Title: Last Chance to Be Wrong About What Might Be Discovered at the LHC

Date: Sep 21, 2011 02:00 PM

URL: http://pirsa.org/11090101

Abstract: The Large Hadron Collider (LHC) is now running (after a rocky start). This talk reviews why the start was rocky and how this constrains the physics program over the next few years. I will briefly survey how 'naturalness'
arguments argue why something should be discovered, and why theoretical proposals fall into three main categories. If time permits I will close by telling you why I think the cosmological constant problem implies the LHC will strike paydirt and make quantum gravity an experimental science.

The Large Hadron Collider

Last chance to be wrong about what the LHC will find

C.P. 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?
  - *The orthodoxy*
  - *Quantum Gravity in your face*
- Outlook

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What is it?

- The Machine
- Recent Events

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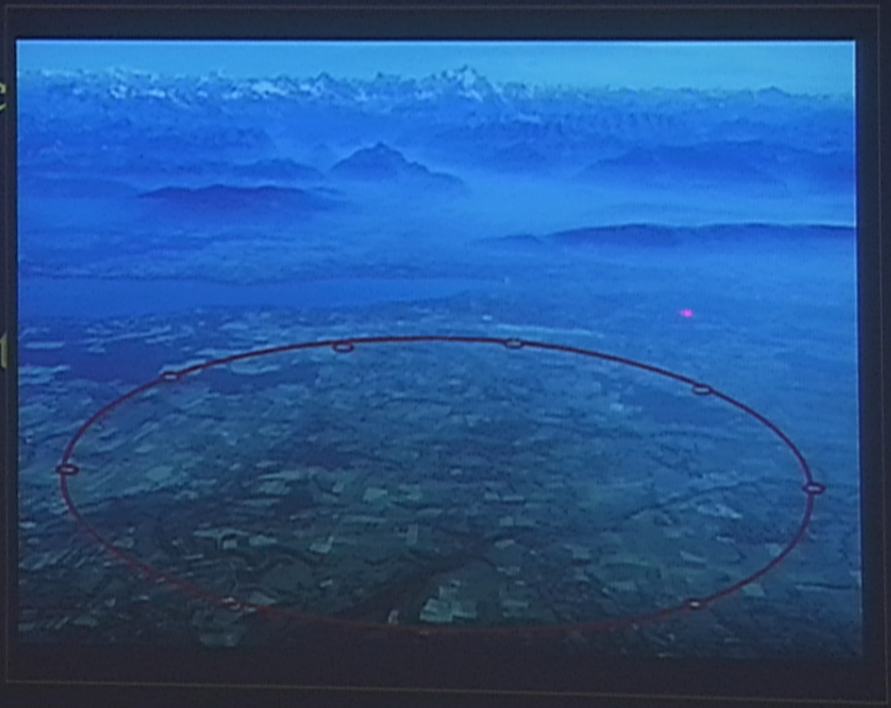
What is it?

- The Machine
- Recent Event



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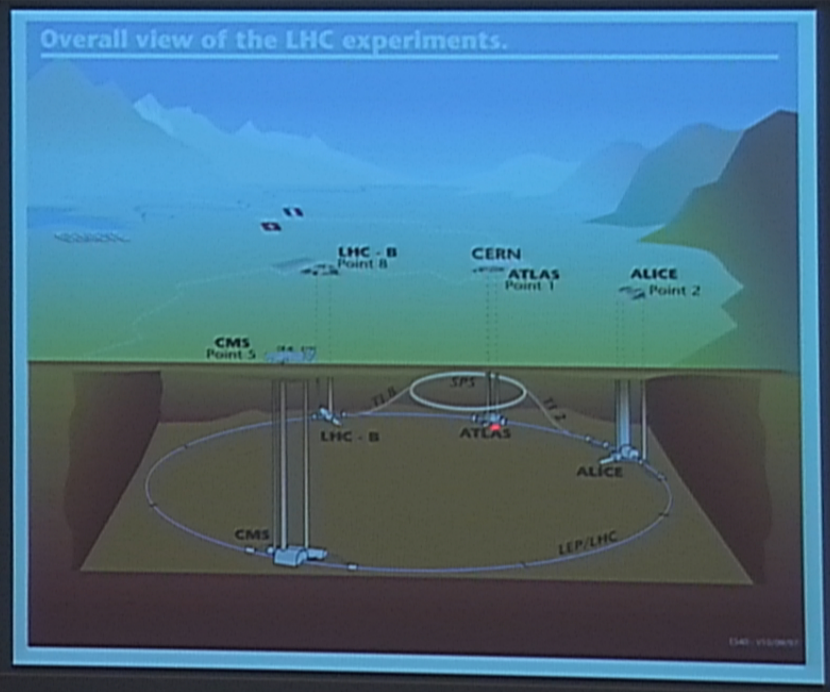

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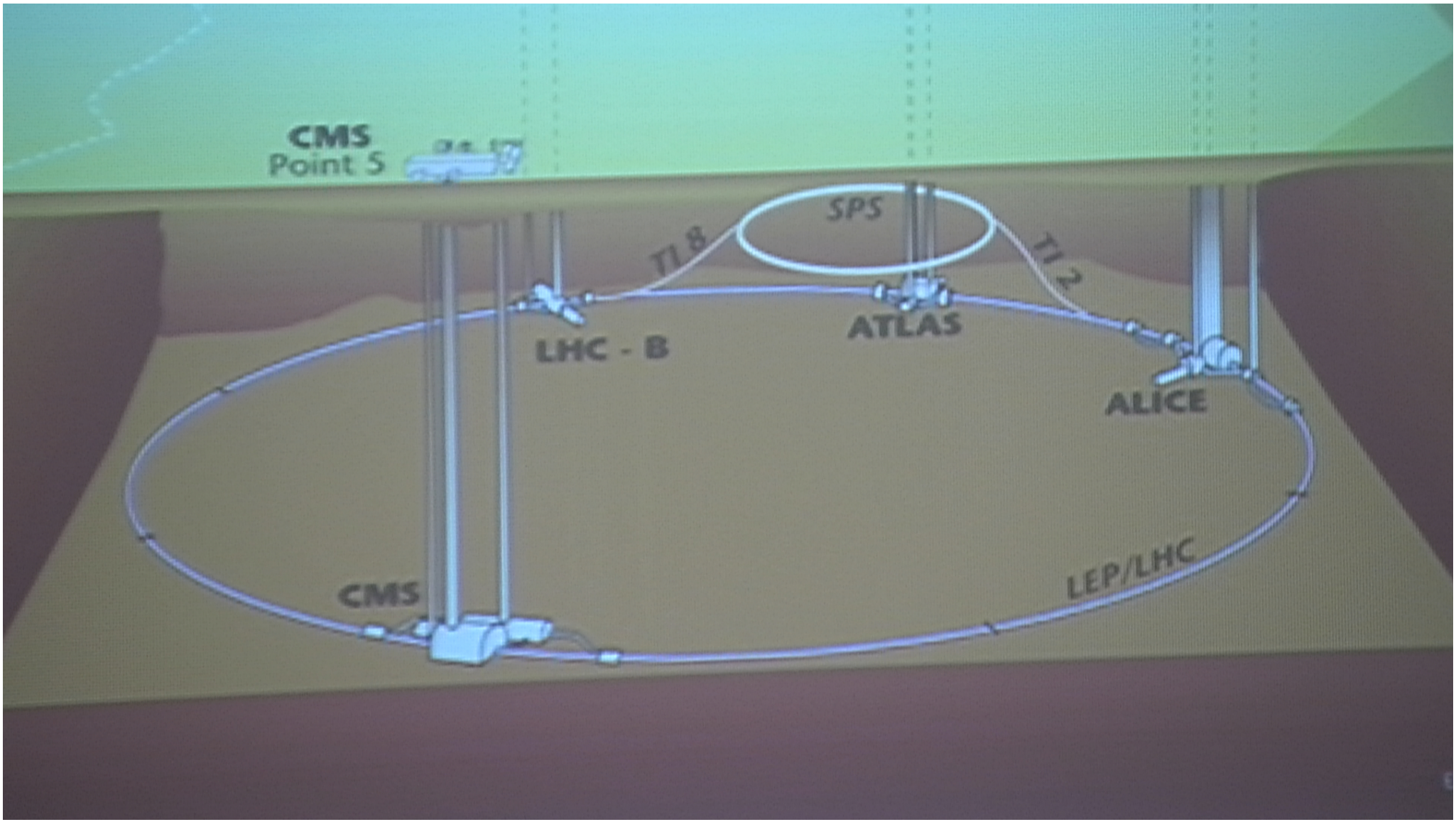
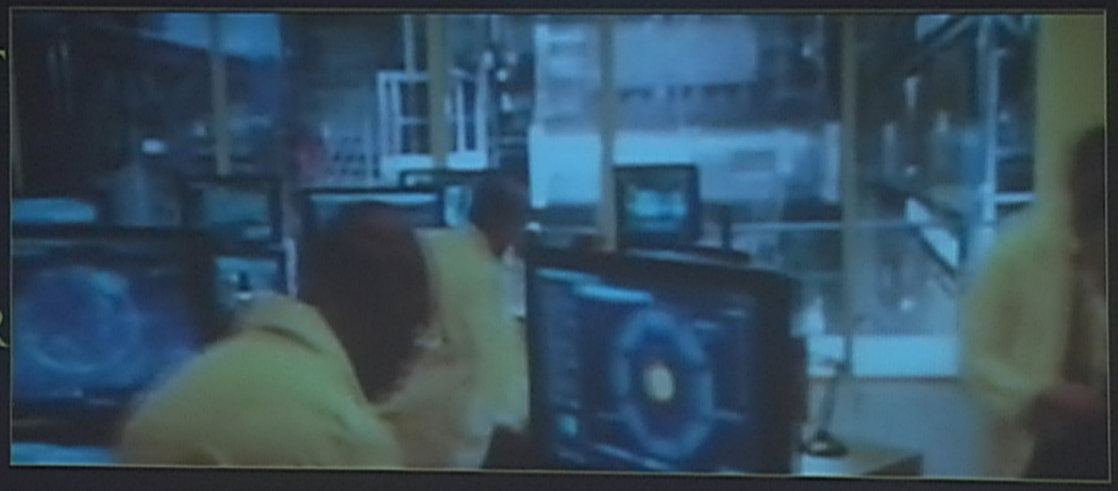

CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

What is it?

- T
- R



Angels & Demons

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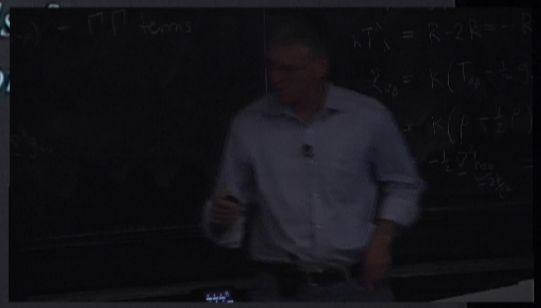
What is it?

