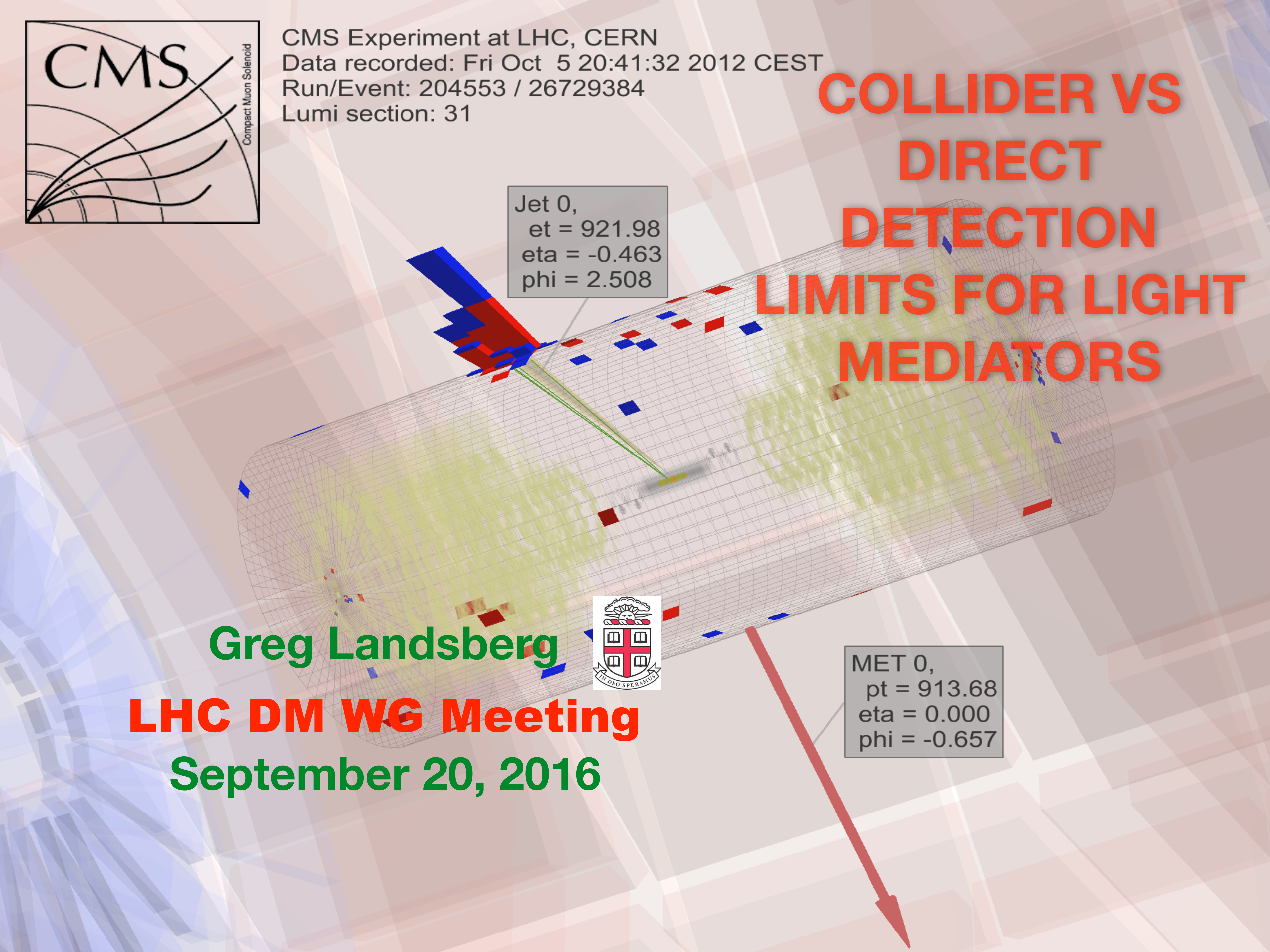


# COLLIDER VS DIRECT DETECTION LIMITS FOR LIGHT MEDIATORS

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**LHC DM WG Meeting**

**September 20, 2016**

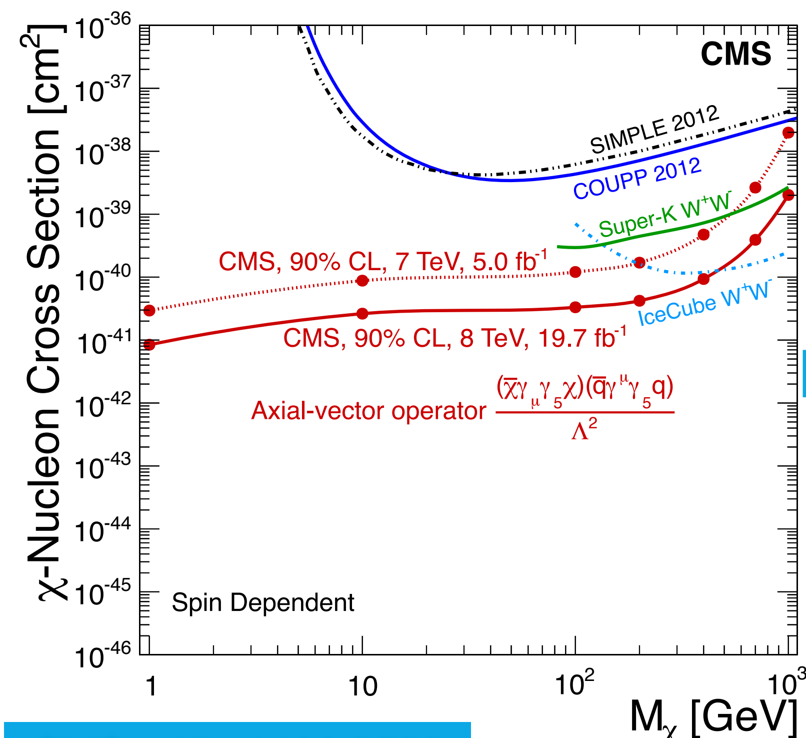
# Outline

- How "they" see "us"
- (Very) light mediator caveats
- Proposal for an improved way of presenting collider limits

