DISCUSSION ON DM AT COLLIDERS

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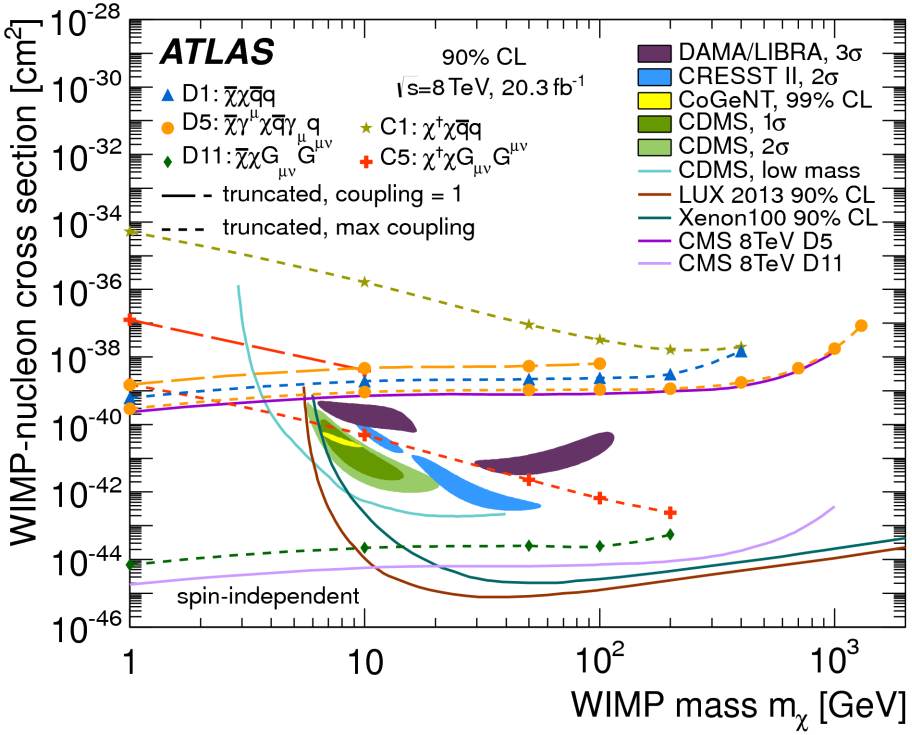
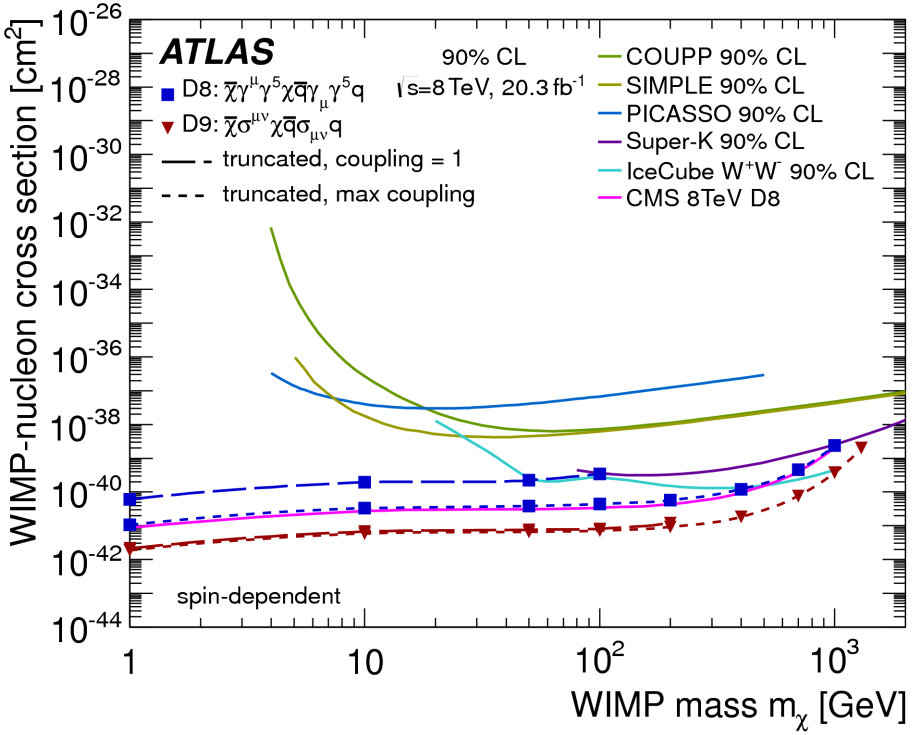
+ e-mail input from Antonio Boveia (ATLAS/CMS DM Forum)

25/03/2015 – MITP "Effective Theories for Dark Matter"

COMPLEMENTARITY OF DD/ID/COLLIDERS (1)





Questions for discussion:

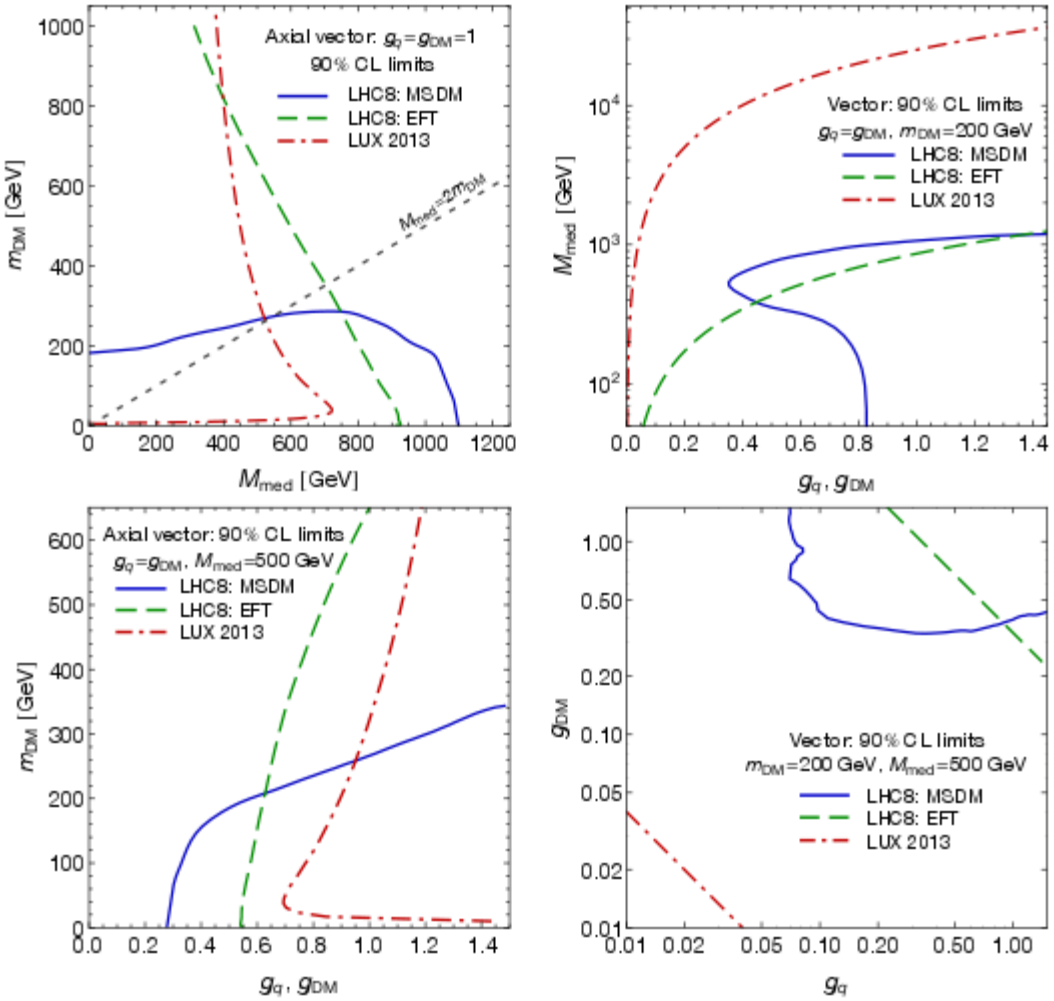
1) is a comparison on this plane reasonable?

2) what uncertainties (e.g. production uncertainties) uncorrelated with non-collider results should be included in the EFT limits, and how?

COMPLEMENTARITY OF DD/ID/COLLIDERS (2) (FEEDBACK FROM DARK MALT WORKSHOP)

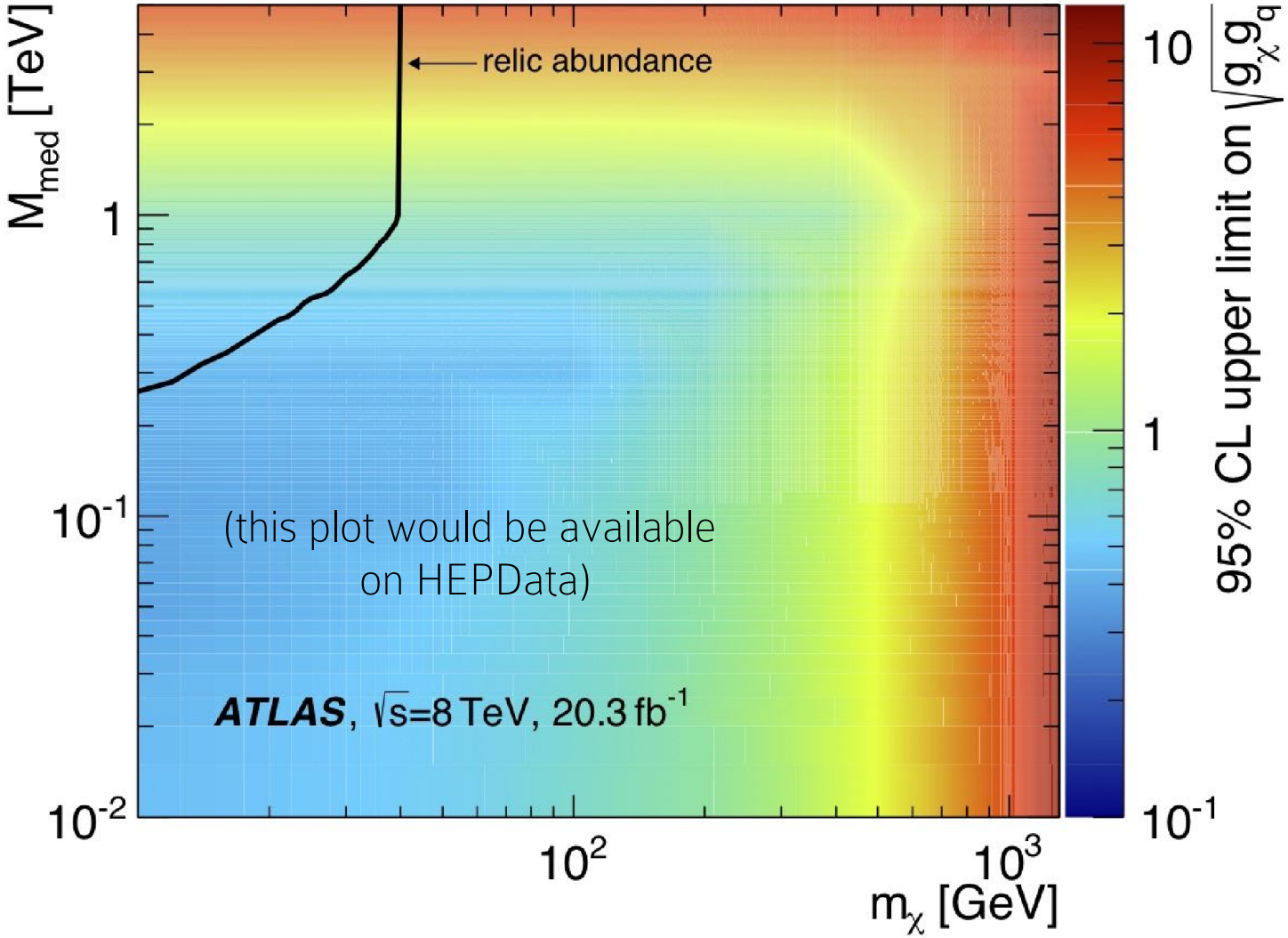
Proposal slides from Bristol workshop (1407.8257)

