

Searches for Dark Matter production with ATLAS (MET+X)

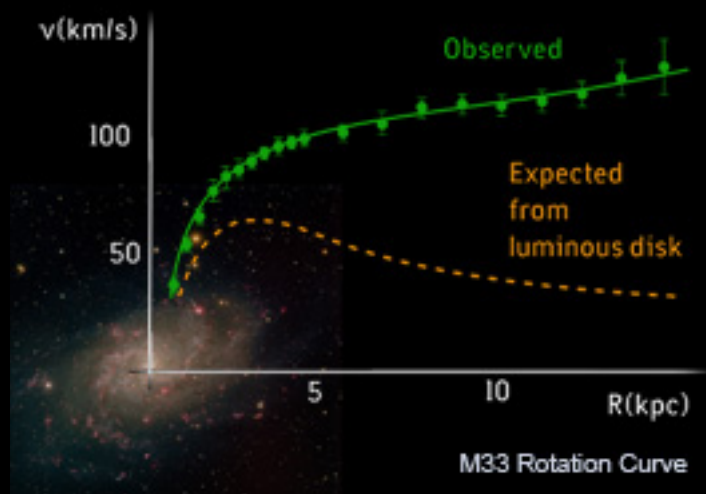
LHCP, Lund

Ruth Pöttgen, on behalf of the ATLAS Collaboration

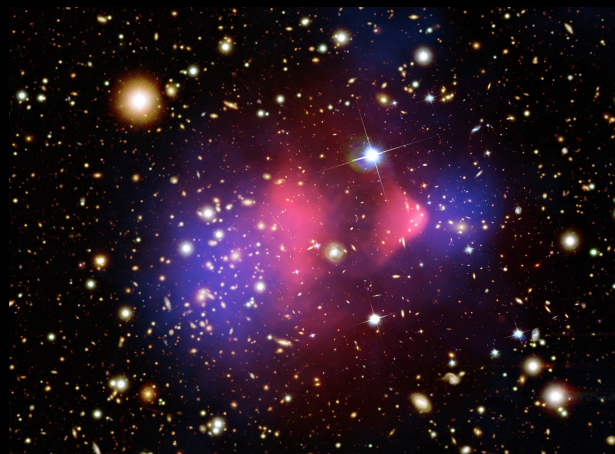
17 June 2016

Why Dark Matter?

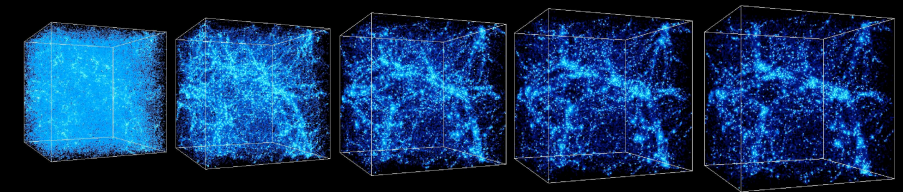
rotation velocity curves
of stars in galaxies



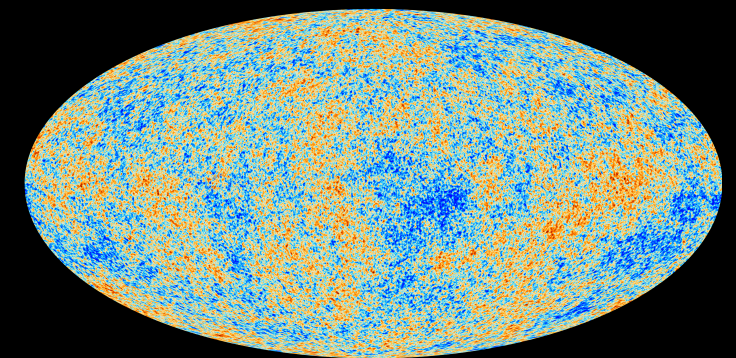
galaxy clusters



structure formation



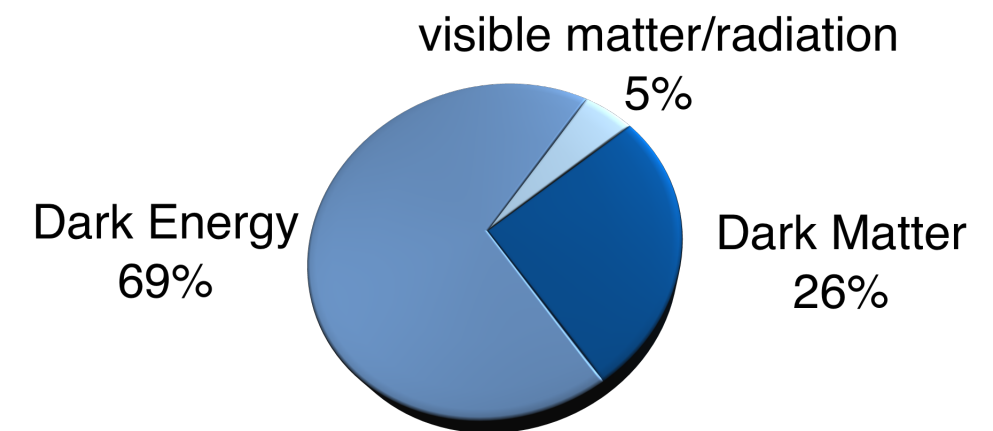
cosmic microwave background



- ▶ compelling **evidence** for existence of non-luminous matter on largely different **cosmological** scales

