To Higgs or not to Higgs?

This is one of the questions

being studied at the LHC

John Ellis
King's College London
(& CERN)

The ‘Standard Model’

= Cosmic DNA

The matter particles

The fundamental interactions

Gravitation electromagnetism weak nuclear force strong nuclear force

Summary of the Standard Model

- Particles and SU(3) × SU(2) × U(1) quantum numbers:

L_L E_R	$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L , \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L , \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L$ $e_R^- , \mu_R^- , \tau_R^-$	$(\mathbf{1},\mathbf{2},\text{-}1)$ $(\mathbf{1},\mathbf{1},\text{-}2)$
Q_L U_R D_R	$\begin{pmatrix} u \\ d \end{pmatrix}_L , \begin{pmatrix} c \\ s \end{pmatrix}_L , \begin{pmatrix} t \\ b \end{pmatrix}_L$ u_R , c_R , t_R d_R , s_R , b_R	$(\mathbf{3},\mathbf{2},+1/3)$ $(\mathbf{3},\mathbf{1},+4/3)$ $(\mathbf{3},\mathbf{1},\text{-}2/3)$

- Lagrangian:

$$\begin{aligned} \mathcal{L} &= -\frac{1}{4} F^a_{\mu\nu} F^{a\,\mu\nu} \\ &+ i\bar{\psi} \not{D} \psi + h.c. \\ &+ \psi_i y_{ij} \psi_j \phi + h.c. \\ &+ |D_\mu \phi|^2 - V(\phi) \end{aligned}$$

gauge interactions

matter fermions

Yukawa interactions

Higgs potential

No direct evidence

Status of the Standard Model

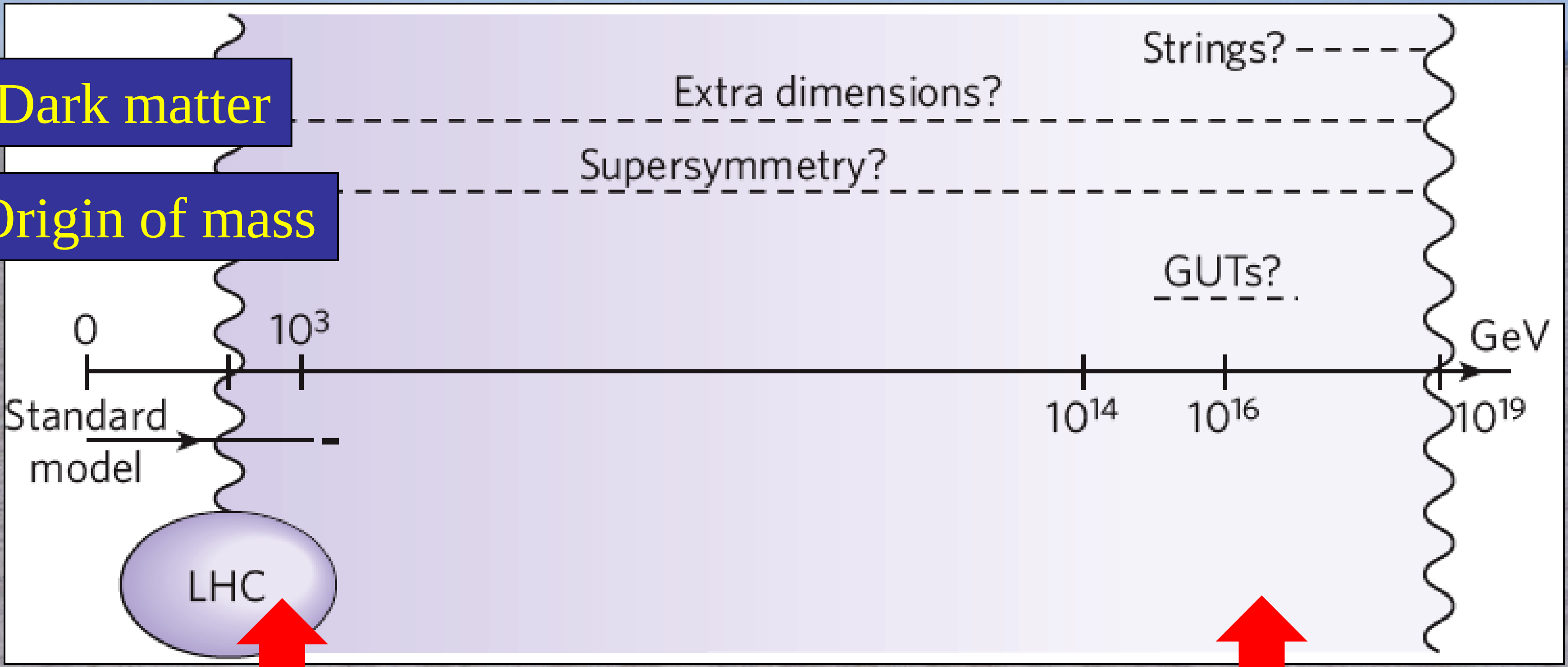
- Perfect agreement with all *confirmed* accelerator data
- Consistency with precision electroweak data (LEP et al) *only if there is a 'Higgs boson'*
- Agreement seems to require *a relatively light Higgs boson* weighing < ~ 180 GeV
- Raises many unanswered questions:

mass? flavour? unification?

Open Questions beyond the Standard Model

- What is the origin of particle masses? due to a Higgs boson? LHC
- Why so many flavours of matter particles? LHC
- What is the dark matter in the Universe? LHC
- Unification of fundamental forces? LHC
- Quantum theory of gravity? LHC

At what Energy is the New Physics?



Dark matter

Origin of mass

A lot accessible to the LHC

Some accessible only via astrophysics & cosmology

Why do Things Weigh?

Newton:

Weight proportional to Mass

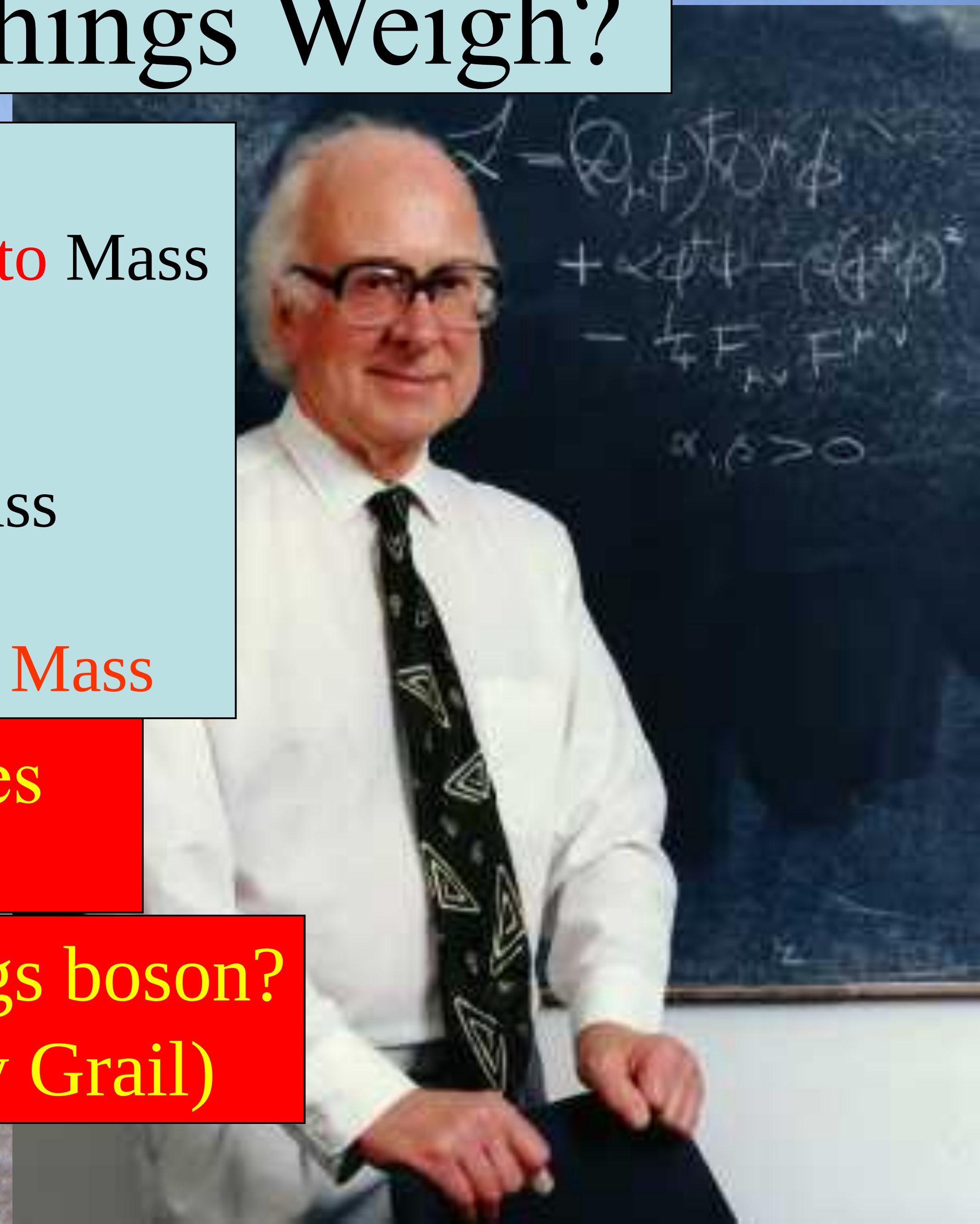
Einstein:

Energy related to Mass

Neither explained origin of Mass

Where do the masses come from?

Are masses due to Higgs boson?
(the physicists' Holy Grail)



Think of a Snowfield

Skier moves fast:
Like particle without mass
e.g., photon = particle of light

Snowshoer sinks into snow,
moves slower:
Like particle with mass
e.g., electron

The LHC will look for the snowflake: The Higgs Boson

Hiker sinks deep,
moves very slowly:
Particle with large mass

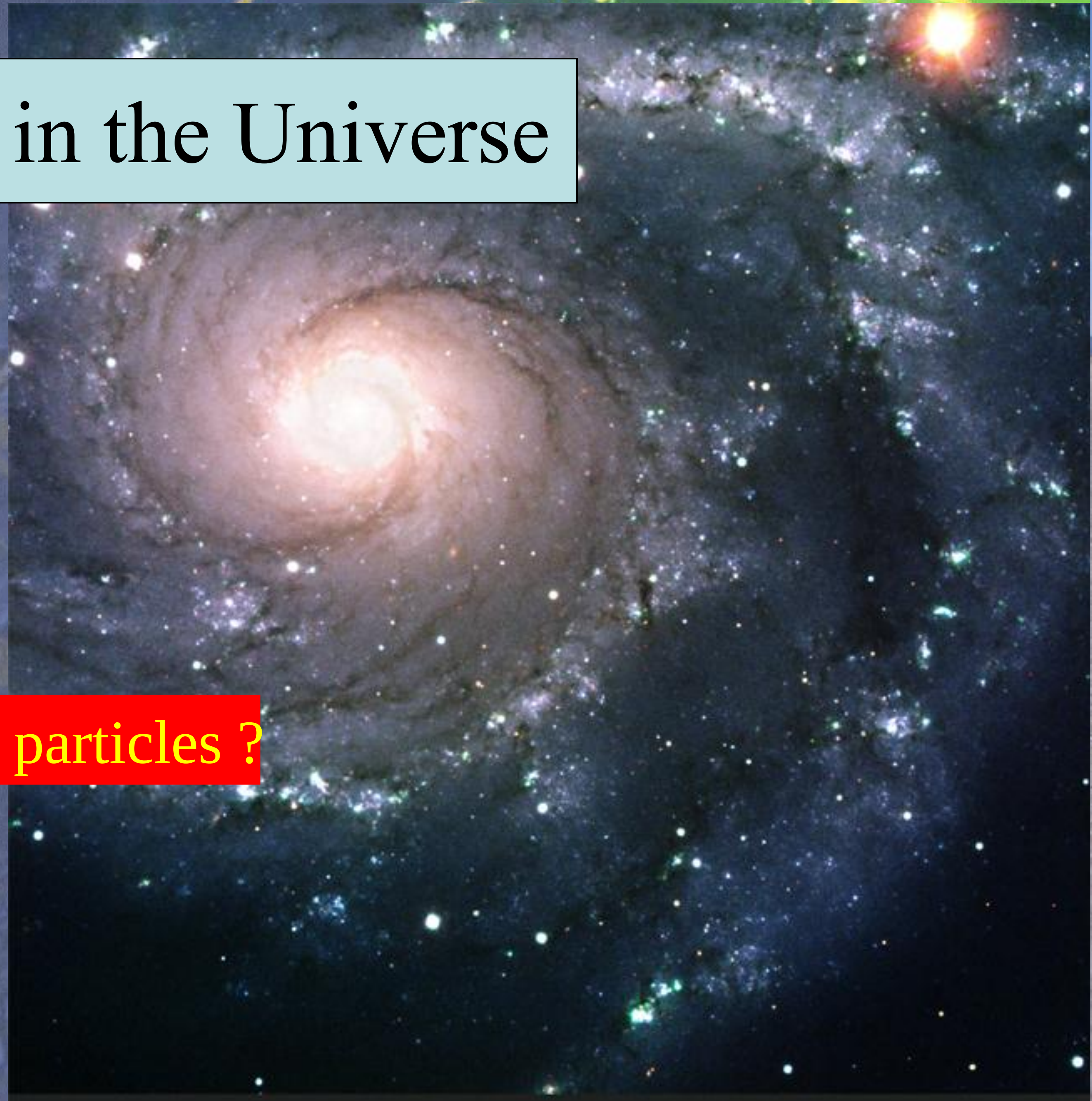
A Simulated Higgs Event @ LHC

Dark Matter in the Universe

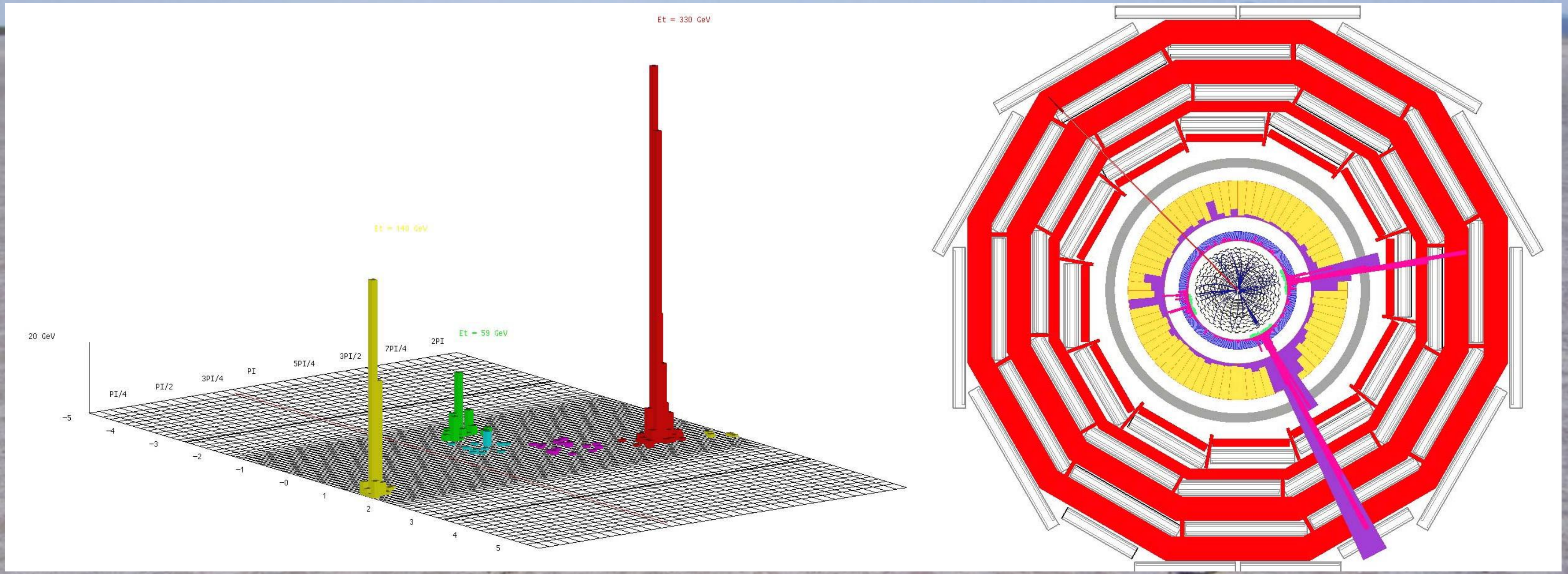
Astronomers say that most of the matter in the Universe is invisible
Dark Matter

'Supersymmetric' particles ?

We shall look for them with the LHC



Classic Dark Matter Signature



Missing transverse energy
carried away by dark matter particles

General Interest in Antimatter Physics

Physicists cannot make enough for
Star Trek or Dan Brown!

How do Matter and Antimatter Differ?

Dirac predicted the existence of antimatter:
same mass
opposite internal properties:
electric charge, …
Discovered in cosmic rays
Studied using accelerators

Matter and antimatter not quite equal and opposite: WHY?

Why does the Universe mainly contain matter, not antimatter?

Experiments at LHC and elsewhere looking for answers

How to Create the Matter in the Universe?

Sakharov

- Need a difference between matter and antimatter
  - observed in the laboratory
- Need interactions able to creat matter
  - present in unified theories
  - not yet seen by experiment
- Must break thermal equilibrium
  - Possible in the decays of heavy particles

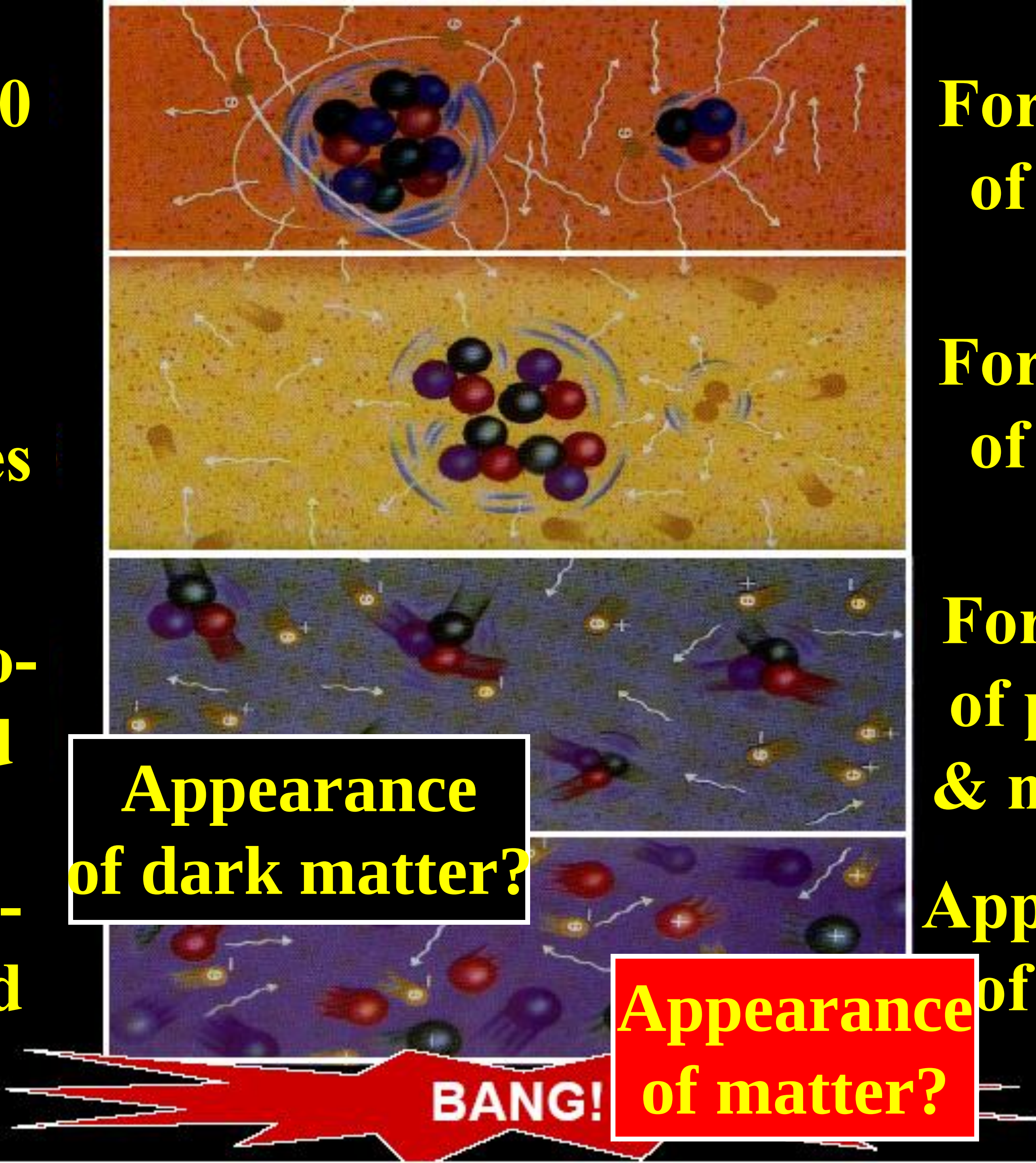
Will we be able to calculate using laboratory data?

