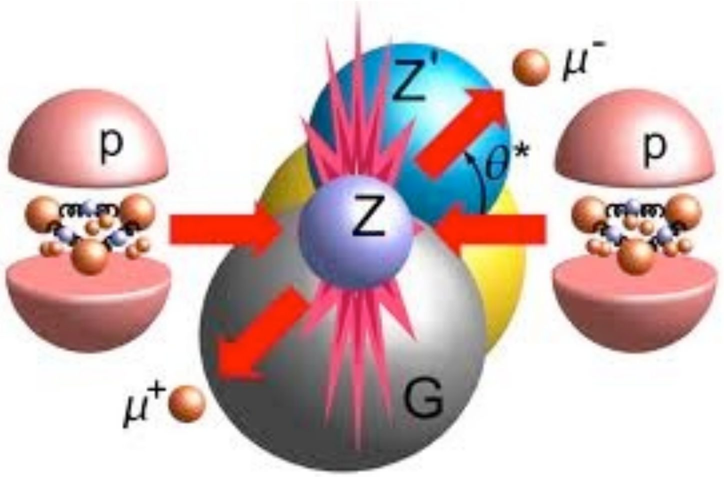
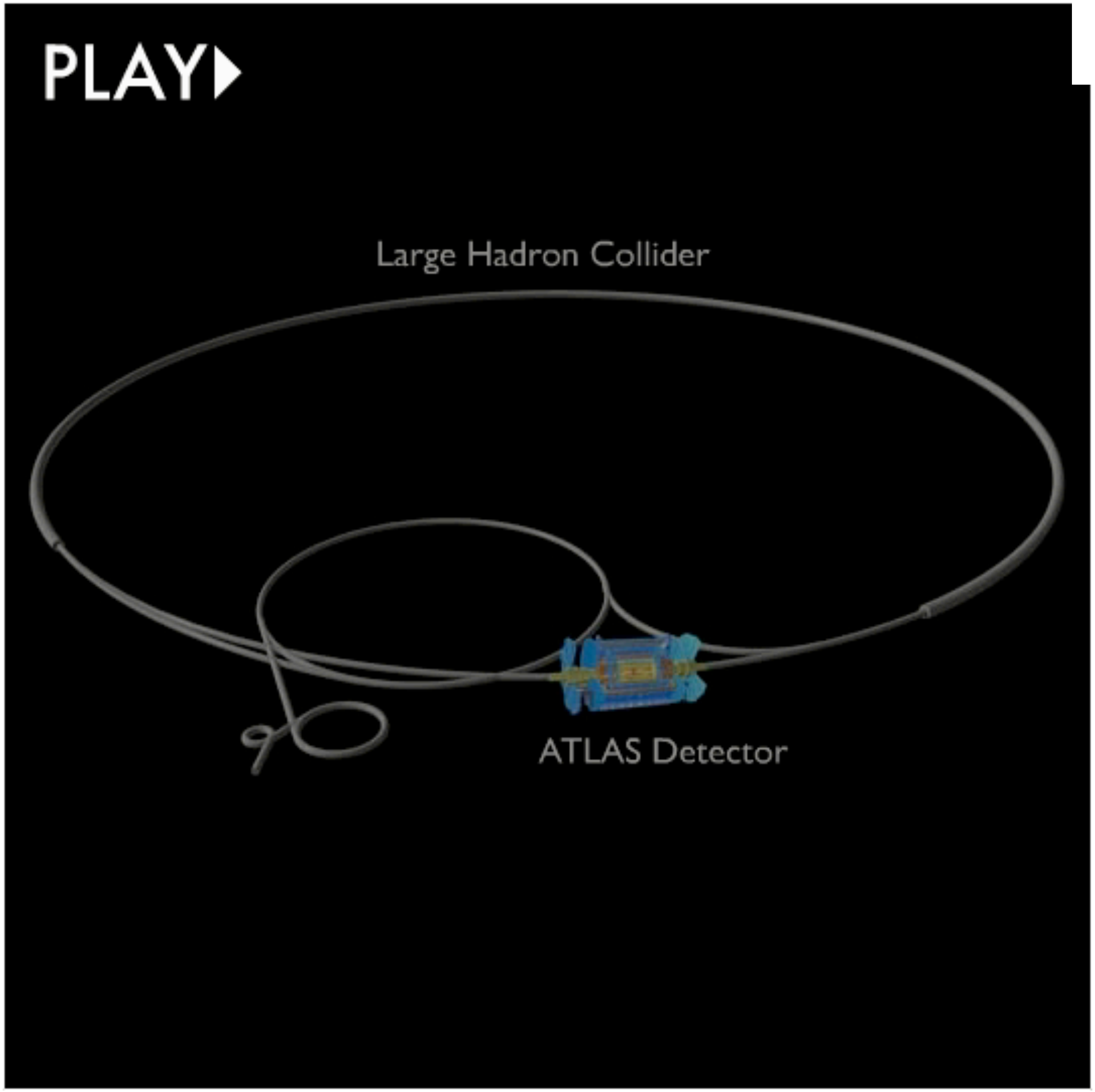
RESULTS FROM THE LHC: HIGGS ANDSUSY.

Carlos Pires
Grupo de física e cosmologia do DF da UFPB

5° VERÃO QUÂNTICO
UBU, UFES

Large hadron Collider(LHC)

