Searches for Dark Matter With CMS

SUSY-17: 25th International Conference on SUSY and Unification of Fundamental Interactions

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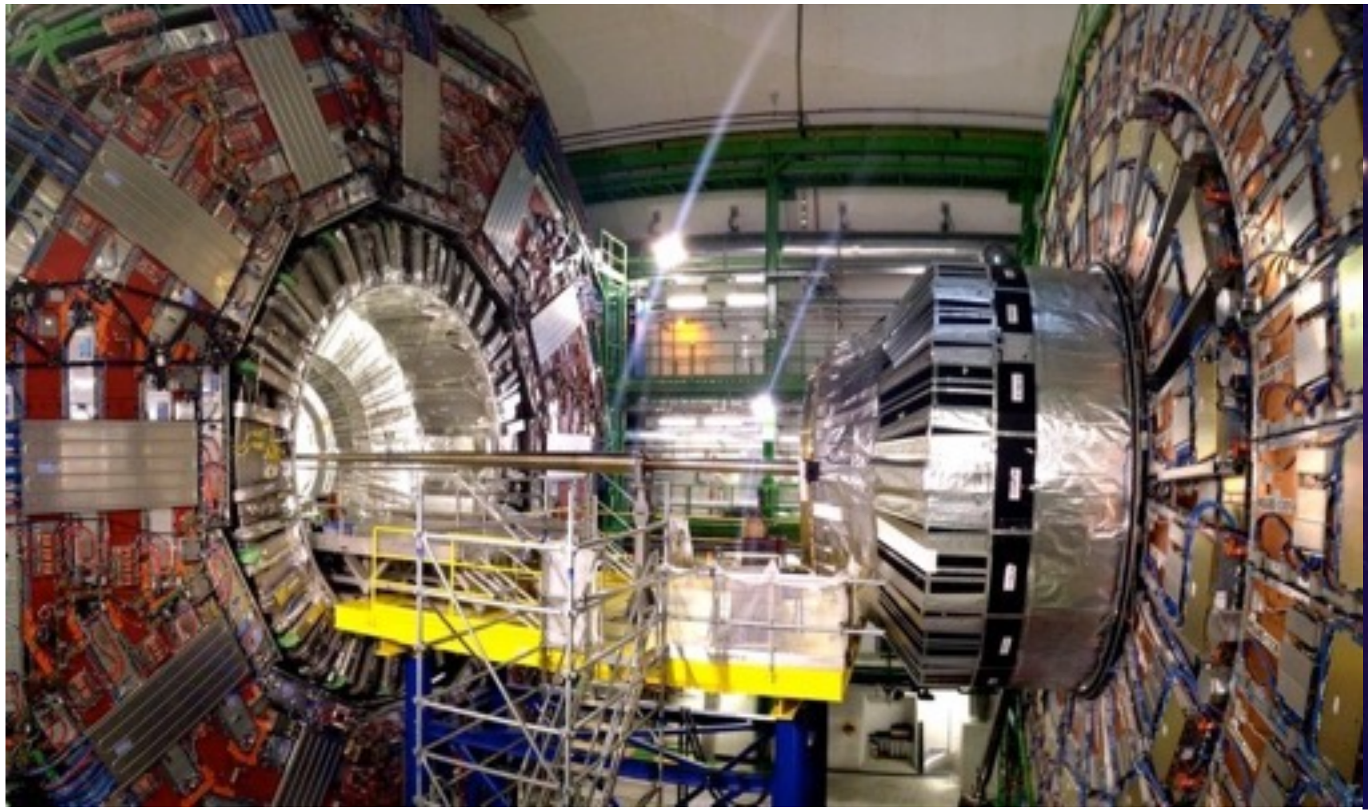
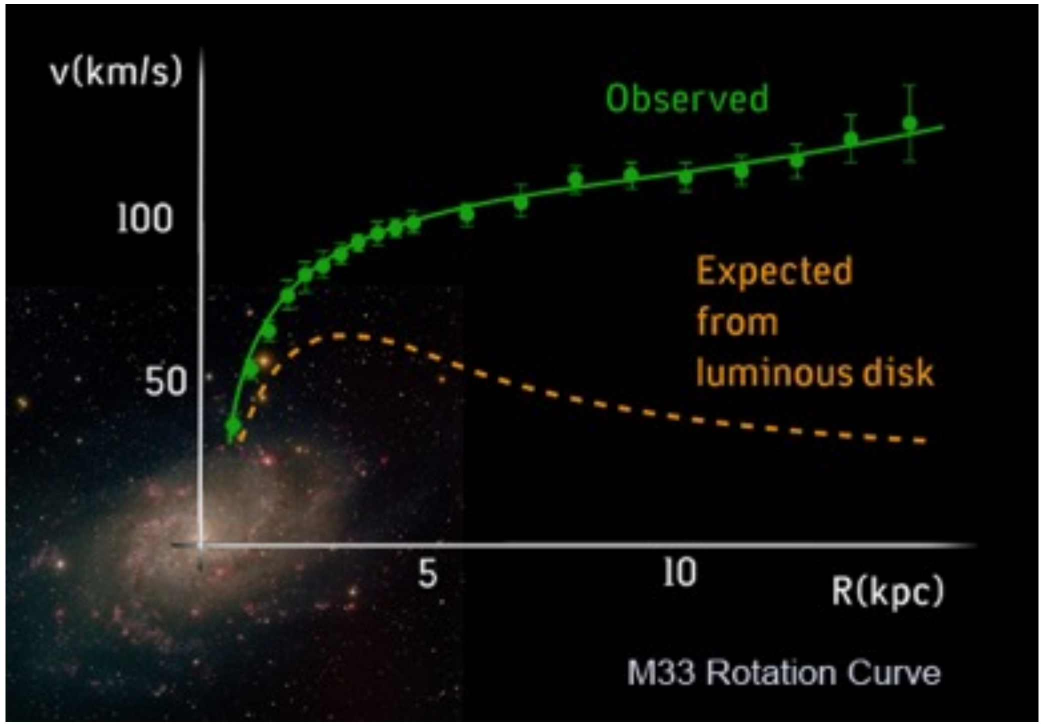
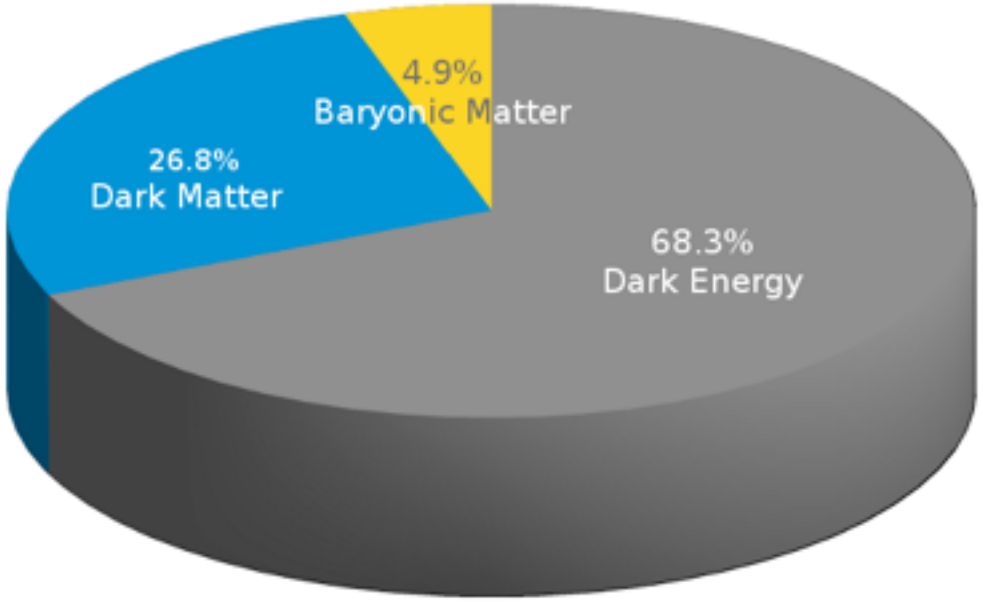


Search for Dark Matter(DM)

- Strong astrophysical evidence for the existences of dark matter (rotation curve, CMBR, gravitational lensing)
  - Nature of DM is still unknown
  - No direct observation yet



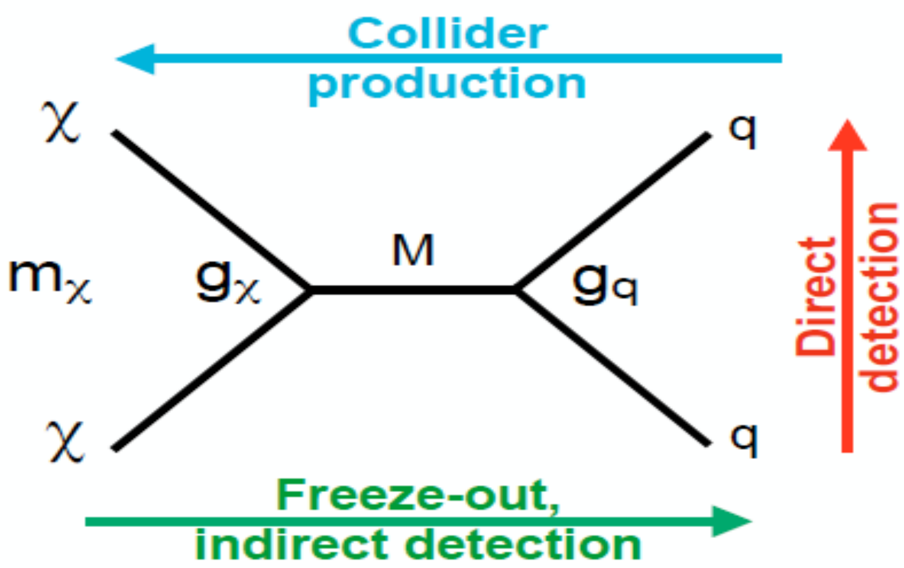
- LHC a prime lab for production of DM in pp collision
  - Can probe a variety of DM/SM interactions

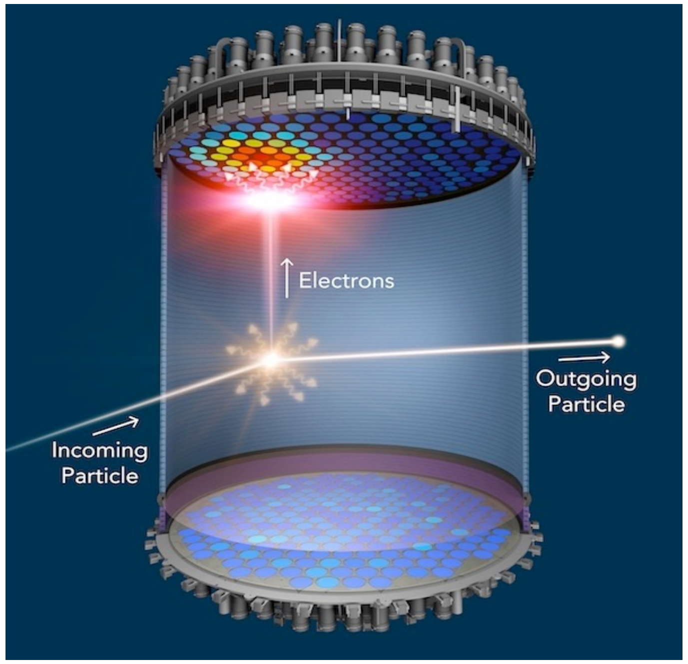


DM Production and Detection

Focus of this talk ⇒

LHC





LUX, PANDAX, CDMS

PAMELA, AMS

DM Production & Run-2 Searches

- **Simplified models (ATLAS-CMS DM forum) to interpret results**
  - DM particle is Dirac fermion
  - Pair produced via massive mediators (vector, axial-vector, scalar, pseudoscalars)
  - Minimal set of parameters: M_{DM}, M_{MED}, g_q, g_{DM}
  - Mediator has minimal decay width

- **$\sqrt{s}$=13 TeV Searches at the CMS**

Presented in this talk

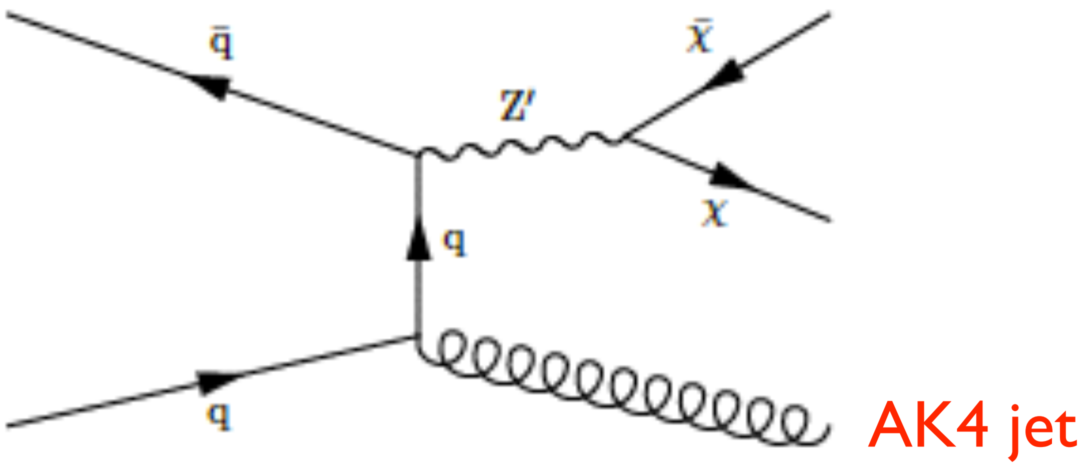
Final State	Dataset	CMS Documents
H(γγ)+MET	2016, 35.9 fb^{-1}	EXO-16-054
Z(ll)+MET	2016, 35.9 fb^{-1}	EXO-16-052
top(hadronic)+MET	2016, 35.8 fb^{-1}	EXO-16-051
Photon+MET	2016, 12.9 fb^{-1}	EXO-16-039
Jet or V (hadronic)+MET	2016, 35.9 fb^{-1}	EXO-16-048
top pair+MET	2015, 2.2 fb^{-1}	EXO-16-005
Interpretations in terms of DM Simplified Model		
Dijet Search	2016, 35.9 fb^{-1}	EXO-17-001, EXO-16-056
Dijet Angular Distribution	2016, 35.9 fb^{-1}	EXO-16-046
tt(ll)+MET	2016, 35.9 fb^{-1}	SUS-17-001

Mono-Jet/V: Event Selection

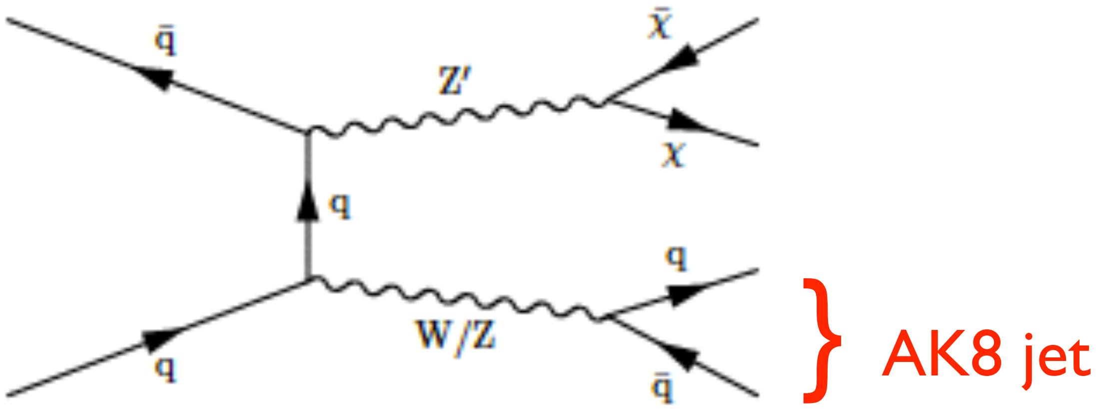
- **Look for high P_T jet and large missing transverse energy (MET)**

- **Trigger:**
  - MET

- **Mono-jet**
  - MET > 250 GeV
  - $P_T^{leading}$ (AK4-jet) > 100 GeV



- **Mono-V**
  - MET > 250 GeV
  - $P_T^{leading}$(AK8-jet) > 250 GeV
  - N-subjetiness < 0.6
  - Mass: 65-105 GeV



EXO-16-048

Mono-Jet/V: Background

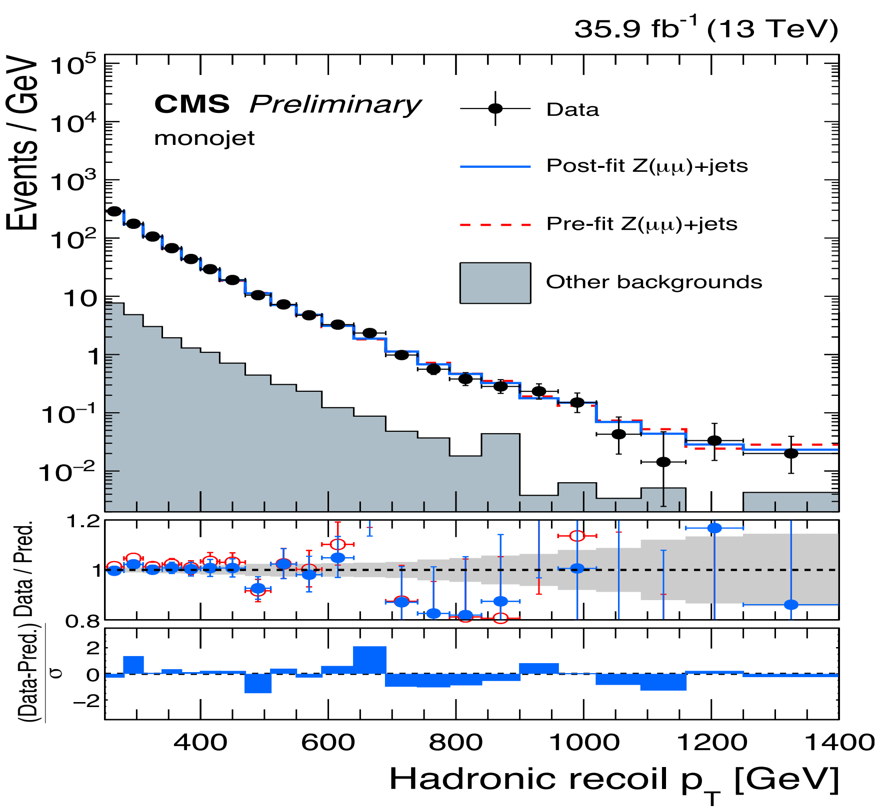
- Main backgrounds:
  - $Z(\nu\nu)$+Jets (60%)
  - W+Jets (30%)

- Background are estimated from simultaneous fit of five mutually exclusive control data samples with signal region
  - $Z(\mu\mu)$+Jets, $Z(ee)$+Jets,
  - $W(\mu\nu)$+Jets, $W(e\nu)$+Jets
  - and γ+Jets

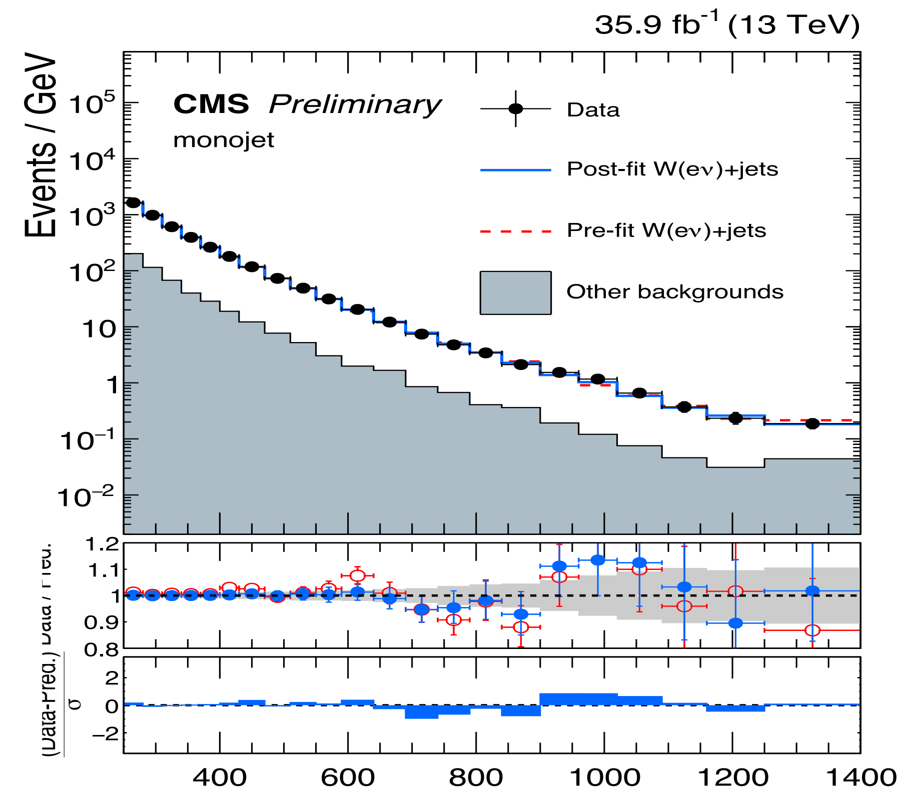
- Recent improvements on theoretical uncertainty (arXiv:1705.04664)

- **Transfer factor are used for extrapolation from control regions to signal regions**
  - **Rely on theory prediction of the ratio of V+jet cross sections**

