



Searches for Dark Matter Production with CMS

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Fermilab

on behalf of the CMS Collaboration

LHCP 2016

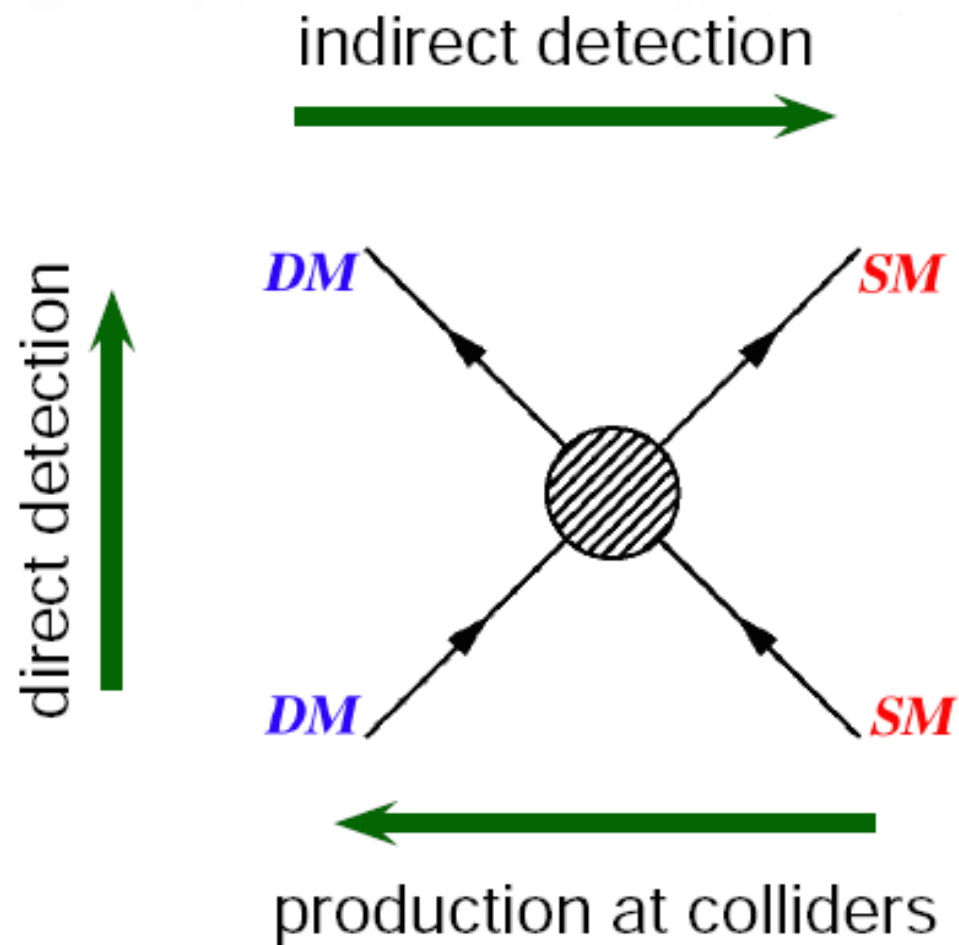
Lund, Sweden

17 June 2016

The search for dark matter

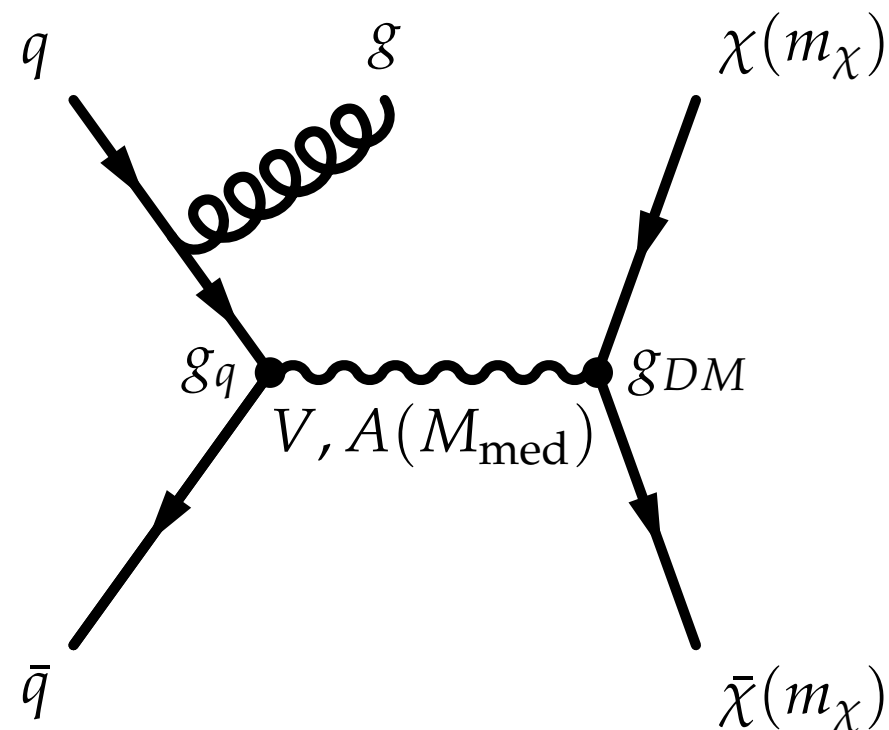


- Existence of dark matter is well established from cosmological observations
 - Exact nature of it is unknown
- Ways to look for (particle) DM
 - Direct searches via **DM-nucleon scattering**
 - Indirect searches via **DM annihilation**
 - Search for **production of DM at colliders**
- LHC provides a prime laboratory for production of DM
 - Search for evidence of DM production along with (visible) SM particles
 - Can characterize DM interaction as function of spin/parity, coupling, etc



Benchmark signatures for LHC DM searches

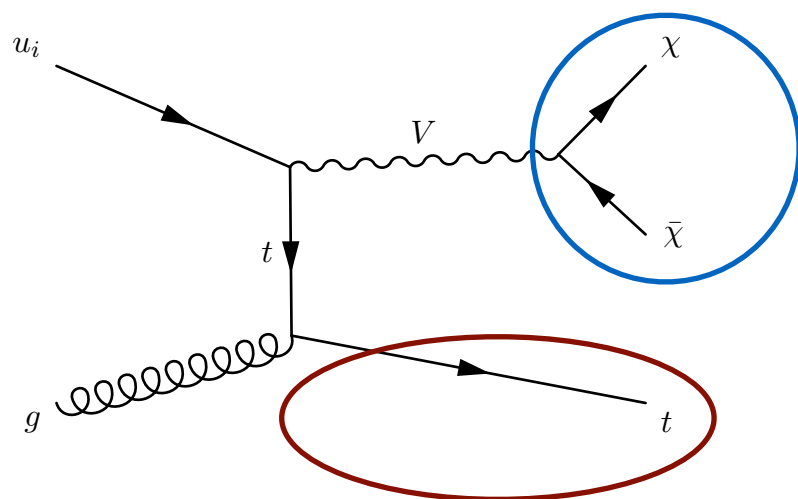
- Searches for DM at the LHC look for $\mathbf{E_T^{miss}+X}$
 - $X = \text{jet, } W, Z, \gamma, H, tt, bb, t, \text{ etc.}$
- Run 2: Adopt **simplified models** to interpret results (arXiv:1507.00966)
 - Assume new massive particle which mediates DM-SM interaction
 - DM particle is a Dirac fermion χ
 - Keep to a minimal set of parameters
 - $M_{\text{med}}, m_\chi, g_{\text{SM}}, g_{\text{DM}}, \Gamma_{\text{med}}$



General strategy



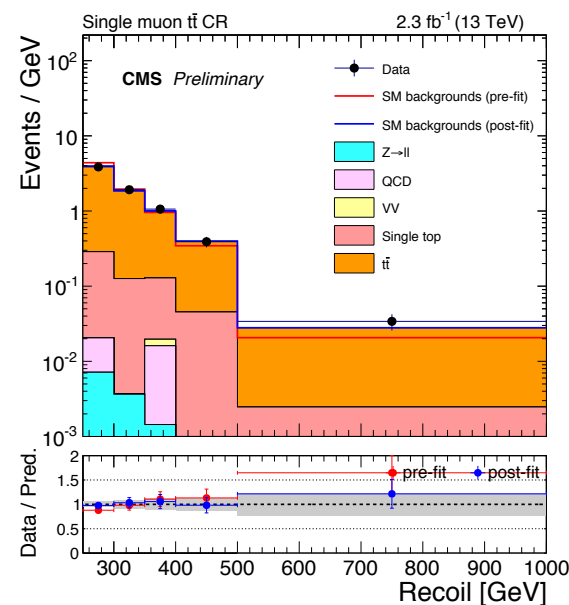
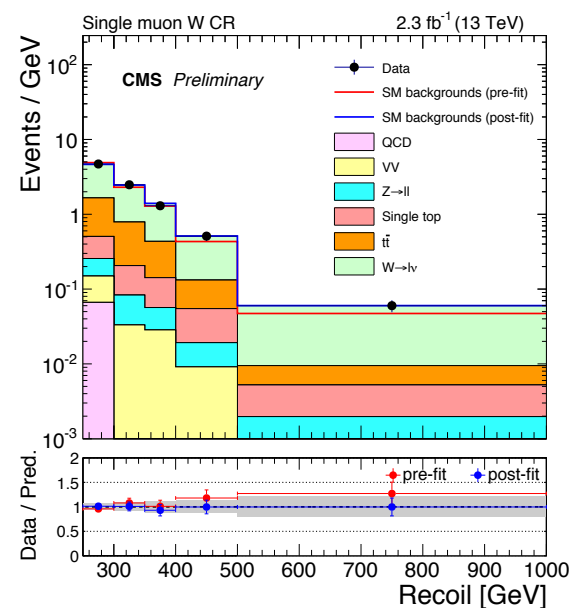
1. Select events



