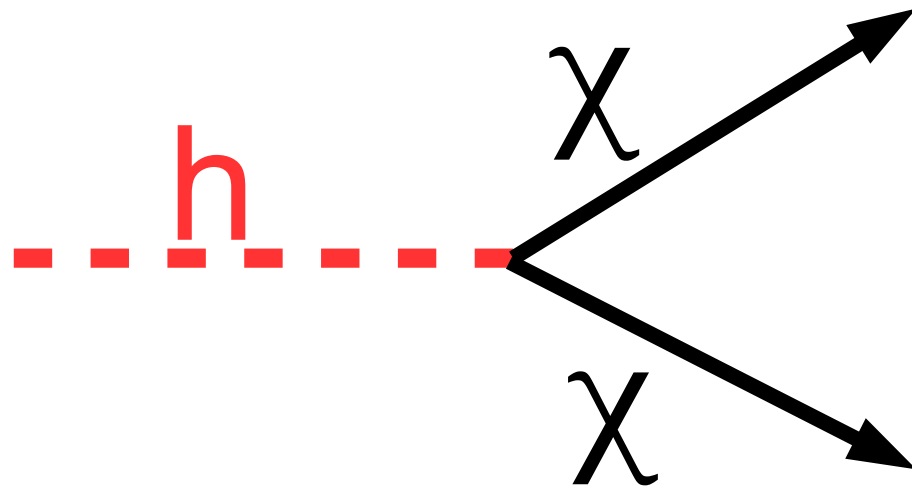


# Dark Matter

## Working Group@Higgs

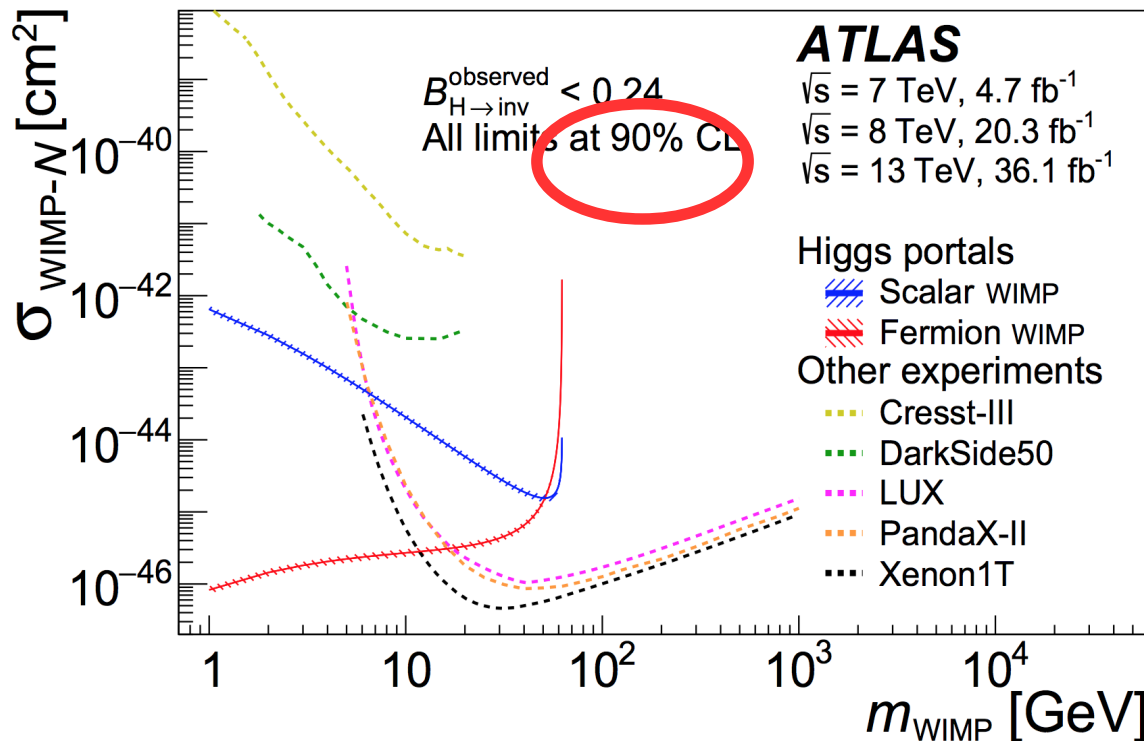


P.Harris(MIT-CMS), O. Brandt(Cambridge-ATLAS),  
C. Ohm (KTH-ATLAS)→F. Ungaro(Melbourne-ATLAS)  
, T.Tait(UCI-Theory), U. Haisch(MPI-MPP-Theory)  
X. Cid(USC-LHCb),

