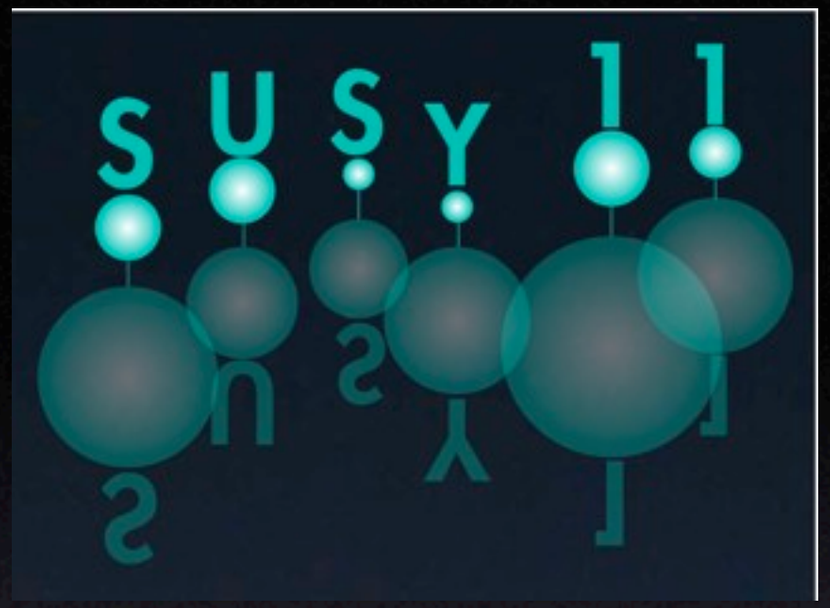

Why do SUSY in 2011?

Hitoshi Murayama (IPMU Tokyo & Berkeley)

SUSY 2011 @ Fermilab, Aug 28, 2011

Third Birthday

IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

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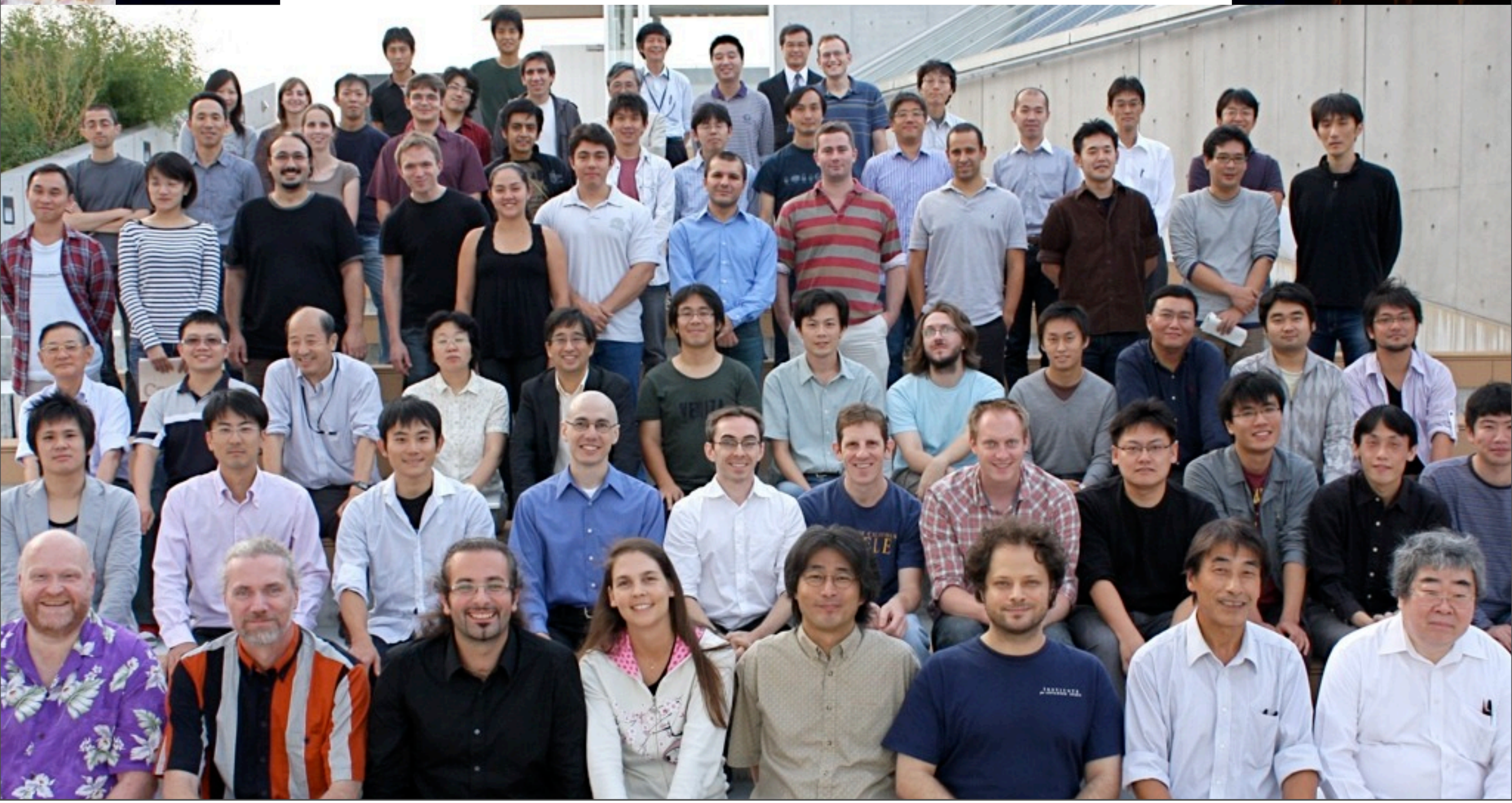

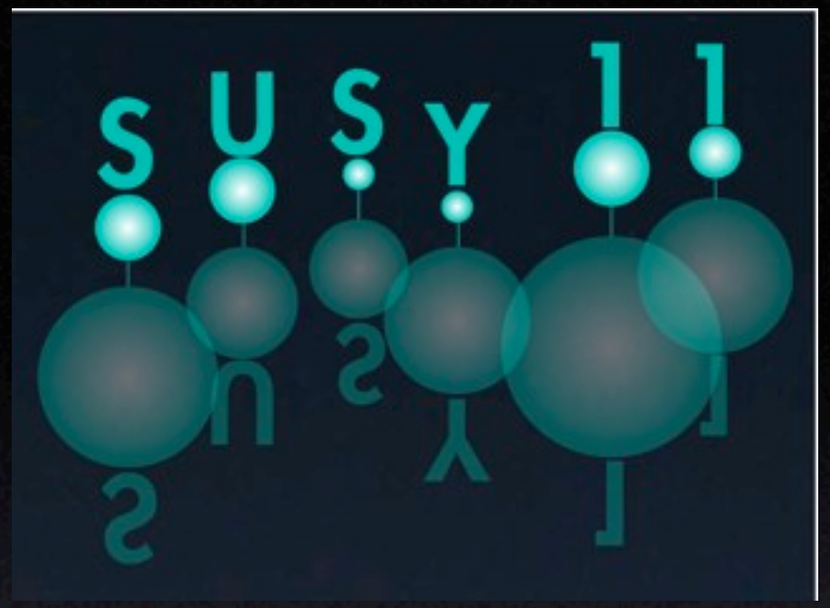

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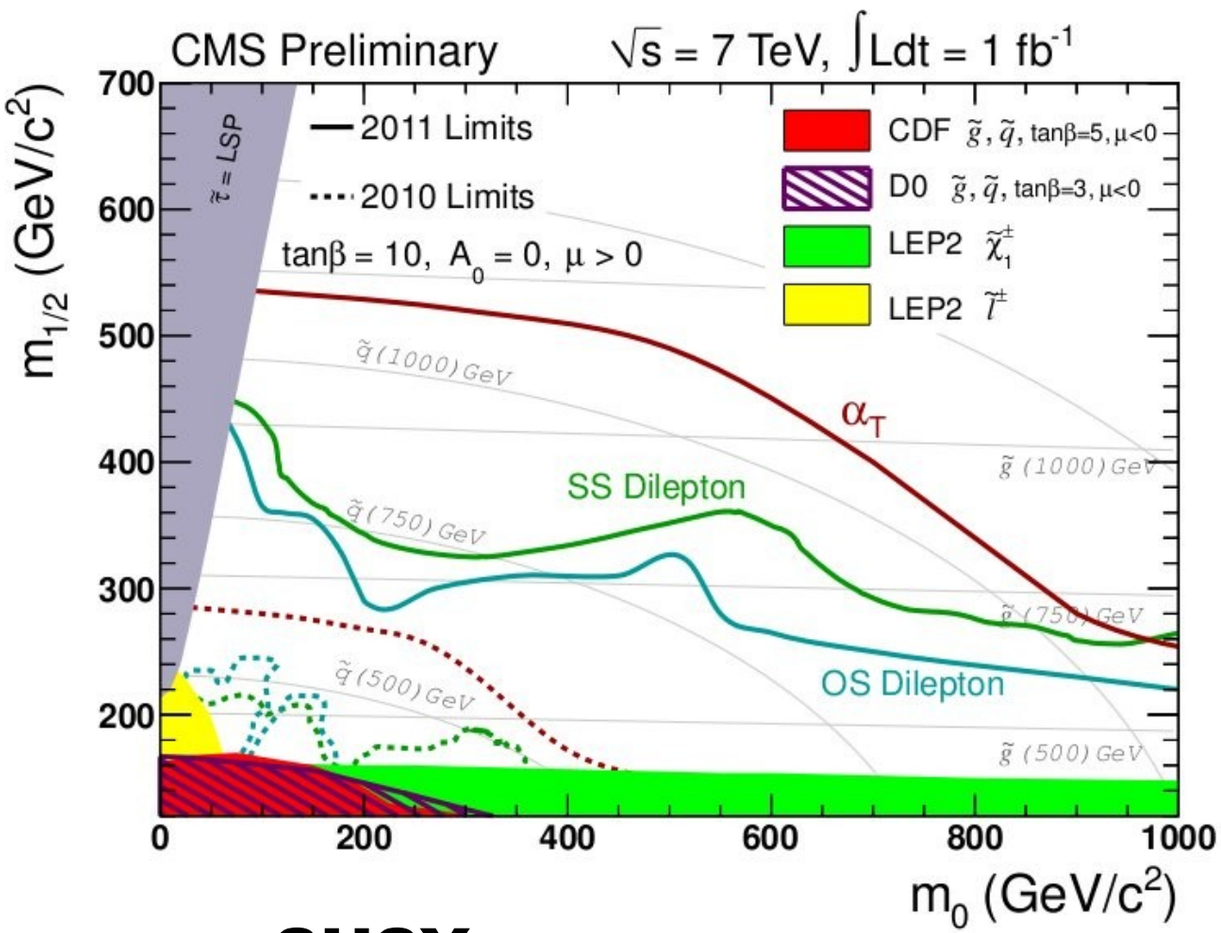
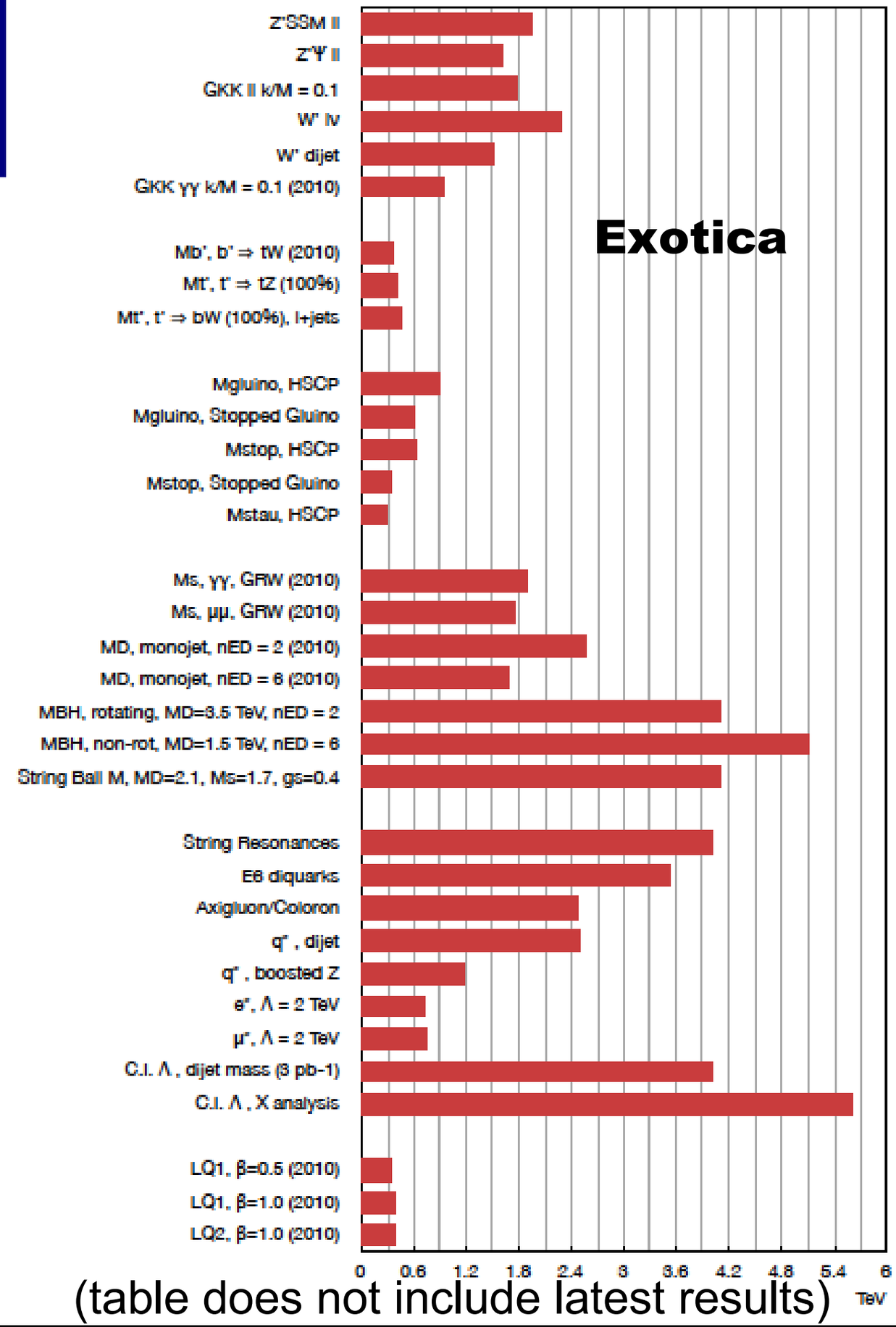
Summary (CMS)



SUSY



Exotica

(only a selection of results)

(table does not include latest results)

BBC NEWS

SCIENCE & ENVIRONMENT

27 August 2011 Last updated at 02:41 ET

LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

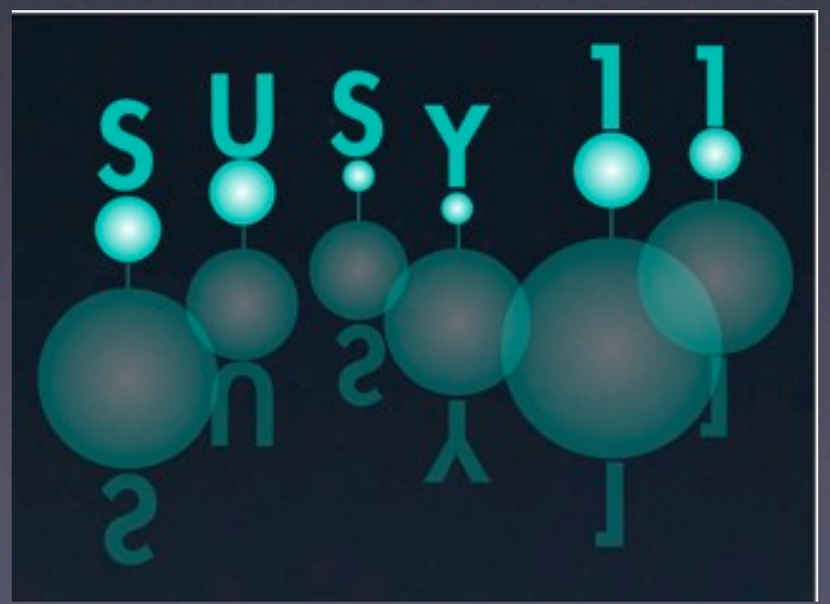
IPMU

BERKELEY CENTER FOR THEORETICAL PHYSICS

Do we still expect new physics at the LHC?

Hitoshi Murayama (IPMU Tokyo & Berkeley)

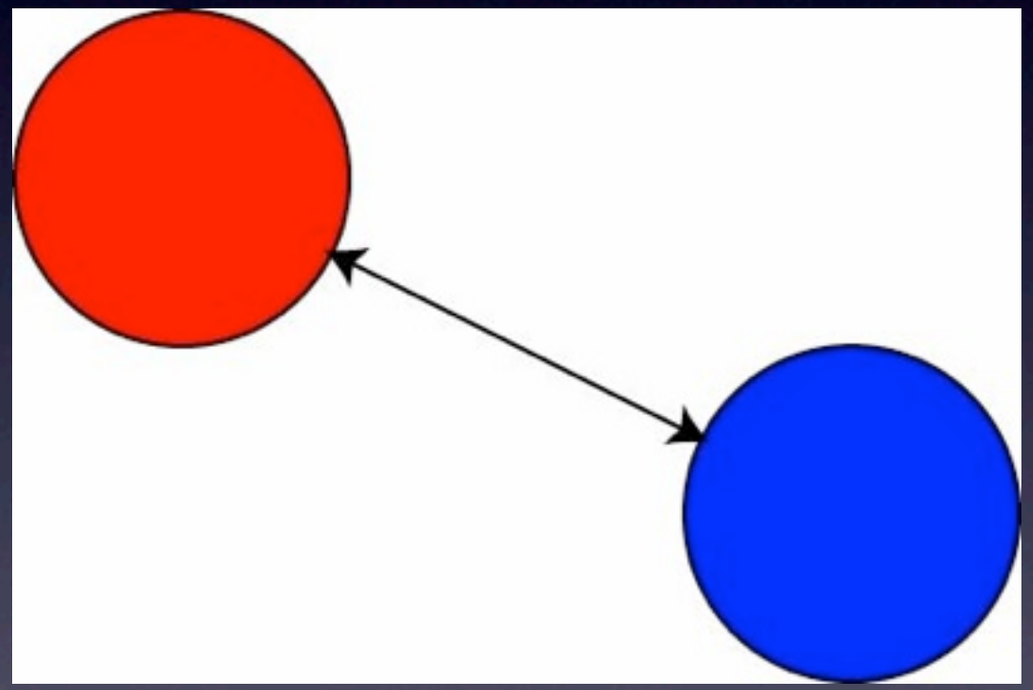
SUSY 2011 @ Fermilab, Aug 28, 2011



Why are we probing the Terascale?

Mystery of the weak force

- Gravity pulls two massive bodies (long-ranged)
- Electric force repels two like charges (long-ranged)
- Weak force pulls protons and electrons (short-ranged) acts only over 0.000000001 nanometer
- We know the energy scale: ~0.3 TeV using $\hbar$ and c



New Era

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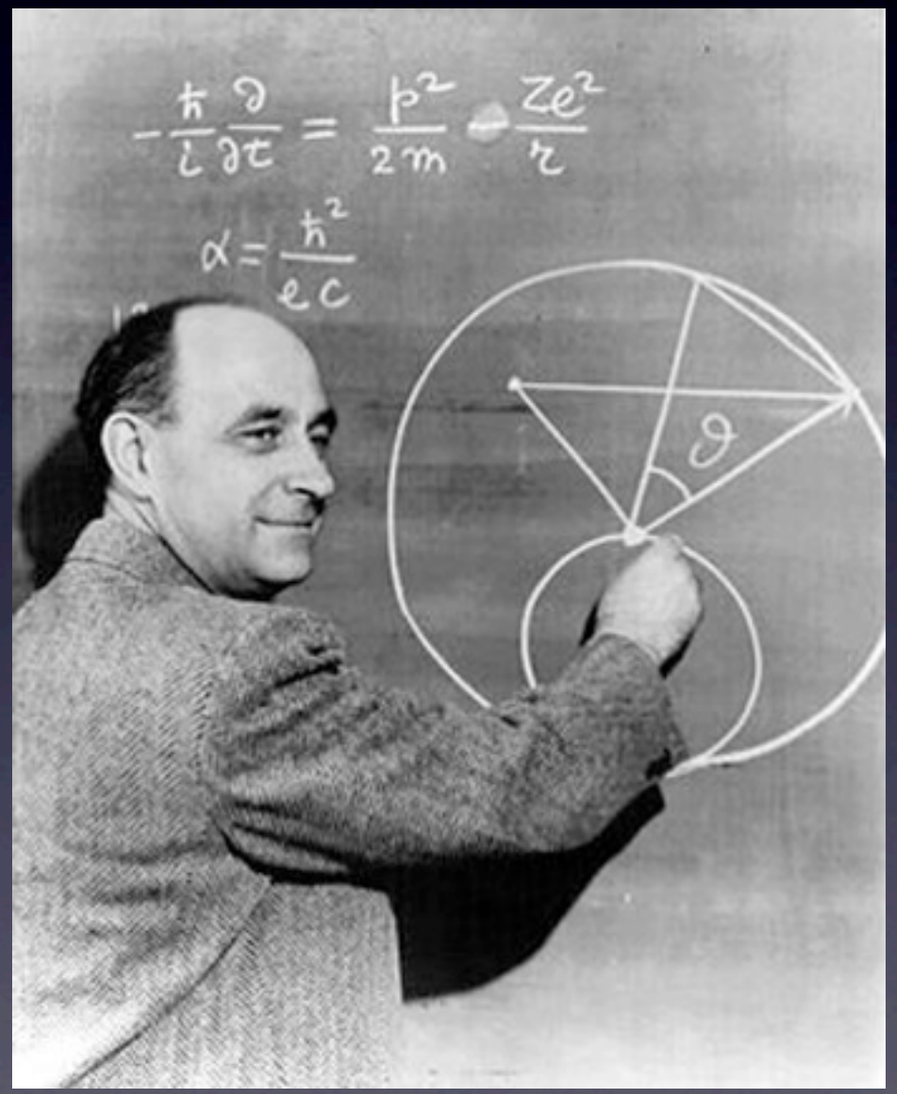
- We'll start with Higgs boson(s)

Fermi's dream era

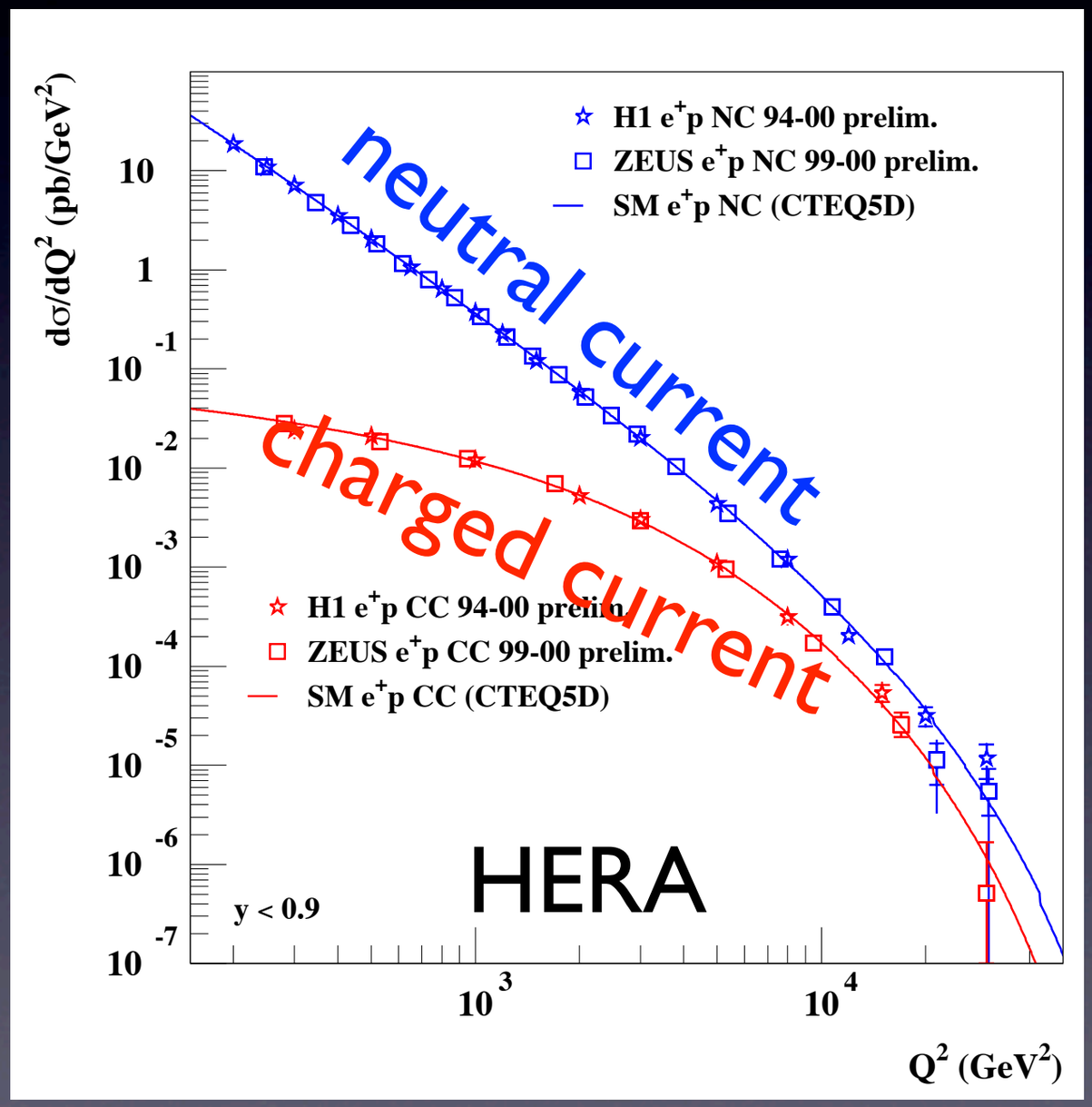
- Fermi formulated the first theory of the weak force (1932)

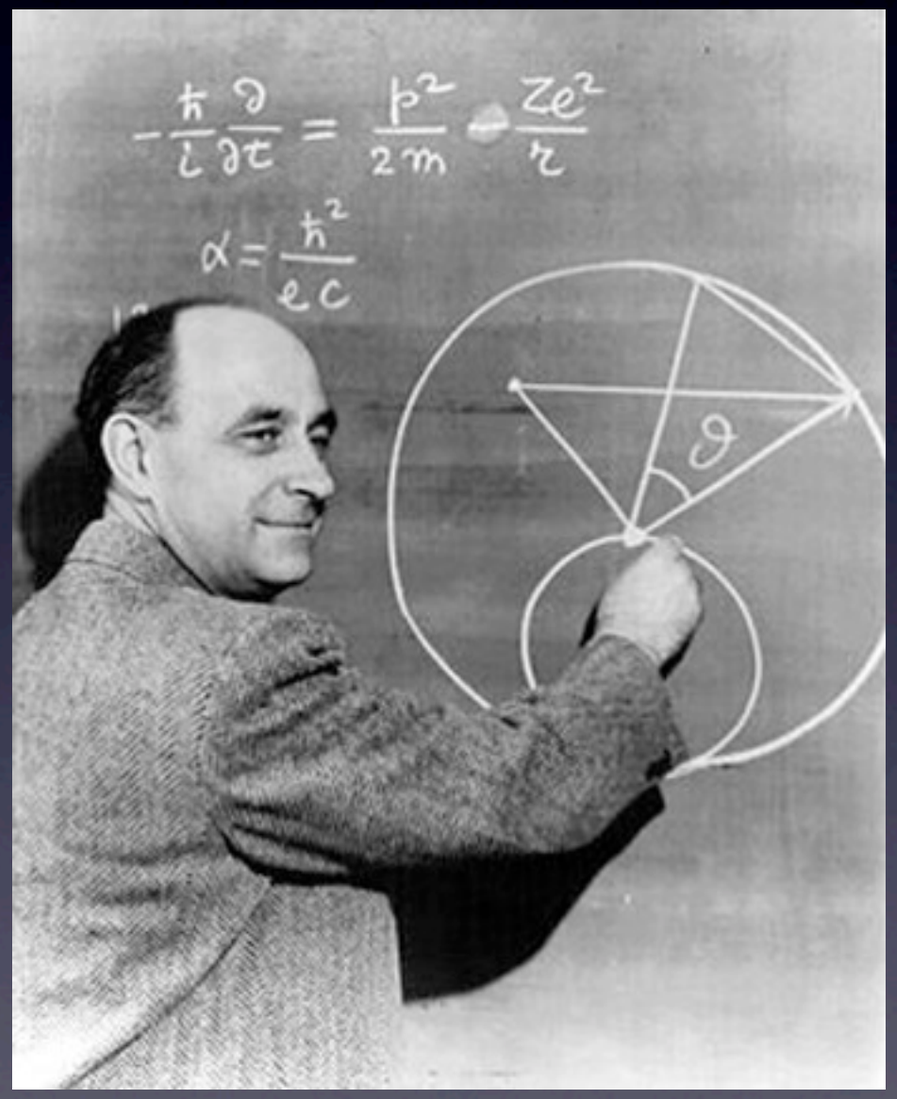
- *The required energy scale to study the problem known since then:* ~TeV

- We are finally getting there!



Fermi's dream era





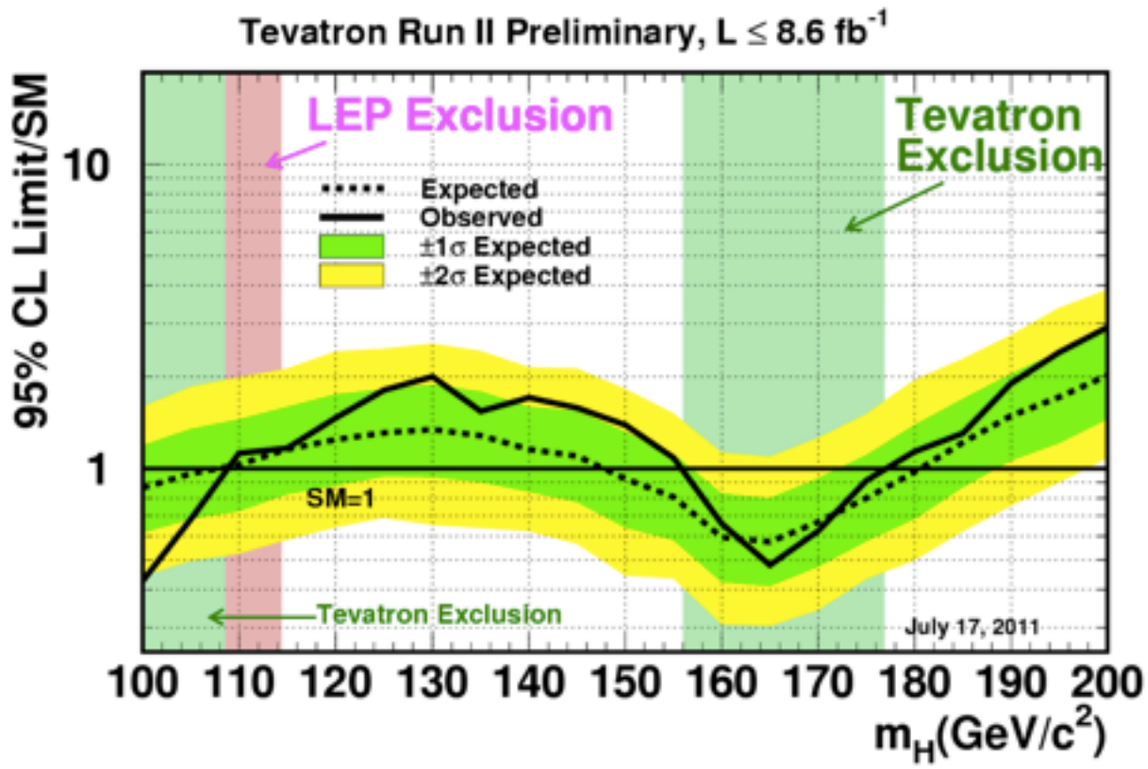
Cosmic Superconductor

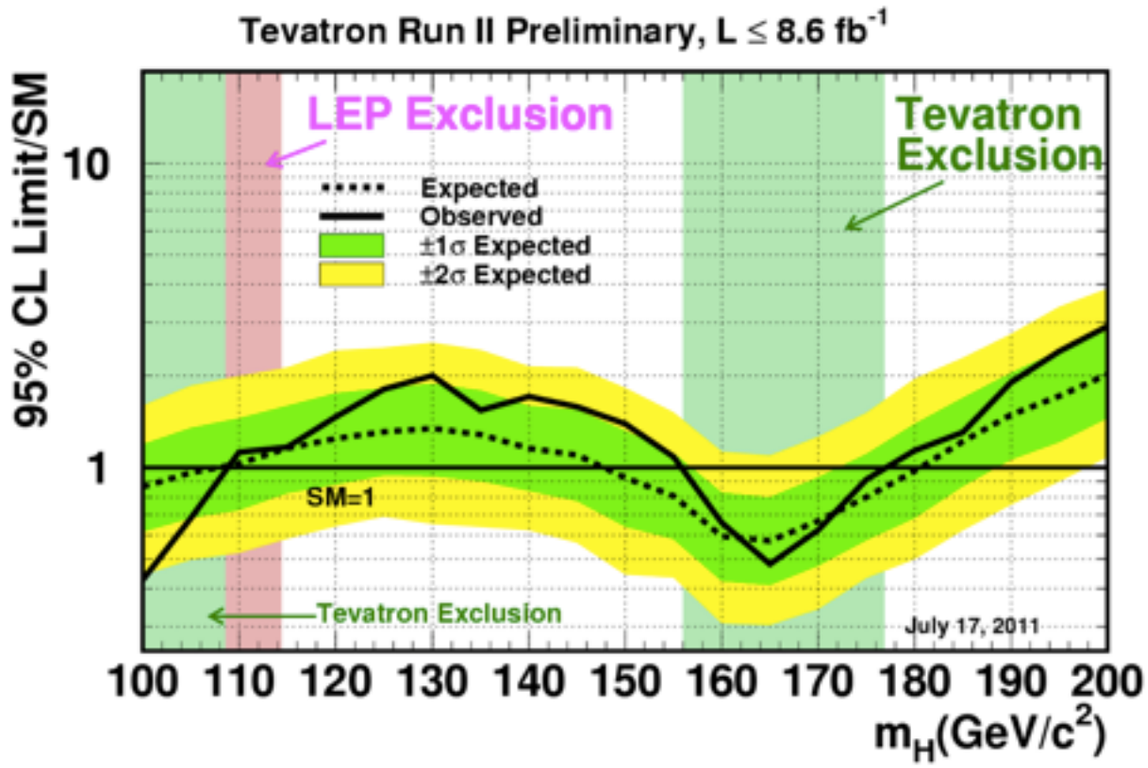
- In a superconductor, magnetic field gets repelled (Meißner effect), and penetrates only over the "penetration length"

  ⇒ Magnetic field is short-ranged!

