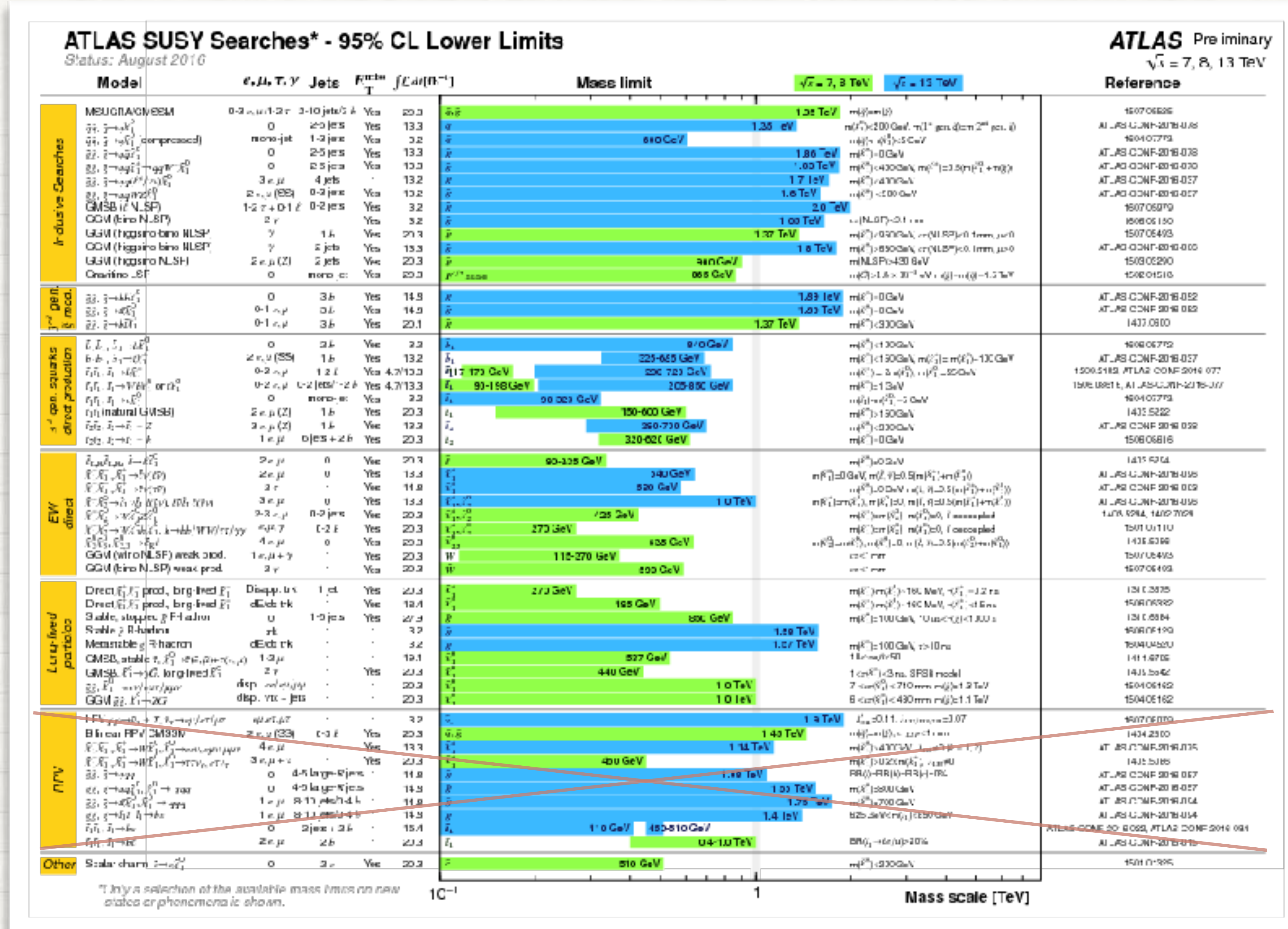
LHC AND DARK MATTER SEARCHES: STATUS AND PERSPECTIVES

MICHELE PAPUCCI (LBNL)

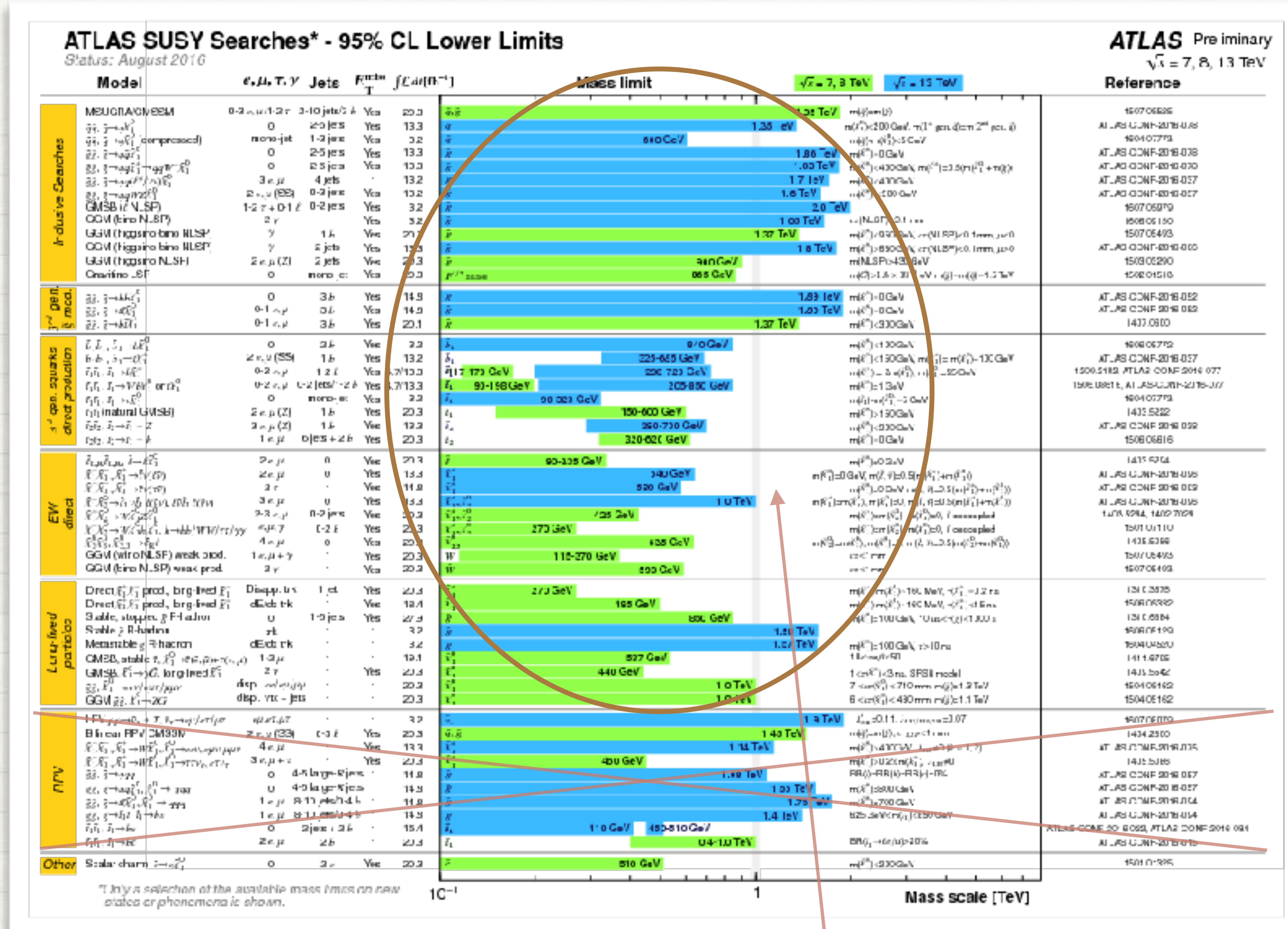
3RD BERKELEY WORKSHOP ON DM DD, DEC 5, 2016

LHC SUSY SEARCHES = DM SEARCHES



Look for Missing E_T → invisible particles escaping detection (DM)

LHC SUSY SEARCHES = DM SEARCHES

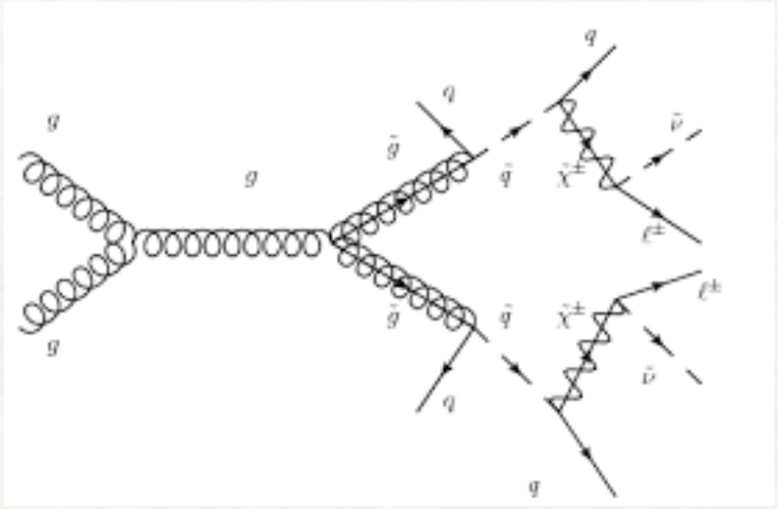


Limits on parent non-DM particles

Look for Missing E_T → invisible particles escaping detection (DM)