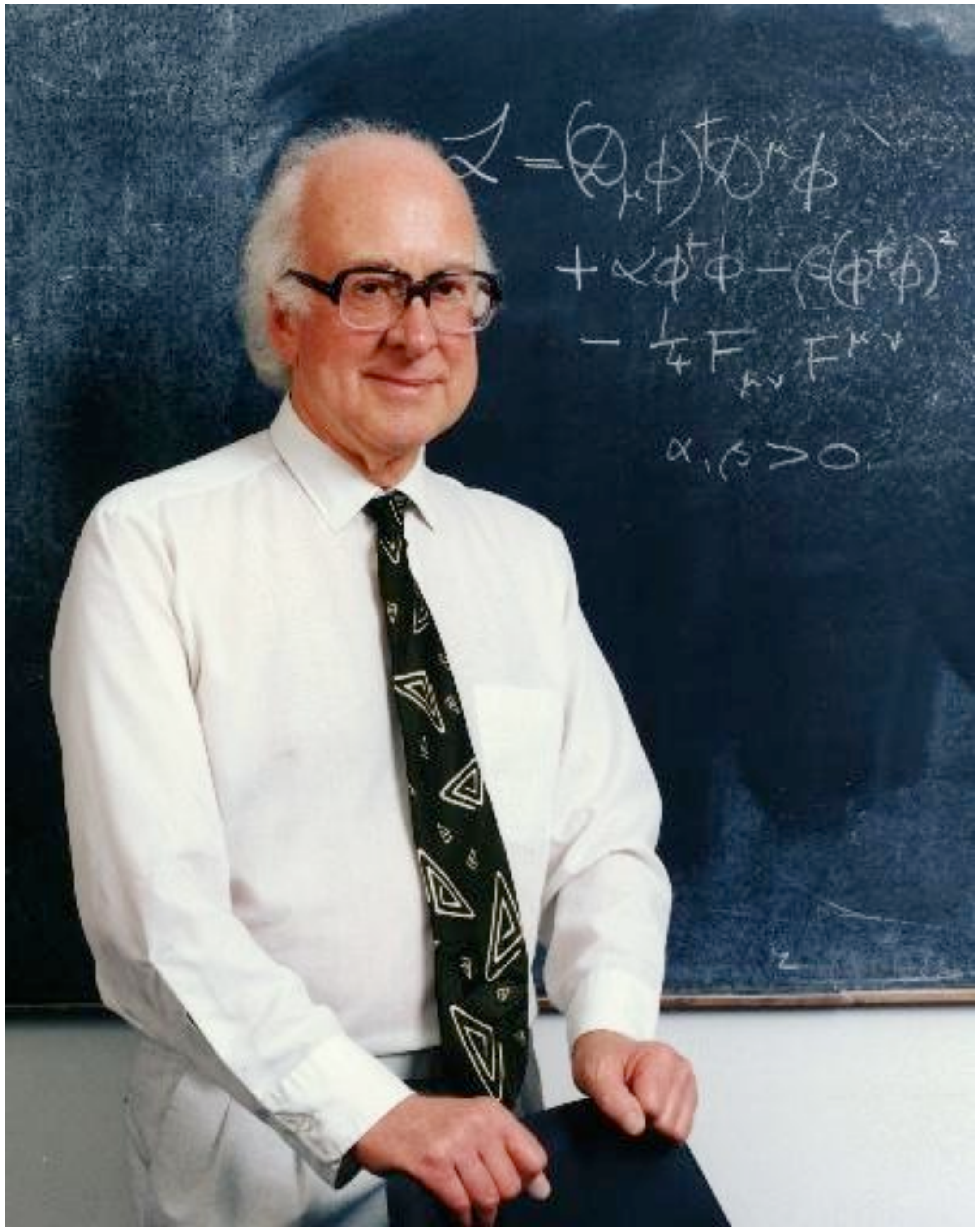




MAIN GOAL OF THE LHC:

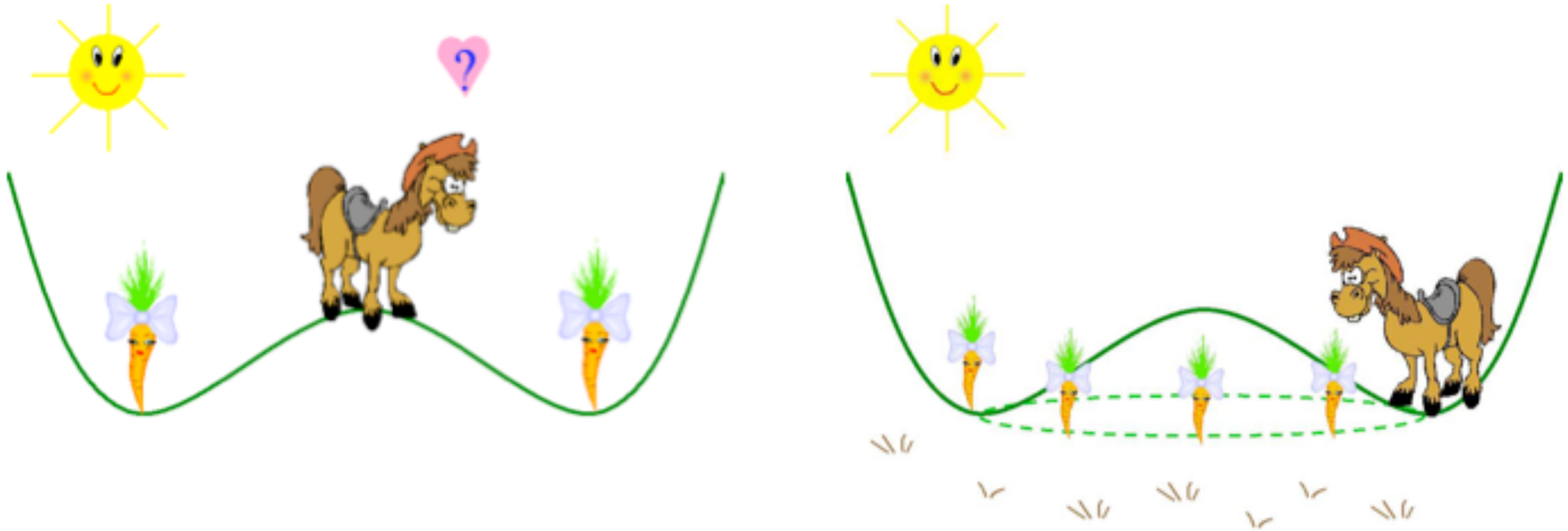
Find the Higgs

Probe new physics mainly in the form of susy



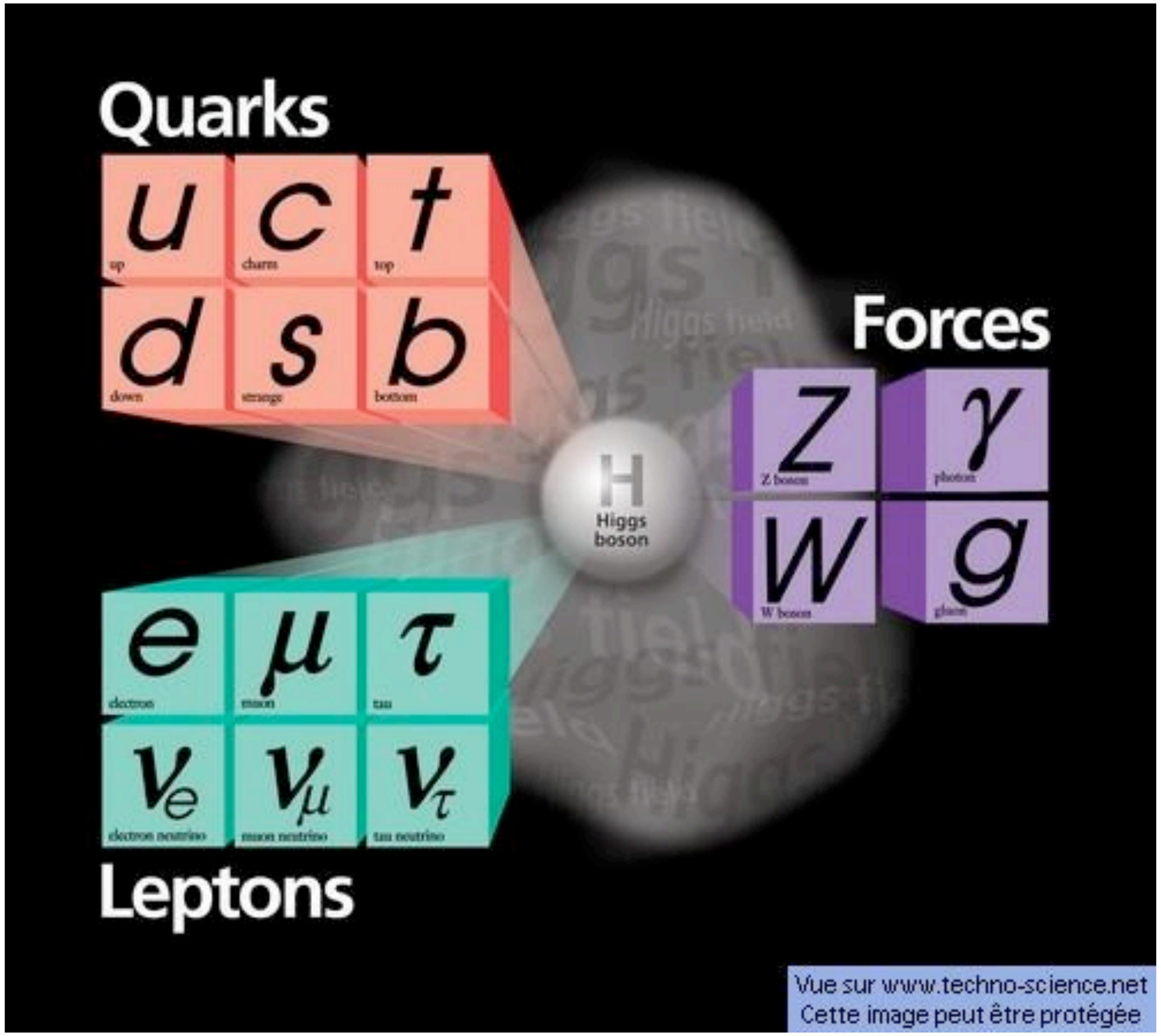
Why the Higgs is so important?!

