Physics Beyond the Standard Model

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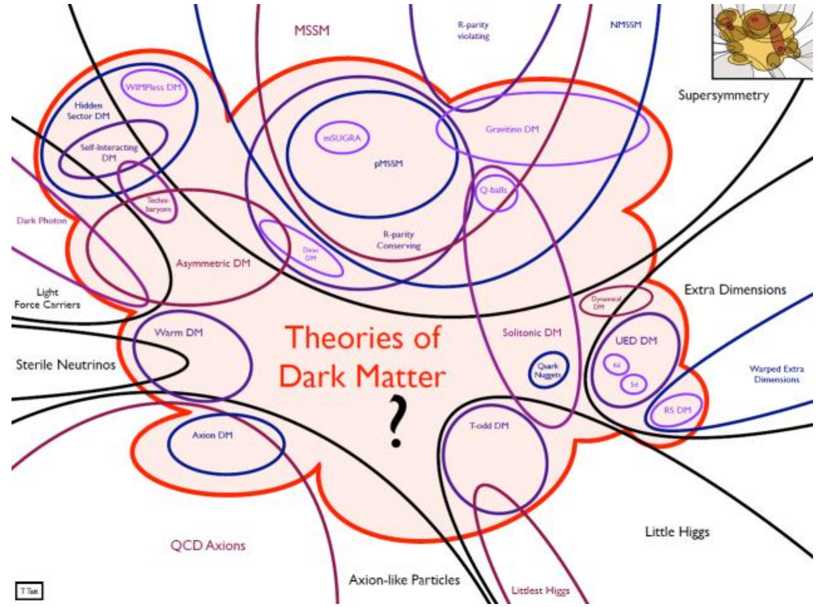


L1. Introduction. EFT (SMEFT, EFT for DM)

L2. UV complete theories (SUSY, Extra Dimensions)

L3. Simplified models. Concluding remarks

L3

Searches above threshold

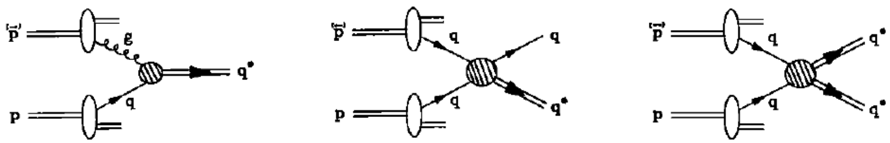
- Simplified models

Exited top quark

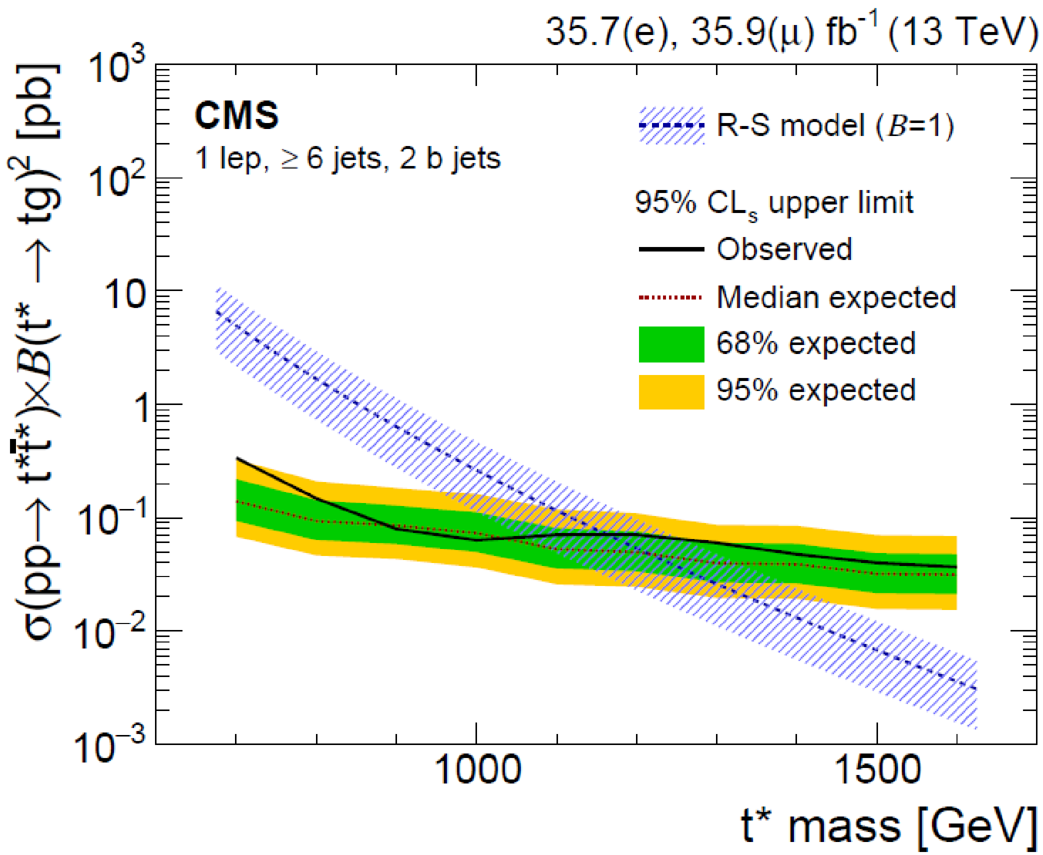
Baur, Spira, Zerwas

$$\mathcal{L}_{gauge} = \bar{f}^{*}\gamma^{\mu}\left[g_s\frac{\lambda^a}{2}G^a_\mu + g\frac{\vec{\tau}}{2}\vec{W}_\mu + g'\frac{Y}{2}B_\mu\right]f^{*}$$

$$\mathcal{L}_{trans} = \frac{1}{2\Lambda}\bar{f}^{*}_{R}\sigma^{\mu\nu}\left[g_s f_s\frac{\lambda^a}{2}G^a_{\mu\nu} + g f\frac{\vec{\tau}}{2}\vec{W}_{\mu\nu} + g' f'\frac{Y}{2}B_{\mu\nu}\right]f_L + h.c.$$



1711.10949



Vector like top partners

Vector-like quarks - spin 1/2 particles with the same colour (triplet) and electroweak quantum numbers for left and right components
Masses not from the BEH mechanism
$\bar{Q}_L Q_R$ mass terms are allowed some gauge symmetry

VLQ appear in many BSM extensions

Matsedonskyia, Panicob, Wulzer

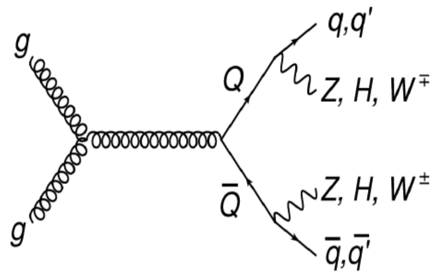
partner (MG name)	Q	$W^\pm$	Z	h	$W^\pm W^\pm$
$T_{2/3}$ (T23)	2/3	c_L^{TW}, c_R^{TW}	c_L^{TZ}, c_R^{TZ}	c_L^{Th}, c_R^{Th}	—
$B_{1/3}$ (B13)	-1/3	c_L^{BW}, c_R^{BW}	c_L^{BZ}, c_R^{BZ}	c_L^{Bh}, c_R^{Bh}	—
$X_{5/3}$ (X53)	5/3	c_L^{XW}, c_R^{XW}	—	—	—
$Y_{4/3}$ (Y43)	-4/3	c_L^{YW}, c_R^{YW}	—	—	—
$V_{8/3}$ (V83)	8/3	—	—	—	c_L^{VW}, c_R^{VW}

Example of the simplified model Lagrangian
(after mixing and mass matrix diagonalization)

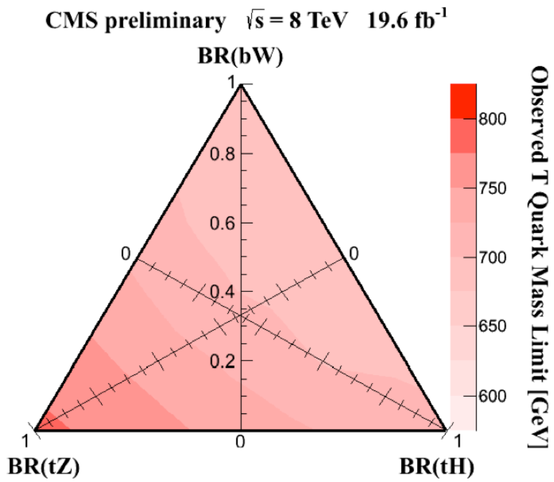
$$\frac{g_w}{2} c_L^{TW} \left[\overline{T}_L \gamma_\mu b_L W^\mu \right] + h.c.$$

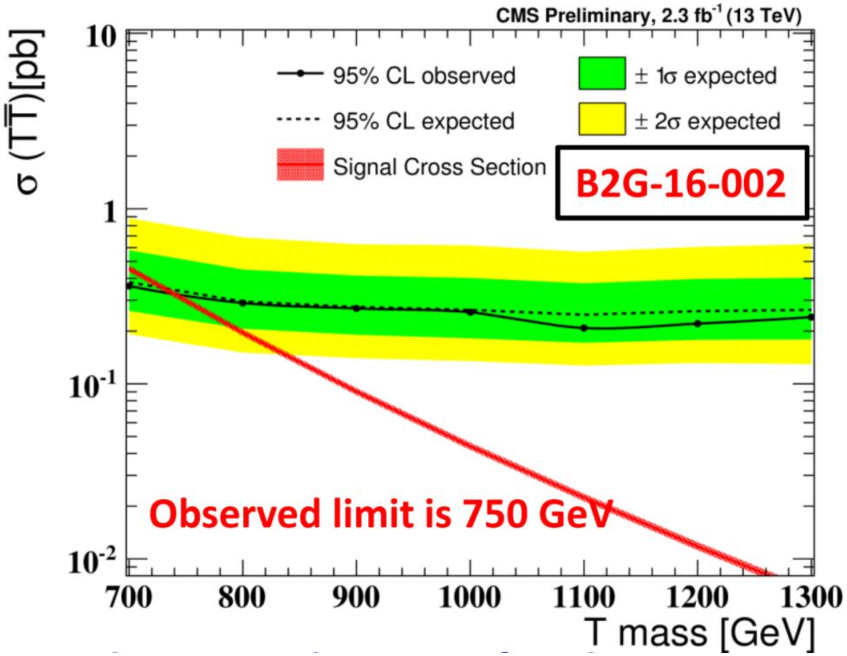
$$c_L^{Th} \left[\overline{T}_R t_L h \right] + h.c.$$

Similar limit at 13 TeV with just 2.3 fb^{-1} integrated luminosity



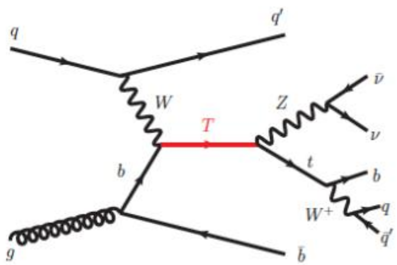
T → Zt, T → Wb, T → Ht for Q_T=2/3

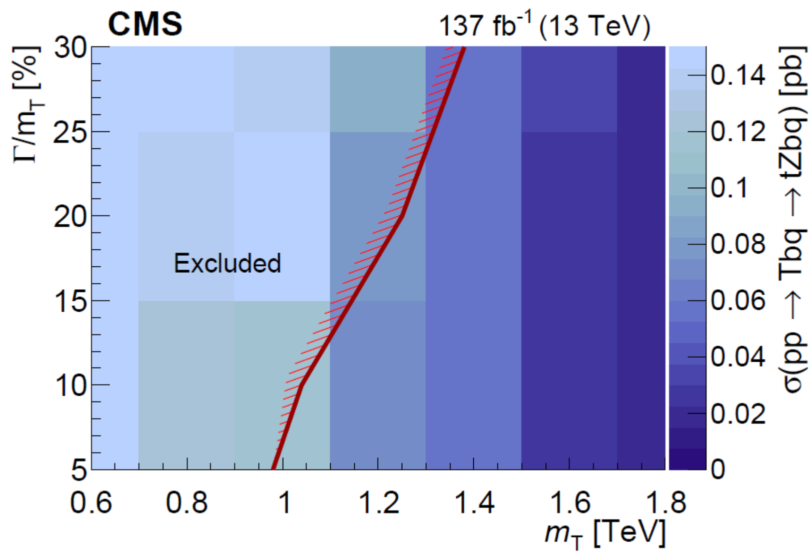


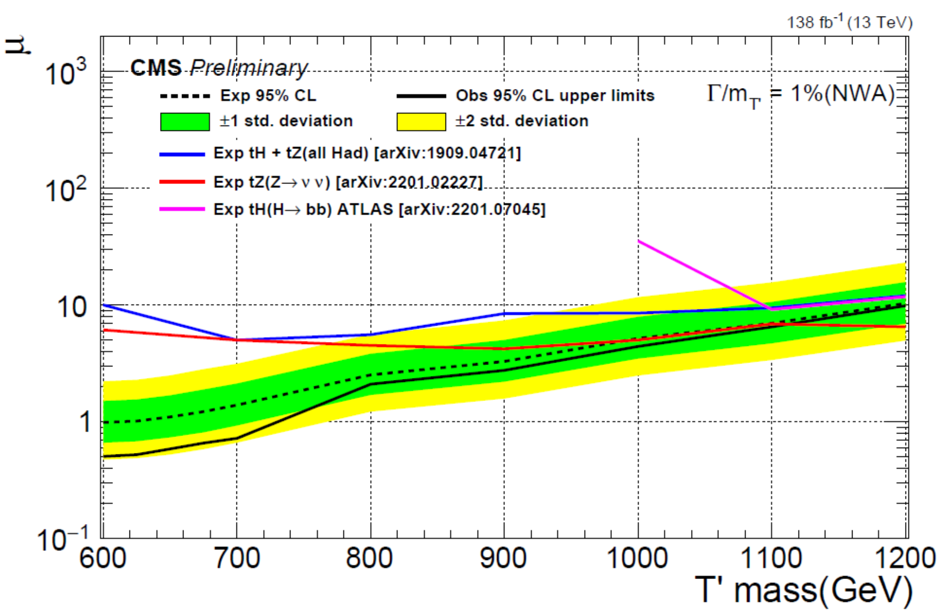


Also some limits are set on couplings and masses from single VLQ production

Limits are set on couplings and masses from single VLQ production





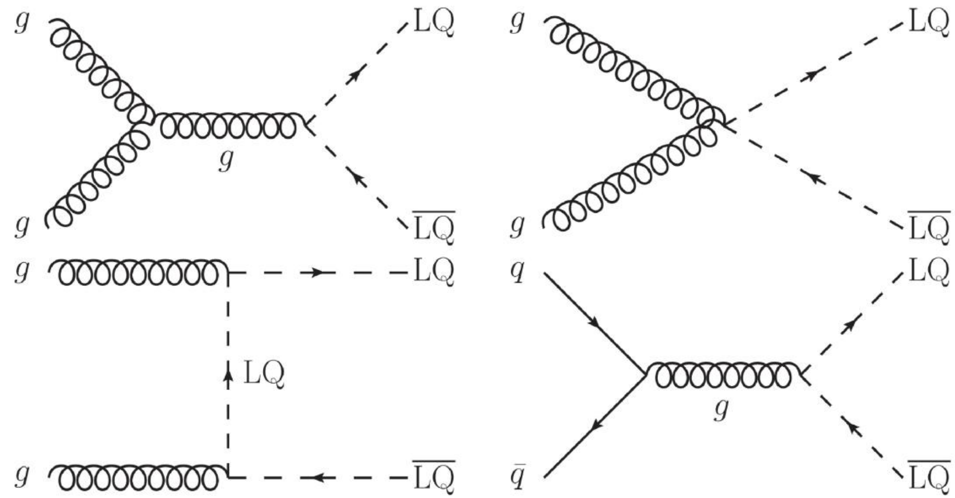


T' masses up to 730 GeV are excluded at 95% confidence level

Leptoquark searches

LQs are predicted by composite models, GUT …

Production channels



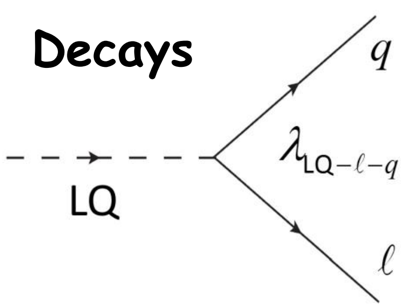
Blumlein, E.B., Kryukov

$$\mathcal{L}_S^g = \sum_{scalars} \left[\left(D_{ij}^{\mu} \Phi^j \right)^{\dagger} \left(D_{\mu}^{ik} \Phi_k \right) - M_S^2 \Phi^{i\dagger} \Phi_i \right]$$

$$\mathcal{L}_V^g = \sum_{vectors} \left\{ -\frac{1}{2} G_{\mu\nu}^{i\dagger} G_i^{\mu\nu} + M_V^2 \Phi_{\mu}^{i\dagger} \Phi_i^{\mu} - i g_s \left[(1-\kappa_G) \Phi_{\mu}^{i\dagger} t_{ij}^a \Phi_{\nu}^j \mathcal{G}_a^{\mu\nu} + \frac{\lambda_G}{M_V^2} G_{\sigma\mu}^{i\dagger} t_{ij}^a G_{\nu}^{j\mu} \mathcal{G}_a^{\nu\sigma} \right] \right\}$$

