Dark Matter at HL/HE-LHC

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LHC DM working group, 18/12/2017

Yellow Report on HL/HE-LHC

- Aims to consistently present physics potential of High-Lumi LHC
  - Stimulate new ideas for measurements, extend discovery reach, improvement modeling towards measurements at ultimate precision.
- Opportunity to present physics at a high-energy collider in the LHC ring at 27 TeV (HE-LHC)
- All experiments contributing within existing structure of upgrade physics
- Lot of theory contributions expected and studies on-going
- Workshop Organisation:
  - Steering group with CMS, ATLAS, LHCb, ALICE and theory contacts
  - Working group :
    - Standard Model (QCD, EW and Top physics)
    - Higgs boson and EW symmetry breaking
    - BSM (WG3)
    - Flavour
    - Heavy Ion
- limit efforts on key channels for dedicated contributions.
- WG3: together with me (ATLAS), we have Keith Ulmer (CMS), Xabier Cid (LHCb), Riccardo Torre, Patrick Fox (theorists)

YR Documentation

▸ This is considered a one year long workshop, started with the 30 Oct 2017 meeting - https://indico.cern.ch/event/647676/overview

▸ Results will be documented in a Yellow CERN report end of 2018 as input to European Strategy discussion.

▸ The individual chapters of the Yellow Report will also be submitted to the arXiv.

▸ In agreement with all experiments/theorists the following proposal emerged:

▸ *Volume 1:*

  ▸ The results will be written up in five chapters corresponding to the working groups (an additional performance chapter is being discussed).
    The editors of each chapter are the working group conveners (experiments+theory), but the authors are all contributors

▸ *Volume 2:*

  ▸ ATLAS, CMS and LHCb will prepare public notes on key results, e.g. (Di-)Higgs couplings that use internal software and are approved in the standard way by the collaboration.
    This also includes performance projections or combinations with other experiments.
    The results of these notes will be used by the workshop contributions in Vol1
   and properly referenced.

Organization of material

▸ We have started a twiki collecting Table of contents and relevant links
  ▸ https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop
▸ WG3 has also put together a spreadsheet to collect the topics people would like to follow:
  ▸ https://docs.google.com/spreadsheets/d/1iXV41m5inPbxFpoWMrt5vXVGva5F6GYO7XwxTMHc5hQ/edit?usp=sharing
▸ So far, no DM studies are listed yet

Aim to have a complete set of studies to be
reviewed at the next general meeting in June 2018

Monica D'Onofrio, DM LHC WG

Dark Matter searches

- EFT → simplified models considered
- Comprehensive re-assessment of current efforts for HL-LHC not yet done [analyses are often systematics limited, experimental sources hard to estimate, theoretical uncertainties might be conservative]
- **Classic jet + MET**
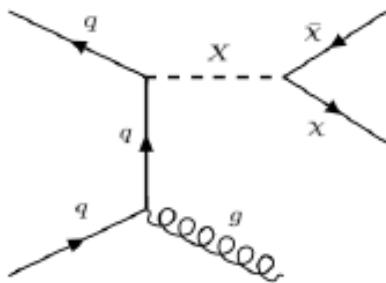
Spin-1 mediator, axialvector
$g_{SM} = 0.25$, $g_{DM} = 1$

Systematic scenarios considered:
(a) Nominal = same level of unc. as now (b) reduced by 2 (c) reduced by 4.
[most relevant uncertainty: knowledge of MET at high ET]

