BEYOND THE STANDARD MODEL

LEC1A: WHY NEW PHYSICS?

Flip Tanedo
UC Riverside Particle Theory

29 JULY 2019

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Outline

1a. **The Hierarchy problem**, qualitative

1b. **Supersymmetry**, overview

2a. **Supersymmetry**, tools

2b. **Extra dimensions/compositeness**, qualitative

3a. **Extra dimensions**, tools

3b. **Compositeness**, tools

3c. **Naturalness and WIMP dark matter**

Suggestion: take notes of some sort

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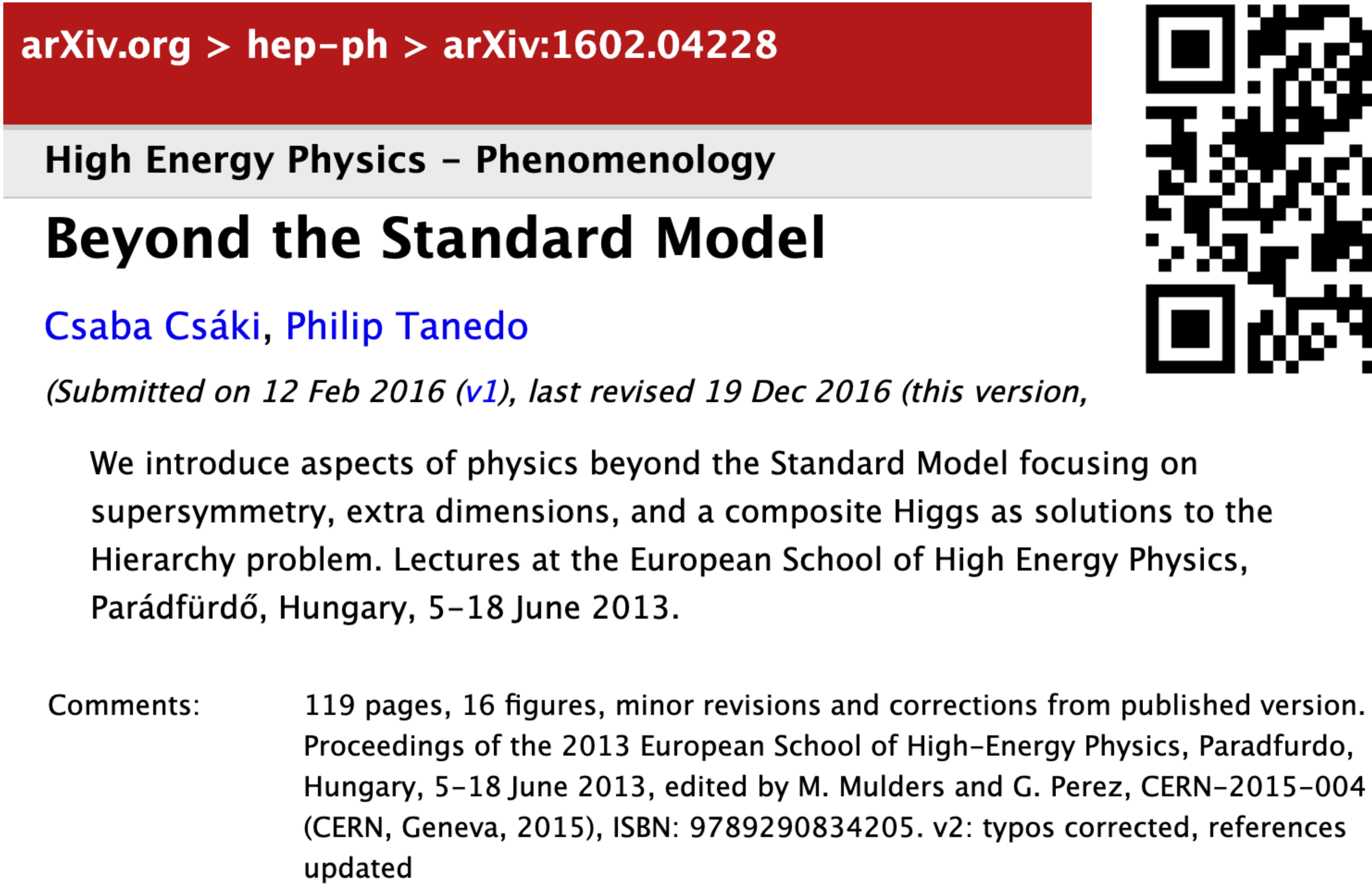
References



arXiv.org > hep-ph > arXiv:1602.04228

High Energy Physics – Phenomenology

Beyond the Standard Model

Csaba Csáki, Philip Tanedo

(Submitted on 12 Feb 2016 (v1), last revised 19 Dec 2016 (this version,

We introduce aspects of physics beyond the Standard Model focusing on supersymmetry, extra dimensions, and a composite Higgs as solutions to the Hierarchy problem. Lectures at the European School of High Energy Physics, Parádfürdő, Hungary, 5–18 June 2013.

Comments: 119 pages, 16 figures, minor revisions and corrections from published version. Proceedings of the 2013 European School of High-Energy Physics, Paradfurdo, Hungary, 5–18 June 2013, edited by M. Mulders and G. Perez, CERN-2015-004 (CERN, Geneva, 2015), ISBN: 9789290834205. v2: typos corrected, references updated

…. and references therein

Why go *beyond* the Standard Model?

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My top 5 (personal, not exhaustive)

1. **The Hierarchy Problem**: why is the Higgs light?
2. **Dark matter**: what is it? *(Graciela)*
3. **Baryogenesis**: why so much matter?
4. **Strong CP problem**: why no neutron EDM?
5. **Grand unification**: why is Y quantized?
Bonus: relation to neutrino mass?*(Joachim)*

Particle Physics, circa 1990s

(chiral)

fundamental forces

matter particles

Field	Spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
Q	$1/2$	$\square$	$\square$	$1/6$
$\bar{u}$	$1/2$	$\overline{\square}$	$\mathbb{1}$	$-2/3$
$\bar{d}$	$1/2$	$\overline{\square}$	$\mathbb{1}$	$1/3$
L	$1/2$	$\mathbb{1}$	$\square$	$-1/2$
$\bar{e}$	$1/2$	$\mathbb{1}$	$\mathbb{1}$	-1
H ?	0	$\mathbb{1}$	$\square$	$1/2$

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Particle Physics, circa 1990s

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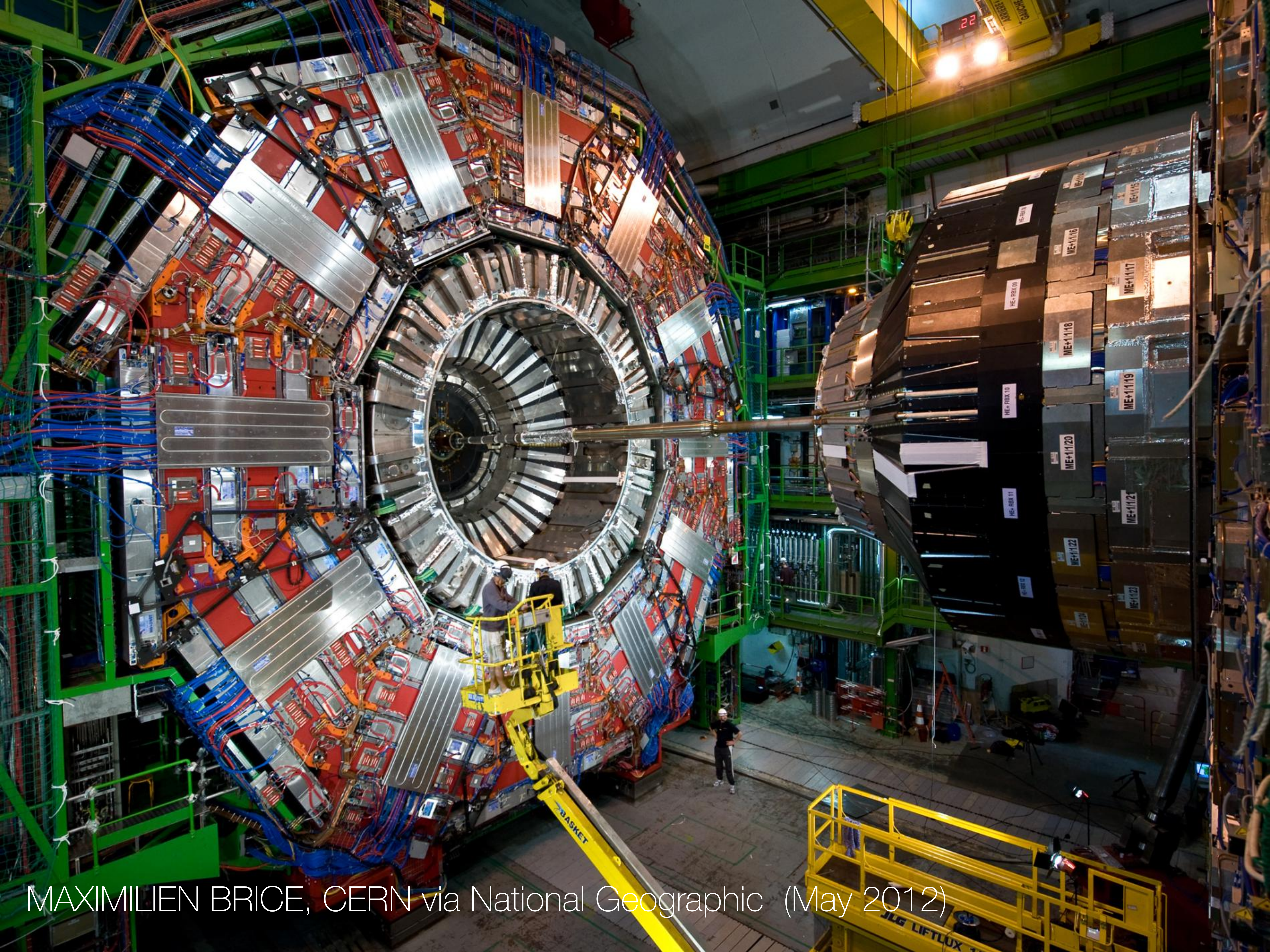
H ?	0	$\mathbb{1}$	$\square$	$1/2$

or *something* to explain
unitarity of WW scattering


ME CALL IT A "PARTICLE COLLIDER"



MAXIMILIEN BRICE, CERN via National Geographic (May 2012)

Physicists Find Elusive Particle Seen as Key to Universe

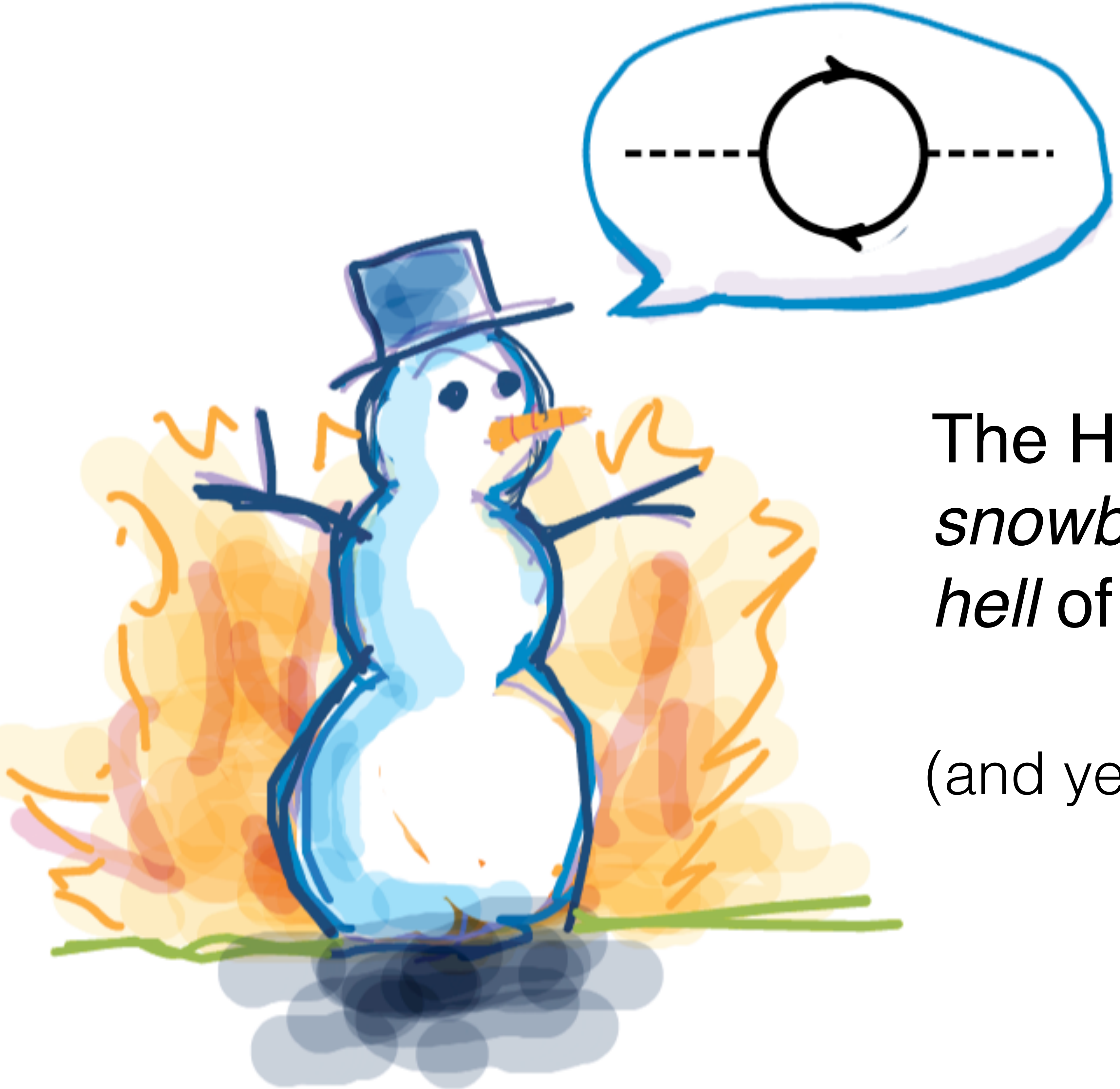
By DENNIS OVERBYE   JULY 4, 2012

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

Pool photo by Denis Balibouse

D. Overbye, New York Times, 4 July 2012

The Hierarchy Problem

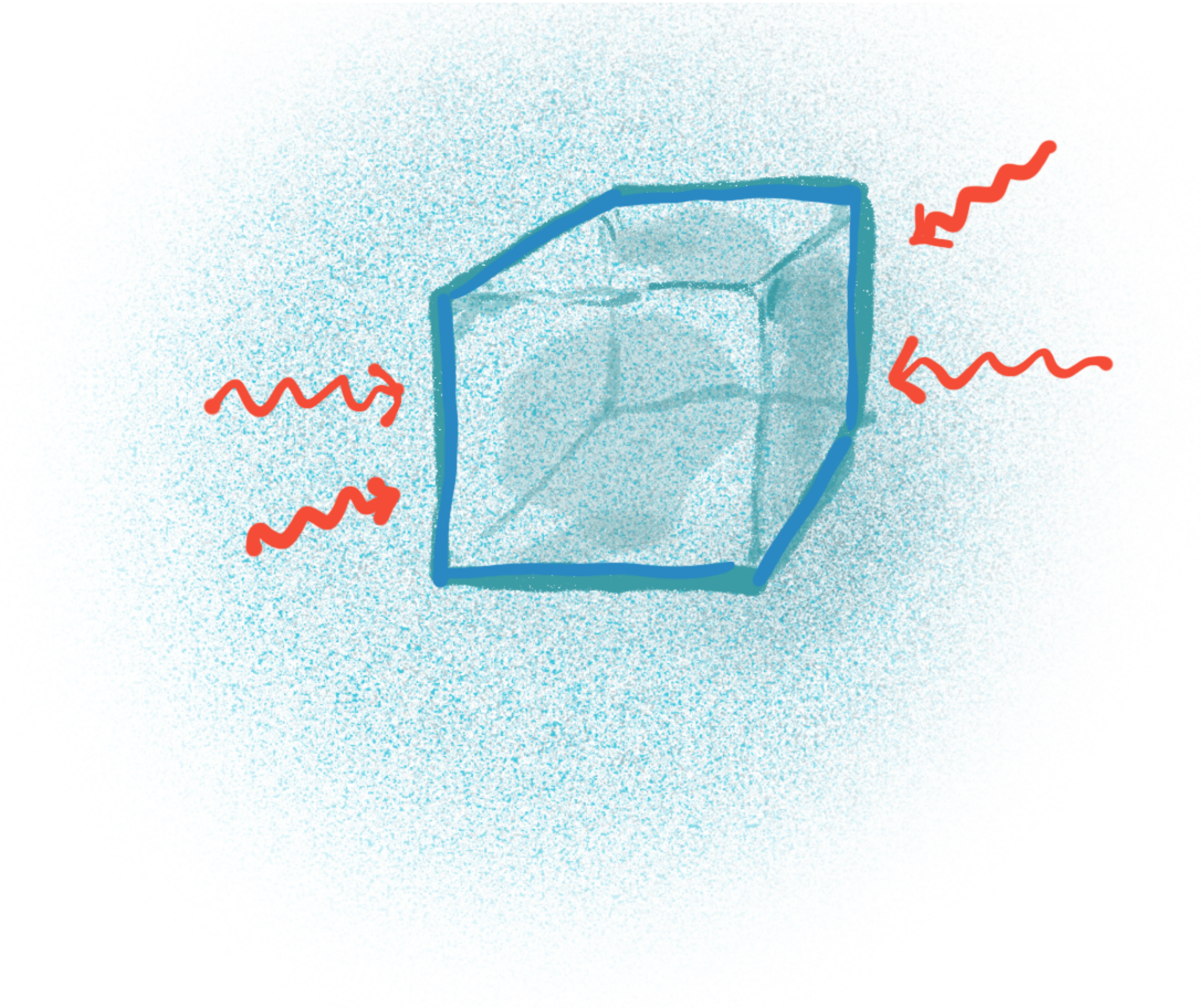


The Higgs has a *snowball's chance in hell* of being 125 GeV.

