Searches for dark matter in association with top quarks at CMS

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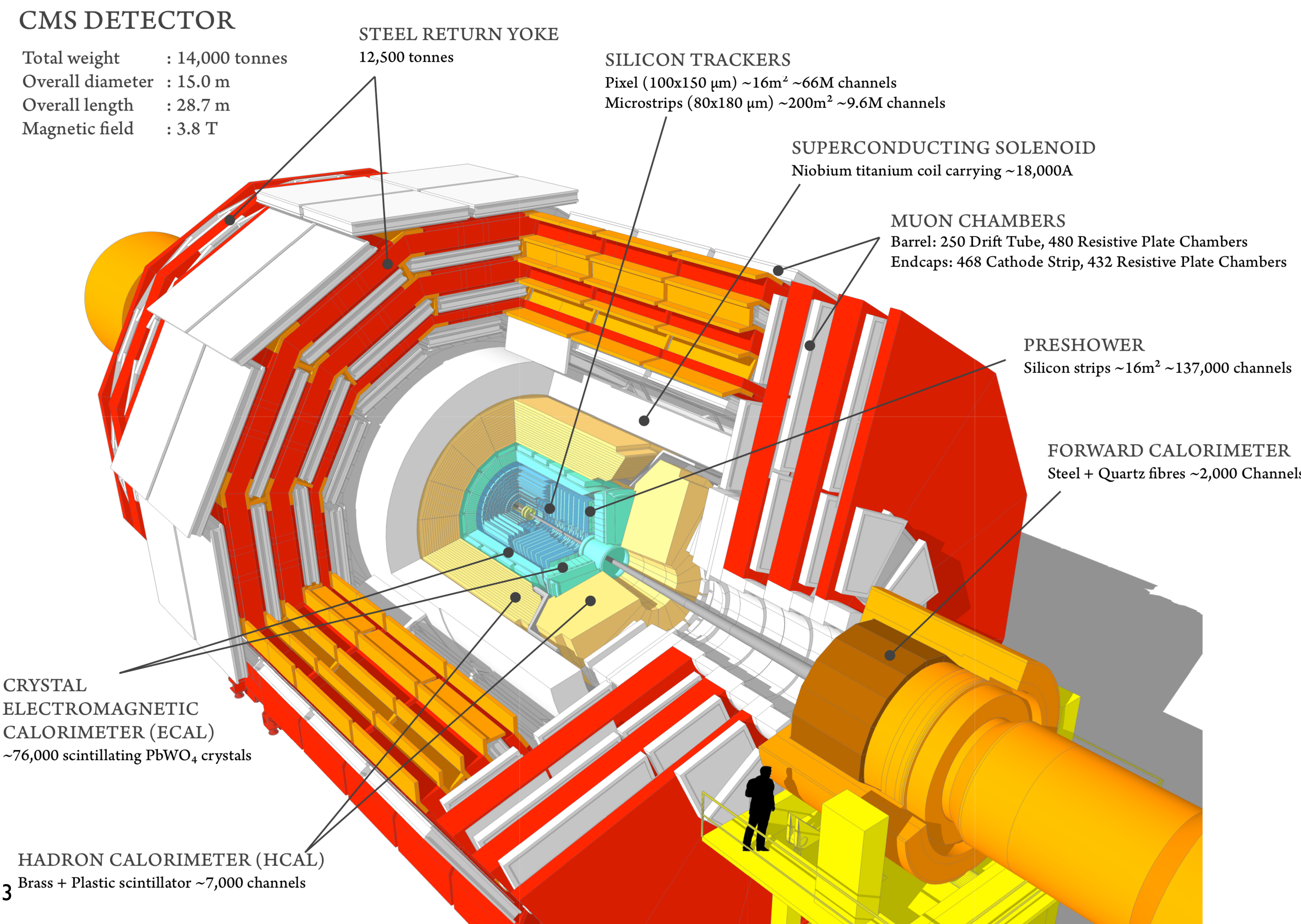
introduction

- dark matter (DM) is estimated to account for about 23% of the total mass of the Universe
  - how does it interact with ordinary matter?
  - a weakly interacting massive particle arises naturally in several models of physics BSM such as supersymmetry
- at CMS we have looked for DM in association with one or two top quarks
- tt + DM
  - the DM particle is assumed to interact with quarks via a four-fermion contact interaction, which can be described by an EFT
  - sensitivity for a scalar interaction can be improved by searching for final states with third generation quarks ➠ we have considered only scalar coupling between DM and top quarks
- t + DM
  - the invisible particle can be either a scalar or a vector boson
  - assume invisible-to-up-quark coupling strengths $a_{FC} = 0.1$

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G



missing transverse energy

- the energy imbalance in the transverse plane (MET) is crucial to distinguish DM from SM
  - the MET strongly depends on a proper determination of the jet energy scale
  - in addition, a lot of effort has been put in place to mitigate the impact of pileup events on the MET
  - **fake high MET events have been removed with dedicated filters**, like misfires of the HCAL laser calibration and electronics noise in HB and HE