Projections - Axialvector

CMS-PAS-FTR-16-005
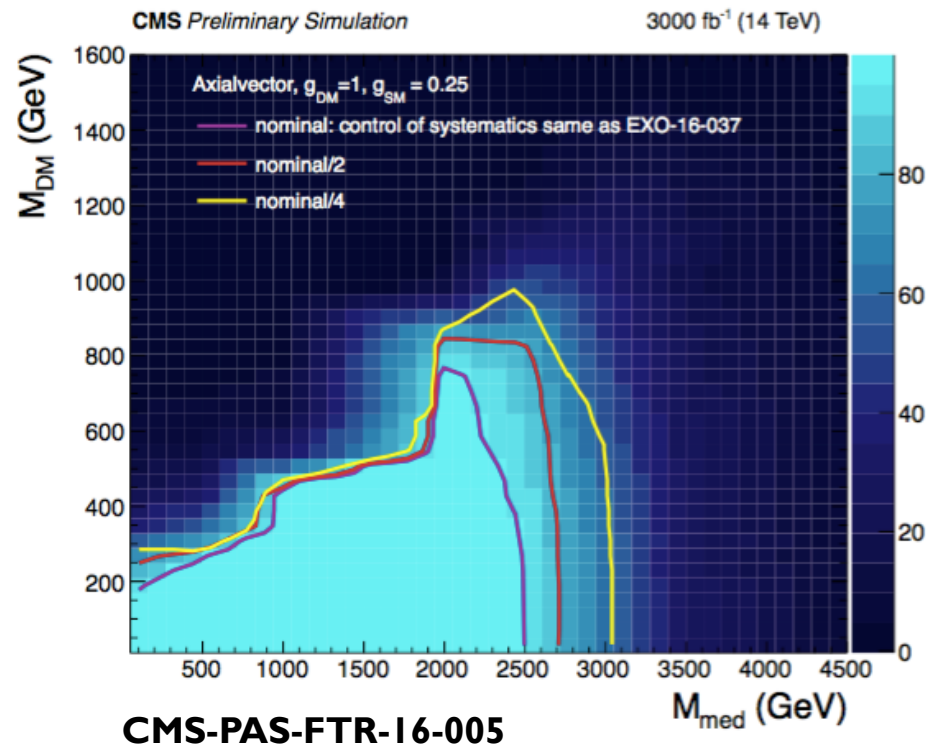
Dark Matter searches (II)

▸ EFT → simplified models considered

▸ Comprehensive re-assessment of current efforts for HL-LHC not yet done [analyses are often systematics limited, experimental sources hard to estimate, theoretical uncertainties might be conservative]

▸ **Classic jet + MET**
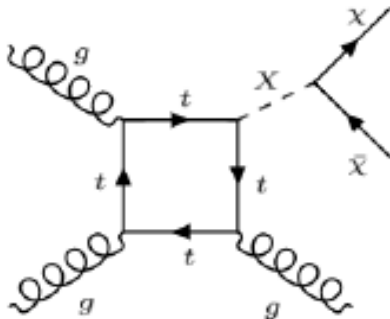
Spin-0 mediator, pseudoscalar
$g_{SM} = 1, g_{DM} = 1$

Different systematic scenarios again considered
(a) Nominal = same level of unc. as now (b) reduced by 2 (c) pure scaling of lumi

Projections - Pseudoscalar
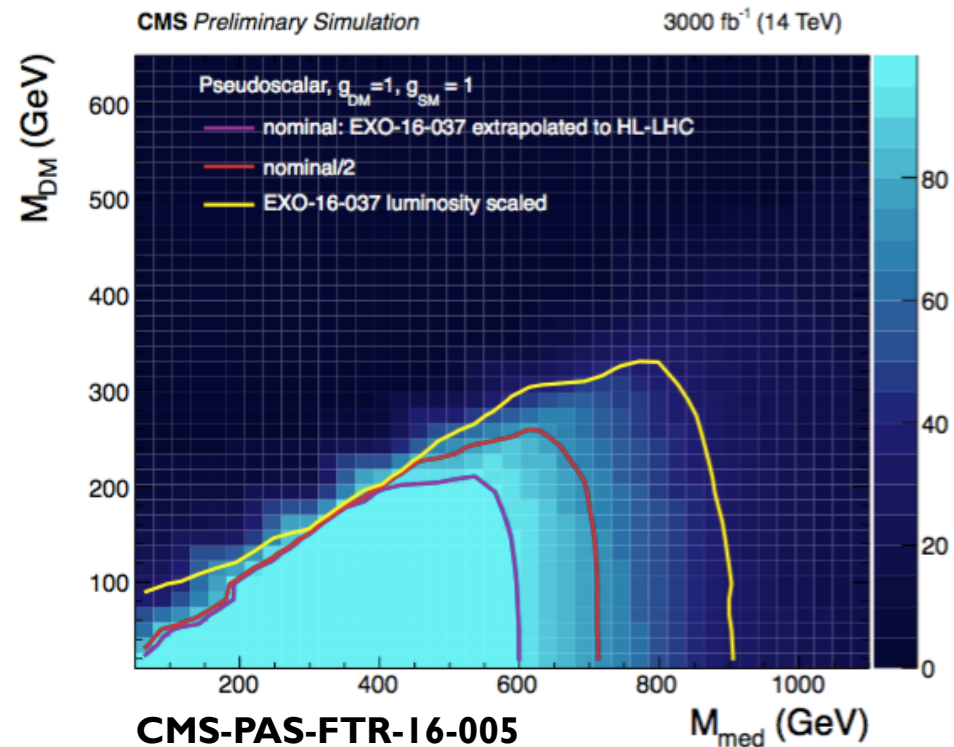
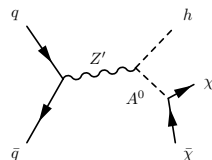

CMS-PAS-FTR-16-005

Dark Matter: more to be explored!