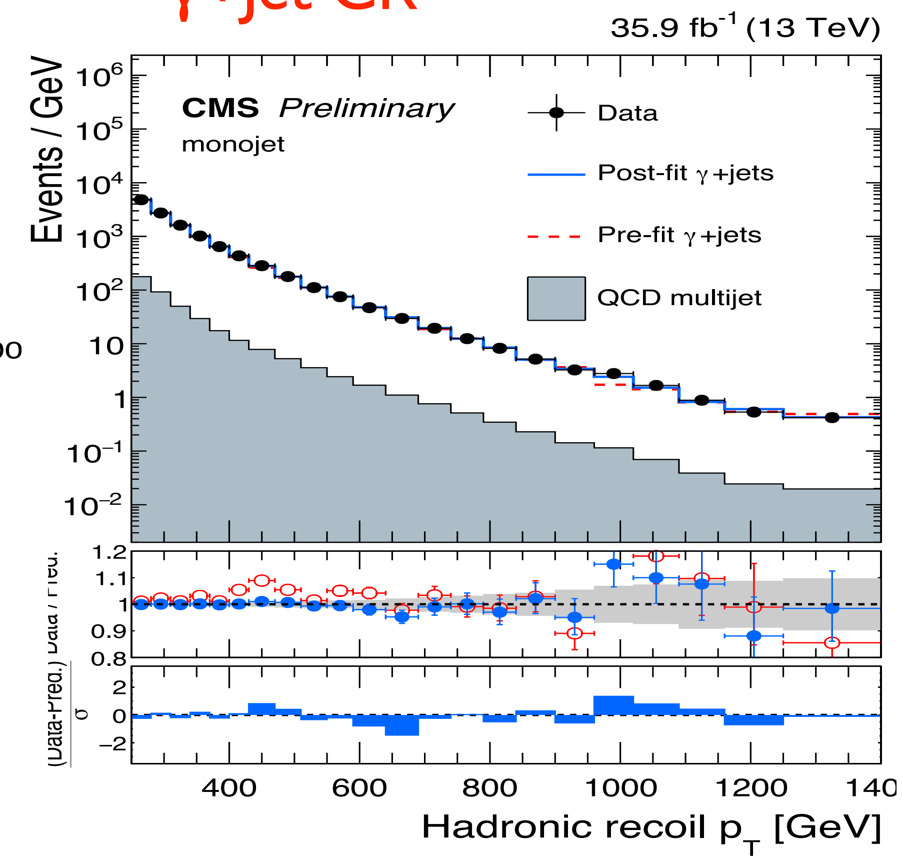
Mono-Jet/V: Background

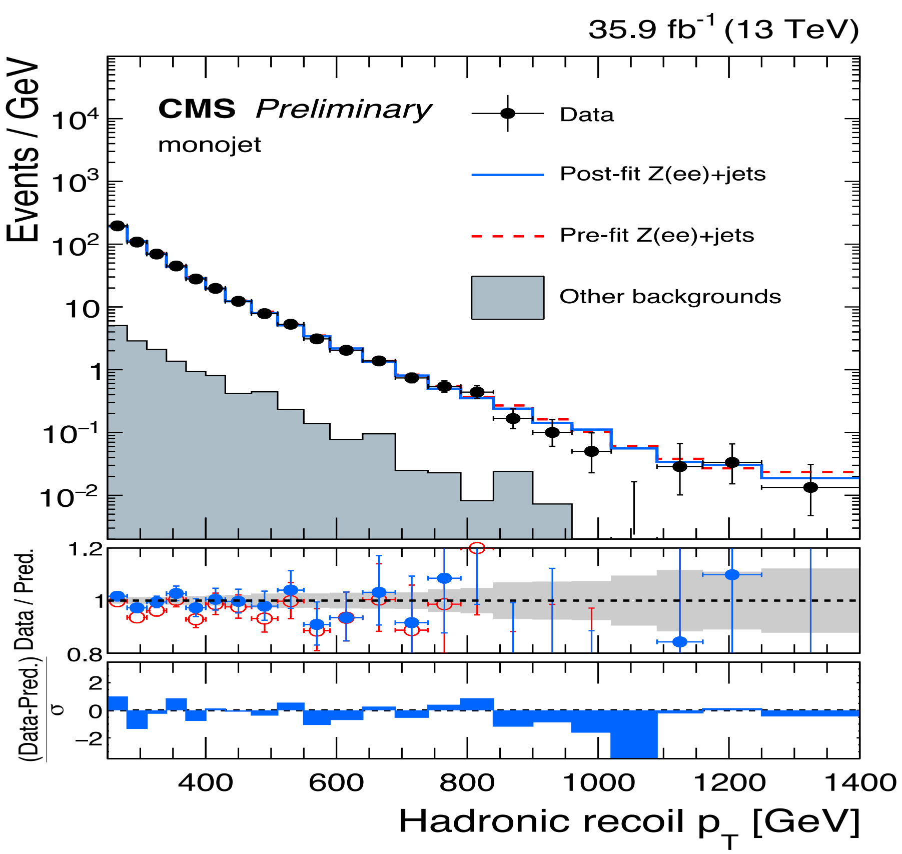


W+Jet CR

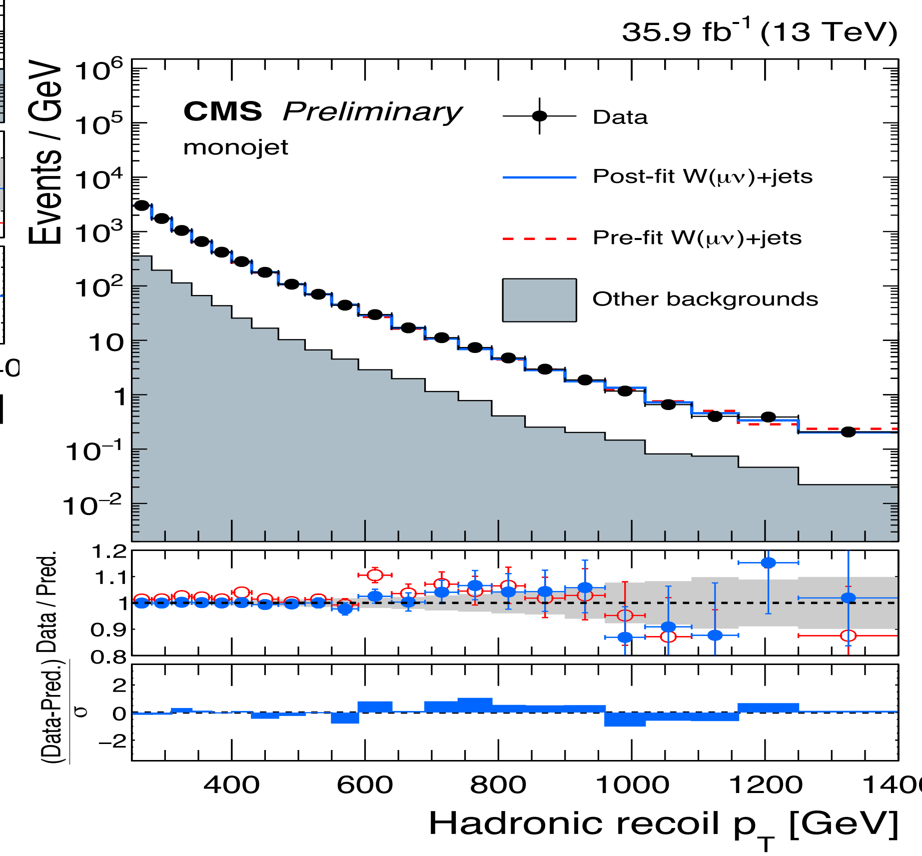


γ+Jet CR





Z+Jet CR

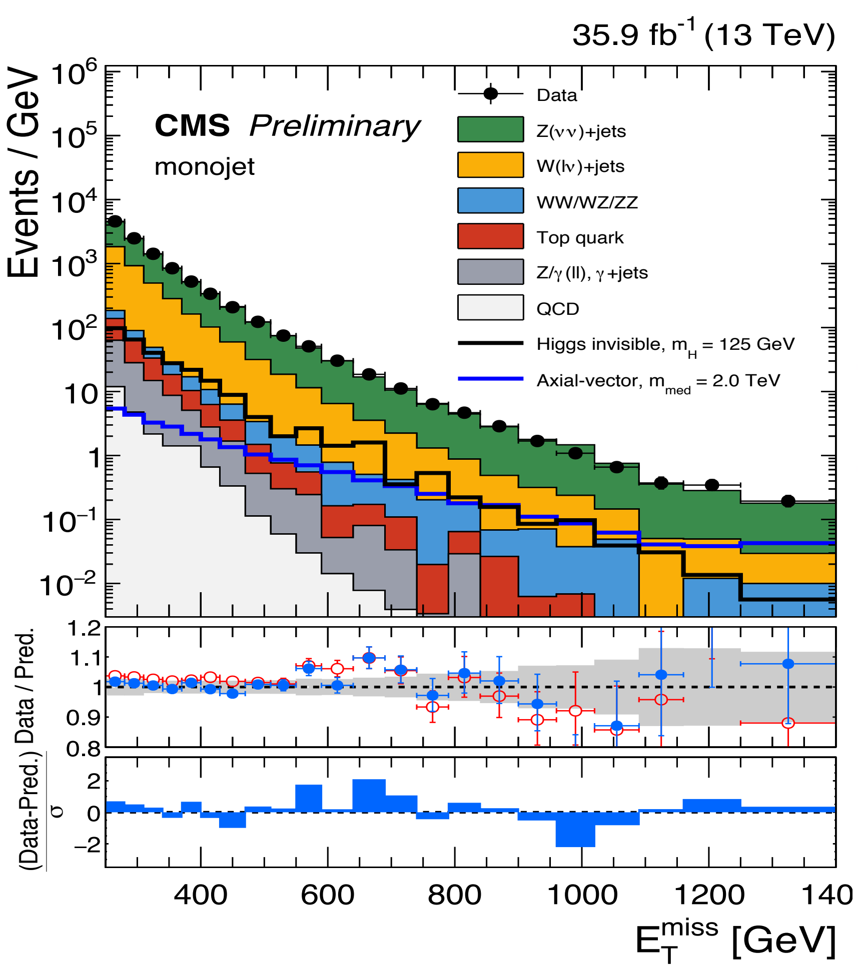


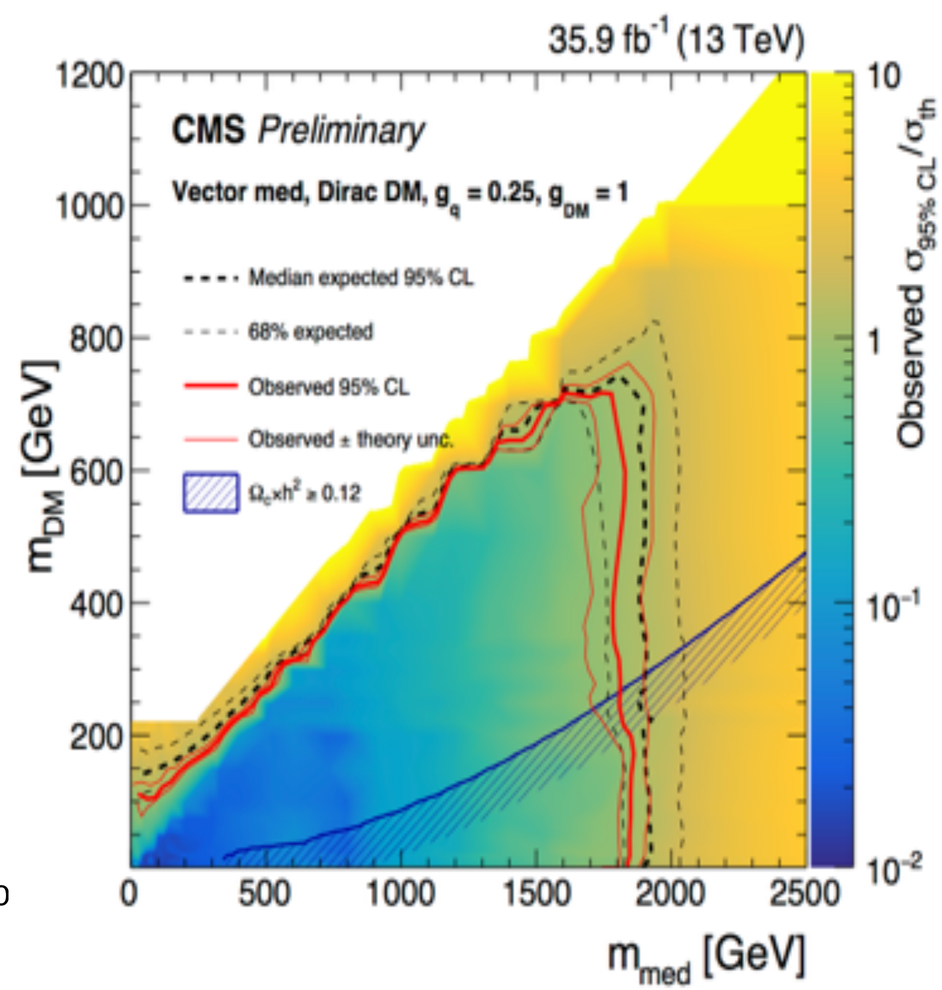
EXO-16-048

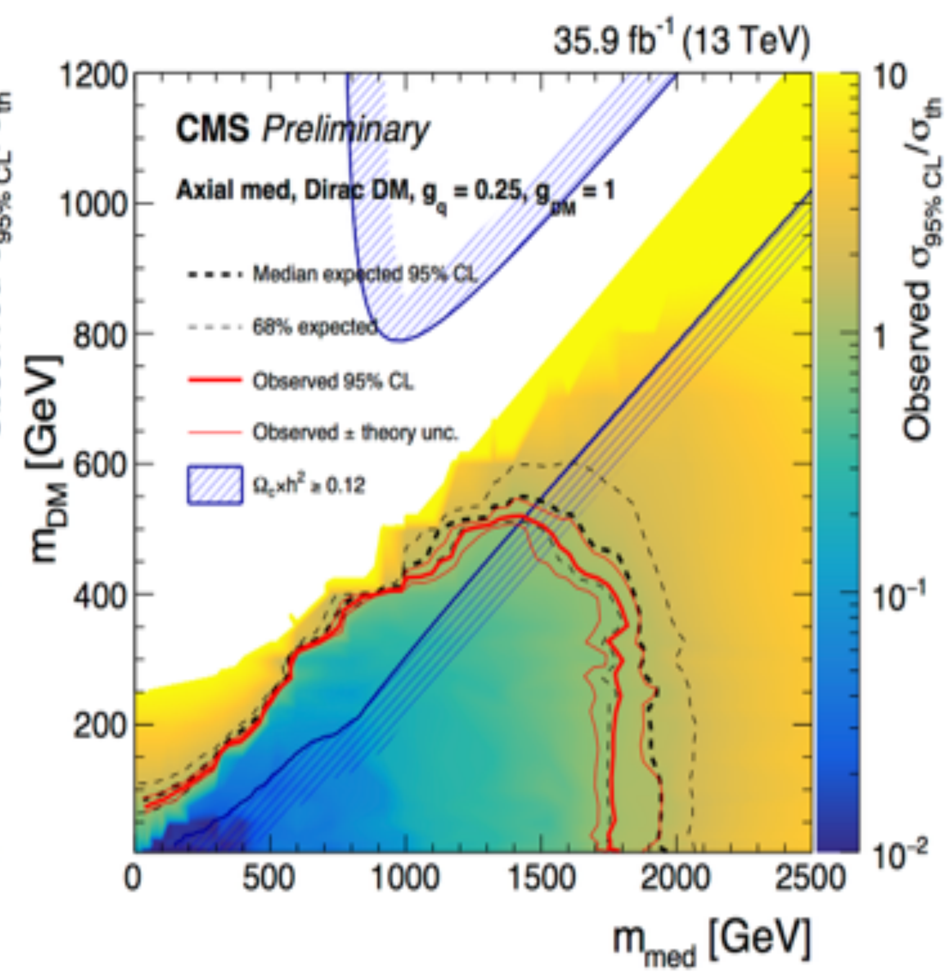
Mono-Jet/V: Results

- **Mediator (vector, axial-vector) of mass upto 1.8 TeV is excluded**
- **Pseudo-scalar of mass upto 400 GeV is excluded**
- **Fermion portal DM model: exclusion upto 1.4 TeV**

EXO-16-048

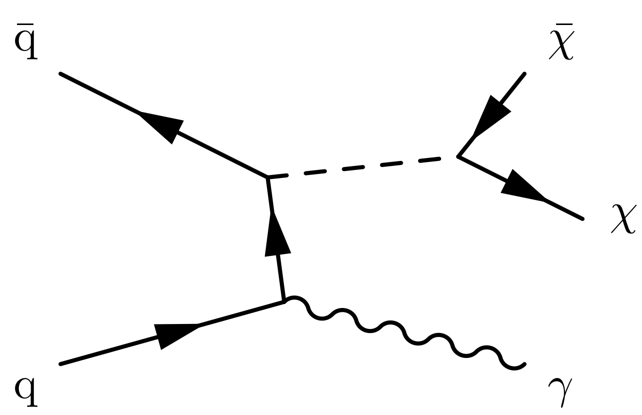


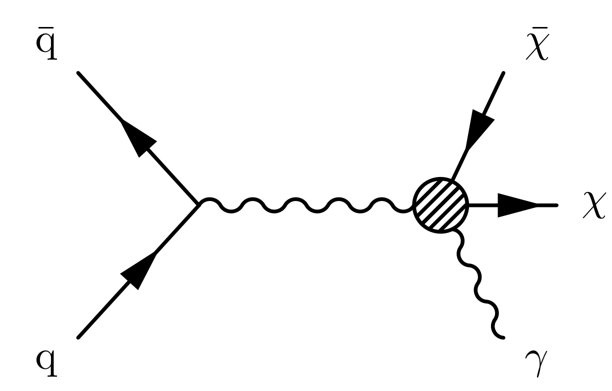




Mono-γ: Production and Selection

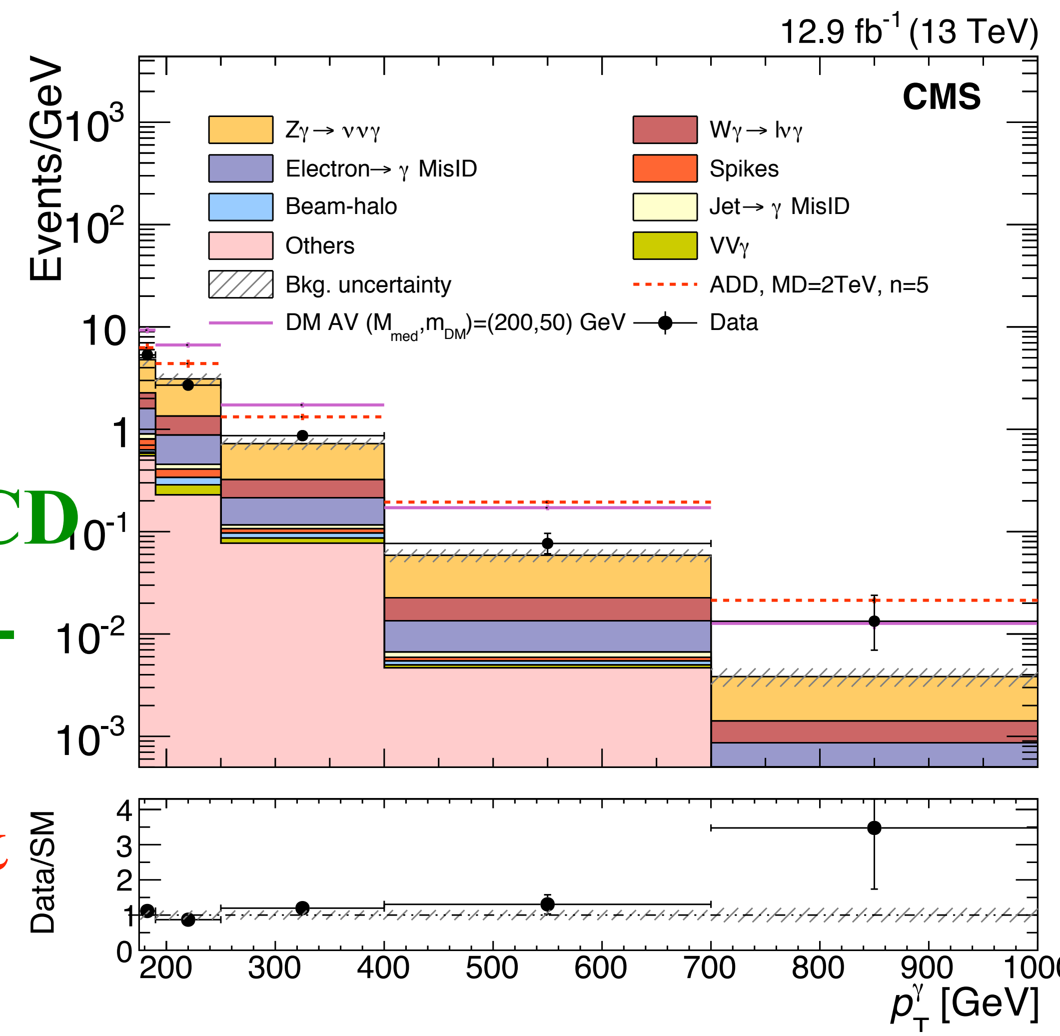
- Main backgrounds:
  - Z(νν)+Jets (~55%)
  - W(lν)+Jets (~15%)





- Kinematic Selections:
  - $P_T(\gamma) > 175$ GeV
  - MET > 170 GeV
  - Lepton Veto
  - $\Delta\phi(\gamma,\mathrm{MET}) > 2.0$

EXO-16-039

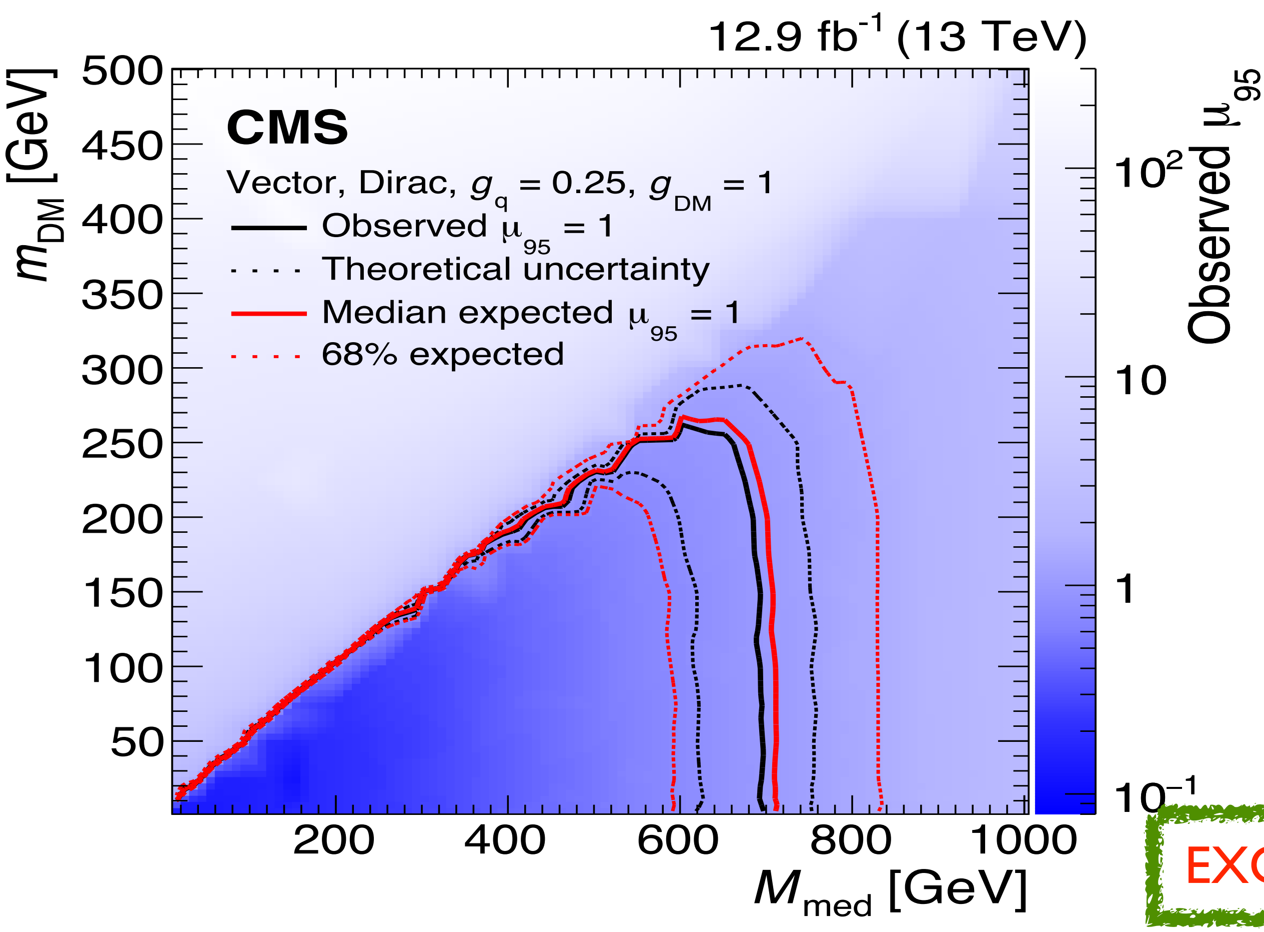


- **Data driven background estimation for QCD multijet, electron-to-photon fakes and non-collision background e.g., beam halo**
- Dominant source of uncertainty from QCD & EWK corrections

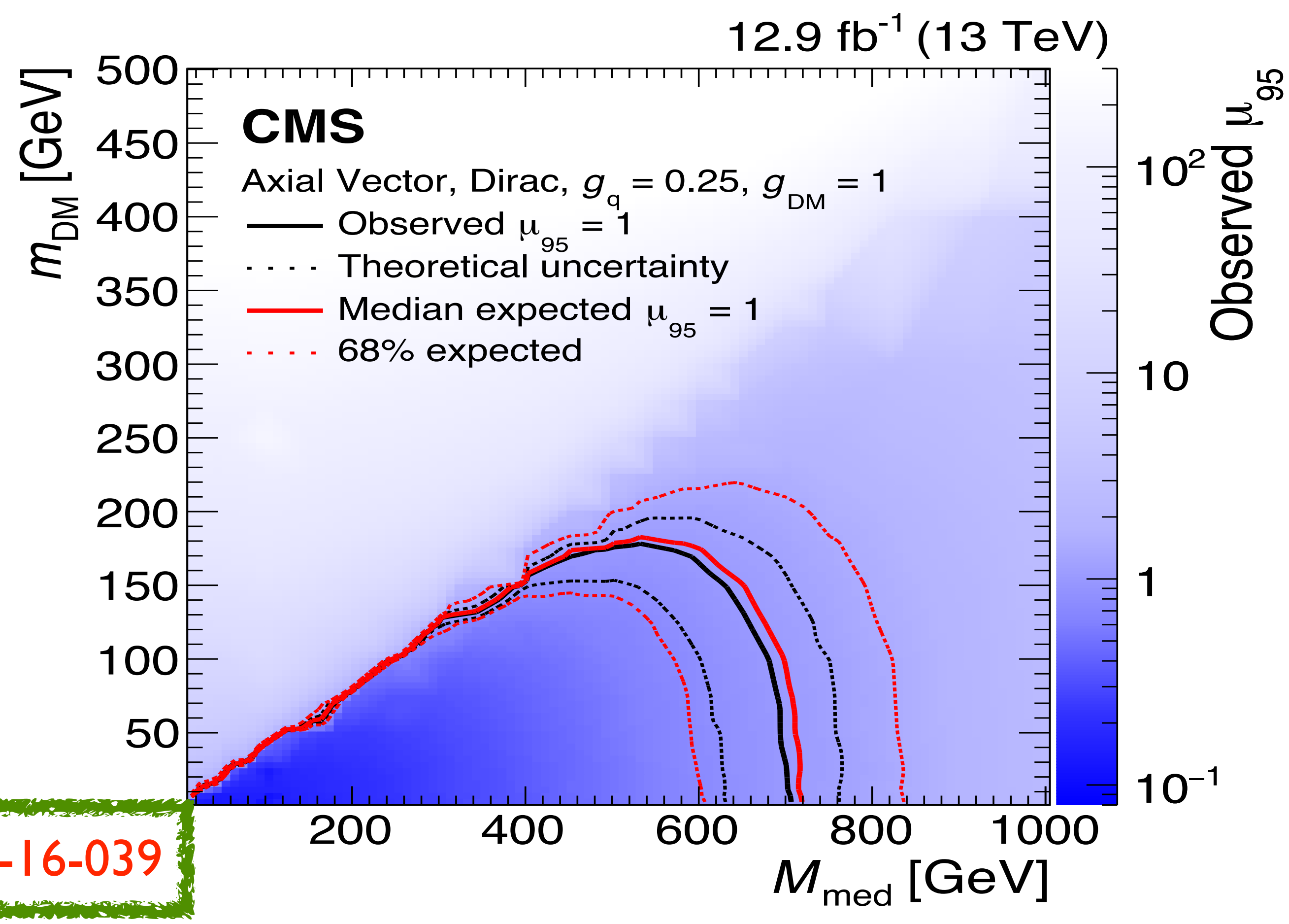
Mono-γ: Background and Results

- **No excess is observed in this final state**
- **Mediator mass upto 700 GeV excluded for different coupling types (vector, axial vector)**

Process	Events
$Z(\to \nu\bar{\nu}) + \gamma$	215 ± 32
$W(\to \ell\nu) + \gamma$	57.2 ± 8.0
Electron misidentification	52.7 ± 4.2
ECAL spikes	8.5 ± 6.7
Beam halo	$5.5\,^{+9.3}_{-5.5}$
γ + jets	10.1 ± 5.7
$W \to \mu\nu$	8.5 ± 3.0
$t\bar{t}\gamma$	8.2 ± 0.6
Jet misidentification	5.9 ± 1.7
$VV\gamma$	5.5 ± 1.8
$W \to \tau\nu$	5.2 ± 2.3
$Z(\to \ell\bar{\ell}) + \gamma$	2.9 ± 0.2
Total background	386 ± 36
Data	400

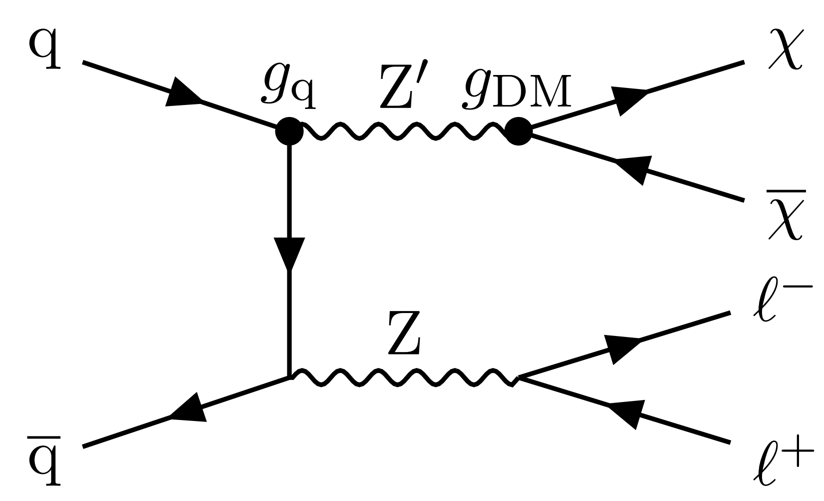


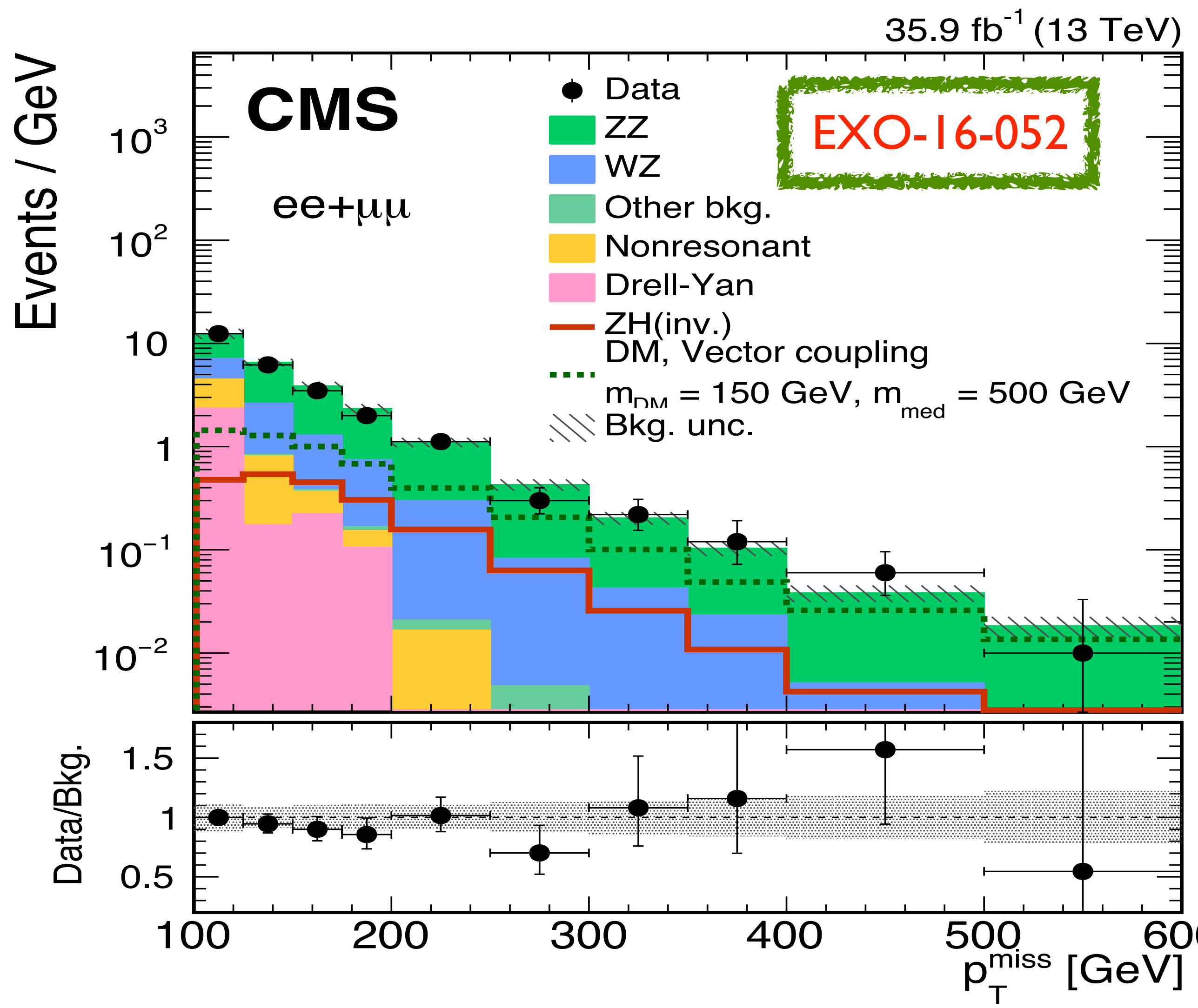
EXO-16-039



Mono-Z(→ll)

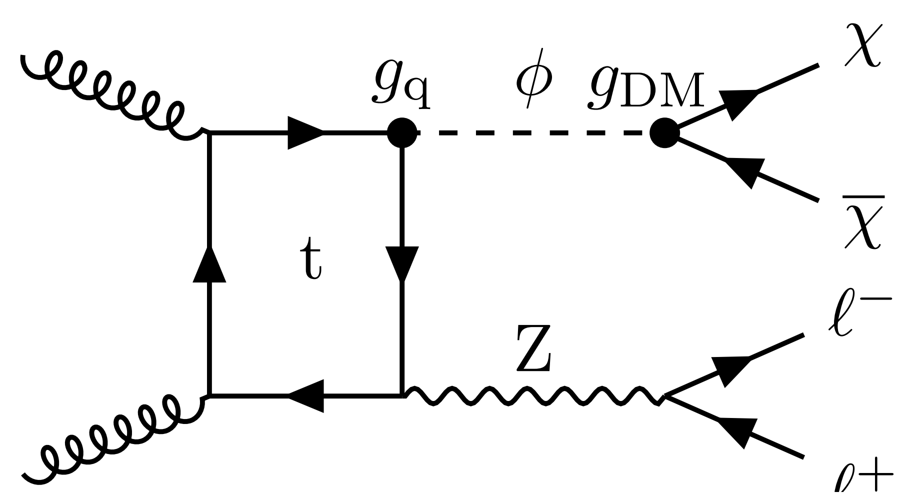
- Main backgrounds:
  - WW, WZ
- Kinematic Selections:
  - $P_T(ll) > 60$ GeV
  - MET > 100 GeV
  - Veto event with extra e, μ, τ, >1 jet and b-jet
- **CR in data for three and four leptons are used to estimate normalisation of main background**
- **Non resonance background from e-μ enriched data sample**

