Search For Dark Matter in the Monophoton Final State at CMS

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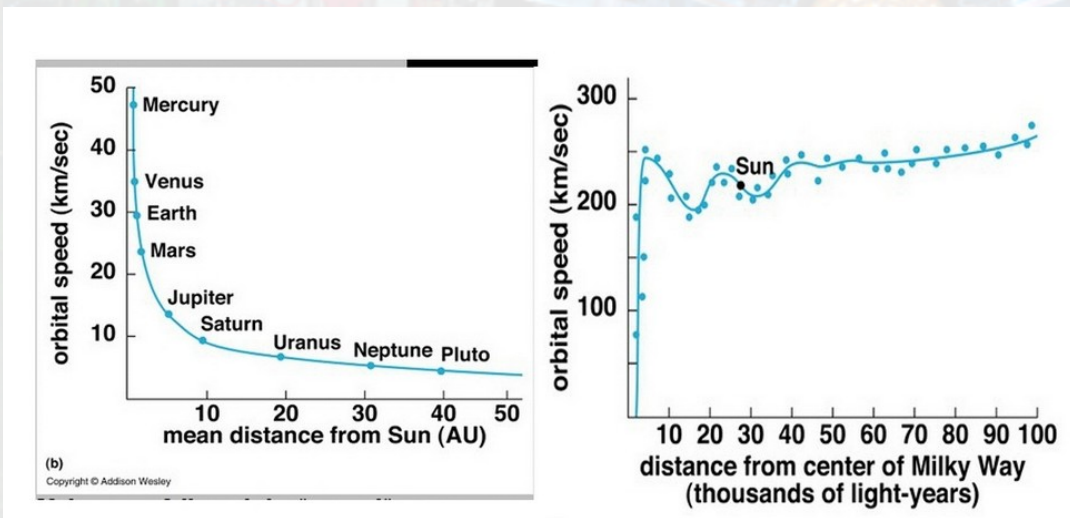
Introduction:

- What is Dark matter
- Evidence of Dark Matter
- What are its properties
- How to search for the Dark matter(DM)

Evidence:



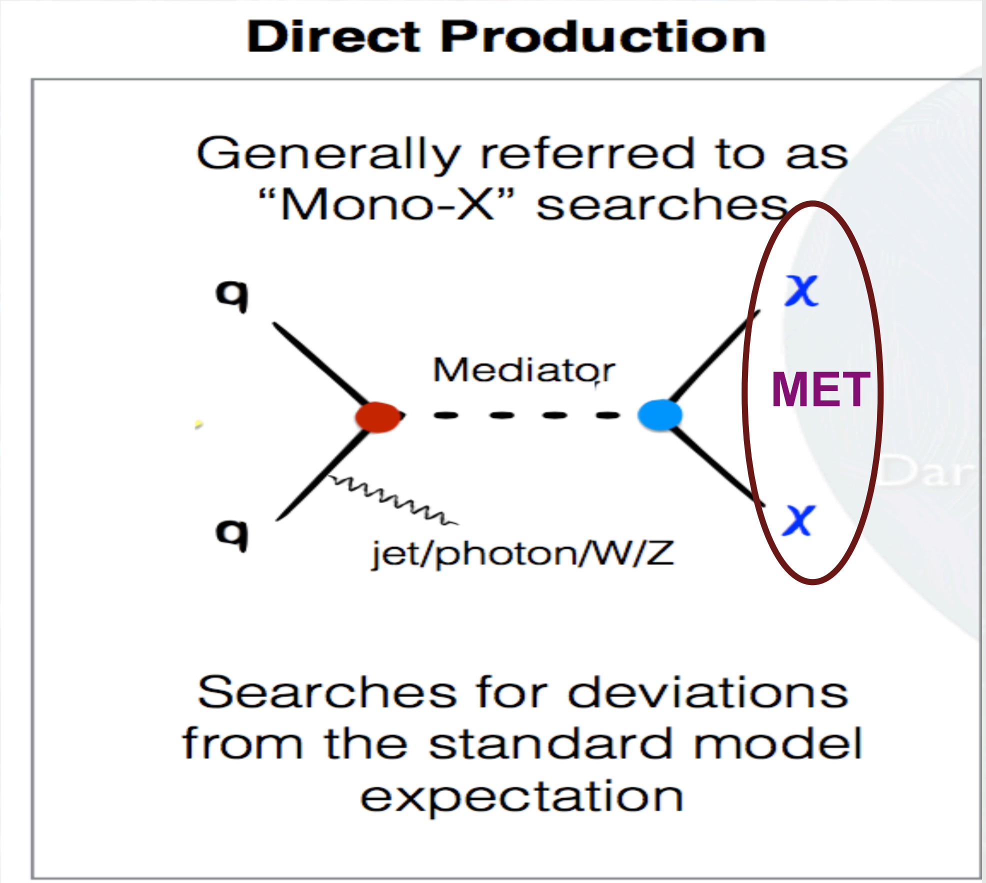
Rotational curve of the galaxy

Bullet Cluster

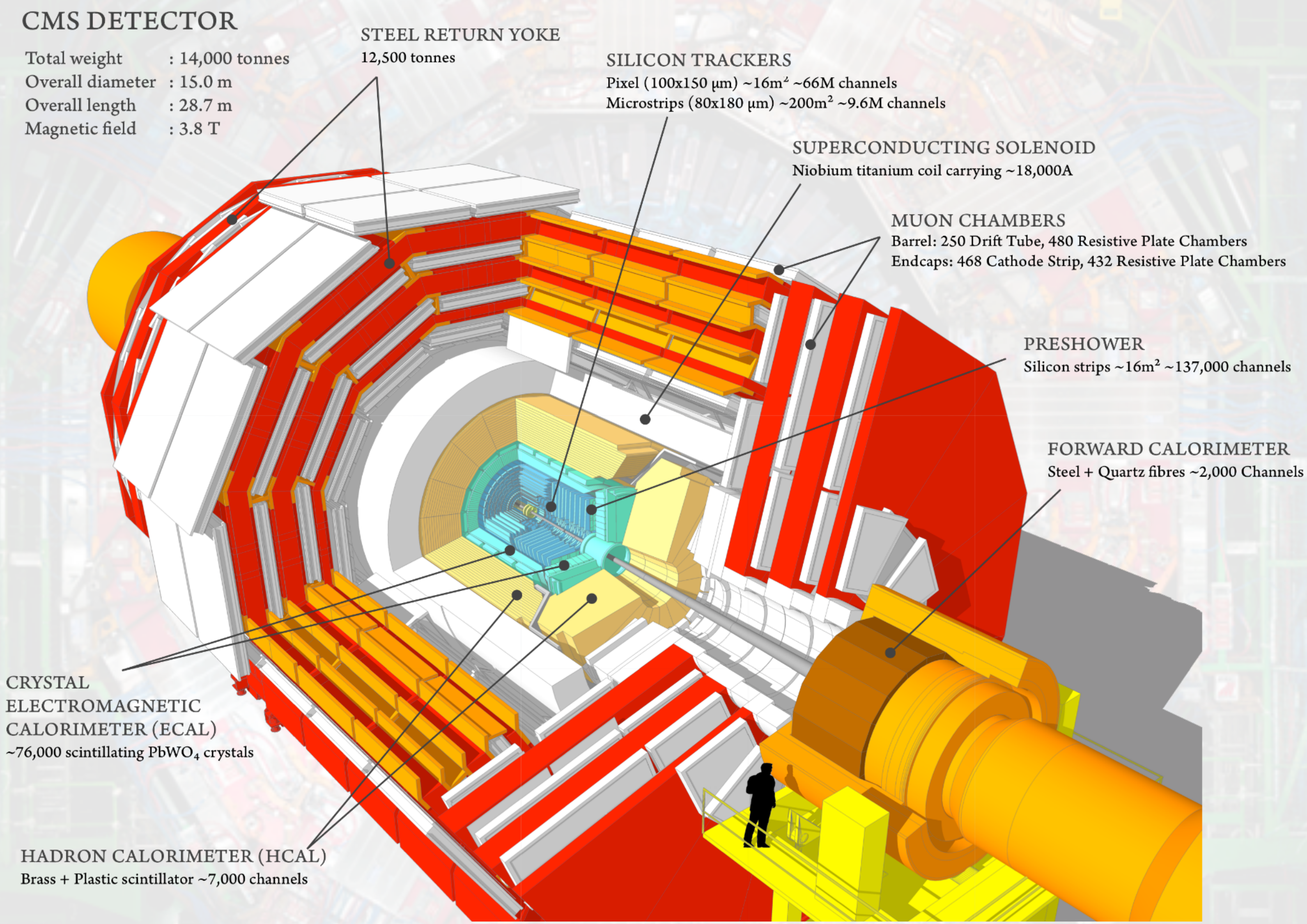
Images taken by Chandra X-Ray Observatory