It is the signature of the mechanism of spontaneous breaking of symmetries in particle physics: the so-called Higgs mechanism



Its discovery is the experimental proof that the spontaneous breaking of symmetries is the way particles gain masses.

The standard model



The standard model

Symmetry group:

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

Matter content.

$$L_1 = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L, \quad e_{R_1} = e^-_R, \quad Q_1 = \begin{pmatrix} u \\ d \end{pmatrix}_L, \quad u_{R_1} = u_R, d_{R_1} = d_R$$

$$L_2 = \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L, \quad e_{R_2} = \mu^-_R, \quad Q_2 = \begin{pmatrix} c \\ s \end{pmatrix}_L, \quad u_{R_2} = c_R, d_{R_2} = s_R$$

$$L_3 = \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L, \quad e_{R_3} = \tau^-_R, \quad Q_3 = \begin{pmatrix} t \\ b \end{pmatrix}_L, \quad u_{R_3} = t_R, \ d_{R_3} = b_R.$$

Higgs: $$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

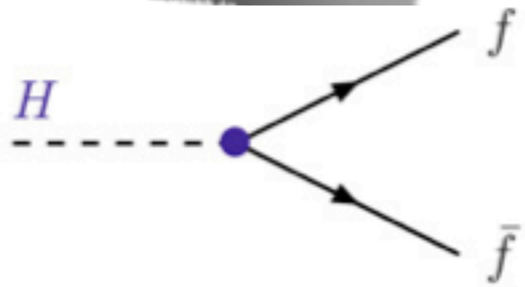
Unitary gauge

$$\Phi(x) = \begin{pmatrix} \theta_2 + \mathrm{i}\theta_1 \\ \frac{1}{\sqrt{2}}(v + H) - \mathrm{i}\theta_3 \end{pmatrix} = \mathrm{e}^{\mathrm{i}\theta_a(x)\tau^a(x)/v} \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(v + H(x)) \end{pmatrix}$$

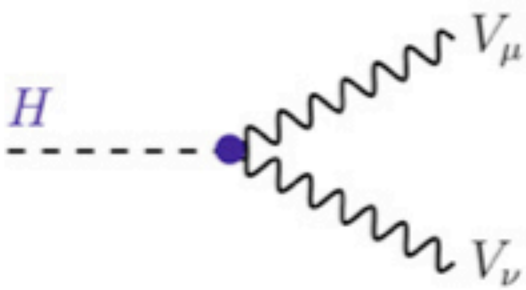
$$= \frac{1}{\sqrt{2}} \binom{0}{v+H}$$

Gauge bosons: $$W^+, W^-, Z^0, A, g$$

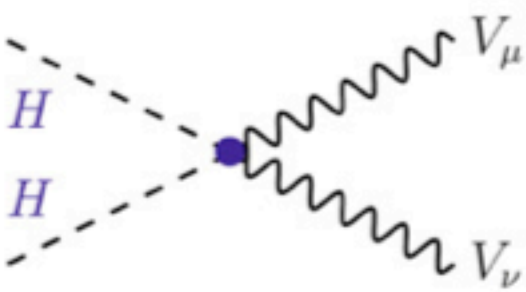
Higgs couplings



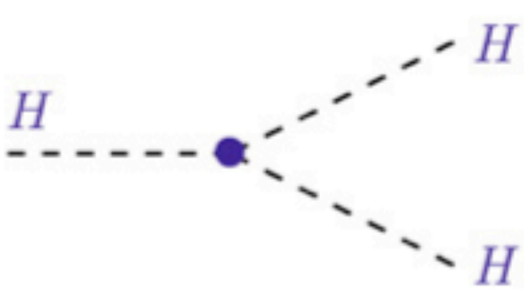
$$g_{Hff} = m_f/v = (\sqrt{2}G_\mu)^{1/2}\, m_f \qquad \times (-i)$$



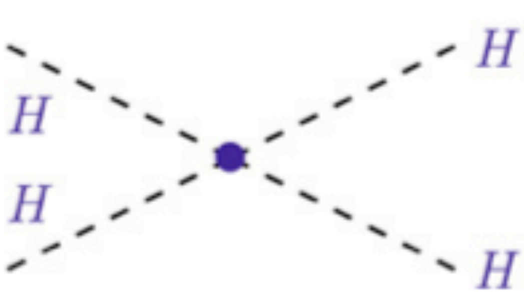
$$g_{HVV} = 2M_V^2/v = 2(\sqrt{2}G_\mu)^{1/2}\, M_V^2 \qquad \times (ig_{\mu\nu})$$



