

ATLAS/CMS DARK MATTER FORUM INTRO

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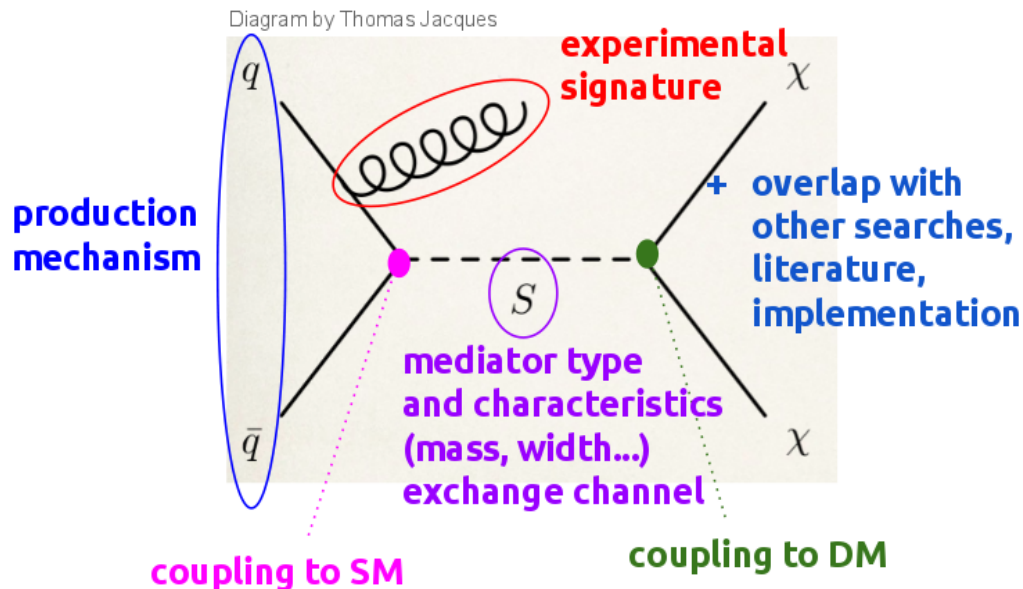
Sarah Alam Malik – Imperial College

Steve Mrenna – Fermilab

RECAP: DARK MATTER FORUM MANDATE

ATLAS/CMS Dark Matter Forum:
experiment/theory discussion towards early Run-2 DM searches

Many possibilities
to be used as building blocks:



This Forum will agree upon:

- Prioritized **set of simplified models**
- Common **model implementation and details** (e.g. matching, scales) towards MC generation of benchmarks
- **EFT validity** assessment procedure

This Forum will document:

models and choices
(arXiv write-up + SVN repository)

STATUS OF SIMPLIFIED MODEL WORK

- **Models for all MET+X searches**

Vector s-channel, scalar s-channel, scalar t-channel mediators
Models and parameter scans available, collecting & writing up

- **Models for searches with EW bosons**

Direct DM-boson couplings (EFT):

- models/plots/grid scans available
- ongoing **discussion on validity/completions**

Mono-Higgs models: **more work needed!**

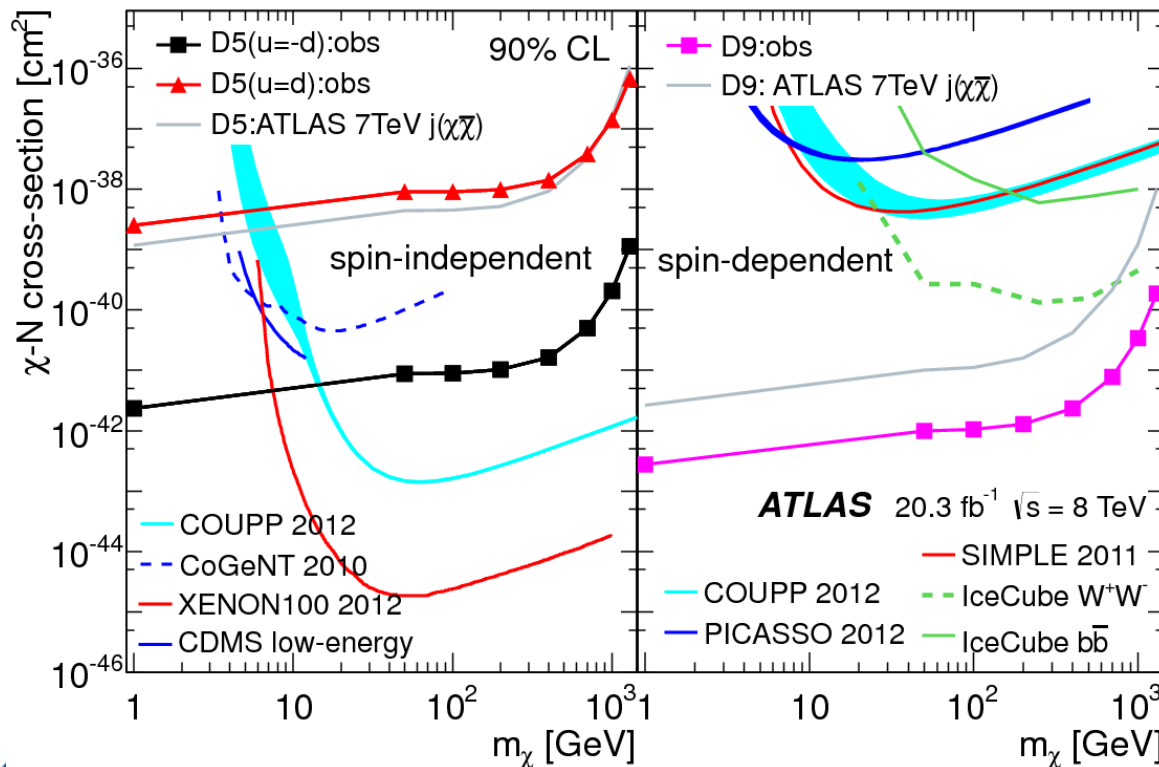
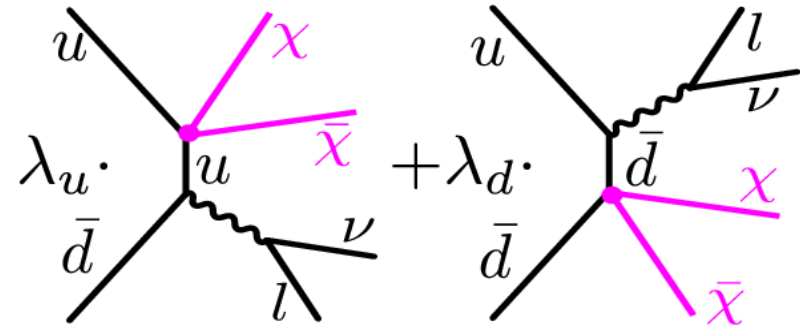
- **Models with single top/b+MET and ttbar/bbar+MET**

