Dark Matter searches at CMS

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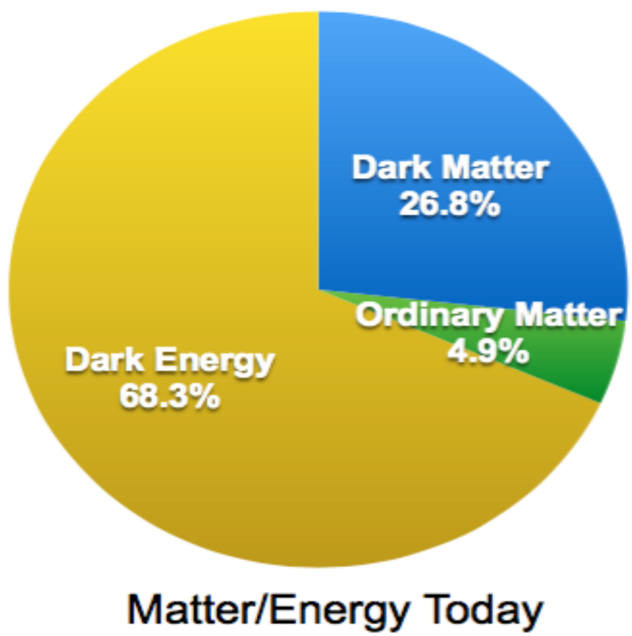
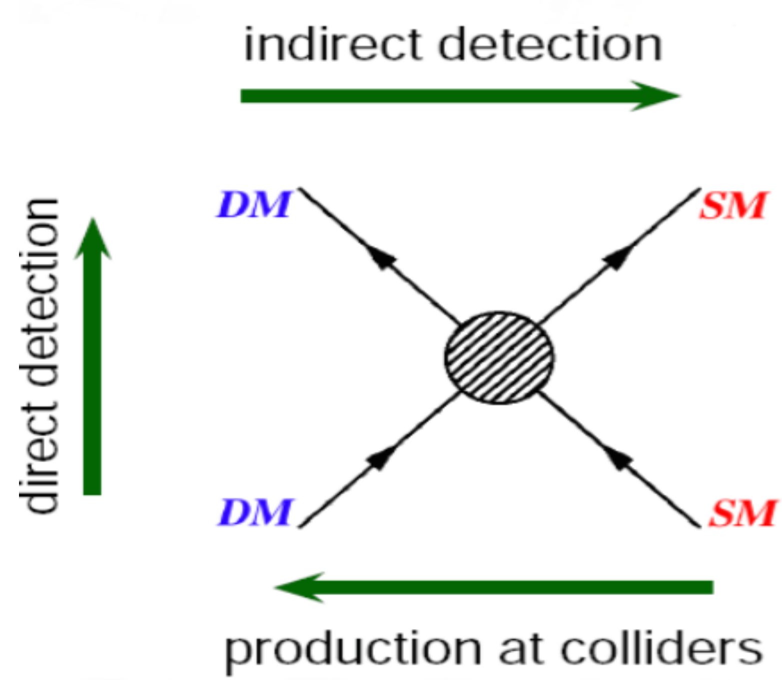
The search for Dark Matter

- **Evidence of dark matter well established from astrophysical observations**
  - The exact nature of DM is still unknown
- **LHC provides a prime laboratory for production of DM**
  - Can probe a wide range of DM/SM interaction types



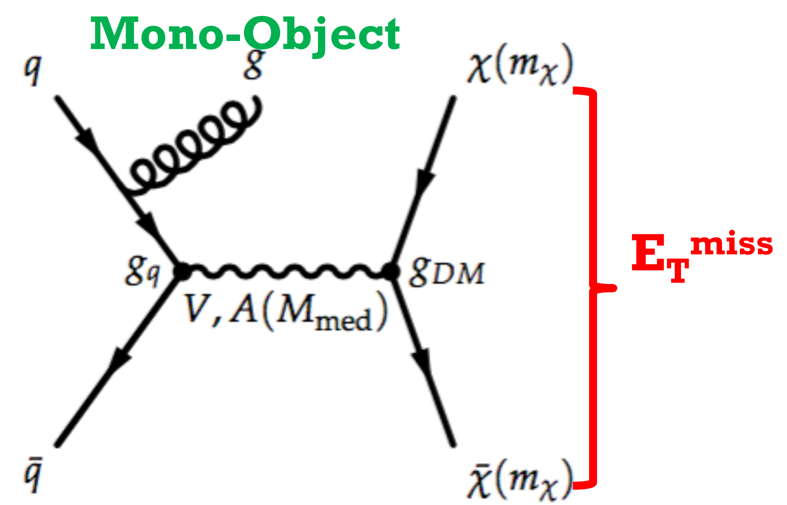


Benchmark signatures for LHC DM searches

- **Typically look for E_T^{miss} + X**
  - X = jet , γ, W, Z, H, tt, bb, t

- **Use Simplified models to interpret results (arXiv : 1507.00966)**
  - DM particle is a Dirac fermion
  - DM particles are pair-produced
  - A new massive particle mediates the DM-SM interaction
  - Minimal flavor violation
  - Mediator has minimal decay width

- **Minimal set of parameters**
  - M_{MED}, M_{DM}, g_{SM}, g_{DM}



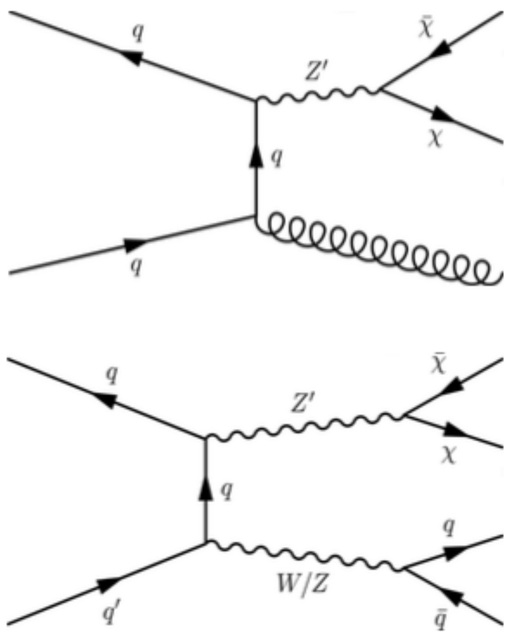
CMS 13 TeV Searches for Dark Matter

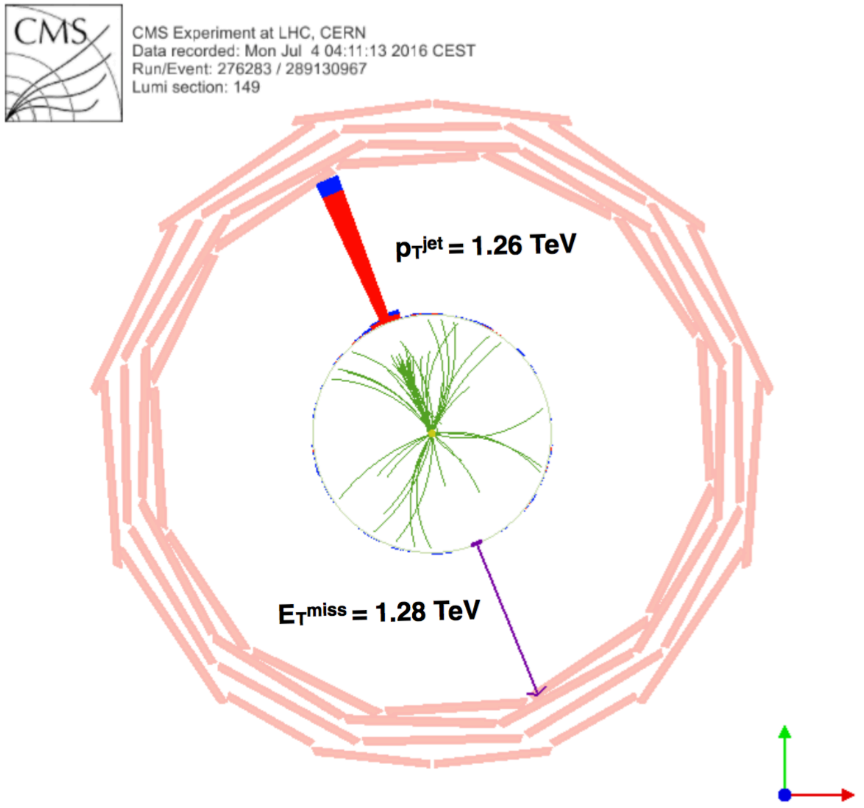
Focus of this talk

X	Dataset	CMS Documentation
jet or V (hadronic)	2016, 12.9 fb	EXO-16-037
photon	2016, 12.9 fb	EXO-16-039
Z (ll)	2015, 2.3 fb	EXO-16-010
Z (ll)	2016, 12.9 fb	EXO-16-038
Higgs (bb)	2015, 2.3 fb	EXO-16-012
Higgs (γγ)	2015, 2.3 fb	EXO-16-011
tt (semilep+had)	2015, 2.2 fb	EXO-16-005
t (hadronic)	2016, 12.9 fb	EXO-16-040

Mono-jet/jets/Hadronic W And Z

- Search for large E^T_{miss} and > high–p_T jets, veto e, μ, τ, γ, b-jet
  - Encompasses both monojet and mono-W/Z (decaying hadronically)

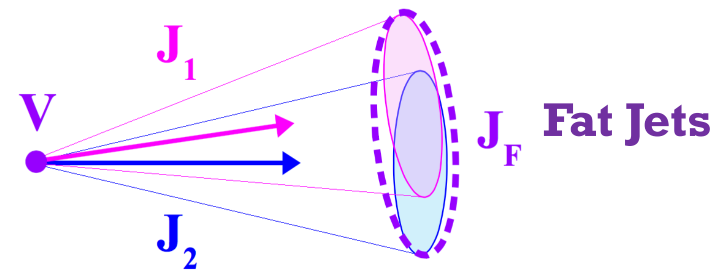


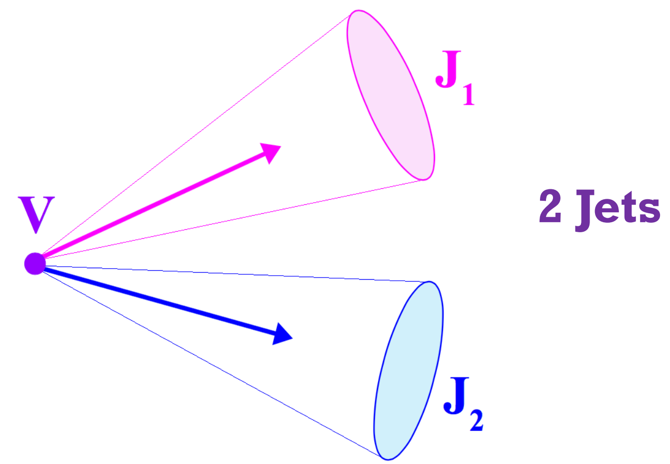


Mono-jet/jets/Hadronic W And Z

- **Search for large E^T_{miss} and > high–p_T jets, veto e, μ, τ, γ, b-jet**
  - Encompasses both monojet and mono-W/Z (decaying hadronically)

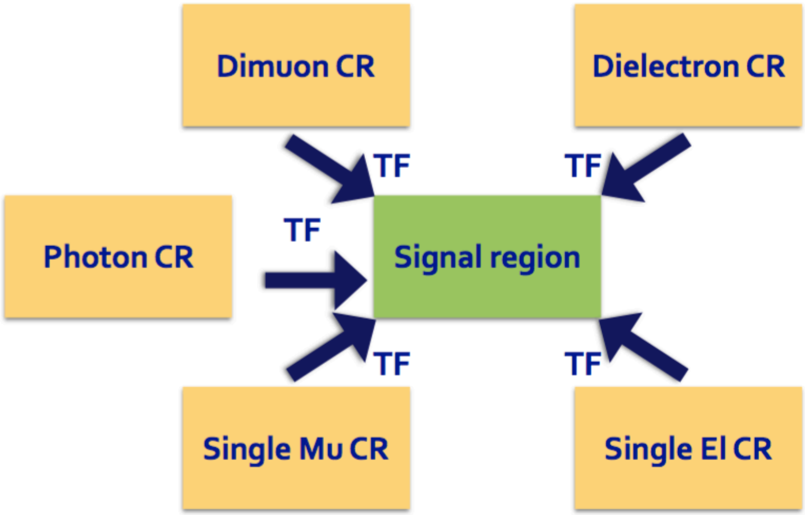
- **After basic ID, separate into two categories for each**
  - **Mono-V :** "fat jets" ak8jets for highly boosted W/Z
    - **E^T_{miss}, p_T^{j1} > 250 GeV**
    - **Jet sub-structure**
      - **Mass 65 – 105 GeV**
      - **N-subjettiness (τ_N) : Likelihood of originating from 2 jets variable**
        - **$\tau_2/\tau_1 < 0.6$**
  - **Mono-jet :** remaining events with E^T_{miss} > 200 GeV and p_T^{j1} > 100 GeV





Mono-jet/jets/Hadronic W And Z

- **Background dominated by Z(νν)+jets and W(lν)+jets**
- **Definition of multiple control regions (CRs) to constrain EWK backgrounds**
  - Dilepton (μμ/ee), Single-lepton(μ/e) and Photon + jets
- **Bin-by-bin transfer factors (TF) used to derive event yields from control to signal region from data**
  - Combined maximum-likelihood fit to SR and CR's

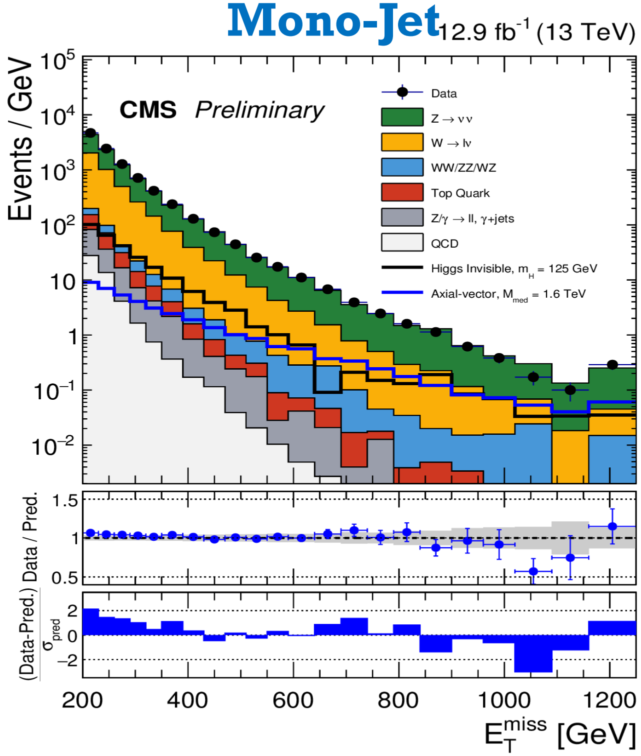


Mono-jet/jets/Hadronic W And Z

- Search for large E^T_{miss} and > high–p_T jets, veto e, μ, τ, γ, b-jet
  - Encompasses both monojet and mono-W/Z (decaying hadronically)

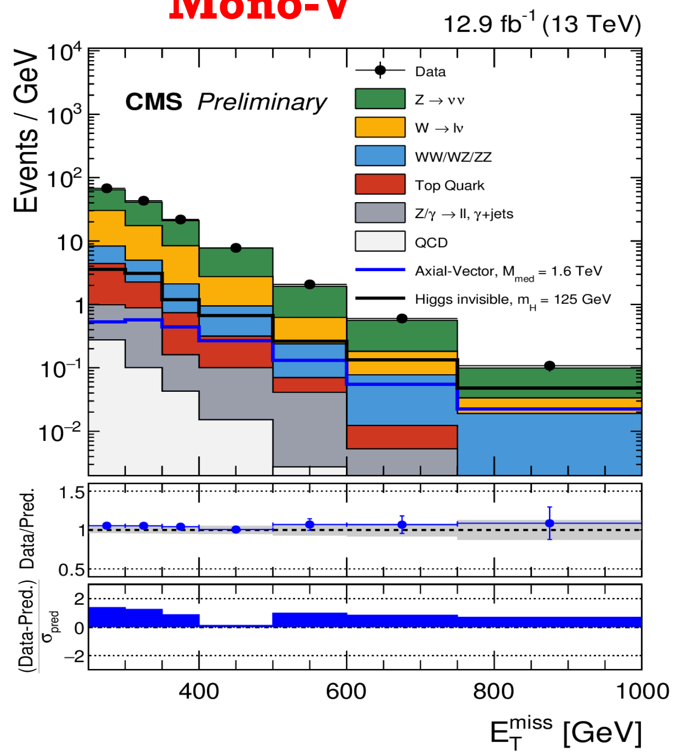
- **Background dominated by Z(νν)+jets and W(lν)+jets**

Mono-Jet



(a)