$$g_{HHVV} = 2M_V^2/v^2 = 2\sqrt{2}G_\mu\, M_V^2 \qquad \times (ig_{\mu\nu})$$

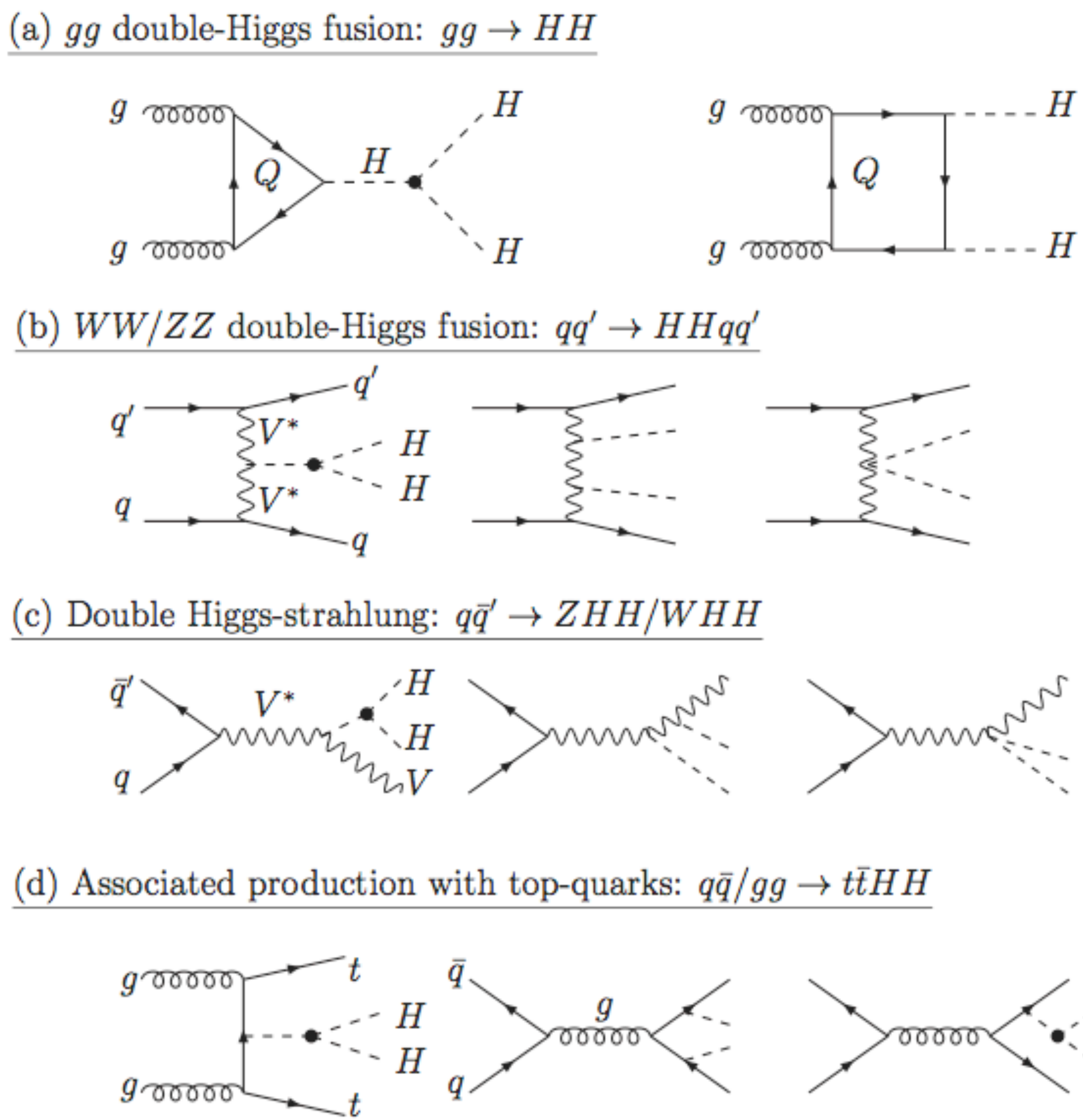


$$g_{HHH} = 3M_H^2/v = 3(\sqrt{2}G_\mu)^{1/2}\, M_H^2 \qquad \times (-i)$$



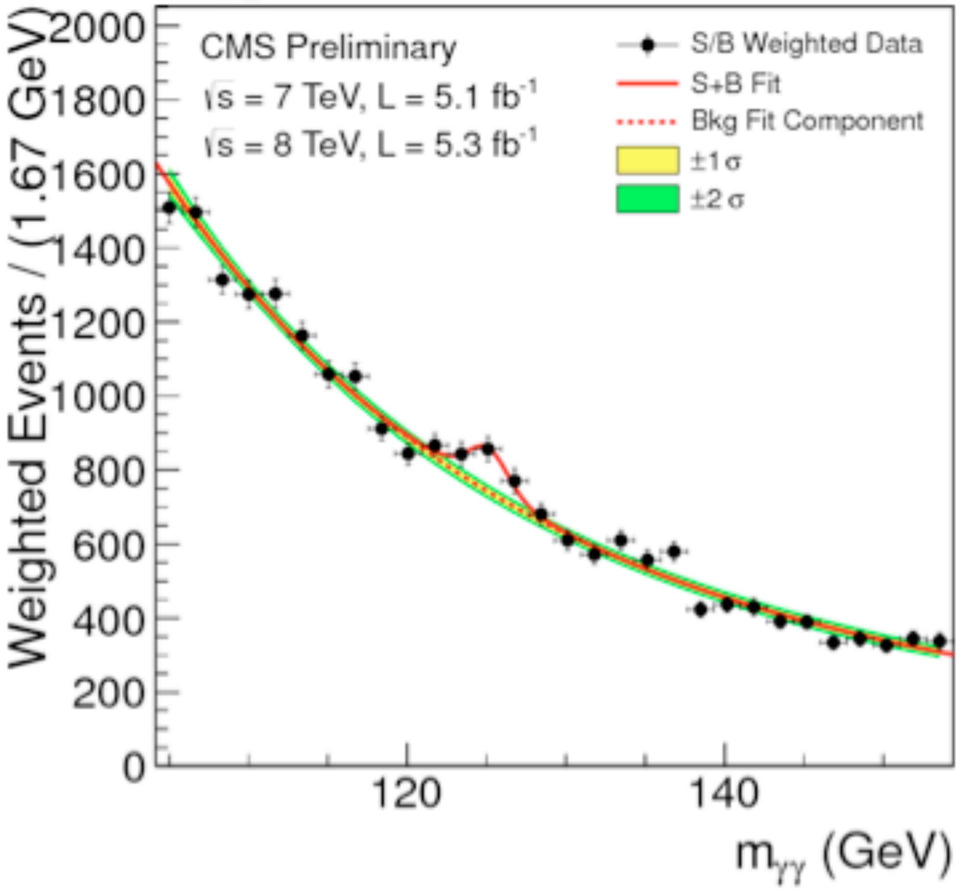
$$g_{HHHH} = 3M_H^2/v^2 = 3\sqrt{2}G_\mu\, M_H^2 \qquad \times (-i)$$