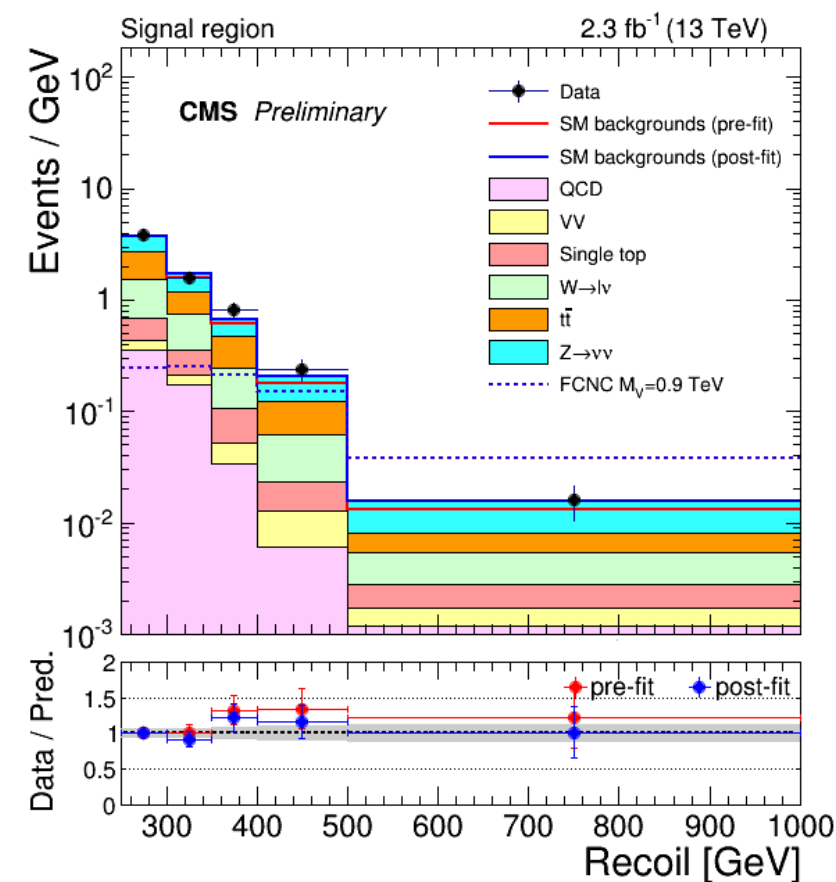
Large E_T^{miss}

“Tag” with recoiling object

2. Constrain backgrounds



3. Search high E_T^{miss}

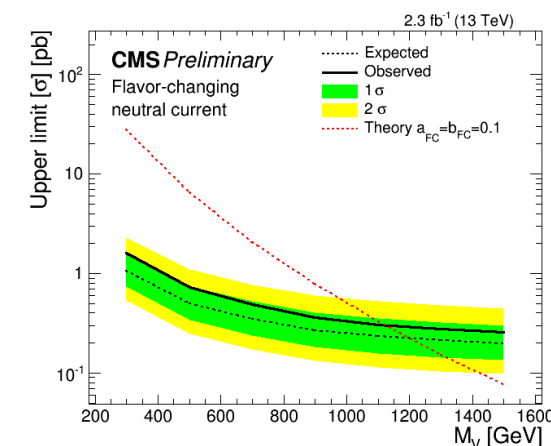


4. Find excess

5. ????

6. Profit!

OR 4.



CMS searches for dark matter

- Focus will be on 13 TeV (2015 dataset) preliminary results

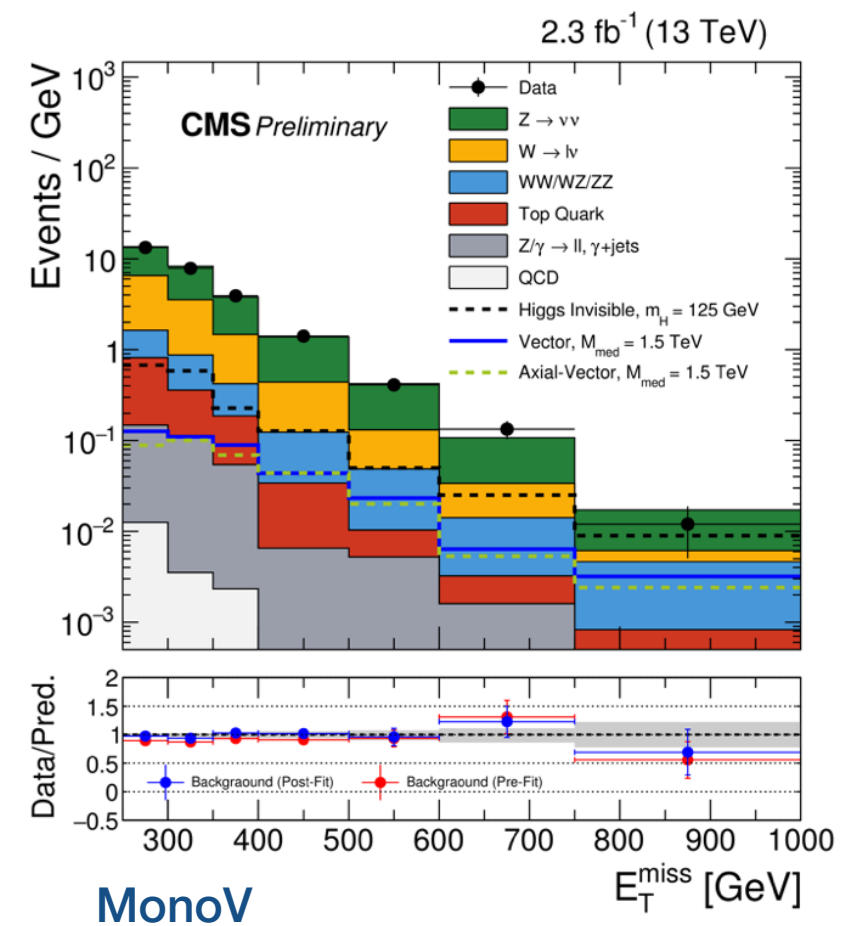
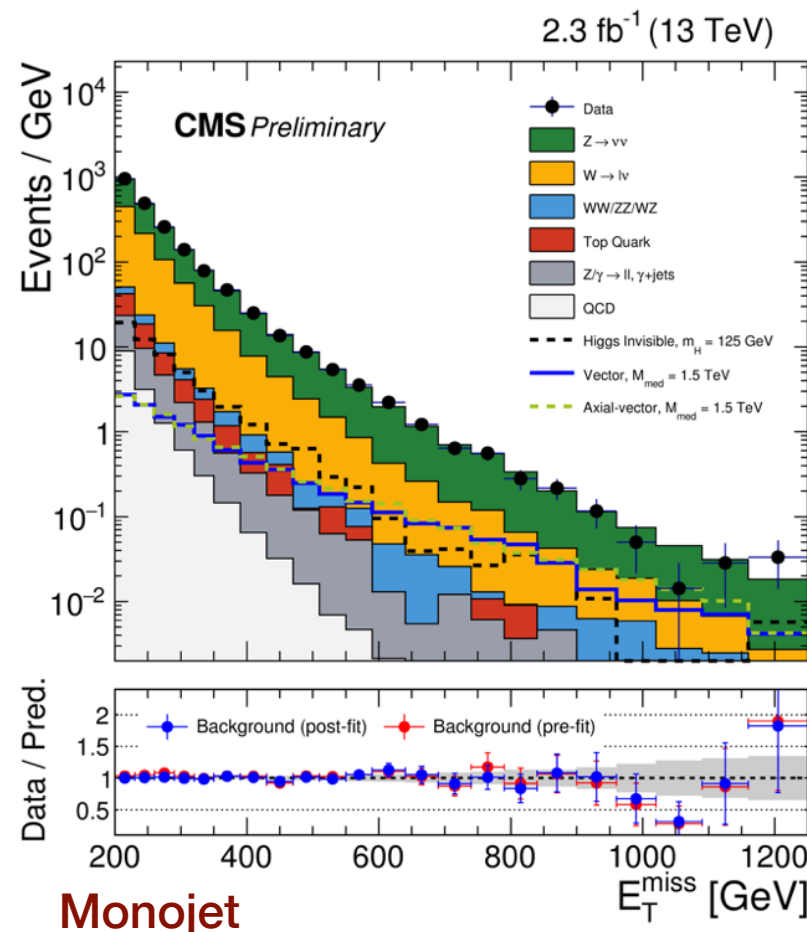
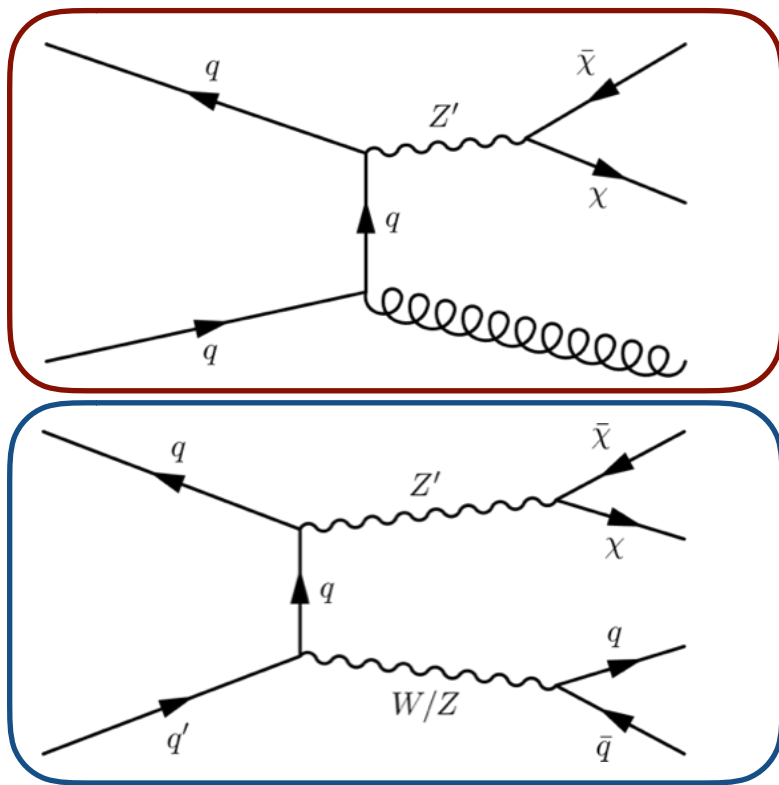
X	Dataset	CMS Doc	Available
Jets,W/Z(qq)	13 TeV, 2.3/fb	EXO-16-013	April 2016
γ	13 TeV, 2.3/fb	EXO-16-014	June 2016
bb	13 TeV, 2.2/fb	B2G-15-007	March 2016
t (hadronic)	13 TeV, 2.3/fb	EXO-16-017	June 2016

- Other CMS dark matter results

X	Dataset	CMS Doc	Published
Dijet	8 TeV, 20/fb	EXO-14-004	Submitted to JHEP
Z(l\bar{l})	8 TeV, 20/fb	EXO-12-054	PRD 93, 052011 (2016)
tt(l+jets)	8 TeV, 20/fb	B2G-14-004	JHEP 06 (2015) 121
t (hadronic)	8 TeV, 20/fb	EXO-12-022	PRL 114, 101801 (2015)
γ	8 TeV, 20/fb	EXO-12-047	PLB 755 (2016) 102
W(lν)	8 TeV, 20/fb	EXO-12-060	PRD 91, 092005 (2015)