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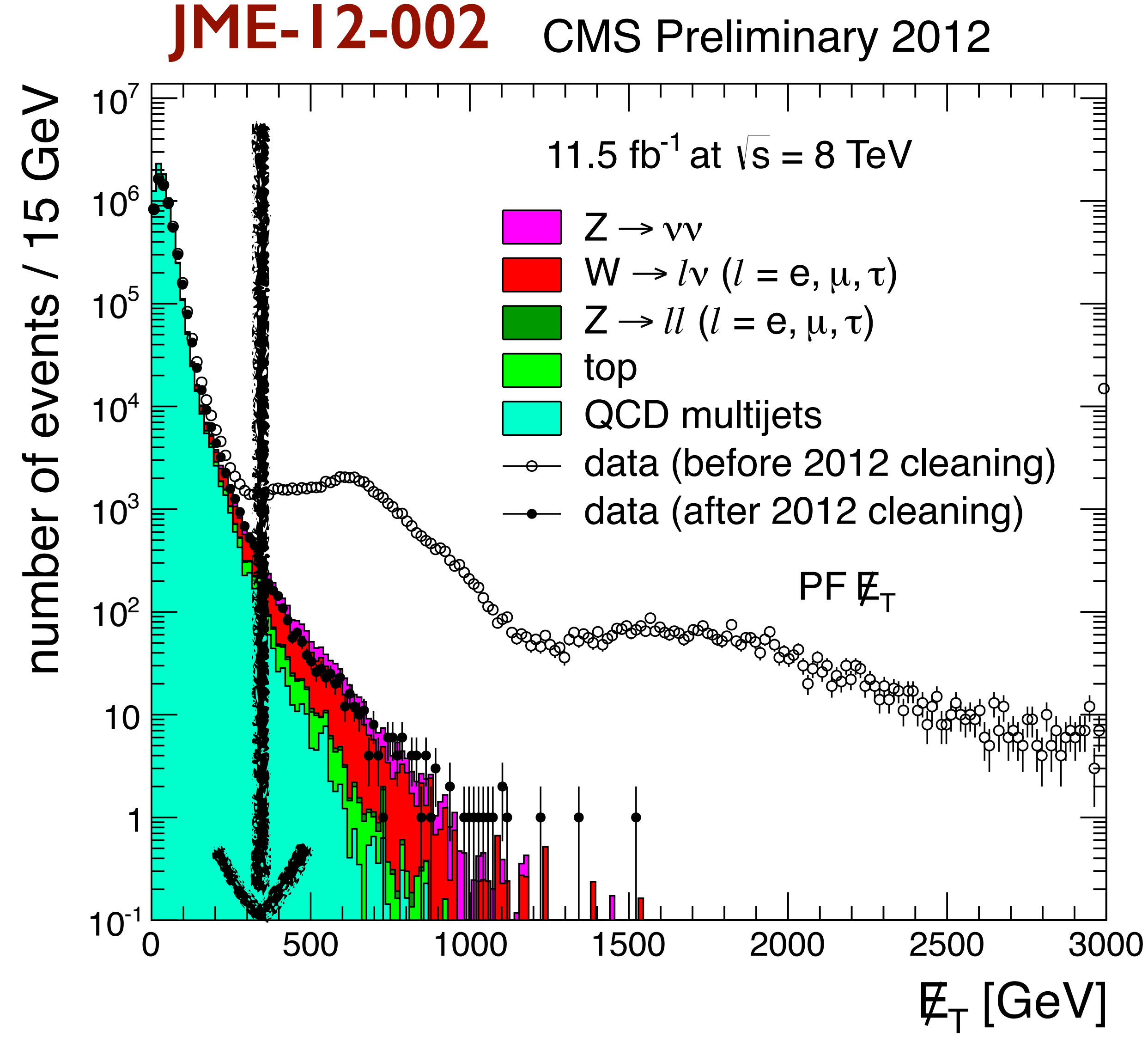
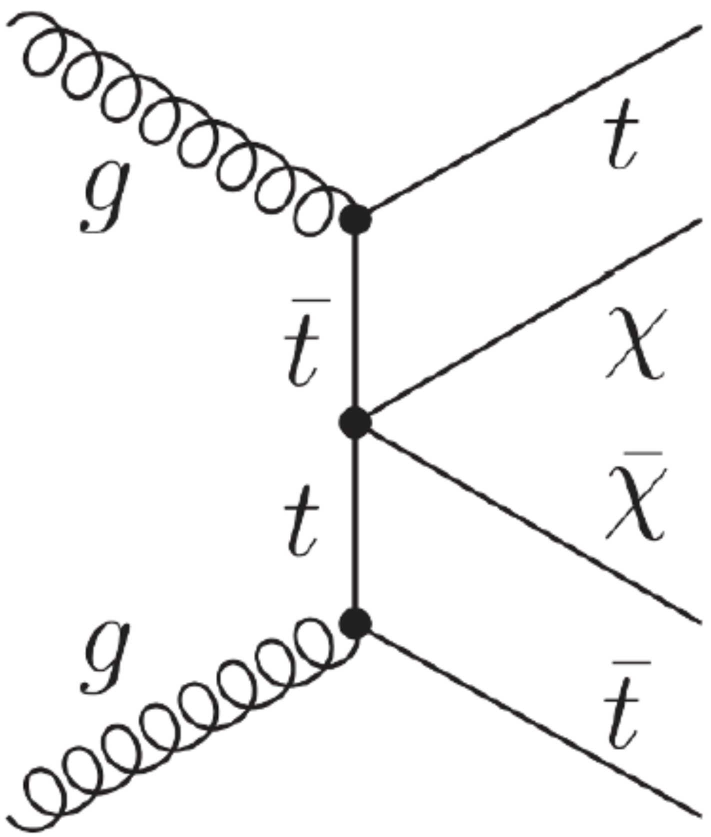


a similar effort on the identification of anomalous MET events is ongoing with 13 TeV data

