Dark Matter studies for CMS PhaseII Upgrade

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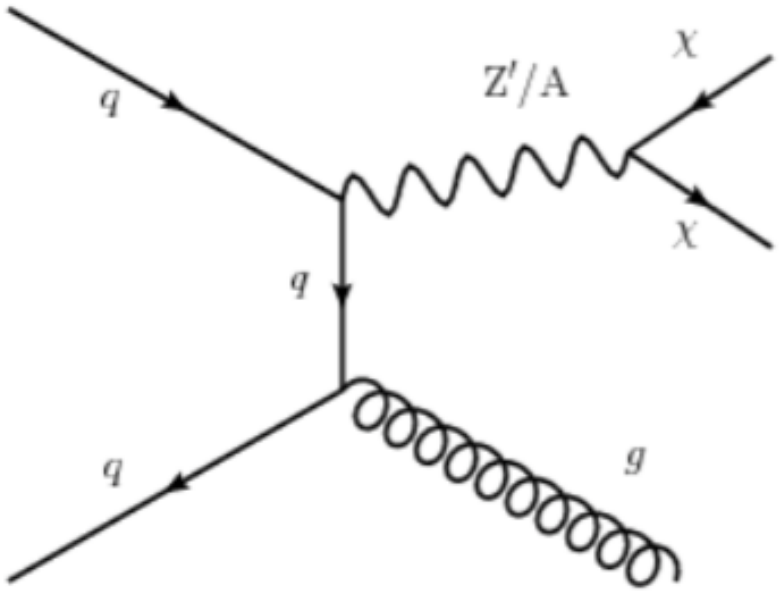
DRAFT

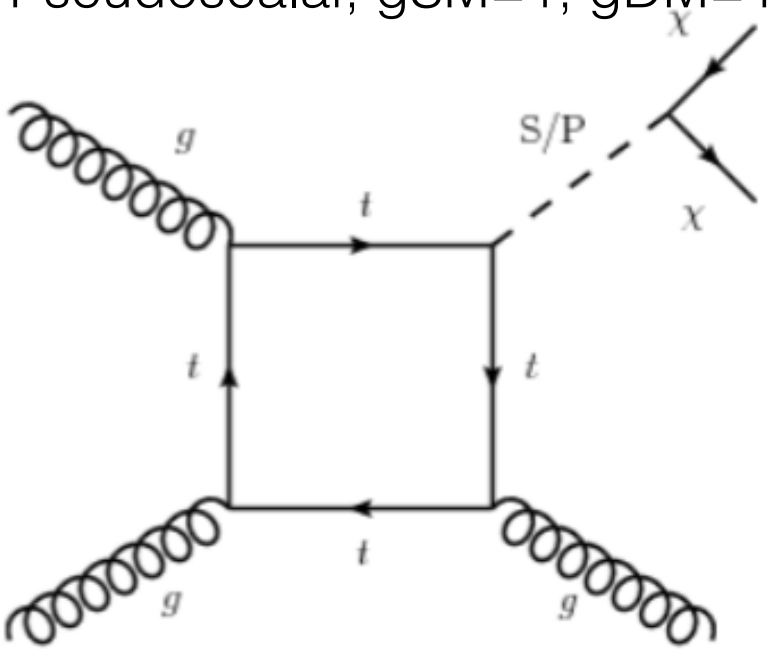
Introduction

- One of key goals of HL-LHC - shed light on dark matter
- Simplest signature for generic pair production of dark matter at collide: monojet+MET
- Goal: Study reach of HL-LHC in search for dark matter for some representative simplified models of DM using a monojet search

