Dark Matter Search at ATLAS

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HEP Seminar

It Is Unknown What Dark Matters Are

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We Know What They Are Not

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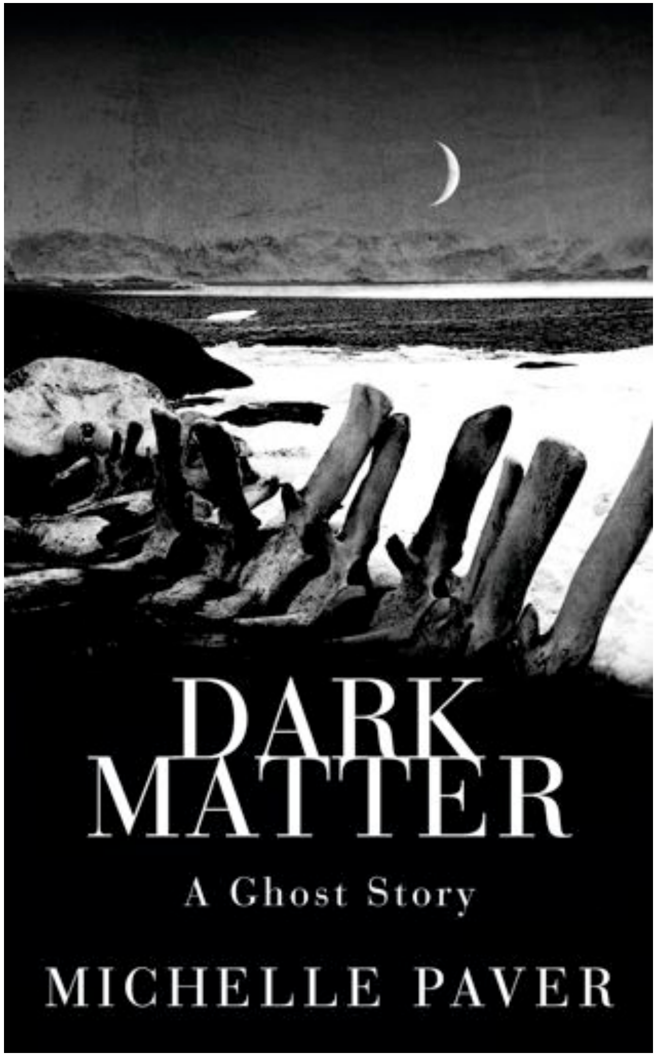
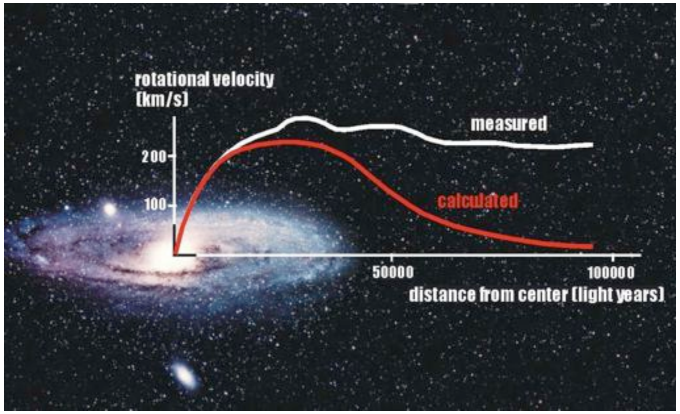
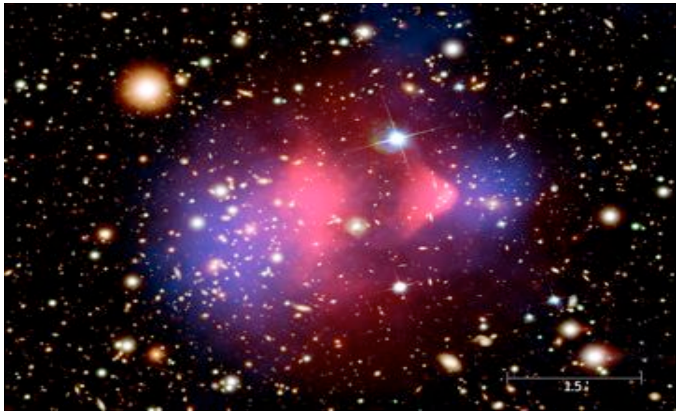


We Know What They Could Be

- DM is BSM physics that we know exists:
  - galaxy rotational curves, bullet clusters, etc

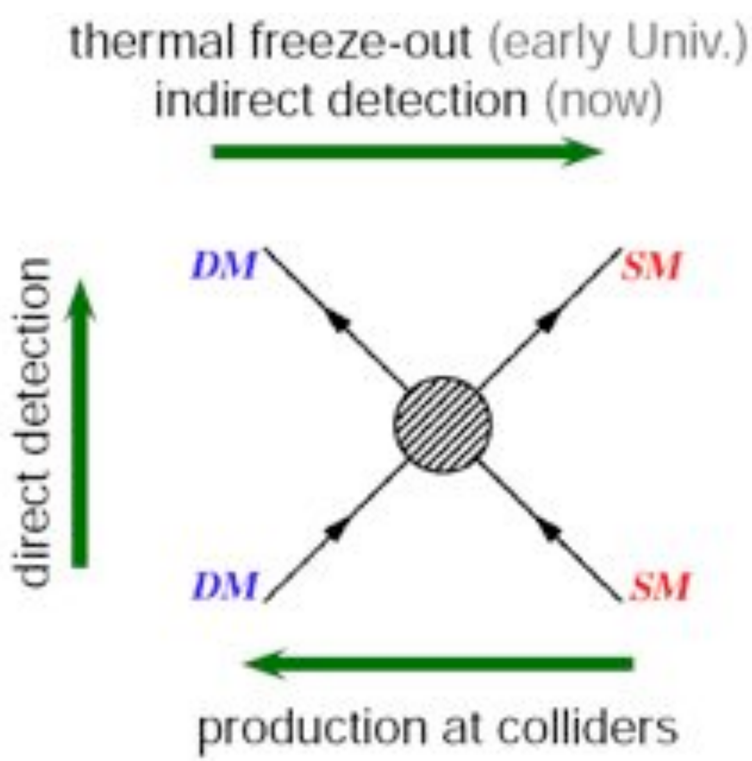


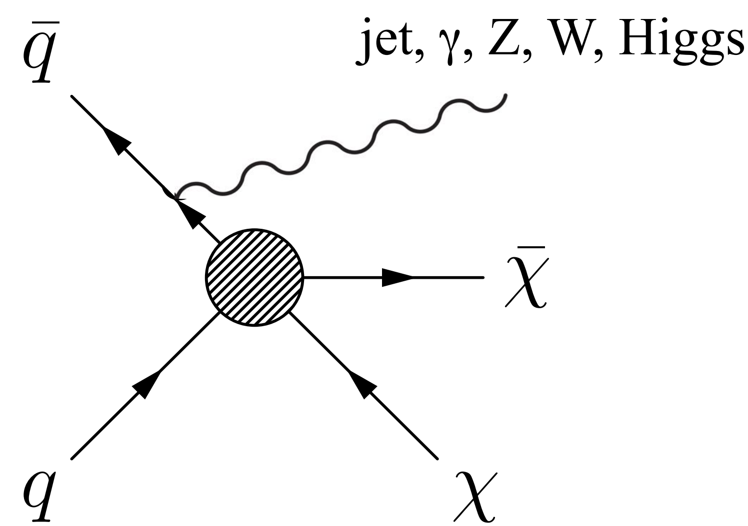


- It could be Weakly Interacting Massive Particle (WIMP):
  - Naturally account for the amount of dark matter we observe in the Universe
  - Occurs in many models of physics beyond the SM
  - We can use particle physics experimental techniques to search for it

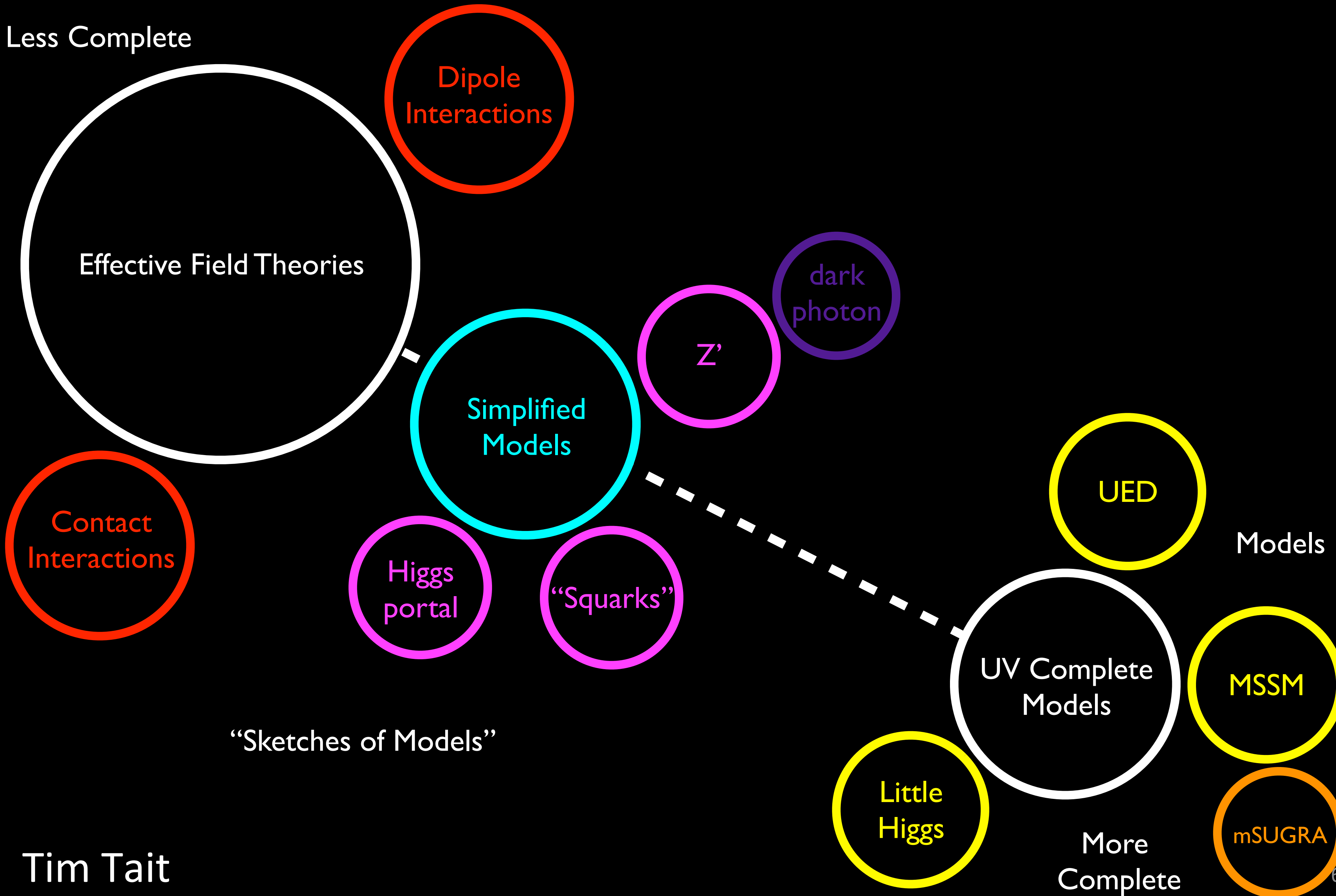
Dark Matter Searches at Colliders

- Produce DM from pp collision
- Mono-X (X = jet, photon, W/Z, etc) searches
  - DMs direct production in association with visible objects





Spectrum of Theory Space



Tim Tait

Spectrum of Theory Space

Less Complete

“Sketches of M

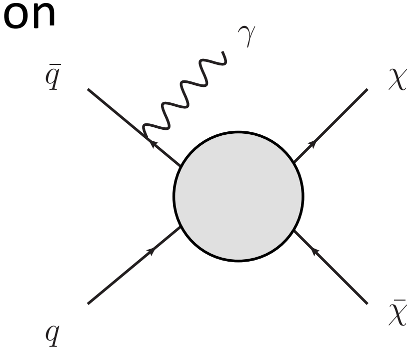
Effective field theory (EFT)

- Broad coverage of models by integrating out the details
- Suppression scale M* and DM mass m_χ

DM couplings with quark/gluon

- SM particle from initial state radiation

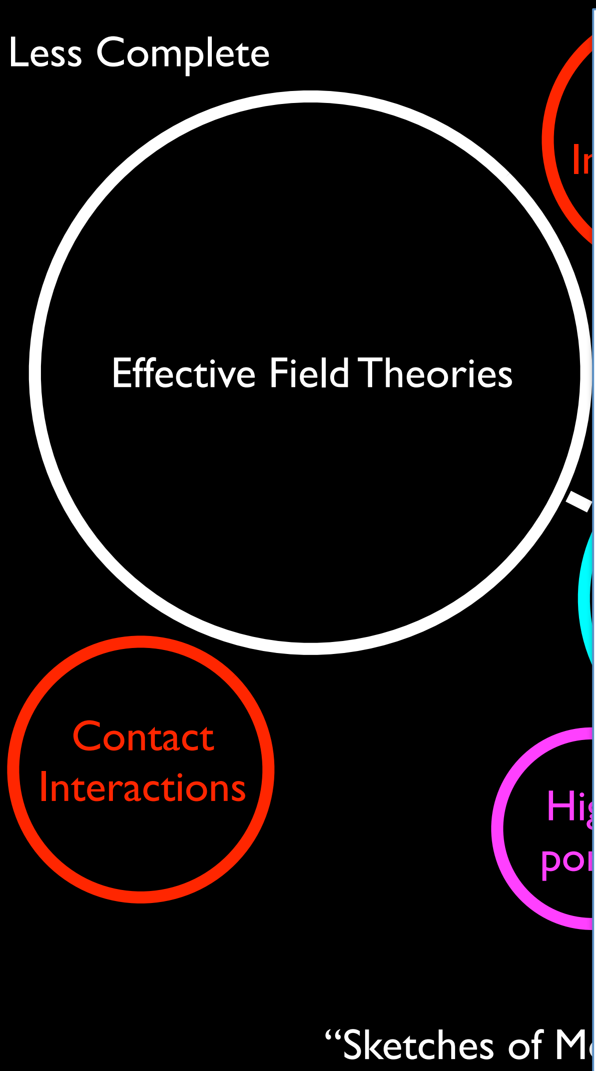
[J. Goodman et al. arXiv:1008.1783]
[Y. Bai et al. arXiv:1005.3797]
[P. Fox et al. arXiv:1109.4398]
[J. Feng et al arXiv:1102.4331]
and many others



- Most cases mono-jet search has strongest sensitivity
- Some scenario (opposite couplings to up and down quark) boosts the mono-W process

Vector	Axial vector	Tensor
$\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q/M_*^2$	$\bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{q}\gamma_{\mu}\gamma^{5}q/M_*^2$	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q/M_*^2$

Spectrum of Theory Space



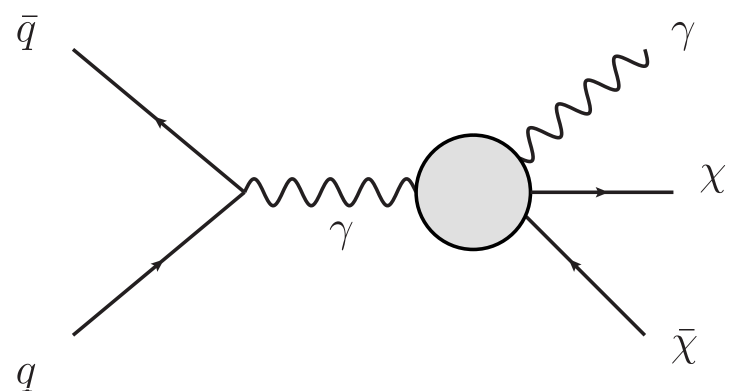
Effective field theory (EFT)

- Broad coverage of models by integrating out the details
- Suppression scale M* and DM mass m_χ

DM couplings with boson

- SM particle from main interaction
- Mono-photon, W/Z etc searches

[A.J. Nelson et al. arXiv:1307.5064]
[N. Lopez, NZ et al. arXiv: 1403.6734]



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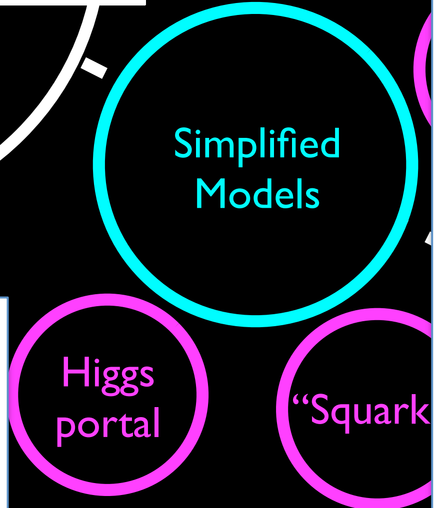
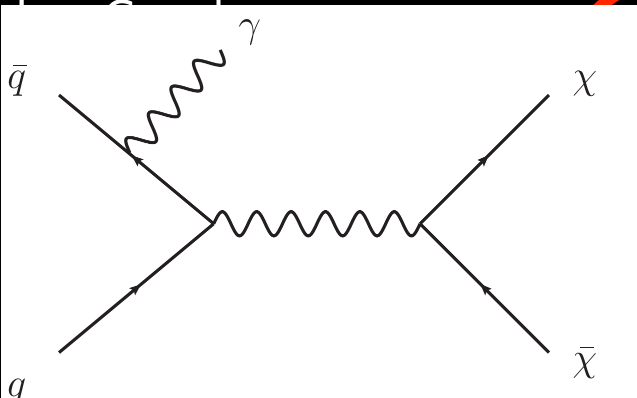
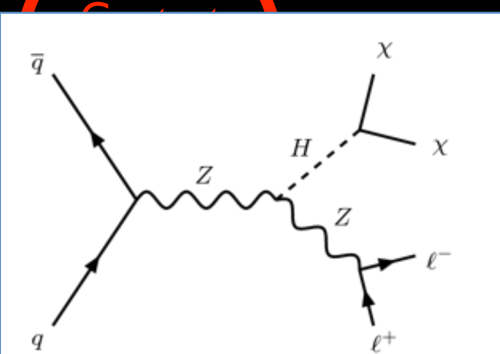