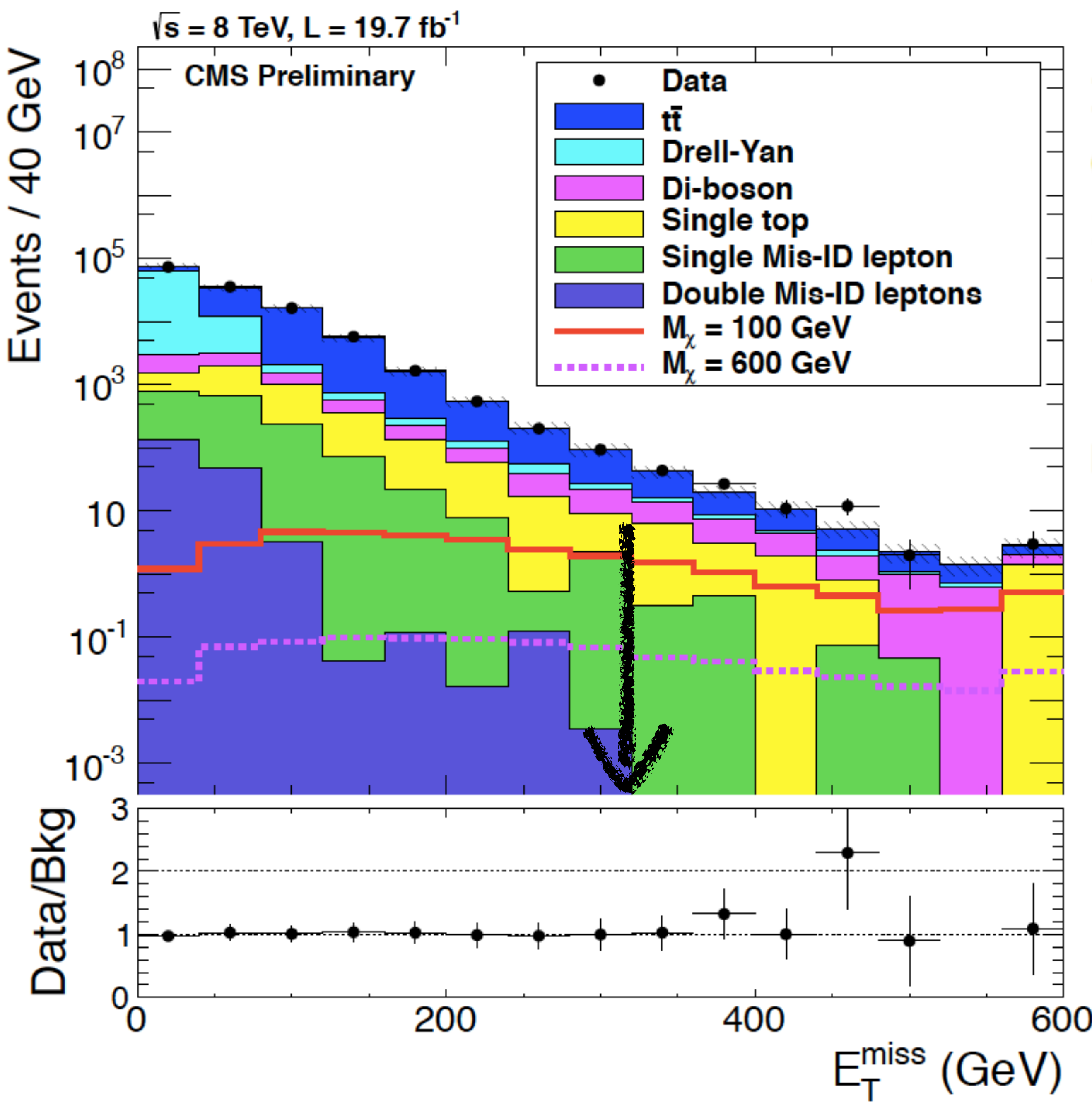
tt+DM

- dileptonic final state **B2G-13-004**
  - exactly two isolated leptons out of the Z peak
  - at least two jets
  - **the signal has two dark matter particles ➠ MET > 320 GeV**
  - *pt* sum of the two leading jets < 400 GeV
  - *pt* sum of the two leptons > 120 GeV
  - dominant backgrounds are tt+jets, single top, diboson
  - largest systematic uncertainties are JES and top *pt* reweighing
- semileptonic final state **JHEP 06 (2015) 121**
  - at least three jets
  - at least one b-jet
  - only one prompt isolated lepton
  - **MET > 320 GeV**
  - m_T > 160 GeV against semileptonic tt and W+jets (for them $m_T < m_W$)
  - **dominant background is tt dileptonic with a lost lepton ➠ use $m_{T2}w$ > 200 GeV** (see backup)

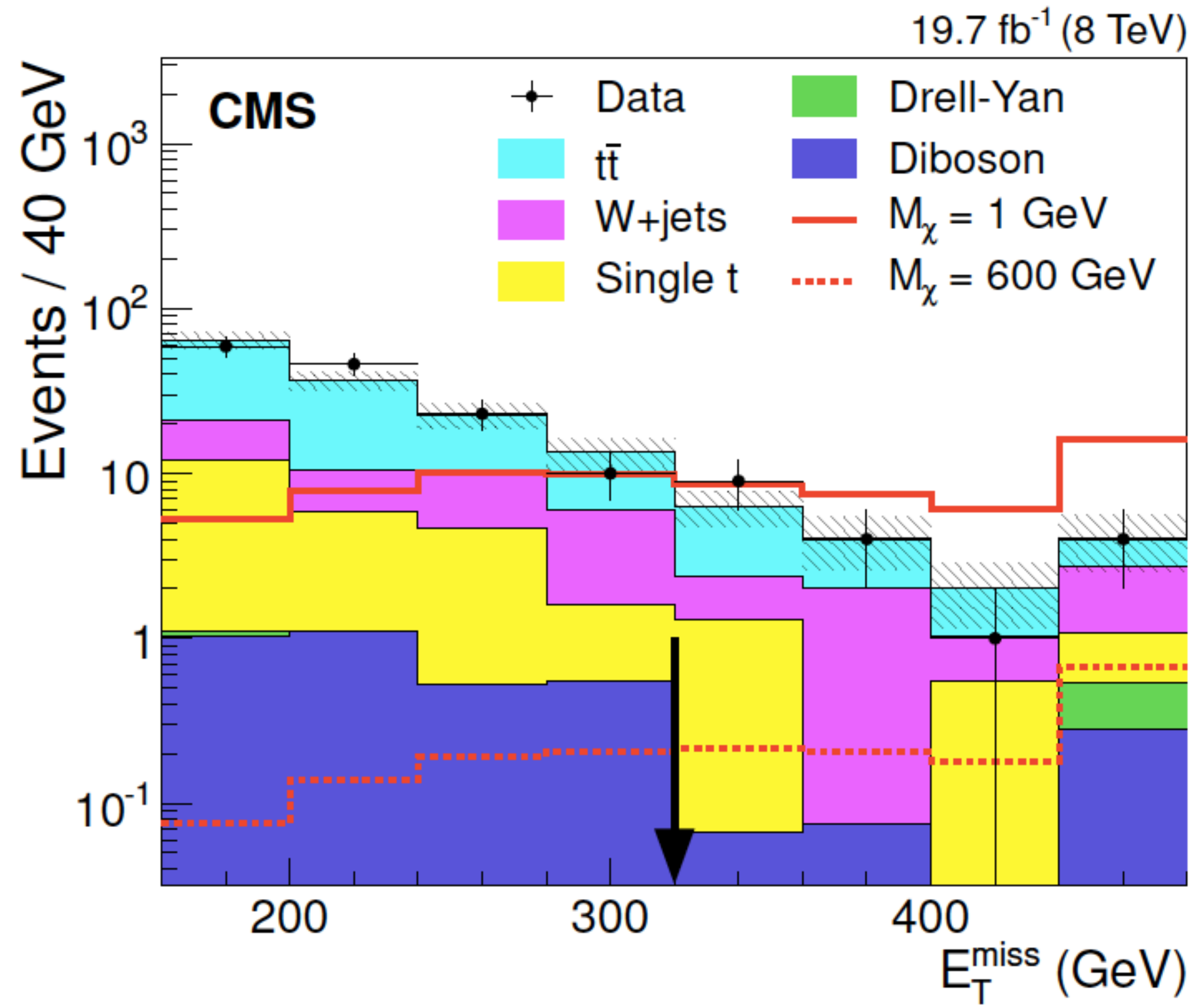


tt+DM MET distributions

dileptonic



semileptonic



tt+DM final yields

dileptonic

Background Source	Yield
$t\bar{t}$	$0.87 \pm 0.18 \pm 0.27$
Single top	$0.48 \pm 0.46 \pm 0.09$
Di-boson	$0.32 \pm 0.09 \pm 0.05$
Drell-Yan	$0.19 \pm 0.14 \pm 0.03$
One Mis-ID lepton	$0.02 \pm 0.07 \pm 0.02$
Double Mis-ID leptons	$0.00 \pm 0.00 \pm 0.00$
Total Bkg	$1.89 \pm 0.53 \pm 0.39$
Data	1
Signal	$1.88 \pm 0.11 \pm 0.07$

