3RD INTERNATIONAL CONFERENCE ON PARTICLE PHYSICS AND ASTROPHYSICS

OCTOBER 2 - 5, 2017

MOSCOW, RUSSIA

ICPPA-2017

DEADLINES
INVITATION REQUESTS – 21 AUG 2017
REGISTRATION – 21 AUG 2017
PROCEEDINGS – 10 NOV 2017

The Grand Palace in Tsaritsyno park, Moscow

Theory Vision of HEP' 17

Dmitry Kazakov
JINR (Dubna)

THE PRINCIPLES

- Three gauged symmetries SU(3)xSU(2)xU(1)
- Three families of quarks and leptons ($\underline{3}$x$\underline{2}$, $\underline{3}$x$\underline{1}$, $\underline{1}$x$\underline{2}$, $\underline{1}$x$\underline{1}$)
- Brout-Englert-Higgs mechanism of spontaneous EW symmetry breaking -> Higgs boson
- CKM and PMNS mixing of flavours
- CP violation via phase factors
- Confinement of quarks and gluons inside hadrons
- Baryon and lepton number conservation
- CPT invariance -> existence of antimatter

The ST principles allow:

- Extra families of quarks and leptons
- Presence or absence of right-handed neutrino
- Majorana or Dirac nature of neutrino
- Extra Higgs bosons

THE LAGRANGIAN

$$\mathcal{L} = \mathcal{L}_{gauge} + \mathcal{L}_{Yukawa} + \mathcal{L}_{Higgs},$$

$$\begin{aligned}\mathcal{L}_{gauge} = &-\frac{1}{4}G^a_{\mu\nu}G^a_{\mu\nu} - \frac{1}{4}W^i_{\mu\nu}W^i_{\mu\nu} - \frac{1}{4}B_{\mu\nu}B_{\mu\nu}\\ &+i\overline{L}_\alpha\gamma^\mu D_\mu L_\alpha + i\overline{Q}_\alpha\gamma^\mu D_\mu Q_\alpha + i\overline{E}_\alpha\gamma^\mu D_\mu E_\alpha\\ &+i\overline{U}_\alpha\gamma^\mu D_\mu U_\alpha + i\overline{D}_\alpha\gamma^\mu D_\mu D_\alpha + (D_\mu H)^\dagger(D_\mu H),\end{aligned}$$

$$\boxed{+i\overline{N}_\alpha\gamma^\mu\partial_\mu N_\alpha} \longleftarrow$$

possible right handed neutrino ?

$$\mathcal{L}_{Yukawa} = y^L_{\alpha\beta}\overline{L}_\alpha E_\beta H + y^D_{\alpha\beta}\overline{Q}_\alpha D_\beta H + y^U_{\alpha\beta}\overline{Q}_\alpha U_\beta\tilde{H} + h.c.,$$

$$\boxed{+y^N_{\alpha\beta}\overline{L}_\alpha N_\beta\tilde{H}} \longleftarrow$$

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$$+i\overline{L}_\alpha\gamma^\mu D_\mu L_\alpha + i\overline{Q}_\alpha\gamma^\mu D_\mu Q_\alpha + i\overline{E} \quad D_\mu E_\alpha$$

Three gauge couplings

$$+i\overline{U}_\alpha\gamma^\mu D_\mu U_\alpha + i\overline{D}_\alpha\gamma^\mu D_\mu D_\alpha + (D_\mu H)^\dagger(D_\mu H),$$

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Three or four Yukawa matrices

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Two parameters

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All these parameters are not predicted by the SM and determined experimentally

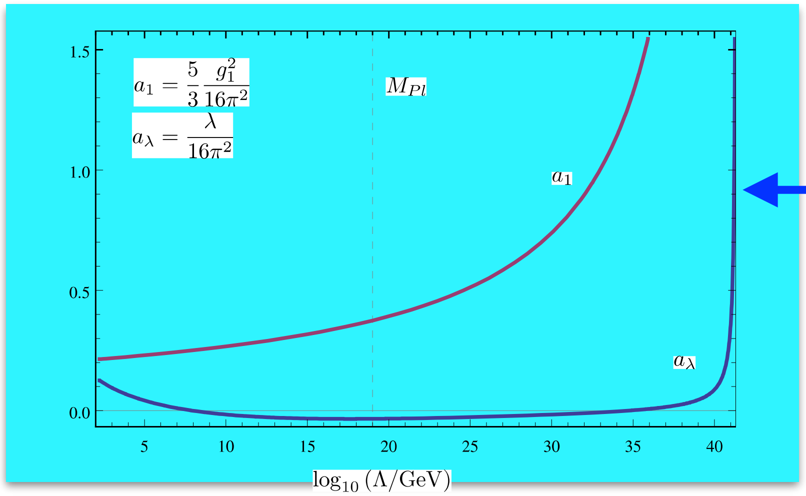
Three gauge couplings

Three or four Yukawa matrices

Two parameters

THE PROBLEMS

- The running couplings possess the Landau ghost poles at high energies



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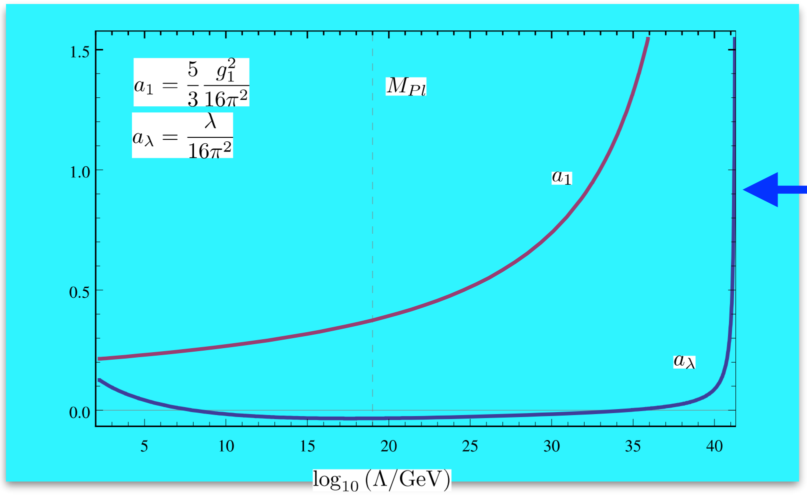

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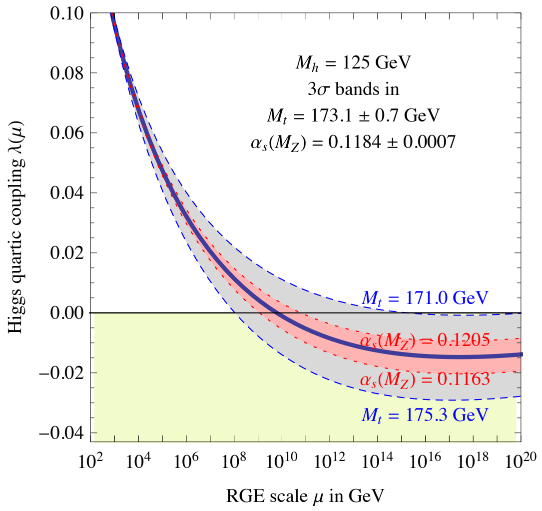
- Quantum corrections can make the vacuum unstable

- the situation crucially depends on the top and Higgs mass values and requires severe fine-tuning and accuracy



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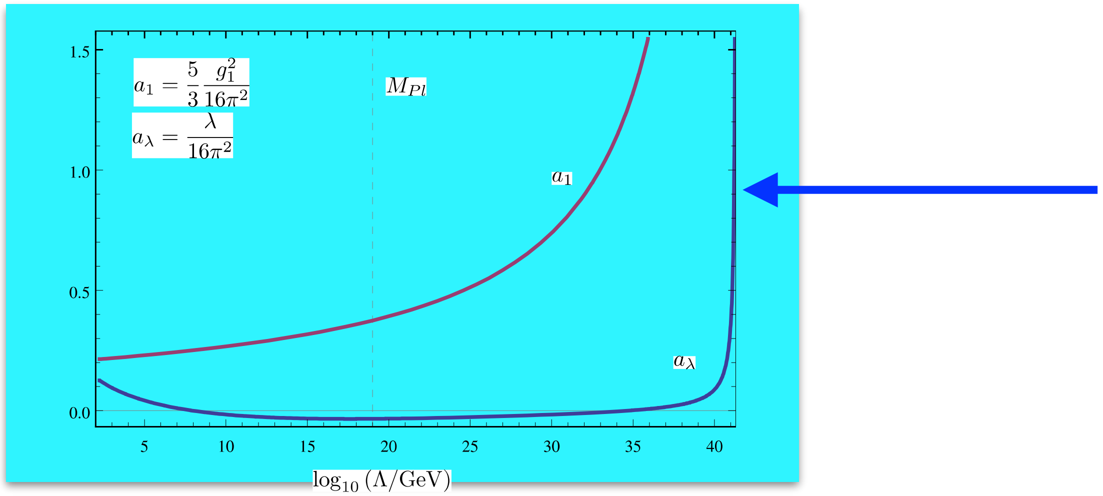

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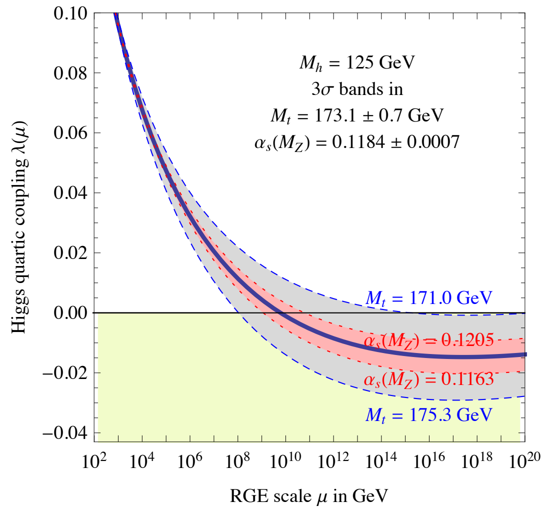


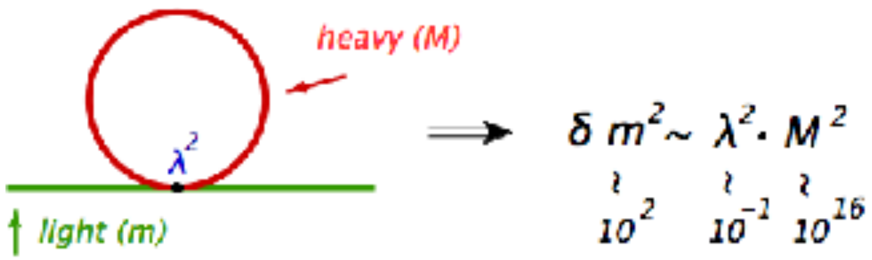
- The situation may change in GUTs due to new heavy fields @ the GUT scale

- requires modification of the ST at VERY high energies

THE PROBLEMS

New physics at high scale may destroy the EW scale of the SM

- The Higgs sector is not protected by any symmetry
- This does not happen with the gauge bosons or fermions. Their masses are protected by gauge invariance and chiral nature of the EW sector
- Quantum corrections to the Higgs potential due to New physics



- creates the hierarchy problem
- requires modification of the SM

$$\frac{m_H}{m_{GUT}} \sim 10^{-14}$$

- This is not the problem of the SM itself (quadratic divergences are absorbed into the unobservable bare mass).
- This creates power law dependence of the low energy physics on unknown high energy physics that is not acceptable
    - The way out might be the new physics at higher scale

THE OPEN QUESTIONS

Why's?

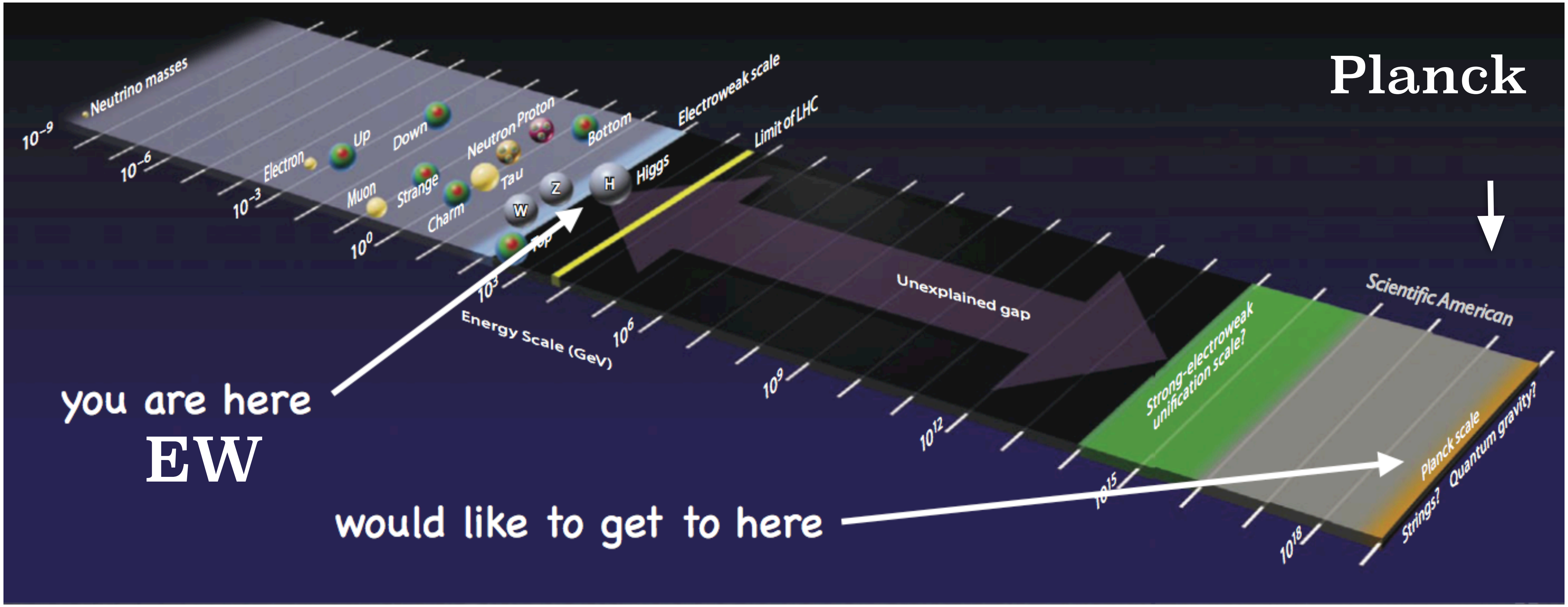
- why the SU(3)xSU(2)xU(1) ?
- why 3 generations ?
- why quark-lepton symmetry?
- why V-A weak interaction?
- why L-R asymmetry?
- why B & L conservation?
- etc

How's?

- how confinement actually works ?
- how the quark-hadron phase transition happens?
- how neutrinos get a mass?
- how CP violation occurs in the Universe?
- how to protect the SM from would be heavy scale physics?

- Is it self consistent ?
- Does it describe all experimental data?
- Are there any indications for physics beyond the SM?
- Is there another scale except for EW and Planck?
- Is it compatible with Cosmology? Where is dark matter?

IS THERE ANOTHER SCALE EXCEPT FOR EW AND PLANK?



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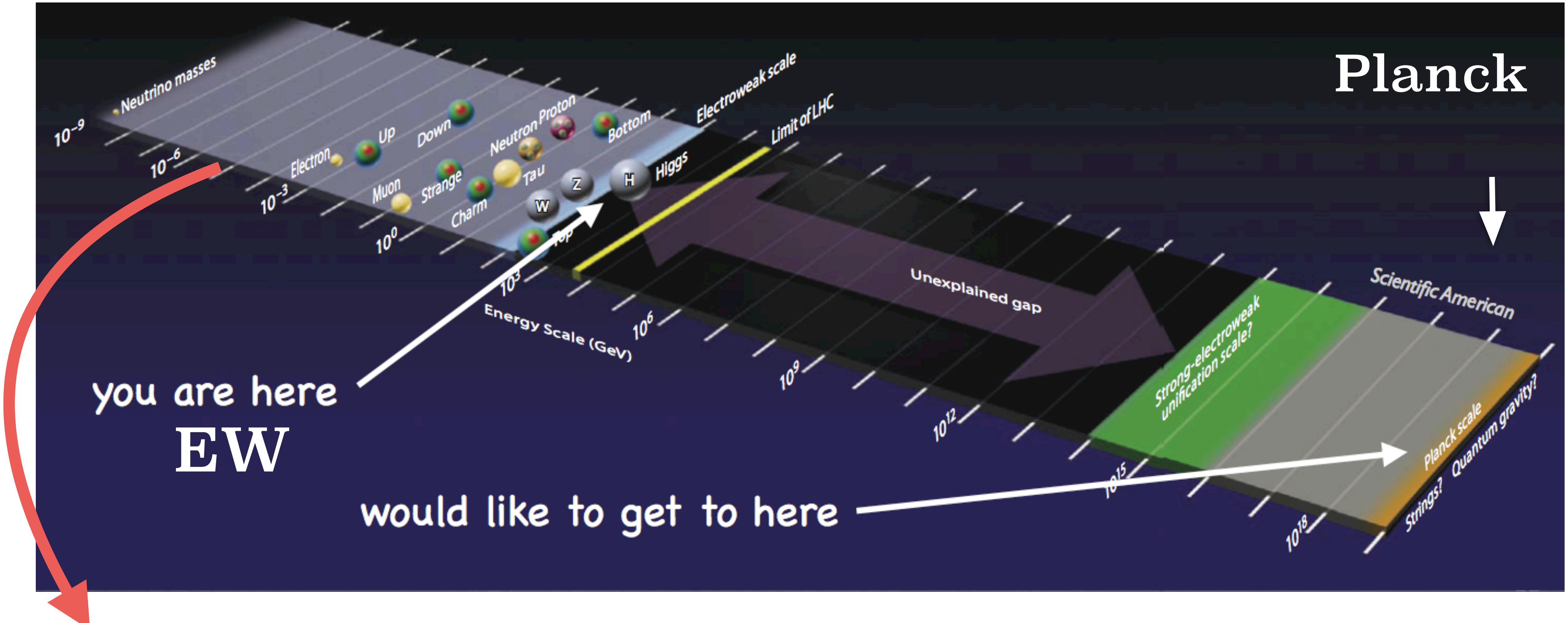

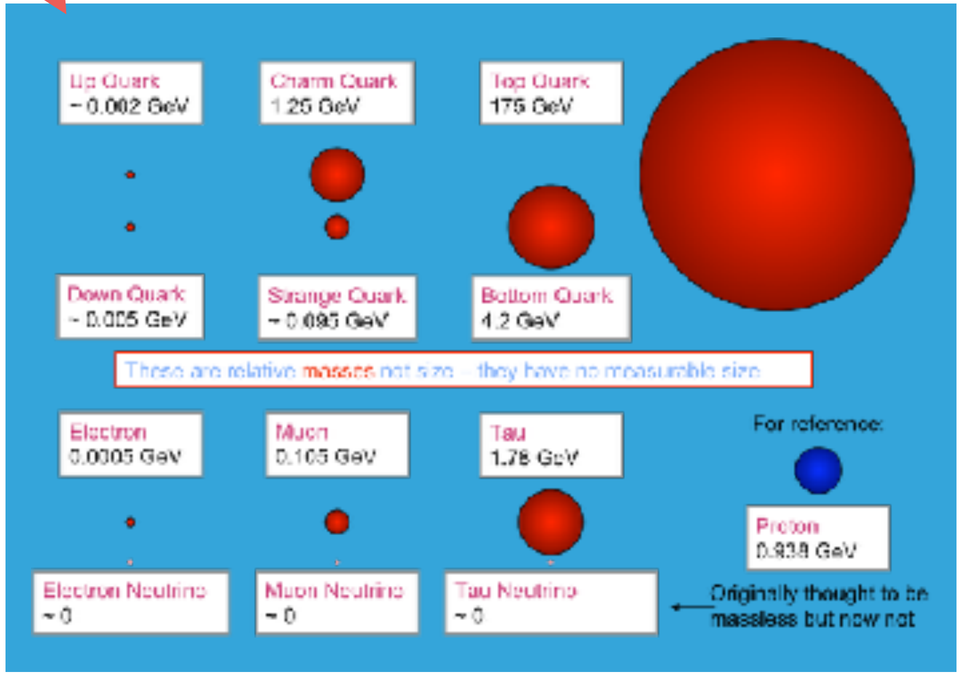

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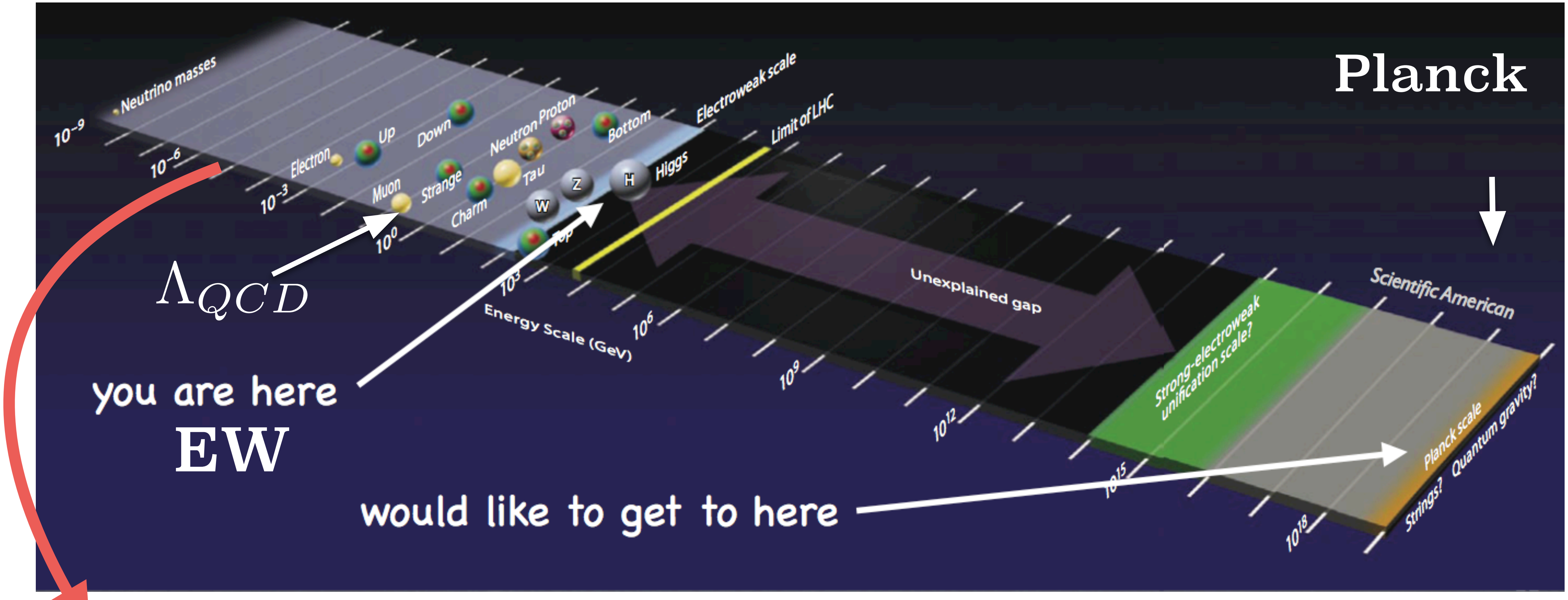


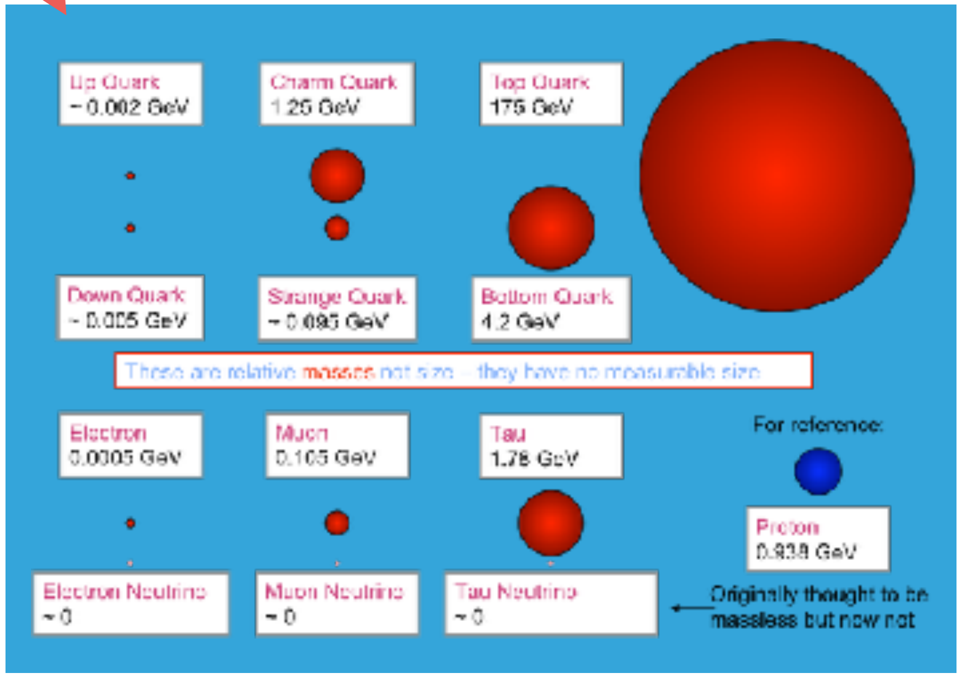
Planck

Λ_{QCD}

you are here

EW

would like to get to here



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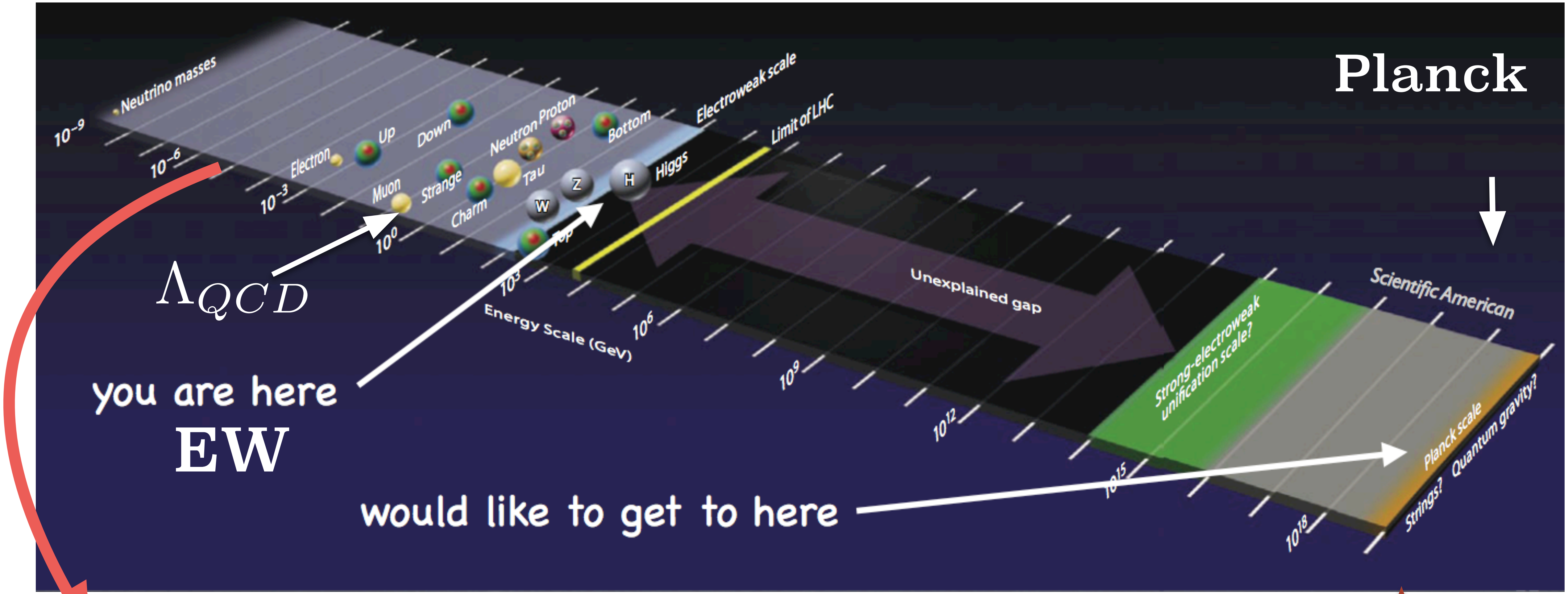

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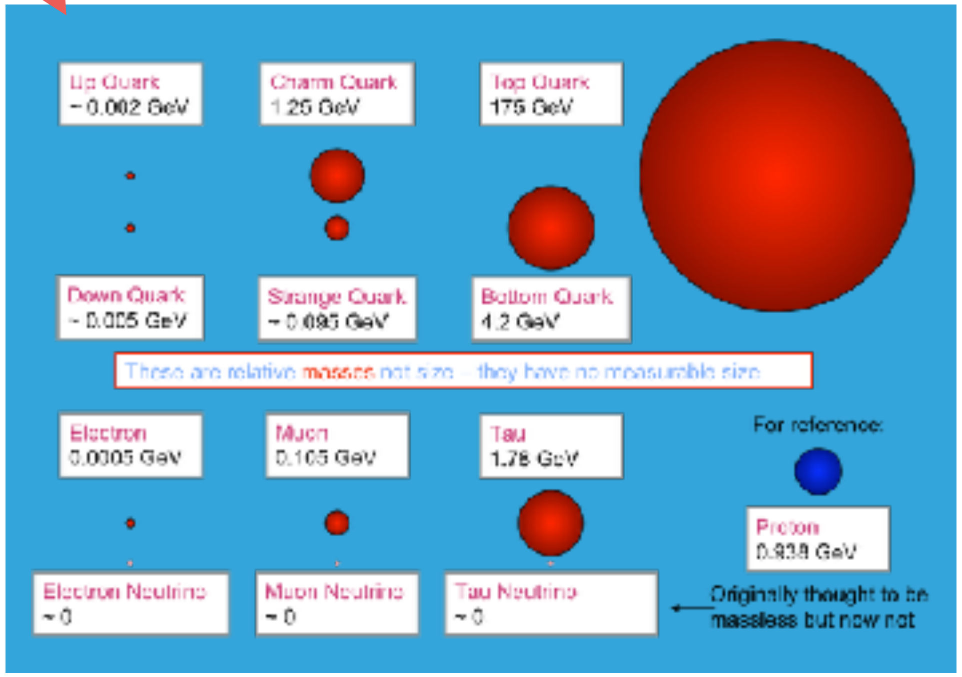
Up Quark ~ 0.002 GeV

Charm Quark 1.25 GeV

Top Quark 175 GeV

Down Quark ~ 0.005 GeV

Strange Quark ~ 0.095 GeV

Bottom Quark 4.2 GeV

These are relative masses not size – they have no measurable size

Electron 0.0005 GeV

Muon 0.105 GeV

Tau 1.78 GeV

For reference:

Proton 0.938 GeV

Electron Neutrino ~ 0

Muon Neutrino ~ 0

Tau Neutrino ~ 0

Originally thought to be massless but now not

Planck scale ~ 10^{19} GeV

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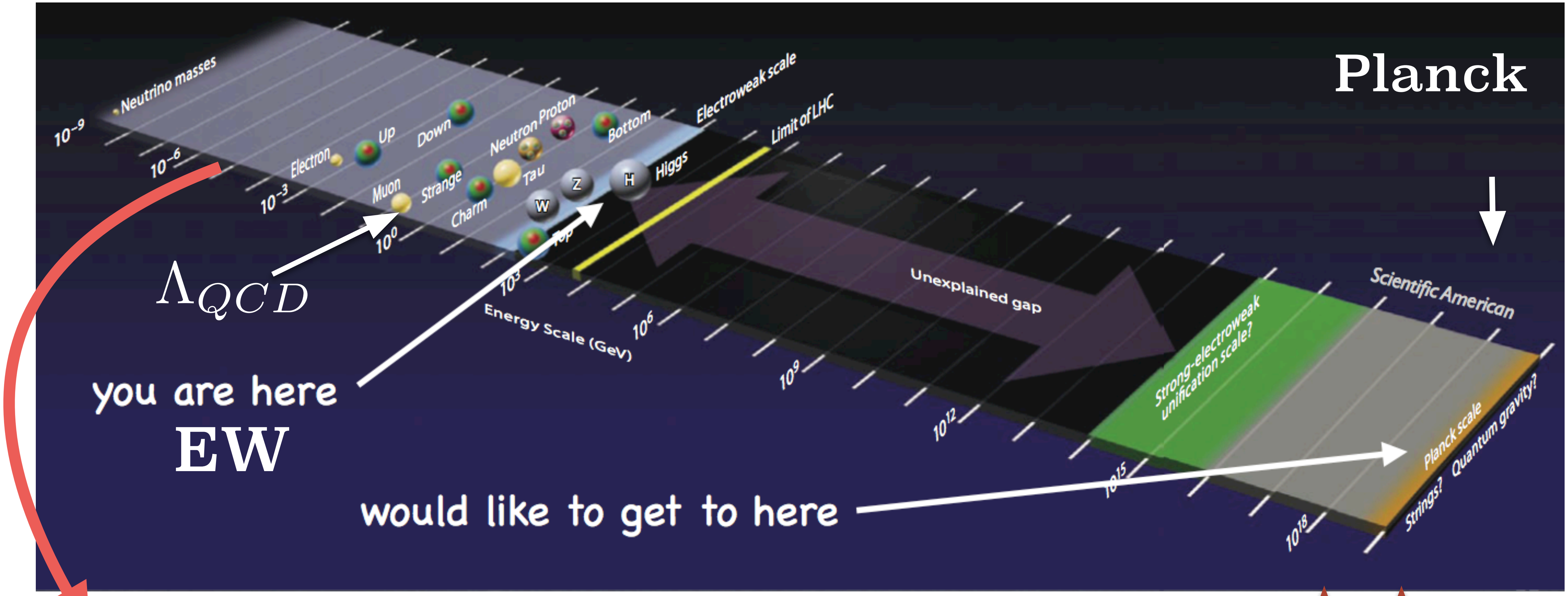

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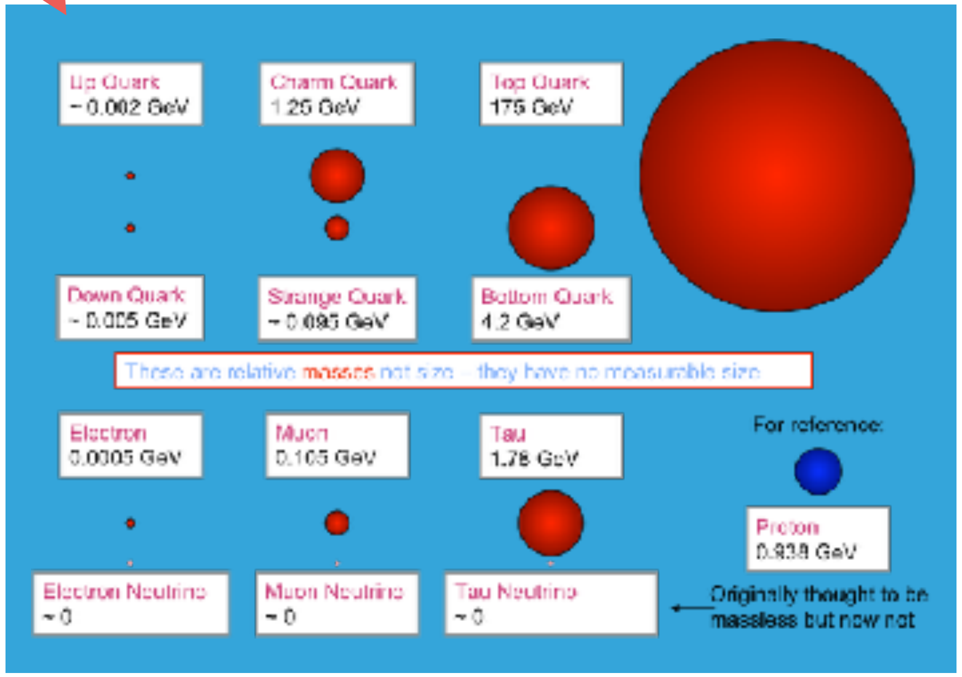

String scale ~ 10^{18} GeV

Planck scale ~ 10^{19} GeV

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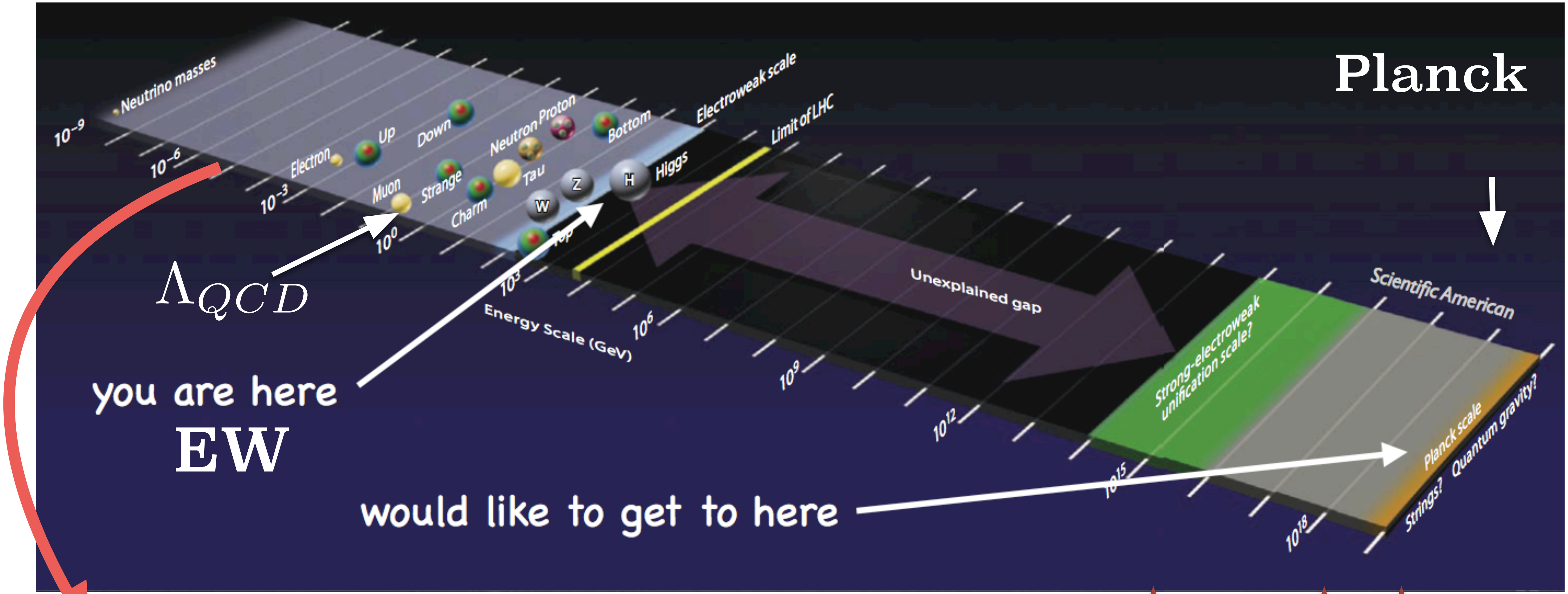

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EW

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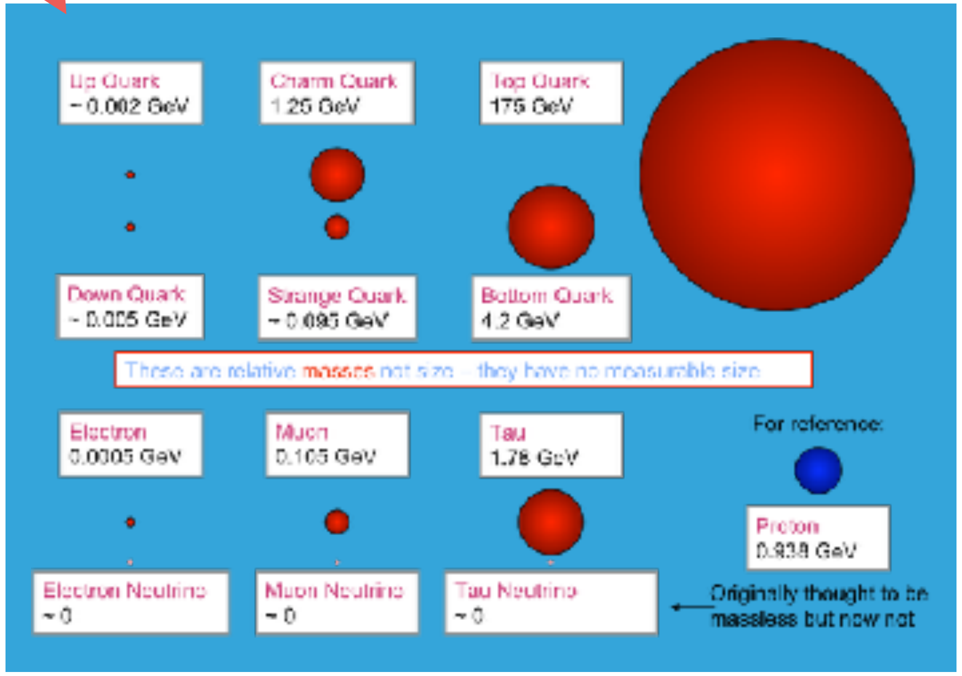

