Title: LHC and Particle Physics

Date: Jul 29, 2010 01:00 AM

URL: http://pirsa.org/10070032

Abstract: Since the dawn of civilization, humans have attempted to dissect the world and uncover its fundamental constituents. Today, this quest continues in the field of particle physics, the study of the fundamental subatomic particle that make up everything in the universe.
The Large Hadron Collider (LHC) is a massive underground particle accelerator that physicists hope will reveal new secrets about the physical world. Located just outside Geneva, Switzerland at CERN, it has a circumference of 27 km and is the product of a collaboration that involves thousands of scientists worldwide.

This presentation will talk about the LHC and some of the exciting new ideas it may confirm.

The Large Hadron Collider

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

LARGE HADRON COLLIDER

C.P. Burgess

The Large Hadron Collider

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

C.P. Burgess

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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The Machine

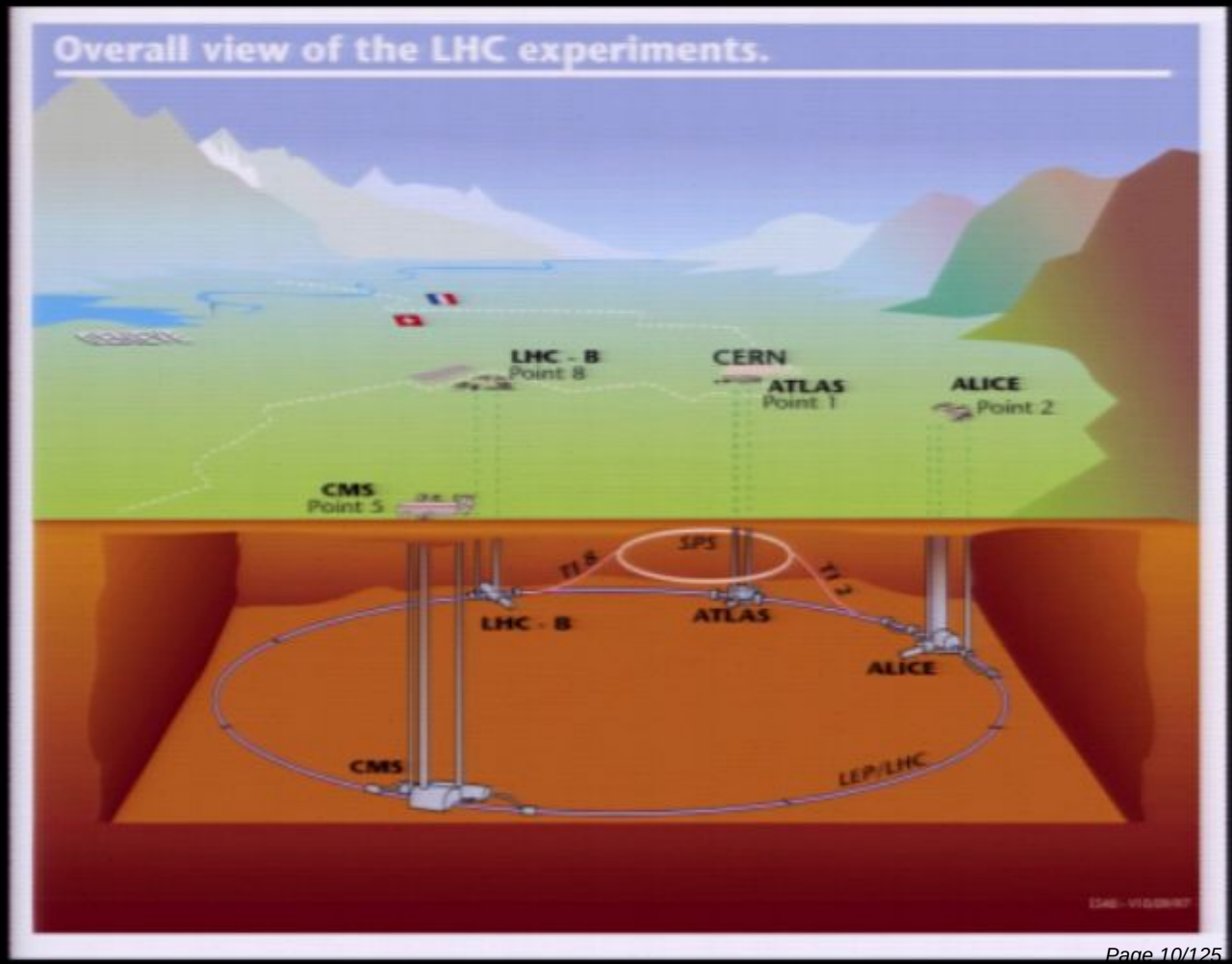
- The Accelerator
- The Detectors

The Machine

- The Accelera
- The Detector

The Machine

- The Accelera
- The Detector



The Machine

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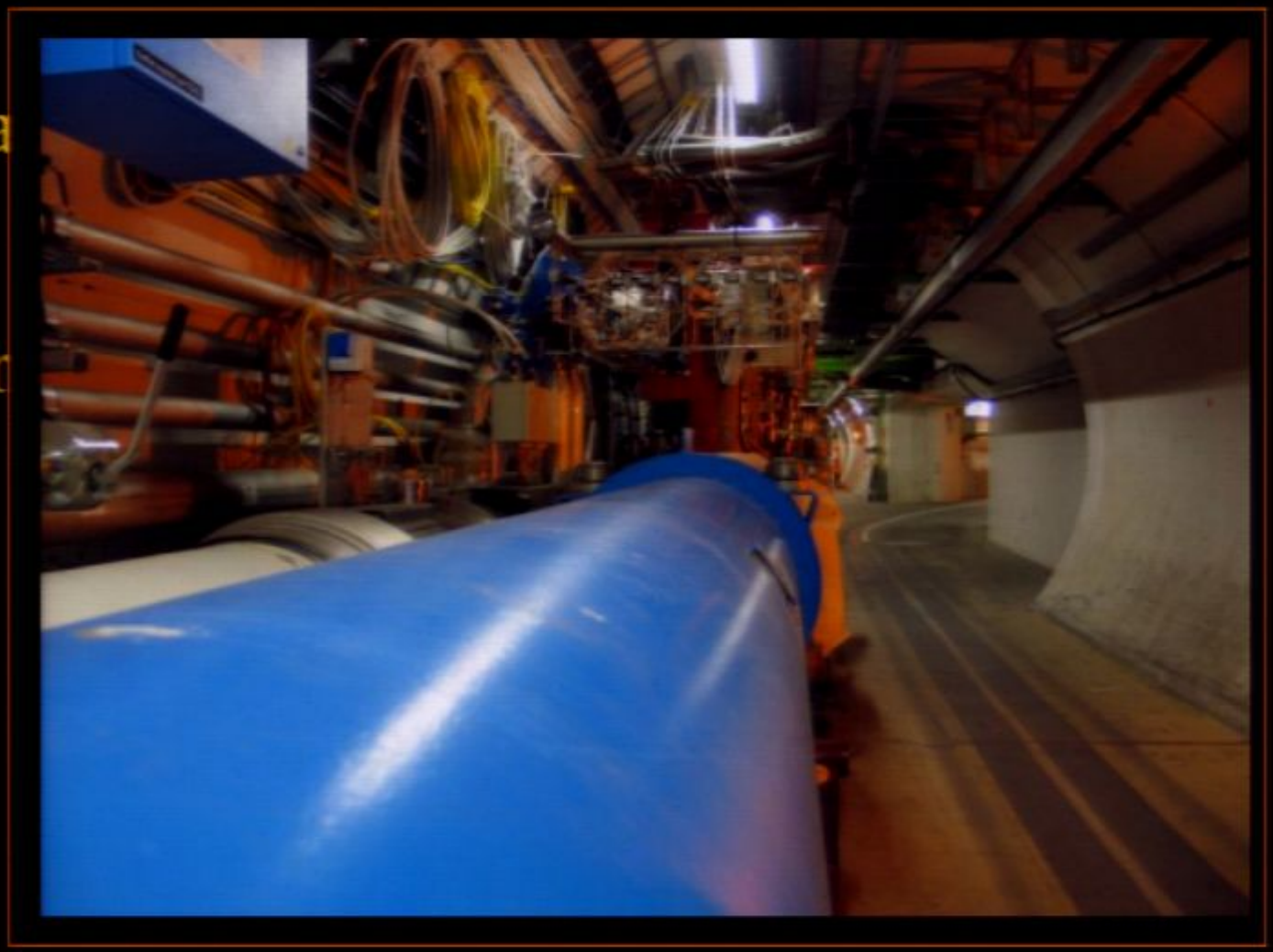

The Movie

- The Plot
- *Scenes at CERN*
- Scenes in Rome

The Movie

- The Plot
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The Movie

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- Scenes in Rome

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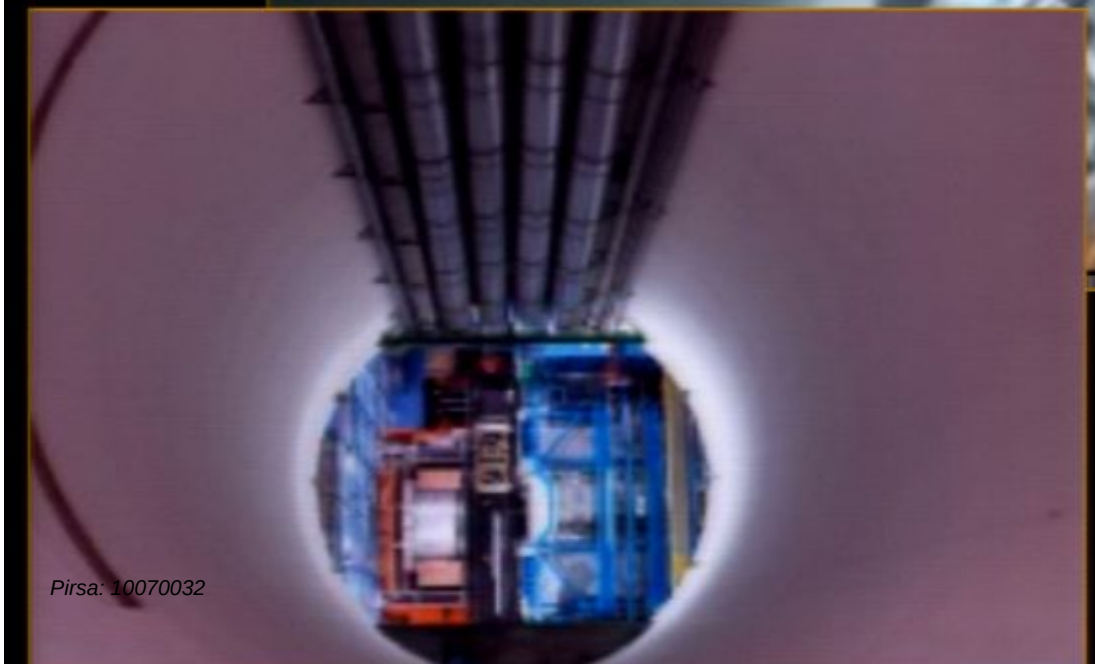
- The



The Movie

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The Movie

- Scenes in Rome

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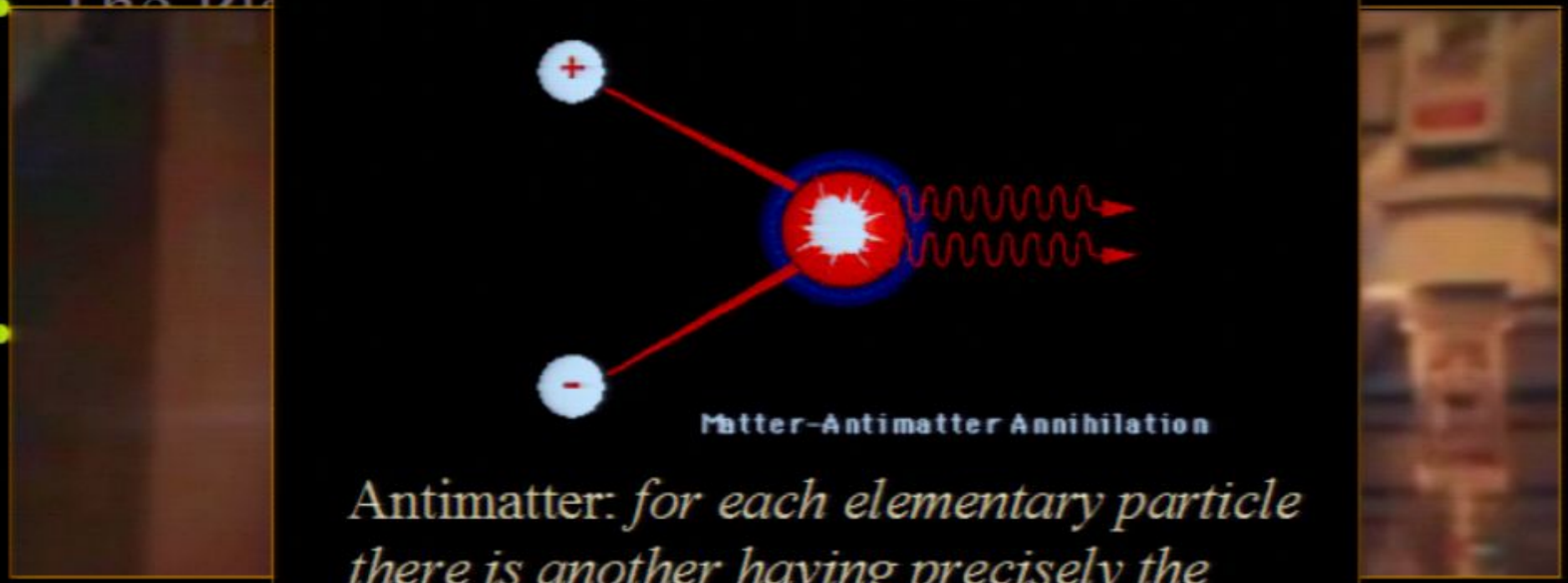
- Scenes in Rome

The Movie

The Movie

- The Pl
- Scenes Movie



Matter-Antimatter Annihilation

Antimatter: *for each elementary particle there is another having precisely the same mass and opposite charge.*

The Movie

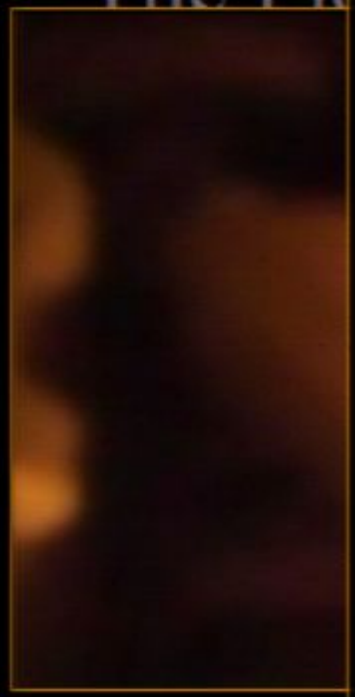
- The Plot

The Movie

- Scenes in Rome

The Movie

- The Pl

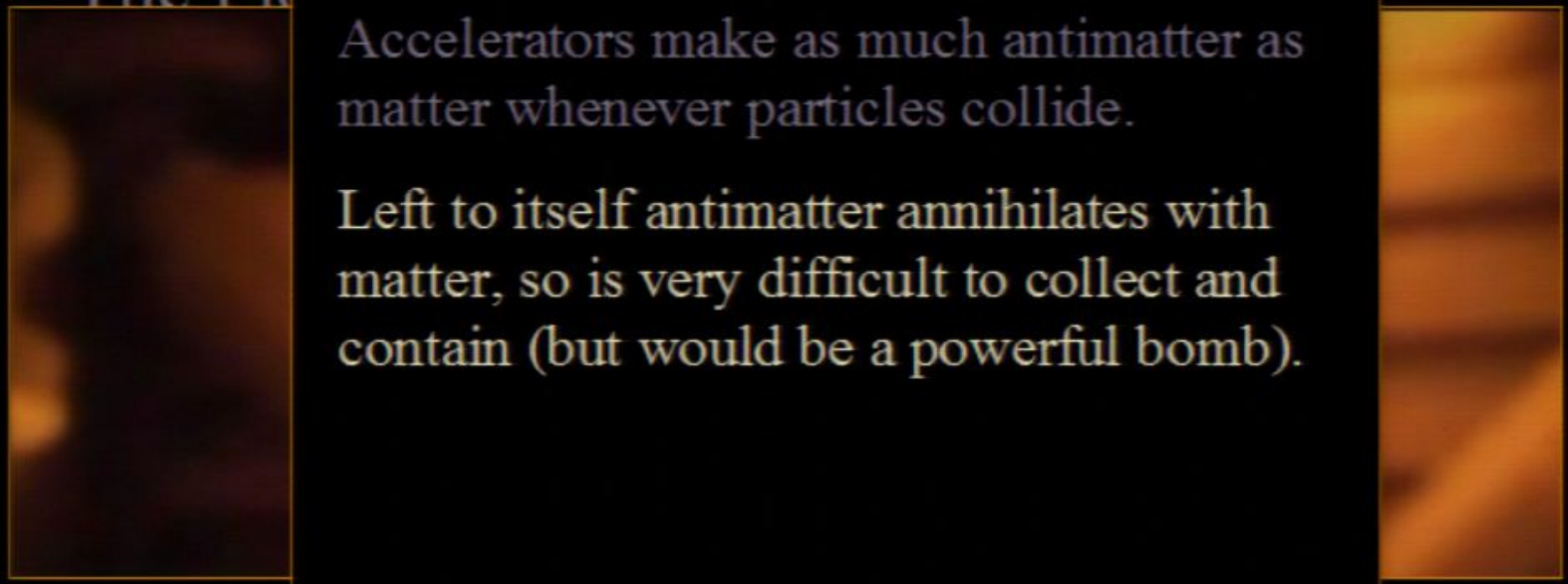


Accelerators make as much antimatter as matter whenever particles collide.

- Scenes *Movie*

The Movie

- The Pl



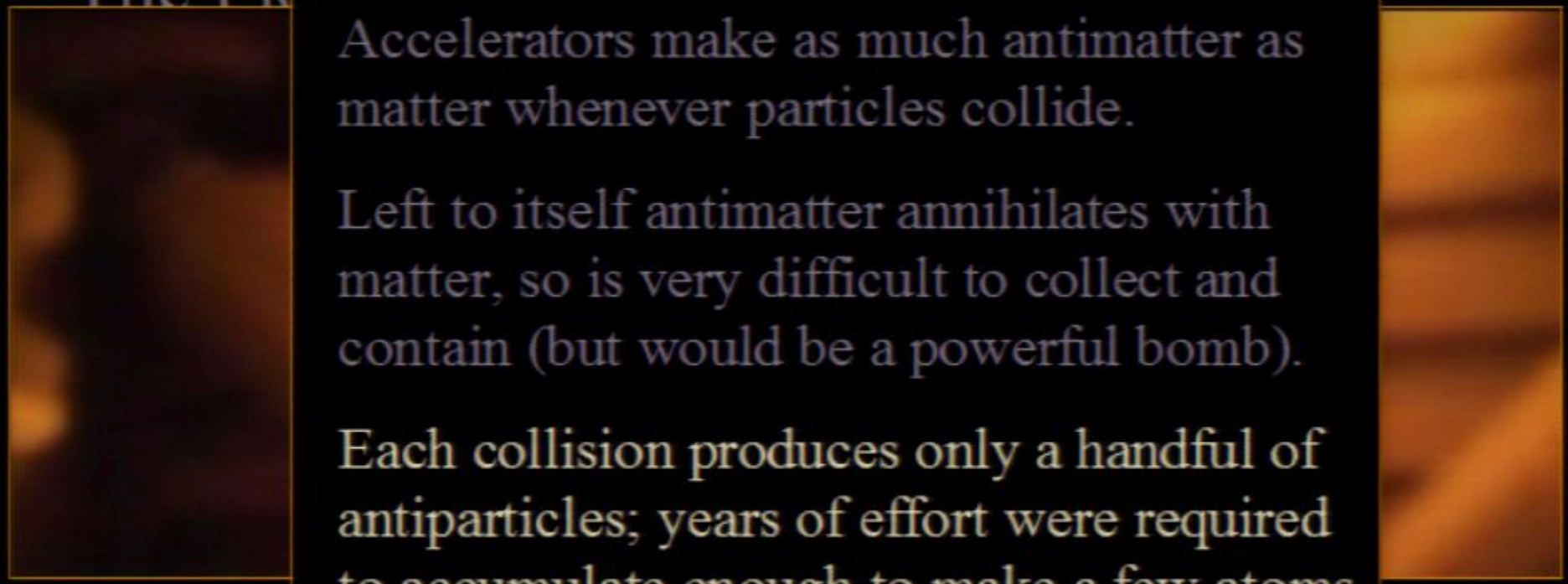
Accelerators make as much antimatter as matter whenever particles collide.

Left to itself antimatter annihilates with matter, so is very difficult to collect and contain (but would be a powerful bomb).

- Scenes *Movie*

The Movie

- The Pl



Accelerators make as much antimatter as matter whenever particles collide.

