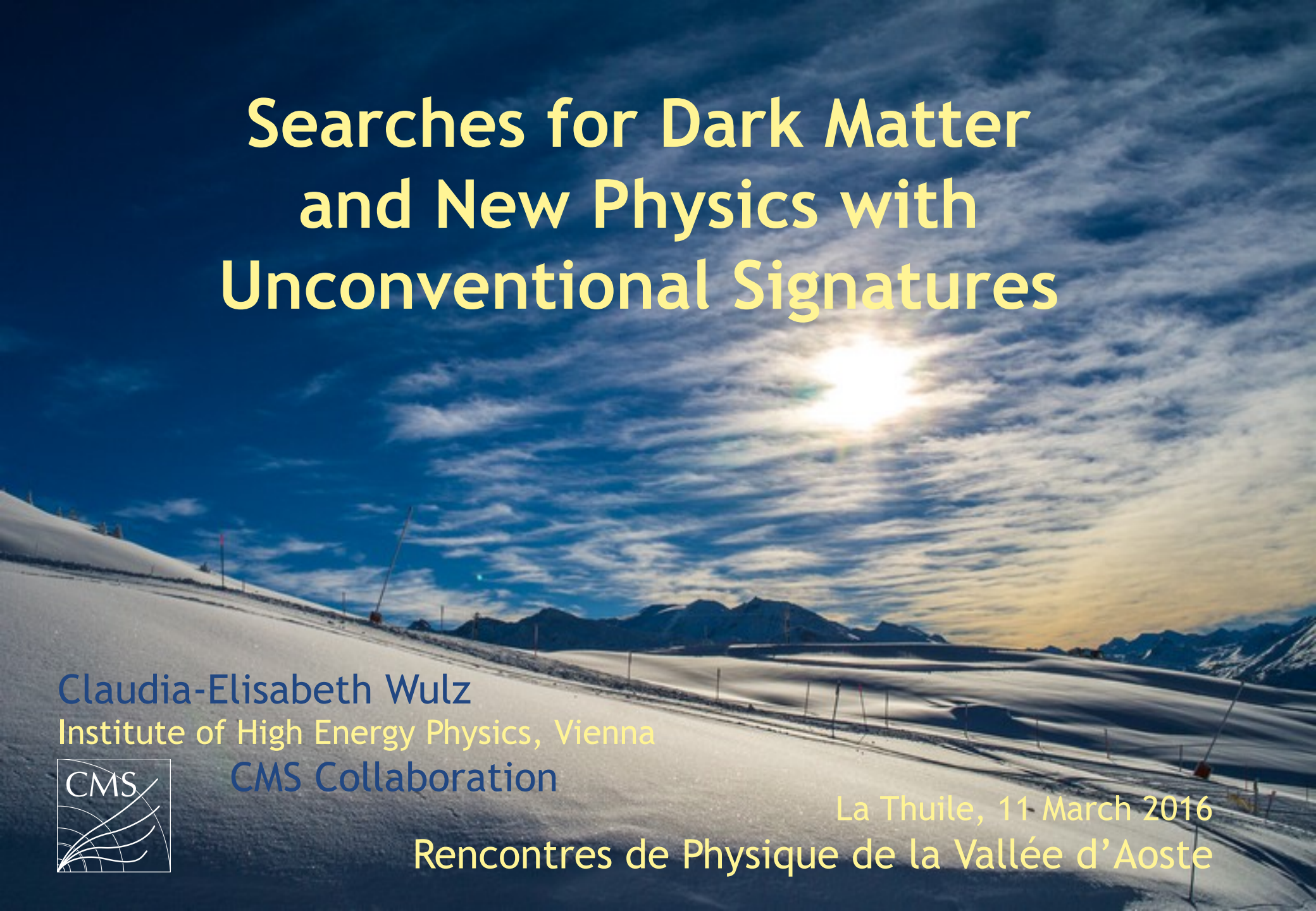
Searches for Dark Matter and New Physics with Unconventional Signatures



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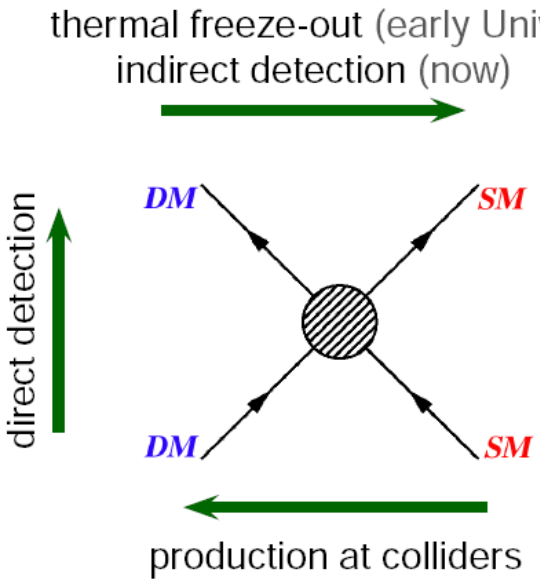
Institute of High Energy Physics, Vienna
CMS Collaboration

La Thuile, 11 March 2016
Rencontres de Physique de la Vallée d'Aoste

Dark Matter Searches

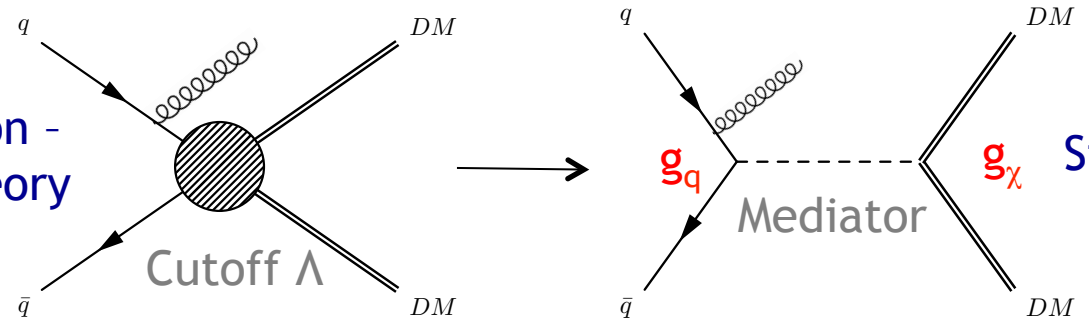


Direct: DM-nucleon scattering (LUX, XENON, CDMS,CRESST, ..)

Indirect: DM annihilation (AMS, Fermi, Pamela, IceCube, …)

Production: at colliders (ATLAS, CMS, …)
Best for low DM mass and spin-dependent couplings
Production in decays: SUSY cascades, Higgs portal
Direct production: only detectable as missing transverse momentum in association with additional, visible objects ("mono-X" channels, with X = q, g, γ, W, Z, t, $t\bar{t}$, b, $b\bar{b}$)

Contact interaction – effective field theory



Simplified models

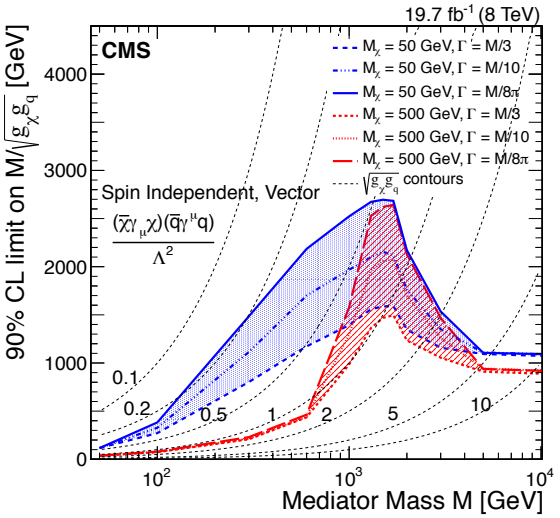
DM parameters: DM and mediator masses, couplings, type of interaction (scalar, pseudoscalar, vector, axial-vector, tensor)

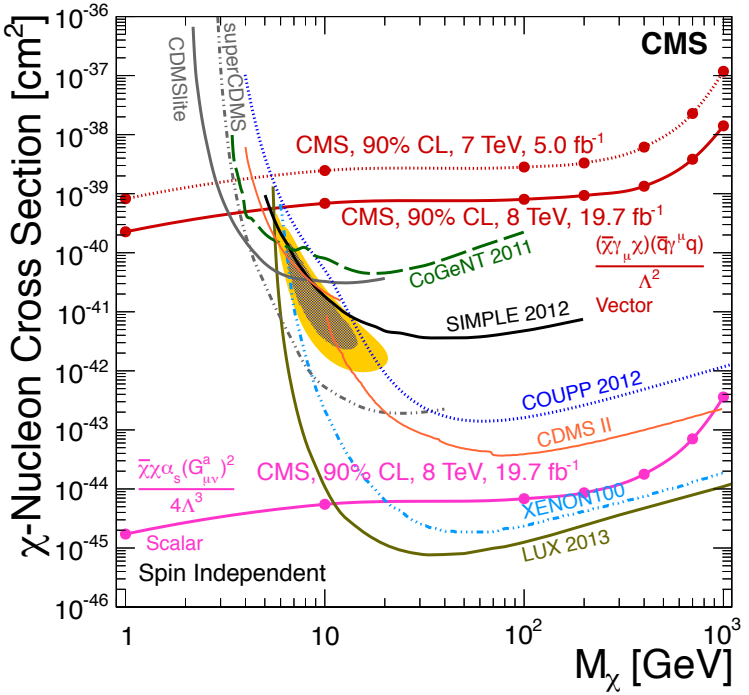
e.g. *ATLAS/CMS DM Forum, arXiv 1507.0966 (2015)*

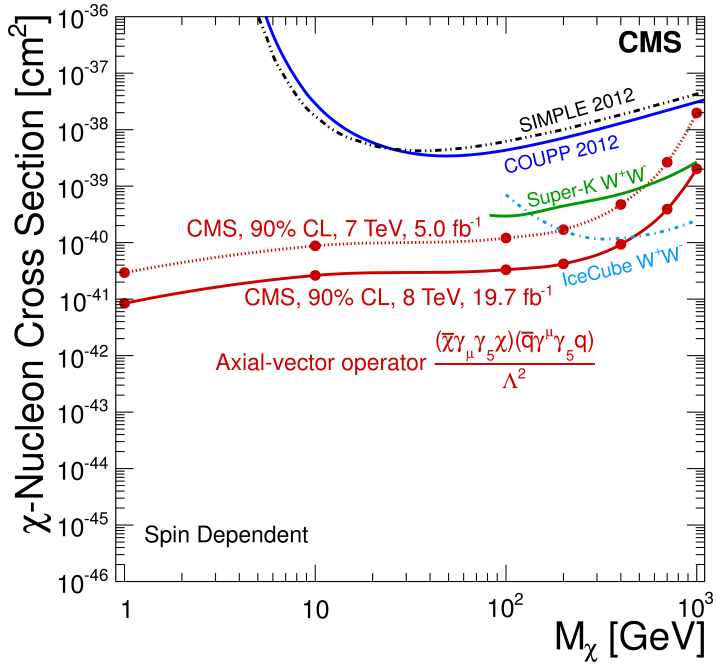
Dark Matter Searches - Monojets

CMS-EXO-12-048, EPJC 75 (2015) 235

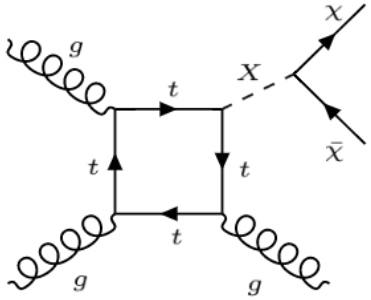
Data sample:
19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV, 5.0 fb^{-1} at $\sqrt{s}$ = 7 TeV
Background:
Z(νν) estimated from Z(μμ) control sample,
$t\bar{t}$ and QCD multijets removed by excluding events with more than 2 jets with p_T > 30 GeV