100 GeV DM mass
100 GeV interaction scale

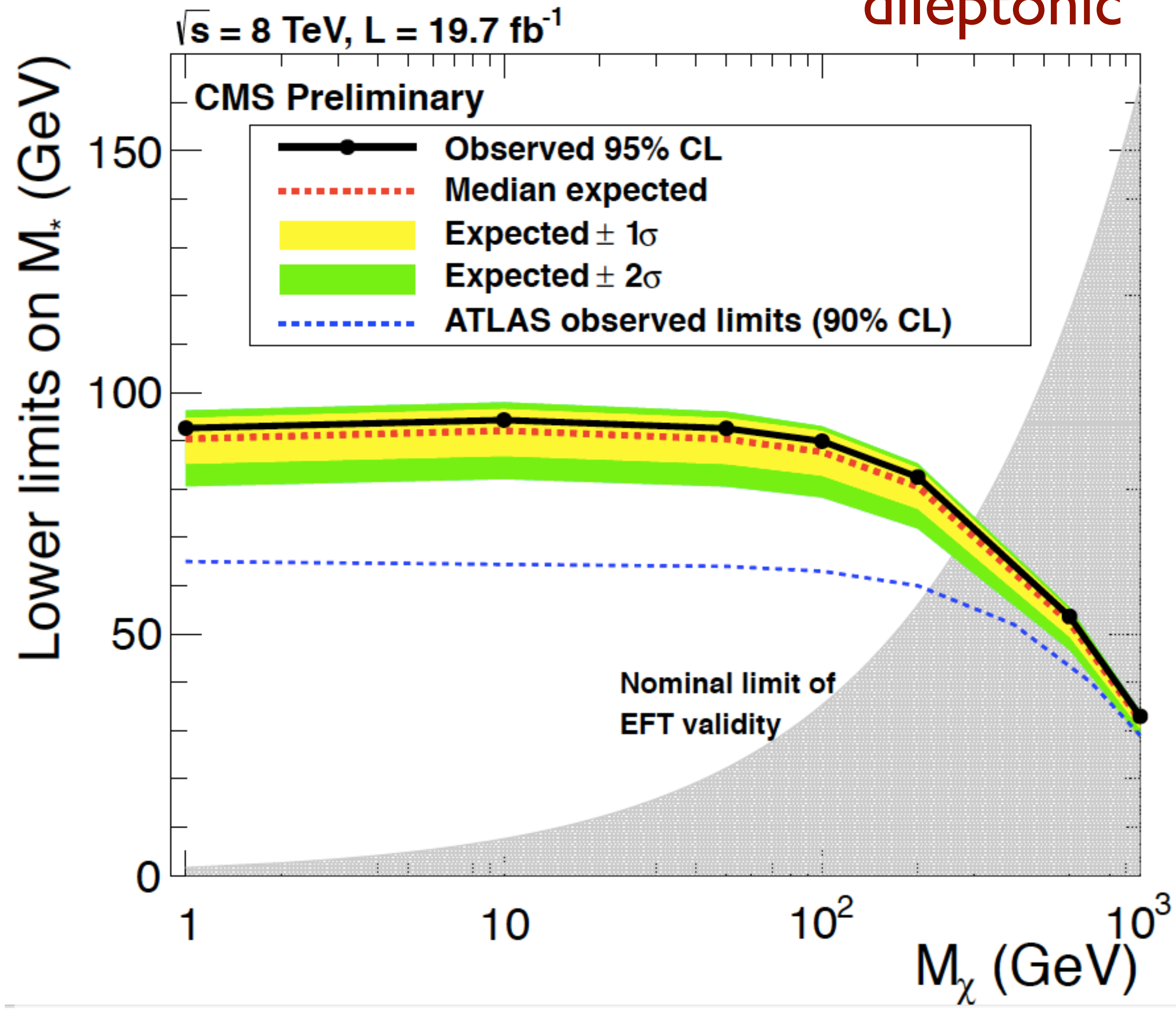
semileptonic

Source	Yield ($\pm$stat $\pm$syst)
$t\bar{t}$	$8.2 \pm 0.6 \pm 1.9$
W	$5.2 \pm 1.8 \pm 2.1$
Single top	$2.3 \pm 1.1 \pm 1.1$
Diboson	$0.5 \pm 0.2 \pm 0.2$
Drell-Yan	$0.3 \pm 0.3 \pm 0.1$
Total Bkg	$16.4 \pm 2.2 \pm 2.9$
Data	18