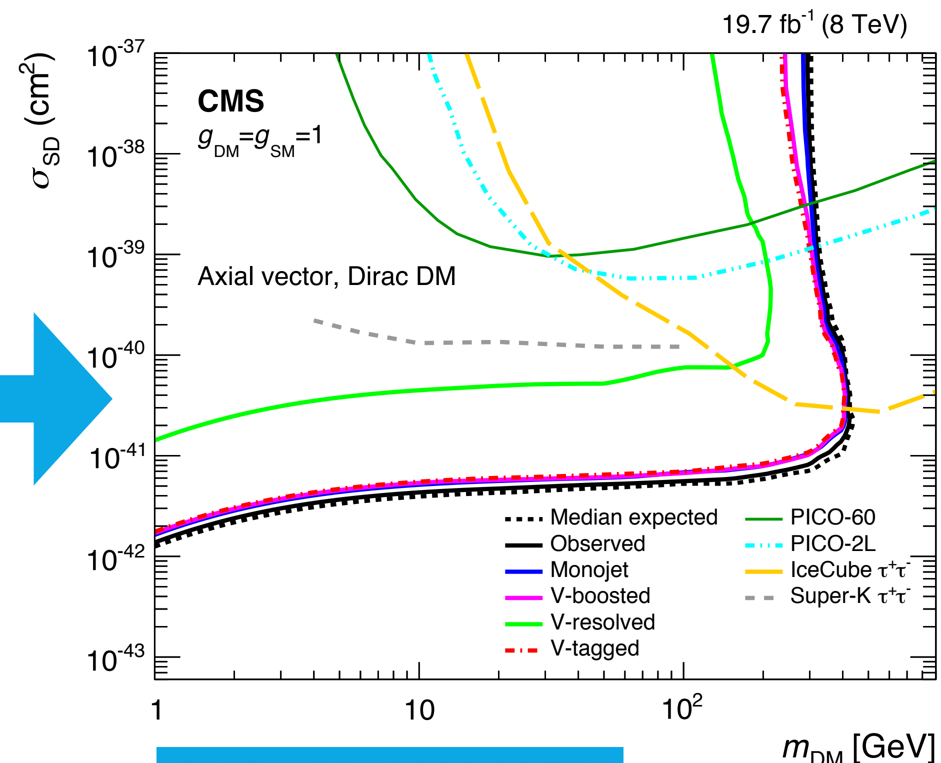
*) Based on a number of interactions with DD community members, and with thanks to Michele Papucci and Kathryn Zurek for useful discussions

# The Limit Evolution

- Switch from dominant EFT interpretation to SMDM interpretation in the past two years
  - More accurate comparison between the collider and DD limits
  - Emphasis on complementarity