- Imagine a physicist living in a superconductor
- She finally figured:
  - magnetic field must be long-ranged
  - there must be a mysterious charge-two condensate in her "Universe"
  - But doesn't know what the condensate is, nor why it condenses
  - Didn't have enough energy (gap) to break up Cooper pairs

That's the stage where we are!


Tevatron Run II Preliminary, L ≤ 8.6 fb^{-1}
95% CL Limit/SM
LEP Exclusion
Tevatron Exclusion
Expected
Observed
±1σ Expected
±2σ Expected
SM=1
Tevatron Exclusion
July 17, 2011
10
1
100 110 120 130 140 150 160 170 180 190 200
m_H(GeV/c^2)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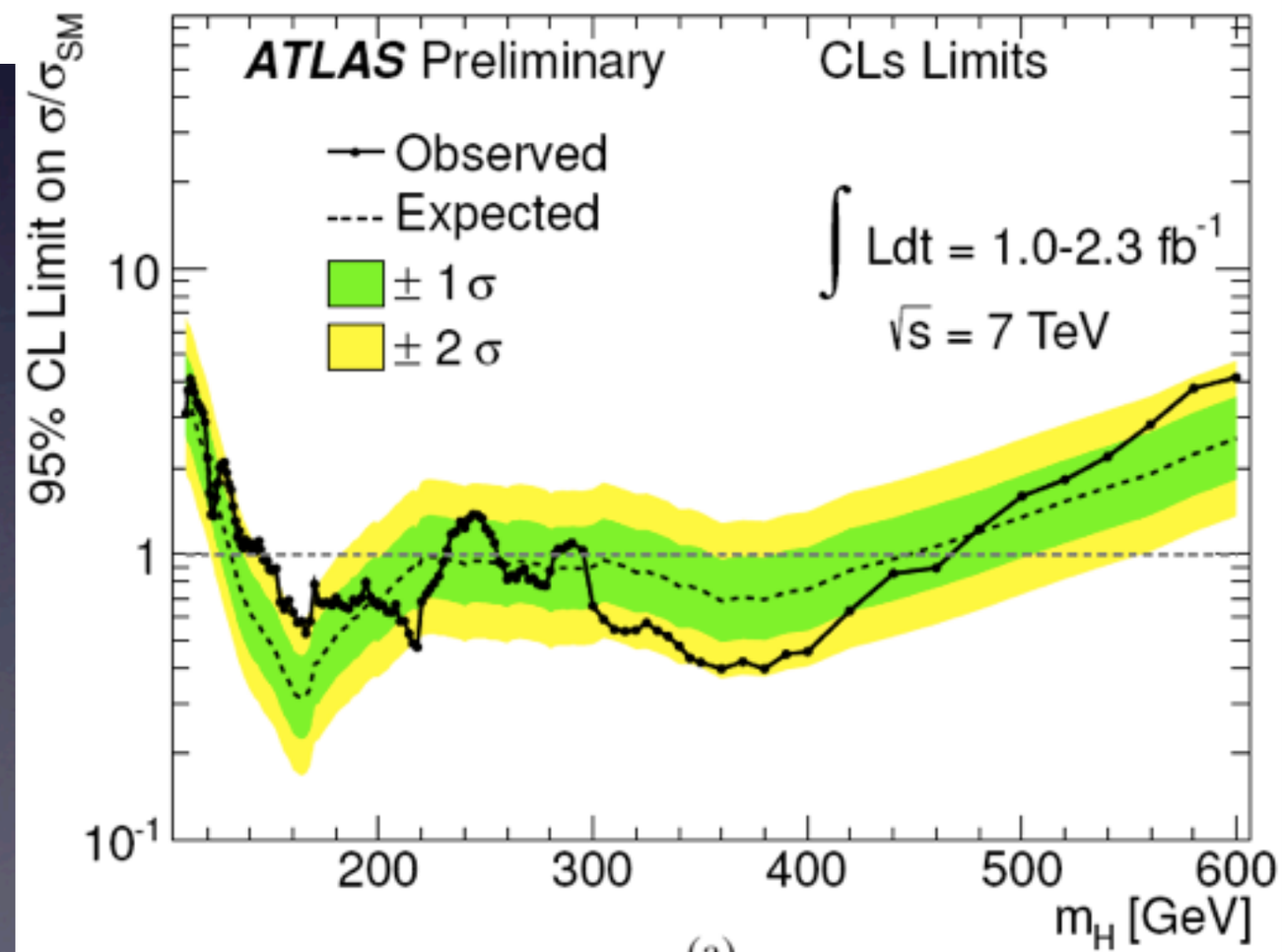
ATLAS Preliminary
CLs Limits
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± 1 σ
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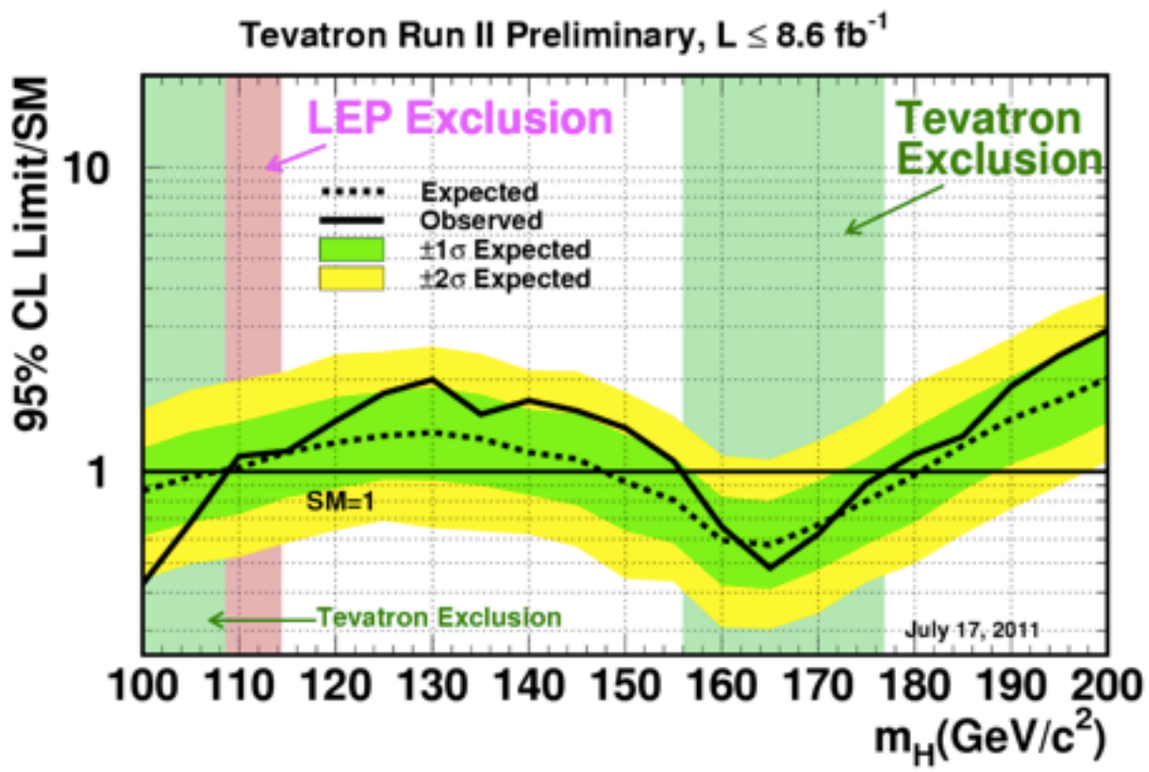
∫ Ldt = 1.0-2.3 fb-1
√s = 7 TeV
95% CL Limit on σ/σSM
10
1
10-1
200 300 400 500 600
mH [GeV]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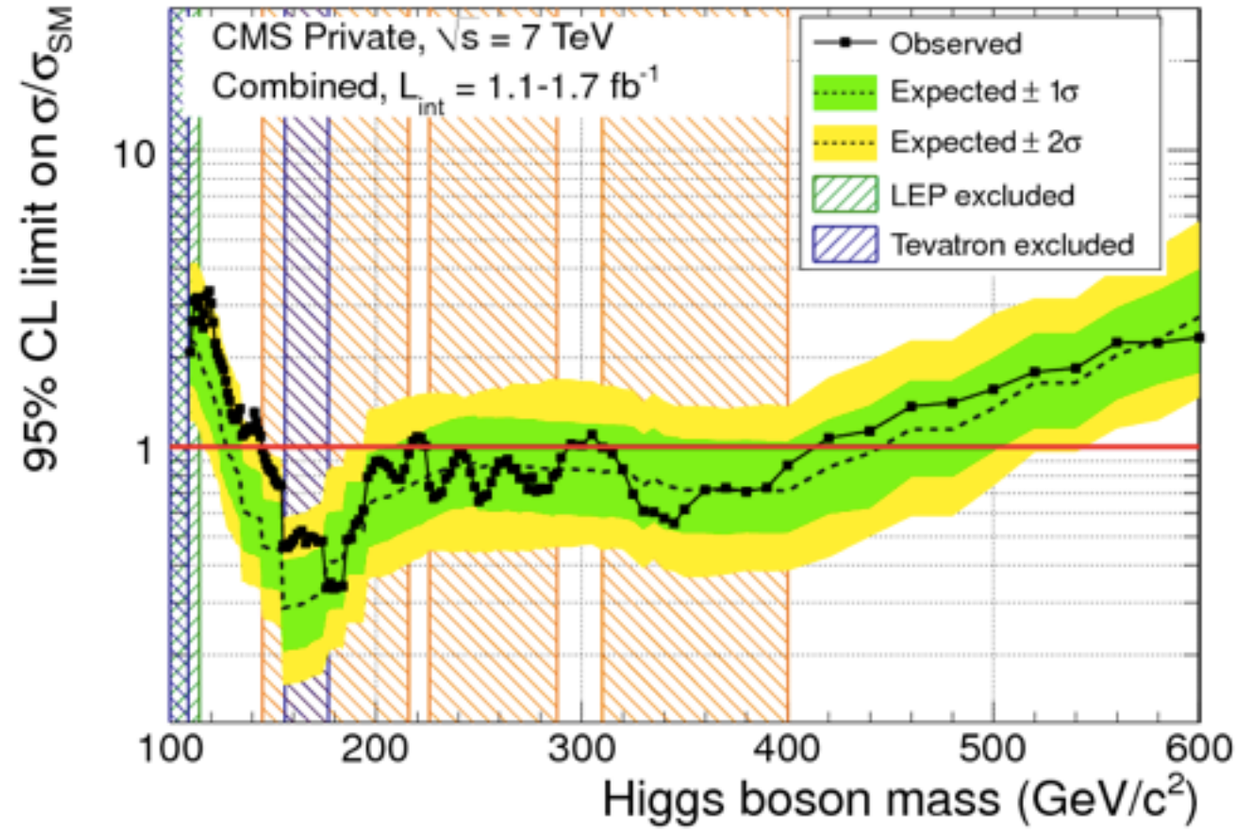
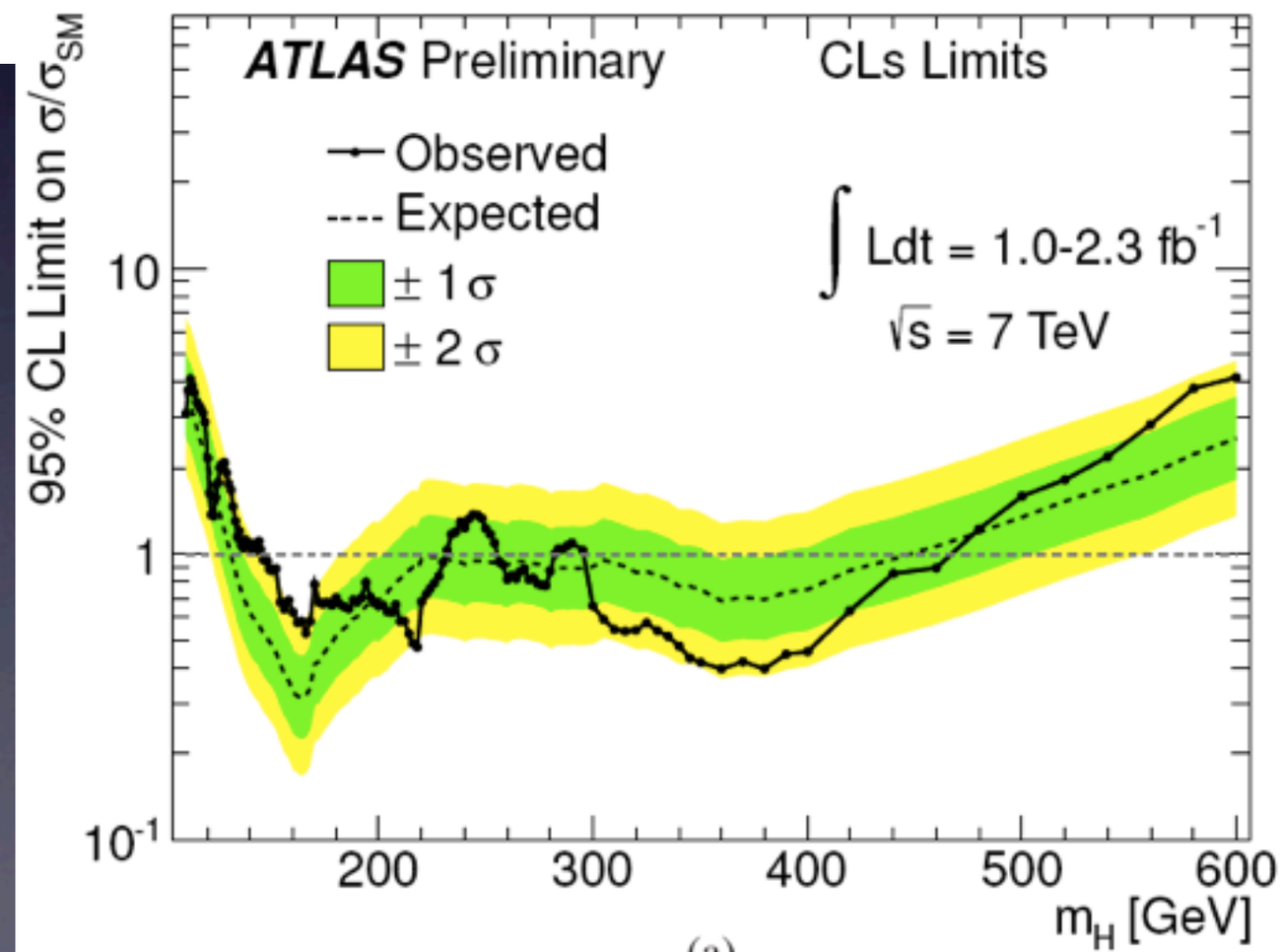

CMS Private, √s = 7 TeV
Combined, Lint = 1.1-1.7 fb-1
Observed
Expected ± 1σ
Expected ± 2σ
LEP excluded
Tevatron excluded
95% CL limit on σ/σSM
Higgs boson mass (GeV/c2)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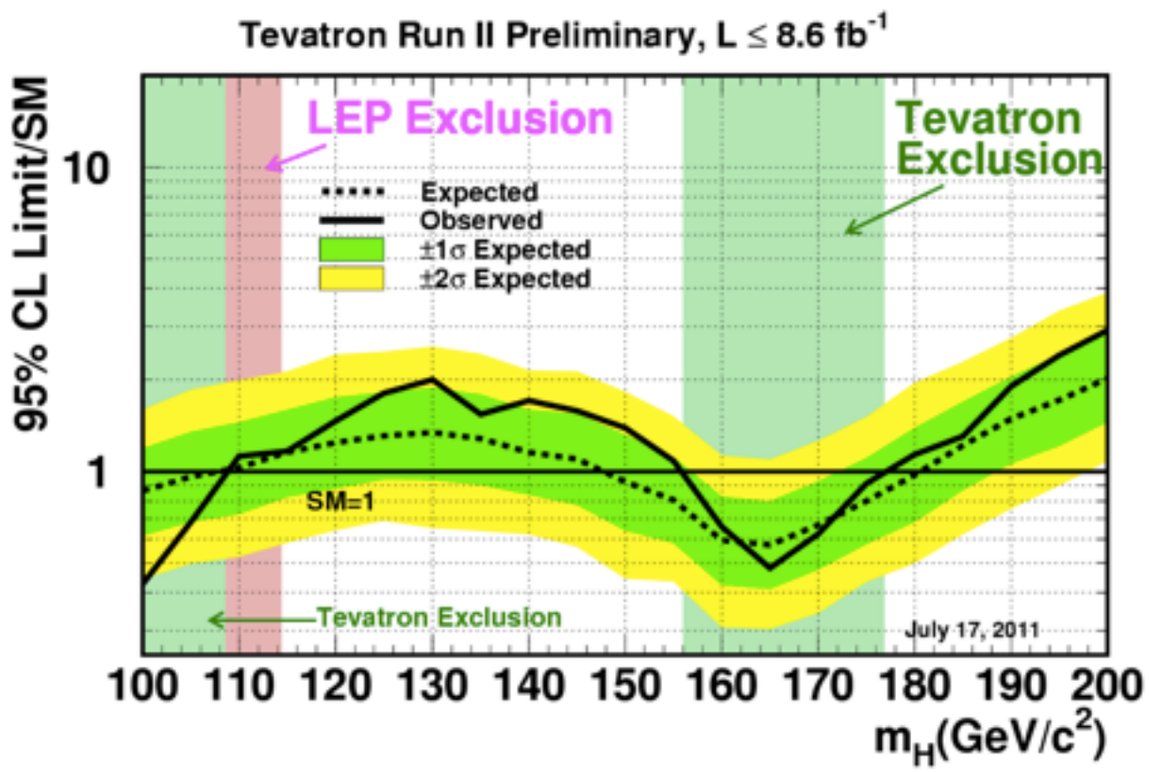
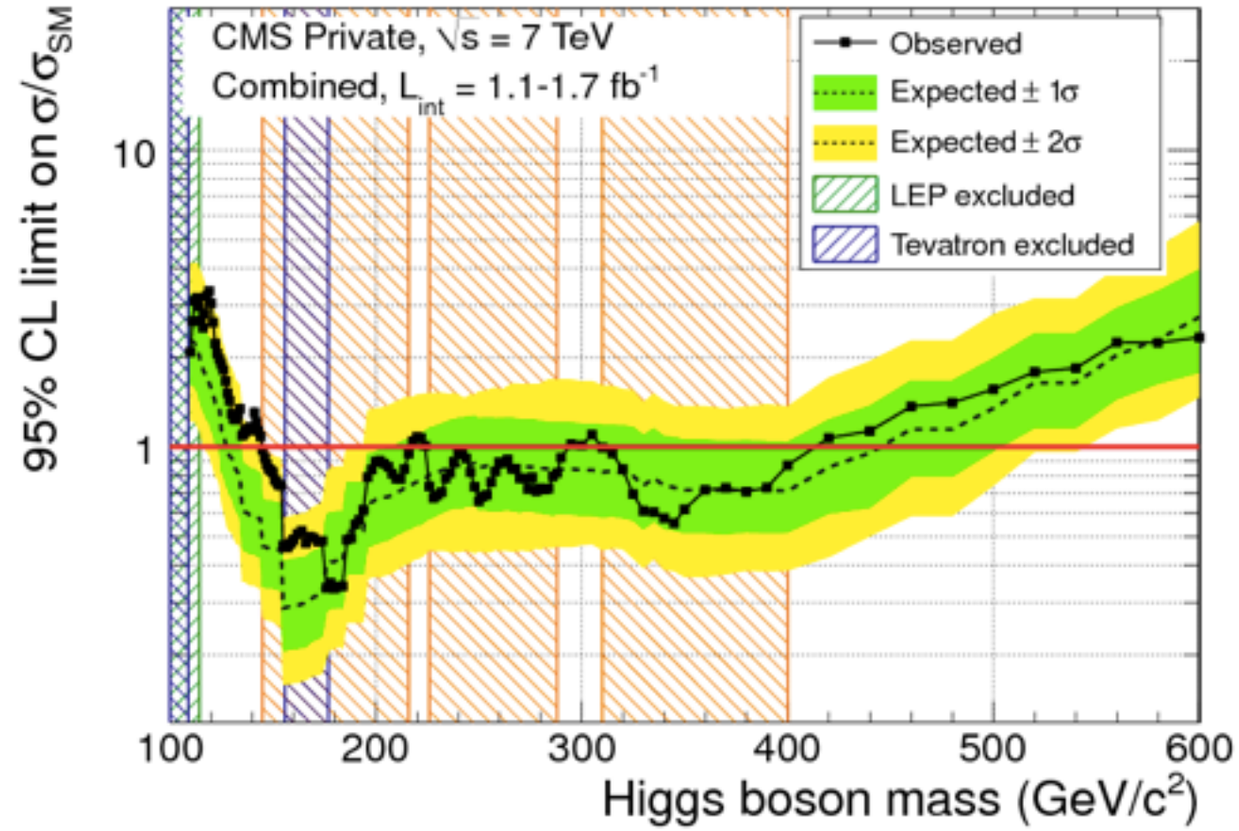
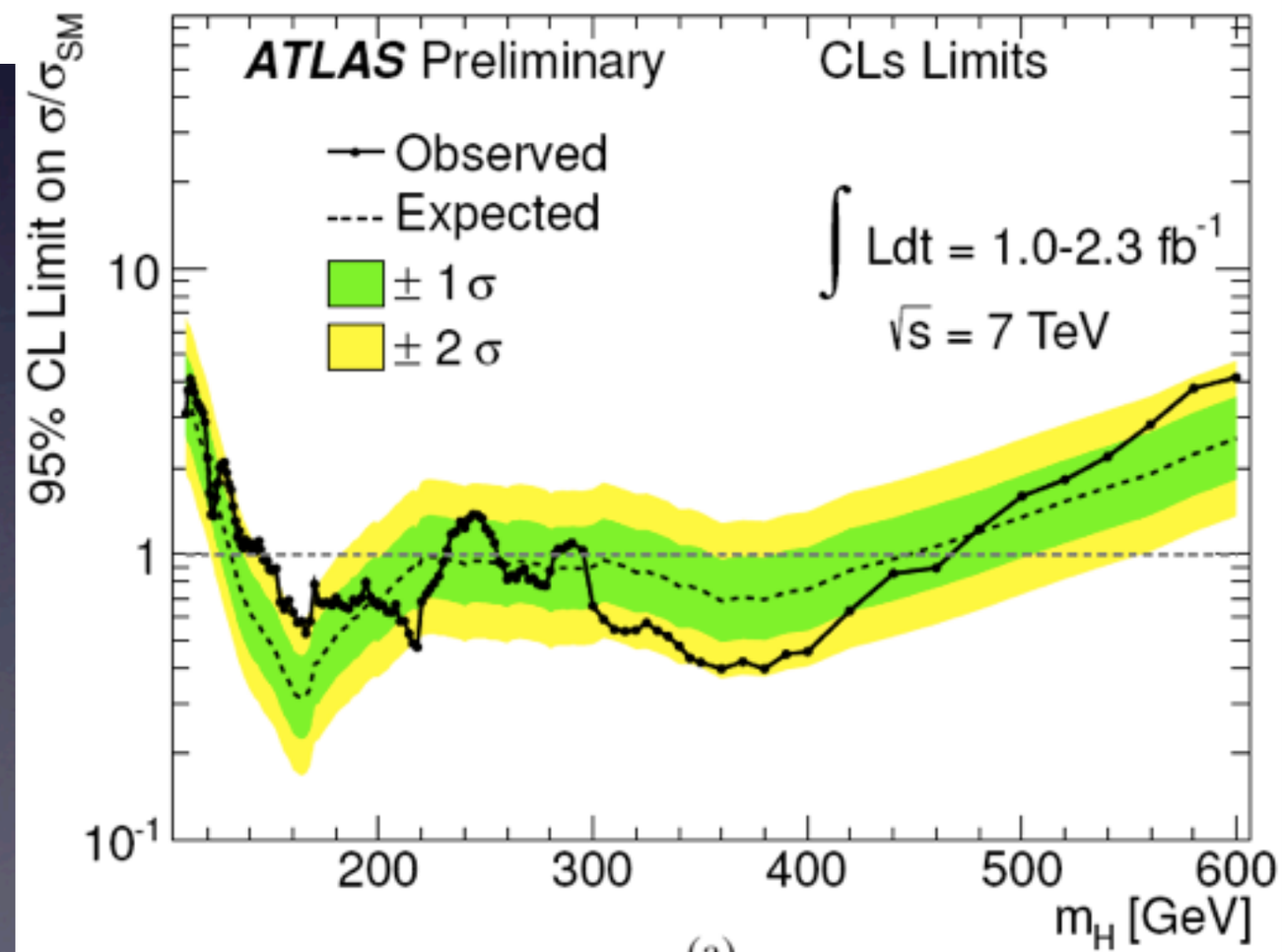


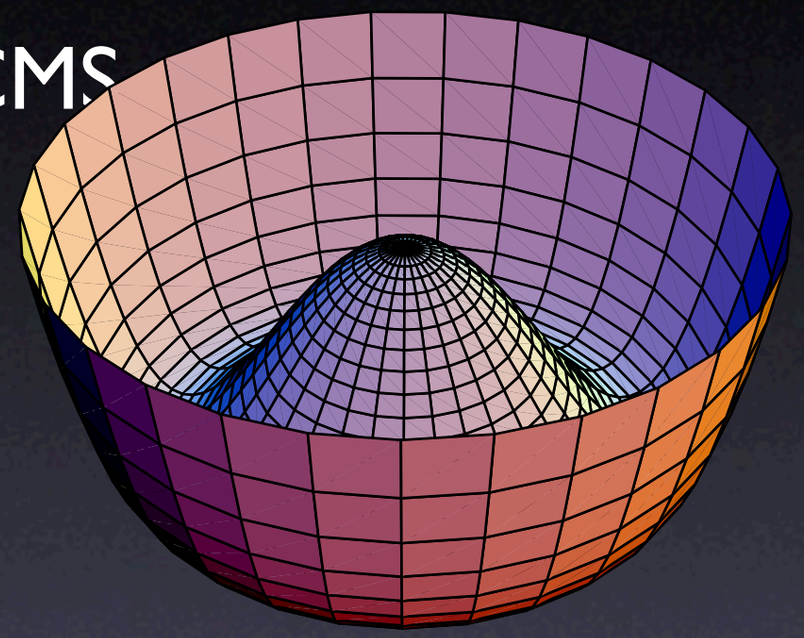


- truly impressive progress
- 115-145? 288-296? >466?
- if not standard model, maybe ~2sigma excess around 140 GeV?
- Anyway, a lot to look forward to!



What is behind Higgs?

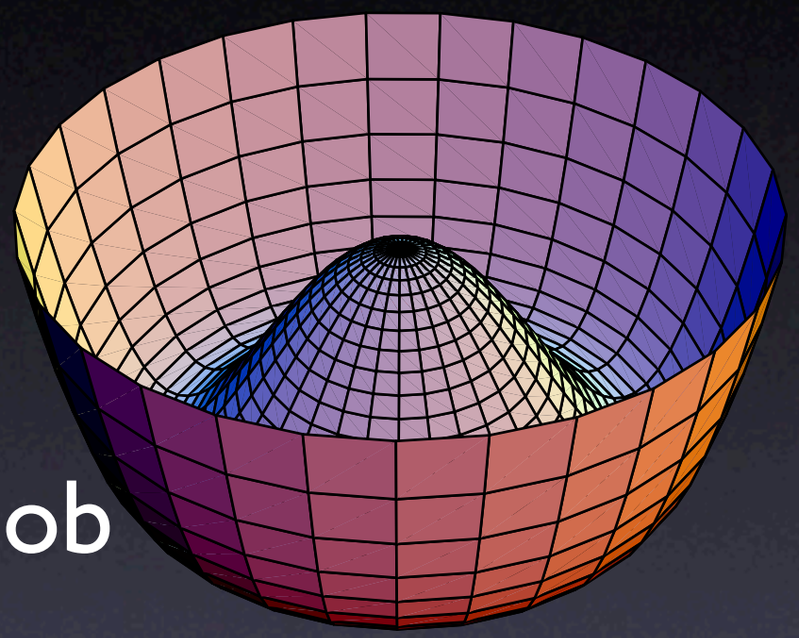
Post-Higgs Problem



- robust discovery reach by ATLAS/CMS
- We will see "what" is condensed
- But we still won't know "why"
- Two problems:
  - Why anything is condensed at all
  - Why is the scale of condensation $\sim \mathrm{TeV} \ll M_{Pl} = 10^{15}\mathrm{TeV}$
- Explanation most *likely* to be at ~TeV scale because this is the relevant energy scale

Strange

- Higgs boson is the *only spin 0 particle* in the standard model
  - one of its kind
  - but does the most important job
- looks rather artificial
- *Higgsless theories*: possible but not favored by EW precision data
- another problem: naturalness



Once upon a time, there was a naturalness problem...

- At the end of 19th century: a "crisis" about electron
  - Like charges repel: hard to keep electric charge in a small pack
  - Electron is point-like
  - At least smaller than 10^{-17}cm
- Need a lot of energy to keep it small!