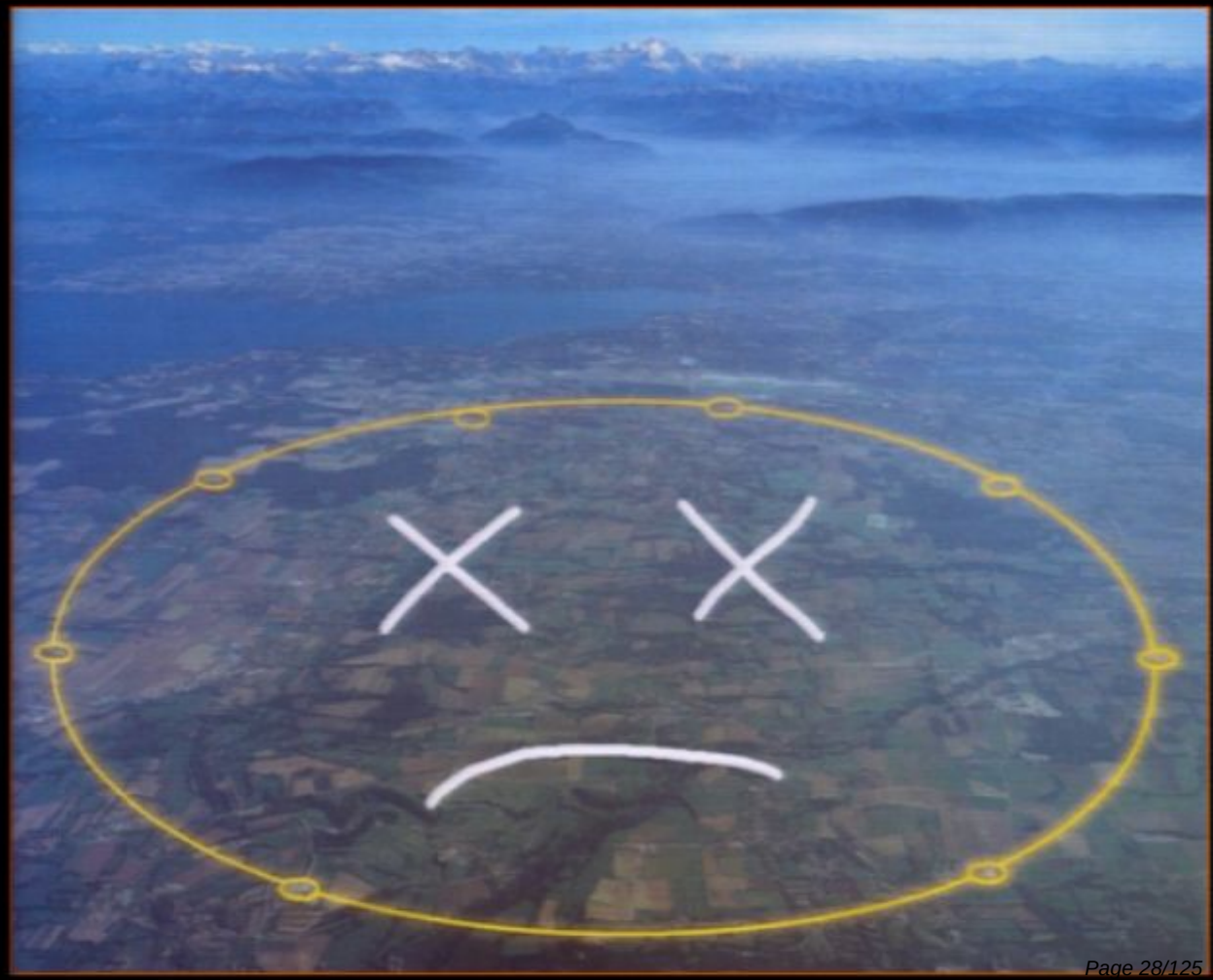
Left to itself antimatter annihilates with matter, so is very difficult to collect and contain (but would be a powerful bomb).

Each collision produces only a handful of antiparticles; years of effort were required to accumulate enough to make a few atoms of anti-hydrogen (destroyed after use).

- Scenes *Movie*

The Machine

- The Accelera
- The Detector



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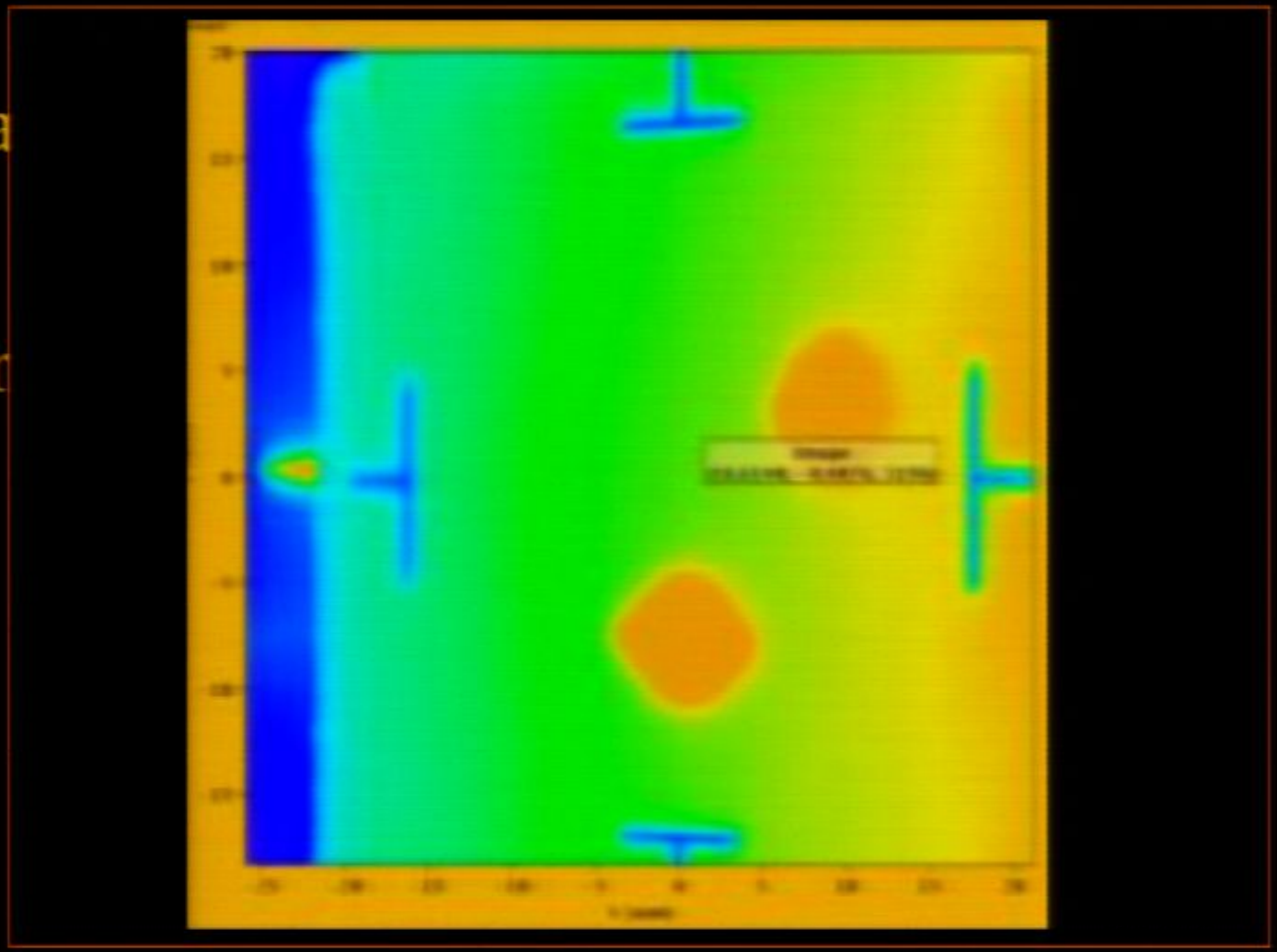

The Machine

W. Trischuk

- The Accelera
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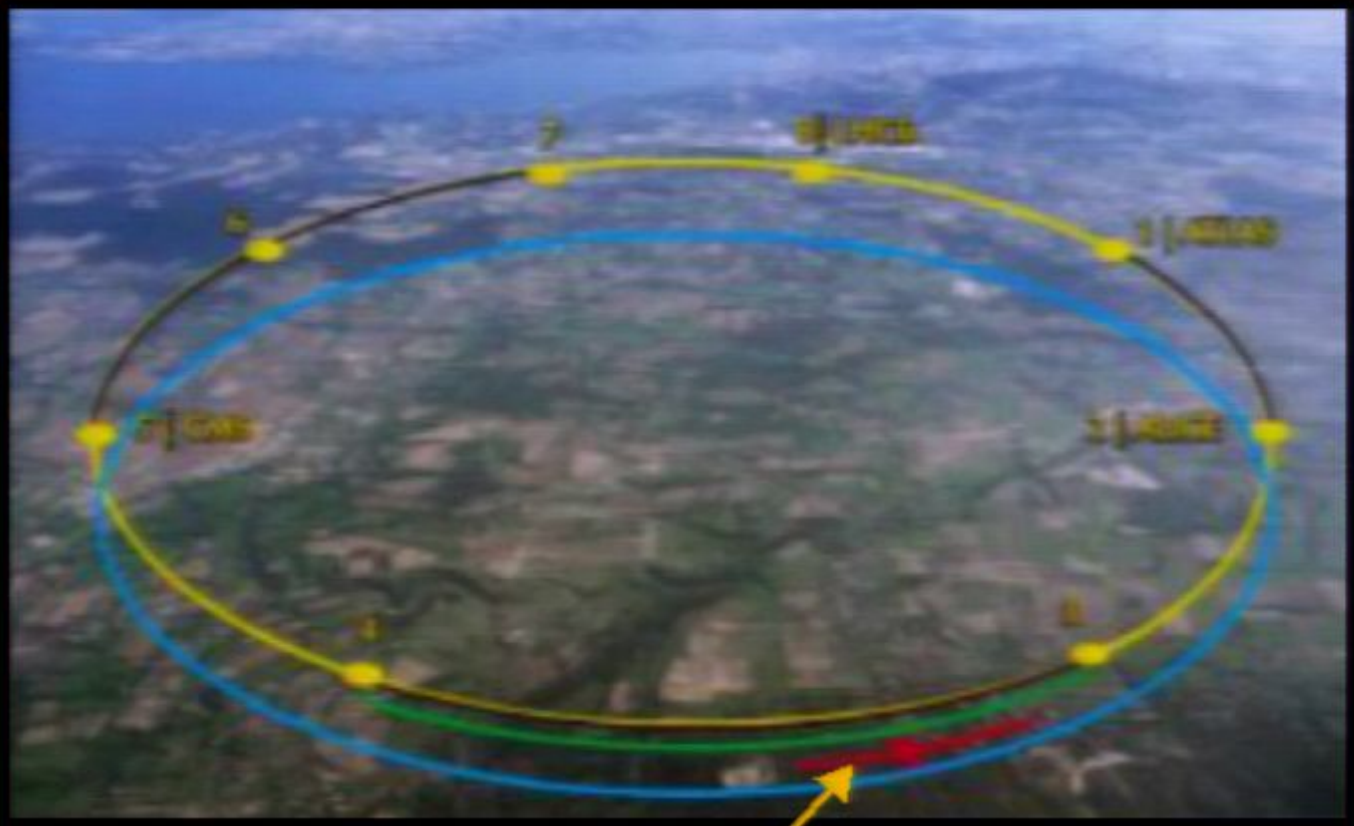

The Machine

W. Trischuk

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1200 superconducting magnets

The Machine

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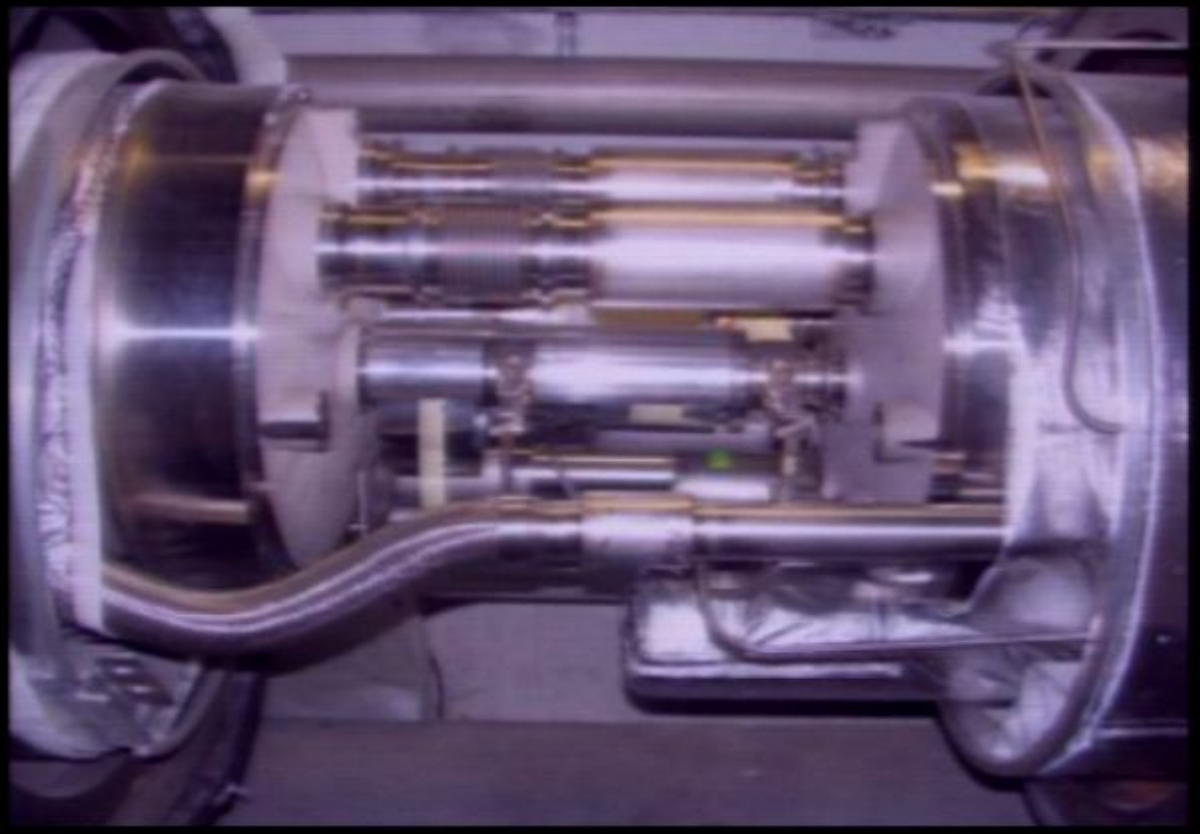

dipole interconnect

The Machine

W. Trischuk

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dipole interconnect

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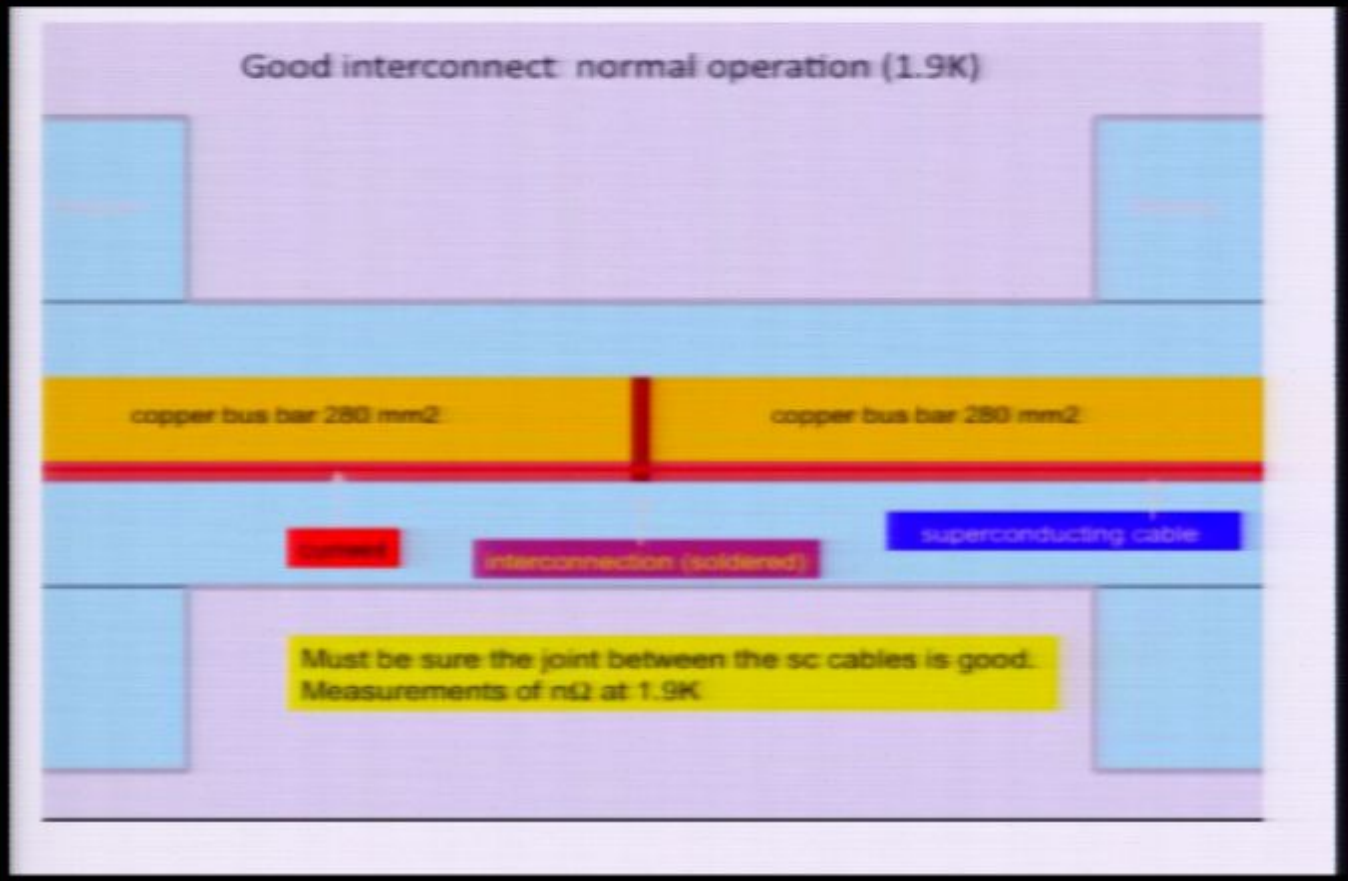

schematic connection

The Machine

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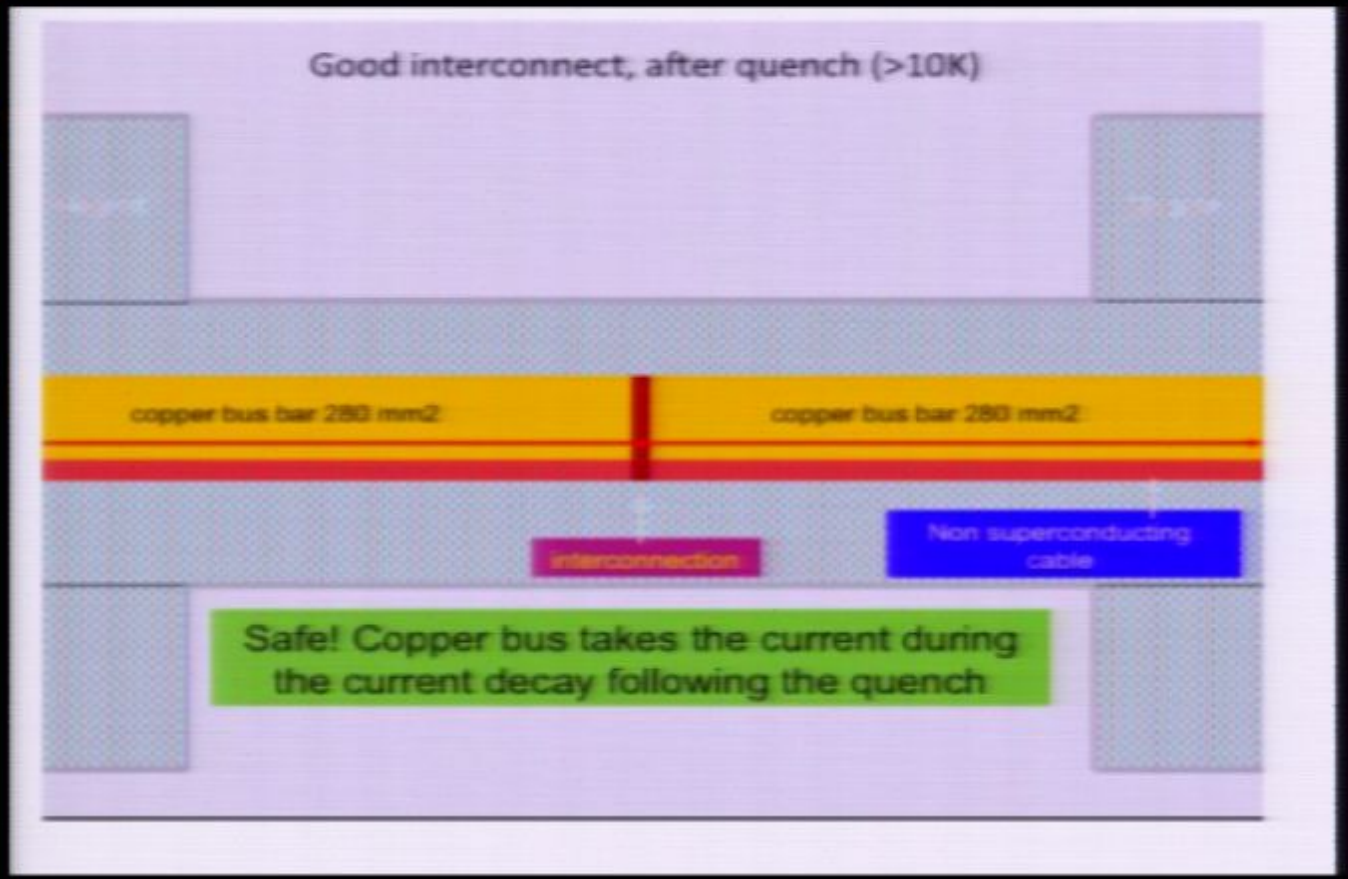