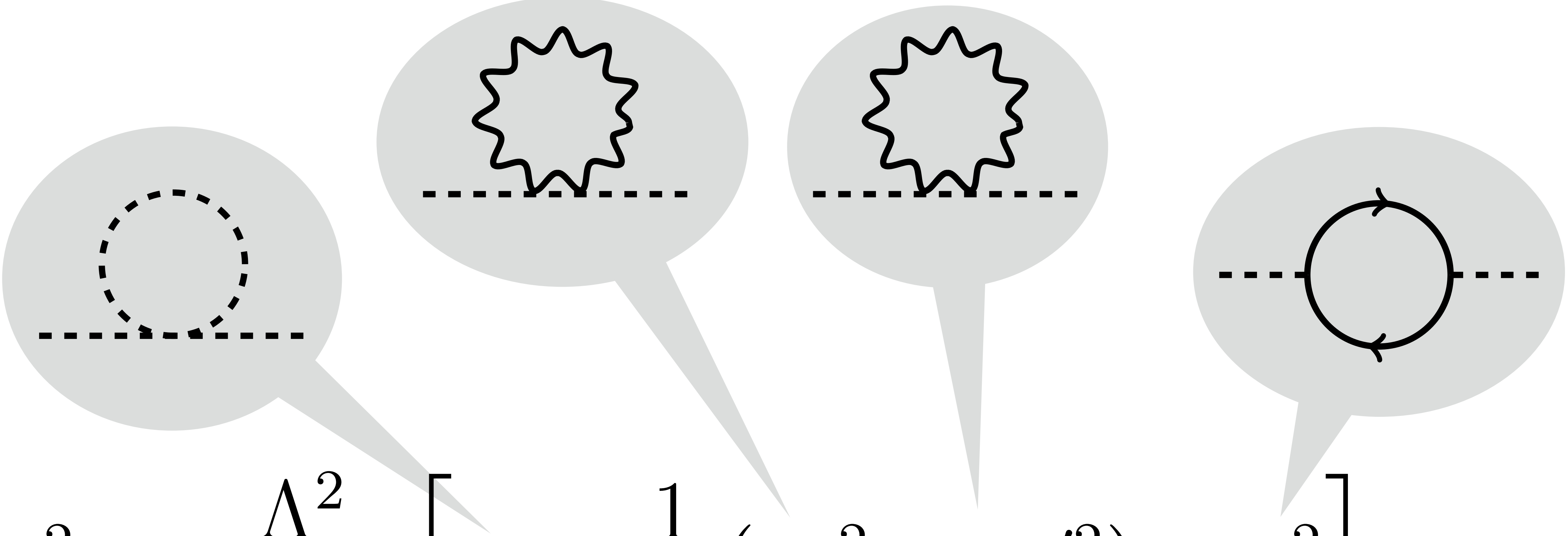
(and yet here we are)

FT, *Quantum Diaries*, "The Hierarchy Problem" (2012)

Analogy: thermal randomness



quantum contributions to Higgs mass



$$\delta m_H^2 = \frac{\Lambda^2}{32\pi^2}\left[6\lambda + \frac{1}{4}\left(9g^2 + 3g'^2\right) - y_t^2\right]$$

SCALARS

GAUGE

FERMIONS

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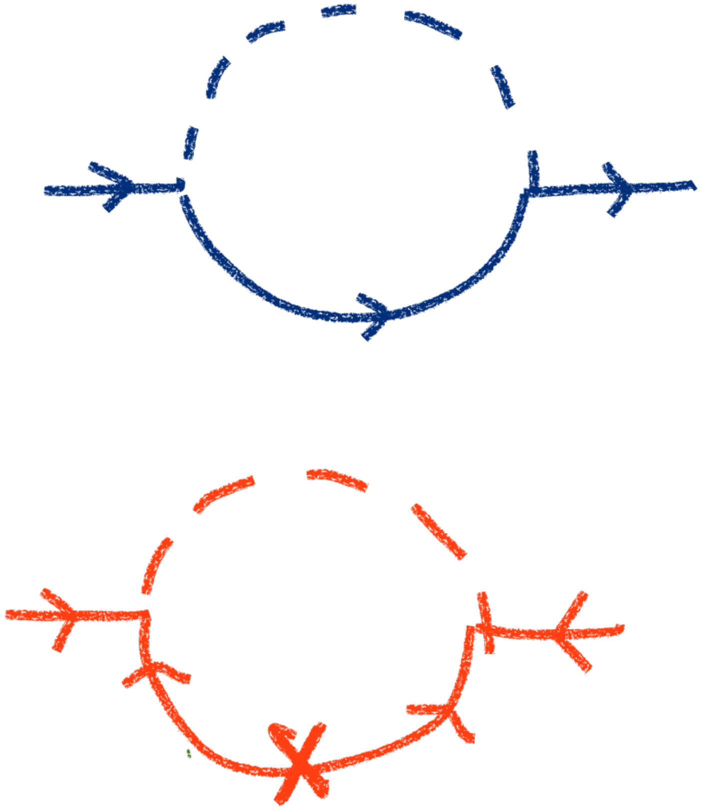
Other “hierarchy problems” ?

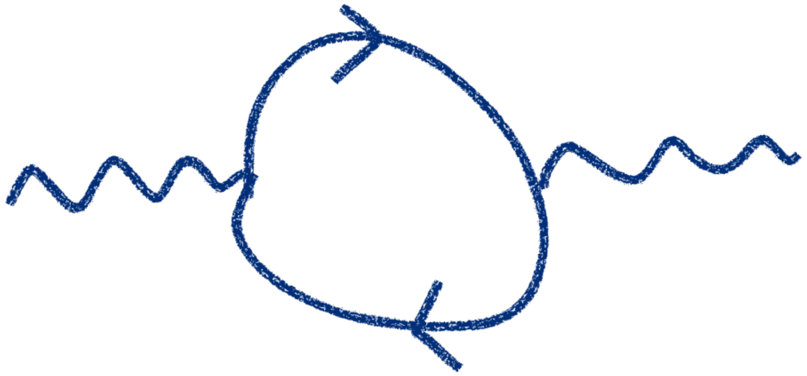
Standard Model Fermions

$$\Delta m_e \sim m_e \ln\left(\frac{\Lambda}{m_e}\right)$$



Massive Gauge Bosons

$$\Delta M_W^2 \sim M_W^2 \ln\left(\frac{\Lambda}{M_W}\right)$$



…what about dim-reg?

$$\int \frac{d^d\ell}{(2\pi)^d}\,\frac{1}{(\ell^2-\Delta)^n} = \frac{(-1)^n\, i}{(4\pi)^{d/2}}\,\frac{\Gamma(n-\frac{d}{2})}{\Gamma(n)}\left(\frac{1}{\Delta}\right)^{n-\frac{d}{2}}$$

$$\frac{\Gamma(2-\frac{d}{2})}{(4\pi)^{d/2}}\left(\frac{1}{\Delta}\right)^{2-\frac{d}{2}} = \frac{1}{(4\pi)^2}\left(\boxed{\frac{2}{\epsilon}}-\log\Delta-\gamma+\log(4\pi)+\mathcal{O}(\epsilon)\right)$$

$$\epsilon = 4-d.$$

voila, no quadratic divergences!

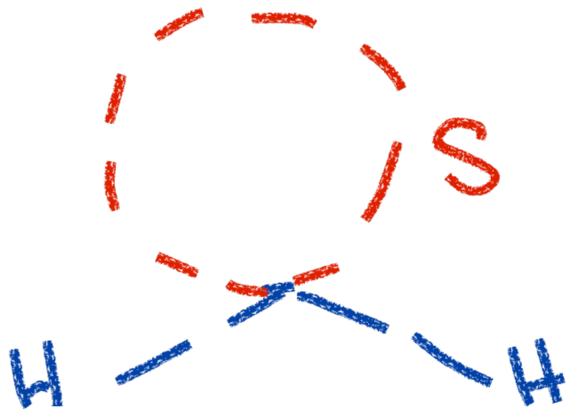
… but it was never about quadratic divergences

from Peskin & Schroeder, *Introduction to Quantum Field Theory*

…what about dim-reg?

$$\Delta\mathcal{L} = \lambda_S |H|^2 S^2$$

$$\delta m_H^2 = \frac{\lambda_S}{16\pi^2}\left[\cancel{\Lambda_{\text{UV}}^2} - 2m_S^2 \ln\left(\frac{\overset{\mu\text{, RG SCALE}}{\Lambda_{\text{UV}}}}{m_S}\right) + (\text{finite})\right]$$



Hierarchy problem is about **separation of scales**.

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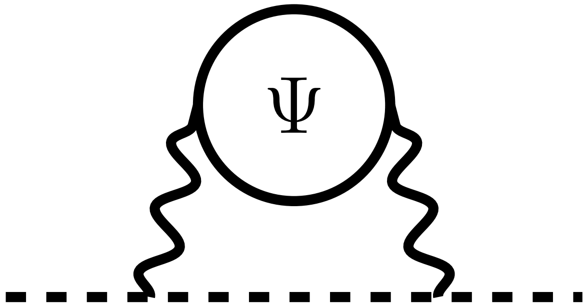
…what about dim-reg?



$$\delta m_H^2 \sim \left(\frac{g^2}{16\pi^2}\right)^2 \left[a\Lambda_{\mathrm{UV}}^2 + 48 m_F^2 \ln\frac{\Lambda_{\mathrm{UV}}}{m_F} + (\text{finite})\right]$$

… even if we sequester the new physics.

Frameworks for Hierarchy Problem

Supersymmetry: enforce a cancellation

Extra dimensions: effective UV scale is lower… maybe because gravity is diluted in 5D?

Compositeness: effective UV scale is lower… because you resolve Higgs substructure

Other? maybe that's just the way things are.

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BEYOND THE STANDARD MODEL

LEC1B: SUSY, QUALITATIVELY

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UC Riverside Particle Theory

29 JULY 2019

PHYSICS & ASTRONOMY

PI · SNOLAB · TRIUMF
TRISEP

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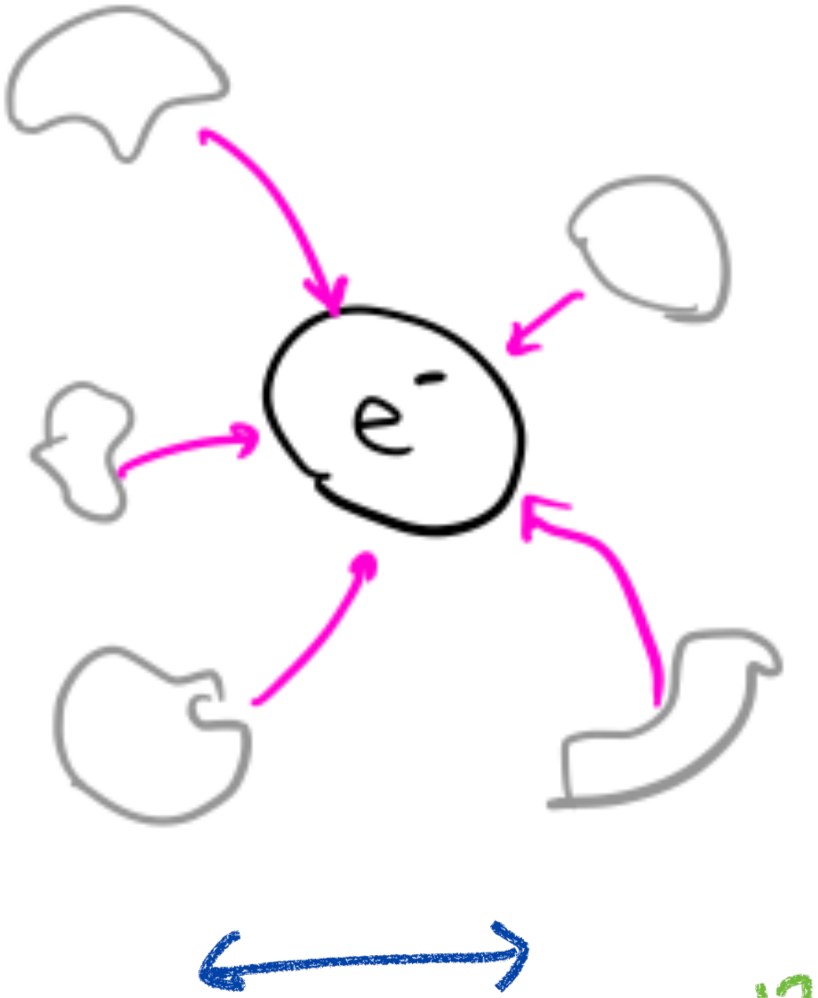
The semi-classical electron

Why is the mass of electron small?



Imagine bringing together pieces of the electron from far away.

$r_e \lesssim 10^{-17}$ cm

The semi-classical electron

$E = m_e c^2$ @ REST $\qquad m = \frac{1}{2}\ \text{MeV}$

$= m_0 c^2 + \underline{\Delta E_{\text{coulomb}}}$

"BARE MASS" not observable

"SELF ENERGY" from self-repulsion

$$\Delta E_{\text{COULOMB}} = \frac{\alpha}{\boxed{r_e}}$$

"radius" of e^-

expt: $r_e \lesssim 10^{-17}$

$\Rightarrow \Delta E \gtrsim 10\ \text{GeV}$

$$\text{GeV cm} = 5 \times 10^{13}$$

The semi-classical electron

$$m_e = m_0 + \Delta E_{\text{coulomb}}$$

0.5 MeV

10,000 MeV

$-9{,}999.5$ MeV

$\gtrsim$ 0.1% TUNING!

The semi-classical electron

If the electron is semiclassically natural, then the correction should be no larger than ~ m_e

$$\Delta E = \frac{\alpha}{\underbrace{r_{NP}}_{\text{new physics scale}}} = m_e \Rightarrow r_{NP} = \frac{\overset{\sim 10^{-2}}{\alpha}}{\underset{5\times 10^{-4}\,\text{GeV}}{m_e}}$$

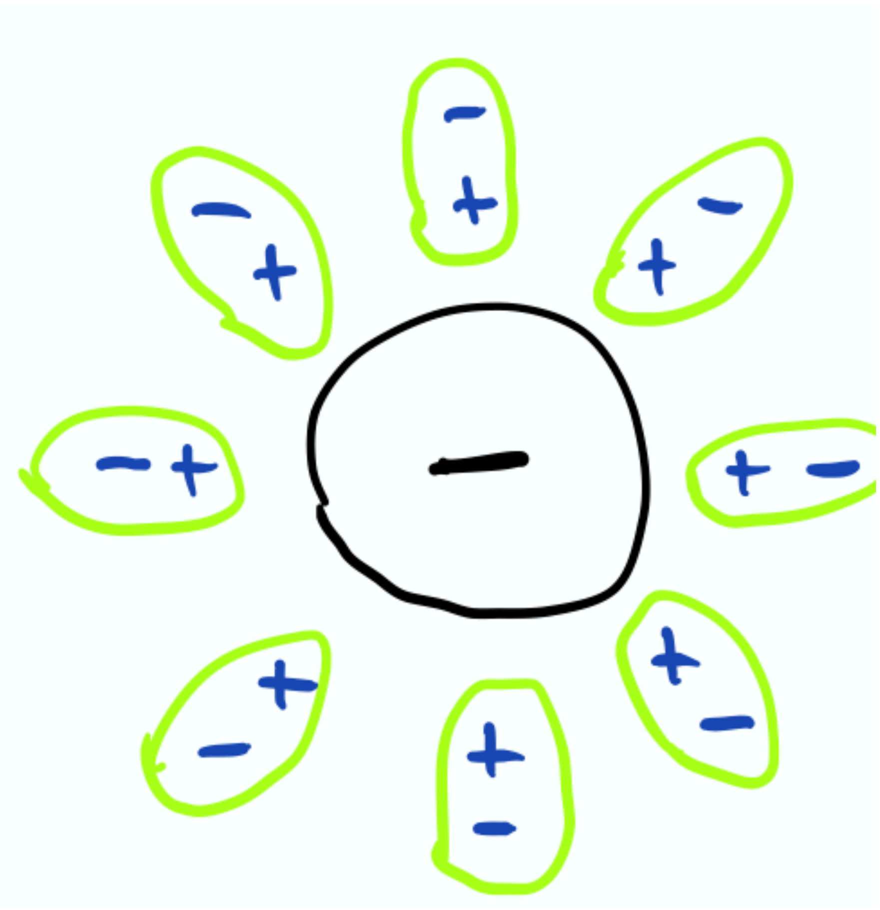
$$= 10^{-2}/(2\times 10^{10})\ \text{cm}$$

$$= \boxed{5\times 10^{-13}\ \text{cm}}$$

$$\text{GeV cm} = 5\times 10^{13}$$

The semi-classical electron

We know something interesting happens on length scales on the order of the electron mass.



vacuum polarization from virtual particle-antiparticle pairs

renormalization of charge, screening by virtual pairs

HAPPENS @ $r \sim (2m_e)^2$
(eg HEISENBERG $\Delta t \Delta E \sim 1$)

$1/\alpha \sim 100$ times sooner than naturalness requires!

