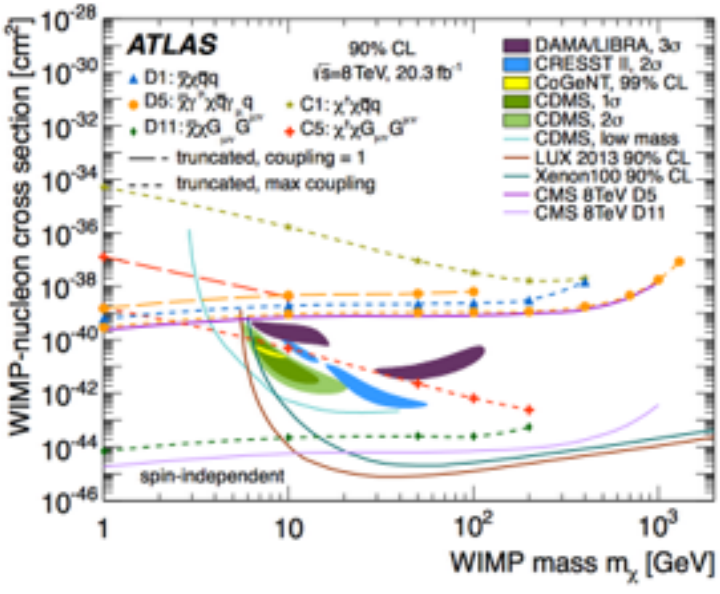
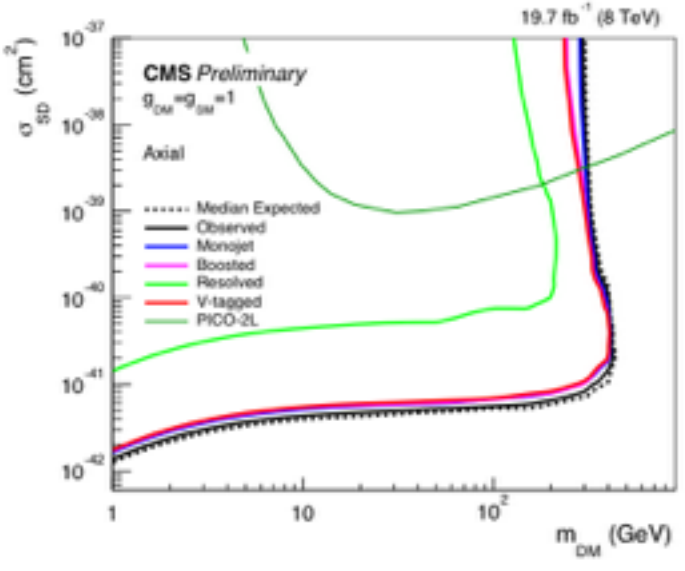
Antonio Boveia (ATLAS)
Oliver Buchmueller (CMS)
Caterina Doglioni (ATLAS)
Kristian Hahn (CMS)
Uli Haisch (TH)
Michelangelo Mangano (TH, LPCC contact)

COMPARING COLLIDER DM SEARCHES WITH DIRECT AND INDIRECT DETECTION EXPERIMENTS USING SIMPLIFIED MODELS

FIRST MEETING OF THE NEW LHC DARK MATTER WORKING GROUP. *DECEMBER 10-11*





Follow-up on yesterday

- 16:00 Proposal for presentation of results: detailed discussions

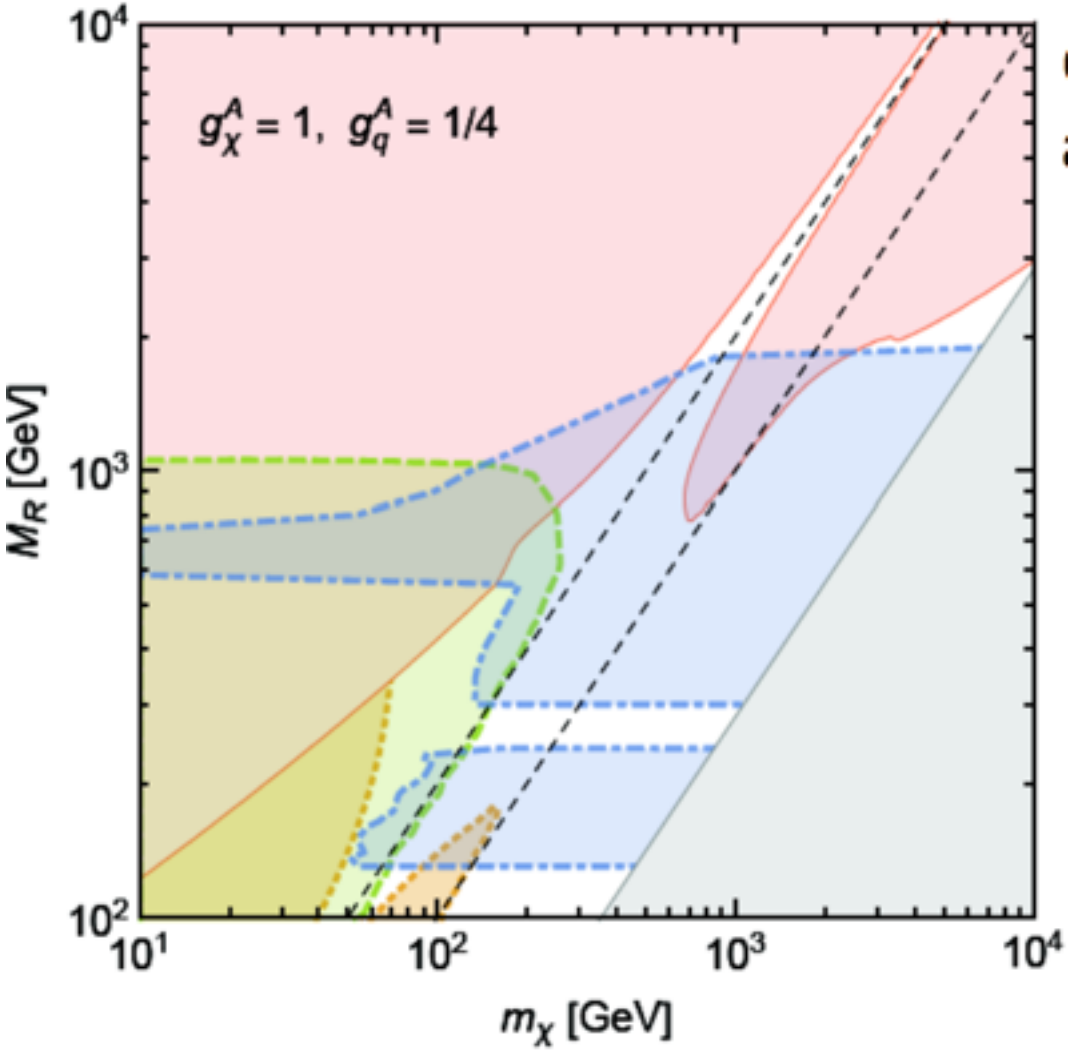
13:30 **Introduction to the proposal** *30'*
Speaker: Oliver Buchmueller (Imperial College Sci., Tech. & Med. (GB))
Intro to Proposal C... Intro to Proposal C...

14:00 **Translating collider limits to DD-nucleon xsec plane** *20'*
Speaker: Christopher McCabe (University of Amsterdam)
mccabe_translatio...

14:20 **Mass planes and couplings chosen for comparisons** *20'*
Speaker: Felix Kahlhoefer (DESY)
DMWG_Kahlhoefer...

14:40 **Discussion** *30'*

What can be shown on "mass-mass" plane

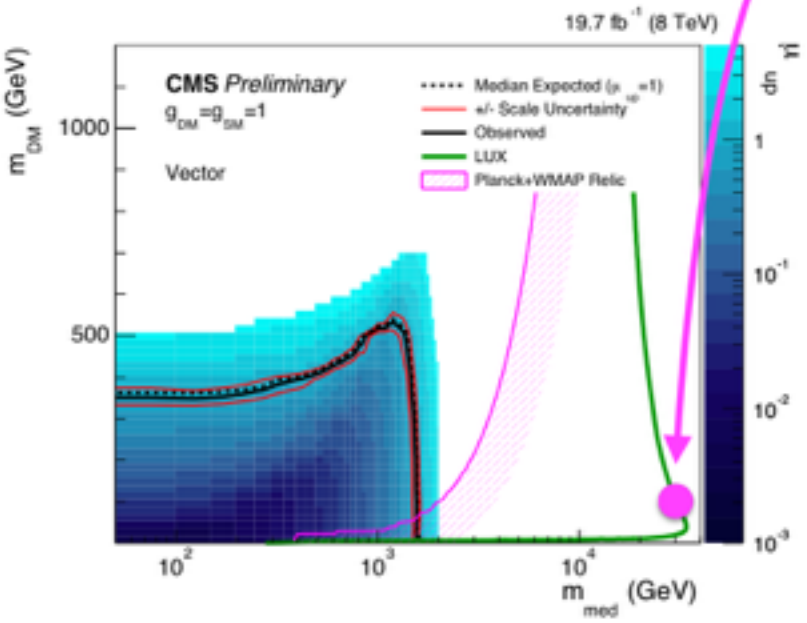


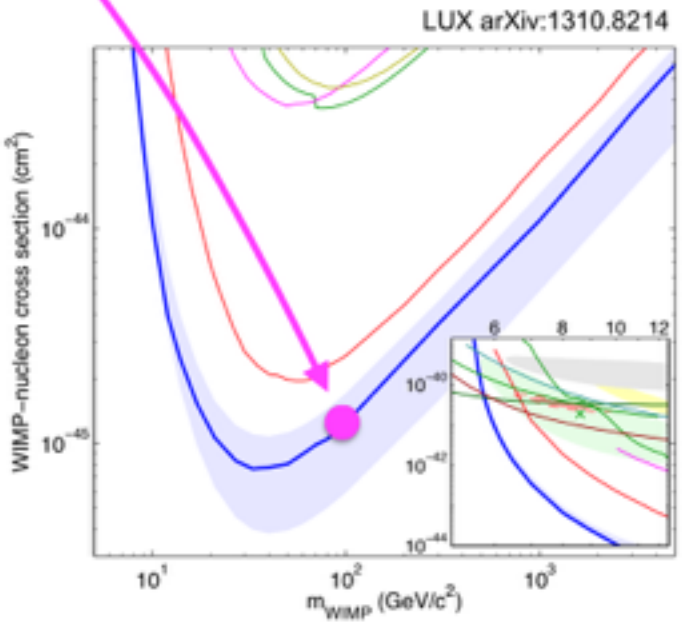
Red (solid line): Relic density
Green (dashed line): Monojets
Orange (dotted line): Direct detection
Blue (dot-dashed line): Dijets
Grey (solid line): Perturbativity

