WARSAW, OCT/2014

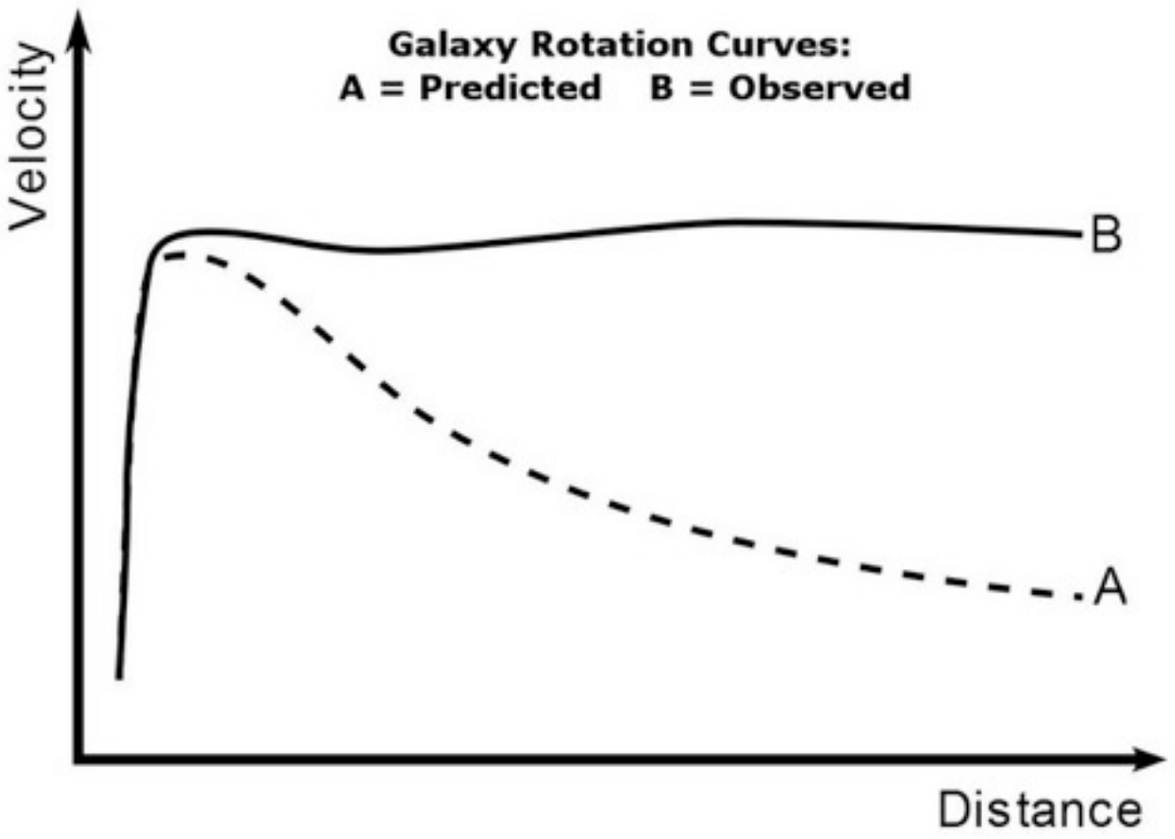
"SIMPLIFIED DARK MATTER MODELS FOR LHC ANALYSES"

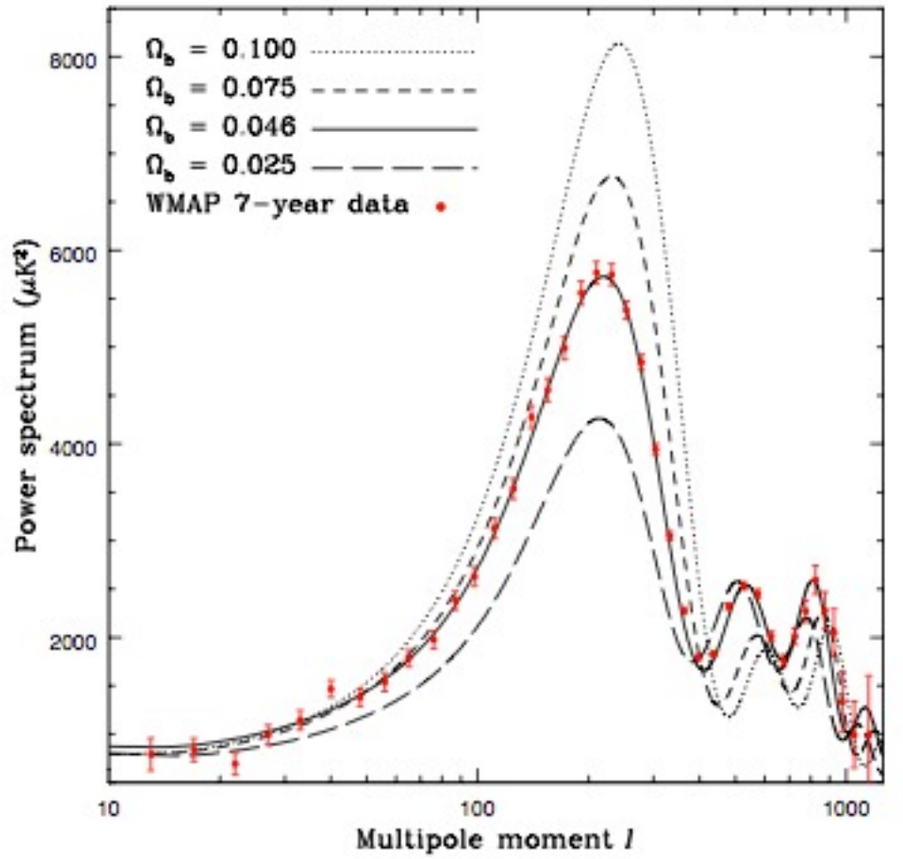
B. ZALDIVAR

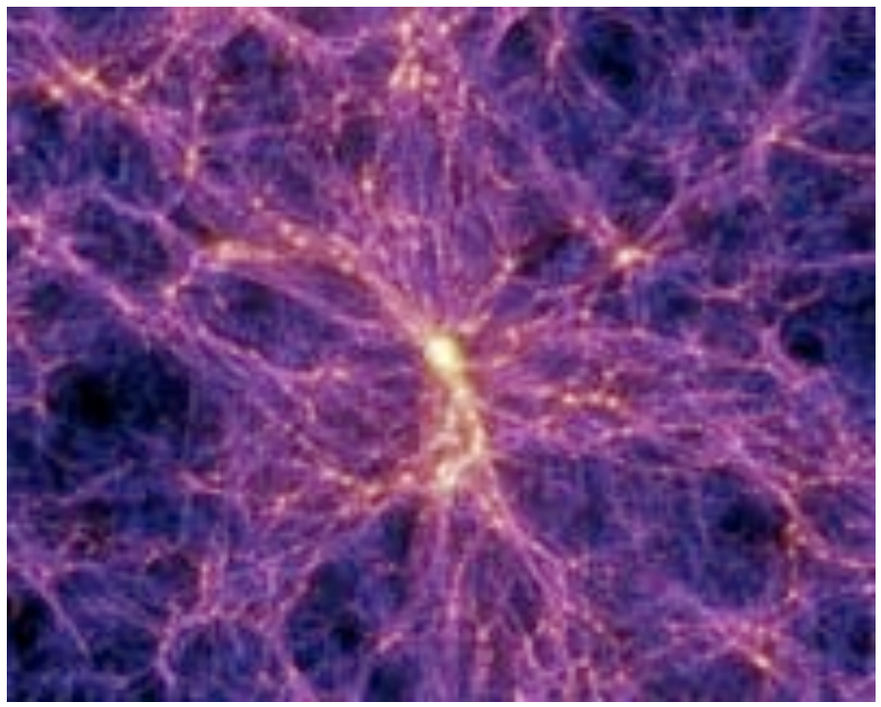
UNIVERSITÉ LIBRE DE BRUXELLES

BELGIUM

A ONE MINUTE MOTIVATION







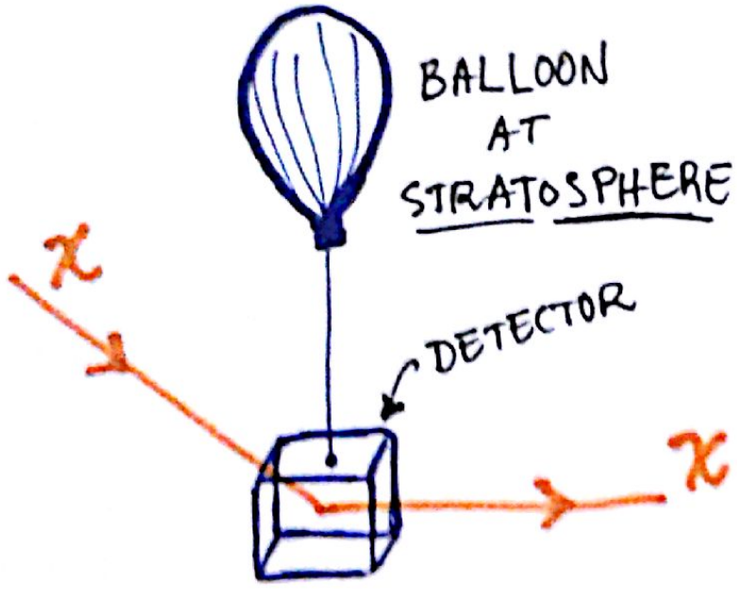
WHAT DO WE KNOW ABOUT DM ?

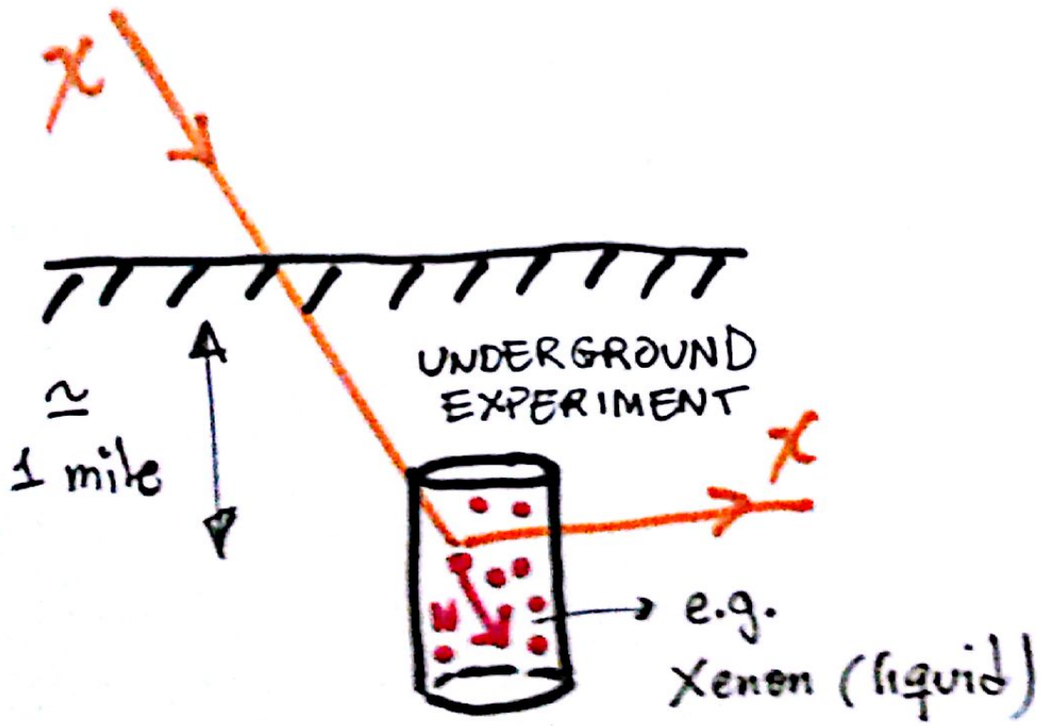
* At least gravitationally interacting
* Stable (or very very long lived) → decaying DM ... many authors...
* Electrically neutral (or at most millicharged) → T. Hambye, C. Kouvaris, G. Shiv, ...

BUT...

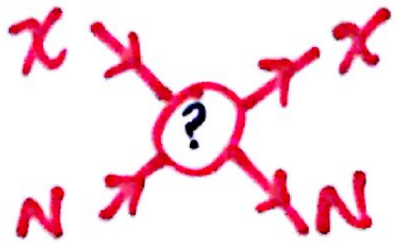
- A fundamental particle ? → Maybe not ("Macro DM", "quark nuggets", ...)
- Other types of interaction ?? ⟹ ELECTROWEAK / MUCH WEAKER ? / STRONGER ?
- Thermal Relic ? Axions, Gravitinos, FIMPs, WIMPzillas, ...
- Mass ??
- ...

HOW DO WE SEARCH FOR DM?

