Dark Matter Searches at Colliders

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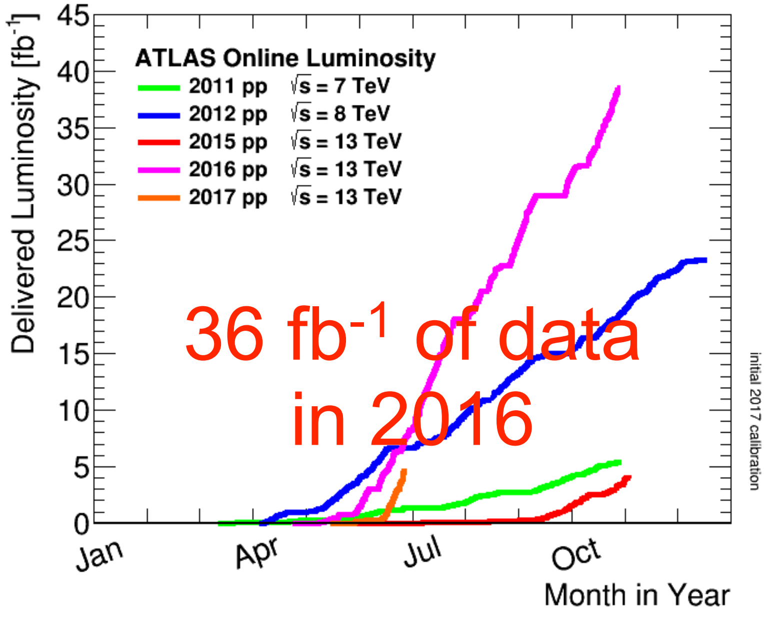
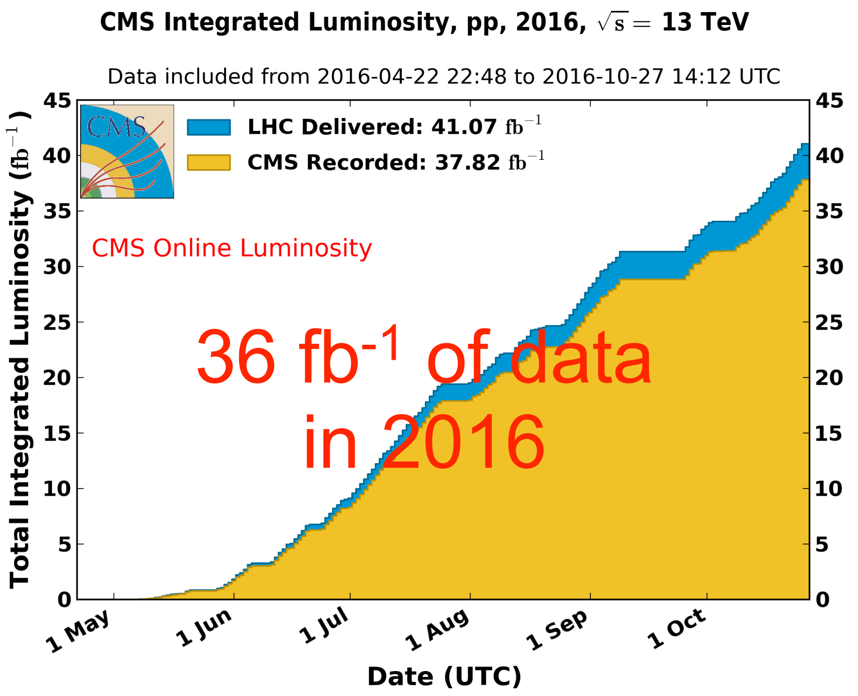
On behalf of the ATLAS, CMS, and LHCb Collaborations

6 July 2017
EPS Conference on High Energy Physics, Venice, Italy

Outline

- Overview of DM searches at colliders
- Searches for direct production of DM or mediators
    - Experimental techniques
    - Interpretation of results
- Searches for DM in cascade decays
- Conclusion and outlook



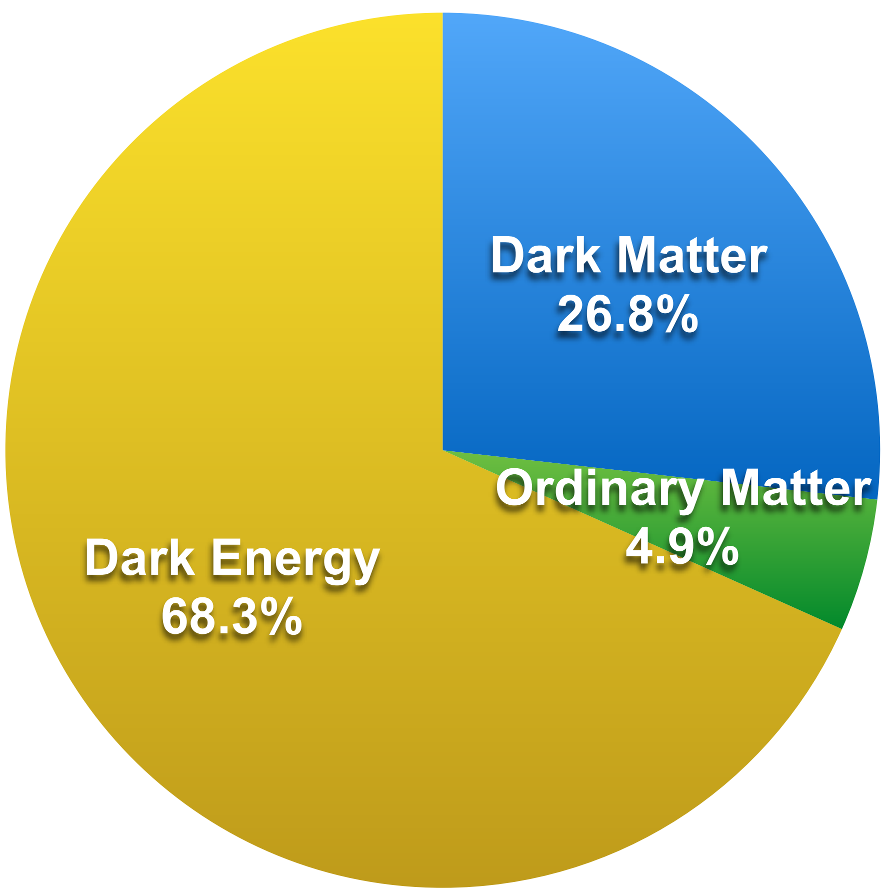


See following talks for more details of the results from each experiment

Deborah Pinna, "Searches for dark matter in hadronic final states at CMS"
Valerio Ippolito, "Dark Matter searches with the ATLAS Detector"
Andrea Mauri, "Search for long-lived scalar particles in B decays at LHCb"

Complementarity of Dark Matter Searches

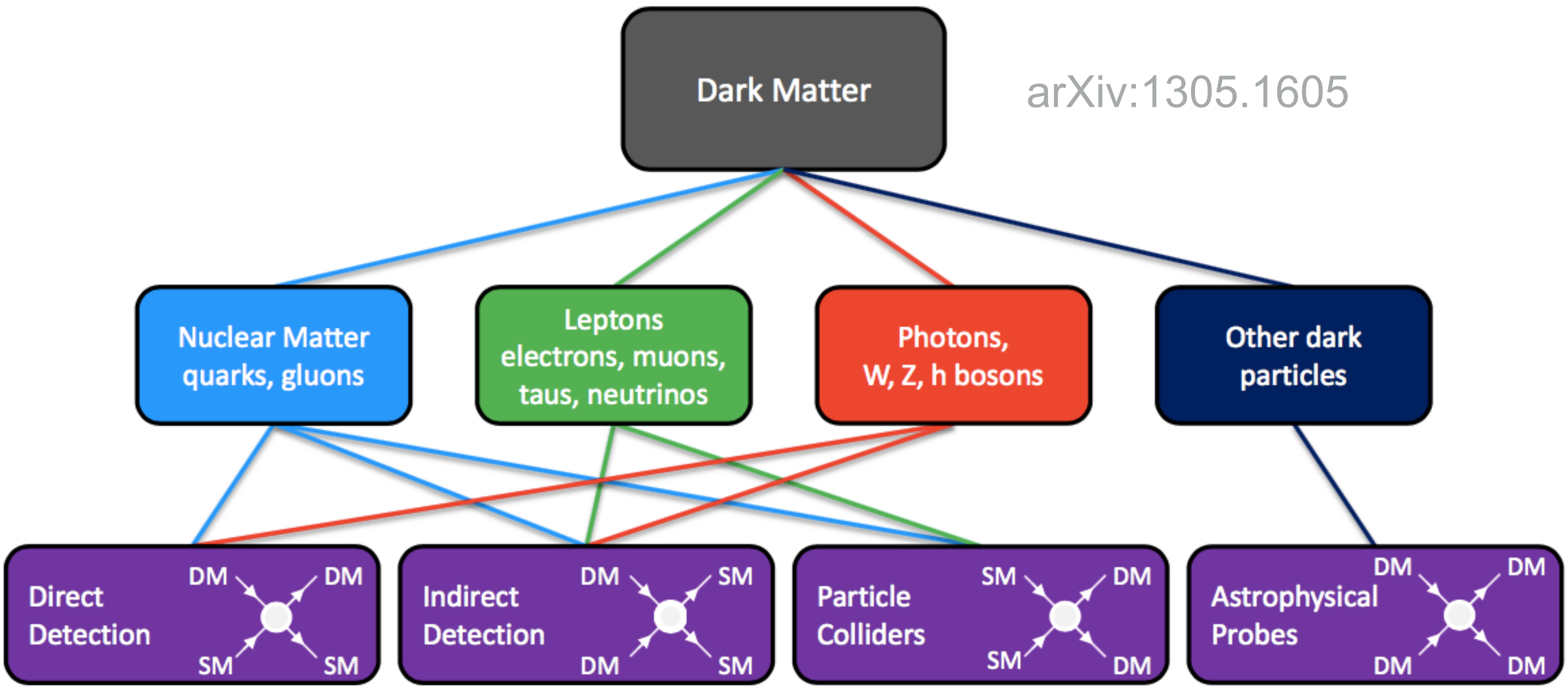
- Evidence of dark matter well established from astrophysical observations
  - The exact nature of DM is still unknown



Matter/Energy Today

Complementarity of Dark Matter Searches

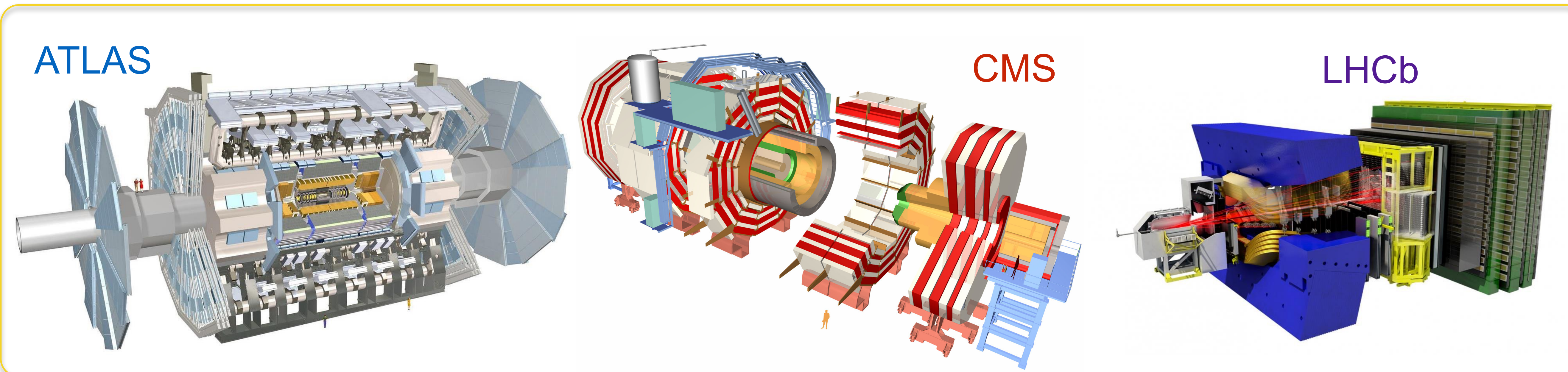
- Evidence of dark matter well established from astrophysical observations
  - The exact nature of DM is still unknown



arXiv:1305.1605

Dark Matter Searches at Colliders

- LHC provides a prime laboratory for production of DM
    - Can probe a wide range of DM/SM interaction types



1 GeV~1 TeV

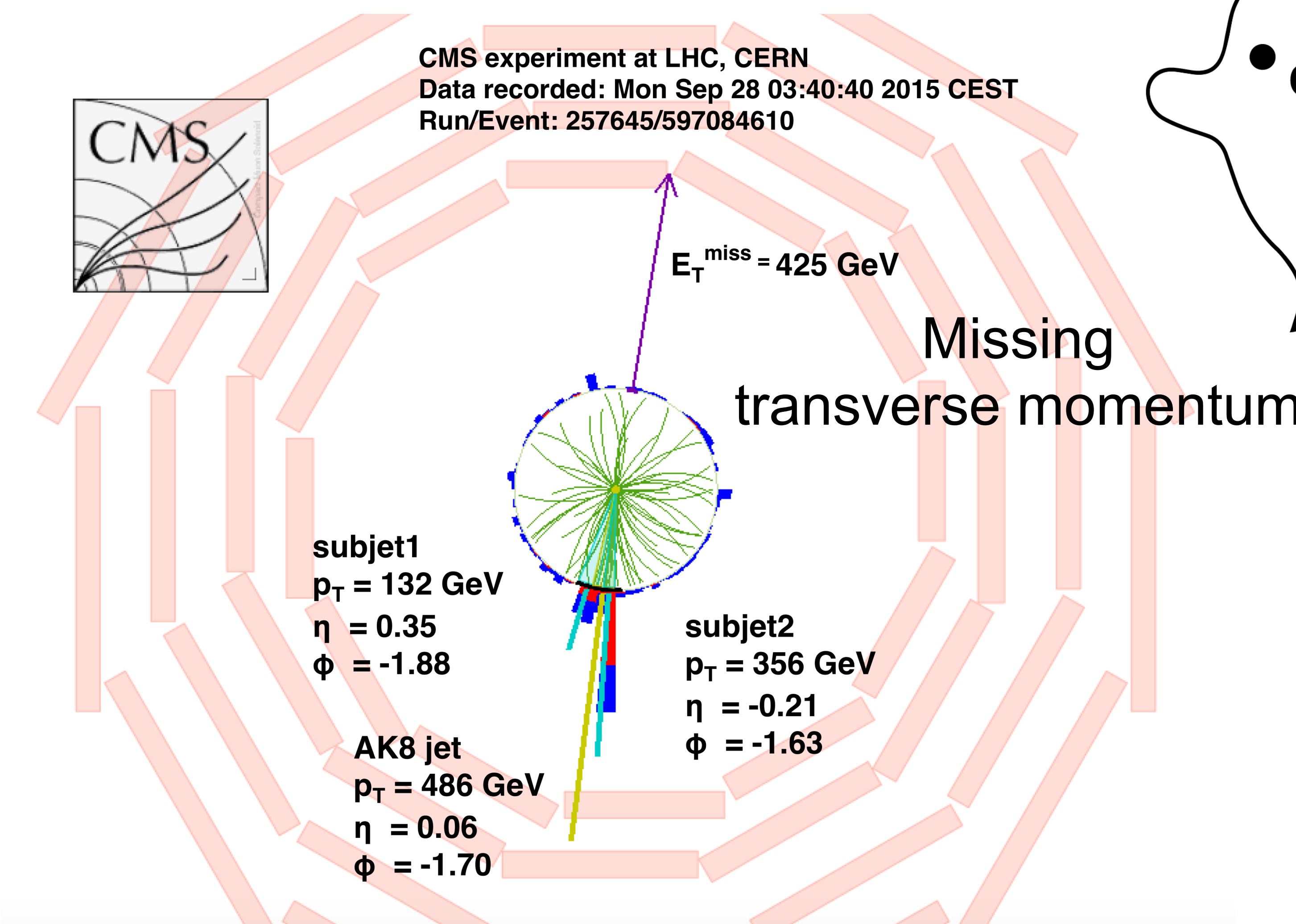
must be bosonic ← Collider Reach → must be composite

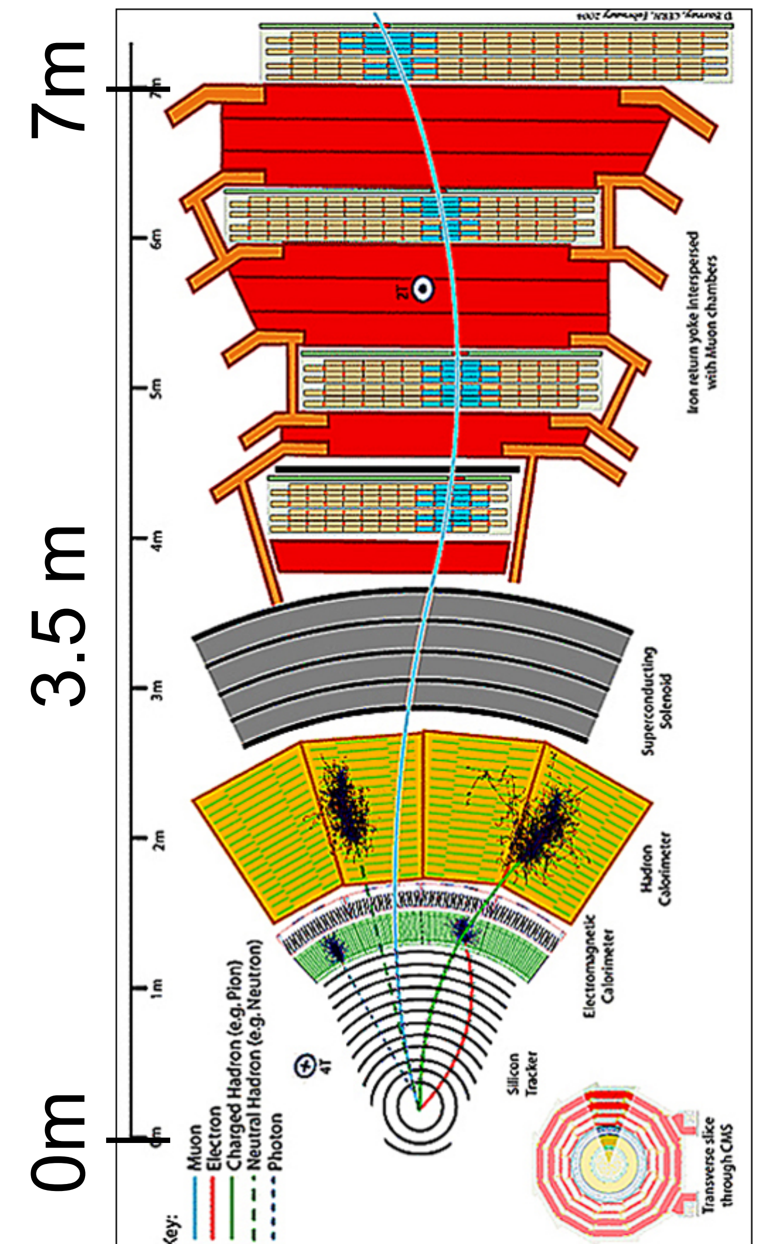
$\sim 10^{-20}$ eV ← ~ 100 eV — m_{Pl} $\sim 10^{19}$ GeV → $\sim 100 M_{\odot}$

m_{DM}

What Is Dark Matter at Colliders?

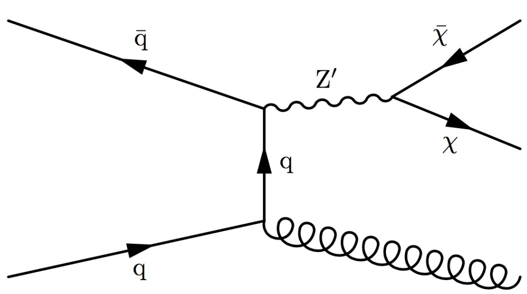
- Neutral, weakly-interactive, massive, and stable on the distance-scales of tens of meters
  - Dark matter appears as missing transverse momentum in collider detectors





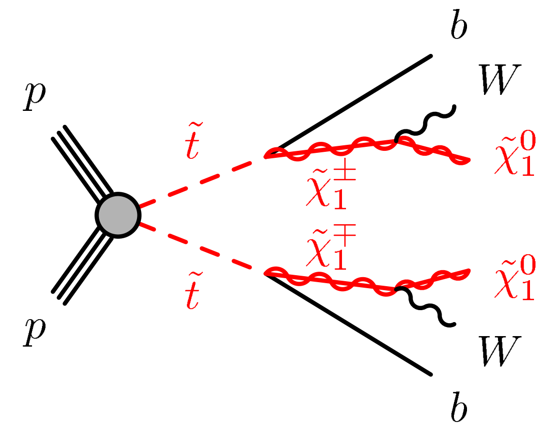
Search Approaches at Colliders

- Dark matter produced directly
  - Pair production of DMs
  - Mono-X signature where X=**j**, **γ, W, Z, h, bb, tt, t**
- Search for mediators
  - via dijet, dilepton, or Higgs



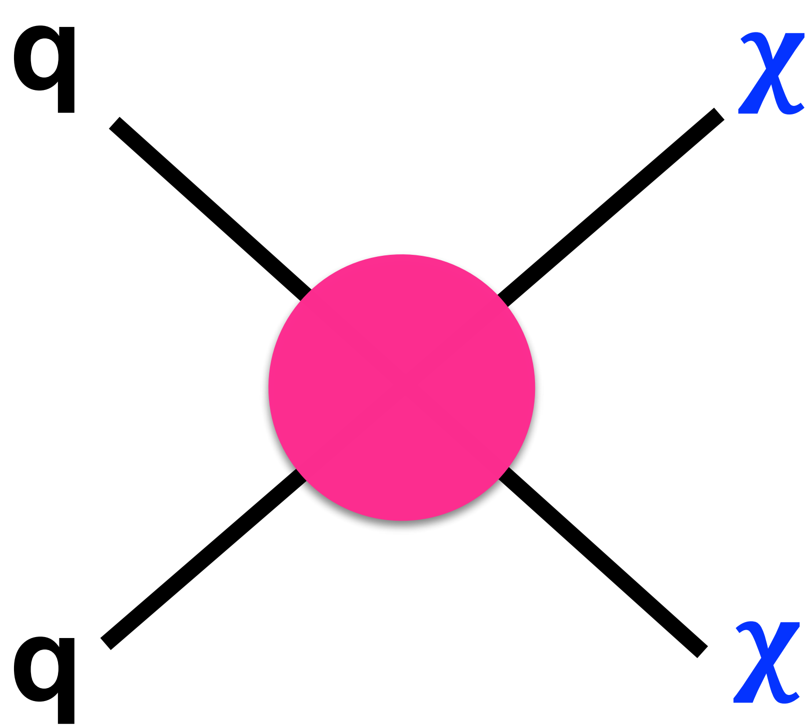
- Dark matter in cascade decays
  - SUSY WIMPs, with R-parity conservation, 2 LSPs in final state
  - NLSPs, LSPs, gluinos, or stops with long life time→displaced vertex, disappearing tracks, heavy stable charged particle (HSCP)

$$R = (-1)^{2s+3B+L} = \begin{Bmatrix} +1 \text{ SM} \\ -1 \text{ SUSY} \end{Bmatrix}$$



Evolution of Models for Direct DM Production

Effective Field Theory



$$\frac{g_\chi g_q}{Q_{tr}^2 - M^2} = -\frac{g_\chi g_q}{M^2}\left(1 + \frac{Q_{tr}^2}{M^2} + O\left(\frac{Q_{tr}^4}{M^4}\right)\right)$$

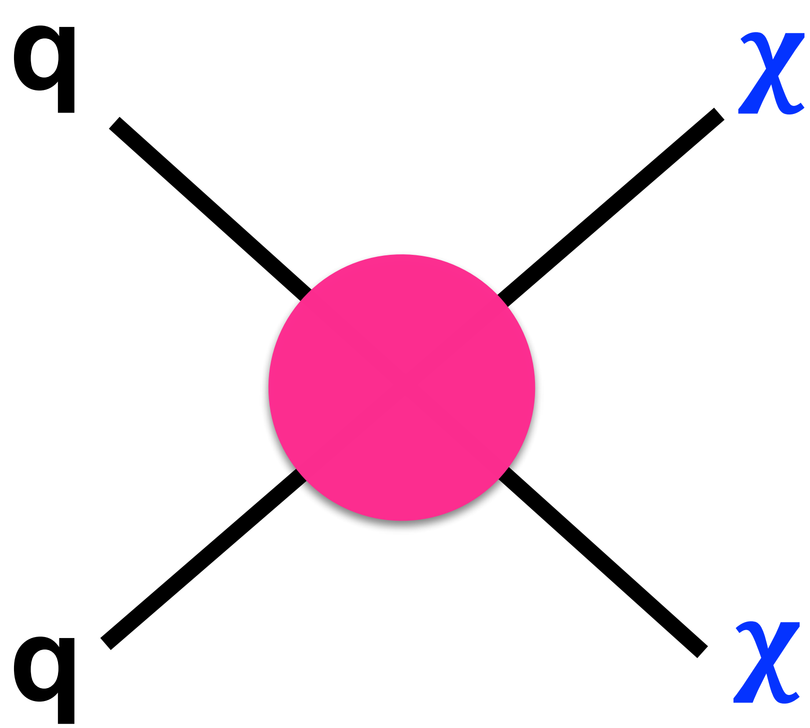
$$\simeq -\frac{g_\chi g_q}{M^2} = -\frac{1}{M_*^2}$$

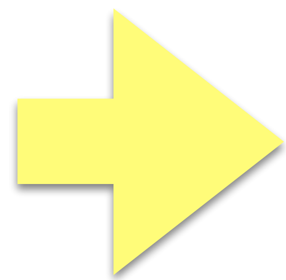
$$M_* \equiv \frac{M}{\sqrt{g_\chi g_q}}$$

- m_{DM}, M_*, underlying coupling type, DM types
- Valid when $Q_{tr}^2 \ll M^2$

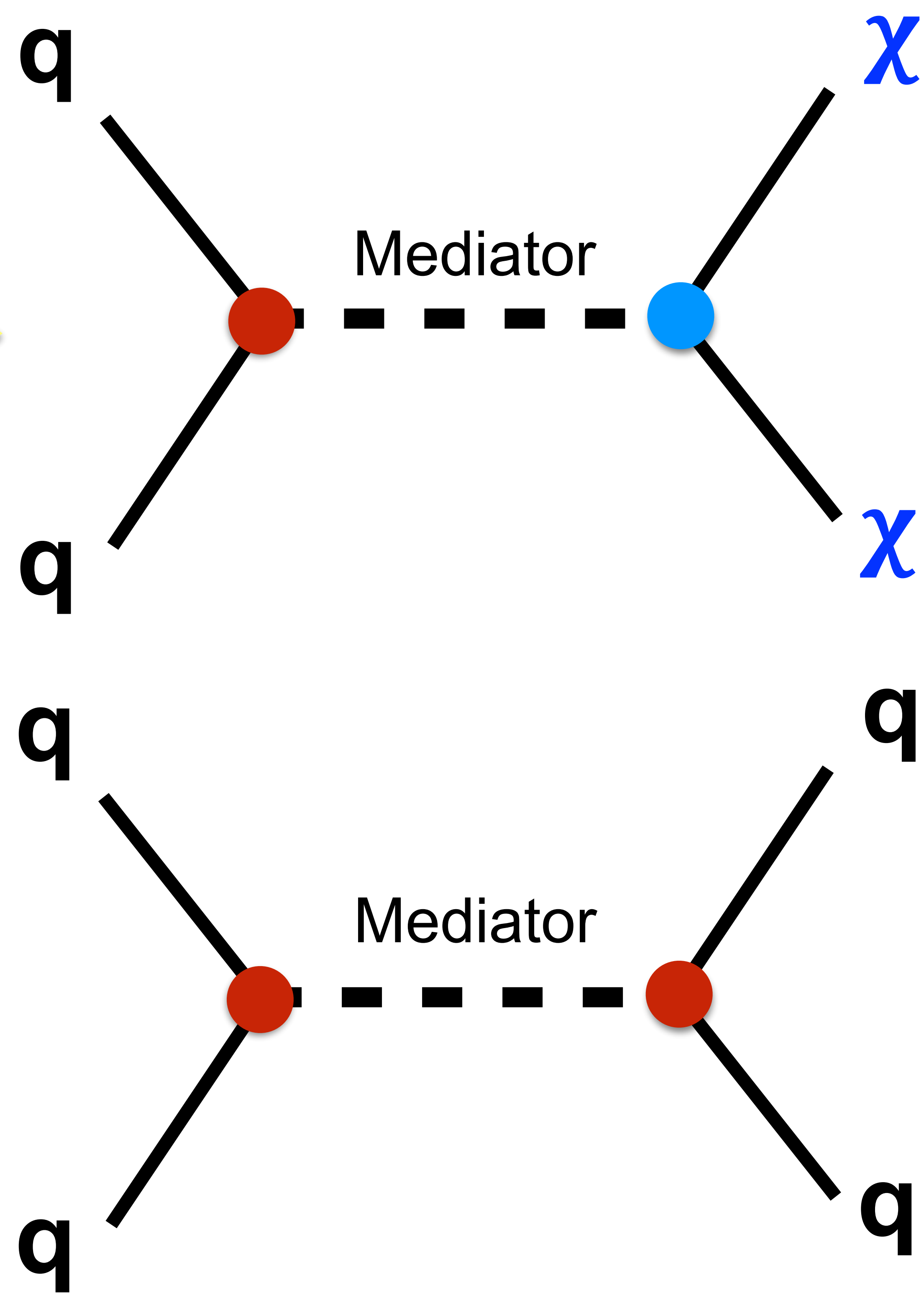
Evolution of Models for Direct DM Production

Effective Field Theory





Simplified Model



- m_{DM}, M_*, underlying coupling type, DM types
- Valid when $Q_{tr}^2 \ll M^2$

