The LHC is Safe

CERN Colloquium

John Ellis

August 14th, 2008

LHC Safety Assessment Group (LSAG):
JE, Gian Giudice, Michelangelo Mangano, Igor Tkachev, Urs Wiedemann

Preview of LSAG's Conclusions

- **"We conclude by reiterating the conclusion of the LHC Safety Group in 2003: there is no basis for any conceivable threat from the LHC. Indeed, theoretical and experimental developments since 2003 have reinforced this conclusion"**

S.B. Giddings and M. Mangano, *http://arXiv.org/pdf/0806.3381*
LSAG, *http://arXiv.org/pdf/0806.3414*
Scientific Policy Committee Review,
http://indico.cern.ch/getFile.py/access?contribId=20&resId=0&materialId=0&confId=35065
CERN public web page, *http://public.web.cern.ch/public/en/LHC/Safety-en.html*

General Background

- Great projects attract great attention
  - LHC no exception: 'no such thing as bad publicity'?
- Concern expressed perennially before start-ups of new accelerators
  - Lawsuit to stop RHIC (1999)
  - Review by Busza, Jaffe, Sandweiss & Wilczek (RMP)
  - LHC Safety Study Group(*) report (2003)

    (*) J. Blaizot, J. Iliopoulos, J. Madsen, G. Ross, P. Sonderegger, H. Specht
- LSAG set up by CERN Management (2007)
  - Many private & media enquiries
- Lawsuit in Hawaii to stop LHC (2008)

Previous Reports

Review of speculative "disaster scenarios" at RHIC

R. L. Jaffe, W. Busza, and F. Wilczek

Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

J. Sandweiss

Yale University, New Haven, Connecticut 06520

This paper discusses speculative disaster scenarios inspired by hypothetical new fundamental processes that might occur in high-energy relativistic heavy-ion collisions. The authors estimate the parameters relevant to black-hole production and find that they are absurdly small. They show that other accelerator and (especially) cosmic-ray environments have already provided far more auspicious opportunities for transition to a new vacuum state, so that existing observations provide stringent bounds. The possibility of producing a dangerous strangelet is discussed in most detail. The authors argue that four separate requirements are necessary for this to occur: existence of large stable strangelets, metastability of intermediate size strangelets, negative charge for strangelets along the stability line, and production of intermediate size strangelets in the heavy ion environment. Both theoretical and experimental reasons why each of these appears unlikely are discussed. In particular, the authors know of no plausible suggestion for why the third or especially the fourth might be true. Given minimal physical assumptions, the continued existence of the Moon, in the form we know it, despite billions of years of cosmic-ray exposure, provides powerful empirical evidence against the possibility of dangerous strangelet production.

1999

Will relativistic heavy-ion colliders destroy our planet?

Arnon Dar [a,b], A. De Rújula [a], Ulrich Heinz [a]

[a] *Theory Division, CERN, CH-1211 Geneva 23, Switzerland*

[b] *Department of Physics and Space Research Institute, Technion, Israel Institute of Technology, Haifa 32000, Israel*

Received 2 November 1999; accepted 3 November 1999

Editor: R. Gatto

Abstract

Experiments at the Brookhaven National Laboratory will study collisions between gold nuclei at unprecedented energies. The concern has been voiced that "strangelets" – hypothetical products of these collisions – may trigger the destruction of our planet. We show how naturally occurring heavy-ion collisions can be used to derive a safe and stringent upper bound on the risk incurred in running these experiments.

STUDY OF POTENTIALLY DANGEROUS EVENTS DURING HEAVY-ION COLLISIONS AT THE LHC: REPORT OF THE LHC SAFETY STUDY GROUP

J.-P. Blaizot
CEA/Saclay-Orme des Merisiers, Gif-sur-Yvette, France

J. Iliopoulos
École Normale Supérieure, Paris, France

J. Madsen,
University of Aarhus, Århus, Denmark

G.G. Ross,
University of Oxford, Oxford, UK

P. Sonderegger,
CERN, Geneva, Switzerland

H.-J. Specht,
University of Heidelberg, Heidelberg, Germany

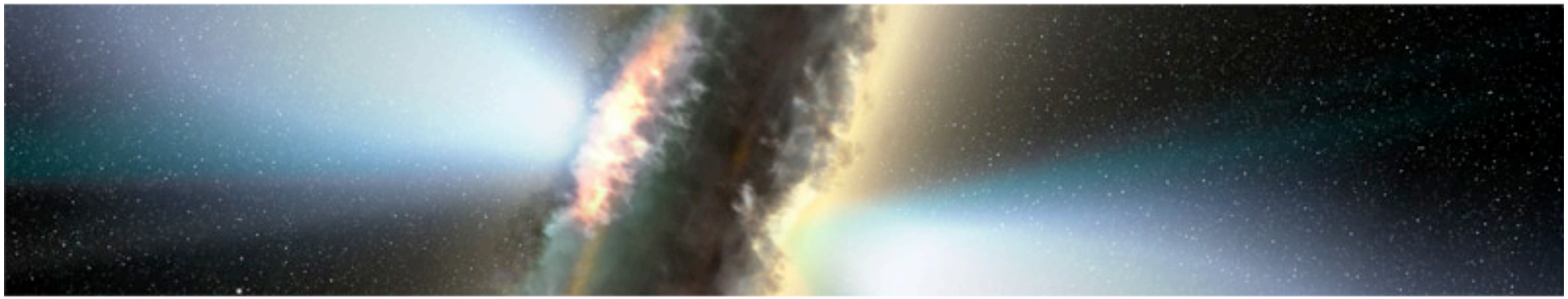
2003

Abstract

We review the possibility of producing dangerous objects during heavy-ion collisions at the Large Hadron Collider. We consider all such objects that have been theoretically envisaged, such as negatively charged strangelets, gravitational black holes, and magnetic monopoles. We find no basis for any conceivable threat.

Actions by CERN

- Mandate to LSAG:
  - Review, update and (where necessary) complement previous studies
  - Express conclusions in accessible terms
  - Respond to emailed questions (lsag@cern.ch)
- Public web page addressing (some) issues
- Respond to media enquiries
- Address issues on Open Day



Safety at the LHC

The Large Hadron Collider (LHC) can achieve energies that no other particle accelerators have reached before. The energy of its particle collisions has previously only been found in Nature. And it is only by using such a powerful machine that phyicists can probe deeper into the key mysteries of the Universe. Some people have expressed concerns about the safety of whatever may be created in high-energy particle collisions. However there are no reasons for concern.

Modest by Nature's standards

Accelerators recreate the natural phenomena of cosmic rays under controlled laboratory conditions. Cosmic rays are particles produced in

Actions by LSAG

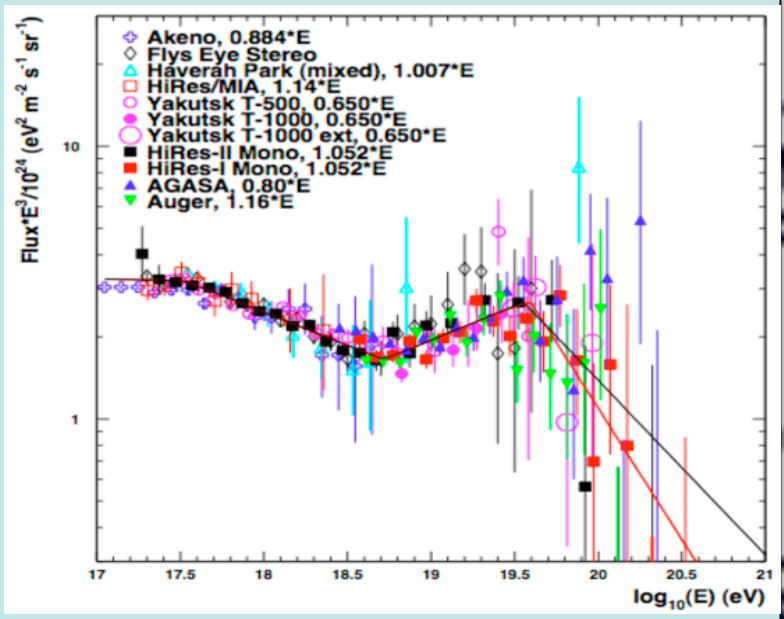
- Review previous studies
  - Cosmic-ray fluxes, mini black holes, strangelets, false vacua, magnetic monopoles
- More studies for mini black holes
  - LHC collisions in centre of mass
  - What if mini black hole stable?
    - Detailed study by S. Giddings & M. Mangano → PRD
- Update to strangelets on basis of RHIC data
- Review studies in accessible terms
  - Report presented to SPC in May
  - Published after Council meeting in June

Scientific Assessment

- **There is no conceivable cause for concern**
- Cosmic rays have been doing LHC experiments repeatedly for billions of years
  - Most people reassured by this
  - Scientists have no concerns
- ‘Semi-scientists’ need further arguments
- LHC collisions in centre of mass
  - What if mini black holes stable, neutral?
  - What if strangelets negatively charged?