GUT scale ~ 10^{16} GeV

String scale ~ 10^{18} GeV

Planck scale ~ 10^{19} GeV

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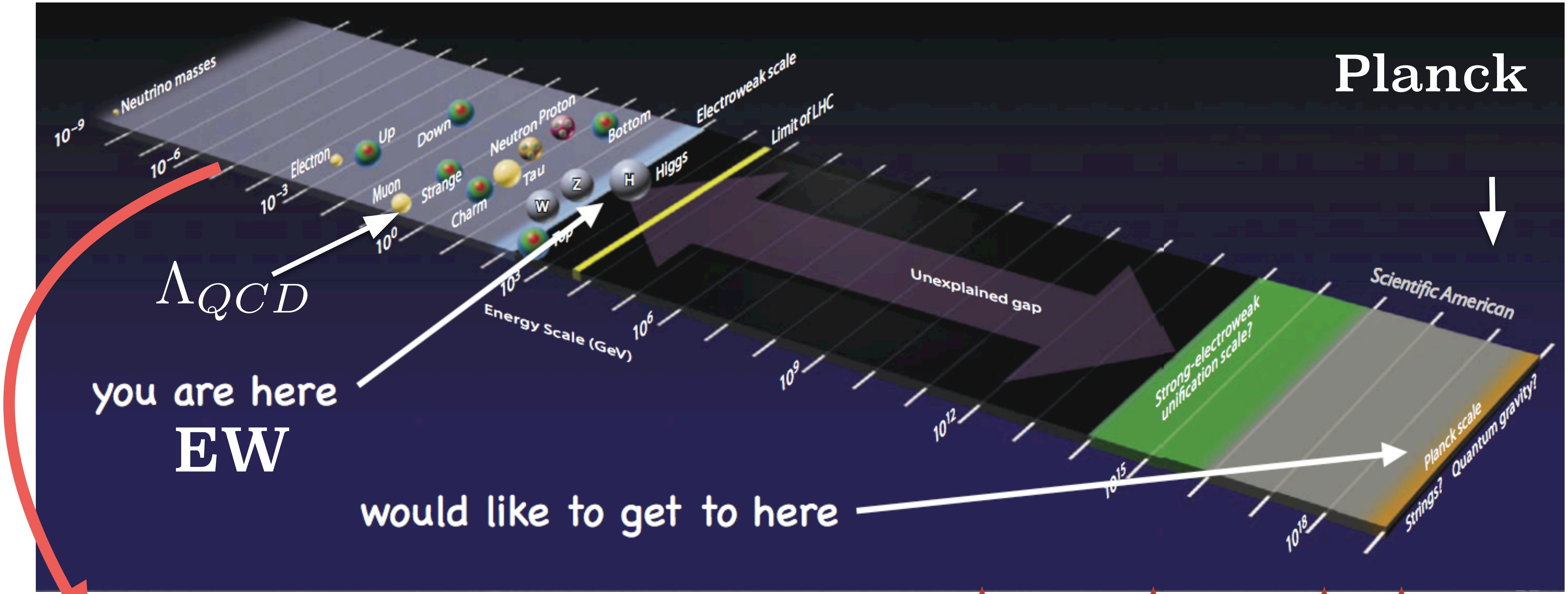

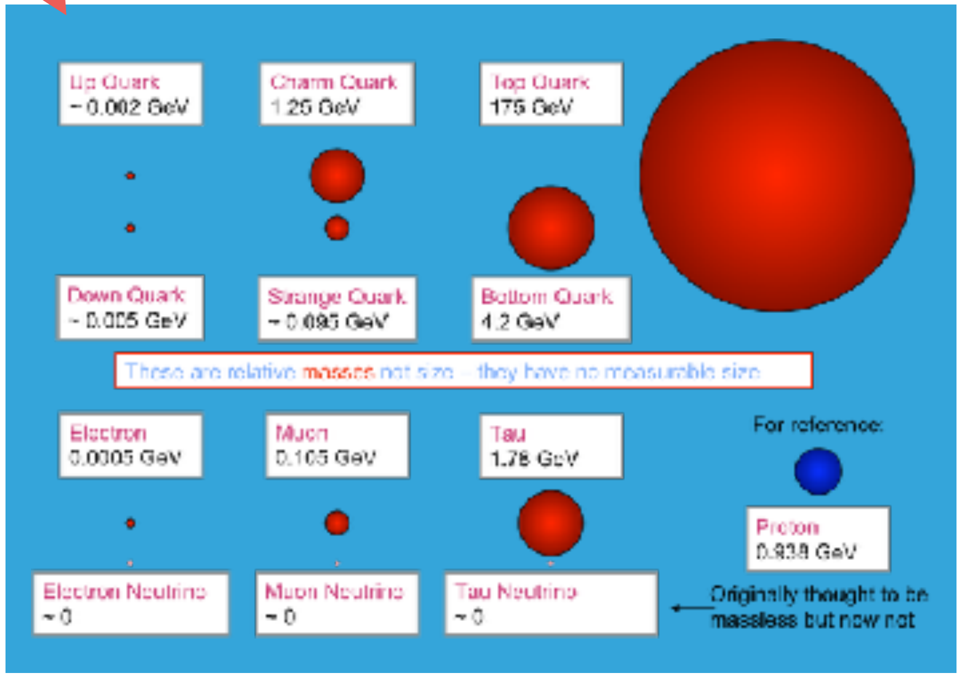

Majorana scale ~ 10^{12} GeV

GUT scale ~ 10^{16} GeV

String scale ~ 10^{18} GeV

Planck scale ~ 10^{19} GeV

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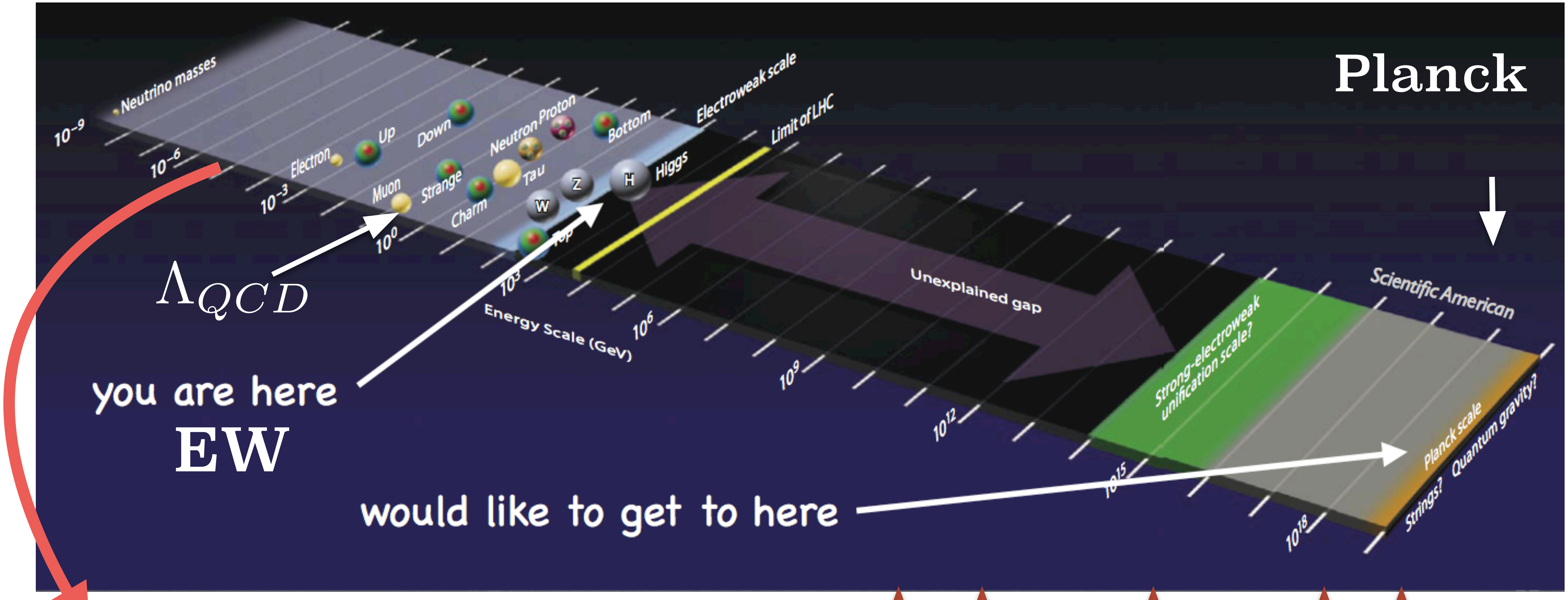

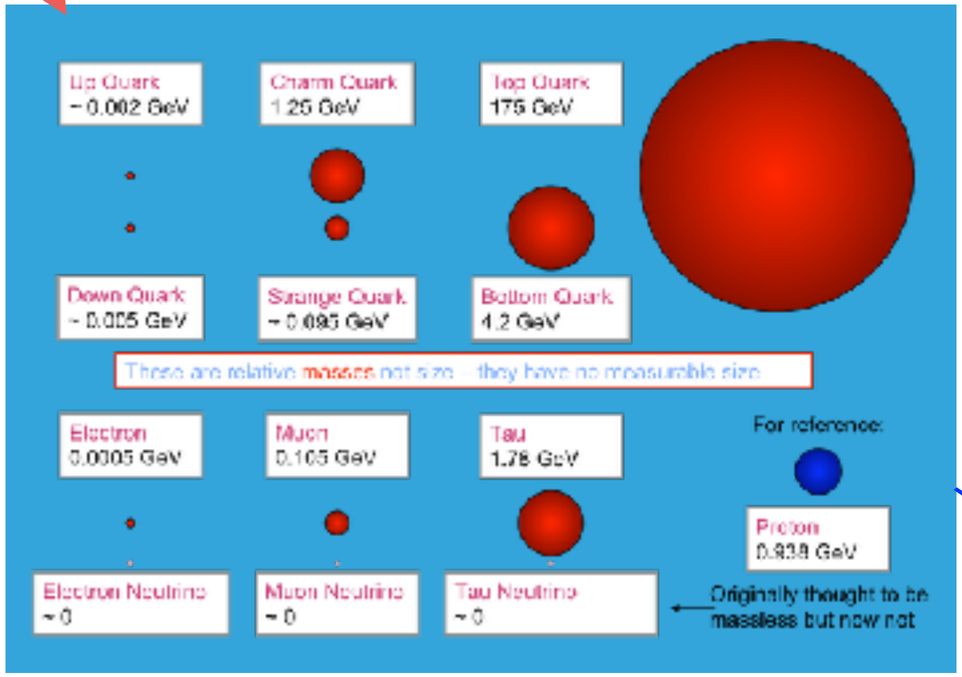

Vacuum Stab ~ 10^{11} GeV

Majorana scale ~ 10^{12} GeV

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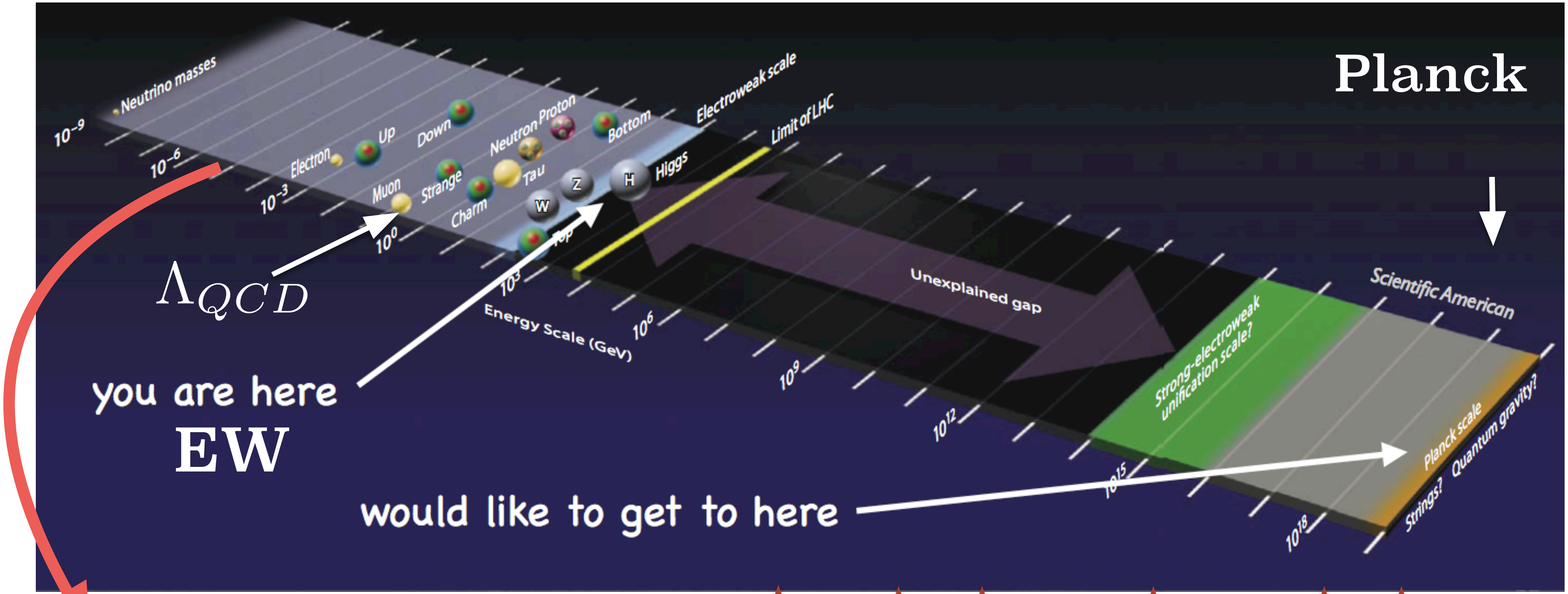

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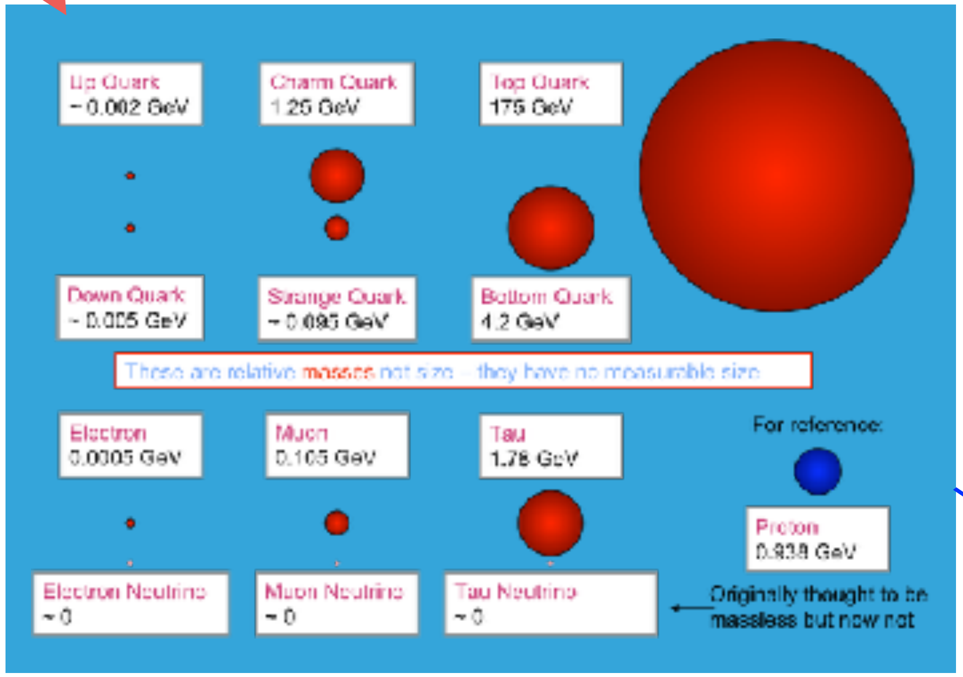

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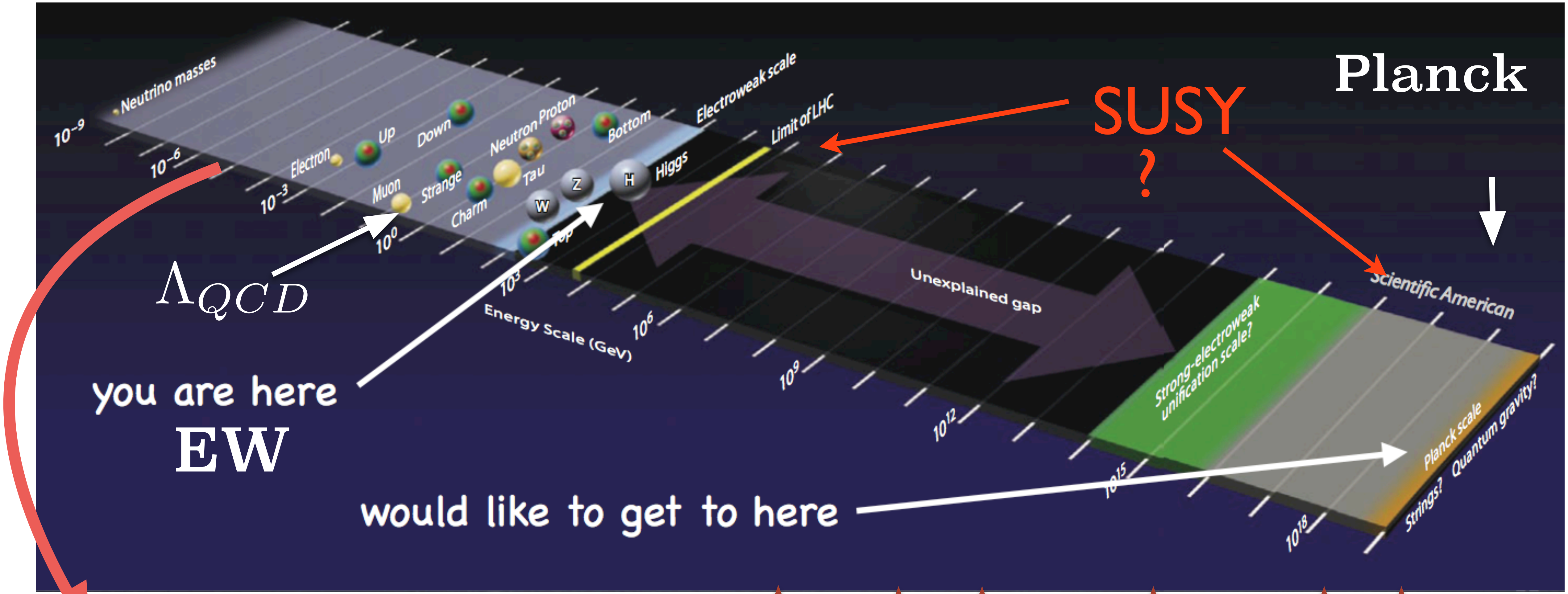

Planck

SUSY
?

Λ_{QCD}

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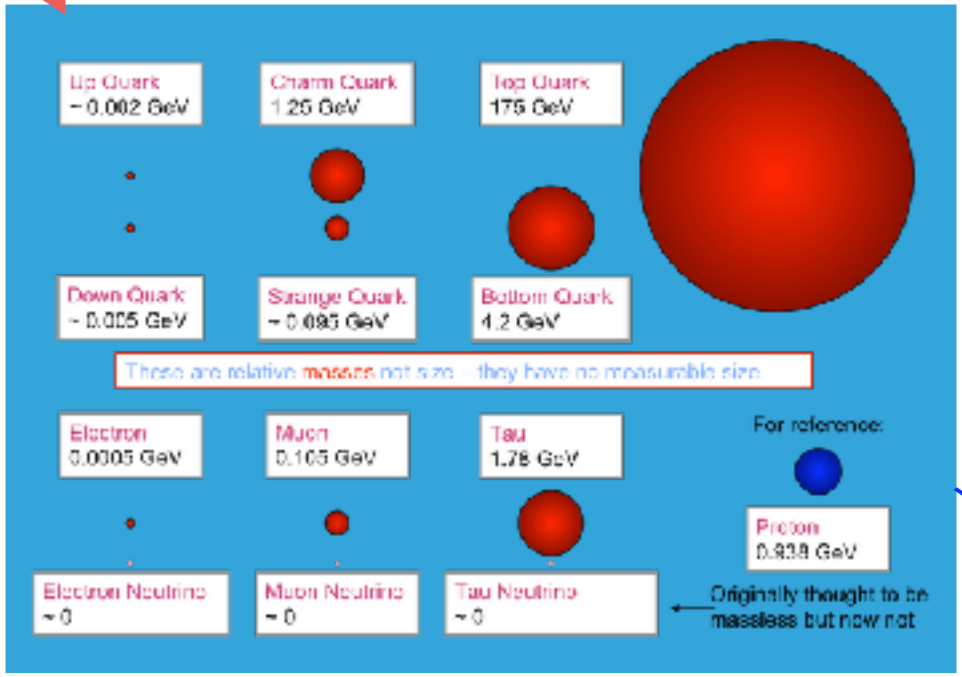
would like to get to here



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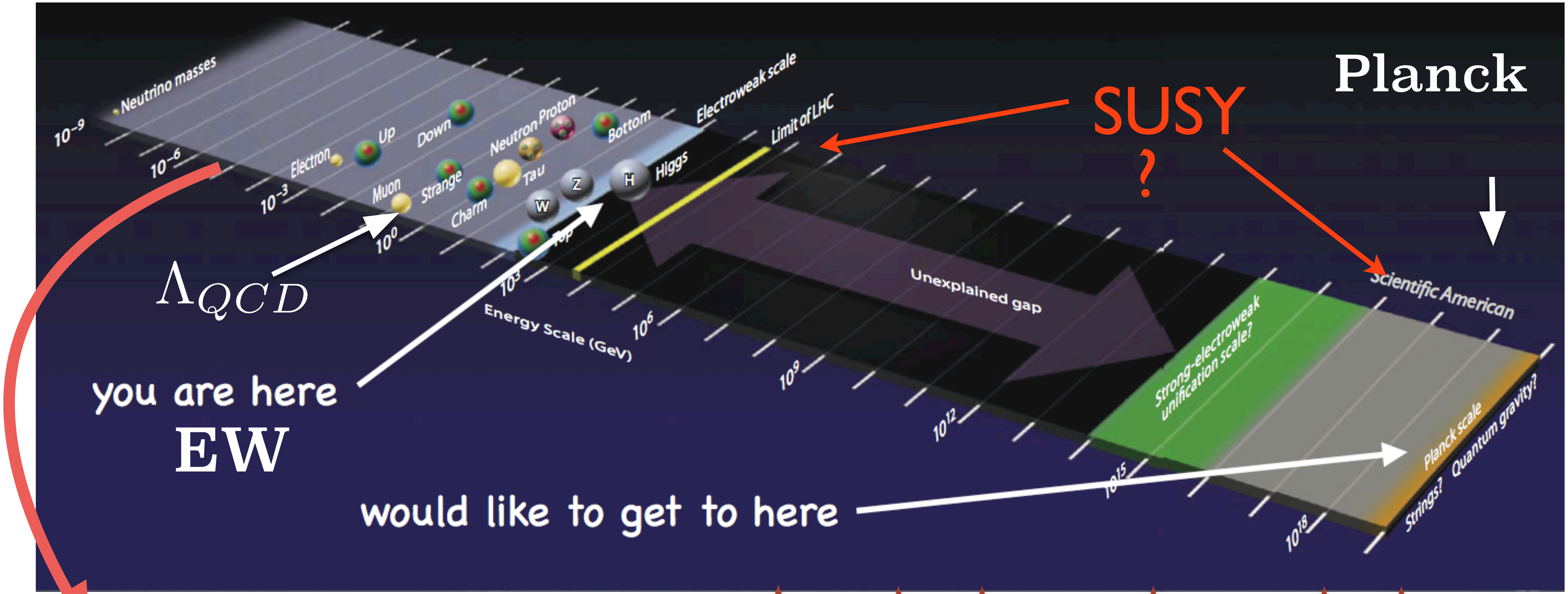

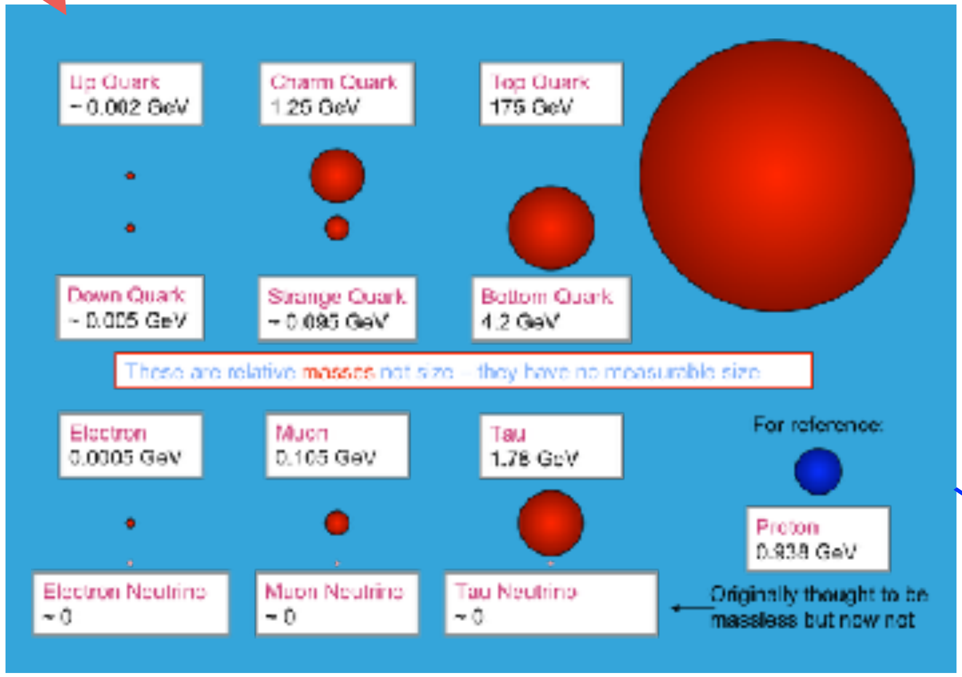

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POSSIBLE PHYSICS BEYOND THE STANDARD MODEL

Fabio Zwirner, EPS HEP 2017

Today's feeling in HEP

POSSIBLE PHYSICS BEYOND THE STANDARD MODEL

Fabio Zwirner, EPS HEP 2017

Today’s feeling in HEP

We live in data driven era and need an experimental hint to proceed

THE WAYS BEYOND

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- Extension of symmetry group of the SM : SUSY, GUT, new U(1)'s

-> may solve the problem of Landau pole, the problem of stability, the hierarchy problem, may give the DM particle

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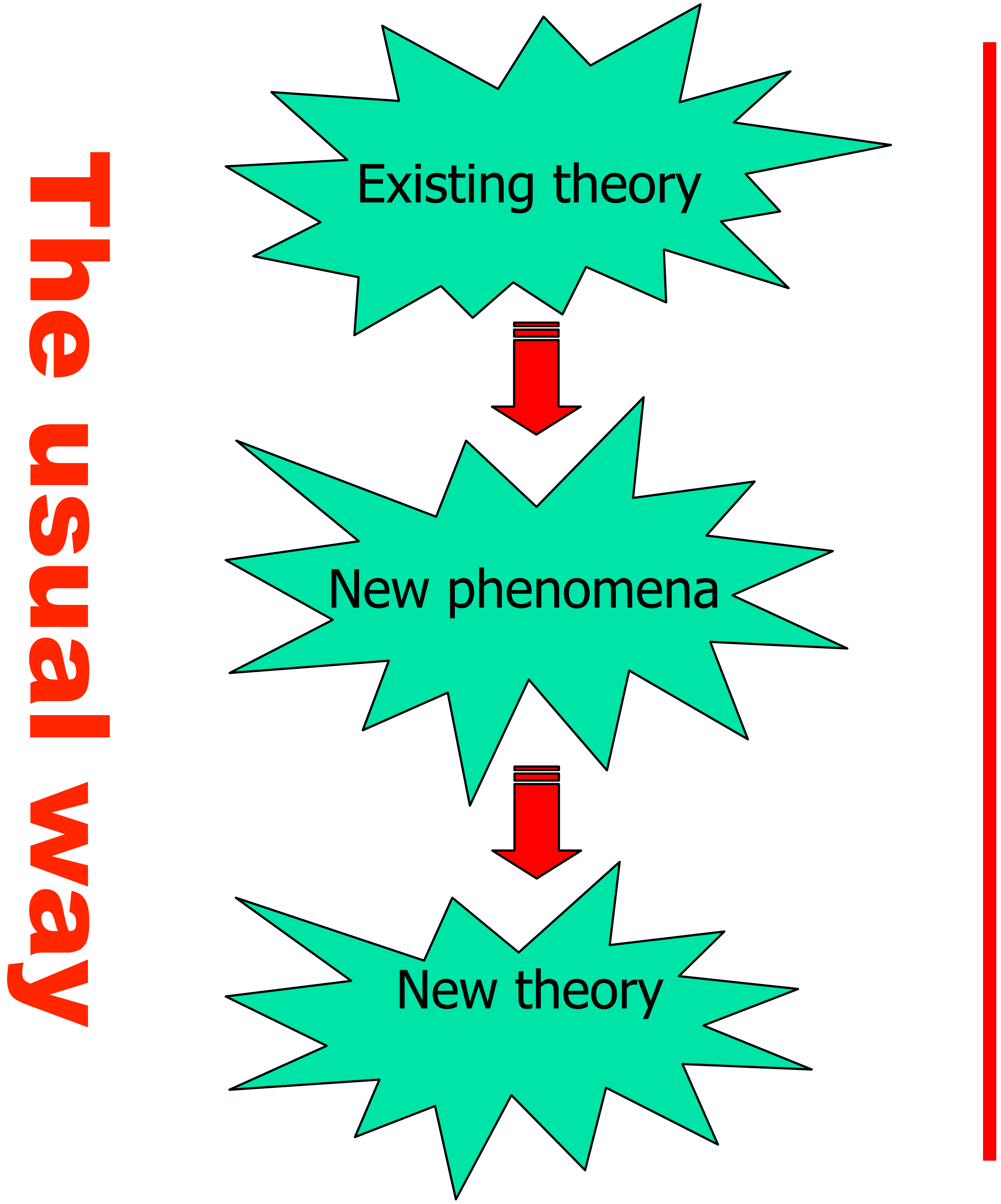
- New paradigm beyond local QFT: string theory, brane world, etc
  -> main task is unification with gravity and construction of quantum gravity

HEP PARADOX



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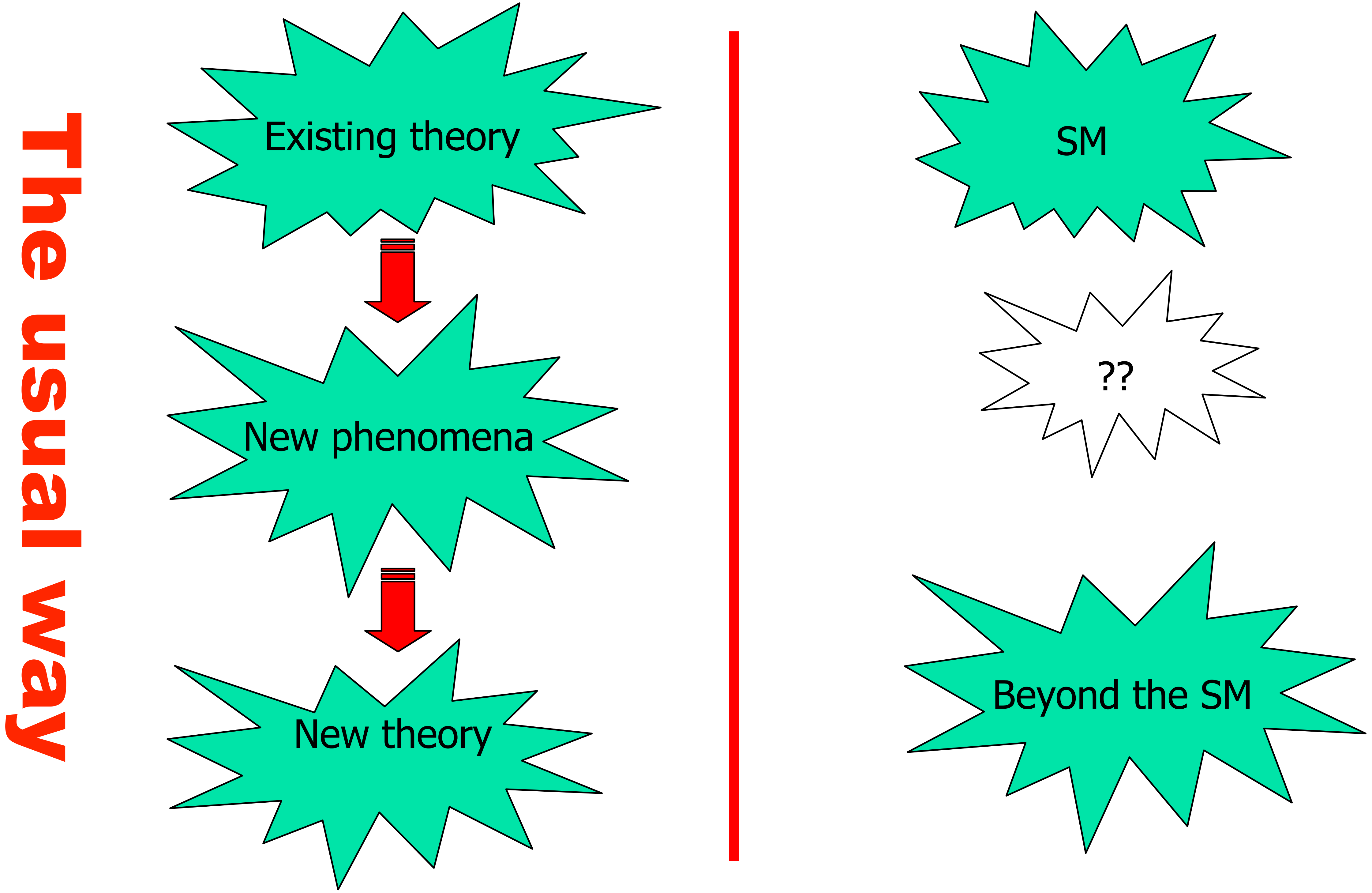

The usual way

Existing theory

New phenomena

New theory

Modern HEP

SM

??

Beyond the SM

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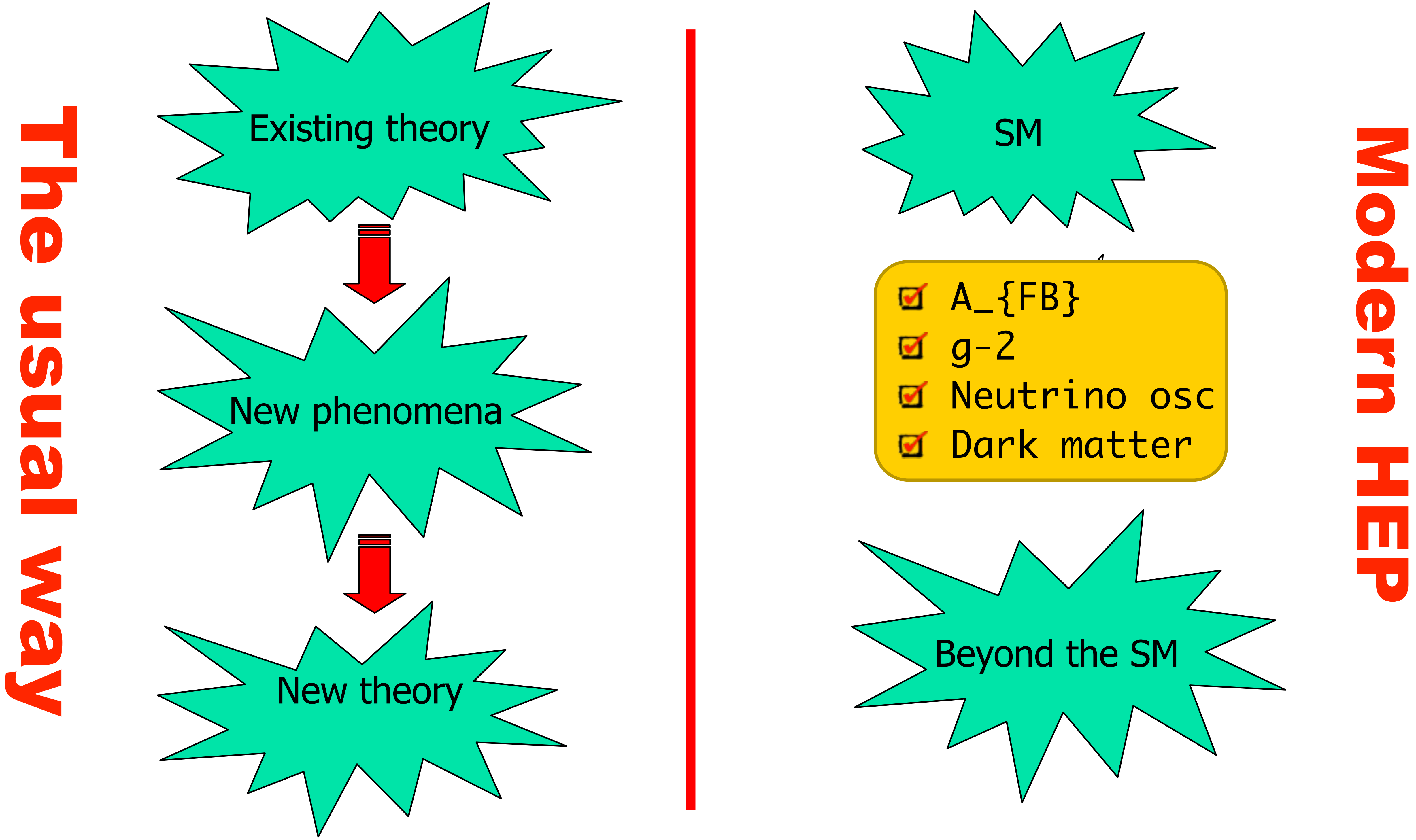

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SM

- ☑ A_{FB}
- ☑ g-2
- ☑ Neutrino osc
- ☑ Dark matter

Beyond the SM

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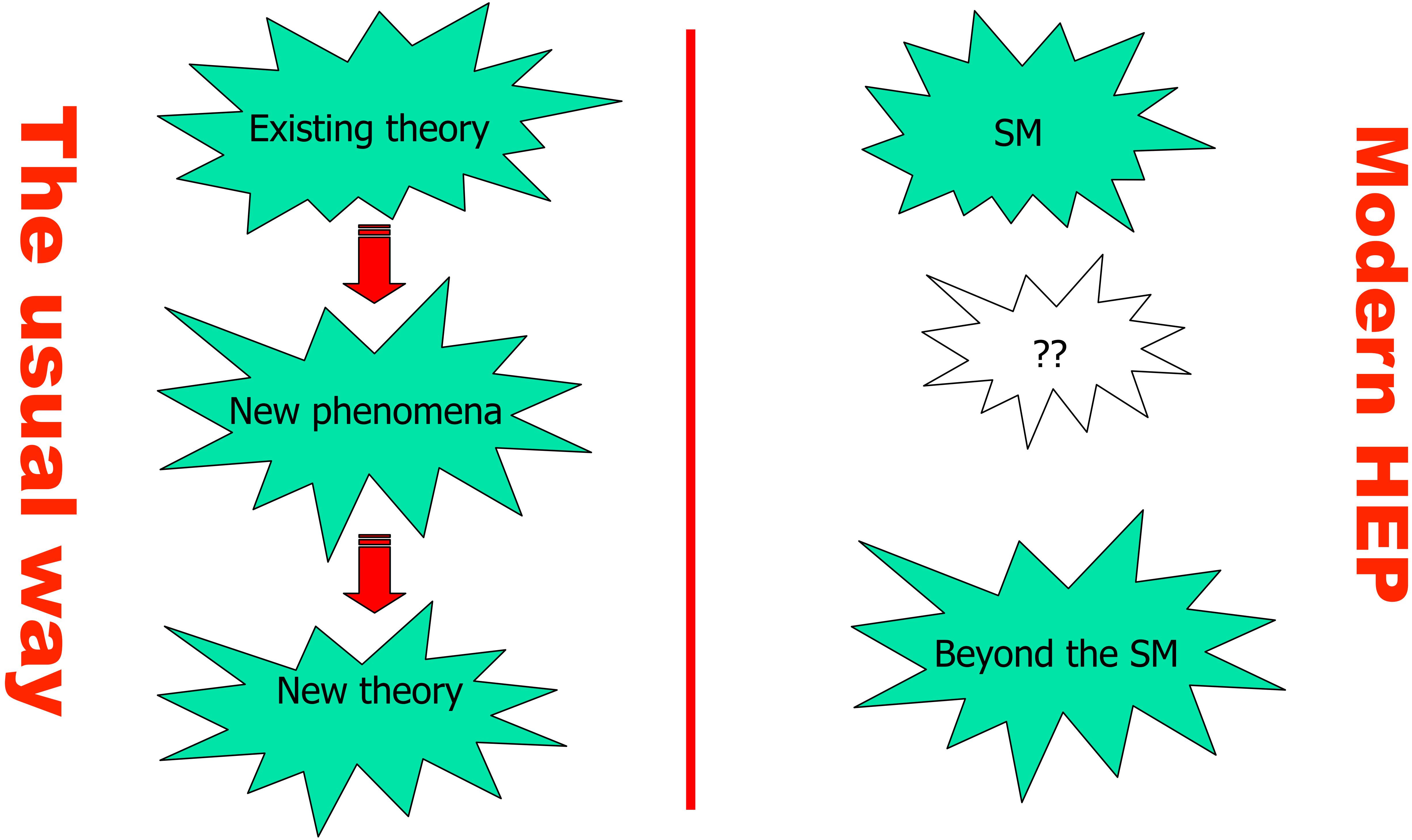