$\kappa_G = \lambda_G = 0$ Yang-Mills coupling $\kappa_G = 1, \lambda_G = 0$ Minimal coupling

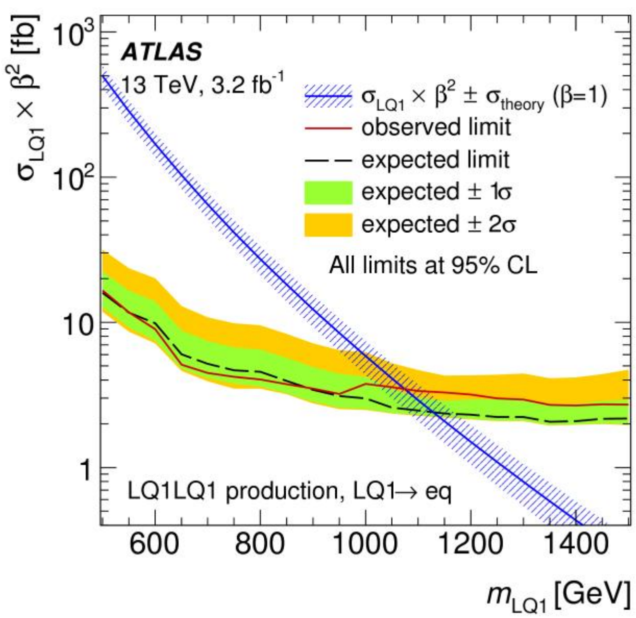
Decays

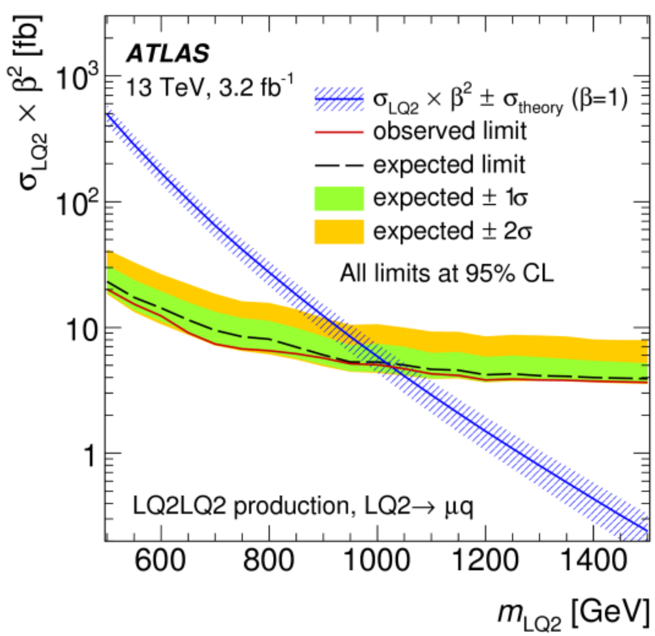


Final states for leptoquarks of three generations

LQ1 → eu, ed, ν_eu, ν_ed
LQ2 → μc, μs, ν_μc, ν_μs
LQ3 → τt, τb, ν_τt, ν_τb

1st generation LQ mass limit for β=1 RUN1 • CMS: 1010 GeV; ATLAS 1060 GeV
2nd generation LQ mass limit for β=1 RUN1 • CMS: 1080 GeV; ATLAS 1050 GeV





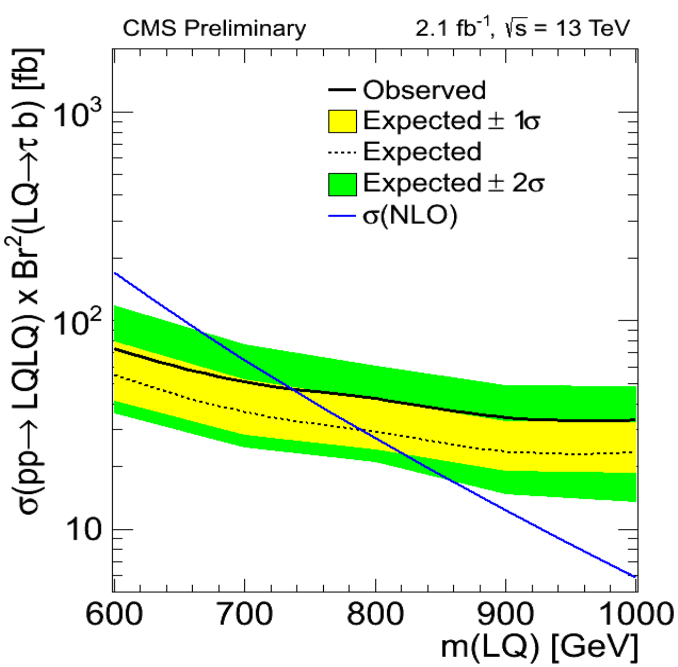
1130 GeV for β=1

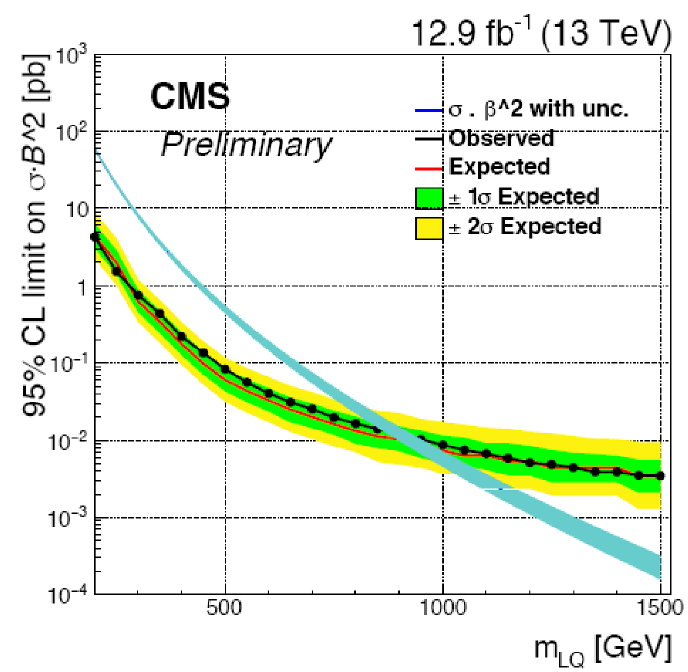
1165 GeV for β=1

Sensitivity is similar for ~20 fb^{-1} at $\sqrt{s}$ = 8 TeV and for ~3 fb^{-1} at $\sqrt{s}$ = 13 TeV

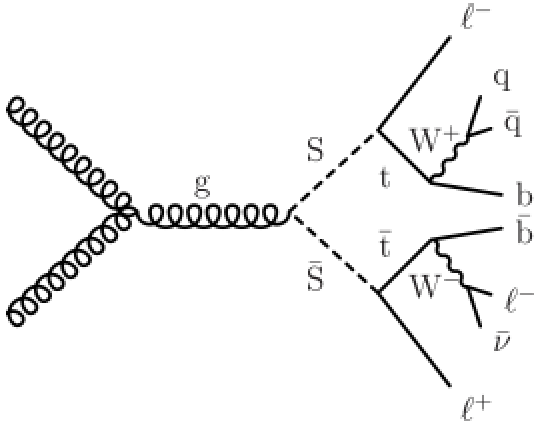
Limits on 3d generation leptoquarks

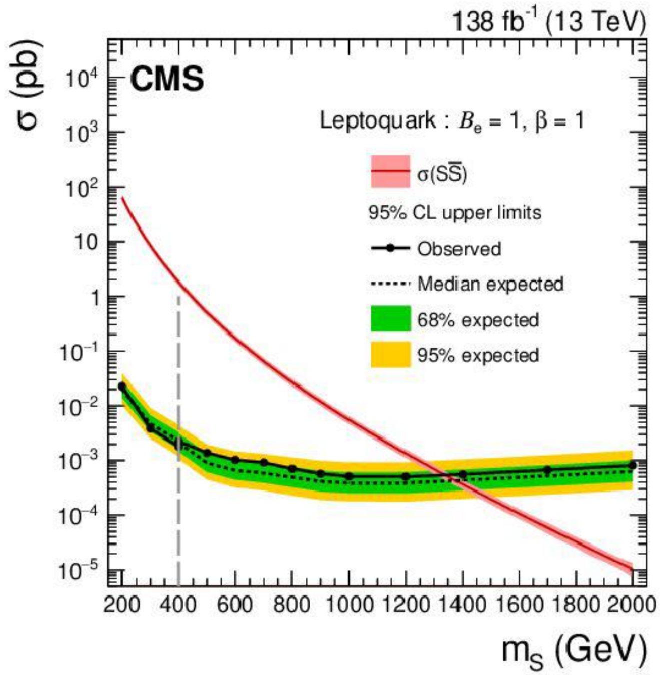
β = BR(LQ→lq)