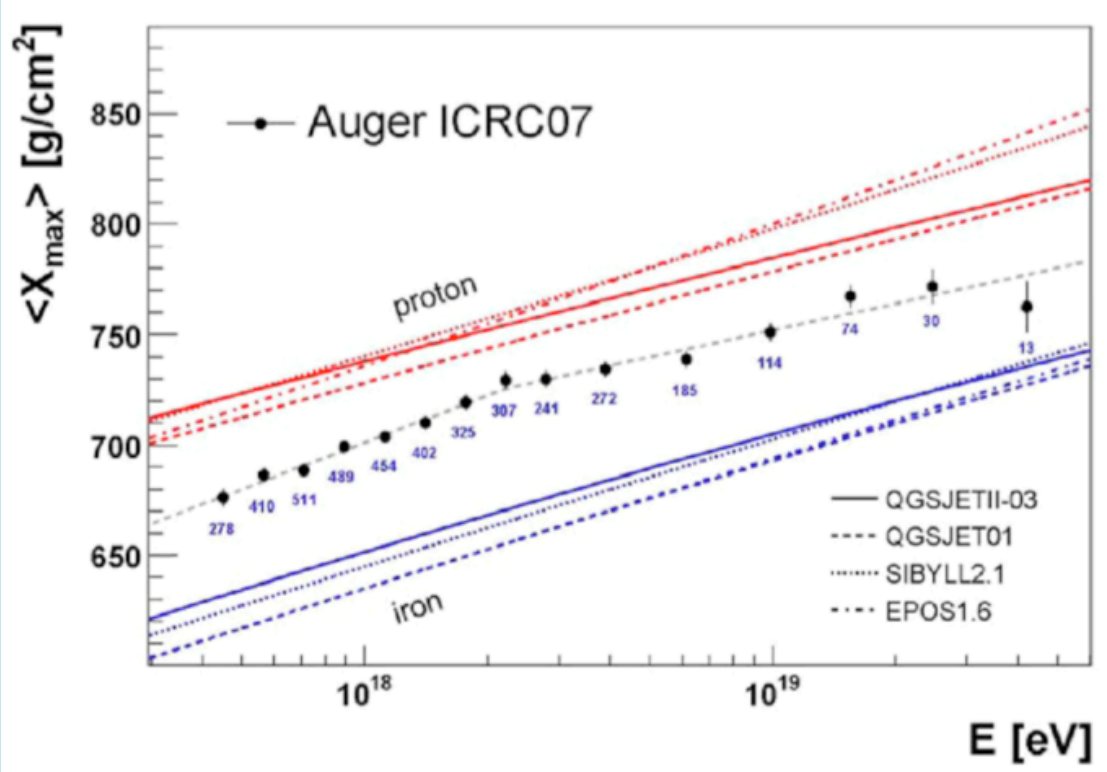
Cosmic-Ray Fluxes

- LHC @ 14 TeV = cosmic rays @ 10^{17} eV
- Cosmic rays seen to 10^{20} eV
- Protons and/or Iron?
- ~ 3.10^{22} cosmic rays above 10^{17} eV have struck Earth
- Equivalent to 10^{5} LHCs
- Area of Sun 10^{4} larger
- 10^{11} stars in Galaxy, 10^{11} galaxies in Universe
- Nature has performed 10^{31} LHC programmes
- Nature carries out 3.10^{13} LHC programmes per second



Cosmic-Ray Composition

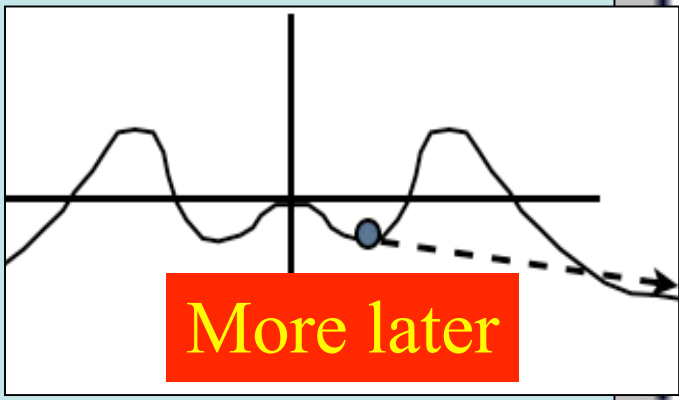
- Rates reduced by 1/A if all heavy nuclei
  - Auger → not all Fe



- Even if all Fe at source, ≥ 10% protons on arrival

False Vacua, Magnetic Monopoles

- Bubble of false vacuum would destroy Universe
- Cosmic-ray collisions would make bubbles of false vacuum
- **Cosmic rays ⇒ no risk**
- In grand unified theories, magnetic monopoles could catalyze proton decay, destroy nuclei
  - Magnetic monopoles produced by cosmic rays would stop in Earth
- If produced, cannot 'eat' matter: **no risk**



More discussion needed for BHs, strangelets

Microscopic Black Holes

- Predicted by some scenarios with extra dimensions
- Such scenarios also predict they are short-lived, with lifetimes ~ 1/TeV ~ 10^{-27} seconds
- **Could stable microscopic black holes exist?**
- By time reversal, production ⇒ decay
  - Specifically via Hawking radiation (quantum effect in curved space)
  - but more general (time reversal of production)
- Stability would require maximal CPT violation

Nevertheless, what if BHs stable?

S. Giddings & M. Mangano

- Mini-BHs produced by cosmic rays would be stopped in Earth if charged
  - What if neutral?
- Accretion rate negligible if 7 or more dimensions
  - What if 5 or 6 dimensions?
- Mini-BHs would be captured by neutron stars and white dwarf stars
  - These would accrete matter and destroy them
- Persistence of NSs and WDs excludes even 'dangerous' neutral mini-BHs in 5 or 6 dimensions

Main present concern: fully addressed

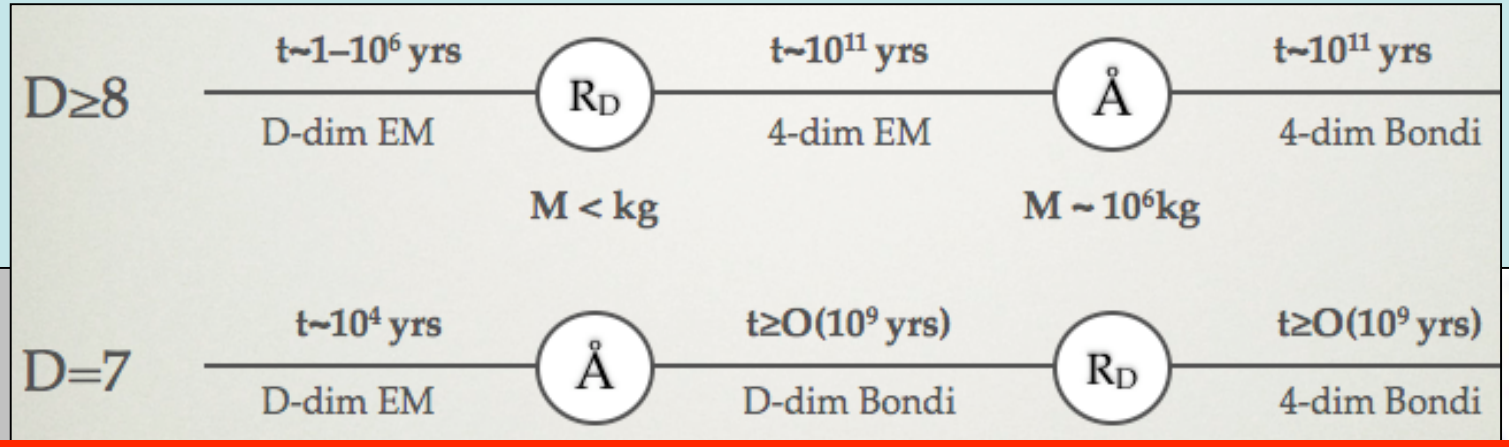
Steps in BH Argument

- Most are expected to be charged (qq, qg collisions), in which case they stop inside Earth
- Problem only if **ALL** neutral, or if charge 'bleached' (Schwinger mechanism: e^+e^- pair creation at surface?) and eat atoms
- Accretion rate $\frac{dM}{dt} = \pi \rho v r_c^2(M)$ r_c accretion radius
- Use large rate for Earth (danger), small for NS (conservative)

Accretion Calculations

S. Giddings & M. Mangano

- Use standard Bondi approach to accretion
- Distinguish different regimes:
  - Nuclear: $r_c <$ fm
  - Subatomic: fm $< r_c <$ Å
  - Atomic: $r_c >$ Å
- Accretion in Earth: long time for $D \geq 7$

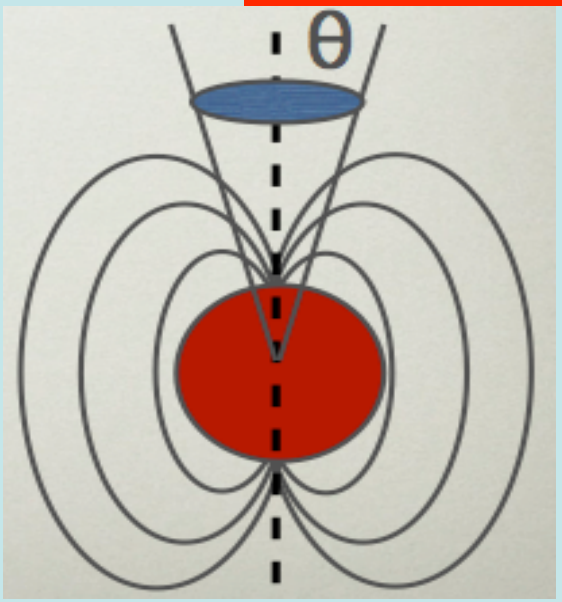


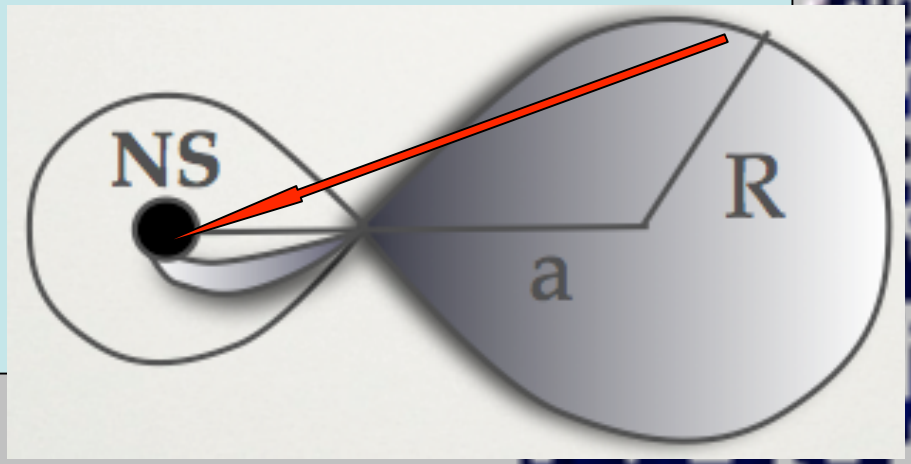
Extension to lower D: consider white dwarfs and neutron stars

Rates for CR Collisions on WD, NS

S. Giddings & M. Mangano

- E limited by synchrotron radiation in large magnetic field
- Only CRs in small solid angle retain energy
- Binary companions act as ‘beam dumps’
- Produce neutral BHs that hit NS

