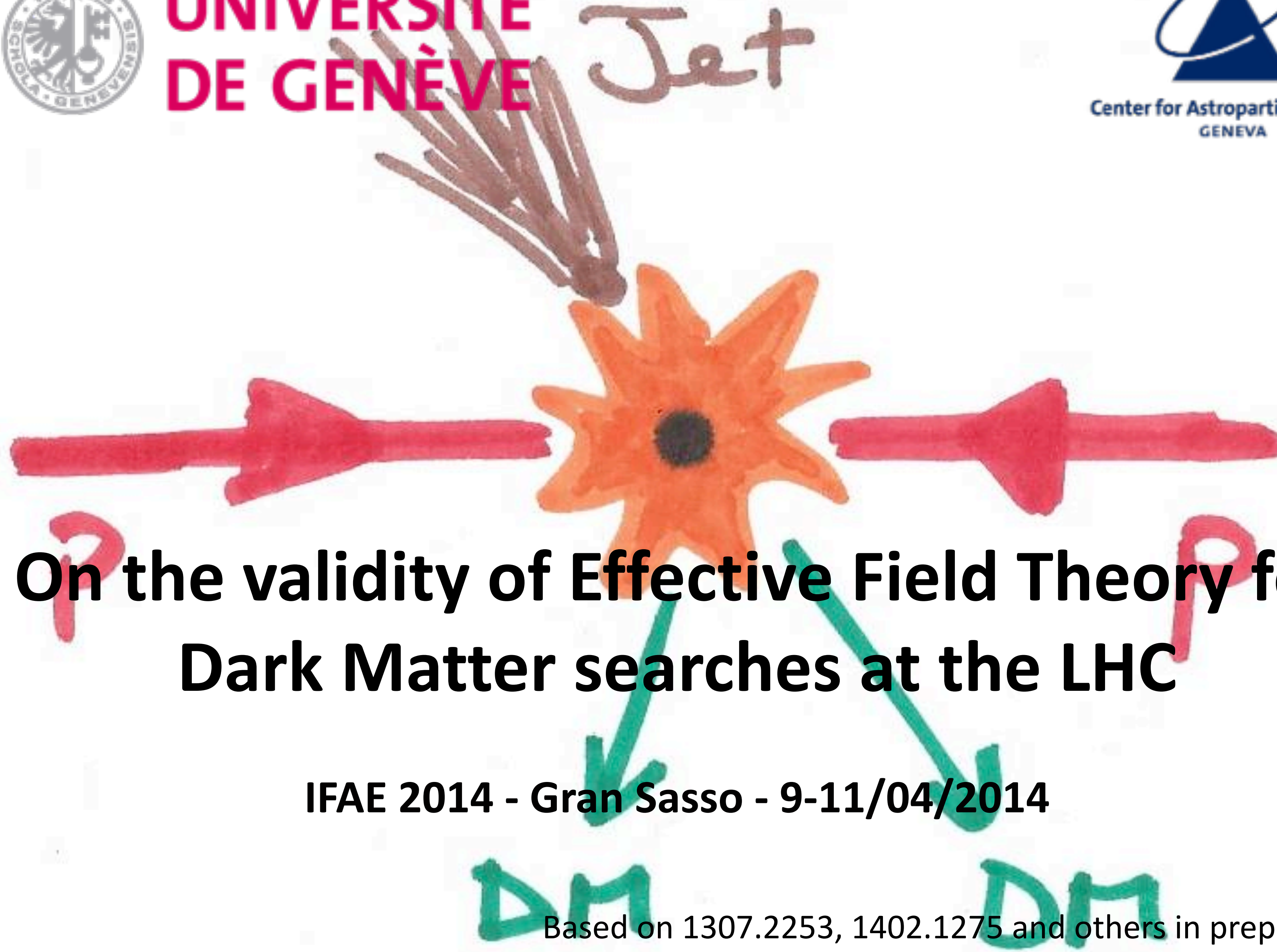


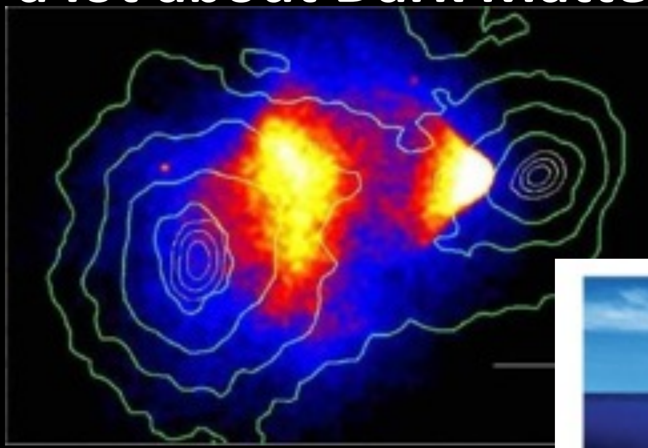
On the validity of Effective Field Theory for Dark Matter searches at the LHC

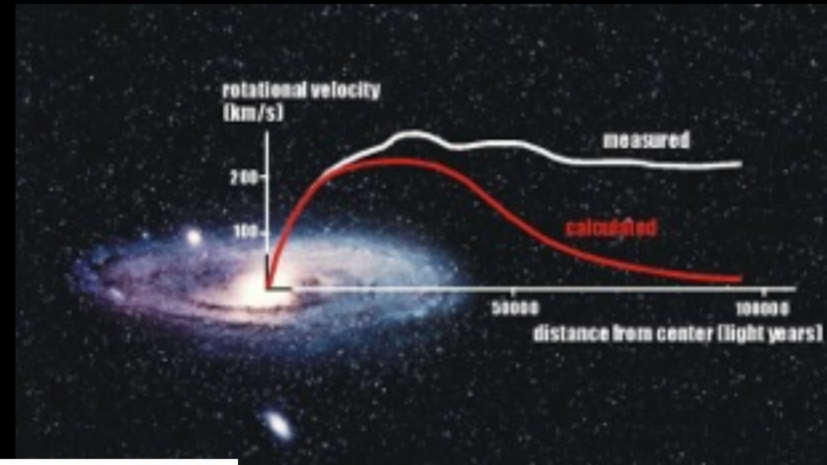
IFAE 2014 - Gran Sasso - 9-11/04/2014

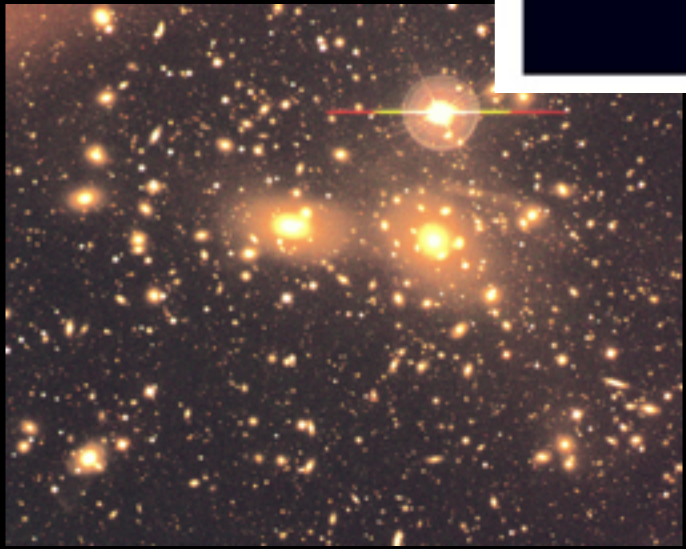
Based on 1307.2253, 1402.1275 and others in preparation

UNIVERSITÉ DE GENÈVE
Center for Astroparticle Physics GENEVA
EM with G. Busoni, A. De Simone, J. Gramling, T. Jacques, T. Riotto