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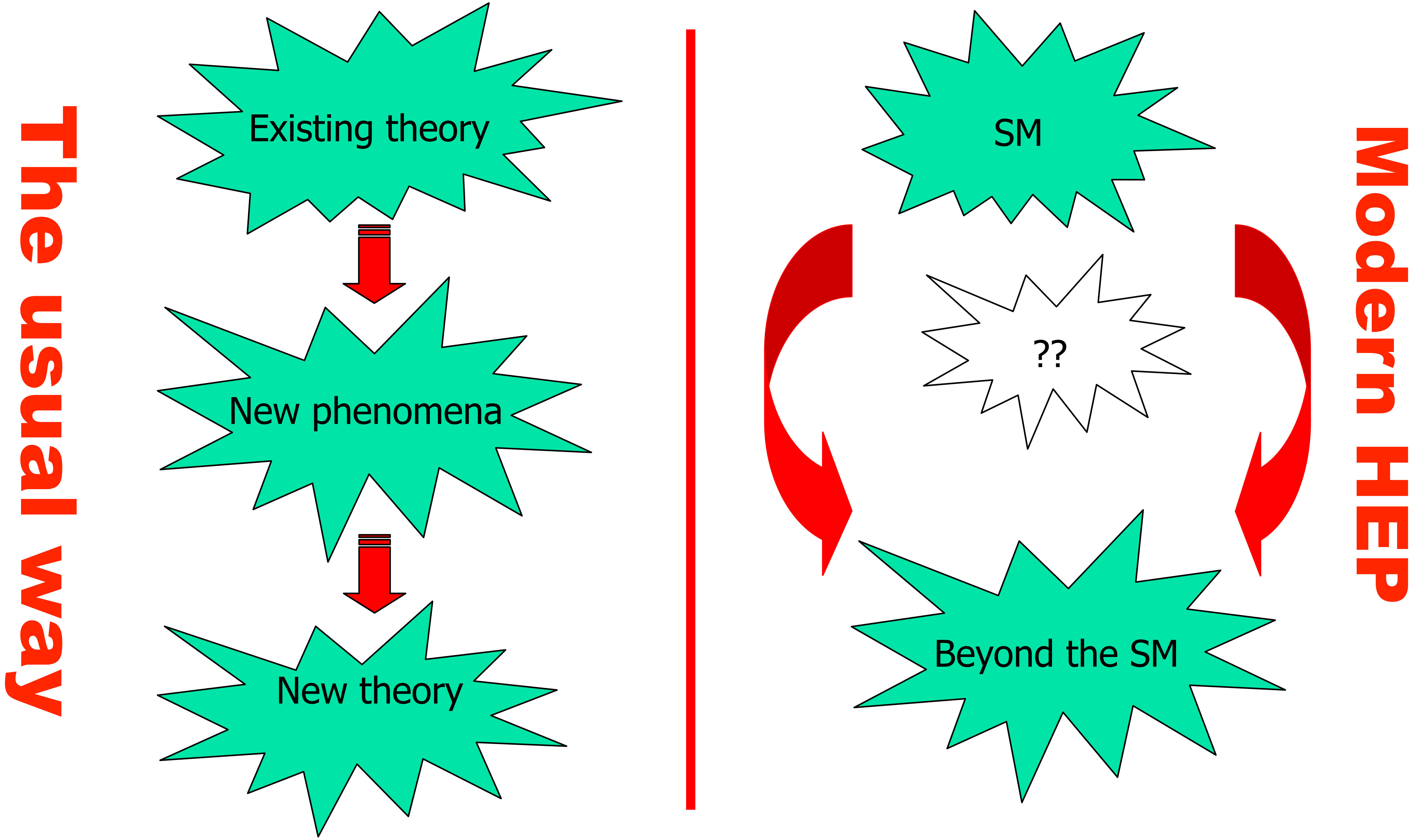

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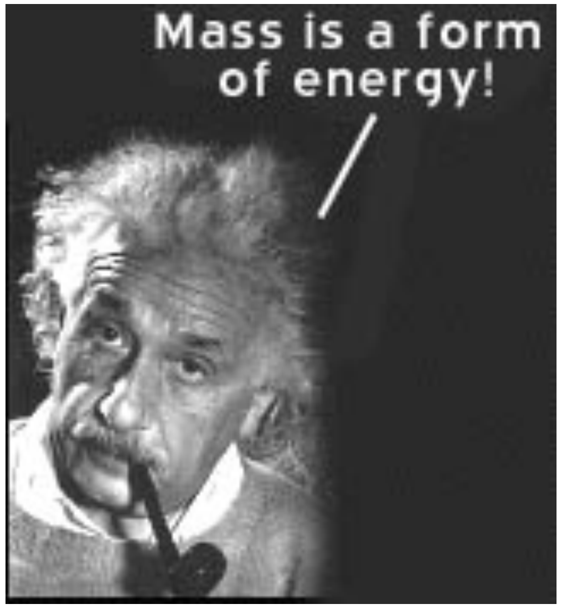
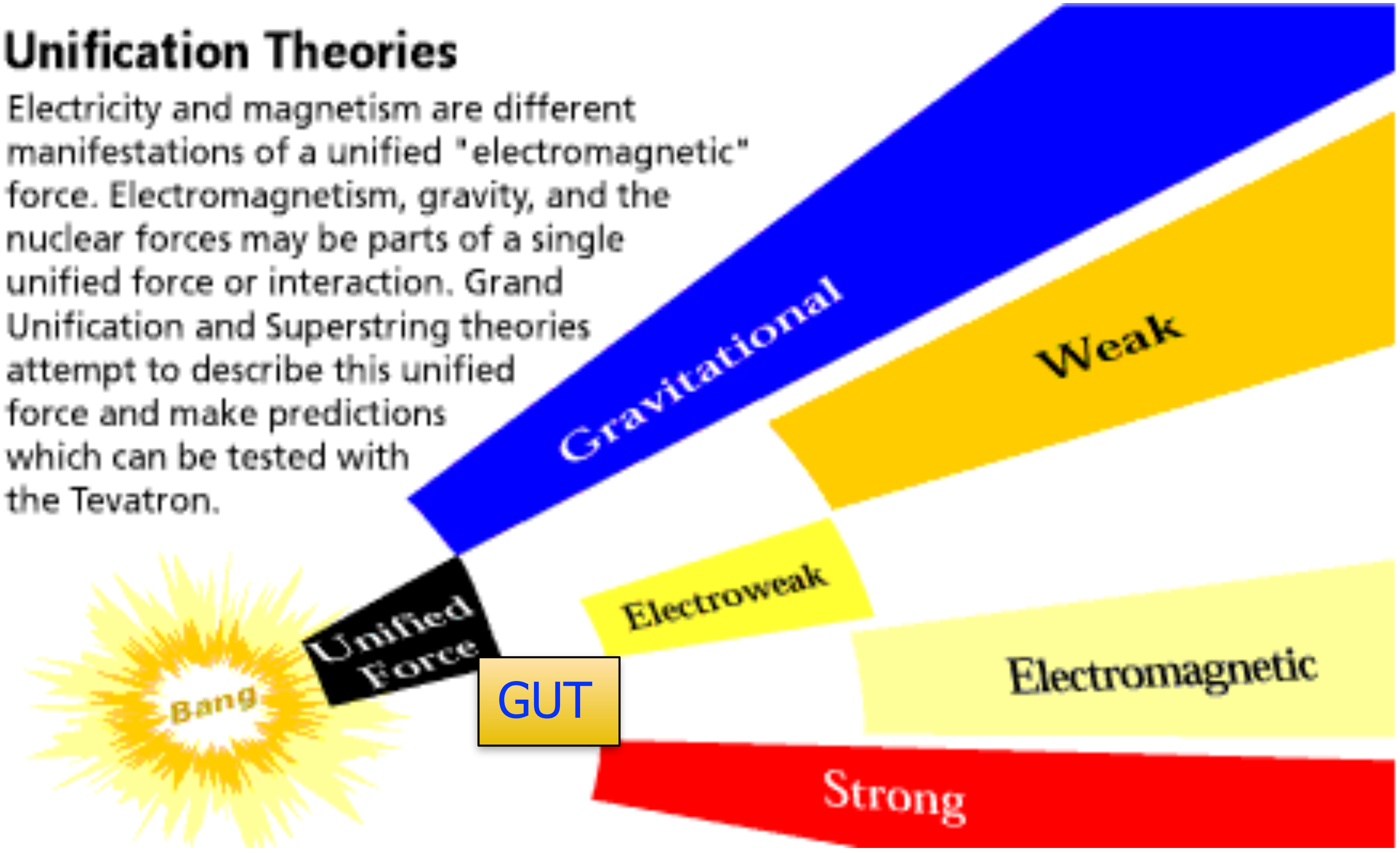
THE UNIFICATION PARADIGM





Unification Theories

Electricity and magnetism are different manifestations of a unified "electromagnetic" force. Electromagnetism, gravity, and the nuclear forces may be parts of a single unified force or interaction. Grand Unification and Superstring theories attempt to describe this unified force and make predictions which can be tested with the Tevatron.

10^{-34} cm

D=10

- Unification of strong, weak and electromagnetic interactions within Grand Unified Theories is a new step in unification of all forces of Nature
- Creation of a unified theory of everything based on string paradigm seems to be possible

NEW SYMMETRIES

SUPERSYMMETRY

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Supersymmetry is an extension of the Poincare symmetry of the SM

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Supersymmetry is an extension of the Poincare symmetry of the SM

Poincare Algebra

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\begin{aligned}
&[P_\mu, P_\nu] = 0, \\
&[P_\mu, M_{\rho\sigma}] = i(g_{\mu\rho}P_\sigma - g_{\mu\sigma}P_\rho), \\
&[M_{\mu\nu}, M_{\rho\sigma}] = i(g_{\nu\rho}M_{\mu\sigma} - g_{\nu\sigma}M_{\mu\rho} - g_{\mu\rho}M_{\nu\sigma} + g_{\mu\sigma}M_{\nu\rho})
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Super Poincare Algebra $Q_i, \; \bar{Q}_i$

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&[Q^i_\alpha, P_\mu] = [\bar{Q}^i_{\dot\alpha}, P_\mu] = 0, \\
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&\{Q^i_\alpha, \bar{Q}^j_{\dot\beta}\} = 2\delta^{ij}(\sigma^\mu)_{\alpha\dot\beta}P_\mu, \\
&\{Q^i_\alpha, Q^j_\beta\} = 2\epsilon_{\alpha\beta}Z^{ij}, \qquad Z^{ij} = Z^+_{ij}, \\
&\{\bar{Q}^i_{\dot\alpha}, \bar{Q}^j_{\dot\beta}\} = -2\epsilon_{\dot\alpha\dot\beta}Z^{ij}, \qquad [Z_{ij}, anything] = 0, \\
&\alpha, \dot\alpha = 1, 2 \qquad i, j = 1, 2, \ldots, N.
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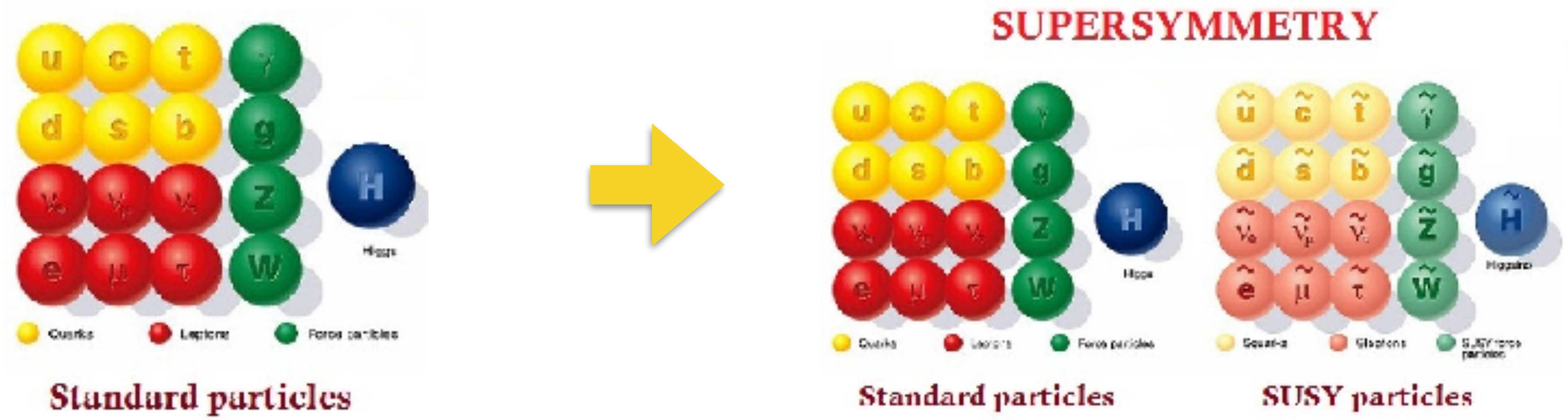
Supersymmetry is a dream of a unified theory of all particles and interactions



Supersymmetry remains, to this date, a well-motivated, much anticipated extension to the Standard Model of particle physics

- ◆ Advent of the LHC: huge new ground within reach
- ◆ A search is defined by its signature and by its background estimation method.

◆ If SUSY is the answer to the "naturalness" problem, then there must exist light colored particles

◆ This is a crucial moment: either we find SUSY at the LHC eventually or we have to solve the hierarchy problem some other way! (which way?)

THE SIMPLEST (N=1) SUSY MULTIPLETS

Bosons and Fermions come in pairs

$$(\varphi, \psi) \qquad (\lambda, A_\mu) \qquad (\tilde{g}, g)$$

Spin 0 Spin 1/2 Spin 1/2 Spin 1 Spin 3/2 Spin 2

scalar

chiral fermion

majorana fermion

vector

gravitino

graviton

THE R-PARITY

$$R = (-)^{3(B-L)+2S}$$

The Usual Particle : R = + 1
SUSY Particle : R = - 1

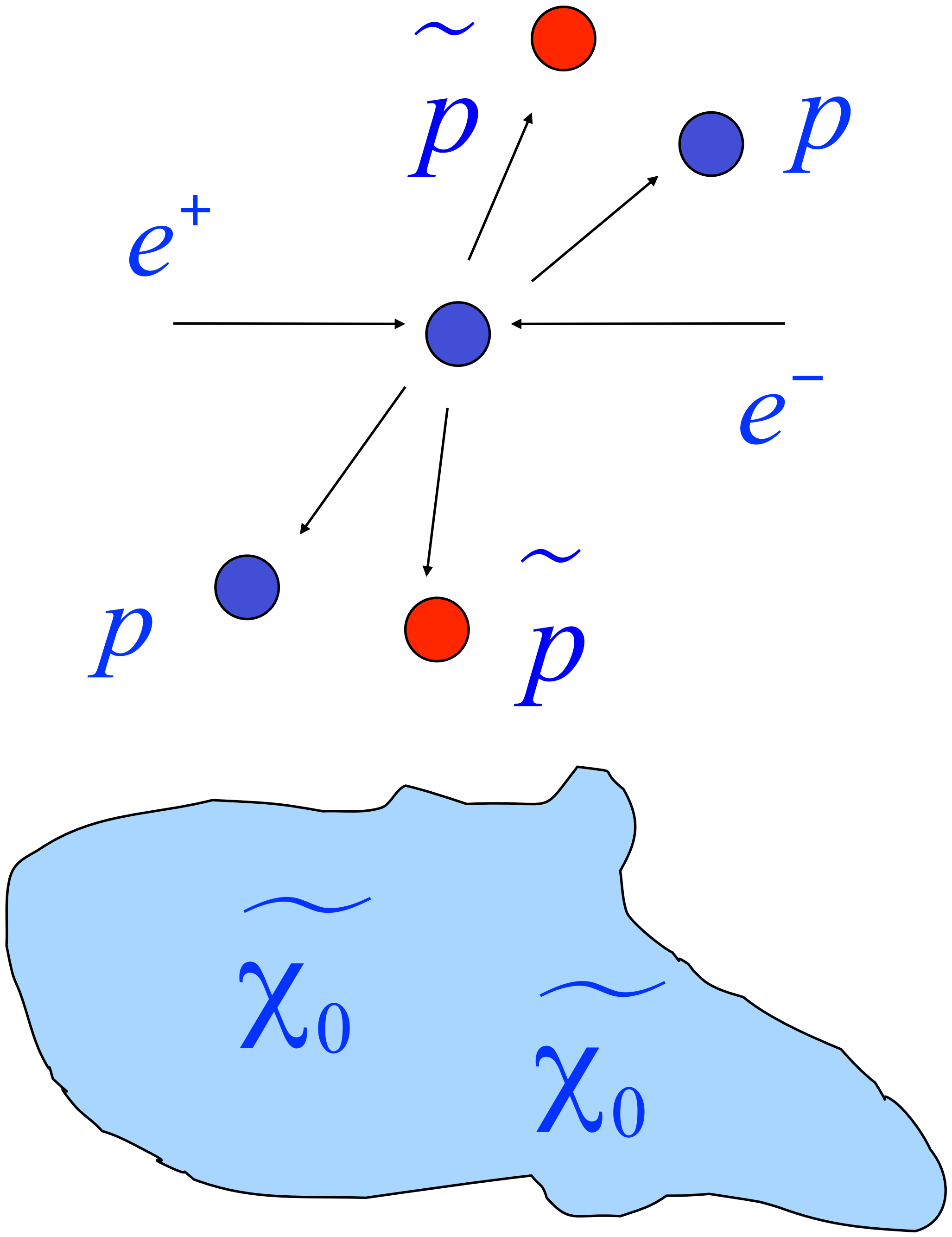
B - Baryon Number
L - Lepton Number
S - Spin

The consequences:

- The superpartners are created in pairs
- The lightest superparticle is stable

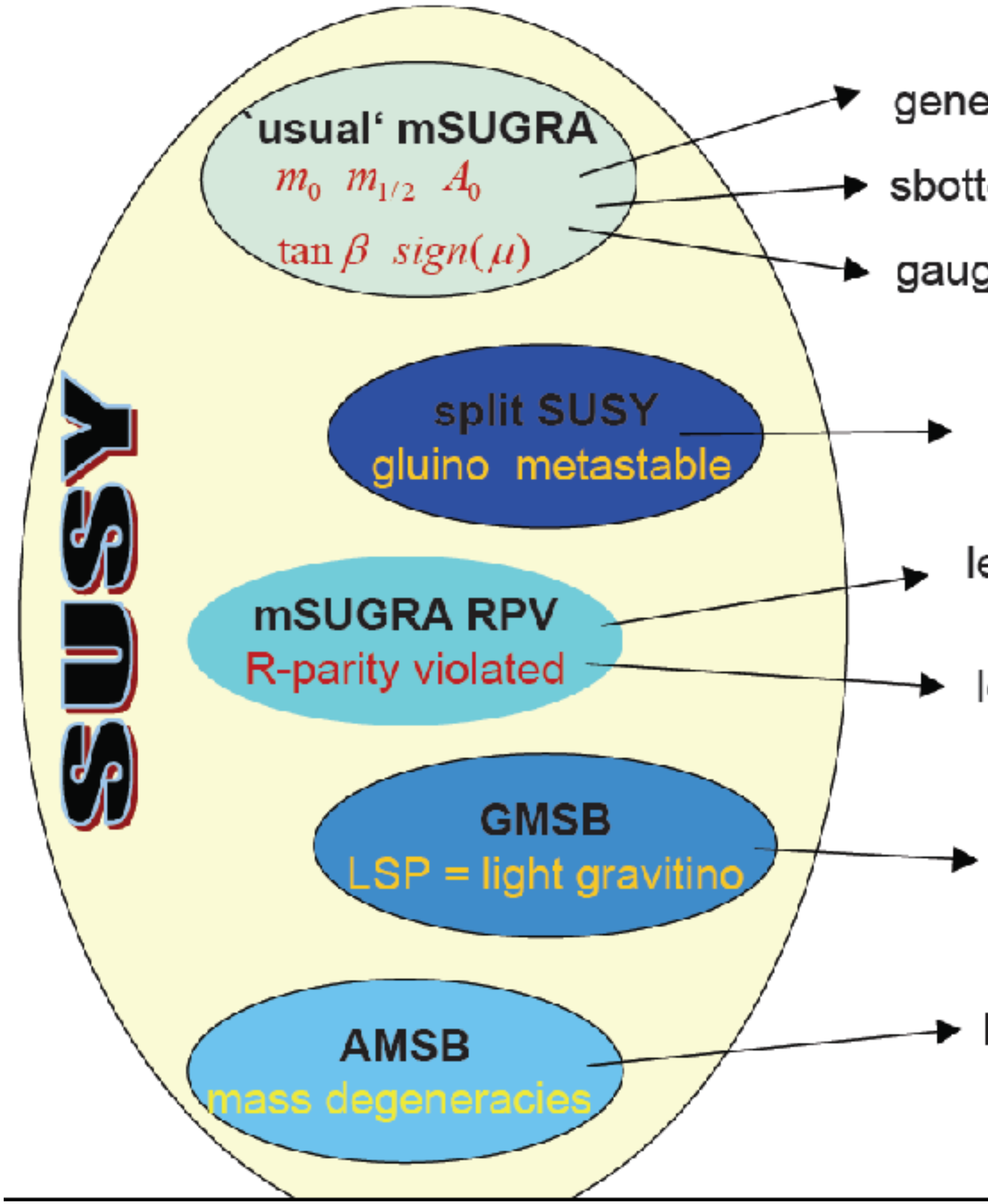
⇓

- The lightest superparticle (LSP) should be neutral - the best candidate is neutralino (photino or higgsino) $\tilde{\chi}_0$
- It can survive from the Big Bang and form the Dark matter in the Universe



SUSY Models and Signatures

T.Hebbeker



SUSY

`usual' mSUGRA
$m_0 \quad m_{1/2} \quad A_0$
$\tan\beta \quad sign(\mu)$

- generic squarks and gluinos
- sbottom and stop — might be light
- gauginos → leptons

split SUSY
gluino metastable

- stopping gluinos — gluinos $\tilde{g}$ long lived, form `R hadrons'

mSUGRA RPV
R-parity violated

- lepton-lepton couplings
- lepton-quark couplings

GMSB
LSP = light gravitino

- photons + missing energy

$$NLSP = \tilde{\chi}_1^0 \rightarrow \gamma\,\tilde{G}$$

AMSB
mass degeneracies

- long lived heavy charged particles

decay inside detector

Mirage unification

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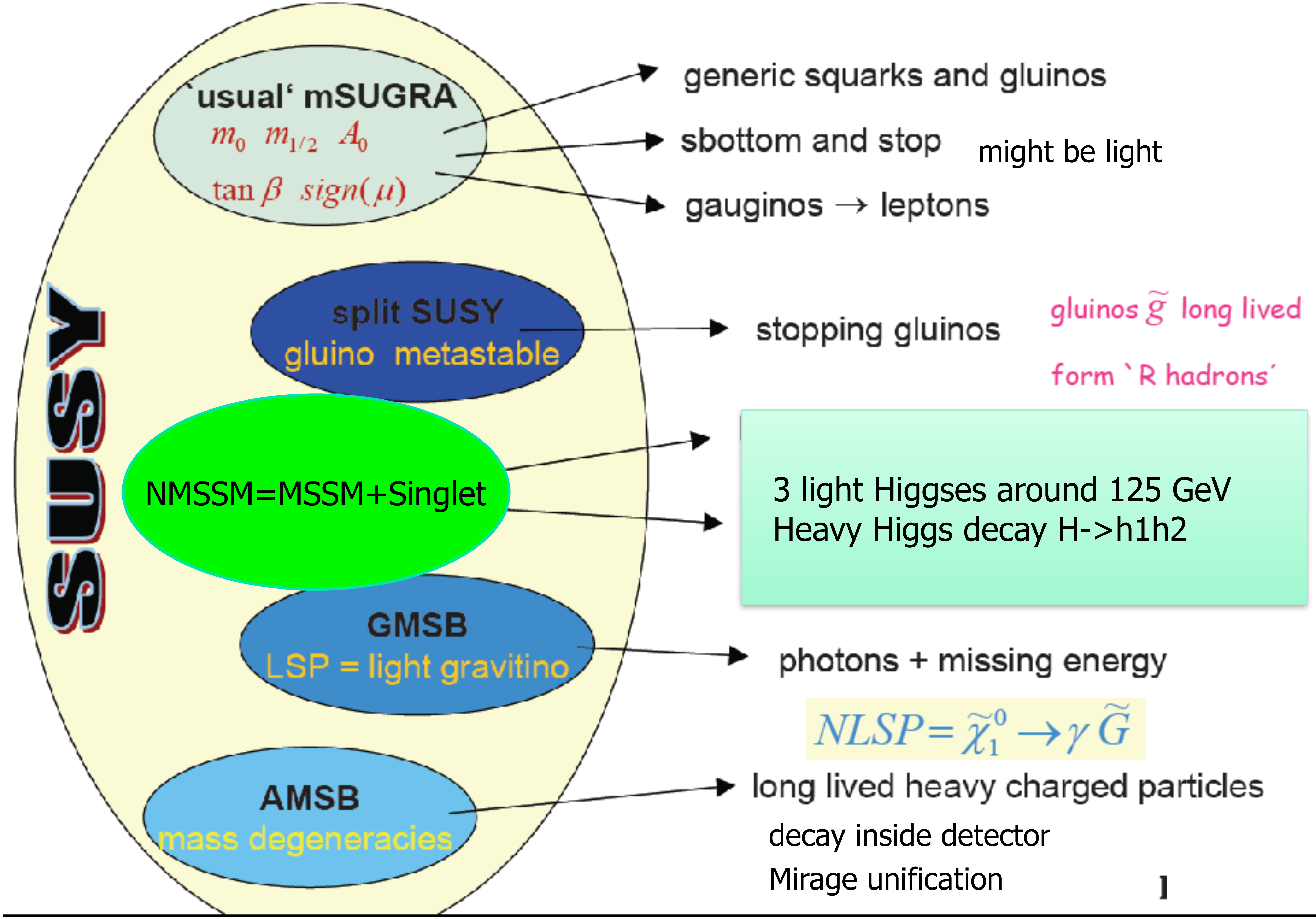

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NMSSM=MSSM+Singlet

3 light Higgses around 125 GeV
Heavy Higgs decay H->h1h2

GMSB
LSP = light gravitino

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WHAT IS THE LHC REACH?

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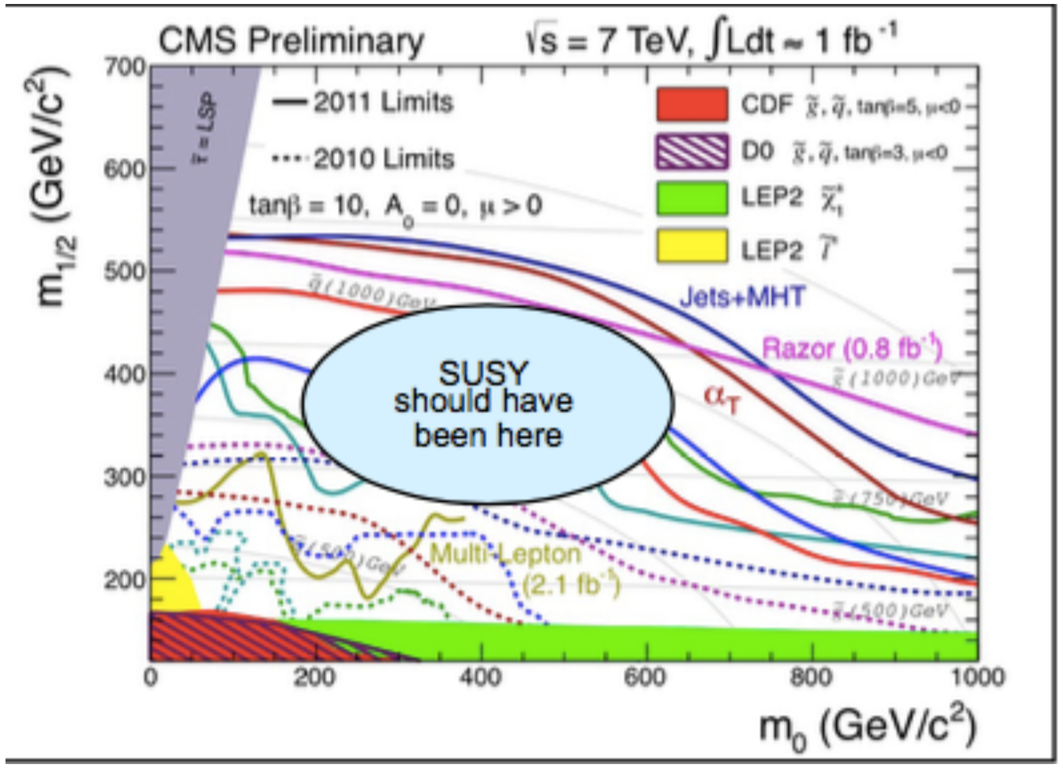

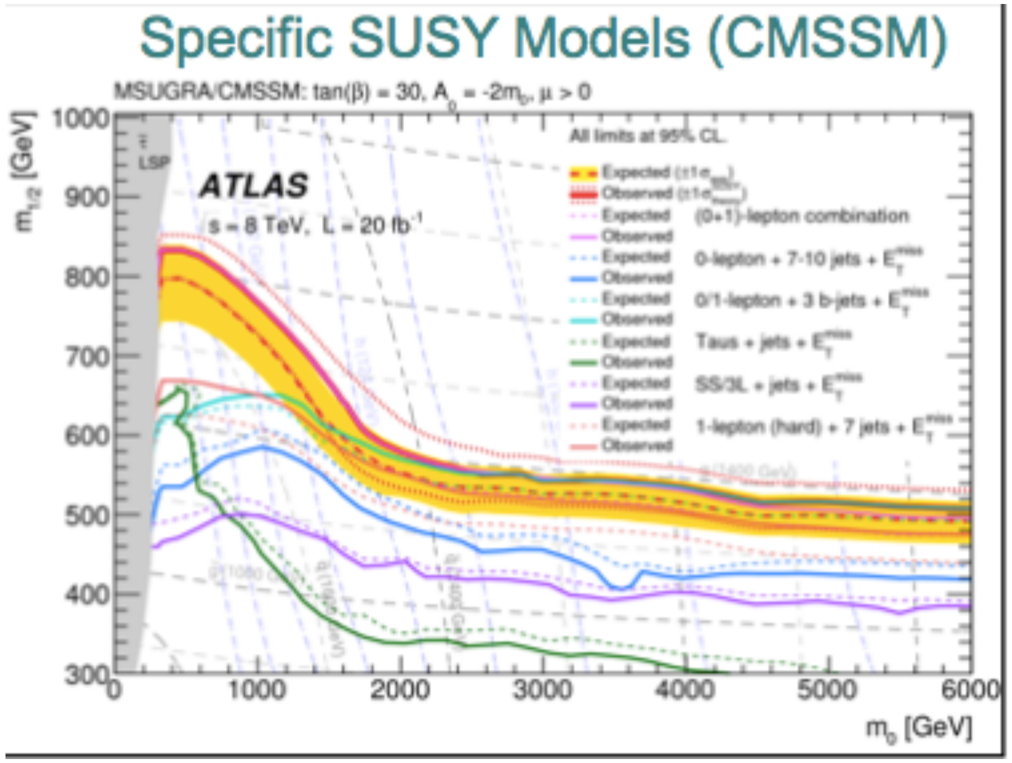

Universal parameters

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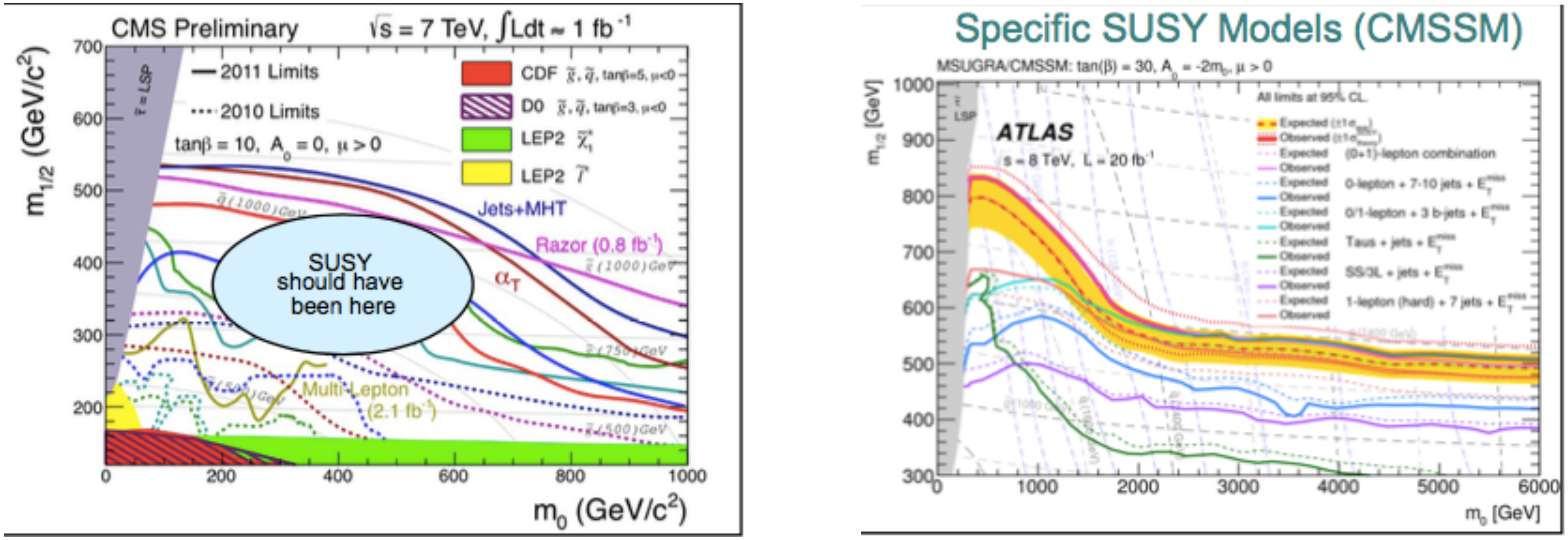

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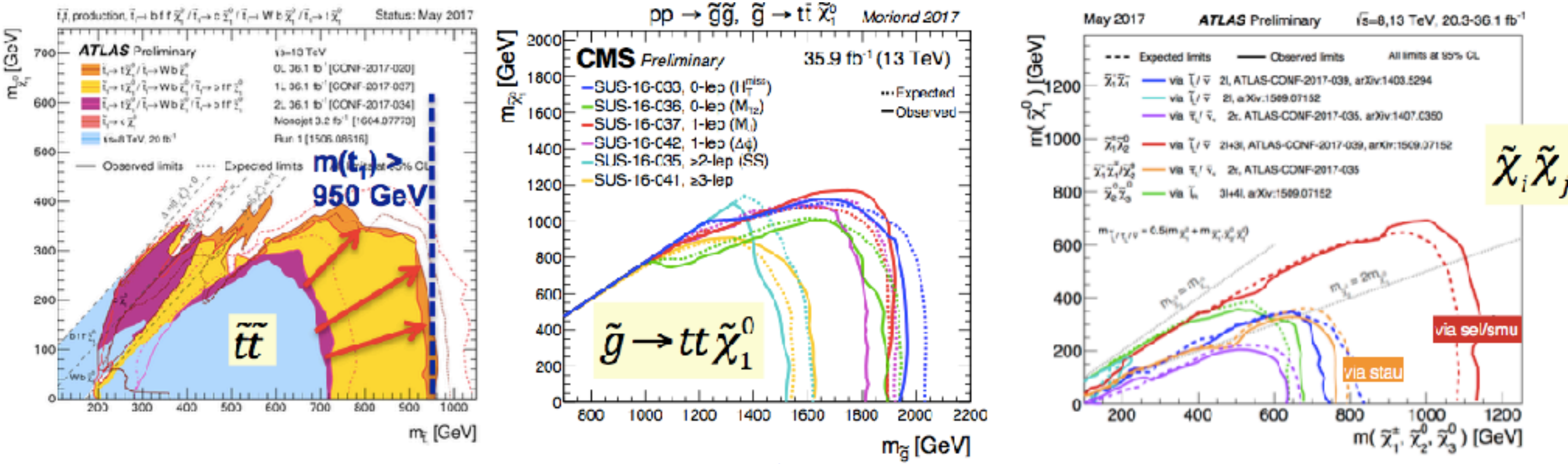
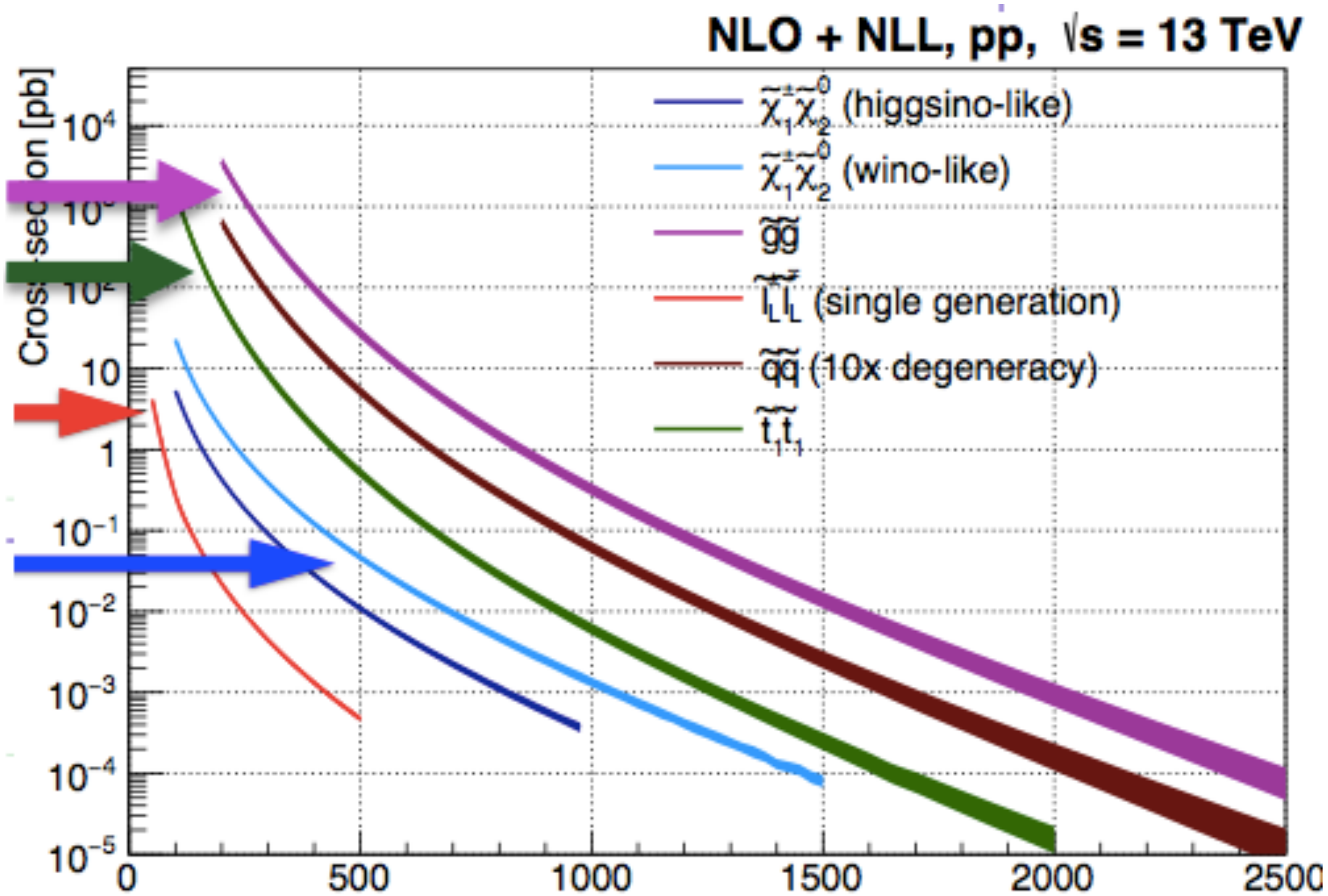


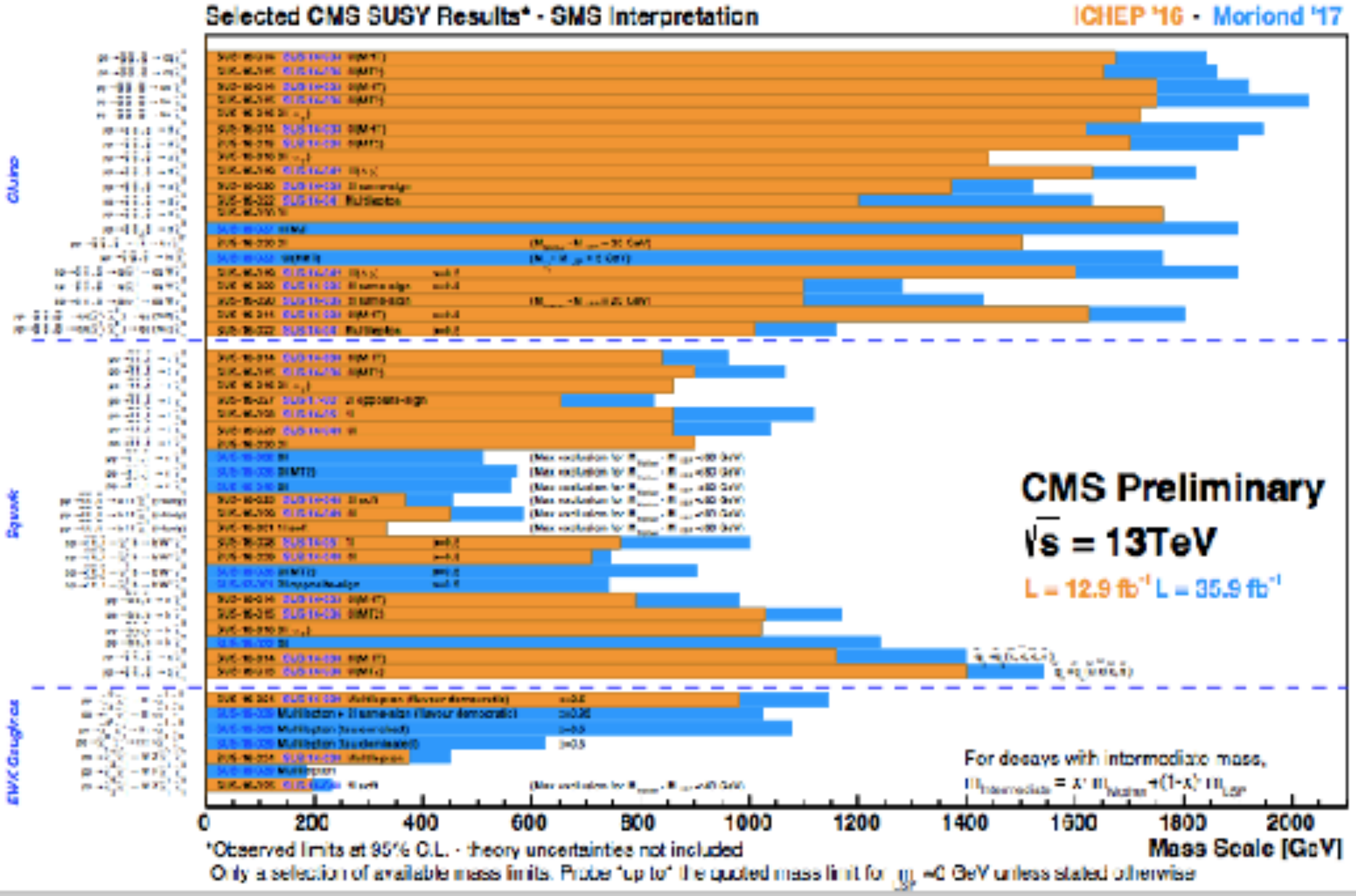
Masses of superpartners

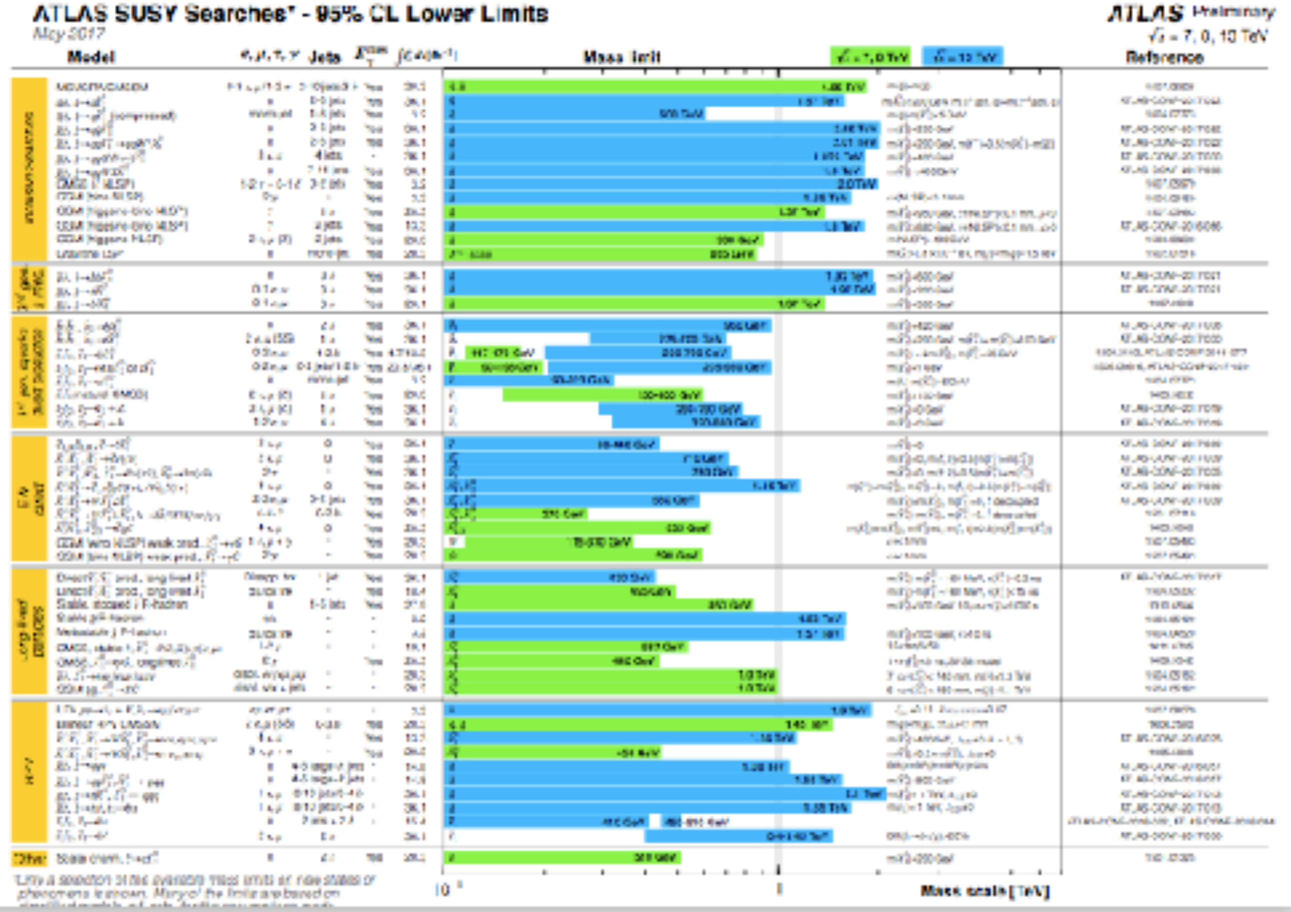
WHERE ARE WE NOW?

