Missing Energy Excess at the LHC Sign of Dark Matter, or other new physics?

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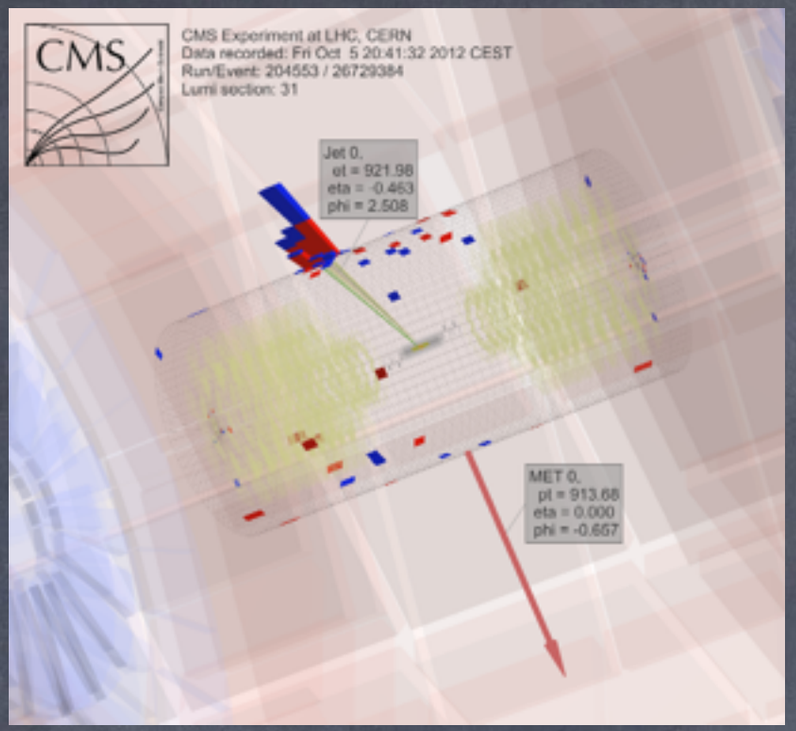
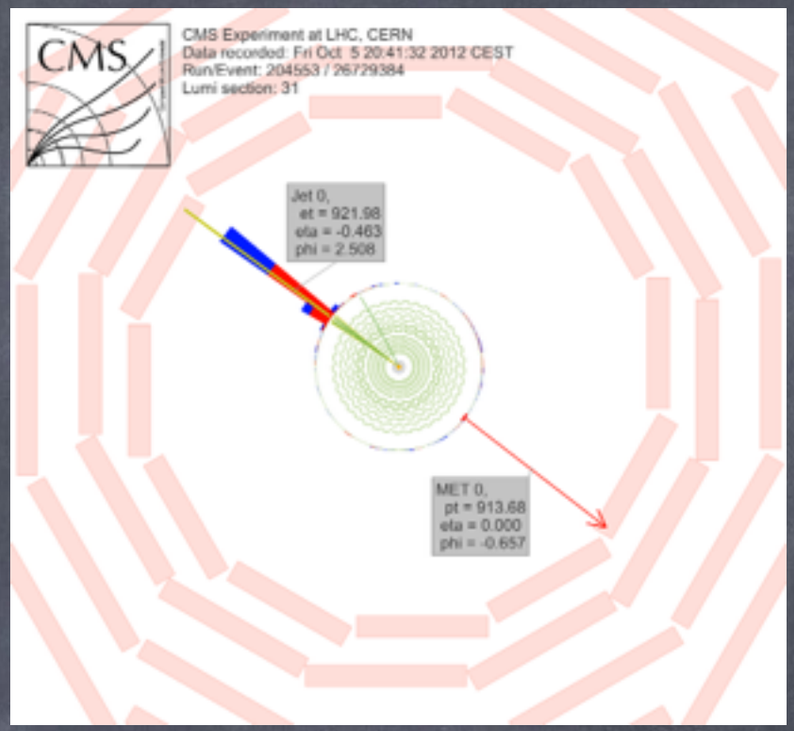
outline

- ATLAS and CMS observe an excess in the monojet + missing energy channel
- Possible interpretations for the excess
  - direct dark matter (DM) production, SUSY, extra dimensions, etc.
- Confirmation from direct detection experiments
- LHC can constrain the parameter space
- Confirmation from indirect detection experiments

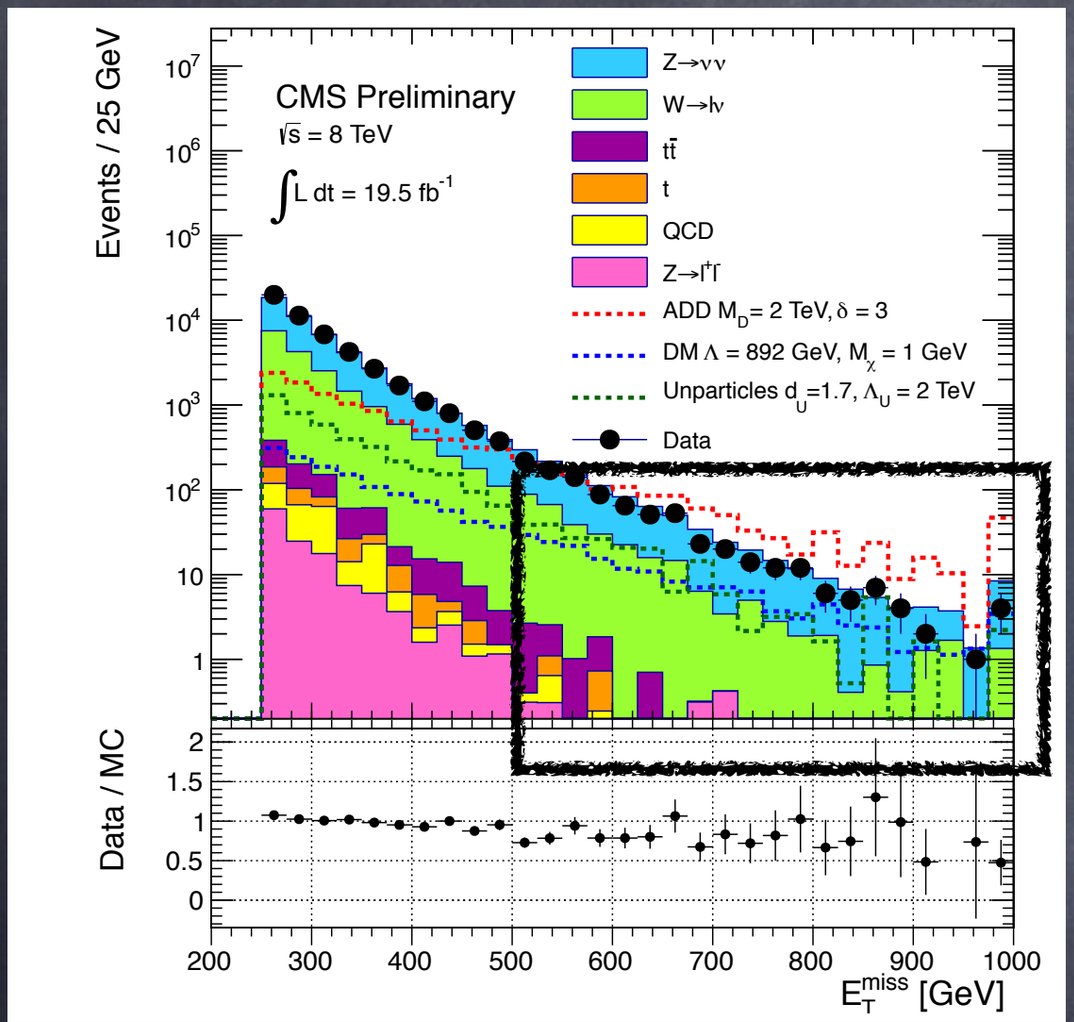
Monojet event display





As a layman I would say: I think we have it. You agree?