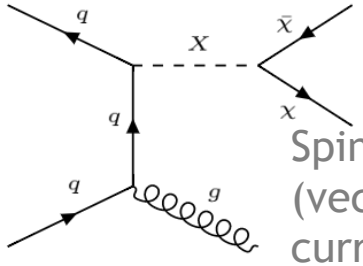






Dark Matter Searches - Monojets

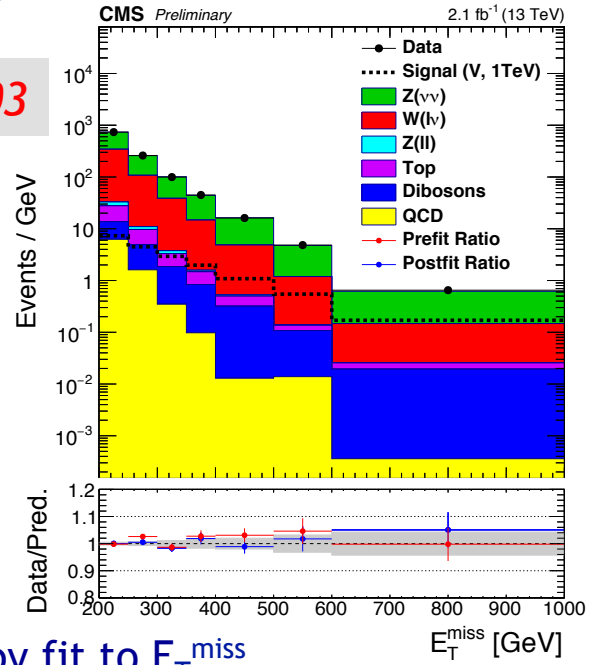




Spin-1 mediator X (vector or axial-vector current)

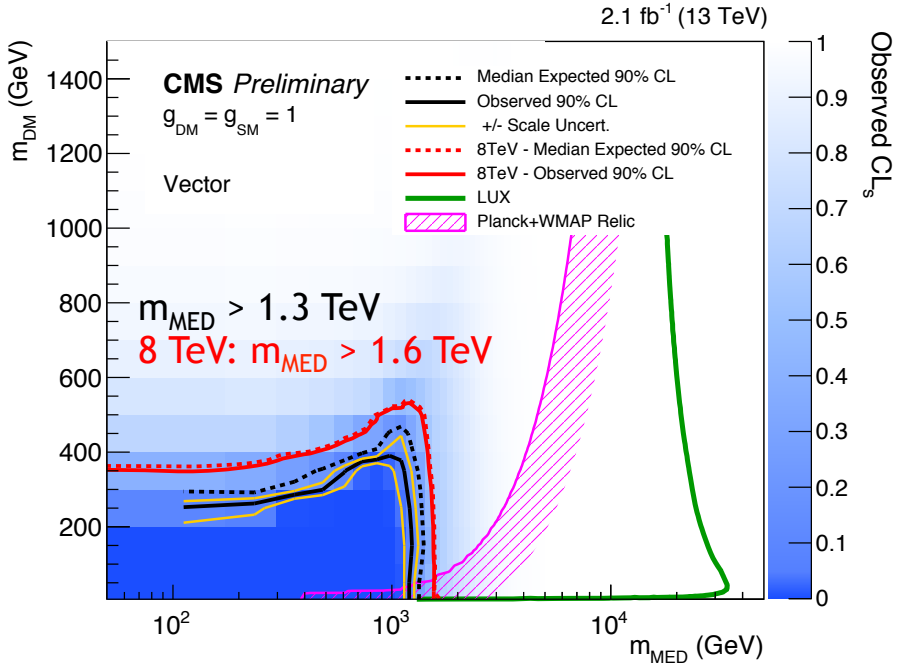
Spin-0 mediator X (scalar or pseudoscalar current)

NEW: CMS-EXO-15-003

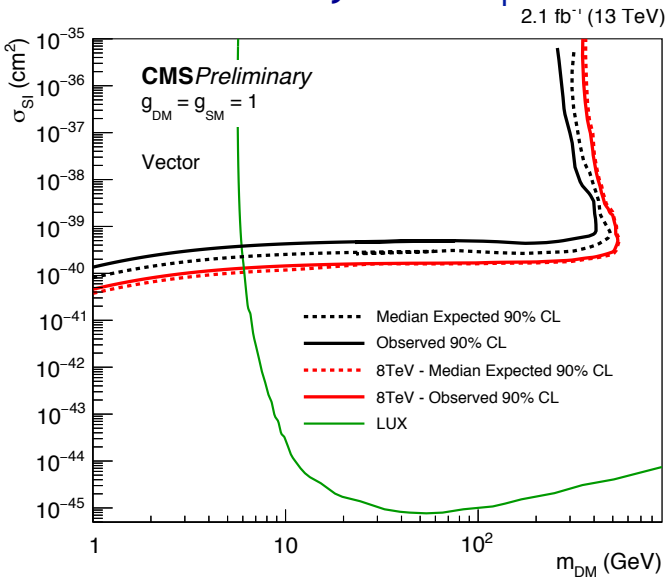


Event selection: ≥ 1 jets with E_T > 100 GeV, E_T^{miss} > 200 GeV

Data sample: 2.1 fb^{-1} at √s = 13 TeV



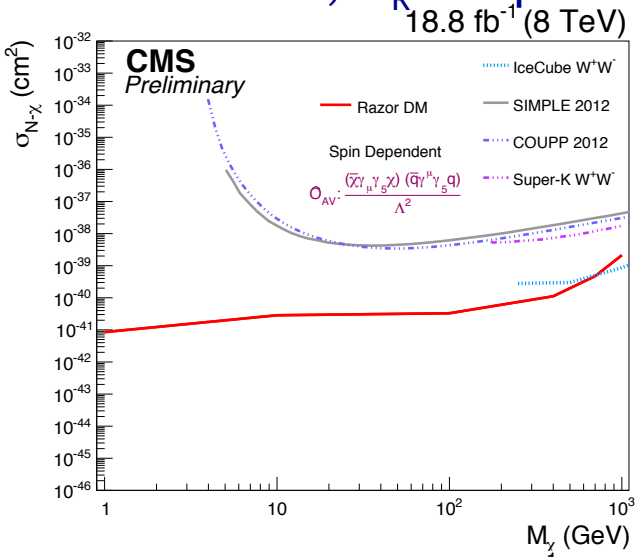
DM signal extracted by fit to E_T^{miss}



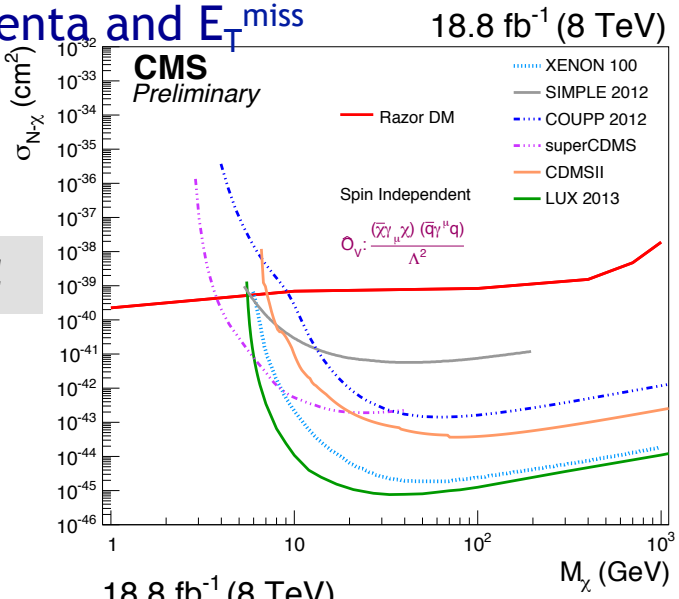
Dark Matter Searches - Razor dijet analysis

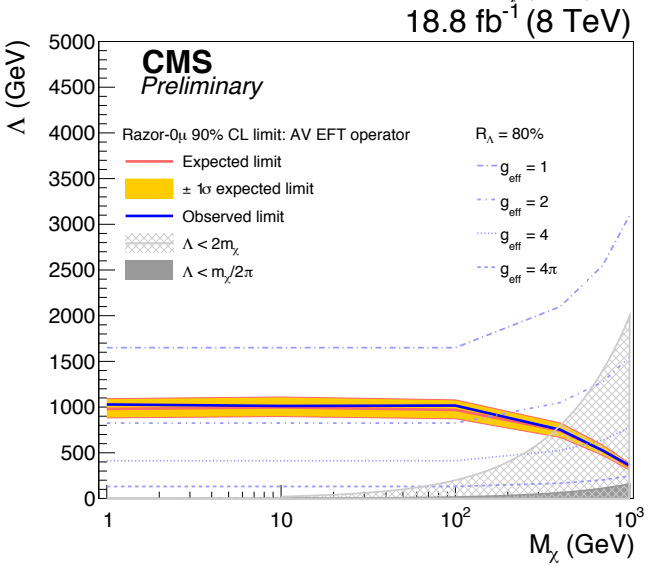
Signature: Dijets + E_T^{miss}, no leptons

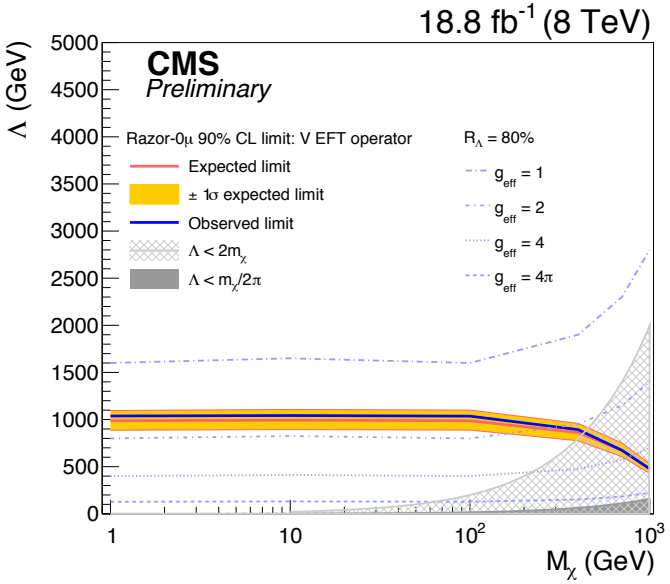
Razor variables: R^2, M_R computed from the jet momenta and E_T^{miss}



CMS-EXO-14-004







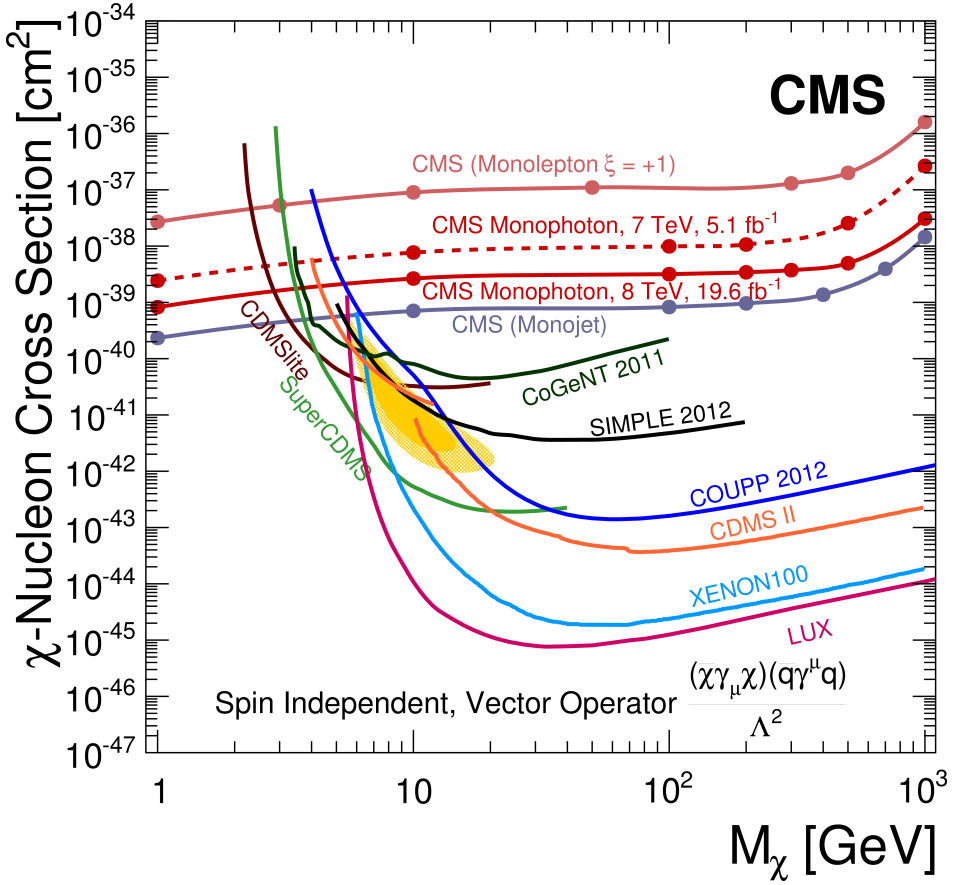
R_Λ quantifies fraction of events for which EFT hypothesis is still valid