Maybe plot m_DM on the x axis, (on log scale)



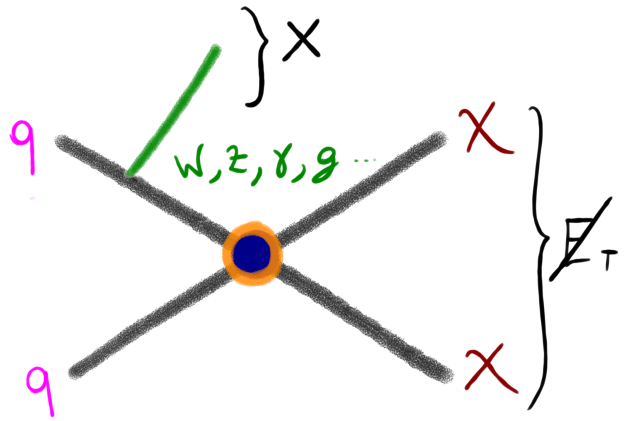
SIMP. MODEL REINTERPRETATION (FEEDBACK FROM DARK MALT WORKSHOP)

Example of vector mediator (Z'-like)



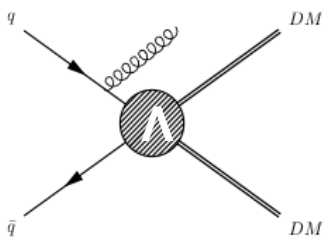
Commonly used benchmark at colliders:

Contact Interaction (Effective Field Theories)



arxiv:1008.1783

EFT Operators



CI approximation valid if

$$Q_{tr} < M_{med}$$

(minimal constraint)

Truncation procedures available
(see backup, slides from this morning)

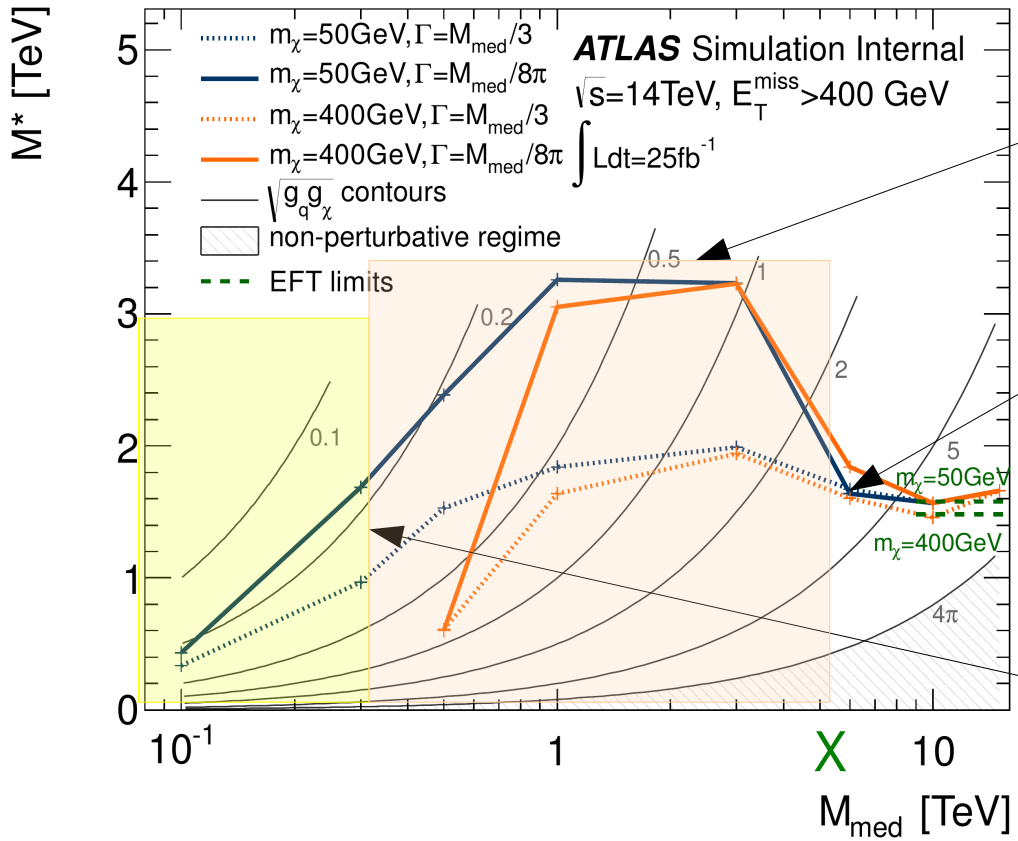
Question for discussion:

1. Is this EFT/CI still a **viable/useful benchmark** for colliders?
   If so, how to make sure its caveats are known →
   Can/should we do something about its **validity**?

SIMPLIFIED MODELS LIMITS AS EFT LIMITS?

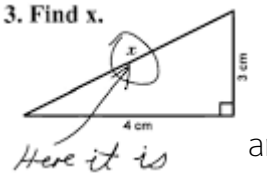
Question for discussion:

what about experimentalists only give an EFT-like limit coming from simplified models with very high mass mediators?



You don't want to use an EFT here (it would be too conservative)

Region of interest for EFT limits: Mmed > X



We would need to study the "turn-on": generate more points around on/off-shell region

You don't want to use an EFT here (it would contain invalid events)

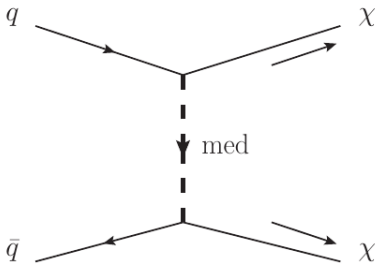
Question for discussion:

Is it easy for theorists to map simplified model back to an EFT?

