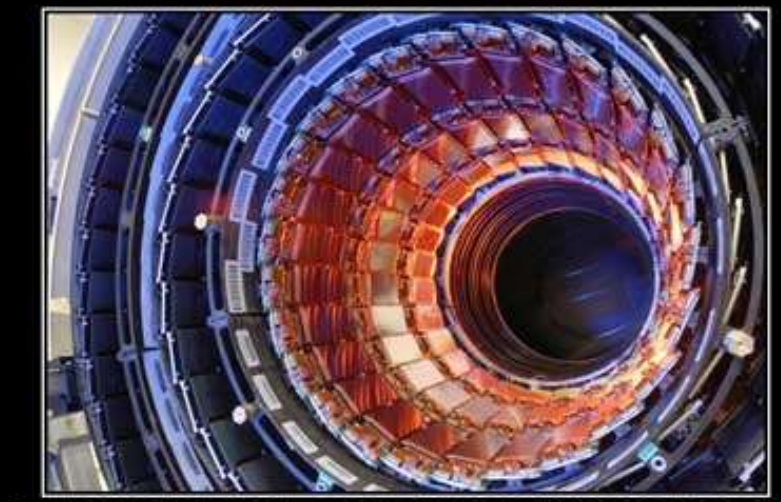
The Large Hadron Collider

Start of a New Era

or the End of the World?



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

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The Machine

- The Accelerator
- The Detectors

The Machine

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- The Detectors

The Machine

- The Accelera
- The Detector

The Machine

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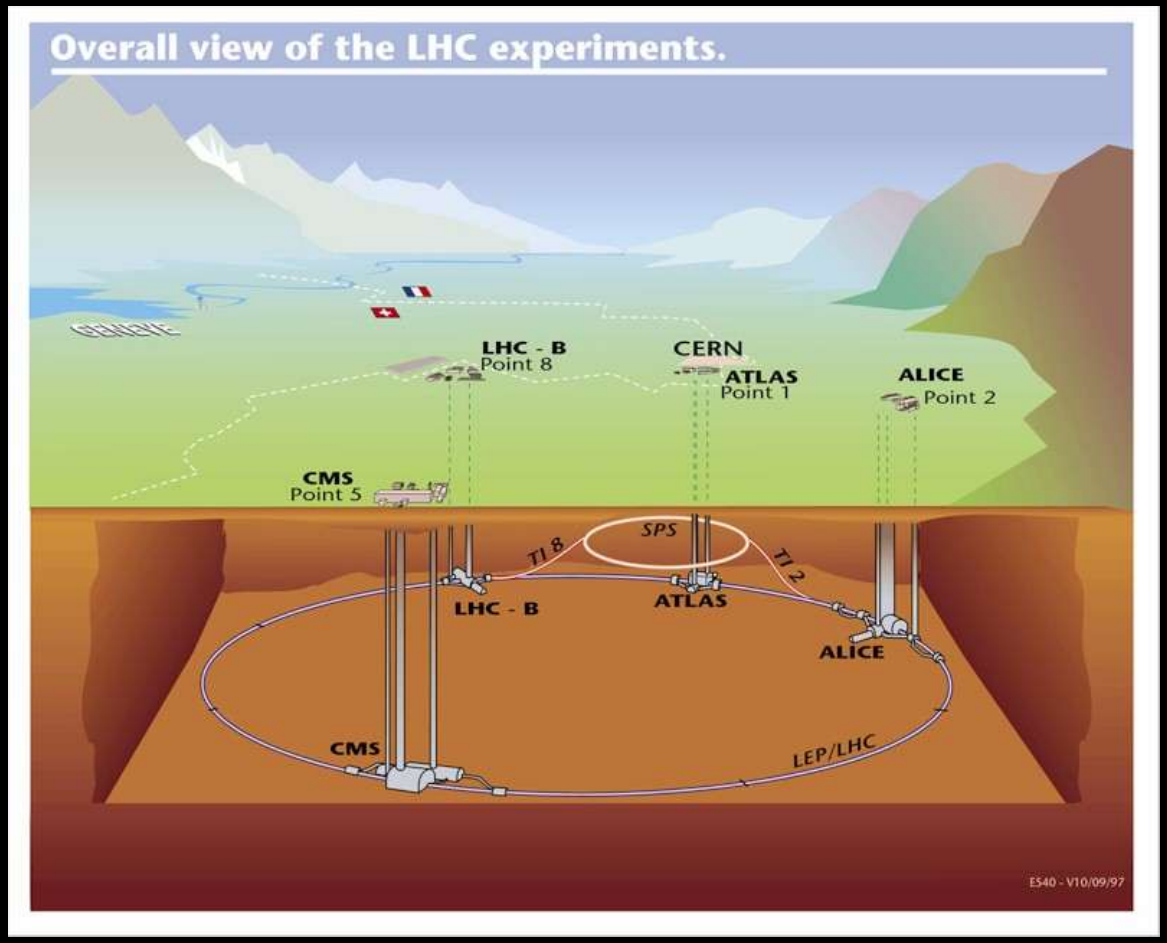
- The Detector



The Machine

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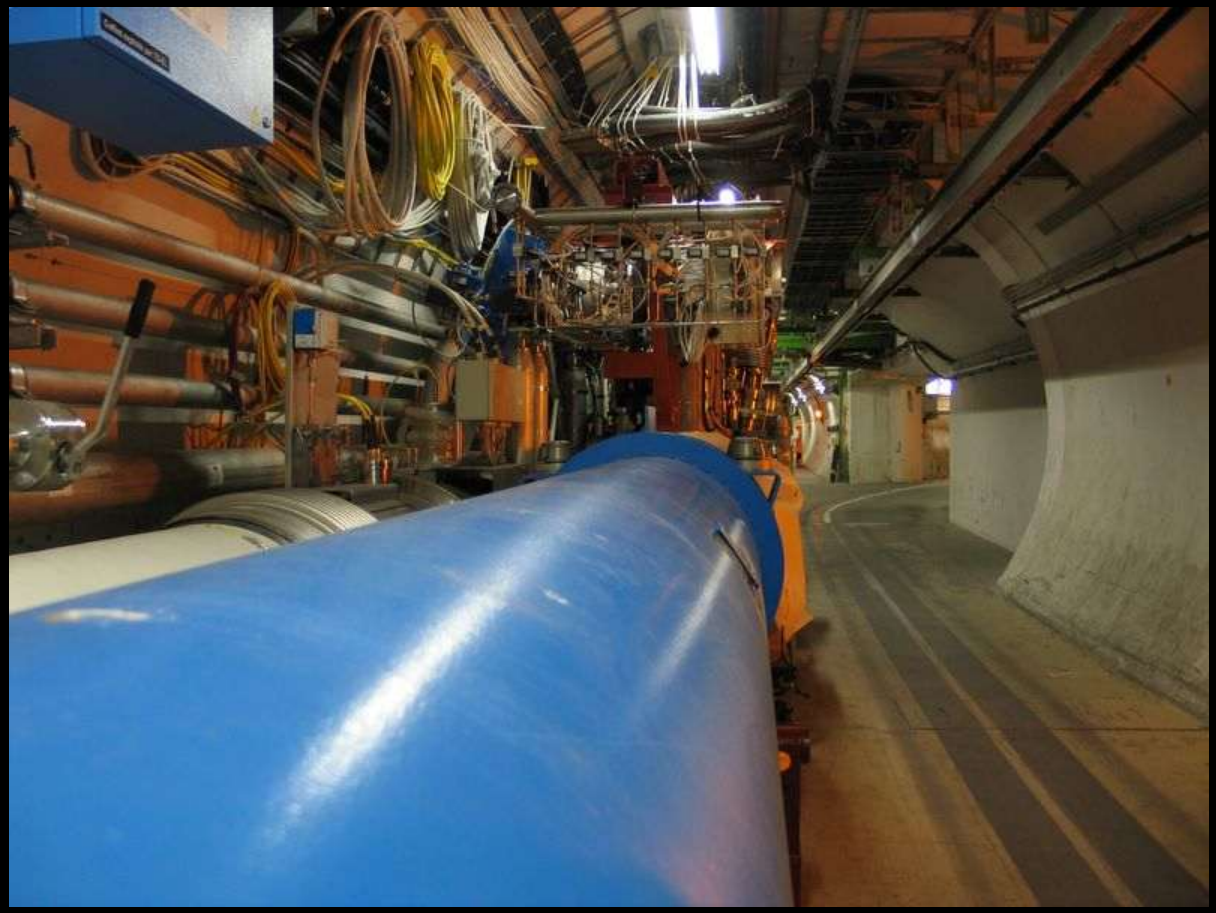