- Many more DM scenarios are actively pursued by ATLAS, CMS and LHCb with 13 TeV data → yet to be fully considered for HL-LHC. Examples:
  - **@ATLAS/CMS:** Mono-photon, Mono-W/Z/Higgs; mono-top;
  - Knowledge of high-MET tails and boosted objects reconstruction very relevant

Higgs in bb+ E_T^{Miss}
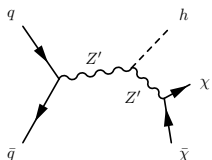
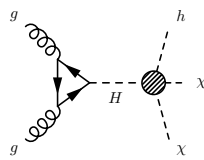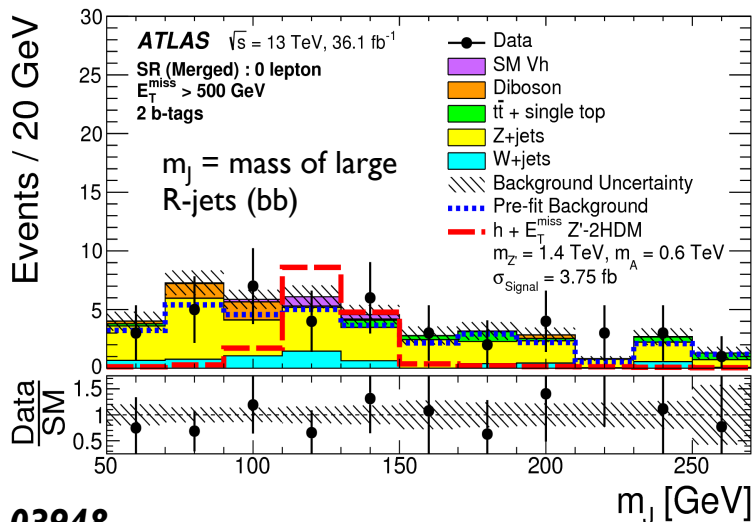**top + E_T^{Miss}**

Z' model   Z'/2HDM model   Heavy scalar model

FCNC

Heavy scalar

Higgs: *e.g.* in bb final states

1706.03948
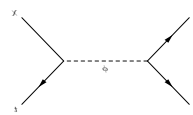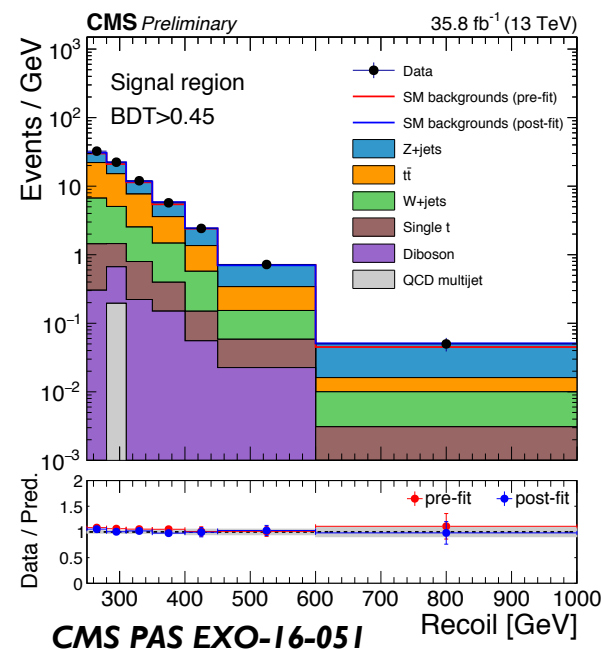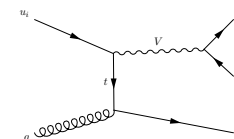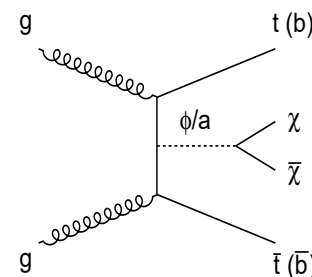


CMS PAS EXO-16-051

Dark Matter: more to be explored!

