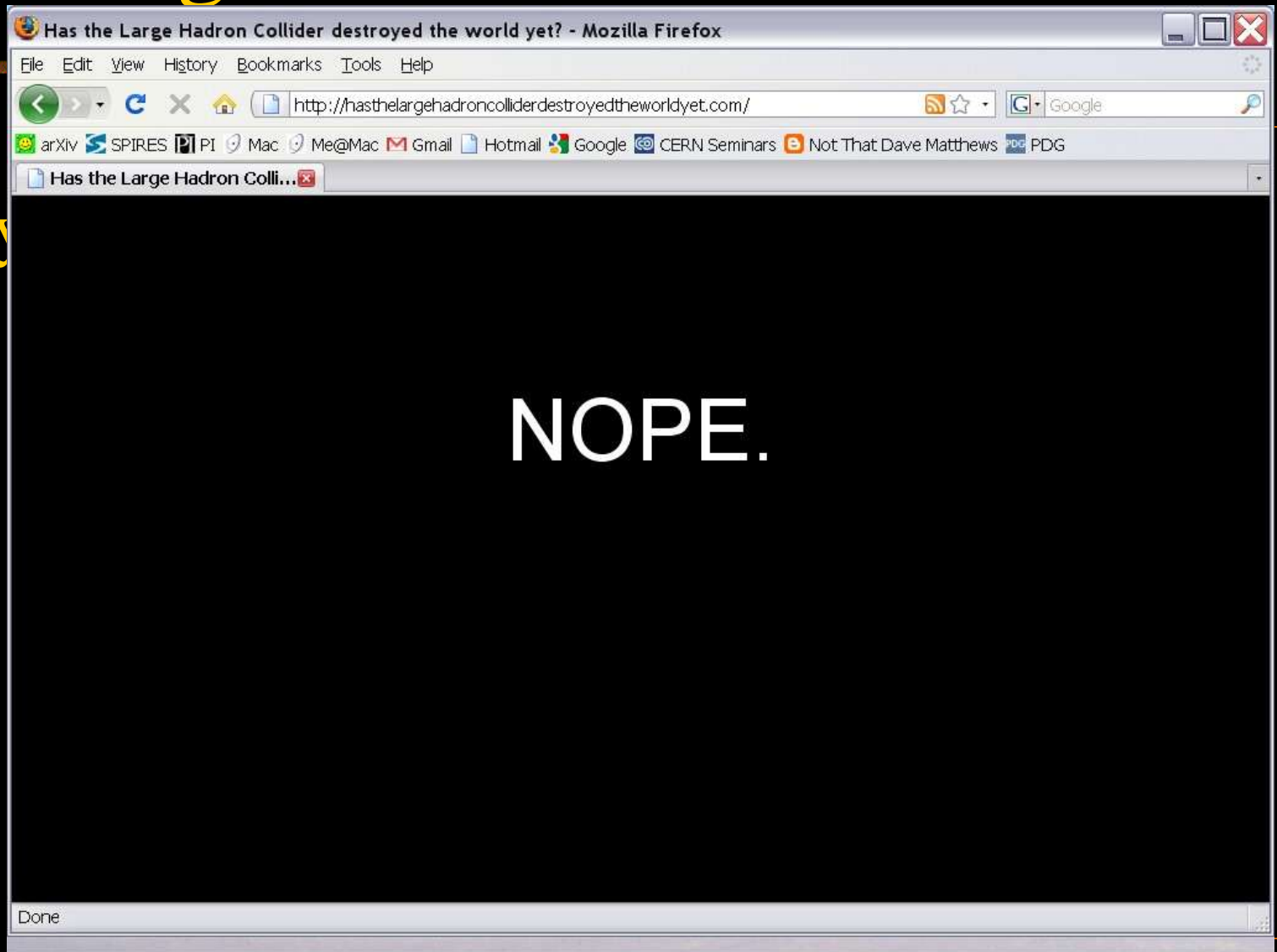
[Has the Large Hadron Collider Destroyed the World Yet](#) - Webmonkey
[Has the Large Hadron Collider Destroyed the World Yet?](#) By Scott Gilbertson
September 10, 2008 Categories: Humor . hope Where would science be without the ...
[www.webmonkey.com/.../Has_the_Large_Hadron_Collider_Destroyed_the_World_Yet](#)
- Cached - Similar

