WHAT MAKES US THINK THAT PHYSICS BEYOND THE STANDARD MODEL EXISTS?

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BLTP JINR

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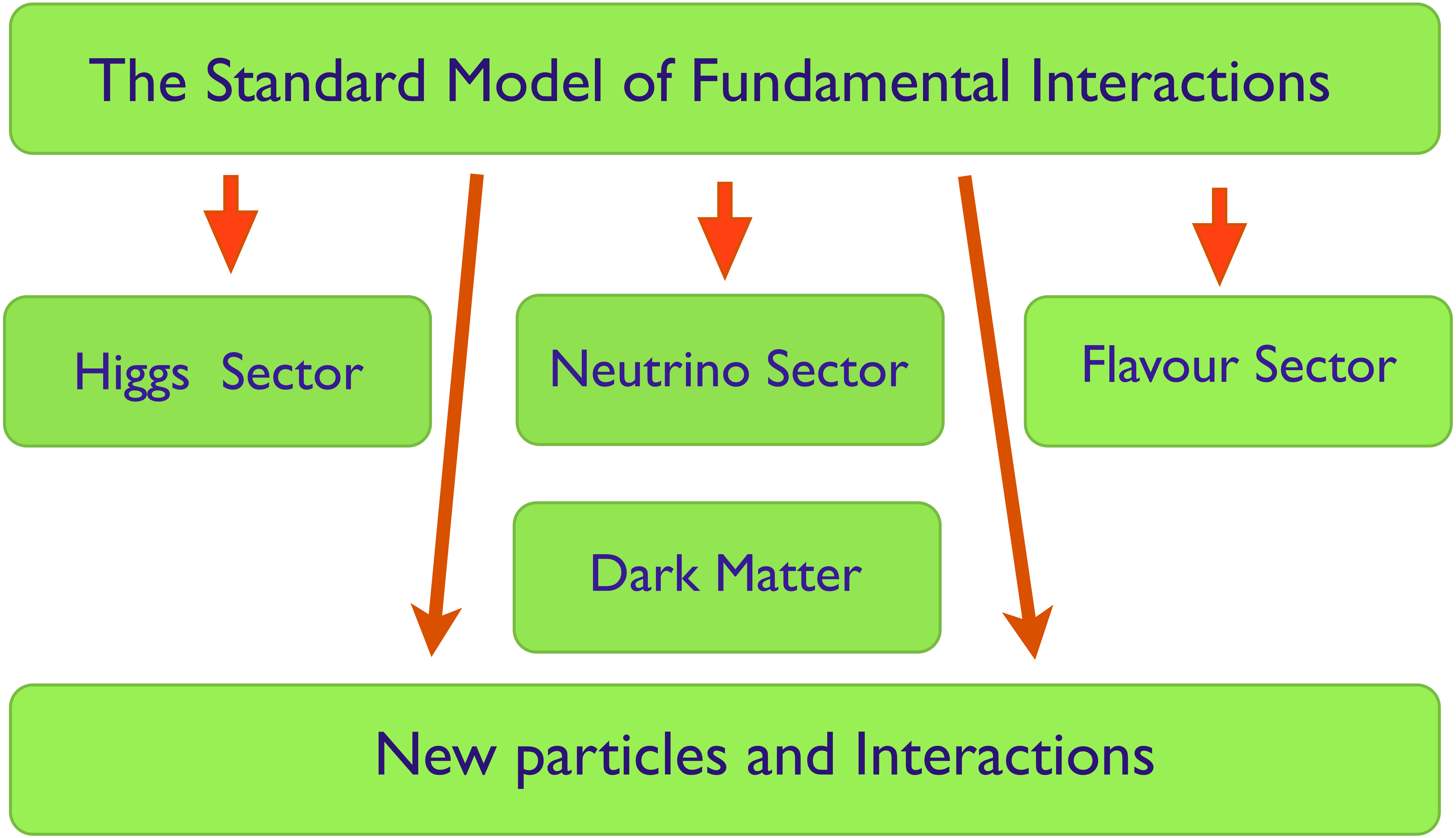
THE STANDARD MODEL: THE WAYS BEYOND



THE LAGRANGIAN

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

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

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

possible right handed neutrino ?

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

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

$$\mathcal{L}_{Higgs} = -V = m^2 H^\dagger H - \frac{\lambda}{2} (H^\dagger H)^2$$

THE LAGRANGIAN

$$\mathcal{L} = \mathcal{L}_{gauge} + \mathcal{L}$$

$$\mathcal{L}_{gauge} = -\frac{1}{4}G^{a}_{\mu}$$

$$+i\overline{L}_\alpha \gamma^\mu D_\mu L_\alpha$$

$$+i\overline{U}_\alpha \gamma^\mu D_\mu U_\alpha +$$

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

$$\mathcal{L}_{Yukawa} = y^L_{\alpha\beta}\overline{L}_\alpha E_\beta H$$

$$+y^N_{\alpha\beta}\overline{L}_\alpha N$$

$$\mathcal{L}_{Higgs} = -V$$

$$\begin{gathered}
\mathcal{L}_{SM} = -\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - igc_w(\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)) - \\
igs_w(\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - \\
W^-_\nu \partial_\nu W^+_\mu)) - \tfrac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \tfrac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - \\
Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w (A_\mu Z^0_\nu (W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu) - \tfrac{1}{2}\partial_\mu H \partial_\mu H - 2M^2\alpha_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \tfrac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \\
\beta_h \left(\tfrac{2M^2}{g^2} + \tfrac{2M}{g}H + \tfrac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right) + \tfrac{2M^4}{g^2}\alpha_h - \\
g\alpha_h M \left(H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-\right) - \\
\tfrac{1}{8}g^2\alpha_h \left(H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2\right) - \\
gMW^+_\mu W^-_\mu H - \tfrac{1}{2}g\tfrac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \\
\tfrac{1}{2}ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \\
\tfrac{1}{2}g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \tfrac{1}{2}g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + \\
M\left(\tfrac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+\right) - ig\tfrac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_w MA_\mu(W^+_\mu\phi^- - \\
W^-_\mu\phi^+) - ig\tfrac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
\tfrac{1}{4}g^2 W^+_\mu W^-_\mu \left(H^2 + (\phi^0)^2 + 2\phi^+\phi^-\right) - \tfrac{1}{8}g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu \left(H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-\right) - \\
\tfrac{1}{2}g^2\tfrac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \tfrac{1}{2}ig^2\tfrac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
W^-_\mu\phi^+) + \tfrac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - \\
g^2 s_w^2 A_\mu A_\mu\phi^+\phi^- + \tfrac{1}{2}ig_s\,\lambda^a_{ij}(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda(\gamma\partial + m_\nu^\lambda)\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + \\
m_u^\lambda)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_w A_\mu\left(-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \tfrac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right) + \\
\tfrac{ig}{4c_w}Z^0_\mu\{(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{d}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 - 1 - \gamma^5)d^\lambda_j) + \\
(\bar{u}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 + \gamma^5)u^\lambda_j)\} + \tfrac{ig}{2\sqrt{2}}W^+_\mu\left((\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)U^{lep}{}_{\lambda\kappa}e^\kappa) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \\
\tfrac{ig}{2\sqrt{2}}W^-_\mu\left((\bar{e}^\kappa U^{lep\dagger}{}_{\kappa\lambda}\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right) + \\
\tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m_e^\kappa(\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa}(1-\gamma^5)e^\kappa) + m_\nu^\lambda(\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa}(1+\gamma^5)e^\kappa\right) + \\
\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m_e^\lambda(\bar{e}^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1+\gamma^5)\nu^\kappa) - m_\nu^\kappa(\bar{e}^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1-\gamma^5)\nu^\kappa\right) - \tfrac{g}{2}\tfrac{m_\nu^\lambda}{M}H(\bar{\nu}^\lambda\nu^\lambda) - \\
\tfrac{g}{2}\tfrac{m_e^\lambda}{M}H(\bar{e}^\lambda e^\lambda) + \tfrac{ig}{2}\tfrac{m_\nu^\lambda}{M}\phi^0(\bar{\nu}^\lambda\gamma^5\nu^\lambda) - \tfrac{ig}{2}\tfrac{m_e^\lambda}{M}\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda) - \tfrac{1}{4}\,\bar{\nu}_\lambda\,M^R_{\lambda\kappa}\,(1-\gamma_5)\hat{\nu}_\kappa - \\
\tfrac{1}{4}\,\overline{\bar{\nu}_\lambda\,M^R_{\lambda\kappa}\,(1-\gamma_5)\hat{\nu}_\kappa} + \tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j\right) + \\
\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j\right) - \tfrac{g}{2}\tfrac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \\
\tfrac{g}{2}\tfrac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2}\tfrac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \tfrac{ig}{2}\tfrac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu + \\
\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \tfrac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \\
\partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \\
\partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \\
\partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \\
\partial_\mu\bar{X}^- X^-) - \tfrac{1}{2}gM\left(\bar{X}^+ X^+ H + \bar{X}^- X^- H + \tfrac{1}{c_w^2}\bar{X}^0 X^0 H\right) + \tfrac{1-2c_w^2}{2c_w}igM\left(\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-\right) + \\
\tfrac{1}{2c_w}igM\left(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-\right) + igMs_w\left(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-\right) + \\
\tfrac{1}{2}igM\left(\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0\right).
\end{gathered}$$

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Three gauge couplings

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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