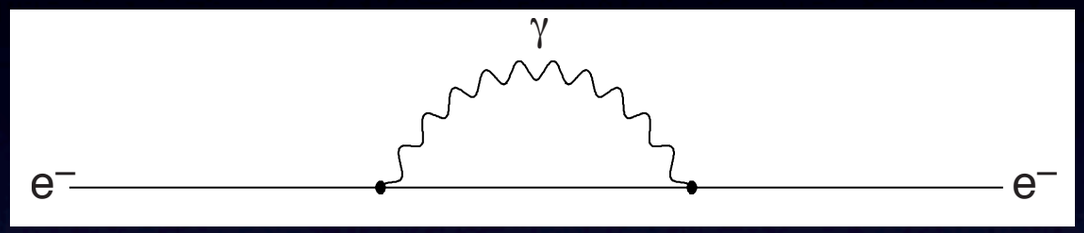
$$\Delta m_e c^2 \sim \frac{e^2}{r_e} \sim \mathrm{GeV}\frac{10^{-17}\mathrm{cm}}{r_e}$$

- Correction $\Delta m_e c^2 > m_e c^2$ for $r_e < 10^{-13}$cm
- Breakdown of theory of electromagnetism

  $\Rightarrow$ Can't discuss physics below 10^{-13}cm

Anti-Matter Comes to Rescue by Doubling of #Particles

- Electron creates a force to repel itself



- Vacuum bubble of matter anti-matter creation/annihilation
- Electron annihilates the positron in the bubble

⇒ only 10% of mass even for Planck-size $r_e \sim 10^{-33}$cm

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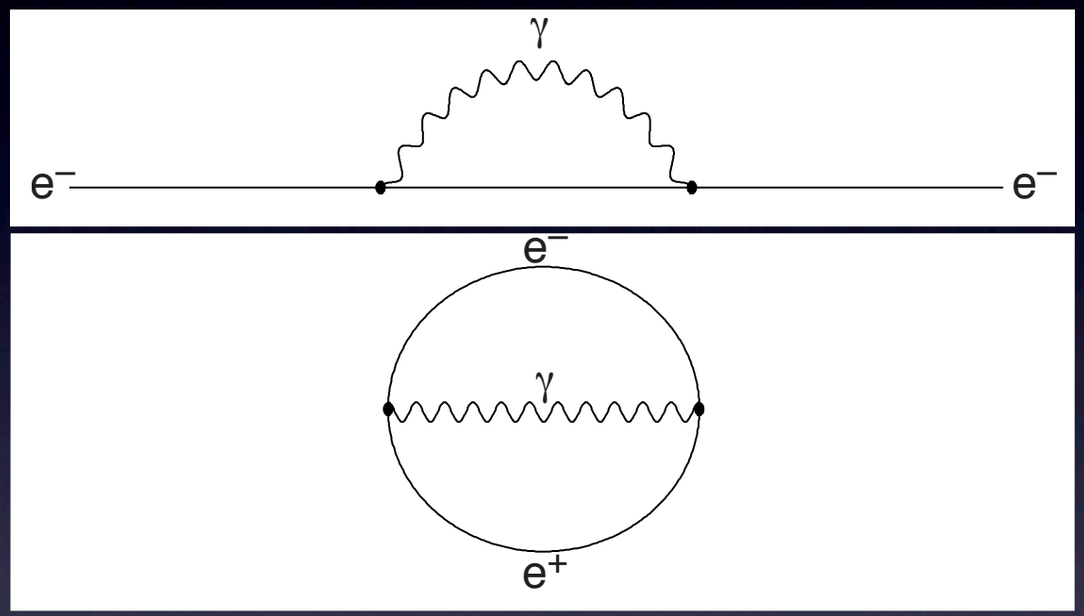

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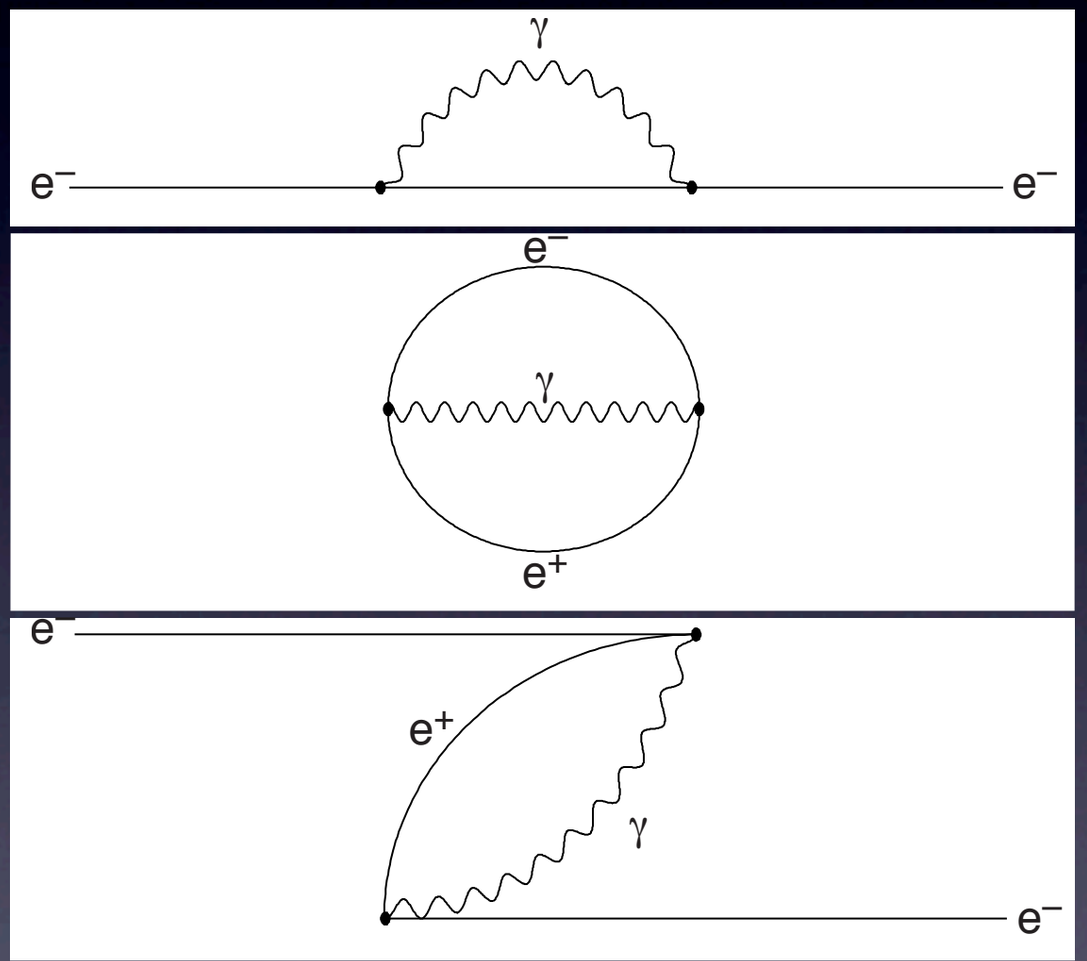

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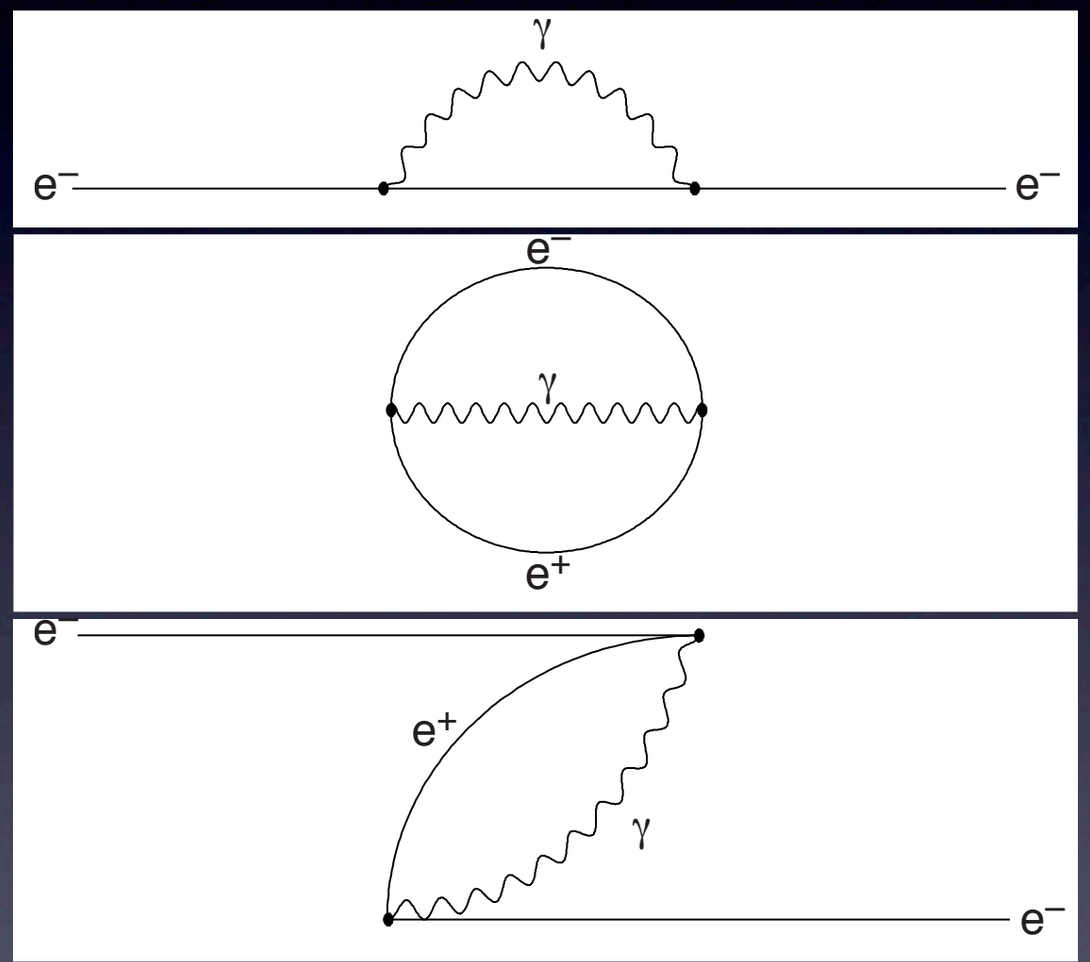
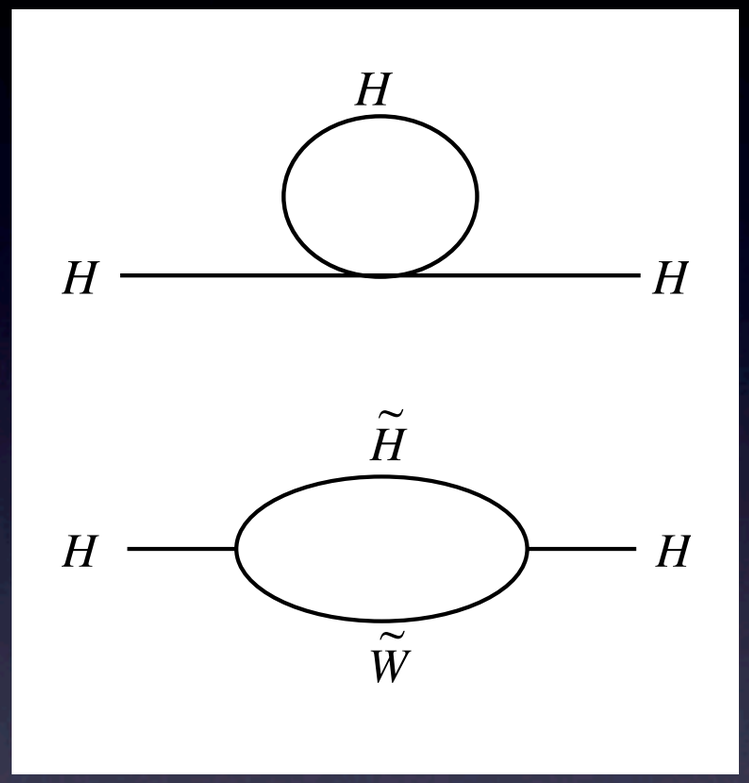


$$\Delta m_e \sim m_e \frac{\alpha}{4\pi} \log(m_e r_e)$$

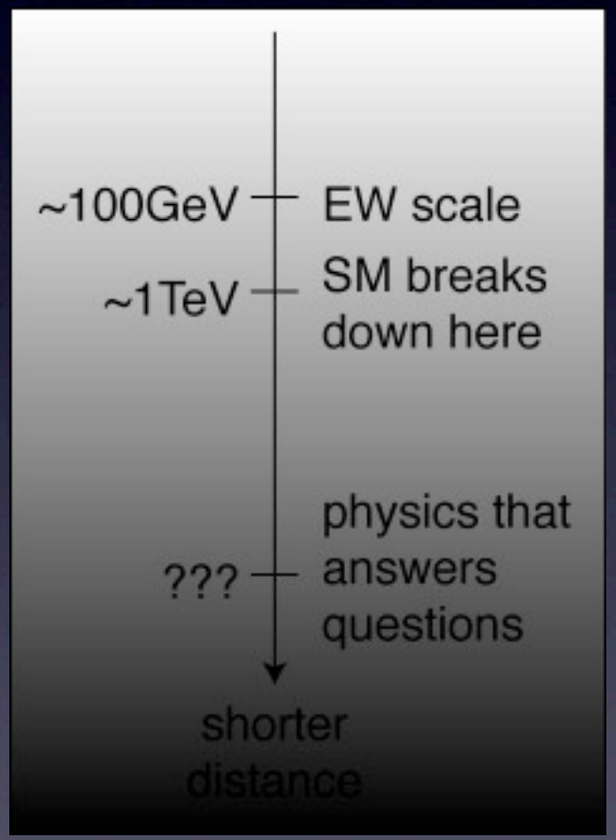
History repeats itself?

- Higgs also repels itself
- Double #particles again
  $\Rightarrow$ superpartners
- "Vacuum bubbles" of superpartners cancel the energy required to contain Higgs boson in itself
- Standard Model made consistent with whatever physics at shorter distances



$$\Delta m_H^2 \sim \frac{\alpha}{4\pi} m_{SUSY}^2 \log(m_H r_H)$$

Opening the door



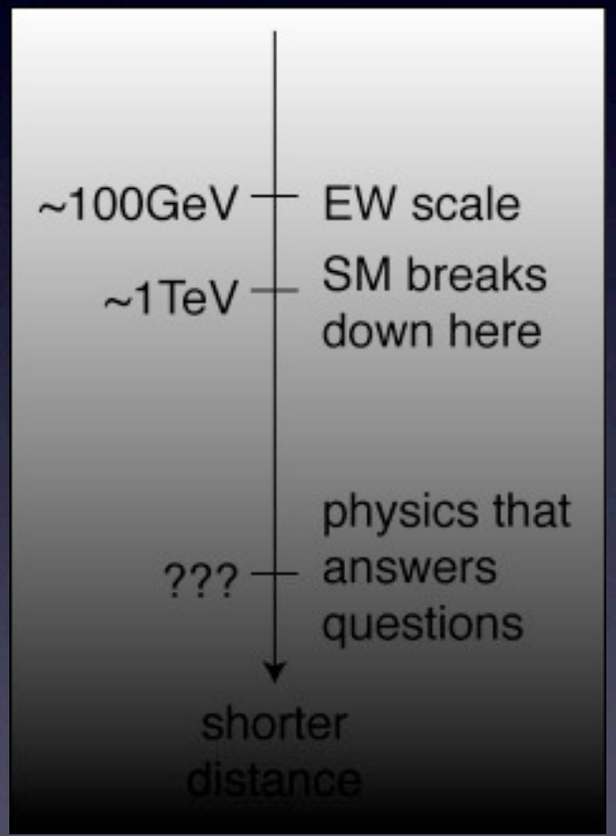
Opening the door

- Once the naturalness problem solved, we can get started to discuss physics at shorter distances and earlier universe.

- It opens the door to the next level:

  Hope to answer big questions

- The solution to the naturalness problem itself, e.g., SUSY, provides additional probe to physics at short distances



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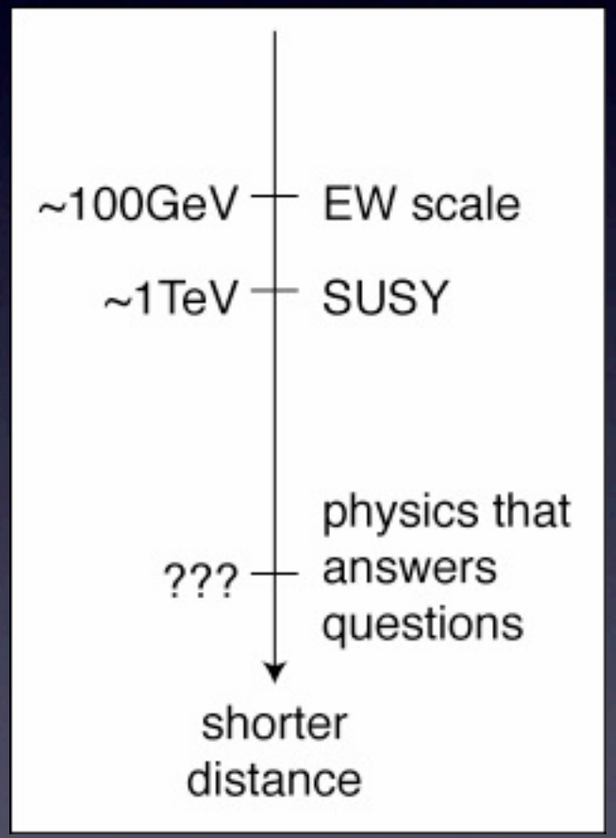
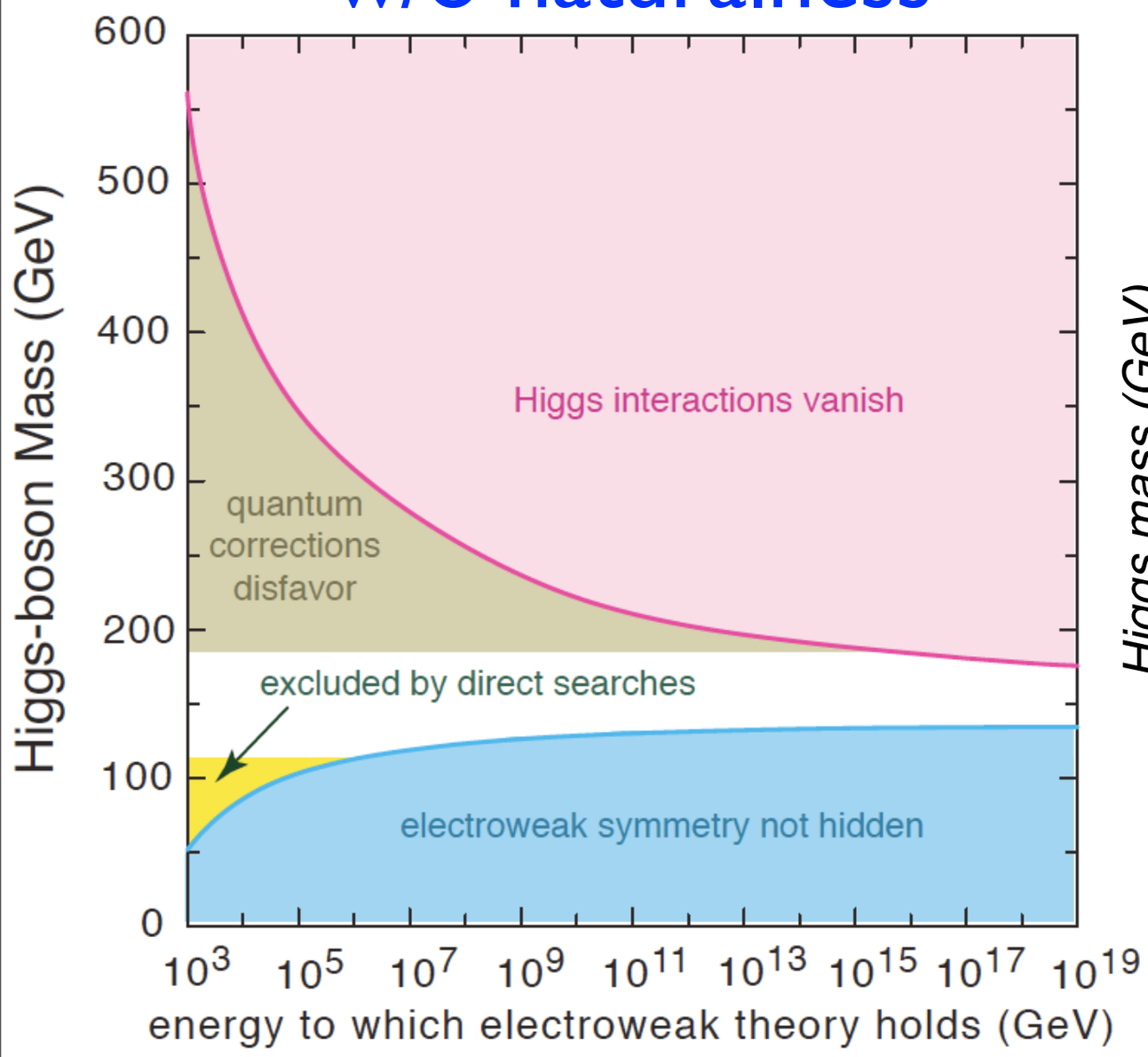
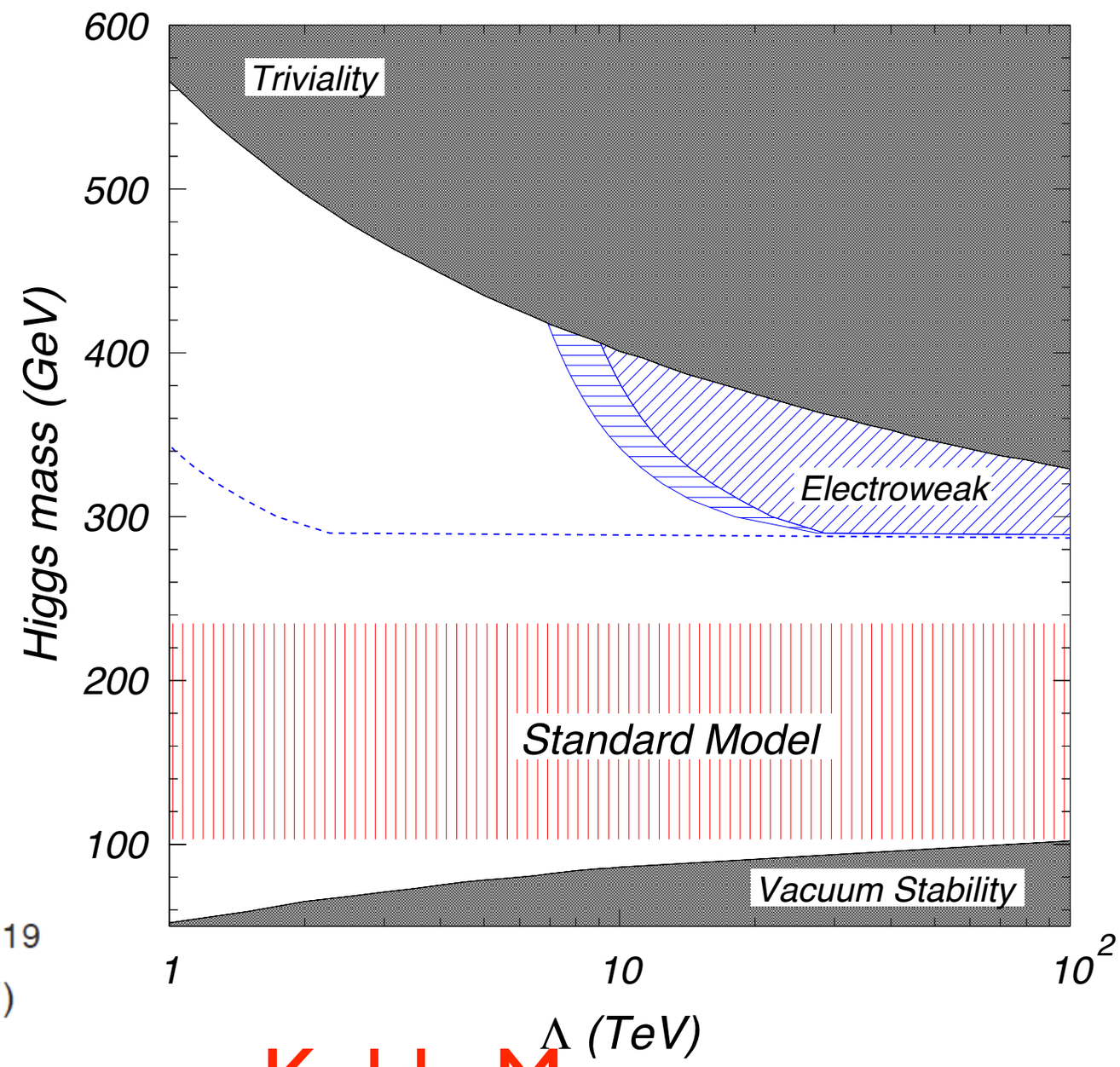


Where is the next energy scale?

w/o naturalness



Mättig



Kolda Murayama

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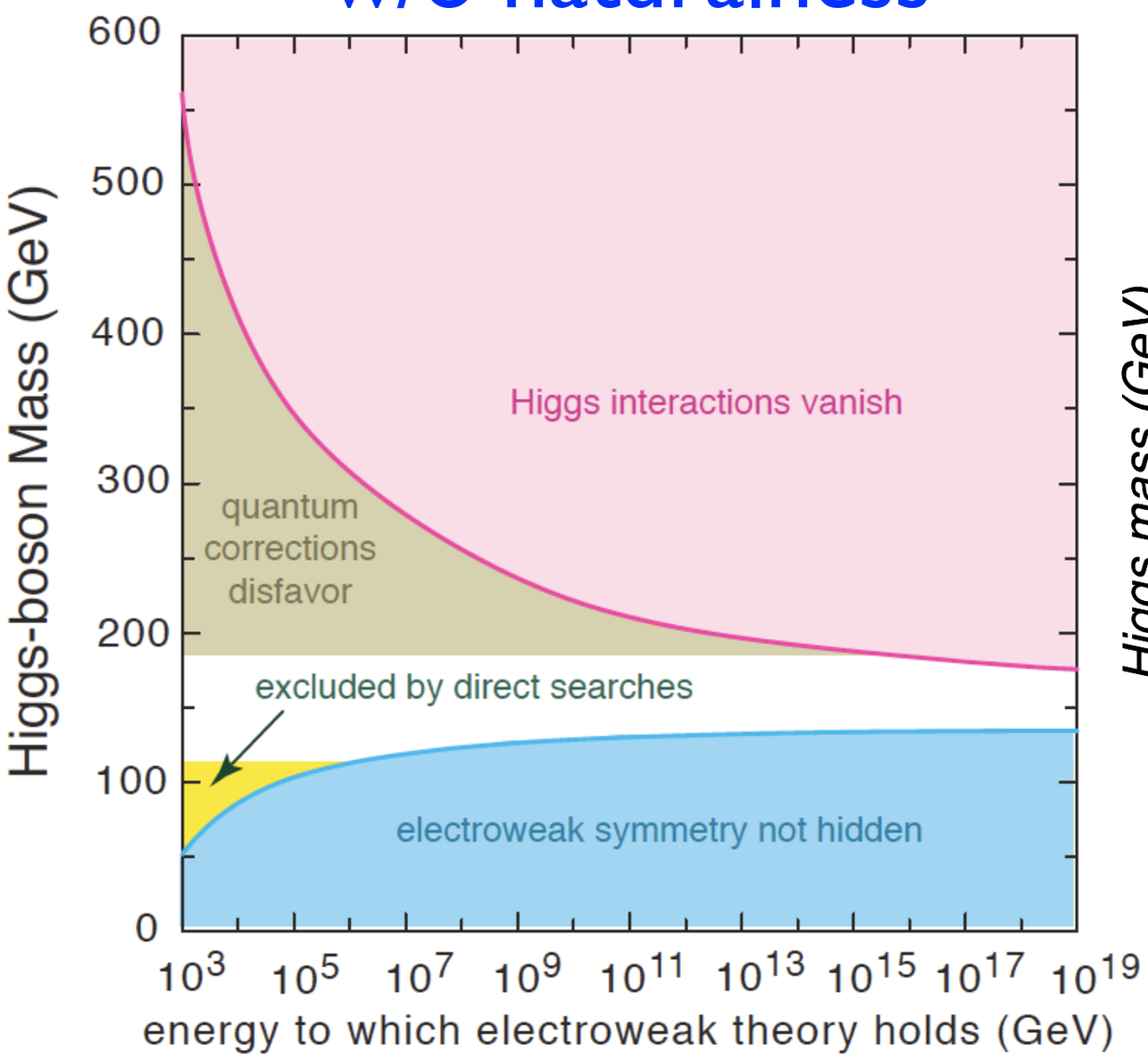
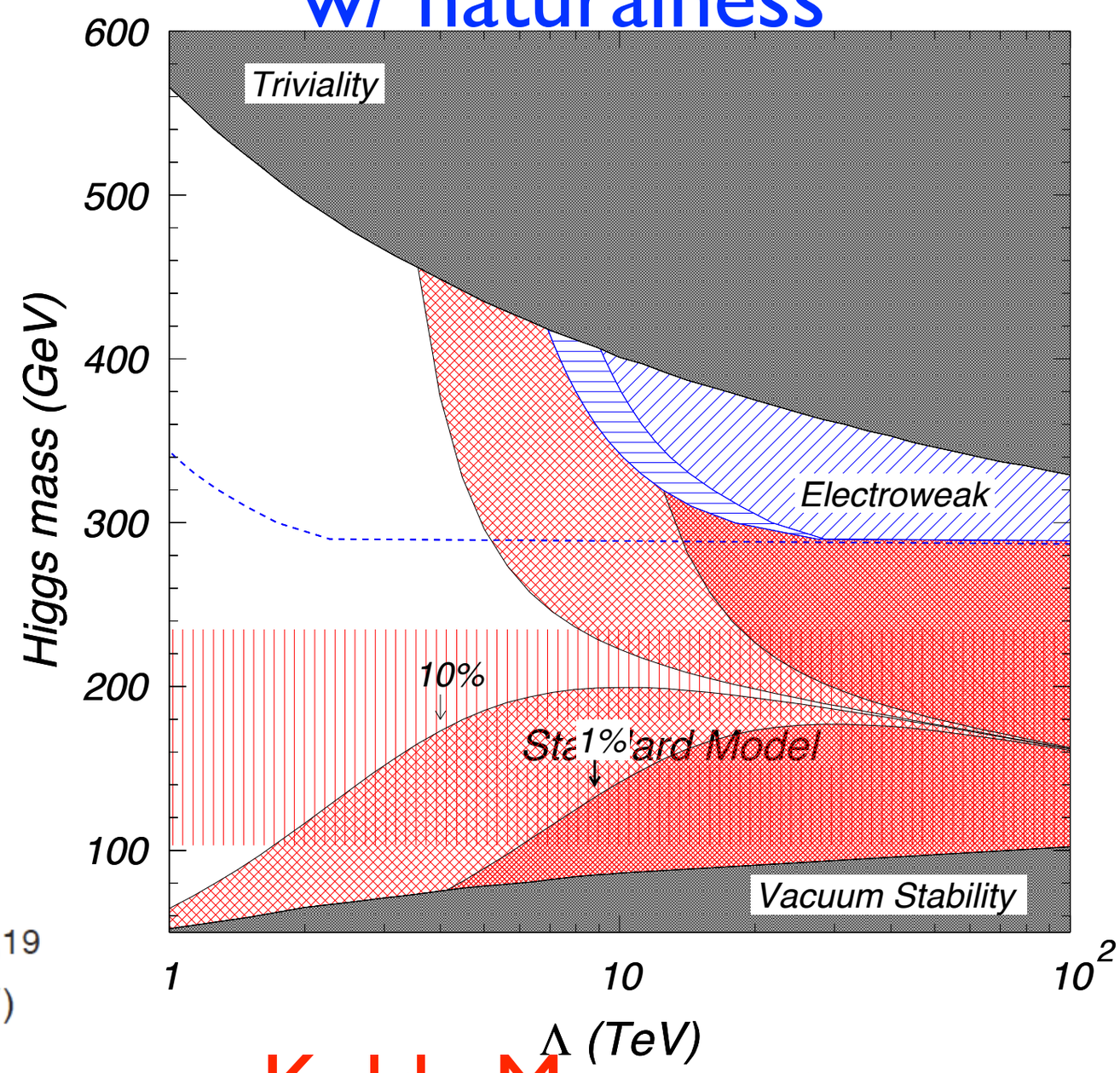


Mättig

w/ naturalness



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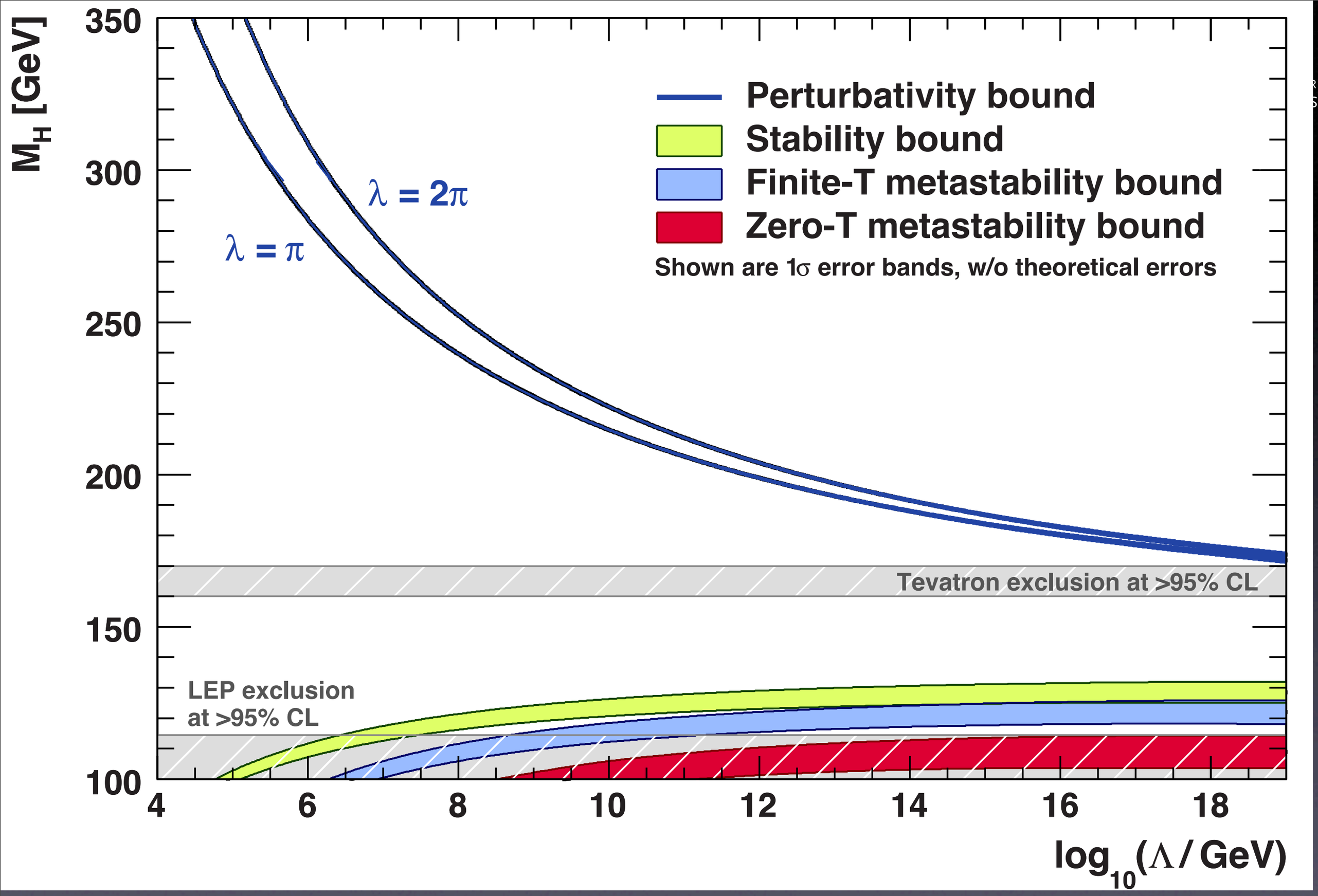
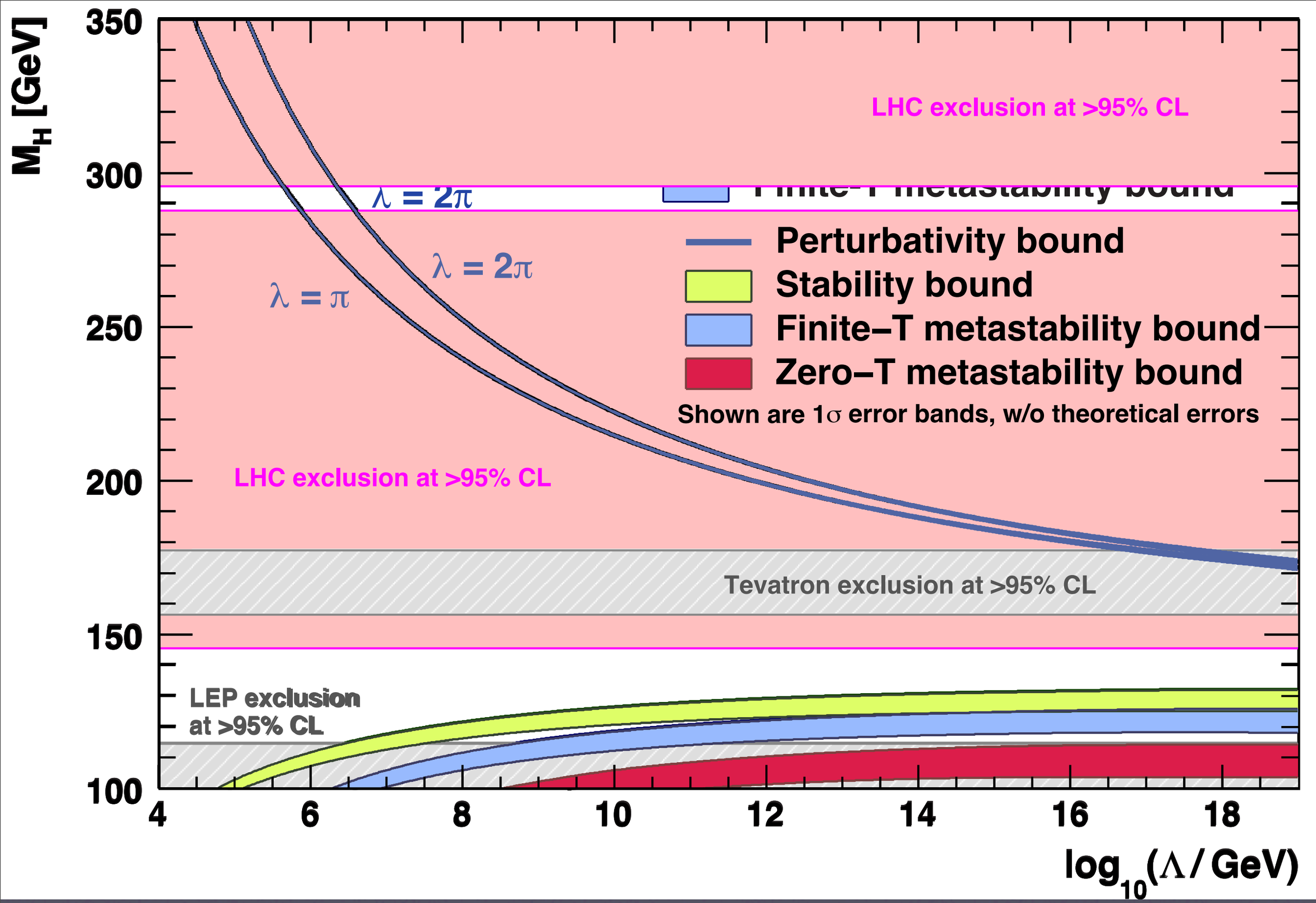