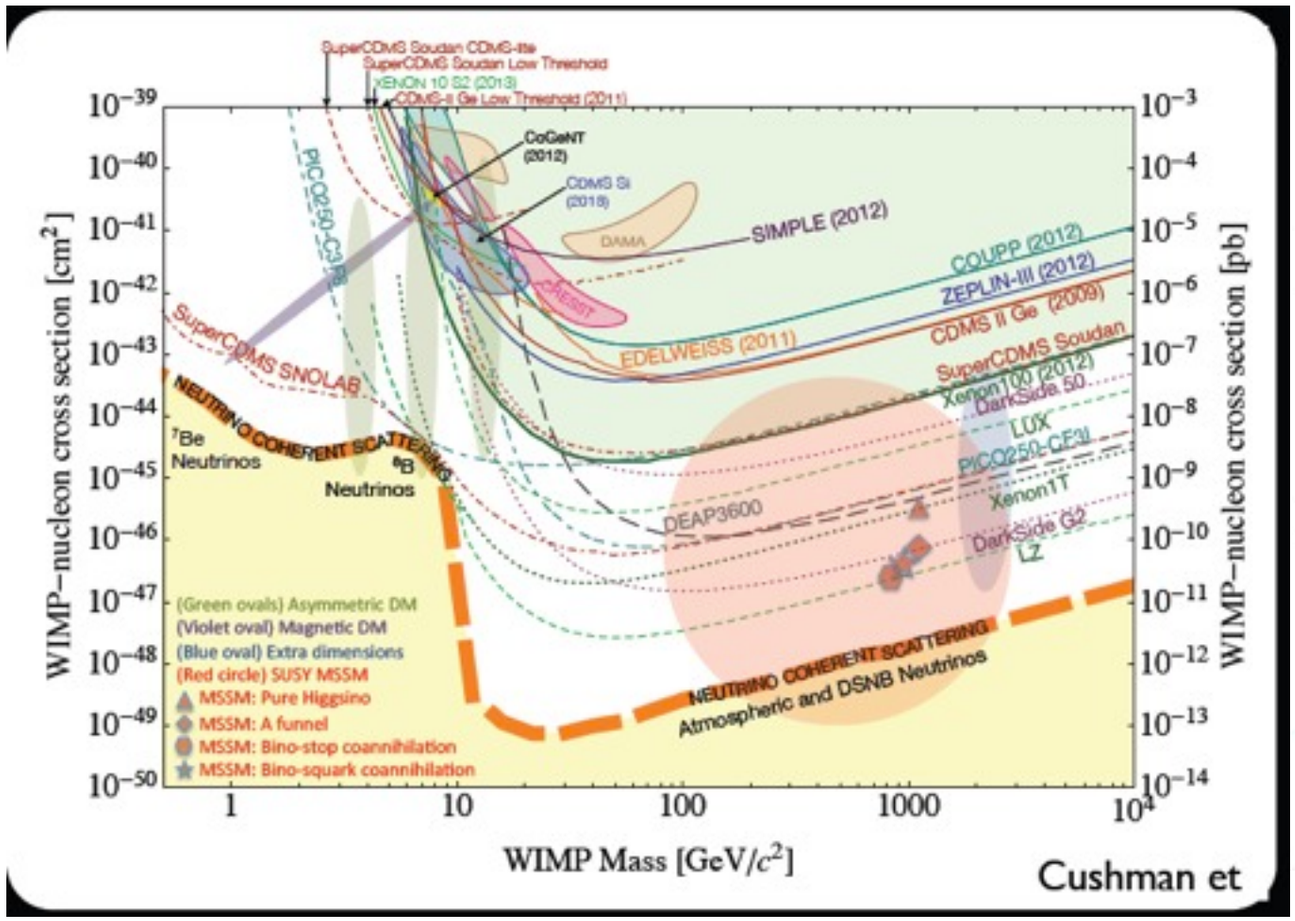




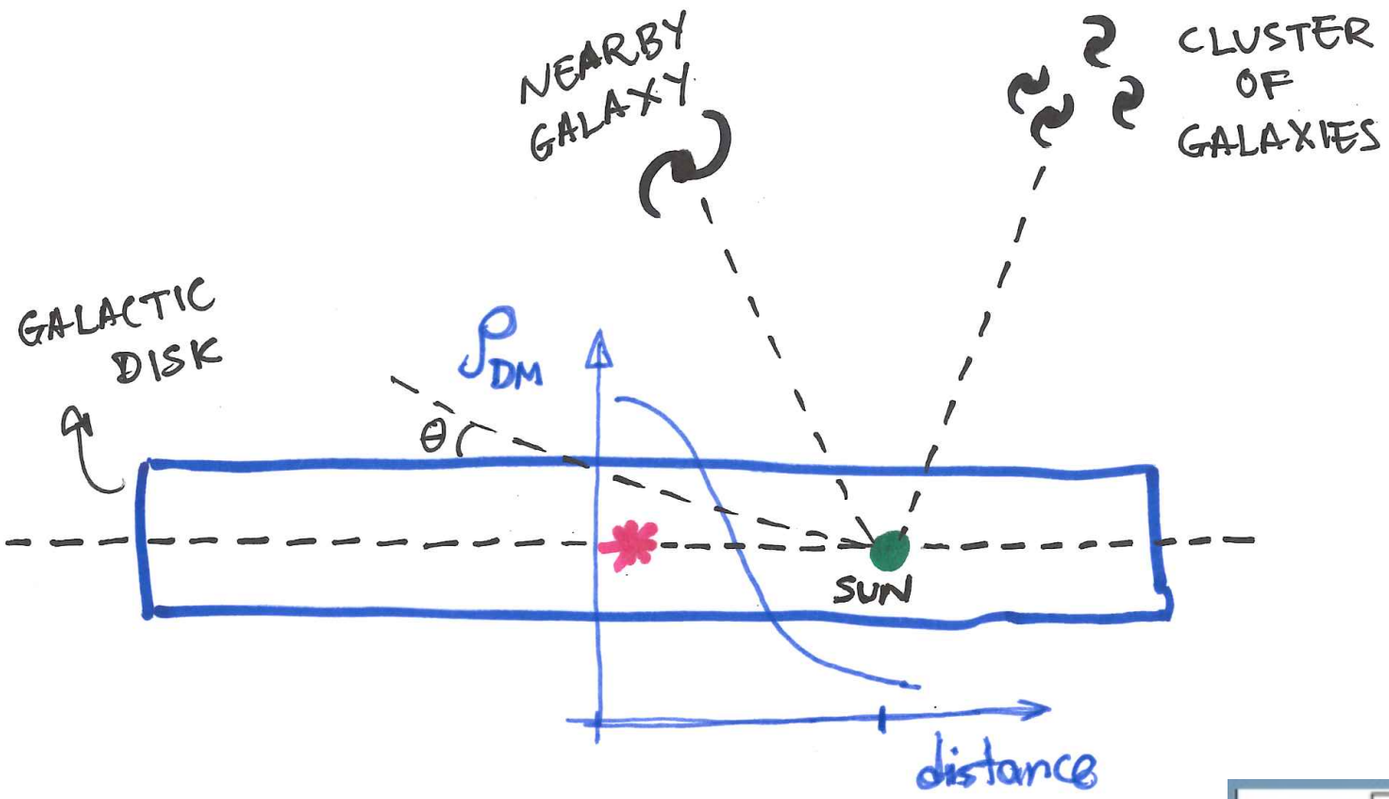
DIRECT DETECTION



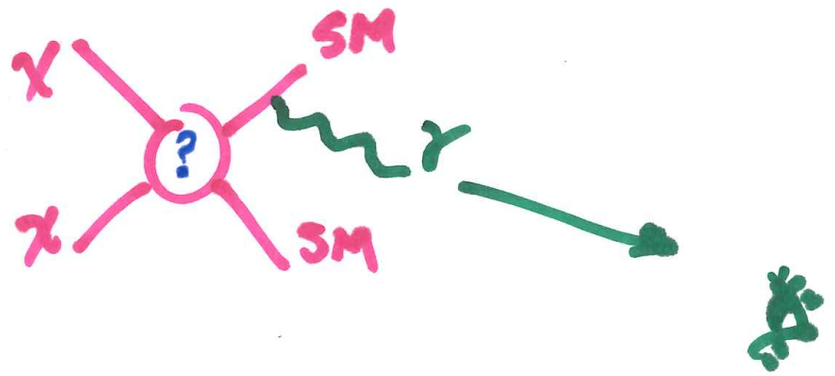
(see Talk by C. Tunnell, "Dark Matter @ LHC" Conference, 2014)



A LESS CONTROLLED STRATEGY



INDIRECT DETECTION

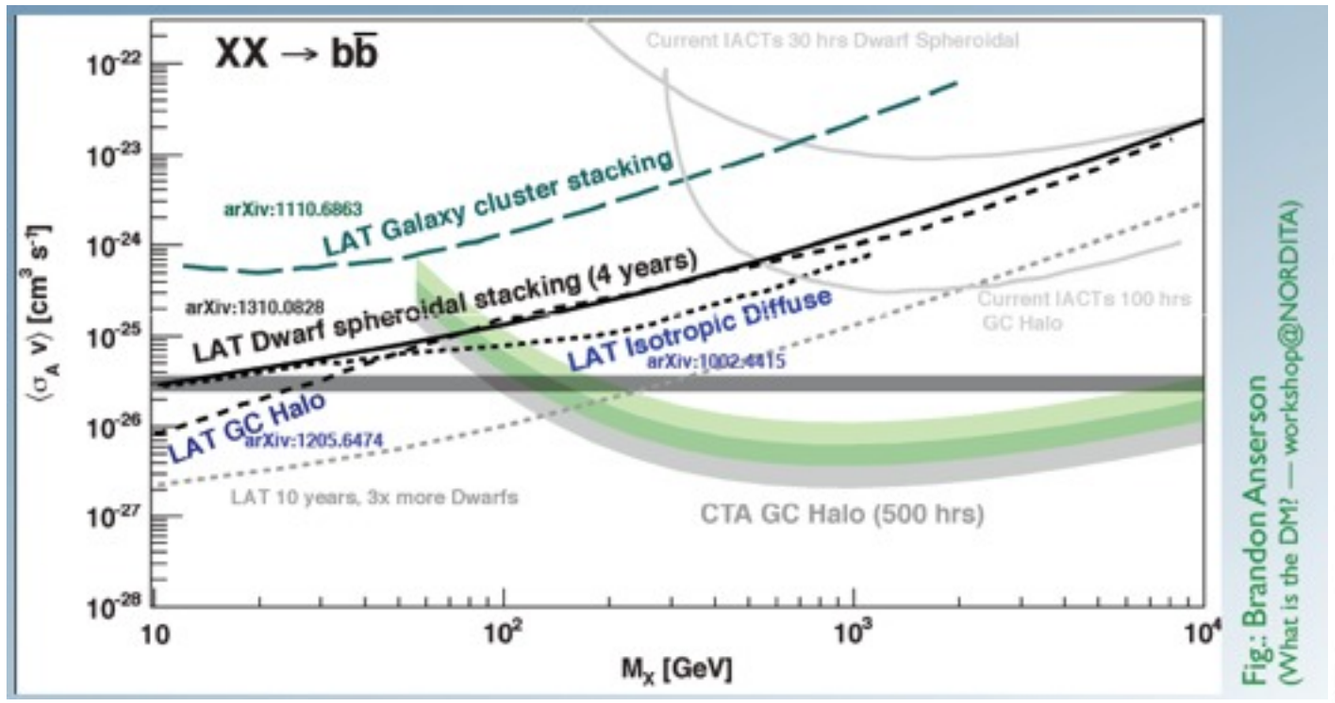


* ASTROPHYSICS NOT QUITE UNDERSTOOD

⇓

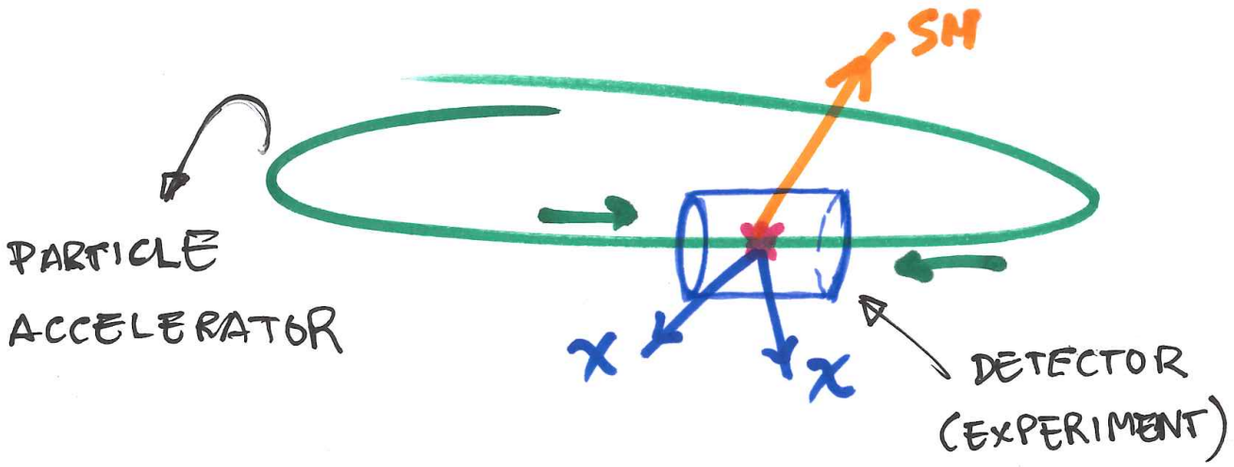
- BACKGROUND MODELLING COMPLICATED

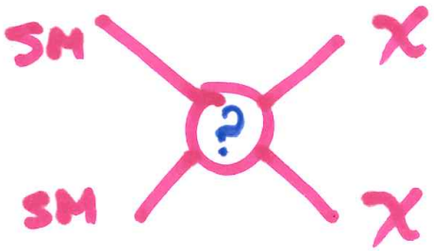
⇒ VERY DIFFICULT TO CLAIM DISCOVERY



A VERY CONTROLLED ENVIRONMENT

DARK MATTER PRODUCTION AT COLLIDERS





$$pp \to \underbrace{\chi + \bar{\chi}}_{\text{STABLE}} + SM$$

⇓

INVISIBLE TO DETECTORS!!

