“Dark Matter at the LHC”
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Validity of the EFT interpretation of Monojet results at the LHC

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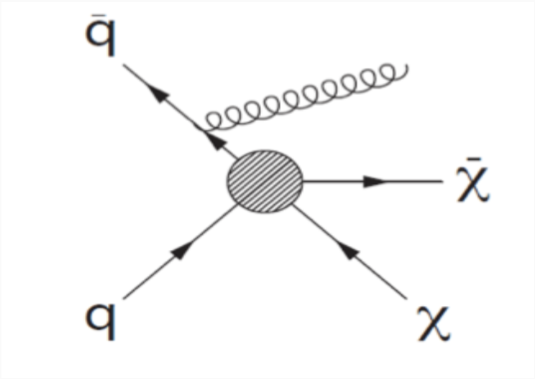
Outline

- Motivation to use EFT
- Conditions of Validity for an EFT
- Idea of this study
  - MadGraph details
  - Introduction of R_Λ
  - Procedure
- Comparison with analytical result
- Moving to a scenario better comparable to experimental limits
- Comparison to experimental limits
  - Loopholes? Couplings!

Many thanks to Andrea de Simone for discussions and suggestions!

Why EFT?

- Monojet (and other collider) analyses are interpreted in terms of an effective field theory (EFT)
- **Idea:** heavy particle mediating the interaction between SM particles and DM particles
  - Much too heavy to be produced on-shell → can be integrated out, interaction treated as contact interaction!



- **Advantage:** model depends only on a few parameters
  - m_{DM}, cut-off scale Λ or M_*

    → much easier than e.g. a full SUSY model
  - Allows easy comparison to direct or indirect DM detection experiments

Conditions of EFT

1. $g_q, g_\chi < 4\pi$

- to stay in the perturbative regime

2. $m_M > m_{DM}$

- assuming that M can't be produced, but DM can
- Minimal constraint: $\Lambda = m_M/\sqrt{(g_q g_\chi)} > m_M/4\pi < m_{DM}/4\pi$

3. $m_M > Q_{TR}$

- assuming that M can't be produced
- Minimal constraint: $\Lambda > m_M/4\pi > Q_{TR}/4\pi$

4. $Q_{TR} > 2m_{DM}$: assuming that DM is pair-produced on-shell

- Combining 3 & 4 gives stronger constraint than 2!
  - Minimal constraint: $\Lambda > Q_{TR}/4\pi > 2m_{DM}/4\pi$

How to judge EFT Validity?

- Choice of coupling used in the following: $\sqrt{(g_q g_\chi)} = 1$
  - Leading to **Λ > Q_{TR} > $2m_{DM}$**
- At LHC, Q_{TR} can be of the order of 1 TeV. The limits that can be set on Λ are of the same order or even smaller...
  - → Validity of EFT approach questionable
- **Idea:** access fraction of "valid" EFT events by just comparing Q_{TR} and Λ and check, if condition is fulfilled
  - First suggested in *arXiv:1307.2253v1* by A. de Simone et al.
  - Here: not analytical, but using MadGraph simulation

