

Dark Matter Forum summary

Sarah Alam Malik (Imperial College London)
on behalf of ATLAS-CMS Dark Matter Forum organizers

DM@LHC Amsterdam

- ATLAS-CMS Dark Matter Forum formed in Nov 2014
 - ATLAS representatives : Antonio Boveia, Caterina Doglioni
 - CMS representatives : Steven Lowette, Sarah Malik, Steve Mrenna
- Primary goal of forum : form consensus on the use of simplified models and EFTs to guide early Run-2 searches, by bringing together expertise on DM from experimental and theory communities.

<https://twiki.cern.ch/twiki/bin/view/LHCDMF/Mandate>

- I. A prioritized, small set of **benchmark simplified models** should be agreed upon by both collaborations for Run-2 searches.
2. The **matrix element implementation** of the simplified models should be standardized, and other common technical details (order of the calculation, showering). This will also lead to a single set of theory uncertainties, which will be easier to deal with when comparing results from the two collaborations.
3. On the same timescale, the forum could also discuss the conditions under which the **EFT interpretation** may still be desirable.
4. An **arxiv document** should be prepared summarising these items, suitable both as a reference for the internal ATLAS and CMS audiences and as an explanation for theory and non-collider readers.

Twiki: <https://twiki.cern.ch/twiki/bin/view/LHCDFM/WebHome>

- Kick-off meeting : Jan 16th 2015,
- Discussion on simplified model list: Jan 28th
- Discussion of monojet/monophoton like models: Feb 6th
- Discussion of electroweak models: Feb 16th
- Meeting on electroweak models and parameter scans : March 5th
- Meeting on EFT validity : March 12th
- Meeting on EFT validity, heavy flavor models : Apr 23rd
- DM forum closing meeting : Jun 26

- Final report of the DM forum :
arXiv:1507.00966

- 150 page document, detailing the recommended set of DM simplified models, presentation of EFT results, matrix element implementation etc

- Document reviewed by external reviewers

- ~150 signatories: CMS, ATLAS, theorists

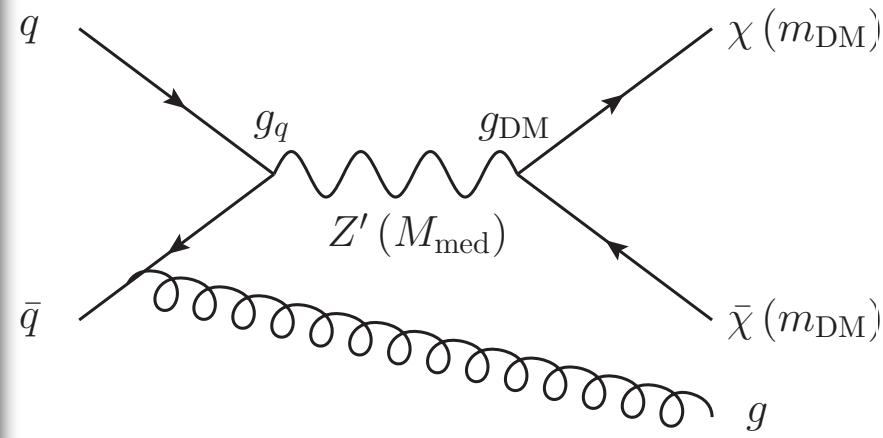
- Dark Matter Benchmark Models for Early LHC Run-2 Searches:
Report of the ATLAS/CMS Dark Matter Forum