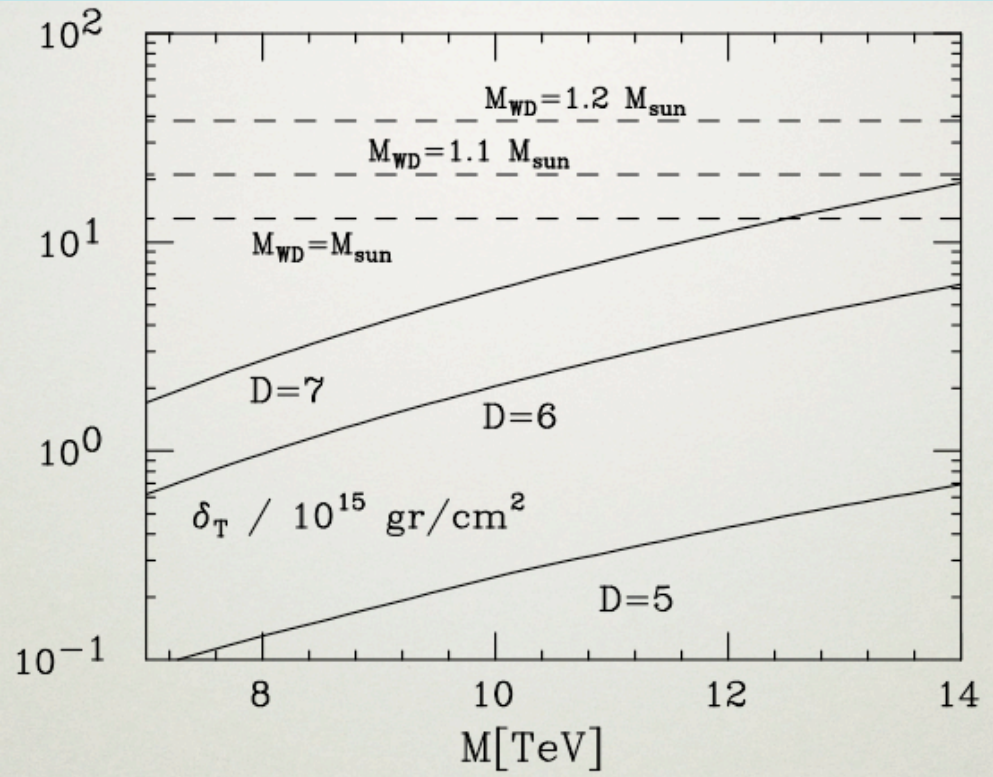




Stopping & Accretion of White Dwarfs

S. Giddings & M. Mangano

- Stopping power of white dwarfs
  - Conservative estimate using accretion only
  - Stopping guaranteed for M < 14 TeV

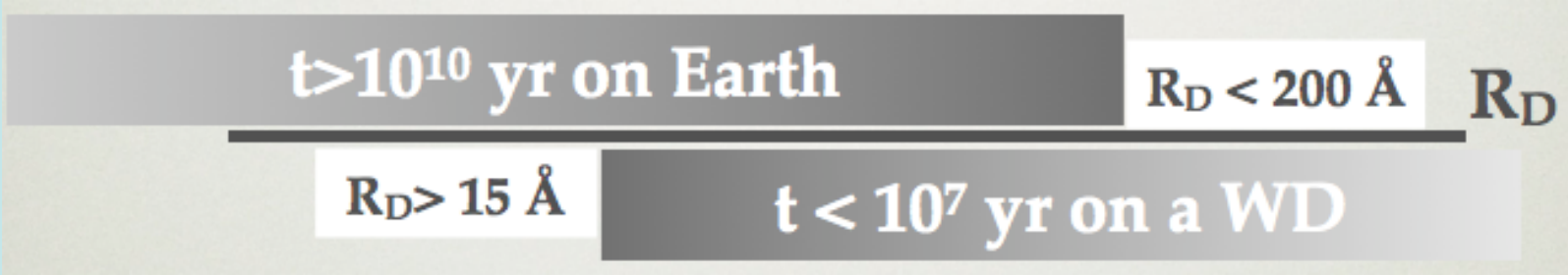


- Accretion: Eddington limit not important

Bottom Line on Accretion

S. Giddings & M. Mangano

- For D = 4:

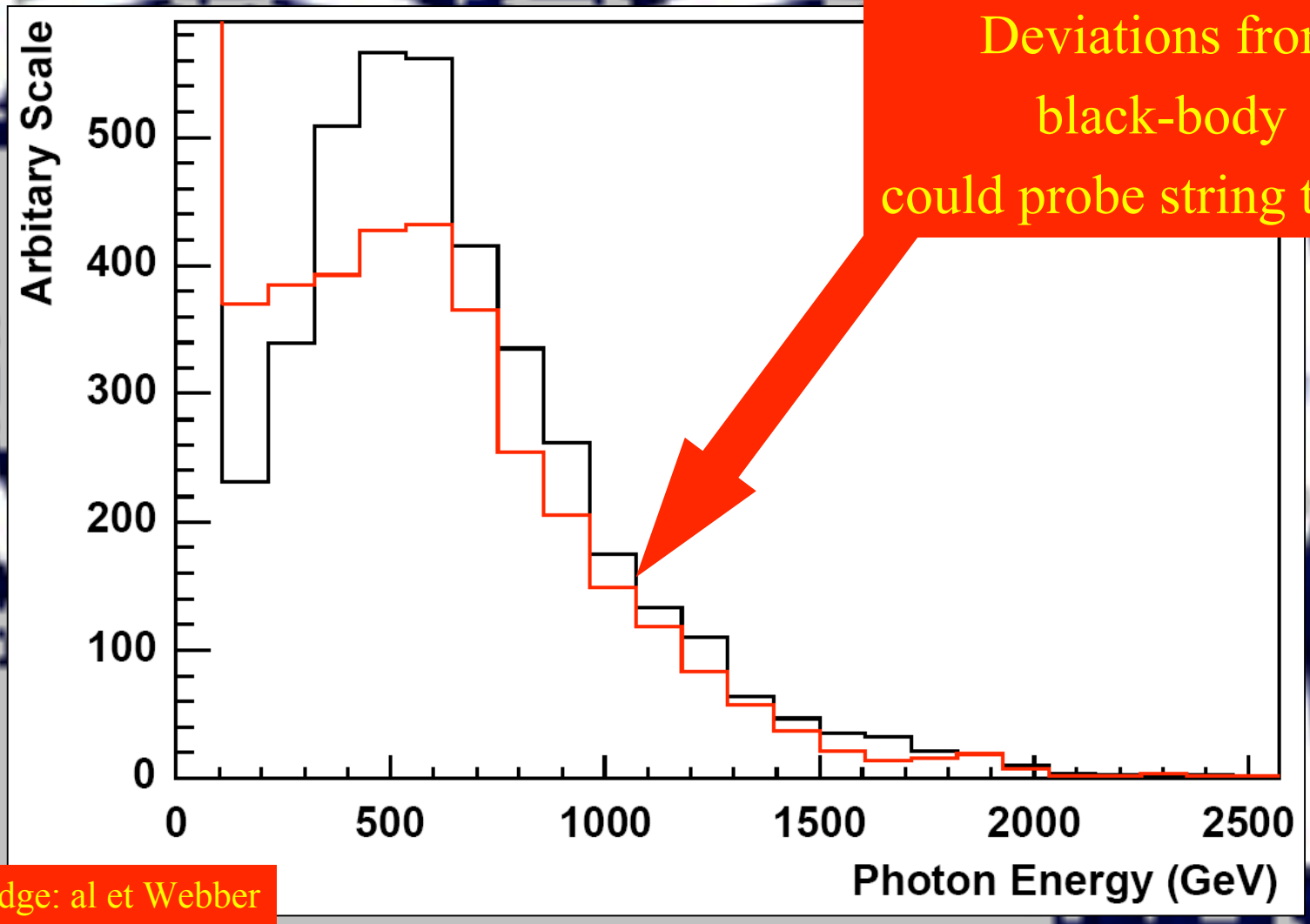


- Neutron stars are accreted for all D in < Myr
- White dwarfs are accreted for D < 8 in < few × 10 Myr
- Some neutron stars and white dwarfs known to be older

Summary on Microscopic Black Holes

- Existence very speculative
  - particular extra D scenarios
- **IF** they exist, surely unstable
  - Hawking, decay related to production
- **EVEN IF** stable, accretion rate negligible if high D
- **EVEN IF** low D, some of those produced by cosmic rays would be charged
  - would have stopped in Earth: not been 'eaten'
- **EVEN IF** all neutral, some would have been produced on white dwarfs and neutron stars
  - would have stopped: not been 'eaten'

Black Hole Decay Spectrum

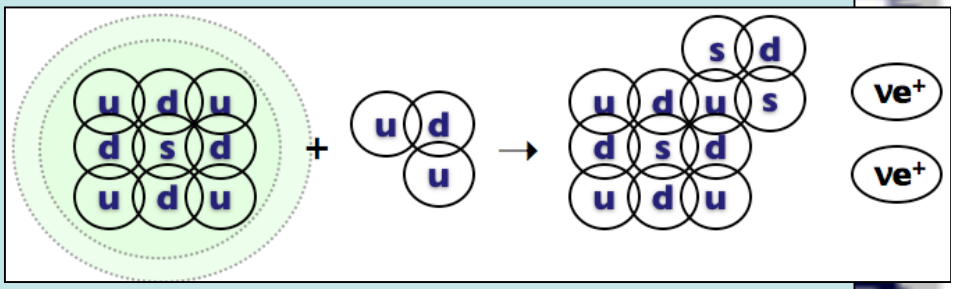


Deviations from black-body could probe string theory

Cambridge: al et Webber

Strangelets

- Hypothetical matter containing ~ equal fractions of *u*, *d* and *s* quarks
  - Existence very speculative
- Could accrete nuclei
- Expected to have positive charge ($m_s > m_{u,d}$)
  ⇒ repelled by nuclei ⇒ no accretion
- But -ve charge not excluded by theory
- CR on Earth mainly make fast-movers: break up?
- Slow-movers produced by CR-CR collisions
  -ve strangelet problematic if only metastable