LHC Dark Matter Forum and Working Group

- SUSY simplified models to search for DMs in cascade decays are standardized already at Run I
- Starting from Run II, simplified models for direct DM searches are standardized and discussed in the LHC DM forum and working group, GitLab
  - Consensus of simplified models for MET signatures
  - Guidelines for the comparison of LHC and non-LHC DM search results
  - Guidelines for the comparison of direct DM searches and visible mediator searches
  - Prediction of major background

arXiv.org > hep-ex > arXiv:1507.00966 **arXiv:1507.00966**

High Energy Physics – Experiment

Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum

Daniel Abercrombie, Nural Akchurin, Ece Akilli, Juan Alcaraz Maestre, Brandon Allen, Barbara Alvarez Gonzalez, Jeremy Andrea, Alexandre Arbey, Georges Azuelos, Patrizia Azzi, Mihailo Backović, Yang Bai, Swagato Banerjee, James Beacham, Alexander Belyaev, Antonio Boveia, Amelia Jean Brennan, Oliver Buchmueller, Matthew R. Buckley, Giorgio Busoni, Michael Buttignol, Giacomo Cacciapaglia, Regina Caputo, Linda Carpenter, Nur Filipe Castro, Guillelmo Gomez Ceballos, Yangyang Cheng, John Paul Chou, Arely Cortes Gonzalez, Chris Cowden, Francesco D'Eramo, Annapaola De Cosa, Michele De Gruttola, Albert De Roeck, Andrea De Simone, Aldo Deandrea, Zeynep Demiragli, Anthony DiFranzo, Caterina Doglioni, Tris du Pree, Robin Erbacher, Johannes Erdmann, Cora Fischer, Henning Flaecher, Patrick J. Fox, et al. (94 additional authors not shown)

arXiv.org > hep-ex > arXiv:1603.04156 **arXiv:1603.04156**

High Energy Physics – Experiment

Recommendations on presenting LHC searches for missing transverse energy signals using simplified s-channel models of dark matter

Antonio Boveia, Oliver Buchmueller, Giorgio Busoni, Francesco D'Eramo, Albert De Roeck, Andrea De Simone, Caterina Doglioni, Matthew J. Dolan, Marie-Helene Genest, Kristian Hahn, Ulrich Haisch, Philip C. Harris, Jan Heisig, Valerio Ippolito, Felix Kahlhoefer, Valentin V. Khoze, Suchita Kulkar Greg Landsberg, Steven Lowette, Sarah Malik, Michelangelo Mangano, Christopher McCabe, Stephen Mrenna, Priscilla Pani, Tristan du Pree, Anton Riotto, David Salek, Kai Schmidt-Hoberg, William Shepherd, Tim M.P. Tait, Lian-Tao Wang, Steven Worm, Kathryn Zurek

arXiv.org > hep-ex > arXiv:1703.05703 **arXiv:1703.05703**

High Energy Physics – Experiment

Recommendations of the LHC Dark Matter Working Group: Comparing LHC searches for heavy mediators of dark matter production in visible and invisible decay channels

Andreas Albert, Mihailo Backovic, Antonio Boveia, Oliver Buchmueller, Giorgio Busoni, Albert De Roeck, Caterina Doglioni, Tristan DuPree, Malcolm Fairbairn, Marie-Helene Genest, Stefania Gori, Giuliano Gustavino, Kristian Hahn, Ulrich Haisch, Philip C. Harris, Dan Hayden, Valerio Ippolito, Isabelle John, Felix Kahlhoefer, Suchita Kulkarni, Greg Landsberg, Steven Lowette, Kentarou Mawatari, Antonio Riotto, William Shepherd, Tim M.P. Tait, Emma Tolley, Patrick Tunney, Bryan Zaldivar, Markus Zinser

arXiv.org > hep-ph > arXiv:1705.04664 **arXiv:1705.04664**

High Energy Physics – Phenomenology

Precise predictions for V+jets dark matter backgrounds

J. M. Lindert, S.Pozzorini, R. Boughezal, J. M. Campbell, A. Denner, S. Dittmaier, A. Gehrmann-De Ridder, T. Gehrmann, N. Glover, Kallweit, P. Maierhöfer, M.L. Mangano, T.A. Morgan, A. Mück, F. Petriello, G.P. Salam, M. Schönherr, C. Williams

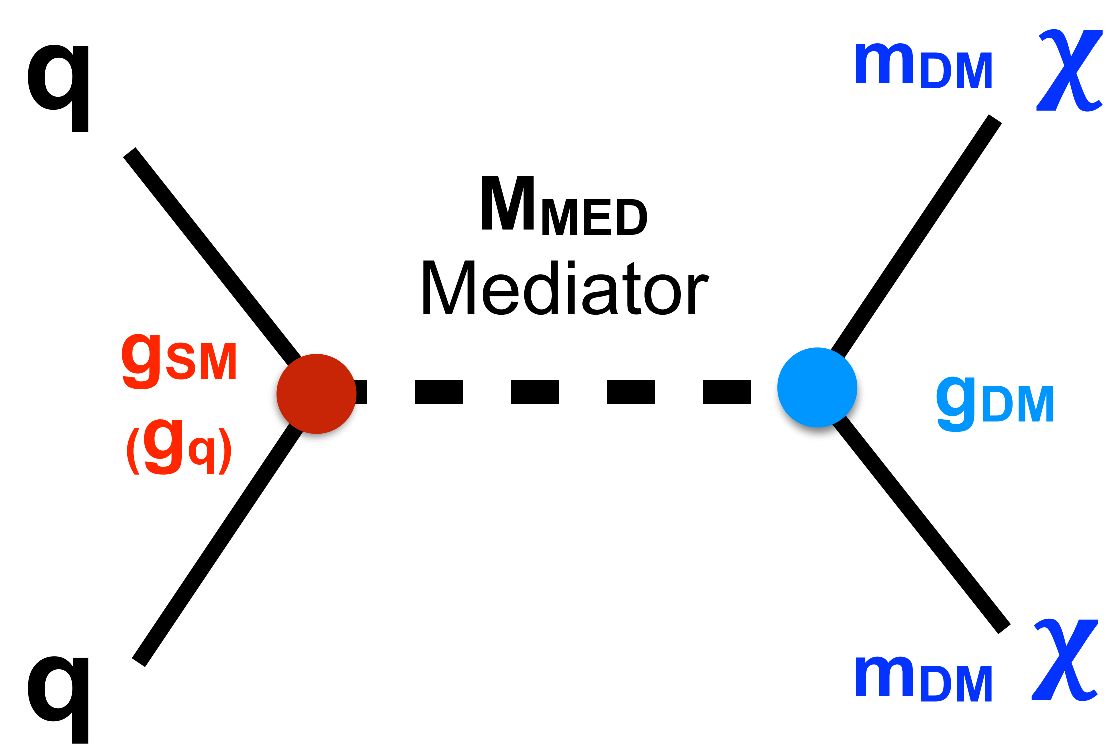
Simplified Models for Direct DM Production

Features of Mediators

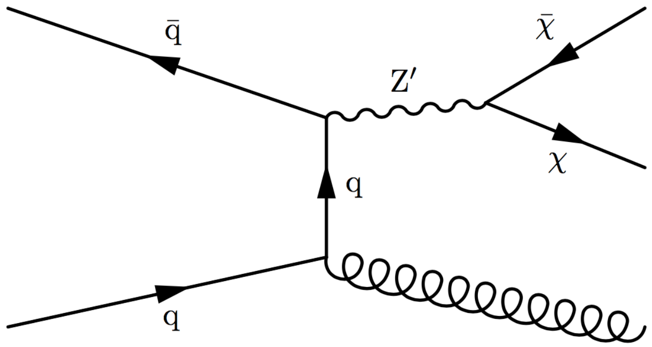
	spin 0	spin 1
Charge Q	$Q_{med} = 0$ for s-channel	
Mass m	unknown	
Dark sector bosons similar to	H [1609.09079]	γ, Z, Z'
Lorentz structure	scalar 1 pseudosc. γ_5	vector γ^μ axial v. $\gamma^\mu \gamma_5$
Coupling "g"	$\propto$ mass	$\propto$ charge
Consequences	$m_b \gg m_d$	$Q_b = Q_d$

Tae Min Hong, LHCP 2017

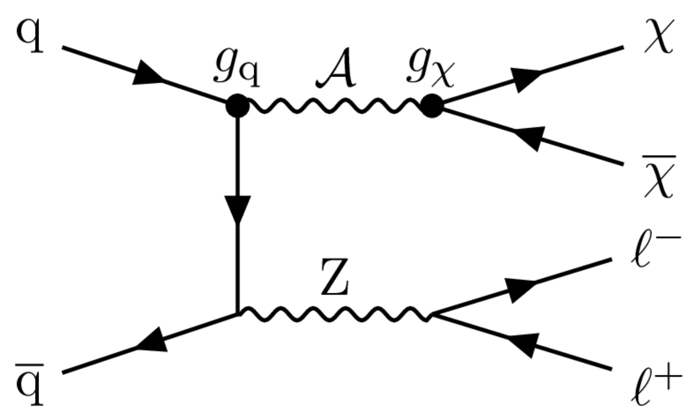
- Mediator has minimal decay width
- Minimal flavor violation
- Minimal set of parameters
    - coupling structure, M_{MED}, m_{DM}, g_{SM} (g_q), g_{DM}



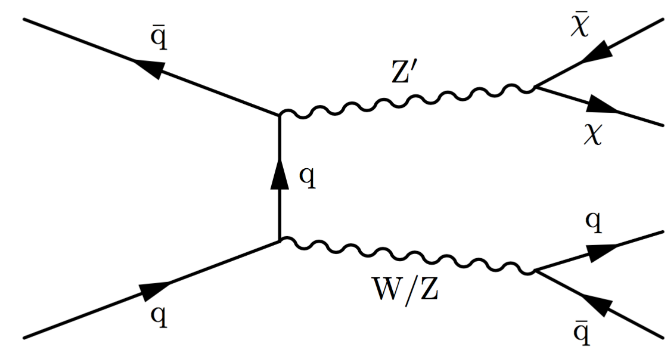
Mono-X Diagrams of Direct DM Production



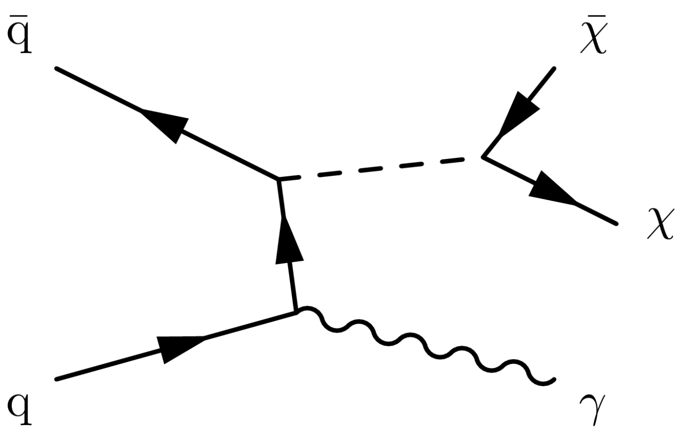
Mono-jet



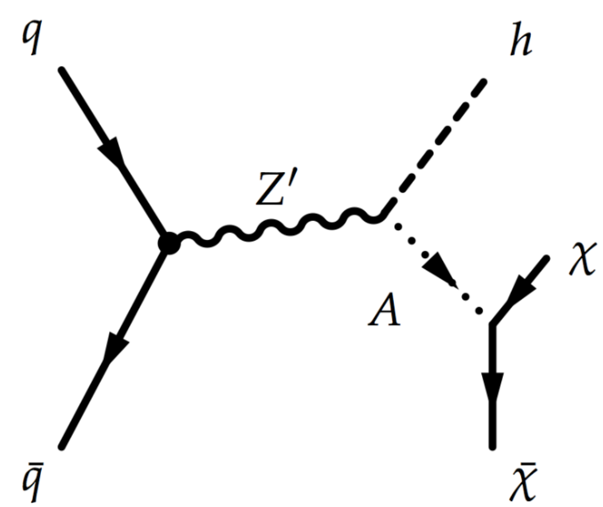
Mono-Z(leptonic)



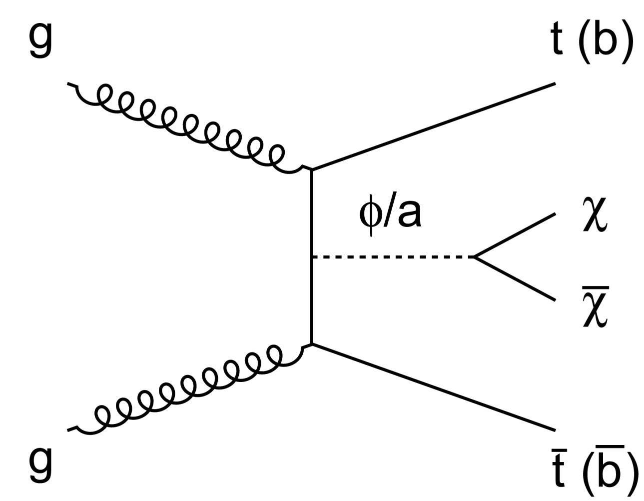
Mono-W/Z(hadronic)



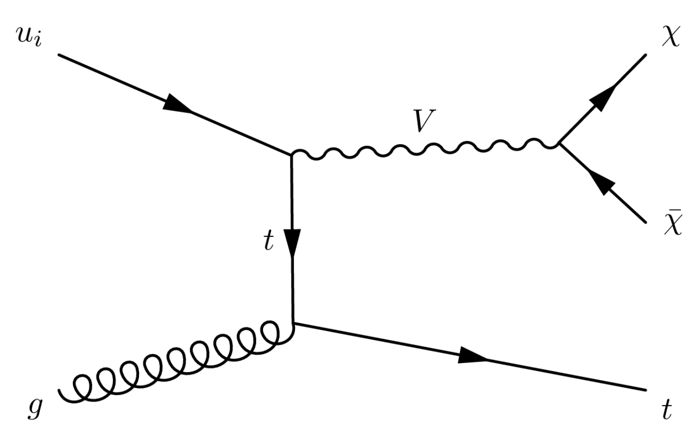
Mono-photon



Mono-h (bb, $\gamma\gamma$)

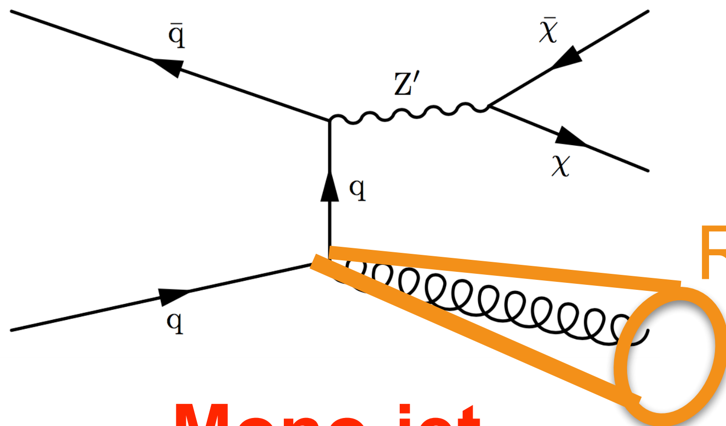


Mono-tt/bb



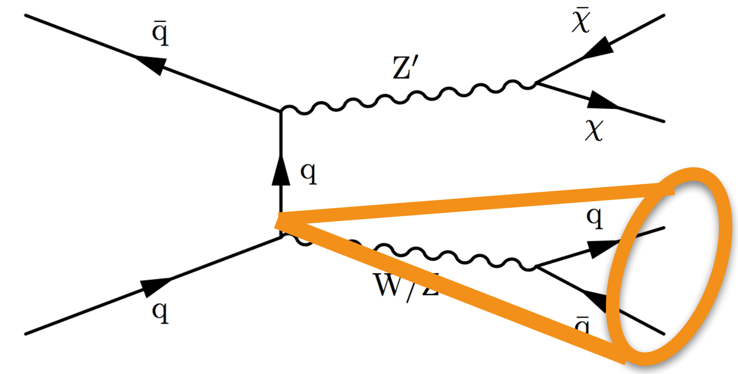
Mono-top

Mono-X Searches in Hadronic Final State



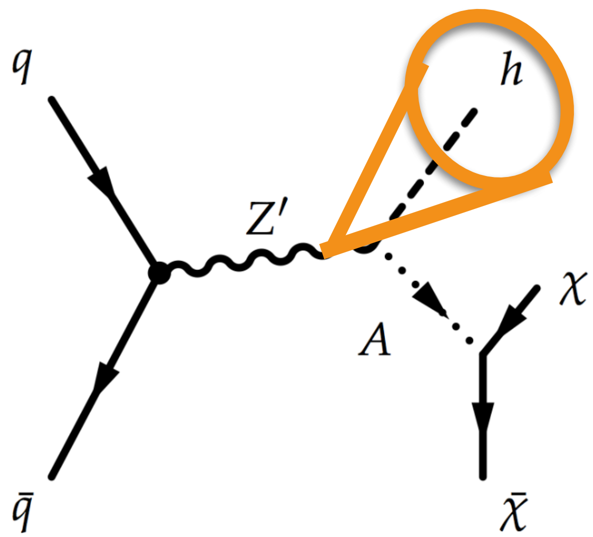
R=0.4

Mono-jet



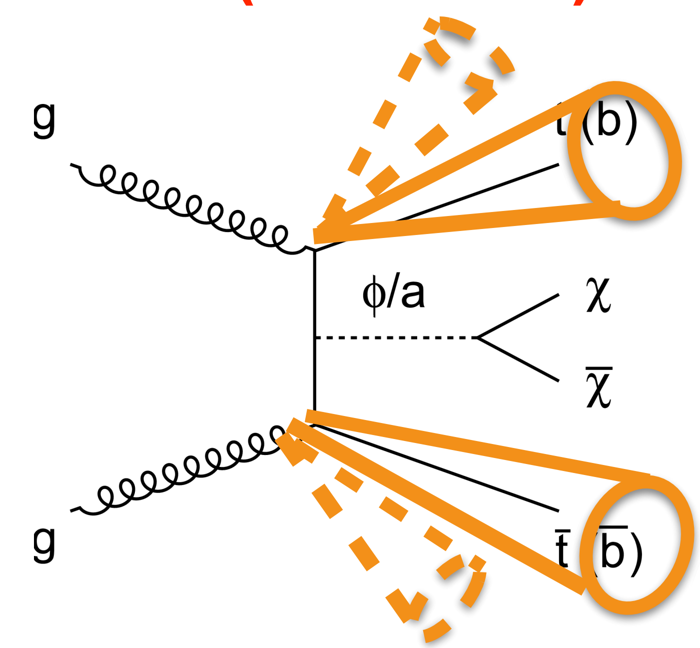
R=0.8 or 1.0

Mono-W/Z(hadronic)



R=0.4, 0.8 or 1.0

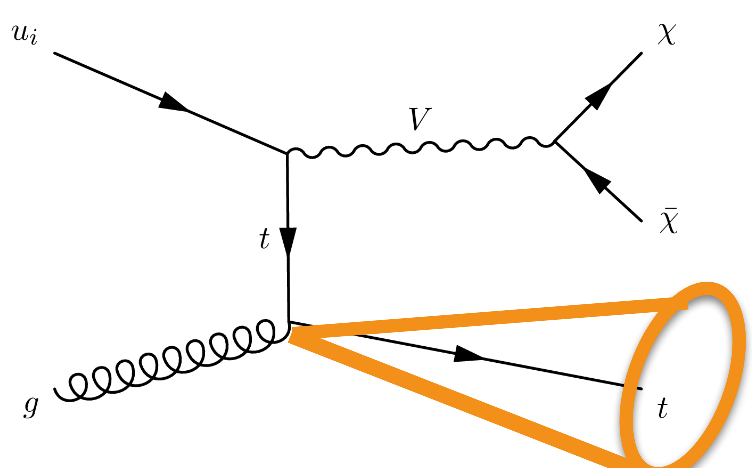
Mono-h (bb)



R=0.4

R=0.4

Mono-tt/bb

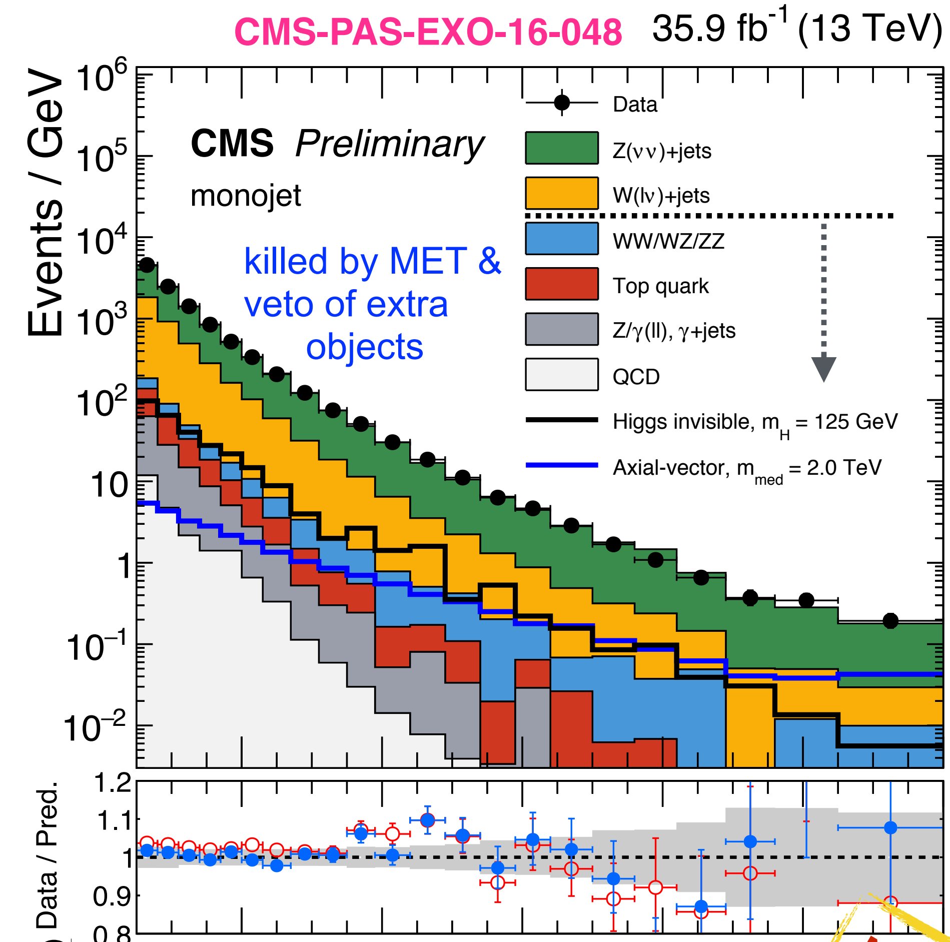


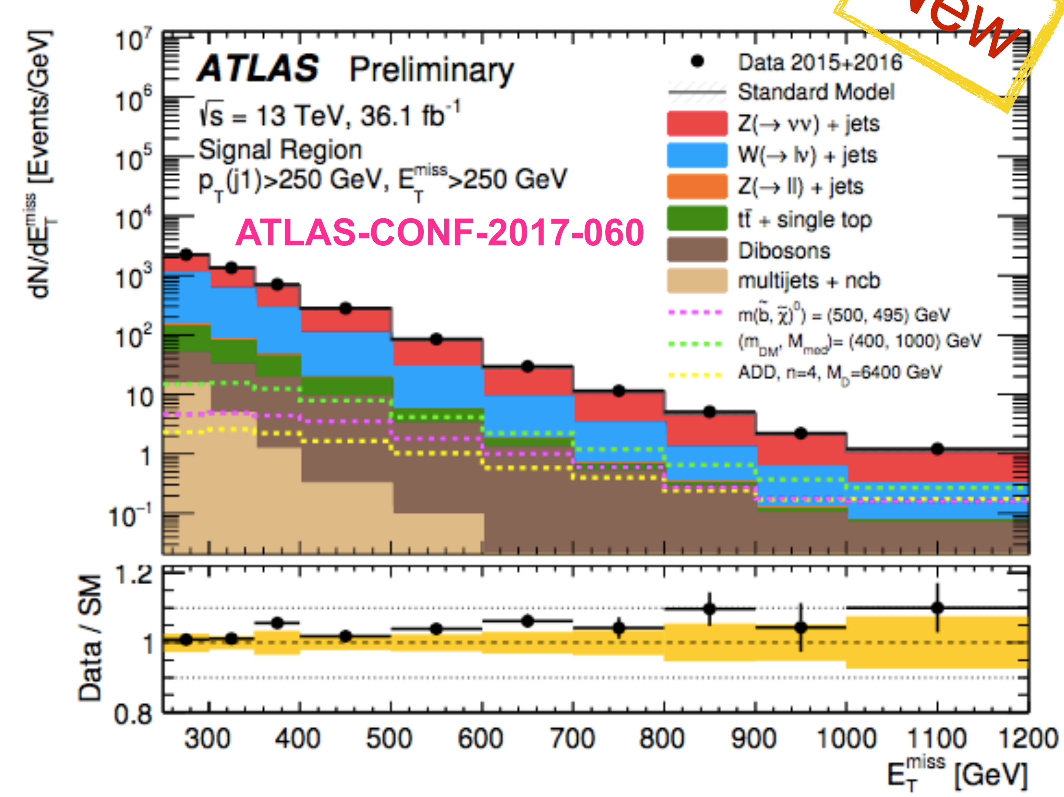
Mono-top

R=1.5

Mono-X Searches in Hadronic Final State

- Rely on MET triggers (offline MET cut ≳200 GeV)
- Major background from Z(→νν)+jets, W(→~~l~~ν)+jets
  - Estimated from a binned likelihood fit to five control samples: Z(→ee), Z(→μμ), γ, W(→eν), W(→μν) + jets data, transfer factors from MC reweighed with NLO QCD and nNLO EWK, uncertainty studied following 1705.04664
  - 3 QCD uncertainties: scale variation, shape with p_T dependence, difference between K-factors
  - 3 EWK uncertainties: missing NNLO effects, difference between NNL Sudakov approx. and NLO EWK, unknown Sudakov logs





arXiv: 1706.02581 ATLAS-CONF-2017-037 CMS-PAS-EXO-16-051

arXiv:1703.01651 arXiv:1707.01302 CMS-PAS-SUS-17-001

Mono-X Searches in Non-Hadronic Final State

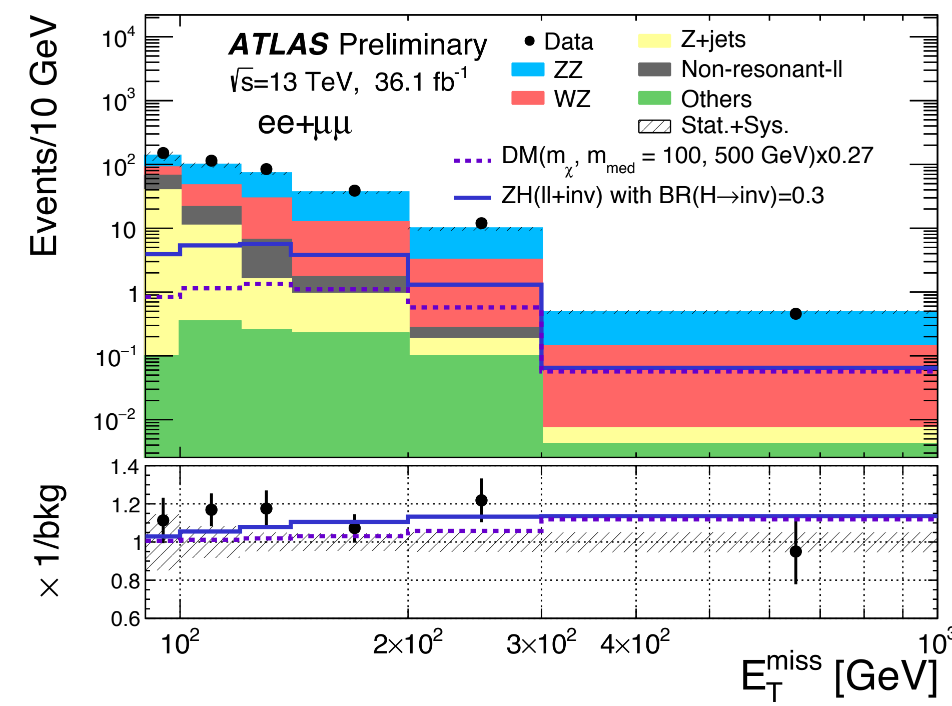
New

- Rely on lepton or photon triggers, can probe models with lower MET
- Mono-Z (ll), mono-photon:
  - Major background is W/Z+X where X=Z or γ, estimated from a binned likelihood fit of MET in the control regions (by reverting the lepton-veto)
  - Transfer factor derived from simulation with NNLO QCD and NLO EWK corrections
- Mono-h ($\gamma\gamma$)
  - Fit to the $m_{\gamma\gamma}$ spectra in data, background includes resonant and non-resonant contribution

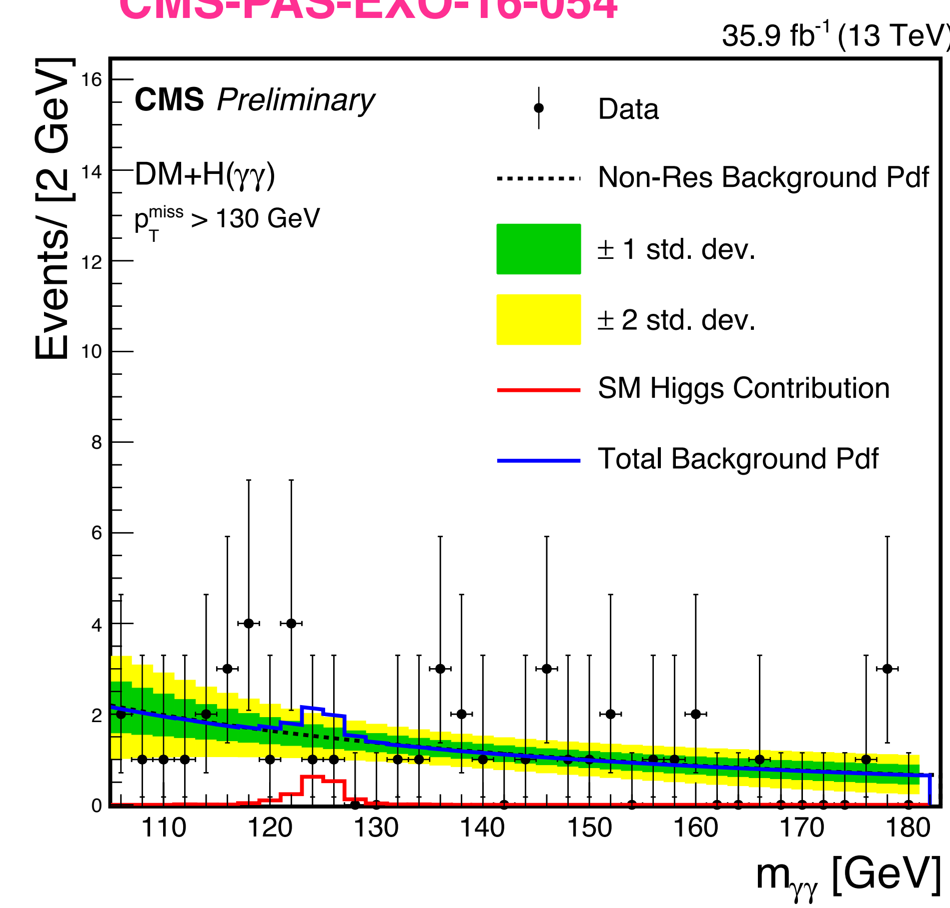
CMS-PAS-EXO-16-052
arXiv:1706.03794
Eur. Phys. J. C 77 (2017) 393