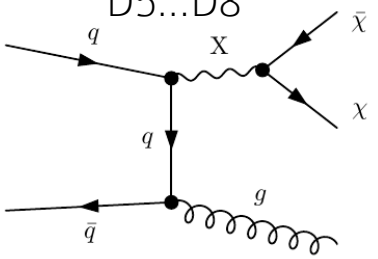
Commonly used operators for collider searches (distinct kinematics/ SD/ID differences)

Name	Initial state	Type	Operator
C1	qq	scalar	$\frac{m_q}{M_\star^2}\chi^\dagger\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_\star^2}\chi^\dagger\chi\alpha_s(G^a_{\mu\nu})^2$
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
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	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

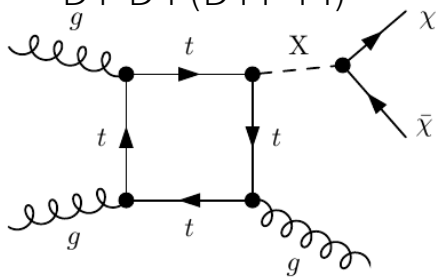
Linear combination of D1, D8, D9



D5...D8

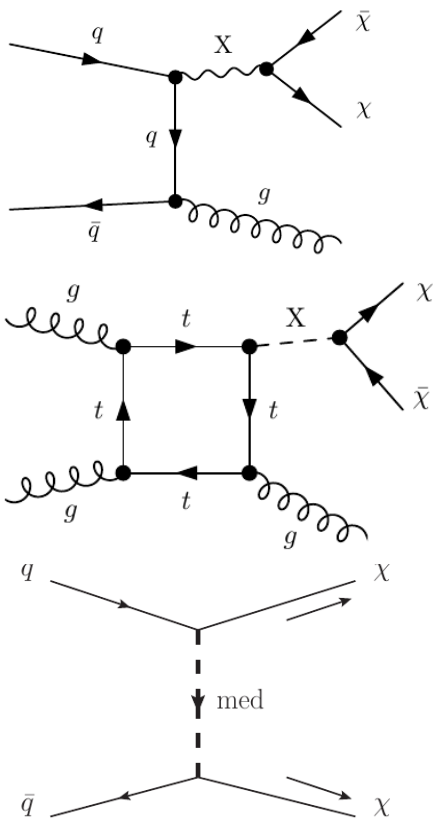


D1-D4 (D11-14)



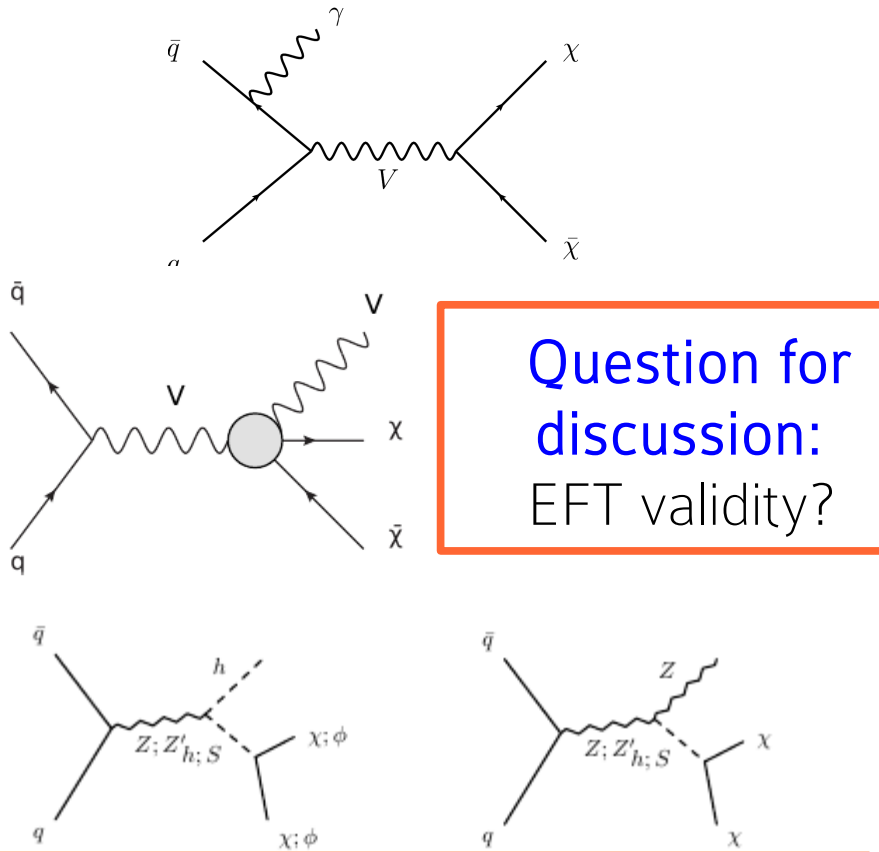
PRIORITIZED LIST OF SIMPLIFIED MODELS FOR ATLAS/CMS

Prioritized list of models for jet+MET search



More models for ttbar+MET searches, single top+ MET searches

Prioritized list of models for W/Z/γ+MET searches



Question for discussion:
EFT validity?

Question for discussion:
Are we missing something?
What about colored vector t-channel / charged (heavy fermion) mediators

Further questions for discussion:

1) Should we constrain the **initial state partons** to light quarks only (done so far) or turn on heavy quarks?