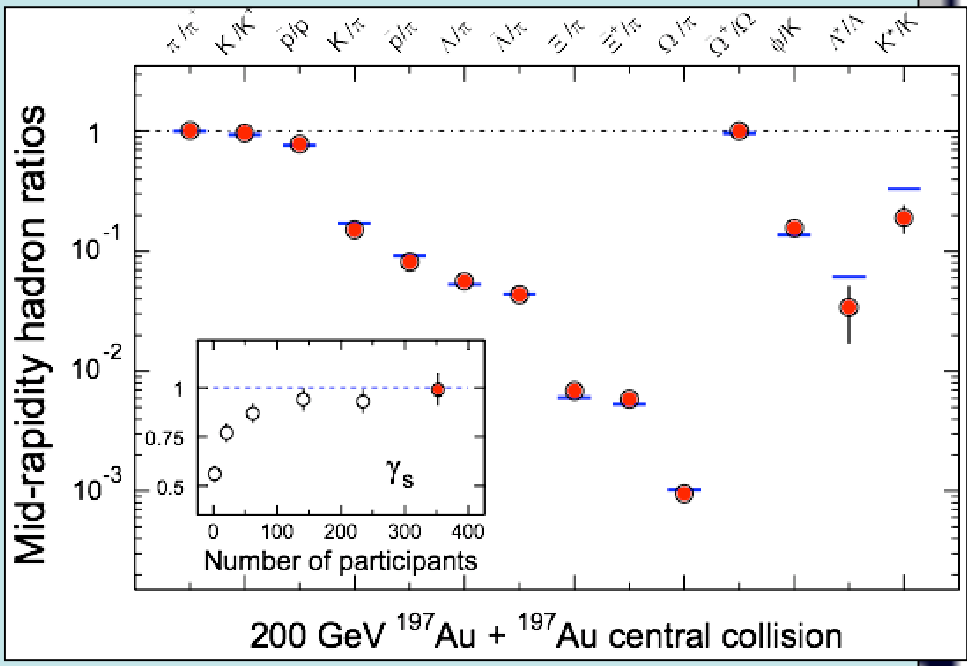


Main concern in previous lawsuit @ RHIC

Main subject of 2003 LHC Safety Study Group

Strange Particle Production @ RHIC

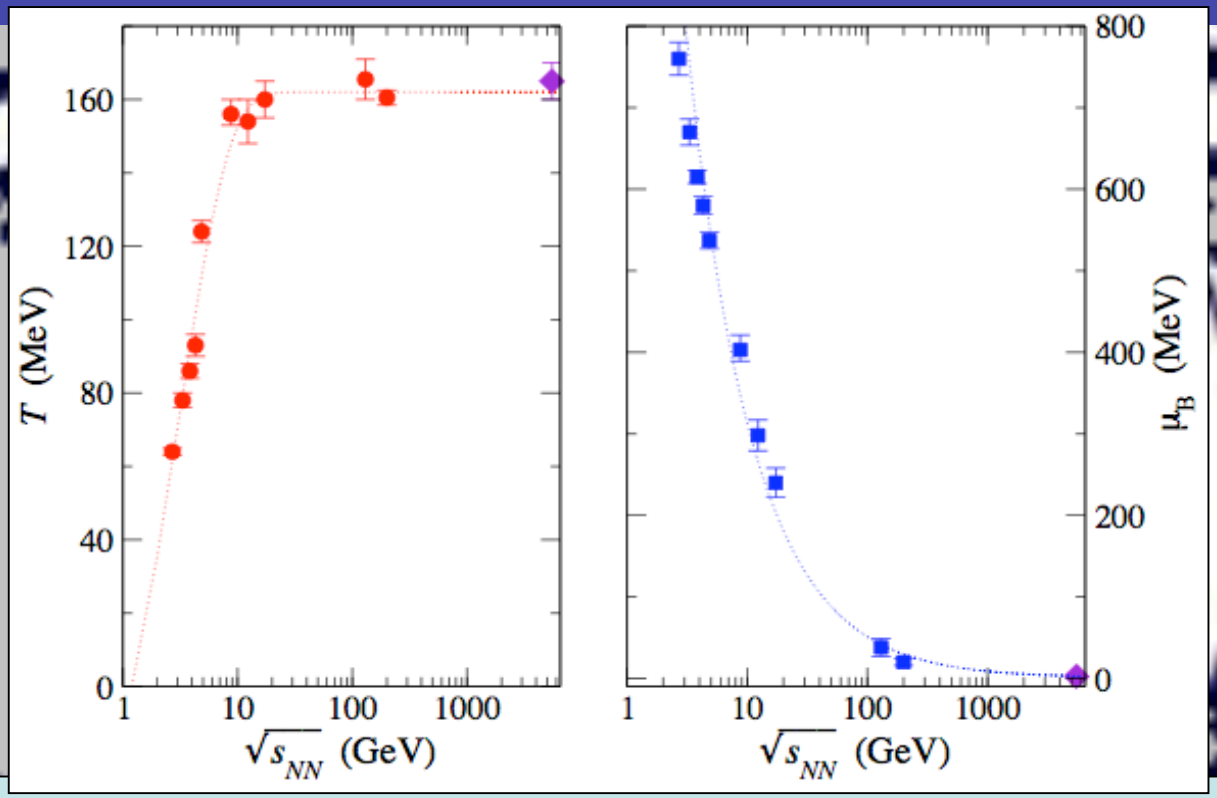
- Perfect agreement with simple statistical thermodynamic model:
  - T ~ 163 MeV
  - μ_B ~ 29 MeV
  - T ~ lower energies
  - B chemical potential $\mu_B \downarrow$
  - Strangeness saturated: $\gamma_s \sim 1$
- No strangelets ever seen
  - Fewer at lower μ_B
- Expect similar T, lower μ_B at LHC
- Model can be verified with first ~ 1000 events



Even if strangelets exist:

Not expected to be produced at LHC, can check

Energy Dependences of T and μ_B



As energy increases:

- Temperature T saturates at ~ 160 MeV
- Baryon chemical potential μ_B decreases

Strangelet production rate would decrease

LSAG Conclusions

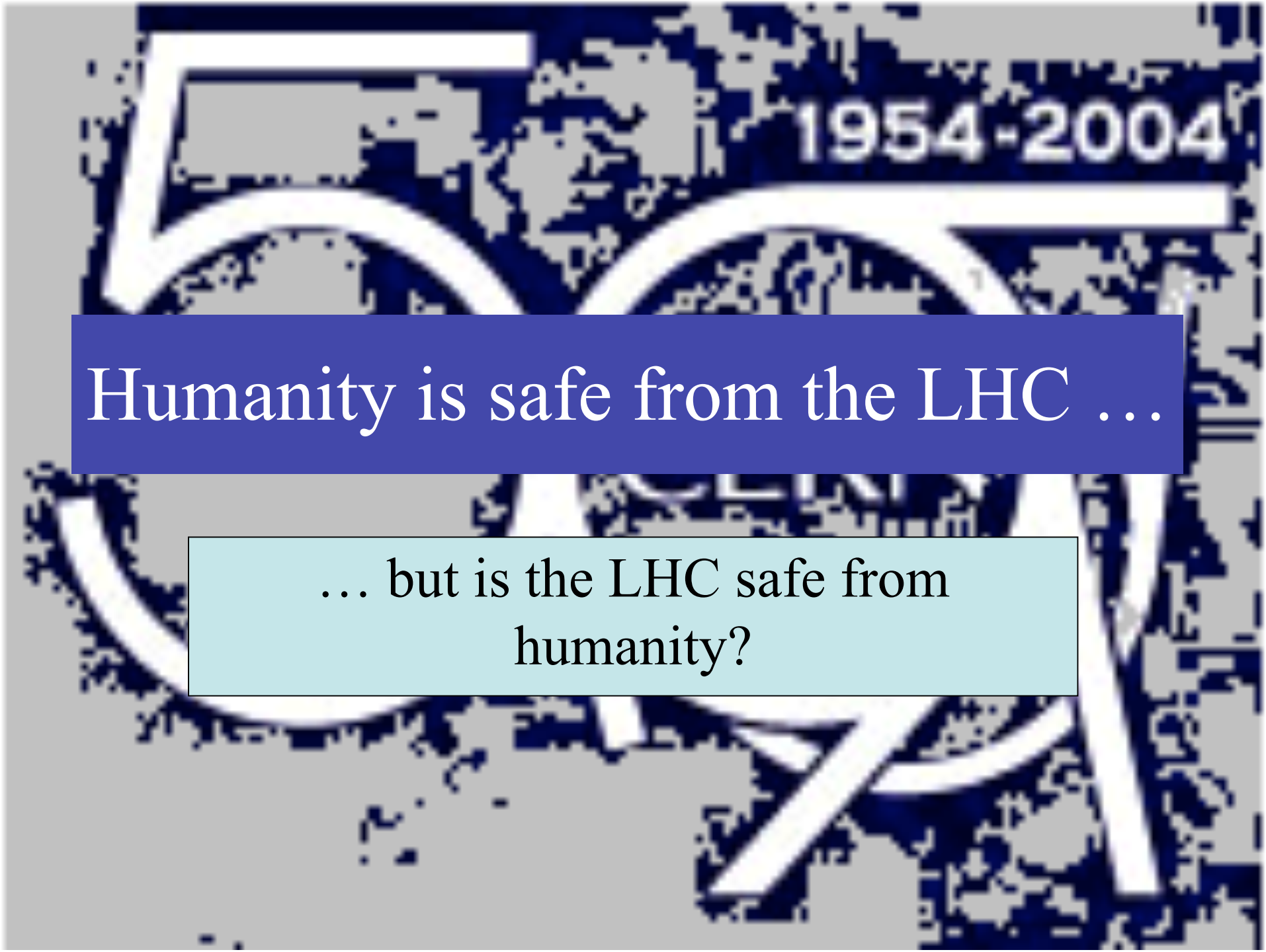
- **"Having reviewed the theoretical and experimental developments since the previous safety report was published, we confirm its findings. There is no basis for any concerns about the consequences of new particles or forms of matter that could possibly be produced by the LHC"**

S.B. Giddings and M. Mangano, *http://arXiv.org/pdf/0806.3381*
LSAG, *http://arXiv.org/pdf/0806.3414*
Scientific Policy Committee Review,
http://indico.cern.ch/getFile.py/access?contribId=20&resId=0&materialId=0&confId=35065
CERN public web page, *http://public.web.cern.ch/public/en/LHC/Safety-en.html*

Scientific Policy Committee Report

- Panel reviewed LSAG documents in detail
  - P. Braun-Munzinger, M. Cavalli-Sforza, G. 't Hooft, B. Webber, F. Zwirner
- Endorsed by full SPC:

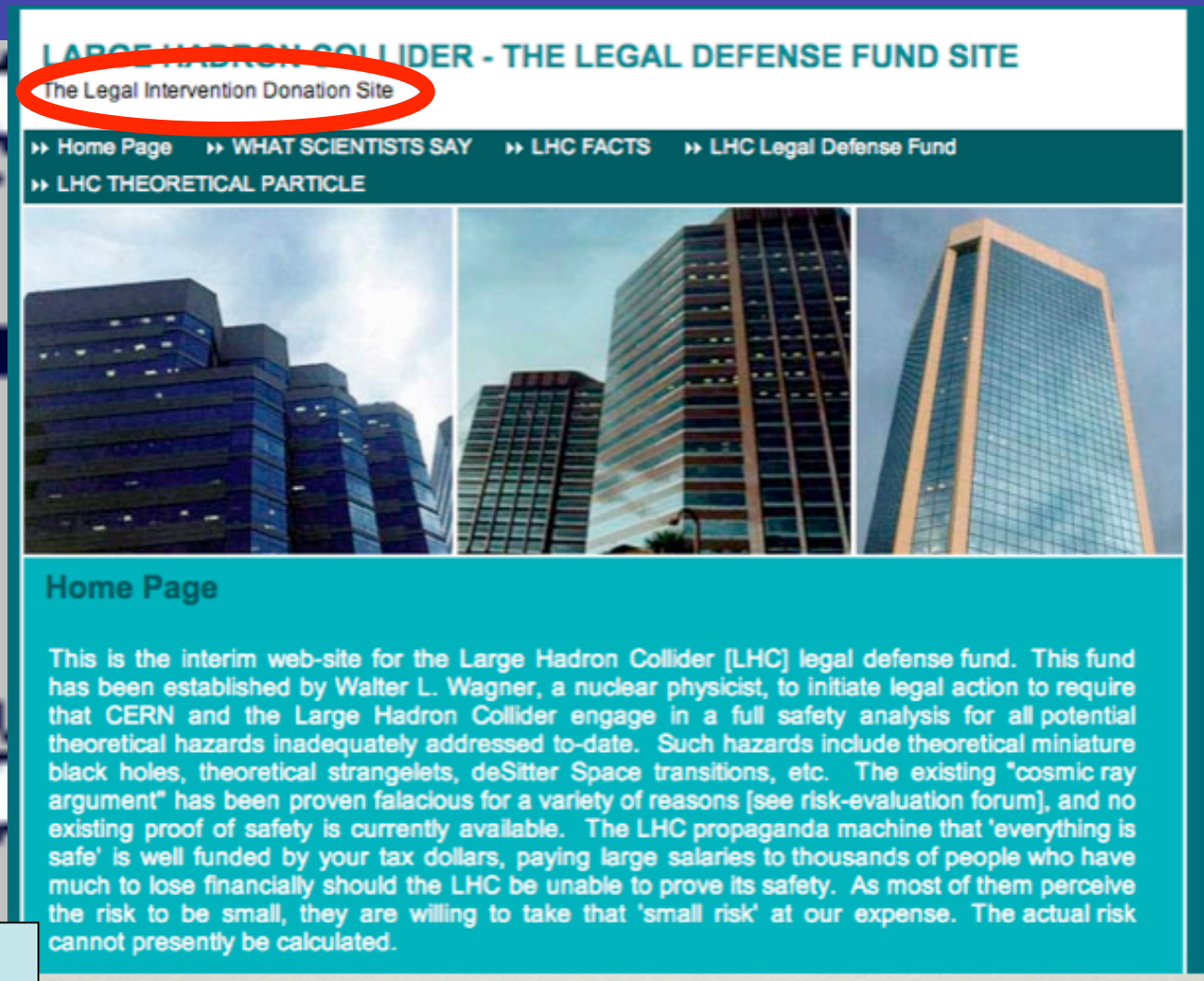
"To summarize, we fully endorse the conclusions of the LSAG report: there is no basis for any concerns about the consequences of new particles or forms of matter that could possibly be produced at the LHC."



Humanity is safe from the LHC …

… but is the LHC safe from humanity?

Not the End of the Story … I



Look at the blogosphere …

http://www.lhcdefense.org/

http://www.lhcconcerns.com/

Stop the LHC - until we know it's SAFE!

Citizens Against The Large Hadron Collider is a non-profit organization established for the purpose of using legal action to prevent the operation of the Large Hadron Collider (LHC) until further safety tests are conducted.

The LHC is a particle accelerator located on the France/Switzerland border; it has been dubbed the largest, most expensive, most powerful experiment ever attempted, certainly dwarfing all particle colliders ever built before, both in terms of size and power.

Some experts fear that the risk of operating the LHC disproportionately outweighs anything science might gain from this experiment. It is not possible to know what the outcome of the experiment will be, but even CERN (the European Organization for Nuclear Research) scientists concede that there is a real possibility of creating destructive theoretical anomalies such as miniature black holes, strangelets and deSitter space transitions. These events have the potential to fundamentally alter matter and destroy our planet.

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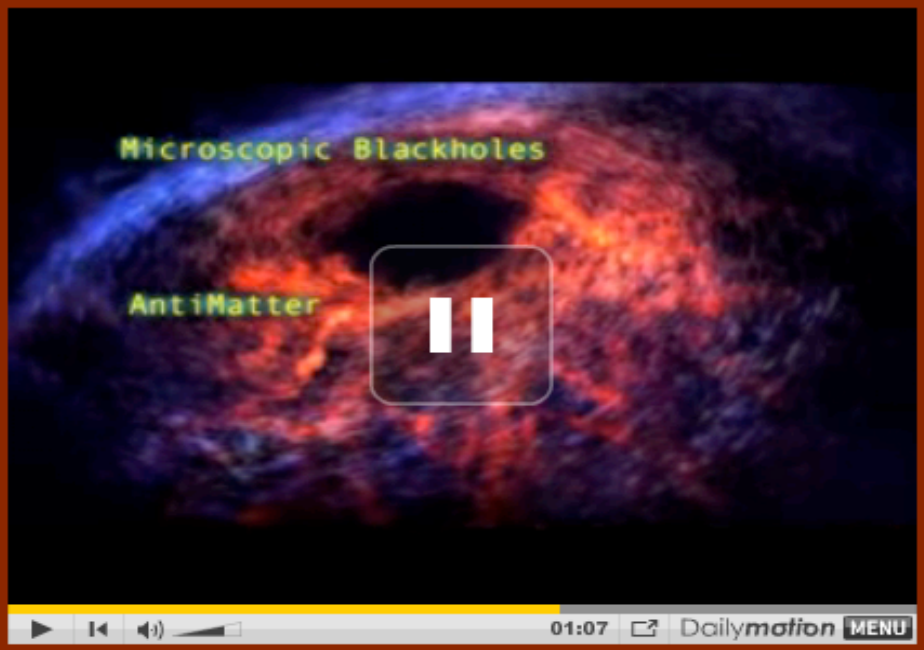
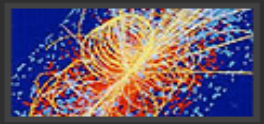


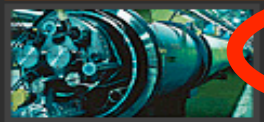
Latest News

The Potential for Danger in Particle Collider Experiments



The Large Hadron Collider (LHC) is a gigantic scientific instrument near Geneva, where it spans the border between... read more

Critics Fear Collider Could Doom Earth



61% of over 250,000 participants in an AOL survey say that operating the LHC is not worth the risk... take the survey

Caught in our own Web!

You may smile …
… but read some of the postings

Good!!! At long last "certain" scientist can "prove" (pre-aranged of course) there own little pet "theories". And keep their Jobs! While the rest of the World goes to hell. Be carefull: Yuo might have "guest's. With Guns. /\Hurry up Booyzzz.

Dr. Xxxxx Xxxxxxx (Sent Saturday, June 21, 2008 11:46 PM)

Some Signs of Sanity?

LSAG provides the tools to get involved yourselves

Re: LSAG Report is out

by [redacted] on Sat Jun 21, 2008 5:15 am

> **jtankers wrote:**
> Quote from the report: "cosmic rays do not produce such black holes, and hence neither will the LHC"
>
> The report provides reasonable evidence that when a single cosmic ray particle collides with Earth or a Neutron star, dangerous black holes are not produced.
>
> Unfortunately the report failed to address the safety of colliding thousands of anti-matter particles head on against thousands of matter particles at 99.9999991% of the speed of light with powerful magnets and opposing momentums to focus the energy to a single point in space. Conditions that might create dangerous black holes.
>
> This report just asks us to make **one hell of an assumption**, that a single cosmic ray particle impact with Earth or Neutron stars will produce **the same results** as colliding thousands of anti-matter particles head on against thousands of matter particles with powerful magnets and opposing momentums to focus the energy to a single point in space. We are asked to accept that these conditions must create the same results, without a single scientific explaination to support what appears to me to be a rather far fetched assumption "hence neither will the LHC".
>
> Please complete this report by providing the requested proof of equivalence or delay LHC operations until reasonable proof of safety may be provided.

Your answer isn't right, and it isn't even wrong.

1) The LHC will be colliding matter against matter, not matter against anti-matter. Not that this is relevant anyway, it just shows how little you understand.

2) The fact that beams in question are focused to the level of 10's of microns is completely irrelevant. Typically 1-2 interactions will happen per crossing when collisions begin (first of all), just like a cosmic ray event. As the luminosity increases, there will be at most 20-40 interactions per crossing, not "thousands of antimatter particles colliding against thousands of matter particles" as you (erroneously) state. These will occur widely separated in the longitudinal direction, i.e. centimeters apart. Far from being "focused", what will actually happen is that particles will collide one-on-one, just like a cosmic ray. Any resulting black holes will decay before they even whisper near another piece of matter.

Anything else?

"What the HELL was that?"
"Spaceball 1".
"They've gone to PLAID!"

… and from the other Superpower

ИЗВЕСТИЯ
МУЛЬТИМЕДИА

Армагеддон переносится. Ожидайте 10.07.08

Be prepared to get involved, wherever you are

Not the End of the Story … II

- Lawsuit in Hawaii
  - Preliminary arguments and counterarguments filed
  - Next hearing Sept. 2nd
  - CERN has not been informed officially
  - Complainants are citing CERN for default
- Lawsuit in Switzerland
  - Filed in June
  - dismissed because of lack of jurisdiction
- Lawsuit against BMBF in Germany

Not the End of the Story … III

Abraham-Solution to Schwarzschild Metric Implies That CERN Miniblack Holes Pose a Planetary Risk

O.E. Rössler
Division of Theoretical Chemistry, University of Tübingen, 72076 F.R.G.

Abstract

A recent mathematical re-interpretation of the Schwarzschild solution to the Einstein equations implies global constancy of the speed of light c in fulfilment of a 1912 proposal of Max Abraham. As a consequence, the horizon lies at the end of an infinitely long funnel in spacetime. Hence black holes lack evaporation and charge. Both features affect the behavior of miniblack holes as are expected to be produced soon at the Large Hadron Collider at CERN. The implied nonlinearity enables the "quasar-scaling conjecture." The latter implies that an earthbound minihole turns into a planet-eating attractor much earlier than previously calculated – not after millions of years of *linear* growth but after months of *nonlinear* growth. A way to turn the almost disaster into a planetary bonus is suggested.