Astrophysics and cosmology tell us a lot about Dark Matter…

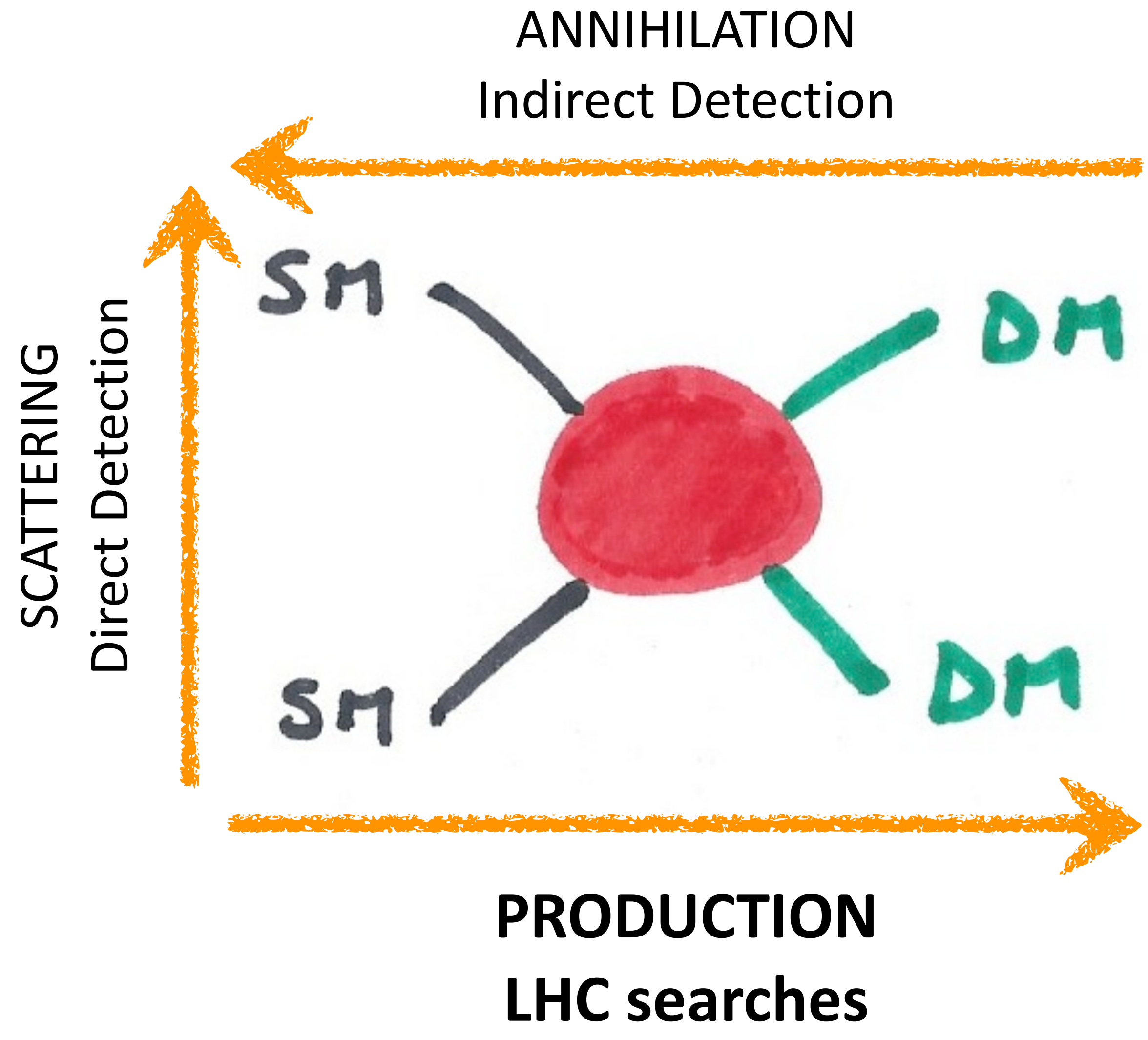






…but we still have
no evidence about it's particle nature!

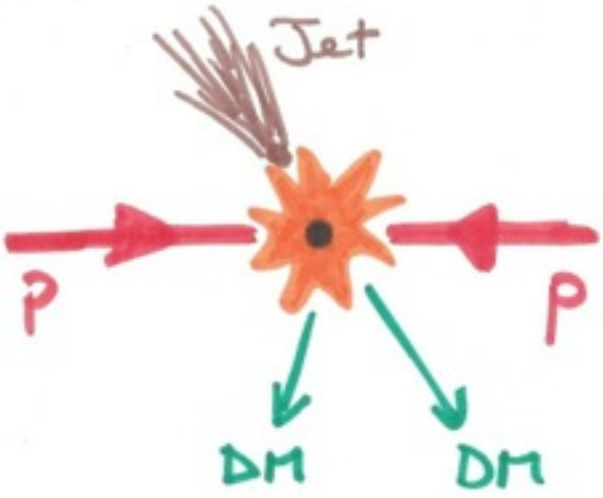
How can we test DM interactions with the Standard Model?

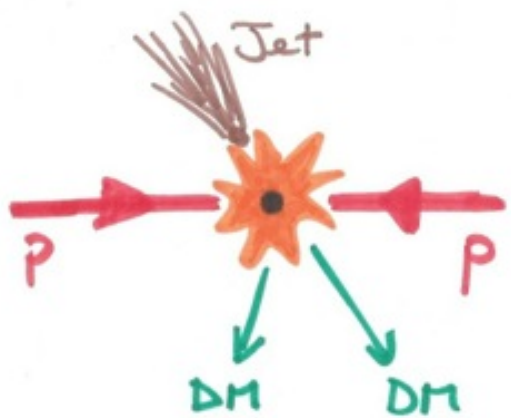


DM at LHC

Produce and detect Dark Matter particles is one of the main goal of the LHC. But…how do we look for them?

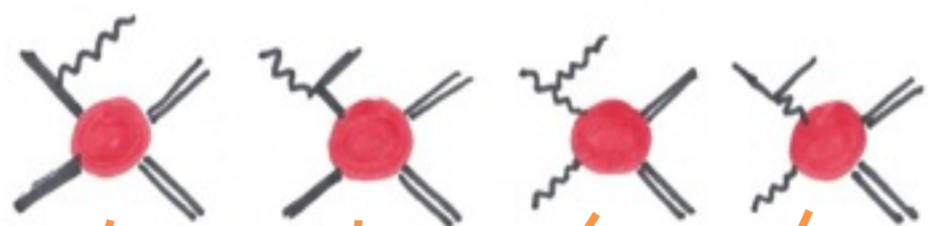
- DM is non interacting, so an event like p+p—> DM+DM is invisible
- A good channel to look at is p+p—> DM+DM+jet/photon
- Invisible DM particles "appear" as missing momentum in the transverse plane



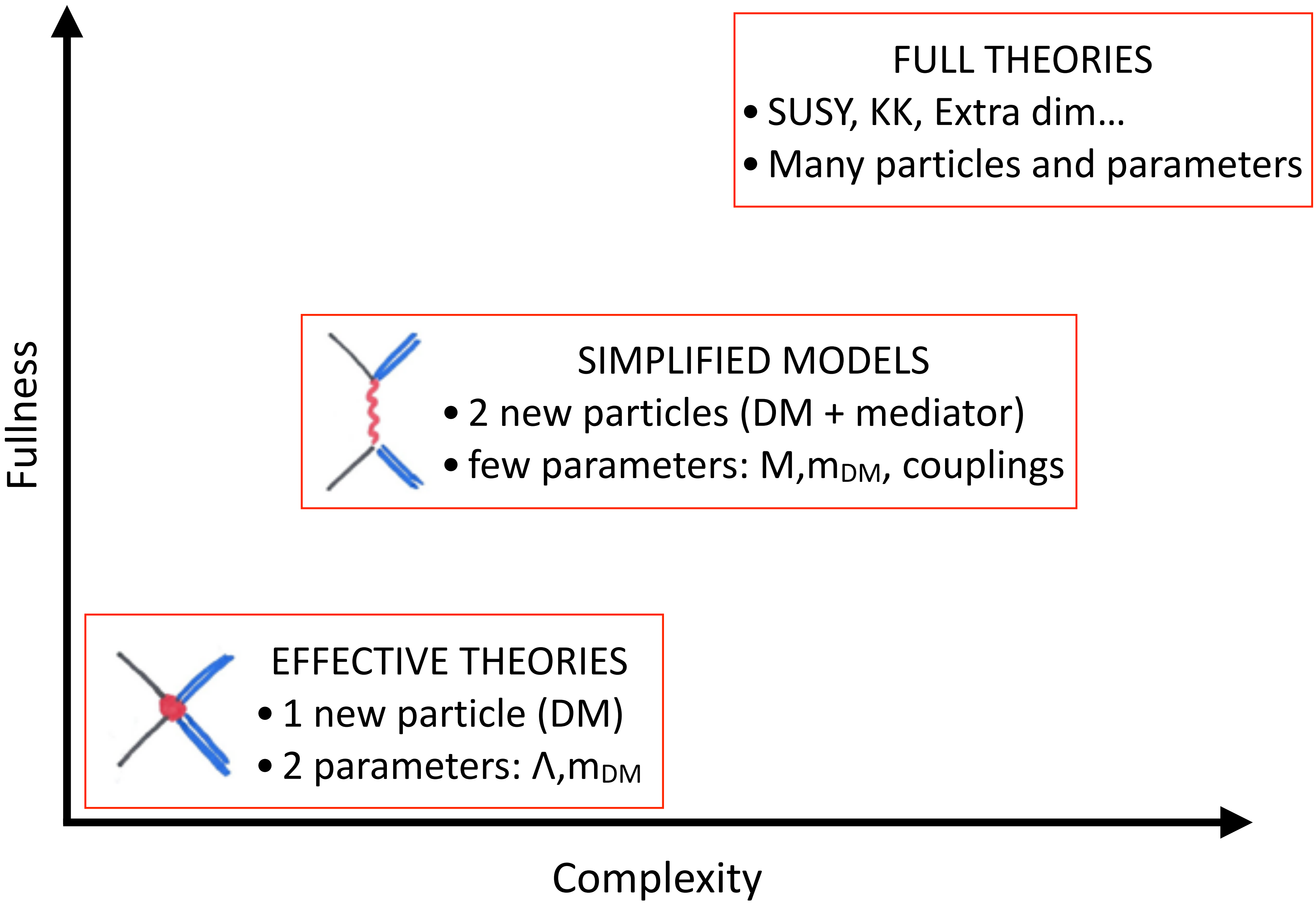


At the parton level the process is

$$q\bar{q} \rightarrow \chi\chi + g$$
$$gg \rightarrow \chi\chi + g$$
$$qg \rightarrow \chi\chi + q$$
$$\bar{q}g \rightarrow \chi\chi + \bar{q}$$