Strong production
(gluinos, squarks)

EWK production
(charginos, neutralinos, sleptons)







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$$\begin{array}{ccccl}
 & \text{Low energy} & & \Rightarrow & \text{High energy} \\
SU_c(3)\otimes & SU_L(2)\otimes & U_Y(1) & \Rightarrow & G_{GUT} \quad (or\ G^n + \text{discrete symmetry}) \\
\text{gluons} & W, Z & \text{photon} & \Rightarrow & \text{gauge bosons} \\
\text{quarks} & \text{leptons} & & \Rightarrow & \text{fermions} \\
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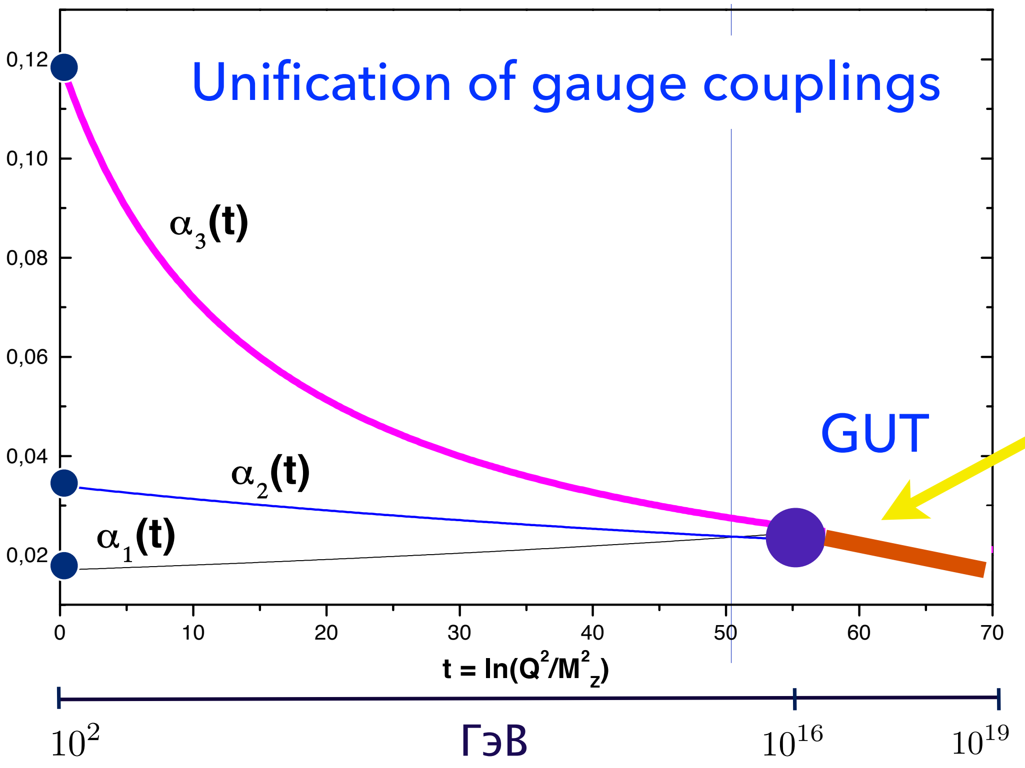

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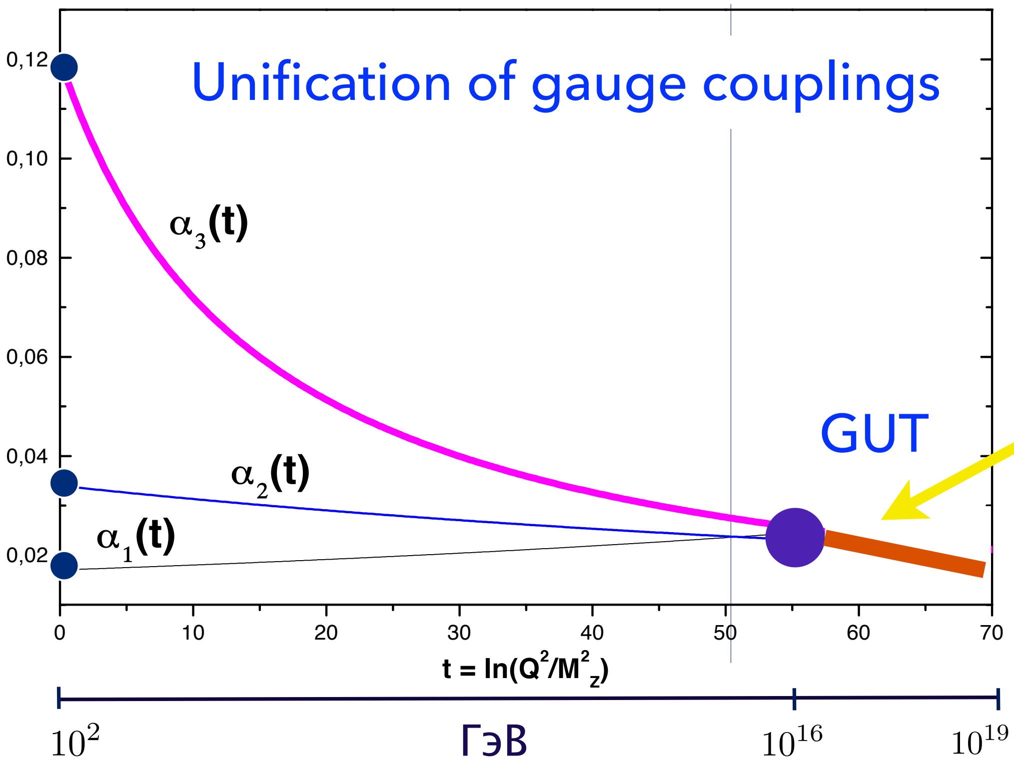

Unification of gauge couplings

$$SU(3) \times SU(2) \times U(1) \subset G_{GUT}$$

$$Ex: SU(5), SO(10), E(6), SU(5) \times U(1),$$
$$SU(4) \times SU(2) \times SU(2), SO(10) \times U(1)$$

GRAND UNIFICATION

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Solves many problems of the SM:

- absence of Landau pole
- Decreases the number of parameters
- All particles in a single representation (**16** of SO(10))
- Unifies quarks and leptons -> spectrum and mixings from «textures»
- A way to **B** and **L** violation

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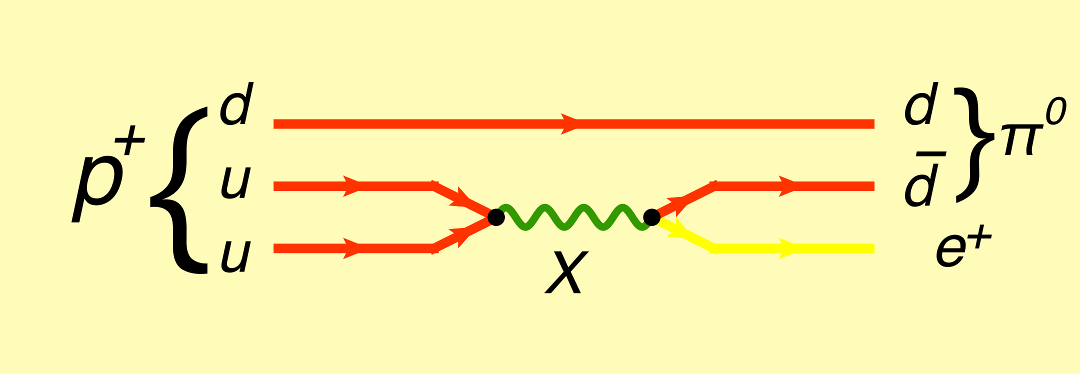

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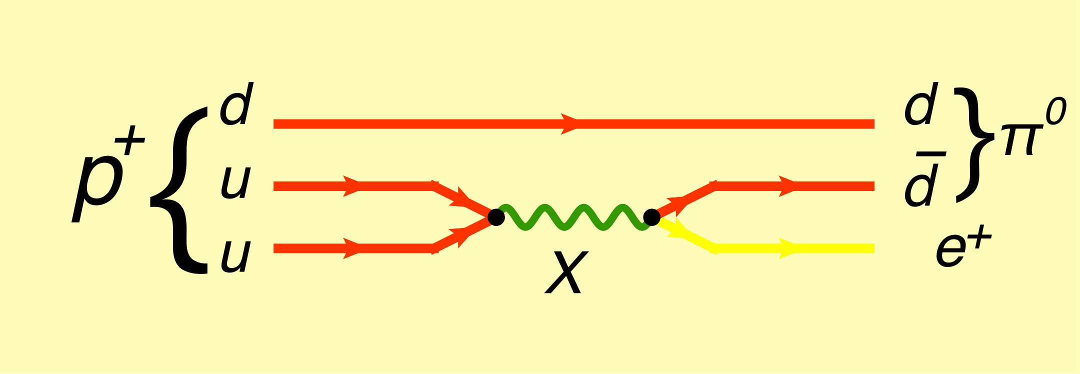

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Experiment:

mean life time > $10^{31} - 10^{33}$ years

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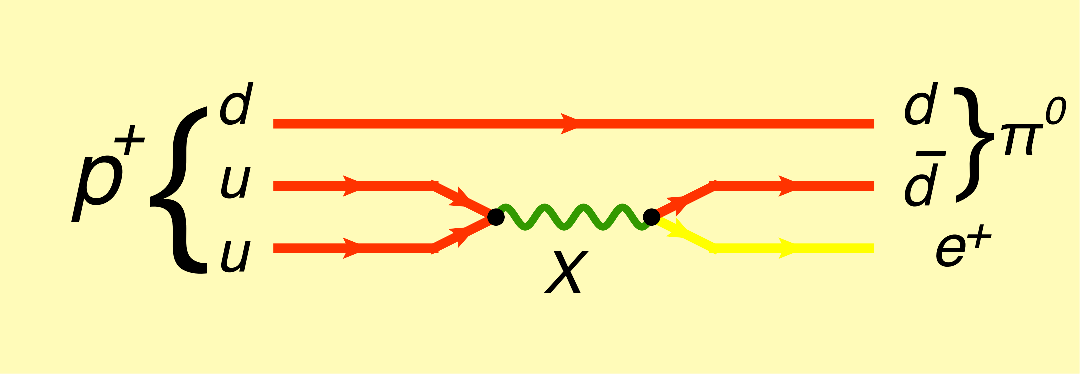

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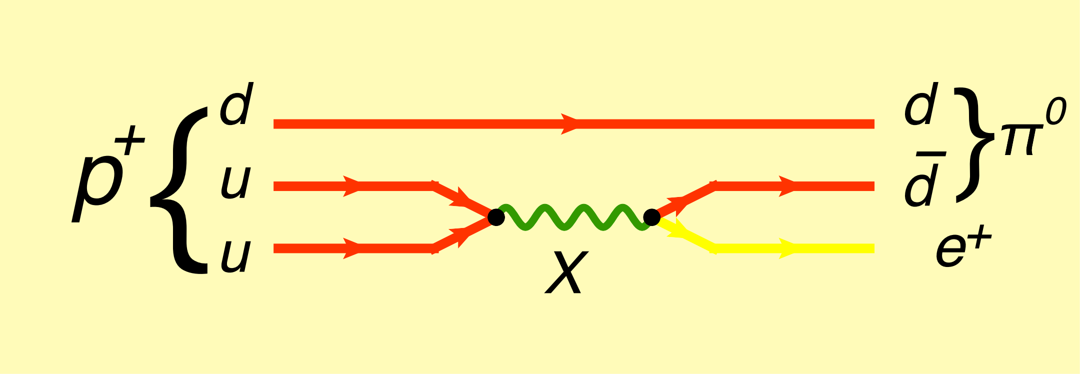

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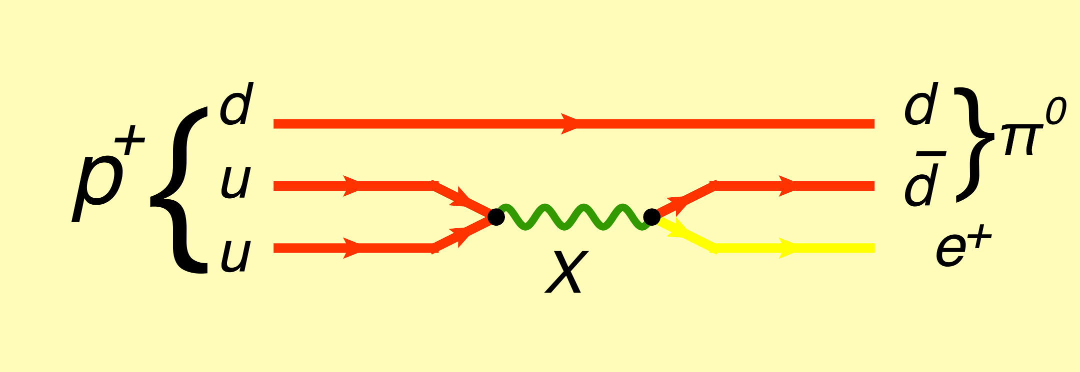

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Low energy SUSY

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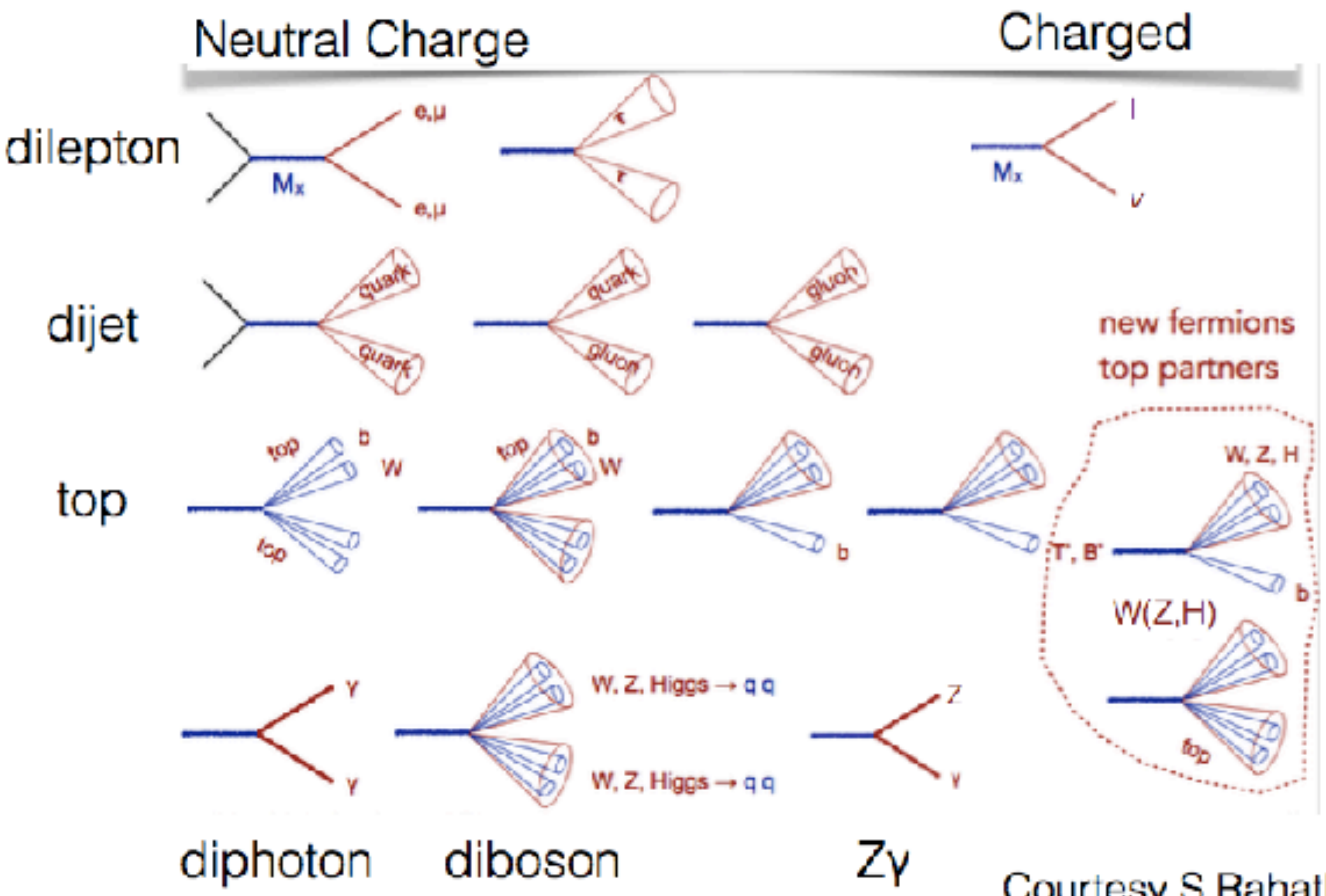

Courtesy S.Rahatlou

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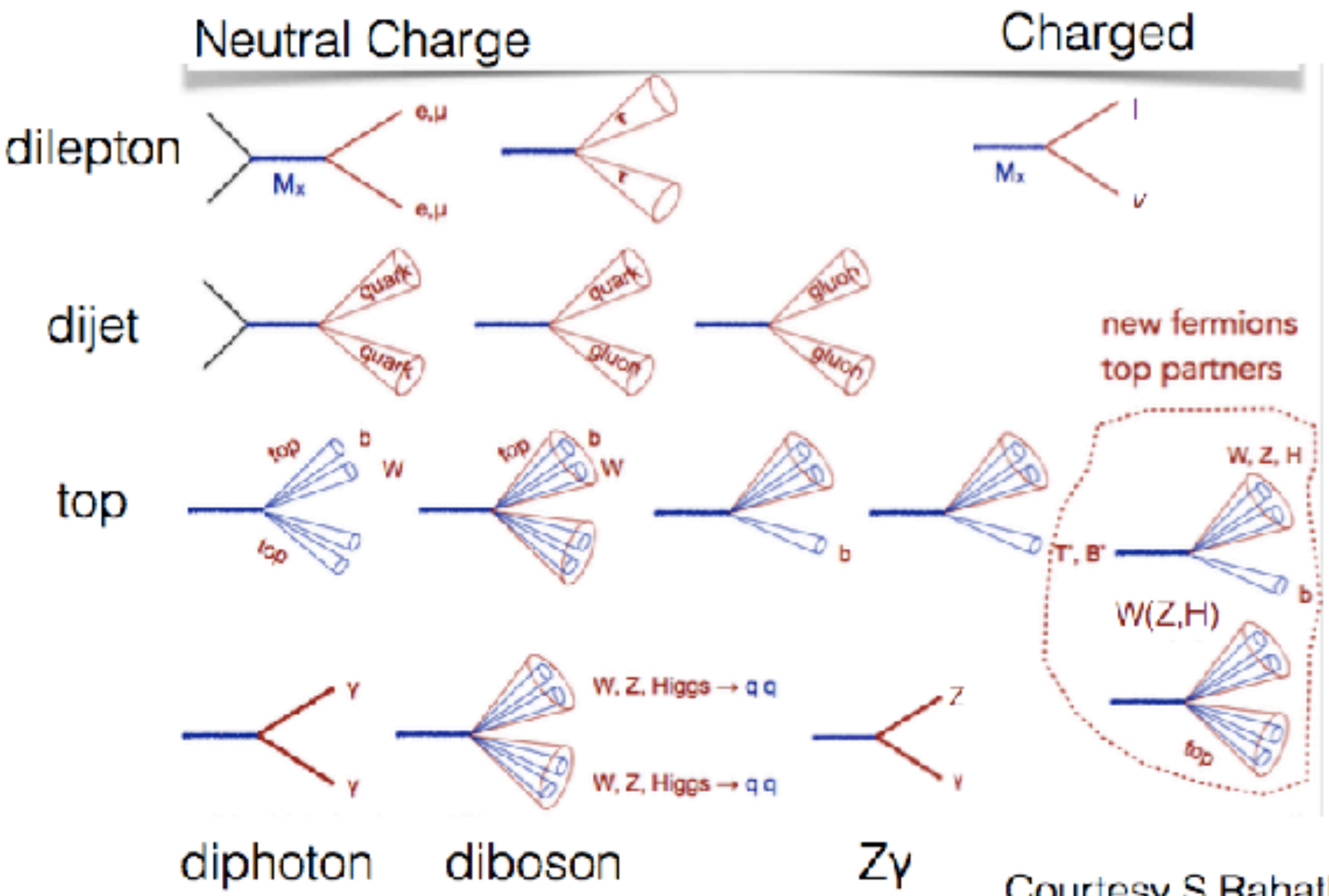

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EXTRA U(1)', SU(2)'

Used as possible Dark matter candidate - Dark photon

Mixture of a usual EM U(1) photon and a new U(1)' one

$$\mathcal{L} \sim F_{\mu\nu} F'^{\mu\nu}$$

Dedicated experiment to look for conversion of a usual photon into a dark one

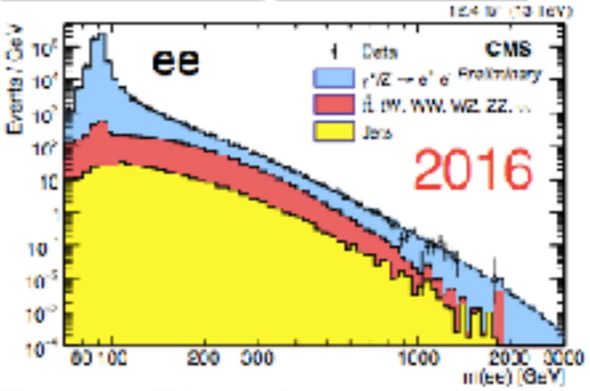
ADDITIONAL GAUGE BOSONS

Experiment

- Search for Z’ (Di-muon events)
- Search for W’ (single muon/ jets)
- Search for resonance decaying to t-tbar
- Search for diboson resonances
- Monojets + invisible

Same Flavor Opposite Sign (ee, μμ, ττ)

ATLAS-CONF-2016-045 CMS-PAS-EXO-16-031

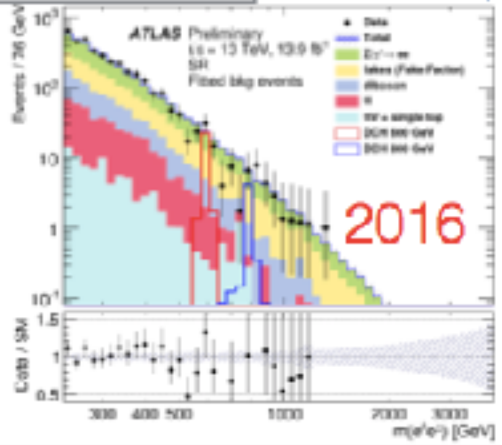


Same Sign (ee, μμ)

Z'_{SSM}(3% width) >4 TeV

Z'_{χ} (0.5% width) >3.36 TeV

ATLAS-CONF-2016-051

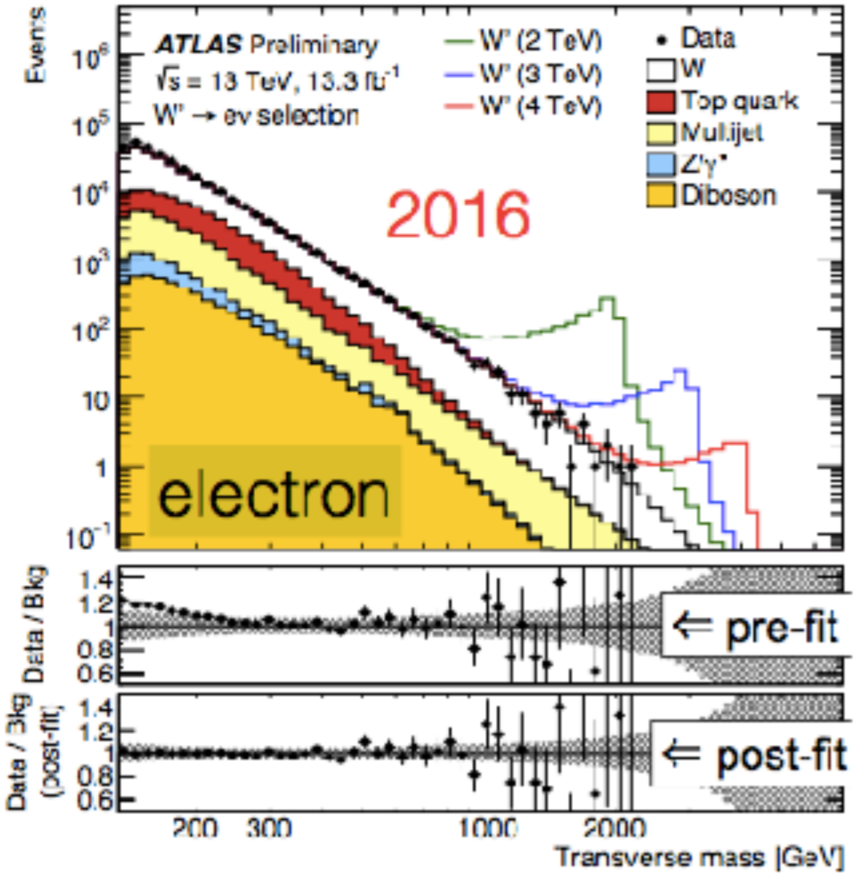


95% CL exclusion limit

$H_R^{\pm\pm}$ >420 GeV

$H_L^{\pm\pm}$ >570 GeV

ATLAS-CONF-2016-061 CMS-PAS-EXO-15-006



SSM W’ >4.74 TeV

No indication so far - experimental limits on Z’ and W’ masses around few TeV

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EXTENDED HIGGS SECTOR

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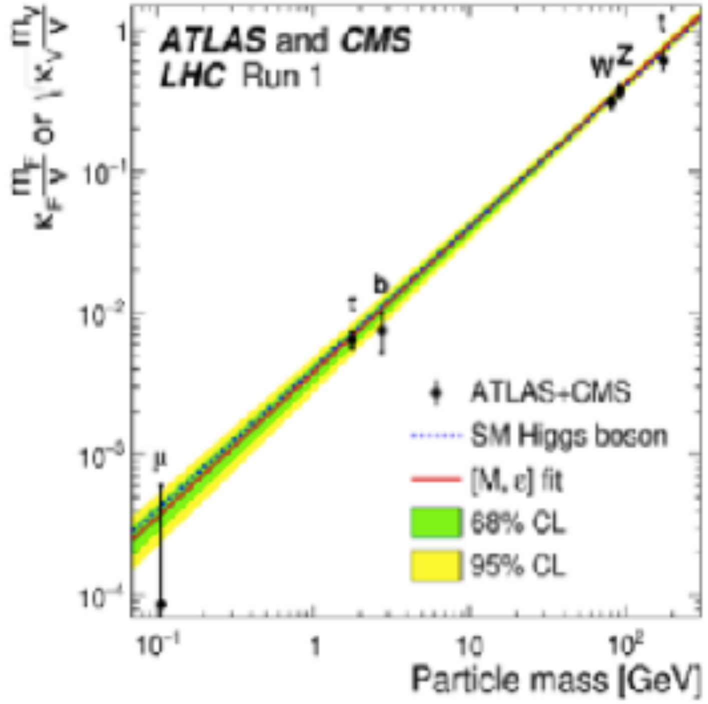

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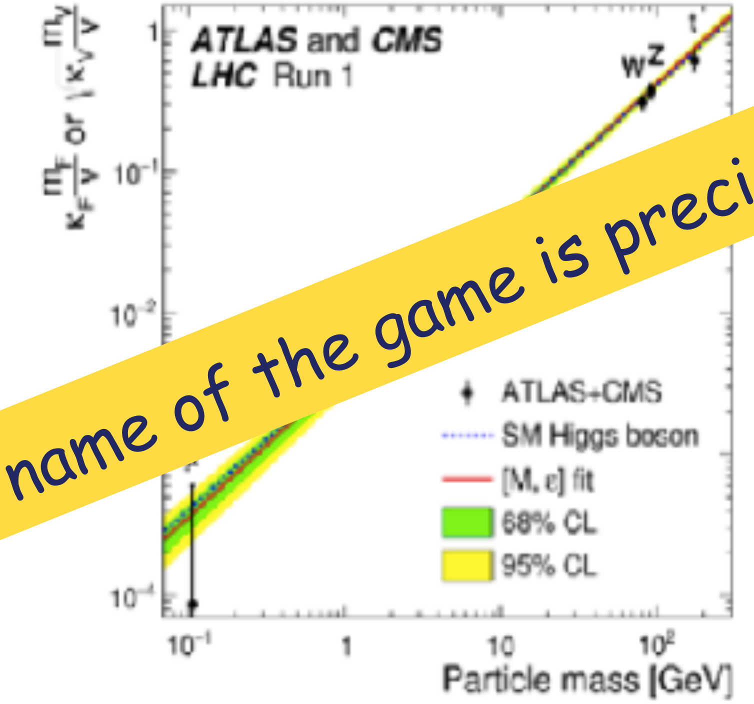

The name of the game is precision

A. Singlet extension
B. Higgs doublet extension
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NEW PARTICLES

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How to probe?

- Perform direct search for additional scalars

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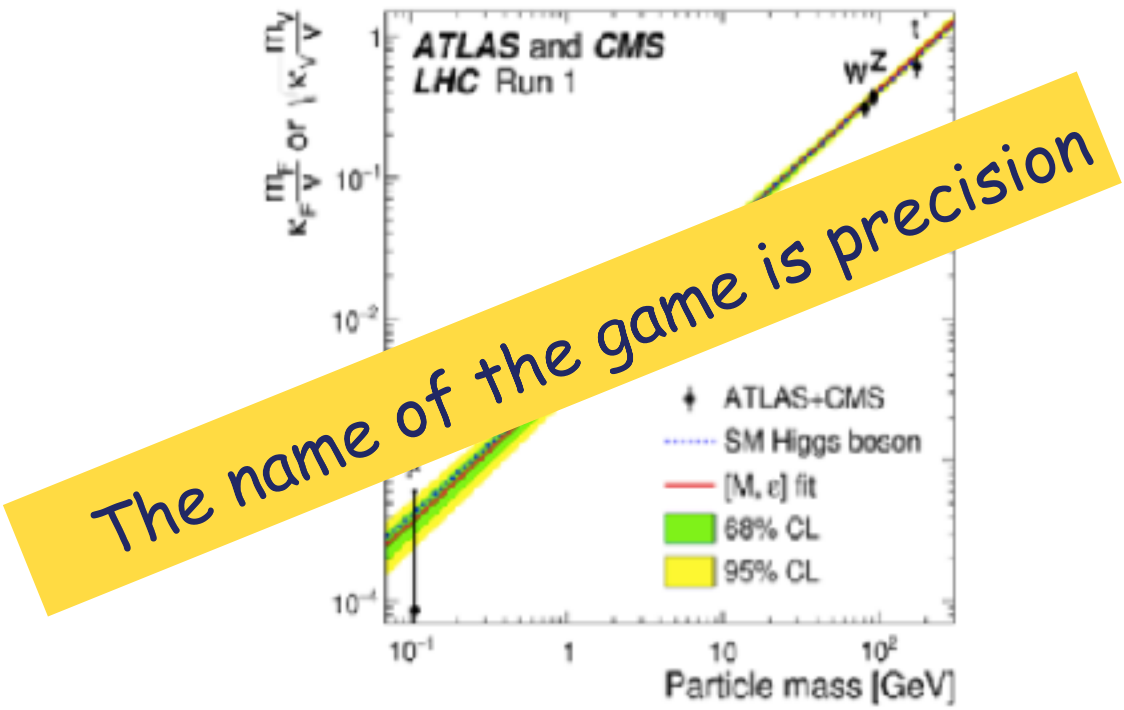

The name of the game is precision

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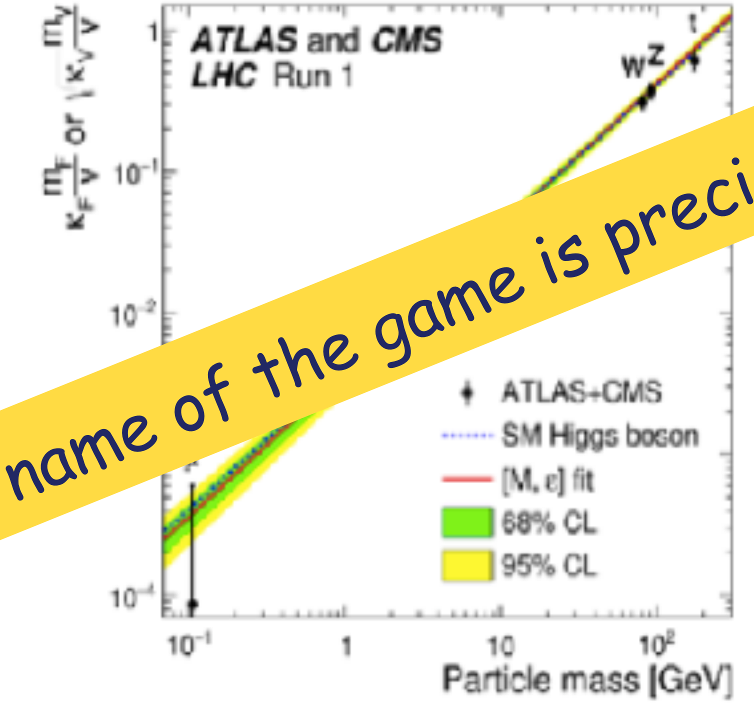

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EXTENDED HIGGS SECTOR

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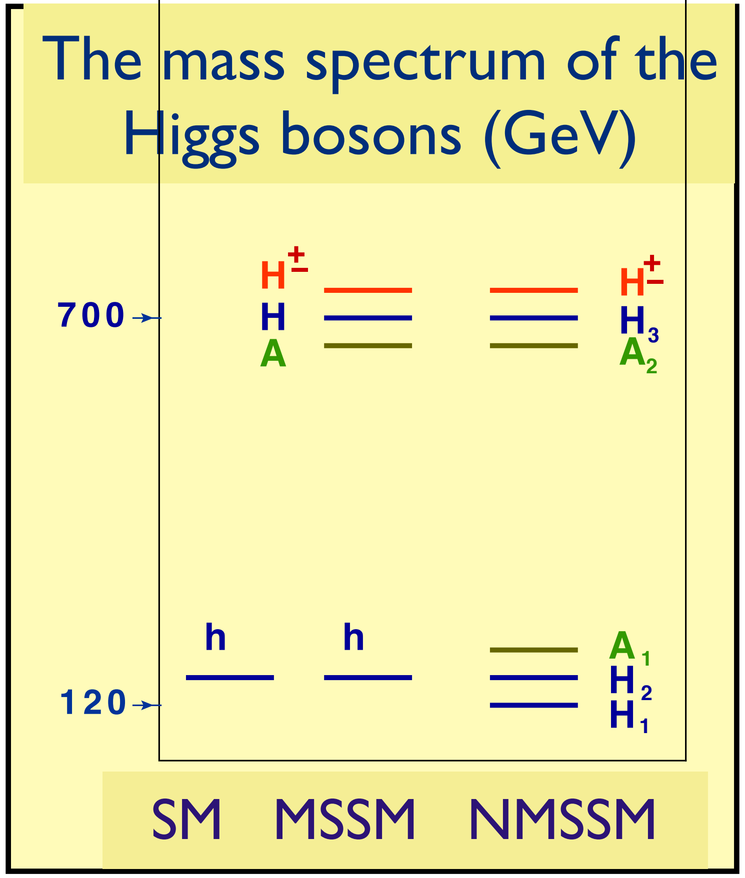
The mass spectrum of the Higgs bosons (GeV)

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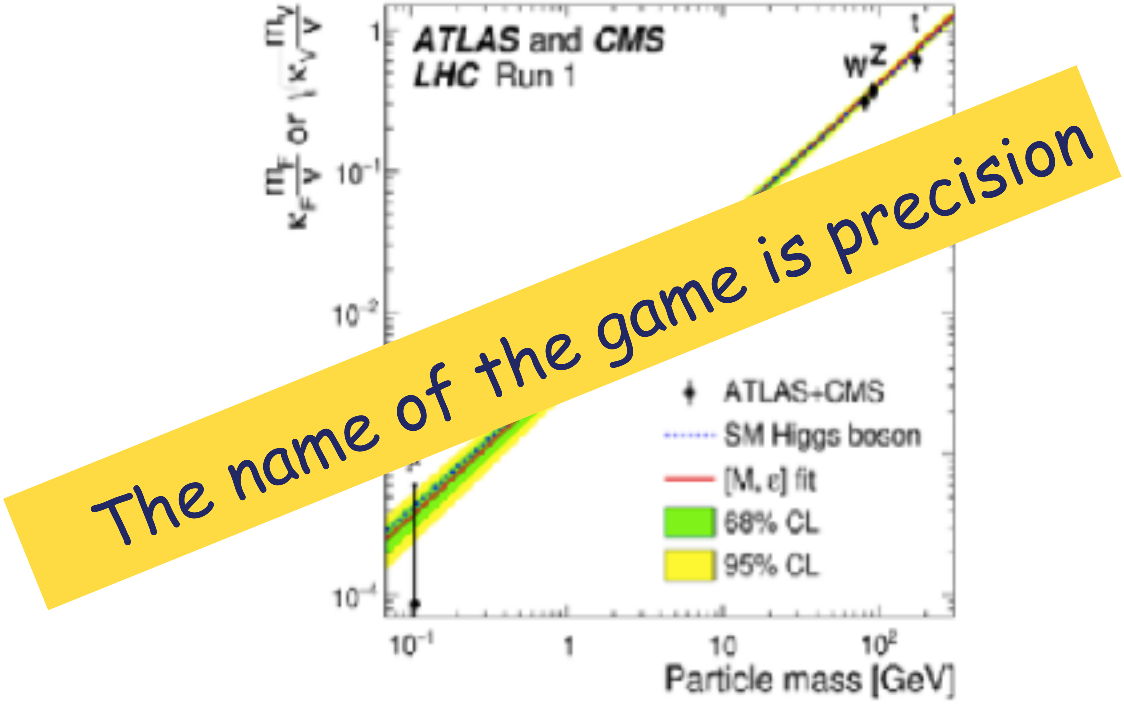