Harigaya, Matsumoto, HM



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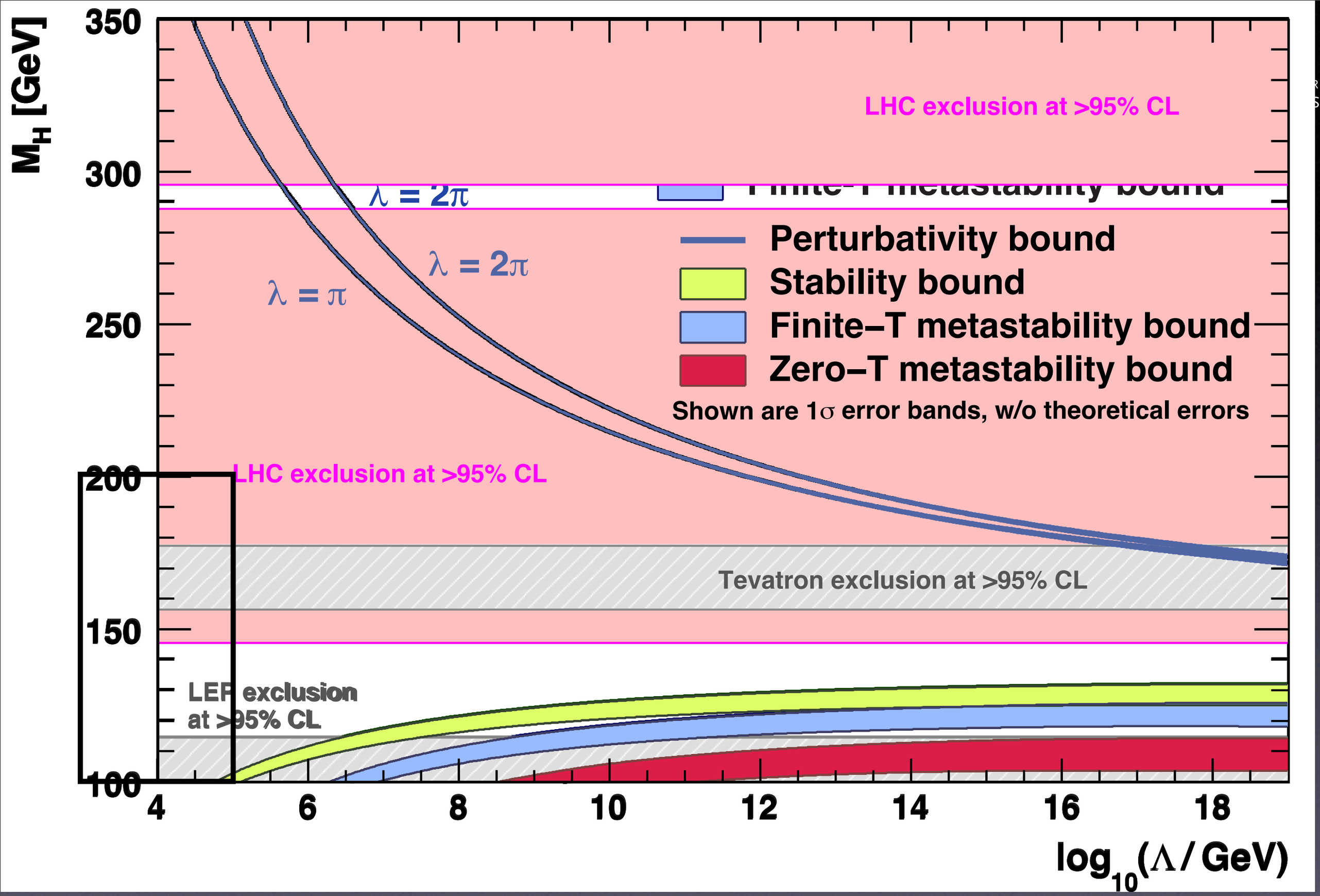

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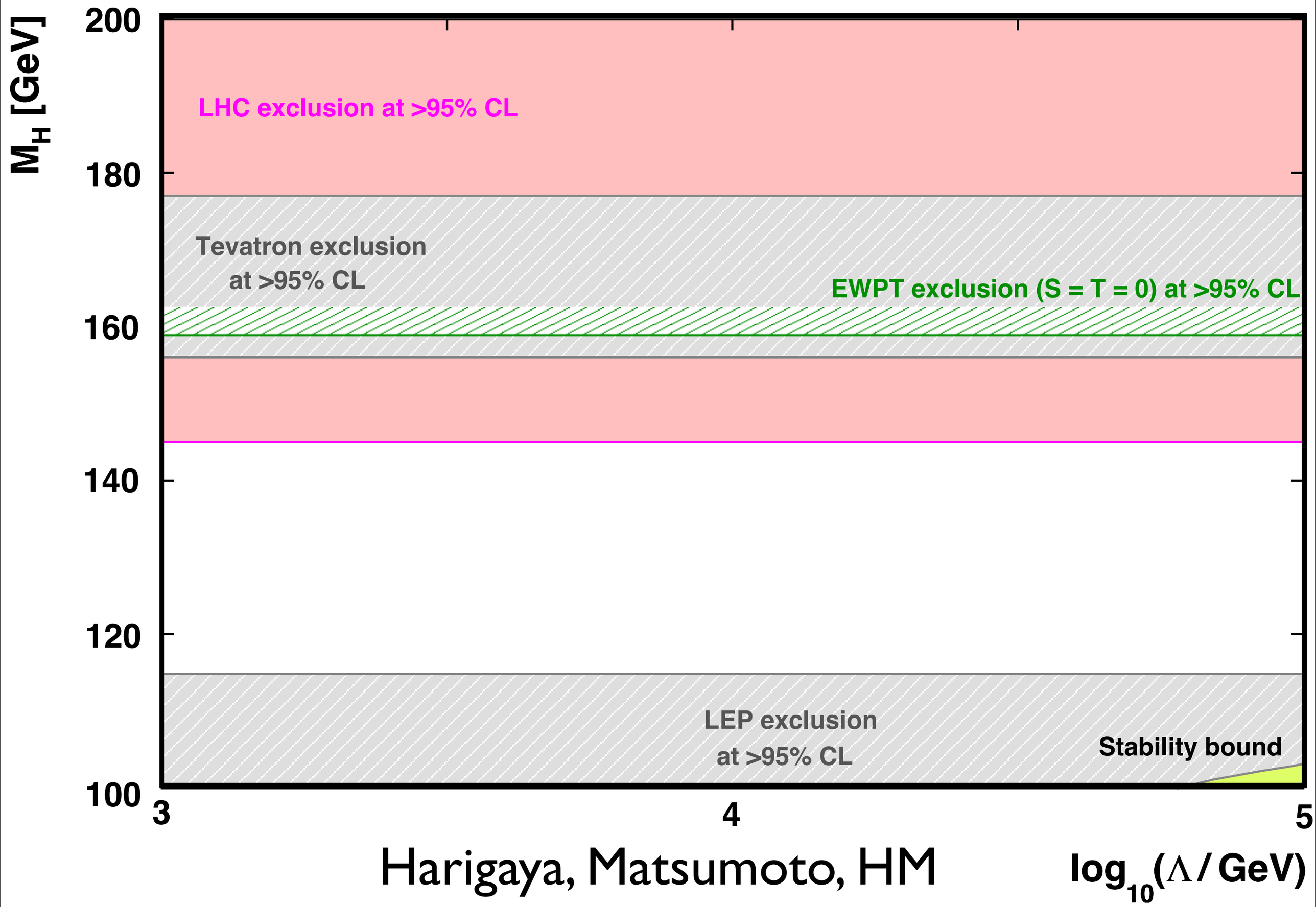

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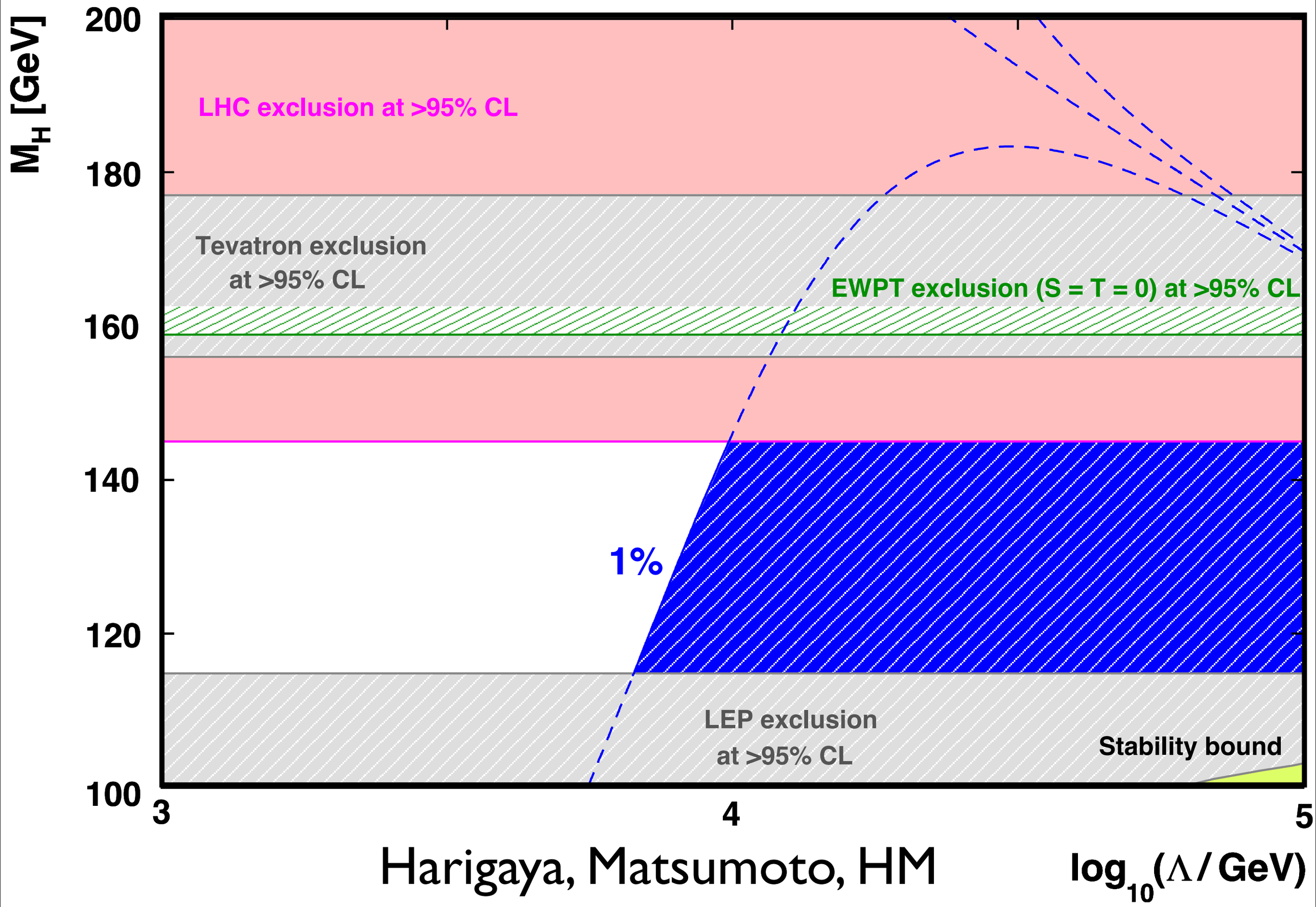

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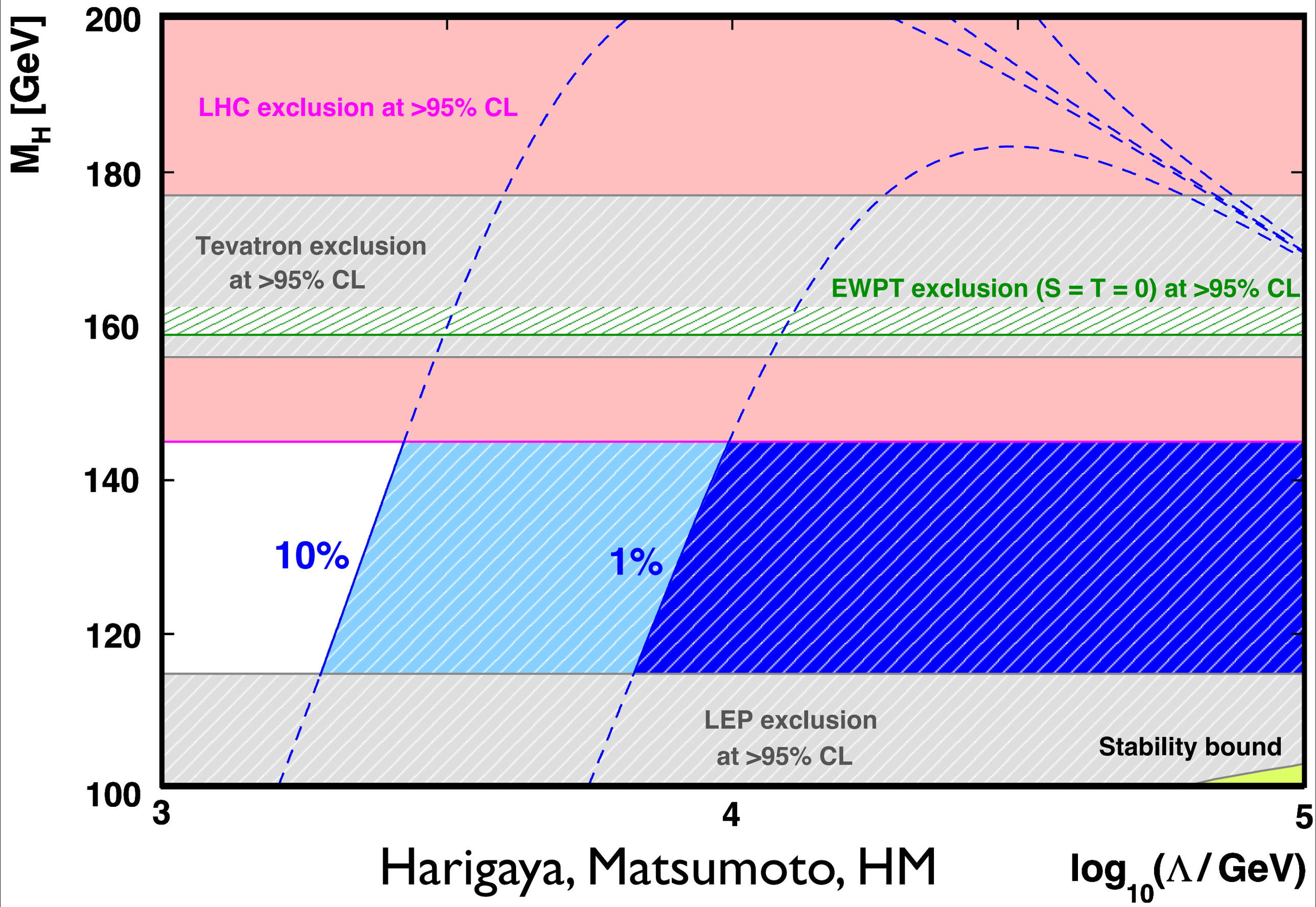
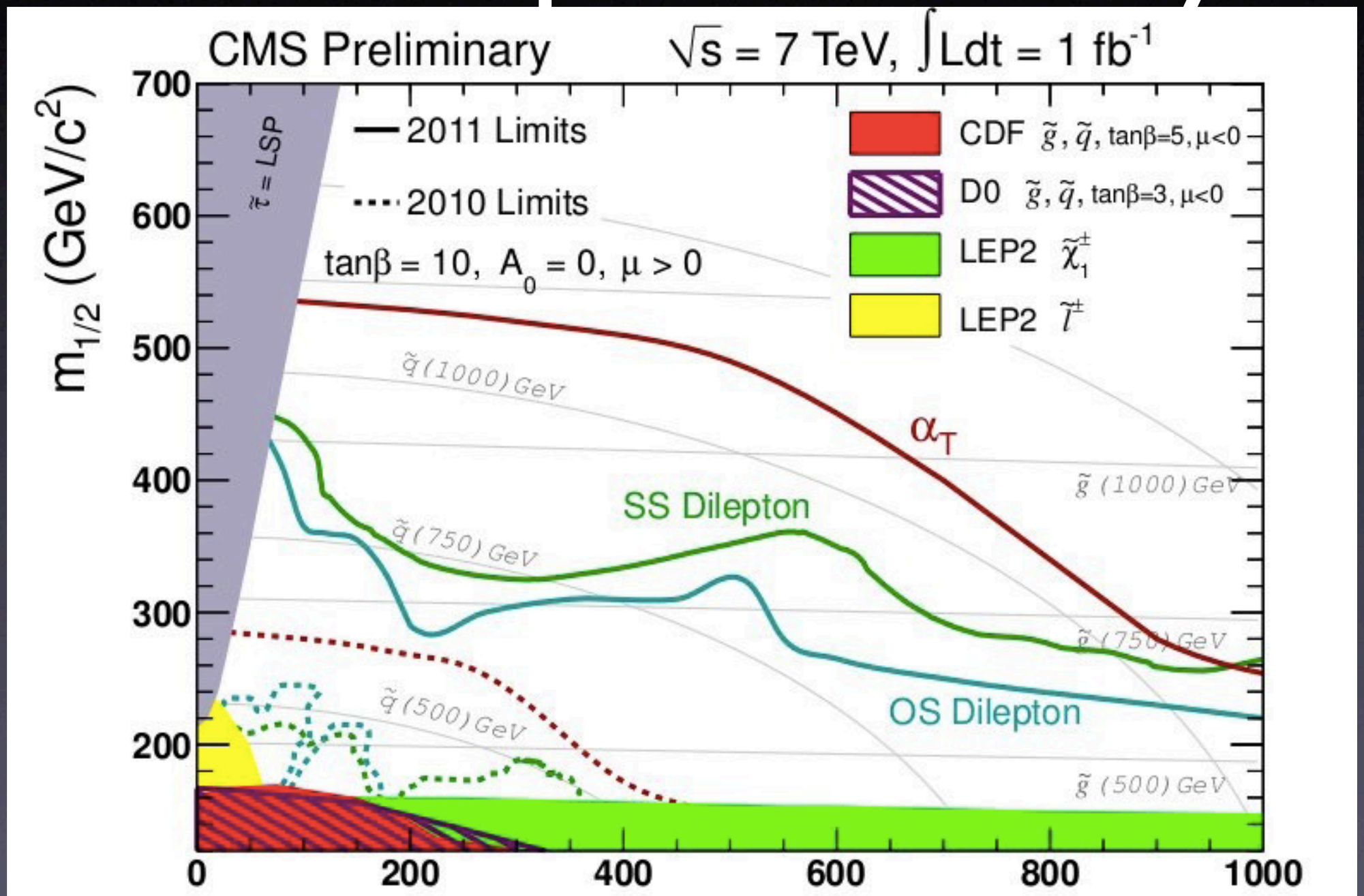


Harigaya, Matsumoto, HM

impressive, worrisome, but not quite there yet



Henri Bachacou, Lepton-Photon 2011

Three Directions

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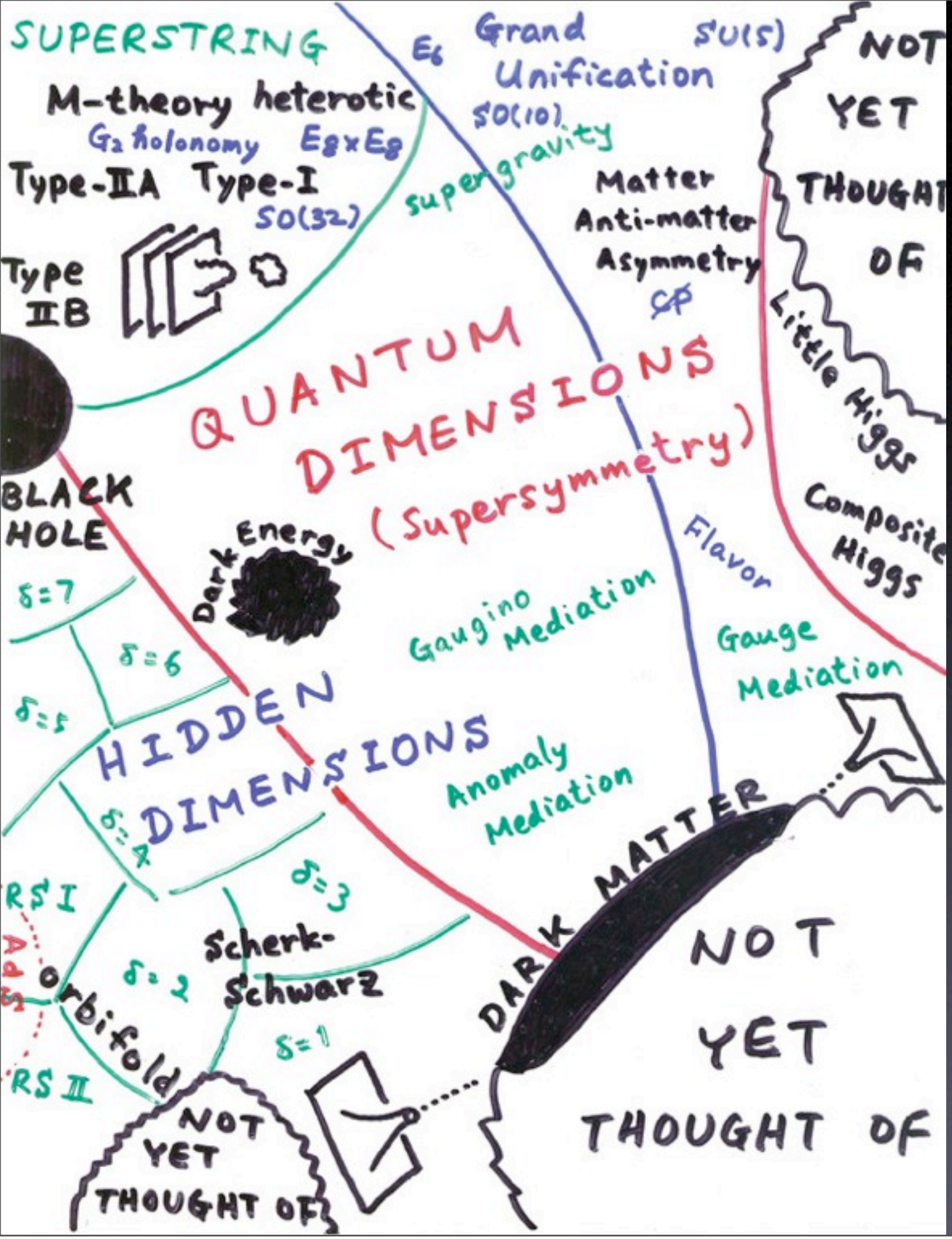
Physics as we know it ends at TeV

- Ultimate scale of physics: quantum gravity
- May have quantum gravity at TeV
  ⇒ hidden dimensions (0.1 mm to 10^{-17} cm)


SUPERSTRING
M-theory heterotic
G_2 holonomy
$E_8 \times E_8$
Type-IIA
Type-I
SO(32)
Type IIB
E_6
Grand Unification
SU(5)
SO(10)
supergravity
Matter Anti-matter Asymmetry
CP
NOT YET THOUGHT OF
Little Higgs
Composite Higgs
QUANTUM DIMENSIONS (Supersymmetry)
BLACK HOLE
Dark Energy
Flavor
Gaugino Mediation
Gauge Mediation
Anomaly Mediation
HIDDEN DIMENSIONS
δ=7
δ=6
δ=5
δ=4
δ=3
δ=2
δ=1
RS I
AdS
RS II
orbifold
Scherk-Schwarz
DARK MATTER
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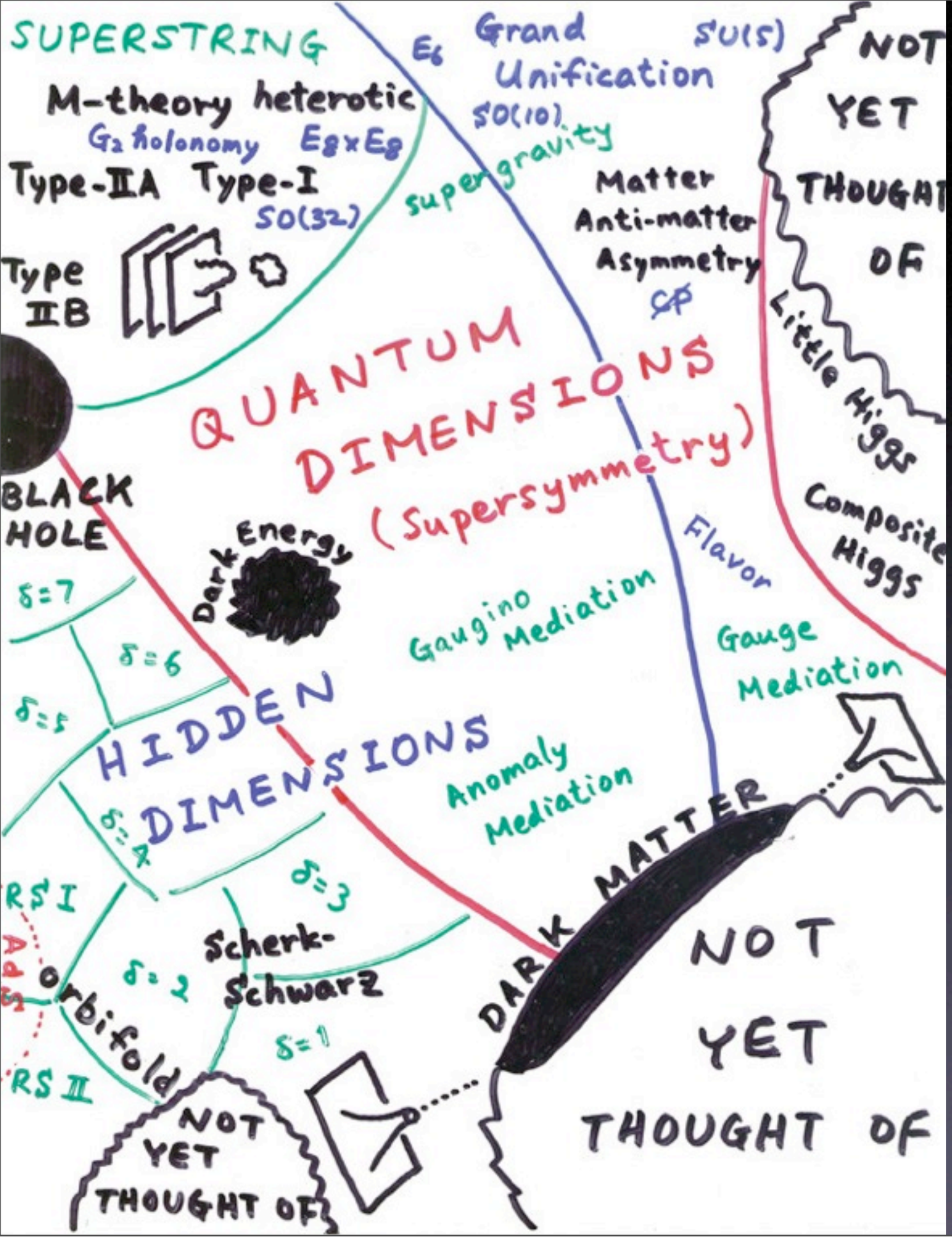

- We really don't know what is going on at TeV
- stupid theorists!
- Can we zoom in onto a point on this map?
- Expect the unexpected

Growing Concern among theorists

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  - precision electroweak
  - flavor physics
  - LEP/Tevatron/LHC searches

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- after all, cosmological constant tuned 10^{-120}
- maybe there isn't anything beyond the Standard Model? → *There definitely is!*

make our eyes wider

- For example, collider searches for SUSY models assumed light elementary Higgs à la MSSM (e.g., m_H<135 GeV)
- note SUSY can come with a composite Higgs: *Fat Higgs* (Harnik, Kribs, Larson, HM)
- Higgs can be heavy, naturalness constraints can be eased by an order of magnitude
- but usual search topologies look OK

BBC NEWS

SCIENCE & ENVIRONMENT

27 August 2011 Last updated at 02:41 ET

LHC results put supersymmetry theory 'on the spot'

Some old ideas that emerged around the same time as supersymmetry are being resurrected now there is a prospect that supersymmetry may be on the wane.

One has the whimsical name of "Technicolor".

According to Dr Lykken, some younger theoretical physicists are beginning to develop completely novel ideas because they believe supersymmetry to be "old hat" .