schematic connection

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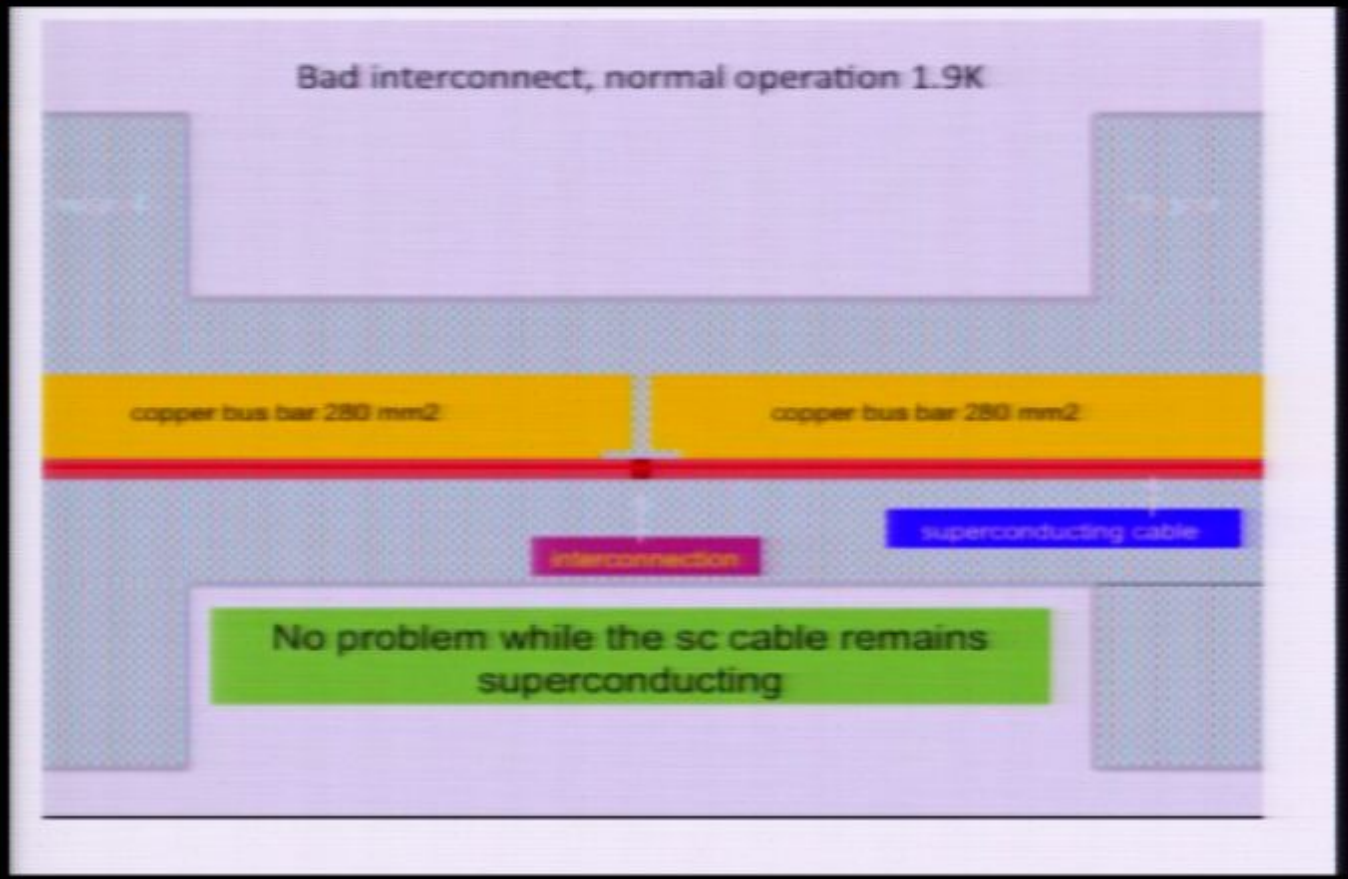

schematic connection

The Machine

W. Trischuk

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mechanical damage

The Machine

W. Trischuk

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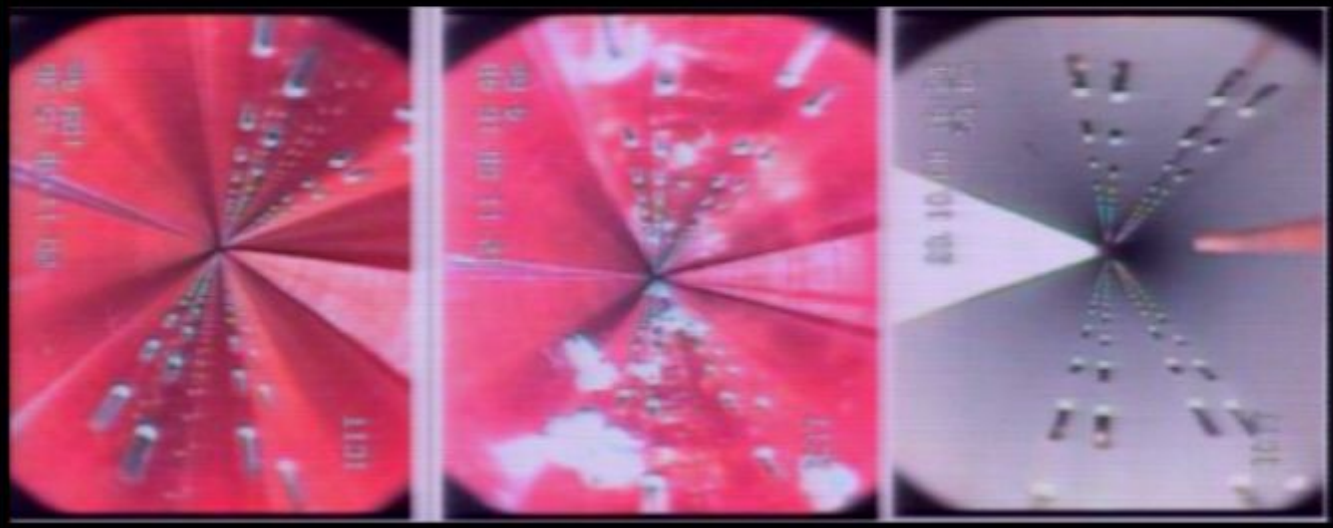
- The Detector



soot in the beam pipe

(normal copper looks red)

The Machine

W. Trischuk

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Replaced 14 quadrupoles and 29 dipoles,
34 interconnections fully repaired

The Machine

W. Trischuk

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What if there are also problems with the other magnets that did not 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

Some sectors remain cold

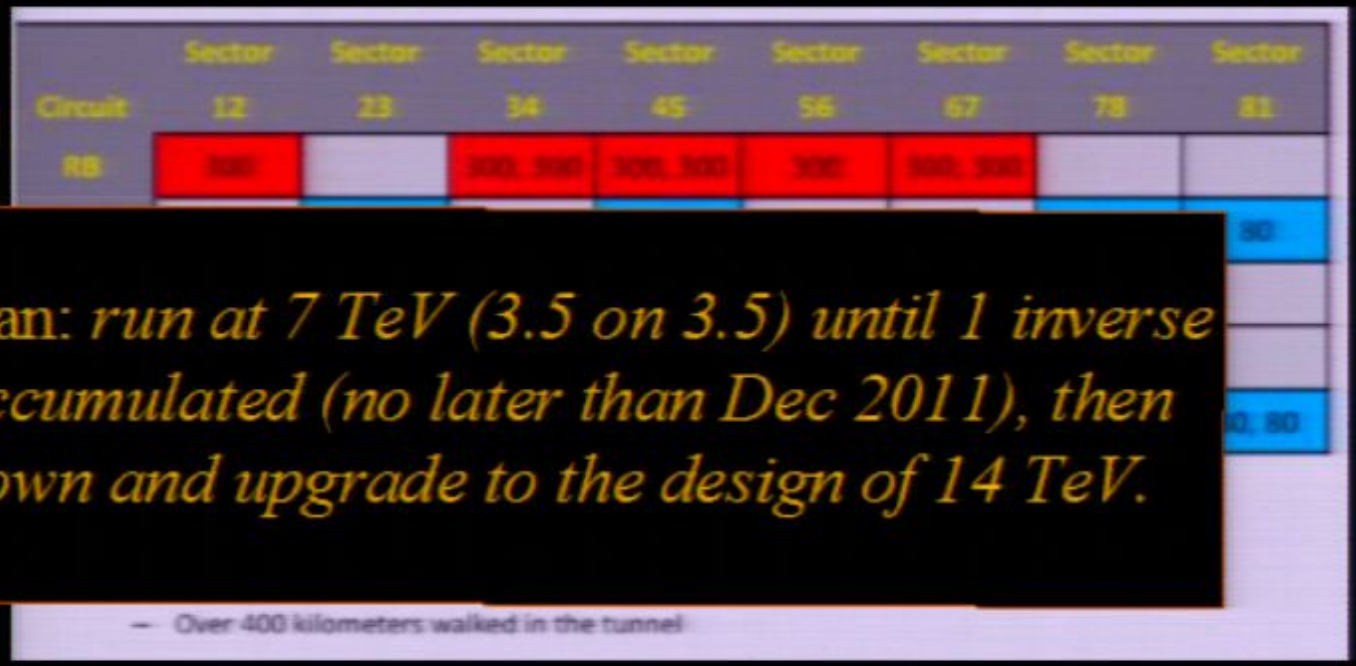
Takes months to heat and recool and there is not enough storage for the He

The Machine

W. Trischuk

- The Accelera
- The D

The Plan: *run at 7 TeV (3.5 on 3.5) until 1 inverse fb is accumulated (no later than Dec 2011), then shut down and upgrade to the design of 14 TeV.*



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20.11.2009: LHC about to restart

The LHC tunnel. Illustration shows the beampipes inside a dipole magnet. [M.Brice, CERN]

On 18 November, the LHC was handed over for operation. Teams are now preparing for injecting and circulating the first beams of 2009.

For latest updates, follow us on Twitter: twitter.com/cern

The LHC is now back!

The Machine

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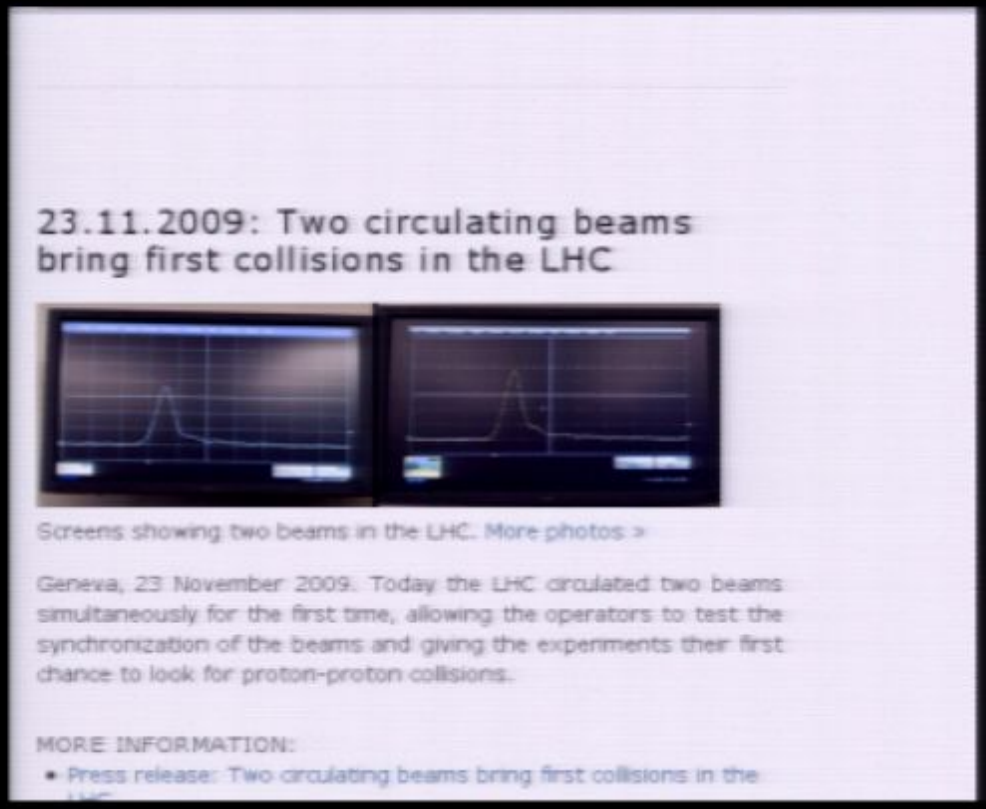

23.11.2009: Two circulating beams bring first collisions in the LHC

Screens showing two beams in the LHC. More photos »

Geneva, 23 November 2009. Today the LHC circulated two beams simultaneously for the first time, allowing the operators to test the synchronization of the beams and giving the experiments their first chance to look for proton-proton collisions.

MORE INFORMATION:

- Press release: Two circulating beams bring first collisions in the

The LHC is now back!

The Machine

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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

The LHC is now back!

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The most important machine at CERN

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The most important machine at CERN

next

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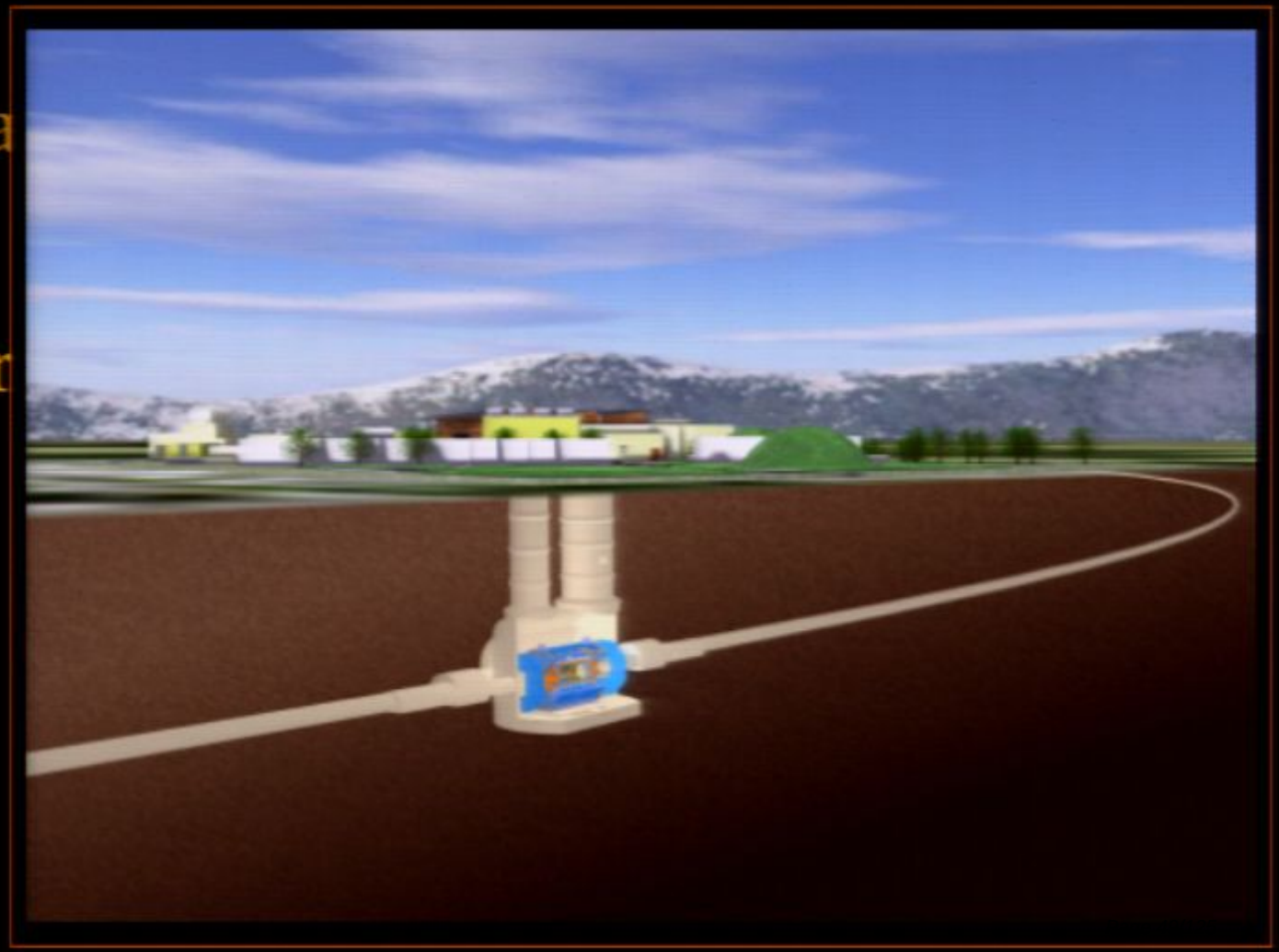

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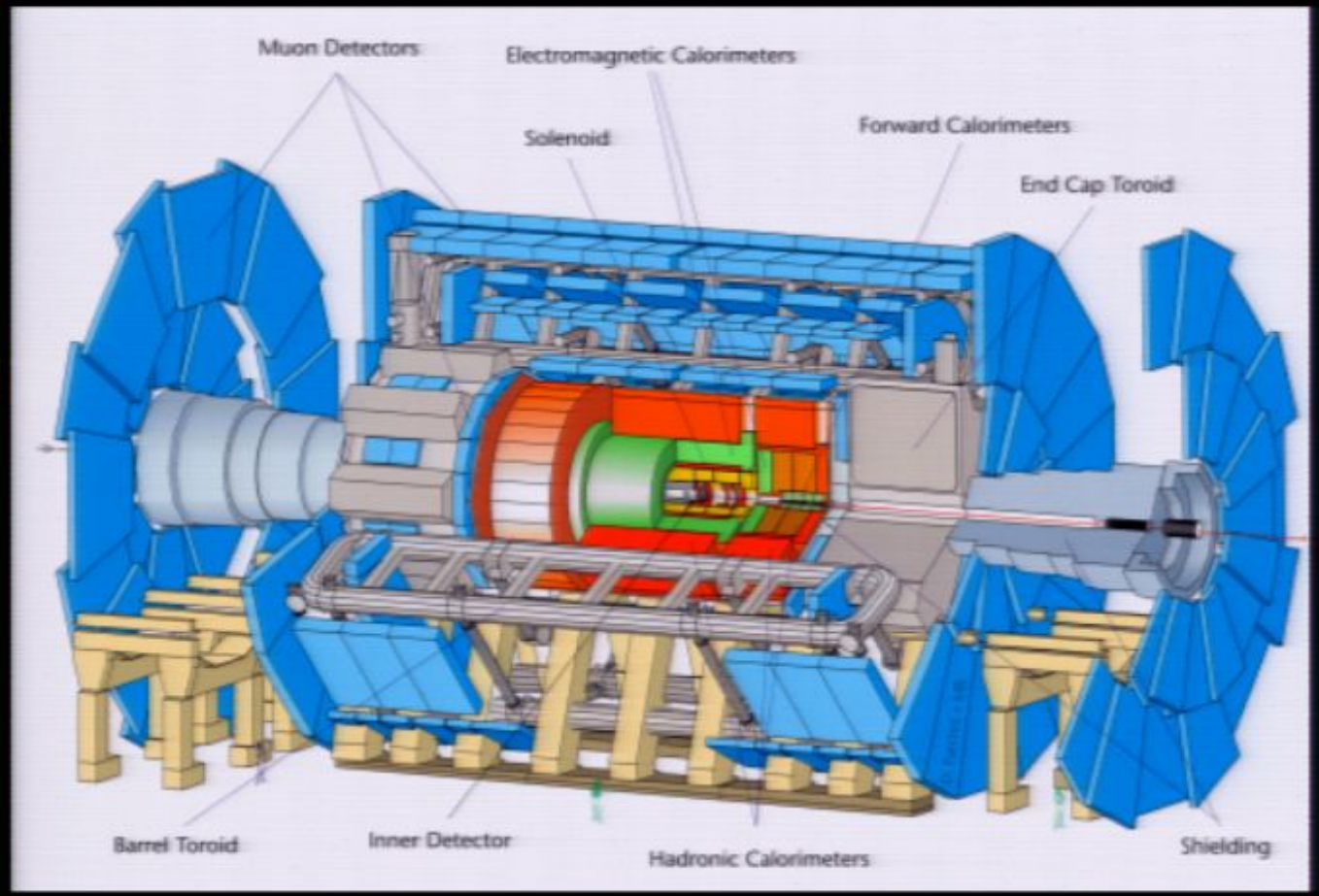

The ATLAS Detector

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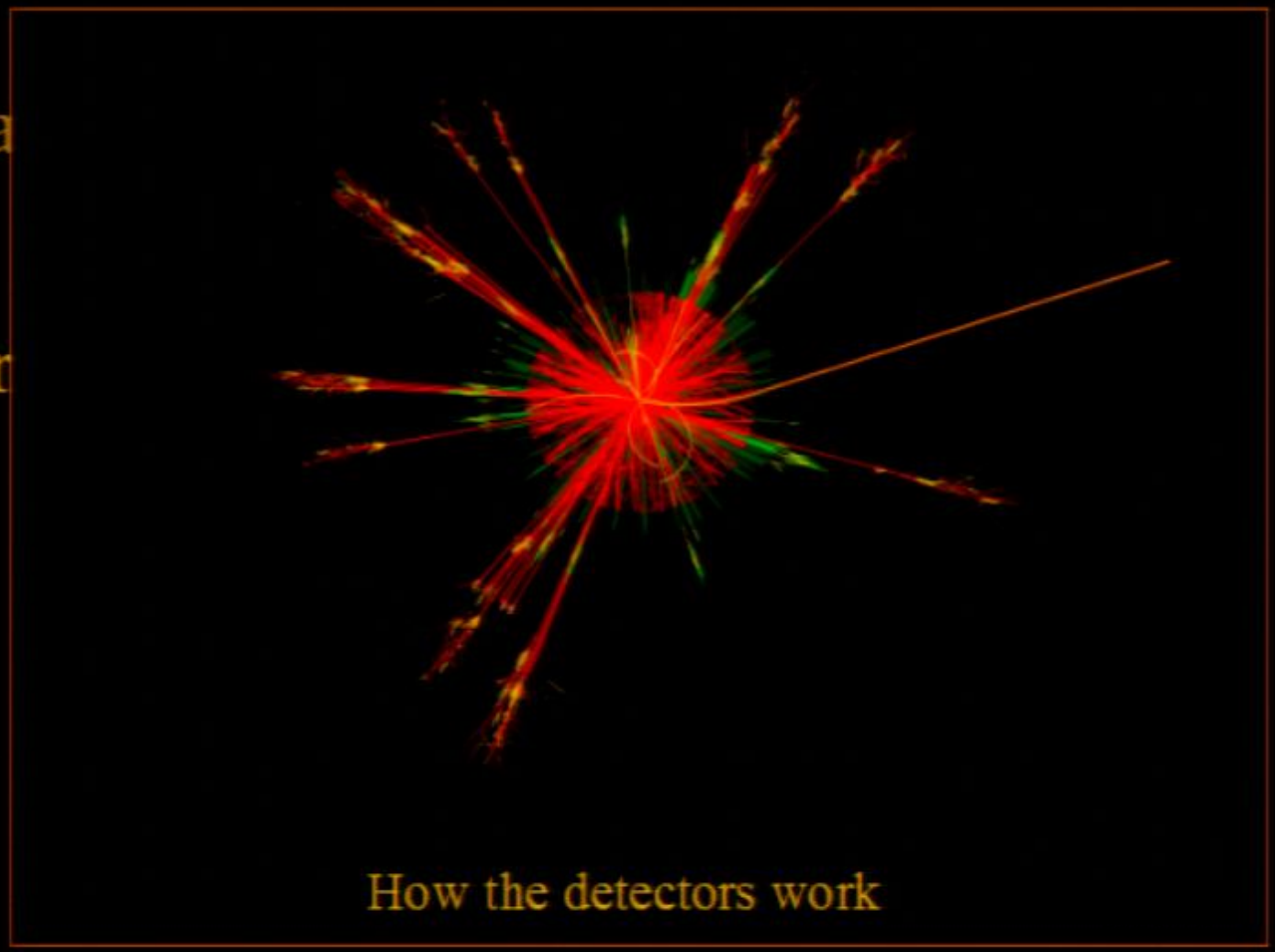
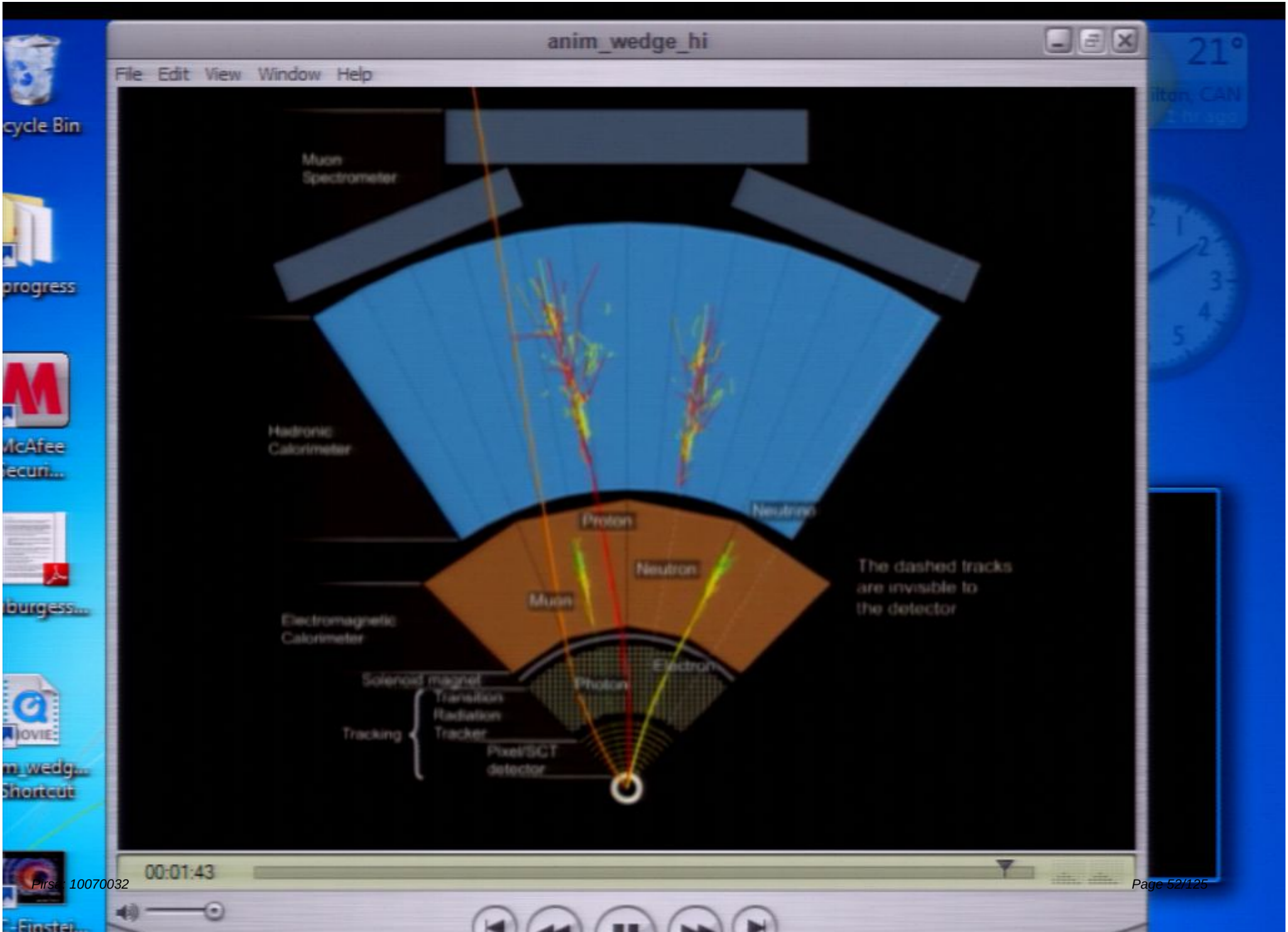