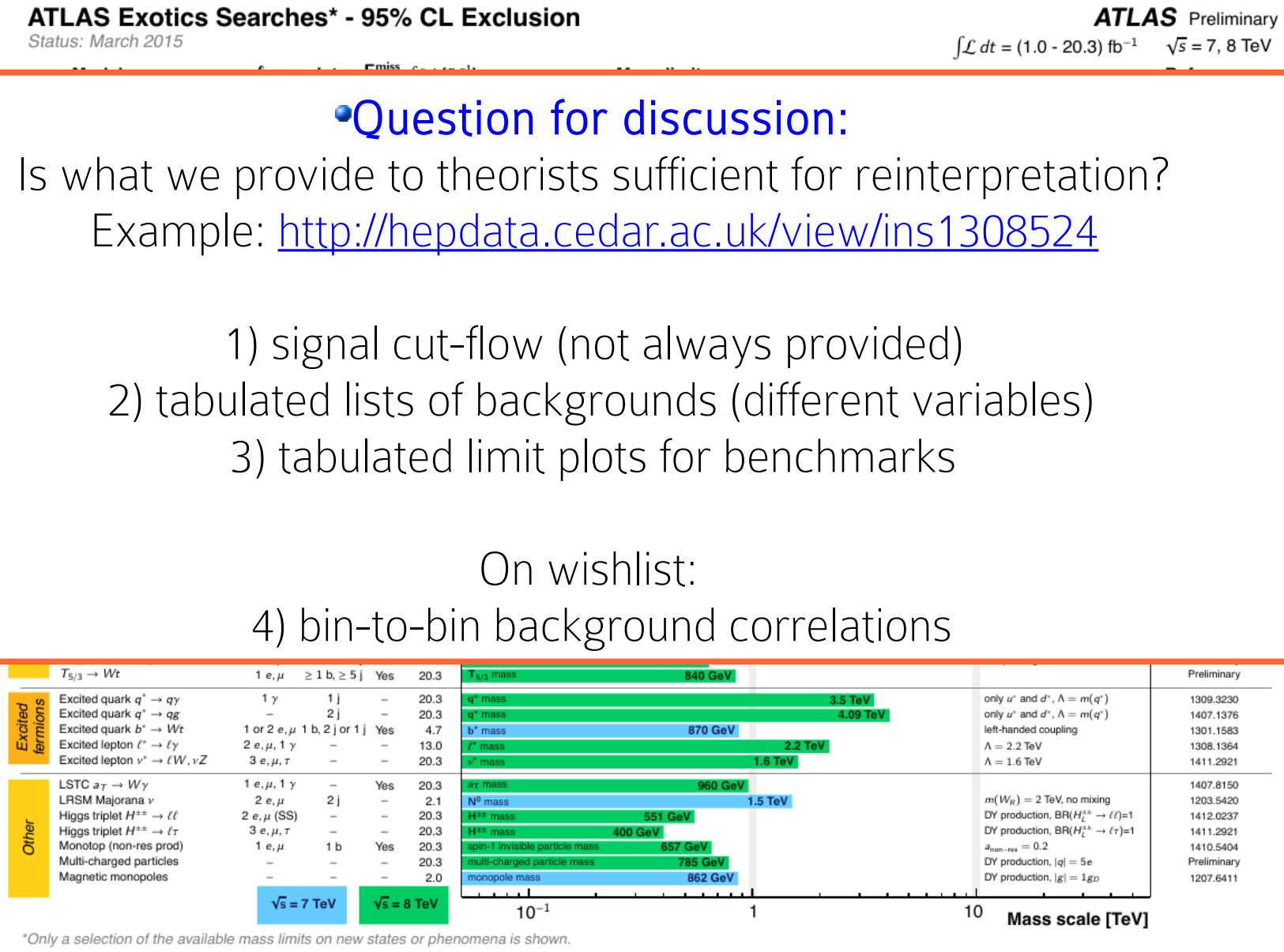
2) is it useful to draw a distinction between mq-dependent / Yukawa EFT coefficients and those without (→ **MFV**)?
Are the variants well-motivated?

3) what about **spin-2 mediators**?
Is this covered by combinations of tensor EFT?

4) if we see **no signal**, are there **higher dimension** mono-jet-like operators that would become well-motivated?

5) how do we **proceed in case of signal**
(see Emanuele's talk, other ideas?)

REINTERPRETATION



- **Question for discussion:**

Is what we provide to theorists sufficient for reinterpretation?
Example: http://hepdata.cedar.ac.uk/view/ins1308524

1) signal cut-flow (not always provided)
2) tabulated lists of backgrounds (different variables)
3) tabulated limit plots for benchmarks

On wishlist:
4) bin-to-bin background correlations

BACKUP SLIDES

EFT OPERATORS FOR MET+X SEARCHES

Name	Initial state	Type	Operator
C1	qq	scalar	$\frac{m_q}{M_\star^2}\chi^\dagger\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_\star^2}\chi^\dagger\chi\alpha_s(G^a_{\mu\nu})^2$
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D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

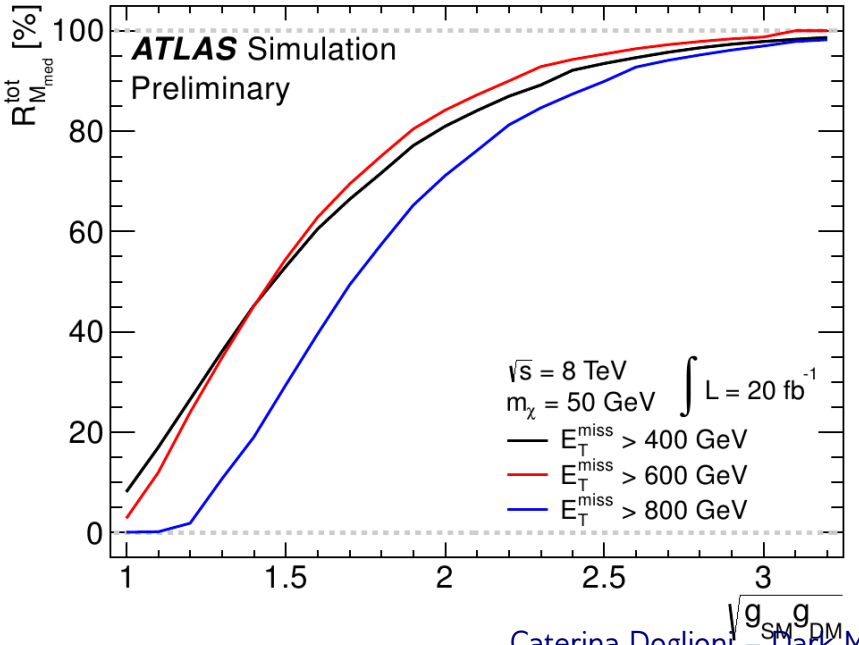
MONO-JET PROSPECTS AND EFT VALIDITY [ATL-PHYS-PUB-2014-007]