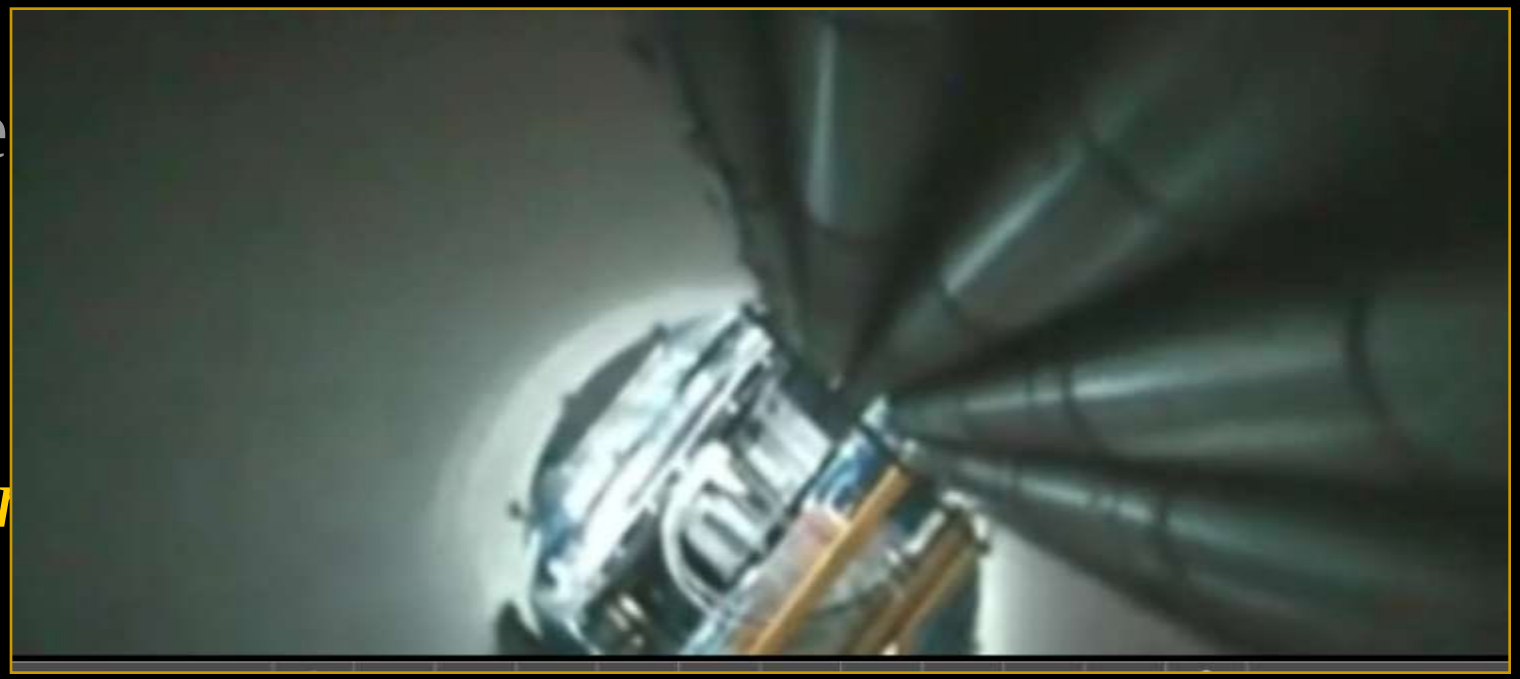
CERN: The Movie

- The Plot
- S
- S

CERN: The Movie

- The

- *Scer*



The Movie

CERN: The Movie

- The

The Movie

CERN

CERN: The Movie

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The Movie

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The Movie

CERN

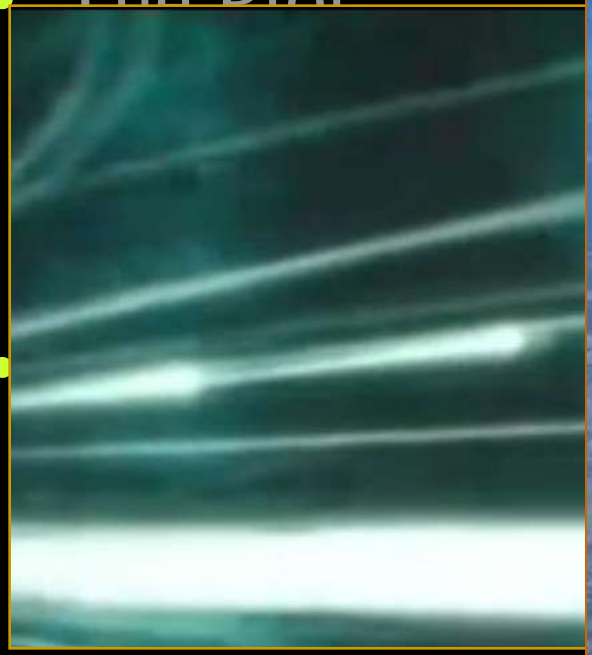
CERN: The Movie

- The Plot
-

The Movie

CERN: The Movie

- The Plot



The Machine

W. Trischuk

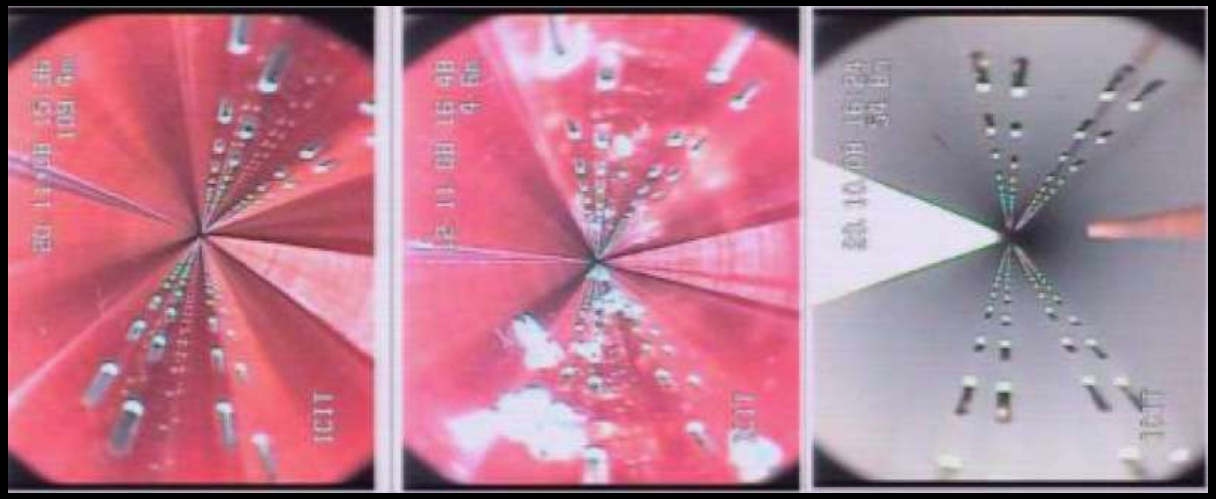
- The Accelera
- The Detector

mechanical damage

The Machine

W. Trischuk

- The Accelera
- The Detector



soot in the beam pipe

(normal copper looks red)

The Machine

W. Trischuk

- The Accelera
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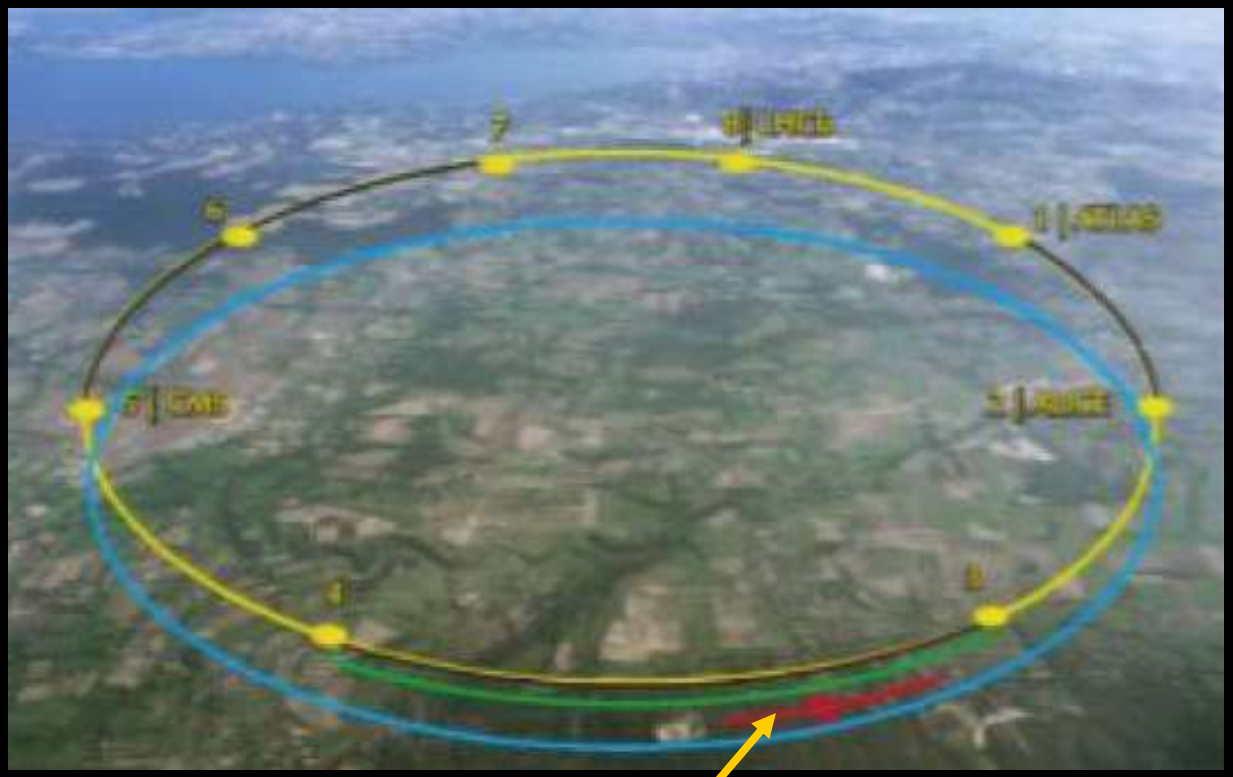

The Incident

The Machine

W. Trischuk

- The Accelera
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1200 superconducting magnets

The Machine

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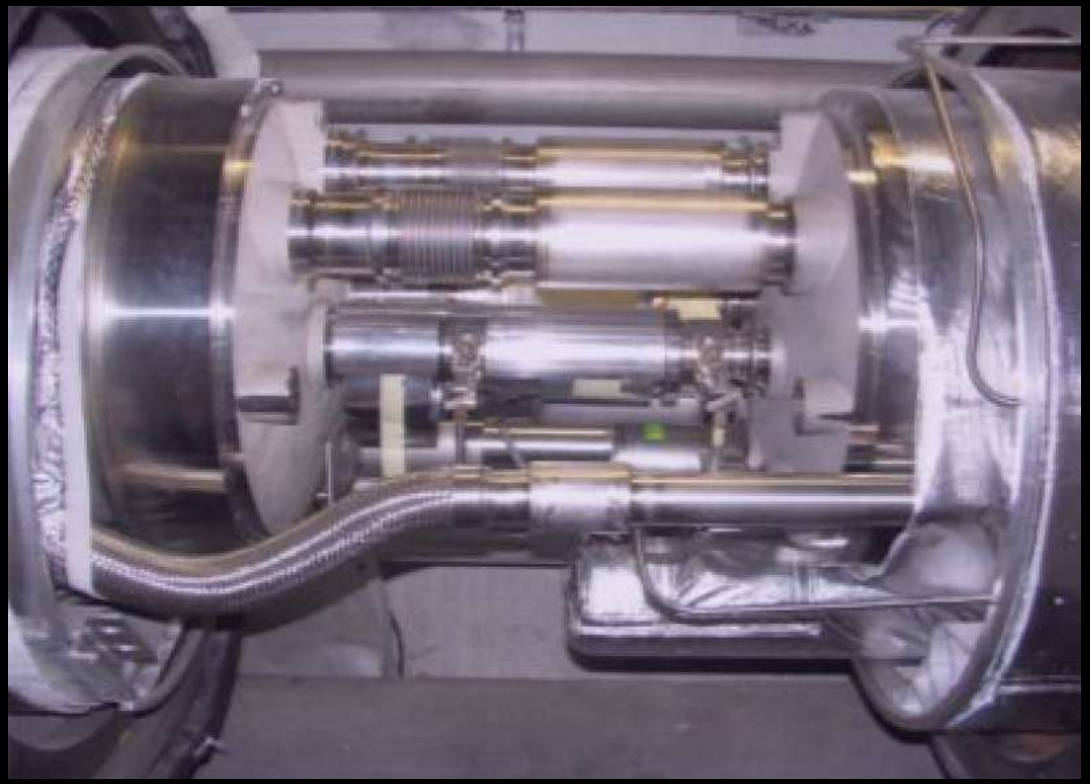

dipole interconnect

The Machine

W. Trischuk

- The Accelera
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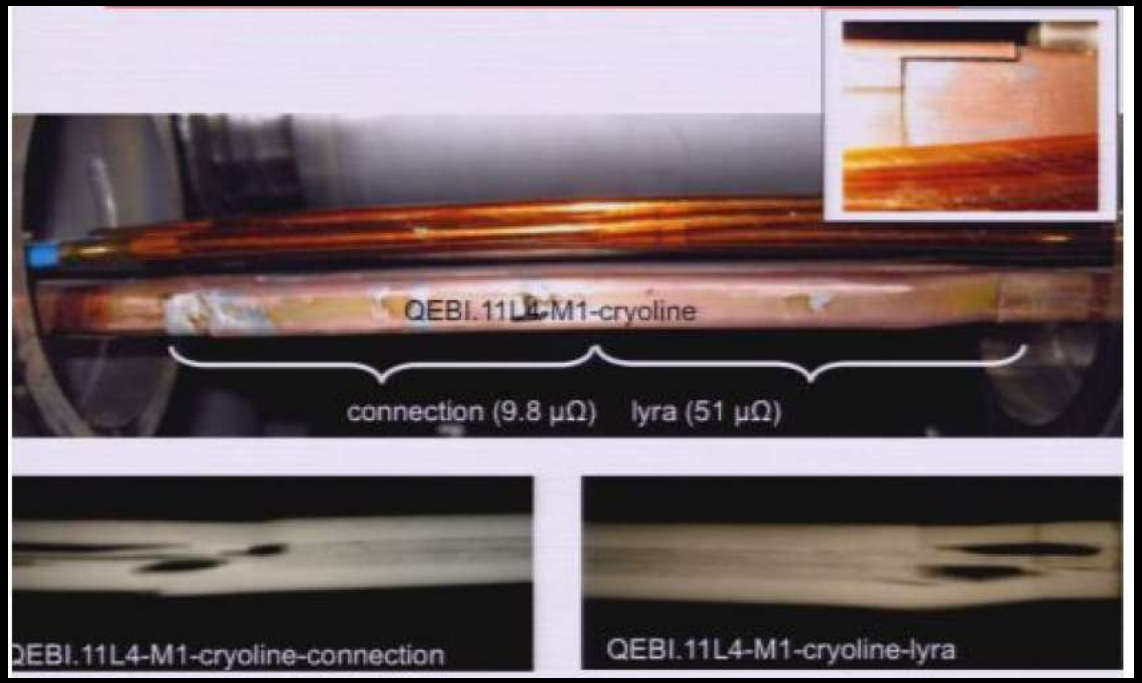

dipole interconnect

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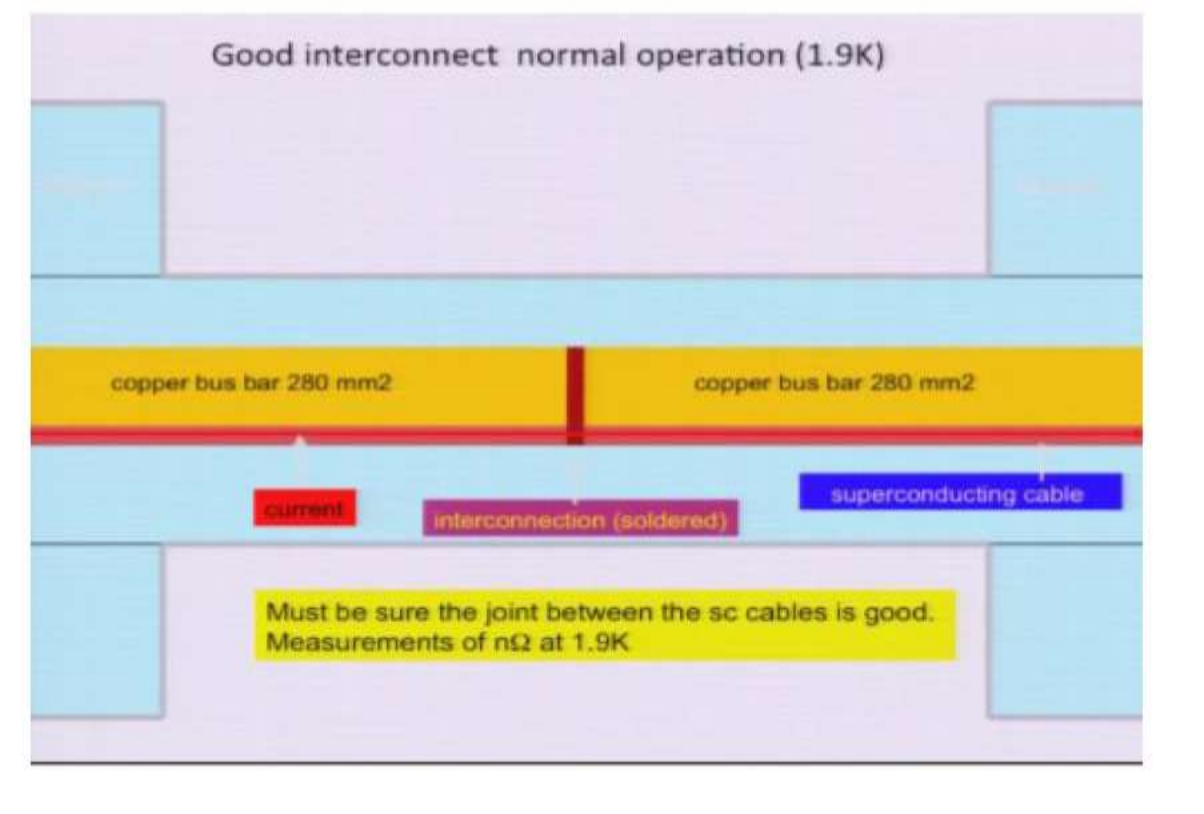

