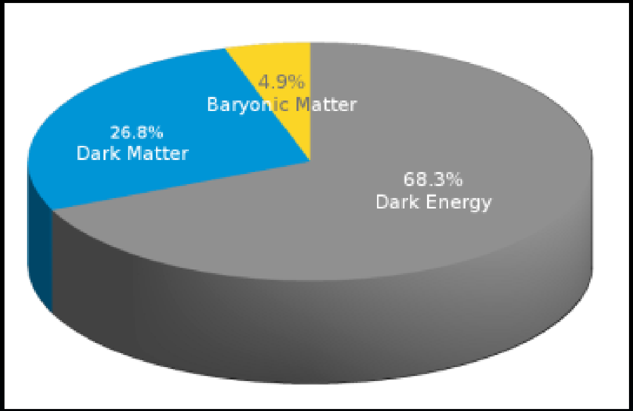
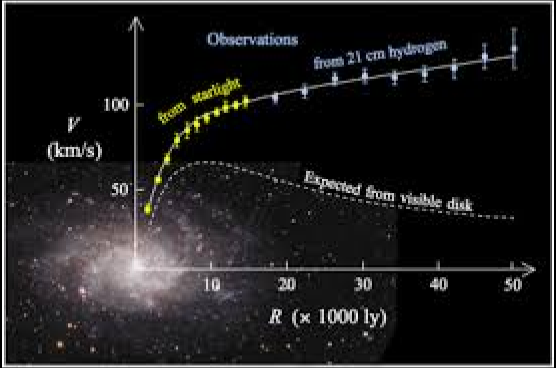
# *Search for dark matter with CMS in final state with missing ET and a single photon*

Shamik Ghosh

- On behalf of CMS collaboration

- Astrophysical observations point to the existence of Dark Matter (DM)

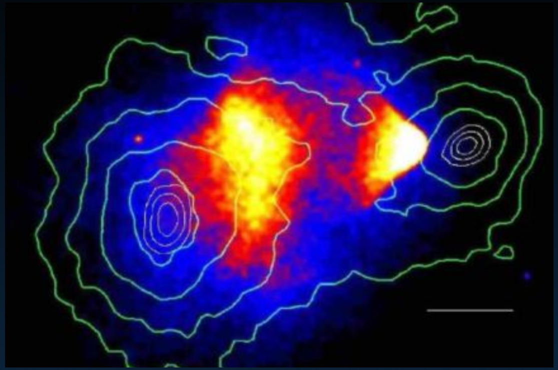



Rotation curves

- Nature of DM remains unknown
- Our knowledge about dark matter comes from non-interactions and gravity
- Electrically neutral, non-baryonic, long-lived, non-relativistic, interaction cross-section ~ weak interaction

- **WIMP:** Motivation to consider collider searches for DM

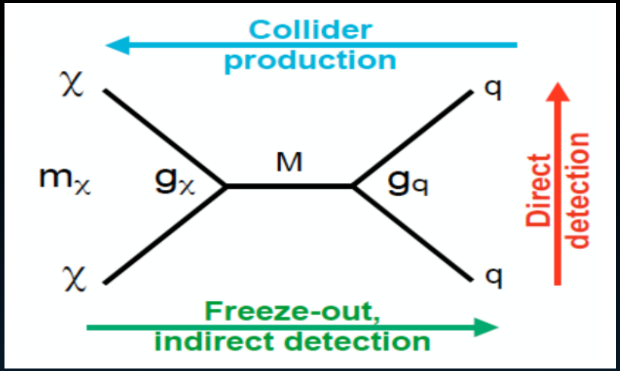


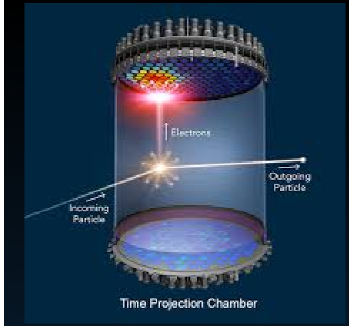
Bullet Cluster

# DM Production and Detection

DM may be pair produced in pp collisions at the LHC, Yields experimental signature of MET

**LHC**




Scattering of DM particles on nuclei of detector material ; detect recoil. For a given cross section sensitivity scales with detector size.

**LUX, PANDAX**

Assume annihilation of DM particles, eg. In the sun. Detect annihilation products.

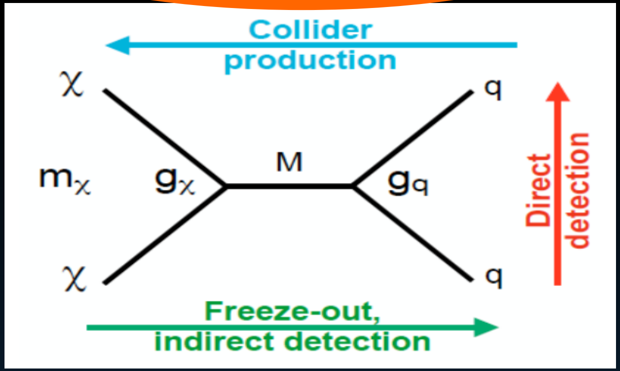
**PAMELA, AMS**

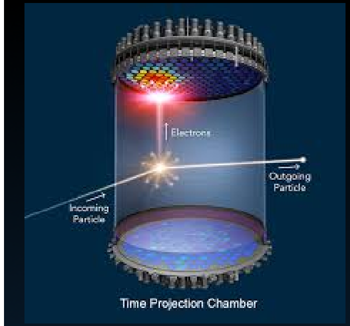
# DM Production and Detection

DM may be pair produced in pp collisions at the LHC, Yields experimental signature of MET

