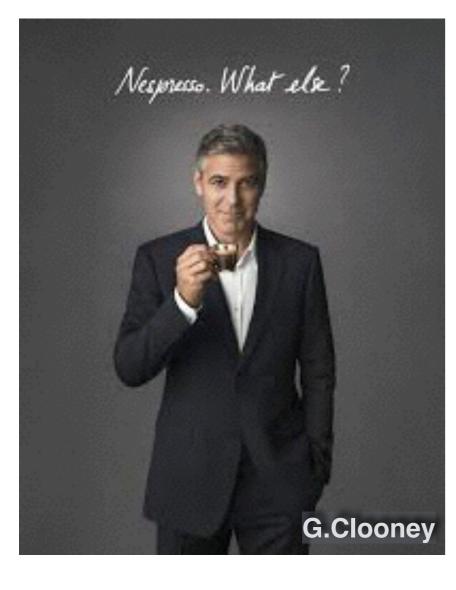
High energy physics & future colliders

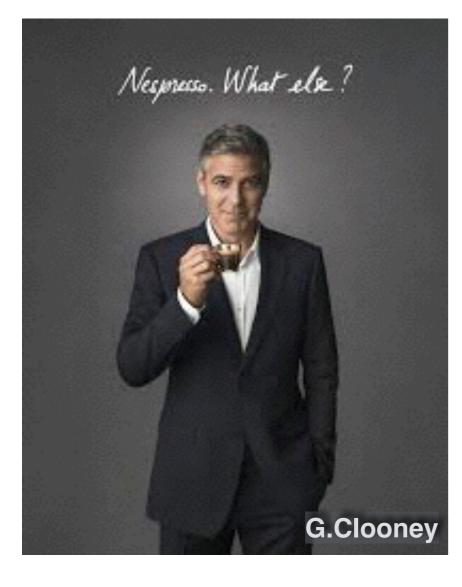




Michelangelo L. Mangano Theory Department, CERN, Geneva

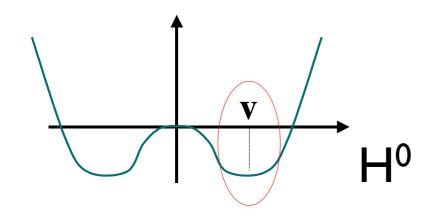


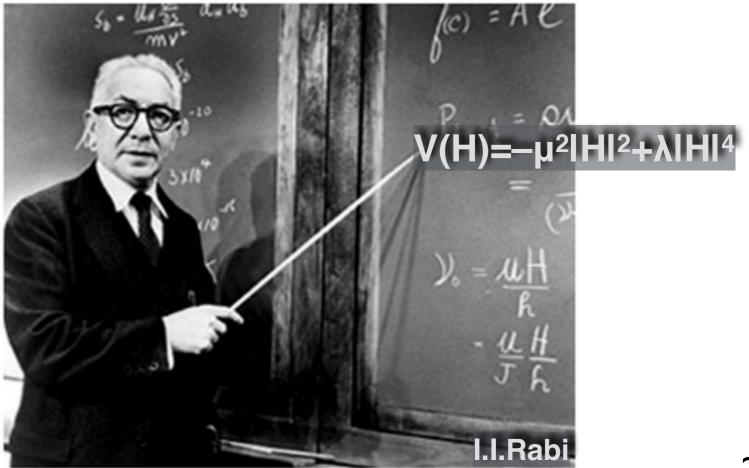
Higgs what else?



Higgs what else?

Who ordered that ?

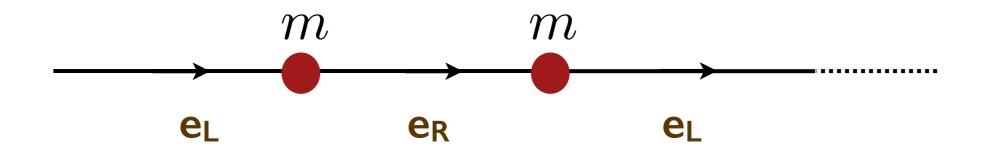




Parity asymmetry and mass for spin-1/2 particles

 $\gamma_5 \psi_{L,R} = \pm \psi_{L,R}$

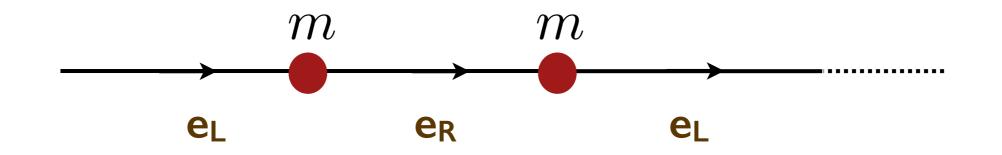
$$H \propto i\overline{\psi_L}\,\partial \cdot \gamma\,\psi_L + i\overline{\psi_R}\,\partial \cdot \gamma\,\psi_R + m\,\overline{\psi_L}\,\psi_R$$



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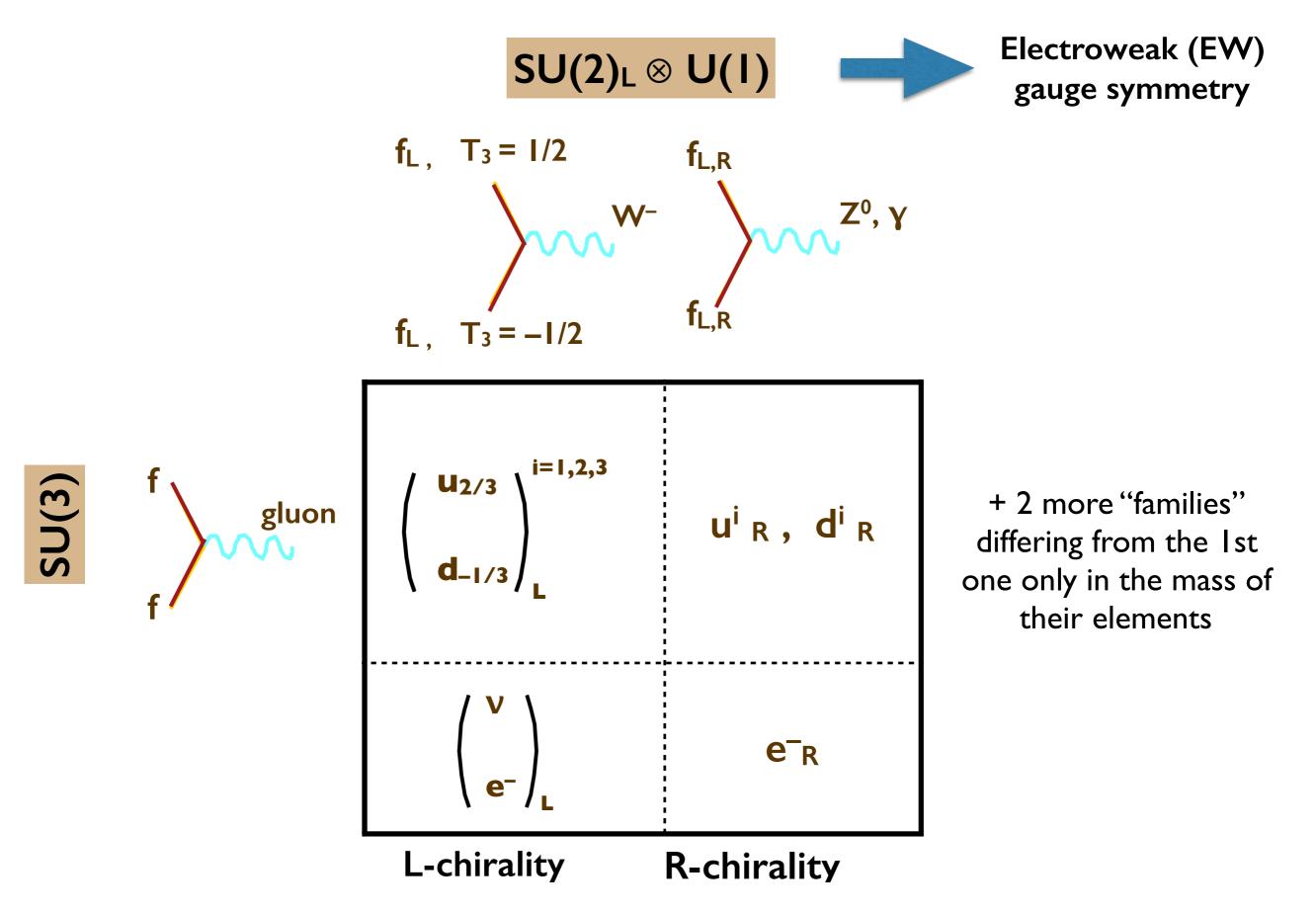
$$H \propto i\overline{\psi_L}\,\partial \cdot \gamma\,\psi_L + i\overline{\psi_R}\,\partial \cdot \gamma\,\psi_R + m\,\overline{\psi_L}\,\psi_R$$



For a massive particle, chirality does not commute with the Hamiltonian, so it cannot be conserved

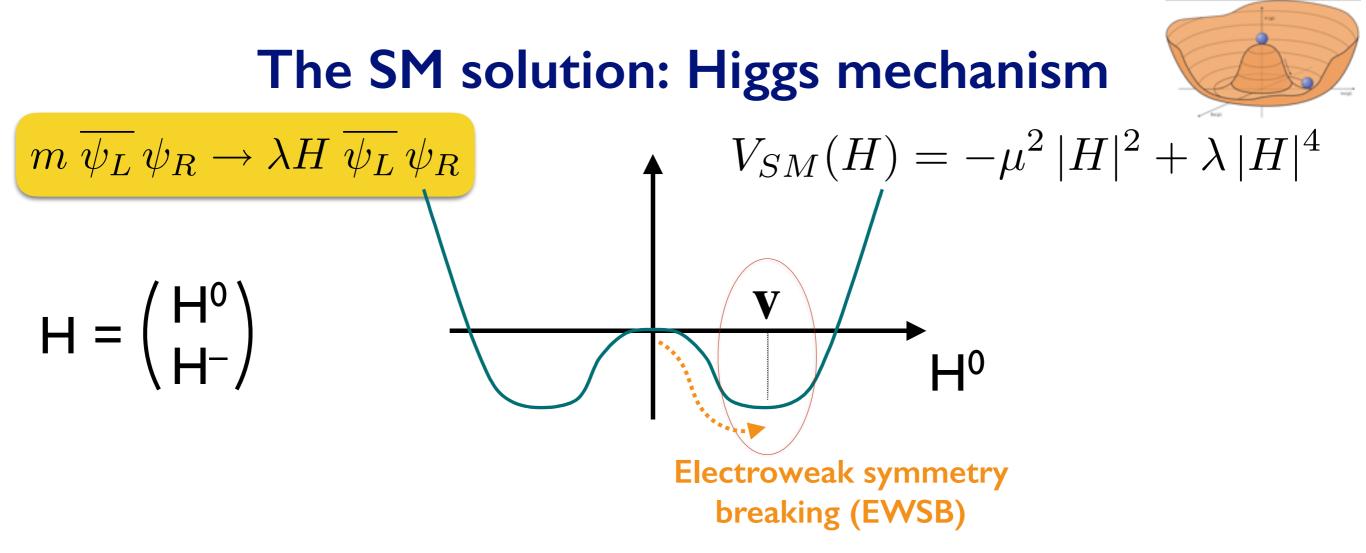
Chirality eigenstates of a massive particle cannot be Hamiltonian (physical) eigenstates

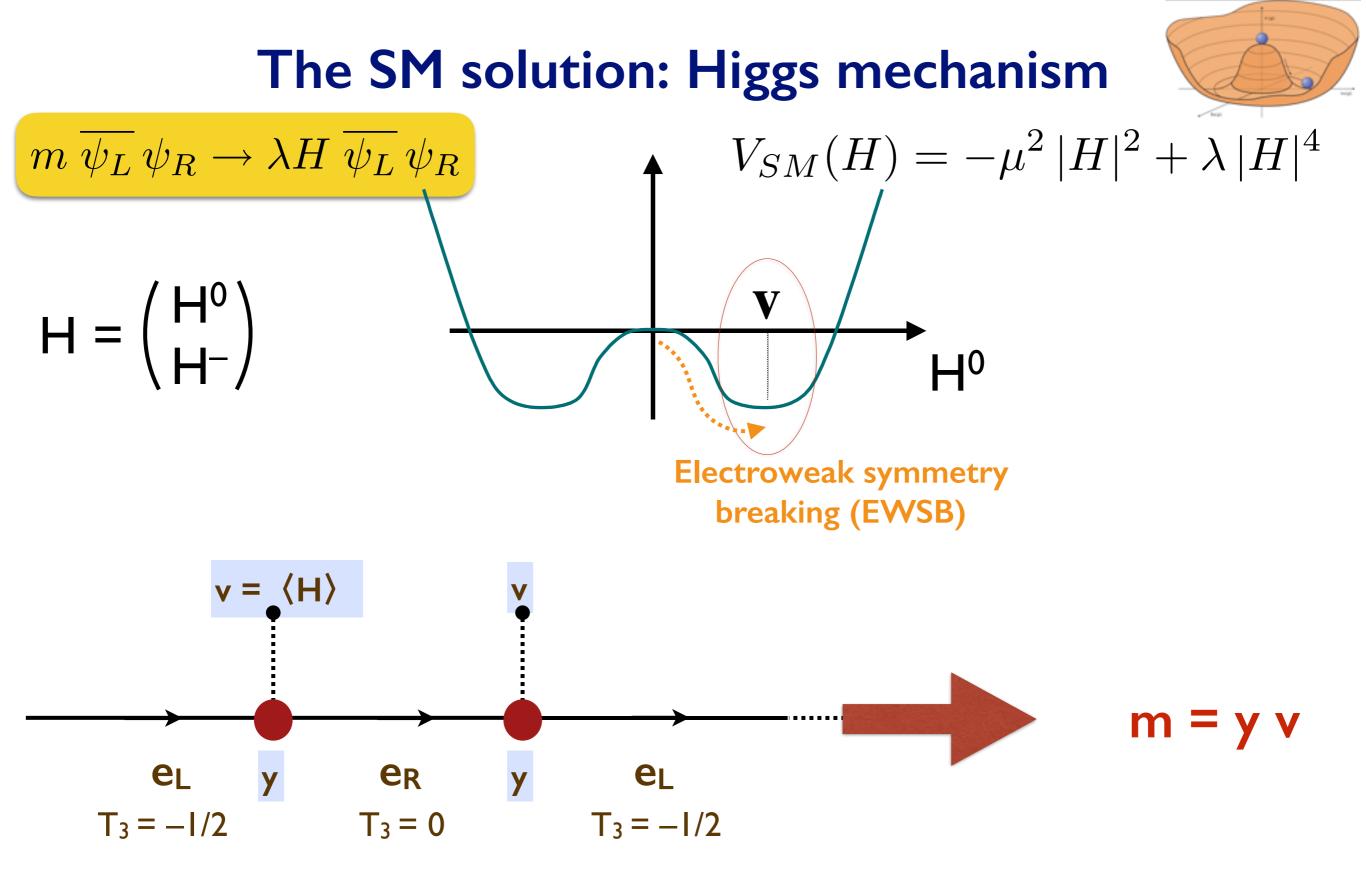
Nothing wrong with that in principle unless chirality is associated to a conserved charge!