schematic connection

The Machine

W. Trischuk

- The Accelera
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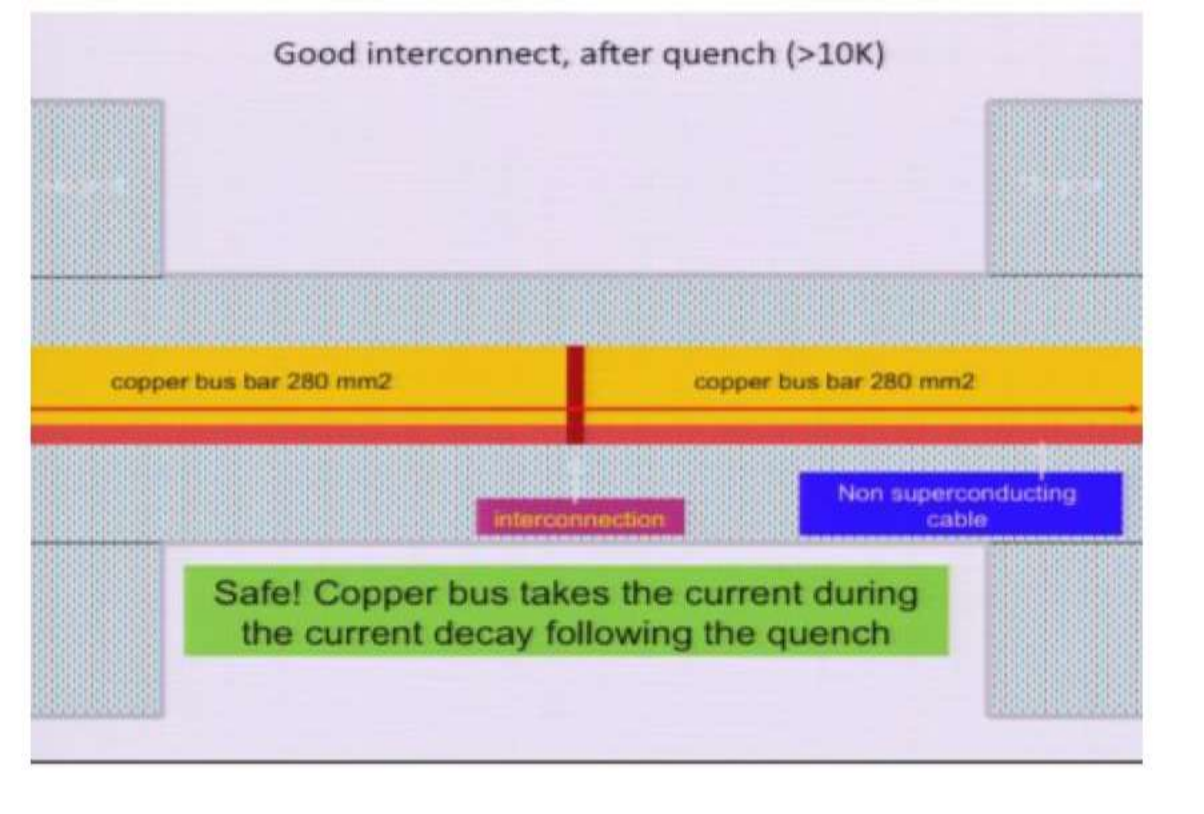

schematic connection

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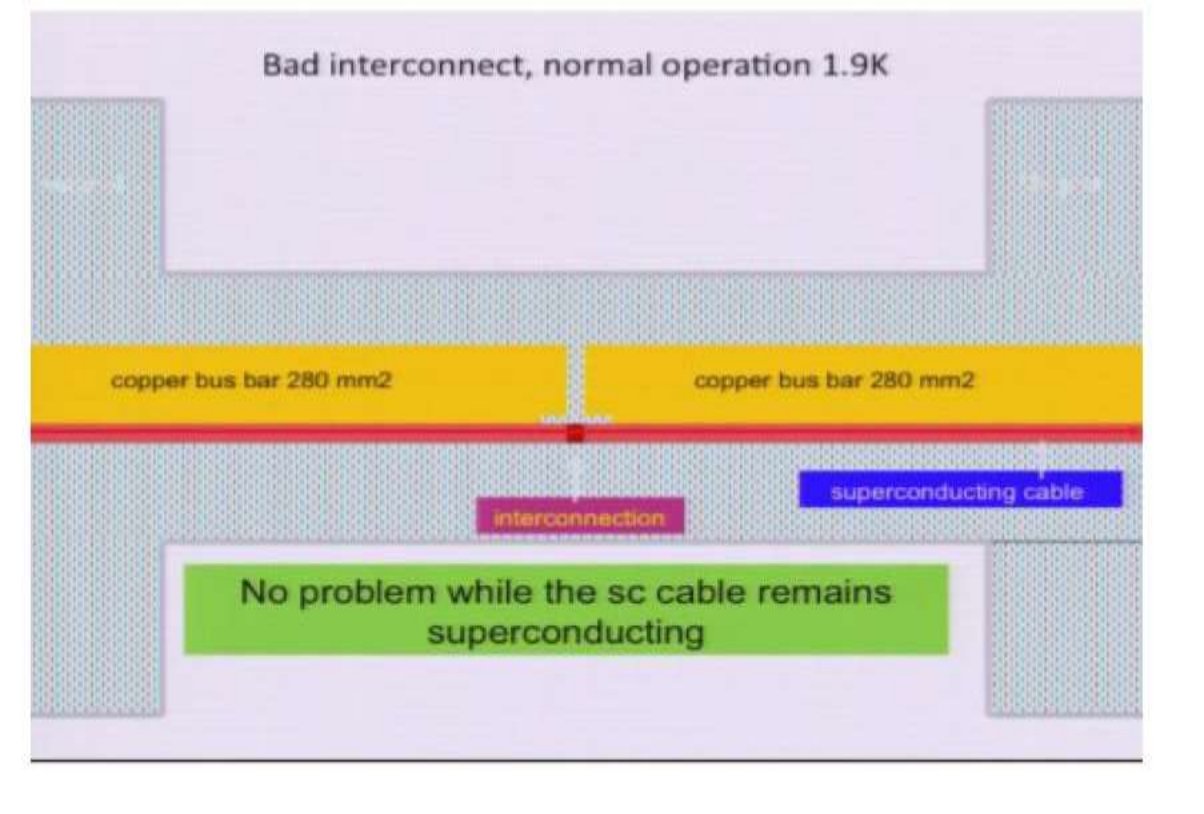


schematic connection

The Machine

W. Trischuk

- The Accelera
- The Detector

Replaced 14 quadrupoles and 29 dipoles,
34 interconnections fully repaired

The Machine

W. Trischuk

- The Accelera
- The Detector

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

Can measure resistance of connections to infer which are bad

worst magnet (at 300K): 50 μΩ

At 7 TeV believed safe even with 120 μΩ

At 10 TeV believed safe even with 70 μΩ

The Machine

W. Trischuk

- The Accelera
- The Detector

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

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

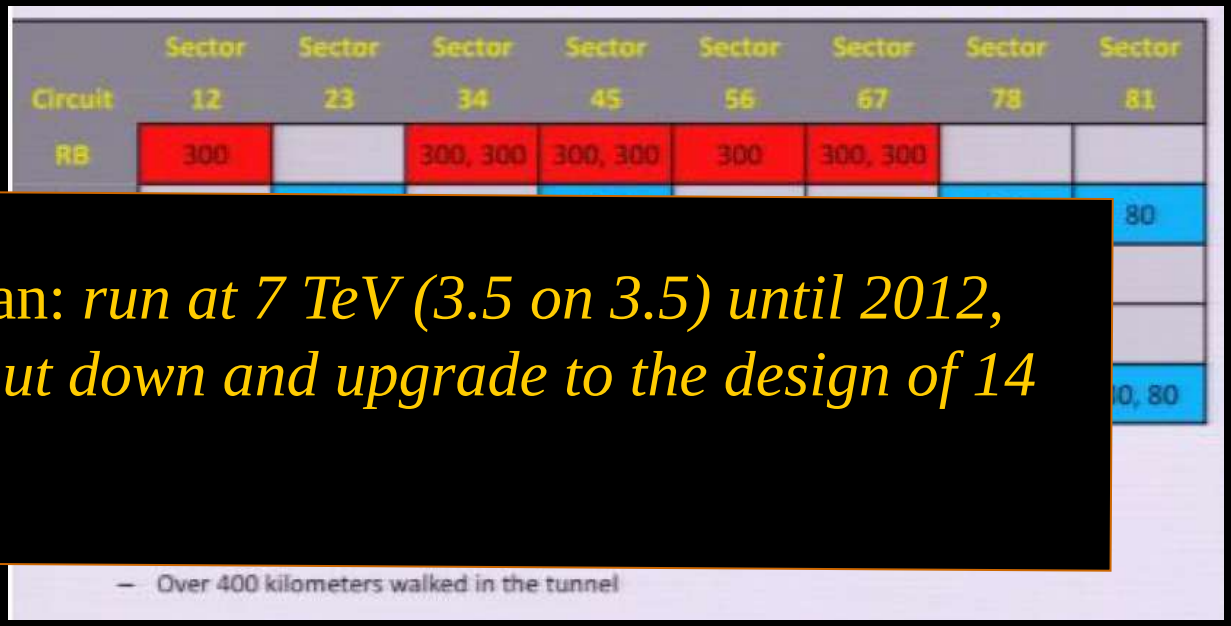
But some sectors remain cold

Takes months to heat and recool and there is not enough storage for the He: ***nΩ resistance***

The Machine

W. Trischuk

- The Accelera
- The D



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: ***nΩ resistance***

The Machine

- The Accelera
- The Detector

30 November 2009

LHC sets new world record

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

Up and running again for some time

The Machine

- The Accelerator
- The Detectors (a personal look)

The Machine

- The Accelera
- The Detector

The most important machine at CERN

The Machine

- The Accelera
- The Detector

The most important machine at CERN

next

The Machine

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The Machine

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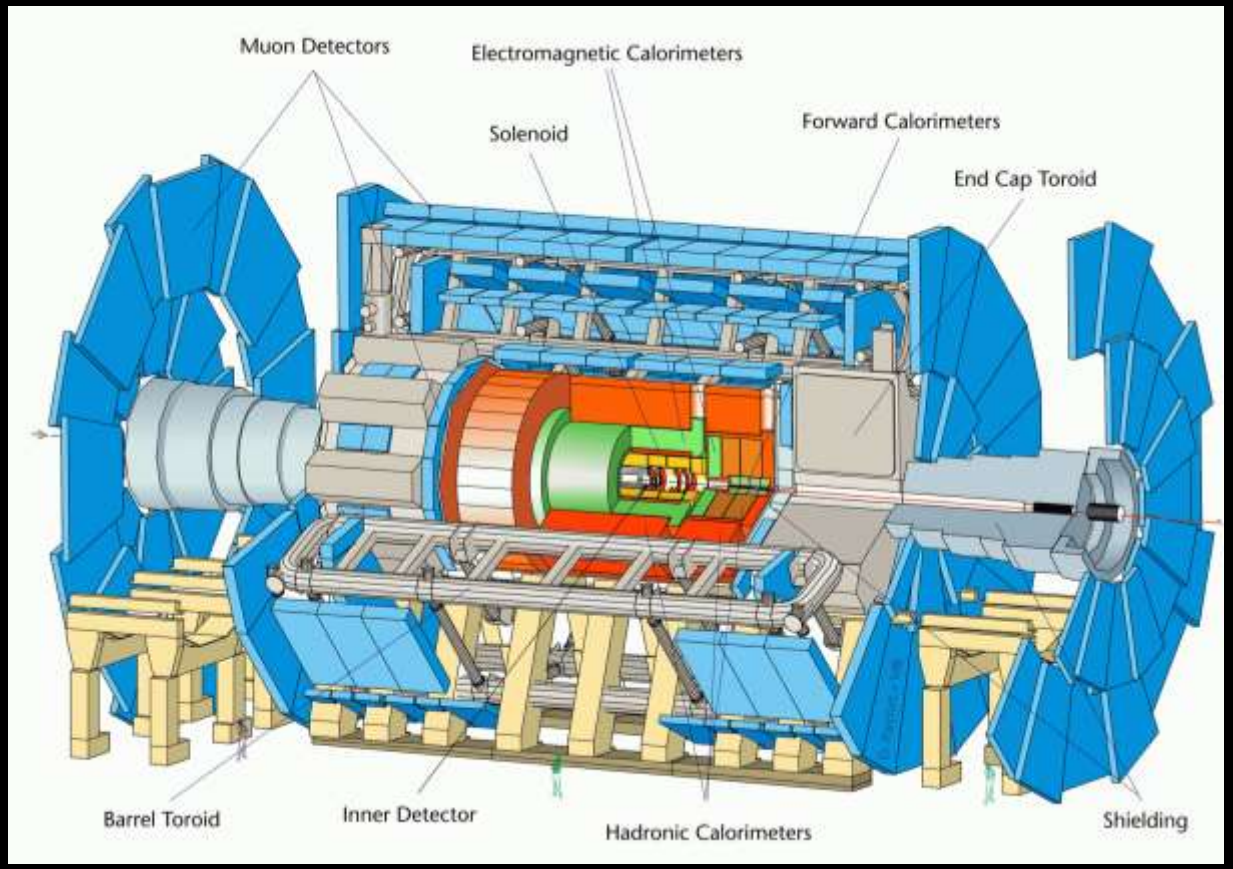
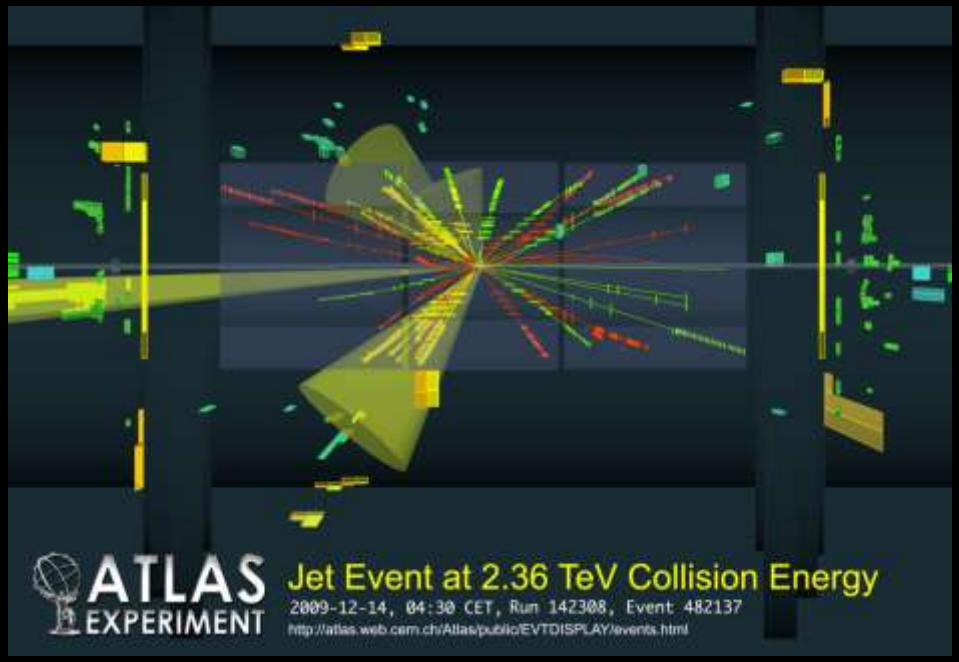