Dark Matter Searches at CMS:

- ✓ Search for Dark Matter with Monophoton final state
- ✓ 2016 published results JHEP 02 (2019) 274



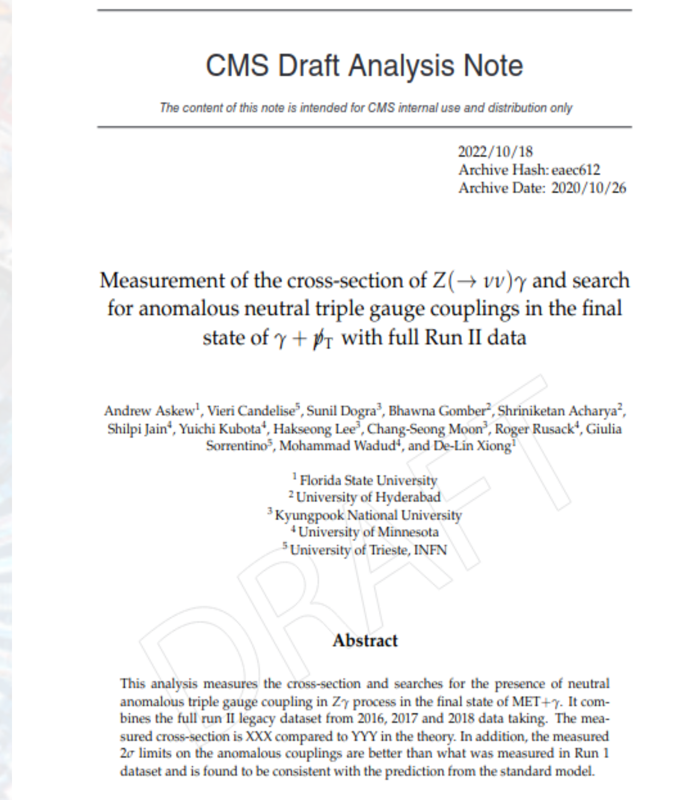
Compact Muon Solenoid Detector (CMS):



Monophoton Analysis:

- ✓ Monophoton channel : High p_T photon against large missing p_T
  - ✓ Standard Model : mostly $Z(\nu\nu) + \gamma$
- ✓ New physics models predict excesses in this channe above SM background
- ✓ **Simplified model for dark matter**
- ✓ Set of parameters are $\{g_q, g_\chi, m_\chi, M_{med}\}$ with $g_q=0.25, g_\chi=1.0$ following ATLAS-CMS recommendation https://arxiv.org/pdf/1507.00966.pdf

where M_{med} is mass of SM-DM mediator, m_x is mass of DM particle, g_x and g_q are its coupling to dark matter and quark


CMS Draft Analysis Note

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Archive Date: 2020/10/26

Measurement of the cross-section of $Z(\rightarrow \nu\nu)\gamma$ and search for anomalous neutral triple gauge couplings in the final state of $\gamma + p_T^{miss}$ with full Run II data

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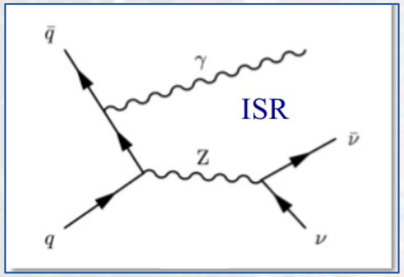
[2] University of Hyderabad
[3] Kyungpook National University
[4] University of Minnesota
[5] University of Trieste, INFN

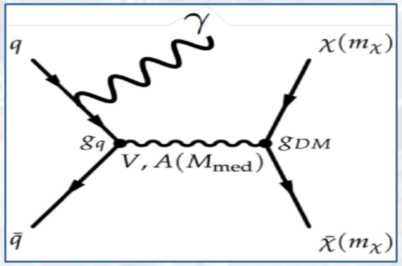
DRAFT

Abstract

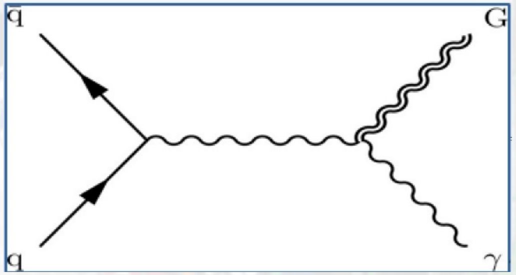
This analysis measures the cross-section and searches for the presence of neutral anomalous triple gauge coupling in $Z\gamma$ process in the final state of MET+γ. It combines the full run II legacy dataset from 2016, 2017 and 2018 data taking. The measured cross-section is XXX compared to YYY in the theory. In addition, the measured 2σ limits on the anomalous couplings are better than what was measured in Run 1 dataset and is found to be consistent with the prediction from the standard model.