Mono-V

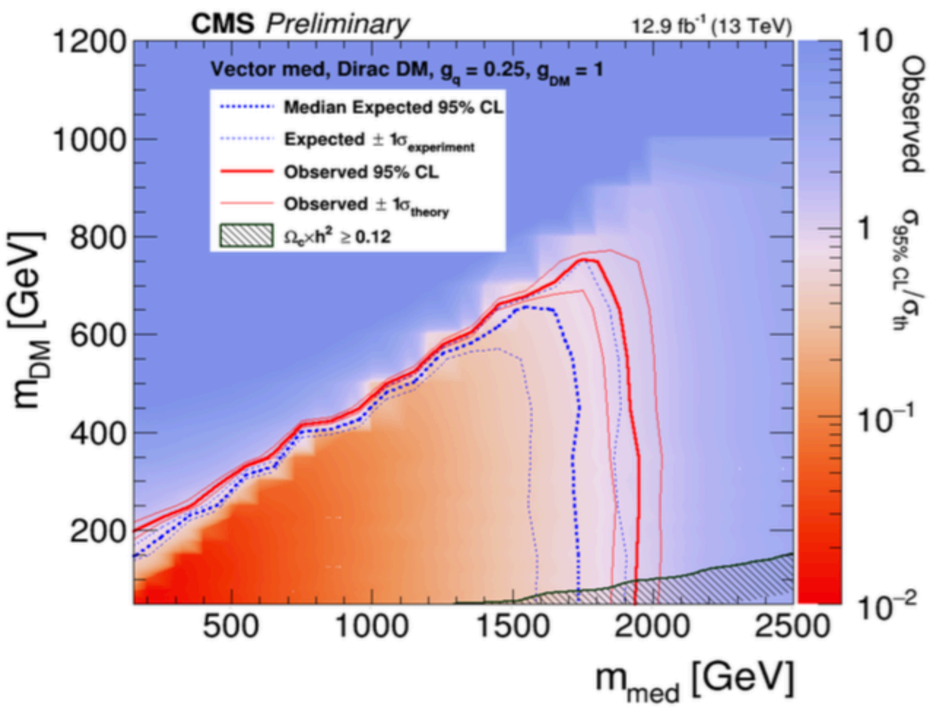


(b)

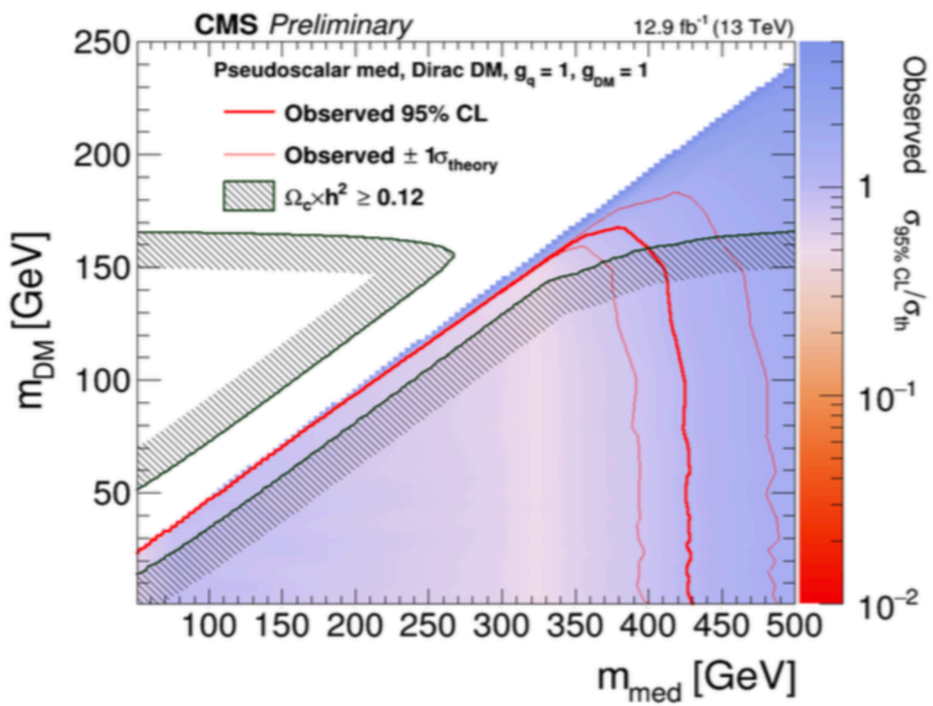
Mono-jet/jets/Hadronic W And Z

- No excess observed : set limits on cross section in simplified model
- Vector/Axial mediator mass **up to 1.95 TeV** excluded
- (Psuedo) scalar mediator mass **up to (430) 100 GeV** excluded

Vector Mediator

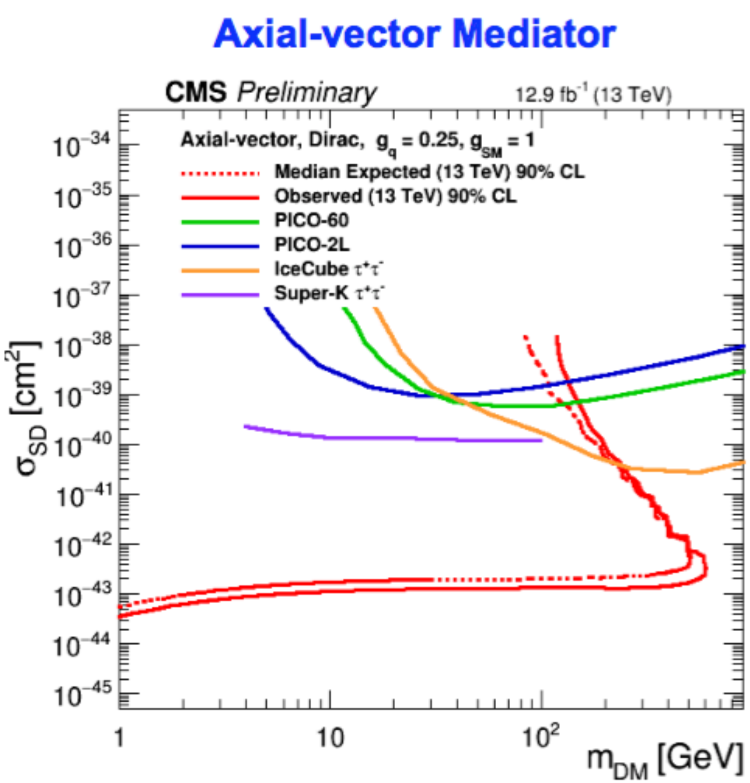


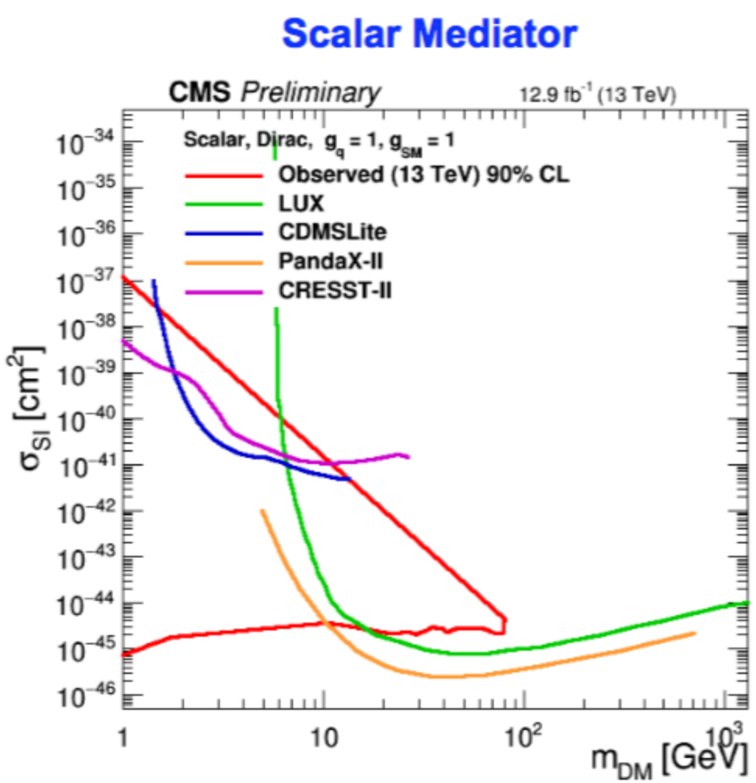
Pseudo-scalar Mediator



Mono-jet/jets/Hadronic W And Z

- BR (h(125) -> invisble) < 0.44 (0.56 expected)
- Results recast to limits on SI/SD DM-nucleon scattering cross sections
- Compare to direct detection experiment limits

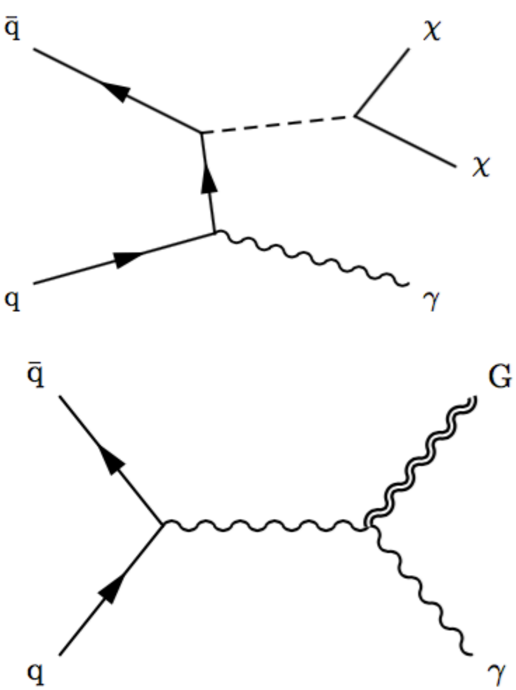


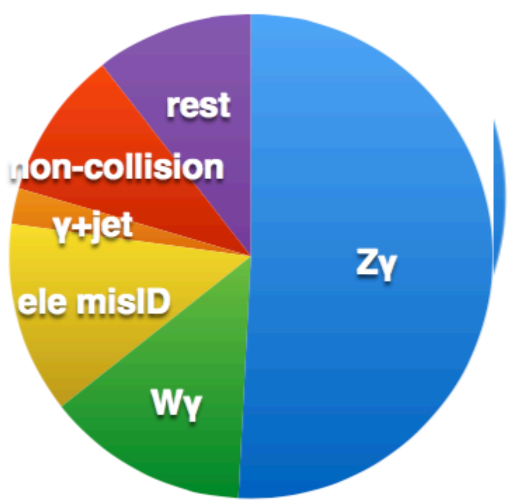


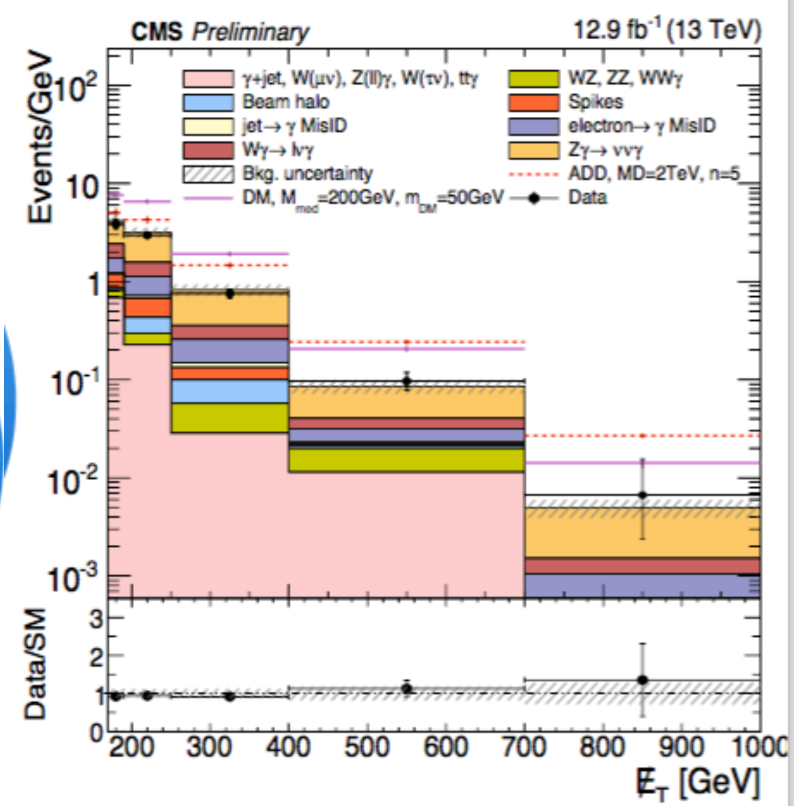
+ Mono-Photon

- Look for events with E^{T}_{miss} > 170 GeV and > 1 central photon with P_T > 175 GeV, veto e, μ

- Z(νν)γ and W(lν)γ estimated using MC with NNLO QCD (DYRES) + NLO EWK corrections, misID and non-collision backgrounds estimated from data

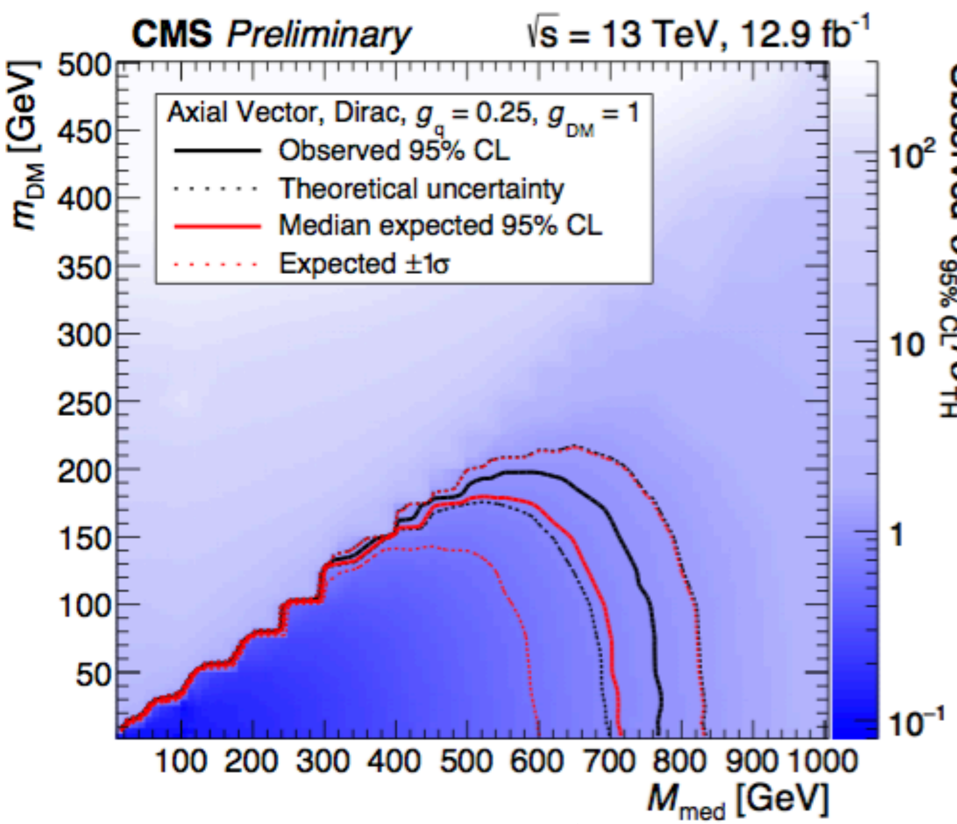


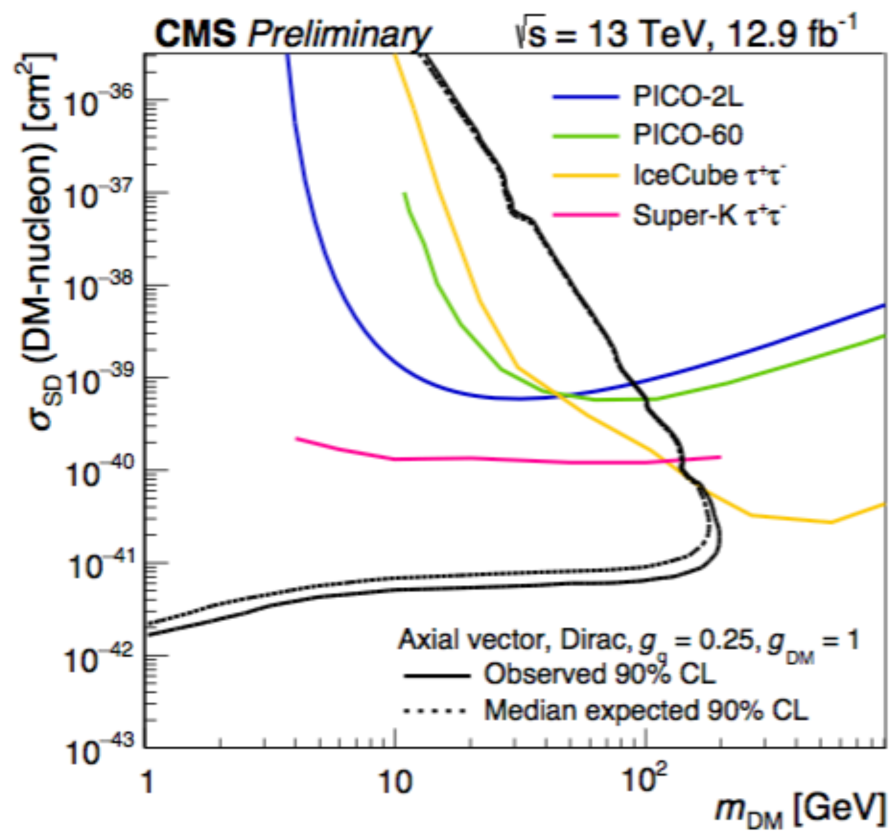




Mono-Photon

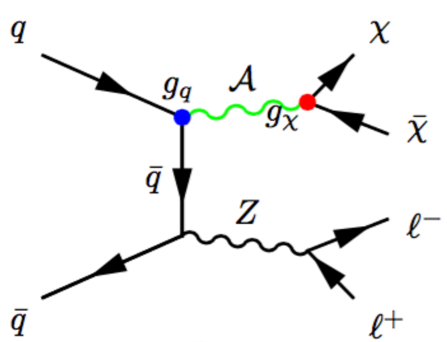
- No excess observed, set limits on DM and ADD LED graviton
  - Mediator mass up to 760 GeV excluded (vector/axial vector)
  - Dim-7 EFT scale lambda up to 620 GeV excluded
  - ADD LED MD > 2.44 to 2.60 TeV for n=3 to n=6 extra dimension