- T
- R

Angels
Demo

CERN



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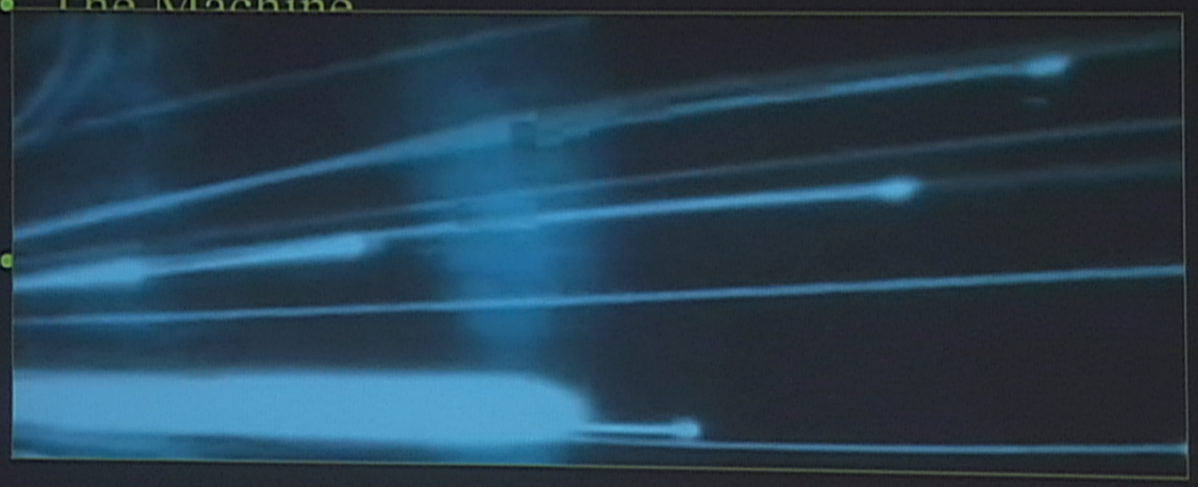

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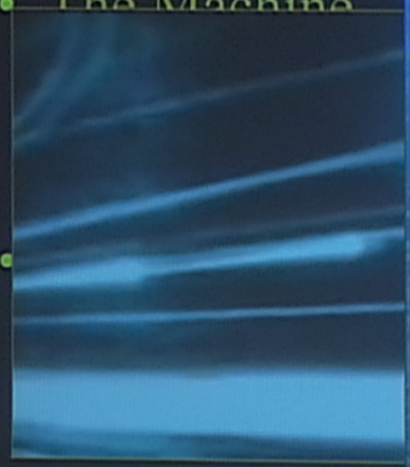

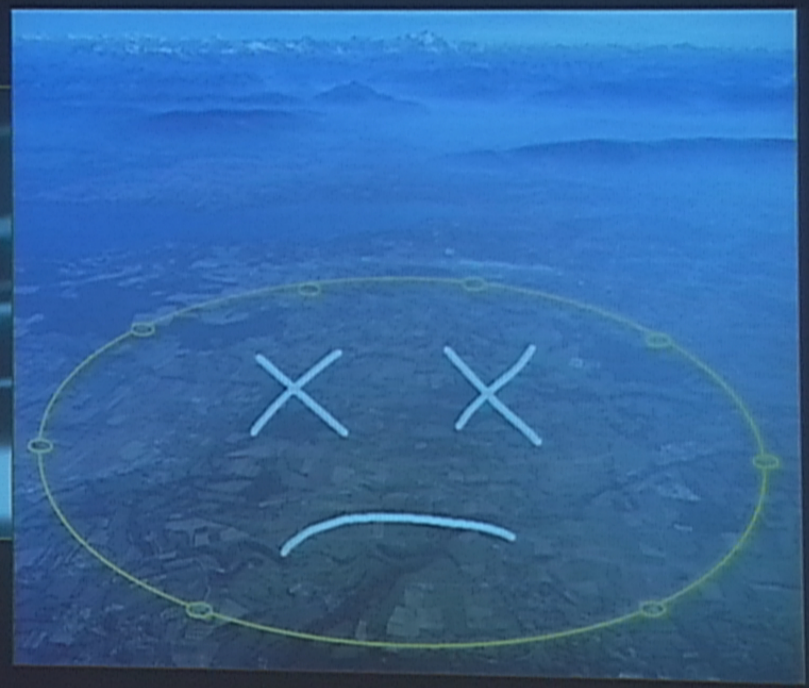

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What is it?

W. Trischuk

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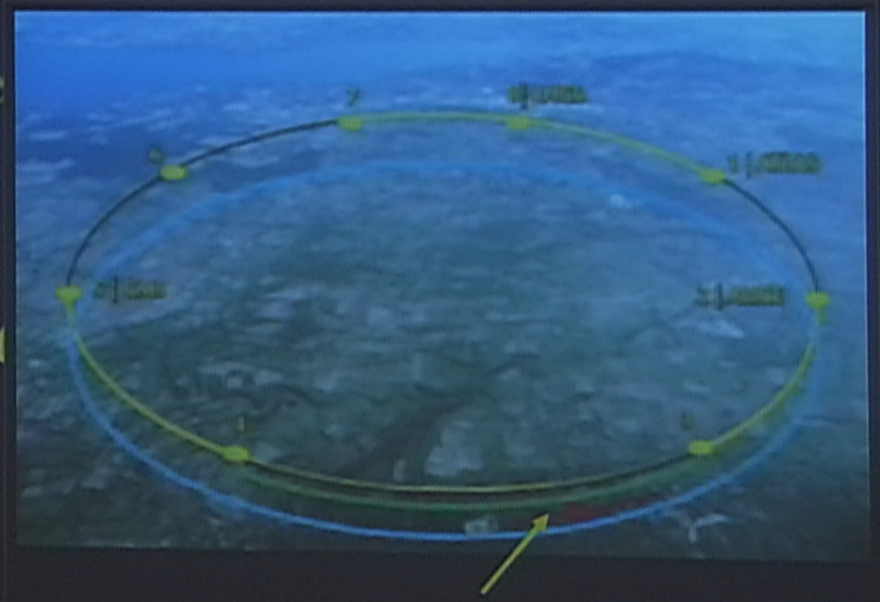

The Incident

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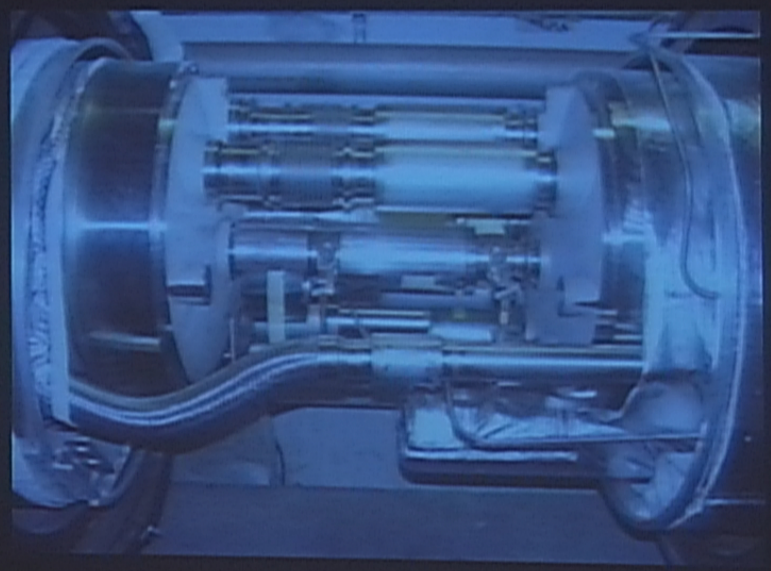

dipole interconnect

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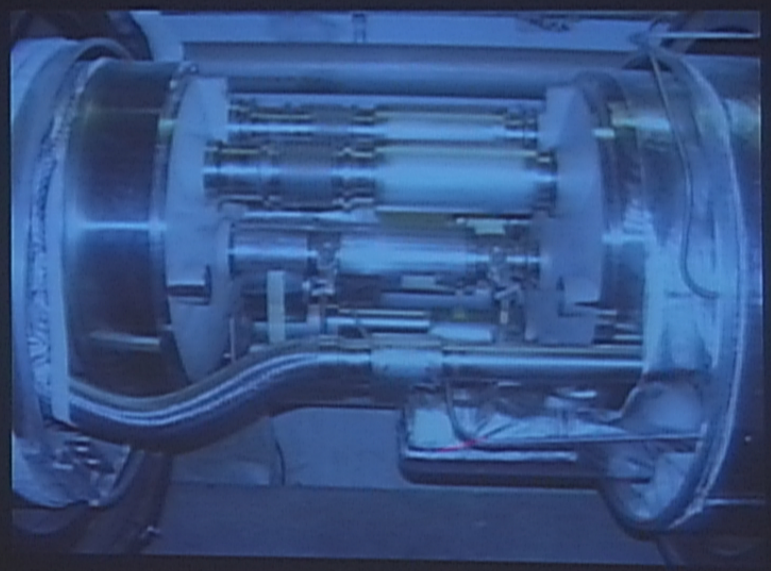

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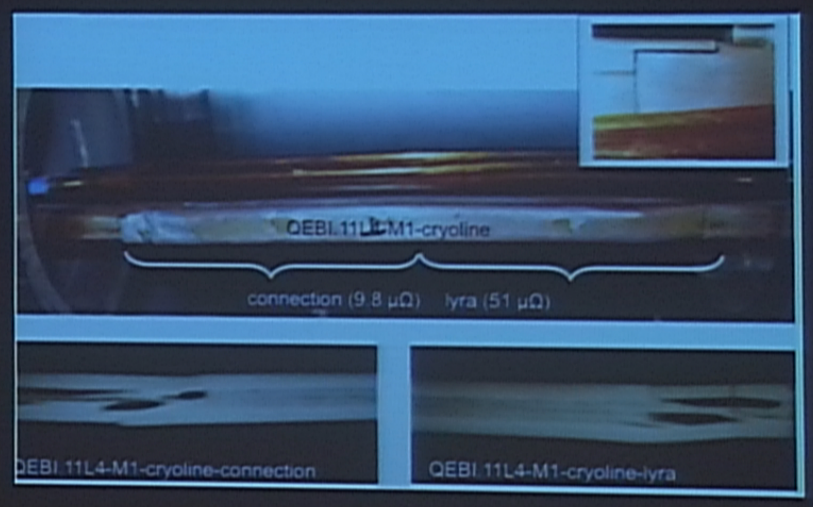

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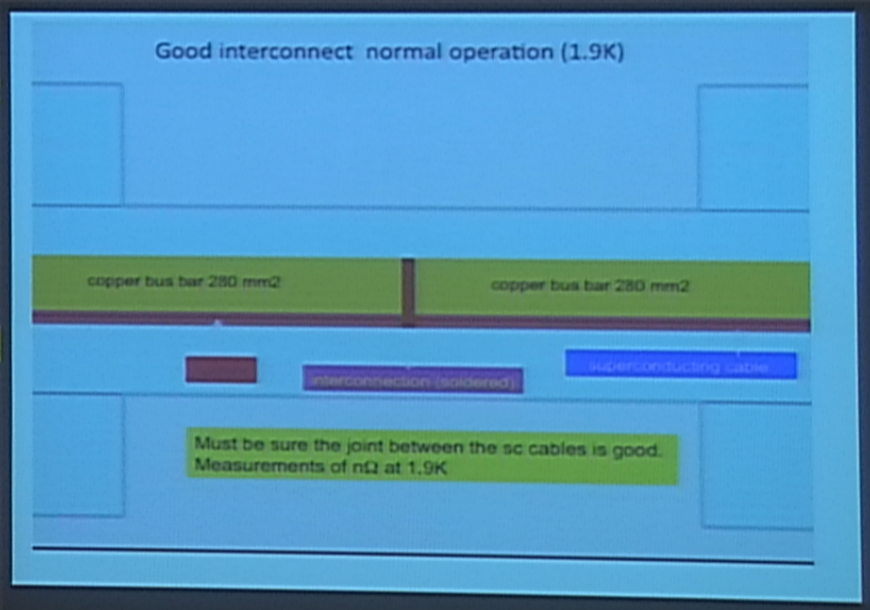

schematic connection

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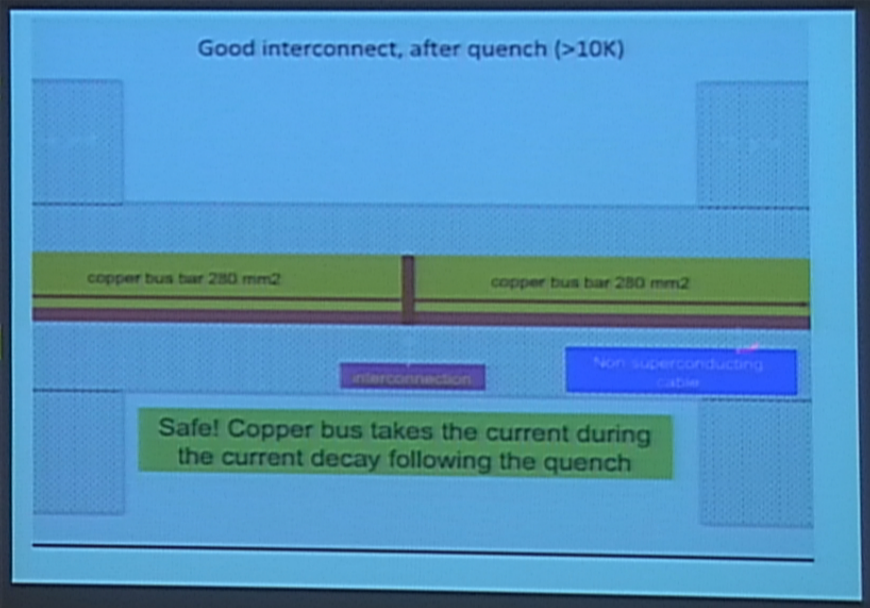