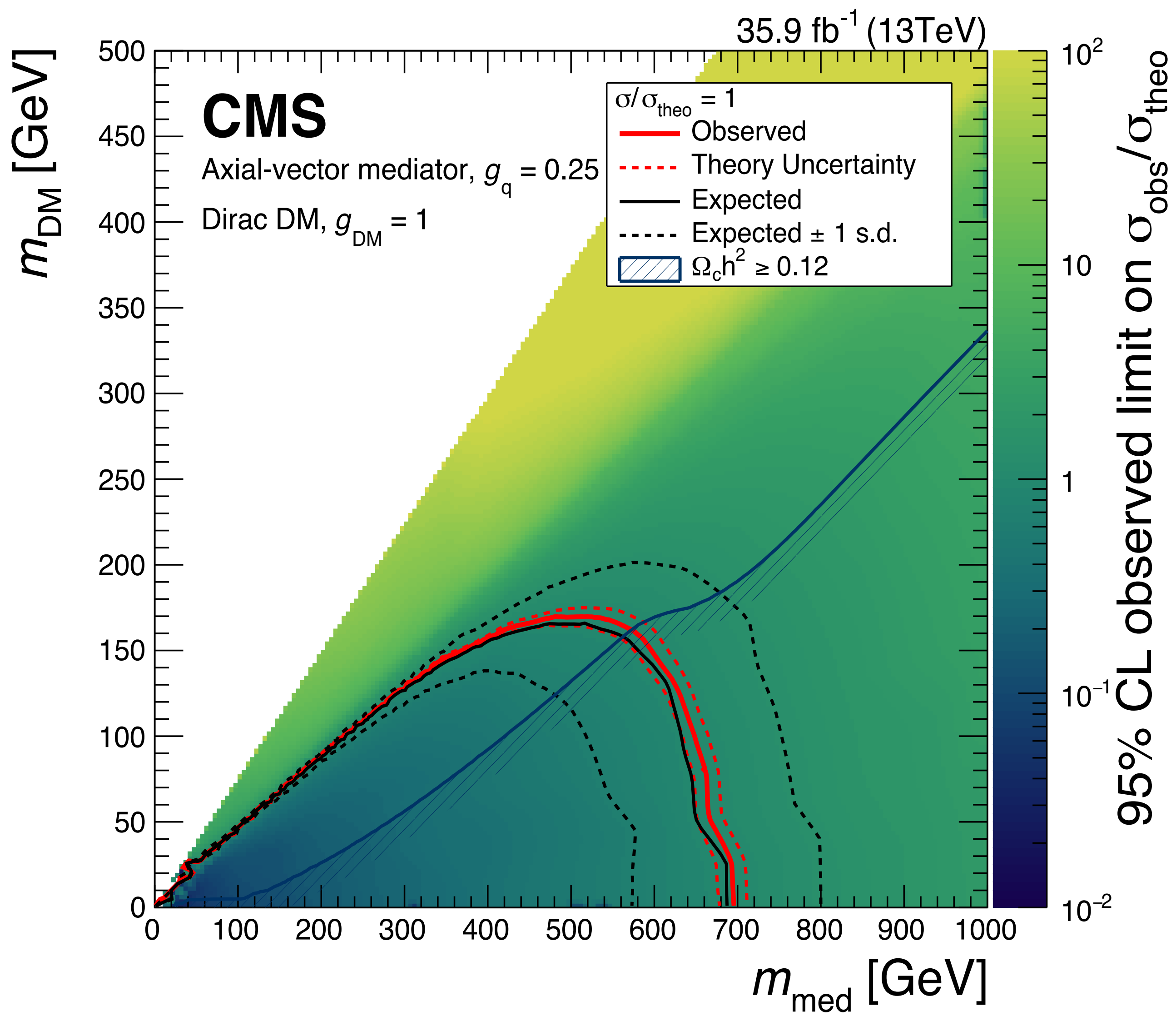


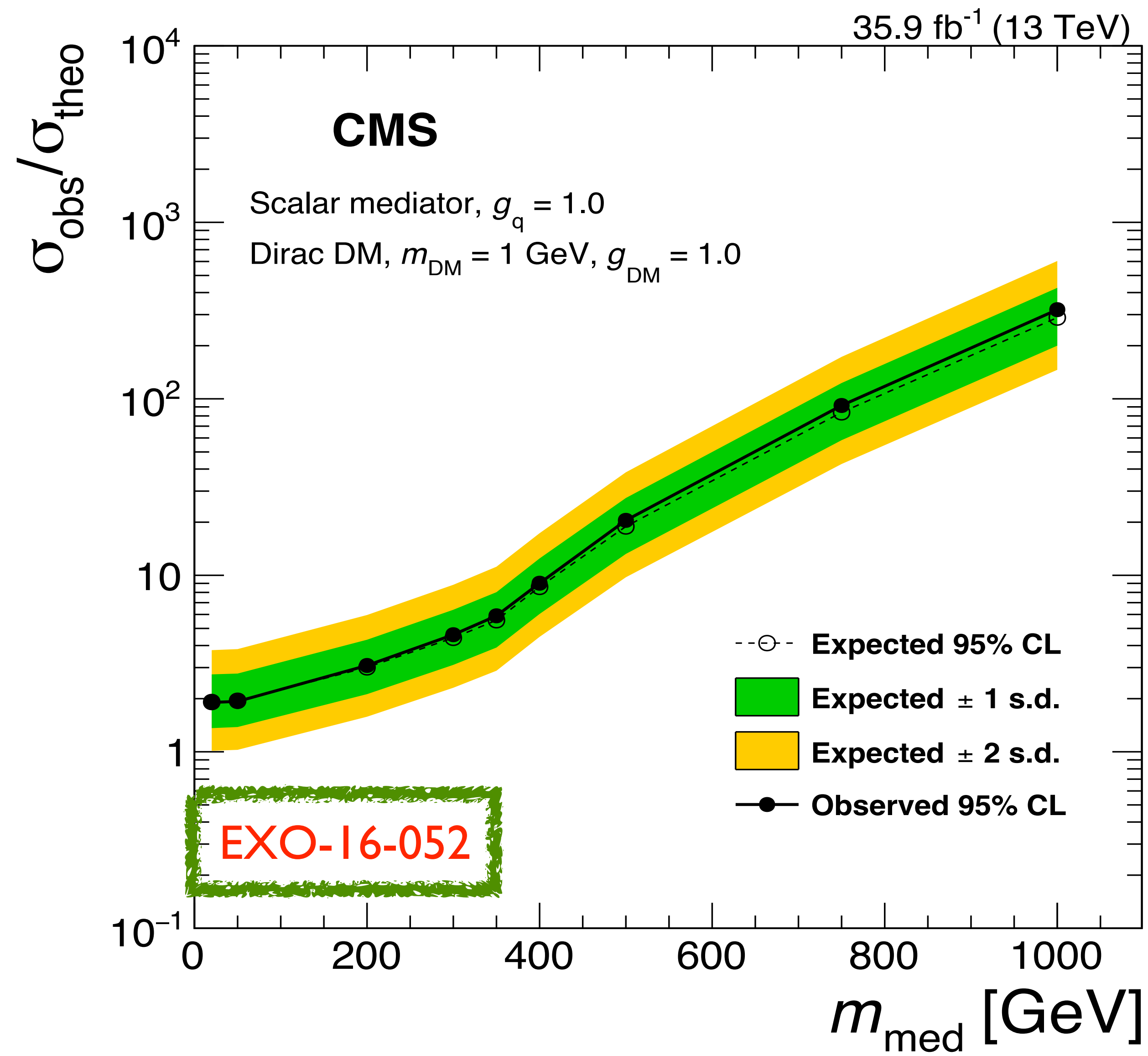


Mono-Z(→ll)

- Limits are evaluated for vector, axial vector, scalar and pseudo-scalar mediators



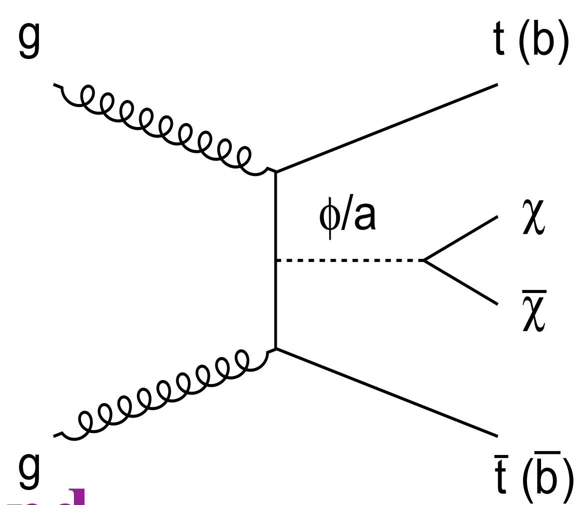


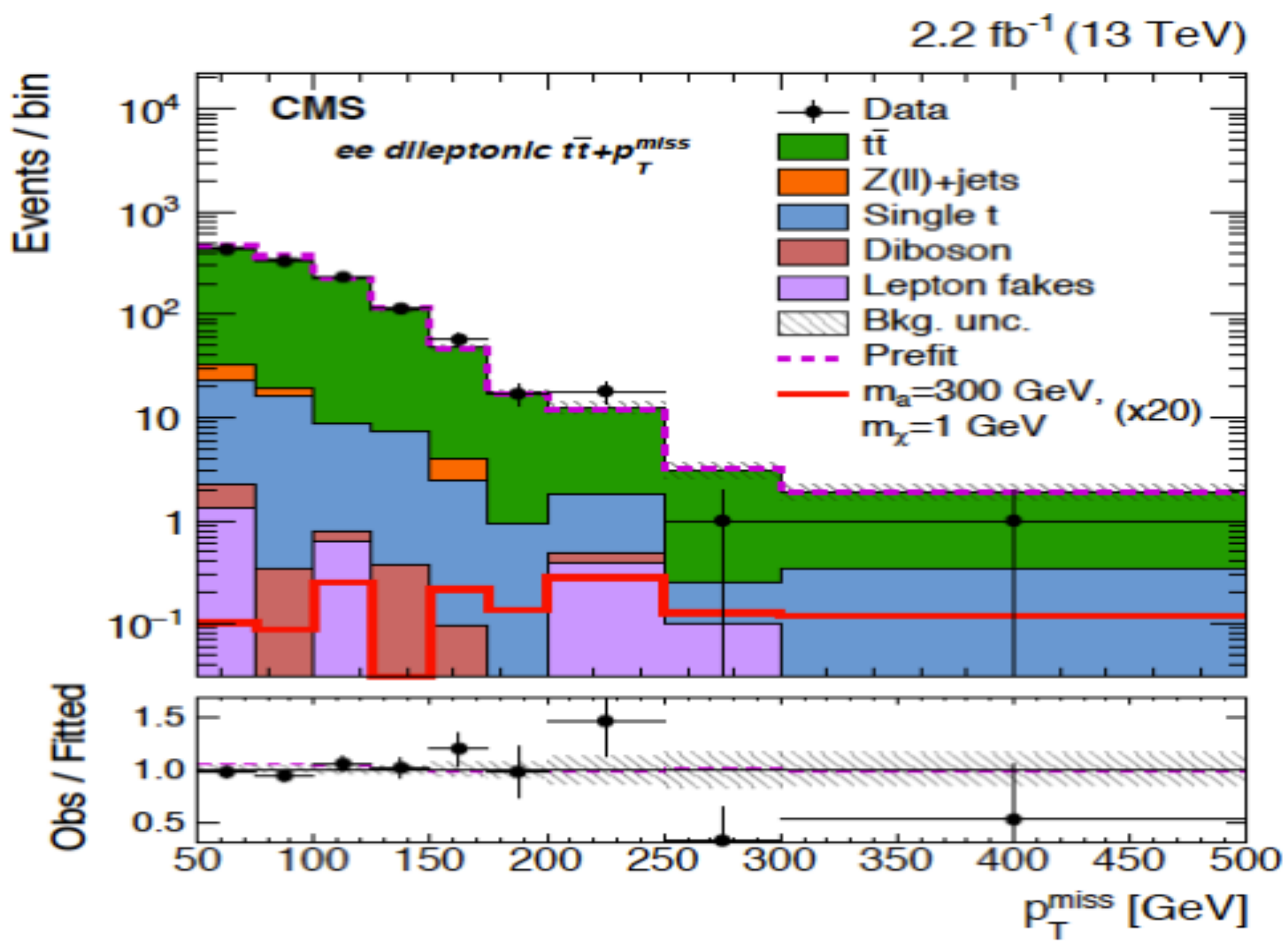


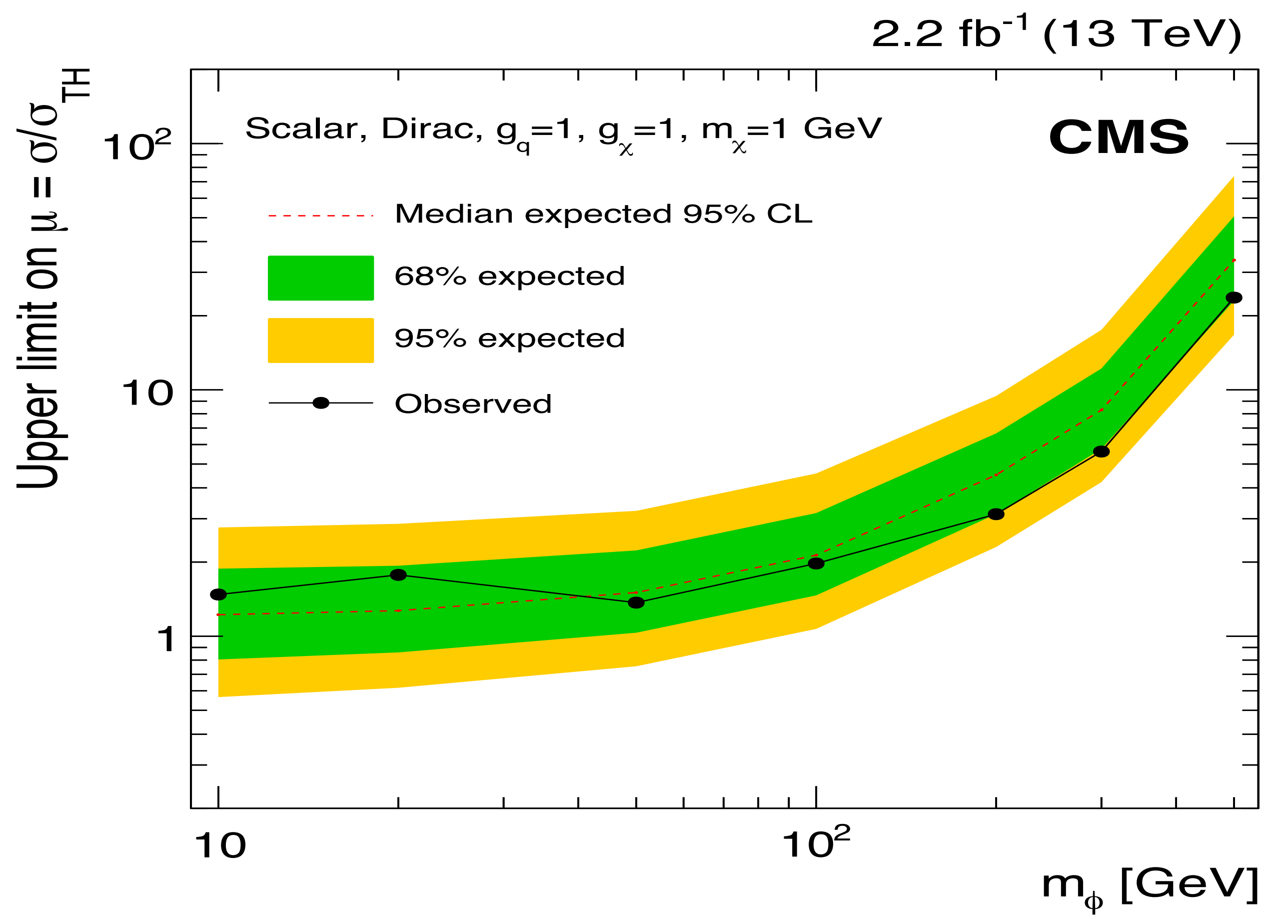
Searches with tt(/bb)+MET

- Kinematic Selection(dilepton+MET):
  - $P_T(l_1) > 30$ GeV, $P_T(l_2) > 10$ GeV
  - MET > 50 GeV
  - Veto event with third lepton
  - $N_{jets} \geq 2$, $N_{b\text{-}jets} \geq 1$
- **Many CRs and SRs based on final topology for background estimation**

EXO-16-005



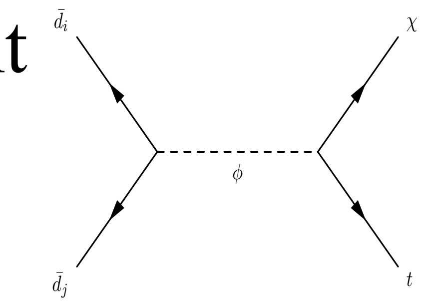


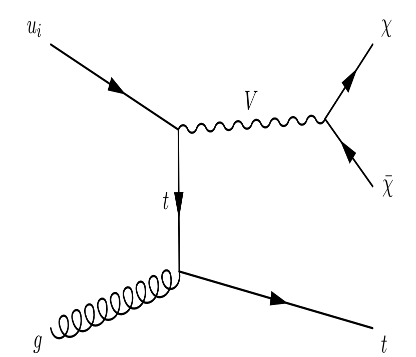


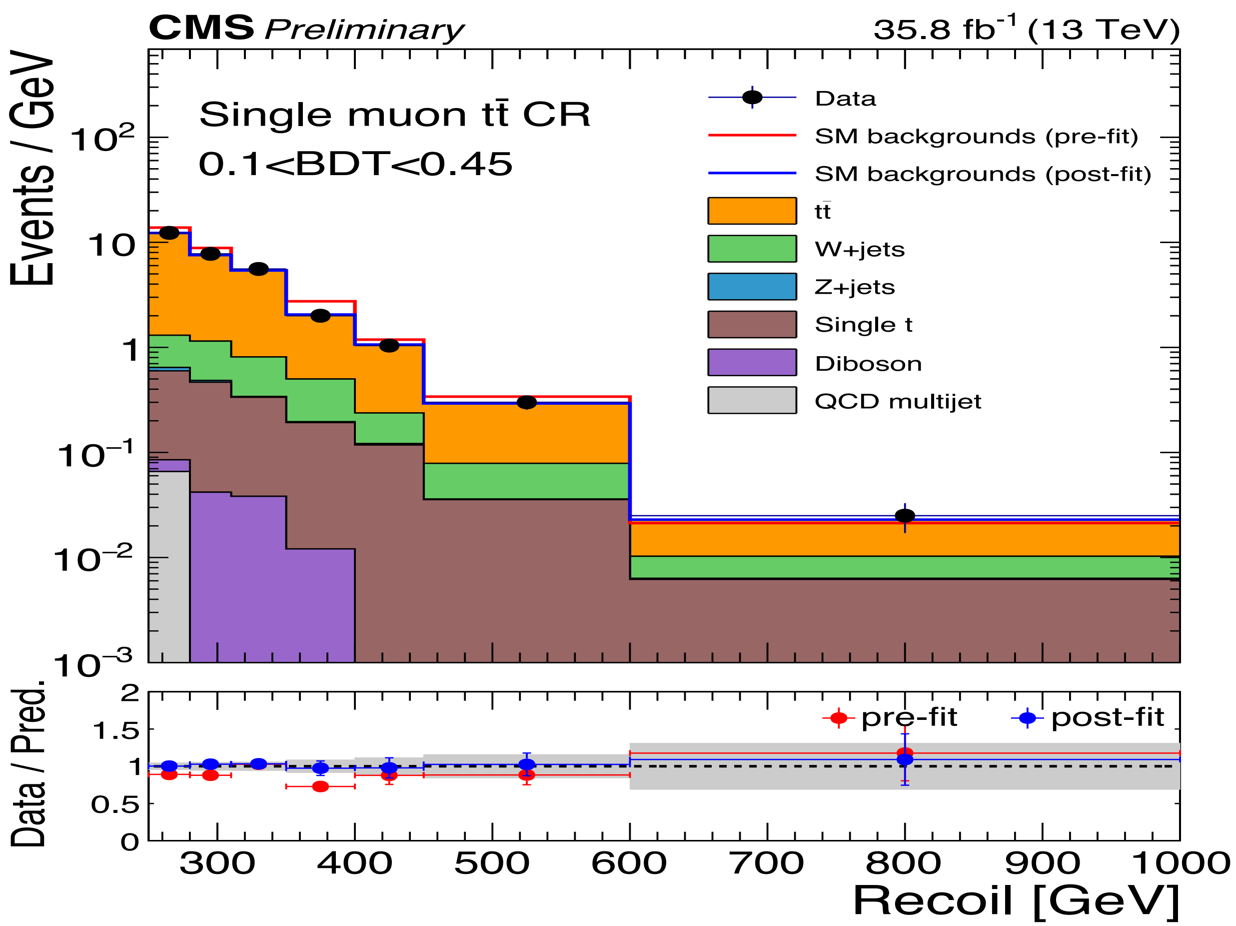
Searches with t(had.)+MET

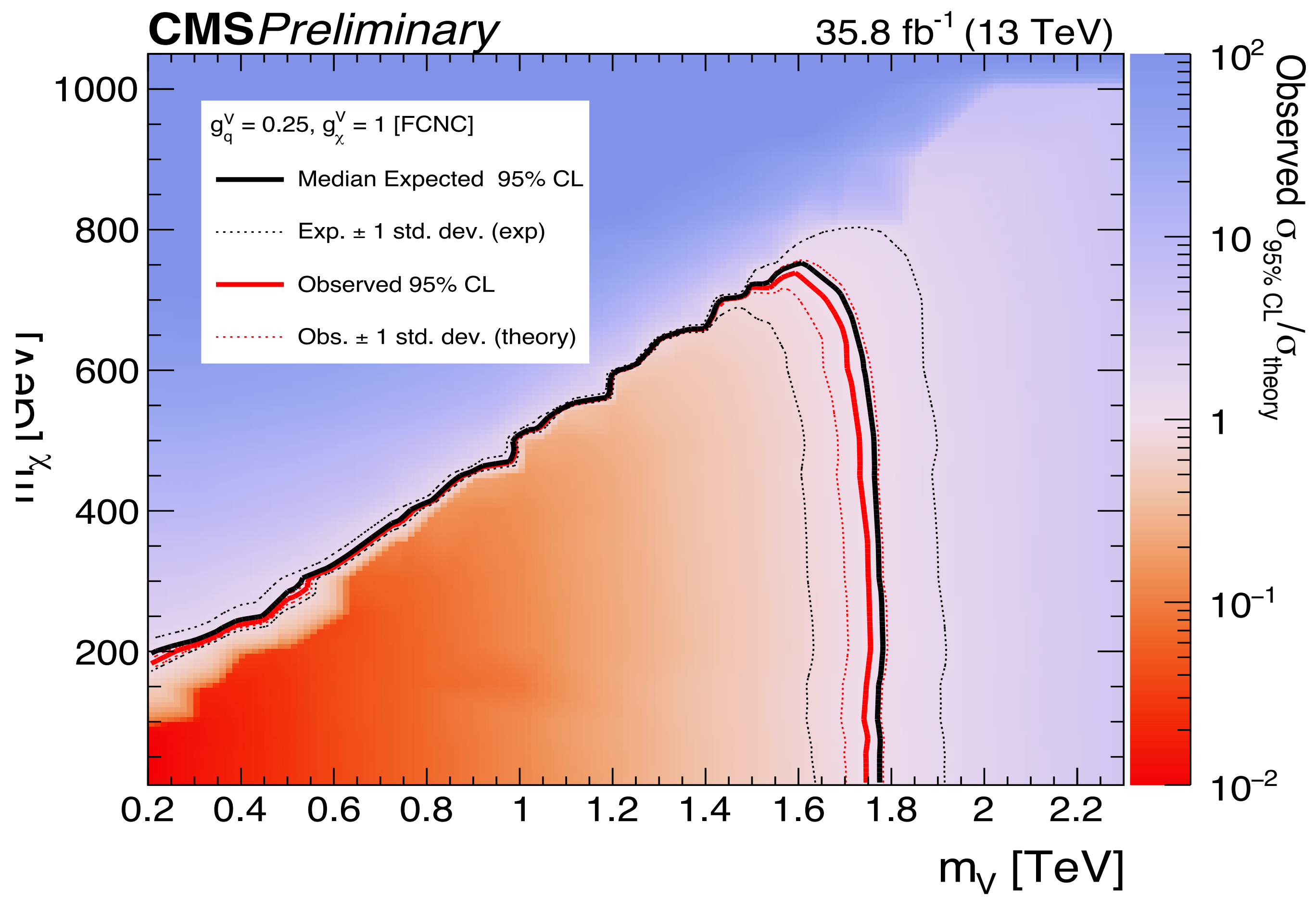
- Mono-top production: resonant and flavour-mixing neutral current
- Kinematic Selection:
  - Exactly one fat jet P_T> 250 GeV with ΔR=1.5
  - Recoil > 250 GeV
  - b-tagging: loose WP
  - Top-tagging: soft drop mass and BDT cuts
- **Two categories: tight (BDT >0.45) and loose (0.1<BDT<0.45)**

EXO-16-051





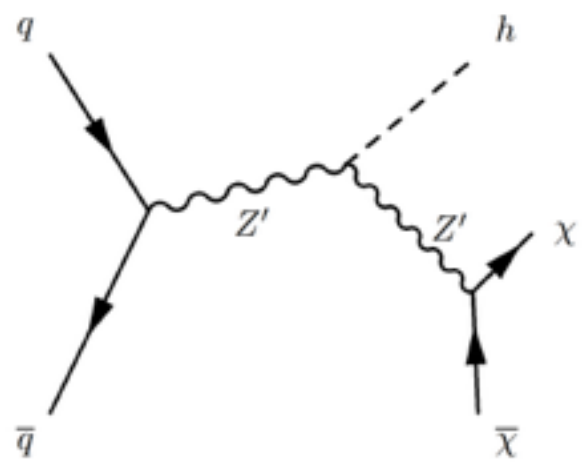




Mono-H(→γγ)

EXO-16-054

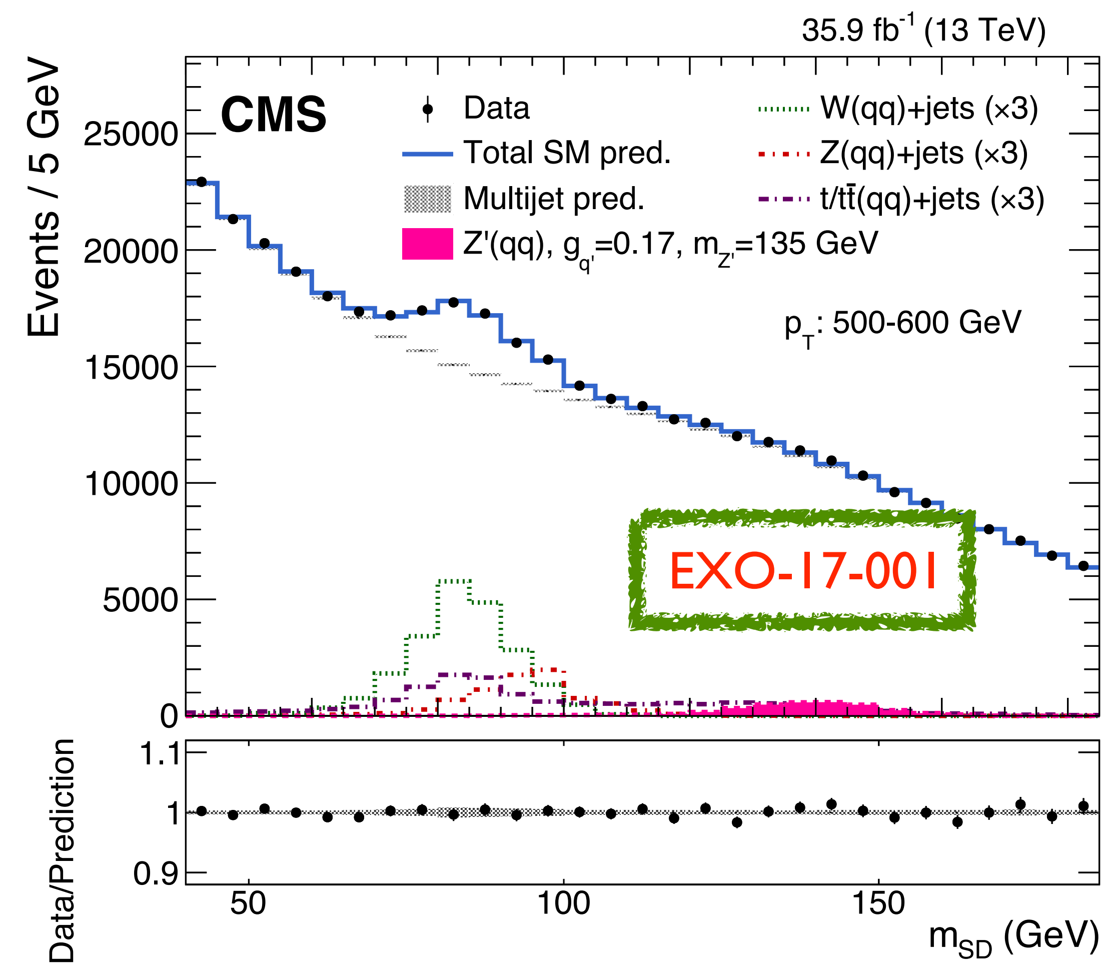
- Similar analysis as SM H→γγ bump hunt search
  - Improved photon-id for high Z' mass
- Two MET categories
  - 50-130 GeV, >130 GeV
- Background estimated using fit to data
  - Simultaneous fit to data in two MET categories