MadGraph Details

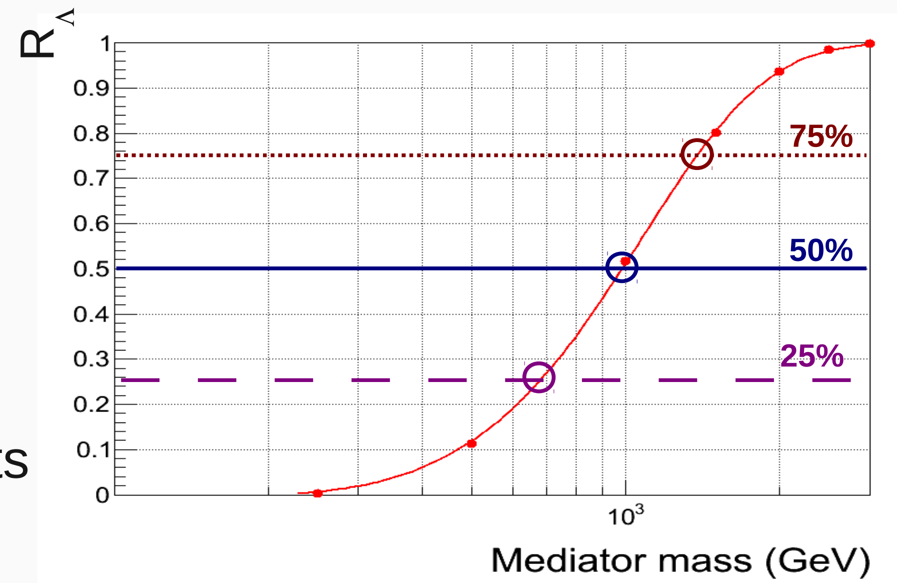
- Use model implementation by T.Tait, et al. (*arXiv:1008.1783v2*)
  - Only two new particles: DM particle χ, Mediator M
  - χ is Dirac Fermion
  - Mediator has no propagator → contact interaction
  - Only two parameters: m_{DM} and Λ/M_*
- 14 Operators possible, pick characteristic set

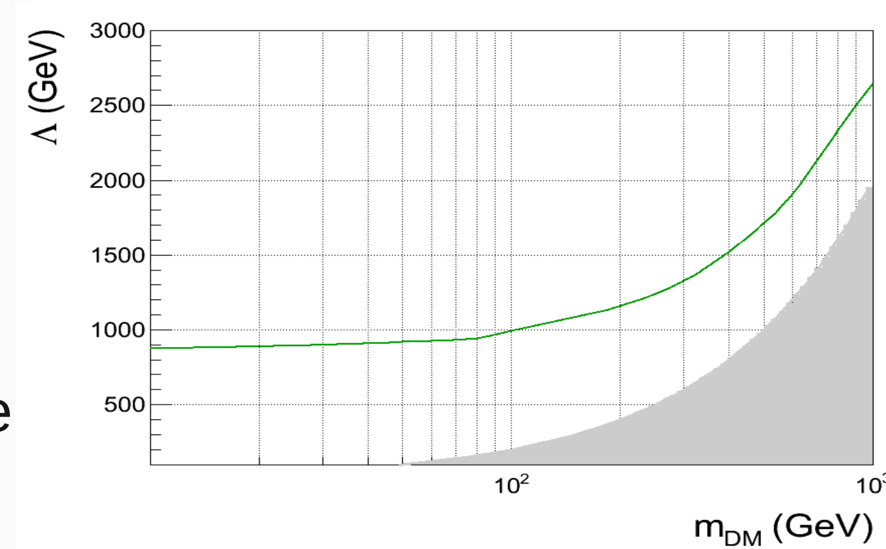
Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$ → $\frac{1}{M_*^2}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G_{\mu\nu}^a)^2$

Procedure

$$R_\Lambda = \left(1 - e^{-a_0\left(\frac{\Lambda - 2m_{DM}}{a_1}\right)^{a_2}}\right)\cdot\left(1 - e^{-a_3\left(\frac{\Lambda + 2m_{DM}}{a_1}\right)^{a_4}}\right)$$