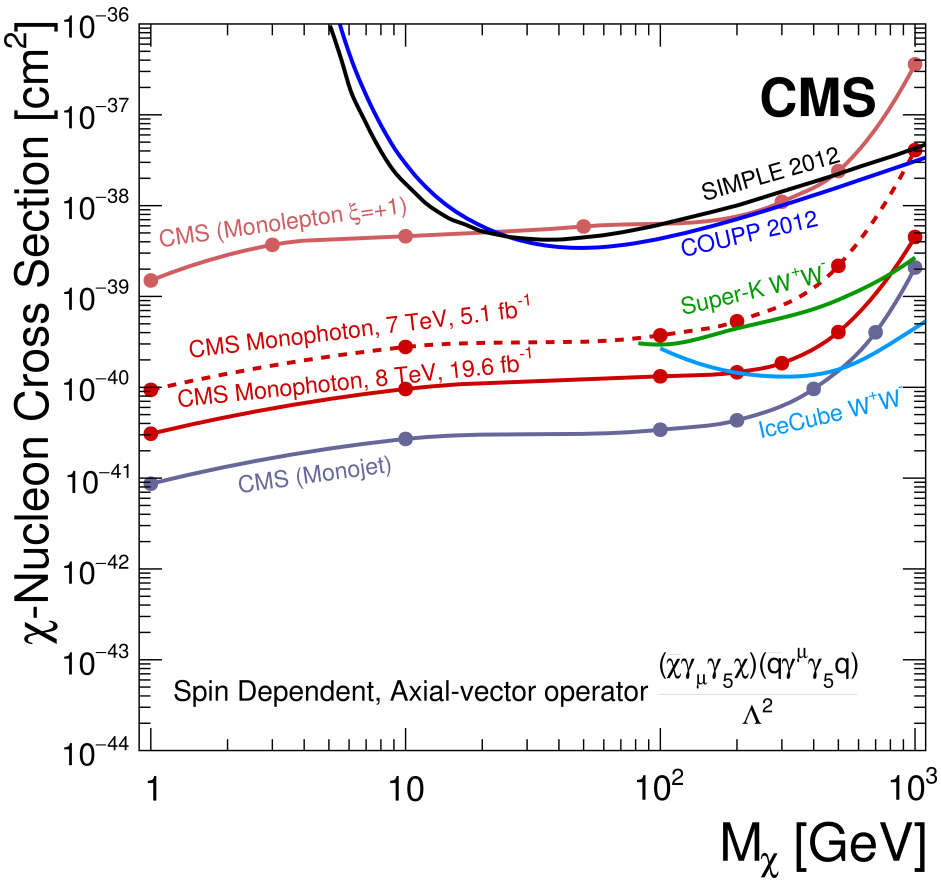
$g_{eff} = \sqrt{g_q g_\chi}$

Dark Matter Searches - Monophotons

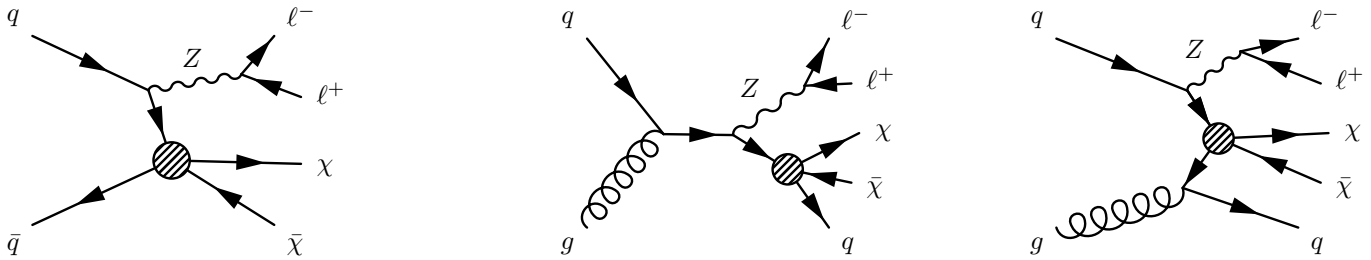
CMS-EXO-12-047, PLB 755 (2016)102

Data sample: 19.6 fb^{-1} at $\sqrt{s}$ = 8 TeV, 5.1 fb^{-1} at $\sqrt{s}$ = 7 TeV
Event selection: single photon with E_T > 145 GeV and $|\eta| \leq 1.44$, E_T^{miss} > 140 GeV





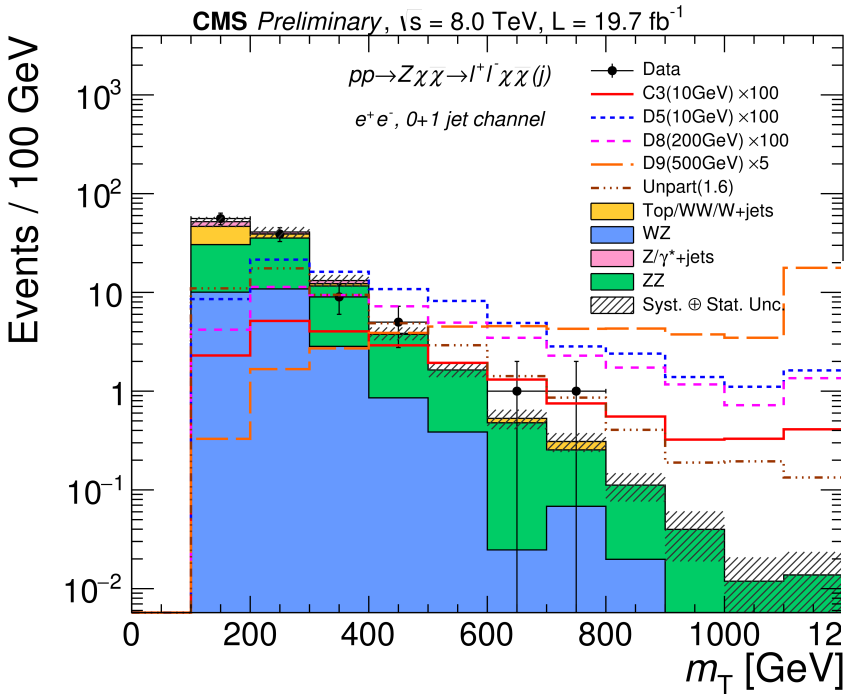
Dark Matter Searches - Mono-Z



Data sample: 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV

Event selection: 2 isolated, opposite-charge e/μ each with p_T > 20 GeV and invariant mass compatible with Z, no additional e/μ with p_T > 20 GeV, dilepton p_T > 50 GeV, no b-tagged jet

CMS-EXO-12-054



Operators for Dirac fermion (D) or complex scalar (C) DM coupling to SM quarks, Λ being the coupling scale of interactions between DM and quarks:

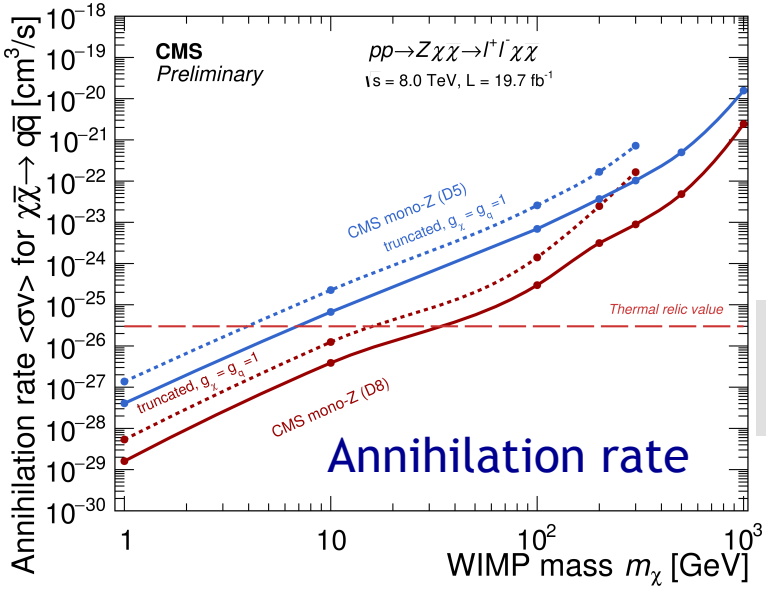
Vector coupling, spin-independent (D5): $\frac{\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q}{\Lambda^2}$

Axial-Vector coupling, spin-dependent (D8): $\frac{\bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{q}\gamma_{\mu}\gamma^{5}q}{\Lambda^2}$

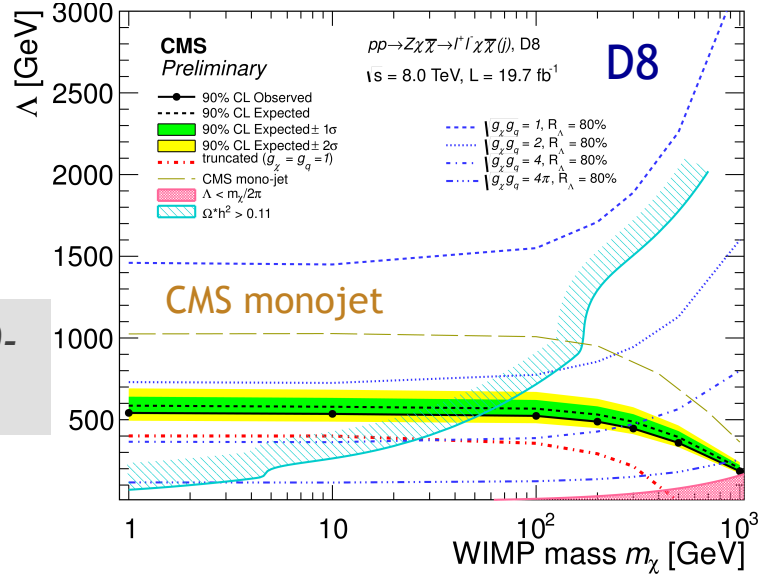
Tensor coupling, spin-dependent (D9): $\frac{\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q}{\Lambda^2}$

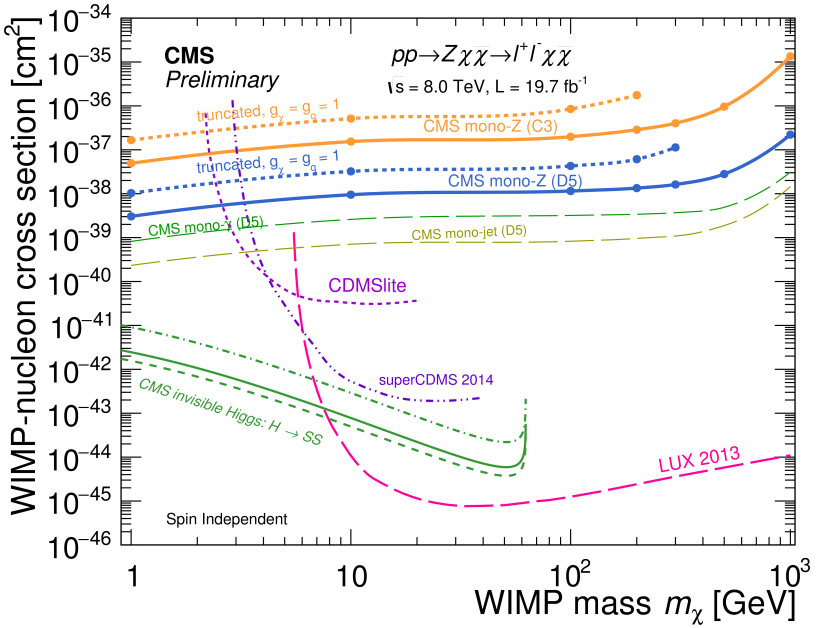
Vector coupling, spin-independent (C3): $\frac{\chi^{\dagger}\overleftrightarrow{\partial_{\mu}}\chi\bar{q}\gamma^{\mu}q}{\Lambda^2}$