SM process



Simplified model

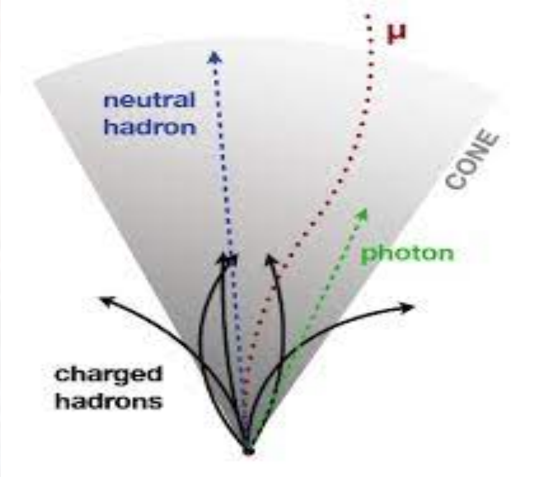


ADD model

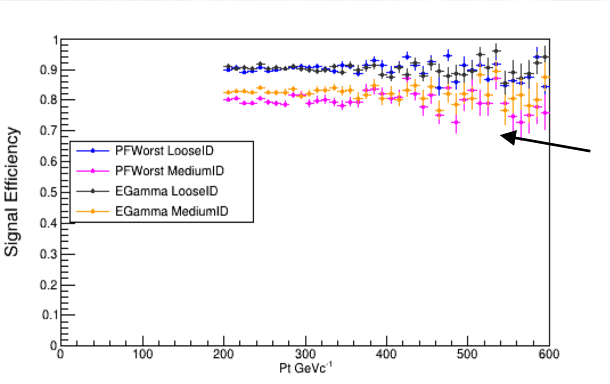
https://cms.cern.ch/iCMS/analysisadmin/cadilines?line=SMP-22-009

Isolation Variables

- **Particle Flow Worst Charged Hadron Isolation:** Maximum value of Sum of P_T of all charged hadron computed with respect to all reconstructed vertices
- **Particle Flow Neutral Isolation:** Sum of P_T of all neutral hadrons within a cone of $\Delta R = 0.3$ about the supercluster
- **Particle Flow Photon Isolation:** Sum of P_T of all photons within a cone of $\Delta R = 0.3$ about the supercluster excluding a strip in $\Delta\eta = 0.015$ about the supercluster

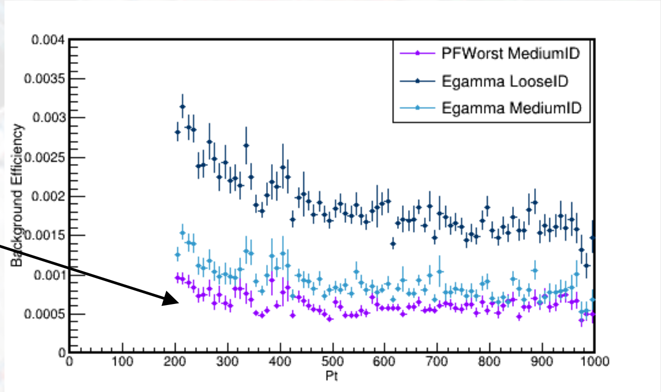


	sigmaIeta	H/E	WorstChargeIsolation	Neutral Isolation	Photon Isolation
Loose (90%)	0.0103	0.031	8.61	7.26	0.18
Medium(80%)	0.0103	0.023	2.14	7.25	0.17



Using γ+jet samples

We use 80% signal efficiency WP in the analysis



Using QCD p_T binned samples

Backgrounds Composition

- Z γ -> $\nu\nu$ + γ ~55%
- W γ -> lν + γ ~15%

Using Simultaneous fit to Control Regions

- W -> ev, e fakes γ ~15%
- Jets faking γ ~2%
- Non-collision (beam-halo, spikes) ~3-4%

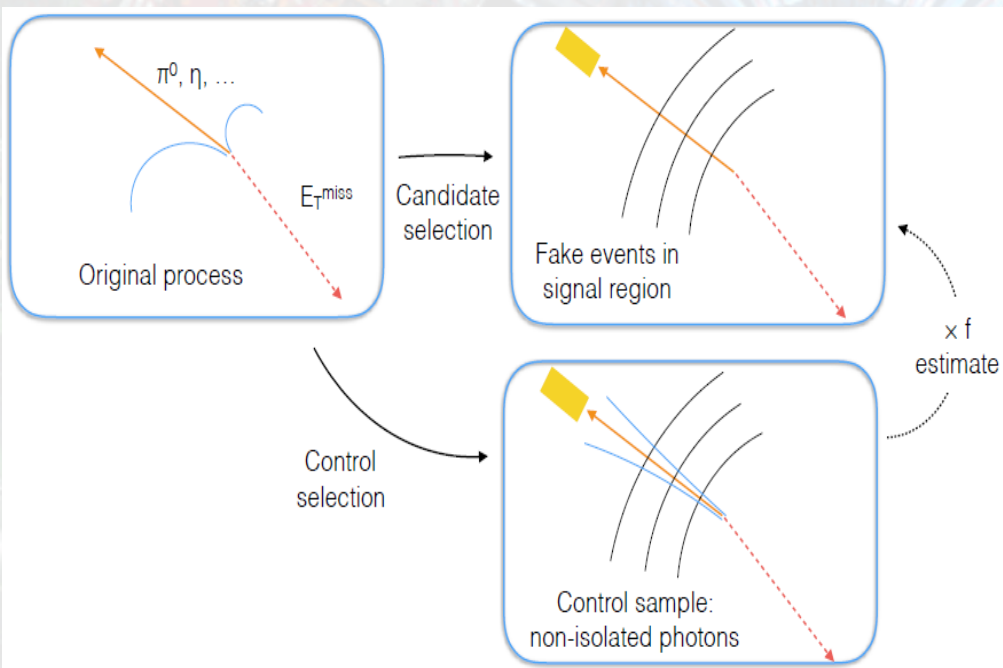
Data Driven Methods

- γ + jets, mis-measured ET ~3%
- Minor SM : tt + γ, Z(ll) + γ, W(μ/τ + ν) ~5%

MC

QCD fake rate : Method

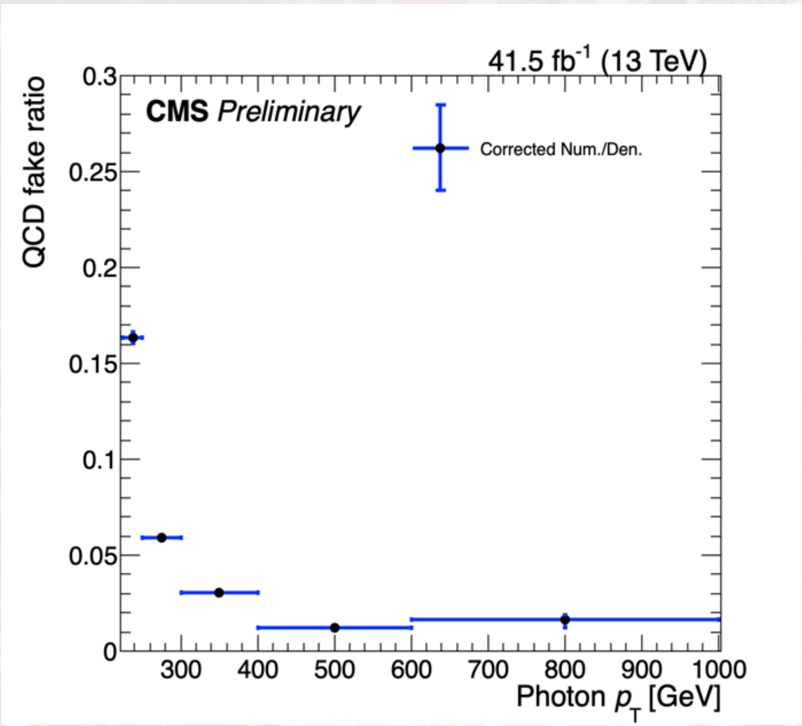
- ✓ Data-driven strategy
  - ✓ Count number of photon-like jets failing a loose isolation cut
  - ✓ Multiply a fake ratio to get number of jet to photon fakes
  - ✓ Fake ratio is evaluated in MET < 30 GeV control region
  - ✓ Subtract real photon contribution, obtained from template fit based on σiηiη