The ATLAS Detector

The Machine

- The Accelera
- The Detector



The detectors have been working well

Outline

- What is it?
  - *The machine*
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  - *Problems*
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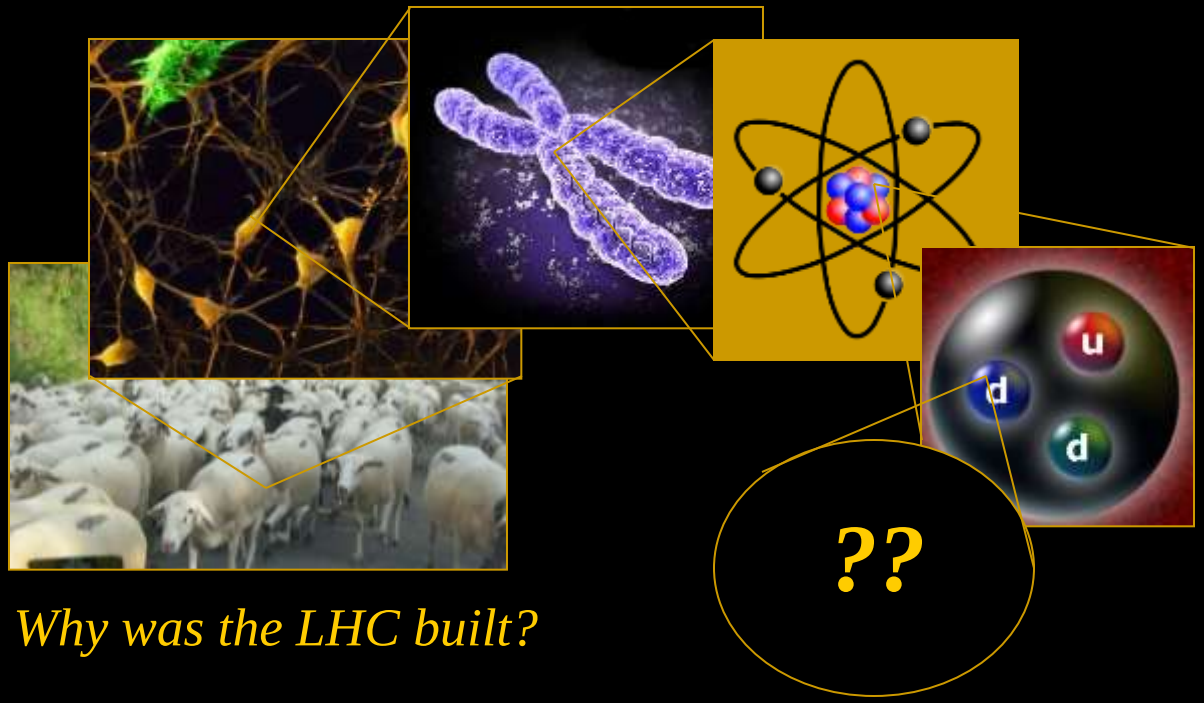


Why was the LHC built?

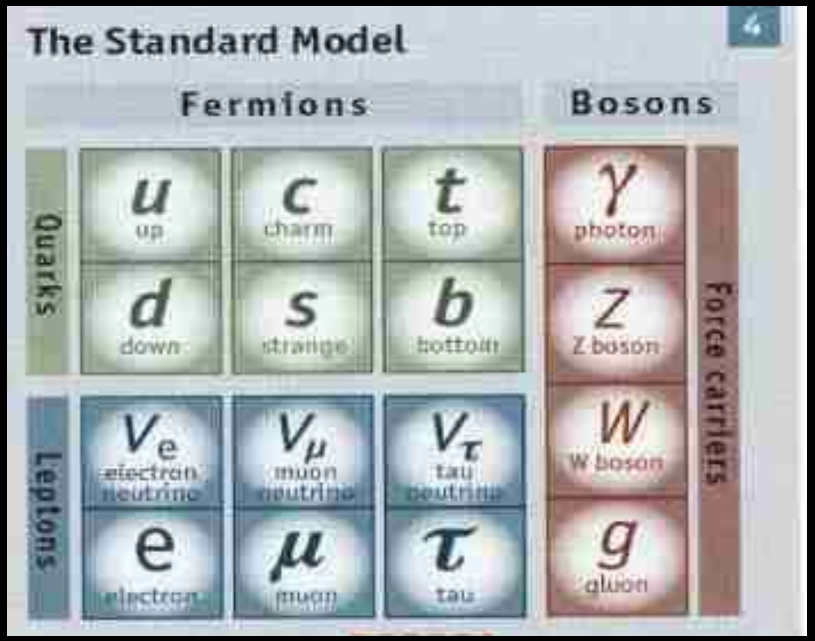
Our presently successful understanding of elementary particles and the four forces through which they interact must break down at distances just out of reach.

The Standard Model

- The particles and interactions
- Successes
- Limitations

The Standard Model

- The particles interactions
- Successes
- Limitations



The 12 known constituents of matter and the 4 fundamental forces

The Standard Model

- The particles interactions
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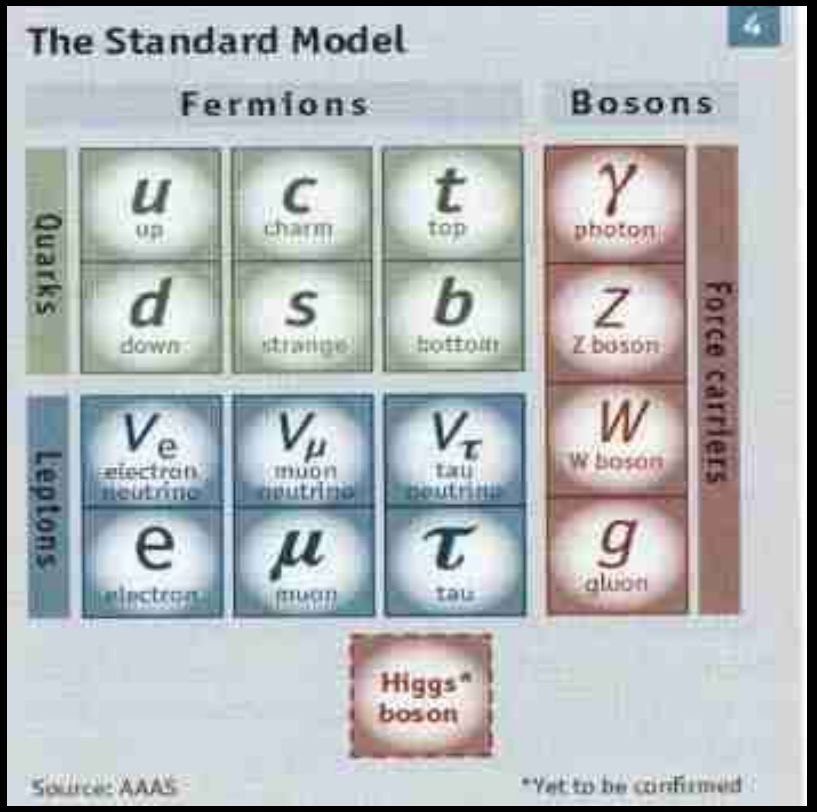
- Limitations



One SM particle remains AWOL: the Higgs boson

AAAS

The Standard Model

- The particles interactions
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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
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- Limitations

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

The Standard Model

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

The Standard Model

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The Standard Model

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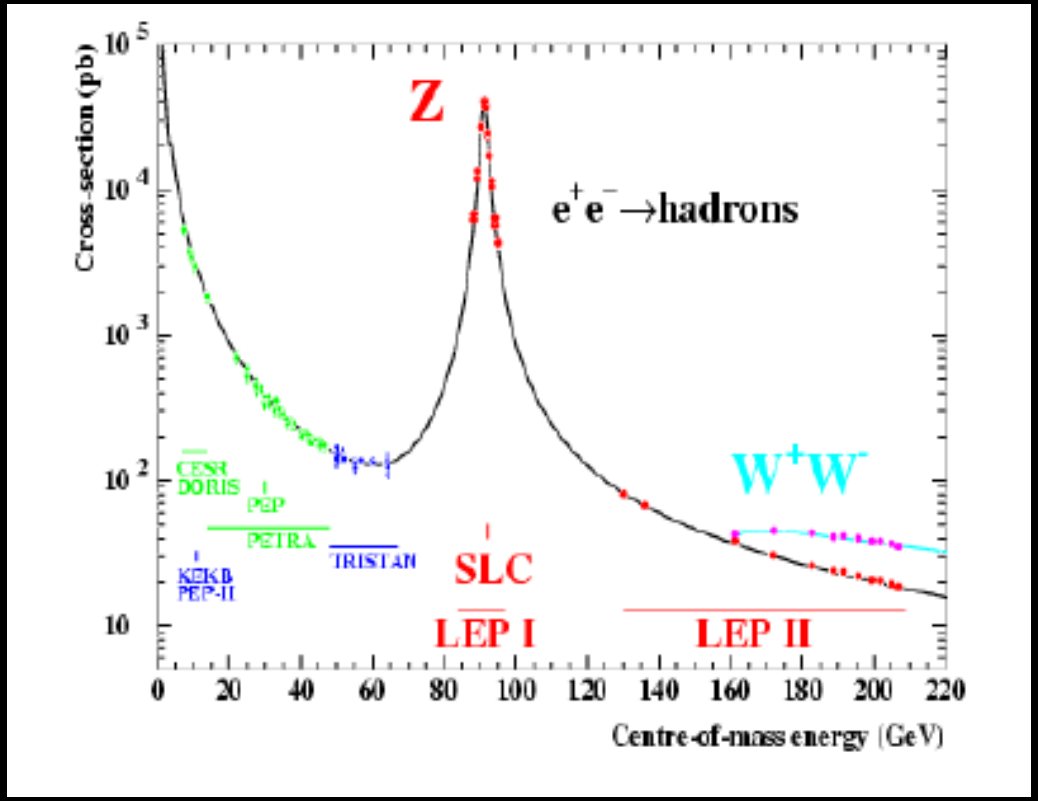