=> "**Dark Matter**"

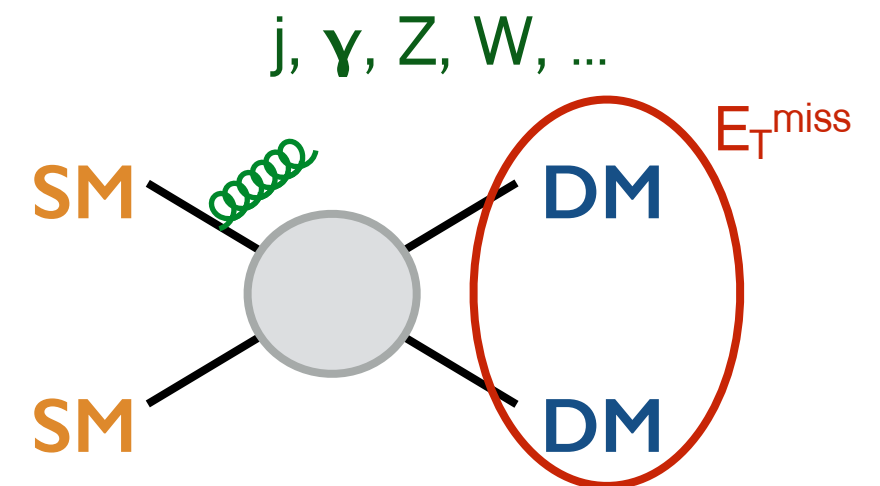
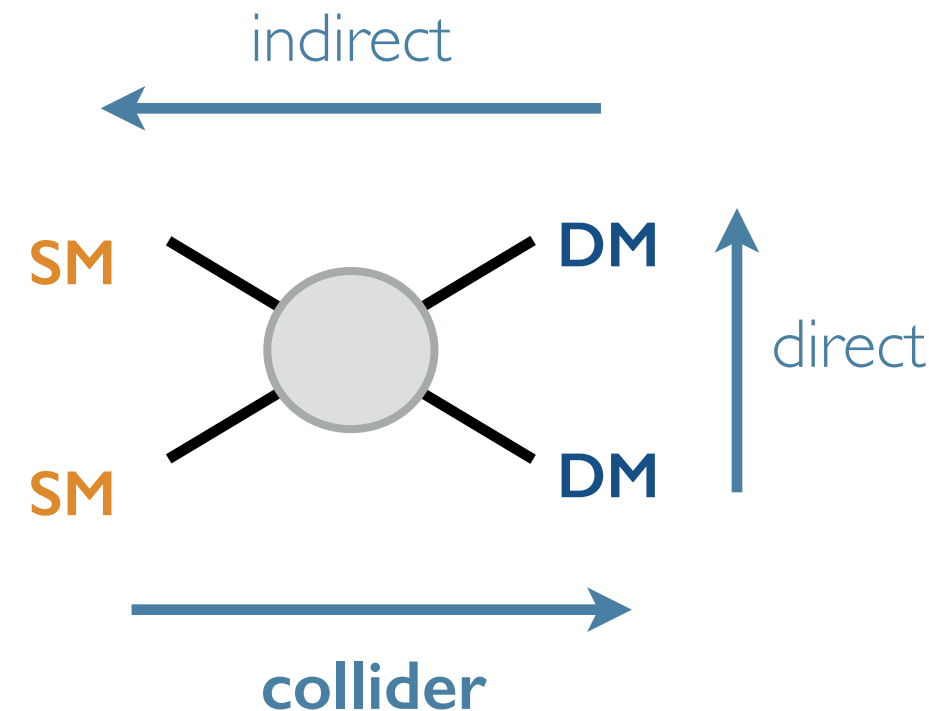
- ▶ **~1/4** of the universe's matter-energy budget
 - ▶ ~5 times as much as 'normal' matter