Converging, see today's presentations

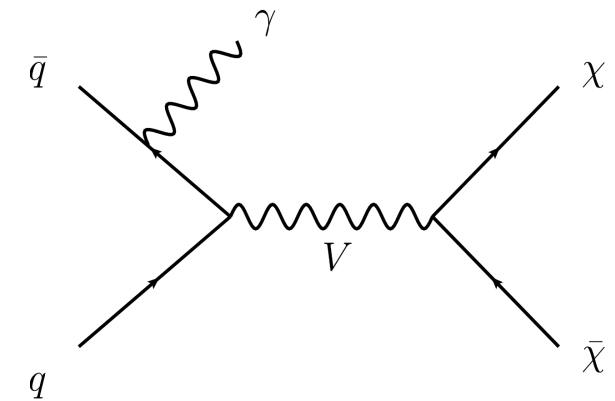
- **Need agreement on handling of theoretical uncertainties**

W+MET, VECTOR MEDIATOR UPDATE: INTERFERENCE

Run-1: Exploiting constructive interference between diagrams (depending on DM couplings to u/d) for increased sensitivity of mono-W



Also applies for vector mediator simplified model

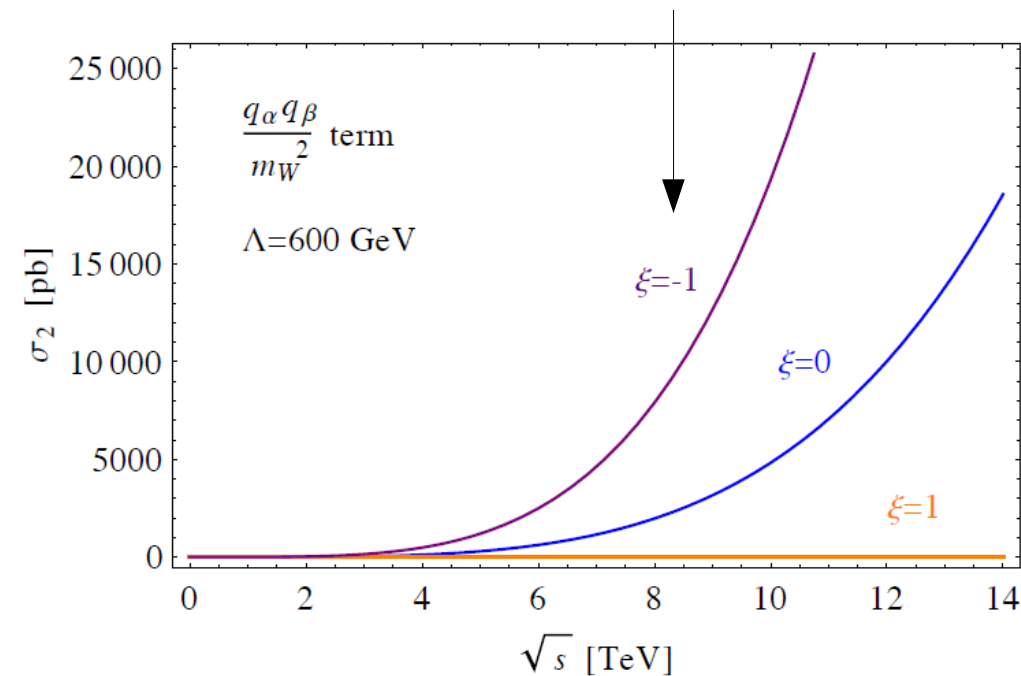


With sensitivity comparable/better than monojet, this seems like a good benchmark!