Avial vector, gSM=0.25, gDM=1



Pseudoscalar, gSM=1, gDM=1



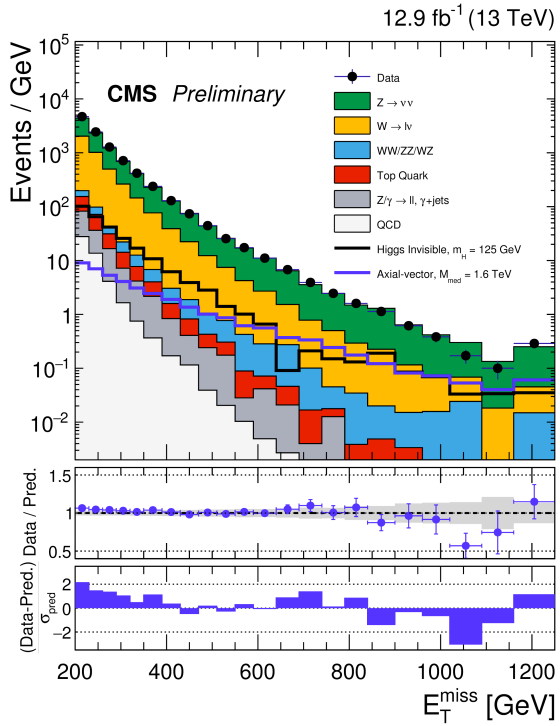
Suppressed in direct detection
Collider provides complementary sensitivity

Not accessible to direct detection

Monojet analysis implementation

CMS-EXO-16-037

- Events pass the E_T^{miss} triggers described in Table 5
- Events pass the E_T^{miss} filters described in [21] (suppress detector noise and beam backgrounds)
- Leading ak4 jet in the event has $p_T > 100$ GeV and $|\eta| < 2.5$
- Leading ak4 jet in the event passes the cleaning cuts described in Sec. 5.3
- $\Delta\phi(\text{jet}, E_T^{miss}) > 0.5$ for the first four leading ak4 jets in the event (suppress QCD)
- Require $|E_{T\ calo}^{miss} - E_{T\ PF}^{miss}| / E_{T\ calo}^{miss} < 0.5$
- Lepton veto i.e. no loose electrons, muons or taus (suppress electroweak backgrounds)
- Photon veto i.e. no loose photons (suppress electroweak backgrounds - $Z(\nu\nu)\gamma$+jets, $W(\ell\nu)\gamma$+jets)
- B-jet veto (suppress top background)
- Recoil > 200 GeV (E_T^{miss} threshold consistent with the trigger turn-on)



22 exclusive bins in MET

MET 200-230	MET 230-260	MET 260-290	MET 290-320	MET 320-350	MET 350-390
MET 390-430	MET 430-470	MET 470-510	MET 510-550	MET 550-590	MET 590-640
MET 640-690	MET 690-740	MET 740-790	MET 790-840	MET 840-900	MET 900-960
MET 960-1020	MET 1020-1090	MET 1090-1160	MET > 1160		

Monojet analysis validation

- Use the background yields and systematics provided by CMS-EXO-12-037
- Generate dedicated signal samples with **13 TeV,** pass through Pythia8, **Run 2 CMS detector card** and implementation of CMS monojet analysis
- Compare the event yields obtained for a typical signal model

POWHEG v2 13 TeV → Pythia v8 → Delphes v3.3.3pre15 → monojet selection

Axial vector (Mmed = 1500 GeV, MDM= 1 GeV)

MET bins	EXO-16-037	This analysis	ratio
300 - 400	61992.3	75718.2	0.818724
400 - 500	36447	44935.9	0.811089
500 - 600	21339.9	25277.7	0.844218
600 - 700	12536.7	12966.7	0.966838
700 - 800	7599.91	7551.76	1.00638
800 - 900	4438.48	4662.5	0.951953
900 - 1000	2621.89	2787.34	0.940642
1000 - 1100	1518.06	1530.74	0.991716
1100 - 1200	886	956.577	0.926219
1200 - 1300	631	529.447	1.19181
1300 -	1127.73	982.25	1.14811