Planck result

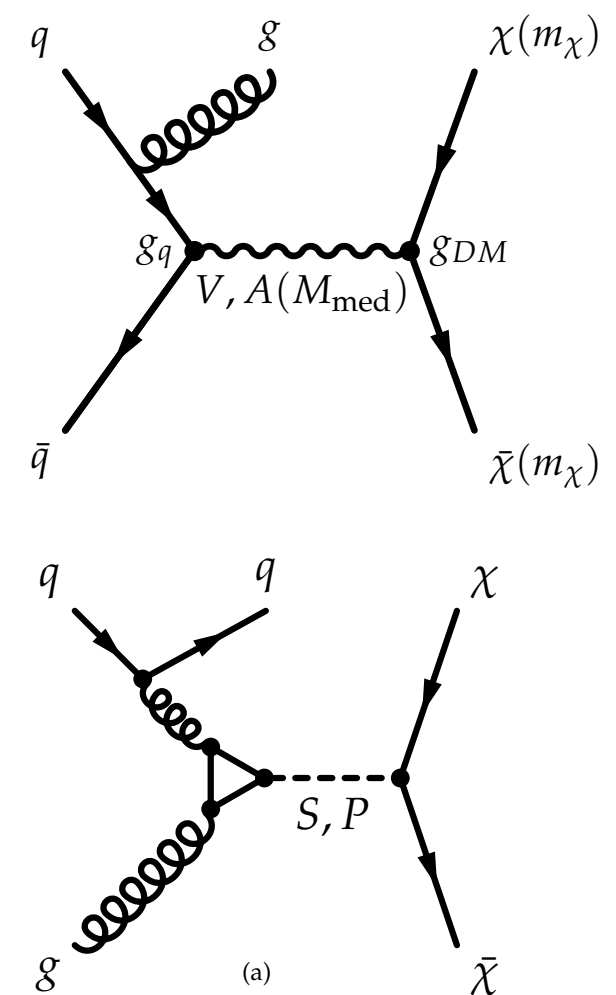
Dark Matter Searches

- ▶ **no viable candidate** within Standard Model (SM)
- ▶ popular generic class of new particles:
weakly interacting massive particles (**WIMPs**)
 - ▶ broad search programme, mainly 3 approaches
 - ▶ **interacting** = interacting non-gravitationally
 - ▶ **weakly** interacting
 - > escape collider experiment undetected
 - ▶ **additional** (high p_T) object to **trigger** on
 - ▶ missing transverse energy (E_T^{miss})
from recoiling WIMPs
 - ▶ => "mono-X" searches
 - ▶ **massive** —> can account for relic density



Models

- ▶ LHC Run-1: “traditional” effective field theory (**EFT**) approach
 - ▶ assume mediator too heavy to be produced
 - ▶ 2 parameters: WIMP mass (m_χ) & suppression scale (M^*)
 - ▶ some comparisons to simplified models
- ▶ for Run-2: benchmark **simplified models** (where possible)
 - ▶ provide basis for re-interpretations (distinct kinematics)
 - ▶ collected by **ATLAS/CMS DM forum**
(now LHC DM working group)
 - ▶ Dirac-fermionic WIMPs
 - ▶ mostly 4 parameters:
 - ▶ mediator mass (M_{Med})
 - ▶ WIMP mass (m_χ)
 - ▶ 2 couplings (g_{DM}, g_q), **typically (1, 0.25)**
 - ▶ different types of mediators, minimal width



Models

- ▶ LHC Run-1: “traditional” effective field theory (**EFT**) approach

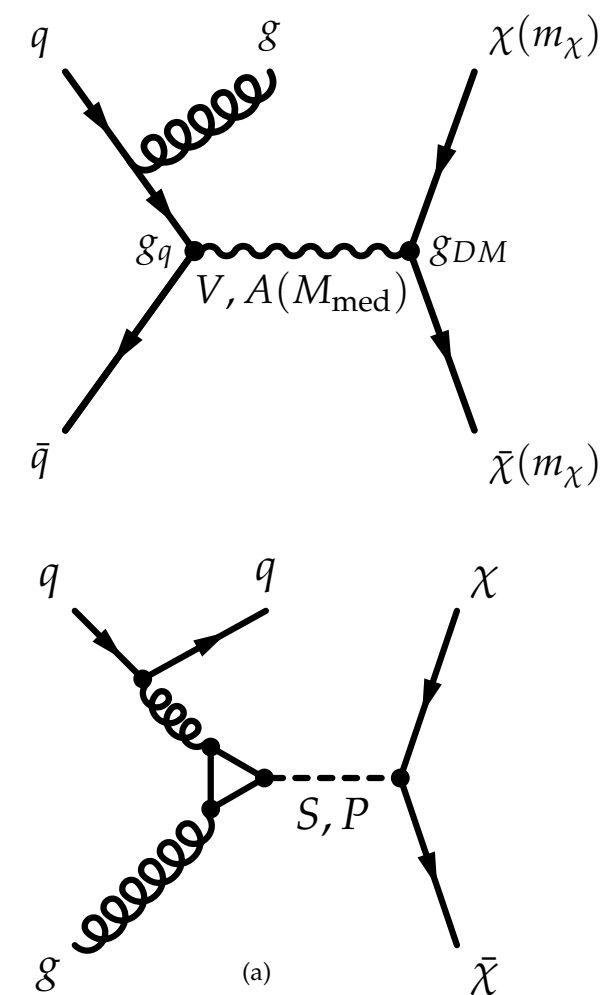
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VALIDITY @ LHC?