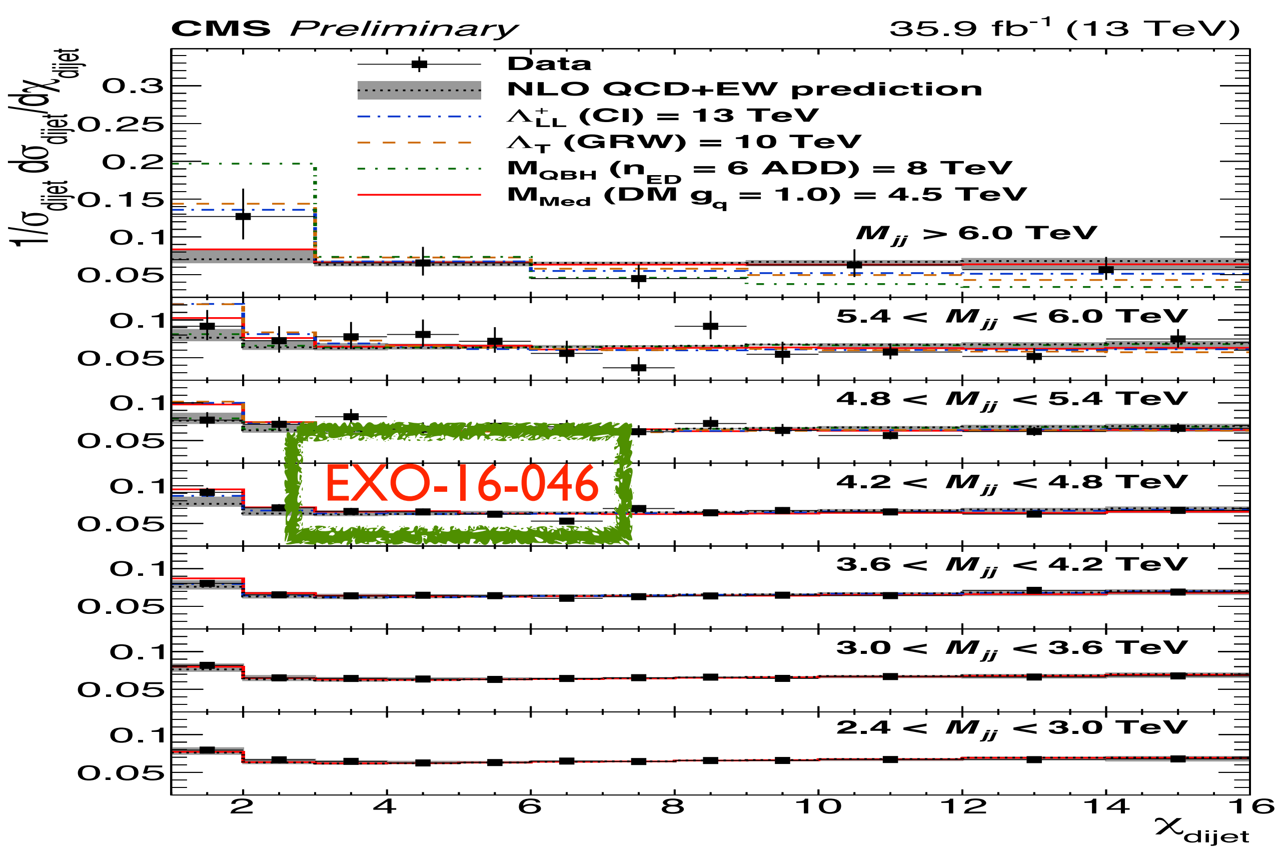


More details and results along with H(→bb) in next talk

Dijet: DM Interpretation

- Low mass vector resonance search in dijet final state
  - Substructure technique used for boosted *jj*
  - Extending low mass limits (< 50 GeV)





- Dijet angular distributions as a discriminant for new physics search

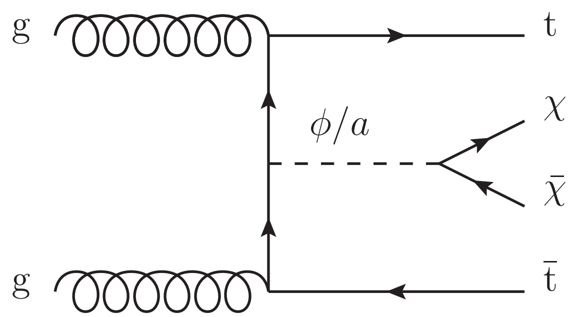
$$\chi_{\text{dijet}} = \exp(|(y_1 - y_2)|)$$

  - $P_{T(j1,\,j2)} > 200$ GeV

- High mass dijet search also exclude mediator masses below 2.7 TeV for vector and axial-vector mediator couplings

EXO-16-056

tt(ll)+MET: DM Interpretation

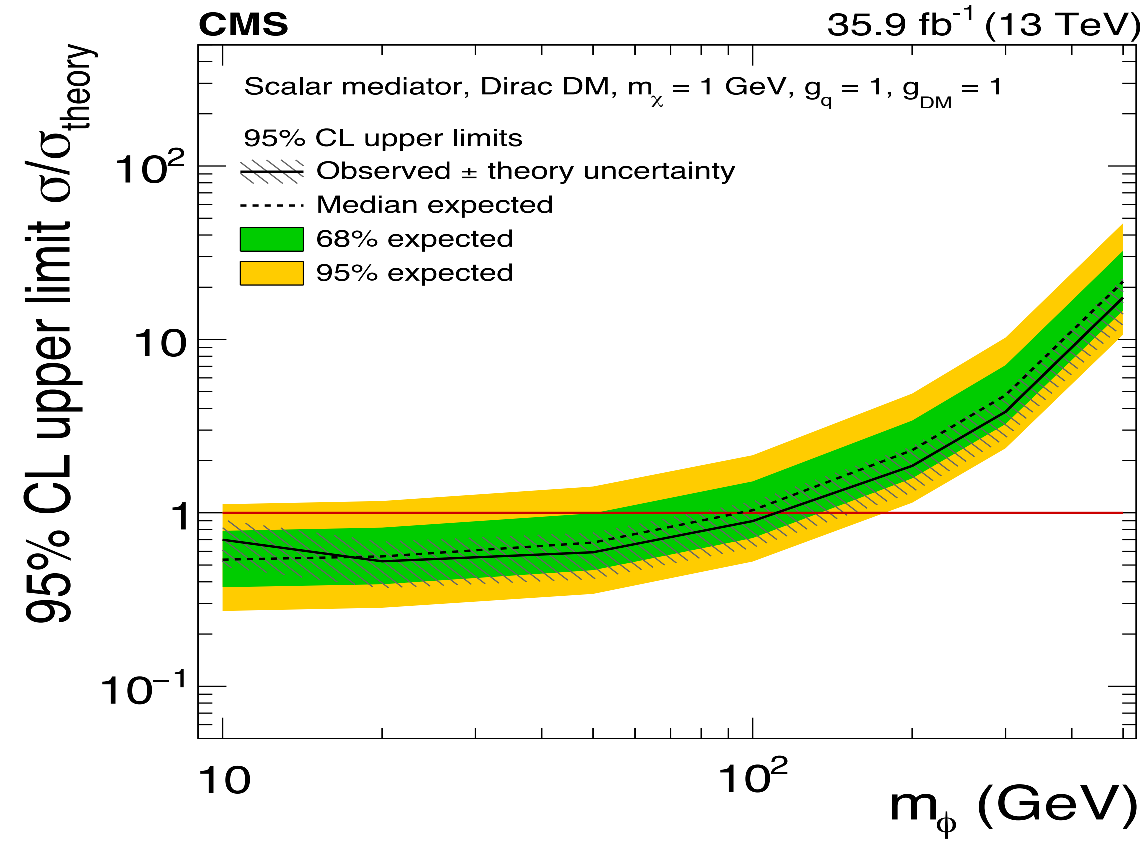


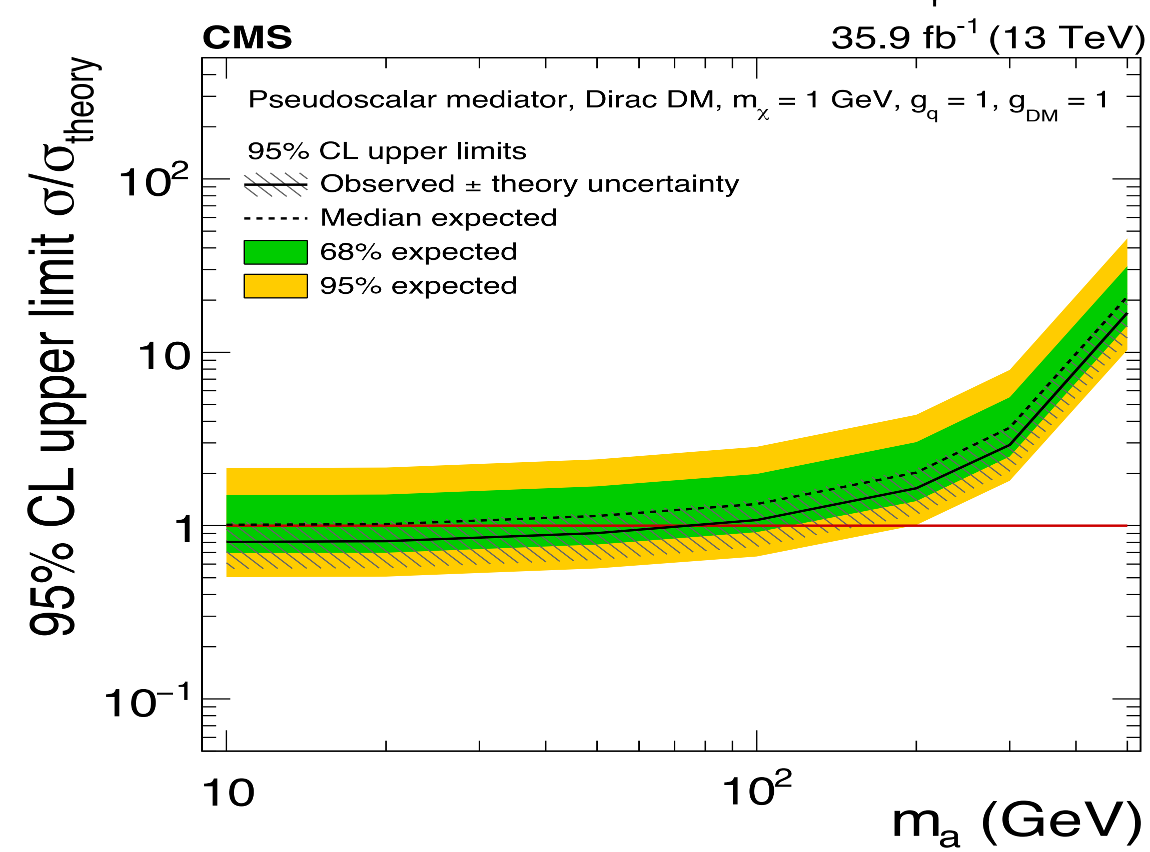
SUS-17-001

- Top pair production with large MET
  - Two opposite sign leptons
  - $M(ll) > 20$ GeV, $|M_Z - M(ll)| < 15$ GeV
  - MET > 80 GeV
  - $N_{jets} \geq 2$, $N_{b\text{-}jets} \geq 1$
- Key variable:

$$M_{T2}(\ell\ell) = \min_{\vec{p}_T^{\,miss1} + \vec{p}_T^{\,miss2} = \vec{p}_T^{\,miss}} \left(\max \left[M_T(\vec{p}_T^{\,vis1}, \vec{p}_T^{\,miss1}), M_T(\vec{p}_T^{\,vis2}, \vec{p}_T^{\,miss2}) \right] \right)$$

- **Pseudo (scalar) mass upto 50 GeV(100 GeV) excluded for M_{DM}=1 GeV**

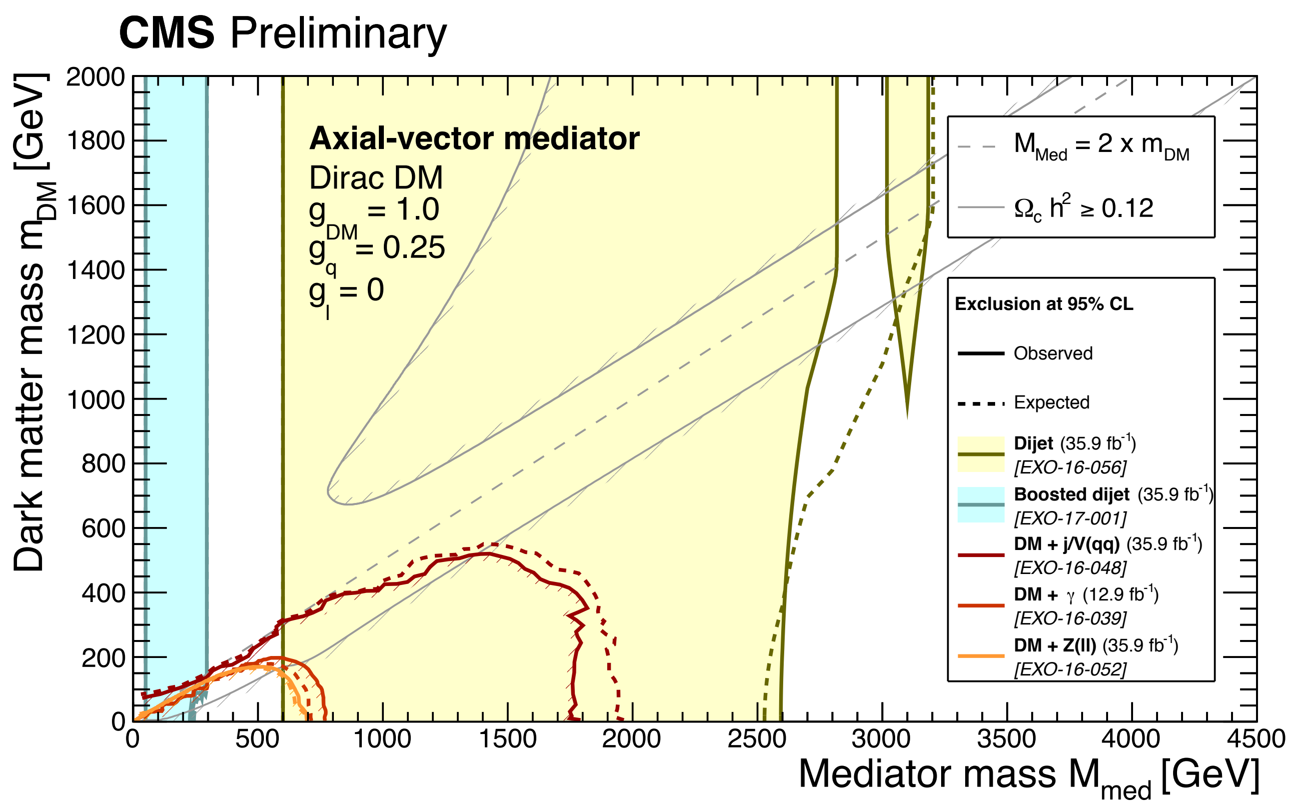


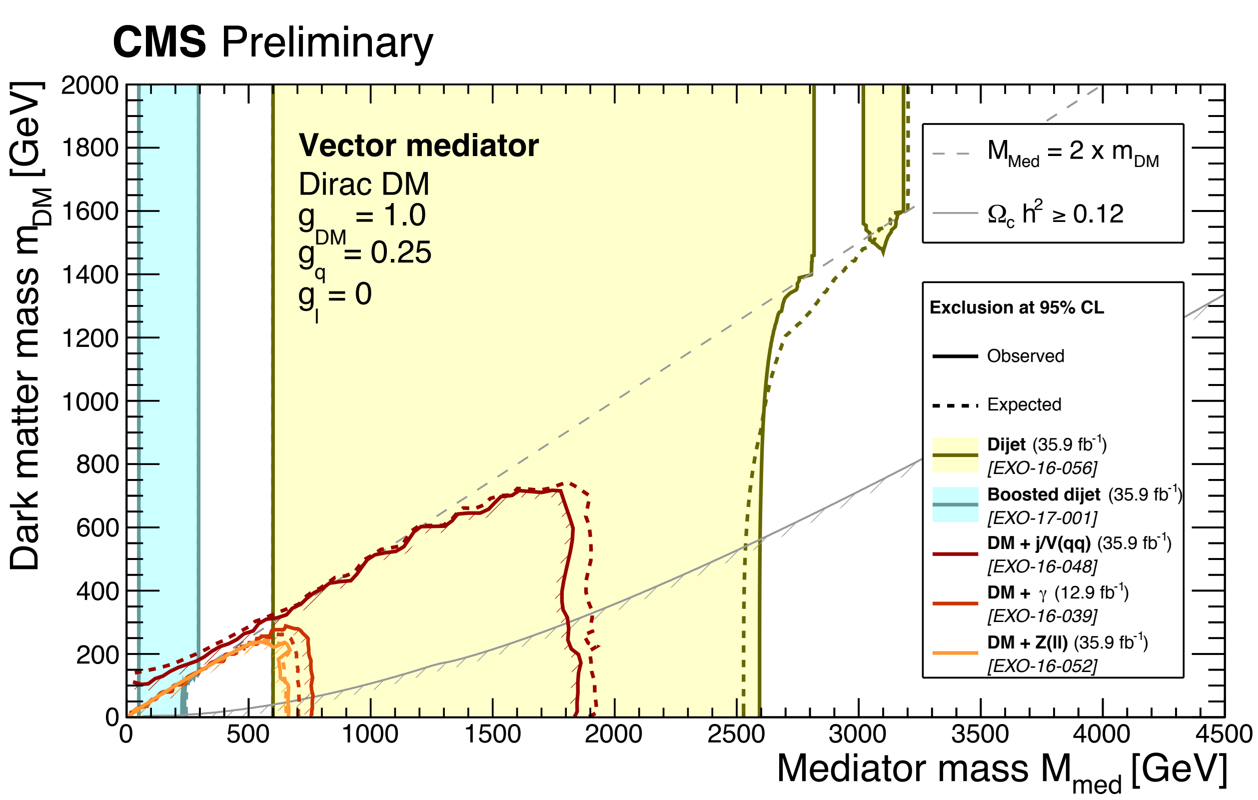


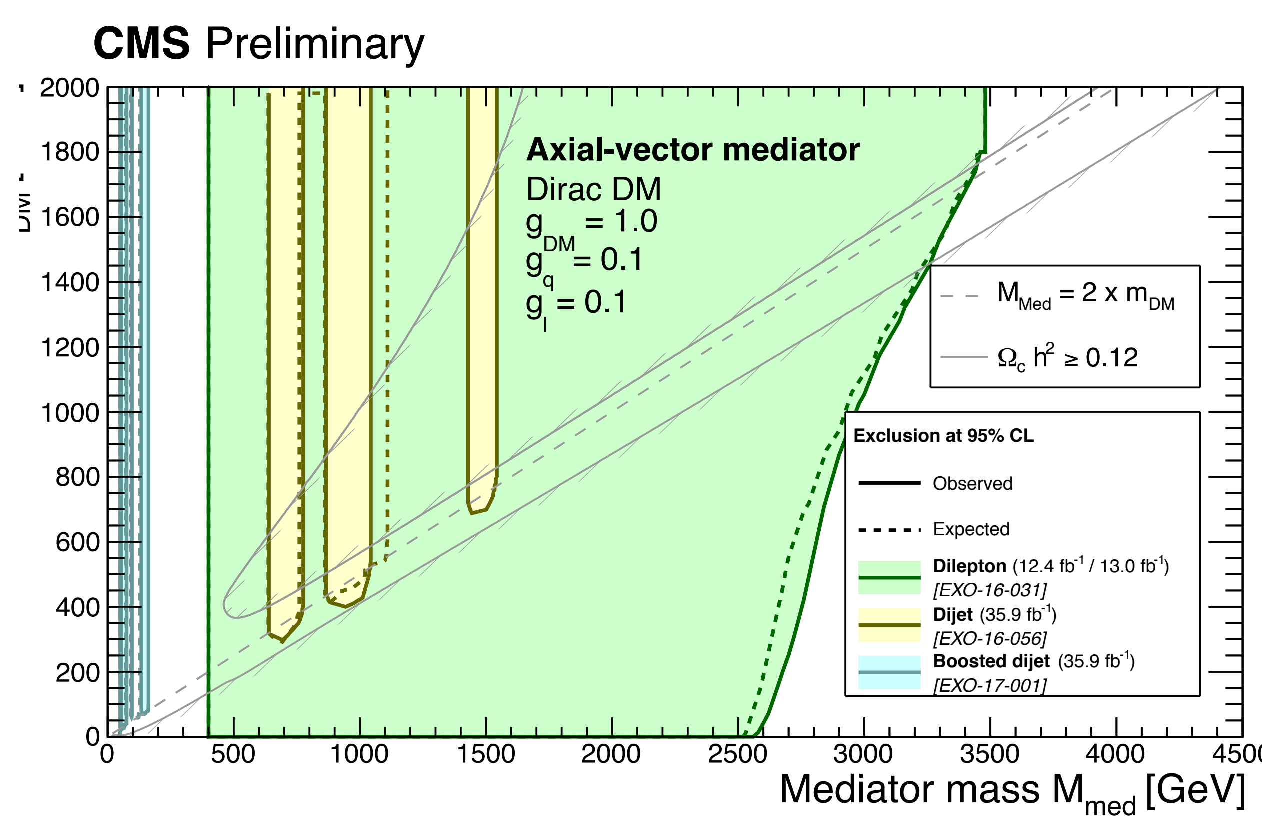
Summary: Spin-1 Limits

- **Mediator couplings :**
  - g_q=0.25 g_{DM}=1.0 g_l= 0
  - g_q=1.0 g_{DM}=1.0 g_l=0.1

- **95% CL exclusion region on DM mass -Mediator mass plane**



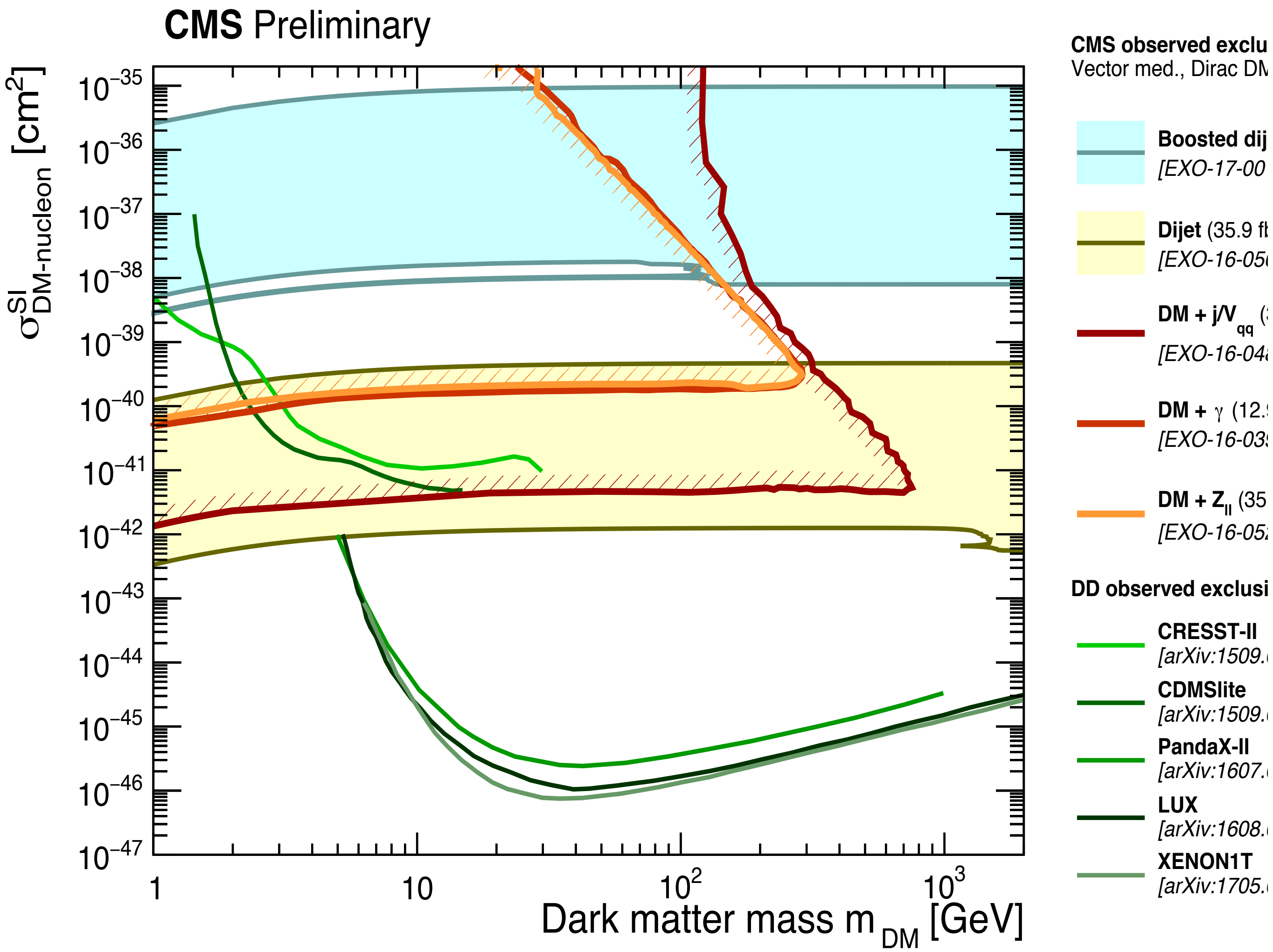


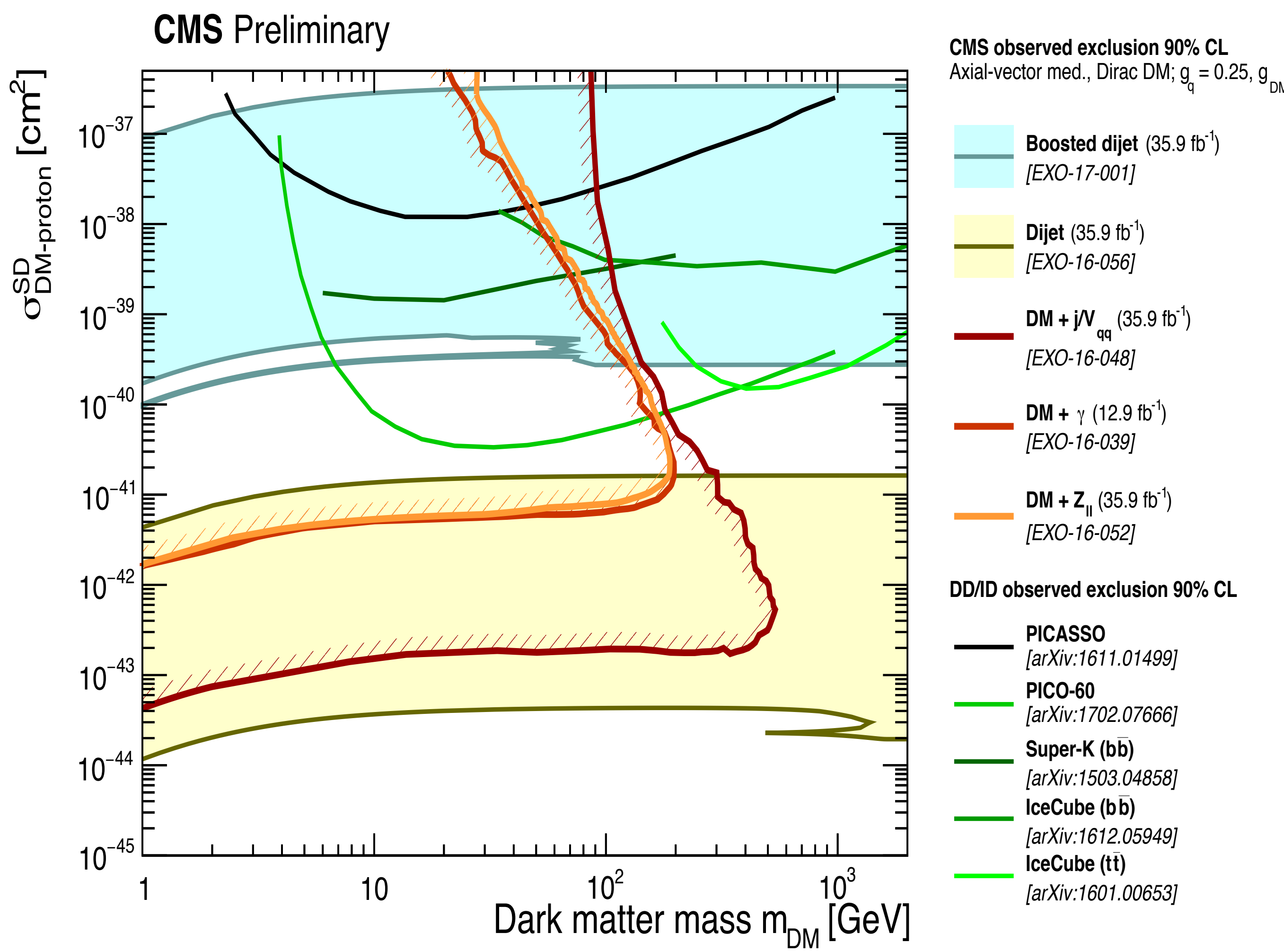


Spin-1 Limit: CMS Limits Comparison with DD

- Limit on Mediator - DM mass plane could be converted to DM-nucleon cross section