How the detectors work


anim_wedge_hi
File Edit View Window Help
Muon Spectrometer
Hadronic Calorimeter
Electromagnetic Calorimeter
Solenoid magnet
Transition Radiation Tracker
Tracking
Pixel/SCT detector
Proton
Neutron
Muon
Photon
Electron
Neutrino
The dashed tracks are invisible to the detector
00:01:43

The Machine

- The Accelera
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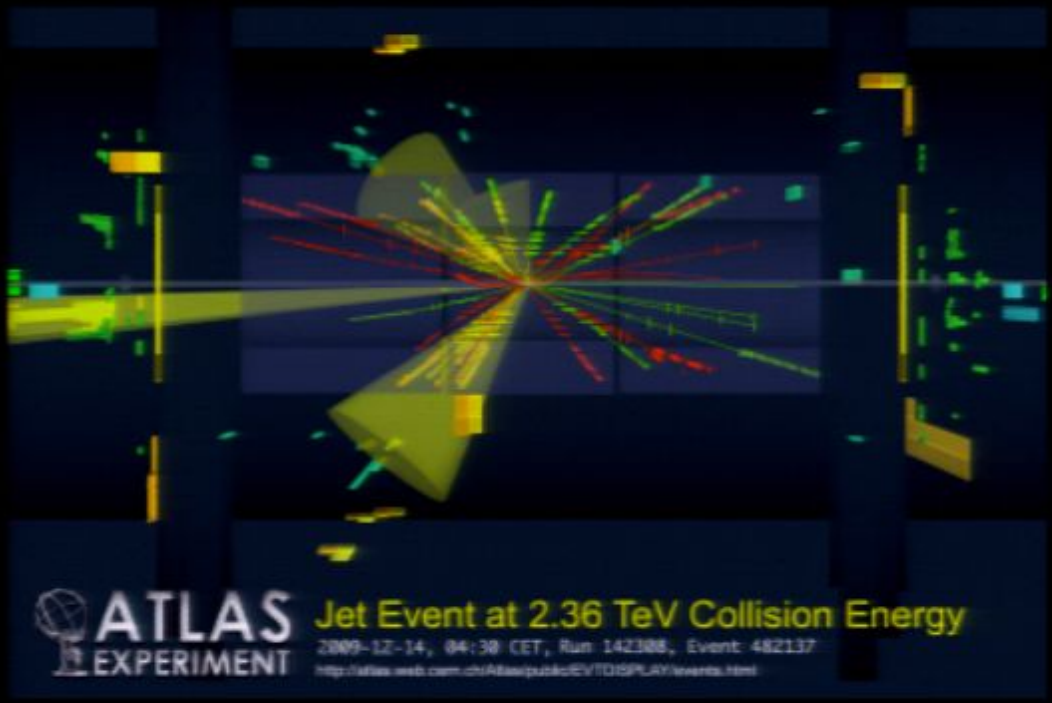

The detectors have been recording data

The Machine

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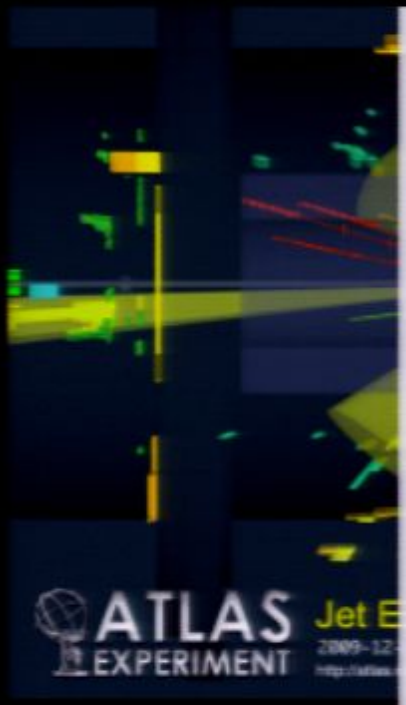

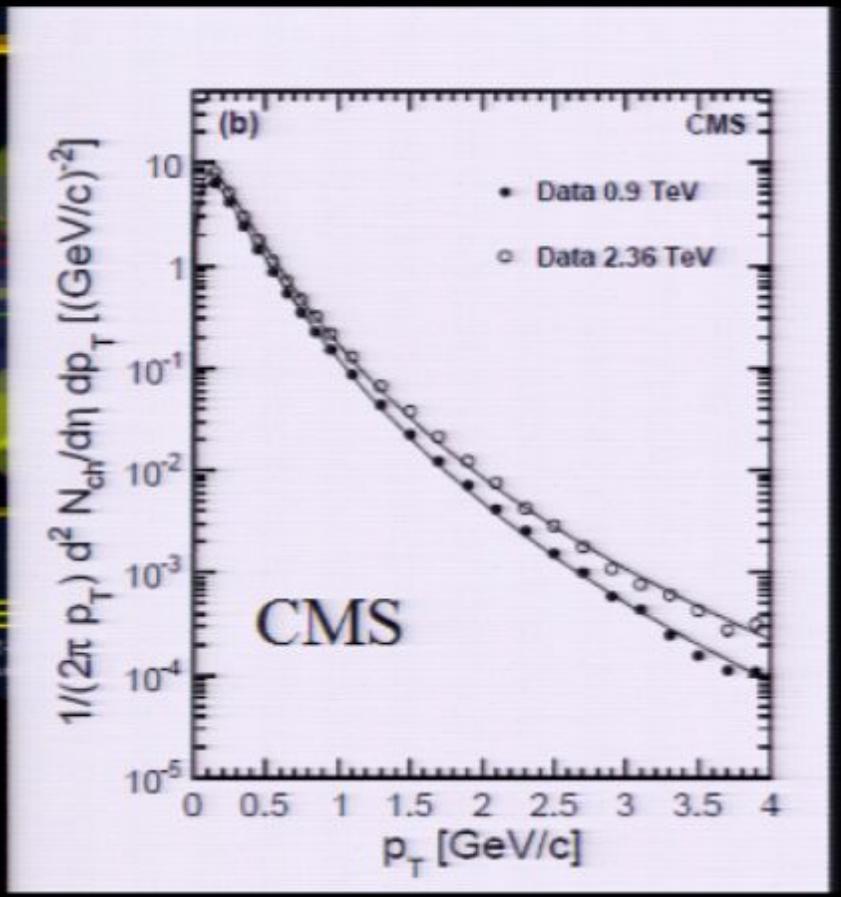

The first papers have come out

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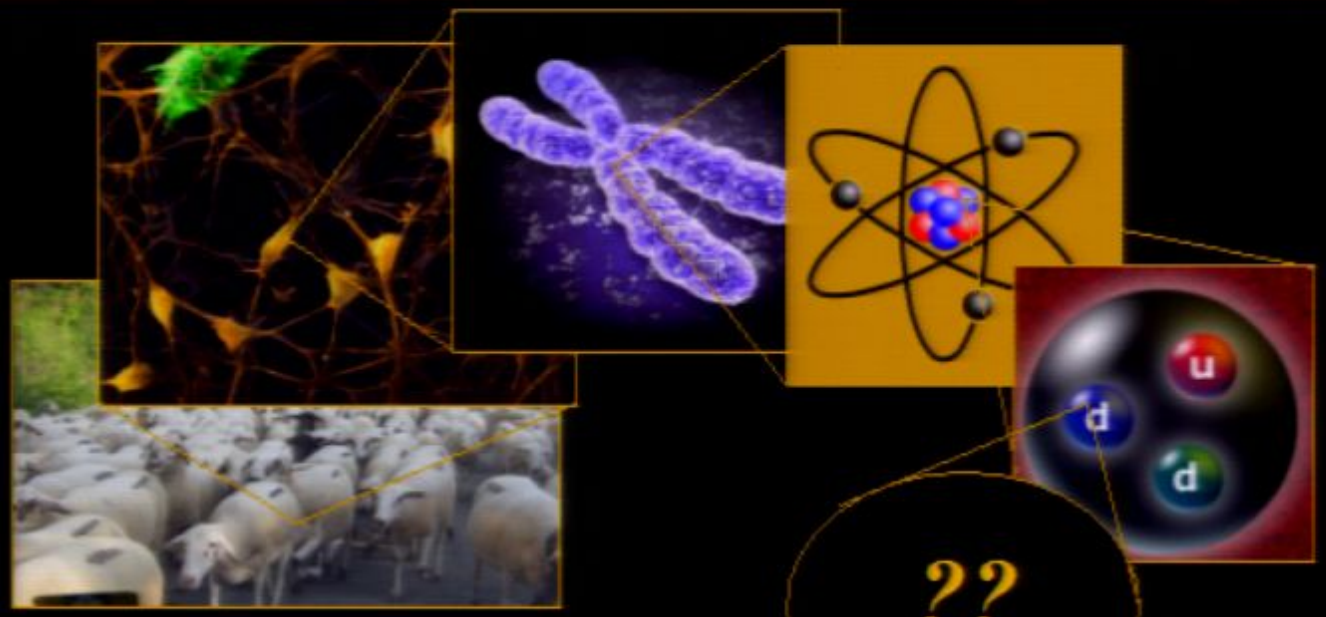

Why was the LHC built?

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 particle interactions
- 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.

The Standard Model

- The particles interactions
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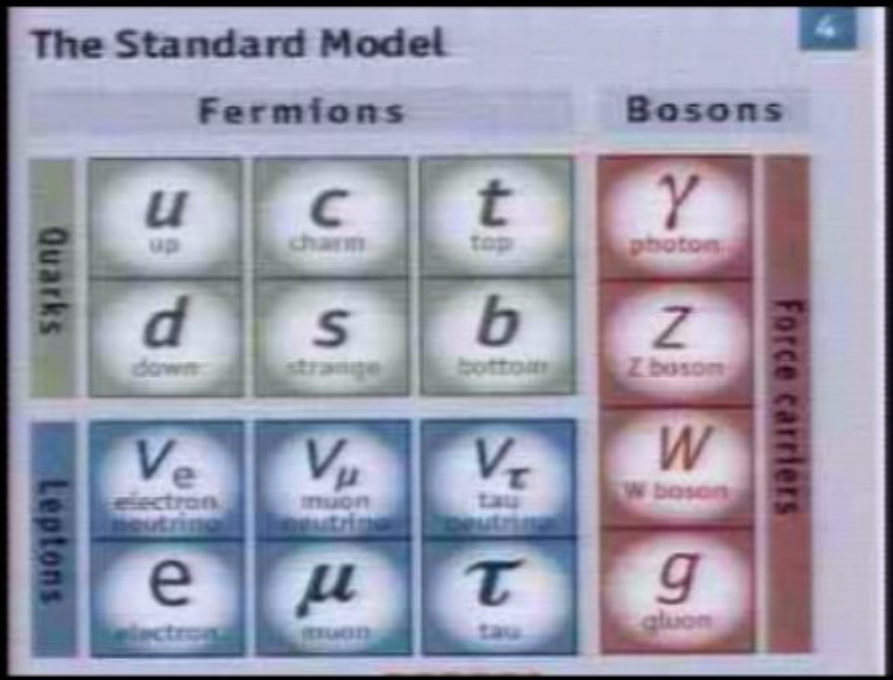

The 12 known constituents of matter and the 4 fundamental forces

The Standard Model

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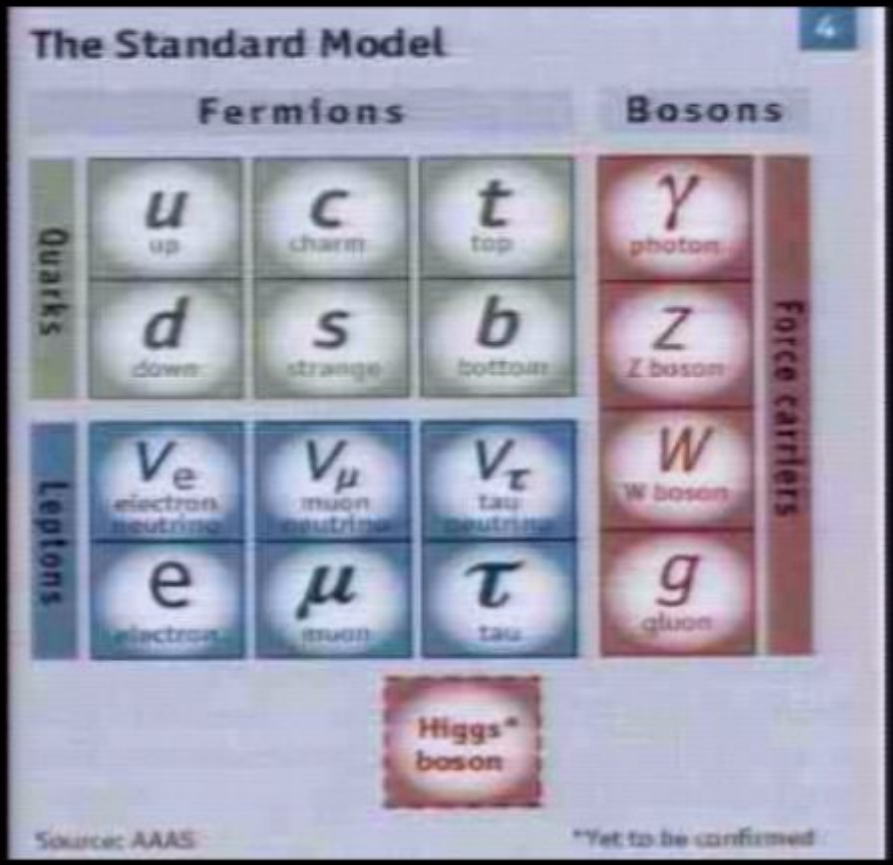

One SM particle remains AWOL: the Higgs boson

The Standard Model

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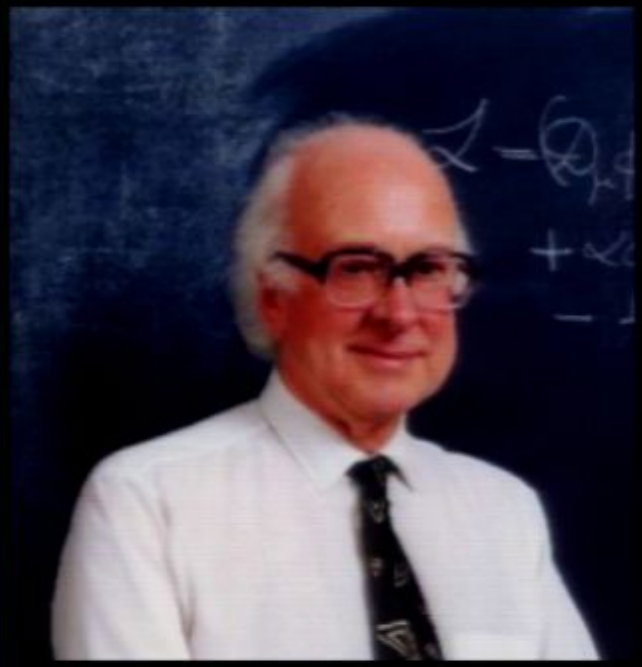

The Higgs boson is inferred theoretically, because it is associated with the *Higgs mechanism*: the reason why all of the SM particles have any mass at all.

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

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

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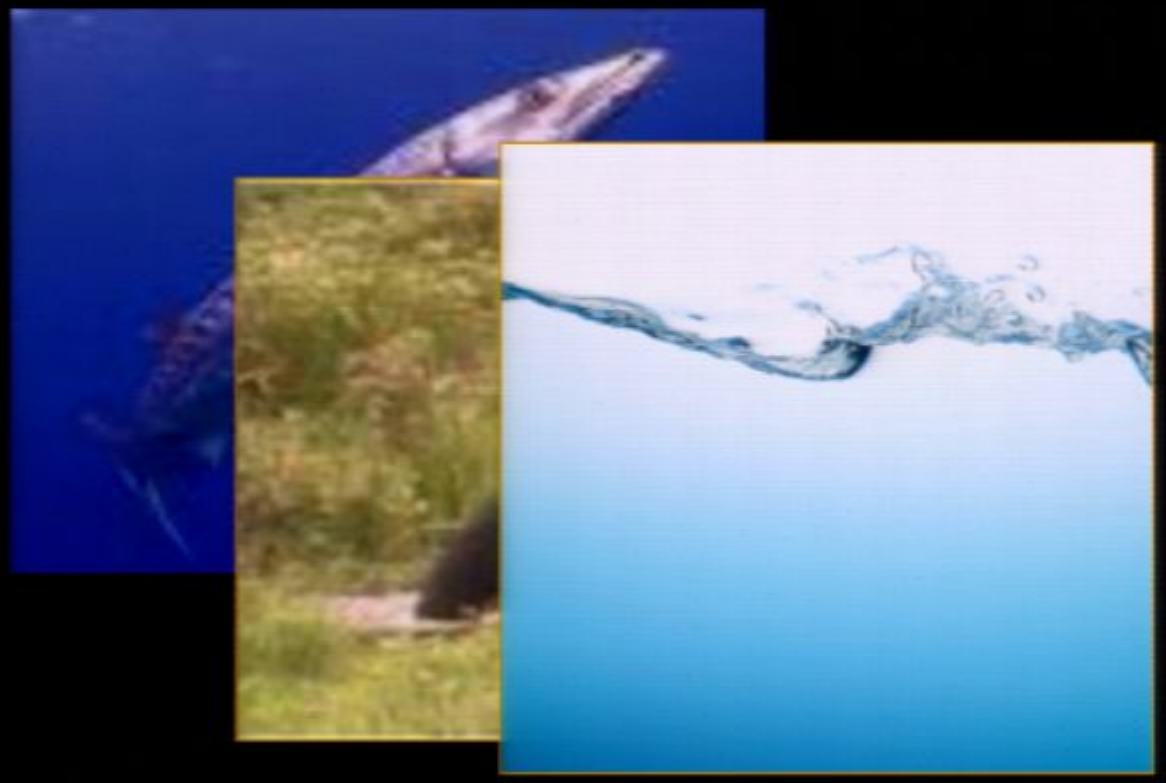

The Higgs *particle* is a wave moving through this Higgs vacuum.