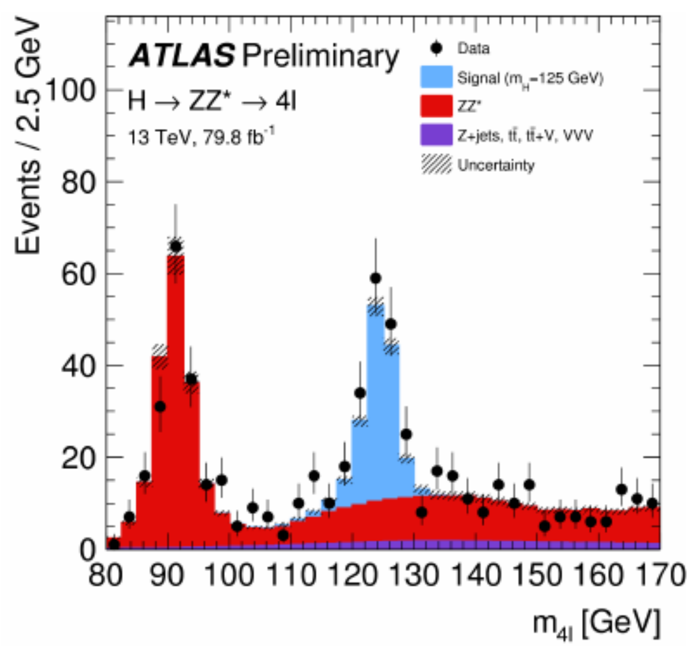
Three gauge couplings

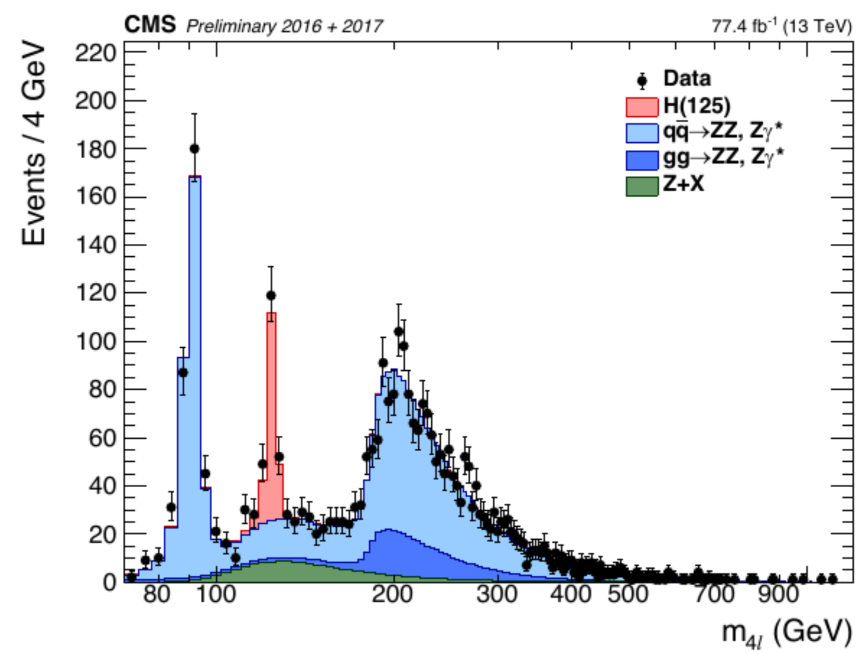
Three or four Yukawa matrices

Two parameters

Higgs bosons - entering precision era

Run-2 analyses with 80 fb^{-1} for the first time – higher precision is coming!





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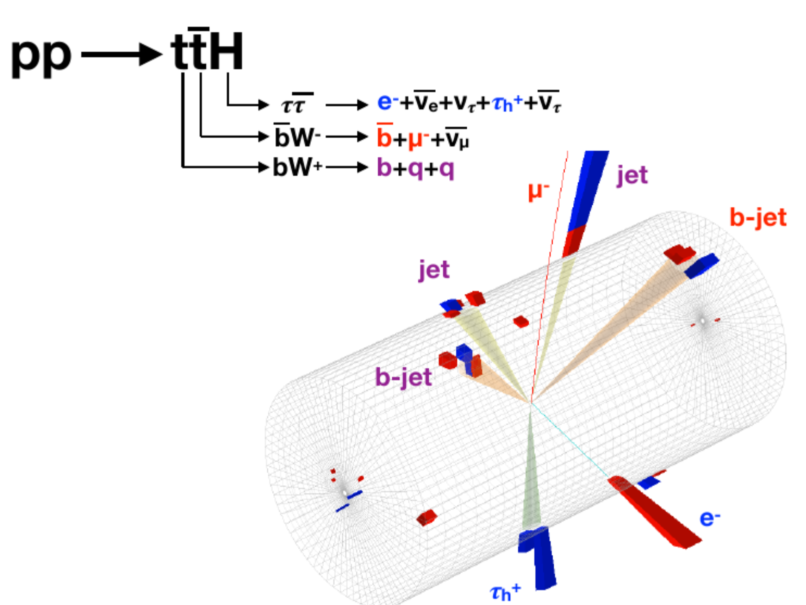
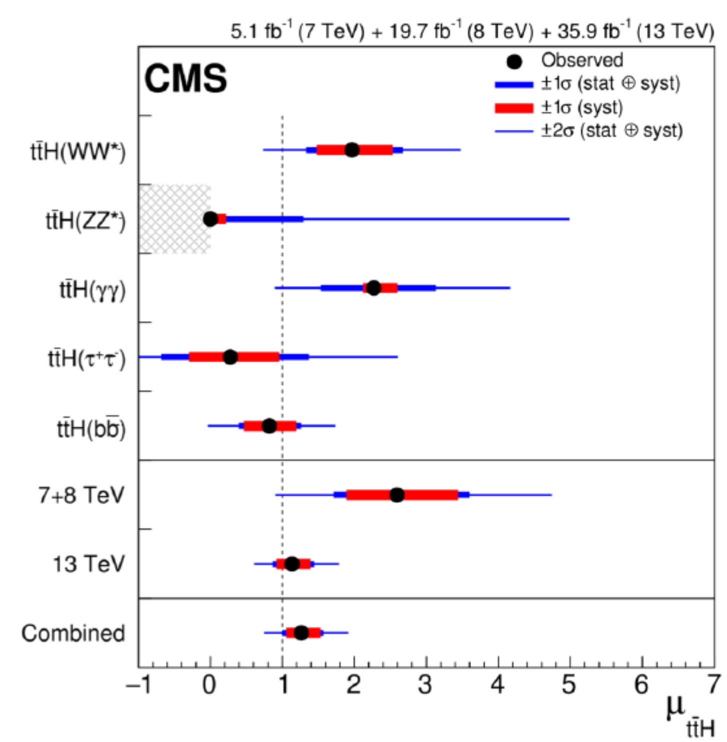
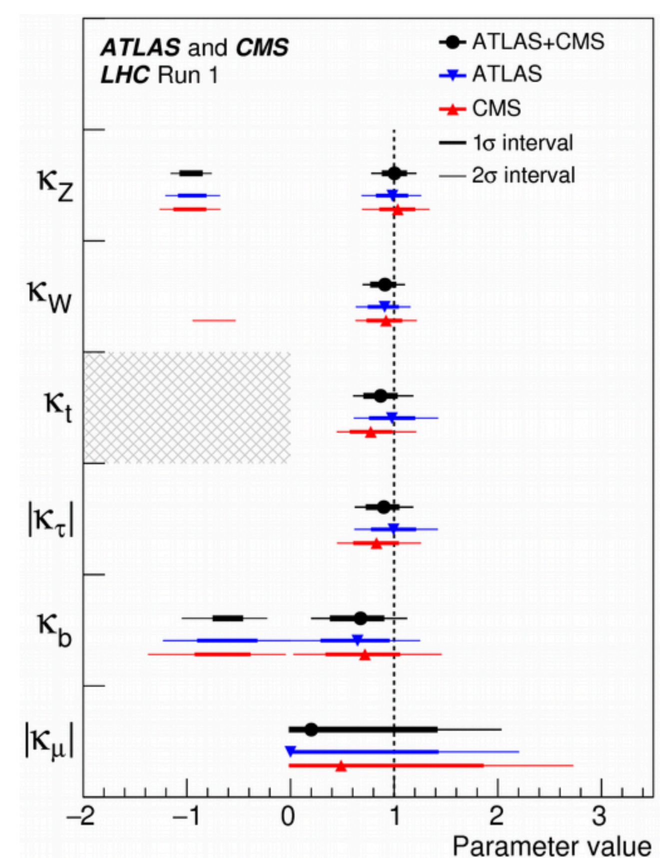
ttH observation