SEARCHING FOR DM AT THE LHC

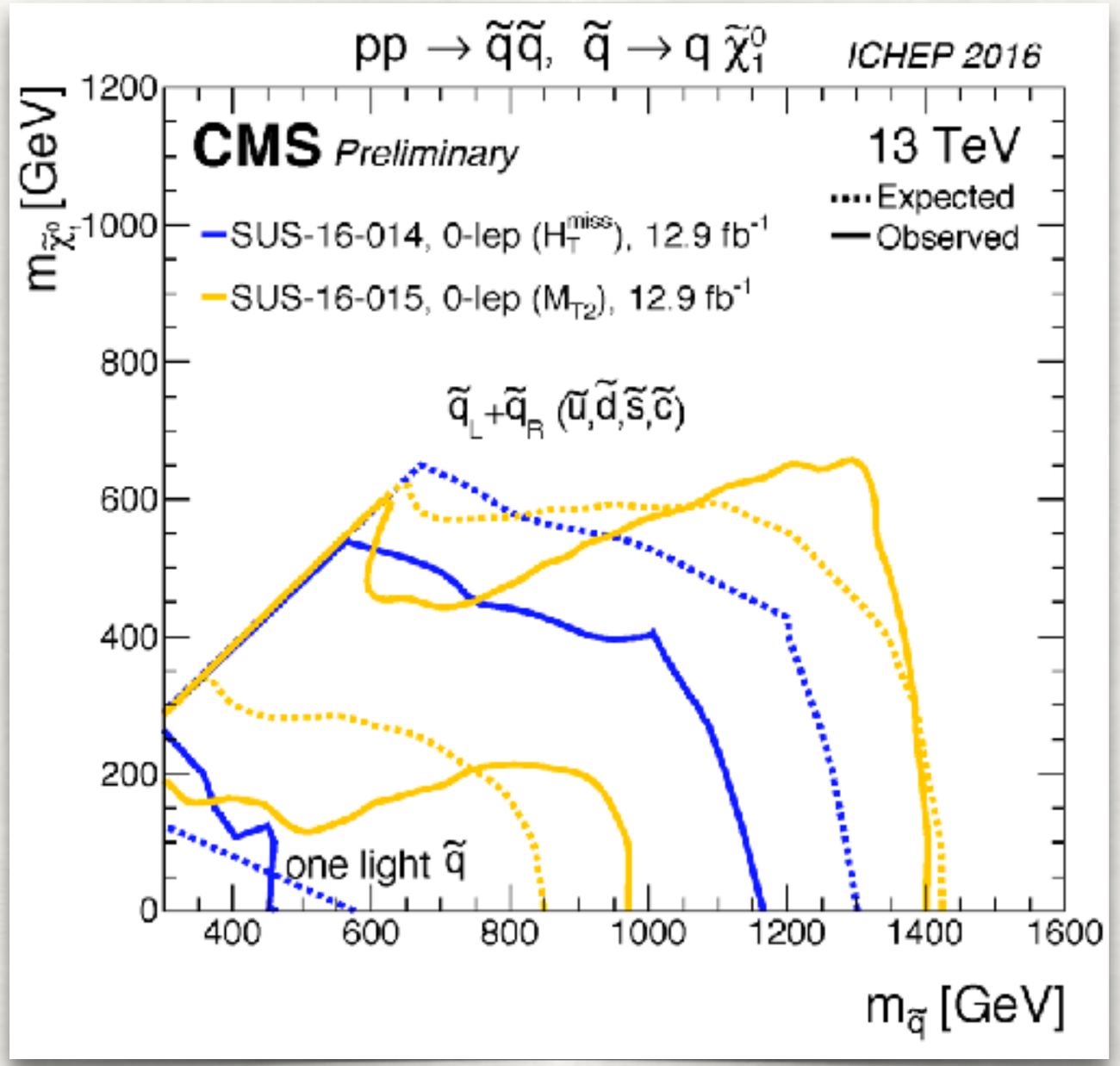
- LHC IS A "MEDIATOR" DIRECT DETECTION PROBE → DM ONLY PROBED INDIRECTLY



SEARCHING FOR DM AT THE LHC

- LHC IS A "MEDIATOR" DIRECT DETECTION PROBE → DM ONLY PROBED INDIRECTLY

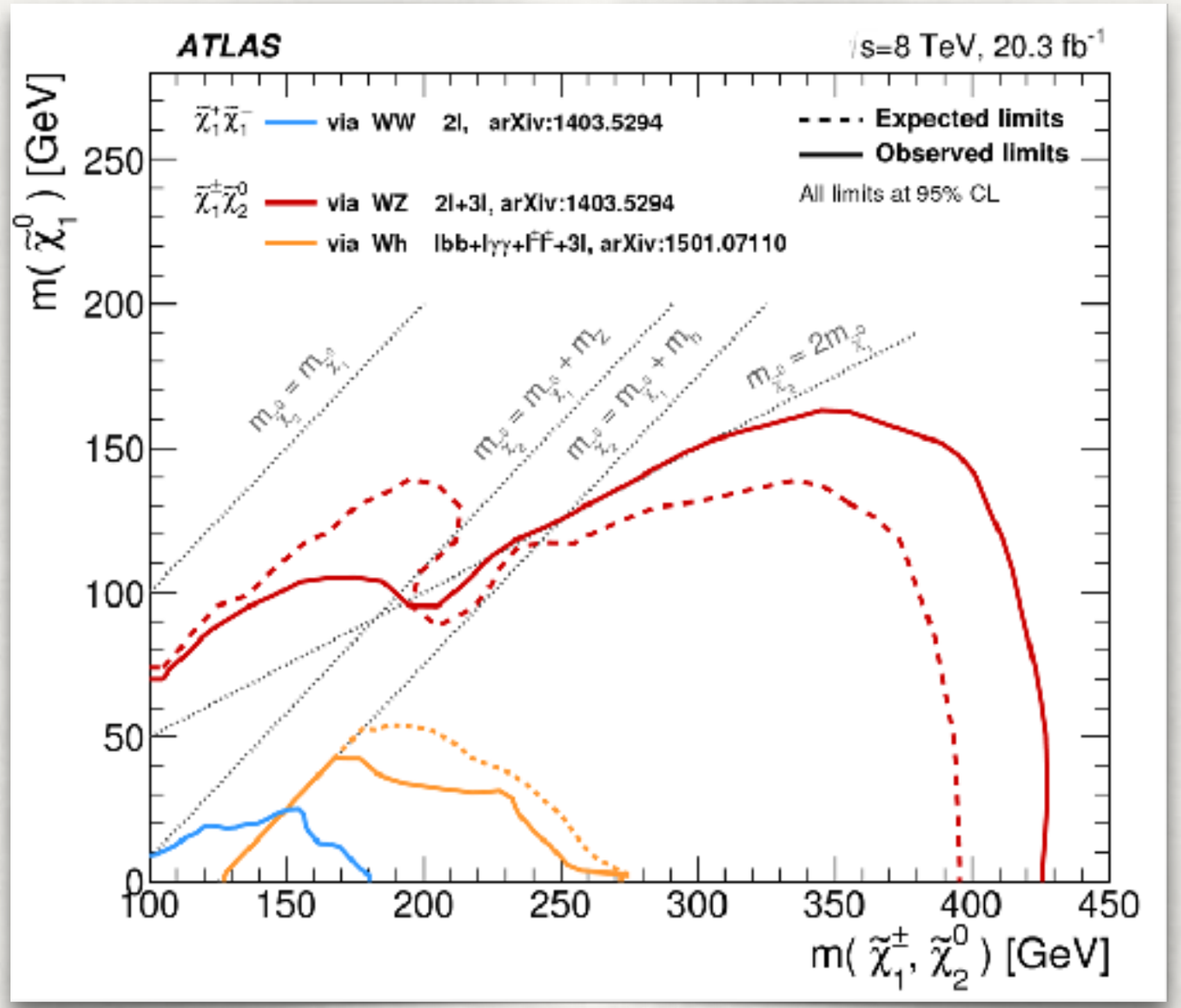
- STRONG LIMITS FOR COLORED MEDIATORS (> 1 TEV)



SEARCHING FOR DM AT THE LHC

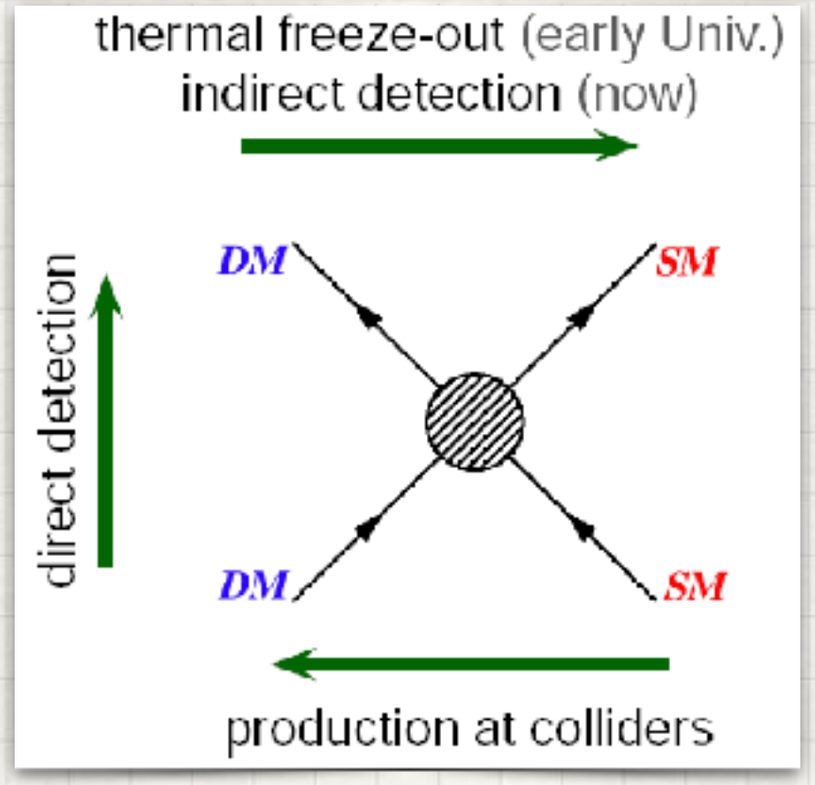
- LHC IS A "MEDIATOR" DIRECT DETECTION PROBE → DM ONLY PROBED INDIRECTLY

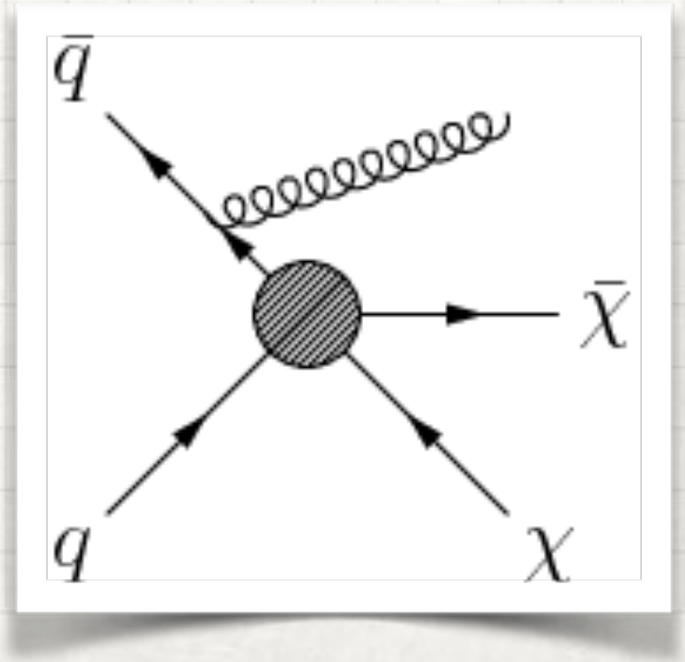
- WEAK LIMITS FOR WEAKLY COUPLED MEDIATORS (FEW x 100 GEV)



LHC AS DM MACHINE

- Mono-jet idea is an old one (early 80s)
- More recently: use it to probe the DM-SM interactions model independently (Beltran et al. + many many others)
- It's the same "blob" in direct detection and LHC production…





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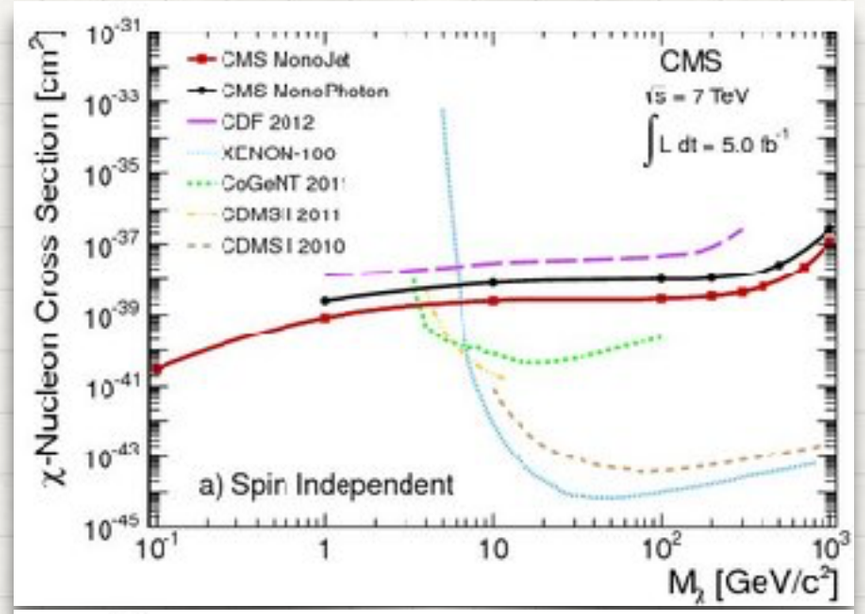
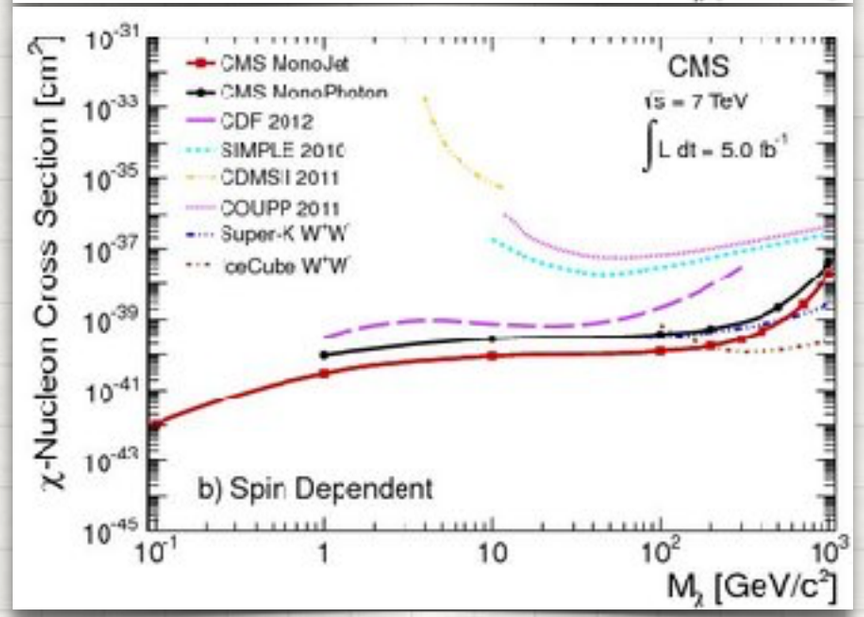
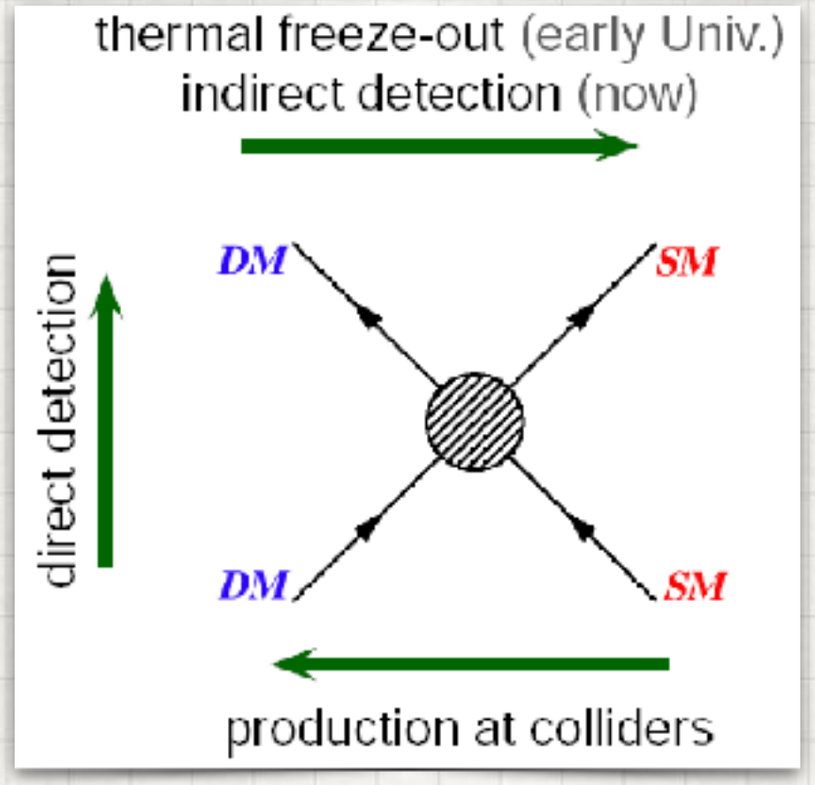
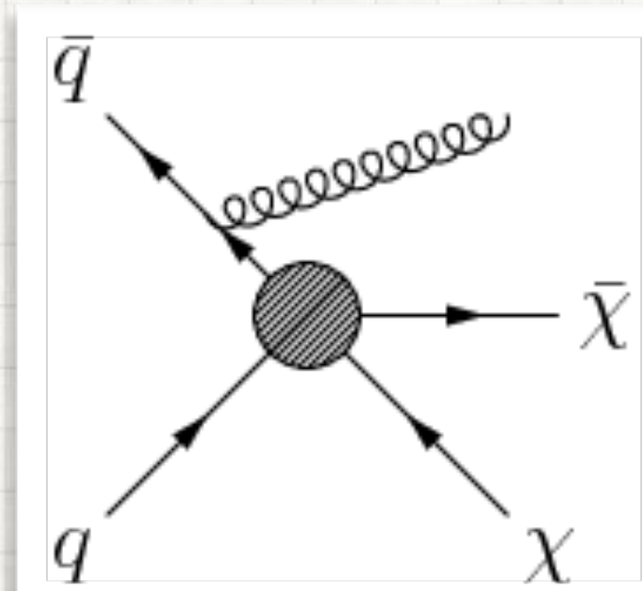