Dipole
eractions

of Models"





Simplified model

- Keep the information of intermediate state
- s-channel (Z' portal, higgs portal, etc)
- t-channel (colored scalar, etc)

[J. Abdallah, NZ et al. arXiv: 1409.2893]

In the limit of heavy mediator mass, can be approximated by EFT

$$\frac{g_f^2 g_\chi^2}{(Q_{tr}^2 - m_V^2)^2} \xrightarrow{Q_{tr} << m_V} \frac{g_f^2 g_\chi^2}{m_V^4} = \frac{1}{M_*^4}$$

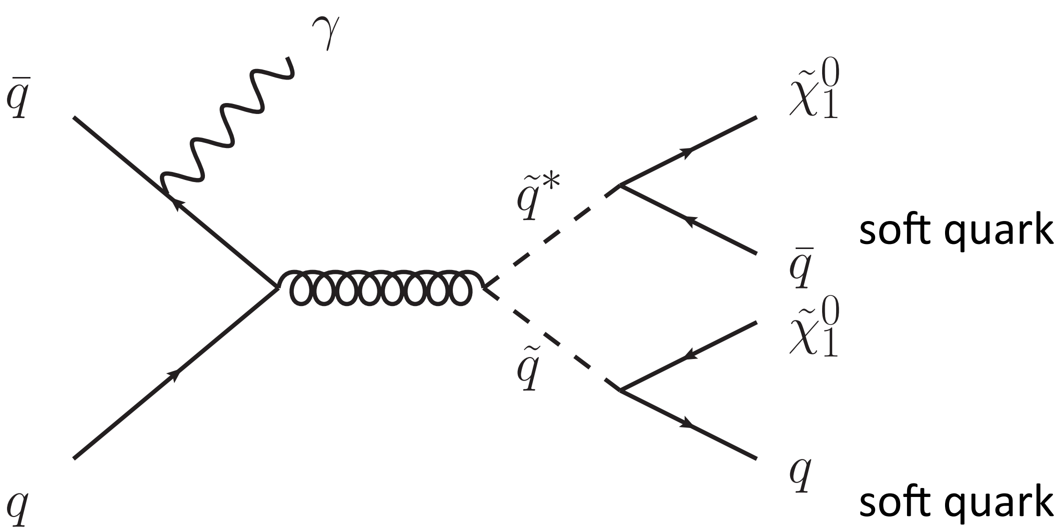
$$M_* = m_V / \sqrt{g_f g_\chi}$$

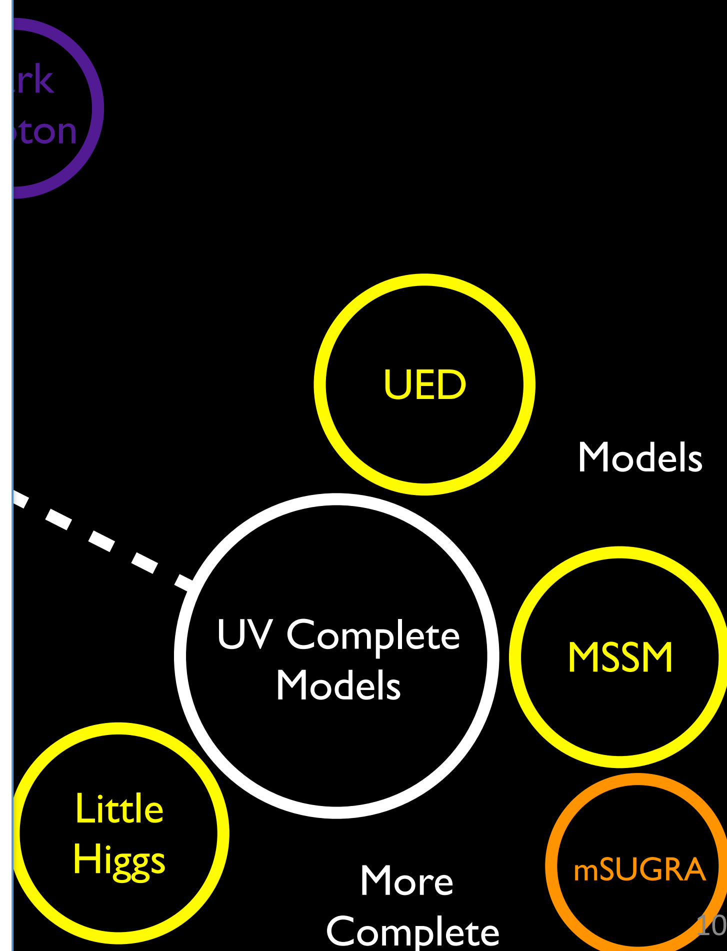
Spectrum of Theory Space

SUSY: Full theory model

Compressed SUSY => Mono-X signature

- Squark-LSP mass splitting small
- Jets being too soft to be reconstructed
- ISR SM particles





Outline

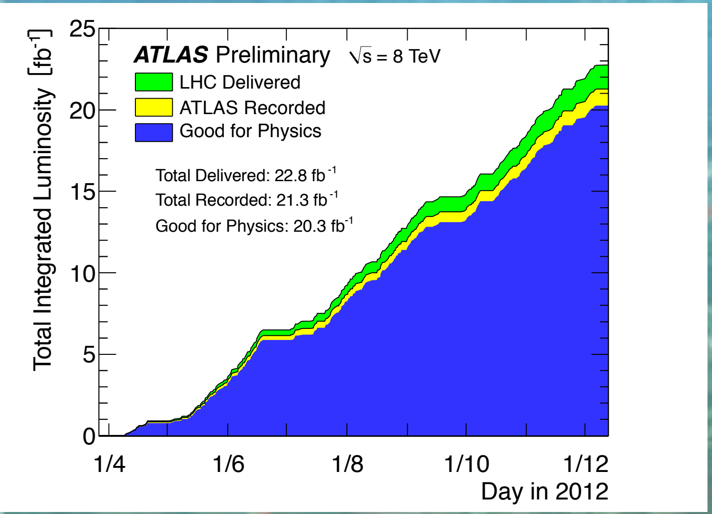
- This seminar is based on

8 TeV	Mono-γ	Mono-W(jj)	ttH(invisible)
Reference	ATLAS-CONF-2014-051	PRL 112, 041802 (2014) arXiv:1309.4017 N. Lopez, NZ et al arXiv:1403.6734	NZ et al, arXiv:1408.0011
EFT with q/g	✔	✔	
EFT with boson	✔	✔	
Z'-portal	✔		
Higgs-portal		✔	✔
SUSY compressed	✔		

The ATLAS detector

- One of the two general-purpose experiments at LHC
  - Inner detector: track $|\eta|<2.5$
  - Electromagnetic calorimeter: γ and e $|\eta|<2.37$ and 2.47
  - Hadronic calorimeter: jet $|\eta|<4.5$
  - Muon spectrometer: μ $|\eta|<2.4$

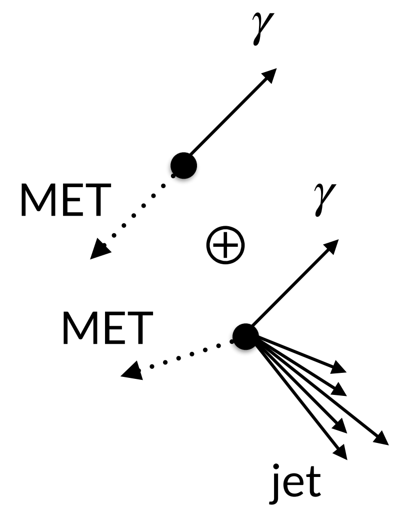
- New DM result: 8 TeV mono-photon search

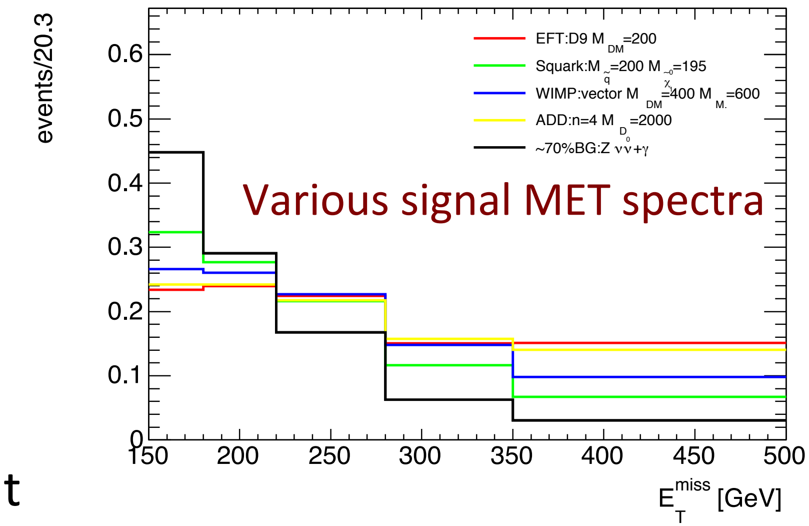


- **Mono-photon**
  - **ATLAS new DM result**

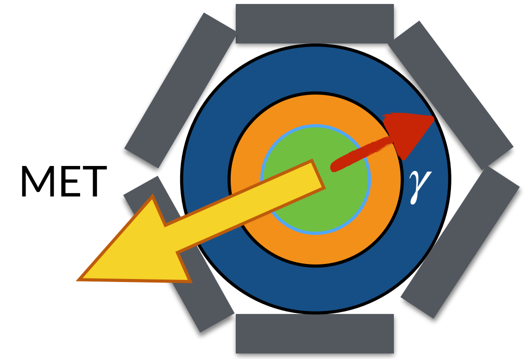
Search Strategy

- Signature: Missing transverse energy (MET) and single energetic isolated photon
- Signal region (SR) selection:
  - MET trigger with threshold of 80 GeV
  - Calorimeter-based MET > 150 GeV
    - Muons are treated as invisible
    - $Z(\mu\mu)+\gamma$ is similar to $Z(\nu\nu)+\gamma$ in MET spectrum
  - Photon with $E_T > 125$ GeV, $|\eta|<1.37$
    - Tight identification, Isolated in calorimeter
    - Away from MET direction
  - Veto on other objects
    - No more than one jet (pT > 30 GeV)
    - No electron (pT > 7 GeV)
    - No muon (pT > 6 GeV)
- Cut-and-count experiment
  - Simple and flexible to be recast for different





SM Background



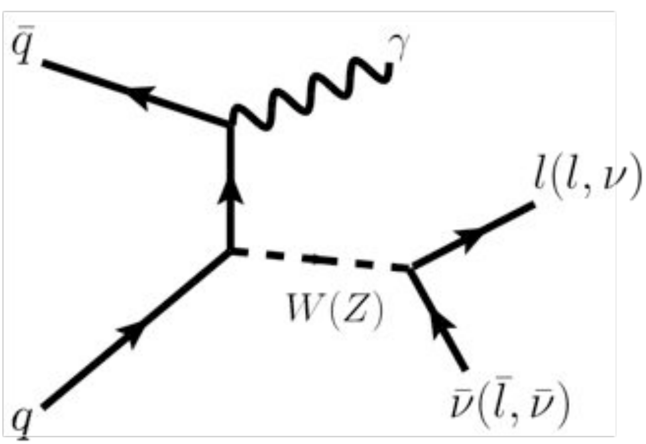
- Irreducible
  - $\gamma + Z(\nu\nu)$ 70%
  - $\gamma + W(\ell\nu)$ 15%
  - $\gamma + Z(\ell\ell)$ 0.4%
- Reducible
  - W/Z+jets, diboson, top (electron/jet fake) 15%
  - γ + jets < 0.1%

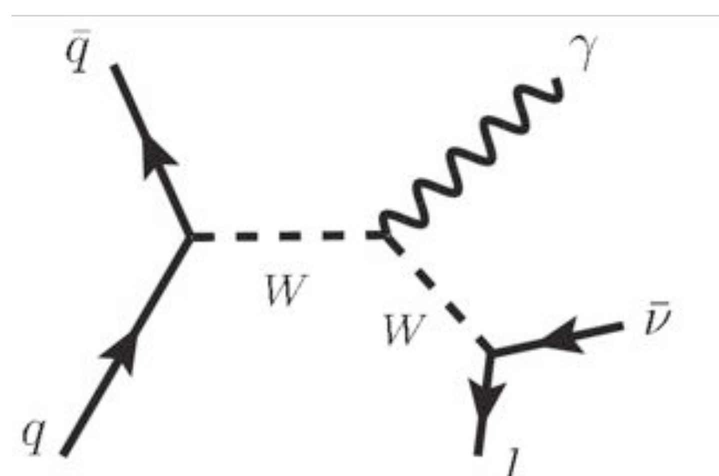
- Background estimation strategy:
  - Given the fact that SM calculation of these backgrounds has large theoretical uncertainties especially for high photon E_T, we rely on data-driven estimates whenever possible

Electroweak Background

- γ+Z with Z decaying to neutrinos
- γ+W with W leptonic decay
  - lepton is mis-identified or tau decays hadronically

- Estimation from data control regions (CR)
  - γ+W has one additional diagram
  - With more statistics at 8TeV, we afford to estimate γ+W and γ+Z separately
    - γ+Z from γ+Z($\ell\ell$) CR
    - γ+W from γ+W($\mu\nu$) CR

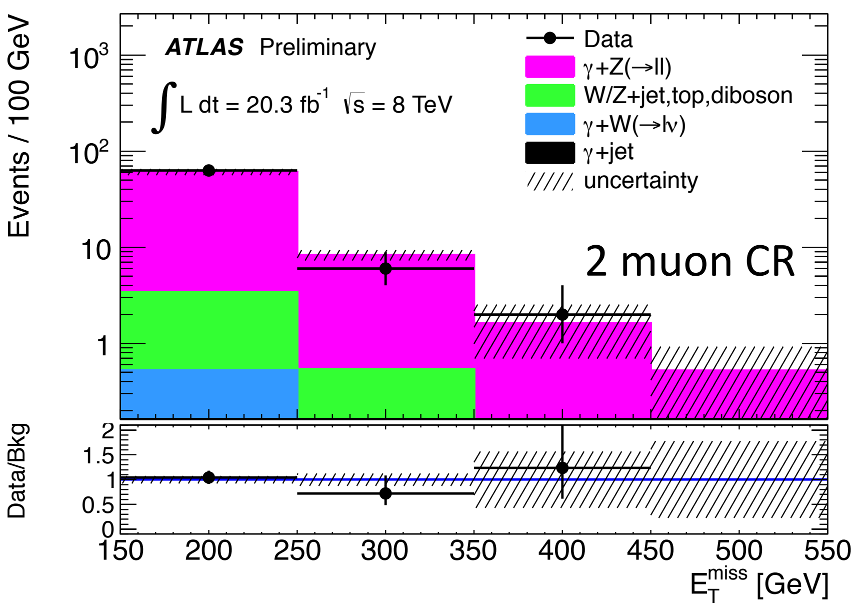


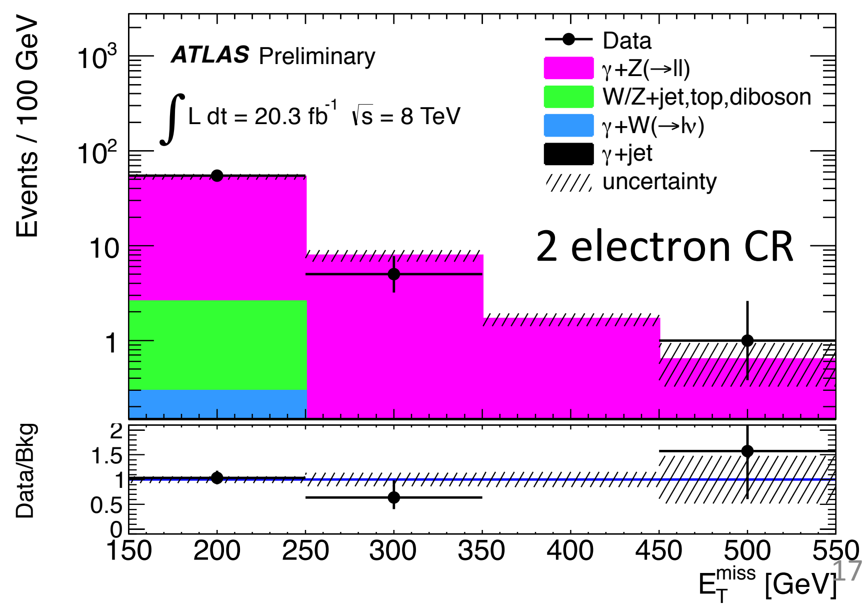


γ + Z(ℓℓ) Control Region

- γ + Z(ℓℓ) have similar kinematics as γ + Z(νν) events
  - M(ℓℓ) > 50 GeV: suppress low mass Drell-Yan process
  - Photon away from lepton: suppress photon radiated from charged lepton
- γ + Z(ℓℓ) CRs suffer from low statistics
  - Extend γ |η| range to 2.37
  - γ + Z(μμ): 71 events
  - γ + Z(ee): 61 events, put electron energy into MET