Precision EW mass measurements

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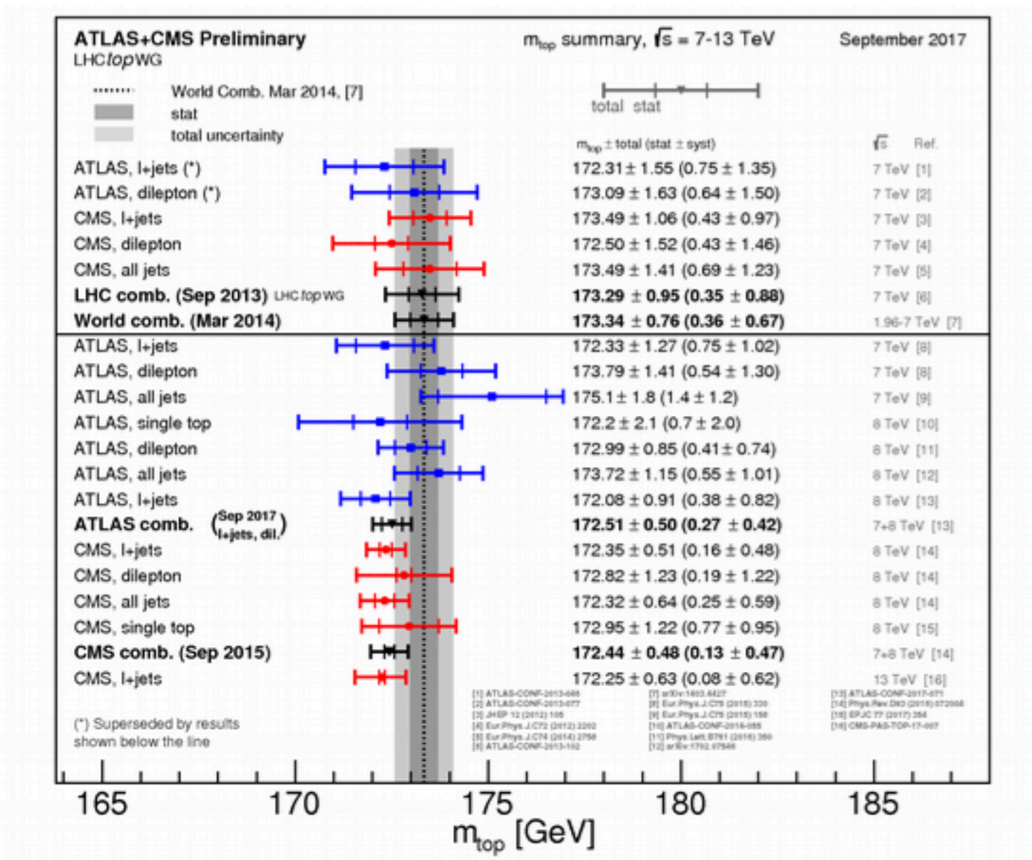
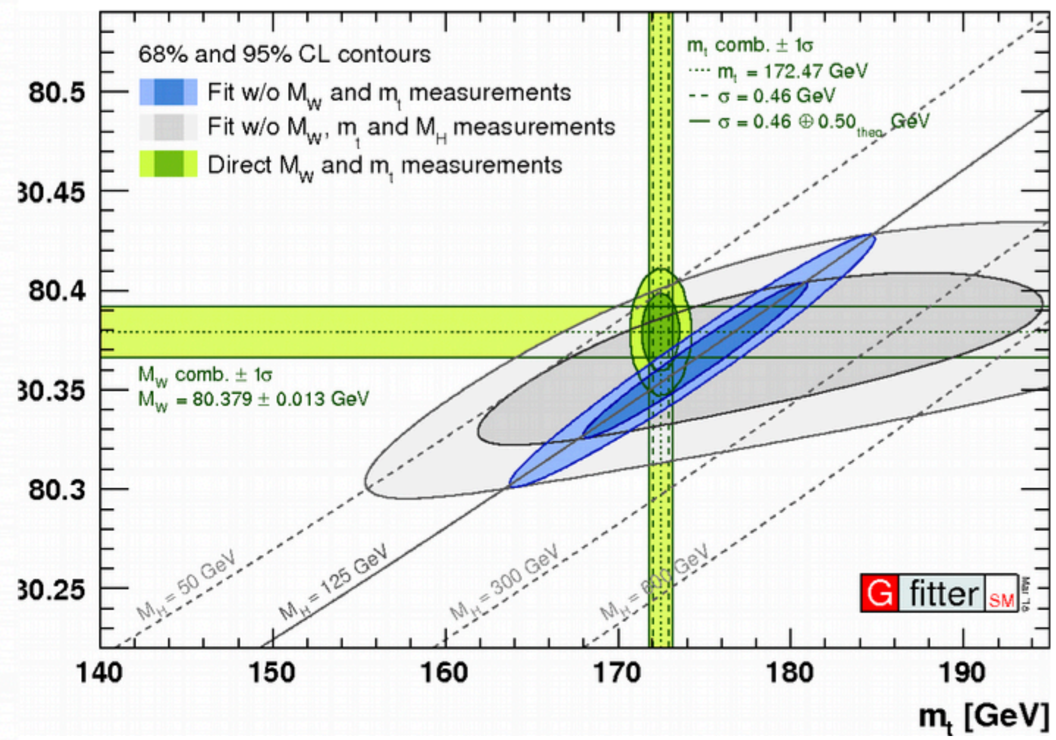
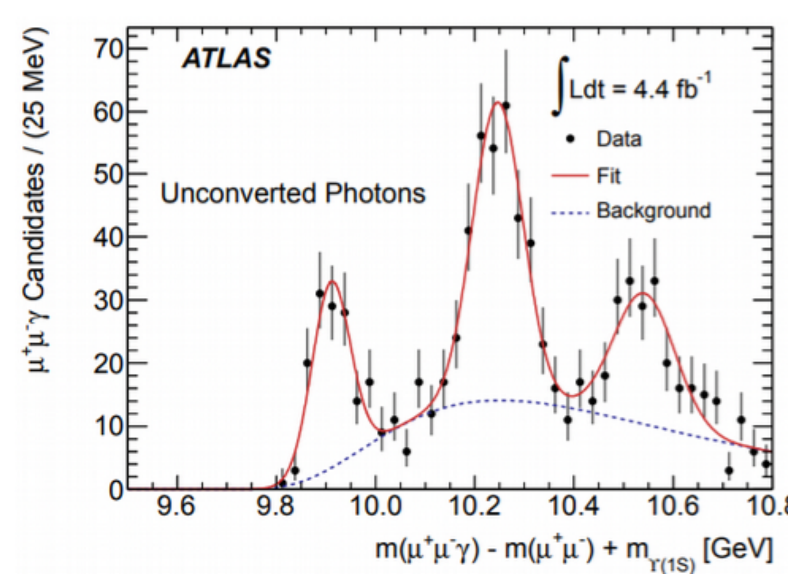


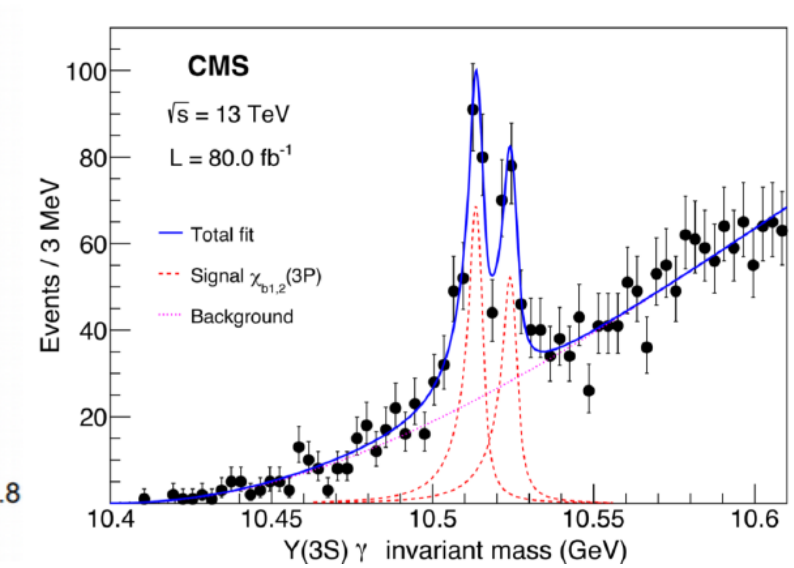


Precision spectroscopy!

$$m(\chi_{b2}(3P)) - m(\chi_{b2}(3P)) =$$

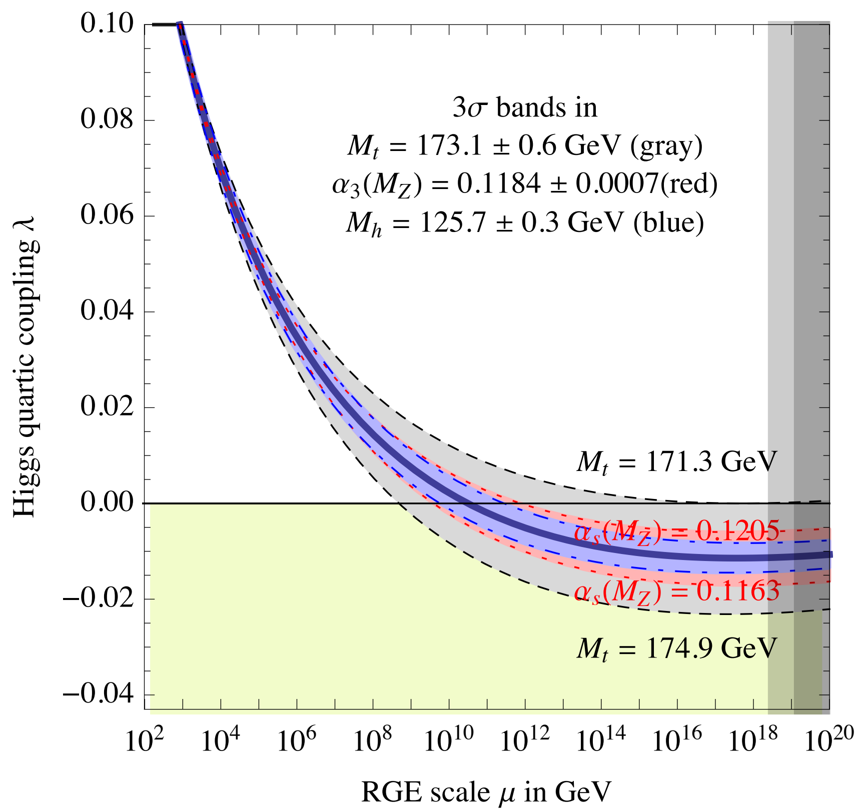
$$10.60 \pm 0.64(stat) \pm 0.17\ (syst)\ MeV$$

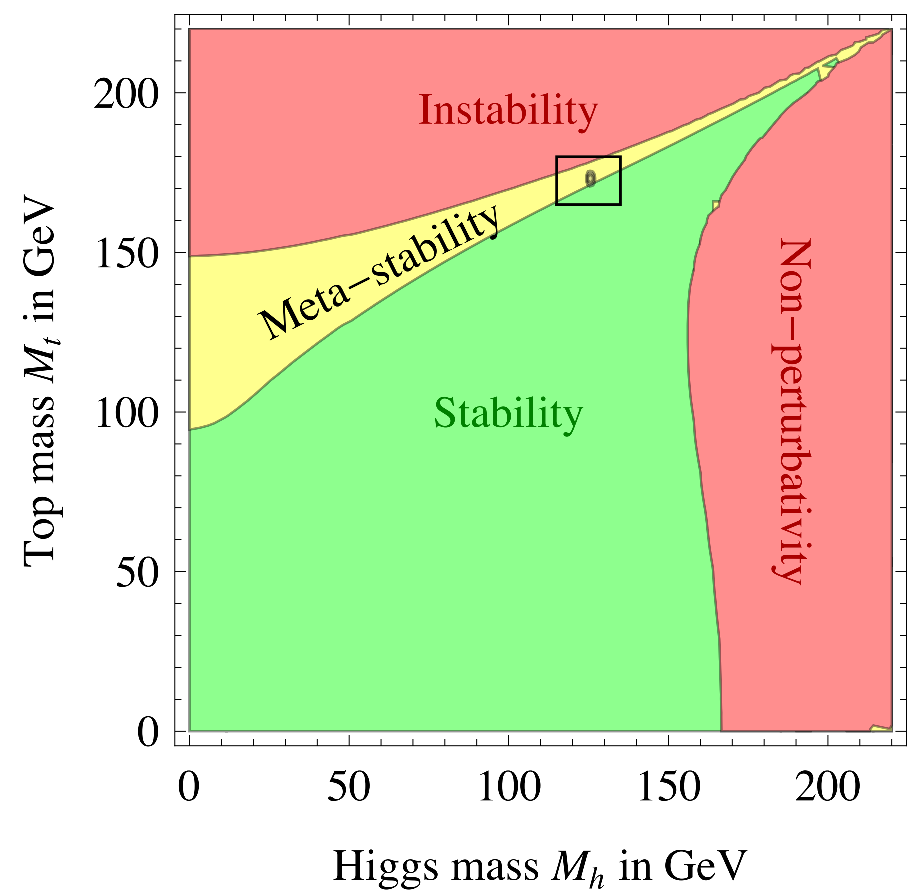




- The electroweak vacuum is unstable under radiative corrections

- The whole construction of the SM may be in trouble being metastable or even unstable



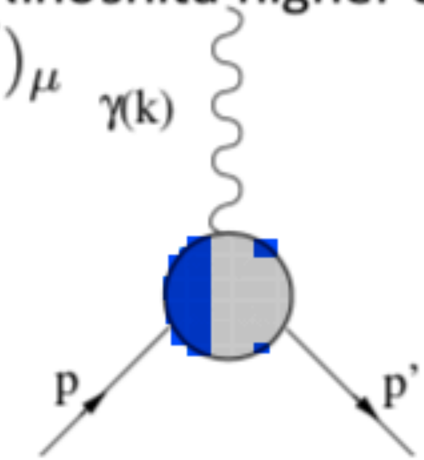


- the situation crucially depends on the top and Higgs mass values and requires severe fine-tuning and high accuracy of calculations (3 loops)

Muon anomalous magnetic moment

(Schwinger α/π,
Kinoshita higher orders in α)

$$ie\bar{u}_\ell(p')\left[\gamma^\mu - \frac{a_\ell}{2m_\ell} i\sigma^{\mu\nu}q_\nu\right]u_\ell(p)\epsilon^*_\mu, \qquad q_\mu = (p-p')_\mu$$



Dirac equation predicts g=2 $\quad a = (g-2)/2$

For electron a_e theory and experiment agrees!