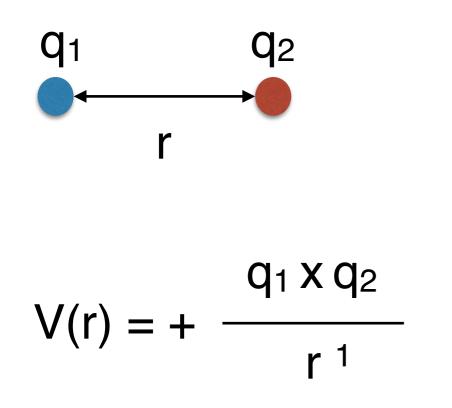
The symmetry associated with the conservation of the weak charge must therefore be broken for leptons and quarks to have a mass

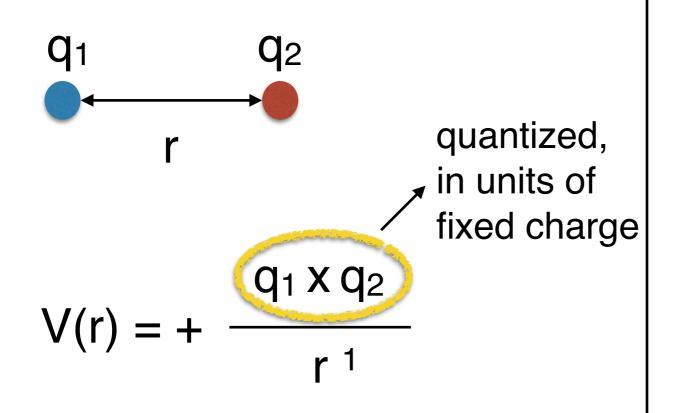
In this process, weak gauge bosons must also acquire a mass. This needs the existence of <u>new degrees of freedom</u>

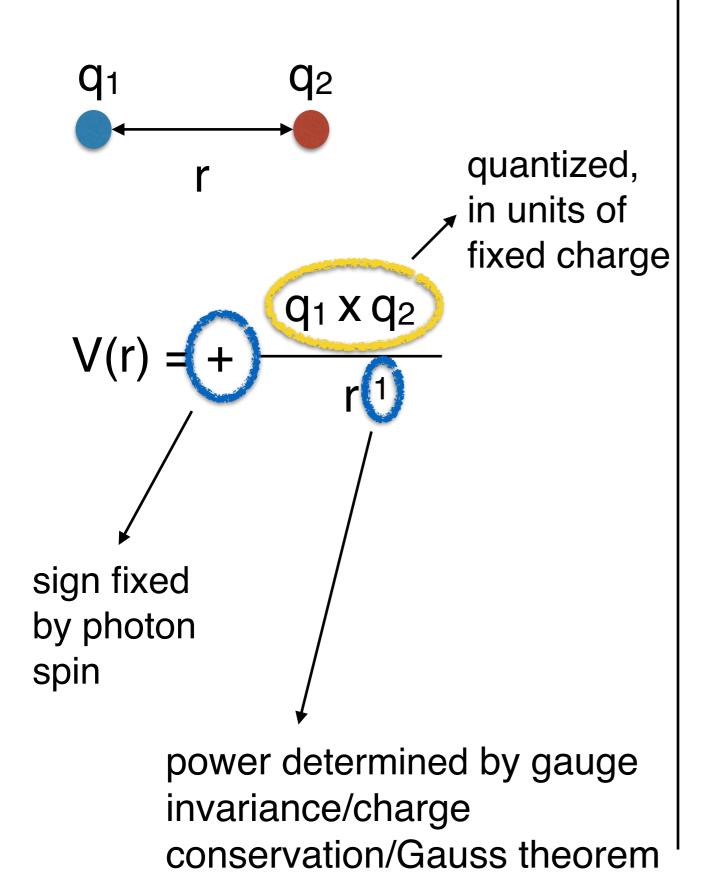


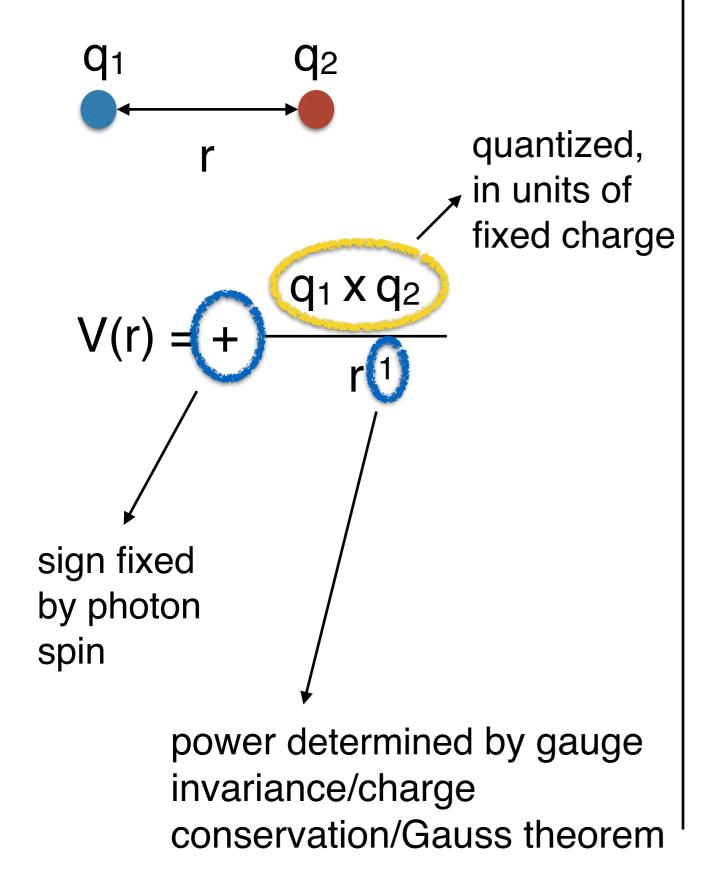


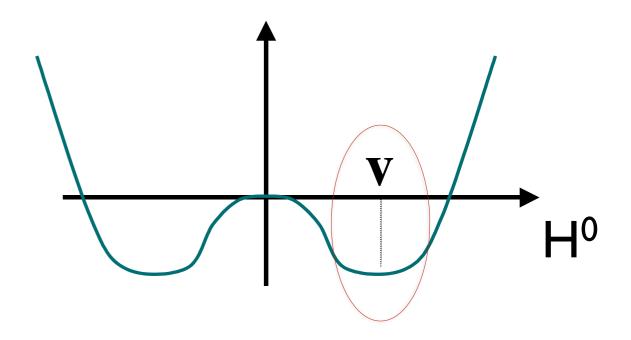
The transition between L and R states, and the absorption of the changes in weak charge, are ensured by the interaction with a background scalar field, H. Its "vacuum density" provides an infinite reservoir of weak charge.



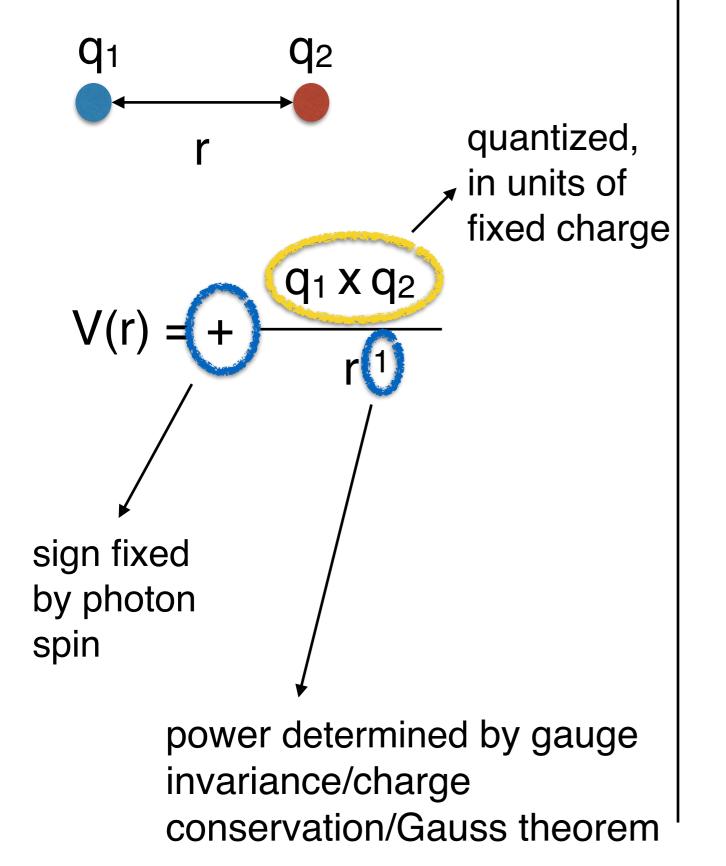


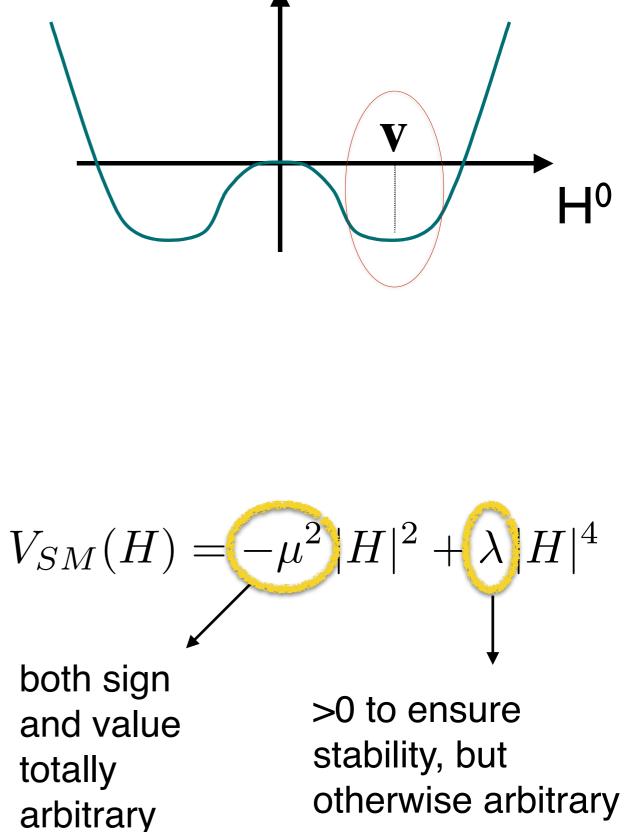


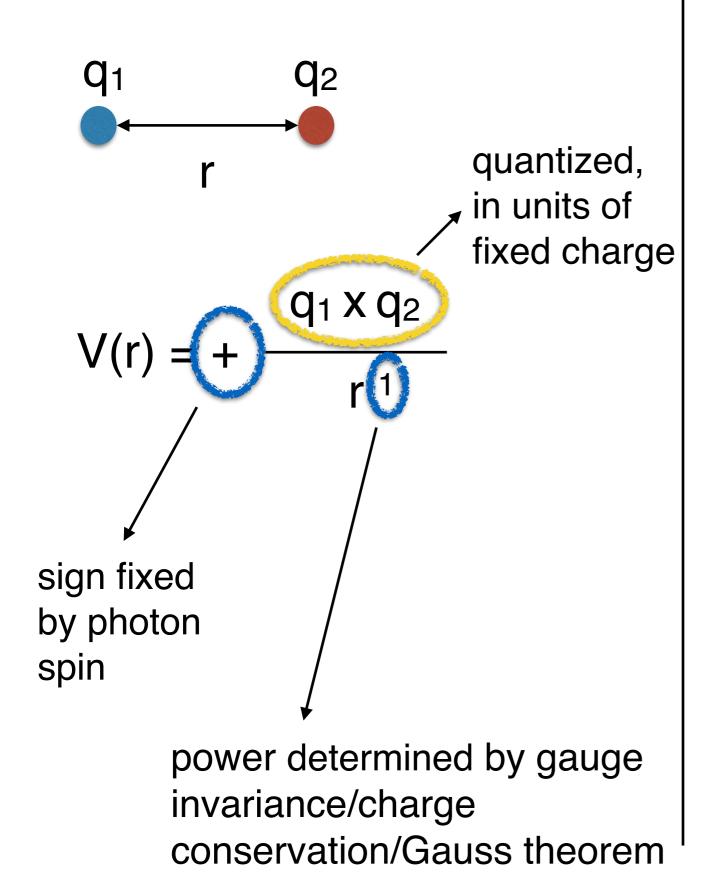


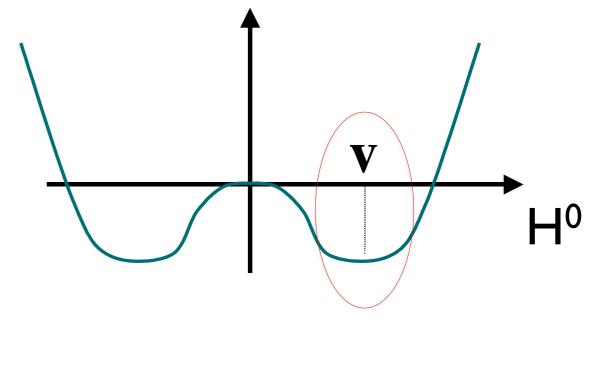


$V_{SM}(H) = -\mu^2 |H|^2 + \lambda |H|^4$









any function of IHI² would be ok wrt known symmetries

 $V_{SM}(H) =$

both sign and value totally arbitrary

>0 to ensure stability, but otherwise arbitrary

 $-\mu^2 H^2 + \lambda$

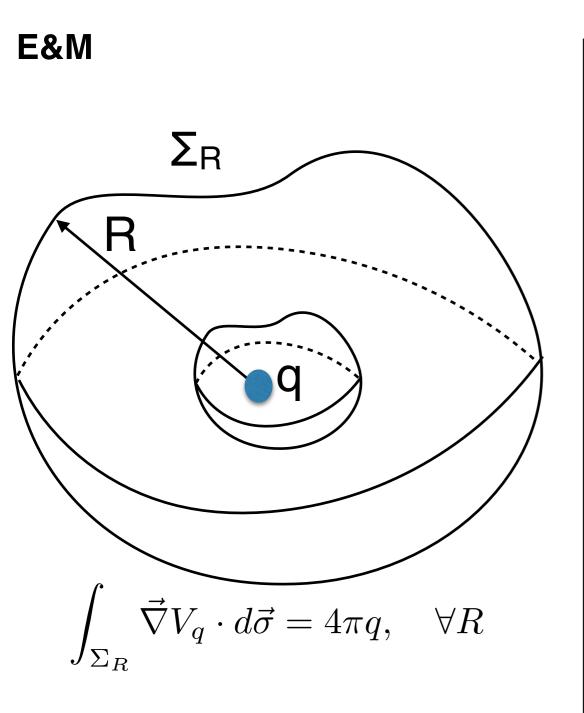
a historical example: superconductivity

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• The relation between the Higgs phenomenon and the SM is similar to the relation between superconductivity and the Landau-Ginzburg theory of phase transitions: a quartic potential for a bosonic order parameter, with negative quadratic term, and the ensuing symmetry breaking. If superconductivity had been discovered after Landau-Ginzburg, we would be in a similar situations as we are in today: an experimentally proven phenomenological model. But we would still lack a deep understanding of the relevant dynamics.

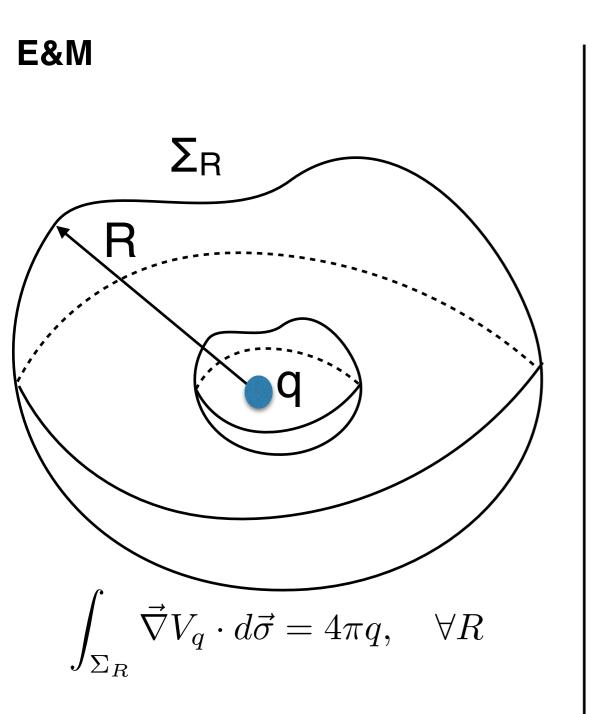
a historical example: superconductivity

- The relation between the Higgs phenomenon and the SM is similar to the relation between superconductivity and the Landau-Ginzburg theory of phase transitions: a quartic potential for a bosonic order parameter, with negative quadratic term, and the ensuing symmetry breaking. If superconductivity had been discovered after Landau-Ginzburg, we would be in a similar situations as we are in today: an experimentally proven phenomenological model. But we would still lack a deep understanding of the relevant dynamics.
- For superconductivity, this came later, with the identification of e⁻e⁻ Cooper pairs as the underlying order parameter, and BCS theory. In particle physics, we still don't know whether the Higgs is built out of some sort of Cooper pairs (composite Higgs) or whether it is elementary, and in both cases we have no clue as to what is the dynamics that generates the Higgs potential. With Cooper pairs it turned out to be just EM and phonon interactions. With the Higgs, none of the SM interactions can do this, and we must look beyond.