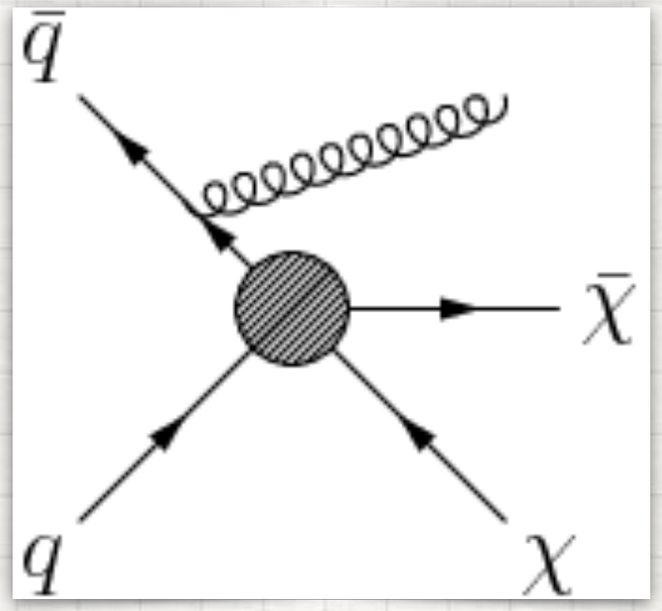
- LHC results on **σ** vs. M_{DM} plane
- strong constraints, competitive with DD in SI, better for SD!





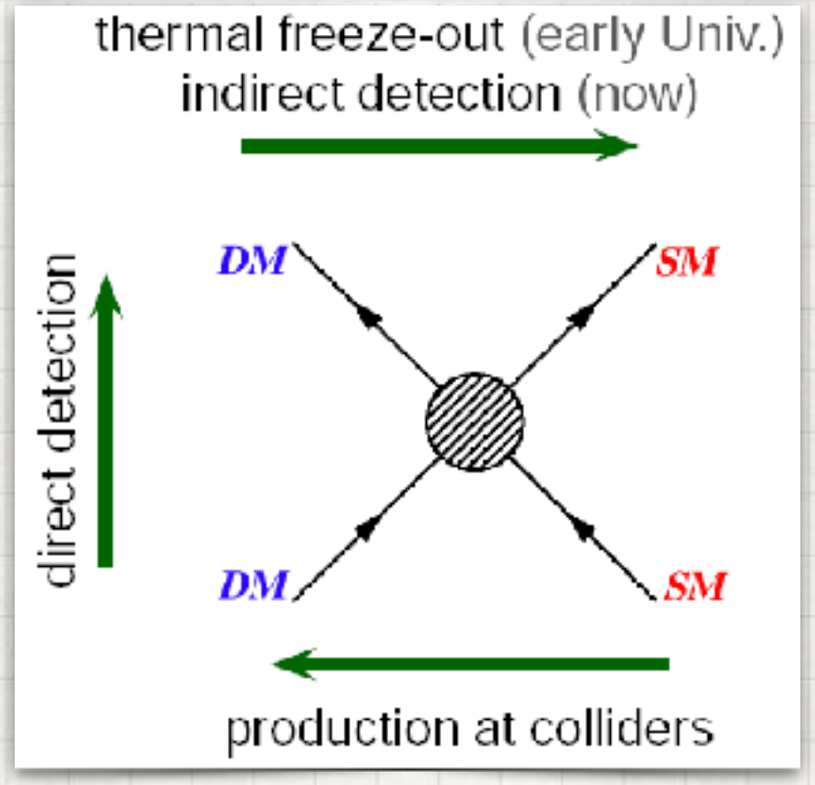
MONO-X CRAZE

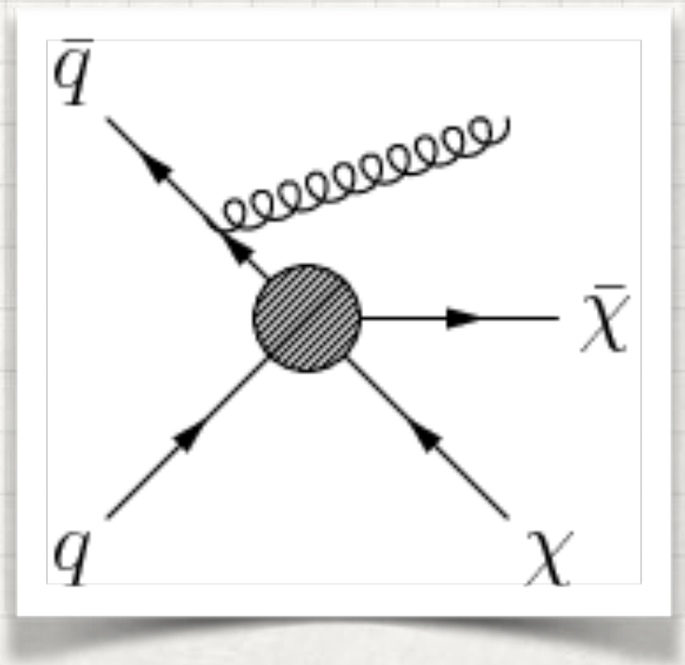
- Many Mono-X searches:
  - mono-jet
  - mono-photon
  - mono-Z
  - mono-W
  - mono-Higgs
  - mono-b
  - mono-top
- When are they useful? Are all of them powerful? How do they compare with traditional searches using Missing E_T?



NOT SO FAST…

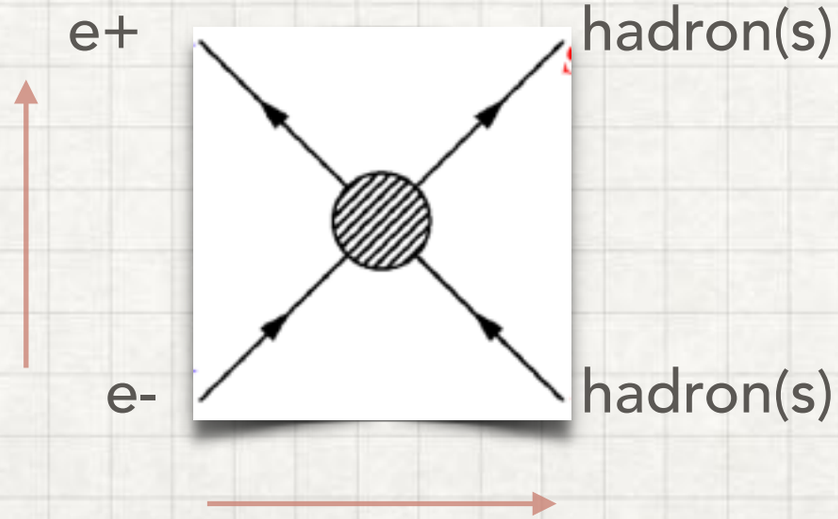
- Mono-jet idea is an old one (early 80s)
- More recently: use it to probe the DM-SM interactions model independently (Beltran et al. + many many others)
- It's the same "blob" in direct detection and LHC production…
- … but energies are VERY different!

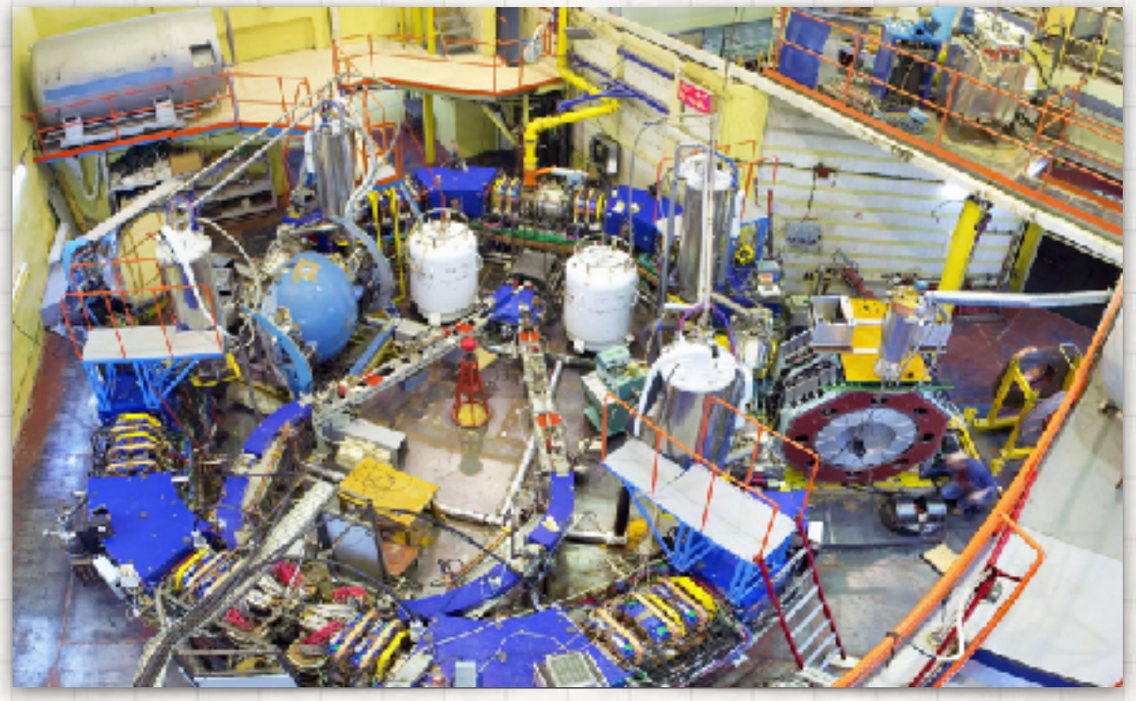




NOT SO FAST…

It's the same "blob" describing $e^+e^- \rightarrow$ hadrons at low energy and deep inelastic scattering, but you need a model (QCD) that tells you what's inside the "blob" to connect the two experiments