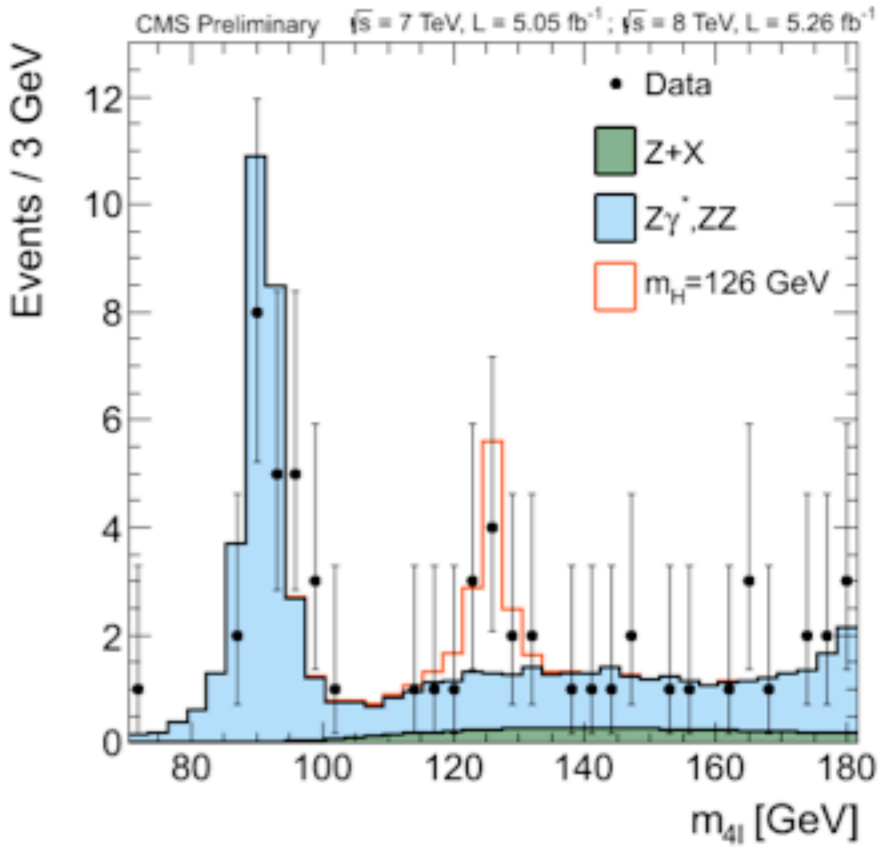
Higgs production at LHC



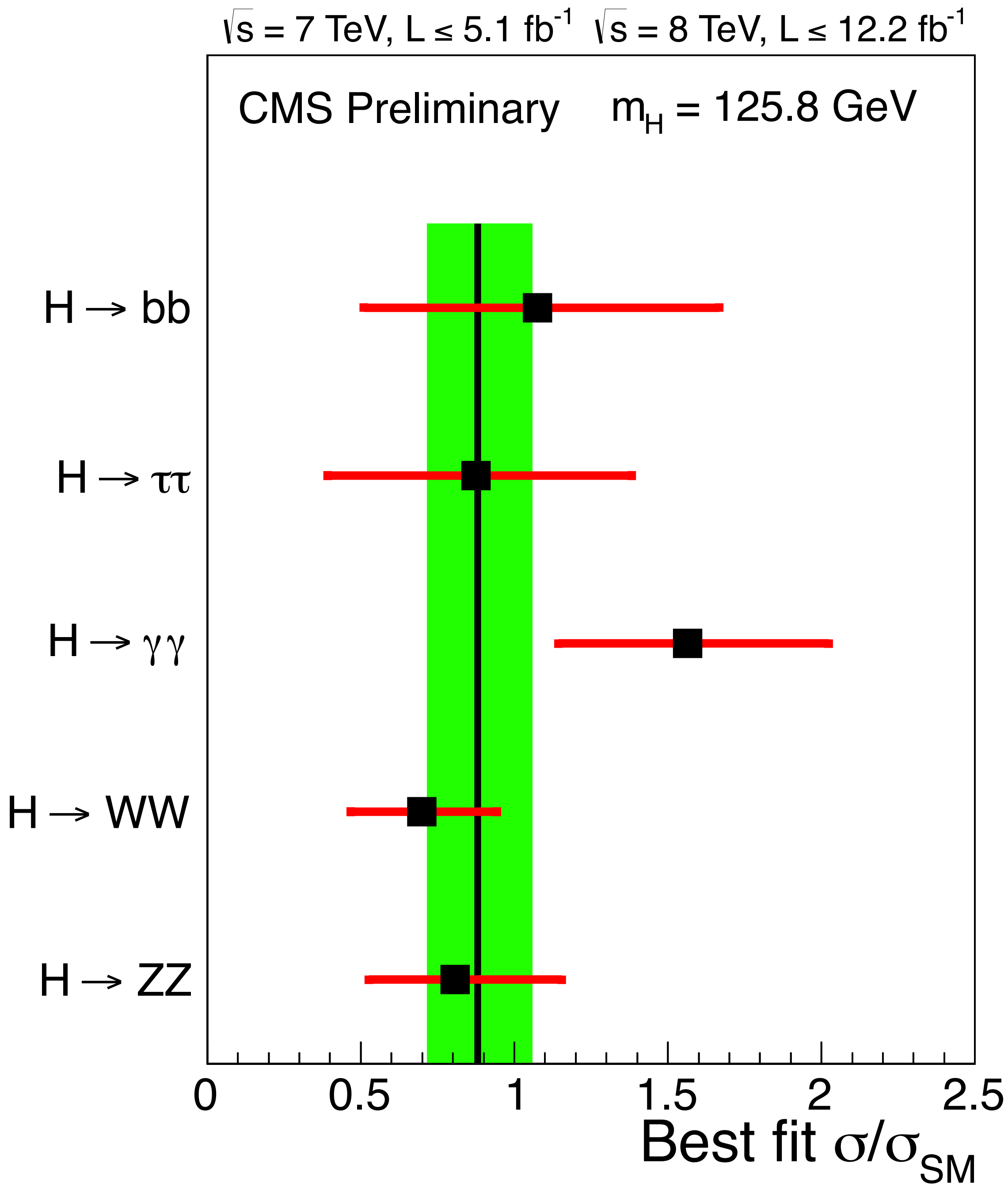
LHC results about Higgs:

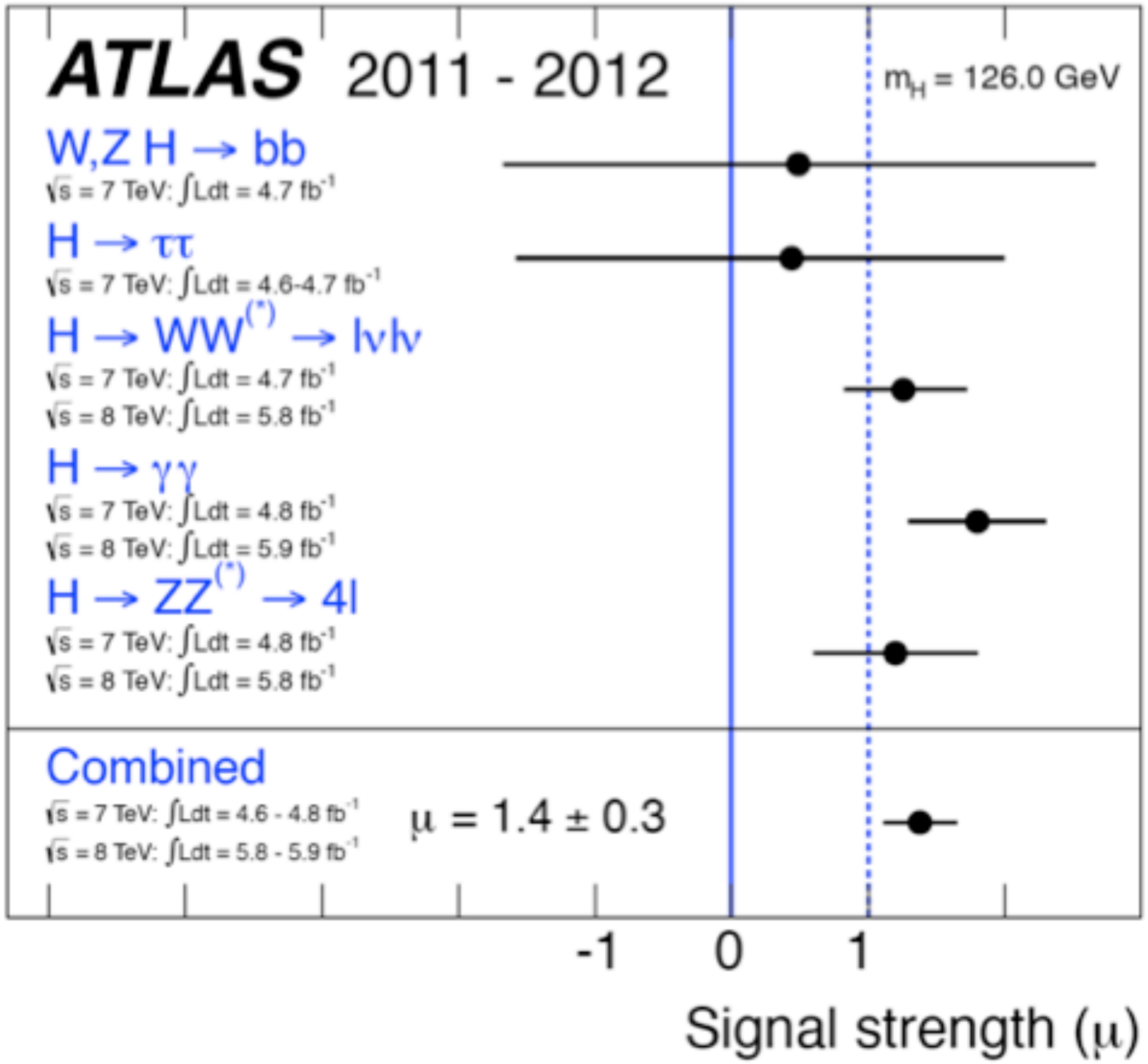
First result: CMS and ATLAS detected a ressonance with mass around 124-126-GeV





Higgs features:

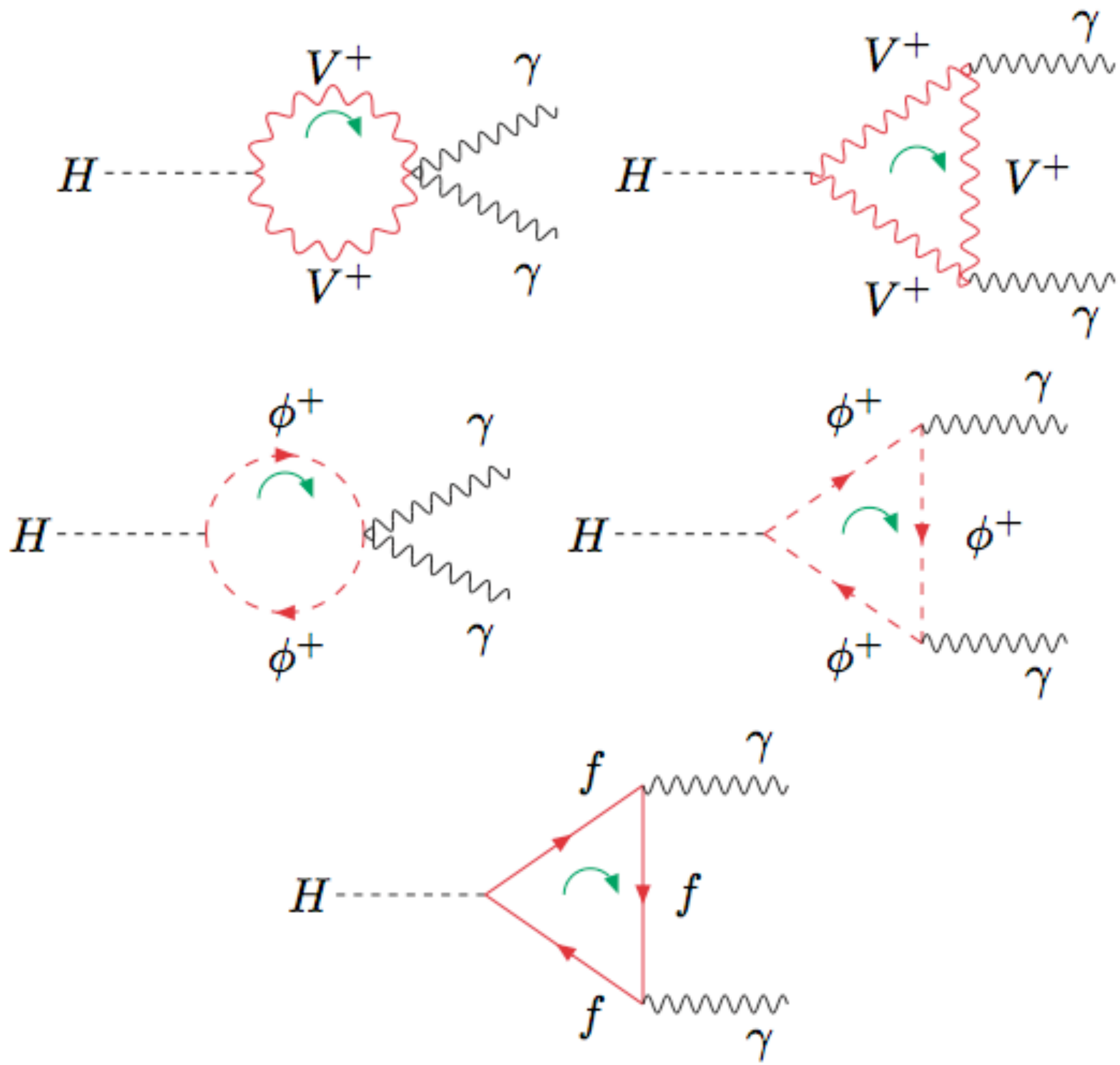




It is a scalar (spin zero)

Its decay in two photons is not standard! → It would be a signal of new physics?

Higgs diphoton decay channels:



Perhaps this excess is pointing two new particles with double electric charge pires at al PDR2011, EPJC2013

The one-loop diagrams that contribute to the $H \to \gamma\gamma$ decay amplitude in a generic model.

Effective Lagrangian ⟶ $$\mathcal{L}_{H\gamma\gamma} = \sum_i \frac{\alpha N_{ci} Q_i^2 F_i}{8\pi} (\sqrt{2} G_F)^{\frac{1}{2}} H F^{\mu\nu} F_{\mu\nu}$$

Is the diphoton excess results surprises for a higgs mass of 126GeV?

Vacuum stability of the standard model at three loops until Planck scale: JHEP08(2012)098

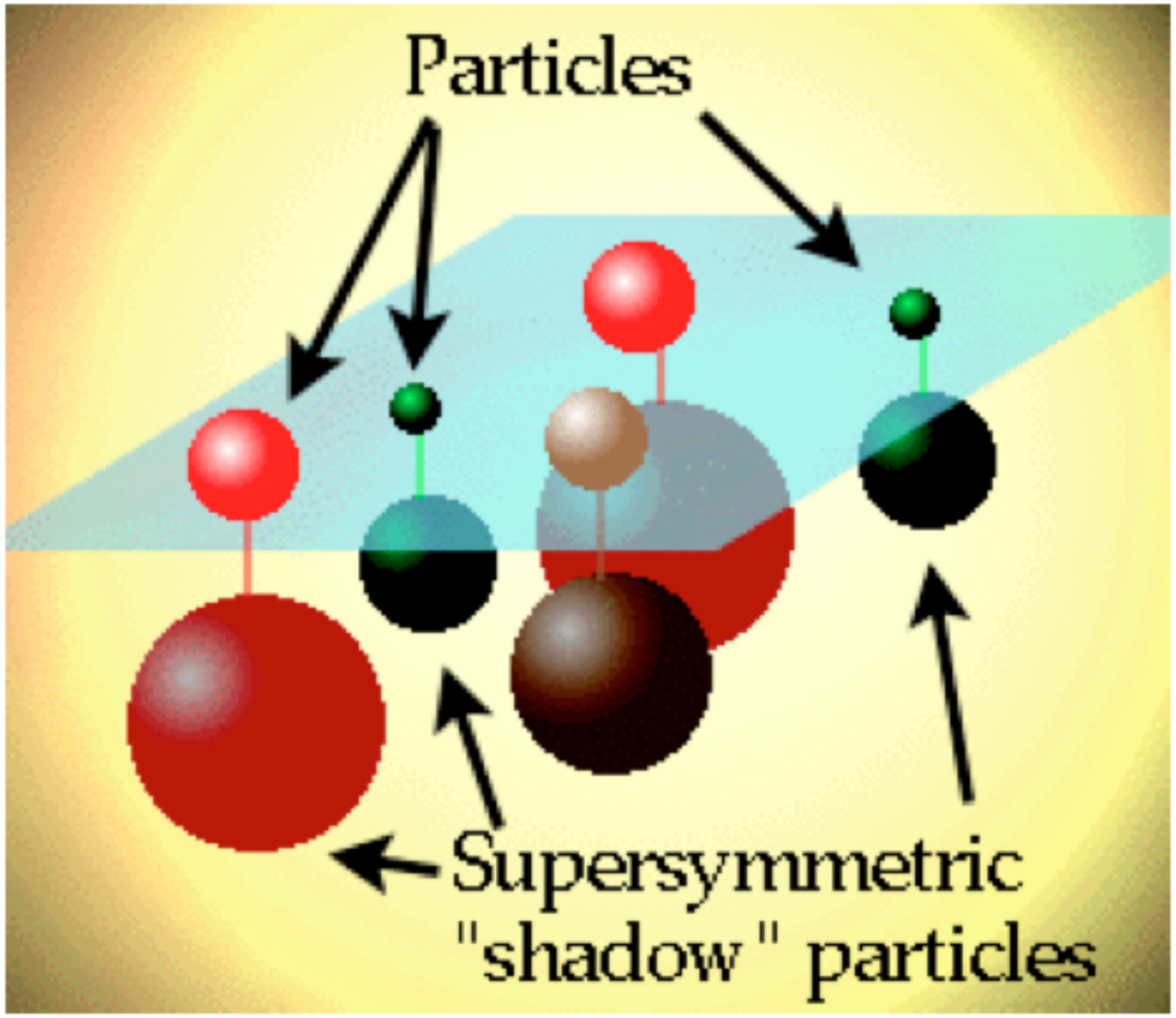
$$M_h\ [\text{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\text{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\text{th}}$$

On substituting the respective values of Mt and αs:

$$M_h > 129.4 \pm 1.8\ \text{GeV}.$$

From this result we conclude that vacuum stability of the SM up to the Planck scale is excluded at 2σ (98% C.L. one sided) for $M_h < 126\,\text{GeV}$.