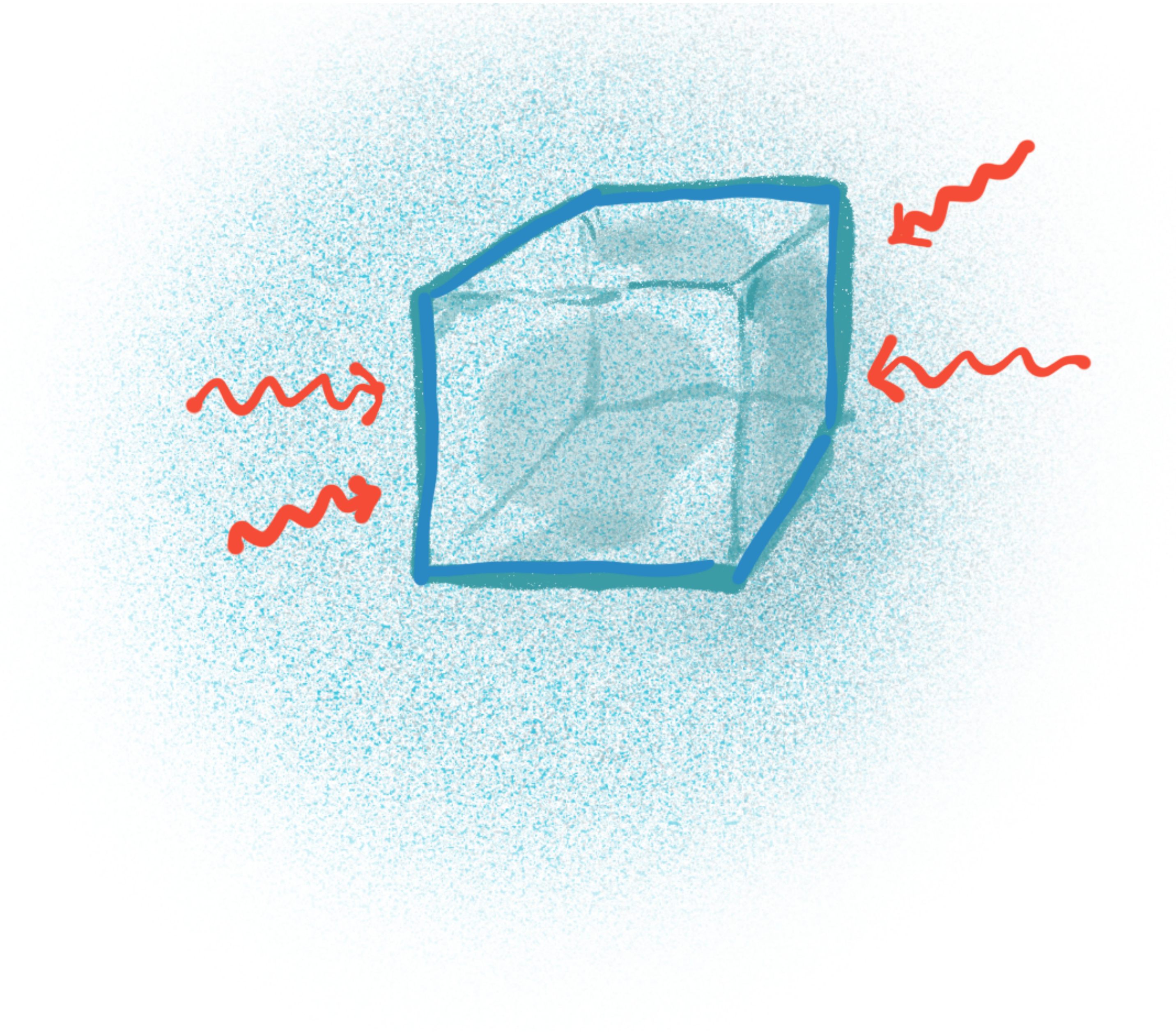
$$\text{GeV cm} = 5 \times 10^{13}$$

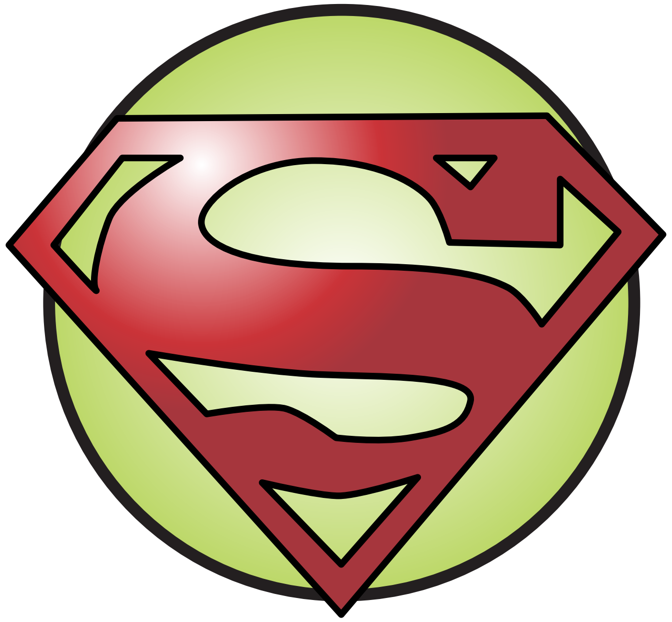
Supersymmetry
a qualitative introduction

S. Martin, *A SUSY Primer* hep-ph/9709356

Quevedo et al. *Cambridge Lectures on SUSY* 1011.1491

Supersymmetry

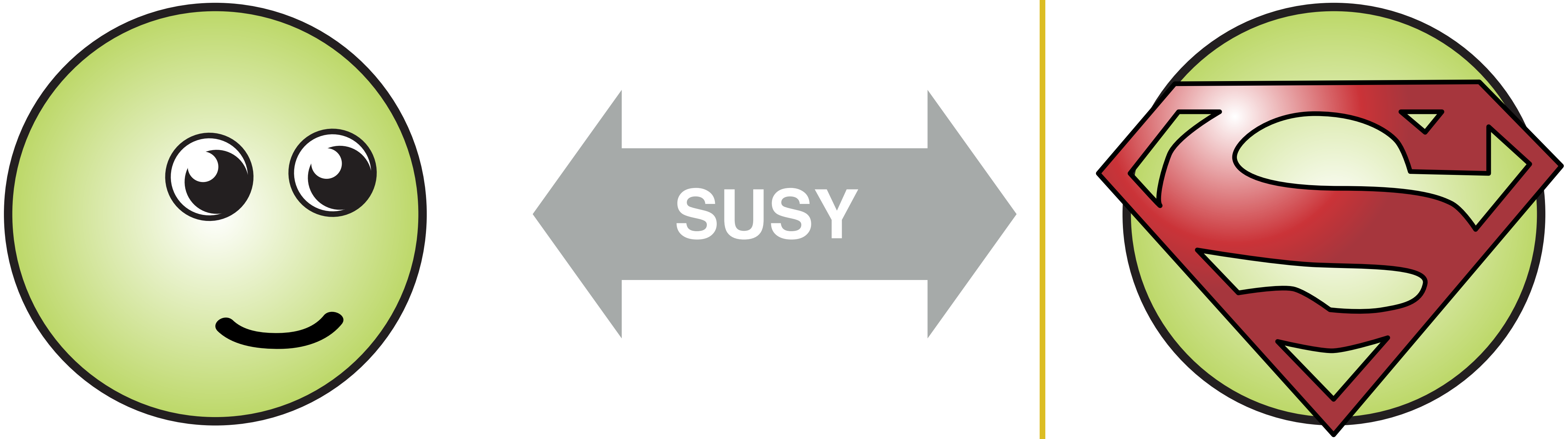




Supersymmetry

VISIBLE STUFF

NEW PARTICLES



matter particle ↔ **force particle**

force particle ↔ **matter particle**

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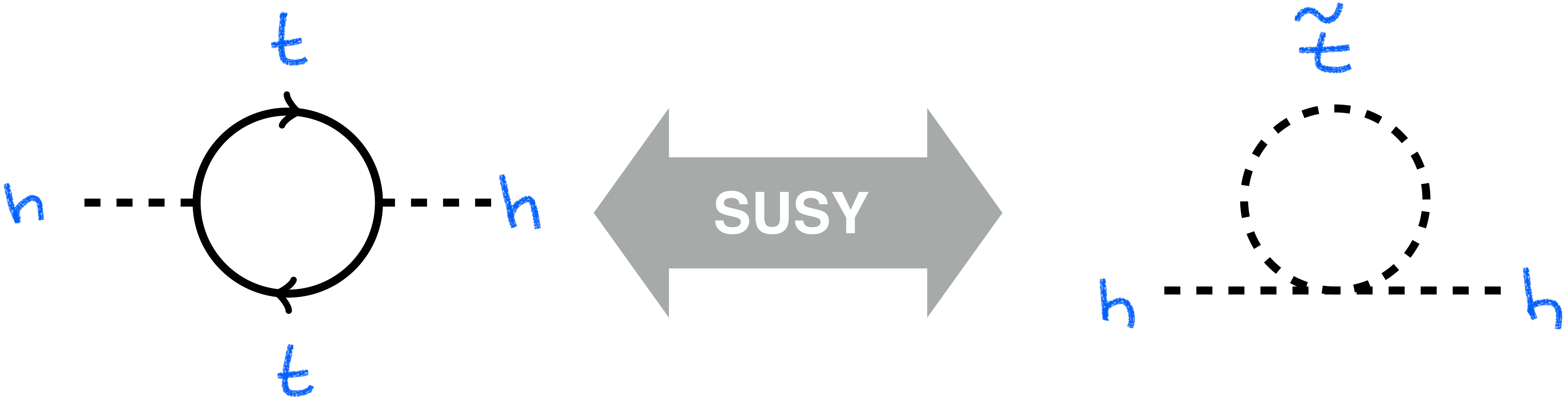
Supersymmetry

VISIBLE STUFF

NEW PARTICLES



superpartners also contribute to Higgs mass

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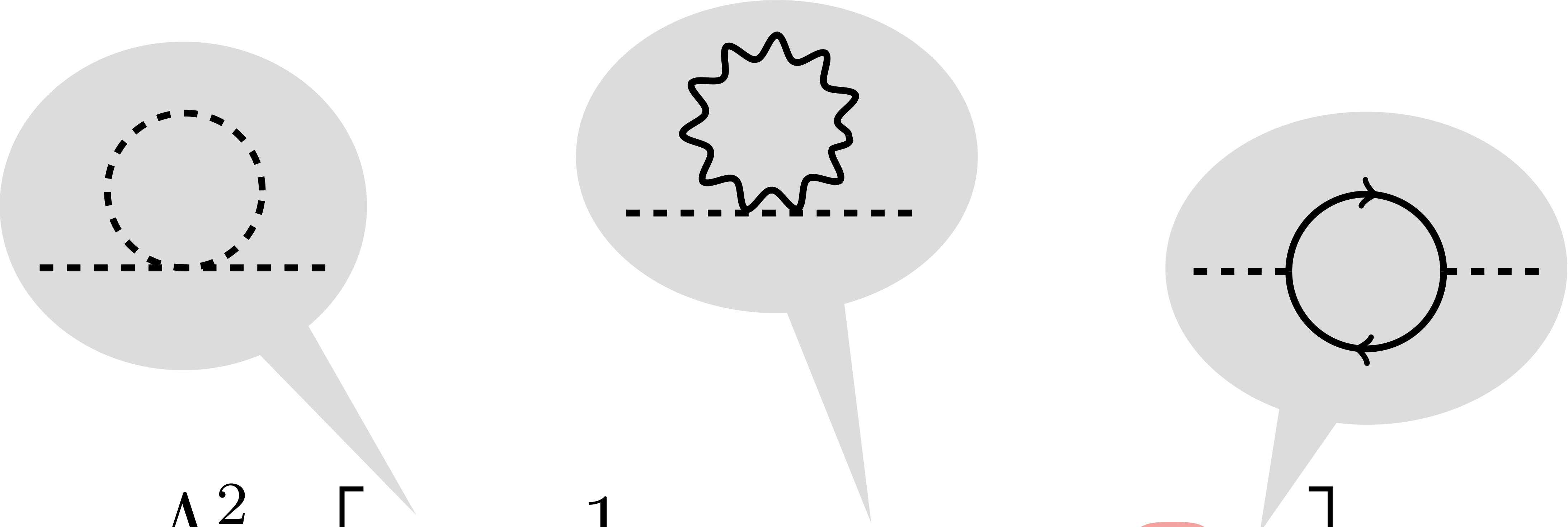
why this could work



$$\delta m_H^2 = \frac{\Lambda^2}{32\pi^2}\left[6\lambda + \frac{1}{4}\left(9g^2 + 3g'^2\right) - y_t^2\right]$$

relative sign between boson
and fermion loops

!

… just need [super]symmetry to enforce
appropriate particles and couplings

the naming of squarks

The MSSM (s)particle content

… compare to “The Naming of Cats” by TS Eliot

Multiplets to supermultiplets

also known as super*fields*

$$H = \begin{pmatrix} \phi^1 \\ \phi^2 \end{pmatrix}$$

SU(2) ROTATION

$$H = \phi^1 \mathbf{e_1} + \phi^2 \mathbf{e_2}$$

← BASIS OF GAUGE MULTIPLET

FERMIONIC BASIS

$\mathbb{1}$

$$\boxed{\Phi(y,\theta) = \varphi(y) + \sqrt{2}\theta\psi(y) + \theta^2 F(y)}$$

$$y^\mu = x^\mu + i\theta\sigma^\mu\bar{\theta}$$

Rule of thumb: SUSY spectrum

$$\Phi(y,\theta) = \varphi(y) + \sqrt{2}\theta\psi(y) + \theta^2 F(y)$$

Chiral superfield: matter superfield

complex scalar, Weyl fermion, auxiliary field

$$V = -\,\theta\sigma^\mu\bar{\theta}V_\mu(x) + i\theta^2\bar{\theta}\bar{\lambda}(x) - i\bar{\theta}^2\theta\lambda(x) + \frac{1}{2}\theta^2\bar{\theta}^2 D(x)$$

Vector superfield: force superfield

spin-1, Majorana fermion, auxiliary field

auxiliary fields are analogous to gauge-redundant degrees of freedom

The superfields

vector superfields (forces)

χSF	$\mathrm{SU}(3)_\mathrm{c}$	$\mathrm{SU}(2)_\mathrm{L}$	$\mathrm{U}(1)_\mathrm{Y}$
Q	$\mathbf{3}$	$\mathbf{2}$	$1/6$
$\bar{U}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$-2/3$
$\bar{D}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$1/3$
L	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1
H_d	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
H_u	$\mathbf{1}$	$\mathbf{2}$	$1/2$

chiral (matter)
superfields

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example: quark doublet

χSF	SU(3)$_\text{c}$	SU(2)$_\text{L}$	U(1)$_\text{Y}$
Q	$\mathbf{3}$	$\mathbf{2}$	$^1\!/_6$

example: quark doublet

χSF	SU(3)$_\text{c}$	SU(2)$_\text{L}$	U(1)$_\text{Y}$
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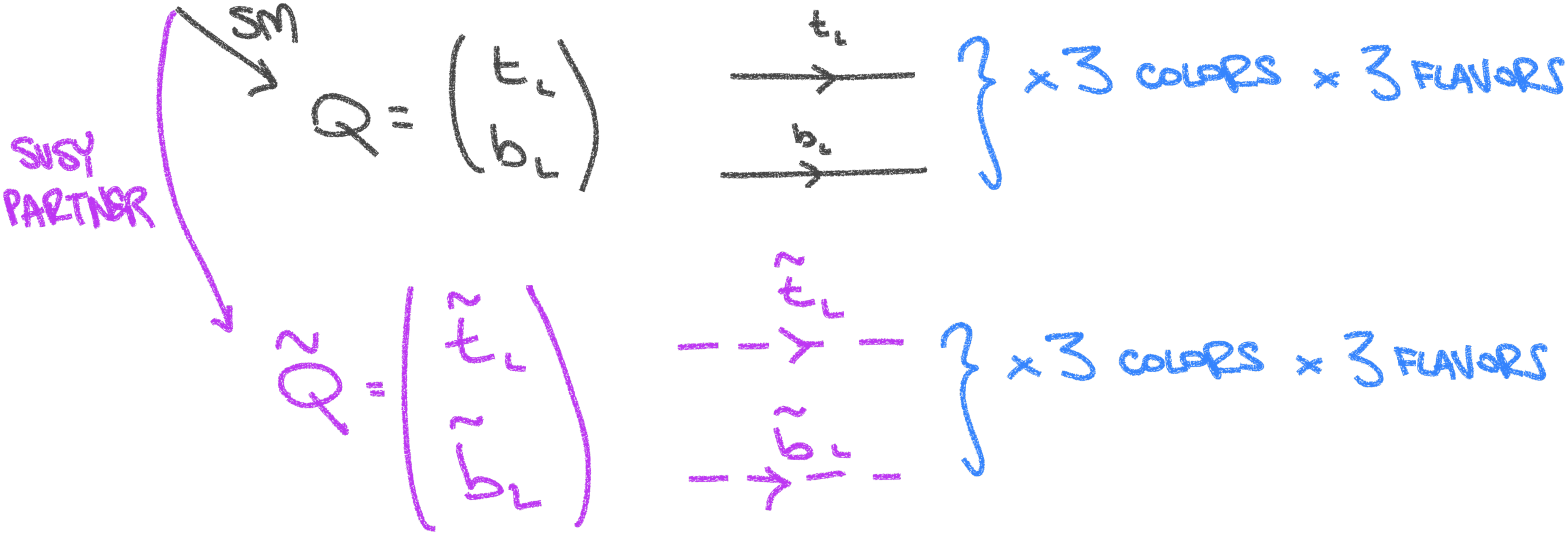


The superfields

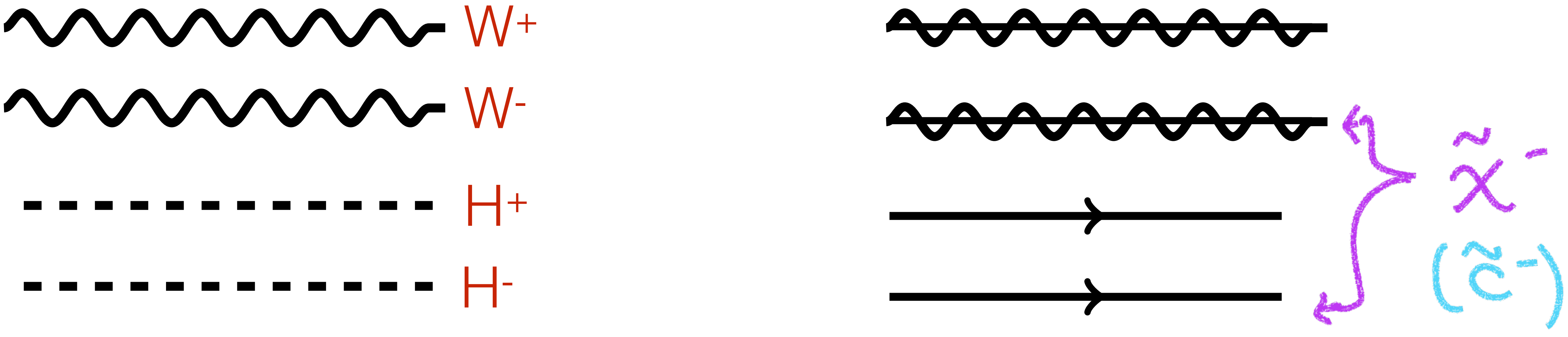
SM BOSON → -ino
SM FERMION → S-

		g/gluinos	W^a/winos	B/bino	
	χSF	$\text{SU}(3)_\text{c}$	$\text{SU}(2)_\text{L}$	$\text{U}(1)_\text{Y}$	
LH up LH down	Q	$\mathbf{3}$	$\mathbf{2}$	$1/6$	sup-L sdown-L
RH up*	$\bar{U}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$-2/3$	sup-R*
RH down*	$\bar{D}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$1/3$	sdown-R*
LH neutrino LH electron	L	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	sneutrino selectron-L
RH electron*	$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1	selectron-R
H^+, H^1	H_d	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	higgsinos
H^2, H^-	H_u	$\mathbf{1}$	$\mathbf{2}$	$1/2$	higgsinos

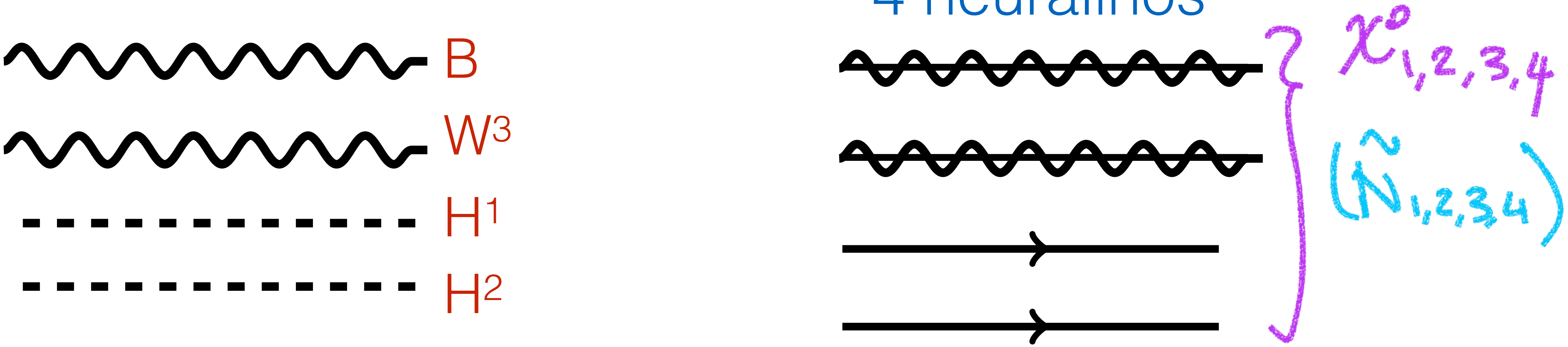
“sfermions” (squarks and sleptons)   gauginos

Gaugino mixing

2 charginos + h.c.