After event selection shown in previous slide, normalized to 3000 fb^{-1}

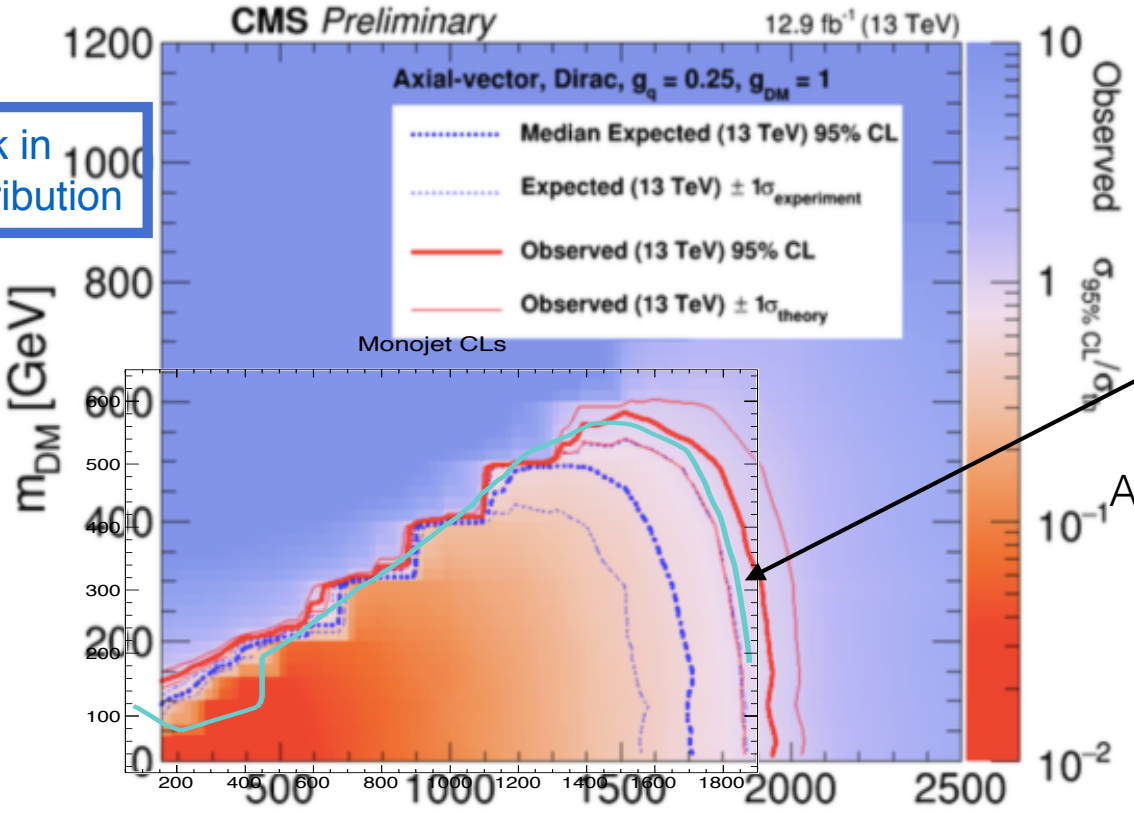
Yields are consistent within ~ 20%

Monojet analysis validation

- Use the background yields and systematics provided by CMS-EXO-12-037
- Generate dedicated signal samples with **13 TeV,** pass through Pythia8, **Run 2 CMS detector card** and implementation of CMS monojet analysis and limit setting procedure

POWHEG v2 13 TeV → Pythia v8 → Delphes v3.3.3pre15 → monojet selection → Limit setting

CMS internal work in progress. Not for distribution



Agreement to within ~1sigma of expected limits

*Limit setting procedure combines the 22 exclusive MET bins to produce a limit, but does not include correlations in systematic uncertainties between these bins.