- June 22, 2015

- Nural Akchurin *Texas Tech University, USA*
- Ece Akilli *Université de Genève, DPNC, Switzerland*
- Juan Alcaraz Maestre *Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain*
- Barbara Alvarez Gonzalez *CERN, Switzerland*
- Jeremy Andrea *Institut Pluridisciplinaire Hubert Curien/Département Recherches Subatomiques, Université de Strasbourg/CNRS-IN2P3, France*
- Georges Azuelos *University of Montreal and TRIUMF, Canada*
- Patrizia Azzi *INFN Padova, Italy*
- Mihailo Backović *Centre for Cosmology, Particle Physics and Phenomenology (CP3), Université catholique de Louvain, Belgium*
- Yang Bai *Department of Physics, University of Wisconsin-Madison, USA*
- Swagato Banerjee *University of Wisconsin-Madison, USA*
- James Beacham *Ohio State University, USA*
- Alexander S. Belyaev *School of Physics and Astronomy, University of Southampton, United Kingdom*
- Antonio Boveia (editor) *CERN, Switzerland*
- Amelia Jean Brennan *The University of Melbourne, Australia*
- Oliver Buchmueller *Imperial College London, United Kingdom*
- Matthew R. Buckley *Department of Physics and Astronomy, Rutgers University, USA*
- Giorgio Busoni *SISSA and INFN, Sezione di Trieste, Italy*
- Michael Buttignol *Institut Pluridisciplinaire Hubert Curien/Département Recherches Subatomiques, Université de Strasbourg/CNRS-IN2P3, France*
- Giacomo Cacciapaglia *Université de Lyon and Université Lyon 1, CNRS/IN2P3, UMR5822, IPNL, France*
- Regina Caputo *Santa Cruz Institute for Particle Physics, Department of Physics and Department of Astronomy and Astrophysics, University of California at Santa Cruz, USA*
- Linda Carpenter *Ohio State University, USA*
- Nuno Filipe Castro *LIP-Minho, Braga, and Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto, Portugal*
- John Paul Chou *Rutgers University, USA*
- Arely Cortes Gonzalez *IFAE Barcelona, Spain*
- Chris Cowden *Texas Tech University, USA*
- Francesco D'Eramo *University of California and LBNL, Berkeley, USA*
- Annapaola De Cosa *University of Zurich, Switzerland*
- Michele De Gruttola *CERN, Switzerland*
- Andrea De Simone *SISSA and INFN, Sezione di Trieste, Italy*

Grounding assumptions

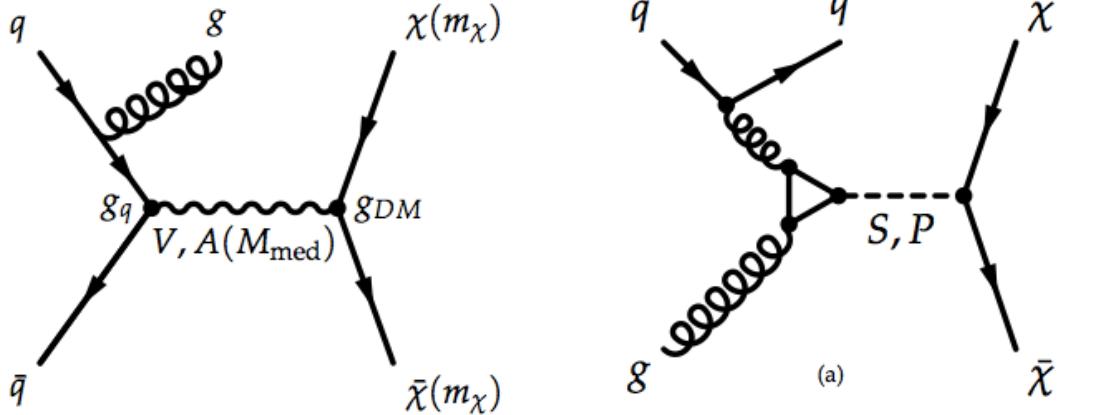
- Assume interaction exists between SM and DM
- DM is single particle, Dirac fermion
- Minimal Flavor Violation
- Assume minimal decay width for particle mediating interaction
- These assumptions only add a limited number of new particles and new interactions to the SM.
Simplified models can be used as starting points to build more complete theories.



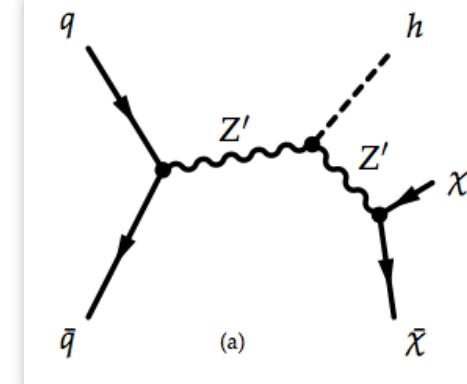
Factorised approach does not always lead to full theories but useful as a starting point giving a **distinct but complementary set of signatures to explore**.