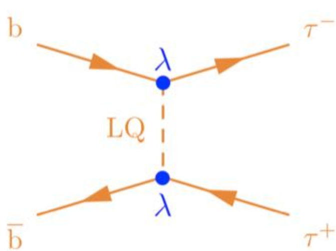


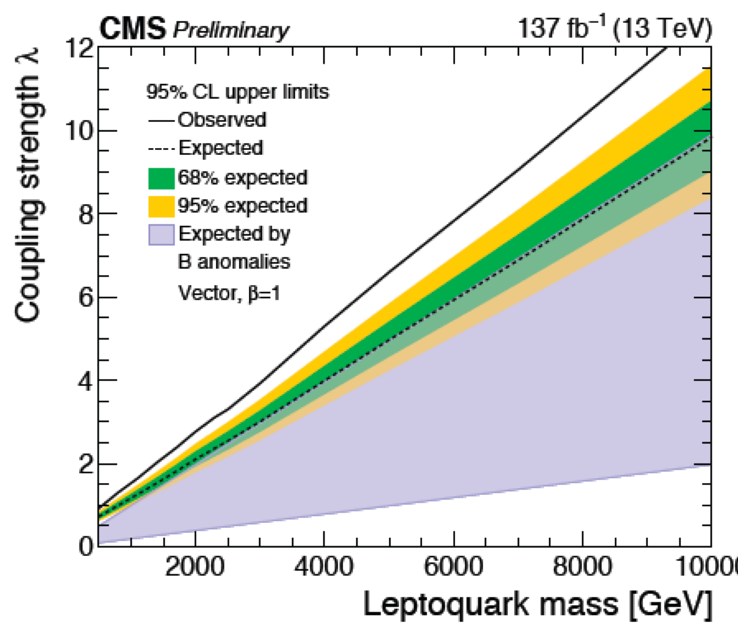
Limit: M(LQ3) > ~900 GeV



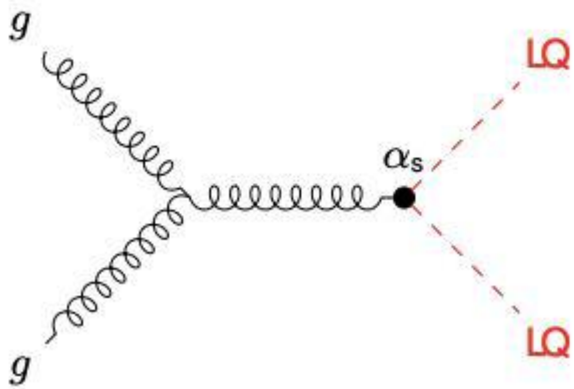


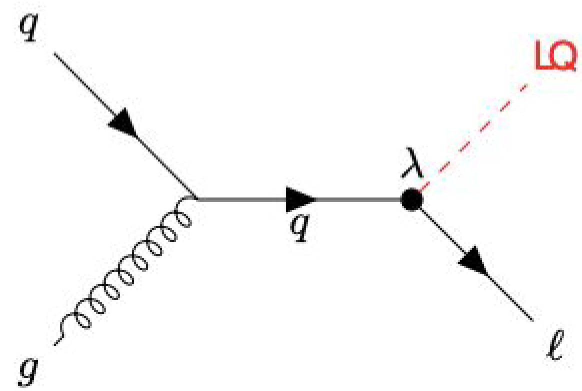
nonresonant





LQ-Pair production decaying to third generation quarks and leptons





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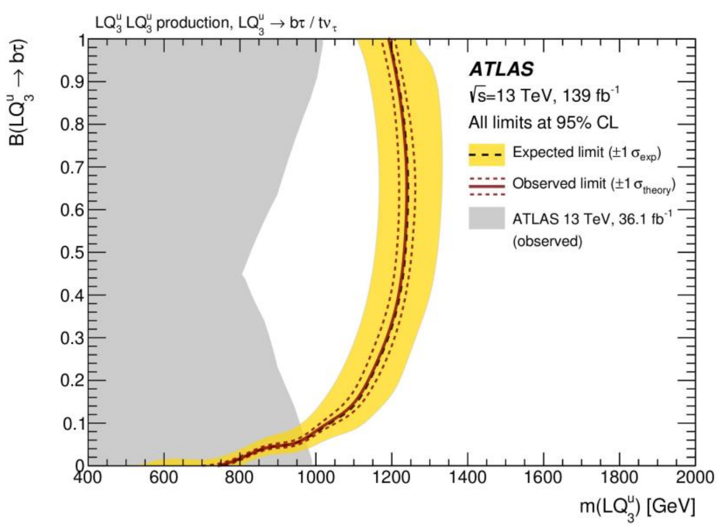
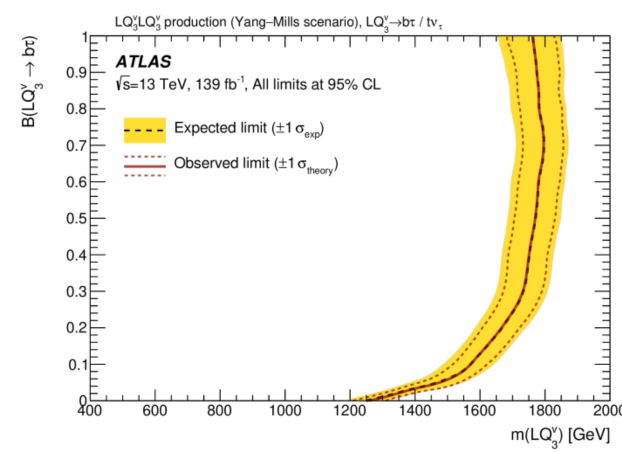
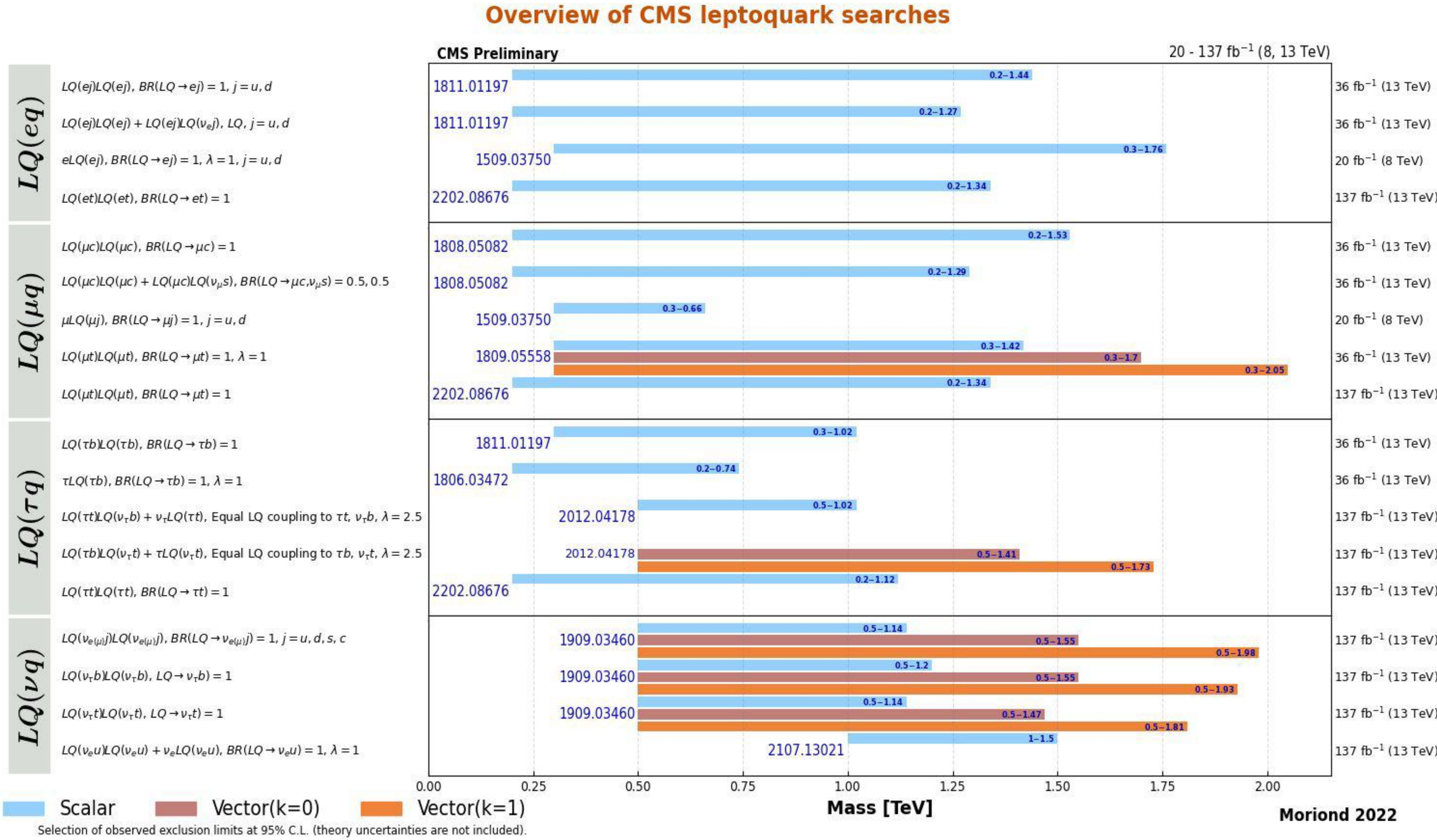




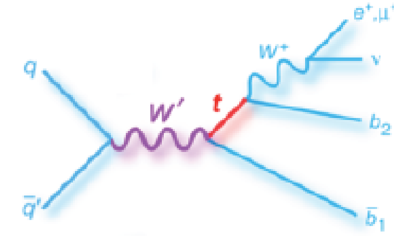
Exclusion up to 1.25 TeV for scalar

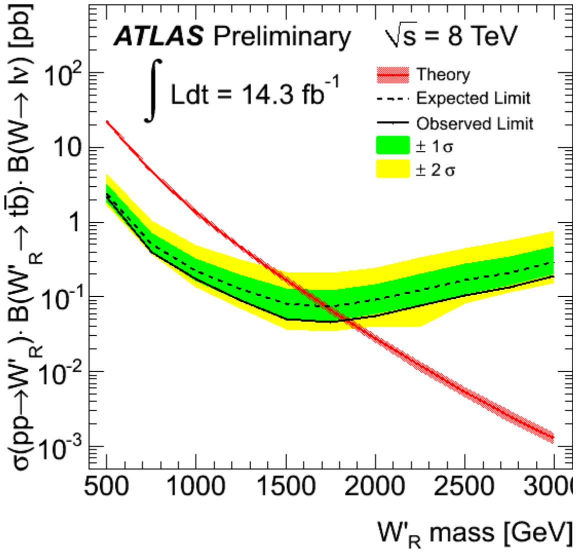
1.5 / 1.8 TeV for vector LQLQ in minimal / Yang–Mills case

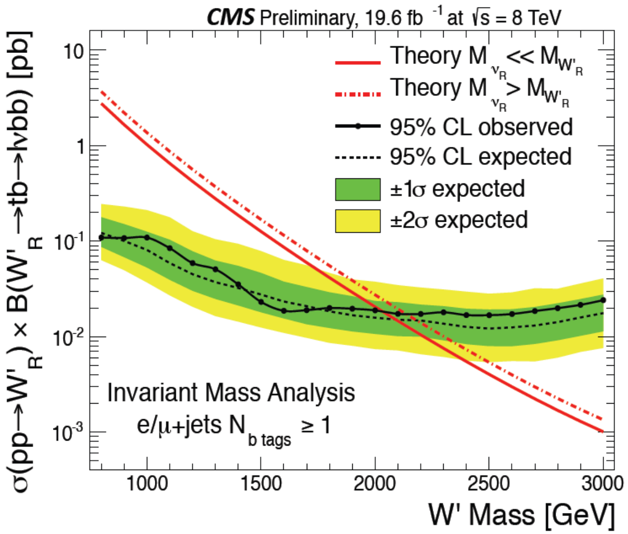


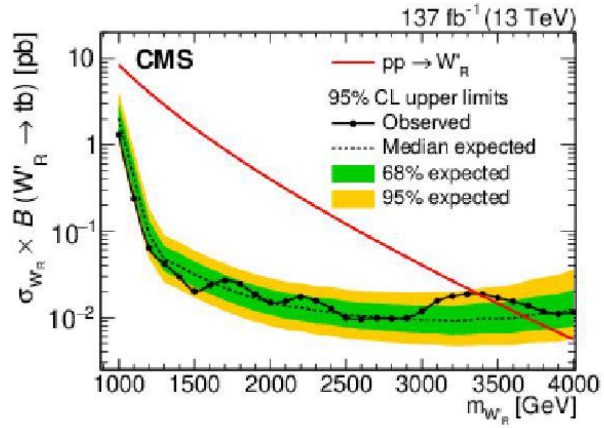
Overview of CMS leptoquark searches
CMS Preliminary
20 - 137 fb^{-1} (8, 13 TeV)
LQ(eq)
LQ(μq)
LQ(τq)
LQ(νq)
LQ(ej)LQ(ej), BR(LQ→ej) = 1, j = u, d
1811.01197
0.2−1.44
36 fb^{-1} (13 TeV)
LQ(ej)LQ(ej) + LQ(ej)LQ(ν$_e$j), LQ, j = u, d
1811.01197
0.2−1.27
36 fb^{-1} (13 TeV)
eLQ(ej), BR(LQ→ej) = 1, λ = 1, j = u, d
1509.03750
0.3−1.76
20 fb^{-1} (8 TeV)
LQ(et)LQ(et), BR(LQ→et) = 1
2202.08676
0.2−1.34
137 fb^{-1} (13 TeV)
LQ(μc)LQ(μc), BR(LQ→μc) = 1
1808.05082
0.2−1.53
36 fb^{-1} (13 TeV)
LQ(μc)LQ(μc) + LQ(μc)LQ(ν$_μ$s), BR(LQ→μc,ν$_μ$s) = 0.5, 0.5
1808.05082
0.2−1.29
36 fb^{-1} (13 TeV)
μLQ(μj), BR(LQ→μj) = 1, j = u, d
1509.03750
0.3−0.66
20 fb^{-1} (8 TeV)
LQ(μt)LQ(μt), BR(LQ→μt) = 1, λ = 1
1809.05558
0.3−1.42
0.3−1.7
0.3−2.05
36 fb^{-1} (13 TeV)
LQ(μt)LQ(μt), BR(LQ→μt) = 1
2202.08676
0.2−1.34
137 fb^{-1} (13 TeV)
LQ(τb)LQ(τb), BR(LQ→τb) = 1
1811.01197
0.3−1.02
36 fb^{-1} (13 TeV)
τLQ(τb), BR(LQ→τb) = 1, λ = 1
1806.03472
0.2−0.74
36 fb^{-1} (13 TeV)
LQ(τt)LQ(ν$_τ$b) + ν$_τ$LQ(τt), Equal LQ coupling to τt, ν$_τ$b, λ = 2.5
2012.04178
0.5−1.02
137 fb^{-1} (13 TeV)
LQ(τb)LQ(ν$_τ$t) + τLQ(ν$_τ$t), Equal LQ coupling to τb, ν$_τ$t, λ = 2.5
2012.04178
0.5−1.41
0.5−1.73
137 fb^{-1} (13 TeV)
LQ(τt)LQ(τt), BR(LQ→τt) = 1
2202.08676
0.2−1.12
137 fb^{-1} (13 TeV)
LQ(ν$_{e(μ)}$j)LQ(ν$_{e(μ)}$j), BR(LQ→ν$_{e(μ)}$j) = 1, j = u, d, s, c
1909.03460
0.5−1.14
0.5−1.55
0.5−1.98
137 fb^{-1} (13 TeV)
LQ(ν$_τ$b)LQ(ν$_τ$b), LQ→ν$_τ$b) = 1
1909.03460
0.5−1.2
0.5−1.55
0.5−1.93
137 fb^{-1} (13 TeV)
LQ(ν$_τ$t)LQ(ν$_τ$t), LQ→ν$_τ$t) = 1
1909.03460
0.5−1.14
0.5−1.47
0.5−1.81
137 fb^{-1} (13 TeV)
LQ(ν$_e$u)LQ(ν$_e$u) + ν$_e$LQ(ν$_e$u), BR(LQ→ν$_e$u) = 1, λ = 1
2107.13021
1−1.5
137 fb^{-1} (13 TeV)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Mass [TeV]
Scalar
Vector(k=0)
Vector(k=1)
Moriond 2022
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