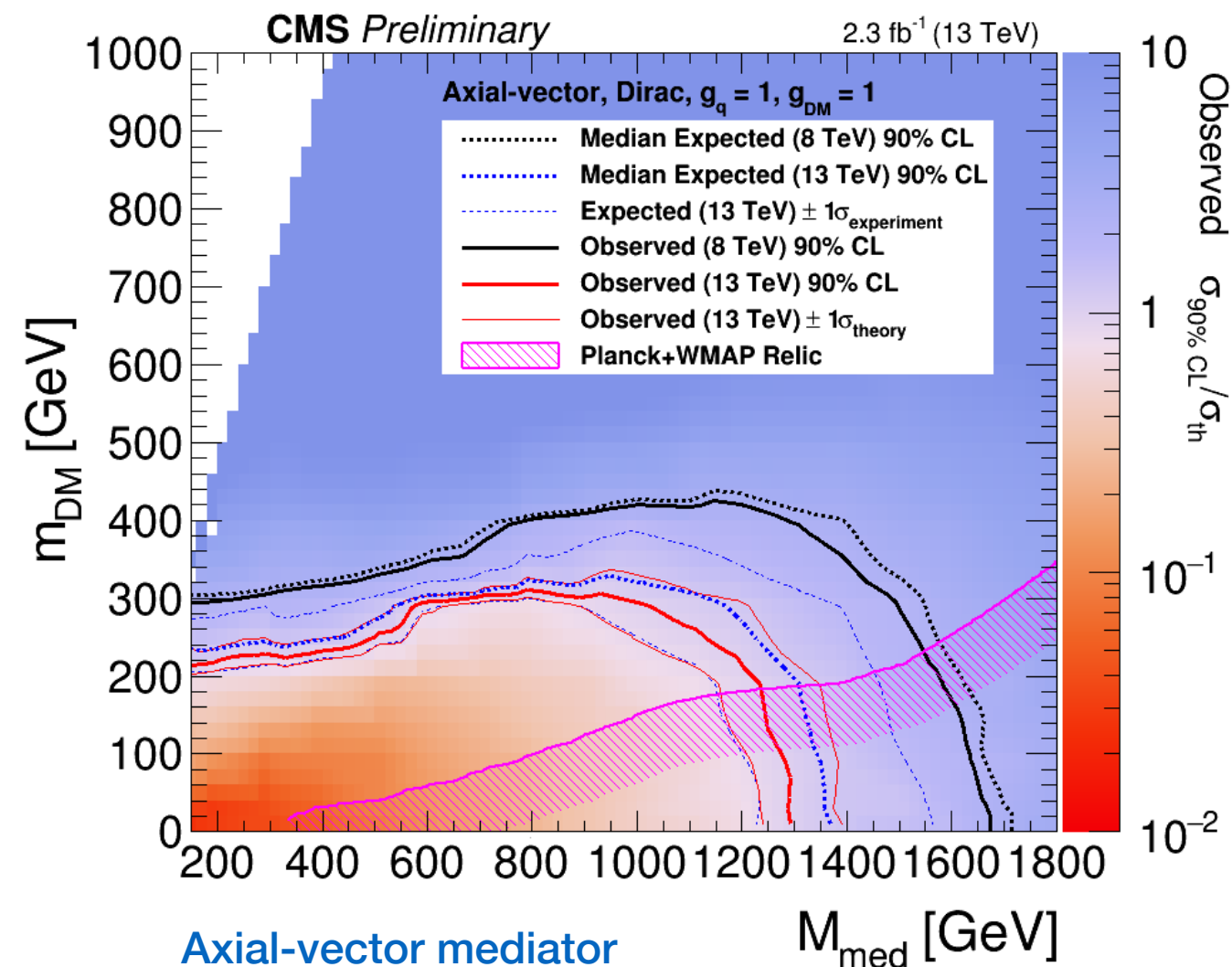
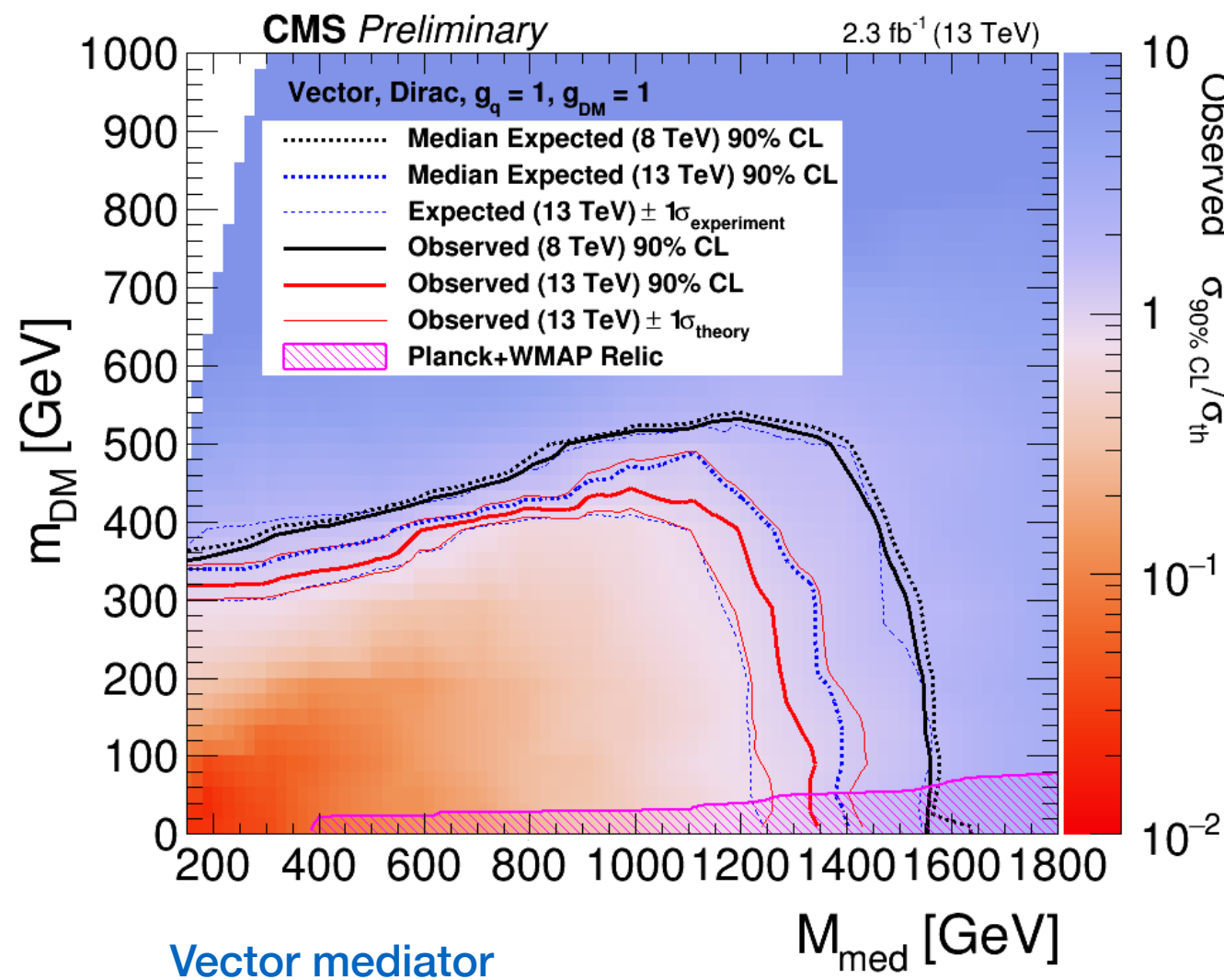
Mono-jet/jets/W/Z

- Search for large E_T^{miss} and ≥ 1 high- p_T jets
- Encompasses both **monojet** and **mono-W/Z** (decaying hadronically)
- After basic ID, separate into two categories for each
 - **Mono-V**: large-radius jets for highly boosted W/Z: $[E_T^{\text{miss}}, p_T^{j1}] > 250$ GeV
 - **Mono-jet**: remaining events with $E_T^{\text{miss}} > 200$ GeV, $p_T^{j1} > 100$ GeV
- Backgrounds dominated by $Z(\nu\nu)+\text{jets}$ and $W(l\nu)+\text{jets}$
 - Veto events with isolated leptons or b-tags
- Fit background and signal predictions to E_T^{miss} in data



Mono-jet/jets/W/Z: results

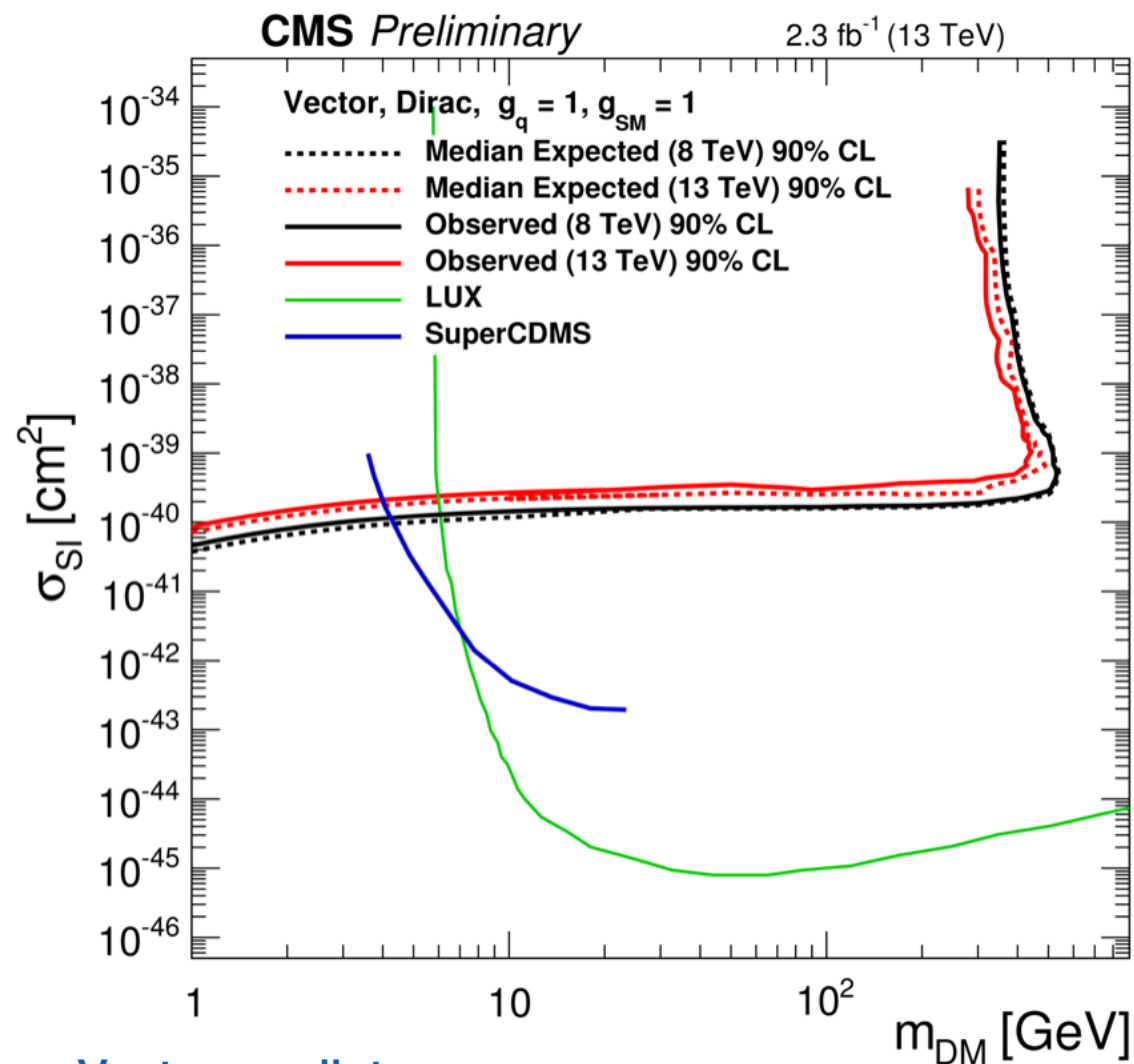
- No excess observed: set limits on cross section in simplified model
 - Fix $g_q = g_{DM} = 1$ (direct comparison with 8 TeV) and scan in M_{med} and m_χ
 - **$M_{med} > 1.3 \text{ TeV}$ @90%CL**