What would the excess look like?



E_T^{miss} (GeV) →	> 450	> 500	> 550
Z($\nu\nu$)+jets	1394 ± 127	671 ± 81	370 ± 58
W+jets	516 ± 31	269 ± 20	128 ± 13
$t\bar{t}$	13 ± 6.5	6 ± 3.0	3 ± 1.5
Z($\ell\ell$)+jets	4 ± 2.0	2 ± 1.0	1 ± 0.5
Single t	2 ± 1.0	1 ± 0.5	0 ± 0
QCD Multijets	2 ±1.0	1 ± 0.5	0 ± 0
Total SM	1931 ± 131	949 ± 83	501 ± 59
Data	1772	894	508
Exp. upper limit	229	165	125
Obs. upper limit	157	135	131

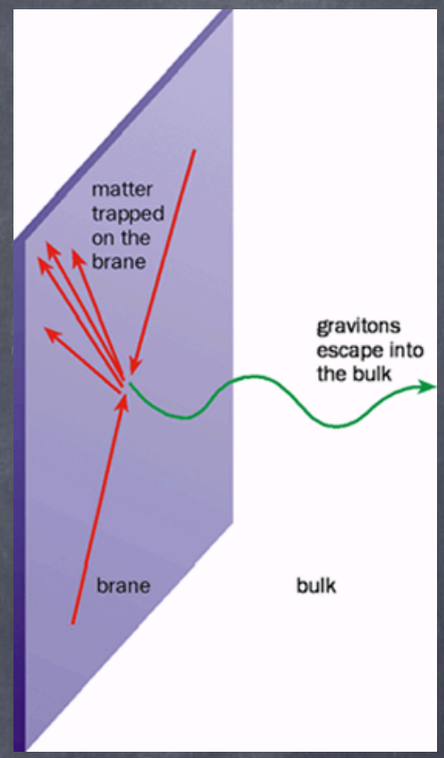
- Expect an excess on the tail of the MET distribution in run 2
- Different models could explain the excess:
  - EFT DM
  - ADD (Arkani-Hamed, Dimopoulos, Dvali 1998)
  - unparticles
  - SUSY

→ what if data yield in ET^{miss} >550 were 800

What can it be if not Dark Matter?

Monojet: Signature for several BSM physics models

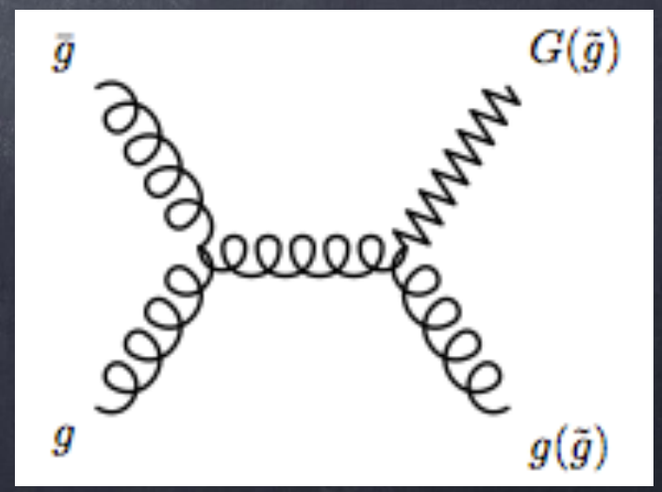
- ADD model gravitons with large extra dimensions
  - Graviton produced in association with a jet
  - Model aimed at setting the scale of gravity close to the weak scale
  - ATLAS and CMS both use monojet to search



- Unparticles
  - Wide spectrum of weakly interacting particles
  - CMS uses monojet to search

- No way for collider searches to determine if produced particle is stable or merely long-lived.

→ Long-lived R-parity violating SUSY?

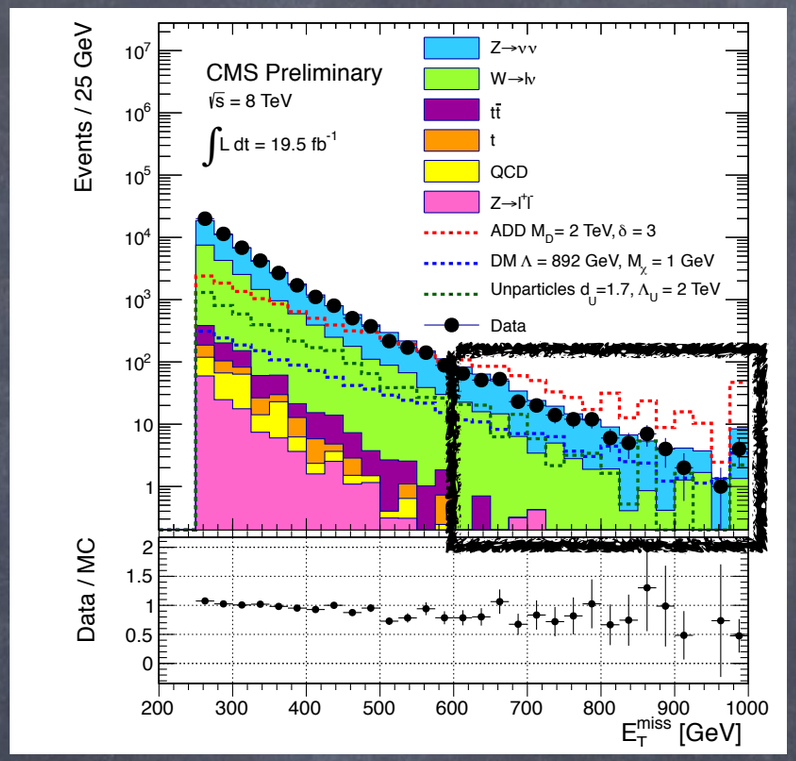


LHC Search Status

Monojet+MET signal

Look for excess in other channels

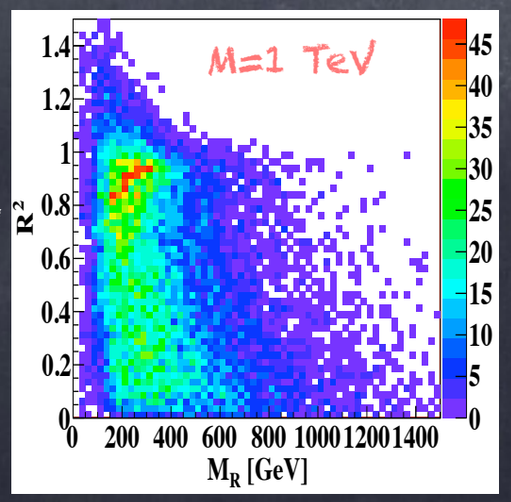
- Monopholton
- Mono-Z
- Mono-W
- Mono-H