Simplified models/signatures

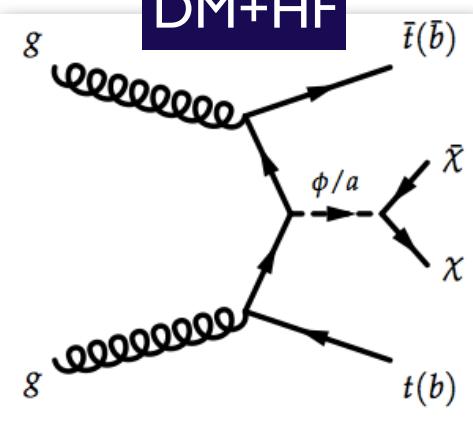
MET+X, (X = jet, photon, W, Z)



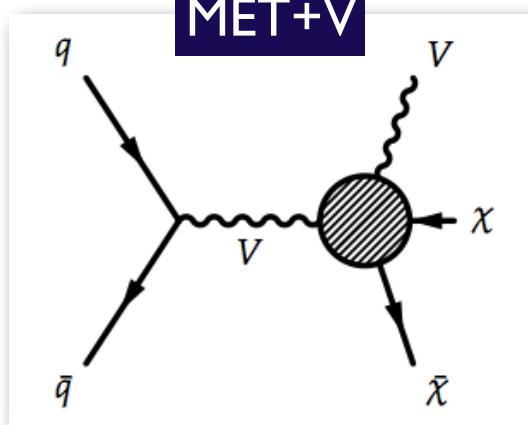
mono-Higgs



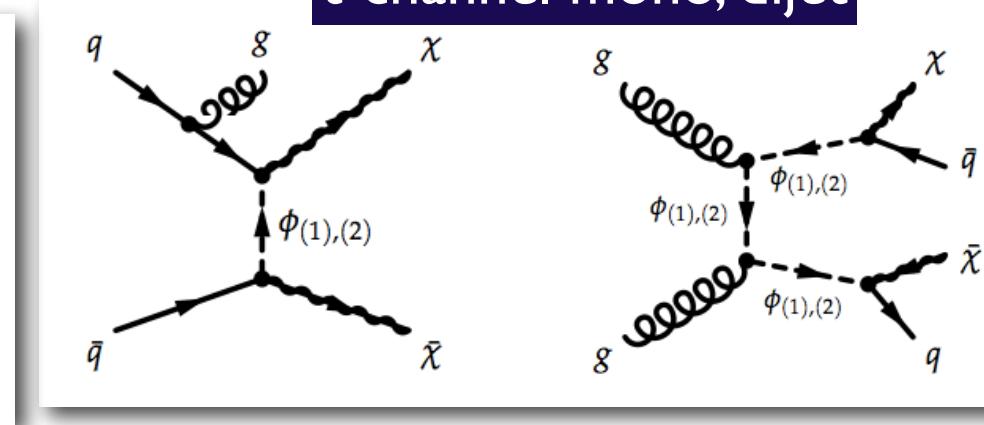
DM+HF



MET+V



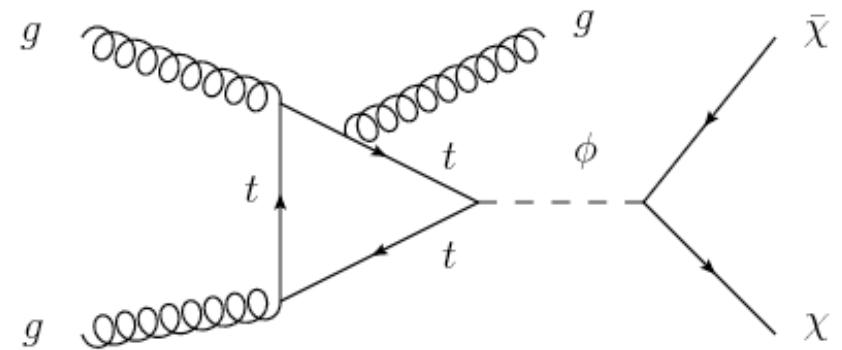
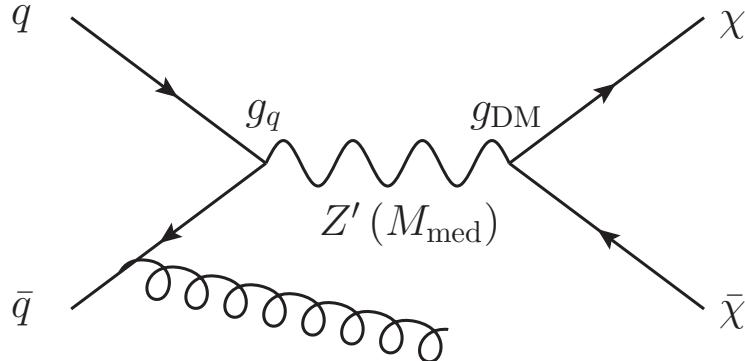
t-channel mono, dijet