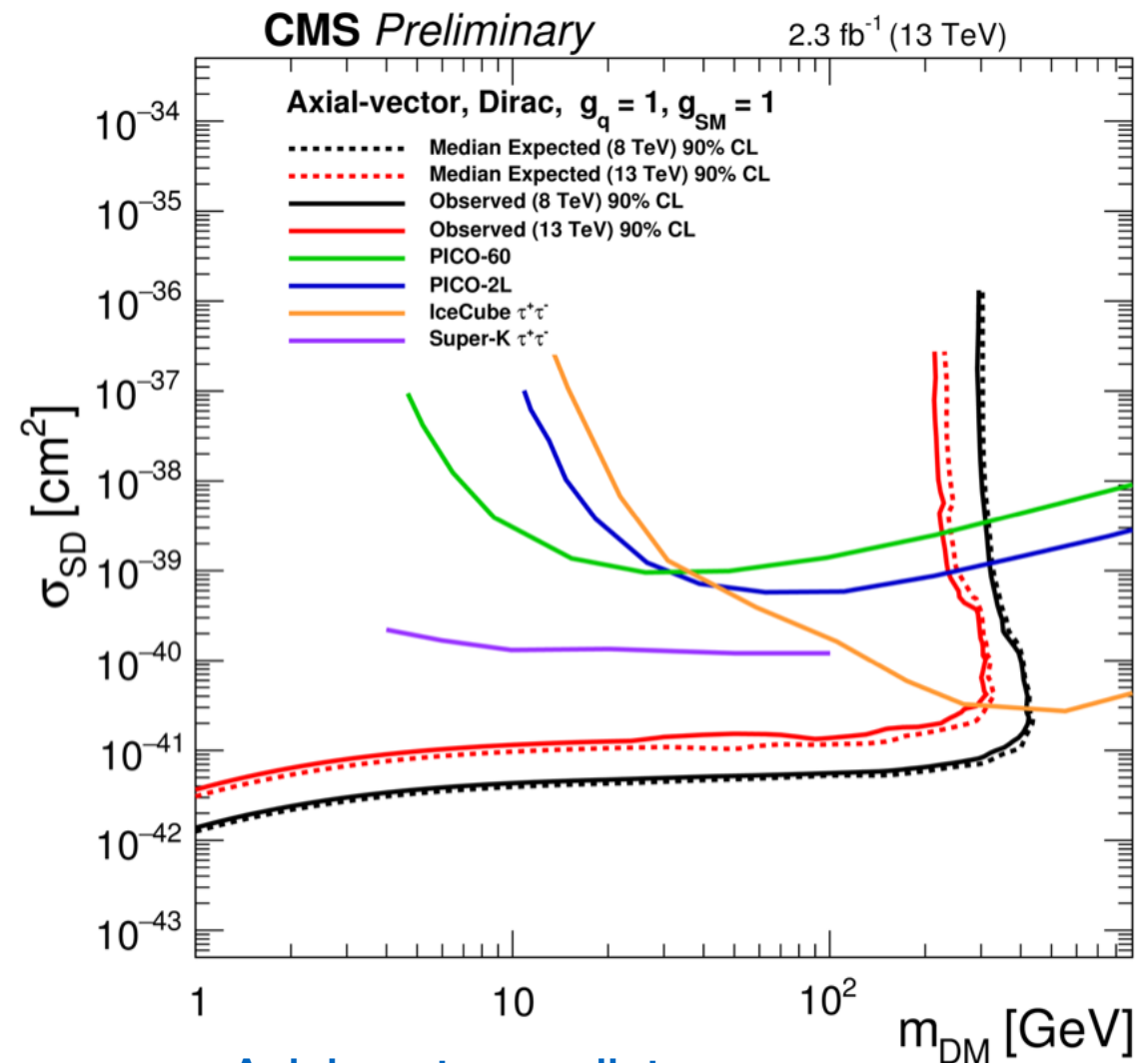
EXO-16-013

Mono-jet/jets/W/Z: interpretation

- Results can be recast in terms of nucleon-DM scattering cross section
- Compare to direct detection search limits



Vector mediator



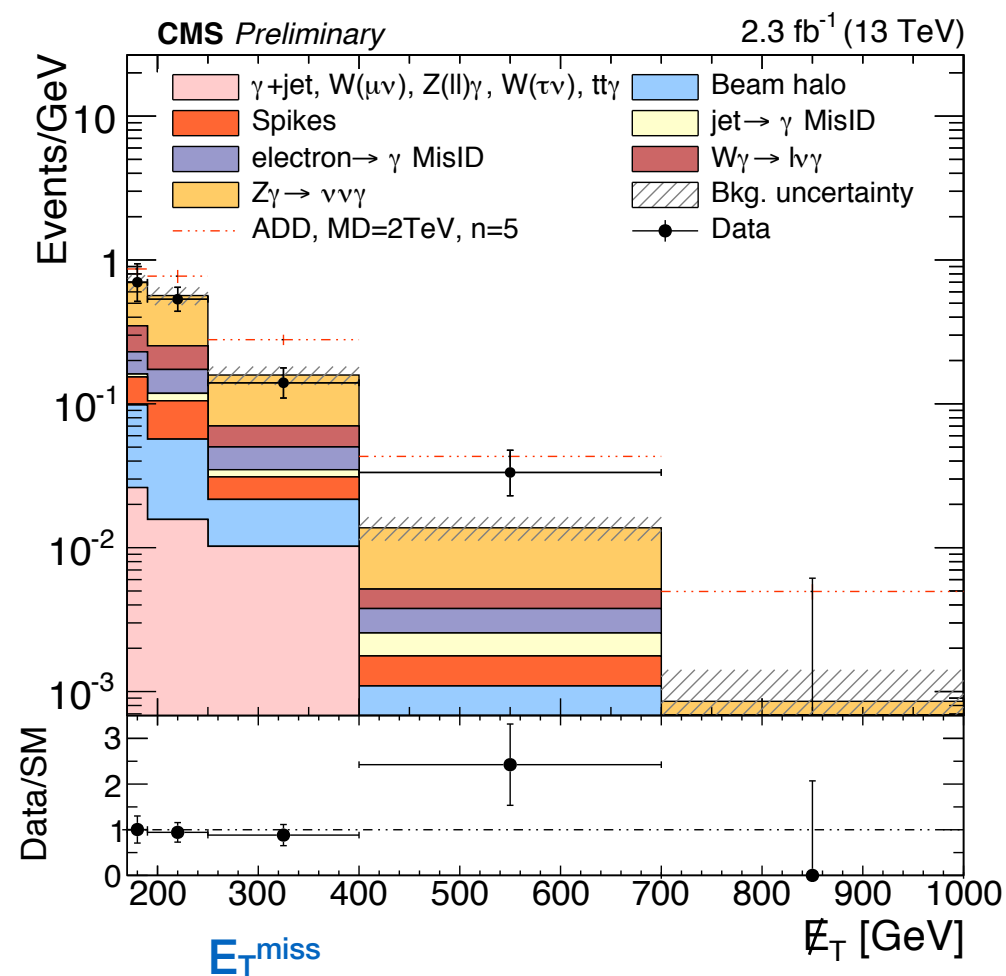
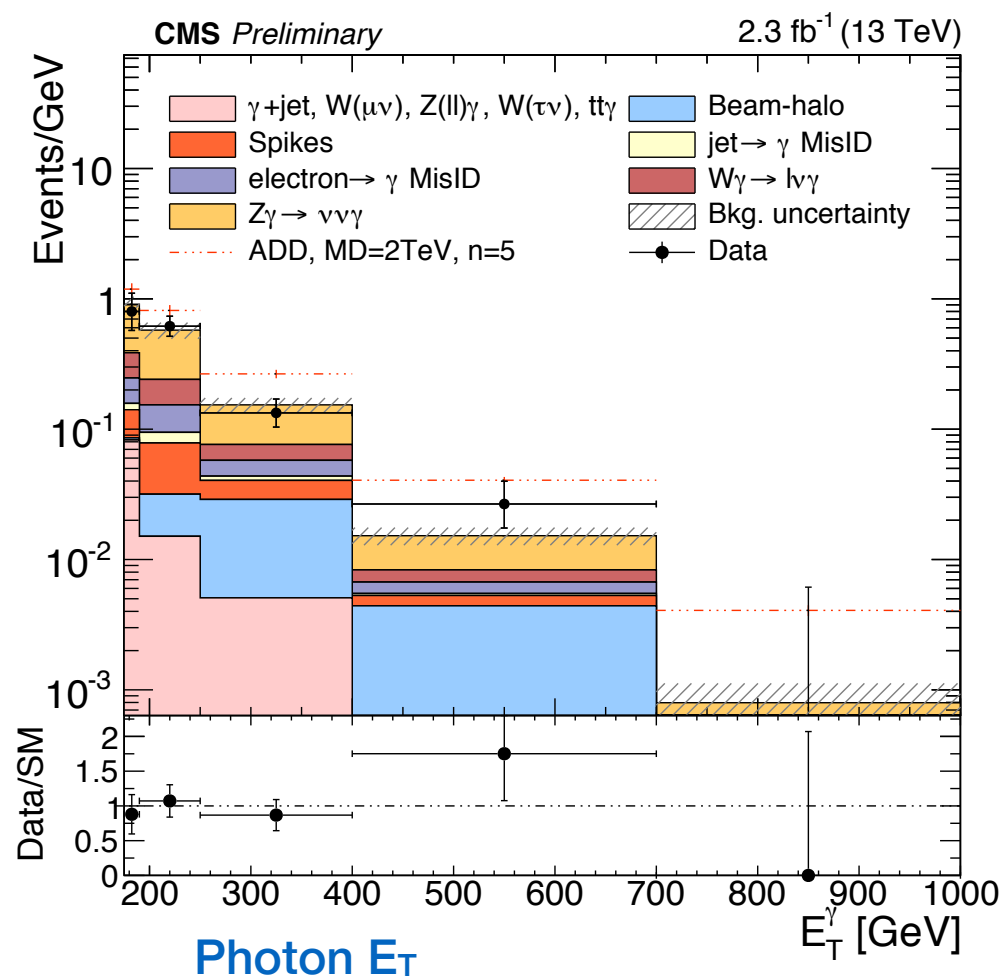
Axial-vector mediator