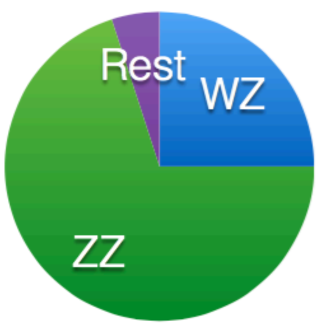


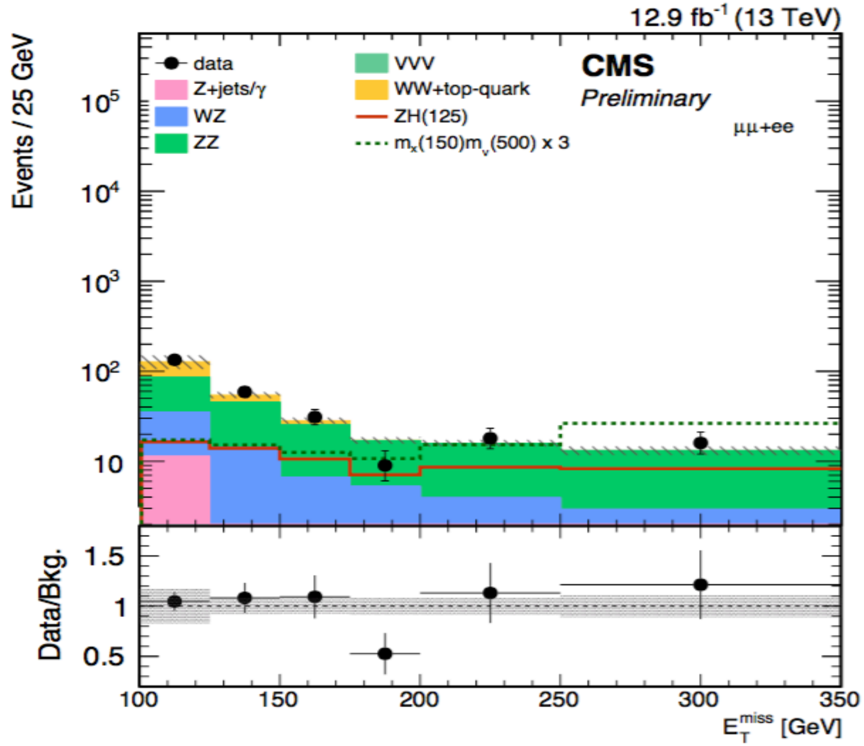


Mono-Z (ll)

- Require E^T_{miss} > 100 GeV and ee/μμ with P_T^{ll} > 60 GeV, E^T_{miss} and P_T^{ll} balance, veto extra e, μ, τ, b-jet, events with more than 1 jet
- ZZ/WZ background estimated from MC (with NNLO QCD and NLO EWK corrections), tt, W, WW, tW , Z ->ττ background estimated from the eμ data.



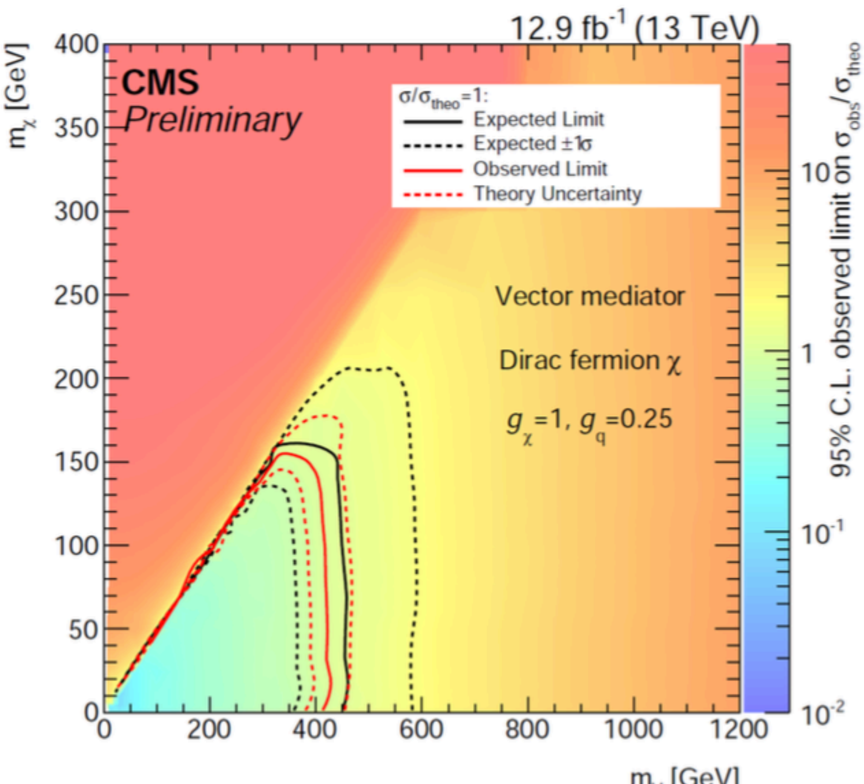


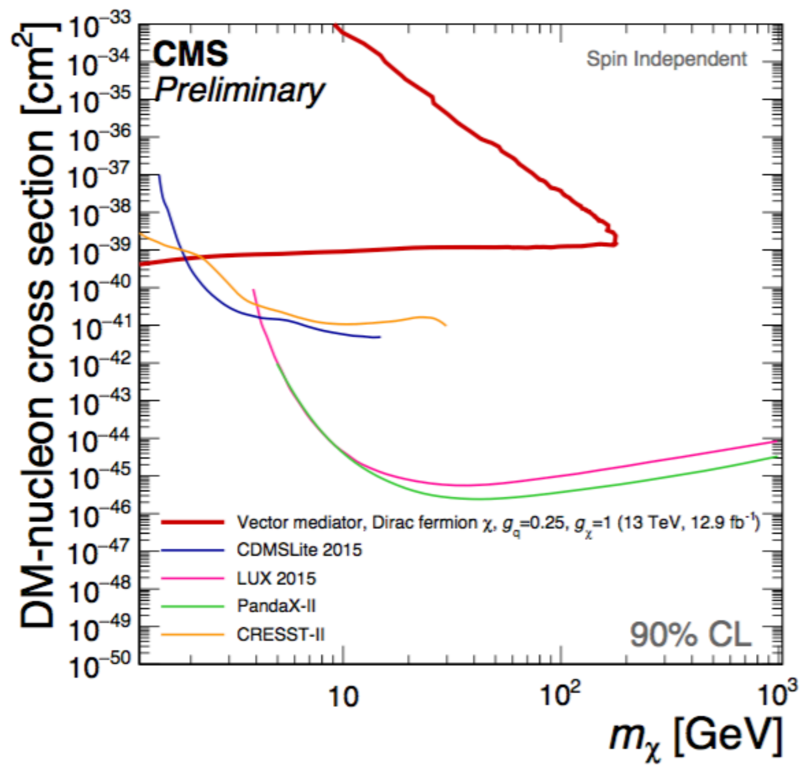


Mono-Z (ll)

- No excess observed. Limits on cross section with 2D-scan of m_{DM} vs M_{MED} for vector/axial mediators
  - Mediator mass up to 400 GeV excluded

- BR (h(125)->invisible) < 0.86 (0.70 expected), included ggZh

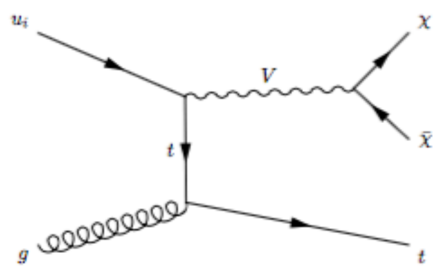


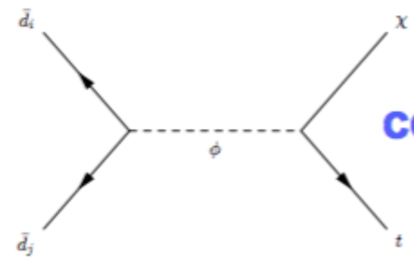


Mono-Top : Hadronic

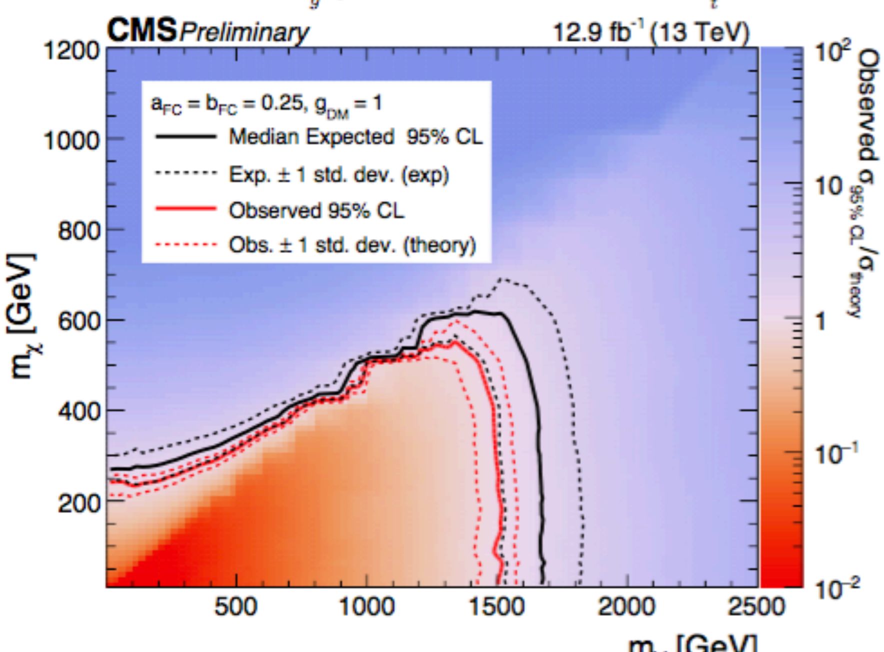
- P_T of jet and E^T_{miss} > 250 GeV, top-tagged jet mass 110-210 GeV, Jet sub-structure
- Flavor changing neutral current (FCNC) vector up to 1.5 TeV, charged scalar 0.9- 2.7 TeV excluded

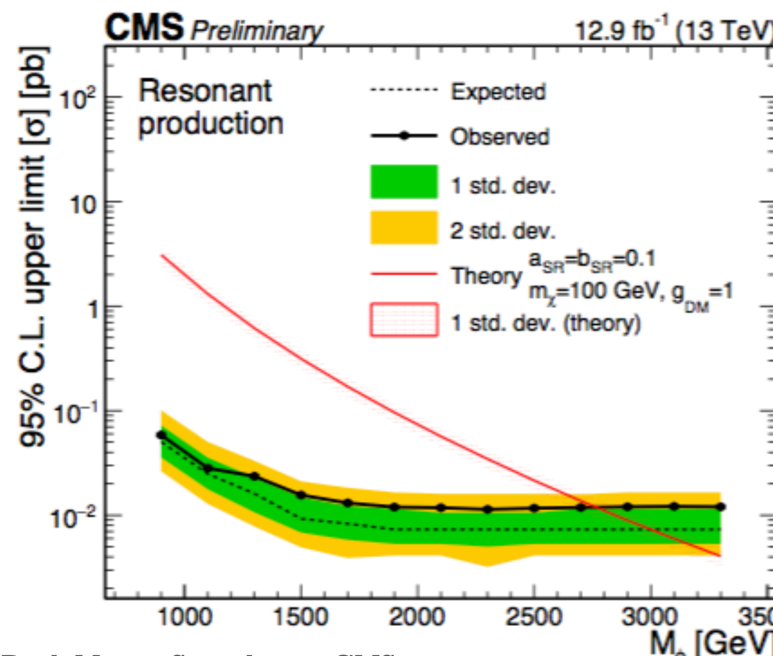
FCNC





color-charged scalar

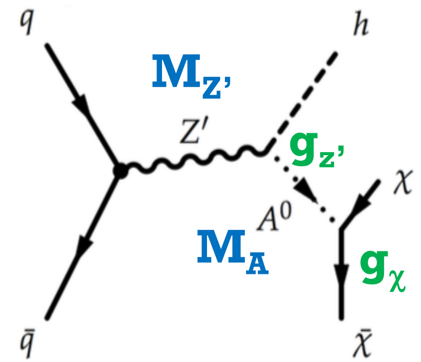




Mono-Higgs (bb, γγ)

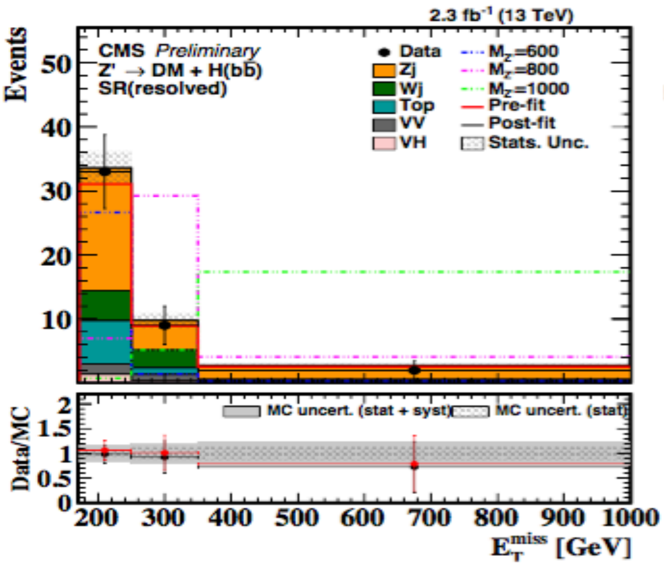
- Higgs -> bb
  - Largest BF (58%), but poor mass resolution (10 %)
  - Resolved : 2 b-tagged jets, $p_T^{bb}/E^T_{miss} >$ 150/170 GeV
  - Boosted : 1 fat jet with subjets b-tagged, $p_T^{bb}/E^T_{miss} >$ 200 GeV

2HDM

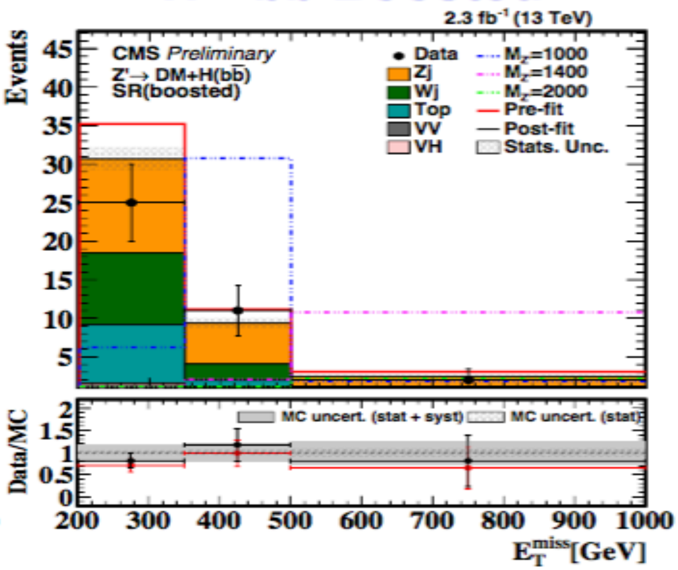


- Higgs -> γγ:
  - Small BF (~0.2%), but mass resolution (1-2%)
  - $E^T_{miss} >$ 105 GeV, $p_T^{\gamma\gamma} >$ 90 GeV, $p_T^{\gamma1}(p_T^{\gamma2})/ m^{\gamma\gamma} >$ 0.5 (0.25)