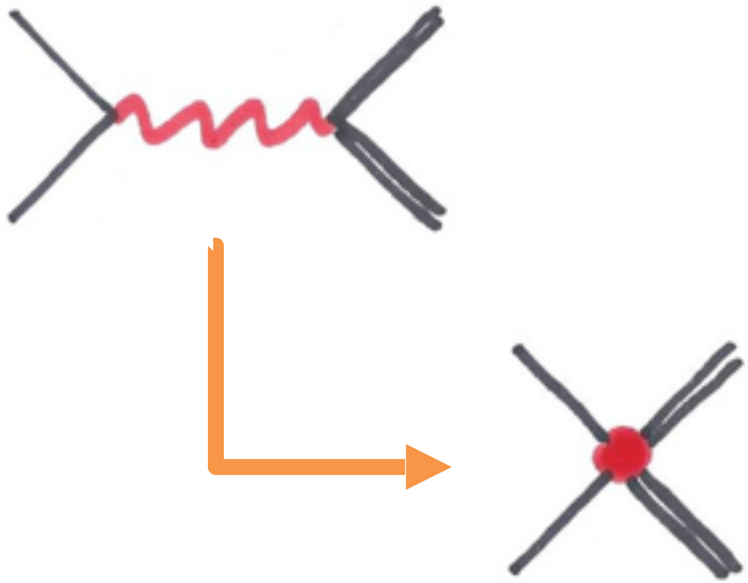
How do we describe these interactions??


FULL THEORIES
• SUSY, KK, Extra dim…
• Many particles and parameters
SIMPLIFIED MODELS
• 2 new particles (DM + mediator)
• few parameters: M,mDM, couplings
EFFECTIVE THEORIES
• 1 new particle (DM)
• 2 parameters: Λ,mDM
Fullness
Complexity

Domain of validity of EFT

"True" condition

$$Q_{\rm tr}^2 < \Lambda^2$$



What people (Atlas, CMS) usually do…

- EFT is reliable if

$$\Lambda \equiv \frac{M}{\sqrt{g_q g_\chi}} > \frac{Q_{\rm tr}}{\sqrt{g_q g_\chi}}$$

- To produce DM on shell

$$Q_{\rm tr} > 2 m_{\rm DM}$$

- To remain in the perturbative regime

$$g'{\rm s} < 4\pi$$

- The applied condition is then

$$\Lambda > \frac{m_{\rm DM}}{2\pi}$$

See e.g. ATLAS-CONF-2012-147

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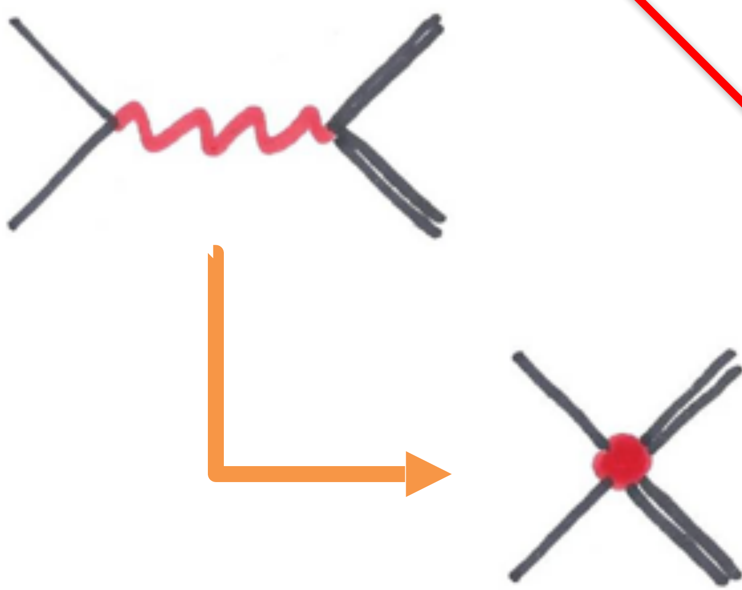

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MUCH WEAKER!!

See e.g. ATLAS-CONF-2012-147

Cross sections imposing $Q_{tr}<\Lambda$

To quantify the goodness/badness of EFT we can compute the cross section with or without imposing the condition on Q_{tr}

$$R_{\Lambda}^{\rm tot} \equiv \frac{\sigma_{\rm eff}\big|_{Q_{\rm tr}<\Lambda}}{\sigma_{\rm eff}} = \frac{\int_{p_{\rm T}^{\rm min}}^{1\ \rm TeV} {\rm d}p_{\rm T} \int_{-2}^{2} {\rm d}\eta \left.\frac{{\rm d}^2\sigma_{\rm eff}}{{\rm d}p_{\rm T}{\rm d}\eta}\right|_{Q_{\rm tr}<\Lambda}}{\int_{p_{\rm T}^{\rm min}}^{1\ \rm TeV} {\rm d}p_{\rm T} \int_{-2}^{2} {\rm d}\eta \frac{{\rm d}^2\sigma_{\rm eff}}{{\rm d}p_{\rm T}{\rm d}\eta}}$$

- $R_{\Lambda} = 1 \Rightarrow$ EFT valid
- $R_{\Lambda} < 1 \Rightarrow$ EFT not valid

Cross sections imposing $Q_{tr}<\Lambda$

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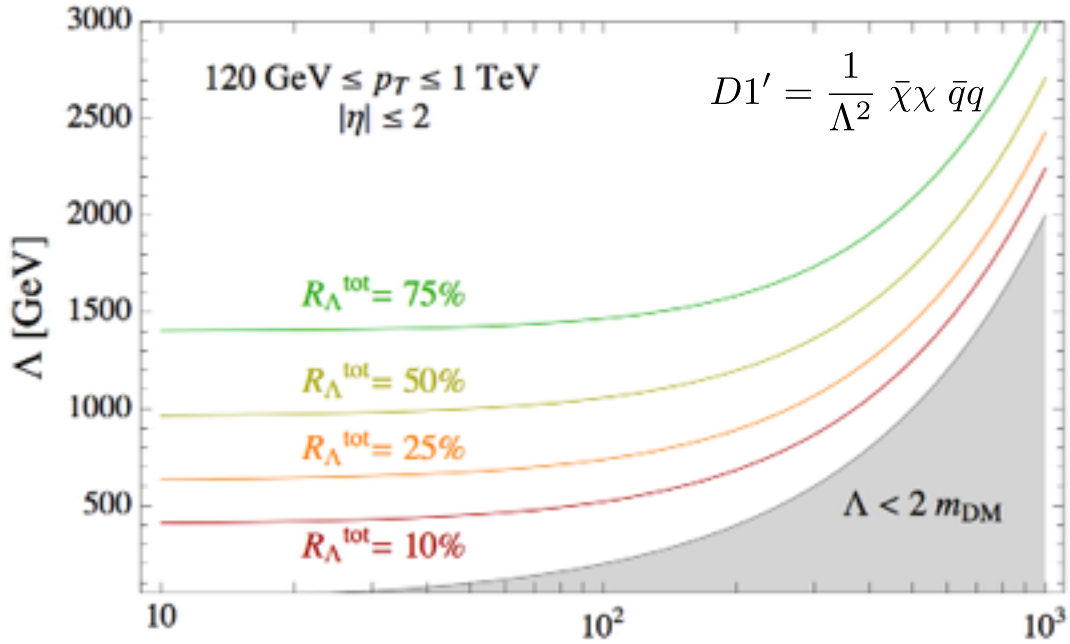
R_Λ is a good measure!