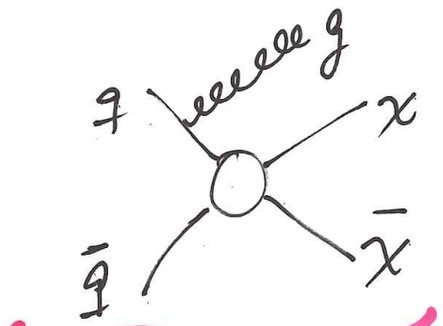
$pp \to SM + \underbrace{\not{E}_T}_{\text{missing energy}}$

- 1, 2, 3, 4 jets
- .... leptons
- photons

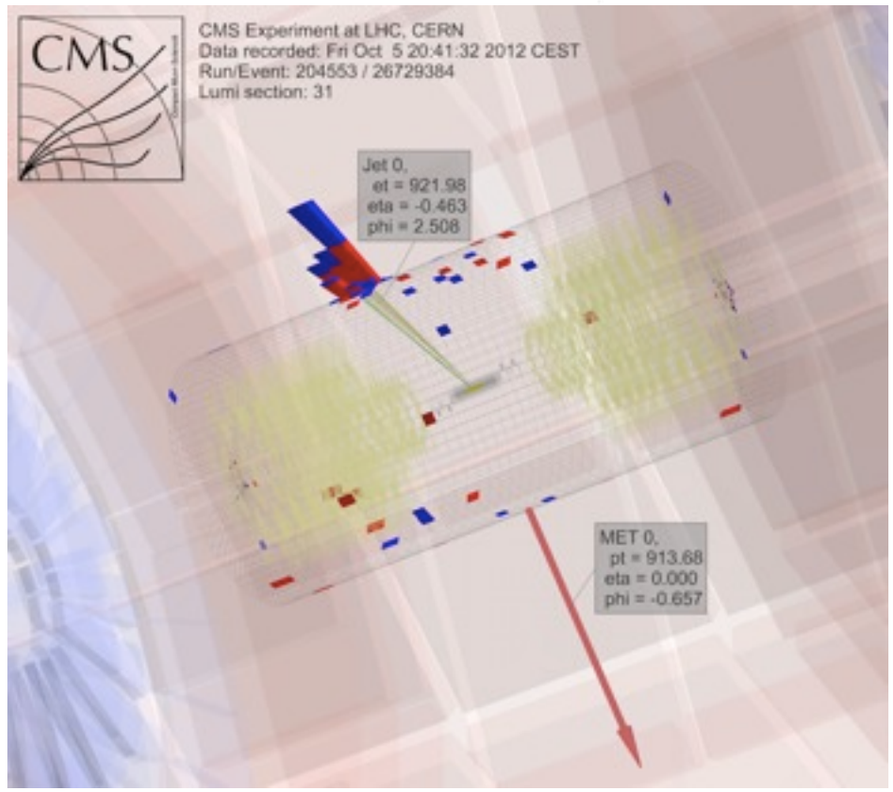
$\not{E}_T$ DOES NOT MEAN IT IS DARK MATTER!

HERE:

$$pp \to (1j, 1\gamma, 1l, \ldots) + \not{E}_T$$



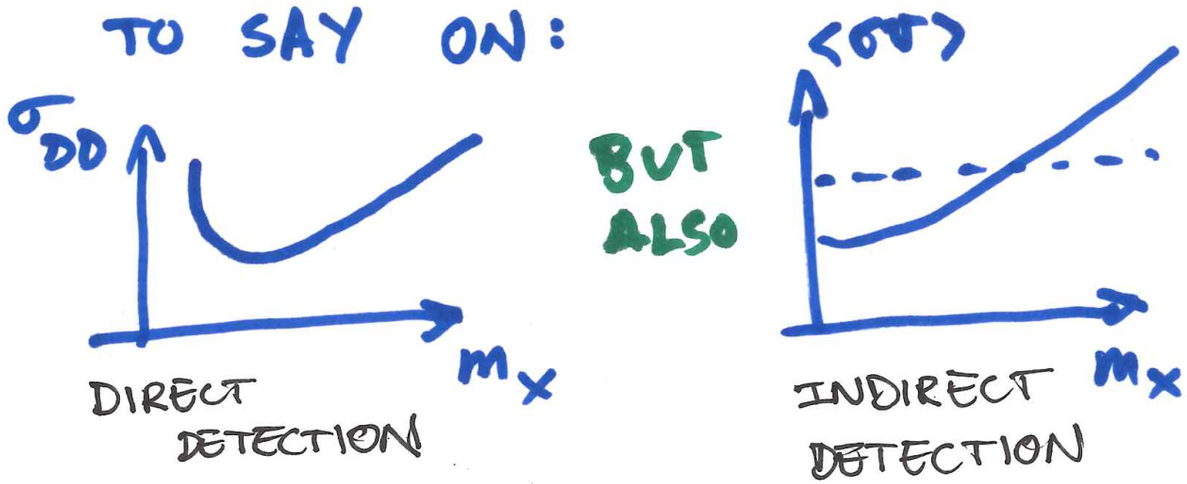
These are the cleanest topologies!!



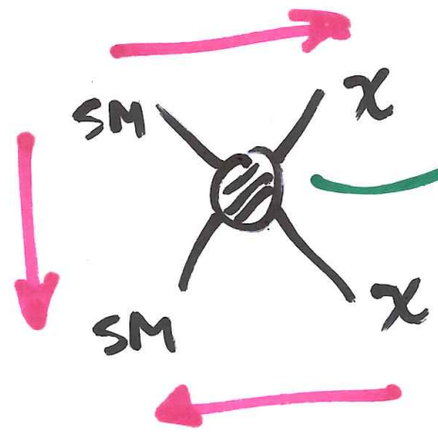
WHAT IF $\not{E}_T$ IS DARK MATTER ?

* LINK TO OTHER (DARK MATTER-SPECIFIC) SEARCHES IS MANDATORY !

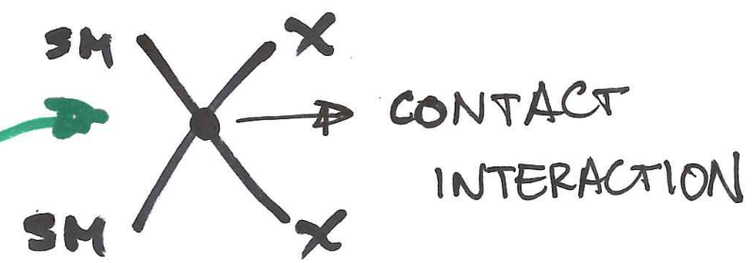
WHAT DOES LHC HAVE TO SAY ON:



* INTRODUCTION OF MODEL-DEPENDENCE IS UNAVOIDABLE



THE "SIMPLEST" PROPOSAL: EFFECTIVE FIELD THEORY



e.g. $$\mathcal{O} = \frac{1}{\Lambda^2}(\bar{\chi}\Gamma_\mu\chi)(\bar{f}\Gamma^\mu f)$$

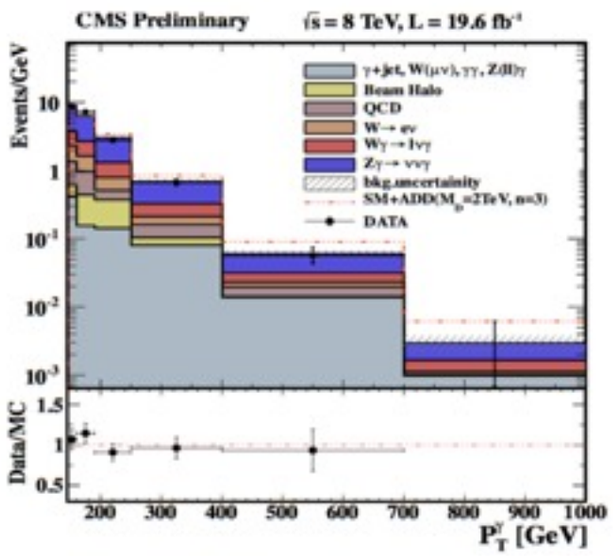
NOW EXPERIMENTALISTS CAN PLAY!

Λ, m_χ

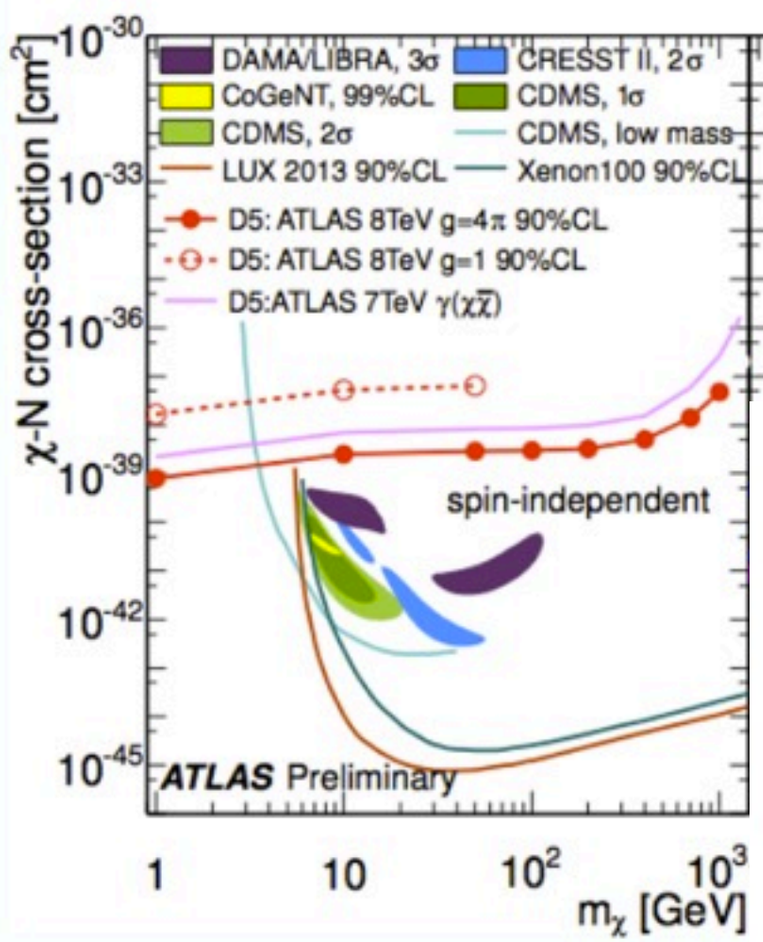
EFFECTIVE FIELD THEORY AT COLLIDERS

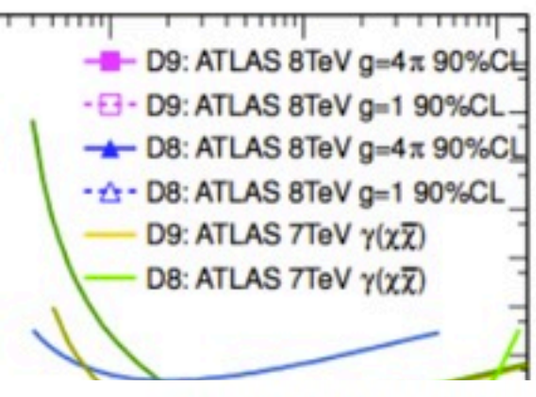
R. LUCAS (DM@LHC, OXFORD)