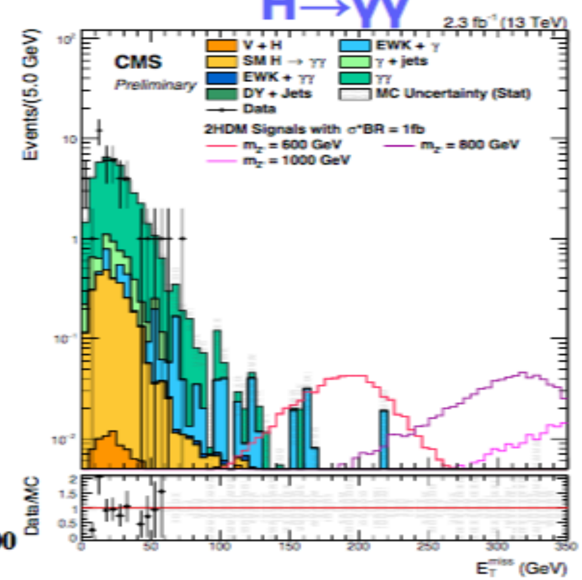
H→bb Resolved



H→bb Boosted

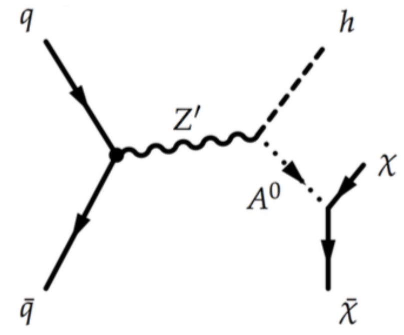


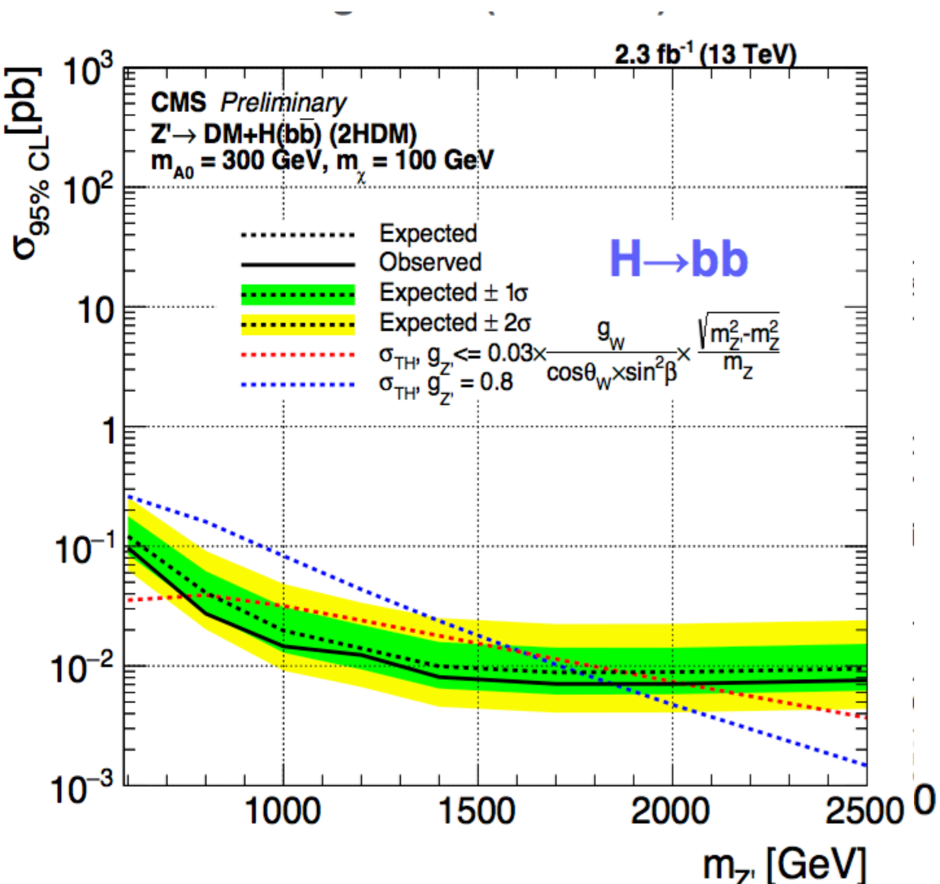
H→γγ

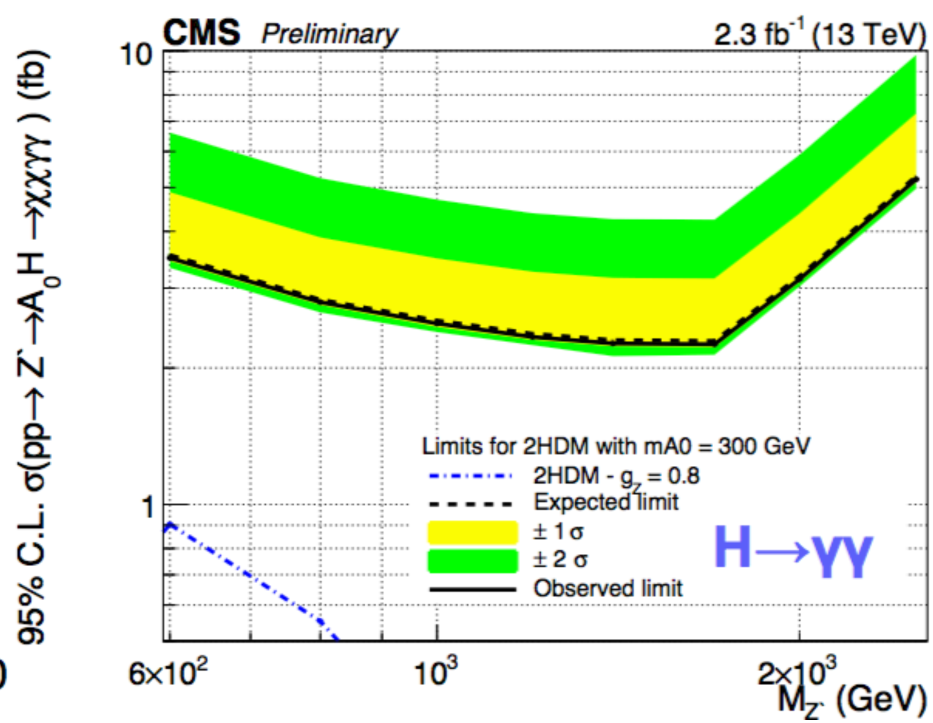


Mono-Higgs (bb, γγ)

- No excess observed, set limits on Type-2 2HDM
  - For M_A=300 GeV, excluded Mz'=600 GeV to 1863 GeV with gz =0.8

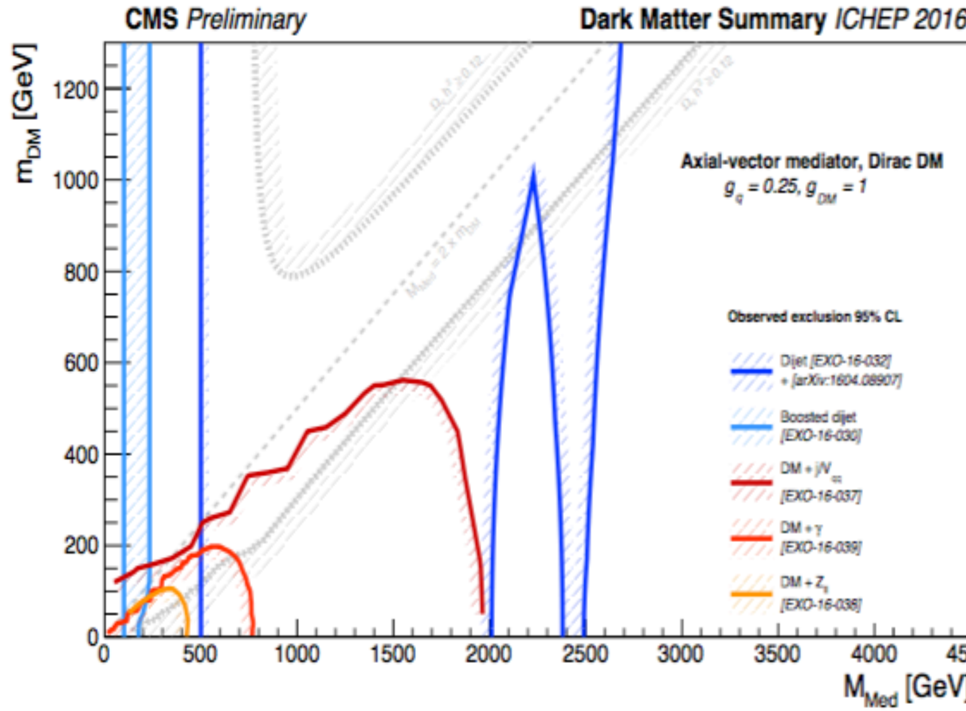


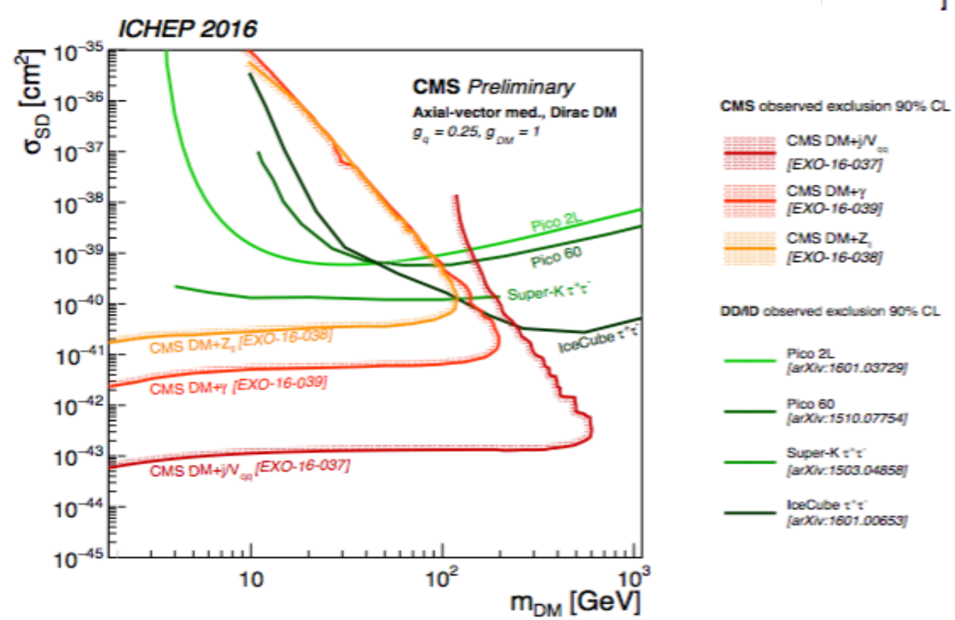




+ Summary of Mono-X searches

- **Fix g_q = 0.25 and g_{DM} =1**
- **Reinterpret dijet searches with resolved and boosted jets**
  - Cover the off-shell region



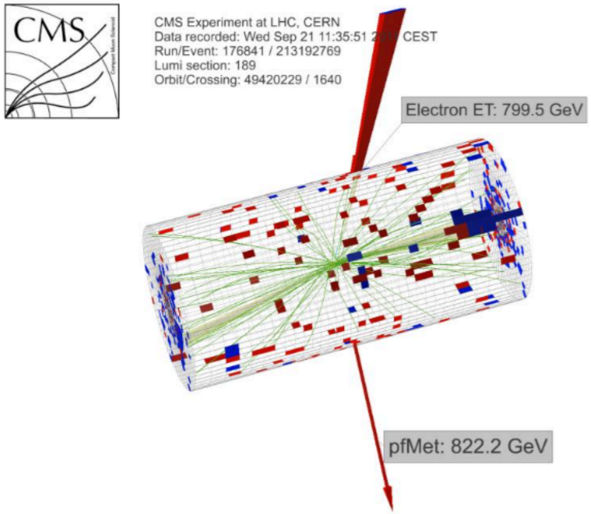


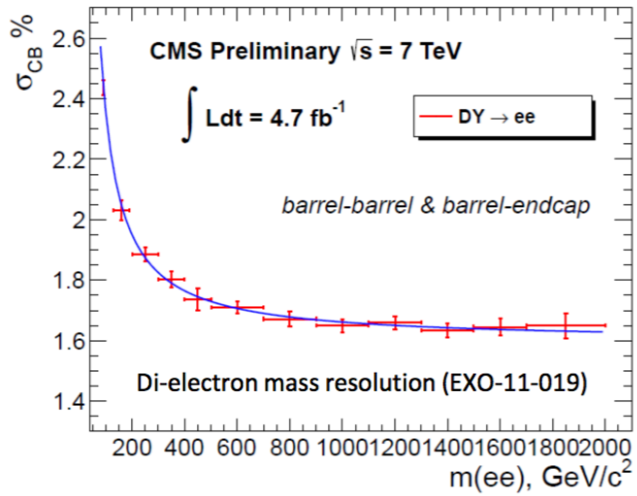
Conclusion

- **CMS searches for dark matter have been performed with various mono-X final states**
  - Results with 2016 data from mono-jet/photon/Z/top
  - First results from mono-Higgs and mono-tt (hadronic)
- **No sign of excess yet**
  - Provide limits on simplified models and EFTs
  - Results were recast in terms of nucleon-DM scattering cross section
- **Expect updated with the full 2016 data and combinations of different mono-X channels**

+ Backup

Electron Selection



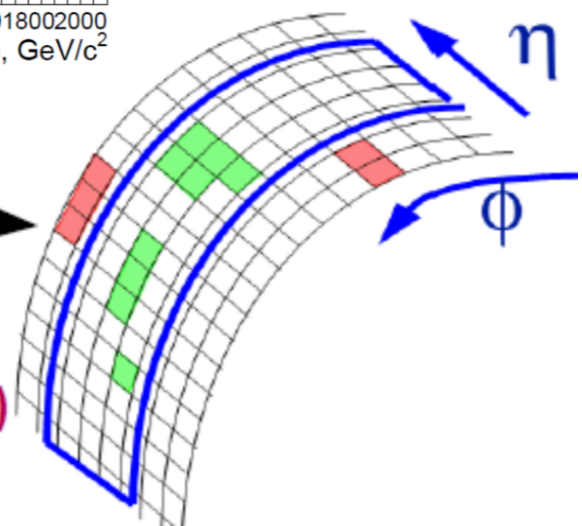


ECAL made of matrix of fully active crystals. Measured energy resolution ~2%

Electrons are reconstructed from energy clusters In the ECAL and tracks from the silicon tracker

Electron ID optimized for high E_T requires:

- $E_T > 85$ GeV
- $|\eta| < 1.442$ (barrel) or $1.56 < |\eta| < 2.5$ (endcap)
- Good quality of track and cluster
- Matching between the two
- Isolation



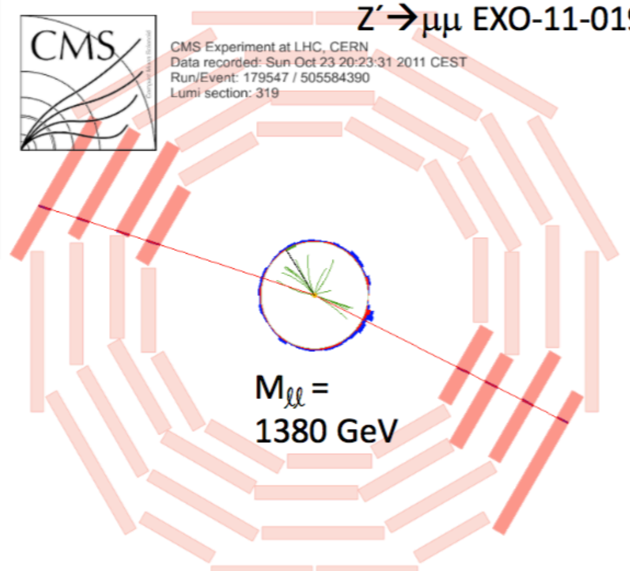
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

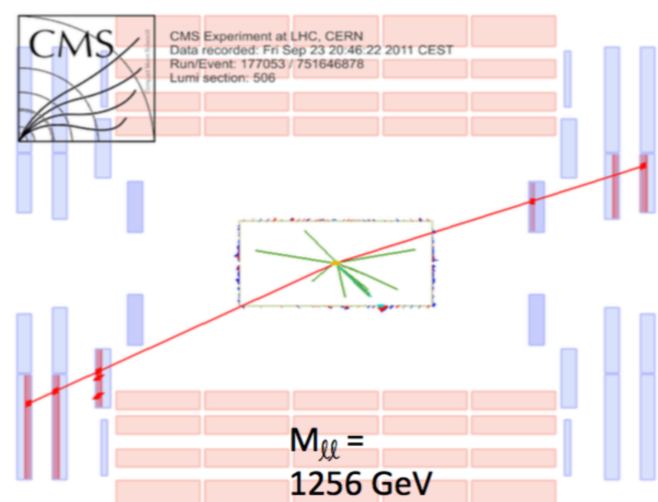
K.Hoepfner, RWTH Aachen | CMS Heavy Resonances |

Muon Selection

High redundancy of mu system, 4 stations along track
Iron between stations may cause **bremsstrahlung** for O(TeV) muons
p_T<200 GeV tracker in B=3.8T, p_T>200 GeV mu+tracker

Event displays from Z′→μμ EXO-11-019



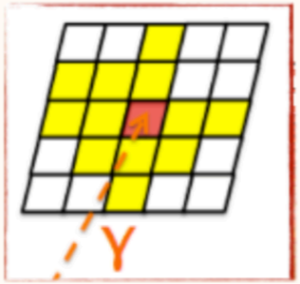


Dedicated muon selection:

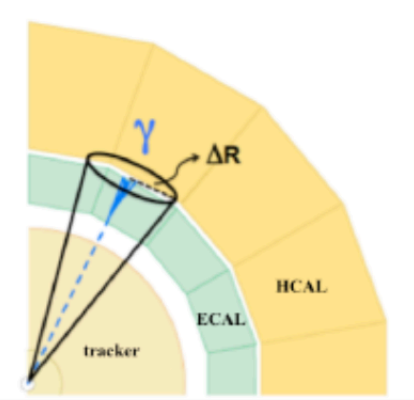
- Special algorithm to consider showering
- At least 1 pixel hit
- Number of measured tracker layers > 8
- Transverse impact parameter d0 < =0.2cm (Z′), 0.02cm (W′) reject cosmics, value for W′ tighter than other analyses, Z′ rejects in addition back-to-back muons
- >= 2 matched muon segments
- Relative track isolation <0.10 in $\Delta R < 0.3$
- No cut on chi2 cut introduces a 4-6% inefficiency for muons >500 GeV