How to translate between planes

$$\sigma^0 = \frac{f^2(g_{\rm SM})g_{\rm DM}^2}{\pi}\frac{\mu_{n\chi}^2}{M_{\rm med}^4}$$

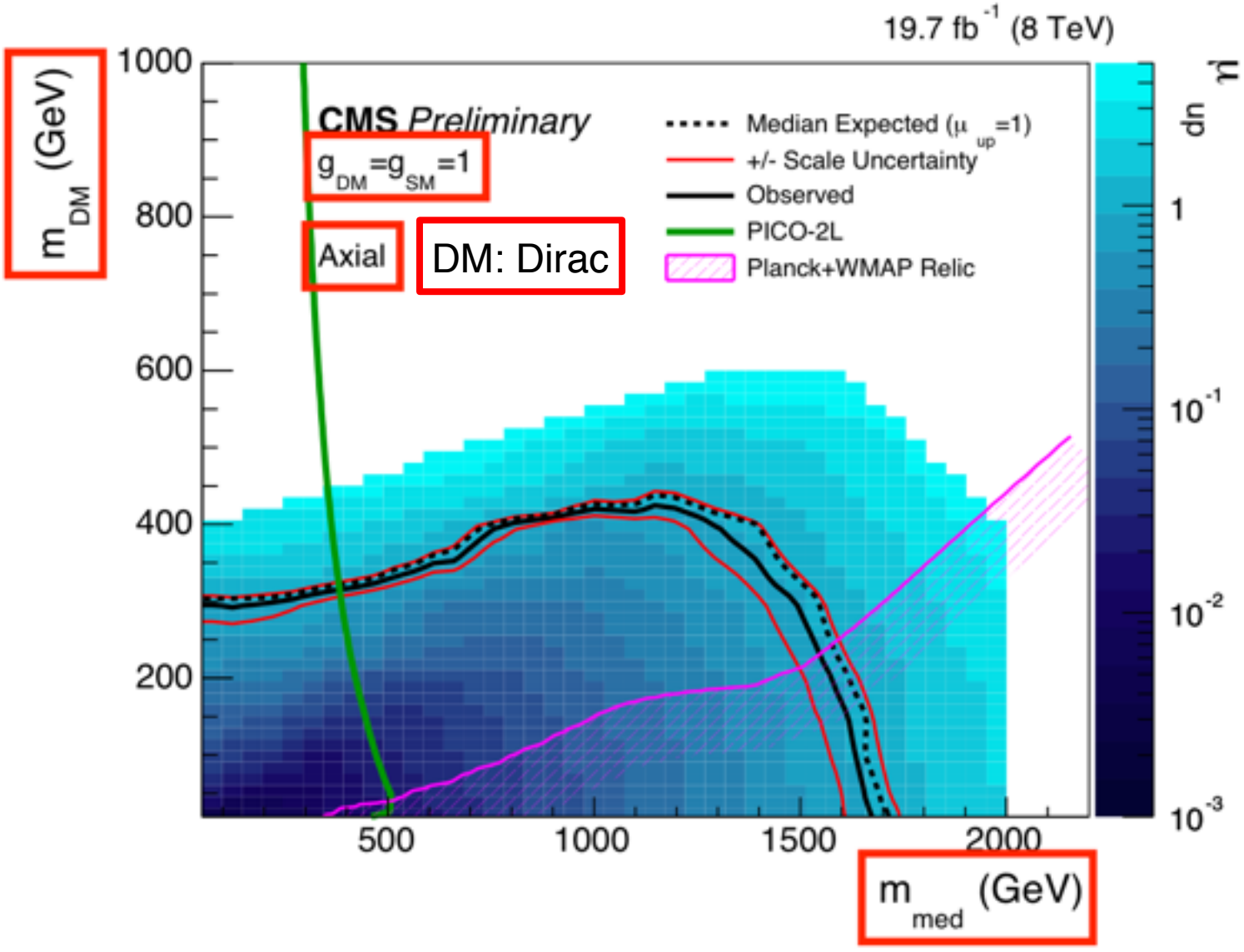
$$M_{\rm med} = \left(\frac{f^2(g_{\rm SM})g_{\rm DM}^2}{\pi}\frac{\mu_{n\chi}^2}{\sigma^0}\right)^{1/4}$$





Detailed instruction on how to translate between these planes are provided
In an informal write-up attached to the agenda entry [it's a first draft]

Assumption must be clearly stated!



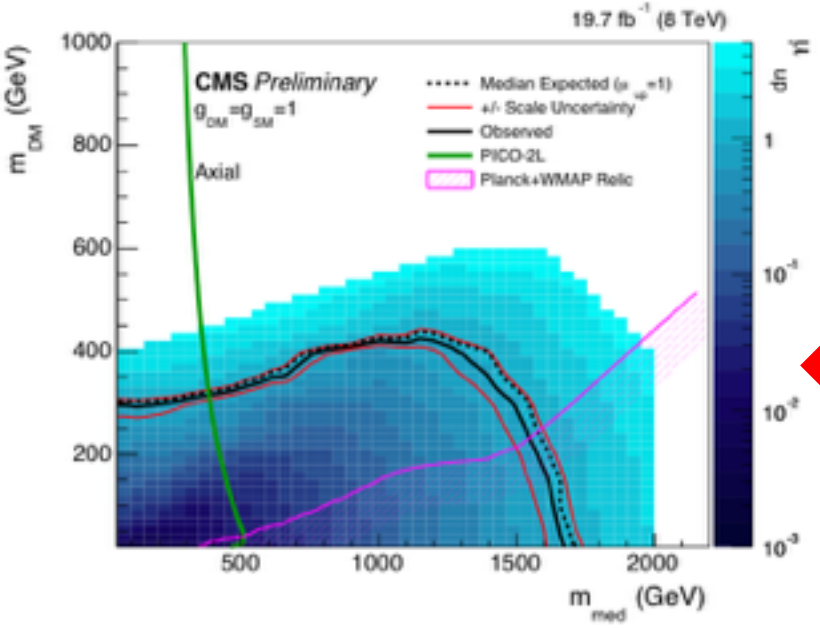
Summary (so far)

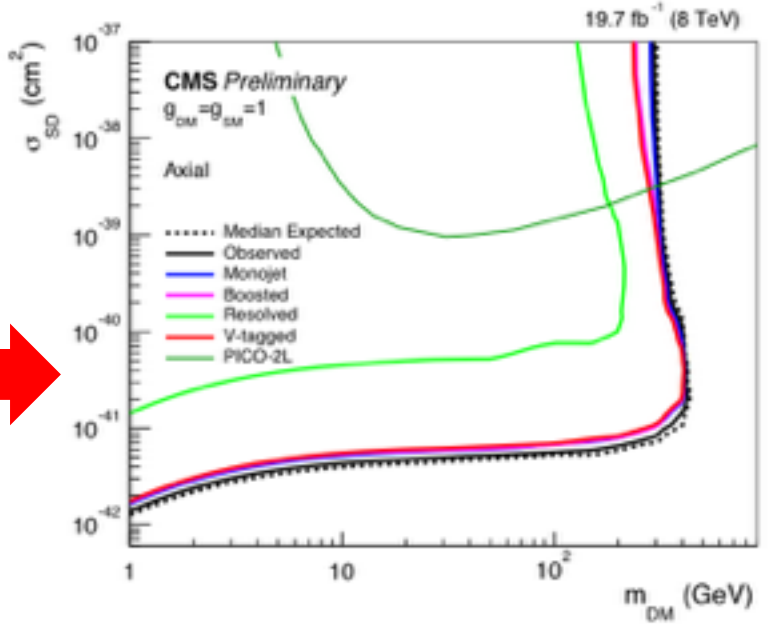
- Mass-mass plot (M_{med}-M_{DM}) is a good plane to show collider limits.
- Allows for multiple complementary collider limits to be displayed simultaneously e.g. mono-jet, di-jet.
- All assumptions should be clearly stated on the plots: coupling choices, mediator and dark matter type
- Displaying both the signal strength and the limit lines is useful.