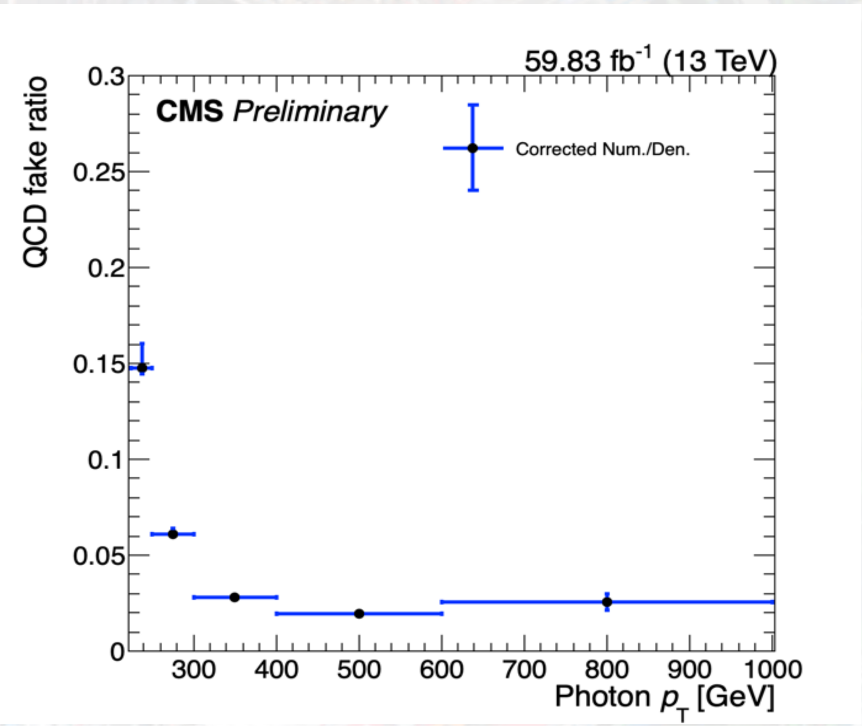
$$f = \frac{N_{\text{iso}}(\text{EM Object})}{N_{\text{non-iso}}(\text{EM Object})}$$

QCD fake rate using Optimised ID

✓ Obtained QCD fake rate which is jets faking photon background in the analysis



2017



2018

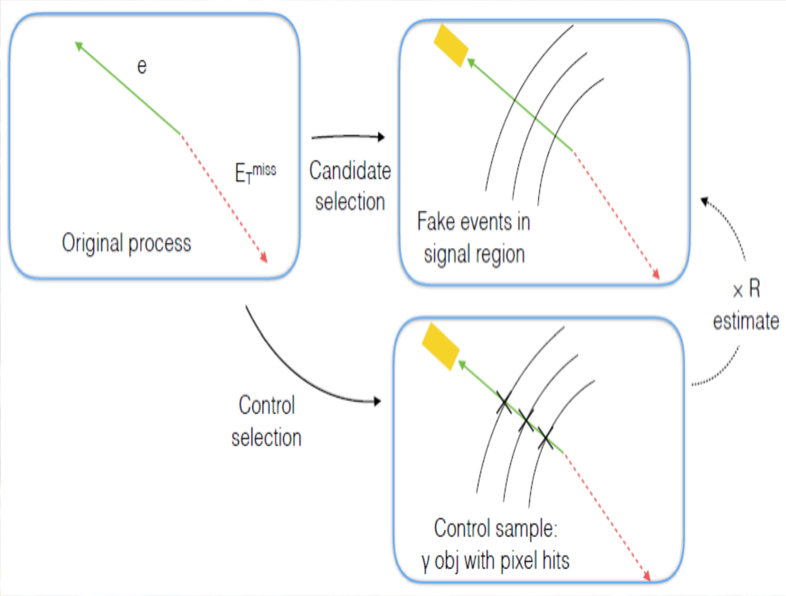
Electron faking photon

Data-driven strategy

Using Z->ee events

Tag is electron (passing 70% signal efficiency)

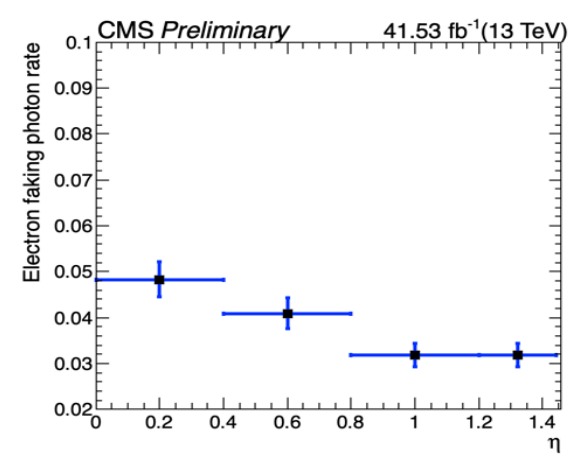
Probe is photon ((passing 80% signal efficiency)



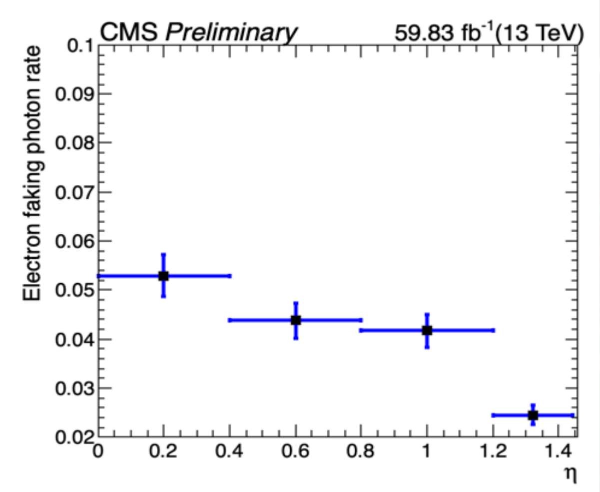
Fit ee and eγ distribution and estimate fake rate