→ Wide variety of simplified models studied

→ Forum provided detailed recommendations for model parameters, grid scan, presentation of results

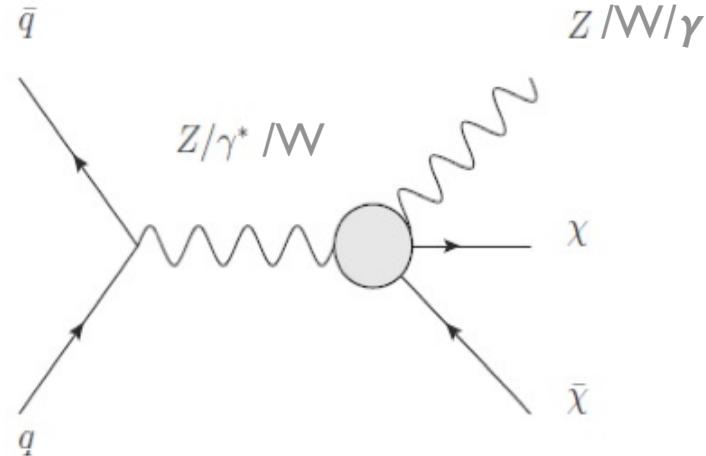
→ Monojet-like models (jets+MET)



Motivation	generic, some of these models velocity suppressed in DD, collider searches exploring unprobed region
Model details	DM : Dirac fermion Mediator: s-channel vector(axialvector)/scalar (pseudoscalar) t -channel, colored mediator
Technical	ME implementation in POWHEG, Madgraph, MCFM
Signature	jets +MET

→ Mono-W, mono-Z, mono-photon, mono-Higgs....

Direct DM-V coupling

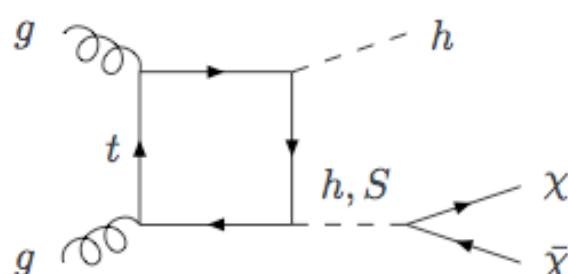
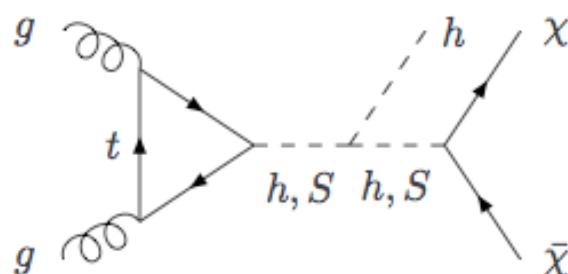
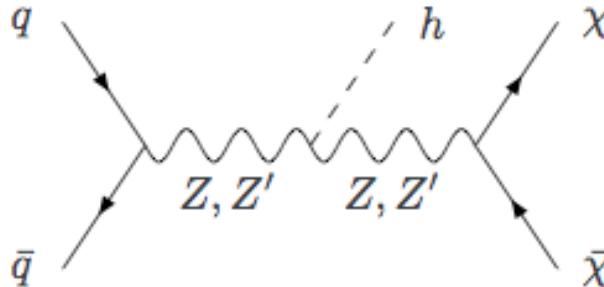
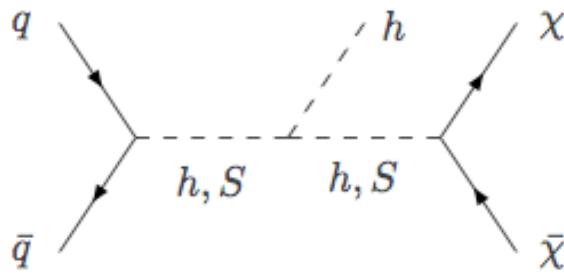


Motivation	low bgd, explore interesting portals, many are hard for DD
Model details	DM: fermion/scalar Gauge invariance correlated gamma/Z/W channels, 2 couplings k_1/k_2
Technical	ME implementation ready for W/Z/gamma
Signature	W/Z/gamma +MET