CMS arXiv:1408.3583




CMS arXiv:1607.05764

# The Message Evolution

- What was the message implicitly given to the DD community?
- EFT Era:
  - DD folks are wasting their time with SD experiments - colliders already do much better and will do even better in the future up to ~1 TeV DM mass
    - Arrogant and actually incorrect
- Post-EFT Era:
  - Colliders win (in both SD and SI searches) at low DM masses (<5-10 GeV), while at larger DM masses there is nice complementarity between the DD and colliders
    - Moderate and somewhat correct
- Is this a fully correct message the DD community reads off our plot?
  - Not quite!
  - Caveat: the case of (very) light mediator

# Comparing the Sensitivity



- DD:

$$\sigma(\chi N \to \chi N) \sim \frac{g_q^2 g_\chi^2}{M^4} \mu_{\chi N}^2$$

  - Sensitivity increases dramatically as the mediator (M) gets lighter due to the kinematics of t-channel exchange
  - This is a *big deal* given strong limits on SUSY-like WIMPs - exploring light DM and light mediators is becoming more and more important
    - New ideas in DD community are being developed, e.g. semiconductor detectors exploring electron recoil to be sensitive to light (sub-GeV) DM

- Colliders:

$$\sigma_{1j} \sim \begin{cases} \alpha_s \, g_\chi^2 \, g_q^2 \, \frac{1}{p_T^2} & M \lesssim p_T \,, \\ \alpha_s \, g_\chi^2 \, g_q^2 \, \frac{p_T^2}{M^4} & M \gtrsim p_T \,, \end{cases}$$

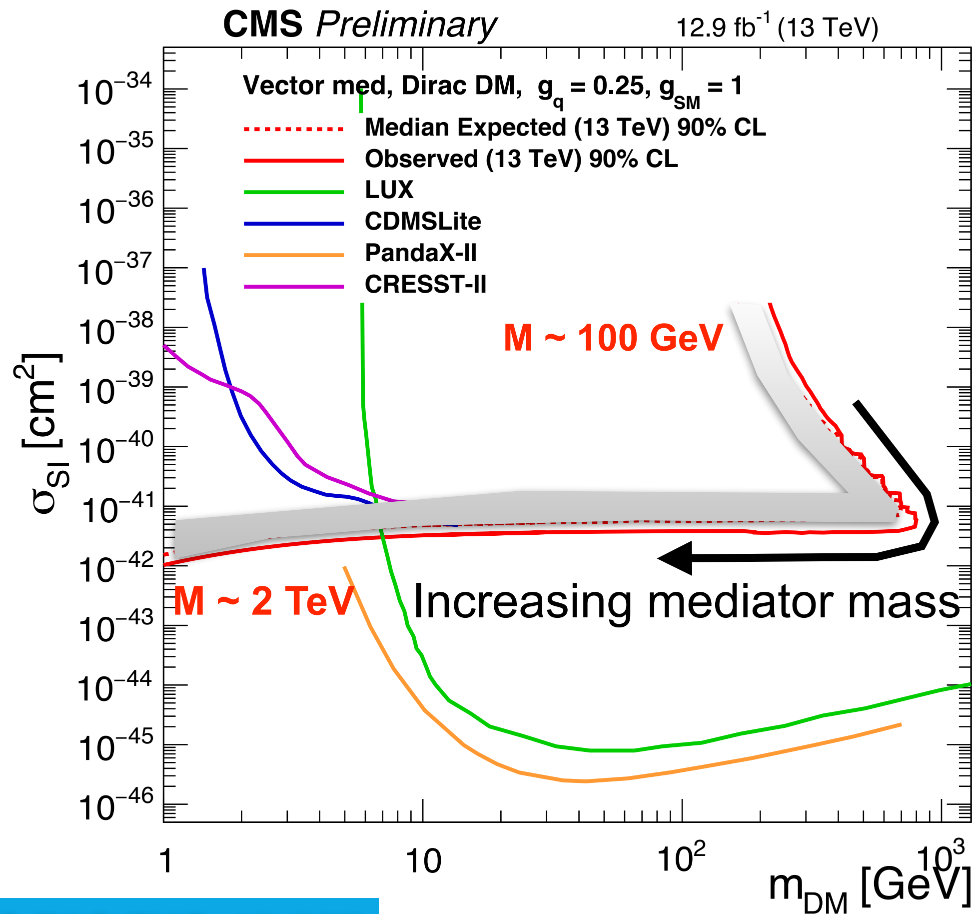
  - For light mediator ($M << ME_T$), cross section doesn't depend on the mediator mass
  - Clearly, at some point the DD wins over colliders - why don't we see this in the plots?