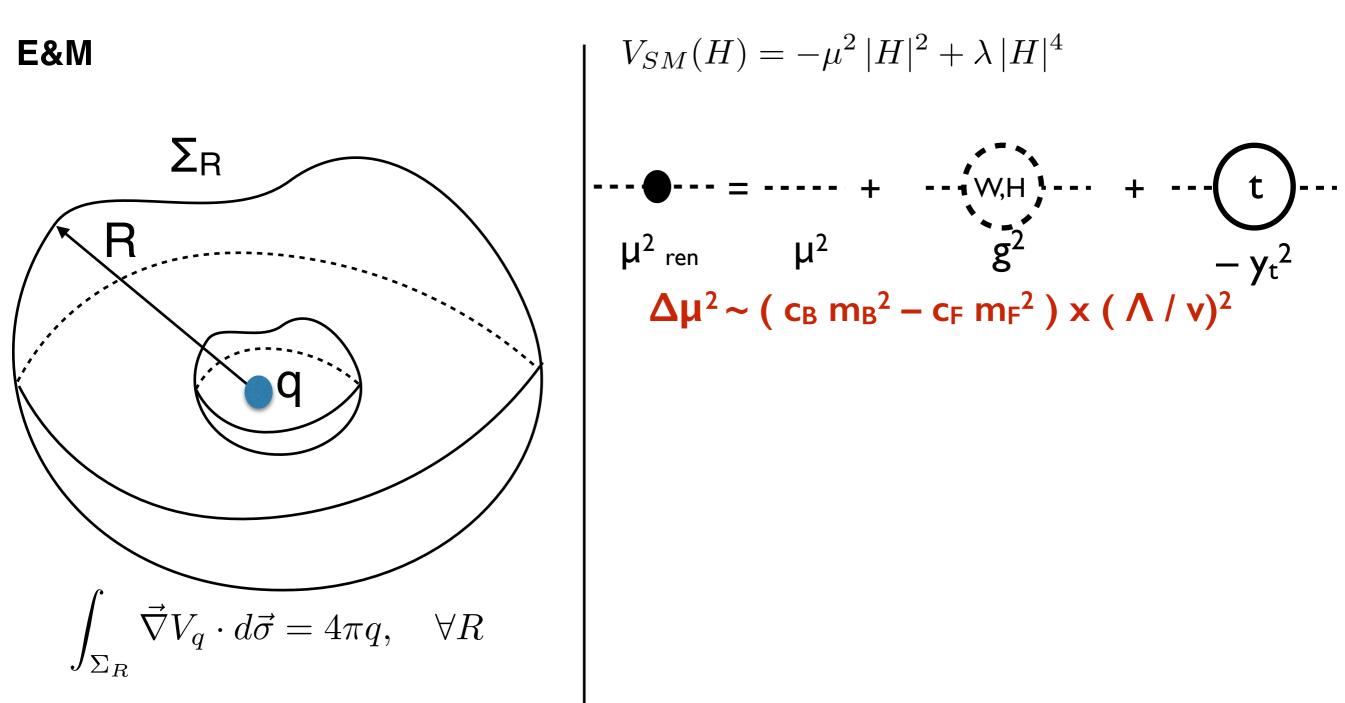


short-scale physics does not alter the charge seen at large scales

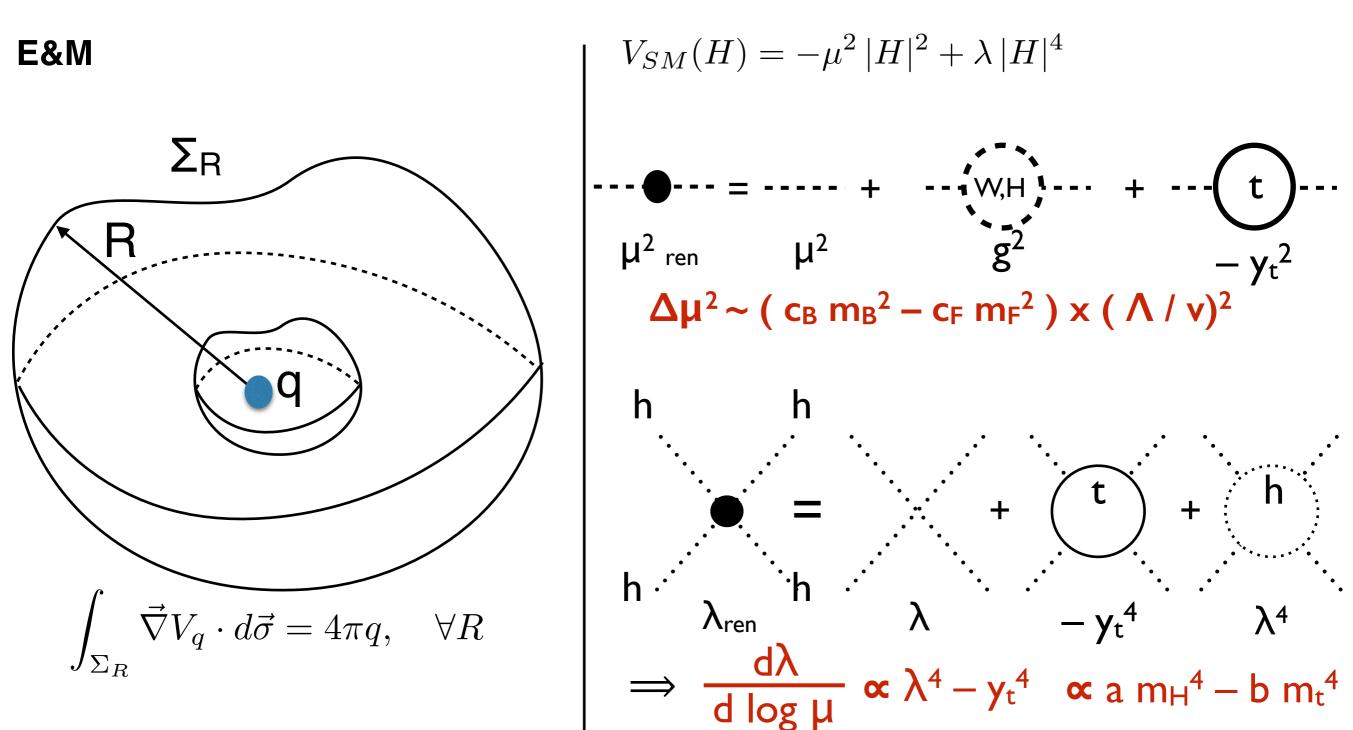
 $V_{SM}(H) = -\mu^2 |H|^2 + \lambda |H|^4$



short-scale physics does not alter the charge seen at large scales



short-scale physics does not alter the charge seen at large scales



short-scale physics does not alter the charge seen at large scales

high-energy modes can change size and sign of both μ^2 and λ , dramatically altering the stability and dynamics

bottom line

- To predict the properties of EM at large scales, we don't need to know what happens at short scales
- The Higgs dynamics is sensitive to all that happens at any scale larger than the Higgs mass !!! A very unnatural fine tuning is required to protect the Higgs dynamics from the dynamics at high energy
- This issue goes under the name of hierarchy problem
- Solutions to the hierarchy problem require the introduction of new symmetries (typically leading to the existence of new particles), which decouple the high-energy modes and allow the Higgs and its dynamics to be defined at the "natural" scale defined by the measured parameters v and m_H

\Rightarrow naturalness



• Supersymmetry: stop vs top (colored naturalness)



 $\tilde{t}_L, \ \tilde{t}_R$

• Supersymmetry: stop vs top (colored naturalness)

 t_R



- Supersymmetry: stop vs top (colored naturalness) • (
- Extra-dimensions: Planck scale closer than in 4-D, or Higgs as 4-D scalar component of a higher-dim gauge vector (KK modes, etc)

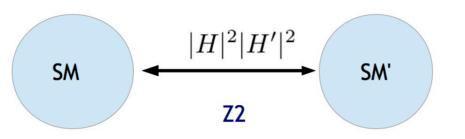
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folded SUSY (SU(3)_B stops cancel Higgs couplings to SU(3)_A tops)

The LHC experiments have been exploring a vast multitude of scenarios of physics beyond the Standard Model

In search of the origin of known departures from the SM

- Dark matter, long lived particles
- Neutrino masses
- Matter/antimatter asymmetry of the universe

To explore alternative extensions of the SM

- New gauge interactions (Z', W') or extra Higgs bosons
- Additional fermionic partners of quarks and leptons, leptoquarks, ...
- Composite nature of quarks and leptons
- Supersymmetry, in a variety of twists (minimal, constrained, natural, RPV, ...)
- Extra dimensions
- New flavour phenomena
- unanticipated surprises ...

So far, no conclusive signal of physics beyond the SM

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits Status: July 2017							TeV $\int \mathcal{L} dt = (3.2 - 37.0) \text{ fb}^{-1}$ $\sqrt{s} = 8, 13 \text{ TeV}$		
	Model	ℓ, γ	Jets†	E_{T}^{miss}	∫£ dt[fb	⁻¹] Limit			Reference
Extra dimensions	$\begin{array}{l} \text{ADD } G_{KK} + g/q \\ \text{ADD non-resonant } \gamma\gamma \\ \text{ADD QBH} \\ \text{ADD BH high } \sum \rho_T \\ \text{ADD BH multijet} \\ \text{RS1 } G_{KK} \rightarrow \gamma\gamma \\ \text{Bulk RS } G_{KK} \rightarrow WW \rightarrow qq\ell\nu \\ \text{2UED / RPP} \end{array}$	0 e,μ 2 γ - ≥ 1 e,μ - 2 γ 1 e,μ 1 e,μ	$\begin{array}{c} 1-4j\\ -\\ 2j\\ \geq 2j\\ \geq 3j\\ -\\ 1J\\ \geq 2b, \geq 3 \end{array}$	Yes - - - Yes j Yes	36.1 36.7 37.0 3.2 3.6 36.7 36.1 13.2	M _D M _S M _{th} M _{th} G _{KK} mass KK mass	7.75 TeV 8.6 TeV 8.9 TeV 8.2 TeV 9.55 TeV 4.1 TeV 1.75 TeV 1.6 TeV	$\begin{array}{l} n=2\\ n=3~\text{HLZ NLO}\\ n=6\\ n=6,~M_D=3~\text{TeV, rot BH}\\ n=6,~M_D=3~\text{TeV, rot BH}\\ k/\overline{M}_{PT}=0.1\\ k/\overline{M}_{PT}=1.0\\ \text{Tier (1,1), }\mathcal{B}(A^{(1,1)}\rightarrow\text{tr})=1 \end{array}$	ATLAS-CONF-2017-060 CERN-EP-2017-132 1703.09217 1606.02265 1512.02586 CERN-EP-2017-132 ATLAS-CONF-2017-051 ATLAS-CONF-2016-104
Gauge bosons	$\begin{array}{l} \operatorname{SSM} Z' \to \ell\ell \\ \operatorname{SSM} Z' \to \tau\tau \\ \operatorname{Leptophobic} Z' \to bb \\ \operatorname{Leptophobic} Z' \to tt \\ \operatorname{SSM} W' \to \ell\nu \\ \operatorname{HVT} V' \to WV \to qqqq \mbox{ model} \\ \operatorname{HVT} V' \to WH/ZH \mbox{ model} \\ \operatorname{HVT} V' \to WH/ZH \mbox{ model} \\ \operatorname{LRSM} W'_R \to tb \\ \operatorname{LRSM} W'_R \to tb \end{array}$	1 e, µ	- 2b ≥1b,≥1J/ 2J 8 2b,0-1j ≥1b,1J	Yes - Yes	36.1 36.1 3.2 36.1 36.7 36.1 20.3 20.3	Z' mass Z' mass Z' mass Z' mass W' mass V' mass V' mass W' mass W' mass	4.5 TeV 2.4 TeV 5 TeV 2.0 TeV 5.1 TeV 3.5 TeV 2.93 TeV 1.92 TeV 1.76 TeV	$\Gamma/m = 3\%$ $g_V = 3$ $g_V = 3$	ATLAS-CONF-2017-027 ATLAS-CONF-2017-050 1603.08791 ATLAS-CONF-2016-014 1706.04786 CERN-EP-2017-147 ATLAS-CONF-2017-055 1410.4103 1408.0886
ũ	Cl qqqq Cl {{ qq Cl wutt	– 2 e,µ 2(SS)/≥3 e,µ	2j _ µ≥1b,≥1j	- Yes	37.0 36.1 20.3	A A A	4.9 TeV	21.8 TeV η _{LL} 40.1 TeV η _{LL} C _{RR} = 1	1703.09217 ATLAS-CONF-2017-027 1504.04605
MQ	Axial-vector mediator (Dirac DM) Vector mediator (Dirac DM) VV _{XX} EFT (Dirac DM)	0 e, μ 0 e, μ, 1 γ 0 e, μ	1 – 4 j ≤ 1 j 1 J, ≤ 1 j	Yes Yes Yes	36.1 36.1 3.2	mesed 1 mesed 1.2 T M, 700 GeV	5 TeV IV	$\begin{array}{l} g_q\!=\!0.25,g_{\chi}\!=\!1.0,m(\chi)<400~{\rm GeV}\\ g_q\!=\!0.25,g_{\chi}\!=\!1.0,m(\chi)<480~{\rm GeV}\\ m(\chi)<150~{\rm GeV} \end{array}$	ATLAS-CONF-2017-060 1704.03848 1608.02372
07	Scalar LQ 1 st gen Scalar LQ 2 nd gen Scalar LQ 3 rd gen	2 e 2 μ 1 e,μ	≥ 2 j ≥ 2 j ≥1 b, ≥3 j	– – Yes	3.2 3.2 20.3	LQ mass 1.1 Te LQ mass 1.05 TeV LQ mass 640 GeV		eta = 1 eta = 1 eta = 0	1605.06035 1605.06035 1508.04735
Heavy quarks	$ \begin{array}{l} \mathbb{VLQ} \ TT \rightarrow Ht + X \\ \mathbb{VLQ} \ TT \rightarrow Zt + X \\ \mathbb{VLQ} \ TT \rightarrow Wb + X \\ \mathbb{VLQ} \ BB \rightarrow Hb + X \\ \mathbb{VLQ} \ BB \rightarrow Zb + X \\ \mathbb{VLQ} \ BB \rightarrow Wt + X \\ \mathbb{VLQ} \ BB \rightarrow Wt + X \\ \mathbb{VLQ} \ QQ \rightarrow WqWq \\ \end{array} $	1 e,μ 1 e,μ 1 e,μ 2/≥3 e,μ	$\begin{array}{l} \geq 2 \ b, \geq 3 \) \\ \geq 1 \ b, \geq 3 \) \\ \geq 1 \ b, \geq 1 \ J/ \\ \geq 2 \ b, \geq 3 \) \\ \geq 2/ \geq 1 \ b \\ \geq 1/ \geq 1 \ b, \geq 1 \ J/ \\ \geq 4 \ j \end{array}$	j Yes 2j Yes j Yes -	13.2 36.1 20.3 20.3 36.1 20.3	T mass 1.2 T T mass 1.16 T T mass 1.35 B mass 700 GeV B mass 790 GeV B mass 1.25 Q mass 690 GeV	V TeV	$\begin{split} &\mathcal{B}(T \to Ht) = 1 \\ &\mathcal{B}(T \to Zt) = 1 \\ &\mathcal{B}(T \to Wb) = 1 \\ &\mathcal{B}(B \to Hb) = 1 \\ &\mathcal{B}(B \to Zb) = 1 \\ &\mathcal{B}(B \to Wt) = 1 \end{split}$	ATLAS-CONF-2016-104 1705.10751 CERN-EP-2017-094 1505.04306 1409.5500 CERN-EP-2017-094 1509.04261
Excited fermions	Excited quark $q^* \rightarrow qg$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $b^* \rightarrow bg$ Excited quark $b^* \rightarrow Wt$ Excited lepton ℓ^* Excited lepton ν^*	- 1 γ - 1 or 2 e, μ 3 e, μ 3 e, μ, τ	2j 1j 1b,1j 1b,20j -	- - Yes -	37.0 36.7 13.3 20.3 20.3 20.3	q° mass q° mass b° mass b° mass (° mass v° mass	6.0 TeV 5.3 TeV 2.3 TeV 5 TeV 3.0 TeV 1.6 TeV	only u^* and d^* , $\Lambda = m(q^*)$ only u^* and d^* , $\Lambda = m(q^*)$ $f_d = f_L = f_R = 1$ $\Lambda = 3.0 \text{ TeV}$ $\Lambda = 1.6 \text{ TeV}$	1703.09127 CERN-EP-2017-148 ATLAS-CONF-2016-060 1510.02664 1411.2921 1411.2921
Other	Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$ Monotop (non-res prod) Multi-charged particles Magnetic monopoles	2 e,μ 2,3,4 e,μ (SS 3 e,μ,τ 1 e,μ - -	- 1 b - -	- - Yes -	20.3 36.1 20.3 20.3 20.3 7.0	Nº mass H** mass 870 GeV H** mass 400 GeV spin-1 invisible particle mass 657 GeV multi-charged particle mass 785 GeV monopole mass 1.34	2.0 TeV	$\begin{split} m(W_R) &= 2.4 \text{ TeV, no mixing} \\ \text{DY production} \\ \text{DY production, } \mathcal{B}(H_L^{zz} \to \ell \tau) = 1 \\ a_{\text{non-res}} &= 0.2 \\ \text{DY production, } q &= 5e \\ \text{DY production, } g &= 1g_D, \text{ spin } 1/2 \end{split}$	1506.06020 ATLAS-CONF-2017-053 1411.2921 1410.5404 1504.04188 1509.08059
*On	ly a selection of the available	<mark>5 = 8 TeV</mark> e mass limi	vs = 13		or pher	10-1	TeV	⁰ Mass scale [TeV]	

†Small-radius (large-radius) jets are denoted by the letter j (J).