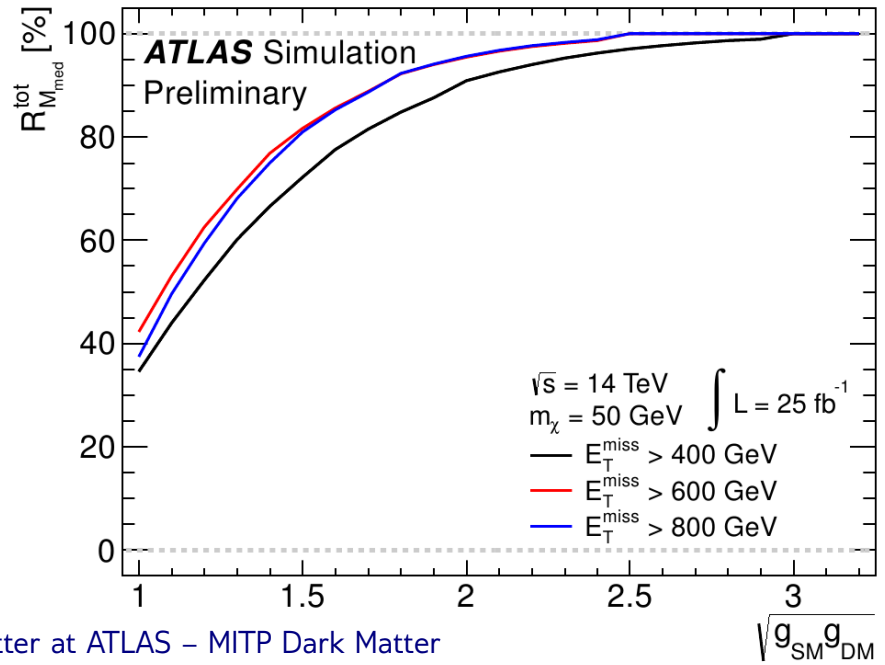
Early DM searches: what do we gain/lose from CoM increase?

- Current monojet analysis: systematically limited at low MET, statistically limited at high MET → How high can we reach in $M*$ at 14 TeV?
- Will we have problems with the EFT validity at a higher CoM energy?

Somehow counterintuitive results! **Competing effects**: $Q_{\mathrm{tr}} < \sqrt{g_{\mathrm{SM}} g_{\mathrm{DM}}} M^*$

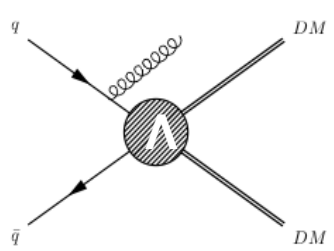
- Higher MET → higher Q_{tr} (weak correlation: MET smeared by detector)
- Increase of reach in M* → higher limits to start with → increased validity





EFT VALIDITY: IS TRUNCATING A SOLUTION?