300,000 years — Formation of atoms

3 minutes — Formation of nuclei

1 micro-second — Formation of protons & neutrons

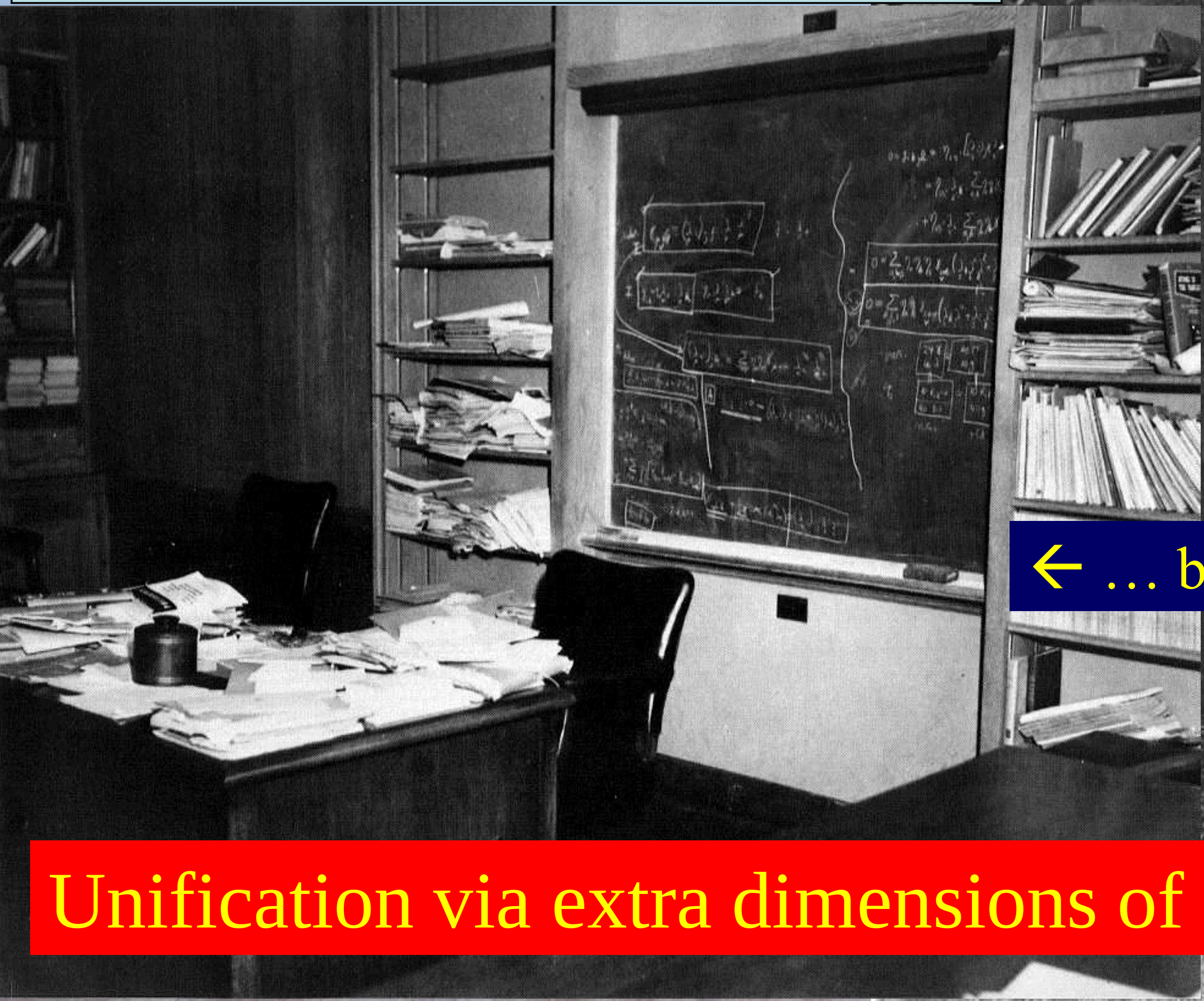
1 pico-second — Appearance of mass?



Appearance of dark matter?

Appearance of matter?

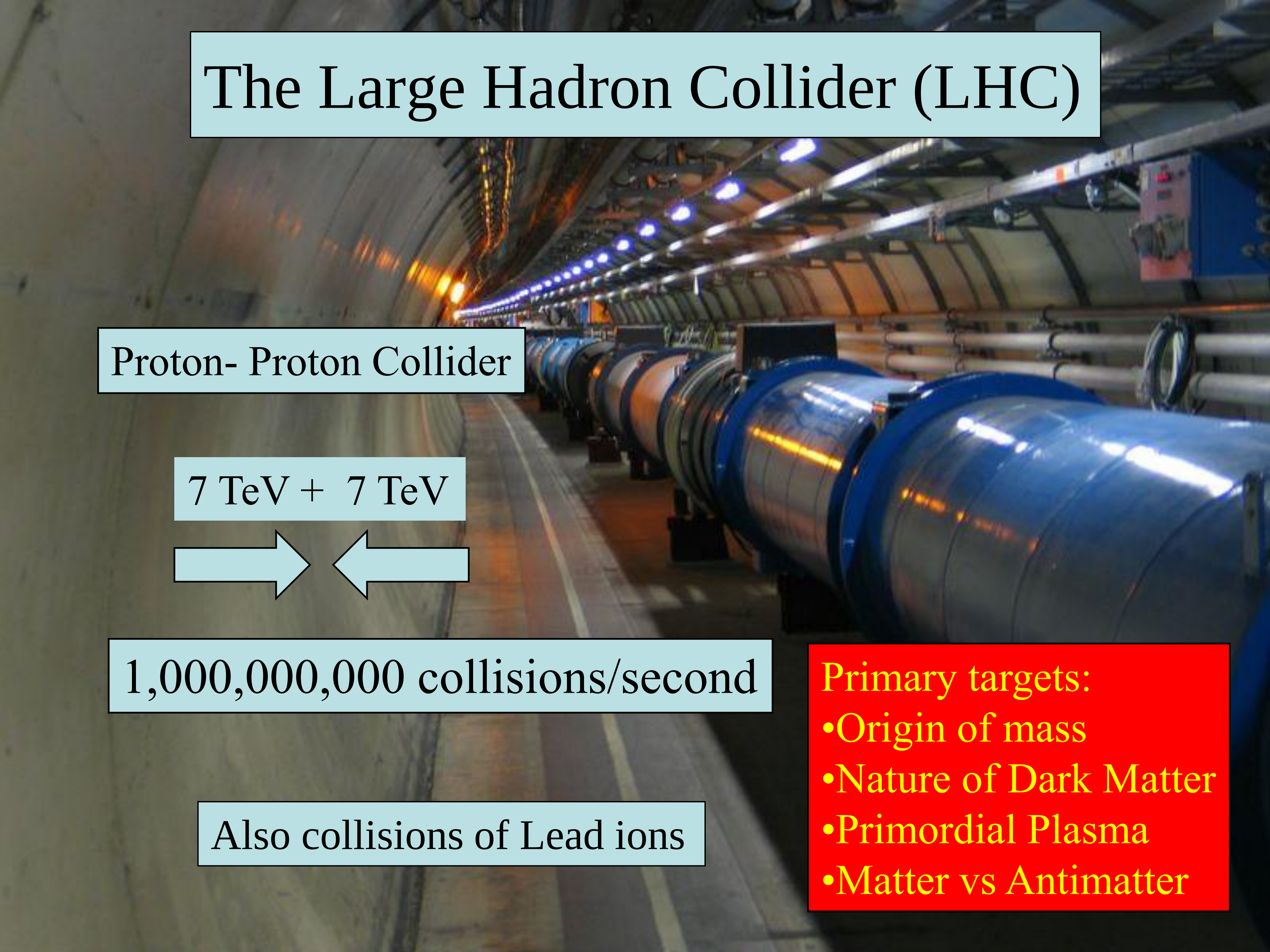
Unify all the Fundamental Interactions: Einstein's Dream …



← … but he never succeeded

Unification via extra dimensions of space?

The Large Hadron Collider (LHC)



Proton- Proton Collider

7 TeV + 7 TeV

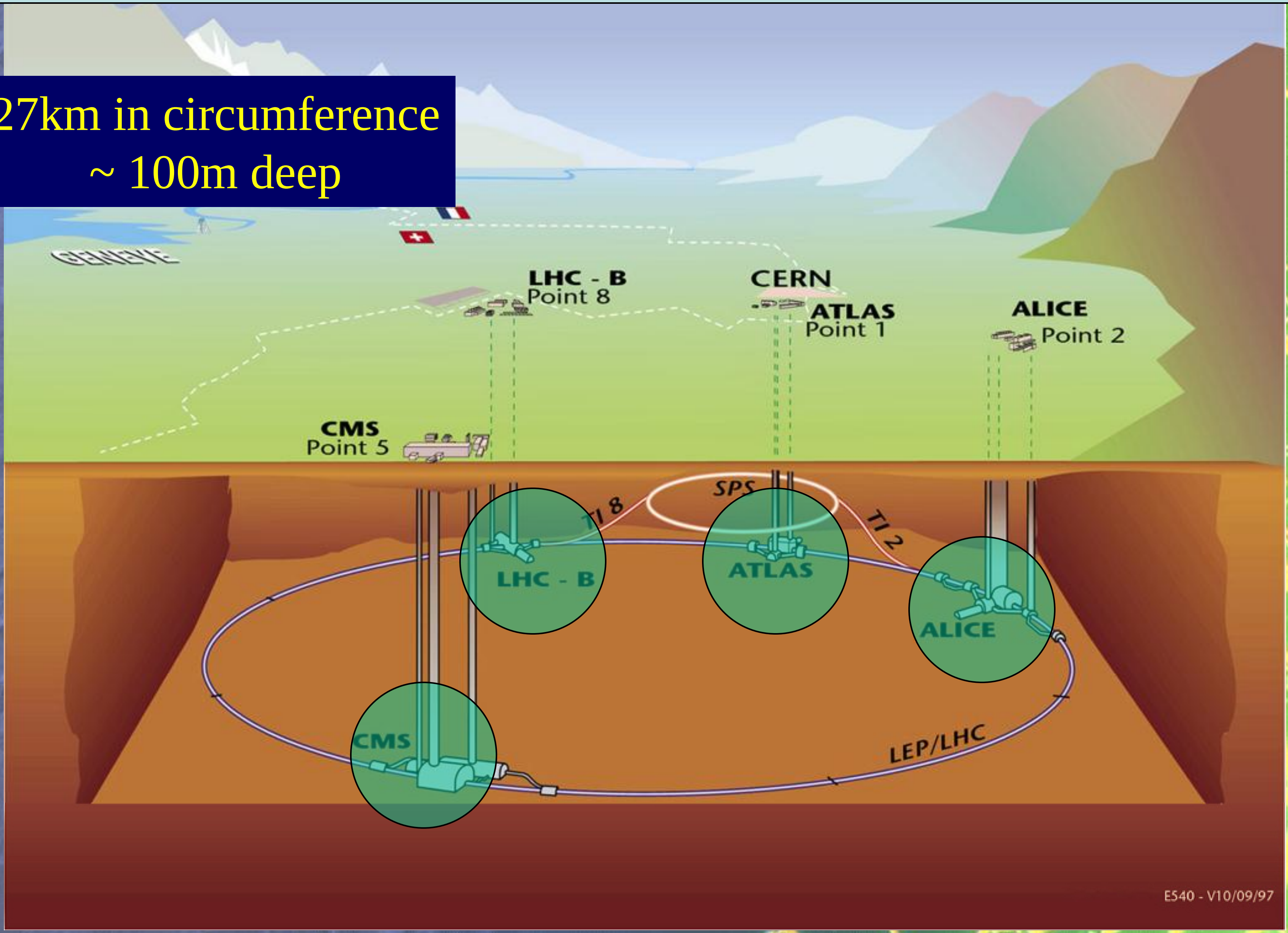
1,000,000,000 collisions/second

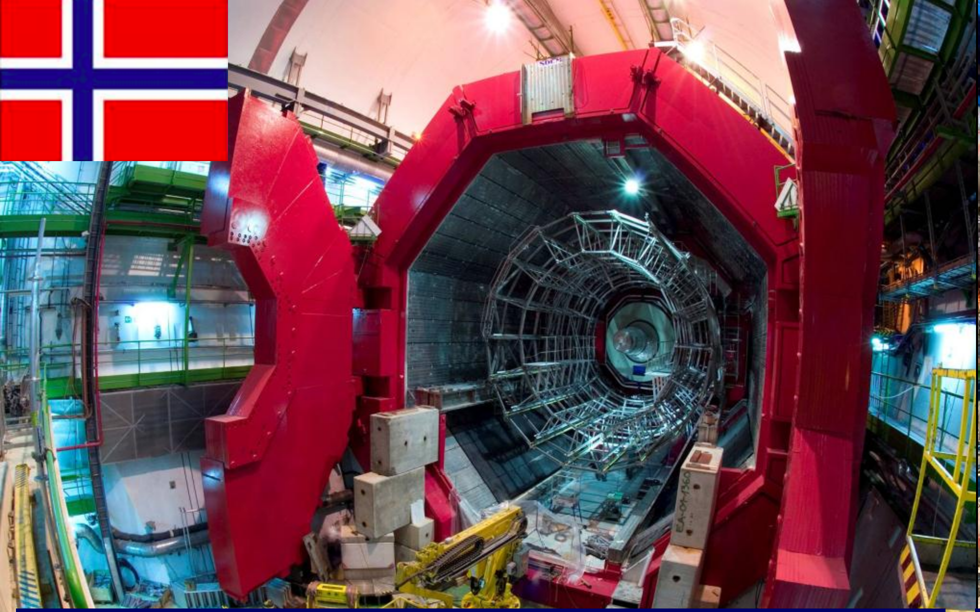
Also collisions of Lead ions

Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

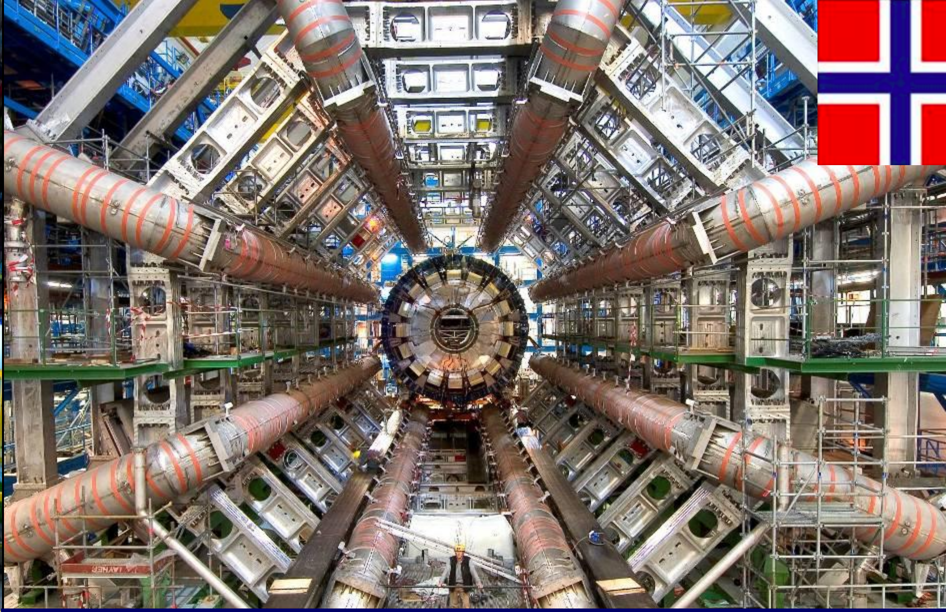
General View of LHC & its Experiments

27km in circumference
~ 100m deep

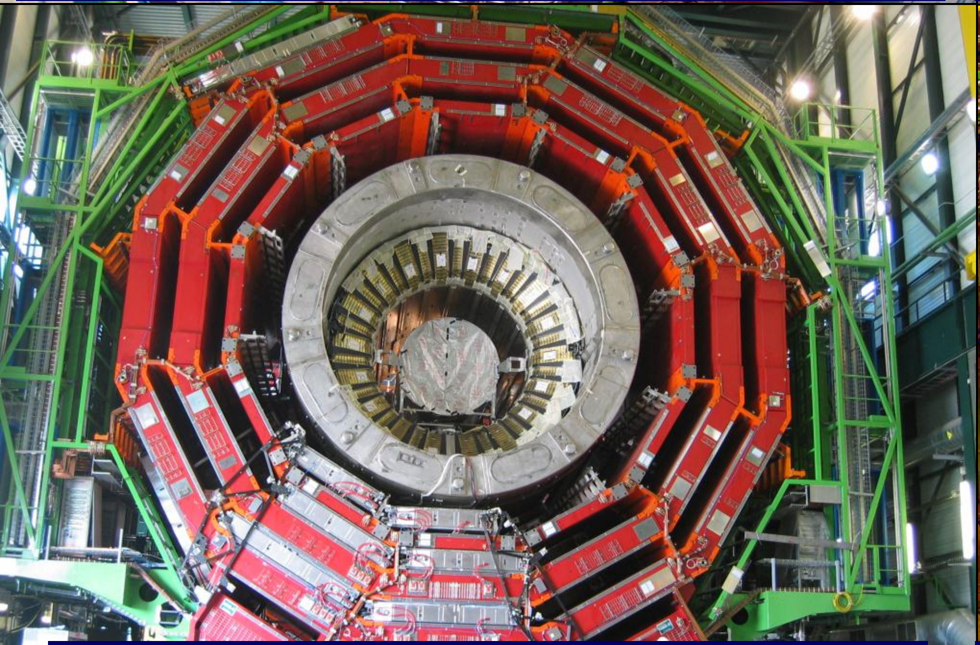




ALICE: Primordial cosmic plasma



ATLAS: Higgs and supersymmetry



CMS: Higgs and supersymmetry

LHCb: Matter-antimatter difference

The Seminal Papers

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

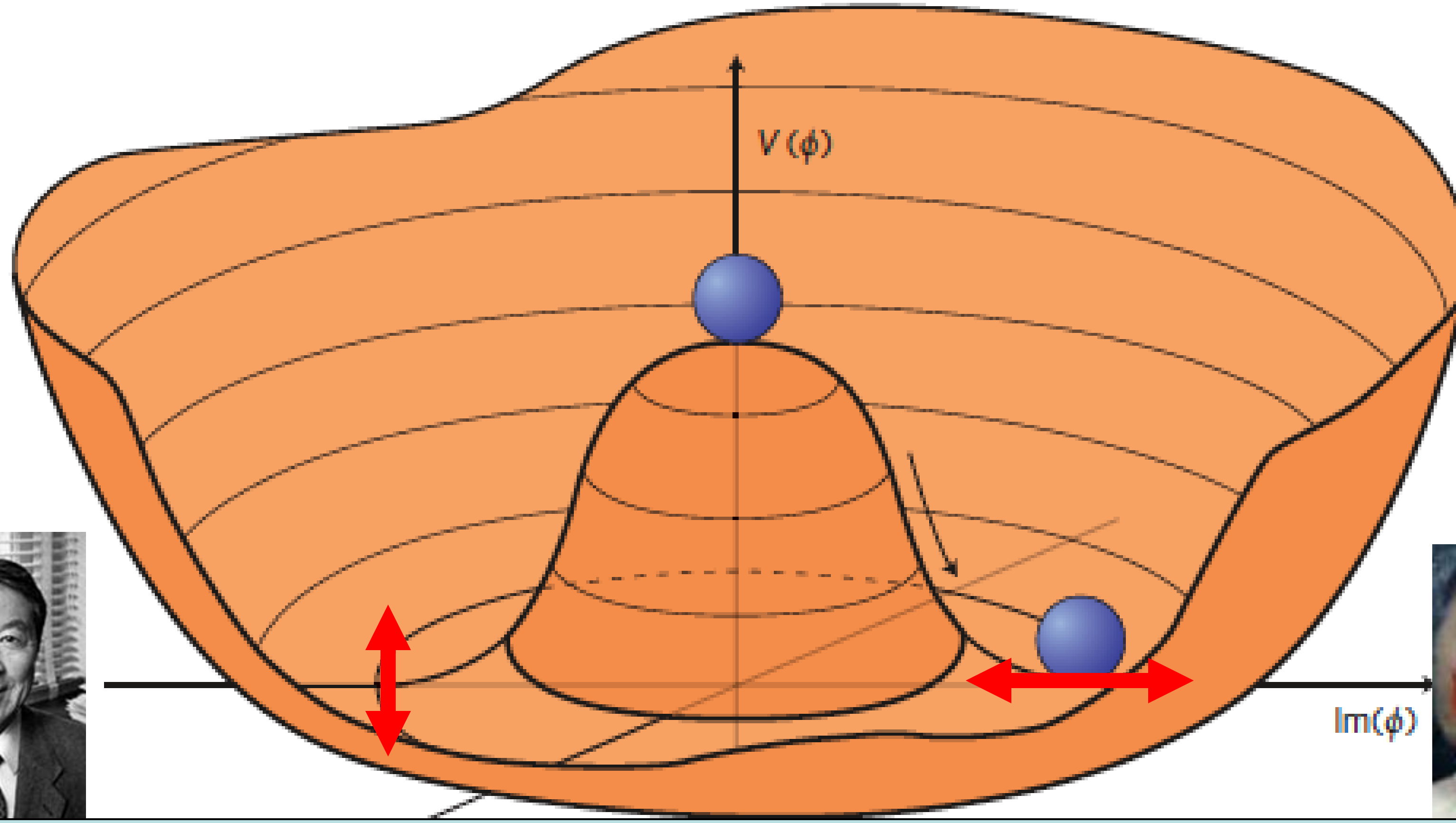
BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)