4 neuralinos



We never talk about photinos or zinos.

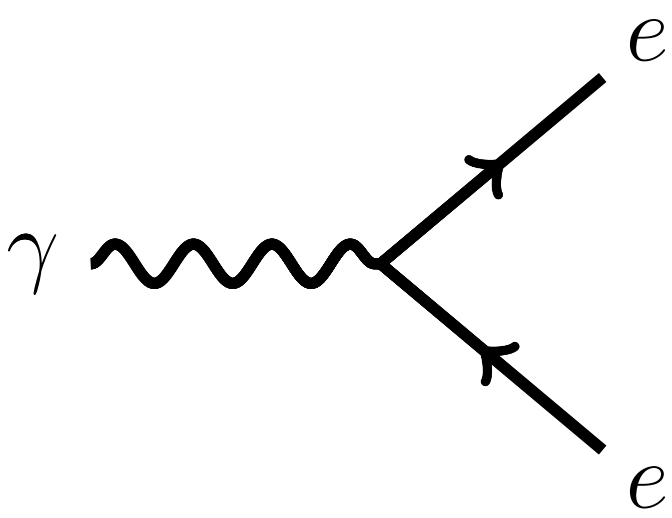
MSSM Feynman Rules

a cheater's guide (SUSY limit)

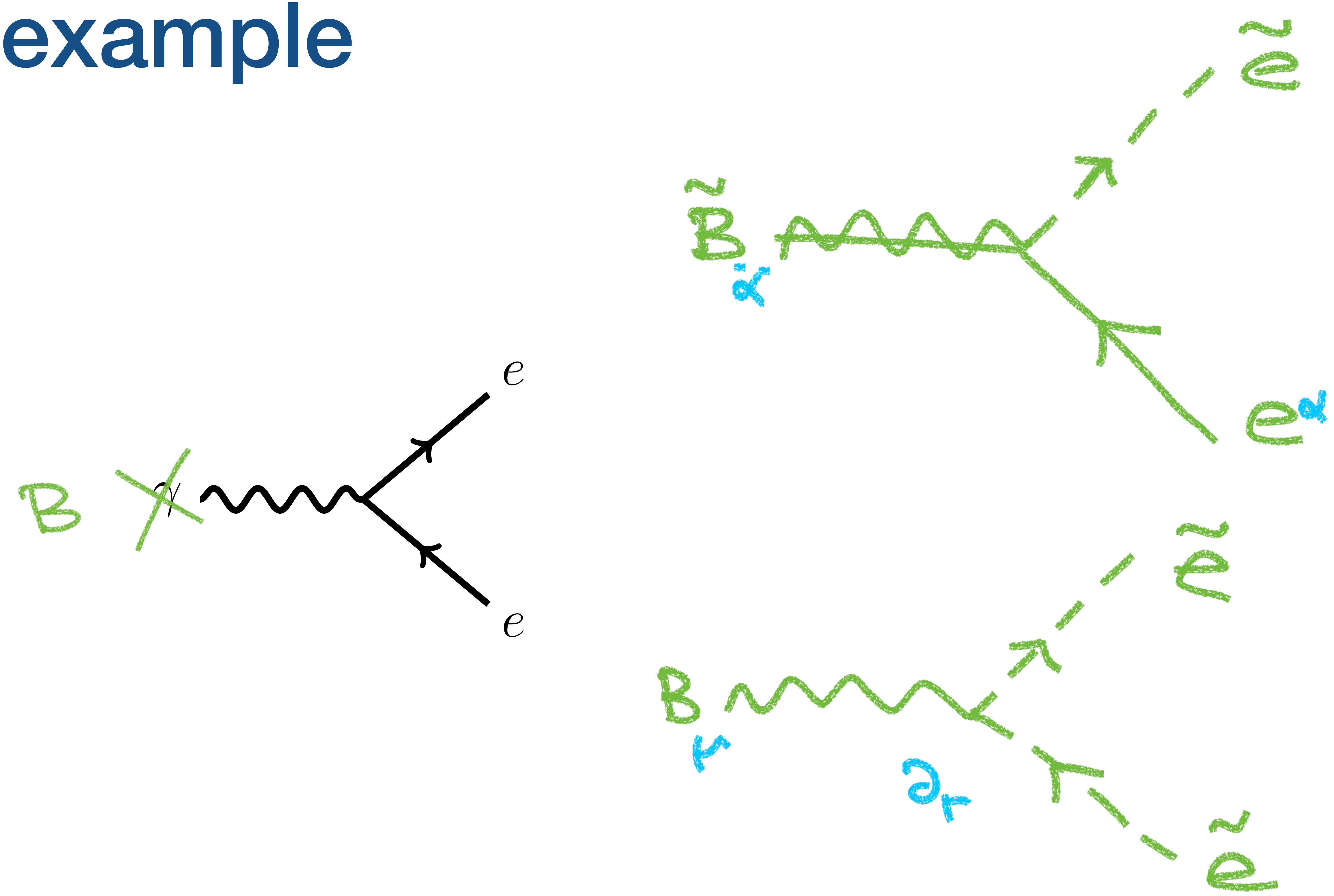
the dirty secret (approximate)

1. take a Standard Model vertex
2. replace two particles with SUSY partners
3. make sure indices contract (they will)

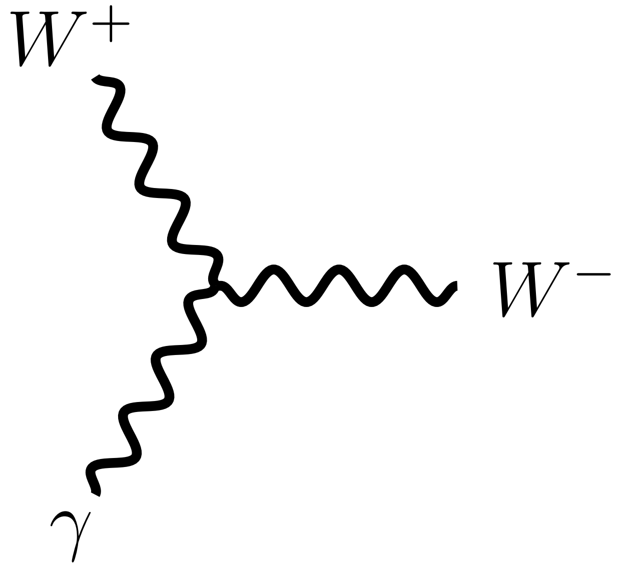
example



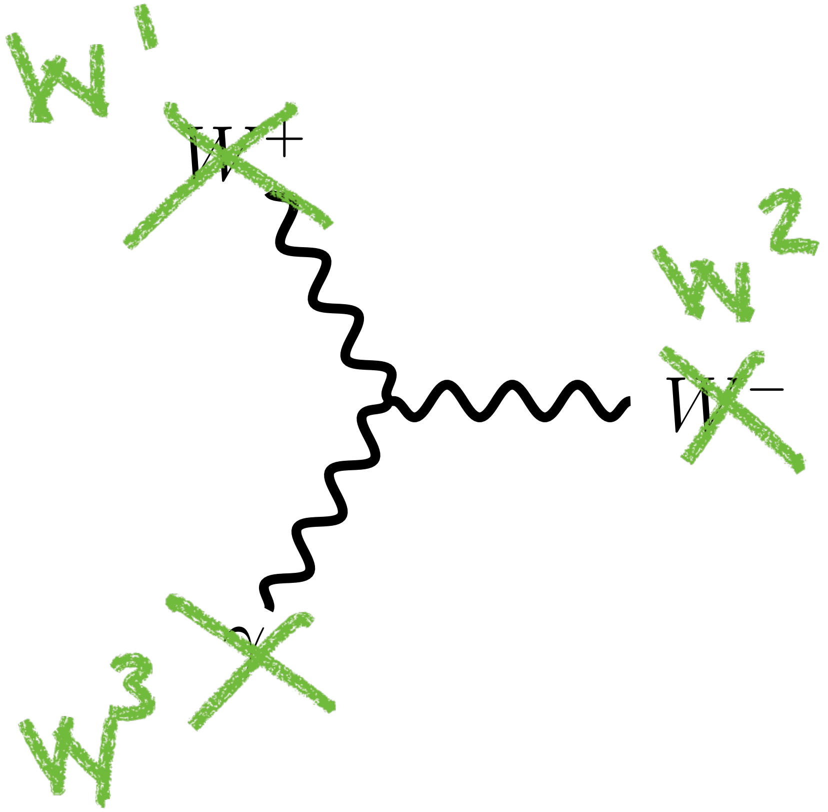
example

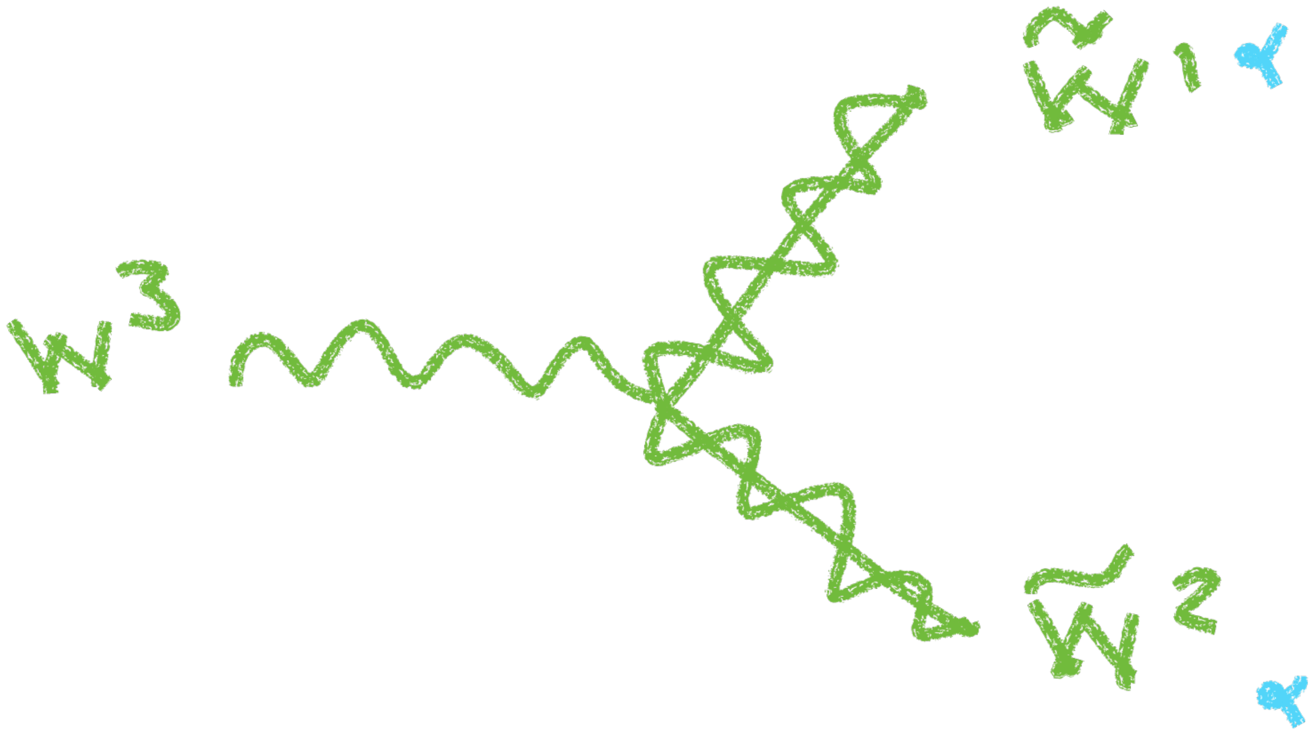

B
~~γ~~
e
e
$\tilde{B}$
$\dot{\alpha}$
$\tilde{e}$
e^{α}
B
μ
∂_μ
$\tilde{e}$
$\tilde{e}$

example

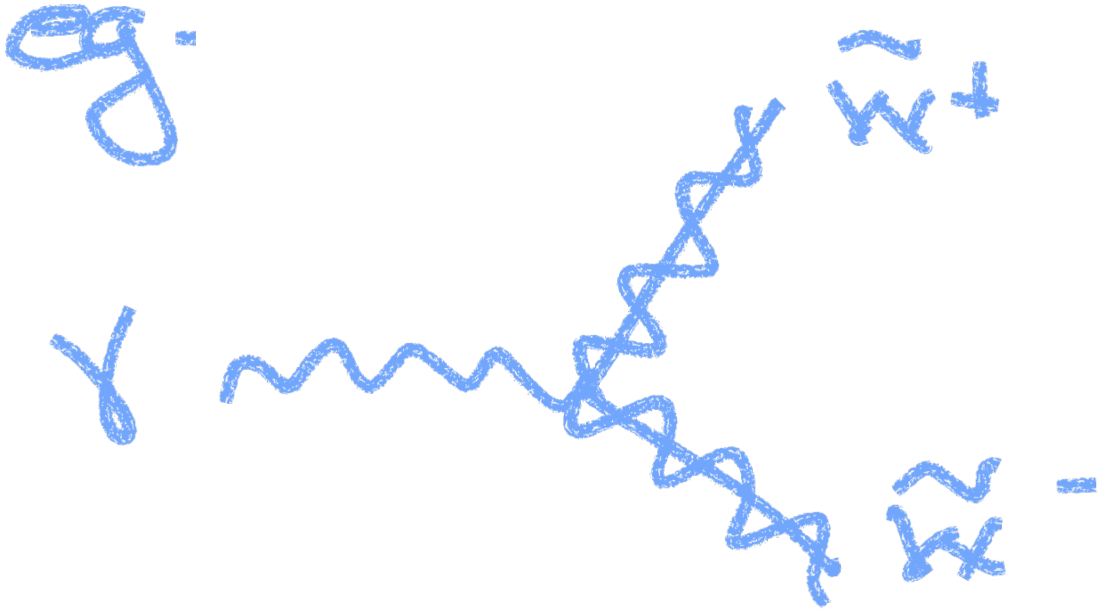


example

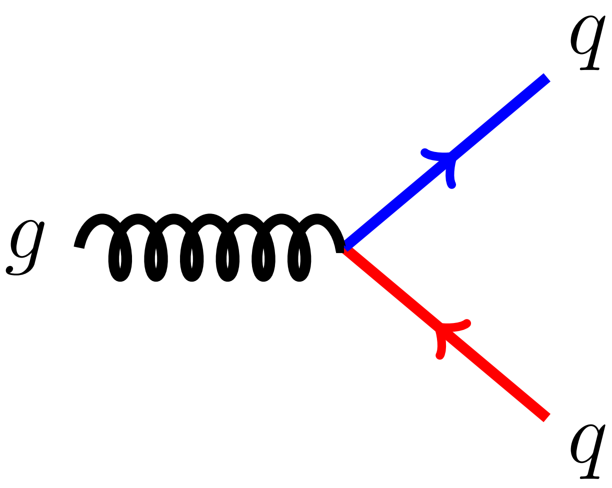

W^1
~~W^+~~
W^2
~~W^-~~
W^3
~~γ~~

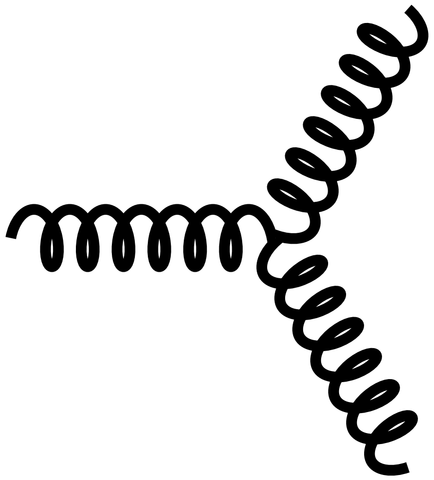

W^3
$\tilde{W}^1$ γ
$\tilde{W}^2$ γ

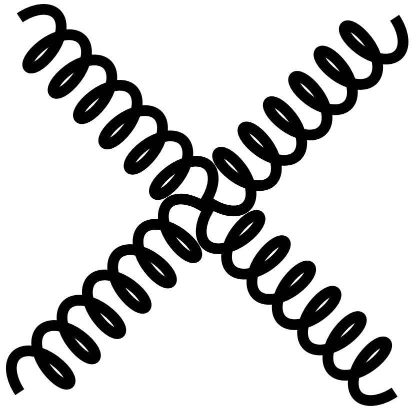
eg.