LHC

Focus of the Talk

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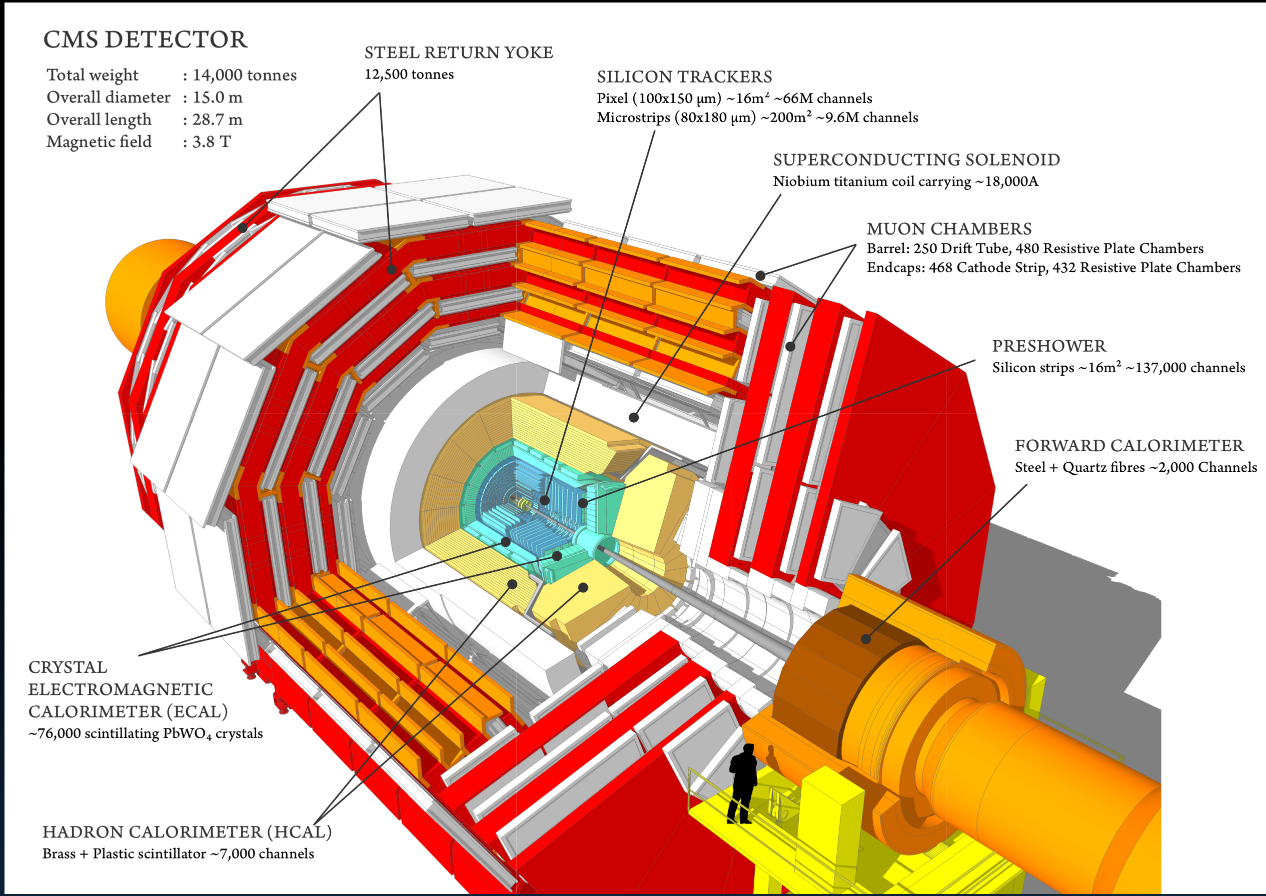
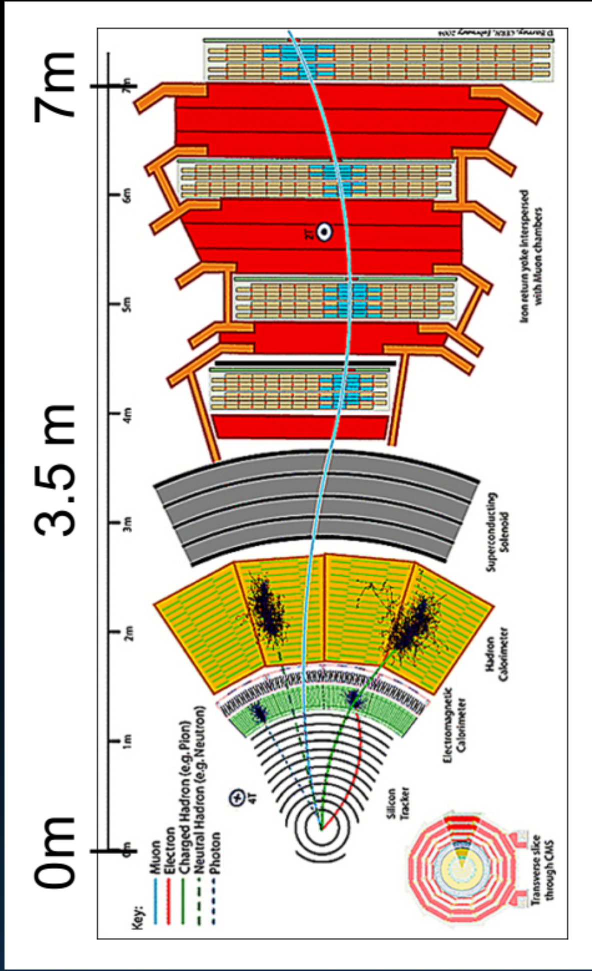
PAMELA, AMS

TM

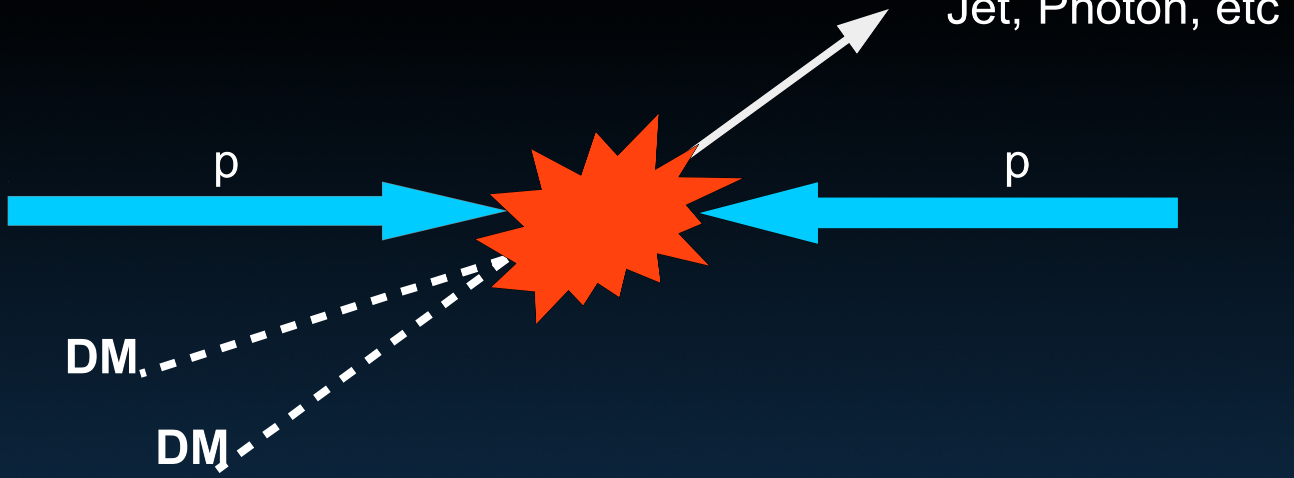
# Compact Muon Solenoid



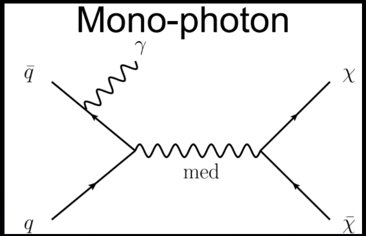



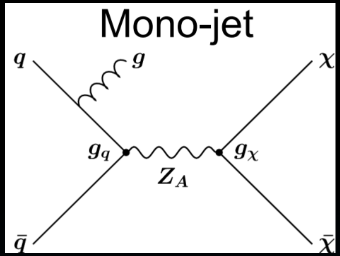
# Dark Matter signatures at LHC

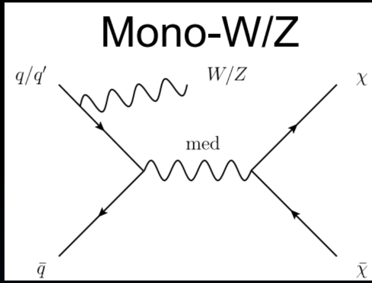
- Dark Matter particles will pass undetected through the detector
- They may recoil against visible high pT object **X** (= jet, photon, Z, etc)
- Large transverse momentum imbalance created as a result
  **$E_T^{miss}$ + X** systems created



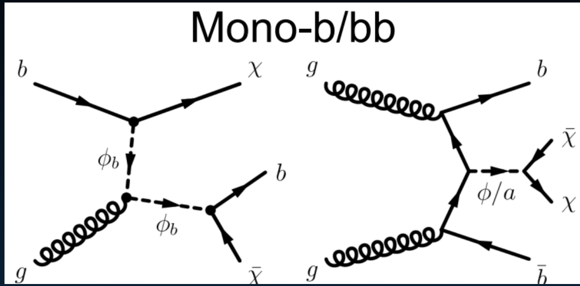
# A wide range of final states can be investigated with CMS