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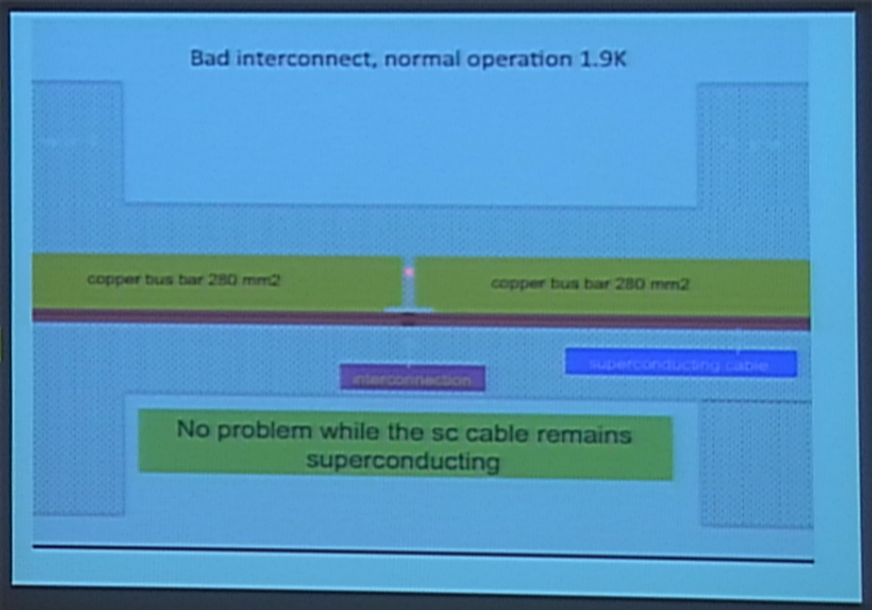

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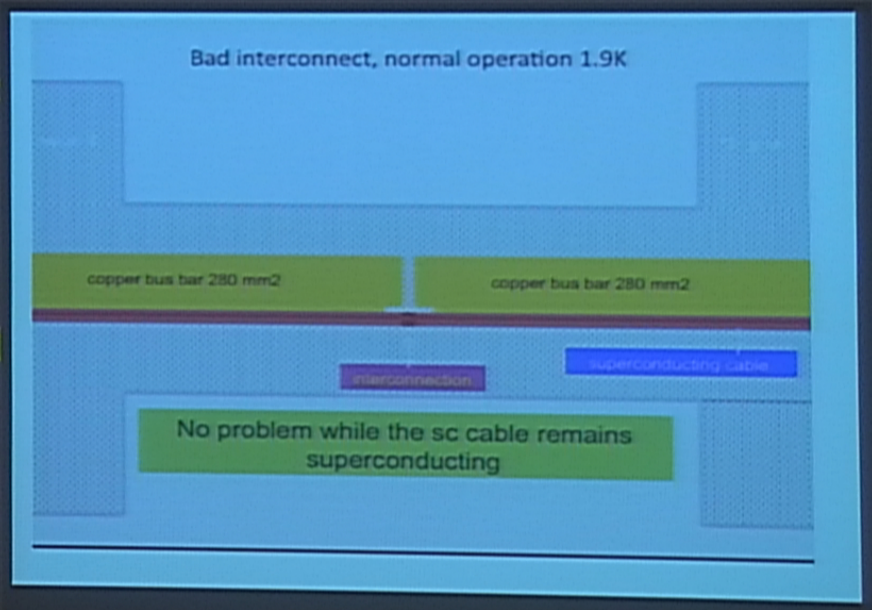

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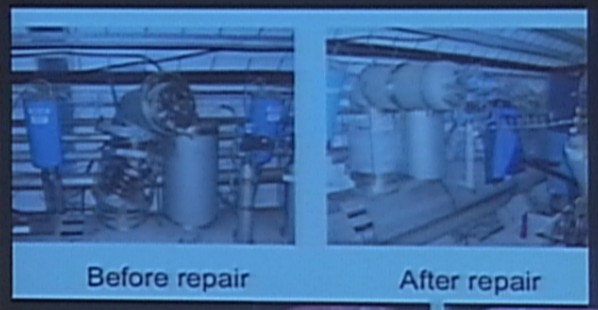

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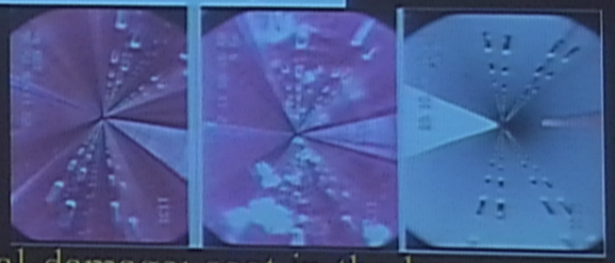

Physical damage; soot in the beam pipe; and so on….

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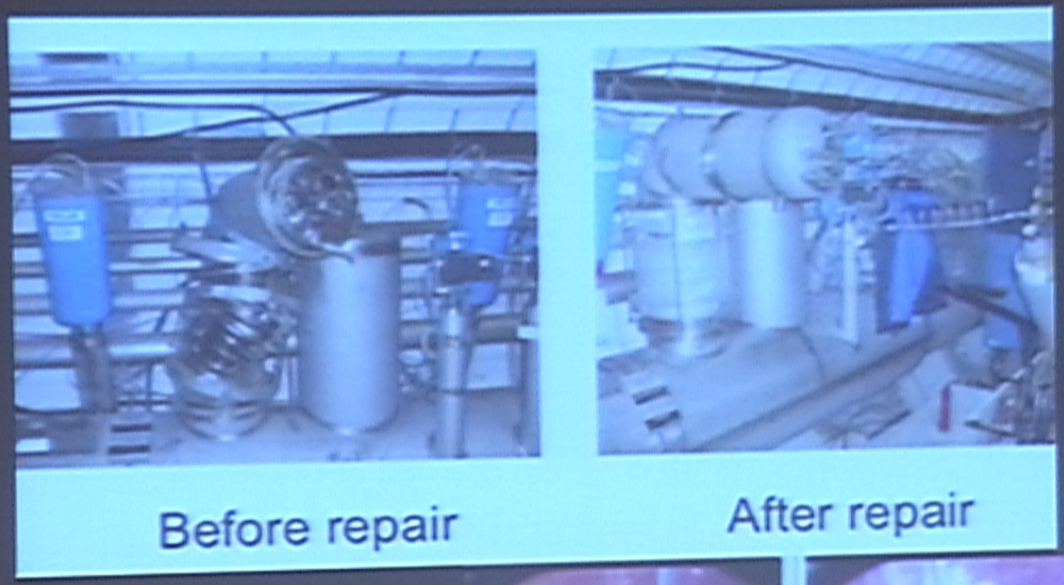
achine

Event



Physical damage; soot in the beam

What is it?

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- The Machine
- Recent Event

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

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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***

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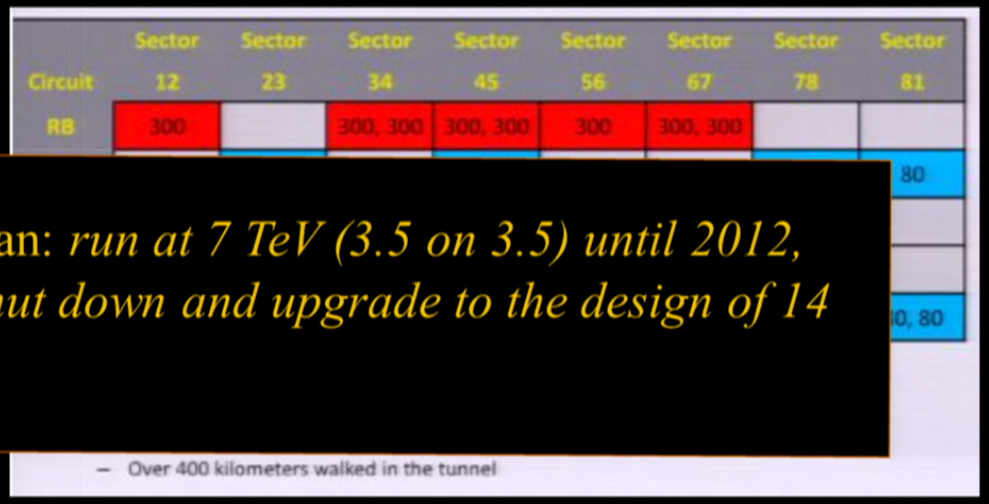
What is it?

W. Trischuk

- The Machine

- Recent

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



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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

Up and running again for some time

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What is it?

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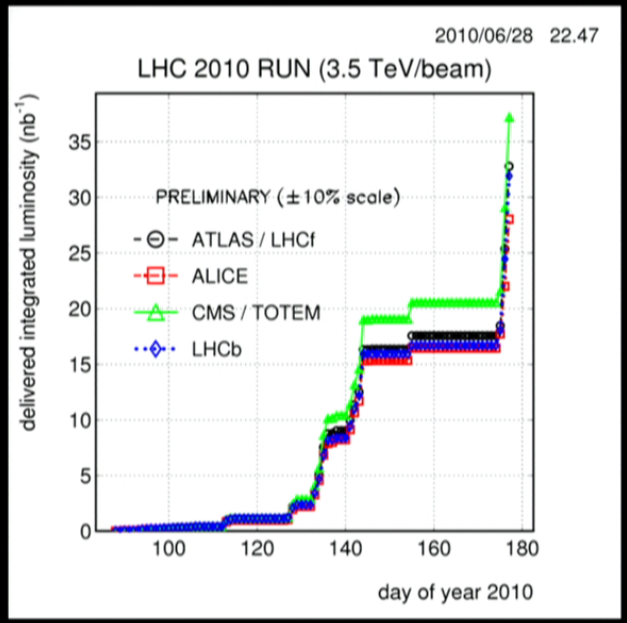

The accelerator has been working superbly

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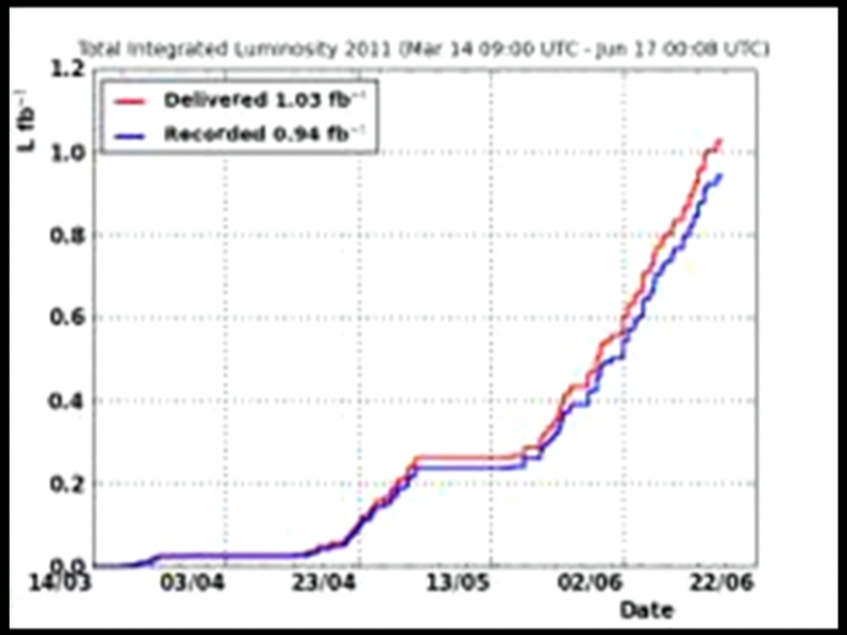

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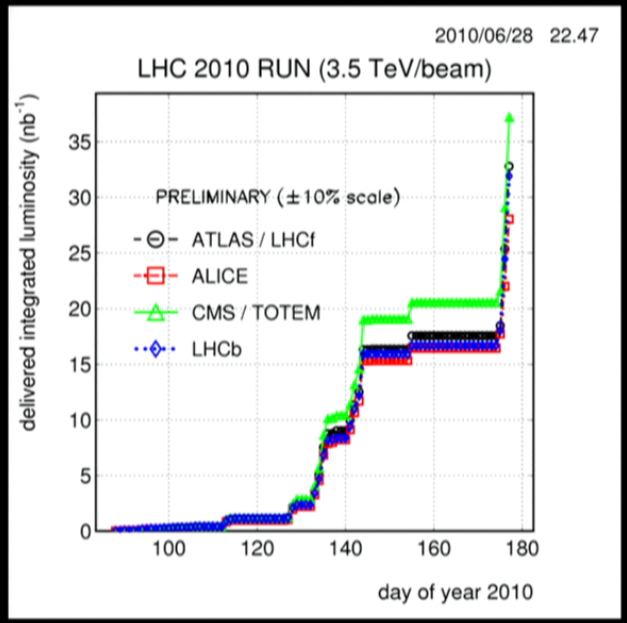