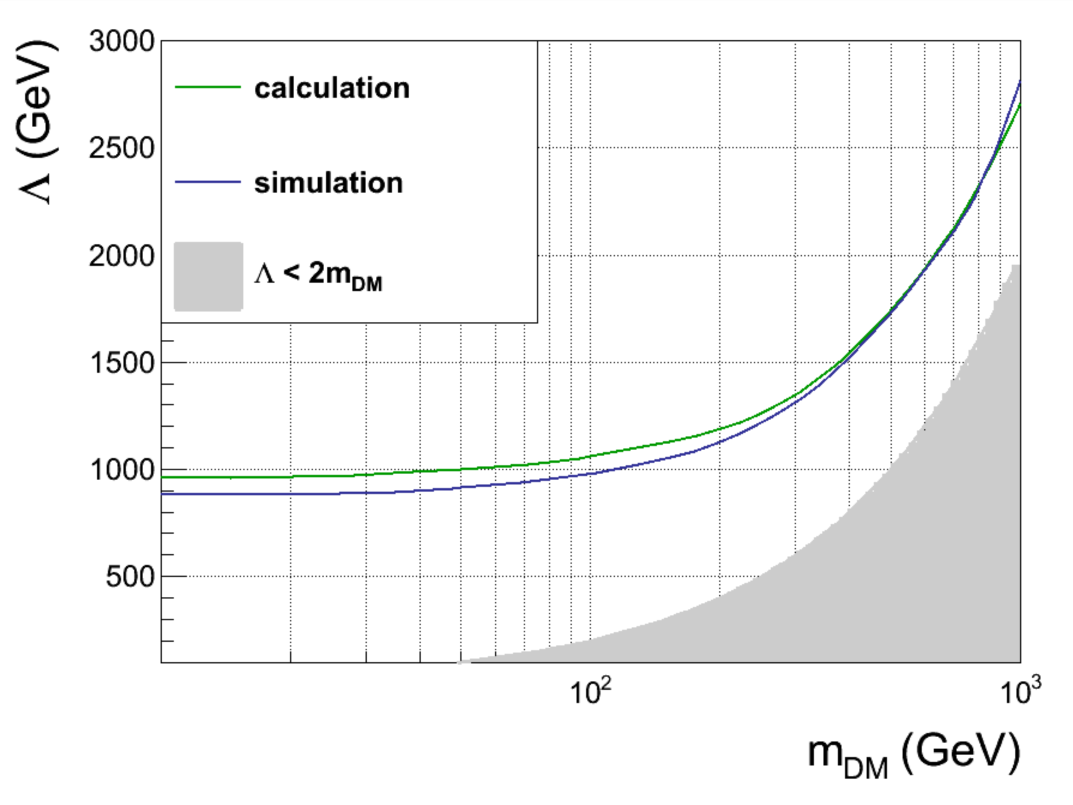
- Simulate events in MadGraph for different DM masses and Mediator masses (20k events for each point)
  - m_{DM}: 10, 50, 80, 100, 400, 600, 800, 1000 GeV
  - m_M: 250, 500, 1000, 1500, 2000, 2500, 3000 GeV
- Count events fulfilling or failing the condition $Q_{TR} < m_M$
  - Construct ratio R_Λ = valid events / all events
- Plot R_Λ vs. mediator mass for each DM mass
  - Fit to extract value of mediator mass for which R_Λ is e.g. 50%
- Construct curve Λ vs m_{DM}, showing the line where R_Λ is e.g. 50%