Photon Selection

- Background contamination and invariant mass resolution depends on:
  - pseudorapidity
  - cluster shape, i.e. conversion probability (R9)



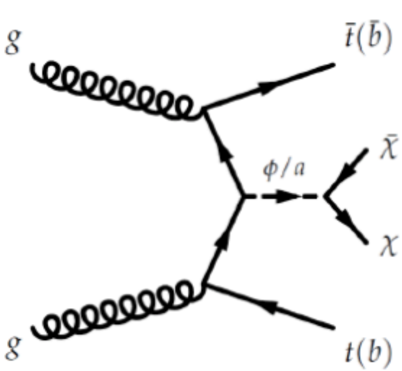
- Same approach like H->γγ standard cut-based photon-ID
  - ECAL fiducial region (|η| < 2.4 excluding EB-EE gap)
  - Isolation and identification requirements:

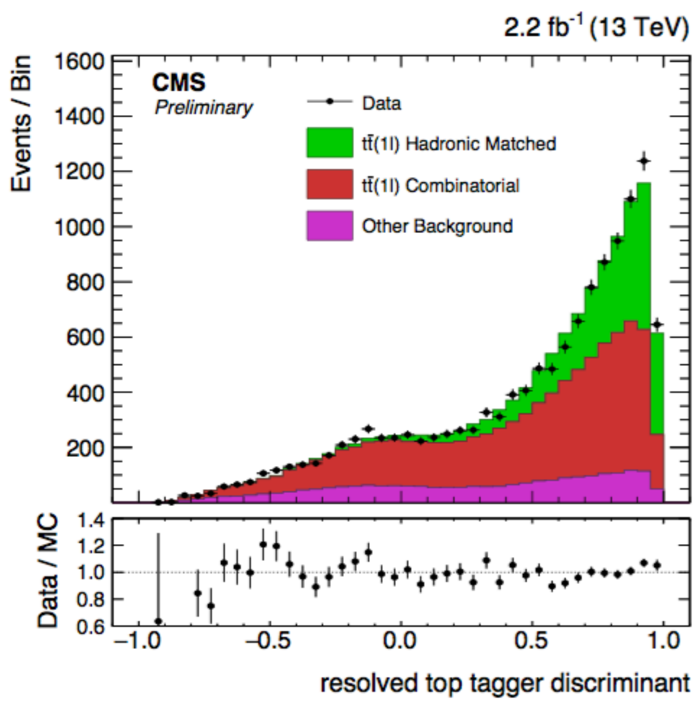


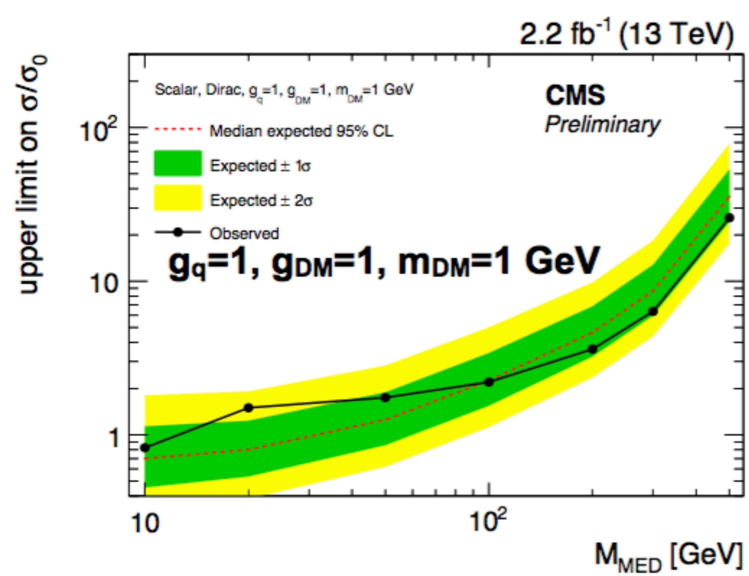
	barrel		endcap	
	$R_9 > 0.94$	$R_9 < 0.94$	$R_9 > 0.94$	$R_9 < 0.94$
PF isolation sum, chosen vertex	6	4.7	5.6	3.6
PF isolation sum worst vertex	10	6.5	5.6	4.4
Charged PF isolation sum	3.8	2.5	3.1	2.2
$\sigma_{i\eta i\eta}$	0.0108	0.0102	0.028	0.028
H/E	0.124	0.092	0.142	0.063
R_9	0.94	0.298	0.94	0.24

+ Mono-tt

- **Hadronic (semileptonic) channel with E^T_{miss} > 200 (160) GeV**
- **Major background from ttbar events with one less hadronic top**
  - Apply resolved-hadronic-top tagger to the hadronic channel and categorize events based on the number of top tags, b-tagged jets, and Δϕ(jet, E^t_{miss}), up to 30% improvement







Mono-Photon : Main Backgrounds

Same Final Stat

$Z\gamma \rightarrow \nu\nu\gamma$, $W\gamma \rightarrow (\ell)\nu\gamma$ (ℓ not reconstructed) ~ 80% of total background

- estimated from **simulations** with **NNLO QCD** & **NLO EW** corrections
- validated using **data control samples**: $Z\gamma \rightarrow \ell^+\ell^-\gamma$, $W\gamma \rightarrow \ell\nu\gamma$

Fake photons

$W \rightarrow e\nu$ with e misidentified as a **photon**

- measured in $W \rightarrow e\nu$ data, with data-driven $e \rightarrow \gamma$ **mis-ID rate**

QCD multijet events with a **jet** misidentified as a **photon**

- measured in **jet-enriched** data, with data-driven **jet** $\rightarrow \gamma$ **mis-ID rate**

Noncollision

Noncollision background (mostly **beam halo**)

Measured in data from a **template fit** to calorimeter **timing profiles**

Non Collision Backgrounds

Full Timing

- Non-collision backgrounds are estimated using the ECAL timing information
- First we look at full timing distribution of photons
  - Default supercluster reconstruction algorithm discards hits with |t|> 3 ns cut
  - Full re-reconstruction of 2015 performed removing this constraint

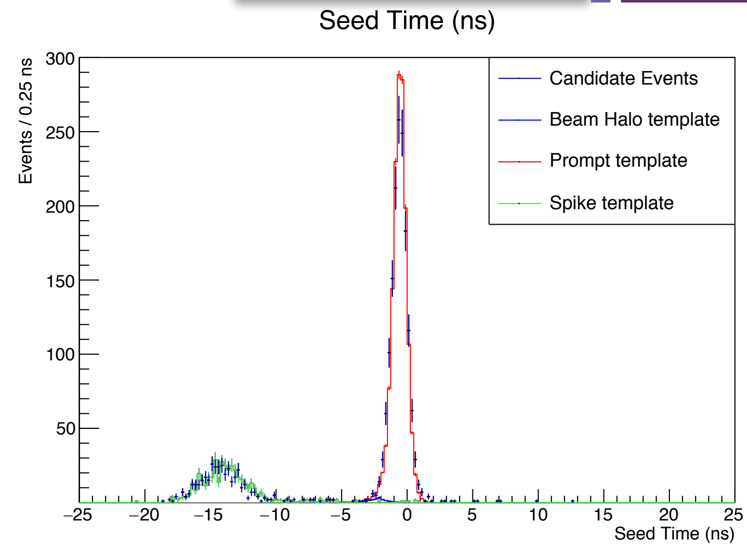
Halo Template : Mip total energy > 4.9 GeV

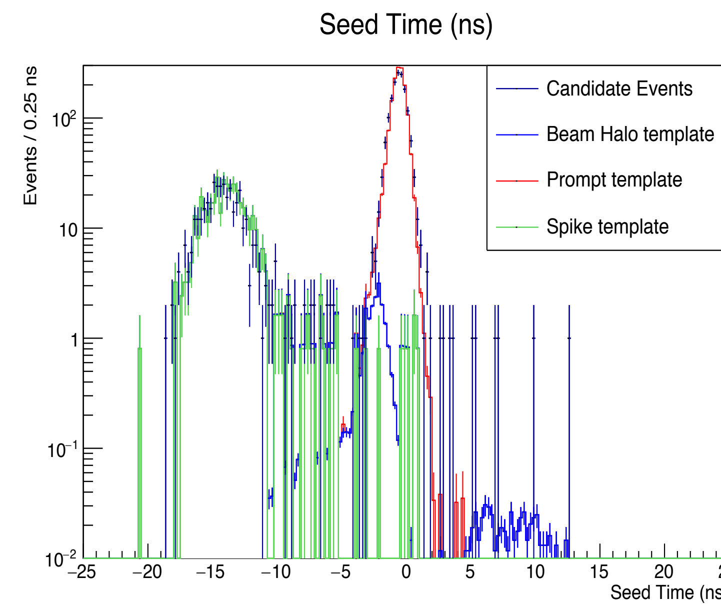
Spike Template : Full candidate selection and reverse the topological shower shape spike cleaning cuts

Prompt Template : W Candidates selection with pixel match and good shower shape

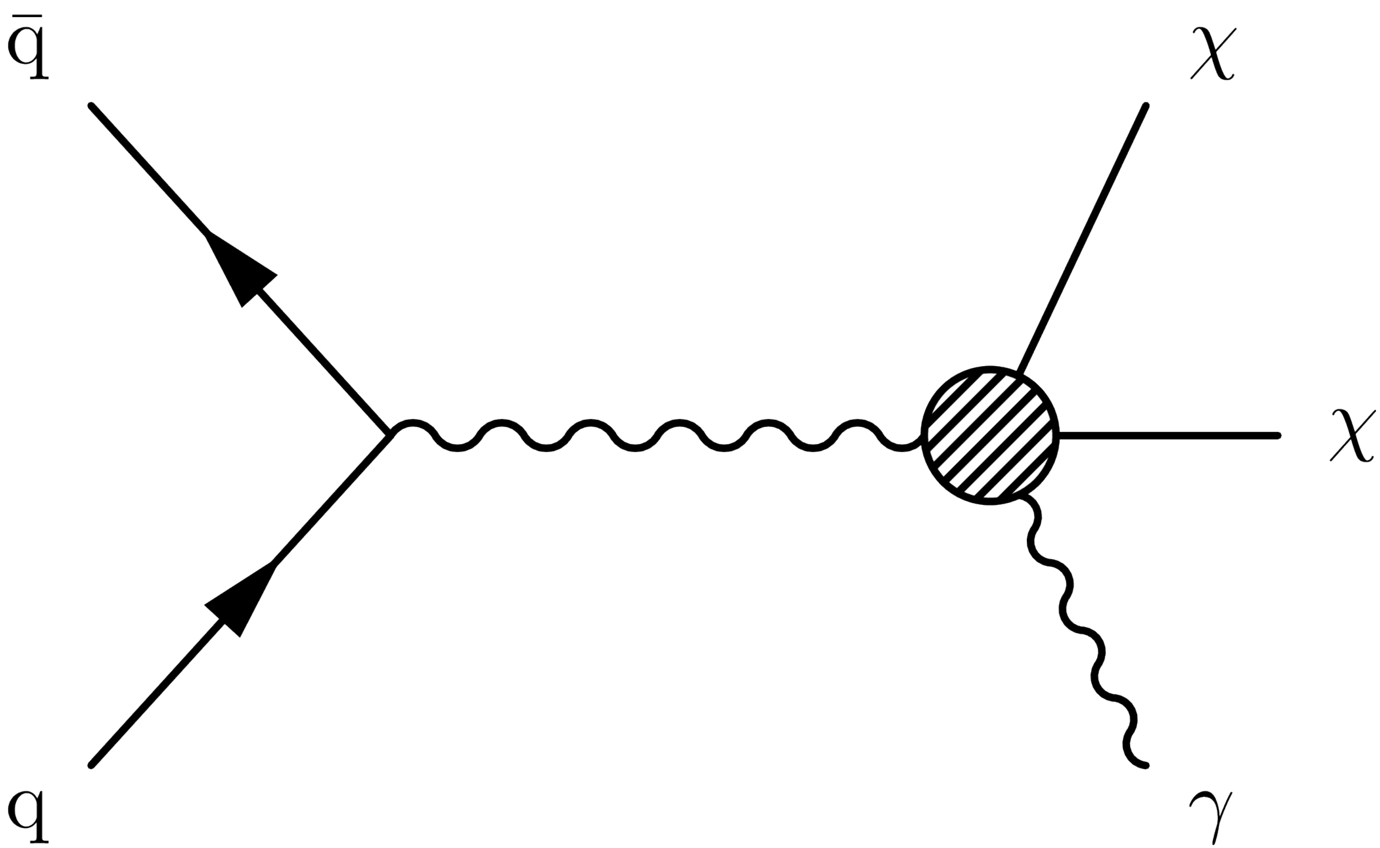
Beam Halo : 13.41 +/- 6.27 events

Spike : 5.63 +/- 2.2 events



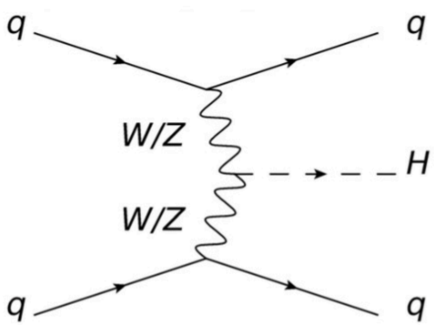


Dim-7 operator



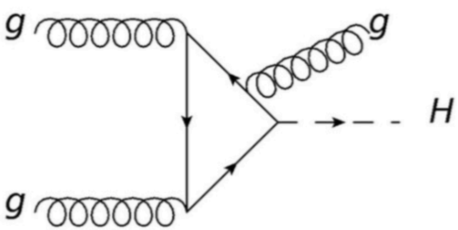
Higgs Portal

- In Higgs-portal models of DM, a Higgs boson is the only mediator between DM and SM sectors
  - the Higgs can be produced with SM cross section, but have a significant branching fraction to DM particles (B_{inv})
- The Higgs must be produced in association with a visible system
  - several channels considered and combined

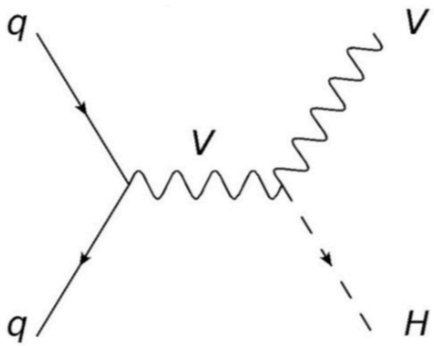


Vector Boson Fusion (VBF)

2 forward jets with large η separation and invariant mass



Monojet



"Higgs-strahlung"

$W \rightarrow q\bar{q}', \ Z \rightarrow q\bar{q} \,/\, \ell^{+}\ell^{-} \,/\, b\bar{b}$

How To Translate (Scalar)

In general, the SI DM-nucleon scattering cross section takes the form

$$\sigma_{\rm SI} = \frac{f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4}\,, \qquad (4.1)$$

where $\mu_{n\chi} = m_n m_{\rm DM}/(m_n + m_{\rm DM})$ is the DM-nucleon reduced mass with $m_n \simeq 0.939\,\text{GeV}$

For the simplified model with scalar mediator exchange we follow the recommendation of ATLAS/CMS DM Forum [1] and assume that the scalar mediator couples to all quarks (like e.g. the SM Higgs). In general the formula for $f(g_q)$ is

$$f^{n,p}(g_q) = \frac{m_n}{v} \left[\sum_{q=u,d,s} f_q^{n,p} g_q + \frac{2}{27} f_{\rm TG}^{n,p} \sum_{Q=c,b,t} g_Q \right]. \qquad (4.4)$$

these values, we find that numerically

$$f(g_q) = 1.16 \cdot 10^{-3} g_q\,,$$

and therefore the size of a typical cross section is

$$\sigma_{\rm SI} \simeq 6.9 \times 10^{-43}\ \text{cm}^2 \cdot \left(\frac{g_q g_{\rm DM}}{1}\right)^2 \left(\frac{125\,\text{GeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\text{GeV}}\right)^2 .$$

How To Translate (Vector)

In general, the SI DM-nucleon scattering cross section takes the form

$$\sigma_{\mathrm{SI}} = \frac{f^2(g_q) g_{\mathrm{DM}}^2 \mu_{n\chi}^2}{\pi M_{\mathrm{med}}^4}, \tag{4.1}$$

where $\mu_{n\chi} = m_n m_{\mathrm{DM}}/(m_n + m_{\mathrm{DM}})$ is the DM-nucleon reduced mass with $m_n \simeq 0.939\,\mathrm{GeV}$

For the vector mediator,

$$f(g_q) = 3 g_q\,,$$

and hence

$$\sigma_{\mathrm{SI}} \simeq 6.9 \times 10^{-41}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{\mathrm{DM}}}{0.25}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\mathrm{GeV}}\right)^2 .$$