Event selection for projection studies

Pre-selection - closely resembles current monojet analysis, exception pt(j1) cut increased to 250 GeV for AV and 200 GeV for PS

ECFA selection
AK4/PUPPI jets, pt(j1) $>$ 250 for AV (200 for PS), $\|\eta\| < 2.5$
$\Delta\phi$(jet, MET) > 0.5
veto electrons, $p_T > 10, \|\eta\| < 2.4$
veto muons, $p_T > 10, \|\eta\| < 2.5$
veto taus, $p_T > 18, \|\eta\| < 2.3$
b-jet veto, 'Loose', $p_T > 15, \|\eta\| < 2.5$
MET $>$ 200 GeV

- 22 exclusive MET bins - for PS, binning is same as current analysis
- For AV, the binning is changed to 100 GeV bins and extended to higher MET
- Only 0PU scenario considered for this study
- Only V+jets background considered - dominant one for this search.
- Cross-sections scaled to account for higher order QCD corrections and also a correction at the level of 20-25% applied to high MET region to account for higher order electroweak corrections

Systematic scenarios

For the axial vector model, MET binning for ECFA study extended to MET > 2.4 TeV.

The systematic scenarios considered:

- 'nominal' : assume that the level of systematic control of the MET distribution will be the same at HL-LHC (with the extended range to > 2 TeV) as the current analysis (where last bin is 1.2 TeV)
- sys 1 : systematic uncertainties from the 'nominal' scenario are reduced by factor of 2.
- sys 2 : systematic uncertainties from the 'nominal' scenario are reduced by a factor of 4.

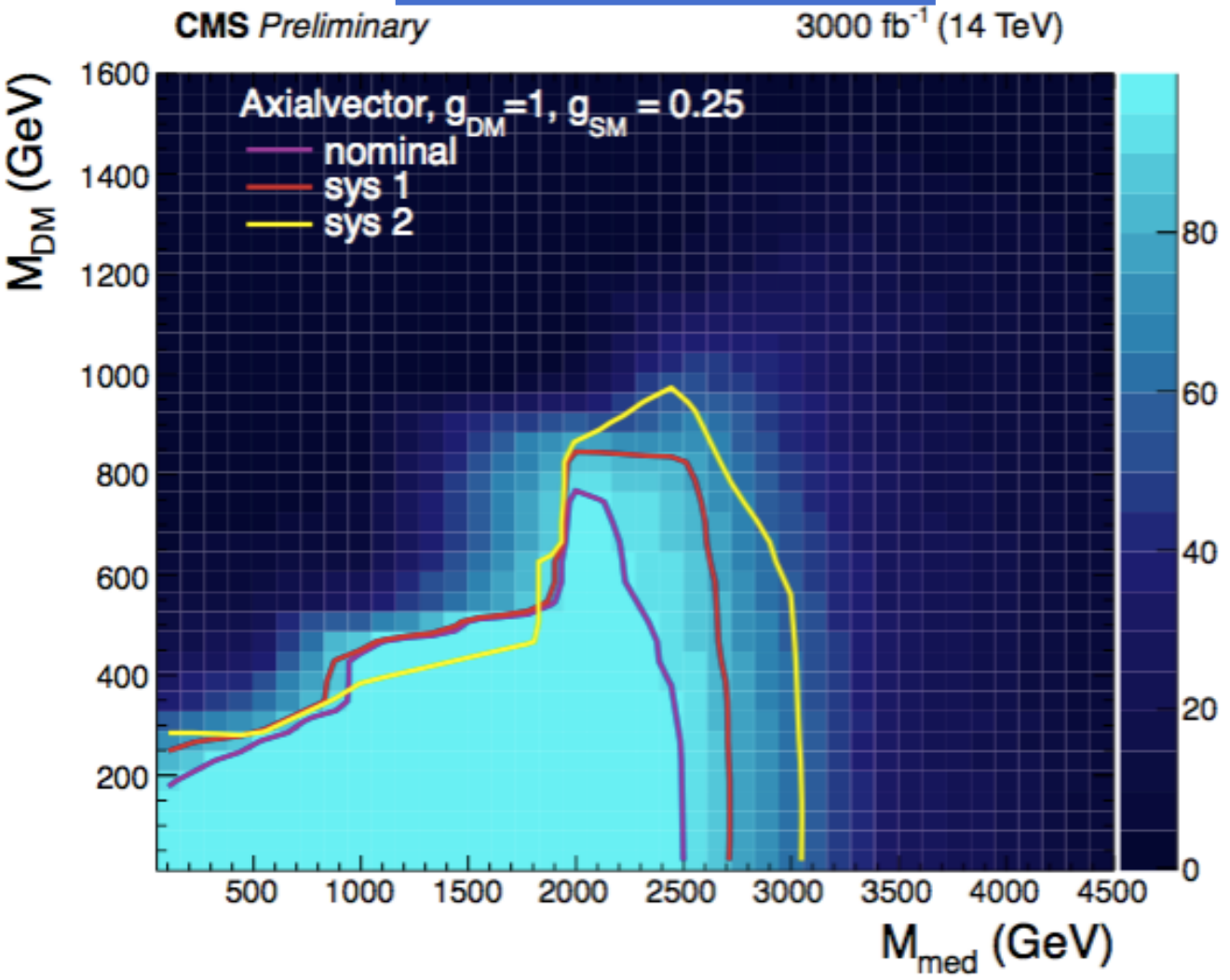
For the pseudo scalar model, MET binning for ECFA study is kept same as EXO-16-037.