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=> all this justifies the focus on the program of precision Higgs physics measurements

The Higgs potential

The Higgs sector is defined in the SM by two parameters, μ and λ : V(H) $V_{SM}(H) = -\mu^2 |H|^2 + \lambda |H|^4$

$$\frac{\partial V_{SM}(H)}{\partial H}|_{H=v} = 0 \quad \text{and} \quad m_H^2 = \frac{\partial^2 V_{SM}(H)}{\partial H \partial H^*}|_{H=v} \quad \Rightarrow \quad \begin{array}{l} \mu &= m_H \\ \lambda &= \frac{m_H^2}{2v^2} \end{array}$$

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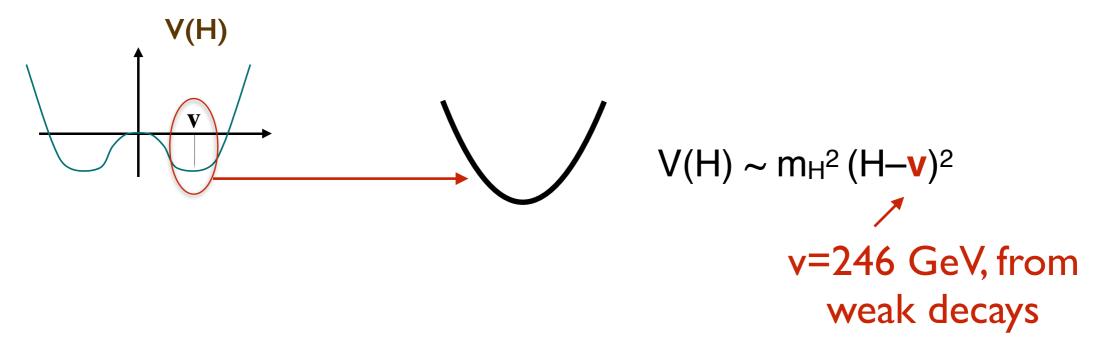
These relations uniquely determine the strength of Higgs selfcouplings in terms of the two now-known parameters m_H and v

$$\cdots \bullet \bullet \vdots \overset{\circ}{\mathbf{g}}_{\mathbf{3H}} \Rightarrow 4\lambda v = \frac{2m_H^2}{v} \qquad \qquad \bullet \bullet \bullet \overset{\circ}{\mathbf{s}} \overset{\circ}{\mathbf{s}}_{\mathbf{4H}} \Rightarrow \lambda = \frac{m_H^2}{2v^2}$$

These relations between Higgs self-couplings, m_H and v entirely depend on the functional form of the Higgs potential. Their measurement is therefore an important test of the SM nature of the Higgs mechanism

How far have we tested the Higgs potential?

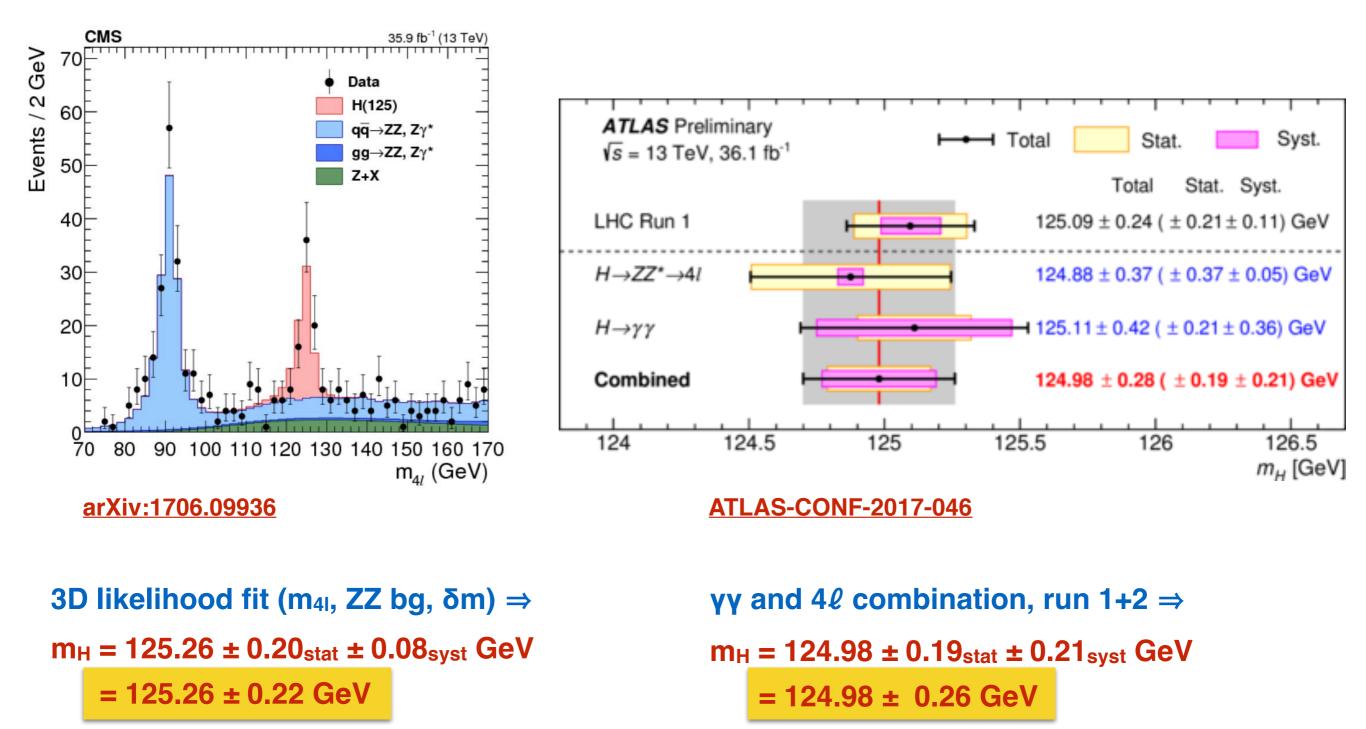
parameters of the potential



Higgs mass, 2017

CMS



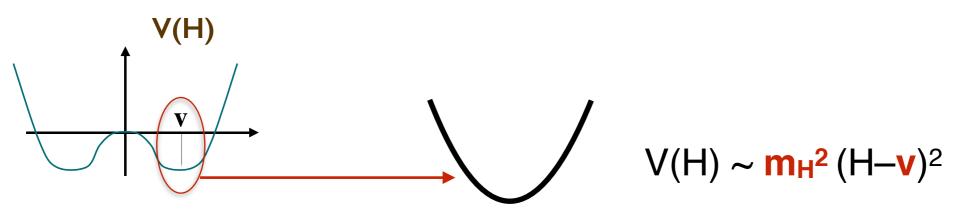


 \Rightarrow 2 x 10⁻³ precision

it took over 6 years from 1983 discovery to get below 5 x 10⁻³ on m_z (1989: CDF, SLC, LEP) 17

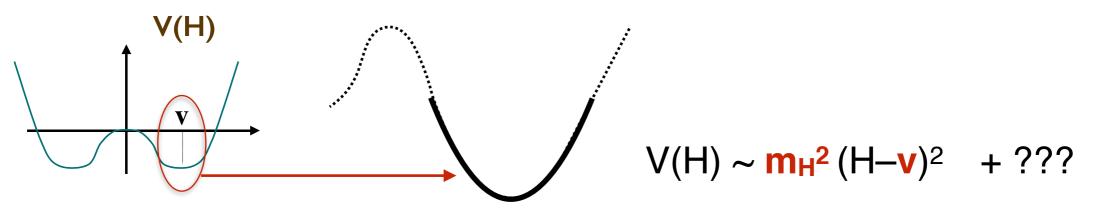
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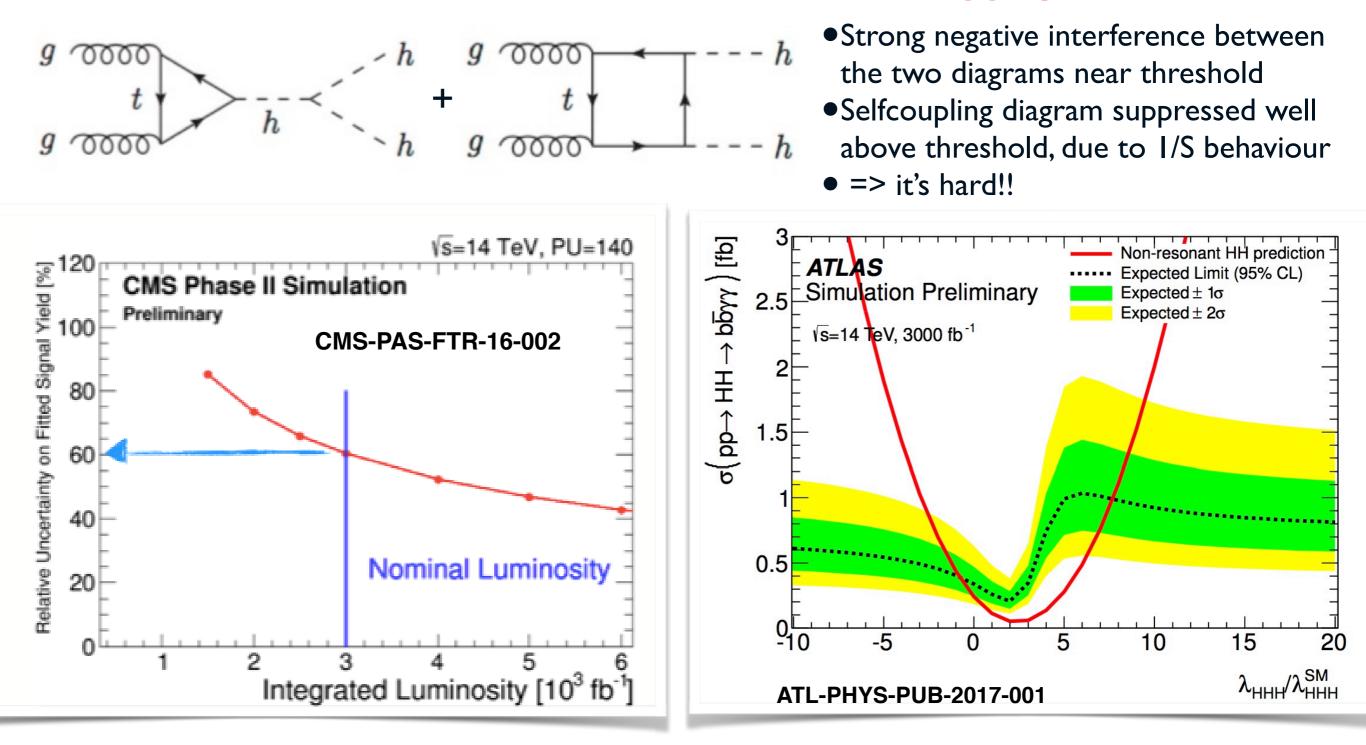


How far have we tested the Higgs mechanism?

parameters of the potential



What will HL-LHC tells us about the Higgs potential?



Barely 1-2 σ evidence for Higgs pair production, but no quantitatively significant determination of λ : -0.8 < λ/λ_{SM} < 7.7 @95%CL -0.2 < λ/λ_{SM} < 2.6

w. kinematical analysis

Higgs couplings: global fit of run I (2010-12) data

ATLAS+CMS ATLAS and CMS $\lambda H \overline{\psi_L} \psi_R = g H V^{\mu} V_{\mu}$ LHC Run 1 --- ATLAS CMS $-\pm 1\sigma$ μ_{ggF} ±2o $\mu = \sigma \mathbf{x} \mathbf{B} \mathbf{R} / [\sigma \mathbf{x} \mathbf{B} \mathbf{R}]_{SM}$ assuming SM BR's in data μ_{VBF} μ_{wh} μ_{zн} **ATLAS+CMS** JHEP 1608 (2016) 045 1.09 ± 0.11 μ_{ttH} μ -1 -0.5 0 0.5 2.5 3 1.5 2 3.5 4 Parameter value

- combination of different production and decay channels, explicit constraints on individual couplings are much less precise than 10% !!

- essential to establish couplings individually, through combinations of different production and decay channels

Since run 2 started in 2015:

 $H \rightarrow \tau \tau$, bb, Htt coupling, all established at >5 σ

 $H \rightarrow \mu\mu$: limits at < 2.8 SM (ATLAS) and 2.6 SM (CMS)

 \Rightarrow so far, so good, the Higgs behaves as predicted by the SM, why do we need to do better?

Sensitivity of various Higgs couplings to examples of beyond-the-SM phenomena

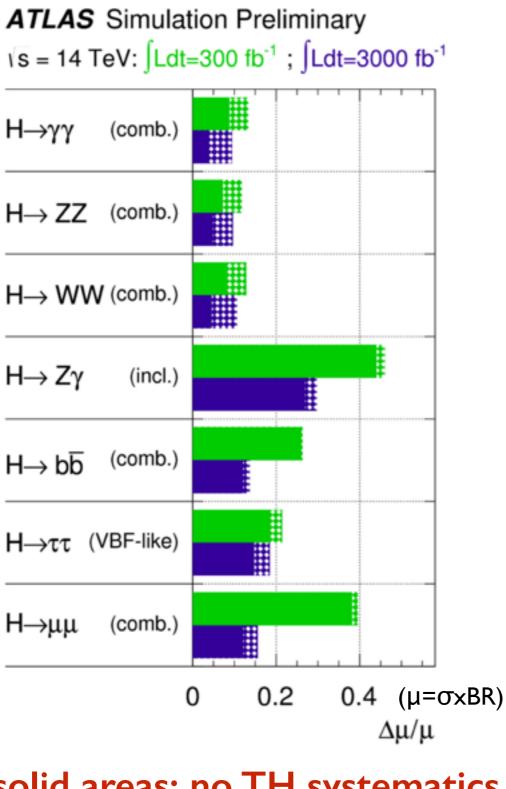
arXiv:1310.8361

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
$2 \mathrm{HDM}$	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

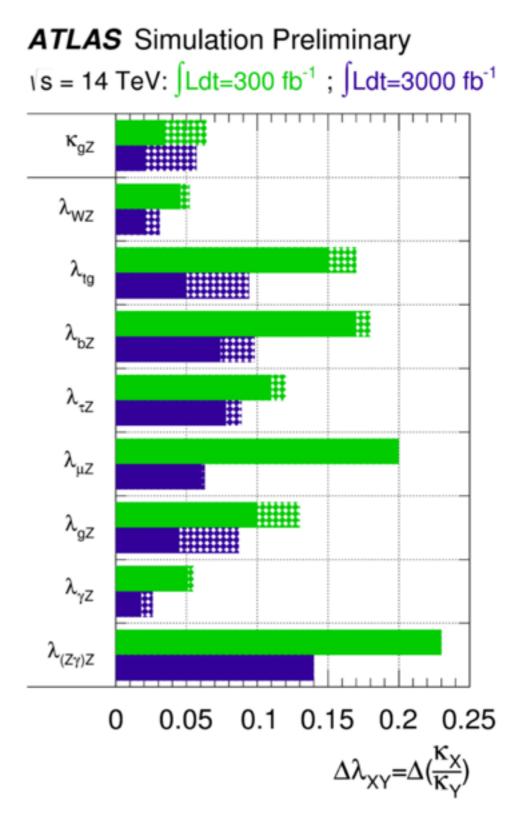
=> the goal should be (sub)percent precision!