Re-Interpretation Of Dijet Searches

$$(g'_B)^2 = \frac{g_B^2}{2}\left(1 + \sqrt{1 + 4\frac{\Gamma_{DM}}{\Gamma(g_B)}}\right)$$

$$\begin{aligned}
\sigma_0(g_B) &= \sigma_{DM}(g'_B, g_{DM} = 1, m_{DM}) \\
&= \frac{(g'_B)^4}{\Gamma_q(g'_B) + \Gamma_{DM}} \frac{C}{M_{med}^4} \\
\rightarrow \frac{g_B^4}{\Gamma(g_B)} &= \frac{(g'_B)^4}{\Gamma_q(g'_B) + \Gamma_{DM}} \\
\rightarrow (g'_B)^2 &= \frac{g_B^2}{2}\left(1 + \sqrt{1 + 4\frac{\Gamma_{DM}}{\Gamma(g_B)}}\right),
\end{aligned}$$

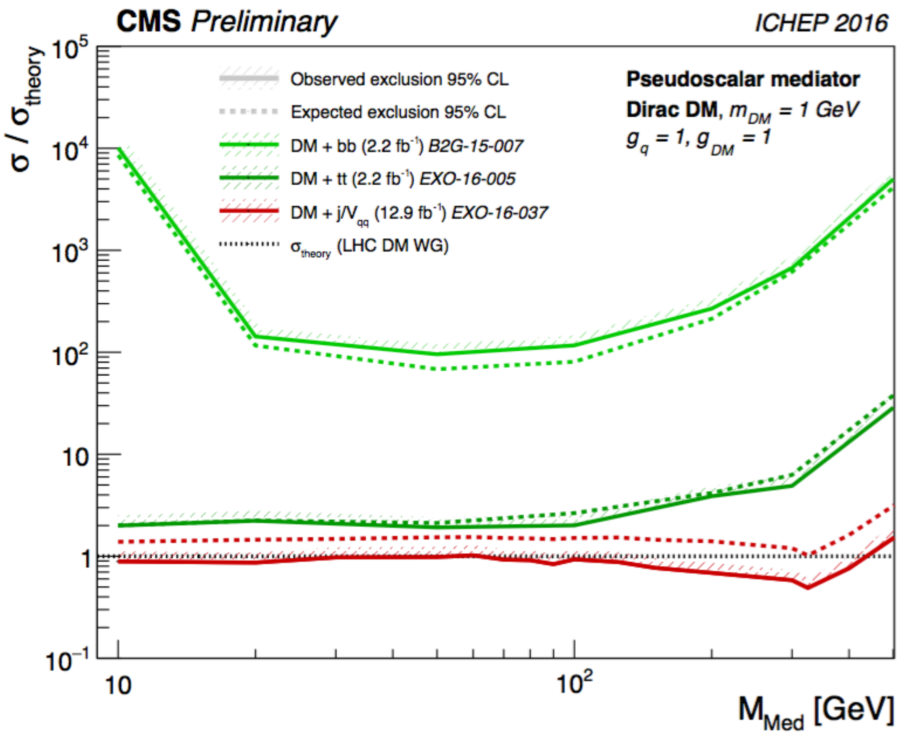
$$\Gamma_{\rm V}^{\chi\bar{\chi}} = \frac{g_{\rm DM}^2 M_{\rm med}}{12\pi}\left(1 - 4\frac{m_{\rm DM}^2}{M_{\rm med}^2}\right)^{1/2}\left(1 + 2\frac{m_{\rm DM}^2}{M_{\rm med}^2}\right) \quad ,$$

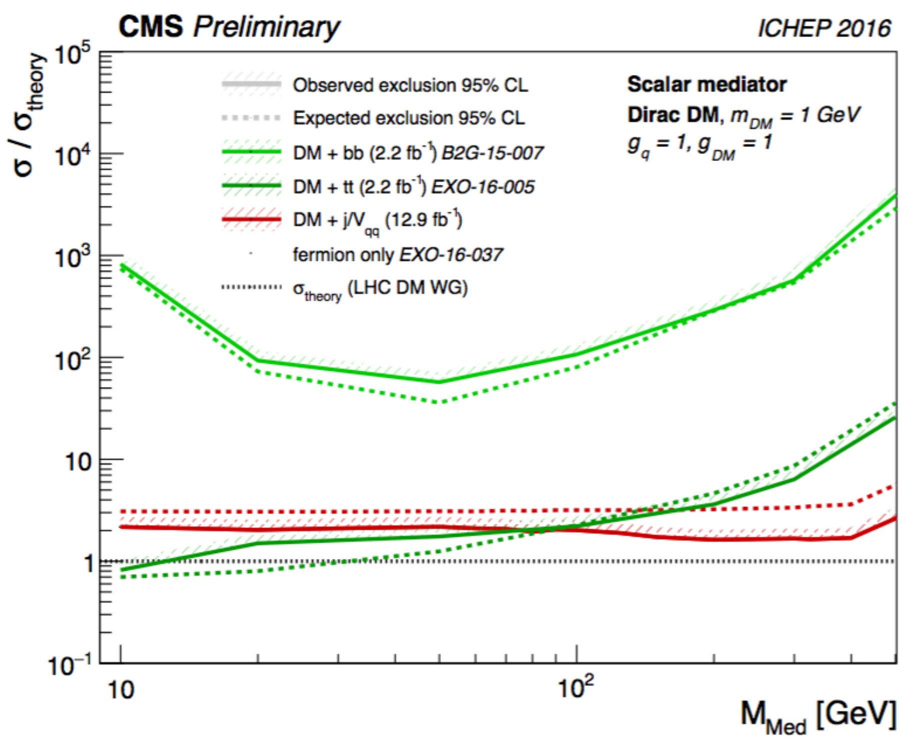
$$\Gamma_{\rm AV}^{\chi\bar{\chi}} = \frac{g_{\rm DM}^2 M_{\rm med}}{12\pi}\left(1 - 4\frac{m_{\rm DM}^2}{M_{\rm med}^2}\right)^{3/2} \quad ,$$

$$\Gamma_{\rm V}^{q\bar{q}} = \frac{g_q^2 M_{\rm med}}{4\pi}\left(1 - 4\frac{m_q^2}{M_{\rm med}^2}\right)^{1/2}\left(1 + 2\frac{m_q^2}{M_{\rm med}^2}\right) \quad ,$$

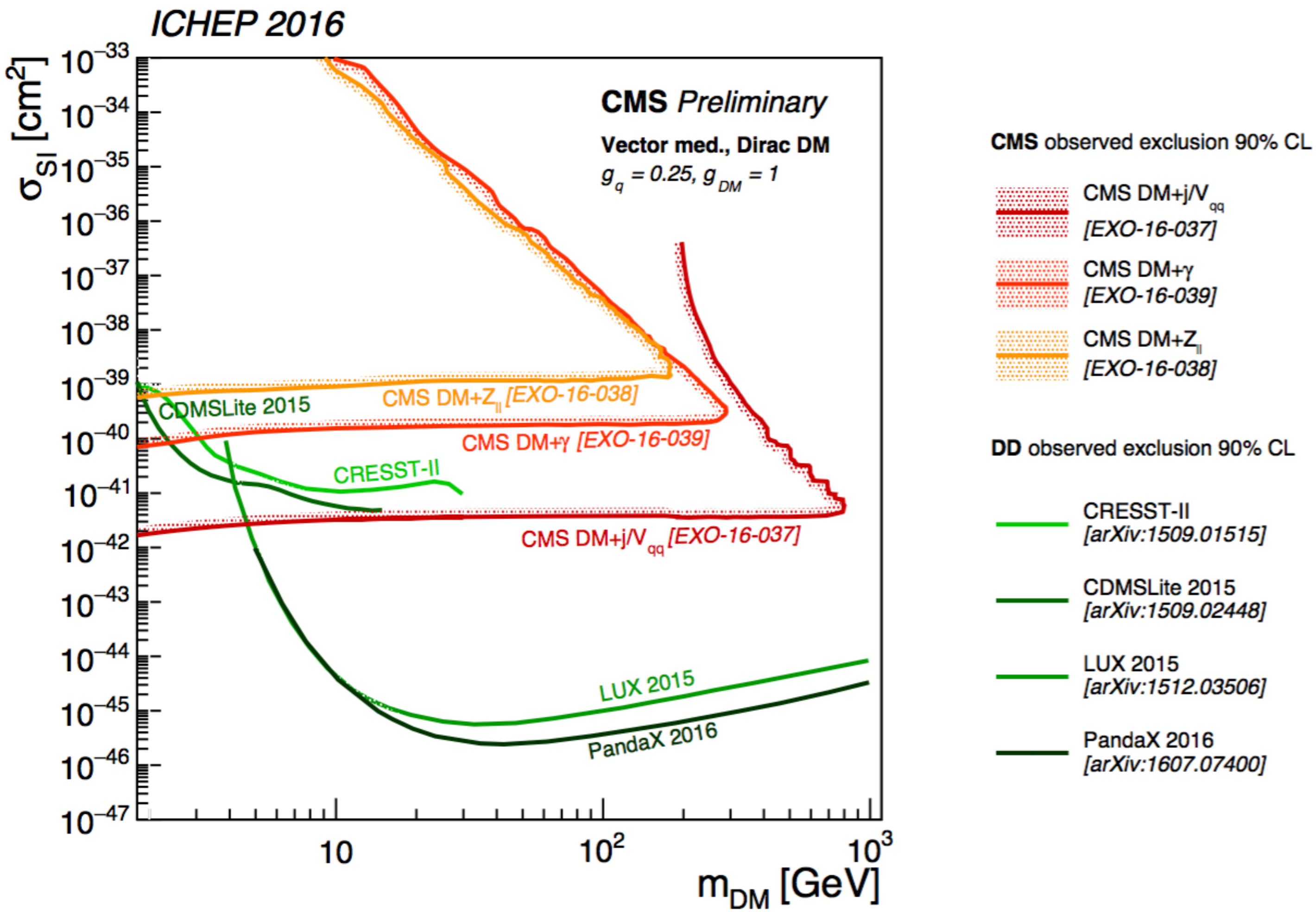
$$\Gamma_{\rm AV}^{q\bar{q}} = \frac{g_q^2 M_{\rm med}}{4\pi}\left(1 - 4\frac{m_q^2}{M_{\rm med}^2}\right)^{3/2} \quad ,$$

Summary For Scalar/Pseudo-Scalar

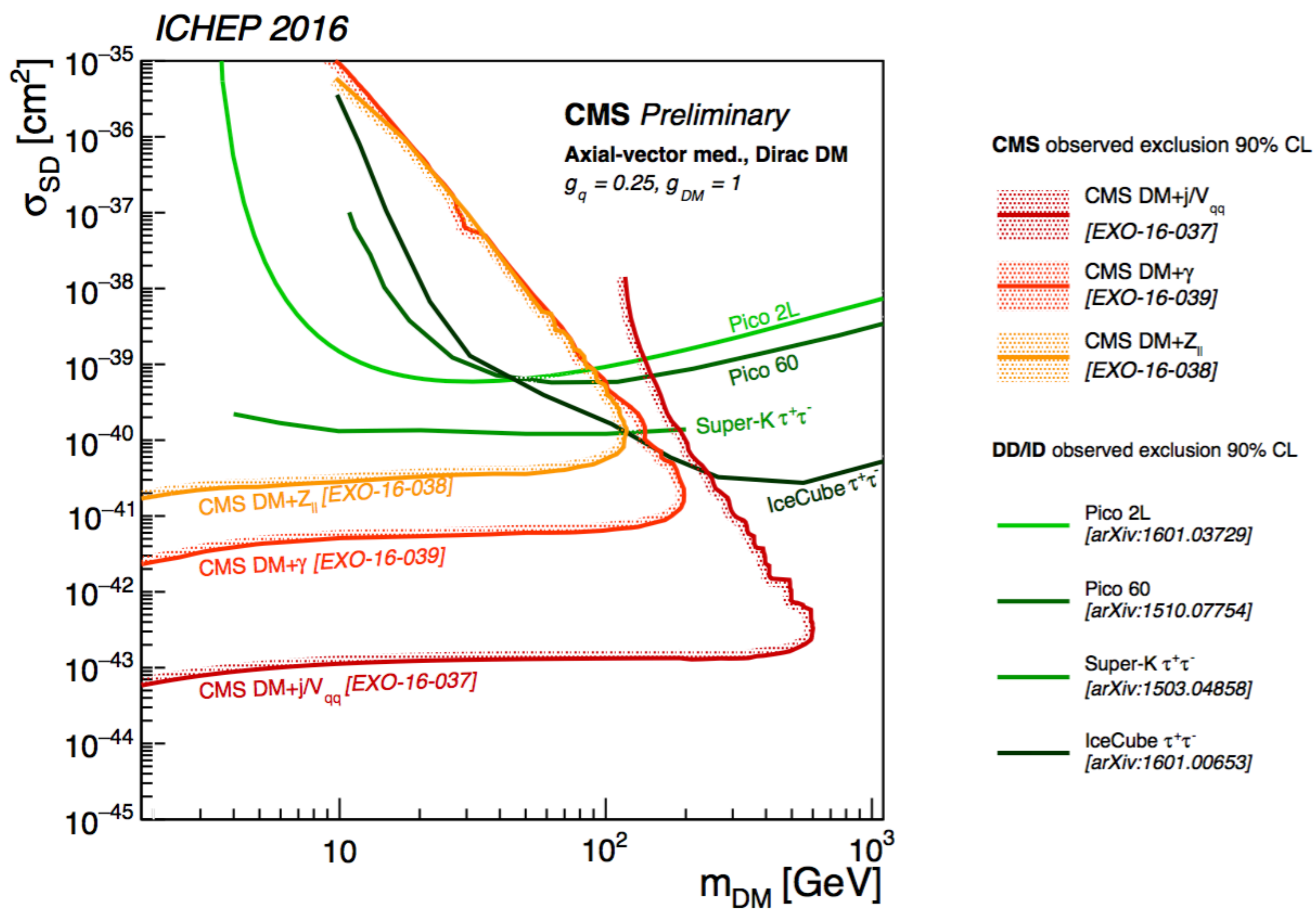




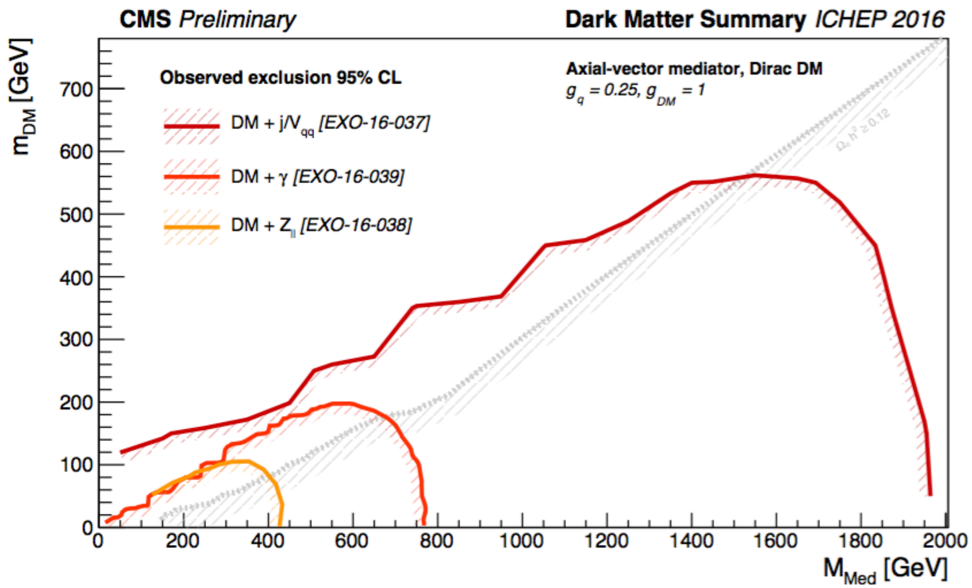
Summary Of Limits On SI Cross Sections

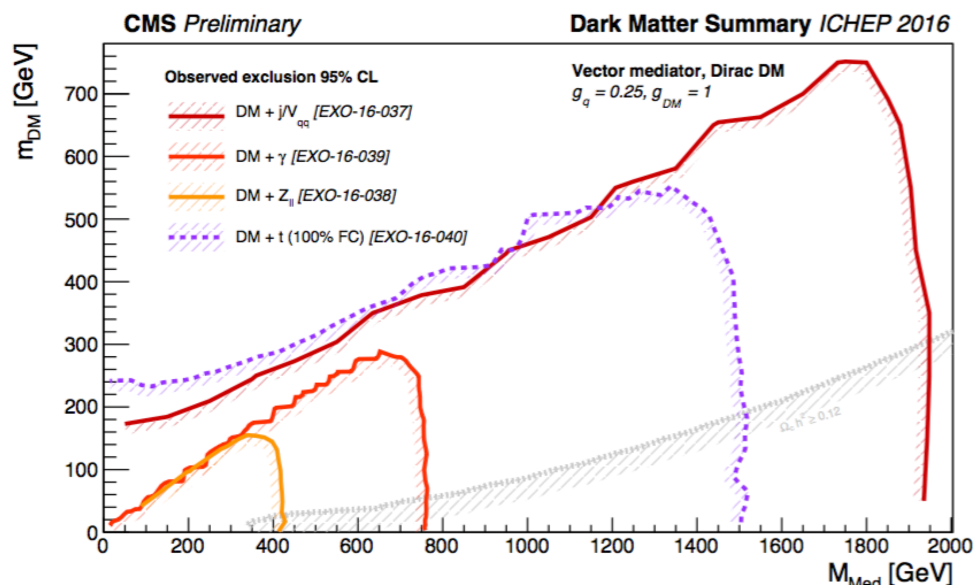


Summary Of Limits On SD Cross Sections



Summary Of Mono-X For Vector/Axial





Method

1. **Take exclusion curve in (M,M) plane**
   - 90%CL
2. **Transform to (M,x-sec) plane**
   - Using formulæ from LHC Dark Matter WG (g_q=0.25, g_{DM}=1)
     - https://arxiv.org/pdf/1603.04156v1.pdf