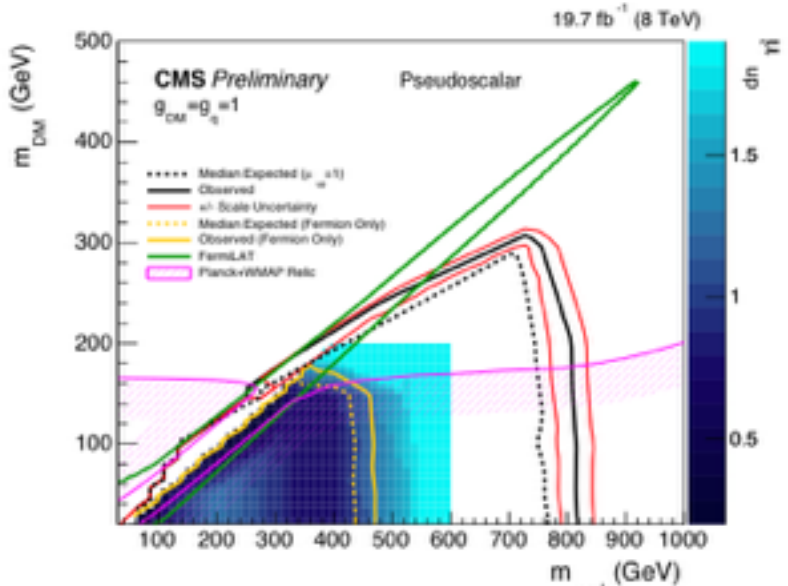
Choices of couplings shown

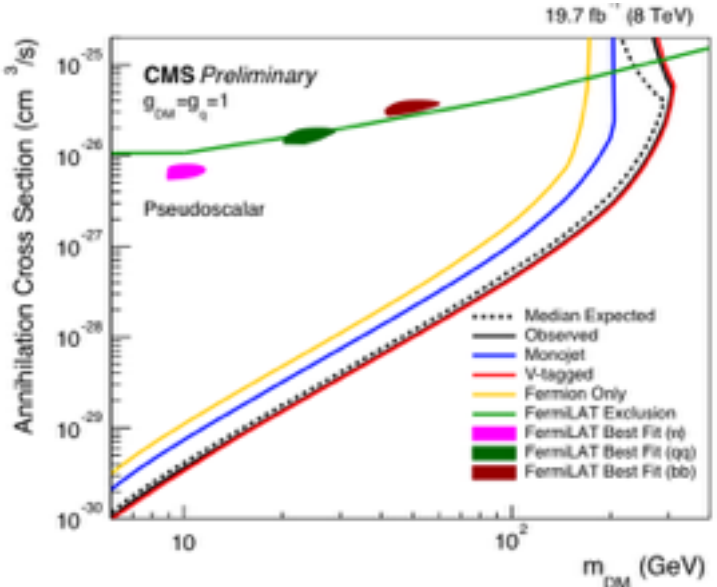
- Fixed couplings:
  - vector/axial: gq=0.25, gDM=1
    - gu = gd vs gu = -gd
      - monojet open point: phase space differences
      - validity of monoV gu = -gd: needs interaction with theorists
  - scalar/pseudoscalar: gq=1, gDM=1
- Sufficient? How to allow reinterpretation for other couplings?
  - scaling laws (at the theorist's risk)
  - sufficient information for redoing the analysis (e.g. MadAnalysis) given a different signal - see DMF appendix and collaboration policies on presentation of results

How to compare?

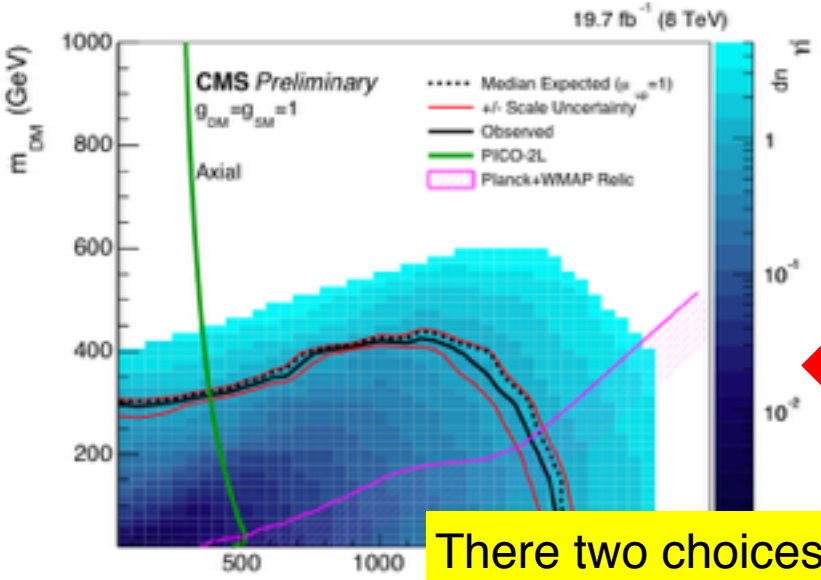


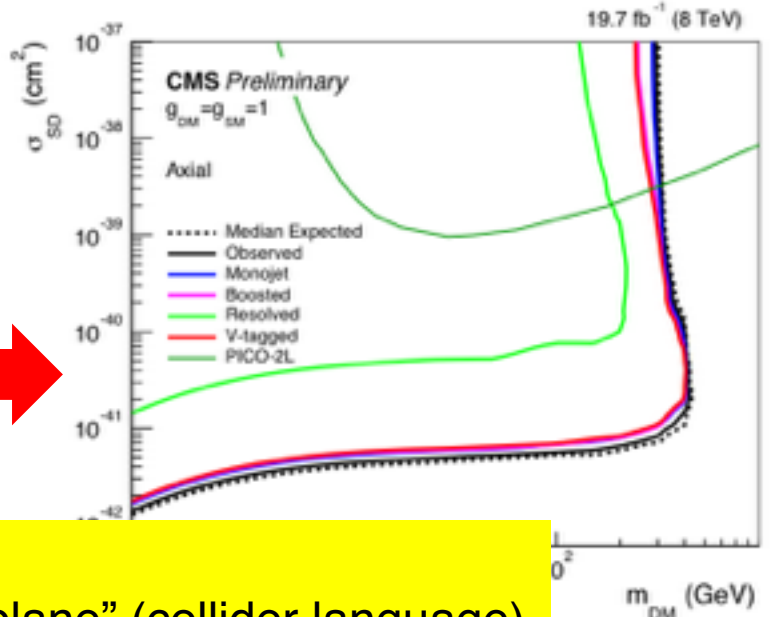






How to compare?

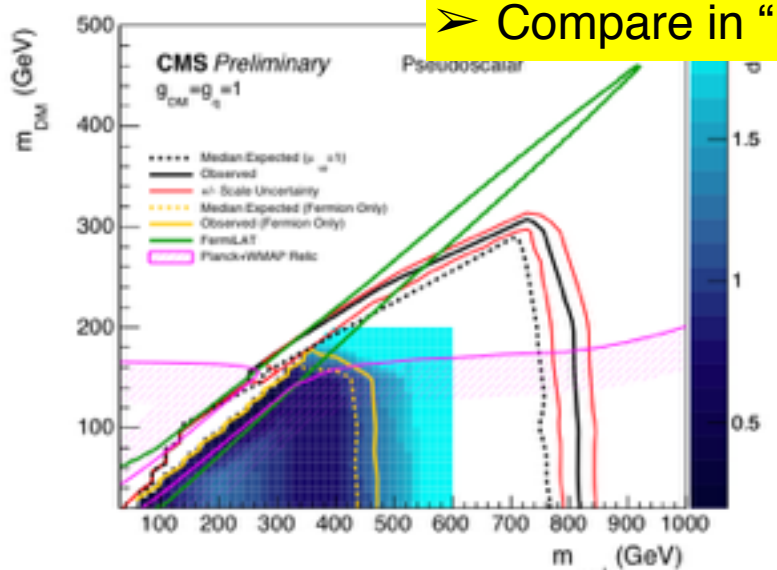


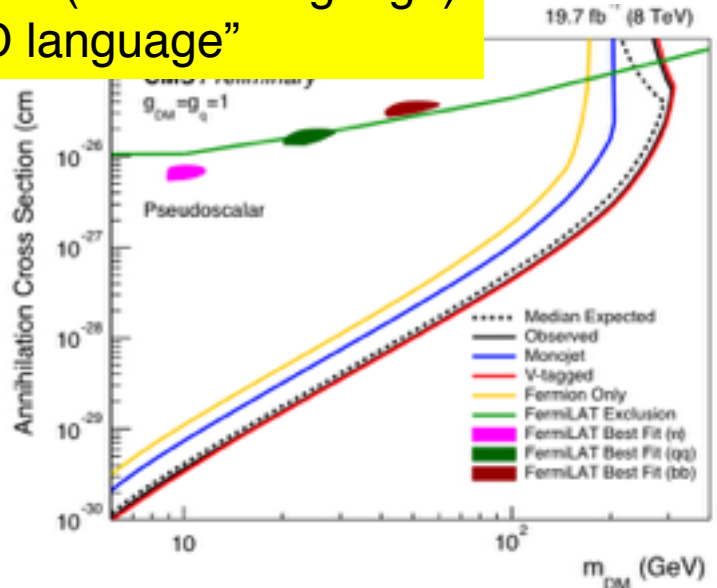


There two choices:

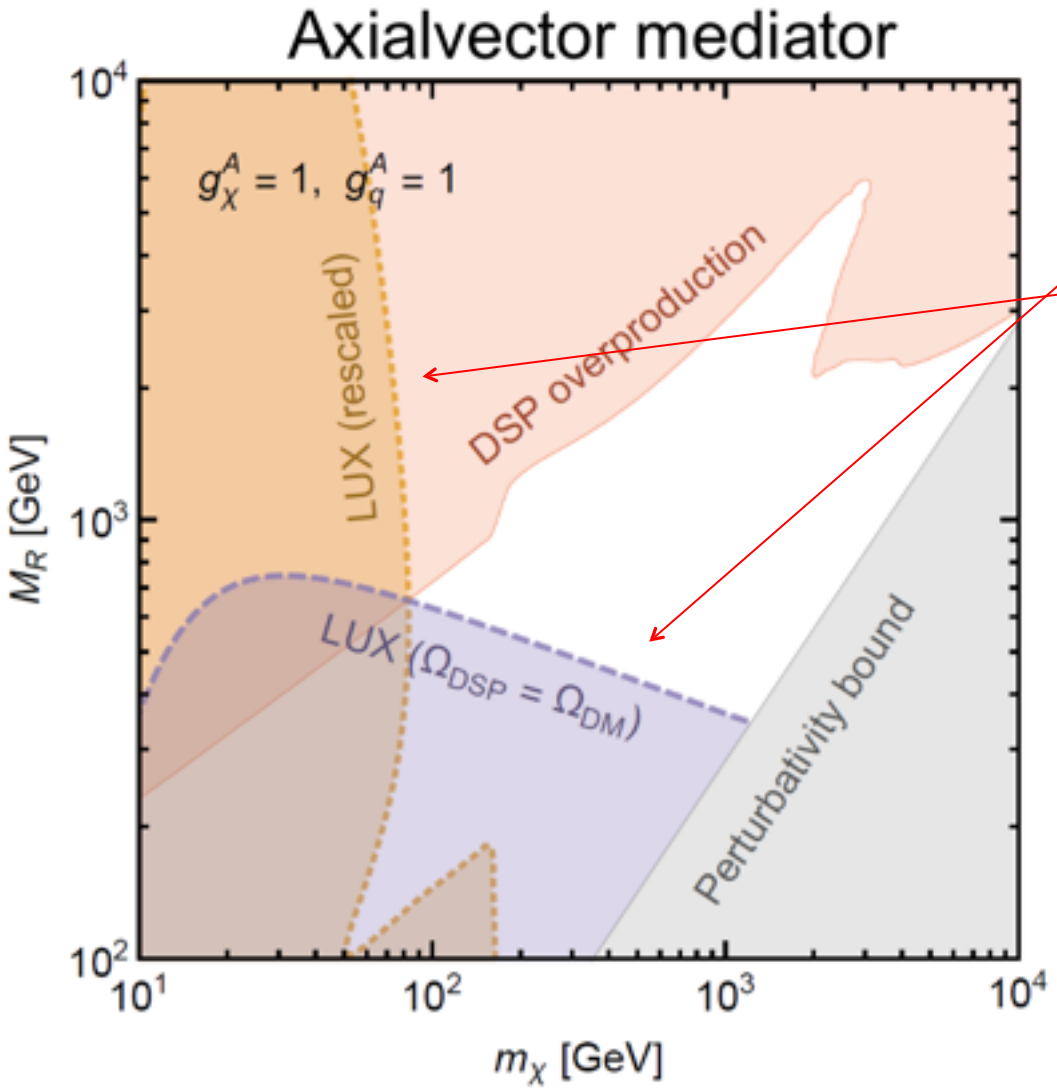
➢ Compare in “mass plane” (collider language)

➢ Compare in “DD and ID language”





How to deal with relic density constraint?



Two options:

- "out of the box"
- rescaled

Recommendation proposal

- Show only the LHC limits and relic density line in the mass-mass plots.
  - Show perturbativity line as well
- Do not translate direct detection or indirect detection onto the mass-mass plot.
- Show the comparison with direct detection and indirect detection in their planes (cross-section — mass/cross-section — velocity) only.
  - Couple to all quarks (MFV)

Advantages

- Can show collider limits at 95% in the mass-mass plots without worrying about consistency with direct detection, which show 90% limits.
- Keeps the presentation of collider results clear so that the interpretation is transparent - plots will not be overcrowded with too many lines
- There is no issue with the consistency of showing the relic density line and scaled/re-scaled for the relic density of direct/indirect detection limits on the mass-mass plane
- When mapping collider limits onto direct/indirect detection planes, assume that the particle saturates the relic density for both direct/ indirect and LHC limits. Don't show a relic density line so there should be no contradiction.

Open points

- Enforcement of relic density for colliders (like DD) or just stating assumptions?
- DD/ID planes (nucleon-DM xsec vs mDM, annihilation xsec* velocity vs mDM)
  - How to convey model uncertainties (coupling choices, caveats…) in extrapolations? Is ‘clearly stating assumptions’ sufficient?

Practical points: how to implement

- Mass-mass plane:
  - Trivial to obtain search results in terms of signal strength
  - Granularity of scan and interpolation between points: how to?
  - Relic density curves can be calculated centrally
- Collider to non-collider planes
  - Formulas can be provided on DMWG SVN for translation of results

Thanks to those who contributed to the preliminary discussions

- In particular, Felix Kahlhoefer and Chris McCabe
- ATLAS: Priscilla Pani, Marie-Helene Genest
- CMS: Sarah Malik, Steve Mrenna, Phil Harris
- Theory: Liantao Wang, Tim Tait, Valya Khoze, Matt McCullough, Toni Riotto, Francesco D'Eramo, Kathryn Zurek

Backhup

INTRODUCTION TO PROPOSAL PRESENTED ON 10/12/2015

New LHC Dark Matter Working Group

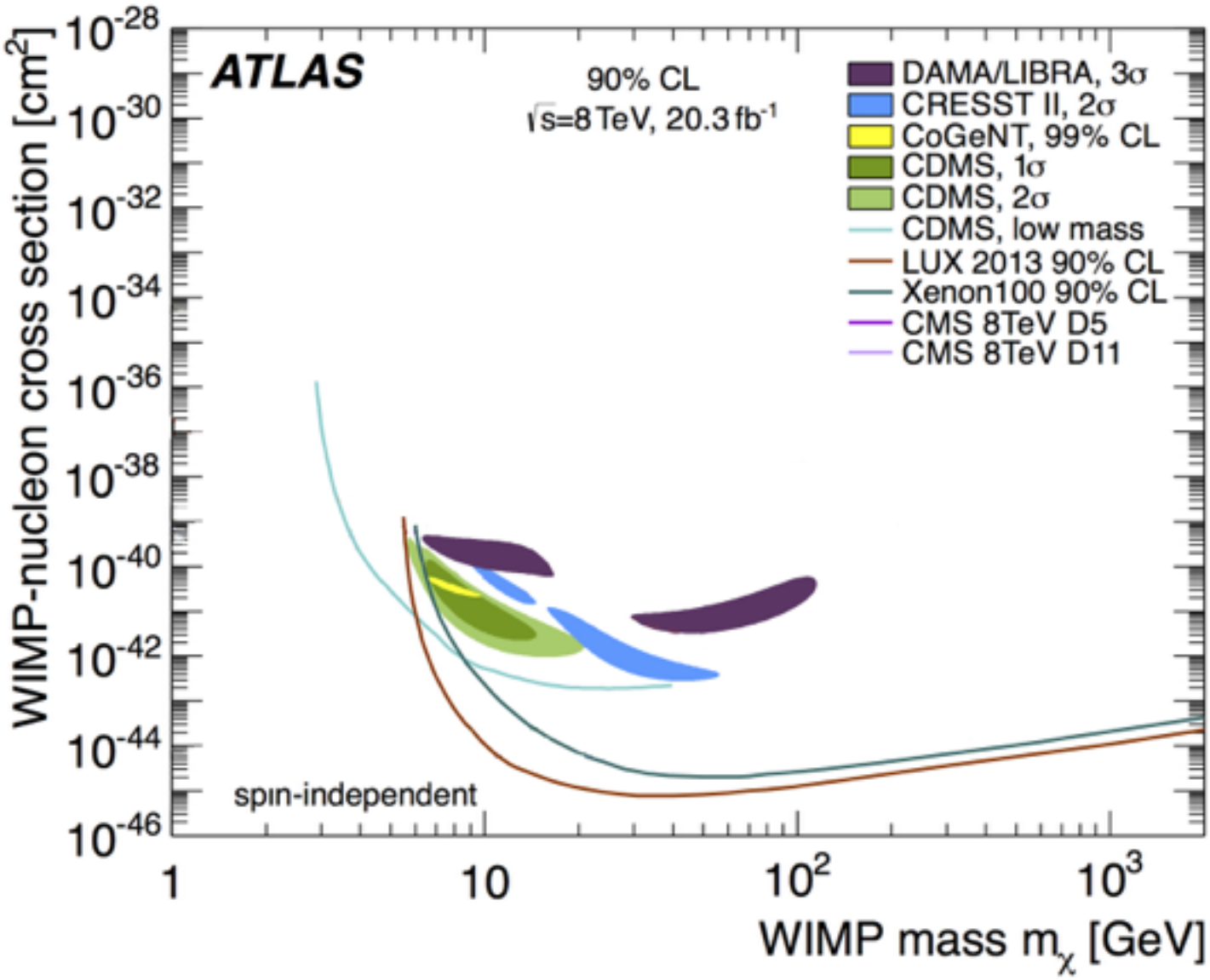
This Working Group brings together theorists and experimentalists to define guidelines and recommendations for the benchmark models, interpretation, and characterisation necessary for broad and systematic searches for dark matter at the LHC. More details can be found at this page:

http://lpcc.web.cern.ch/LPCC/index.php?page=dm_wg

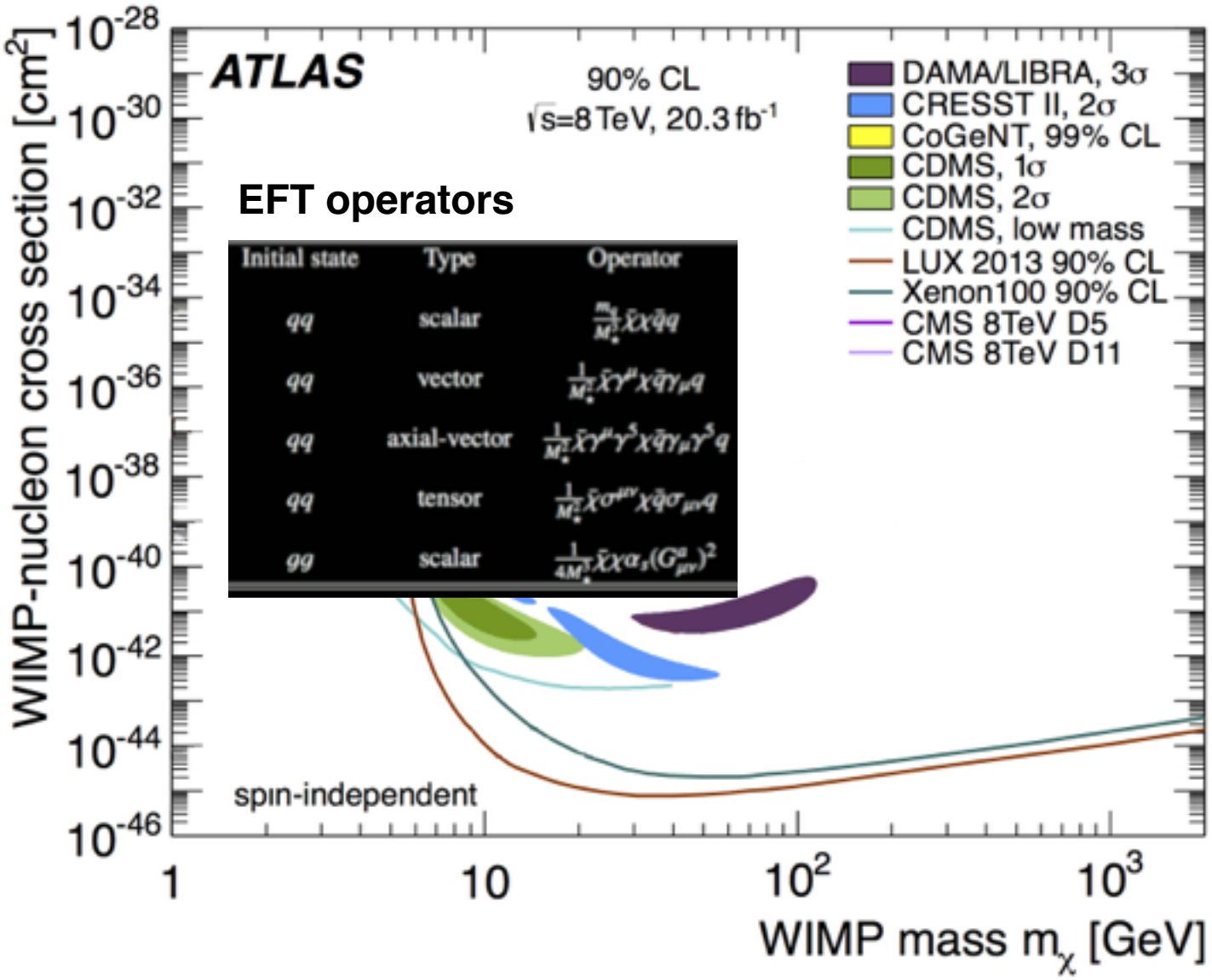
and the mailing list (which now also includes the lhc-dmf@cern.ch mailing list recipients) is lhc-dmwg@cern.ch.

Our first goal is to discuss and agree upon the presentation of collider searches for DM between ATLAS and CMS. Both LHC experiment and theory community will collaborate, in order to decide upon the best format for comparison between collider and non-collider results and on the usability of the material that is made public for the Winter conferences 2016.