[Has the LHC destroyed the world yet?](#) - DonationCoder.com
Have a look at the page source, how neatly they check if the **world has** ended or not. Only I think it's a bug that they don't detect the actual reason of the ...
[www.donationcoder.com/Forums/bb/index.php?topic=14859...](#) - Japan

Done

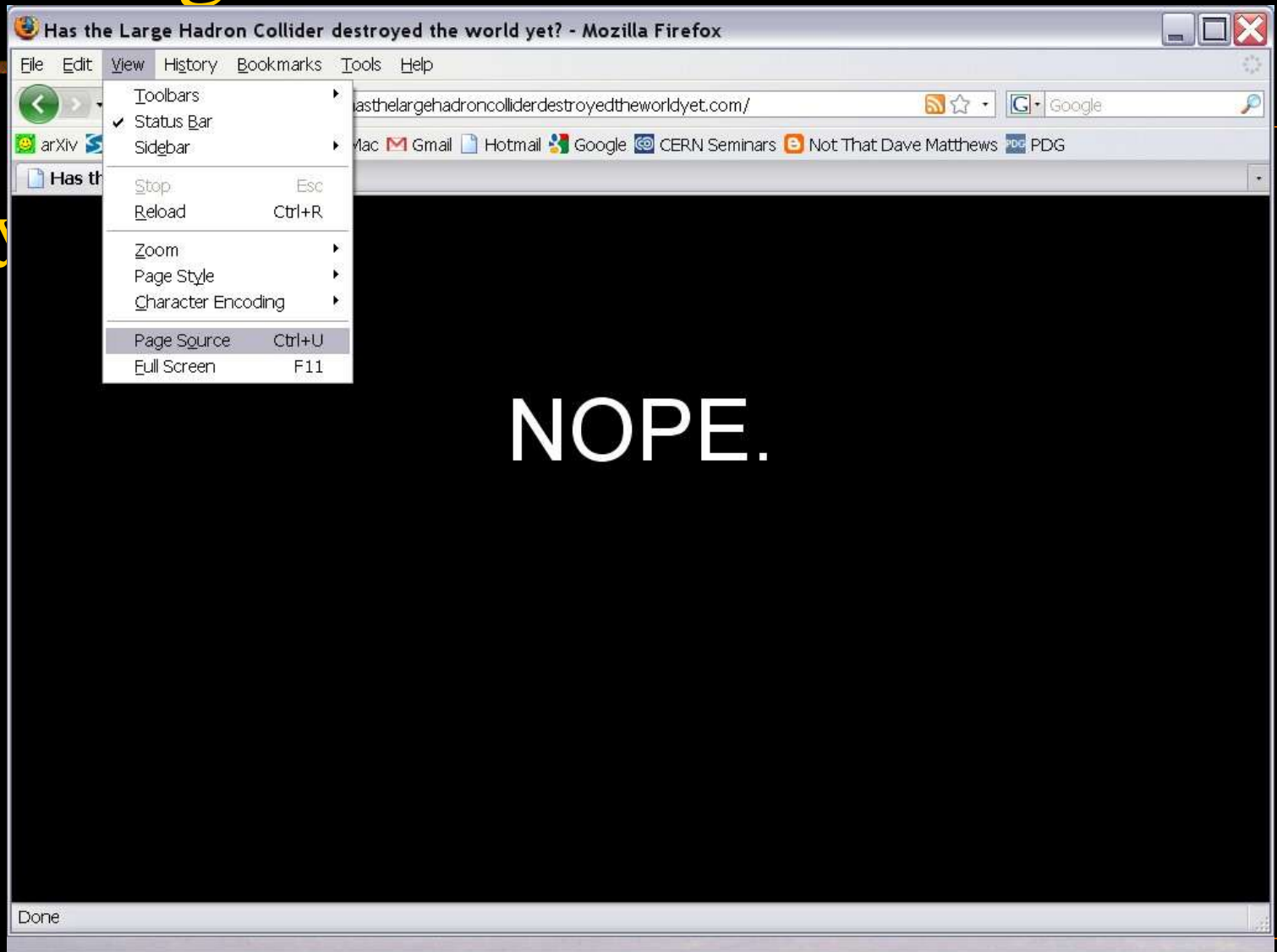
What might be seen

- Beyond



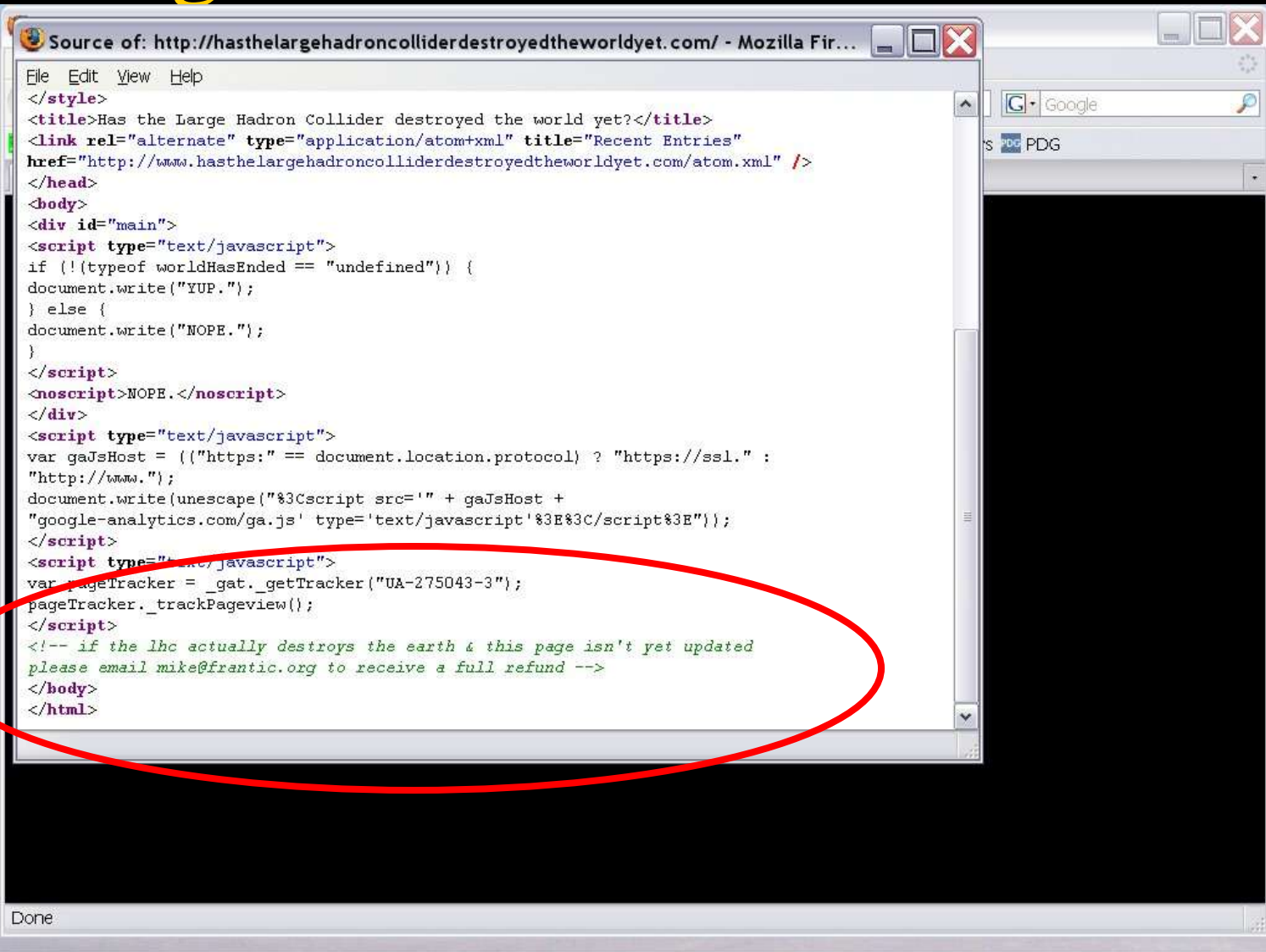
What might be seen

- Beyond



What might be seen

- Beyond



```
Source of: http://hasstheLargeHadronColliderDestroyedTheWorldYet.com/ - Mozilla Fir...
File Edit View Help
</style>
<title>Has the Large Hadron Collider destroyed the world yet?</title>
<link rel="alternate" type="application/atom+xml" title="Recent Entries"
href="http://www.hasstheLargeHadronColliderDestroyedTheWorldYet.com/atom.xml" />
</head>
<body>
<div id="main">
<script type="text/javascript">
if (!(typeof worldHasEnded == "undefined")) {
document.write("YUP.");
} else {
document.write("NOPE.");
}