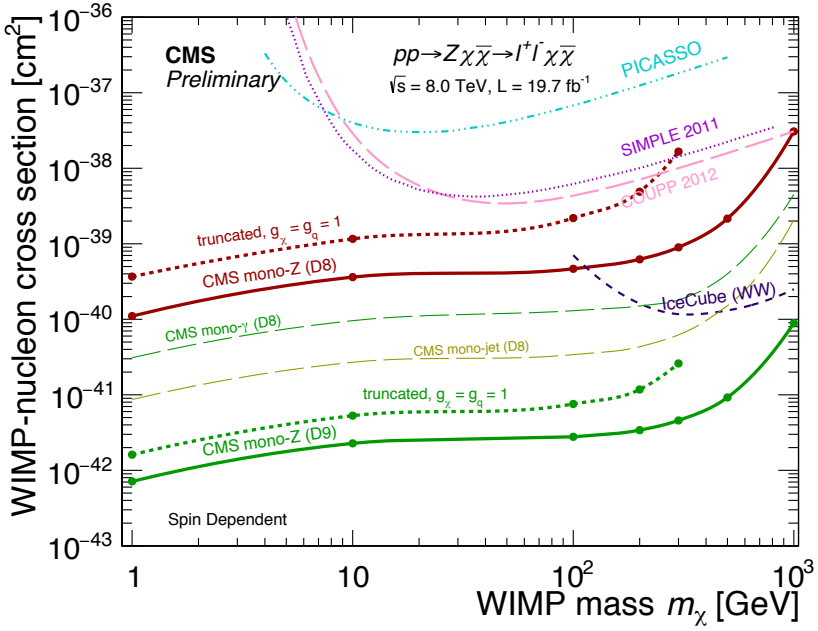
Dark Matter Searches - Mono-Z



CMS-EXO-12-054

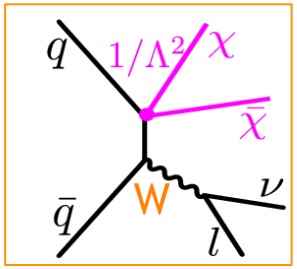




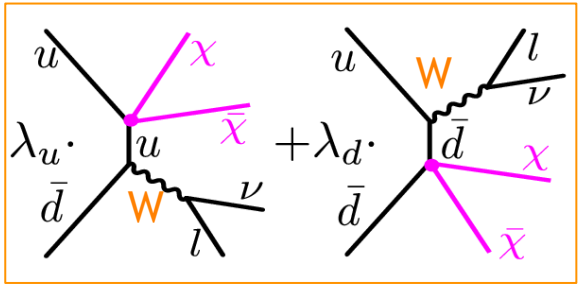


Dark Matter Searches - Mono-W

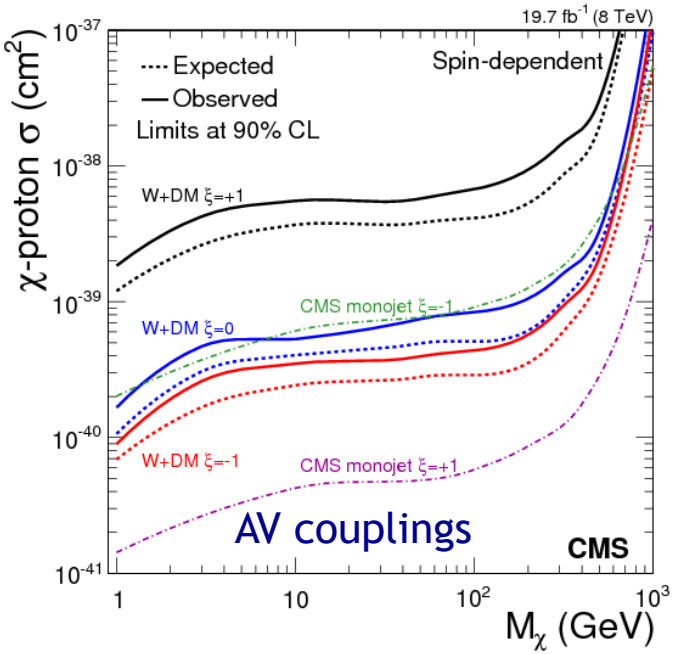
Dark matter interpretation of W' analysis

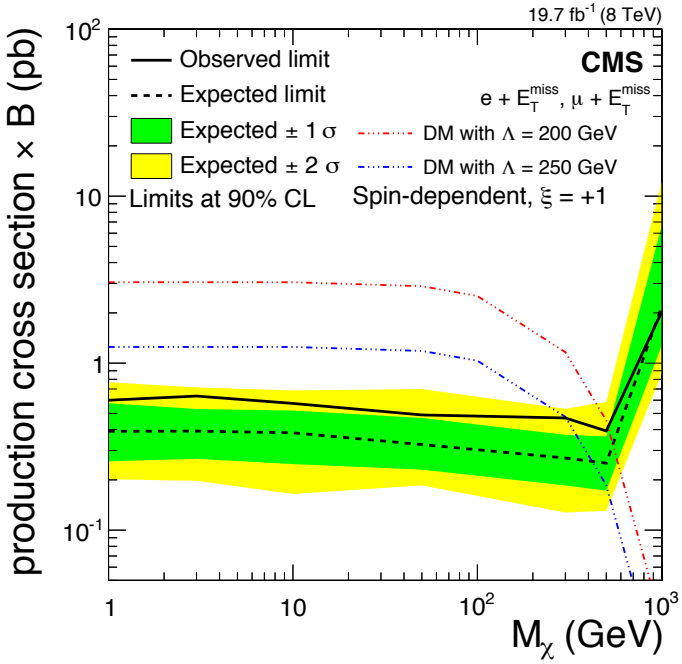


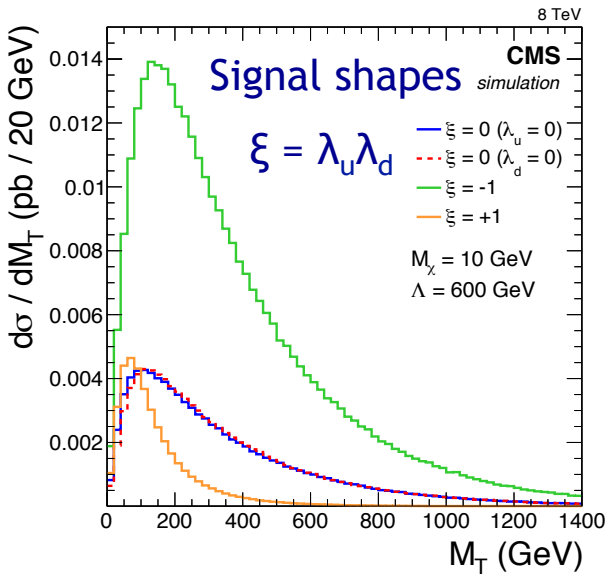
DM interference



Data sample: 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Event selection: prompt or non-prompt (from τ) single e or μ and E_T^{miss}
Advantages over monojet and mono-γ channels: lower SM background and trigger lepton



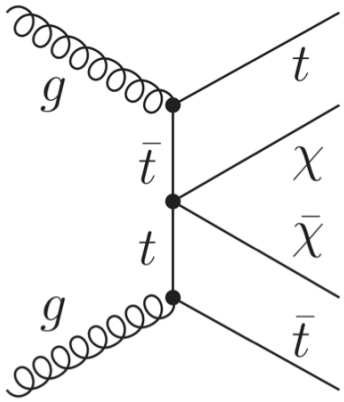




CMS-EXO-12-060, PRD 91 (2015) 092005

Dark Matter Searches - Top Pairs

q-χ couplings for heavy flavors enhanced in scalar interactions



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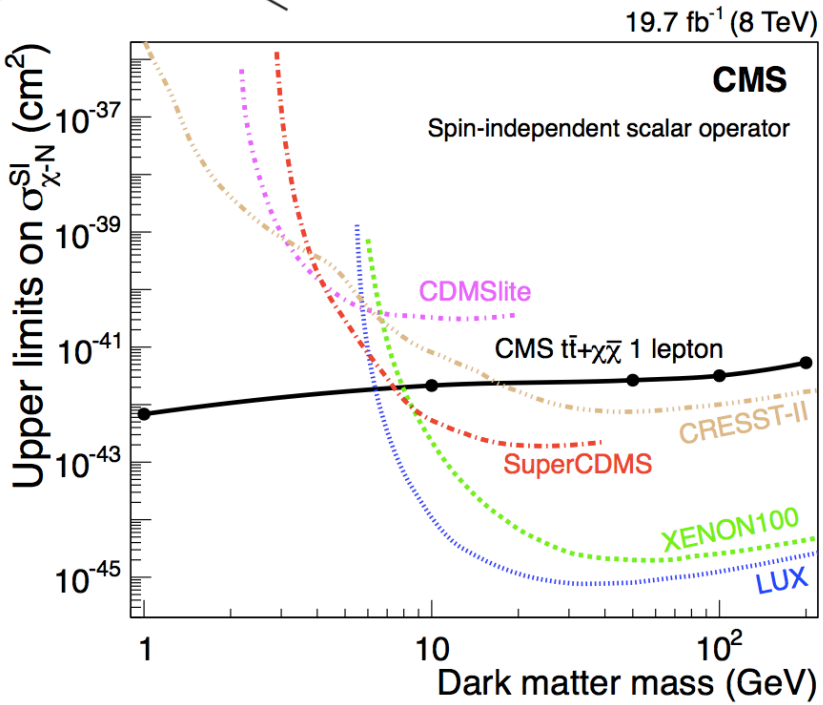
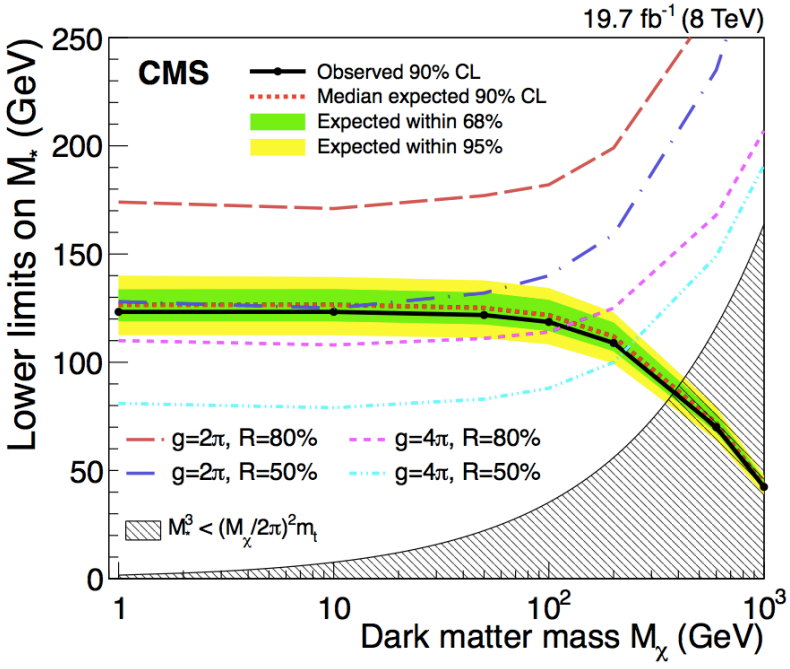
CMS-B2G-14-004