Look at e.g. P_T:

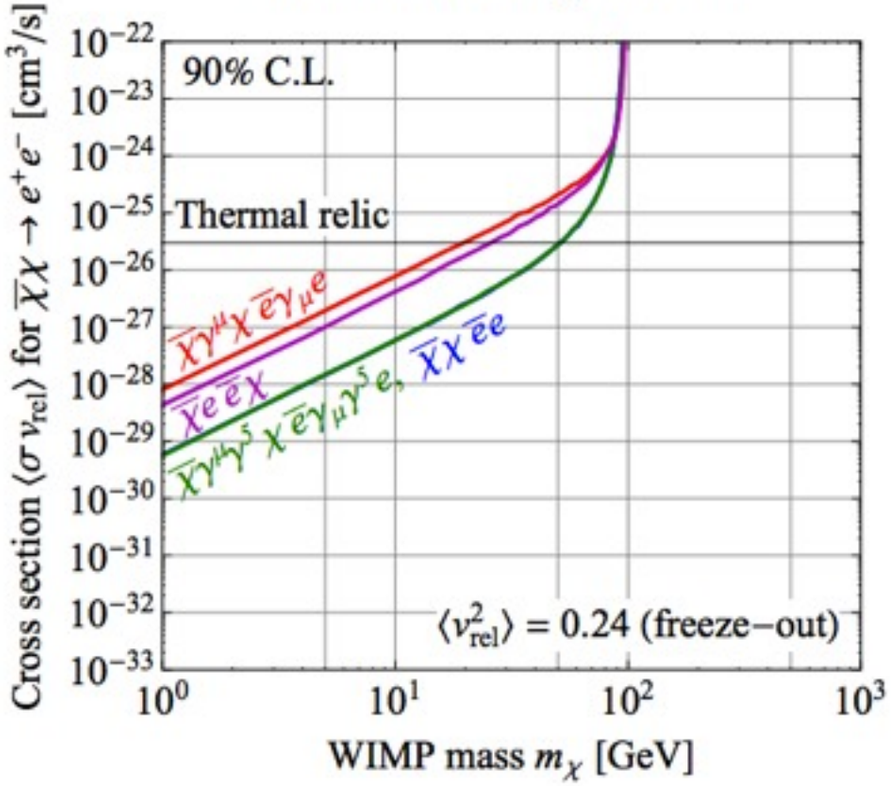


IN THIS FRAMEWORK THIS IS ALL YOU NEED TO MAKE CONNECTION:

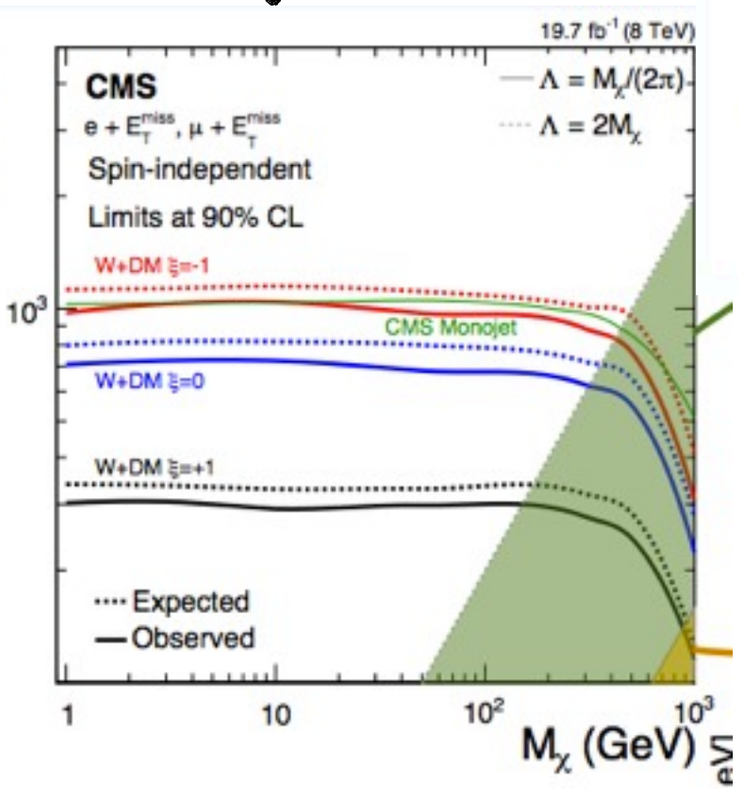




Annihilation only into e^+e^-



FOX ET AL, 1103.0240



S. METE (DM@LHC, OFXORD, 2014)

EXPERIMENTALISTS DON'T LIKE IT ANYMORE?!

BUT... EFT HAS LIMITATIONS!

$$\frac{(\bar{\chi}\chi)(\bar{f}f)}{\Lambda^2} \Rightarrow \Lambda \text{ very large, no dynamics, integrated-out}$$

FOR LHC: $\Lambda \gg p_T > 2m_\chi$

A useful quantification of this:

$$R_\Lambda \equiv \frac{\sigma_{\text{eff}}\big|_{Q_{tr}<\Lambda}}{\sigma_{\text{eff}}}$$

RIOTTO ET AL, 1307.2253

THIS ARE ONLY LIMITATIONS, A PRIORI THERE IS NOTHING WRONG WITH EFT@LHC

CONSEQUENCES:

AS WE LIKE TO THINK THAT NEW PHYSICS "IS AROUND THE CORNER"

⇓

ABOUT TIME TO GO BEYOND EFT

⇓

SIMPLIFIED MODELS OF DARK MATTER

↓

PASHION EXPRESSION AUTUMN 2014

SIMPLIFIED MODELS OF DM

* SMDM ≠ FUNDAMENTAL MODELS

UV ——— $\mathcal{L}$ COMPLETE MODEL

LOW ENERGY ——— { SM only ⇒ EFT ; SM ⊕ EXTRA PARTICLES ⇒ SMDM

IN SMDM, NO NEED FOR CONSISTENCY ALL THE WAY TO HIGH ENERGIES

$\Lambda, m_x \rightarrow M, m_x, \lambda_f, \lambda_x$

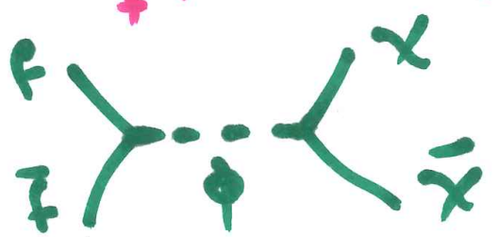
EXPERIMENTALISTS CAN STILL PLAY!!

FOR EXAMPLE:

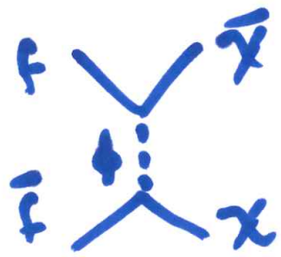
$\mathcal{L}_V^s \supset V_\mu \lambda_f \bar{f} \gamma^\mu f + V_\mu \lambda_x \bar{\chi} \gamma^\mu \chi$ ⇒

} s-channel

$\mathcal{L}_s^s \supset \lambda_f \phi \bar{f} f + \lambda_x \phi \bar{\chi} \chi$ ⇝



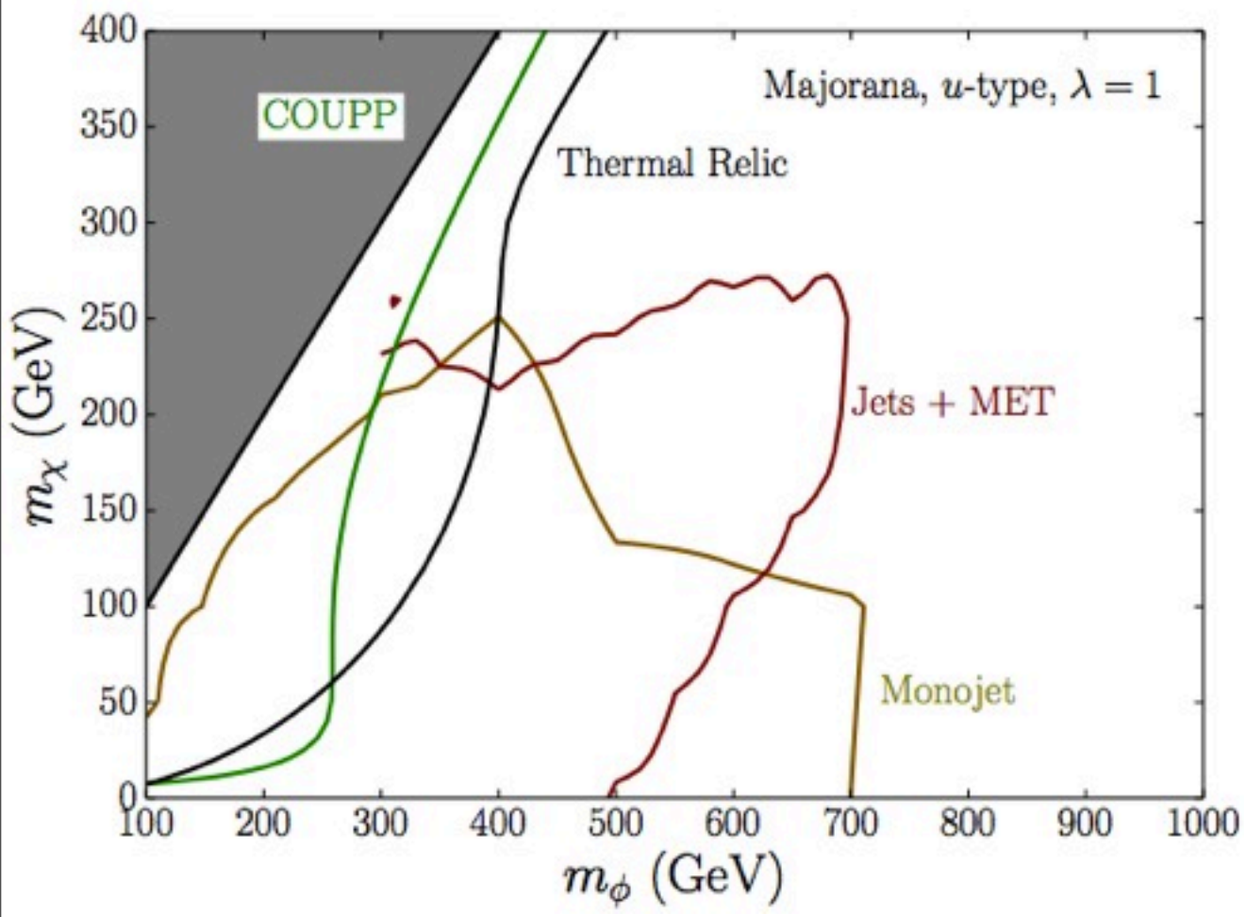
$\mathcal{L}_s^t \supset \lambda \phi \bar{f} \chi$ ↳