Fake rate = Neγ/Nee

Fake rate as a function of photon eta



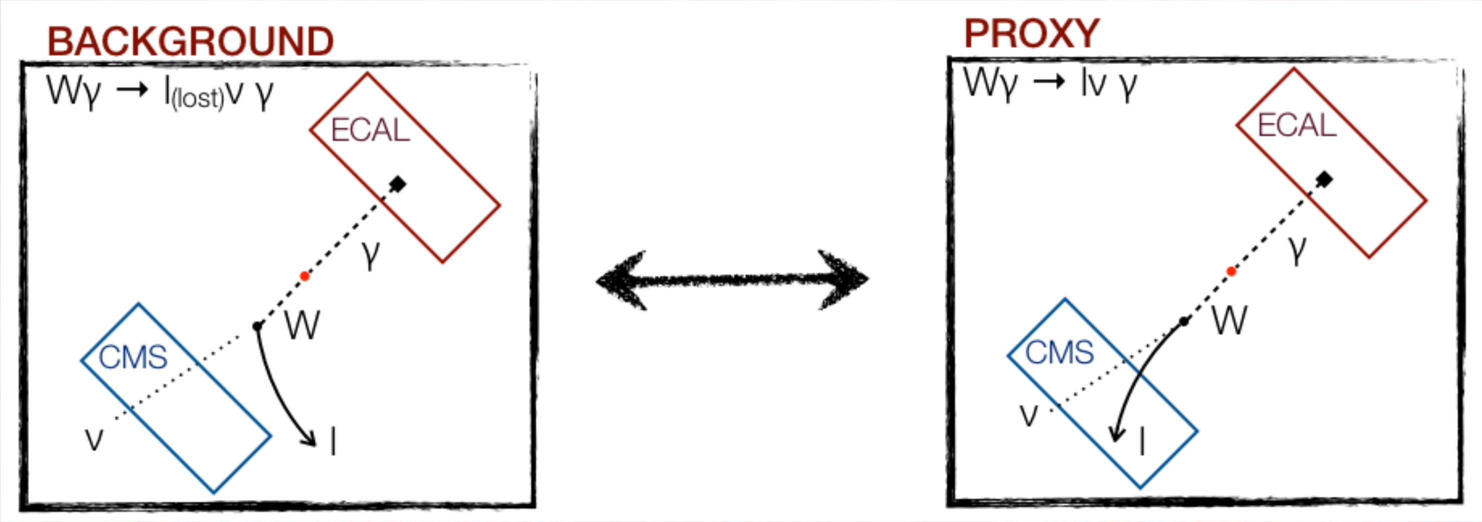
2017



2018

Wγ Control Region

- Final state W (⟶ *l*ν) with the charged lepton falling inside the detector acceptance



Pictorial representation of the relationship between the W γ events passing the signal selection (left) and the ones passing the control region selection (right)

Control Region : Wγ Selection

Single electron control region selection

- Exactly one electron, passing 70% Signal efficiency
- HLT_Photon200
- $p_T > 30$ GeV
- Exactly one photon passing 80% signal efficiency
- Recoil > 200
- No loose muons
- DeltaPhi(pho, recoil) > 0.5
- DeltaPhi(Jet, PFMET) > 0.5
- pfMET > 50
- Transverse mass (lepton, PFMET) < 160 GeV
- Pho_pT / Recoil< 1.4

Single Muon control region selection

Exactly one Muon, passing 70% signal efficiency

- HLT_Photon200
- $p_T > 30$ GeV

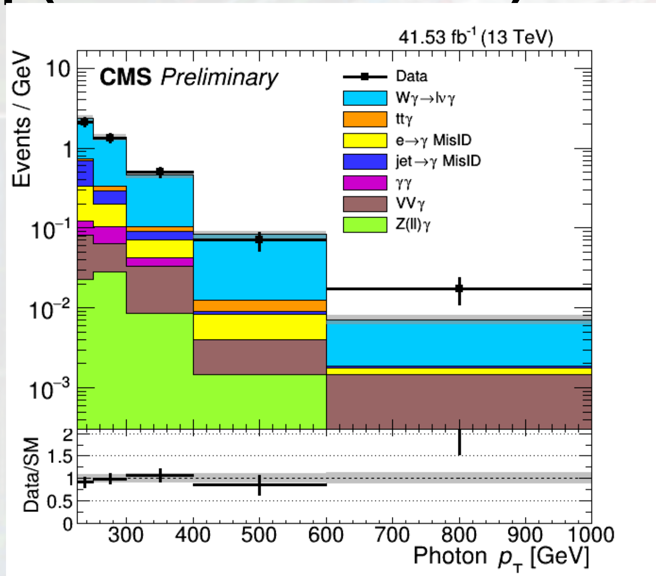
Exactly one photon passing 80% signal efficiency

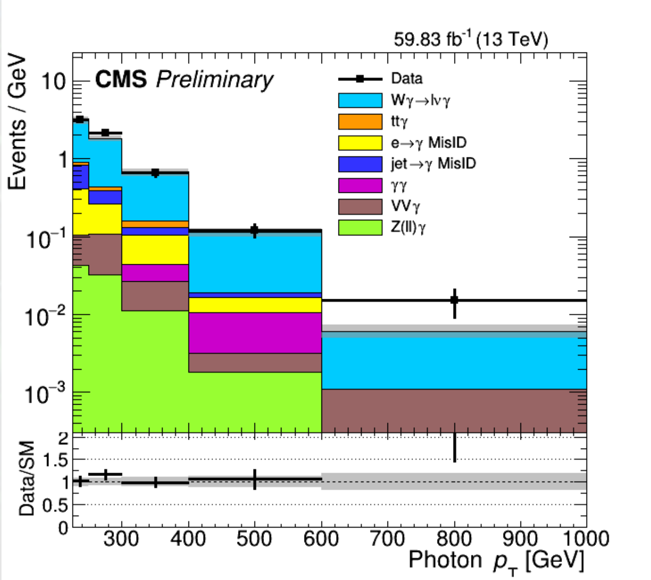
- No loose Ele
- Recoil > 200
- DeltaPhi(pho, recoil) > 0.5
- DeltaPhi(Jet, MET) > 0.5
- Transverse mass (lepton, PFMET) < 160 GeV
- Pho_pT / Recoil< 1.4

Corrections Applied

- Photon pixel seed SF, where SF is efficiency in data/ efficiency in MC
- Electron/muon ID/Iso SF
- Trigger SF

Wγ (electron channel) For Barrel





WenG region 2017

Electron faking photon: 13.7071 +- 1.16694
Z(ll)+Gamma: 3.19564 +- 0.482515
tt+Gamma: 5.0155 +- 0.6596
Diphoton: 4.0176 +- 2.60711
QCD fakes: 15.8276 +- 1.58276
W+gamma: 143.302 +- 15.8744
WZ: 1.73445 +- 0.501961
WW: 4.99773 +- 1.02776
Total background: 191.798 +- 16.2676