Refuted by Hermann Nicolai
(Director, Albert-Einstein-Institut, Berlin)
- Abraham's theory was disproved in 1915
- Fundamental error in interpretation of Schwarzschild metric

Nevertheless …

21. Juli 2008, 19:52, NZZ Online

Couchepin trifft Cern-Kritiker Rössler

Information über die Gefahr Schwarzer Löcher am neuen Beschleuniger

Toolbox
Druckansicht
Artikel kommentieren
Artikel versenden

Der Schweizer Bundespräsident Pascal Couchepin will die Argumente des deutschen Biochemikers und Chaos-Theoretikers Otto Rössler anhören, wonach Experimente am neuen Beschleuniger des Cerns den Weltuntergang auslösen können. Das Eidgenössische Departement des Innern habe Rössler in einem Brief mitgeteilt, dass Couchepin zu einem Treffen bereit sei, hat ein Sprecher Couchepins am Montag erklärt.

President of Switzerland agrees to meet Rössler

Why?

The LHC plays into deep popular fears of science and technology …

… the long-term political consequences are unpredictable and require sensitive treatment

Should we recalibrate our rhetoric?

"Recreating the Big Bang"

"Biggest science experiment"

Not the End of the Story … IV

- ‘Science is too dangerous to be left to the scientists’

Richard A. Posner, Catastrophe: Risk and Response (Oxford and New York: Oxford University Press, 2004).

> “Congress should consider enacting a law that would require all scientific research projects in specified areas, such as **nanotechnology and experimental high-energy physics**, to be reviewed by a federal catastrophic-risks assessment board and forbidden if the board found that the project would create an undue risk to human survival”

- Argues for an ‘economic’ analysis: states that potential benefits « <cost> of danger

Posner’s principal recommendation of how to deal with possible catastrophes is to **establish national or international science courts** composed of lawyers and other public-policy makers. Members of these courts would conduct thorough analyses of the risks involved and the costs of attempting to avert those risks, and would then recommend to government agencies suitable courses of action to take. **Rather than leaving these analyses to the scientific and technical community, Posner argues for the establishment of a scientifically literate legal profession, largely on the grounds of presumed greater impartiality.**

Not only in the United States

- Also in Germany: programme on 3sat TV

nano: Bericht 09.07.2008

Chemiker befürchtet Schwarze Löcher durch das Cern

"Nach meinen Forschungsergebnissen besteht die Gefahr, dass durch die Versuche am Cern ein Schwarzes Loch entsteht, dass sich in die Erde einnistet und die Erde in relativ kurzer Zeit auf die Größe von einem Zentimeter reduziert", sagt der Theoretische Chemiker Otto. Rössler von der Universität Tübingen. "Diese Schwarzen Löcher sind völlig ungefährlich", kontert Rolf-Dieter Heuer vom Cern, "weil sie sofort wieder zerstrahlen und überhaupt nicht genügend Materie haben, um mehr Masse zu akkreditieren."

- 'CERN is a state unto itself, not subject to law'

Cern ist nicht der Rechtsprechung der Staaten unterworfen

"Das Cern befindet sich zwar auf dem Staatsgebiet von der Schweiz und Frankreichs, rein geografisch gesehen", sagt Lutz Möller von der Deutschen [illegible]. "Aber es ist in der Tat ein extraterritoriales Gebiet. [illegible]as bedeutet, dass das [illegible] Cerns nicht der Rechtsprechung dieser beiden Staaten unterworfen ist." Das Cern hat einen sehr exklusiven Status für ein Forschungszentrum, es spricht Recht über sich selbst. Auch das nationale Recht der 20 Mitgliedsstaaten findet auf diesem Gebiet keinerlei Anwendung. "Das oberste Entscheidungsgremium für das Cern ist der Rat des Cerns. Die 20 Mitgliedsstaaten entscheiden über sämtliche Belange des Cerns", so Möller.

Thus Spake Paul Feyerabend

"… societies, especially democratic societies, **must be protected from science**."

"In a democracy scientific institutions, research programmes, and suggestions must therefore be subjected to public control, there must be a separation of state and science, just as there is between state and [religion], and **science should be taught as one view among many**."

1987 Preface to "Against Method"

The LHC will not destroy Earth …

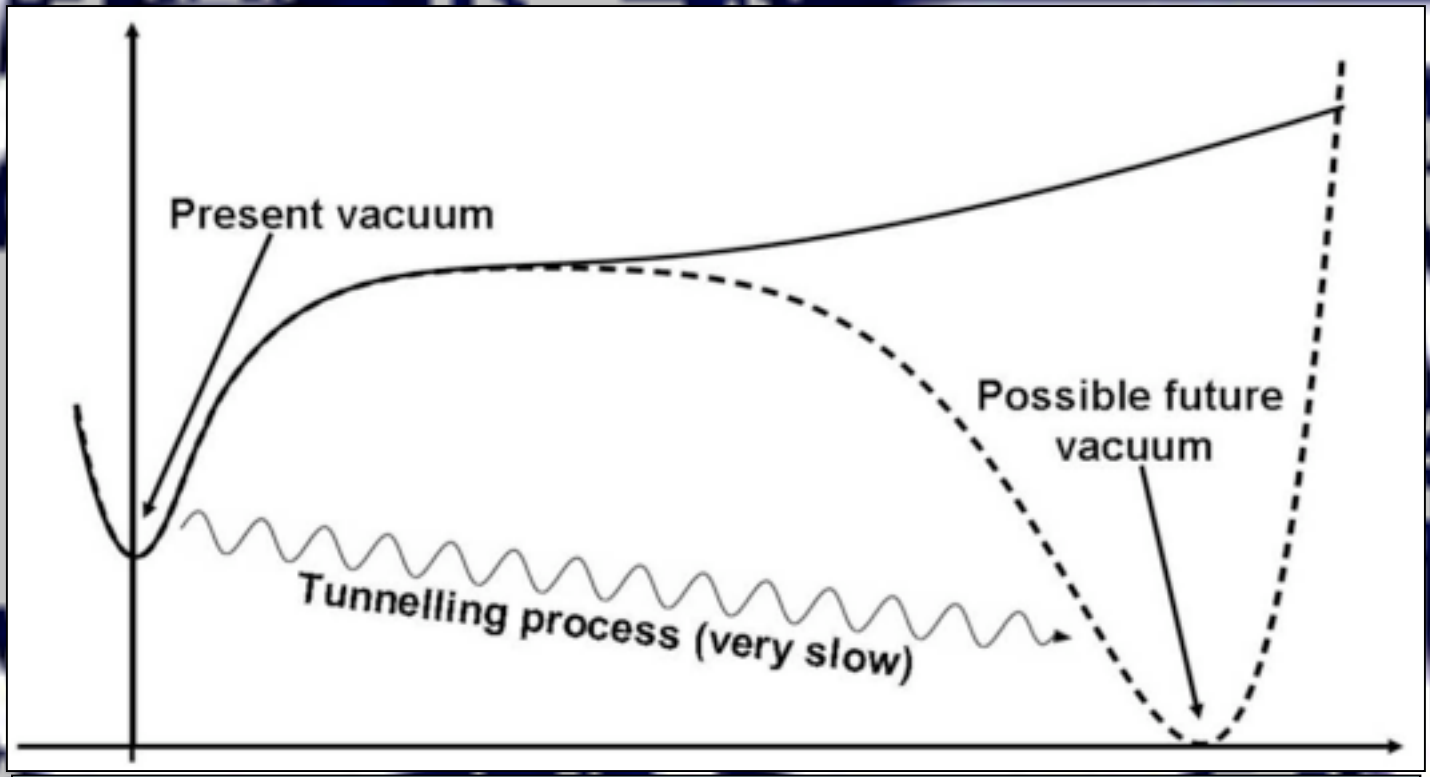
… but will it foretell the fate of the Universe?

Abel, JE, Jaeckel and Khoze

The Present Electroweak Vacuum may well be Unstable

- Within the Standard Model:
  - If Higgs boson is light
- Stabilize vacuum with physics beyond the SM?
  - Supersymmetry a natural choice
- But vacuum unstable in favoured models of supersymmetry breaking
  - May also be unstable in supergravity/string
- **The LHC will provide insight:**
  - **Measure Higgs and/or sparticle masses**