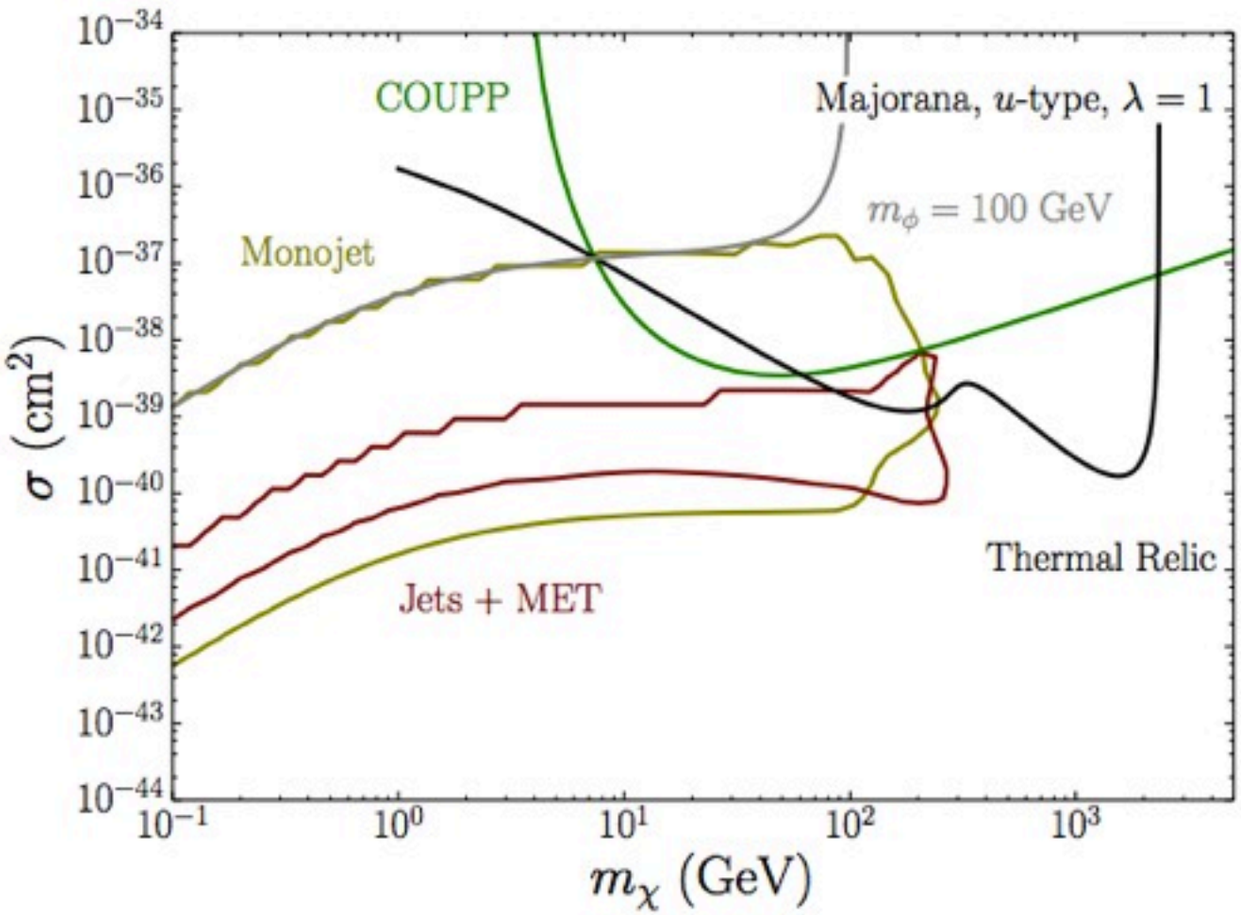


} t-channel

t-Channel

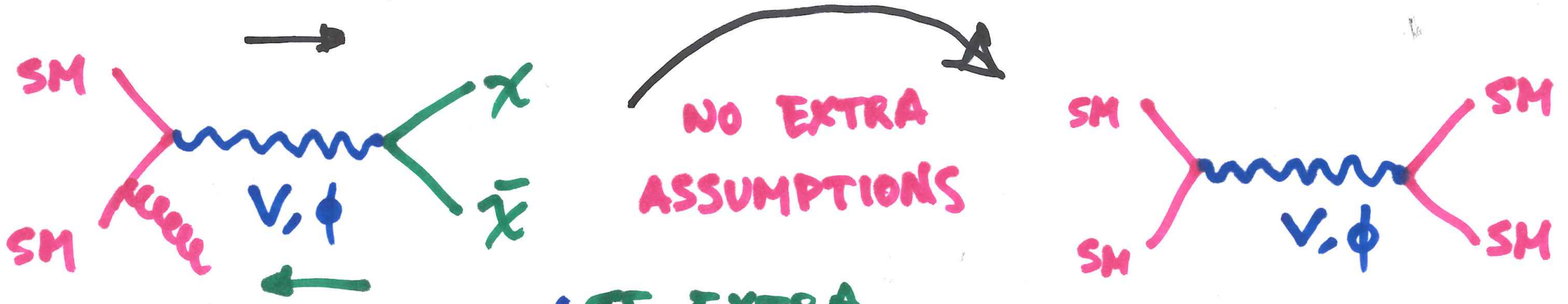
Y. Bai, J. Berger hep-ph/1308.0612





But also Papucci, Vichi, Zurek, 1402.2285

S-Channel



IN COLLABORATION WITH:

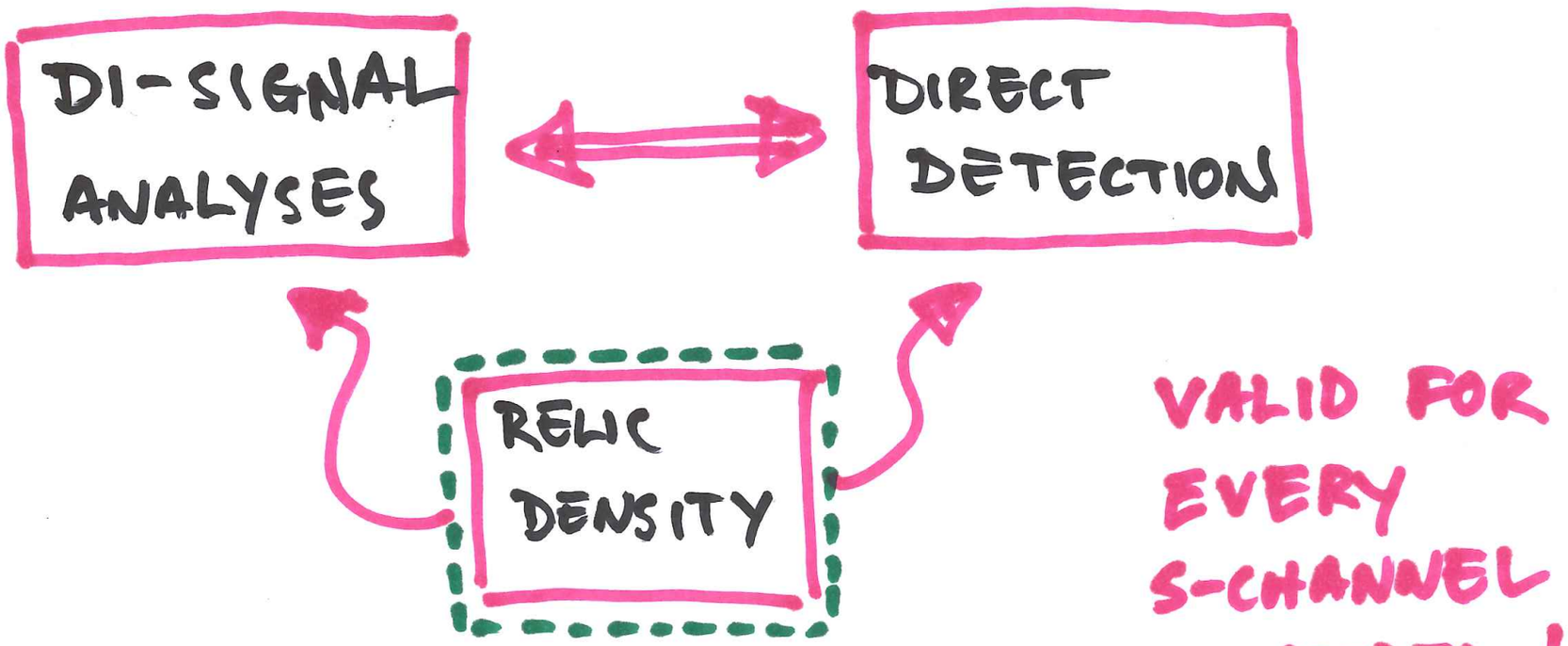
G. Arcadi

M. Badziak

S. Pokorski

M. Tytgat

Y. Mambrini



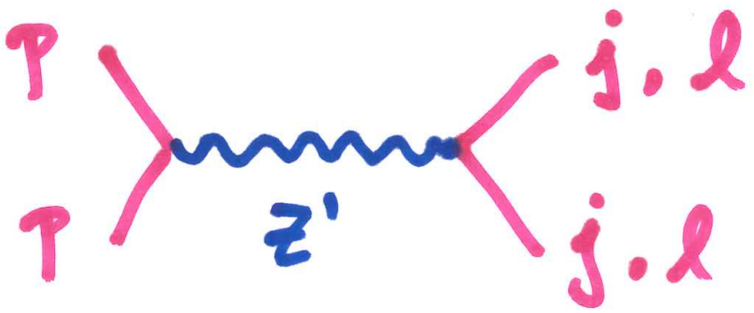
VALID FOR EVERY S-CHANNEL MODEL!

A POPULAR EXAMPLE

- A new boson Z' (neutral)
  - Assume couplings to SM fermions identical to those of Z gauge boson } so-called Sequential Model

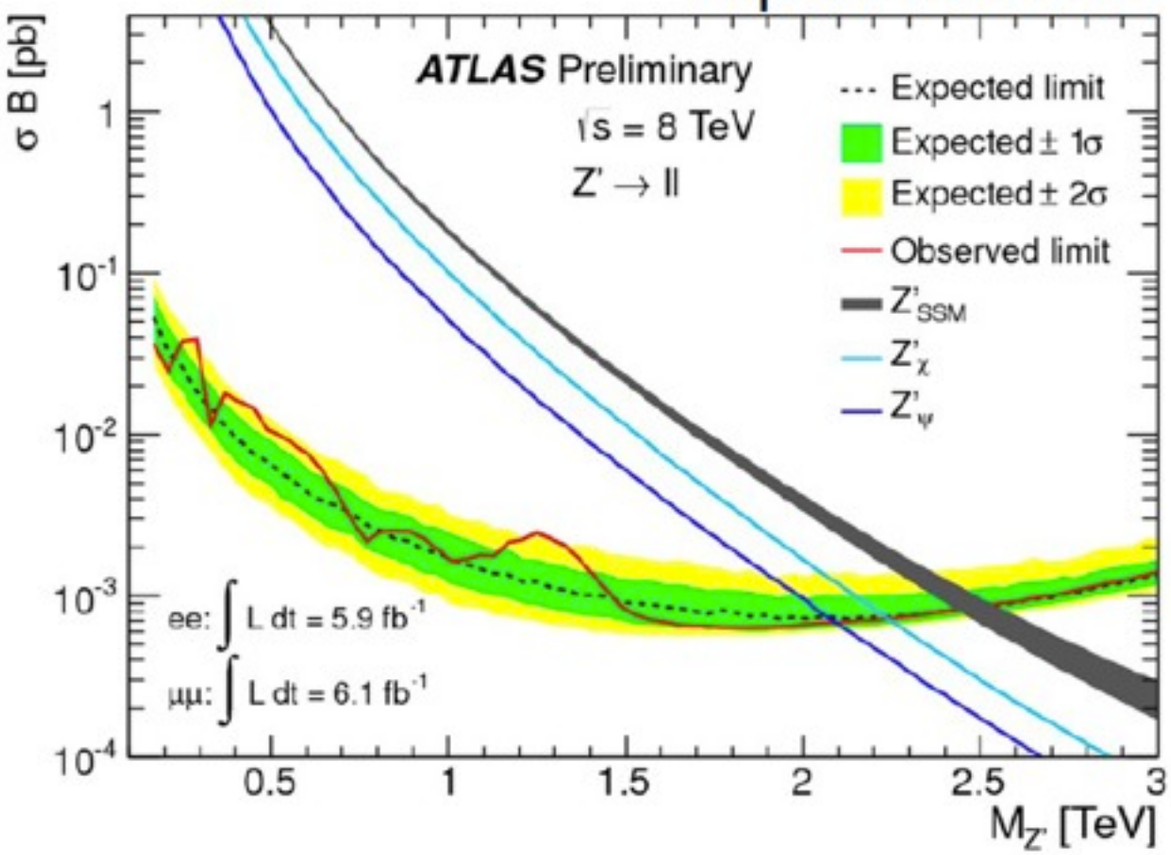
Among the strongest constraints from LHC!

study of RESONANCE production



hep-ex/1212.6175 ⇐ ANALOGOUS RESULT FROM CMS

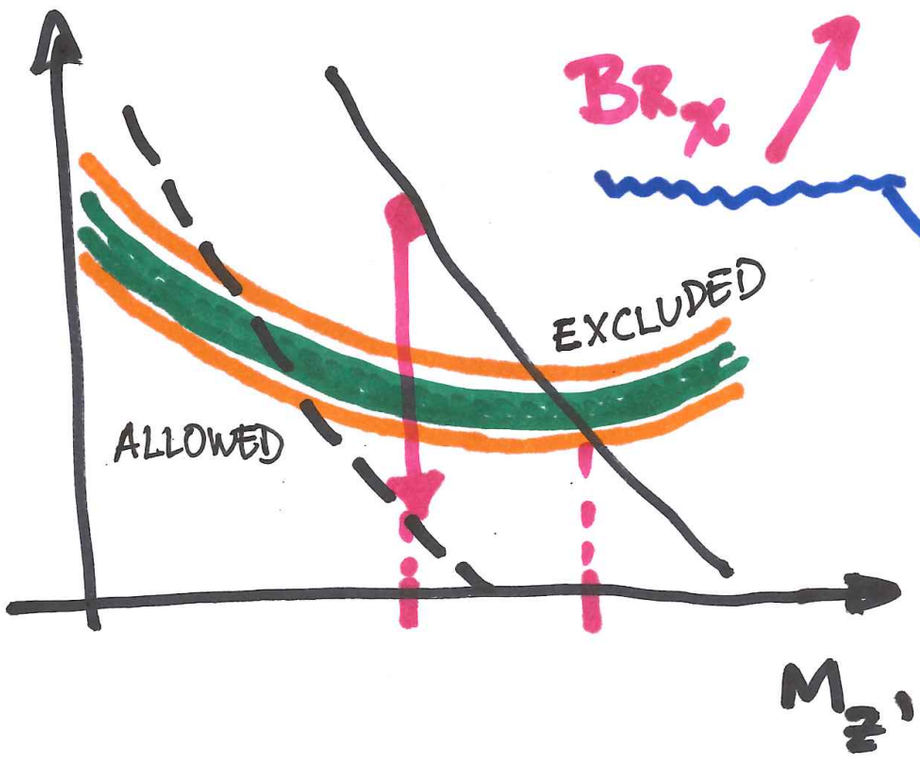
hep-ex/1209.2535



ADDING INVISIBLE BRANCHING

$$\sigma(q\bar{q}\to Z'\to \bar{l}l) \approx \frac{g_D^4}{12\pi}\left(|V_q|^2+|A_q|^2\right)\left(|V_l|^2+|A_l|^2\right) \times \left(\frac{s}{(s-M_{Z'}^2)^2+\Gamma_{Z'}^2 M_{Z'}^2}\right)$$

$$\frac{M_{Z'}}{\Gamma_{Z'}}\pi\delta(s-M_{Z'}^2) = \frac{M_{Z'}}{\Gamma_{Z'}^{SM}}(1-BR_\chi)\pi\delta(s-M_{Z'}^2)$$