MC MET spectra, normalized to data

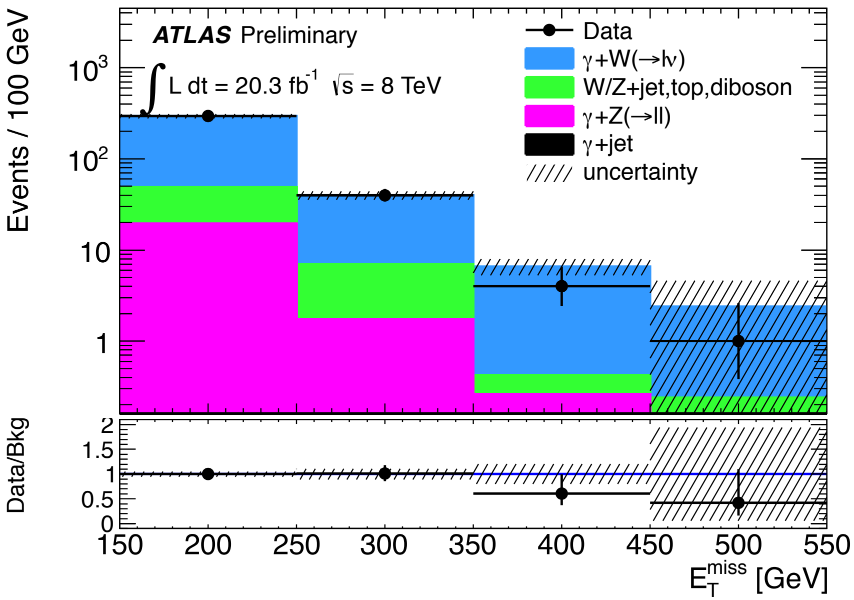




γ + W($\mu\nu$) Control Region

- γ + W($\ell\nu$) contribution in SR is composed with
  - Tau decays hadronically
  - Electron or muon fails the lepton identification criteria
- Constrain it from γ + W($\mu\nu$) with muon identified
  - The MC lepton selection (veto) efficiency is corrected to that measured in data
- γ + W($\mu\nu$) CR: one isolated muon
  - Extend γ $|\eta|$ range to 2.37
  - Data: 340 events

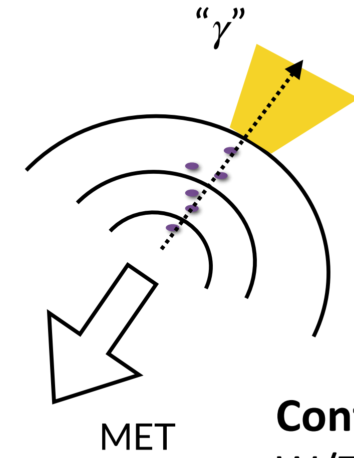
MC MET spectrum, normalized to data



Electron Fakes

- We try to reconstruct unconverted photon (w/o associated track) and converted photon (w associated track)
- Electrons sometimes are mis-identified as converted photons

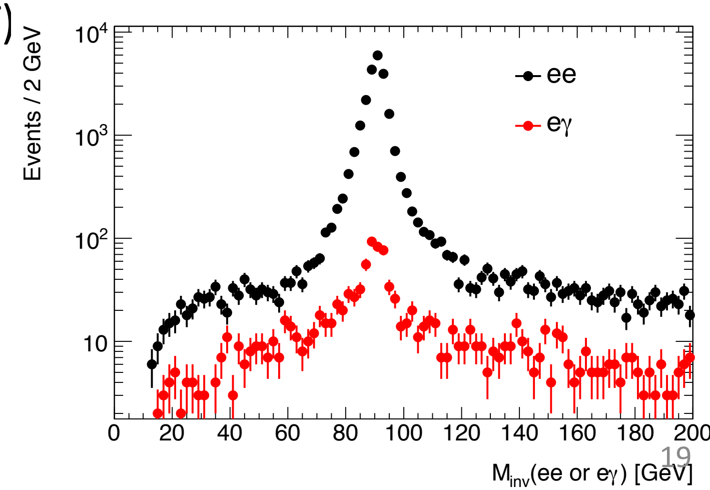
$$N(e_{reco}) \times \frac{P(\gamma_{reco} | e_{real})}{P(e_{reco} | e_{real})} =$$



Electron + MET CR: Same kinematics requirement as photon

Measured from Z peak with tag & probe method: tag one electron and probe the other EM cluster (high pT) to get the prob of being electron or photon

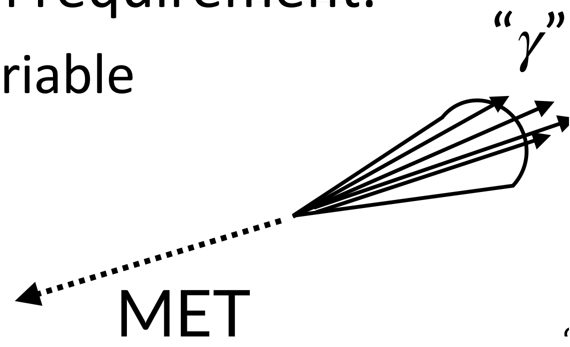
Contributions: W/Z+jets, diboson, top



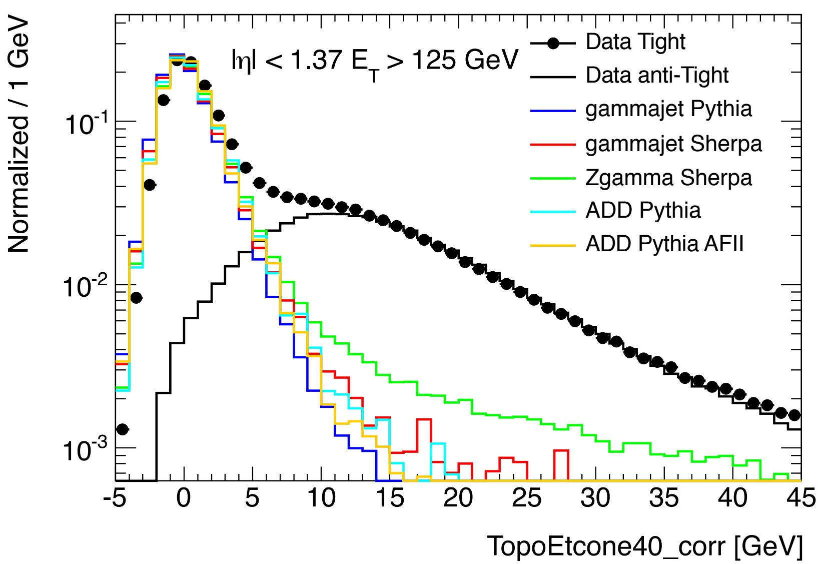
- Estimate electron fakes in SR and CRs

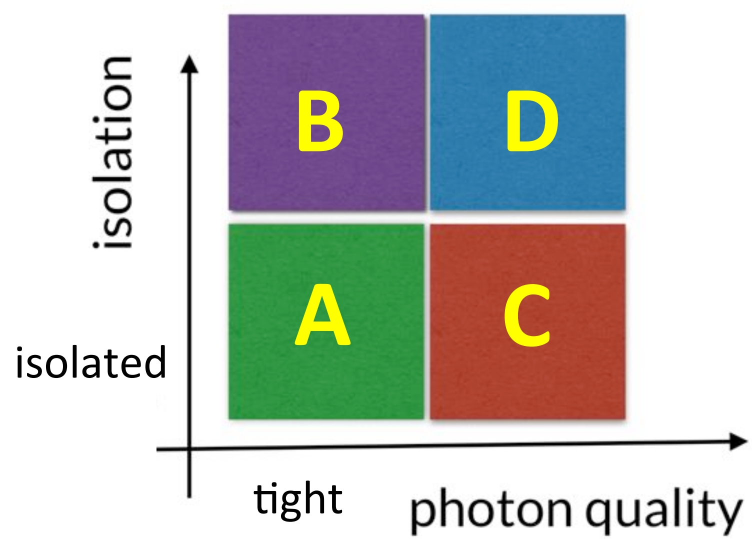
Jet Fakes

- There is some probability of jet to fake photon, especially pi0 jet, even after photon tight identification and isolation requirement.
  - Jet fakes have broader distribution of isolation variable



- Estimation: ABCD method
  - Extrapolation from non-isolated region
  - The extrapolation function is obtained from non-tight-photon CR.



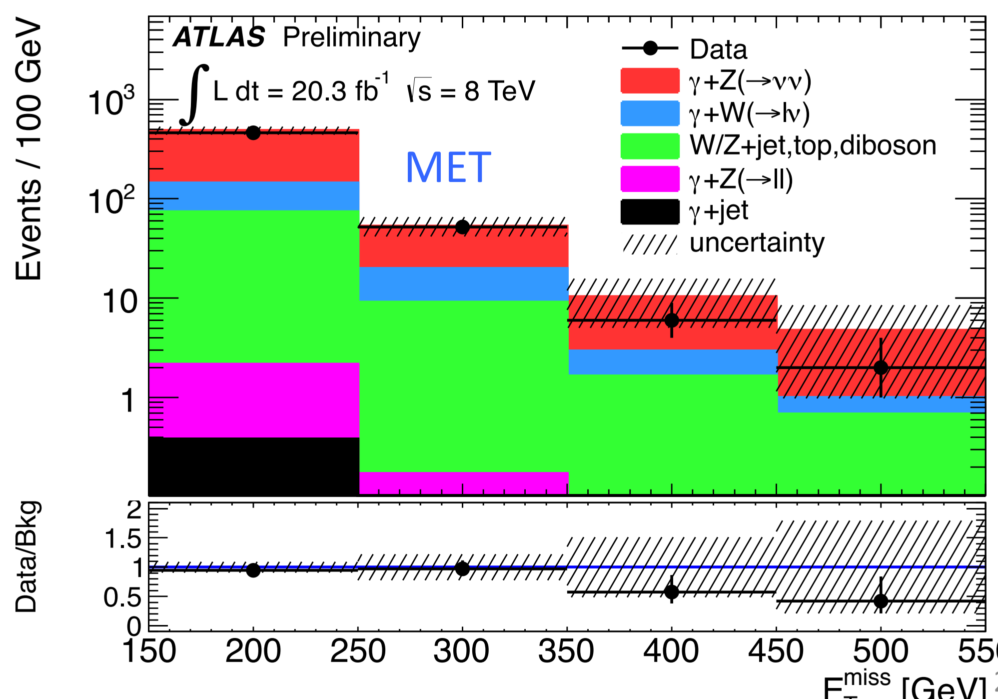


Electroweak Background Determination

- Three CRs: γ + Z(ee), γ + Z($\mu\mu$) and γ + W($\mu\nu$)
- Fit simultaneously to get the normalizations of γ+W/Z (cut and count)
- Poiss(Data | N_Zγ + N_Wγ + N_fake)

To be fitted and used to determine W/Z+γ in SR

Process	Event yield (SR)
$Z(\to \nu\nu) + \gamma$	$389 \pm 36 \pm 10$
$W(\to \ell\nu) + \gamma$	$82.5 \pm 5.3 \pm 3.4$
W/Z + jet, $t\bar{t}$, diboson	$83 \pm 2 \pm 28$
$Z(\to \ell\ell) + \gamma$	$2.0 \pm 0.2 \pm 0.6$
γ + jet	$0.4^{+0.3}_{-0.4}$
Total background	$557 \pm 36 \pm 27$
Data	521



Model-independent Limits

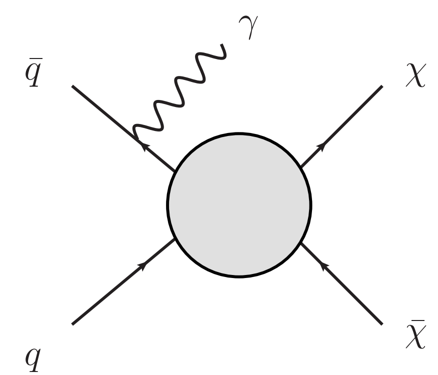
- Model-independent limits are set on the fiducial cross section σ x A.
- Fiducial region defined at truth particle level
  - Mimic the reconstruction level selections
  - Factorize out the signal acceptance
- The reconstruction efficiency tends to be constant (ε = 69%)
  - Computed from ADD and WIMP models with no quark/gluon produced from the main interaction vertex

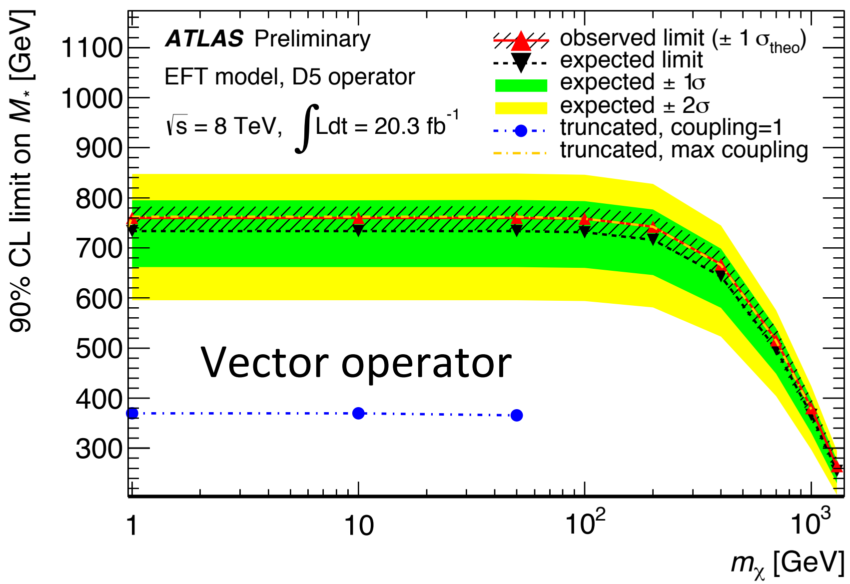
σ x A limit	90% CL	95% CL
Expected	5.1 fb	6.1 fb
Observed	**4.4 fb**	**5.3 fb**

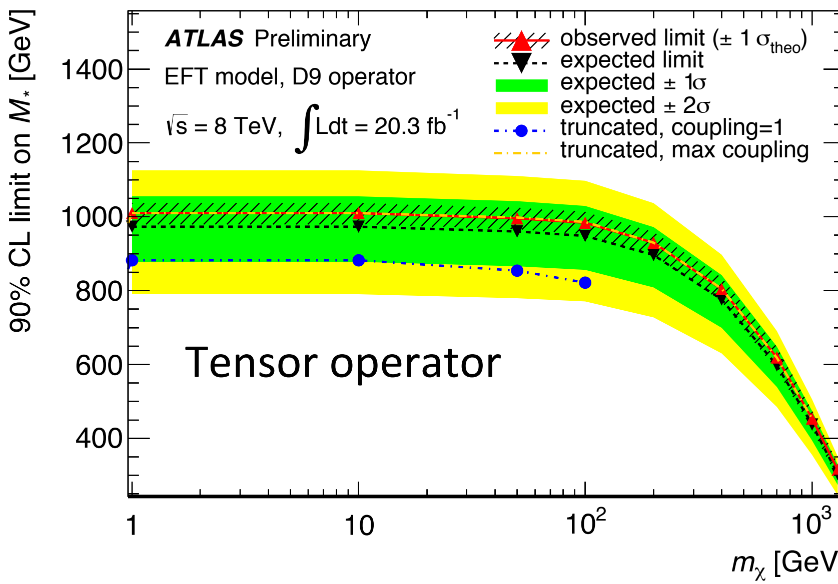
- Applicable to various models producing photon and invisible particles in the fiducial region

EFT Limits

- Convert the cross section limits into the lower limits on M* for different DM mass m_χ.
- Collider searches are sensitive to low DM masses due to the production energy limitation.
- Complementary to astrophysical experiments