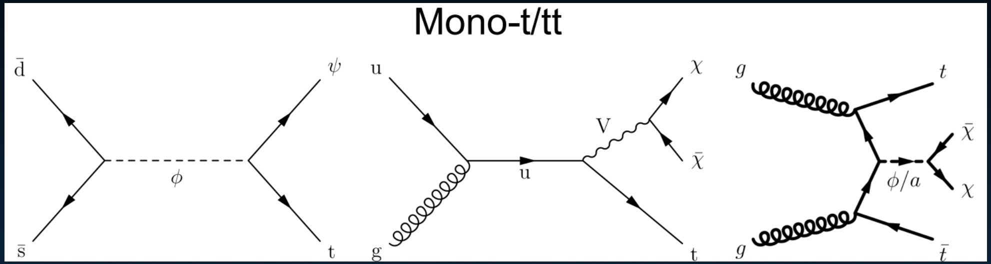



Mono-X Signatures – simple and striking



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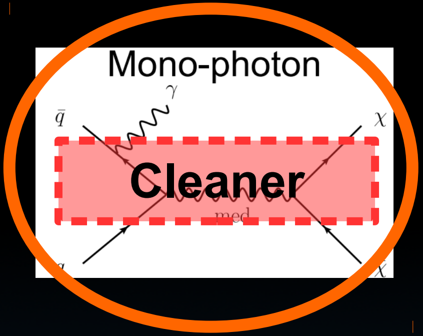
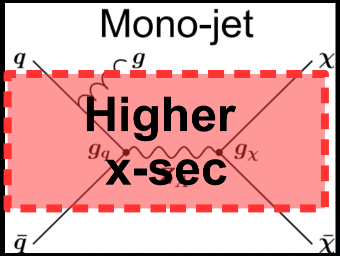
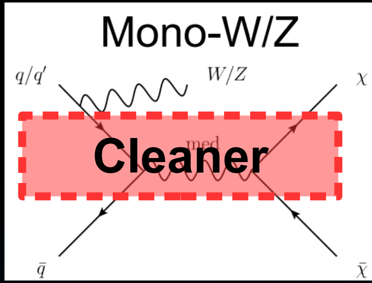
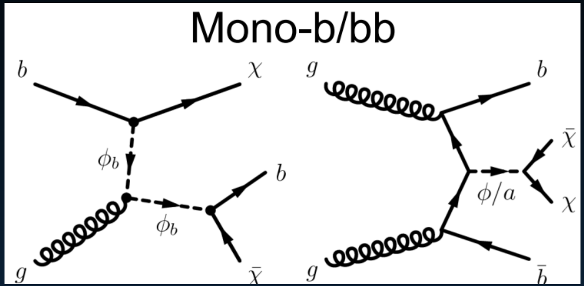
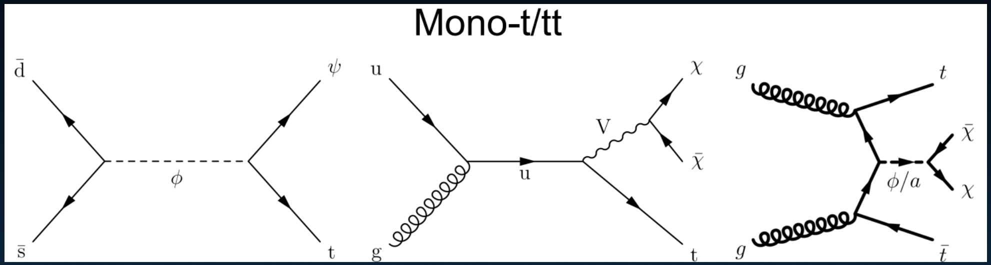



Mono-X Signatures – simple and striking



# Dark Matter Simplified Models

- Searches interpreted using generic 'simplified models'

  Fermionic DM pair and a massive boson that mediates the interaction between DM and SM quarks

- Model Parameters :

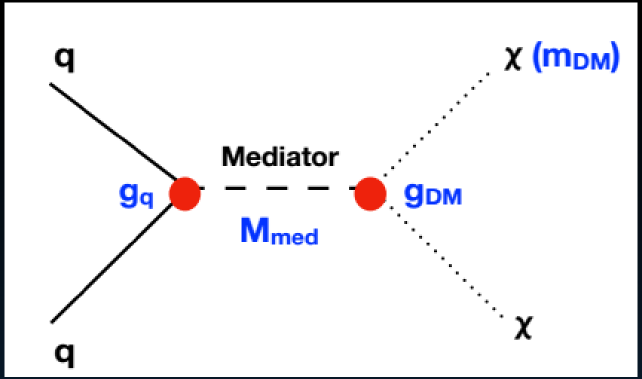
➢ Spin/parity of the mediator

➢ Mediator mass ($M_{med}$)

➢ DM mass ($m_{DM}$)

➢ Mediator coupling to quarks ($g_q$)

➢ Mediator coupling to DM ($g_{DM}$)

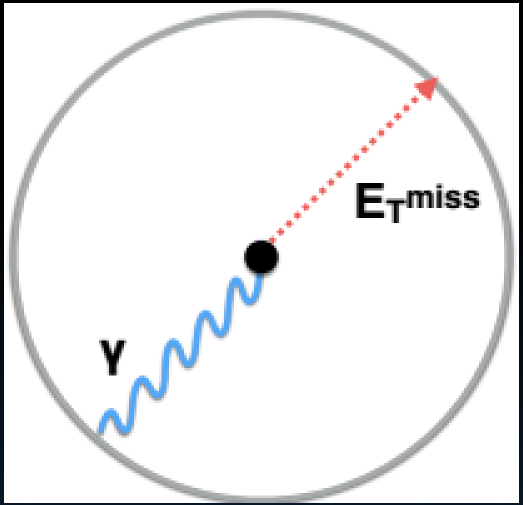



ArXiv:1507.00966

# *Monophoton: Event Selection*

Searching for single photon recoiling against $E_T^{miss}$

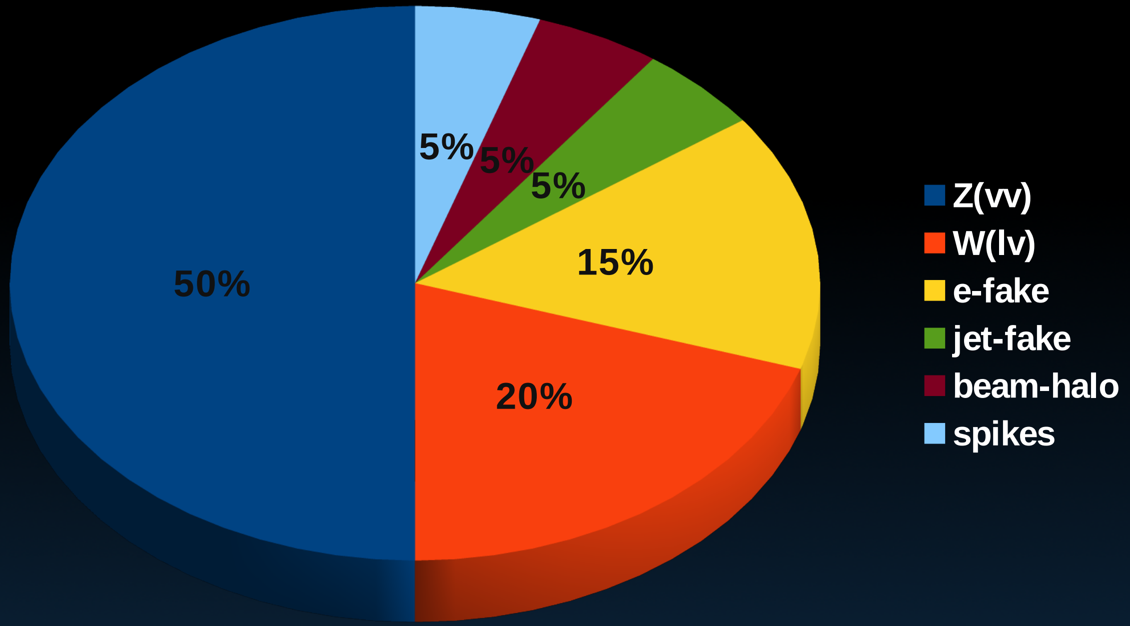
- High energetic photon with $p_T$ > 175 GeV : $|\eta| < 1.4442$
- Missing Transverse Energy $E_T^{miss}$ > 170 GeV
- $\Delta\phi(\gamma, E_T^{miss}) > 0.5$ : to reject W+jets and fake $E_T^{miss}$ from $\gamma$
- $\Delta\phi(j, E_T^{miss}) > 0.5$ : to reject fake $E_T^{miss}$ from jets
- $E_T^{\gamma} / E_T^{miss} < 1.4$ : $\gamma$ + jets reduction
- Veto electrons and leptons with $p_T$ > 10GeV




ArXiv:1810.00196

# Monophoton: Main Backgrounds

| | | |
|---|---|---|
| Irreducible | Z (νν) + γ | W (łν) + γ |
| Fakes | Electrons | Hadrons |
| Anomalous | Beam Halo | Spike |