The systematic scenarios considered:

- 'nominal' : scale the systematics at low MET which are dominated by lepton ID/ISO to HL-LHC recommendation, scale the systematics at high MET by lumi.
- sys 1 : scale the current systematic uncertainties in the full MET range by luminosity.
- sys 2 : systematic uncertainties from the 'nominal' scenario are reduced by a factor of 2.

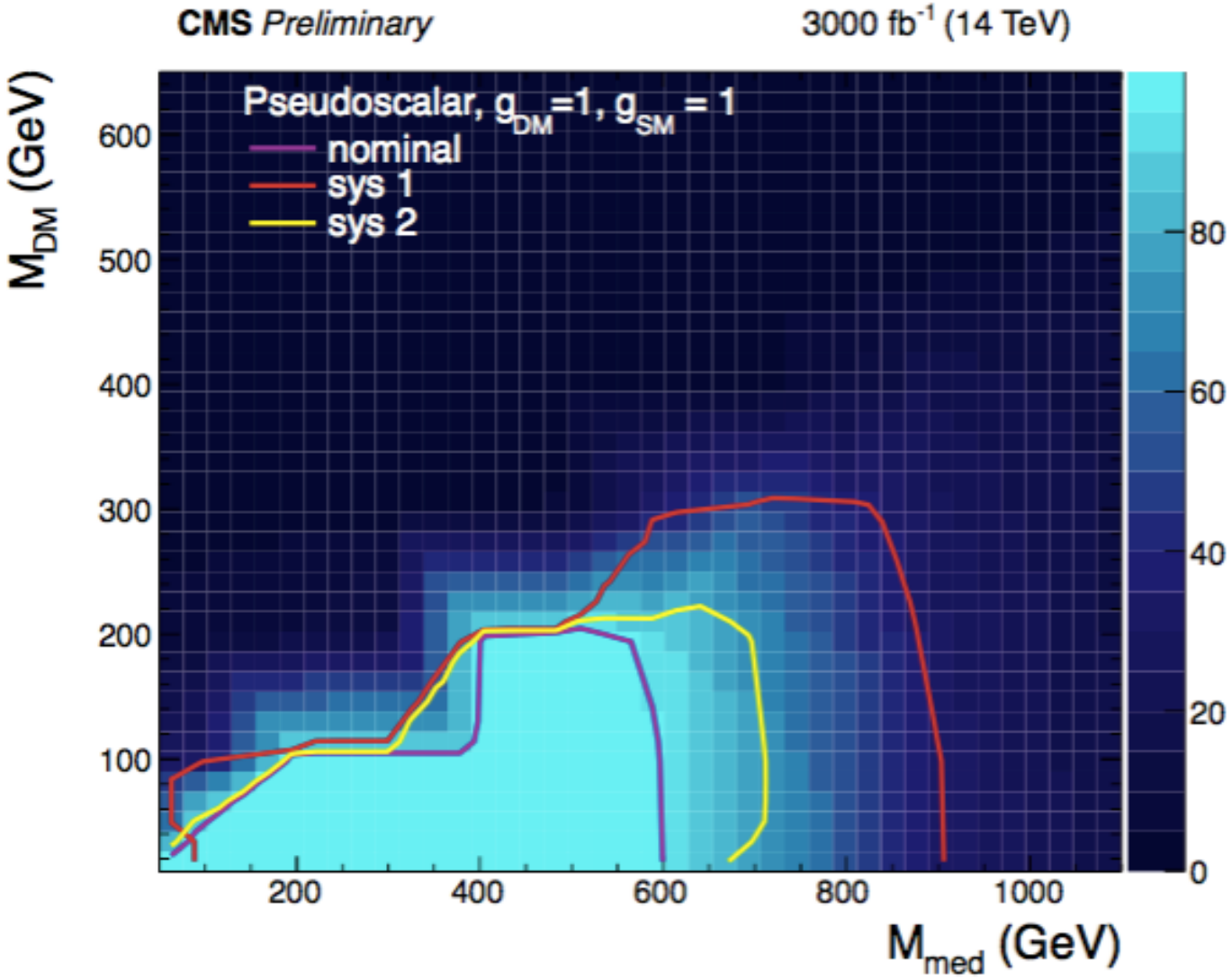
ECFA projections for axial-vector

CMS internal work in progress. Not for distribution



ECFA projections for pseudo scalar

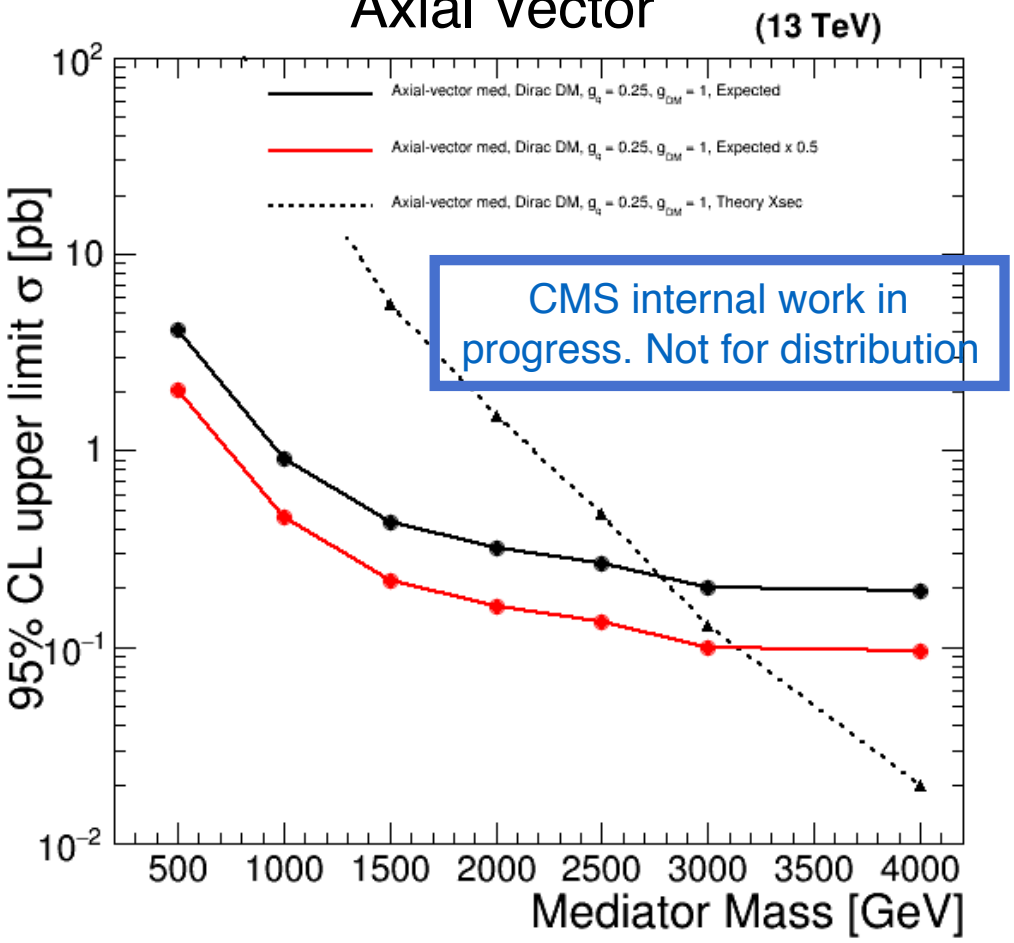
CMS internal work in progress. Not for distribution