Searches for W' in top+b

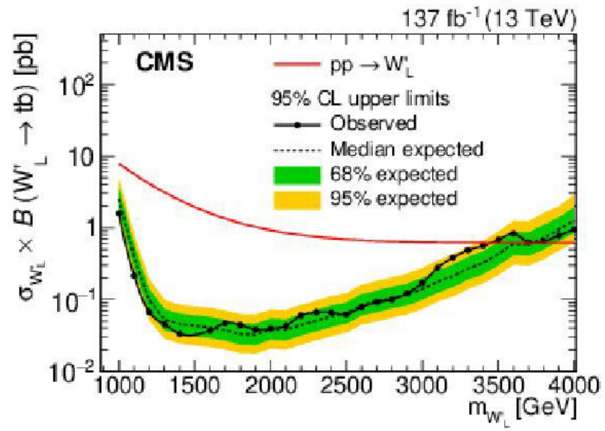






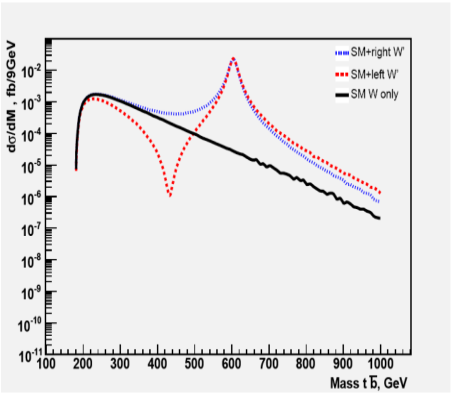


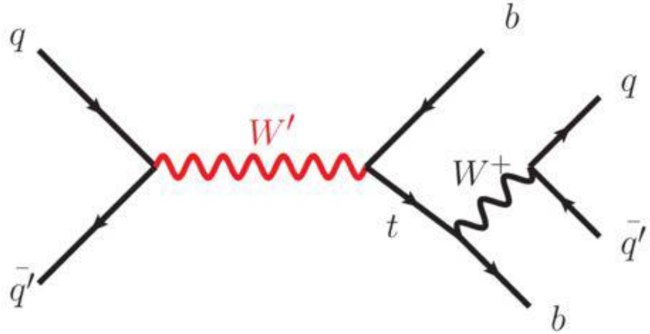
E.B., Bunichev, Dudko, Perfilov

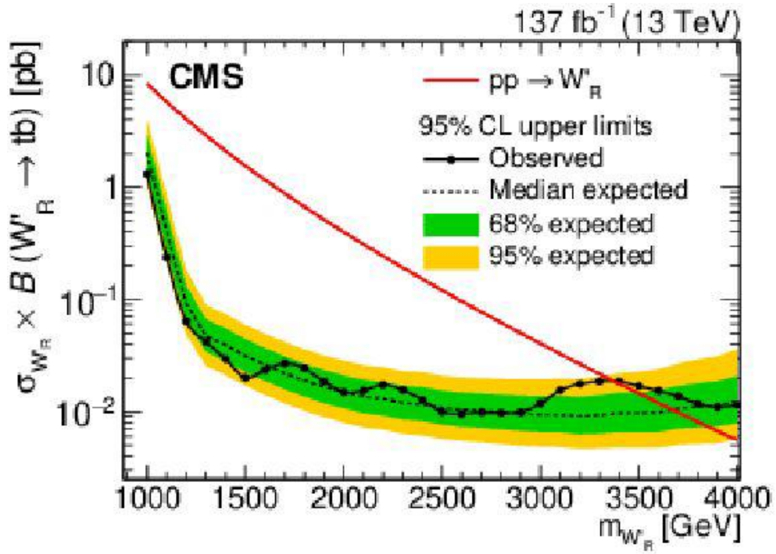


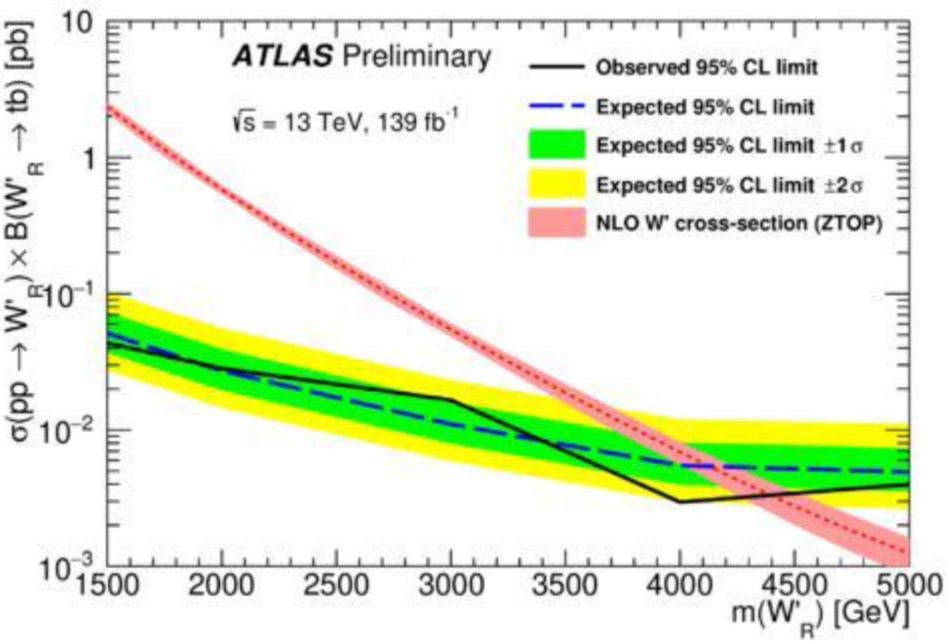
$$\mathcal{L} = \frac{V_{f_i f_j}}{2\sqrt{2}} g_w \overline{f}_i \gamma_\mu \left(a^{\mathrm{R}}_{f_i f_j}(1+\gamma^5) + a^{\mathrm{L}}_{f_i f_j}(1-\gamma^5)\right) \mathrm{W}'^{\mu} f_j + \mathrm{h.c.}$$

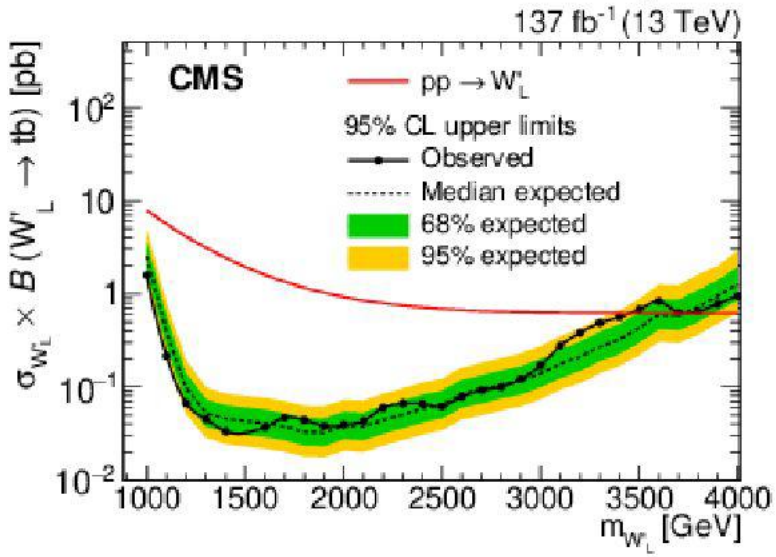
Negative interference




q
W′
b̄
W+
q
q̄′
t
q̄′
b

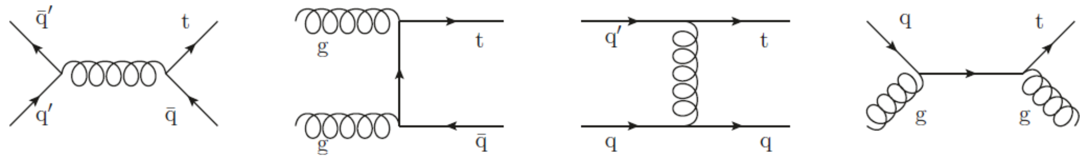

137 fb-1 (13 TeV)
CMS
pp → W'R
95% CL upper limits
Observed
Median expected
68% expected
95% expected
σW'R × B (W'R → tb) [pb]
mW'R [GeV]

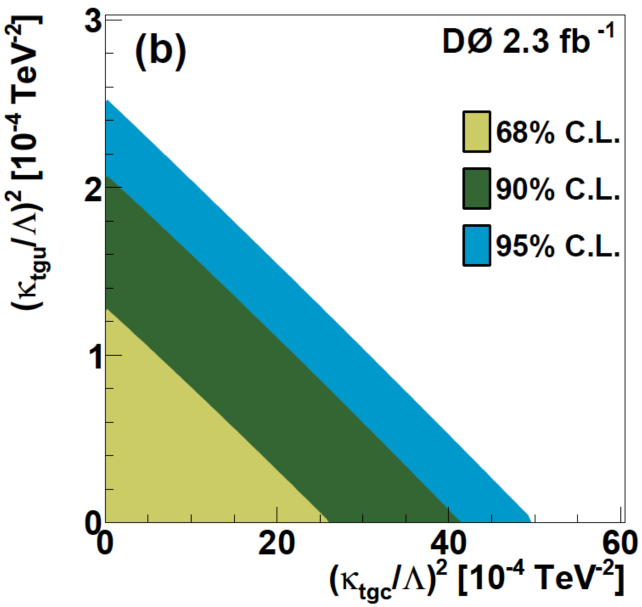

ATLAS Preliminary
√s = 13 TeV, 139 fb-1
Observed 95% CL limit
Expected 95% CL limit
Expected 95% CL limit ±1σ
Expected 95% CL limit ±2σ
NLO W' cross-section (ZTOP)
σ(pp → W'R) × B(W'R → tb) [pb]
m(W'R) [GeV]

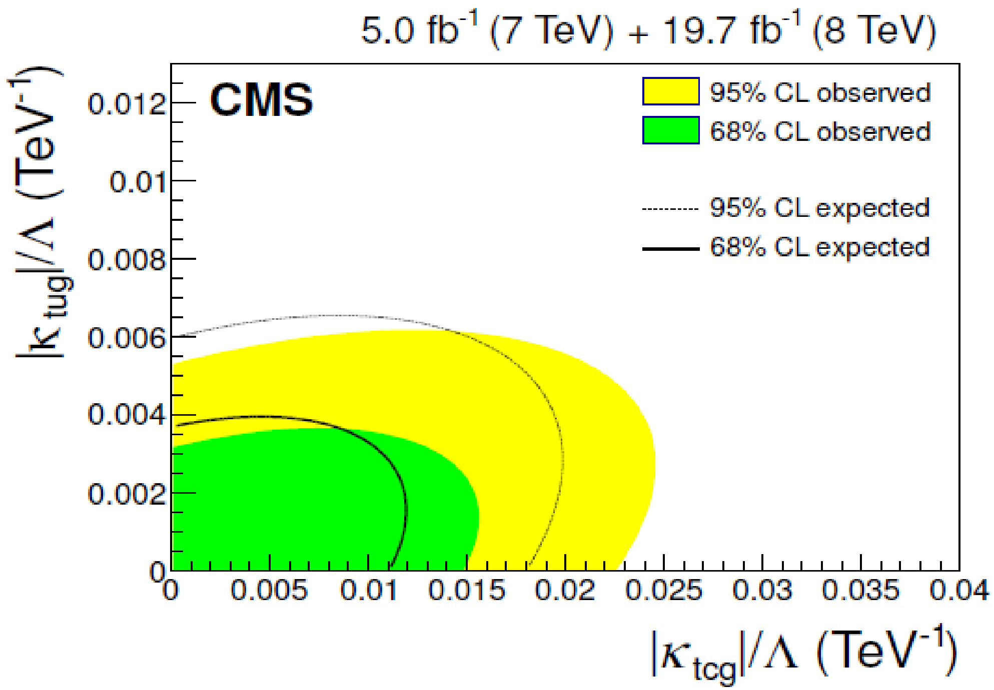

137 fb-1 (13 TeV)
CMS
pp → W'L
95% CL upper limits
Observed
Median expected
68% expected
95% expected
σW'L × B (W'L → tb) [pb]
mW'L [GeV]

FCNC anomalous top couplings

$$g_s \frac{\kappa_{tug}}{\Lambda}\ \bar{u}\ \sigma^{\mu\nu}\frac{\lambda^a}{2} t\ G^a_{\mu\nu} + g_s \frac{\kappa_{tcg}}{\Lambda}\ \bar{c}\ \sigma^{\mu\nu}\frac{\lambda^a}{2} t\ G^a_{\mu\nu} + \ h.c.$$



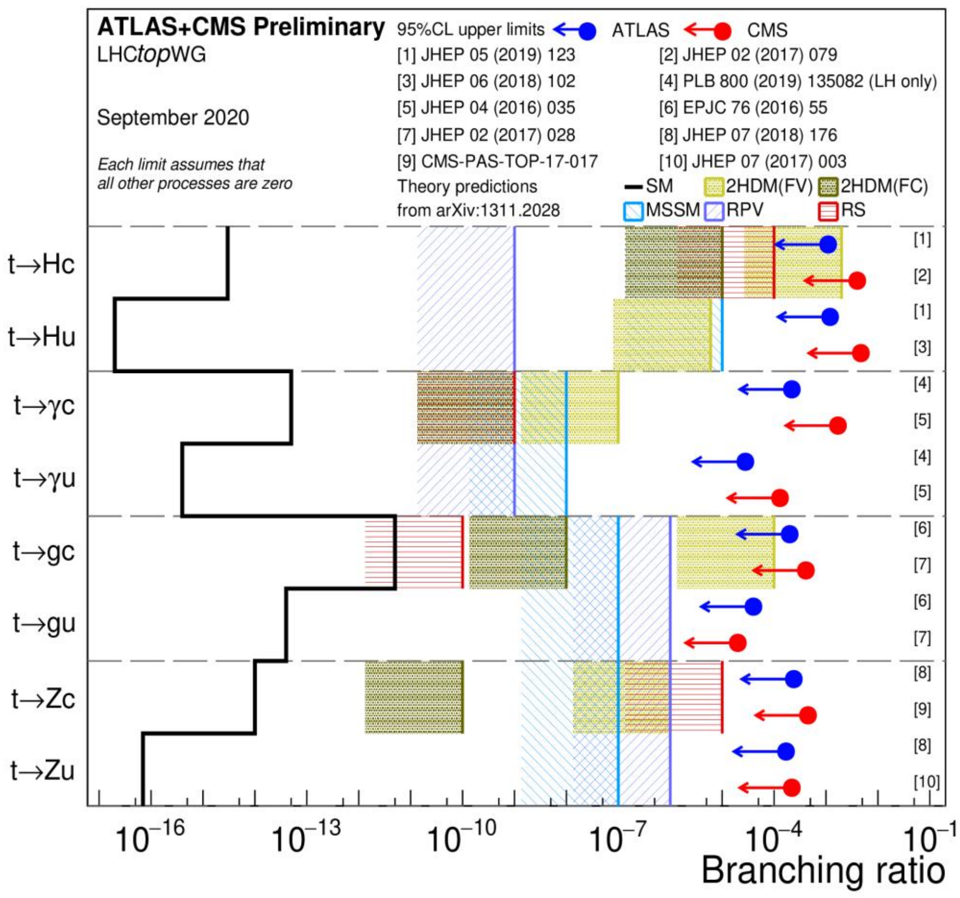




$$\Gamma(t \to qg) = \left(\frac{\kappa^g_{tq}}{\Lambda}\right)^2 \frac{8}{3}\alpha_s m_t^3 \quad , \quad \Gamma(t \to q\gamma) = \left(\frac{\kappa^\gamma_{tq}}{\Lambda}\right)^2 2\alpha m_t^3,$$

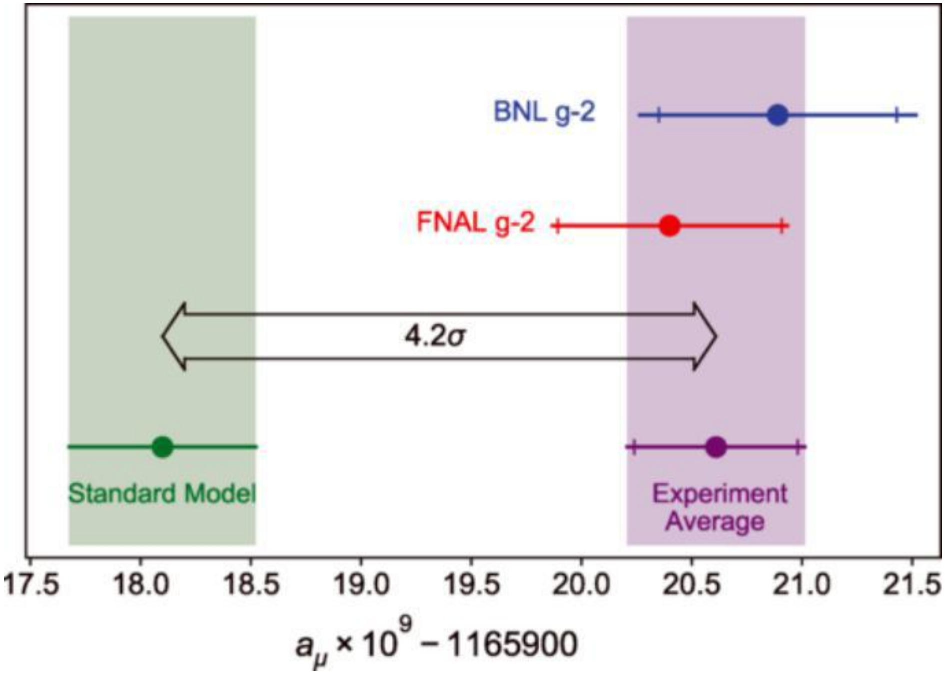
$$\Gamma(t \to qZ)_\gamma = \left(|v^Z_{tq}|^2 + |a^Z_{tq}|^2\right) \alpha\, m_t^3 \frac{1}{4M_Z^2 \sin^2 2\theta_W} \left(1 - \frac{M_Z^2}{m_t^2}\right)^2 \left(1 + 2\frac{M_Z^2}{m_t^2}\right),$$

$$\Gamma(t \to qZ)_\sigma = \left(\frac{\kappa^Z_{tq}}{\Lambda}\right)^2 \alpha\, m_t^3 \frac{1}{\sin^2 2\theta_W} \left(1 - \frac{M_Z^2}{m_t^2}\right)^2 \left(2 + \frac{M_Z^2}{m_t^2}\right)$$