Nambu **EB, GHK** **and Higgs**



Spontaneous symmetry breaking: massless Nambu-Goldstone boson **'eaten' by gauge boson**

Accompanied by massive particle

Indirect Constraints on Higgs Mass

- Electroweak observables sensitive via quantum loop corrections:

$$m_W^2 \sin^2\theta_W = m_Z^2 \cos^2\theta_W \sin^2\theta_W = \frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

- Sensitivity to top, Higgs masses:

$$\frac{3G_F}{8\pi^2\sqrt{2}}m_t^2 \qquad \frac{\sqrt{2}G_F}{16\pi^2}m_W^2\left(\frac{11}{3}\ln\frac{M_H^2}{m_Z^2}+\ldots\right),\ M_H >> m_W$$

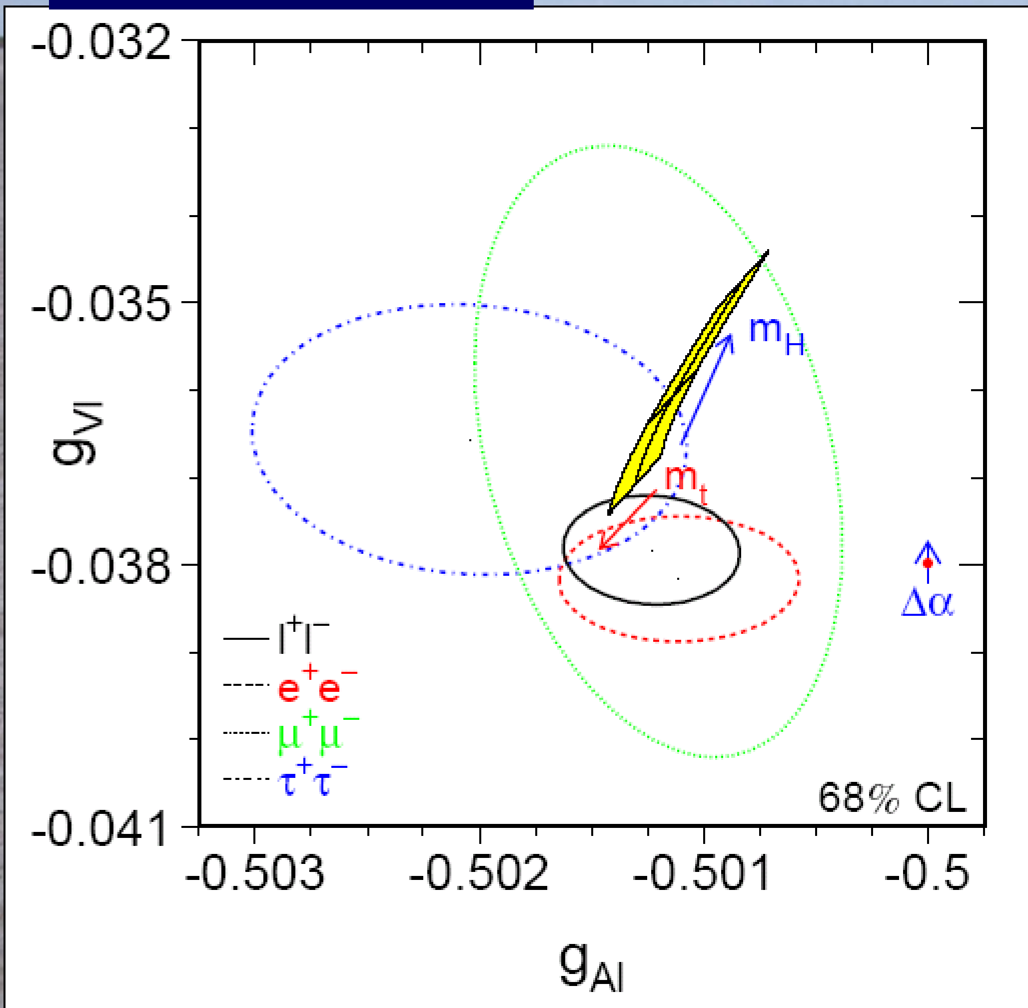
- Preferred Higgs mass: **$m_H \sim 80 \pm 30$ GeV**
- Compare with lower limit from direct searches:

$m_H > 114$ GeV

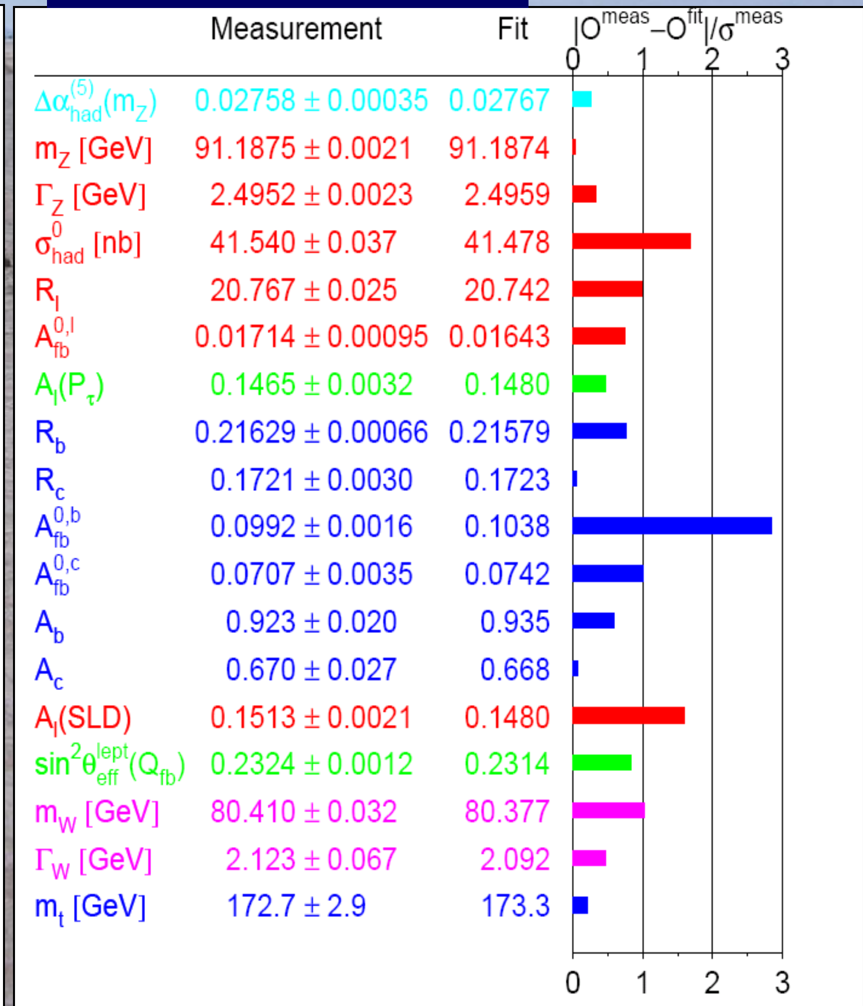
- No conflict!

Precision Tests of the Standard Model

Lepton couplings

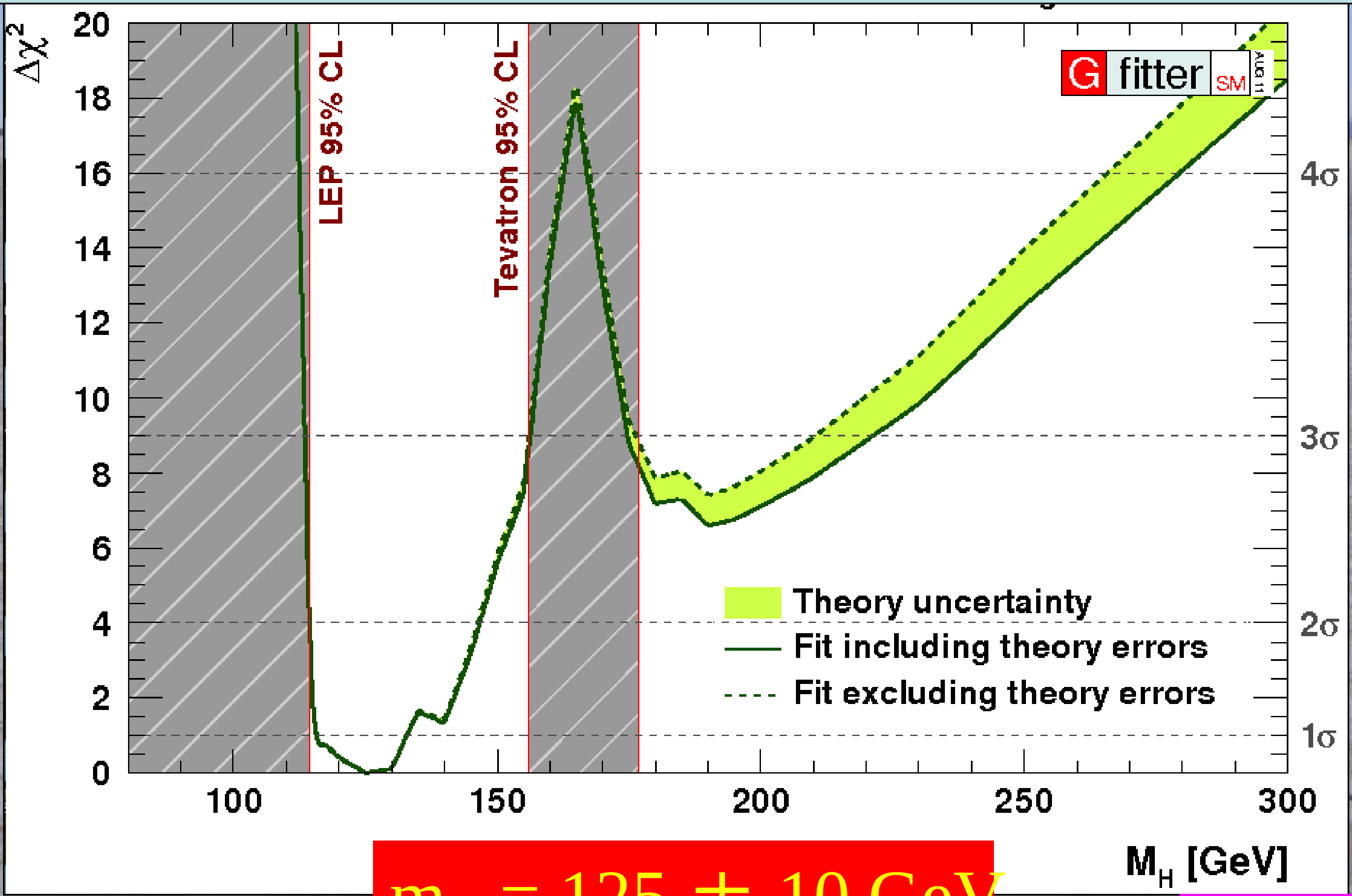


Pulls in global fit



	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.742	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01643	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1723	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1480	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.410 ± 0.032	80.377	
Γ_W [GeV]	2.123 ± 0.067	2.092	
m_t [GeV]	172.7 ± 2.9	173.3	

Combining the Information from Direct Searches and Indirect Data

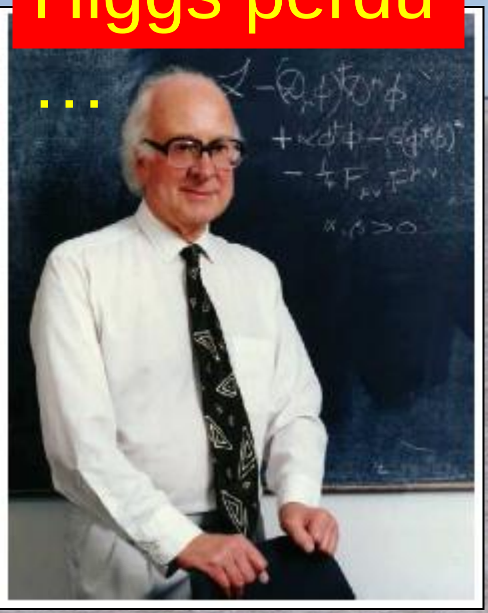


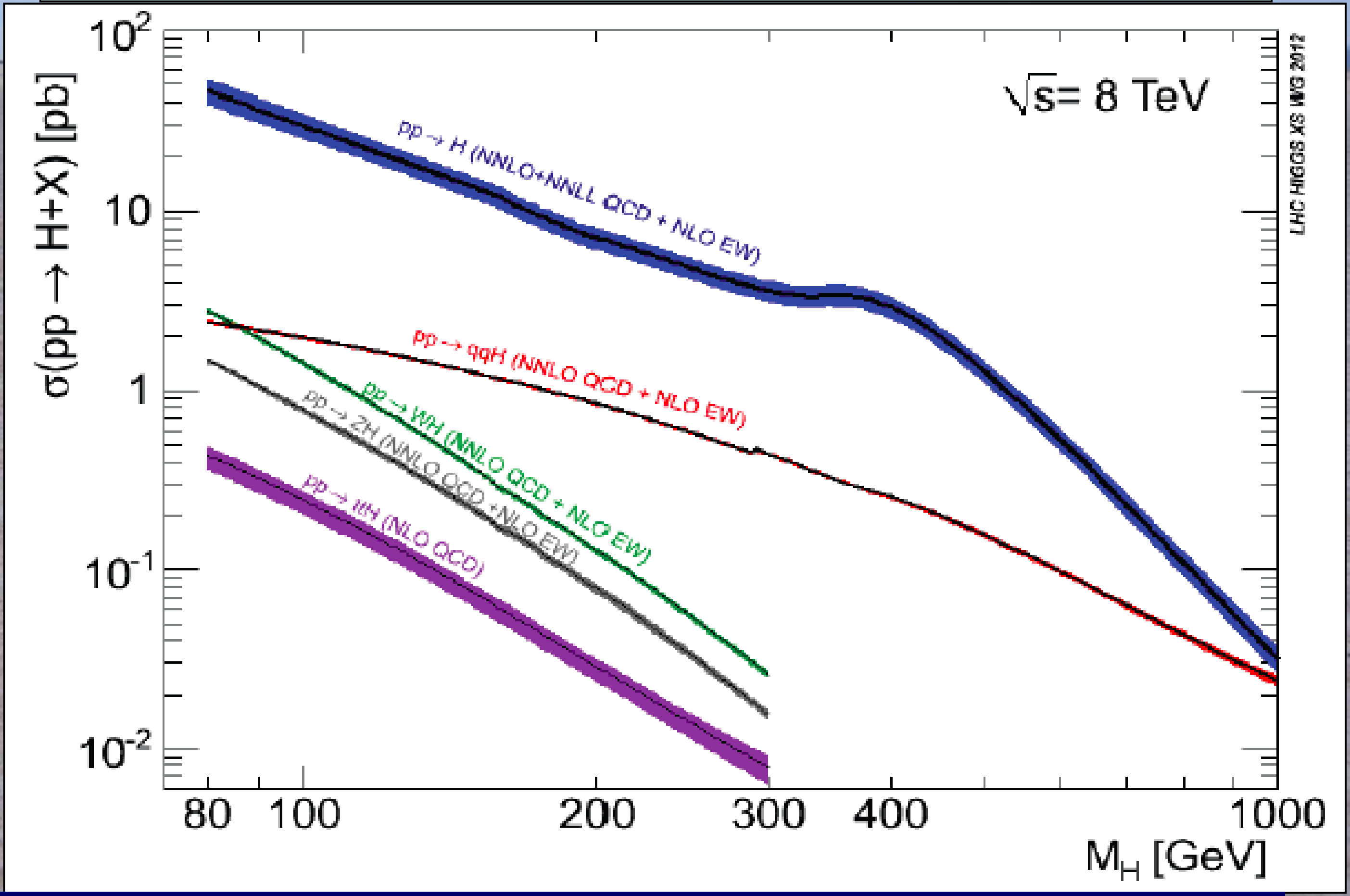
$m_H = 125 \pm 10$ GeV

Gfitter collaboration

A la recherche du Higgs perdu …

Higgs Production at the LHC

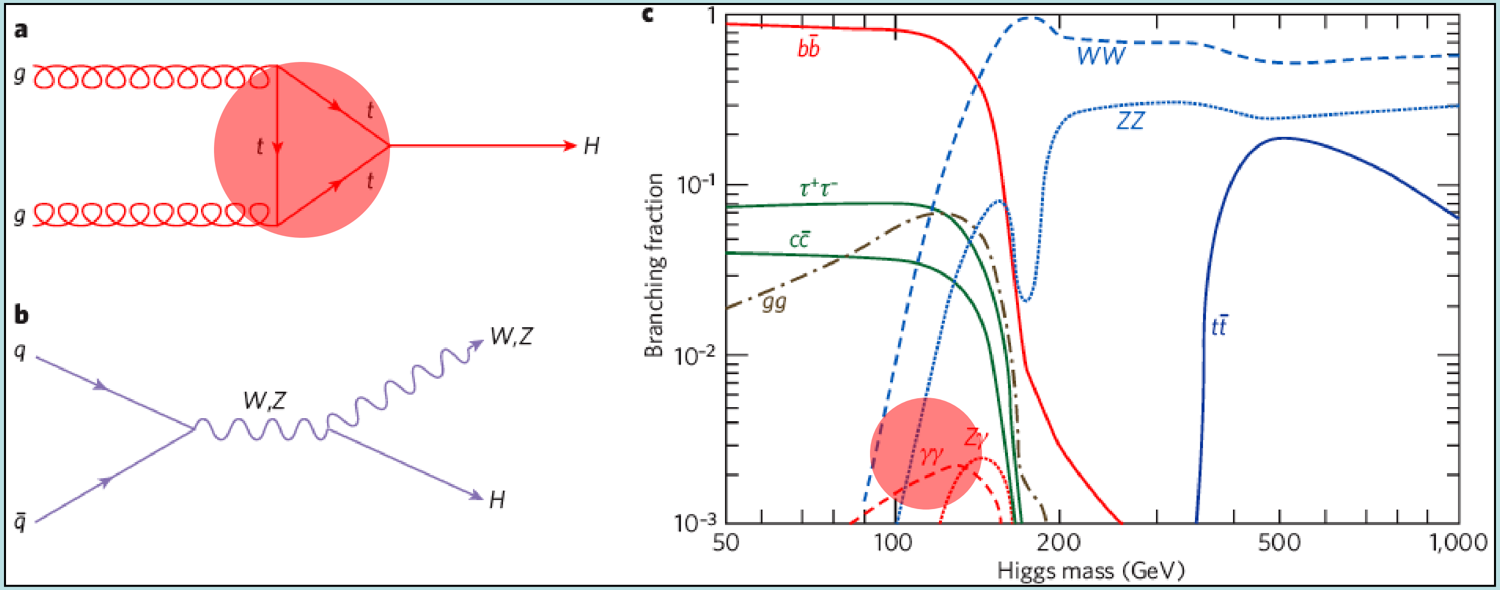




Many production modes measurable if M_h ~ 125 GeV

Higgs Decay Branching Ratios

- Couplings proportional to masses (?)