EFT validity

- EFT being a valid approximation requires $Q_{tr} < m_V$ (mediator)
  - Not all the events generated from EFT are valid.
  - cut off those invalid events (truncation)
  - Depending on the couplings and DM mass

$$M_* = m_V / \sqrt{g_f g_\chi}$$

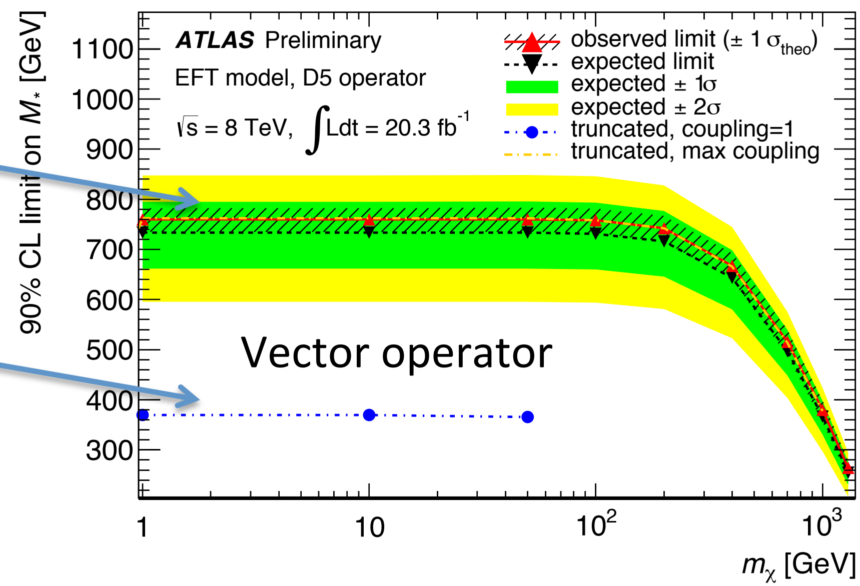
$$\frac{g_f^2 g_\chi^2}{(Q_{tr}^2 - m_V^2)^2} \xrightarrow{Q_{tr} << m_V} \frac{g_f^2 g_\chi^2}{m_V^4} = \frac{1}{M_*^4}$$

$$\sqrt{g_f g_\chi} \in [0, 4\pi)$$

- For unit coupling, beyond DM mass 50 GeV, the valid fraction is so small that we are not sensitive to the model at all. (vector operator for instance)

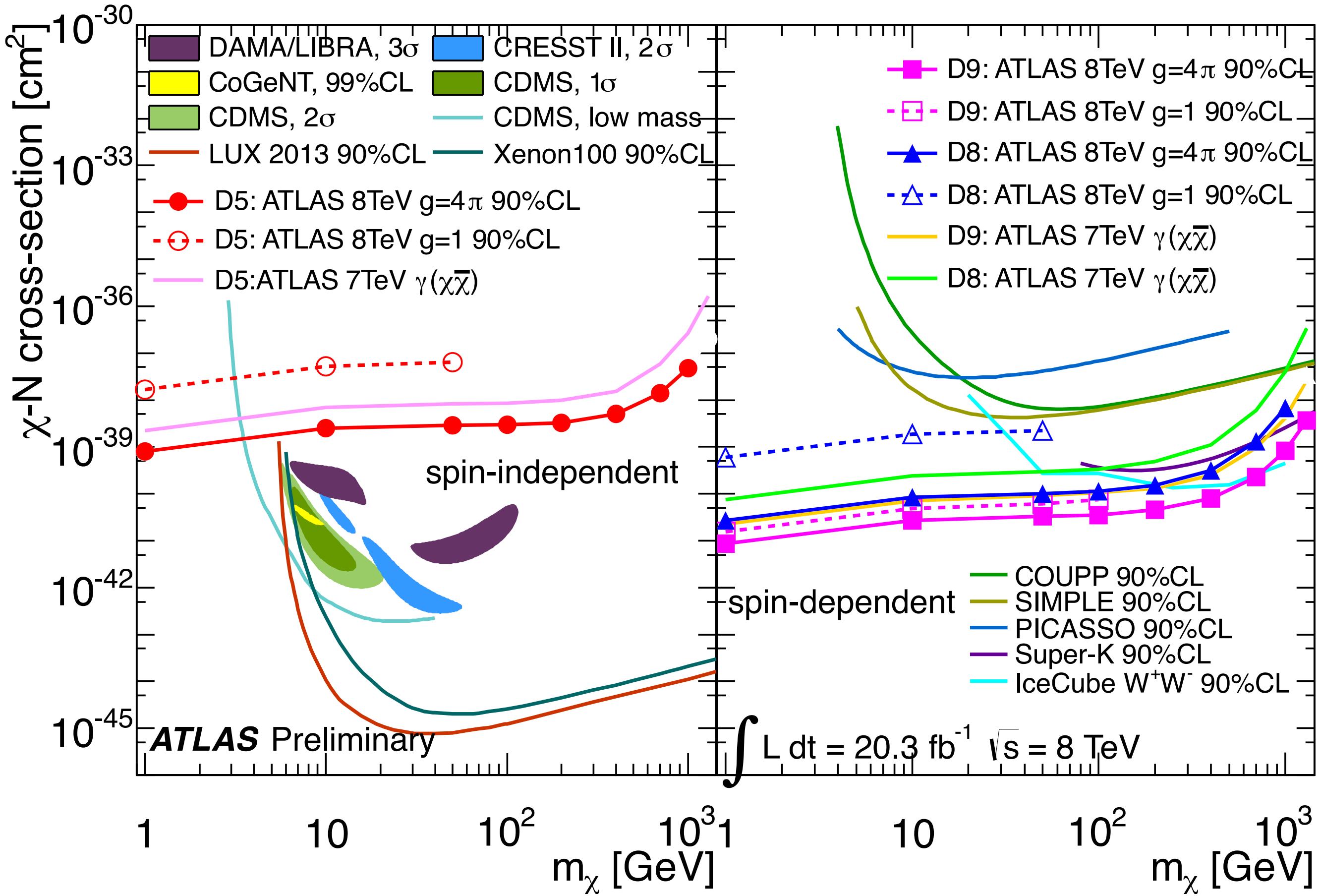
Maximum coupling 4π

Unit coupling 1



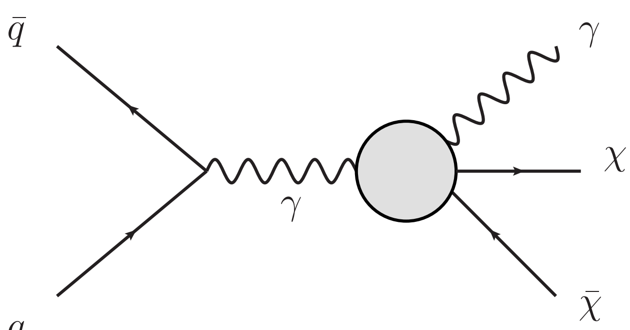
Constraints on Direct Detection

- For the comparison with astrophysics experiments, we produce collider constraints on DM – nucleon scattering cross section.
  - Spin-independent: vector operator
  - Spin-dependent: axial-vector and tensor operators

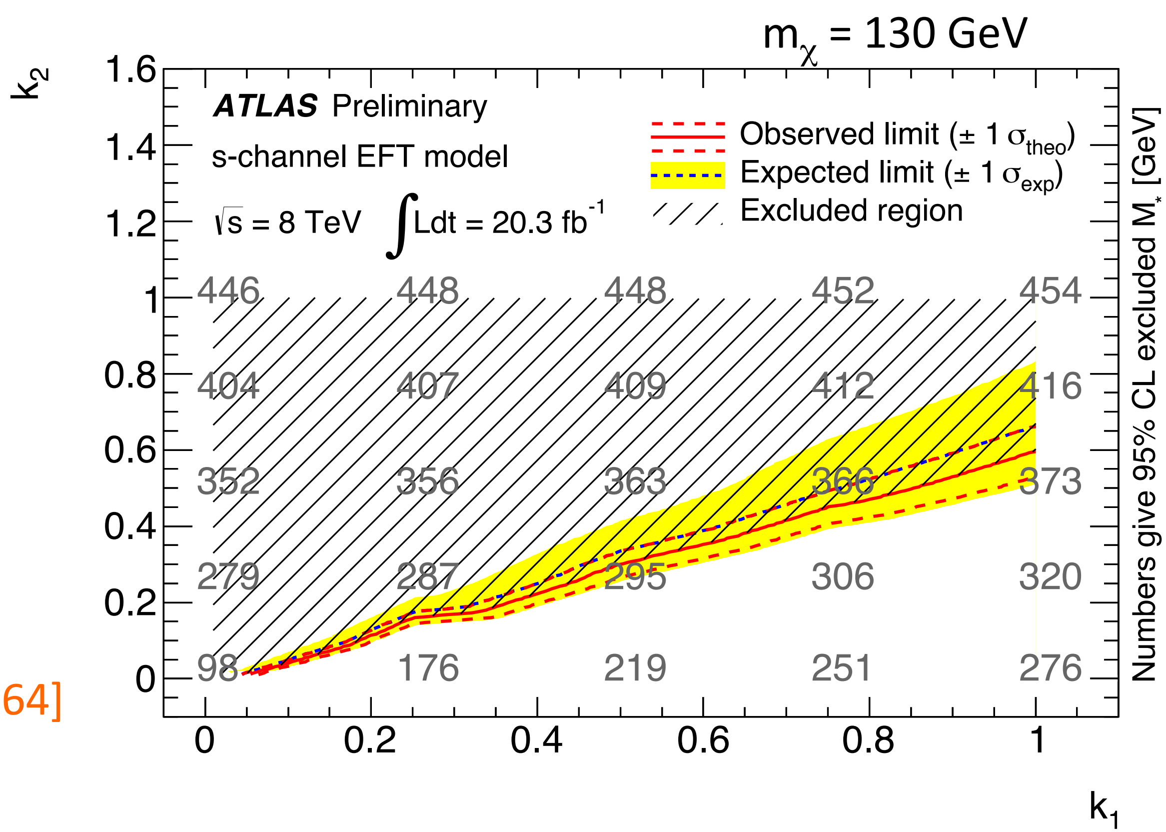


Constraints on Indirect Detection

- s-channel model with $\gamma\gamma\chi\chi$ EFT vertex
  - Aim at explain the Fermi-LAT γ-ray line at 130 GeV
  - k1, k2: effective coupling to SM U(1) and SU(2)
- Constrain effectively the parameter space
- Good example to be able to cross-check astrophysical excess from colliders

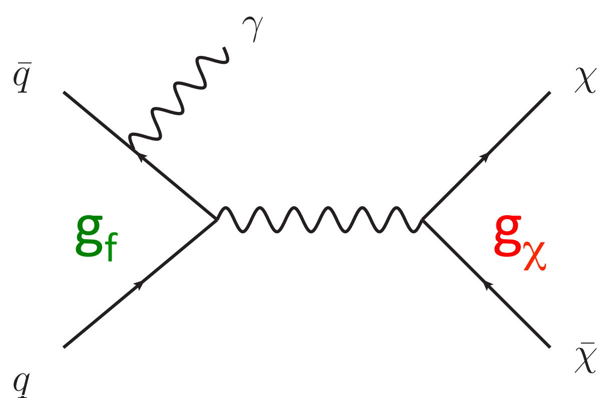


[A.J. Nelson et al. arXiv:1307.5064]



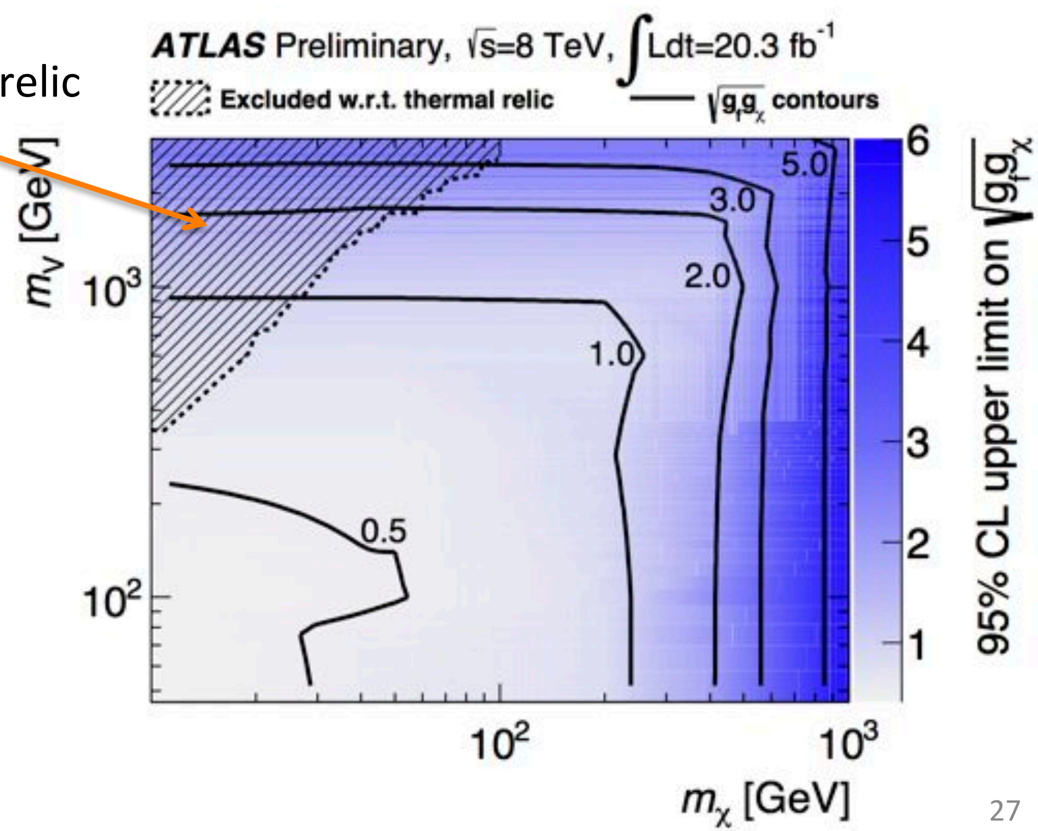
Simplified Model

- Go beyond EFT with a UV-complete simplified model
- Z'-like mediator with vector/axial-vector interaction
  - Parameter: mediator mass m_V, mediator width Γ, dark matter mass m_χ
- Limits are set on the coupling $\sqrt{(g_f g_\chi)}$ and compared to the the thermal relic abundance requirement.



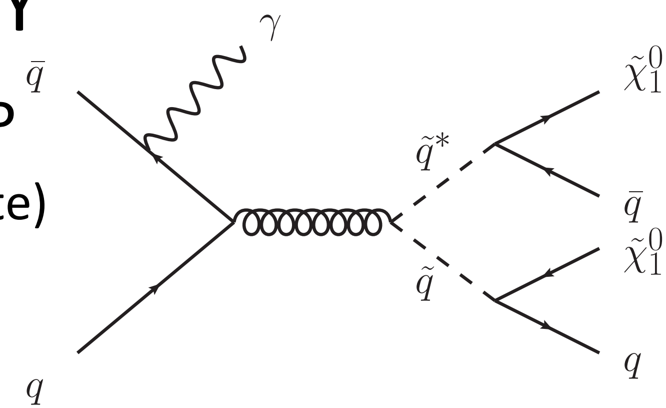
[P. Fox et al. arXiv:1109.4398]

Simplified model results in higher relic density

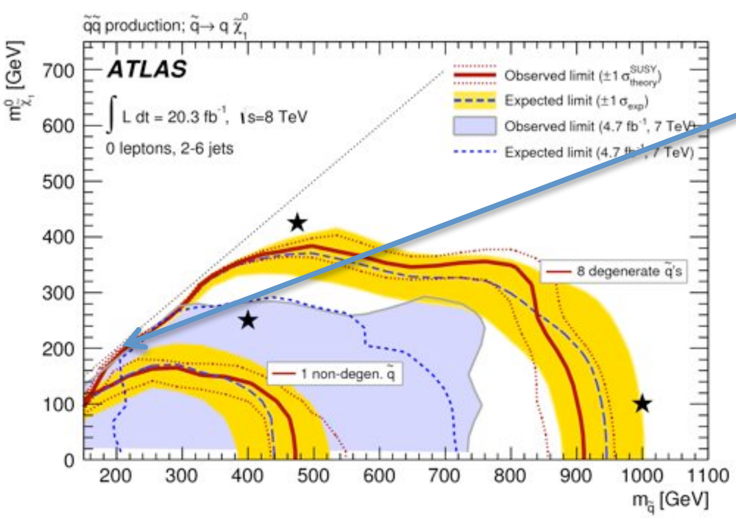


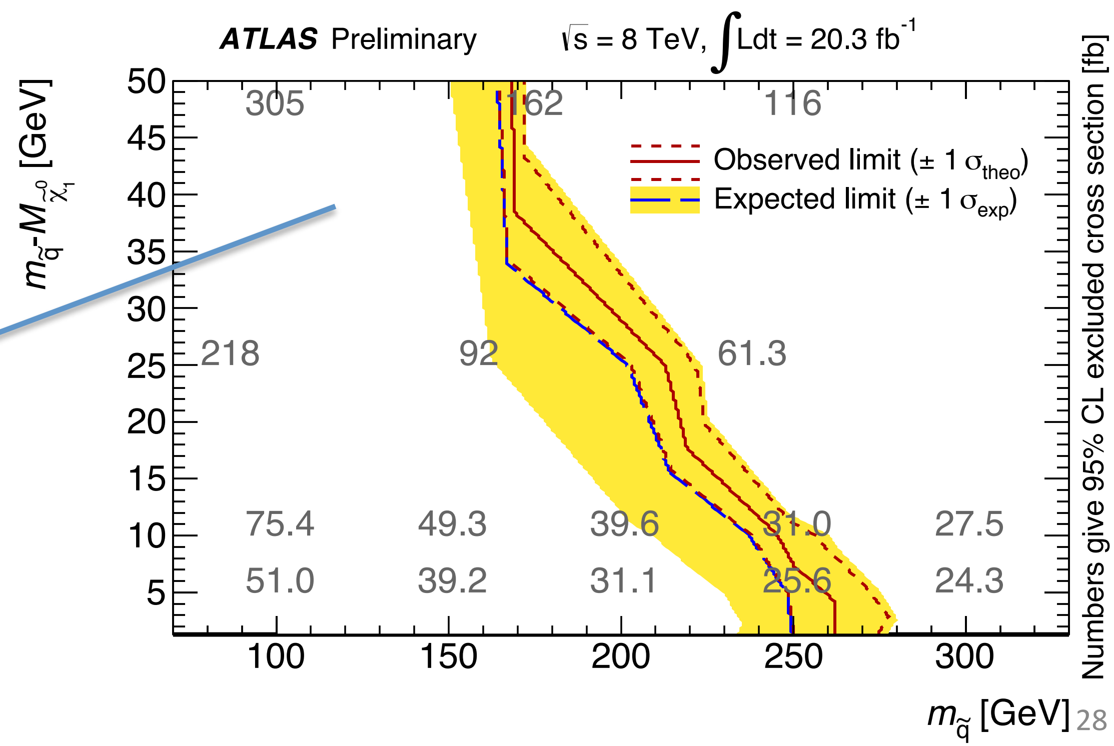
Compressed SUSY

- Small mass splitting between squark and LSP
  - Consider first two squark generations (degenerate)
  - Quarks too soft to be reconstructed as jets