- **Vector**

$$\sigma_{\mathrm{SI}} \simeq 6.9 \times 10^{-41}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{\mathrm{DM}}}{0.25}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\mathrm{GeV}}\right)^2 . \qquad (4.3)$$

  - **c_SI =** 6.9e-41*1e12, **mR =** (0.939*mDM)/(0.939+mDM), **xsec =** (c_SI*(mR*mR)/(mMed*mMed*mMed*mMed))

- **Axial**

$$\sigma^{\mathrm{SD}} \simeq 2.4 \times 10^{-42}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{\mathrm{DM}}}{0.25}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\mathrm{GeV}}\right)^2 . \qquad (4.10)$$

  - **c_SD =** 2.4e-42*1e12, **mR =** (0.939*mDM)/(0.939+mDM), **xsec =** (c_SD*(mR*mR)/(mMed*mMed*mMed*mMed))

Mono-H (bbar)

$$g_{Z'} = 0.03 \cdot \frac{g_W}{\cos\theta_W \sin^2\beta} \frac{\sqrt{m_{Z'}^2 - m_Z^2}}{m_Z},$$

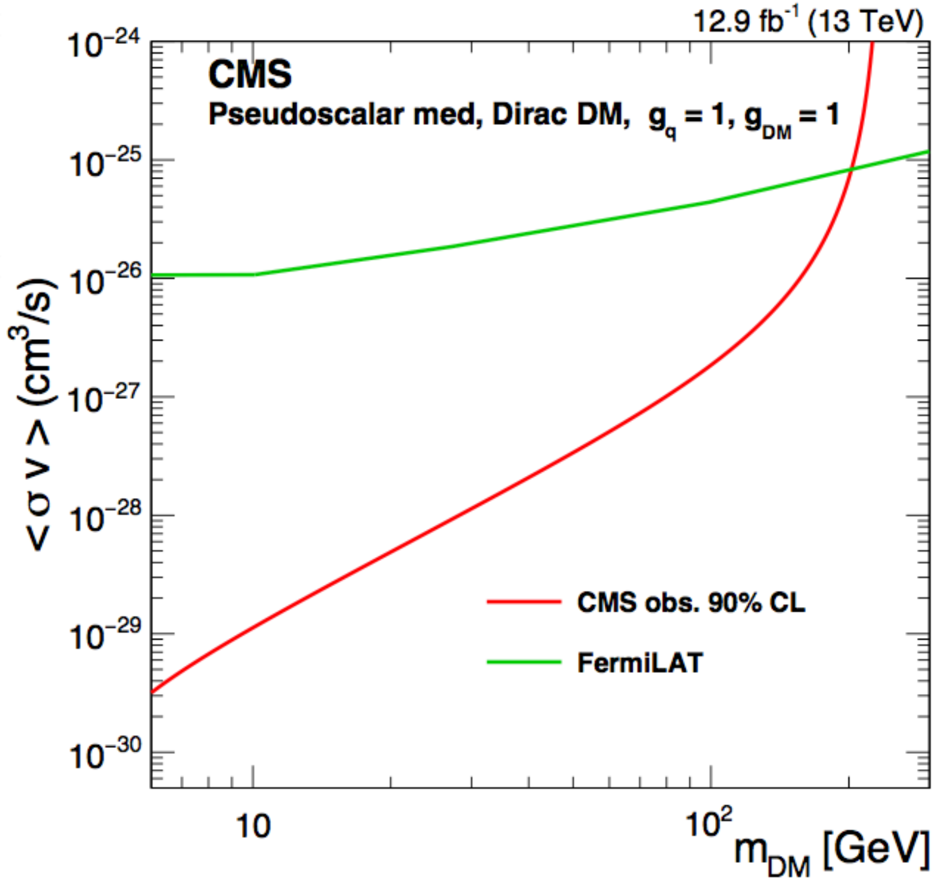
providing $g_{Z'} = 0.485$ for $m_{Z'} = 1$ TeV, and $g_{Z'} = 0.974$ for $m_{Z'} = 2$ TeV.

Simultaneous Fit

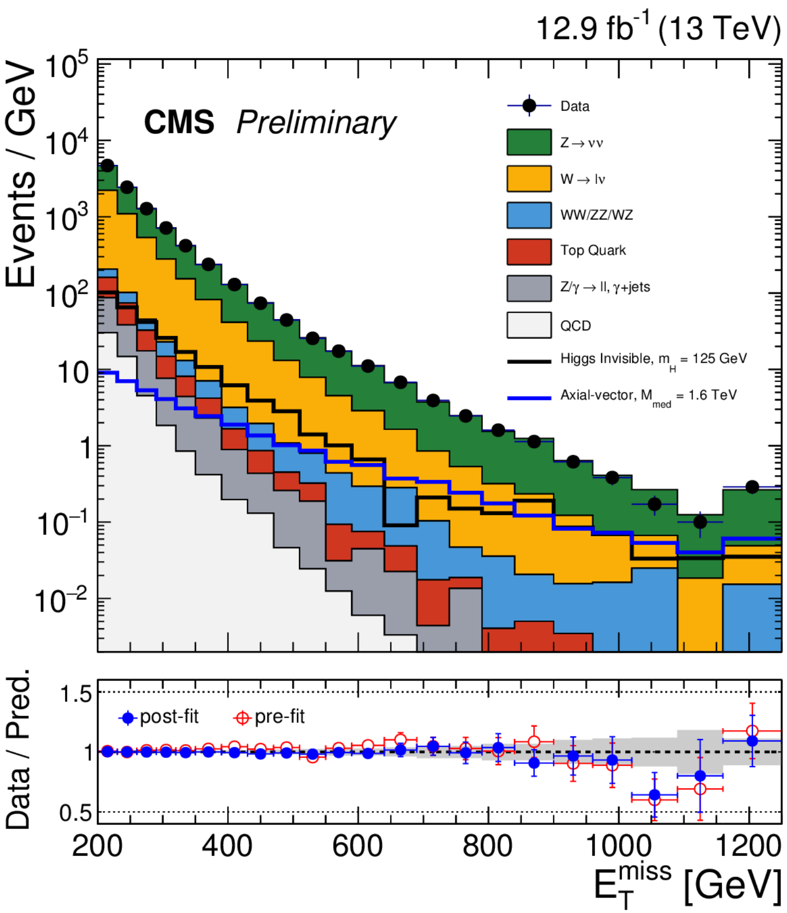
$$
\begin{aligned}
\mathcal{L}_k(\boldsymbol{\mu}^{\mathrm{Z}(\nu\bar{\nu})}, \boldsymbol{\mu}, \boldsymbol{\theta}) = & \prod_i \mathrm{Poisson}\left(d_i^{\gamma} | B_i^{\gamma}(\boldsymbol{\theta}) + \frac{\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})}}{R_i^{\gamma}(\boldsymbol{\theta})}\right) \\
& \times \prod_i \mathrm{Poisson}\left(d_i^{\mu\mu} | B_i^{\mu\mu}(\boldsymbol{\theta}) + \frac{\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})}}{R_i^{\mu\mu}(\boldsymbol{\theta})}\right) \\
& \times \prod_i \mathrm{Poisson}\left(d_i^{\mathrm{ee}} | B_i^{\mathrm{ee}}(\boldsymbol{\theta}) + \frac{\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})}}{R_i^{\mathrm{ee}}(\boldsymbol{\theta})}\right) \\
& \times \prod_i \mathrm{Poisson}\left(d_i^{\mu} | B_i^{\mu}(\boldsymbol{\theta}) + \frac{f_i(\boldsymbol{\theta})\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})}}{R_i^{\mu}(\boldsymbol{\theta})}\right) \\
& \times \prod_i \mathrm{Poisson}\left(d_i^{\mathrm{e}} | B_i^{\mathrm{e}}(\boldsymbol{\theta}) + \frac{f_i(\boldsymbol{\theta})\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})}}{R_i^{\mathrm{e}}(\boldsymbol{\theta})}\right) \\
& \times \prod_i \mathrm{Poisson}\left(d_i | B_i(\boldsymbol{\theta}) + (1 + f_i(\boldsymbol{\theta}))\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})} + \boldsymbol{\mu} S_i(\boldsymbol{\theta})\right)
\end{aligned}
$$

where $\mathrm{Poisson}(x|y) = y^x \mathrm{e}^{-y}/x!$. The symbols $d_i^{\gamma}, d_i^{\mu\mu}, d_i^{\mathrm{ee}}, d_i^{\mu}, d_i^{\mathrm{e}}$, and d_i denote the observed number of events in each bin i of the γ+jets, dimuon, dielectron, single-muon, and single-electron control samples, and the signal region, respectively. The symbol f_i denotes the transfer factor between the $\mathrm{Z}(\nu\bar{\nu})$+jets and $\mathrm{W}(\ell\nu)$+jets backgrounds in the signal region, and represents a constraint between these backgrounds. The symbols $R_i^{\gamma}, R_i^{\mu\mu}, R_i^{\mathrm{ee}}, R_i^{\mu}$, and R_i^{e} are the transfer factors from the γ+jets, dimuon, dielectron, single-muon, and single-electron control samples, respectively, to the signal region; the contributions from other background processes in these control samples are denoted by $B_i^{\gamma}, B_i^{\mu\mu}, B_i^{\mathrm{ee}}, B_i^{\mu}$, and B_i^{e}, respectively. The parameter $\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\bar{\nu})}$ represents the yield of the $\mathrm{Z}(\nu\bar{\nu})$+jets background in each bin i of $E_{\mathrm{T}}^{\mathrm{miss}}$ in the signal region, and this parameter is left floating in the fit. The likelihood also includes a term for the signal region in which B_i represents all the backgrounds apart from $\mathrm{Z}(\nu\bar{\nu})$+jets and $\mathrm{W}(\ell\nu)$+jets, S_i represents the nominal signal prediction, and $\boldsymbol{\mu}$ denotes the signal strength parameter. The systematic uncertainties are modeled as nuisance parameters ($\boldsymbol{\theta}$).

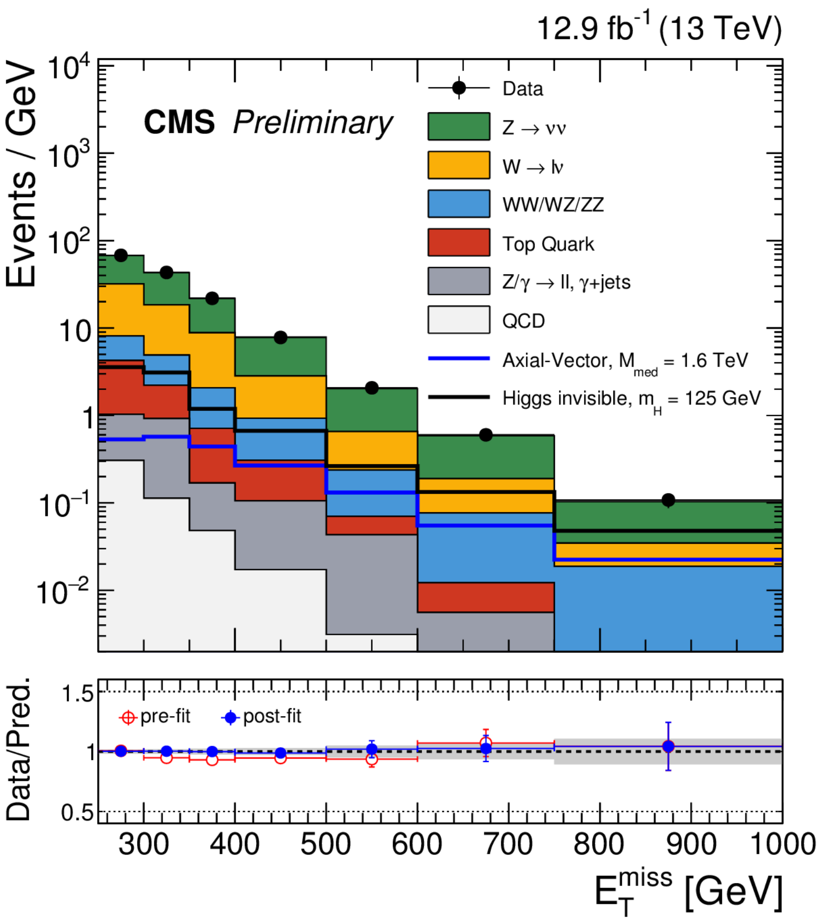
Monojet : Pseudo-Scalar



Monojet : Fit results



(a)



(b)

Monojet : Uncertainties

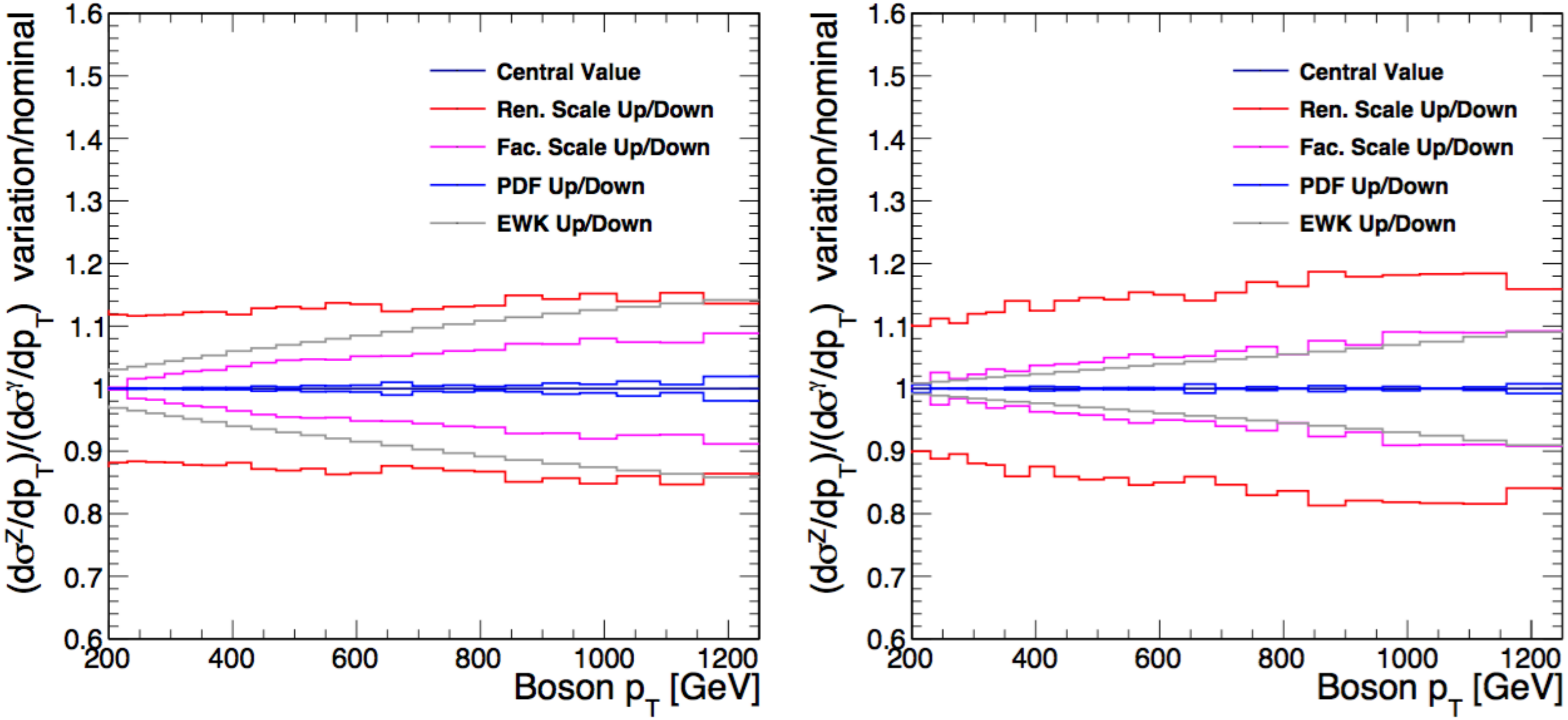


Figure 72: Theoretical uncertainties on the Z/γ (left) and Z/W (right) transfer factors.