CMS-PAS-EXO-16-054
arXiv:1706.03948
ATLAS-CONF-2017-040

mono-Z **ATLAS-CONF-2017-040**



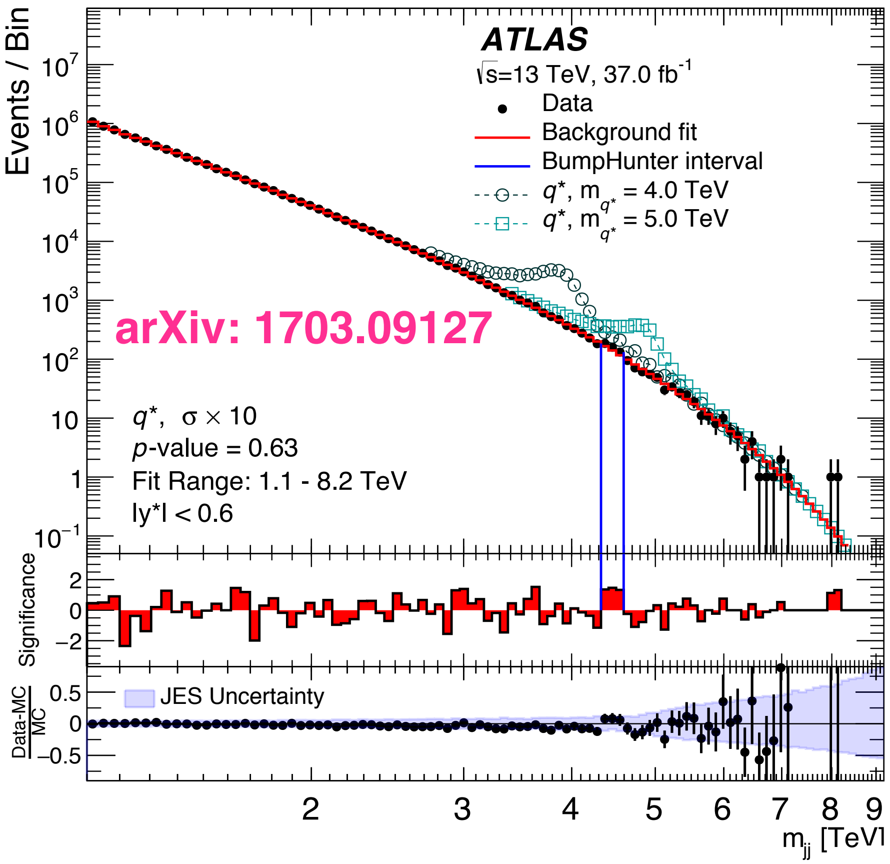
CMS-PAS-EXO-16-054



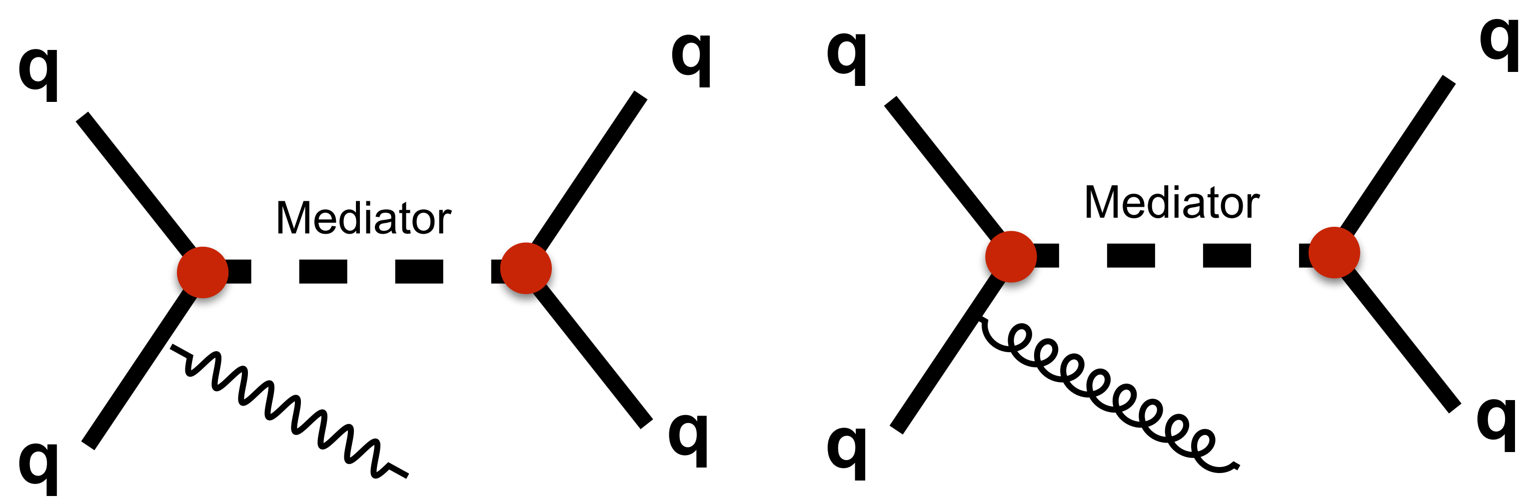
Visible Mediator Searches

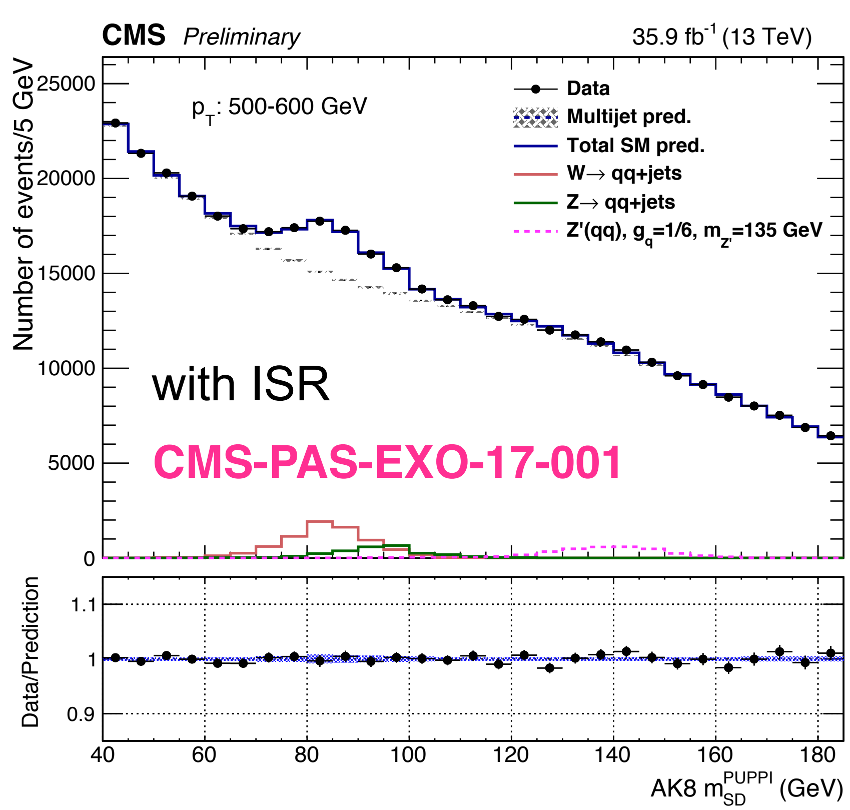
CMS-PAS-EXO-17-001
CMS-PAS-EXO-16-056
arXiv: 1703.09127

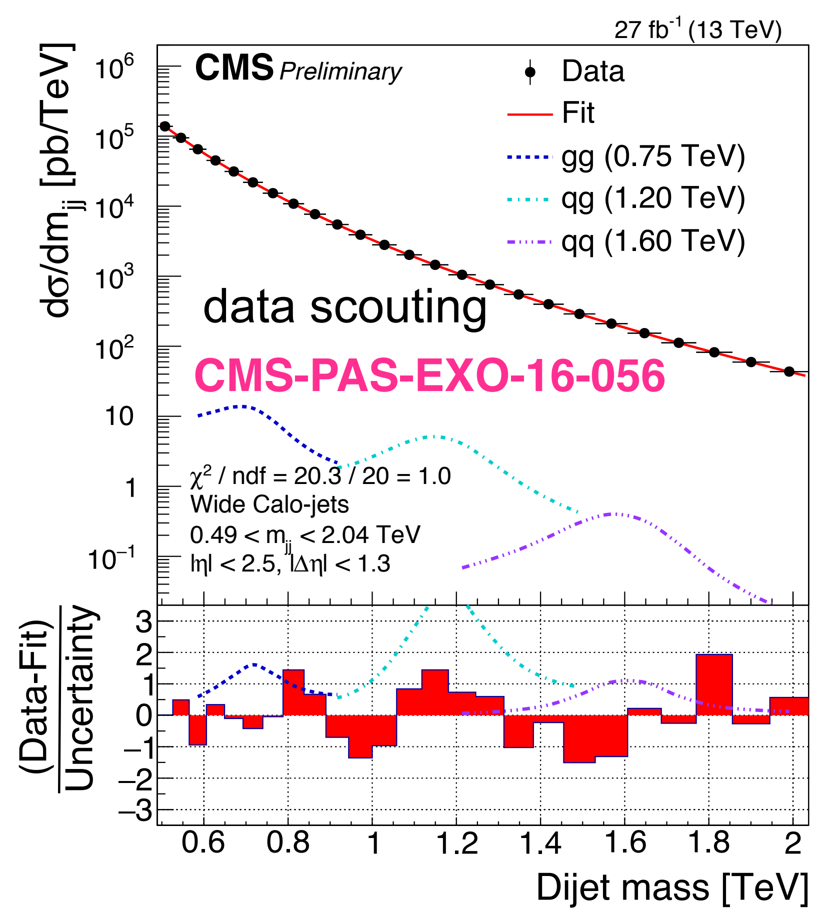
ATLAS-CONF-2016-060
ATLAS-CONF-2016-030
ATLAS-CONF-2016-070

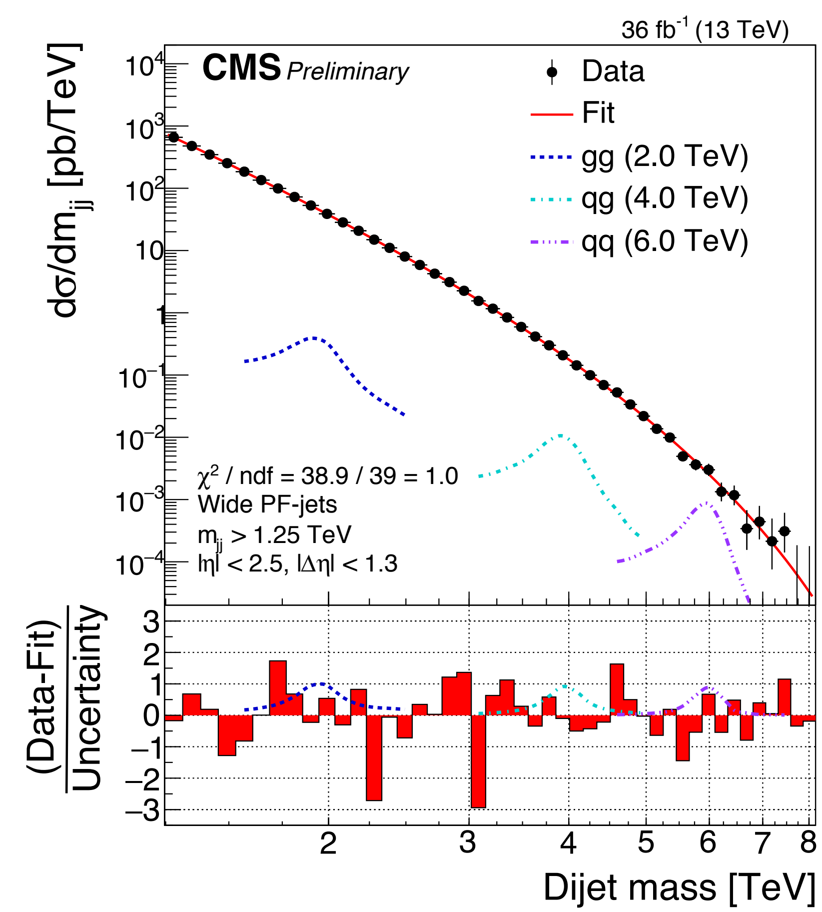


- high-p_T/H_T trigger for large-Mjj, ISR γ/jet tag or data with only trigger-level objects (data scouting) for small-Mjj









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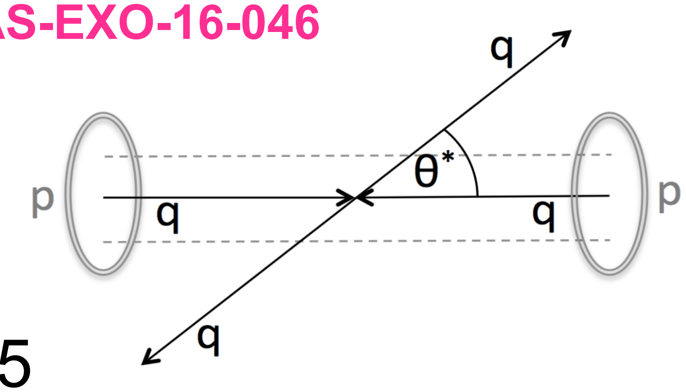
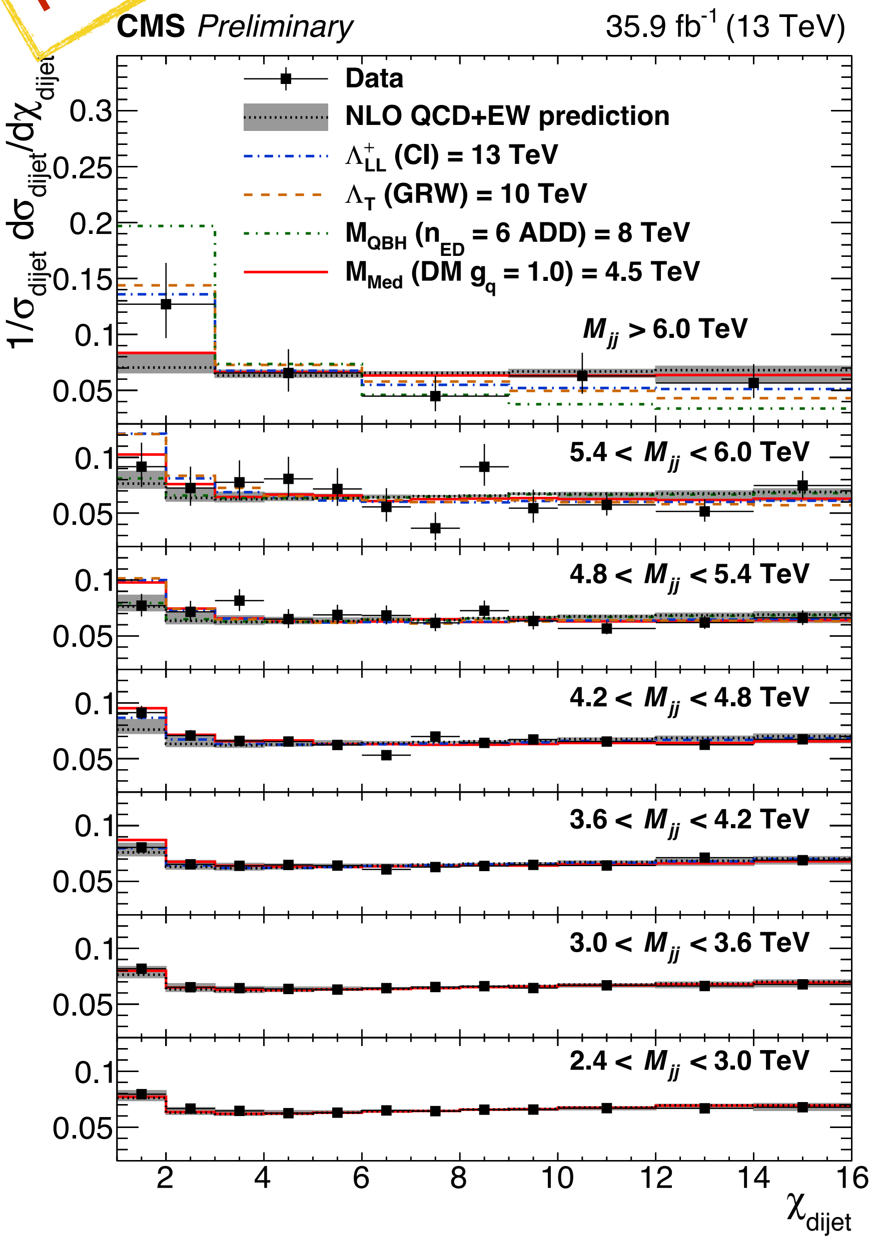
arXiv: 1703.09127
CMS-PAS-EXO-16-046

Dijet Angular Distributions

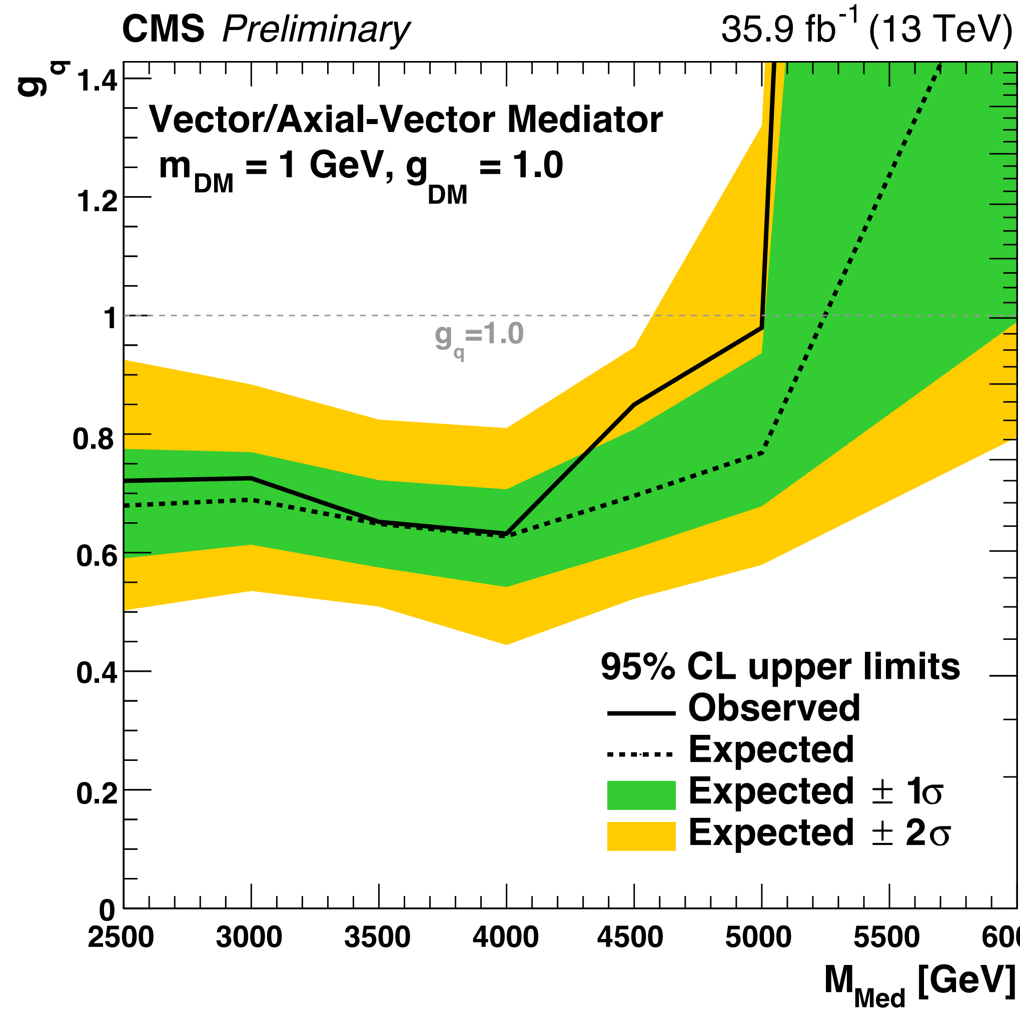


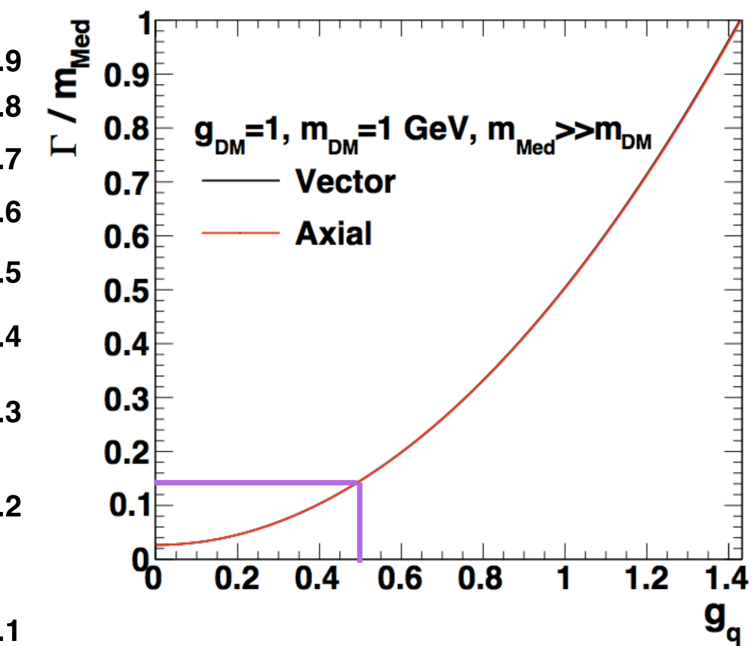
- Sensitive to wide mediators or non-resonant signature
- Dijet resonance searches exclude g_q in the range of 0.07-0.35 depending on M_{MED}



- For $g_q \geq 1$, M_{MED}=2.5-5 TeV excluded

$$\chi_{dijet} = e^{|y_1 - y_2|} \sim \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$





$$\Gamma^{q\bar{q}}_{\text{axial-vector}} = \frac{g_q^2 M_{\text{MED}}}{4\pi}\left(1 - 4\frac{m_q^2}{M_{\text{MED}}^2}\right)^{\frac{3}{2}}$$

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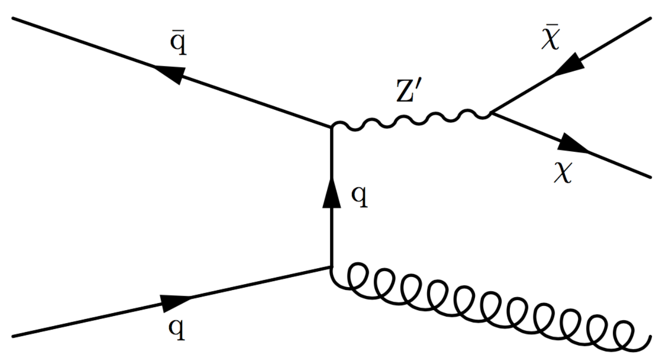
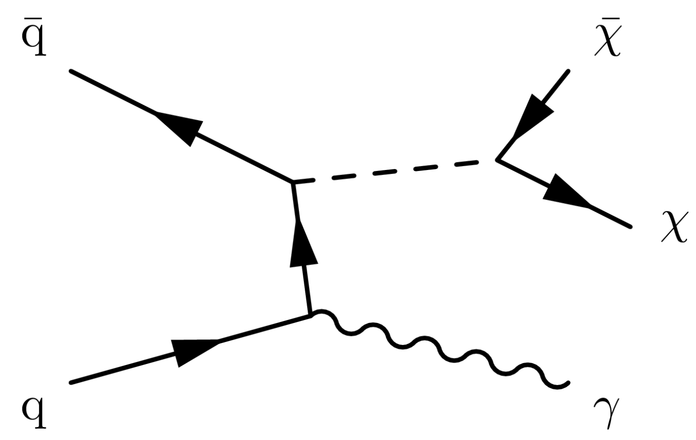
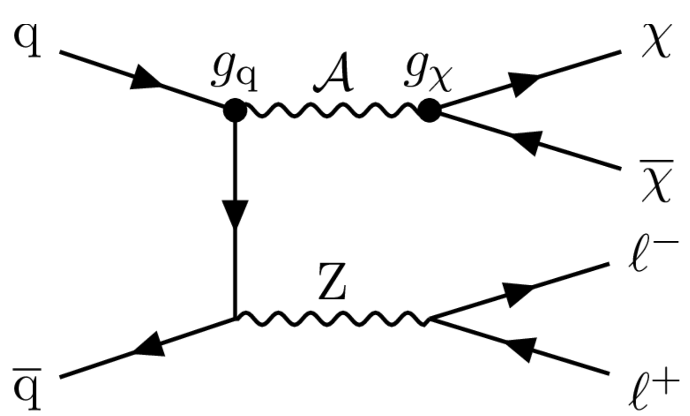
Mono-X With Vector/Axial Mediators



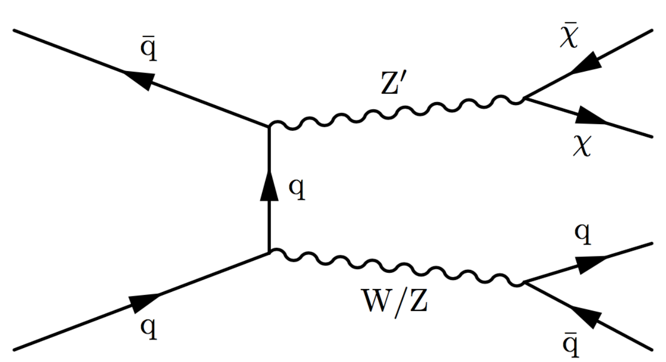
Mono-jet



Mono-photon

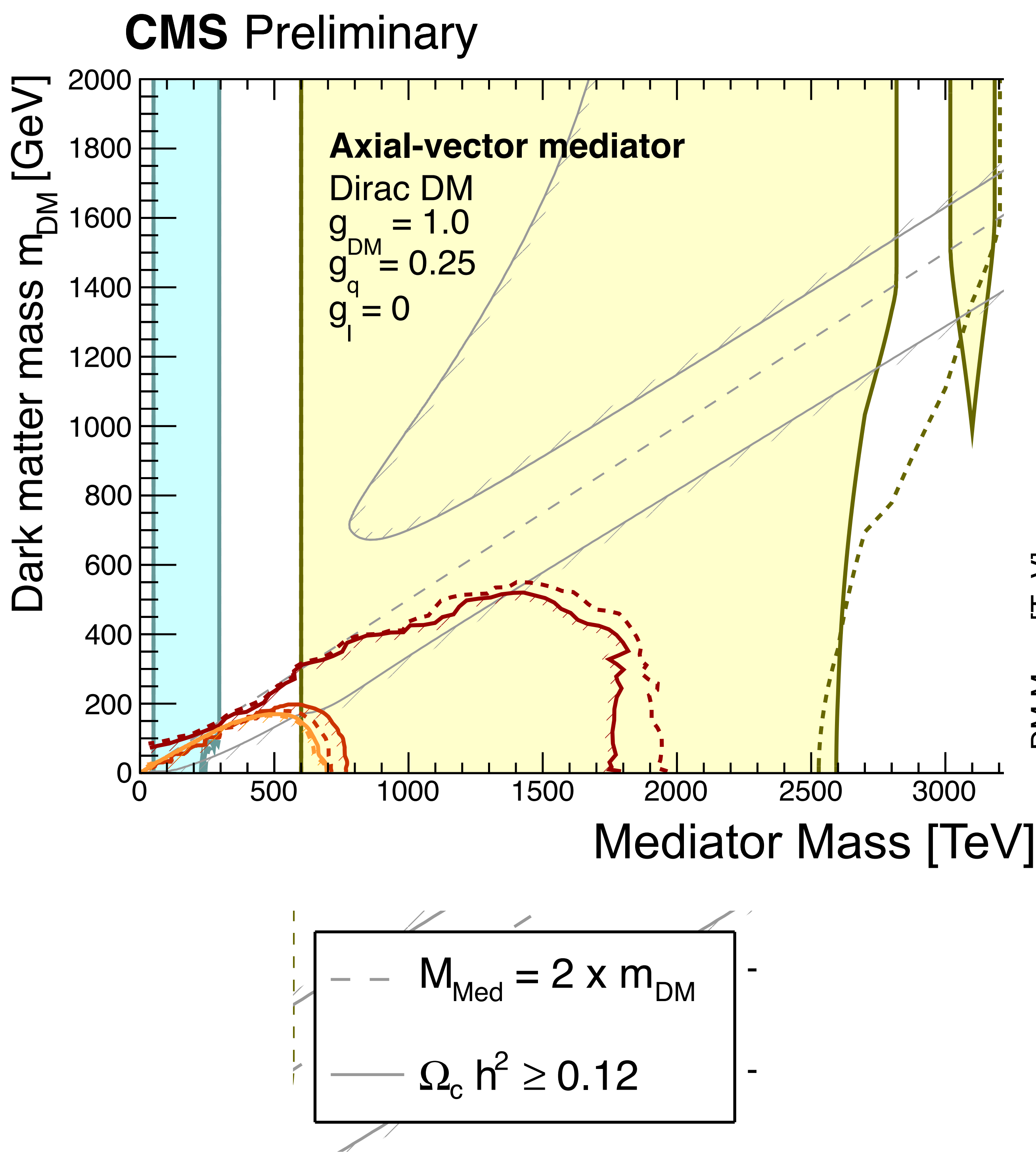


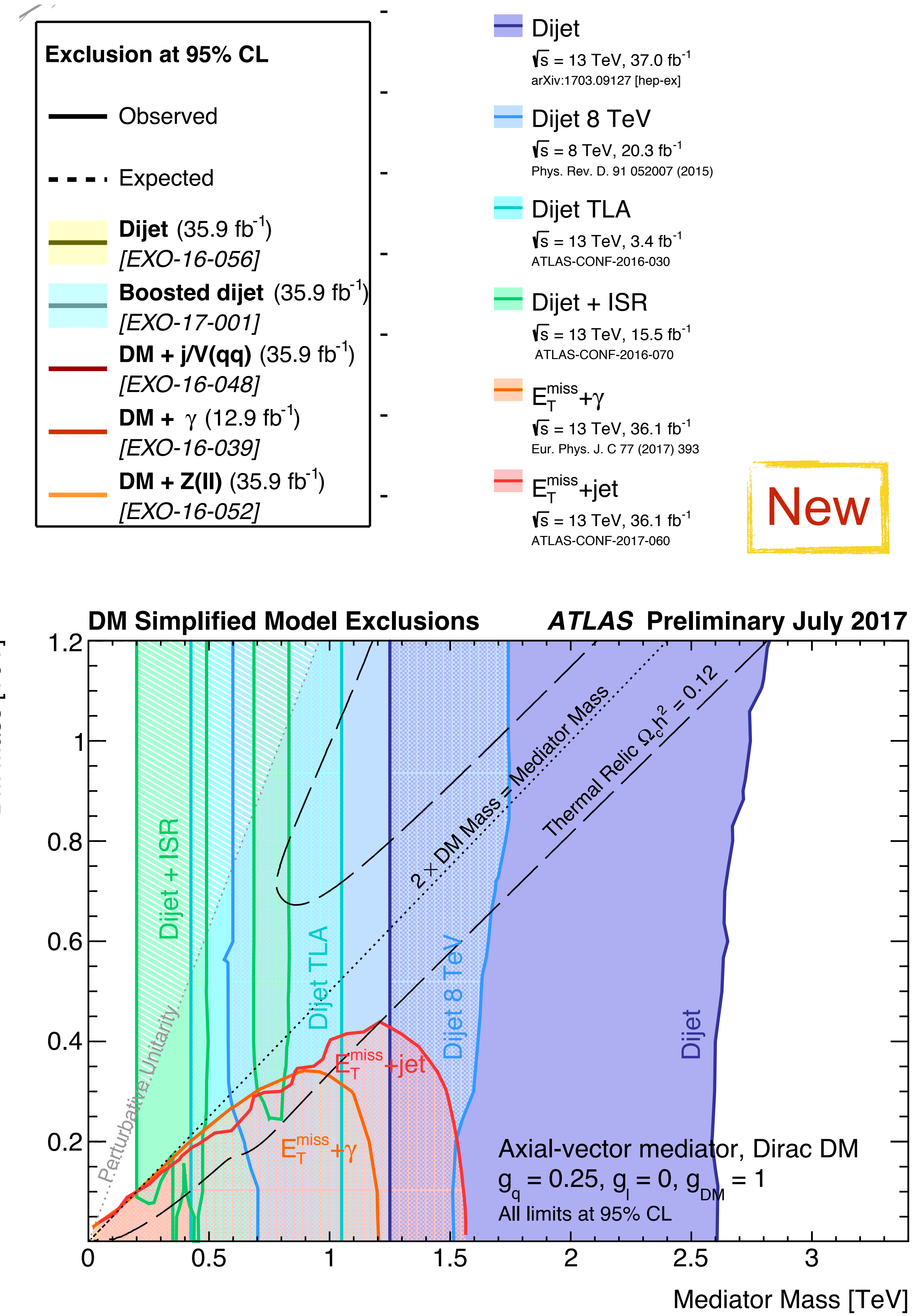
Mono-Z(leptonic)