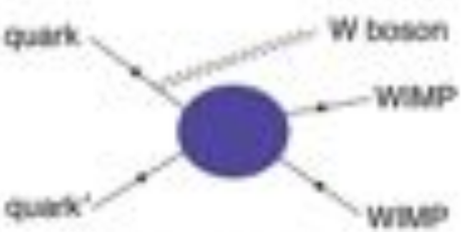
- ISR photon gives mono-photon signature: complementary to SUSY zero-lepton search





- **Mono-W/Z**
  - **Other mono-boson channels**

Synopsis: Looking for the Invisible at Colliders



Adapted from G. Aad et al., Phys. Rev. Lett. (2014)

Search for Dark Matter in Events with a Hadronically Decaying W or Z Boson and Missing Transverse Momentum in pp Collisions at s=8 TeV with the ATLAS Detector

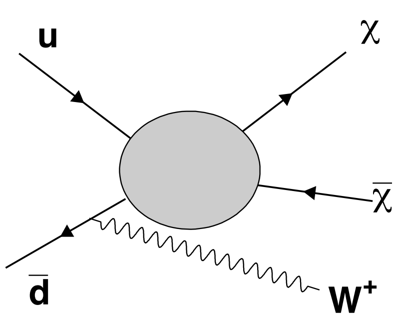
G. Aad et al. (ATLAS Collaboration)a
Phys. Rev. Lett. **112**, 041802 (2014)

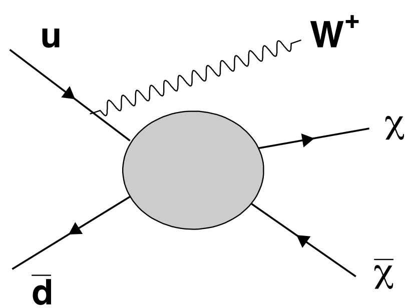
Published January 29, 2014

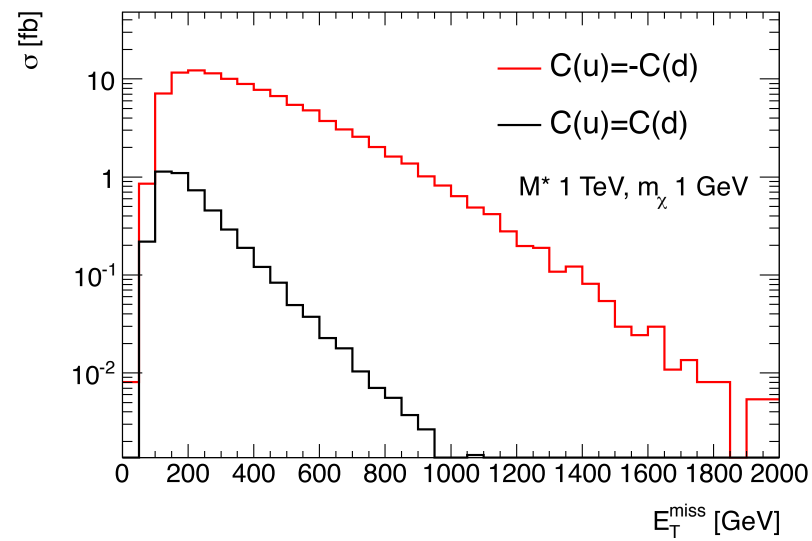
We have no idea what dark matter is. Most attempts to unravel the mystery entail trying to directly detect primordial dark matter particles as they stream by Earth. But it is, in principle, possible to produce dark matter particles in colliders. Until now, bounds from direct detection have been stronger than such collider searches. Now, the ATLAS collaboration at the LHC reports in *Physical Review Letters* that it has used the absence of a certain type of such collider production to place the strongest constraints yet on some models of dark matter.

Mono-W and mono-Z

- If the mediator couplings to up and down quarks are the same.
  - Mono-jet dominates the mono-X sensitivity [NZ et al. arXiv:1302.3619]
- Mono-W: C(up) = - C(down) [Y. Bai, T. Tait arXiv:1208.4361]
  - Constructive interference for vector and axial vector operators
  - Larger production rate and W are strongly boosted
  - Mono-W has the best sensitivity





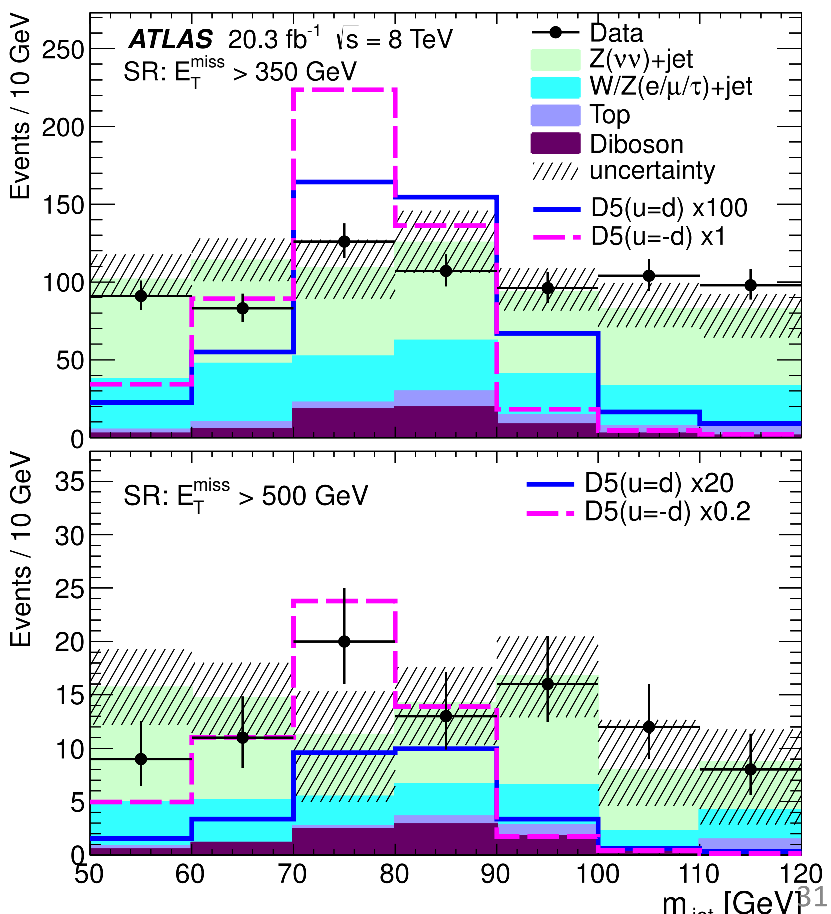


- We focus on hadronic decay
  - Better sensitivity than leptonic channel
  - More challenging to reconstruct hadronic W/Z

Signal Region

- Large MET: MET > 350 GeV, MET > 500 GeV
- Use large-R jet substructure to identify boosted boson
- SM background: dominated by Z(νν)+jets and W(ℓν)+jets

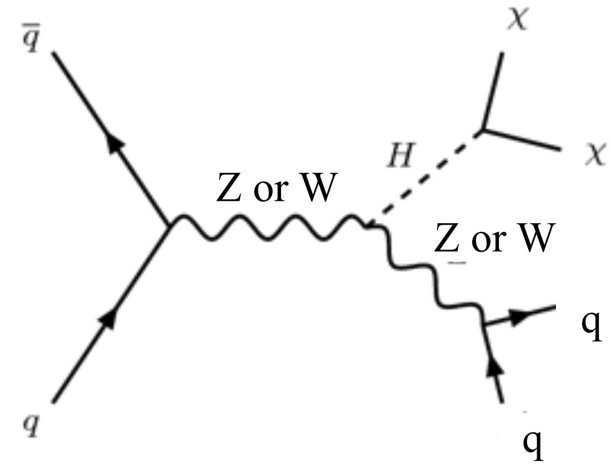
Process	$E_T^{miss} > 350$ GeV	$E_T^{miss} > 500$ GeV
$Z \to \nu\bar{\nu}$	402^{+39}_{-34}	54^{+8}_{-10}
$W \to \ell^{\pm}\nu,\ Z \to \ell^{\pm}\ell^{\mp}$	210^{+20}_{-18}	22^{+4}_{-5}
WW, WZ, ZZ	57^{+11}_{-8}	$9.1^{+1.3}_{-1.1}$
$t\bar{t}$, single t	39^{+10}_{-4}	$3.7^{+1.7}_{-1.3}$
Total	707^{+48}_{-38}	89^{+9}_{-12}
Data	705	89



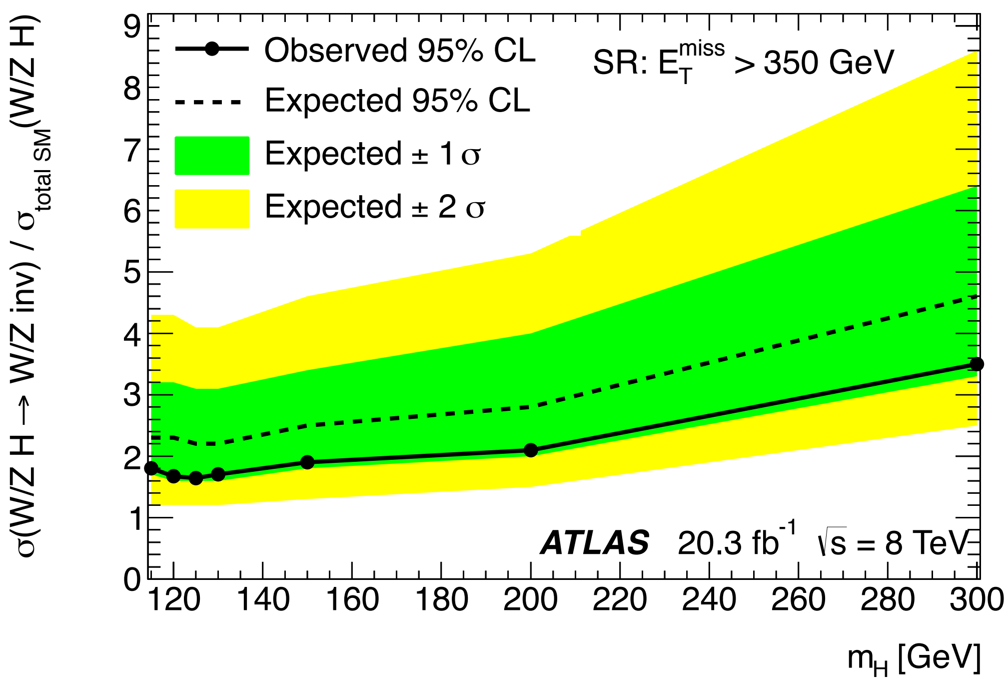
- Large-R jet mass spectrum
  - Model independent
- Limits are set on EFT models

Higgs-Portal Dark Matter

- Higgs invisible decay
- VH production: same signature
- Use mono-W/Z(jj) result to constrain it
  - Not fully optimized for Higgs-portal model

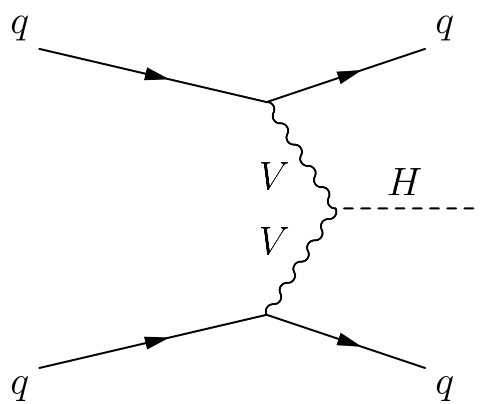


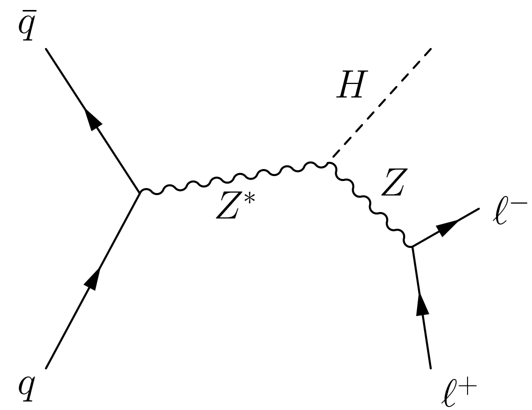
- BR(inv) = σ(W/Z+H) x BR(H->invisible) / σ_{SM}(W/Z+H) < 1.6 @ 95%CL

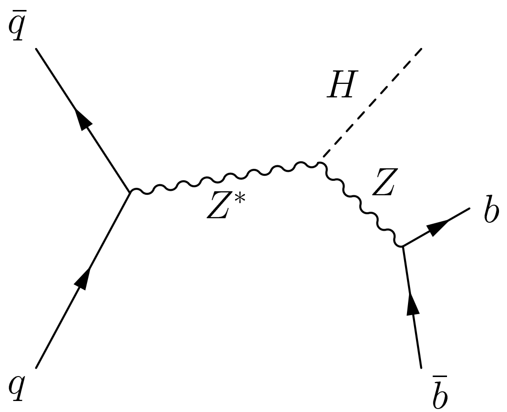


Higgs Invisible Searches

- Current searches for Higgs invisible decay
  - Indirect constraint: BR < 0.13-0.19 [G. Belanger et al arXiv:1306.2941, J. Ellis T. You arXiv:1303.3879, P. Giardino et al arXiv:1303.3570]
  - Direct constraint: ATLAS (arXiv:1402.3244, arXiv:1309.4017) and CMS (arXiv:1404.1344)





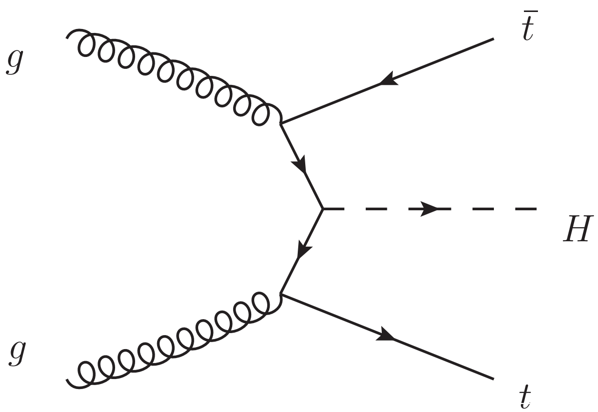


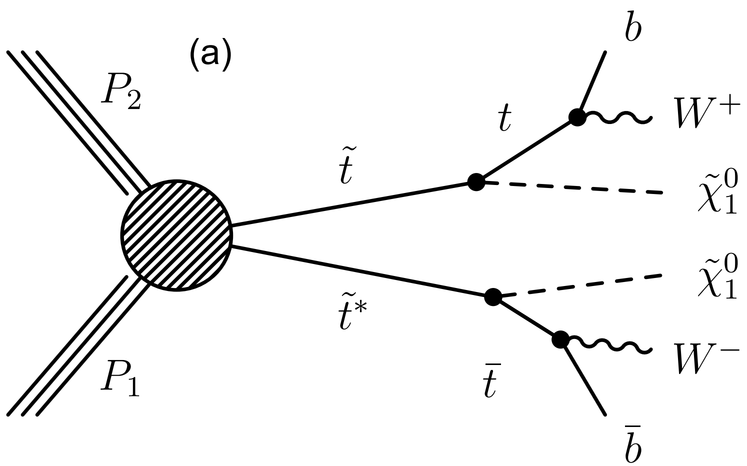
BR limits 95%CL obs (exp) 125 GeV	**VBF H(inv)**	**Z(ll) H(inv)**	**V(jj) H(inv)**
ATLAS	-	0.75 (0.62)	1.6 (2.2)
CMS	0.65 (0.49)	0.81 (0.83)	-

- **ttbarH**
  - **A new searching channel for Higgs invisible decay**
  - **arXiv: 1408.0011**
  - **Accepted by Phys. Rev. Lett. (editors' suggested paper)**

ttbarH

- The SM Higgs has sizeable coupling to top quark
- Higgs invisible decay: Top pair plus MET
  - Similar signature as SUSY stop quark pair production