- The LHC limits are more stringent in lower DM masses and for spin dependent cross sections





Conclusions & Outlook

- **Extensive DM search program at the CMS experiment**
  - CMS has looked MET+X final states for search of DM with full 2016 data
  - Stringent bounds are put on parameter space using simplified models for DM
  - Di-jet/tt+MET BSM results are interpreted in terms of simplified model for DM

- **The LHC results compliment direct detection searches**

- **No evidence of DM yet but parameter space not fully explored**

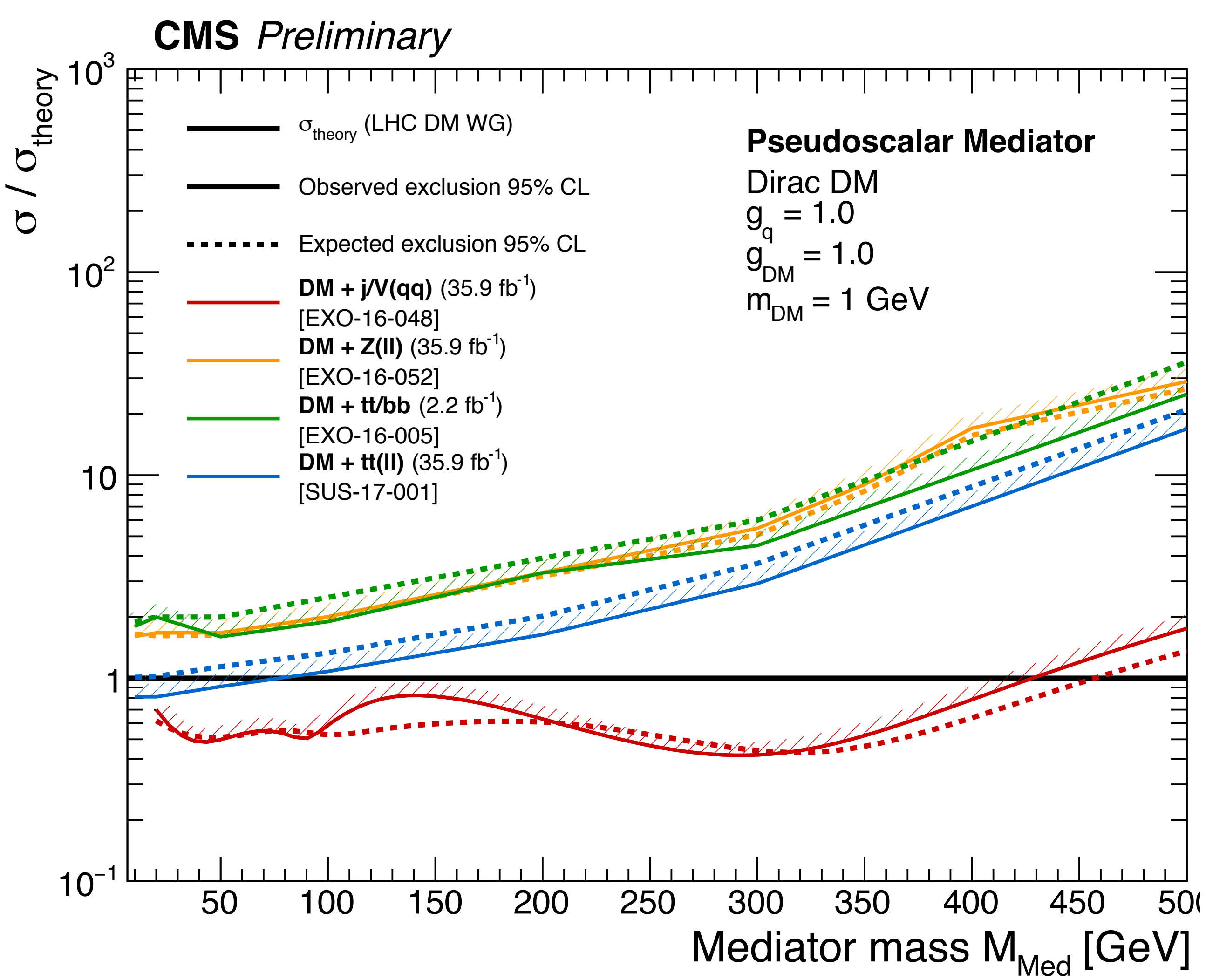
- **Stay tuned for new results!!!**

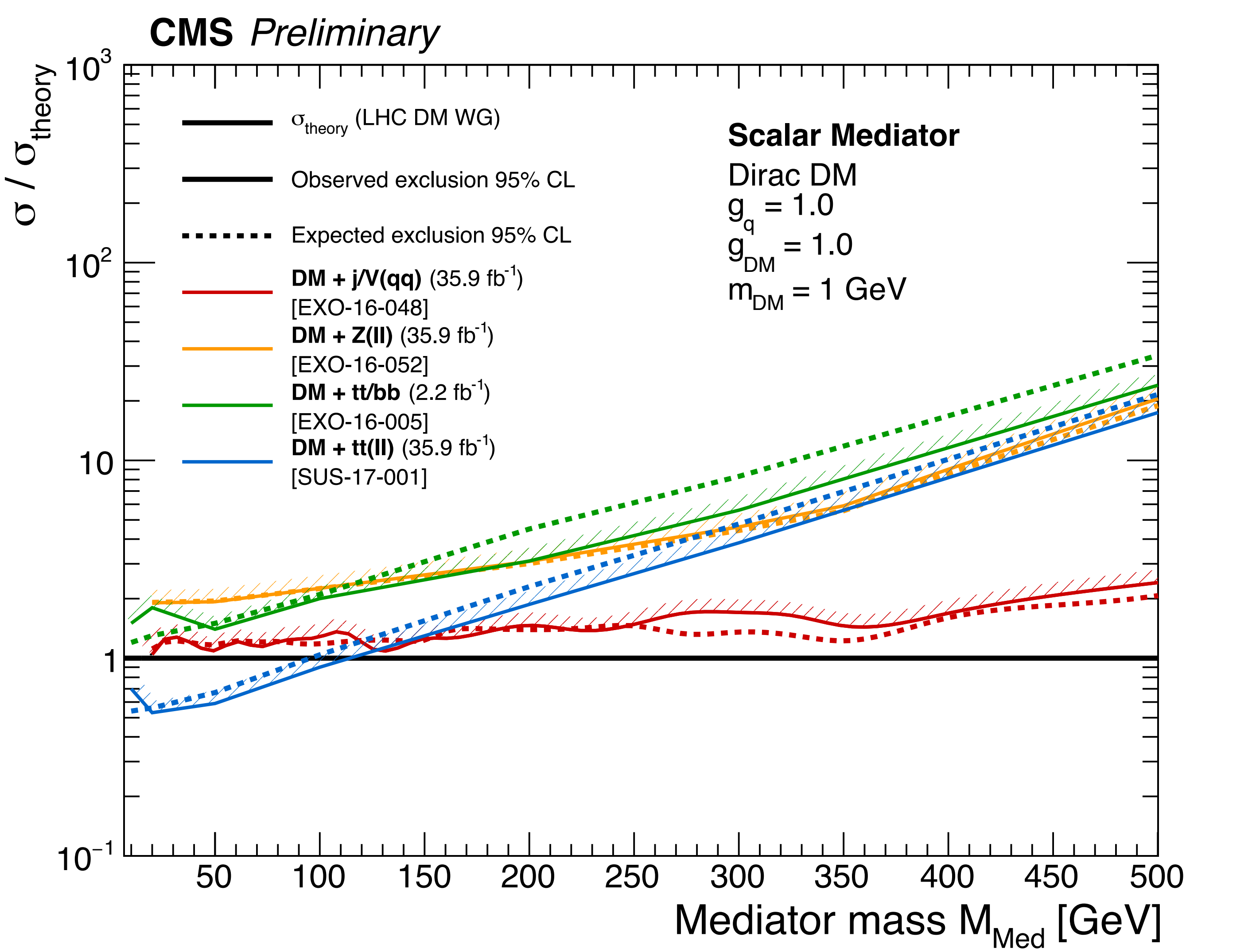
Back-up Slides

Summary: Spin-0 Limits

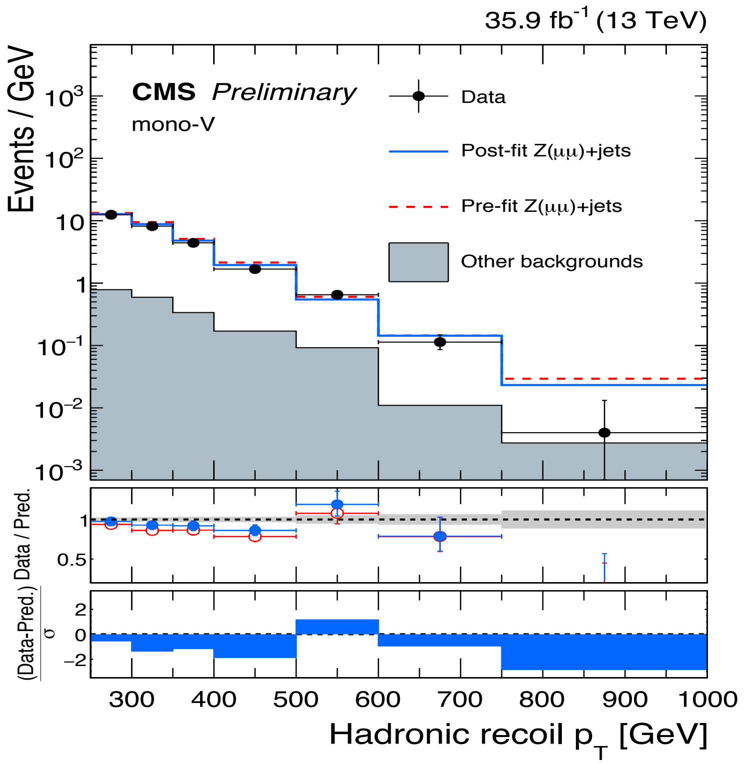
- 95 % CL upper limit on signal strength as a function of mass of mediator

- Mediator couplings:
  - g_q=1.0, g_{DM}=1.0, M_{DM}=1.0 GeV

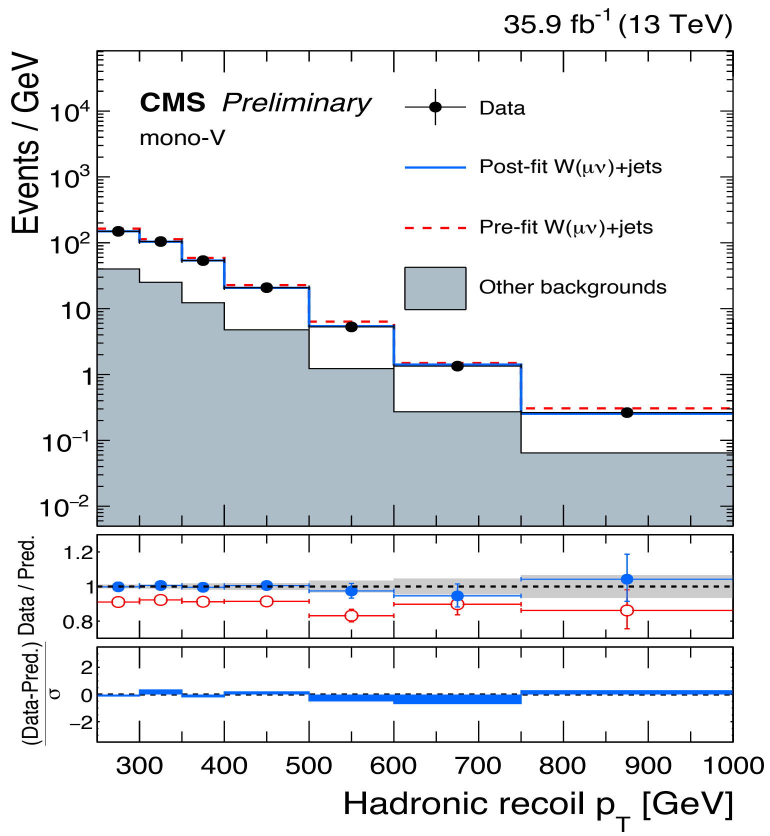




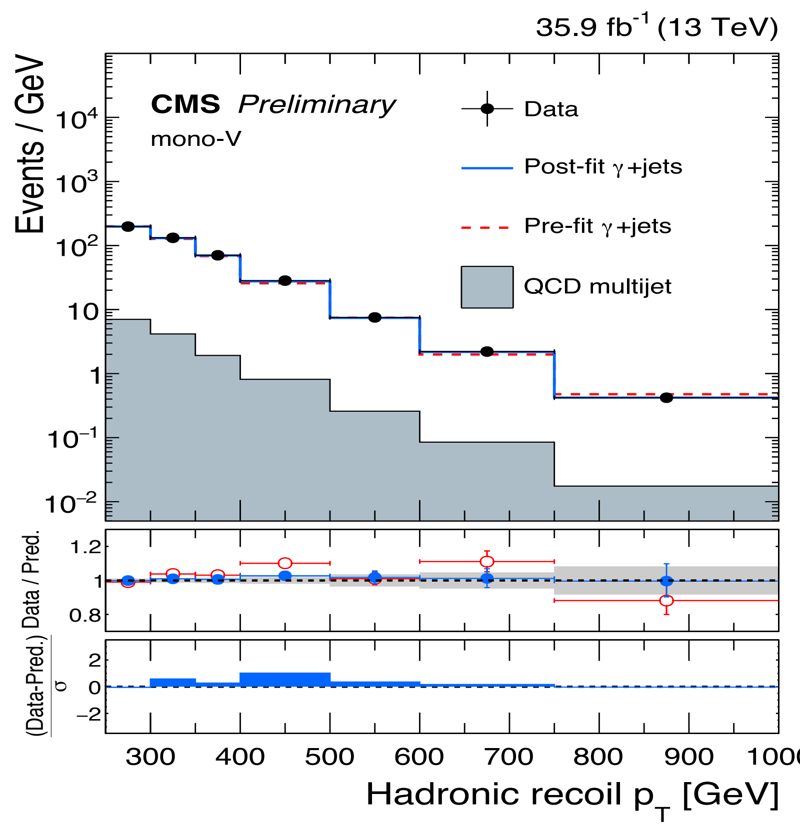
Mono-Jet/V: Background (Mono-V)