- ▶ for Run-2: benchmark **simplified models** (where possible)

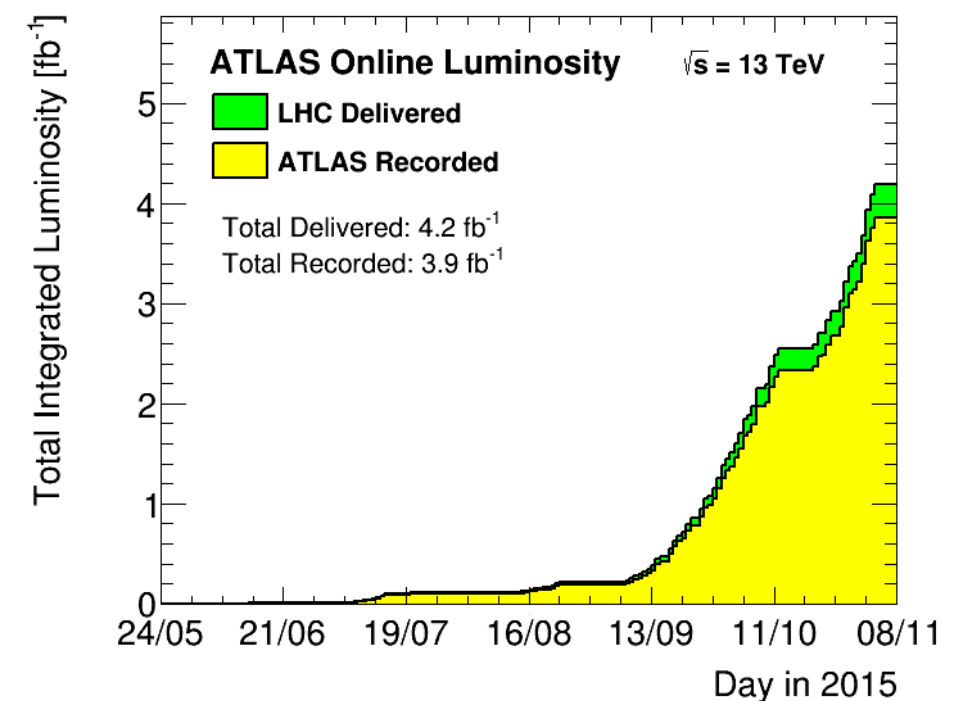
- ▶ provide basis for re-interpretations (distinct kinematics)
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- ▶ different types of mediators, minimal width



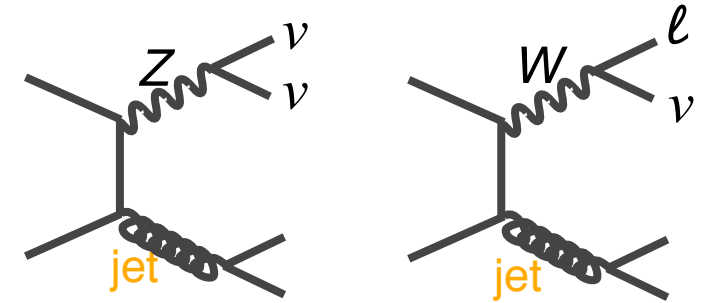
General Remarks

- main challenge: **estimation of irreducible/dominant backgrounds**
 - **control regions** (CR) in **data**
 - in most cases “global fit” to all CRs simultaneously
- sub-dominant backgrounds often taken from **MC**
 - typical exceptions: multi-jet and non-collision background (data-driven)
- in most cases E_T^{miss} as **discriminant** variable
 - **search for excess** in different regions of high E_T^{miss}
 - if no excess: **limits** on model parameters
- all results based on **full 2015 data set**,
i.e. **3.2/fb @ $\sqrt{s}=13$ TeV**
- data taking efficiency: 93%



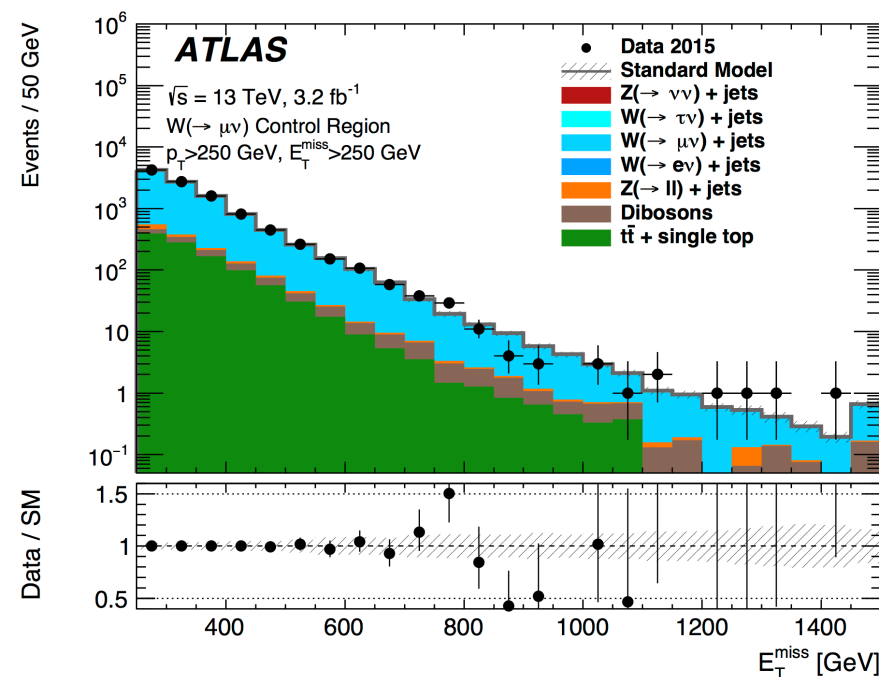
- ▶ $E_T^{\text{miss}} > 250$ GeV (trigger: 70 GeV)
- ▶ leading jet: $p_T > 250$ GeV
- ▶ ≤ 3 additional jets with $p_T > 30$ GeV
- ▶ $\Delta\phi(E_T^{\text{miss}}, \text{jets}) > 0.4$ (suppress multijet)