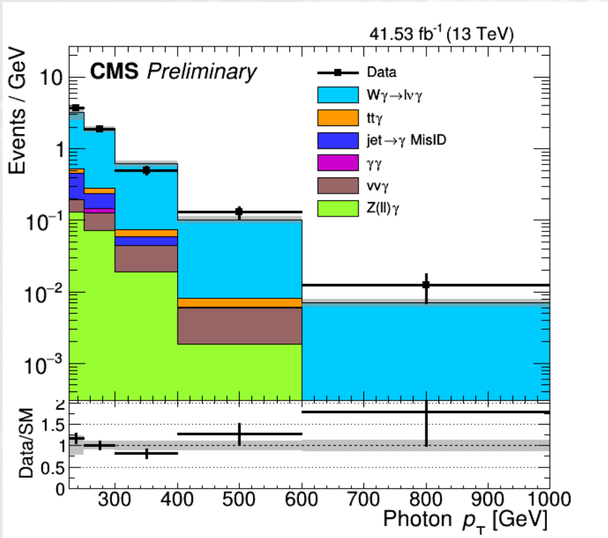
Data: 192

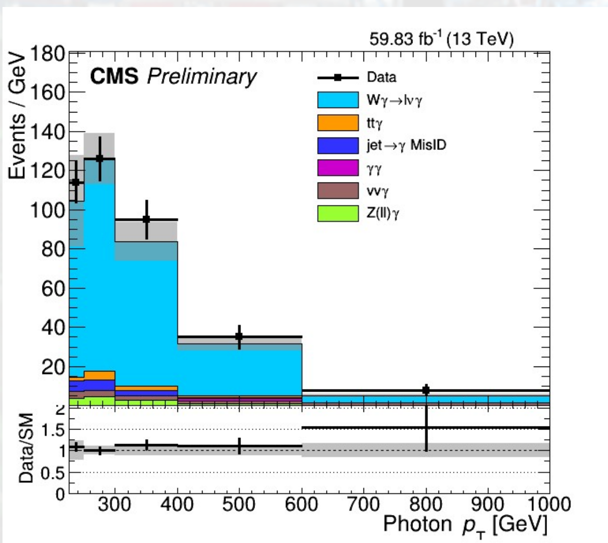
WenG region

Electron faking photon: 23.3573 +- 1.76971
Z(ll)+Gamma: 4.23077 +- 0.703943
tt+Gamma: 6.79697 +- 0.831706
Diphoton: 1.65204 +- 1.79247
QCD fakes:19.8924 +- 1.98924
W+gamma: 196.429 +- 21.4589
WZ: 1.89369 +- 0.636913
WW: 5.64572 +- 1.3039
Total background:259.898 +- 21.7734

Data: 281

Wγ (muon channel) For Barrel





WmnG region 2017

Z(ll)+Gamma: 9.1834 +- 1.37521

Diphoton: 1.07261 +- 1.20814

QCD fakes: 12.476 +- 1.2476

W+gamma: 221.187 +- 0

tt+Gamma: 5.75969 +- 0.679759

WZ: 1.55483 +- 0.487861

WW: 6.29278 +- 1.19074

Total background: 257.526 +- 2.65052

Data: 267

WmnG region 2018

Z(ll)+Gamma: 12.4634 +- 1.83654

Diphoton: 1.58704 +- 1.78887

QCD fakes: 13.0937 +- 1.30937

W+gamma: 301.803 +- 28.0403

tt+Gamma: 10.2056 +- 1.01963

WZ: 3.05112 +- 0.817359

WW: 8.82513 +- 1.69223

Total background: 351.029 +- 28.2686

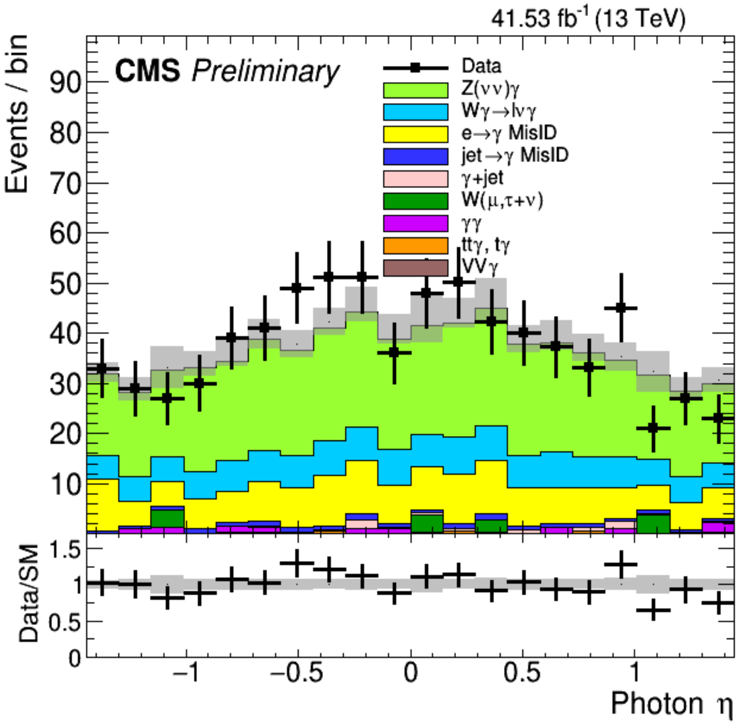
Data: 379

Signal Region Selection

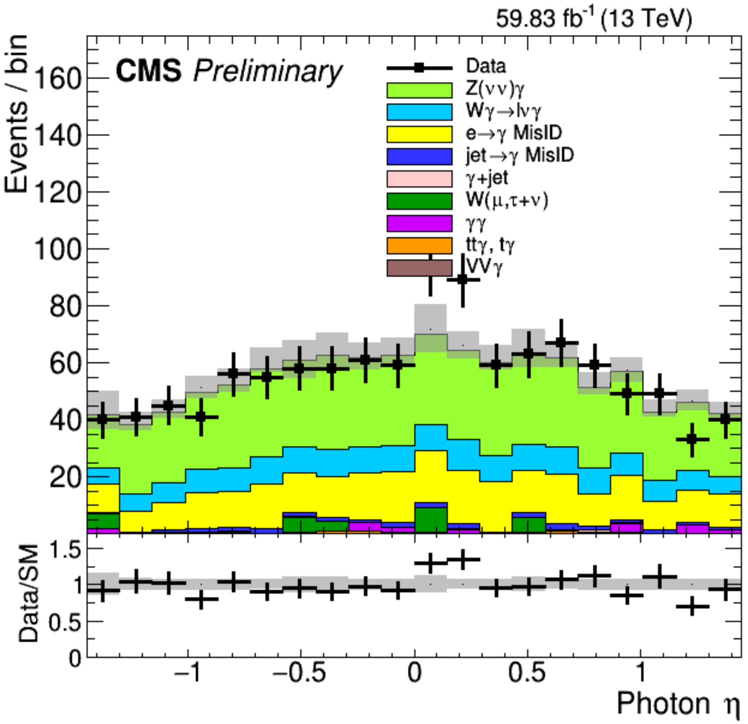
Signal region Selection

- ✓ Exactly one photon passing 80% signal efficiency
- ✓ HLT_Photon200
- ✓ Photon p_T > 225 GeV
- ✓ PFMET > 200 GeV
- ✓ DeltaPhi(pho, PFMET) > 0.5
- ✓ DeltaPhi(Jet, PFMET) > 0.5
- ✓ Lepton veto (electrons and muons)
- ✓ Pho_p_T / PFMET < 1.4
- ✓ Hem veto (2018) [excluding the events with jet p_T in ($-3.0<|\eta|<-1.3$) and ($-1.57<|\Phi|<-0.87$)]
- ✓ Blinding policy : We looked at only photon η and Φ variables in signal
  - The final signal extraction variable photon p_T is blinded