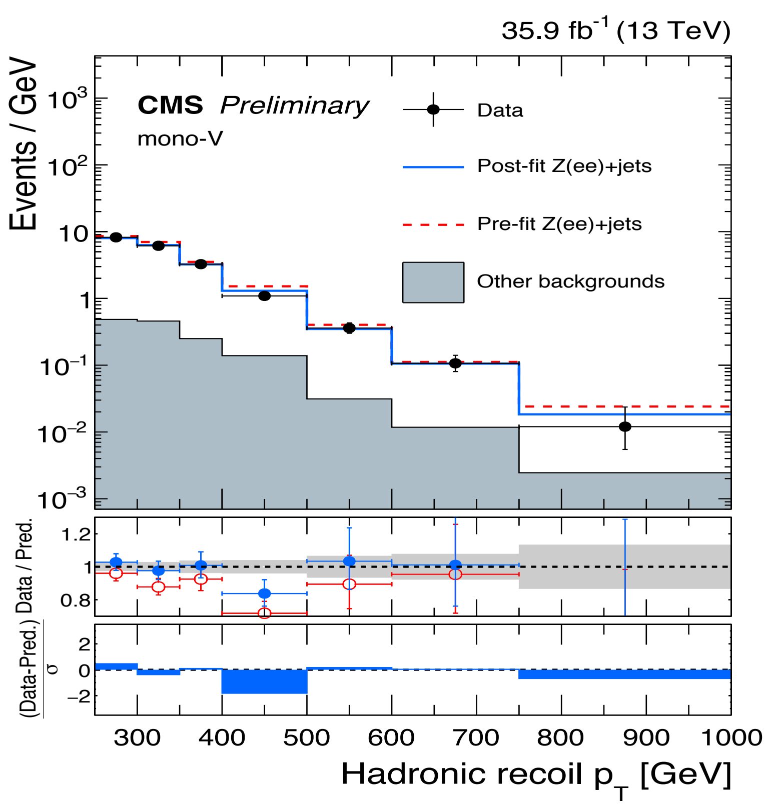


W+Jet CR

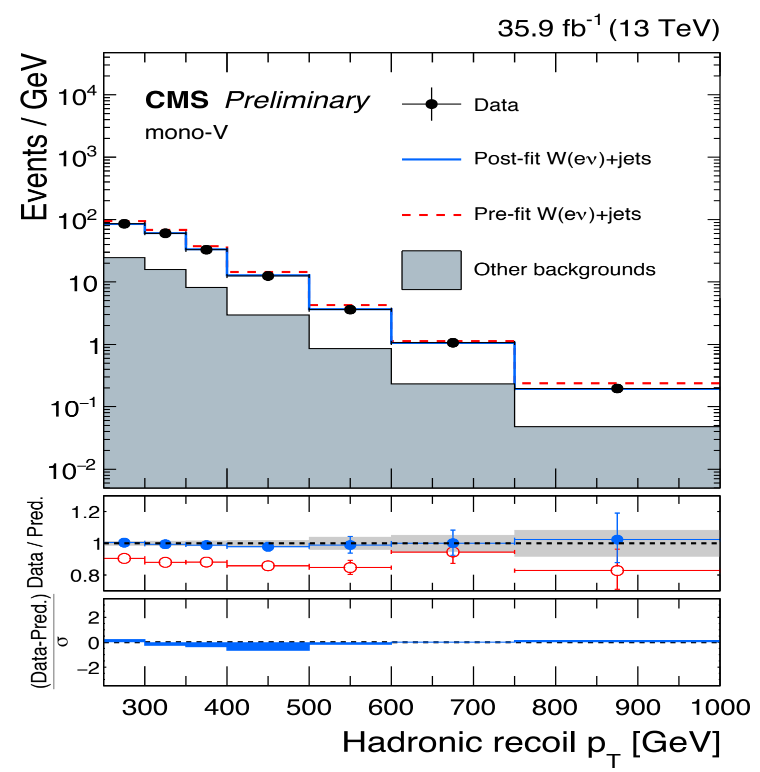


γ+Jet CR





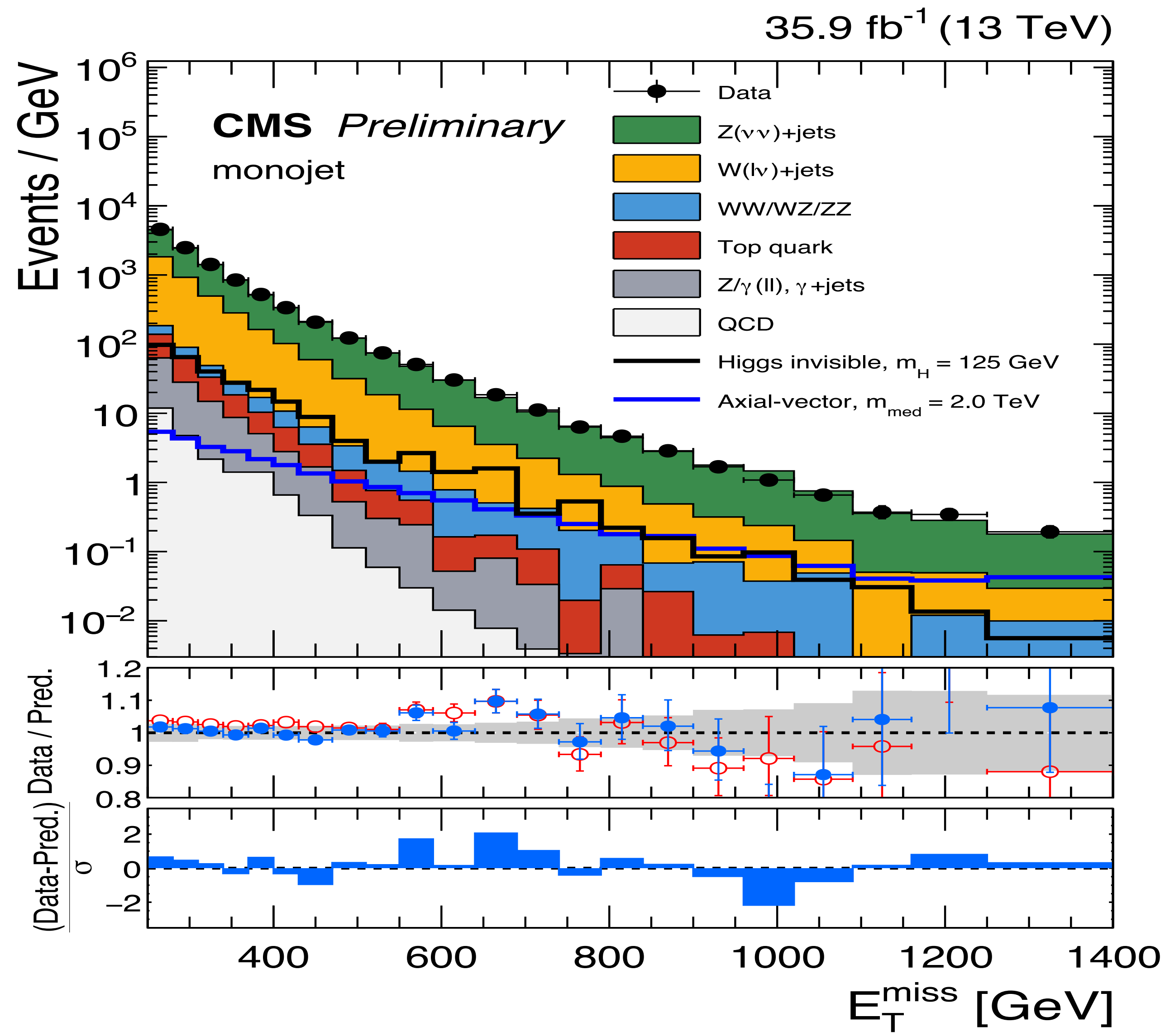
Z+Jet CR



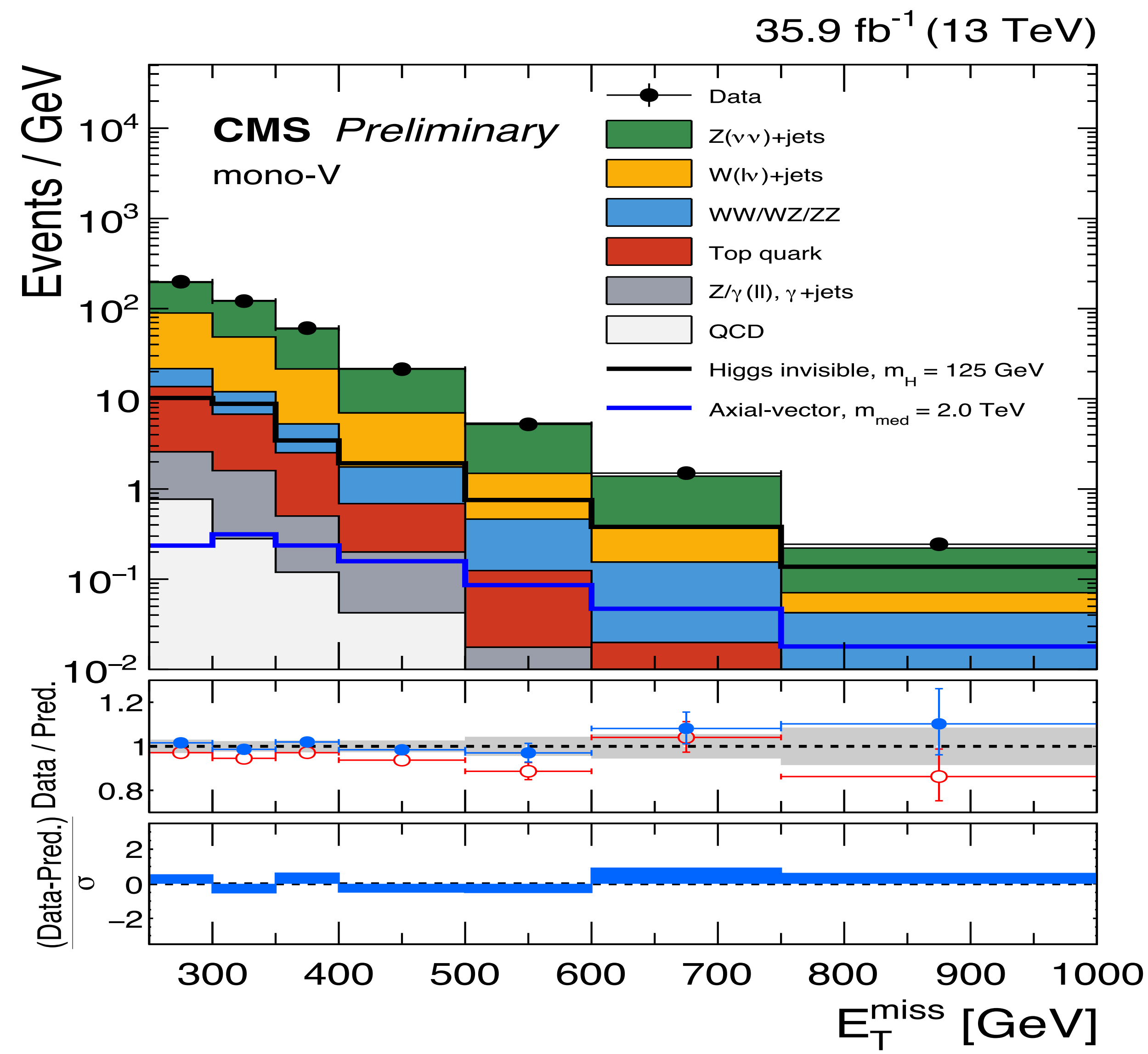
Mono-Jet/V: Background

- No excess is observed

Mono-Jet

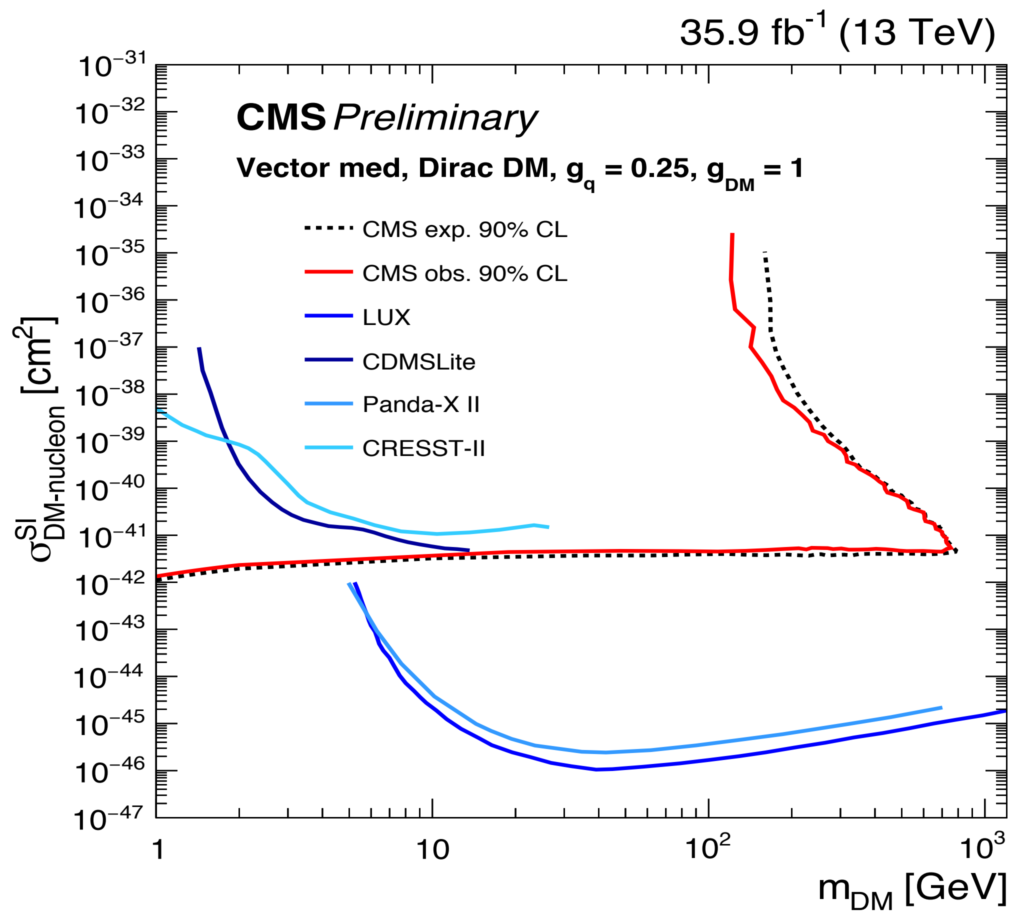


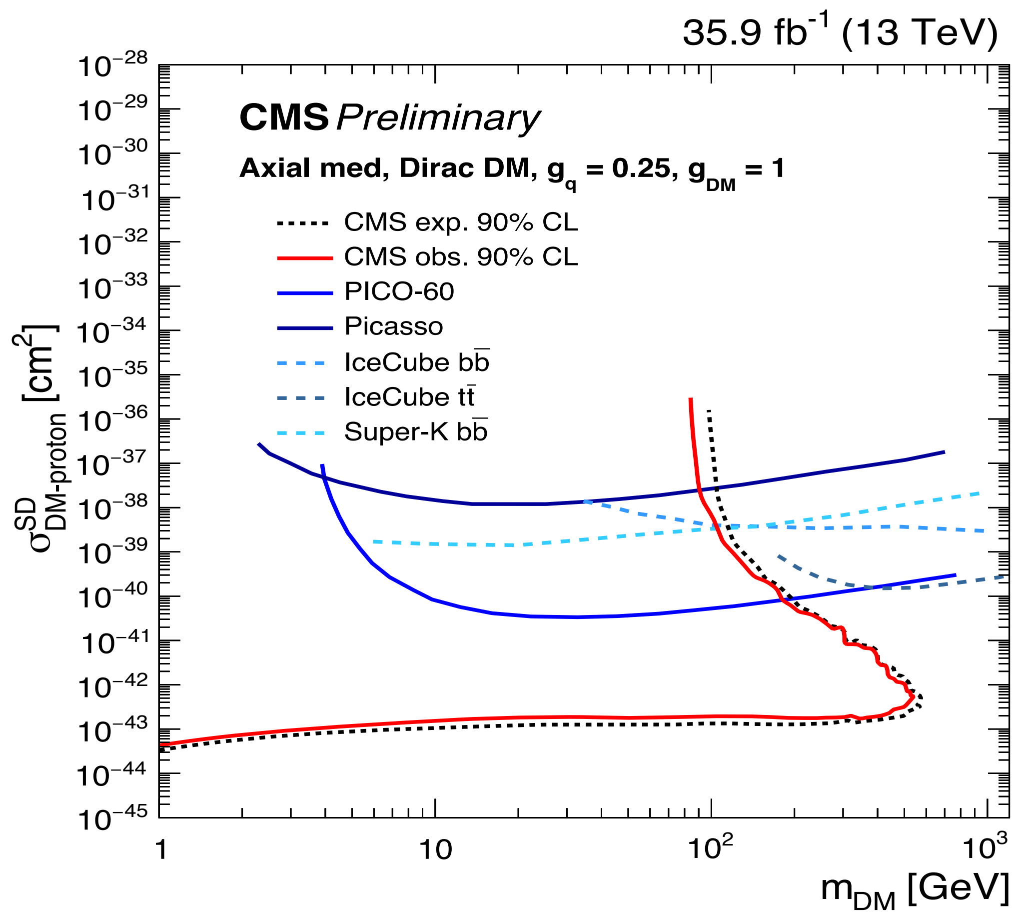
Mono-V

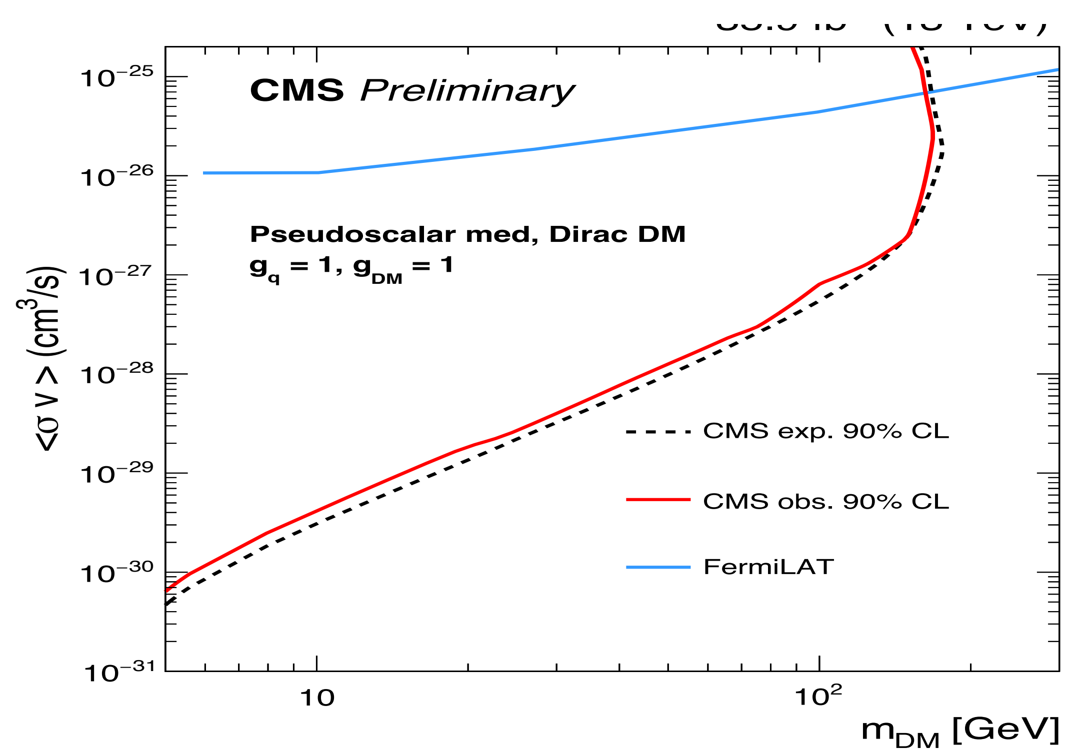


EXO-16-048

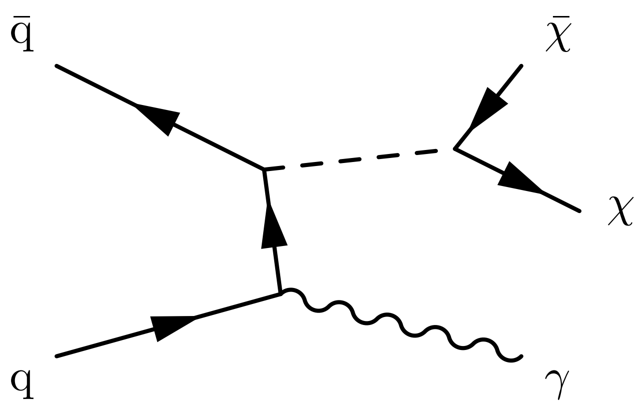
Mono-Jet/V: Results

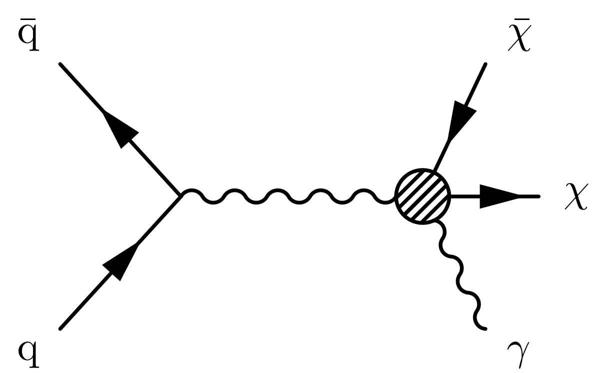






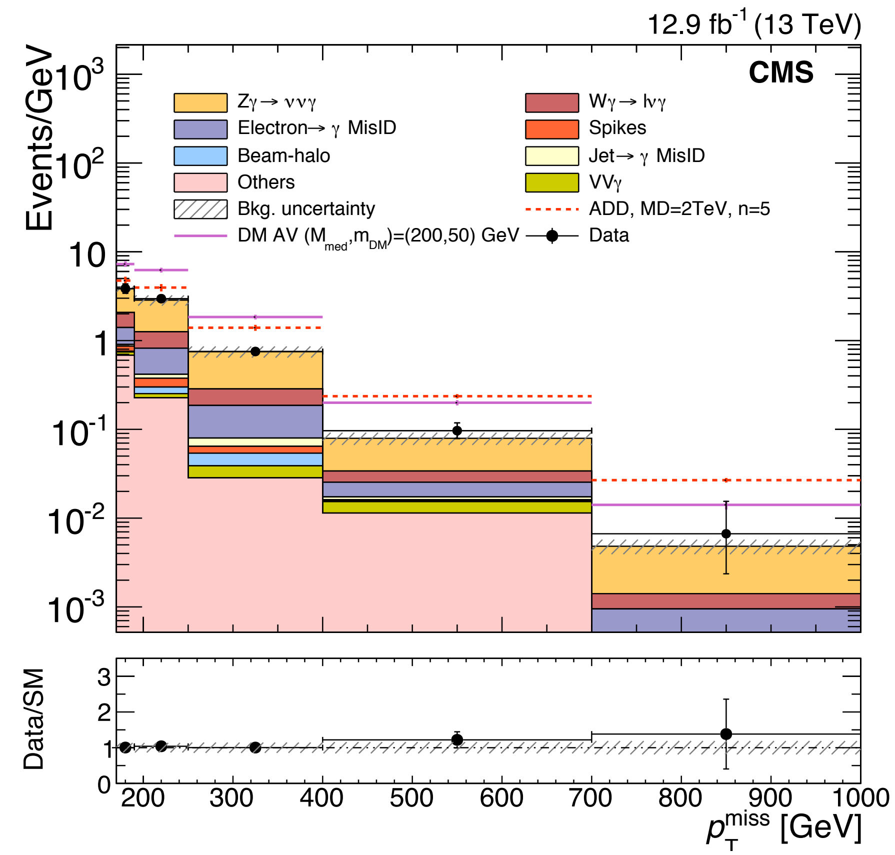
Mono-γ: Production and Selection

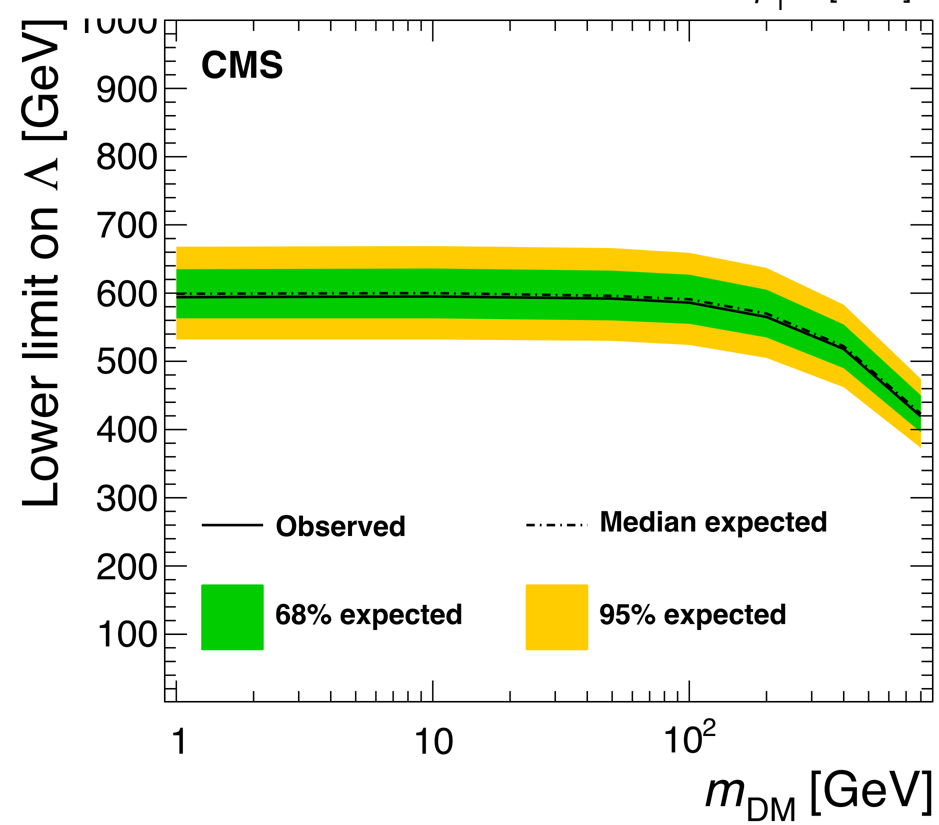




EXO-16-039

Source	Background component	Value
Integrated luminosity [21]	All simulation-based	6.2
Jet and γ energy scale, $p_{\mathrm{T}}^{\mathrm{miss}}$ resolution	All simulation-based	3–4
Data/simulation factor	All simulation-based	6
PDF, μ_R and μ_F	$\mathrm{Z}(\to \nu\overline{\nu})+\gamma, \mathrm{W}(\to \ell\nu)+\gamma$	5–9
Electroweak higher-order corrections	$\mathrm{Z}(\to \nu\overline{\nu})+\gamma, \mathrm{W}(\to \ell\nu)+\gamma$	7–11
Hadronic misidentification ratio	Jet misid.	29
Electron seeding ϵ	Electron misid.	6
ECAL spikes template shape	ECAL spikes	75
Beam halo template shape	Beam halo	$+169/-100$
$\gamma+$jets yield	$\gamma+$jets	54





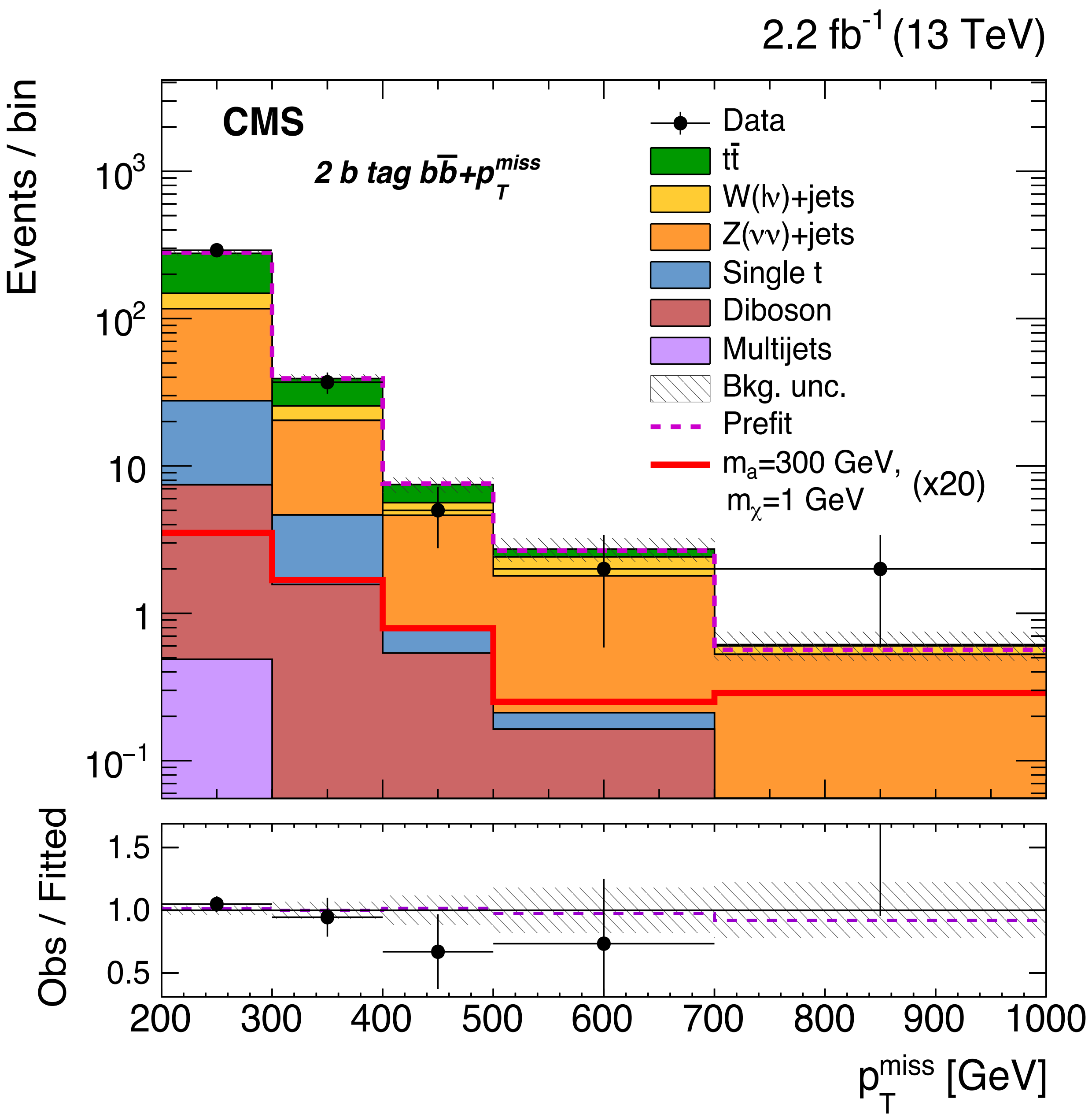
Searches with tt(/bb)+MET

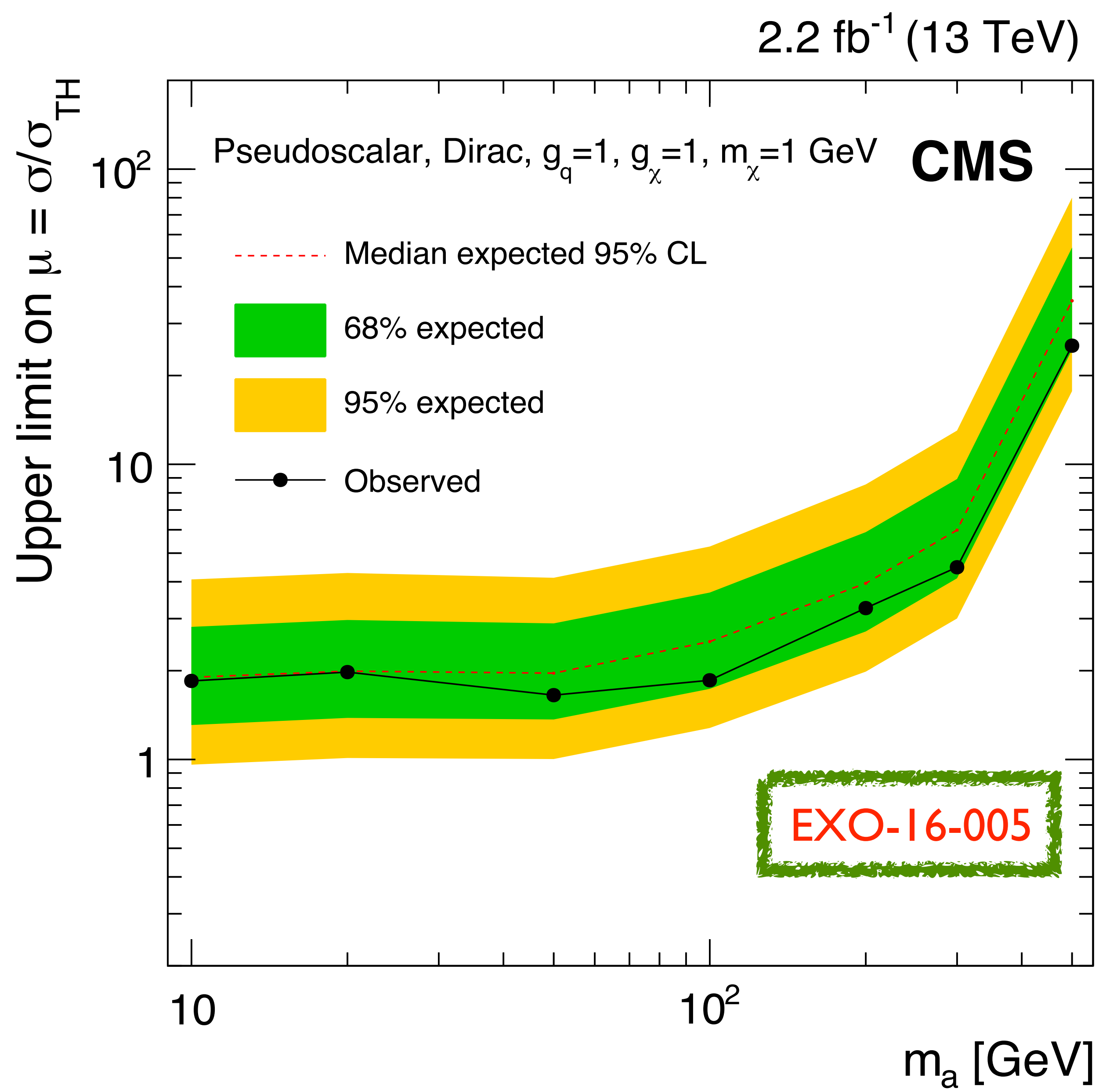
EXO-16-005

Signal regions	Leptons	Jets	b jets	p_T^{miss}	Other selections
Dileptonic $t\bar{t} + p_T^{miss}$	ee	≥ 2	≥ 1	$\geq 50\,\mathrm{GeV}$	$\min \Delta\phi(\vec{p}_T^{\ell\ell}, \vec{p}_T^{miss}) > 1.2\,\mathrm{rad}$ $m_{\ell\ell} > 20\,\mathrm{GeV}$ $\lvert m_{ee,\mu\mu} - m_Z \rvert > 15\,\mathrm{GeV}$ Dileptonic $t\bar{t}$ control region veto $Z +$ jets control region veto
	eμ				
	$\mu\mu$				
$\ell +$ jets $t\bar{t} + p_T^{miss}$	e or μ	≥ 3	≥ 1	$\geq 160\,\mathrm{GeV}$	$M_T > 160\,\mathrm{GeV}$ $M_{T2}^{W} > 200\,\mathrm{GeV}$ $\min \Delta\phi(\vec{p}_T^{jet_i}, \vec{p}_T^{miss}) > 1.2\,\mathrm{rad}$
All-hadronic $t\bar{t} + p_T^{miss}$	0	≥ 4	≥ 2	$\geq 200\,\mathrm{GeV}$	0,1RTT $\min \Delta\phi(\vec{p}_T^{jet_i}, \vec{p}_T^{miss}) > 1.0\,\mathrm{rad}$
		≥ 6	≥ 1		2RTT $\min \Delta\phi(\vec{p}_T^{jet_i}, \vec{p}_T^{miss}) > 0.4\,\mathrm{rad}$
$b\bar{b} + p_T^{miss}$	0	1 or 2	1	$\geq 200\,\mathrm{GeV}$	$\min \Delta\phi(\vec{p}_T^{jet_i}, \vec{p}_T^{miss}) > 0.5\,\mathrm{rad}$
		2 or 3	2		

Searches with tt(/bb)+MET

- **Pseudo(scalars) of masses below 128 GeV (124 GeV) are excluded for g_q,= g_{DM} =1.5**

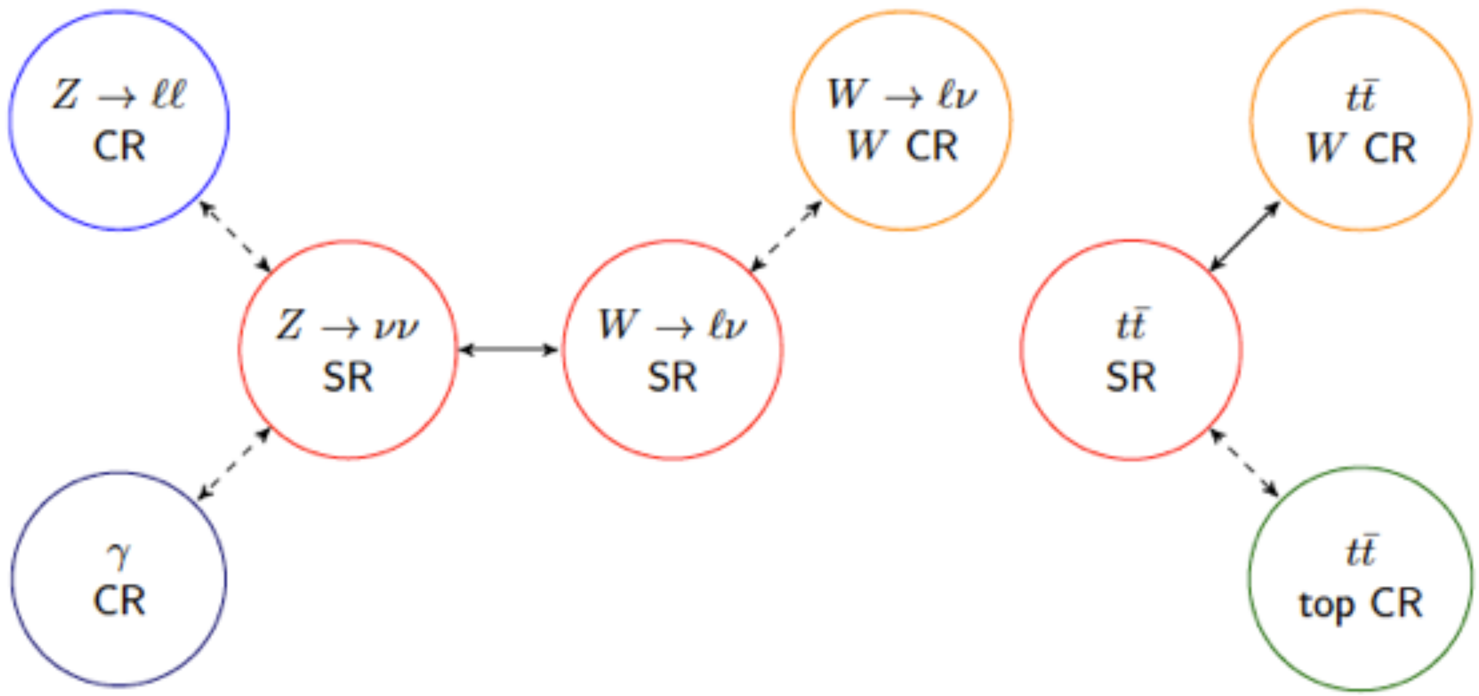




Search with t(had.)+MET

EXO-16-051

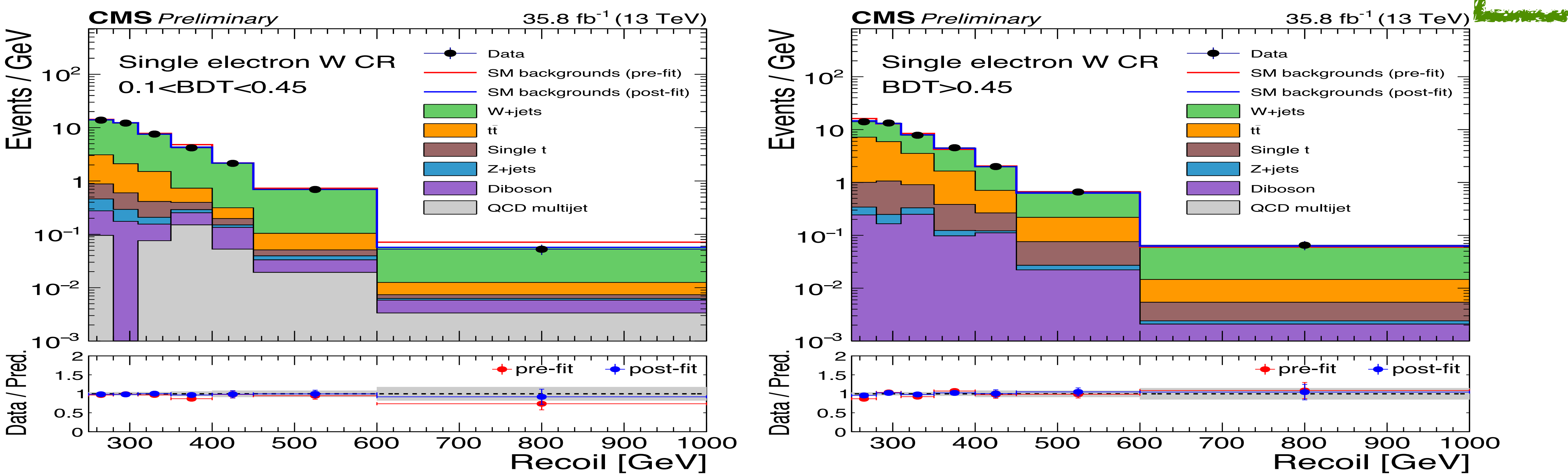
- Analysis Strategy:



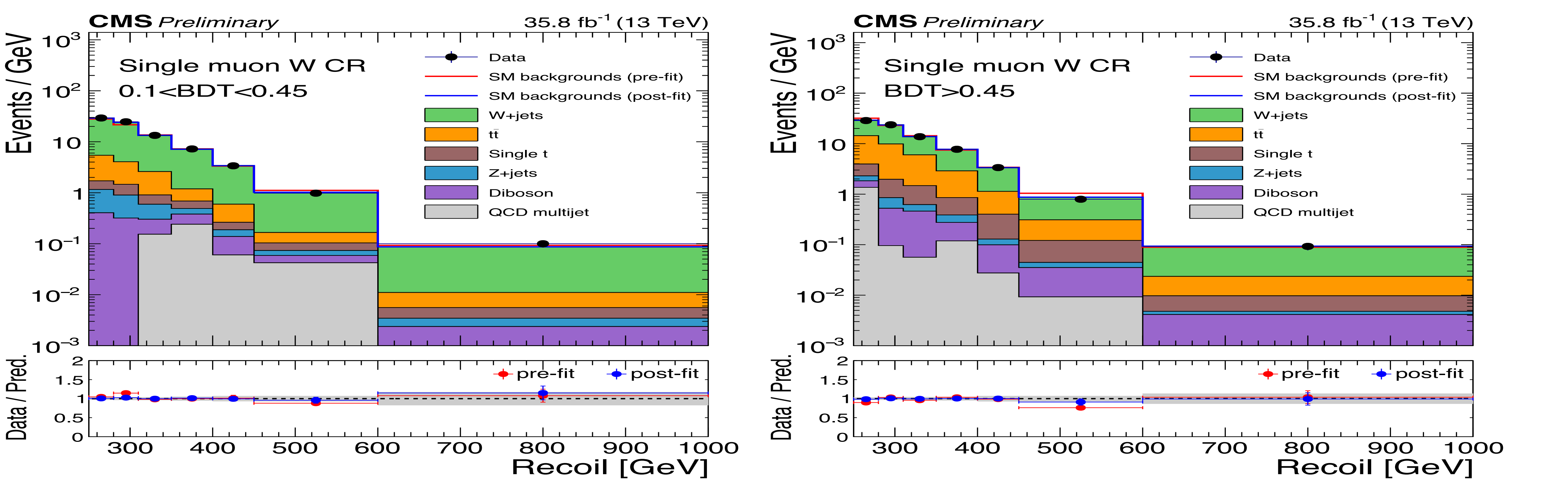
Region(s)	Main process(es)	N_e	N_μ	N_γ	$N^{\mathrm{iso}}_{\text{b-tag}}$	Fat jet b-tag
Signal	$W \to (\ell)\nu$, $Z \to \nu\nu$, $t\bar{t} \to (b)qq' + b(\ell)\nu$	0	0	0	0	1
Single-e (b-tagged)	$t\bar{t} \to bqq' + be\nu$	1	0	0	1	1
Single-μ (b-tagged)	$t\bar{t} \to bqq' + b\mu\nu$	0	1	0	1	1
Single-e (anti-b-tagged)	$W \to e\nu$	1	0	0	0	0
Single-μ (anti-b-tagged)	$W \to \mu\nu$	0	1	0	0	0
Dielectron	$Z \to ee$	2	0	0	0	–
Dimuon	$Z \to \mu\mu$	0	2	0	0	–
Photon	γ	0	0	1	0	–

Search with t(had.)+MET

EXO-16-051



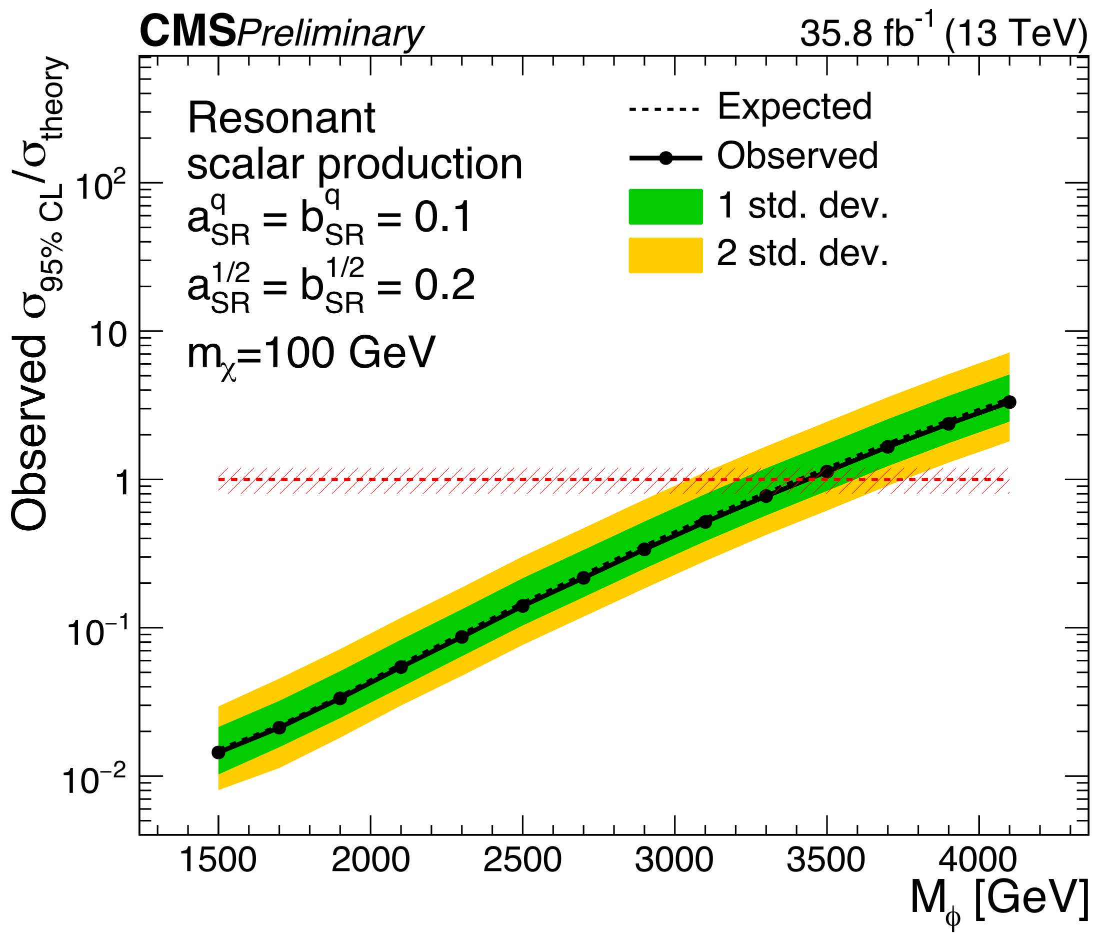
(a)

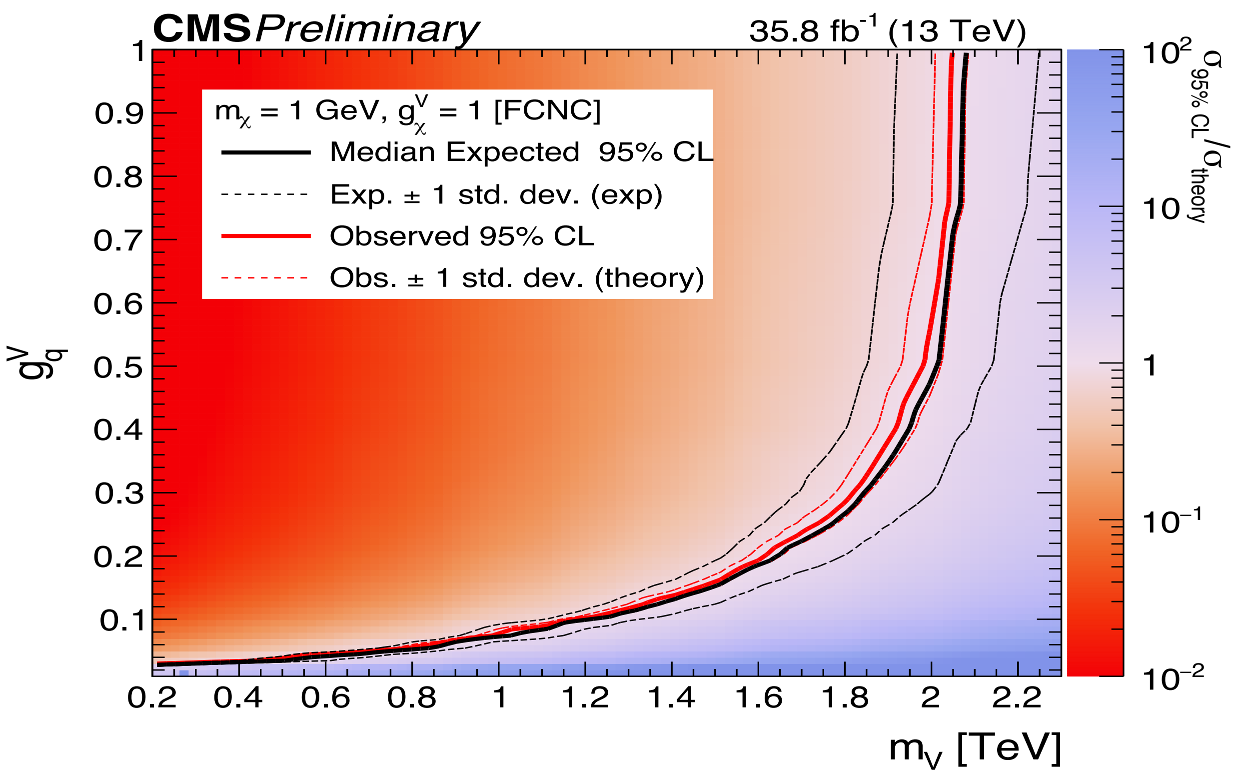


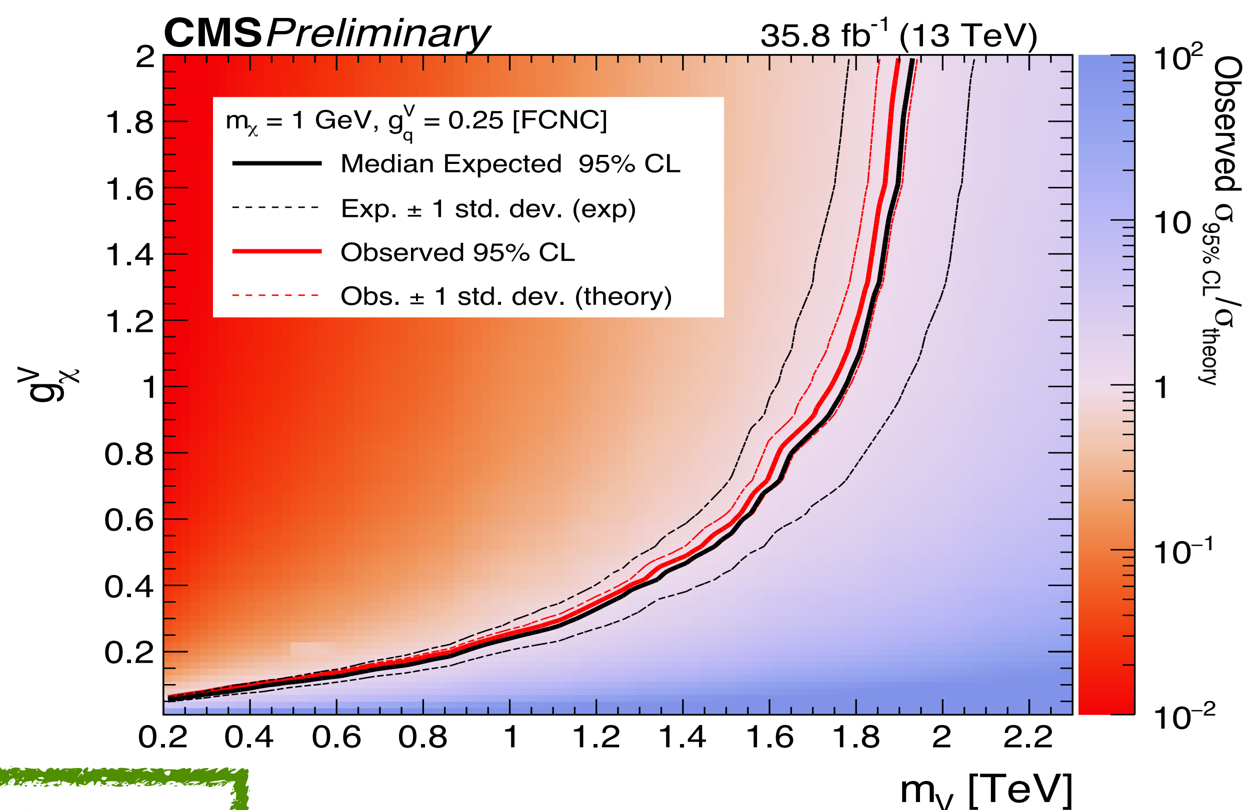
(b)

Search with t(had.)+MET

- **For non-resonance(FCNC) Mediator masses upto 1.75 TeV are excluded**
- **For resonant scaler mediator limits are set < 3.4 TeV**



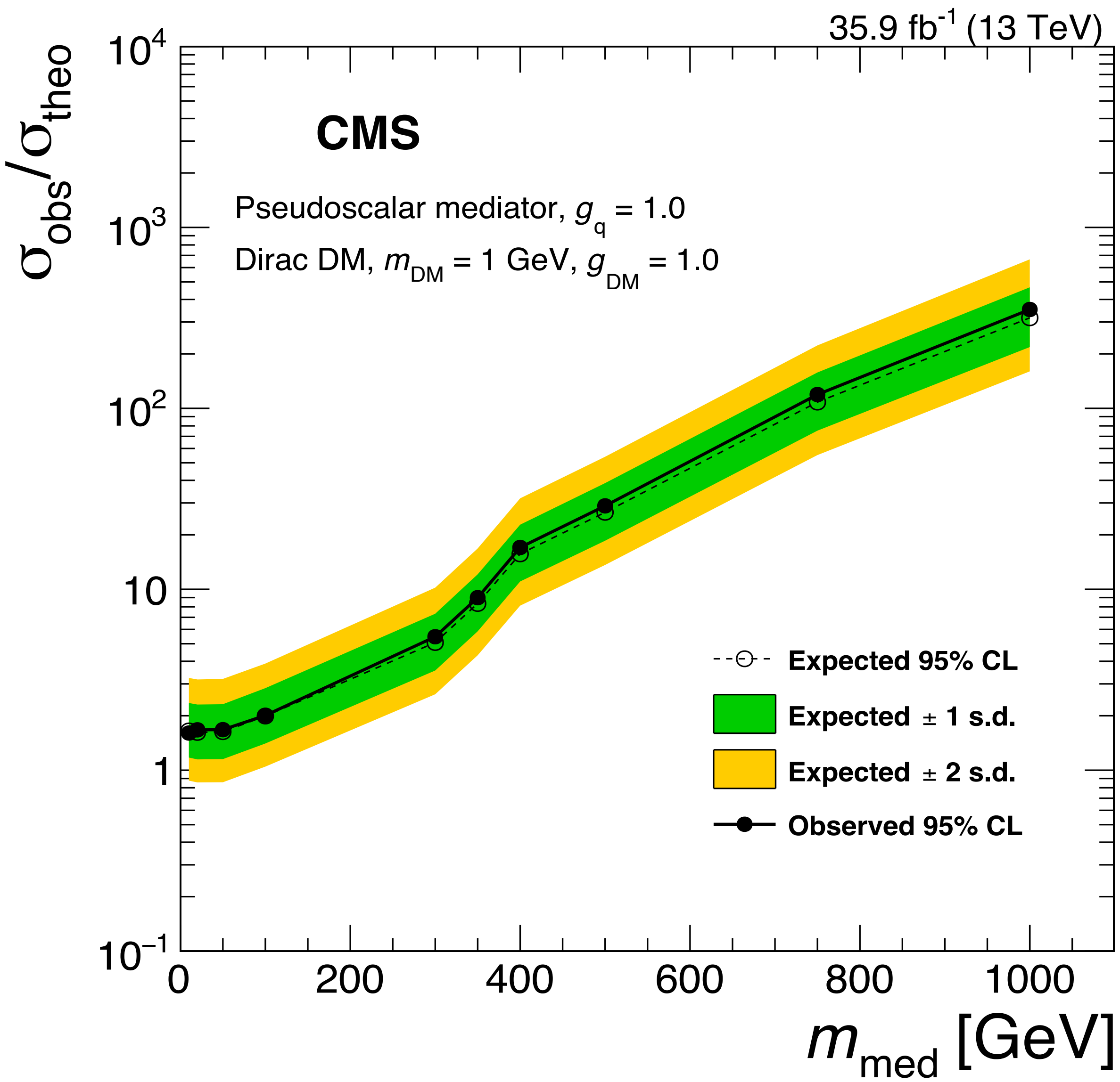


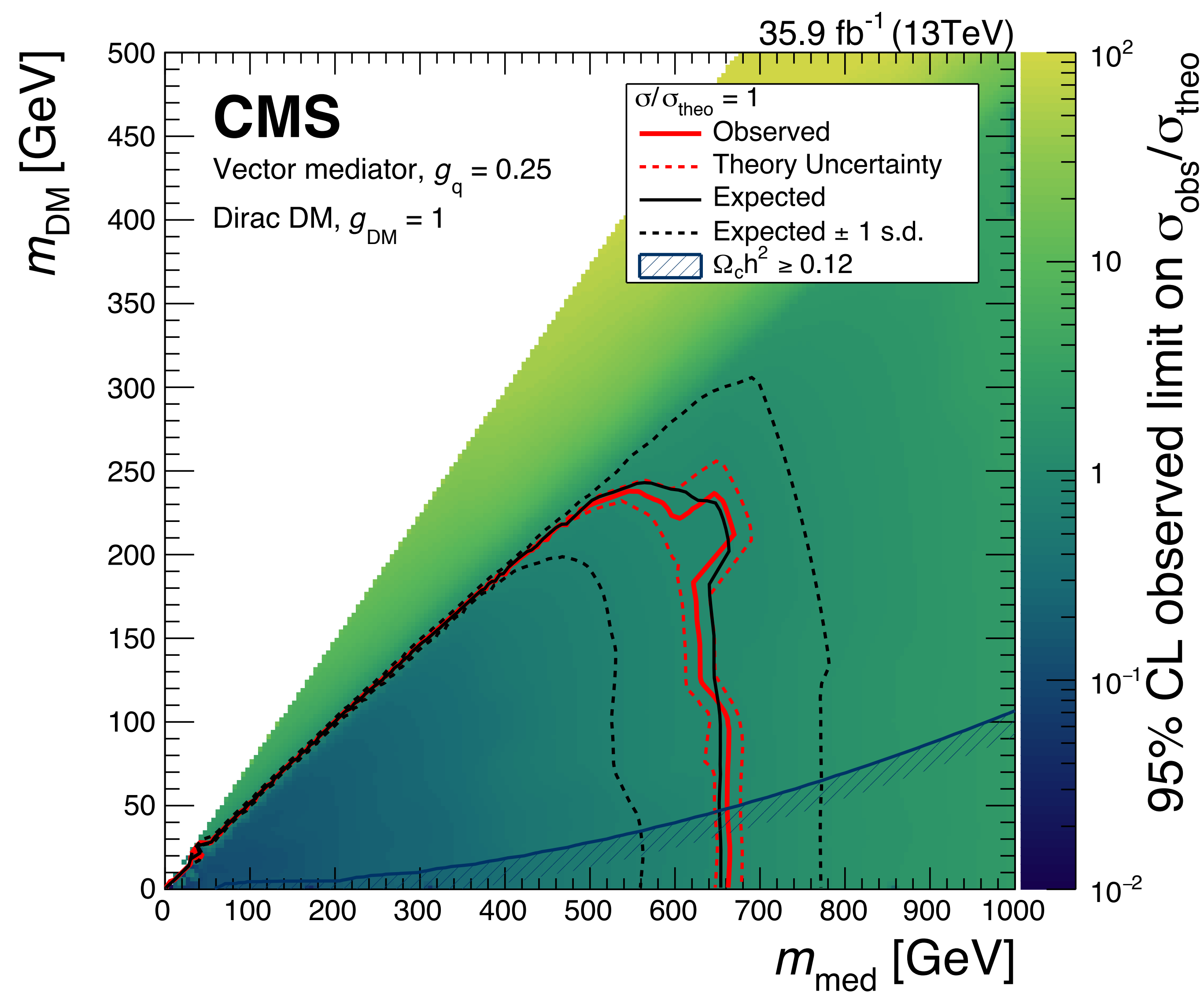


EXO-16-051

Mono-Z(→ll)

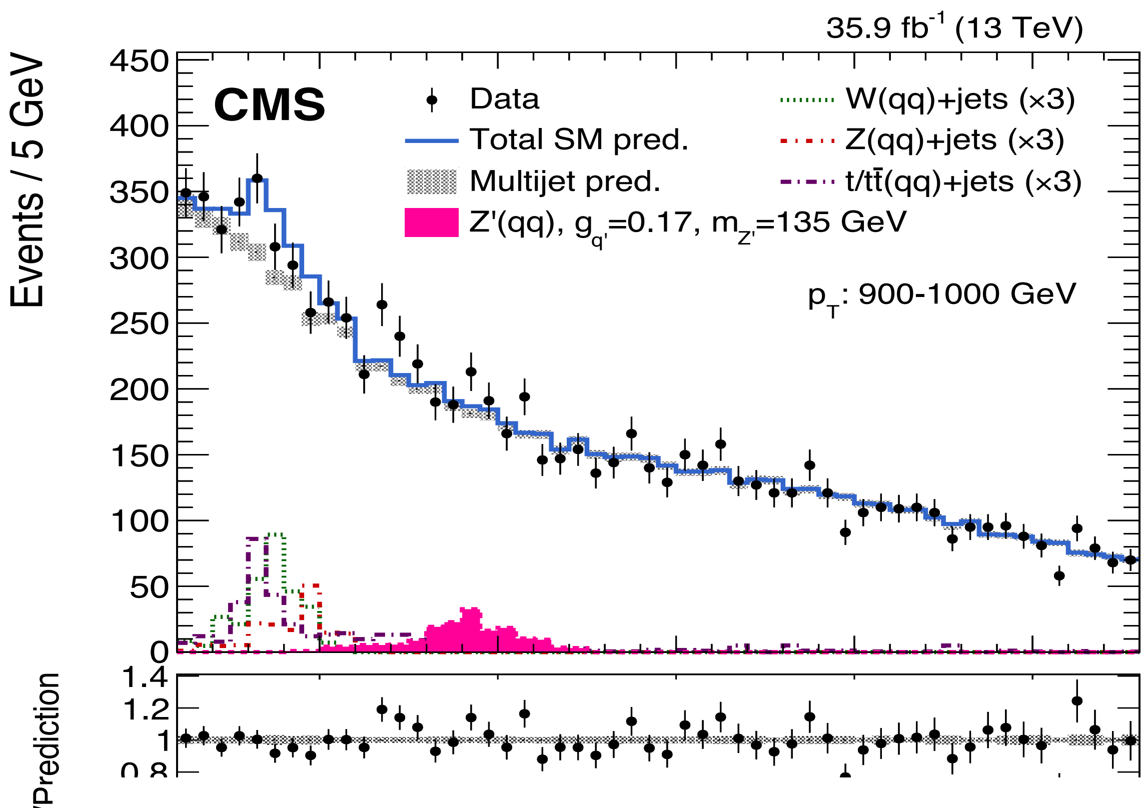
EXO-16-052



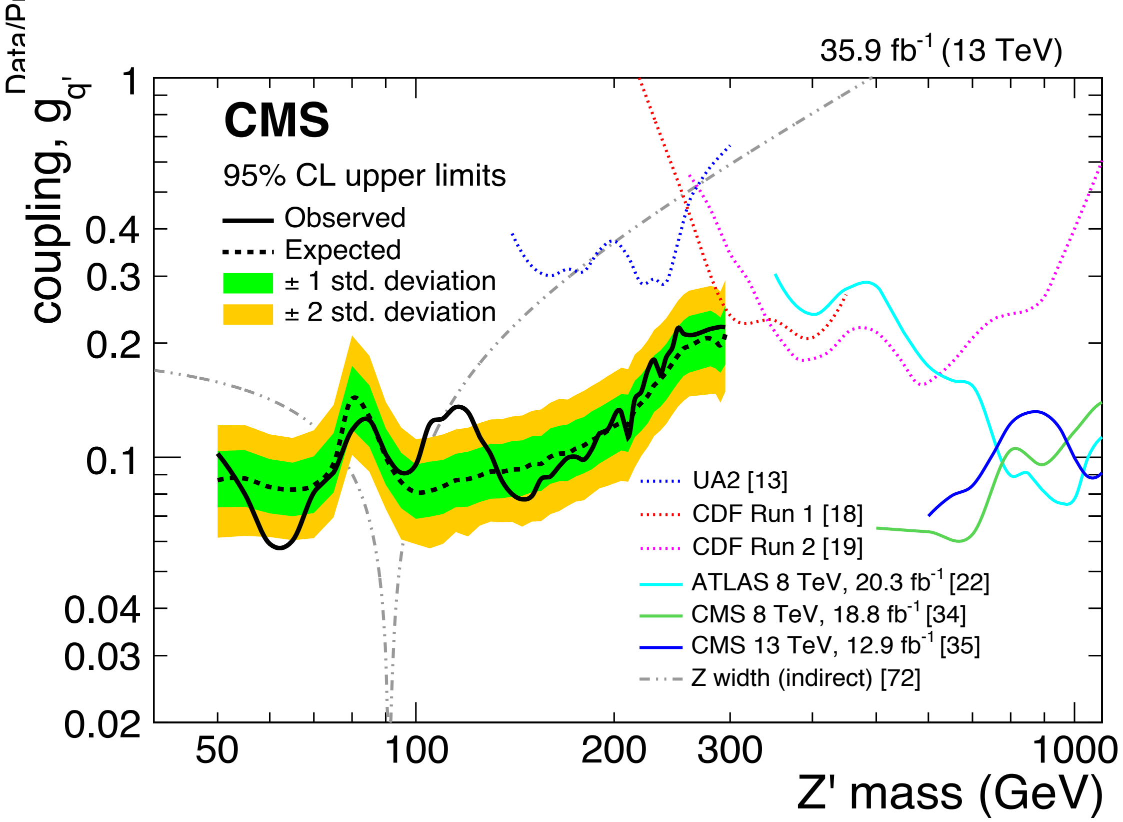


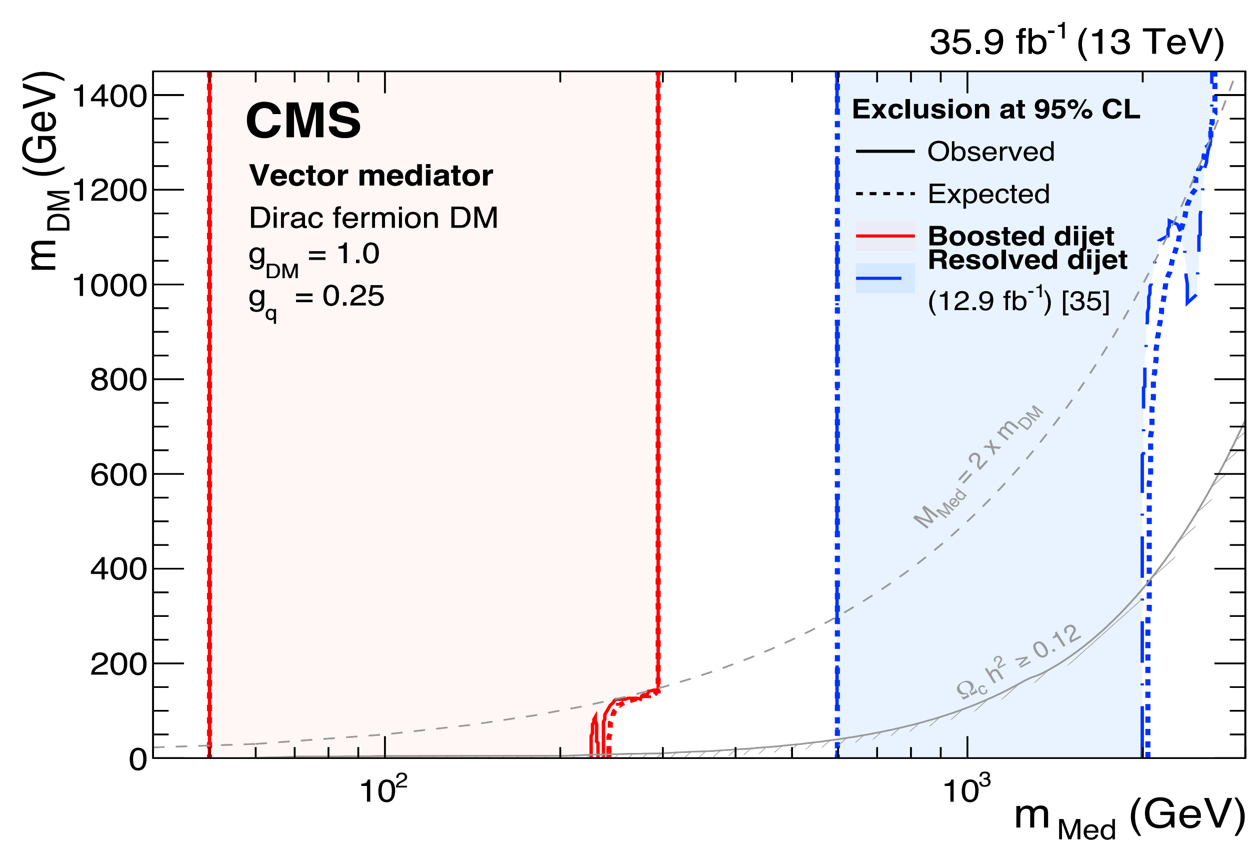
Dijet: DM Interpretation

EXO-17-001



Systematic source	Multijet	Z′	W/Z	$t\bar{t}$
Lepton veto efficiency	—	0.5%	0.5%	—
Jet mass scale†	—	0.5%	0.5%	—
Jet mass scale (p_T dependence) †△	—	0.5–2%	0.5–2%	—
Trigger efficiency	—	2%	2%	—
Top quark mistag rate	—	—	—	2%
Integrated luminosity	—	2.5%	2.5%	—
Multijet fit parameters	1–3%	—	—	—
$N_2^{1,DDT}$ selection efficiency	—	9%	9%	—
Top quark background normalization	—	—	—	10%
Jet energy resolution†	—	10%	10%	—
NLO QCD corrections	—	10%	10%	—
NLO EW corrections△	—	—	15–35%	—
NLO EW W/Z decorrelation	—	—	5–15%	—