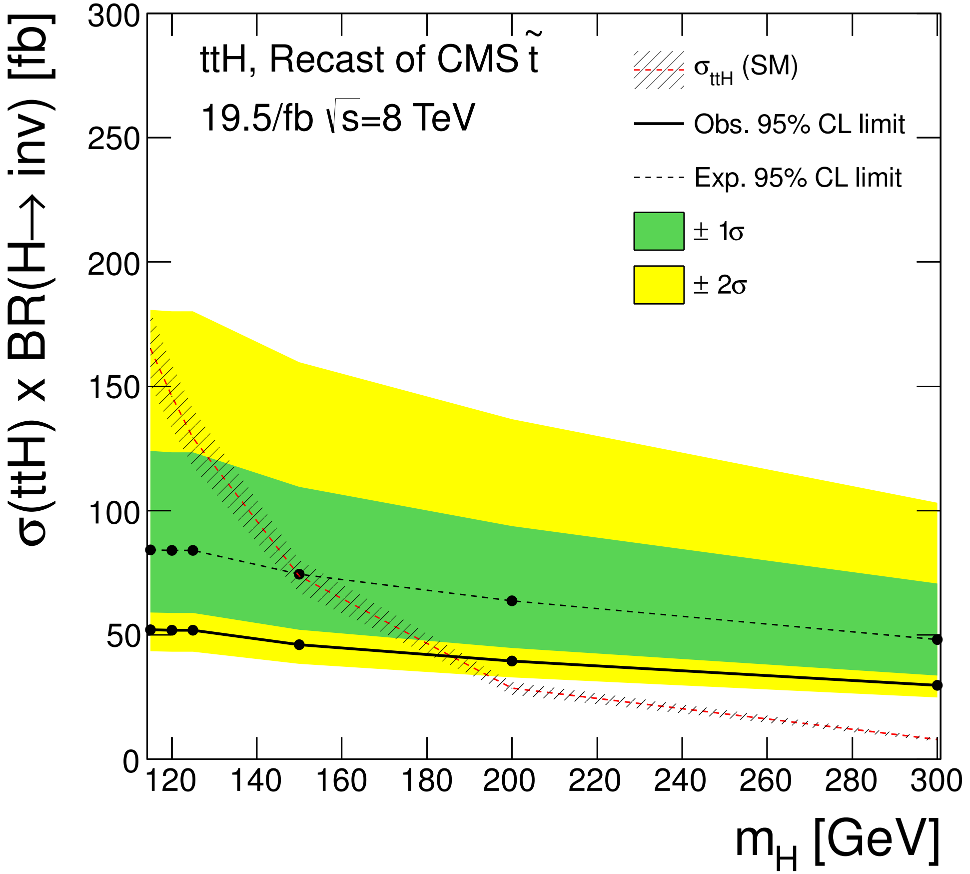
- Idea: re-interpret SUSY direct stop search results as a starting point
- Channels: ttbar semi-leptonic decay
  - Sizable branching ratio
  - Low background

CMS SUSY Stop Search

- CMS (arXiv:1308.1586) has published nice SUSY stop search result in single lepton channel with 8TeV 19.5 fb^{-1} data
  - The CMS cut-based analysis makes the re-interpretation straightforward
  - Dominant backgrounds are ttbar semileptonic and dileptonic decays
- Signal ttbarH:
  - Generation with MADGRAPH5,
  - Showering/hadronization with PYTHIA,
  - Simulation through DELPHES
  - Validation from reproduction of the predicted ttbar background
- We tested all the 16 SRs and found the SR with best expected limit:
  - MET> 250 GeV and the set of cuts for stop->top+LSP with large mass splitting

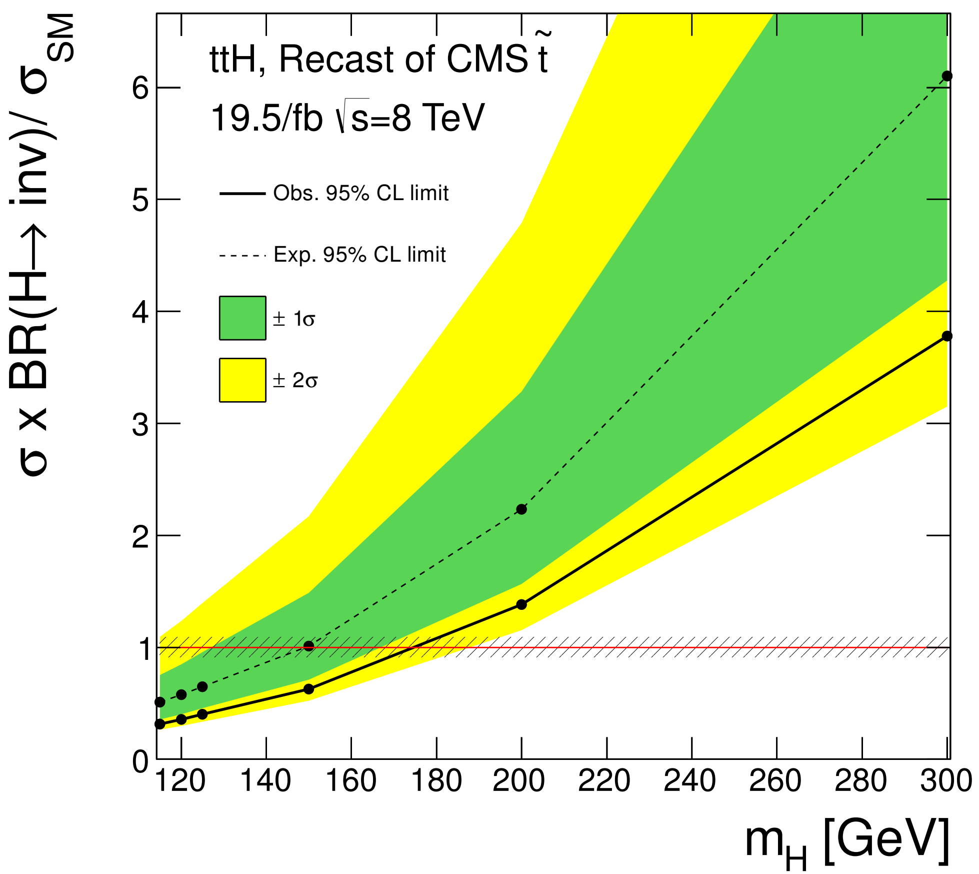
Re-interpret CMS Result

- Data: 3 events and predicted background 9.5 ± 2.8
- The signal (125 GeV Higgs) yield is 11.4 events
  - Assuming 100% inv BR
  - Independent to DM mass below half Higgs mass



Constraints on Higgs Invisible BR

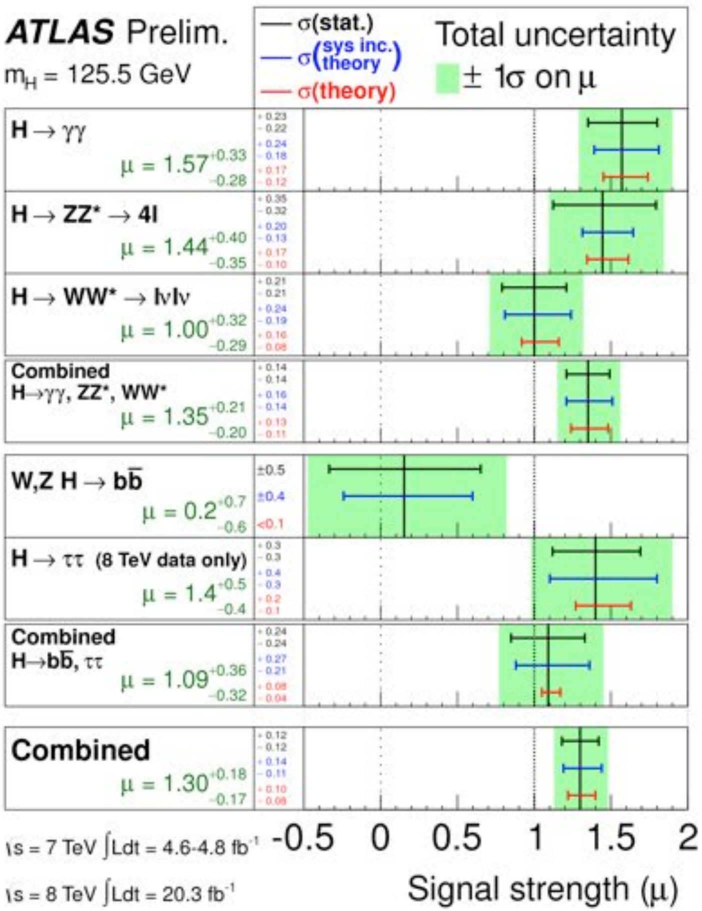
- We set constraints on Higgs invisible BR,
  - Assume SM ttbarH rate
- BR < 0.40 obs (0.65 exp) at 95%CL for Higgs mass 125 GeV



Combination

- We combine all the existing Higgs invisible searches with our ttbarH
- Treat each channel as a simple counting experiment

Exp.	Mode	Dataset	Background	Obs.	Signal
ATLAS [11]	$Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$	7 TeV	25.4 ± 1.9	28	8.9
	$Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$	8 TeV	138 ± 10	152	44
CMS [12]	$Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$	7 TeV	19.7 ± 9.8	19	5.4
		8 TeV	89.0 ± 8.5	82	25.0
	$Zh \to \ell\ell + j + E_{\mathrm{T}}^{\mathrm{miss}}$	7 TeV	5.4 ± 1.6	5	0.9
		8 TeV	24.4 ± 10.0	28	4.1
CMS[12]	$Zh \to bb + E_{\mathrm{T}}^{\mathrm{miss}}$	8 TeV, low p_{T}^{H}	40.5 ± 4.1	38	1.6
		8 TeV, med p_{T}^{H}	64.8 ± 181.3	61	3.6
		8 TeV, high p_{T}^{H}	181.3 ± 9.8	204	12.6
CMS[12]	$qqH \to jj + E_{\mathrm{T}}^{\mathrm{miss}}$	8 TeV	332 ± 58	390	224
CMS recast[18]	$t\bar{t}H \to 1\ell + 4j + E_{\mathrm{T}}^{\mathrm{miss}}$	8 TeV	9.5 ± 2.8	3	11.4



Combination

- Finally we obtain BR < 0.40 obs (0.40 exp) at 95% CL
- Dominated by ttbarH channel

TABLE II: Observed and expected limits at 95%CL on BF($H \to$inv.) in each channel and combinations. Note these are our analysis of the reported results as single-bin experiments, and so in some cases are slightly weaker than the reported results.

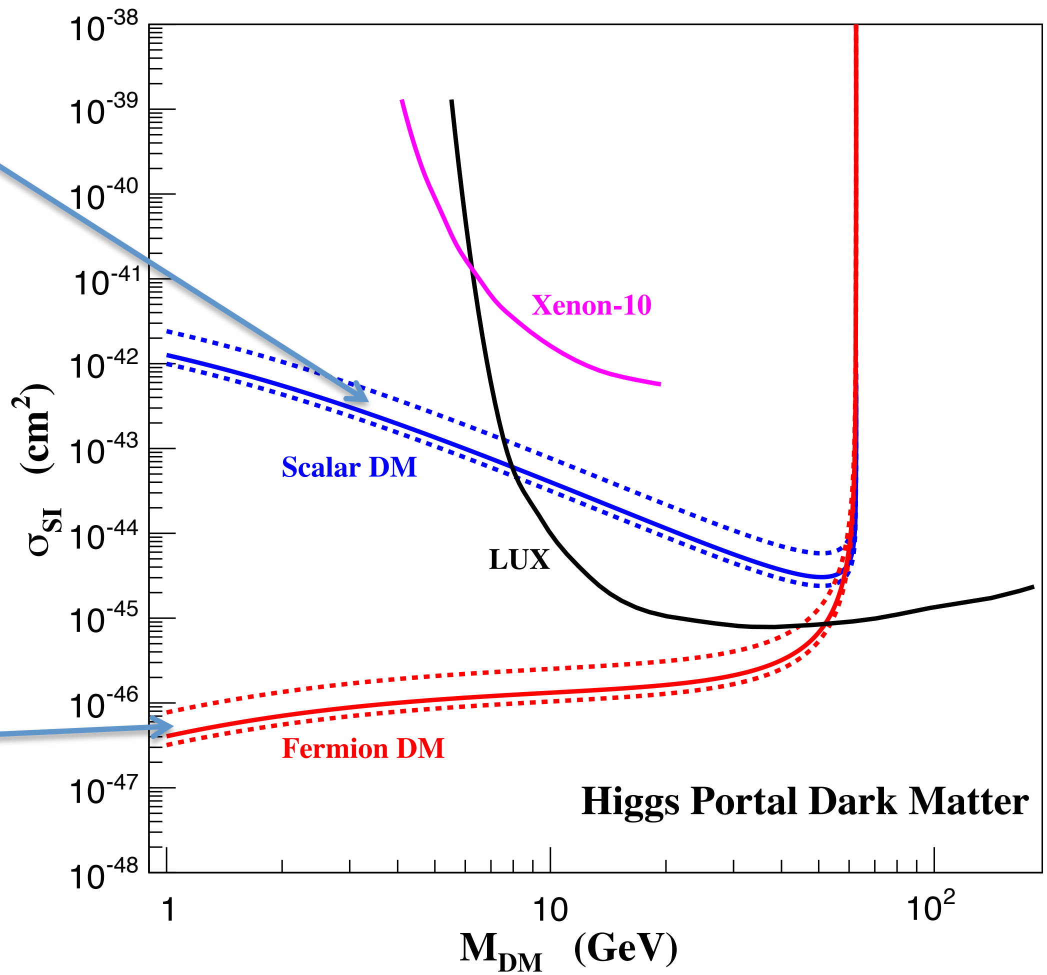
Exp.	Mode	Obs. (Exp.) limit
ATLAS [11]	$Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$	1.04 (0.81)
CMS [12]	$Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$	1.02 (1.19)
CMS [12]	$Zh \to bb + E_{\mathrm{T}}^{\mathrm{miss}}$	3.15 (2.69)
CMS [12]	$qqH \to jj + E_{\mathrm{T}}^{\mathrm{miss}}$	0.76 (0.57)
CMS recast[18]	$t\bar{t}H \to 1\ell 4j + E_{\mathrm{T}}^{\mathrm{miss}}$	0.40 (0.65)
CMS[12, 18]	$qqH + t\bar{t}H$	0.45 (0.47)
All[11, 12]	All but $t\bar{t}H$	0.63 (0.46)
All[11, 12, 18]	All	0.40 (0.40)

Constraints on DM-Nucleon Scattering

- We convert the BR<0.40 into constraints on DM-nucleon spin-independent cross section.

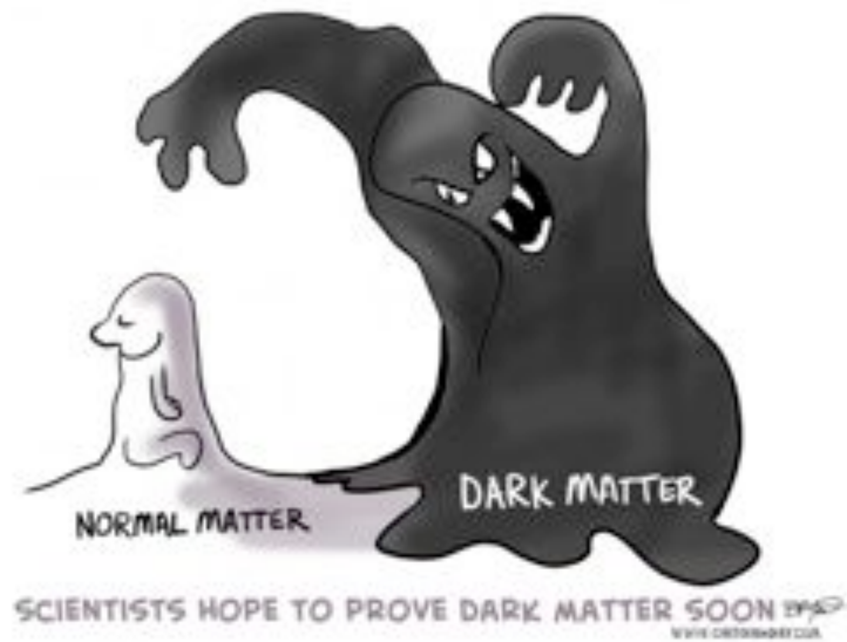
Scalar DM model

Fermion DM model



Summary

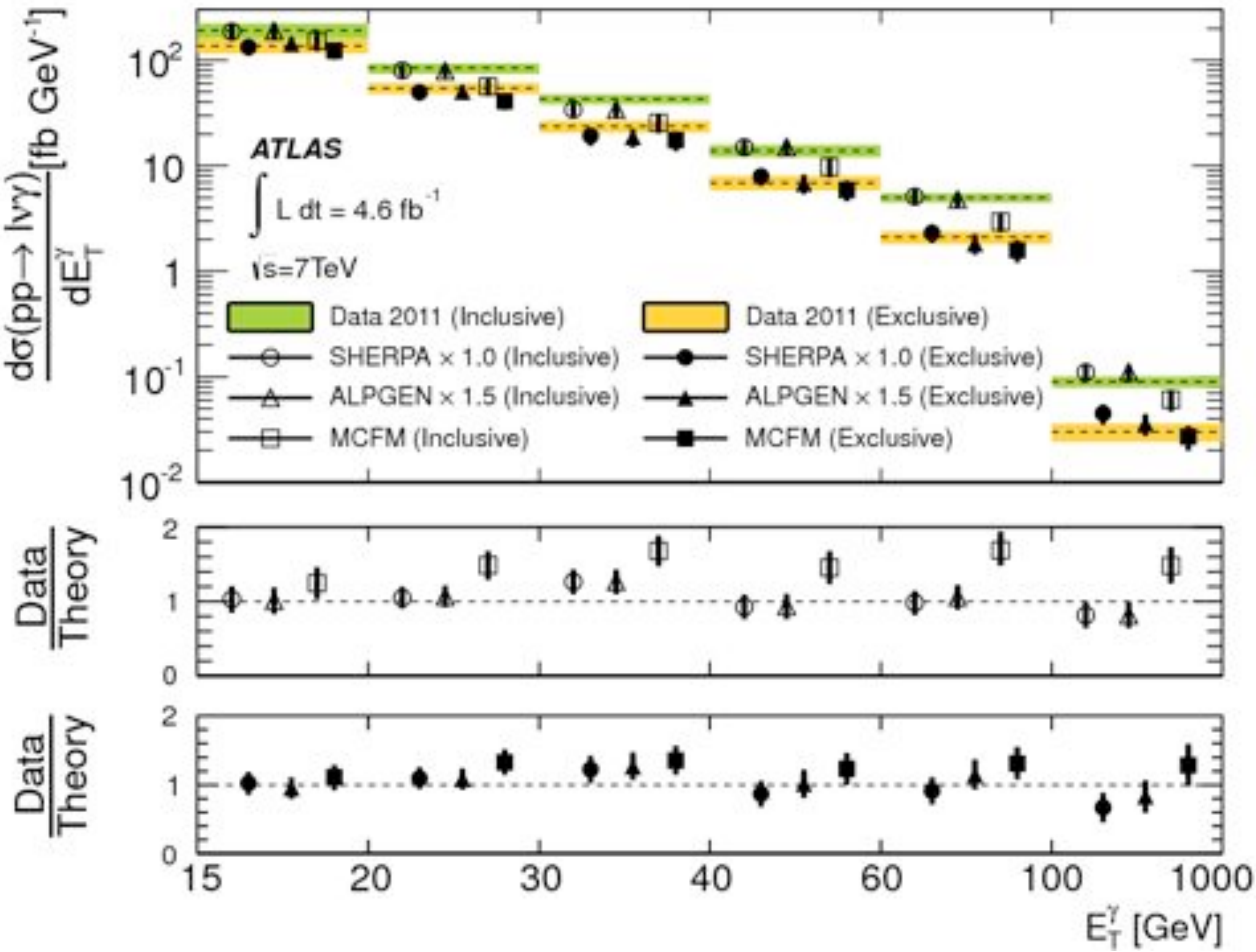
- LHC may be able to produce dark matter and detect it.
- We've performed various signature-based mono-X searches for it.
- From ATLAS Run-I intensive dark matter searches (including SUSY dark matter candidates), we have not discovered a dark matter candidate yet.
- Let's continue with LHC Run-II data!



