

New Physics

what it is and how we are looking for it

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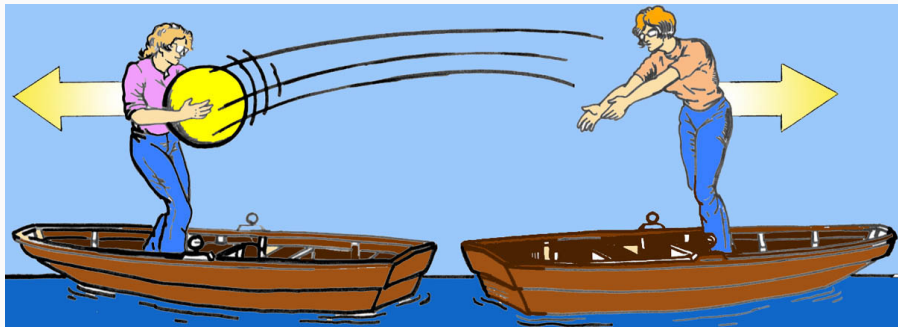
ISMD 2023 Conference Outreach Session

26 August 2023, Hungary

*Lengyel, magyar – két jó barát,
együtt harcol s issza borát.*

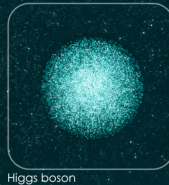
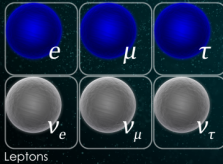
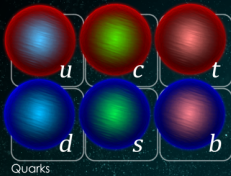
Standard Model