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$$L = \bar{E}DE + \bar{L}DL + \bar{Q}DQ + \bar{U}DU + \bar{D}DD$$
$$+ B_{\mu\nu}B^{\mu\nu} + W^{a}_{\mu\nu}W^{\mu\nu}_{a} + G^{\alpha}_{\mu\nu}G^{\mu\nu}_{\alpha} + G^{\alpha}_{\mu\nu}\tilde{G}^{\mu\nu}_{\alpha}$$
$$+ H(\bar{L}y_l E) + H(\bar{Q}y_d D) + H^{*}(\bar{Q}y_u U)$$
$$+ D_{\mu}H^{*}D^{\mu}H + \lambda(H^{*}H - v^2)^2$$

A model only a mother could love…

The Standard Model

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A model only a mother could love…
What is beautiful about the Standard Model is that it is the most general way that the given particles can interact at low energies (with the given gauge symmetries)

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A model only a mother could love…
What is beautiful about the Standard Model is that it is the most general way that the given particles can interact at low energies (with the given gauge symmetries) Typical of a low-energy 'effective theory'

The Standard Model

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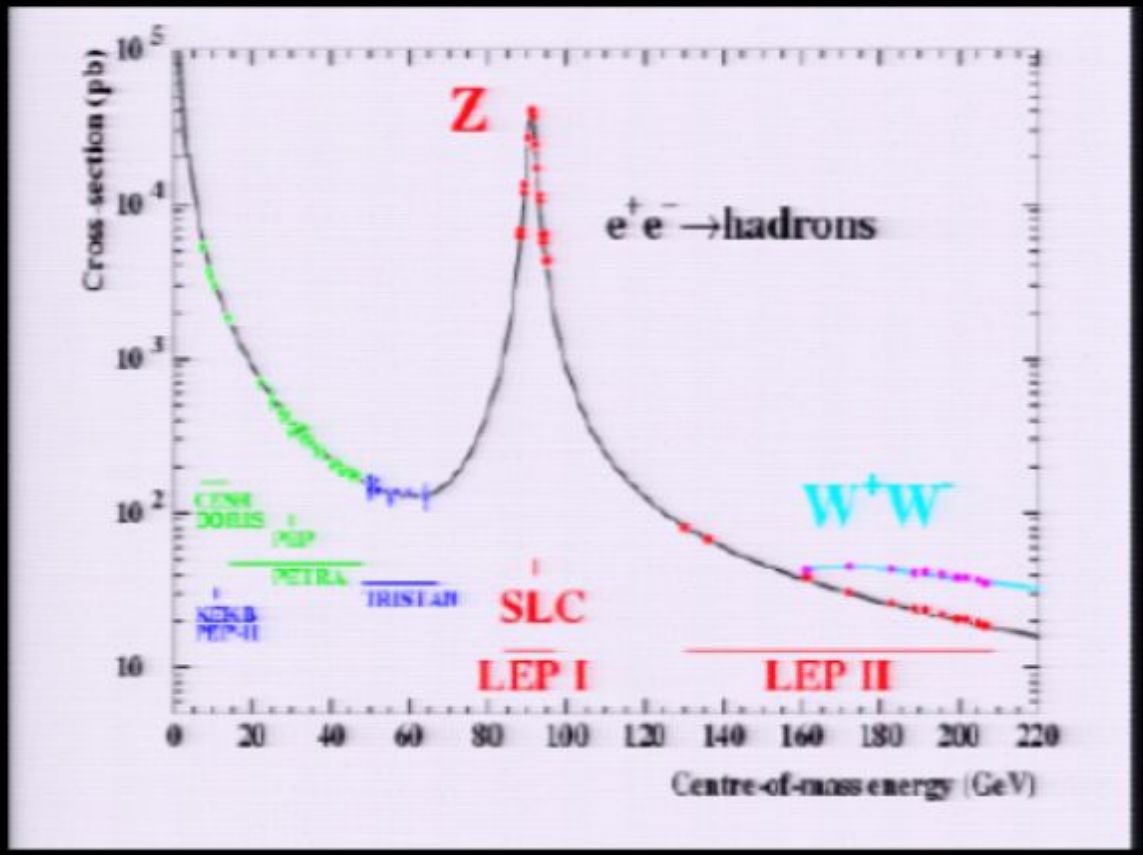

The SM is tested in detail, such as through e^+e^- collisions

The Standard Model

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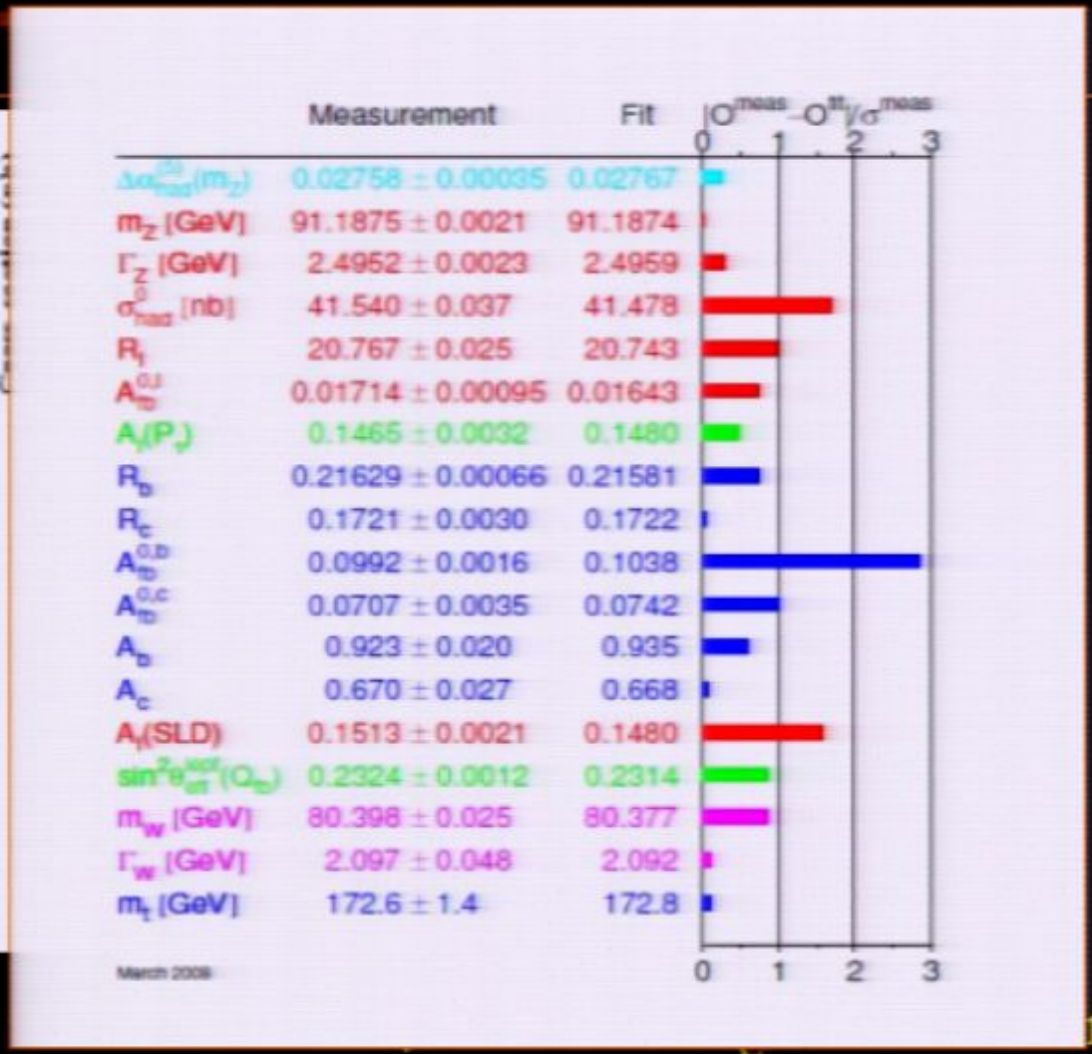

The SM

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M. Vazzoshi IGHEP 2008

The Standard Model

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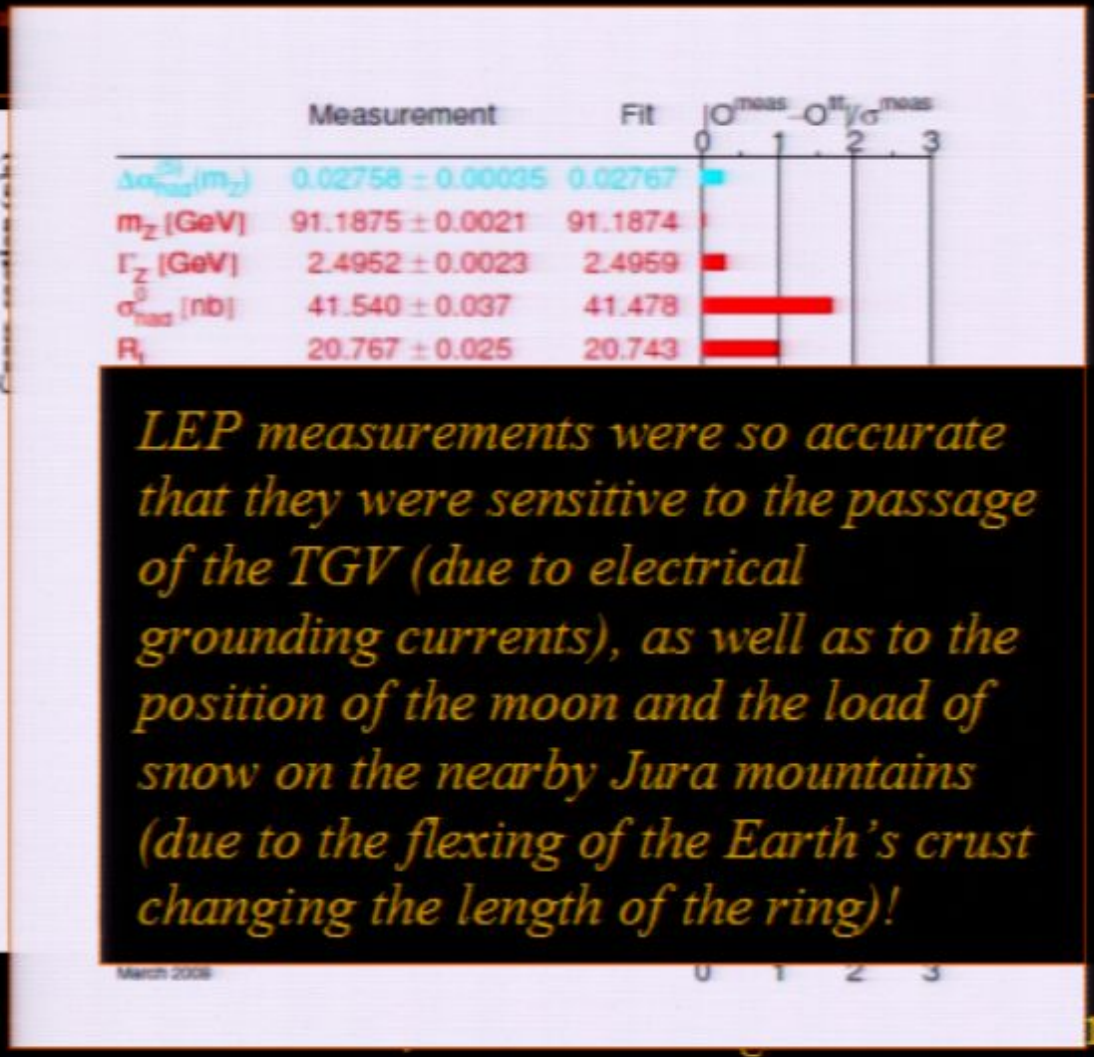

LEP measurements were so accurate that they were sensitive to the passage of the TGV (due to electrical grounding currents), as well as to the position of the moon and the load of snow on the nearby Jura mountains (due to the flexing of the Earth's crust changing the length of the ring)!

The SM

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M. Vergeshi: ICHEP 2008

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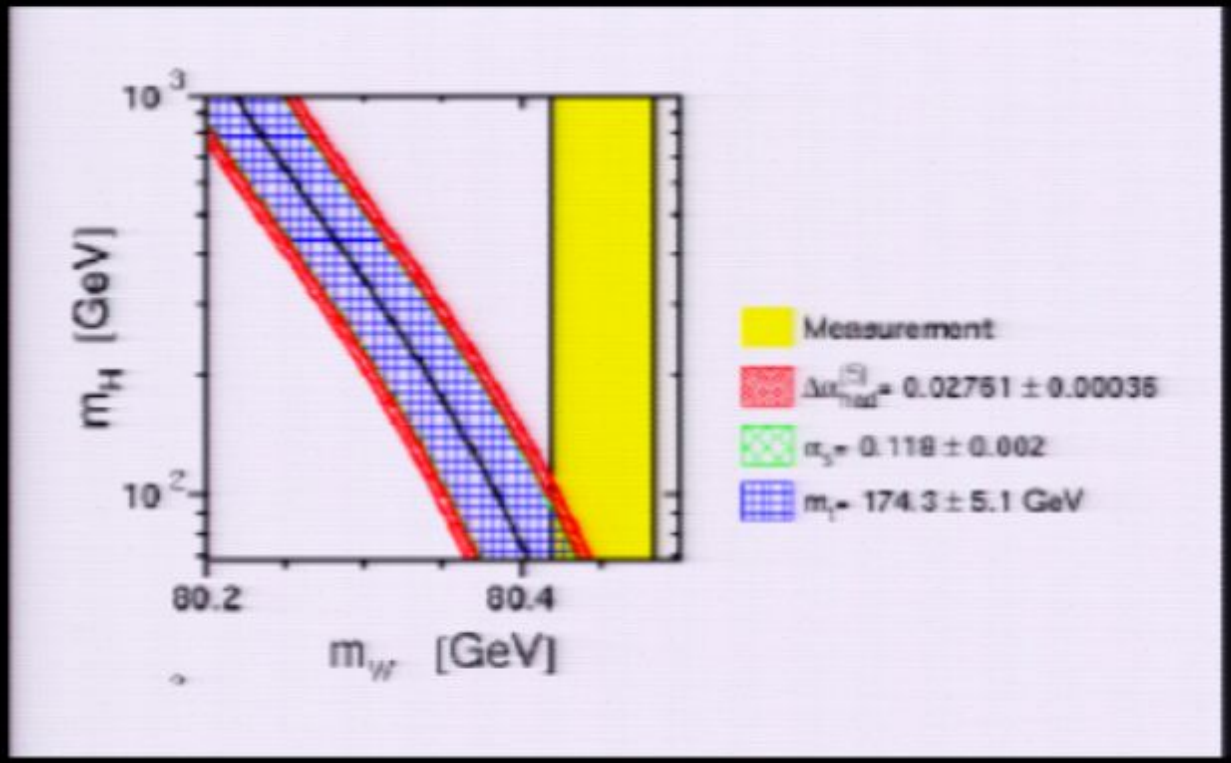

Unknown quantities, like the Higgs mass, are strongly constrained by the accuracy of these tests

A. Tonazzo, Moriond 2003

The Standard Model

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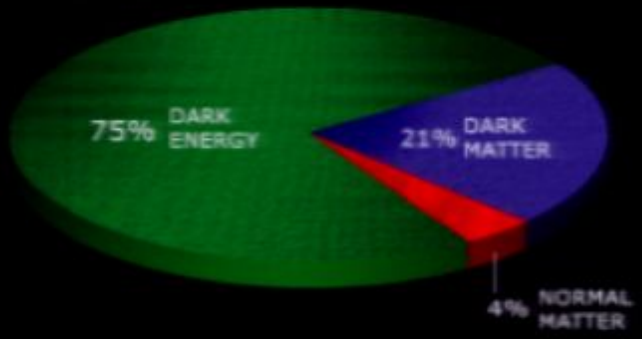
The Standard Model

- The particles interactions

So what's wrong with the Standard Model?

Observational Problems:

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



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

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

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 $m_p = 1$ 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
Neutrinos: L-violation scale $M_L = M_W^2 / m_\nu \sim 10^{11}$ GeV

The Standard Model

- The particles
- Successe
- Limitatio

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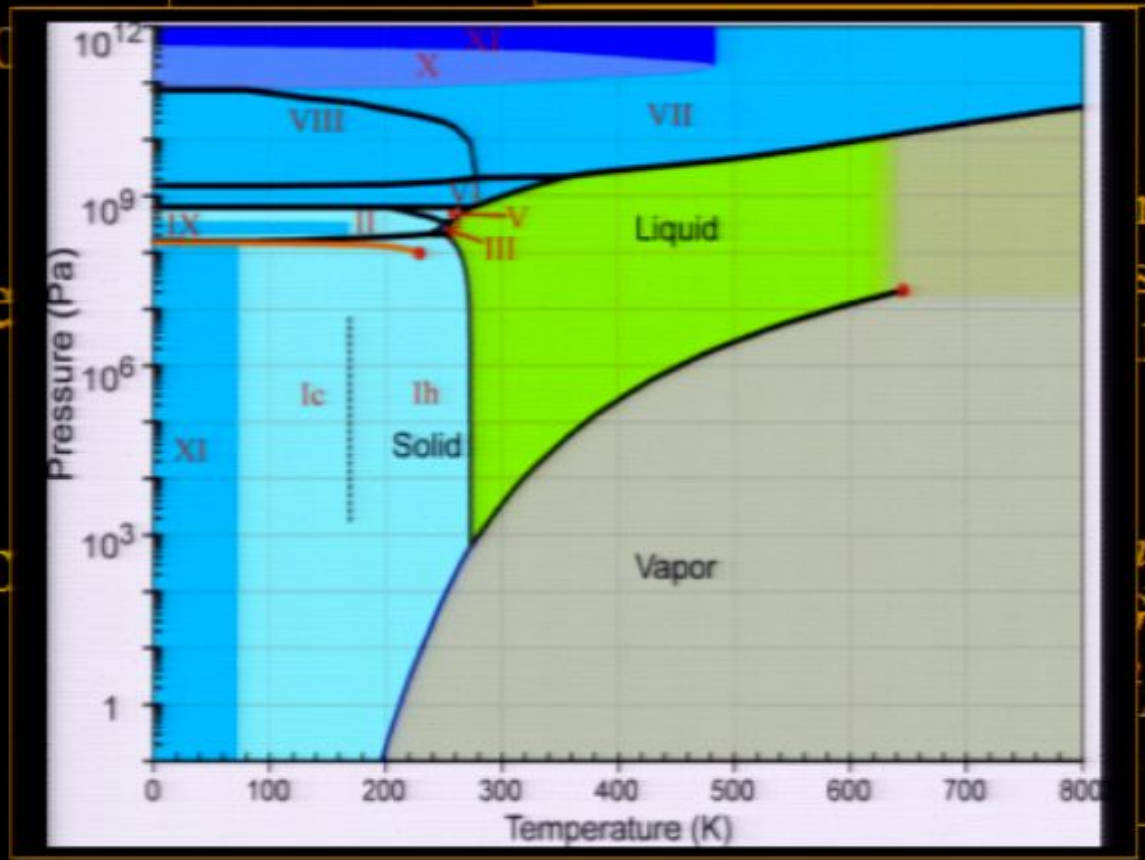

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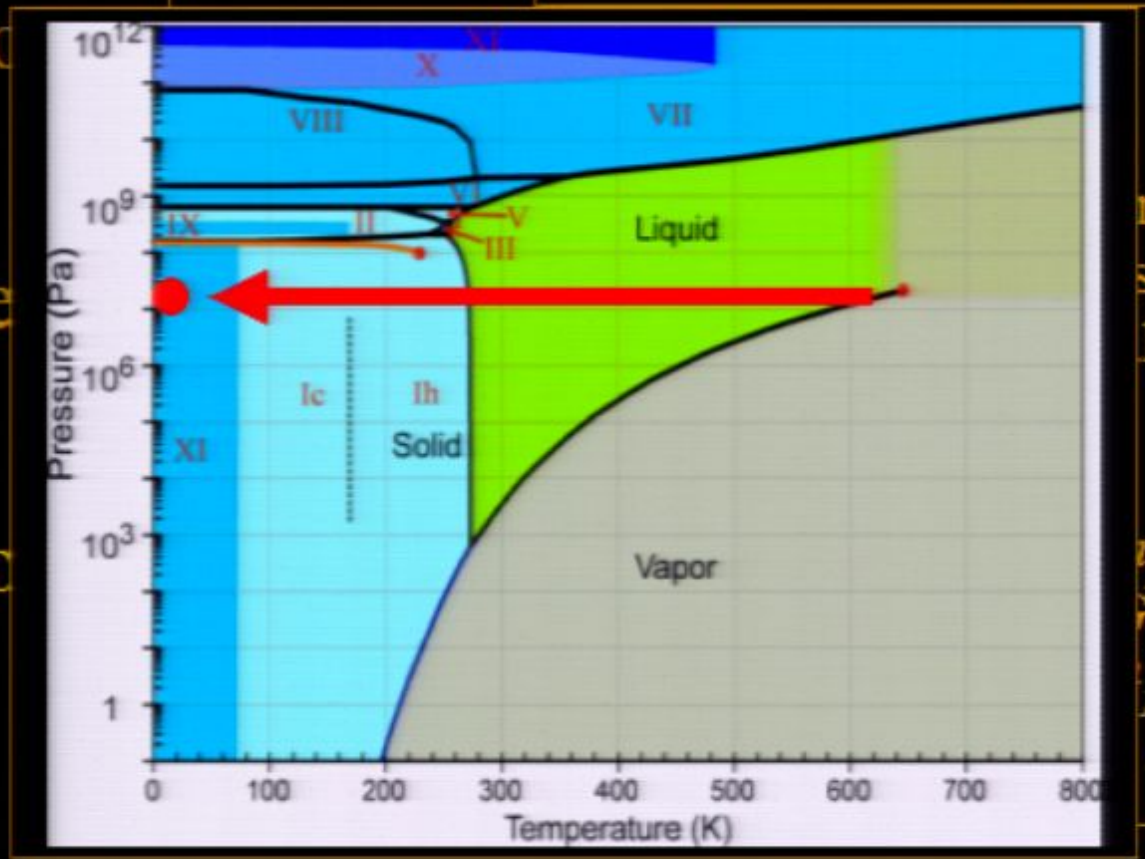

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What might be seen

- Nothing?