Comparison with analytical results

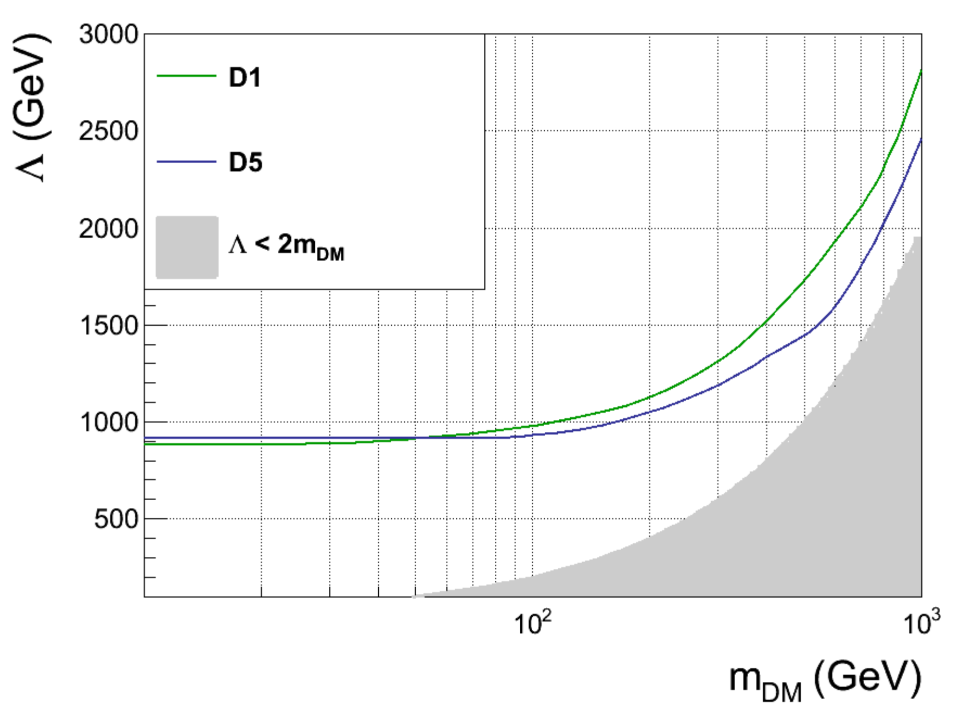
- **Scenario:** 1 gluon jet with p_T above 120 GeV with $|\eta| < 2$
- Good qualitative agreement, small difference
  - Keep in mind: completely different approaches
  - Differences: upper jet p_T cut of 1 TeV in analytical calculation
  - Slightly different use of fitting function

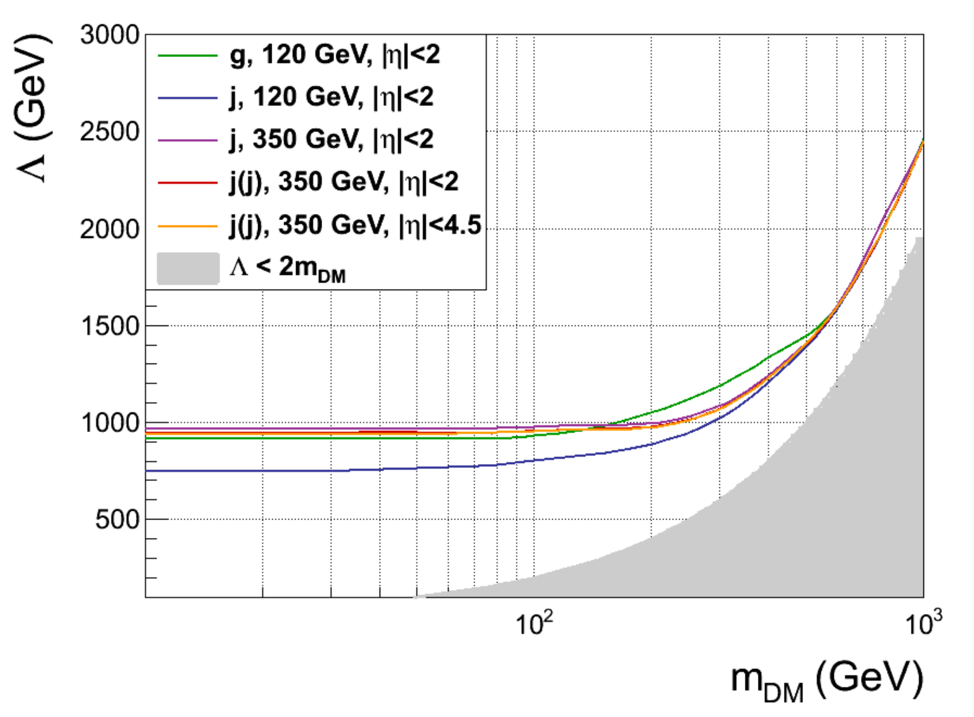


Way to a more realistic scenario

- **Analysis**
  - Limits on operators D5, D8, D11
  - No restriction to gluon jets
  - leading jet p_T above 350 GeV
  - 1 or 2 jets
  - Second jet within $|\eta| < 4.5$