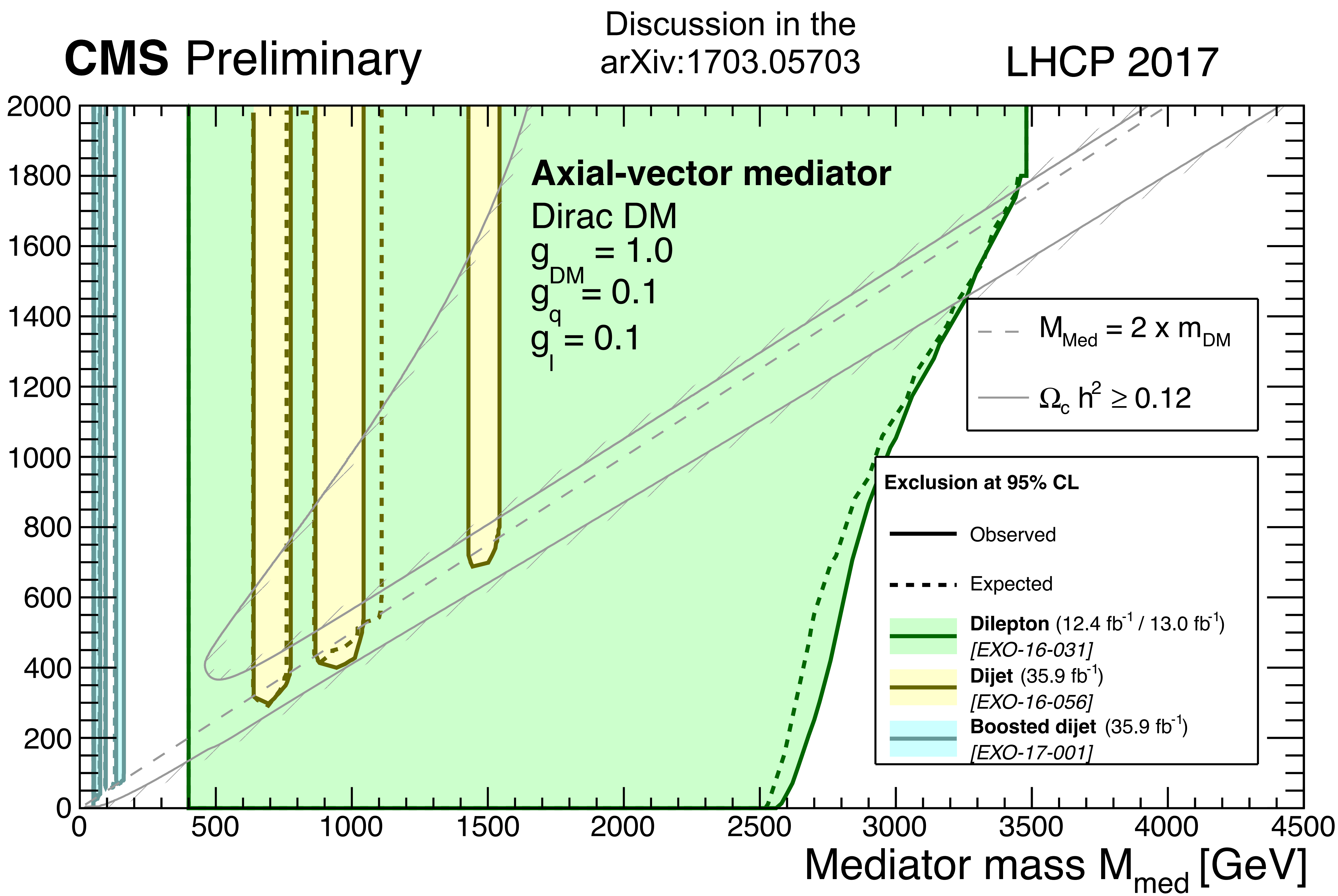
Mono-W/Z(hadronic)

Collider Results Only





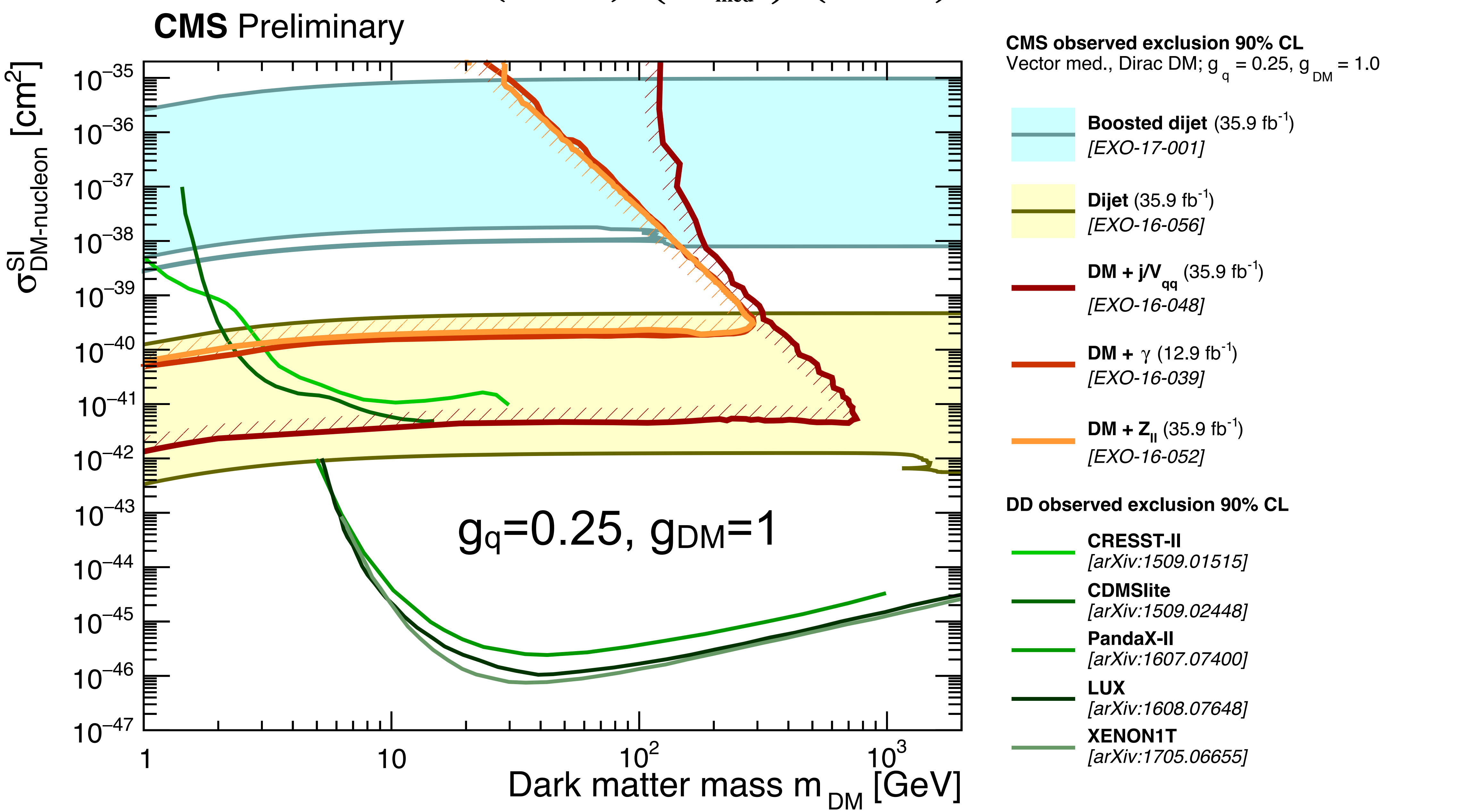
If We Use Different Parameter Values

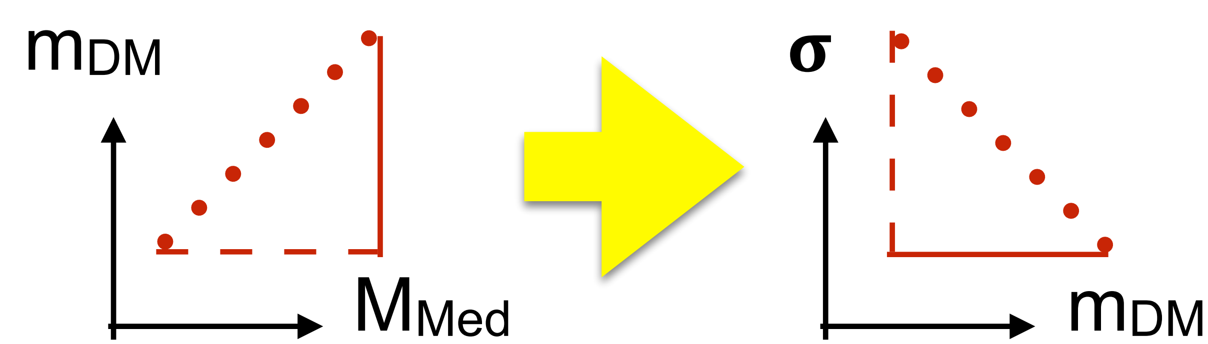


Collider v.s. Non-Collider Experiments (SI)

$$\sigma_{\rm SI}^{\rm vector} \simeq 6.9\times10^{-41}\,{\rm cm}^2 \left(\frac{g_q g_{\rm DM}}{0.25}\right)^2 \left(\frac{1\ {\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

See ATLAS results in the backups

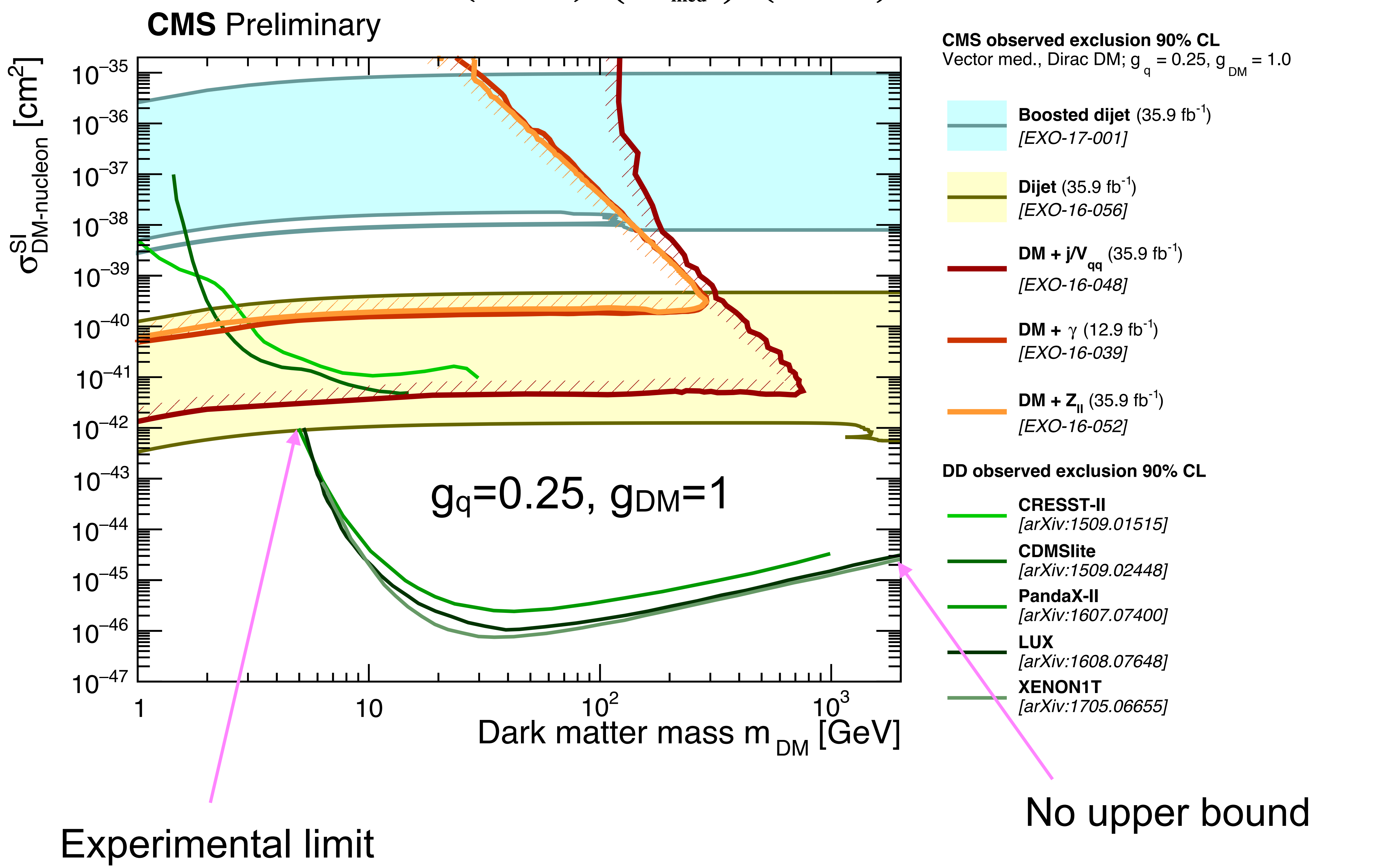




Collider v.s. Non-Collider Experiments (SI)

$$\sigma_{SI}^{vector} \simeq 6.9\times10^{-41}\,\mathrm{cm}^2 \left(\frac{g_q g_{DM}}{0.25}\right)^2 \left(\frac{1\ \mathrm{TeV}}{M_{med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$$

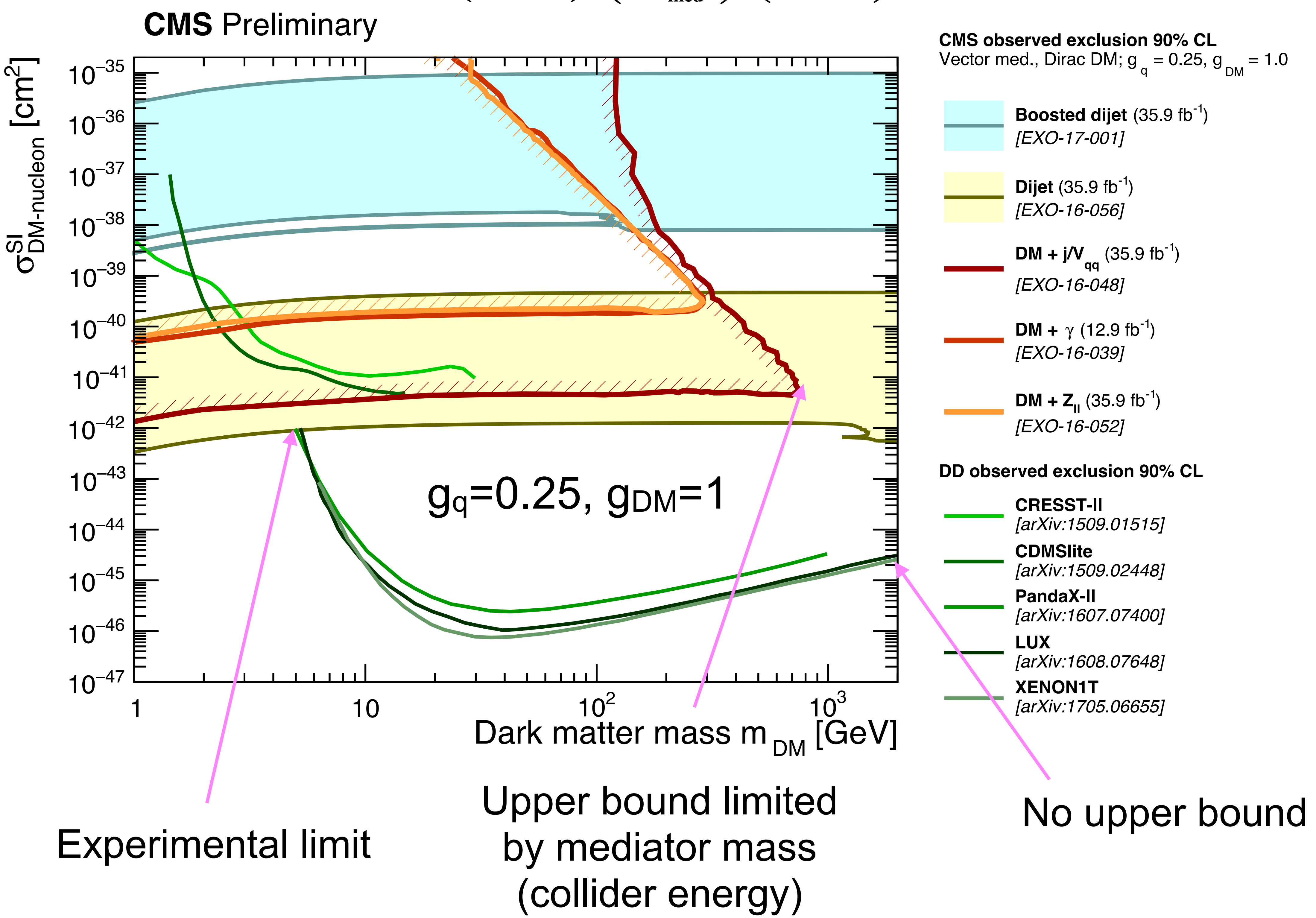
See ATLAS results in the backups



Collider v.s. Non-Collider Experiments (SI)

$$\sigma_{SI}^{vector} \simeq 6.9\times10^{-41}\,\mathrm{cm}^2\left(\frac{g_q g_{DM}}{0.25}\right)^2\left(\frac{1\ \mathrm{TeV}}{M_{med}}\right)^4\left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$$

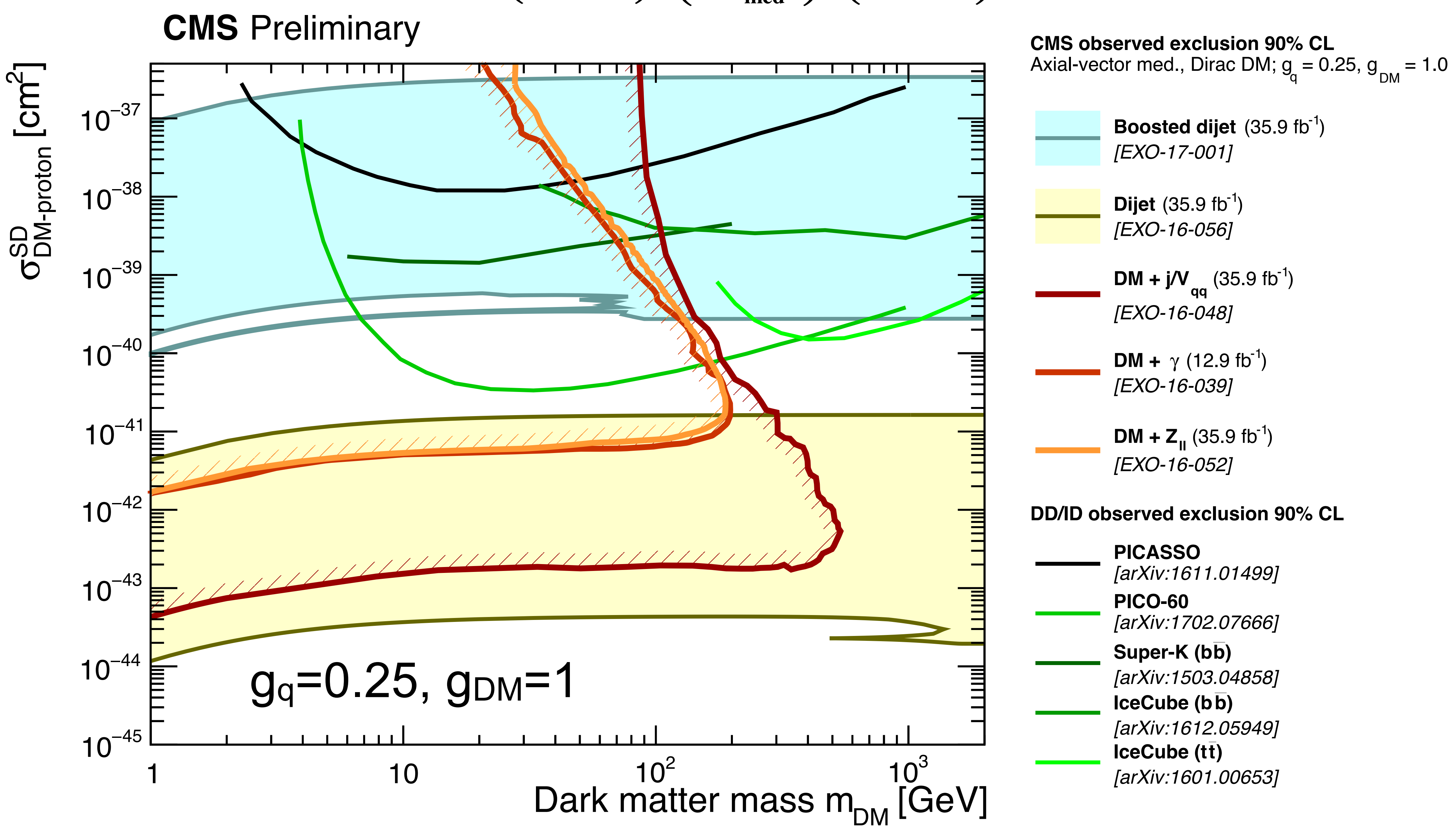
See ATLAS results in the backups



Collider v.s. Non-Collider Experiments (SD)

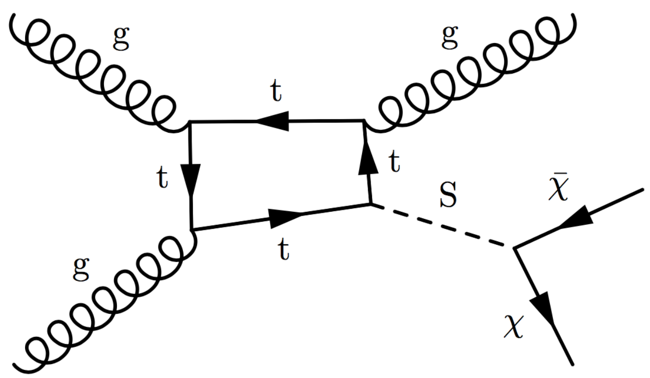
$$\sigma_{SD}^{axial} \simeq 2.4\times10^{-42}\,\mathrm{cm}^2 \left(\frac{g_q g_{DM}}{0.25}\right)^2 \left(\frac{1\ \mathrm{TeV}}{M_{med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$$

See ATLAS results in the backups

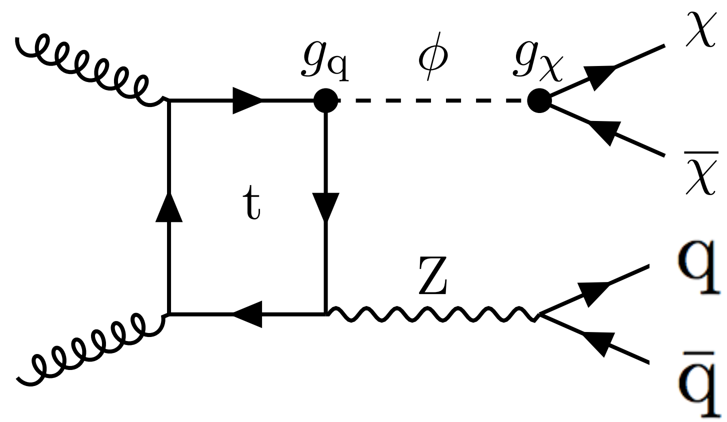


For the model parameters considered here, collider experiments can probe SD cross sections 2-3 orders of magnitude smaller than the non-collider experiments.