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| | | |
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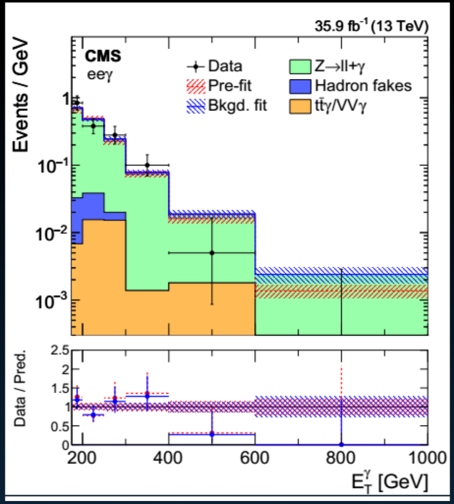
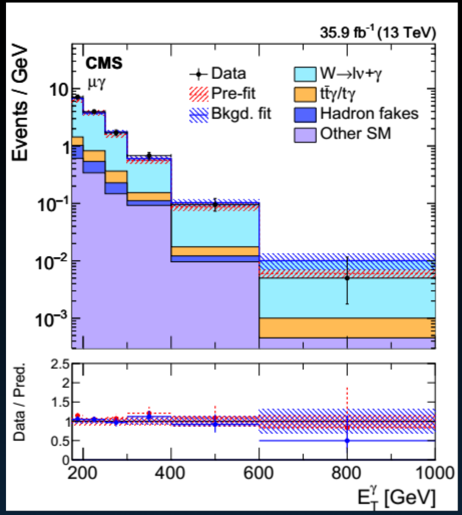
Simultaneous fits between signal and control region (single and di-lepton)
Transfer factors to connect them




Zγ->(ee)γ




Wγ->(μν)γ

# Monophoton: Main Backgrounds

| | | |
|---|---|---|
| Irreducible | Z (νν) + γ | W (łν) + γ |
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} Data driven estimations

# Monophoton: Main Backgrounds

| | | |
|---|---|---|
| Irreducible | $Z(\nu\nu) + \gamma$ | $W(\ell\nu) + \gamma$ |
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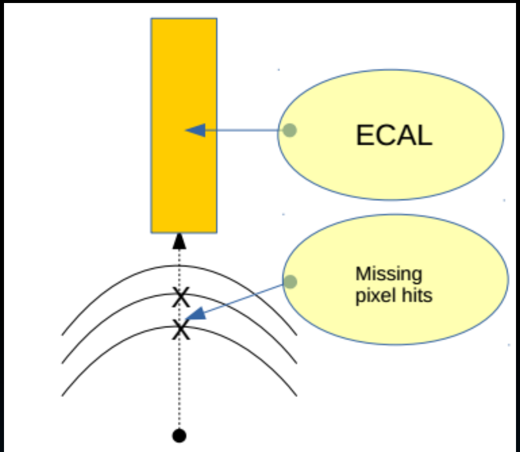


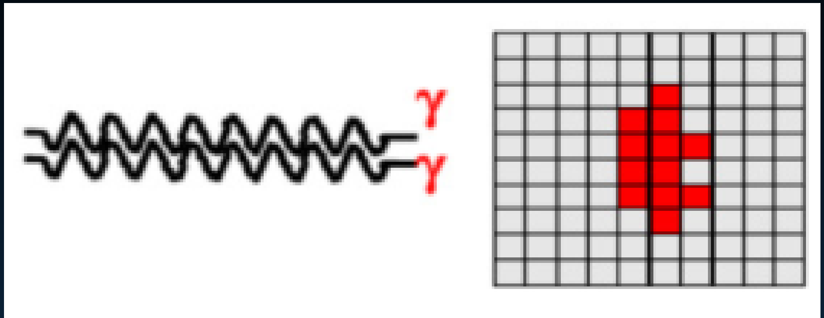

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| | | |
|---|---|---|
| Irreducible | $Z (\nu\nu) + \gamma$ | $W (\ell\nu) + \gamma$ |
| Fakes | Electrons | Hadrons |
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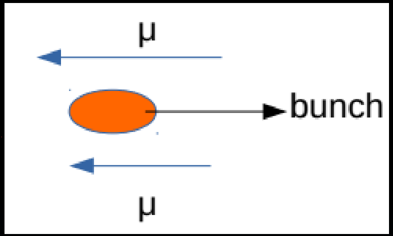
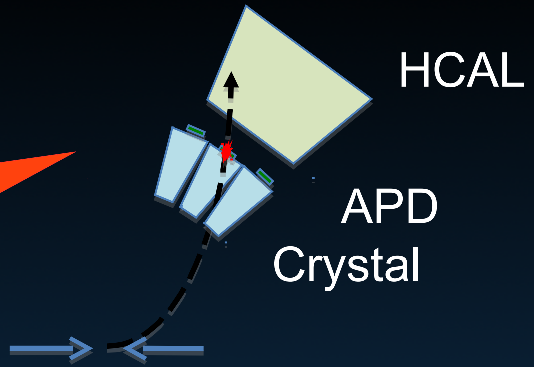
**Interesting peculiar experimental backgrounds**




Anomalous signals from APD in ECAL barrel

# Monophoton: Main Backgrounds

| | | |
|---|---|---|
| Irreducible | Z (vv) + γ | W (łv) + γ |
| Fakes | Electrons | Hadrons |
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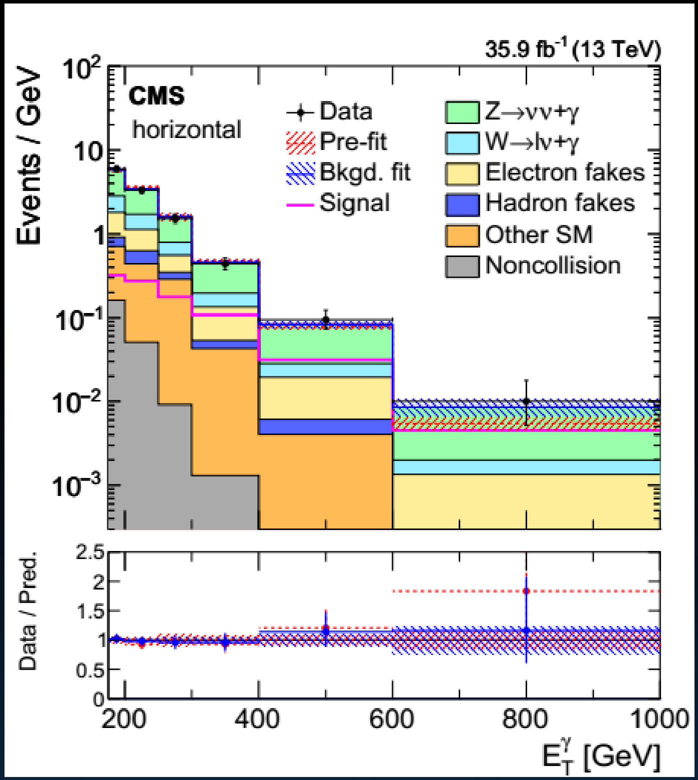
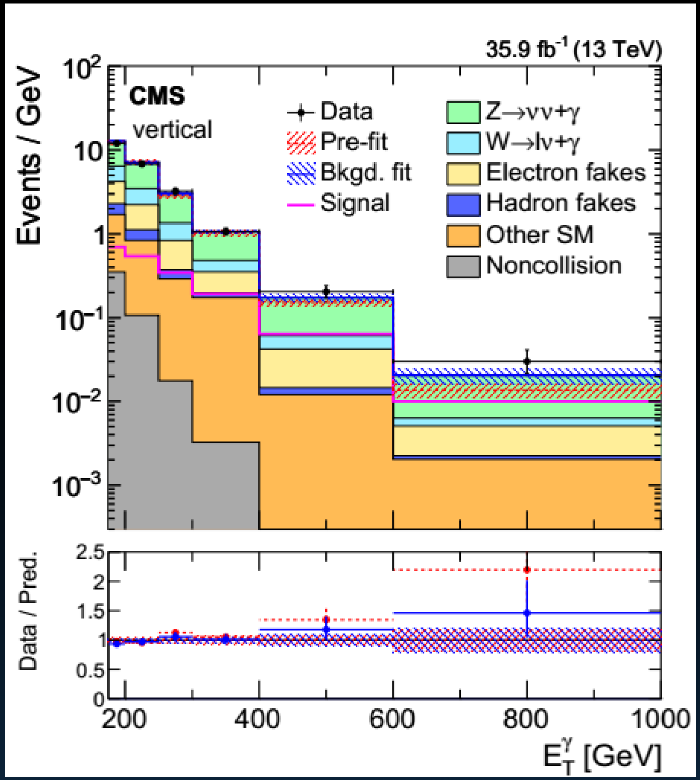
To constrain beam halo normalisation, signal region is split into high and low phi regions