(18) (18) (2072) (120) (18) (2)

$$a_\mu^{th} - a_\mu^{exp} = -(3.06 \pm 0.76) \times 10^{-8}$$ 4 σ

Theory: uncertainty in hadronic contributions to the muon g – 2, (Jägerlehner, 1802.08019).
Lattice QCD great progress light-by-light study (RBC & UKQCD, 1801.07224).

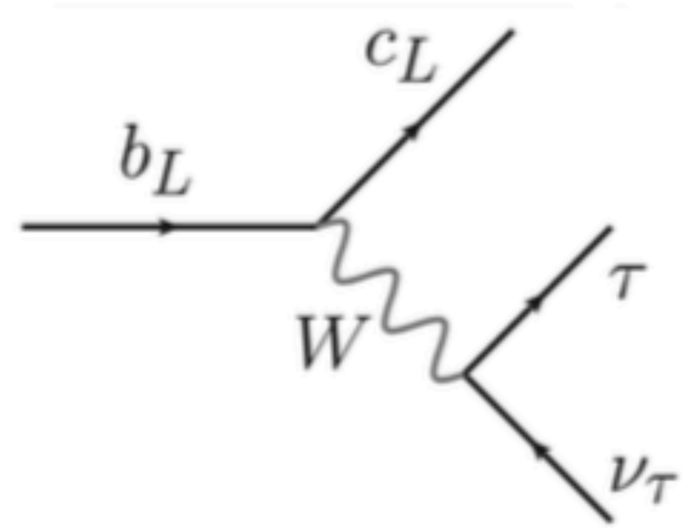
Fermilab and J-Park experiments are expected to clarify existing discrepancy!

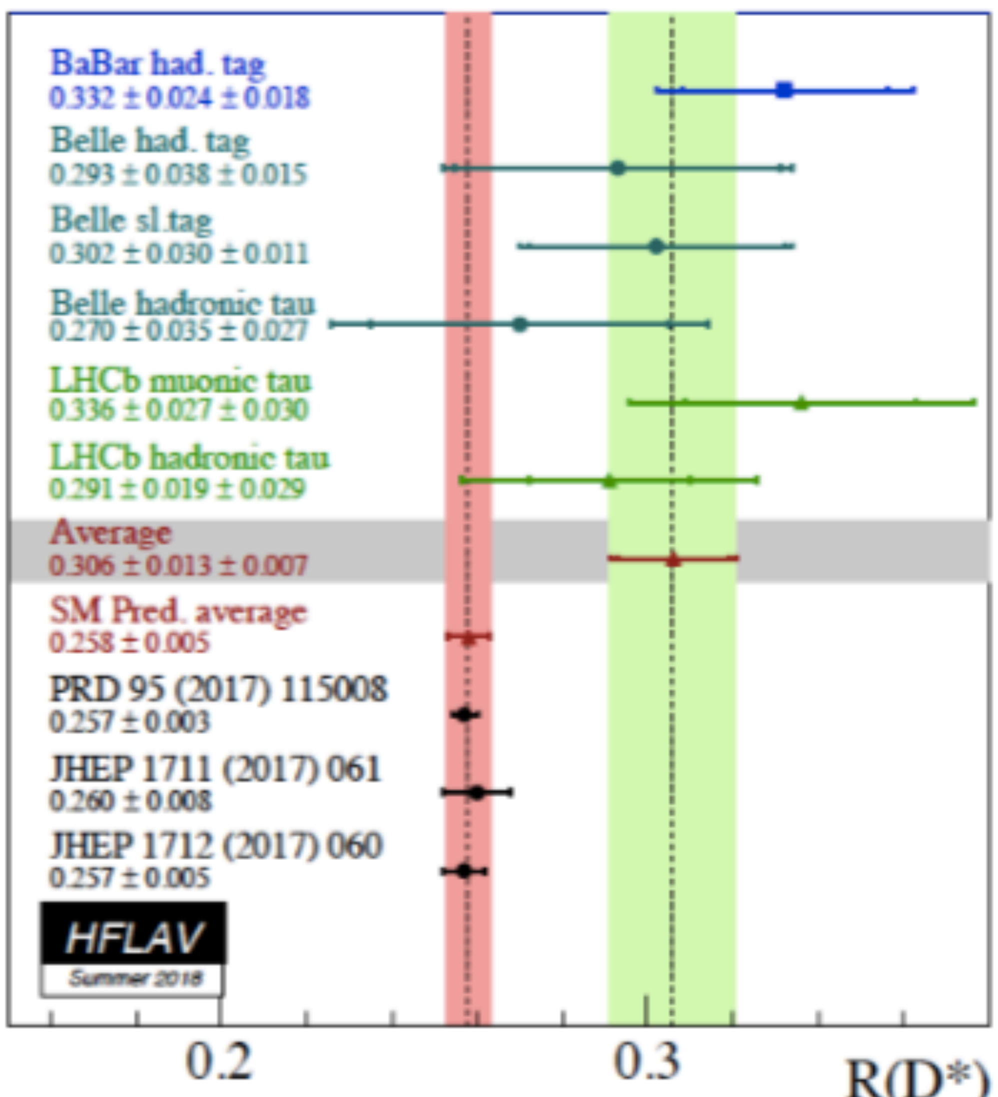
B physics anomalies: experimental results ≠ SM predictions!

charged current (SM tree level)

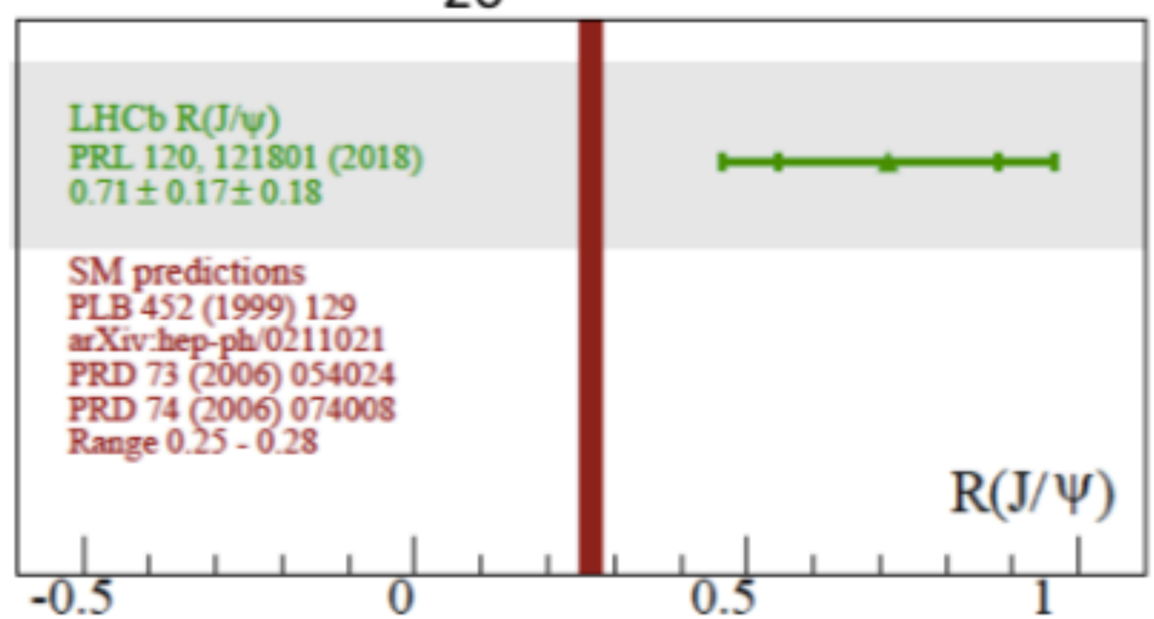
$$R_{D^{(*)}} = \frac{BR(B \to D^{(*)}\tau\nu_\tau)}{BR(B \to D^{(*)}\mu\nu_\mu)}$$