# The Plot Anatomy



- SI case:

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




**Why do we stop at M ~100 GeV?**

**Can we go lower?**

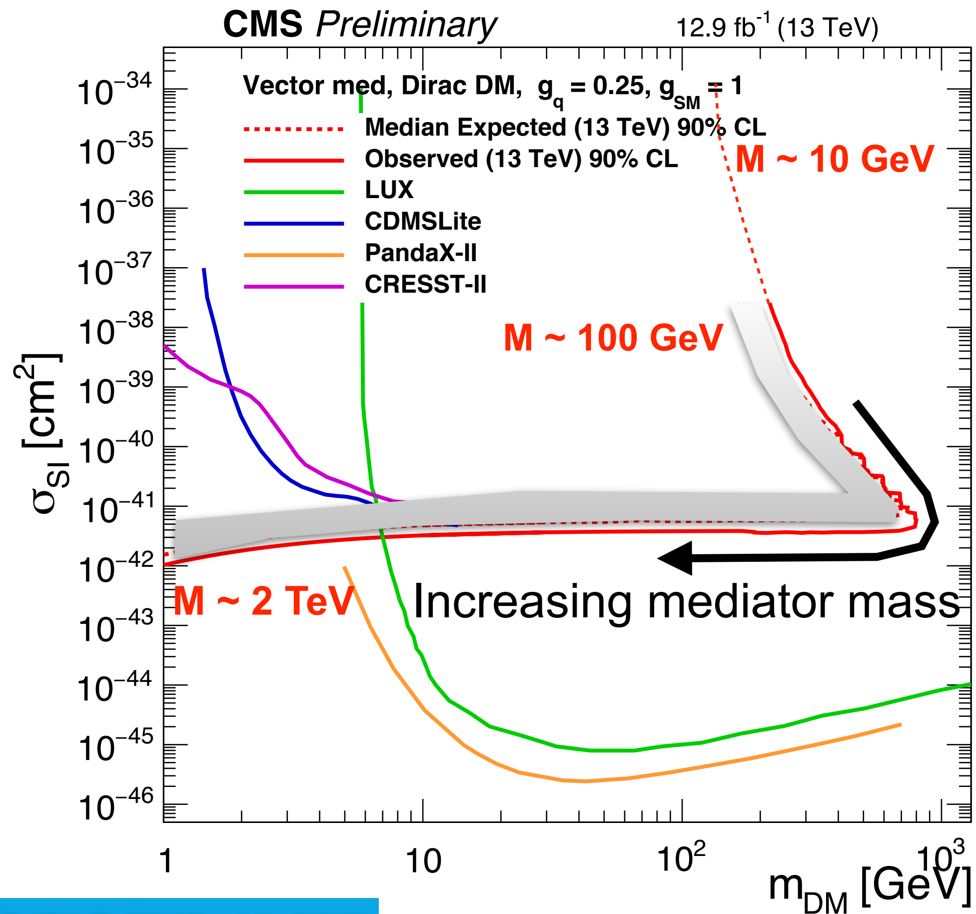
CMS PAS EXO-16-037

# The Plot Anatomy



## ✦ SI case:

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




**Why do we stop at M ~100 GeV?**

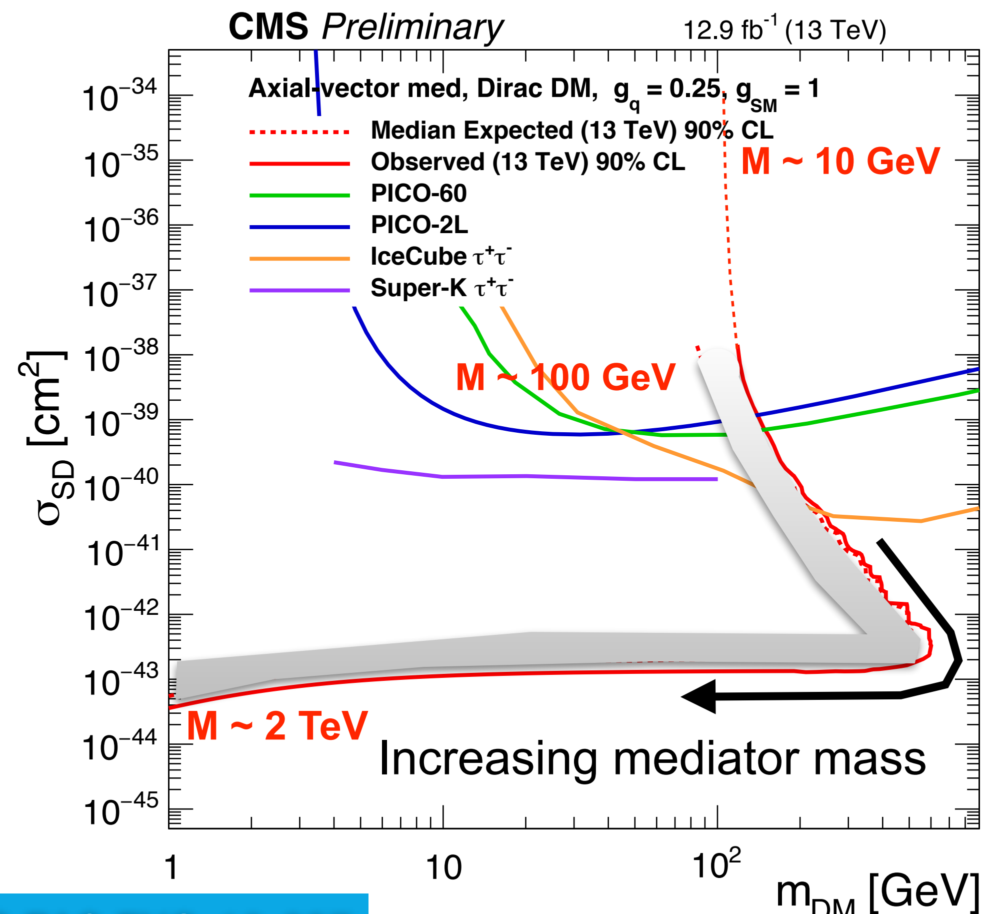
**Can we go lower?**

CMS PAS EXO-16-037

# The Plot Anatomy

- SD case:

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




CMS PAS EXO-16-037

# Where to Stop?

- There are a number of problems in lowering the mediator mass in the SMDM approach:
  - Moving in the fairly low-x regime at the LHC
    - M ~ 10 GeV => x ~ $10^{-2}$ for on-shell production
    - PDF and scale uncertainties become large, even if regulated by the minimum ISR $p_T$ requirement
  - For the vector mediator case need to account for the interference/mixing with Z boson and DY
    - The cross section for the latter becomes large <10 GeV
  - Need to account for various low-mass quarkonia resonances at least for the vector case below 10 GeV
  - Unitarity violation (see arXiv:1603.04156, Section 3.3.2)
    - DM Yukawa coupling becomes non-perturbative for $m < M\sqrt{\pi/2}$ (for $g_{DM}$ =1, see arXiv:1503.05916, 1510.02110)

# Other Considerations

- Going below M ~ 100 GeV requires proper accounting of other constraints in the SMDM framework:
  - Limits from Z boson decays with missing energy (should apply to vector, axial vector, and scalar mediators)
  - Limits from B-physics and other rare decays for mediator masses below ~10 GeV
- Perhaps, with some work and careful literature review one could go as low as ~10 GeV
  - Not clear we really benefit from this, as limitations of simplified models for such light mediator become quite severe and the results are not trustworthy without a complete model
- However, 100 GeV (110 GeV is currently used in CMS plots for EXO-16-037) appears to be a solid number at least for (axial)vector case, where limitations are minor
- For (pseudo)scalars exploring lighter M may be prudent (but then the contours for scalars are already closed, and for pseudoscalars DD limits vanish)