- No need to know the UV completion
- $R_\Lambda \approx$ fraction of events in the EFT validity region

→ Good quantity for experimentalists!

Cross sections imposing $Q_{tr}<\Lambda$

Results for D1’ at 8 TeV:

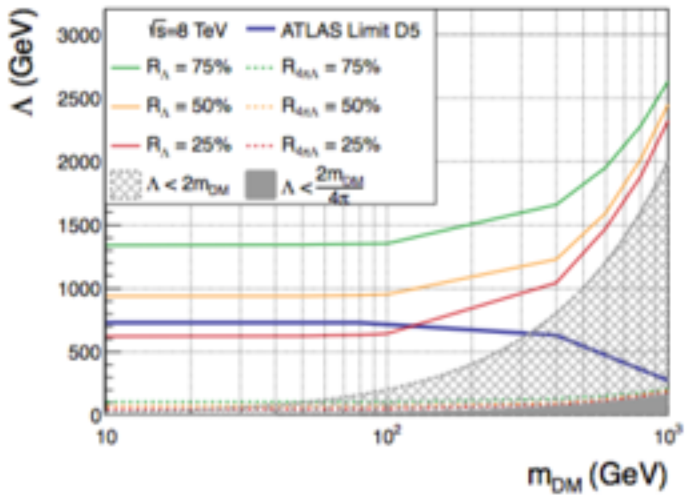


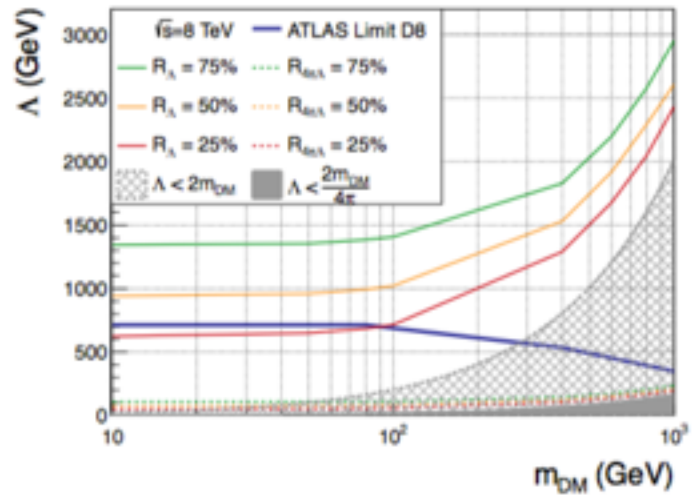
- Computed for the full set of s-channel ops at both 8 and 14 TeV
- Only a small dependence on the cuts
- Worse for 14 TeV

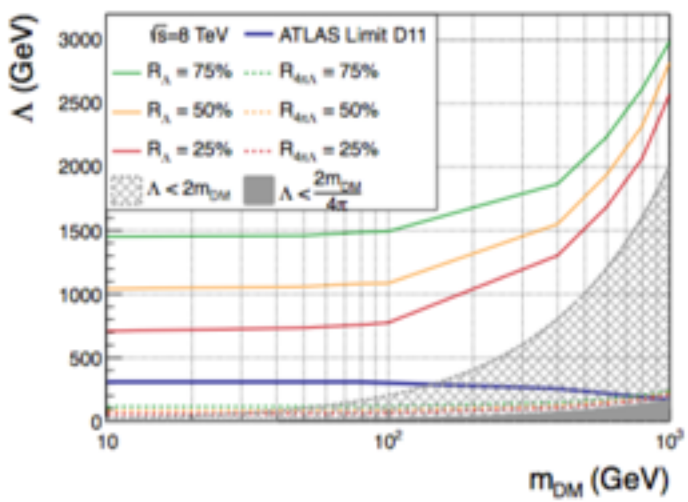
Busoni, De Simone, EM, Riotto 1307.2253
Busoni, De Simone, Gramling, EM, Riotto 1402.1275

Implications for LHC searches

Bounds in the Λ vs. m_{DM} plane by ATLAS fall well inside the region of EFT non-validity



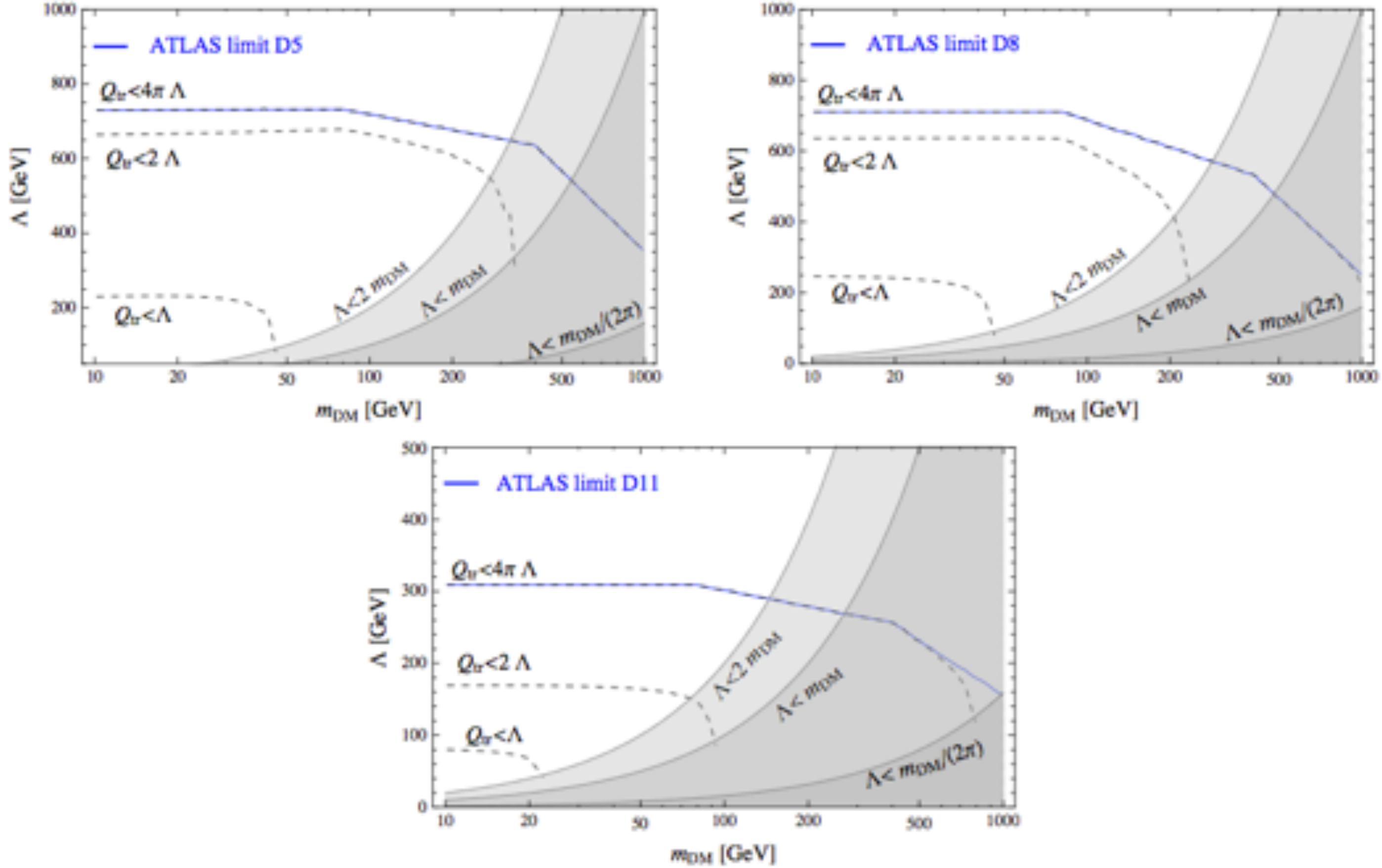




1402.1275

Implications for LHC searches

How do these bounds change if we use EFT correctly?