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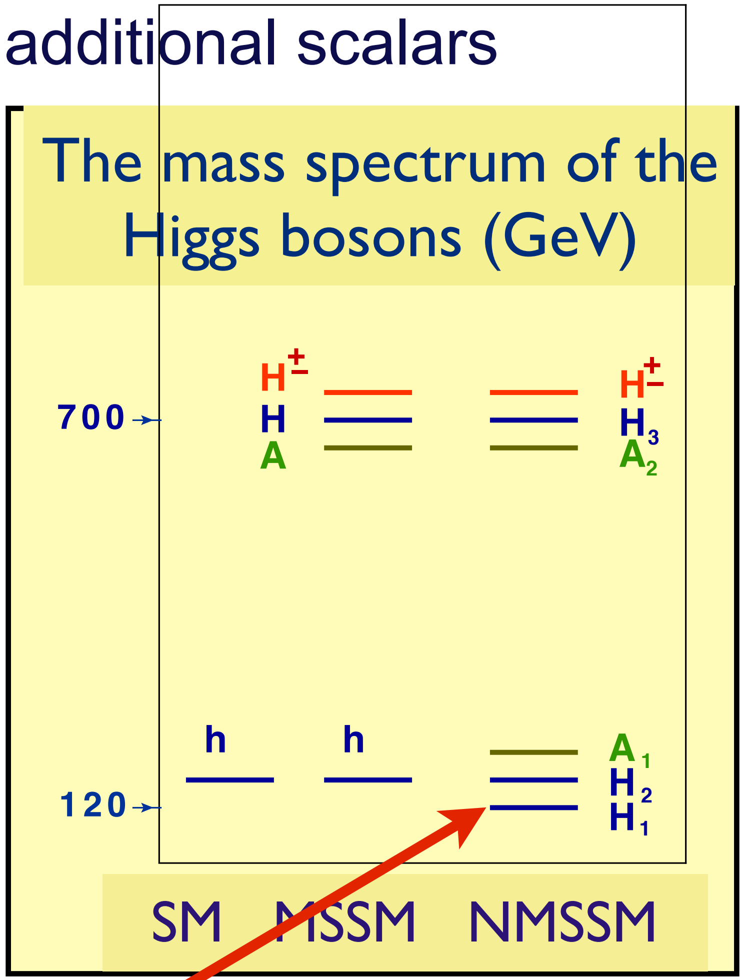

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We may have found one of these states

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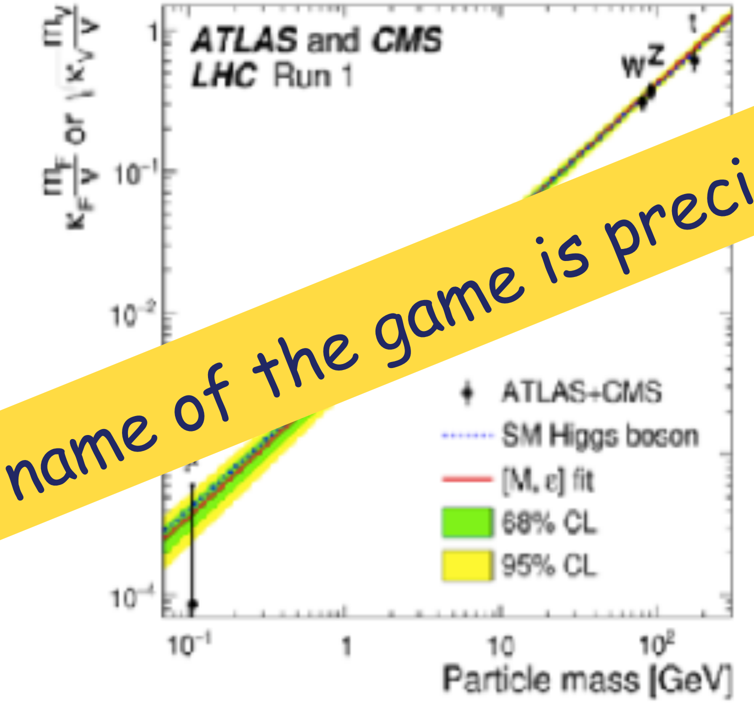

The name of the game is precision

- The Higgs physics has already started
- This is the task of vital importance.
- May require the electron-positron collider

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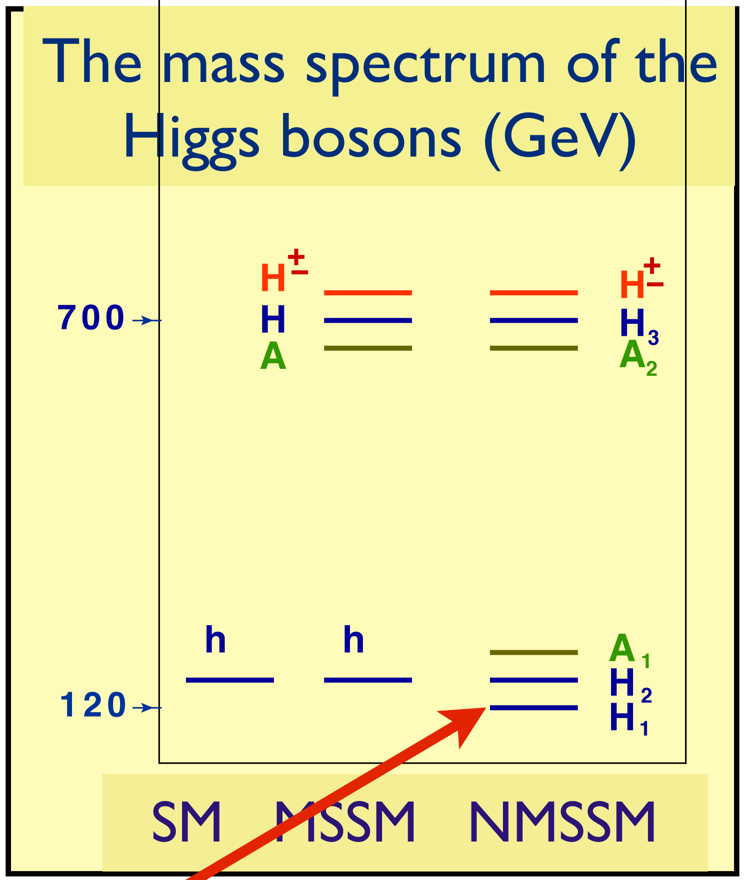

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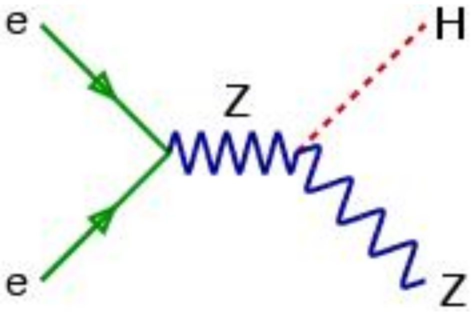
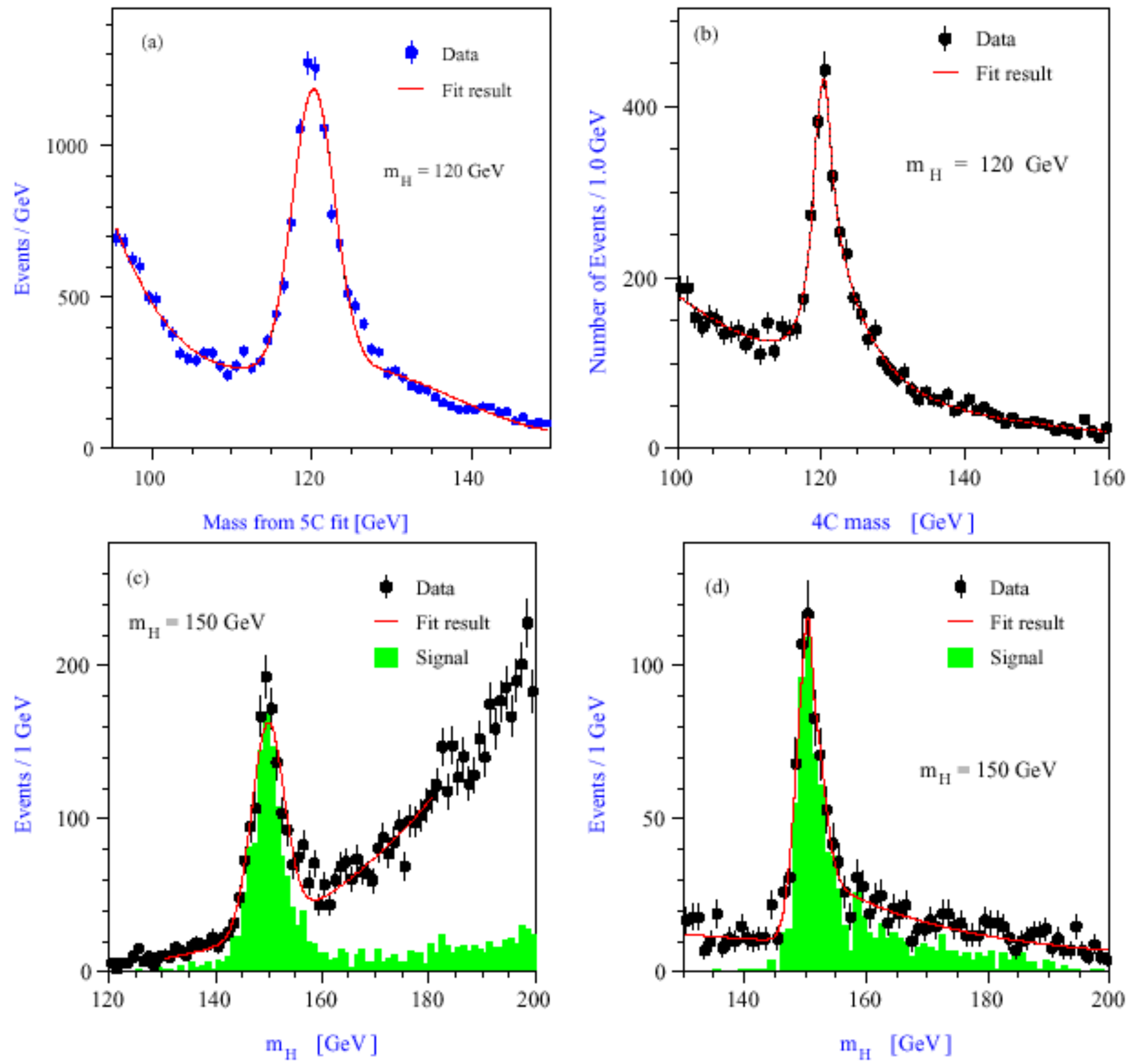
PRECISION PHYSICS OF THE HIGGS BOSONS



$\to b\bar{b}q\bar{q}$

$\to q\bar{q}\ell^+\ell^-$

ee -> HZ diff. decay channels



$\Delta m_H =$ 40 MeV

$\to W^+W^-q\bar{q}$

$\to W^+W^-\ell^+\ell^-$

$\Delta m_H =$ 70 MeV

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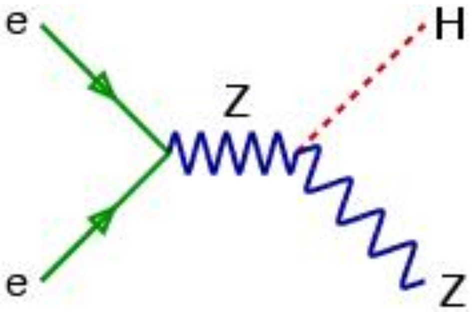

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Int Linear Collider

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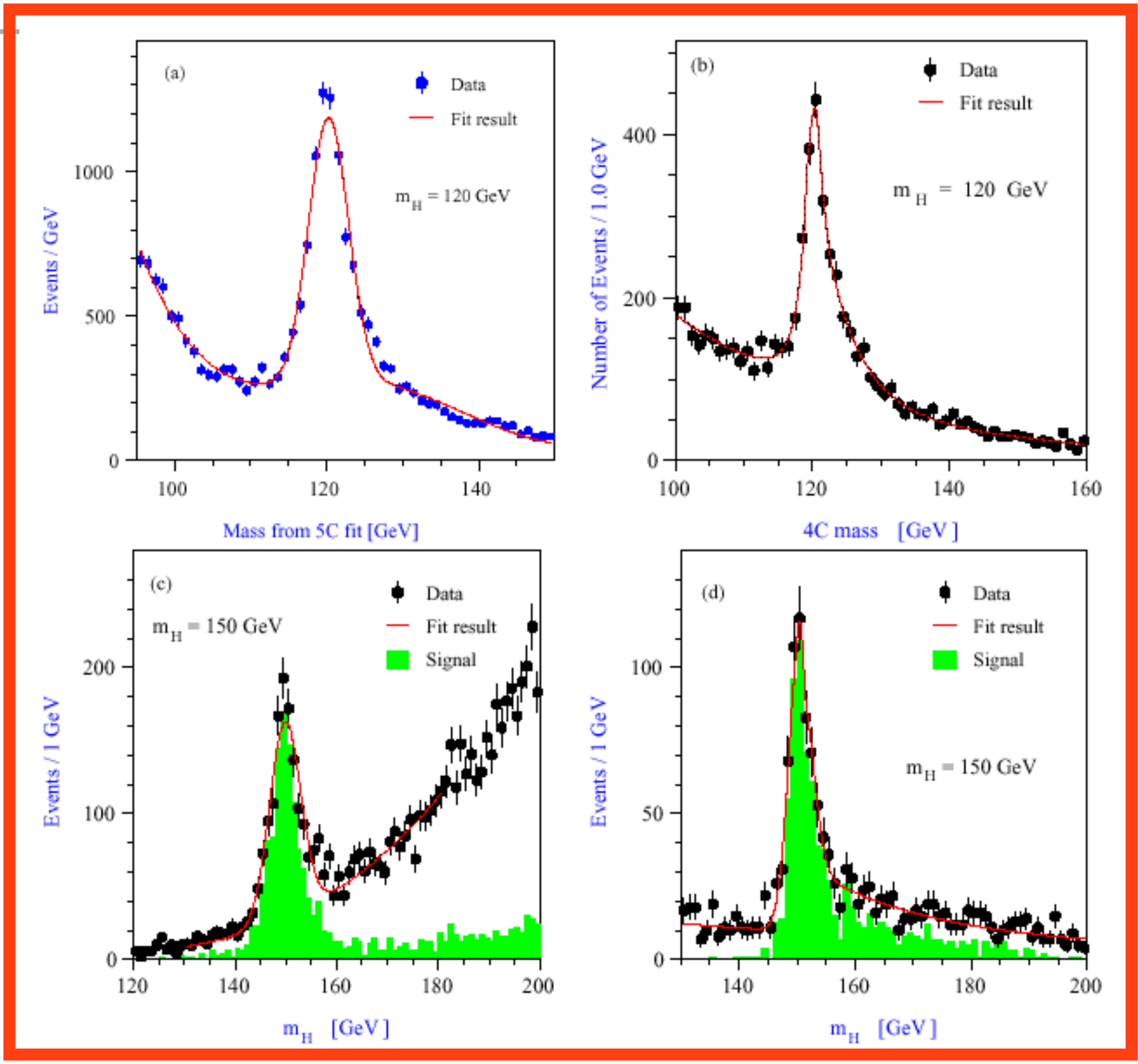

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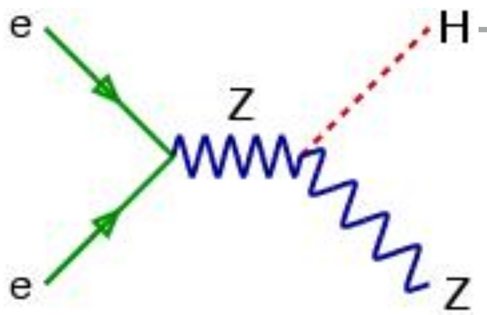

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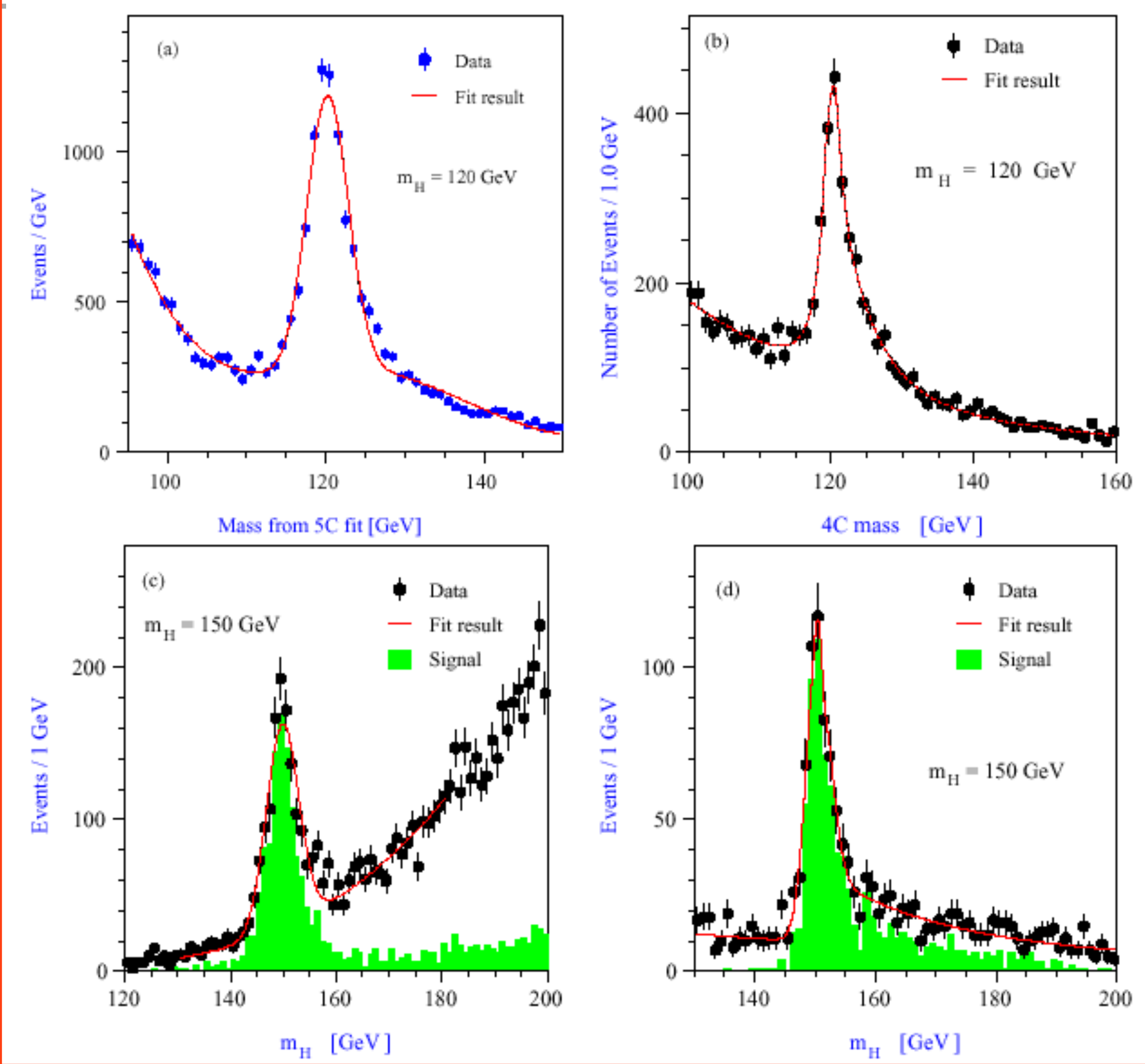

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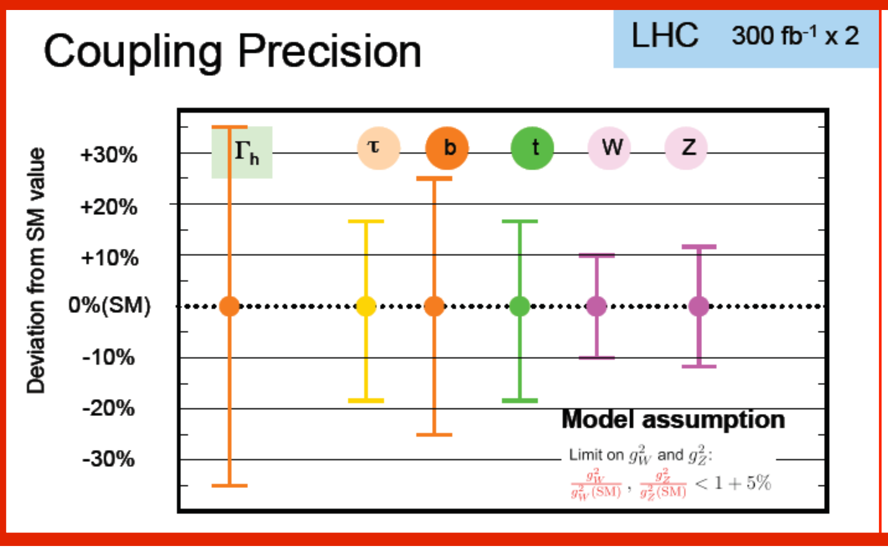

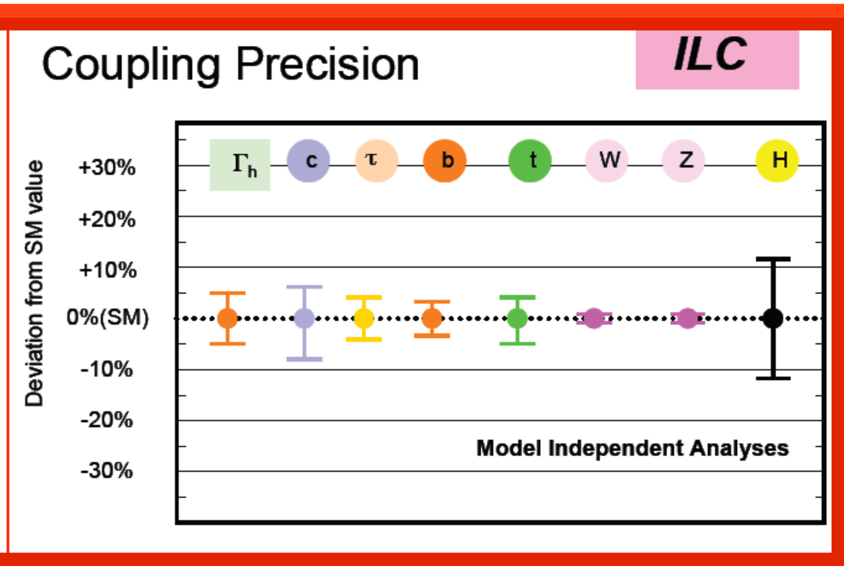

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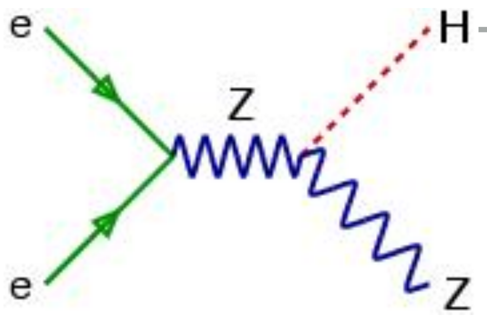

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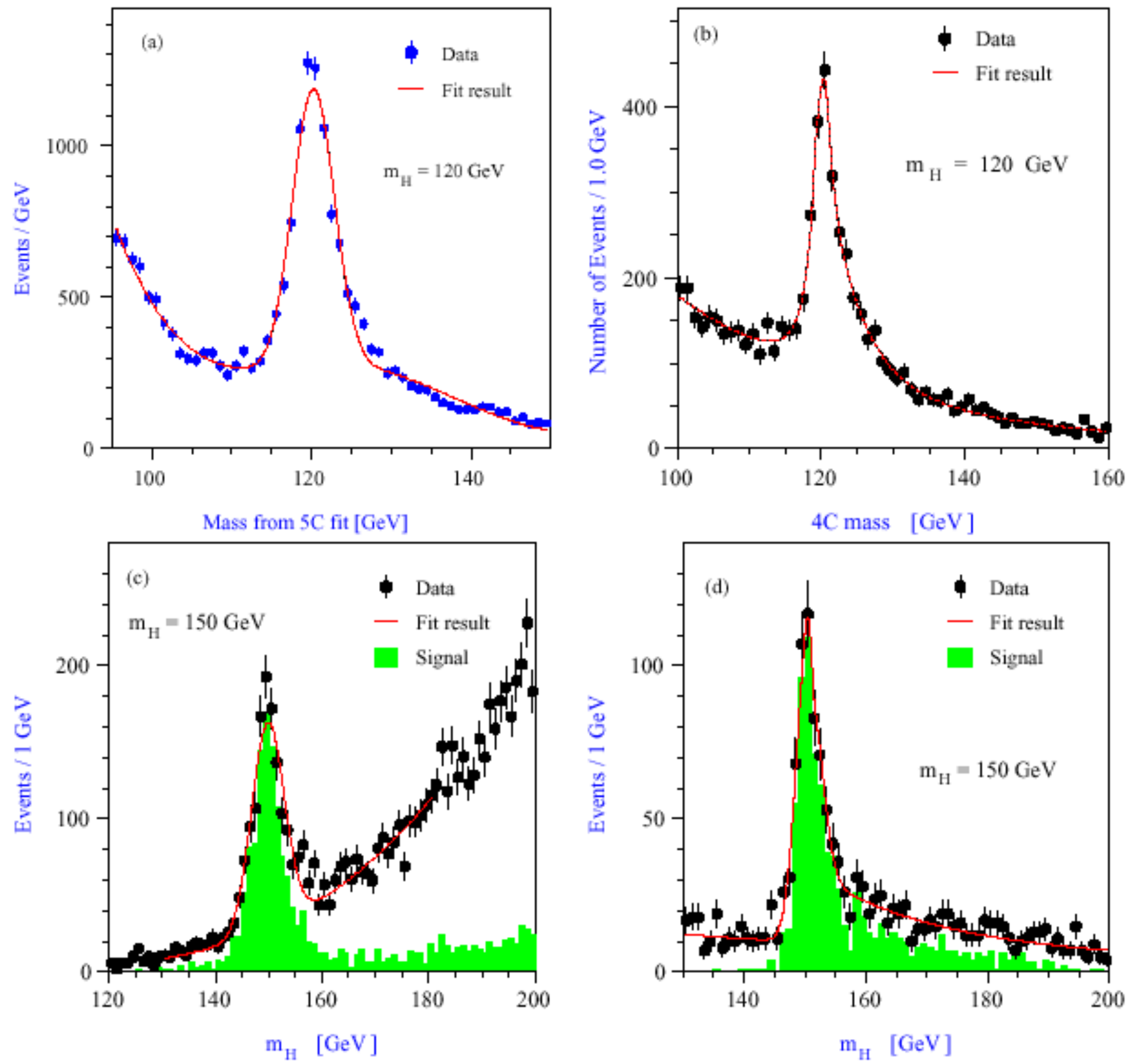

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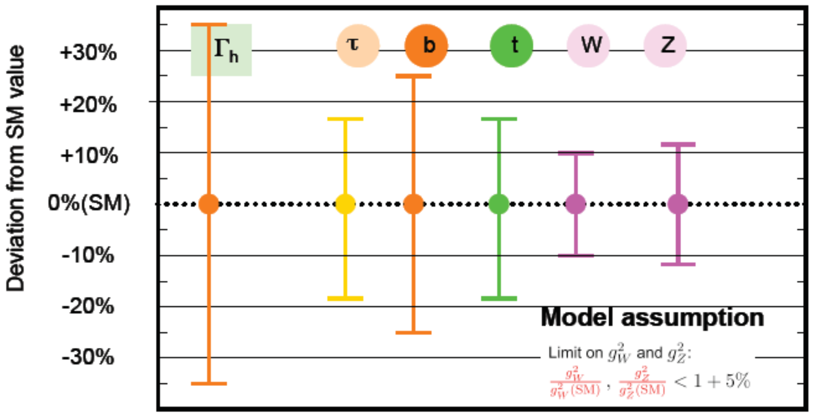
Coupling Precision

LHC 300 fb^{-1} x 2

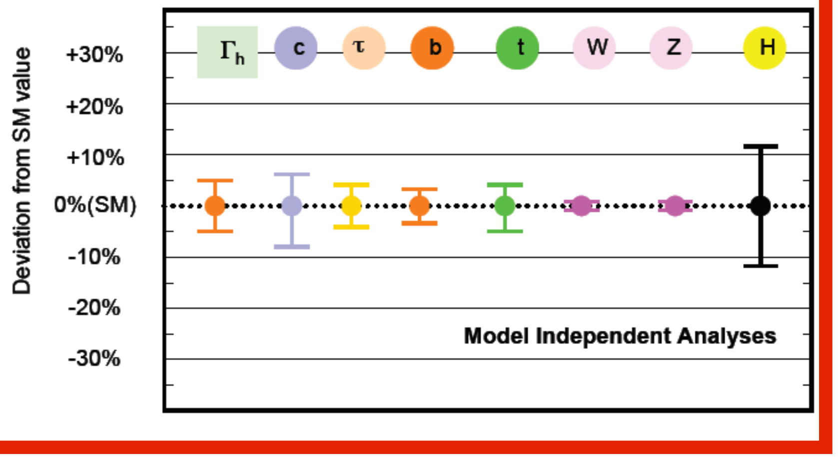


Model assumption

Limit on g_W^2 and g_Z^2: $\frac{g_W^2}{g_W^2(\mathrm{SM})}, \frac{g_Z^2}{g_Z^2(\mathrm{SM})} < 1+5\%$

Coupling Precision

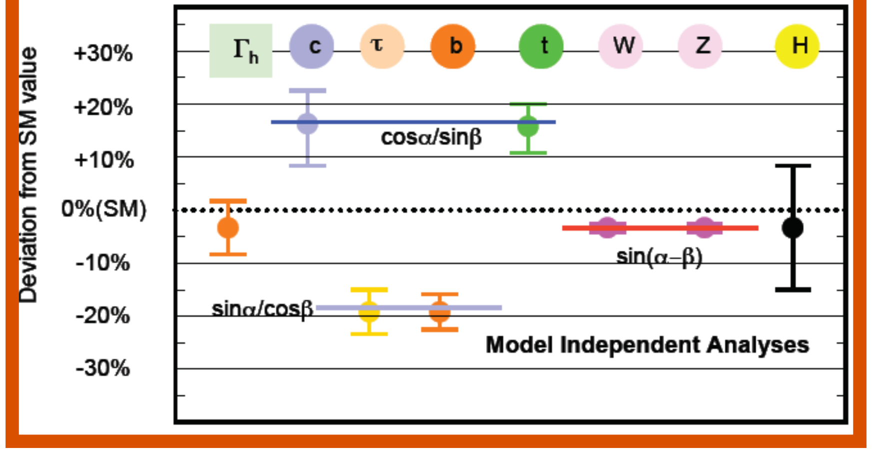
ILC



Model Independent Analyses

SUSY or 2HDM

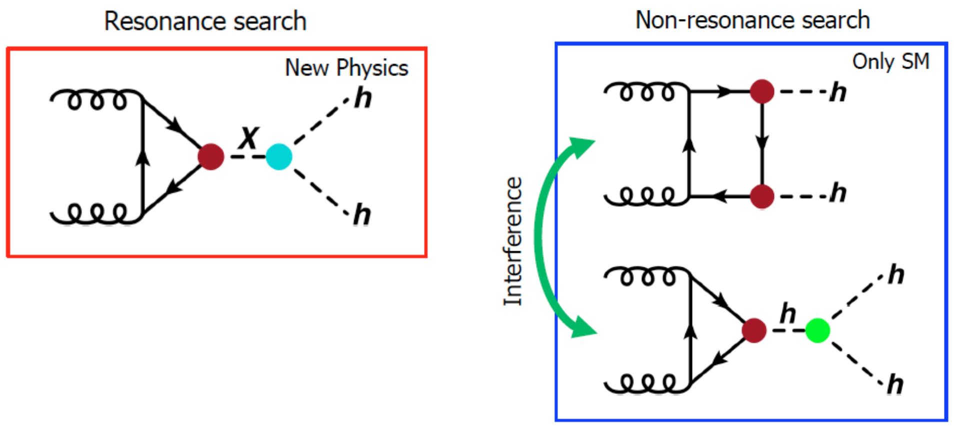
ILC

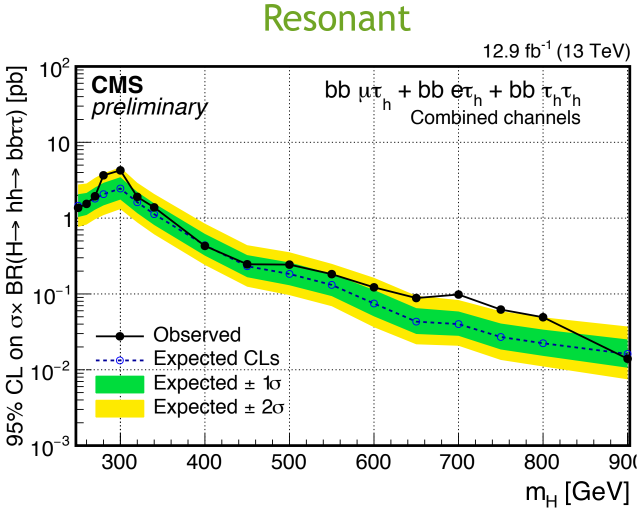


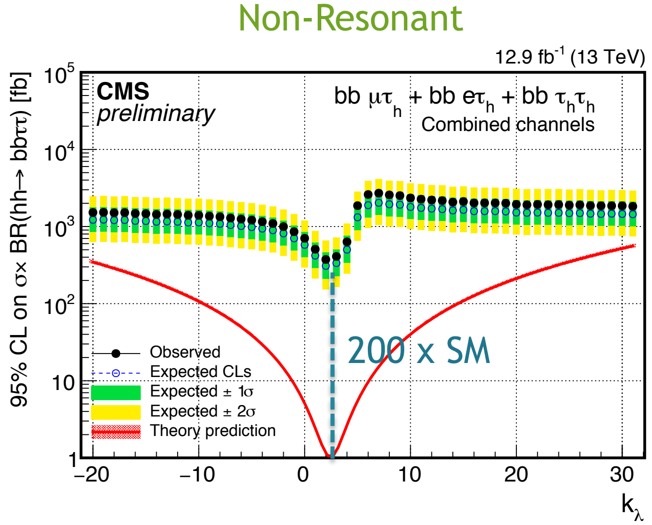
Model Independent Analyses

EXTRA HIGGS BOSONS

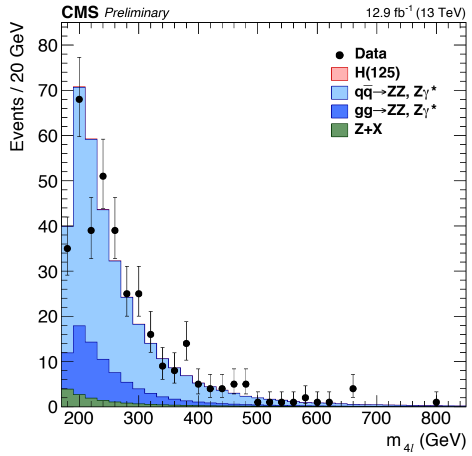
Higgs→hh→bbττ

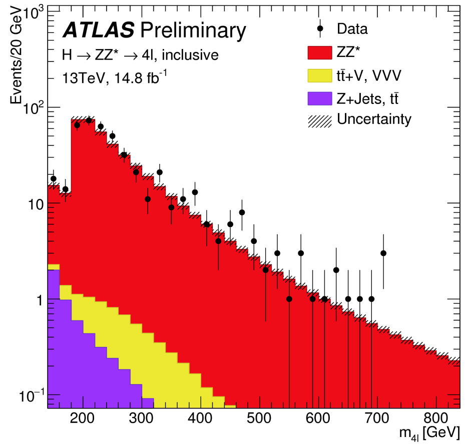




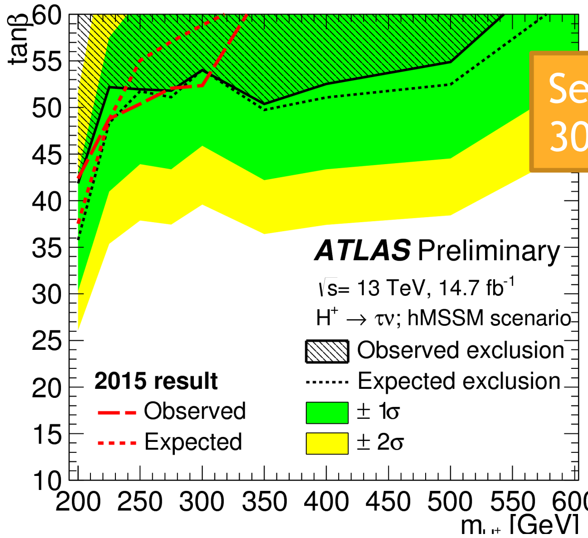


Heavy Higgs→ZZ→4l



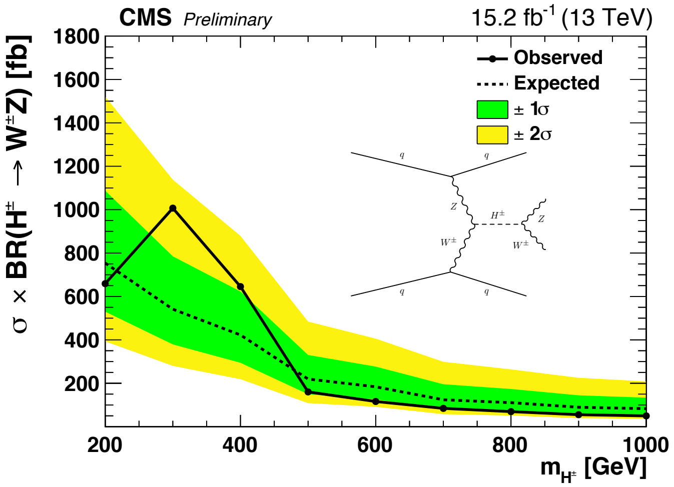


Charged Higgs



Search for H±→tb 300<$m_{H^\pm}$<1000 GeV

Search for H±WZ



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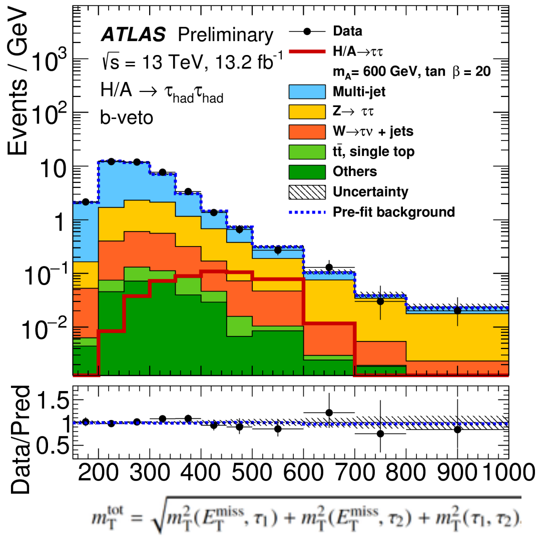
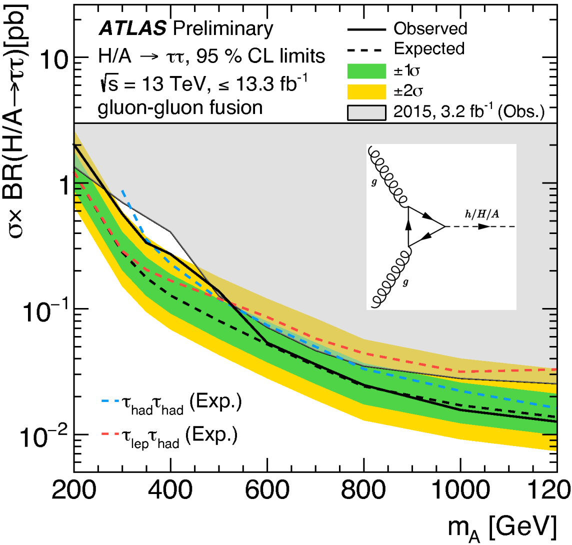




NEW PARTICLES

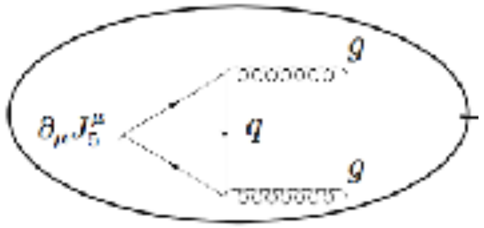
AXION OR AXION-LIKE PARTICLES

Javier Redondo, EPS HEP 2017

- **CP violation in QCD sector: CKM angle** $\delta_{13} = 1.2 \pm 0.1\,\mathrm{rad}$ **AND flavour-neutral phase** $\theta = \theta_{\mathrm{QCD}} + N_f\delta$

$$\mathcal{L}_{\mathrm{SM}} \in -\bar{q}_L \begin{pmatrix} m_u e^{i\delta/2} & 0 & \dots \\ 0 & m_d e^{i\delta/2} & \dots \\ 0 & 0 & \dots \end{pmatrix} \begin{pmatrix} u \\ d \\ \dots \end{pmatrix}_R - \frac{\alpha_s}{8\pi} G\widetilde{G}\,\theta_{\mathrm{QCD}}$$

Axial anomaly



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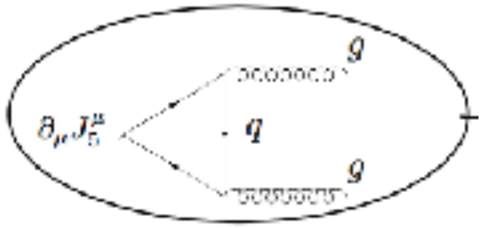
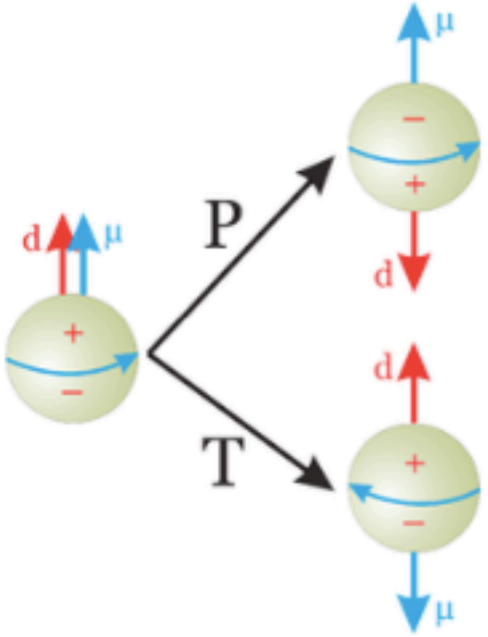


The θ-angle produces flavour-neutral CP violation like Electric Dipole Moments



- **Neutron EDM** **(Guo 1502.02295)**

$$d_n = -4 \times 10^{-3} \times \theta \,[\mathrm{e\,fm}]$$

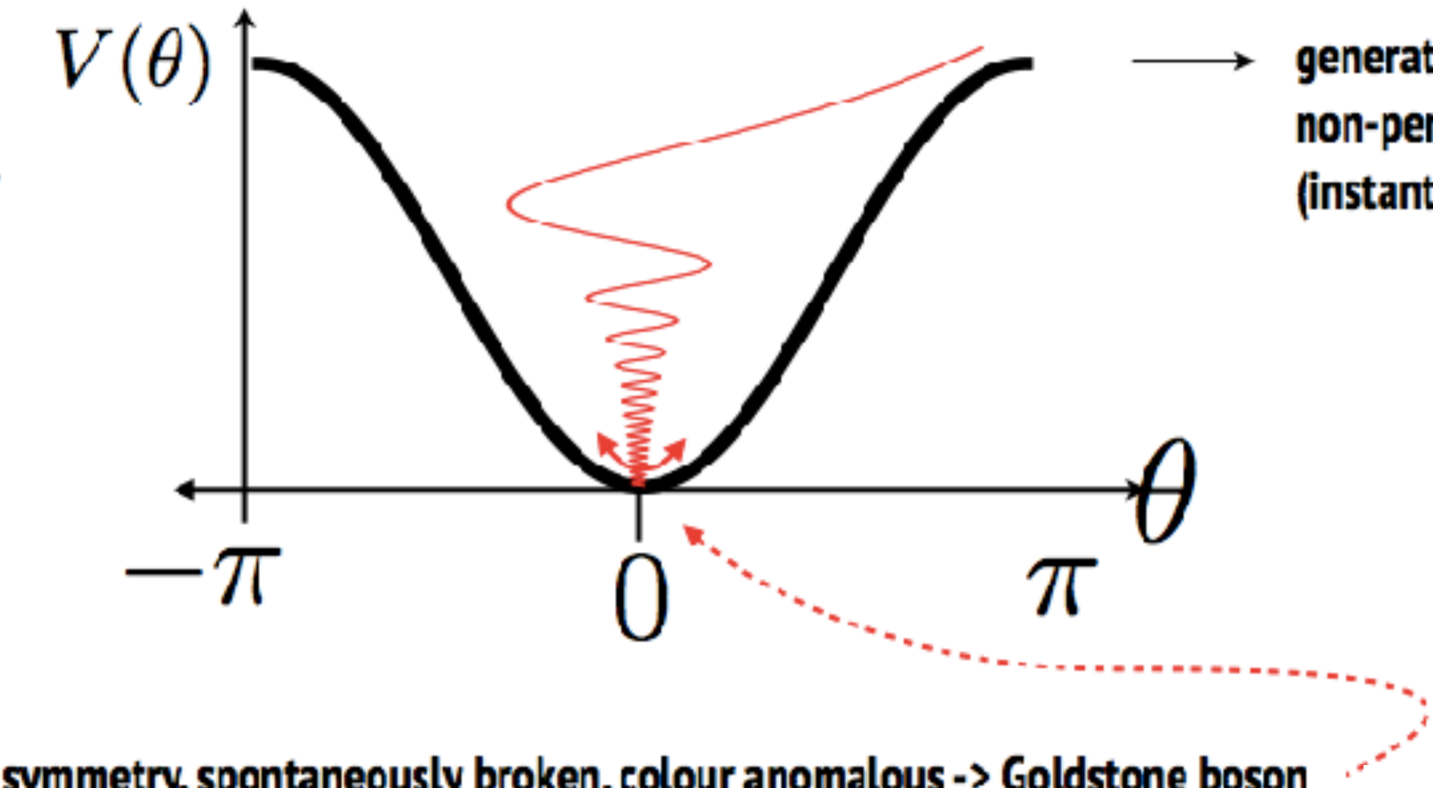
- **Experimental upper limit** **(Grenoble hep-ex/0602020)**

$$|d_n| < 3 \times 10^{-13} \,[\mathrm{e\,fm}]$$

- **Why is $\theta < 10^{-10}$?**

PECCEI-QUINN MECHANISM - AXION

- Any theory promoting θ to a dynamical field, $\theta(t, \mathbf{x})$,will dynamically set $\theta \to 0$ after some time...