3.8σ





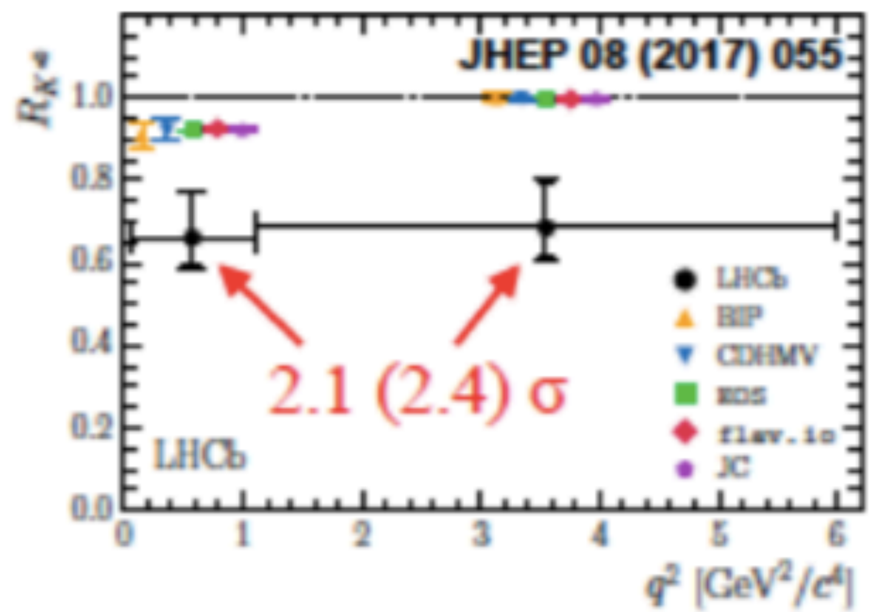
2σ

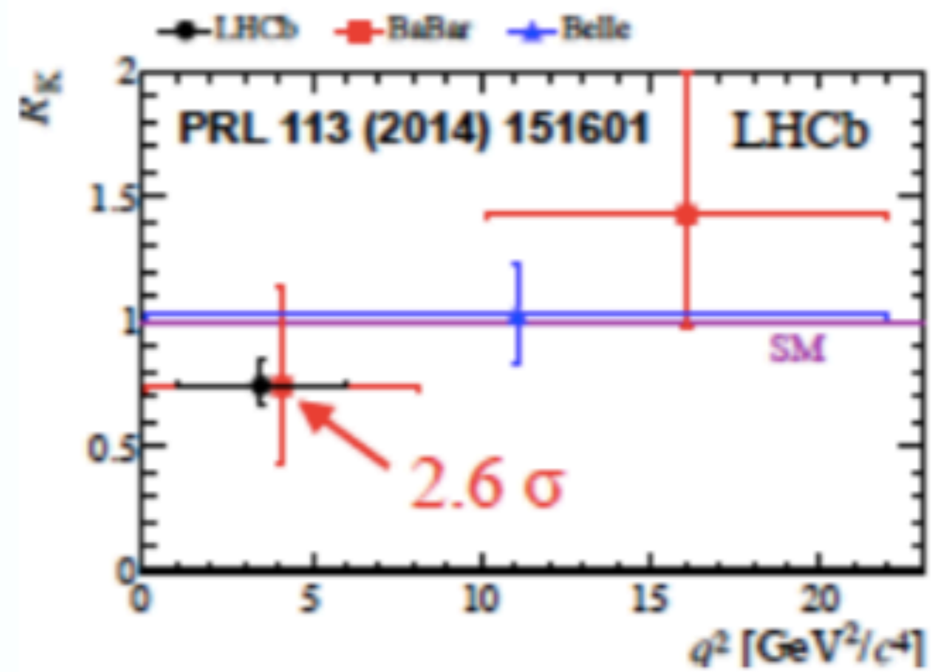


See Leroy's talk at ICHEP2018

FCNC - SM loop process: $R_{K(*)}$ anomaly

$$R_{K^{(*)}} = \left.\frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)}\right|_{q^2 \in [q^2_{min}, q^2_{max}]}$$



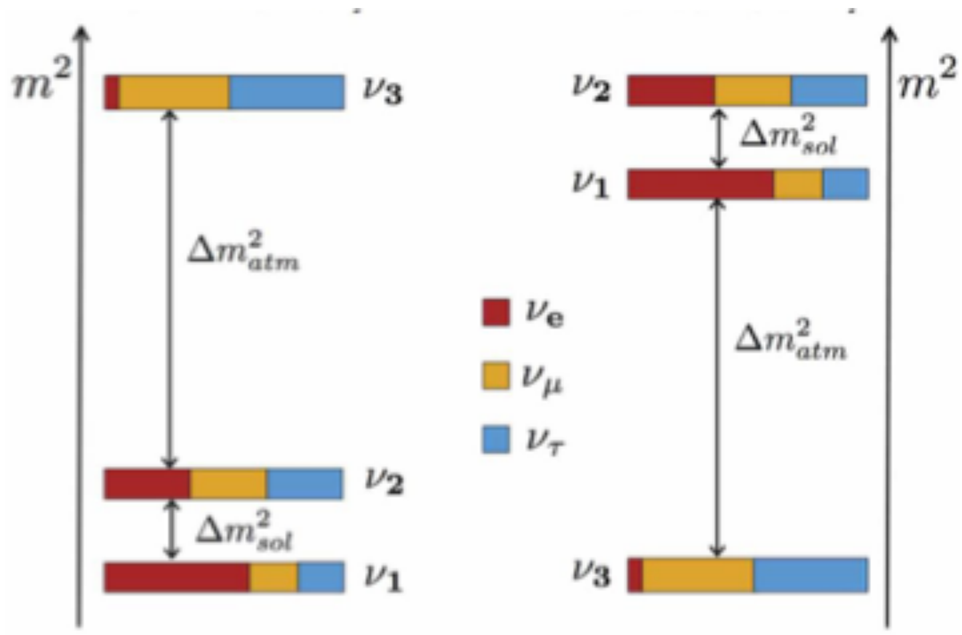


P_5' in $B \to K^* \mu^+ \mu^-$ (angular distribution functions) 3σ

LHCb: the discrepancy present in $B_s \to \phi\mu\mu$ and $\Lambda_b \to \Lambda\mu\mu$

(see Capriotti talk at ICHEP2018)

Neutrino Physics



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$\|\Delta m^2_{31}\|$ [10^{-3}eV^2] (NO)	2.50±0.03	2.41–2.60
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$\sin^2\theta_{12}/10^{-1}$	$3.20^{+0.20}_{-0.16}$	2.73–3.79
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δ/π (NO)	$1.32^{+0.21}_{-0.15}$	0.87–1.94
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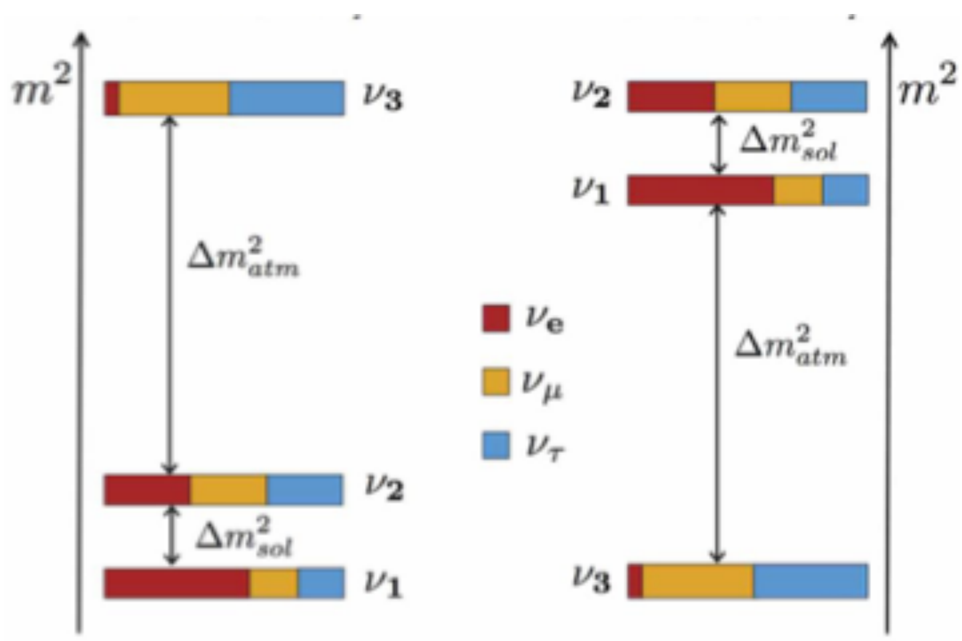
de Salas et al, 1708.01186

Neutrino Physics

- Absolute value of neutrino masses ?
- Mass hierarchy?
- Dirac or Majorana?
- Fourth sterile neutrino?
- Neutrino dark matter?



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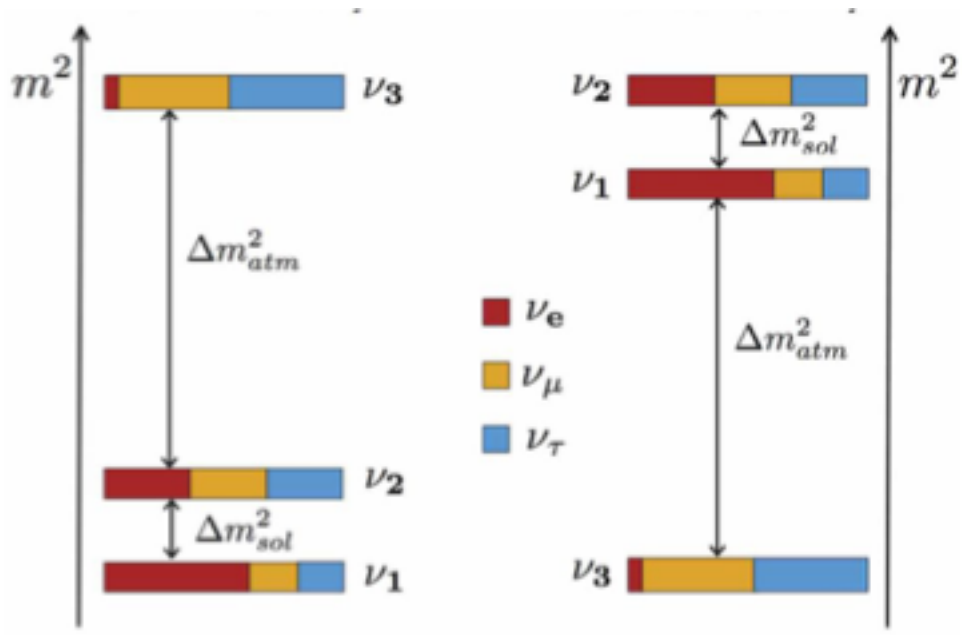

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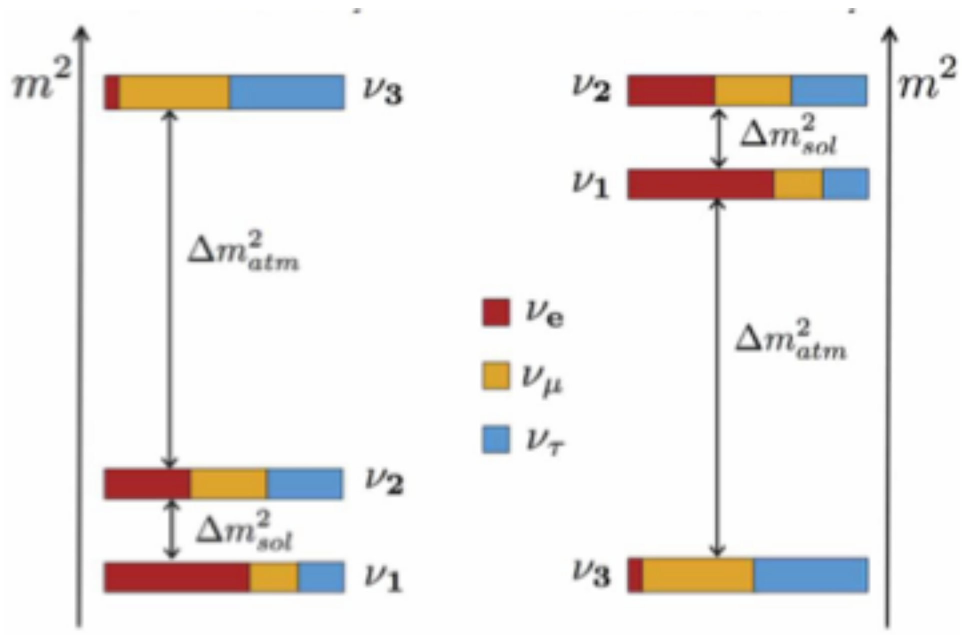
ν-osc (lower bound) — CMB (upper bound)