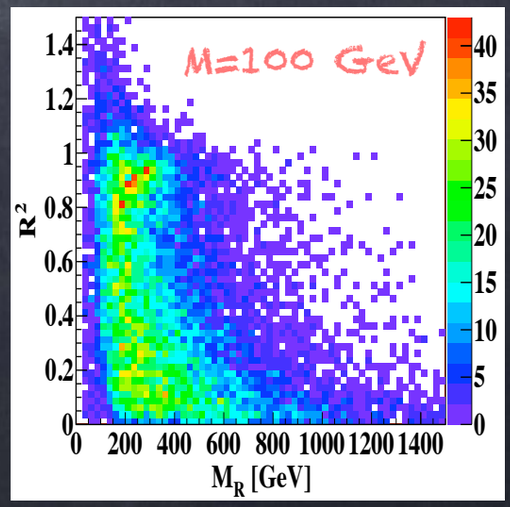


if excess in monojet, multi jet search should also have an excess

Multijet "smarter" analysis could increase sensitivity of colliders

a razor DM analysis could boost discrimination power between different DM models (coming soon for CMS)





Arxiv:1203.1662v3

LHC mono-b

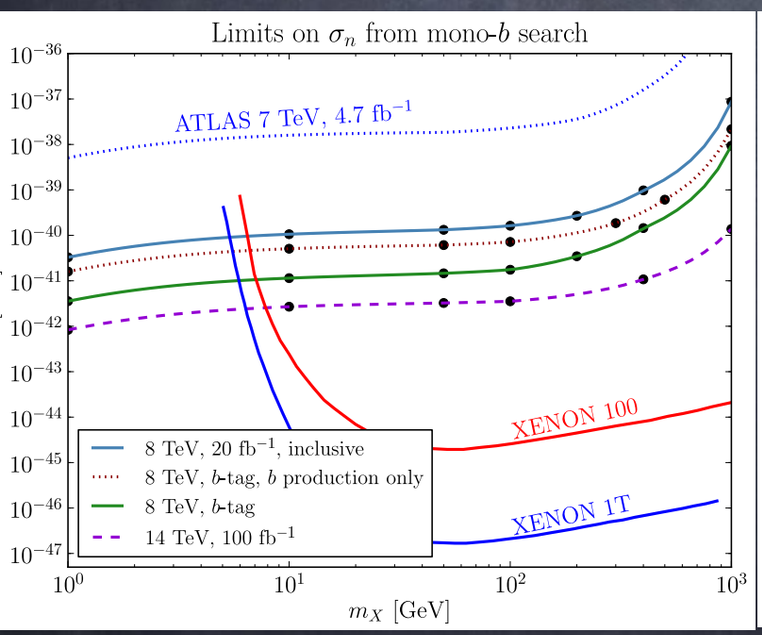
Arxiv:1303.6638

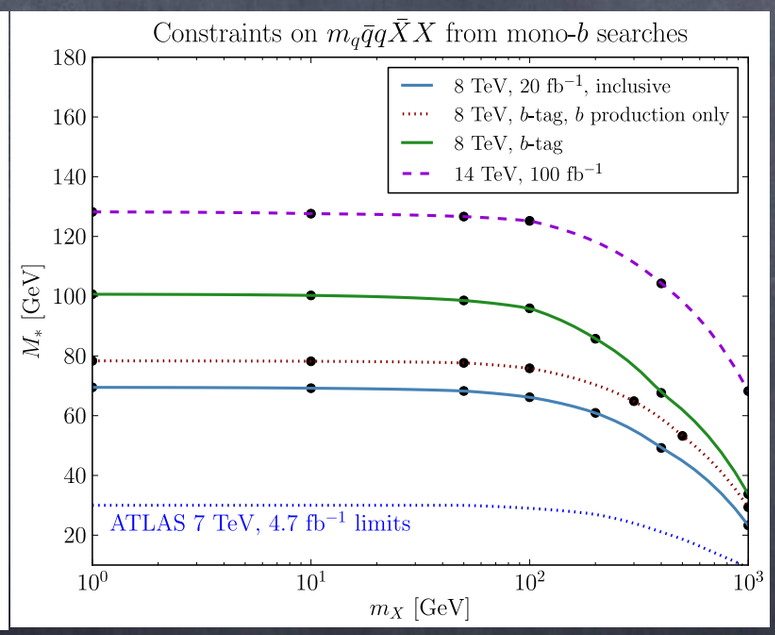
Jets+MET analysis are fairly sensitive to vector and axial-vector mediators

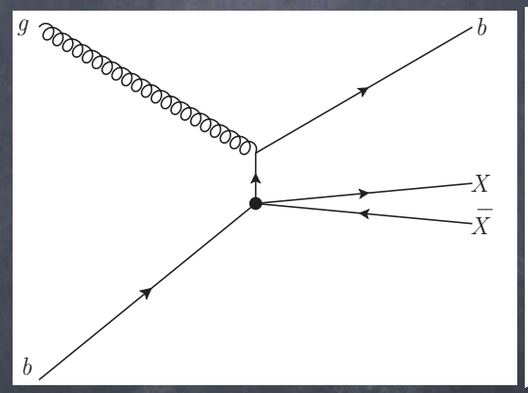
if DM couples through a scalar mediator

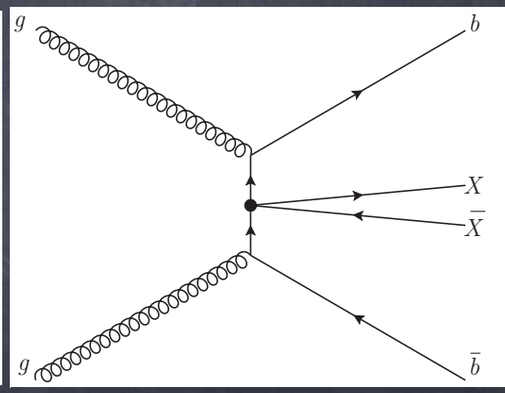
$$\sigma_n = \frac{(0.38 m_n)^2 \mu_X^2}{\pi M_*^6} \approx 2 \times 10^{-38} \mathrm{cm}^2 \left(\frac{30 \text{ GeV}}{M_*} \right)^6$$

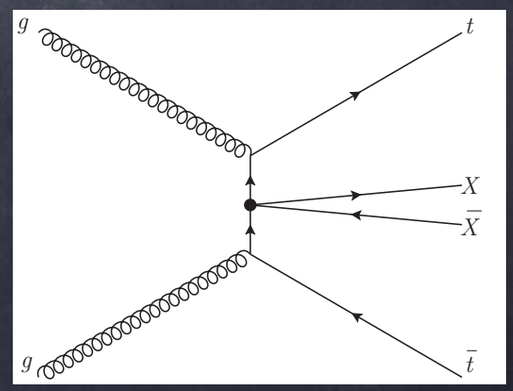
$$\frac{m_q}{\Lambda^3} \chi \bar{\chi} q \bar{q}$$