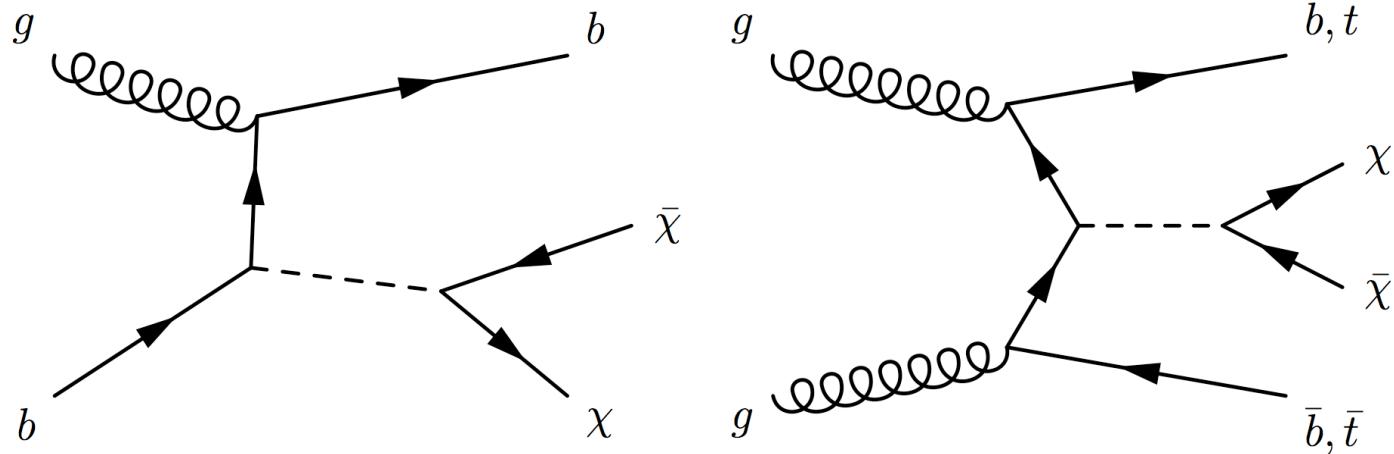


Mono-W, mono-Z, mono-photon, mono-Higgs....

4



Motivation	complementary to invisible Higgs search, probes underlying DM vertex
Model details	DM = scalar/fermion mediator = vector (Z/Z')/scalar(h /single S)
Technical	ME implementation in Madgraph
Signature	Higgs +MET