Signal Region Plots

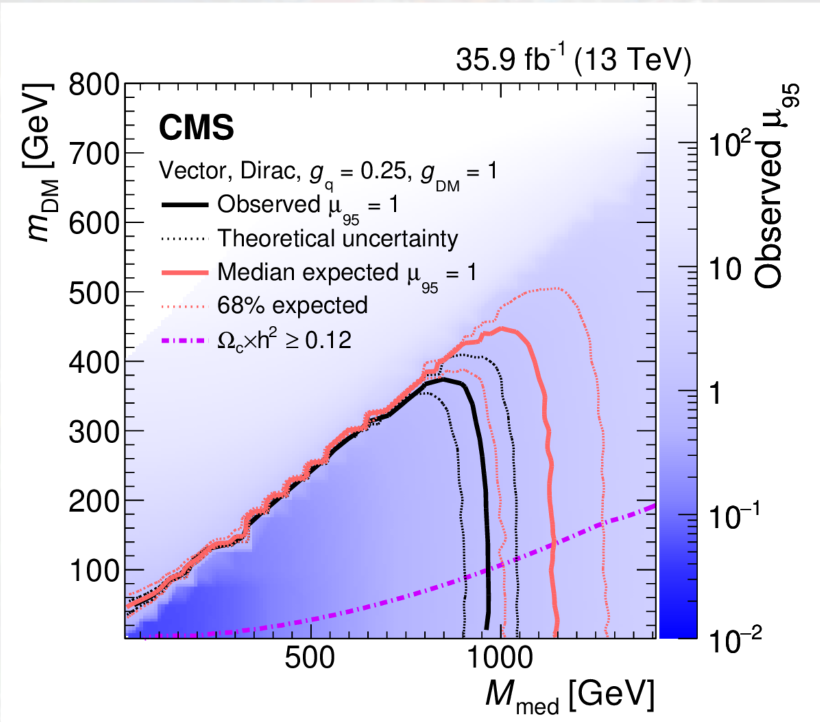


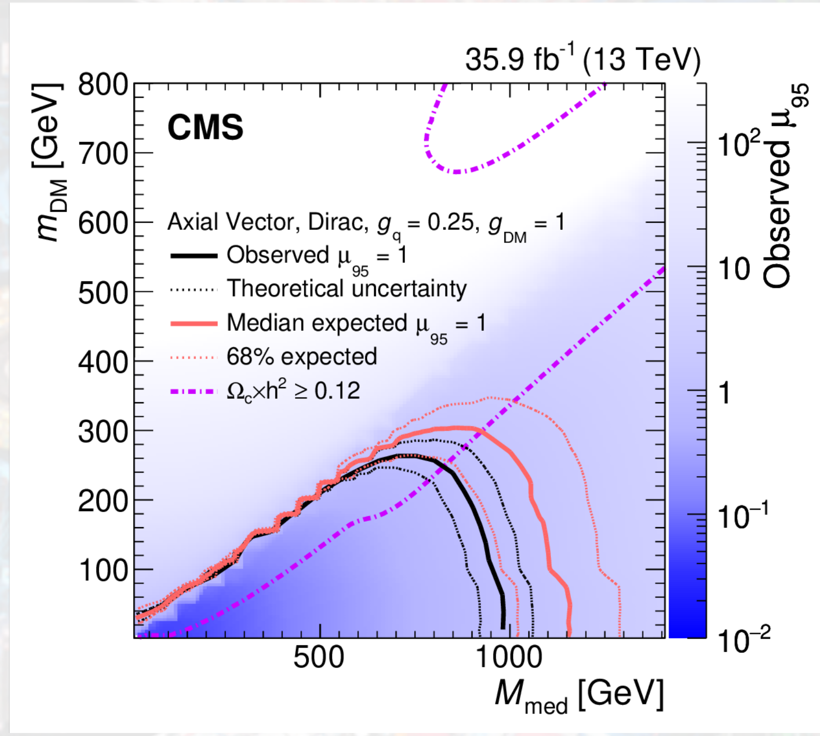
2017



2018

Limits on simplified dark matter models (2016 results)





Mediator mass(M_{med}) upto 1050 GeV has been excluded for 1 GeV dark matter mass (m_{DM})

2016 published results JHEP 02 (2019) 274

Summary

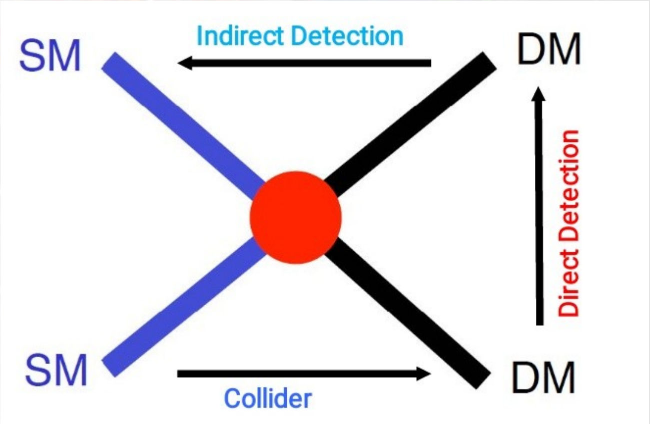
- Presented a monophoton cut based analysis for barrel using photon ID optimised for high p_T photons
- Working on finalising the dark matter (DM) and ADD limits using Run-II data

Thank You

Backup

Properties of Dark Matter:

- Interact gravitationally
- Interact Weakly(Difficult to observe)
- Cosmologically stable
- Electrically Neutral
- Massive Particle (GeV→TeV)



Dark matter = part of cosmological SM

Requires beyond SM physics

Trigger Efficiency

Trigger : HLT_Photon200_* used

Efficiency is measured using orthogonal trigger HLT_PFHT1050

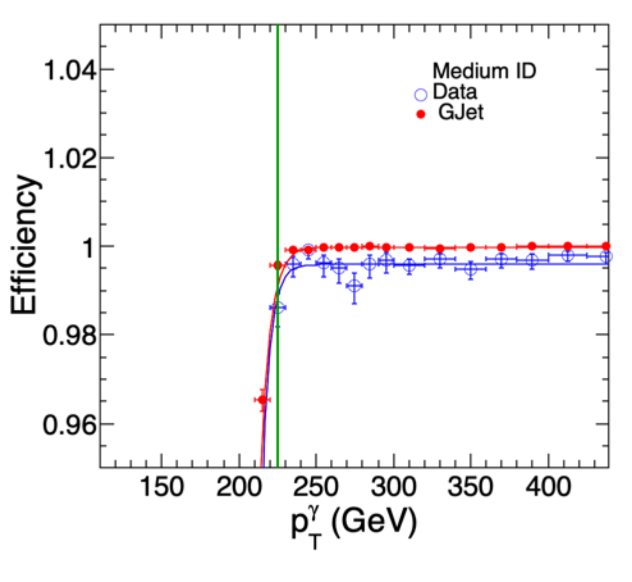
Offline selection is : good photon and HT >1050 GeV

Trigger is > 95% efficient at photon p_T > 225 GeV

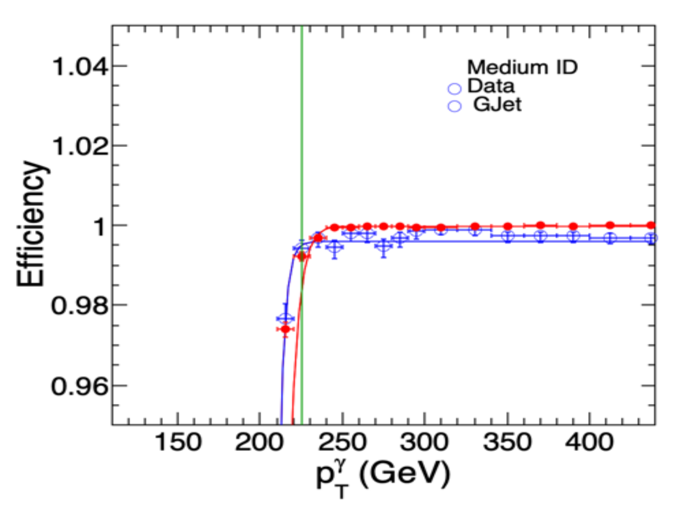
Analysis : Data/MC trigger SF is applied

$$\epsilon(\texttt{HLT\_Photon200}) = \frac{\text{Offline selection \&\& }\texttt{HLT\_PFHT1050}\text{ \&\& }\texttt{HLT\_Photon200}}{\text{Offline selection \&\& }\texttt{HLT\_PFHT1050}}$$