The SM is tested in detail, such as through e^+e^- collisions

A Tonazzo: Moriond 2002

The Standard Model

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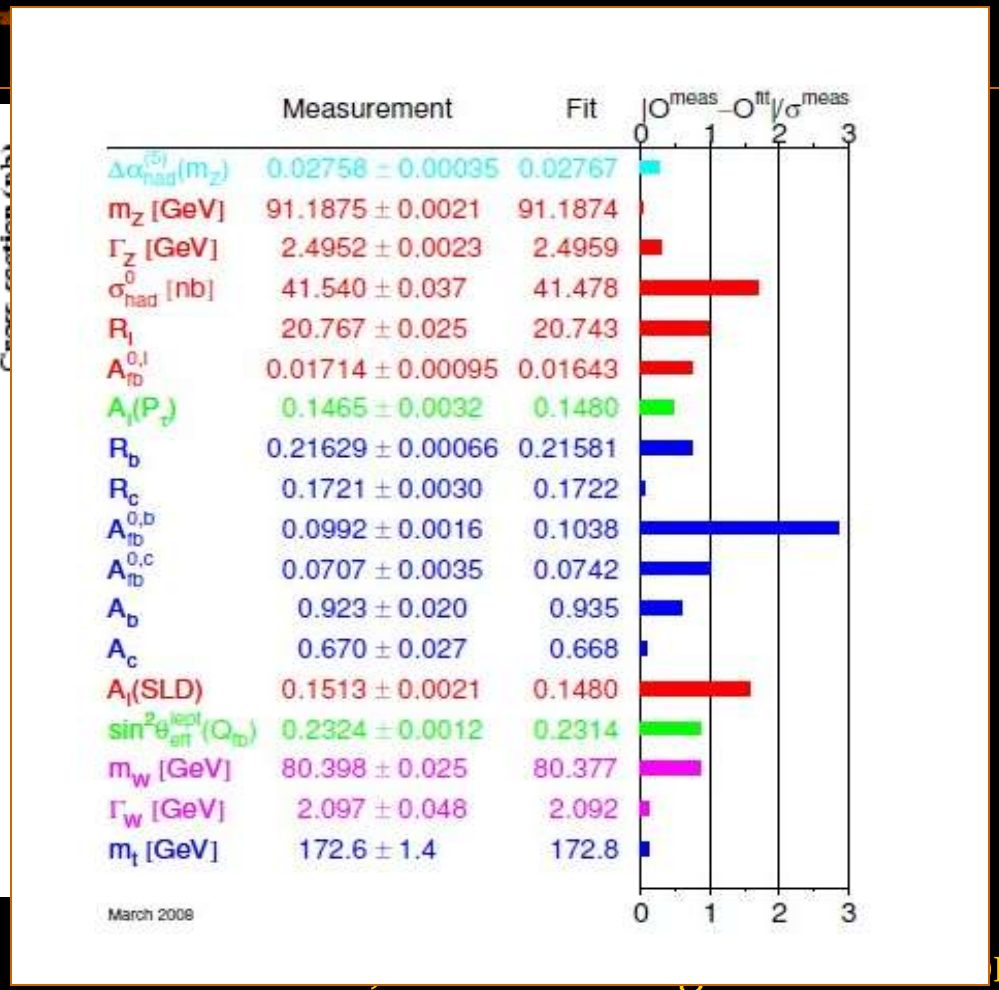

The SM ns

M. Verzocchi: ICHEP 2008

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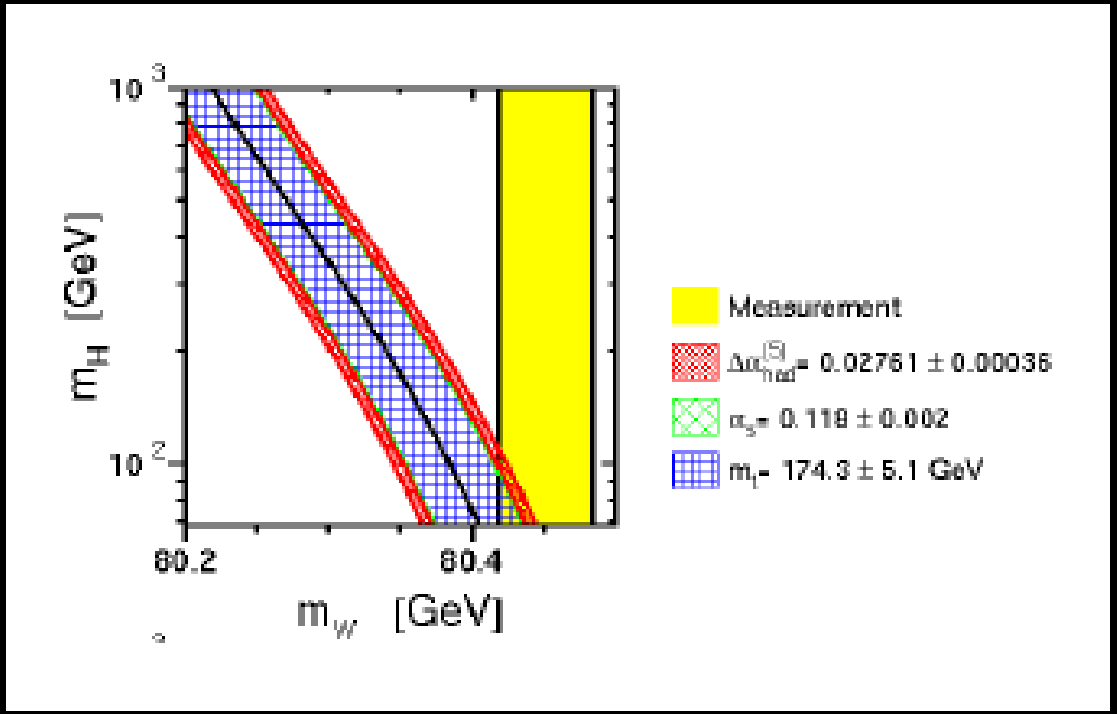

Unknown quantities, like the Higgs mass, are strongly constrained by the accuracy of these tests

A Tonazzo: Moriond 2002

The Standard Model

- The particles and interactions
- Successes
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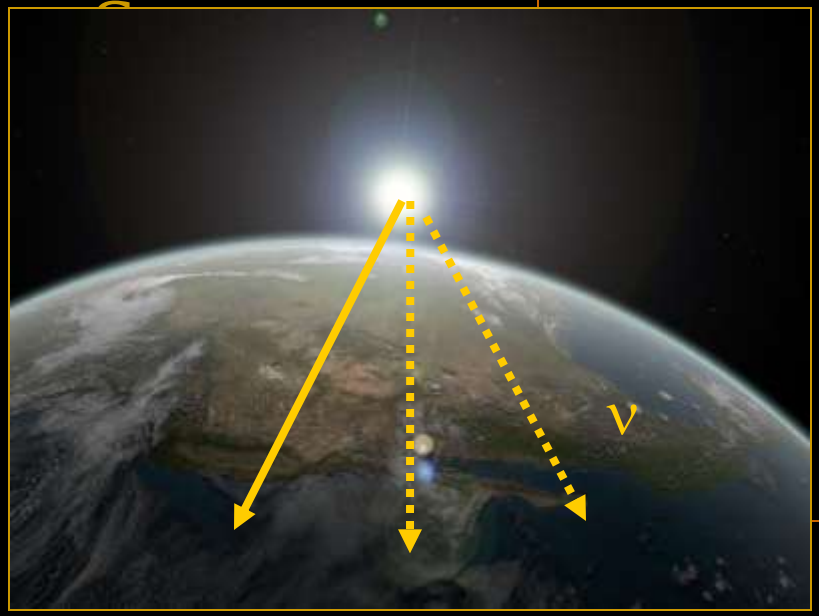
The Standard Model

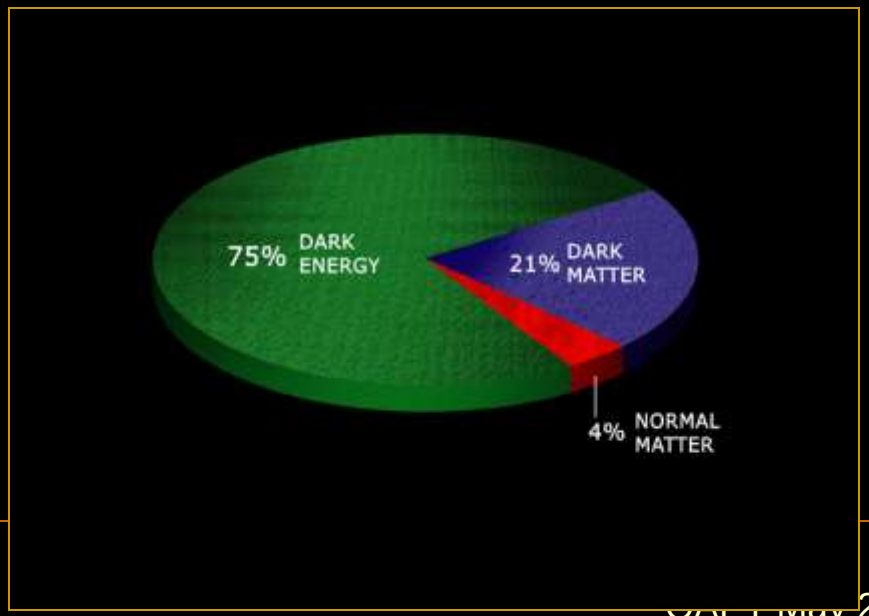
- The particles
interactions

So what's wrong with the Standard Model?

Observational Problems:

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





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So what's wrong with the Standard Model?

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Theoretical Problems:

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

The Standard Model

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Observational Problems:

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Dark Matter and Dark Energy unexplained..

Theoretical Problems:

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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

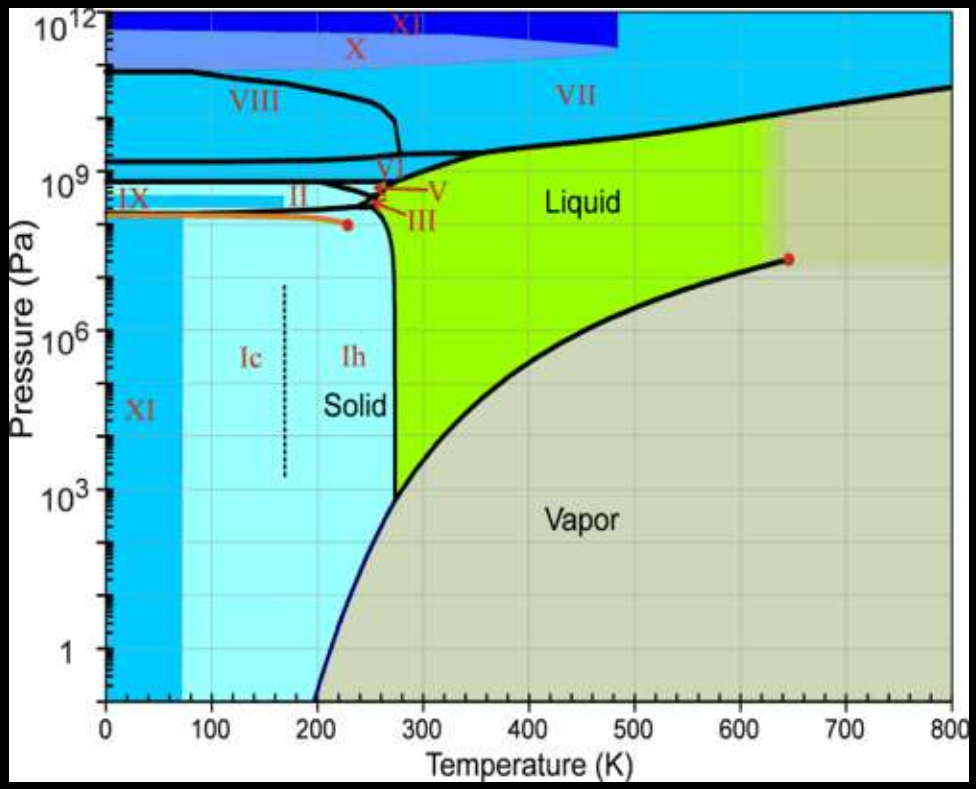
Problem: Why is the *scale* of Higgs symmetry breaking (and so also all known masses) so much smaller than the only other fundamental scales about which we know?

Protons:	the nuclear scale	$m_p \sim 1$ GeV
Higgs:	the weak scale	$M_W = G_F^{-1/2} \sim 10^2$ GeV
Gravity:	the Planck mass	$M_p = G_N^{-1/2} \sim 10^{19}$ GeV

The Standard Model

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

- The particles
- Successe
- Limitatio



mmetry
s) so much
l scales about

$m_p \sim 1$ GeV
$G_F^{-1/2} \sim 10^2$ GeV
$G_N^{-1/2} \sim 10^{19}$ GeV

The Standard Model

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- Successe
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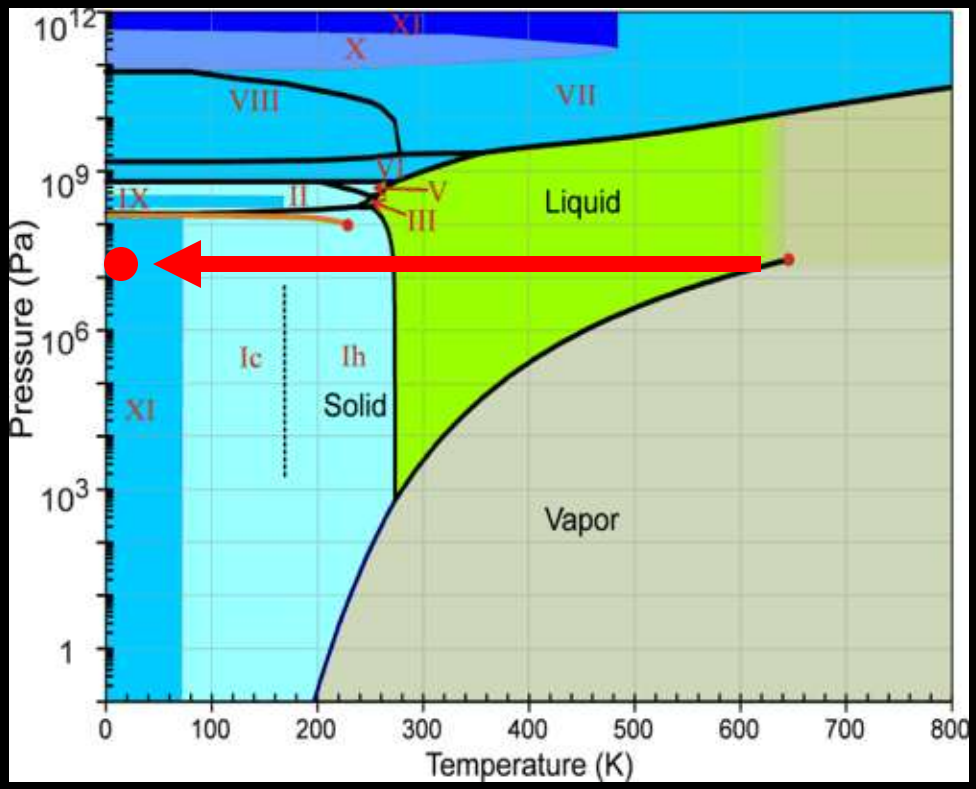