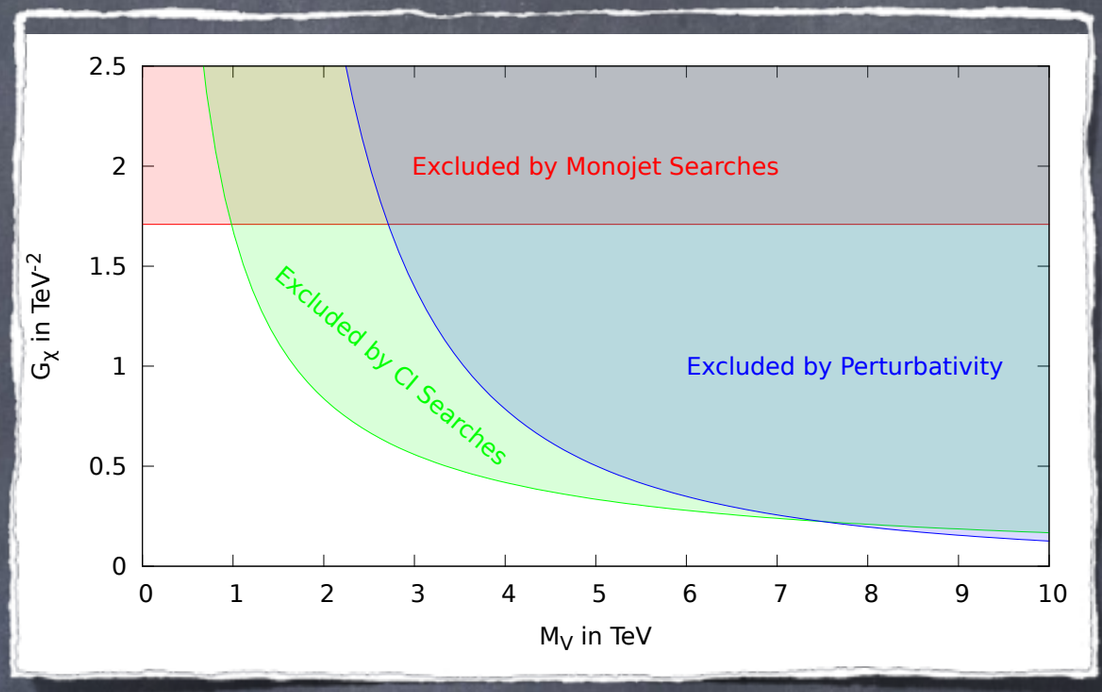


b-tag analysis and t-tag analysis will improve the LHC reach

Validity of the EFT

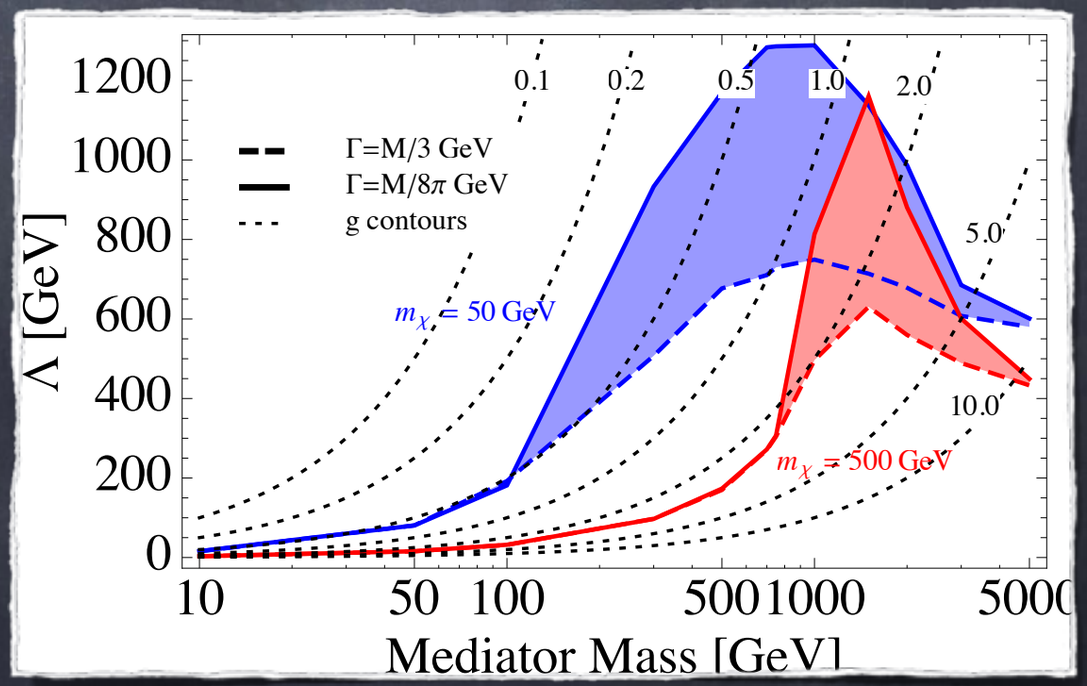
- Some region of the parameter space make EFT not perturbative
- If constraint parameter space for excess lies in the non-perturbative regime
  - suggest to use a more complete theory

$$G_\chi \equiv g_q g_\chi / M_V^2$$



- Mediator mass could be produced at the LHC:
  - Bias the preferred model parameters (DM mass, g)
  - modify cross section for direct/ indirect detection