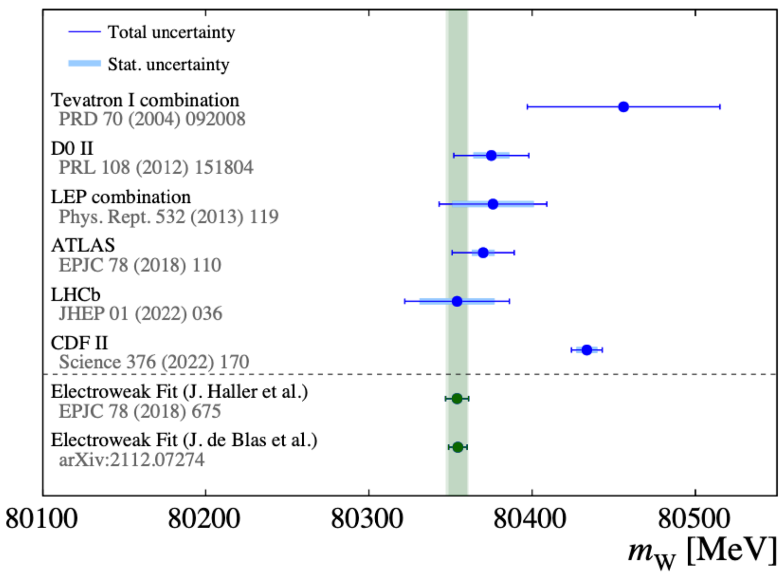
g-2 muon anomaly

E989 data from Brookhaven National Lab(BNL)



W-mass CDF anomaly

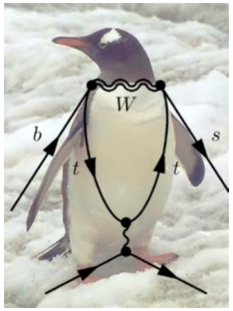
LHCB-FIGURE-2022-003

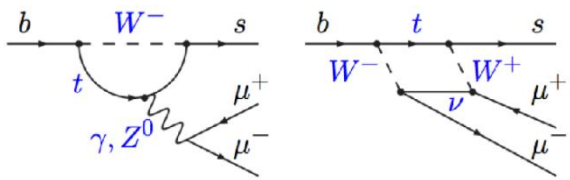


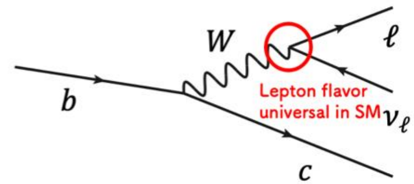
B-anomalies

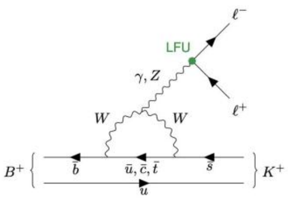
$$b \to s\ell^+\ell^-$$

$$b \to c\ell\nu_\ell$$



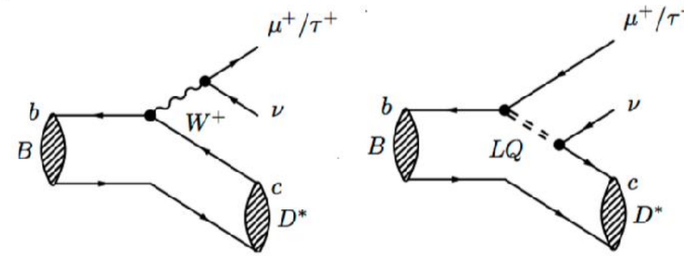




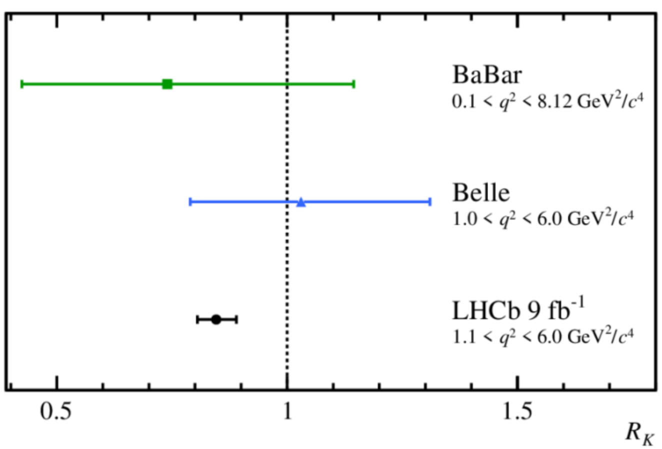


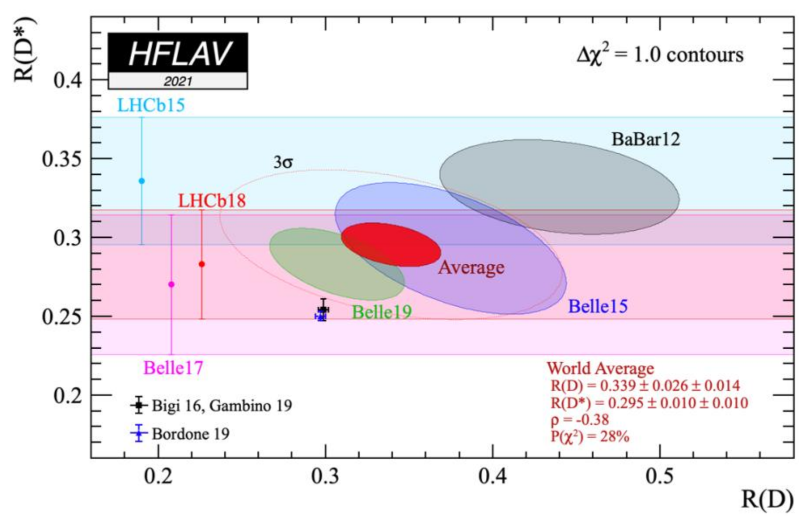
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)}$$

$$R_{K^*} = \frac{\mathcal{B}(B \to K^*\mu^+\mu^-)}{\mathcal{B}(B \to K^*e^+e^-)}$$



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

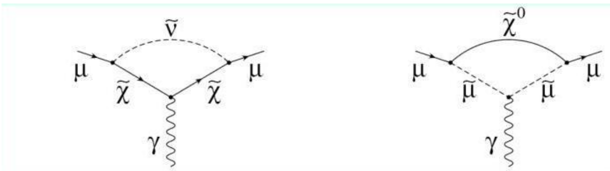




SUSY

2204.04202

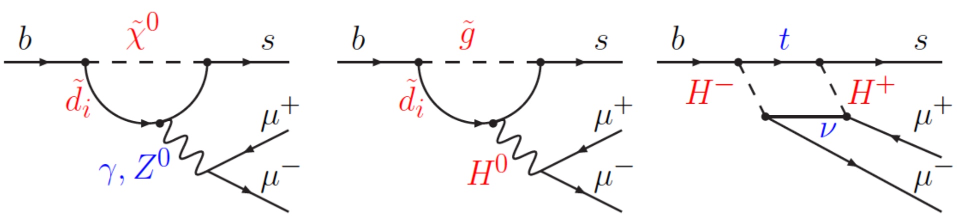
(g-2)

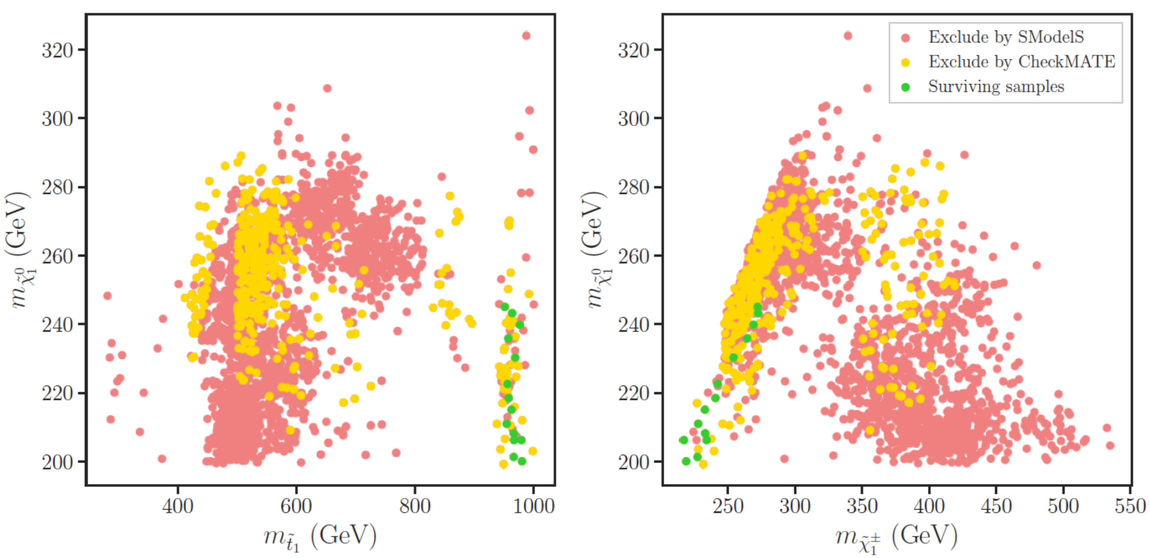


$$\delta M_W \simeq \frac{M_W}{2}\frac{\cos^2\theta_W}{\cos^2\theta_W-\sin^2\theta_W}\Delta\rho$$

$$\begin{aligned}\Delta\rho_0^{\rm SUSY} = \frac{3G_F}{8\sqrt{2}\pi^2}[& -\sin^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{t}}F_0(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2) \\ & -\sin^2\theta_{\tilde{b}}\cos^2\theta_{\tilde{b}}F_0(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2) \\ & +\cos^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}}F_0(m_{\tilde{t}_1}^2, m_{\tilde{b}_1}^2) \\ & +\cos^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}}F_0(m_{\tilde{t}_1}^2, m_{\tilde{b}_2}^2) \\ & +\sin^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}}F_0(m_{\tilde{t}_2}^2, m_{\tilde{b}_1}^2) \\ & +\sin^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}}F_0(m_{\tilde{t}_2}^2, m_{\tilde{b}_2}^2)]\end{aligned}$$

$b \to s\ell^+\ell^-$





Constraints from the new CDF II measurementof M_W, the combined FNAL and BNL muon g -2 results, the B-physics anomalies, the SM Higgs constraints, the upper bound on DM relic density at 95% CL and the DM direct detection 90% CL limits are satisfied

$$b \to s\ell^+\ell^-$$

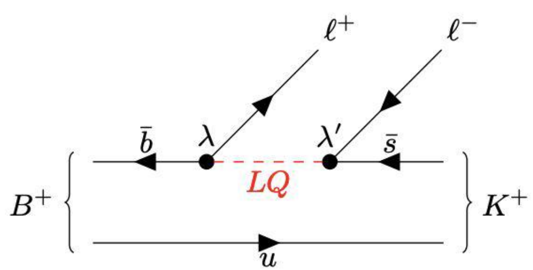
$$b \to c\ell\nu_\ell$$

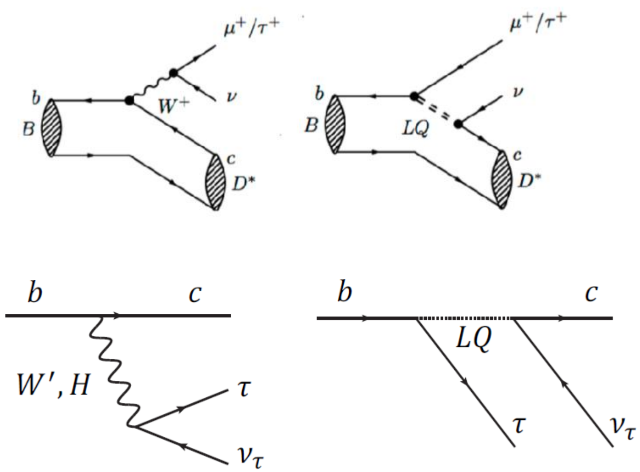
$$\mathcal{H}_{eff}^{bs\mu\mu} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{\alpha}{4\pi} \sum C_i \mathcal{O}_i$$

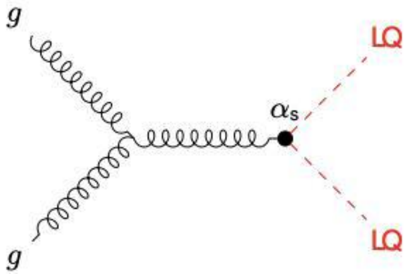
$$\mathcal{H}_{eff}^{bc\tau\nu_\tau} = -\frac{4G_F}{\sqrt{2}} V_{cb} \sum C_i \mathcal{O}_i$$

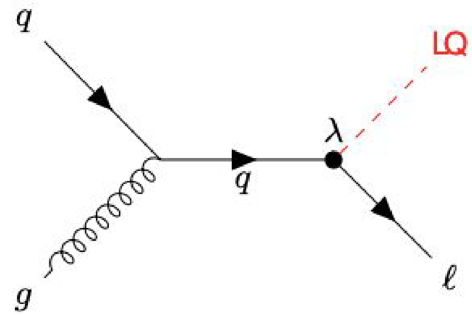
$$\frac{4G_F V_{tb}V_{ts}^*}{\sqrt{2}} \frac{\alpha}{4\pi} \sim \frac{1}{(35\ \text{TeV})^2}$$

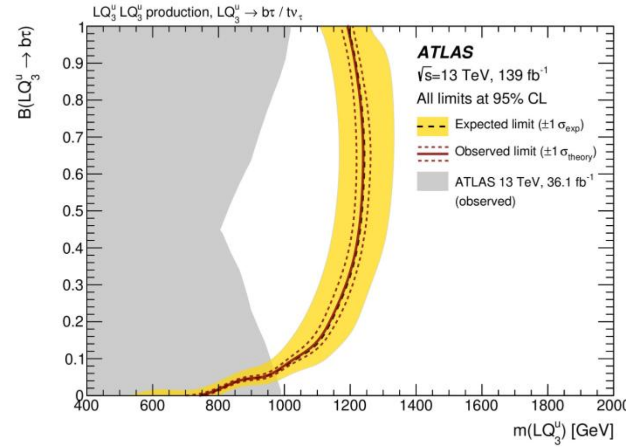
$$\frac{4G_F V_{cb}}{\sqrt{2}} \sim \frac{1}{(1.2\ \text{TeV})^2}$$

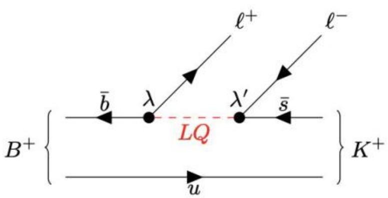




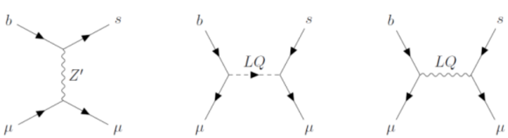


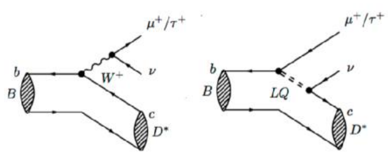




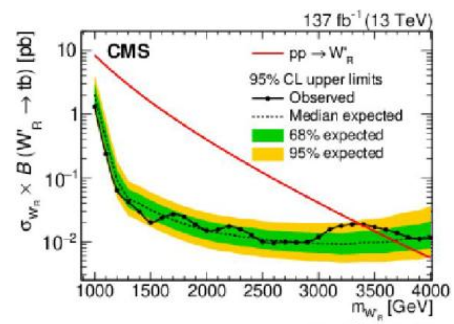


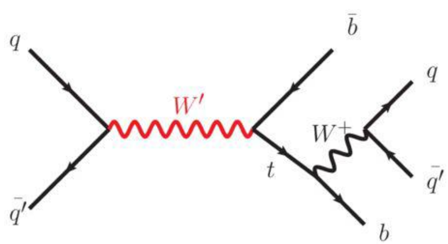
$$\frac{4G_F V_{tb}V_{ts}^*}{\sqrt{2}}\,\frac{\alpha}{4\pi} \sim \frac{1}{(35\ \text{TeV})^2} \sim \frac{g^Q_{bs}\, g^L_{\mu\mu}}{m^2_{Z'}}, \frac{g_{b\mu}\, g_{s\mu}}{m^2_{LQ}}$$