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arXiv:1109.2205 [pdf, other]

Measurement of the Drell-Yan differential cross section at 7 TeV

Stoyan Stoynev, for the CMS Collaboration

arXiv:1109.2242 [pdf, other]

Search for displaced vertices arising from decays of new heavy particles in 7 TeV pp collisions at ATLAS

ATLAS Collaboration

arXiv:1109.2352 [pdf, other]

Search for Supersymmetry at the LHC in Events with Jets and Missing Transverse Energy

CMS Collaboration

arXiv:1109.2457 [pdf, ps, other]

A Search for Higgs Boson in $H\rightarrow W^+W^-$

Kevin Sung, for the CMS Collaboration

arXiv:1109.2576 [pdf, other]

Measurement of the WW Cross Section in 7 TeV pp Collisions with the ATLAS Detector

Haijun Yang on behalf of ATLAS

arXiv:1109.3089 [pdf, ps, other]

Search for a heavy neutral particle decaying into an electron and a muon using 1 fb^-1 of ATLAS data

ATLAS Collaboration

Comments: 5 pages plus author list (17 pages total), 4 figures, 2 tables, submitted to Eur. Phys. J. C Letters

Subjects: **High Energy Physics - Experiment (hep-ex)**

A search is presented for a high mass neutral particle that decays directly to the emu final state. The data sample was recorded by the ATLAS detector in sqrt(s)=7 TeV pp collisions at the LHC from March to June 2011 and corresponds to an integrated luminosity of 1.07 fb^-1. The data are found to be consistent with the Standard Model background. The high emu mass region is used to set 95% confidence level upper limits on the production of two possible new physics processes: tau sneutrinos in an R-parity violating supersymmetric model and Z'-like vector bosons in a lepton flavor violating model.

Good science has been coming out…stay tuned!

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Why was it built?

Why was it built?

- The Standard Model
- Successes
- Limitations

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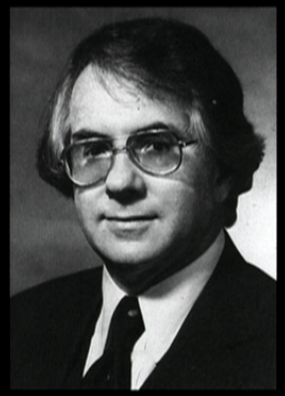
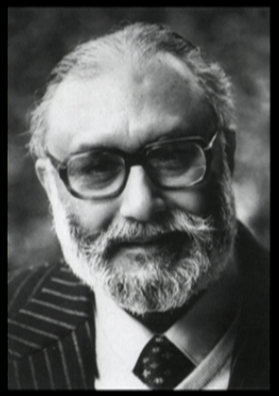

The Standard Model is the theory which describes the known elementary particles and their interactions. It describes well all experiments which have been performed to date, with a few recent exceptions.

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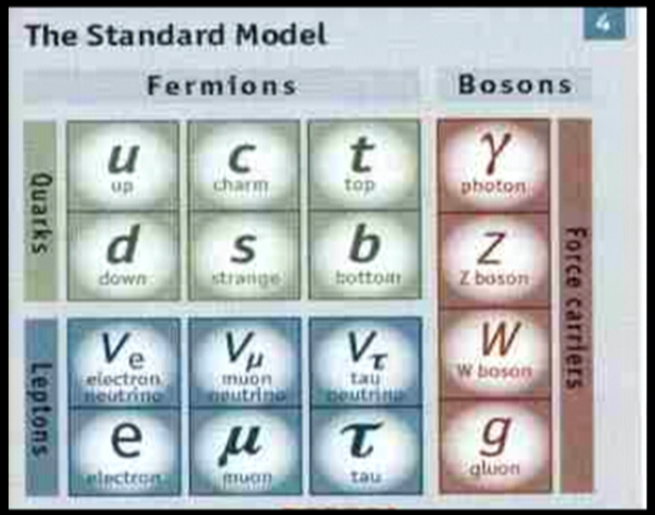

The 12 known constituents of matter
and the 4 fundamental forces

AAAS

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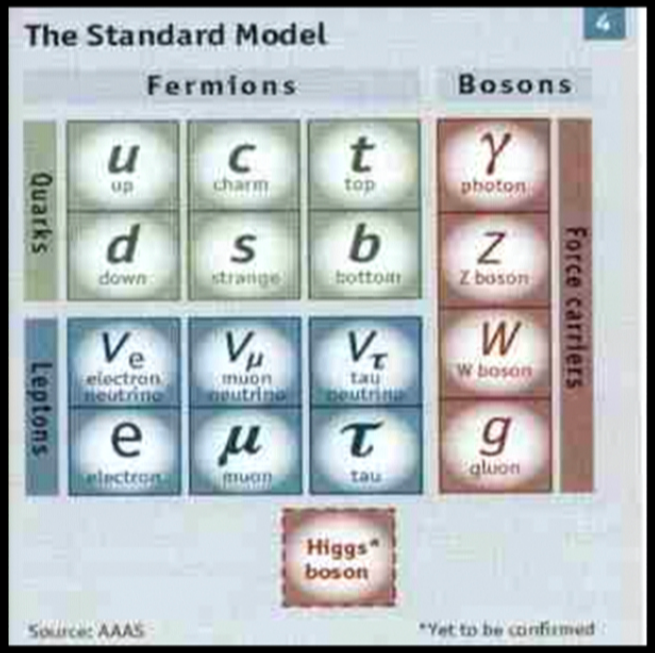

One SM particle remains AWOL: the Higgs boson

AAAS

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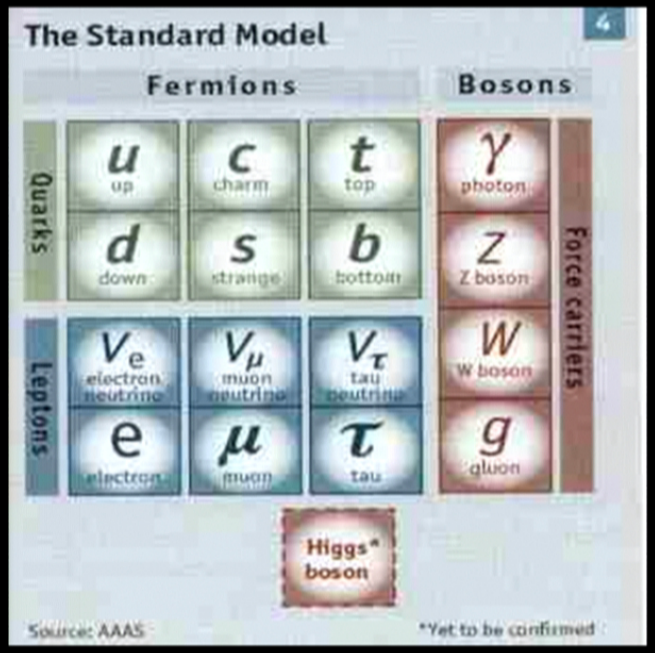

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AAAS

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$$
\begin{aligned}
L = {} & \overline{E}DE + \overline{L}DL + \overline{Q}DQ + \overline{U}DU + \overline{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}\widetilde{G}^{\mu\nu}_{\alpha} \\
& + H\left(\overline{L}y_l E\right) + H\left(\overline{Q}y_d D\right) + H^{*}\left(\overline{Q}y_u U\right) \\
& + D_{\mu}H^{*}D^{\mu}H + \lambda\left(H^{*}H - v^{2}\right)^{2}
\end{aligned}
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A model only a mother could love…

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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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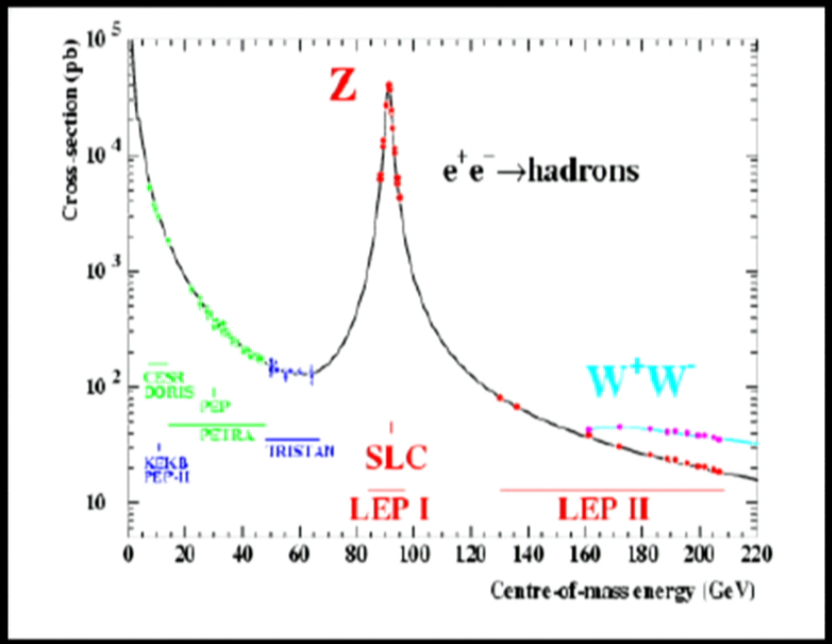

The SM is tested in detail, such as through e^+e^- collisions

A Tonazzo: Moriond 2002

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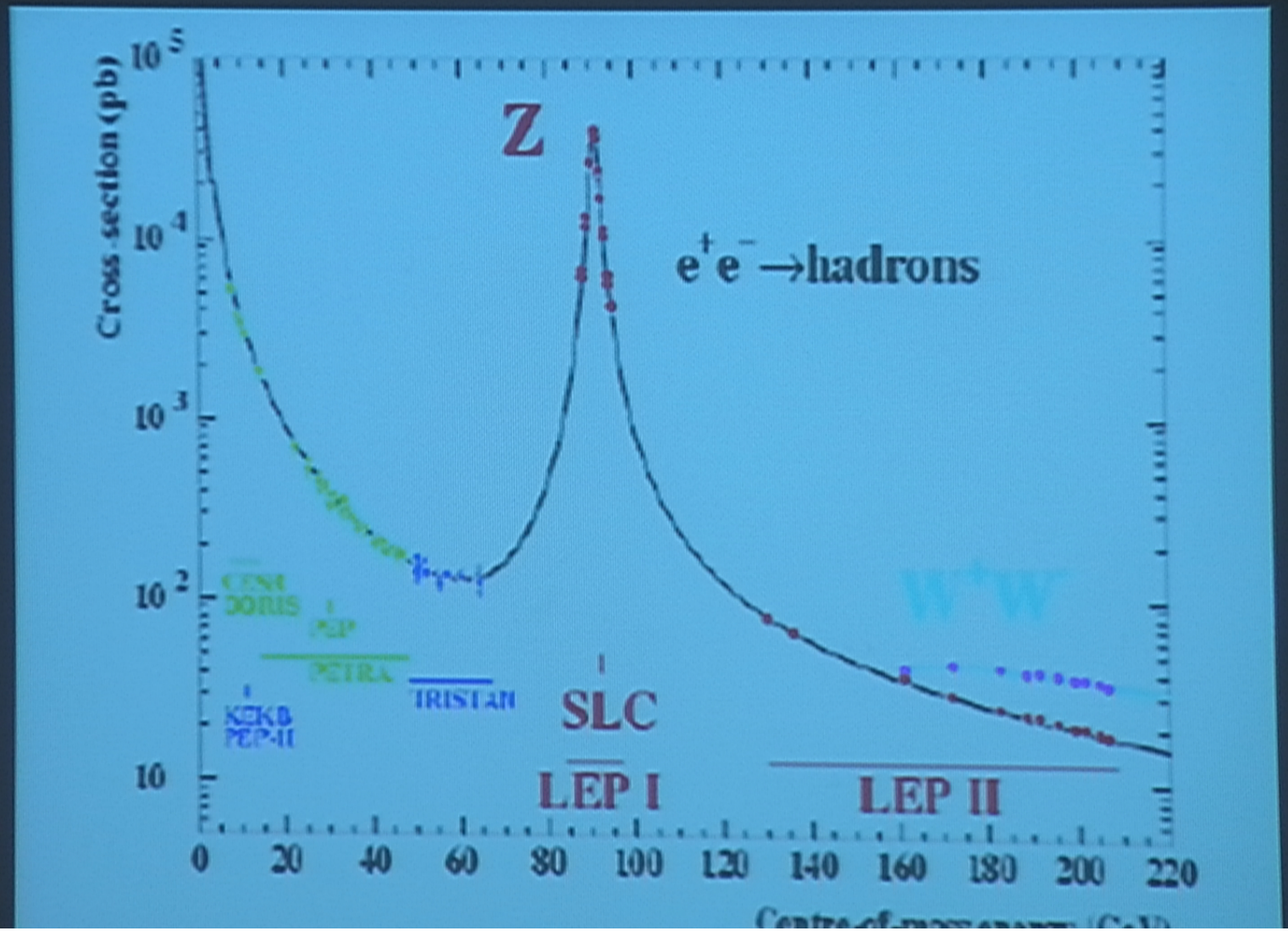
Cross-section (pb)
Z
e+e− →hadrons
W+W−
CESR
DORIS
PEP
PETRA
TRISTAN
KEKB
PEP-II
SLC
LEP I
LEP II
0
20
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60
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100
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140
160
180
200
220