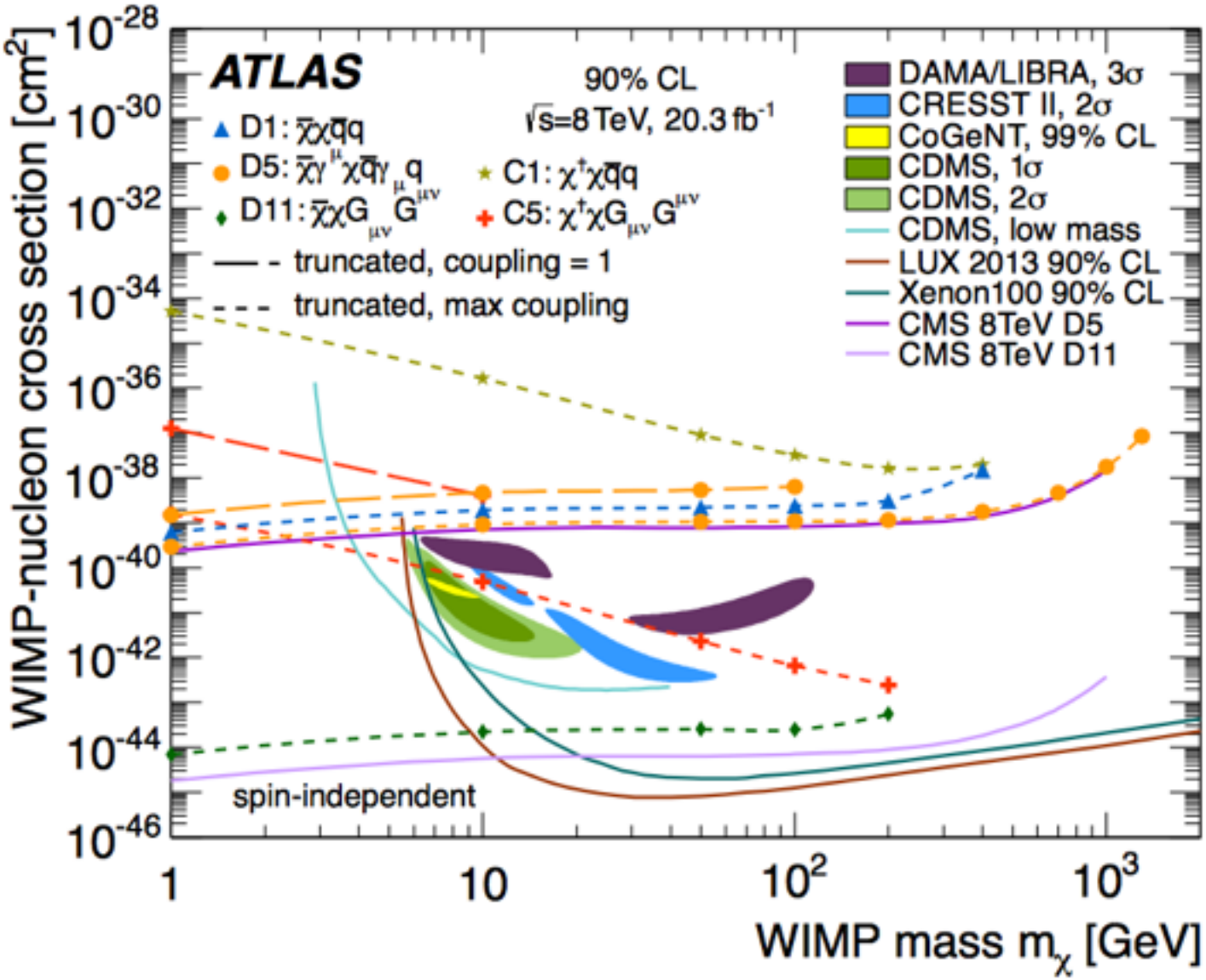
Comparison with Direct Detection: EFT



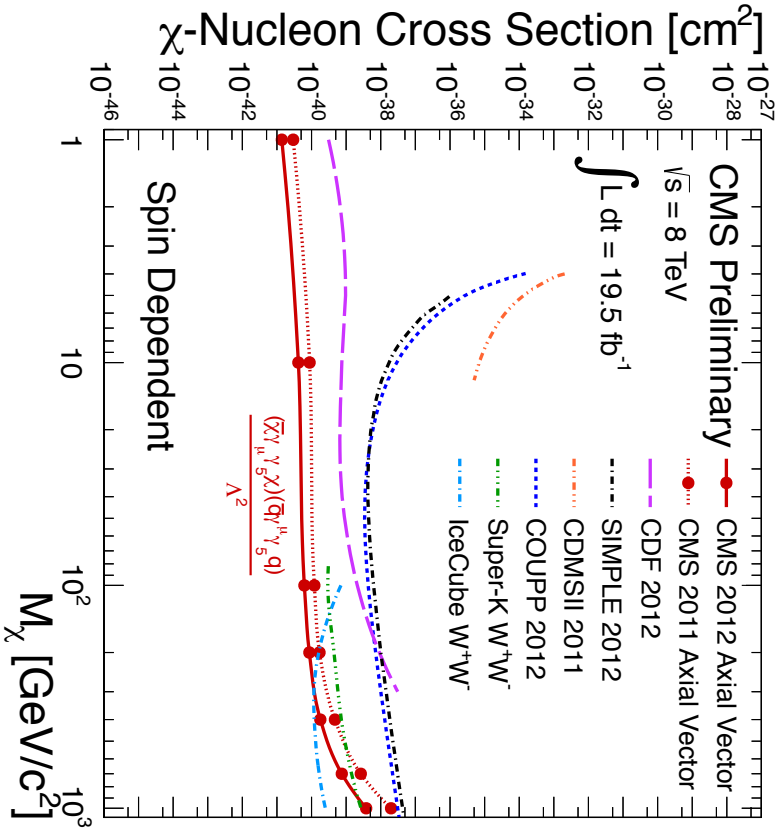
Comparison with Direct Detection: EFT

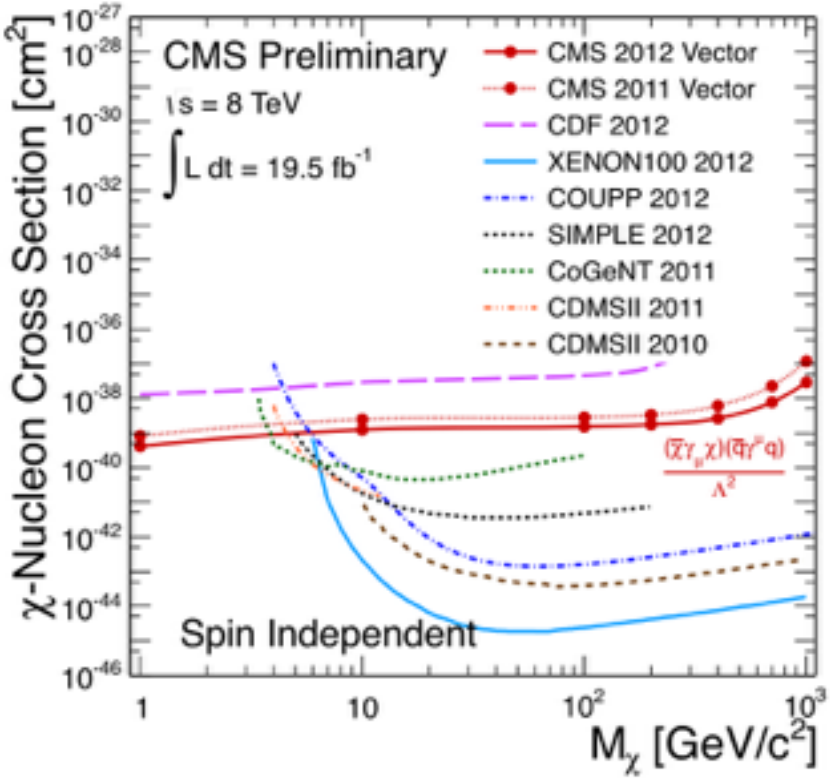


Comparison with Direct Detection: EFT



Comparison with Direct Detection: EFT





Beyond the Effective Field Theory

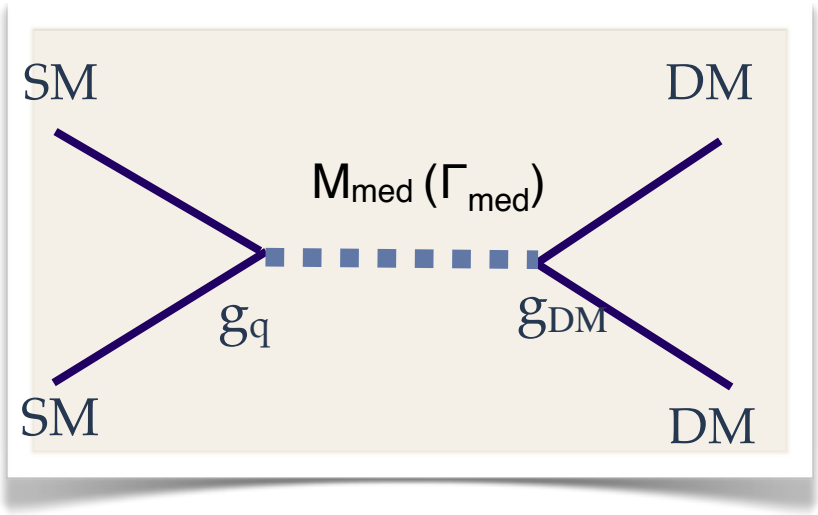
- The interpretation of collider DM searches in the EFT framework and the corresponding comparison with other experiments such as DD and ID has become in question. [see e.g.]

- Y. Bai, P. J. Fox, and R. Harnik, The Tevatron at the Frontier of Dark Matter Direct Detection, JHEP 1012 (2010) 048, [arXiv:1005.3797].
- P. J. Fox, R. Harnik, J. Kopp, and Y. Tsai, Missing Energy Signatures of Dark Matter at the LHC, Phys.Rev. D85 (2012) 056011, [arXiv: 1109.4398].
- J. Goodman and W. Shepherd, LHC Bounds on UV-Complete Models of Dark Matter, arXiv:1111.2359.
- I. M. Shoemaker and L. Vecchi, Unitarity and Monojet Bounds on Models for DAMA, CoGeNT, and CRESST-II, Phys.Rev. D86 (2012) 015023, [arXiv:1112.5457].
- O. Buchmueller, M. J. Dolan, and C. McCabe, Beyond Effective Field Theory for Dark Matter Searches at the LHC, JHEP 1401 (2014) 025, [arXiv:1308.6799].
- G. Busoni, A. De Simone, E. Morgante, and A. Riotto, On the Validity of the Effective Field Theory for Dark Matter Searches at the LHC, Phys.Lett. B728 (2014) 412–421, [arXiv:1307.2253].
- G. Busoni, A. De Simone, J. Gramling, E. Morgante, and A. Riotto, On the Validity of the Effective Field Theory for Dark Matter Searches at the LHC, Part II: Complete Analysis for the s-channel, JCAP 1406 (2014) 060, [arXiv:1402.1275].
- G. Busoni, A. De Simone, T. Jacques, E. Morgante, and A. Riotto, On the Validity of the Effective Field Theory for Dark Matter Searches at the LHC Part III: Analysis for the t-channel, JCAP 1409 (2014) 022, [arXiv:1405.3101].

- The collider community has decided to complement the EFT framework with simplified models to overcome these issues and to facilitate a more comprehensive interpretation (and comparison) of collider DM searches.

Simplified Dark Matter Models

See also DM forum report which brought together experimentalist from ATLAS and CMS as well as theorists. See: arXiv:1507.00966



s-channel

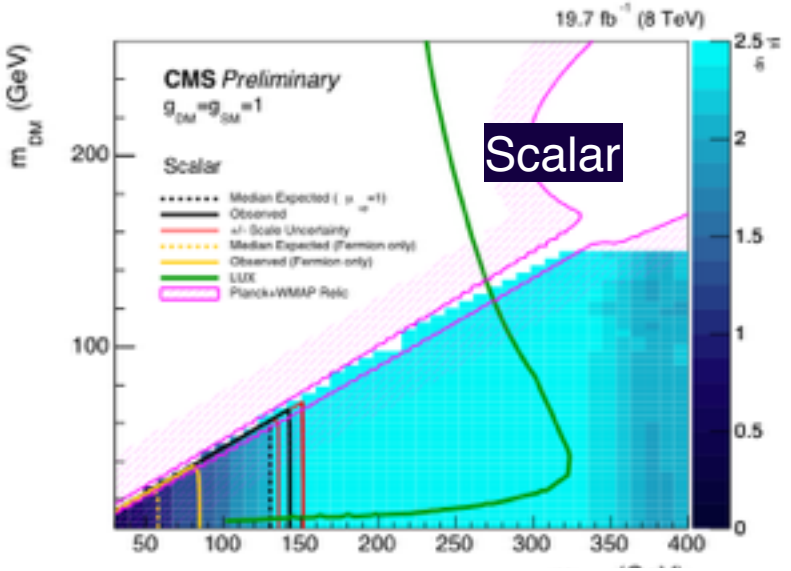
Define simplified model with (minimum) 4 parameters	
Mediator mass (M_{med})	DM mass (M_{DM})
g_q	g_{DM}

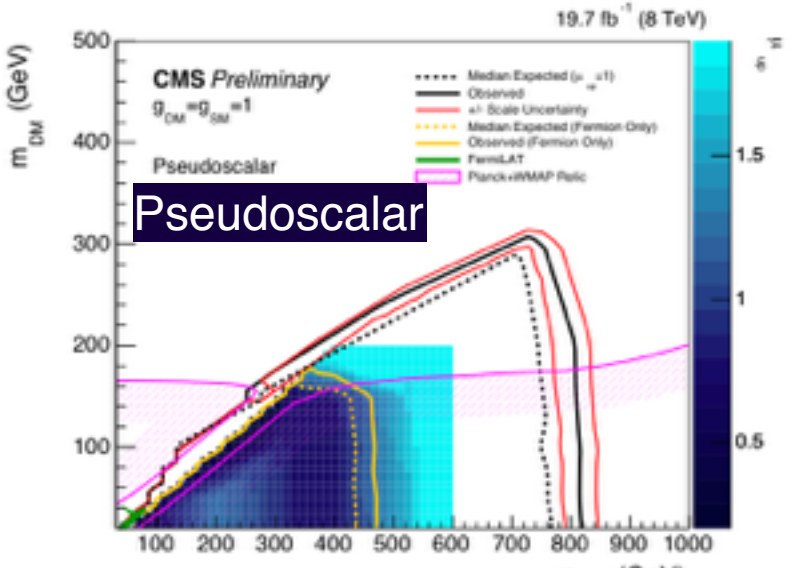
DM	
Dirac fermion	Scalar - real
Majorana fermion	Scalar - complex