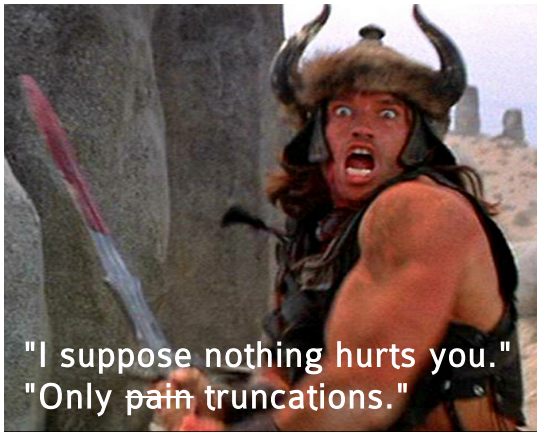
ATLAS: arXiv:1502.01518



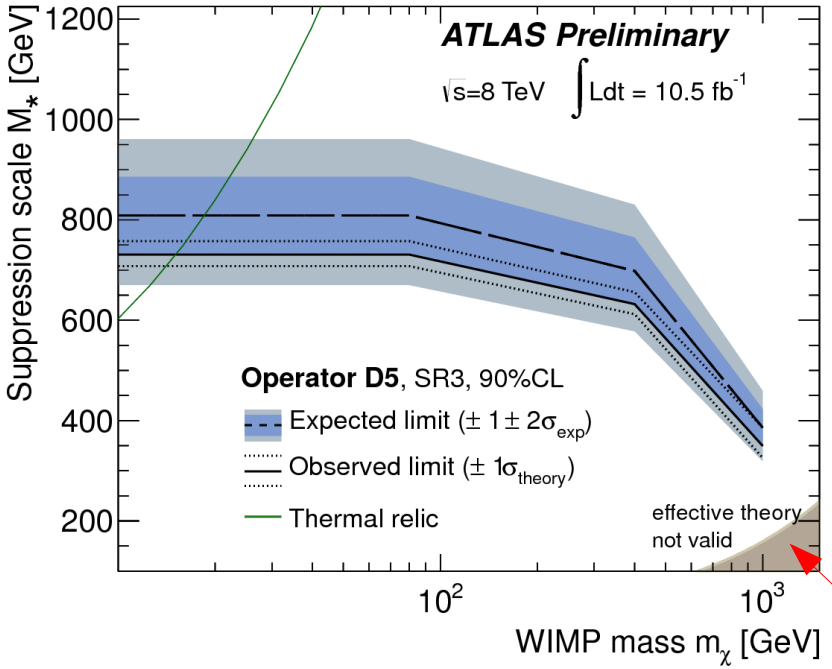
CI approximation valid if

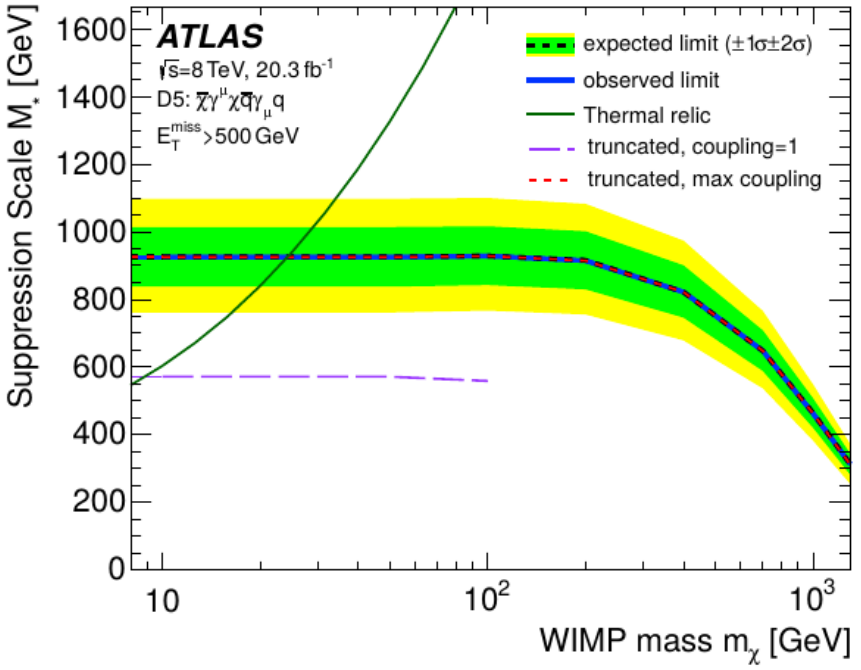
$$Q_{tr} < M_{med}$$

(minimal constraint)



Can we simply remove invalid events and have **conservative** limits at all times?

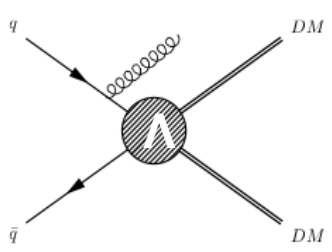




Coupling perturbativity + s-channel mediator

EFT VALIDITY TRUNCATION PROPOSAL (ATLAS)

ATLAS: arXiv:1502.01518



Valid if

$$Q_{tr} < M_{med}$$

(minimal constraint)

Connect **mediator mass and EFT scale Λ**:
need information on **theory completion**
→ coupling-dependent condition,
precise and well-defined within choices

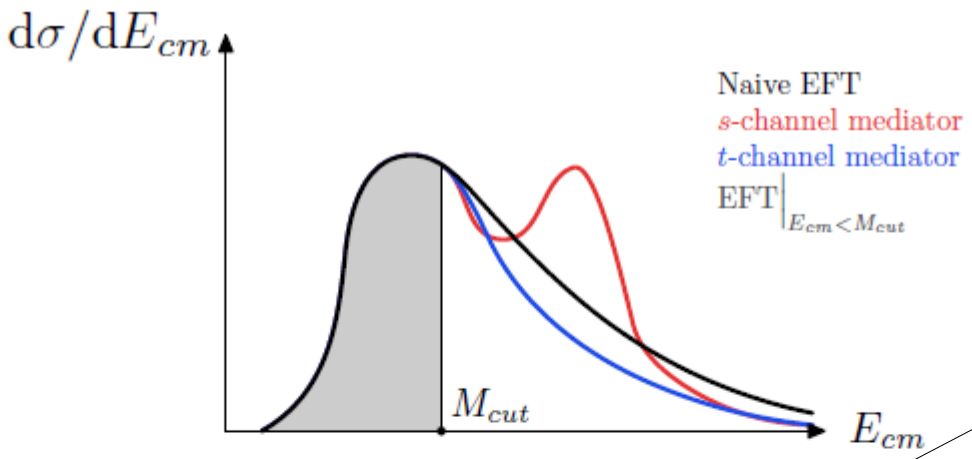
Operator(s)	Relation between M_{med} and M_*	Coupling term range
D1	$M_{med} = \sqrt{y_q g_\chi}\ \sqrt{M_*^3/m_q}$	$0 < \sqrt{y_q g_\chi} < 4\pi$
C1	$M_{med} = y_q \lambda_\chi \zeta_\lambda\ M_*^2/m_q$	$0 < y_q \lambda_\chi \zeta_\lambda < (4\pi)^2 \zeta_\lambda$
D5, D8, D9	$M_{med} = \sqrt{g_q g_\chi}\ M_*$	$0 < \sqrt{g_q g_\chi} < 4\pi$
D11	$M_{med} = \sqrt[3]{a g_\chi}\ M_*$	$0 < \sqrt[3]{a g_\chi} < \sqrt[3]{16\pi}$
C5	$M_{med} = \sqrt{a \lambda_\chi \zeta_\lambda}\ M_*$	$0 < \sqrt{a \lambda_\chi \zeta_\lambda} < 4\sqrt{\pi \zeta_\lambda}$

Key parameter for truncation: $R^{tot}_{M_{med}}$ = fraction of events passing $Q_{tr} < M_{med}$

Two equivalent procedures:

cross-section truncation, corresponding only to valid events(used in 8 TeV papers)
iterative rescaling of M* limits after determining R (used in 14 TeV studies)

ALTERNATIVE EFT VALIDITY TRUNCATION PROPOSAL arXiv:1502.01518 16



$$\mathcal{L}_{\text{EFT}} = -\frac{1}{M_*^2}\left(\overline{X}\gamma^\mu\gamma^5 X\right)\left(\sum_{\text{flavours}}\overline{q}\gamma_\mu\gamma^5 q\right)$$

- We restrict the signal to the events for which

$$E_{\text{cm}} < M_{\text{cut}},$$

where E_{cm} is the total invariant mass of the hard final states of th reaction:

$$E_{\text{cm}} = \sqrt{\hat{s}} = \sqrt{\left(p^\mu(\text{DM}_1) + p^\mu(\text{DM}_2) + p^\mu(\text{jet})\right)^2}.$$

- Indeed, the following *always* holds:

$$\sigma^{\text{signal}}_{\text{true model}} > \sigma^{\text{signal}}_{\text{corresp. EFT}}\Big|_{E_{\text{cm}}<M_{\text{cut}}}.$$

Thus we obtain conservative but reliable limits.