- **Effect on R_Λ**
  - Small difference in shape when going from D1 to D5
  - R_Λ higher for all jet flavors
  - R_Λ lower for higher jet p_T
  - No effect of number of jets
  - No effect of η range

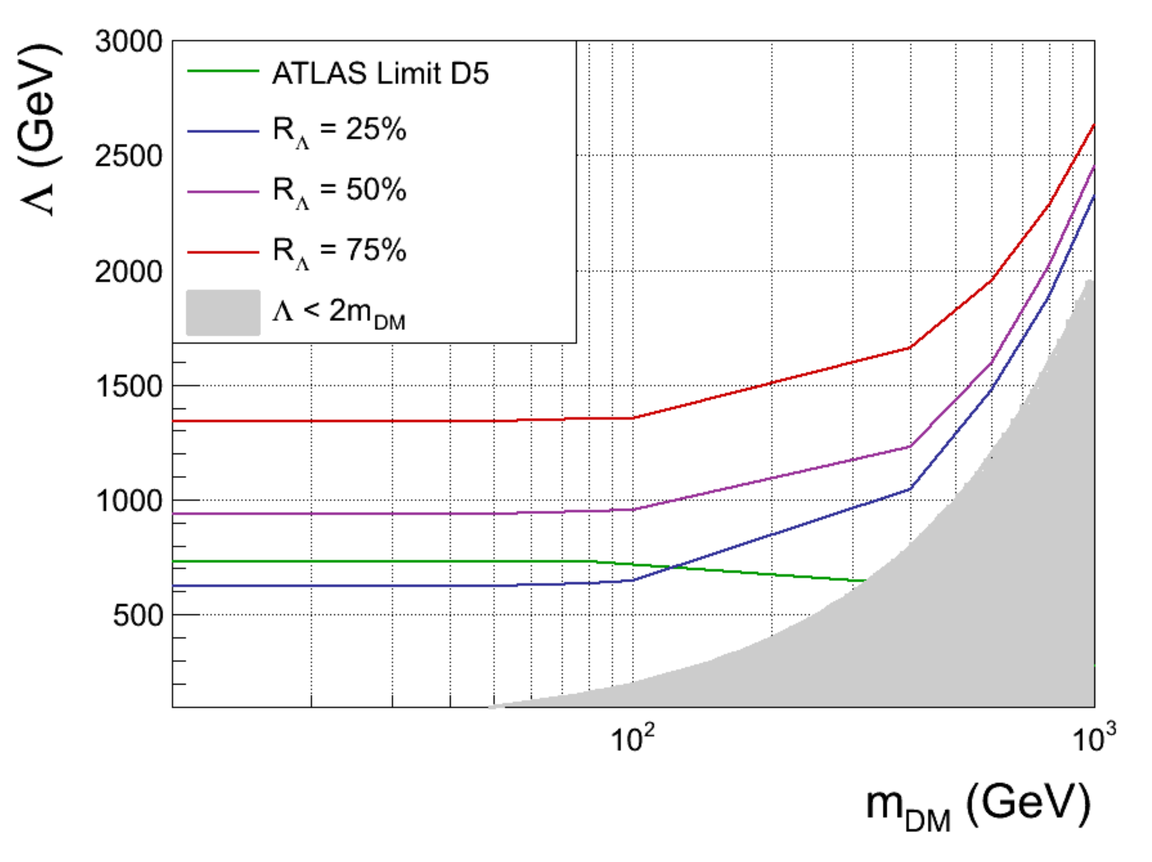