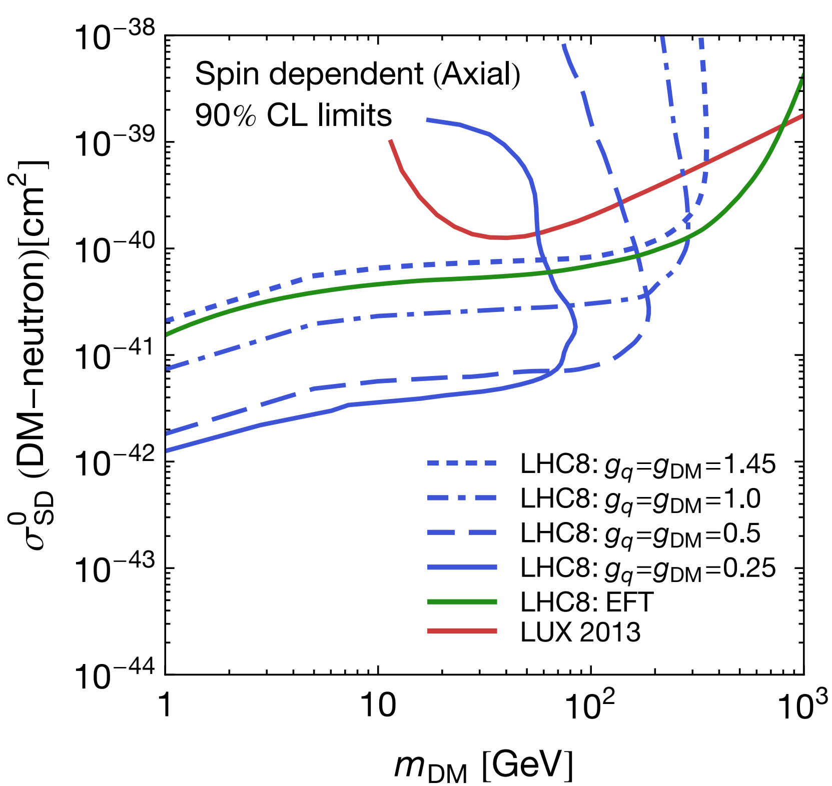
# Other Choice of Couplings

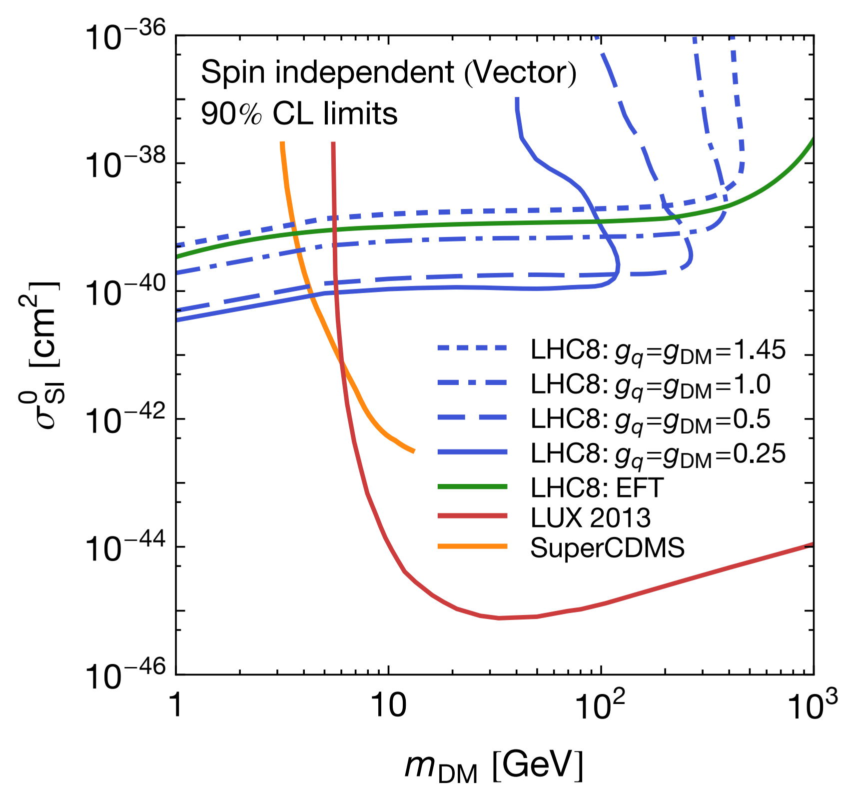




S. Malik et al., arXiv:1409.4075

- ✦ Note that the turnover of the curve for light mediators becomes even more dramatic as the couplings decrease



# Proposal

- Truncate all the collider curves on DD plots at M = 100 GeV
- Show this explicitly as a straight horizontal line, indicating that collider limits only apply to a closed area and further emphasizing an importance of DD experiments to cover the light mediator case
- Explicitly mention the minimum mediator mass for which the limits are applicable (and also truncate the M vs. m "collider style" plots at this mass)