+ Monojet : Uncertainties

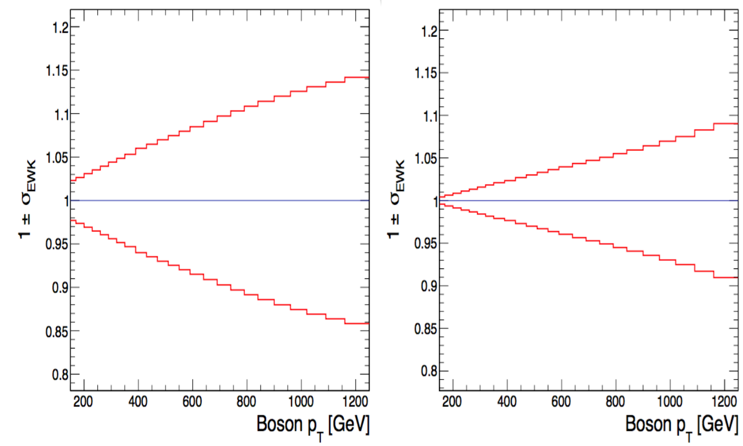
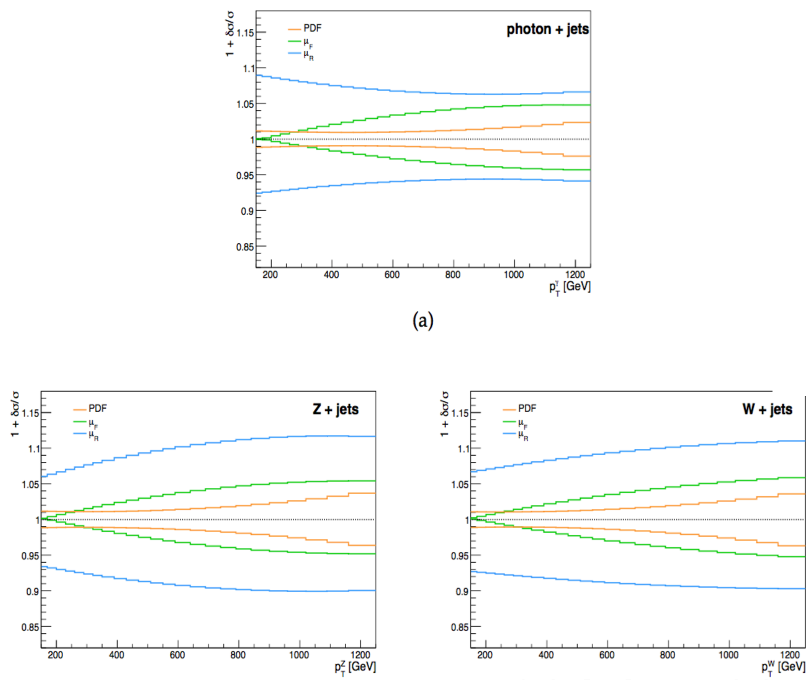


Figure 71: Theoretical uncertainties on the Z/γ (left) and Z/W (right) transfer factors for the uncertainties originating from the electroweak corrections.

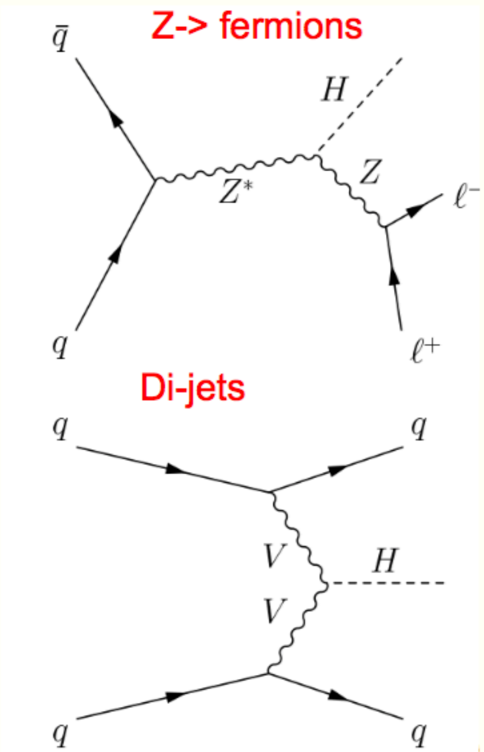


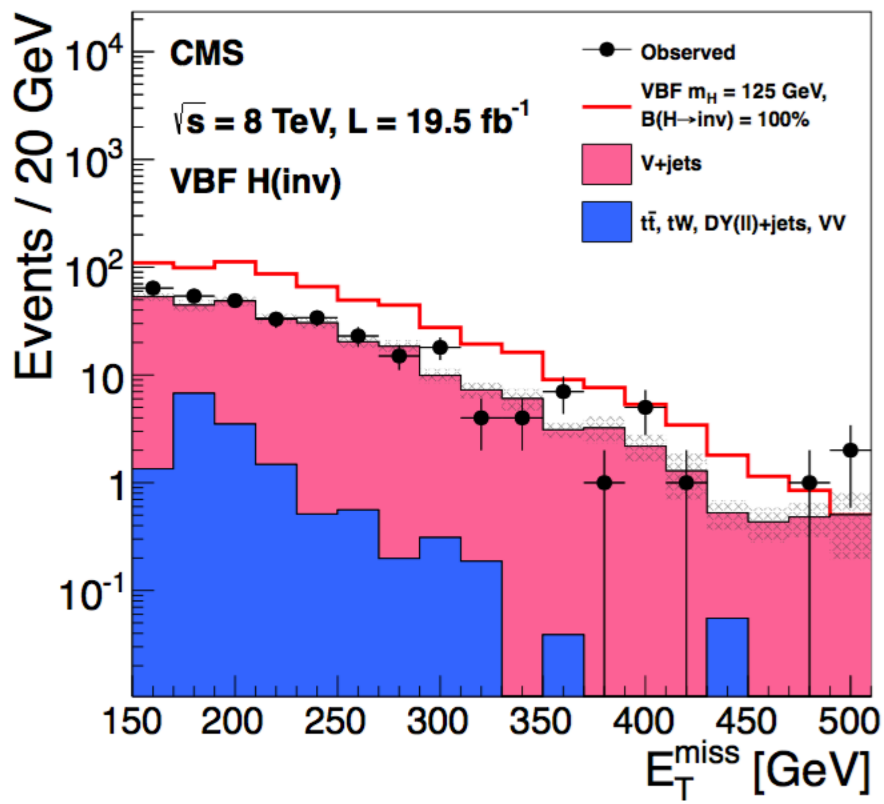
(a) (b) (c)

Figure 70: PDF and QCD scale uncertainties on the photon + jets (a), Z + jets (b), and W + jets (c) p_T^V distributions. Note that the actual uncertainties are evaluated for the ratio of such distributions accounting for correlations.

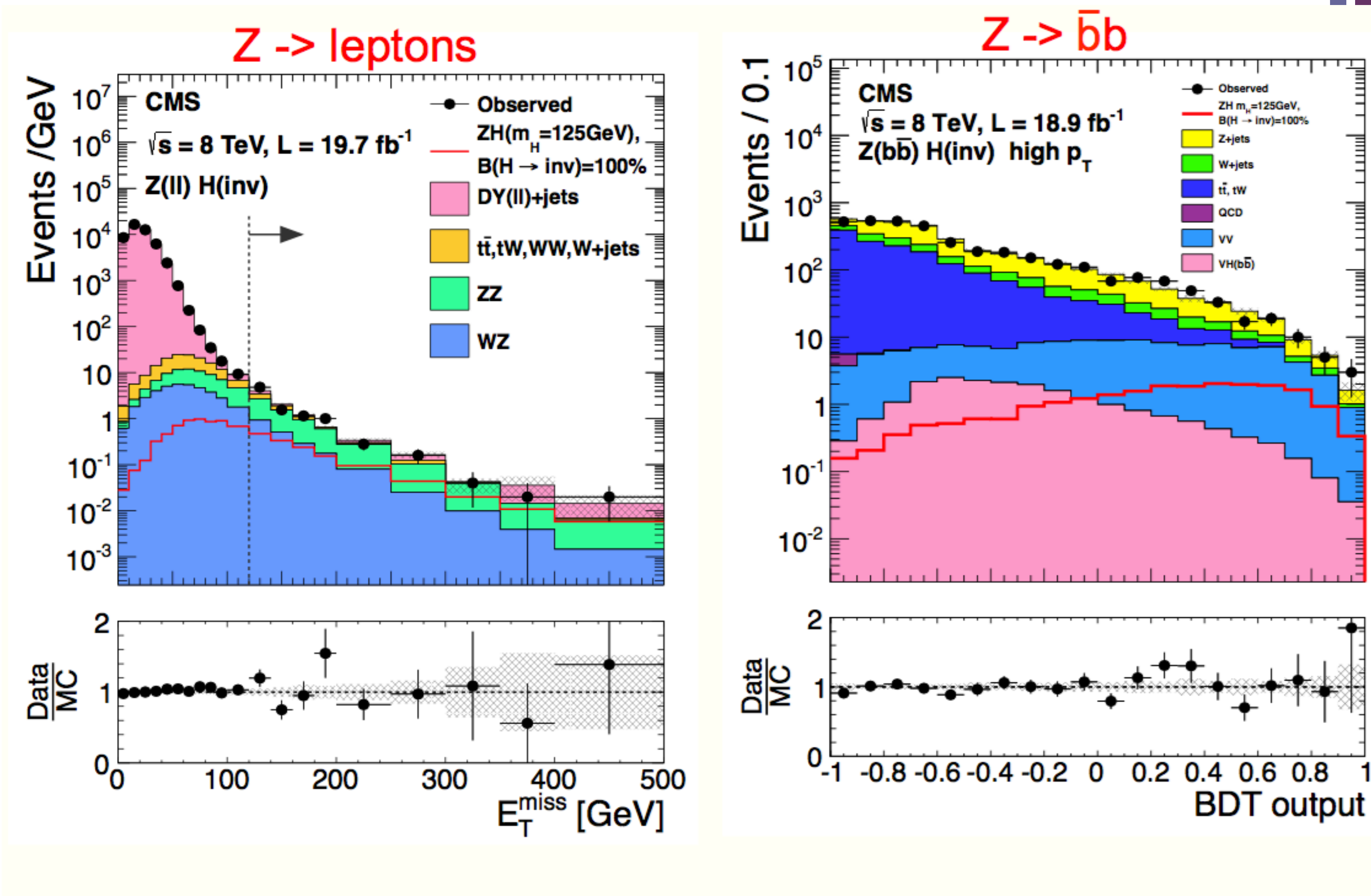
Higgs Modes : CMS VBF

Depending on its nature, DM will couple to theHiggs in various ways. Assuming a Higgs -> Invisible branching, one can search in several channels.

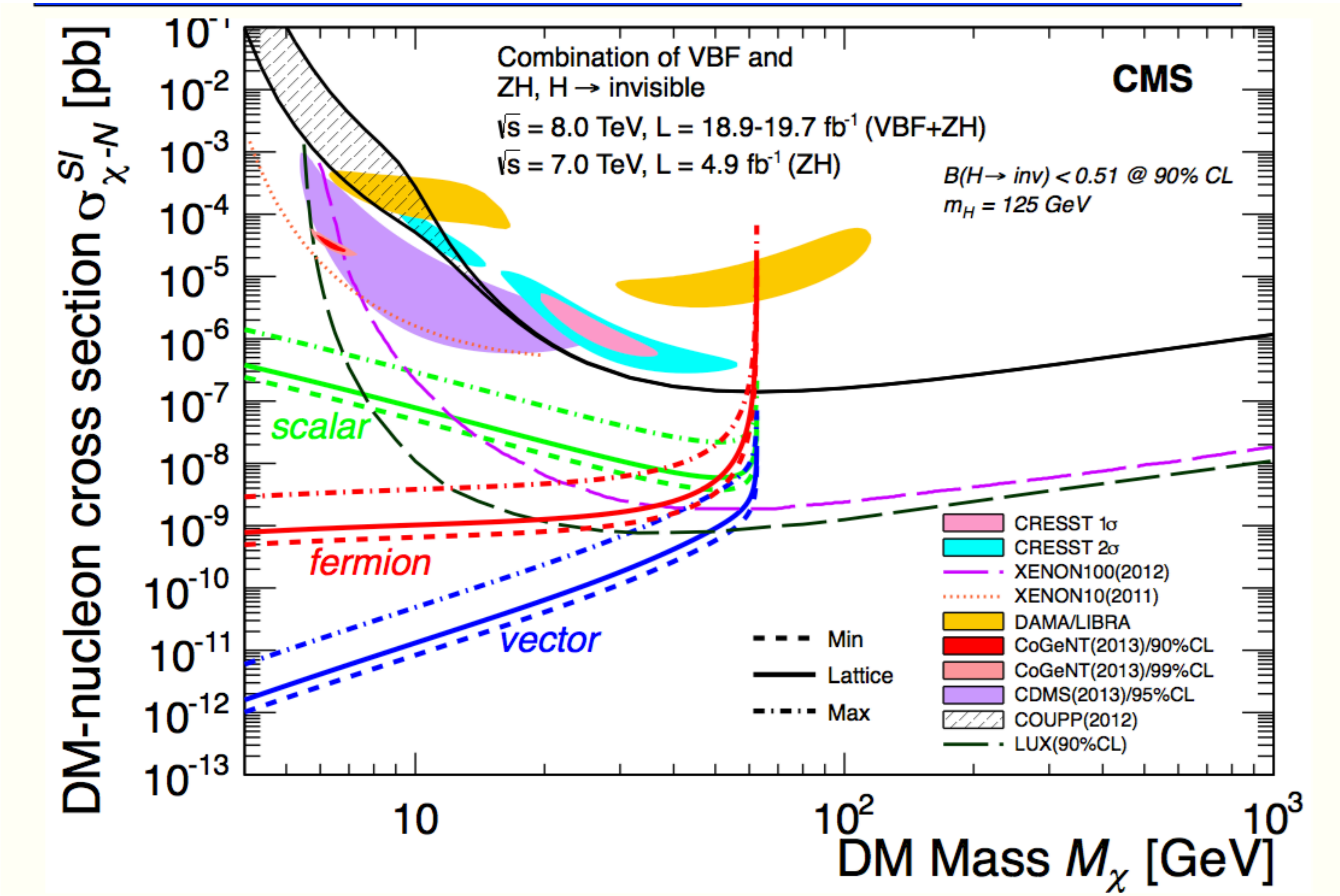




+ Higgs Modes : CMS ZH

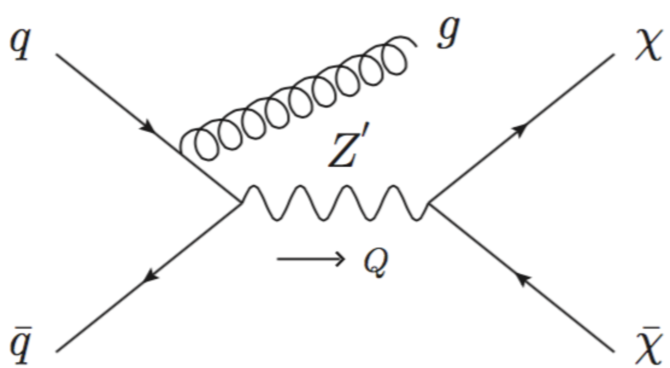


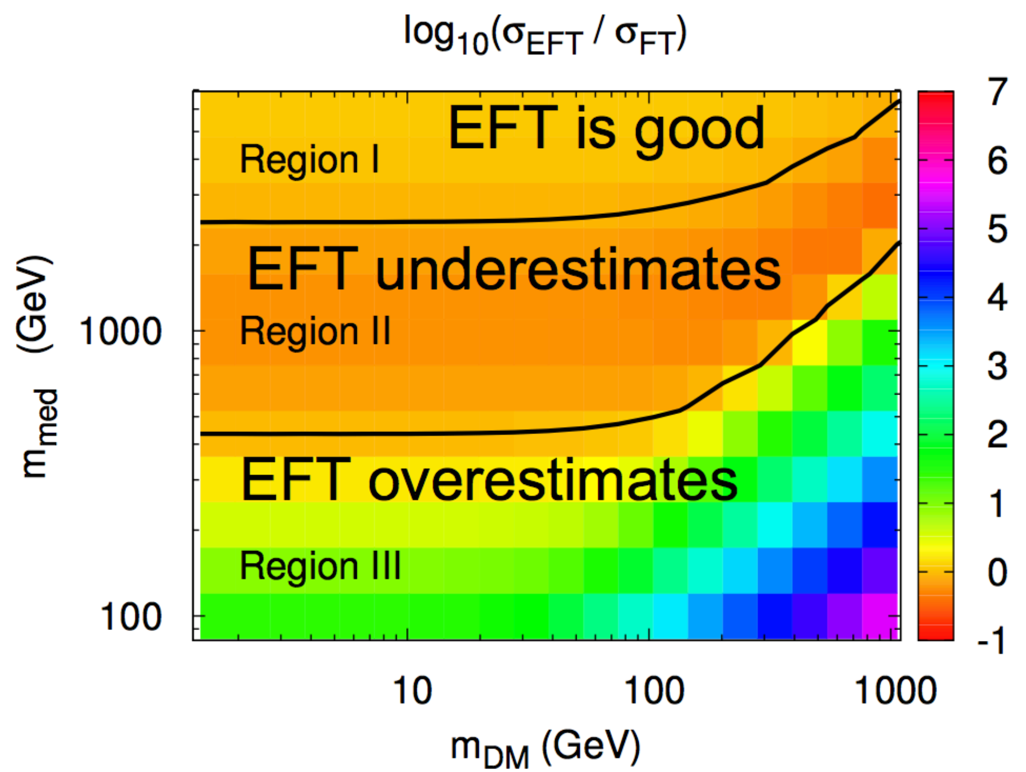
CMS VBF + ZH limits



Light Mediator Case

- The most tricky case is that of light mediator
- First step : put in a mediating particle (e.g s-channel Z') and look at limits vs m_z





- EFT gives good/conservative results above a few hundred GeV (high M)
  - Region I – EFT is good
  - Region II – EFT underestimate
  - Region III – EFT overestimate

Buchmeller, Dolan, McCabe, arXiv : 1308.6799