

Dark matter spin characterization at the LHC in mono-X channels

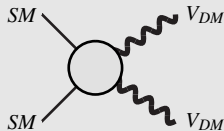
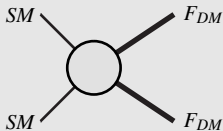
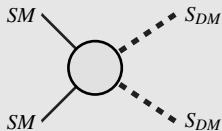
A simplified model analysis

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The role of DM spin

Scalar, Fermion or Vector DM?



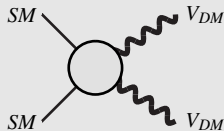
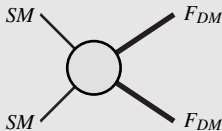
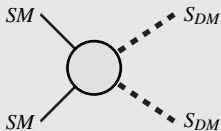
Examples:

- **Supersymmetry**: neutralino (fermion) or sneutrino (scalar)
- **Universal Extra Dimensions**: lightest KK-odd photon partner (scalar or vector depending on the number of dimensions)

**Determining the spin of a DM candidate
would strongly constrain or rule out classes of BSM scenarios**

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**Determining the spin of a DM candidate
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Report of the ATLAS/CMS Dark Matter Forum, arXiv:1507.00966 [hep-ex]:

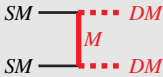
“adjusting the choice of Dirac or Majorana fermions or scalars will produce only minor changes in the kinematic distributions of the visible particle and is expected to have little effect on cut-and-count2 analysis. Thus the choice of Dirac fermion Dark Matter should be sufficient as benchmarks for atlas+cms dark matter forum the upcoming Run-2 searches.”

Most pheno studies focus on fermionic DM, but the kinematical properties of scalar/vector DM can be **sizably different** in certain channels

General topologies

A common feature of DM candidates is that they are **odd** under a Z_2 symmetry under which SM particles are **even**. But what about mediators?

Odd mediators



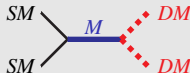
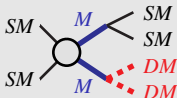
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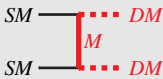
Even mediators



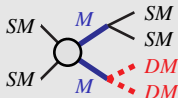
General topologies

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Odd mediators



Even mediators



SM mediators

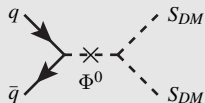


Mono-X from **t-channel** or **loop** topologies for **odd** mediators
and from **s-channel** or **4-leg** topologies for **even** BSM or SM mediators

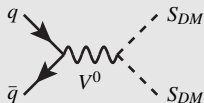
The role of mediator spin

s-channel

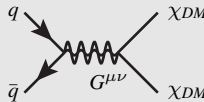
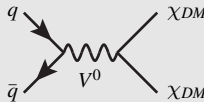
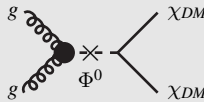
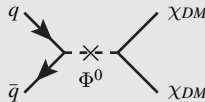
Scalar



Vector



Tensor



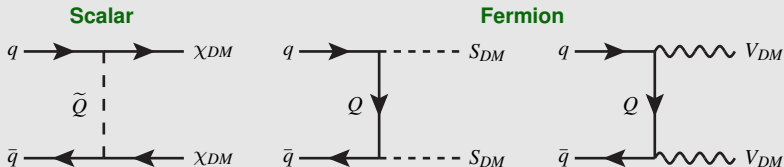
The relevance of gg initiated processes depends on couplings between scalar mediator and SM quarks

Same mediators for scalar and fermion DM

Mono-X channels can be sensitive to the DM spin only if the X object can couple to the DM (e.g. mono-Z or mono-W with Z mediator or mono-Higgs with Higgs mediator)

The role of mediator spin

t-channel



Plus diagrams at one-loop if the mediator does not couple to SM partons

In t-channel the spin of the DM and the spin of the mediator are related

Any mono-X channel can probe the spin of the DM (at least distinguish between fermionic and bosonic DM)