EXO-16-013

Monophoton

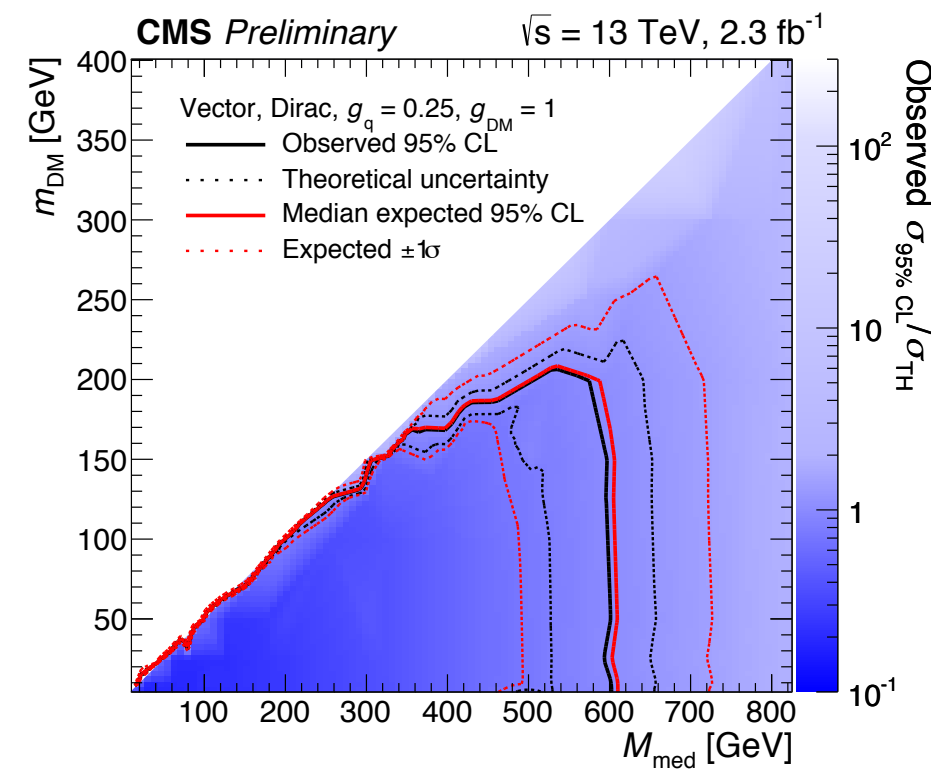


- Search for large E_T^{miss} and a photon
 - Dark matter production with an ISR photon
 - Large extra dimension models with graviton production and a recoiling photon
- Select events with one fiducial photon with $p_T > 175$ GeV and $E_T^{\text{miss}} > 170$ GeV
 - Angular separation between photon and E_T^{miss}
 - Primary background is $Z(\nu\nu)+\gamma$

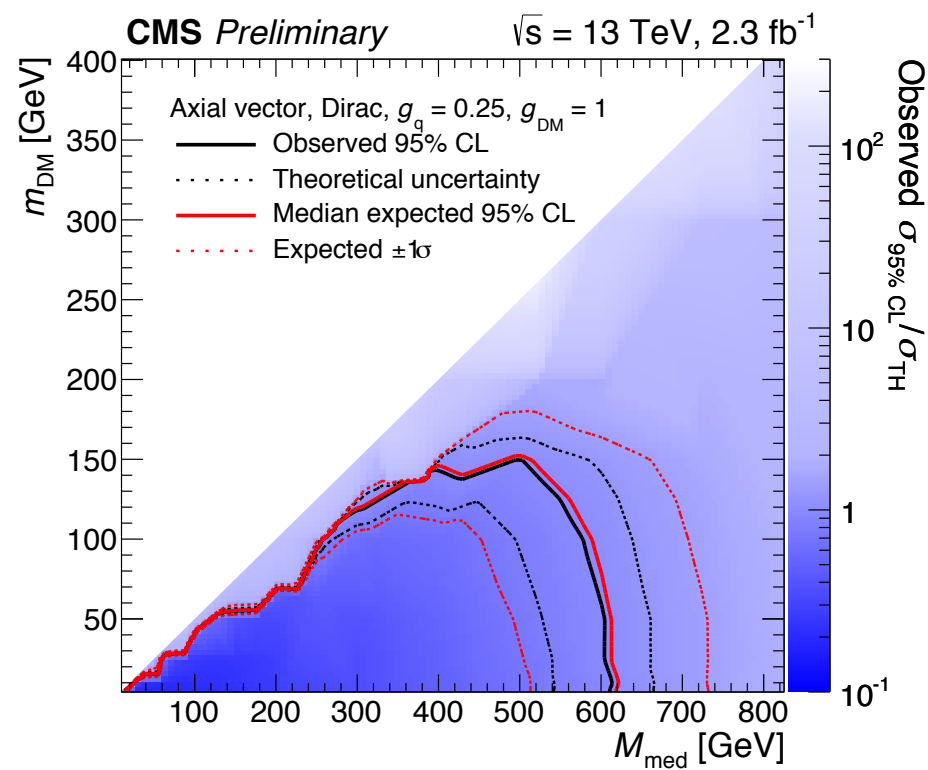


Monophoton results

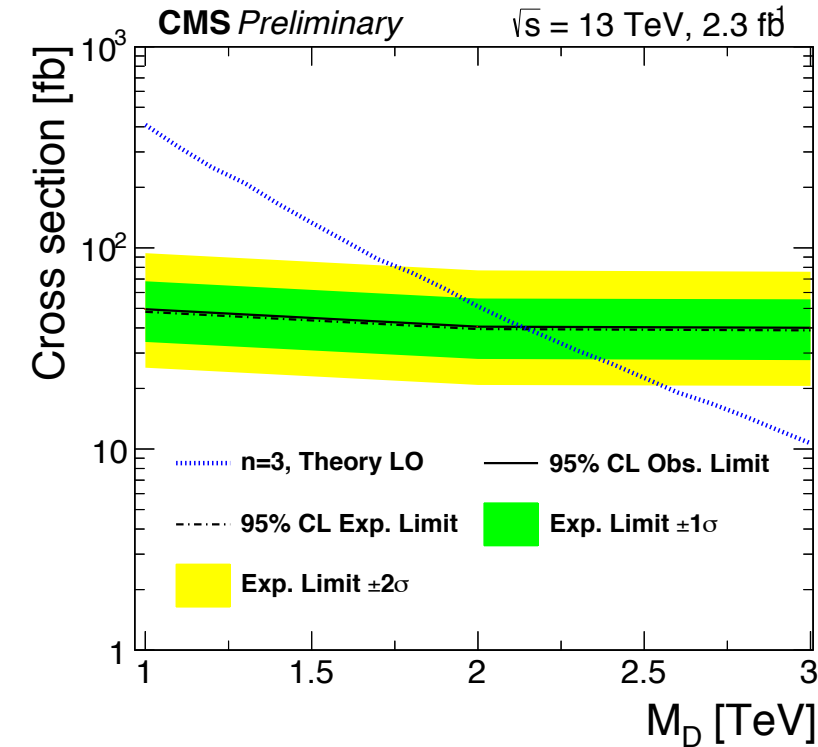
- No excess observed: set limits on cross section in simplified model
 - Fix $g_q = 0.25$, $g_{DM} = 1$ and scan in M_{med} and m_χ
 - **$M_{med} > 600 \text{ GeV}$ @95%CL**
- Place limits on EFT model with contact interaction of type $\gamma\gamma X$
 - Suppression scale $\Lambda > 542 \text{ GeV}$ @95%CL
- Exclude ADD Graviton production up to 2.35 TeV for $n=6$