Naïve treatment, need to understand pT distribution with the Q_{tr} cut

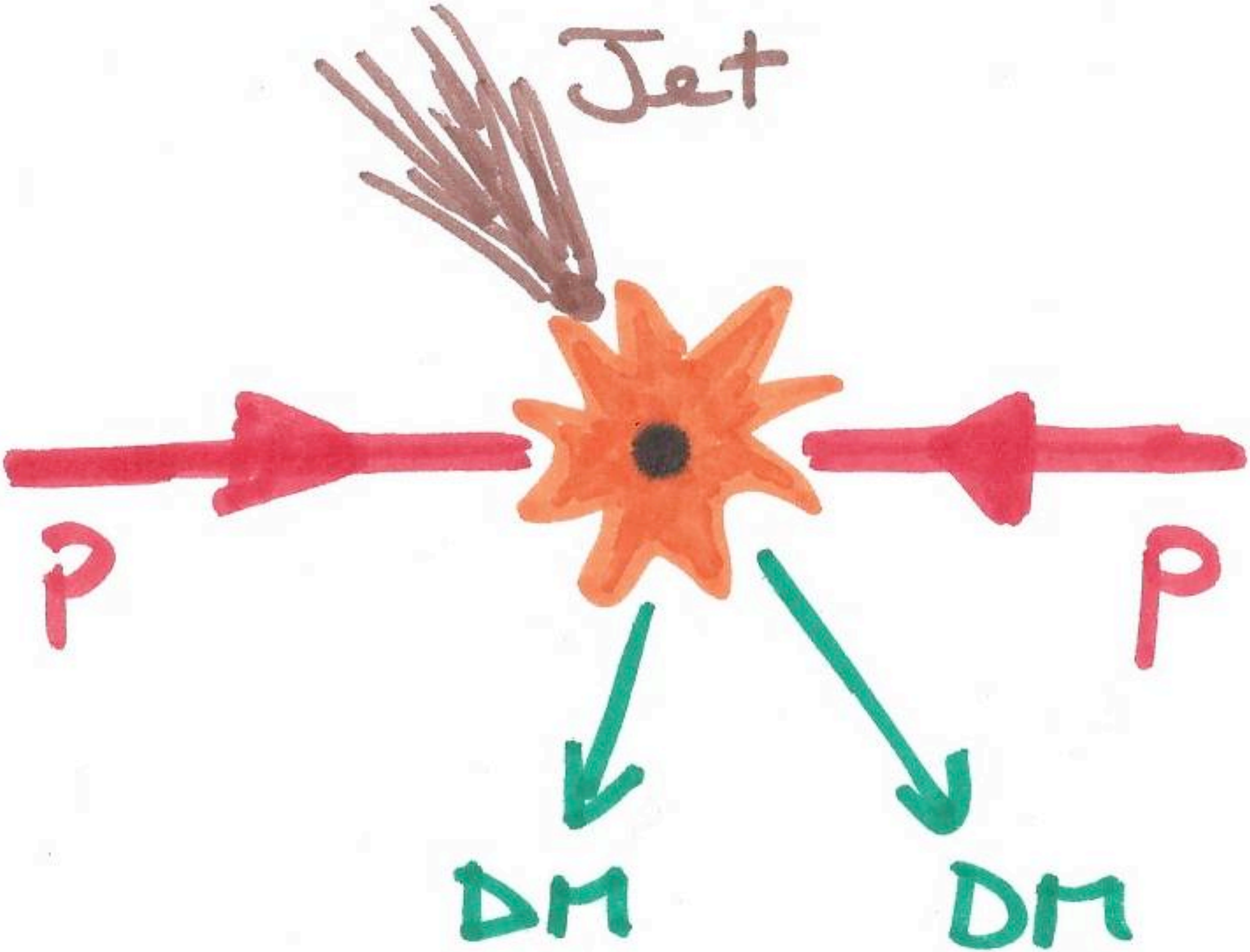
Conclusions

1. **EFTs are a very simple tool for searches of Dark Matter (and not only!) at the LHC;**

2. **Unfortunately, due to the high energy reach, their usage have strong limitations;**

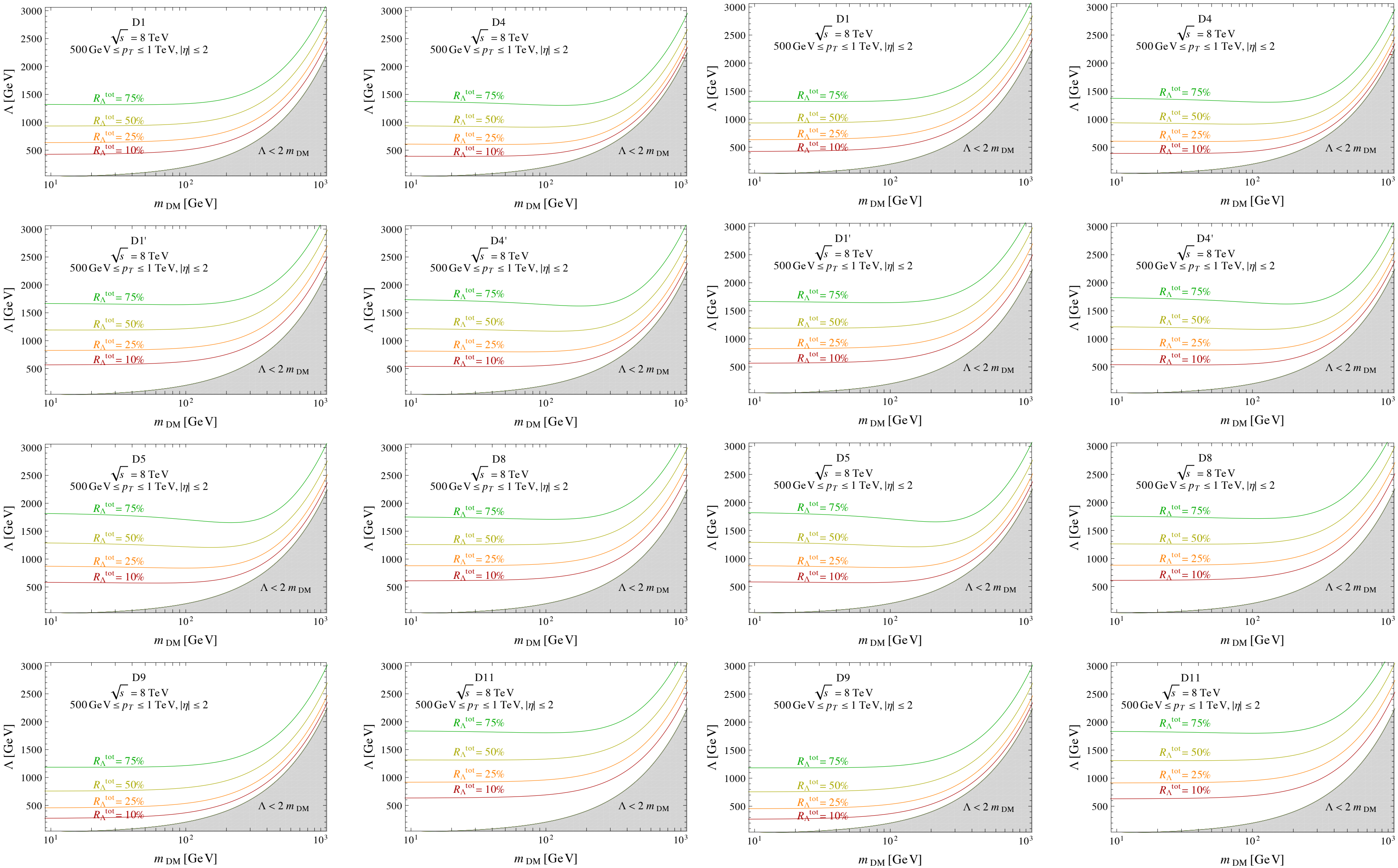
3. **It’s time to look for alternatives! Symplified models seem to be the way.**