LHC should change this way to interpret the results



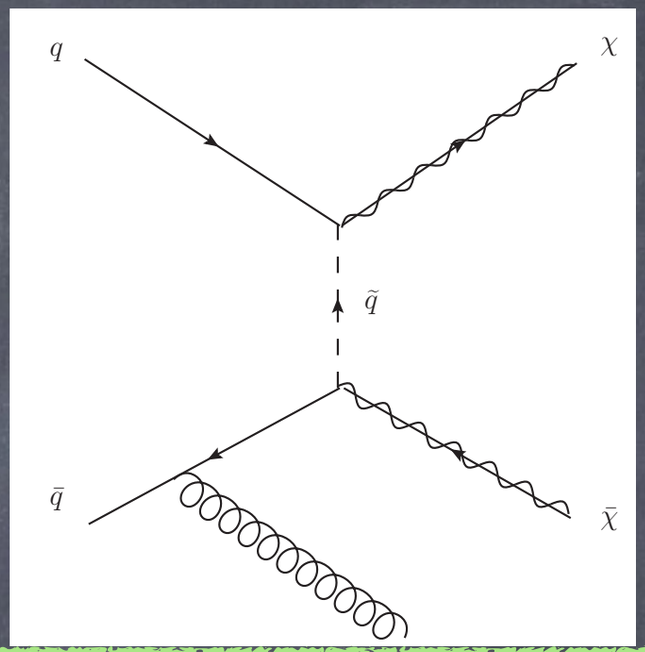
Simplified models

e.g

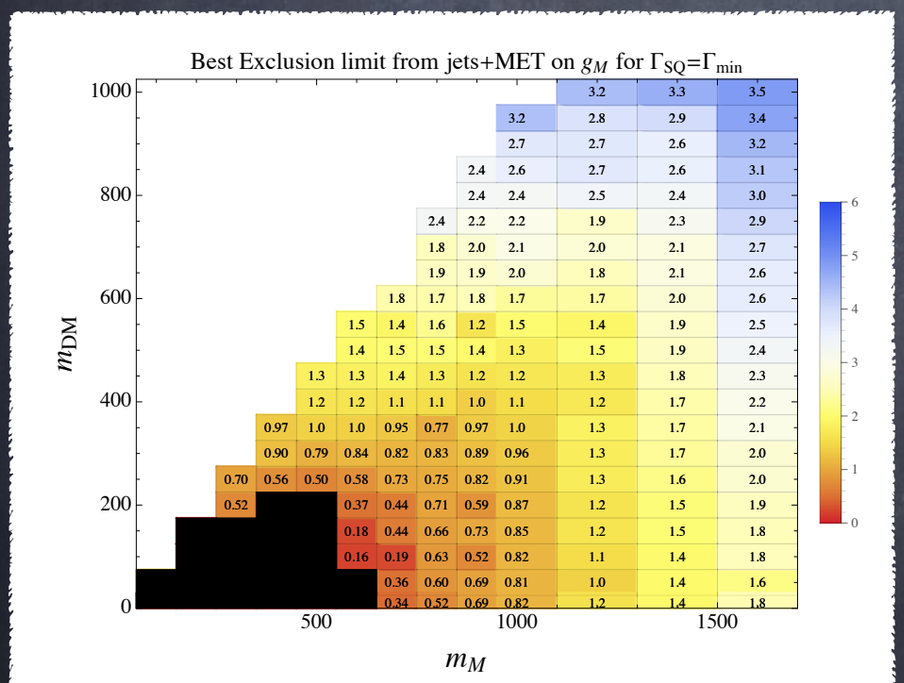
$$\mathcal{L} = \mathcal{L}_{SM} + g_M \sum_{i=1,2} \left(\widetilde{Q}^i_L \bar{Q}^i_L + \tilde{u}^i_R \bar{u}^i_R + \tilde{d}^i_R \bar{d}^i_R \right) \chi + \text{mass terms} + c.c.$$

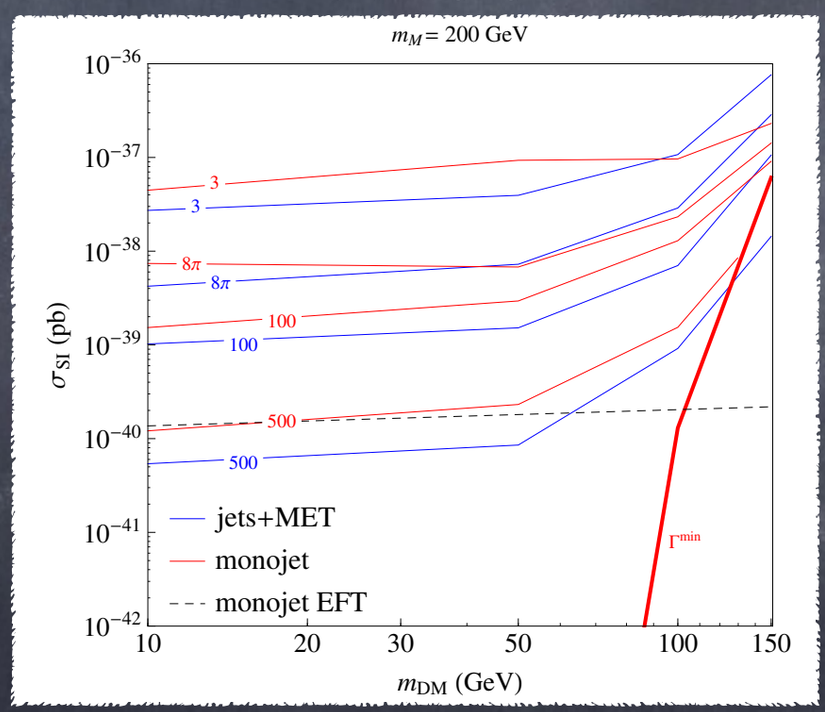
$$\Gamma^{min}_M = \frac{g^2_M m_M}{16\pi} \left(1 - \frac{m^2_{DM}}{m^2_M} \right)^2$$