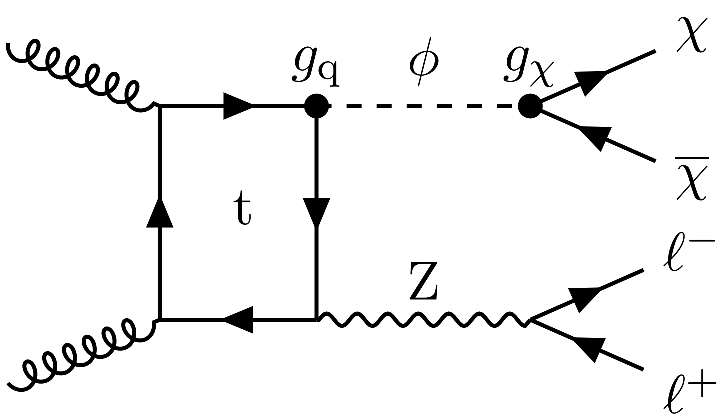
Mono-X with Scalar/Pseudo-Scalar Mediators



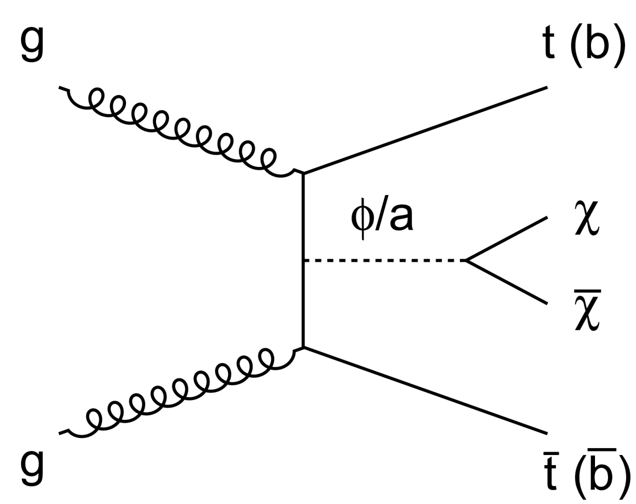
Mono-jet



Mono-Z(hadronic)



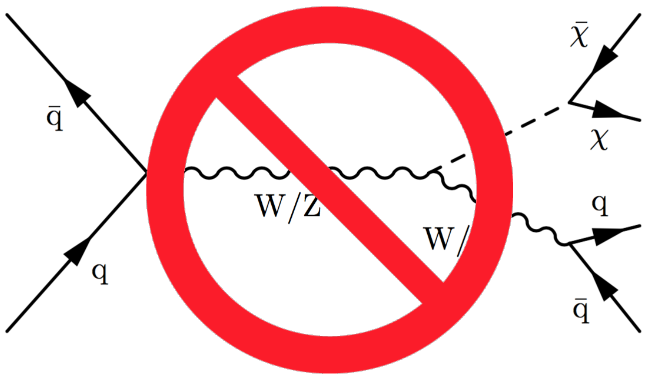
Mono-Z(leptonic)

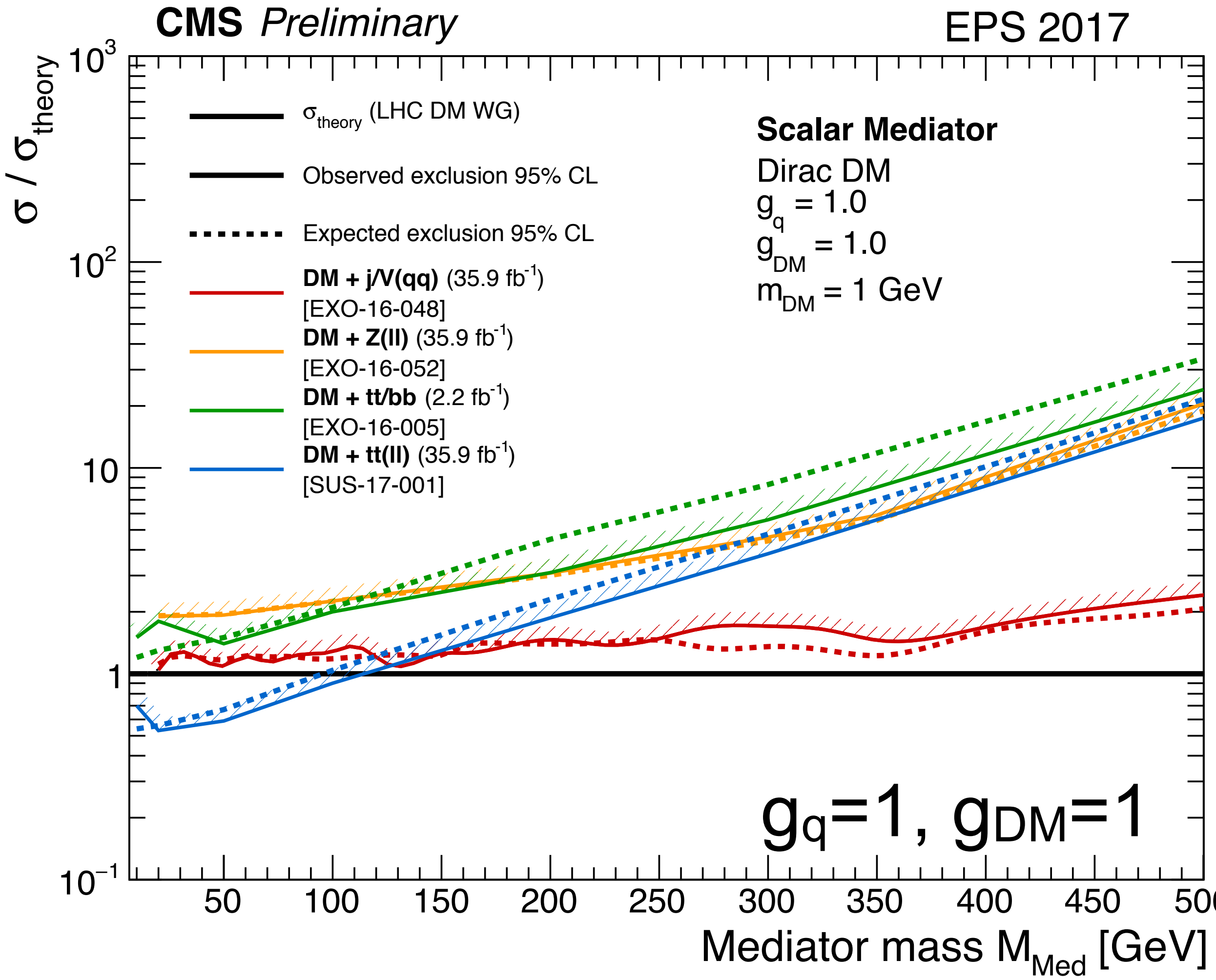


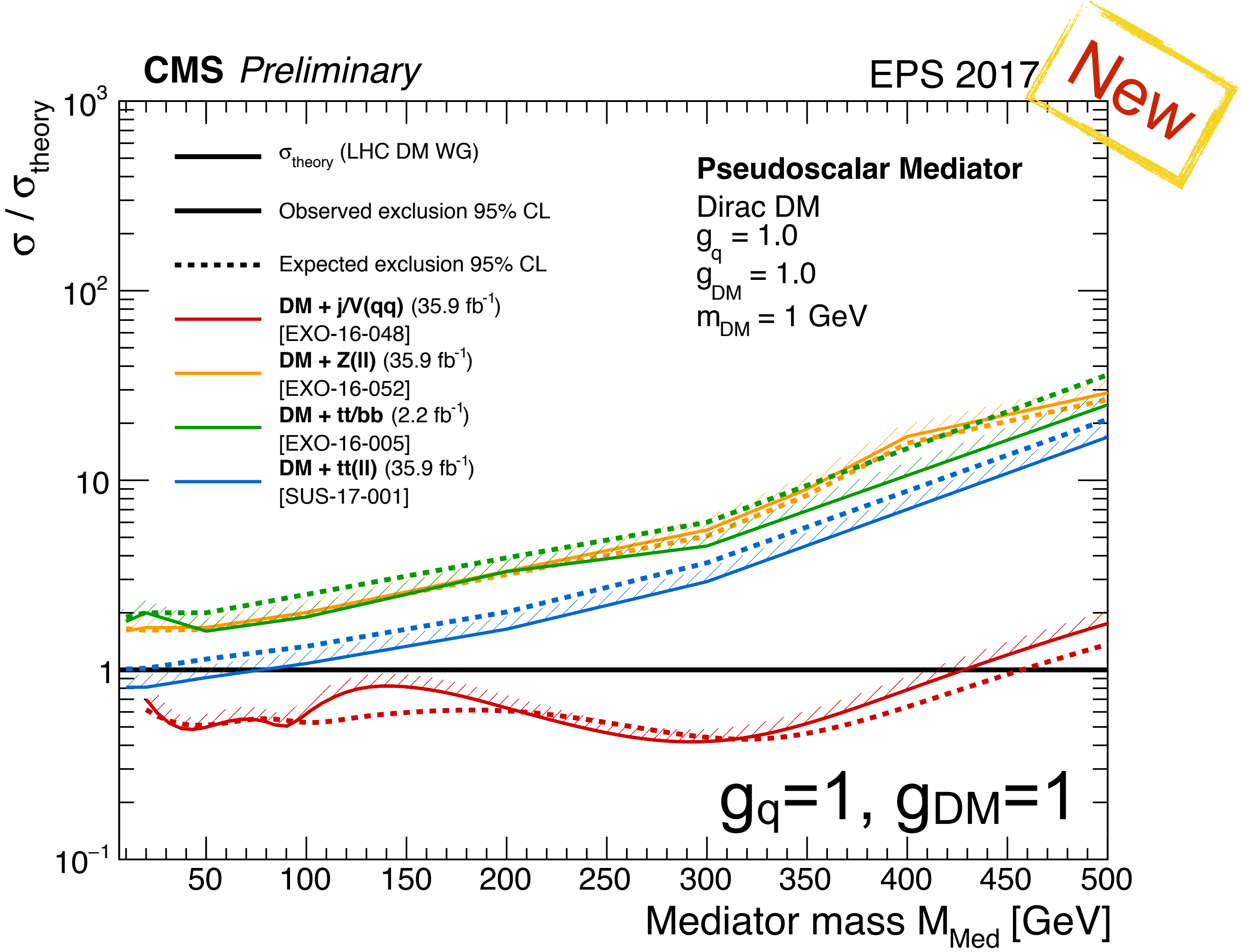
Mono-tt/bb

Collider Results for Scalar/Pseudo-Scalar

- For the mono-V channel, pseudo-scalar/Scalar limits include ggZH diagrams only because VH generators do not yet include mixing with SM Higgs
- ttbar is the best at low-mass

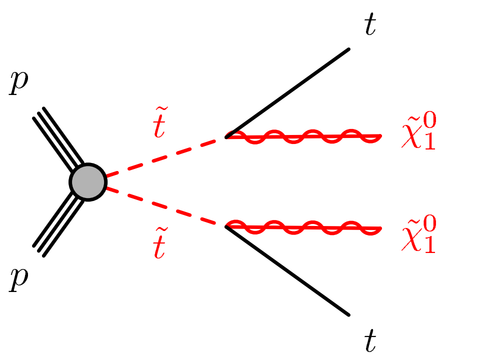


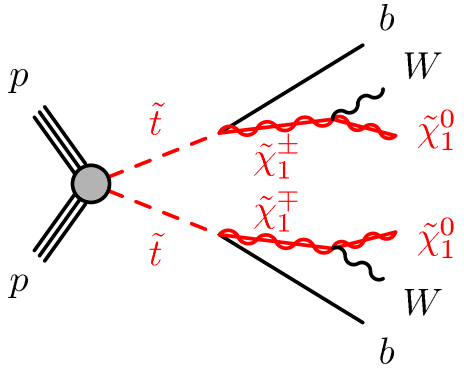


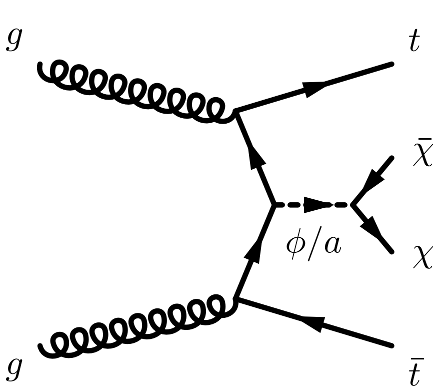


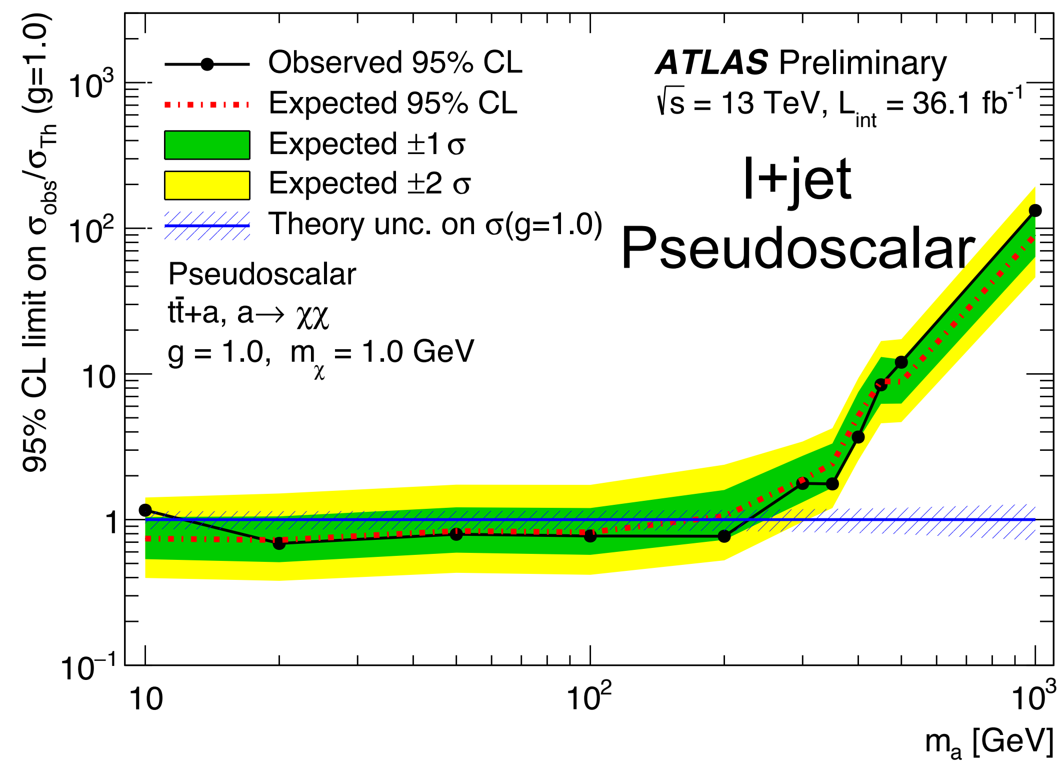
Reinterpretation of STOP Searches

- Recast for mono-tt, limits better than mono-jet for low-mass scalars



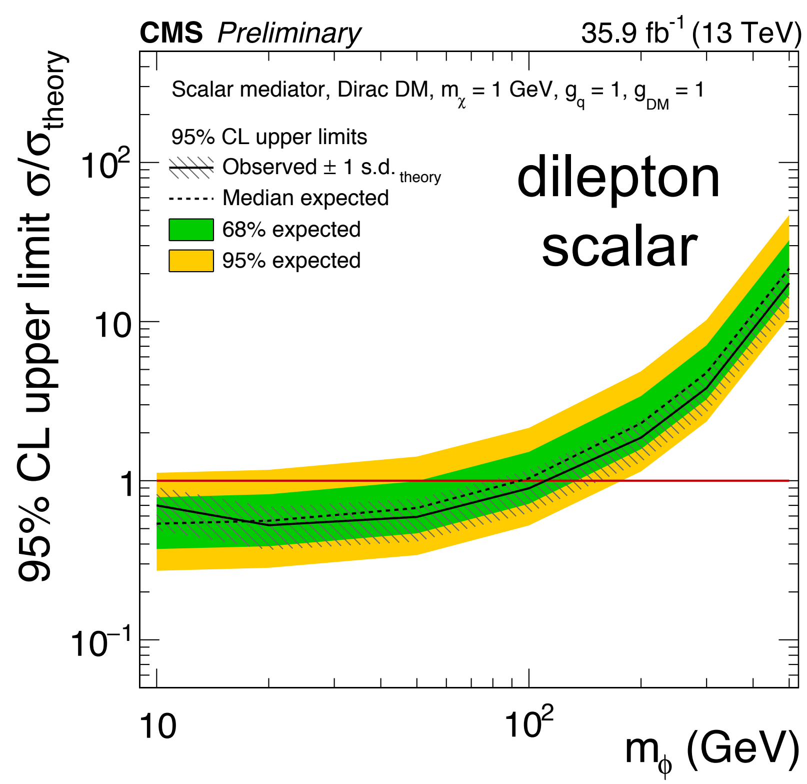


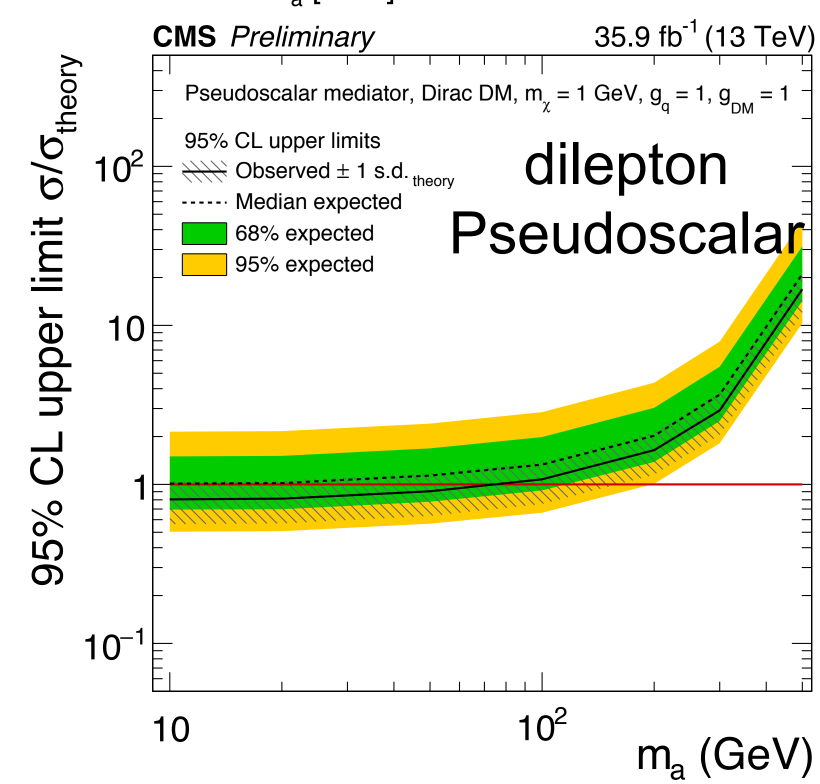




CMS-PAS-SUS-17-001
ATLAS-CONF-2017-037
ATLAS-CONF-2016-076
ATLAS-CONF-2016-077

New





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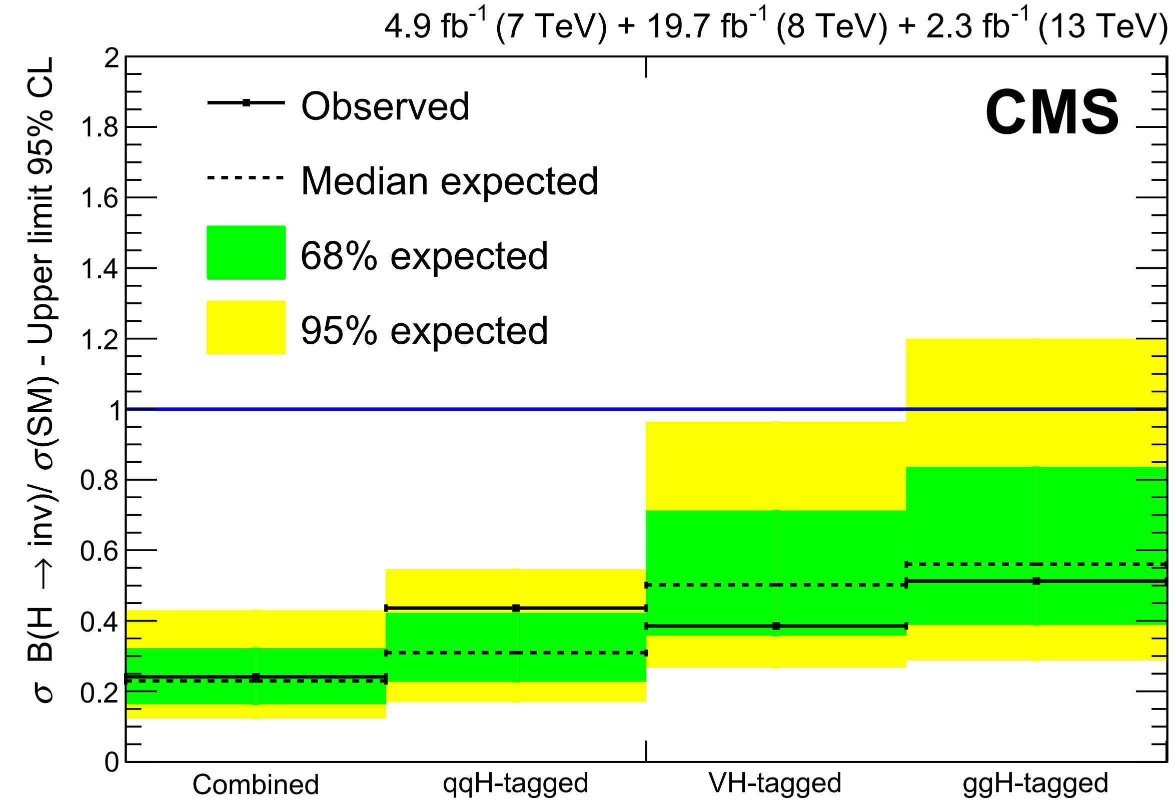
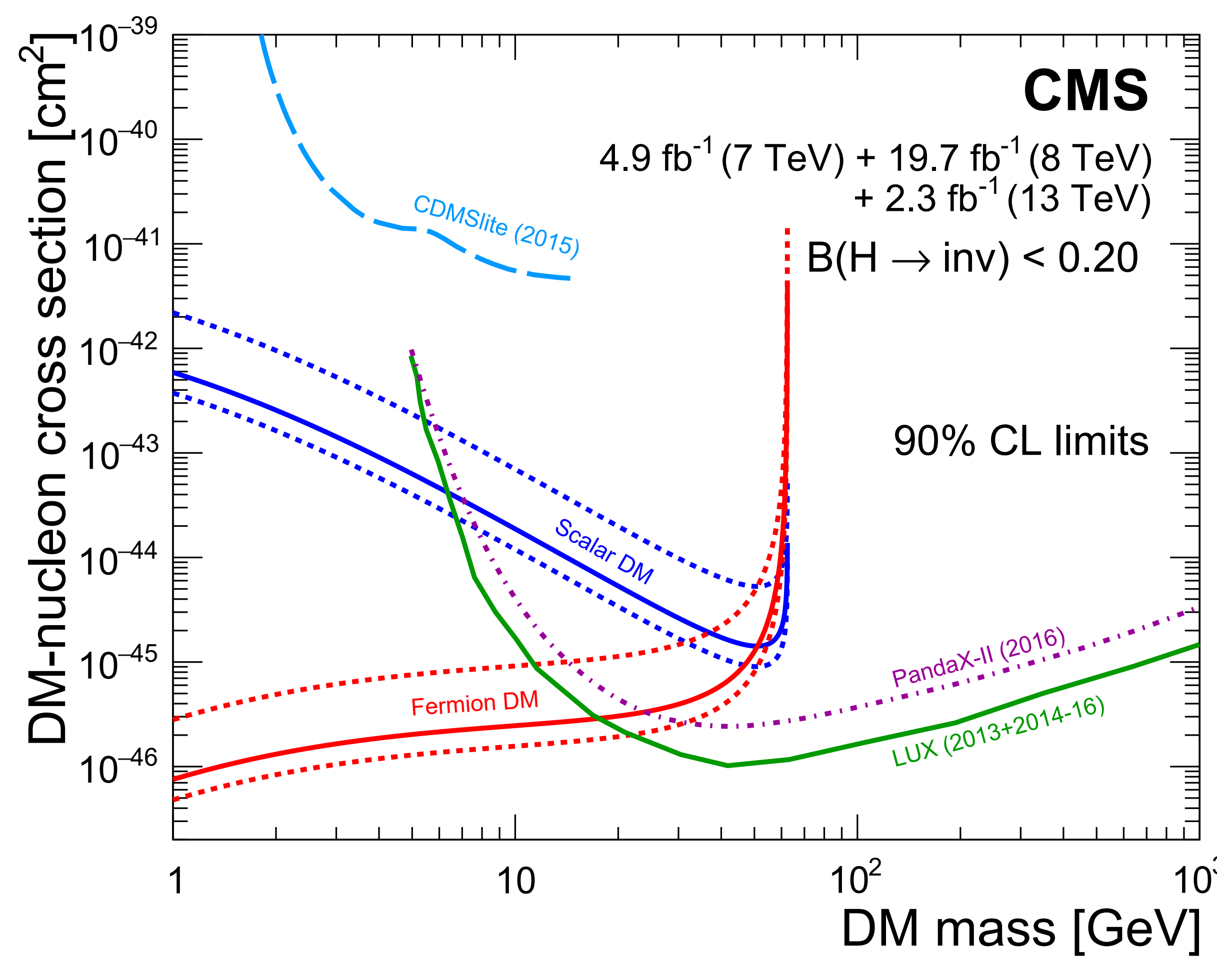
Invisible Higgs Decays

- DM production through the Higgs portal for $m_{DM} < m_H/2$
- Combining qqH VBF production, ZH, ggH, gives BR(H→inv) < 0.24 (0.23) at 95% CL
- Dominated by 8 TeV results
- 2016 mono-X search also recast for BR(H→inv)
  - Mono-jet: < 0.53 (0.40)
  - Mono-Z: < 0.45 (0.44)





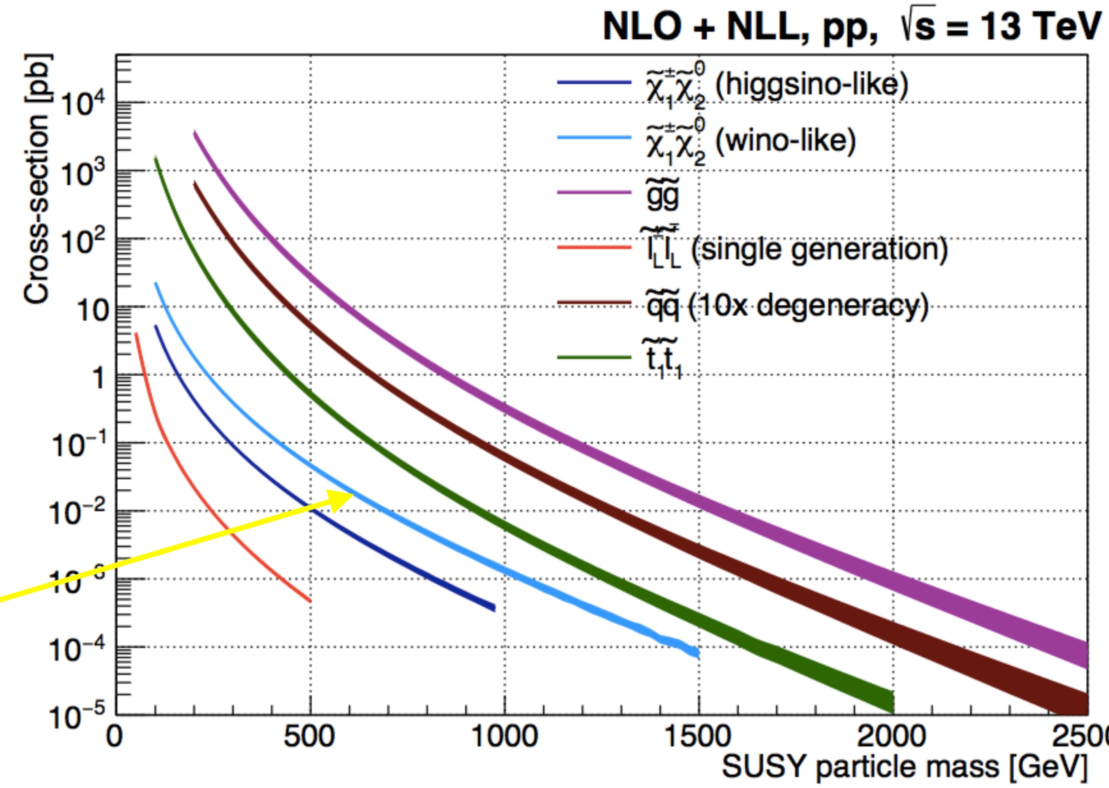
JHEP 02 (2017) 135, ATLAS-CONF-2016-056, JHEP 11 (2015) 206

Search for DM in Cascade Decays

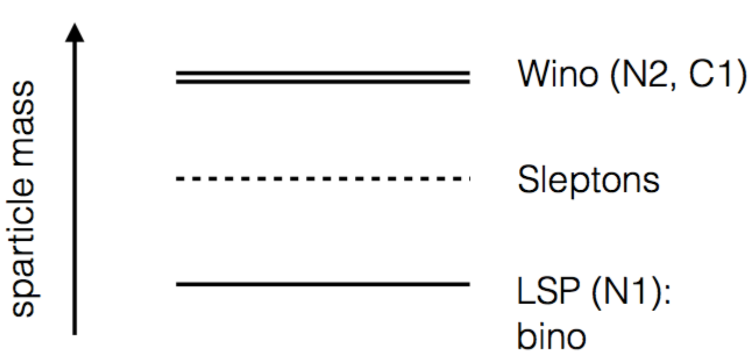
SUSY Primer by Steve Martin, LHCP 2017 by Till Eifert

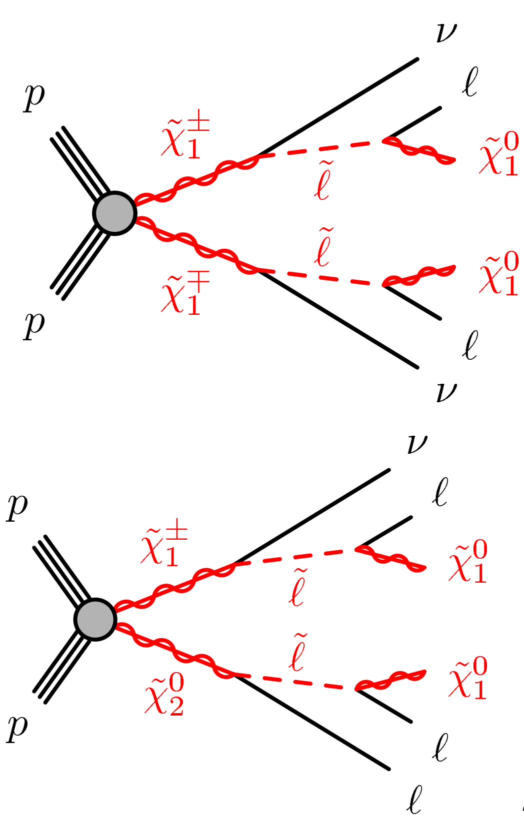
Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	(same)
			$\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$	(same)
			$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \ \tilde{W}^0\ \ \tilde{H}_u^0\ \ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \ \tilde{H}_u^+\ \ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

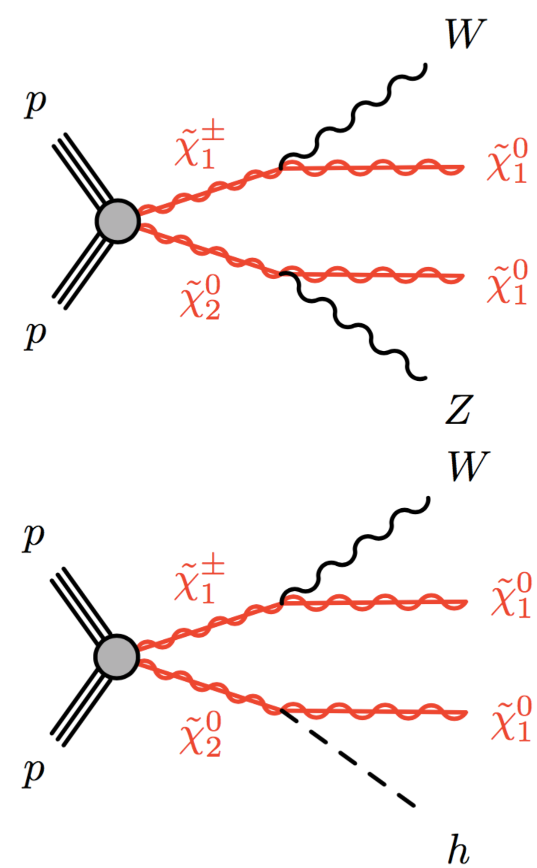
Pair production cross section for various SUSY particles
NLO + NLL Tool, C. Borschensky et al