# Monophoton:Results

Low phi |Φ| < 0.5



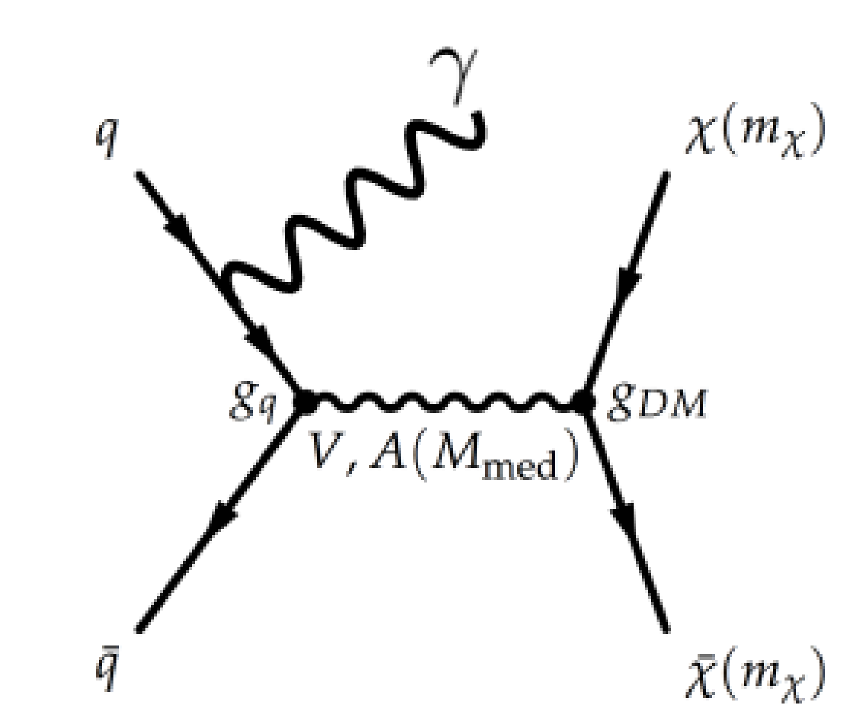

High phi |Φ| > 0.5




- Better resolution and control over uncertainities than ETmiss spectrum.
- No excess observed from expected

# Monophoton: DM Interpretation

## Spin 1 mediator limits



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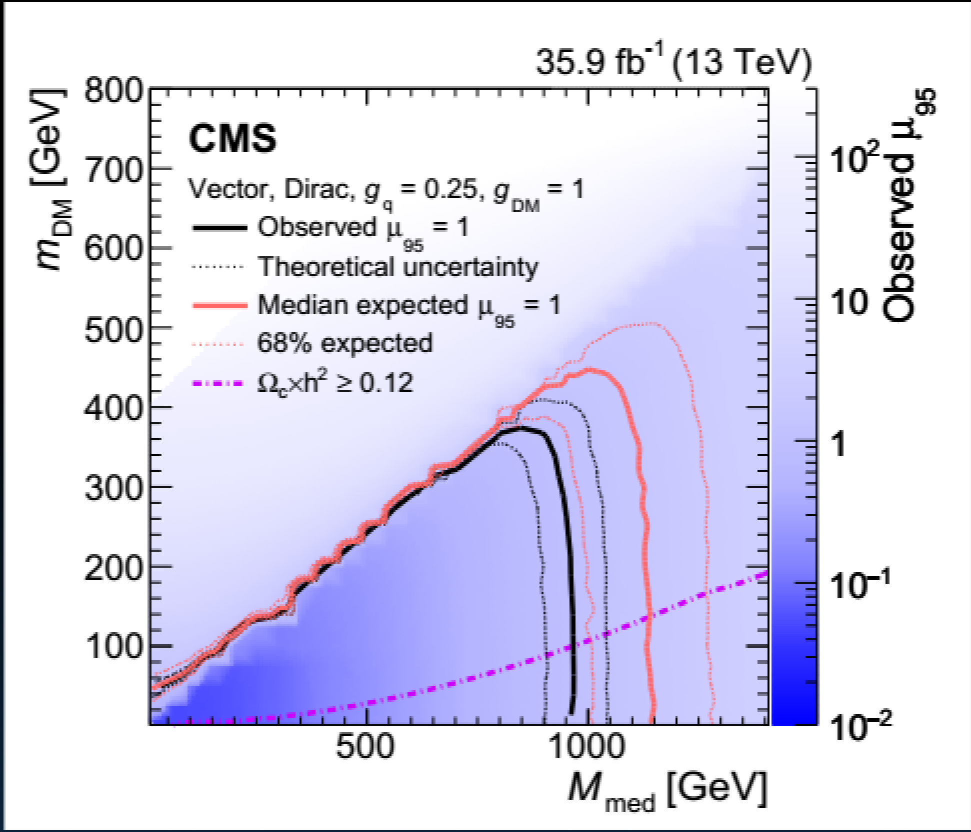