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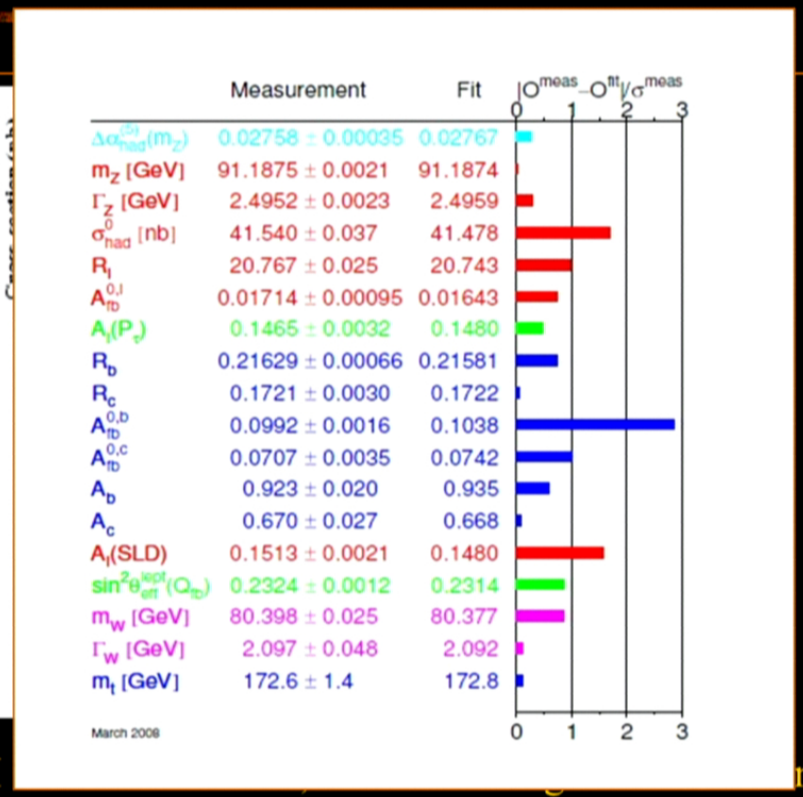

The SM ... ns

M. Verzocchi: ICHEP 2008

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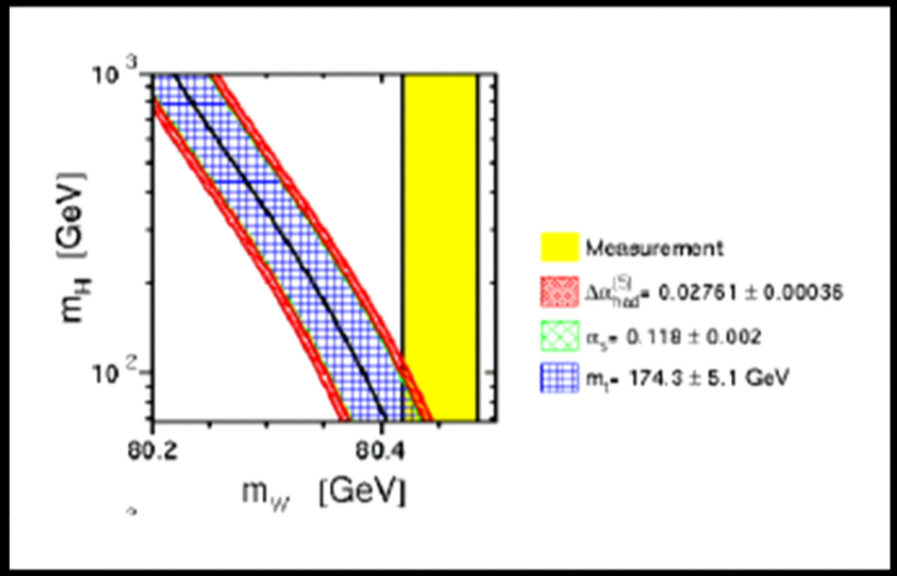

Unknown quantities, like the Higgs mass, are strongly constrained by the accuracy of these tests

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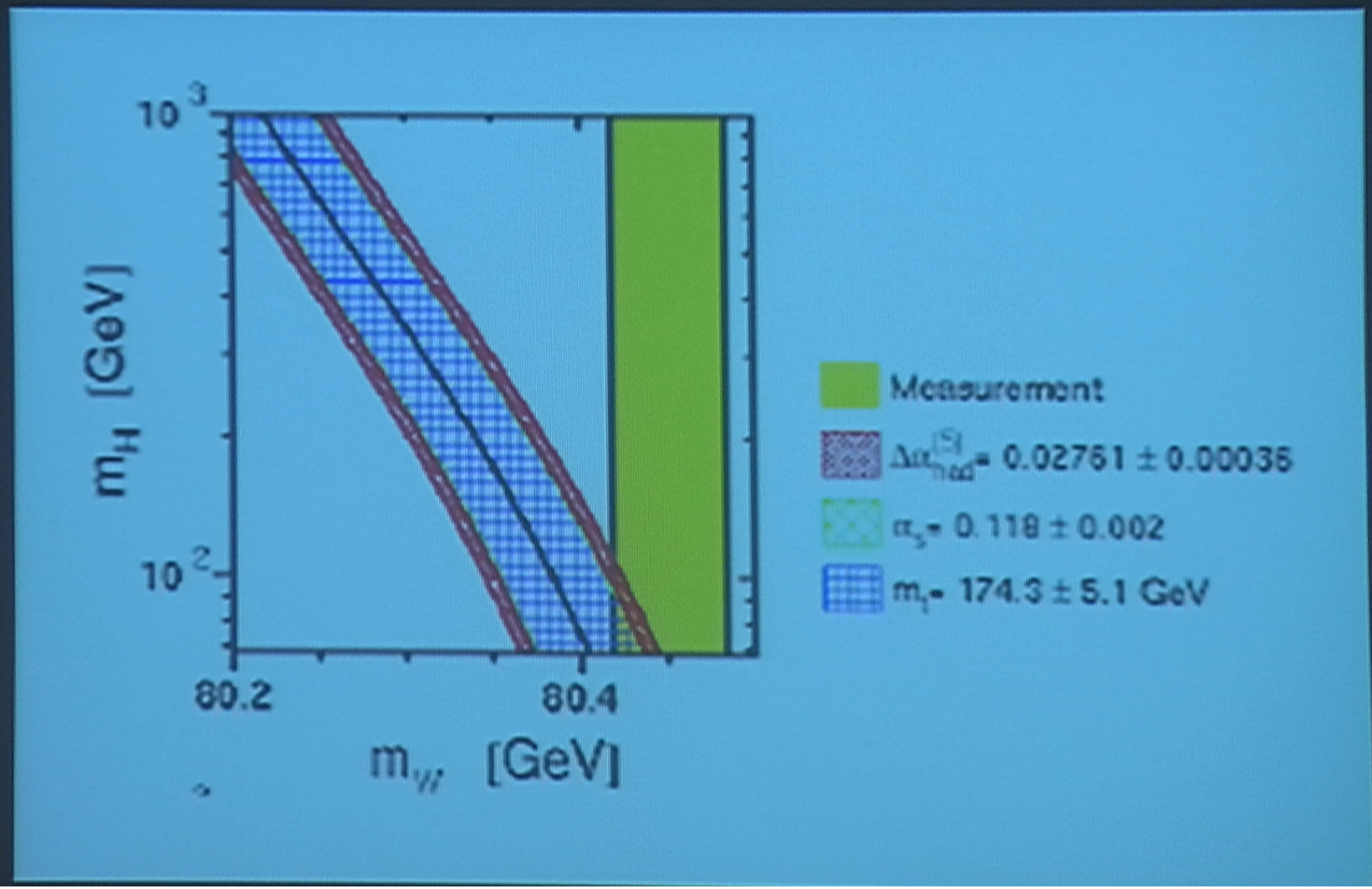

10^3
10^2
m_H [GeV]
80.2
80.4
m_W [GeV]
Measurement
$\Delta\alpha^{(5)}_{had}$ = 0.02761 ± 0.00035
α_s = 0.118 ± 0.002
m_t = 174.3 ± 5.1 GeV

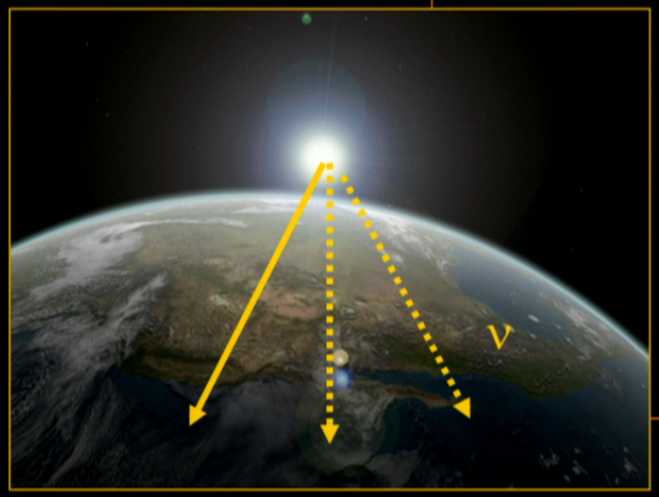
Why was it built?

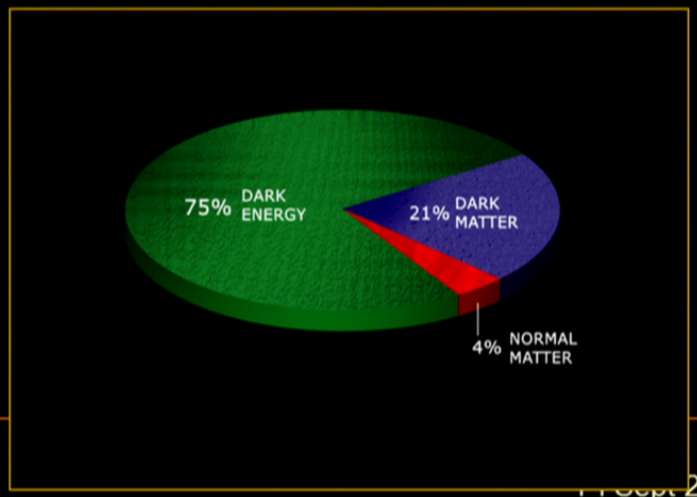
- The Standard
- Successes

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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Neutrinos appear to have masses…
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Theoretical Problems:

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

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Why was it built?

- The Standard
- 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	$M_W \sim G_F^{-1/2} \sim 10^2$ 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

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scale $m_p \sim 1$ GeV

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

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

n scale? $M_L = M_W^2 / m_\nu \sim 10^{11}$ GeV

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Why was it built?

- Ideas for what lies beyond the Standard Model are largely driven by 'technical naturalness'.
  - Motivated by belief that SM is an effective field theory.

$$L_{SM} = m_0{}^2 H^* H \quad + \quad dimensionless$$

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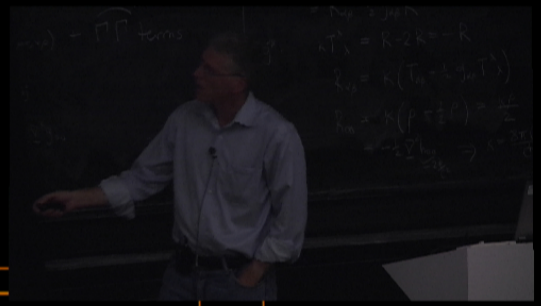

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$M_p \sim 10^{18}$ GeV

$M \sim 10^{11}$ GeV

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BUT: effective theory can be defined at many scales

$$m^2 \approx m_0^2 + \cdots$$

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What might be seen?