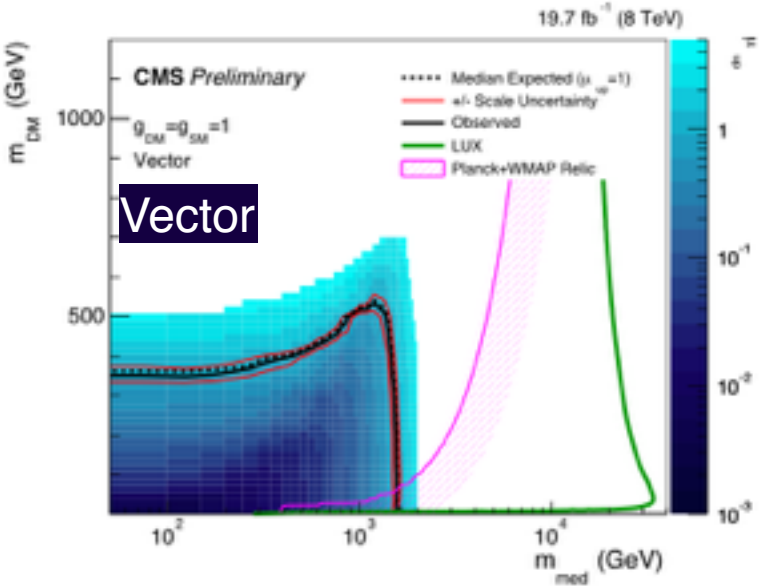
Consider comprehensive set of diagrams for mediator	
Vector	Axial-vector
Scalar	Pseudoscalar

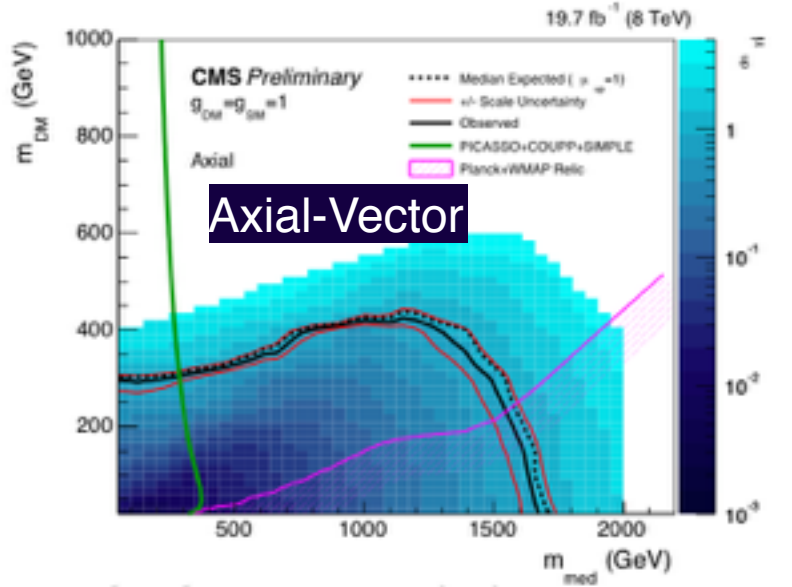
(Γ_{med} can also be free as long As $\Gamma_{med} < M_{med}$)

Recent released CMS "mono-jet" result 8 TeV



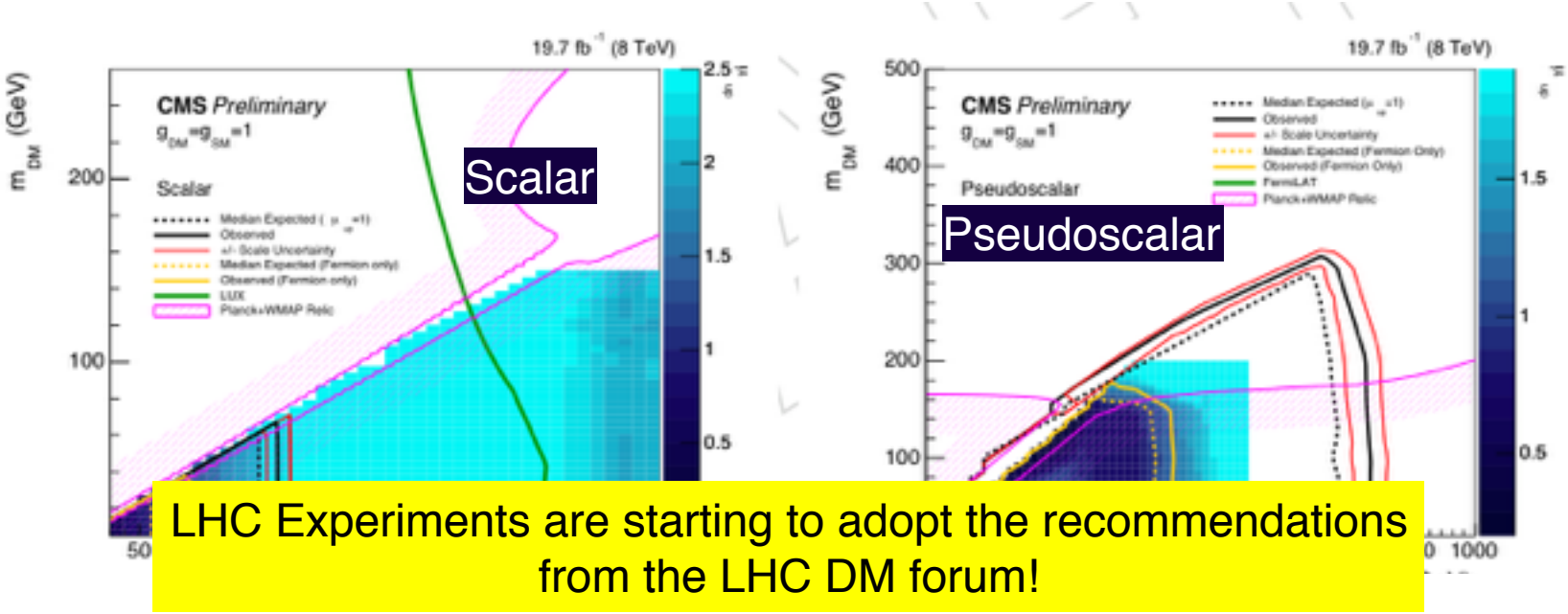




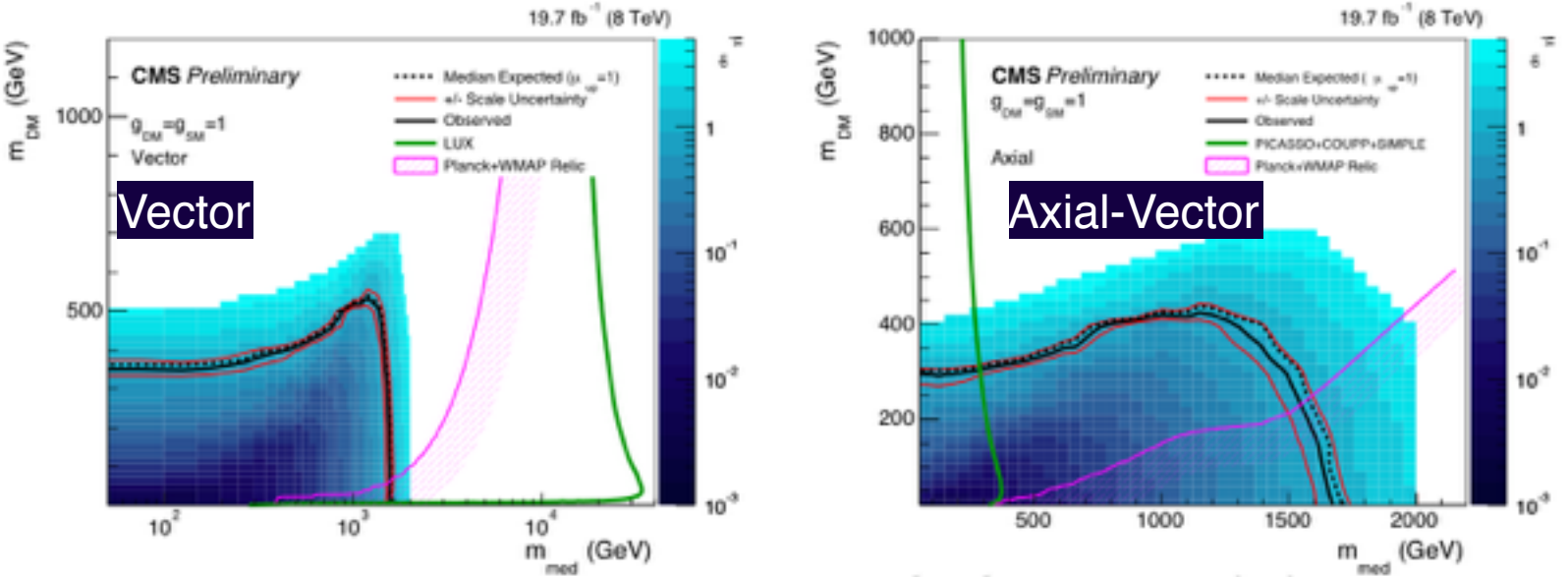


CMS PAS-EXO-12-055

Recent released CMS "mono-jet" result 8 TeV



LHC Experiments are starting to adopt the recommendations from the LHC DM forum!