F.Ungaro is replacing C. Ohm

# Dark Matter Working Group

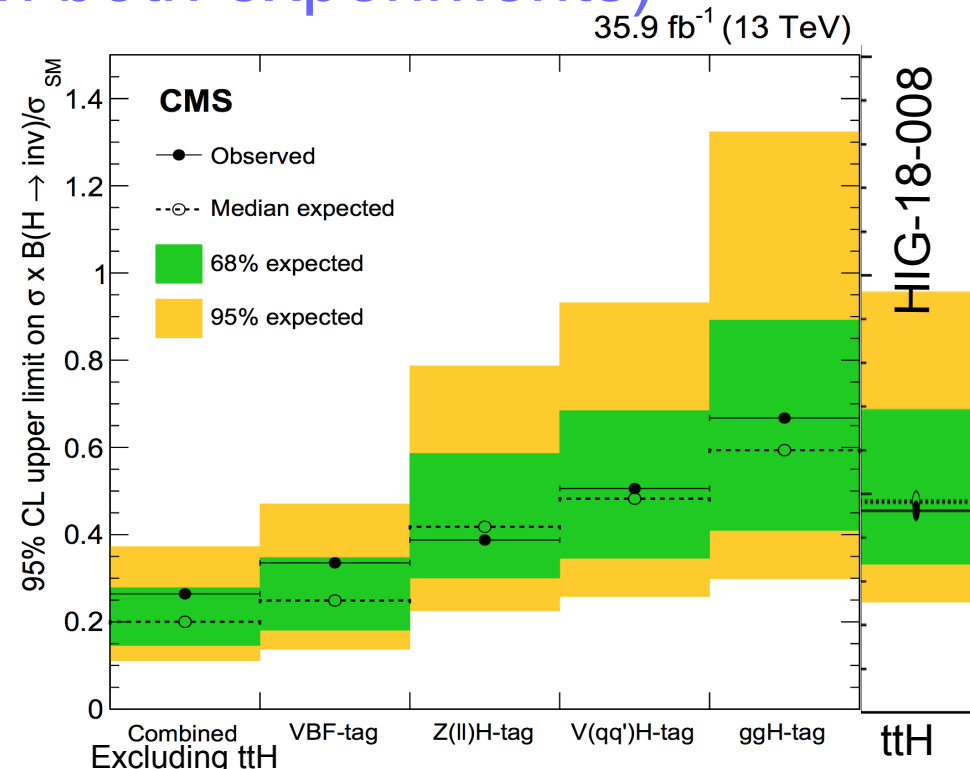
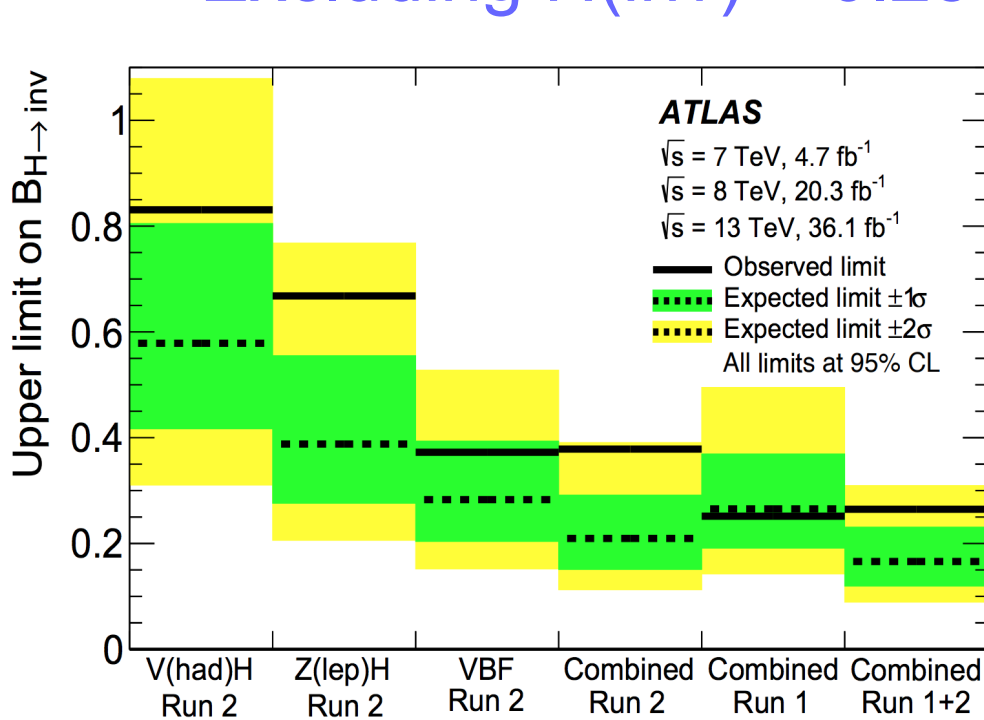
- Our role @LHC is to ensure consistent DM models
  - This allows for the interpretation of DM in global scope
  - Comparisons to Direct/Indirect detection
  - Comparisons across collaborations



Note the 90% CL (this is what DD uses)