4. **More parameters to constraint: how do we present results?**


Jet
P
P
DM
DM

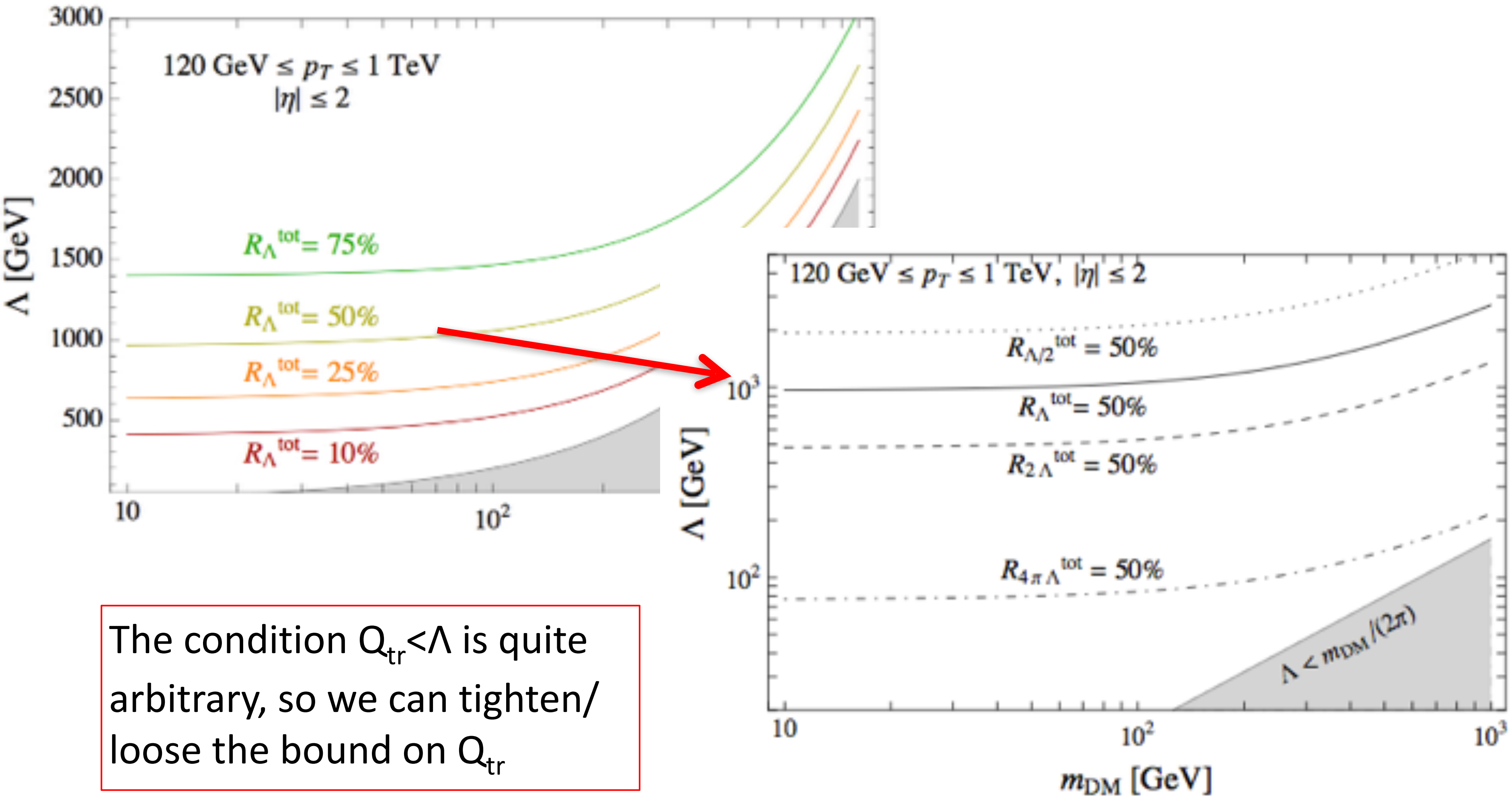
Cross sections imposing $Q_{tr} < \Lambda$

Contours for the full set of operators at 8 & 14 TeV:



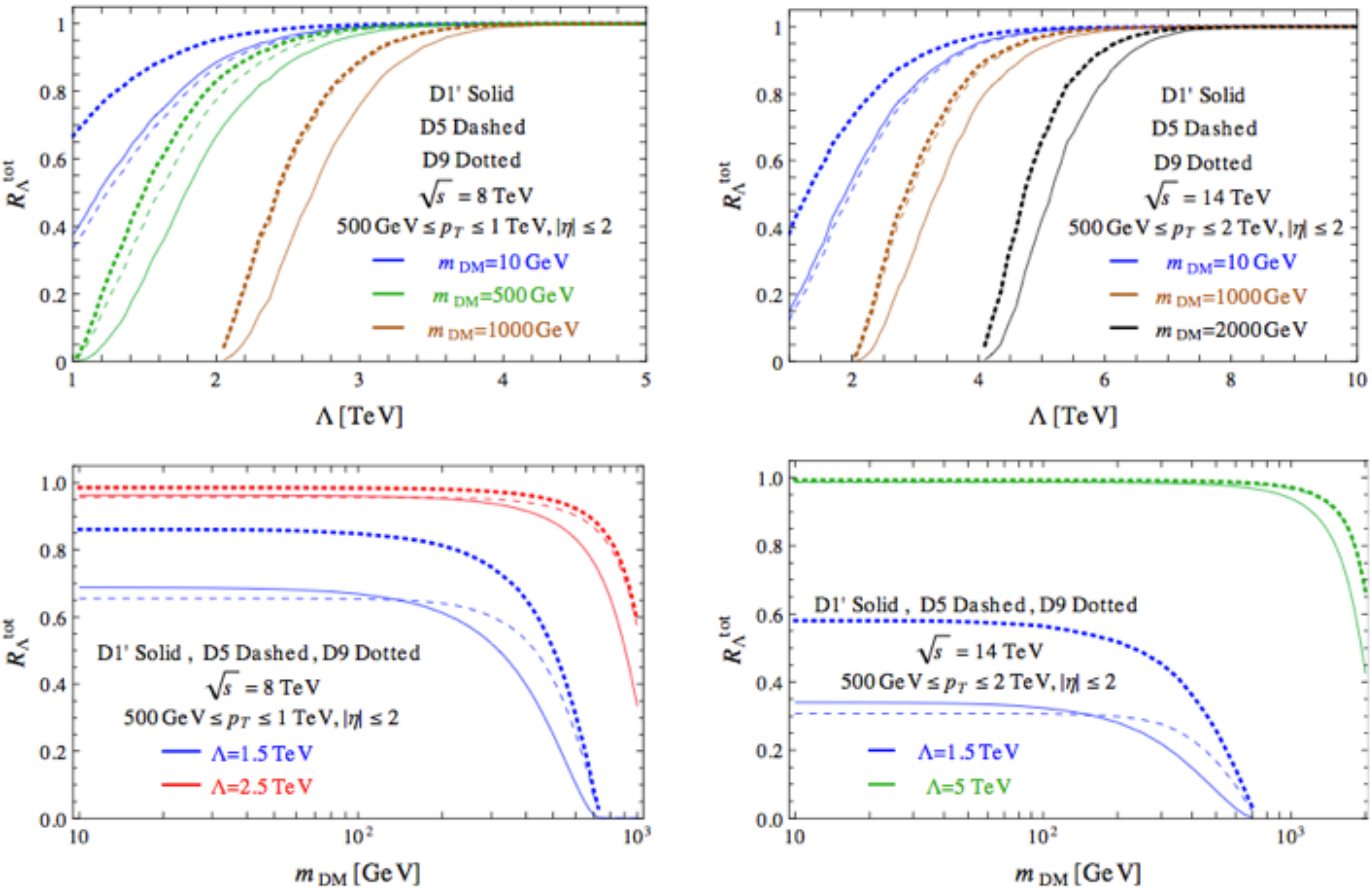
Cross sections imposing $Q_{tr}<\Lambda$

Results for D1' at 8 TeV:



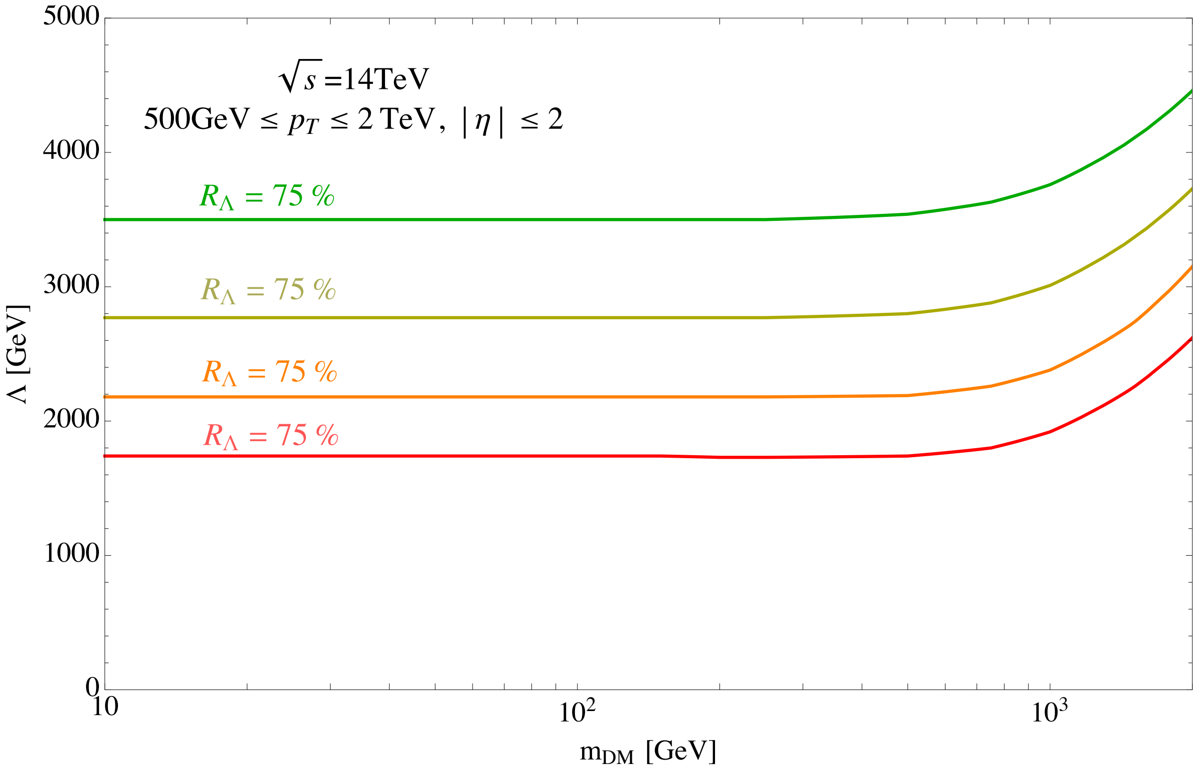
The condition $Q_{tr}<\Lambda$ is quite arbitrary, so we can tighten/ loose the bound on Q_{tr}