Mcut = g*M*

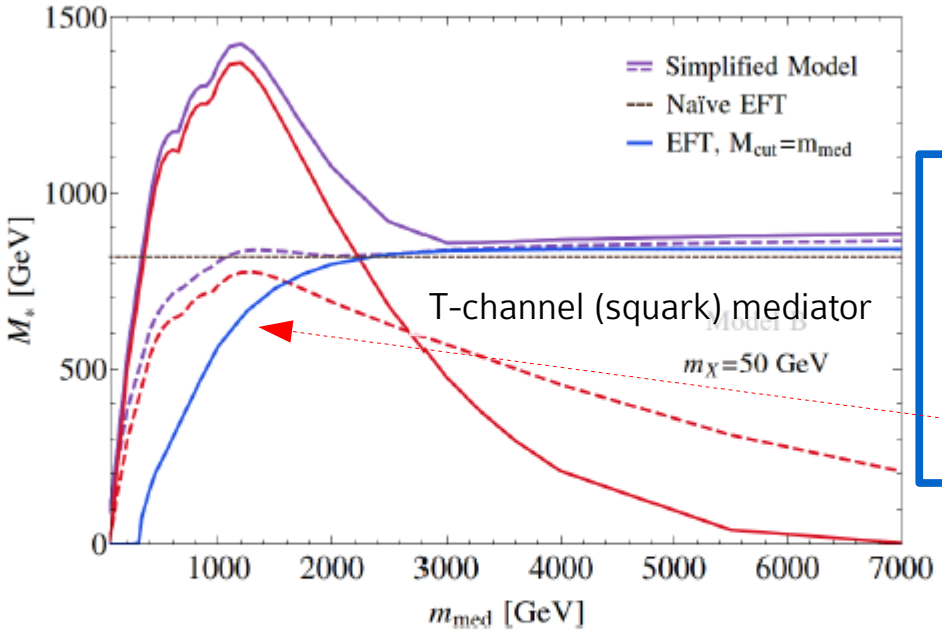
- only depends on parameters of the EFT as opposed to needing information on UV completion (still, physical interpretation requires assumptions)

- can be **scanned**

MORE ON EFT VALIDITY TRUNCATION PROPOSAL

arXiv:1502.01518

Comparison with the simplified model



Direct comparison with simplified model: shows very (too?) conservative region after truncation

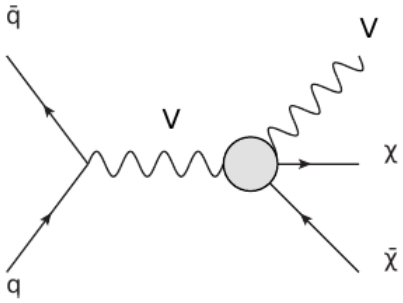
- **Blue line**: from model-independent limit, with the identification

$$M_* = \frac{2\widetilde{m}}{g_{\rm DM}}\,, \qquad M_{\rm cut} = \widetilde{m}\,.$$

- **Red lines**: only from the resonant production of the mediator.

The EFT limit is complemented by the limit from the resonant production.

MODELS WITH DIRECT BOSON-DM COUPLING FOR DIRAC DM



Dimension-7 operators
related by gauge invariance
→ choose benchmark points for k1/k2
that are easy to reinterpret

1. Dimension-5 model

$$\frac{m_W^2}{\Lambda_5^3}\,\bar{\chi}\chi\,W^{+\mu}W^-_\mu + \frac{m_Z^2}{2\Lambda_5^3}\,\bar{\chi}\chi\,Z^\mu Z_\mu$$

Possible choice of initial benchmark

2. Dimension-7 models

$$\mathcal{L} = \frac{1}{\Lambda^3_{C1,2}}\,\bar{\chi}\chi\sum_i k_i F_i^{\mu\nu}F^i_{\mu\nu} + \frac{1}{\Lambda^3_{C3,4}}\,\bar{\chi}\chi\sum_i k_i F_i^{\mu\nu}\tilde{F}^i_{\mu\nu}$$

Possible choice of initial benchmark

scalar

$$\mathcal{L} = \frac{1}{\Lambda^3_{C5,6}}\,\bar{\chi}\gamma^5\chi\sum_i k_i F_i^{\mu\nu}F^i_{\mu\nu} + \frac{1}{\Lambda^3_{C7,8}}\,\bar{\chi}\gamma^5\chi\sum_i k_i F_i^{\mu\nu}\tilde{F}^i_{\mu\nu},$$

pseudoscalar,
(can be reweighted
from scalar)

$$g_{gg} = \frac{k_3}{\Lambda_7^3}$$

$$g_{WW} = \frac{2k_2}{s_w^2\Lambda_7^3}$$

$$g_{ZZ} = \frac{1}{4s_w^2\Lambda_7^3}\left(\frac{k_1 s_w^2}{c_w^2} + \frac{k_2 c_w^2}{s_w^2}\right)$$

$$g_{\gamma\gamma} = \frac{1}{4c_w^2}\frac{k_1+k_2}{\Lambda_7^3}$$

$$g_{Z\gamma} = \frac{1}{2s_w c_w\Lambda_7^3}\left(\frac{k_2}{s_w^2} - \frac{k_1}{c_w^2}\right)$$

Monophoton/monoZ: no different in kinematics from choice of k1, k2 → choose favourable x-sec point

UV-completion is **possible**, but not covered in Forum
Validity criteria under discussion – input?