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- What might it hope to see?
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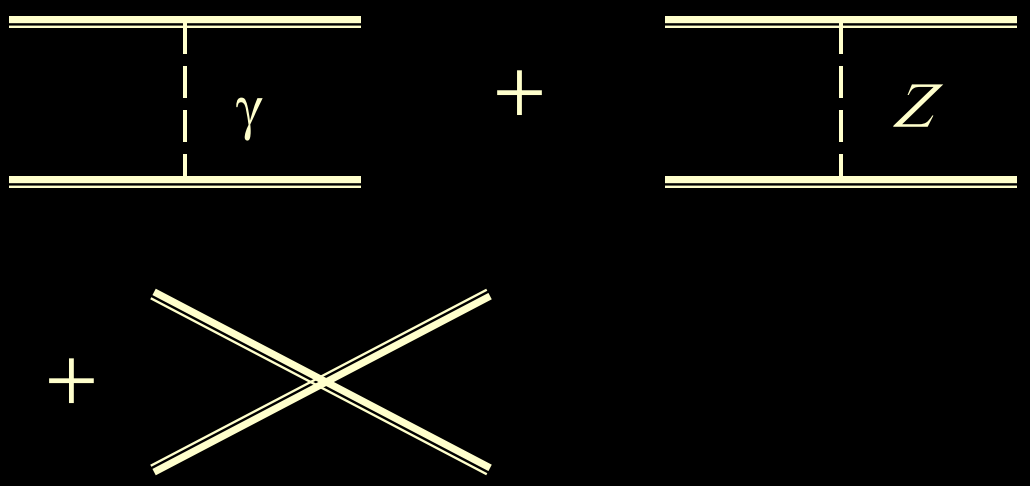
What might be seen

- Nothing?

What might be seen

- Nothing?

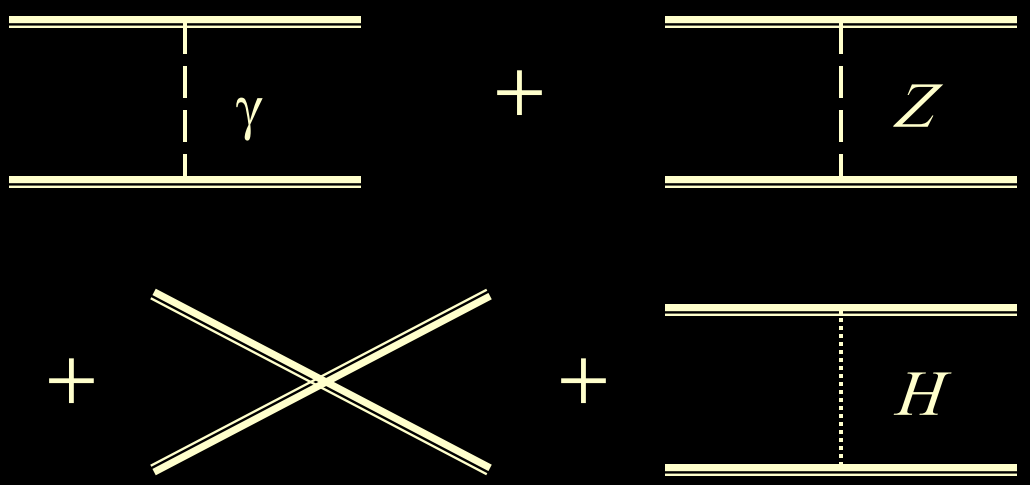


W-W scattering: $\sigma \sim (\alpha^2 \ln E)/M_W^2$

The SM without the Higgs boson must break down at energies of order M_W/α ~ few TeV because $\sigma < 1/E^2$

What might be seen

- Nothing?



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

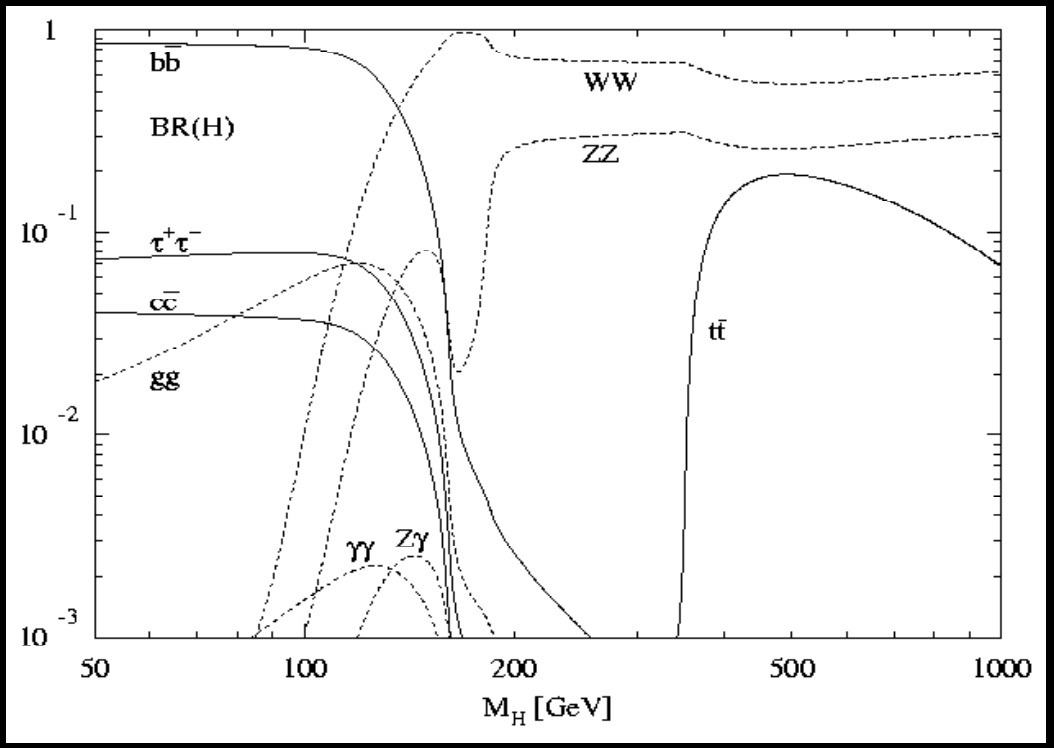
The SM with the Higgs boson *can make sense for energies much larger than* $M_W/\alpha \sim$ few TeV

What might be seen

- The Higgs Boson?

What might be seen

- The Higgs B(

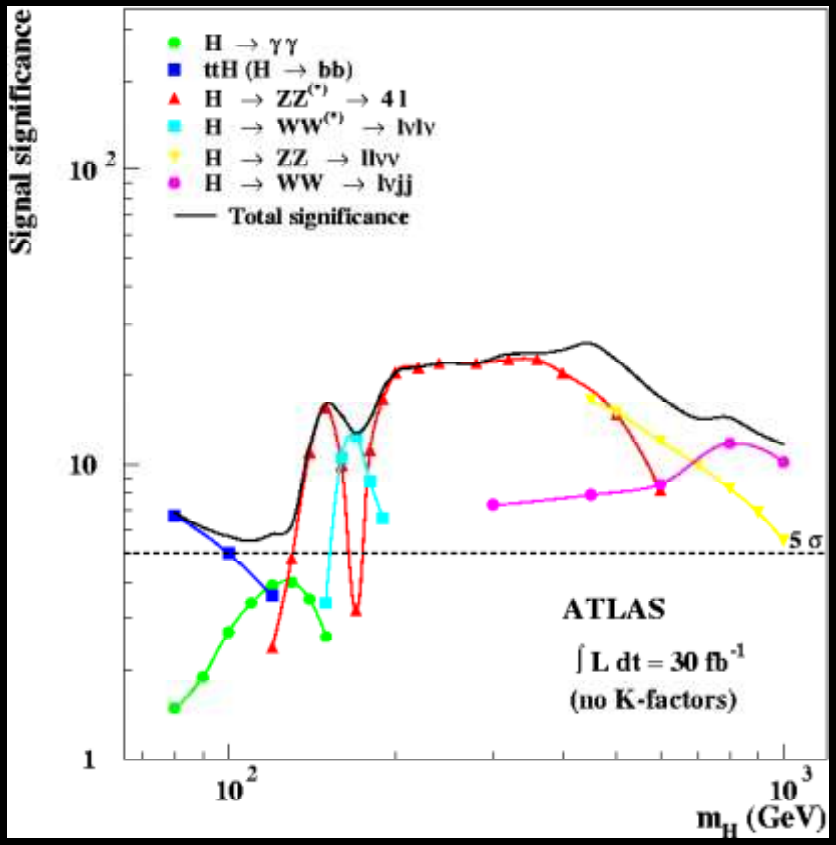


Search strategies depend on what it decays into, and this depends on its mass

M. Lefebvre (Astbury Symposium 2000)

What might be seen

- The Higgs B(



Expect it to be visible for the allowed mass range

M. Lefebvre (Astbury Symposium 2000)

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 S

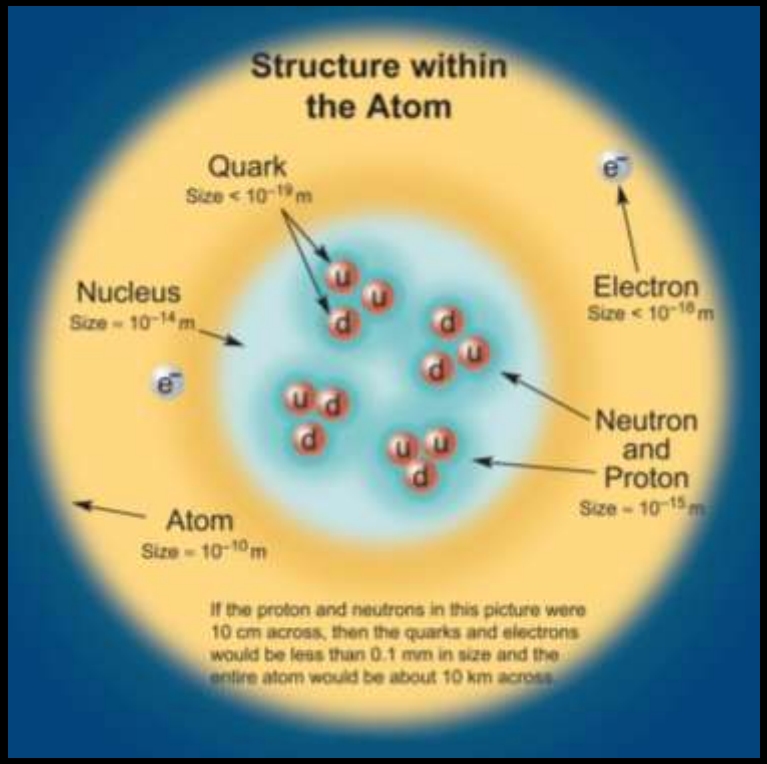
- *Beyond the SM*: basically three options:

  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

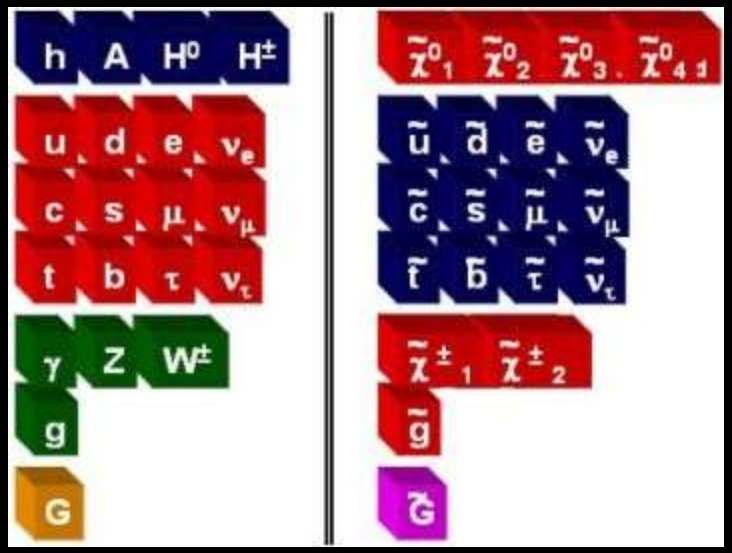
- *Beyond the SM*: basically three options:

  No elementary Higgs:
  - ***Composite models***

  New symmetry alleviating fine tuning:
  - ***Supersymmetry***

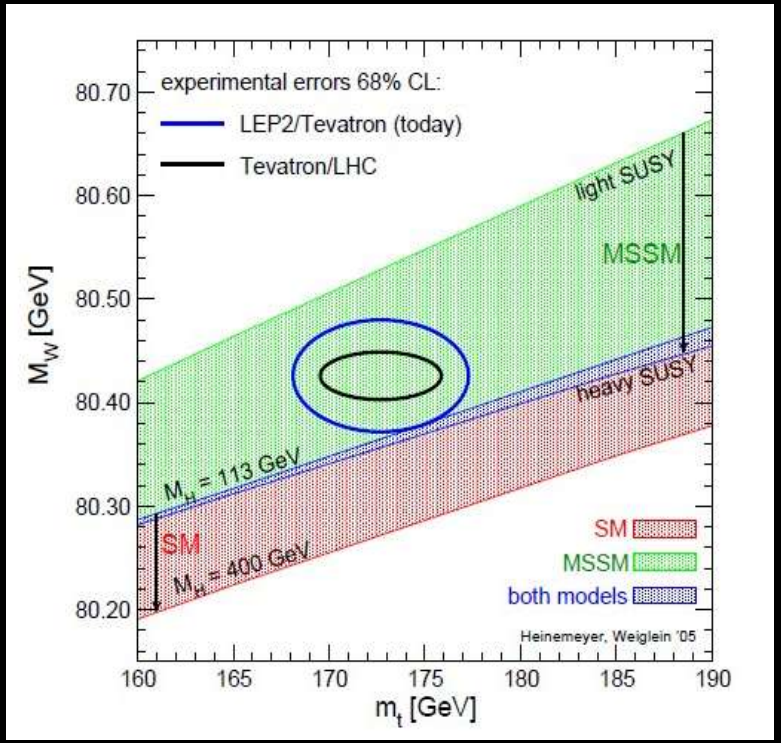
What might be seen

- 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

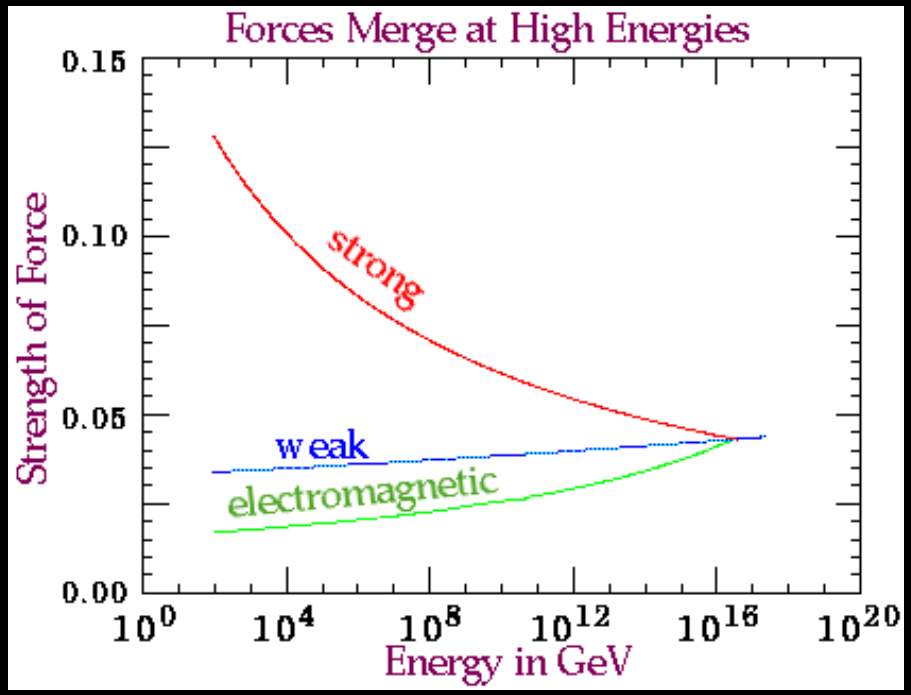


- Hint for supersymmetry: in the preference for light Higgs in precision measurements

A Tonazzo: Moriond 2002

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***

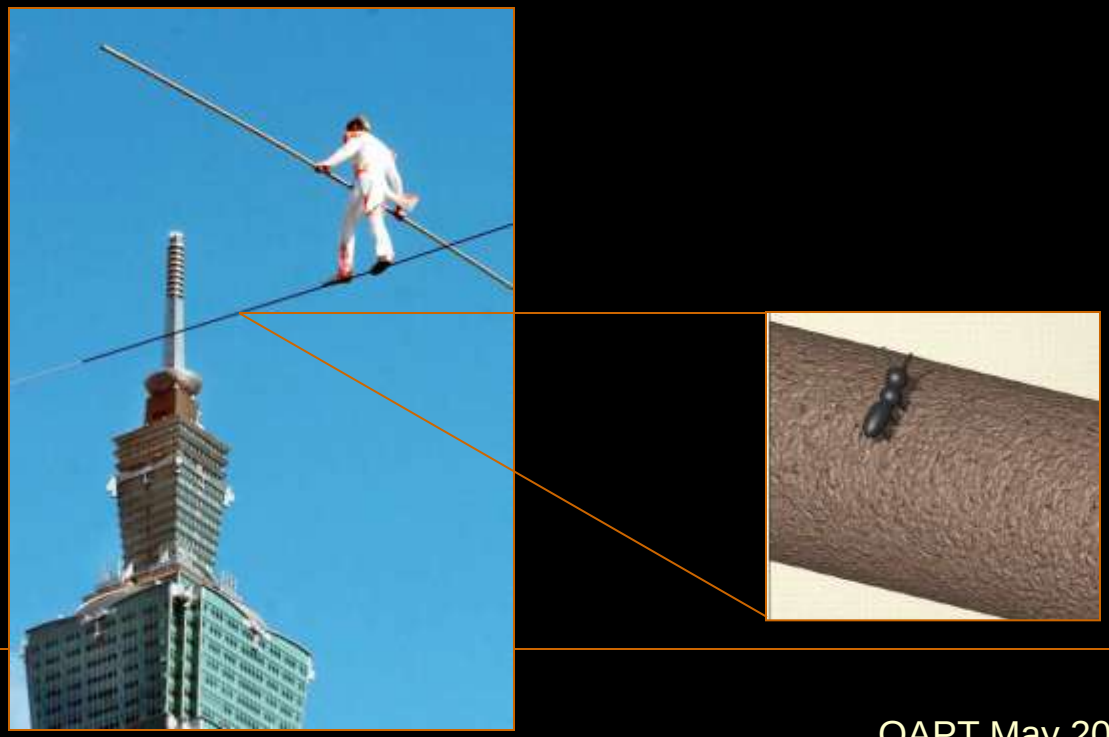
  New symmetry alleviating fine tuning:
  - ***Supersymmetry***

  Gravity scale is not really M_p
  - ***Extra dimensions***

What might be seen

- The Higgs B
- Beyond the S

- If there are extra dimensions and they are large, then the gravity scale could be much lower than we think….



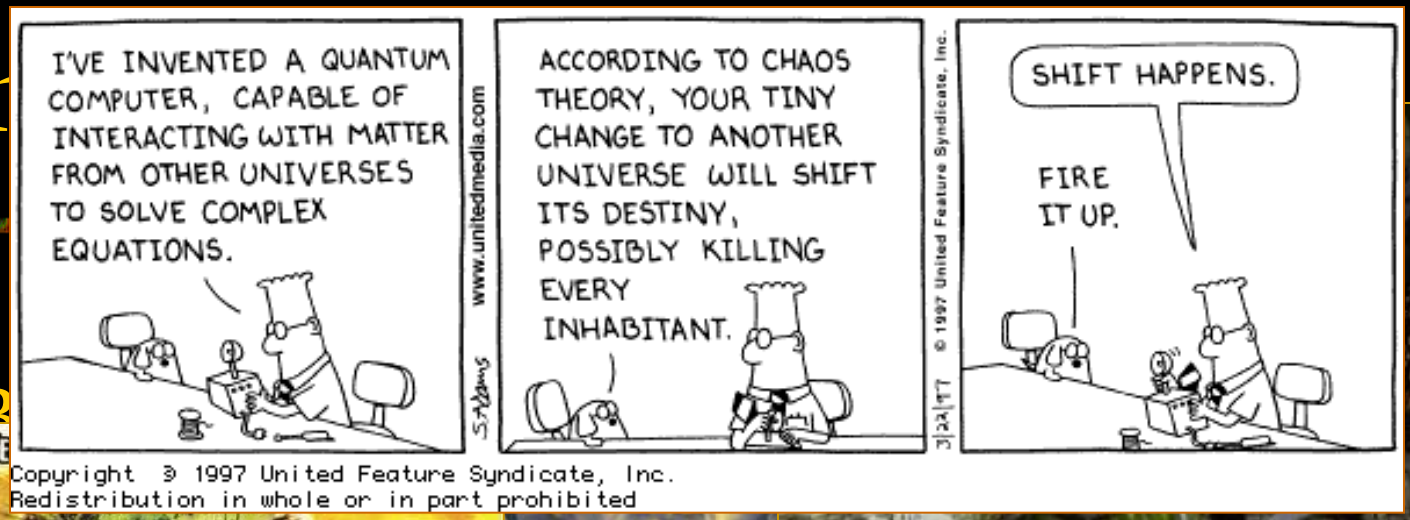
What might be seen

- Beyond the S

This is the scenario that potentially leads to black hole production…

Wh

- B


I'VE INVENTED A QUANTUM COMPUTER, CAPABLE OF INTERACTING WITH MATTER FROM OTHER UNIVERSES TO SOLVE COMPLEX EQUATIONS.
ACCORDING TO CHAOS THEORY, YOUR TINY CHANGE TO ANOTHER UNIVERSE WILL SHIFT ITS DESTINY, POSSIBLY KILLING EVERY INHABITANT.
SHIFT HAPPENS.
FIRE IT UP.
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THE FL
COLLECTIO
INCLUDES:
The Fly
Return of the Fly
UNIVERSAL