Backup

W+γ Measurement

-



Z+γ Measurement

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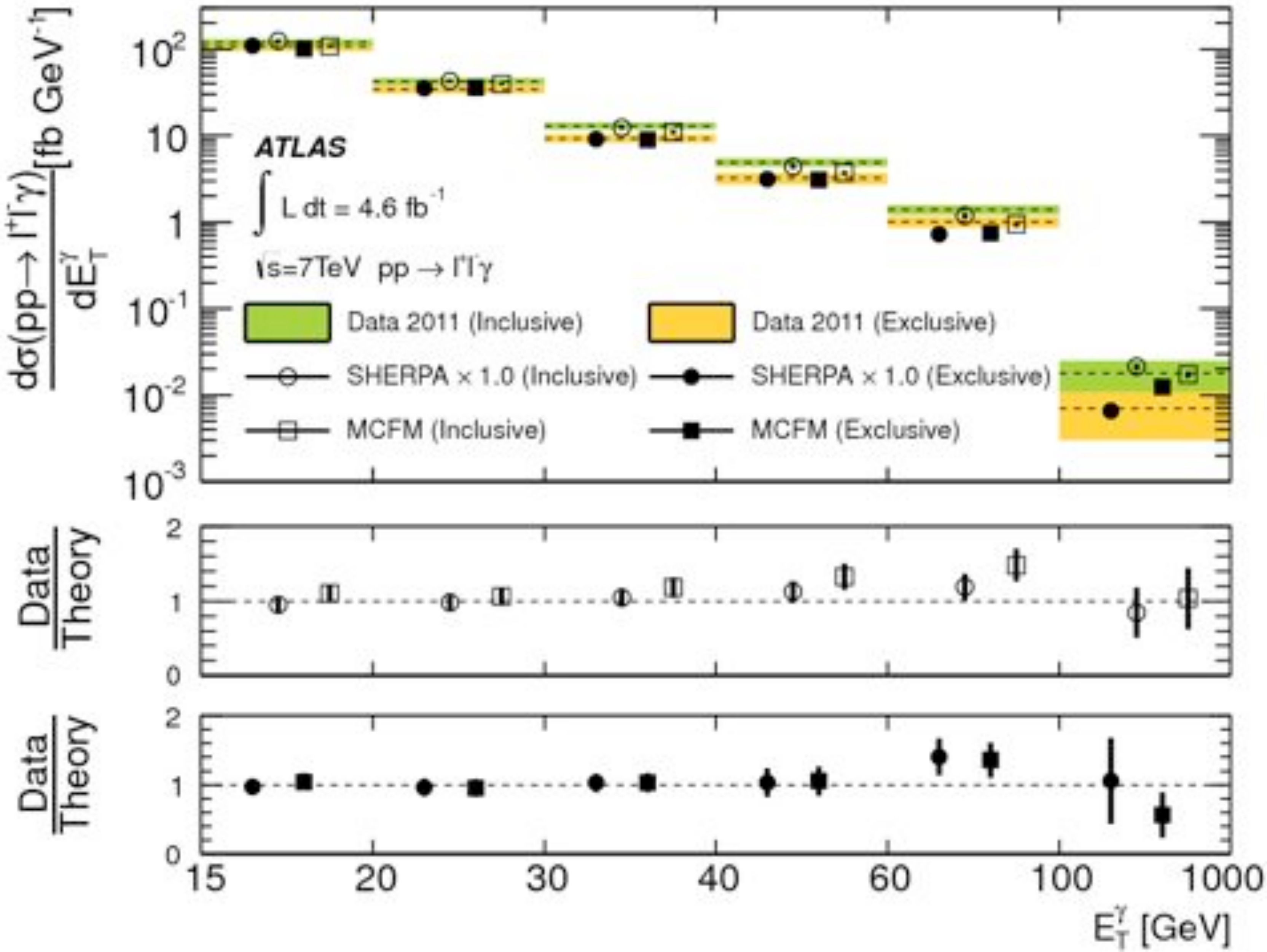

Mono-W/Z Constraints

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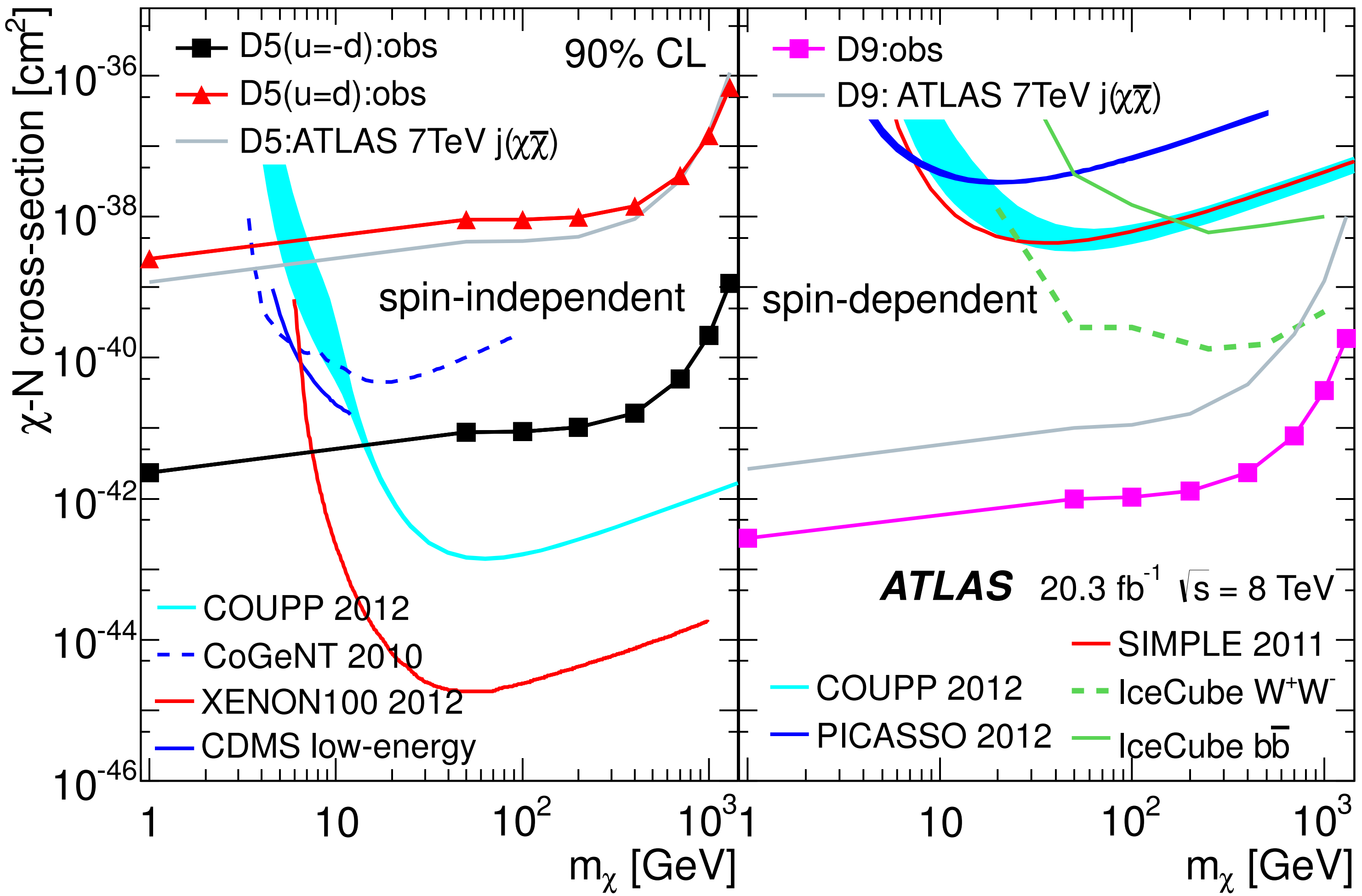


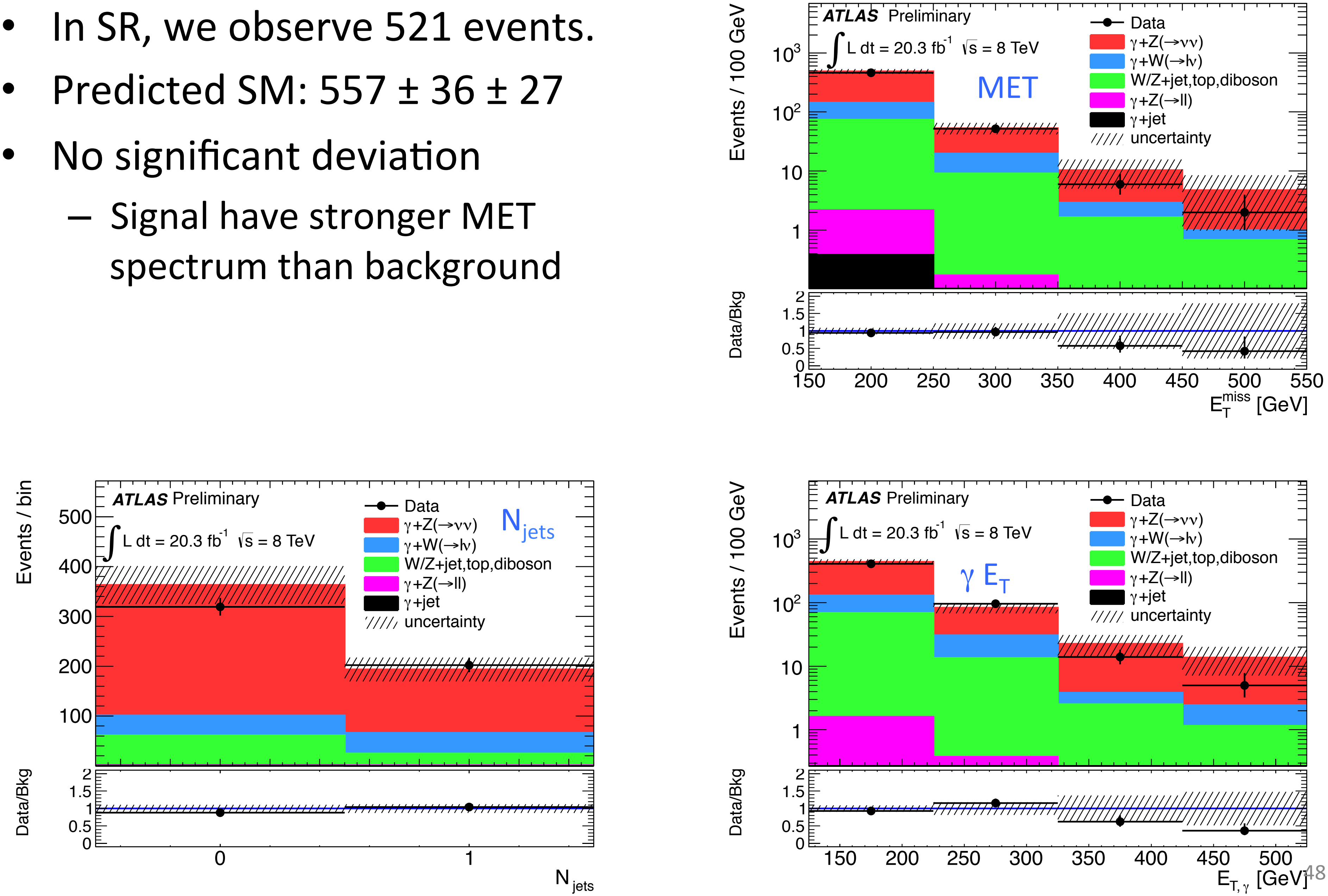
Systematic Uncertainties

- Various systematic uncertainties are suppressed in the simultaneous fit
- The CR statistics gives the largest systematic uncertainties

[% of total bkg from CR fit]	SR
electron fake rate	4.6
electron efficiency	1.3
muon efficiency	0.7
egamma energy scale	0.6
egamma energy resolution	~0.1
photon isolation	~0.1
photon efficiency	~0.1
jet fake rate	0.1
JES	0.1
JER	0.5
MET SoftTerms	0.3
PDF/scale	0.7
trigger, lumi, MET pileup	< 0.1
statistical uncertainty	**~6**

Signal Region

- In SR, we observe 521 events.
- Predicted SM: 557 ± 36 ± 27
- No significant deviation
  - Signal have stronger MET spectrum than background

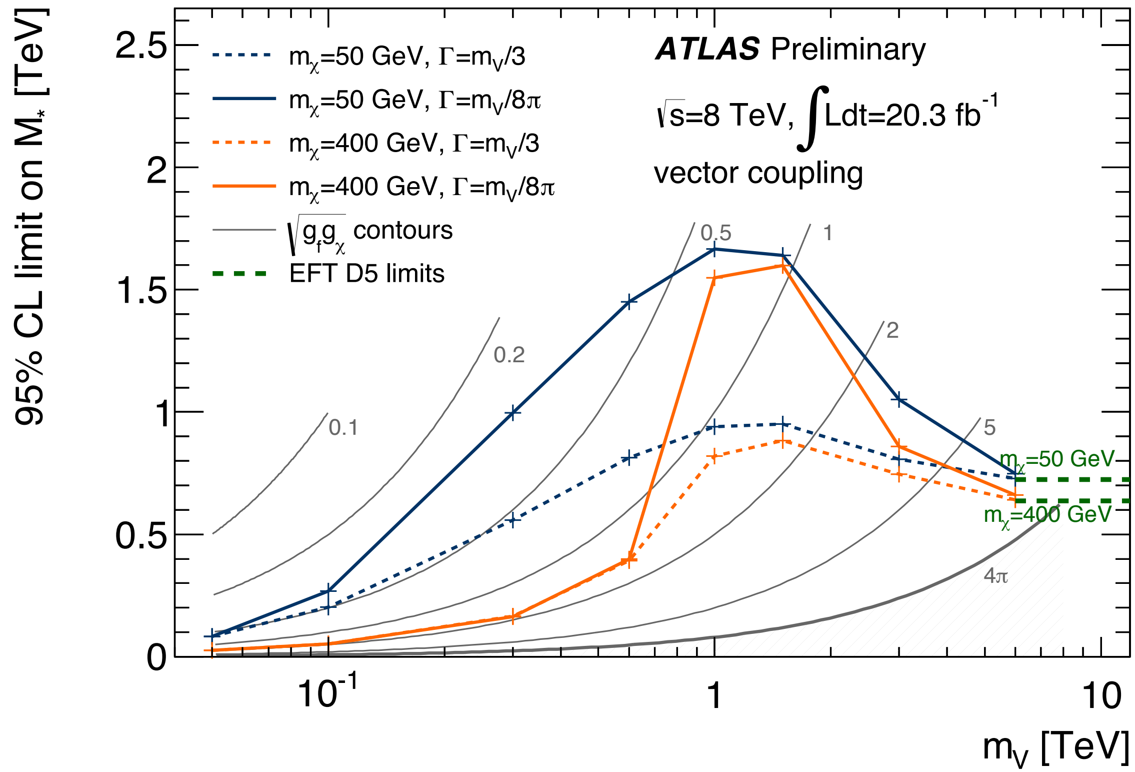


Simplified Model vs EFT

- When m_V goes beyond the LHC reach, this Z'-like simplified model can be approximated by EFT approach.