γ
$\tilde{W}^+$
$\tilde{W}^-$

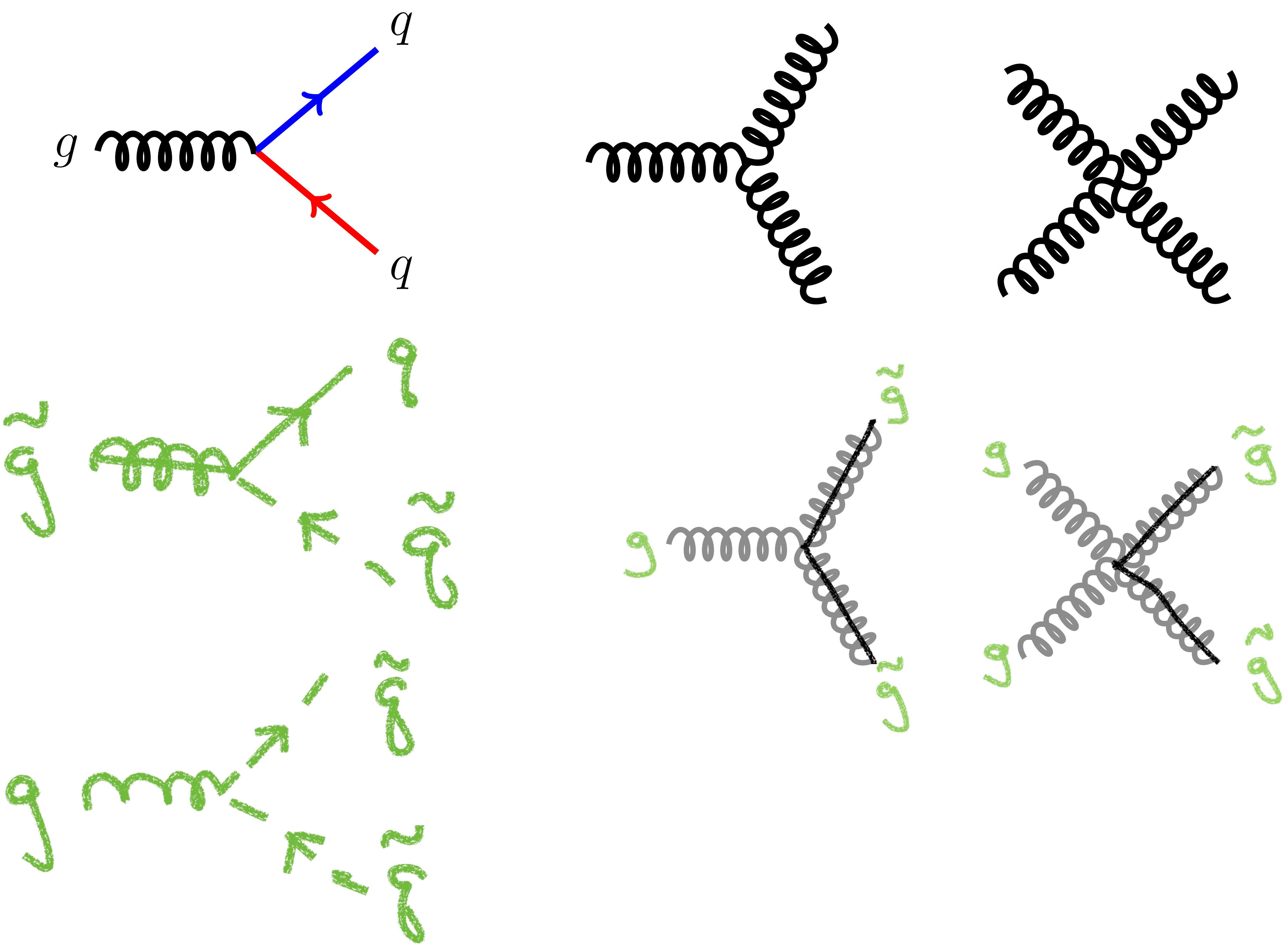
example







example


g
q
q
$\tilde{g}$
q
$\tilde{q}$
g
$\tilde{q}$
$\tilde{q}$
g
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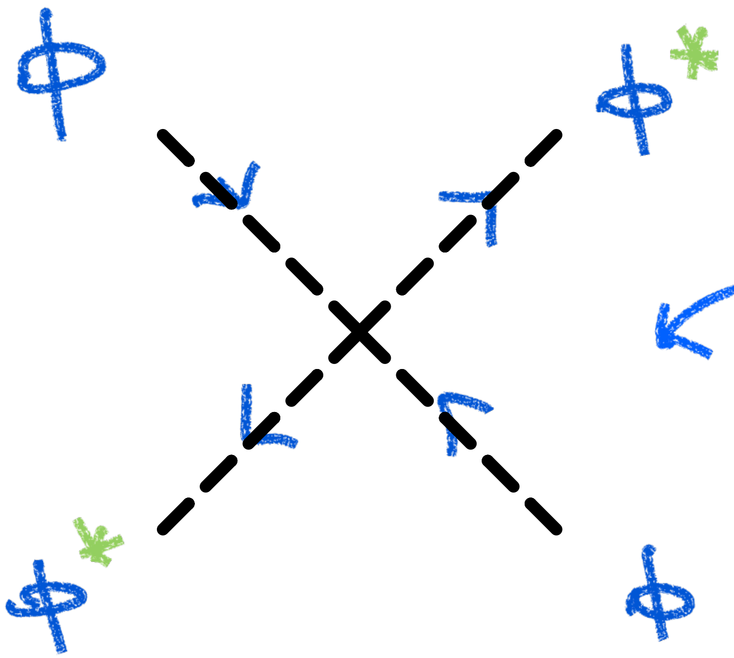
g
g
$\tilde{g}$
$\tilde{g}$

what you miss

scalars charged under gauge group



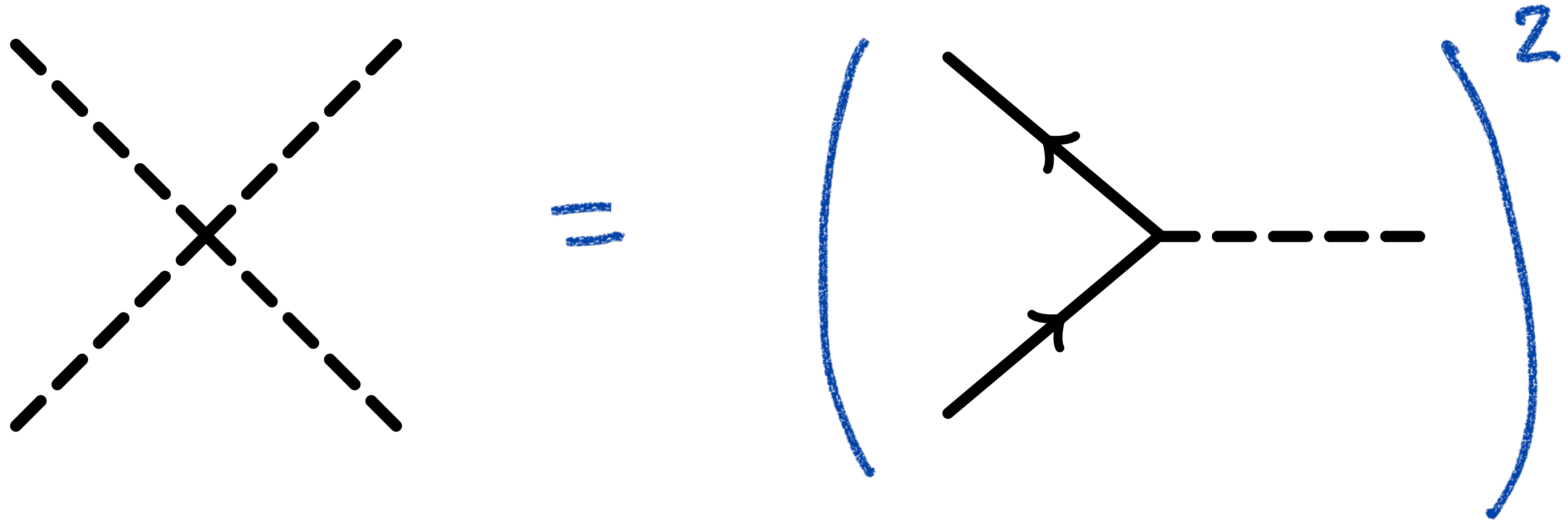
$$\mathcal{L} \supset \frac{1}{2} g^2 \sum_a \left(\phi^* T^a \phi\right)^2$$

sum over gauge generators

Some quartic terms come from kinetic terms, proportional to gauge coupling.

… may make you worry about Higgs sector!

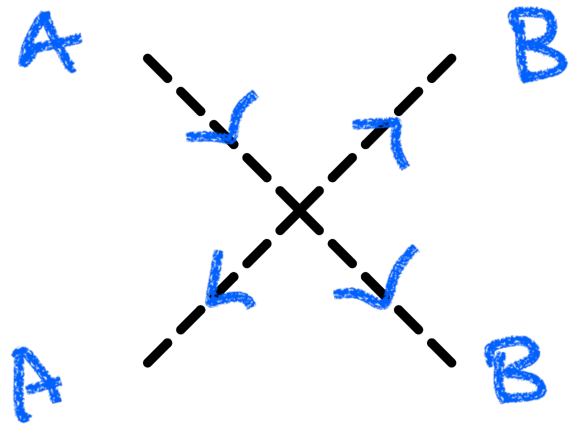
what you miss

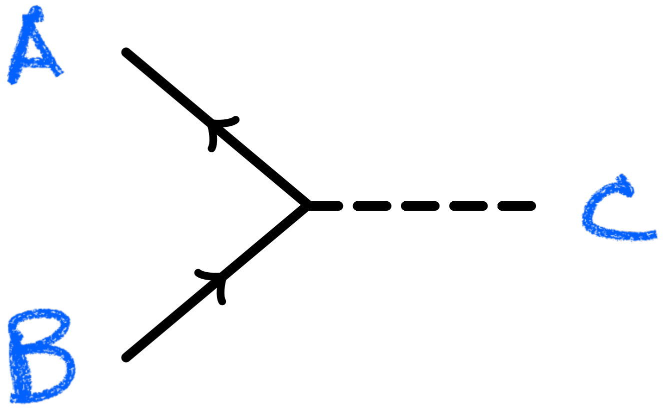


other quartic terms come from Yukawa terms

… this is really important for cancellation of loops

Other Interactions





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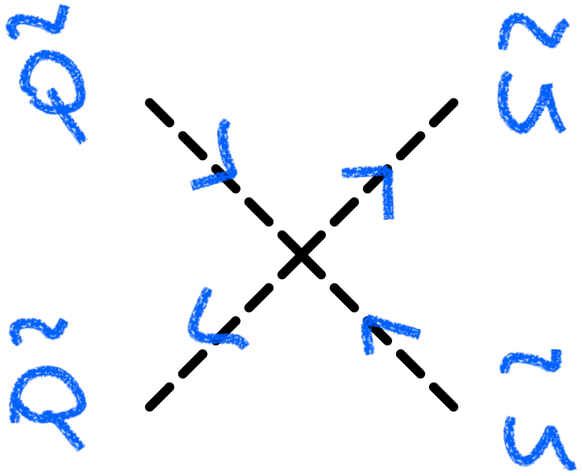
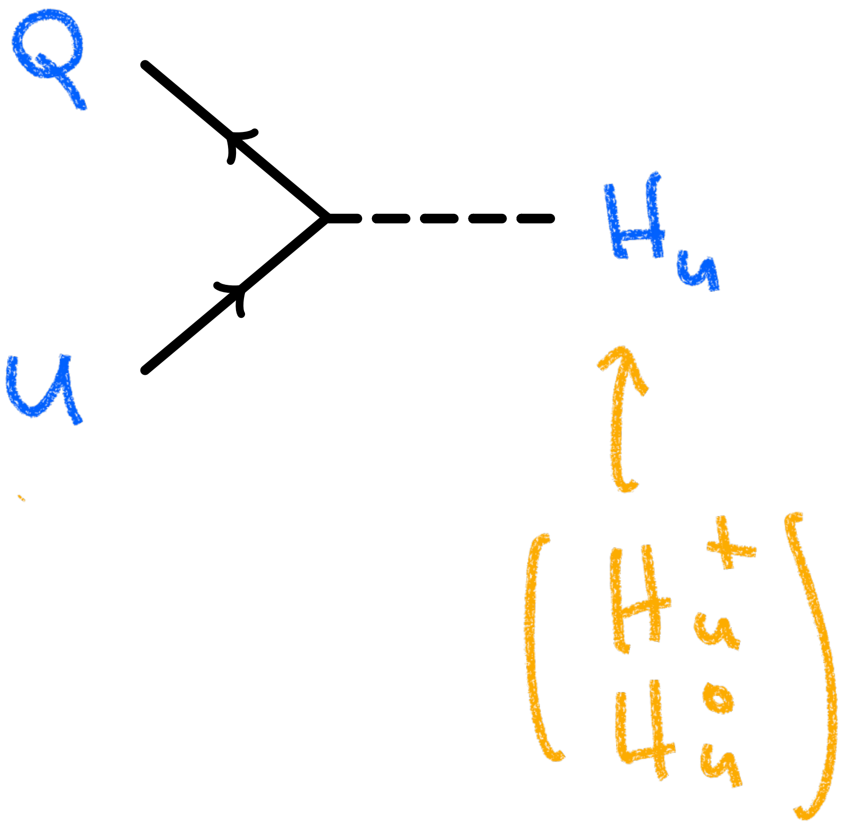
Q	$\mathbf{3}$	$\mathbf{2}$	$^1/_6$
$\bar{U}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$-^2/_3$
$\bar{D}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$^1/_3$
L	$\mathbf{1}$	$\mathbf{2}$	$-^1/_2$
$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1
H_d	$\mathbf{1}$	$\mathbf{2}$	$-^1/_2$
H_u	$\mathbf{1}$	$\mathbf{2}$	$^1/_2$

More fields, more ways to put them together.

Pick gauge invariant combination of 3 XSF, A, B, C

Other Interactions





$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$

eg

χSF	SU(3)$_c$	SU(2)$_L$	U(1)$_Y$	
Q	$\mathbf{3}$	$\mathbf{2}$	$^1/_6$	A
$\bar{U}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$-^2/_3$	B
$\bar{D}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$^1/_3$	
L	$\mathbf{1}$	$\mathbf{2}$	$-^1/_2$	
$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1	
H_d	$\mathbf{1}$	$\mathbf{2}$	$-^1/_2$	
H_u	$\mathbf{1}$	$\mathbf{2}$	$^1/_2$	C

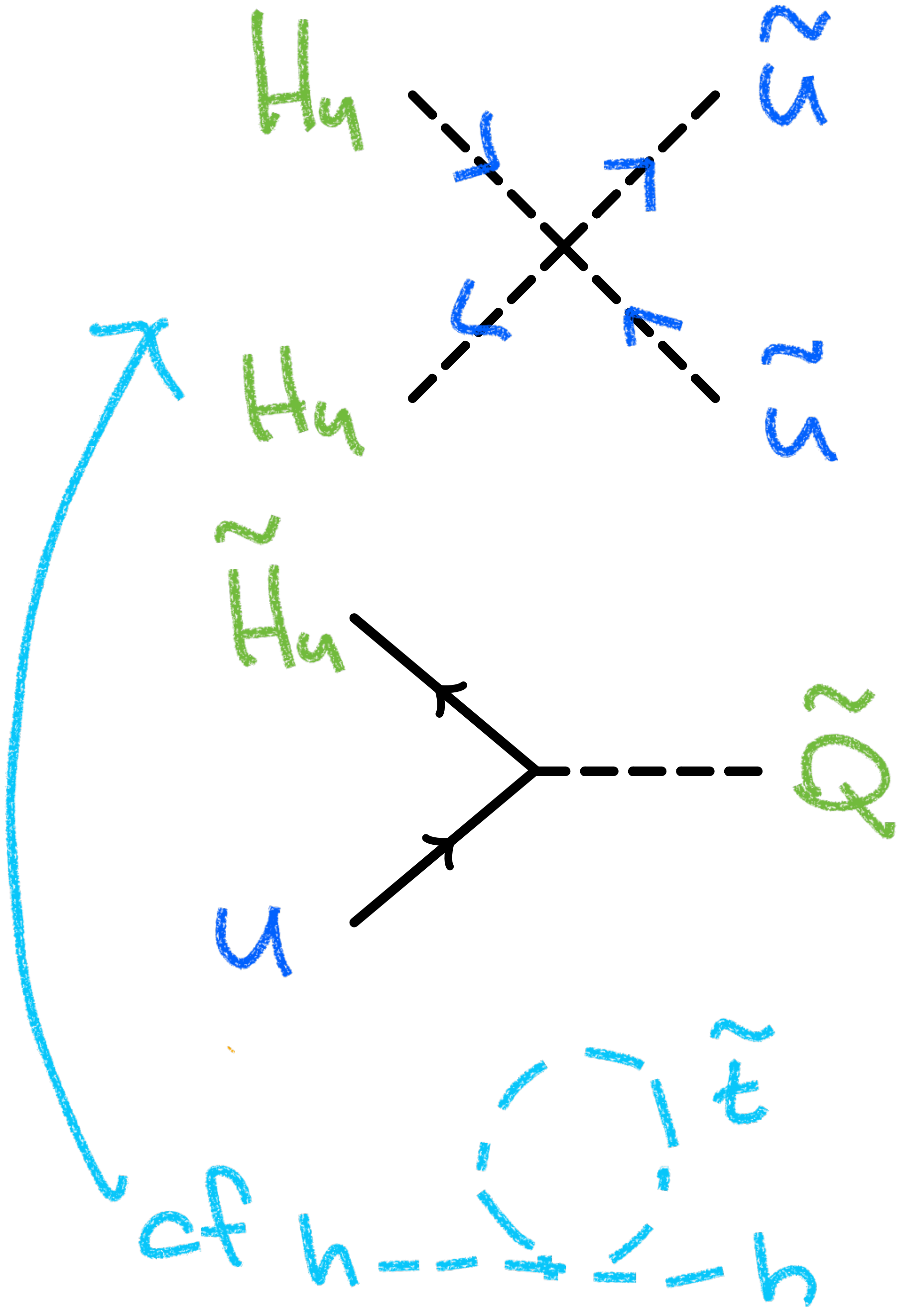
USUAL UP-TYPE YUKAWA

Pick gauge invariant combination of 3 XSF, A, B, C

Other Interactions

$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$

eg



χSF	SU(3)$_c$	SU(2)$_L$	U(1)$_Y$	
Q	$\mathbf{3}$	$\mathbf{2}$	$1/6$	~~A~~ C
$\bar{U}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$-2/3$	B
$\bar{D}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$1/3$	
L	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	
$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1	
H_d	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	
H_u	$\mathbf{1}$	$\mathbf{2}$	$1/2$	~~C~~ A

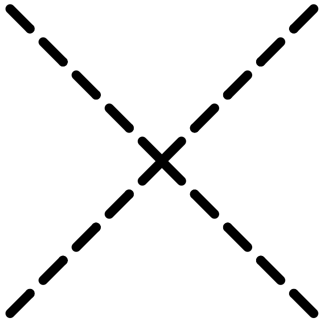
USUAL UP-TYPE YUKAWA

+ SUSY "PARTNER" VERTICES

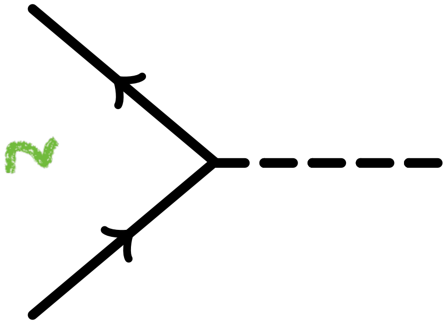
Pick gauge invariant combination of 3 XSF, A, B, C