Mono-jet channel

Parton level preliminary results (LHC@8TeV)

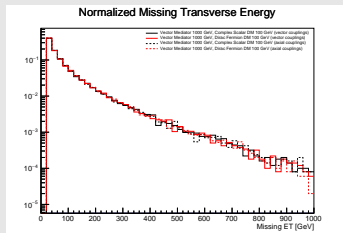
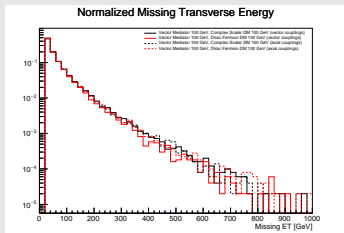
Mono-jet channel

s-channel topologies (example with vector mediator)

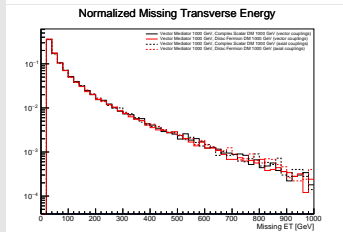
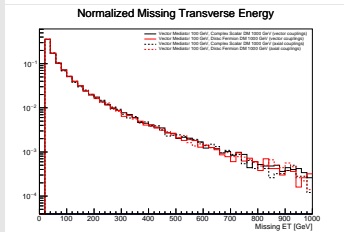
$M_V = 100 \text{ GeV}$

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$M_{DM} 100 \text{ GeV}$



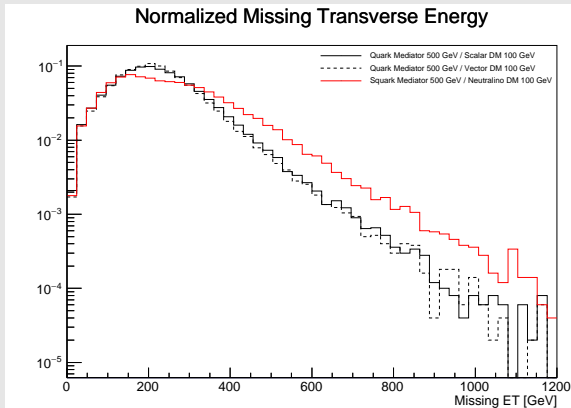
$M_{DM} 1000 \text{ GeV}$



No sensitivity on DM spin (as expected)

Mono-jet channel

t-channel topologies



Better sensitivity on DM spin through the different mediators

**Ambiguity between scalar and vector DM not resolved
because the mediator is the same**

Mono-Z channel

(SM Z mediator scenario)

Parton level preliminary results (LHC@8TeV)

Signal topologies

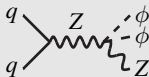
mono-Z

Assumptions

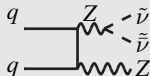
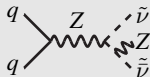
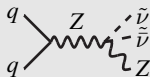
- The DM interacts **only** with the SM gauge bosons
- The DM couplings are of EW strength: $\begin{cases} g_{Z-Z-DM} = e/s_W & (3\text{-leg}) \\ g_{Z-Z-DM-DM} = (e/s_W)^2 & (4\text{-leg}) \end{cases}$

Scalar DM

Real (ϕ)
only 4-leg



Complex ($\tilde{\nu}, \tilde{\bar{\nu}}$)
4-leg and 3-leg

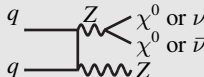
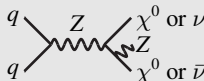


Fermion DM

Majorana (χ^0)

Weyl ($\nu, \bar{\nu}$)

only 3-leg

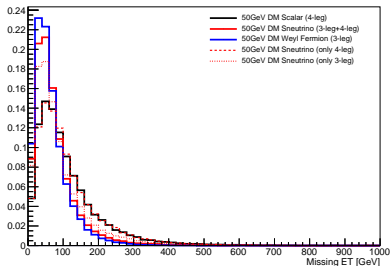


Can we distinguish effects given by spin from effects given by different topologies?