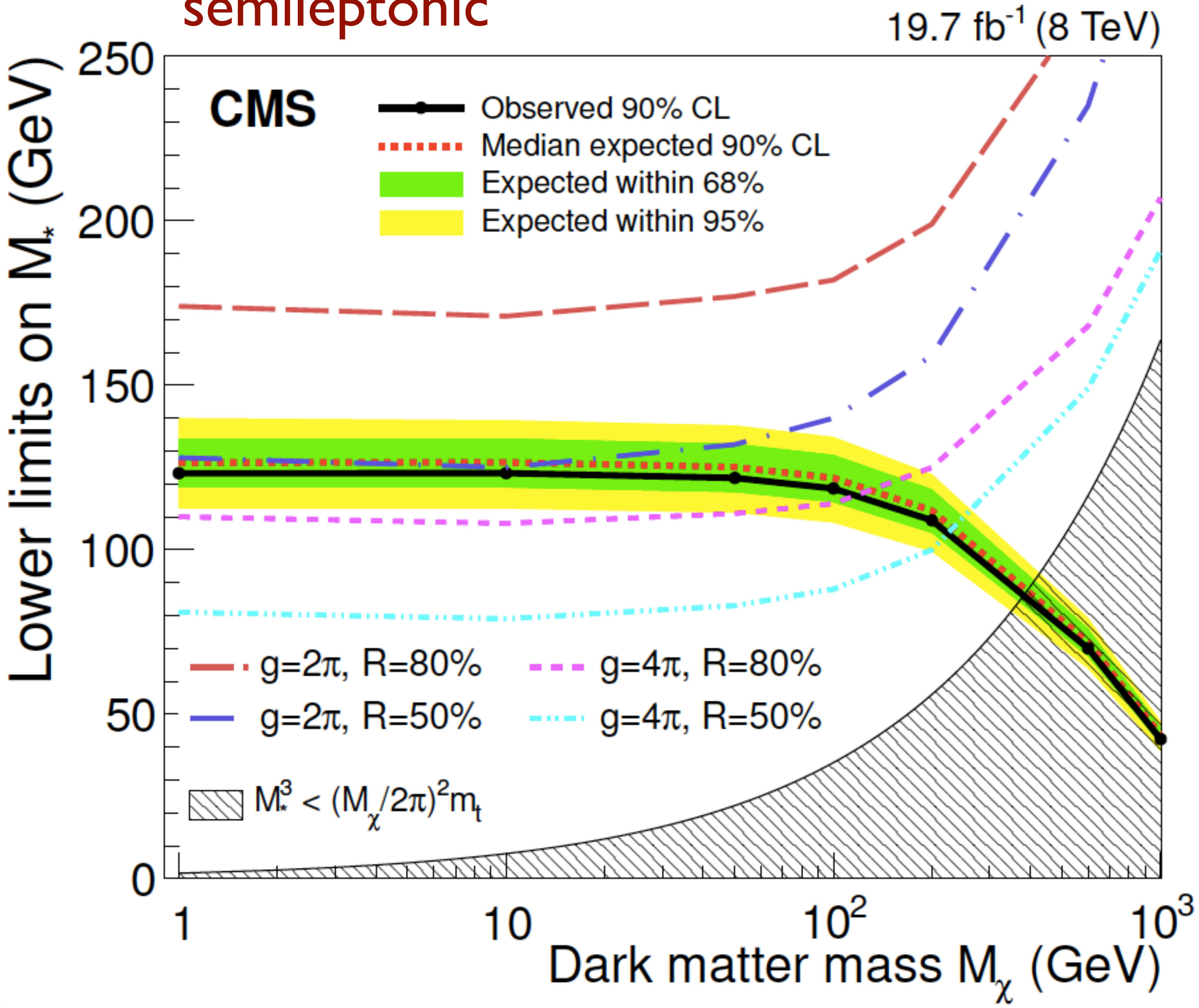
- in both cases the main background is ttbar
  - 46% (50%) for the dileptonic (semileptonic) channel
  - the 8 TeV ttbar cross section is 253 pb