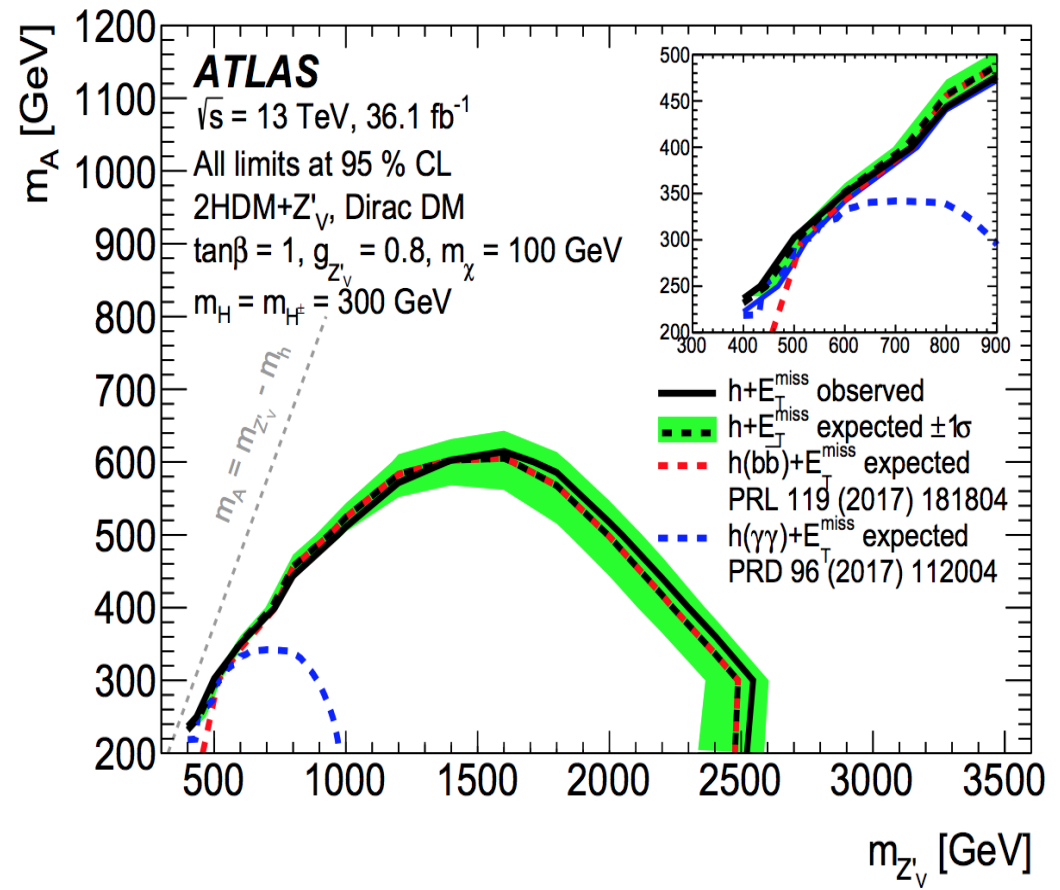
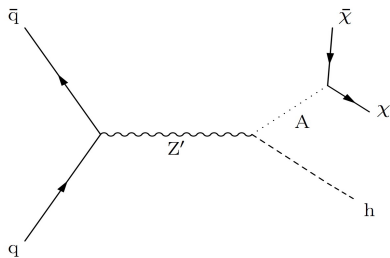
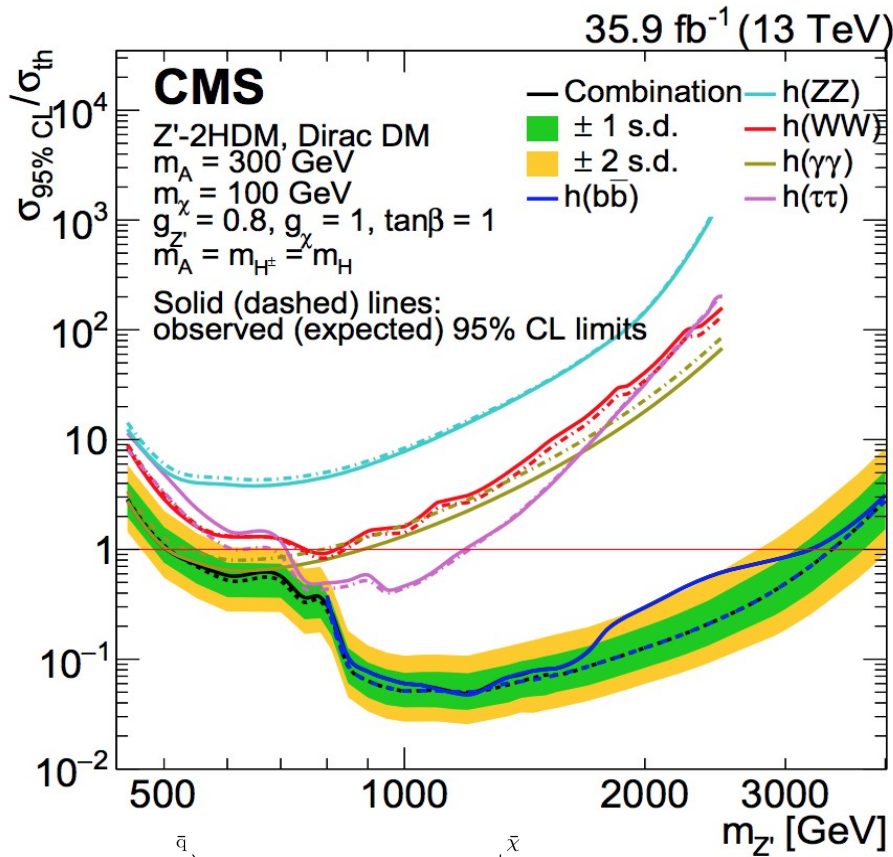
# In Higgs land: Where is DM?

- DMWG overlaps with Higgs XS WG in two ways
  - Higgs to invisible
  - 2HDM interpretations (focusing on mono-higgs)
- Where do we currently stand?
  - Excluding  $H(\text{inv}) < 0.25$  (on both experiments)



# Other Related Results?

- Both ATLAS/CMS have 2HDM+Z' interpretations
  - Aiming additionally to have 2HDM+A (next slide)