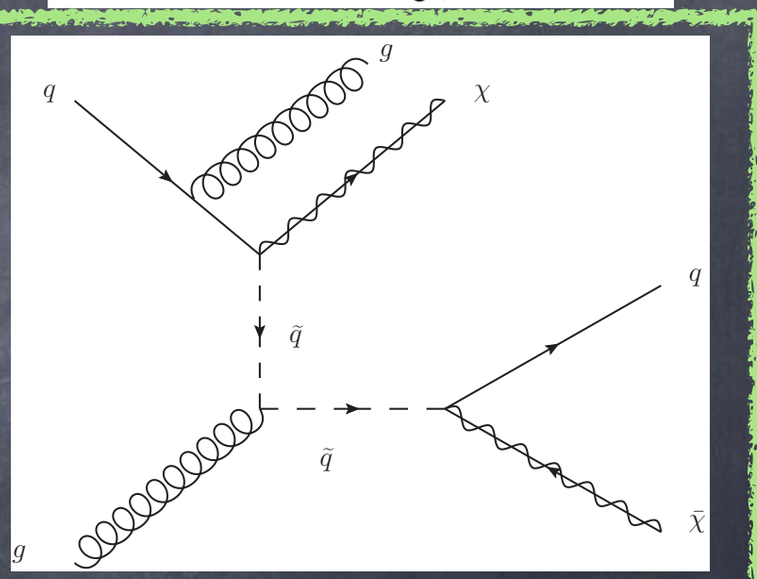
Arxiv:1402.2285v1

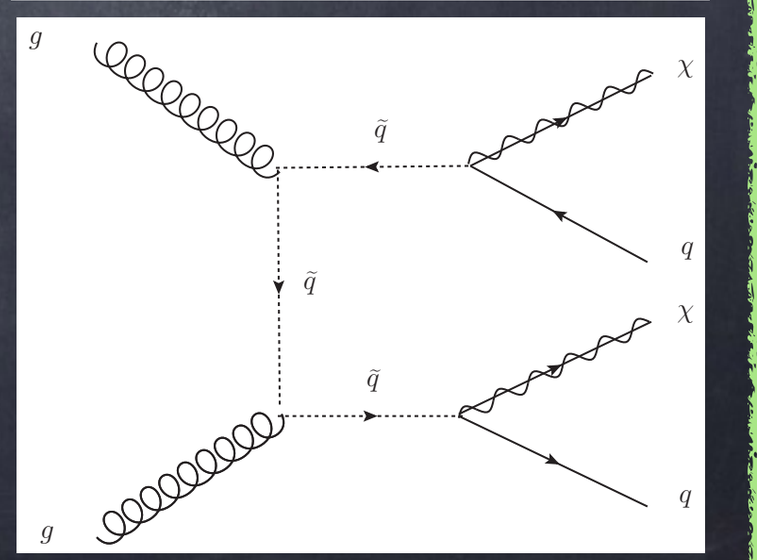


translate limits to DD





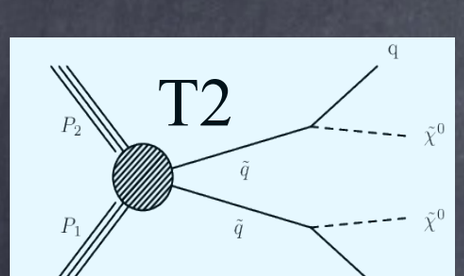


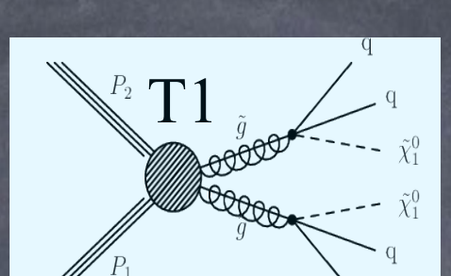


multijet is complementary to monojet

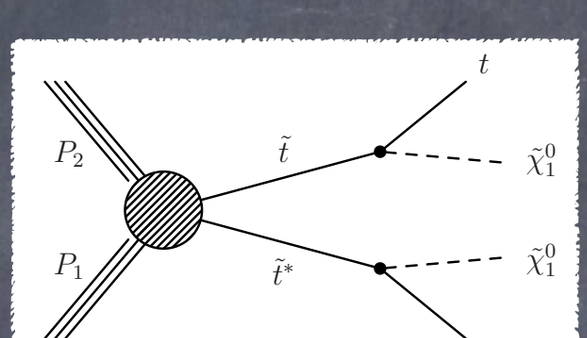
LHC SUSY Searches

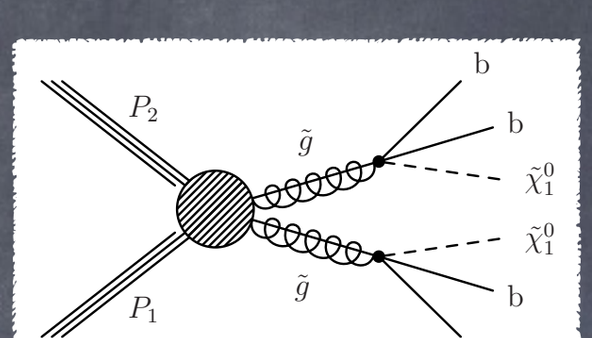
first and second generation coupling

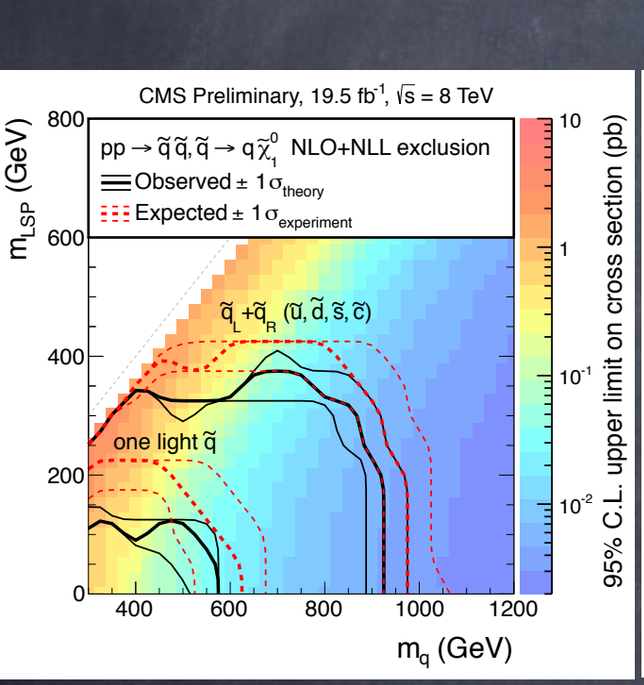


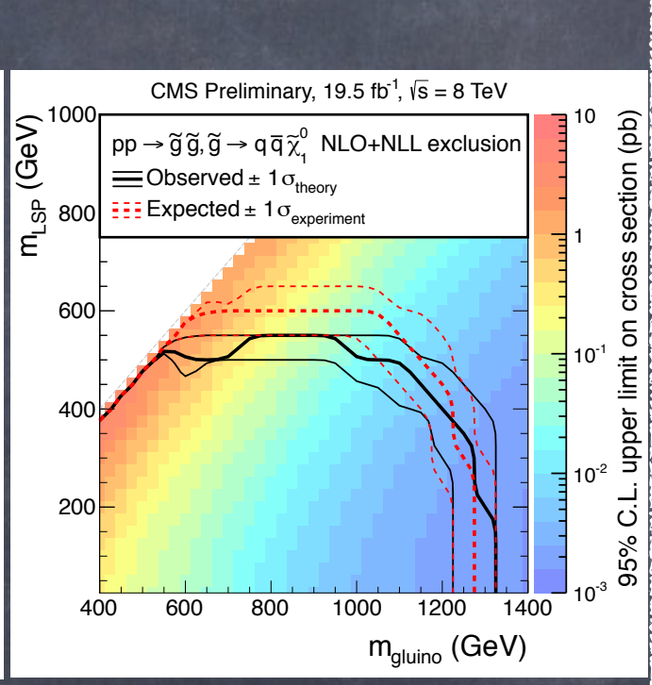


third generation coupling





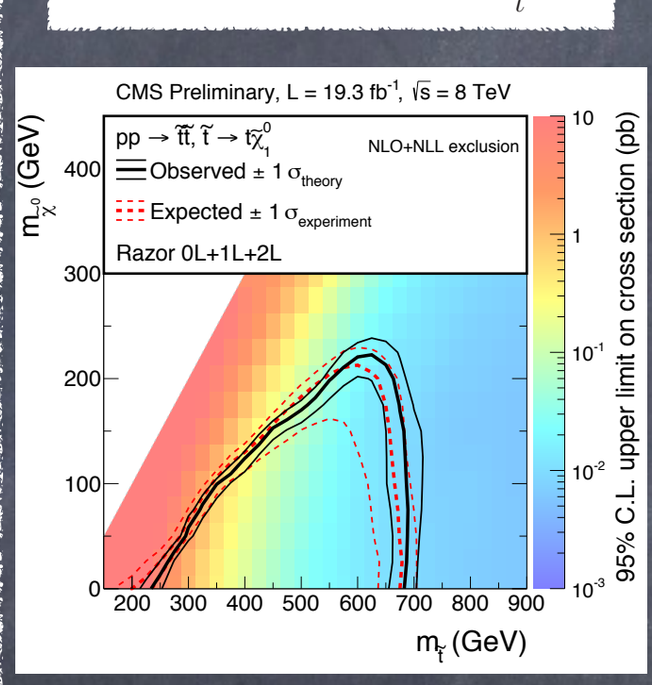


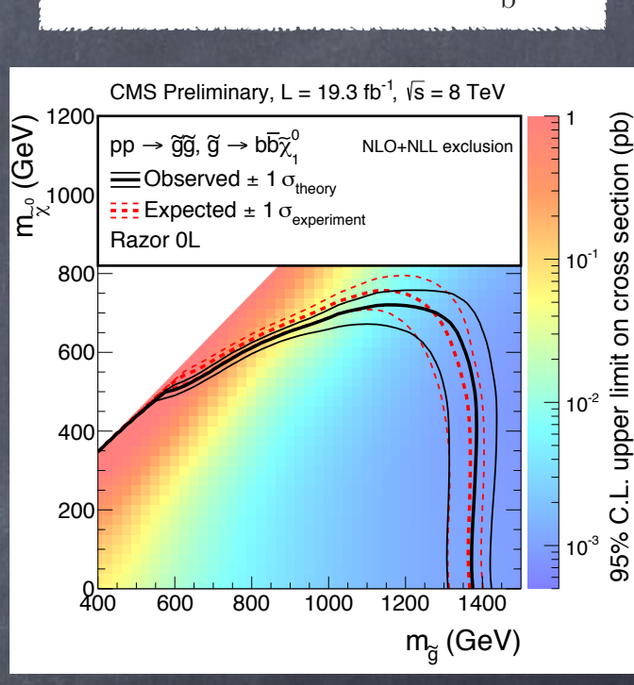


(a)

MT2

7 TeV -> arXiv:1207.1798 [hep-ex]





Razor

Sensitive to gluinio/stop-neutralino mass difference

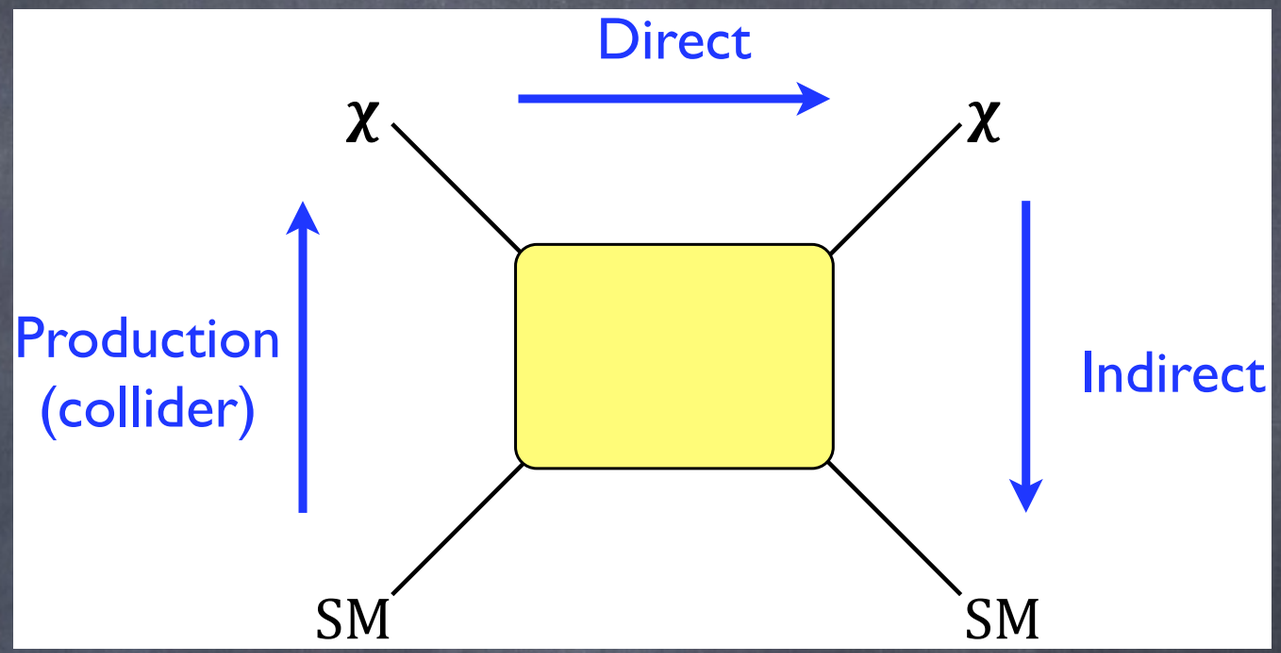
7 TeV -> PhysRevLett.111.081802

LHC Dark Matter Reach

- MET+monoX constrains parameter space for particular DM model
- Multijet + MET should be as sensitive as the monojet+MET analysis
  - allows to exploit kinematics of the event (e.g Razor), could improve model parameter discrimination. New analysis coming soon
- If DM couples preferentially to third generation quarks, dedicated analysis will boost LHC sensitivity. MUST DO for Run2
- Very broad SUSY program at the LHC could give hints about possible compatibility with SUSY DM candidates (e.g R-parity -> neutralino)
- CANNOT determined if observed excess correspond to the cosmological DM
  - Constrain parameters of many BSM models which contain a DM candidate
    - Very important to use shape analysis to increase the discrimination power (forthcoming!)

MET+X is not enough

- Detected particle maybe unstable on cosmological time scales



- Need other probes
  - Indirect and direct detection experiments, $\Omega_\chi \sim 0.26$