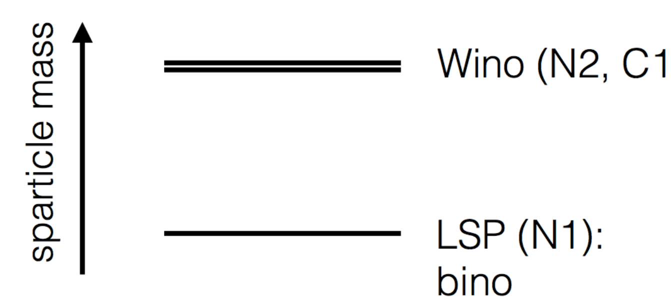
wino→slepton →LSP







wino→LSP



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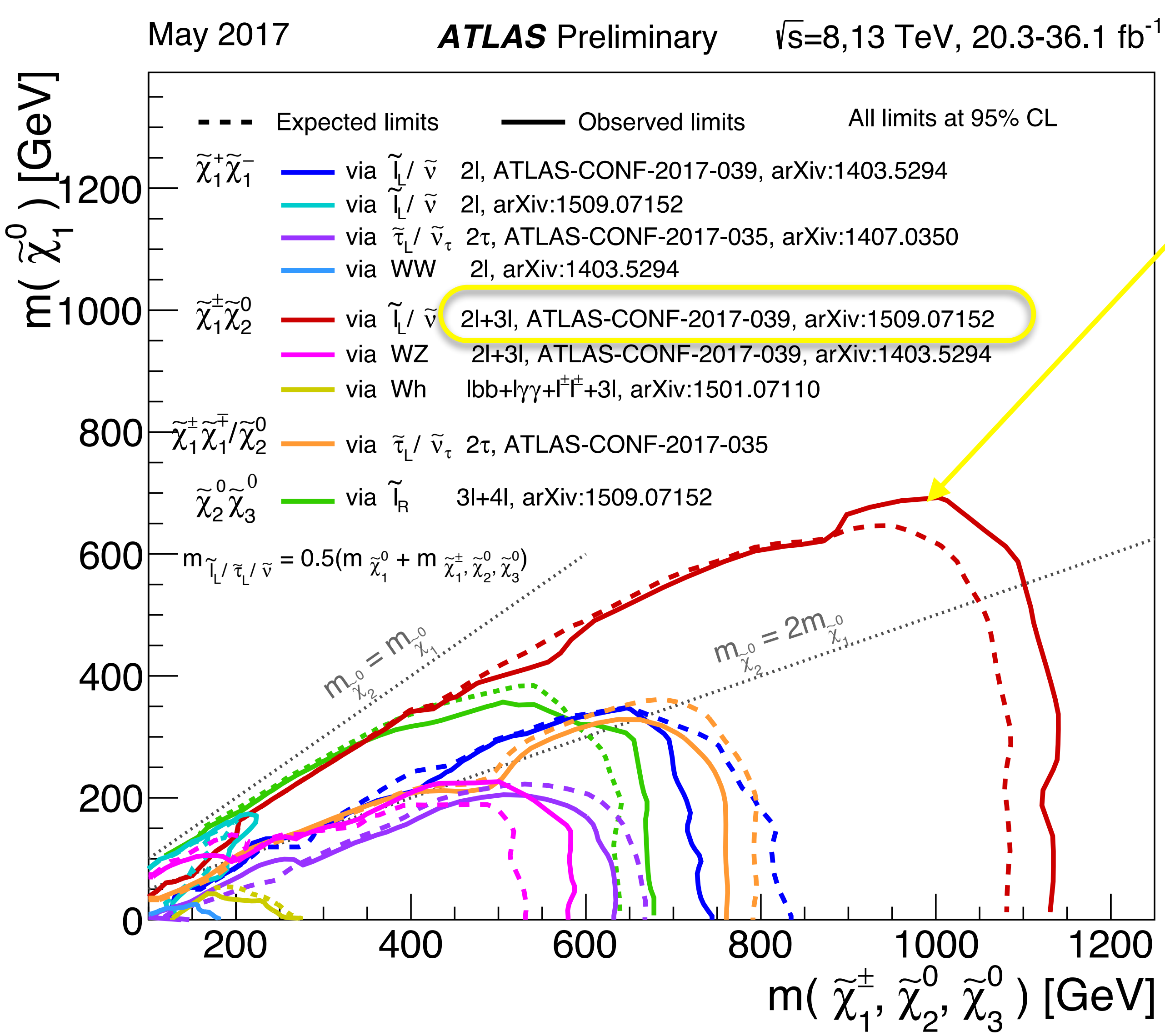
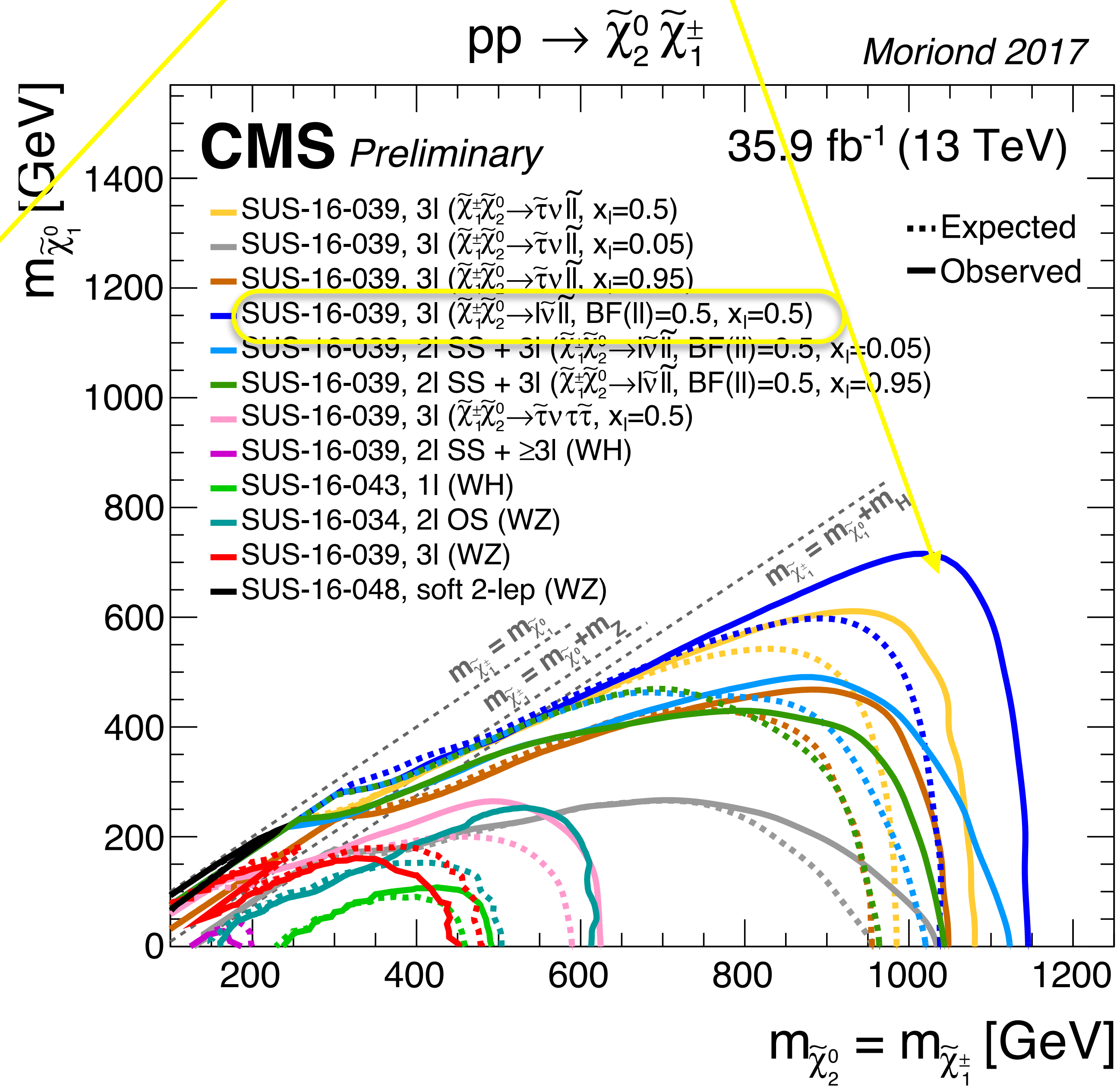
Search for Chargino/Neutralino Production

- For production with decays via slepton, C1/N2 mass of up to ~ 1150 GeV excluded

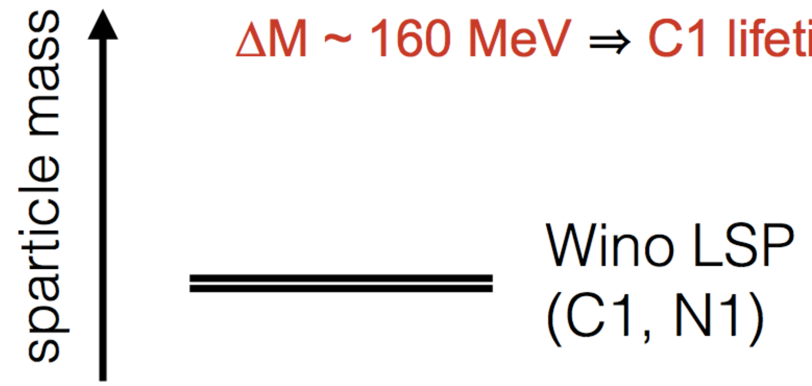
See more details and updates in the "Higgs and new physics" session

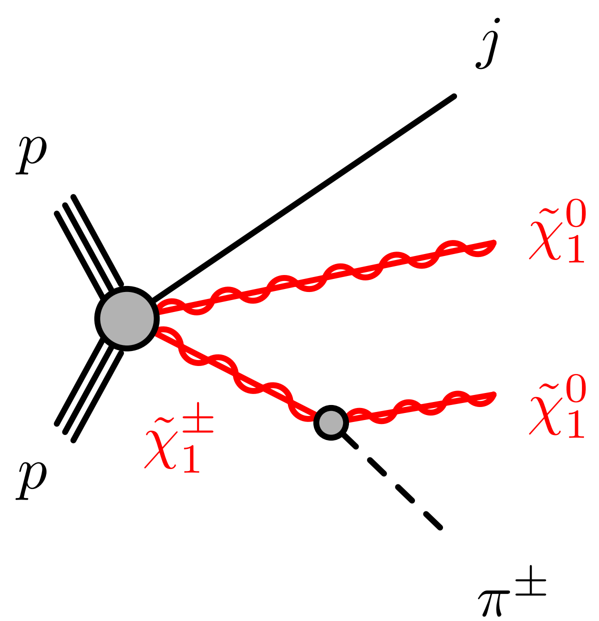




Search for Long-Lived Chargino

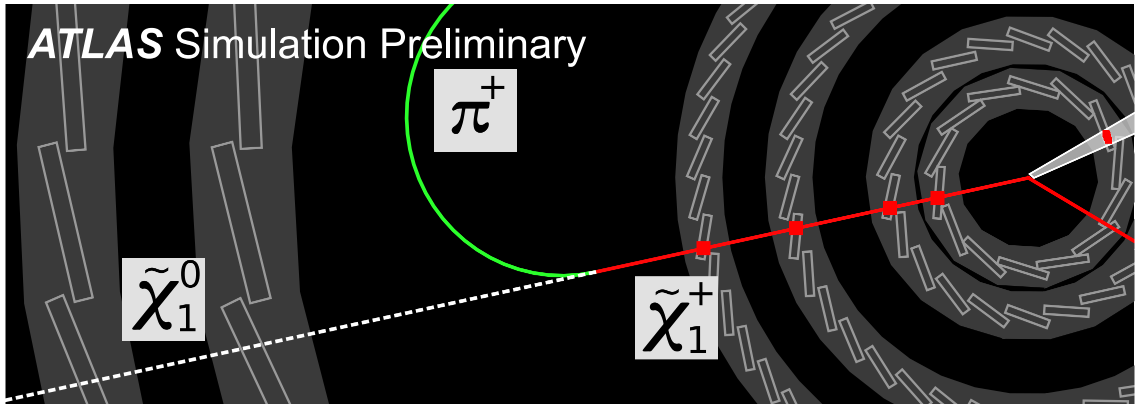
- Wino-only scenario, C1 and N1 nearly degenerate
    - Signature: a disappearing track, a high-pt jet from ISR, MET, and a low-momentum pion

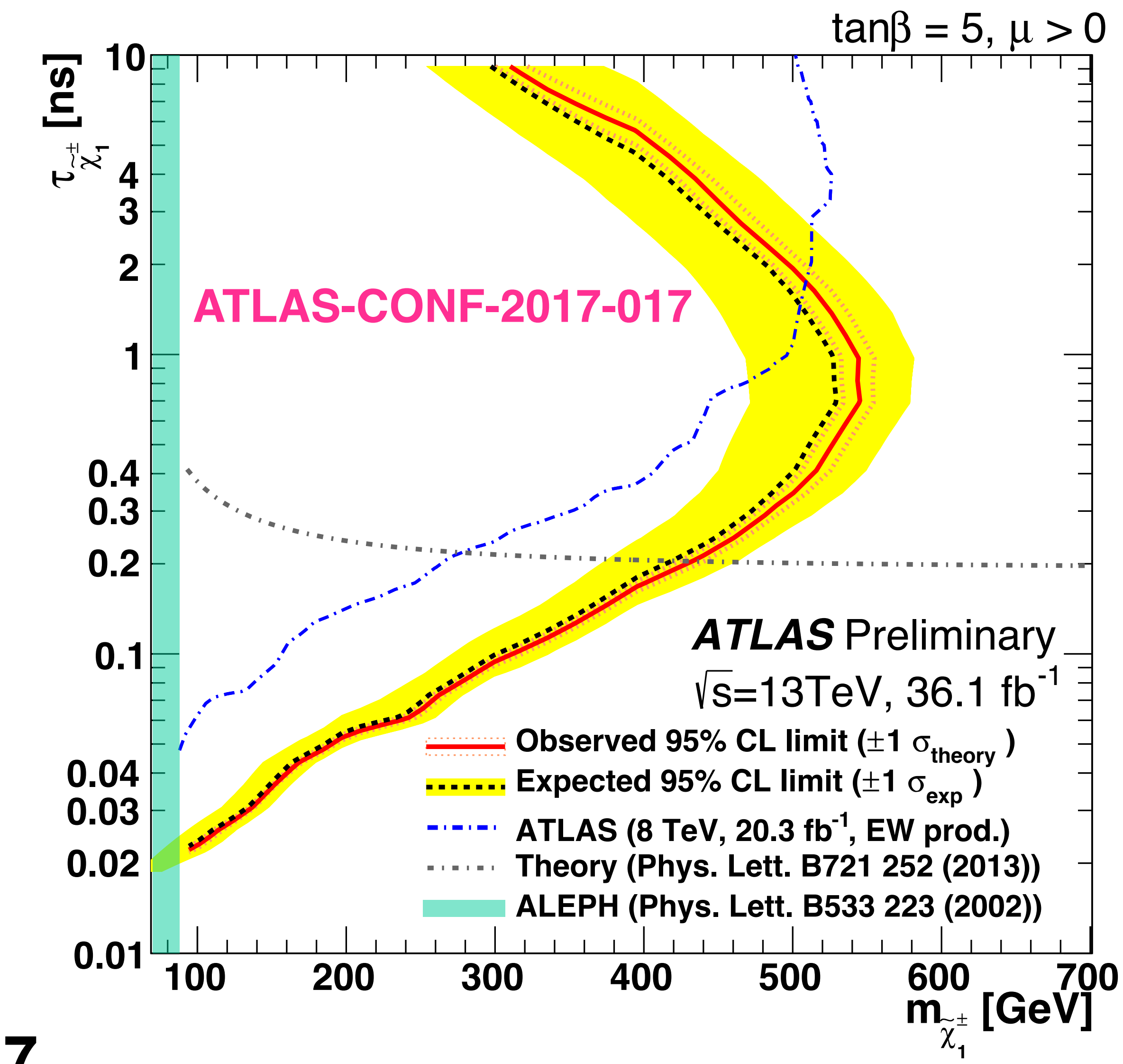




New ATLAS Pixel layer (IBL) allows short-track reconstruction
For C1 with lifetime of 0.2 ns, a mass of up to 430 GeV excluded

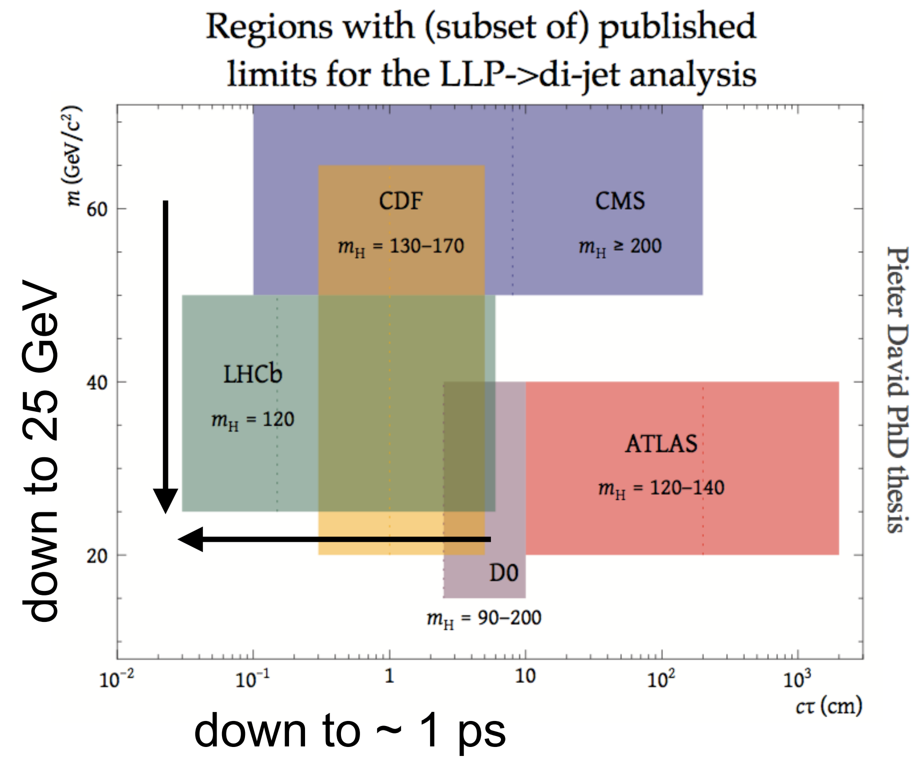
IBL r~3.2 cm



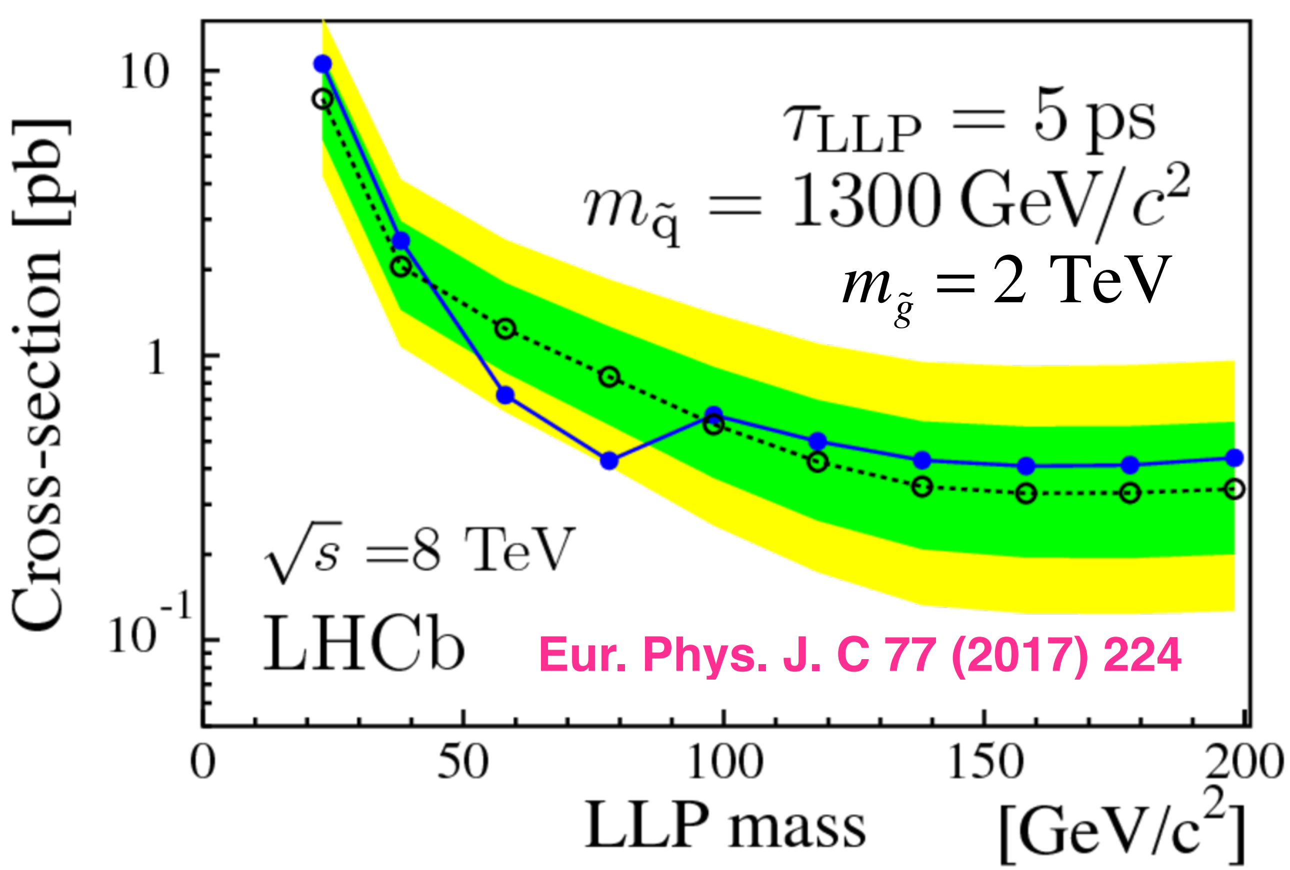


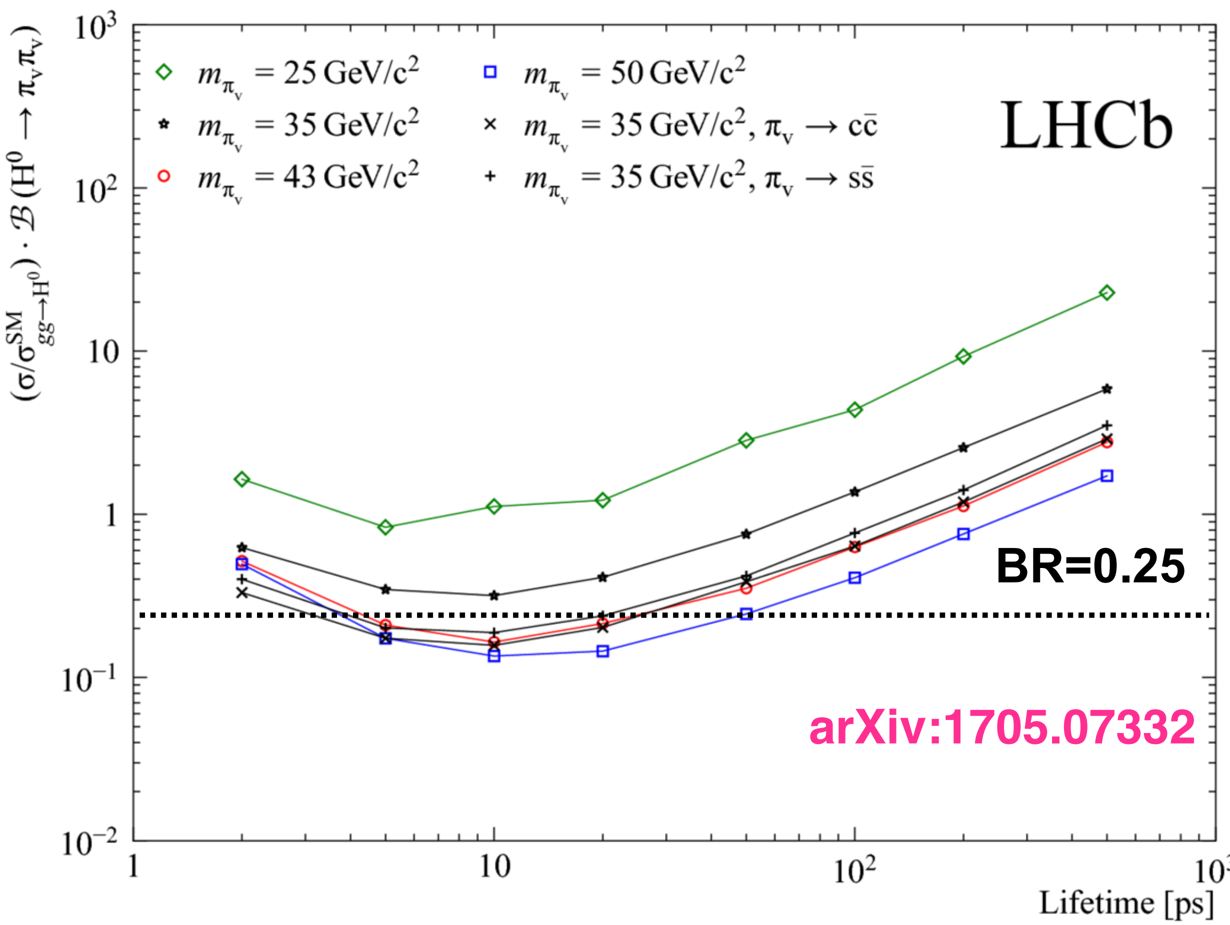
Searches for LLPs at LHCb

- μ+jet: single displaced vertex with several tracks and a high p_T muon, coming from RPV neutralino decays (into a lepton and two quarks)
  - τ_{LLP}=[5,100] ps, m_{LLP}=[23,198] GeV, inclusive mSUGRA neutralino production in PYTHIA 6



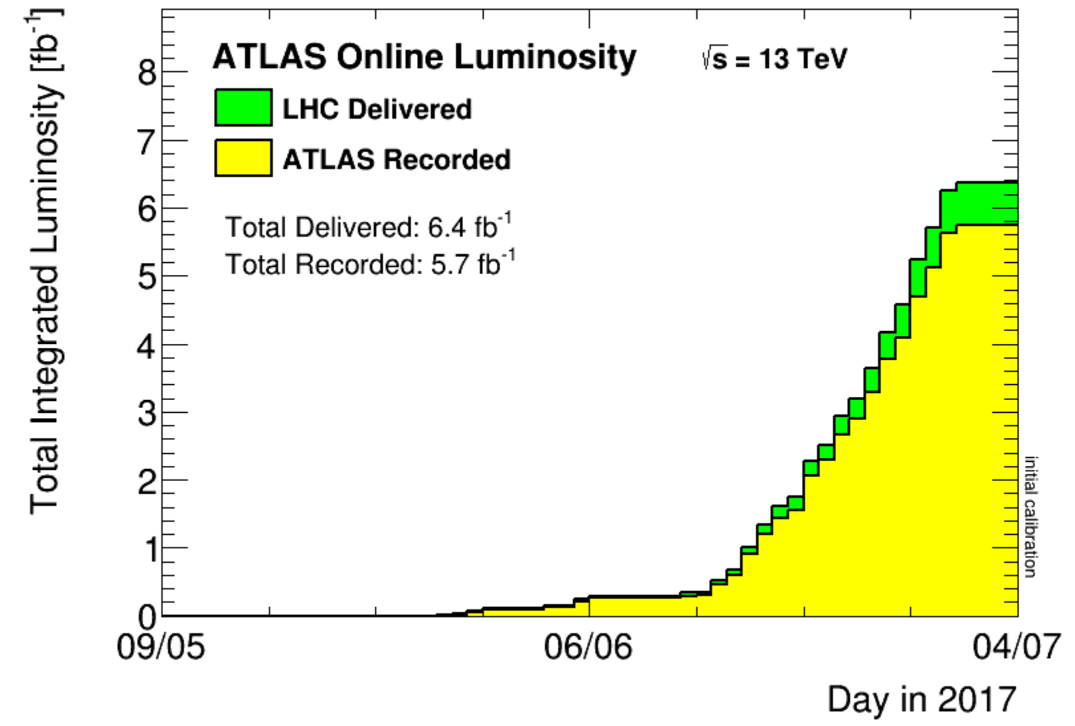
- Di-jet: single displaced vertex with two associated jets, consider H→$\pi_v\pi_v$→qqqq

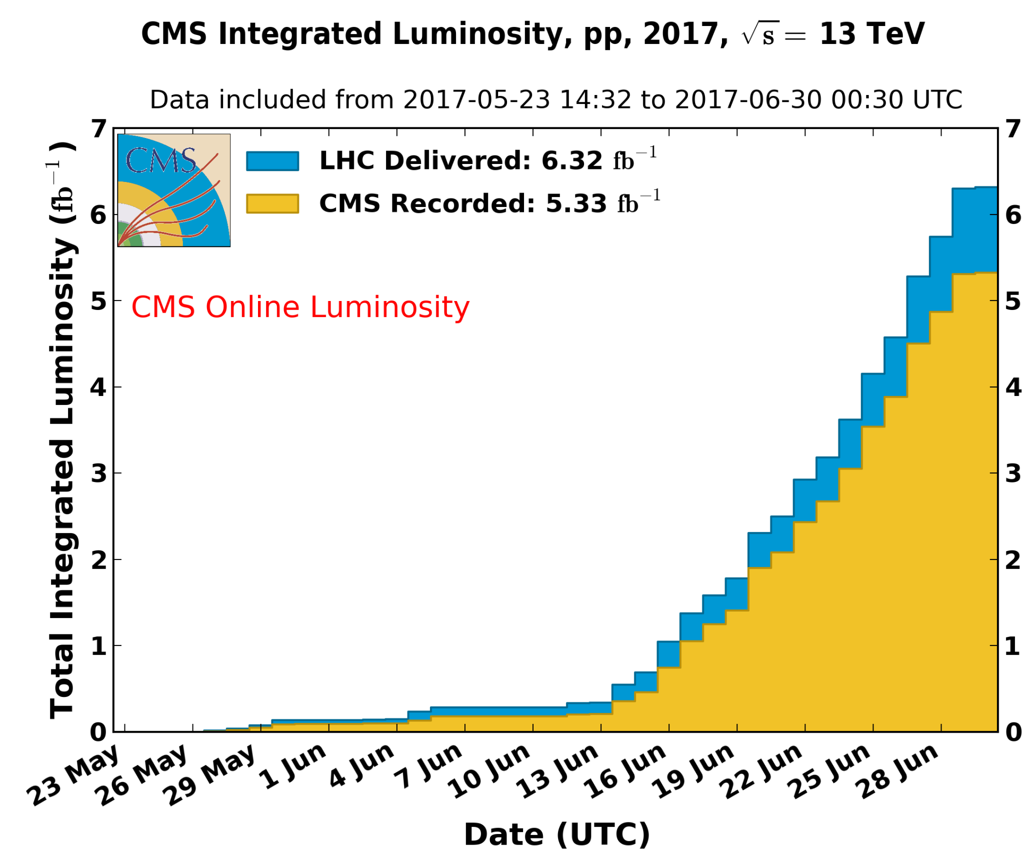




Conclusion and Outlook

- LHC has an extensive dark matter program, including both searches for direct DM production and searches for DM in cascade decays
- 45 fb^{-1} of data expected in 2017
- Moving towards more realistic scalar/ pseudo scalar models
    - New scalar with H mixing, more discussion in 1607.06680
    - Currently DMWG studying 2HDM with extra pseudo-scalar: 1701.07427
    - t-channel production
    - spin-2 mediators, long-lived mediators
    - Beyond MFV