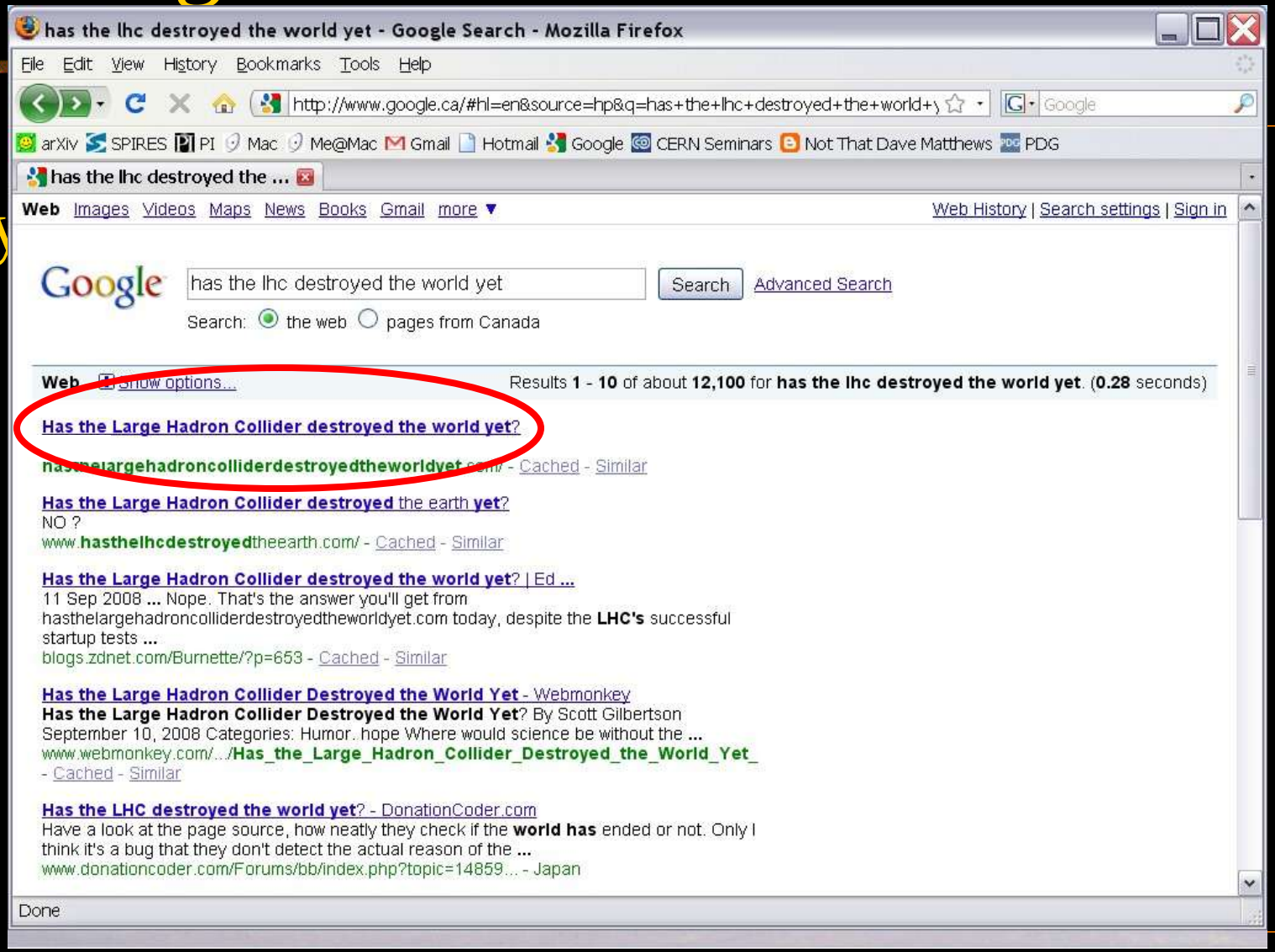
What might be seen

- Beyond the S

This is the scenario that potentially leads to black hole production…

What might be seen

- Bey



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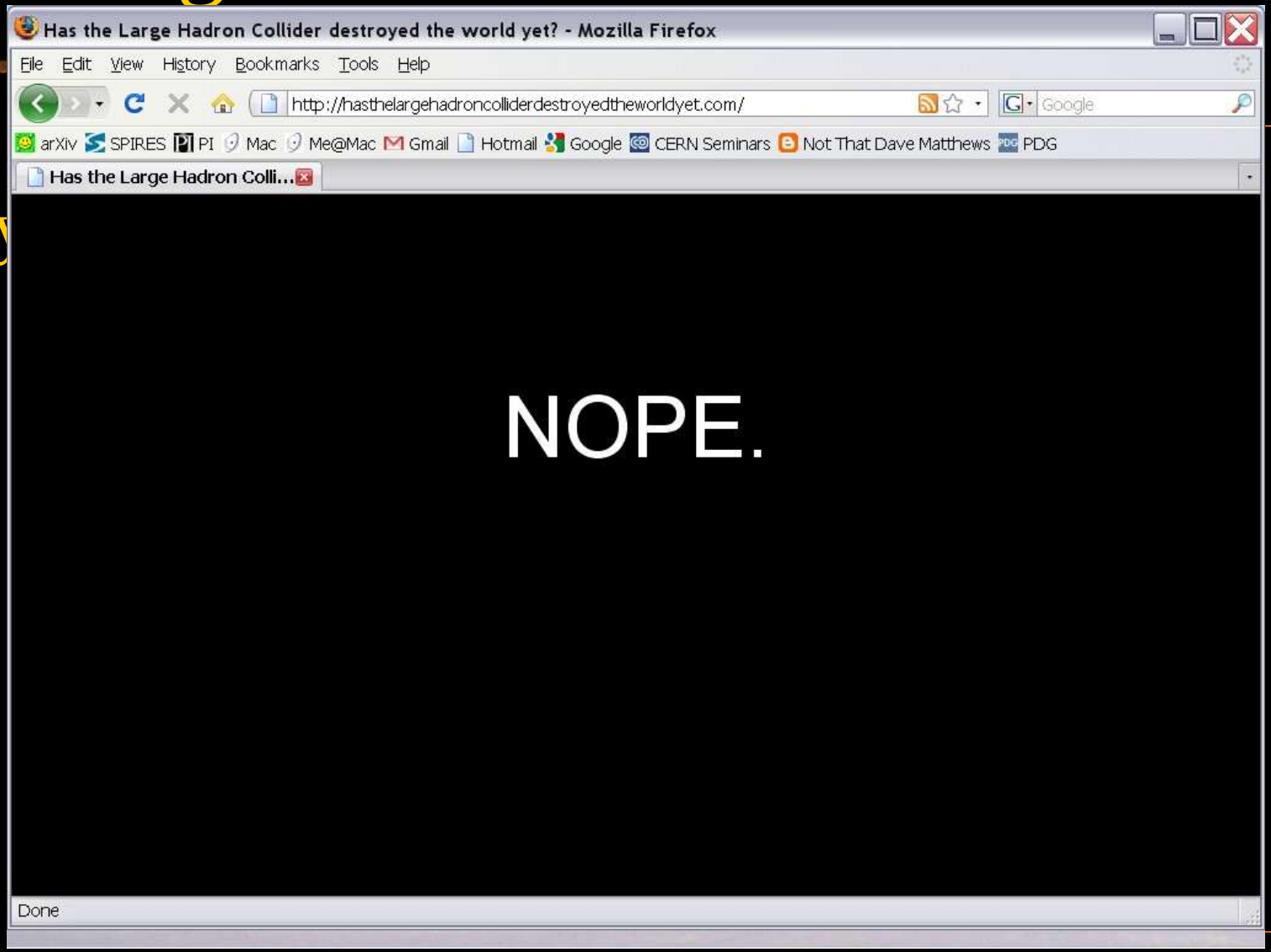

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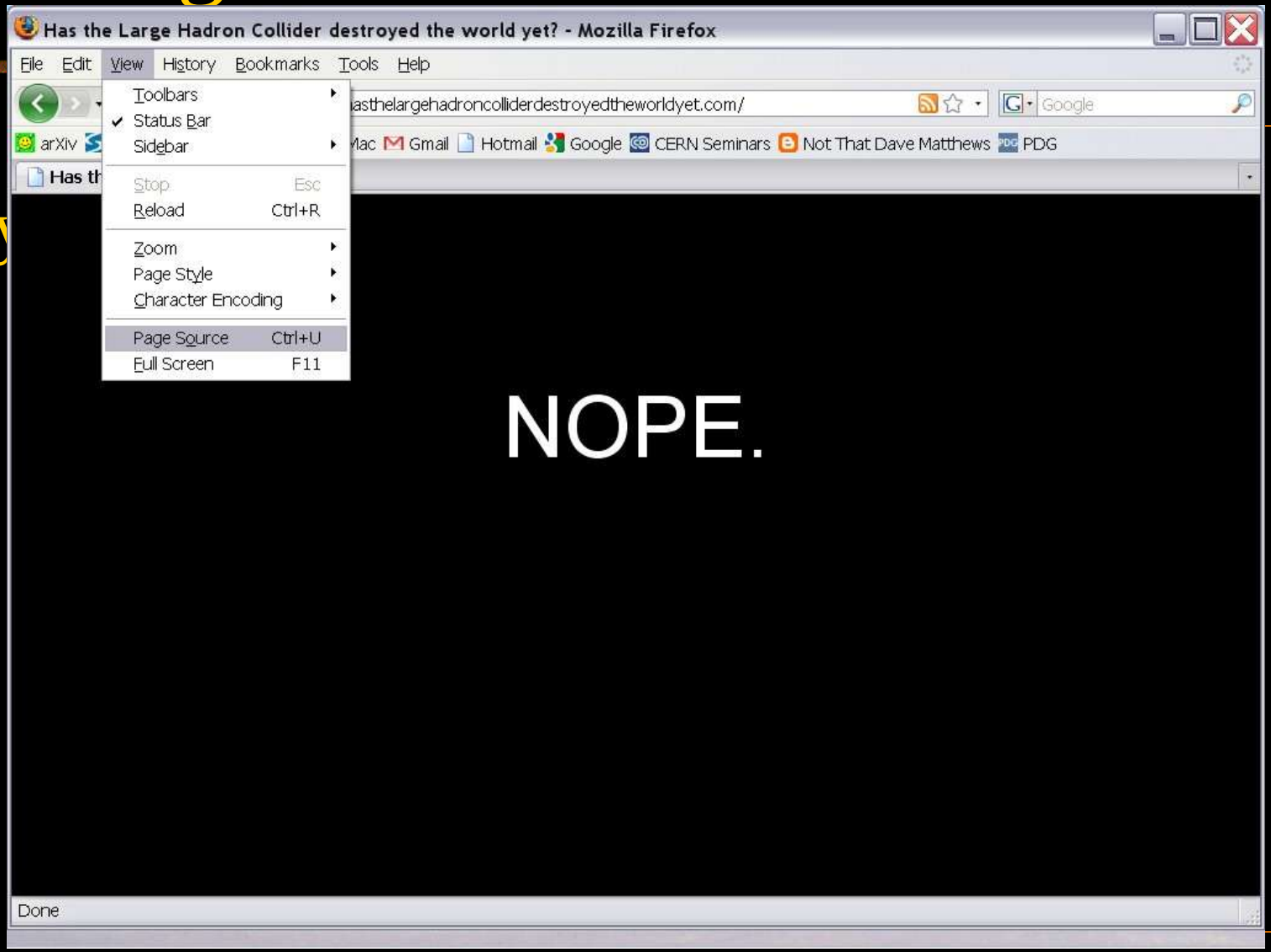

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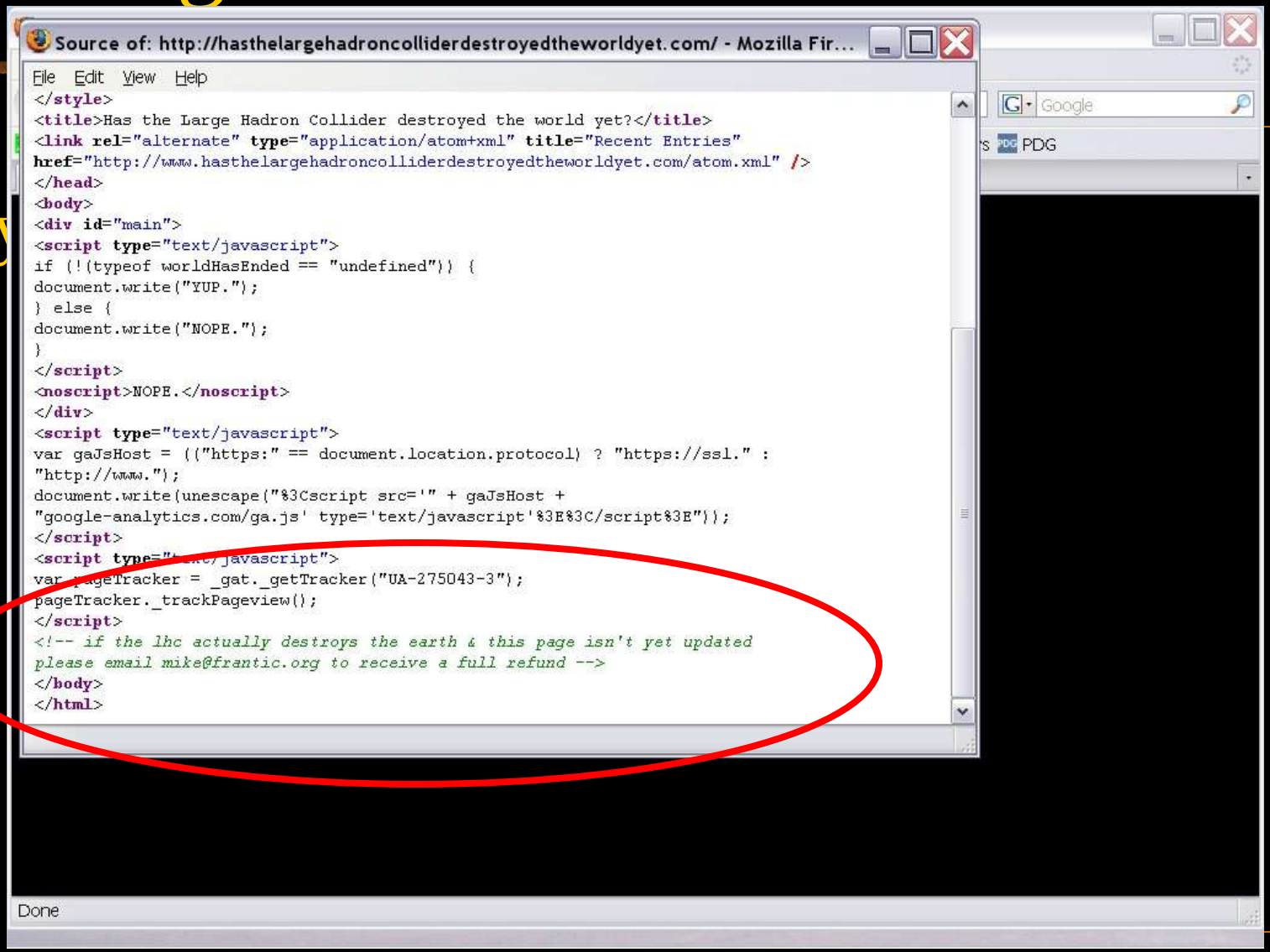

Outline

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

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HOLY SHIT!!

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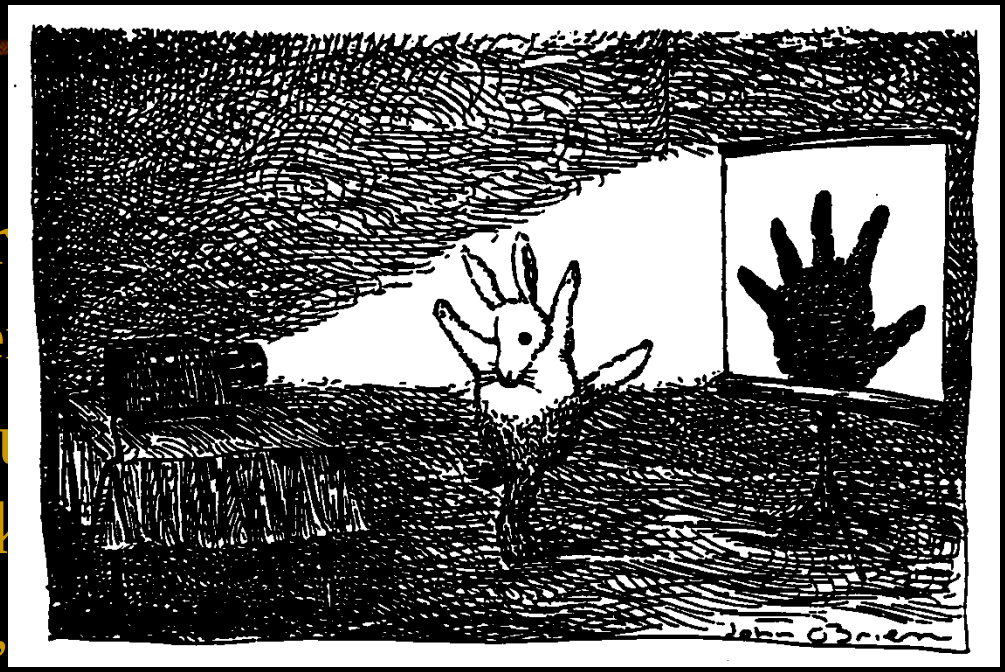

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