Vector mediator



Axial-vector mediator

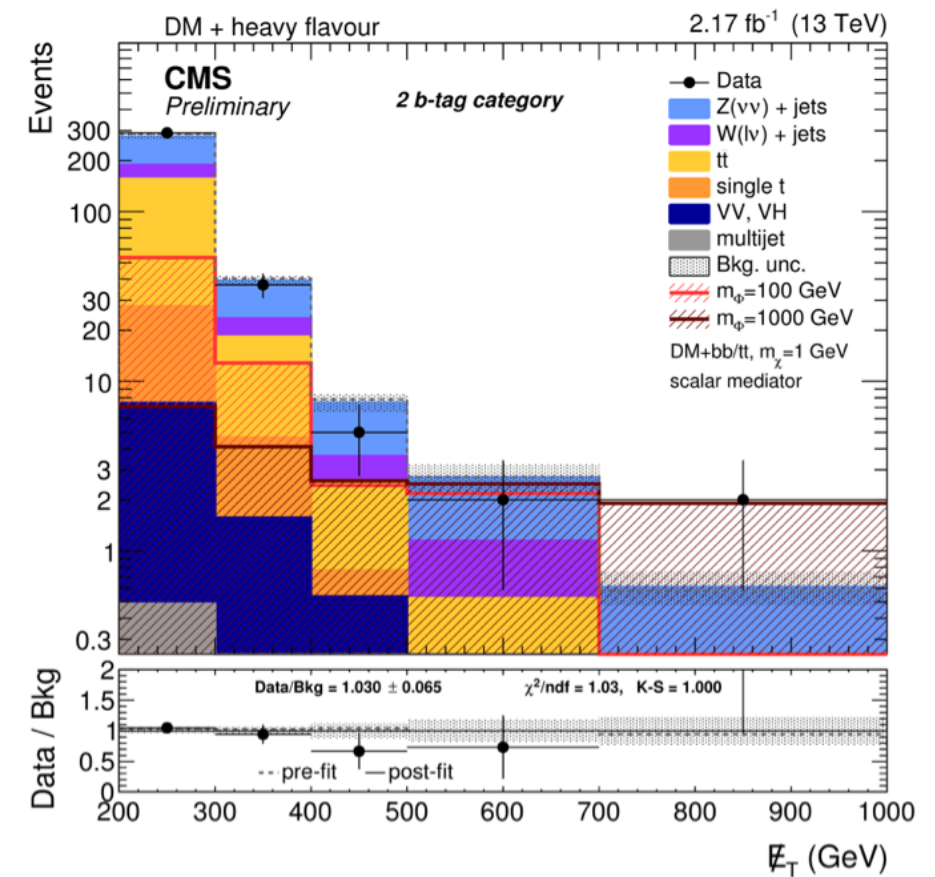
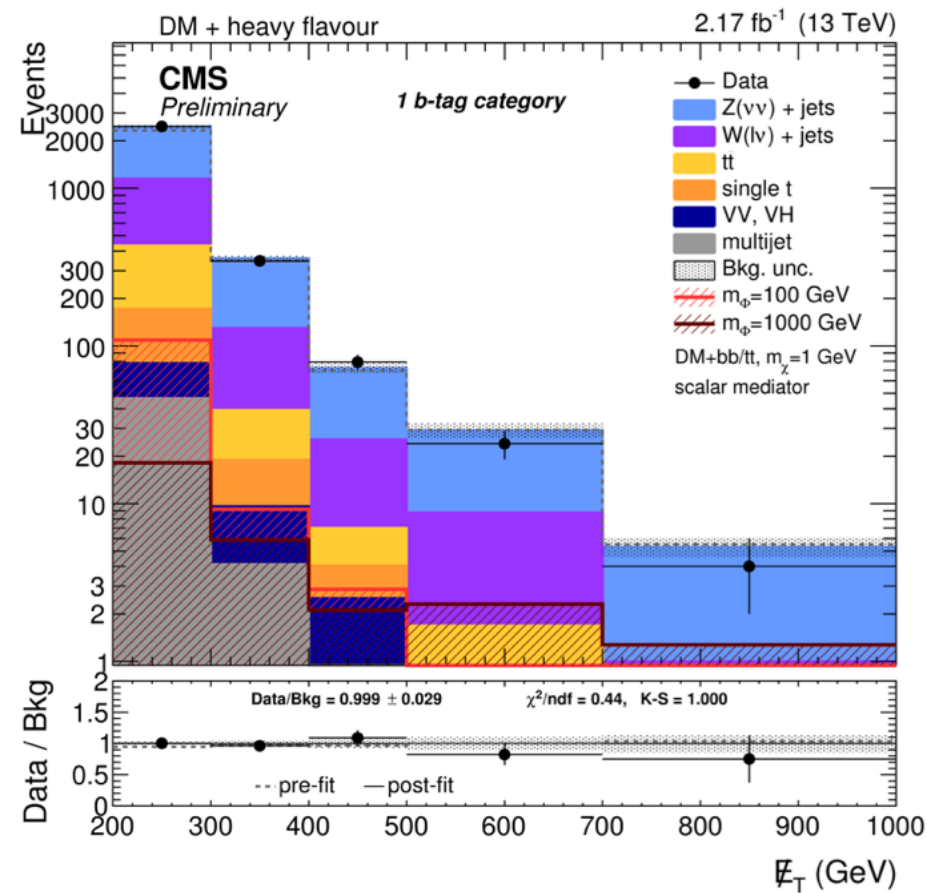
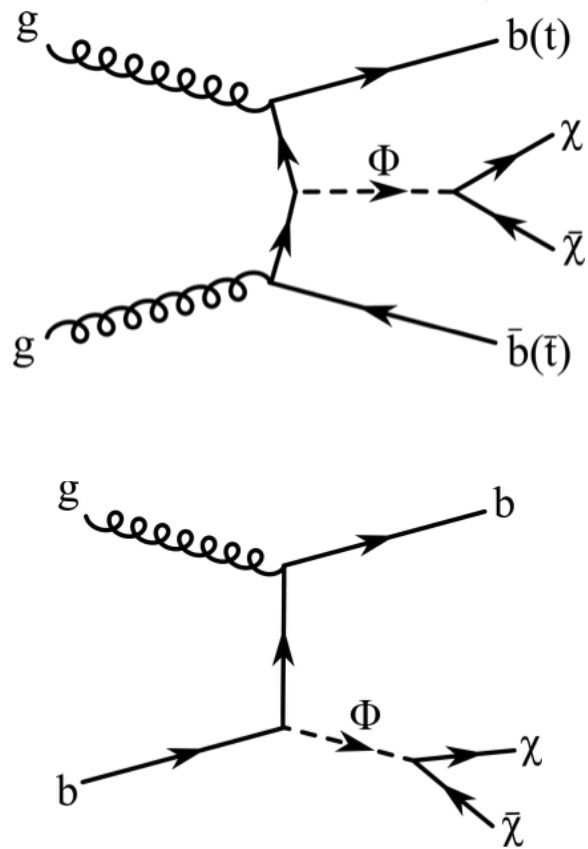


ADD Graviton

EXO-16-014
New

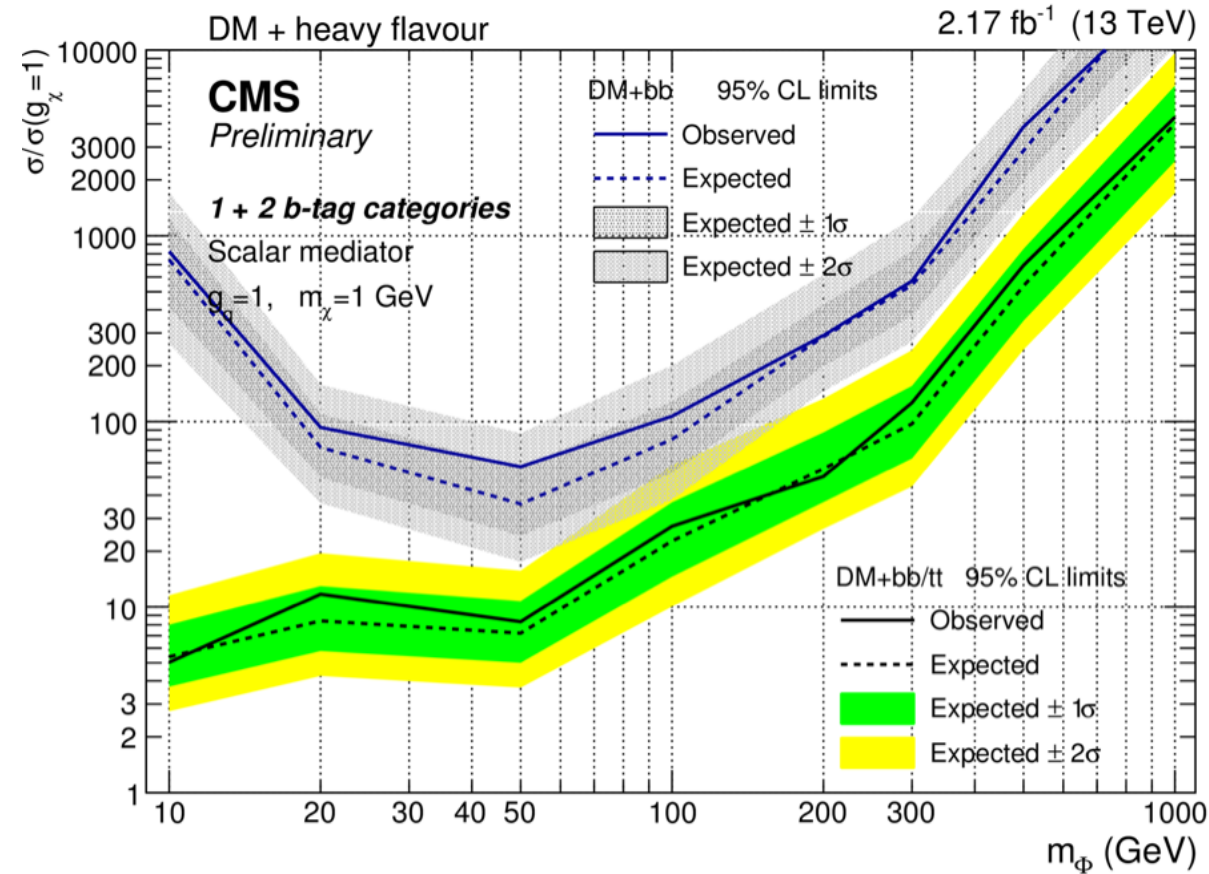
DM+b/bb/tt

- Search for DM recoiling against jets with b quarks
 - Sensitive to tt+DM production as well
- 1-tag: $E_T^{\text{miss}} > 200$ GeV, tagged jet $p_T > 50$ GeV, up to 1 additional jet
- 2-tag: $E_T^{\text{miss}} > 200$ GeV, two tagged jets $p_T > 50$ GeV, up to 1 additional jet
 - Recovers efficiency of tt+DM
- In both cases, veto events with isolated leptons