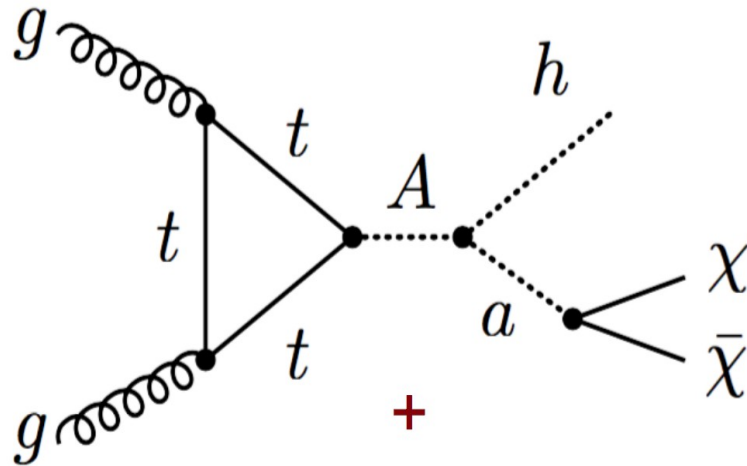


In process of updating  
 coupling choices

# What are plans?

- Aiming to present more results with 2HDM+a

7 Free parameters



## Particle content:

- CP even:  $h, H$
- CP odd:  $A, a$
- Charged:  $H^\pm$
- Dirac DM:  $\chi$

$A, a$  mixed:  $\sin\theta$

$a_0$  (before mixing)  
couples to  $\chi$