The Possible fate of the Vacuum



Our vacuum may decay after billions of years

LHC cannot trigger vacuum decay

But it may give us advance warning

Abel, JE, Jaeckel and Khoze

Vacuum Instability with Light Higgs in Standard Model

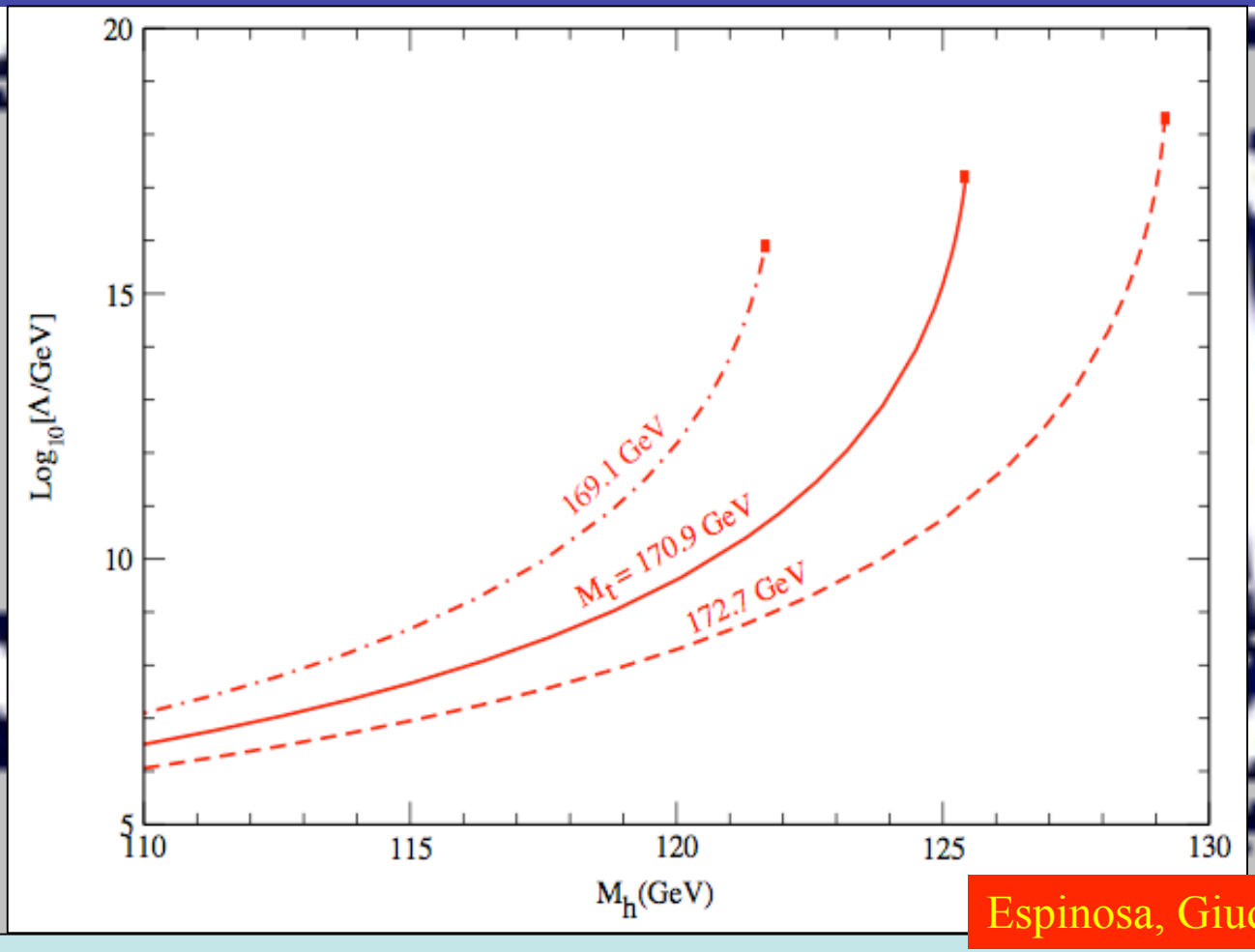
- Renormalization by top-quark Yukawa coupling λ_t may drive Higgs self-coupling $\lambda < 0$ at some effective scale Λ
- Occurs at lower scale Λ if m_h smaller, or if m_t larger
- Absolute stability bound:

$$M_h < M_h^c = 125.4\,\text{GeV} + 3.8\,\text{GeV}\left(\frac{M_t - 170.9\,\text{GeV}}{1.8\,\text{GeV}}\right) - 1.6\,\text{GeV}\left(\frac{\alpha_s(M_Z) - 0.1176}{0.0020}\right) \pm 2\,\text{GeV}$$

- Present value $m_t = 172.5 \pm 1.2$ GeV

Espinosa, Giudice & Riotto

Vacuum Instability with Light Higgs in Standard Model



Espinosa, Giudice & Riotto

SM breaks down at ~ 10^7 GeV if $m_h = 115$ GeV

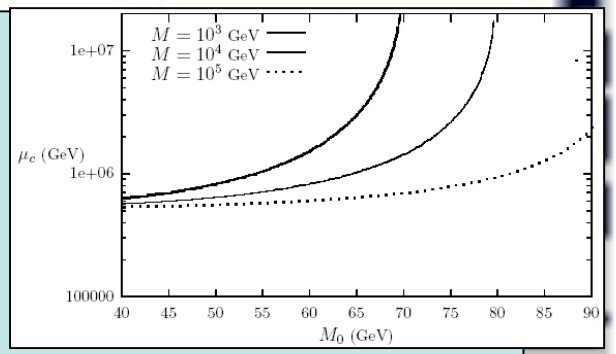
How to Stabilize a Light Higgs Boson?

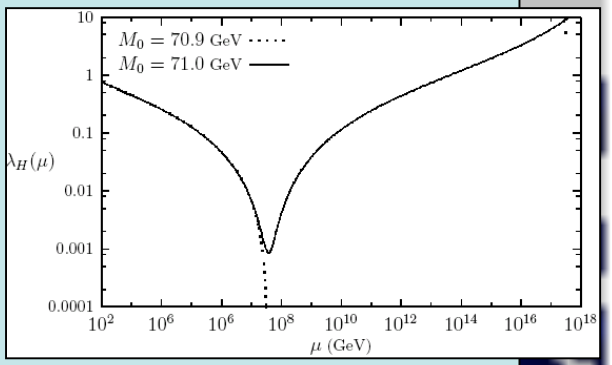
- Top quark destabilizes potential: introduce stop-like scalar:

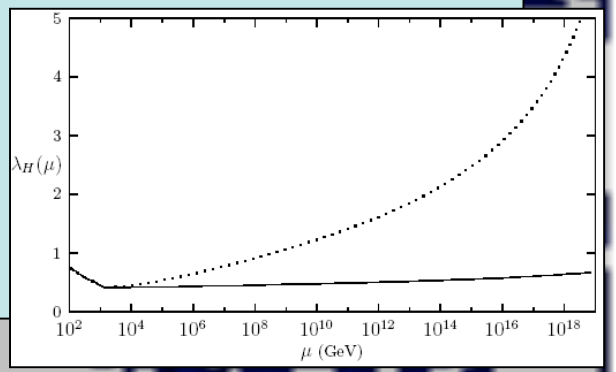
$$\mathcal{L} \supset M^2|\phi|^2 + \frac{M_0}{v^2}|H|^2\,|\phi|^2$$

- Can delay collapse of potential:
- But new coupling must be fine-tuned to avoid blow-up:
- Stabilize with new fermions:
  - just like Higgsinos
- Very like **Supersymmetry!**