… first look at a superpotential

$(\text{coupling})^2 \sim$



$\text{coupling} \sim$



χSF	SU(3)$_\mathrm{c}$	SU(2)$_\mathrm{L}$	U(1)$_\mathrm{Y}$
Q	$\mathbf{3}$	$\mathbf{2}$	$1/6$
$\bar{U}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$-2/3$
$\bar{D}$	$\overline{\mathbf{3}}$	$\mathbf{1}$	$1/3$
L	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1
H_d	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
H_u	$\mathbf{1}$	$\mathbf{2}$	$1/2$

HOW TO READ: $[\text{coupling}]\,\boxed{A\;B\;C}$ χSF

$$W^{(\text{good})} = y_u^{ij} Q^i H_u \bar{U}^j + y_d^{ij} Q^i H_d \bar{D} + y_e^{ij} L^i H_d \bar{E}^j + \mu H_u H_d$$

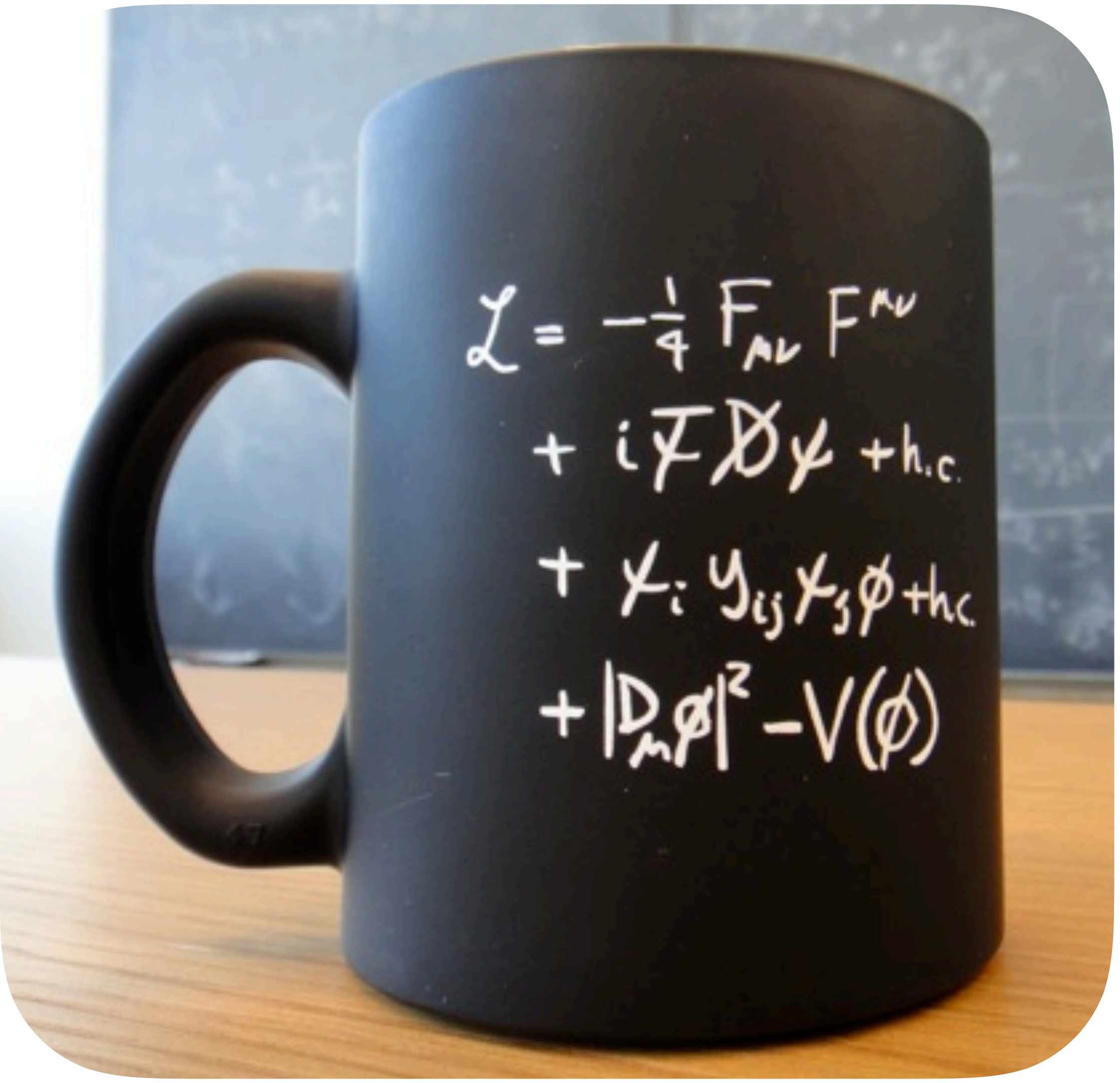
$$W^{(\text{bad})} = \lambda_1^{ijk} Q^i L^j \bar{D}^k + \lambda_2^{ijk} L^i L^j \bar{E}^k + \lambda_3^i L^i H_u + \lambda_4^{ijk} \bar{D}^i \bar{D}^j \bar{U}^k$$

↑ PROBLEMATIC

The MSSM… approximately

Exercise 1: what are the particles of the **minimal supersymmetric Standard Model**?

Exercise 2: what are the SUSY interactions?
ignore quartics,
hint on the right



Supersymmetry

super-shortcomings

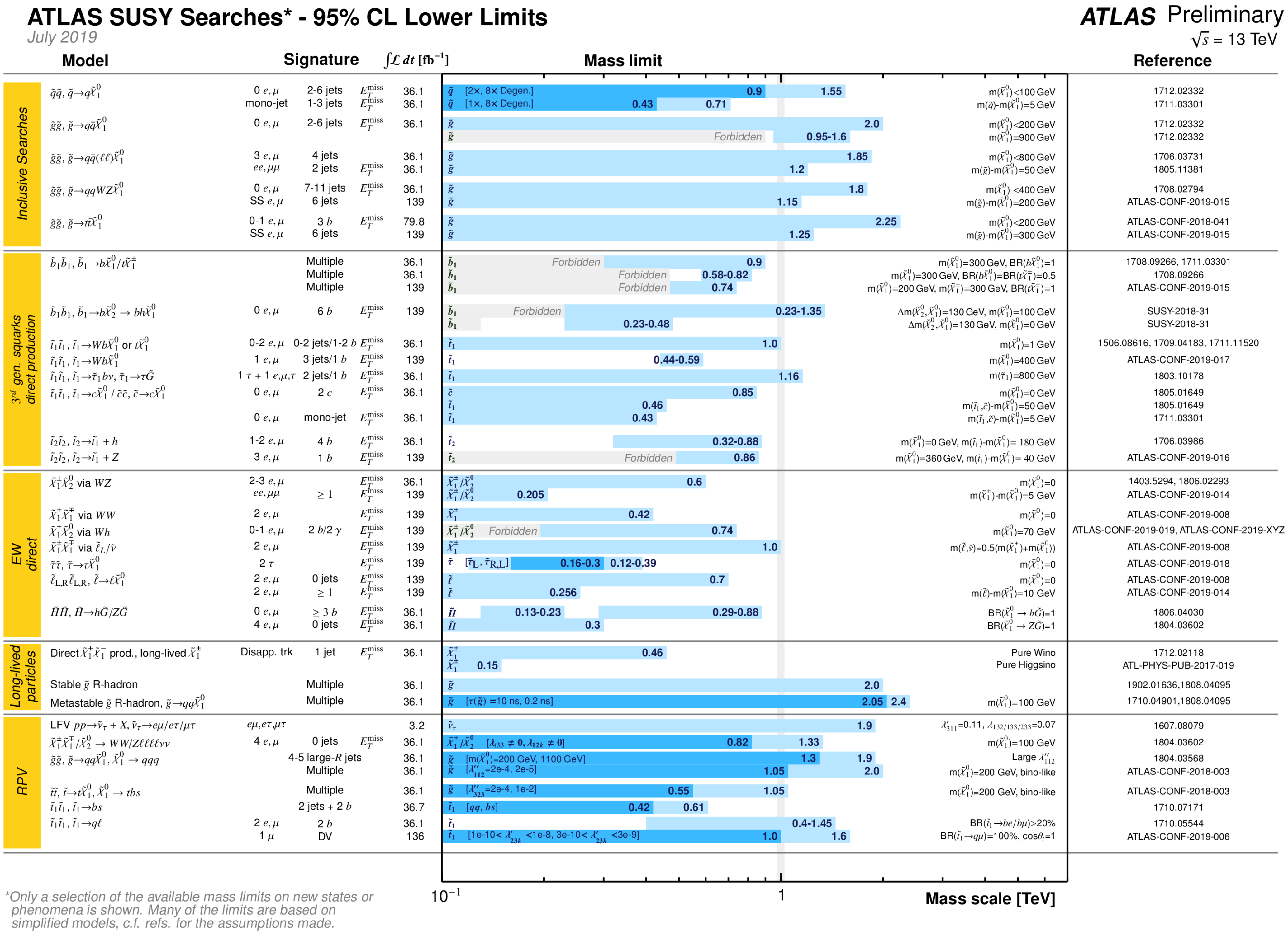
there are no sparticles

The electron has an antiparticle with the same properties except *CP*

… but it definitely does *not* have a super-partner with the same properties except

We would have discovered it a long time ago.

there are no sparticles



ATLAS SUSY Searches* - 95% CL Lower Limits
July 2019

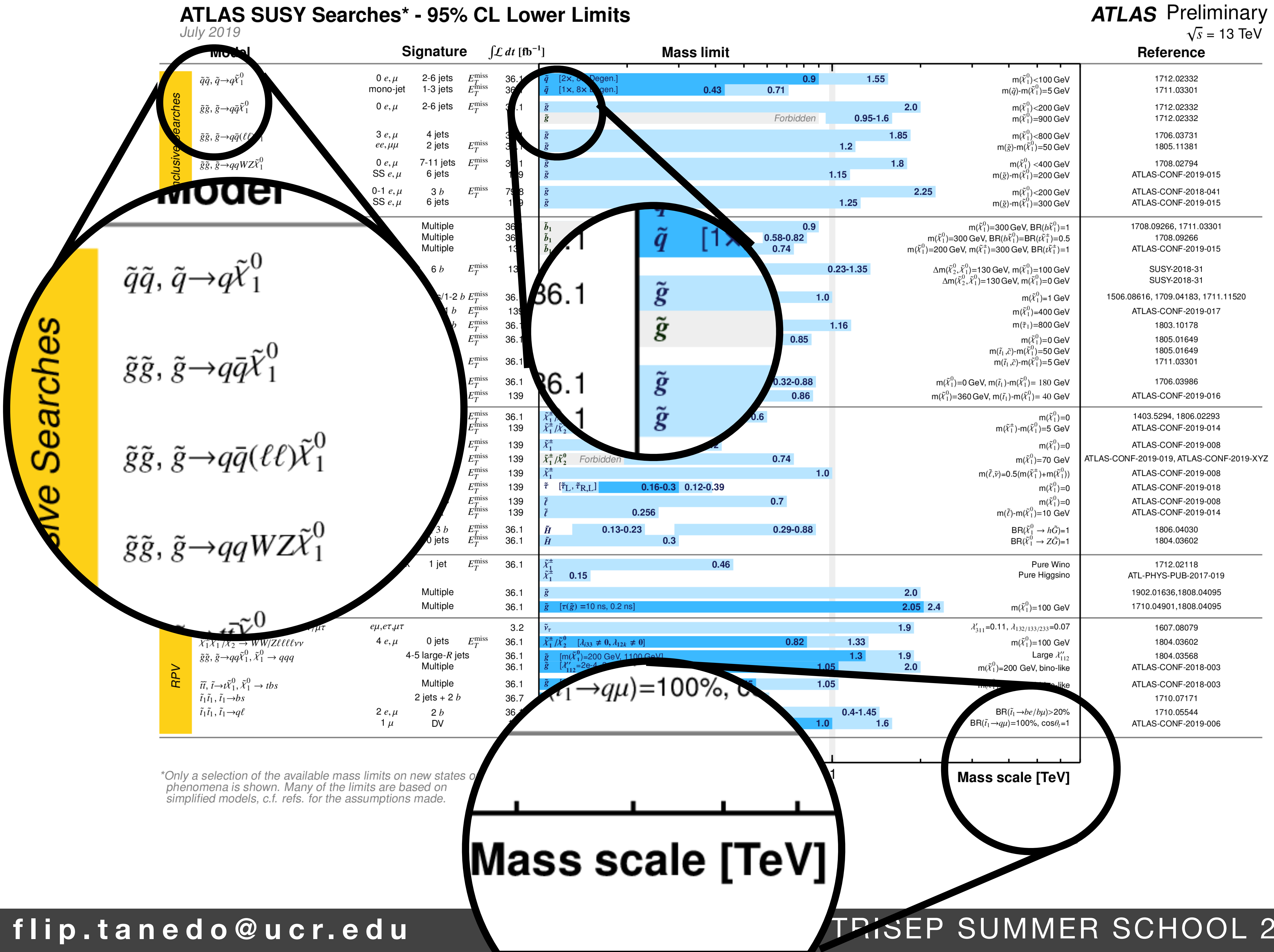
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt\ [\text{fb}^{-1}]$	Mass limit [TeV]		Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ mono-jet	2-6 jets 1-3 jets	E_T^{miss} E_T^{miss}	36.1 36.1	$\tilde{q}$ [2×, 8× Degen.] 0.9 1.55 $\tilde{q}$ [1×, 8× Degen.] 0.43 0.71	$m(\tilde{\chi}^0_1)$<100 GeV $m(\tilde{q})$-$m(\tilde{\chi}^0_1)$=5 GeV	1712.02332 1711.03301
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	36.1	$\tilde{g}$ 2.0 $\tilde{g}$ Forbidden 0.95-1.6	$m(\tilde{\chi}^0_1)$<200 GeV $m(\tilde{\chi}^0_1)$=900 GeV	1712.02332 1712.02332
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	3 e,μ $ee,\mu\mu$	4 jets 2 jets	 E_T^{miss}	36.1 36.1	$\tilde{g}$ 1.85 $\tilde{g}$ 1.2	$m(\tilde{\chi}^0_1)$<800 GeV $m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=50 GeV	1706.03731 1805.11381
	$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ SS e,μ	7-11 jets 6 jets	E_T^{miss}	36.1 139	$\tilde{g}$ 1.8 $\tilde{g}$ 1.15	$m(\tilde{\chi}^0_1)$ <400 GeV $m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=200 GeV	1708.02794 ATLAS-CONF-2019-015
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ SS e,μ	3 b 6 jets	E_T^{miss}	79.8 139	$\tilde{g}$ 2.25 $\tilde{g}$ 1.25	$m(\tilde{\chi}^0_1)$<200 GeV $m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=300 GeV	ATLAS-CONF-2018-041 ATLAS-CONF-2019-015
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_1/t\tilde{\chi}^\pm_1$		Multiple Multiple Multiple		36.1 36.1 139	$\tilde{b}_1$ Forbidden 0.9 $\tilde{b}_1$ Forbidden 0.58-0.82 $\tilde{b}_1$ Forbidden 0.74	$m(\tilde{\chi}^0_1)$=300 GeV, BR($b\tilde{\chi}^0_1$)=1 $m(\tilde{\chi}^0_1)$=300 GeV, BR($b\tilde{\chi}^0_1$)=BR($t\tilde{\chi}^\pm_1$)=0.5 $m(\tilde{\chi}^0_1)$=200 GeV, $m(\tilde{\chi}^\pm_1)$=300 GeV, BR($t\tilde{\chi}^\pm_1$)=1	1708.09266, 1711.03301 1708.09266 ATLAS-CONF-2019-015
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$ Forbidden 0.23-1.35 $\tilde{b}_1$ 0.23-0.48	$\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=100 GeV $\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=0 GeV	SUSY-2018-31 SUSY-2018-31
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	E_T^{miss}	36.1	$\tilde{t}_1$ 1.0	$m(\tilde{\chi}^0_1)$=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ 0.44-0.59	$m(\tilde{\chi}^0_1)$=400 GeV	ATLAS-CONF-2019-017
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to\tilde{\tau}_1 b\nu, \tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	E_T^{miss}	36.1	$\tilde{t}_1$ 1.16	$m(\tilde{\tau}_1)$=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}, \tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$ 0.85 $\tilde{t}_1$ 0.46	$m(\tilde{\chi}^0_1)$=0 GeV $m(\tilde{t}_1,\tilde{c})$-$m(\tilde{\chi}^0_1)$=50 GeV	1805.01649 1805.01649
		0 e,μ	mono-jet	E_T^{miss}	36.1	$\tilde{t}_1$ 0.43	$m(\tilde{t}_1,\tilde{c})$-$m(\tilde{\chi}^0_1)$=5 GeV	1711.03301
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	E_T^{miss}	36.1	$\tilde{t}_2$ 0.32-0.88	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{t}_1)$-$m(\tilde{\chi}^0_1)$= 180 GeV	1706.03986
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$ Forbidden 0.86	$m(\tilde{\chi}^0_1)$=360 GeV, $m(\tilde{t}_1)$-$m(\tilde{\chi}^0_1)$= 40 GeV	ATLAS-CONF-2019-016
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	2-3 e,μ $ee,\mu\mu$	 ≥ 1	E_T^{miss} E_T^{miss}	36.1 139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.6 $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.205	$m(\tilde{\chi}^0_1)$=0 $m(\tilde{\chi}^\pm_1)$-$m(\tilde{\chi}^0_1)$=5 GeV	1403.5294, 1806.02293 ATLAS-CONF-2019-014
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 0.42	$m(\tilde{\chi}^0_1)$=0	ATLAS-CONF-2019-008
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	0-1 e,μ	2 b/2 γ	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ Forbidden 0.74	$m(\tilde{\chi}^0_1)$=70 GeV	ATLAS-CONF-2019-019, ATLAS-CONF-2019-XYZ
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 1.0	$m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}^\pm_1)$+$m(\tilde{\chi}^0_1)$)	ATLAS-CONF-2019-008
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L$, $\tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39	$m(\tilde{\chi}^0_1)$=0	ATLAS-CONF-2019-018
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ 2 e,μ	0 jets ≥ 1	E_T^{miss} E_T^{miss}	139 139	$\tilde{\ell}$ 0.7 $\tilde{\ell}$ 0.256	$m(\tilde{\chi}^0_1)$=0 $m(\tilde{\ell})$-$m(\tilde{\chi}^0_1)$=10 GeV	ATLAS-CONF-2019-008 ATLAS-CONF-2019-014
	$\tilde{H}\tilde{H}, \tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ 4 e,μ	≥ 3 b 0 jets	E_T^{miss} E_T^{miss}	36.1 36.1	$\tilde{H}$ 0.13-0.23 0.29-0.88 $\tilde{H}$ 0.3	BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1 BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	1806.04030 1804.03602
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	E_T^{miss}	36.1	$\tilde{\chi}^\pm_1$ 0.46 $\tilde{\chi}^\pm_1$ 0.15	Pure Wino Pure Higgsino	1712.02118 ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$ 2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$		Multiple		36.1	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.05 2.4	$m(\tilde{\chi}^0_1)$=100 GeV	1710.04901,1808.04095
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$			3.2	$\tilde{\nu}_\tau$ 1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	E_T^{miss}	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.82 1.33	$m(\tilde{\chi}^0_1)$=100 GeV	1804.03602
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^0_1, \tilde{\chi}^0_1\to qqq$		4-5 large-R jets Multiple		36.1 36.1	$\tilde{g}$ [$m(\tilde{\chi}^0_1)$=200 GeV, 1100 GeV] 1.3 1.9 $\tilde{g}$ [λ''_{112}=2e-4, 2e-5] 1.05 2.0	Large λ''_{112} $m(\tilde{\chi}^0_1)$=200 GeV, bino-like	1804.03568 ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t}\to t\tilde{\chi}^0_1, \tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{g}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	$m(\tilde{\chi}^0_1)$=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to q\ell$	2 e,μ 1 μ	2 b DV		36.1 136	$\tilde{t}_1$ 0.4-1.45 $\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to be/b\mu$)>20% BR($\tilde{t}_1\to q\mu$)=100%, $\cos\theta_t$=1	1710.05544 ATLAS-CONF-2019-006