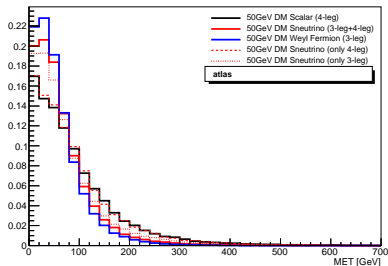
Mono-Z channel

$$M_{DM} = 50\text{GeV}$$

Parton level after Z decay
Normalized Missing Transverse Energy



Detector level (CheckMATE)
Normalised MET

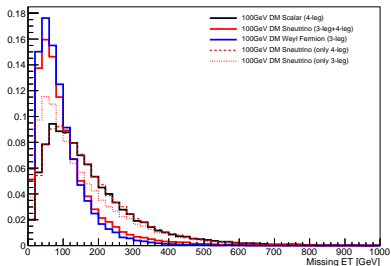


- Difficult to separate spin effects for topologies with **4-leg vertices**
- Spin effects much clearer for topologies with **3-leg vertices**
- Differences **increase** at large DM masses
- Differences are always **large enough** not to be smeared away at detector level

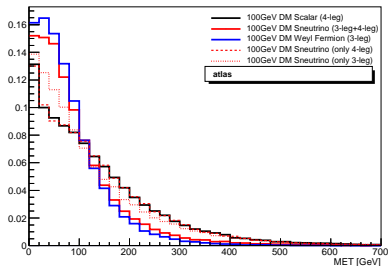
Mono-Z channel

$$M_{DM} = 100\text{GeV}$$

Parton level after Z decay
Normalized Missing Transverse Energy



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Normalised MET

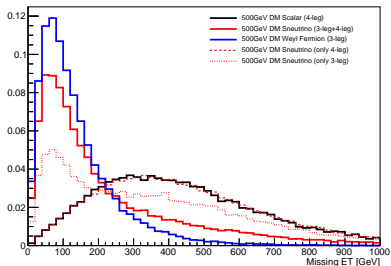


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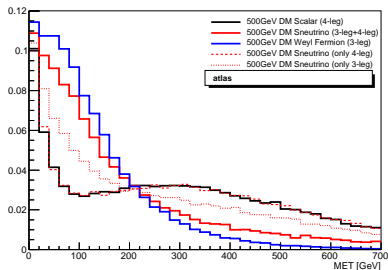
Mono-Z channel

$$M_{DM} = 500\text{GeV}$$

Parton level after Z decay
Normalized Missing Transverse Energy



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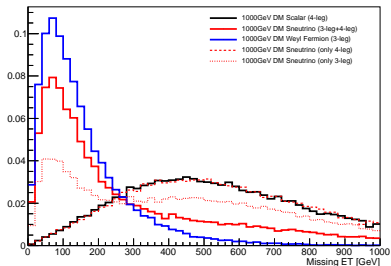


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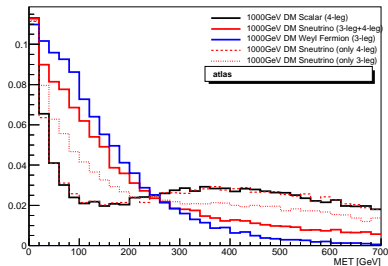
Mono-Z channel

$$M_{DM} = 1000 GeV$$

Parton level after Z decay
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Conclusions and Outlook

Summary

- Characterising the spin of a DM candidate at the LHC would be crucial for the interpretation in terms of theoretical scenarios
- Mono-X channels are mostly sensitive to the mediator spin, but in the t-channel, the spin of the mediator is closely related to the spin of the DM
- If the mediator is a SM state, the most sensitive mono-X channels are those for which the mono-object is the mediator itself

Work in progress

- Determination of constraints on couplings and masses to identify allowed parameter spaces
- Determination of the relevance of mono-photon and mono-W channels
- Exploration of the sensitivity of other channels (non mono-X) for the characterization of the DM spin