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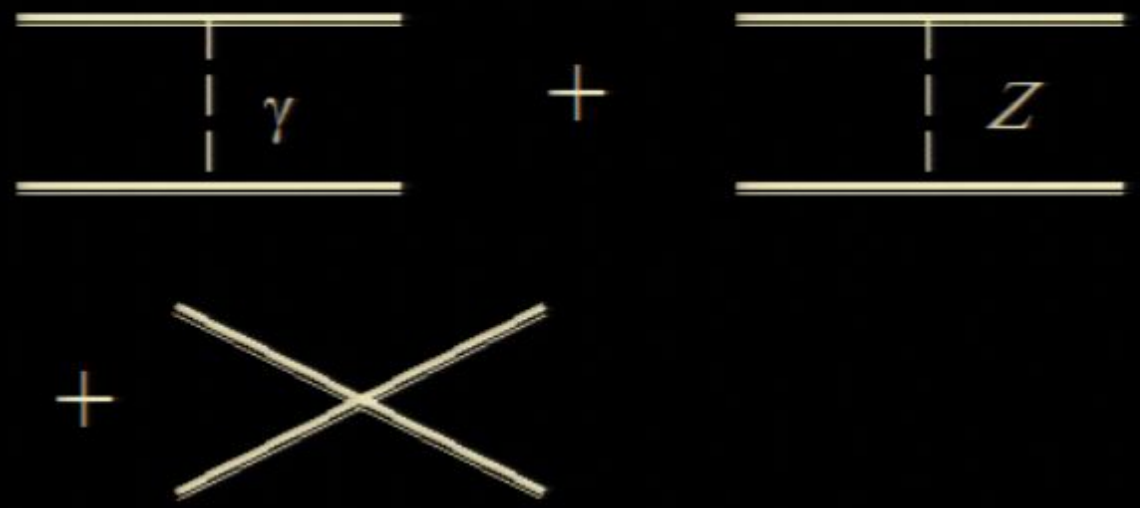

W-W scattering: $\sigma \sim (\alpha^2 \ln E)/M_W^2$

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

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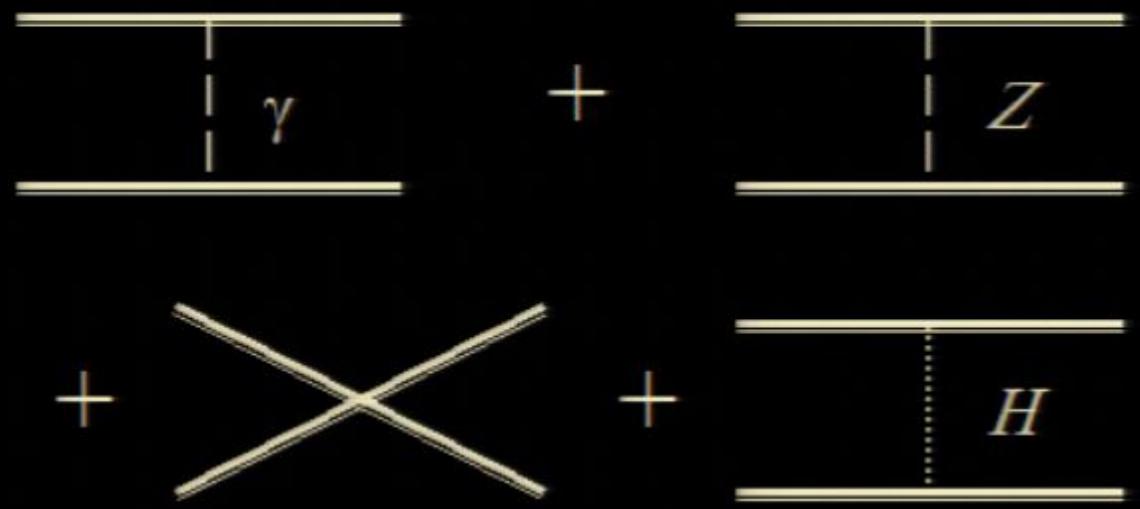


W-W scattering: $\sigma \sim \alpha^2/E^2$

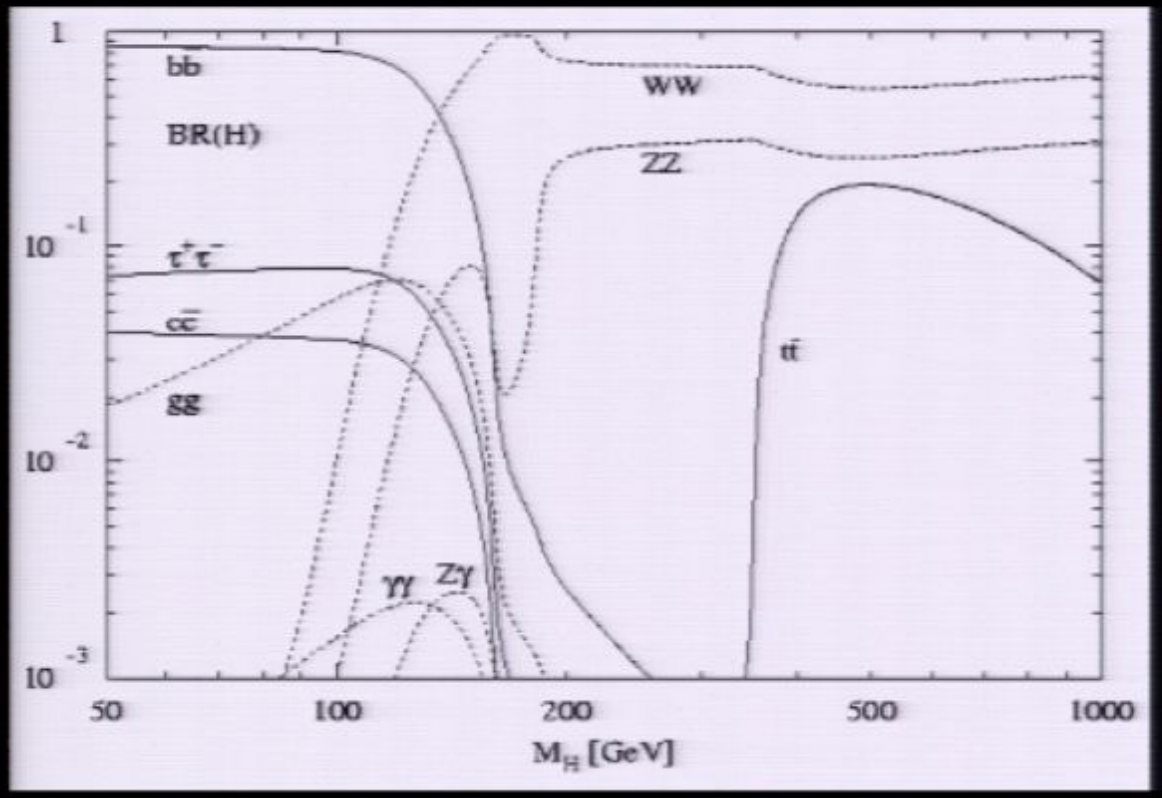
The SM with the Higgs boson *can make sense for energies much larger than* $M_W/\alpha \sim$ few TeV

What might be seen

- The Higgs Boson?

What might be seen

- The Higgs B

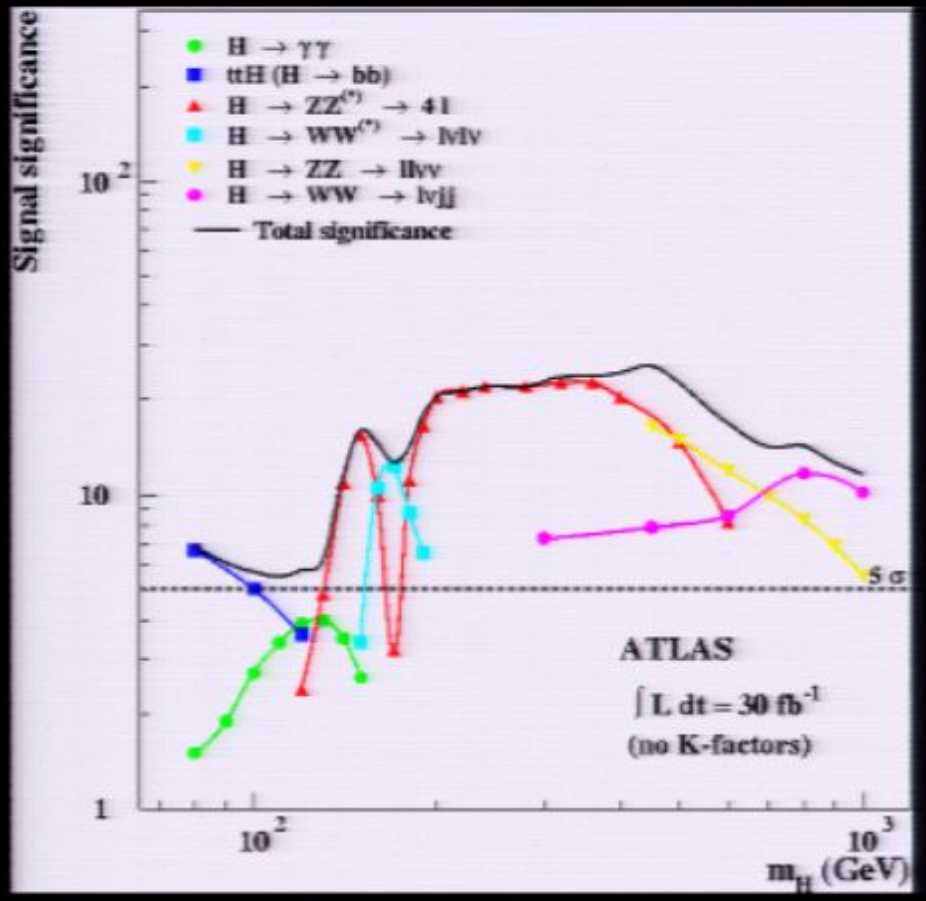


Search strategies depend on what it decays into, and this depends on its mass

M. Lefebvre (Astbury Symposium 2000)

What might be seen

- The Higgs B



Expect it to be visible for the allowed mass range

M. Lefebvre (Asthury Symposium 2009)

What might be seen

- Beyond the Standard Model?

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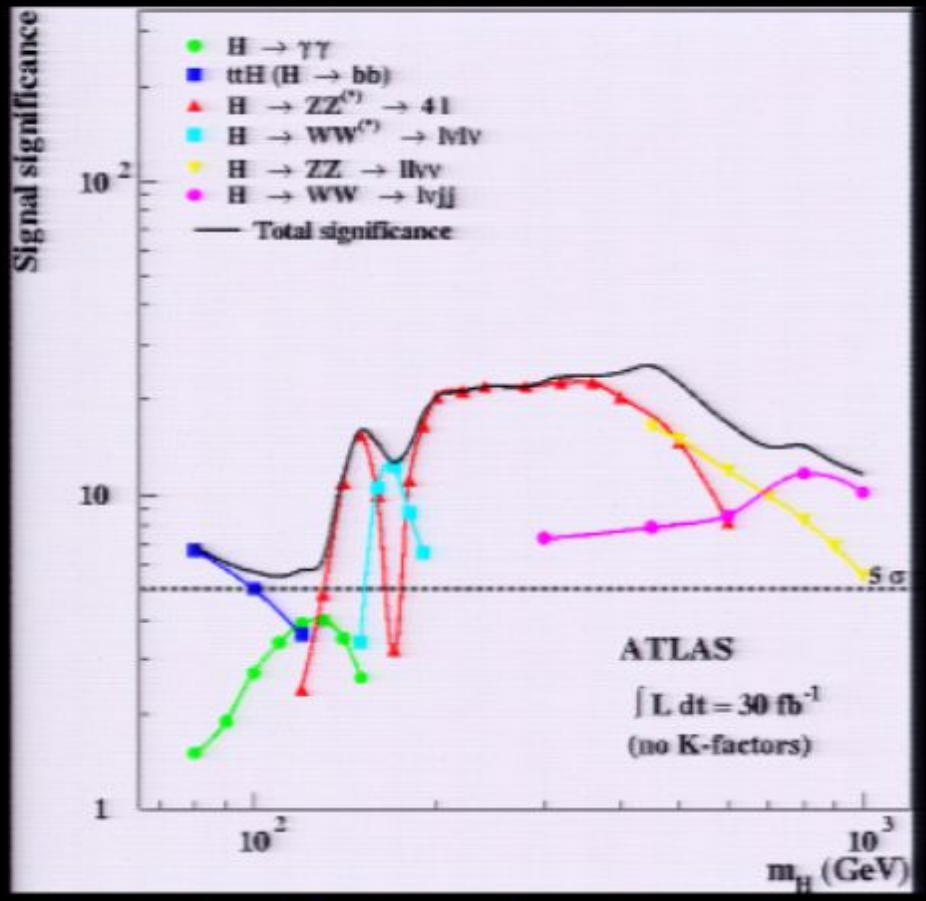

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M. Lefebvre (Aspen Symposium 2009)

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

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- *Beyond the SM*: basically three options:

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

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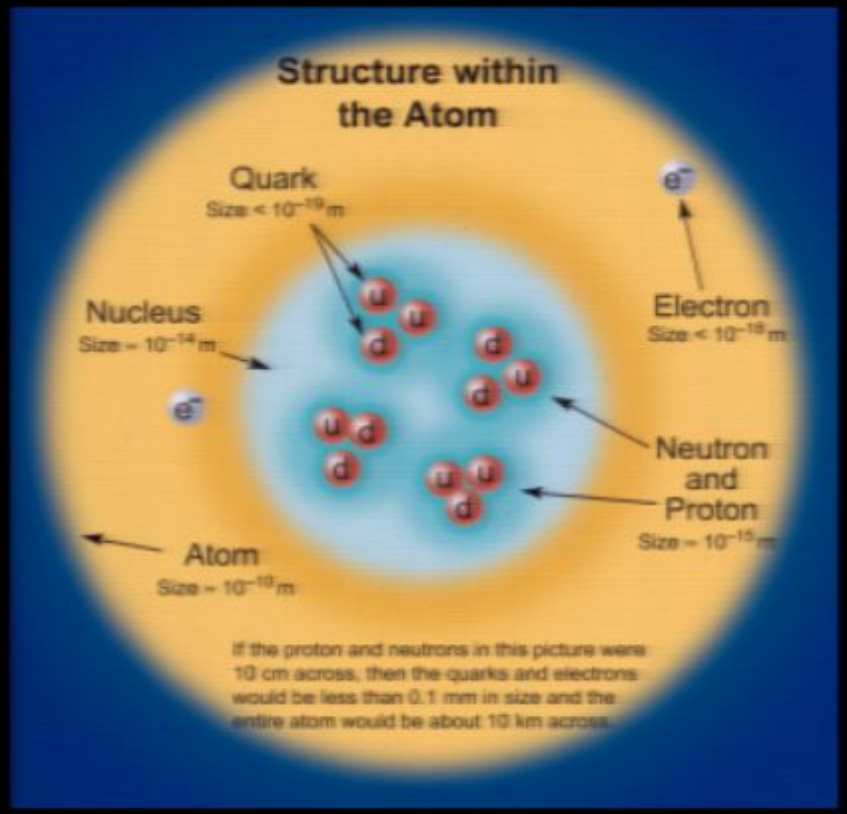


- Another level of substructure is historically the most conservative guess

What might be seen

- Beyond the S

- *Beyond the SM*: basically three options:

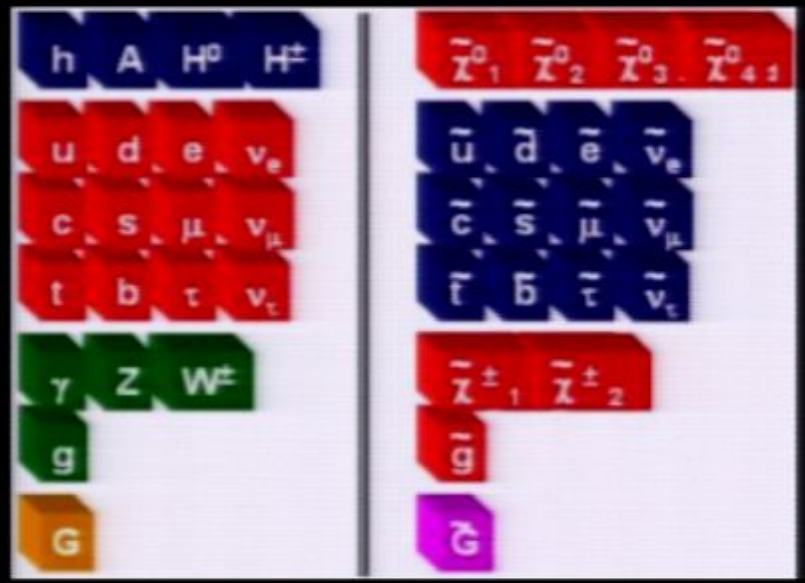
  No elementary Higgs:
  - ***Composite models***

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

What might be seen

- The Higgs B
- Beyond the S

- Usually implies 'superpartners' for each kind of known particle
- lightest superpartner is usually a good dark matter candidate



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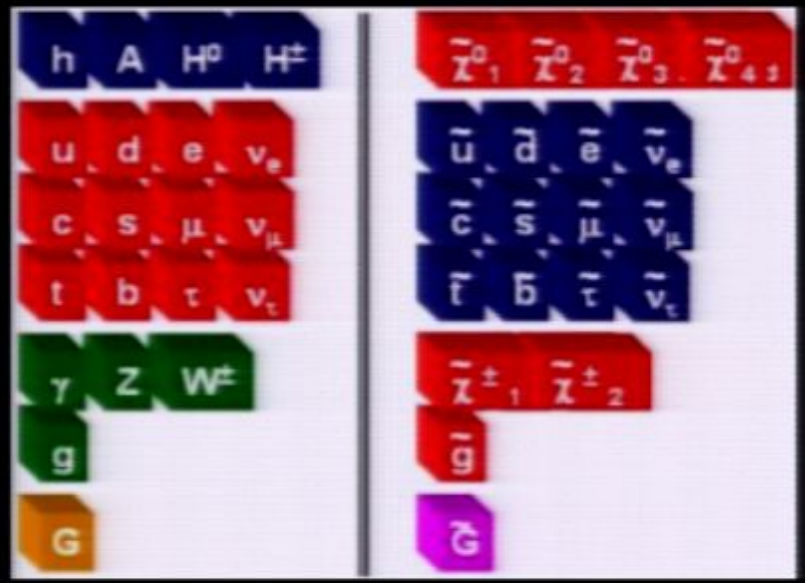

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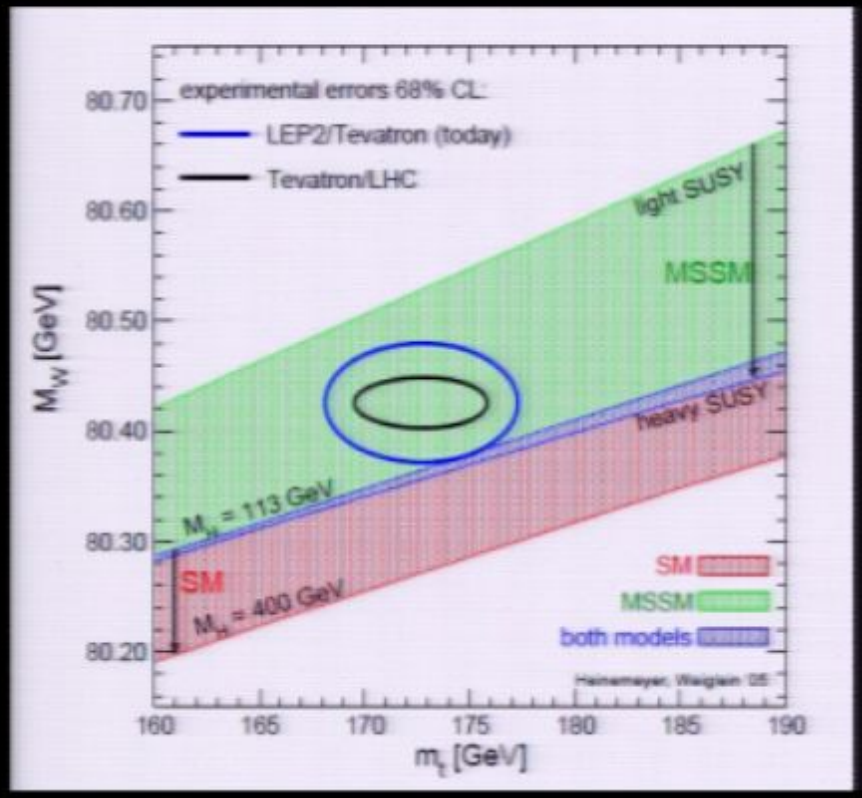

- Hint for supersymmetry: in the preference for light Higgs in precision measurements

What might be seen

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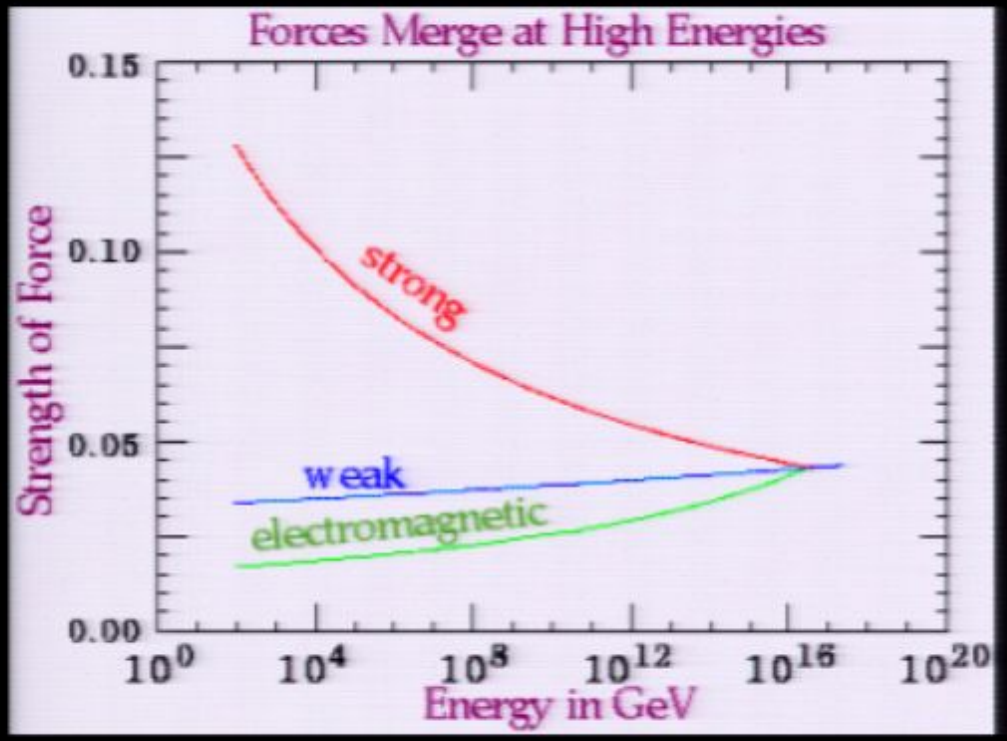

- Hints for supersymmetry: apparent unification of SM couplings

What might be seen

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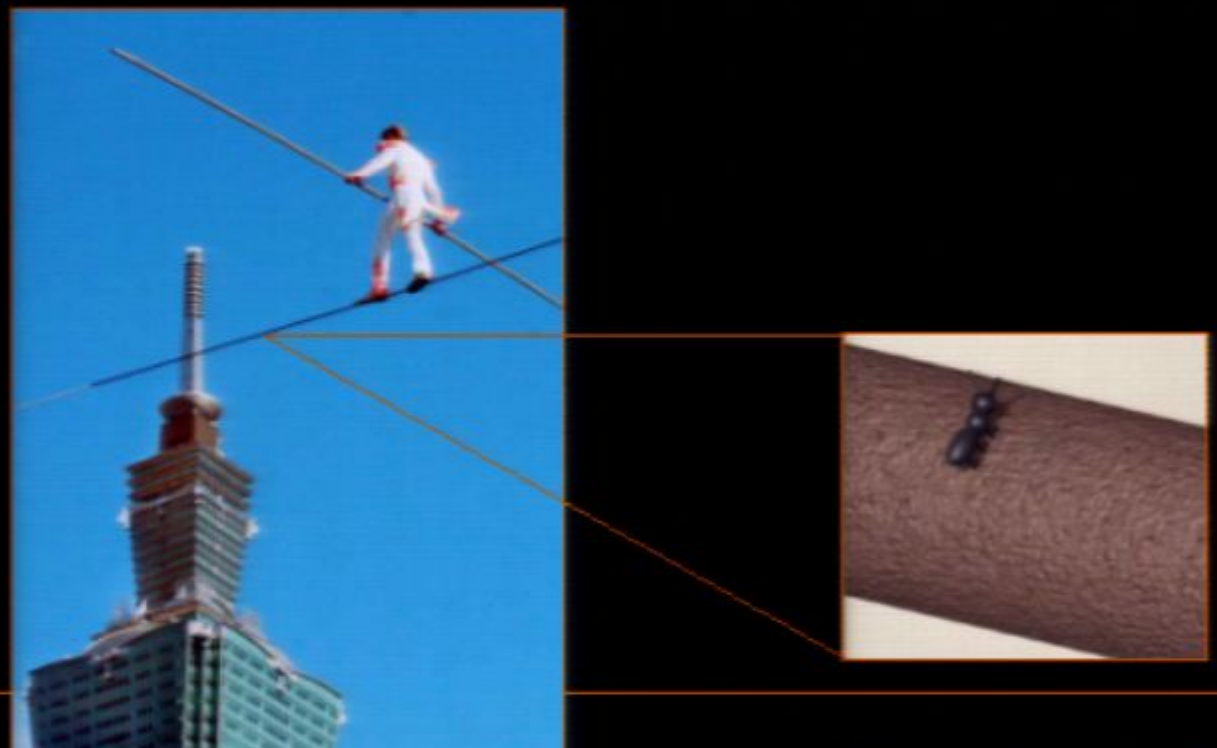
  New symmetry alleviating fine tuning:
  - ***Supersymmetry***

  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….