Quantum Field Theory



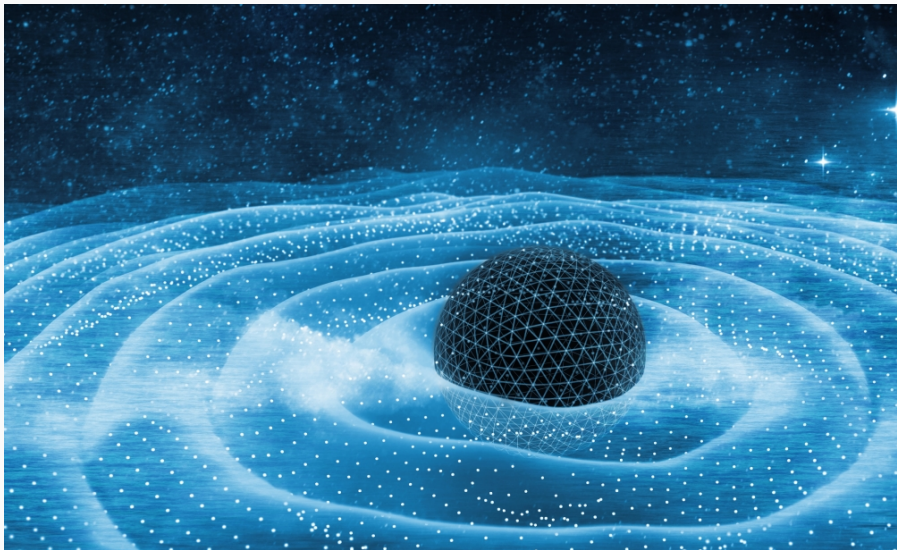
Source: Fermilab

Particles of Standard Model



Standard Model Limitations

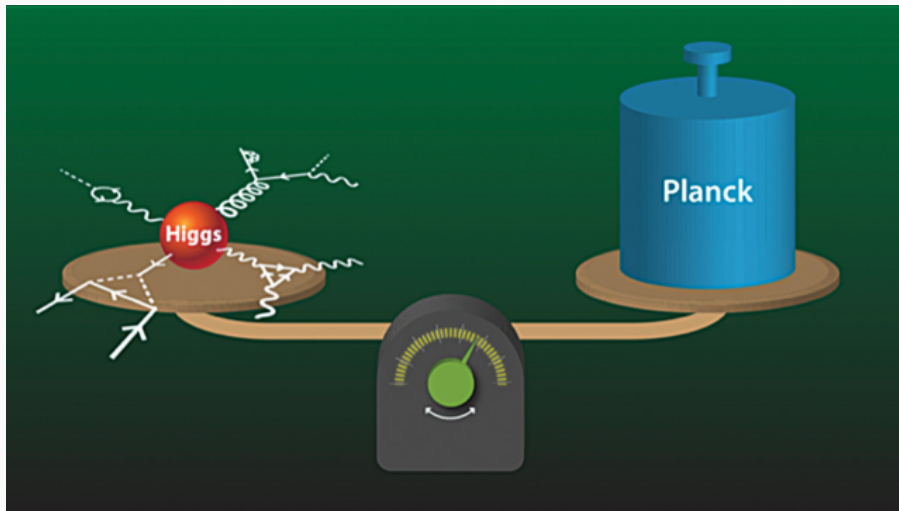
Gravity



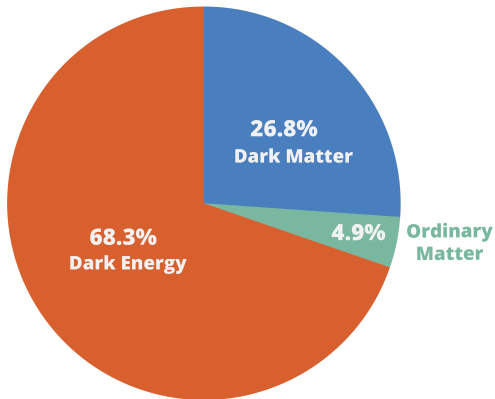
Number of free parameters

Parameters of the Standard Model [hide]			
Symbol	Description	Renormalization scheme (point)	Value
m_e	Electron mass		511 keV
m_μ	Muon mass		105.7 MeV
m_τ	Tau mass		1.78 GeV
m_u	Up quark mass	$\mu_{\overline{MS}} = 2 \text{ GeV}$	1.9 MeV
m_d	Down quark mass	$\mu_{\overline{MS}} = 2 \text{ GeV}$	4.4 MeV
m_s	Strange quark mass	$\mu_{\overline{MS}} = 2 \text{ GeV}$	87 MeV
m_c	Charm quark mass	$\mu_{\overline{MS}} = m_c$	1.32 GeV
m_b	Bottom quark mass	$\mu_{\overline{MS}} = m_b$	4.24 GeV
m_t	Top quark mass	On-shell scheme	172.7 GeV
θ_{12}	CKM 12-mixing angle		13.1°
θ_{23}	CKM 23-mixing angle		2.4°
θ_{13}	CKM 13-mixing angle		0.2°
δ	CKM CP-violating Phase		0.995
g_1 or g'	U(1) gauge coupling	$\mu_{\overline{MS}} = m_Z$	0.357
g_2 or g	SU(2) gauge coupling	$\mu_{\overline{MS}} = m_Z$	0.652
g_3 or g_s	SU(3) gauge coupling	$\mu_{\overline{MS}} = m_Z$	1.221
θ_{QCD}	QCD vacuum angle		~0
v	Higgs vacuum expectation value		246 GeV
m_H	Higgs mass		~ 125 GeV (tentative)

Hierarchy problem



Estimated matter-energy content of the Universe



New Physics

Beyond Standard Model:

Supersymmetry?

Symmetry

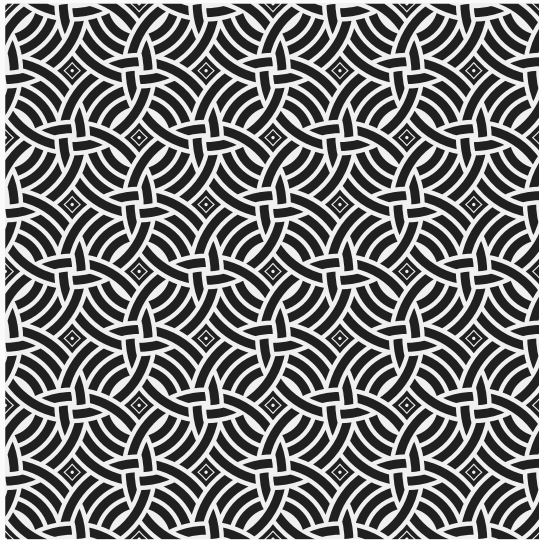
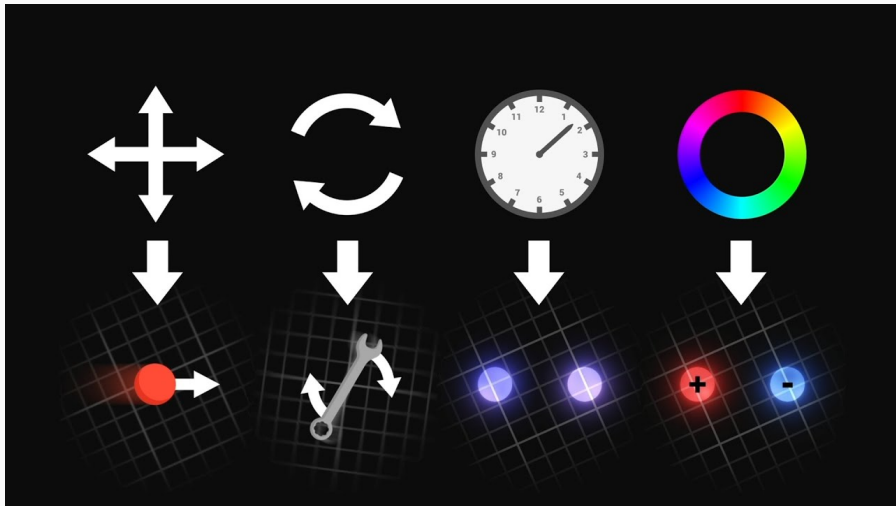