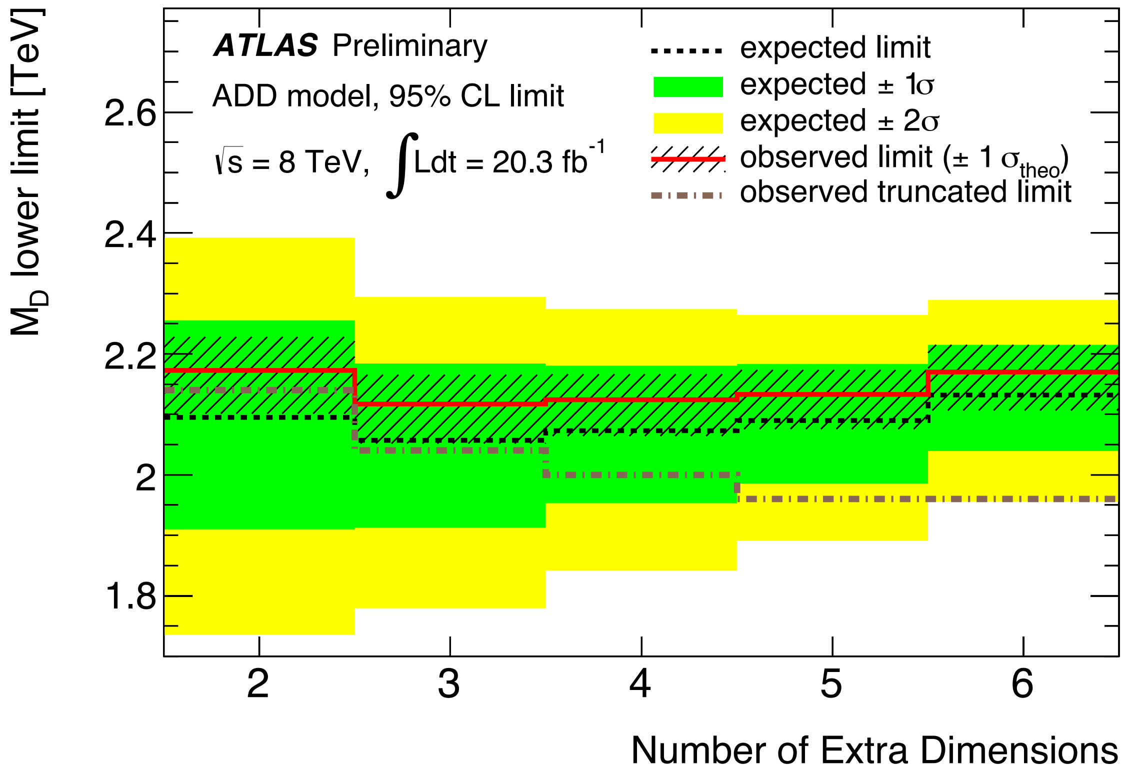
$$\frac{g_f^2 g_\chi^2}{(Q_{tr}^2 - m_V^2)^2} \xrightarrow{Q_{tr} << m_V} \frac{g_f^2 g_\chi^2}{m_V^4} = \frac{1}{M_*^4} \qquad M_* = m_V / \sqrt{g_f g_\chi}$$

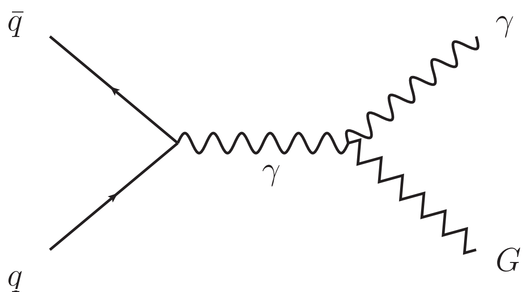
- Z'-like simplified model has resonant enhancement



ADD Model

- Model of large extra spatial dimension
  - To solve the hierarchy problem with *n* additional dimensions and new fundamental scale M_D
- EFT: we also test the effect of suppressing events with interaction energy above M_D





CMS SUSY Stop Search

- CMS (arXiv:1308.1586) has published nice SUSY stop search result in single lepton channel with 8TeV 19.5 fb^{-1} data
  - The CMS cut-based analysis makes the re-interpretation straightforward
- 16 SRs (overlapped) were defined, optimized for various stop decay scenarios

Table 1: Summary of the variables used as inputs for the BDTs and of the kinematic requirements in the cut-based analysis. All signal regions include the requirement $M_T > 120$ GeV. For the $\widetilde{t} \to t\widetilde{\chi}_1^0$ BDT trained in the region where the top quark is off-shell, the hadronic top χ^2 is not included and the leading b-tagged jet p_T is included. The lepton p_T is used only in the training of the $\widetilde{t} \to b\widetilde{\chi}^+$ BDT in the case where the W boson is off-shell.

	$\widetilde{t} \to t\widetilde{\chi}_1^0$			$\widetilde{t} \to b\widetilde{\chi}^+$		
		Cut-based			Cut-based	
Selection	BDT	Low ΔM	High ΔM	BDT	Low ΔM	High ΔM
E_T^{miss} (GeV)	yes	$>$ 150, 200, 250, 300	$>$ 150, 200, 250, 300	yes	$>$ 100, 150, 200, 250	$>$ 100, 150, 200, 250
M_{T2}^W (GeV)	yes		$>$200	yes		$>$200
min $\Delta\phi$	yes	$>$0.8	$>$0.8	yes	$>$0.8	$>$0.8
H_T^{ratio}	yes			yes		
Hadronic top χ^2	(on-shell top)	$<$5	$<$5			
Leading b-tagged jet p_T (GeV)	(off-shell top)			yes		$>$100
$\Delta R(\ell$,leading b-tagged jet)				yes		
Lepton p_T (GeV)				(off shell W)		

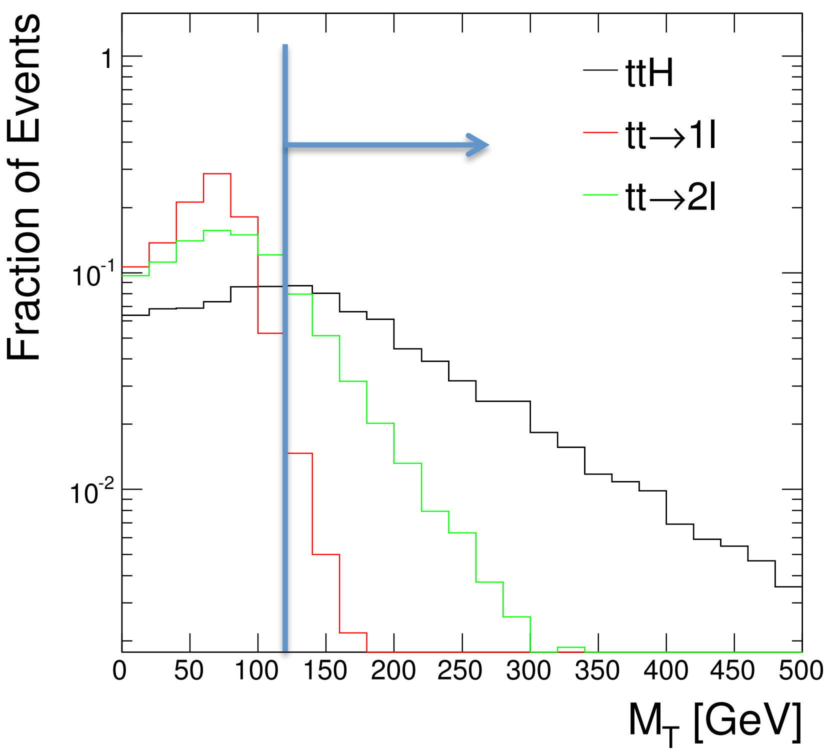
CMS SUSY Stop Search

- CMS (arXiv:1308.1586) has published nice SUSY stop search result in single lepton channel with 8TeV 19.5 fb^{-1} data
  - The CMS cut-based analysis makes the re-interpretation straightforward
- 16 SRs (overlapped) were defined, optimized for various stop decay scenarios
  - Exactly one electron or muon
  - At least three jets (at least one b-tagged)
  - MET: 100, 150, 200, 250, 300 GeV
  - M_T>120 GeV: transverse mass of lepton and MET system
  - $\min(\Delta\phi(MET,jet))>0.8$: the minimum angle between MET and any jet
  - $\chi^2_{had}<5$: the compatibility of a triplet of jets with t->Wb->qqb hypothesis
  - M_{T2}^W >200 GeV: the minimal particle mass compatible with ttbar topology
- Dominant backgrounds are ttbar semileptonic and dileptonic decays

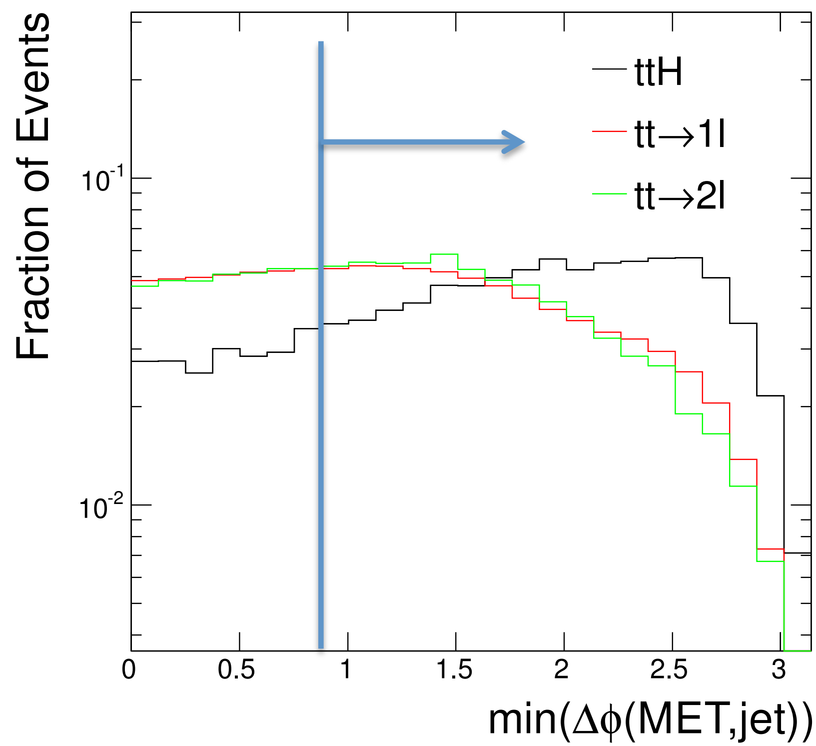
Kinematic Distribution

- Signal ttbarH:
  - Generation with MADGRAPH5,
  - Showering/hadronization with PYTHIA,
  - Simulation through DELPHES
- Validation from reproduction of the predicted ttbar background

transverse mass of lepton and MET



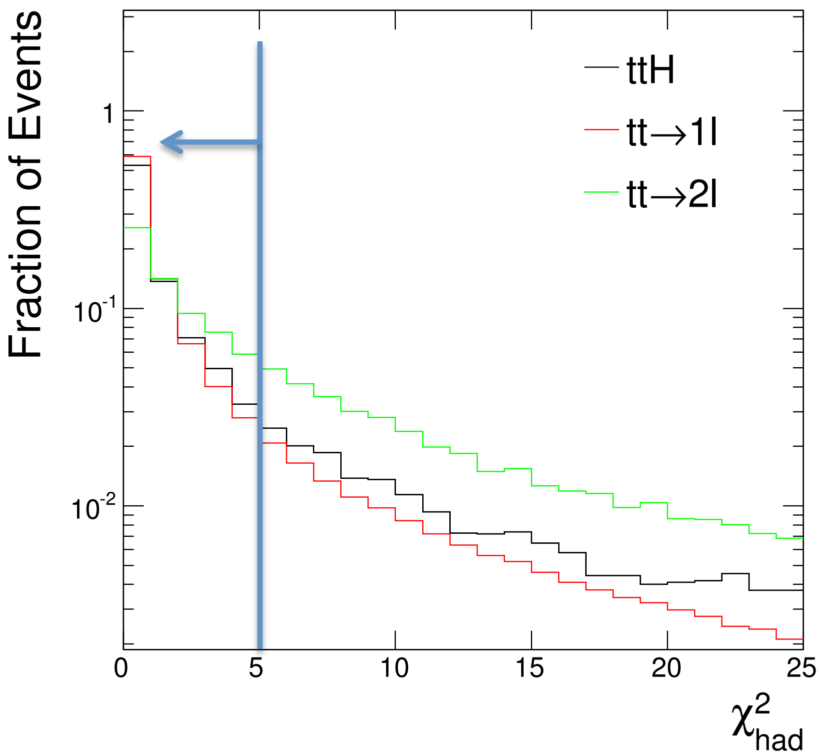
minimum angle between MET and any jet



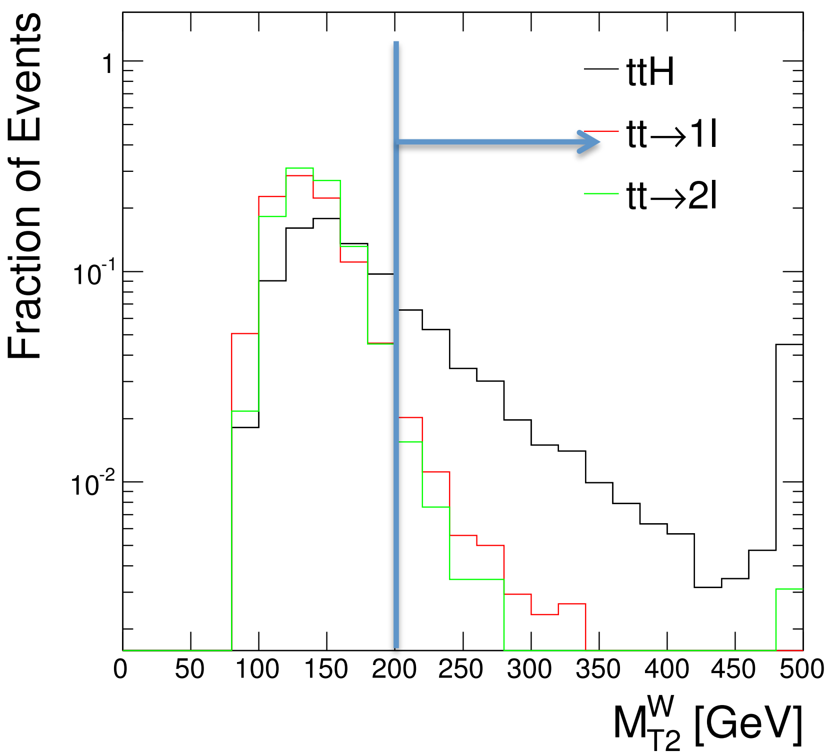
Kinematic Distribution

- All of these kinematic variables provide good ttbarH and background discrimination.
- Some further optimizations on the cut threshold etc are still possible.

the compatibility of a triplet of jets with t->Wb->qqb hypothesis



the minimal particle mass compatible with ttbar topology



CMS Signal Region Yield

- Data and background yields with uncertainties.

Table 4: The result of the $\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ cut-based analysis. For each signal region the individual background contributions, total background, and observed yields are indicated. The uncertainty includes both the statistical and systematic components. The expected yields for two example signal models are also indicated (statistical uncertainties only). The first and second numbers in parentheses indicate the top-squark and neutralino masses, respectively, in GeV.

Sample	$E_T^{miss} > 150$ GeV	$E_T^{miss} > 200$ GeV	$E_T^{miss} > 250$ GeV	$E_T^{miss} > 300$ GeV
		Low ΔM Selection		
$t\bar{t} \rightarrow \ell\ell$	131 ± 15	42 ± 7	17 ± 5	5.6 ± 2.5
1ℓ top	94 ± 47	30 ± 19	9 ± 6	3.1 ± 2.4
W + jets	10 ± 3	5 ± 1	2 ± 1	1.0 ± 0.4
Rare	16 ± 8	7 ± 4	4 ± 2	1.8 ± 0.9
Total	251 ± 50	83 ± 21	31 ± 8	11.5 ± 3.6
Data	227	69	21	9
$\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ (250/50)	108 ± 3.7	32 ± 2.0	12 ± 1.2	5.2 ± 0.8
$\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ (650/50)	8.0 ± 0.1	7.2 ± 0.1	6.2 ± 0.1	4.9 ± 0.1
		High ΔM Selection		
$t\bar{t} \rightarrow \ell\ell$	8 ± 2	5 ± 2	3.2 ± 1.4	1.4 ± 0.9
1ℓ top	13 ± 6	6 ± 4	3.0 ± 2.2	1.4 ± 1.0
W + jets	4 ± 1	2 ± 1	1.5 ± 0.5	0.9 ± 0.3
Rare	4 ± 2	3 ± 1	1.8 ± 0.9	1.0 ± 0.5
Total	29 ± 7	17 ± 5	9.5 ± 2.8	4.7 ± 1.4
Data	23	11	3	2
$\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ (250/50)	10 ± 1.1	4.6 ± 0.8	2.3 ± 0.5	1.4 ± 0.4
$\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ (650/50)	4.9 ± 0.1	4.7 ± 0.1	4.3 ± 0.1	3.7 ± 0.1