2017



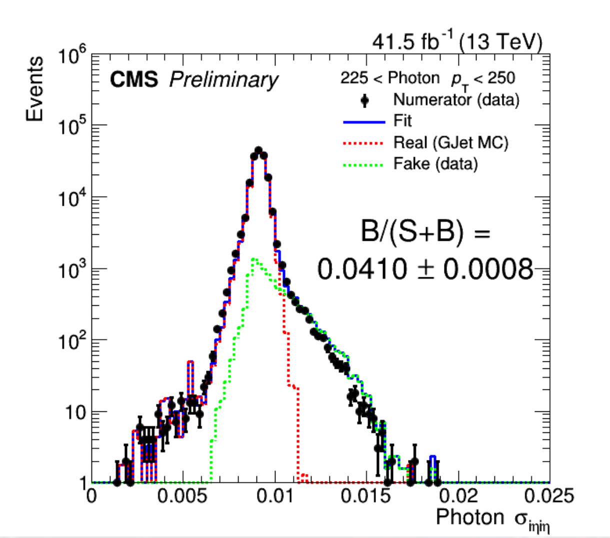
2018



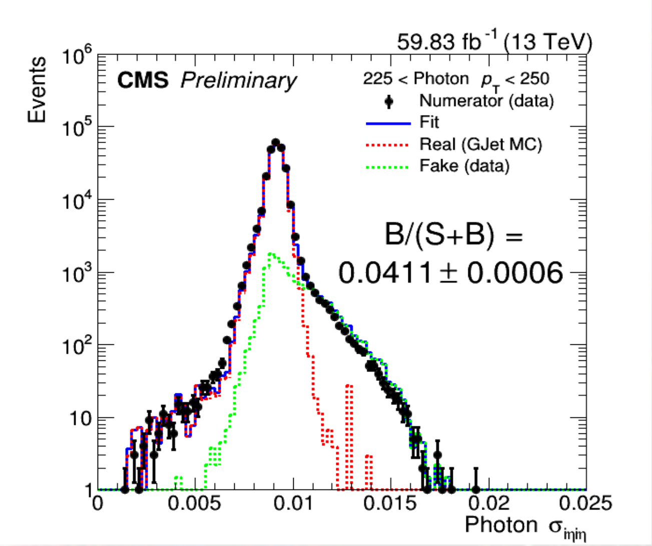
Jets faking photon

✓ Numerator of fake ratio
  ✓ QCD fake events passing photon medium ID selection
  ✓ Subtract real photon contribution, obtained from template fit based on σiηiη
  ✓ Real photon template : γ + jets MC
  ✓ Fake photon template : charged worst hadron isolation sideband in data

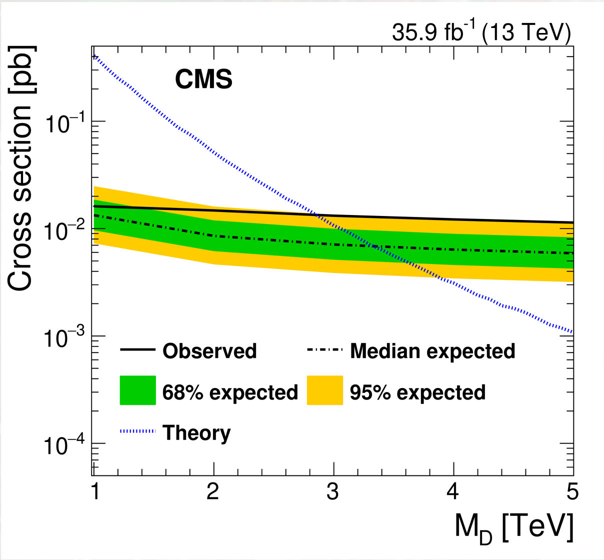
2017

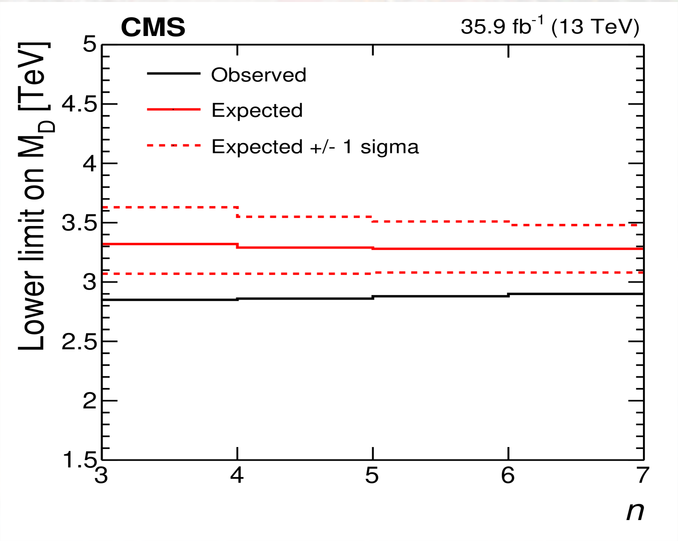


2018



Limits on ADD model(2016 results)





Number of Extra dimensions

95% CL observed and expected lower limits on M_D as a function of n

n	Obs. limit [TeV]	Exp. limit [TeV]
3	2.85	3.32
4	2.86	3.29
5	2.88	3.28
6	2.90	3.28

- ✔ M_D upto 2.90 TeV for n=6 are excluded

Signal Region 2017

Jet faking photon: 15.4638 +- 1.3263
Electron faking photon: 150.02 +- 9.40866
ZNuNu+gamma: 402.583 +- 41.1198
W+gamma: 121.117 +- 19.3241
GJets: 6.76433 +- 2.36506
Z(ll)+Gamma: 5.42475 +- 0.699534
tt+Gamma: 4.73935 +- 0.507329
t+Gamma: 0.563257 +- 0.172559
Diphoton: 10.616 +- 3.20825
WZ: 6.59656 +- 0.996783
ZZ: 1.62752 +- 0.545273
WMuNu: 3.54143 +- 3.55656
WTauNu: 10.5433 +- 6.38701
WW: 8.3955 +- 1.31747
Total background: 741.366 +- 47.1339

Data: 753.254

Signal Region 2018

Jet faking photon: 25.0446 +- 2.18024
Electron faking photon: 269.882 +- 16.6044
ZNuNu+gamma: 566.406 +- 65.3649
W+gamma: 167.619 +- 31.2503
GJets: 4.03805 +- 1.09163
Z(ll)+Gamma: 5.16523 +- 1.13975
tt+Gamma: 8.27733 +- 0.81674
t+Gamma: 1.48357 +- 0.387657
Diphoton: 10.9415 +- 4.24642
WZ: 7.67788 +- 1.261
ZZ: 1.62617 +- 0.545961
WMuNu: 5.06592 +- 5.11724
WTauNu: 25.6498 +- 11.5287
WW: 10.9995 +- 1.86566
Total background: 1109.78 +- 75.6004

Data: 1115