- Important couplings through loops:
  – gluon + gluon → Higgs → γγ

Many decay modes measurable if M_h ~ 125 GeV

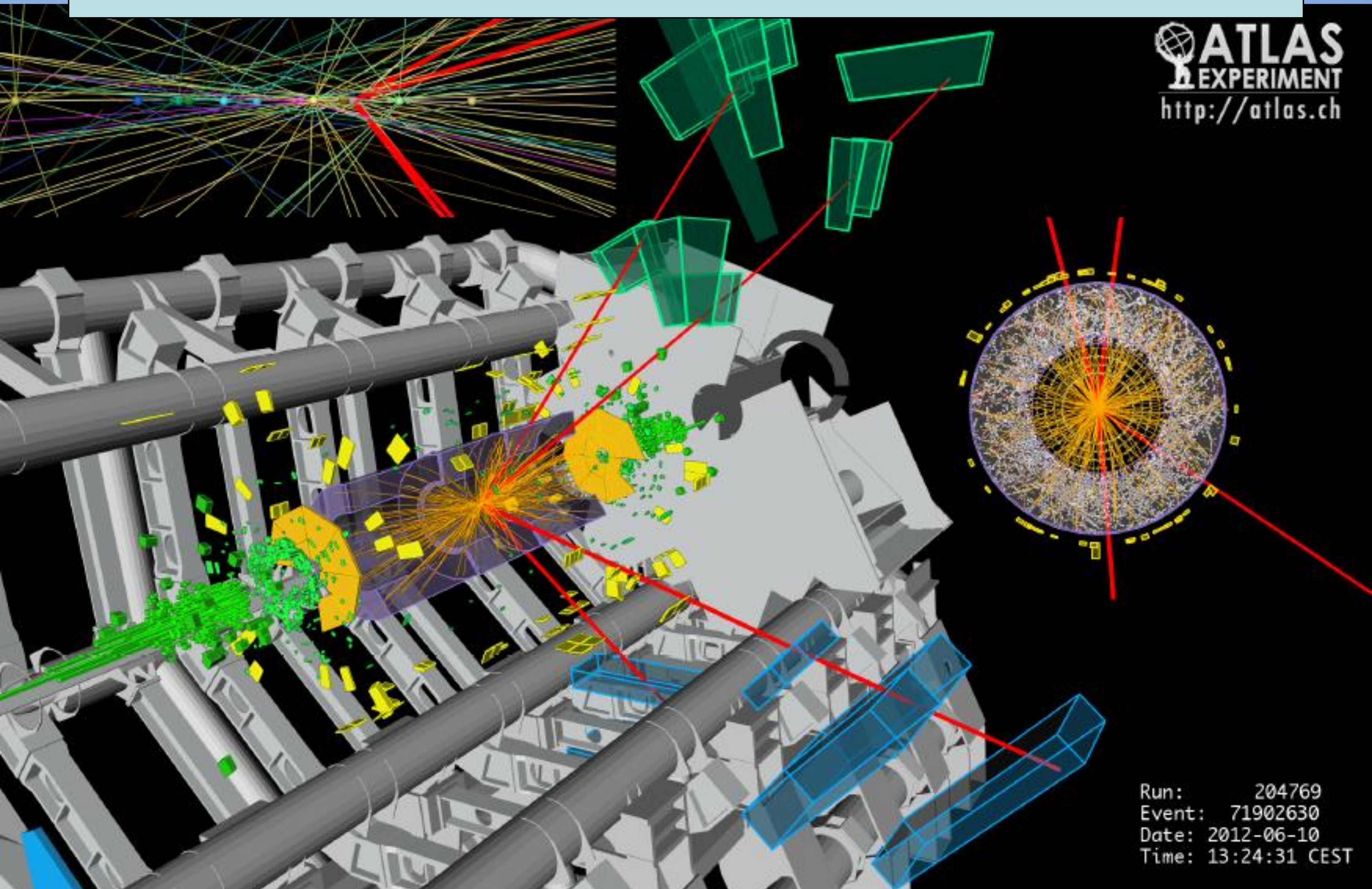
Is the Higgs Boson finally being Revealed?

Mass Higgsteria

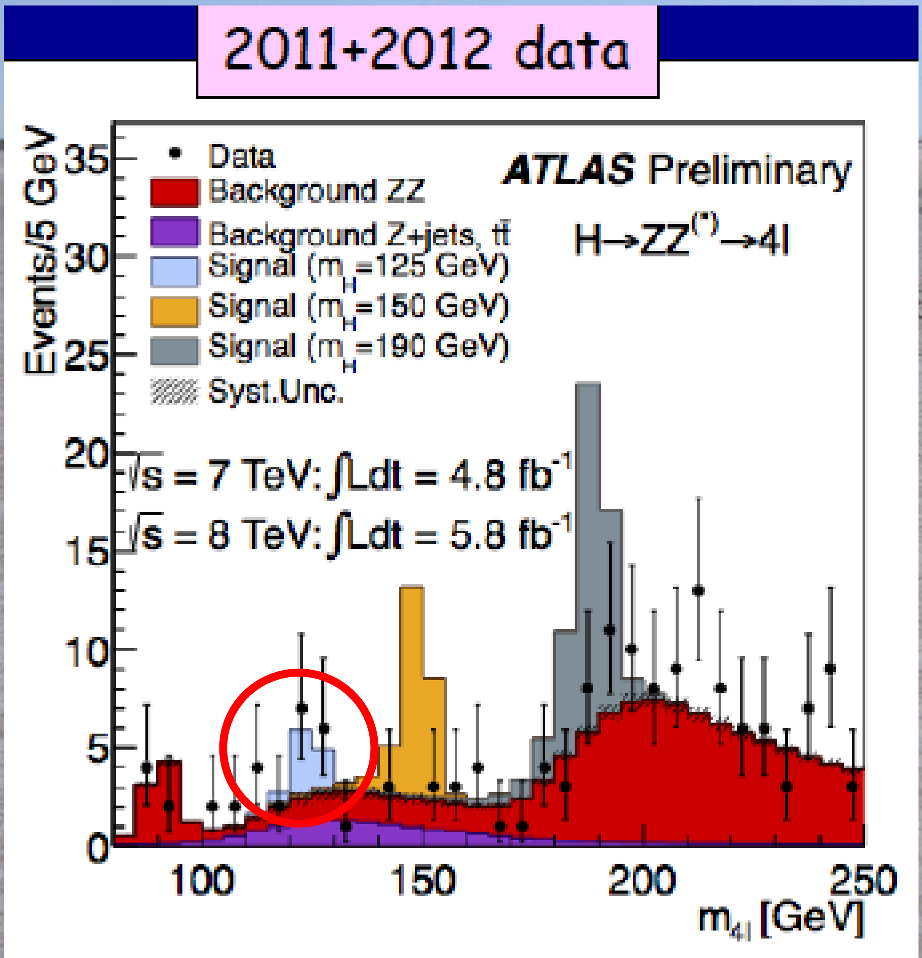
July 4th 2012
The discovery of a new particle

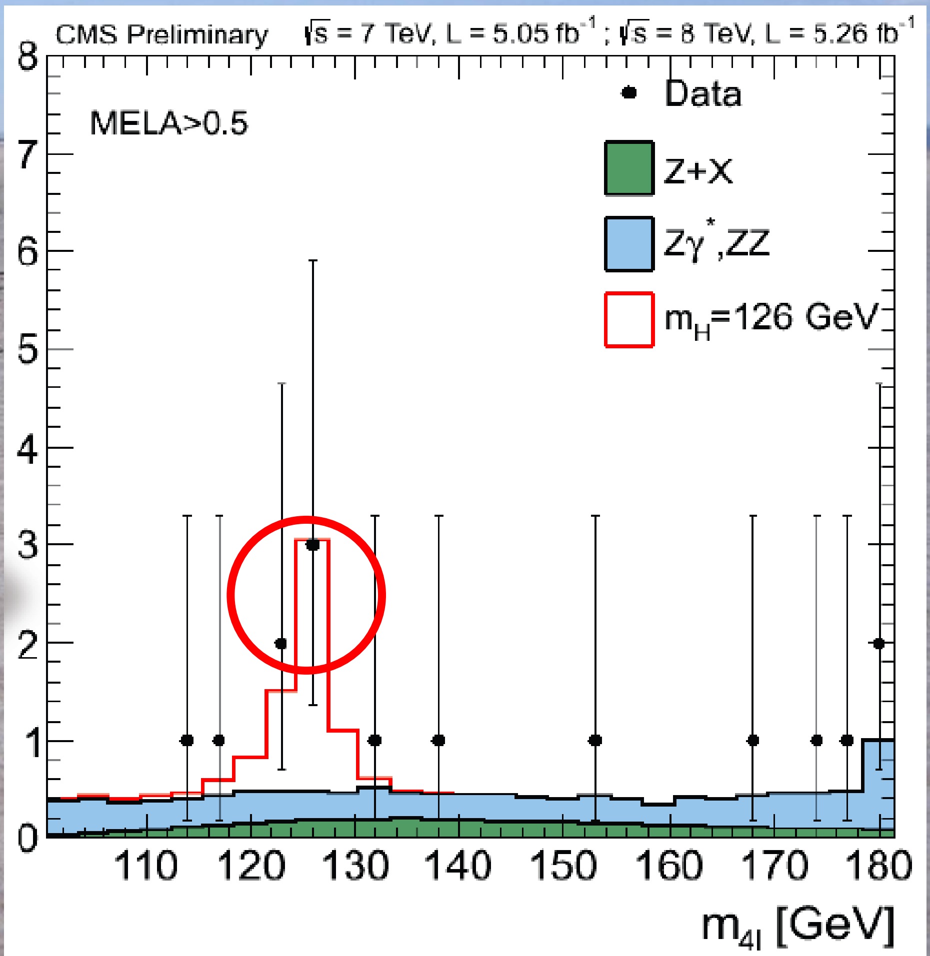
Higgsdependence Day!