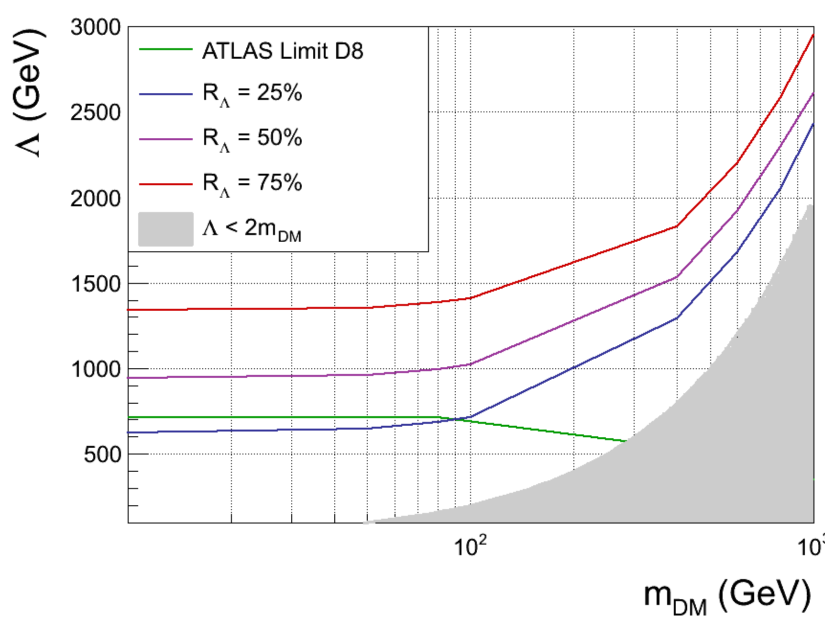


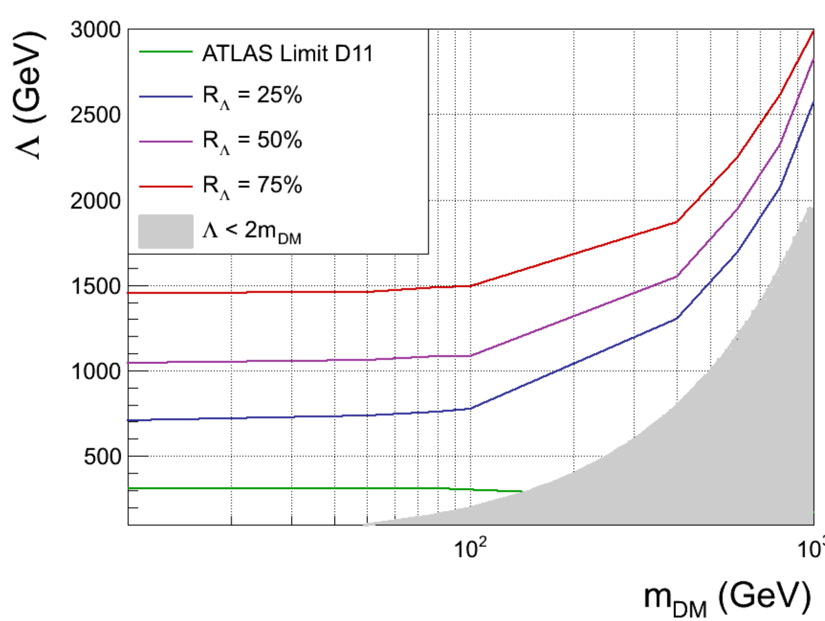
Comparison with latest ATLAS results

- Limits are in Region of R_Λ = 30% or even below!
  - Especially bad: D11 (gluon operator)
- At m_{DM} ~ 100 GeV limit goes down, whereas the R_Λ curves go up