</script>
<noscript>NOPE.</noscript>
</div>
<script type="text/javascript">
var gaJsHost = (("https:" == document.location.protocol) ? "https://ssl." :
"http://www.");
document.write(unescape("%3Cscript src='" + gaJsHost +
"google-analytics.com/ga.js' type='text/javascript'%3E%3C/script%3E"));
</script>
<script type="text/javascript">
var pageTracker = _gat._getTracker("UA-275043-3");
pageTracker._trackPageview();
</script>
<!-- if the lhc actually destroys the earth & this page isn't yet updated
please email mike@frantic.org to receive a full refund -->
</body>
</html>
```

Outline

- What is it?
 - *The machine*
- Why was it built?
 - *The Standard Model and its limitations*
- What might it hope to see?
 - *Problems*
- Outlook

Outlook

- The LHC is finally producing physics results!
 - Runs at full beam energy could begin in a few years.

Outlook

- The LHC is finally producing physics results!
 - Runs at full beam energy could begin in a few years.

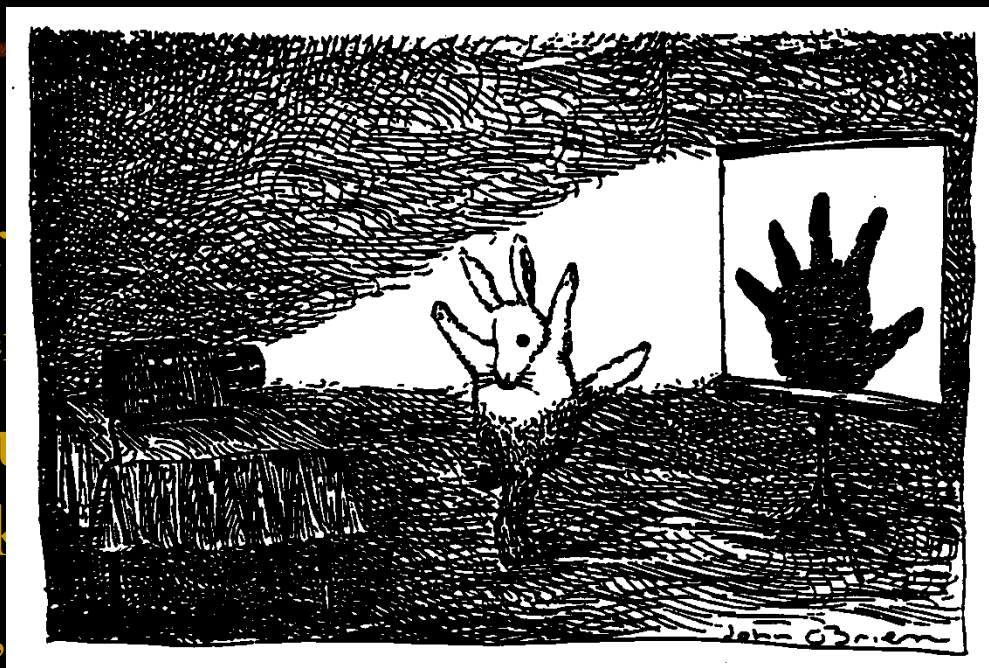
HOLY SHIT!!

Outlook

- The LHC is finally producing physics results!
 - Runs at full beam energy could begin in a few years.
- The LHC should tell us if the Higgs mechanism is right, and how it works.
 - The SM Higgs boson, or its alternative, should be found.

Outlook

- The LHC is finally producing results
 - Runs at full beam energy
- The LHC should tell us if we are right, and how it works
 - The SM Higgs boson, and whether it is the one we expect
- Surprises are inevitable!
 - The LHC is likely to represent a major change to our understanding of Nature at its most elementary level.



Outlook

- The LHC is finally producing physics results!
 - Runs at full beam energy could begin in a few years.
- The LHC should tell us if the Higgs mechanism is right, and how it works
 - The SM Higgs boson, or its alternative, should be found.
- Surprises are inevitable!
 - The LHC is likely to represent a major change to our understanding of Nature at its most elementary level.