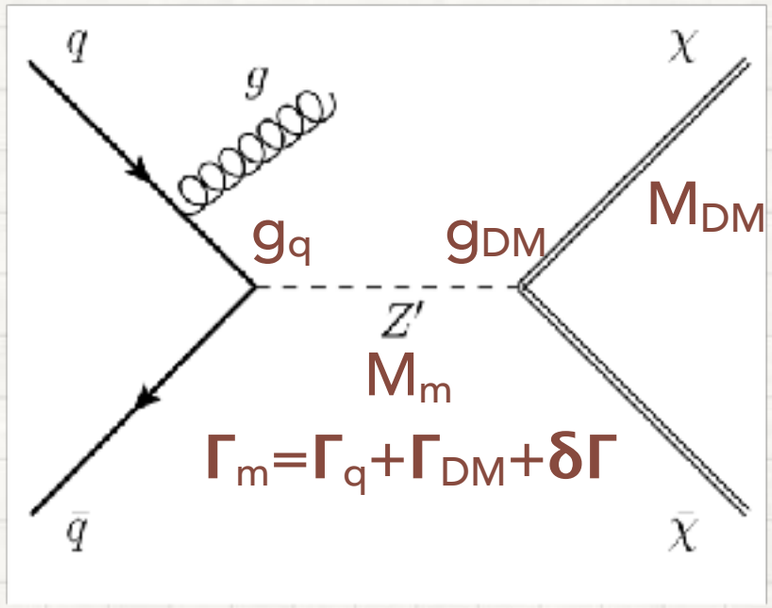


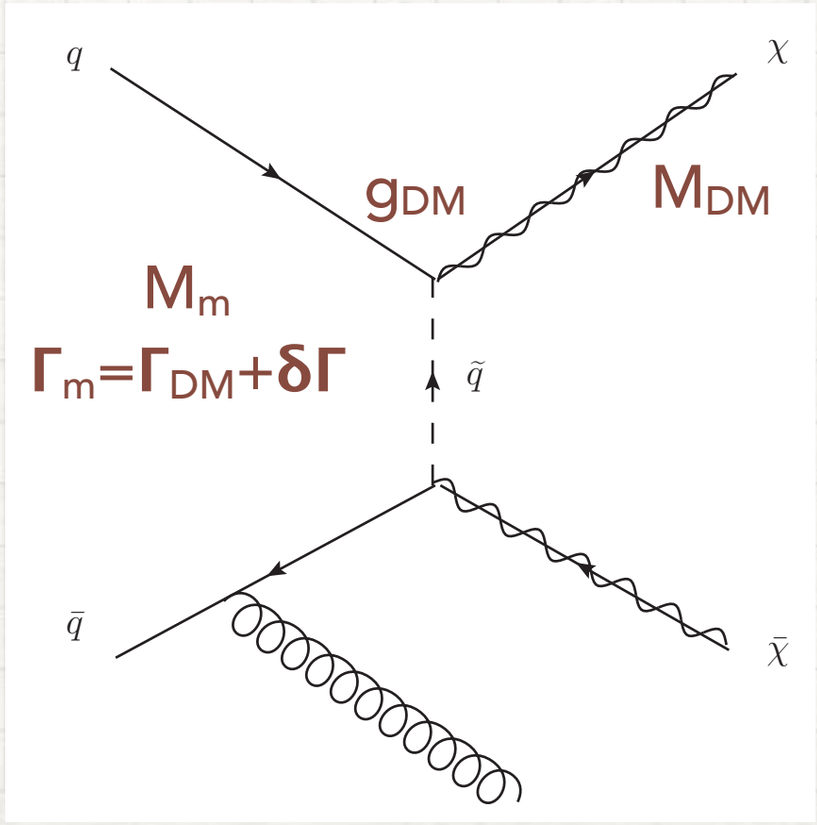
NEED MODELS TO DESCRIBE EFFECTIVE INTERACTIONS BETWEEN SM AND DM

THE NEED FOR (SIMPLIFIED) MODELS

- Various models producing the same blob
- Direct detection: 2 parameters, m_{DM} and coupling strength ($\leftrightarrow\sigma_N$)
- Models: at least 4 parameters, often more
- Mapping of LHC results in (σ, m)-plane subject to assumptions

What to do?





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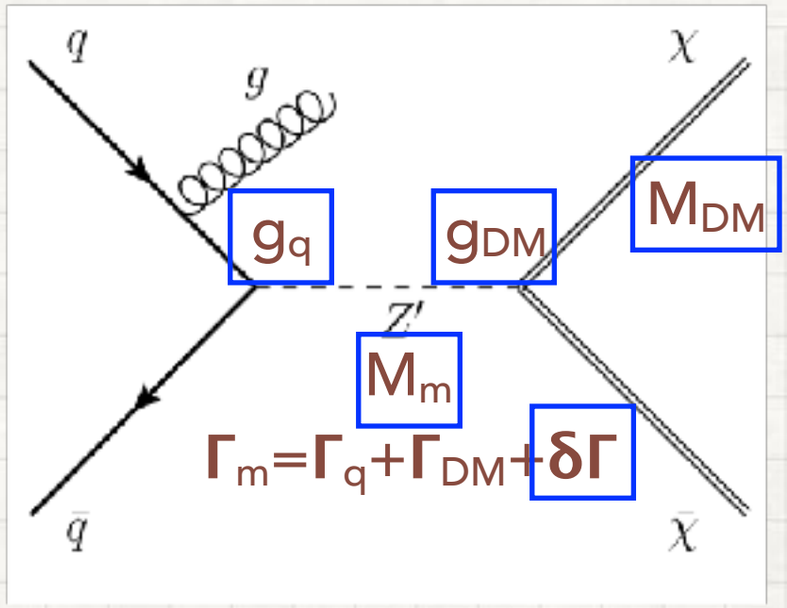
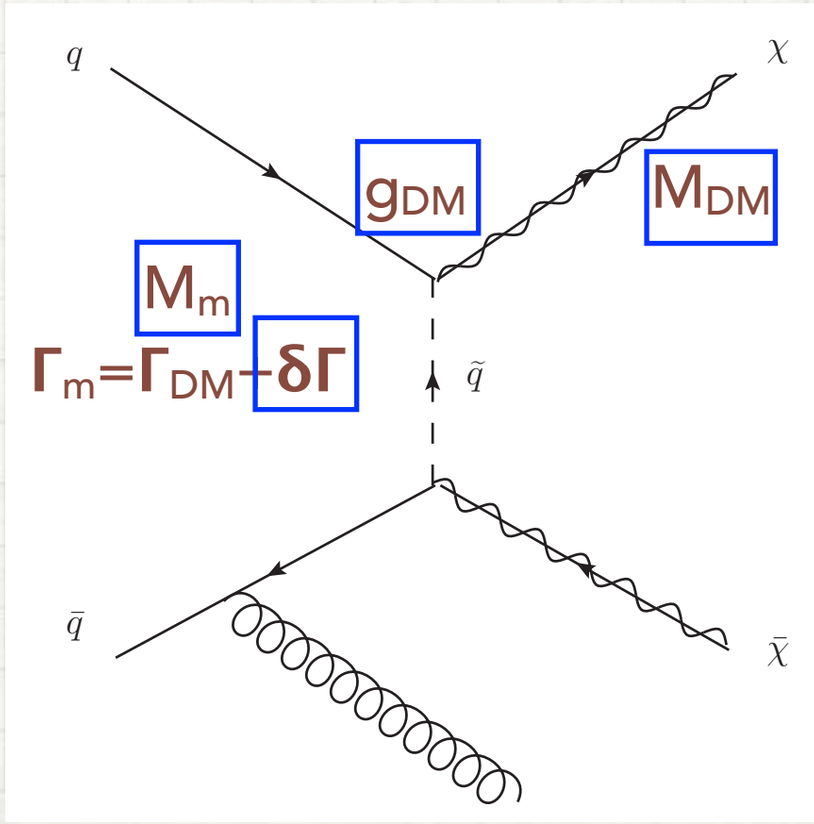


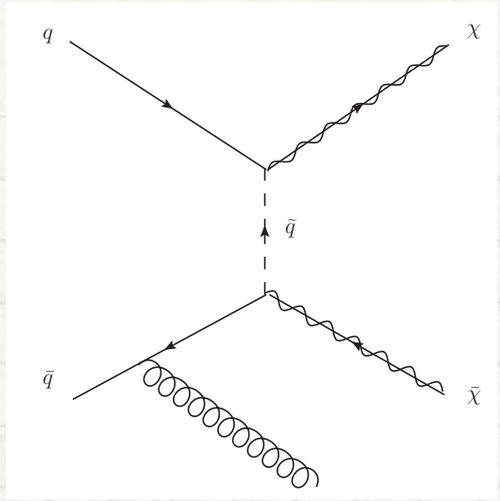
5 parameters

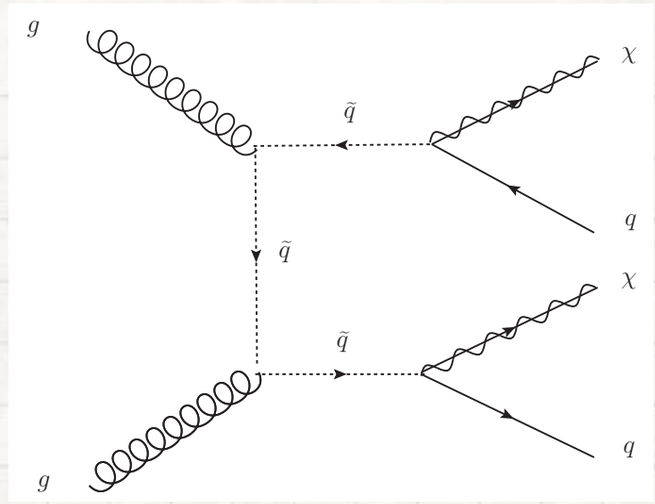


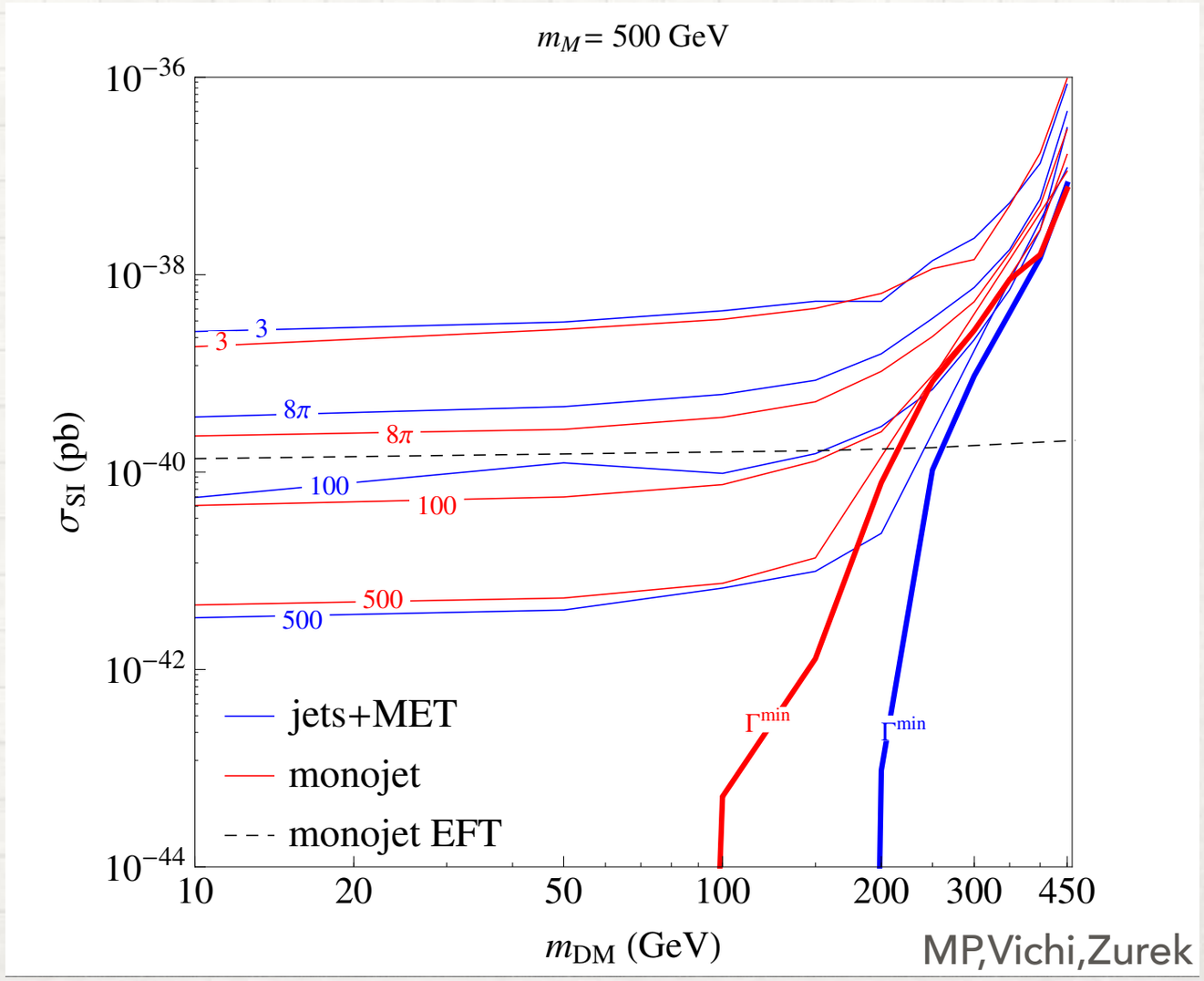
4 parameters

THE NEED FOR (SIMPLIFIED) MODELS

- With models one can compare different LHC searches and find when mono-X searches to complement existing ones
- Residual parameter dependence significantly changes the limits when presented in (σ_{DD}, m)–plane