ATLAS Four-Muon Event



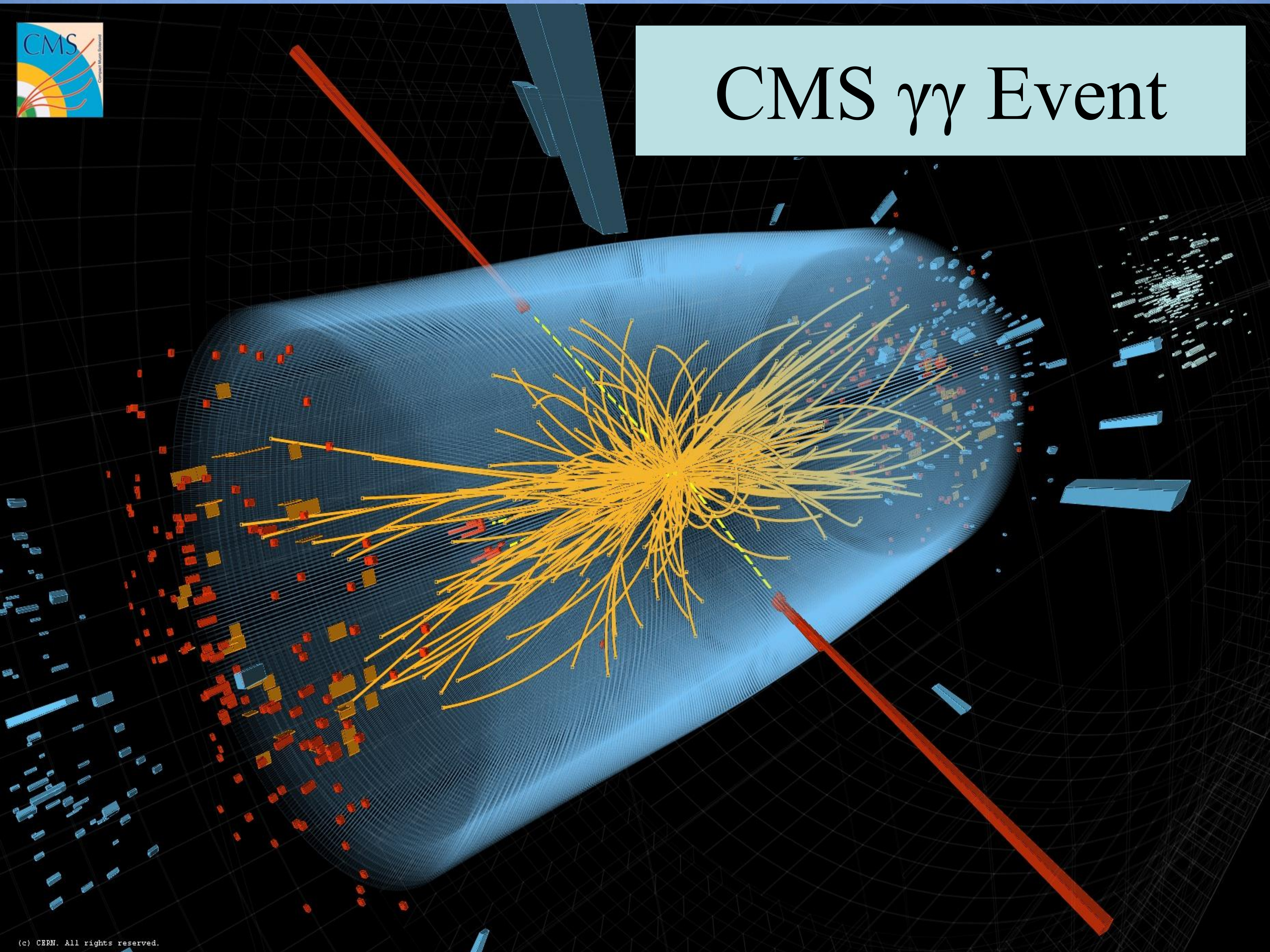
Evidence in the ZZ* Channel



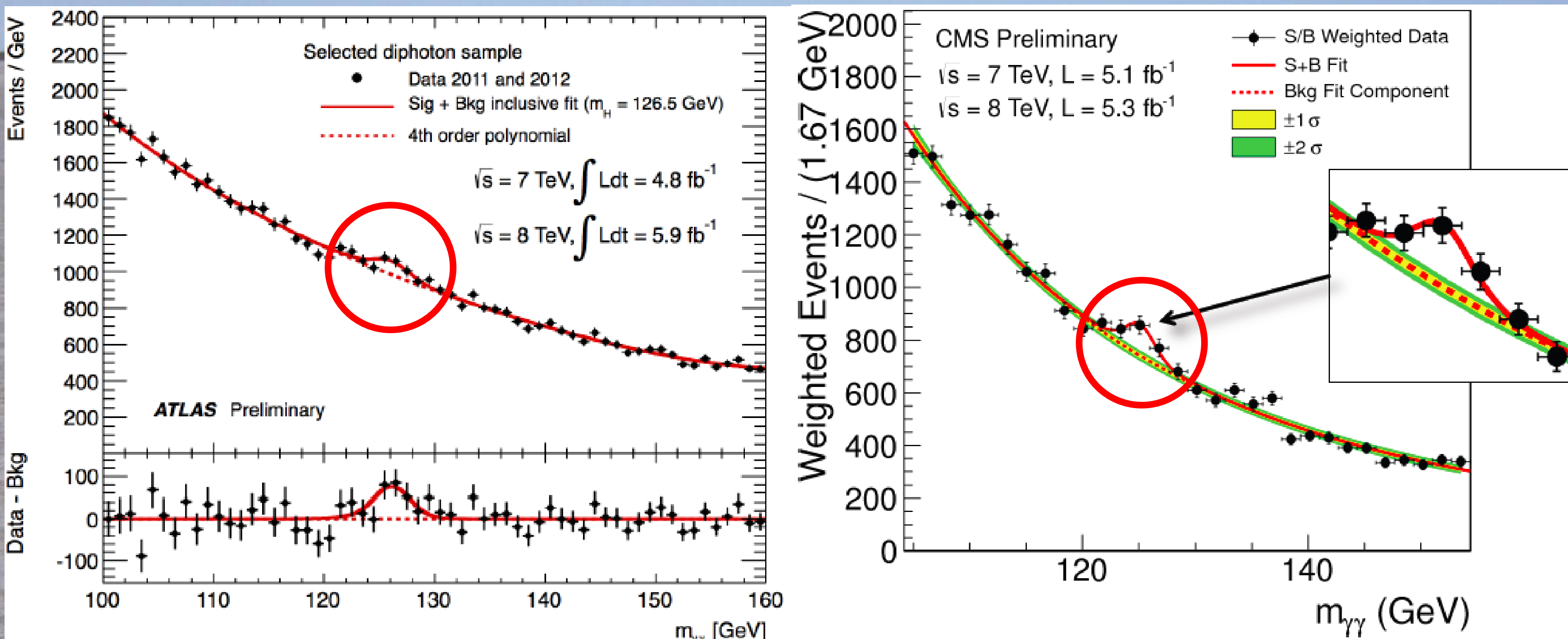


Signals around M_h = 125 GeV

CMS $\gamma\gamma$ Event



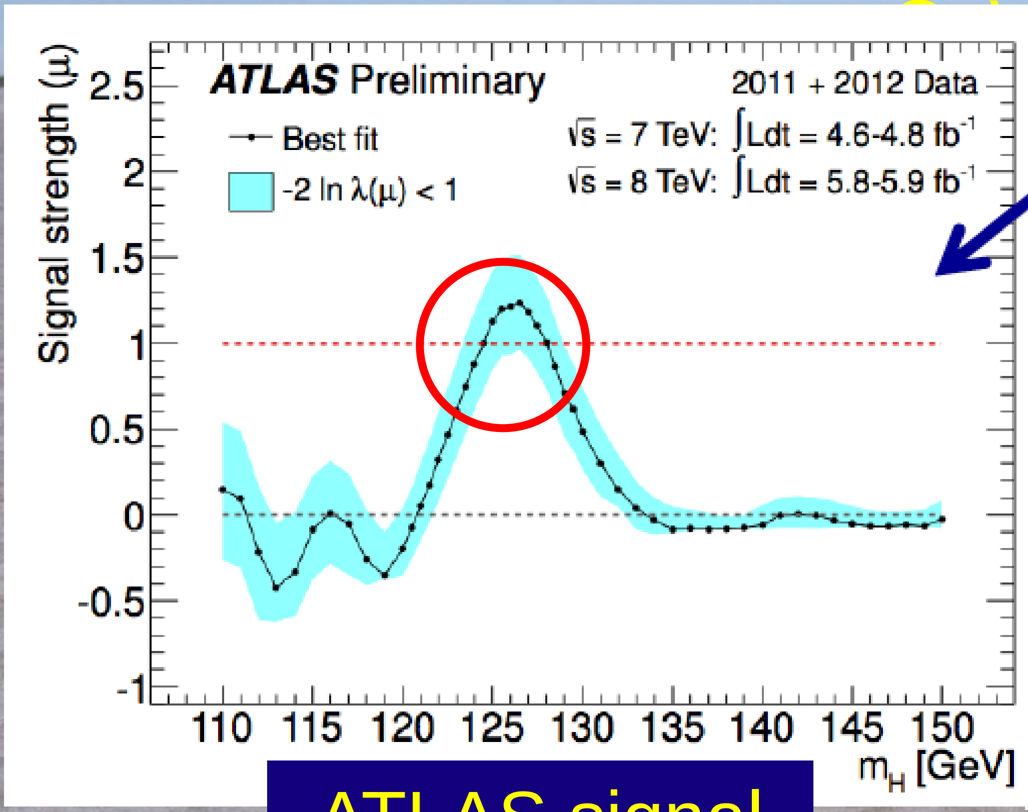
Evidence in the γγ Channel

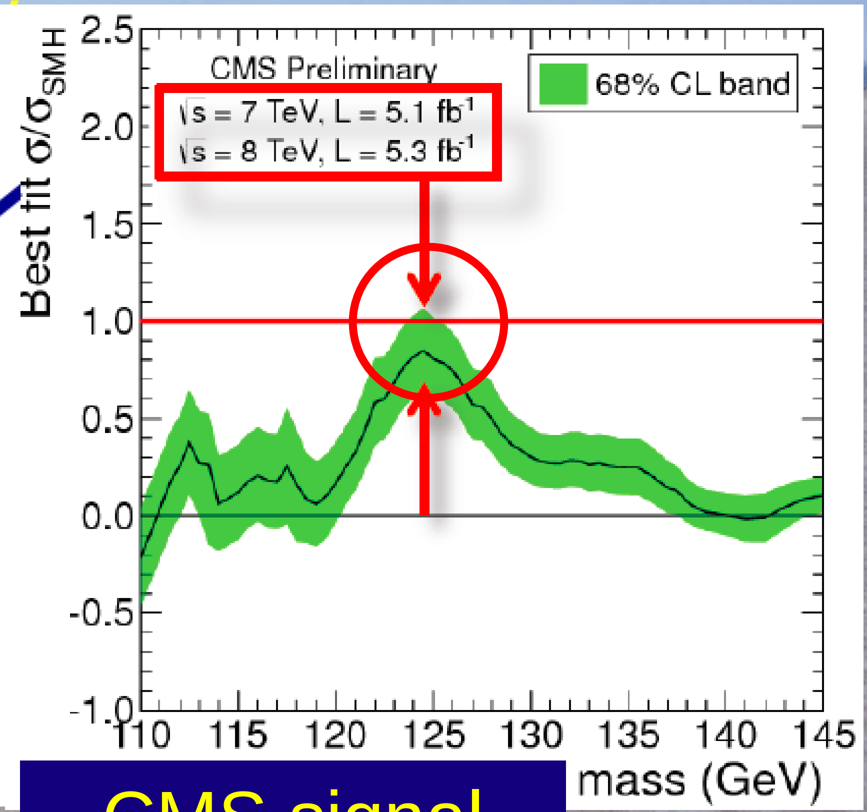


Signals around M_h = 125 GeV

A New Particle has been Discovered

Independent discoveries around M_h = 125 to 126 GeV

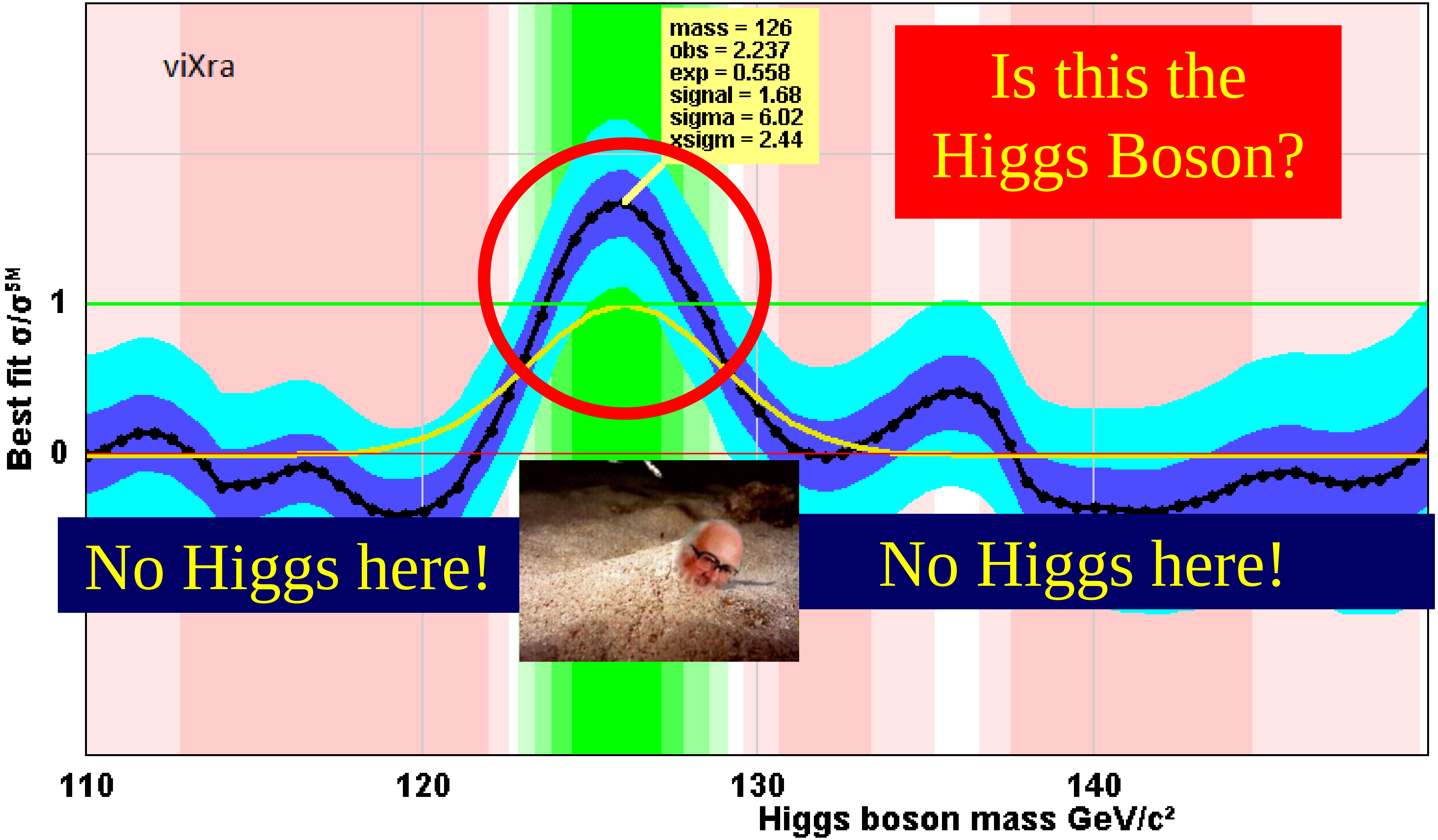




ATLAS signal
$(1.2 \pm 0.3) \times$ SM

CMS signal
$(0.8 \pm 0.2) \times$ SM

Unofficial Combination of Higgs Search Data from July 4th



The Particle Higgsaw Puzzle

Is LHC finding the missing piece?

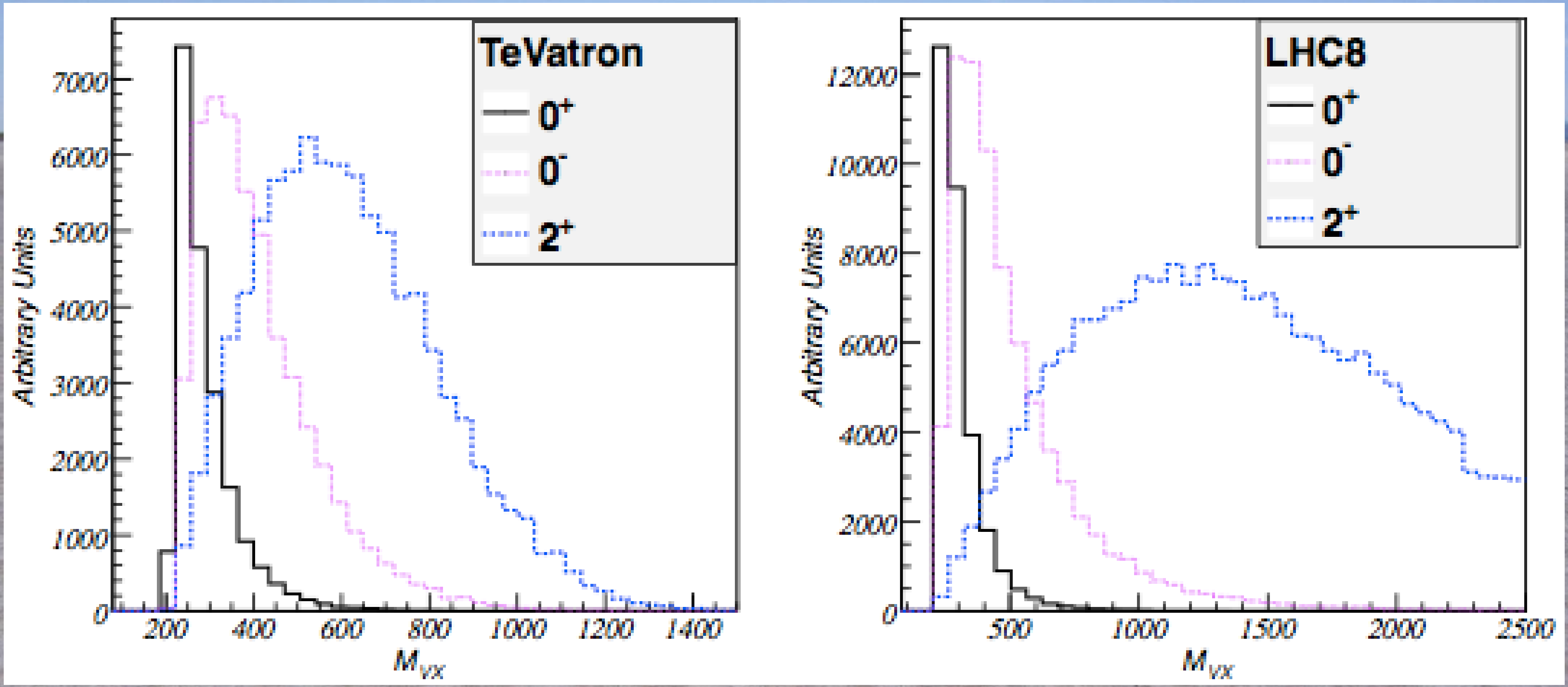
Is it the right shape?

Is it the right size?

Does the 'Higgs' have Spin Zero ?

- Decays into γγ, so cannot have spin 1
- **Spin 0 or 2?**
- Can diagnose spin via
  – angular distribution of γγ
  – angular correlations of leptons in WW, ZZ decays
  – Production in association with W or Z
- Do selections of WW and ZZ events already favour spin 0?

Does the ‘Higgs’ have Spin Zero ?

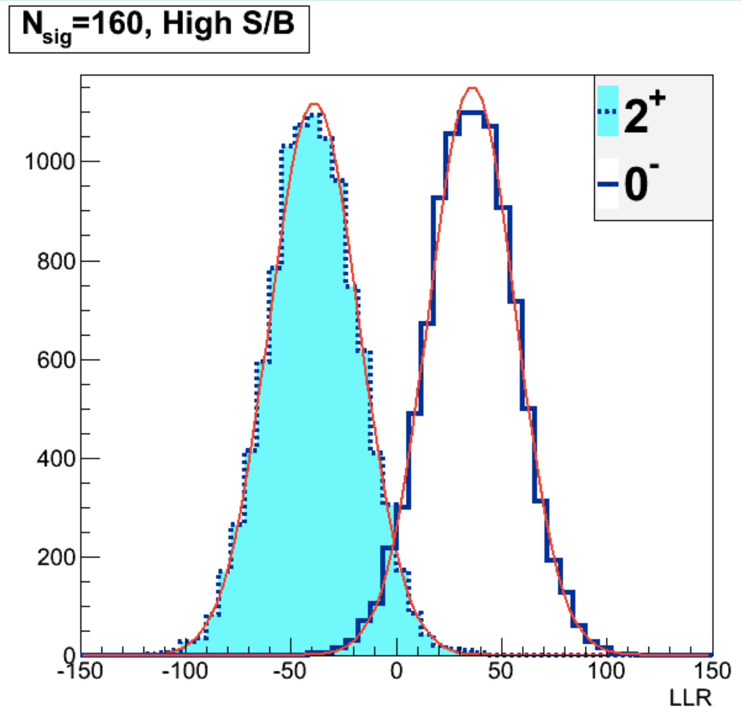


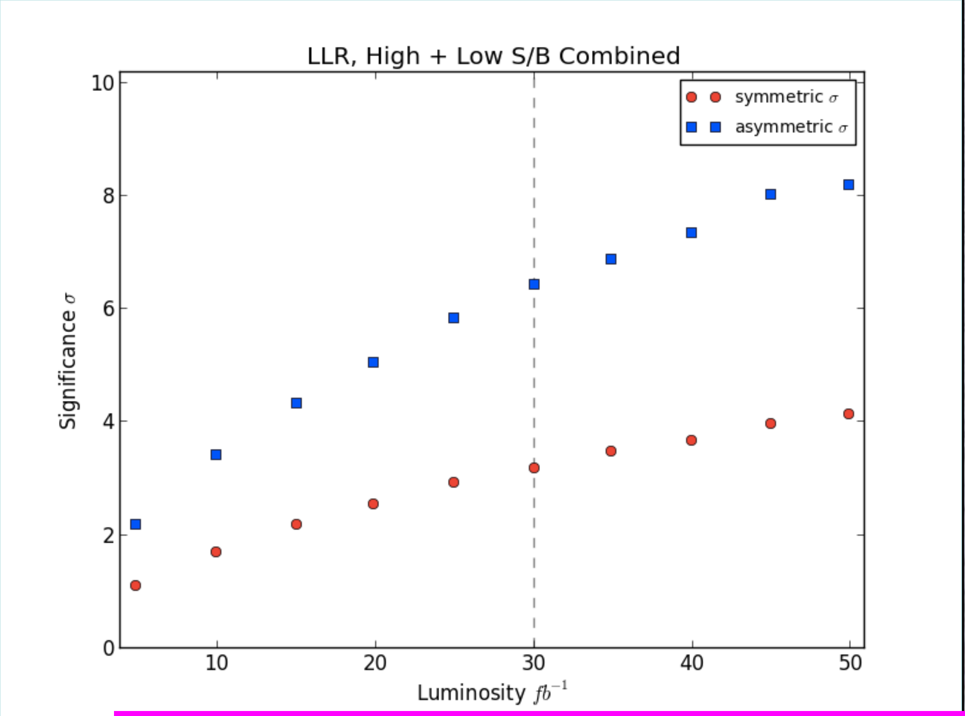
Vector boson + ‘Higgs’ combined invariant mass very different for spins 0 and 2

JE, Hwang. Sanz & You: arXiv:1208.6002

Does the 'Higgs' have Spin Zero ?

- Discrimination spin 2 vs spin 0 via angular distribution of decays into γγ,





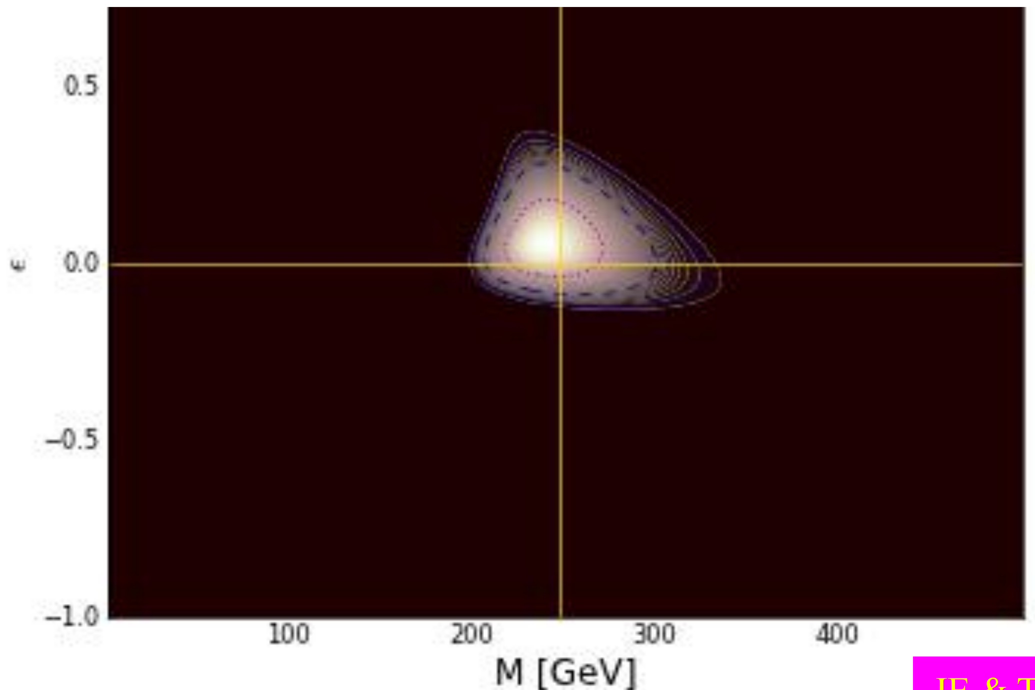
JE, Fok, Hwang, Sanz & You: arXiv:1210.5229

It Walks and Quacks like a Higgs

- Do couplings scale ~ mass? With scale = v?

$$\lambda_f = \sqrt{2}\left(\frac{m_f}{M}\right)^{1+\epsilon}, \; g_V = 2\left(\frac{m_V^{2(1+\epsilon)}}{M^{1+2\epsilon}}\right)$$

Global fit



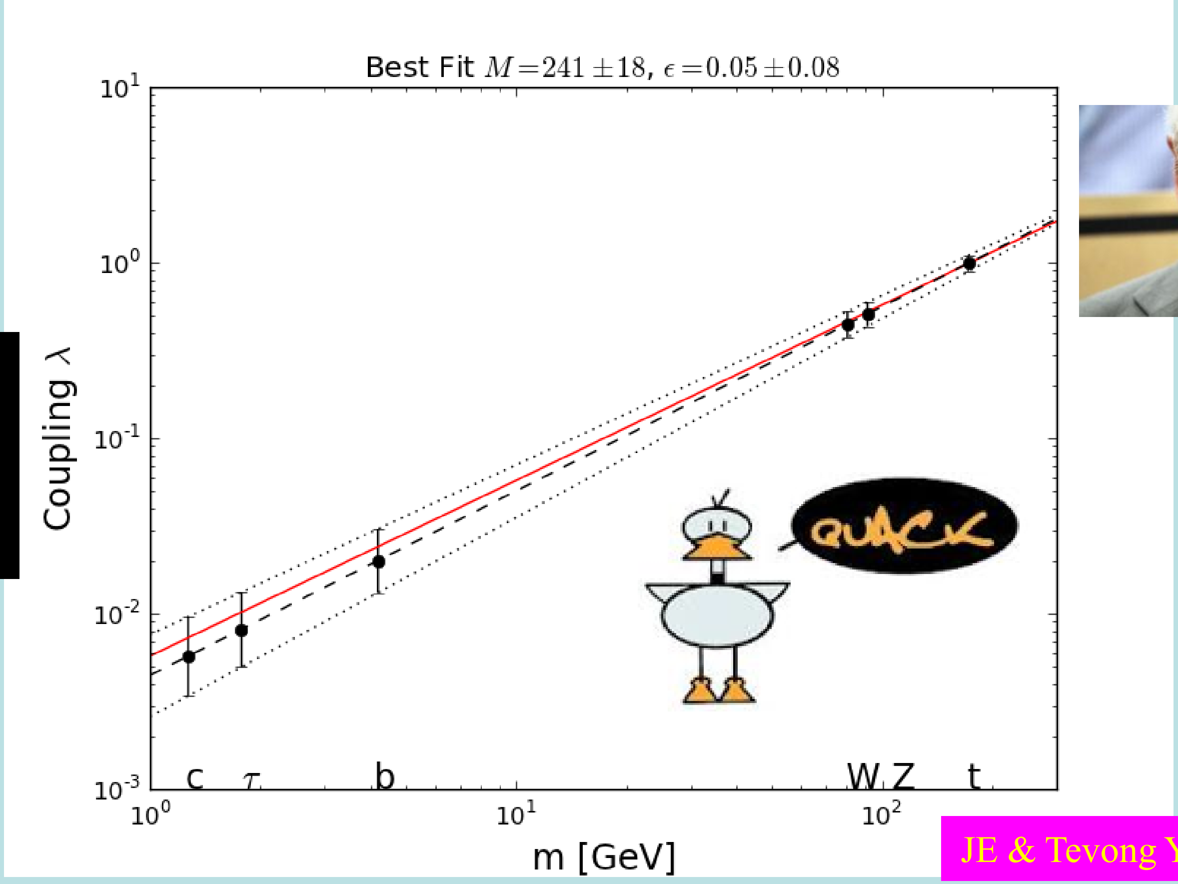
JE & Tevong You, arXiv:1207.1693

- Standard Model Higgs: ε = 0, M = v

It Walks and Quacks like a Higgs

- Do couplings scale ~ mass? With scale = v?