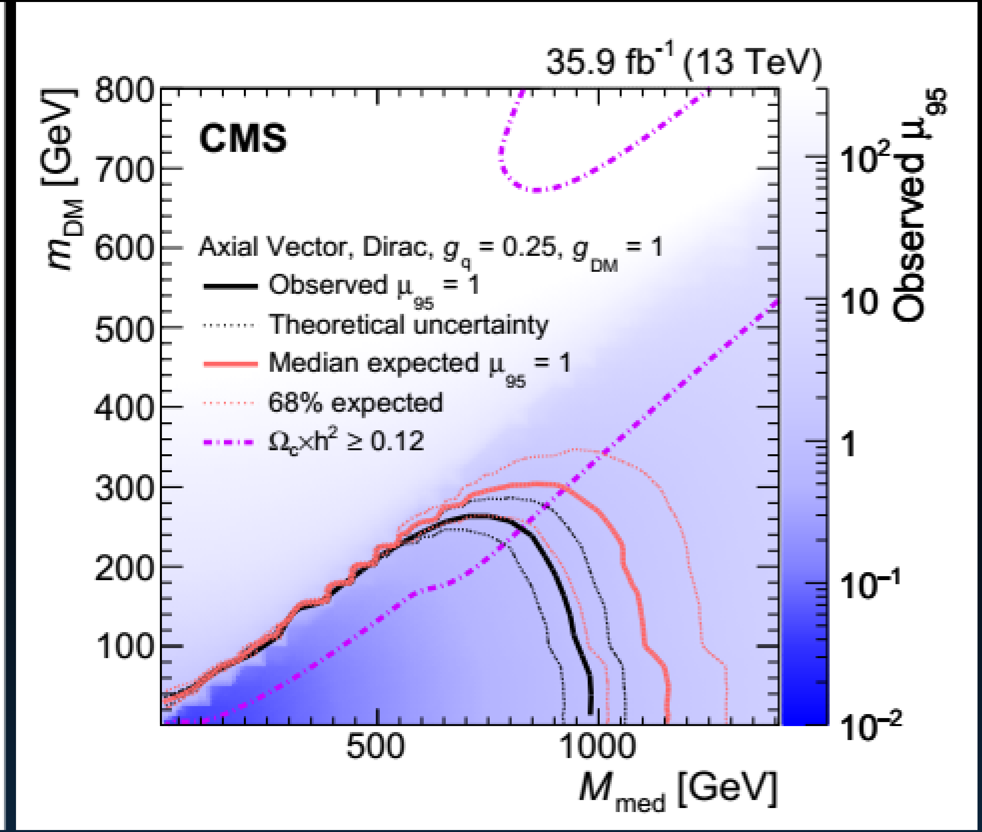

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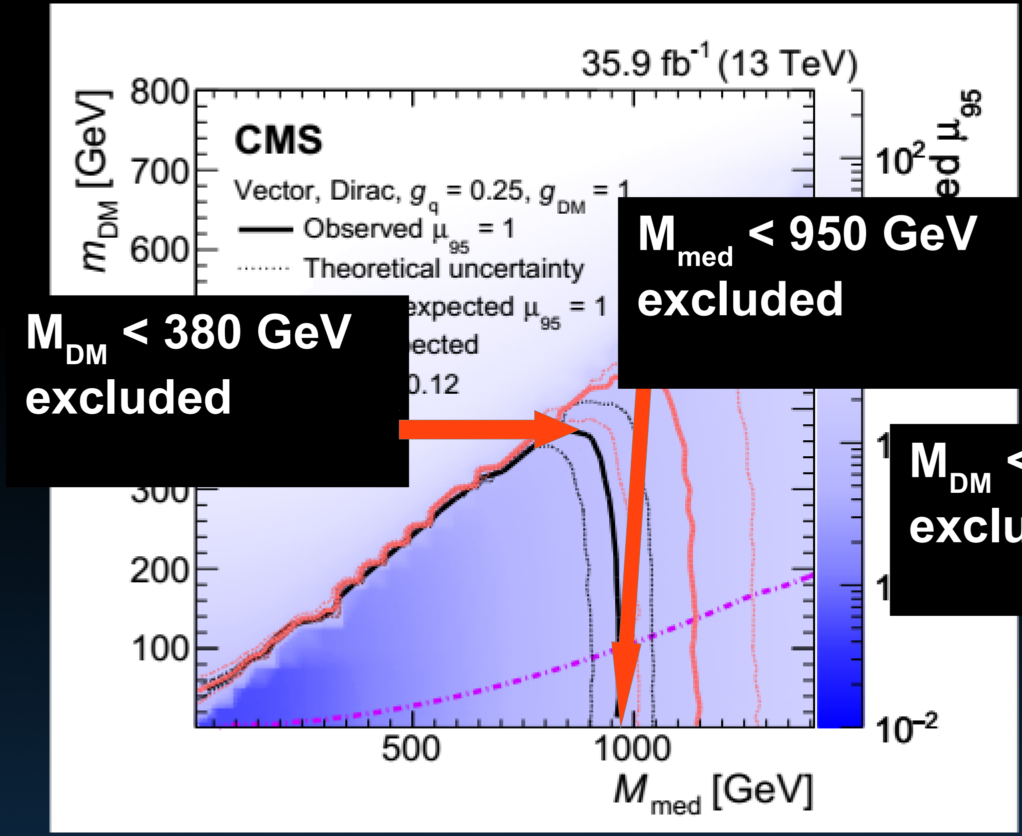
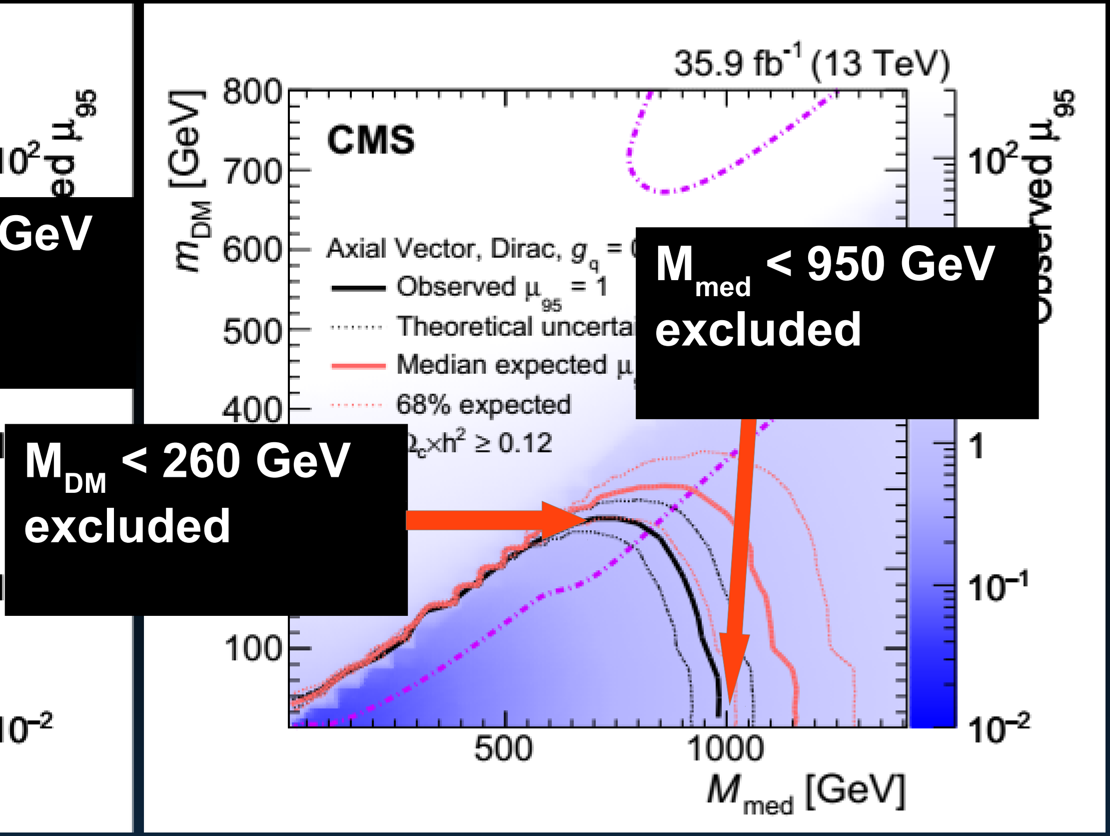
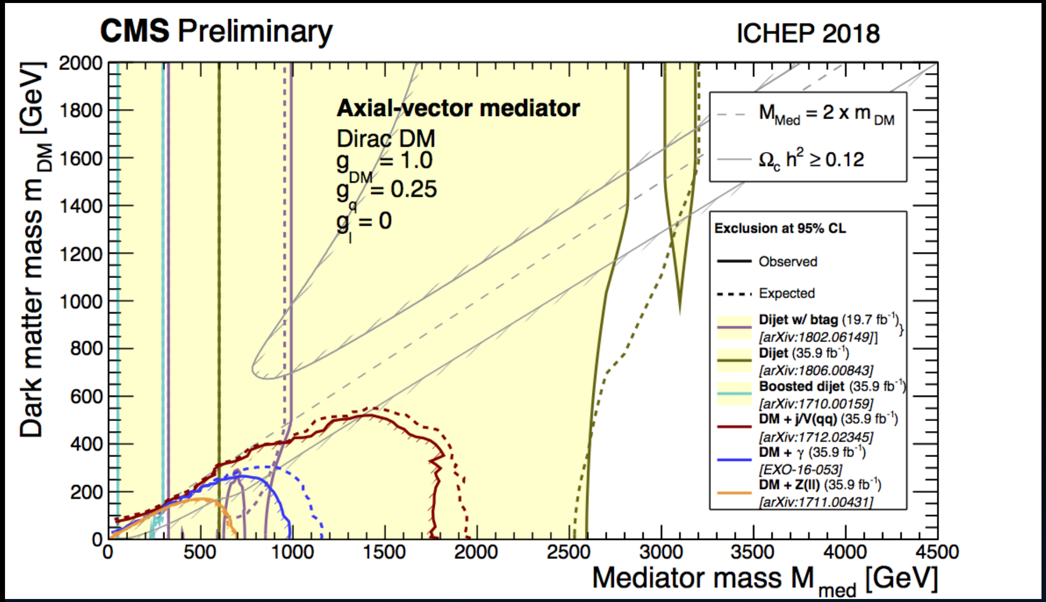
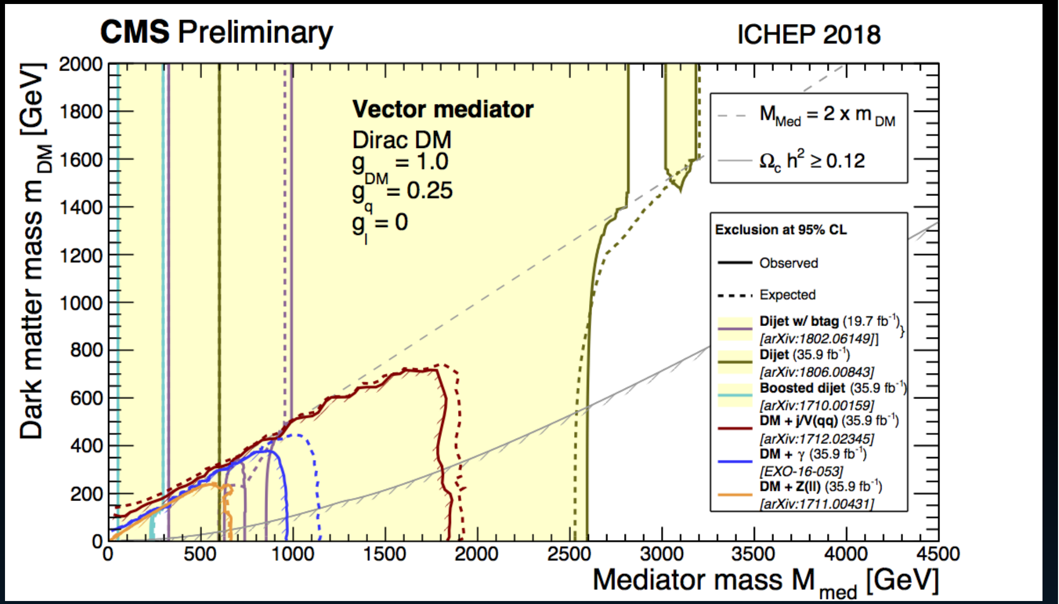