$tt + E_t^{miss}$ signature:
single lepton with jets, at least 1 b-tagged





M_*: scale of the interaction

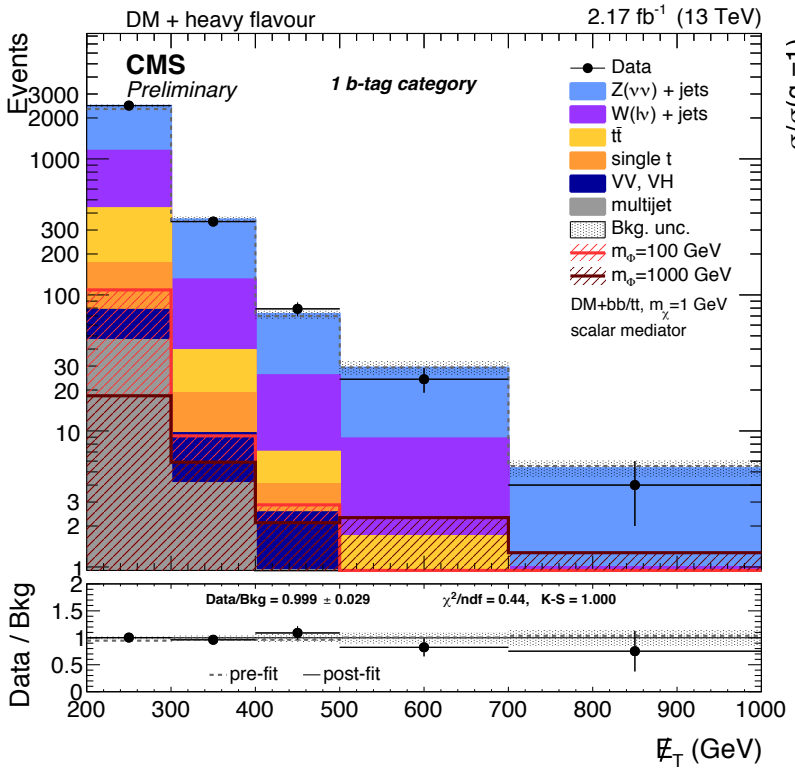
Dark Matter in association with b quarks

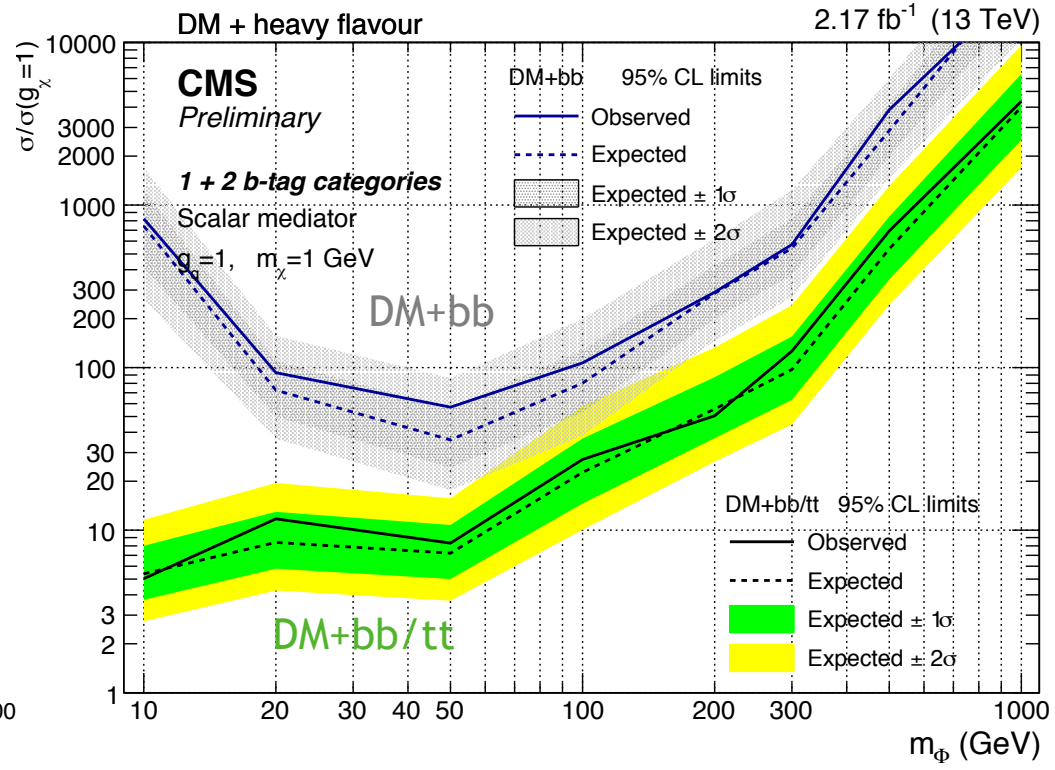
Data sample: 2.17 fb^{-1} at $\sqrt{s}$ = 13 TeV

Signature: b (1 or 2) + E_T^{miss}

This analysis is sensitive also to DM production processes in association with t quarks, which decay to b's.

NEW: CMS-EXO-B2G-15-007

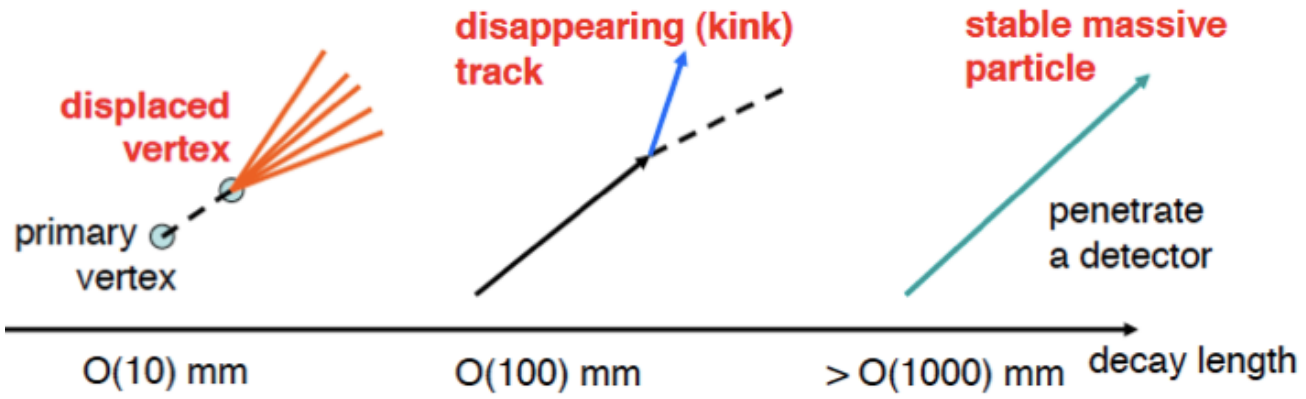




Mediator-DM couplings up to 5 x $\sigma/\sigma_{g_{DM}=1}$ are excluded.

Unconventional Signatures

Signatures:
Displaced objects
Disappearing or kinked tracks
Delayed objects
Stopped particles
Lepton jets



Long-lived particles are predicted in many BSM scenarios
SUSY: GMSB, AMSB, split SUSY, RPV SUSY
Hidden valley scenarios

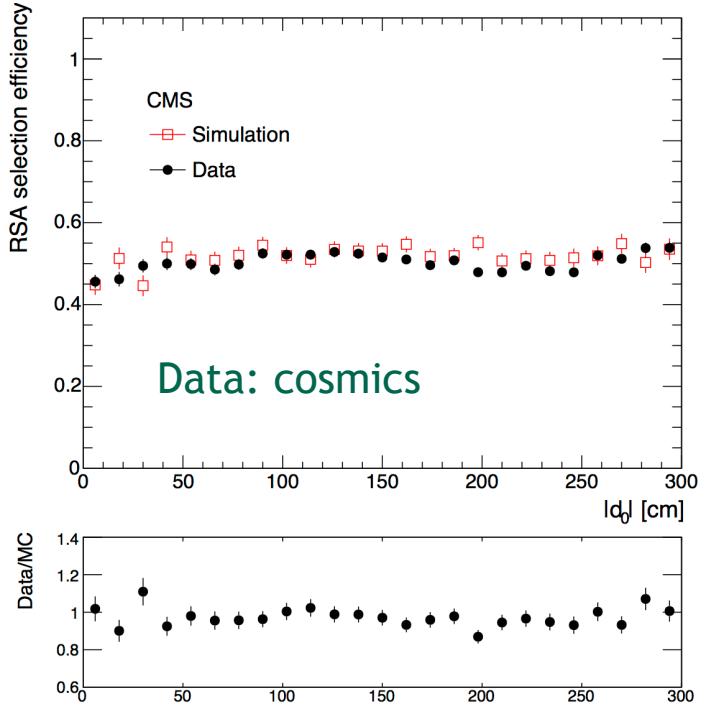
Long-lived Neutral Particles Decaying to Muons

Topology: Two muons originating from displaced secondary vertex, detected in muon chambers only

Limits derived for two specific models:

1) H^0 -> XX -> 4μ (H^0 … non-SM Higgs boson, X … long-lived boson with spin 0)
2) 2 squark pairs, with $\tilde{q}$ -> $q\tilde{\chi}^0$, long-lived $\tilde{\chi}^0$ -> μμν (R-parity violated)

μ reconstruction and selection efficiency



d^0: transverse impact parameter

CMS-EXO-14-012

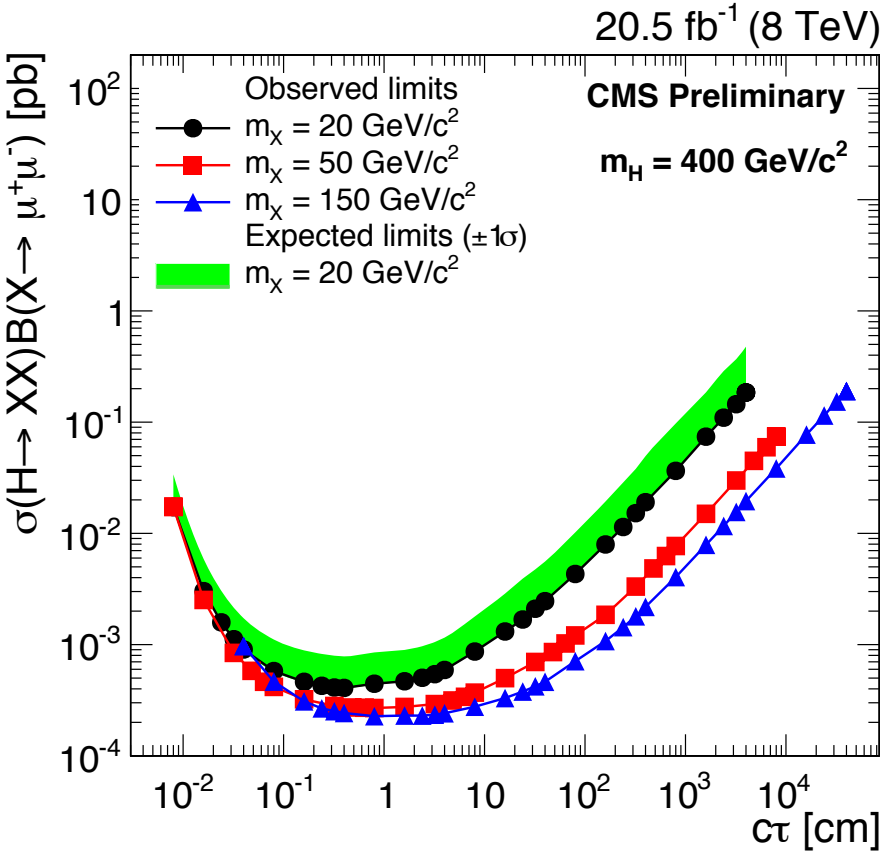
Signal systematic errors Source	Uncertainty
Pileup modelling	2%
Tracking efficiency from cosmics	3%
Trigger efficiency	15%
Parton distribution functions	< 1%
Renormalisation and factorisation scales	< 0.5%
NLO effects	5 – 7%

This analysis is orthogonal to a previous one that used only the tracker (arXiv: 1411.6977) – the two analyses have been combined to improve limits