Projected precision on H couplings at HL-LHC

ATL-PHYS-PUB-2014-016



solid areas: no TH systematics shaded areas: with TH systematics



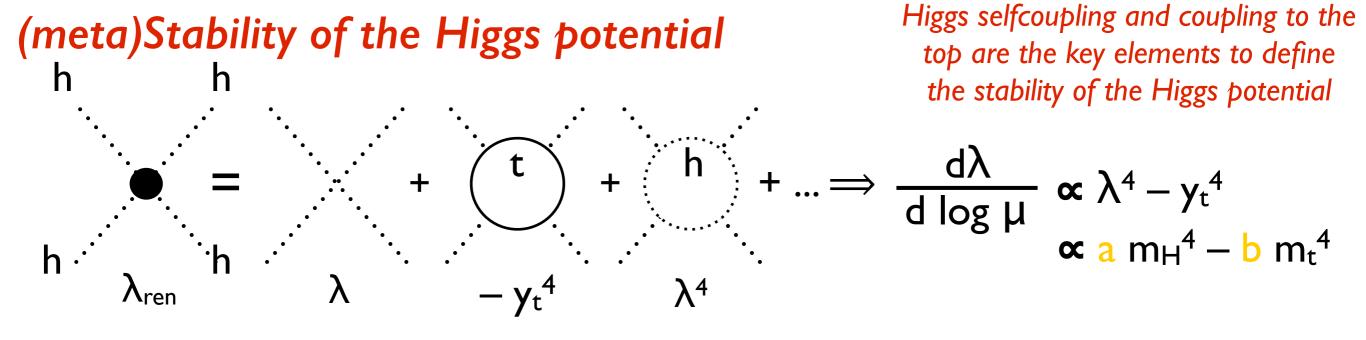
The Higgs boson is directly connected to several questions:

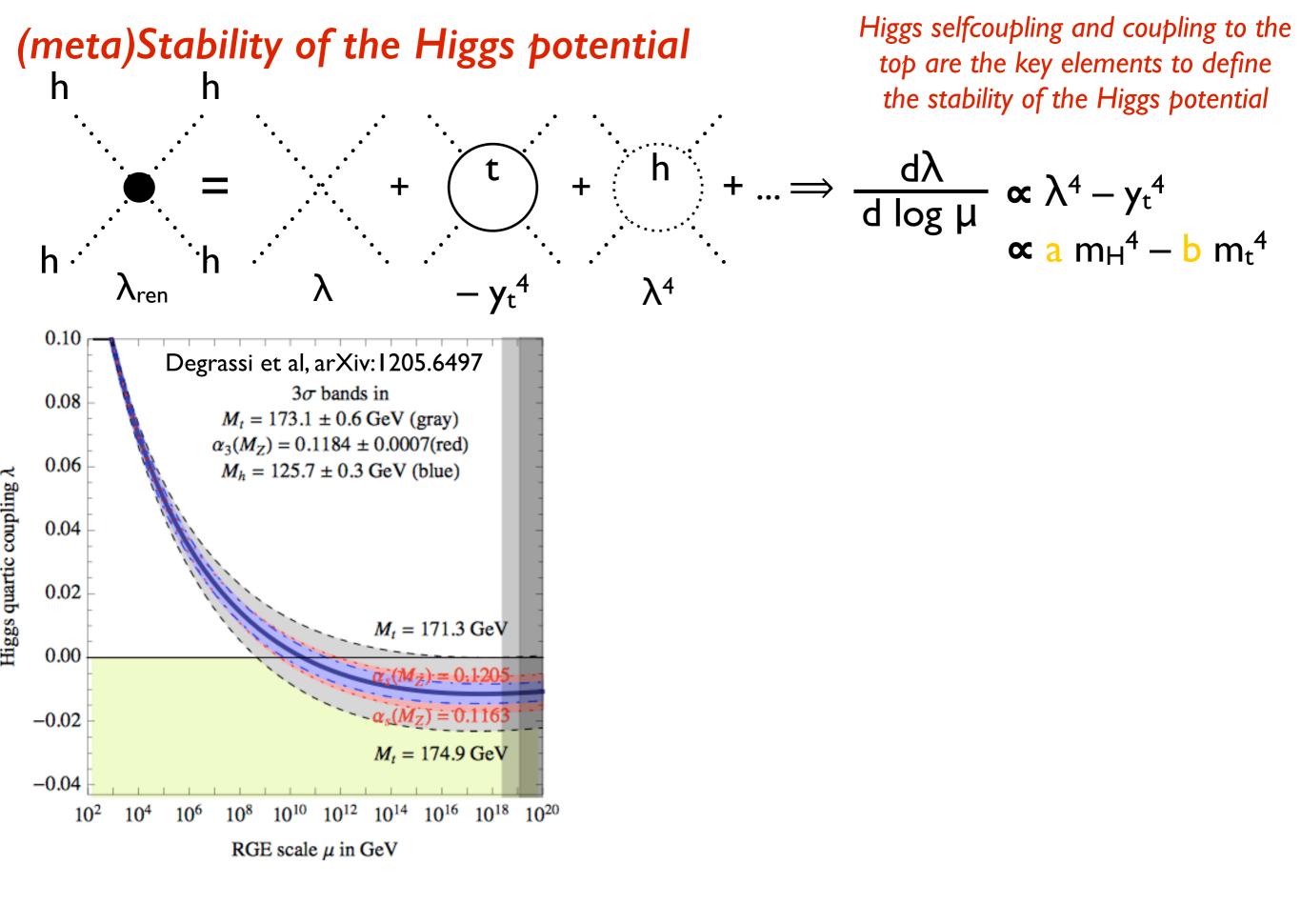
• Is the Higgs the only (fundamental?) scalar field, or are there other Higgs-like states (e.g. H[±], A⁰, H^{±±}, ..., EW-singlets,) ?

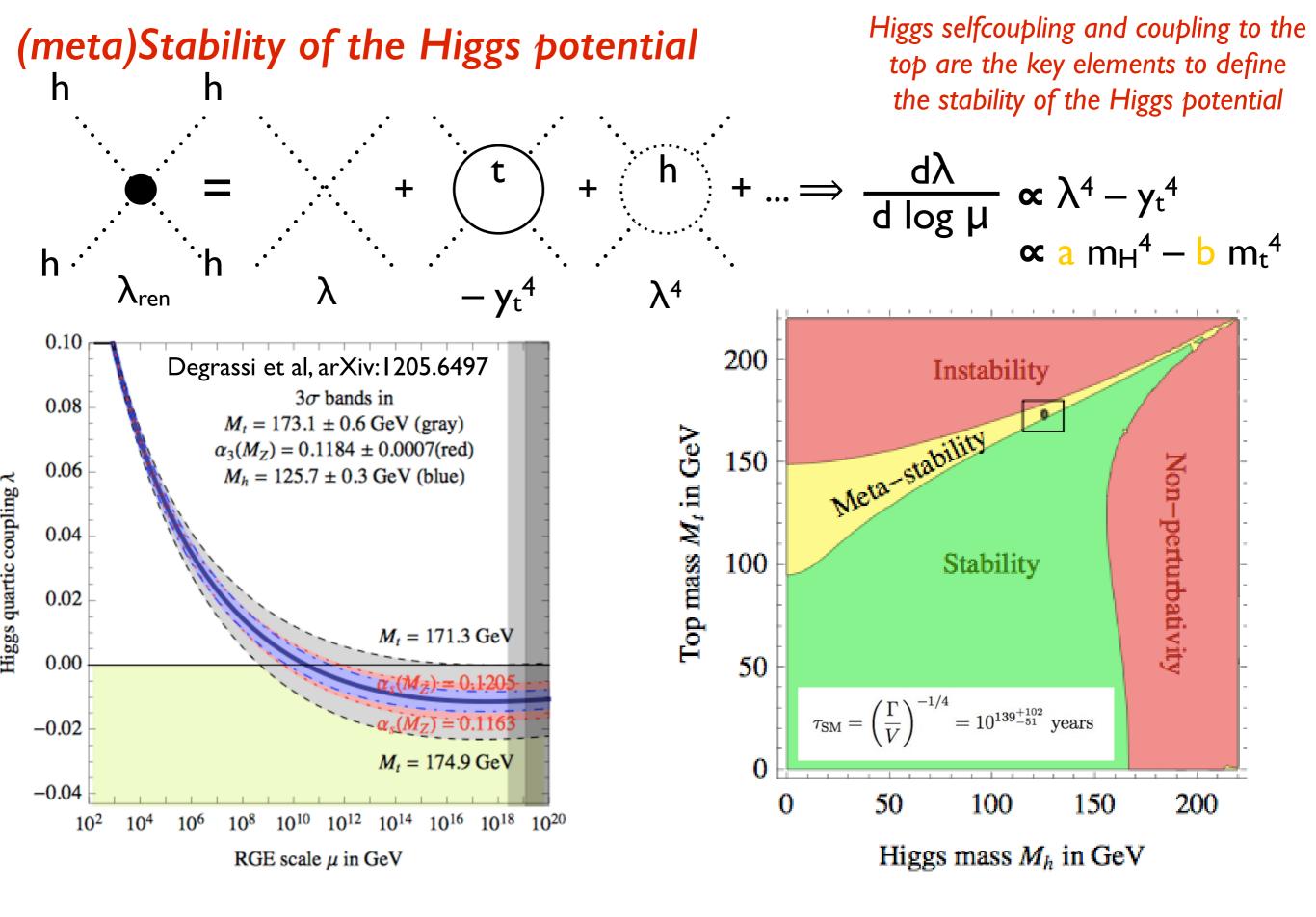
- Is the Higgs the only (fundamental?) scalar field, or are there other Higgs-like states (e.g. H[±], A⁰, H^{±±}, ..., EW-singlets,) ?
- What happens at the EW phase transition (PT) during the Big Bang?
 - what's the order of the phase transition?
 - are the conditions realized to allow EW baryogenesis?
 - does the PT wash out possible pre-existing baryon asymmetry?

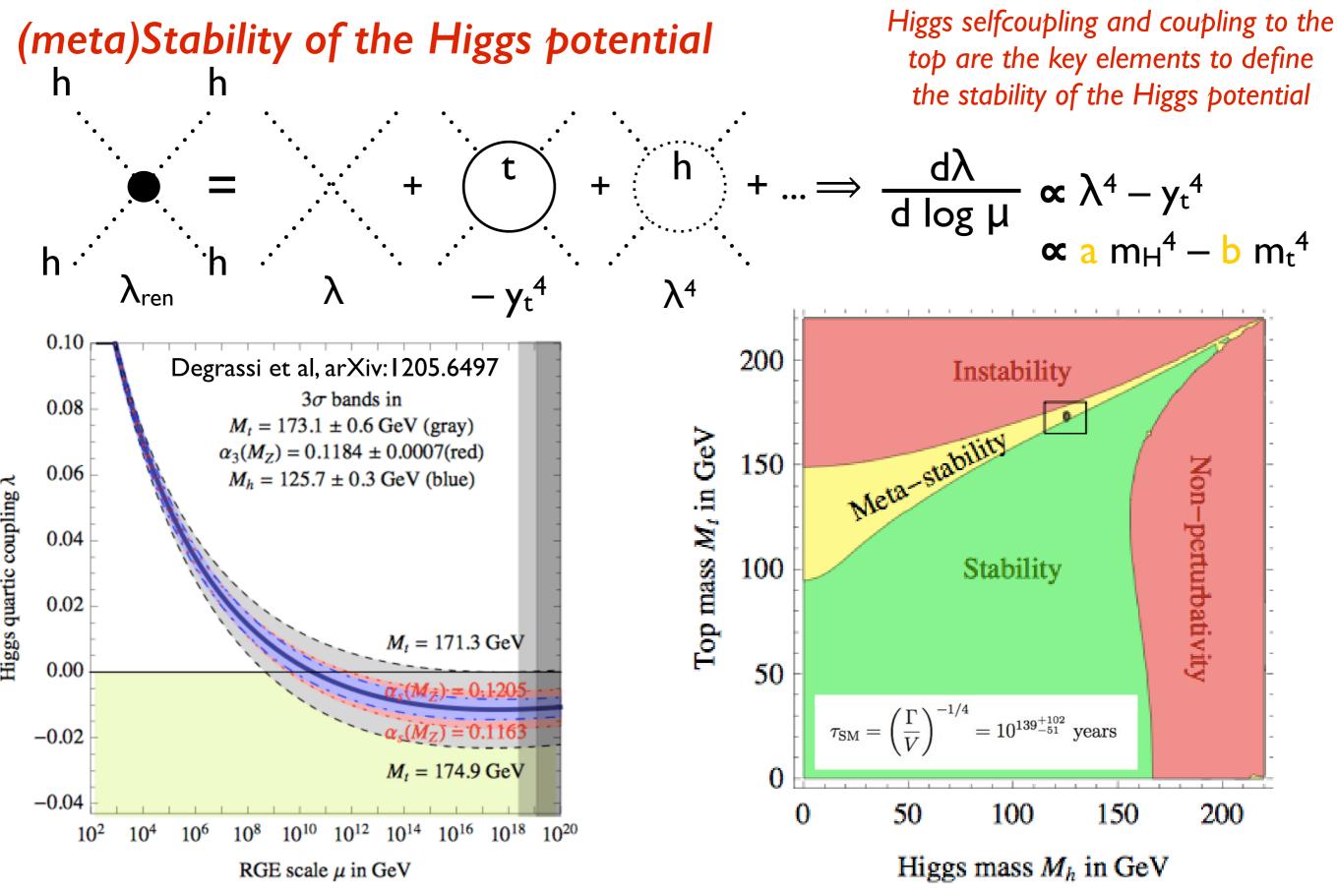
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- Is there a relation between any amongst Higgs/EWSB, baryogenesis, Dark Matter, inflation?
- Is there a deep reason for the apparent metastability of the Higgs vacuum?



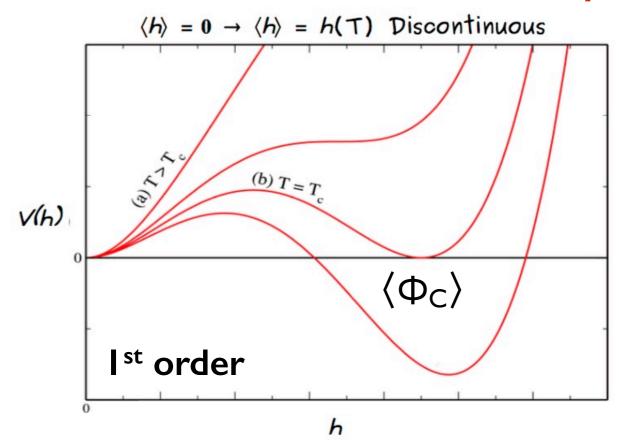


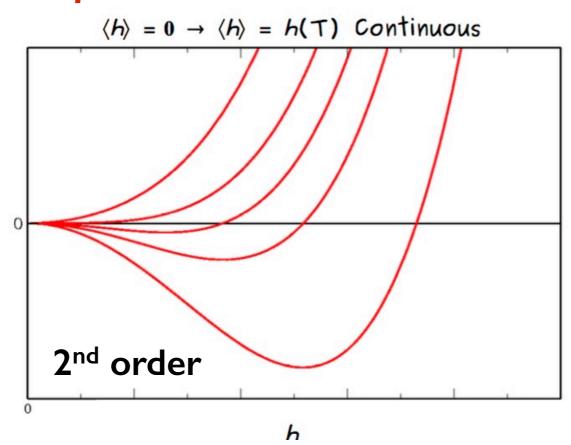


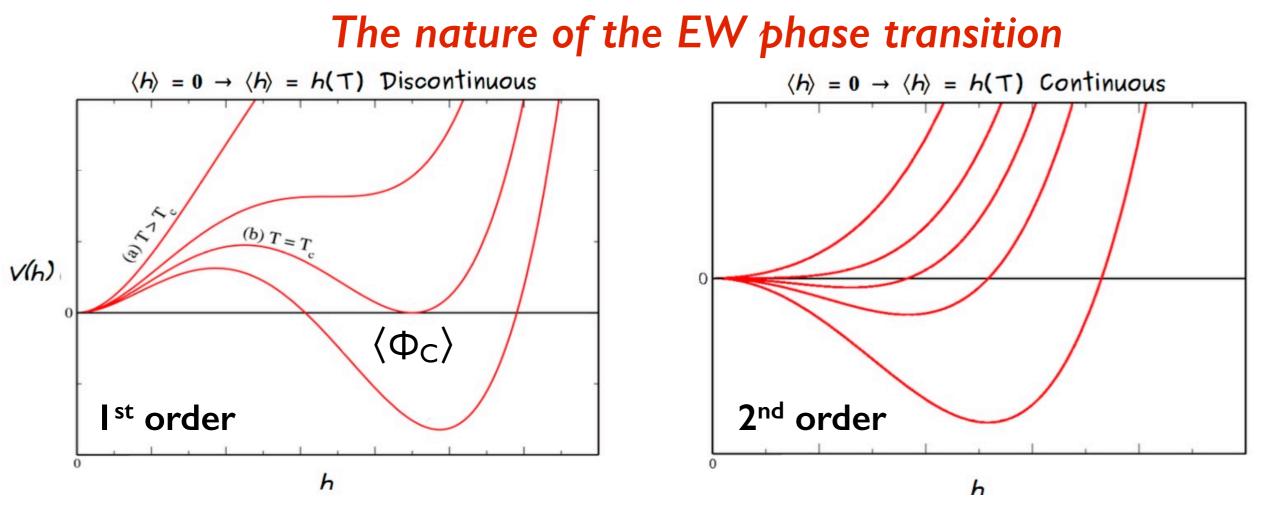


Not an issue of concern for the human race.... but the closeness of mtop to the critical value where the Higgs selfcoupling becomes 0 at M_{Planck} (namely 171.3 GeV) might be telling us something fundamental about the origin of EWSB ... incidentally, $y_{top}=1$ (?!)