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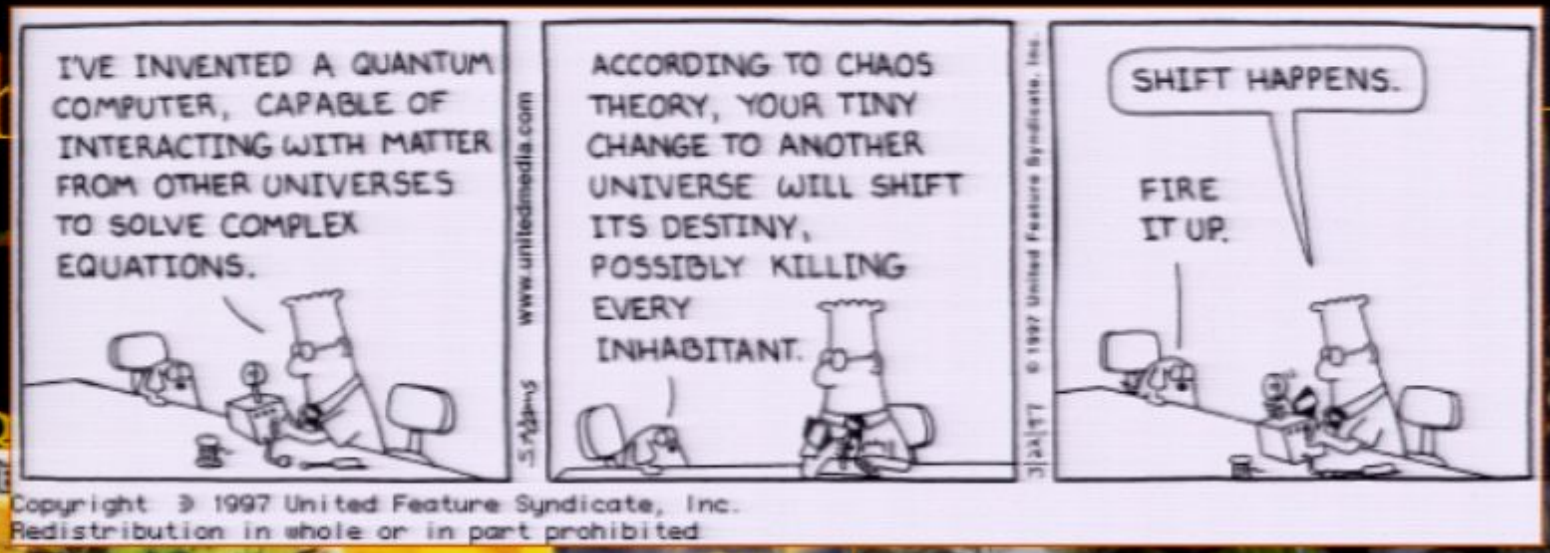
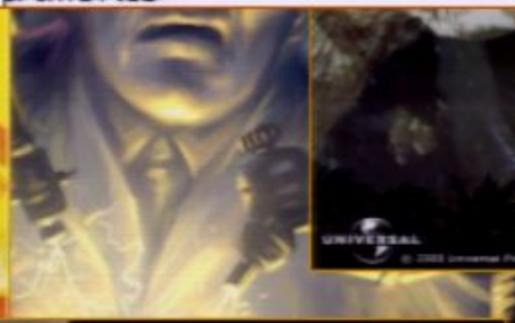
This is the scenario that potentially leads to black hole production…





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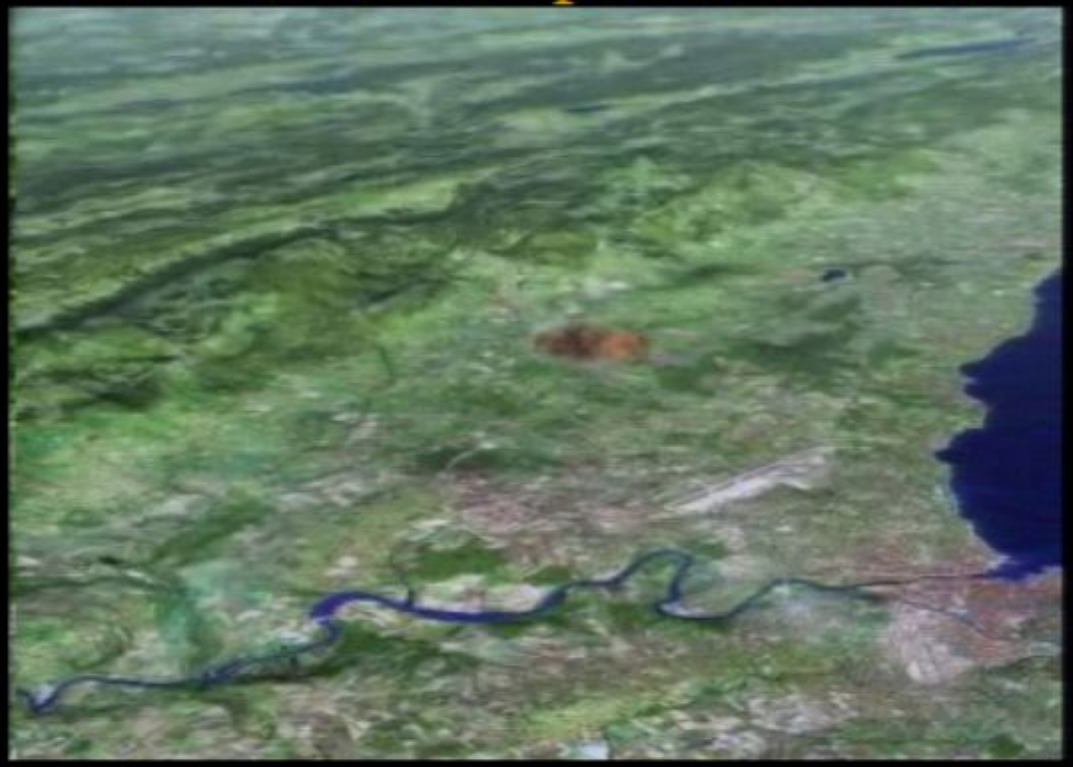

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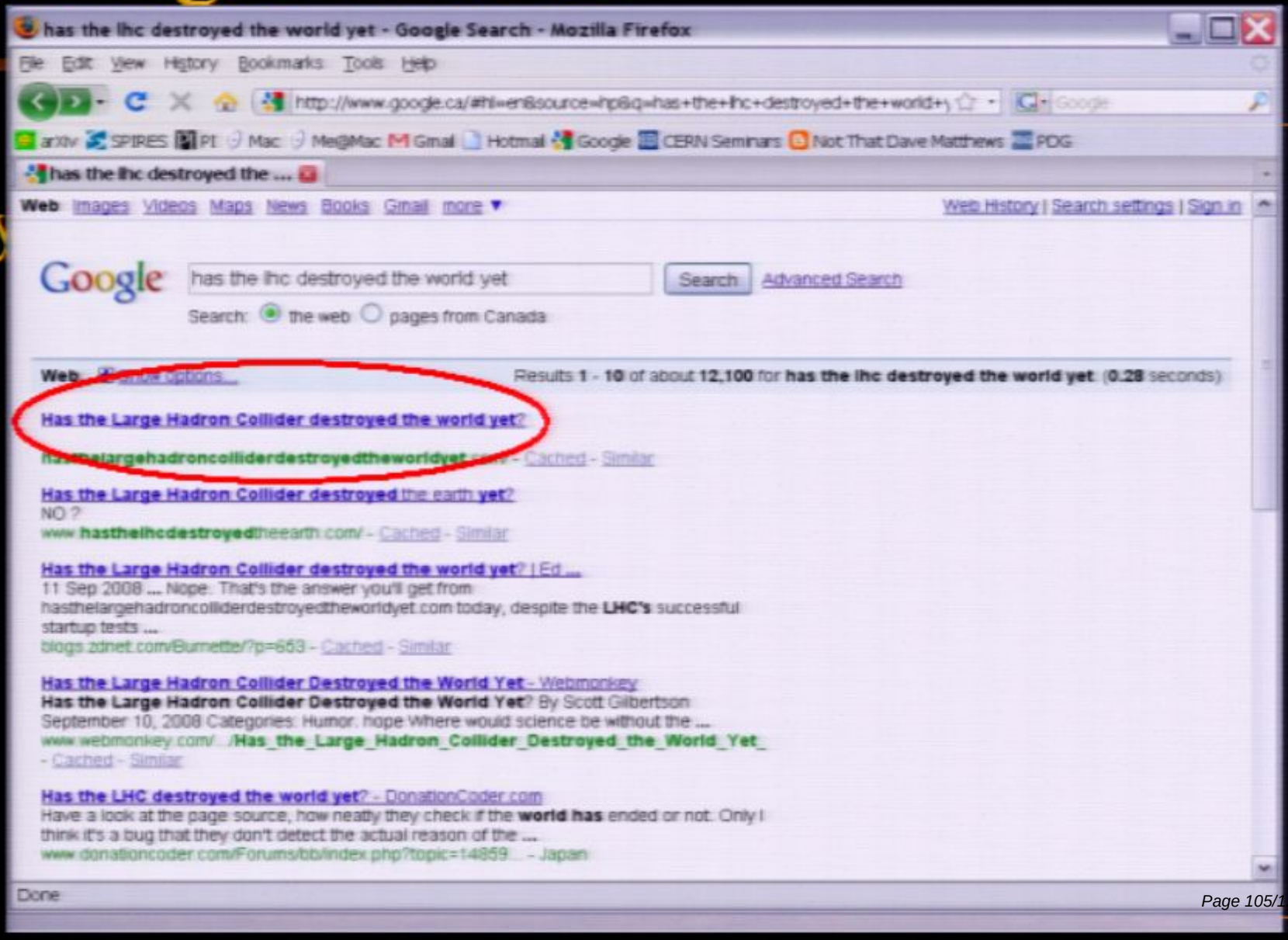

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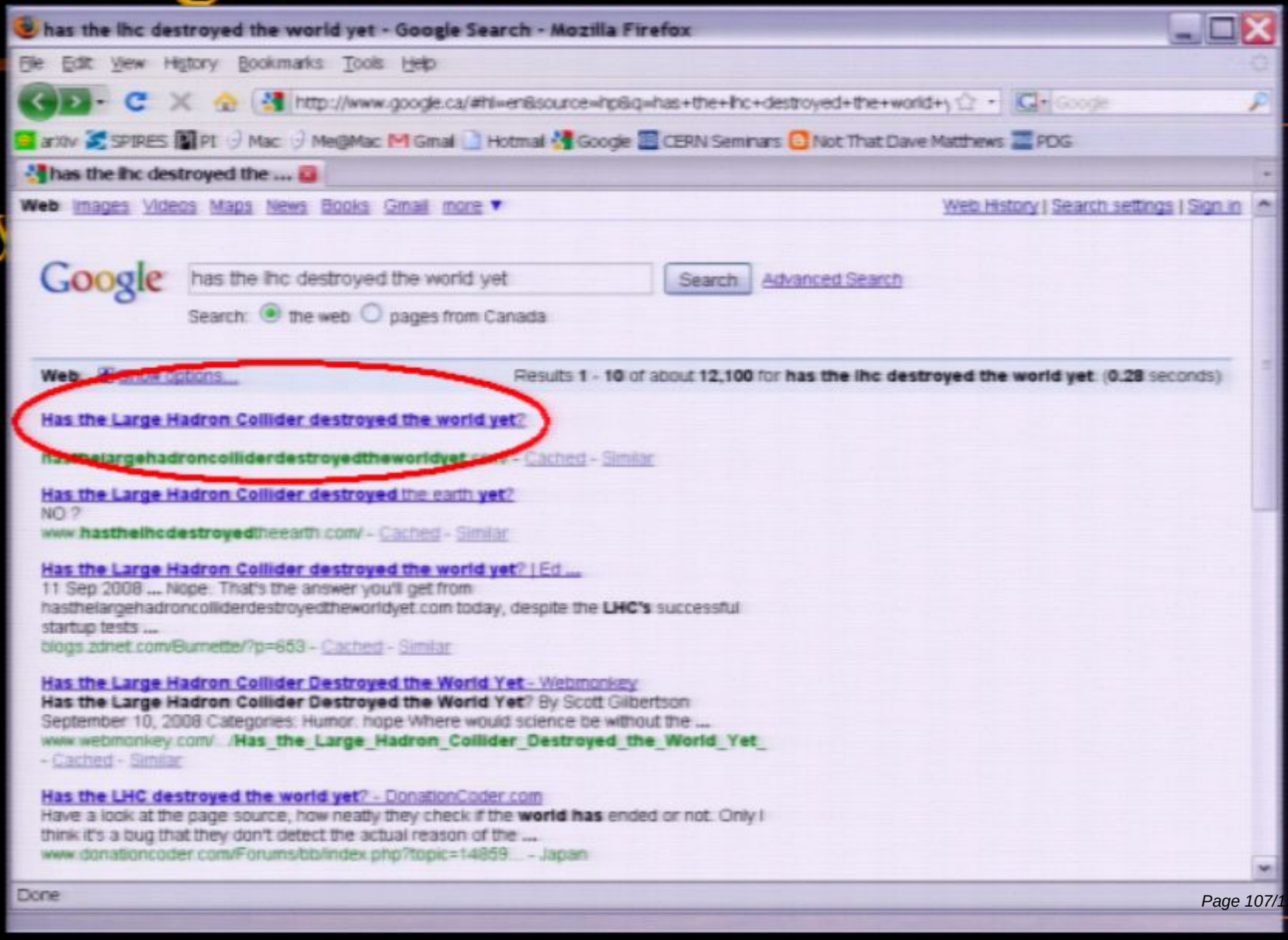

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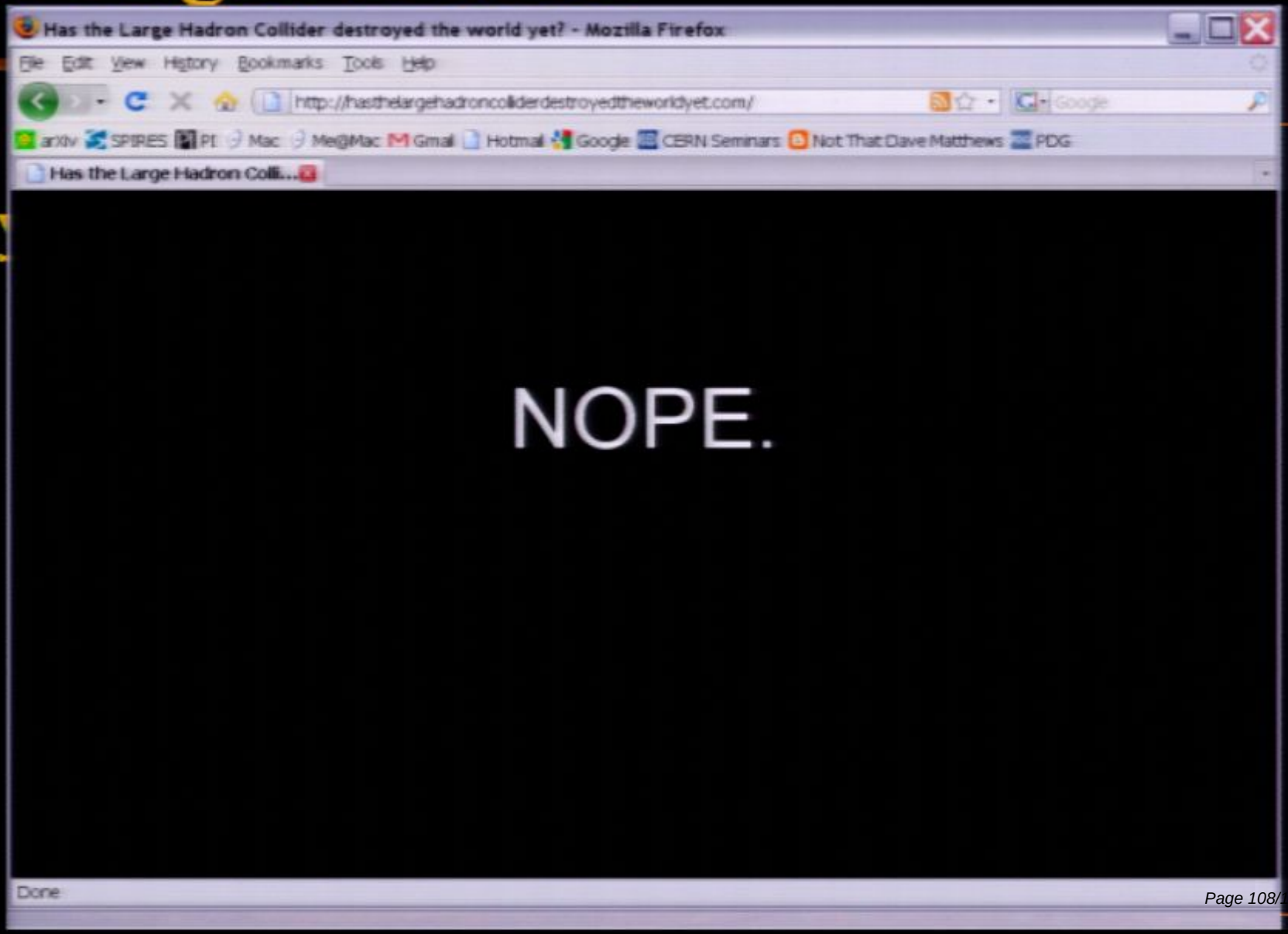

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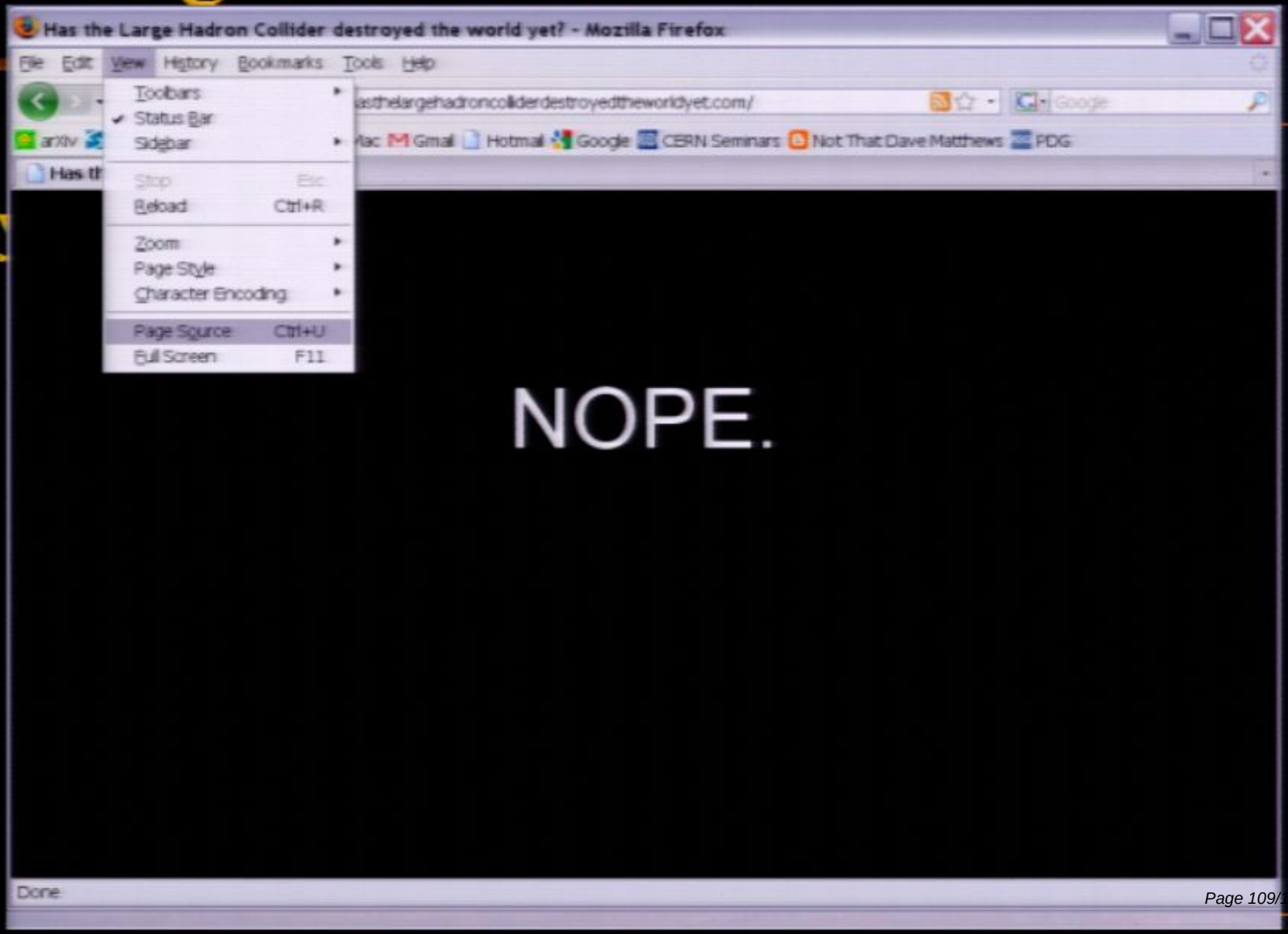