Neutrino Physics



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PMNS-matrix parameters are measured with high accuracy of few %

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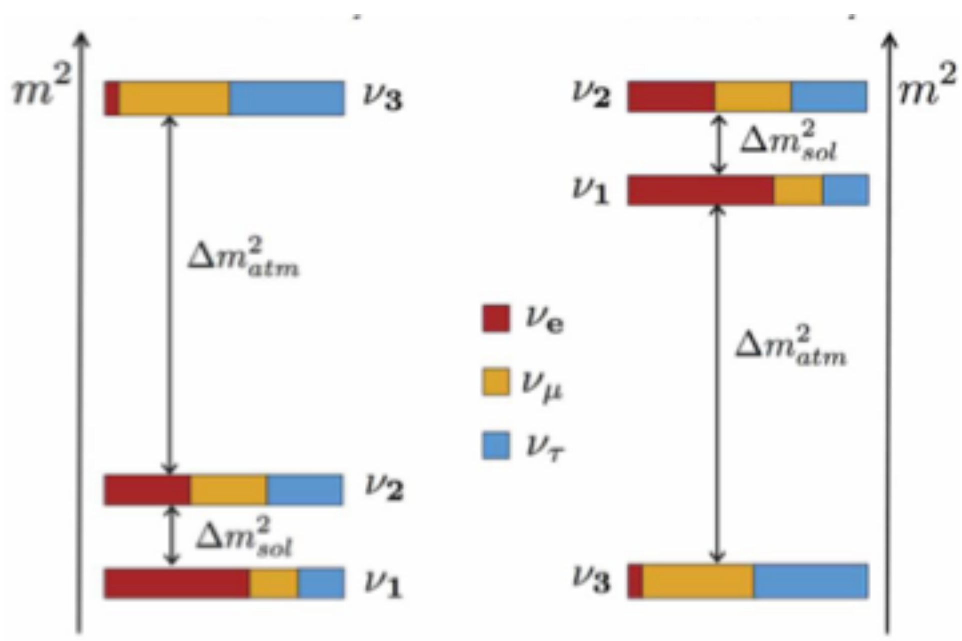

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ν-osc　　　CMB

PMNS-matrix parameters are measured with high accuracy of few %

- Normal hierarchy favoured at 3.1 σ
- Nonzero CP phase favoured
- Upper octant favoured

Is it just the SM or requires New physics?

Three Types of Seesaw Mechanisms

Require the existence of new degrees of freedom (particles) beyond those present in the SM

Type I seesaw mechanism: ν_{lR} - RH νs' (heavy).

Type II seesaw mechanism: H(x) - a triplet of H^0,H^-,H^{--} Higgs fields.

Type III seesaw mechanism: T(x) - a triplet of fermion fields.

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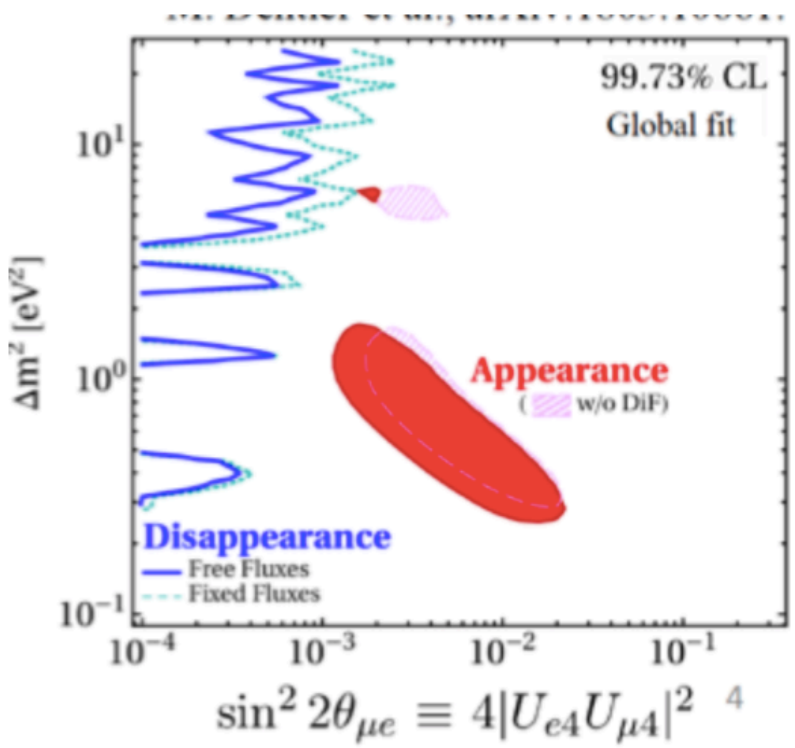
M. Weber ICHEP2018

- **Possible Sterile Neutrino?**
  - New MiniBooNE consistent with LSND (but low energy excess?)
  - Reactor anomaly questioned by Daya Bay/RENO time dependence
  - New SBL and source experiments
  - Conflict with ν_μ disappearance



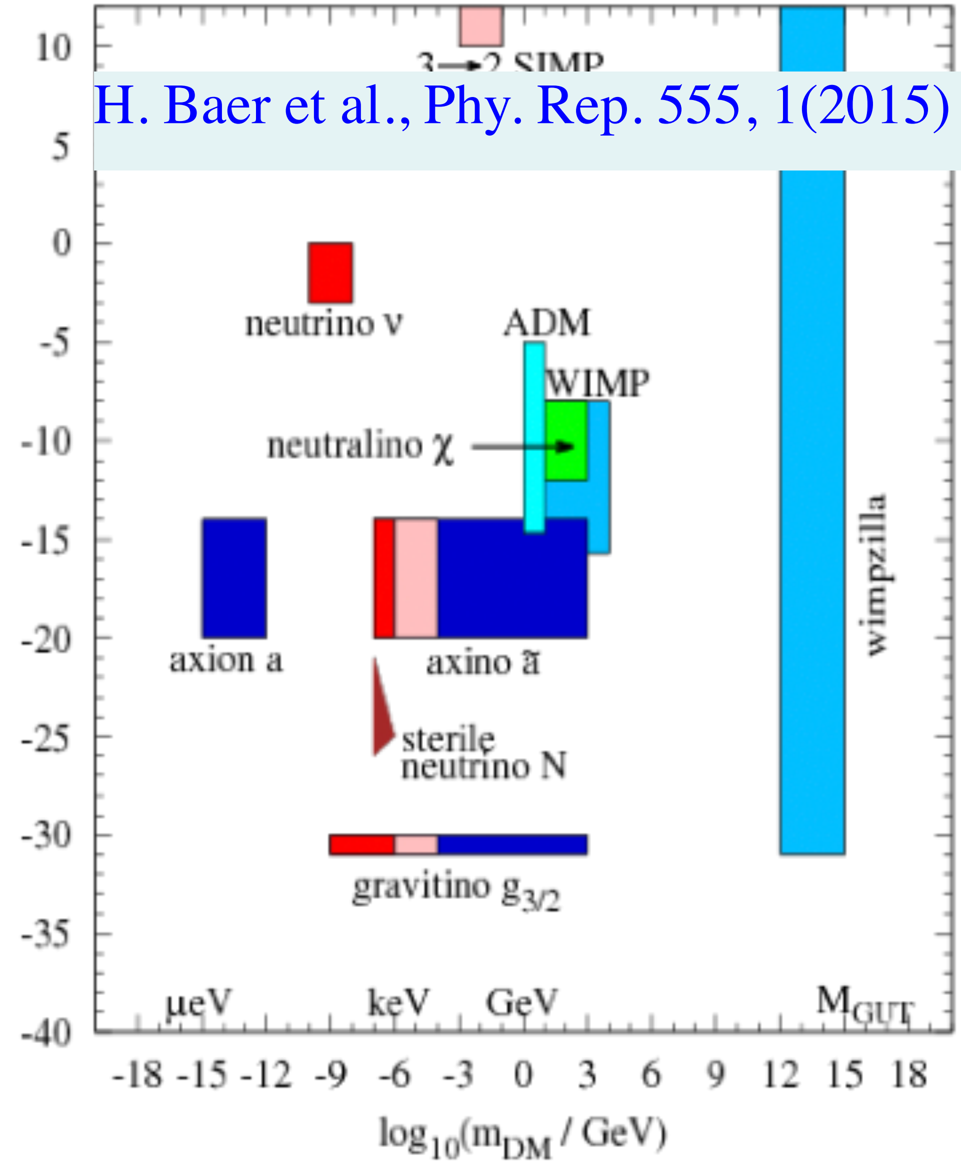
4

Major problem: 85% of matter is dark and remains invisible!

Is this compatible with the SM?

Does it requires modification of the SM or addition of gravity?

- **Many candidates in many orders of magnitude of mass:**
  - **MOND** (Problems: large scales, Bullet cluster)
  - **Primordial black holes** (LIGO, but constraints)
  - **Fuzzy** (very light bosons)
  - **Warm** (KeV sterile)
  - **WIMP**
  - **Axions/ALPs**
  - **Dark sector**
  - **Gravitinos**
  - **Moduli**
  - **Wimpzillas**



H. Baer et al., Phy. Rep. 555, 1(2015)

M. Drees

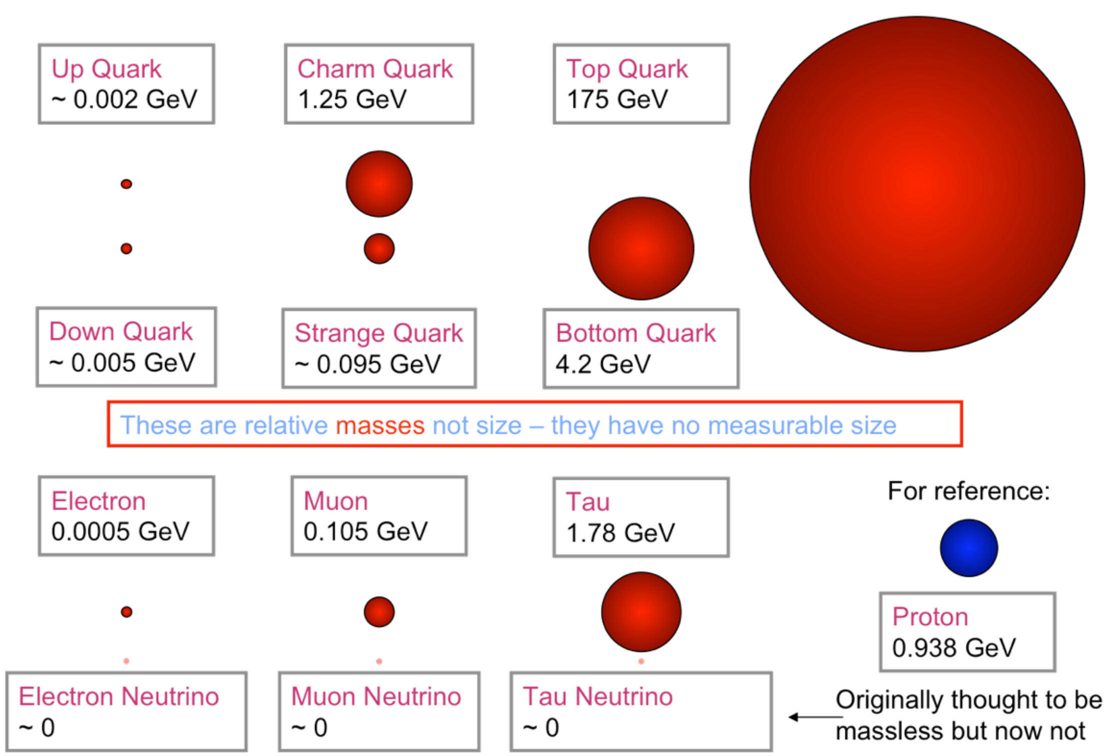
- **Direct, indirect, collider**

BEYOND THE STANDARD MODEL: THE MASS SPECTRUM AND MIXINGS

- Mass spectrum?