The nature of the EW phase transition



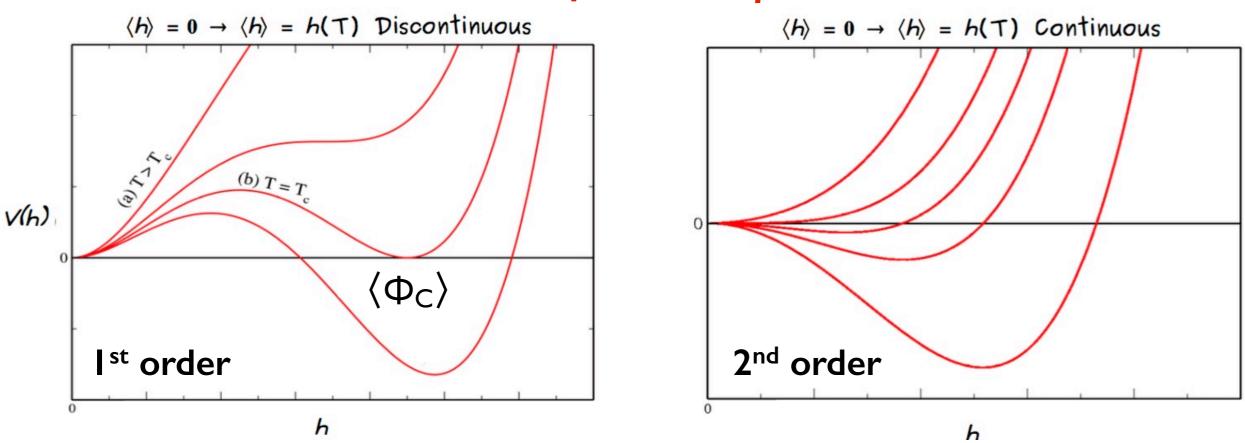




Strong Ist order phase transition is required to induce and sustain the out of equilibrium generation of a baryon asymmetry during EW symmetry breaking

Strong Ist order phase transition $\Rightarrow \langle \Phi_C \rangle > T_C$





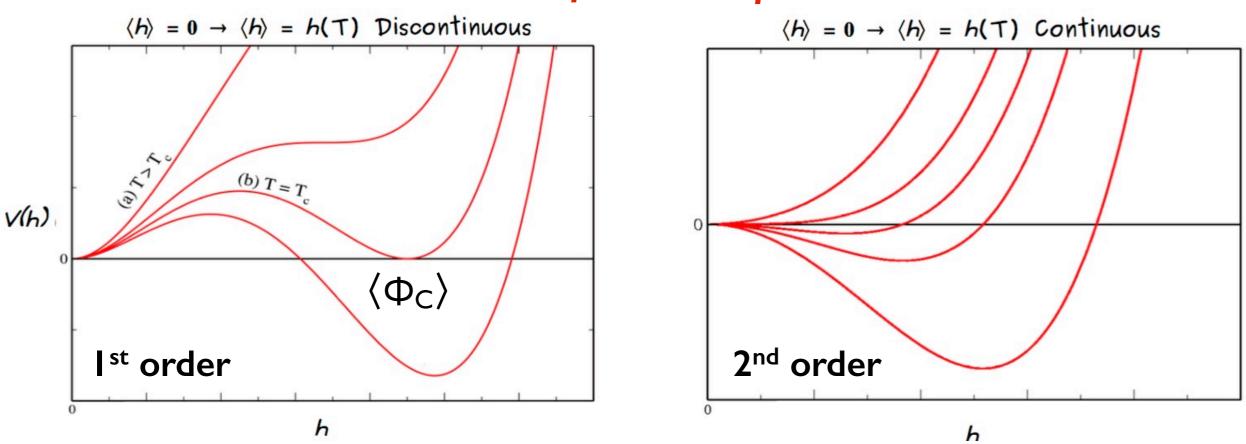
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Since $m_H = 125$ GeV, new physics, coupling to the Higgs and effective at scales O(TeV), must modify the Higgs potential to make this possible





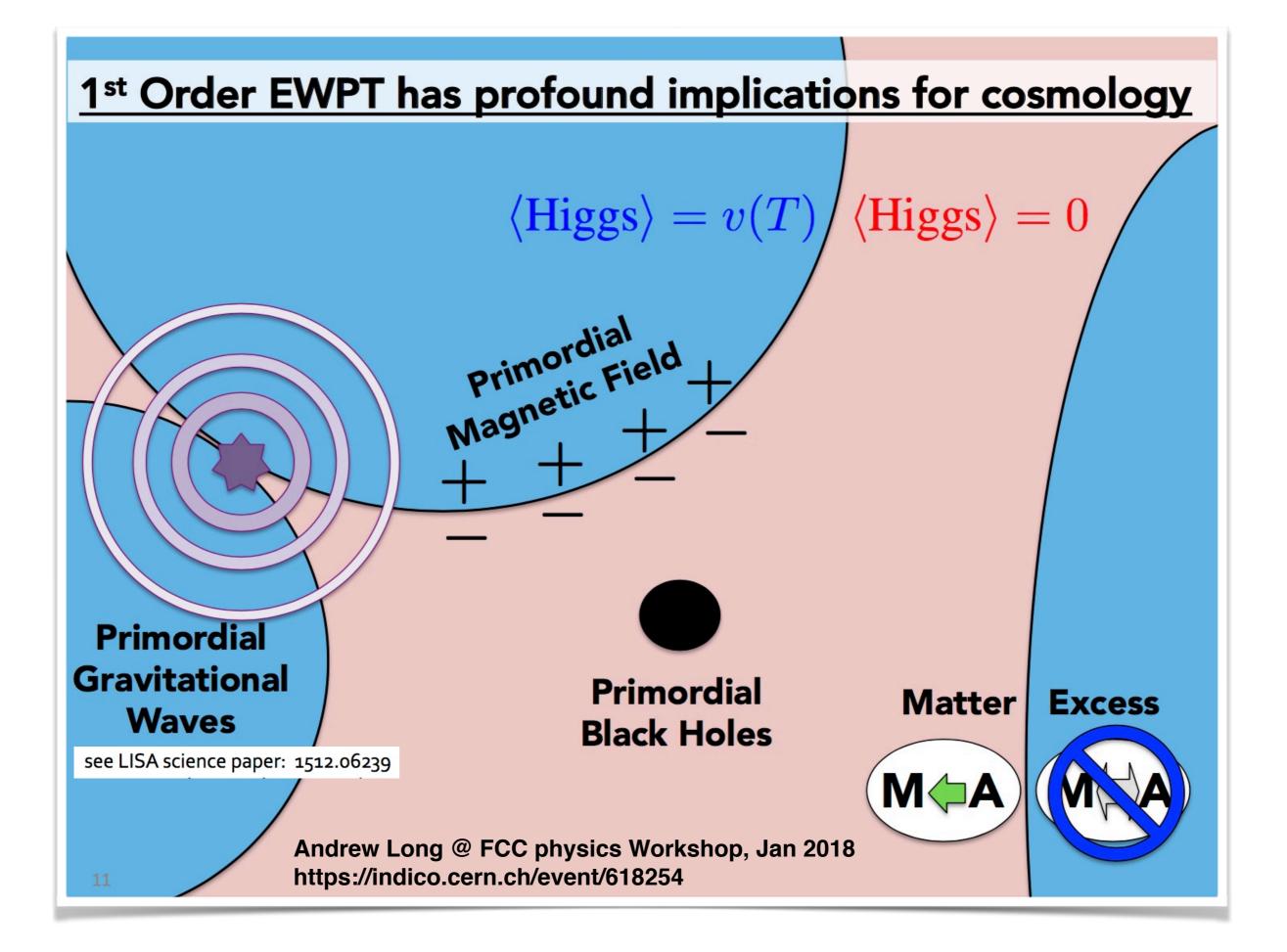
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- Probe higher-order terms of the Higgs potential (selfcouplings)
- Probe the existence of other particles coupled to the Higgs



<u>Key question for the future developments of HEP:</u> Why don't we see the new physics we expected to be present around the TeV scale ? <u>Key question for the future developments of HEP:</u> Why don't we see the new physics we expected to be present around the TeV scale ?

• Is the mass scale beyond the LHC reach ?