### 4 affect MET shape:

- $m_a$
  - $m_A$
  - $m_H$
  - $\sin(\theta)$  ← couplings
- kinematics & channels*

### 3 only affect total cross-section:

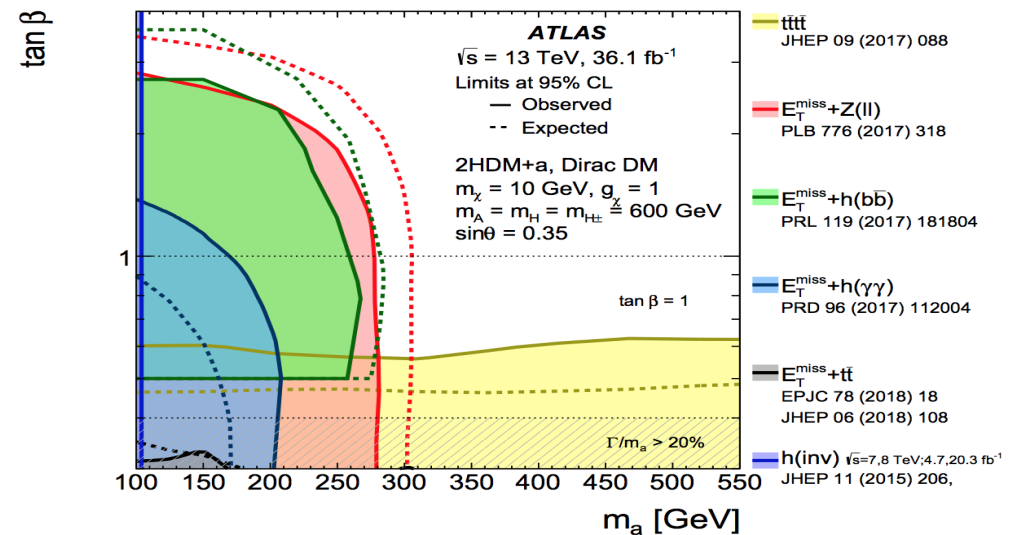
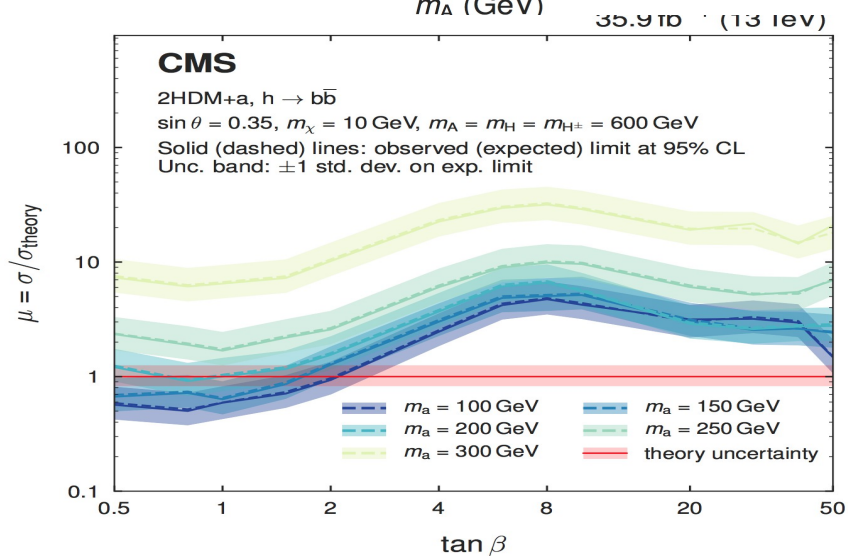
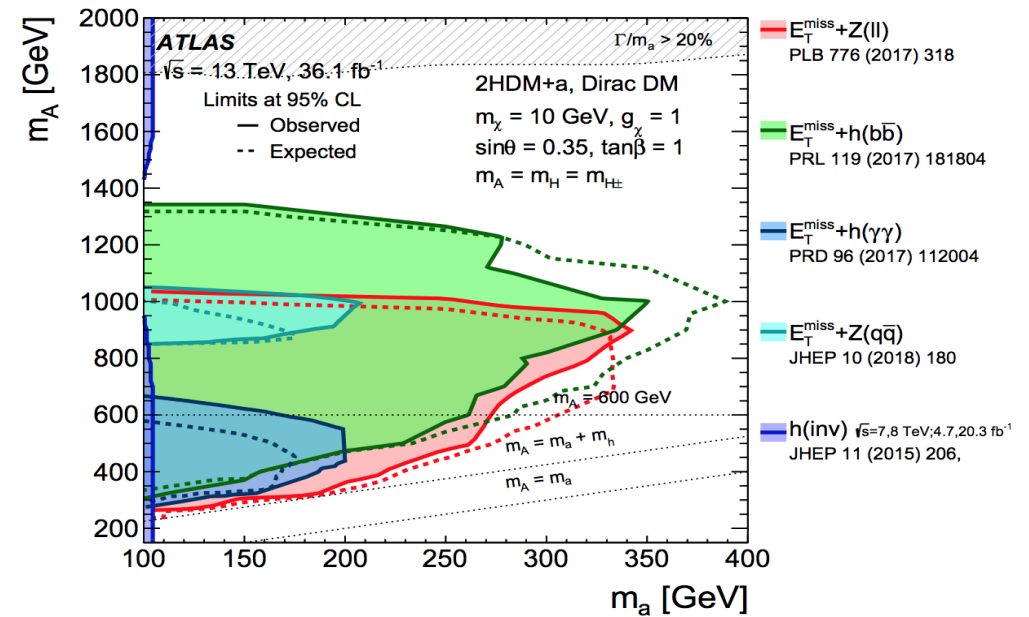
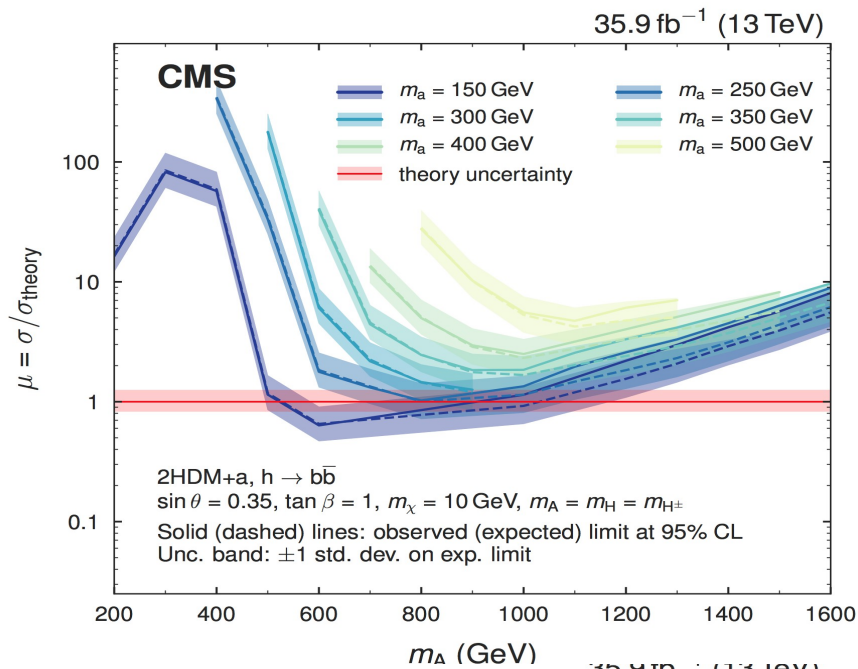
- $\tan(\beta)$  [1]
- $m_\chi$  [2]
- $y_\chi$  ← DM Yukawa