CANNOT INCREASE ARBITRARILY :

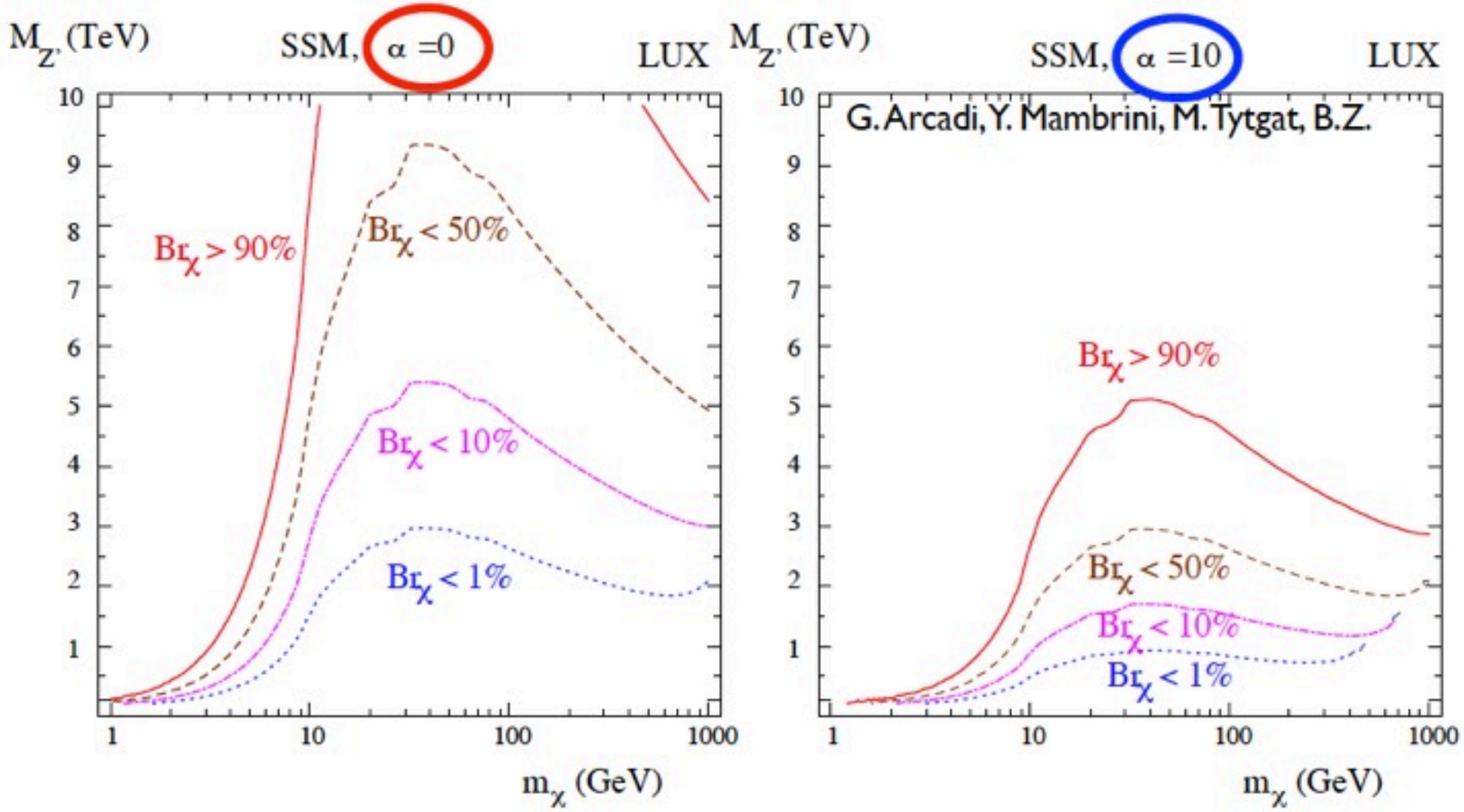
DIRECT DETECTION !

CONSTRAINING $BR_{INVISIBLE}$

$$BR_\chi = \left[1 + \frac{g_D^4}{M_{Z'}^4} \frac{\#}{(1+\alpha^2)\,\sigma_{SI}}\right]^{-1}$$

$$\alpha \equiv \frac{A_\chi}{V_\chi}$$

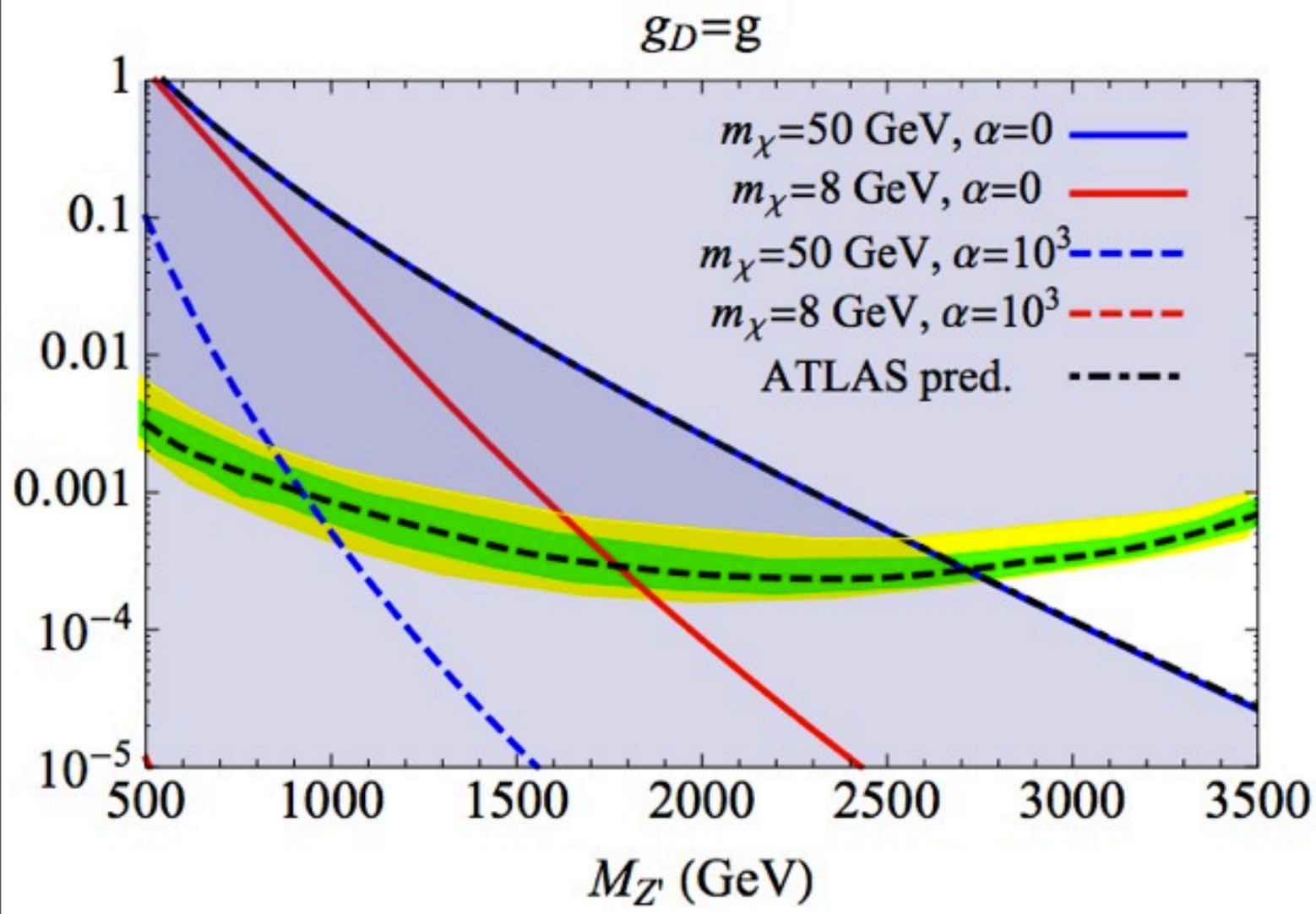
$$\mathcal{L} \supset Z'_\mu \gamma^\mu (V_\chi + \gamma^5 A_\chi) \bar{\chi}\chi$$