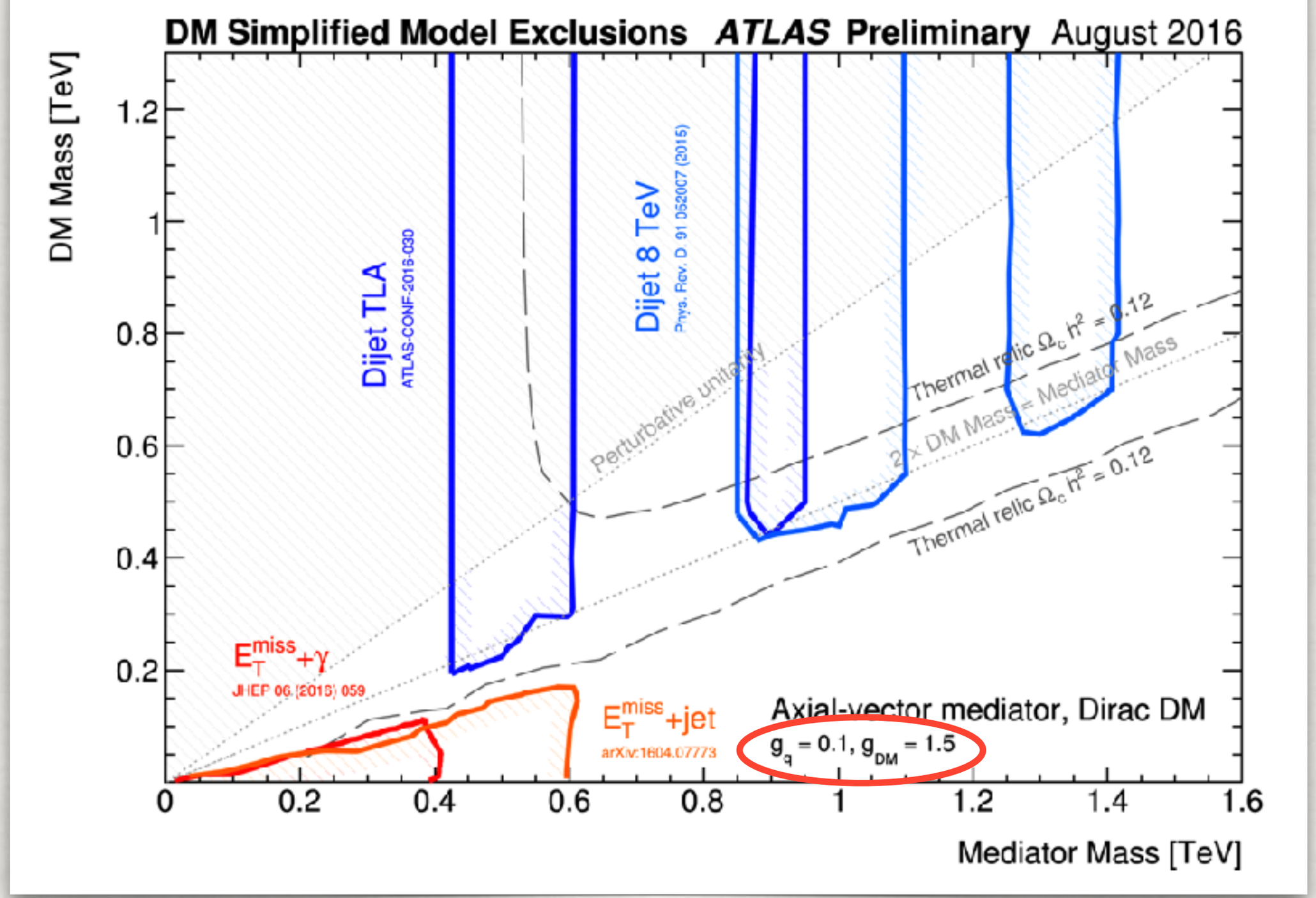
...MANY MANY THEORY PAPERS AND 2 JOINT ATLAS+CMS+THEORY WORKING GROUPS LATER...

Abercombie et al. 2015:
models/parameters/MC samples/assumptions/plots to use

s-channel and t-channel models fleshed out, rest of models
(mostly relevant for mono-Z,h,W,t) still requires work

RECENT RESULTS

(s-channel, $\delta\Gamma$=0)



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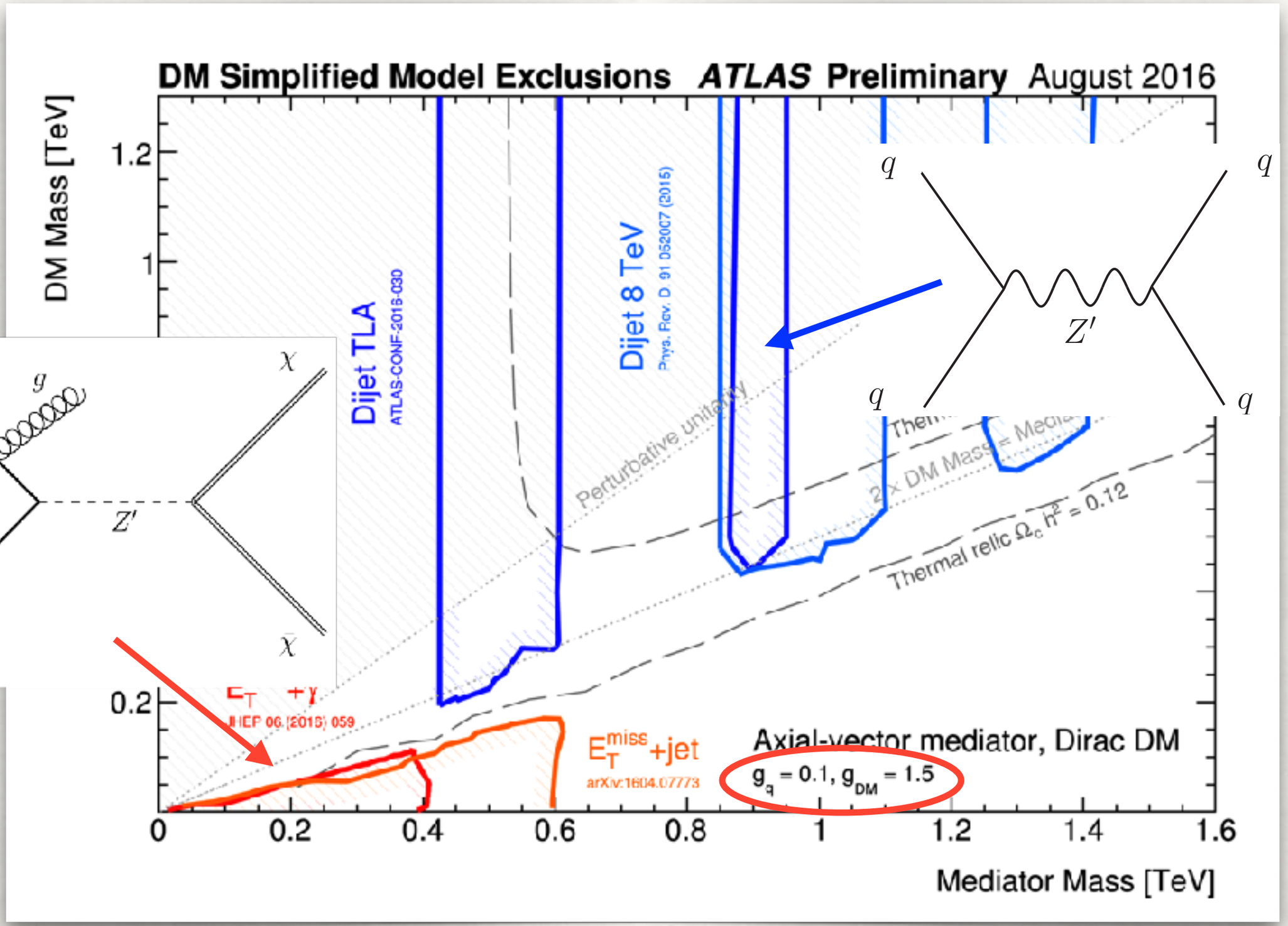

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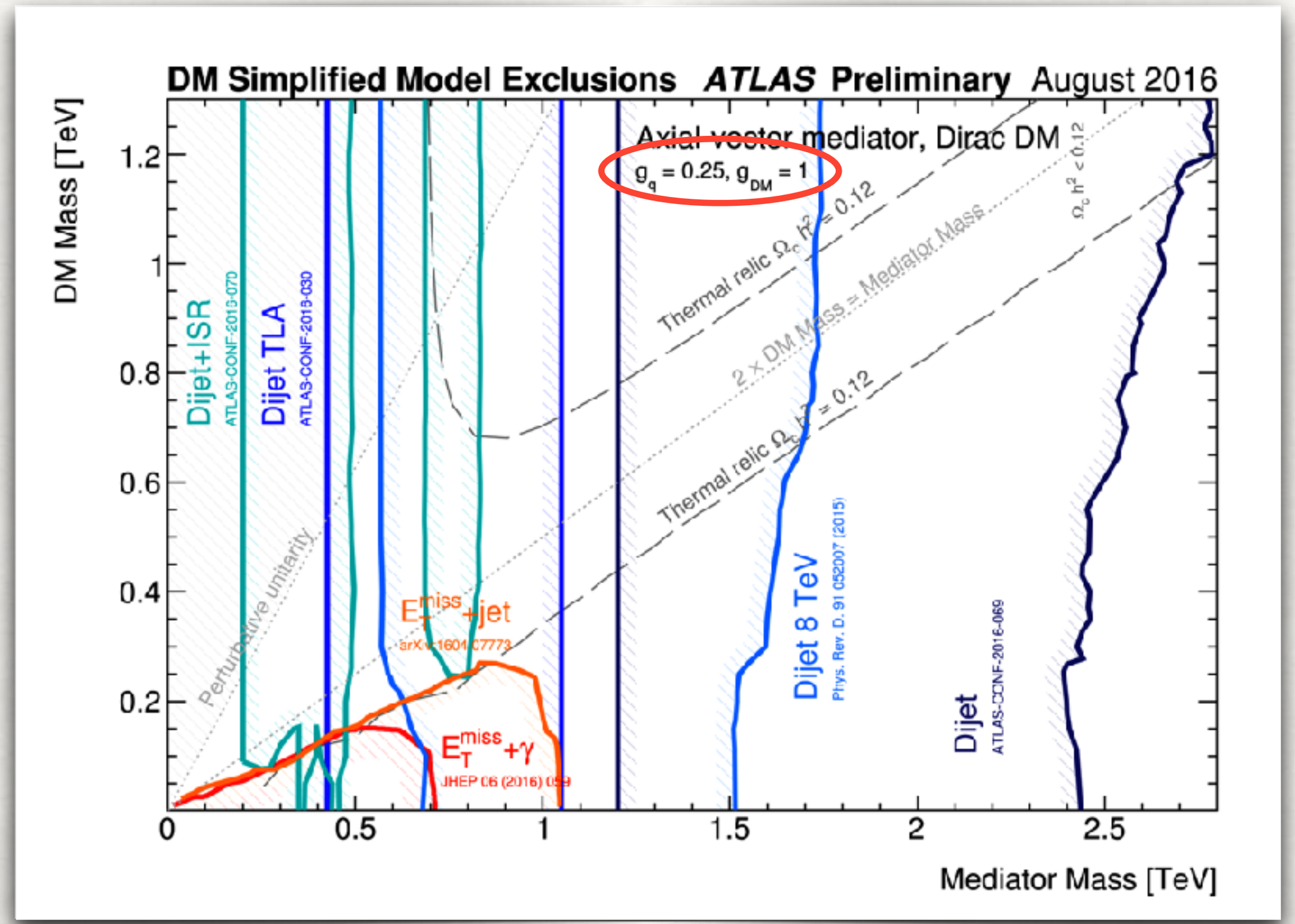