- Many more DM scenarios are actively pursued by ATLAS, CMS and LHCb with 13 TeV data → yet to be fully considered for HL-LHC. Examples:

  - **DM + bb**: b-jets might be **forward ($|\eta|$ > 2.4)**,

    analysis could benefit from extended tracking

    [in progress **@ATLAS/CMS**]

  - **DM +ttbar**: several studies on-going (more in Uli's talk in parallel session)

    - **@ATLAS/CMS:** Exploit angular correlations of leptons from top decays (2l+2b+MET signatures)

   - Clear improvements with larger HL-LHC dataset

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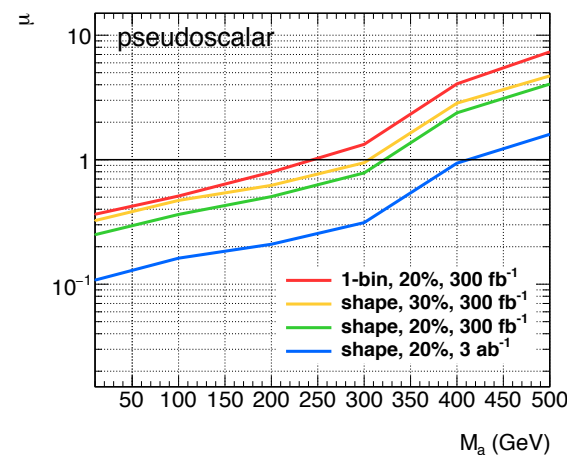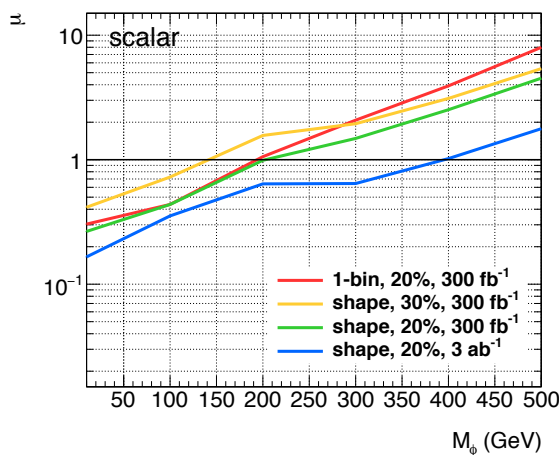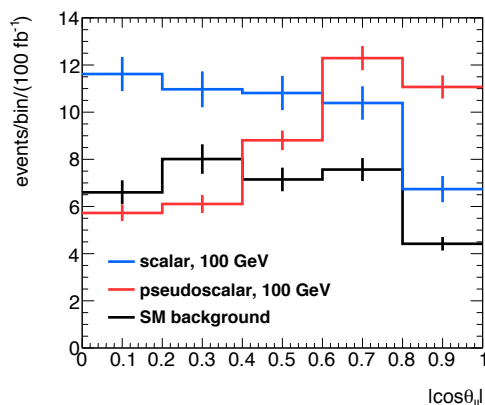
Methodologies

- Experiments use different approaches to perform analyses:
  - **Method 1 – truth + smearing (ATLAS):** truth-level events overlaid with jets (full sim) from pileup library, reconstruct particles (electrons, muons, jets, MET) from truth+overlay and smear their energy and pT using appropriate smearing functions
    - Cross checked with some of the 'real' data analyses
  - **Method 2 – Full analysis with parameterized detector performance (CMS):** use DELPHES with up-to-date phase-2 detector performance (tracking, vertexing, timing, dedicated PUPPI jet algorithms, increased acceptance, performance of new detectors)
    - Analysis steps (cuts) guided by present analysis. Limited optimization for HL-LHC conditions. Cross checks with present analysis.
  - **Method 3: projections (mostly CMS and LHCb)**
    - Existing signal and background samples (simulated at 13 TeV) scaled to higher luminosity and sqrt(s)=14 TeV. Analysis steps (cuts) from present analyses.
    - Three scenarios for systematics: (1) keep present systematics (2) Improved by a fixed factor (3) no systematics, only statistics
- Each approach has pros and cons and results might be very different depending on the assumptions (e.g. on systematic uncertainties, detector performances, contributions from rare background)

Delphes card

▸ The tool for simulating the detector response for HE-LHC studies has been discussed at length by the steering group of the YR

▸ Michele Selvaggi prepared the configuration of a generic detector for the *Delphes* package → Most likely, this will be also the tool for "standalone" HL-LHC studies that some theorist might like to perform.