So far, no conclusive signal of physics beyond the SM

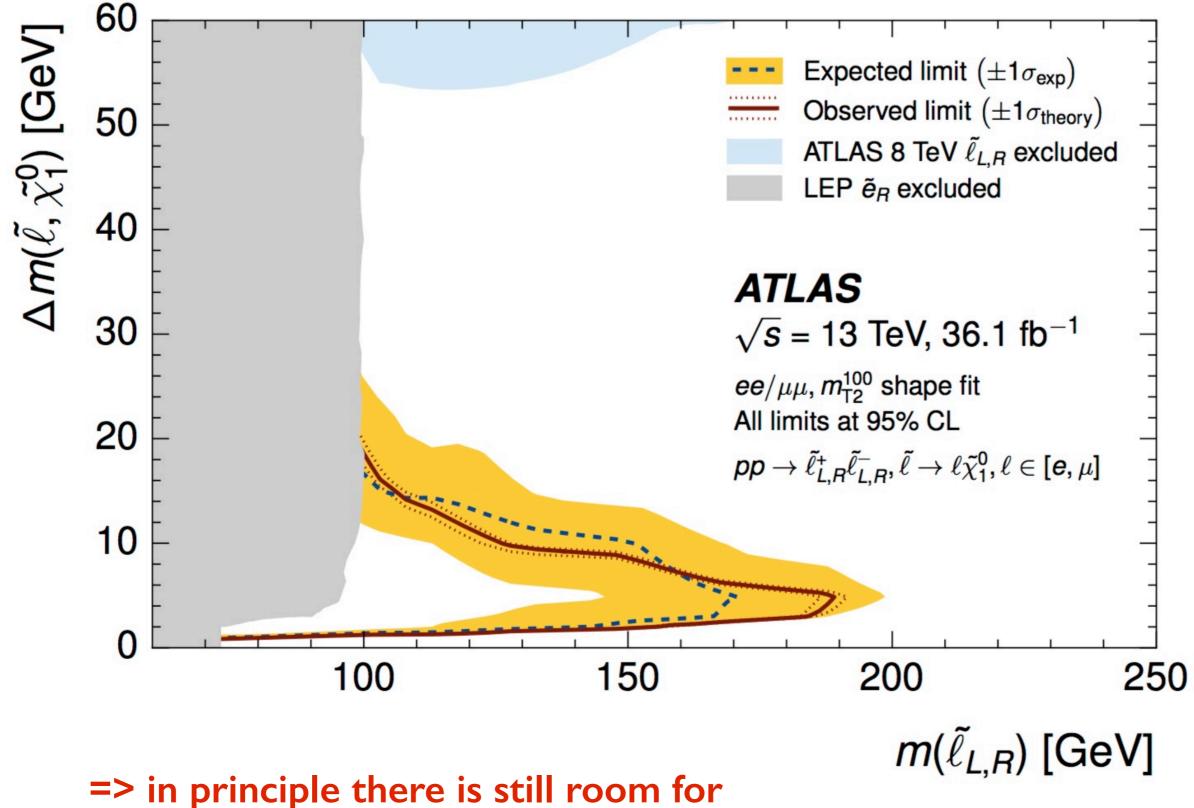
	TLAS SUSY Sear	rches*	- 95%	6 CI	Lo	ver Limits	ı TeV		ATLAS Preliminary $\sqrt{s} = 7, 8, 13 \text{ TeV}$
	Model	e, μ, τ, γ	Jets	E_{T}^{miss}	∫£ dı[N	-1) Mass limit	$\sqrt{s} = 7,3$	B TeV $\sqrt{s} = 13 \text{ TeV}$	Reference
Inclusive Searches	$ \begin{array}{l} \bar{q} \bar{q}, \ \bar{q} \rightarrow q \bar{k}_{1}^{0} \\ \bar{q} \bar{q}, \ \bar{q} \rightarrow q \bar{k}_{1}^{0} \ (compressed) \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} \bar{k}_{1}^{0} \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} \bar{k}_{1}^{0} \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} \bar{q} \bar{k}_{1}^{0} \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} \bar{q} \ell \ell \ell \bar{k}_{1}^{0} \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} \ell \ell \ell / \bar{k}_{1}^{0} \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} \ell \ell \ell / \bar{k}_{1}^{0} \\ \bar{g} \bar{g}, \ \bar{g} \rightarrow q \bar{q} W Z \bar{\ell}_{1}^{0} \\ GMSB (\ell \text{ NLSP}) \\ GGM (bino \text{ NLSP}) \\ GGM (higgsino-bino \text{ NLSP}) \\ Gravitino LSP \end{array} $	0 mono-jet 0 ee.μμ 3 e.μ 0 1-2 τ + 0-1 ℓ 2 γ γ 0	2-6 jets 1-3 jets 2-6 jets 2-6 jets 2 jets 4 jets 7-11 jets 0-2 jets - 2 jets mono-jet	Yes Yes Yes Yes Yes Yes Yes Yes	36.1 36.1 36.1 14.7 36.1 36.1 36.1 36.1 36.1 20.3	i i <t< td=""><td>2.01 TeV 1.7 TeV 1.87 TeV 1.8 TeV 2.0 TeV 2.15 Te</td><td>$\begin{split} m(\tilde{t}_{1}^{0}) &< 200 \text{GeV}, \ m(1^{w} gen. \tilde{q}) + m(2^{wd} gen. \tilde{q}) \\ m(\tilde{q}) - m(\tilde{t}_{1}^{0}) &< 5 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &< 200 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &< 200 \text{GeV}, \ m(\tilde{t}^{1}) = 0.5(m(\tilde{t}_{1}^{0}) + m(g)) \\ m(\tilde{t}_{1}^{0}) &< 300 \text{GeV}, \\ m(\tilde{t}_{1}^{0}) &< 300 \text{GeV}, \\ m(\tilde{t}_{1}^{0}) &< 400 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &< 400 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &= 1700 \text{GeV}, \ c\tau(\text{NLSP}) < 0.1 \text{mm}, \ \mu > 0 \\ m(\tilde{t}_{1}^{0}) &= 1700 \text{GeV}, \ c\tau(\text{NLSP}) < 0.1 \text{mm}, \ \mu > 0 \\ m(\tilde{t}_{1}^{0}) &= 1.5 \text{TeV} \end{split}$</td><td>1712.02332 1711.03301 1712.02332 1712.02332 1611.05791 1706.03731 1708.02794 1607.05979 ATLAS-CONF-2017-080 ATLAS-CONF-2017-080 1502.01518</td></t<>	2.01 TeV 1.7 TeV 1.87 TeV 1.8 TeV 2.0 TeV 2.15 Te	$\begin{split} m(\tilde{t}_{1}^{0}) &< 200 \text{GeV}, \ m(1^{w} gen. \tilde{q}) + m(2^{wd} gen. \tilde{q}) \\ m(\tilde{q}) - m(\tilde{t}_{1}^{0}) &< 5 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &< 200 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &< 200 \text{GeV}, \ m(\tilde{t}^{1}) = 0.5(m(\tilde{t}_{1}^{0}) + m(g)) \\ m(\tilde{t}_{1}^{0}) &< 300 \text{GeV}, \\ m(\tilde{t}_{1}^{0}) &< 300 \text{GeV}, \\ m(\tilde{t}_{1}^{0}) &< 400 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &< 400 \text{GeV} \\ m(\tilde{t}_{1}^{0}) &= 1700 \text{GeV}, \ c\tau(\text{NLSP}) < 0.1 \text{mm}, \ \mu > 0 \\ m(\tilde{t}_{1}^{0}) &= 1700 \text{GeV}, \ c\tau(\text{NLSP}) < 0.1 \text{mm}, \ \mu > 0 \\ m(\tilde{t}_{1}^{0}) &= 1.5 \text{TeV} \end{split}$	1712.02332 1711.03301 1712.02332 1712.02332 1611.05791 1706.03731 1708.02794 1607.05979 ATLAS-CONF-2017-080 ATLAS-CONF-2017-080 1502.01518
R med.	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\tilde{h}\tilde{\chi}_1^0$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0 0-1 e,µ	3b 3b	Yes Yes	36.1 36.1	R R	1.92 TeV 1.97 TeV	m(t ⁰ ₁)<600 GeV m(t ⁰ ₁)<200 GeV	1711.01901 1711.01901
3rd gen. squarks 3 direct production	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\ell}_1^0$ $\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\ell}_1^0$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow b \tilde{\ell}_1^A$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow b \tilde{\ell}_1^0$ or $t \tilde{t}_1^0$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{\ell}_1^0$ $\tilde{t}_1 \tilde{t}_1 (natural GMSB)$ $\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$ $\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + h$	0 2 e, µ (SS) 0-2 e,µ 0-2 e,µ 0 2 e,µ (Z) 3 e,µ (Z) 1-2 e,µ	2 b 1 b 1 - 2 b 0 - 2 jets/1 - 2 : mono-jet 1 b 1 b 1 b 4 b		36.1 36.1 4.7/13.3 20.3/36.1 36.1 20.3 36.1 36.1 36.1	b1 950 GeV b1 275-700 GeV 117-170 GeV 200-720 GeV 11 117-170 GeV 11 90-198 GeV 1 90-198 GeV 1 90-430 GeV 1 150-600 GeV 12 290-790 GeV 12 320-880 GeV		$\begin{split} m(\hat{t}_{1}^{0}) &<\!$	1708.09266 1706.03731 1209.2102, ATLAS-CONF-2016-077 1506.08616, 1709.04183, 1711.11520 1711.03301 1403.5222 1706.03986 1706.03986
EW direct	$ \begin{array}{c} \tilde{\ell}_{L,R} \tilde{\ell}_{L,K}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_1^0 \\ \tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow \tilde{\ell} \nu (\ell \tilde{\nu}) \\ \tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_2^0, \tilde{\chi}_1^+ \rightarrow \tilde{\tau} \nu (\tau \tilde{\nu}), \tilde{\chi}_2^0 \rightarrow \tilde{\tau} \tau (\nu \tilde{\nu}) \\ \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow \tilde{\ell}_L \nu \tilde{\ell}_L \ell (\tilde{\nu} \nu), \ell \tilde{\nu} \tilde{\ell}_L \ell (\tilde{\nu} \nu) \\ \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow W \tilde{\chi}_1^0 \tilde{\chi}_1^0 \\ \tilde{\chi}_2^+ \tilde{\chi}_2^0 \rightarrow W \tilde{\chi}_1^0 \tilde{\chi}_1^0, h \rightarrow b \tilde{b} / W W / \tau \tau / \gamma \gamma \\ \tilde{\chi}_2^0 \tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0 \rightarrow \tilde{\ell}_R \ell \\ \text{GGM (wino NLSP) weak prod., } \tilde{\chi}_1^0 \rightarrow \end{array} $		0 0 0-2 jets 0-2 b 0 -	Yes Yes Yes Yes Yes Yes Yes Yes	36.1 36.1 36.1 36.1 20.3 20.3 20.3 36.1	i 90-500 GeV $\hat{\chi}_{1}^{\pm}$ 750 GeV $\hat{\chi}_{1}^{\pm}$ 760 GeV $\hat{\chi}_{1}^{\pm}, \hat{\chi}_{2}^{\pm}$ 760 GeV $\hat{\chi}_{1}^{\pm}, \hat{\chi}_{2}^{\pm}$ 760 GeV $\hat{\chi}_{1}^{\pm}, \hat{\chi}_{2}^{\pm}$ 580 GeV $\hat{\chi}_{1}^{\pm}, \hat{\chi}_{2}^{\pm}$ 580 GeV $\hat{\chi}_{2,3}^{\pm}$ 635 GeV $\hat{\psi}$ 115-370 GeV $\hat{\psi}$ 1.06 Te	m(\tilde{t}_{2}^{0})-	$\begin{split} m(\tilde{k}_{1}^{0}) = 0 \\ m(\tilde{k}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{\imath}) = 0.5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{0})) \\ m(\tilde{k}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{\imath}) = 0.5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{0})) \\ m(\tilde{k}_{2}^{0}), m(\tilde{k}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{\imath}) = 0.5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{0})) \\ m(\tilde{k}_{1}^{+}) = m(\tilde{k}_{2}^{0}), m(\tilde{k}_{1}^{0}) = 0, \tilde{\ell} \text{ decoupled} \\ m(\tilde{k}_{1}^{+}) = m(\tilde{k}_{2}^{0}), m(\tilde{k}_{1}^{0}) = 0, \tilde{\ell} \text{ decoupled} \\ m(\tilde{k}_{3}^{0}), m(\tilde{k}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{\imath}) = 0.5(m(\tilde{k}_{2}^{0}) + m(\tilde{k}_{1}^{0})) \\ cr < 1 mm \\ cr < 1 mm \end{split}$	ATLAS-CONF-2017-039 ATLAS-CONF-2017-039 1708.07875 ATLAS-CONF-2017-039 ATLAS-CONF-2017-039 1501.07110 1405.5086 1507.05493 ATLAS-CONF-2017-080
Long-lived particles	Direct $\hat{x}_{1}^{*}\hat{x}_{1}^{-}$ prod., long-lived \hat{x}_{1}^{*} Direct $\hat{x}_{1}^{*}\hat{x}_{1}^{-}$ prod., long-lived \hat{x}_{1}^{*} Stable, stopped \tilde{g} R-hadron Stable \tilde{g} R-hadron Metastable \tilde{g} R-hadron Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q \tilde{q} \tilde{\xi}_{1}^{0}$ GMSB, stable $\tilde{\tau}, \hat{x}_{1}^{0} \rightarrow \tau(\tilde{e}, \hat{\mu}) + \tau(e, \mu)$ GMSB, $\hat{x}_{1}^{0} \rightarrow \gamma \tilde{O}$, long-lived \hat{x}_{1}^{0} $\tilde{g}_{\tilde{g}}, \hat{x}_{1}^{0} \rightarrow eev/e\mu v/\mu \mu v$	Disapp. trk dE/dx trk 0 trk dE/dx trk displ. vtx 1-2 μ 2 γ displ. ee/eμ/μ	1 jet - 1-5 jets - - - - -	Yes Yes - Yes - Yes - Yes	36.1 18.4 27.9 3.2 3.2 32.8 19.1 20.3 20.3	x̂ [±] 460 GeV x̂ [±] 495 GeV \$ 850 GeV \$ 950 GeV <td< td=""><td></td><td>$\begin{split} m(\hat{\tilde{r}}_1^+) &-m(\hat{\tilde{r}}_1^0) \sim 150 \text{ MeV}, \ r(\hat{\tilde{r}}_1^+) = 0.2 \text{ ns} \\ m(\hat{\tilde{r}}_1^+) -m(\hat{\tilde{r}}_1^0) = 160 \text{ MeV}, \ r(\hat{\tilde{r}}_1^+) < 15 \text{ ns} \\ m(\hat{\tilde{r}}_1^0) = 100 \text{ GeV}, \ 10 \ \mu s < r(\hat{\tilde{r}}) < 1000 \text{ s} \\ \end{split} \\ \end{split} \\ \begin{split} m(\hat{\tilde{r}}_1^0) &= 100 \text{ GeV}, \ r > 10 \ ns \\ \hline \textbf{TeV}, \ r(\hat{\tilde{s}}) = 0.0 \text{ GeV} \\ 10 < tanjs < 50 \\ 1 < r(\hat{\tilde{r}}_1^0) < 3 \text{ ns}, \text{ SPS8 model} \\ 7 < cr(\hat{\tilde{r}}_1^0) < 740 \text{ mm}, \ m(\hat{g}) = 1.3 \text{ TeV} \end{split}$</td><td>1712.02118 1506.05332 1310.6584 1606.05129 1604.04520 1710.04901 1411.6795 1409.5542 1504.05162</td></td<>		$\begin{split} m(\hat{\tilde{r}}_1^+) &-m(\hat{\tilde{r}}_1^0) \sim 150 \text{ MeV}, \ r(\hat{\tilde{r}}_1^+) = 0.2 \text{ ns} \\ m(\hat{\tilde{r}}_1^+) -m(\hat{\tilde{r}}_1^0) = 160 \text{ MeV}, \ r(\hat{\tilde{r}}_1^+) < 15 \text{ ns} \\ m(\hat{\tilde{r}}_1^0) = 100 \text{ GeV}, \ 10 \ \mu s < r(\hat{\tilde{r}}) < 1000 \text{ s} \\ \end{split} \\ \end{split} \\ \begin{split} m(\hat{\tilde{r}}_1^0) &= 100 \text{ GeV}, \ r > 10 \ ns \\ \hline \textbf{TeV}, \ r(\hat{\tilde{s}}) = 0.0 \text{ GeV} \\ 10 < tanjs < 50 \\ 1 < r(\hat{\tilde{r}}_1^0) < 3 \text{ ns}, \text{ SPS8 model} \\ 7 < cr(\hat{\tilde{r}}_1^0) < 740 \text{ mm}, \ m(\hat{g}) = 1.3 \text{ TeV} \end{split}$	1712.02118 1506.05332 1310.6584 1606.05129 1604.04520 1710.04901 1411.6795 1409.5542 1504.05162
RPV	$ \begin{array}{l} LFV pp \rightarrow \tilde{v}_\tau + X, \tilde{v}_\tau \rightarrow e\mu/e\tau/\mu\tau \\ Blinear \ RPV \ CMSSM \\ \tilde{\mathcal{X}}_1^+ \tilde{\mathcal{X}}_1^-, \tilde{\mathcal{X}}_1^+ \rightarrow W \tilde{\mathcal{X}}_1^0, \tilde{\mathcal{X}}_1^0 \rightarrow eev, e\mu v, \mu\mu v \\ \tilde{\mathcal{X}}_1^+ \tilde{\mathcal{X}}_1^-, \tilde{\mathcal{X}}_1^+ \rightarrow W \tilde{\mathcal{X}}_1^0, \tilde{\mathcal{X}}_1^0 \rightarrow \tau\tau v_e, e\tau v_\tau \\ \tilde{\mathcal{X}}_2^+, \tilde{\mathcal{X}}_1^-, \tilde{\mathcal{X}}_1^+ \rightarrow Q q q \\ \tilde{\mathcal{X}}_2^+, \tilde{\mathcal{X}}_1^-, \tilde{\mathcal{X}}_1^0 \rightarrow q q q \\ \tilde{\mathcal{X}}_2^+, \tilde{\mathcal{X}}_1^- \tilde{\mathcal{X}}_1^0 \rightarrow \tilde{\mathcal{Y}}_1^0 \rightarrow \tilde{\mathcal{Y}}_1^0 \\ \tilde{\mathcal{X}}_1^- \tilde{\mathcal{Y}}_1^-, \tilde{\mathcal{Y}}_1^- \rightarrow bs \\ \tilde{\mathcal{I}}_1 \tilde{\mathcal{I}}_1, \tilde{\mathcal{I}}_1 \rightarrow b\ell \end{array} $	1 e,μ 8 1 e,μ 8	- 0-3 b - - 5 large-R je 1-10 jets/0-4 1-10 jets/0-4 2 jets + 2 b 2 b	ь - ь -	3.2 20.3 13.3 20.3 36.1 36.1 36.1 36.7 36.7 36.1	9, 4. ž 4. ž 1.14 \hat{X}_1^{\pm} 450 GeV ž 2 ž 2 \hat{X}_1 100-470 GeV 480-610 GeV 0.	1.875 TeV	$\begin{split} &\mathcal{X}_{j+1}{=}0.11, \lambda_{110/133/220}{=}0.07 \\ &m(\tilde{q}){=}m(\tilde{z}), c\tau_{25P}{<}1 \text{ mm} \\ &m(\tilde{r}_1^0){>}{+}000 \text{GeV}, \lambda_{124} \neq 0 (k=1,2) \\ &m(\tilde{r}_1^0){>}0.2{\times}m(\tilde{r}_1^1), \lambda_{233} \neq 0 \\ &m(\tilde{r}_1^0){=}1075 \text{ GeV} \\ &\textbf{m}(\tilde{r}_1^0){=}1 \text{ TeV}, \lambda_{112} \neq 0 \\ &m(\tilde{r}_1){=}1 \text{ TeV}, \lambda_{323} \neq 0 \\ &\text{BR}(\tilde{r}_1{\rightarrow}br/\mu){>}20\% \end{split}$	1607.08079 1404.2500 ATLAS-CONF-2016-075 1405.5086 SUSY-2016-22 1704.08493 1704.08493 1710.07171 1710.05544
Other	Scalar charm, $\tilde{c} \rightarrow c \tilde{t}_1^0$	0	20	Yes	20.3	č 510 GeV		m(t̃ ⁰ ₁)<200 GeV	1501.01325
phén	a selection of the available mas omena is shown. Many of the l ified models, c.f. refs. for the a	imits are ba	sed on	s or	1	0 ⁻¹	TeV	Mass scale [TeV]	