"Young theorists especially would love to see supersymmetry go down the drain, because it means that the real thing is something they could invent - not something that was invented by the older generation," he said.

uneasiness in cosmology

- Before COBE, upper limit on CMB anisotropy kept getting better and better
- Before 1998, the universe appeared younger than oldest stars
- cosmologists got antsy
- "crisis in standard cosmology"
- it turned out a little "fine-tuned"
  - low quadrupole
  - dark energy

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"Big Bang not yet dead but in decline"
Nature 377, 14 (1995)

"Bang! A Big Theory May Be Shot"
A new study of the stars could rewrite the history of the universe
Times, Jan 14 (1991)

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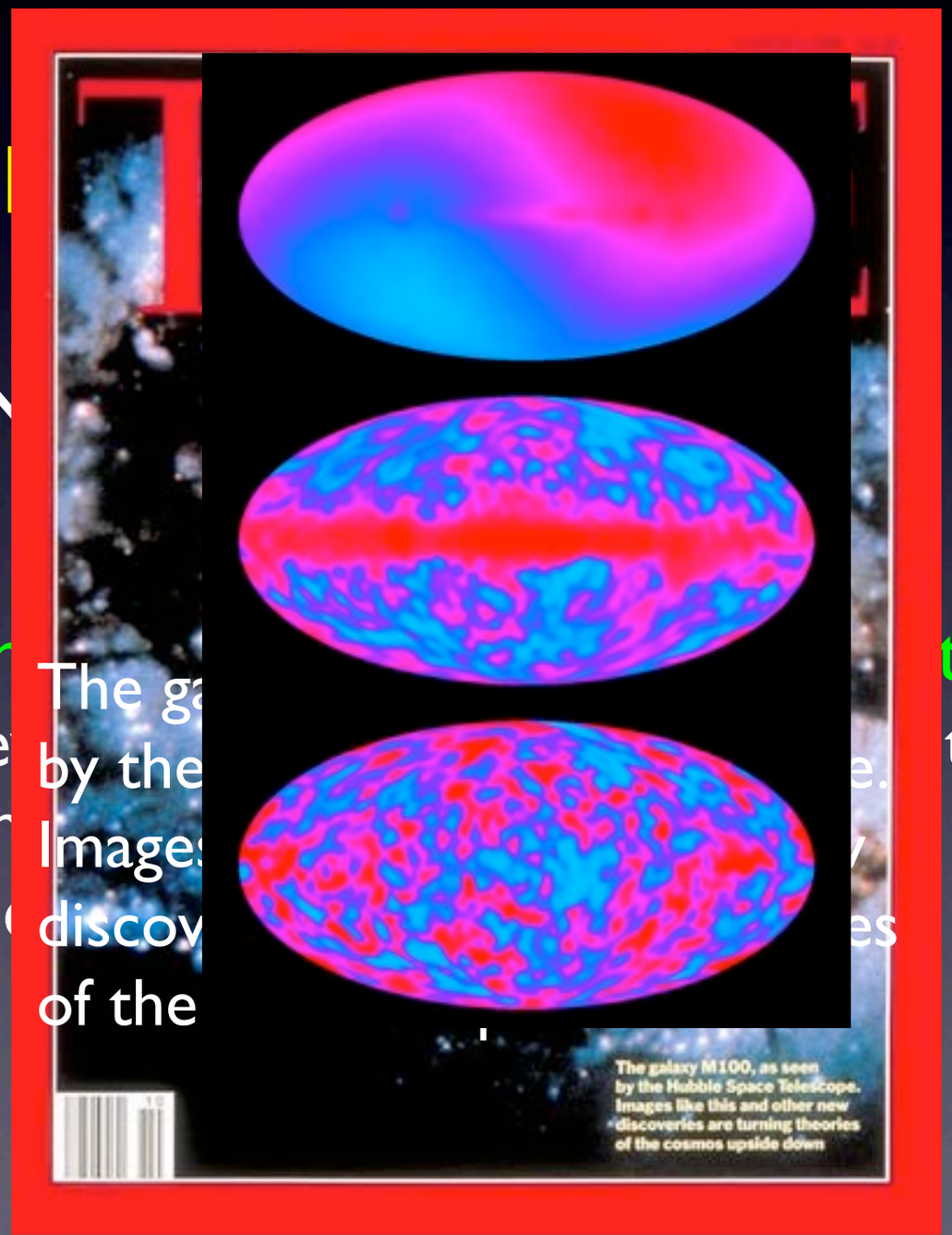

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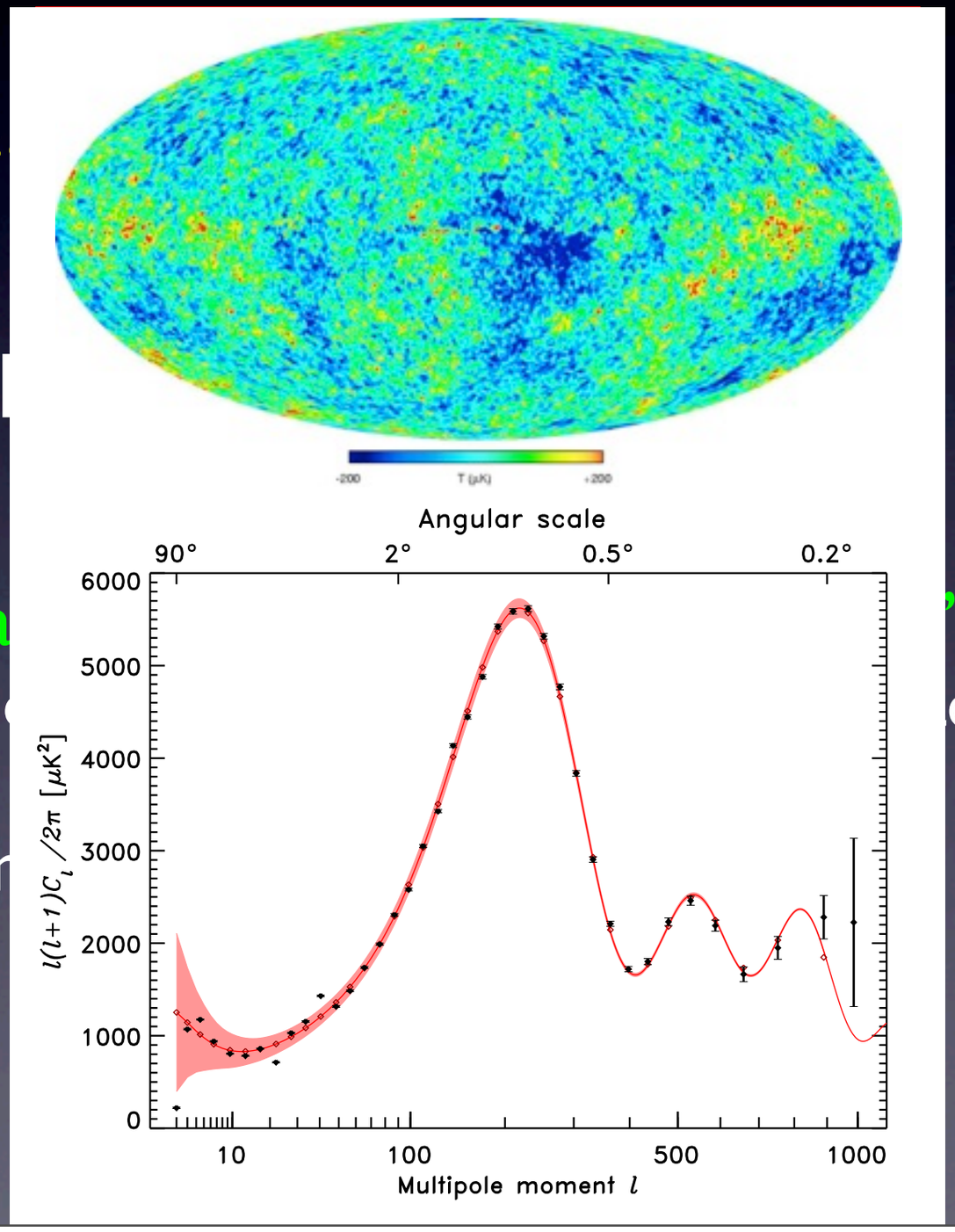

Five empirical evidences

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Dark Matter

Energy Budget of the Universe

- stars
- neutrinos
- baryon
- dark matter
- dark energy

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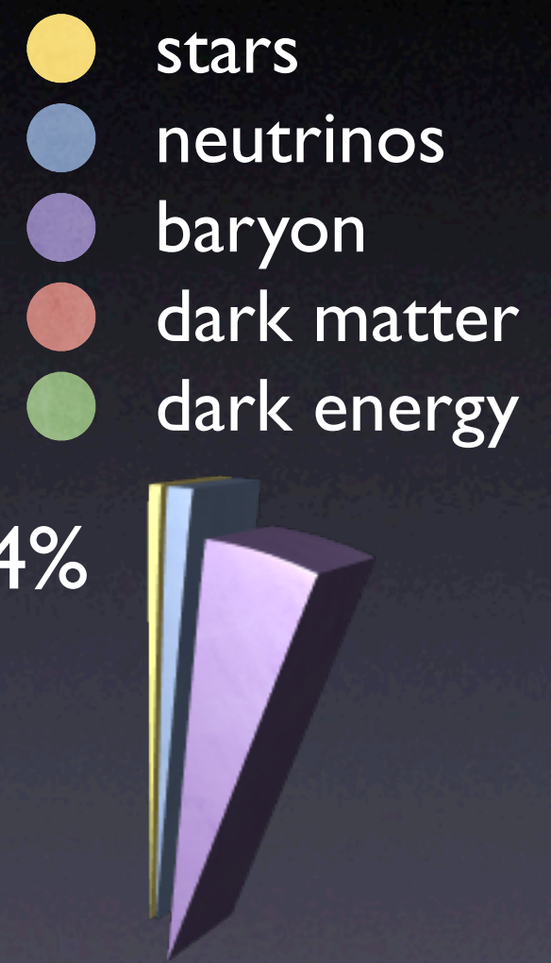

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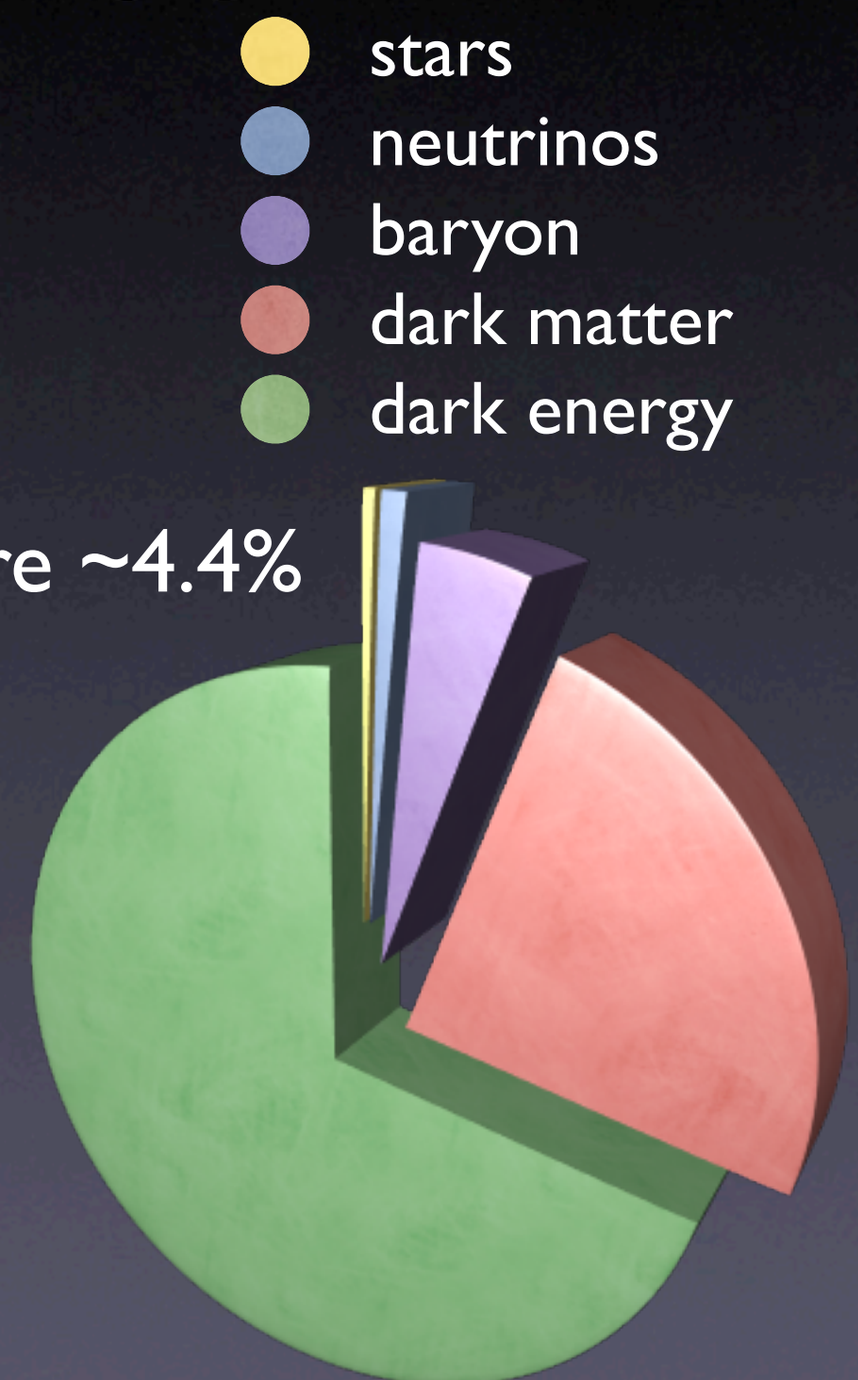

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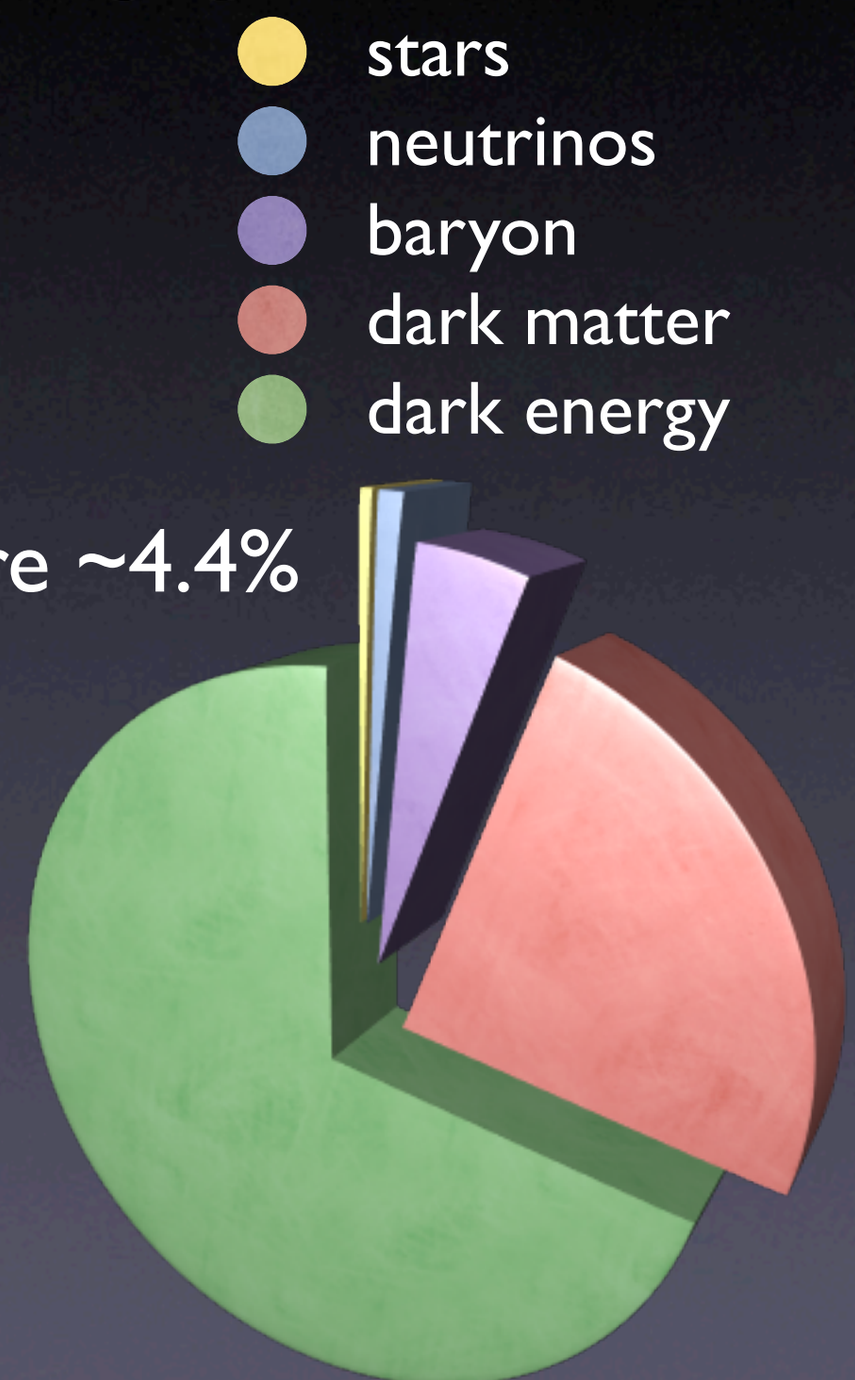

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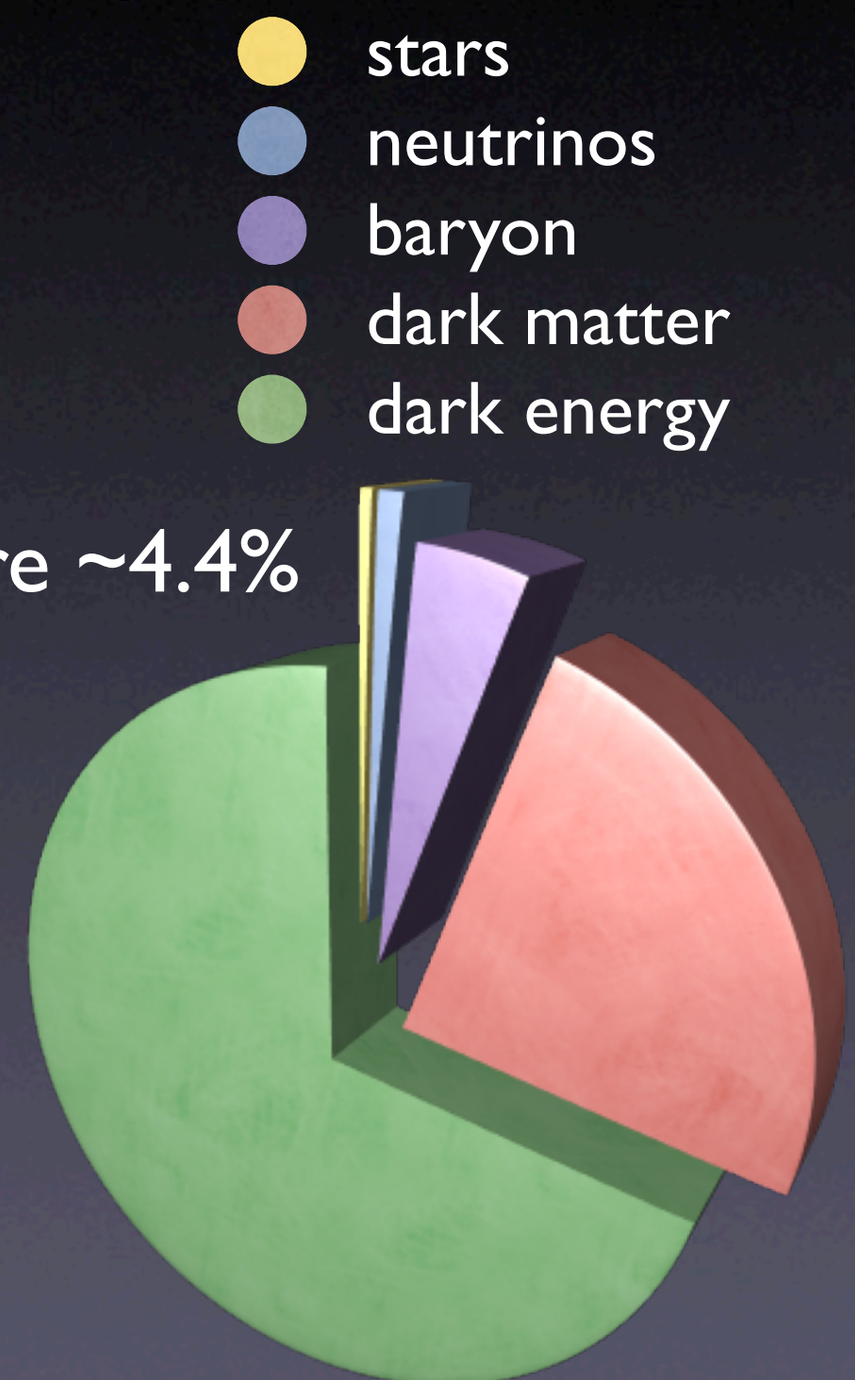

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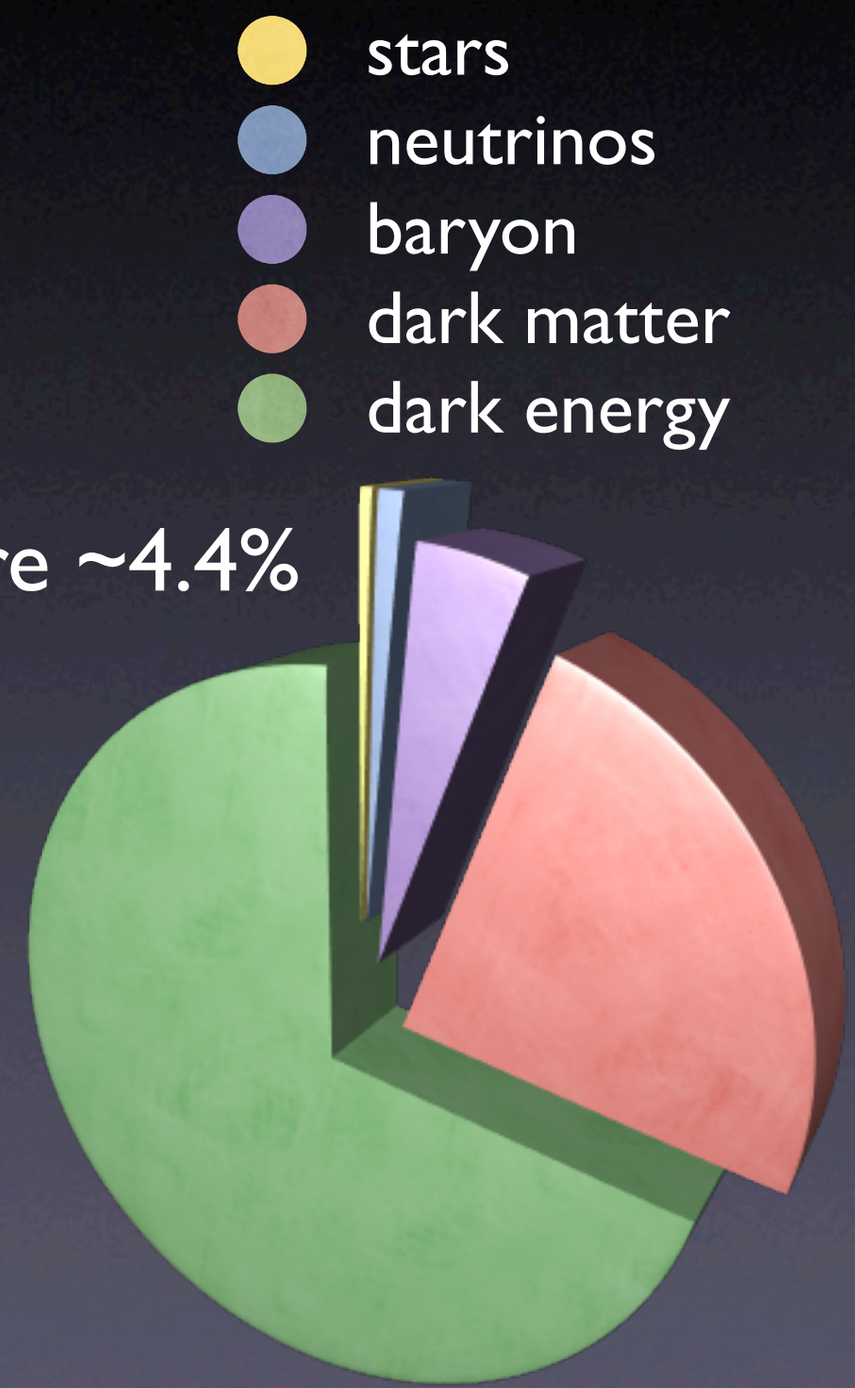
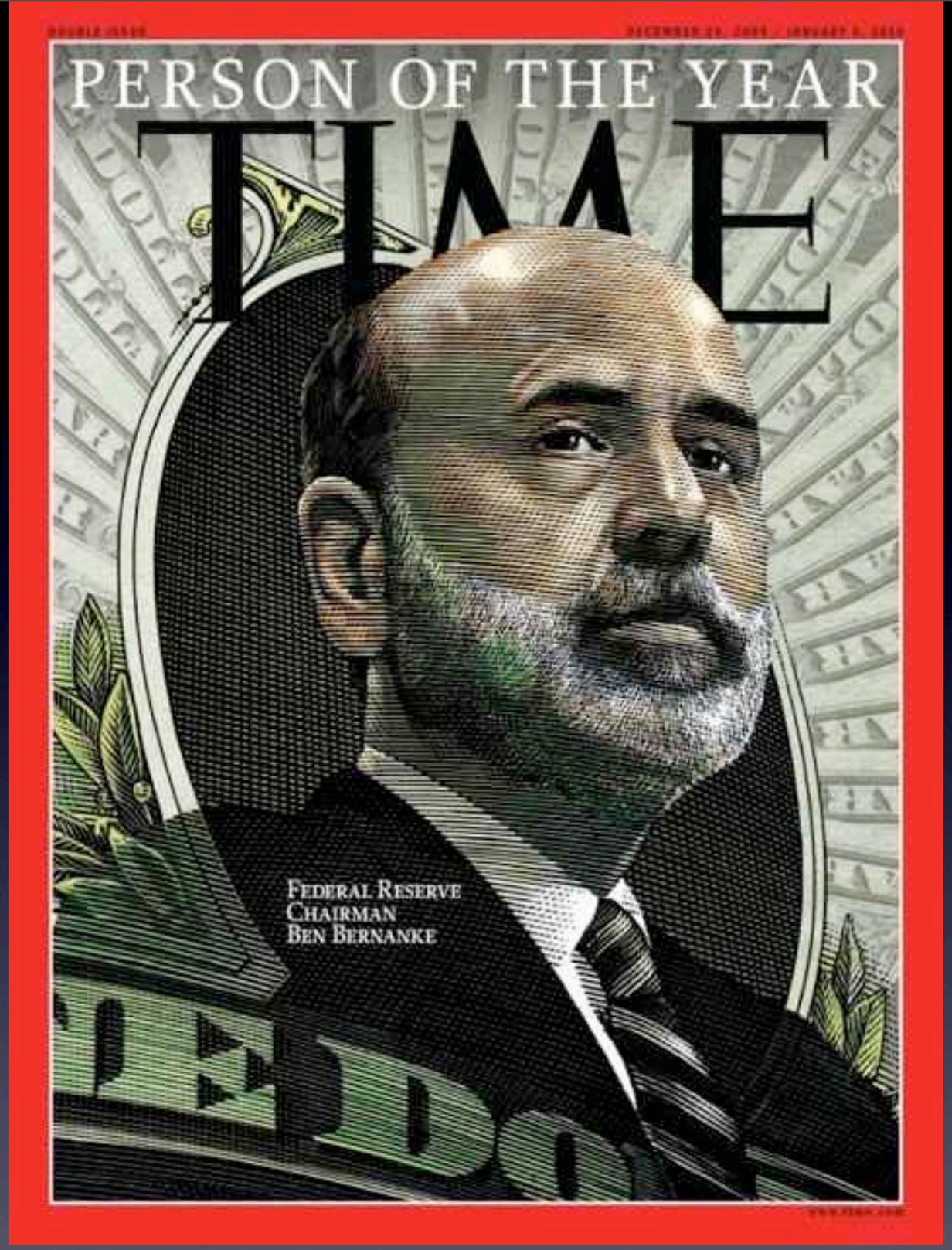
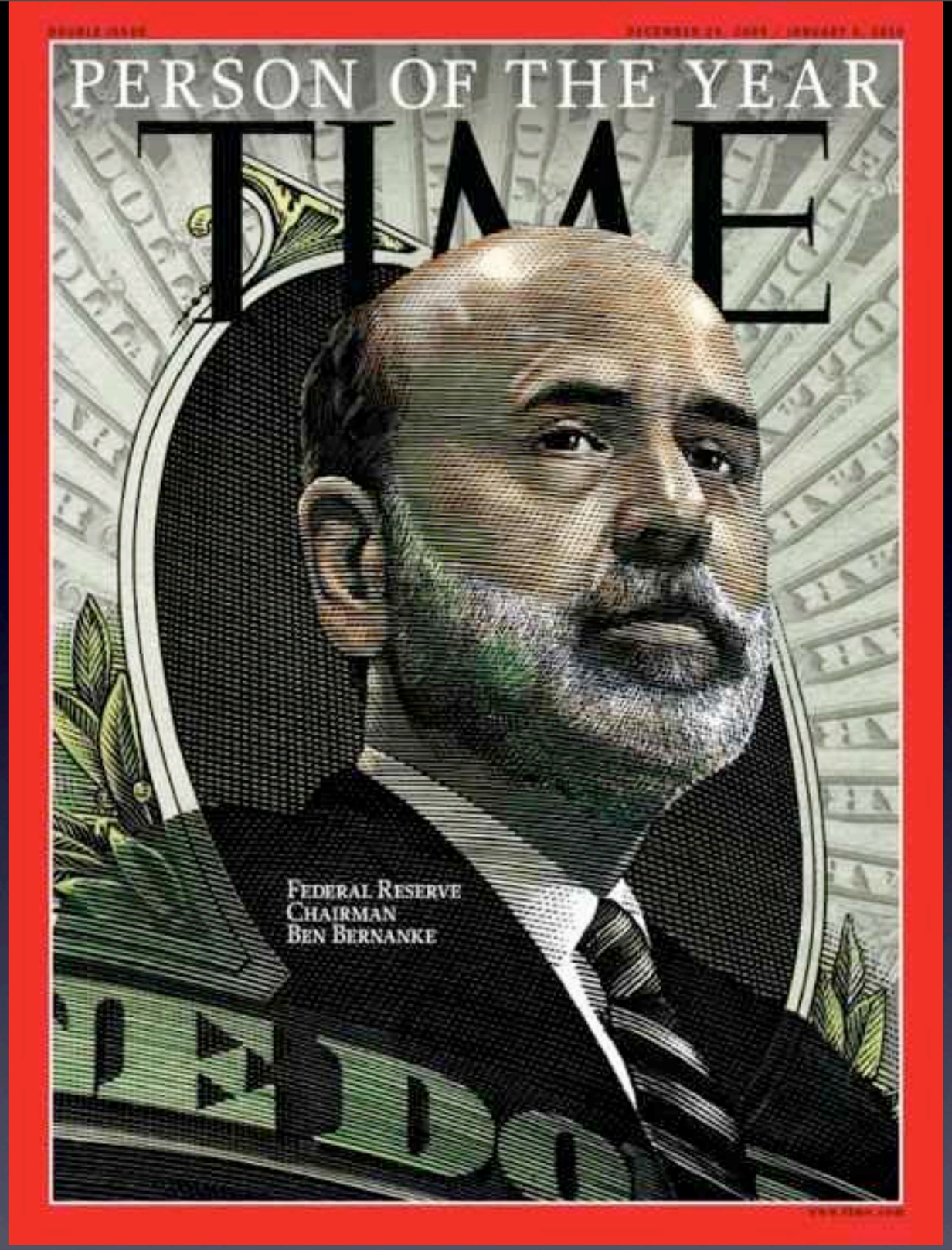
budget deficit!




PERSON OF THE YEAR
TIME
FEDERAL RESERVE
CHAIRMAN
BEN BERNANKE



Act now to put in place a credible plan for reducing future deficits

Dim Stars?