tt+DM limits

dileptonic

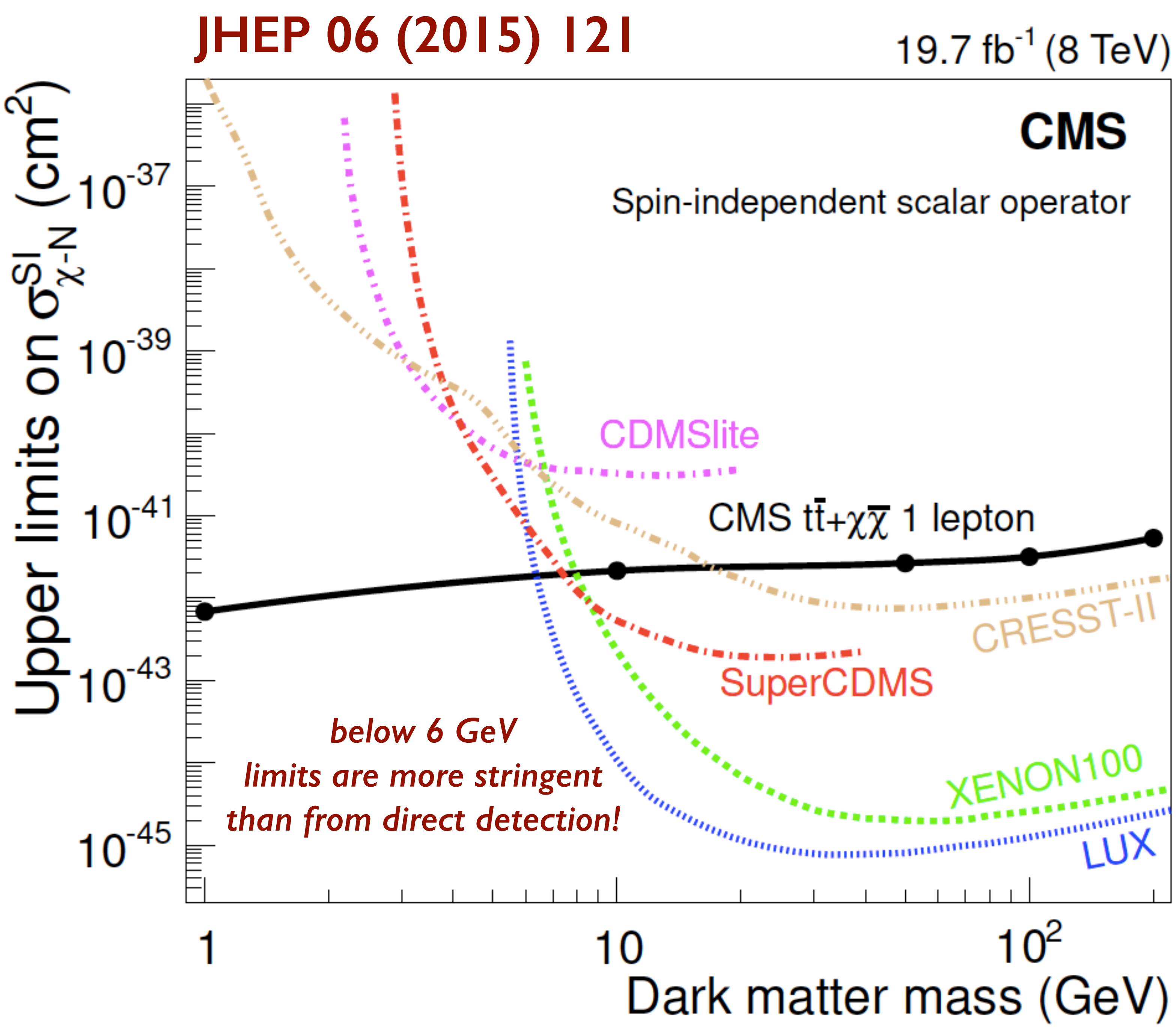


semileptonic



assuming 100 GeV DM the interaction scale is excluded at 95% CL below 90 GeV

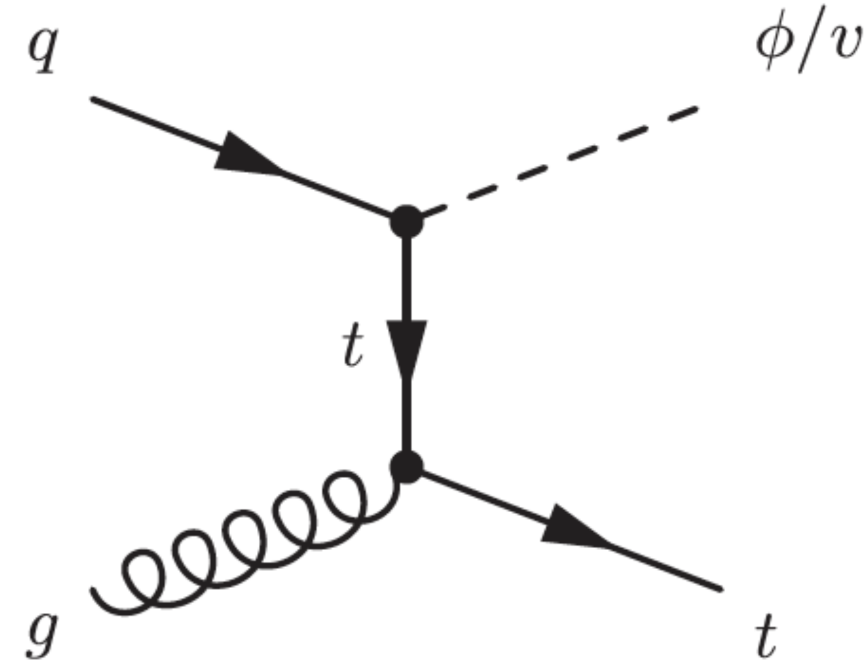
assuming 100 GeV DM the interaction scale is excluded at 95% CL below 119 GeV

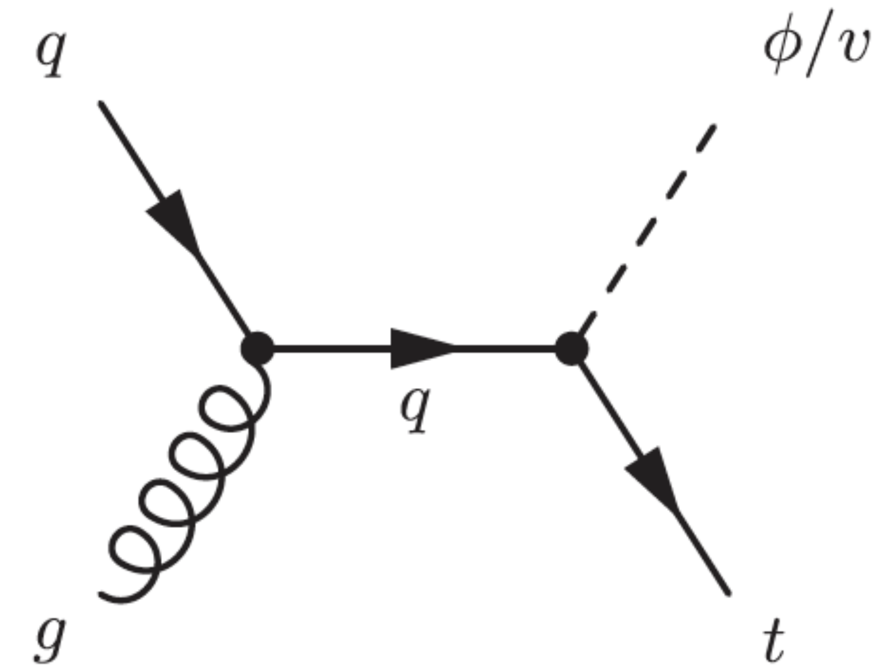


the limits on the interaction scale can be translated to limits on the DM-nucleon scattering cross section

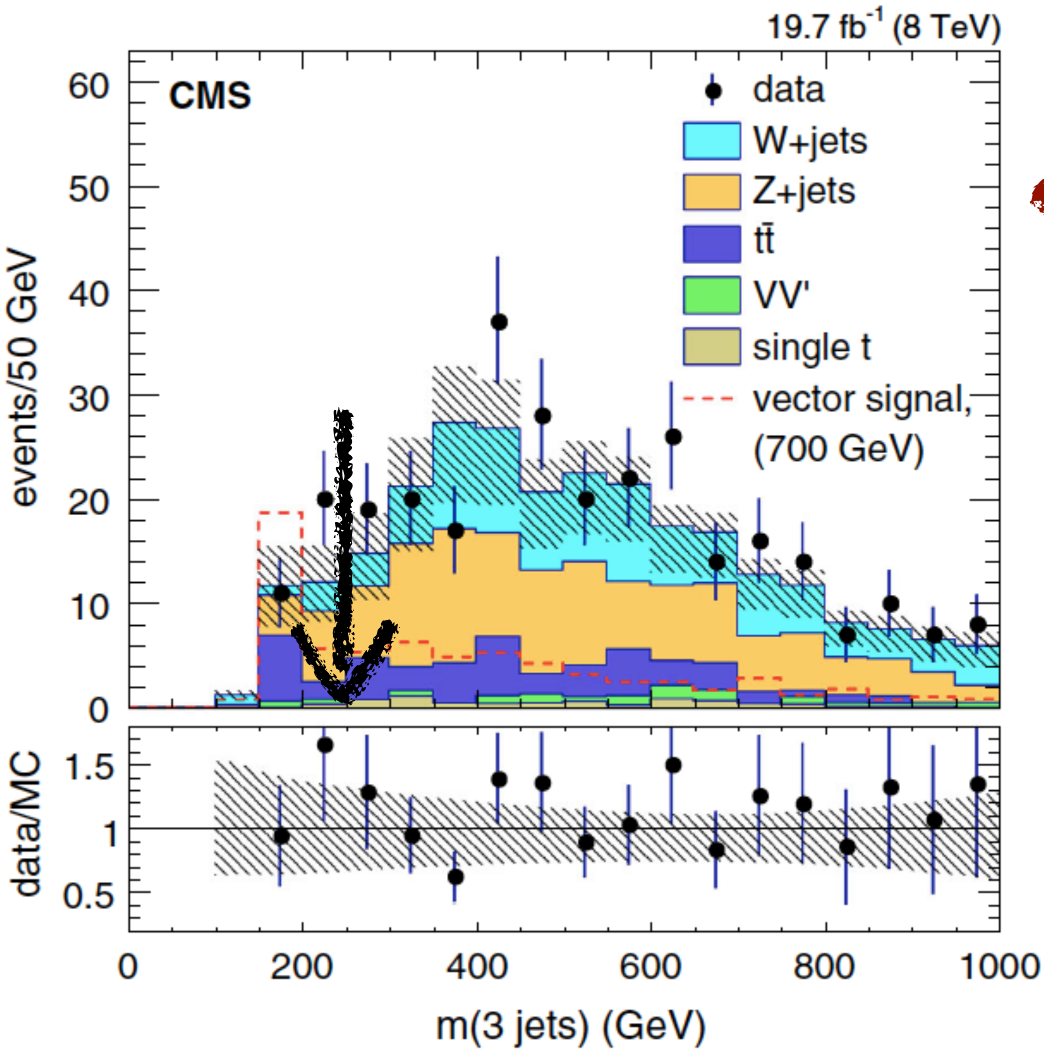
search for monotop signatures

- t → bW → bqq' selection
  - *pt* > 60 GeV for first 2 jets, *pt* > 40 GeV for third
  - *m3jet* < 250 GeV
  - one b-tag
  - reject events with isolated leptons
  - **MET > 350 GeV**
- main backgrounds
  - tt+jets
  - W+jets and Z+jets estimated from CR which requires 1 (W) or 2 (Z) isolated leptons