W+MET, VECTOR MEDIATOR UPDATE: INTERFERENCE

Recent paper by N. Bell & al (<http://arxiv.org/abs/1503.07874>):
increase in cross-section is due to EW gauge symmetry violation
(analogy to WW scattering non-unitarity fixed by Higgs)

Cross-section enhancement in symmetry-violating term



DM Forum plan:

1. Recommend s-channel mediator as benchmark
- do not highlight interference
2. Point to alternative UV-complete model (Y. Bai)
- potential model for future
3. Add colored t-channel mediator as alternative
- Mediator can also emit gauge boson

EFT VALIDITY AT COLLIDERS: OPTIONS SO FAR

- **Do not consider EFT as a benchmark at all**
 - Pros:** Focus on simplified models
 - Cons:** Theory community appreciates simplicity of EFT
- **Keep EFT, untruncated**
 - Pros:** Keeps things simple for whoever knows how to use it
 - Cons:** Will be misinterpreted, can't be compared to direct detection
- **Truncate EFT (two methods available)**
 - Pros:** Consistent procedure, established within ATLAS
 - Cons:** Model-dependent, takes away from EFT simplicity
 - One more procedure will be shown today by Juan Alcaraz**
- **Only provide high-mediator-mass limit for simplified models**
 - Pros:** Equivalent to EFT to all effects, avoids validity problem by explicitly mentioning presence of mediator
 - Cons:** Needs EFT for models without clear UV completion/limit

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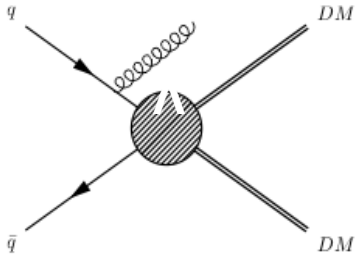
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CONTACT INTERACTION VALIDITY : TRUNCATION (ATLAS)



Valid if

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

(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	$M_{\text{med}} = \sqrt{y_q g_\chi} \sqrt{M_*^3 / m_q}$	$0 < \sqrt{y_q g_\chi} < 4\pi$
C1	$M_{\text{med}} = y_q \lambda_\chi \zeta_\lambda M_*^2 / m_q$	$0 < y_q \lambda_\chi \zeta_\lambda < (4\pi)^2 \zeta_\lambda$
D5, D8, D9	$M_{\text{med}} = \sqrt{g_q g_\chi} M_*$	$0 < \sqrt{g_q g_\chi} < 4\pi$
D11	$M_{\text{med}} = \sqrt[3]{a g_\chi} M_*$	$0 < \sqrt[3]{a g_\chi} < \sqrt[3]{16\pi}$
C5	$M_{\text{med}} = \sqrt{a \lambda_\chi \zeta_\lambda} M_*$	$0 < \sqrt{a \lambda_\chi \zeta_\lambda} < 4\sqrt{\pi \zeta_\lambda}$

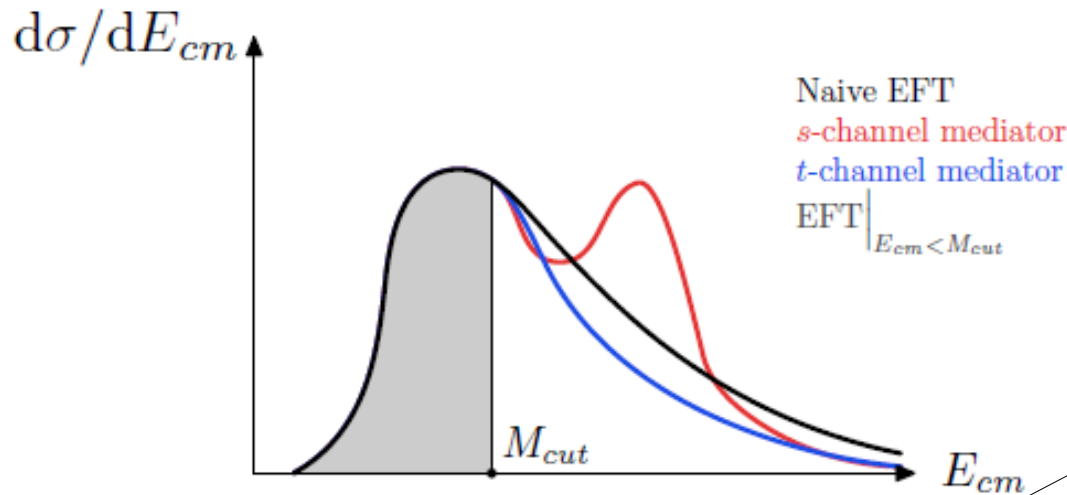
Key parameter for truncation: $R_{M_{\text{med}}}^{\text{tot}}$ fraction of events passing $Q_{\text{tr}} < M_{\text{med}}$

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 CI TRUNCATION



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

$$M_{\text{cut}} = g^* M^*$$

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

- can be scanned

- 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 the 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:

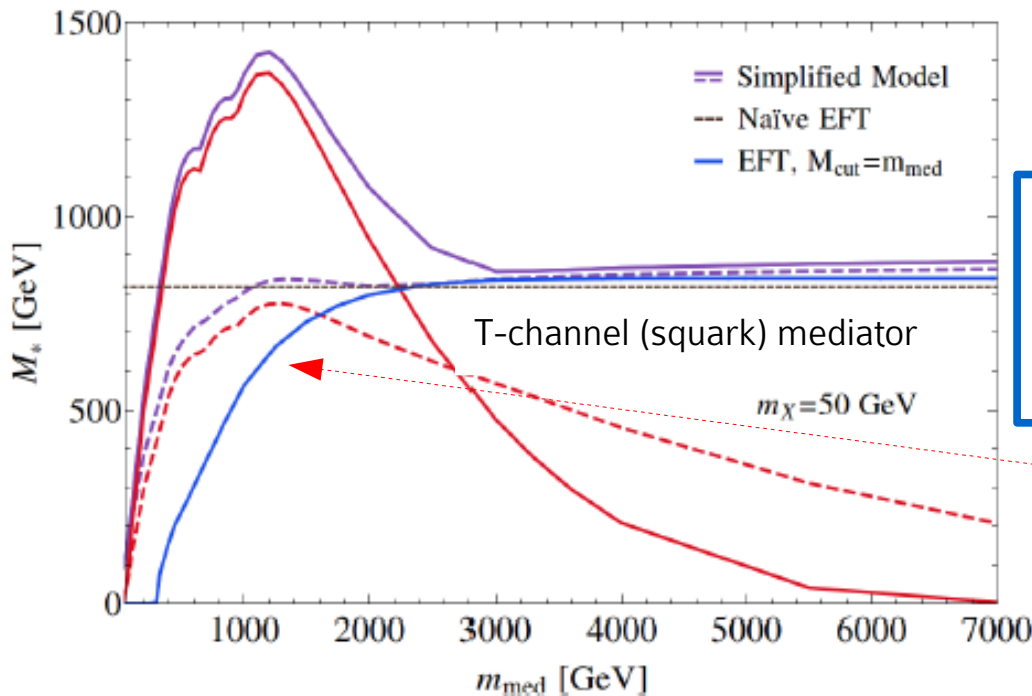
$$\sigma_{\text{true model}}^{\text{signal}} > \sigma_{\text{corresp. EFT}}^{\text{signal}} \Big|_{E_{\text{cm}} < M_{\text{cut}}}$$

Thus we obtain conservative but reliable limits.



ALTERNATIVE CI TRUNCATION

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

$$M_* = \frac{2\tilde{m}}{g_{DM}}, \quad M_{\text{cut}} = \tilde{m}.$$

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

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

EFT VALIDITY AT COLLIDERS: OPTIONS DISCUSSED

- **Do not consider EFT as a benchmark at all**

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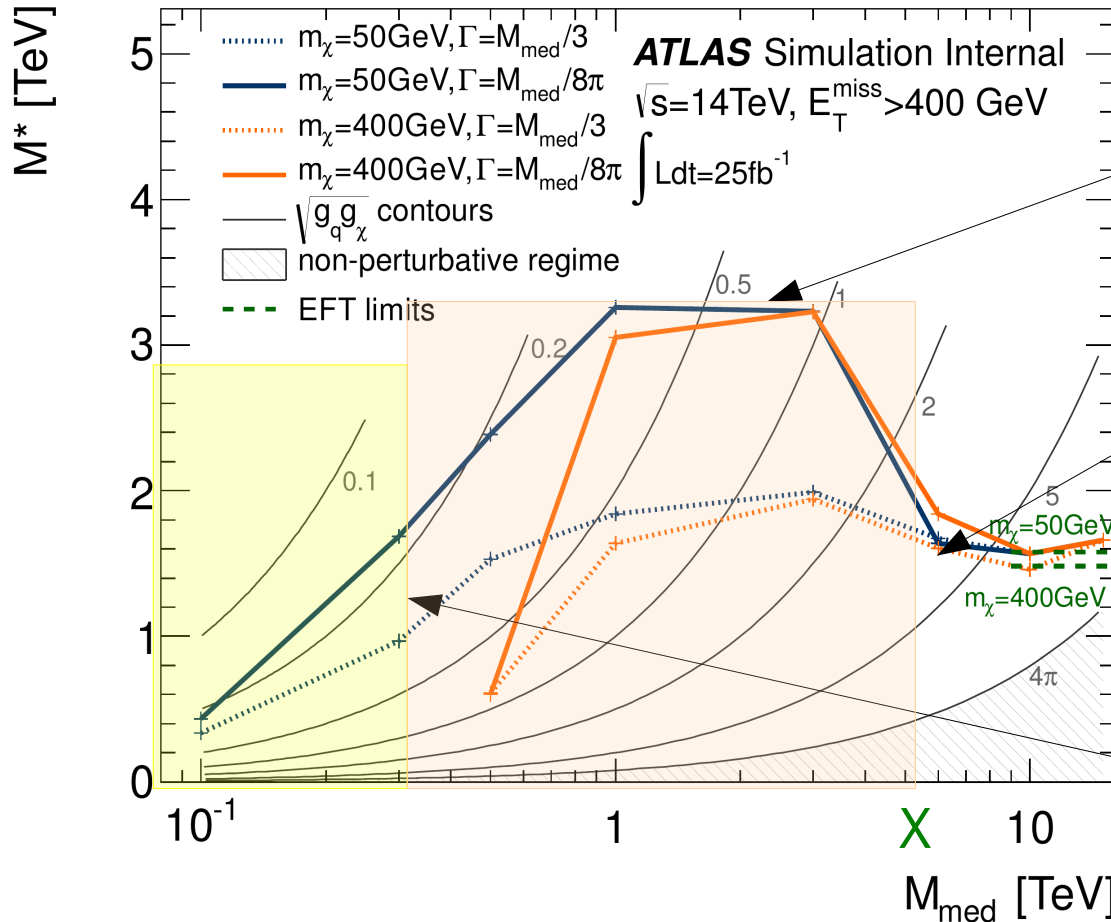
- **Only provide high-mediator-mass limit for simplified models**

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HIGH-MASS MEDIATORS AS EFT

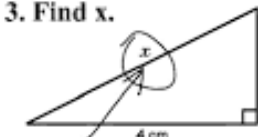
Suggestion: experimentalists only give a Contact Interaction limit from models with explicit mediator, with very high mass mediators?