Search for MACHOs
(Massive Compact Halo Objects)

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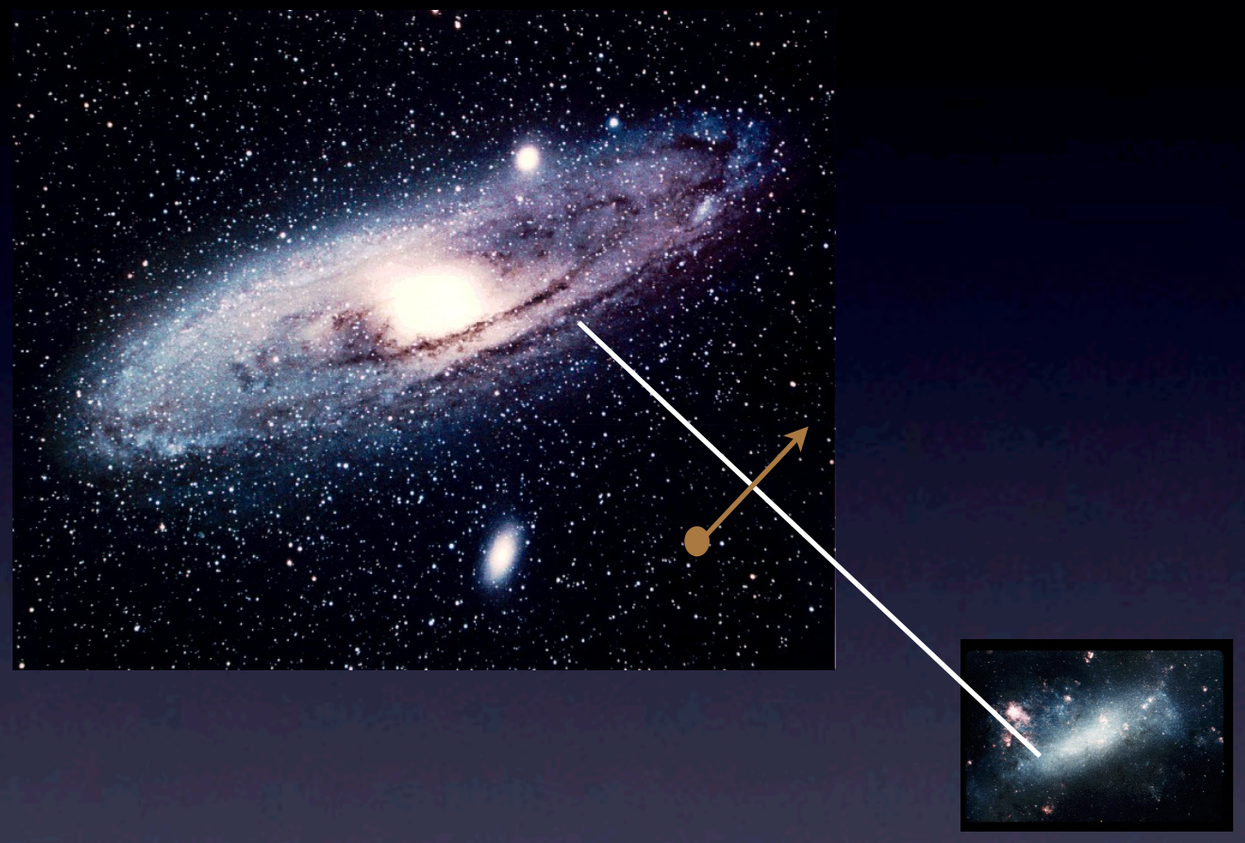

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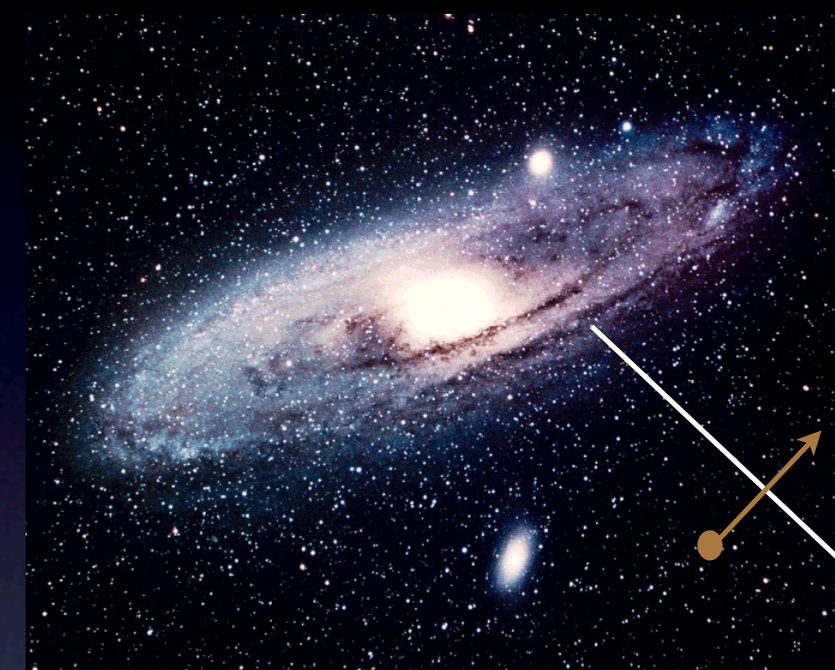

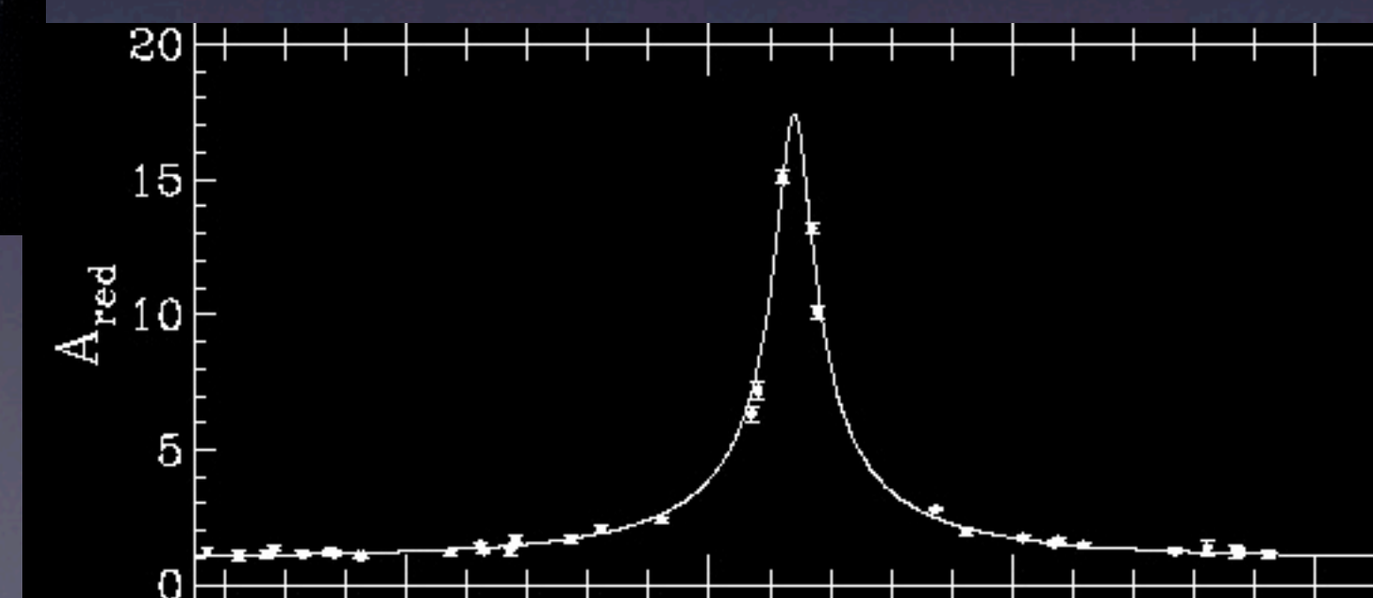

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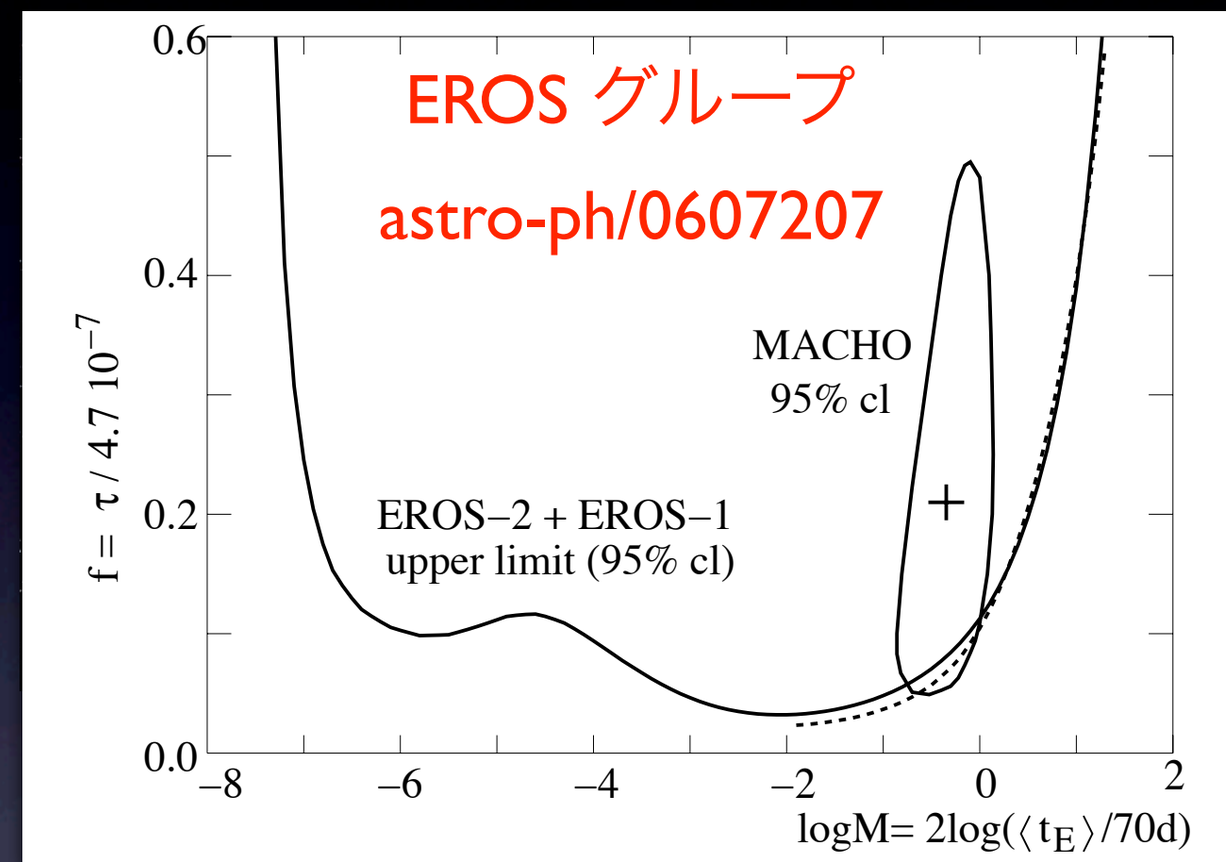

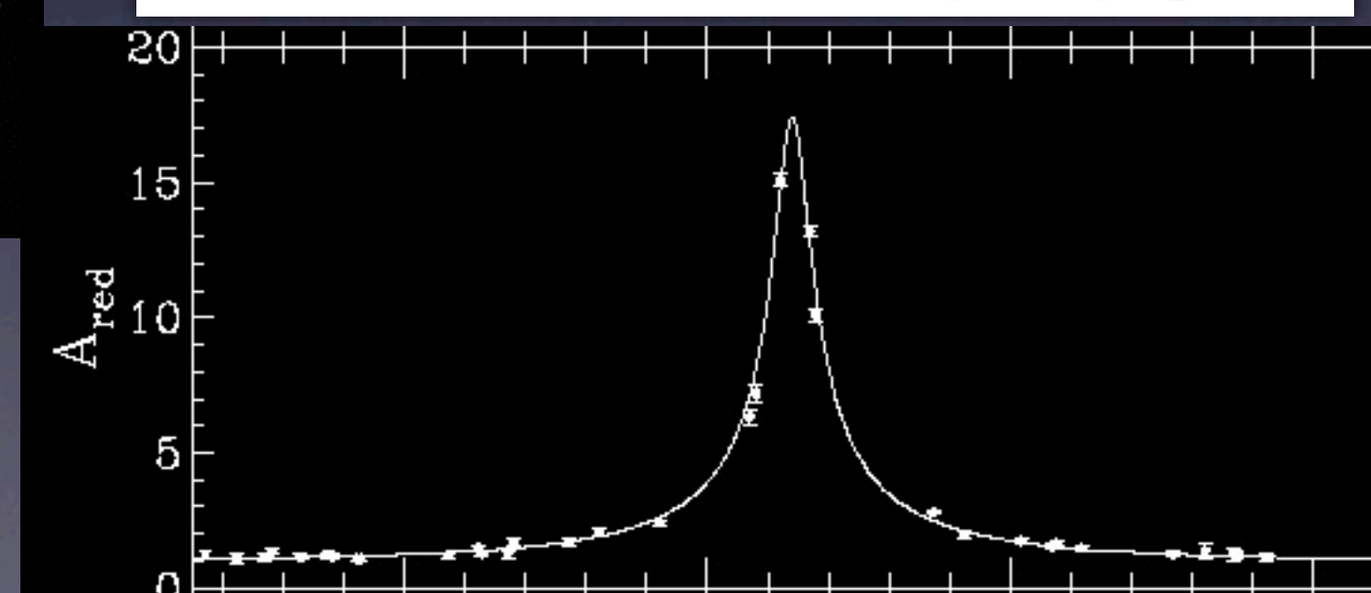

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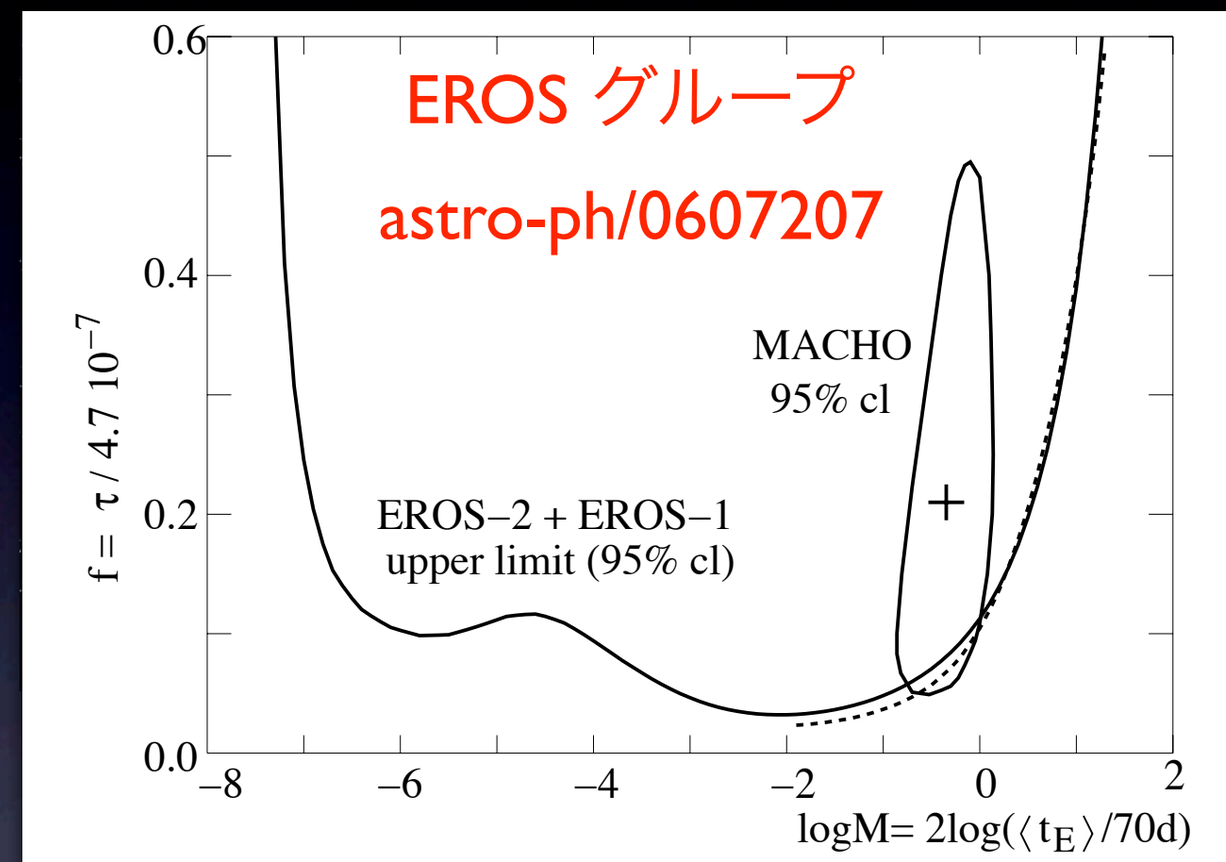

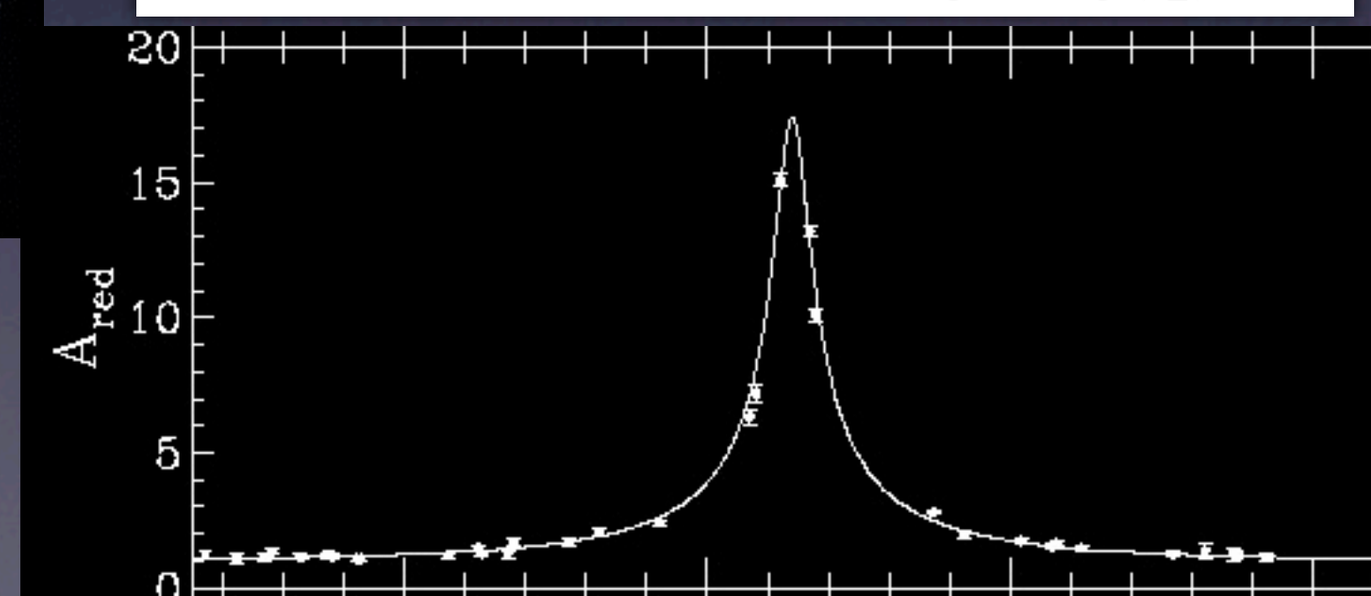

Not enough of them!

Mass Limits

"Uncertainty Principle"

- Clumps to form structure
- imagine $V = G_N \frac{Mm}{r}$
- "Bohr radius": $r_B = \frac{\hbar^2}{G_N M m^2}$
- too small m ⇒ won't "fit" in a galaxy!
- m >10^{-22} eV "uncertainty principle" bound
  (modified from Hu, Barkana, Gruzinov, astro-ph/0003365)

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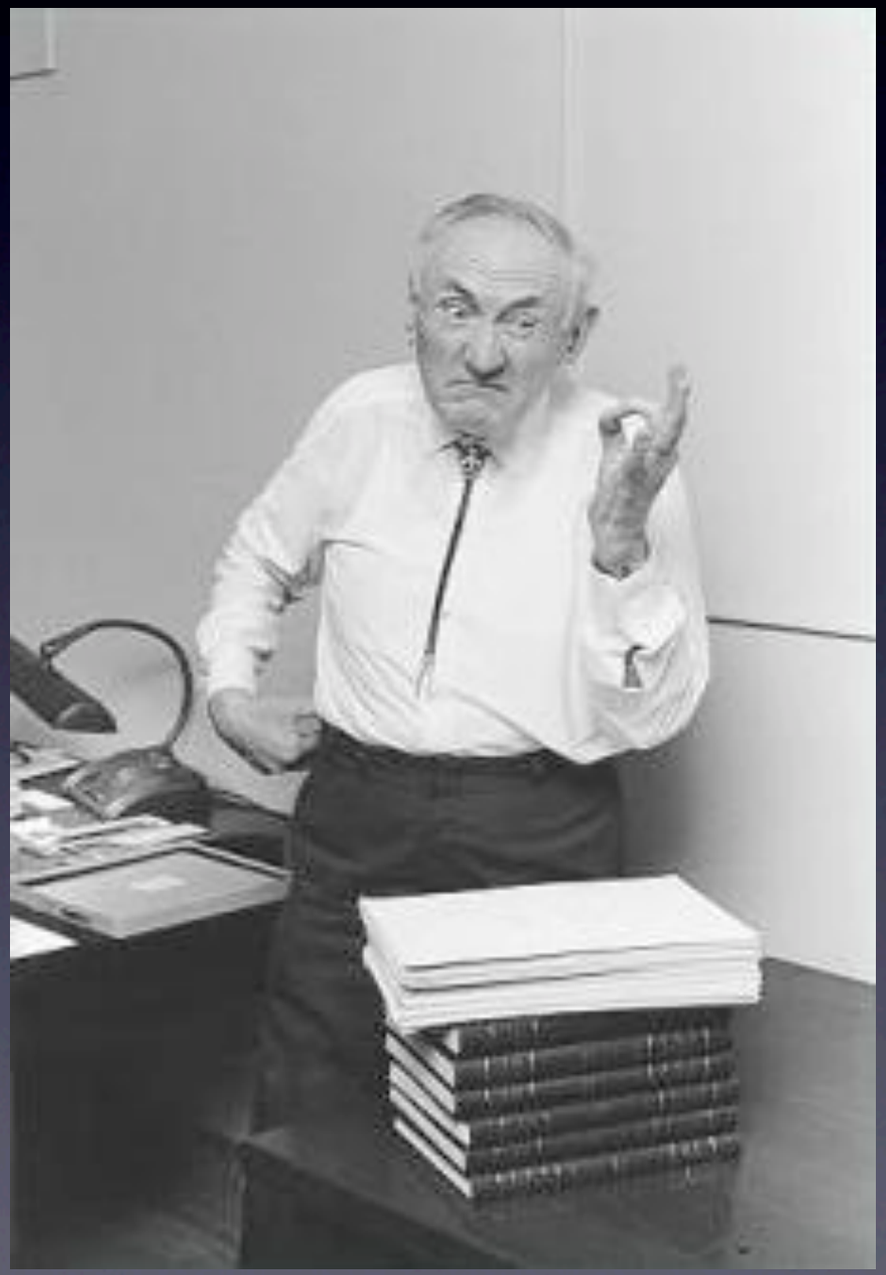
- a big progress in 70 years since Zwicky



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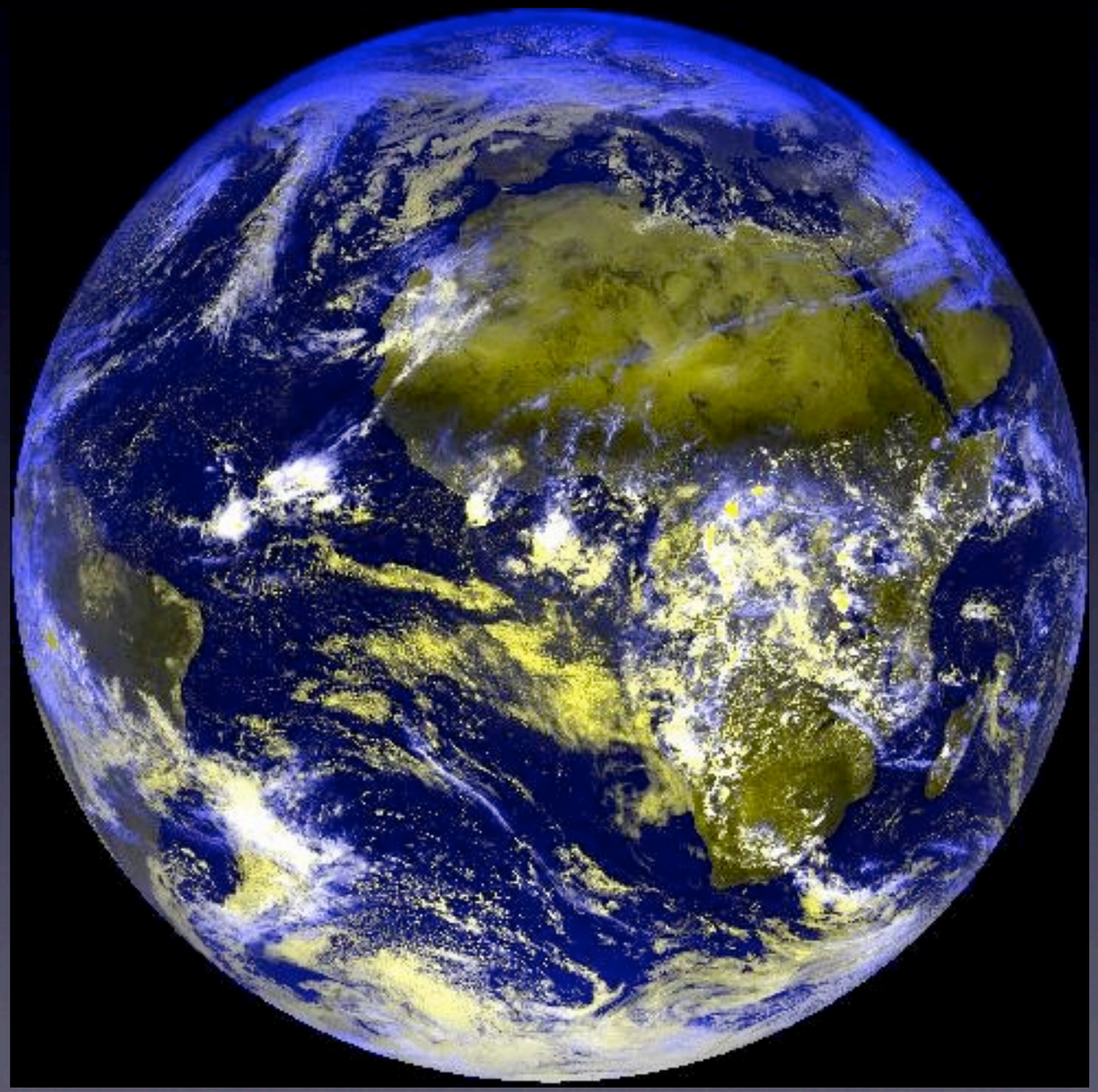
BERKELEY CENTER FOR THEORETICAL PHYSICS

MACHO $\Rightarrow$ WIMP



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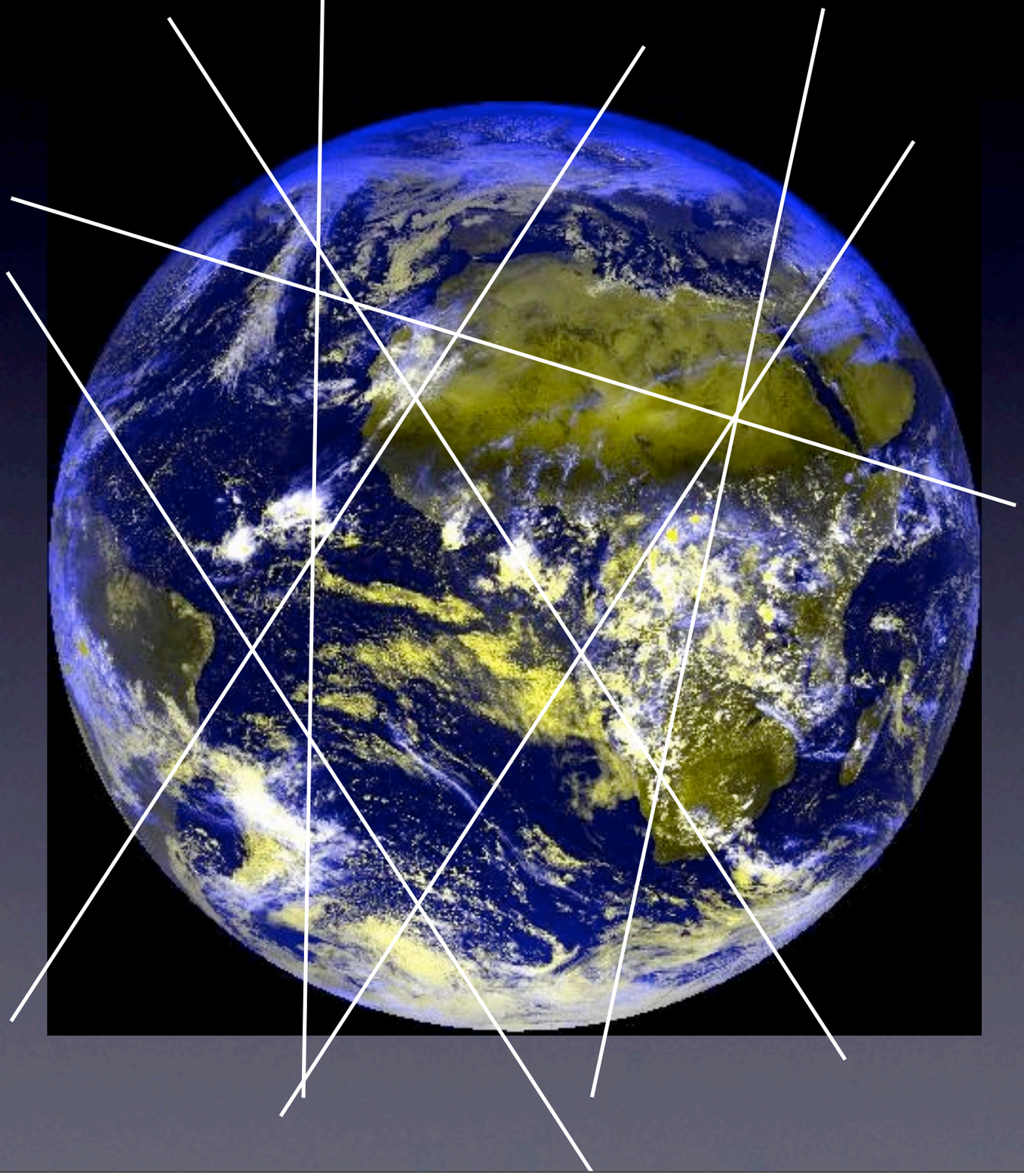

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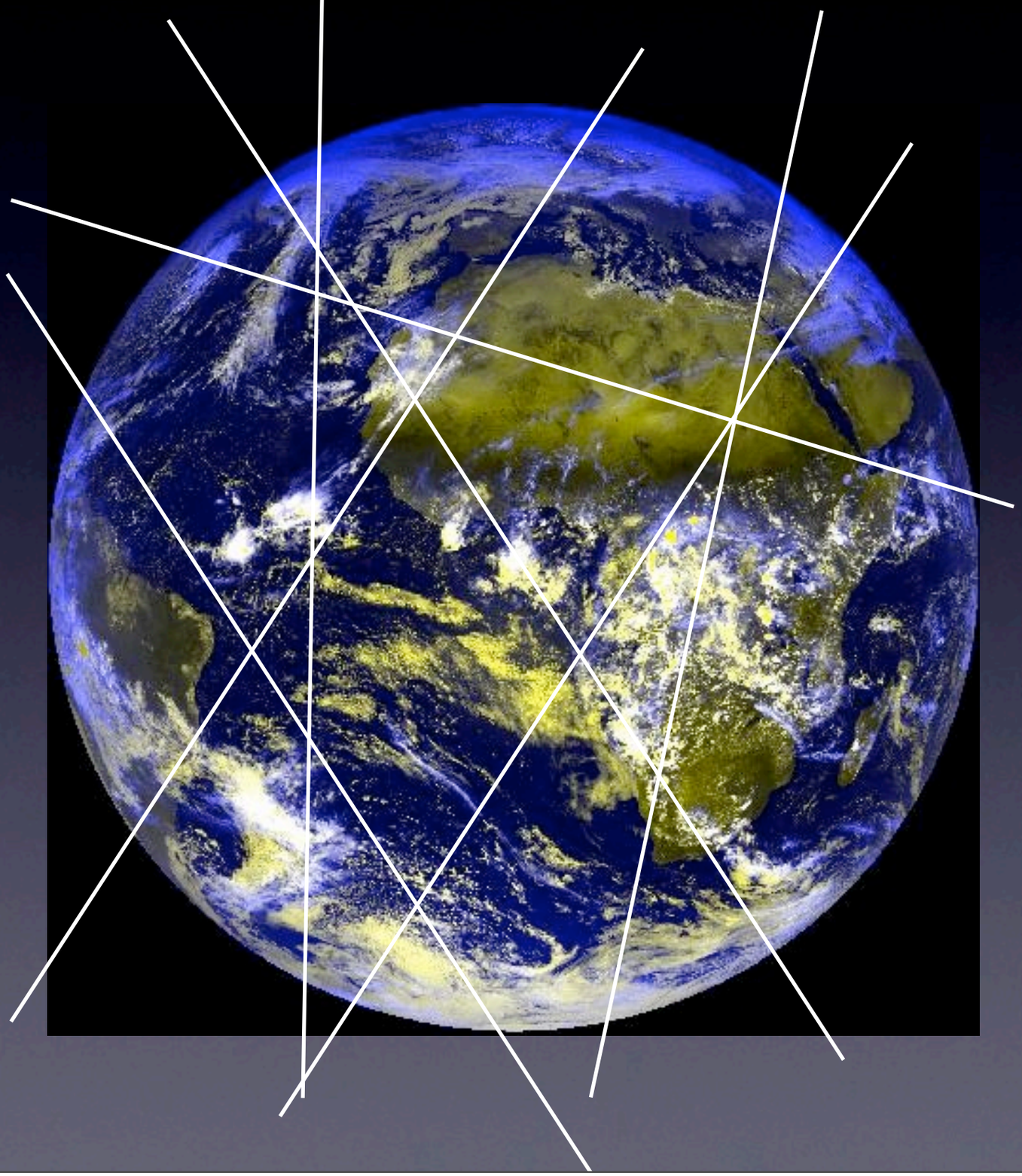

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- *Stable heavy particle produced in early Universe, left-over from near-complete annihilation*

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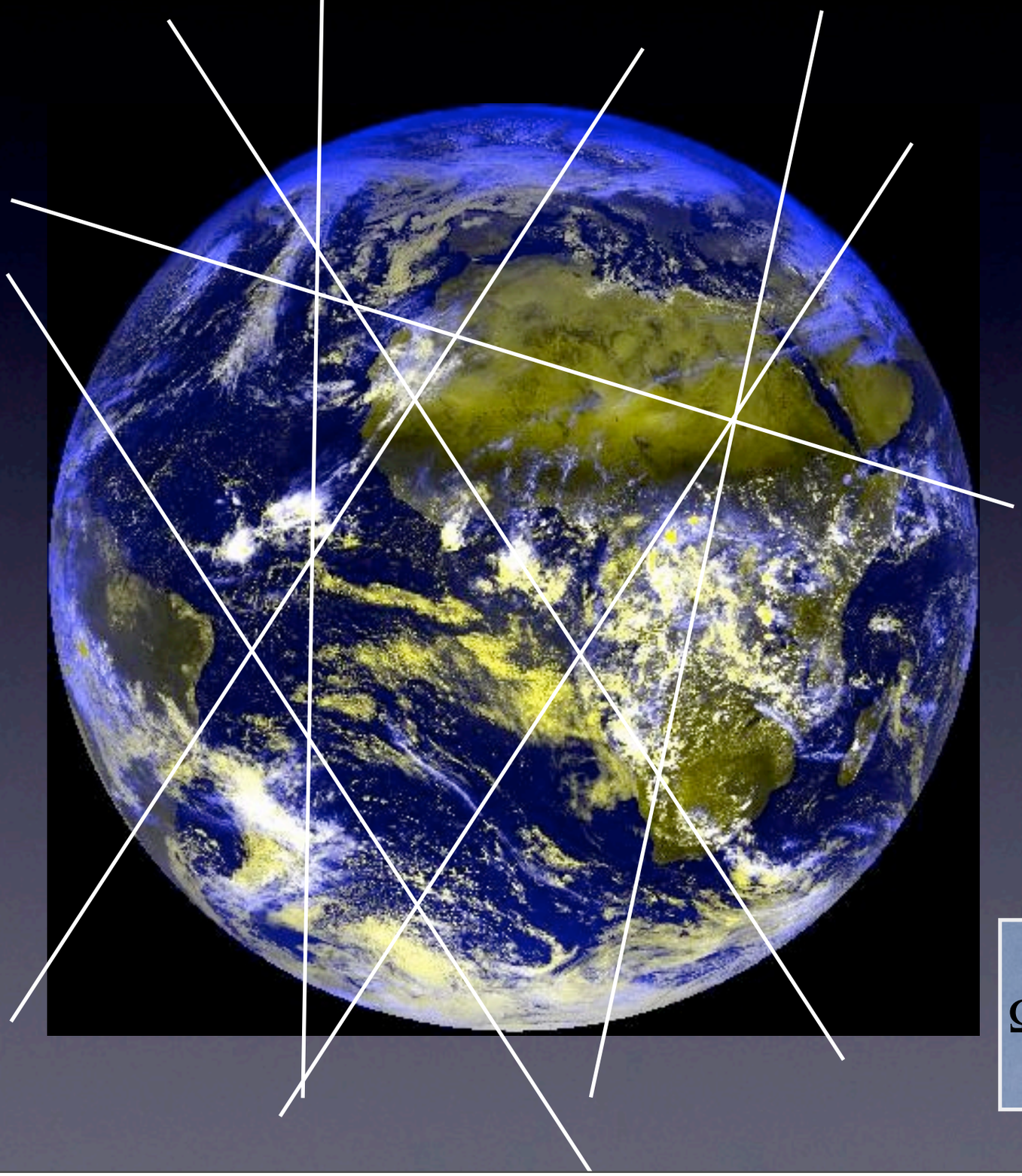