PRL 114, 101801 (2015)



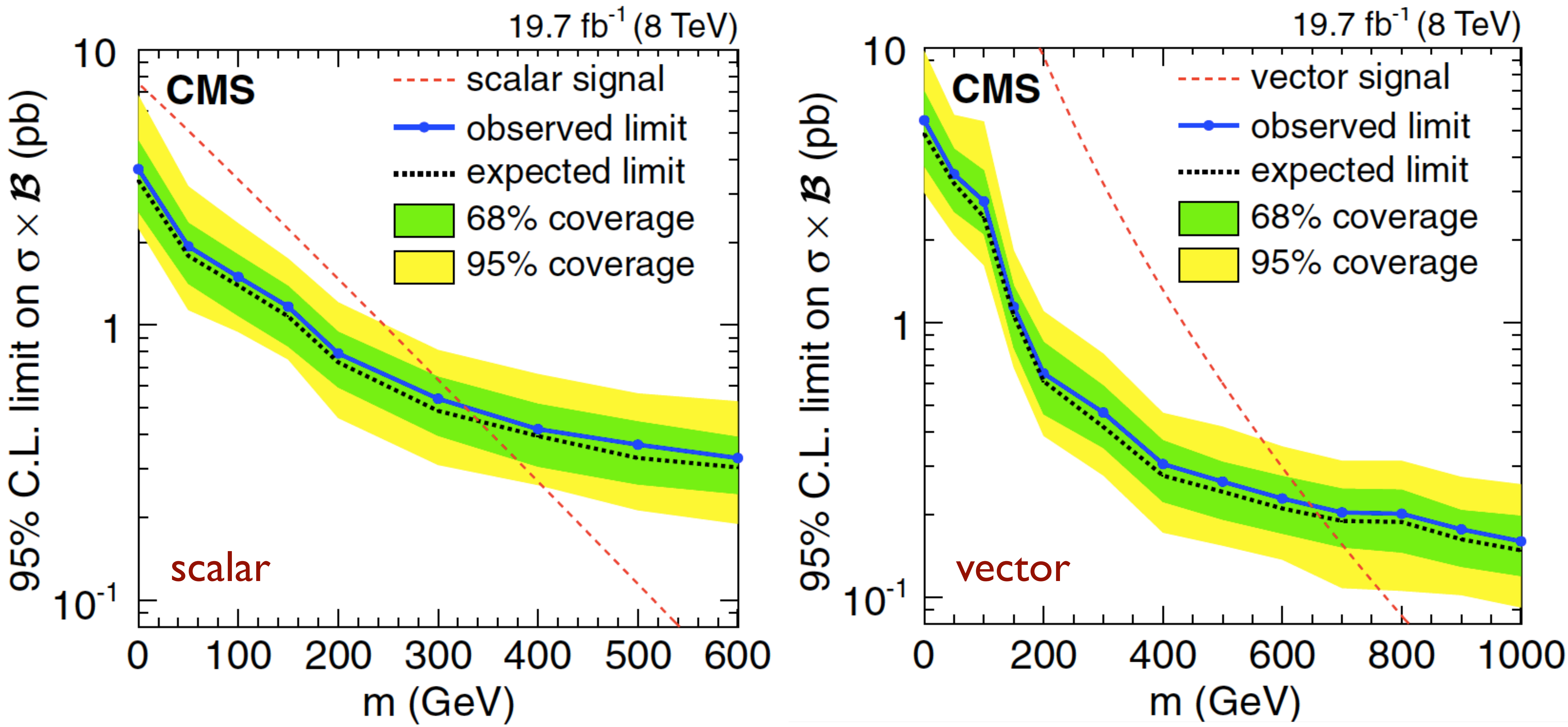
m3jets for events with 1 b-tag

the signal xs and multijet background are both measured using a likelihood, based on the observed events with no b-tag and 1 b-tag

with no b-tag (1-btag) the dominant backgrounds are V+jets (tt+jets and Z+jets)

	No b tag	One b tag
$t\bar{t}$	$6 \pm 0 \pm 5$	$12 \pm 0 \pm 12$
$W + $jets	$18 \pm 9 \pm 7$	$3 \pm 1 \pm 2$
$Z + $jets	$103 \pm 33 \pm 9$	$11 \pm 10 \pm 1$
Single top	$2 \pm 1 \pm 1$	$1 \pm 1 \pm 1$
VV'	$5 \pm 0 \pm 0$	$0 \pm 0 \pm 0$
Multijet	$6(\pm 39)$	$1(\pm 9)$
Total background	140 ± 36	28 ± 16
Signal	2 ± 6	3 ± 11
Data	143	30