dominant
backgrounds:
Z($\nu\nu$)+jets
W(lv)+jets



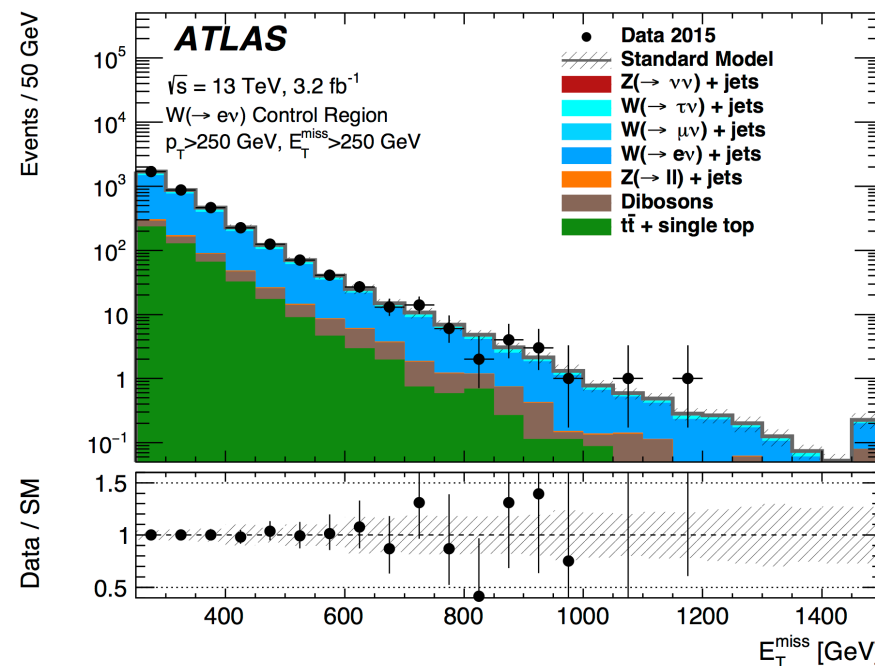
W($\mu\nu$)+jets CR

- ▶ 1 muon, 0 electrons
- ▶ m_T in [30, 100] GeV



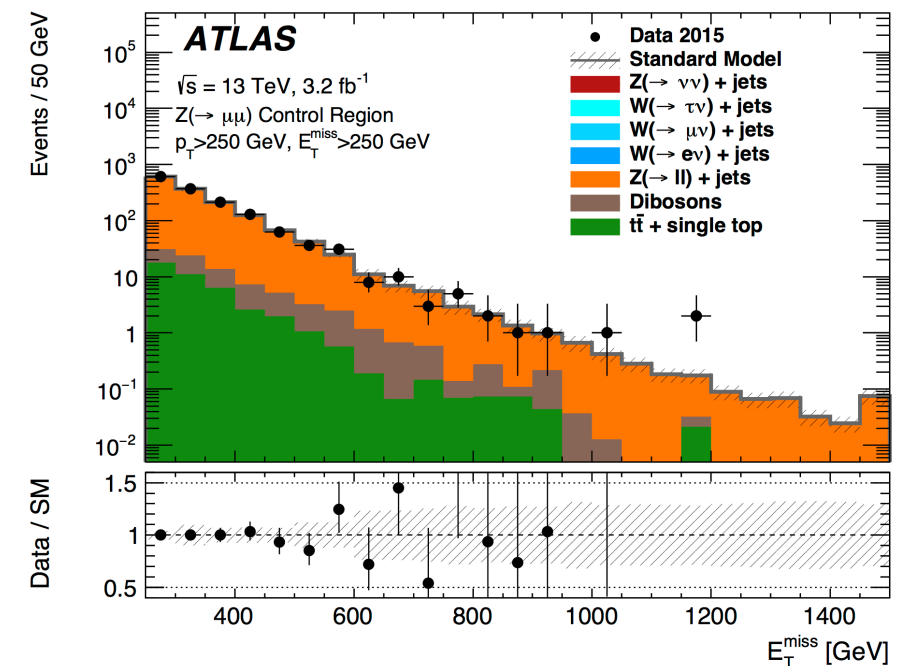
W(e ν)+jets CR

- ▶ 1 electron, 0 muons



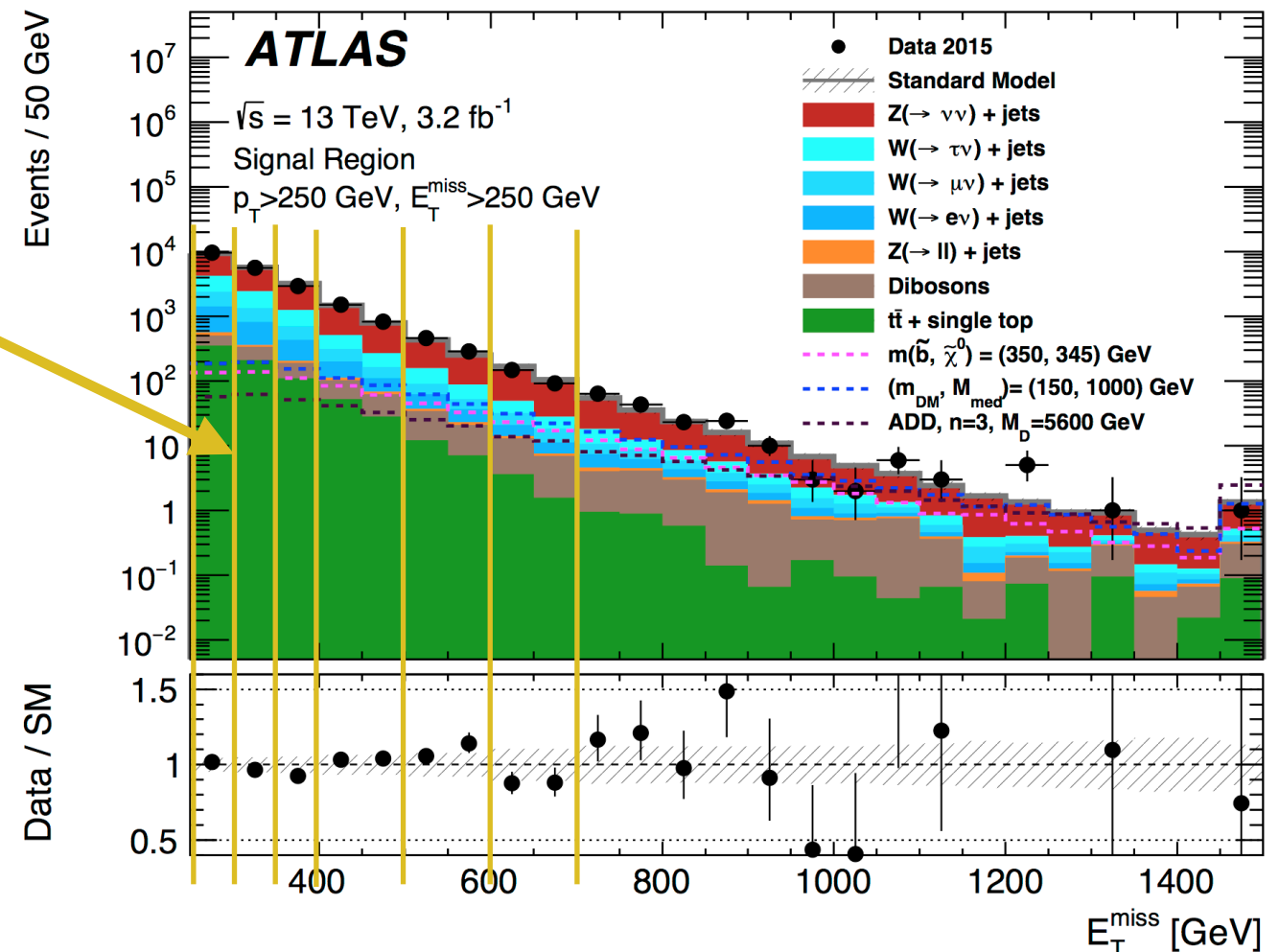
Z($\mu\mu$)+jets CR

- ▶ 2 muons
- ▶ m_{ll} in [66, 116] GeV



▶ good **agreement** in CRs \rightarrow confidence in background modelling

- ▶ **SRs:** muon and electron **veto**
 - ▶ inclusive and exclusive in E_T^{miss}
- ▶ largest uncertainties:
 - ▶ W/Z transfer: 2-4%
 - ▶ data statistics in CRs: up to 10%
 - ▶ theory uncertainties on top: 3%