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$$\Omega_M = \frac{0.756(n+1)x_f^{n+1}}{g^{1/2}\sigma_{ann}M_{Pl}{}^3}\frac{3s_0}{8\pi H_0^2} \approx \frac{\alpha^2/(TeV)^2}{\sigma_{ann}}$$

No shortage of models

- motivated from the naturalness argument
- Supersymmetry with R-parity
  - neutralino
  - gravitino
- Universal Extra Dimensions
- Little Higgs with T-parity
- Warped Extra Dimensions with KK parity
- virtually any models at the TeV scale with a nearly stable neutral particle...

improving searches with m_{T2}

Universal Extra Dimensions particularly hard because of near degeneracy in the spectrum

HM, Nojiri, Tobioka

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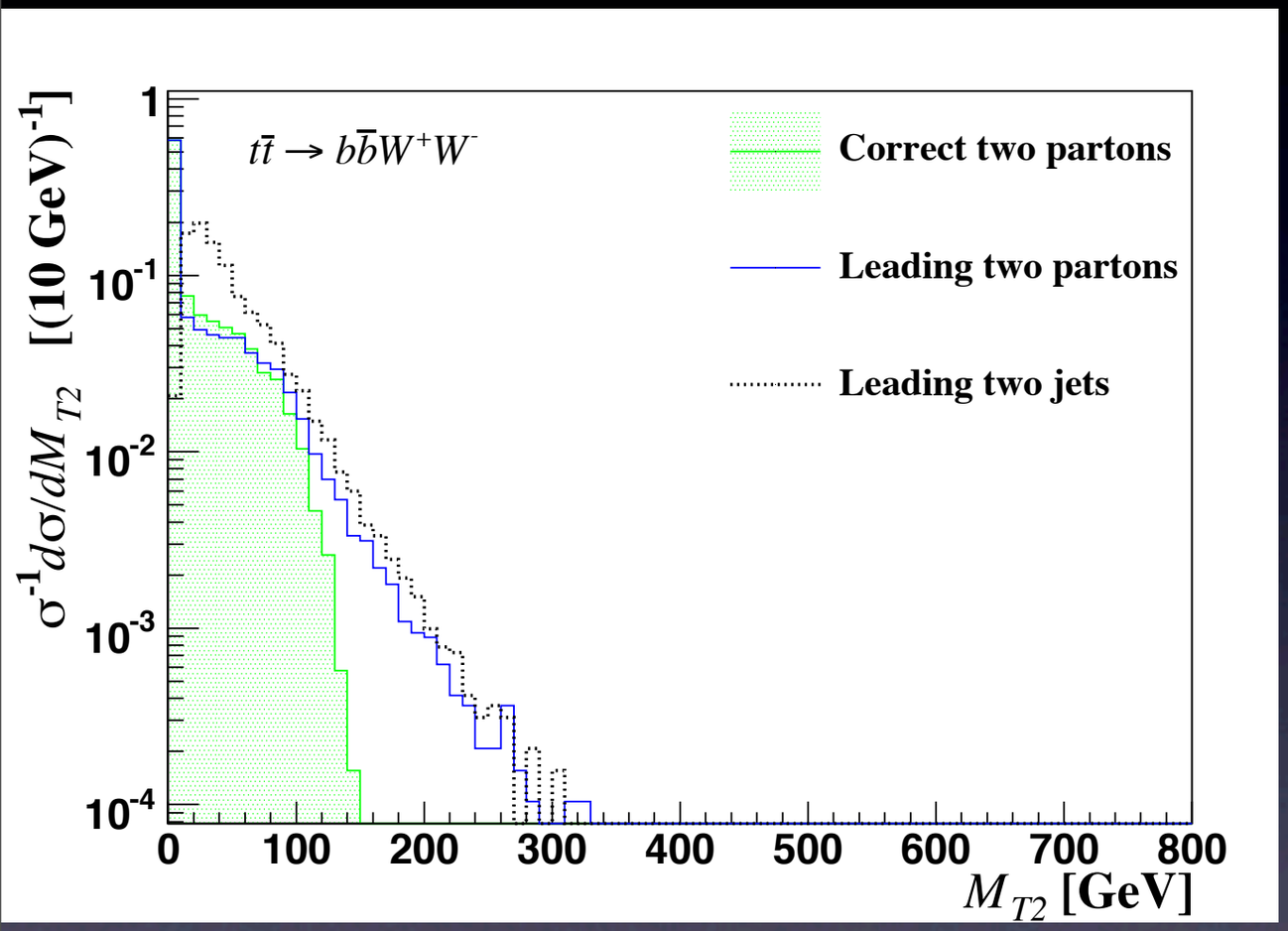

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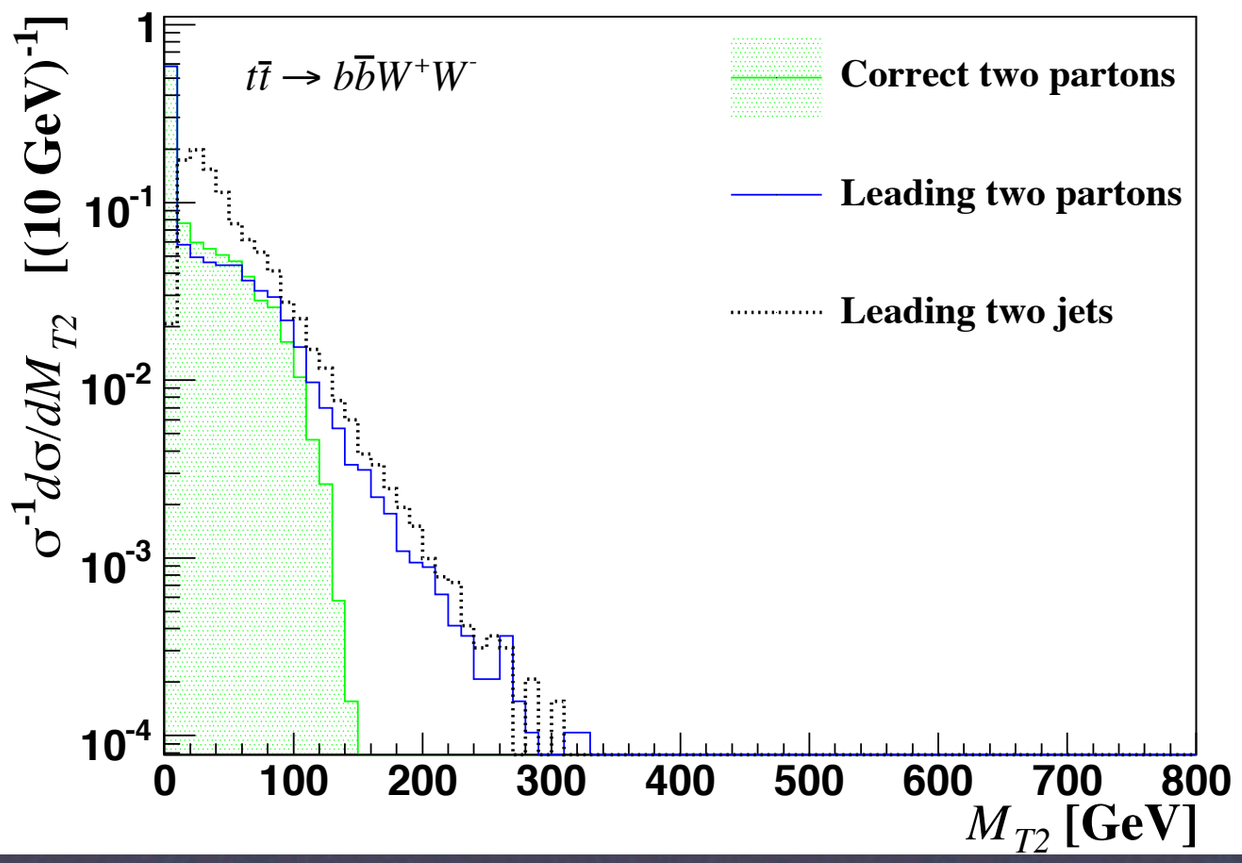

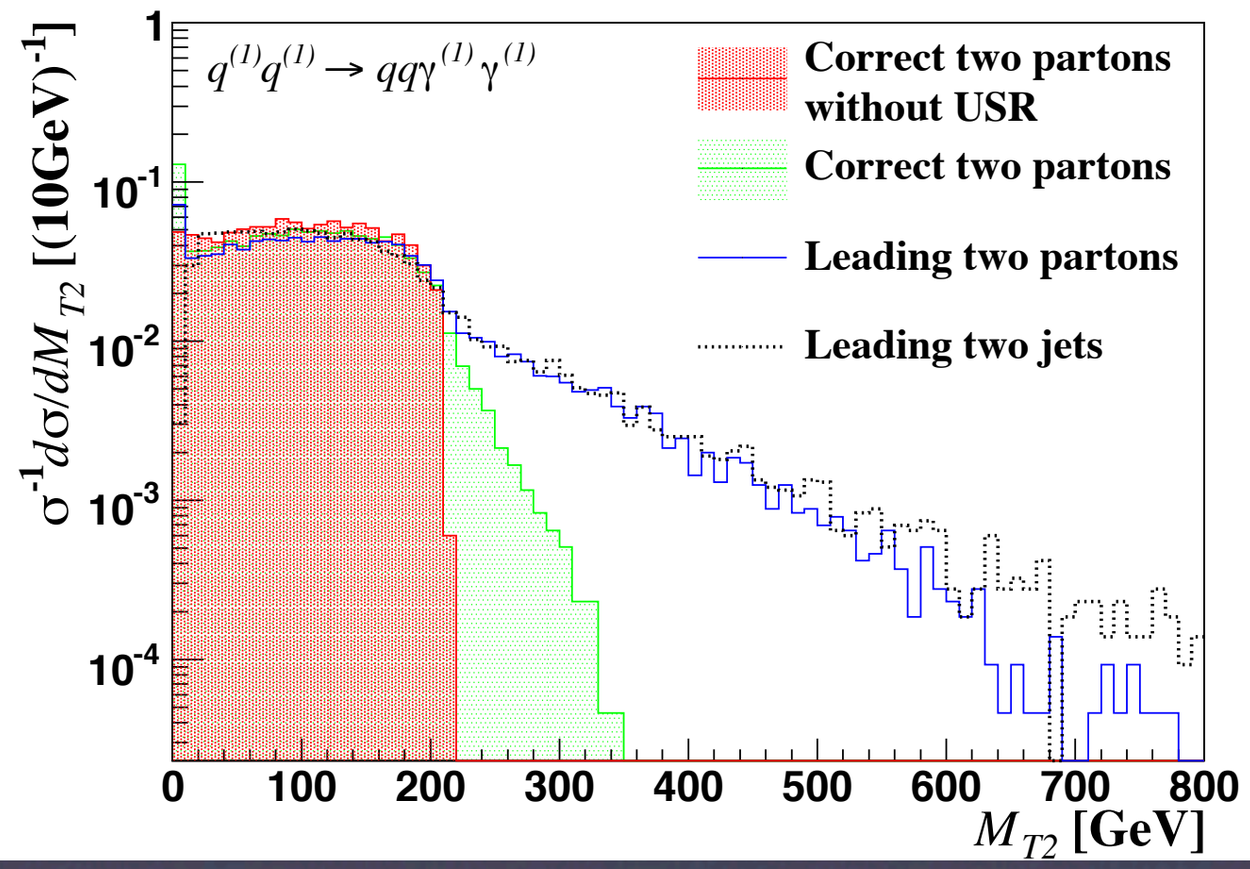

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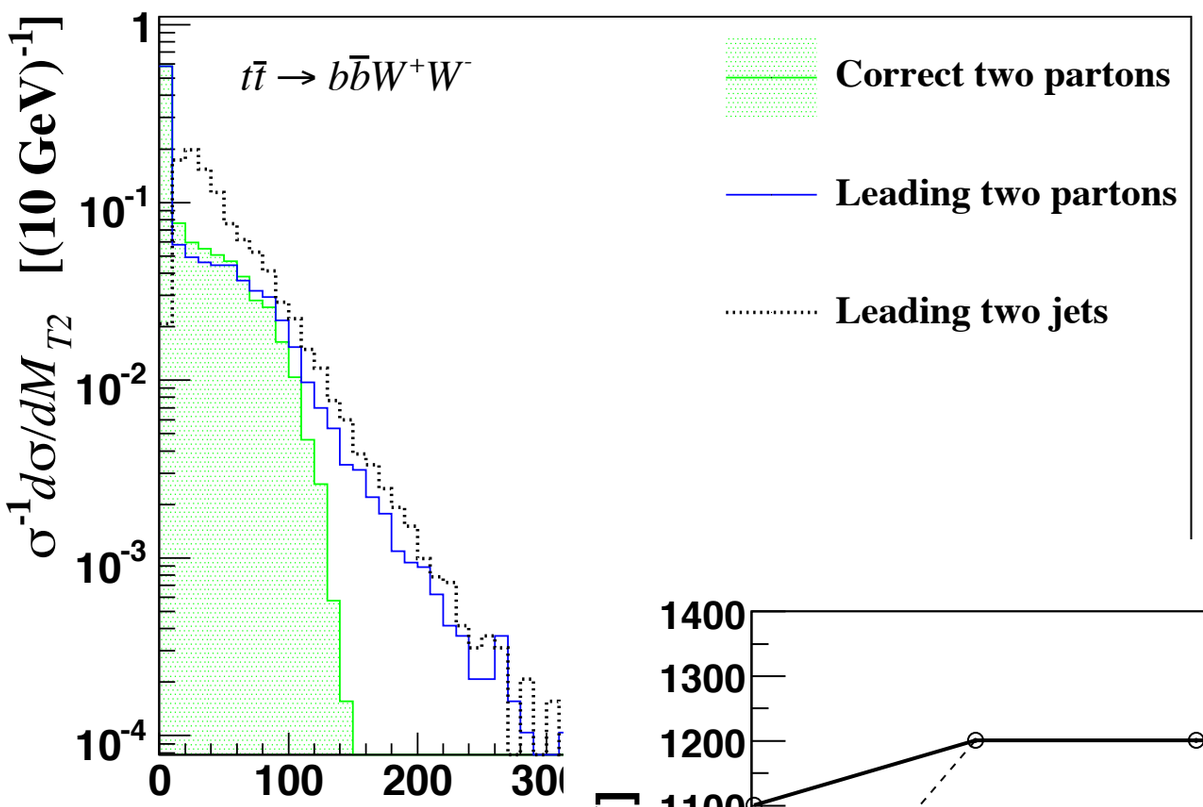

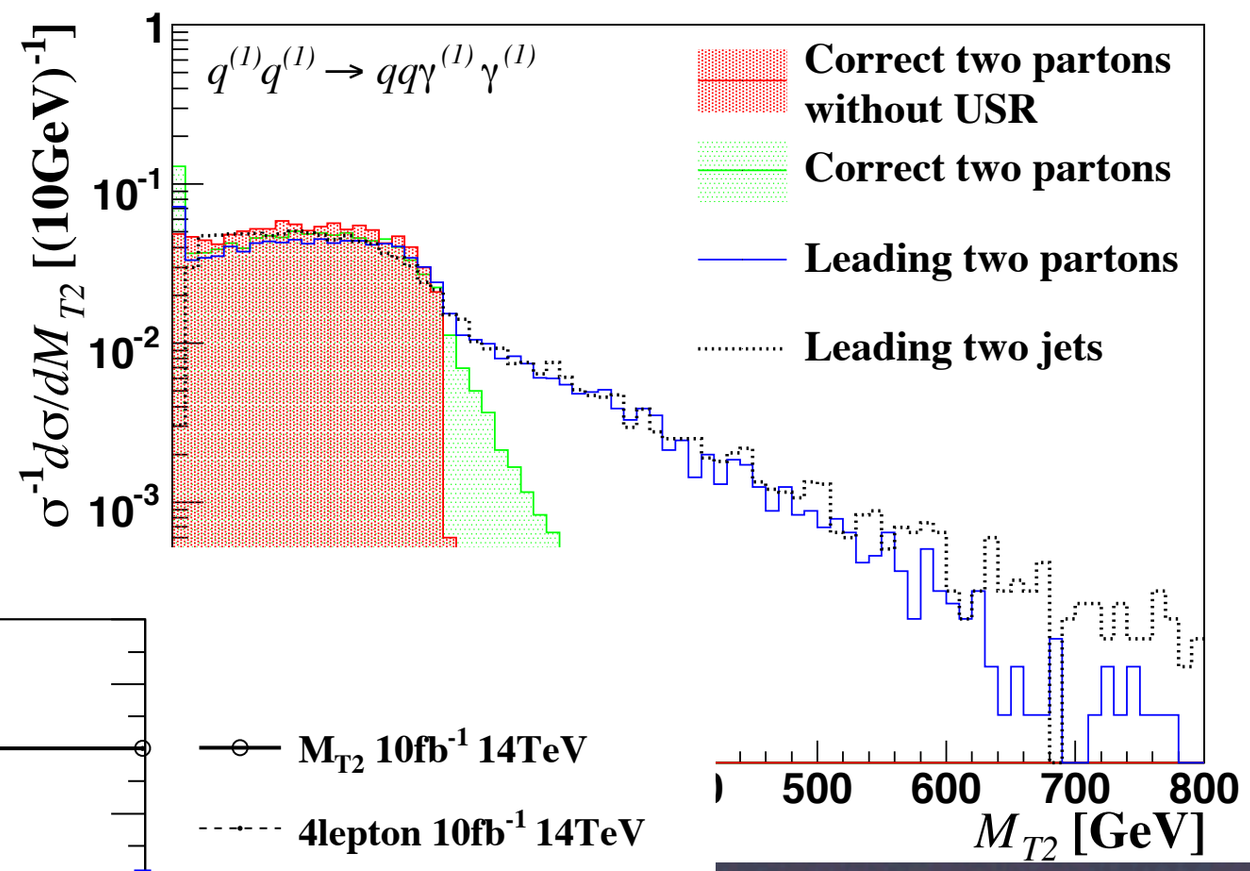

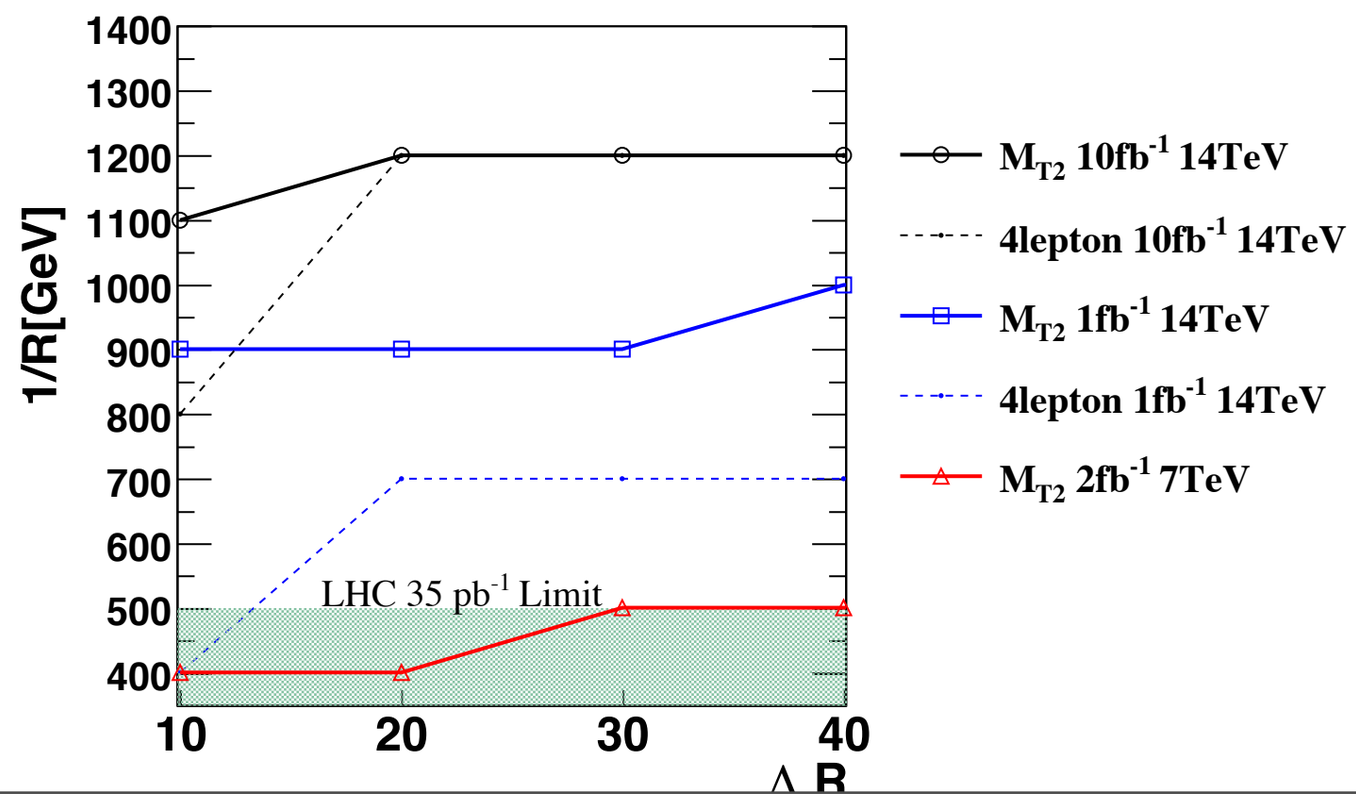

Unive hard
becau ctrum

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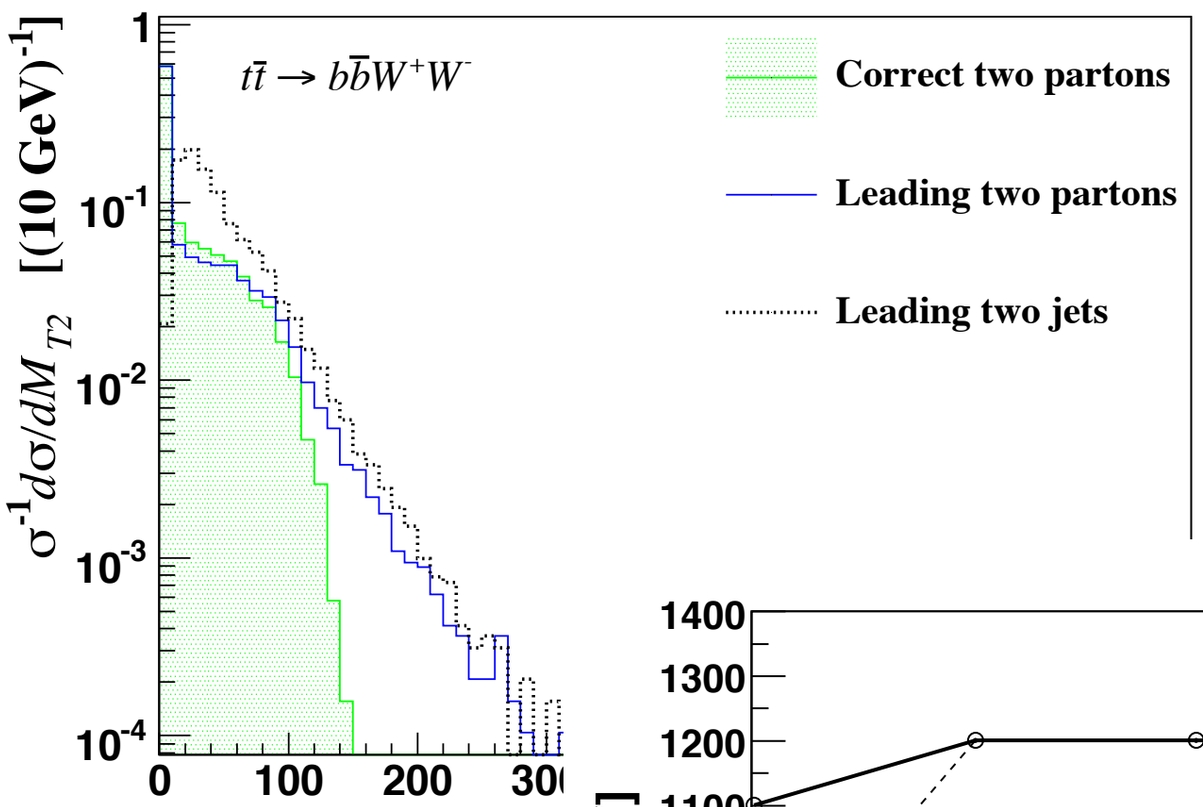

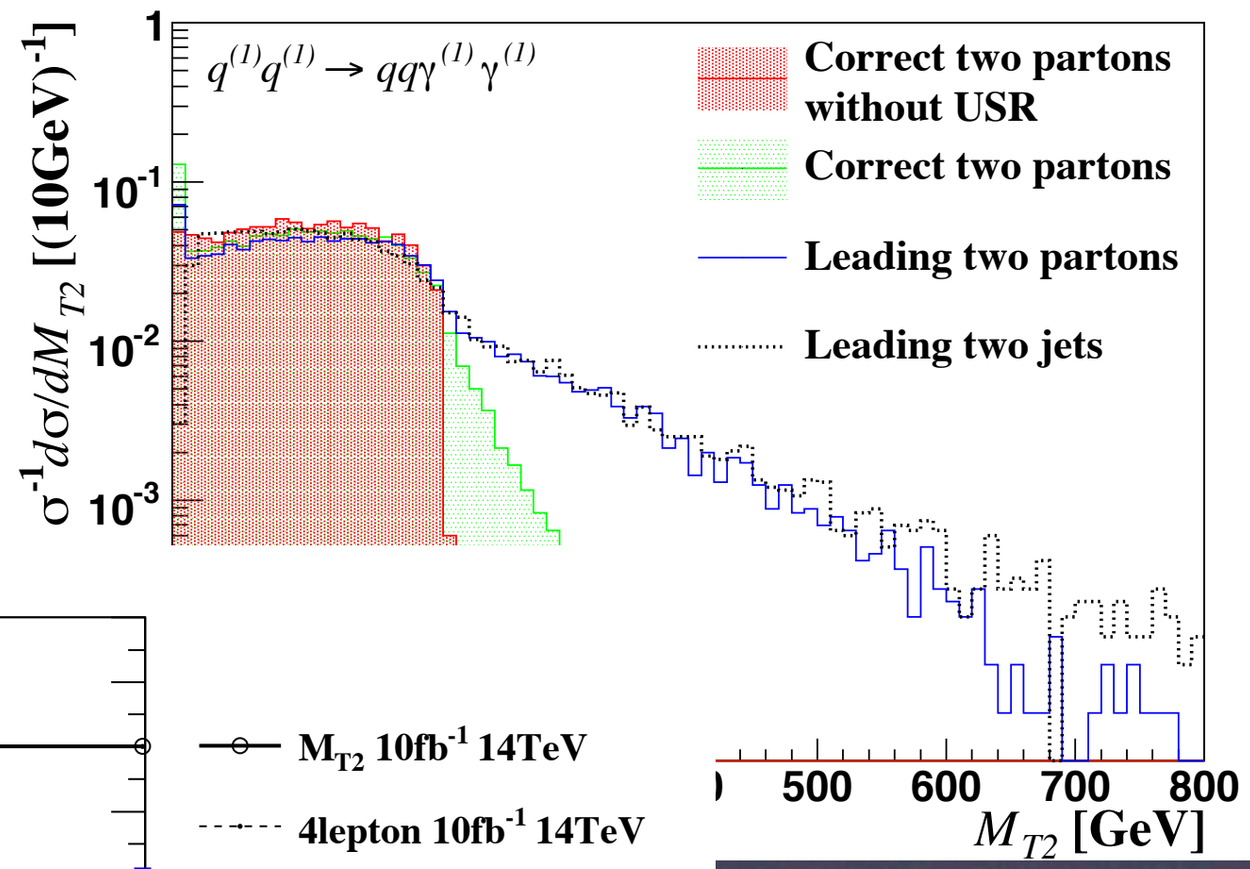

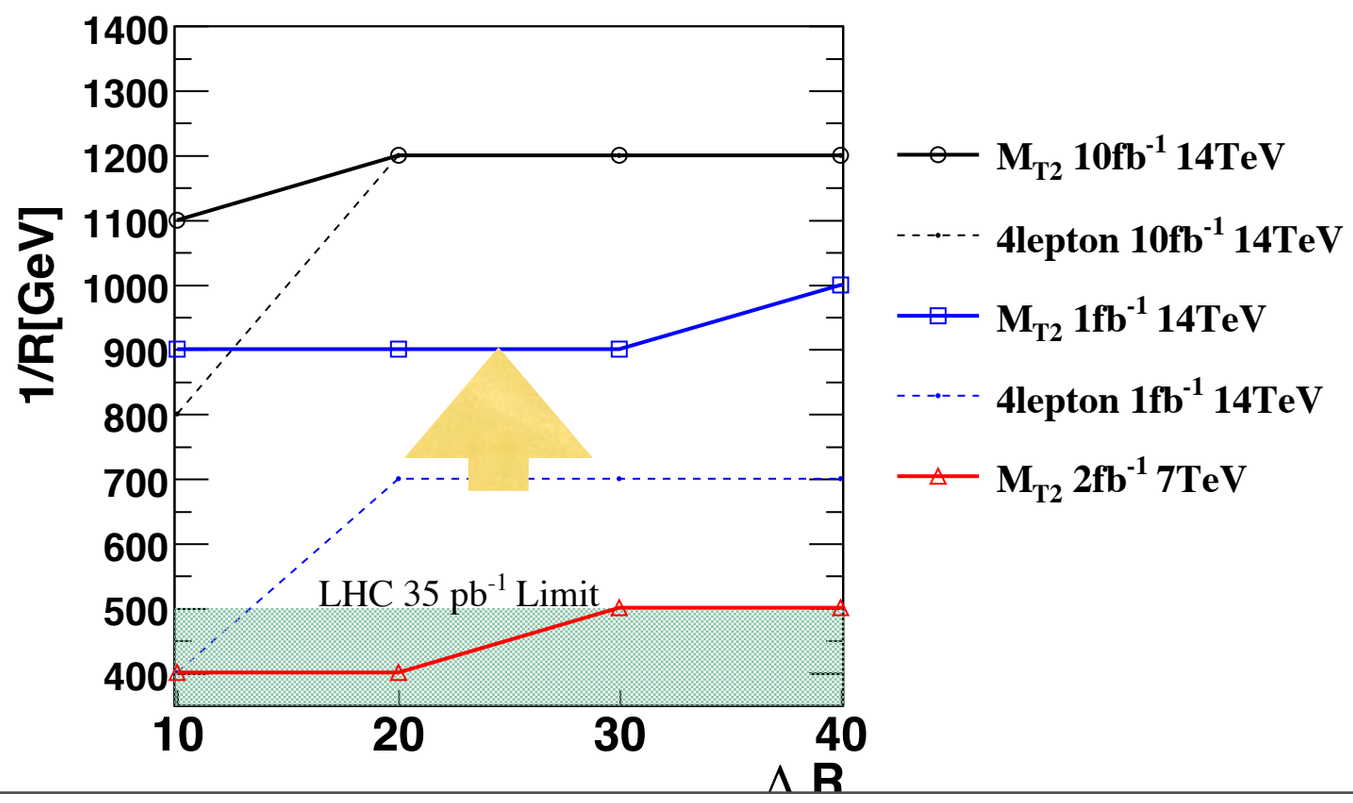

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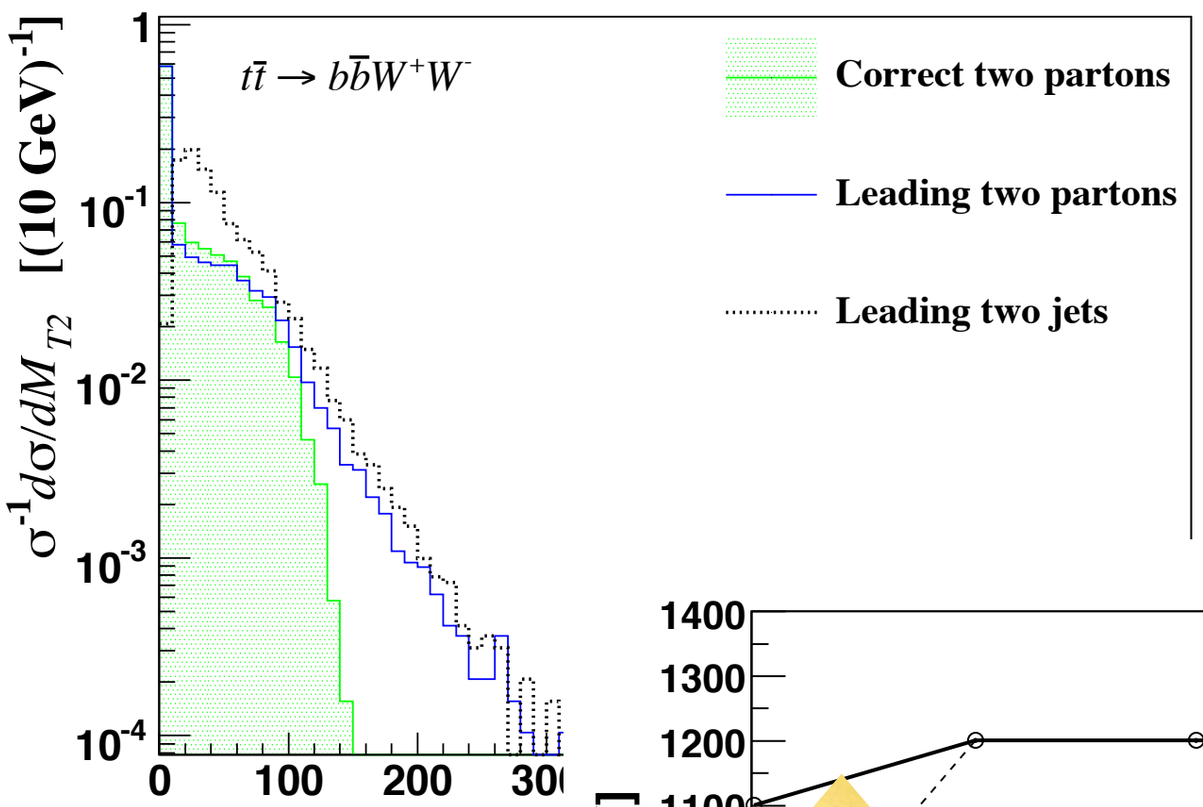