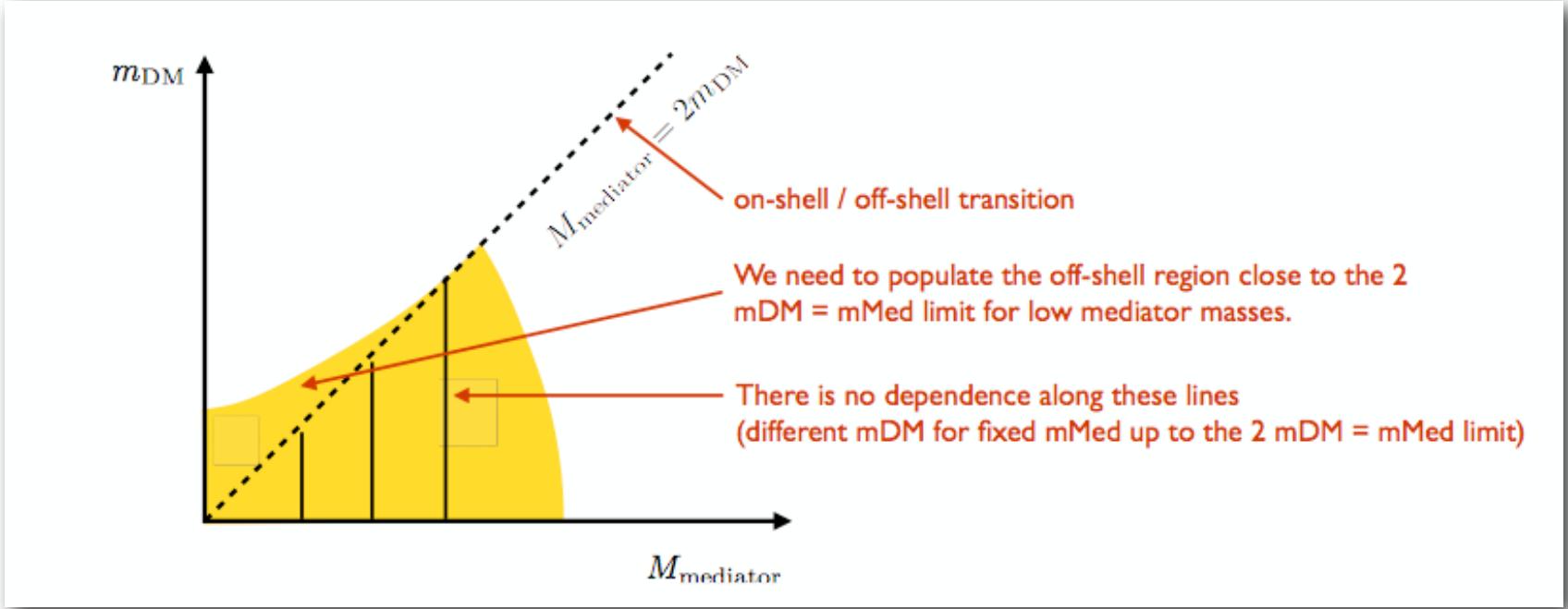


Motivation	enhanced couplings to heavy quarks, can explore models proposed to explain excesses in indirect det
Model details	DM = fermion mediator = scalar, s-channel, yukawa coupling to SM
Technical	ME implementation in Madgraph
Signature	$b/bb + \text{MET}$, $tt + \text{MET}$

Reduction of signal points

- 4 parameter model, vary M_{DM} , M_{MED} , g_{DM} , g_q
- To map out entire parameter space, would require $O(100s)$ of signal points

M_{DM}	M_{MED}
g_{DM}	g_q



- Studies carried out to exploit similarities in kinematic distributions and reduce the # of generated signal points to populate the plane.

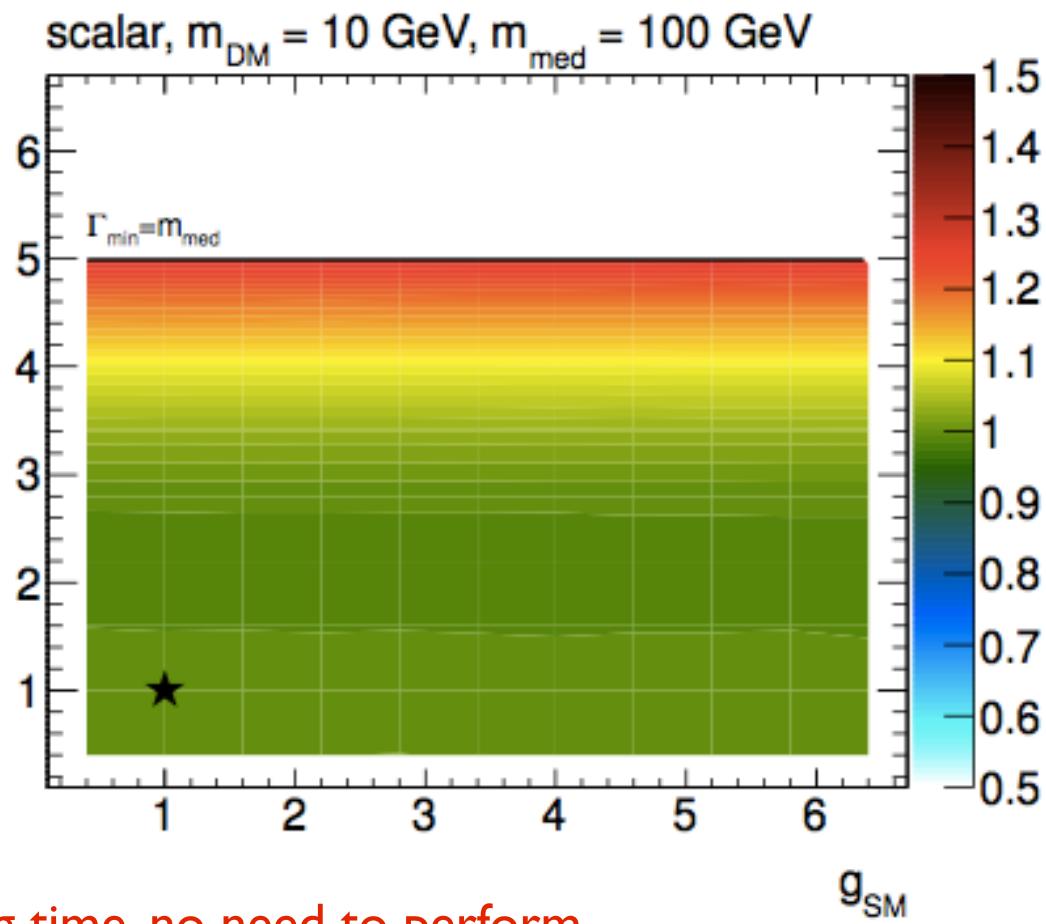
Reduction of signal points

- Desirable to constrain the couplings plane in addition to mass planes
- Collider can add complementarity here, since it breaks the degeneracy between the couplings, whereas DD expts sensitive to $g_{DM}g_q$.