- Nothing?
- The orthodoxy
- Quantum Gravity in your face

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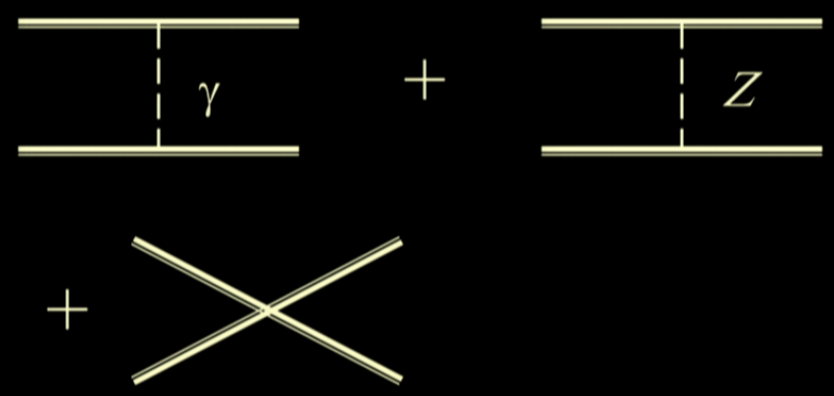

W-W scattering: $\sigma \sim (\alpha^2 \ln E)/M_W^2$

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

AAAS

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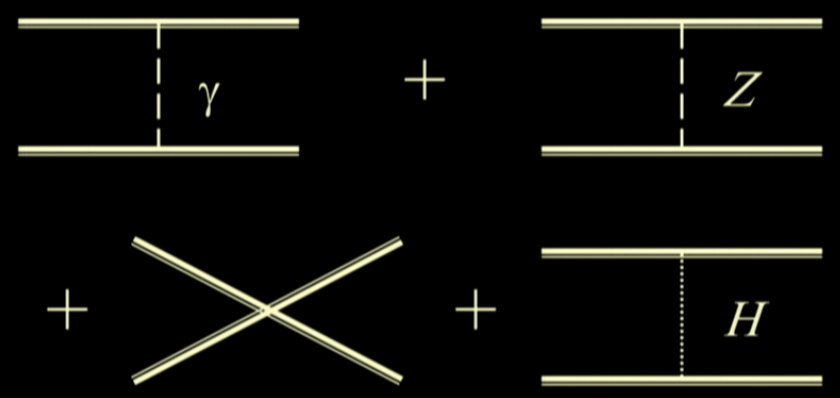

W-W scattering: $\sigma \sim \alpha^2/E^2$

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

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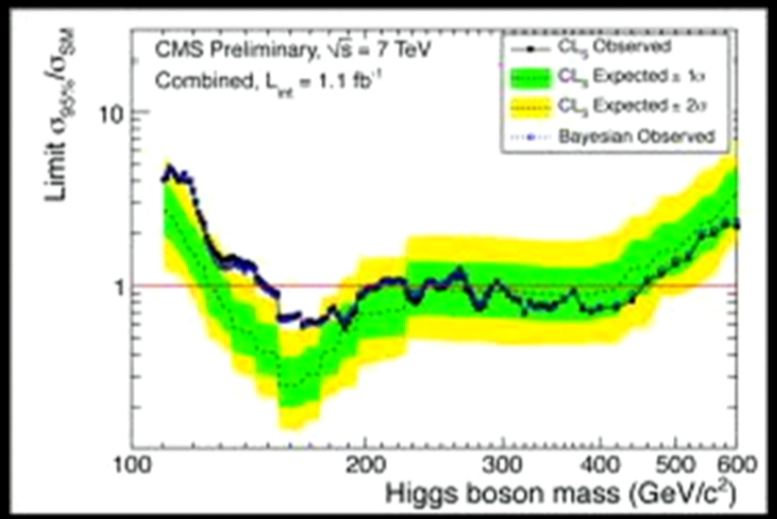

The Standard Model Higgs?

The SM Higgs boson decays into the heaviest particle it can, so search strategies depend on its assumed mass

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- *Beyond the SM*: basically three options:

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

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What might be seen?

- N
- Th
- Qu

$M_p \sim 10^{18}$ GeV

$M \sim 10^{11}$ GeV

$M_w \sim 10^{2}$ GeV

No H field, so no m^2 HH term to worry about

$$m^2 \approx \underbrace{m_1^2 + kM^2}_{} + \cdots$$

$$m^2 \approx m_0^2 + \cdots$$

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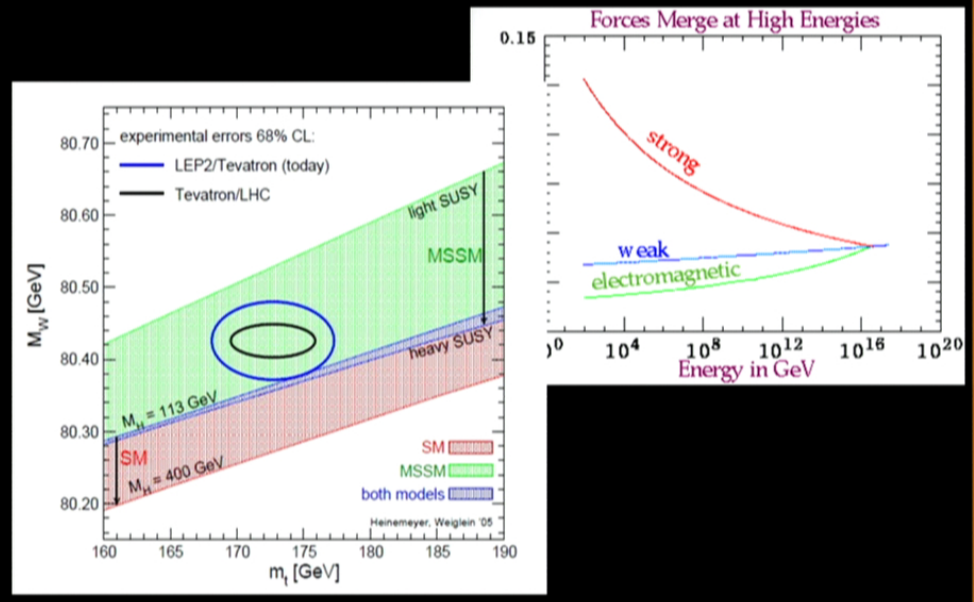

The data contain tantalizing hints for susy for those who wish to find it…

A Tonazzo: Moriond 2002

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Gravity scale is really the weak scale

- ***Large extra dimensions***

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What might be seen?

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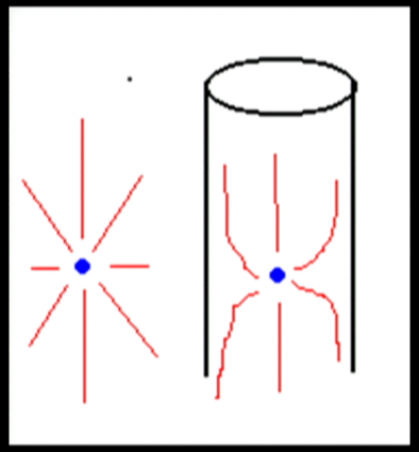
- If there are extra dimensions and they are large, then the gravity scale could be much lower than we think….



$$F = \frac{GMm}{r^{d-1}} \qquad r < a$$

$$F = \frac{GMm}{r^2 a^{d-3}} \qquad r > a$$

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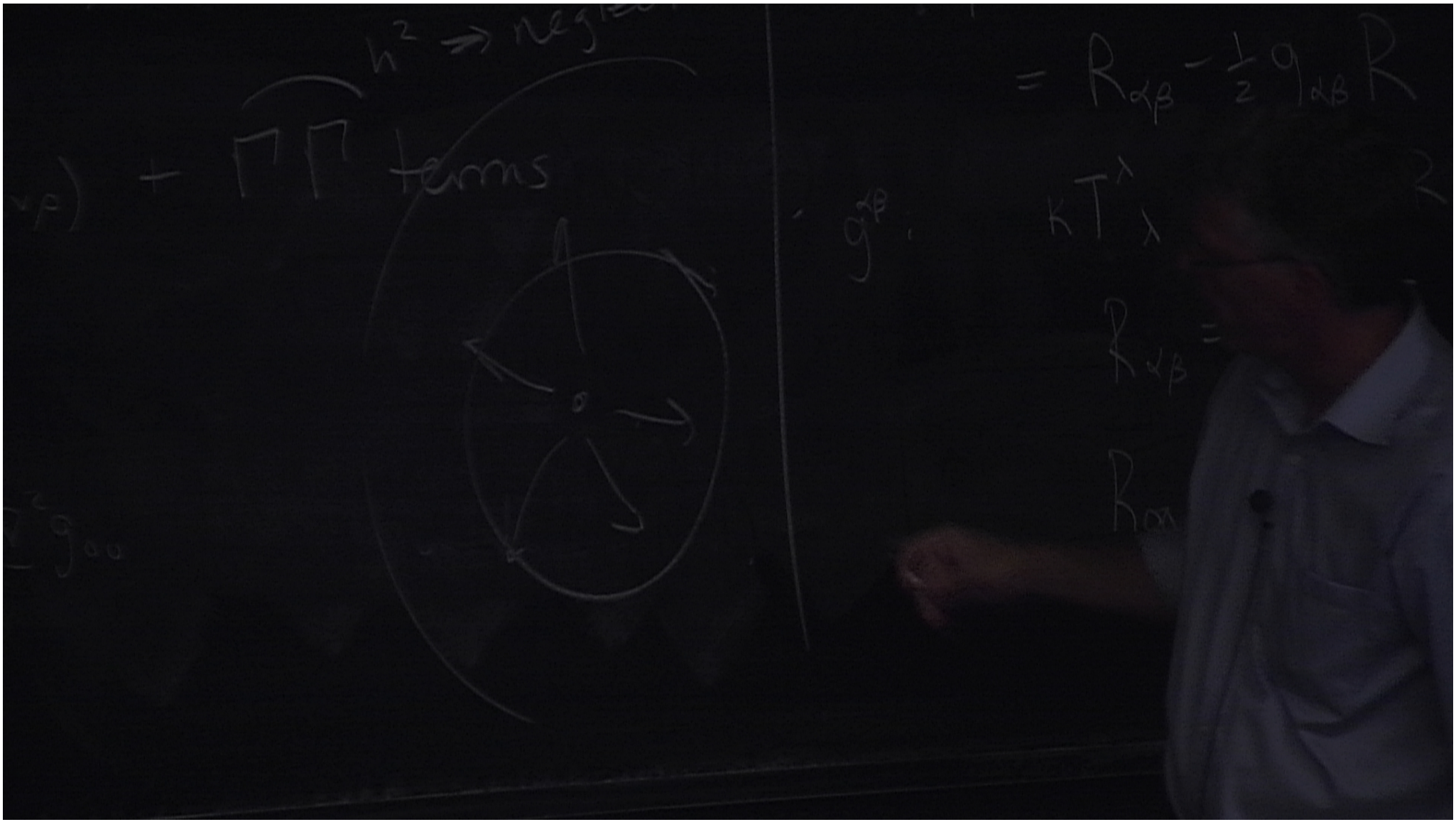
h² → negl
+ ΓΓ terms
= R_αβ − ½ g_αβ R
g^αβ
κ T^λ_λ
R_αβ =

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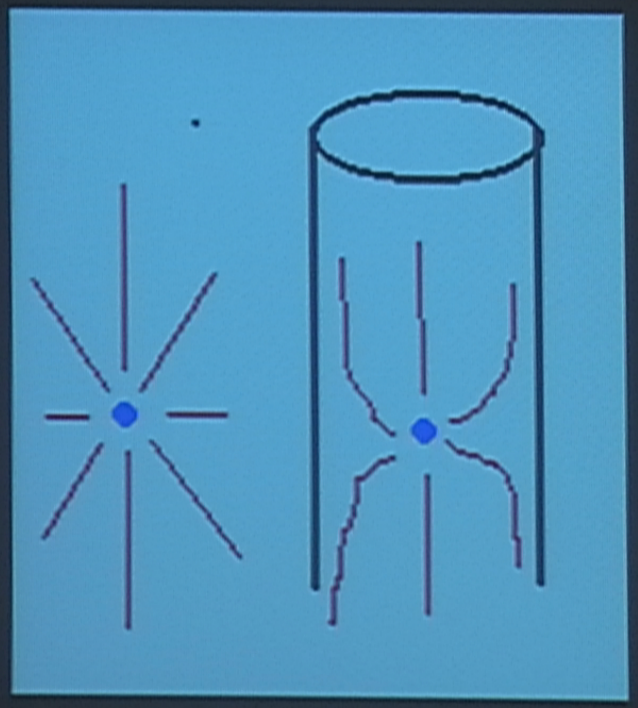

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No elementary Higgs:

posite models

metry alleviating fine tuning:

rsymmetry

cale is really the weak scale

e extra dimensions

Absolutely no evidence (yet) for any of these options.....