Image by zarubin-leonid on Freepik

Role of Symmetries in Physics



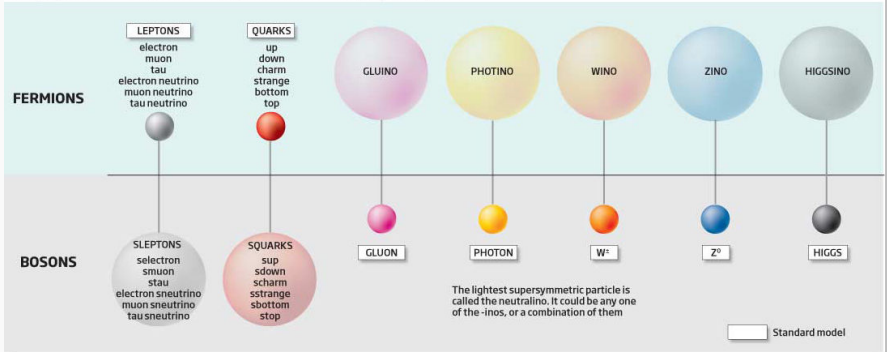
Source: [youtube.com/@ScienceClicEN](https://www.youtube.com/@ScienceClicEN)

Supersymmetry (SUSY)

Particle zoo

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Particles are divided into two families called bosons and fermions. Among them are groups known as leptons, quarks and force-carrying particles like the photon. Supersymmetry doubles the number of particles, giving each fermion a massive boson as a super-partner and vice versa. The LHC is expected to find the first supersymmetric particle