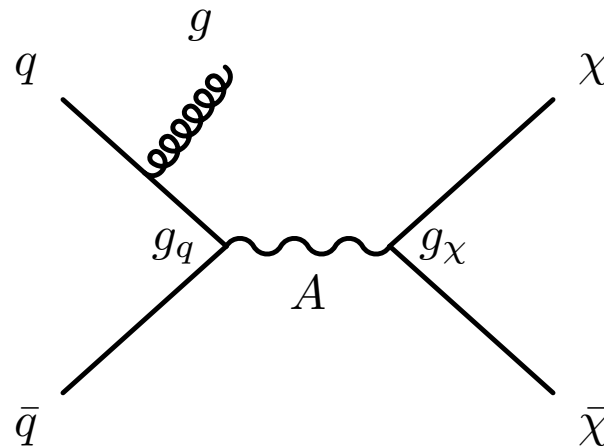


no significant excess

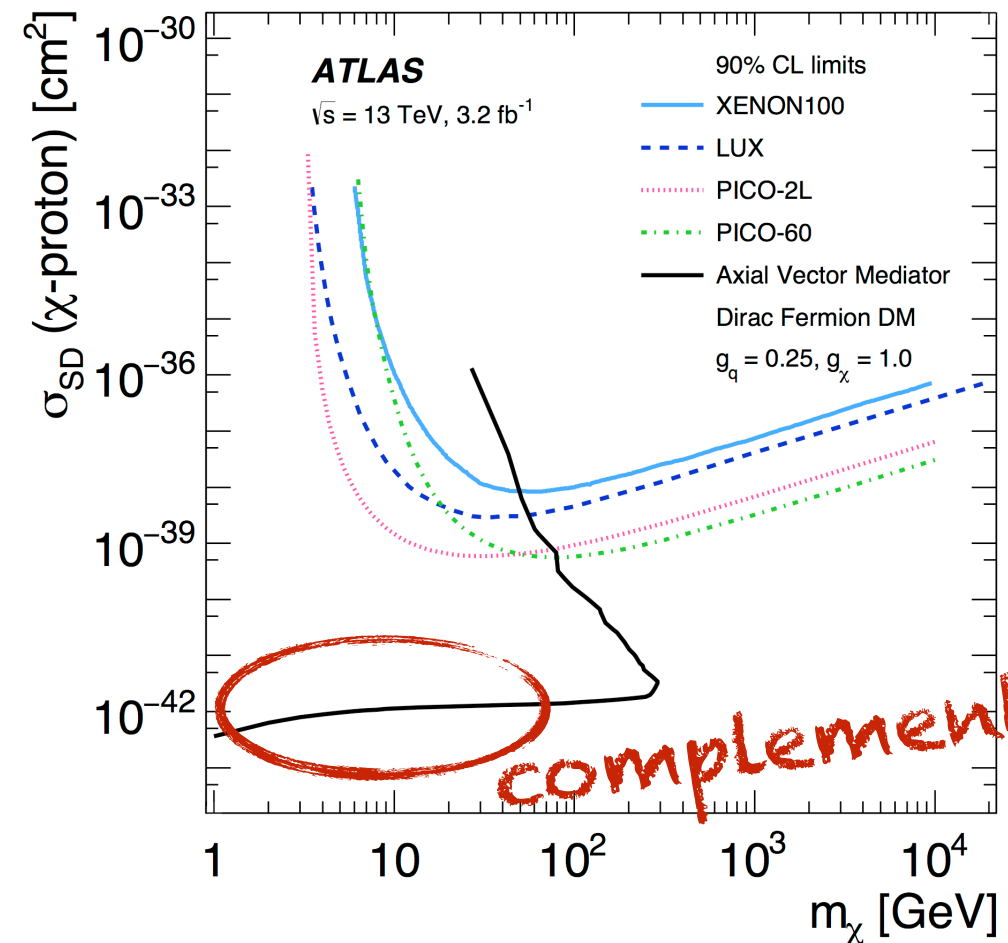
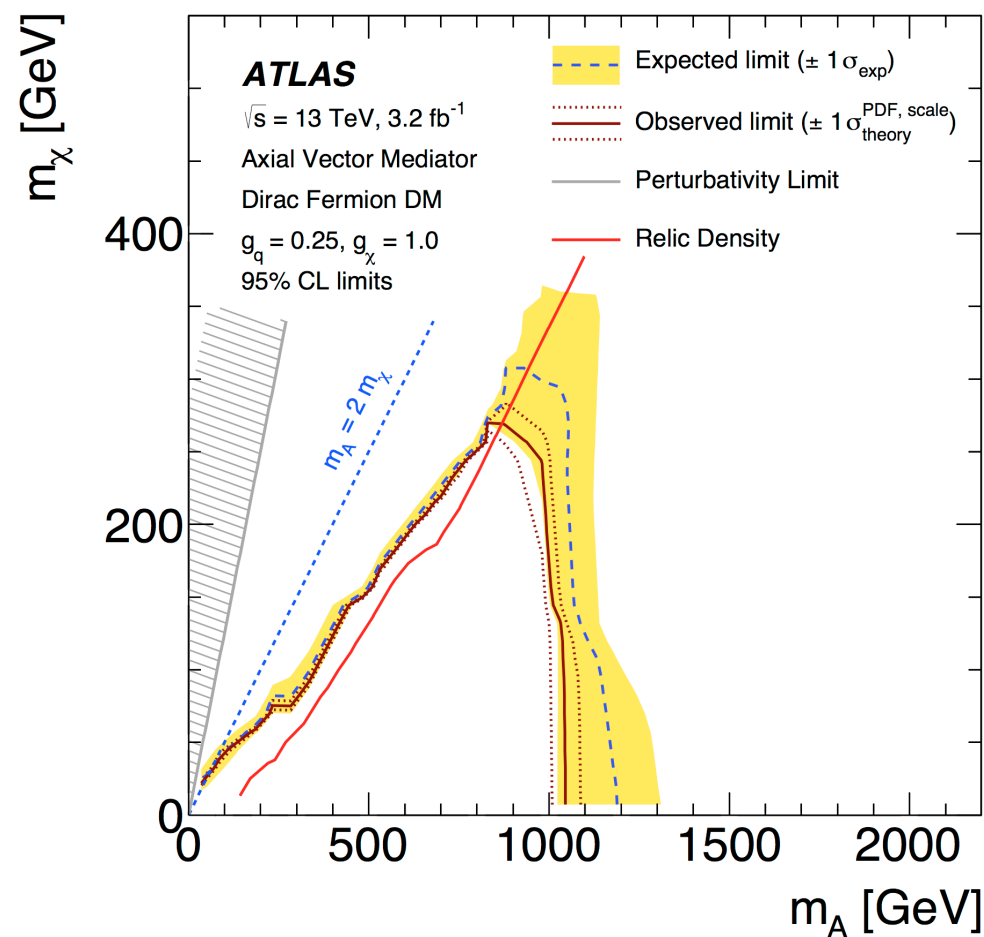
- ▶ inclusive regions for model independent limits
- ▶ exclusive regions (=bins) for limits on DM model