2HDM+a is a **complete/complicated model**

Full ground work for (pseudo)scalar simplified models  
Two new final states : resonant (mono-H and mono-Z)

# Current Results with 2HDM+a

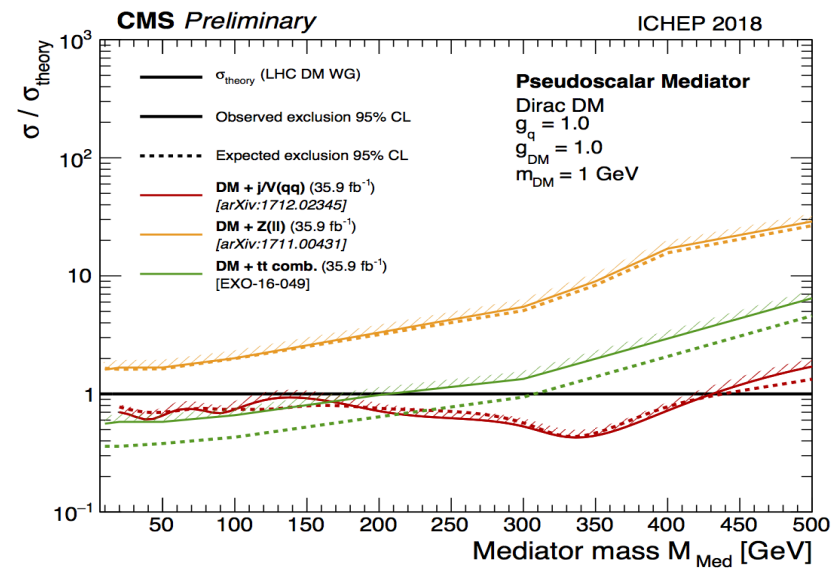
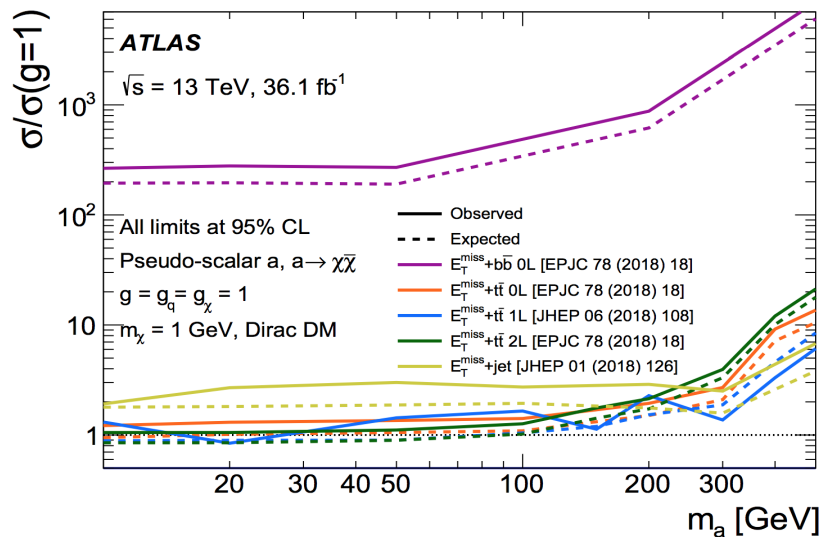
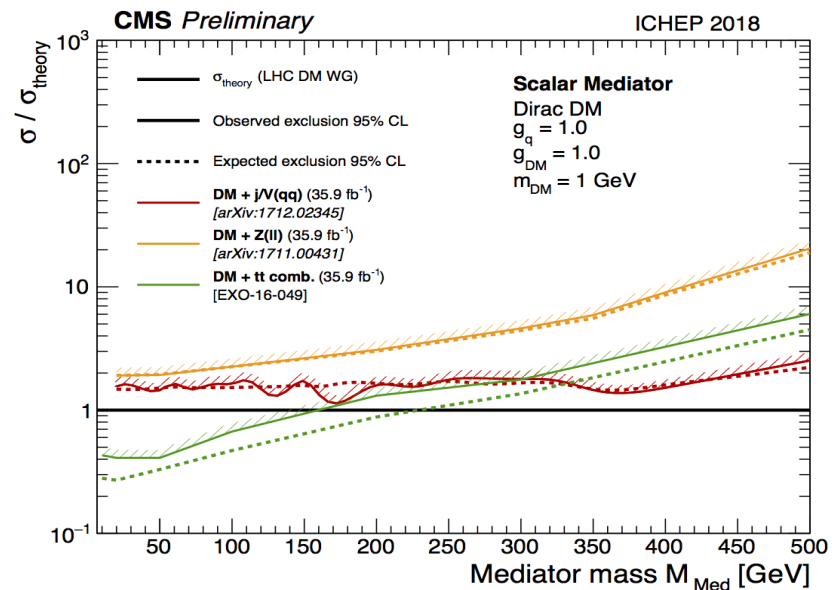
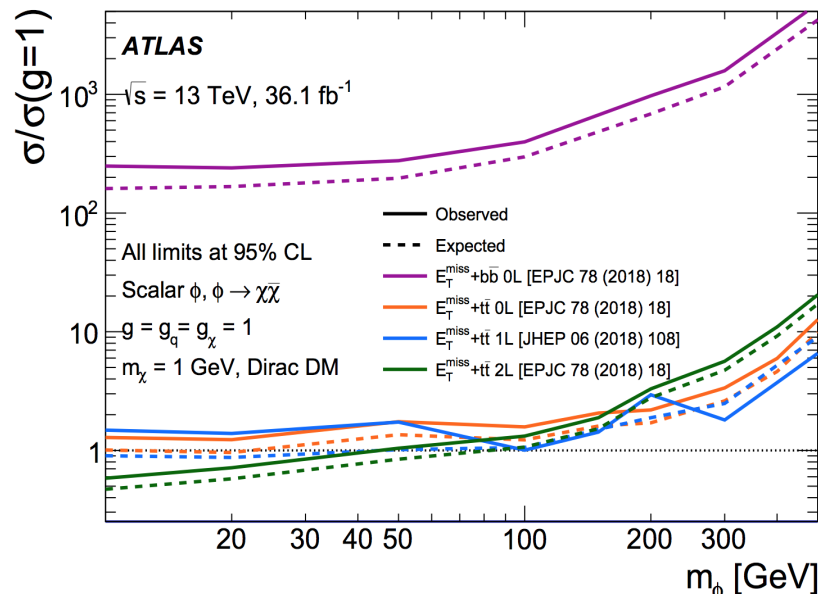
- Will be a focus of mono-H in ATLAS/CMS





# Other Results

- Generic Scalar/Pseudoscalar below 200/350



# Pertinent Updates from LHCDMWG

- Investigating the use of NLO for scalar models
  - Mostly pertains to  $tt+DM$
  - Very difficult to do NLO for monojet/ $t+DM$
  - Likely we will agree on NLO k-factors
  - Unlikely that we will change baseline interpretation
- Update of couplings from  $2HDM+Z'$ 
  - Current benchmarks largely excluded
  - Need smaller couplings given large exclusion
  - Plan to reduce overall cross section