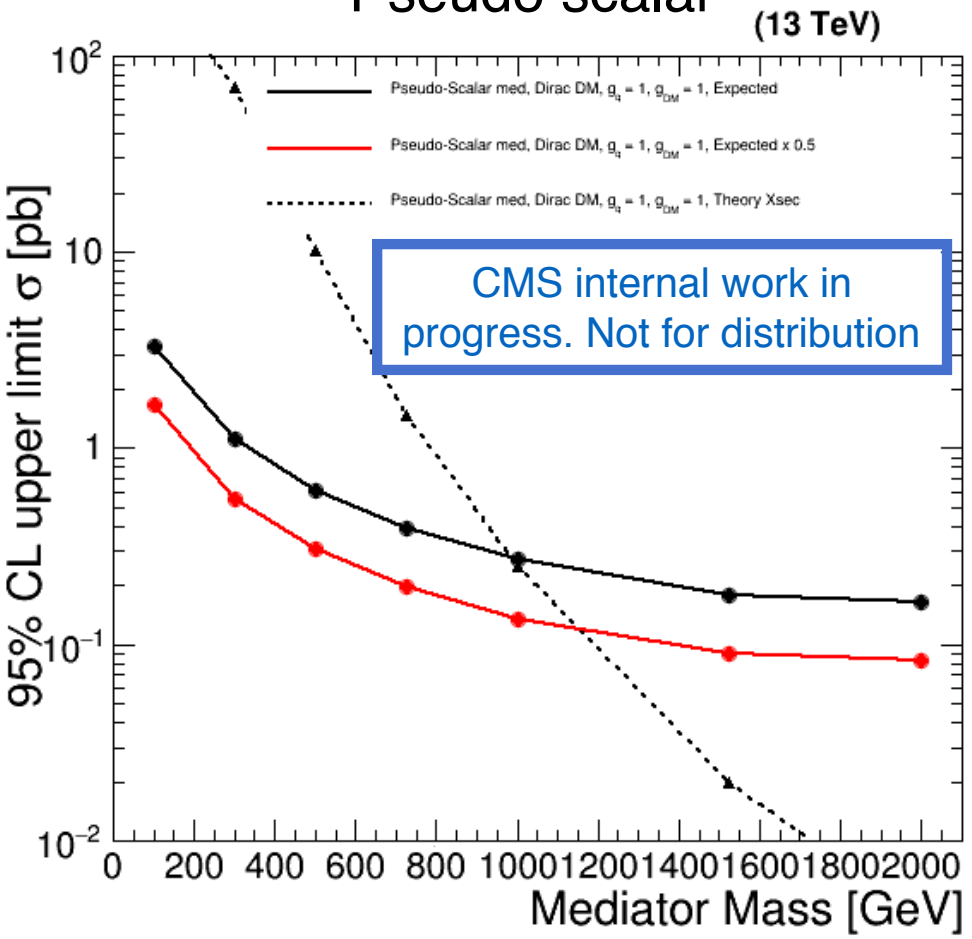
Projections : Cross-section limits

Imperial College London

Axial Vector



Pseudo scalar



For Axial Vector & Pseudoscalar, the xsec limit starts flattening out after 3 TeV and 1.5 TeV respectively

Summary

- Projections for 14 TeV 3000 fb-1 with Phase 2 detector simulation made for monojet analysis, focusing on some key benchmark simplified models of dark matter
- Event selection optimized for HL-LHC and several scenarios for the evolution of the systematic uncertainties considered.
- Validations performed with current analysis - good agreement observed
- So far, focused only on 0PU, studies with 200PU forthcoming