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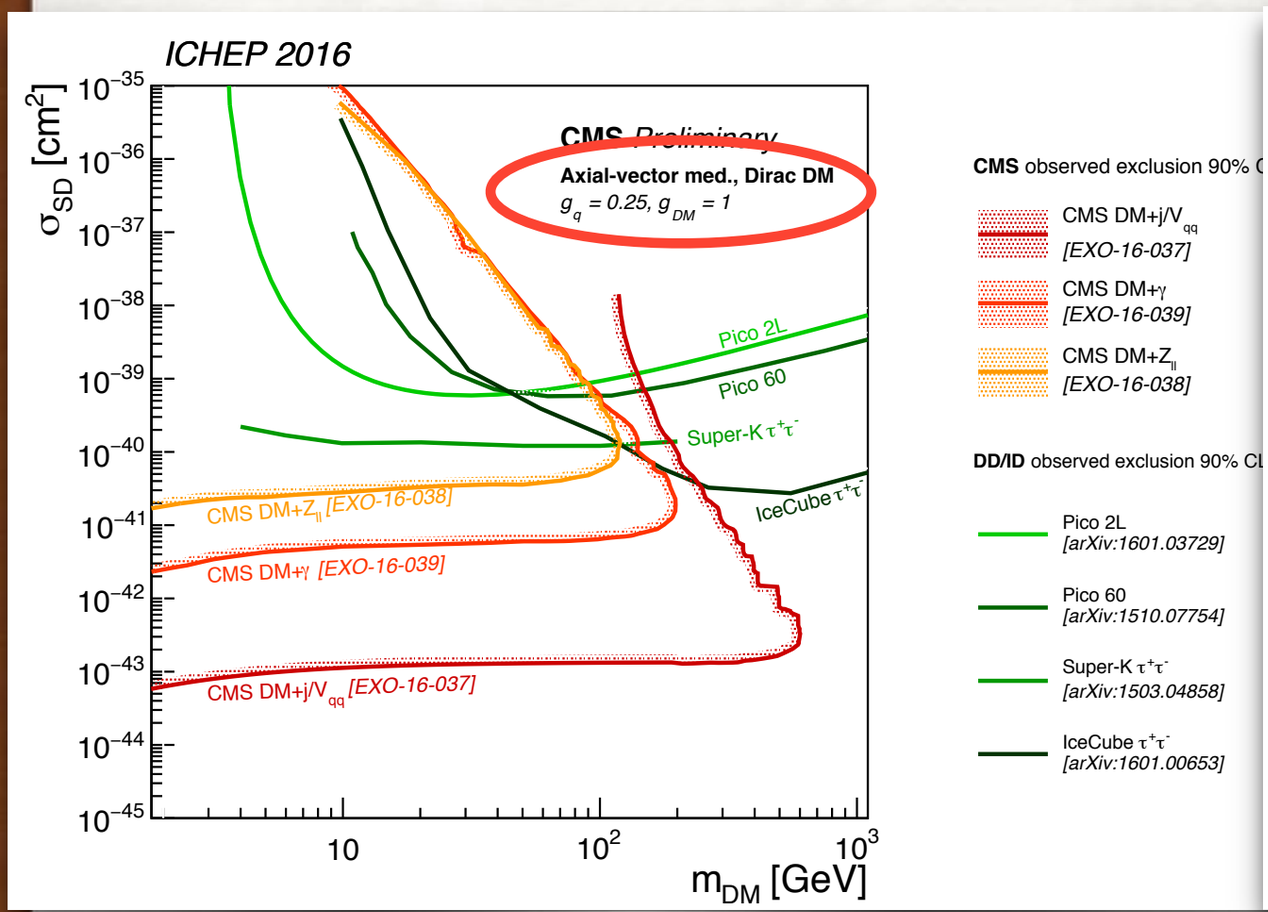

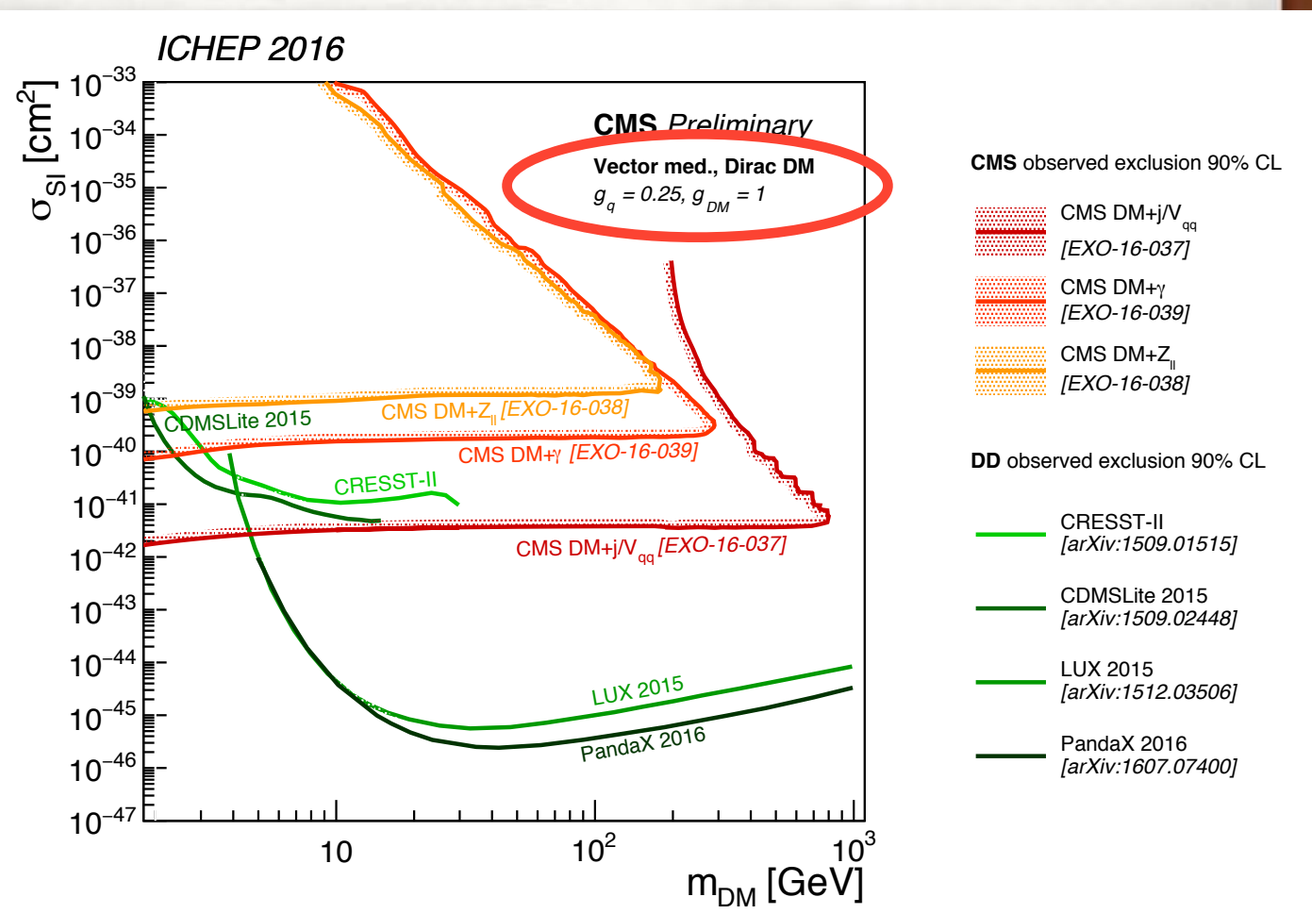

Parameters chosen to make mono-X look best against DD and non-mono-X LHC searches (di-jets here)

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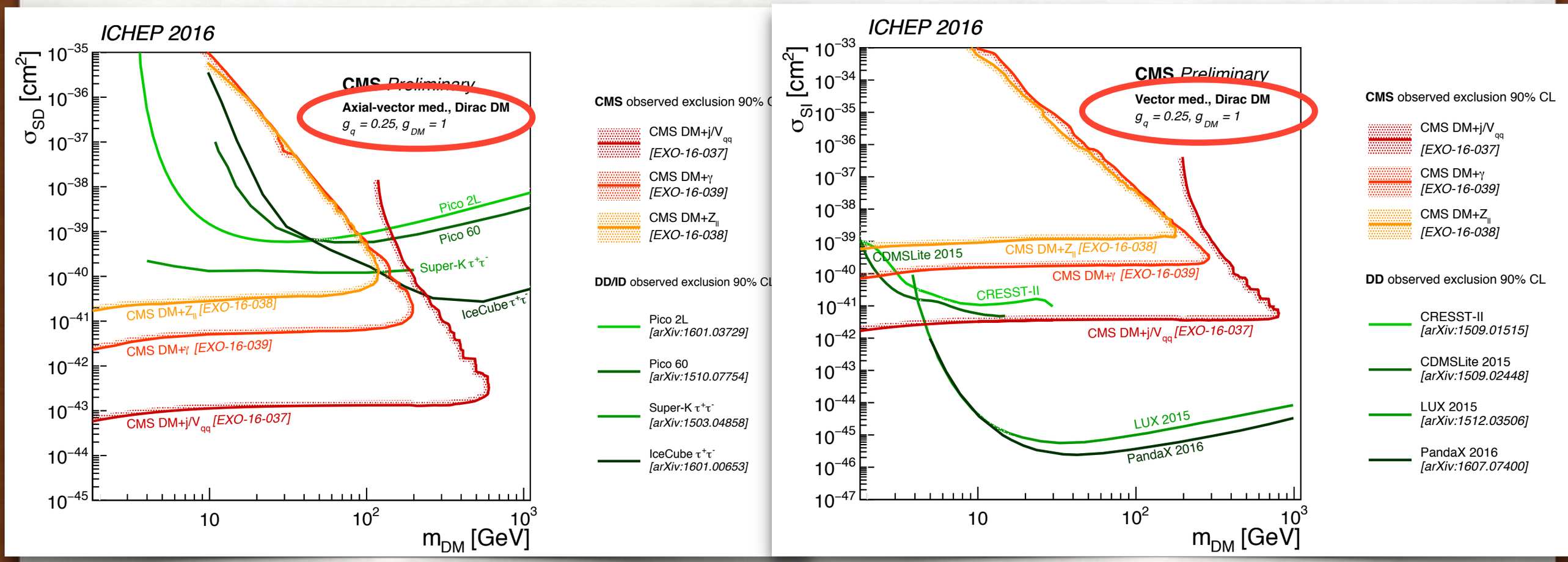
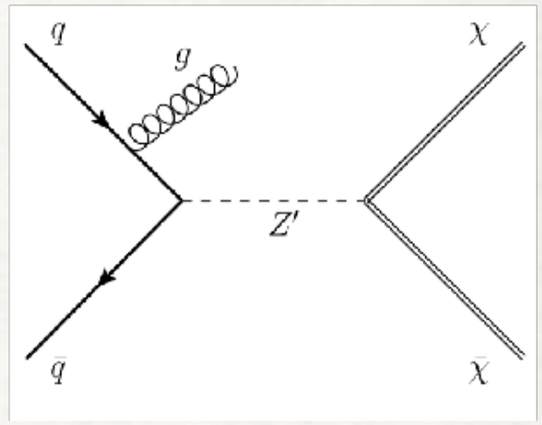


Parameters chosen to make mono-X look best against DD and non-mono-X LHC searches (di-jets here)