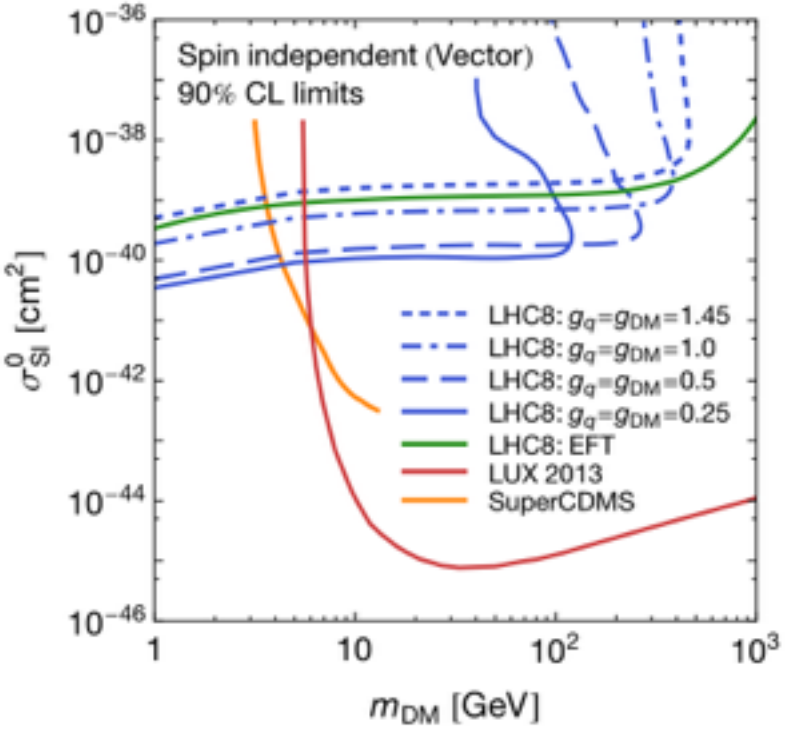
CMS PAS-EXO-12-055

Comparison of collider with DD and ID

"Direct translation of M_{med}-M_{DM} collider limits into $\sigma_{SI/SD}$ planes

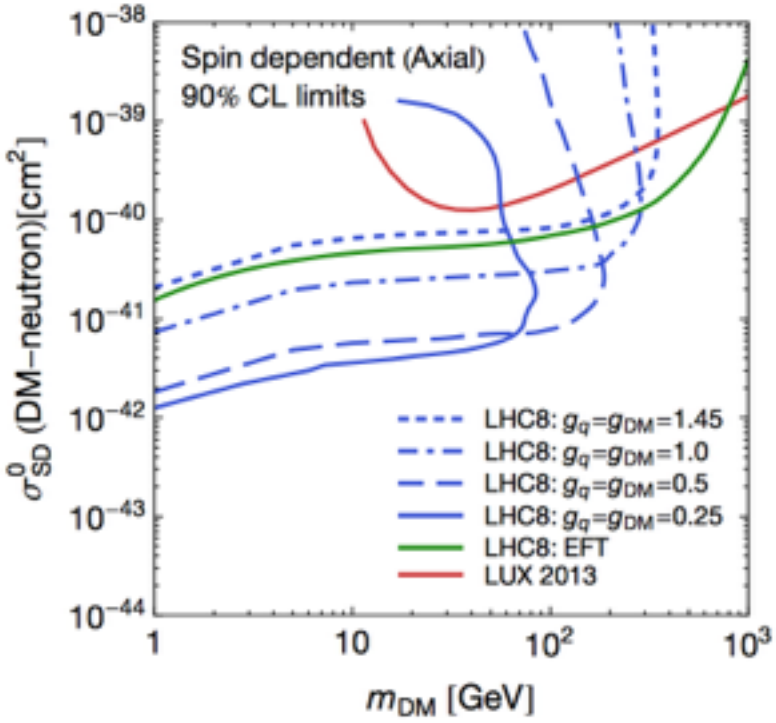
arXiv:1407.8257

arXiv:1409.4075



$$\sigma^0_{\rm SI} = \frac{9\, g^2_{\rm DM}\, g^2_q\, \mu^2_{n\chi}}{\pi M^4_{\rm med}}$$

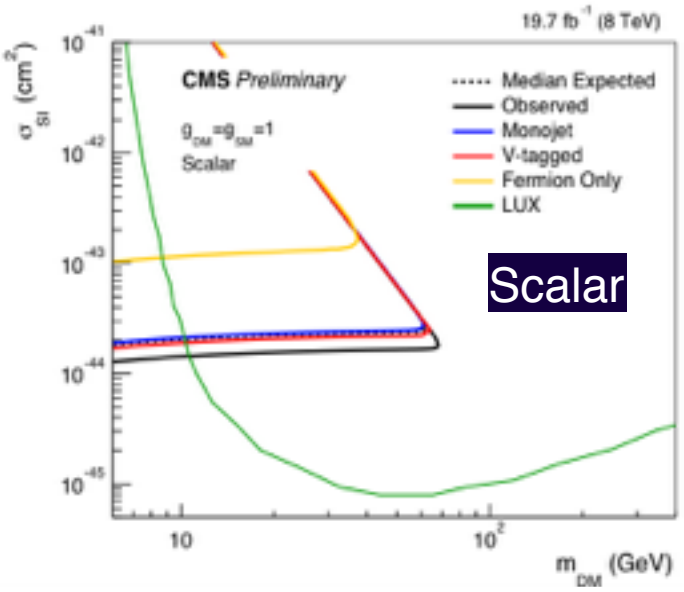
$$\approx 1.1 \times 10^{-39}\ {\rm cm}^2 \cdot \left(\frac{g_{\rm DM}\, g_q}{1}\right)^2 \left(\frac{1\ {\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

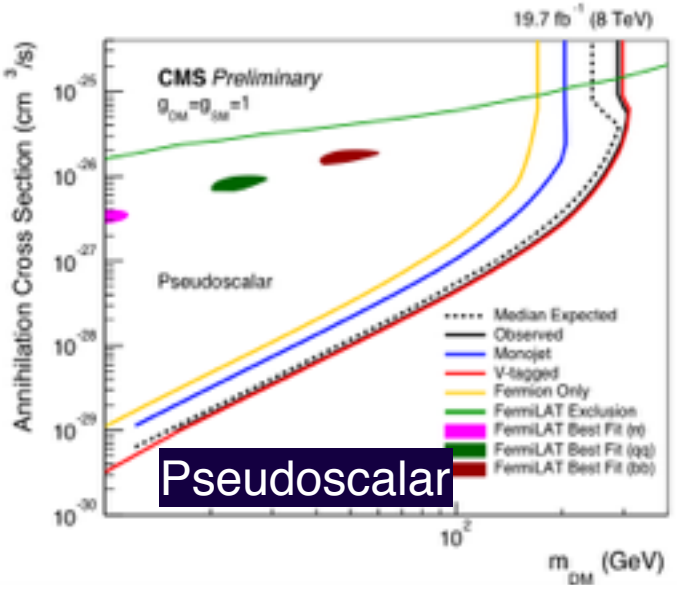


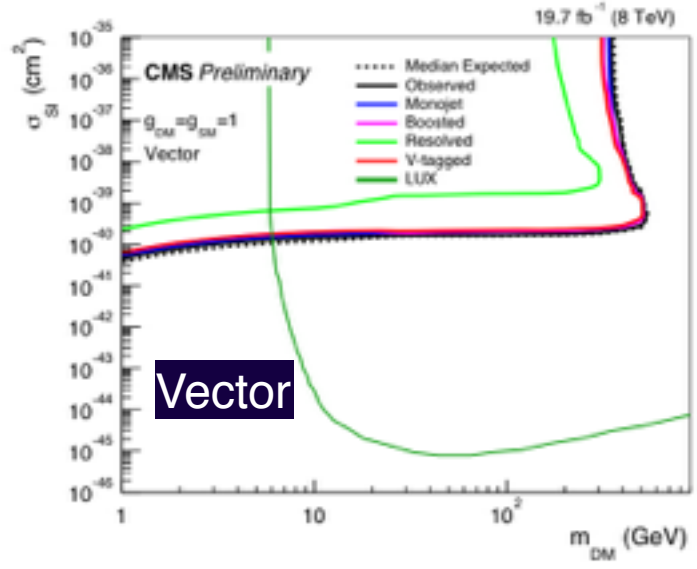
$$\sigma^0_{\rm SD} = \frac{3\, g^2_{\rm DM}\, g^2_q (\Delta_u + \Delta_d + \Delta_s)^2\, \mu^2_{n\chi}}{\pi M^4_{\rm med}}$$

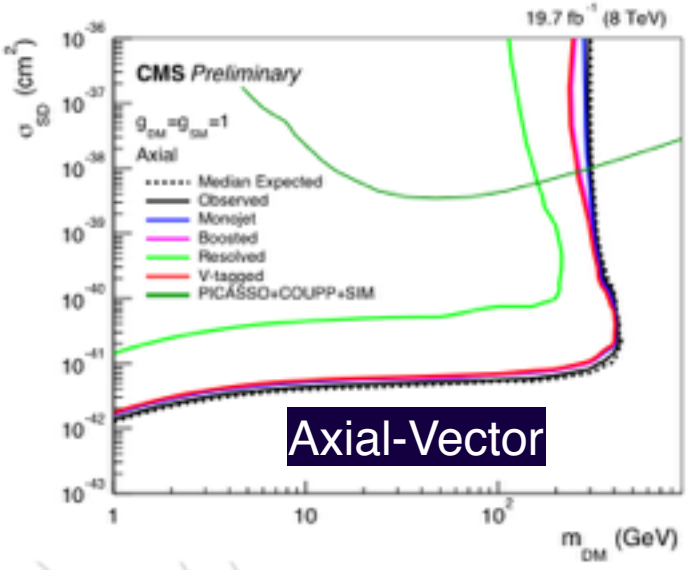
$$\approx 4.6 \times 10^{-41}\ {\rm cm}^2 \cdot \left(\frac{g_{\rm DM}\, g_q}{1}\right)^2 \left(\frac{1\ {\rm TeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

Comparison of collider with DD and ID (II)









CMS PAS-EXO-12-055

Further Details

- The next two talks by Chris McCabe and Felix Kahlhoefer will provide further details on the use of the limit mass plans and how these can be translated into the language of the DD and ID experiments (or vise versa).

- These talks will be followed by a 30 min discussion