Cross sections imposing $Q_{tr} < \Lambda$



Results for t-channel operators

Operators in the t-channel show a similar behaviour



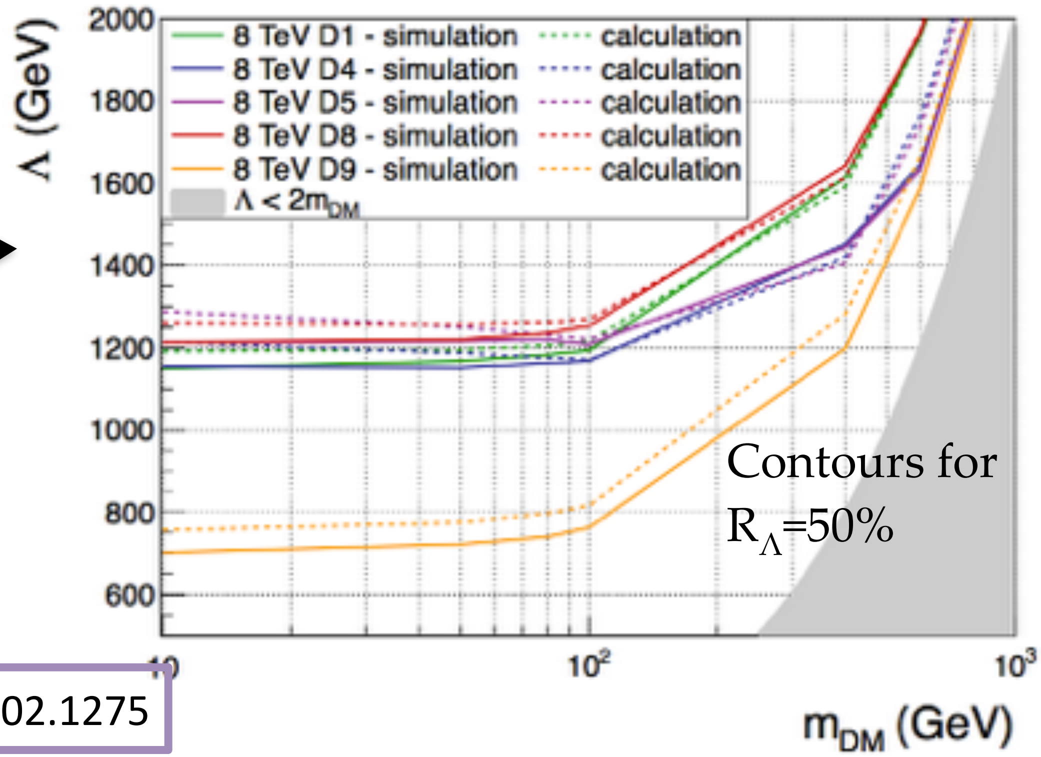
Busoni, De Simone, Jacques, EM, Riotto, *coming soon*

Comparison with MonteCarlo simulations

We computed the quantity R_Λ using MadGraph5

- Better comparison with experimentalists' techniques
- Includes hadronization of jets
- Includes quark-initiated jets

Analytical & MC results are in good agreement



Busoni, De Simone, Gramling, EM, Riotto 1402.1275

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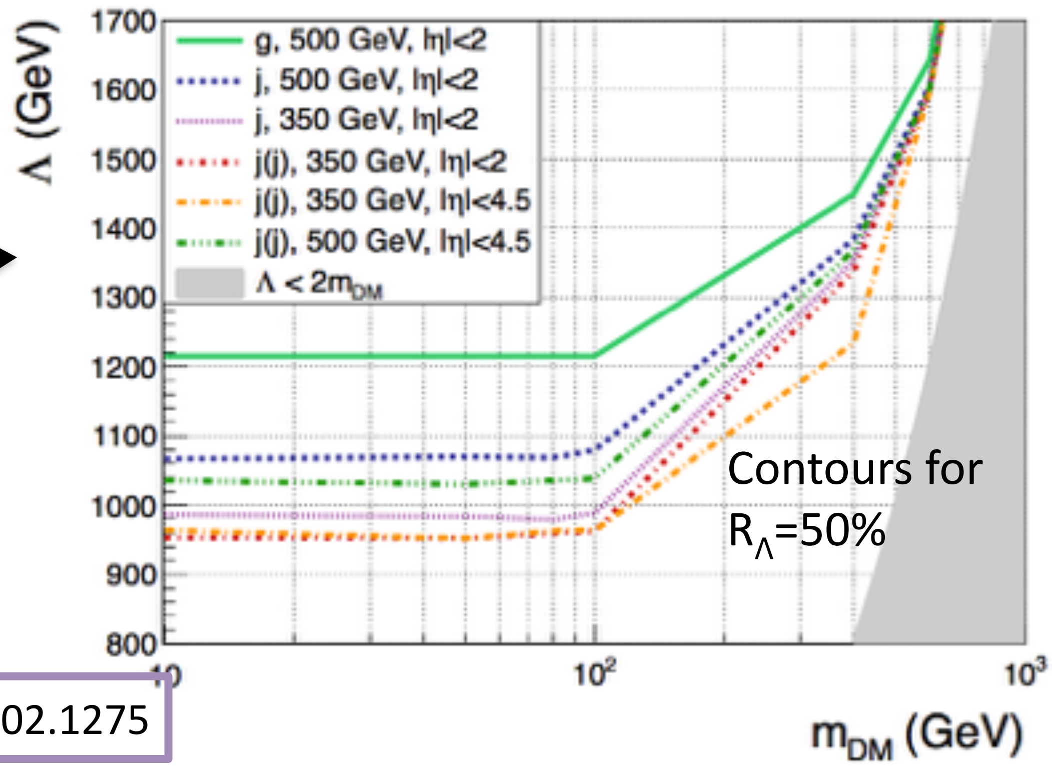
Vary kinematical cuts doesn't change the situation



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2: Comparison with UV completion

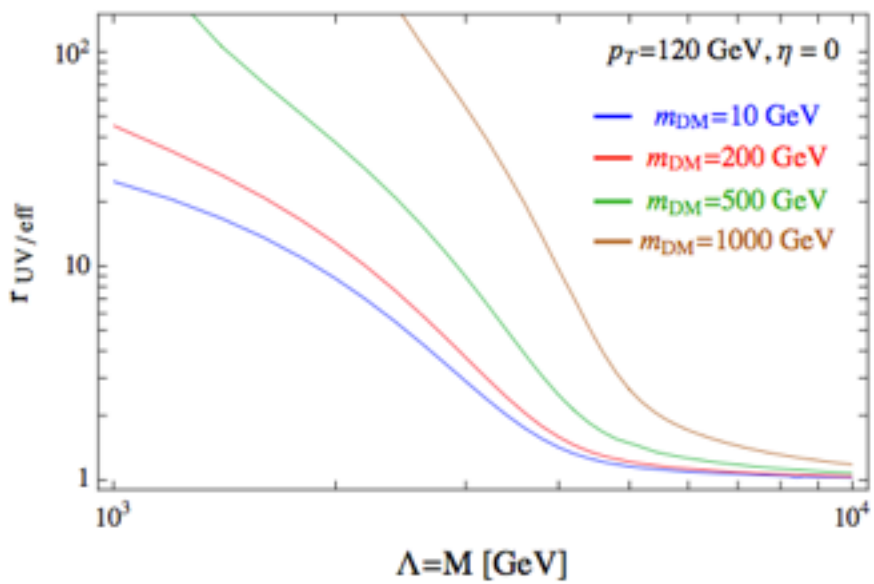
- Complete the D1' lagrangian by adding a scalar field as a mediator