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What might be seen?

w Aghababaie, Parameswaran & Quevedo 03 and w van Nierop 11

- Nothing?

- *Beyond the SM*: basically three options:

No elementary Higgs:

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New symmetry alleviating fine tuning:

- ***Supersymmetry***

Gravity scale is not really M_p

- ***Extra dimensions***

My Bet

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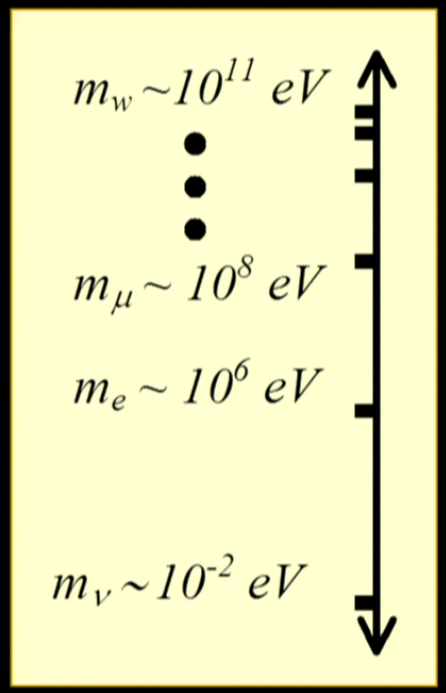
- 

Can apply same argument to scales between TeV and sub-eV scales.

$$L_{SM} = \sqrt{-g}\ \mu_0{}^4 + \cdots$$

$$\mu^4 \approx \mu_0^4 + k_\nu m_\nu^4$$

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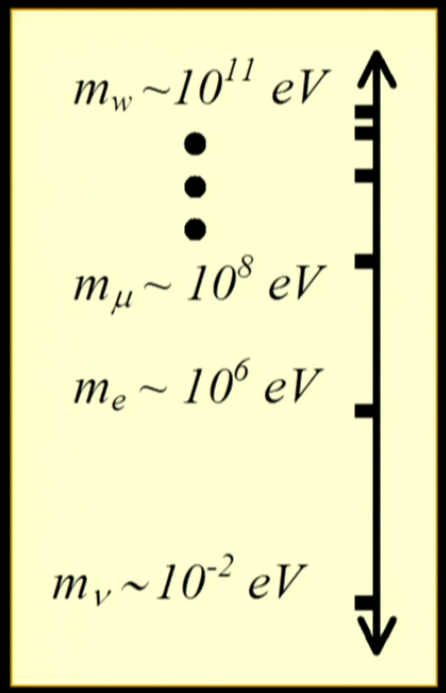
- 

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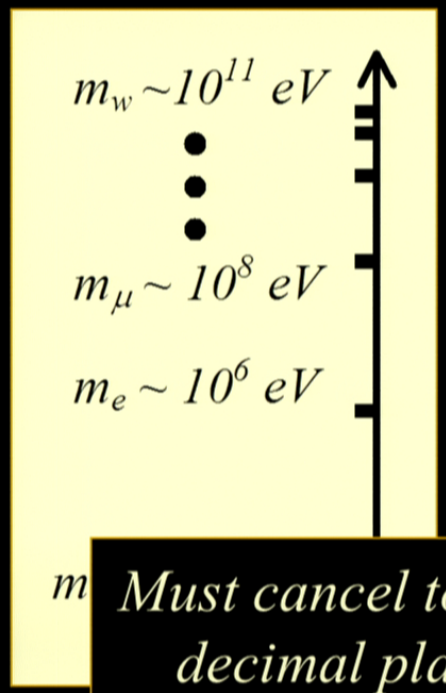
- 

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$$\mu^4 \approx \mu_0^4 + k_\nu m_\nu^4$$

Must cancel to 32 decimal places!!

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What might be seen?

- *The problem:* Einstein requires two things to be equal that seem to be different.

  IN 4 DIMENSIONS

  1. curvature of the observed universe

  2. energy density of Lorentz-invariant vacuum

$$G_{MN} = \kappa^2 T_{MN} \neq \lambda\, g_{MN}$$

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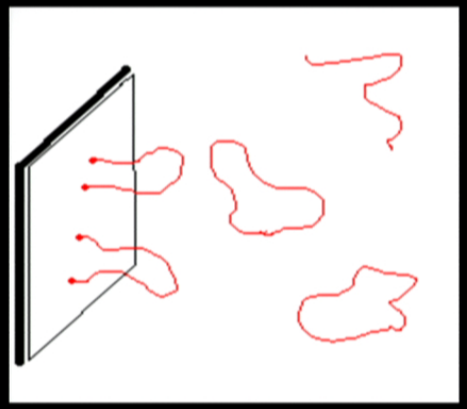
What might be seen?

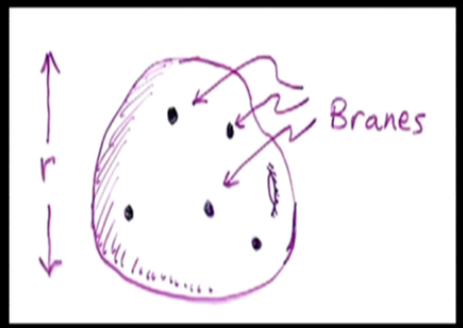
Polchinski
Shaposhnikov

- e.g. ***Can get localized lorentz-invariant energy density in string theory or field theory:***

  Particles can be localized on surfaces (branes, or defects) within the extra dimensions

  Gravity is not similarly localized





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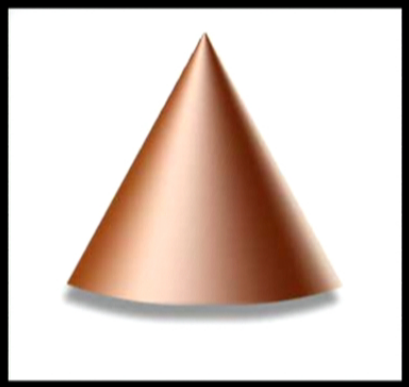
What might be seen?

- In extra dimensions 4D vacuum energy can curve the other dimensions and not the ones we can see *(eg geometry of a cosmic string)*



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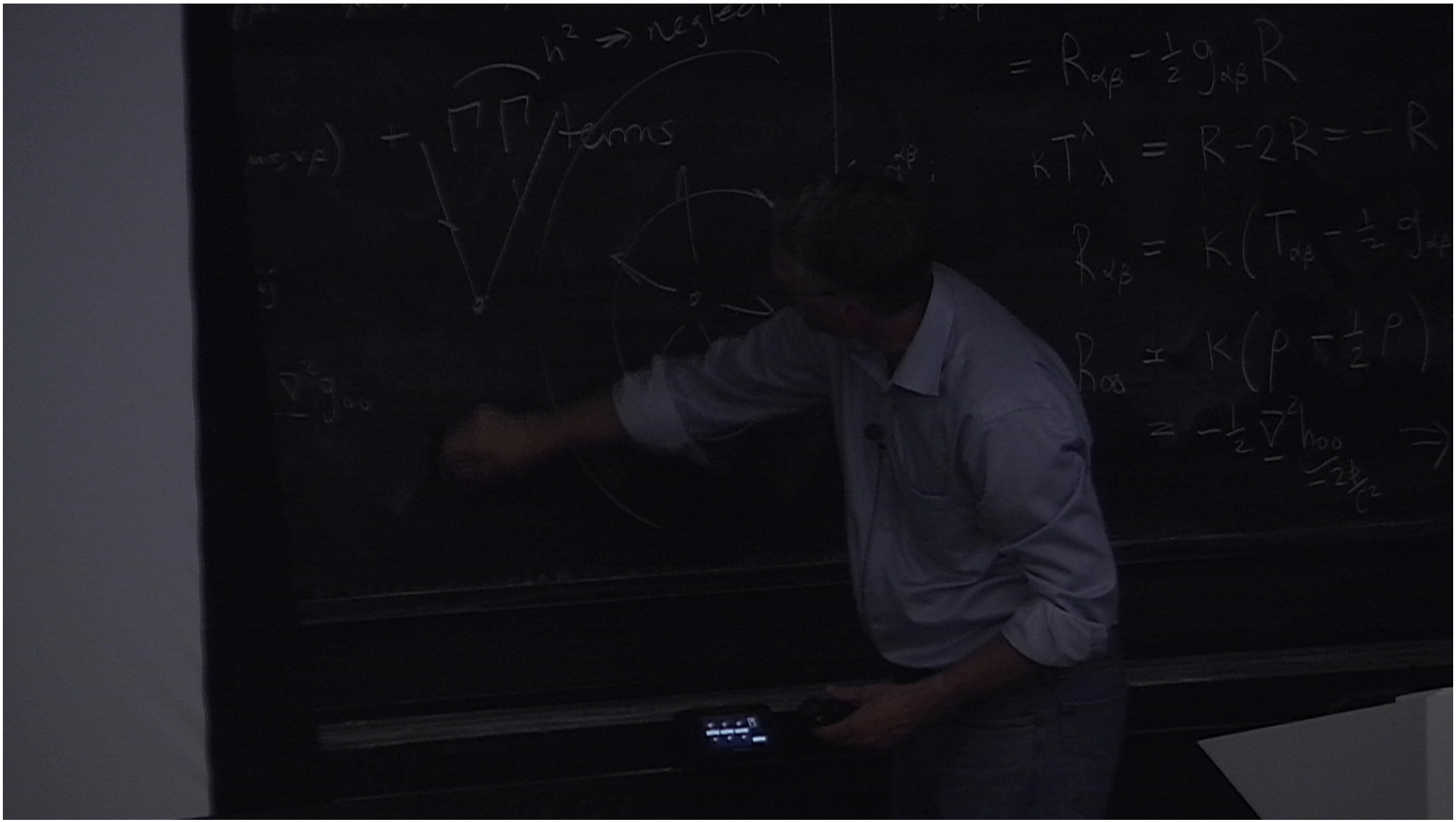
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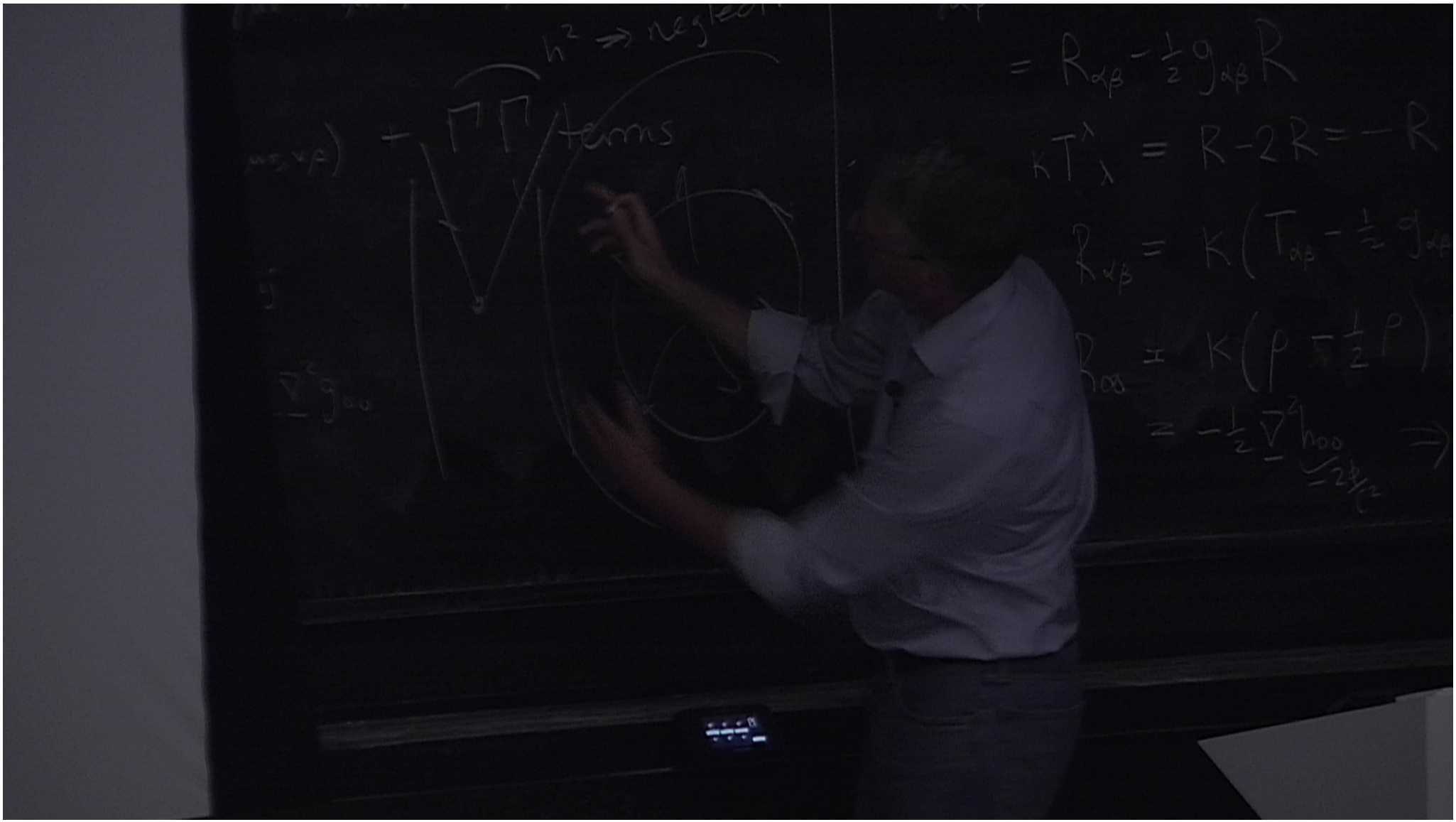
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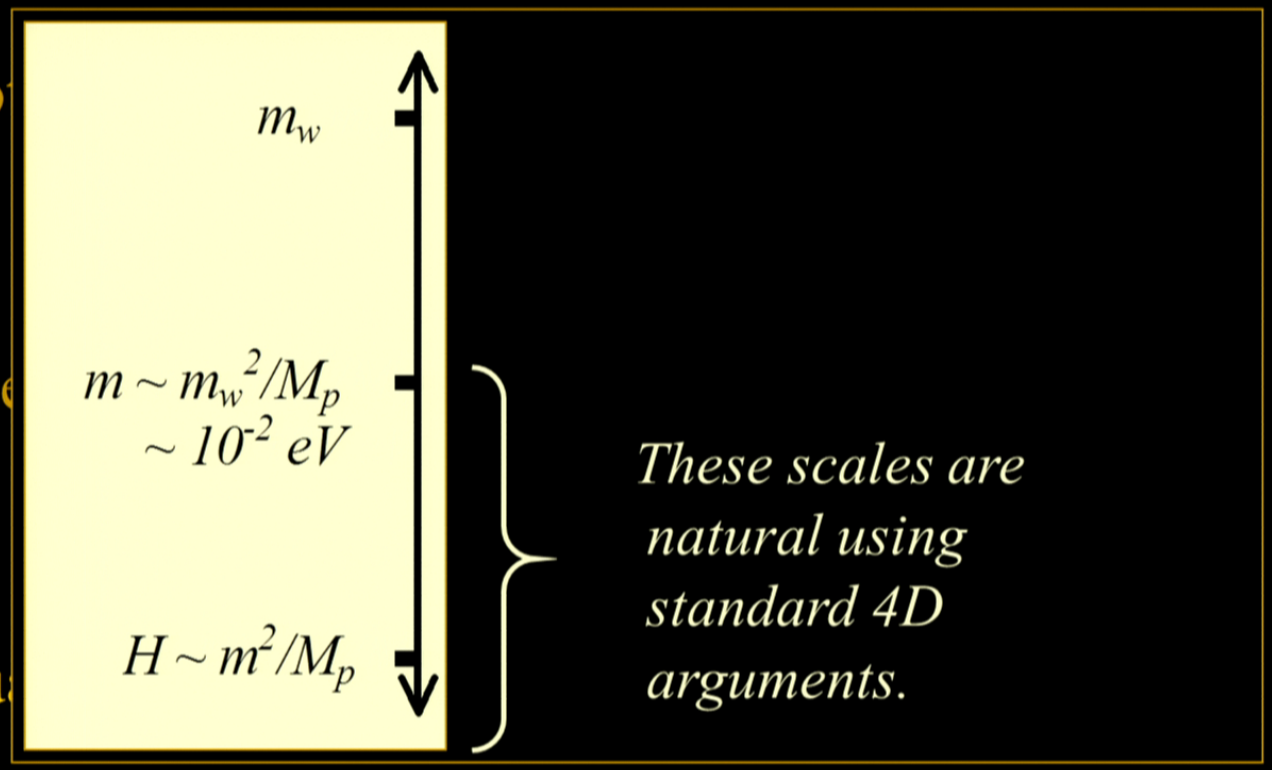