Global fit



JE & Tevong You, arXiv:1207.1693

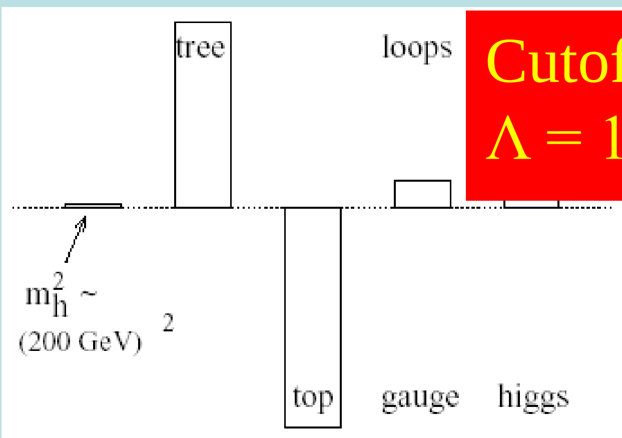
- **Red line = SM**, dashed line = best fit

Elementary Higgs or Composite?

- Higgs field:

  $<0|H|0> \neq 0$

- Quantum loop problems



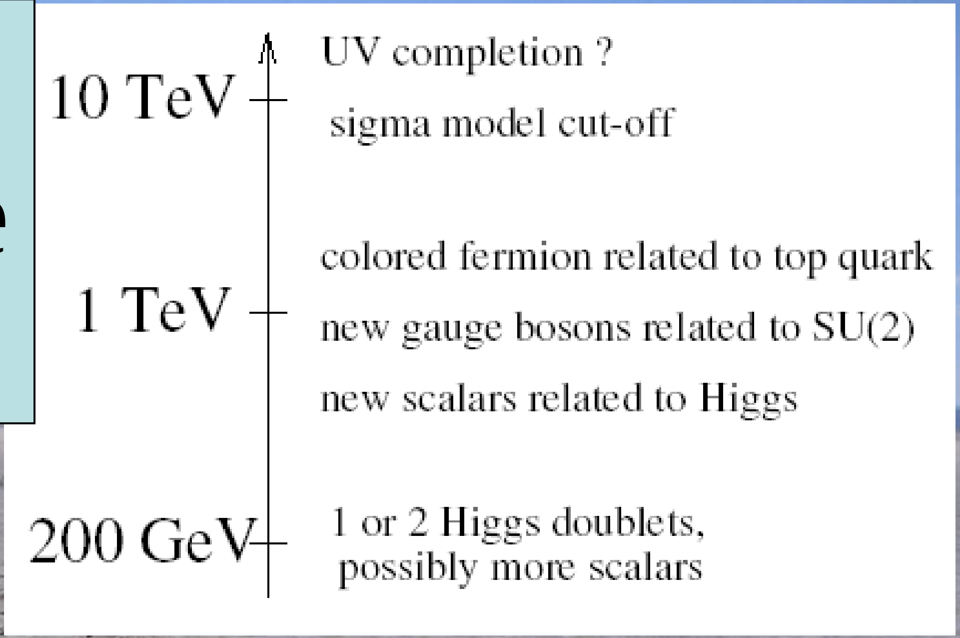
Cutoff
$\Lambda = 10$ TeV

Cut-off $\Lambda \sim 1$ TeV with Supersymmetry?

- Fermion-antifermion condensate
- Just like QCD, BCS superconductivity
- Top-antitop condensate? needed $m_t > 200$ GeV

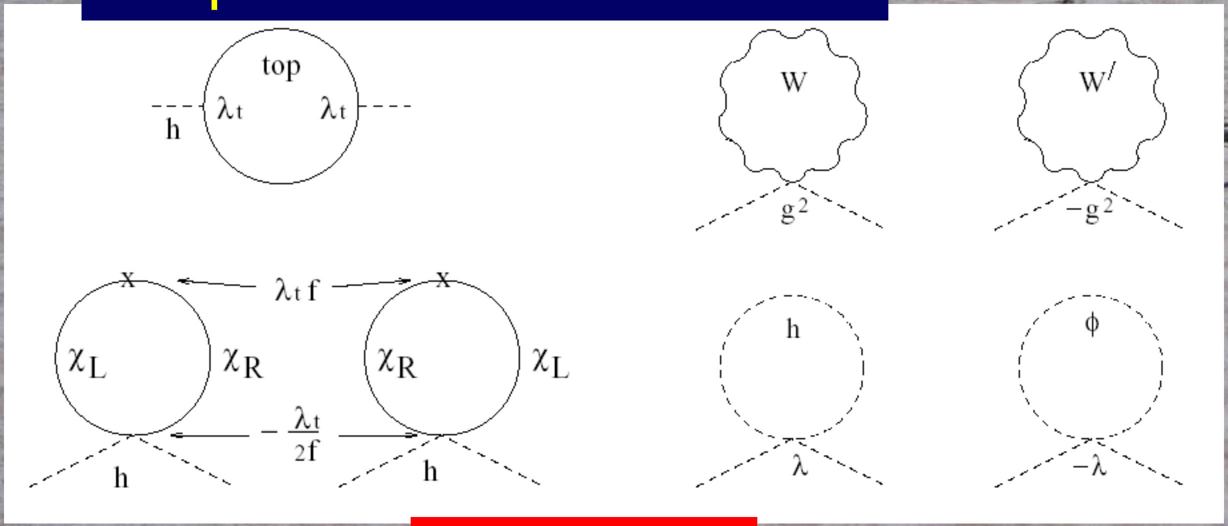
New technicolour force?
- Heavy scalar resonance?
- Inconsistent with precision electroweak data?

Higgs as a Pseudo-Goldstone Boson

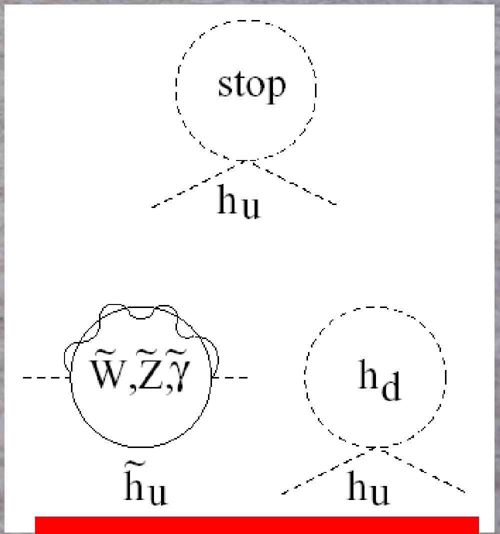


‘Little Higgs’ models
(breakdown of larger symmetry)

Loop cancellation mechanism



Little Higgs



Supersymmetry

General Analysis of ‘unHiggs’ Models

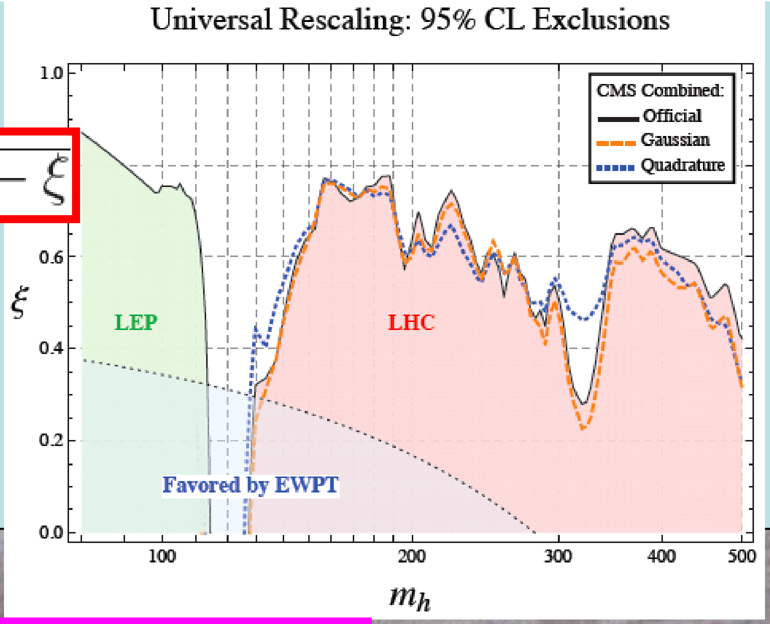
- Parametrization of effective Lagrangian:

$$\mathcal{L}^{(2)} = \frac{1}{2}(\partial_\mu h)^2 + \frac{v^2}{4}\mathrm{Tr}\left(D_\mu \Sigma^\dagger D^\mu \Sigma\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \cdots\right)$$

$$- \frac{v}{\sqrt{2}}\lambda^u_{ij}\left(\bar{u}_L^{(i)}, \bar{d}_L^{(i)}\right)\Sigma\left(u_R^{(i)}, 0\right)^T\left(1 + c_u\,\frac{h}{v} + c_{2u}\,\frac{h^2}{v^2} + \cdots\right)$$

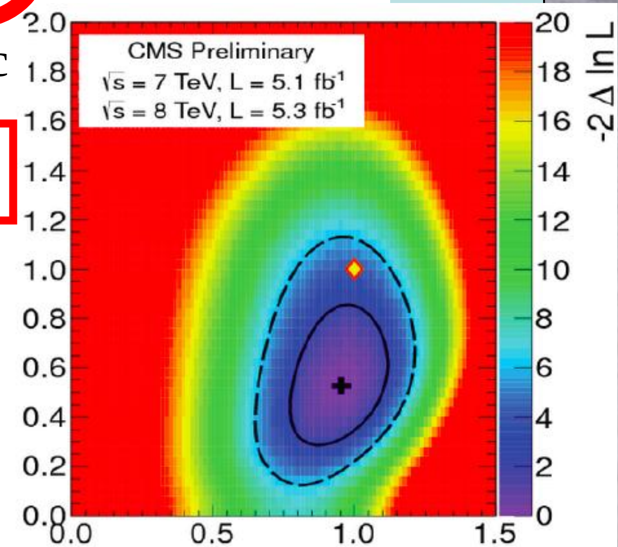
- Fits

$$a = c = \sqrt{1-\xi}$$



$$a \neq c$$

c



a

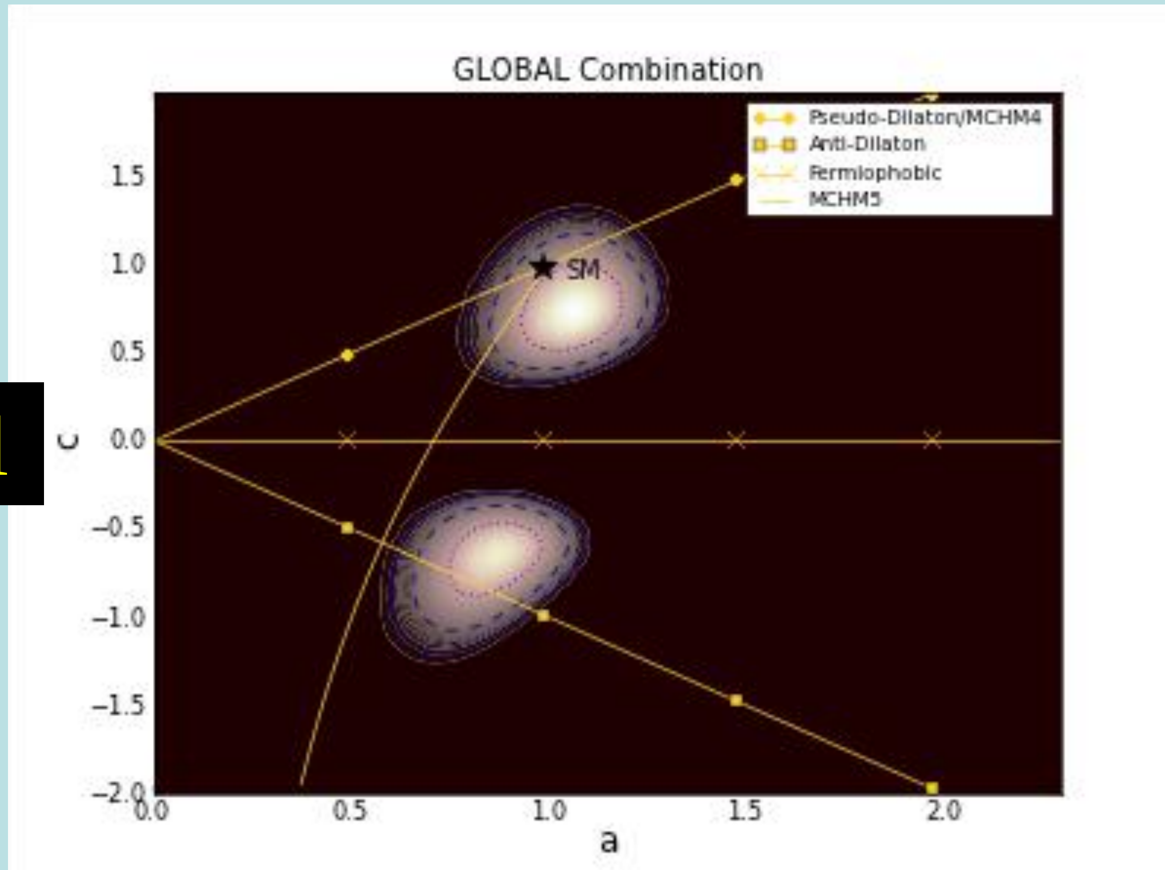
CMS fit assuming c > 0

Azatov, Contino, Galloway: arXiv:1202.3415

Global Analysis of Higgs-like Models

- Rescale couplings: to bosons by *a*, to fermions by *c*

Global
0



- Standard Model: $a = c = 1$

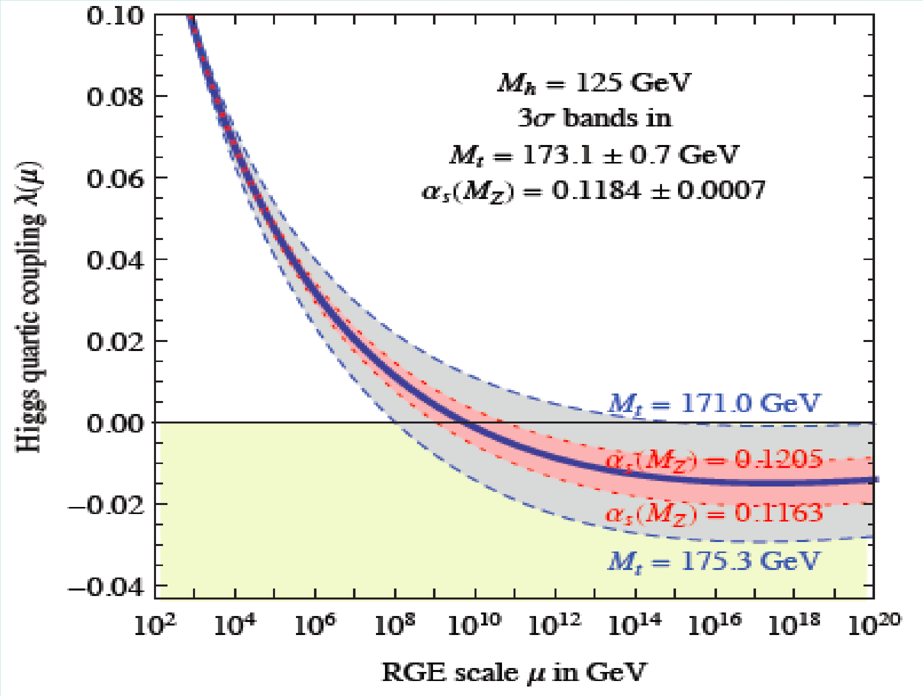
JE & Tevong You, arXiv:1207.1693

The Stakes in the Higgs Search

- How is gauge symmetry broken?
- Is there any elementary scalar field?
- **Likely portal to new physics**
- Would have caused phase transition in the Universe when it was about 10^{-12} seconds old
- May have generated then the matter in the Universe: **electroweak baryogenesis**
- A related **inflaton** might have expanded the Universe when it was about 10^{-35} seconds old
- Contributes to today's **dark energy: 10^{60} too much!**

Theoretical Constraints on Higgs Mass

- Large M_h → large self-coupling → blow up at low-energy scale Λ due to renormalization
- Small: renormalization due to t quark drives quartic coupling < 0 at some scale Λ → vacuum unstable



- Vacuum could be stabilized by **Supersymmetry**

Degrassi, Di Vita, Elias-Miro, Giudice, Isodori & Strumia, arXiv:1205.6497

Supersymmetry?

- Would unify matter particles and force particles
- Related particles spinning at different rates

  0 - ½ - 1 - 3/2 - 2

  Higgs - Electron - Photon - Gravitino – Graviton

- Many phenomenological motivations
  - Would help fix particle masses
  - Would help unify forces
  - Predicts light Higgs boson
  - Could fix discrepancy in g_μ - 2
- **Could provide dark matter for the astrophysicists and cosmologists**

Minimal Supersymmetric Extension of Standard Model (MSSM)

- Double up the known particles:

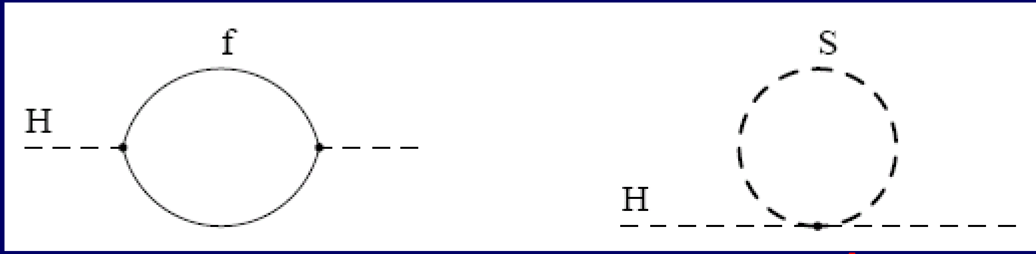
$$\begin{pmatrix} \frac{1}{2} \\ 0 \end{pmatrix} \; e.g., \; \begin{pmatrix} \ell \; (lepton) \\ \tilde{\ell} \; (slepton) \end{pmatrix} \; or \; \begin{pmatrix} q \; (quark) \\ \tilde{q} \; (squark) \end{pmatrix}$$

$$\begin{pmatrix} 1 \\ \frac{1}{2} \end{pmatrix} \; e.g., \; \begin{pmatrix} \gamma \; (photon) \\ \tilde{\gamma} \; (photino) \end{pmatrix} \; or \; \begin{pmatrix} g \; (gluon) \\ \tilde{g} \; (gluino) \end{pmatrix}$$

- Two Higgs doublets
  - 5 physical Higgs bosons:
  - 3 neutral, 2 charged
- Lightest neutral supersymmetric Higgs looks like the single Higgs in the Standard Model

Loop Corrections to Higgs Mass^2

- Consider generic fermion and boson loops:



- Each is quadratically divergent: $\int^\Lambda d^4k/k^2$

$$\Delta m_H^2 = -\frac{y_f^2}{16\pi^2}[2\Lambda^2 + 6m_f^2 \ln(\Lambda/m_f) + ...]$$

$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}[\Lambda^2 - 2m_S^2 \ln(\Lambda/m_S) + ...]$$

- Leading divergence cancelled if

$$\lambda_S = y_f^2 \text{ x } 2$$

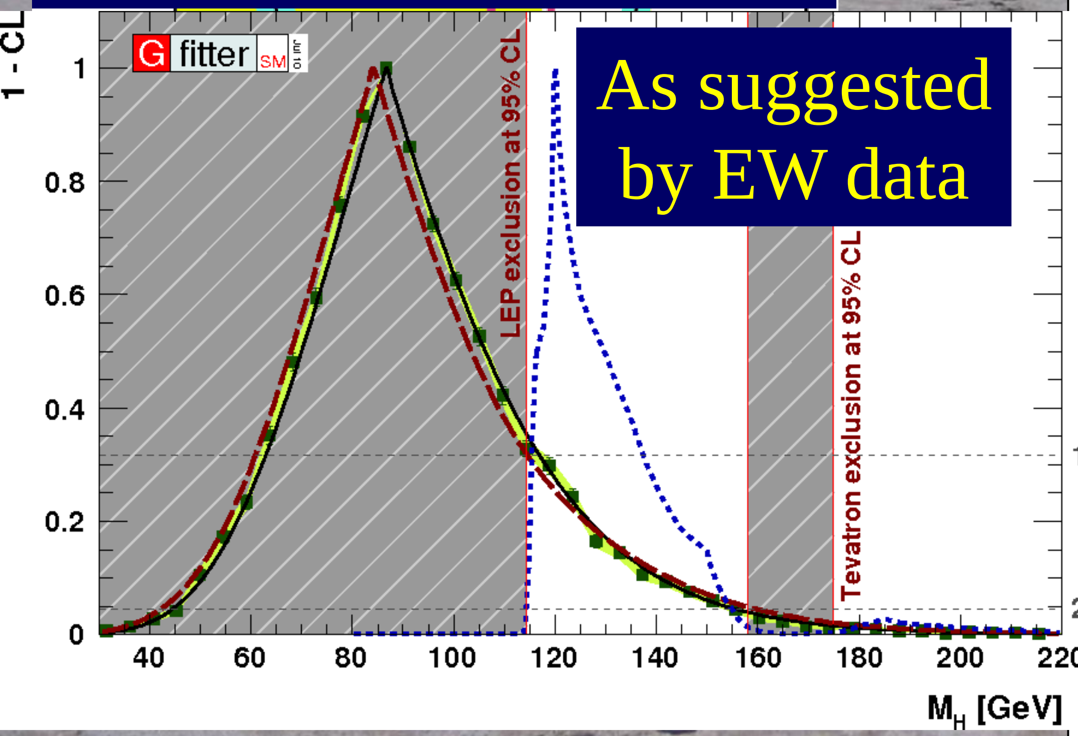
Supersymmetry!