Potential energy density

→ generated by QCD non-perturbative dynamics (instantons)

- PQ Mechanism: Global U(1) axial symmetry, spontaneously broken, colour anomalous -> Goldstone boson

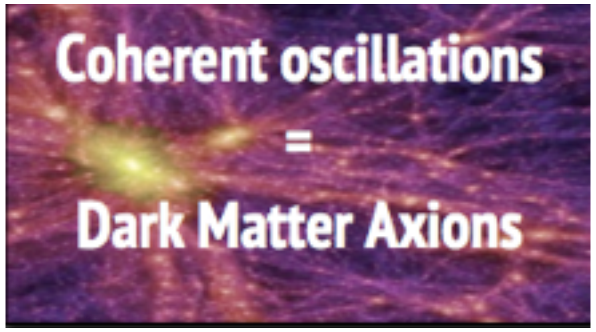
$$\mathcal{L}_\theta = \frac{1}{2}(\partial_\mu \theta)(\partial^\mu \theta) f_a^2 - \frac{\alpha_s}{8\pi} G_{\mu\nu a} \widetilde{G}_a^{\mu\nu} \theta$$

New Spontaneous symmetry breaking [energy] scale f_a

Canonically normalised θ field is the QCD AXION! $a(x) = \theta(x) f_a$

WW Axion

WHAT IS THE MASS TO GET $\Omega_{CDM}h^2 = 0.12$?



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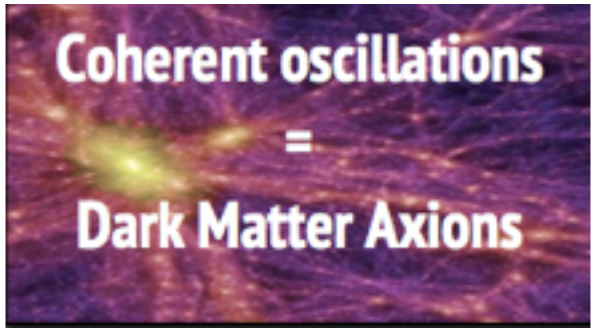

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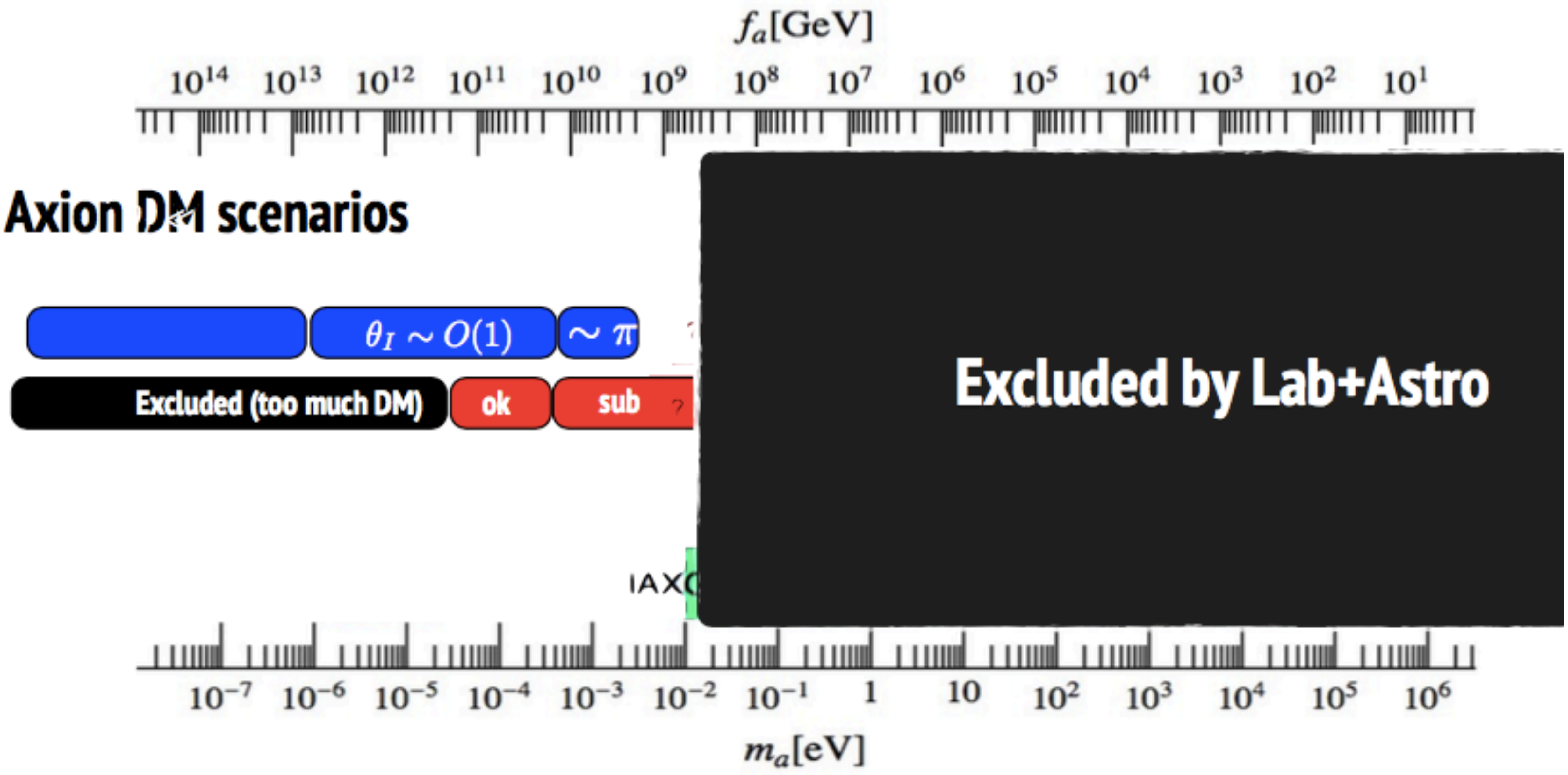
- Axion DM scenarios



- Less minimal axion models have further possibilities ....

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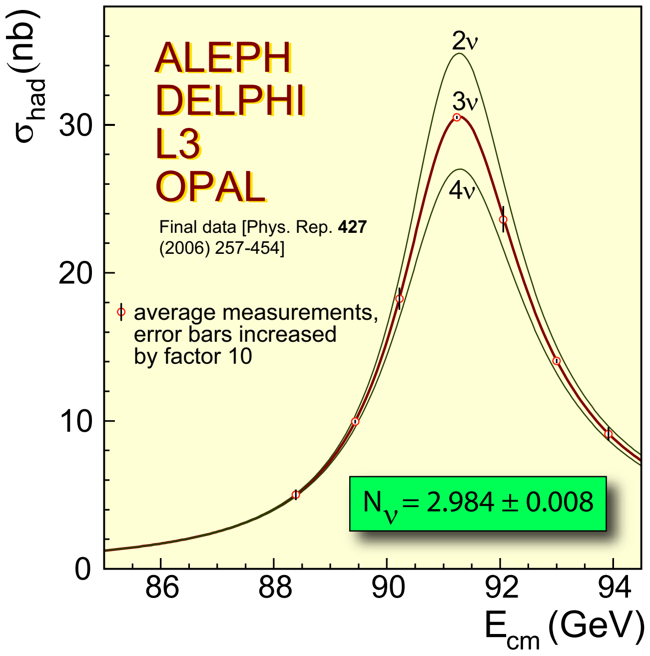
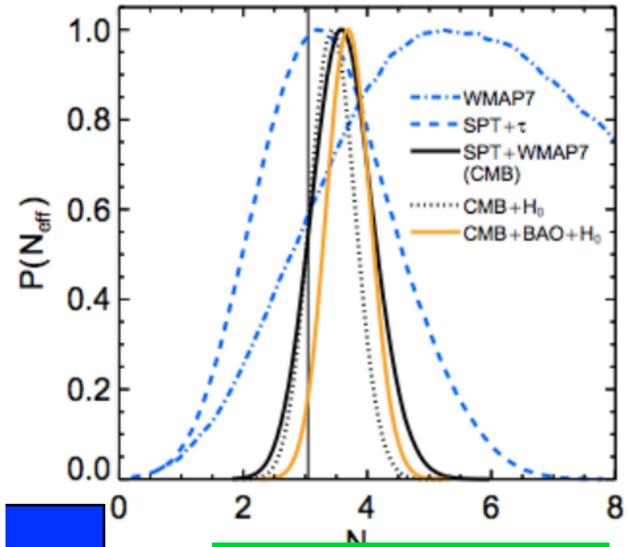
- Number of Generations=3?

- The width of the Z-boson (LEP)



NEUTRINOS

- The CMB spectrum (Planck)



$N_\nu^{eff} < 3.30 \pm 0.27$

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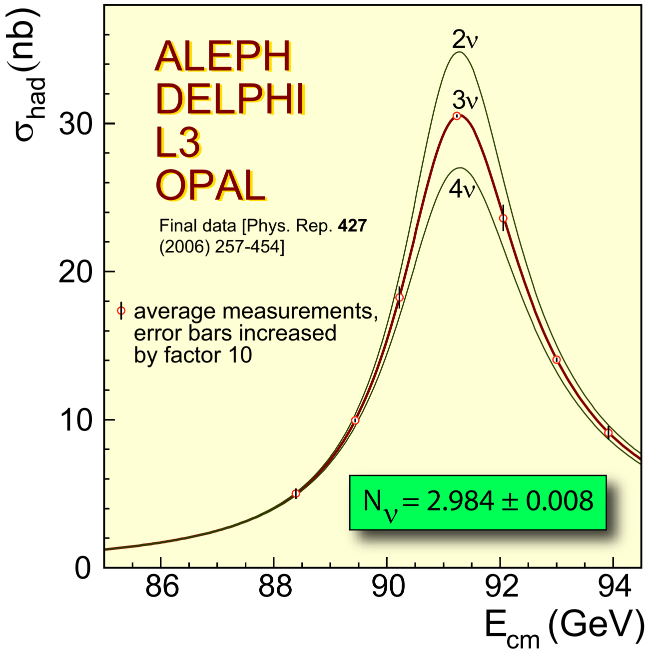

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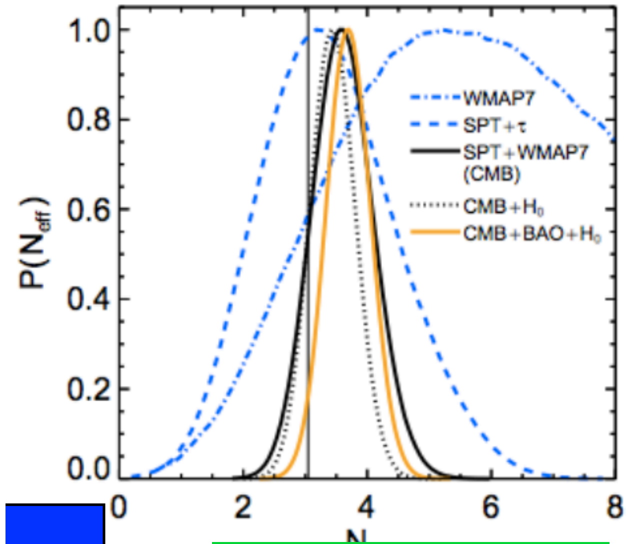

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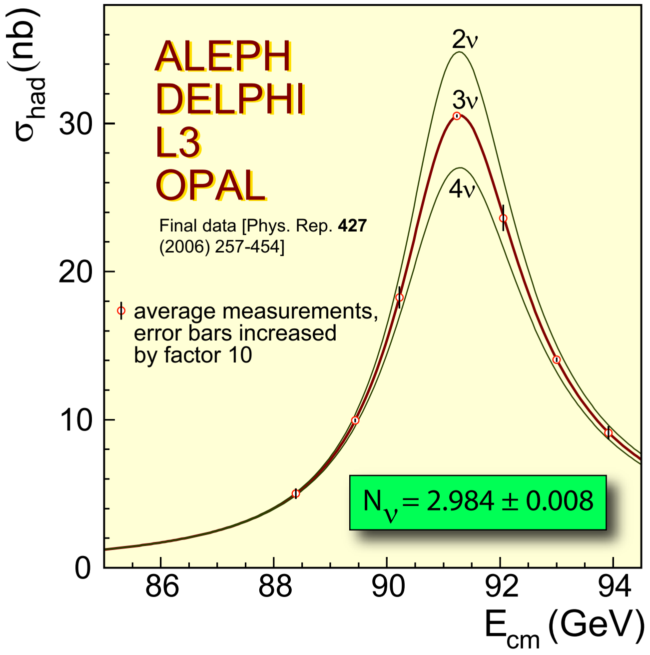

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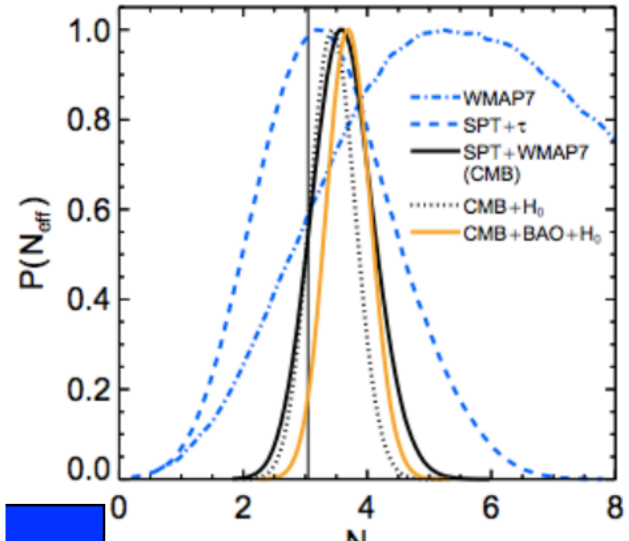

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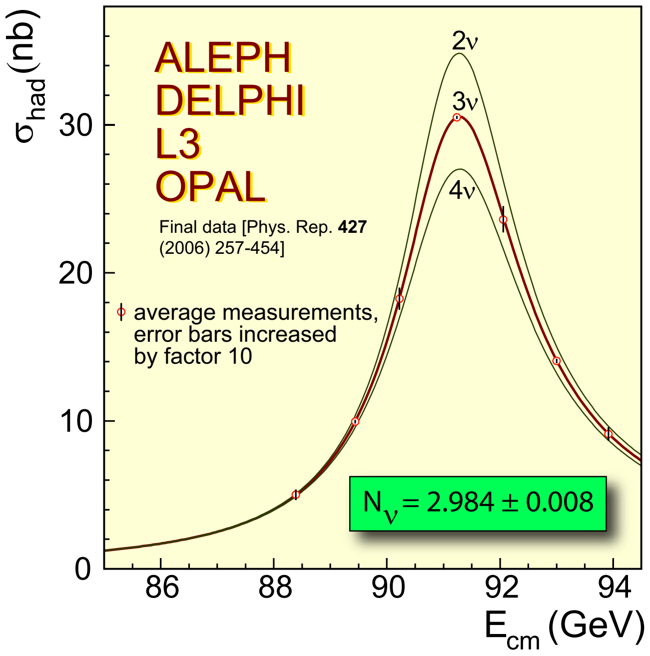

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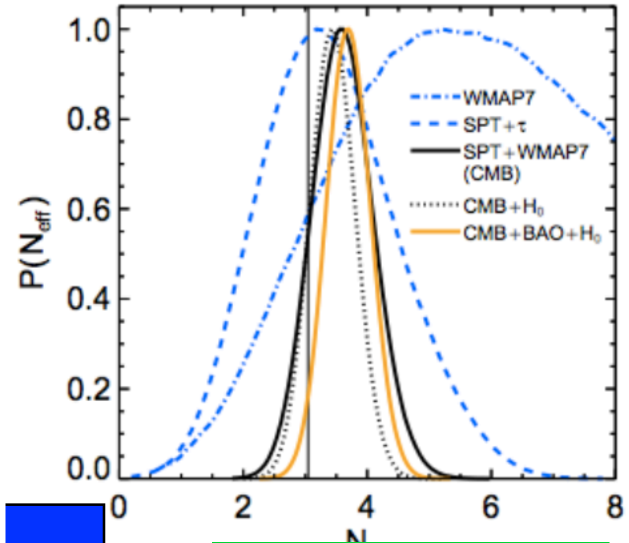

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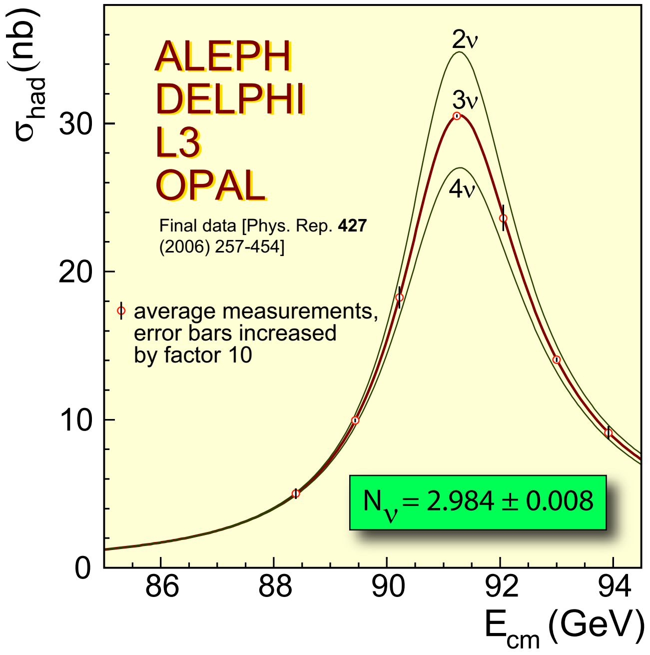

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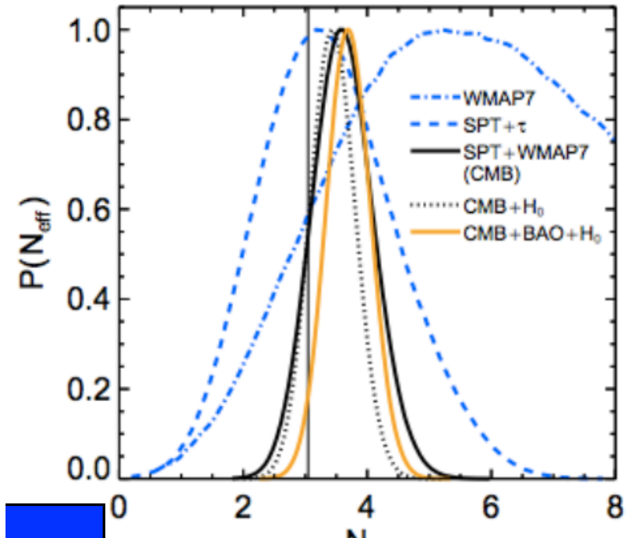

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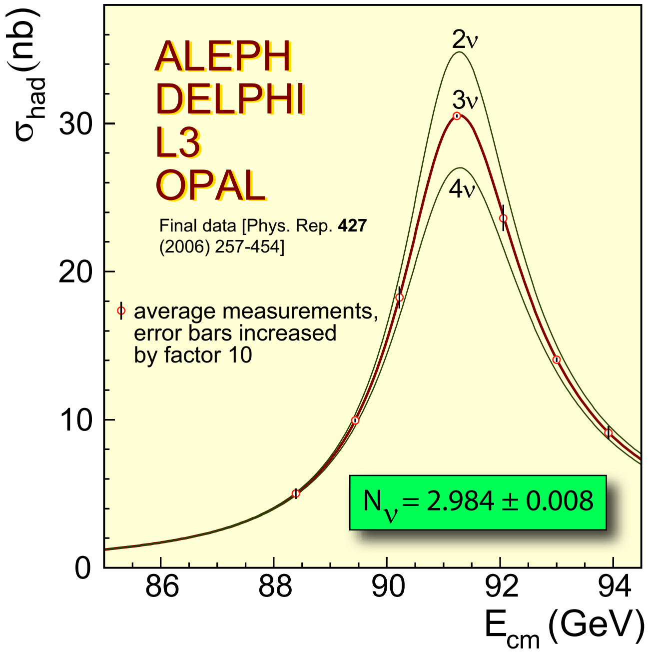

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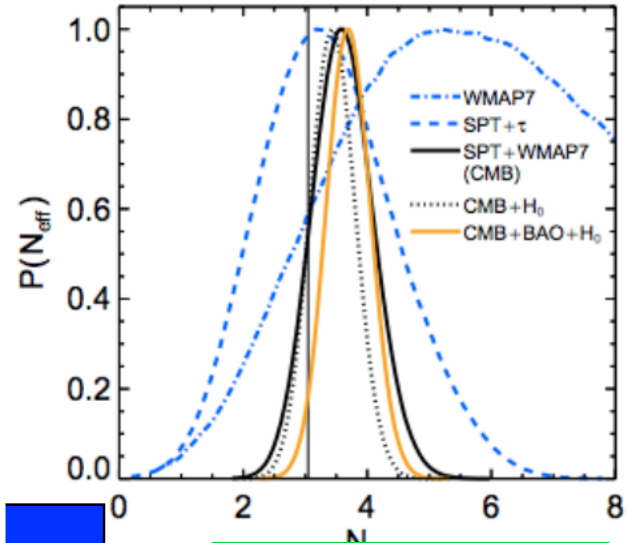

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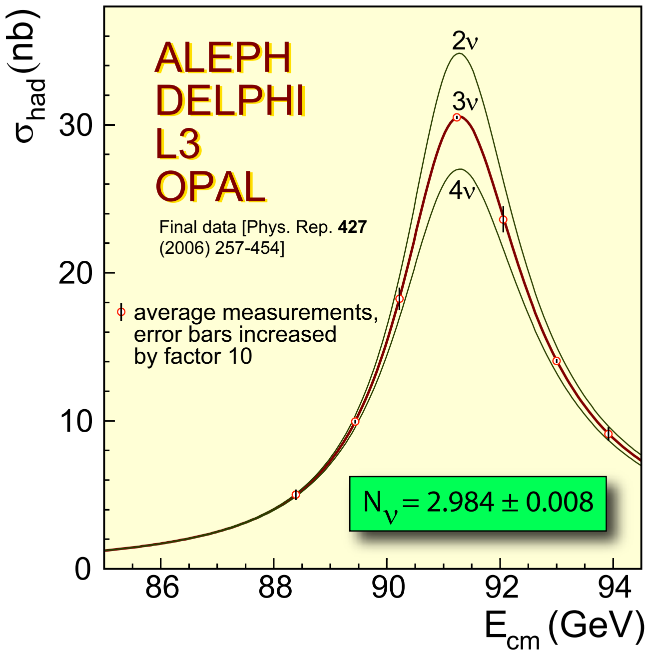

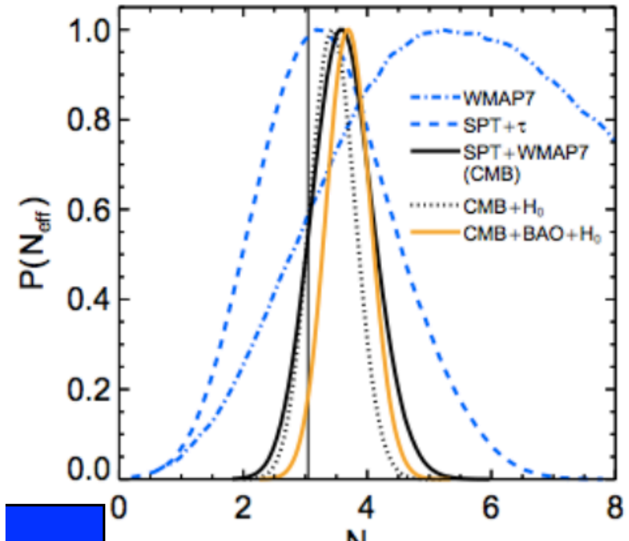

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- Do we see all neutrinos or there are heavy right-handed ones? (Majorana)

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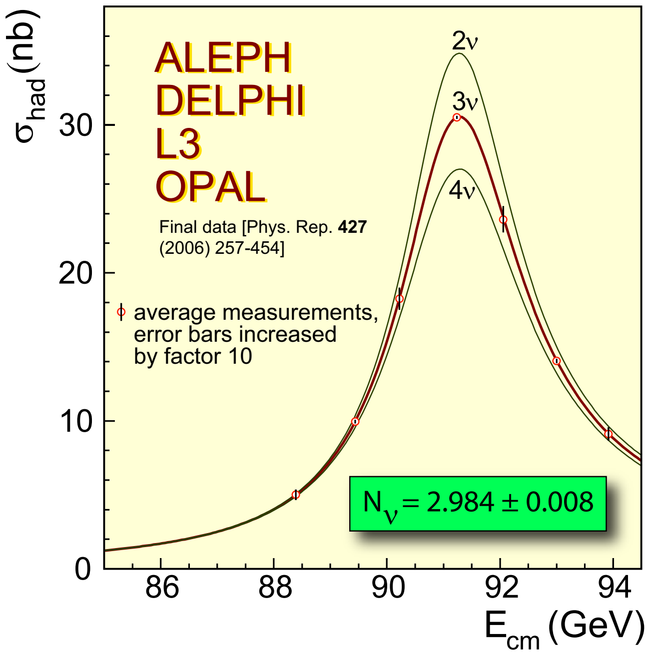
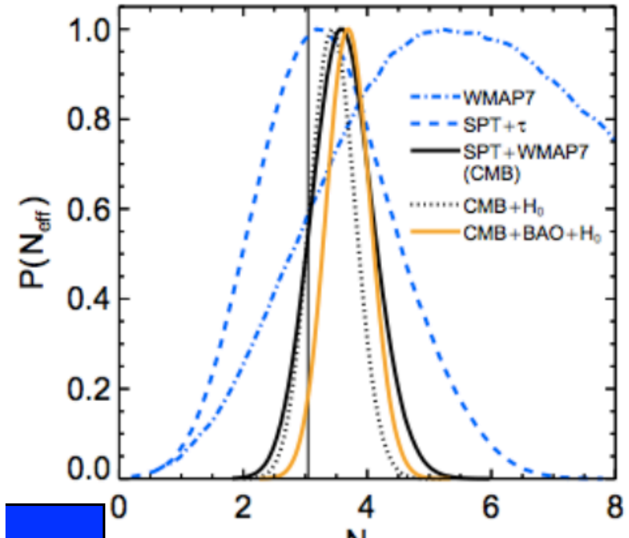


NEUTRINOS

- The CMB spectrum (Planck)



$N_\nu^{eff} < 3.30 \pm 0.27$

- The fourth generation of quarks is excluded also by precision measurement of rare decays

- Do we see all neutrinos or there are heavy right-handed ones? (Majorana)

- Are there any new sterile neutrinos? (To release the constraints from LSND/MiniBoone and reactor anomaly, etc)

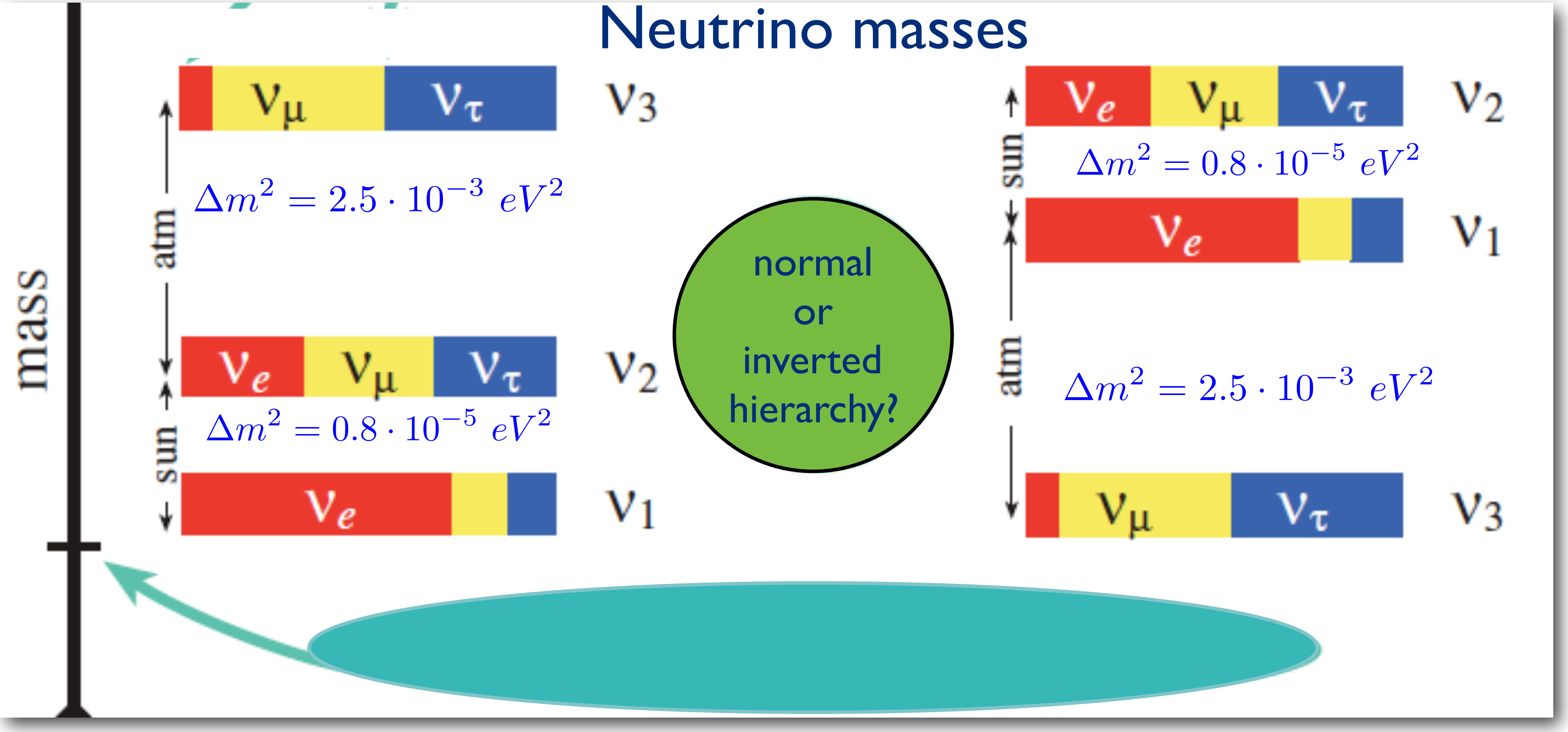
NEW PARTICLES

NEUTRINOS

NEW PARTICLES

NEUTRINOS

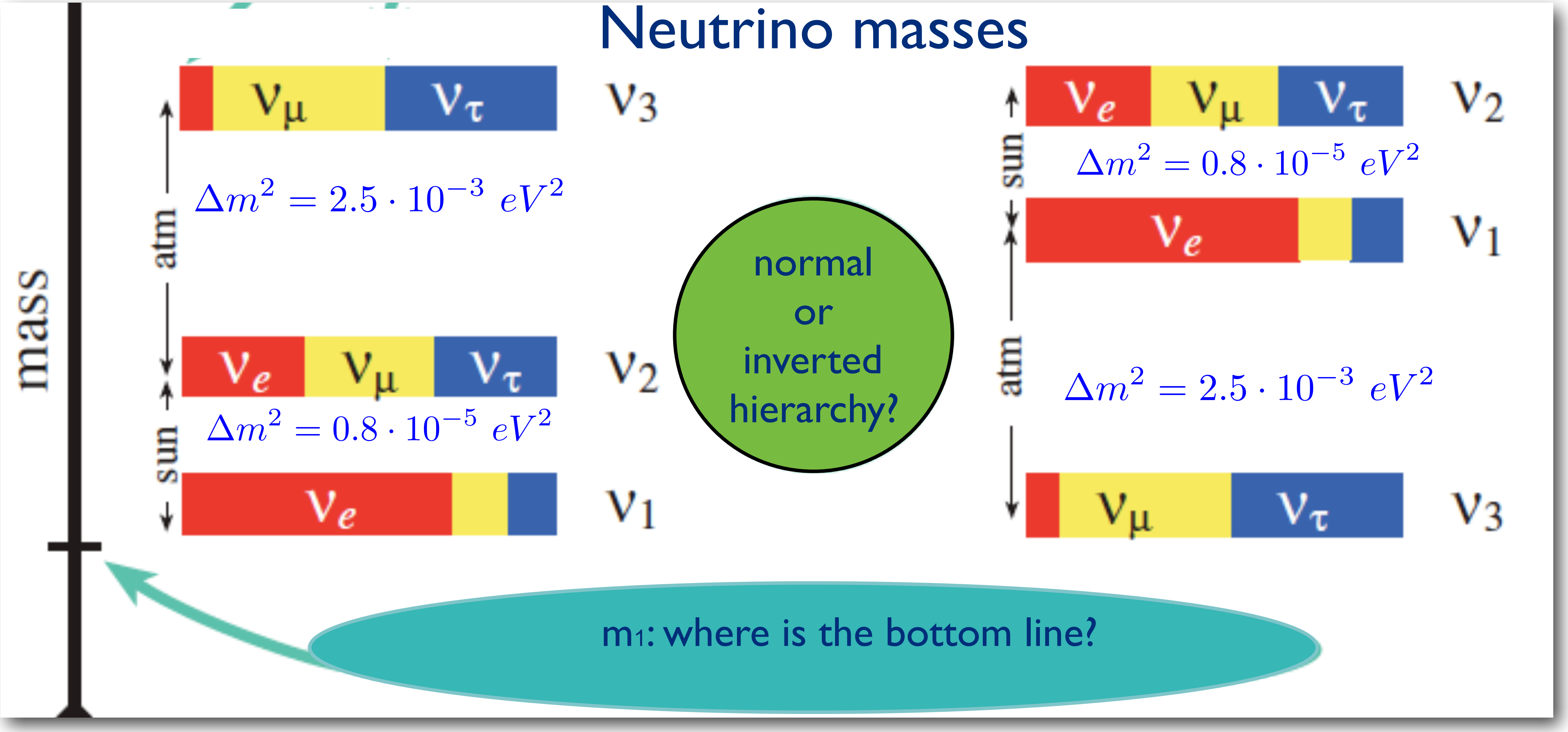
Neutrino masses



normal
or
inverted
hierarchy?

NEW PARTICLES

NEUTRINOS



NEW PARTICLES

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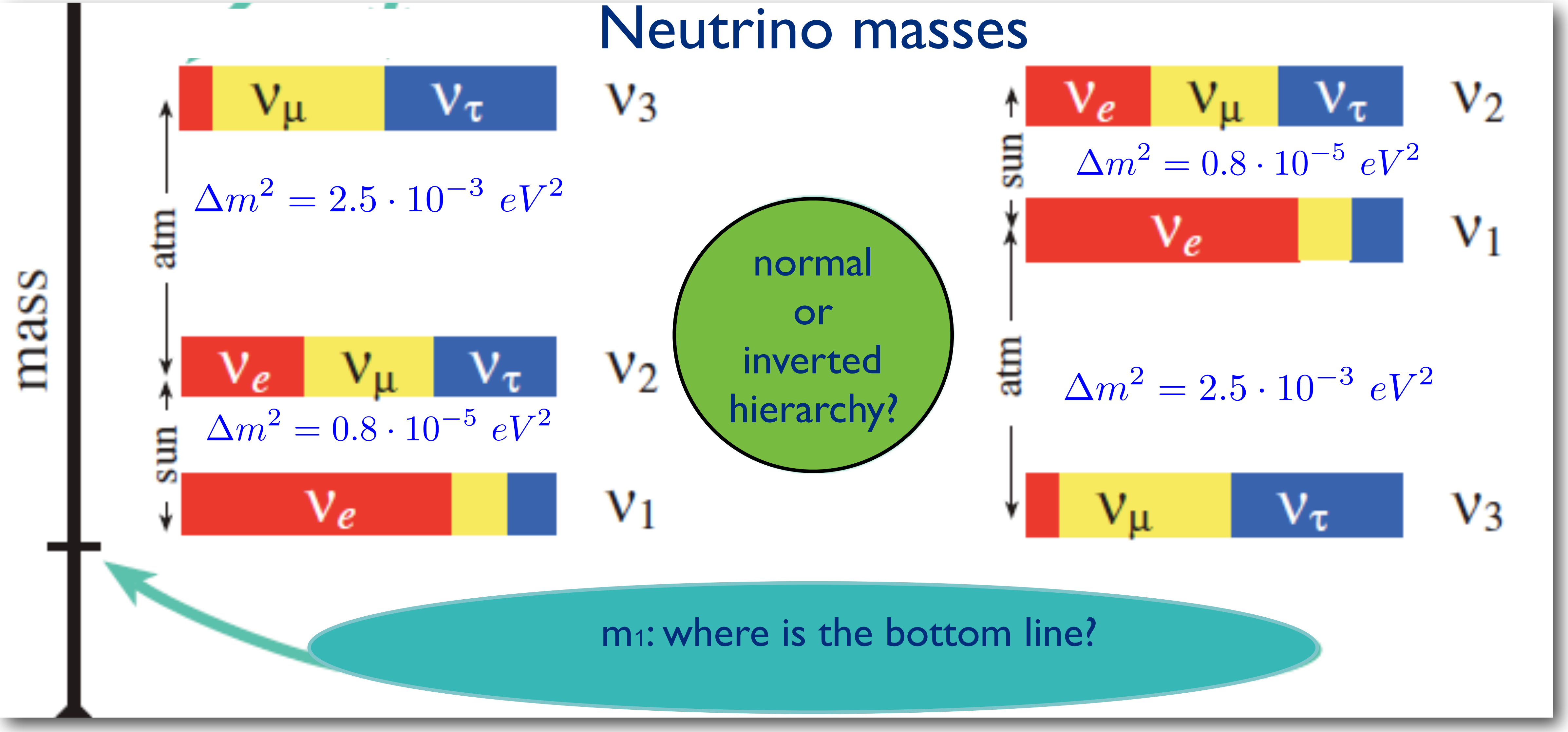


normal or inverted hierarchy?

m1: where is the bottom line?