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

ATLAS SUSY summary results

there are no sparticles



Supersymmetry is broken

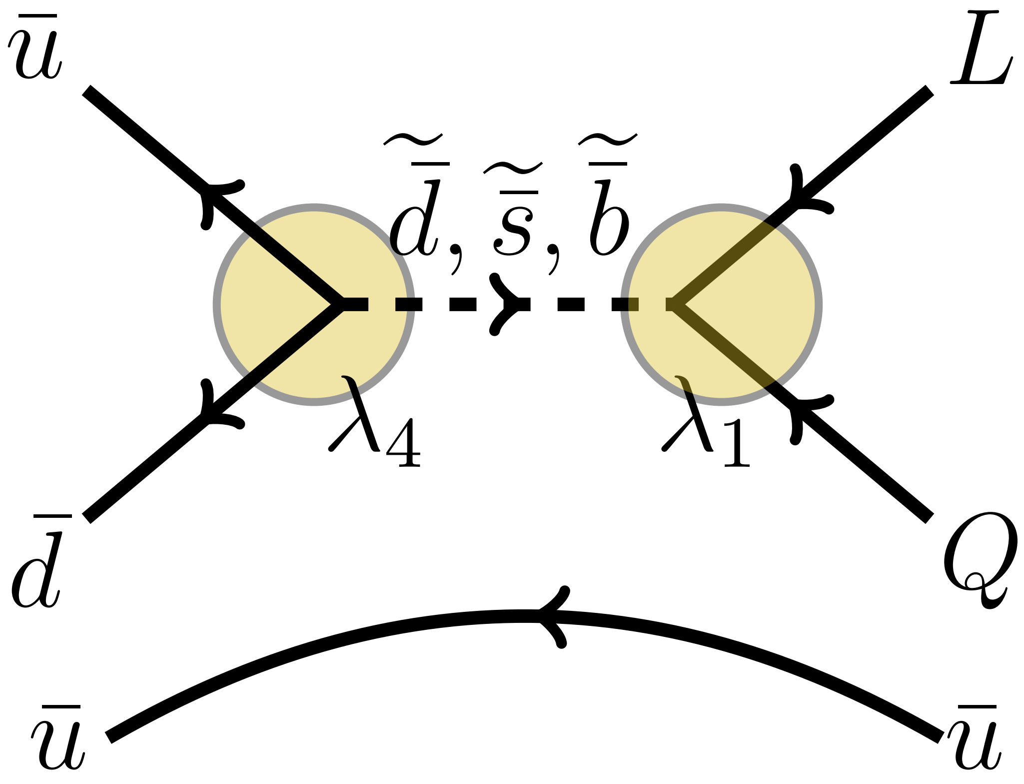
$$m_{\text{fermion}} \neq m_{\text{boson}}$$

SUSY is not a good symmetry of nature.
c.f. electroweak symmetry

Can it solve the Hierarchy Problem?
Soft SUSY breaking

$$\Delta m_H^2 = m_{\text{soft}}^2 \left[\frac{\lambda}{16\pi^2} \ln(\Lambda_{\text{UV}}/m_{\text{soft}}) + \dots \right]$$

proton decay



$$P_R = (-)^{3(B-L)+2s}$$

P_R[ordinary matter] = +

P_R[superpartner] = –

$$W^{(\text{good})} = y_u^{ij} Q^i H_u \bar{U}^j + y_d^{ij} Q^i H_d \bar{D} + y_e^{ij} L^i H_d \bar{E}^j + \mu H_u H_d$$

$$W^{(\text{bad})} = \lambda_1^{ijk} Q^i L^j \bar{D}^k + \lambda_2^{ijk} L^i L^j \bar{E}^k + \lambda_3^i L^i H_u + \lambda_4^{ijk} \bar{D}^i \bar{D}^j \bar{U}^k$$

Added bonus:
lightest superpartner is stable.

Image: *We Have No Idea*, Whiteson & Cham

electroweak symmetry breaking

The Higgs potential is a challenge in SUSY.

$$V_H = \frac{1}{8}(g^2+g'^2)\left(|H_u^0|^2-|H_d^0|^2\right)^2+\sum_{i=u,d}\left(|\mu|^2+m_{H_i}^2\right)|H_i^0|^2-2B_\mu \mathrm{Re}(H_u^0H_d^0)$$

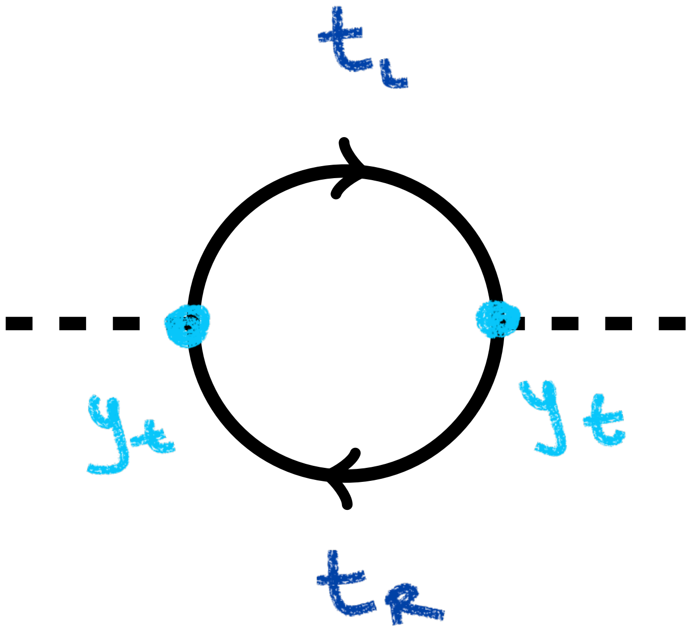
Two Higgses, both get vevs.
Only one quartic direction (other is D-flat)

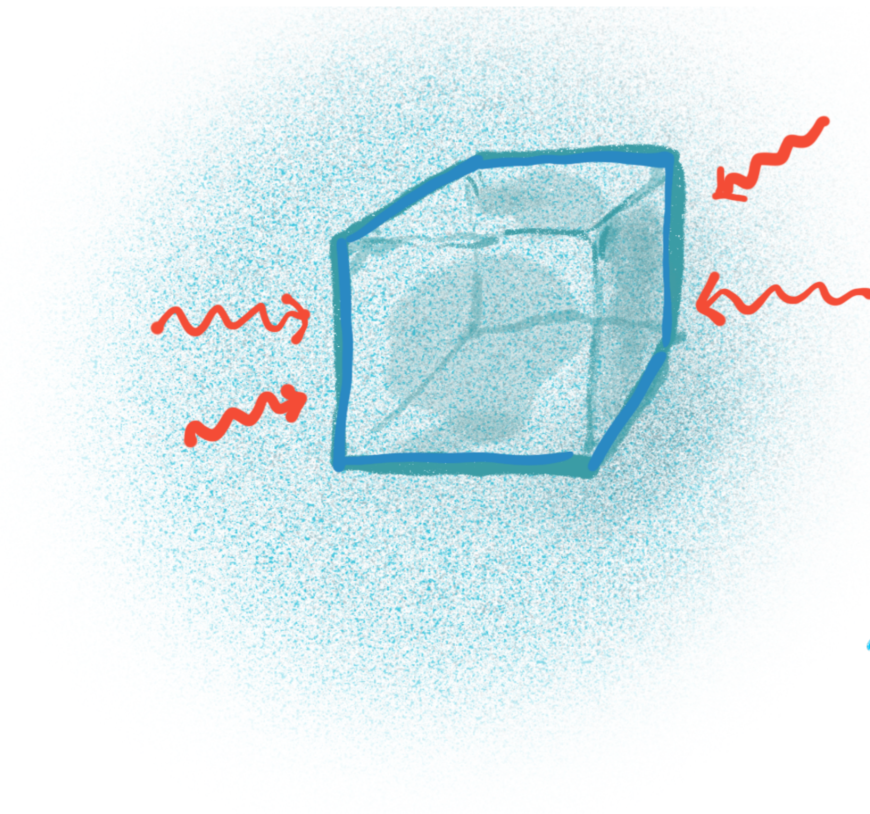
Relies on apparent conspiracy between supersymmetric and SUSY-beaking terms.

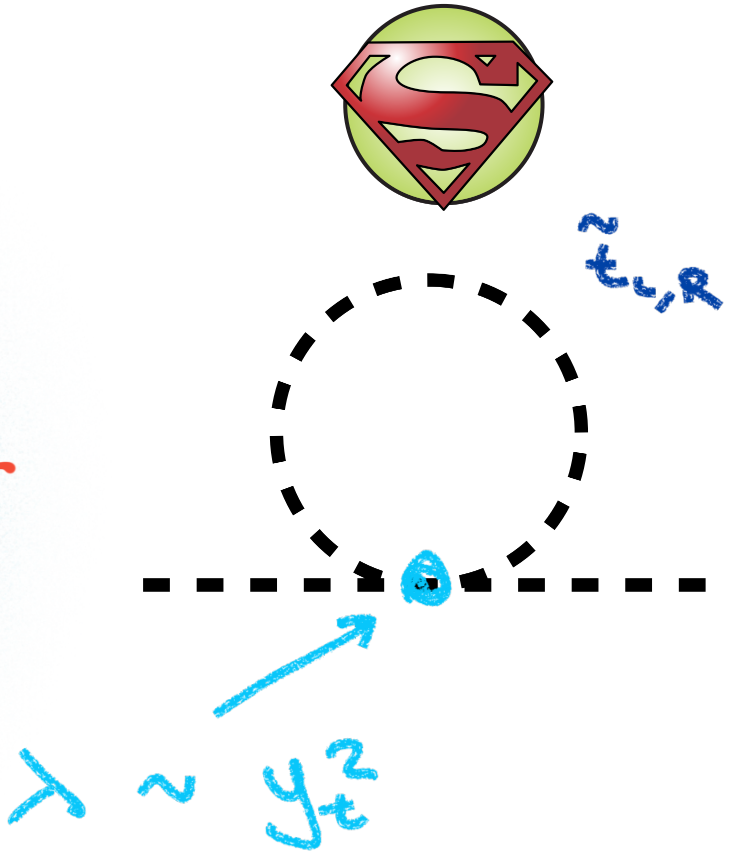
Supersymmetry

why we really like(d) it

Solves Hierarchy Problem

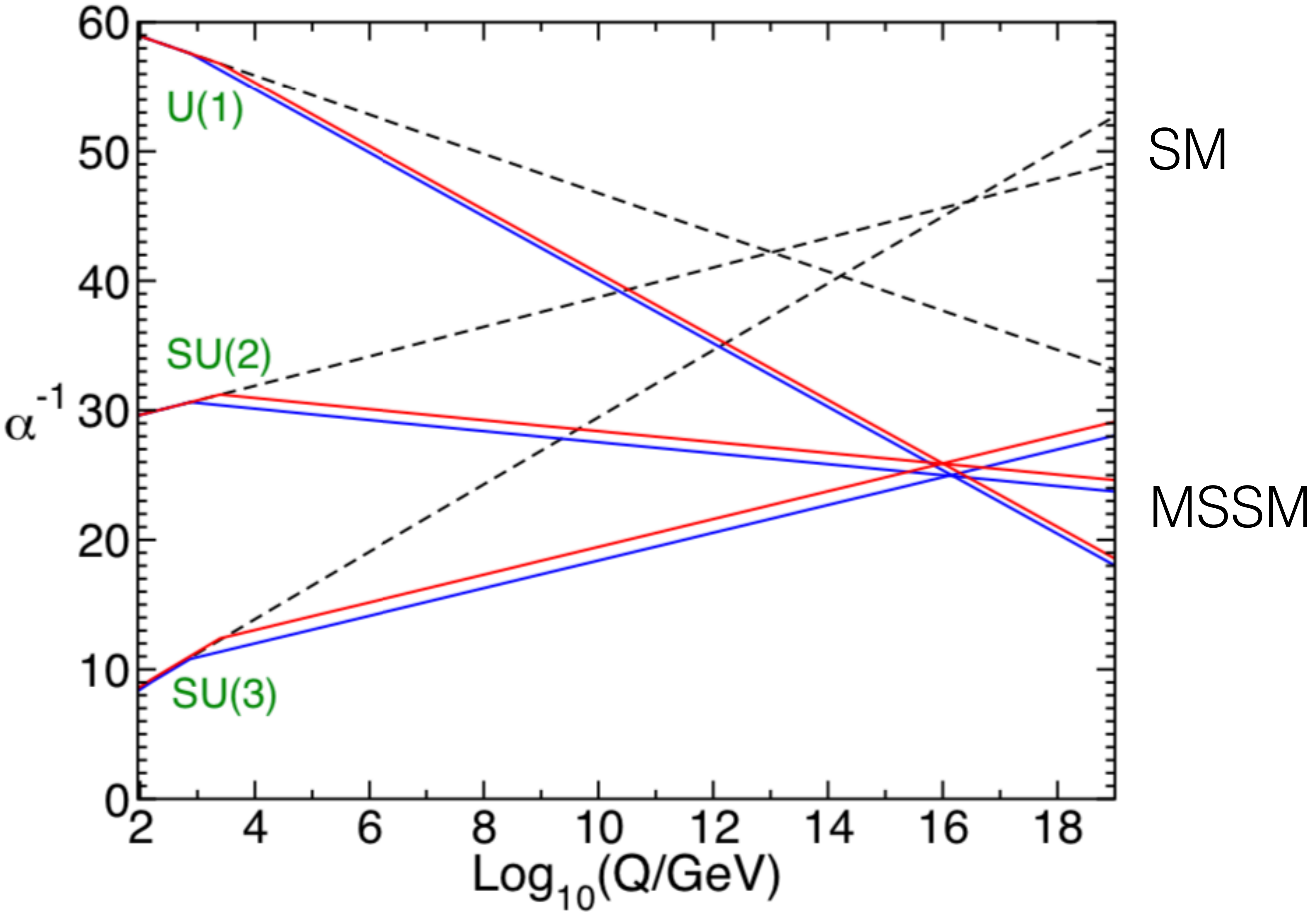






Symmetry principle that protects Higgs mass from quantum corrections in the UV.

gauge unification for free



S. Martin hep-ph/9709356 Fig 6.8

nice dark matter candidate

Requirements: stable, uncharged.
What’s a good dark matter candidate?

caveat: there’s a lot we’re sweeping under the rug
… R-parity and all that (for now)

nice dark matter candidate

Requirements: stable, uncharged.
What's a good dark matter candidate?

caveat: there's a lot we're sweeping under the rug
… R-parity and all that (for now)

the $\tilde{N}_1 \leftarrow$ LIGHTEST NEUTRALINO

(COMBINATION OF $\tilde{H}_u^0, \tilde{H}_d^0, \tilde{B}, \tilde{W}^3$

sometimes: **gravitino** is lightest such state

The MSSM is…

simple enough to understand how and why it works (at least in the SUSY limit)

complex enough to generate many kinds of phenomenological signatures

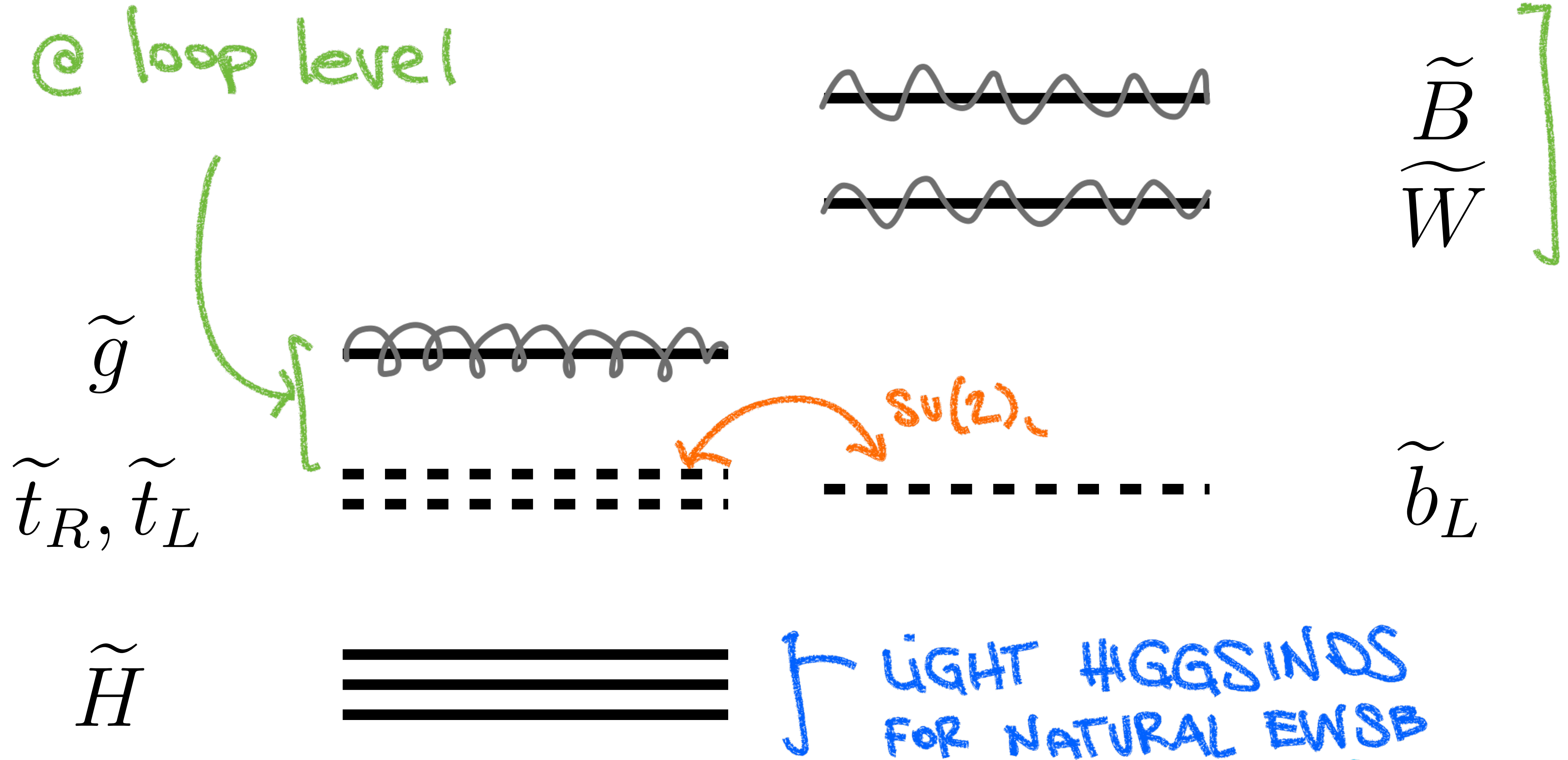
MSSM

basic pheno

natural SUSY spectrum

EW-inos not too heavy (for GUT)