▸ A kind of "beta-release" of DEPLHES (mainly for standalone HE-LHC studies) is now available.
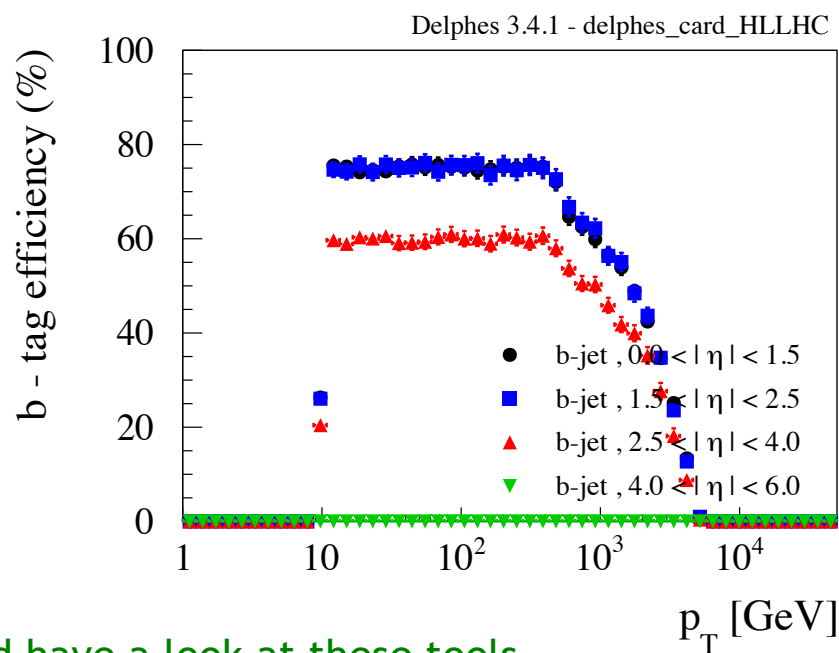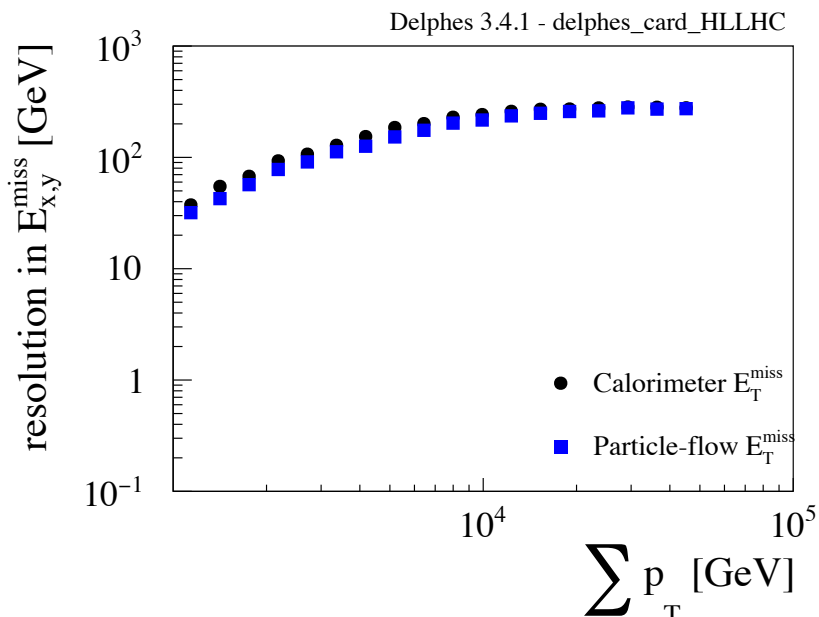
Would be good if people could have a look at these tools
– please let me know if this is the case!

Summary

- In the past years, experiments have focused on the completion of the detector proposals and optimization of performance

  - Lot of benchmark studies have been carried out, with continued efforts to evaluate the prospects of BSM searches in parallel to data analyses

  - New ideas are being explored and hopefully we will get more at this workshop!

- Analyses have been carried out using different approaches (projections / truth-smearing / DELPHES) or assumptions (PU, modeling uncertainties, treatment of rare backgrounds)

  - For the YR, we should ensure a **coherent set of approaches**

- **DM studies are not yet fully exploited for HL-LHC and HE-LHC: huge potential for contributions!**

- There is also potential also in terms of complementarities:

  - Push for a synergic approach across HL-LHC experiments in dark matter and dark sectors in general