# Additional DMWG activities

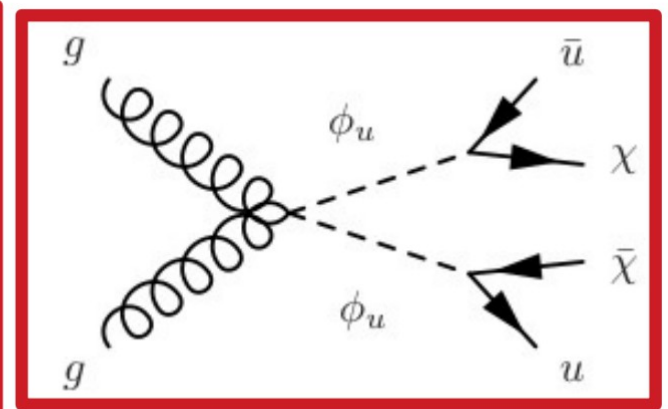
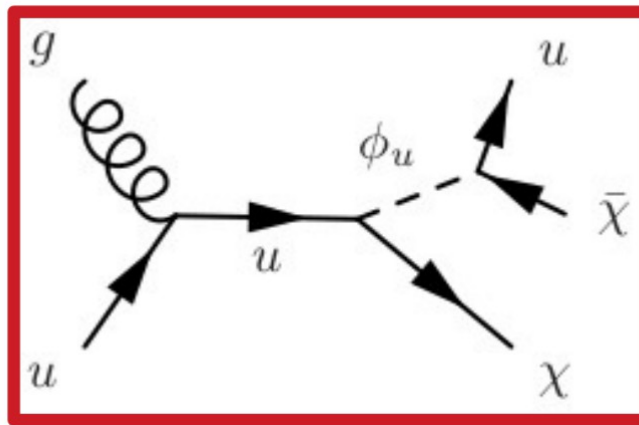
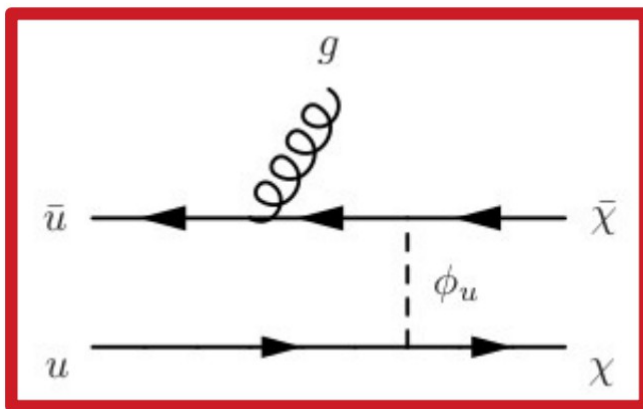
- Working towards a t-channel white paper

$$\mathcal{L}_\chi = \lambda \bar{\chi}_L q_R \phi^* + \text{h.c.}$$

This model includes SUSY as a special case

coupling      quark      Dark mediator, (colored) complex scalar

Dark matter, can be Dirac or Majorana  
Important differences in the signal.



Aiming to write a t-channel white paper over winter time

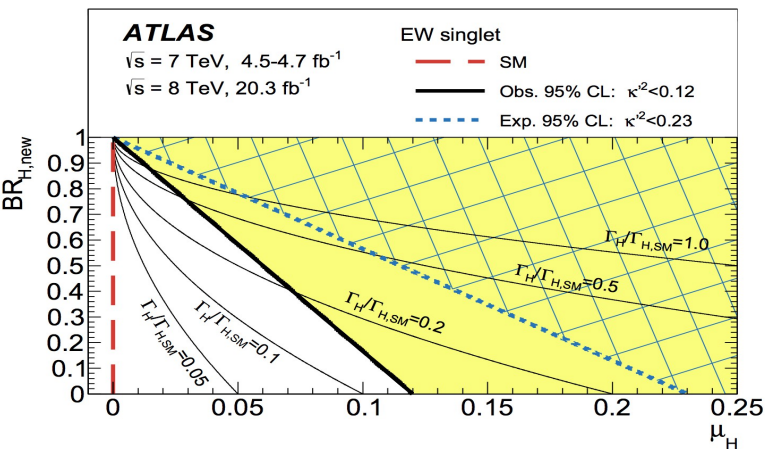
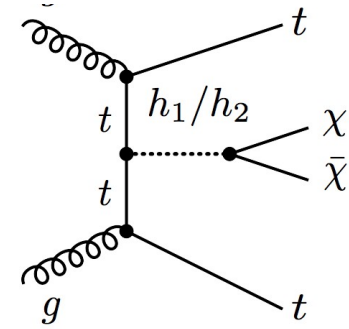
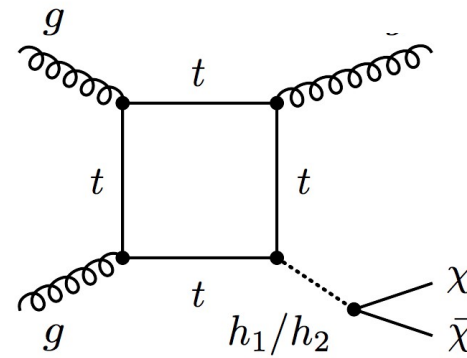
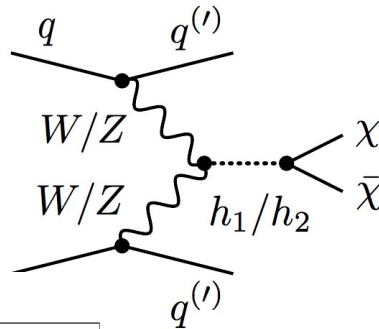
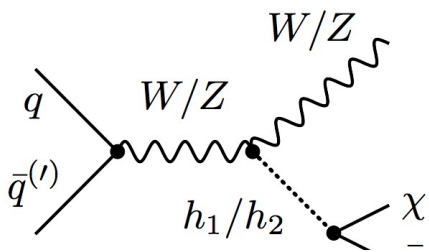
# Non-DMWG Overlaps