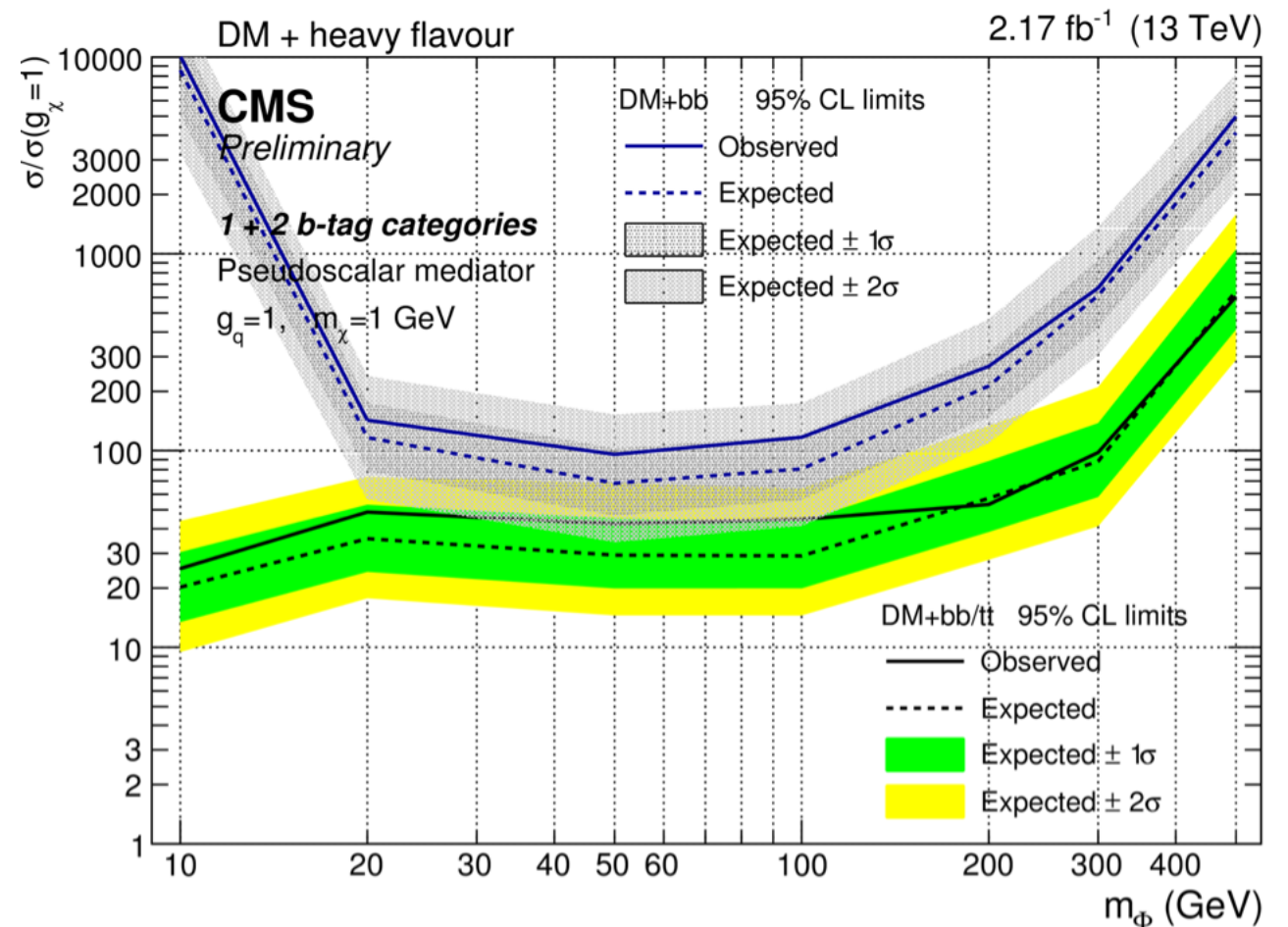


DM+bb/tt results

- No excess seen: set limits combining both tag categories
- Interpret as a function of scalar and pseudoscalar mediator masses
 - Fix $m_\chi = 1$ GeV



Scalar mediator

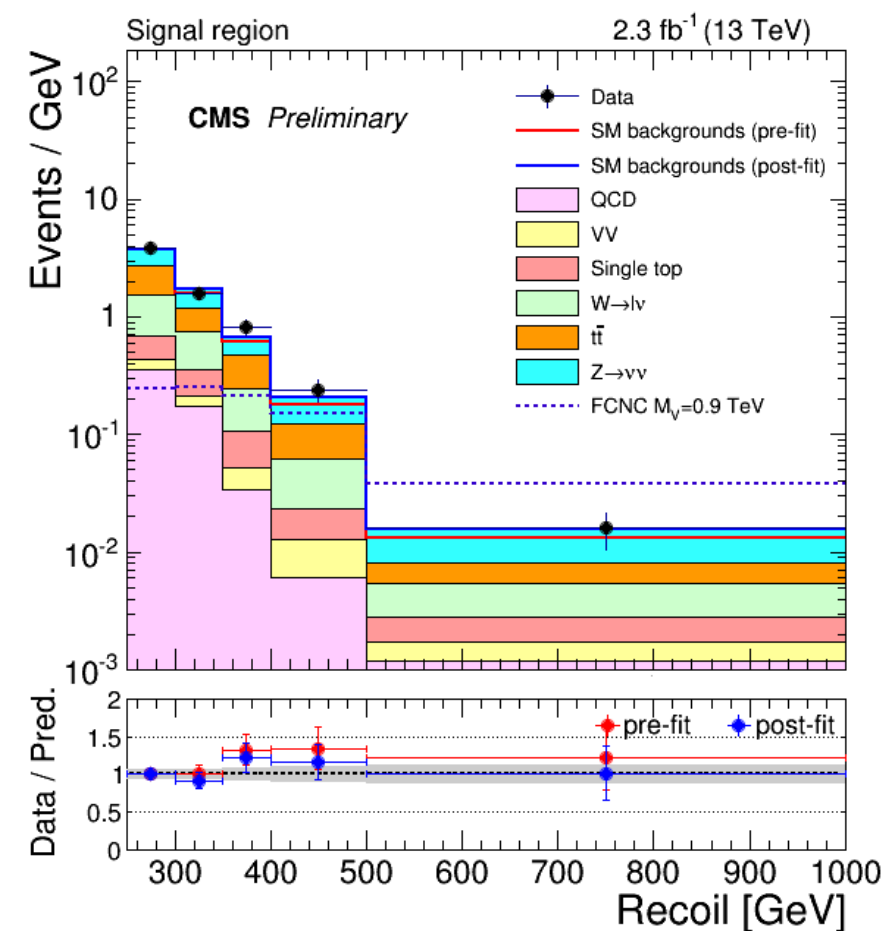
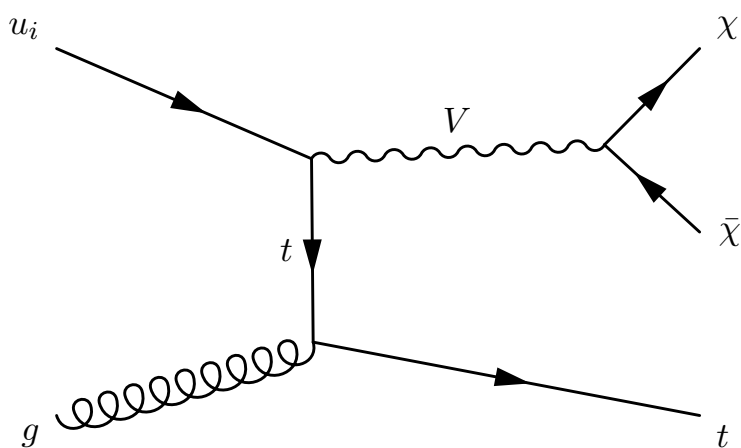


Pseudoscalar mediator

Monotop

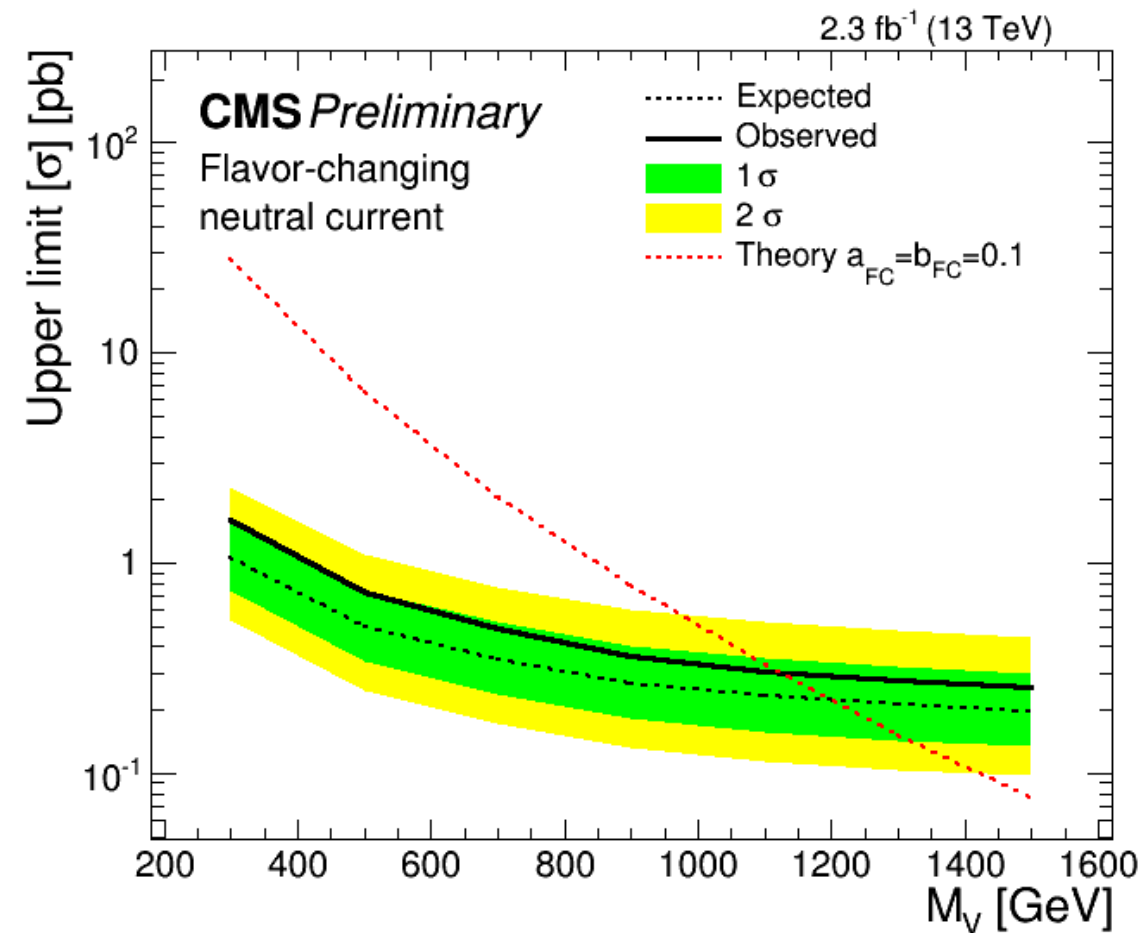


- Search for single top quark and large E_T^{miss}
 - Sensitive to models producing DM+top via FCNC
 - Analogous to monojet but with FCNC
- Select events with $E_T^{\text{miss}} > 250$ GeV
 - Top decay products in boosted events merged into “fat jet”, $p_T > 250$ GeV
 - b-tagged subjet, Jet mass: $[110, 210]$ GeV, and τ_3/τ_2 to ID top quarks
 - Veto leptons and additional b-tags
- Dominant backgrounds are V+jets and $t\bar{t}$