Direct searches for SUSY

ATLAS SUSY Searches* - 95% CL Lower Limits

March 2023

ATLAS Preliminary

$\sqrt{s} = 13$ TeV

Model	Signature	[$\mathcal{L} \text{ dt}$] [fb^{-1}]	Mass limit	Reference	
Inclusive Searches	$\tilde{g}\tilde{g}, \tilde{q}\tilde{q} \rightarrow \tilde{q}\tilde{q}^0$	0 e, μ , mono-jet	2-6 jets $E_{T,miss}^{200}$ 139	\tilde{g} [16, 18, Degen] 1.0 1.85 \tilde{q} [16, Degen] 0.9 \tilde{g} Forbidden 1.15-1.95 2.3 \tilde{q} 2.2 \tilde{g} 2.2	$m(\tilde{t}_1^0) = 400$ GeV 210.14290 $m(\tilde{g}) - m(\tilde{t}_1^0) = 5$ GeV 2102.10874 $m(\tilde{t}_1^0) = 1000$ GeV 2010.14293 2010.14293
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	1 e, μ , 2-6 jets	$E_{T,miss}^{200}$ 139	\tilde{g} 2.2 \tilde{q} 2.2	$m(\tilde{t}_1^0) = 600$ GeV 2101.01629 $m(\tilde{t}_1^0) = 700$ GeV 2204.13072
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 (W, Z) \tilde{q}^0$	0 e, μ , 7-11 jets	$E_{T,miss}^{200}$ 139	\tilde{g} 1.15 1.97	$m(\tilde{t}_1^0) < 600$ GeV 2008.06032 $m(\tilde{g}) - m(\tilde{t}_1^0) = 200$ GeV 1909.08457
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W Z \tilde{q}^0$	0 e, μ , 6 jets	$E_{T,miss}^{200}$ 139	\tilde{g} 1.15 1.97	$m(\tilde{t}_1^0) < 600$ GeV 2008.06032 $m(\tilde{g}) - m(\tilde{t}_1^0) = 200$ GeV 1909.08457
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0$	0-1 e, μ , 3 b	$E_{T,miss}^{200}$ 139	\tilde{g} 1.25 2.45	$m(\tilde{t}_1^0) = 500$ GeV 2101.08129 $m(\tilde{g}) - m(\tilde{t}_1^0) = 300$ GeV 1909.08457
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0$	0 e, μ , 2 b	$E_{T,miss}^{200}$ 139	\tilde{g} 0.68 1.255	$m(\tilde{t}_1^0) = 400$ GeV 2101.12527 $m(\tilde{g}) - m(\tilde{t}_1^0) = 20$ GeV 2101.12527
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b}, \tilde{t}_1 \rightarrow \tilde{b}\tilde{t}_1^0 \rightarrow \tilde{b}\tilde{t}_1^0$	0 e, μ , 6 b	$E_{T,miss}^{200}$ 139	\tilde{g} Forbidden 0.13-0.85 0.23-1.35	$m(\tilde{t}_1^0) = 100$ GeV $\Delta m(\tilde{t}_1^0, \tilde{t}_1^0) = 130$ GeV, $m(\tilde{t}_1^0) = 100$ GeV $\Delta m(\tilde{t}_1^0, \tilde{t}_1^0) = 130$ GeV, $m(\tilde{t}_1^0) = 100$ GeV
3 rd gen. squarks direct production	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	0-1 e, μ , ≥ 1 jet	$E_{T,miss}^{200}$ 139	\tilde{t}_1 1.25	$m(\tilde{t}_1^0) = 1$ GeV 2004.14060, 2012.03799
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W \tilde{b}\tilde{t}_1^0$	1 e, μ , 3 jets+1 b	$E_{T,miss}^{200}$ 139	\tilde{t}_1 Forbidden 0.85 1.25	$m(\tilde{t}_1^0) = 500$ GeV 2012.03799
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tau, b, \nu, \tilde{t}_1 \rightarrow \tau G$	1-2 τ , 2 jets+1 b	$E_{T,miss}^{200}$ 139	\tilde{t}_1 Forbidden 1.4	$m(\tilde{t}_1^0) = 800$ GeV 2108.07865
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{t}_1^0 / \tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{t}_1^0$	0 e, μ , 2 c	$E_{T,miss}^{200}$ 36.1	\tilde{t}_1 0.55 0.85	$m(\tilde{t}_1^0) = 40$ GeV 1805.01649
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{t}_1^0 / \tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{t}_1^0$	0 e, μ , mono-jet	$E_{T,miss}^{200}$ 139	\tilde{t}_1 0.55 0.85	$m(\tilde{t}_1^0) = 40$ GeV 2102.10874
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow Z/\tilde{b}\tilde{t}_1^0$	1-2 e, μ , 1-4 b	$E_{T,miss}^{200}$ 139	\tilde{t}_1 0.667-1.18	$m(\tilde{t}_1^0) = 500$ GeV 2006.05804
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow \tilde{t}_1 \tilde{t}_1 + Z$	3 e, μ , 1 b	$E_{T,miss}^{200}$ 139	\tilde{b}_1 Forbidden 0.86	$m(\tilde{t}_1^0) = 500$ GeV $m(\tilde{t}_1^0) = 360$ GeV, $m(\tilde{t}_1^0) = 40$ GeV 2006.05804
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	Multiple l/τ jets	$E_{T,miss}^{200}$ 139	$\tilde{t}_1^0, \tilde{t}_1^0$ 0.205 0.96	$m(\tilde{t}_1^0) = 0$, wino-bino $m(\tilde{t}_1^0) - m(\tilde{t}_1^0) = 5$ GeV, wino-bino 2106.01676, 2106.07586 1911.12606
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W \tilde{b}\tilde{t}_1^0$	2 e, μ , Multiple l/τ jets	$E_{T,miss}^{200}$ 139	\tilde{t}_1^0 0.42 1.06	$m(\tilde{t}_1^0) = 0$, wino-bino $m(\tilde{t}_1^0) = 70$ GeV, wino-bino 1908.08215 2004.10964, 2106.07586