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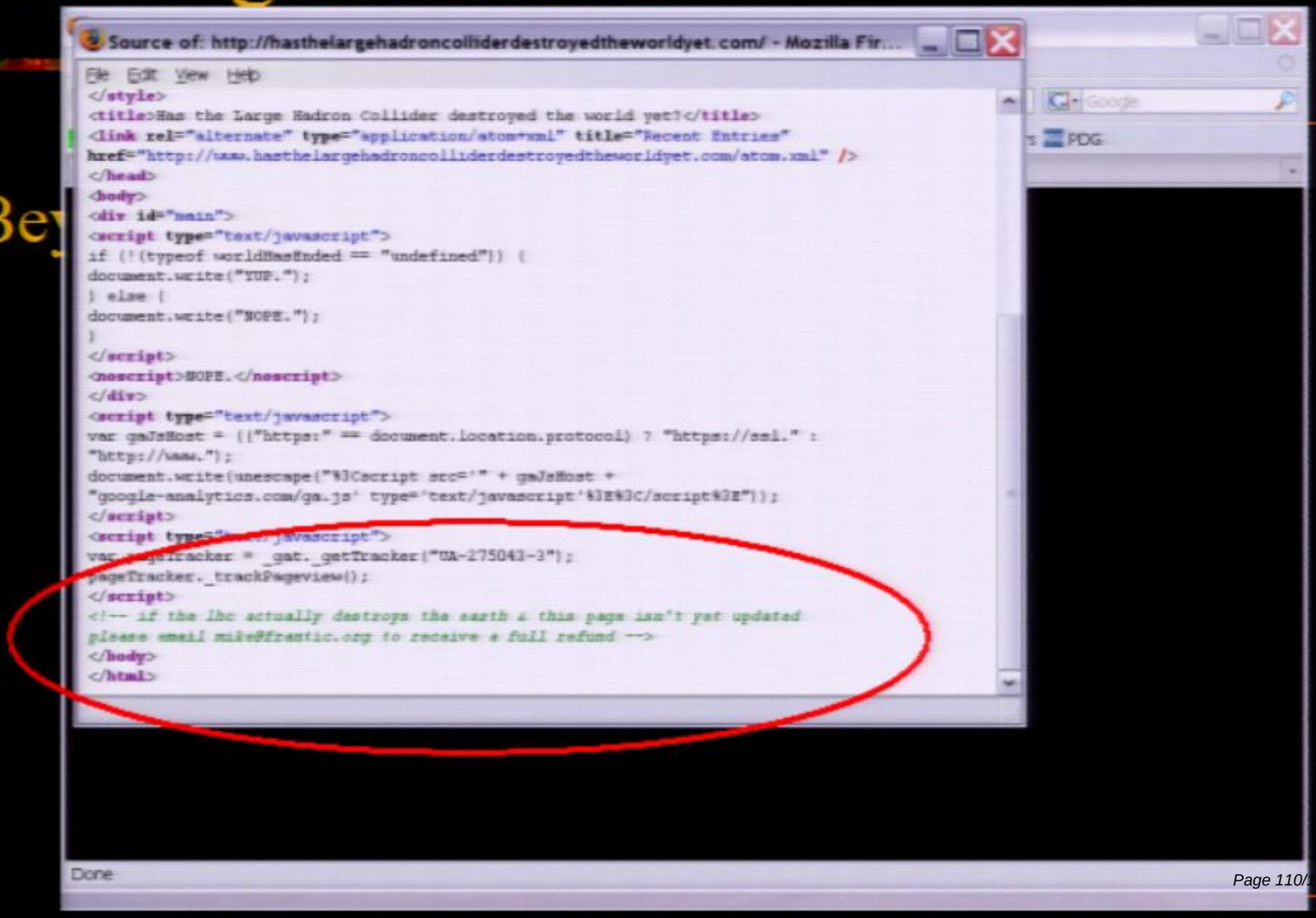

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This is the scenario that potentially leads to black hole production…

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 started a long physics run a few months ago!
  - Runs at full beam energy could begin late next year.

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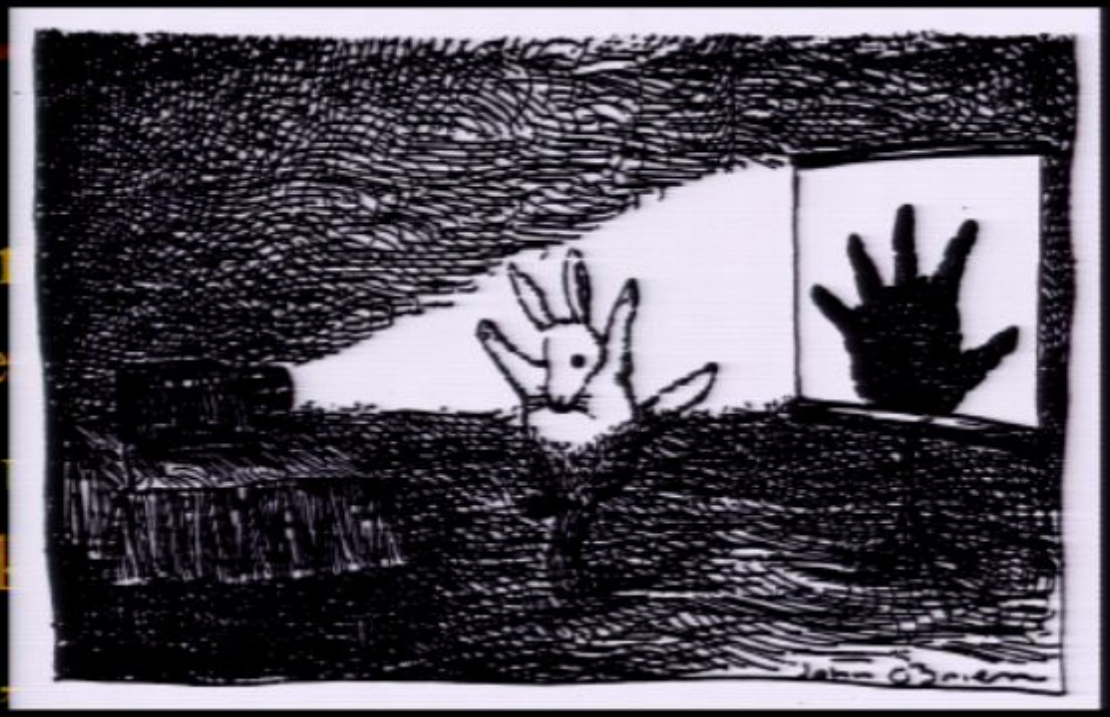
HOLYSHIT!!

Outlook

- The LHC started a long physics run a few months ago!
  - Runs at full beam energy could begin late next year.
- 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



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  - The SM Higgs boson,
- Surprises are inevitable!
  - The LHC is likely to represent a major change to our understanding of Nature at its most elementary level.

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My personal pick: *large extra dimensions and string theory in your face!*

Websites with more information

- The ATLAS and CMS detectors:
  - http://atlas.ch, http://cms.cern.ch
- LHC outreach:
  - http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/
- Particle Data Group outreach:
  - http://pdg.lbl.gov/2006/html/outreach.html
- LHC Rap: http://www.youtube.com/watch?v-j50ZssEojtM


No Signal
VGA-1


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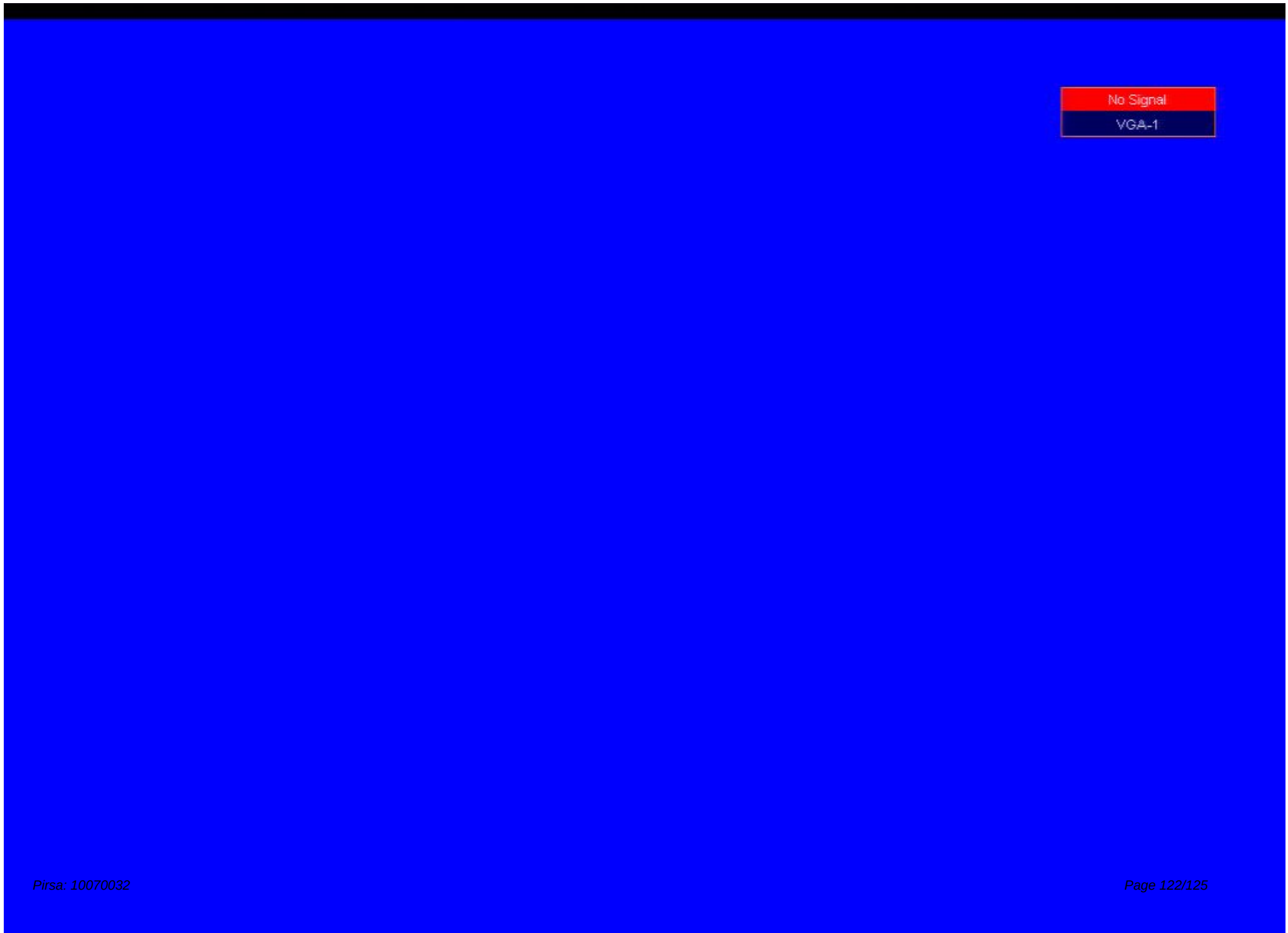
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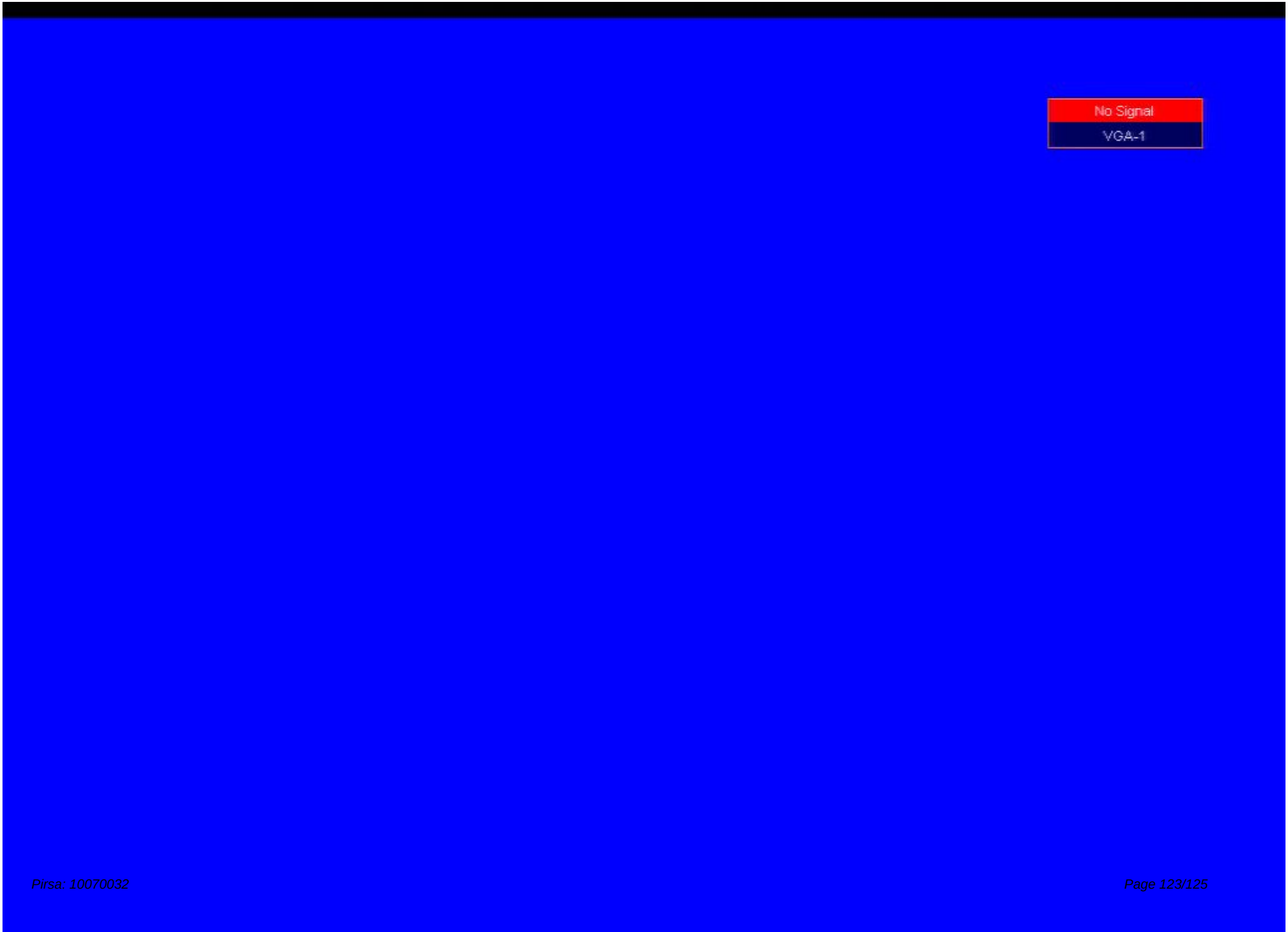
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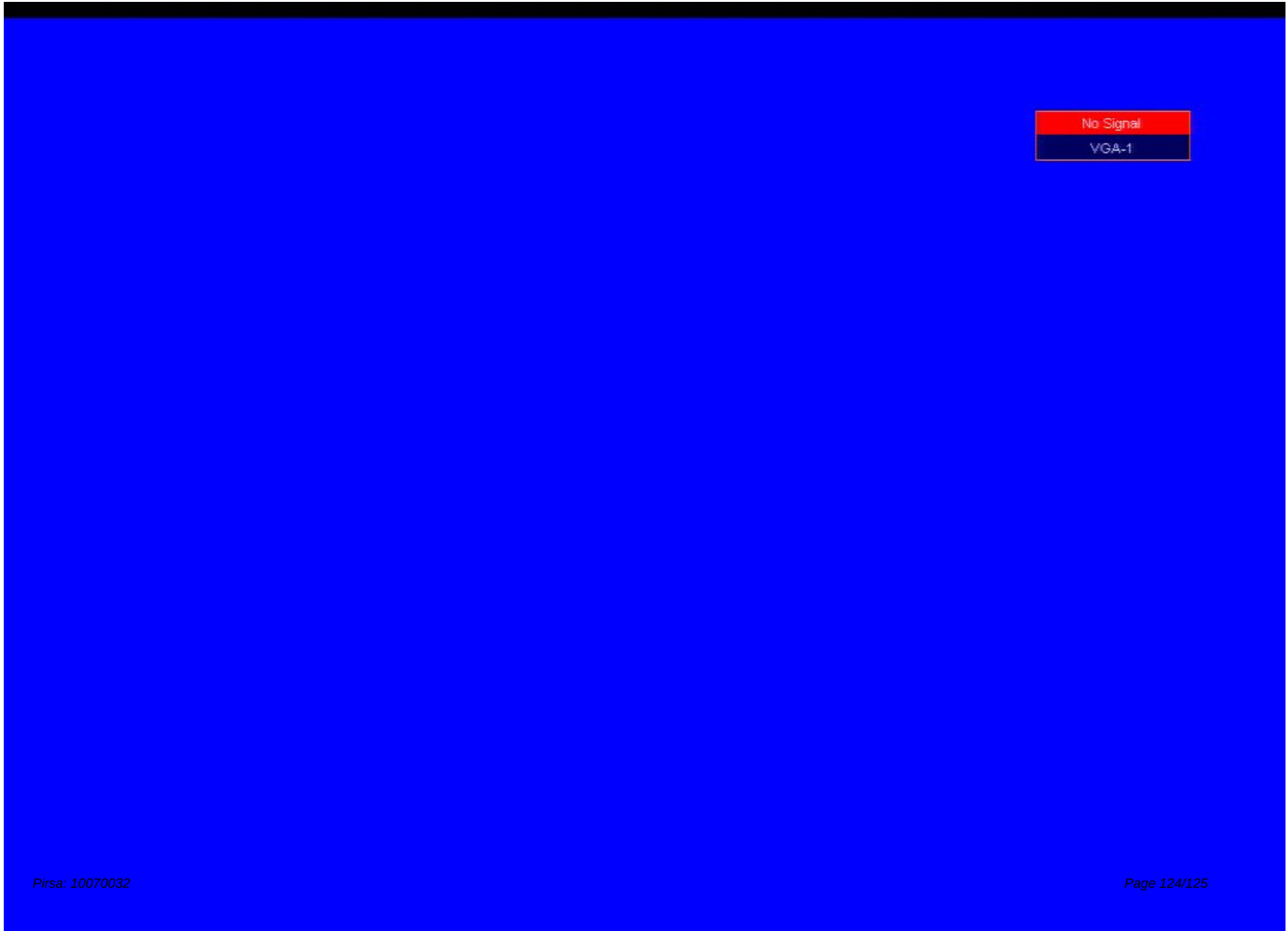
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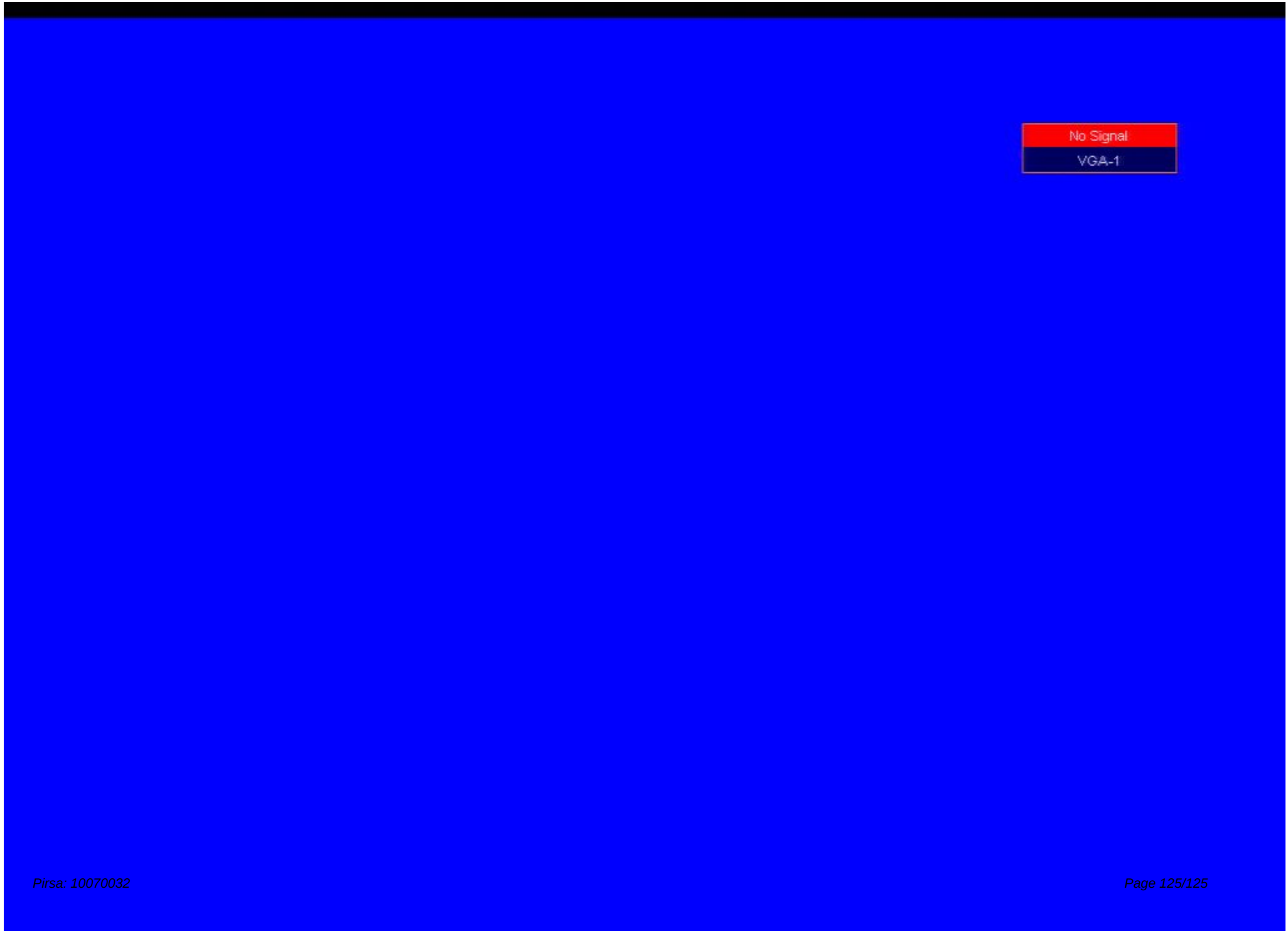
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