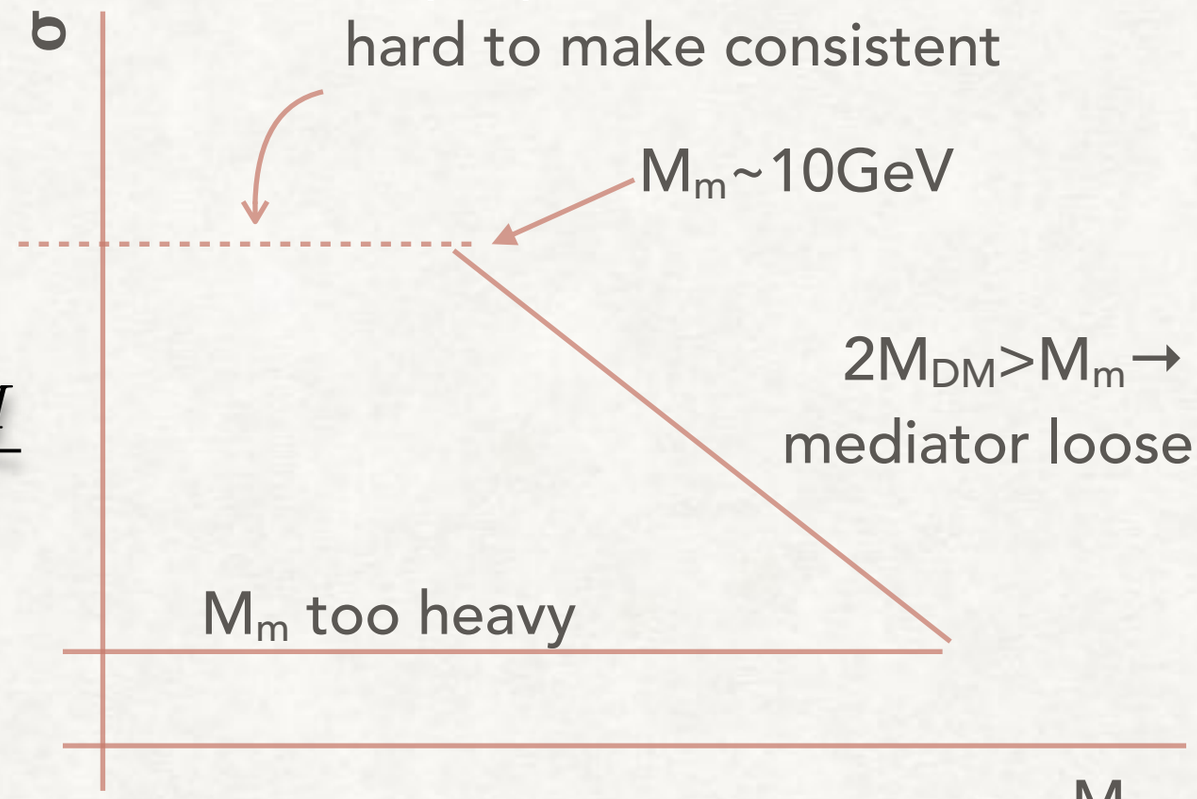
Going forward: expect these limits to improve by O(10) by the end of LHC

HOW TO READ THOSE PLOTS

S-CHANNEL MODEL LIMITS CHEATSHEET



$$\sigma_{DD} \propto \frac{g_q^2 g_{DM}^2}{M_m^4}$$



$$\sigma_{LHC}\Big|_{2M_{DM} \ll M_m} \propto \frac{g_q^2 g_{DM}^2}{g_{DM}^2 + g_q^2} \frac{1}{M_m^{5-6}}$$

$$\sigma_{LHC}\Big|_{2M_{DM} \ll M_m \ll \not{E}_{T,\mathrm{cut}}} \propto \frac{g_q^2 g_{DM}^2}{g_{DM}^2 + g_q^2} \frac{1}{\not{E}_{T,\mathrm{cut}}^{5-6}}$$

HOW TO READ THOSE PLOTS

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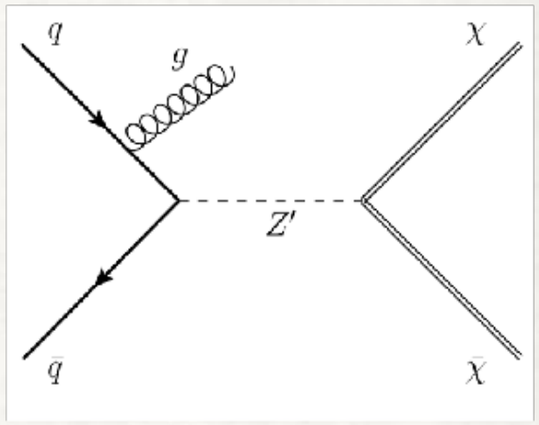

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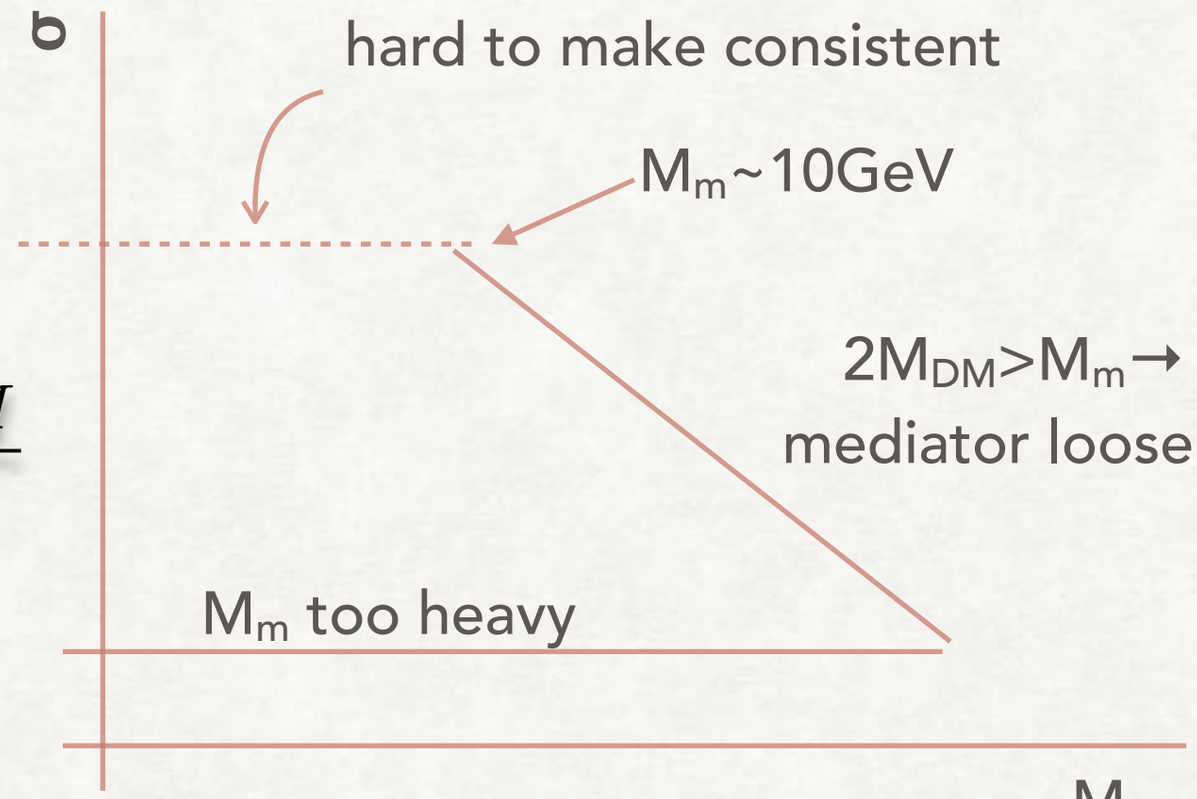


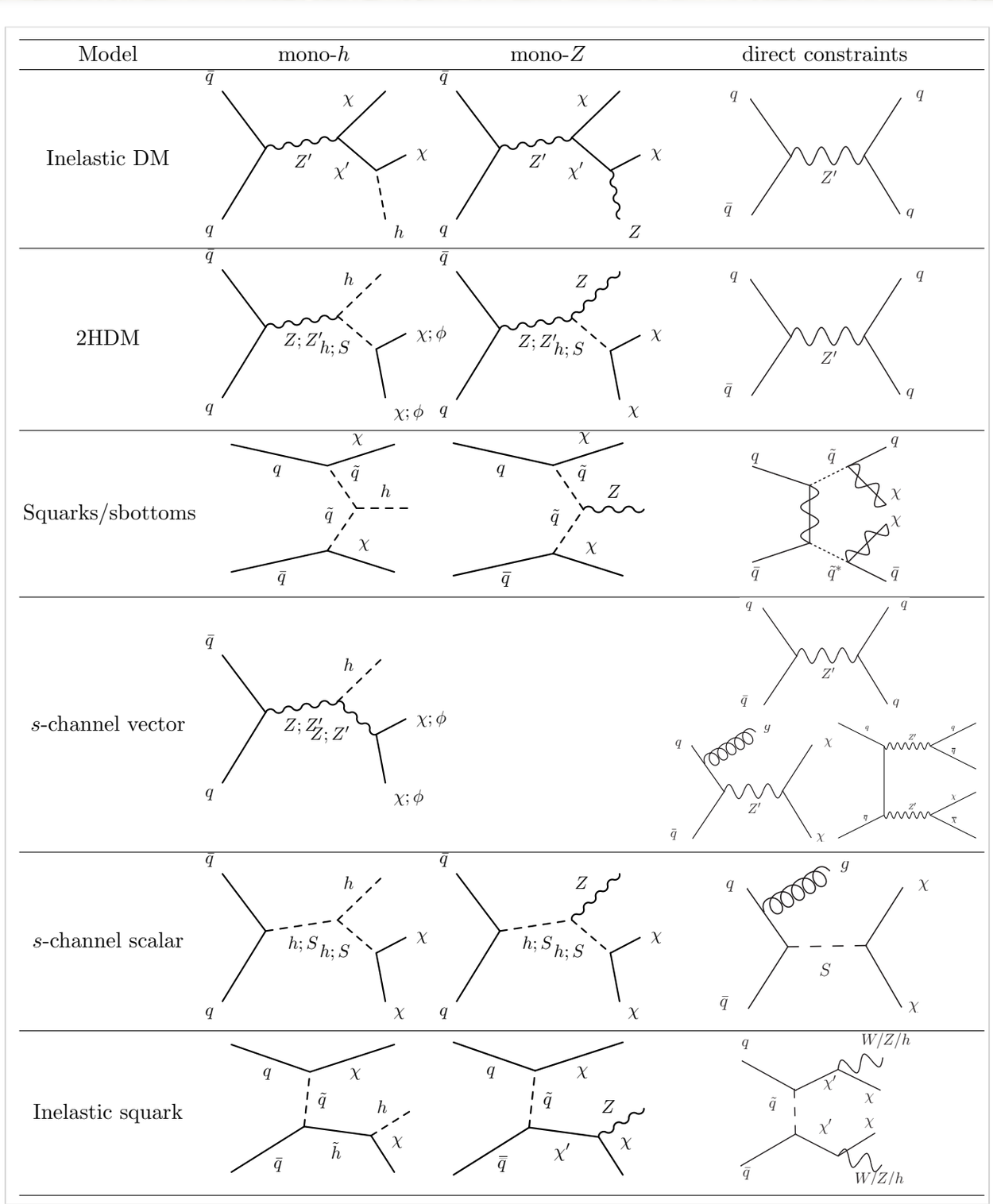
keep lowering g_q and M_m together and LHC limits disappear altogether!!

$$\sigma_{LHC}\Big|_{2M_{DM} \ll M_m} \propto \frac{g_q^2 g_{DM}^2}{g_{DM}^2 + g_q^2} \frac{1}{M_m^{5-6}}$$

$$\sigma_{LHC}\Big|_{2M_{DM} \ll M_m \ll \not{E}_{T,\mathrm{cut}}} \propto \frac{g_q^2 g_{DM}^2}{g_{DM}^2 + g_q^2} \frac{1}{\not{E}_{T,\mathrm{cut}}^{5-6}}$$

MONO-Z,W,H

- Only useful for models when Z,W,H comes from decay of mediator(s)
- Many models can provide these mono-X signatures, but they are competitive against other searches only in a few of them