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W \tilde{b}\tilde{t}_1^0$	2 e, μ , 2 τ	$E_{T,miss}^{200}$ 139	\tilde{t}_1^0 1.0	$m(\tilde{t}_1^0) = 0$, wino-bino $m(\tilde{t}_1^0) = 0, 3m(\tilde{t}_1^0) = m(\tilde{t}_1^0)$ 1908.08215
$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	2 τ	$E_{T,miss}^{200}$ 139	\tilde{t}_1 [16, 18, Degen] 0.16-0.3 0.12-0.39	$m(\tilde{t}_1^0) = 0$ 1911.06660	
EW direct	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	2 e, μ , 0 jets	$E_{T,miss}^{200}$ 139	\tilde{t}_1 0.7	$m(\tilde{t}_1^0) = 0$ 1908.08215
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	≥ 1 jet	$E_{T,miss}^{200}$ 139	\tilde{t}_1 0.255	$m(\tilde{t}_1^0) = 10$ GeV 1911.12606
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow hG/\tilde{Z}\tilde{G}$	0 e, μ , ≥ 3 b	$E_{T,miss}^{200}$ 36.1	\tilde{H} 0.13-0.23 0.29-0.88	$BR(\tilde{H}^0 \rightarrow \tilde{t}_1 \tilde{t}_1^0) = 1$ 1806.04030
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow hG/\tilde{Z}\tilde{G}$	4 e, μ , 0 jets	$E_{T,miss}^{200}$ 139	\tilde{H} 0.55	$BR(\tilde{H}^0 \rightarrow \tilde{t}_1 \tilde{t}_1^0) = 1$ 2103.11684
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow hG/\tilde{Z}\tilde{G}$	0 e, μ , ≥ 3 large jets	$E_{T,miss}^{200}$ 139	\tilde{H} 0.45-0.93	$BR(\tilde{H}^0 \rightarrow \tilde{t}_1 \tilde{t}_1^0) = 1$ 2103.07566
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow hG/\tilde{Z}\tilde{G}$	2 e, μ , ≥ 2 jets	$E_{T,miss}^{200}$ 139	\tilde{H} 0.77	$BR(\tilde{H}^0 \rightarrow \tilde{t}_1 \tilde{t}_1^0) = 1, \lambda(\tilde{Z}) = 0.5$ 2204.13072
Long-lived particles	Direct $\tilde{t}_1^0, \tilde{t}_1^0$ prod., long-lived \tilde{t}_1^0	Disapp. trk 1 jet	$E_{T,miss}^{200}$ 139	\tilde{t}_1^0 0.21 0.66	Pure Wino 2201.02472 Pure Higgsino 2201.02472
	Stable β R-hadron	pixel dE/dx	$E_{T,miss}^{200}$ 139	\tilde{t}_1^0 2.05	$m(\tilde{t}_1^0) = 100$ GeV 2205.06013
	Metastable β R-hadron, $\tilde{g} \rightarrow \tilde{q}\tilde{q}^0$	pixel dE/dx	$E_{T,miss}^{200}$ 139	\tilde{g} [16] ($\tau = 10$ ns) 2.2	2205.06013
	$\tilde{H}, \tilde{L} \rightarrow hG$	Displ. klp	$E_{T,miss}^{200}$ 139	\tilde{H}, \tilde{L} 0.34 0.7	$\tau(\tilde{H}) = 0.1$ ns 2011.07812 $\tau(\tilde{L}) = 0.1$ ns 2103.07566 $\tau(\tilde{L}) = 10$ ns 2205.06013
	$\tilde{H}, \tilde{L} \rightarrow hG$	pixel dE/dx	$E_{T,miss}^{200}$ 139	\tilde{H}, \tilde{L} 0.36	2011.07812 2103.07566 2205.06013
RPV	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	3 e, μ , 0 jets	$E_{T,miss}^{200}$ 139	$\tilde{t}_1^0, \tilde{t}_1^0$ [BR($\tilde{t}_1 \rightarrow \tilde{t}_1^0$), BR($\tilde{t}_1 \rightarrow \tilde{t}_1^0$)] 0.625 1.05	Pure Wino 2011.10543
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1^0$	4 e, μ , 0 jets	$E_{T,miss}^{200}$ 139	$\tilde{t}_1^0, \tilde{t}_1^0$ [$\lambda_{111} \neq 0, \lambda_{121} \neq 0$] 0.95 1.55	$m(\tilde{t}_1^0) = 200$ GeV 2103.11684
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	4-5 large jets	$E_{T,miss}^{200}$ 36.1	\tilde{g} [$m(\tilde{t}_1^0) = 200$ GeV, 1100 GeV] 1.3 1.9	Large \tilde{t}_1 1804.02568
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	Multiple	$E_{T,miss}^{200}$ 36.1	\tilde{g} [$\lambda_{111} > 0, \lambda_{121} > 0$] 0.55 1.05	$m(\tilde{t}_1^0) = 200$ GeV, bino-like $m(\tilde{t}_1^0) = 500$ GeV ATLAS CONF-2018-003
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	$\geq 4b$	$E_{T,miss}^{200}$ 139	\tilde{g} Forbidden 0.95	2010.01015
	$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	2 jets + 2 b	$E_{T,miss}^{200}$ 36.7	\tilde{g} [16, 18, Degen] 0.42 0.61	1710.07717
$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	2 e, μ , 2 b	$E_{T,miss}^{200}$ 36.1	\tilde{g} [16-10 $\times \lambda_{111} < 1e-8, 3e-10 \times \lambda_{121} < 3e-9$] 1.0 0.4-1.45	BR($\tilde{g} \rightarrow \tilde{t}_1 \tilde{t}_1^0$) = 20% 1710.07717 BR($\tilde{g} \rightarrow \tilde{q}\tilde{q}^0$) = 100%, $\cos\theta = 1$ 2010.11956	
$\tilde{g}\tilde{g}, \tilde{b}\tilde{b} \rightarrow \tilde{q}\tilde{q}^0 W \tilde{q}^0$	1 e, μ , 1 DV	$E_{T,miss}^{200}$ 136	\tilde{g} 0.2-0.32	Pure Higgsino 2106.09009	