JE & D. Ross

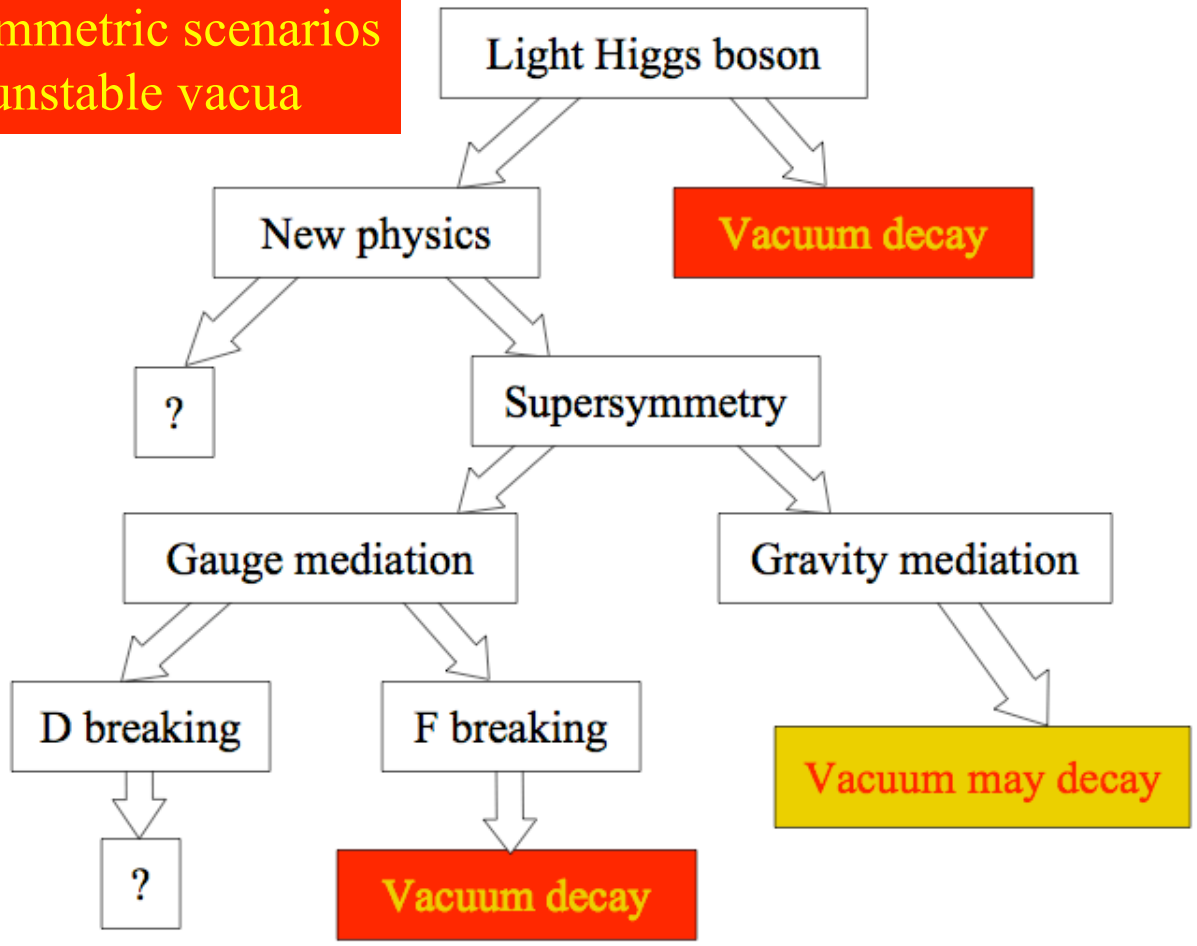






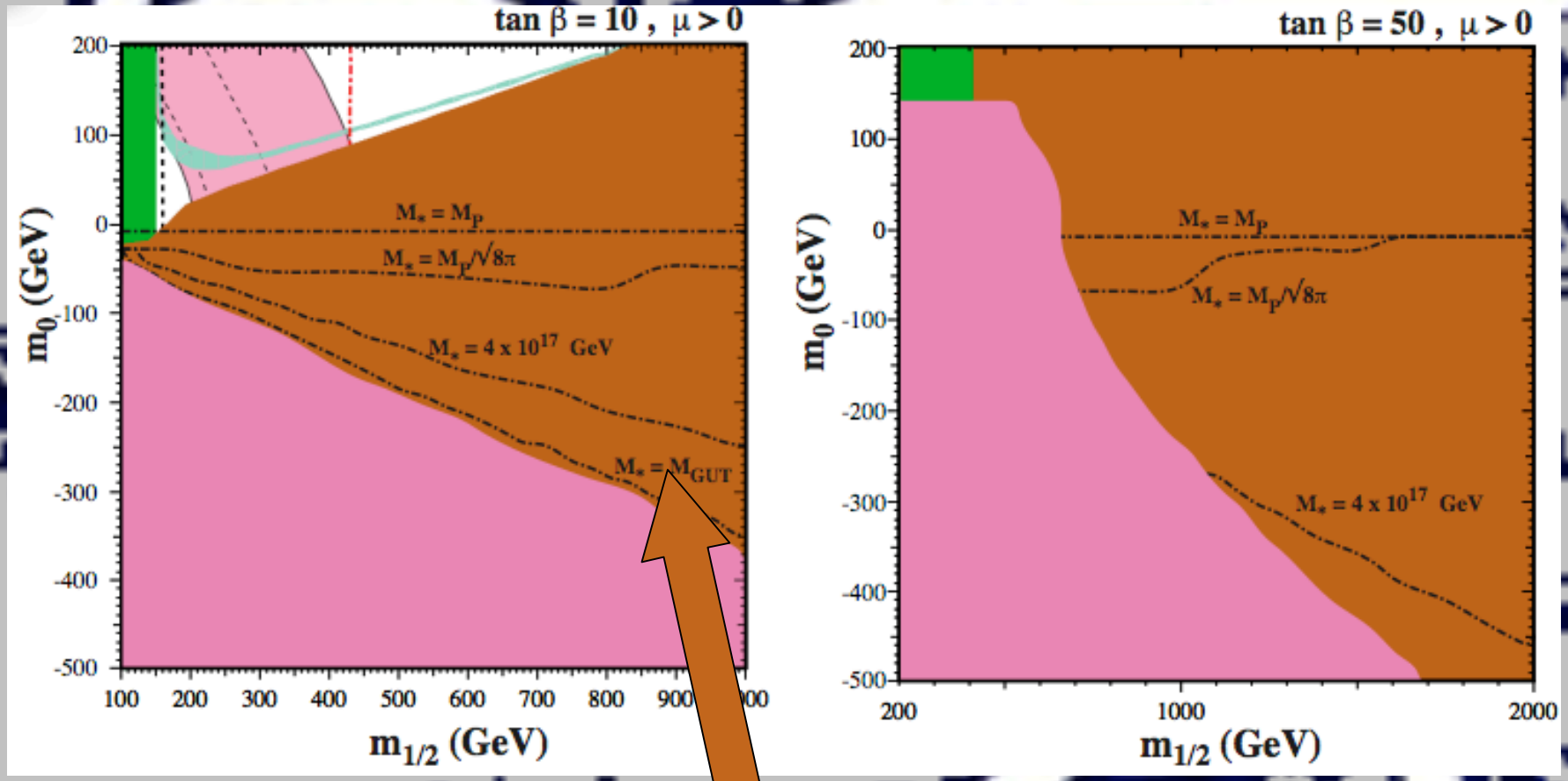
Is our Vacuum Unstable?

Many supersymmetric scenarios also have unstable vacua

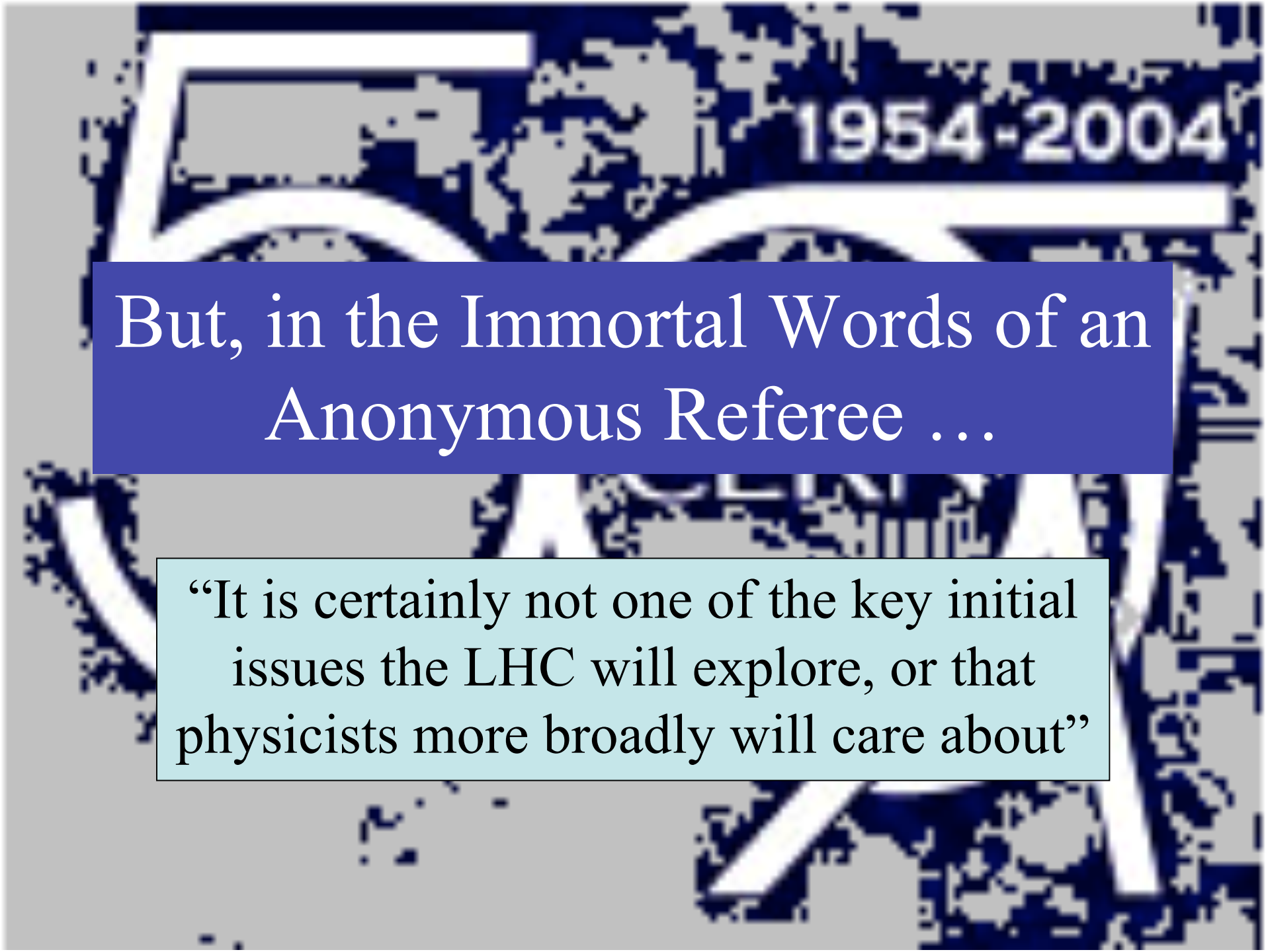


Abel, JE, Jaeckel and Khoze

Vacuum Instability in the CMSSM



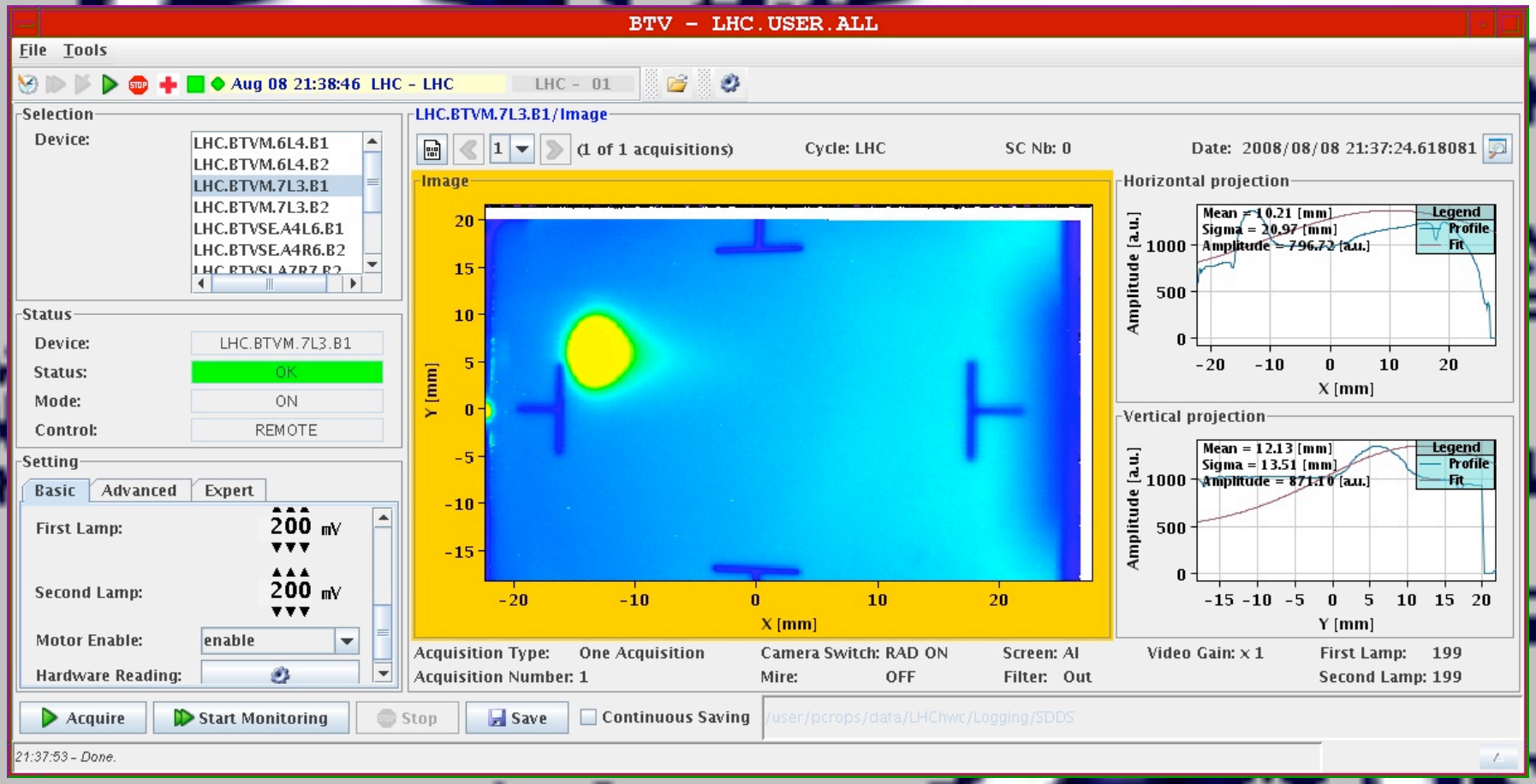
Region allowed if fields initially at/near origin, non-renormalizable $1/M_X^n$ terms in potential, gravitino LSP



But, in the Immortal Words of an Anonymous Referee …

"It is certainly not one of the key initial issues the LHC will explore, or that physicists more broadly will care about"

The Best Answer …



… get the LHC working

Bunch Intensities during Sector Test