Links To Analysis Documentation

Analysis	Documentation and Links
Mono-jet or V-had	CMS-PAS-EXO-16-048, ATLAS-CONF-2017-060
Mono-photon	arXiv:1706.03794, Eur. Phys. J. C 77 (2017) 393
Mono-Z (ll)	CMS-PAS-EXO-16-052, ATLAS-CONF-2017-040
Mono-Higgs (bb)	arXiv:1707.01302
Mono-Higgs (γγ)	CMS-PAS-EXO-16-054, arXiv:1706.03948
Mono-tt/bb	arXiv: 1706.02581, ATLAS-CONF-2016-086, CMS-PAS-SUS-17-001, ATLAS-CONF-2017-037, ATLAS-CONF-2016-076, ATLAS-CONF-2016-077
Mono-top	CMS-PAS-EXO-16-051
Dijet	CMS-PAS-EXO-16-056, arXiv: 1703.09127 CMS-PAS-EXO-16-046, ATLAS-CONF-2016-060
Boosted-dijet	CMS-PAS-EXO-17-001, ATLAS-CONF-2016-030, ATLAS-CONF-2016-070
Invisible Higgs	JHEP 02 (2017) 135, ATLAS-CONF-2016-056, JHEP 11 (2015) 206
Long-lived particles	ATLAS-CONF-2017-017, CMS-PAS-EXO-16-004, CMS-PAS-EXO-17-004
Summary Plots	ATLAS Exotics, CMS Exotica, ATLAS SUSY, CMS SUSY
LHCb long-lived searches	Eur. Phys. J. C 77 (2017) 224, arXiv:1705.07332

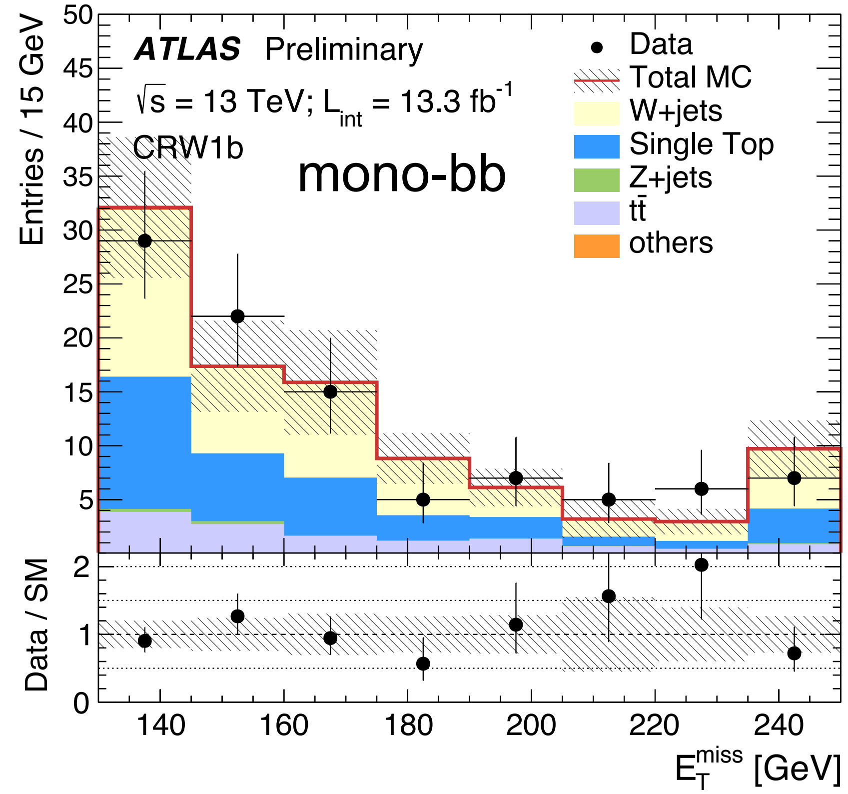

Pick up 2017 data!
Push
Pull
Give
Open
Close
Look
Walk to
Pick up
What is
Use
Turn on
Turn off
Talk
Travel
package
whip

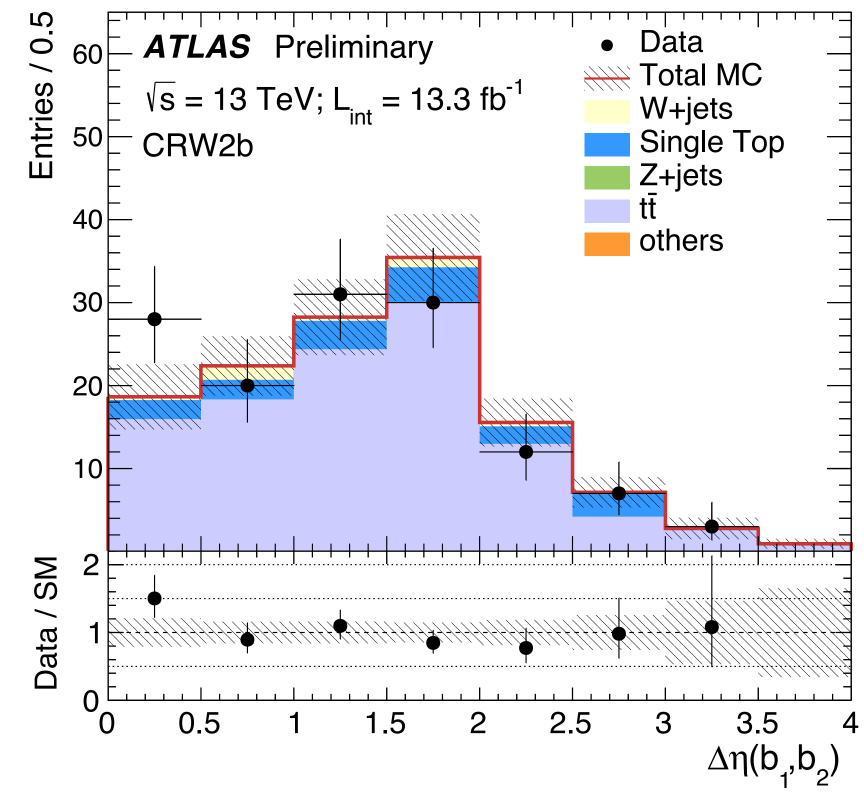
Backup Slides

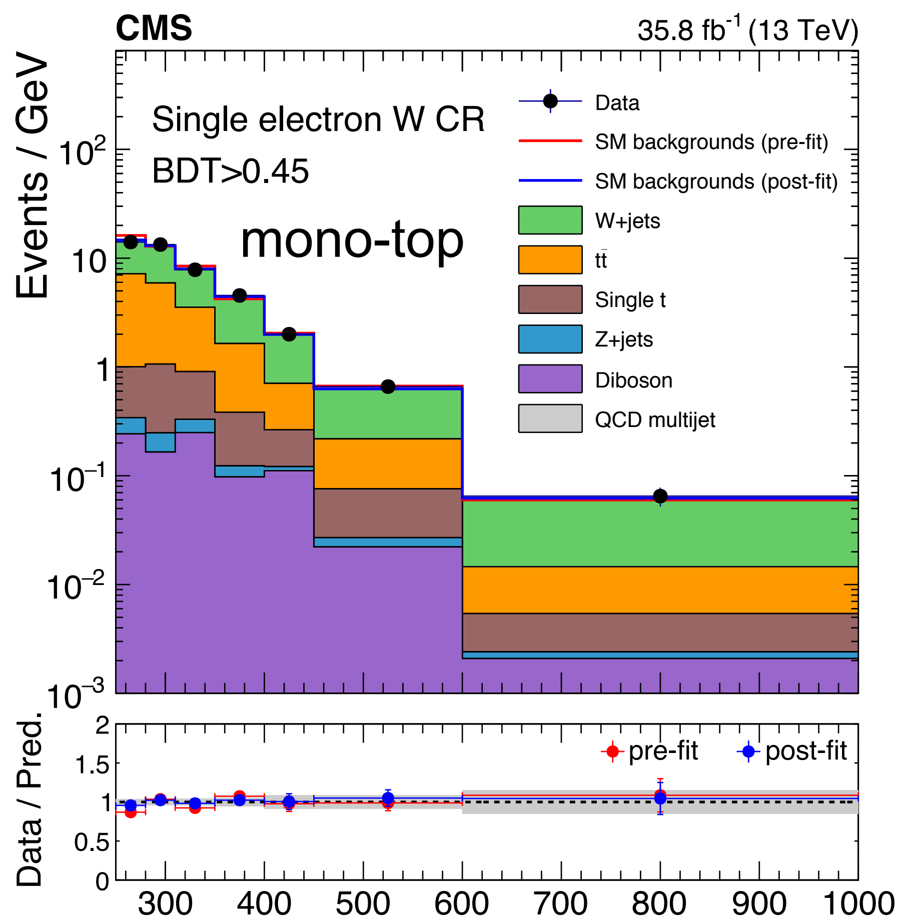
Estimation of Top Background

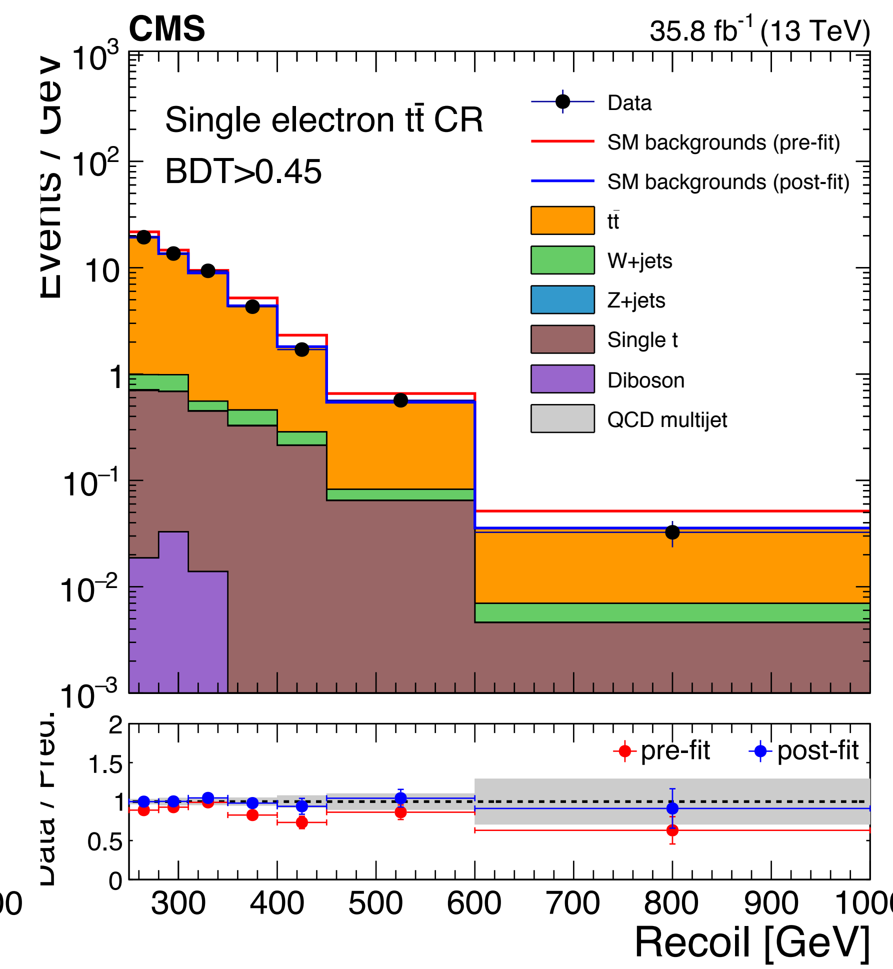
ATLAS-CONF-2016-086

- One of the major backgrounds for mono-h, mono-top, and mono-tt/bb
- Control region defined by allowing extra leptons in addition to the signal selection
- Reduce number of b-tags or anti-b-tag to separate W+jets and top background





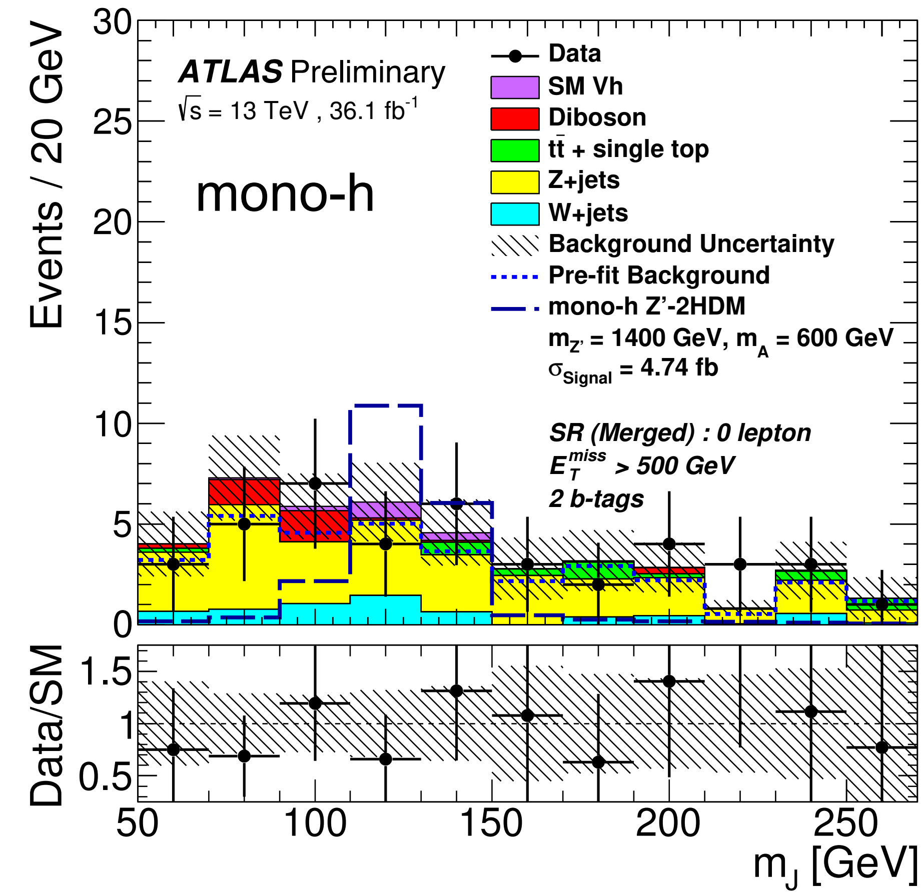


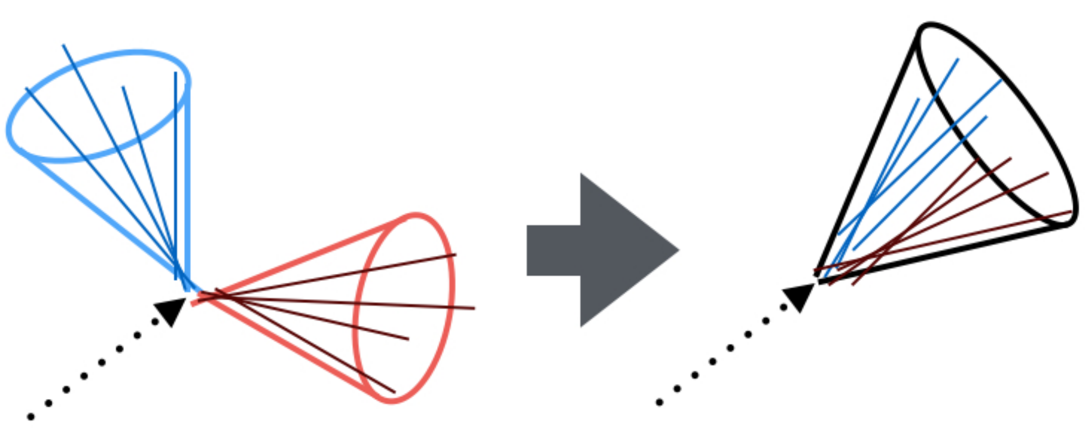


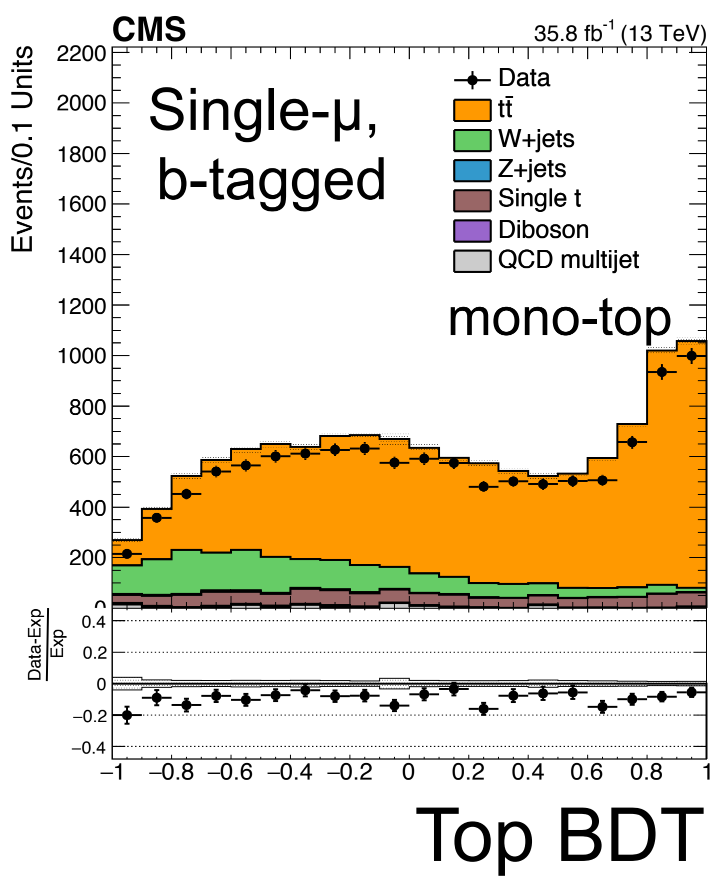
Mono-W/Z/h(bb)/Top

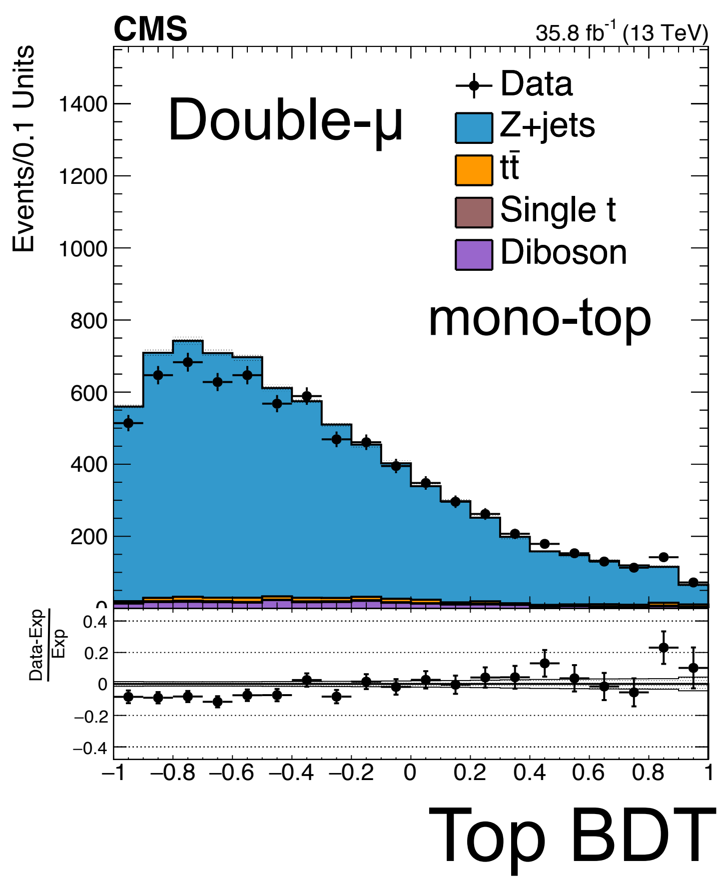
- Reconstructed either with a single large-radius jet or two small-radius jets depending on pT
- Jet substructure variables
  - Mass, N-subjettiness, energy correlation functions, or combination with BDT

ATLAS-CONF-2017-028



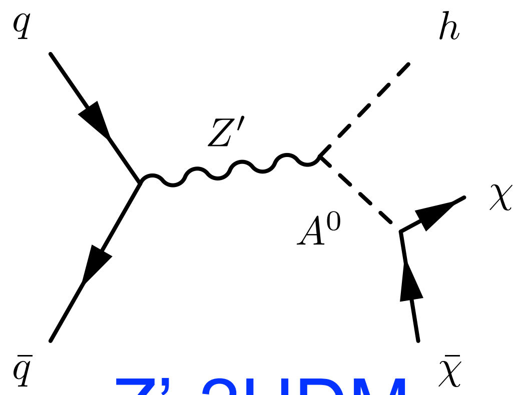




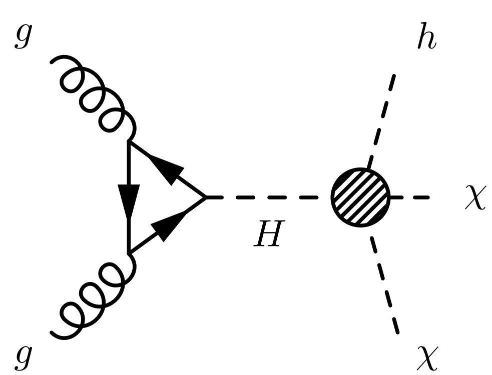


Mono-Higgs (bb, $\gamma\gamma$) Interpretation

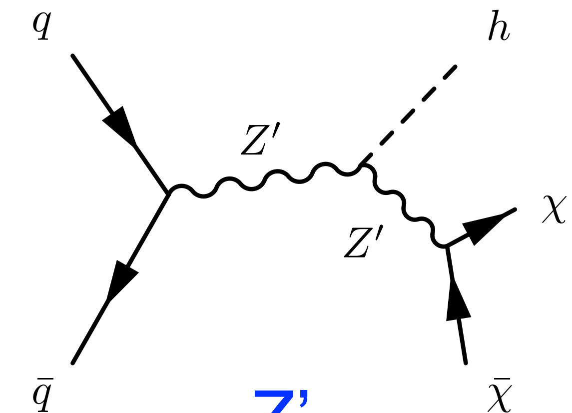
- Dedicated models (not necessary apply to other mono-X), e.g. Z'-2HDM, the bb decay mode dominates the sensitivity
- SI cross section limits similar to that of mono-Z (with Z'_B model)