LHC constraint on supersymmetry(SUSY)



susy is a symmetry that relates fermions with bosons:

$$\bar{Q}\,|\mathrm{boson}\rangle = |\mathrm{fermion}\rangle, \quad Q\,|\mathrm{fermion}\rangle = |\mathrm{boson}\rangle.$$

It is a spacial symmetry. An extension of the poincare group:

$$\{Q_\alpha, \bar{Q}_{\dot{\alpha}}\} = 2\,\sigma^\mu_{\alpha\dot{\alpha}} P_\mu$$

An example of susy lagrangian: Wess-Zunino model

$$\mathcal{L}_{\text{kin}} = \frac{1}{2}(\partial_\mu A)^2 + \frac{1}{2}(\partial_\mu B)^2 + \frac{\mathrm{i}}{2}\overline{\psi}\not{\partial}\psi + \frac{1}{2}(F^2 + G^2).$$

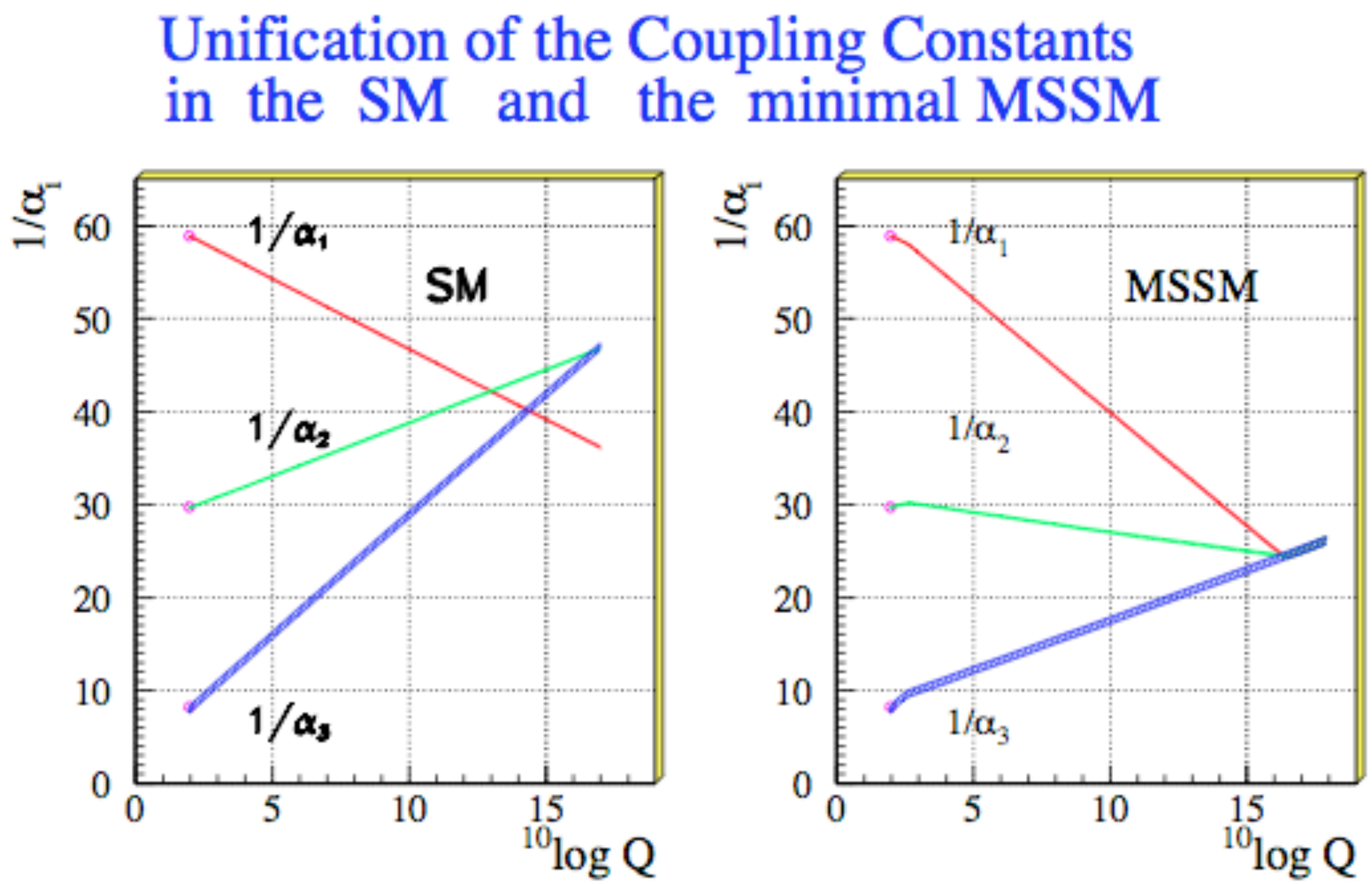
$$\mathcal{L}_{\text{mass}} = -m[\frac{1}{2}\bar{\psi}\psi - GA - FB].$$

Susy transformations:

$$\begin{aligned}
\delta A &= \mathrm{i}\bar{\alpha}\gamma_5\psi, \\
\delta B &= -\bar{\alpha}\psi, \\
\delta\psi &= -F\alpha + \mathrm{i}G\gamma_5\alpha + \not{\partial}\gamma_5 A\alpha + \mathrm{i}\not{\partial}B\alpha, \\
\delta F &= \mathrm{i}\bar{\alpha}\not{\partial}\psi, \\
\delta G &= \bar{\alpha}\gamma_5\not{\partial}\psi,
\end{aligned}$$

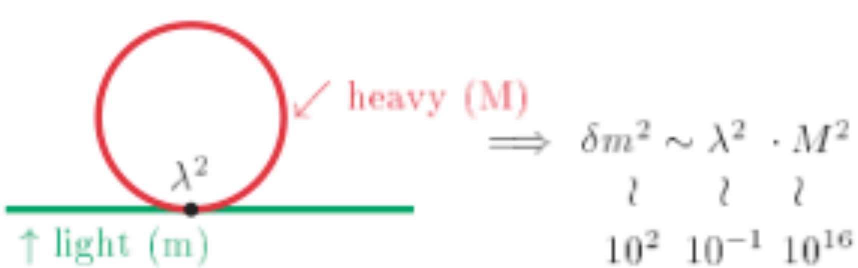
Main susy motivations:

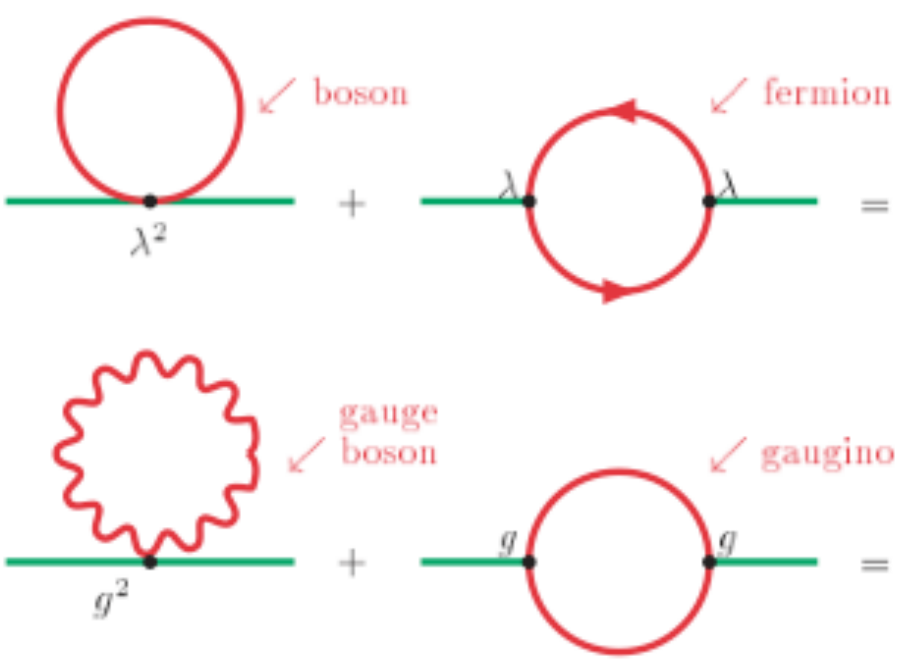
Natural dark matter candidate: neutralino



$$\delta M_h^2 \sim g^2 M_{SUSY}^2 \sim M_h^2.$$

Solution of the hierarchy problem: quadratic divergence





Minimal supersymmetric standard moddel(MSSM). Particle content:

Superfield	Bosons		Fermions		$SU(3)$	$SU(2$	$U_Y(1)$
Gauge							
$\mathbf{G^a}$	gluon	g^a	gluino	$\tilde{g}^a$	8	0	0
$\mathbf{V^k}$	Weak	$W^k\ (W^\pm, Z)$	wino, zino	$\tilde{w}^k\ (\tilde{w}^\pm, \tilde{z})$	1	3	0
$\mathbf{V'}$	Hypercharge	$B\ (\gamma)$	bino	$\tilde{b}(\tilde{\gamma})$	1	1	0
Matter							
$\mathbf{L_i}$	sleptons	$\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	leptons	$L_i = (\nu, e)_L$	1	2	-1
$\mathbf{E_i}$	sleptons	$\tilde{E}_i = \tilde{e}_R$	leptons	$E_i = e^c_R$	1	1	2
$\mathbf{Q_i}$	squarks	$\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	quarks	$Q_i = (u, d)_L$	3	2	1/3
$\mathbf{U_i}$	squarks	$\tilde{U}_i = \tilde{u}_R$	quarks	$U_i = u^c_R$	3*	1	$-4/3$
$\mathbf{D_i}$	squarks	$\tilde{D}_i = \tilde{d}_R$	quarks	$D_i = d^c_R$	3*	1	2/3
Higgs							
$\mathbf{H_1}$	Higgses	H_1	higgsinos	$\tilde{H}_1$	1	2	-1
$\mathbf{H_2}$	Higgses	H_2	higgsinos	$\tilde{H}_2$	1	2	1

Anomaly cancellation requires two Higgs doublet:

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} = \begin{pmatrix} v_1 + \frac{S_1 + iP_1}{\sqrt{2}} \\ H_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} = \begin{pmatrix} H_2^+ \\ v_2 + \frac{S_2 + iP_2}{\sqrt{2}} \end{pmatrix}$$

$\longrightarrow$

$$\begin{cases} G^0 &= -\cos\beta P_1 + \sin\beta P_2, \ \textit{Goldstone boson} \rightarrow Z_0, \\ A &= \sin\beta P_1 + \cos\beta P_2, \ \textit{Neutral CP} - \textit{odd Higgs}, \end{cases}$$

$$\begin{cases} G^+ = -\cos\beta (H_1^-)^* + \sin\beta H_2^+, \ \textit{Goldstone boson} \rightarrow W^+, \\ H^+ = \sin\beta (H_1^-)^* + \cos\beta H_2^+, \ \textit{Charged Higgs}, \end{cases}$$

$$\begin{cases} h &= -\sin\alpha S_1 + \cos\alpha S_2, \ \textit{SM CP} - \textit{even Higgs}, \\ H &= \cos\alpha S_1 + \sin\alpha S_2, \ \textit{Extra heavy Higgs}, \end{cases}$$

MSSM Higgs mass prediction at tree level:

Loop corrections:

$$m_h^2 = M_Z^2 \cos^2 2\beta \quad , \quad m_h^2 = M_Z^2 \cos^2 2\beta + \delta_t^2$$

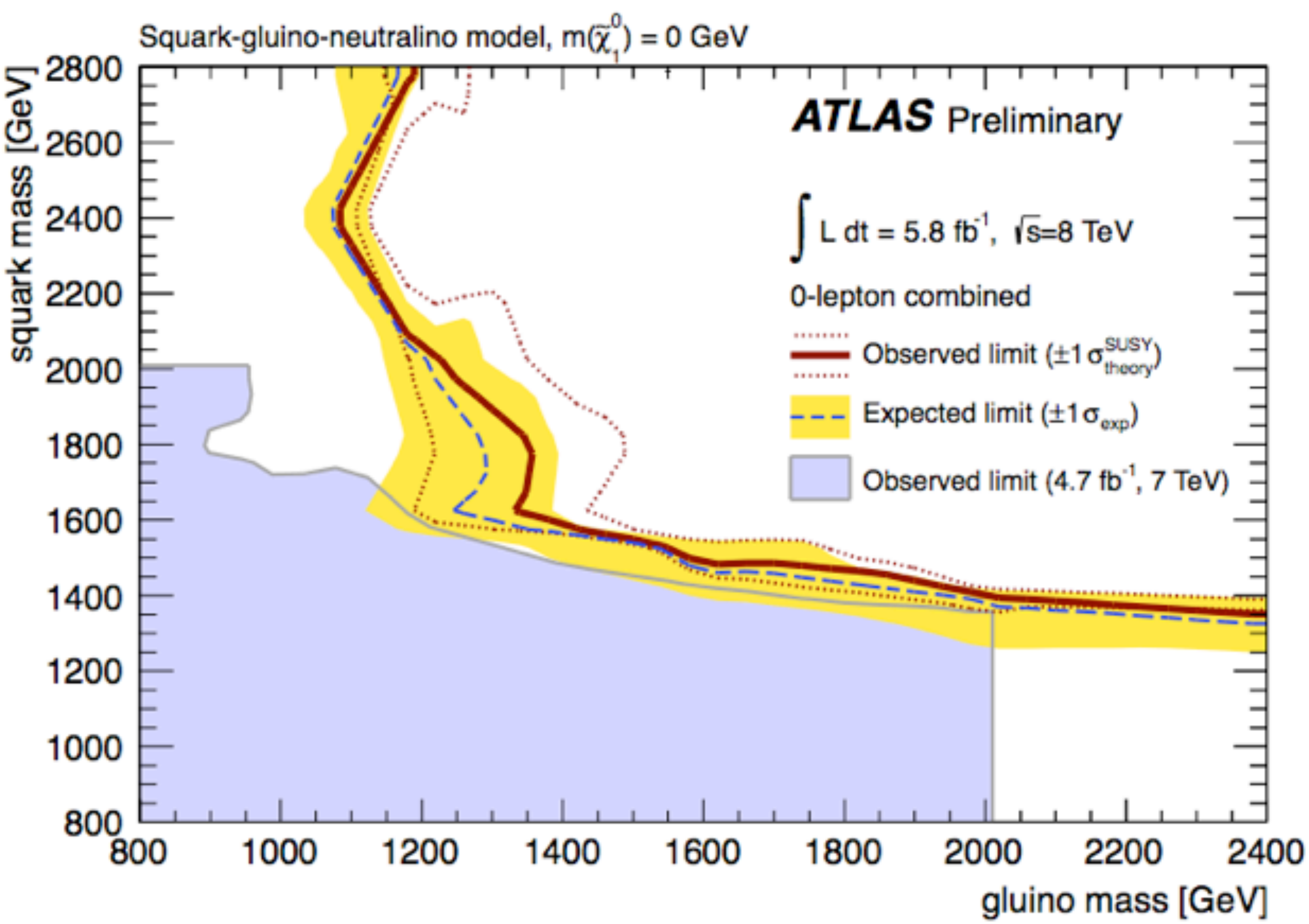
126GeV

<90GeV

$\approx 36 GeV$

SUSY particle constraints

LHC is sensitive to coloured particles: gluinos and squarks



Conclusions:

LHC detected Higgs; mass has its origin in spontaneous breaking of symmetry. Such job already justify the LHC.

Tiny and inconclusive signal of new physics through higgs di-photon decay.

No direct signal of new physics yet(no direct detection of any kind of new particle)

The comunity is looking forward to 2015.

TWO SCENARIOS TO 2015:

if → no signal of susy or any new physics in LHC

if → LHC detects new physics mainly in the form of susy.

THANKS