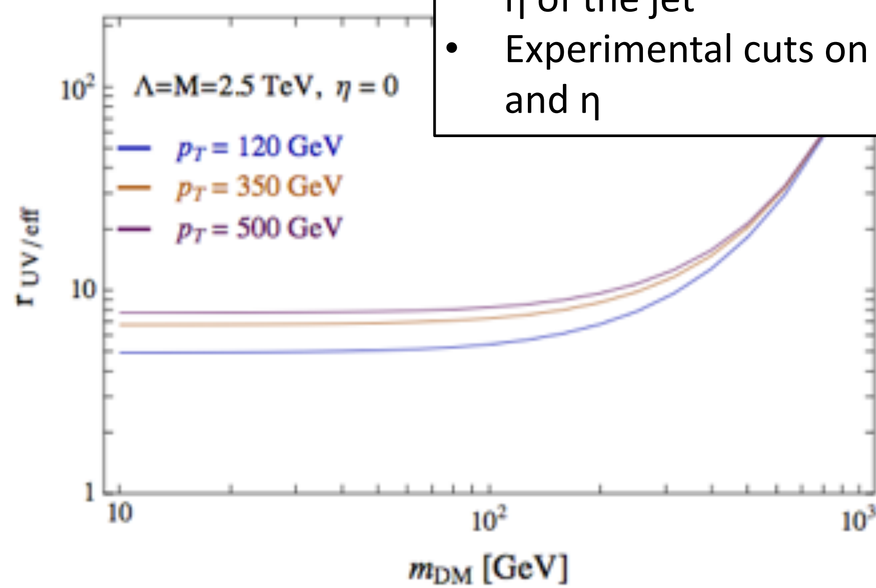
$$\mathcal{L}_{D1'} = \frac{1}{\Lambda^2}(\bar{\chi}\chi)(\bar{q}q) \longleftrightarrow \mathcal{L}_{UV} \supset \frac{1}{2}M^2S^2 - g_q\bar{q}qS - g_\chi\bar{\chi}\chi S$$

- Compute the ratio between the two cross sections

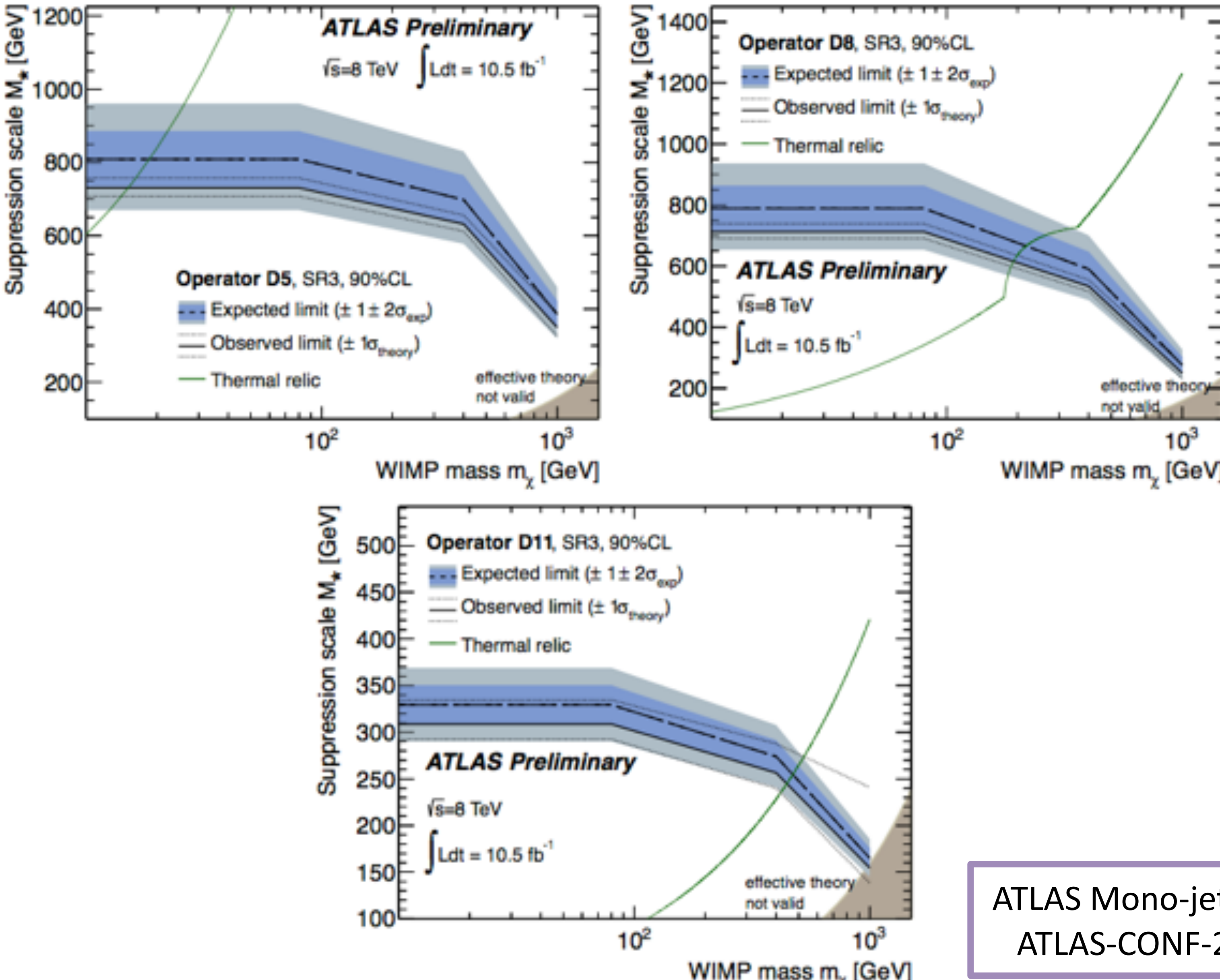
$$r^{tot}_{UV/eff} \equiv \frac{\sigma_{UV}|_{Q_{tr}<M}}{\sigma_{eff}|_{Q_{tr}<\Lambda}} = \frac{\int_{p_T^{min}}^{1\,\mathrm{TeV}} dp_T \int_{-2}^{2} d\eta \left.\frac{d^2\sigma_{UV}}{dp_T d\eta}\right|_{Q_{tr}<M}}{\int_{p_T^{min}}^{1\,\mathrm{TeV}} dp_T \int_{-2}^{2} d\eta \left.\frac{d^2\sigma_{eff}}{dp_T d\eta}\right|_{Q_{tr}<\Lambda}}$$

- Computed analitically at parton level assuming jet = emitted gluon
- Integrated over PDFs imposing the condition on Q_{tr}
- Integrated over pT and η of the jet
- Experimental cuts on pT and η





ATLAS limits



ATLAS Mono-jet analysis
ATLAS-CONF-2012-147

Implications for LHC searches

Very naively, neglecting the statistical and systematical uncertainties, the number of signal events in a given EFT model has to be less than the experimental observation, $N_{\rm signal}(\Lambda, m_{\rm DM}) < N_{\rm expt}$. The cross section due to an operator of mass dimension d scale like $\Lambda^{-2(d-4)}$, so $N_{\rm signal}(\Lambda, m_{\rm DM}) = \Lambda^{-2(d-4)} \tilde{N}_{\rm signal}(m_{\rm DM})$, and the experimental lower bound in the scale of the operator becomes

$$\Lambda > \left[\tilde{N}_{\rm signal}(m_{\rm DM})/N_{\rm exp}\right]^{1/[2(d-4)]} \equiv \Lambda_{\rm expt.} \,. \qquad (4.1)$$

Now, if we do not consider any information about the shapes of the p_T or MET distributions, the experimental bound only comes from the total number of events passing given cuts. The fact that a fraction of the events involve a transfer momentum exceeding the cutoff scale of the EFT means that the number of signal events for placing a limit gets reduced by a factor $R_\Lambda^{\rm tot}$. Therefore, actually $N_{\rm signal}(\Lambda, m_{\rm DM}) \to R_\Lambda^{\rm tot}(m_{\rm DM}) N_{\rm signal}(\Lambda, m_{\rm DM})$, so the new limit is found by solving the implicit equation

$$\Lambda > [R_\Lambda^{\rm tot}(m_{\rm DM})]^{1/2[(d-4)]} [N_{\rm signal}(m_{\rm DM})/N_{\rm exp}]^{1/[2(d-4)]} = [R_\Lambda^{\rm tot}(m_{\rm DM})]^{1/[2(d-4)]} \Lambda_{\rm expt} \qquad (4.2)$$

and it turns out to be weaker than $\Lambda_{\rm expt}$.

Busoni, De Simone, Gramling, EM, Riotto 1402.1275

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