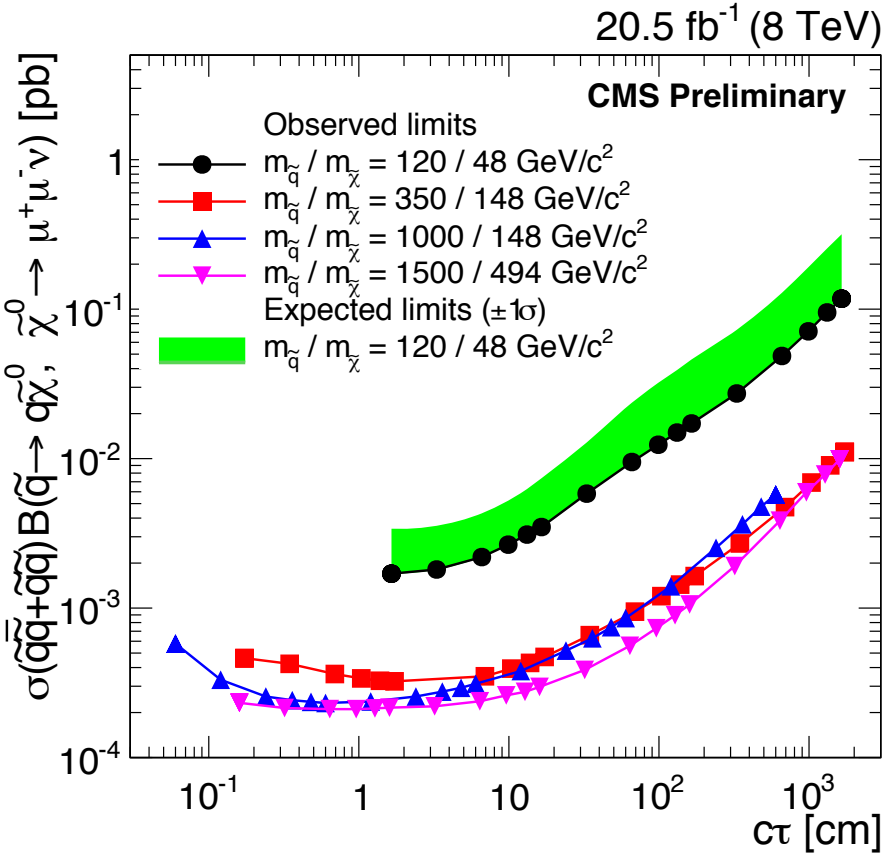
Long-lived Neutral Particles Decaying to Muons

Combined 95% CL upper limits for muon chamber and tracker analyses

$H^0 \rightarrow XX \rightarrow 4\mu$



$\tilde{q} \rightarrow q\tilde{\chi}^0$, $\tilde{\chi}^0 \rightarrow \mu\mu\nu$

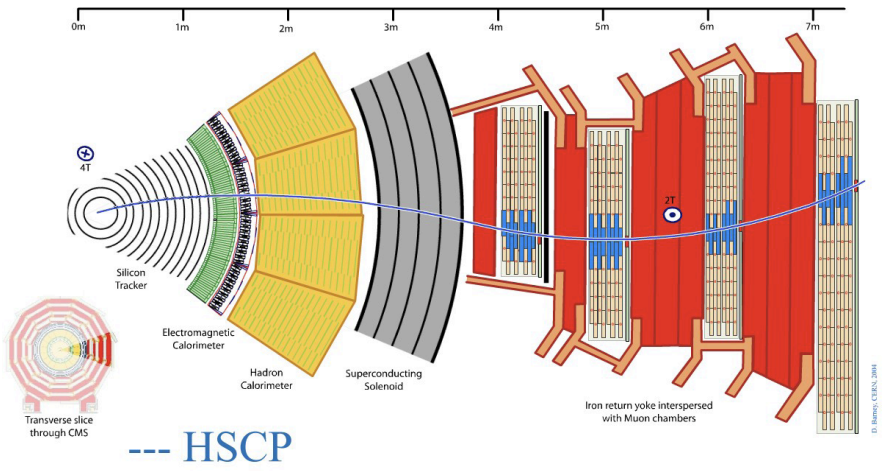


Long-lived Heavy Charged Particles

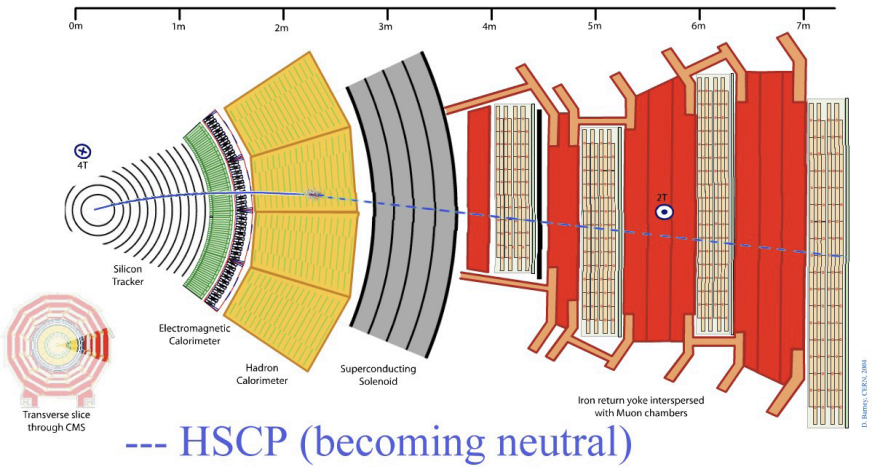
R-hadrons: long-lived gluinos could hadronize to e.g. $\tilde{g}$-qqq states

Stable chargino or stau, etc.

If mass greater than about 100 GeV: $\beta < 0.9$.
Nuclear interactions may lead to charge exchange.



Tracker (high dE/dx) + μ system (long TOF)

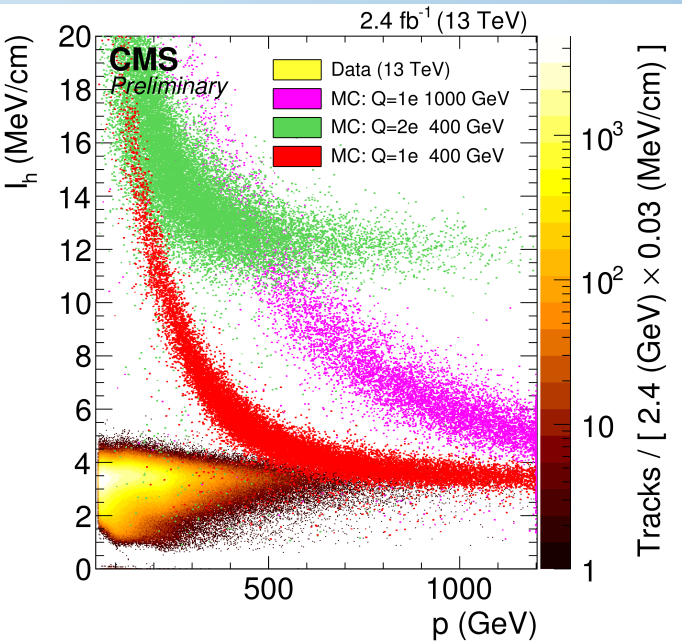


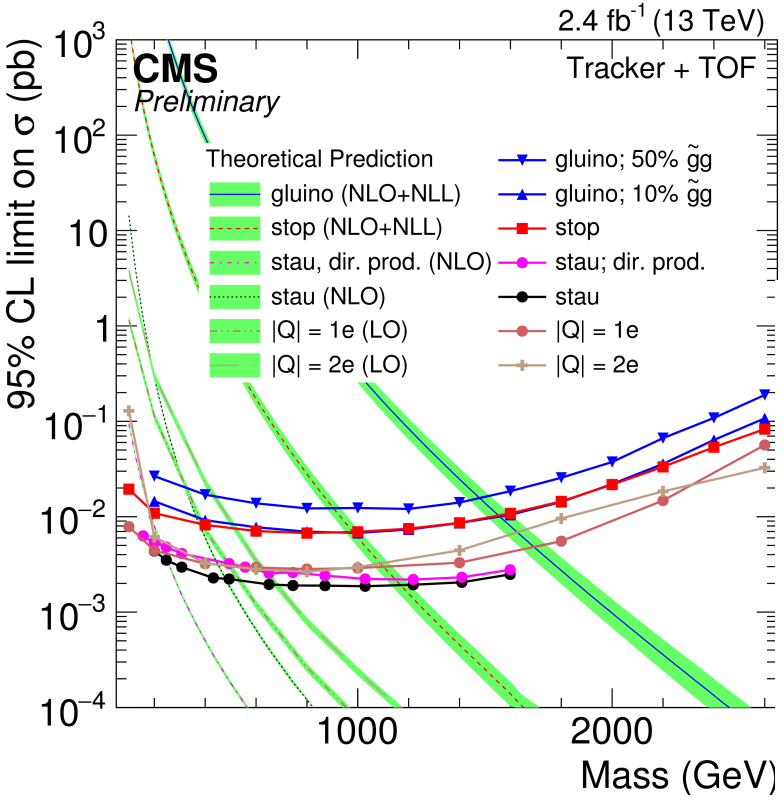
Tracker only (charge exchange)
-> disappearing track

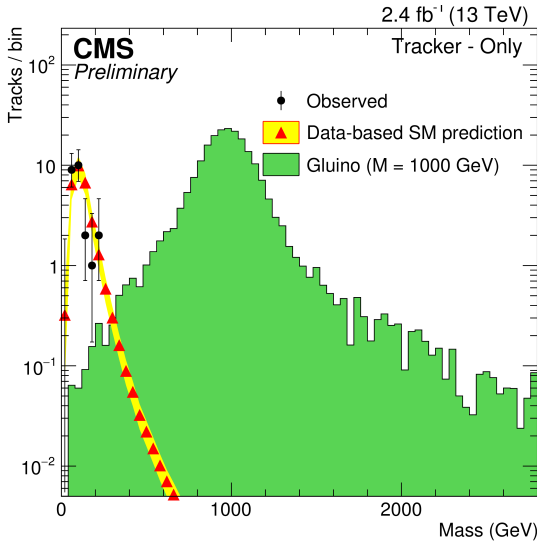
Long-lived Heavy Charged Particles

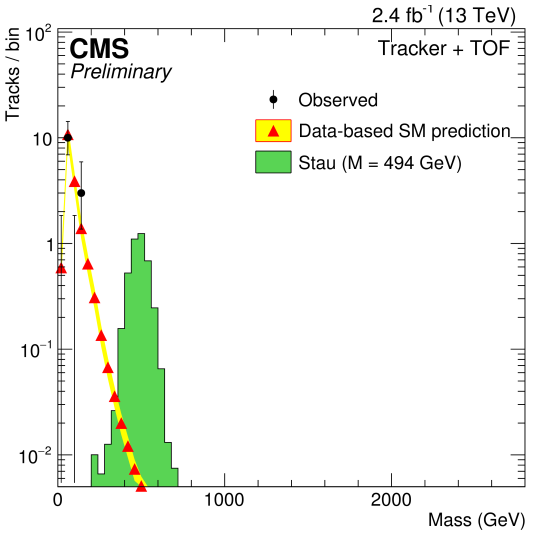
Data sample: 2.4 fb^{-1} at $\sqrt{s}$ = 13 TeV
Signature: anomalously high energy deposit in tracker and long TOF to muon detectors