Don't want to use CI model here (it would be **too conservative**)

Region of interest for EFT limits: $M_{\text{med}} > X$

3. Find x.



Here it is

We would need to study the "turn-on"

Cannot use an EFT here (it would contain **invalid events**)

Set limit on $g_1 g_2$, given that $M_{\text{med}} / \sqrt{g_1 g_2} \rightarrow M^*$

FORUM TIMESCALES (TOWARDS CONCLUSIONS)

- **Draft of full write-up** being finalized:
 - Jet+MET, EW boson, single top, EFT truncation sections available
 - Including kinematic plots and reference material (generator comparisons, x-sections...)
- **April 27th (Monday next week!)**:
 - Conclude on list of models and parameter scan for all channels
 - Circulate **very short summary document** to mailing list, 1 week to comment, then send to collaborations on May 4th
 - no plots yet, just decisions taken so far (supporting plots and rationale in write-up)
 - aim of short summary: have a reference for ATLAS/CMS MC generation
- **May 15th**:
 - Cut-off for submission of material to full write-up (and authorlist)
 - Editors and reviewers work on final version until the end of May
- **End of May**:
 - Submit full write-up to arXiv
 - Close Forum works with wrap-up meeting: what has been achieved, what is left to discuss beyond its Mandate (e.g. comparison of collider results with Direct/Indirect Detection)