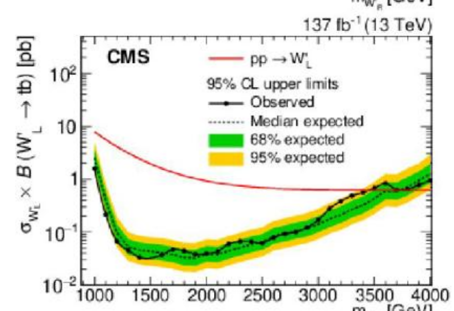




$$\frac{4G_F V_{cb}}{\sqrt{2}} \sim \frac{1}{(1.2\ \text{TeV})^2}$$

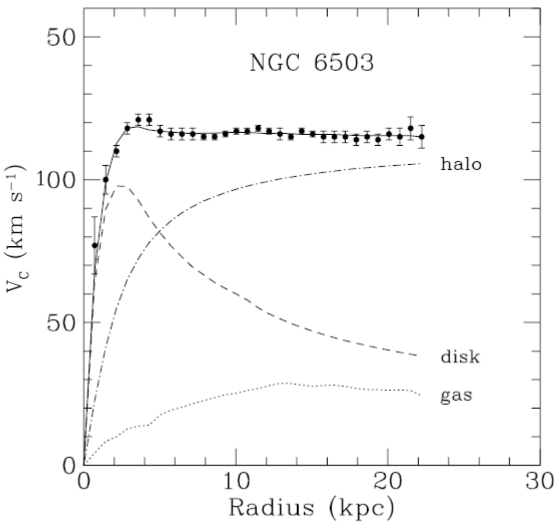




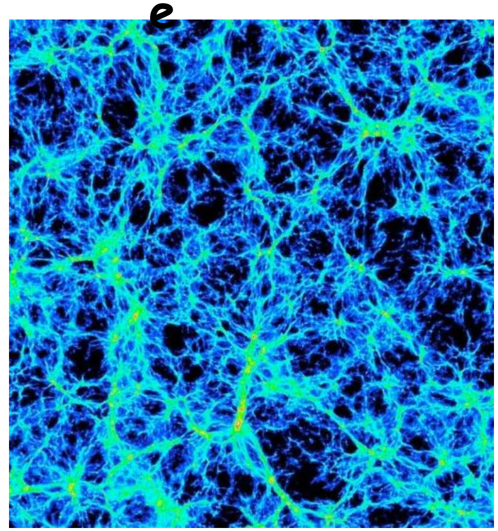


Dark Matter from astronomical observations

Galactic rotation

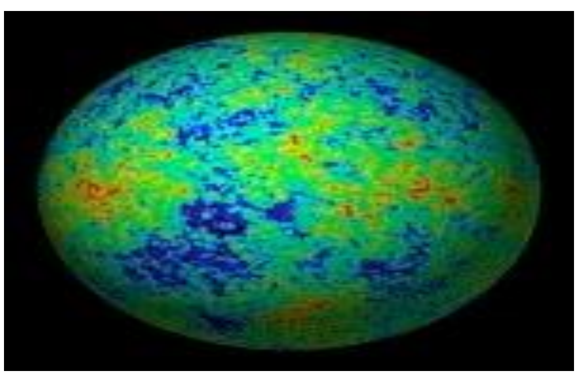


Structure

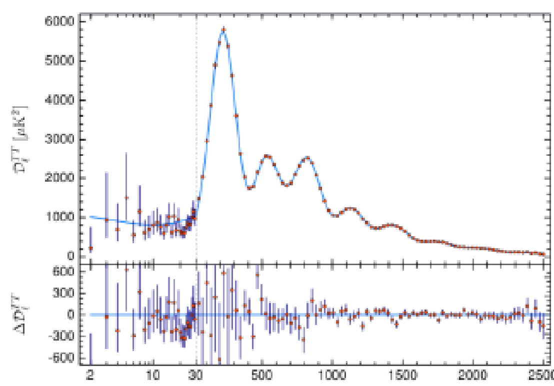


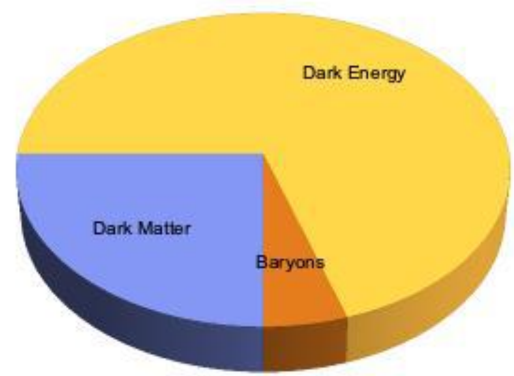
Lensing

CMB



Plank collaboration: 1807.06209





Simplified Models
scalar or pseudoscalar mediator

Assuming that this DM scenario respects the principle of Minimal Flavor Violation, the interactions of a new spin-0 mediator particle follow the same Yukawa coupling structure as in the SM.

Therefore, the mediator would couple preferentially to heavy third-generation quarks.

$$\mathcal{L}_{\text{scalar}} = -g_{\text{DM}}\,\phi\bar{\chi}\chi - g_q\,\frac{\phi}{\sqrt{2}}\sum_{q=u,d,s,c,b,t} y_q\bar{q}q\,,$$

$$y_q = \sqrt{2}m_q/v$$

$$\mathcal{L}_{\text{pseudo-scalar}} = -ig_{\text{DM}}\,\phi\bar{\chi}\gamma_5\chi - ig_q\,\frac{\phi}{\sqrt{2}}\sum_{q=u,d,s,c,b,t} y_q\bar{q}\gamma_5 q$$

$$\Gamma^{\chi\bar{\chi}}_{\text{scalar}} = \frac{g^2_{\text{DM}}M_{\text{med}}}{8\pi}\left(1-4z^2_{\text{DM}}\right)^{3/2}$$

$$\Gamma^{q\bar{q}}_{\text{scalar}} = \frac{3g^2_q y^2_q M_{\text{med}}}{16\pi}\left(1-4z^2_q\right)^{3/2}$$

$$\Gamma^{gg}_{\text{scalar}} = \frac{\alpha^2_s g^2_q M^3_{\text{med}}}{32\pi^3 v^2}\left|f_{\text{scalar}}(4z_t)\right|^2$$

$$\Gamma^{\chi\bar{\chi}}_{\text{pseudo-scalar}} = \frac{g^2_{\text{DM}}M_{\text{med}}}{8\pi}\left(1-4z^2_{\text{DM}}\right)^{1/2}\,,$$

$$\Gamma^{q\bar{q}}_{\text{pseudo-scalar}} = \frac{3g^2_q y^2_q M_{\text{med}}}{16\pi}\left(1-4z^2_q\right)^{1/2}\,,$$

$$\Gamma^{gg}_{\text{pseudo-scalar}} = \frac{\alpha^2_s g^2_q M^3_{\text{med}}}{32\pi^3 v^2}\left|f_{\text{pseudo-scalar}}(4z_t)\right|^2$$

$$f_{\text{scalar}}(\tau) = \tau\left[1+(1-\tau)\arctan^2\left(\frac{1}{\sqrt{\tau-1}}\right)\right]$$

$$f_{\text{pseudo-scalar}}(\tau) = \tau\arctan^2\left(\frac{1}{\sqrt{\tau-1}}\right)$$

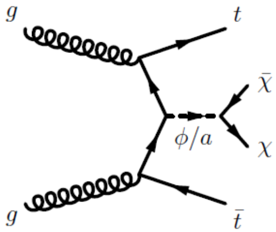
Recommendations form the LHCDM group

Vector mediator: $g_{\rm DM} = 1$ and $g_q = 0.25$.

Axial-vector mediator: $g_{\rm DM} = 1$ and $g_q = 0.25$.

Scalar mediator: $g_q = 1$ and $g_{\rm DM} = 1$.

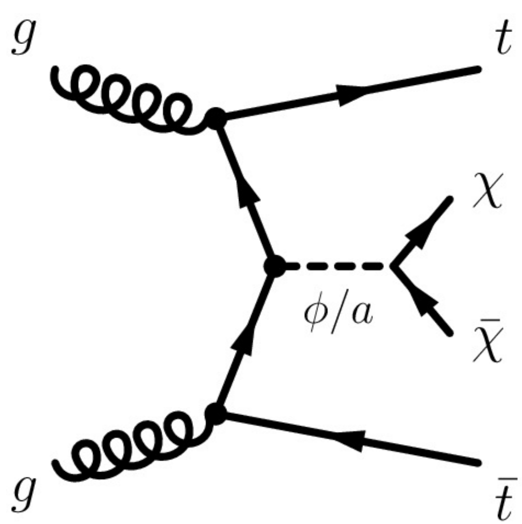
Pseudo-scalar mediator: $g_q = 1$ and $g_{\rm DM} = 1$.

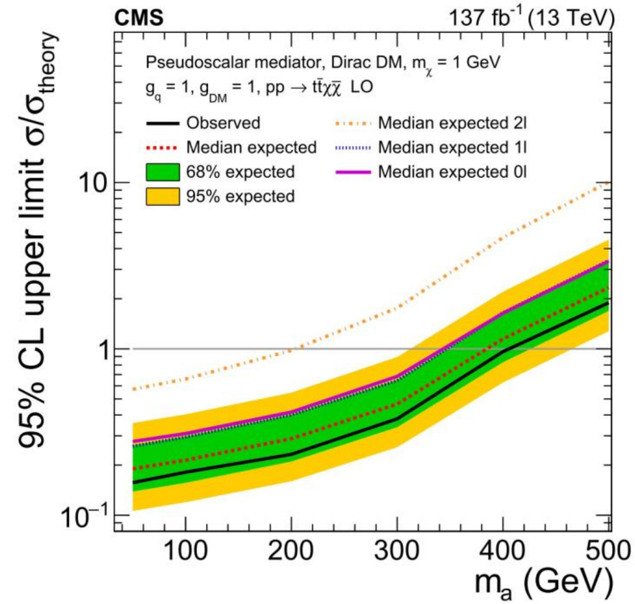


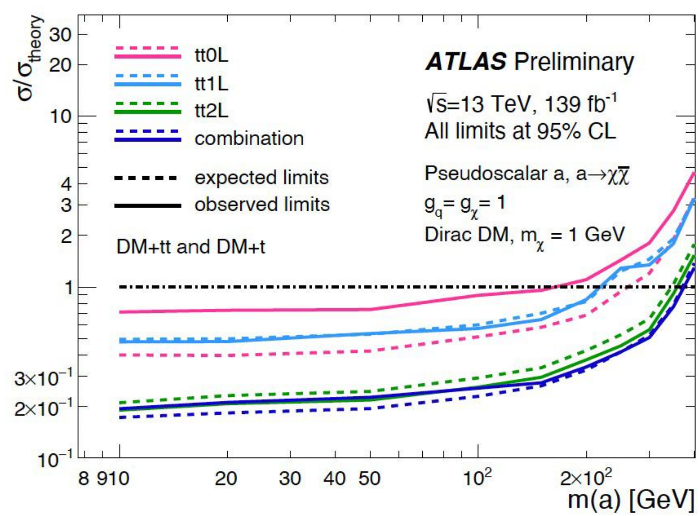
The above requirements ensure the NWA $\Gamma_{\rm med}/M_{\rm med} \lesssim 10\%$

Results could be simply rescaled for various couplings

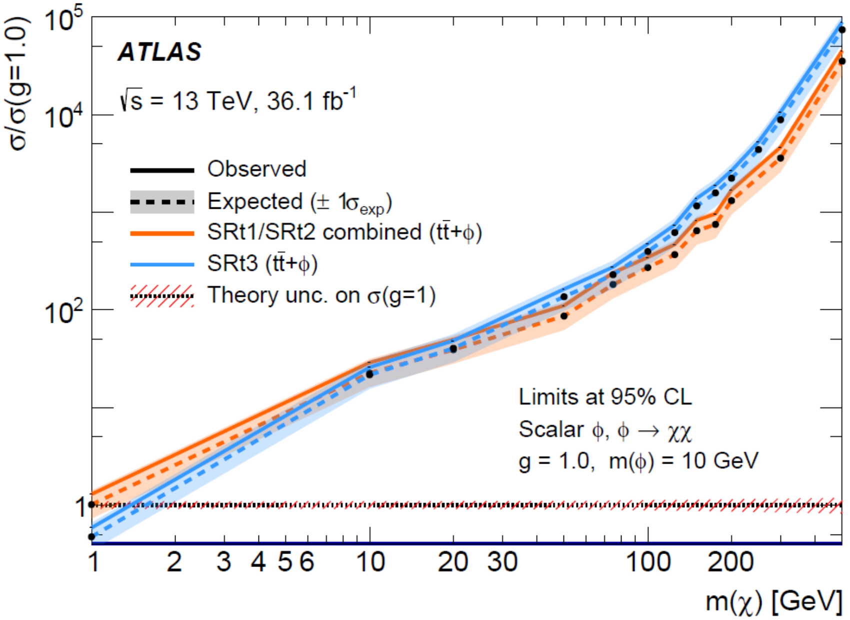
$$\int \frac{ds}{(s-M_{\rm med}^2)^2 + M_{\rm med}^2\Gamma^2} = \frac{\pi}{M_{\rm med}\Gamma} \qquad \sigma \propto \frac{g_q^2 g_\chi^2}{\Gamma}$$

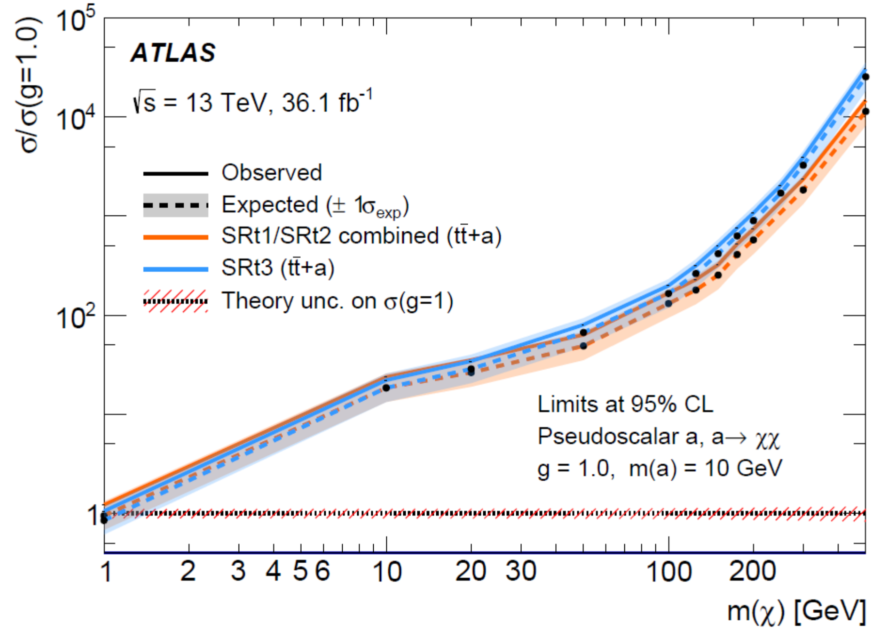

g
t
χ
φ/a
χ̄
g
t̄


CMS
137 fb^-1 (13 TeV)
Pseudoscalar mediator, Dirac DM, m_χ = 1 GeV
g_q = 1, g_DM = 1, pp → tt̄χχ̄ LO
Observed
Median expected
68% expected
95% expected
Median expected 2l
Median expected 1l
Median expected 0l
95% CL upper limit σ/σ_theory
m_a (GeV)


tt0L
tt1L
tt2L
combination
expected limits
observed limits
DM+tt and DM+t
ATLAS Preliminary
√s=13 TeV, 139 fb^-1
All limits at 95% CL
Pseudoscalar a, a→χχ̄
g_q= g_χ= 1
Dirac DM, m_χ = 1 GeV
σ/σ_theory
m(a) [GeV]