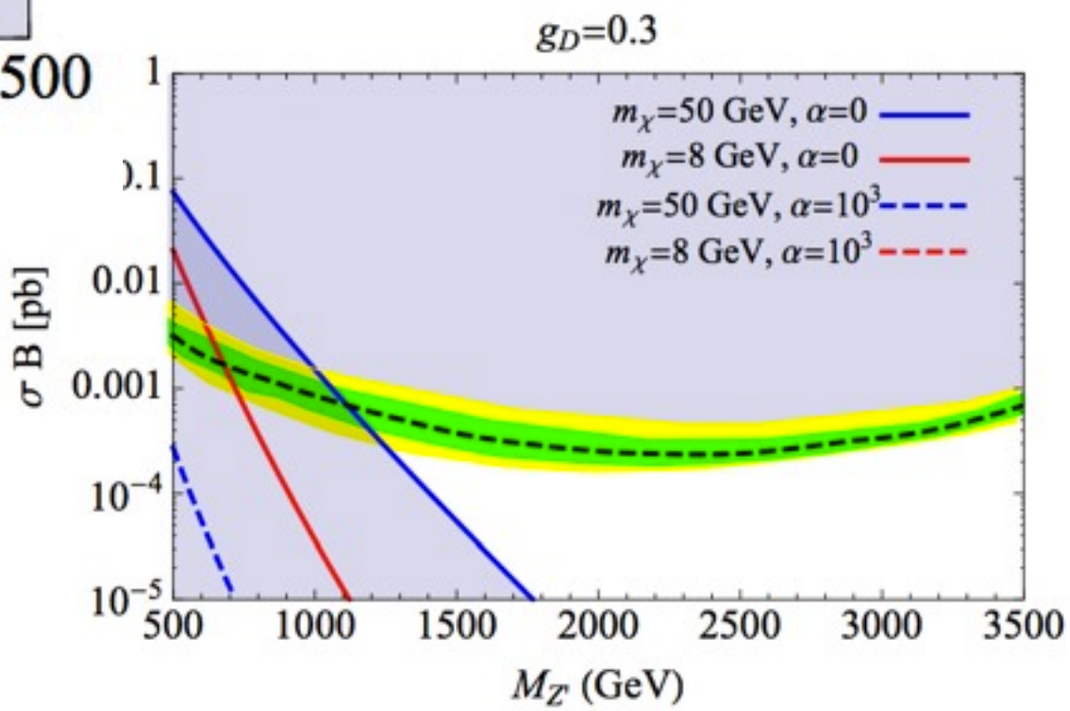


Arcadi, Mambrini, Tytgat, BZ

1401.0221 / hep-ph

RELAXING BRAZILIAN EXCLUSION



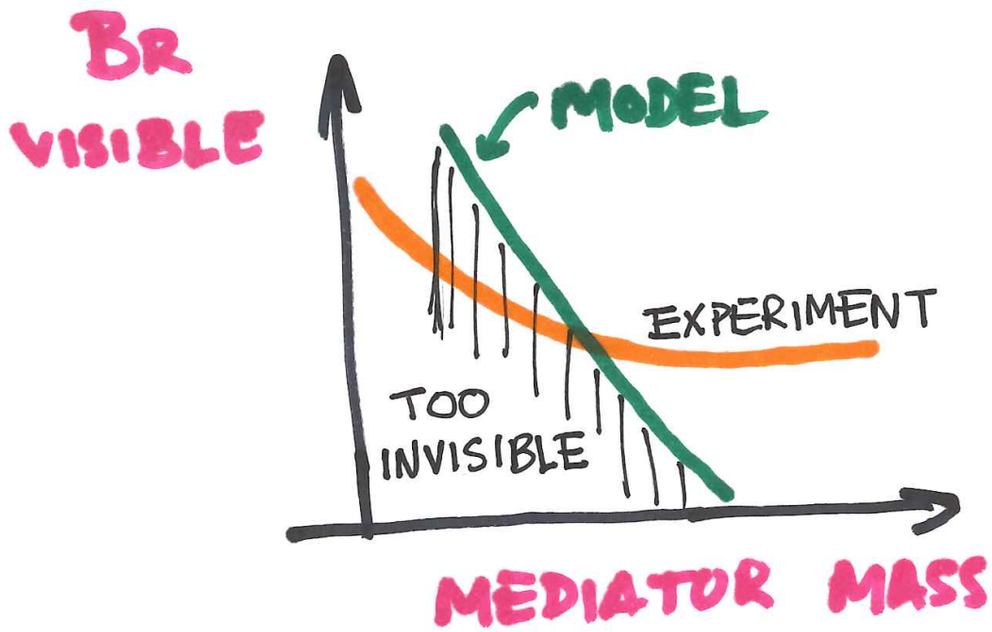


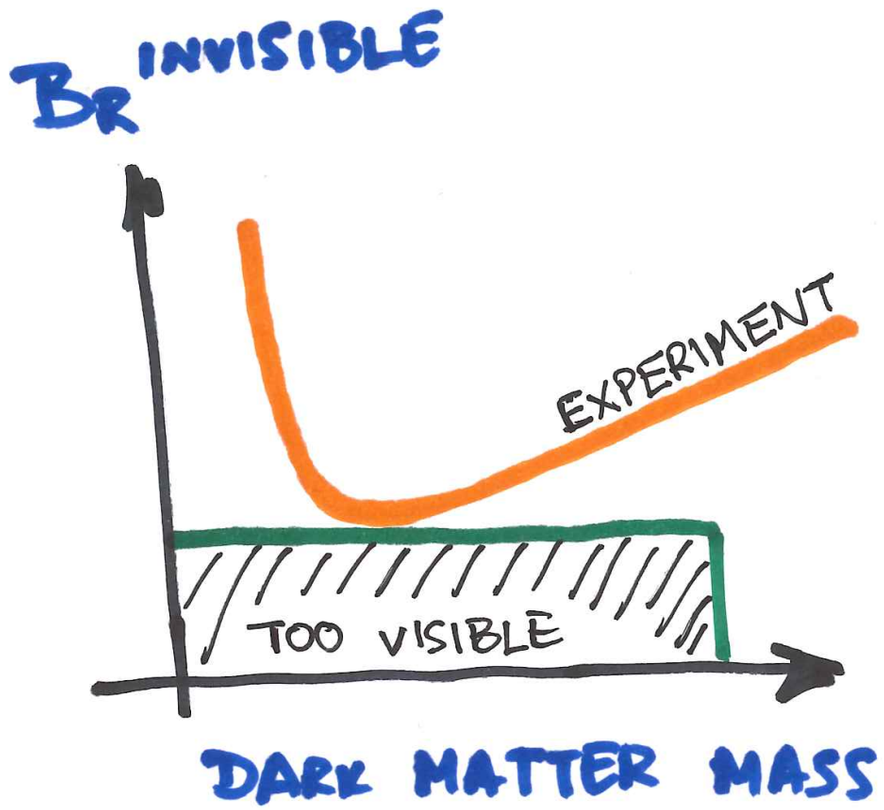
Arcadi, Mambrini, Tytgat, BZ

1401.0221 /hep-ph

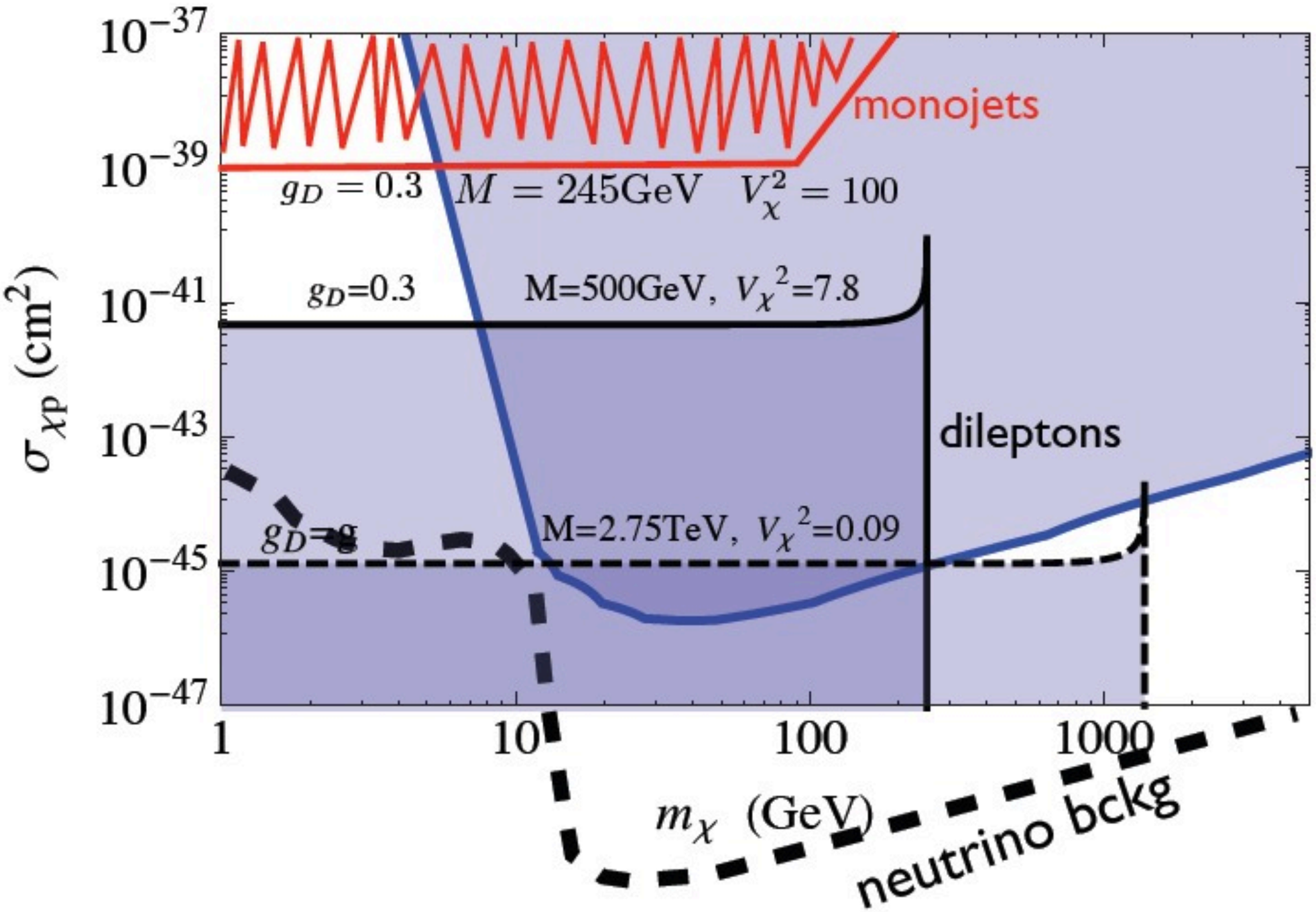
COMPLEMENTARITY

$$BR_{INVISIBLE} + BR_{VISIBLE} = 1.$$

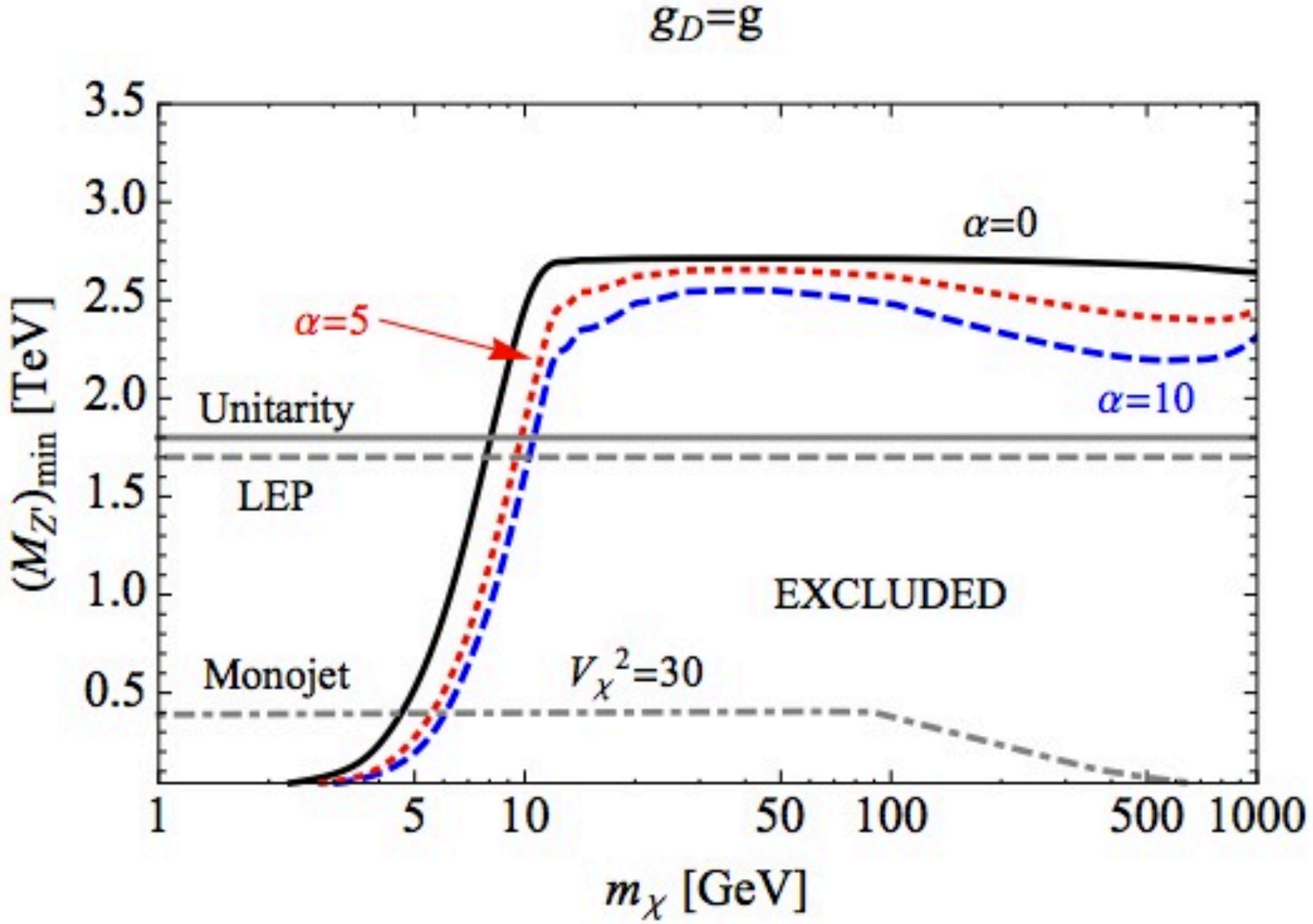




CONSTRAINT ON DIRECT DETECTION



SUMMARY PLOT

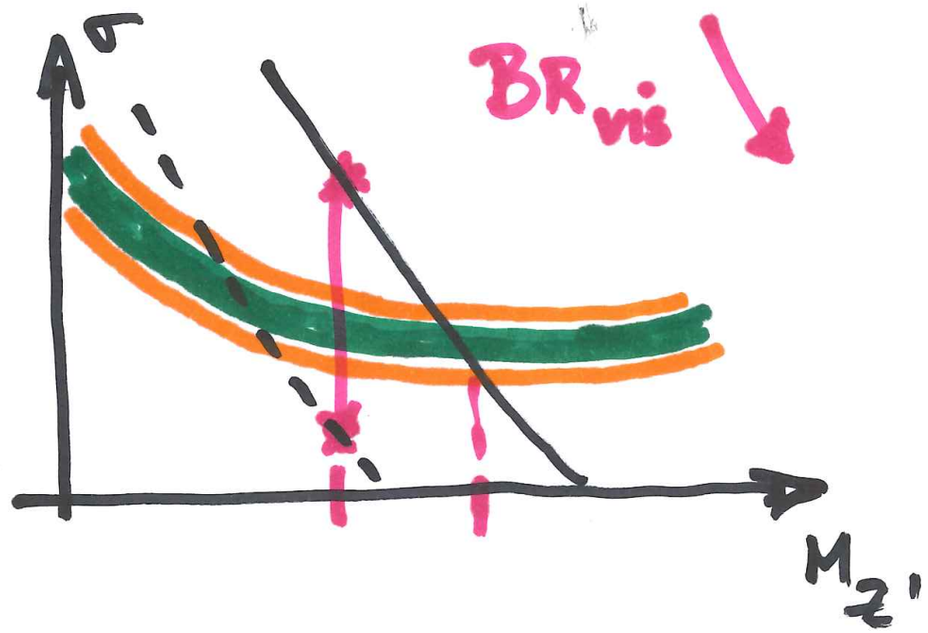


Arcadi, Mambrini, Tytgat, BZ

1401.0221 - hep/ph

DECREASING VISIBLE BRANCHING

$$\sigma(q\bar{q} \to Z' \to \bar{l}l) \propto BR_{VISIBLE}$$



$BR_{VISIBLE}$ CANNOT DECREASE ARBITRARILY:

RELIC ABUNDANCE!

$$\Omega_\chi h^2 \sim \frac{10^{-27}}{\langle\sigma v\rangle / cm^3 s^{-1}}$$

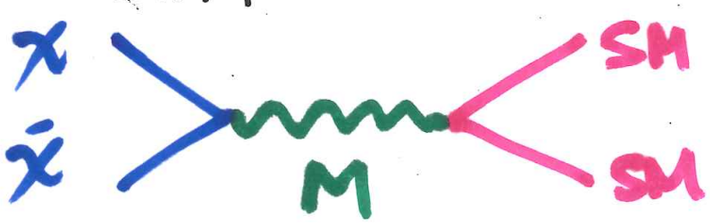
{ DISTINCTION OF TWO REGIMES IS RELEVANT NOW

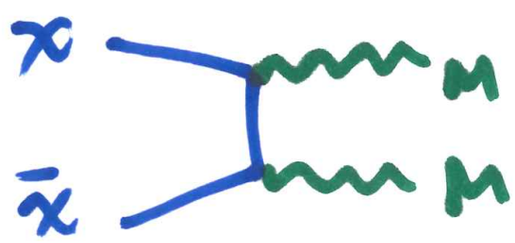
HEAVY MEDIATOR

$M > m_\chi$

$$\langle\sigma v\rangle \propto \frac{g_\chi^2 g_v^2 m_\chi^2}{2\pi M^4} + \mathcal{O}(m_f^2, v^2)$$

e.g. VECTOR MEDIATOR



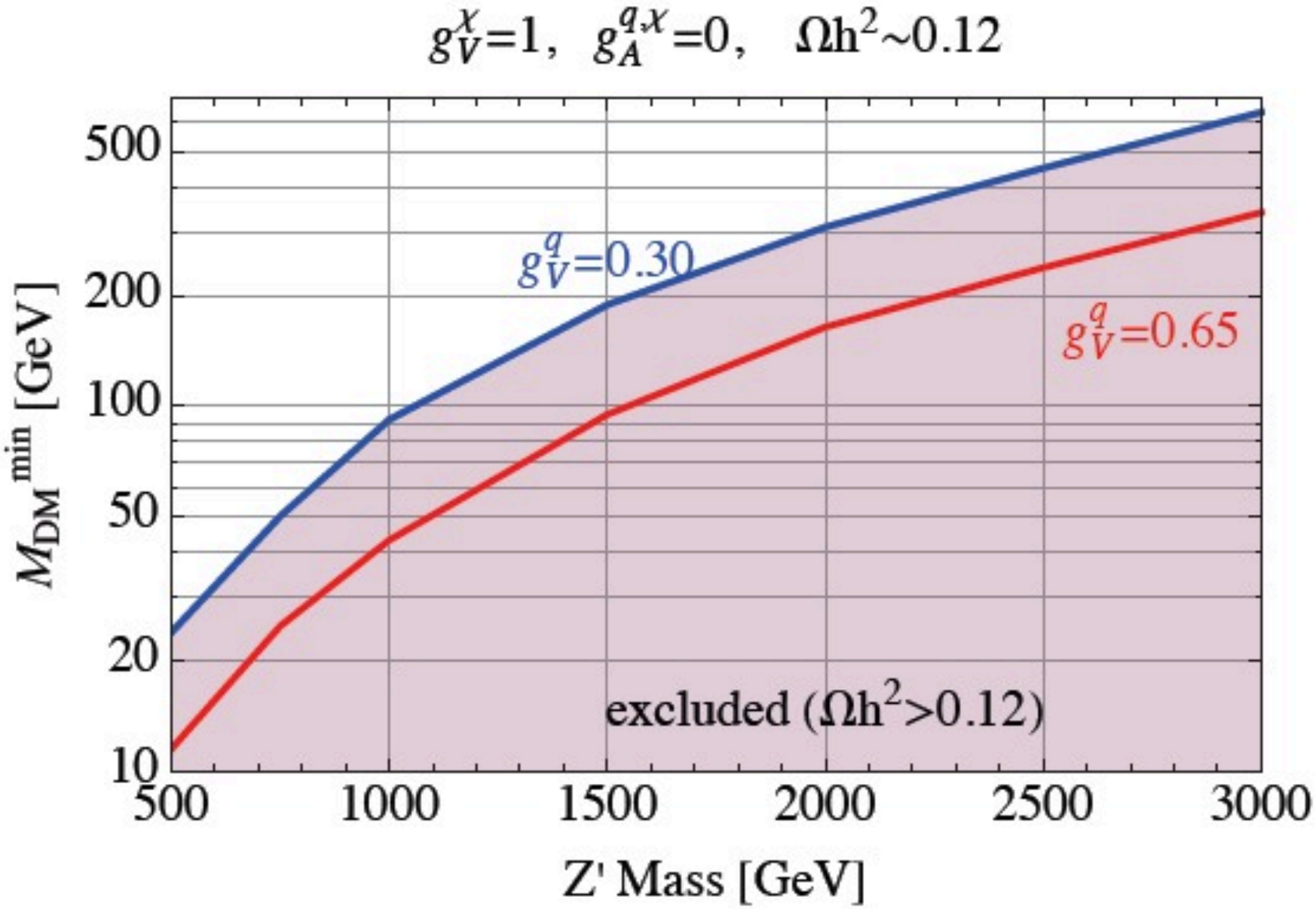


LIGHT MEDIATOR

$M < m_\chi$

$$\langle\sigma v\rangle \propto \frac{g_\chi^4}{16\pi m_\chi^2} + \mathcal{O}(v^2)$$

HEAVY MEDIATOR

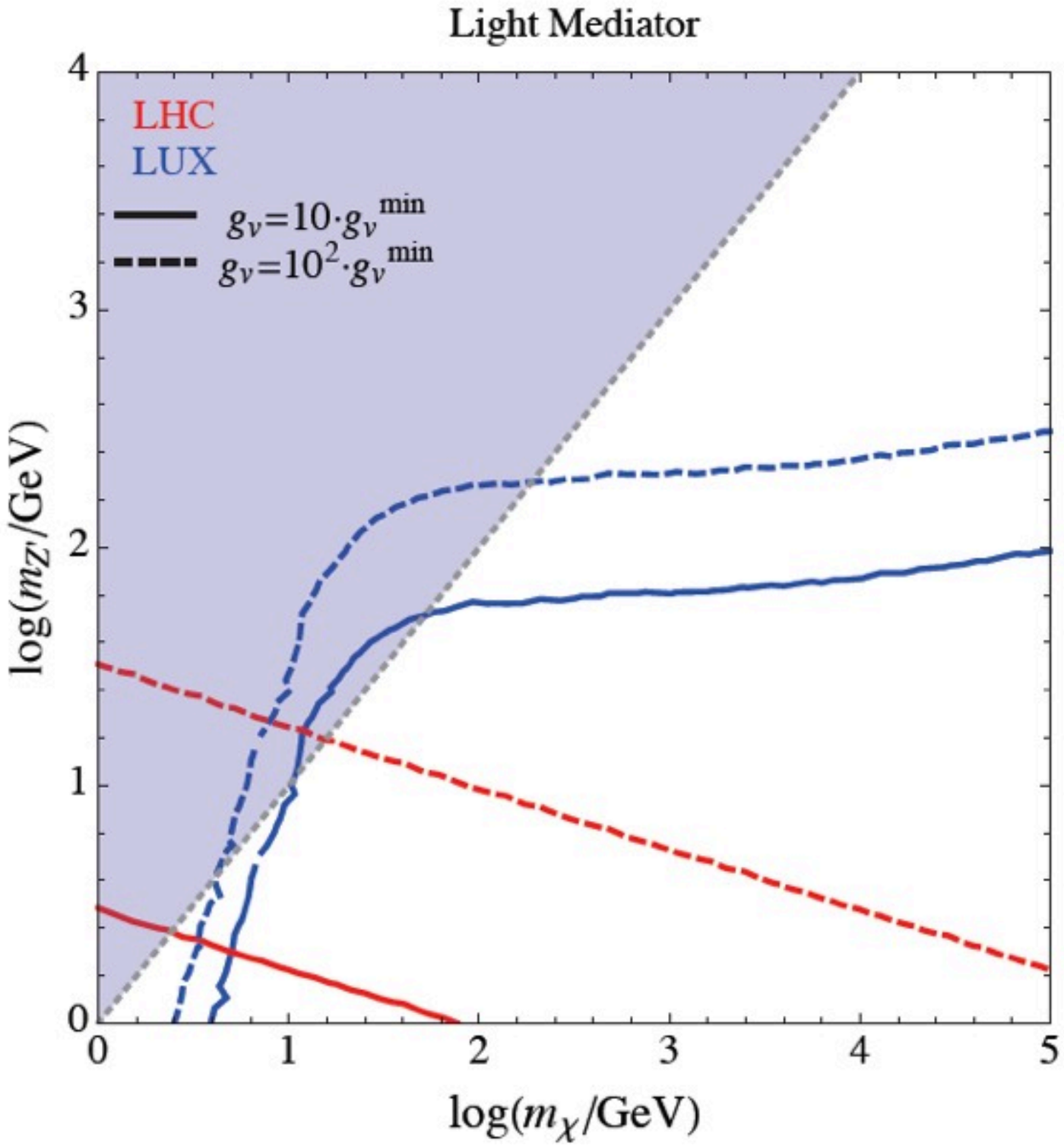


Badziak
Mambrini
Pokorski, BZ. } ongoing work in progress

LIGHT MEDIATOR

DILEPTON
+
RELIC ABUNDANCE

DIRECT DETECTION
+
RELIC ABUNDANCE



Badziak, Mambrini, Pokorski, BZ
(work in progress)

THE GAME

$$\mathcal{L}_{UV} = f(g_v, g_\chi, m_\chi, M)$$

* DIFFERENT EXPERIMENTS CAN BREAK DEGENERACIES !

$$\sigma^{LHC}_{DISIGNAL} = F(g_v, M)$$

$$\sigma_{DD} = H(g_v g_\chi, M)$$

$$\sigma^{LHC}_{MONO\ SIGNAL} = G(g_v g_\chi, m_\chi, M)$$

$$\langle \sigma v \rangle = K(g_v g_\chi, m_\chi, M)$$

$$M = M(m_\chi, \sigma^{EXP}_{LHC}, \sigma^{EXP}_{DD}, \langle \sigma v \rangle^{EXP})$$

CONCLUSIONS

* THE DARK MATTER PUZZLE IS ONE OF THE MOST INTERESTING AND ACTIVE SUBJECTS IN PARTICLE PHYSICS NOWADAYS

* DARK MATTER SEARCHES AT LHC HAS GAINED A LOT OF MOMENTUM IN THE LAST PERIOD

* EFFECTIVE FIELD THEORY GOOD AND SIMPLE FRAMEWORK TO LOOK FOR CONSEQUENCES OF LHC SEARCHES ON DARK MATTER DEDICATED SEARCHES (WITH SOME LIMITATIONS)

* GOING BEYOND EFT HAS IMPORTANT IMPLICATIONS FOR LHC SEARCHES.
  NEXT RUN WILL FOCUS ON SIMPLIFIED MODELS OF DARK MATTER

* FOR S-CHANNEL MODELS,

  MISSING ENERGY + DIRECT DETECTION + PURE VISIBLE SIGNALS

  GIVE ENRICHED COMPLEMENTARITY

* EXTRA (REASONABLE) ASSUMPTIONS ON THE MODEL

  (LIKE RELIC ABUNDANCE) COULD IMPLY INTERESTING

  CONSEQUENCES ON PRESENT LHC DATA INTERPRETATION

* COMPLEMENTARITY IS IMPORTANT :

  IT HELPS DISCRIMINATING MODELS !

Thank you!