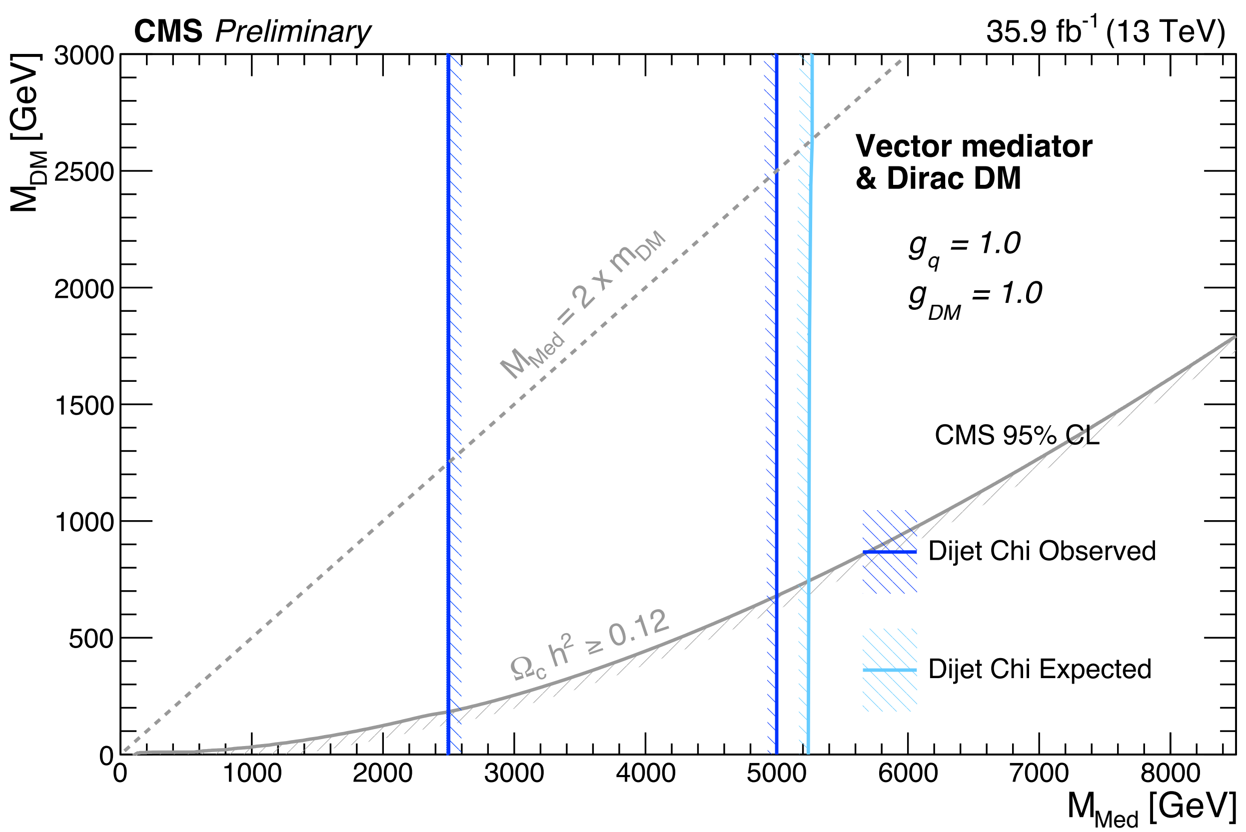


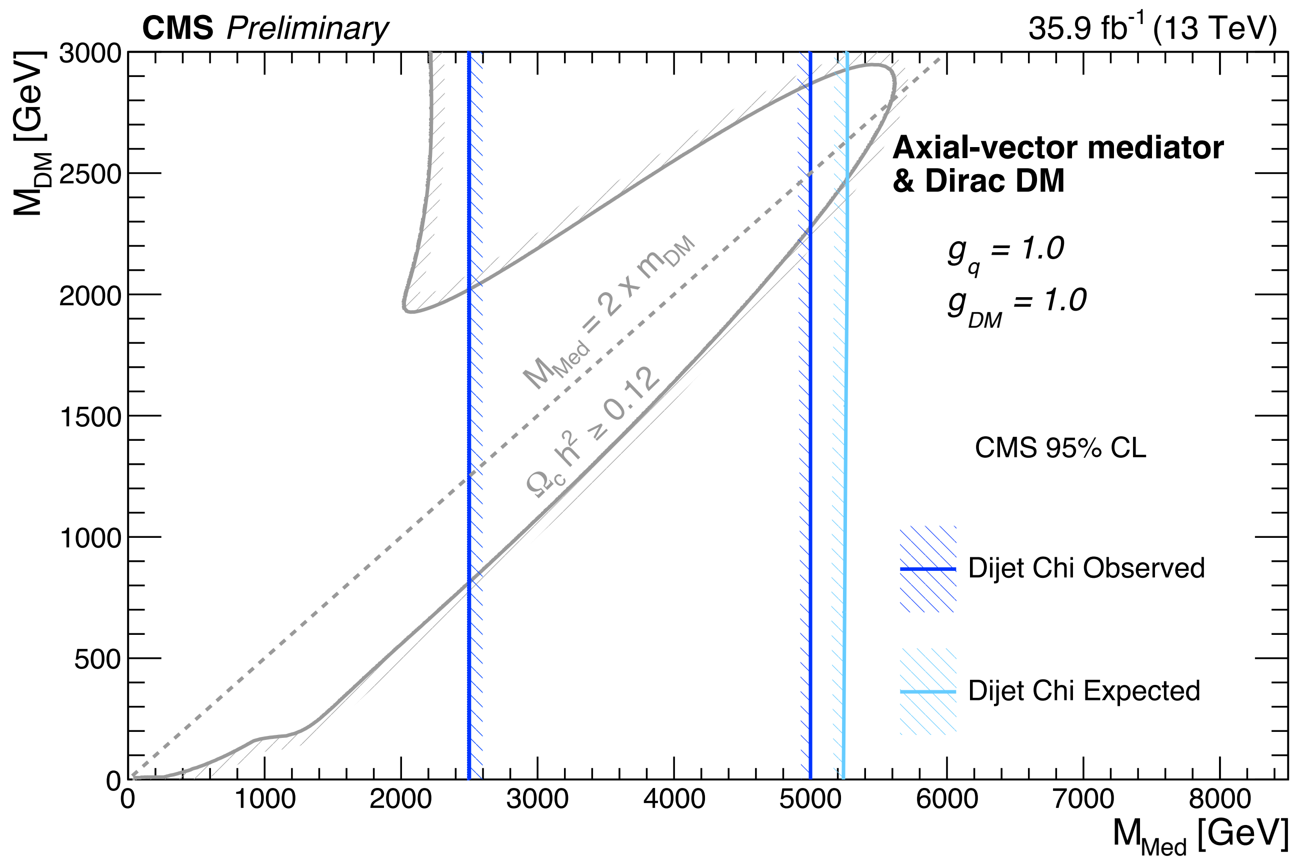


Dijet: DM Interpretation

EXO-16-046

Source of uncertainty	$2.4 < M_{jj} < 3.0$ TeV	$M_{jj} > 6.0$ TeV
Statistical	0.7%	27%
Jet energy scale	3.6%	9.2%
Jet energy resolution (core)	1.0%	1.0%
Jet energy resolution (tails)	1.0%	1.5%
Unfolding, modelling	0.2%	1.5%
Unfolding, detector simulation	0.5%	1.0%
Pileup	<1%	<1%
Total experimental	4.1%	29%
QCD NLO scale (6 changes in μ_R and μ_F)	$^{+8.5\%}_{-3.0\%}$	$^{+19\%}_{-5.8\%}$
PDF (CT14 eigenvectors)	0.2%	0.6%
Non-perturbative effects	<1%	<1%
Total theoretical	8.5%	19%

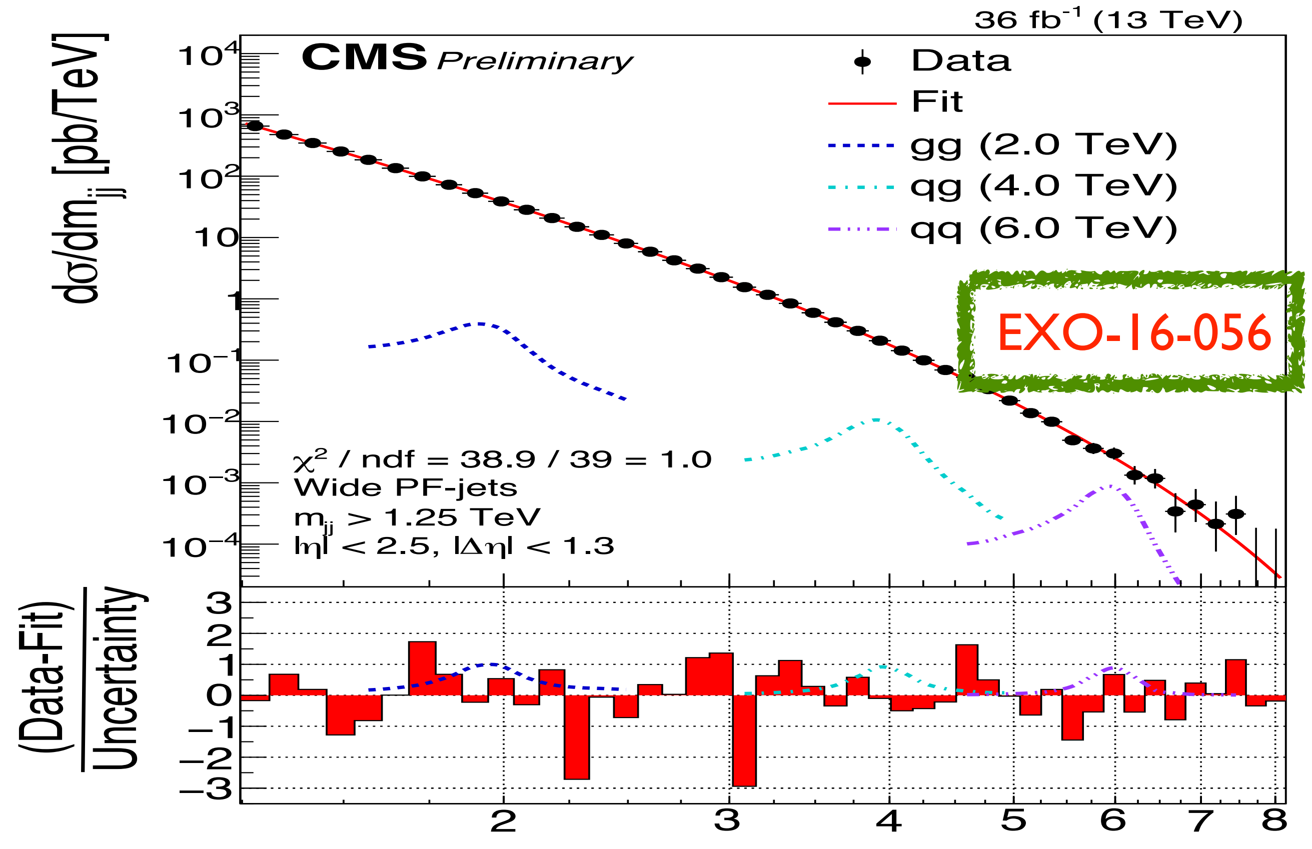


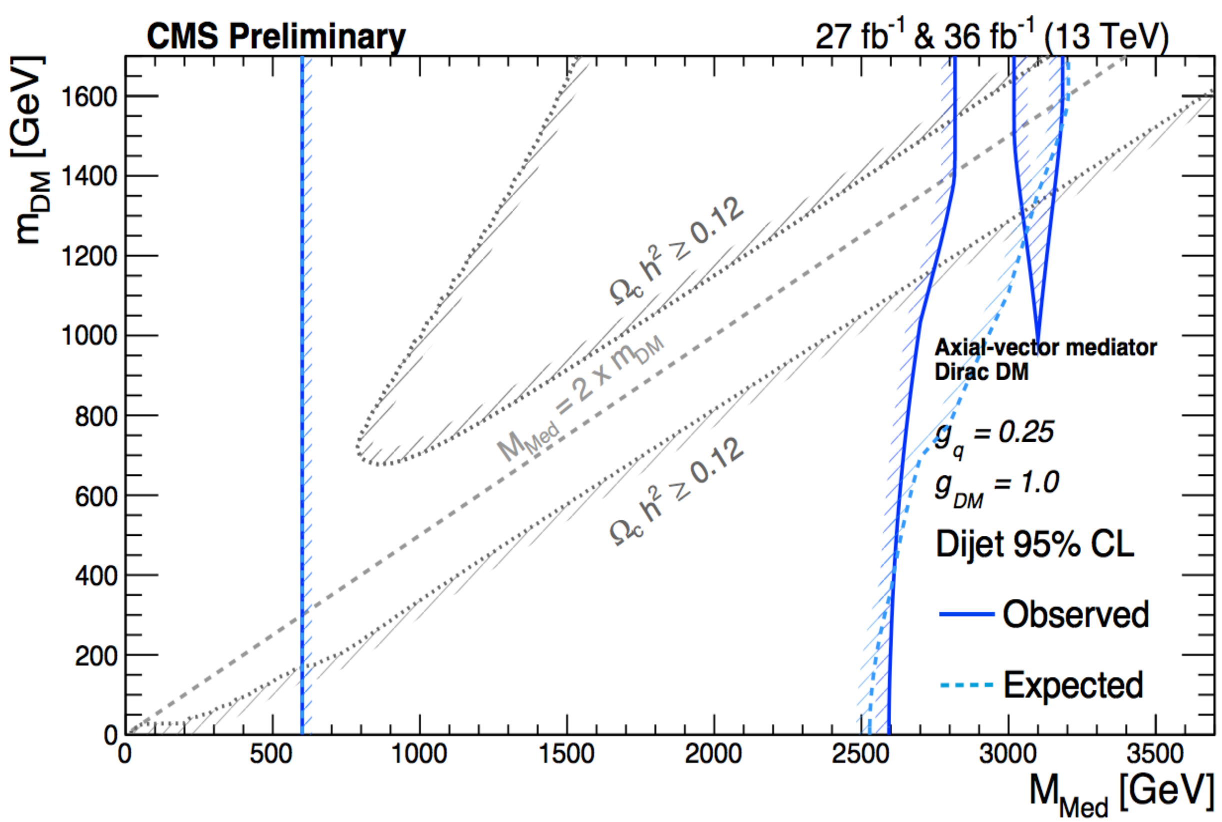


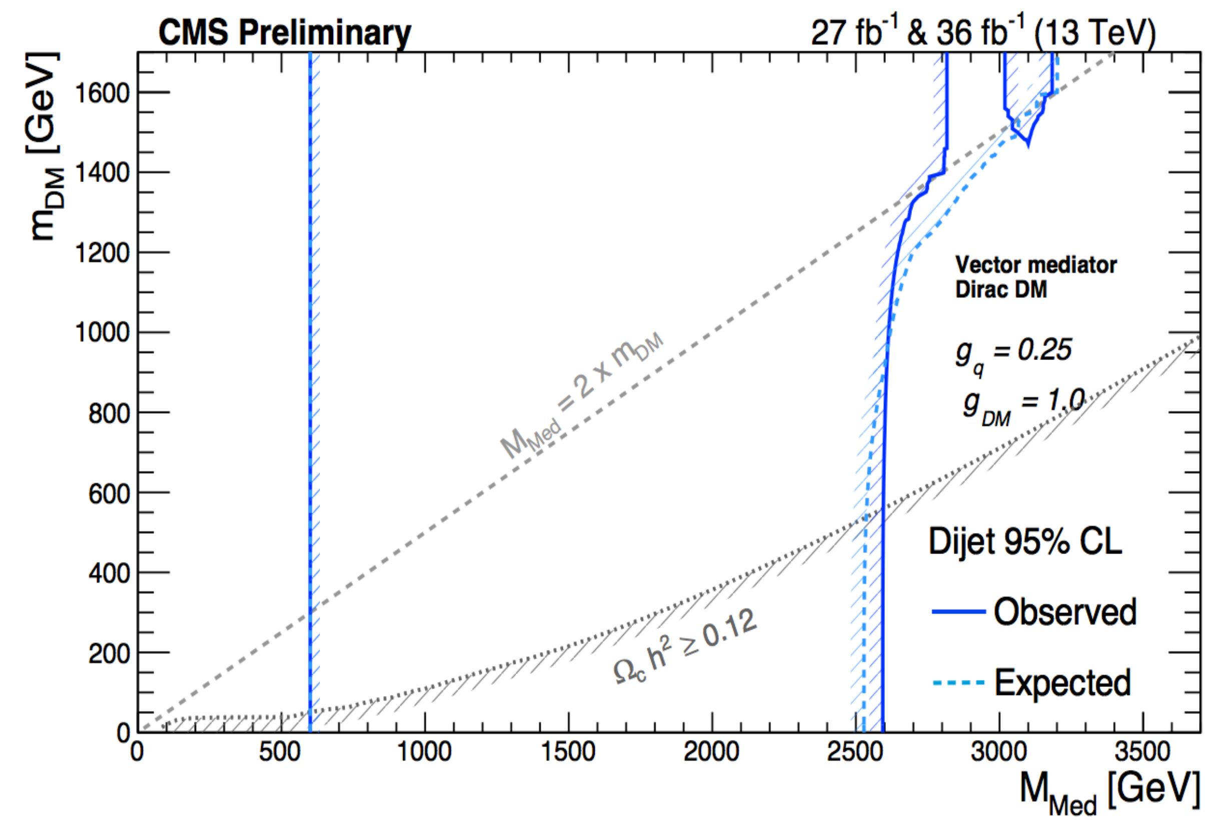
Dijet: DM Interpretation

- Mediator (vector, axial-vector) of masses upto 2.7 TeV are excluded

- Ne excess is observed







Simplified Model

Vector Mediator

$$\mathcal{L}_{\text{vector}} = -g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu \chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q\,,$$

$$\Gamma^{\chi\bar{\chi}}_{\text{vector}} = \frac{g_{\text{DM}}^2 M_{\text{med}}}{12\pi}(1-4z_{\text{DM}})^{1/2}(1+2z_{\text{DM}})\ ,$$

$$\Gamma^{q\bar{q}}_{\text{vector}} = \frac{g_q^2 M_{\text{med}}}{4\pi}(1-4z_q)^{1/2}(1+2z_q)\ ,$$

$$z_{\text{DM},q} = m_{\text{DM},q}^2/M_{\text{med}}^2$$

$$\sigma_{\text{SI}} \simeq 6.9\times10^{-41}\ \text{cm}^2\cdot\left(\frac{g_q g_{\text{DM}}}{0.25}\right)^2\left(\frac{1\,\text{TeV}}{M_{\text{med}}}\right)^4\left(\frac{\mu_{n\chi}}{1\,\text{GeV}}\right)^2$$

Axial-Vector Mediator

$$\mathcal{L}_{\text{axial-vector}} = -g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu\gamma_5 \chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu\gamma_5 q\,.$$

$$\Gamma^{\chi\bar{\chi}}_{\text{axial-vector}} = \frac{g_{\text{DM}}^2 M_{\text{med}}}{12\pi}(1-4z_{\text{DM}})^{3/2}\ ,$$

$$\Gamma^{q\bar{q}}_{\text{axial-vector}} = \frac{g_q^2 M_{\text{med}}}{4\pi}(1-4z_q)^{3/2}\ .$$

$$z_{\text{DM},q} = m_{\text{DM},q}^2/M_{\text{med}}^2$$

$$\sigma^{\text{SD}} \simeq 2.4\times10^{-42}\ \text{cm}^2\cdot\left(\frac{g_q g_{\text{DM}}}{0.25}\right)^2\left(\frac{1\,\text{TeV}}{M_{\text{med}}}\right)^4\left(\frac{\mu_{n\chi}}{1\,\text{GeV}}\right)^2$$

DM Operators

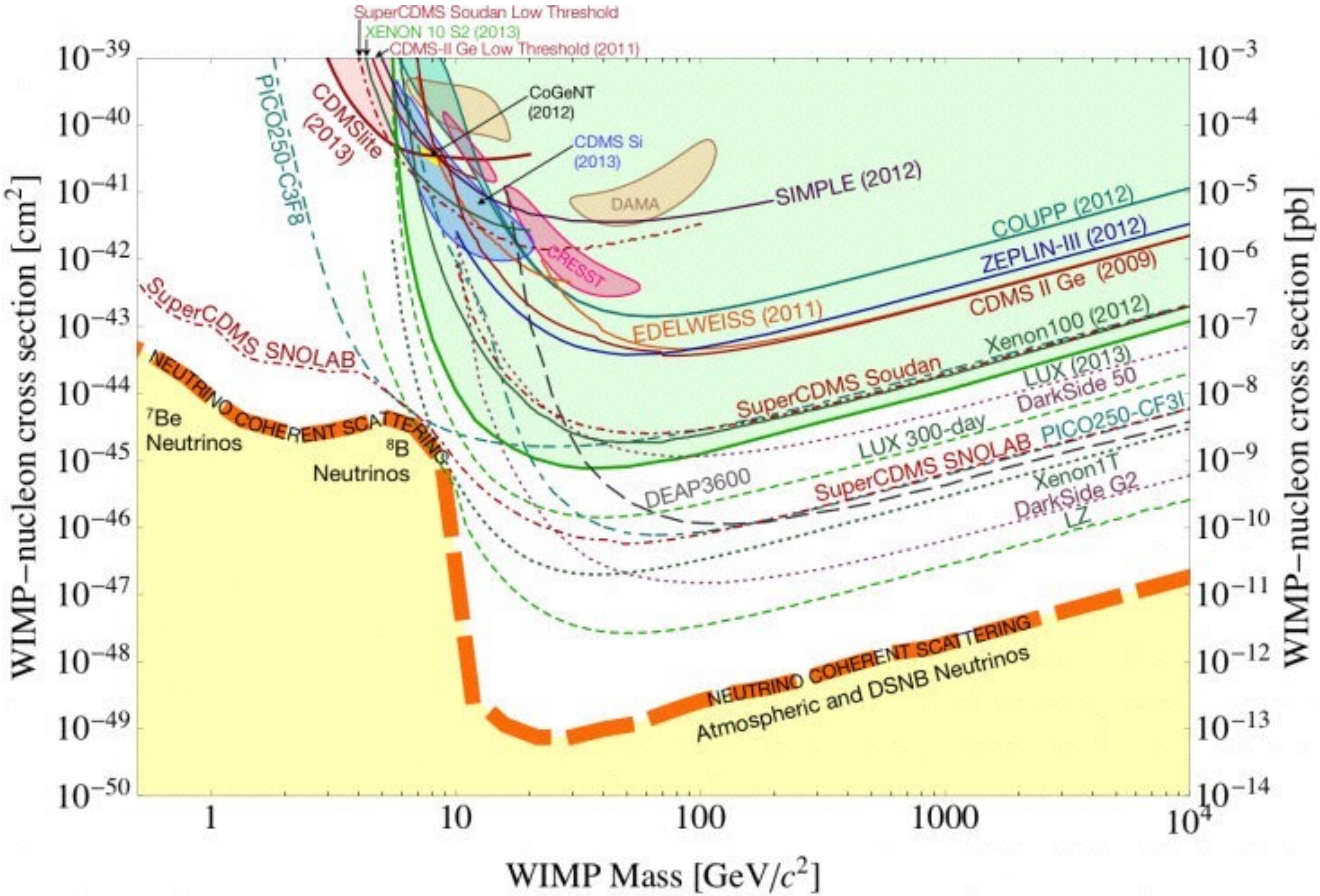
Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

Name	Operator	Coefficient
C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
C2	$\chi^\dagger\chi\bar{q}\gamma^5 q$	im_q/M_*^2
C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
C4	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu\gamma^5 q$	$1/M_*^2$
C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$
C6	$\chi^\dagger\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^2$
R1	$\chi^2\bar{q}q$	$m_q/2M_*^2$
R2	$\chi^2\bar{q}\gamma^5 q$	$im_q/2M_*^2$
R3	$\chi^2 G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/8M_*^2$
R4	$\chi^2 G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/8M_*^2$

$$\sigma_0^{D1} = 1.60\times10^{-37}\text{cm}^2\left(\frac{\mu_\chi}{1\text{GeV}}\right)^2\left(\frac{20\text{GeV}}{M_*}\right)^6,$$
$$\sigma_0^{D5,C3} = 1.38\times10^{-37}\text{cm}^2\left(\frac{\mu_\chi}{1\text{GeV}}\right)^2\left(\frac{300\text{GeV}}{M_*}\right)^4,$$
$$\sigma_0^{D8,D9} = 9.18\times10^{-40}\text{cm}^2\left(\frac{\mu_\chi}{1\text{GeV}}\right)^2\left(\frac{300\text{GeV}}{M_*}\right)^4,$$
$$\sigma_0^{D11} = 3.83\times10^{-41}\text{cm}^2\left(\frac{\mu_\chi}{1\text{GeV}}\right)^2\left(\frac{100\text{GeV}}{M_*}\right)^6,$$
$$\sigma_0^{C1,R1} = 2.56\times10^{-36}\text{cm}^2\left(\frac{\mu_\chi}{1\text{GeV}}\right)^2\left(\frac{10\text{GeV}}{m_\chi}\right)^2\left(\frac{10\text{GeV}}{M_*}\right)^4,$$
$$\sigma_0^{C5,R3} = 7.40\times10^{-39}\text{cm}^2\left(\frac{\mu_\chi}{1\text{GeV}}\right)^2\left(\frac{10\text{GeV}}{m_\chi}\right)^2\left(\frac{60\text{GeV}}{M_*}\right)^4.$$

arXiv:1008.1783

DD Summary



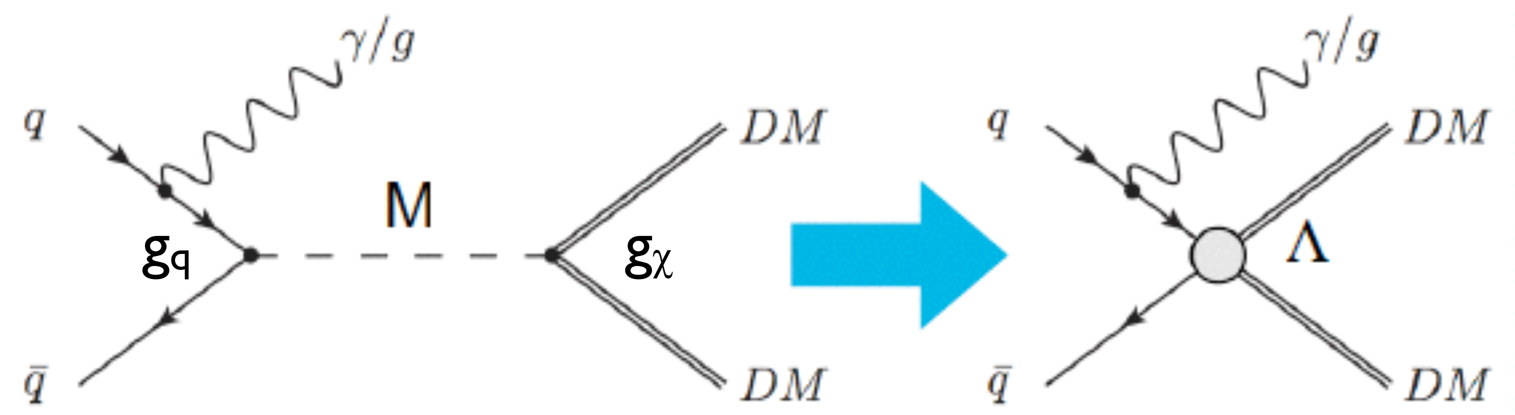
Limit: MLQ >350 @ 95%CL

Dark Matter: Effective Field Theory

- **Effective Field Theory (EFT) Approach:**
  - **Contact interaction with scale Λ, integrating out heavy mediator particle ($M^2 >> Q^2$)**
  - **Simple model with only few parameters e.g. DM mass (m_χ), Λ**
  - **DM could be a fermion, complex or scalar**
  - **Simple mapping of LHC results to χ-nucleon scattering cross section**

$$\sigma(pp \to \bar{\chi}\chi + X) \sim \frac{g_q^2 g_\chi^2}{(q^2 - M^2)^2 + \Gamma^2/4} E^2 \approx \Lambda^{-4} E^2$$

$$\boxed{\Lambda = M/\sqrt{g_\chi g_q}}$$



$$\frac{1}{Q^2 - M^2} = -\frac{1}{M^2}\left(1 + \frac{Q^2}{M^2} + O\left(\frac{Q^2}{M^2}\right)^2\right)$$

$$\sim -\frac{1}{M^2} \quad \text{When} \quad \frac{Q^2}{M^2} \ll 1$$

$$\Lambda = \sqrt[4]{\frac{a_{theory}}{\sigma}}$$

a_{theory} is estimated at Λ~10 TeV with known theoretical cross section σ

EFT allows us to relate different experimental signatures in a model independent way

DM production at LHC

pp → χ χ + x at the LHC

- χ - pair production is characterized with contract interaction operators

- Vector Operator/ Spin Independent (SI)

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

- Axial-Vector Operator/ Spin Dependent (SD)

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

- χ-nucleon cross section depends on DM mass and the scale Λ

$$\sigma_{SI} = 9\frac{\mu^2}{\pi\Lambda^4} \qquad \sigma_{SD} = 0.33\frac{\mu^2}{\pi\Lambda^4} \qquad \mu = \frac{m_\chi m_p}{m_\chi + m_p}$$

- Scale Λ and g_χ, g_q couplings of mediator to the χ and SM particles respectively, are related as

$$\Lambda = M/\sqrt{g_\chi g_q}$$

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Phys.Rev.D82:116010 (2010)
JHEP 1009:037 (2010)