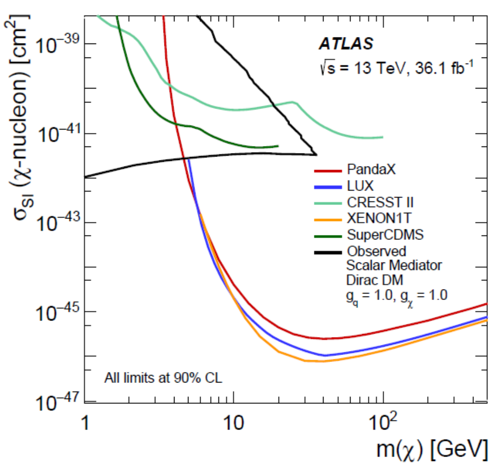
Cross sections above the curves are excluded





Exclusion 95% CL limits for colour-neutral scalar and pseudoscalar models as a function of the DM mass

for a mediator mass of 10 GeV.



$$\sigma_{\rm SI} = \frac{f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4} \qquad \mu_{n\chi} = m_n m_{\rm DM}/(m_n + m_{\rm DM})$$

Spin independent cross section for scalar mediator

$$\sigma_{\rm SI} \simeq 6.9 \times 10^{-43}\ {\rm cm}^2 \cdot \left(\frac{g_q g_{\rm DM}}{1}\right)^2 \left(\frac{125\ {\rm GeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2 .$$

DM constrains

1. Theoretical constraints:
The perturbative unitarity of VV -> hh scattering amplitudes

2. Thermal relic abundance:
DM relic density by numerically solving the Boltzmann equation at each parameter point. $\Omega_{DM}h^2 = 0.1188 \pm 0.0010$

3. Higgs invisible decays:
$\Gamma_{inv}^{h} \leq 0.19\ \Gamma_{total}^{h}$

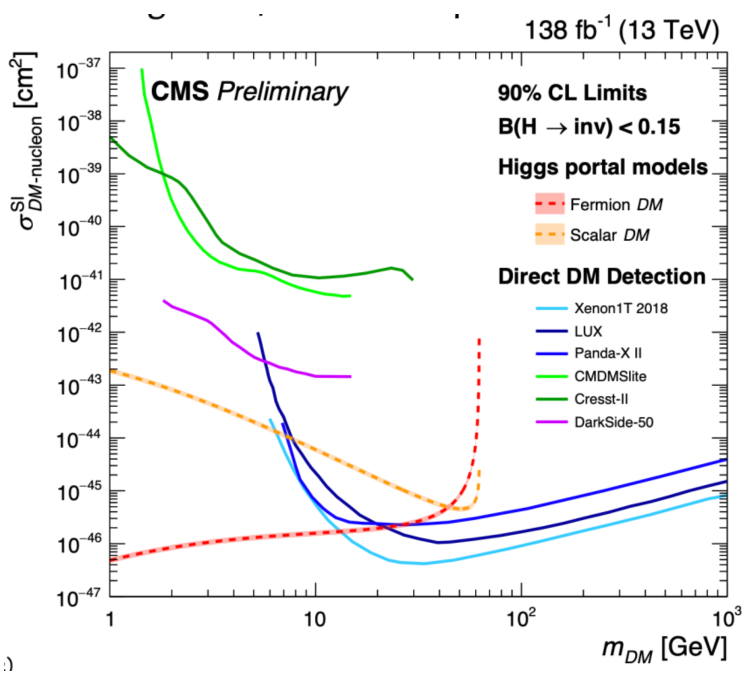
4. Indirect DM detection via gamma rays:
Fermi-LAT data

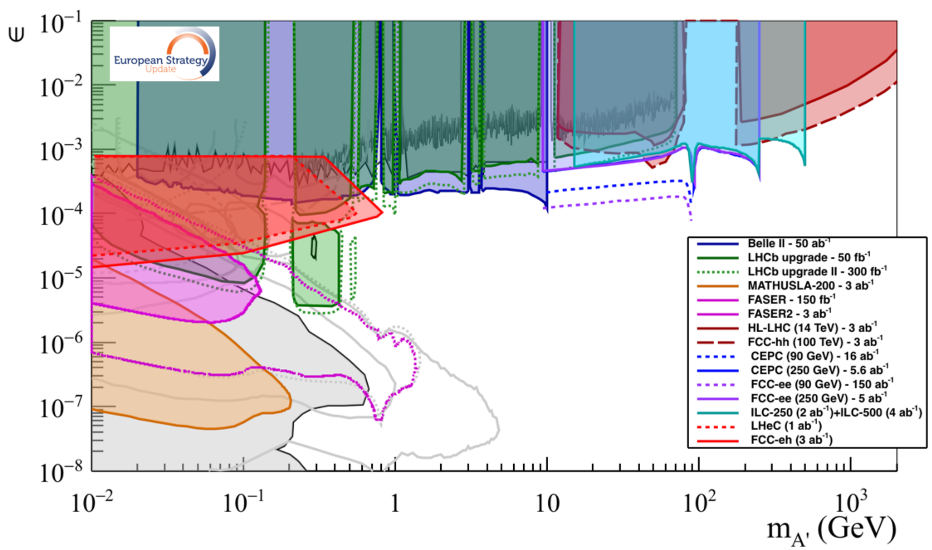
5. Direct DM detection:
XENON1T 2018, LUX 2016, PandaX 2016 and 2017, CDMSlite, CRESSTII, PICO-60 and DarkSide-50 data

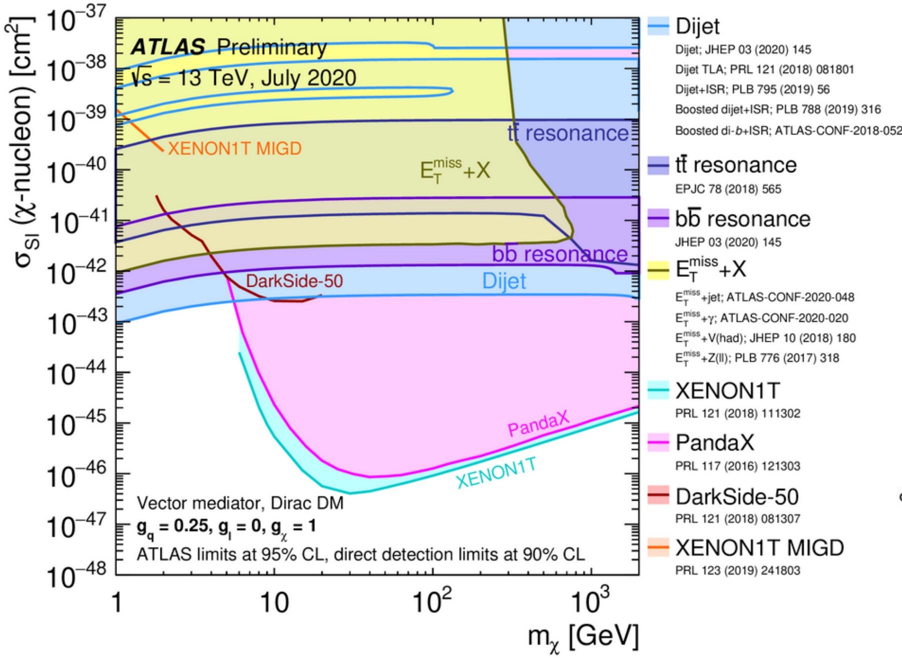
6. DM capture and annihilation in the Sun:
likelihoods from the 79-string IceCube searches for high-energy neutrinos from DM annihilation in the Sun

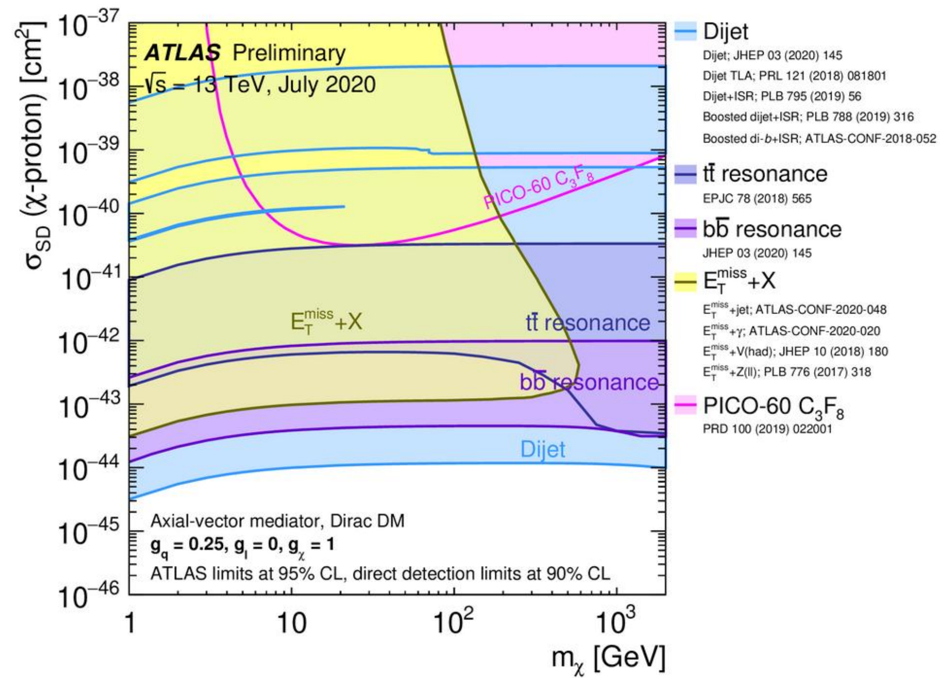
Implemented in the GAMBIT software.

Portal (mediator)	Gauge invariant interactions
Vector (Dark Photon, A_μ)	$-\frac{\varepsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Scalar (Dark Higgs, S)	$(\mu S + \lambda_{HS} S^2) H^\dagger H$
Fermion (Sterile Neutrino, N)	$y_N L H N$
Pseudo-scalar (Axion, a)	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$






ATLAS Preliminary
√s = 13 TeV, July 2020
XENON1T MIGD
E_T^{miss}+X
tt̄ resonance
bb̄ resonance
Dijet
DarkSide-50
PandaX
XENON1T
Vector mediator, Dirac DM
g_q = 0.25, g_l = 0, g_χ = 1
ATLAS limits at 95% CL, direct detection limits at 90% CL
σ_{SI} (χ-nucleon) [cm²]
m_χ [GeV]
Dijet
Dijet; JHEP 03 (2020) 145
Dijet TLA; PRL 121 (2018) 081801
Dijet+ISR; PLB 795 (2019) 56
Boosted dijet+ISR; PLB 788 (2019) 316
Boosted di-b+ISR; ATLAS-CONF-2018-052
tt̄ resonance
EPJC 78 (2018) 565
bb̄ resonance
JHEP 03 (2020) 145
E_T^{miss}+X
E_T^{miss}+jet; ATLAS-CONF-2020-048
E_T^{miss}+γ; ATLAS-CONF-2020-020
E_T^{miss}+V(had); JHEP 10 (2018) 180
E_T^{miss}+Z(ll); PLB 776 (2017) 318
XENON1T
PRL 121 (2018) 111302
PandaX
PRL 117 (2016) 121303
DarkSide-50
PRL 121 (2018) 081307
XENON1T MIGD
PRL 123 (2019) 241803