- Singlet Mixing model

- Adds a second scalar that mixes with the Higgs boson

$$\mathcal{L} \supset -y_{\text{DM}} s \bar{\chi} \chi - \mu s |H|^2$$

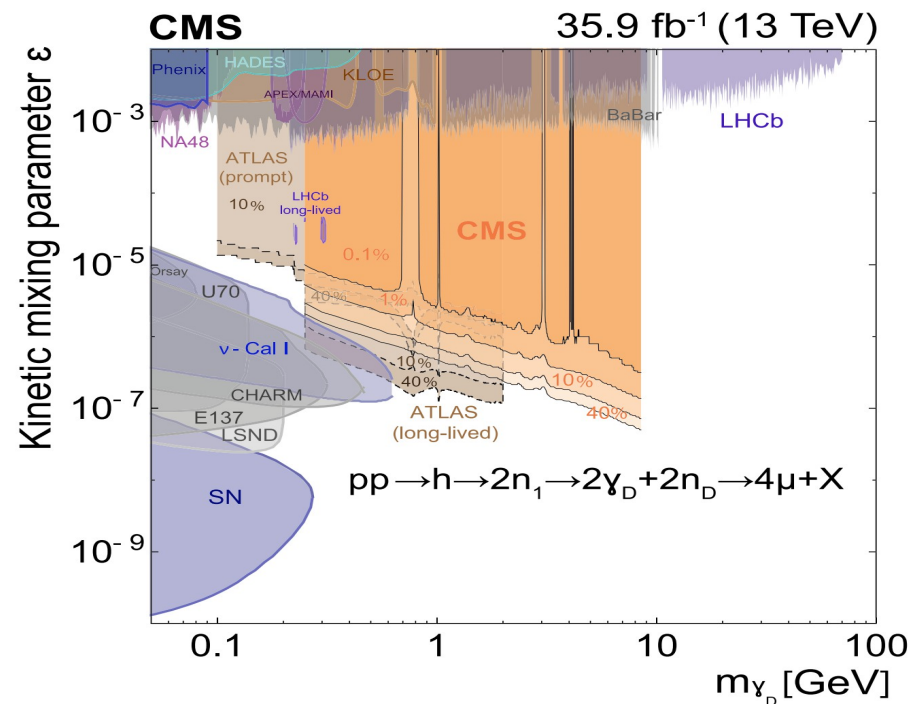
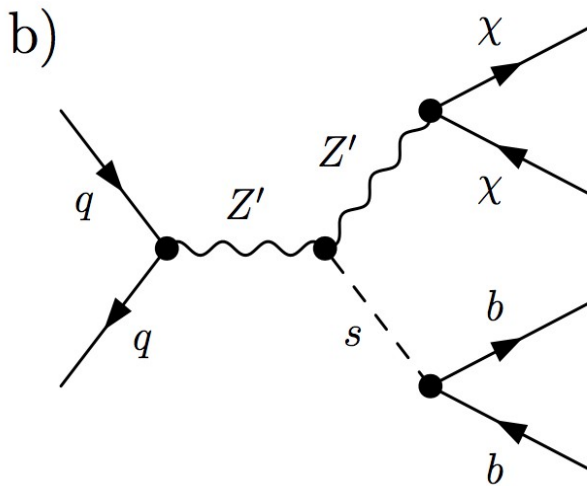
$$\begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} h \\ s \end{pmatrix}$$



Has been probed generically  
by both ATLAS and CMS

# Non-DMWG Dark Higgs

- Given the rise of dark photon models
  - Need a way to give the dark photon mass
  - Can come from dark Higgs or standard Higgs

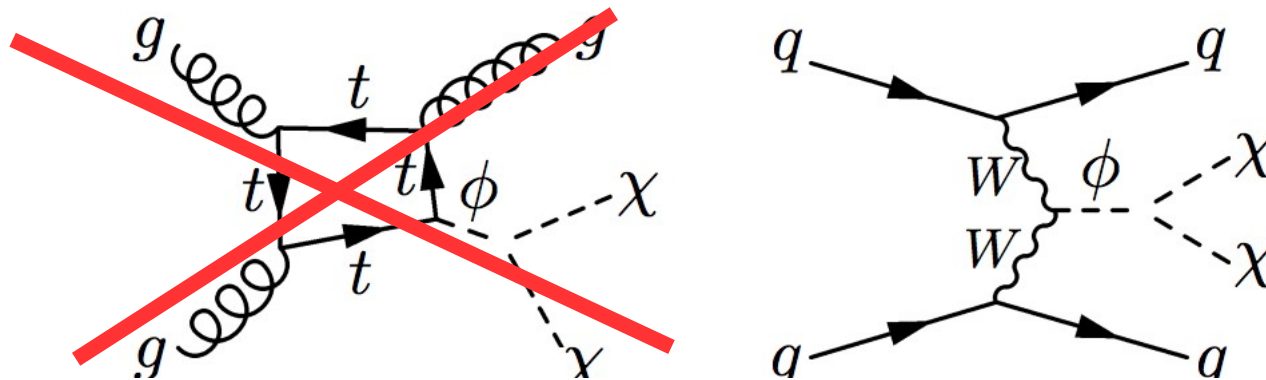


Dark photon has typically not been part of DMWG

Dark matter often assumed offshell (not directly connected)

# Missing Models

- Other models have not been explored
  - Typically there has been a good reason
  - Sometimes we have run out of time or forgot
- One model that could be added
  - Fermiophobic dark matter
  - This model needs very small couplings (hard to find)



$$\mathcal{L}_{S,VV} \supset -2c_{S,VV} S \left( \frac{M_W^2}{v} W^{+\mu} W_{\mu}^{-} + \frac{M_Z^2}{2v} Z^{\mu} Z_{\mu} \right) - \frac{1}{2} m_{\text{MED}}^2 S^2 + \mathcal{L}(S, \bar{\chi}, \chi).$$

# Conclusions

- LHC DM WG covers (psuedo)scalar models
  - These overlap with Higgs through 2HDM models
  - Higgs to invisible ostensibly a subset of this
- Currently no big issues in LHC DM WG
  - Recent work has been towards a t-channel paper
  - Small updates are happening on other aspects
- Looking forward to run II results on the full dataset
- Feel free to ask me about other stuff

# Backup