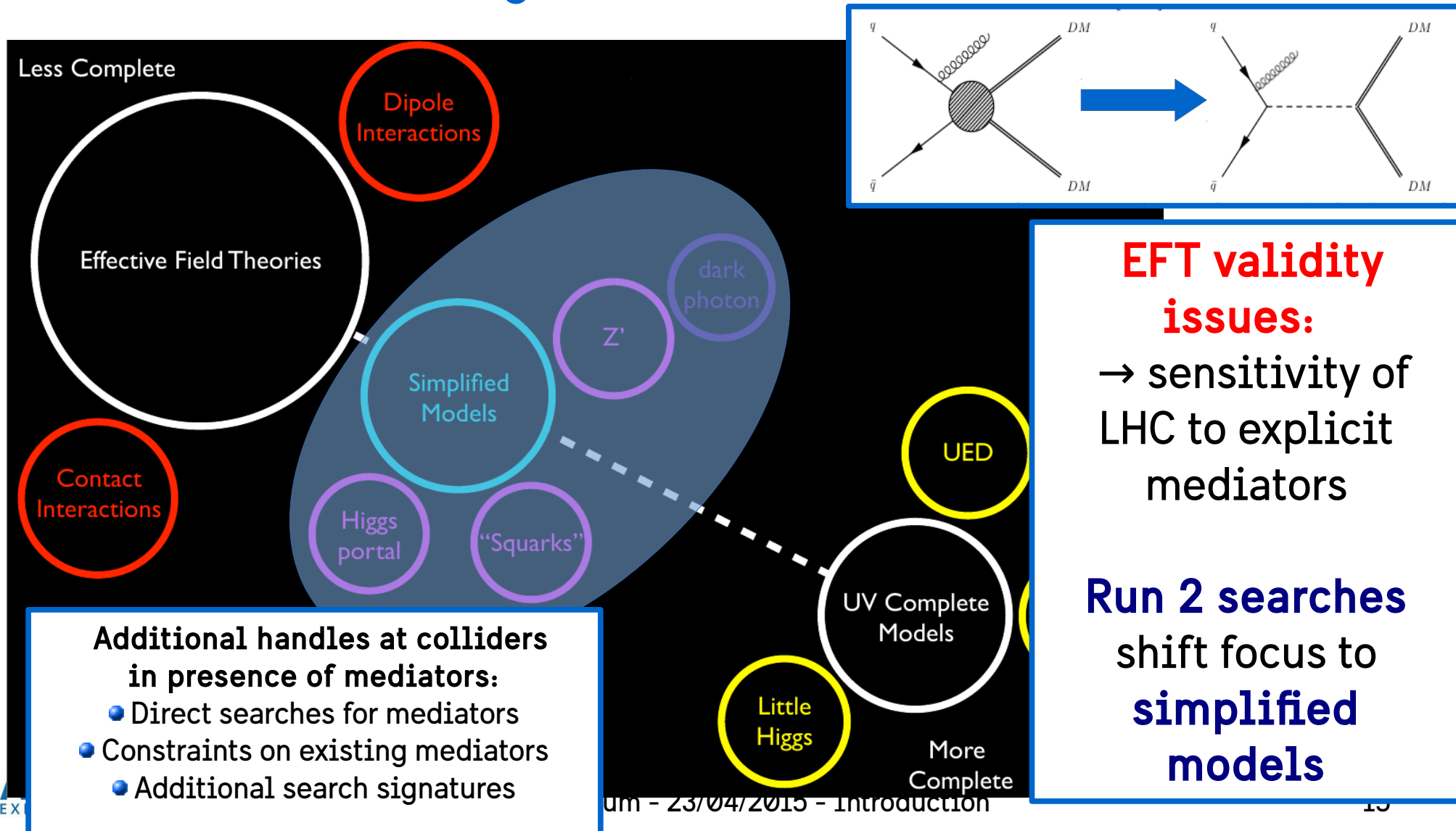


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BACKUP SLIDES

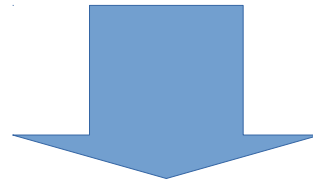
LIST OF SIMPLIFIED MODELS AND PARAMETER SCAN

- Guiding principle for choice of Run-2 benchmarks:
How would a DM signal look at colliders?



LIST OF SIMPLIFIED MODELS AND PARAMETER SCAN

- Further guiding principles for benchmark model choices:
 - **Practical** for experimentalists (MC generation)
 - **Useful** for theorists and DM community as a whole



- Does the **kinematics change** between model/model points
- Does the model **add new, uncovered signatures**?
If so, we need to **generate** these models/model points
If not, we give theorists sufficient information to **reinterpret**

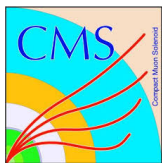
Write-up: outline other benchmarks and possibilities to be investigated in future searches

OVERALL ASSUMPTIONS FOR DM BENCHMARKS

- DM Particle candidate: **Dirac fermion**

Reasons:

- Most popular model benchmark so far → models and theory studies easily available
- Majorana fermion should have similar kinematics
- Assumption: **Minimal Flavor Violation**
Reason: Reasonable assumption to make, without having to rewrite a theory of flavor
- **Signatures considered** (all MET+X searches so far):
Jet+MET, W/Z/gamma/H+MET, heavy flavors + MET, single top



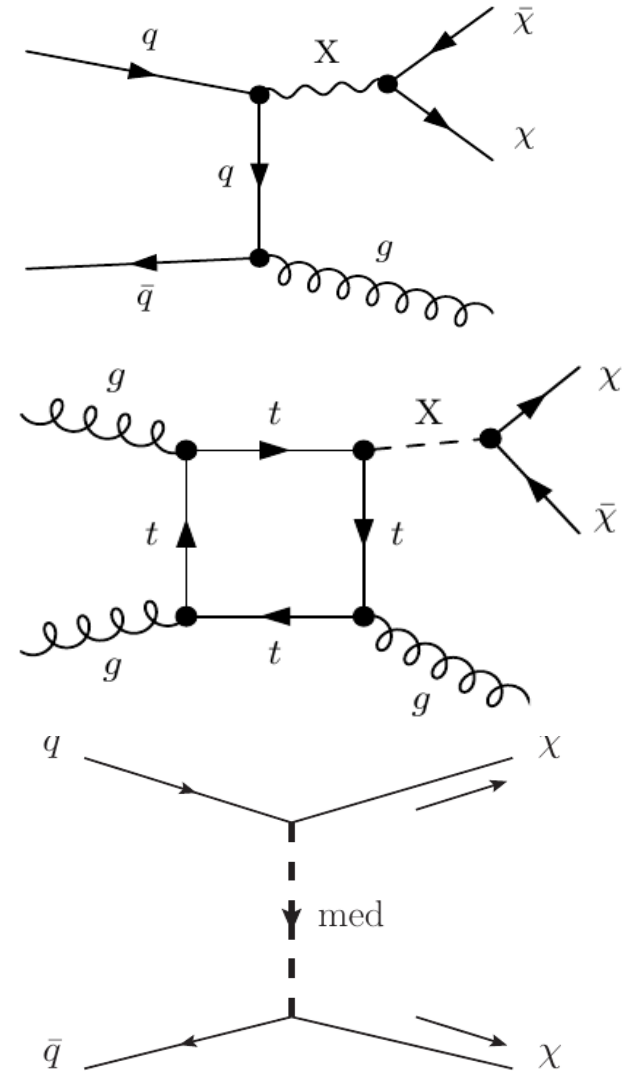
JET+MET: LIST OF SIMPLIFIED MODELS

Benchmark models for jet+MET searches:

1. s-channel vector/axial vector mediator

2. s-channel scalar/pseudoscalar mediator
(top loop explicitly calculated)

3. t-channel colored scalar mediator



JET+MET : SCAN FOR S-CHANNEL MEDIATORS

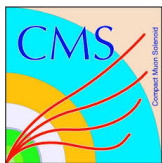
Free parameters: mediator width, couplings, m_{DM} , m_{Mediator}

1. mediator width:

- use minimal width (no additional visible/invisible decays except for quarks and DM), for all MET+X searches
- upper bound on width \rightarrow upper bound on couplings

2. couplings:

- no dependence on kinematics on coupling chirality
- cross-section scaling along lines of constant width \rightarrow fix one coupling, scan on other coupling (order 10 points)