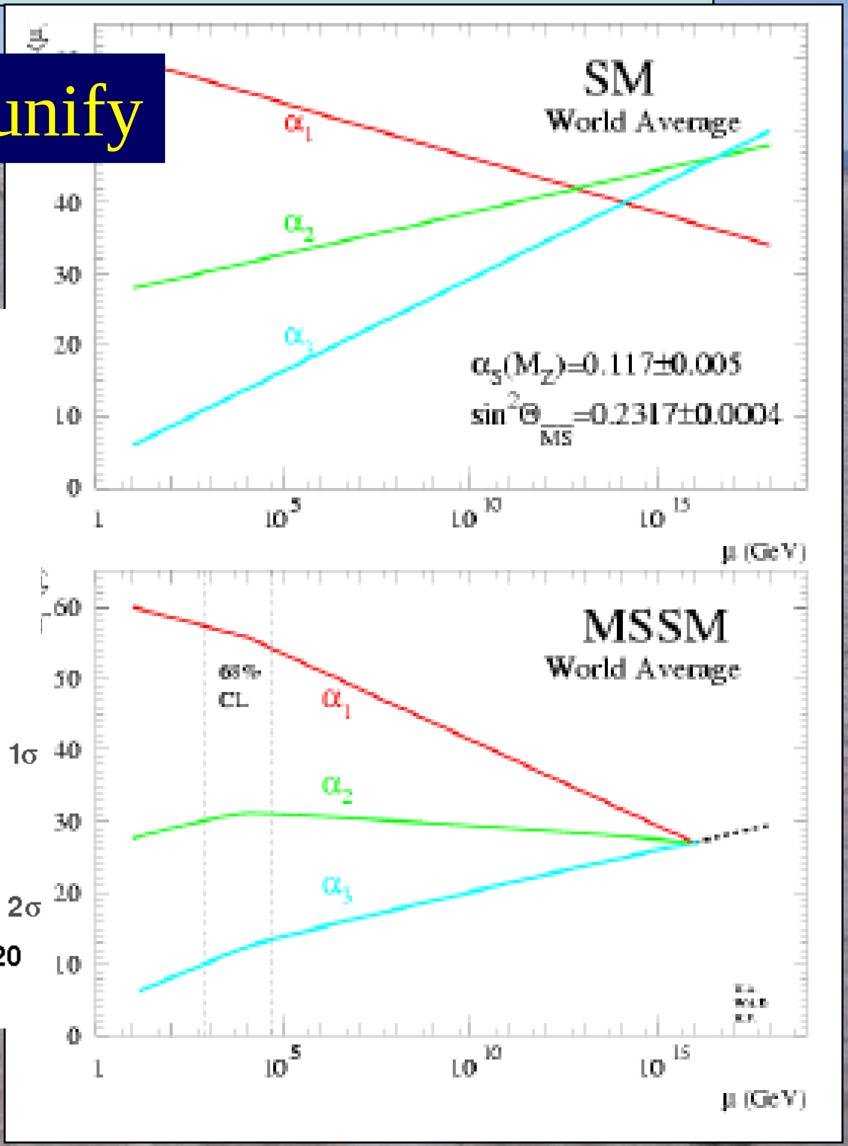
Other Reasons to like Susy

It enables the gauge couplings to unify

It predicts $m_H < 150$ GeV

As suggested by EW data





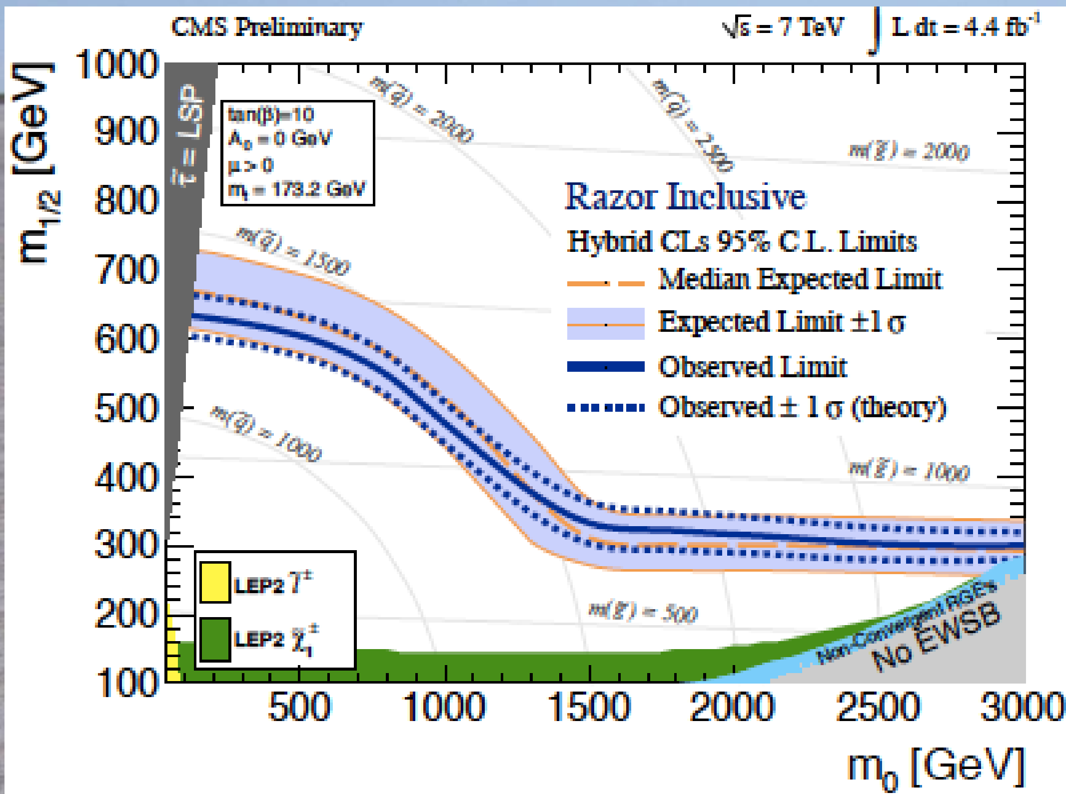
Data

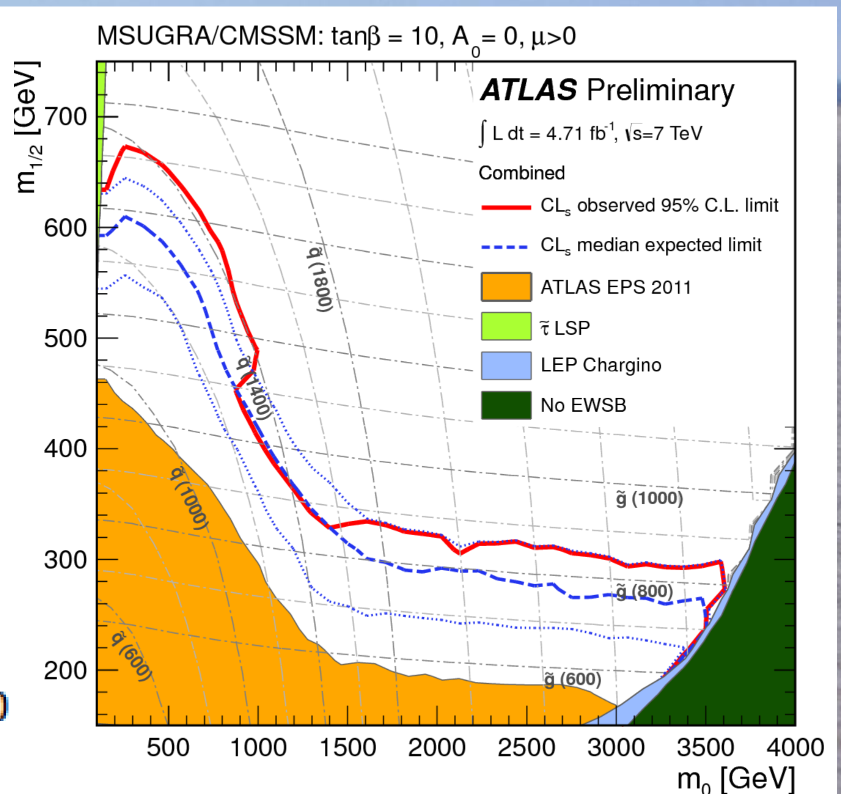
- **Electroweak precision observables**
- **Flavour physics observables**
- g_μ - 2
- Higgs mass
- Dark matter
- **LHC**

Observable	Source Th./Ex.	Constraint
m_t [GeV]	[39]	173.2 ± 0.90
$\Delta\alpha^{(5)}_{\rm had}(m_Z)$	[38]	0.02749 ± 0.00010
M_Z [GeV]	[40]	91.1875 ± 0.0021
Γ_Z [GeV]	[24] / [40]	$2.4952 \pm 0.0023 \pm 0.001_{\rm SUSY}$
$\sigma^0_{\rm had}$ [nb]	[24] / [40]	41.540 ± 0.037
R_l	[24] / [40]	20.767 ± 0.025
$A_{\rm fb}(\ell)$	[24] / [40]	0.01714 ± 0.00095
$A_\ell(P_\tau)$	[24] / [40]	0.1465 ± 0.0032
$R_{\rm b}$	[24] / [40]	0.21629 ± 0.00066
$R_{\rm c}$	[24] / [40]	0.1721 ± 0.0030
$A_{\rm fb}(b)$	[24] / [40]	0.0992 ± 0.0016
$A_{\rm fb}(c)$	[24] / [40]	0.0707 ± 0.0035
A_b	[24] / [40]	0.923 ± 0.020
A_c	[24] / [40]	0.670 ± 0.027
A_ℓ(SLD)	[24] / [40]	0.1513 ± 0.0021
$\sin^2\theta^\ell_{\rm w}(Q_{\rm fb})$	[24] / [40]	0.2324 ± 0.0012
M_W [GeV]	[24] / [40]	$80.399 \pm 0.023 \pm 0.010_{\rm SUSY}$
$\mathrm{BR}^{\rm EXP}_{b\to s\gamma}/\mathrm{BR}^{\rm SM}_{b\to s\gamma}$	[41] / [42]	$1.117 \pm 0.076_{\rm EXP}$ $\pm 0.082_{\rm SM} \pm 0.050_{\rm SUSY}$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	[27] / [37]	$(< 1.08 \pm 0.02_{\rm SUSY}) \times 10^{-8}$
$\mathrm{BR}^{\rm EXP}_{B\to\tau\nu}/\mathrm{BR}^{\rm SM}_{B\to\tau\nu}$	[27] / [42]	$1.43 \pm 0.43_{\rm EXP+TH}$
$\mathrm{BR}(B_d \to \mu^+\mu^-)$	[27] / [42]	$< (4.6 \pm 0.01_{\rm SUSY}) \times 10^{-9}$
$\mathrm{BR}^{\rm EXP}_{B\to X_s\ell\ell}/\mathrm{BR}^{\rm SM}_{B\to X_s\ell\ell}$	[43]/ [42]	0.99 ± 0.32
$\mathrm{BR}^{\rm EXP}_{K\to\mu\nu}/\mathrm{BR}^{\rm SM}_{K\to\mu\nu}$	[27] / [44]	$1.008 \pm 0.014_{\rm EXP+TH}$
$\mathrm{BR}^{\rm EXP}_{K\to\pi\nu\bar\nu}/\mathrm{BR}^{\rm SM}_{K\to\pi\nu\bar\nu}$	[45]/ [46]	< 4.5
$\Delta M^{\rm EXP}_{B_s}/\Delta M^{\rm SM}_{B_s}$	[45] / [47, 48]	$0.97 \pm 0.01_{\rm EXP} \pm 0.27_{\rm SM}$
$\frac{(\Delta M^{\rm EXP}_{B_s}/\Delta M^{\rm SM}_{B_s})}{(\Delta M^{\rm EXP}_{B_d}/\Delta M^{\rm SM}_{B_d})}$	[27] / [42, 47, 48]	$1.00 \pm 0.01_{\rm EXP} \pm 0.13_{\rm SM}$
$\Delta\epsilon^{\rm EXP}_K/\Delta\epsilon^{\rm SM}_K$	[45] / [47, 48]	$1.08 \pm 0.14_{\rm EXP+TH}$
$a^{\rm EXP}_\mu - a^{\rm SM}_\mu$	[49] / [38, 50]	$(30.2 \pm 8.8 \pm 2.0_{\rm SUSY}) \times 10^{-10}$
M_h [GeV]	[26] / [51, 52]	$> 114.4 \pm 1.5_{\rm SUSY}$
$\Omega_{\rm CDM}h^2$	[29] / [53]	$0.1109 \pm 0.0056 \pm 0.012_{\rm SUSY}$
$\sigma^{\rm SI}_p$	[23]	$(m_{\tilde\chi^0_1}, \sigma^{\rm SI}_p)$ plane
jets + $\not{E}_T$	[16, 18]	$(m_0, m_{1/2})$ plane
$H/A, H^\pm$	[19]	$(M_A, \tan\beta)$ plane

MasterCode: O.Buchmueller, JE et al.

Searches with ~ 5/fb @ 7 TeV

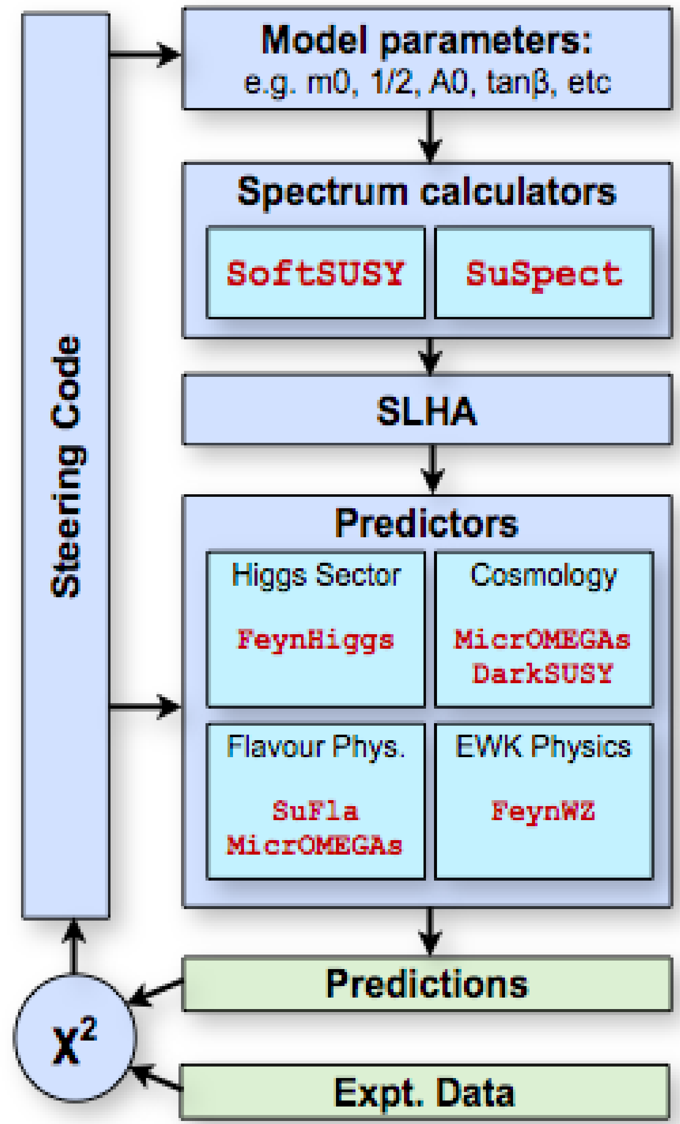




Jets + missing energy

MasterCode

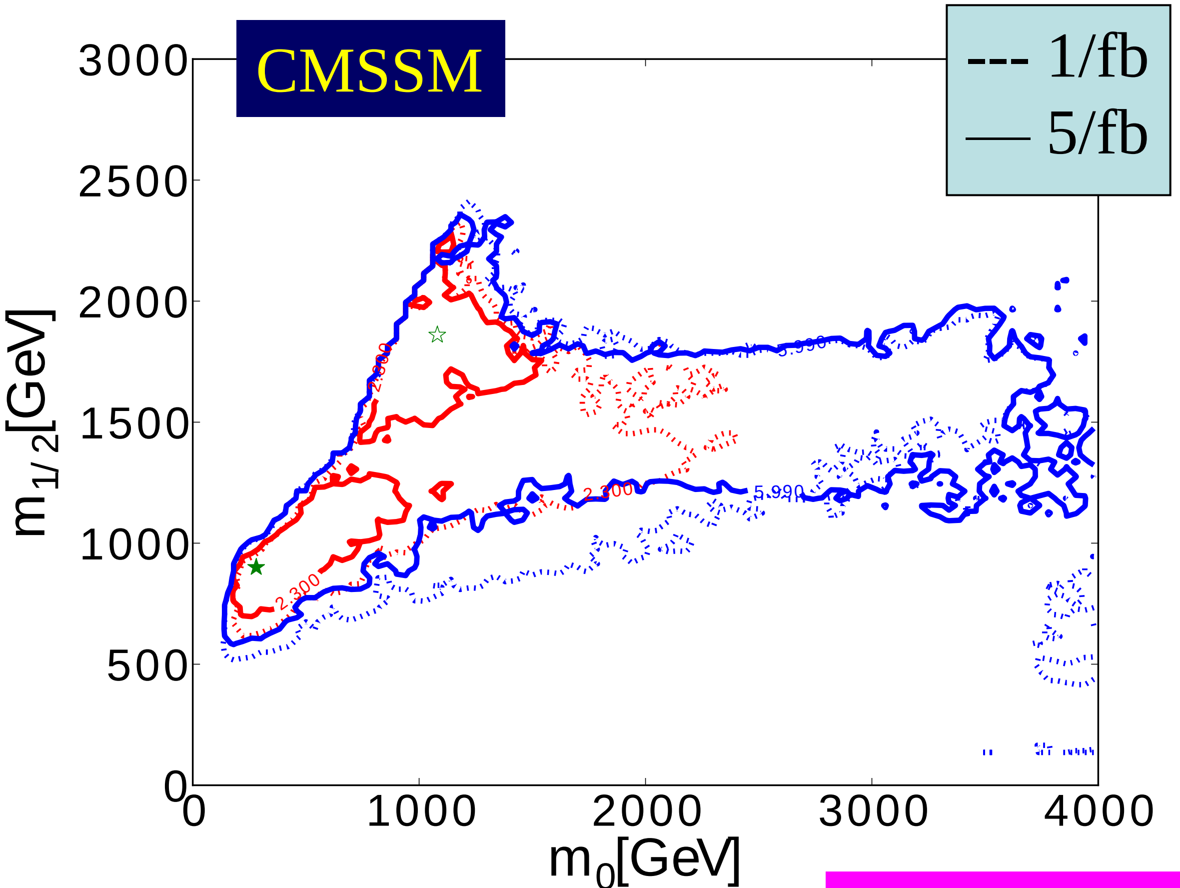
- **Combines diverse set of tools**
  - **different codes : all state-of-the-art**
    - Electroweak Precision (FeynWZ)
    - Flavour (SuFla, micrOMEGAs)
    - Cold Dark Matter (DarkSUSY, micrOMEGAs)
    - Other low energy (FeynHiggs)
    - Higgs (FeynHiggs)
  - **different precisions (one-loop, two-loop, etc)**
  - **different languages (Fortran, C++, English, German, Italian, etc)**
  - **different people (theorists, experimentalists)**
- **Compatibility is crucial! Ensured by**
  - **close collaboration of tools authors**
  - **standard interfaces**



O. Buchmueller, R. Cavanaugh, *M. Citron*, A. De Roeck, M.J. Dolan, J.E., H. Flacher, S. Heinemeyer, G. Isidori,
J. Marrouche, D. Martinez Santos, *S. Nakach*, K.A. Olive, *S. Rogerson*, F.J. Ronga, *K.J. de Vries*, G.