# Summary : Spin 1 mediators




Mono-X searches sensitive to on-shell region
$M_{med} > 2 \times M_{DM}$

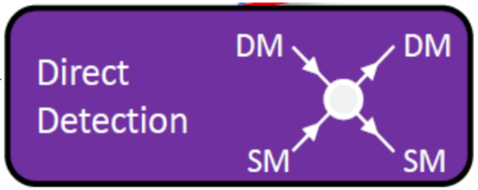
Dijets provide sensitivity to off-shell region
Complementarity to Mono-X searches

# *Collider to Direct Detection Limits*

Limits from collider experiments can be recast to compare with direct detection experiments


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

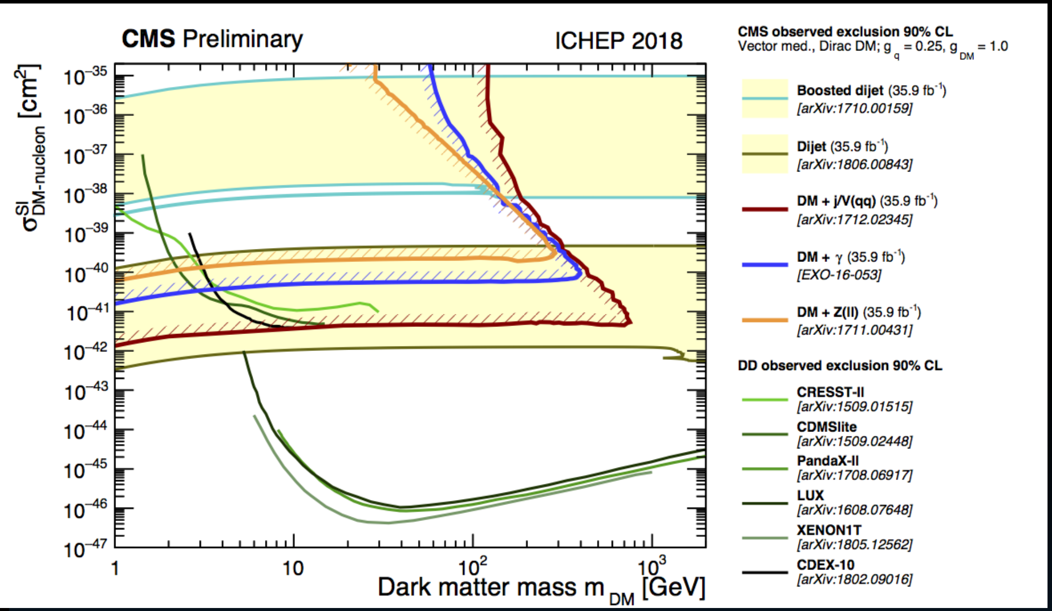
$$\sigma_{\rm SD}^{\rm axial} \simeq 2.4\times10^{-42}\,{\rm cm}^2\left(\frac{g_q g_{\rm DM}}{0.25}\right)^2\left(\frac{1\ {\rm TeV}}{M_{\rm med}}\right)^4\left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