M_{DM}	M_{MED}
g_{DM}	g_q

- Observe no changes in kinematics for different choices of coupling strengths
- Sufficient to perform the full detector simulation for only one point and follow cross section scaling procedure to fill entire plane
- Scaling works to within 20%.

g_{DM}

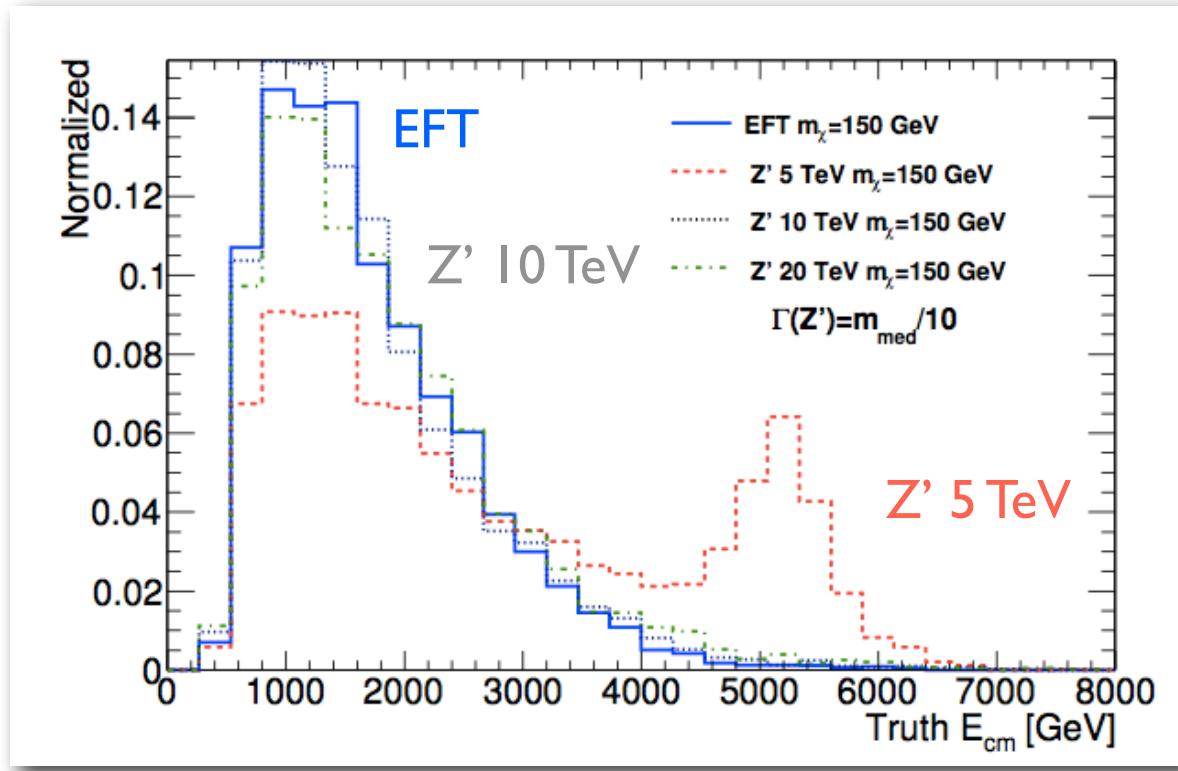


Significant reduction in computing time, no need to perform detector simulation for entire plane

- Primary focus of report on use of simplified models, also discuss the presentation of results in context of EFT
- Even though EFT benchmarks only valid under given conditions, current list of simplified models cannot always characterise the breadth of SM-DM interactions. (e.g composite WIMPs)
- Problematic issue is attempt to derive a limit on the DM-nucleon cross section from the EFT results and comparison with DD experiments (where the EFT is typically valid). NOT discussed during Forum, to be developed further (see next talk).