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How Extra Dimensions Help

- No
- The
- Qu

m_w

$m \sim m_w^2/M_p$
$\sim 10^{-2}$ eV

$H \sim m^2/M_p$

Must rethink how the vacuum gravitates in 6D for these scales.

SM interactions do not change at all!

Only gravity gets modified over the most dangerous distance scales!

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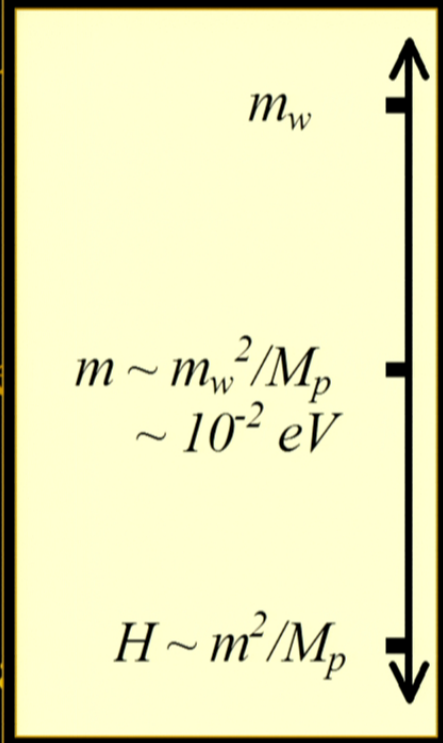

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Tantalizing numerology:

1. dimensions could be large enough to be relevant if there are only two of them (others could also exist if they are much smaller)

2. for two large dimensions same size would solve BOTH the cosm const and the EW hierarchy probs!

$$M_p \approx M_g \left(rM_g\right)^{n/2}$$

with n extra dimensions

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What might be seen?

- I
  la

Perturbing an initially flat geometry: bulk-stabilizing flux dominates curvature

$$\frac{n}{g} = \int F$$

flux quantization forces fields to adjust to change in tension

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What might be seen?

- *Upshot:* Extra-dims can (but need not) cancel brane tensions: with vacuum energy zero at classical level, of order m_{KK}^4 at loop level

Can describe dark energy if extra dims satisfy:

1. two are large as ~10 microns across
2. bulk is supersymmetric;
3. flux-stabilized, with flux able to localize on branes

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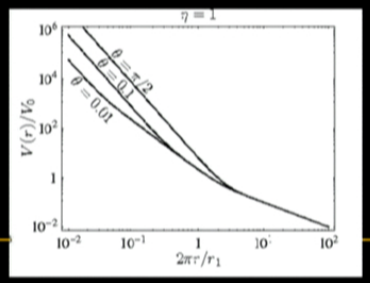
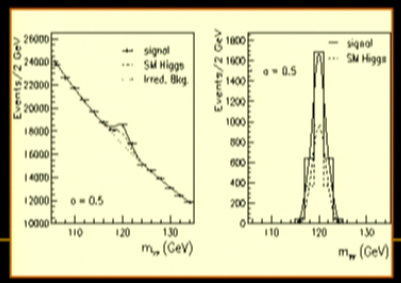
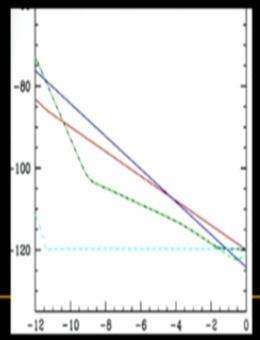
What might be seen?

- Many observational consequences, including:
  1. *dev'n from inverse-sq law at micron scales*
  2. *scalar-tensor gravity over large distances*
  3. ✓ *no MSSM: no selectron, squarks, etc*
  4. *missing energy and quantum gravity at LHC*
  5. *novel neutrino physics?*







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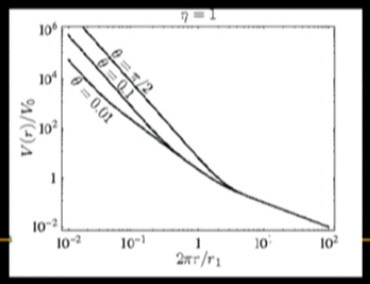

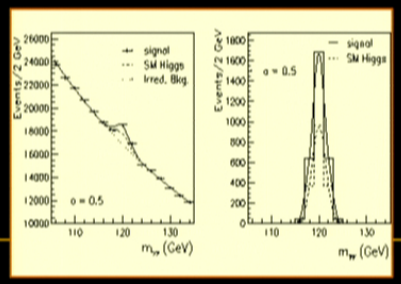

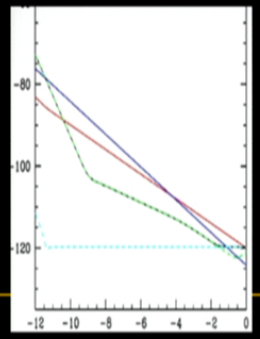

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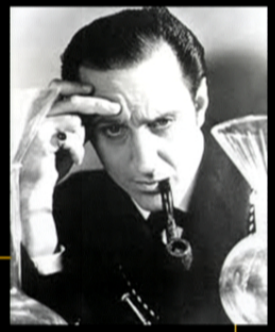

- *“ How often have I said to you that when you have eliminated the impossible, whatever remains, however improbable, must be the truth? ”*

Sherlock Holmes *(‘The Sign of the Four’ 1890)*

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Bottom Line

Outlook

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

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HOLY SHIT!!

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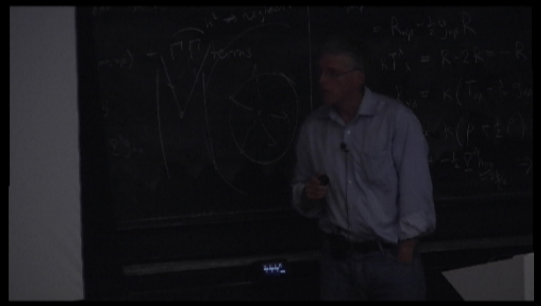

- The LHC is finally producing physics results!
  - Runs at full beam energy could begin in a few years.
- The LHC should tell us if the Higgs mechanism is right, and how it works.
  - The SM Higgs boson, or its alternative, should be found.

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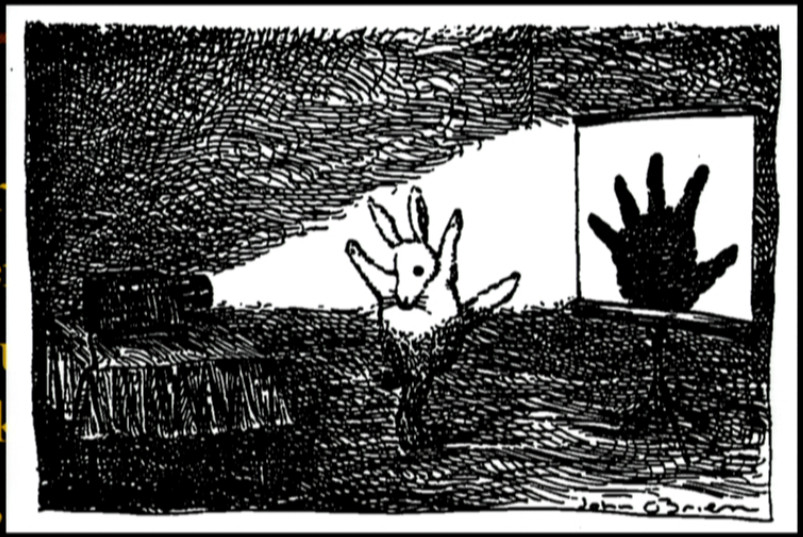
Outlook



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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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