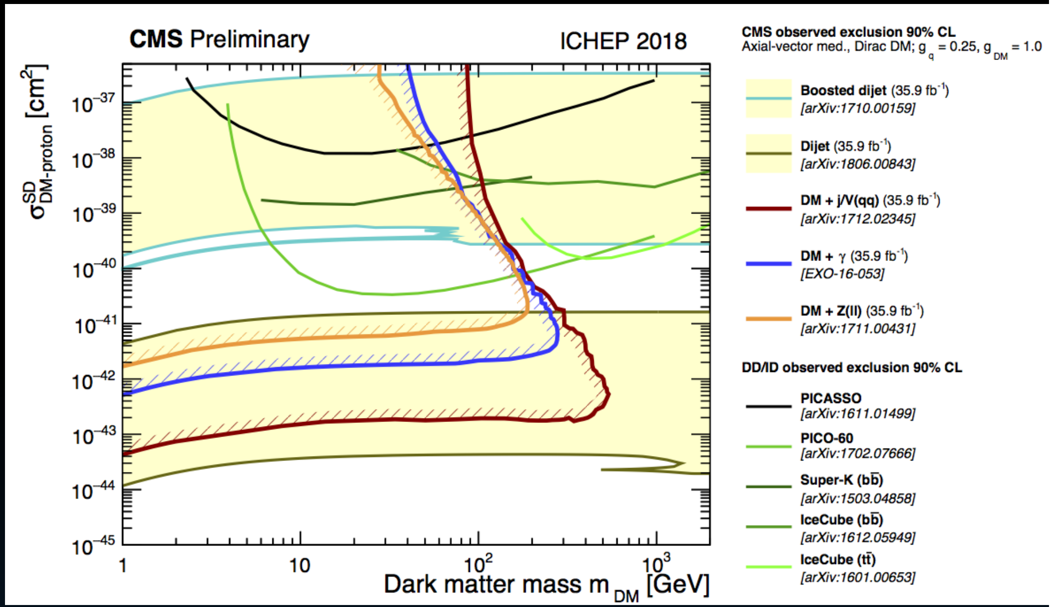



$\mu_{n\chi} = m_n m_{DM}/(m_n + m_{DM})$ is the DM-nucleon reduced mass

ArXiv:1603.04156

# Summary : Direct Detection Limits



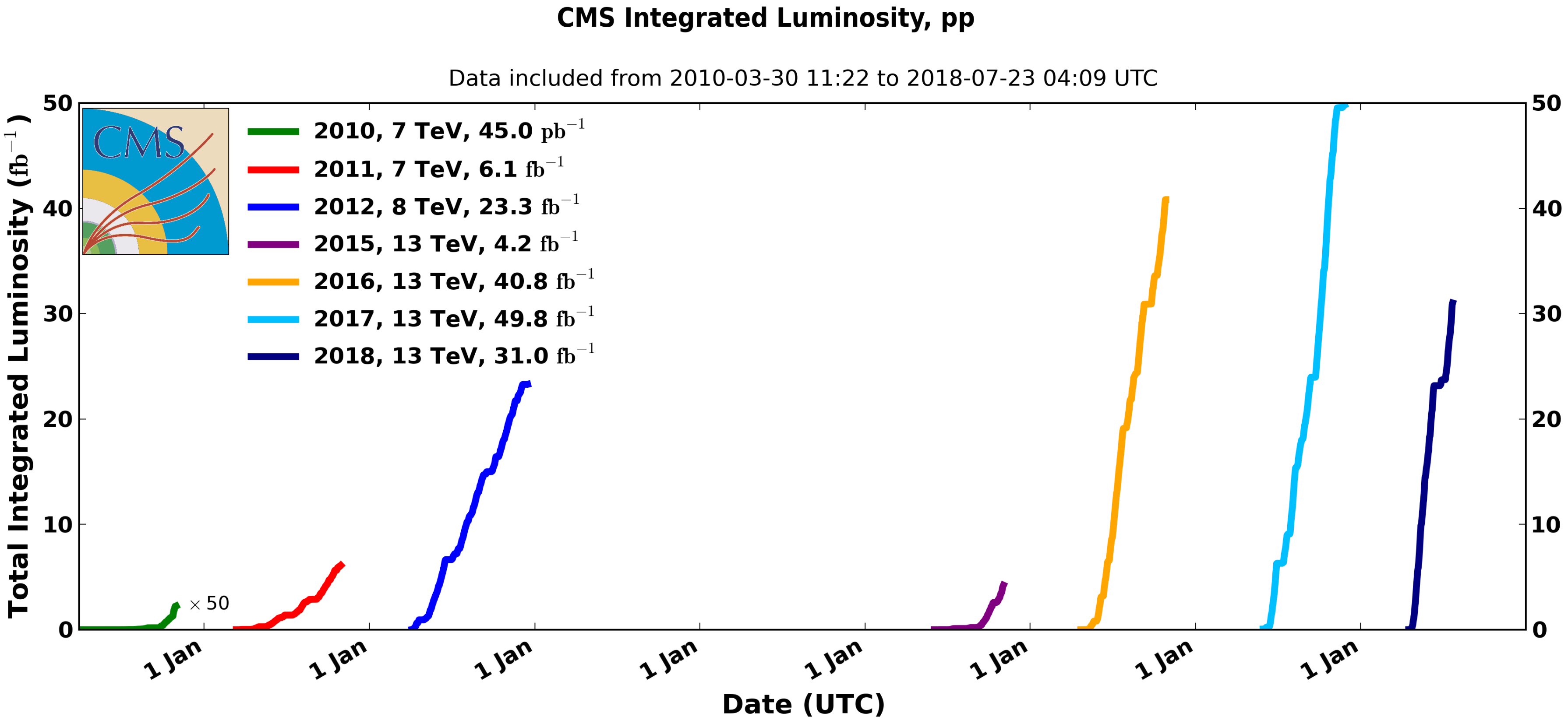

- Collider results sensitive to low DM masses
- More sensitive than Direct detection experiments for spin dependant mediators

# *Summary*

- Extensive dark matter searches going on at LHC (in CMS)
- No DM observed yet, limits are more stringent
- LHC searches provide complementarity to direct detection searches
- Much more LHC data to be analyzed
- Stay tuned !!

***Thanks for your attention!!***

# BACKUPS



CMS Integrated Luminosity, pp
Data included from 2010-03-30 11:22 to 2018-07-23 04:09 UTC
CMS
2010, 7 TeV, 45.0 pb$^{-1}$
2011, 7 TeV, 6.1 fb$^{-1}$
2012, 8 TeV, 23.3 fb$^{-1}$
2015, 13 TeV, 4.2 fb$^{-1}$
2016, 13 TeV, 40.8 fb$^{-1}$
2017, 13 TeV, 49.8 fb$^{-1}$
2018, 13 TeV, 31.0 fb$^{-1}$
× 50
Total Integrated Luminosity (fb$^{-1}$)
0
10
20
30
40
50
1 Jan
Date (UTC)

# monophoton

**Signal region yield:**
**Wγ + Zγ = ( 1 + f ) Zγ**

$$\mathcal{L} = \prod_i \Bigg[ \prod_{K=\text{horiz.,vert.}} \mathcal{P}\left(d_{K,i} \middle| \left(1 + f^{W\gamma}_{Z\gamma,i}(\theta)\right) C_K N_i^{Z\gamma} + h n^{\text{halo}}_{K,i}(\theta) + b_{K,i}(\theta)\right)$$

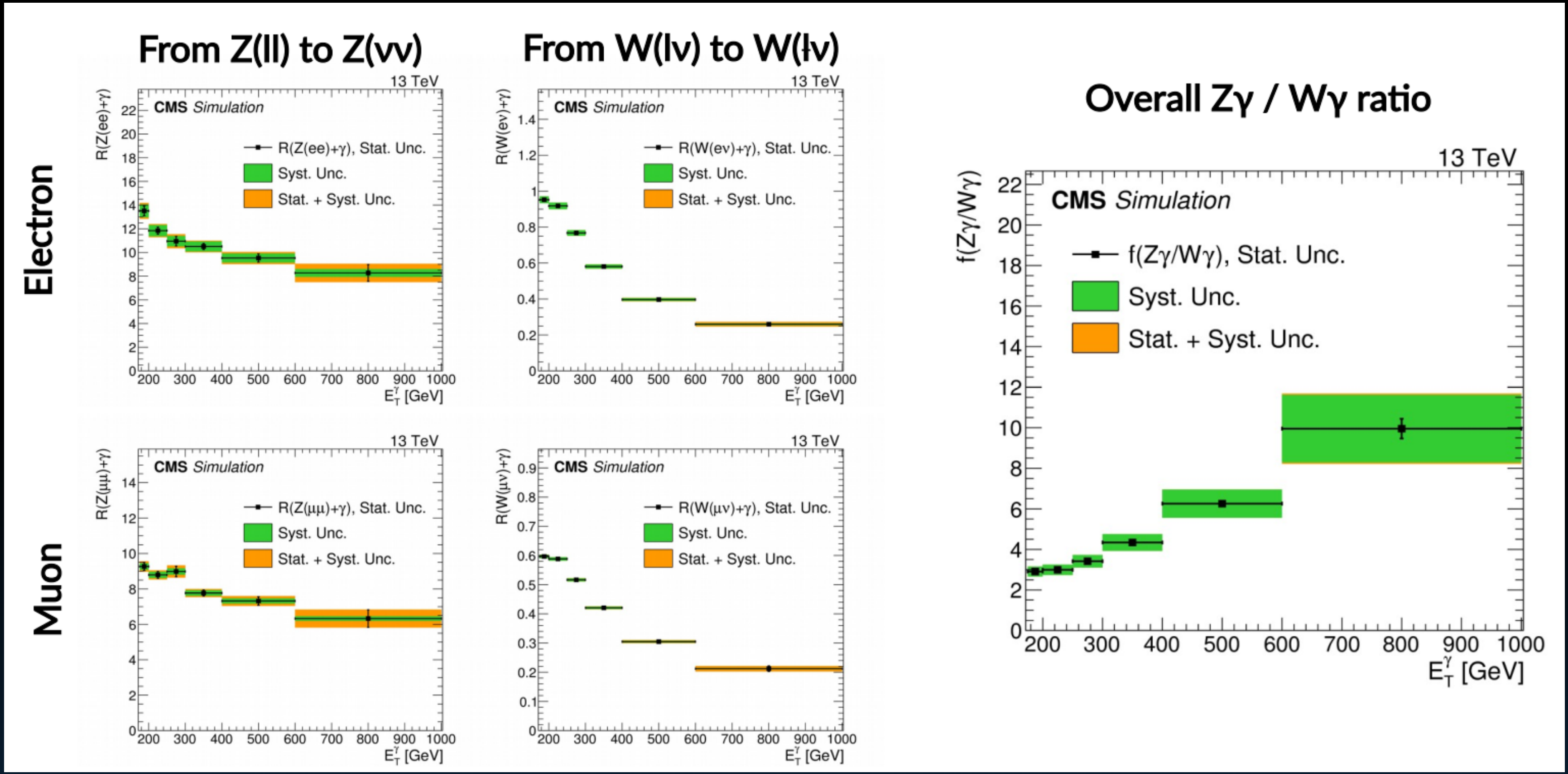
$$\cdot \prod_{K=e\gamma,\mu\gamma} \mathcal{P}\left(d_{K,i} \middle| R^{W\gamma}_{K,i}(\theta) f^{W\gamma}_{Z\gamma,i}(\theta) N_i^{Z\gamma} + b_{K,i}(\theta)\right)$$

$$\cdot \prod_{K=ee\gamma,\mu\mu\gamma} \mathcal{P}\left(d_{K,i} \middle| R^{Z\gamma}_{K,i}(\theta) N_i^{Z\gamma} + b_{K,i}(\theta)\right) \Bigg]$$

$$\cdot \prod_j \mathcal{N}(\theta_j),$$

**Transfer factors from control to signal regions**

Likelihood : From A.Albert ICHEP2018




Ratios : A.Albert ICHEP2018