Post-LHC, Post-XENON100

2011 ATLAS + CMS with 5 fb^{-1} of LHC Data



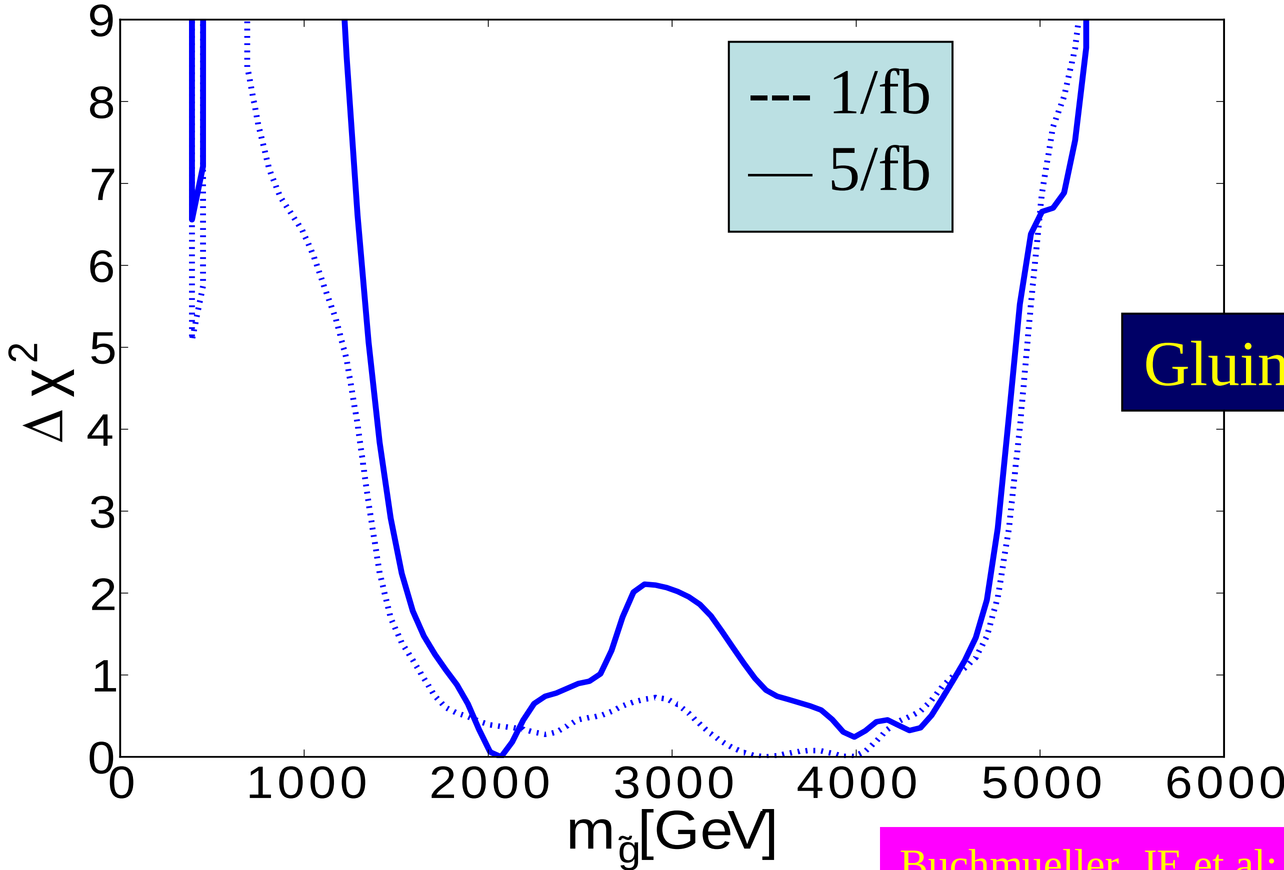
Buchmueller, JE et al: arXiv:1207.3715

Red and blue curves represent $\Delta\chi^2$ from global minimum, located at ☆

p-value of simple models < 10%

Post-LHC, Post-XENON100

2011 ATLAS + CMS with 5 fb^{-1} of LHC Data



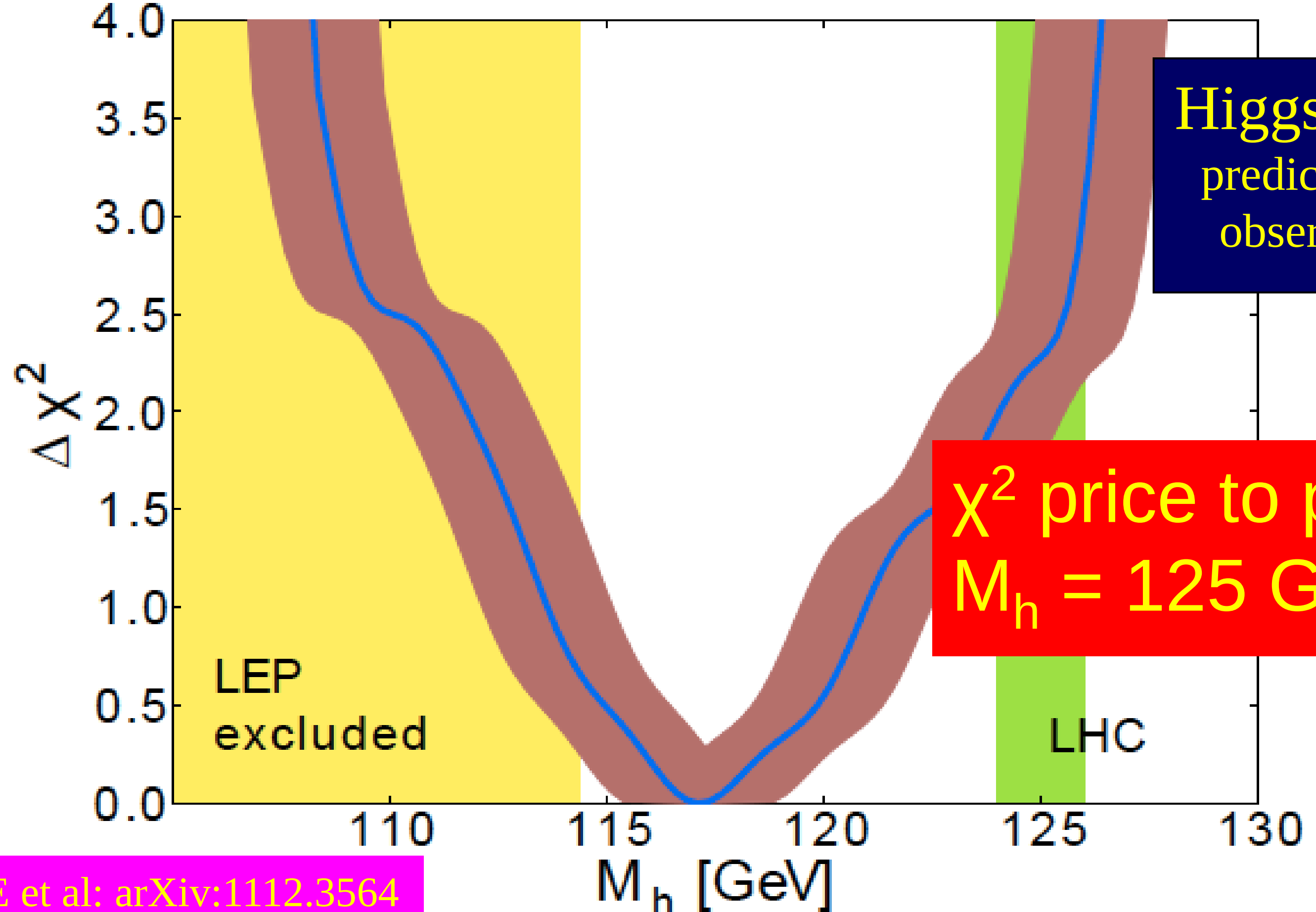
Gluino mass

Buchmueller, JE et al: arXiv:1207.3715

Favoured values of gluino mass significantly above pre-LHC, > 1.5 TeV

Post-LHC, Post-XENON100

2011 ATLAS + CMS with 1 fb^{-1} of LHC Data



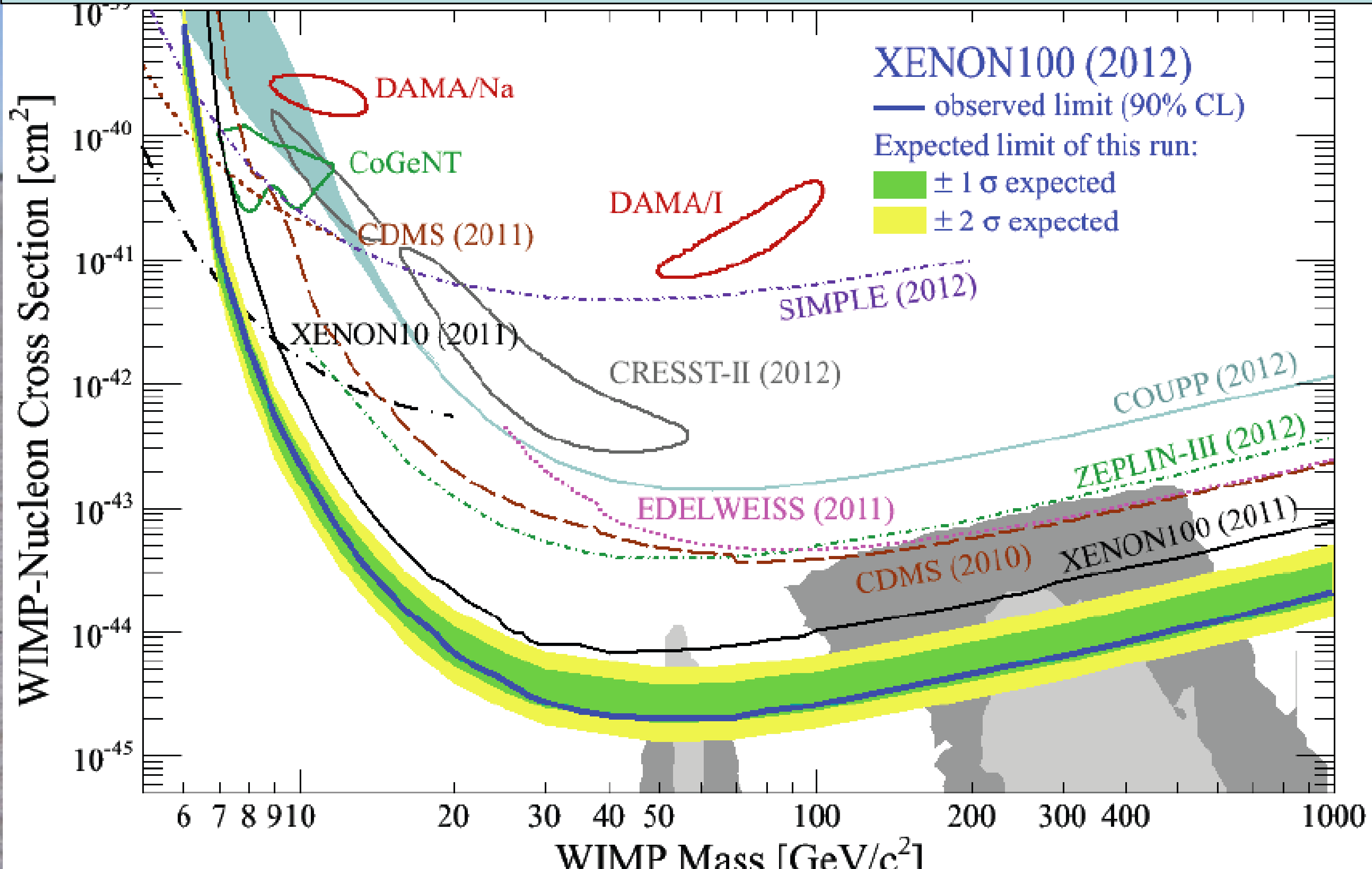
Higgs mass: prediction vs observation

χ^2 price to pay if M_h = 125 GeV is ~ 2

Buchmueller, JE et al: arXiv:1112.3564

Favoured values of $M_h \sim 117 \pm 5$ GeV:
Range consistent with evidence from LHC !

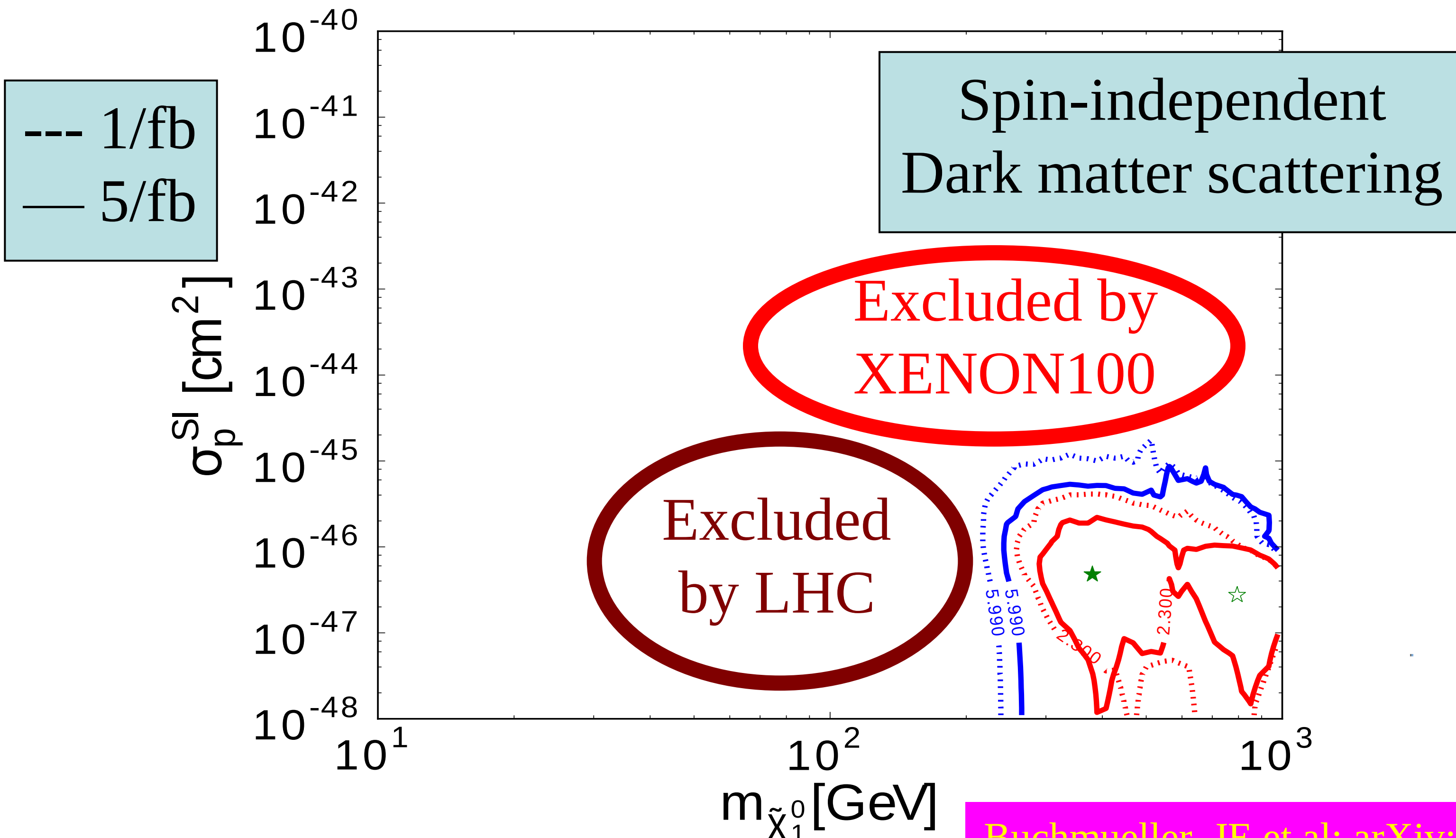
XENON100 & other Experiments



Upper Limit (90% C.L.) is 2×10^{-45} cm^2 for 55 GeV/c^2 WIMP

Post-LHC, Post-XENON100

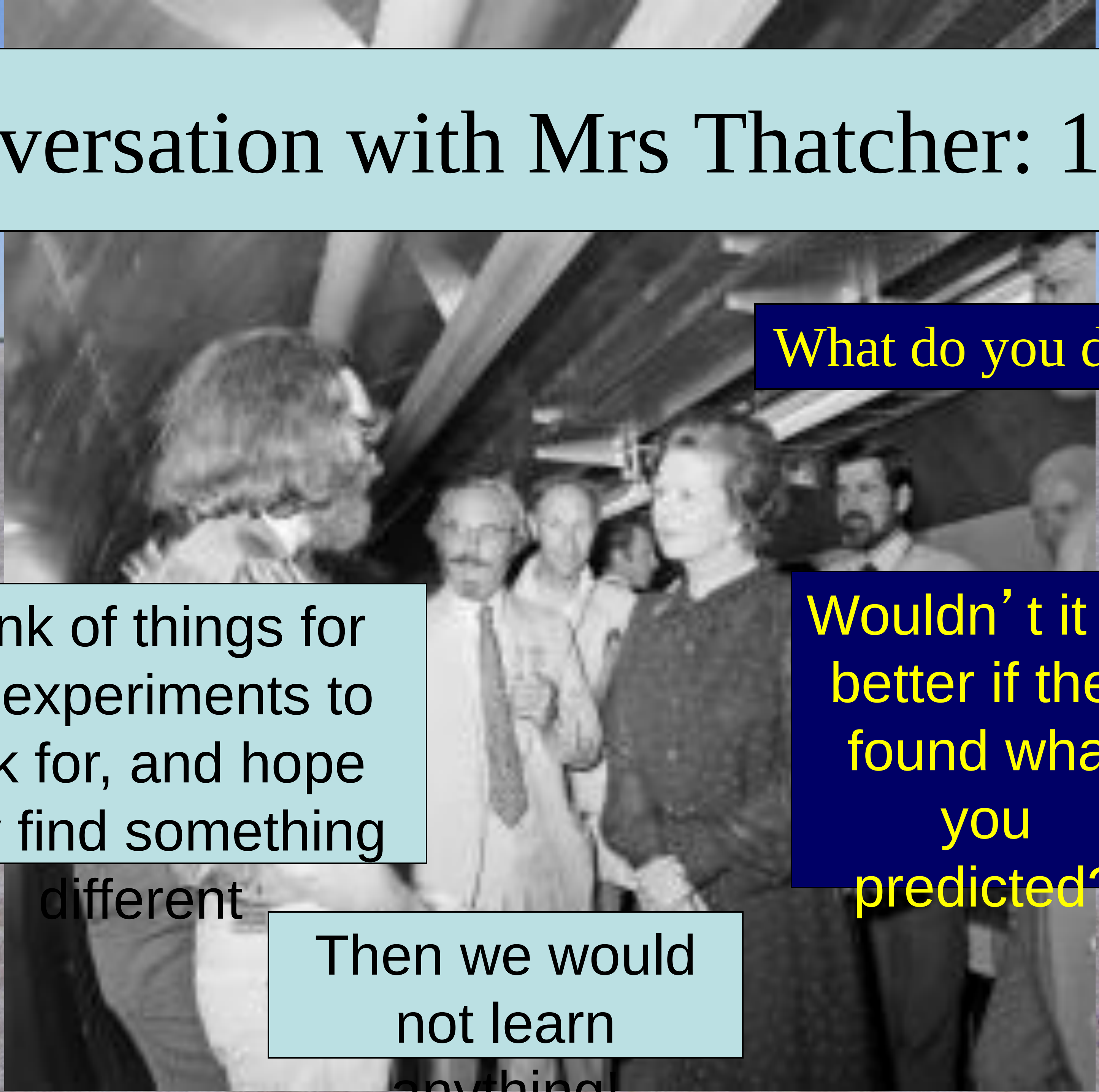
2012 ATLAS + CMS with 5 fb^{-1} of LHC Data



Buchmueller, JE et al: arXiv:1207.3715

Favoured values of dark matter scattering
cross section significantly below XENON100

Conversation with Mrs Thatcher: 1982



What do you do?

Think of things for the experiments to look for, and hope they find something different

Wouldn't it be better if they found what you predicted?

Then we would not learn anything!