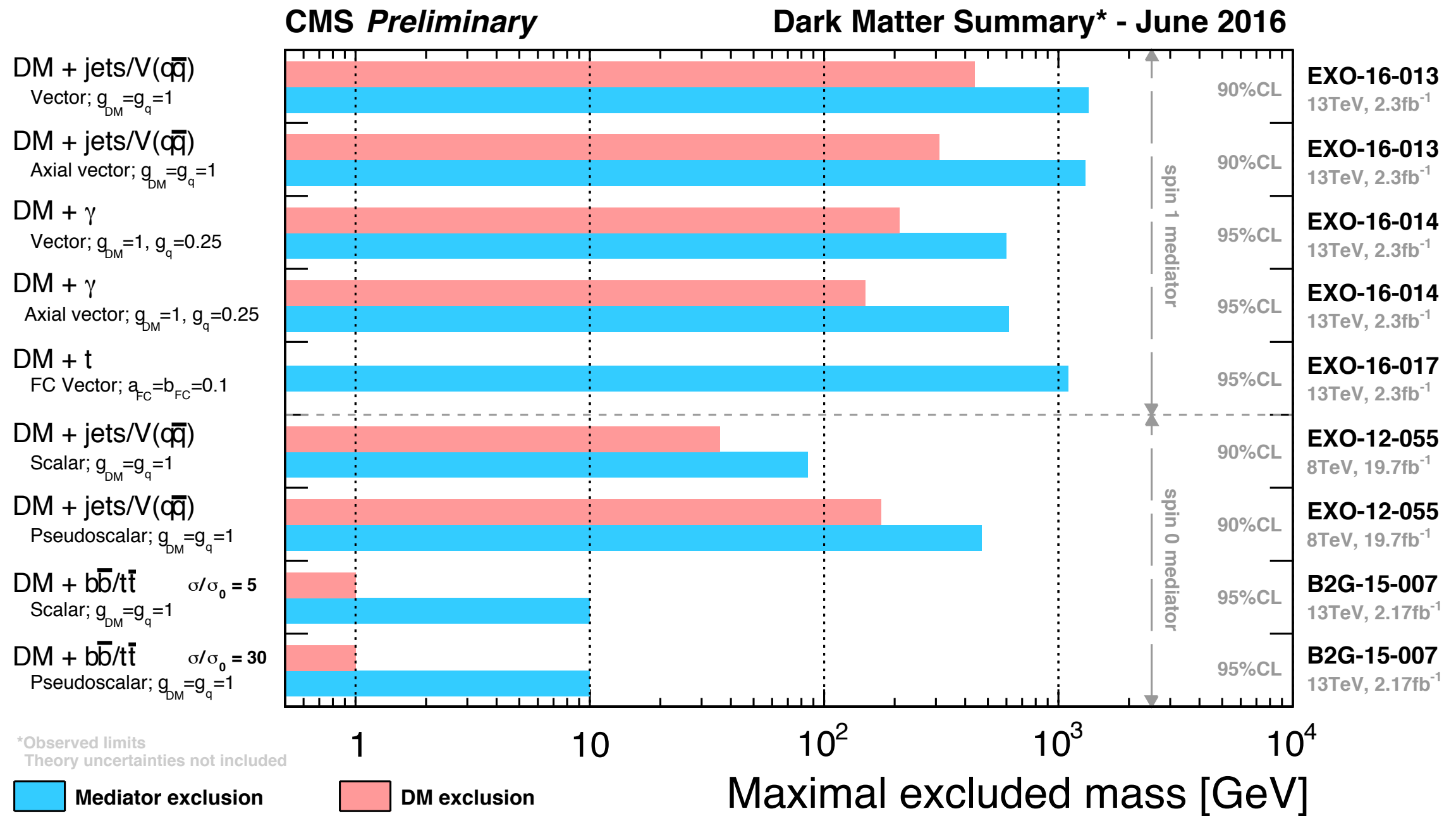
Monotop results

- No excess seen: set limits on FCNC model
 - Exclude mediator masses up to **1.1 TeV @95%CL**
 - Evaluated for $a_{FC}=b_{FC}=0.1$ (roughly $g_{SM}=0.1$, $g_{DM}=1$), $m_\chi=100$ GeV
 - Extends previous monotop limits



EXO-16-017
New

CMS dark matter search summary

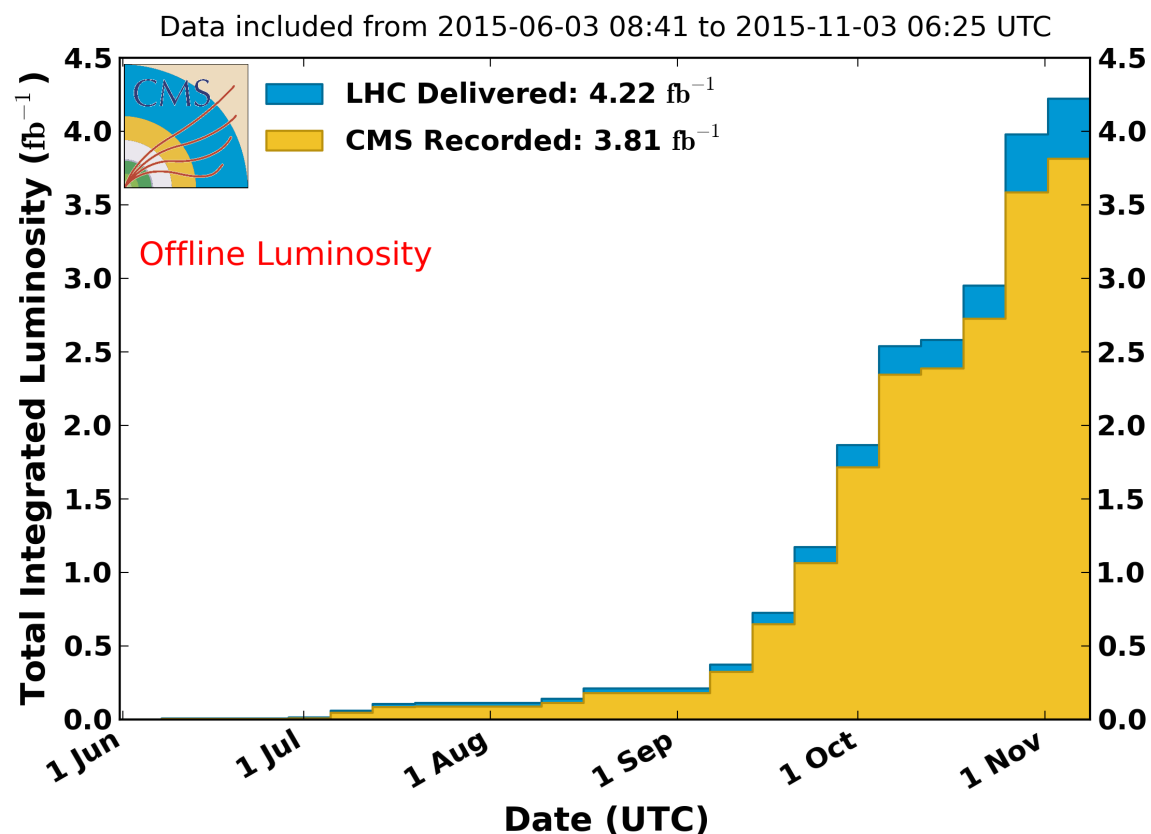


Conclusions

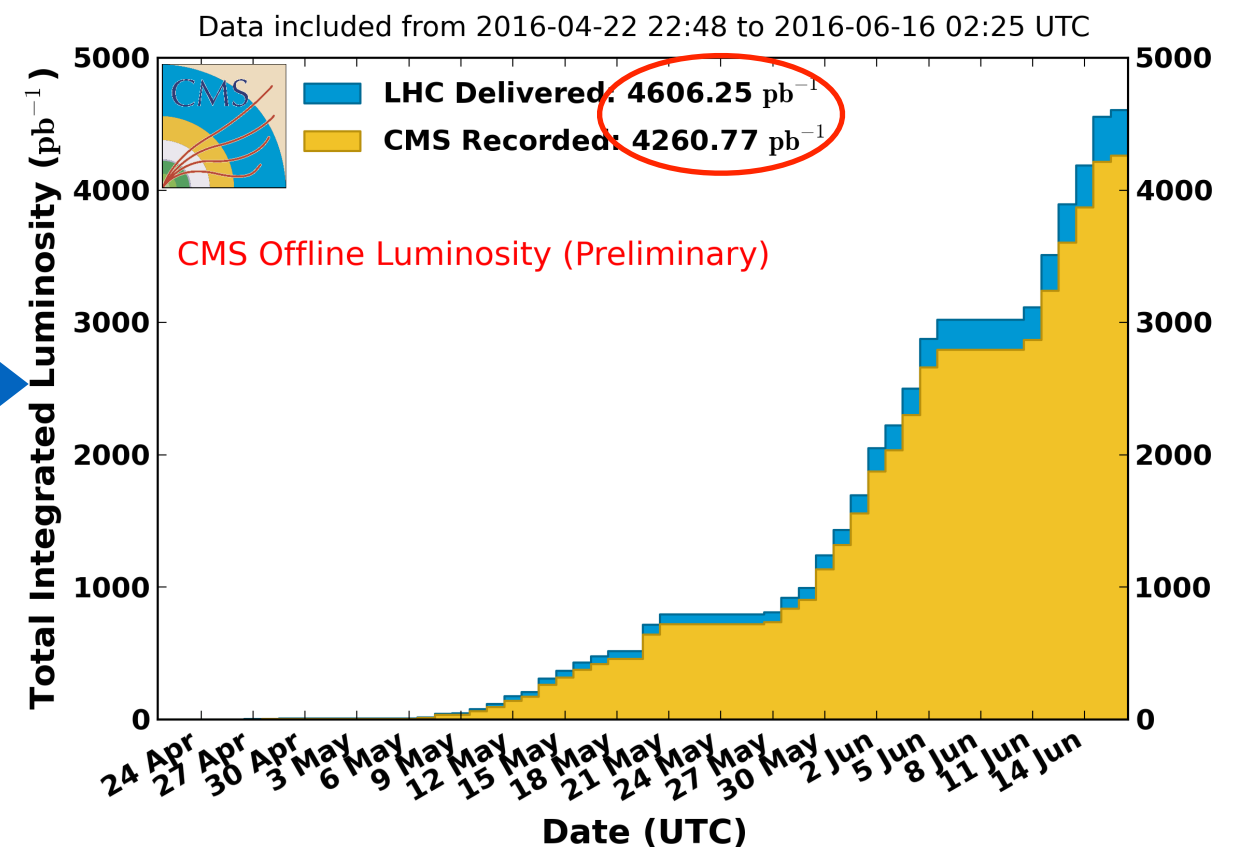


- CMS dark matter searches aim to leave no (collider-based) stone unturned
- Standardized interpretation scheme and models
 - Allows for straightforward comparison of results between experiments
 - Interpretations that compare to direct searches
- First set of Run 2 results now available
 - No signs of excess yet
 - Expect further results (including with 2016 data) in the coming months

CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV



CMS Integrated Luminosity, pp, 2016, $\sqrt{s} = 13$ TeV



Backup

Monophoton: interpretation