ATLAS results from ATLAS-CONF-2012-147

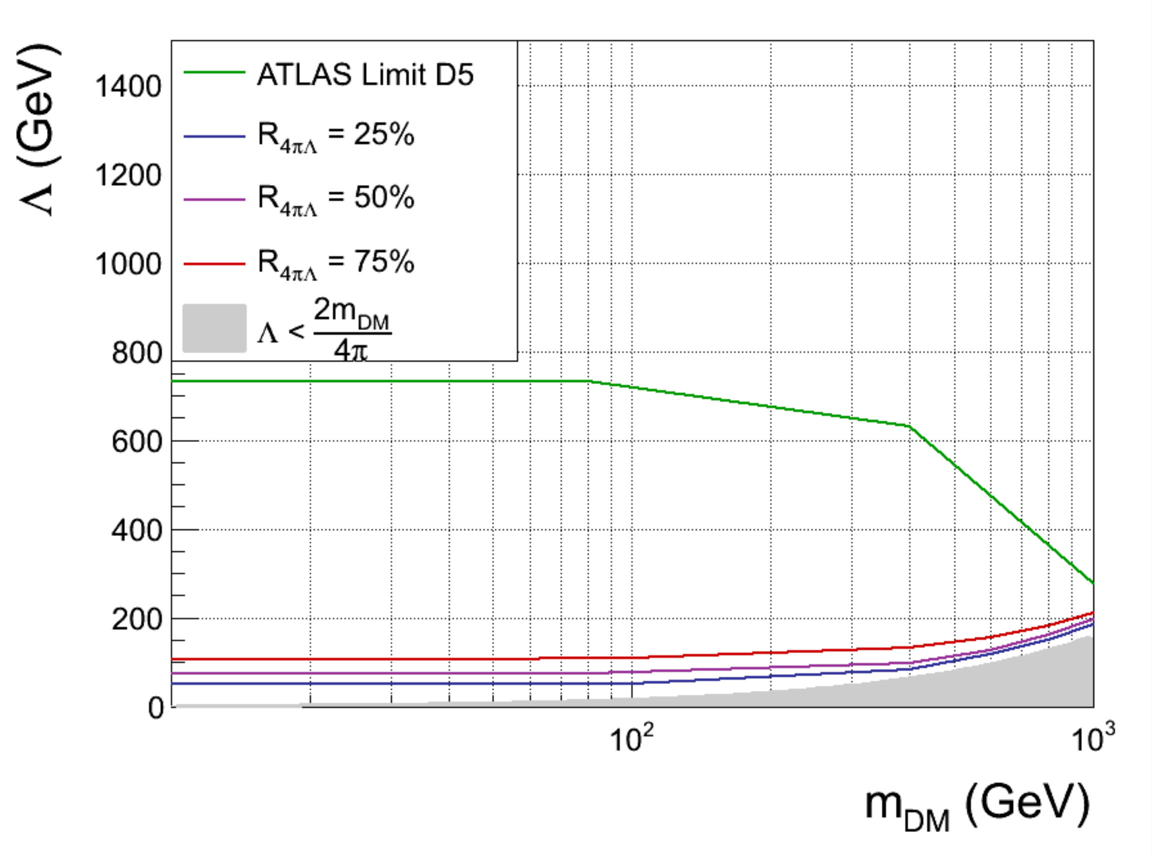


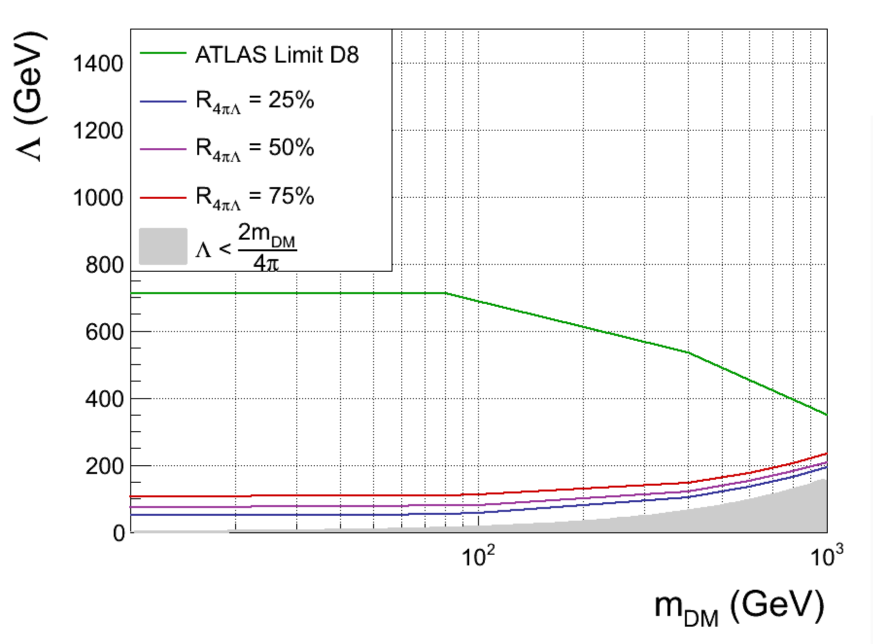


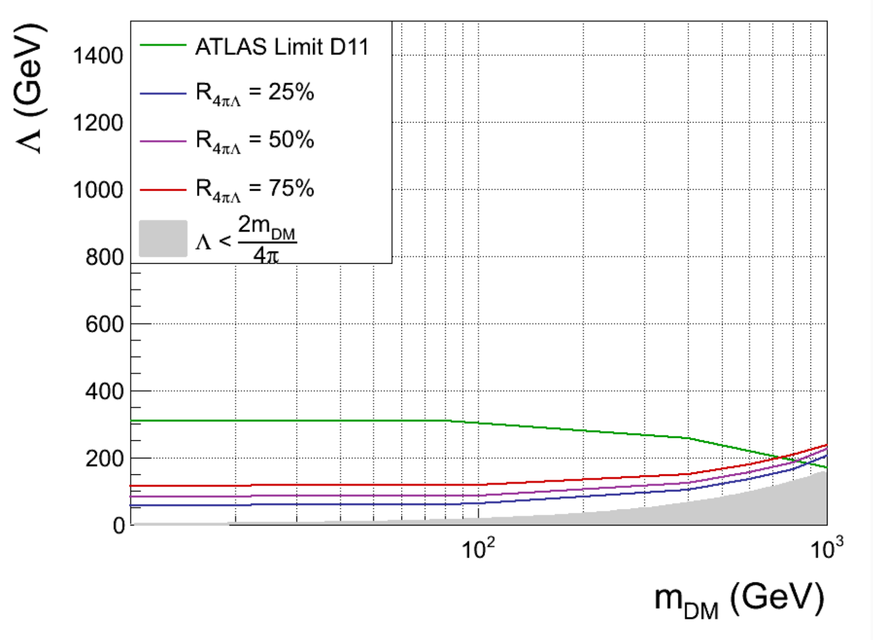


Limiting case: $\sqrt{(g_q g_\chi)} = 4\pi$

- Limits are well above $R_\Lambda = 75\%$!
  - Again: most critical for D11 (gluon operator)
    - R_Λ=75% is crossed at m_{DM} = 600 GeV







Summary

- EFT is very useful to interpret LHC results, e.g. from a Monojet analysis, in terms of DM production
  - Only dependent on very few parameters
  - Problem: how valid is the EFT approach at LHC energies?
- Idea to judge validity of EFT: construct R_Λ
  - MadGraph used to simulate events
  - For each event check, if EFT condition is fulfilled
  - Show lines of “percentage of valid events” in usual limit plots
- Comparison with ATLAS result shows
  - If couplings are taken to be one, limits are in region of 30% valid events
  - If couplings are assumed to be larger, limits are well above critical region
- Maybe interesting addition: check after showering

BACKUP

Analystical Result

- Figure 5 of *arXiv:1307.2253v1*