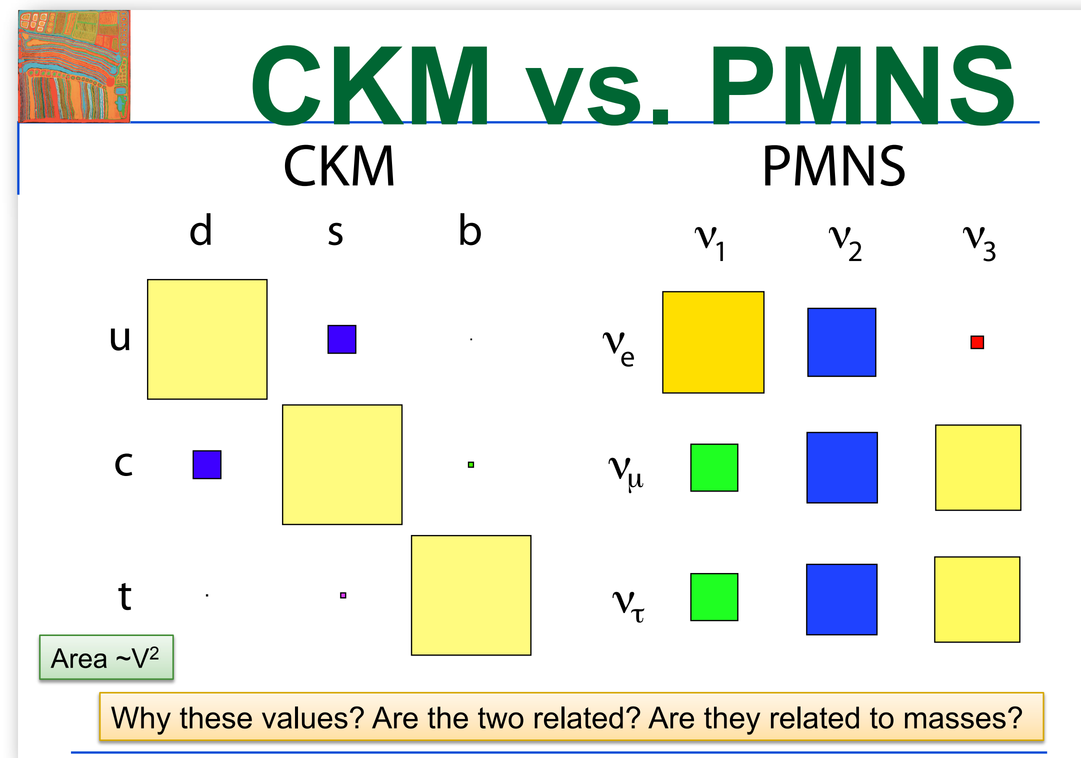
$$m_{quark} = y_{quark} \cdot v$$
$$m_{lepton} = y_{lepton} \cdot v$$
$$m_W = g/\sqrt{2} \cdot v$$
$$m_Z = \sqrt{g^2 + g'^2}/\sqrt{2} \cdot v$$
$$m_H = \sqrt{\lambda} \cdot v$$
$$m_\gamma = 0$$
$$m_{gluon} = 0$$

SM



- Mixing Matrices?

- Quark-Lepton Symmetry
- Strong difference in parameters



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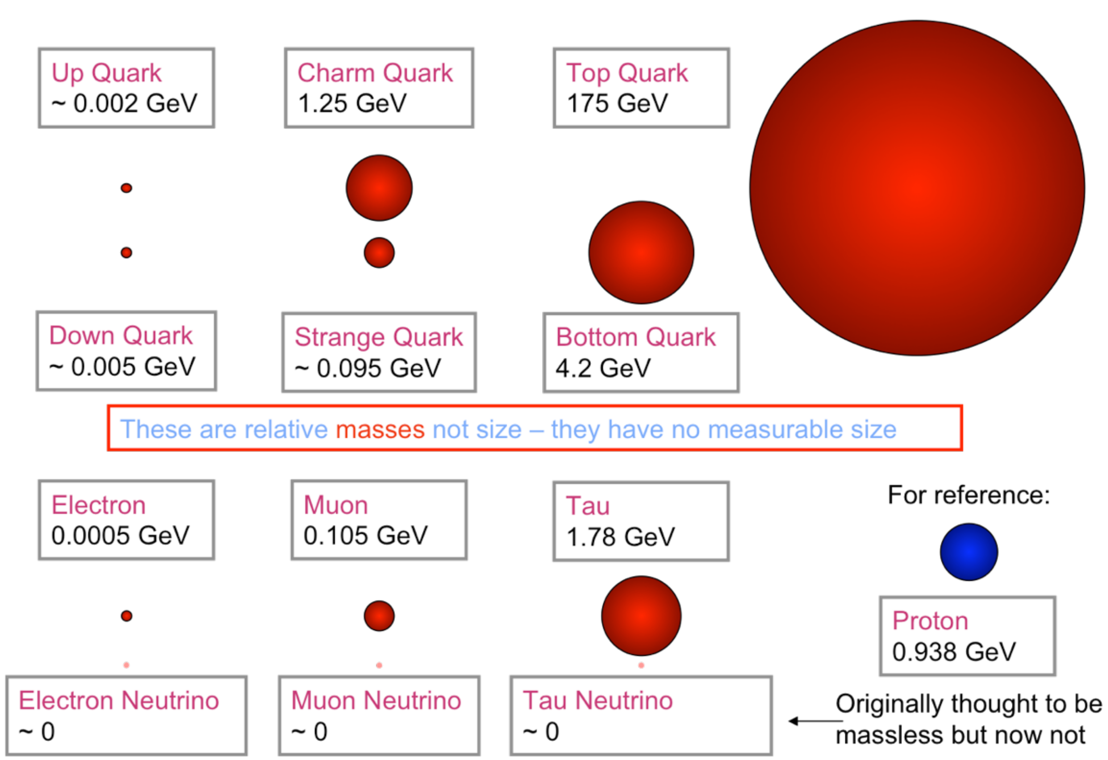

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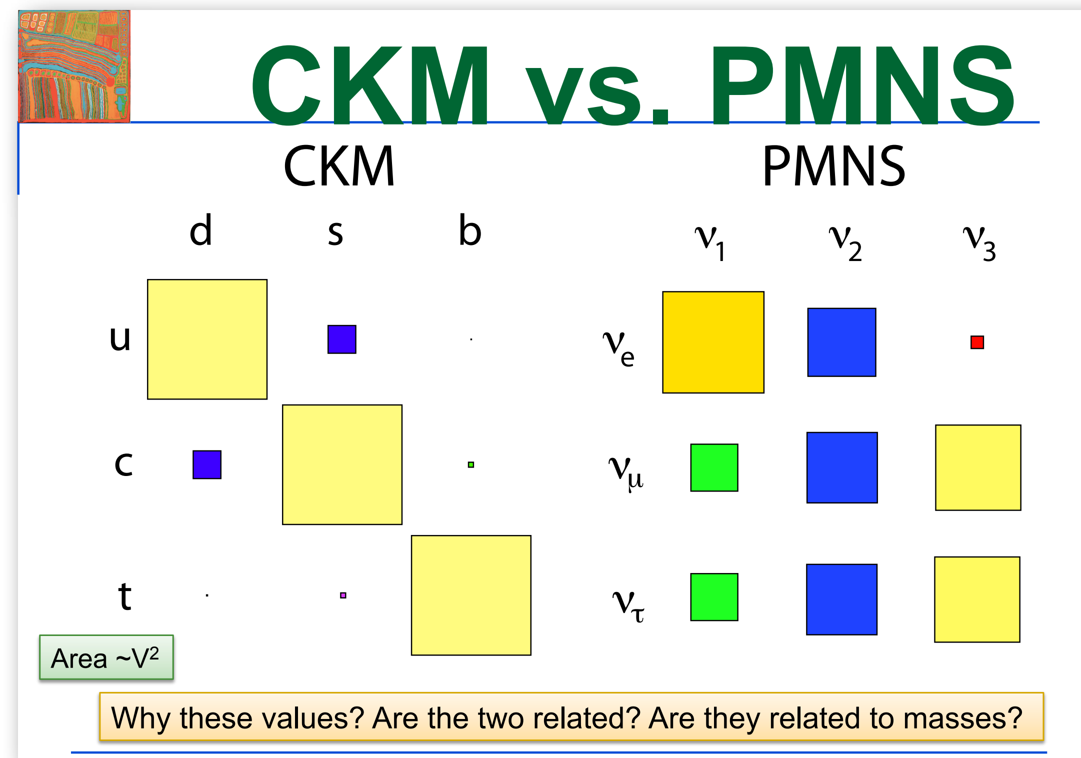