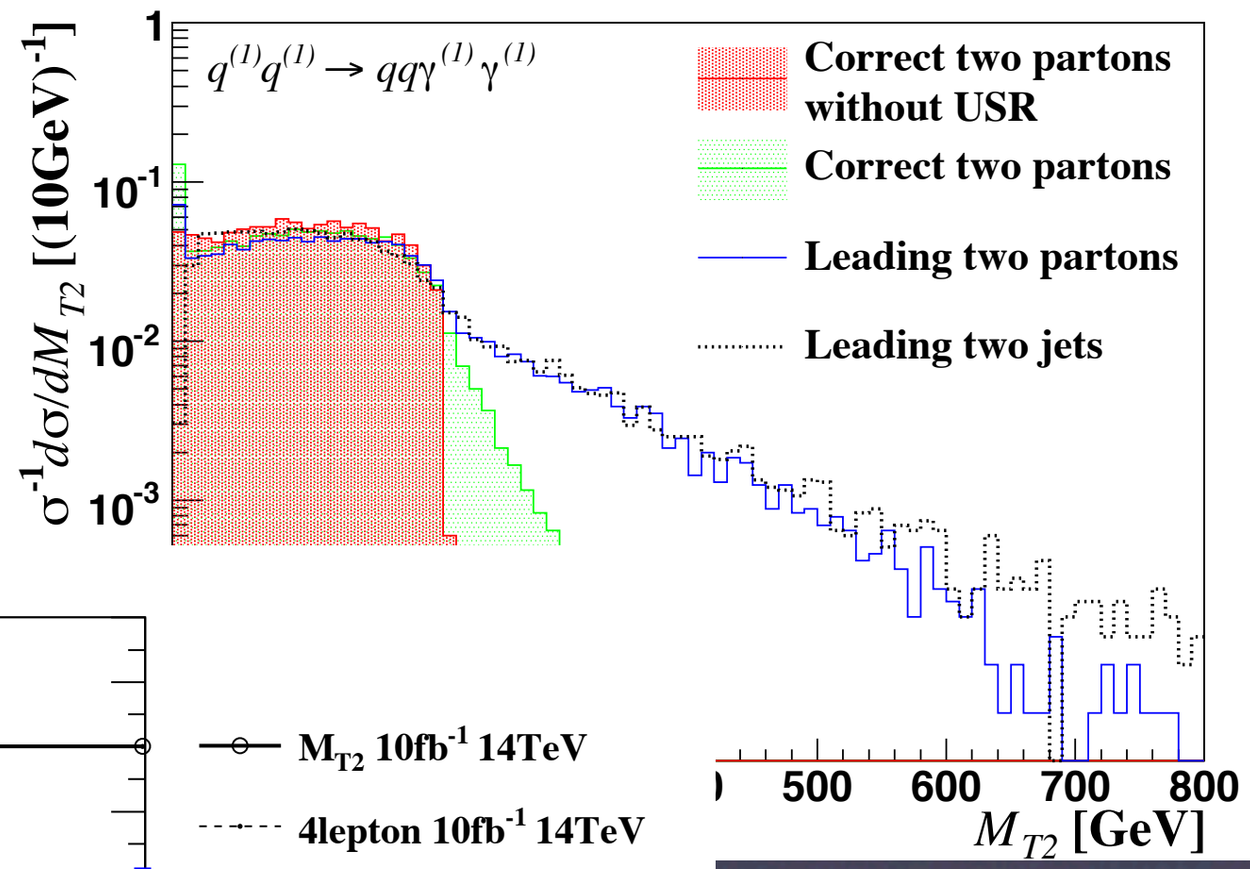

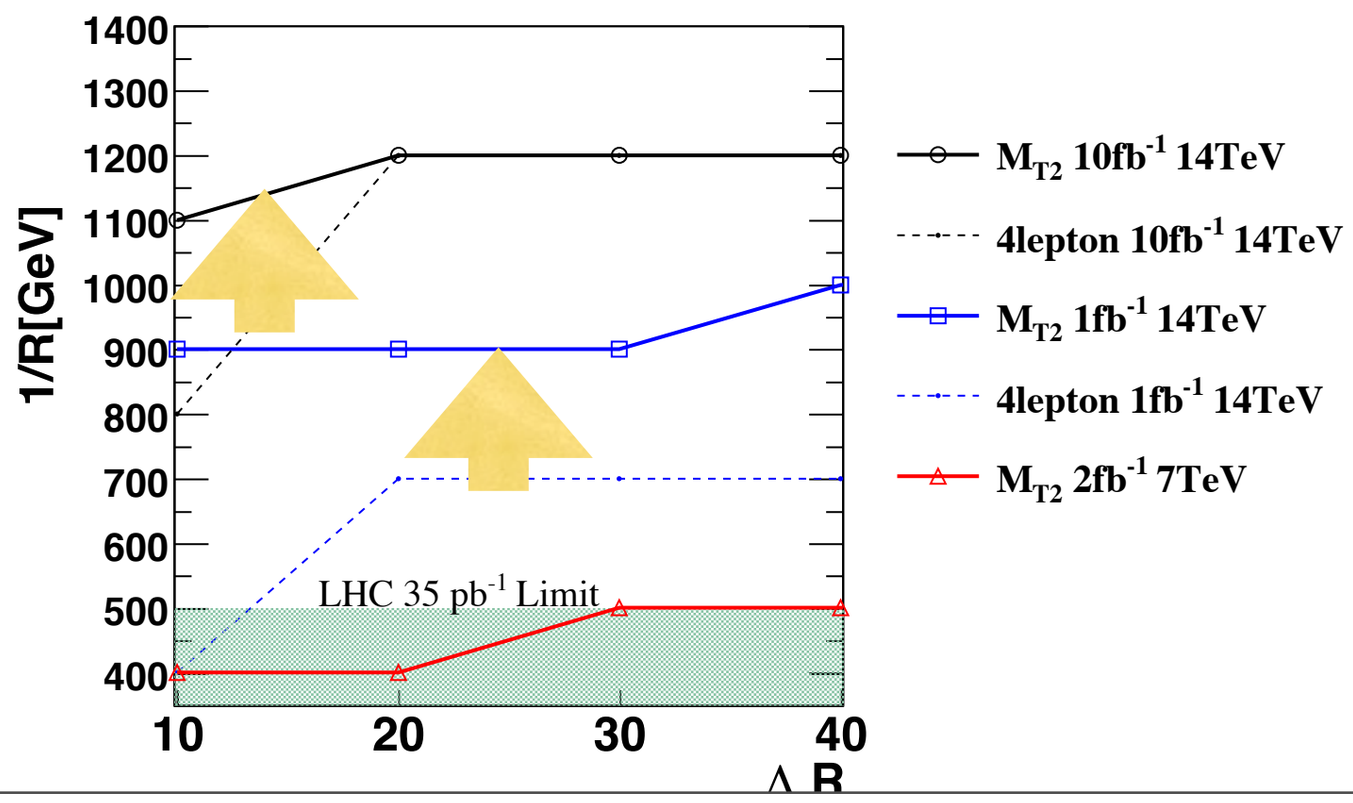

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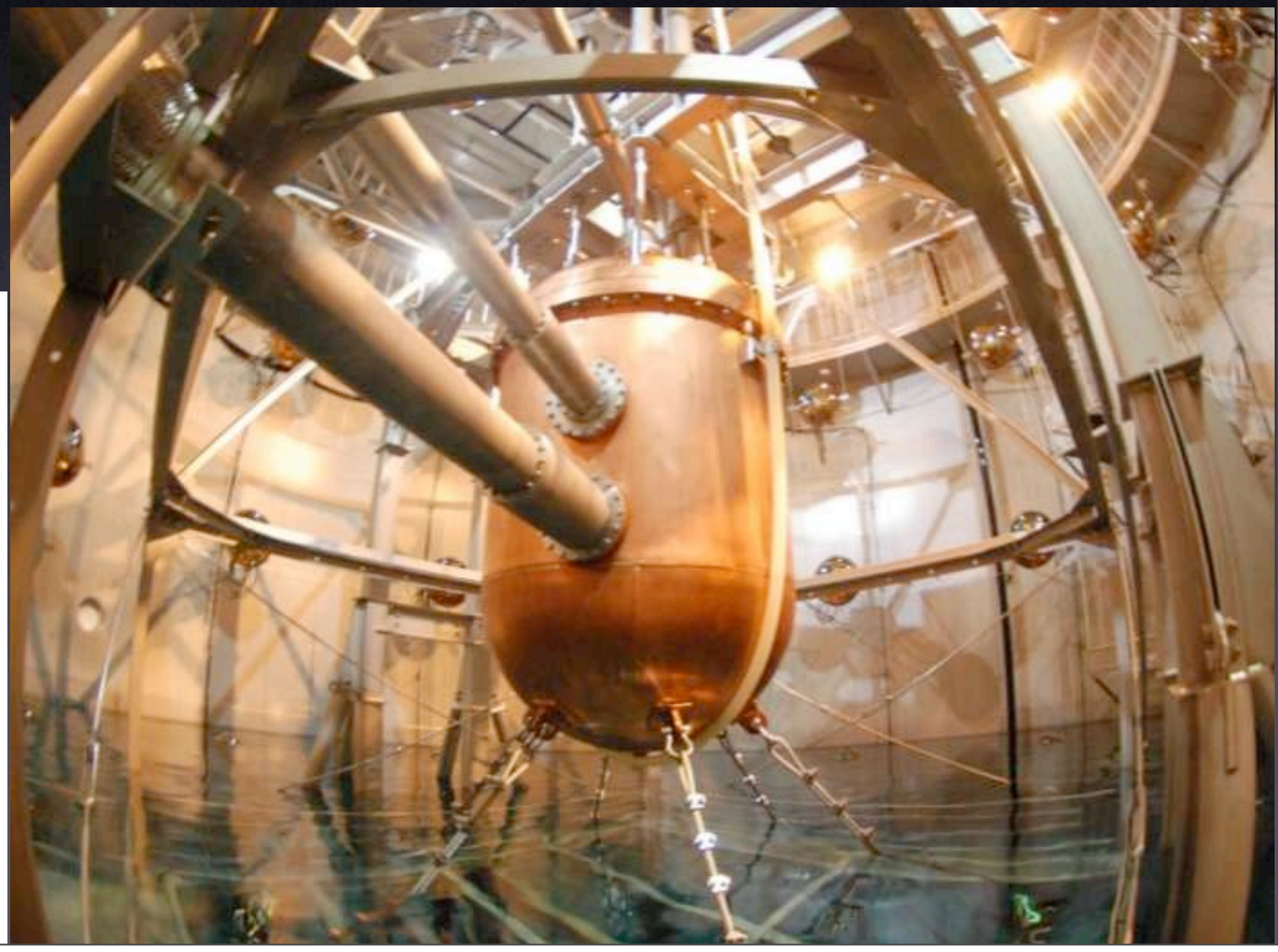
XMASS

1t LXe in Kamioka



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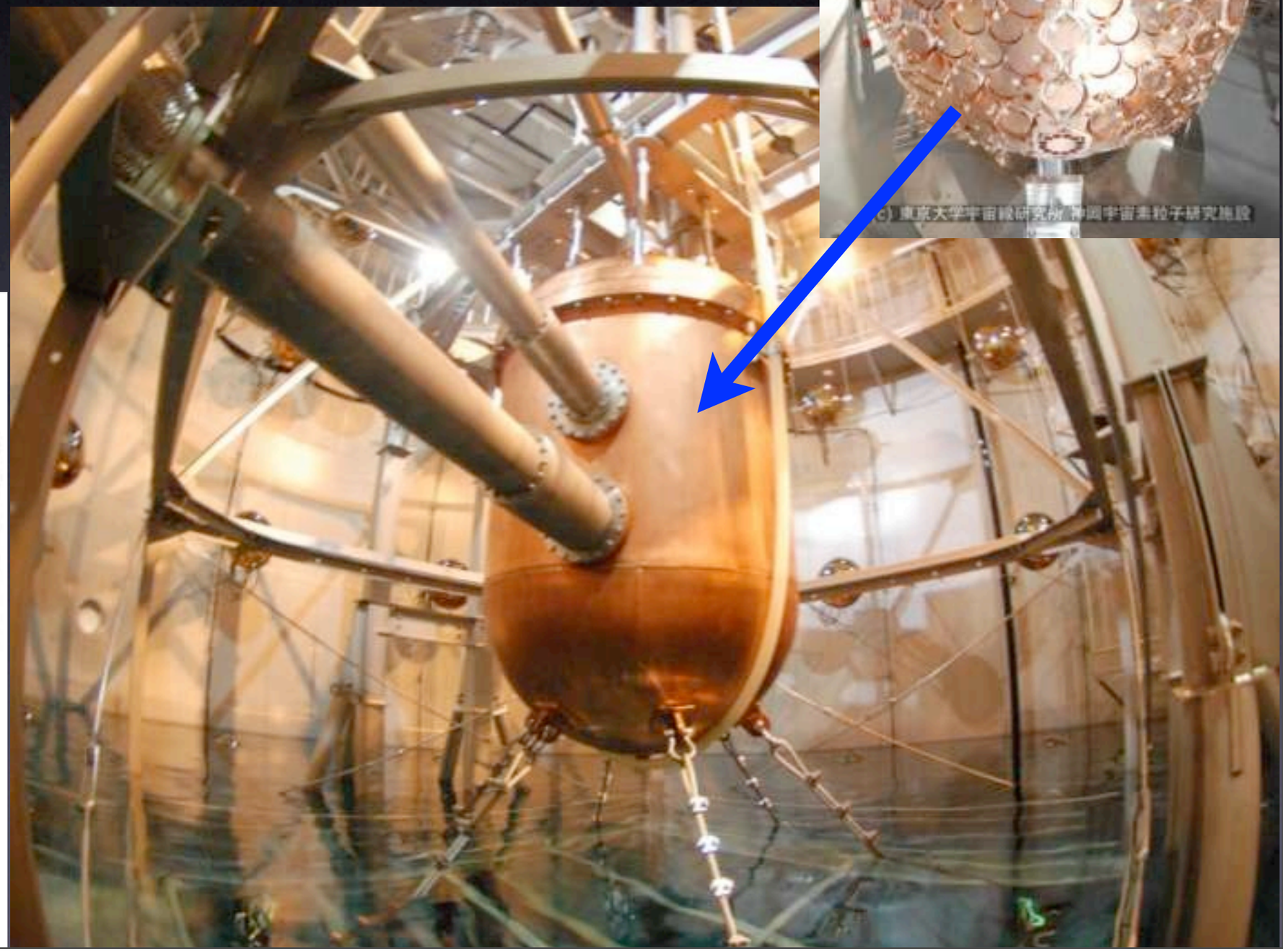
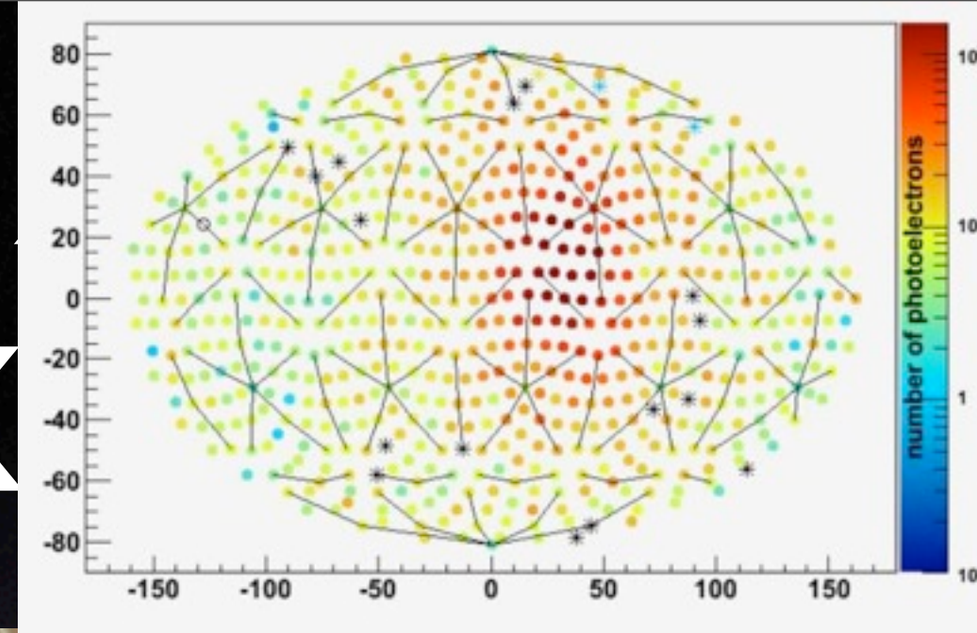
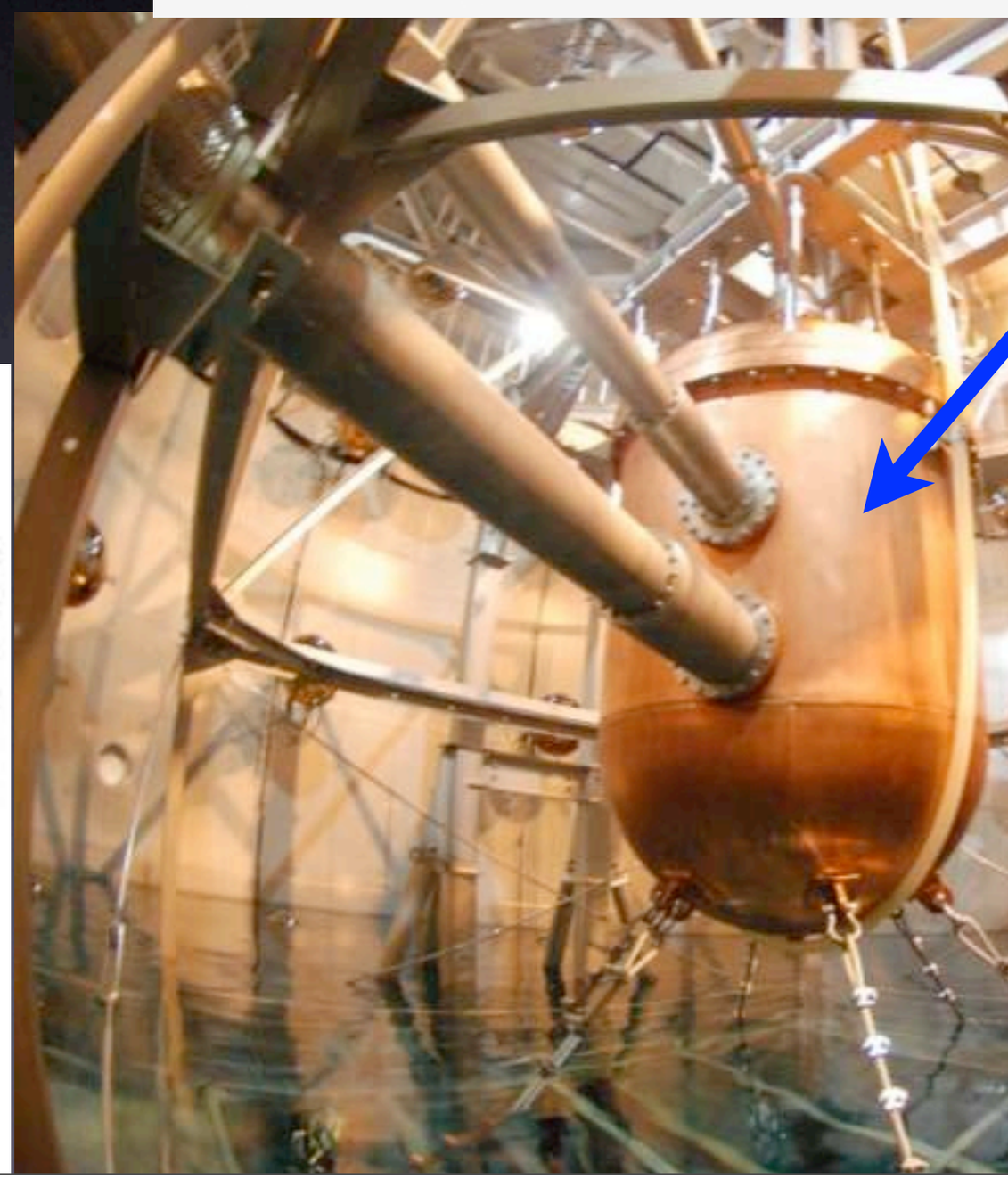
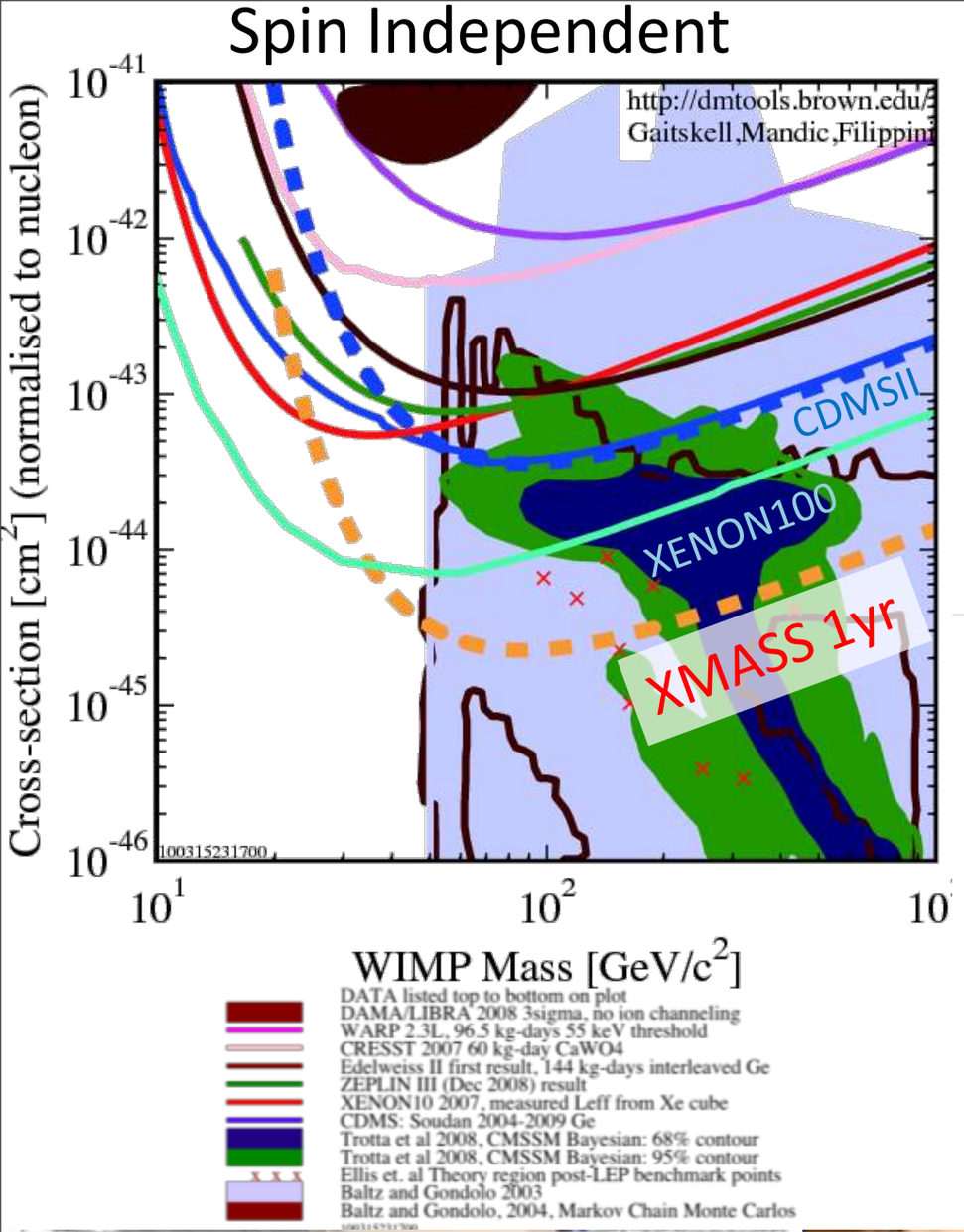


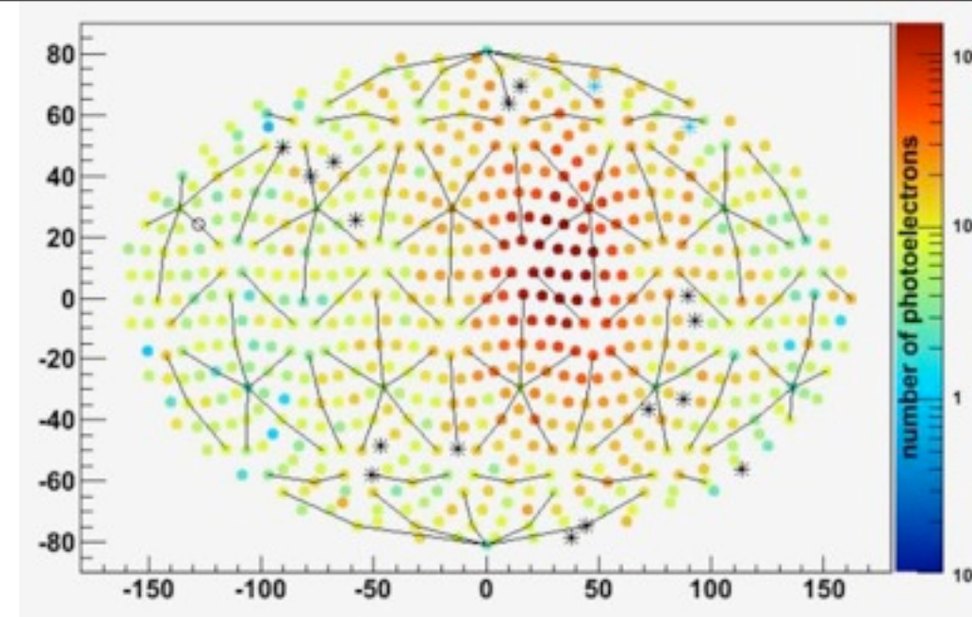
It LX

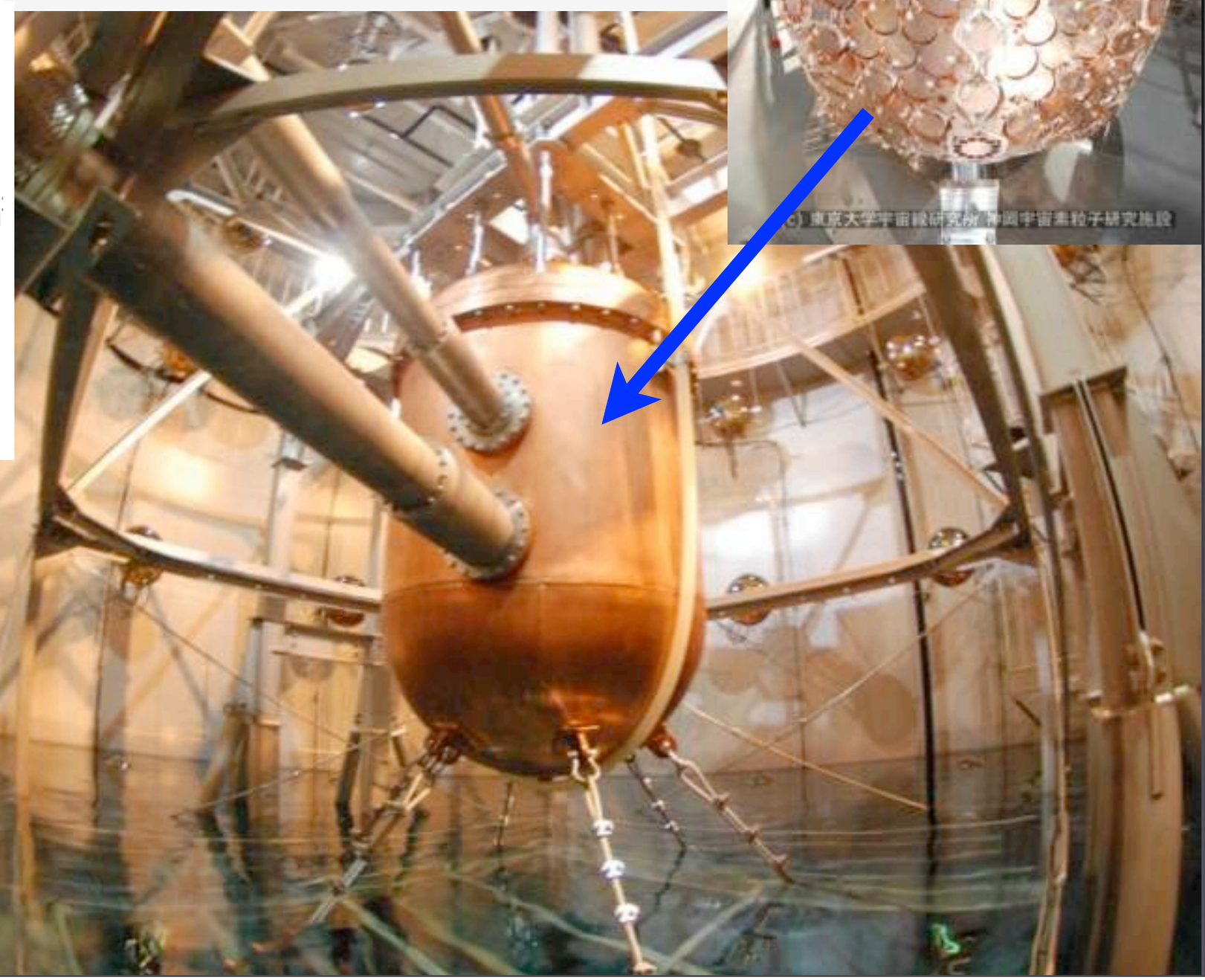

80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
number of photoelectrons

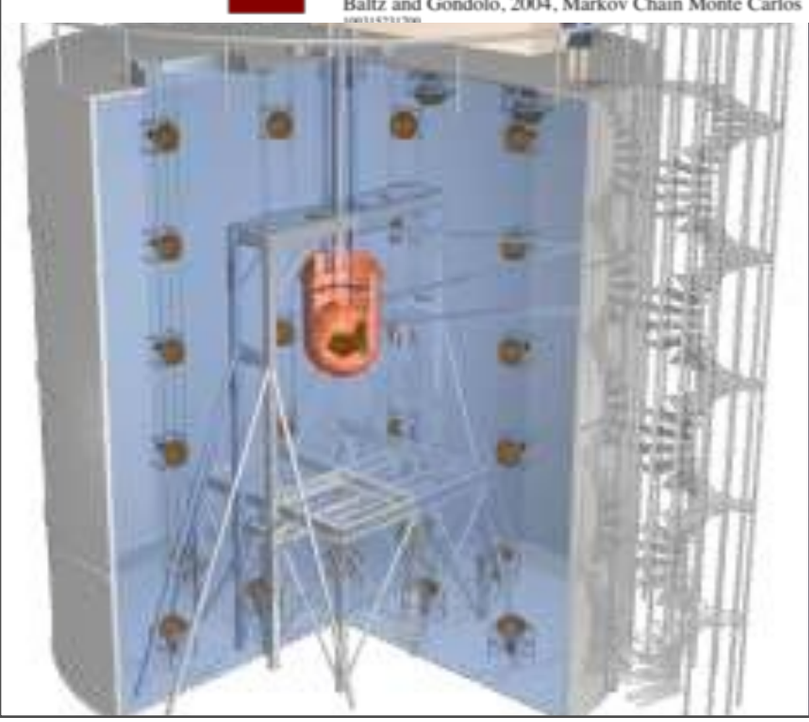


Spin Independent









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I remain optimistic!


dark matter
LHC