NEW: CMS-EXO-15-010





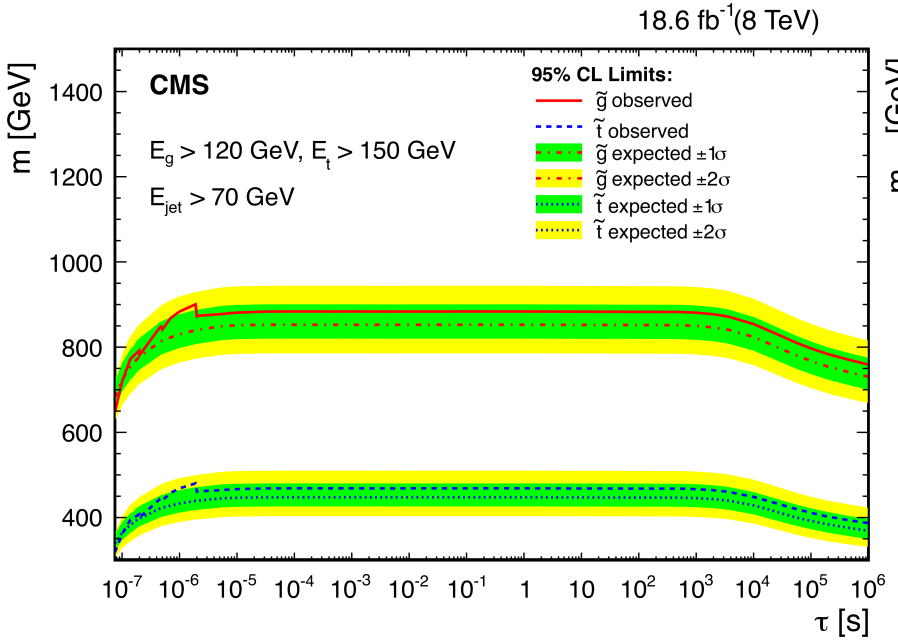


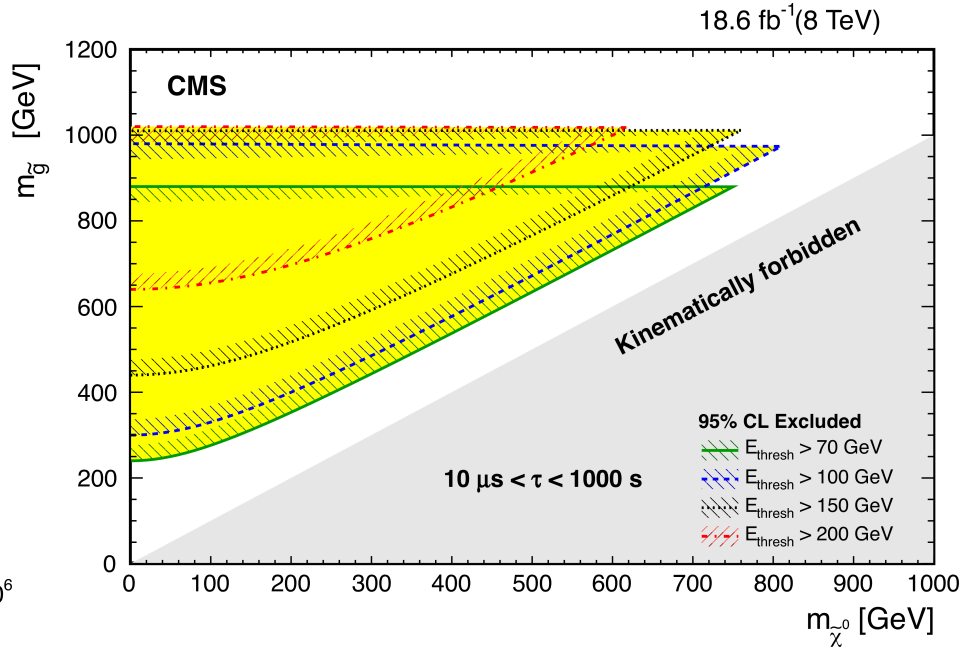


Stopped Particles

Strategy: search for decays of particles with kinetic energies so low that they come to rest in the detector. As $E_{kin} \sim v^2$, $dE/dx \sim 1/v^2$, for $v < 0.45c$ R-hadrons could come to rest inside the calorimeter. Signature assuming decays to at least one SM particle: randomly timed large energy response in a few channels, most easily observed between pp collisions.
Background: cosmic rays, beam halo, instrumental noise.
Data sample: 18.6 fb^{-1} at $\sqrt{s}$ = 8 TeV, with 281 h of dedicated trigger.
Assumption: $B(\tilde{g} \to g\chi^0) = 100\%$, $B(\tilde{t} \to t\chi^0) = 100\%$

CMS-EXO-12-036





Bibliography

- Dark matter
  - Monojets: CMS-PAS-EXO-15-003 ($\sqrt{s}$ = 13 TeV), EXO-12-048 ($\sqrt{s}$ = 8 TeV)
  - Razor dijets: EXO-14-004 (8 TeV)
  - Monophotons: EXO-12-047 (8 TeV)
  - Mono-Z: EXO-12-054 (8 TeV)
  - Mono-W: EXO-12-060 (8 TeV)
  - Mono-top: B2G-14-004, B2G-13-004, B2G-12-022 (8 TeV)
  - Associated b quarks: B2G-15-007 (13 TeV)

- Unconventional signatures
  - Heavy stable charged particles (HSCP):
    EXO-15-010 ($\sqrt{s}$ = 13 TeV), EXO-13-006, EXO-12-026 ($\sqrt{s}$ = 8 TeV)
  - Long-lived neutral particles: EXO-12-038, EXO-12-035, EXO-14-017 (8 TeV)
  - Stopped long-lived particles: EXO-12-036 (8 TeV)
  - Disappearing tracks: EXO-12-034 (8 TeV)
  - Displaced lepton pairs: EXO-12-037, EXO-14-012 (8 TeV)

http://cms-results.web.cern.ch/cms-results/public-results/publications

Conclusions

Dark Matter

- CMS has studied dark matter signatures with $\sqrt{s}$ = 7, 8 and 13 TeV data and has derived limits.

- Simplified models are replacing EFT approach for Run 2 searches.

Unconventional signatures

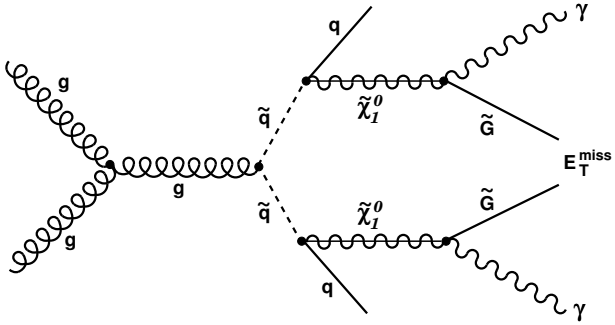
- Several searches for unconventional signatures have been performed.

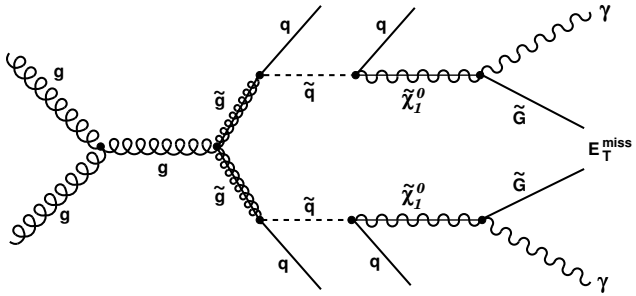
- Special triggers and analysis techniques have been developed.

BACKUP

Long-lived Neutral Particles Decaying to Photons

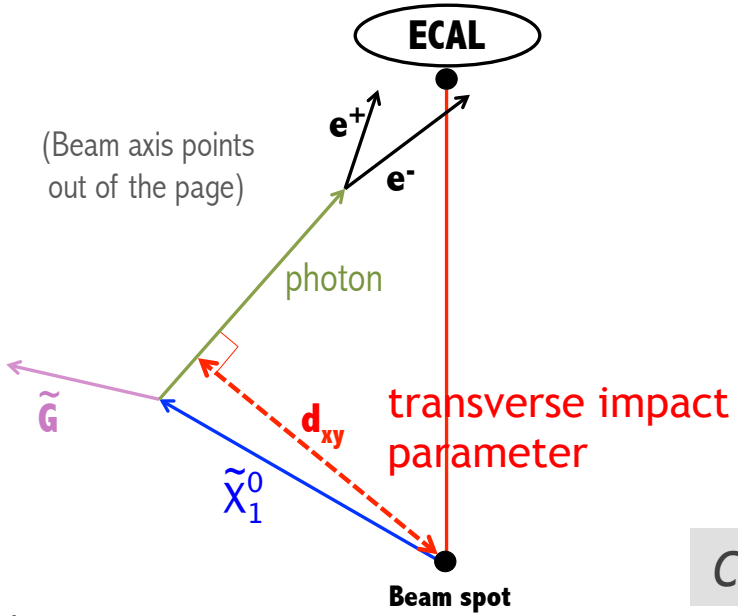
Model with GMSB: long-lived lightest neutralino decays to gravitino and photon

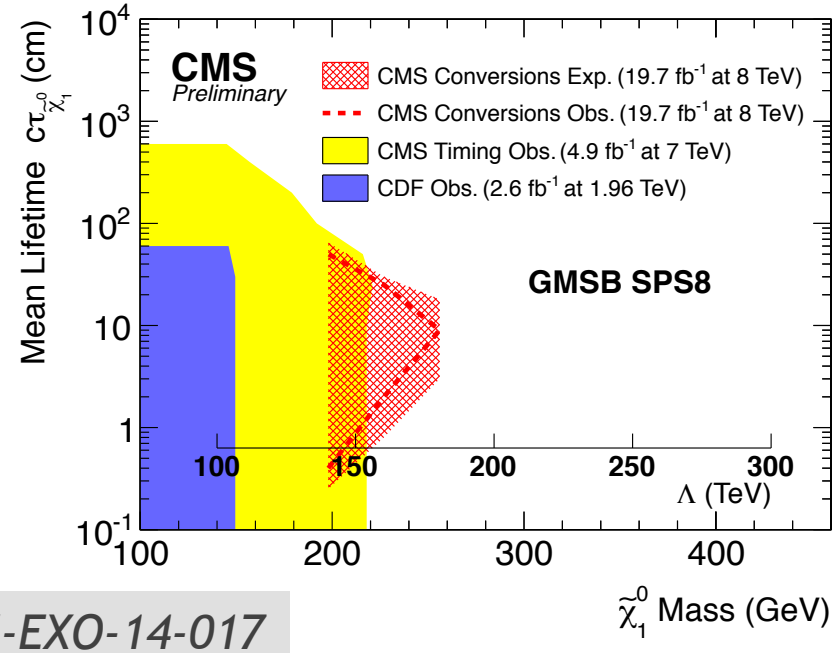




Event selection: 2γ, with one converting to e^+e^-, at least 2 jets, and E_T^{miss}