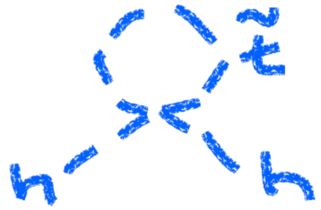
$\tilde{g}$ contribute to $m_{\tilde{t}}$ @ loop level



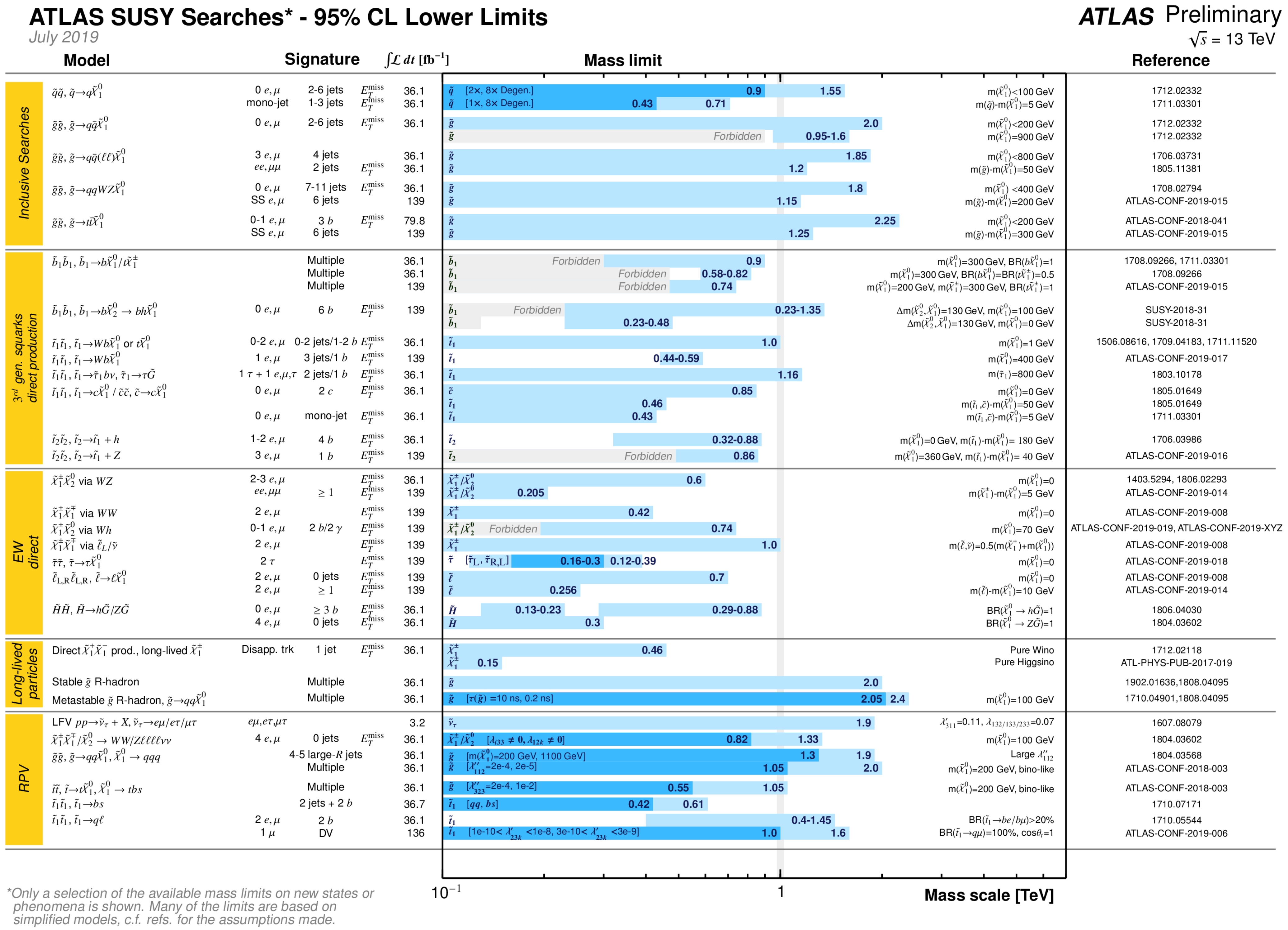
LIGHT HIGGSINOS FOR NATURAL EWSB

$M_{\tilde{H}}$ GOES INTO $V[h]$

LIGHT STOPS



there are no sparticles



ATLAS SUSY Searches* - 95% CL Lower Limits

July 2019

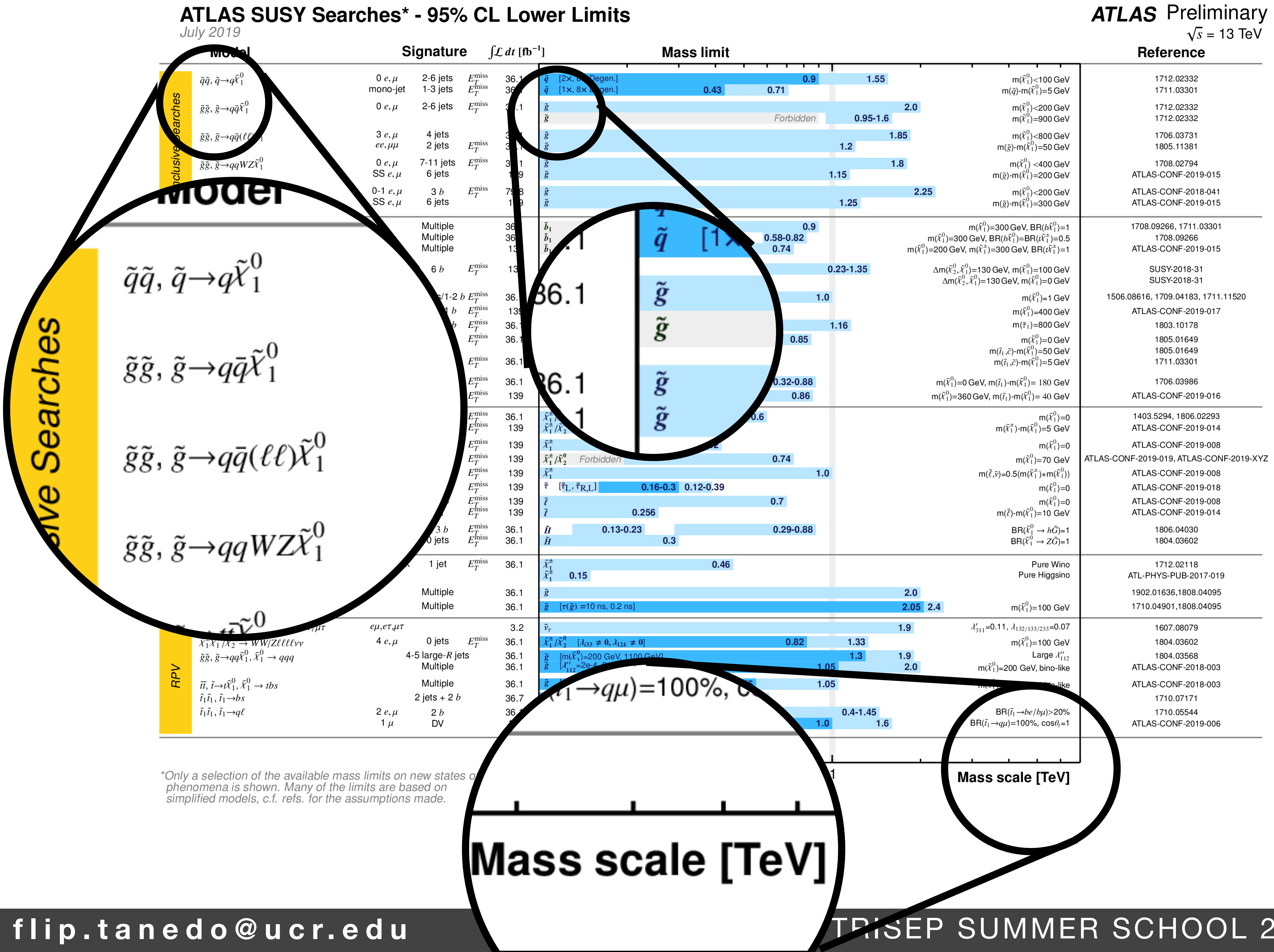
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV

	Model	Signature			$\int\mathcal{L}\,dt$ [fb^{-1}]	Mass limit			Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	36.1	$\tilde{q}$	[2×, 8× Degen.] 0.9 1.55	m($\tilde{\chi}^0_1$)<100 GeV	1712.02332
		mono-jet	1-3 jets	$E_T^{\rm miss}$	36.1	$\tilde{q}$	[1×, 8× Degen.] 0.43 0.71	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	2.0	m($\tilde{\chi}^0_1$)<200 GeV	1712.02332
						$\tilde{g}$	Forbidden 0.95-1.6	m($\tilde{\chi}^0_1$)=900 GeV	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	3 e,μ	4 jets		36.1	$\tilde{g}$	1.85	m($\tilde{\chi}^0_1$)<800 GeV	1706.03731
		$ee,\mu\mu$	2 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	1.2	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ	7-11 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	1.8	m($\tilde{\chi}^0_1$) <400 GeV	1708.02794
		SS e,μ	6 jets		139	$\tilde{g}$	1.15	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=200 GeV	ATLAS-CONF-2019-015
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	$E_T^{\rm miss}$	79.8	$\tilde{g}$	2.25	m($\tilde{\chi}^0_1$)<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$	1.25	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=300 GeV	ATLAS-CONF-2019-015
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1/t\tilde{\chi}^\pm_1$		Multiple		36.1	$\tilde{b}_1$	Forbidden 0.9	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=1	1708.09266, 1711.03301
			Multiple		36.1	$\tilde{b}_1$	Forbidden 0.58-0.82	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=BR($t\tilde{\chi}^\pm_1$)=0.5	1708.09266
			Multiple		139	$\tilde{b}_1$	Forbidden 0.74	m($\tilde{\chi}^0_1$)=200 GeV, m($\tilde{\chi}^\pm_1$)=300 GeV, BR($t\tilde{\chi}^\pm_1$)=1	ATLAS-CONF-2019-015
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$	0 e,μ	6 b	$E_T^{\rm miss}$	139	$\tilde{b}_1$	Forbidden 0.23-1.35	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=100 GeV	SUSY-2018-31
						$\tilde{b}_1$	0.23-0.48	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=0 GeV	SUSY-2018-31
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	1.0	m($\tilde{\chi}^0_1$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	$E_T^{\rm miss}$	139	$\tilde{t}_1$	0.44-0.59	m($\tilde{\chi}^0_1$)=400 GeV	ATLAS-CONF-2019-017
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to\tilde{\tau}_1 b\nu$, $\tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	1.16	m($\tilde{\tau}_1$)=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}$, $\tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	$E_T^{\rm miss}$	36.1	$\tilde{c}$	0.85	m($\tilde{\chi}^0_1$)=0 GeV	1805.01649
						$\tilde{t}_1$	0.46	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.01649
		0 e,μ	mono-jet	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	0.43	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_2$	0.32-0.88	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 180 GeV	1706.03986
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	$E_T^{\rm miss}$	139	$\tilde{t}_2$	Forbidden 0.86	m($\tilde{\chi}^0_1$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 40 GeV	ATLAS-CONF-2019-016
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	2-3 e,μ		$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.6	m($\tilde{\chi}^0_1$)=0	1403.5294, 1806.02293
		$ee,\mu\mu$	≥ 1	$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.205	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV	ATLAS-CONF-2019-014
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1$	0.42	m($\tilde{\chi}^0_1$)=0	ATLAS-CONF-2019-008
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	0-1 e,μ	2 b/2 γ	$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	Forbidden 0.74	m($\tilde{\chi}^0_1$)=70 GeV	ATLAS-CONF-2019-019, ATLAS-CONF-2019-XYZ
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1$	1.0	m($\tilde{\ell}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	ATLAS-CONF-2019-008
	$\tilde{\tau}\tilde{\tau}$, $\tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		$E_T^{\rm miss}$	139	$\tilde{\tau}$	[$\tilde{\tau}_{\rm L}$, $\tilde{\tau}_{\rm R,L}$] 0.16-0.3 0.12-0.39	m($\tilde{\chi}^0_1$)=0	ATLAS-CONF-2019-018
	$\tilde{\ell}_{\rm L,R}\tilde{\ell}_{\rm L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	$E_T^{\rm miss}$	139	$\tilde{\ell}$	0.7	m($\tilde{\chi}^0_1$)=0	ATLAS-CONF-2019-008
		2 e,μ	≥ 1	$E_T^{\rm miss}$	139	$\tilde{\ell}$	0.256	m($\tilde{\ell}$)-m($\tilde{\chi}^0_1$)=10 GeV	ATLAS-CONF-2019-014
	$\tilde{H}\tilde{H}$, $\tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	≥ 3 b	$E_T^{\rm miss}$	36.1	$\tilde{H}$	0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{H}$	0.3	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	1804.03602
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1$	0.46	Pure Wino	1712.02118
						$\tilde{\chi}^\pm_1$	0.15	Pure Higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$	2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$		Multiple		36.1	$\tilde{g}$	[$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.05 2.4	m($\tilde{\chi}^0_1$)=100 GeV	1710.04901,1808.04095
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$			3.2	$\tilde{\nu}_\tau$	1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	[$\lambda_{i33}\neq 0$, $\lambda_{12k}\neq 0$] 0.82 1.33	m($\tilde{\chi}^0_1$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$	[m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$	[λ''_{112}=2e-4, 2e-5] 1.05 2.0	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{g}$	[λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$	[qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$	0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$	[1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	ATLAS-CONF-2019-006

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

ATLAS SUSY summary results

there are no sparticles



there are no sparticles

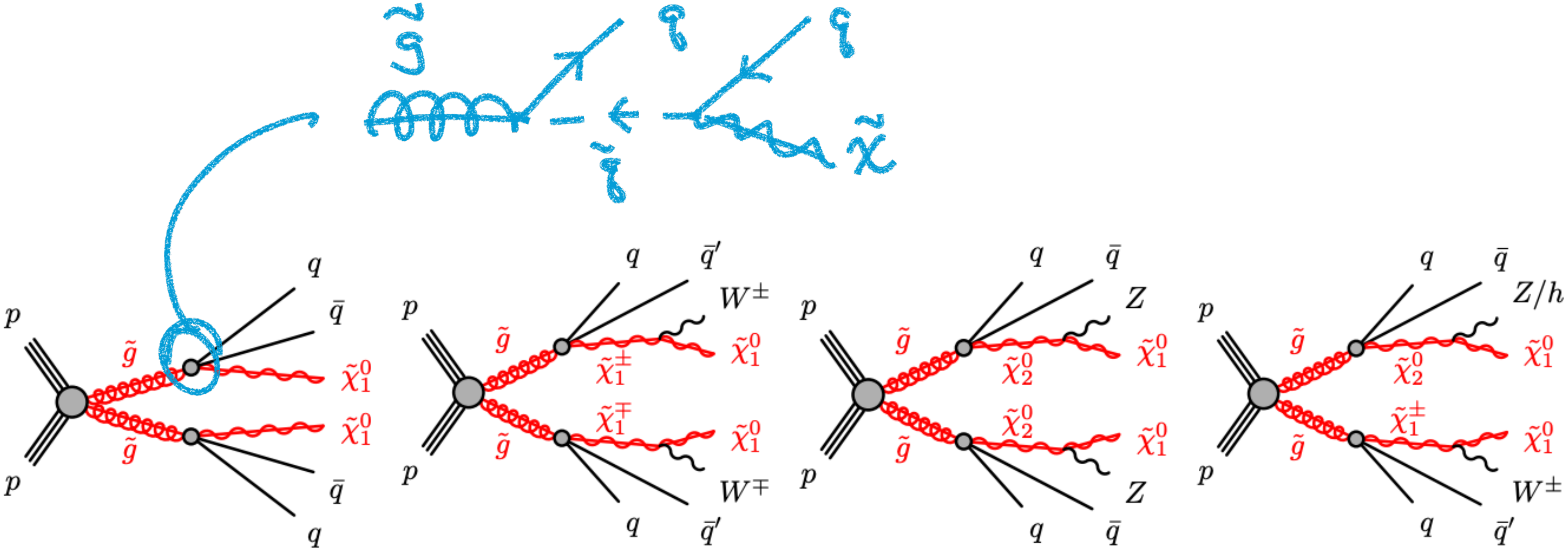
many jets

Model	Signature			$\int\mathcal{L}\,dt$ [fb^{-1}]
$\tilde{g}\tilde{g},\ \tilde{g}\rightarrow q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$\boxed{E_T^{\text{miss}}}$	36.1

no leptons

missing E.

$\tilde{g}$	m($\tilde{\chi}^0_1$)<200 GeV		2.0
$\tilde{g}$	m($\tilde{\chi}^0_1$)=900 GeV	Forbidden	0.95-1.6



1712.02332 via ATLAS