ATLAS Preliminary
√s = 13 TeV, July 2020
PICO-60 C_3F_8
E_T^{miss}+X
tt̄ resonance
bb̄ resonance
Dijet
Axial-vector mediator, Dirac DM
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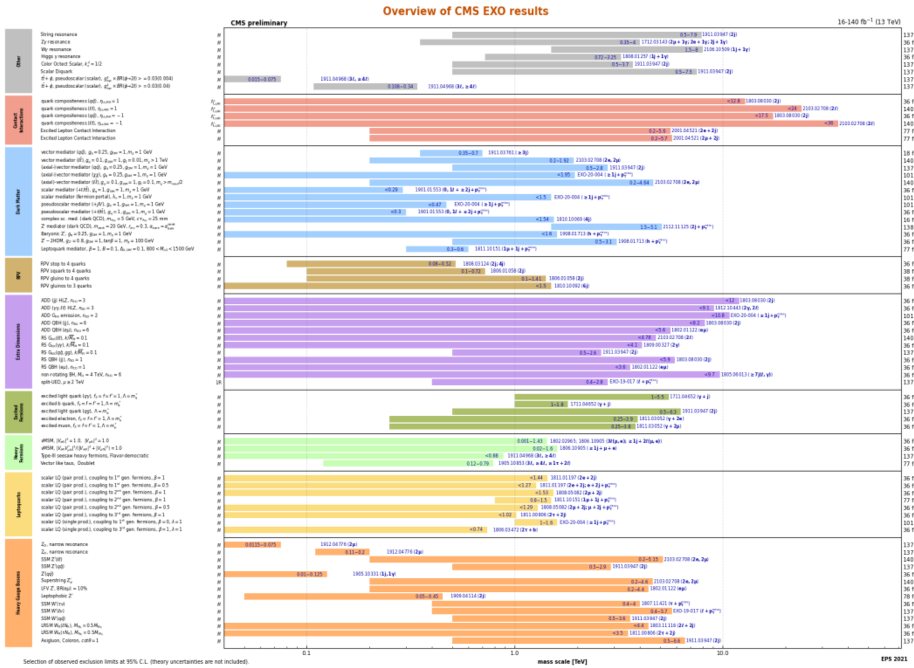
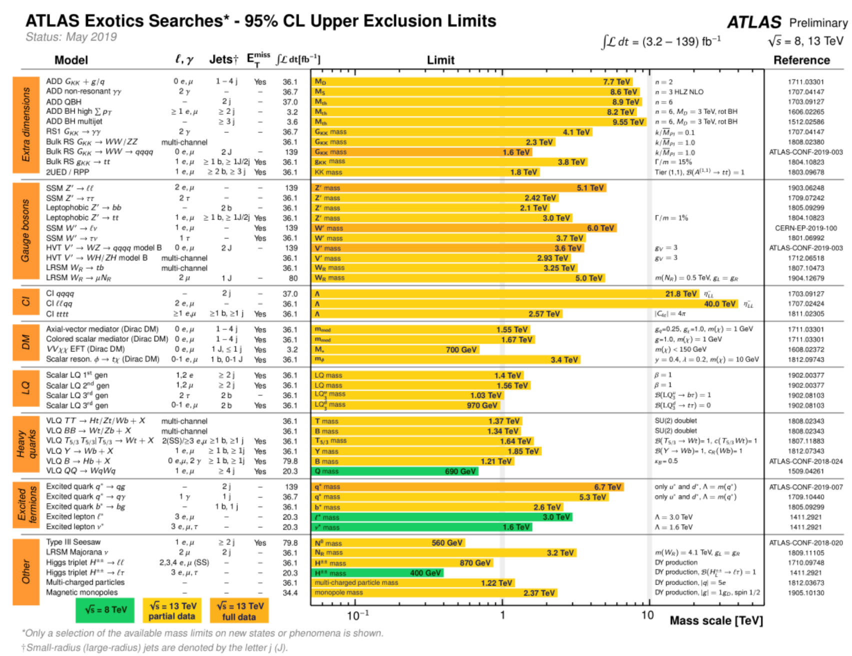
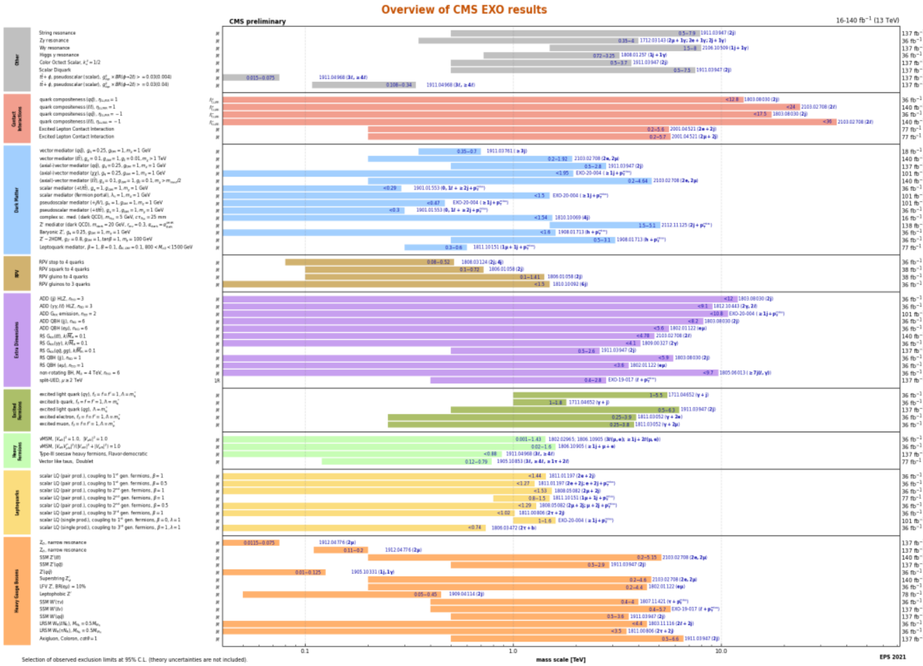
ATLAS limits at 95% CL, direct detection limits at 90% CL
σ_{SD} (χ-proton) [cm²]
m_χ [GeV]
Dijet
Dijet; JHEP 03 (2020) 145
Dijet TLA; PRL 121 (2018) 081801
Dijet+ISR; PLB 795 (2019) 56
Boosted dijet+ISR; PLB 788 (2019) 316
Boosted di-b+ISR; ATLAS-CONF-2018-052
tt̄ resonance
EPJC 78 (2018) 565
bb̄ resonance
JHEP 03 (2020) 145
E_T^{miss}+X
E_T^{miss}+jet; ATLAS-CONF-2020-048
E_T^{miss}+γ; ATLAS-CONF-2020-020
E_T^{miss}+V(had); JHEP 10 (2018) 180
E_T^{miss}+Z(ll); PLB 776 (2017) 318
PICO-60 C_3F_8
PRD 100 (2019) 022001

Many limits already in TeV energy range

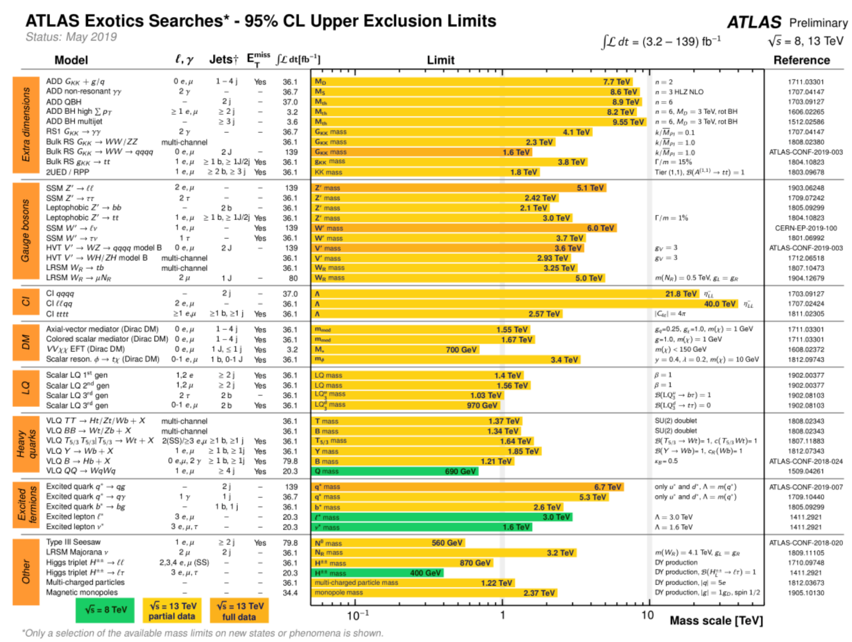




Many limits already in TeV energy range

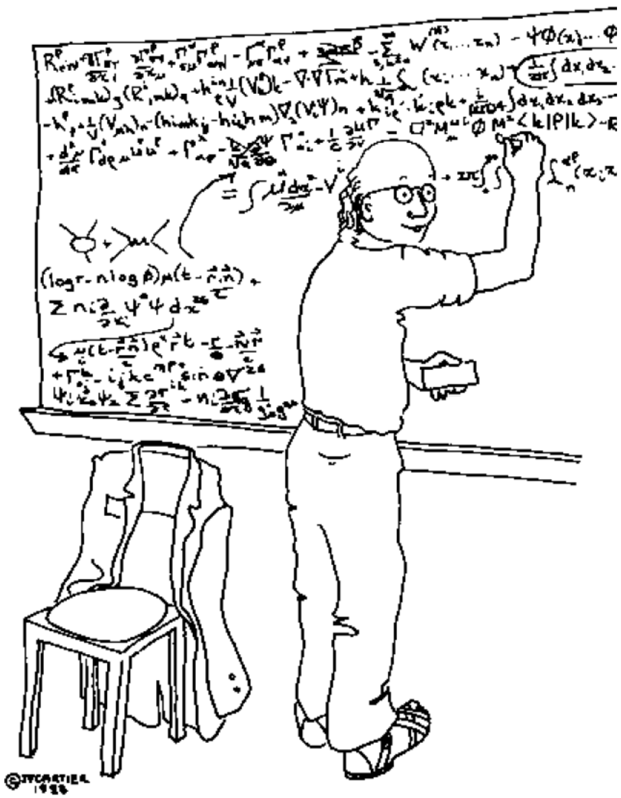


"There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy." -- Hamlet

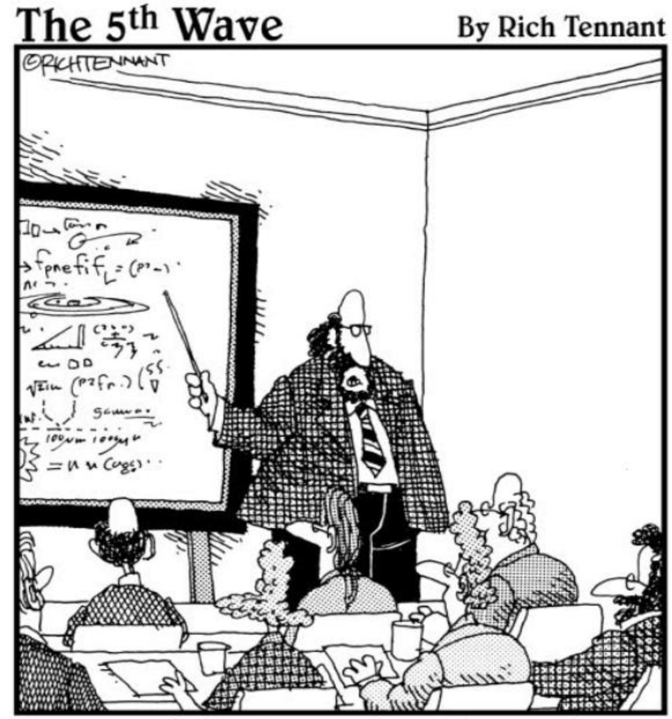


Concluding remarks

- SM works even better than one may expect
- Many facts telling us the SM can not be the final theory
- Many extensions of SM (BSM theories and models)
- Importance of null results in searches for BSM manifestations allowing to close certain regions of new model parameter spaces
- Intensive searches are continued in all possible ways at accelerator, collider, Space and Earth experiments
- May be New Physics is just around the corner but probably new revolutionary (crazy) ideas are needed



"At this point we notice that this equation is beautifully simplified if we assume that space–time has 92 dimensions."



" Along with 'Antimatter,' and 'Dark Matter,' we've recently discovered the existence of 'Doesn't Matter,' which appears to have no effect on the universe whatsoever."

"It doesn't matter how beautiful your theory is,
it doesn't matter how smart you are.
If it doesn't agree with experiment, it's wrong".

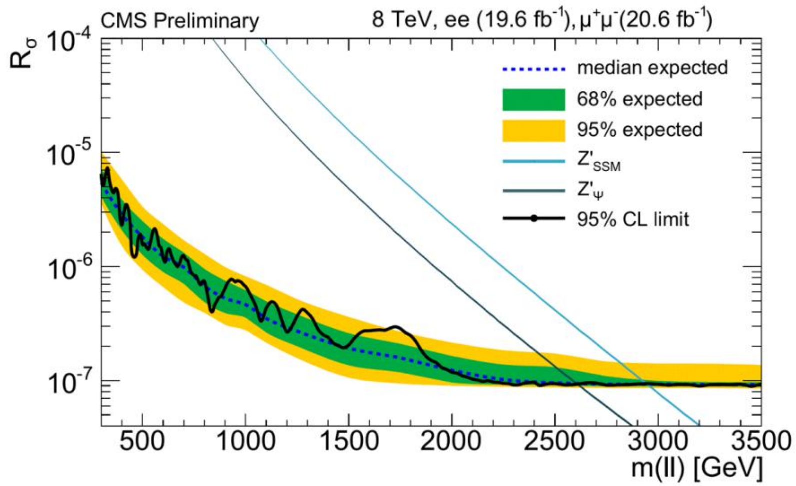
Richard P. Feynman

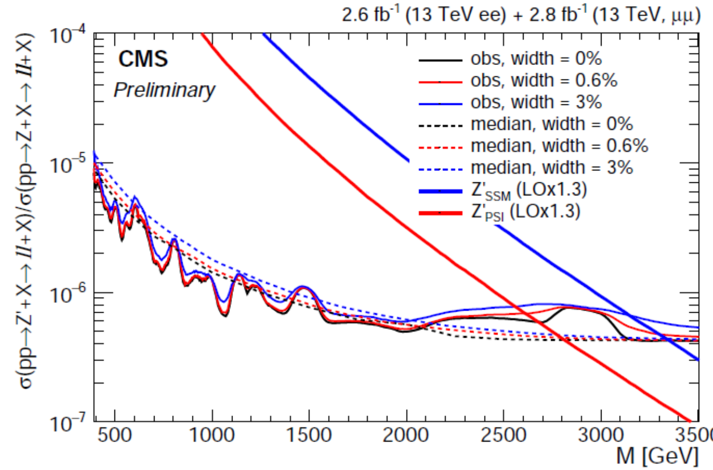
Thank you!

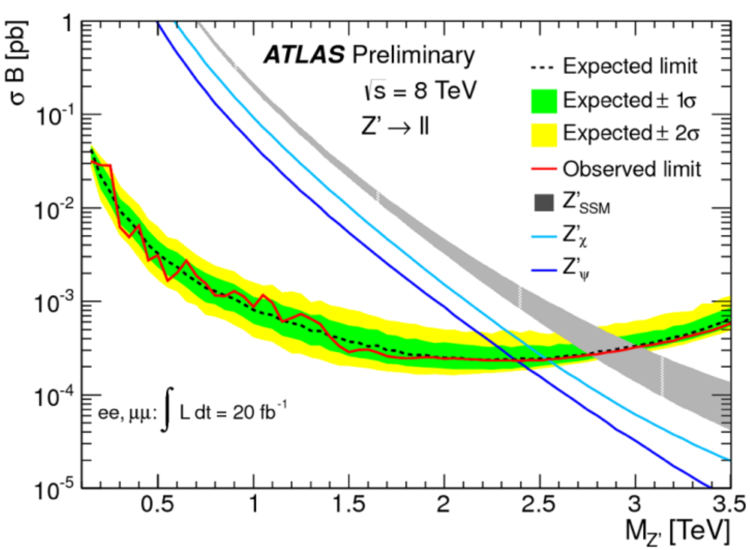
BACKUP SLIDES

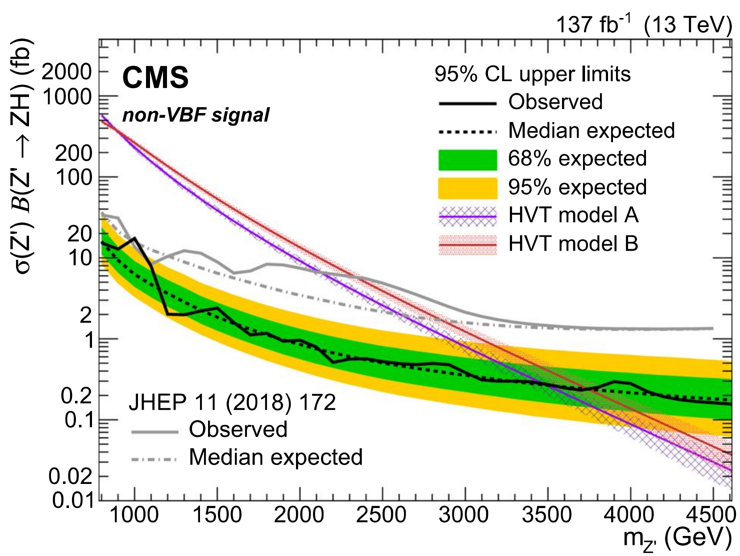
Searches for Z' in dileptons

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

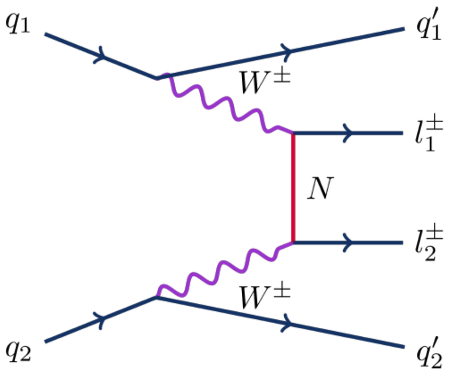








Majorana neutrinos



Heavy Majorana neutrino (HMN) from seesaw

Signature: two same sign μμ, VBF jets

Limits:
HMN exclusion up to mN = 23 TeV!
n Also constrain the EFT dim-5 Weinberg operator C5
ll'