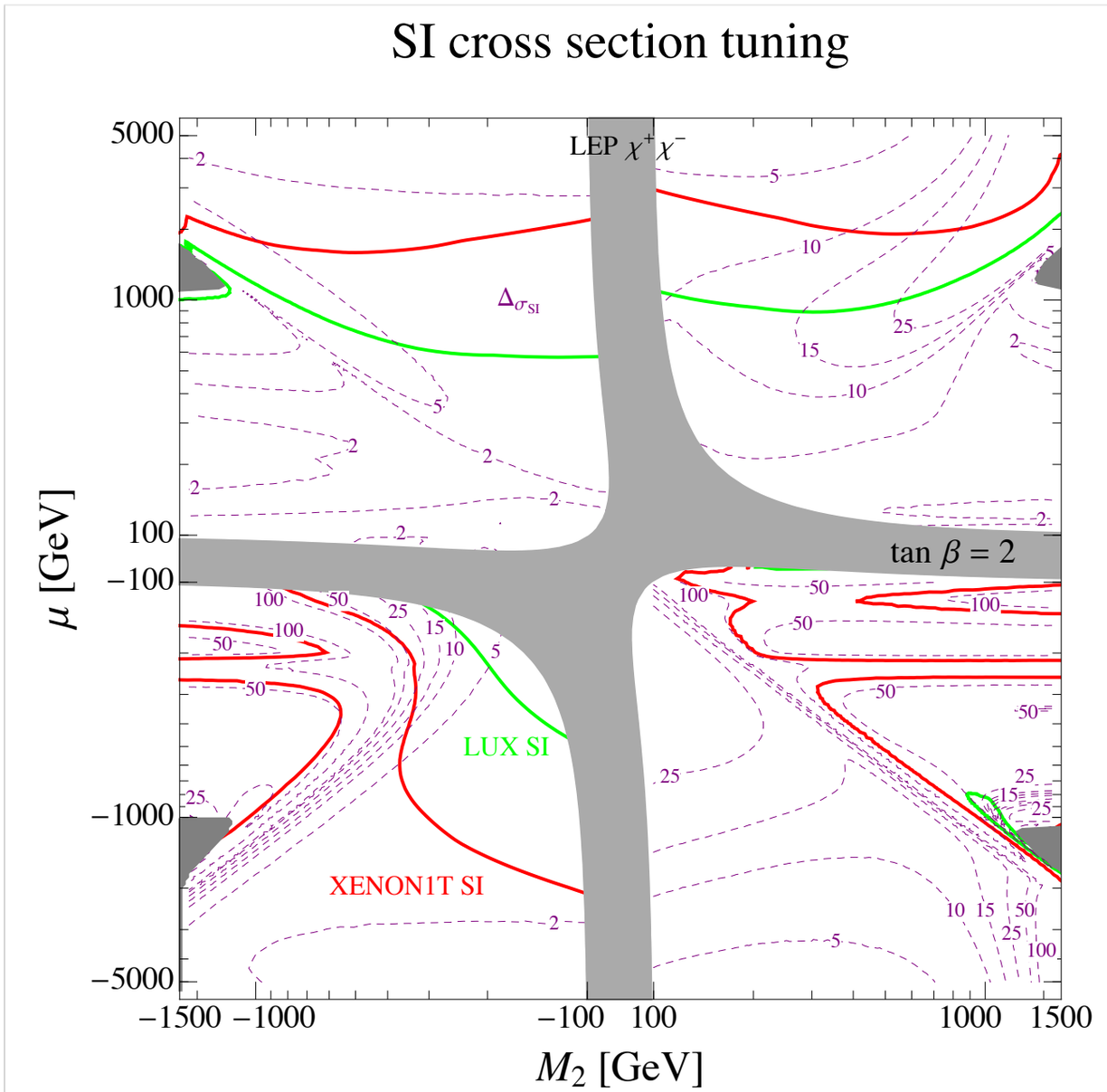
Liew,MP,Vichi,Zurek

SPECIFIC MODELS: WIMP DM

"ELECTROWEAKINOS"

see G. Kribs talk

- DM as Combination of Weak Singlet+Doublet+Triplet (a la MSSM)
- Relevant for Direct Detection: there are points in parameter space where DM coupling to Z and Higgs can be tuned to vanish (for non-tuned pure state case as a target see Graham's talk)
- Pushing σ_N down makes these models progressively more tuned → never excludable but less and less compelling (like the finetuning story for the Higgs)
- By end of 1T-scale experiments, tuning in 1 part in 100 territory



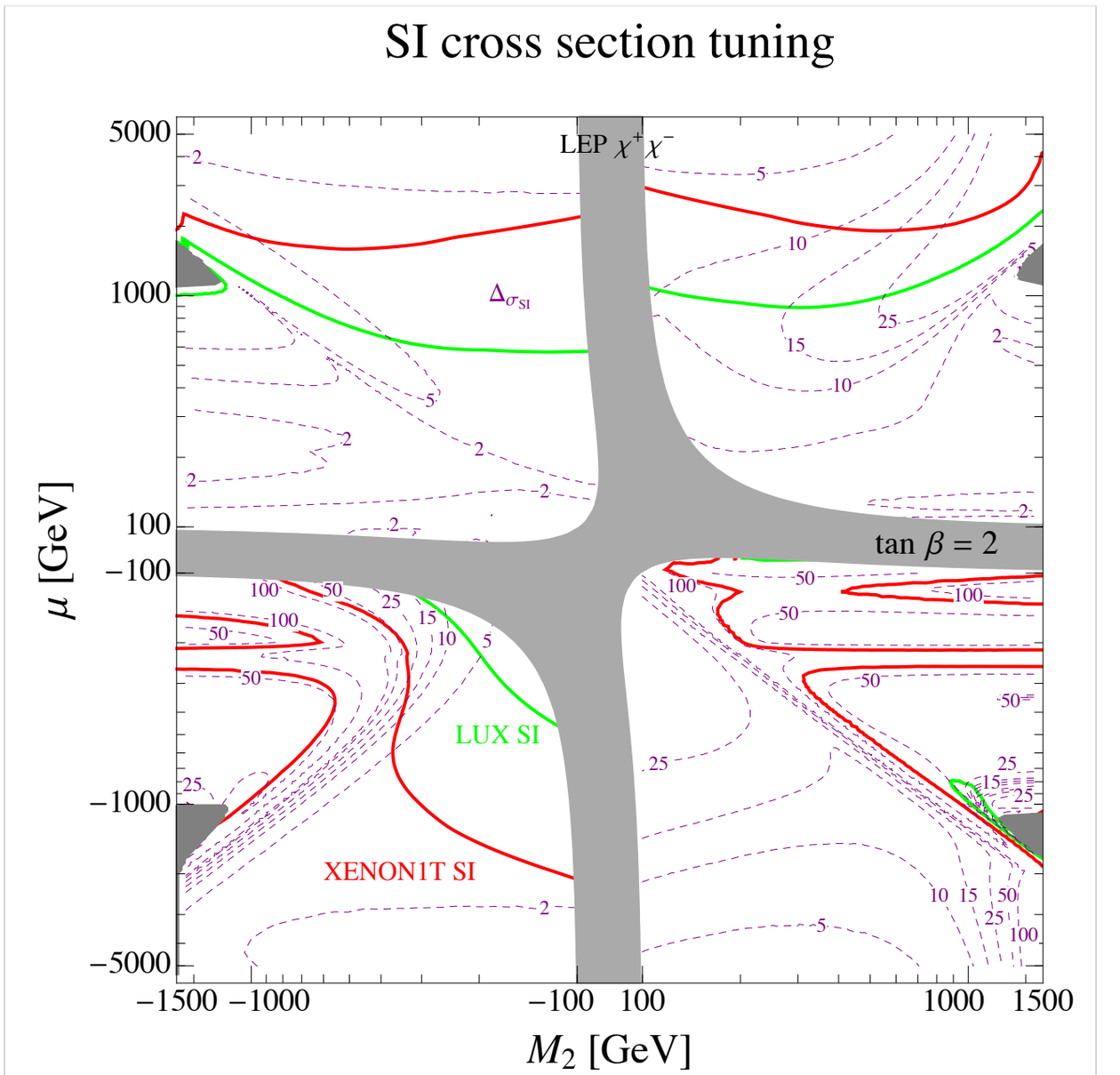
Cheung, Hall, Pinner, Ruderman

SPECIFIC MODELS: WIMP DM

"ELECTROWEAKINOS"

see G. Kribs talk

- One can tune out DM interactions with Z and h, but cannot also tune out electroweak couplings of DM partners (charginos and other neutralinos)
- LHC can produce those and probe the blind spot regions IF -inos are not too heavy
- projected limits are well below TeV for LHC reach
- for heavier masses indirect detection a possibility

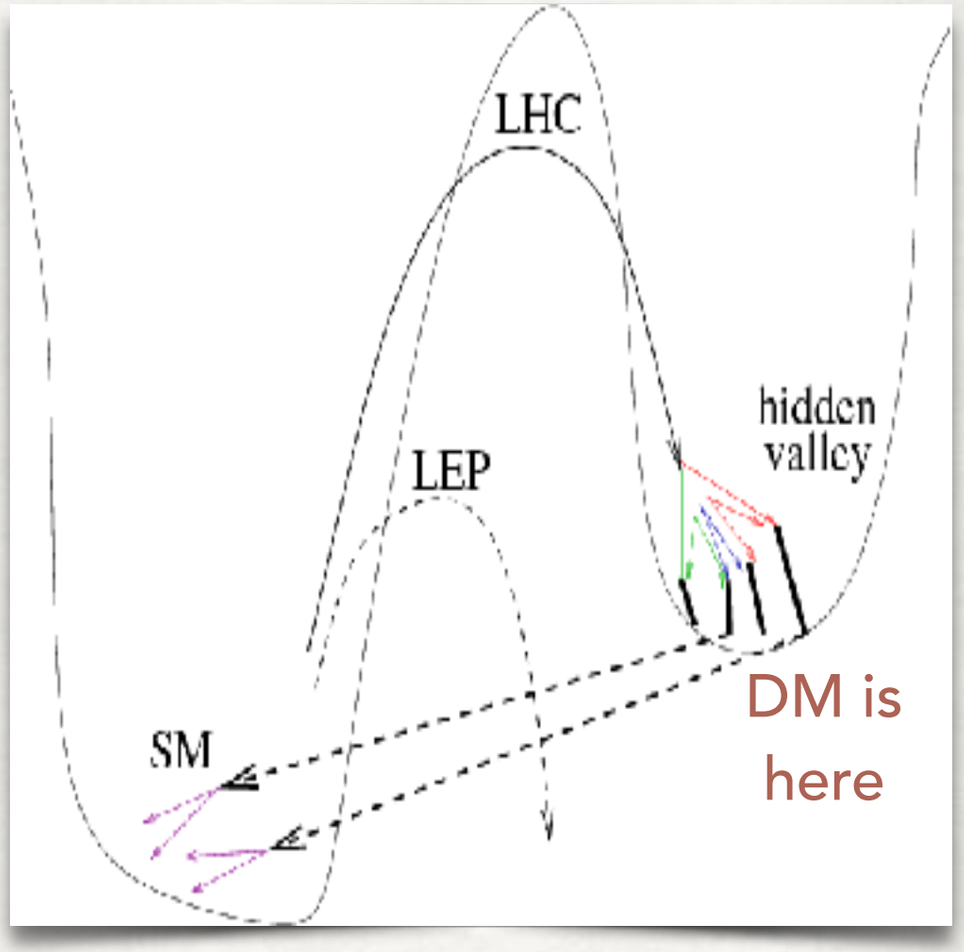


Cheung, Hall, Pinner, Ruderman

HIDDEN SECTOR DM & LHC

(HIDDEN VALLEYS & CO)

- LHC has advantage if heavy mediators are in energy range
  - in general spectacular long cascades of SUSY-like signals with or without long lived particles
- Limits on different interactions than used in Direct Det.' → orthogonal plane in parameter space
- If no heavy mediators in reach:
  - <10GeV mediators (dark photons, etc.) are best probed at intensity frontier exp'
  - 10-100GeV LHC may improve over LEP in the long run? (work needed)



DM @ LHC VS DIRECT DET

- LHC has the potential for probing Dark Matter at and below the weak scale
- It is really a "mediator" machine → best limits if the particles mediating DM interactions with the SM are heavy but in the energy range of the LHC (few x 100 GeV → few x TeV)
- LHC is sensitive on the structure of interactions → Effective operator approach is too simplistic to convert limits to σ_{DD} vs m_{DM}
- Direct detection and LHC are complementary strategies and plenty of parameter space to probe (even at low DM mass) with DD even after LHC has ended its program

“


KEEP
CALM
AND
DIR. DETECT
ON

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