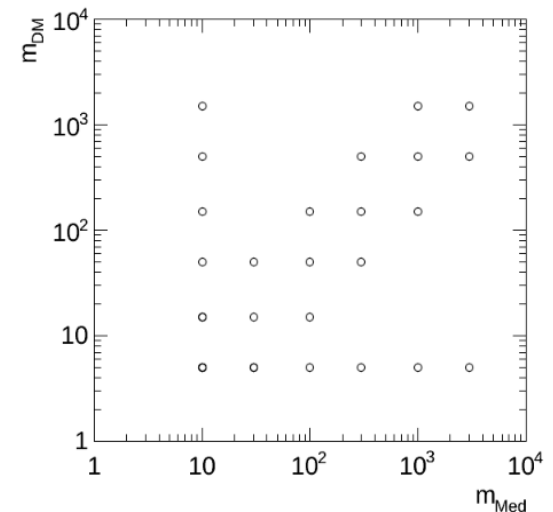
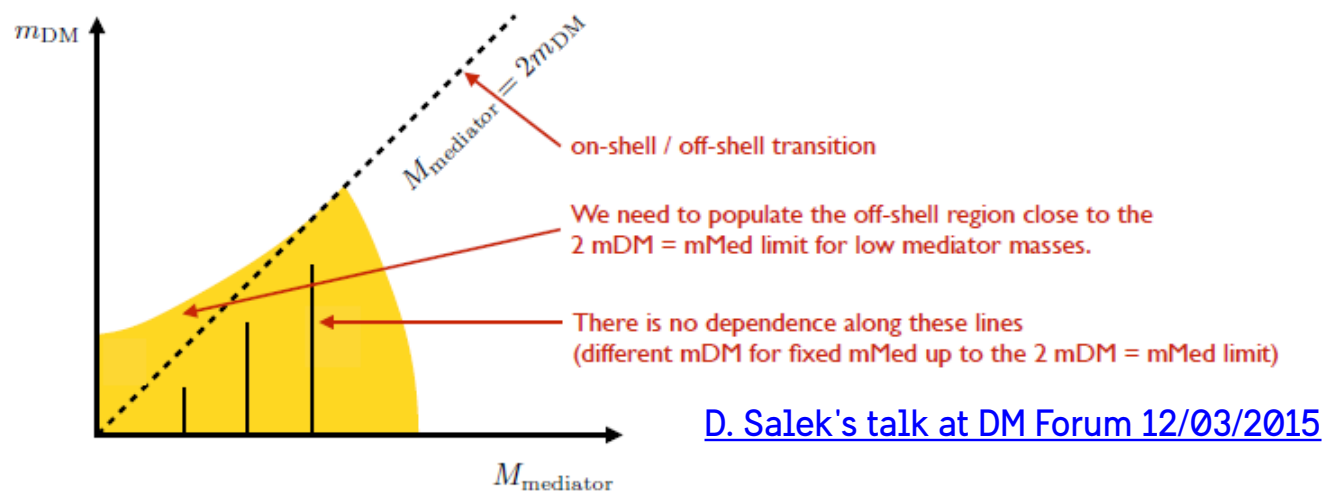
[D. Salek's talk at DM Forum 12/03/2015](#)

JET+MET : SCAN FOR S-CHANNEL MEDIATORS

Free parameters: mediator width, couplings, m_{DM} , $m_{Mediator}$

3. DM/mediator masses:

- scan based on on/off-shell regions
- scalar and pseudoscalar grid takes into account $t\bar{t}$ threshold

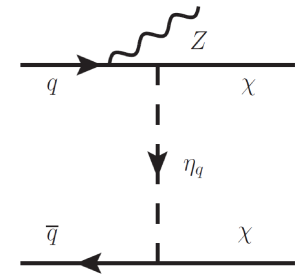
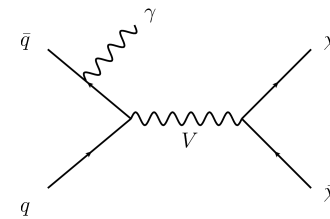


EW BOSON+MET : LIST OF EFT/SIMPLIFIED MODELS

Benchmark models for Z/W/gamma/H+MET searches:

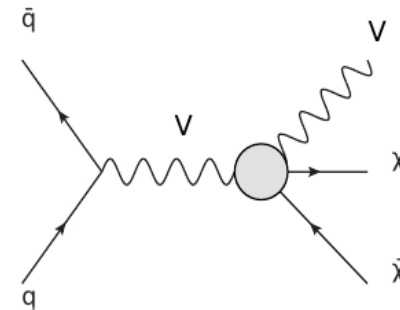
1. Simplified models with boson as radiation

→ s-channel vector mediator,
t-channel colored scalar mediator



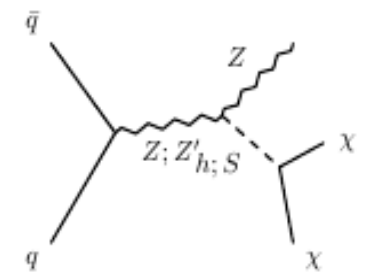
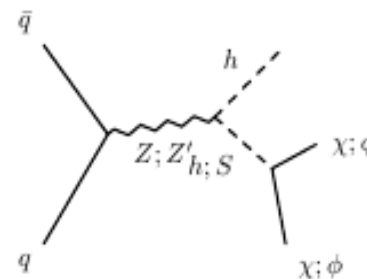
2. Direct boson/DM couplings (EFTs)