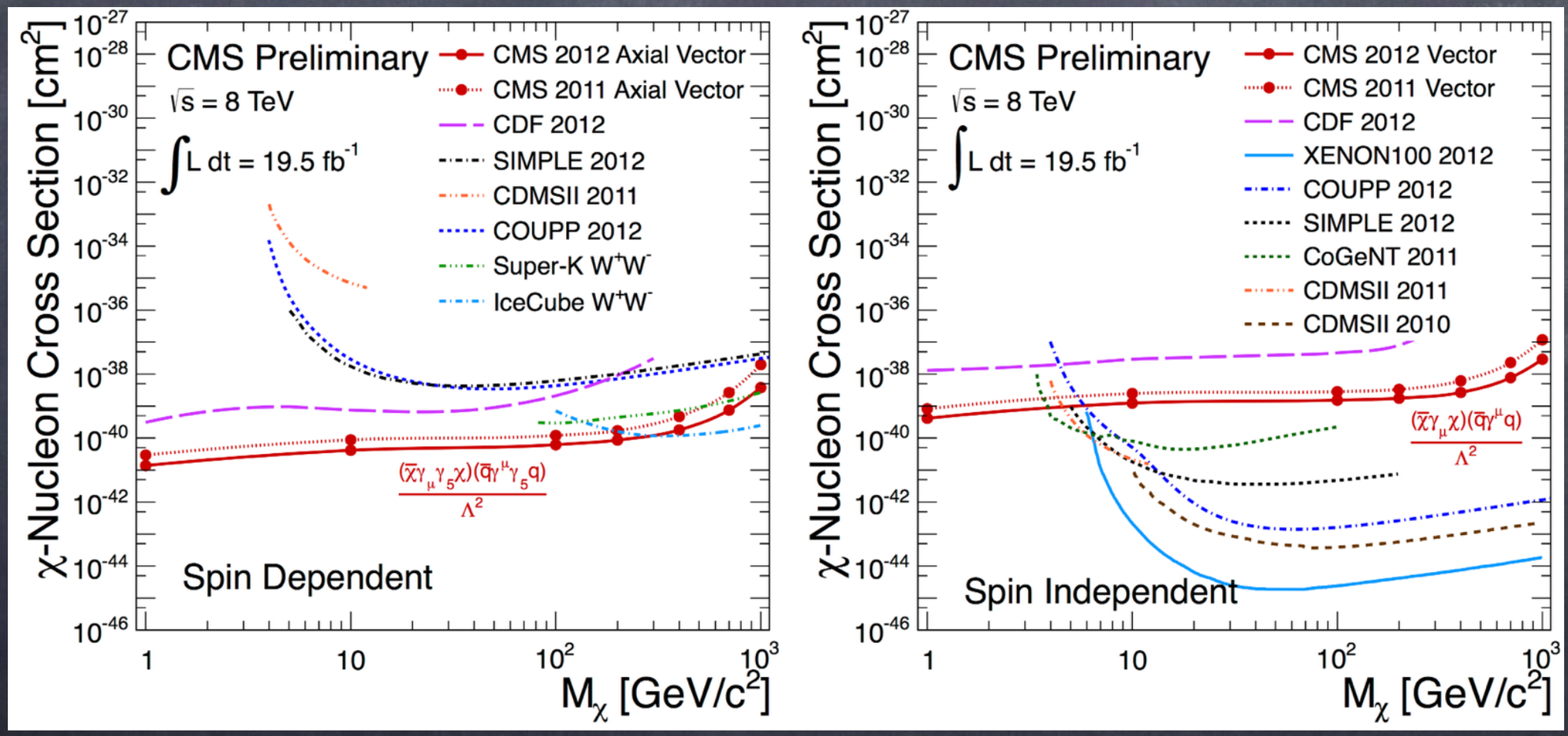
Translating LHC results necessarily model dependent!

Comparing LHC and direct detection

- Direct searches look for collisions of nucleons with DM particles in the galactic halo
- Calculate $\sigma_{\rm SI}, \sigma_{\rm SD}$ in model of choice (EFT, simplified model, SUSY etc.)

For EFT $\langle \sigma v \rangle \propto \frac{1}{\Lambda^4}$

MET excess gives region in $\sigma - m_\chi$ plane



CMS-PAS-EXO-12-048, arXiv:1106.4775 [hep-ex]

Indirect Detection

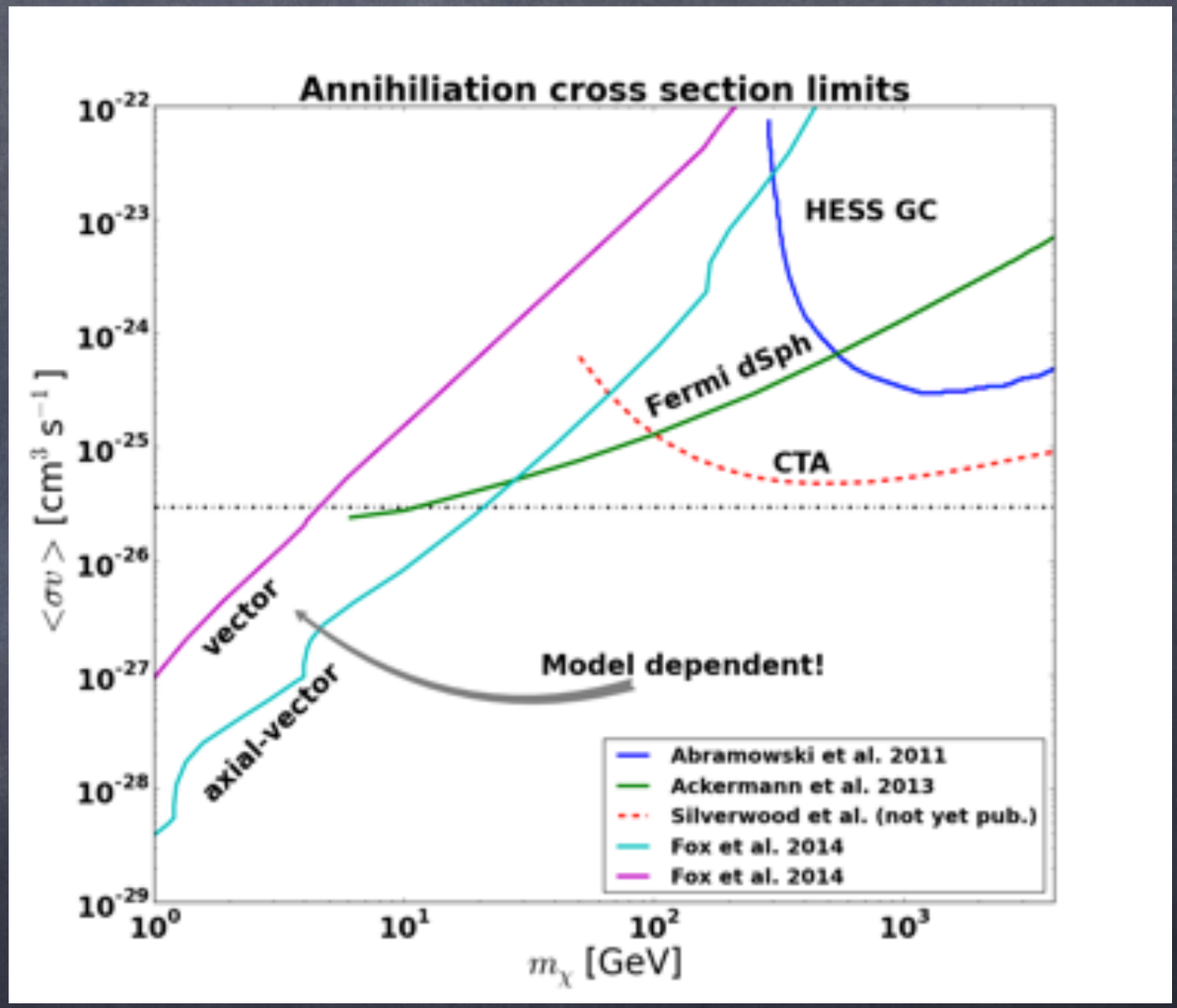
- Look for annihilations from DM in astrophysical sources with high DM density
- Interpret MET excess with favorite DM model then calculate $\langle \sigma v \rangle$ and branching ratios

Example: LHC EFT Limits

ATLAS 7 TeV, 1 fb^{-1} monojet analysis

For EFT $\langle \sigma v \rangle \propto \frac{1}{\Lambda^4}$

Warning: constrain depends on mediator mass



Conclusions

- A MET excess at the LHC is signal for new physics!
- Broad physics analysis at the LHC could severely constrain the nature of the new particle
- Shape analysis will improve sensitivity
- But... not enough to say it's DM (stable on cosmo-scales, abundance in universe etc.)
- Need confirmation from indirect and direct searches
- Translation of results from LHC is model dependent