Two recommendations for presentation of results in terms of EFT

(I) If a simplified model can be mapped on to a given EFT operator (for instance vector mediator s-channel model onto vector operator), then high-mediator-mass limit will converge to the EFT. Recommendation: add one grid point at very high mediator mass (10 TeV)



For vector, s-channel models, mediator of 10 TeV fully reproduces the EFT kinematics

Two recommendations for presentation of results in terms of EFT

- (1) If a simplified model can be mapped on to a given EFT operator (for instance vector mediator s-channel model onto vector operator), then high-mediator-mass limit will converge to the EFT. Recommendation: add one grid point at very high mediator mass (10 TeV)
- (2) If a UV completion is not available, an EFT still captures a range of possible theories, recommend to present the EFT limits using one of the truncation procedures described in the forum report.

Implementation of models

Benchmark models for ATLAS and CMS Run-2 DM searches			
vector/axial vector mediator, s -channel (Sec. 2.1)			
Signature	State of the art calculation and tools	Implementation	References
jet + E_T	NLO+PS (powheg , SVN r3059)	[For15l, For15o]	[HKR13, HR15, ANOR10, Nas04, FNO07]
	NLO+PS (<i>DMsimp</i> UFO + MADGRAPH5_AMC@NLO v2.3.0)	[New15]	[AFF ⁺ 14, ACD ⁺ 14, DDF ⁺ 12]
	NLO (MCFM v7.0)	Upon request	[FW13, HKSW15]
W/Z/ γ + E_T	LO+PS (UFO + MadGraph5_aMC@NLO v2.2.3)	[For15a]	[AFF ⁺ 14, ACD ⁺ 14, DDF ⁺ 12]
	NLO+PS (<i>DMsimp</i> UFO + MADGRAPH5_AMC@NLO v2.3.0)	[New15]	[AFF ⁺ 14, ACD ⁺ 14, DDF ⁺ 12]
scalar/pseudoscalar mediator, s -channel (Sec. 2.2)			
Signature	State of the art calculation and tools	Implementation	References
jet + E_T	LO+PS, top loop (powheg , r3059)	[For15n, For15m]	[HKR13, HR15, ANOR10, Nas04, FNO07]
	LO+PS, top loop (<i>DMsimp</i> UFO + MADGRAPH5_AMC@NLO v2.3.0)	[New15]	[AFF ⁺ 14, HFF ⁺ 11, ACD ⁺ 14, DDF ⁺ 12]
	LO, top loop (MCFM v7.0)	Upon request	[FW13, HKSW15]
W/Z/ γ + E_T	LO+PS (UFO + MadGraph5_aMC@NLO v2.2.3)	[]	[AFF ⁺ 14, ACD ⁺ 14, DDF ⁺ 12]
$t\bar{t}, b\bar{b} + E_T$	LO+PS (UFO + MadGraph5_aMC@NLO v2.2.3)	[For15d]	[AFF ⁺ 14, ACD ⁺ 14, DDF ⁺ 12]
	NLO+PS (<i>DMsimp</i> UFO + MADGRAPH5_AMC@NLO v2.3.0)	[New15]	[AFF ⁺ 14, ACD ⁺ 14, DDF ⁺ 12]

- Using the state of the art calculations that were publicly available at the time
- All model files, parameter cards, and cross sections publicly available to enable reproducibility of results
- SVN repository for models files, parameter cards. Cross sections published on HEPData.

Looking forward

- A number of items beyond the scope of the Forum
- To deliver the urgent need of a basis set of simplified model recommendation in time for Run2 data-taking, had to make many grounding assumptions
- Deviations from those assumptions (such as $DM \neq$ Dirac fermion) not fully explored. So list of recommended models is non-exhaustive and does not cover full list of plausible models, rather a starting point.
- Broader discussion needed on the comparison of experimental results amongst collider and non-collider searches
- Develop further the role of other constraints on the mediator particle from direct searches (past and present colliders) and its impact on the DM parameter space
- To be addressed by the LHC Dark Matter Working Group (see next talk)

- ATLAS-CMS DM forum : Collaborative effort between ATLAS, CMS and theorists
- Main deliverable of the forum : 150-page report detailing the recommended set of DM models for searches in early Run 2.
- Recommendations for models, parameters, grid points to produce etc all set out in the report. Models/parameters also in SVN repository for cross checking.
- Items beyond scope of Forum to be addressed by LHC DM Working Group