→ model with DM coupling to bosons
(V/Z/gamma related by gauge invariance)



3. Specific simplified models

→ mediators: vector (Z') and scalar
(S , coupling with the Higgs)



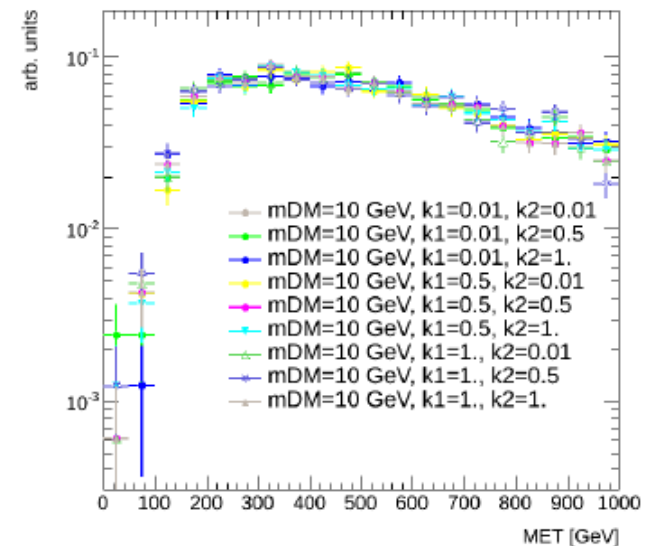
EW BOSON+MET: PARAMETER SCAN

1. Simplified models with boson as radiation:

- follow mono-jet proposal (sensitivity studies ongoing)
- see next slides for specific mono-W case

2. Direct boson/DM couplings (EFTs)

- DM-boson couplings: kinematics does not change
→ don't scan in this parameter
- Fix EFT scale to 3 TeV
- Scan DM mass, preliminary proposal available

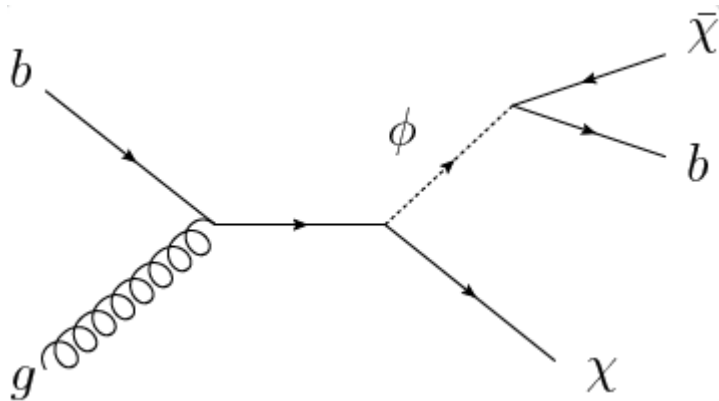


3. Specific simplified models for Higgs+MET searches

- Work ongoing, correlations with mono-jet being investigated

SINGLE B/T+MET: MODELS AND PARAMETERS

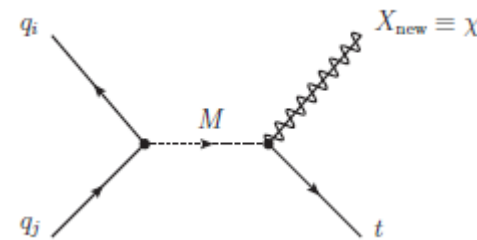
Mono-b signature (1404.1373):



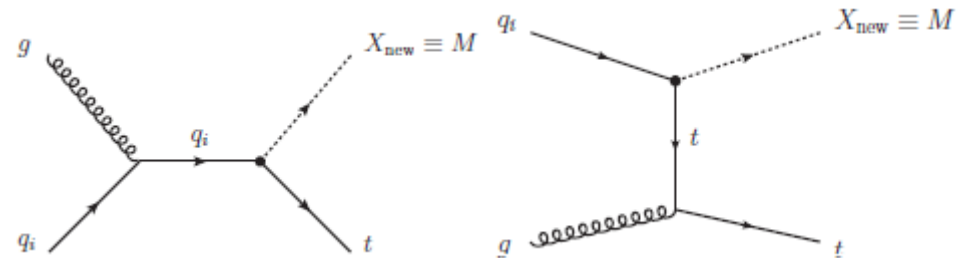
- Scan in mediator/DM mass/coupling(s)
- Proposal to normalize couplings to get right relic density, as in ATLAS DM+HF paper → Need to seek feedback from theorists before recommending

Single top models ([this link](#)):

- Resonant production



- Non-resonant production (interplay with ttbar+X search)



- Only RH quarks considered
- Scan in mediator/DM mass (couplings/width: small changes)

IMPLEMENTATION DETAILS AND UNCERTAINTIES

- Models being collected on CERN SVN: [WSVN link](#)
→ already useful for both collaboration: sensitivity studies and MC requests
- Choice of **MC Generator**:
 - **Jet+MET s-channel models**: Powheg (NLO)
 - **All others**: Madgraph + Pythia (LO)
 - ME/parton shower matching details reviewed case by case
- Agreement on **theory uncertainties**
 - **PDF and scale uncertainties**: seeking feedback within collaborations, agreement will be topic of next meeting