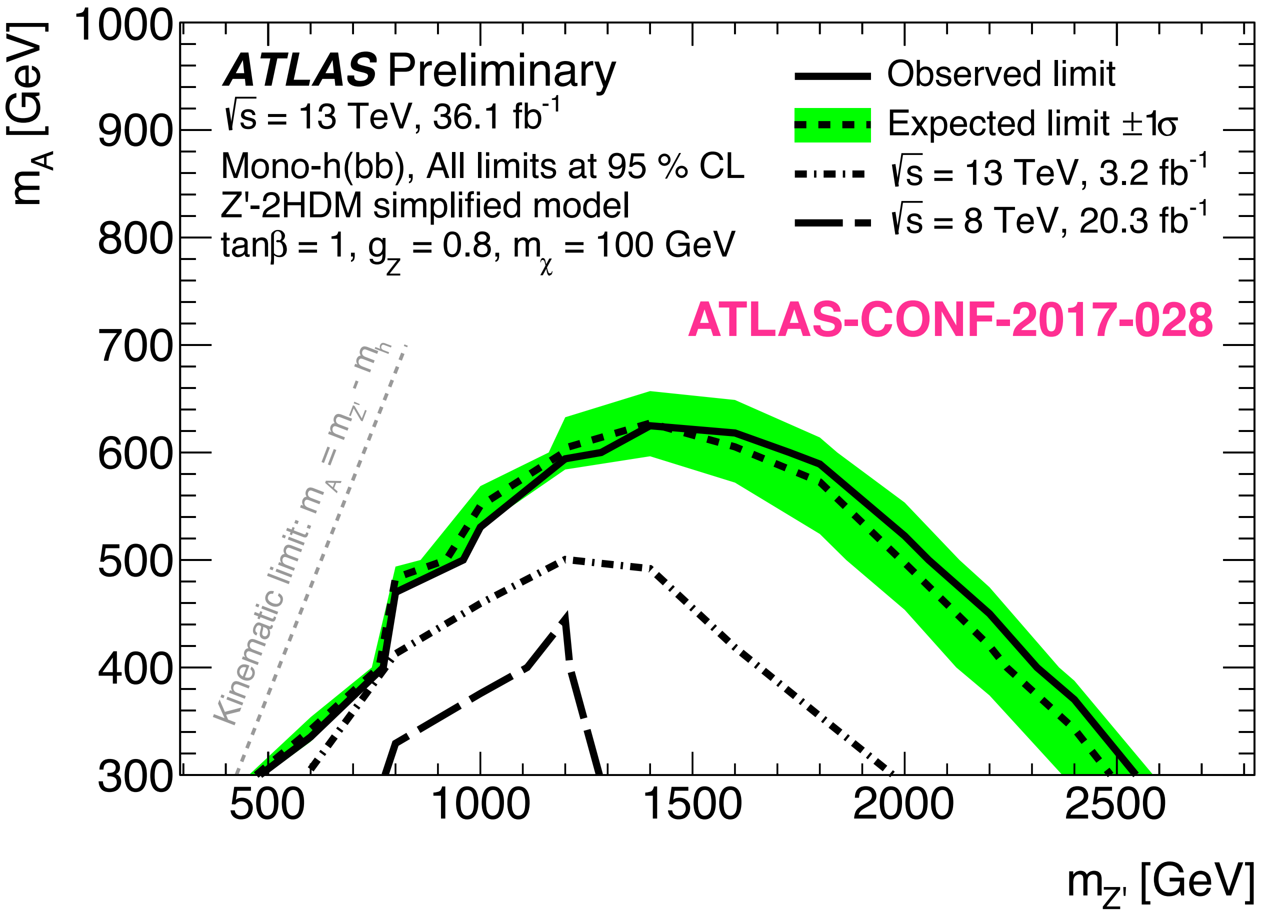
Z'-2HDM

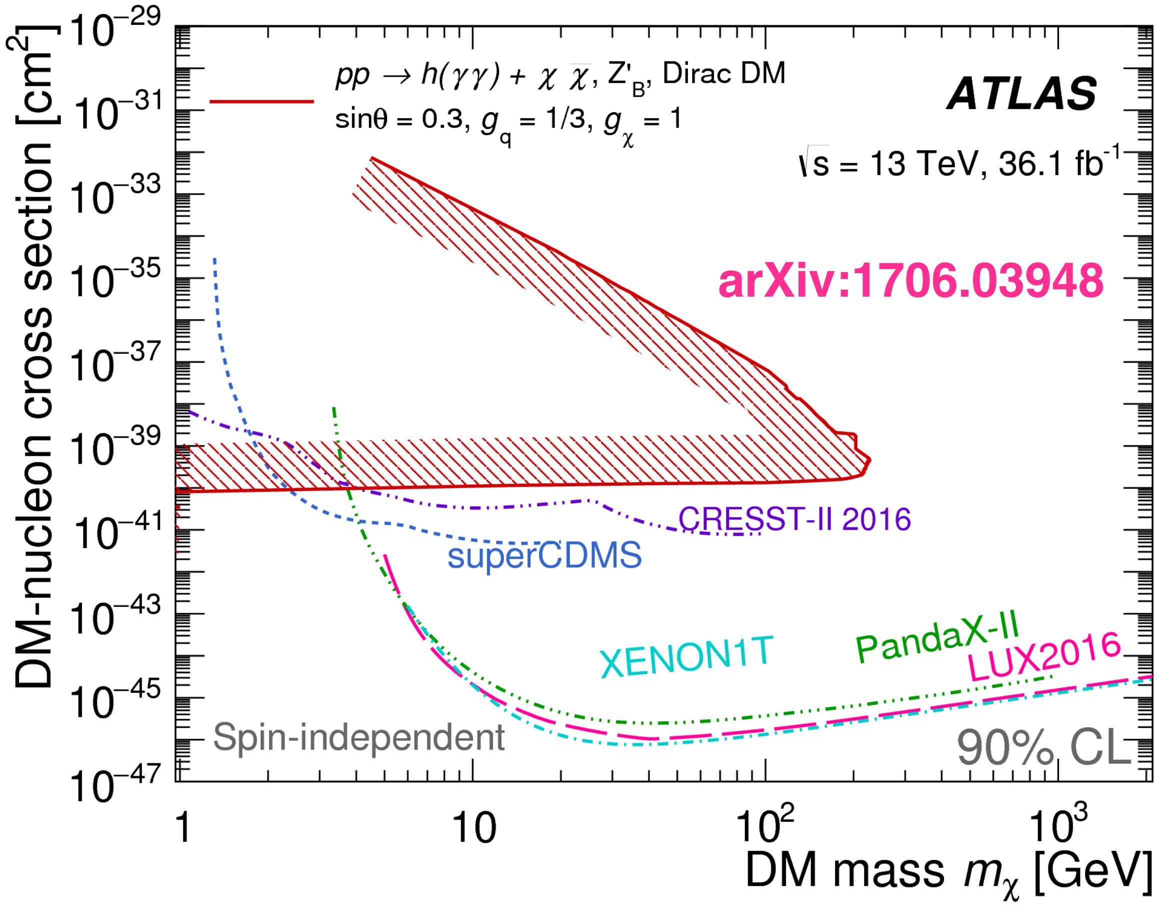


Heavy scalar



Z'_B





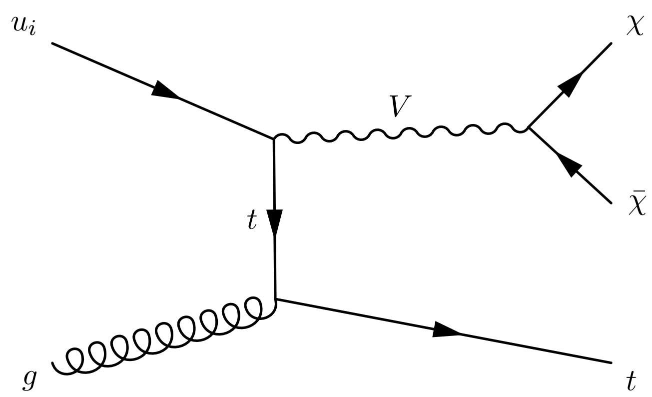
Mono-Top

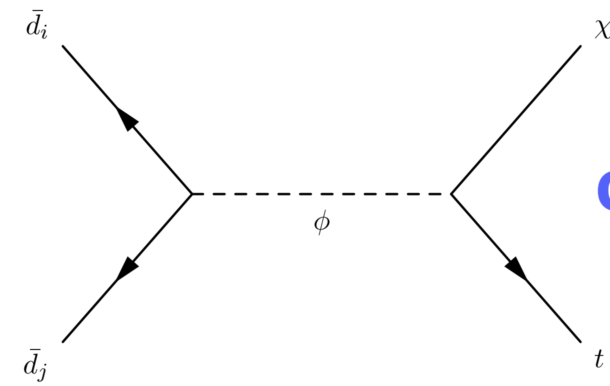
CMS-PAS-EXO-16-051

New

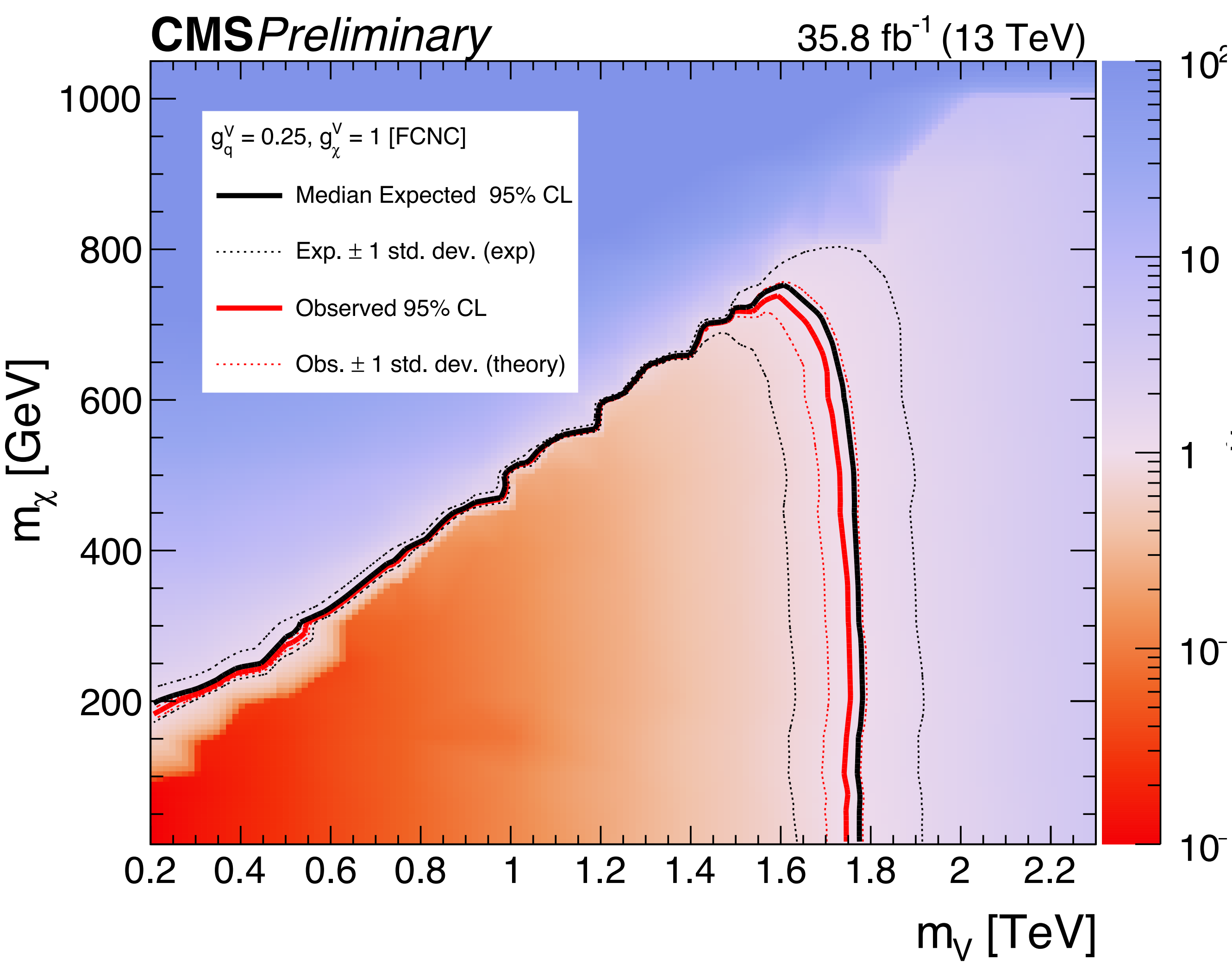
- FCNC vector 0.2-1.75 TeV and charged scalar up to 3.4 TeV excluded

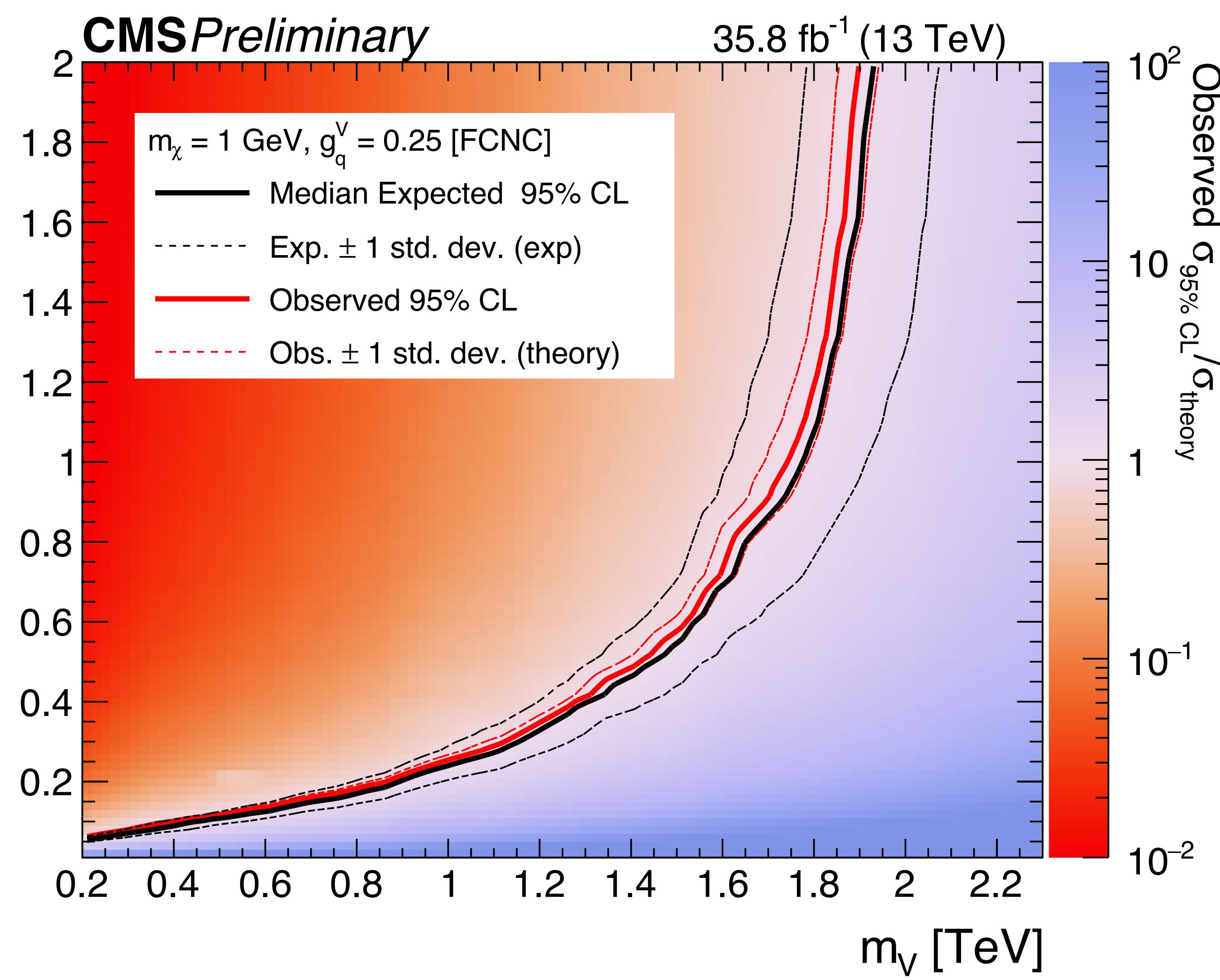
FCNC





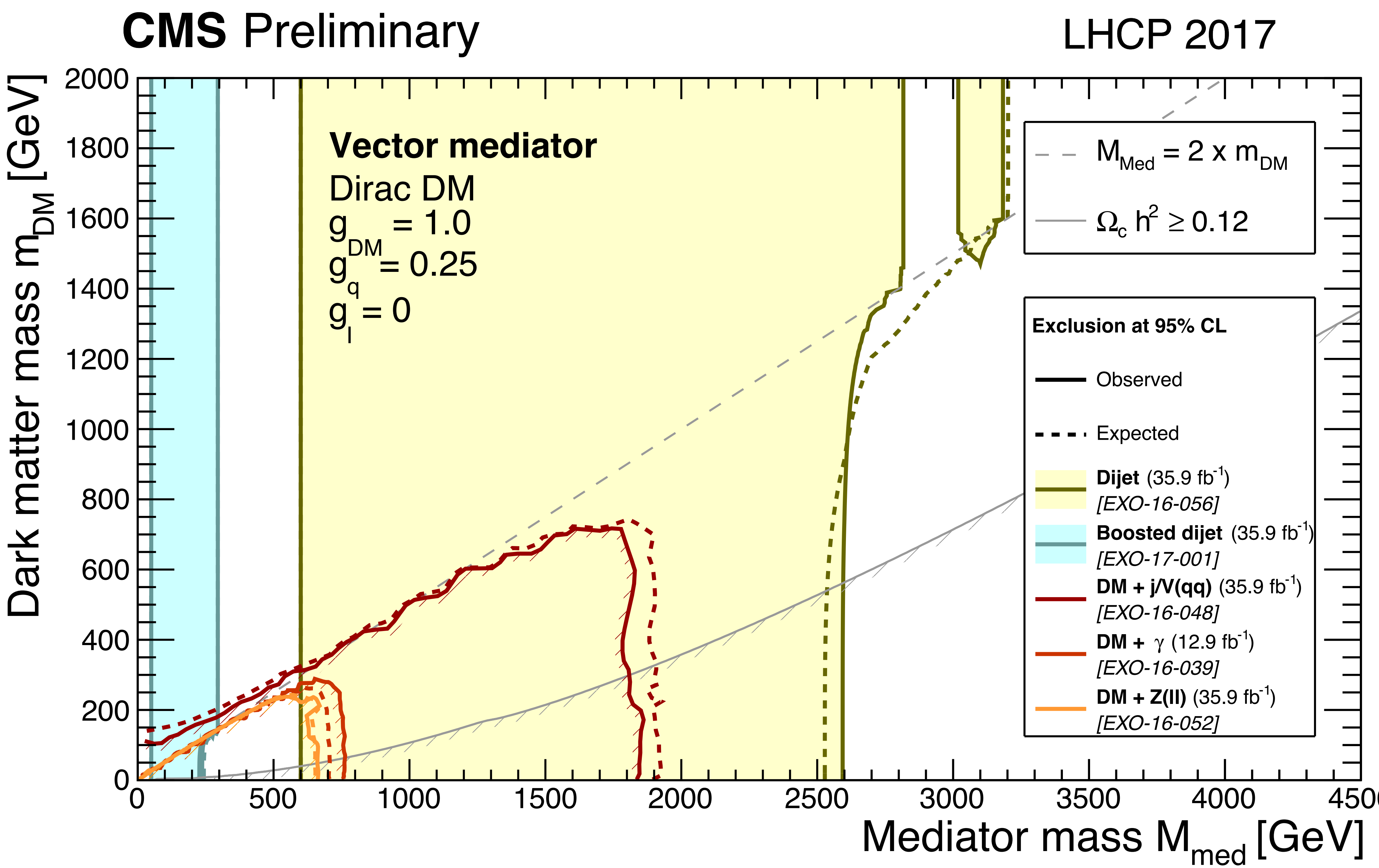
color-charged scalar



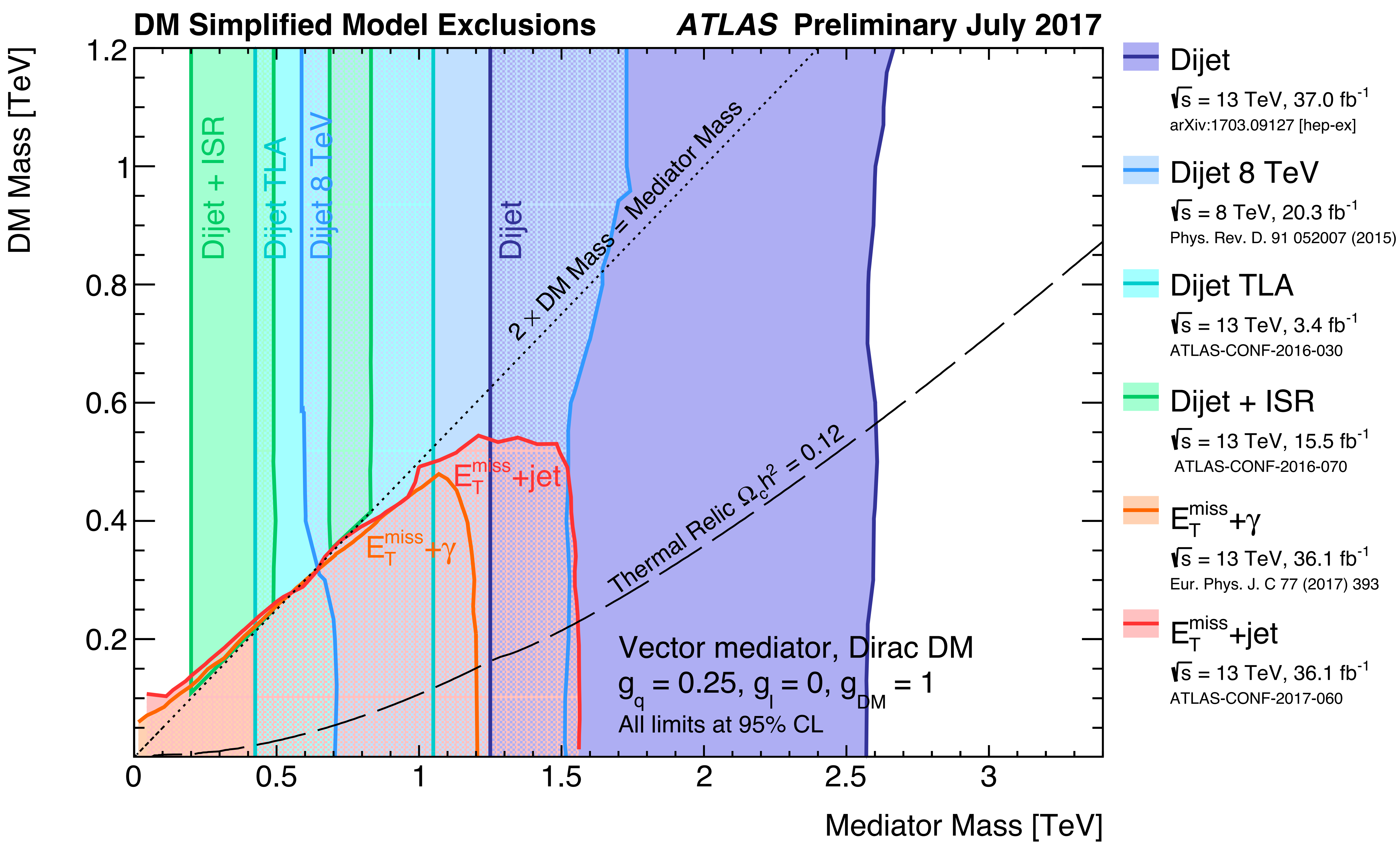


Summary Plots

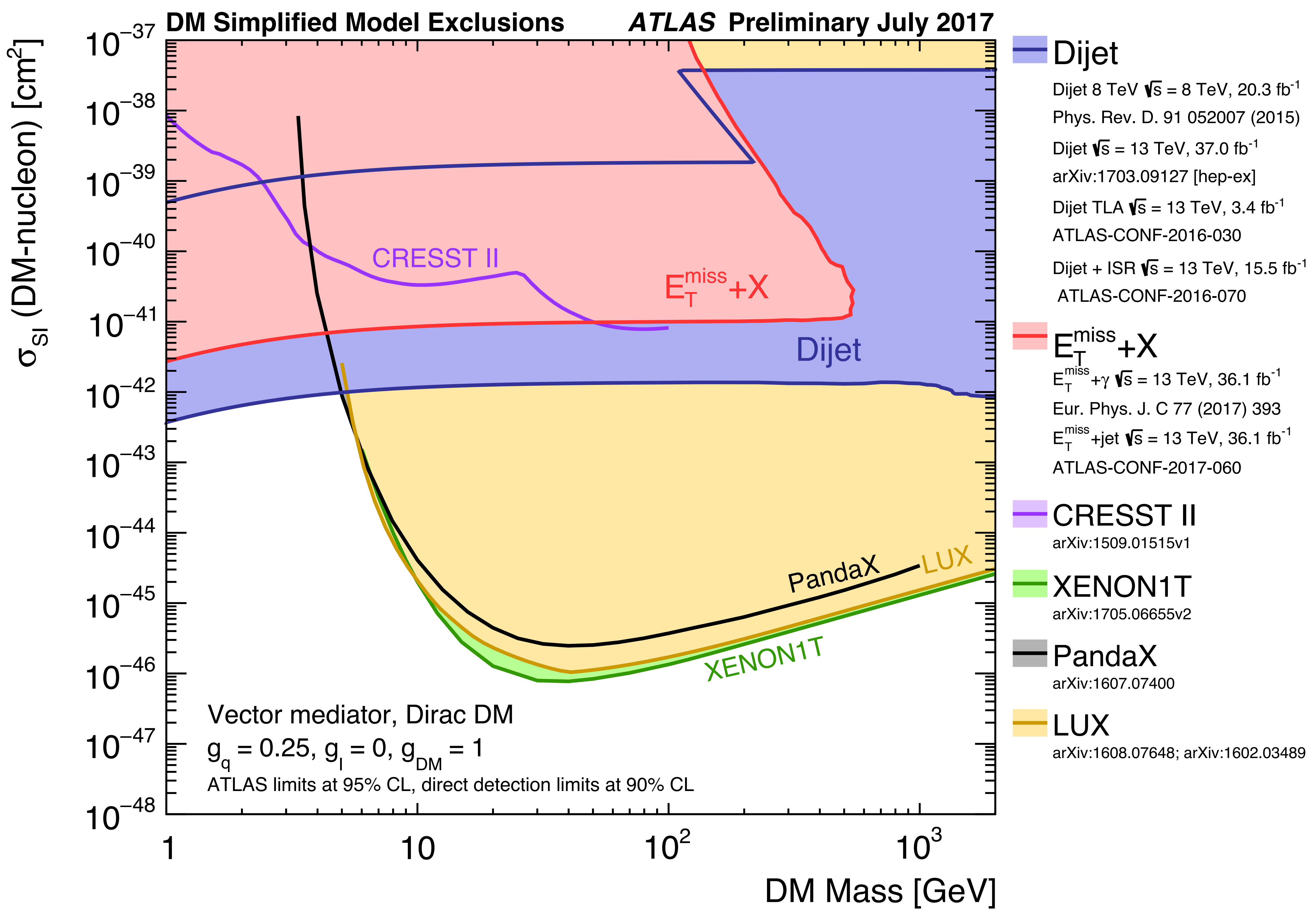
CMS Vector Mediator Results



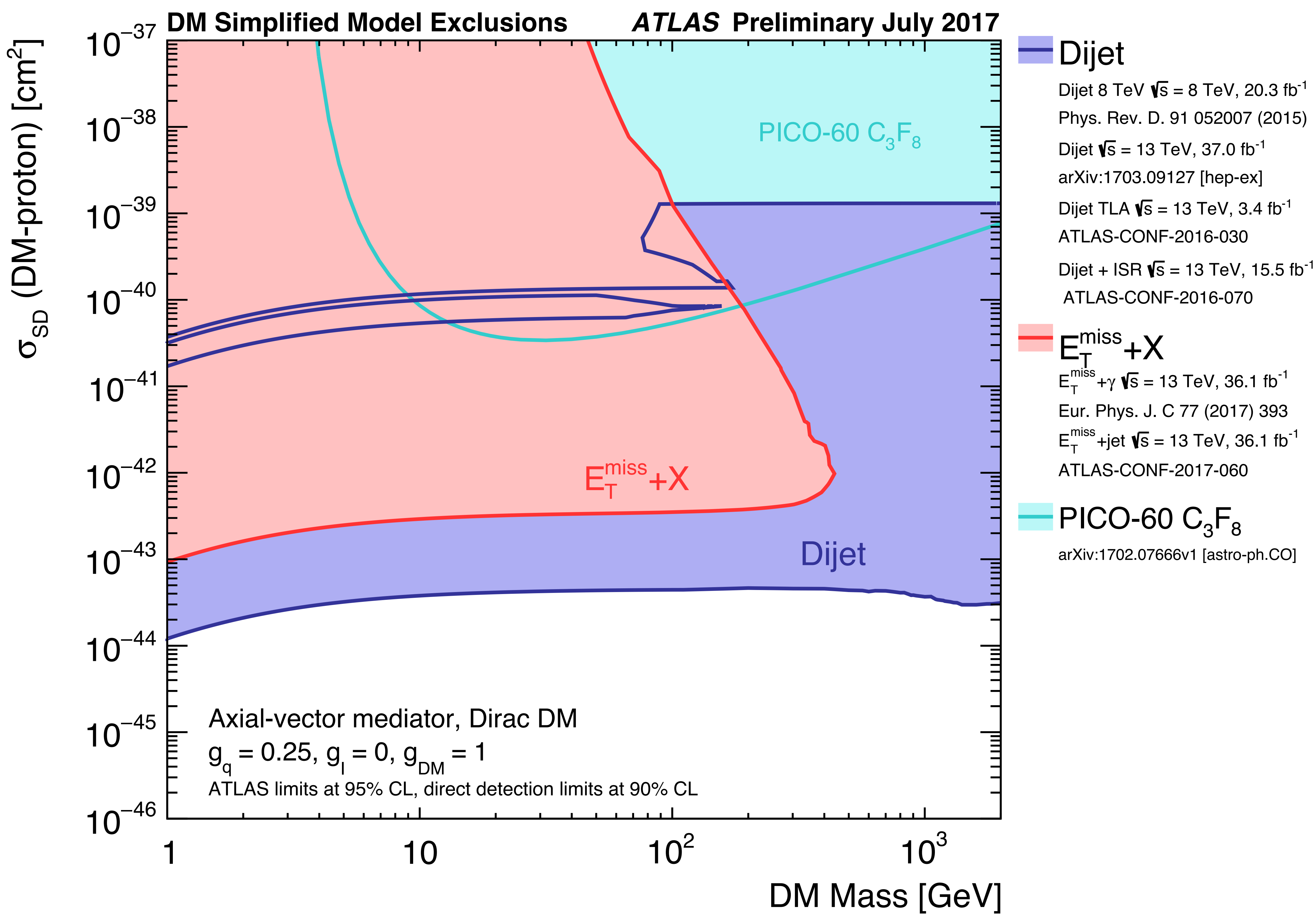
ATLAS Vector Mediator Results



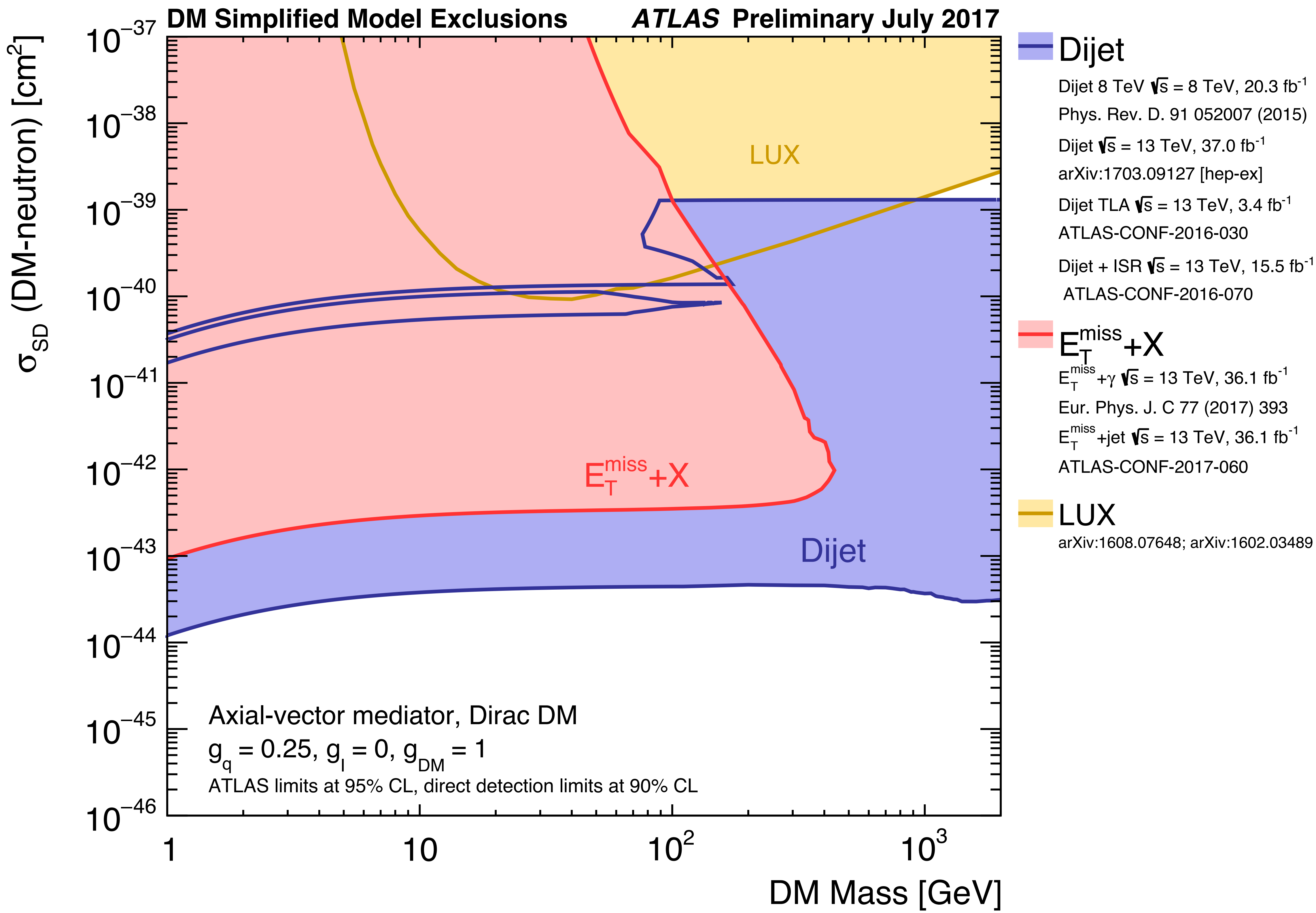
Collider v.s. Non-Collider Experiments (SI)



Collider v.s. Non-Collider Experiments (SDp)



Collider v.s. Non-Collider Experiments (SDn)



How To Translate (Vector)

arXiv: 1603.04156

In general, the SI DM-nucleon scattering cross section takes the form

$$\sigma_{\rm SI} = \frac{f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4}\,, \tag{4.1}$$

where $\mu_{n\chi} = m_n m_{\rm DM}/(m_n + m_{\rm DM})$ is the DM-nucleon reduced mass with $m_n \simeq 0.939\,{\rm GeV}$

For the vector mediator,

$$f(g_q) = 3 g_q\,,$$

and hence

$$\sigma_{\rm SI} \simeq 6.9 \times 10^{-41}\ {\rm cm}^2 \cdot \left(\frac{g_q g_{\rm DM}}{0.25}\right)^2 \left(\frac{1\,{\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,{\rm GeV}}\right)^2 .$$

How To Translate (Axial-Vector)

arXiv: 1603.04156

For the axial-vector mediator, the scattering is SD and the corresponding cross section can be written as

$$\sigma_{\rm SD} = \frac{3 f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4} . \tag{4.7}$$

In general $f^{p,n}(g_q)$ differs for protons and neutrons and is given by

$$f^{p,n}(g_q) = \Delta_u^{(p,n)} g_u + \Delta_d^{(p,n)} g_d + \Delta_s^{(p,n)} g_s , \tag{4.8}$$

Under the assumption that the coupling g_q is equal for all quarks, one finds

$$f(g_q) = 0.32 g_q , \tag{4.9}$$

and thus

$$\sigma^{\rm SD} \simeq 2.4 \times 10^{-42}\ {\rm cm}^2 \cdot \left(\frac{g_q g_{\rm DM}}{0.25}\right)^2 \left(\frac{1\,{\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,{\rm GeV}}\right)^2 . \tag{4.10}$$

How To Translate (Scalar)

In general, the SI DM-nucleon scattering cross section takes the form

$$\sigma_{\rm SI} = \frac{f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4}\,, \tag{4.1}$$

where $\mu_{n\chi} = m_n m_{\rm DM}/(m_n + m_{\rm DM})$ is the DM-nucleon reduced mass with $m_n \simeq 0.939\,{\rm GeV}$

For the simplified model with scalar mediator exchange we follow the recommendation of ATLAS/CMS DM Forum [1] and assume that the scalar mediator couples to all quarks (like e.g. the SM Higgs). In general the formula for $f(g_q)$ is

$$f^{n,p}(g_q) = \frac{m_n}{v}\left[\sum_{q=u,d,s} f_q^{n,p} g_q + \frac{2}{27} f_{\rm TG}^{n,p} \sum_{Q=c,b,t} g_Q\right]. \tag{4.4}$$

these values, we find that numerically

$$f(g_q) = 1.16 \cdot 10^{-3}\, g_q\,,$$

and therefore the size of a typical cross section is

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