monotop + DM results

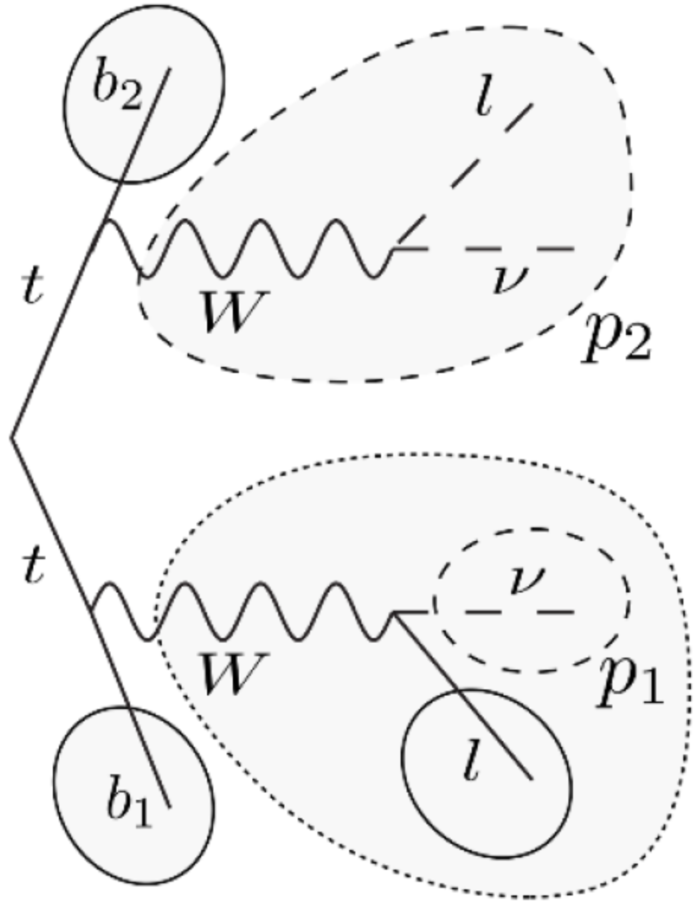


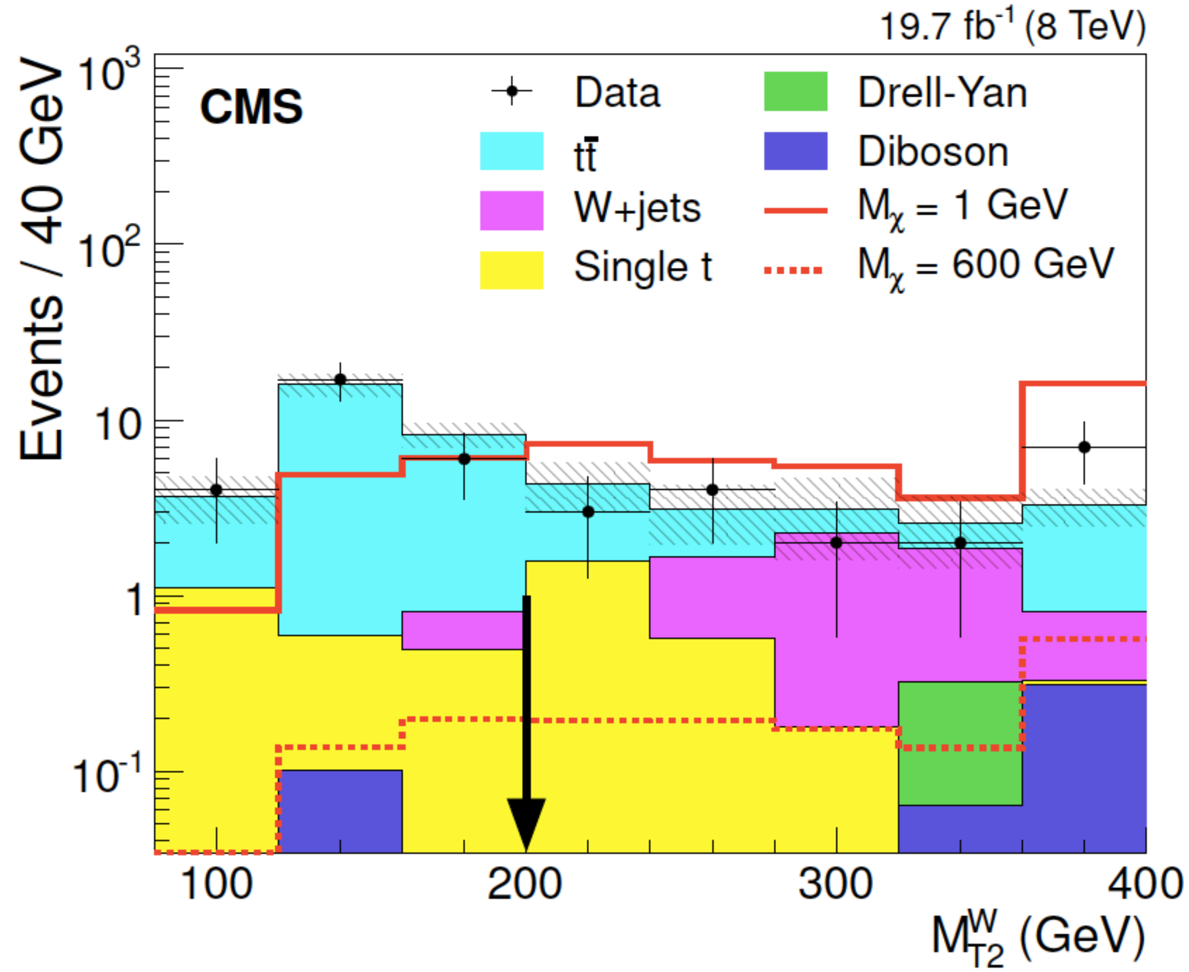
the observed lower limits on mass for invisible particles are set at 330 GeV (scalar) and 650 GeV (vector). For a coupling constant a_{FC} = 0.2 these limits increase to 530 and 930 GeV

conclusions

- no excess of events has been found above the standard model expectation
  - in the tt + DM dileptonic channel, cross sections higher than 0.09 to 0.31 pb are excluded at the 95% CL for dark matter particles with masses ranging from 1 GeV to 1 TeV
  - in the tt + DM semileptonic channel, cross sections higher than 20 to 55 fb are excluded at the 95% CL
  - in the t + DM hadronic channel scalar (vector) invisible masses below 330 (650) GeV have been excluded
- exciting work is on going with 13 TeV data
  - document written by ATLAS and CMS on the benchmark models for early Run 2 searches (arXiv:1507.00966)
  - how do the couplings change the kinematics?
  - how does the mediator mass change the kinematics?
  - use simplified models
- additional top decay channels coming at 13 TeV
- adding boosted top decays at 13 TeV
- *even if CMS wasn't designed for DM searches, promising results are ahead of us*

backup





minimal "parent" particle mass compatible with all the transverse momenta and mass-shell constraints, assuming two identical parent particles, each of mass m_y, decaying to bW

$$M_{\mathrm{T2}}^{\mathrm{W}} = \min\left(m_{\mathrm{y}} \text{ consistent with: } \begin{Bmatrix} \vec{p}_1^{\mathrm{T}} + \vec{p}_2^{\mathrm{T}} = \vec{p}_{\mathrm{T}}^{\mathrm{miss}}, p_1^2 = 0, (p_1 + p_\ell)^2 = p_2^2 = M_{\mathrm{W}}^2, \\ (p_1 + p_\ell + p_{\mathrm{b}1})^2 = (p_2 + p_{\mathrm{b}2})^2 = m_{\mathrm{y}}^2 \end{Bmatrix} \right)$$