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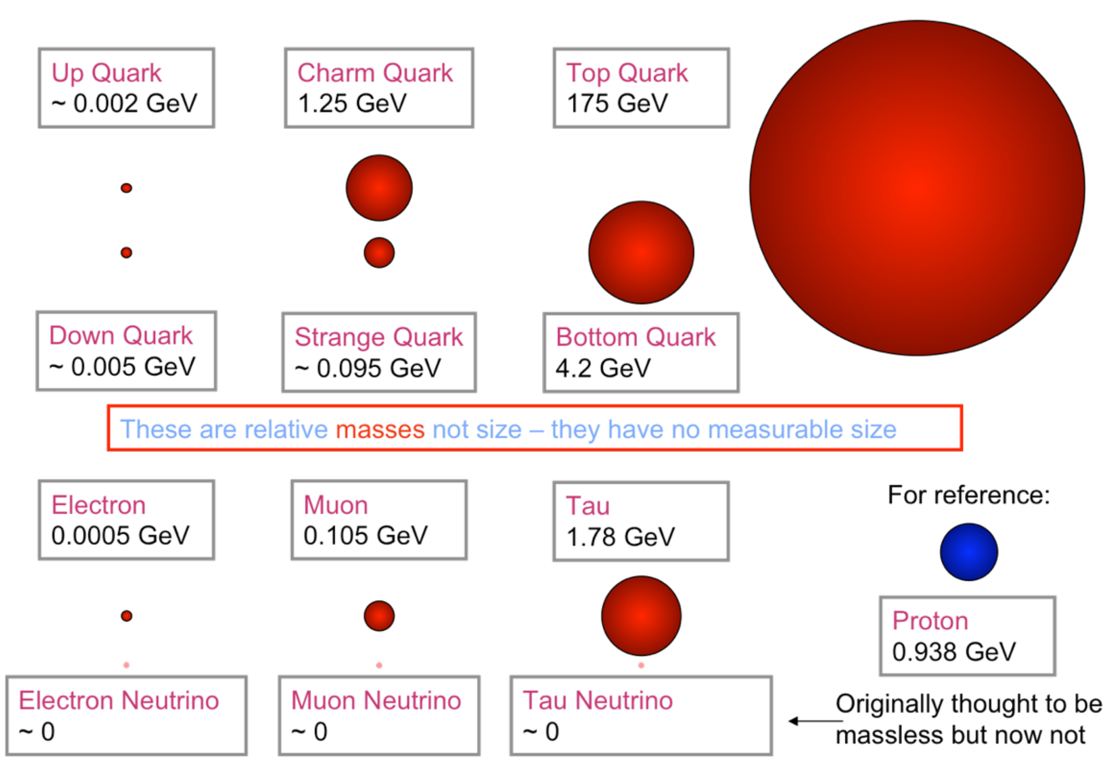

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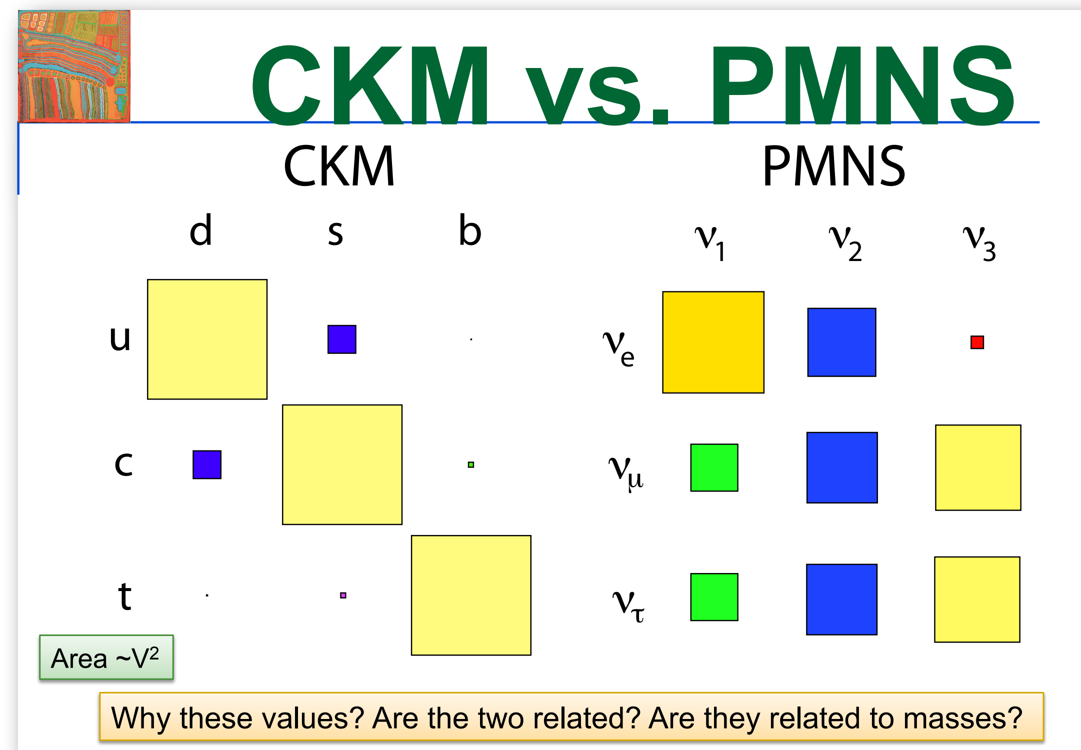

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$$J_{CP} = \frac{1}{8} \sin 2\theta_{12} \sin 2\theta_{23} \sin 2\theta_{13} \cos \theta_{13} \sin \delta$$

Neutrino Mixing: New Symmetry?

- $\theta_{12} = \theta_{\odot} \cong \frac{\pi}{5.4}, \quad \theta_{23} = \theta_{\rm atm} \cong \frac{\pi}{4}(?), \quad \theta_{13} \cong \frac{\pi}{20}$

$$U_{\rm TBM} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \sqrt{\frac{1}{3}} & 0 \\ -\sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & -\sqrt{\frac{1}{2}} \\ -\sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & \sqrt{\frac{1}{2}} \end{pmatrix}; \quad U_{\rm BM} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \pm\frac{1}{\sqrt{2}} & 0 \\ -\frac{1}{2} & \pm\frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \mp\frac{1}{2} & \frac{1}{\sqrt{2}} \end{pmatrix}. \quad U_{\rm HGM} = \begin{pmatrix} \frac{\sqrt{3}}{2} & \frac{1}{2} & 0 \\ -\frac{1}{2\sqrt{2}} & \frac{\sqrt{3}}{2\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ -\frac{1}{2\sqrt{2}} & \frac{\sqrt{3}}{2\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

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Follows the attempts in quark sector with 30 years delay: so far unsuccessful

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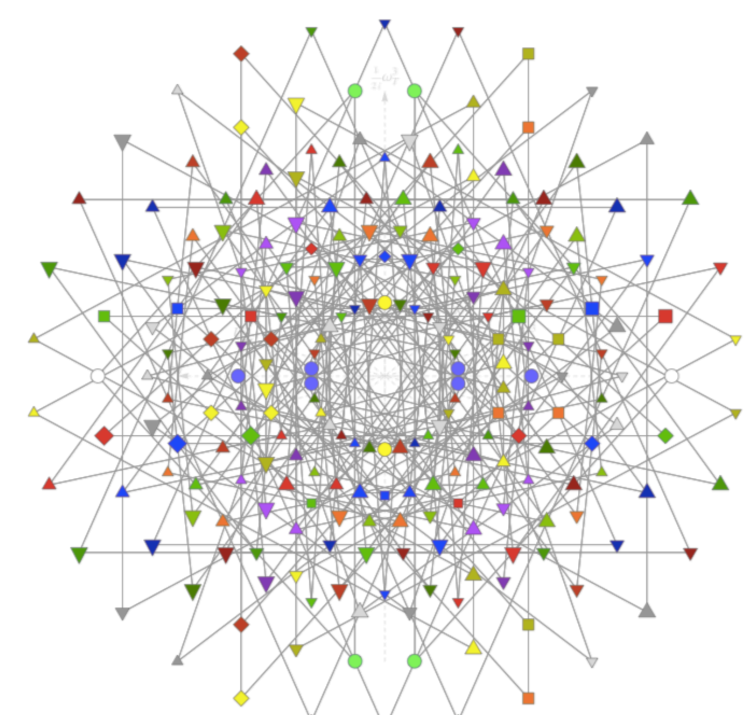

E8 roots

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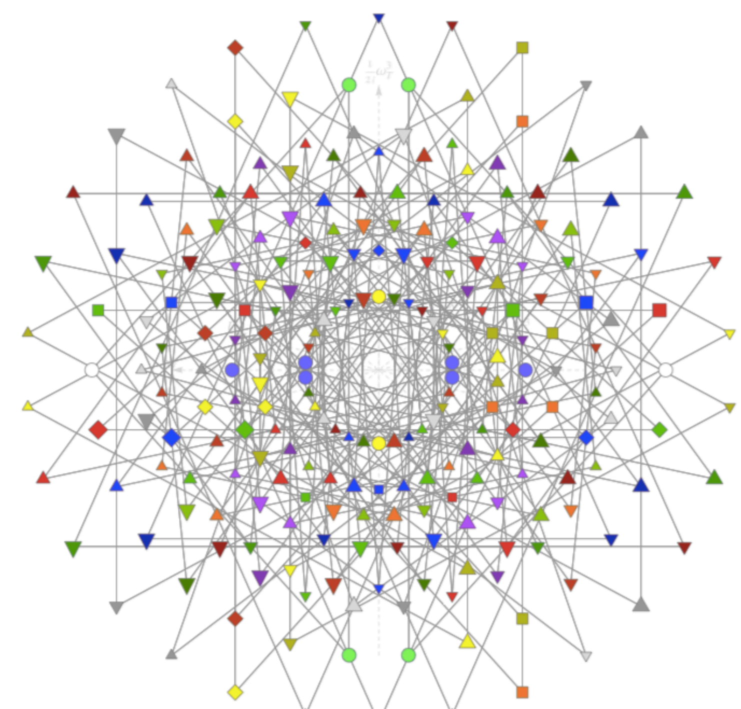

Symmetry might be tricky

E8 roots

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- still not explained
- three conditions (A.D.Sakharov)

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CPT is exact symmetry of Nature

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- New era in gravity due to discovery of gravitational waves and black holes might change the landscape

Ideas (conventional and not)

- Symmetries
  - Supersymmetry, family, ...
- Compositeness
  - Higgs, fermions, ...
- Extra dimensions
  - large, warped, ...
- Dark or hidden sectors
  - Dark, SUSY-breaking, random, ...
- Unification
  - GUT, string, ...
- New dynamical ideas
  - Relaxion, nnaturalness, clockwork, string instantons, ...
- Random or environmental
  - multiverse
- String remnants
  (need not solve SM problem)
  - *Z'*, vector fermions, extended Higgs, dark, moduli, axions, ...

BEYOND THE STANDARD MODEL: CONCLUSIONS

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How Will We Make Progress?

• • •

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. . .

The energy frontier

The precision frontier and neutrinos

Cosmology and astrophysics