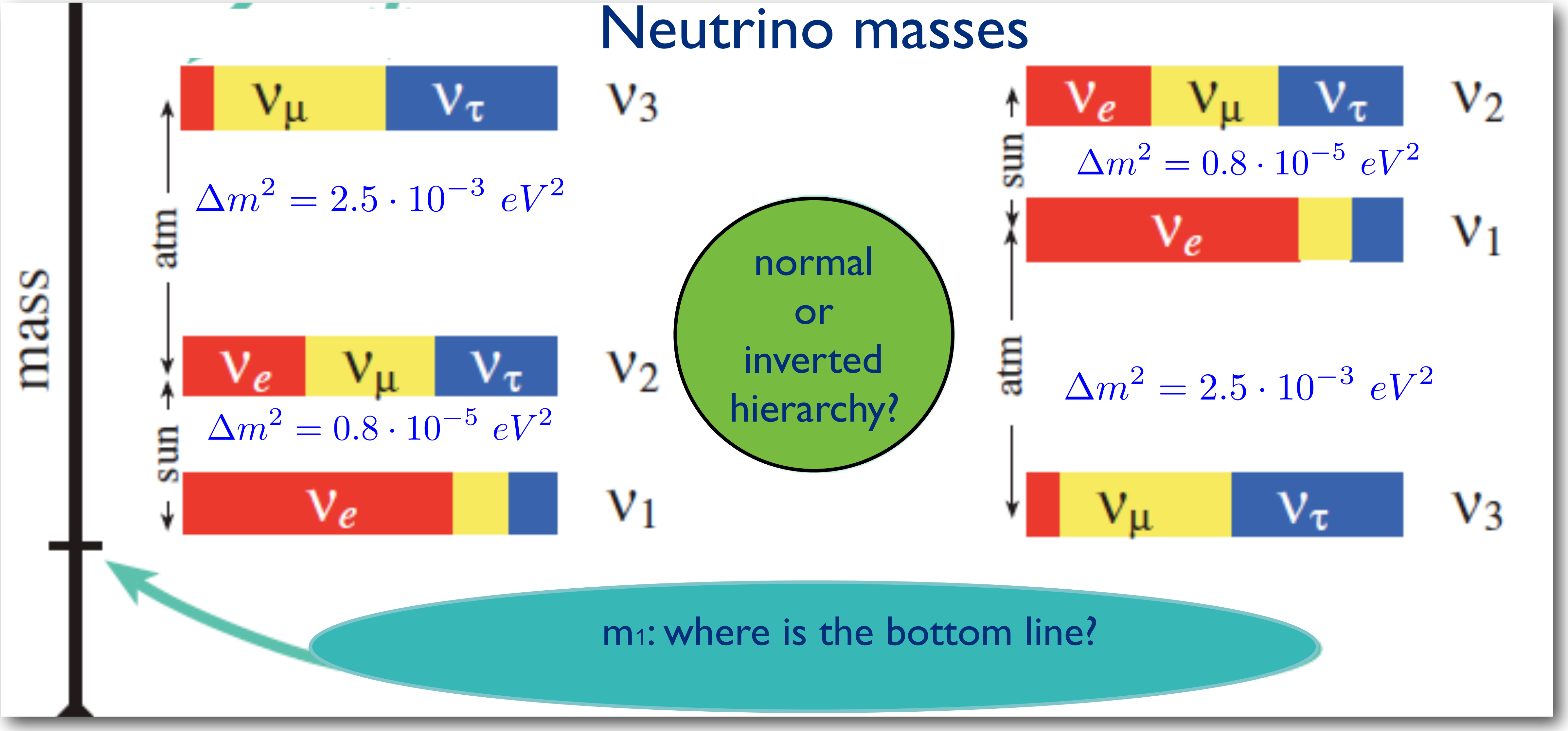
$$\sum m_\nu < 0.23\ eV$$

cosmology: the CMB spectrum

Planck

NEW PARTICLES

NEUTRINOS



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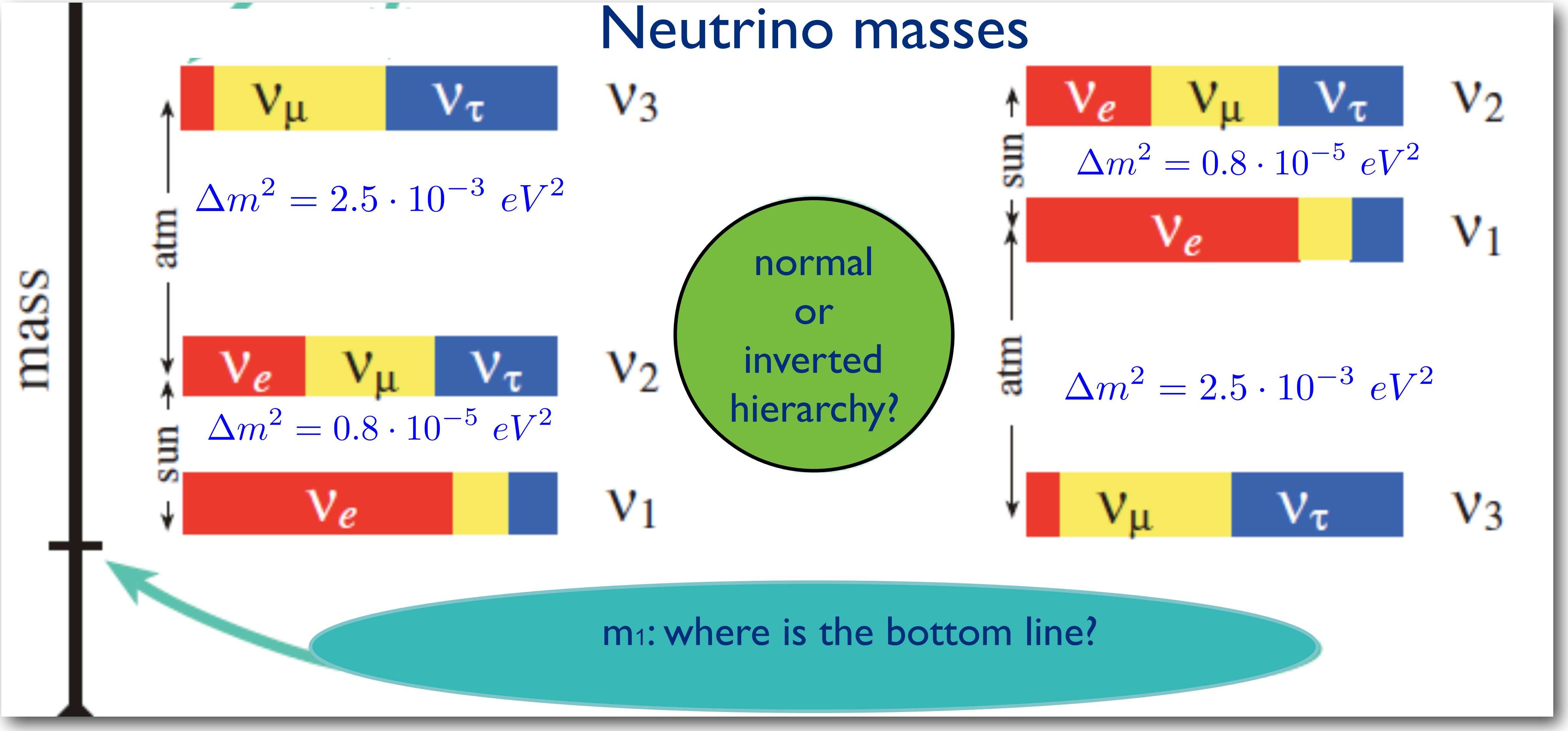
$$m_{\nu_e} < 2\ eV$$

β-decay

Troitsk-Mainz

NEW PARTICLES

NEUTRINOS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$\sum m_\nu < 0.23\ eV$

cosmology: the CMB spectrum

Planck

$m_{\nu_e} < 2\ eV$ → $m_{\nu_e} < 0.2\ eV$

β-decay

Troitsk-Mainz

KATRIN

DIRAC OR MAJORANA?

$$\nu_D = \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix} \qquad \nu_{M_1} = \begin{pmatrix} \xi_1 \\ \xi_1^* \end{pmatrix}, \quad \nu_{M_2} = \begin{pmatrix} \xi_2 \\ \xi_2^* \end{pmatrix}$$

$$\nu_D \neq \nu_D^*$$

$$m_{\nu_L} = m_{\nu_R}$$

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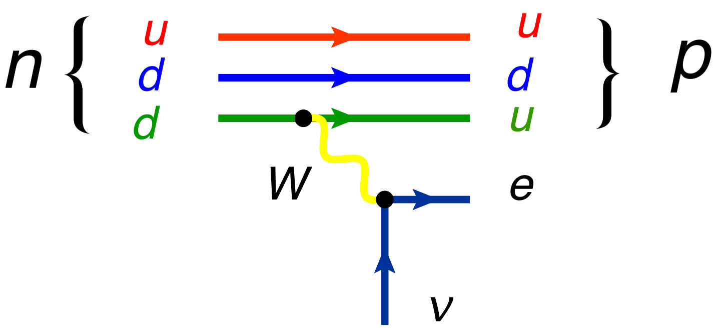
0νββ decay



$0\beta\beta\nu$

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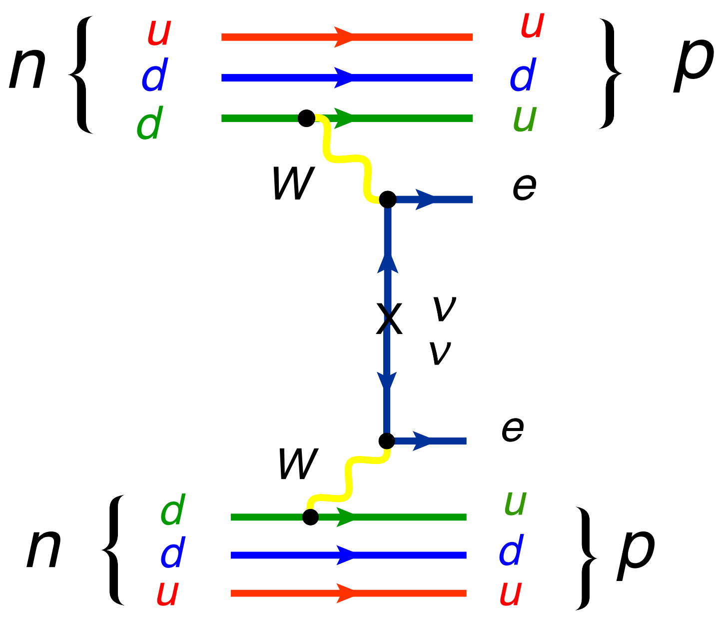

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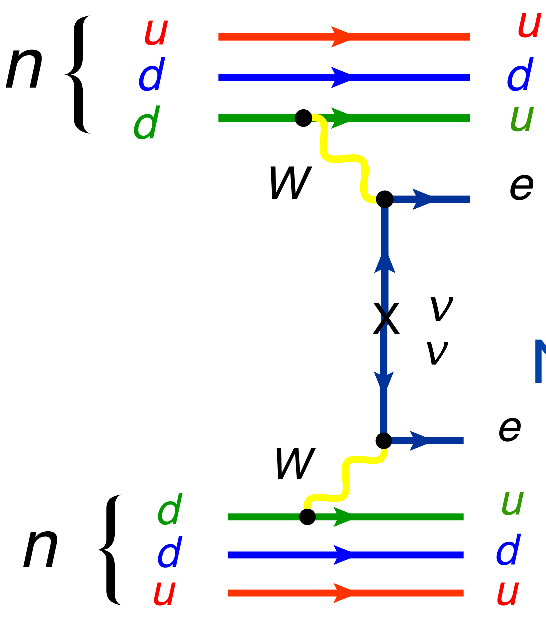

Only Majorana

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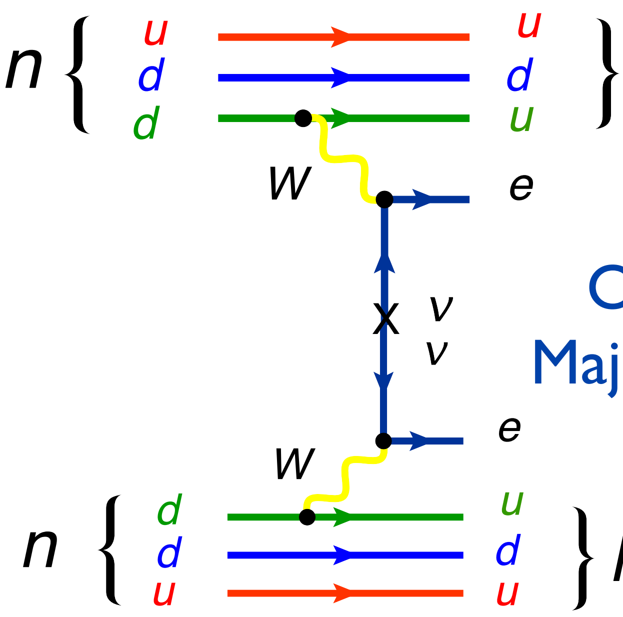

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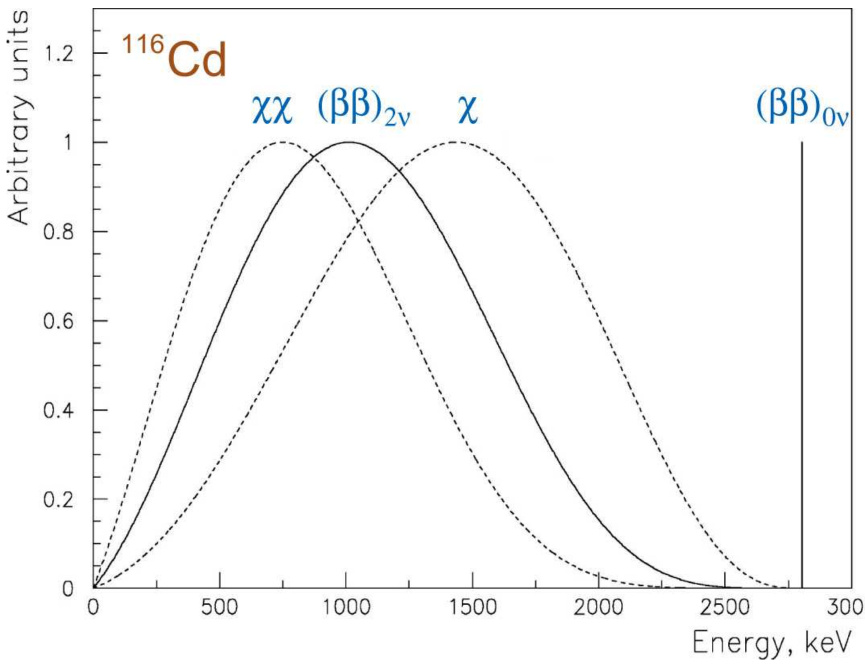

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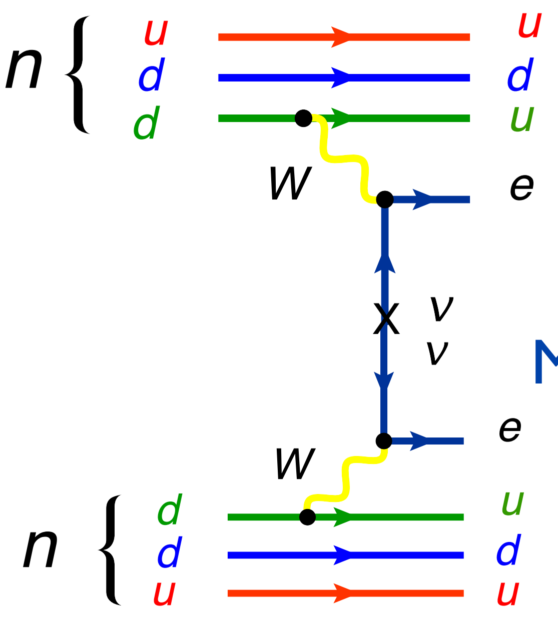

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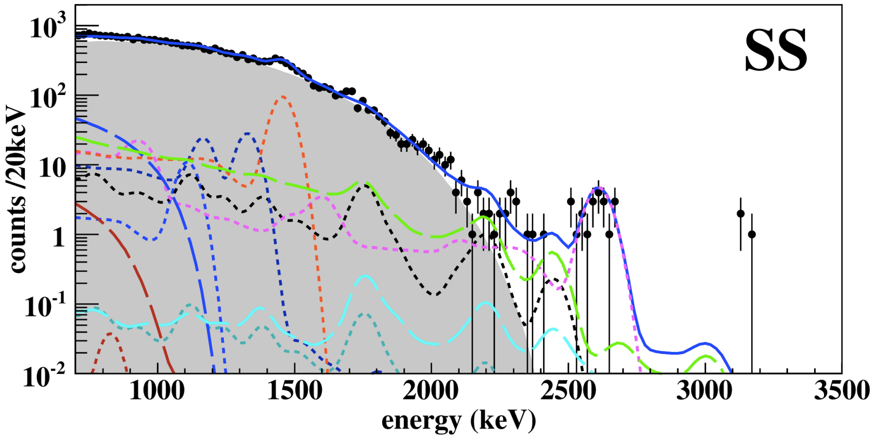

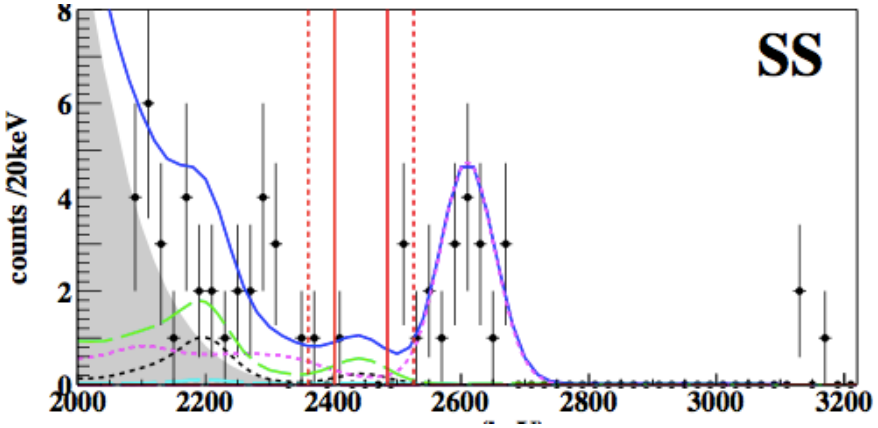

Candidate Isotope	Experiment
^{48}Ca	Candles
^{76}Ge	**Gerda**, Majorana
^{82}Se	SuperNemo,Lucifer
^{130}Te	**CUORE**
^{136}Xe	**EXO**, NEXT, **KamLAND-Zen**
^{150}Nd	SNO+

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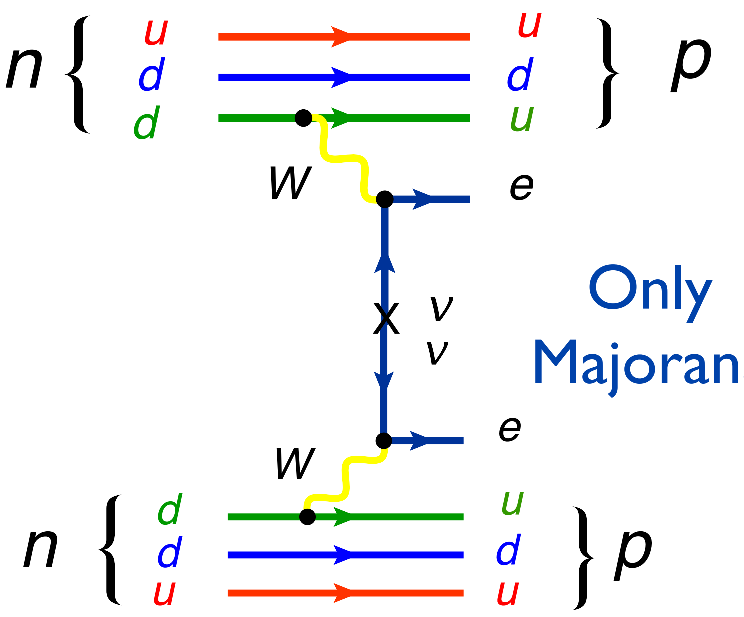

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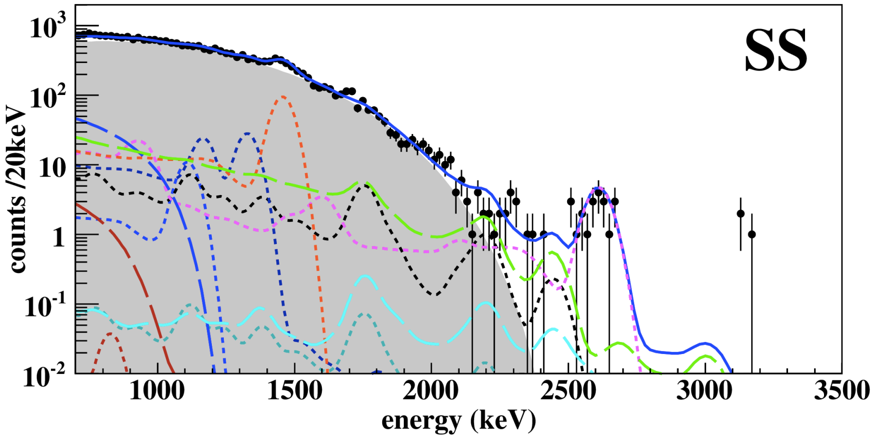

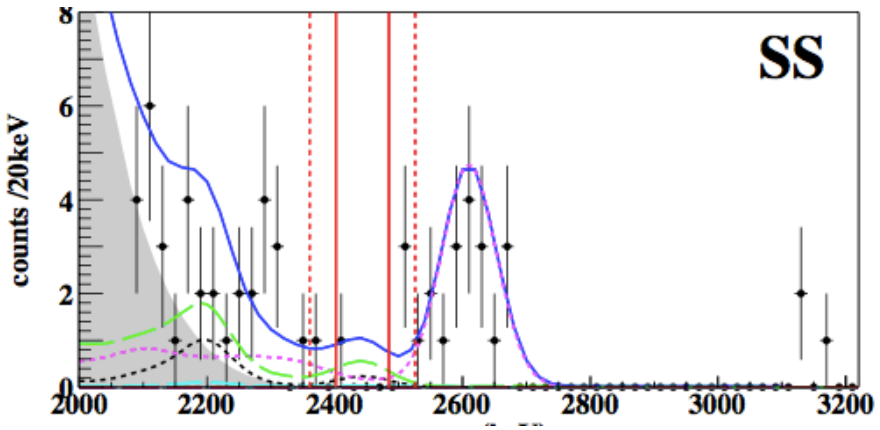

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$T_{1/2}2\nu\beta\beta$ (^{136}Xe) x 10^{21} yr = 2.23 ± 0.017 stat ± 0.22 sys

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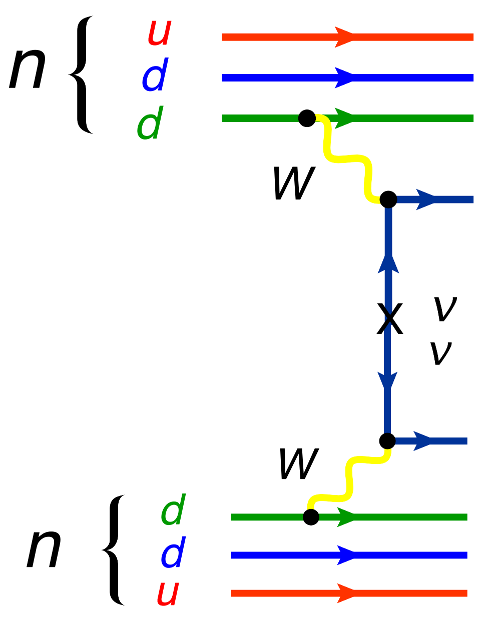

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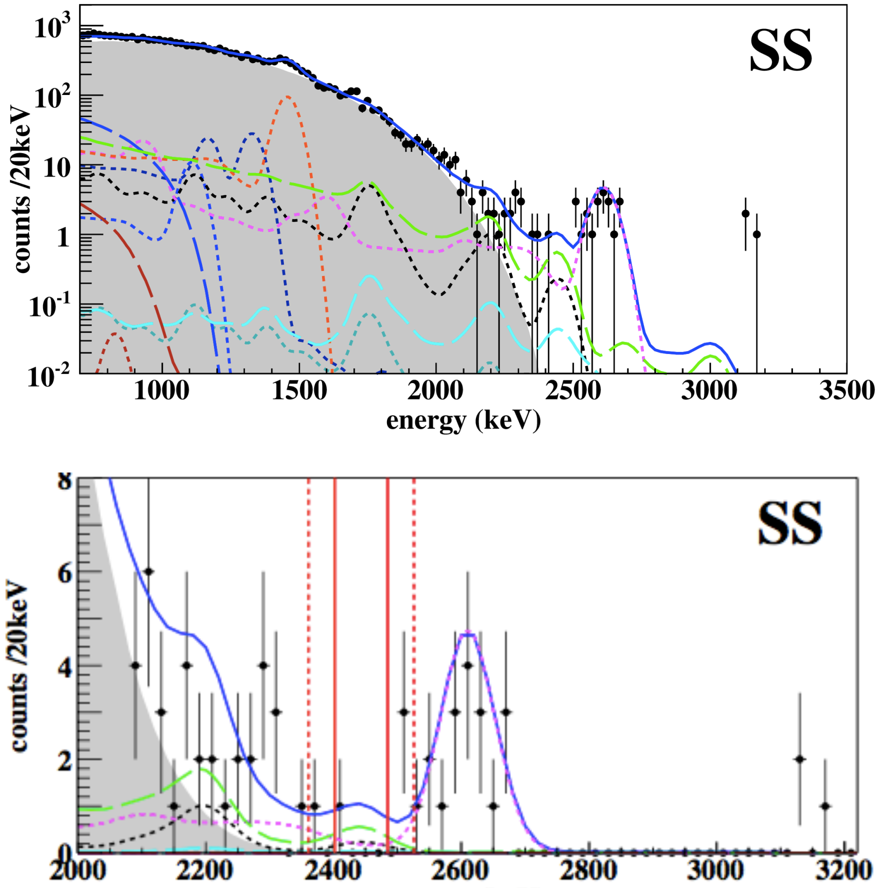

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$T_{1/2}0\nu\beta\beta$ (^{136}Xe) x 10^{25} yr > 1.6 (90% CL)

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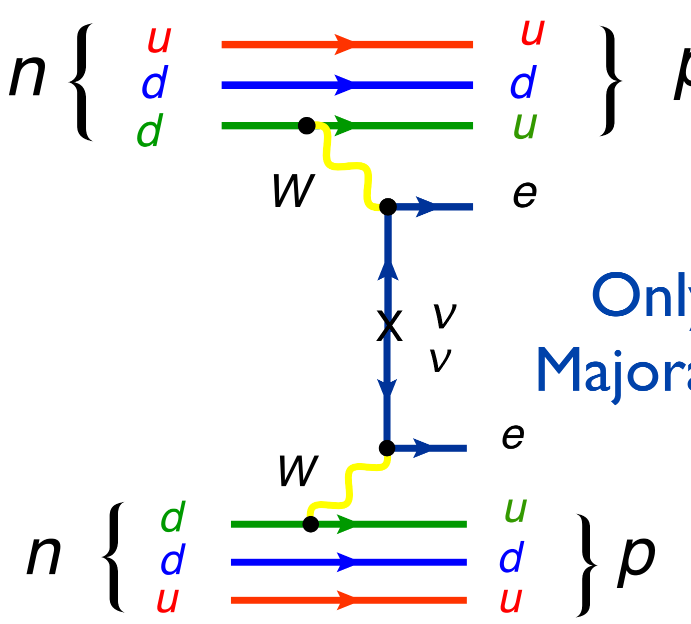

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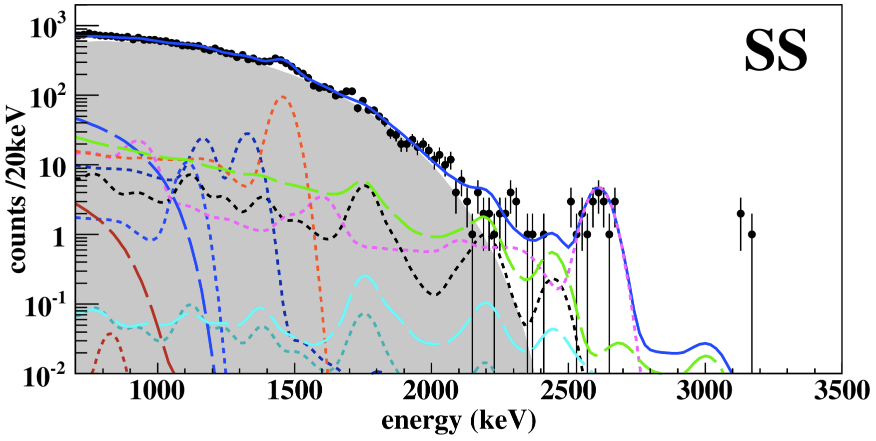
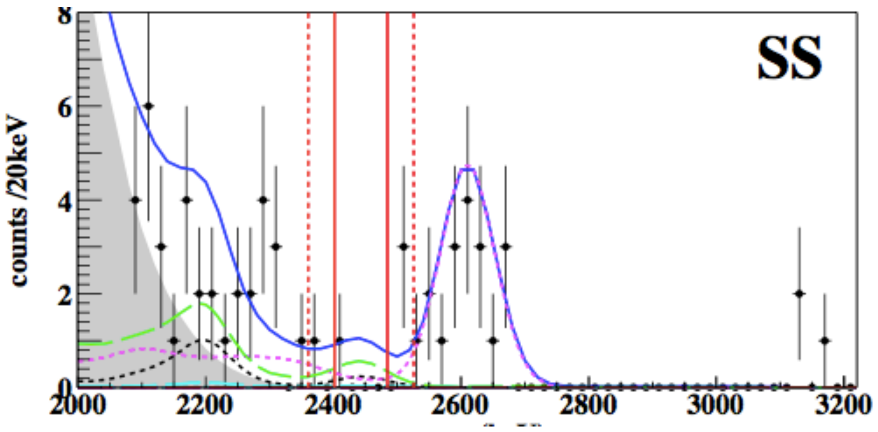
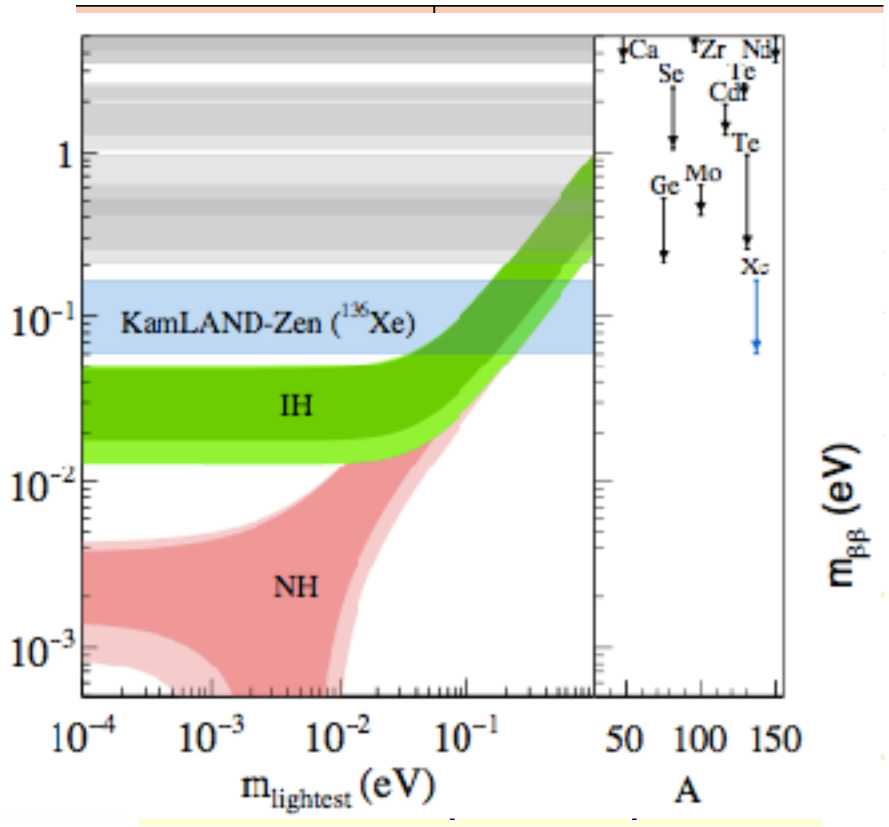


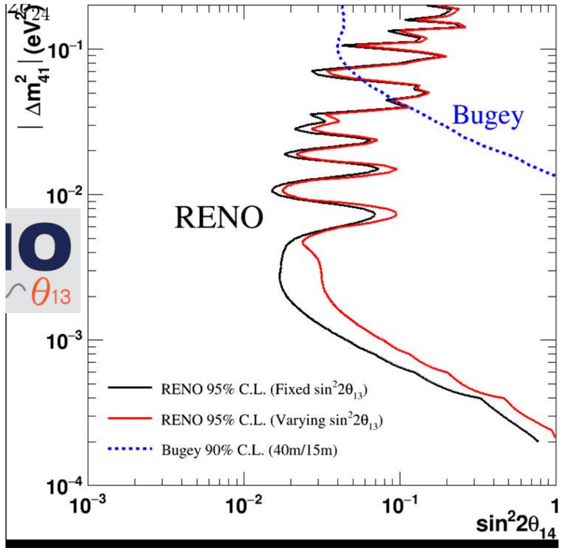




STERILE NEUTRINO

No evidence for sterile neutrinos

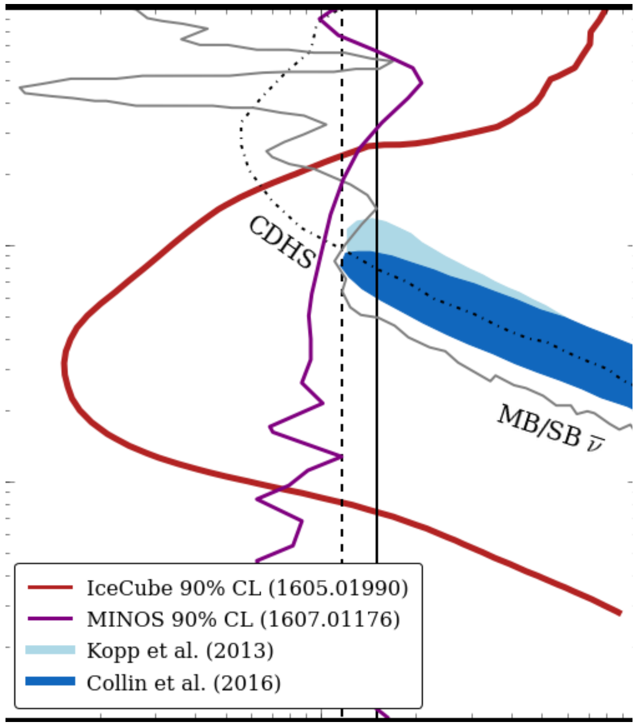
Various exps interpreted within 4 neutrino framework

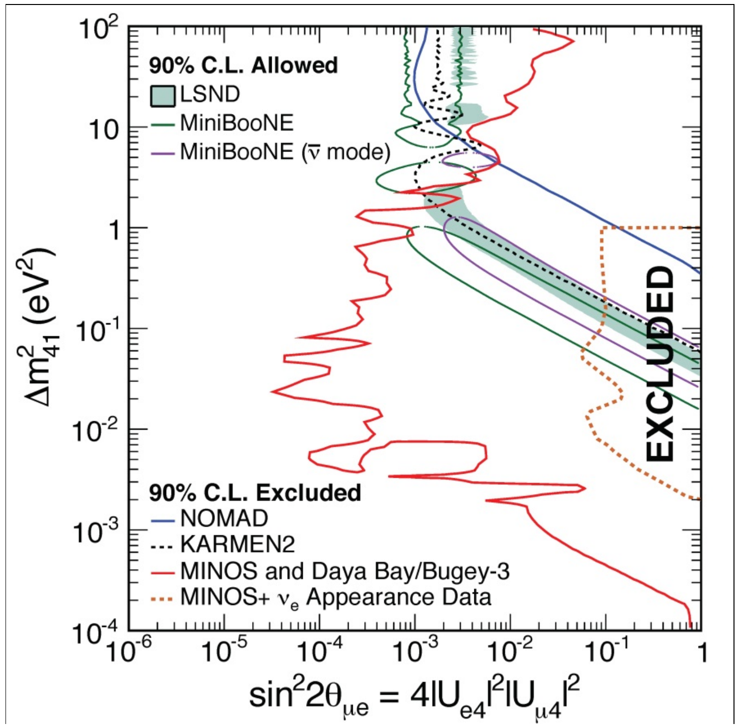


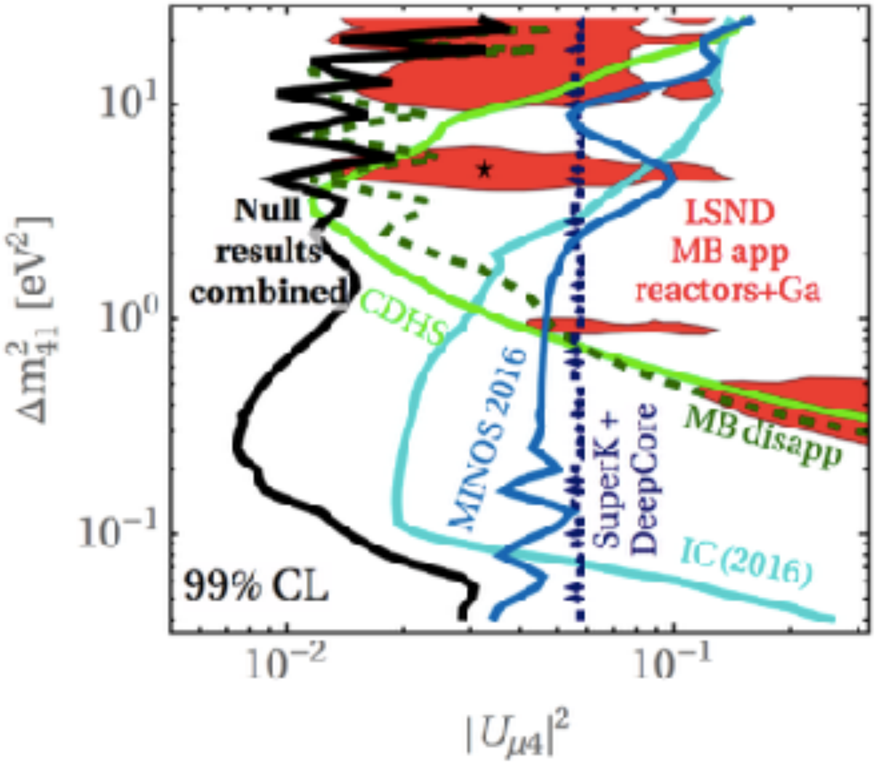
Oscillation channels are related:

$$P_{\nu_e\to\nu_e} \approx 1 - 2|U_{e4}|^2(1-|U_{e4}|^2)$$
$$P_{\nu_\mu\to\nu_\mu} \approx 1 - 2|U_{\mu 4}|^2(1-|U_{\mu 4}|^2)$$
$$P_{\nu_\mu\to\nu_e} \approx 2|U_{e4}|^2|U_{\mu 4}|^2$$

for $4\pi E/\Delta m^2_{41} << L << 4\pi E/\Delta m^2_{31}$







NEW PARTICLES

DARK MATTER

The Dark Matter is made of:

- Macro objects – Not seen
- New particles – right heavy neutrino

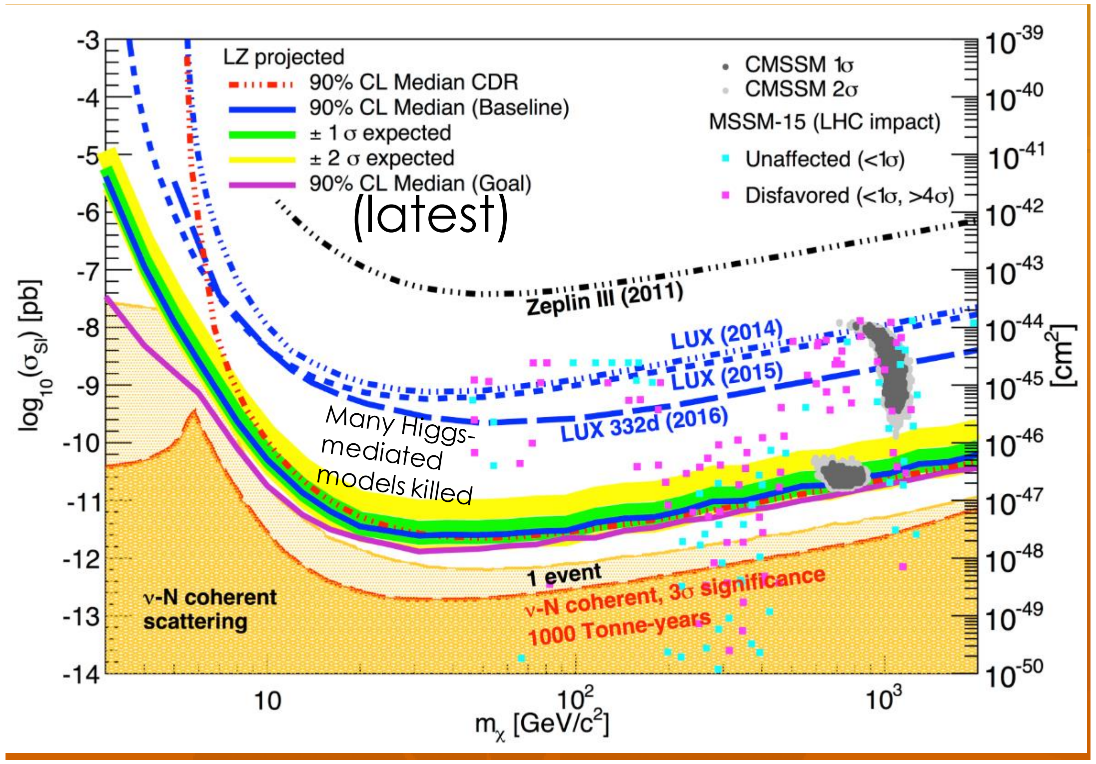
Not from the SM

- - axion (axino)
- - neutralino
- - sneutrino
- - gravitino
- - heavy photon
- - heavy pseudo-goldstone
- - light sterile higgs

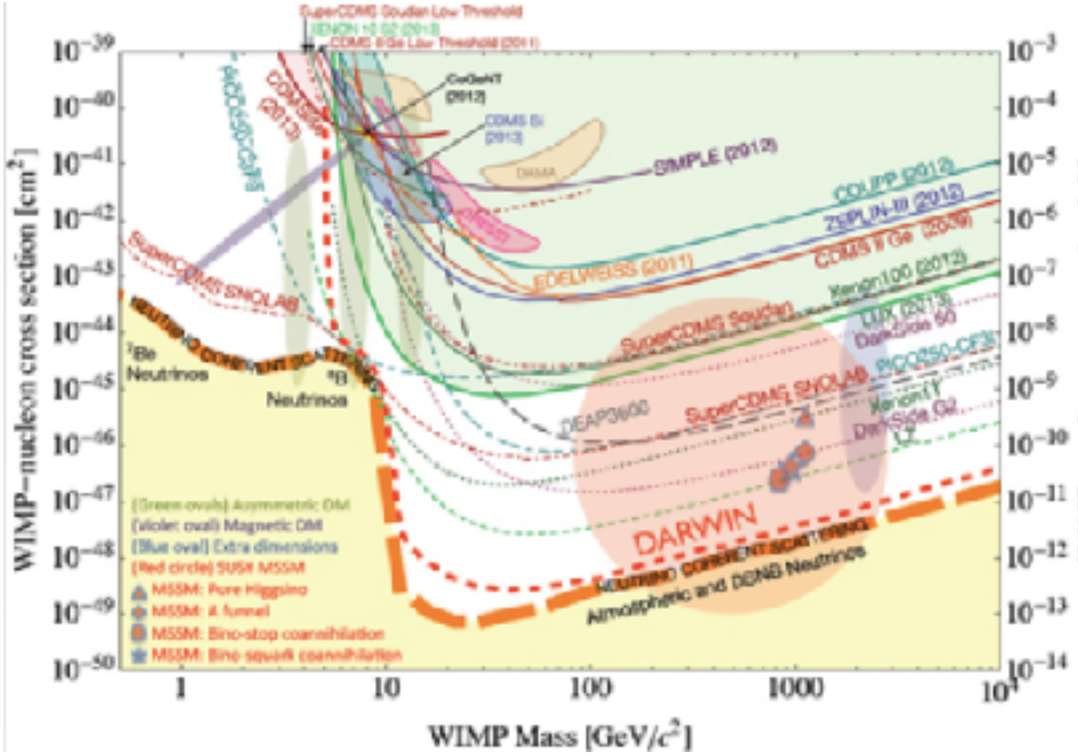
might be invisible (?)

detectable in 3 spheres
less theory favorable
might be undetectable (?)

possible, but not
related to the other
models



Future DM searchers



NEW DIMENSIONS

EXTRA SPACE DIM

$$1+3 \to 1+n, \;\; n>3$$

Motivations

1. String theory
2. Interesting possibility that opens wide opportunities

- String theory suffers conformal anomalies that make it inconsistent.
- Conformal anomaly cancels at D=26 for a bosonic string and D=10 for a fermionic string

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Why don’t we see
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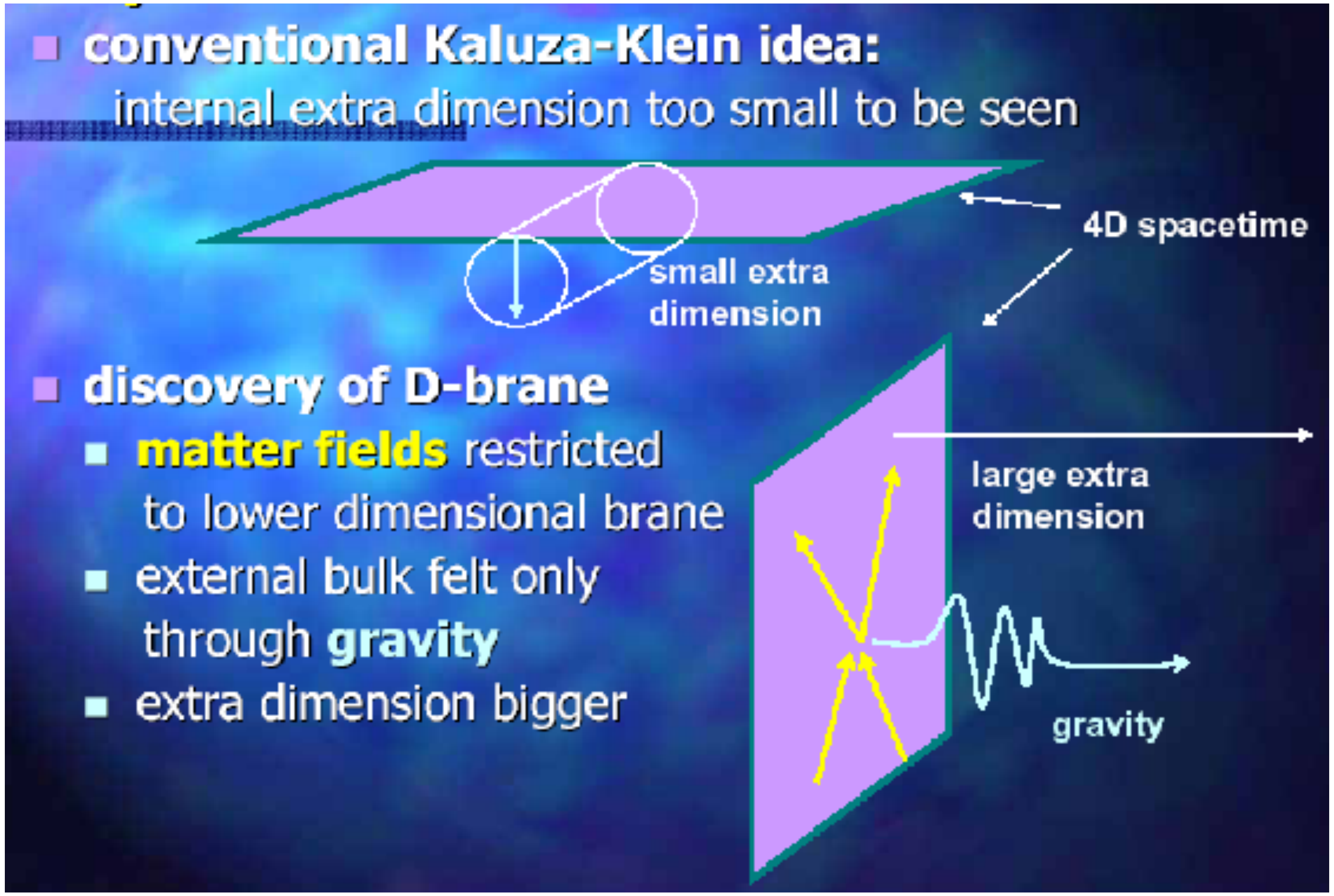

- **conventional Kaluza-Klein idea:**
  internal extra dimension too small to be seen
- **discovery of D-brane**
  - **matter fields** restricted to lower dimensional brane
  - external bulk felt only through **gravity**
  - extra dimension bigger

PHENOMENOLOGY OF EXTRA D

Accelerator signatures

- Gravitational radiation in the bulk => missing energy

Present LHC bounds $M_* \geq 3-5$TeV

- Massive string vibrations => resonances in dijet distribution

$$M_j^2 = M_0^2 + M_s^2 j$$

- Higher spin excitations of quarks and gluons with strong interaction

present LHC limits $M_s \geq 5$ TeV

- Large TeV dimensions => KK resonances of SM gauge bosons

$$M_k = M_0^2 + r^2/R^2, \;\; k = 1, 2, \ldots$$

experimental limits

$$R^{-1} \geq 0.5 - 4 \;\; \text{TeV}$$

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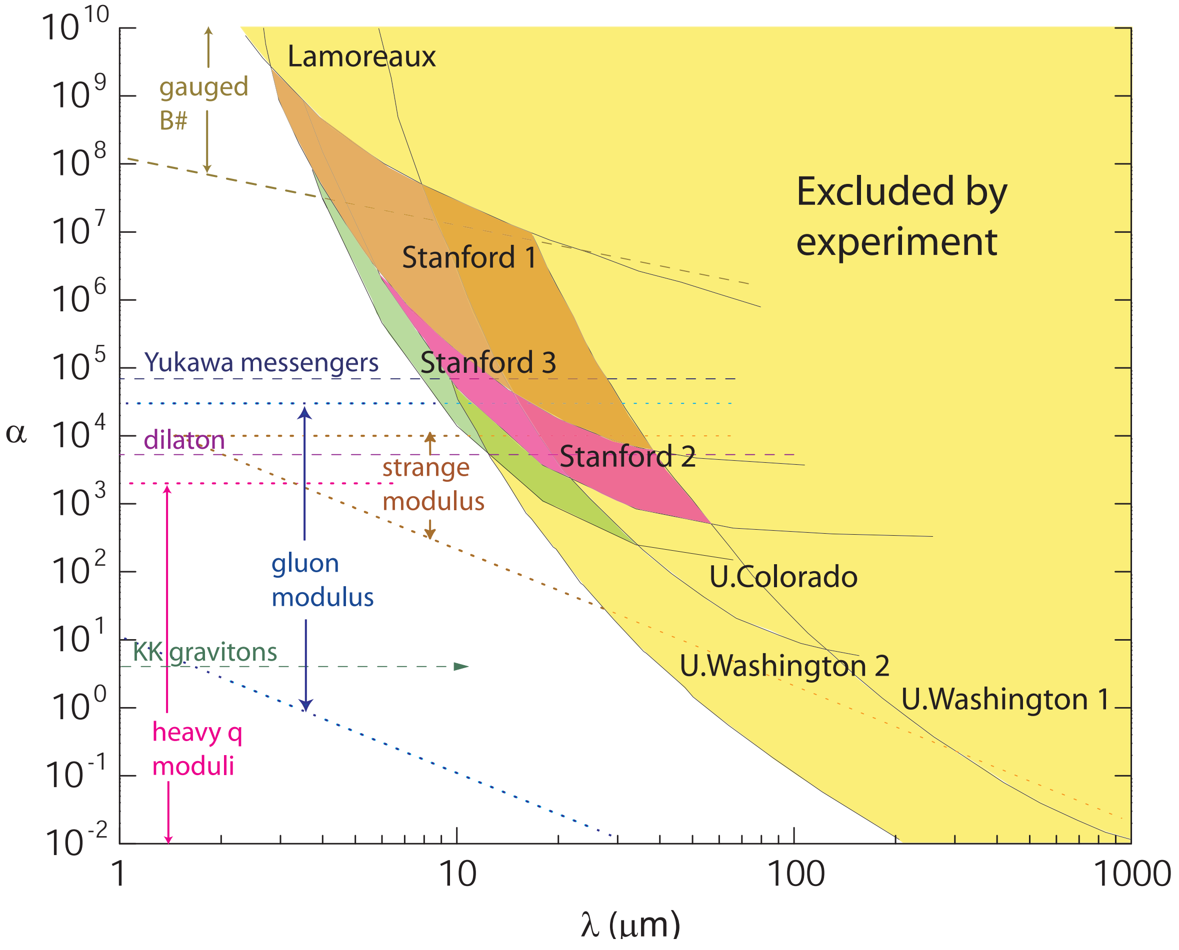
- change of Newton's law at short distances (detectable only in case of 2 large extra dim)
- new short range forces (light scalars and gauge fields)

$$V(r) = -G\,\frac{m_1 m_2}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$



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present LHC li

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$M_k =$ $1, 2, \ldots$

experime

$R^{-1} \geq$ -4 TeV

Vast phenomenology but no indication so far

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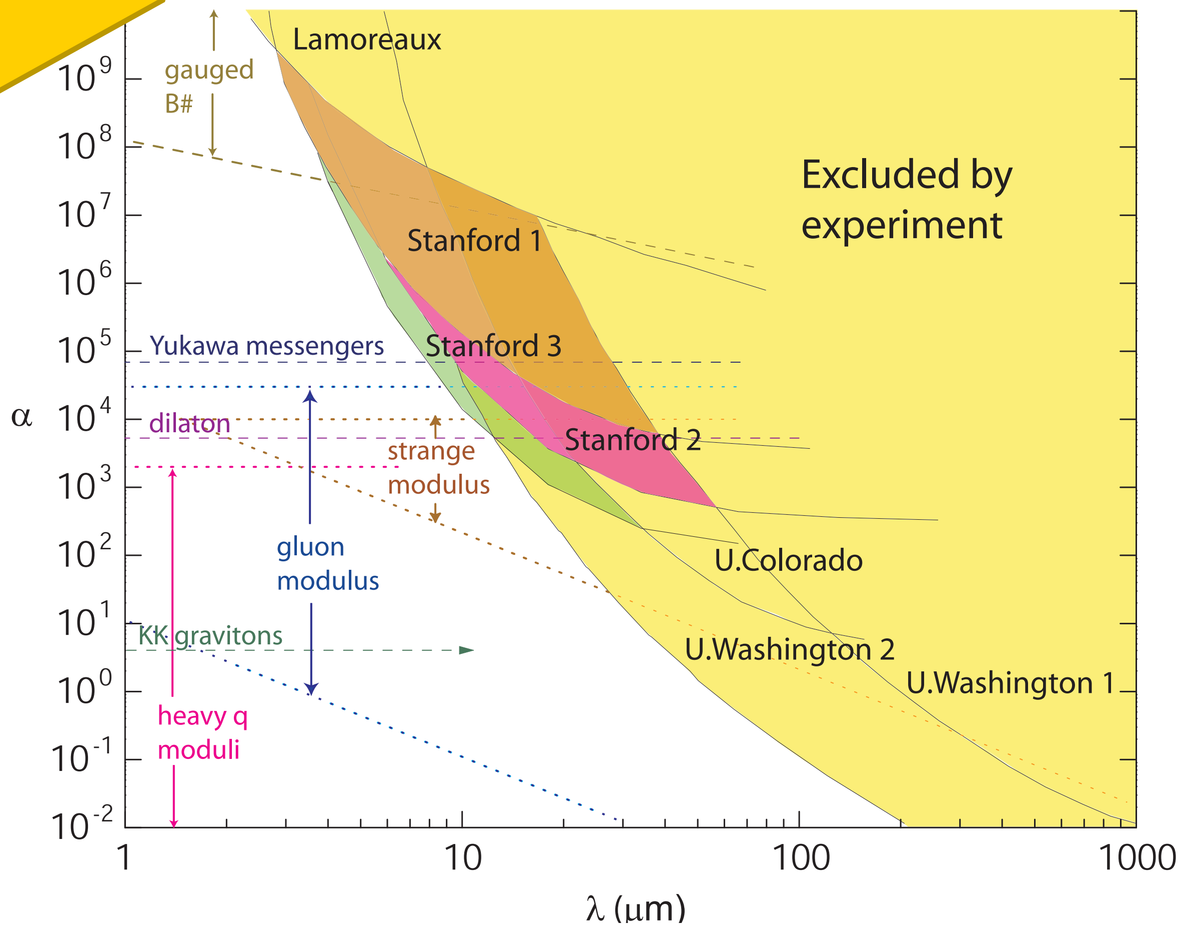
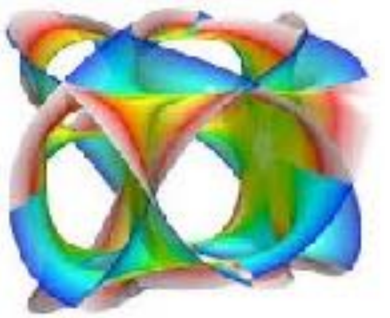
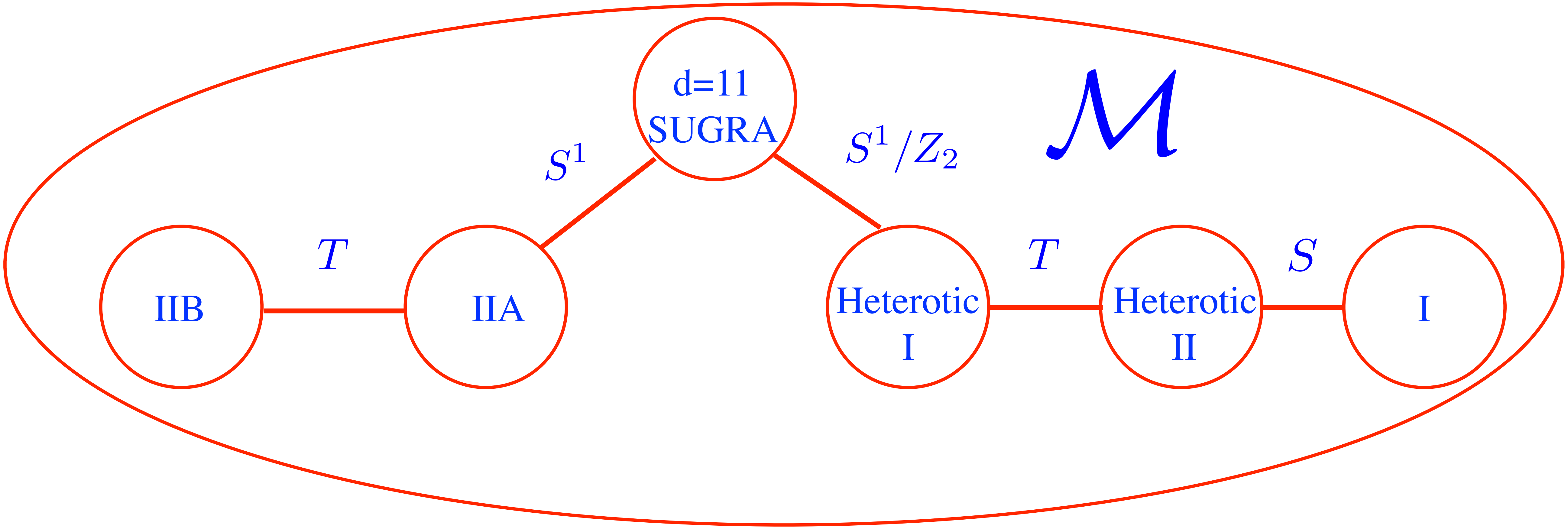


NEW PARADIGM

STRING THEORY

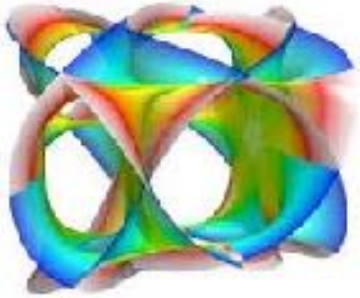


- ✳ There are five types of string theories (IIA, IIB, I, two Heterotic)
- ✳ All five string theories are only consistent in 10 space-time dimensions
- ✳ All five string theories have world-sheet supersymmetry and lead to space-time-supersymmetry in 10 dimensions
- ✳ All five string theories are related and part of a single ''theory'': M-theory



M-theory is a patchwork of the constituent theories plus many "rules".

STRING THEORY



- Higgs from untwisted sector $\Rightarrow$ gauge-Higgs unification

  $\lambda_{\rm top} = g_{\rm GUT} \Rightarrow m_{\rm top} \sim$ IR fixed point $\simeq$ 170 GeV

- Yukawa couplings: hierarchies à le Froggatt-Nielsen

  discrete symmetries $\Rightarrow$ couplings allowed with powers of a singlet field

  $\lambda_n \sim \Phi^n \qquad \langle\Phi\rangle \sim 0.1\, M_s \rightarrow$ hierarchies

  A single anomalous $U(1) \Rightarrow \langle\Phi\rangle \neq 0$ to cancel the FI D-term

- R-neutrinos: natural framework for see-saw mechanism

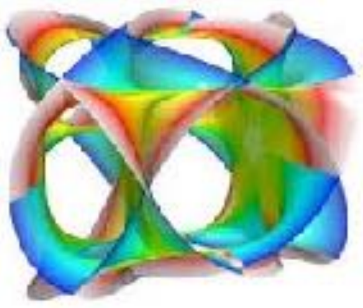
  $\langle h\rangle \nu_L\nu_R + M\nu_R\nu_R \qquad \langle h\rangle = v << M \Rightarrow m_R \sim M\,;\; m_L \sim v^2/M$

- proton decay: problematic dim-5 operators

  in general need suppression higher than M_s or small couplings

- $\not{\rm SUSY}$ in a hidden sector from the other $E_8 \rightarrow$ gravity mediation

STRING THEORY



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  A single anomalous $U(1) \Rightarrow \langle \Phi \rangle \neq 0$ to can

- R-neutrinos: natural frame mechanism

  $\langle h \rangle \nu_L \nu_R + M \nu_R \nu_R$ $\langle h \rangle =$ $M \Rightarrow m_R \sim M\,;\ m_L \sim v^2/M$

- proton decay: problematic dim-5 operators

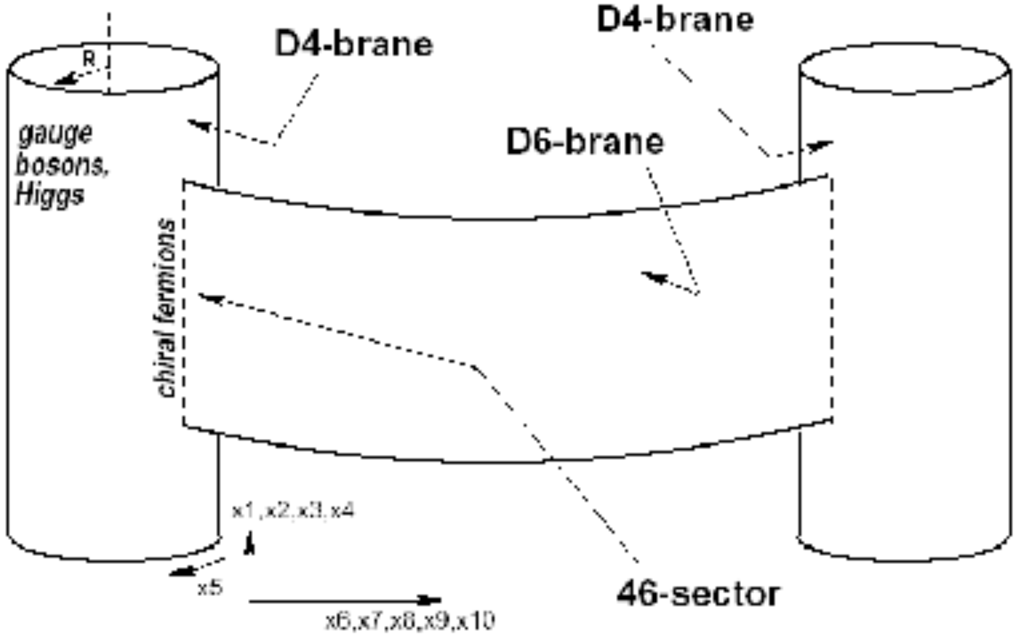
  in general need suppression higher than M_s or small couplings

- $\not{S}$USY in a hidden sector from the other $E_8 \rightarrow$ gravity mediation

- Potentially answering many questions
- Requires SUSY for stabilization
- Difficult to get low-energy outputs

NEW PARADIGM

BRAIN WORLD



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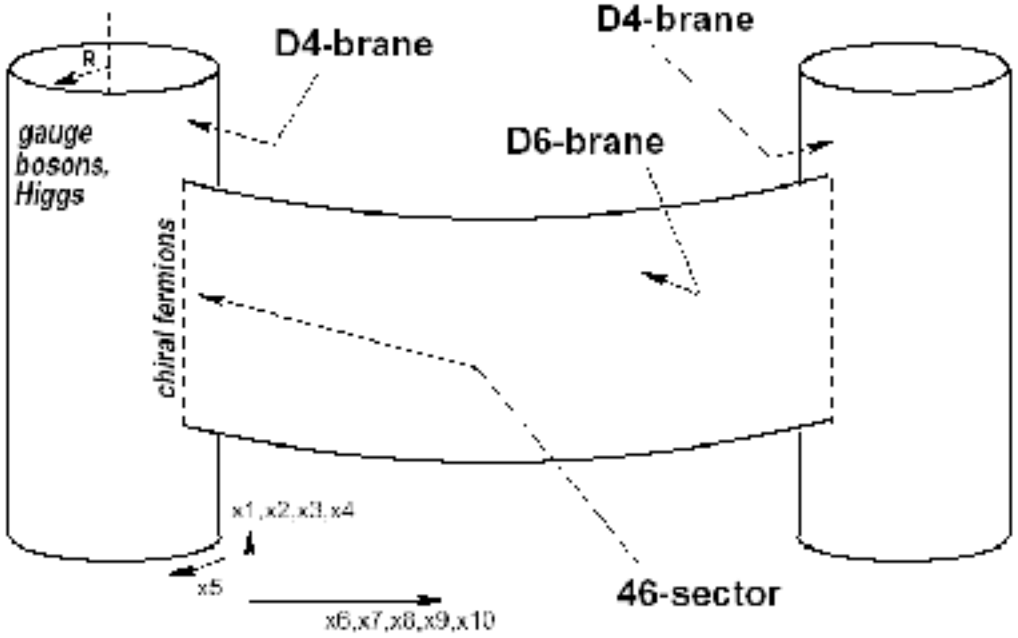

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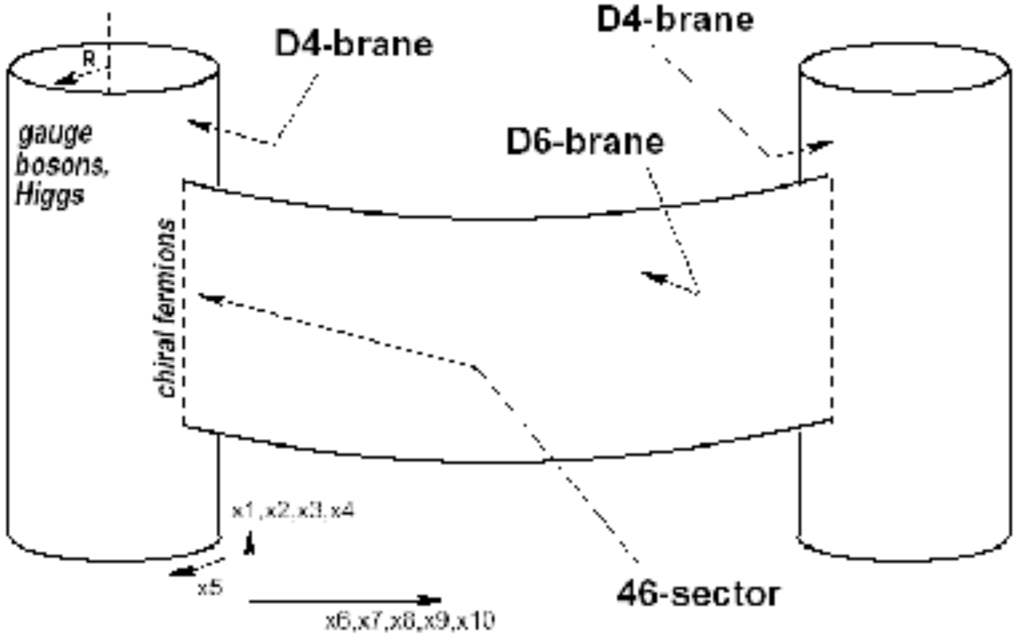

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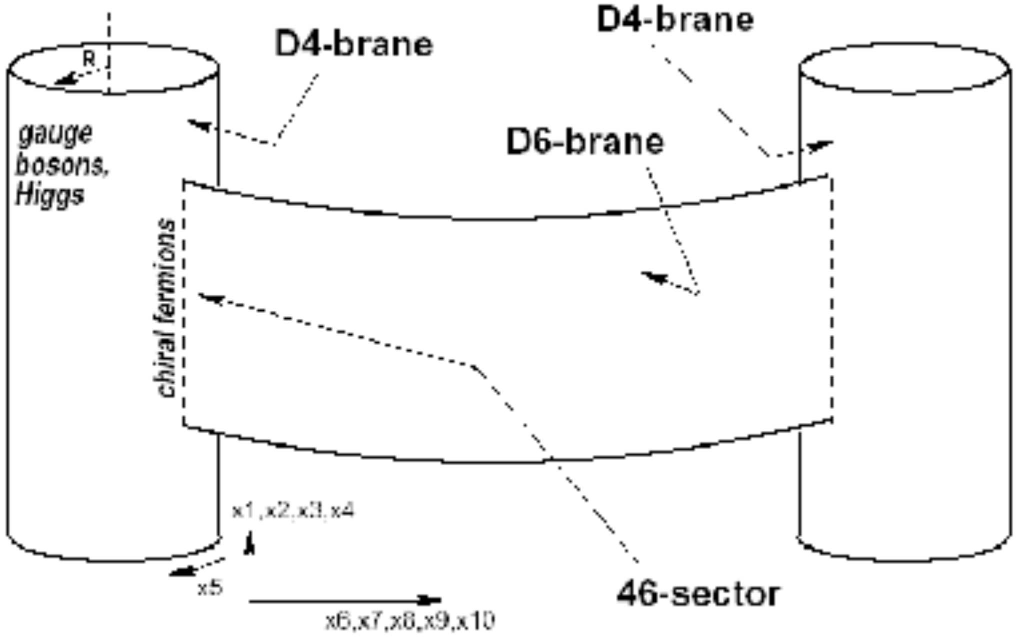

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Q: Do we have good reasons to believe in it?

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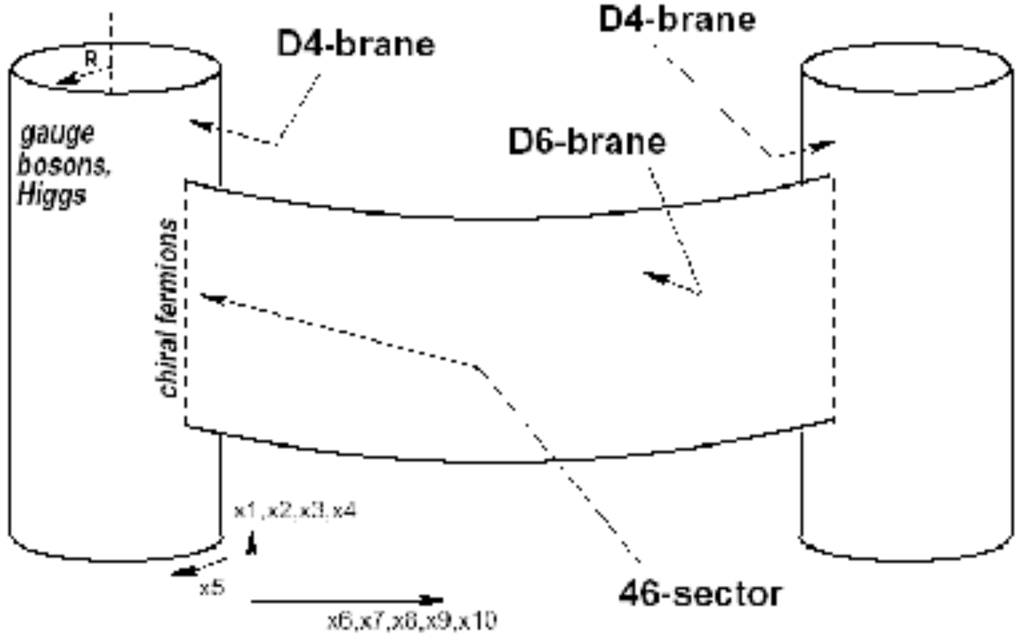

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A: No, but it is appealing

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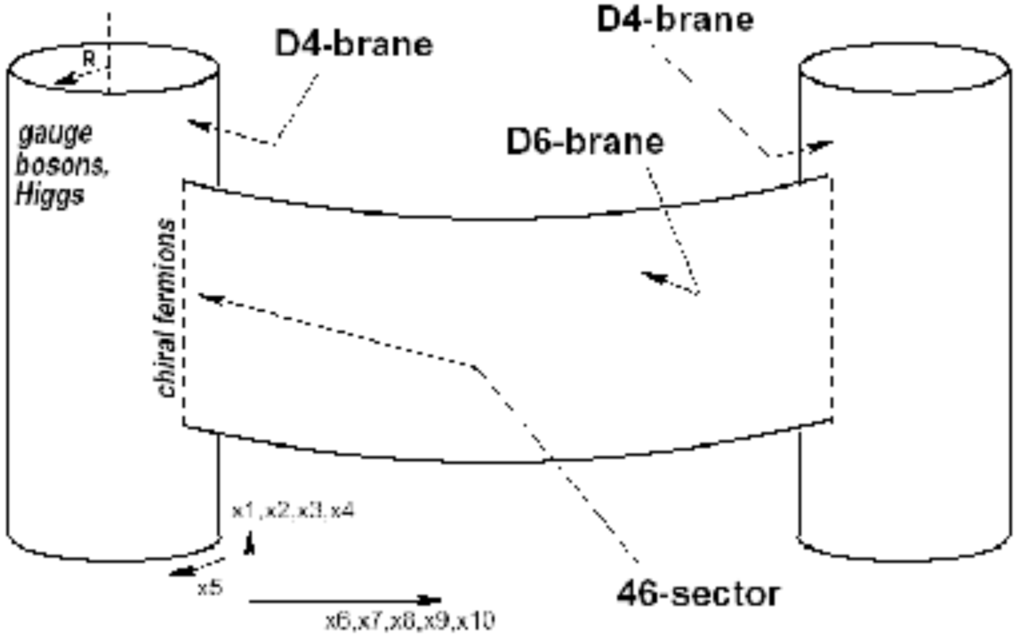

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Q: Why D>4?

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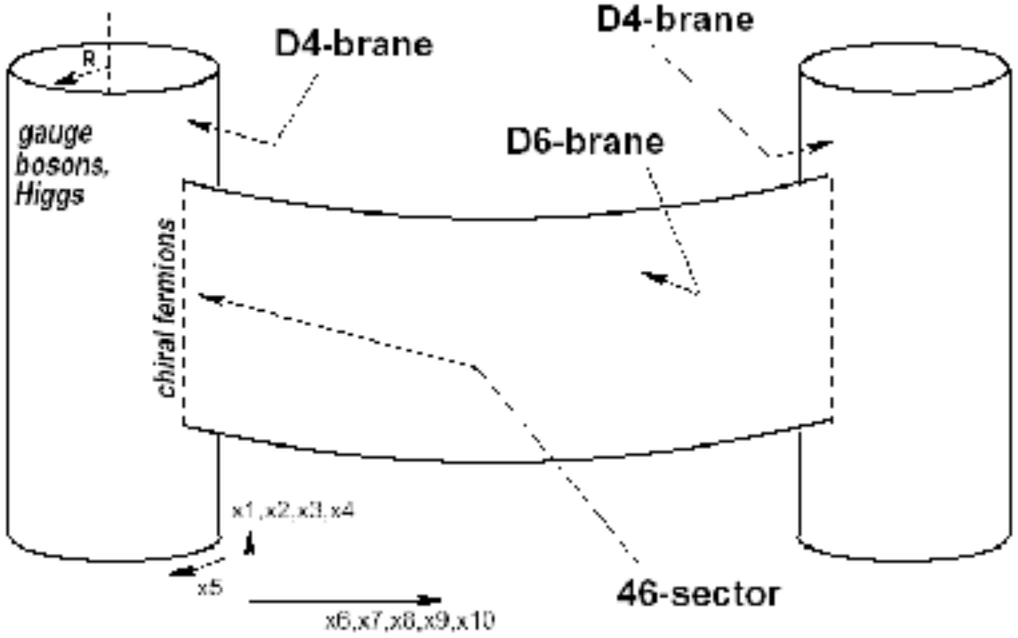

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A: String theory loves it

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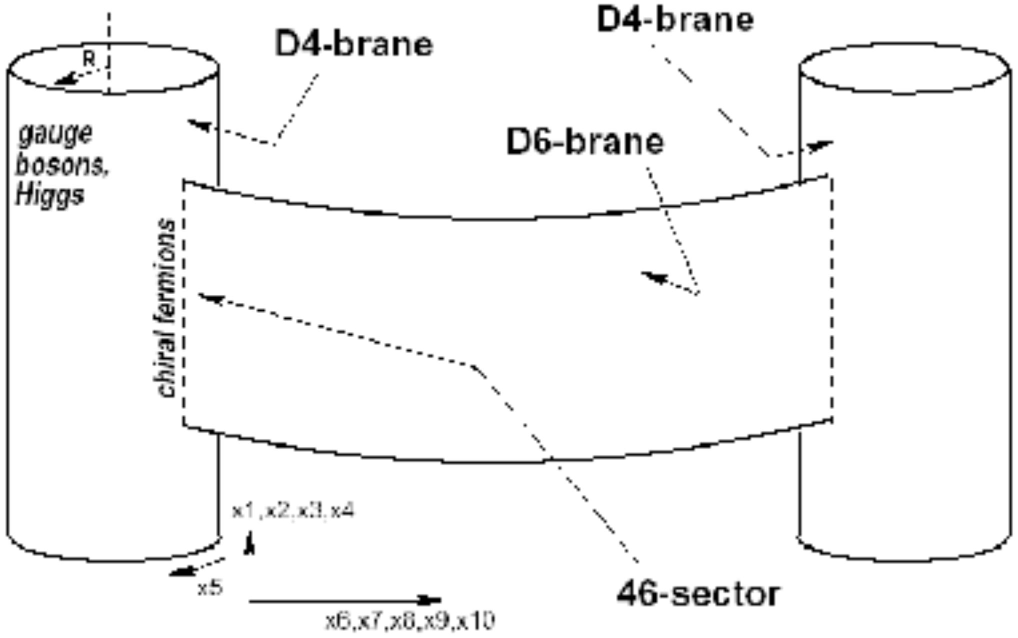

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Q: Is it what we believe in?

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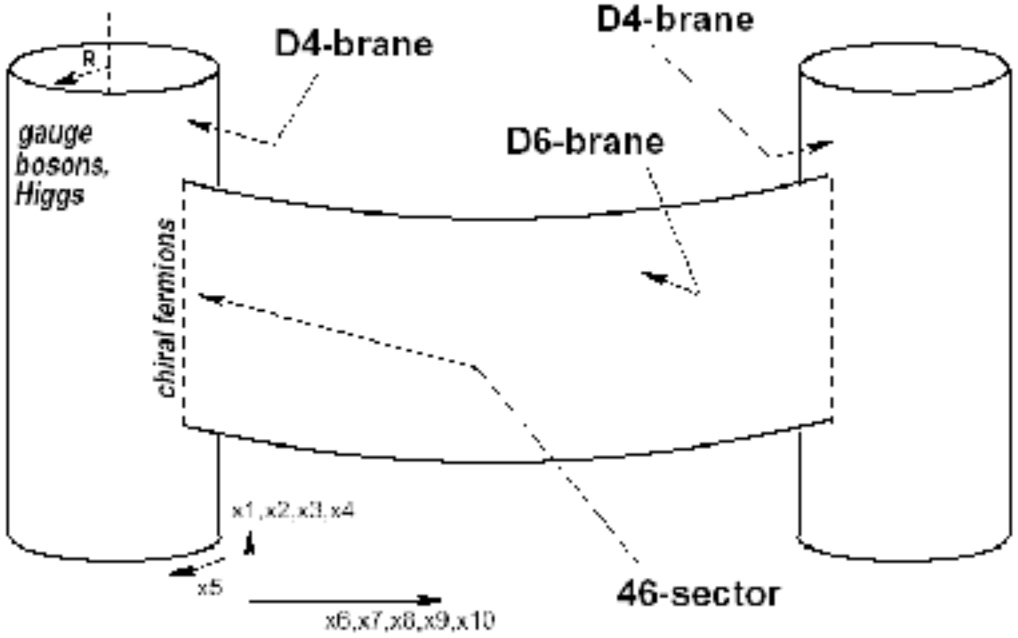

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Q: Do we have good reasons to believe in it?
A: No, but it is appealing
Q: Why D>4?
A: String theory loves it
Q: Is it what we believe in?
A: We believe in BIG deal

CONCLUDING REMARKS

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- ☑ Target #4: New physics (supersymmetry)
- ☑ Future development of HEP crucially depends on LHC outcome
- ☑ Complimentary searches for dark matter and insights in neutrino physics are of extreme importance
- ☑ The areas that were left behind come to the front: confinement, exotic hadrons, dense hadron matter