Scenario: 0.4 cm ≤ cτ ≤ 100 cm

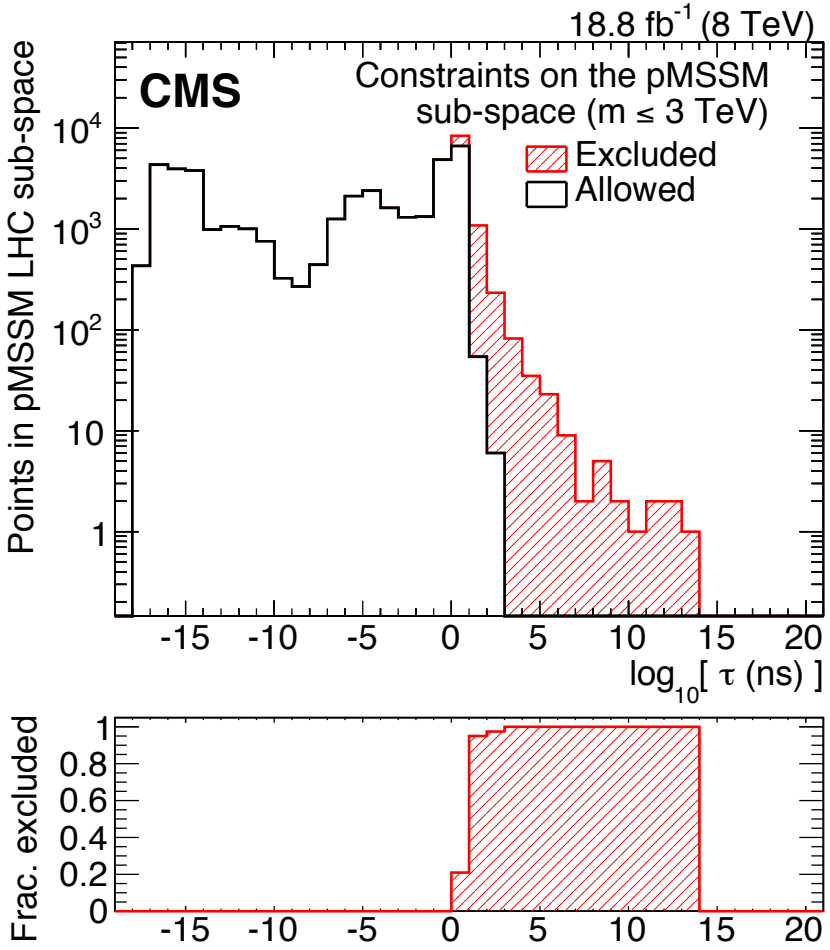


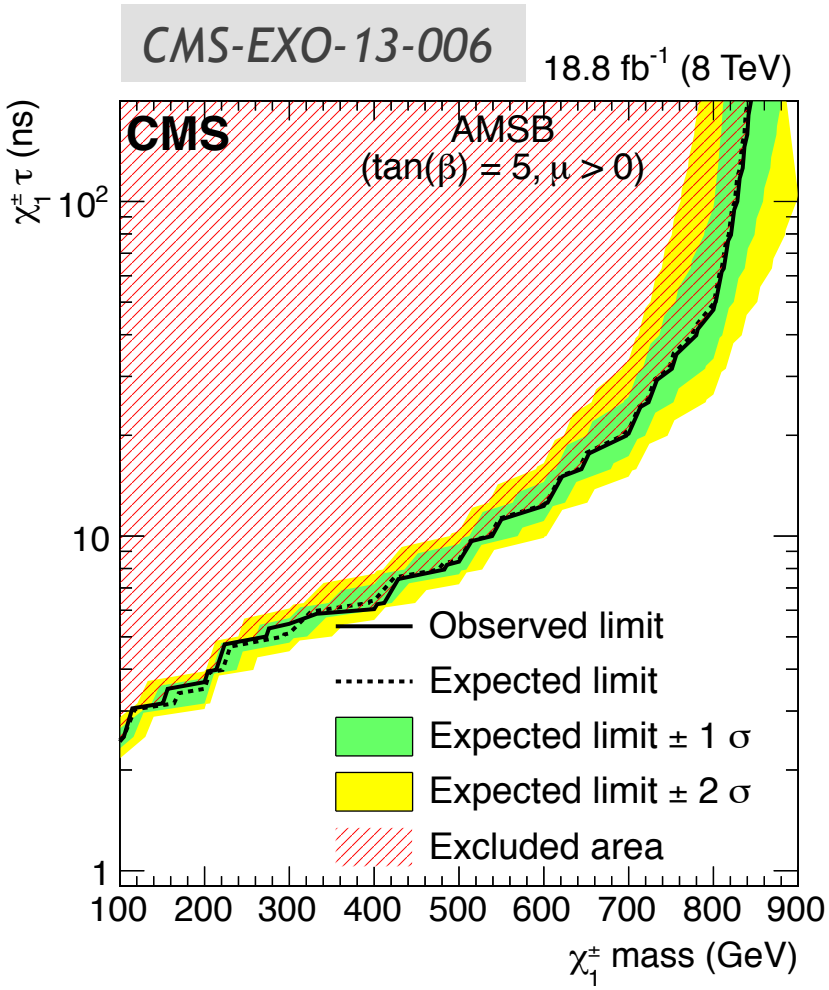


CMS-EXO-14-017

Long-lived Heavy Charged Particles

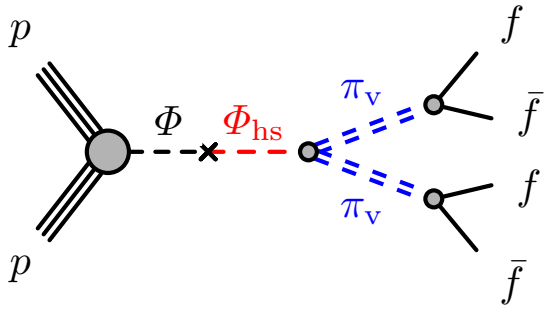
Reinterpretation of previous results on long-lived chargino production [JHEP 07 (2013) 122] in context of pMSSM (first constraints at the LHC) and AMSB models, based on highly-ionizing and penetrating particles

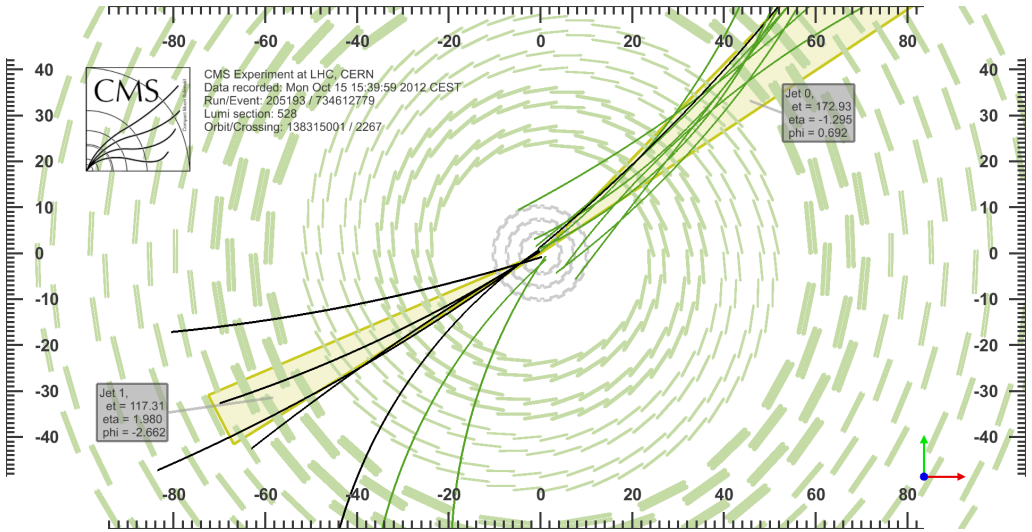




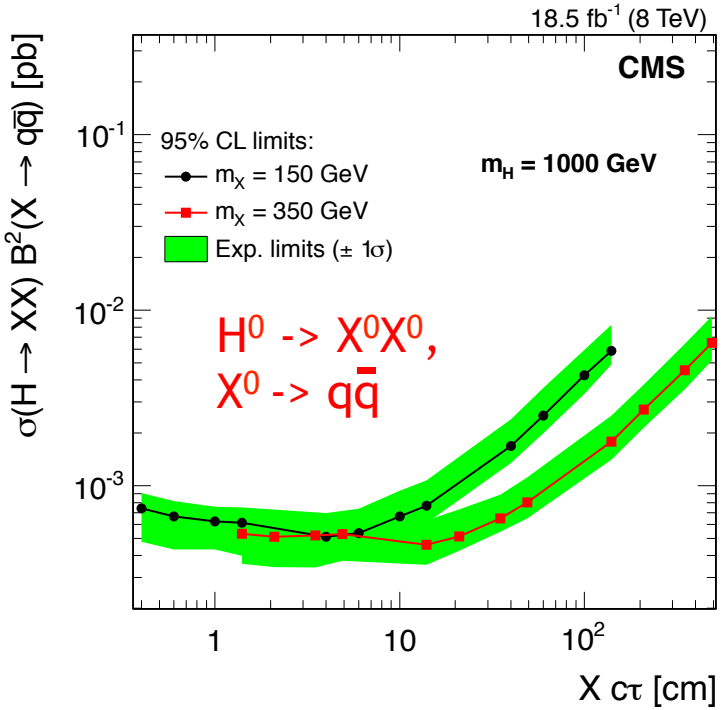
Displaced Jets

Hidden valley benchmark model: $H/\Phi \rightarrow \Phi_{hs} \rightarrow \pi_v\pi_v$ with $\pi_v \rightarrow jj/ll$
Decays of v-particles must occur via hidden sector mediator as they do not couple directly to SM particles.
Topology studied: 2 hadronic jets originating from same displaced vertex.



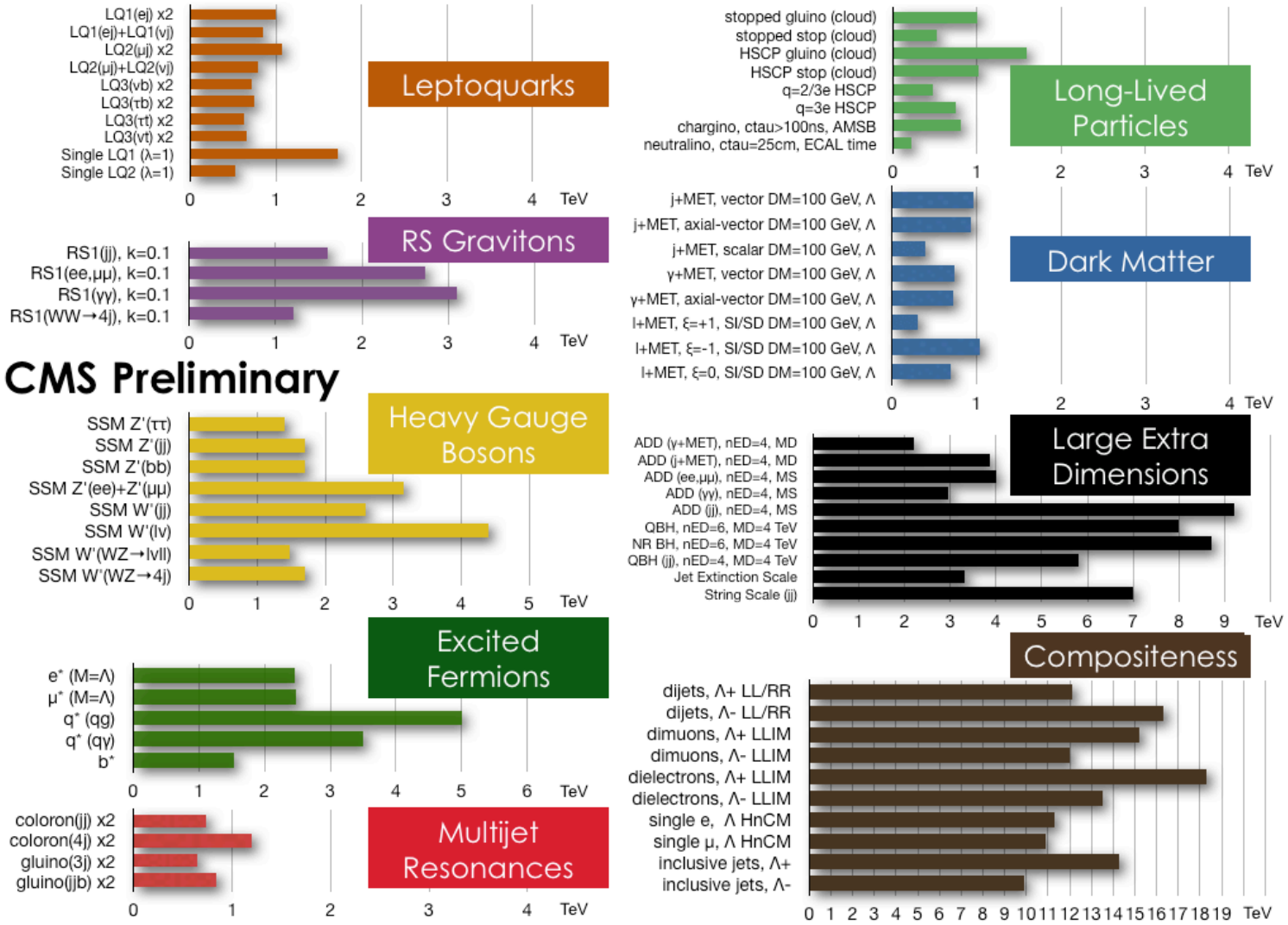


CMS-EXO-12-038, PRD 91 (2015) 012007



Exotica Limits

December 2015



Beyond Two Generations Limits