*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.

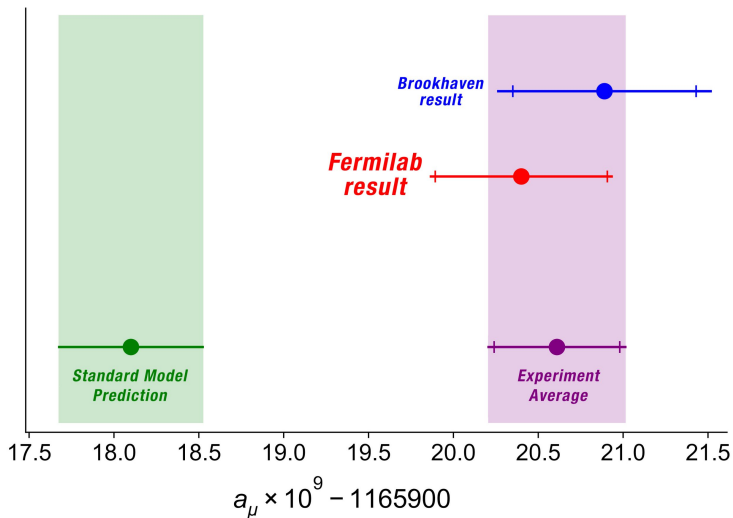
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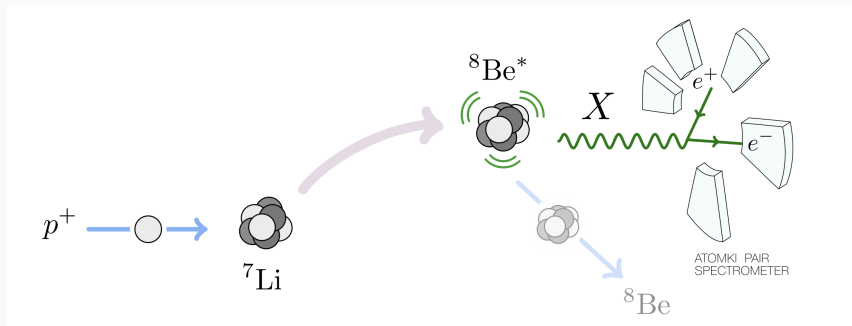
Mass scale [TeV]

Hints of New Physics

Moun anomalous magnetic moment ($g - 2$)



ATOMKI Anomaly – X17



Source: Phys. Rev. D 95, 035017 (2017)