So far, no conclusive signal of physics beyond the SM

	TLAS SUSY Seal ecember 2017 Model	rches* - 95% e,μ,τ,γ Jets			TeV $\sqrt{s} = 7, 8 \text{ TeV}$ $\sqrt{s} = 13 \text{ TeV}$	ATLAS Preliminary $\sqrt{s} = 7, 8, 13 \text{ TeV}$ Reference
Inclusive Searches	$\begin{array}{l} \bar{q}\bar{q}, \ \bar{q} \rightarrow q \hat{k}_{1}^{0} \\ \bar{q}\bar{q}, \ \bar{q} \rightarrow q \hat{k}_{1}^{0} (\text{compressed}) \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q \bar{q} \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q \bar{q} \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q \bar{q} \hat{\ell} \hat{\ell}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q \bar{q} (\ell \ell) \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q \bar{q} (\ell \ell) \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}\bar{s}, \ \bar{g} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{g}\bar{s}\bar{s}, \ \bar{s} \rightarrow q q (\ell \ell) \nu \gamma \hat{k}_{1}^{0} \\ \bar{s}\bar{s}\bar{s}, \ \bar{s} \rightarrow q q (\ell \ell) \bar{s}\bar{s}\bar{s} \end{pmatrix} $	0 2-6 jets mono-jet 1-3 jets 0 2-6 jets 0 2-6 jets 0 2-6 jets ce.μμ 2 jets 3 e.μ 4 jets 0 7-11 jets 1-2 r + 0-1 ℓ 0-2 jets 2 γ - γ 2 jets 0 mono-jet	Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 3.2 Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1	4 7 710 GeV 8 <td>1.57 TeV m(k²₁)<200 GeV, m(1* gen. δ)+m(2nd gen. δ) m(g)-m(k²₁)<5 GeV 2.02 TeV m(k²₁)<200 GeV</td> 2.01 TeV m(k ² ₁)<200 GeV	1.57 TeV m(k ² ₁)<200 GeV, m(1* gen. δ)+m(2 nd gen. δ) m(g)-m(k ² ₁)<5 GeV 2.02 TeV m(k ² ₁)<200 GeV	1712.02332 1711.03301 1712.02332 1712.02332 1611.05791 1706.03731 1708.02794 1607.05979 ATLAS-CONF-2017-080 ATLAS-CONF-2017-080 1502.01518
3 rd gen.	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\tilde{h}\tilde{K}_{1}^{0}$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\bar{t}\tilde{K}_{1}^{0}$	0 3 <i>b</i> 0-1 <i>e</i> ,µ 3 <i>b</i>	Yes 36.1 Yes 36.1	2 2	1.92 TeV m(t ² 1)<600 GeV 1.97 TeV m(t ² 1)<200 GeV	1711.01901 1711.01901
3 rd gen. squarks direct production	$\begin{split} \tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{k}_1^0 \\ \tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow t \tilde{k}_1^n \\ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow b \tilde{k}_1^n \\ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow b \tilde{k}_1^0 \text{ or } t \tilde{t}_1^0 \\ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{k}_1^0 \\ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{t}_1^0 \\ \tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z \\ \tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + h \end{split}$	$\begin{array}{cccc} 0 & 2b \\ 2e,\mu({\rm SS}) & 1b \\ 0.2e,\mu & 1.2b \\ 0.2e,\mu0.2{\rm jets}/1.2b \\ 0 & {\rm mono-jet} \\ 2e,\mu(Z) & 1b \\ 3e,\mu(Z) & 1b \\ 1.2e,\mu & 4b \end{array}$	Yes 36.1 Yes 36.1 Yes 4.7/13.3 Yes 20.3/36.1 Yes 36.1 Yes 20.3 Yes 36.1 Yes 36.1 Yes 36.1	b1 950 GeV b1 275-700 GeV 117-170 GeV 200-720 GeV 117-170 GeV 0.195-1.0 TeV 11 90-430 GeV 11 90-430 GeV 150-600 GeV 150-600 GeV 12 290-790 GeV 12 320-880 GeV	$\begin{split} m(\tilde{r}_{1}^{0}) &< 420 \ GeV \\ m(\tilde{r}_{1}^{0}) &< 200 \ GeV, m(\tilde{r}_{1}^{+}) = m(\tilde{r}_{1}^{0}) + 100 \ GeV \\ m(\tilde{r}_{1}^{+}) &= 2m(\tilde{r}_{1}^{0}), m(\tilde{r}_{1}^{0}) - 55 \ GeV \\ m(\tilde{r}_{1}^{0}) &= 1 \ GeV \\ m(\tilde{r}_{1}^{0}) &= 1 \ GeV \\ m(\tilde{r}_{1}^{0}) &> 150 \ GeV \\ m(\tilde{r}_{1}^{0}) &= 0 \ GeV \\ m(\tilde{r}_{1}^{0}) &= 0 \ GeV \\ m(\tilde{r}_{1}^{0}) &= 0 \ GeV \end{split}$	1708.09266 1706.03731 1209.2102, ATLAS-CONF-2016-077 1506.08616, 1709.04183, 1711.11520 1711.03301 1403.5222 1706.03986 1706.03986
EW direct	$\begin{array}{l} \tilde{\ell}_{1,R}\tilde{\ell}_{1,R}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_1^0 \\ \tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow \tilde{\ell} \nu(\ell \bar{\nu}) \\ \tilde{\chi}_1^+ \tilde{\chi}_1^+ / \tilde{\ell}_2^0, \tilde{\ell}_1^+ \rightarrow \bar{\tau} \nu(\tau \bar{\nu}), \tilde{\chi}_2^0 \rightarrow \bar{\tau} \tau(\nu \bar{\nu}) \\ \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow \tilde{\ell}_1 \nu \tilde{\ell}_1 \ell(\bar{\nu}\nu), \ell \bar{\nu} \tilde{\ell}_1 \ell(\bar{\nu}\nu) \\ \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow W \tilde{\ell}_1^0 \tilde{\chi}_1^0 \\ \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow W \tilde{\chi}_1^0 h \tilde{\chi}_1^0, h \rightarrow b \tilde{b} / W W / \tau \tau / \gamma \gamma \\ \tilde{\chi}_2^0 \tilde{\chi}_3^0, \tilde{\chi}_2^0, \rightarrow \tilde{\ell}_R \ell \\ \text{GGM (w no NLSP) weak prod., } \tilde{\chi}_1^0 \rightarrow \\ \text{GGM (b to NLSP) weak prod., } \tilde{\chi}_1^0 \rightarrow \end{array}$		Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 36.1 Yes 20.3 Yes 20.3 Yes 20.3 Yes 20.3	Image: Problem state sta	$\begin{split} m(\tilde{k}_{1}^{0}) = 0 \\ m(\tilde{k}_{1}^{1}) = 0, m(\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{0})) \\ m(\tilde{k}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{0})) \\ m(\tilde{k}_{1}^{-}) = m(\tilde{k}_{2}^{0}), m(\tilde{k}_{3}^{0}) = 0, m(\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{0})) \\ m(\tilde{k}_{1}^{-}) = m(\tilde{k}_{3}^{0}), m(\tilde{k}_{3}^{0}) = 0, \tilde{\ell} \text{ decoupled} \\ m(\tilde{k}_{2}^{0}) = m(\tilde{k}_{3}^{0}), m(\tilde{k}_{1}^{0}) = 0, m\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{k}_{2}^{0}) + m(\tilde{k}_{3}^{0})) \\ e\tau < 1 mm \\ e\tau < 1 mm \end{split}$	ATLAS-CONF-2017-039 ATLAS-CONF-2017-039 1708.07875 ATLAS-CONF-2017-039 ATLAS-CONF-2017-039 1501.07110 1405.5086 1507.05493 ATLAS-CONF-2017-080
Long-lived particles	Direct \hat{x} \hat{x}_1^- prod., long-lived \hat{x}_1^+ Direct \hat{x} \hat{x}_1^- prod., long-lived \hat{x}_1^+ Stable, it topped \hat{g} R-hadron Stable \hat{g} R-hadron Metastable \hat{g} R-hadron Metastable \hat{g} R-hadron, $\hat{g} \rightarrow qq \hat{x}_1^0$ GMSB, stable $\hat{\tau}, \hat{x}_1^0 \rightarrow \hat{\tau}(\hat{\epsilon}, \hat{\mu}) + \tau(\epsilon, \mu)$ GMSB $\hat{x}_1^0 \rightarrow \gamma \hat{\sigma}$, long-lived \hat{x}_1^0 $\hat{g}_{\hat{x}}, \hat{x}_1^0 \rightarrow eev/e\muv/\mu\muv$	Disapp. trk 1 jet dE/dx trk - 0 1-5 jets trk - dE/dx trk - dSpl. vtx - 1-2 μ - 2 γ - ditpl. ee/eμ/μμ -	Yes 36.1 Yes 18.4 Yes 27.9 - 3.2 - 3.2 Yes 32.8 - 19.1 Yes 20.3 - 20.3	\$\bar{x}_1^+\$ 460 GeV \$\bar{x}_1^+\$ 495 GeV \$\bar{x}\$ 850 GeV \$\bar{x}\$ 90 GeV	$\begin{array}{c} m(\widehat{\epsilon}_{1}^{0}) - m(\widehat{\epsilon}_{1}^{0}) - 160 \ \text{MeVer}(\widehat{\epsilon}_{1}^{0}) = 0.2 \ \text{ns} \\ m(\widehat{\epsilon}_{1}^{0}) - m(\widehat{\epsilon}_{1}^{0}) - 160 \ \text{MeV}, \ m(\widehat{\epsilon}_{1}^{0}) < 15 \ \text{ns} \\ m(\widehat{\epsilon}_{1}^{0}) = 100 \ \text{GeV}, \ 10 \ \mu\text{s} < \pi(\underline{\epsilon}) < 1000 \ \text{s} \\ \hline \textbf{1.58 TeV} \\ \textbf{1.57 TeV} \qquad m(\widehat{\epsilon}_{1}^{0}) = 100 \ \text{GeV}, \ \tau > 10 \ \text{ns} \\ \hline \textbf{2.37 TeV} \qquad r(\underline{\epsilon}) = 0.017 \ \text{ns}, \ m(\widehat{\epsilon}_{1}^{0}) = 100 \ \text{GeV} \\ 10 < \tan\beta < 50 \\ 1 < r(\widehat{\epsilon}_{1}^{0}) < 3 \ \text{ns}, \ \text{SPS8 model} \\ 7 < cr(\widehat{\epsilon}_{1}^{0}) < 740 \ \text{mm}, \ m(\underline{\epsilon}) = 1.3 \ \text{TeV} \\ \end{array}$	1712.02118 1506.05332 1310.8584 1606.05129 1604.04520 1710.04901 1411.6795 1409.5542 1504.05162
RPV	LFV $p_j \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e\mu/e\tau/\mu\tau$ Blines RPV CMSSM $\tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow W \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow eev, e\mu v, \mu\mu v$ $\tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow W \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tau\tau v_e, e\tau v_{\tau}$ $\tilde{g}_{\tilde{S}}, \tilde{g}^- qq \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qqq$ $\tilde{g}_{\tilde{S}}, \tilde{g}^- t_1 t, \tilde{t}_1 \rightarrow bs$ $\tilde{t}_1 \tilde{t}_1, \tilde{t} \rightarrow bs$ $\tilde{t}_1 \tilde{t}_1, \tilde{t} \rightarrow b\ell$	$e\mu, e\tau, \mu\tau$. $2e, \mu$ (SS) 0-3b $4e, \mu$. $3e, \mu + \tau$. 0 4-5 large-R jet $1e, \mu$ 8-10 jets/0-4 $1e, \mu$ 8-10 jets/0-4 0 2 jets + 2b $2e, \mu$ 2b	· 3.2 Yes 20.3 Yes 13.3 Yes 20.3 ts · 36.1 b · 36.1 b · 36.1	Pr 9.8 \$\overline{x}_1^4\$ 1.14 \$\overline{x}_1^4\$ 450 GeV \$\overline{x}_1^4\$ 450 GeV \$\overline{x}_1^4\$ 450 GeV \$\overline{x}_1^4\$ 100-470 GeV \$\overline{x}_1\$ 100-470 GeV	1.9 TeV λ ₁₁₁ =0.11, λ _{132/133/233} =0.07 1.45 TeV m(i)=m(i), ct _{15P} <1 mm	1607.08079 1404.2500 ATLAS-CONF-2016-075 1405.5086 SUSY/2016-22 1704.08493 1704.08493 1710.07171 1710.05544
Other	Scalar charm, $\tilde{c} \rightarrow c \tilde{\chi}_1^0$	0 2c	Yes 20.3	2 510 GeV	m(t ⁰ ₁)<200 GeV	1501.01325
phén	a selection of the available mas omera is shown. Many of the l lified podels, c.f. refs. for the a	imits are based on	^{s or} 1	0 ⁻¹	Mass scale [TeV]	$ \lambda$
	,R, $\tilde{\ell} \rightarrow \ell \tilde{\chi}_1^0$	ĩ			90-500 GeV	$m(\tilde{\chi}_1^0) =$

relaxing the $m(\chi^0)=0$ constraint ...

... LHC has barely improved LEP2 limits ...



discoveries well below the TeV scale

<u>Key question for the future developments of HEP:</u> Why don't we see the new physics we expected to be present around the TeV scale ?

- Is the mass scale beyond the LHC reach ?
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Readiness to address both scenarios is the best hedge for the field:

- precision
- sensitivity (to elusive signatures)
- extended energy/mass reach

<u>Remark</u>

the discussion of the **future** in HEP must start from the understanding that there is no experiment/facility, proposed or conceivable, in the lab or in space, accelerator or nonaccelerator driven, which can *guarantee discoveries* beyond the SM, and *answers* to the big questions of the field

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(2) the **exploration potential**:

- target broad and well justified BSM scenarios but guarantee sensitivity to more exotic options
- exploit both direct (large Q^2) and indirect (precision) probes
- (3) the potential to provide conclusive yes/no answers to relevant, broad questions.

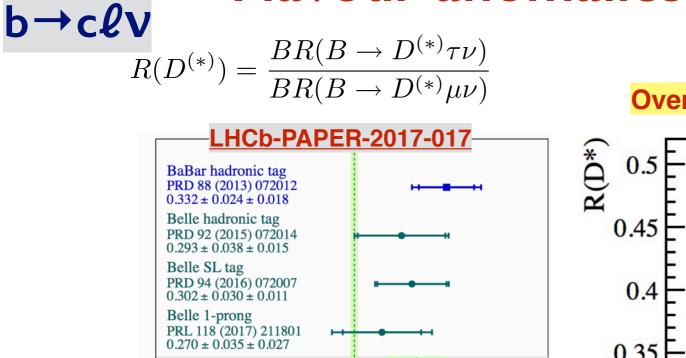
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- More in general, no experiment can guarantee an answer to the question "what is DM?"
- Scenarios in which DM is a WIMP are however compelling and theoretically justified
- We would like to understand whether a future collider can answer more specific questions, such as:
 - do WIMPS contribute to DM?
 - can WIMPS, detectable in direct and indirect (DM annihilation) experiments, be discovered at future colliders? Is there sensitivity to the explicit detection of DM-SM mediators?
 - what are the opportunities w.r.t. new DM scenarios (e.g. interacting DM, asymmetric DM,)?

Flavour anomalies at LHC & Bfact's



LHCb muonic

LHCb 3-prong

LHCb average

PRL 115 (2015) 111803 0.336 ± 0.027 ± 0.030

LHCb-PAPER-2017-017 0.285 ± 0.019 ± 0.028

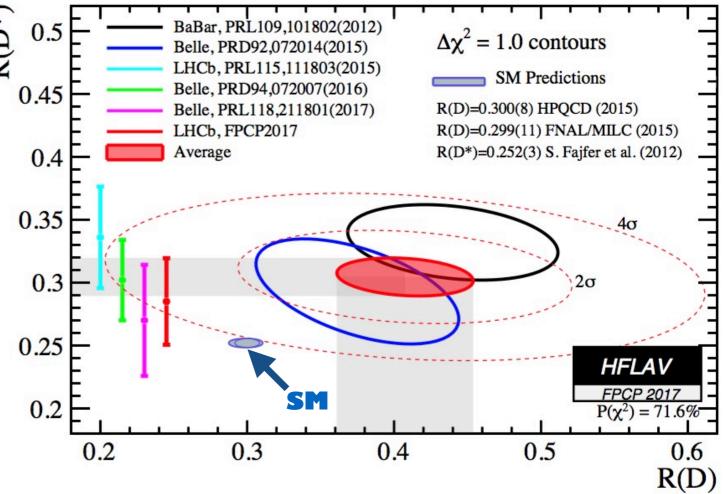
 $0.306 \pm 0.016 \pm 0.022$

Fajfer et al. (SM) PRD 85 (2012) 094025

 0.252 ± 0.003

0.1

Overall combination of R(D) and R(D*) is 4.1σ from SM



b→sℓℓ

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)}$$

0.2

0.3

0.4

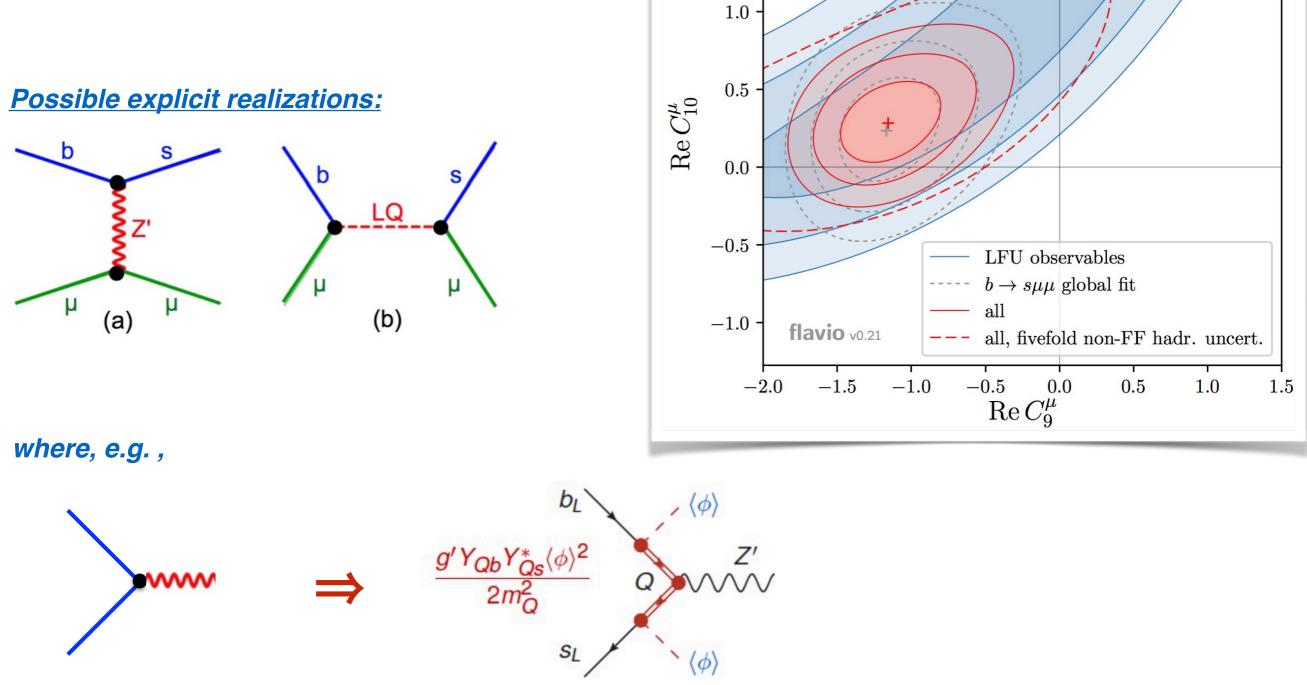
 $R(D^*)$

m _{II} [mass range]	\mathbf{SM}	Exp.
$R_{K}^{[1-6]}$	1.00 ± 0.01	$0.745^{+0.090}_{-0.074}\pm0.036$
$R_{K^*}^{[1.1-6]}$	$1.00 \pm \textbf{0.01}$	$0.685^{+0.113}_{-0.069}\pm0.047$
$R_{K^*}^{[0.045,1.1]}$	0.91 ± 0.03	$0.660^{+0.110}_{-0.070}\pm0.024$

LHCb, PRL 113 (2014) 151601, arXiv:1705.05802

Example of EFT interpretation of R_K

$$O_9^{\ell} = (\bar{s}\gamma_{\mu}P_Lb)(\bar{\ell}\gamma^{\mu}\ell),$$
$$O_{10}^{\ell} = (\bar{s}\gamma_{\mu}P_Lb)(\bar{\ell}\gamma^{\mu}\gamma_5\ell)$$



 $1.5 \cdot$

Altmannshoffer et al, arxiv:1704.05435

Upper limits on Z' and Leptoquark masses are model-dependent, and constrained also by other low-energy flavour phenomenology, but typically lie in the range of $1 \rightarrow O(10)$ TeV \Rightarrow if anomalies confirmed, we may want a no-lose theorem to identify the next facility! 37

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much to be inspired by in the forthcoming lectures of this School!