- axial-vector mediator (A)

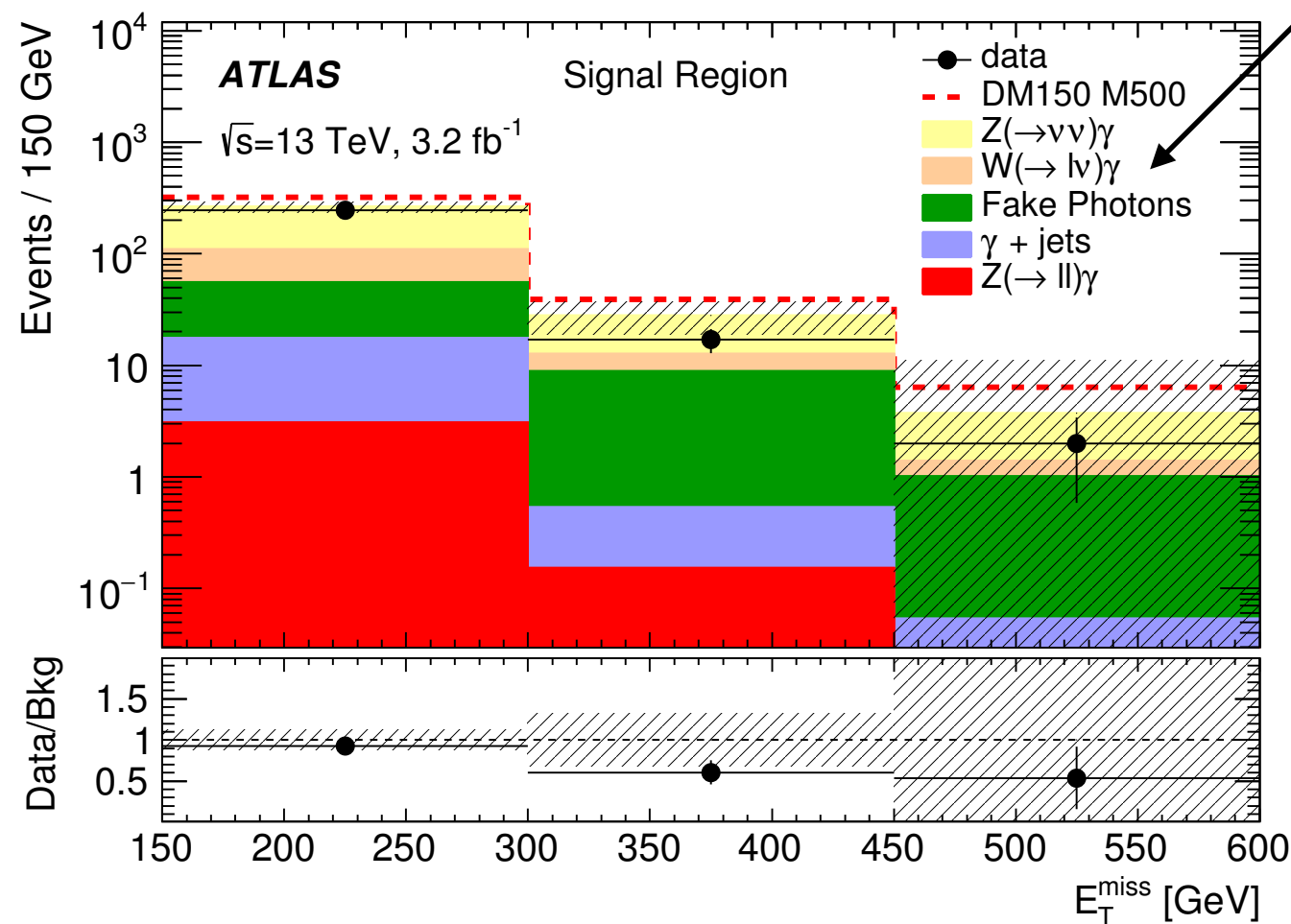
- $g_q=0.25, g_\chi=1$



- presentation of results as recommended by the DM WG ([arxiv:1603.04156](https://arxiv.org/abs/1603.04156))



- ▶ photon trigger, $p_T > 120$ GeV
- ▶ $E_T^{\text{miss}} > 150$ GeV, $p_T^\gamma > 150$ GeV
- ▶ ≤ 1 jet with $p_T > 30$ GeV
- ▶ $\Delta\phi(E_T^{\text{miss}}, \gamma \text{ or jet}) > 0.4$



no significant excess

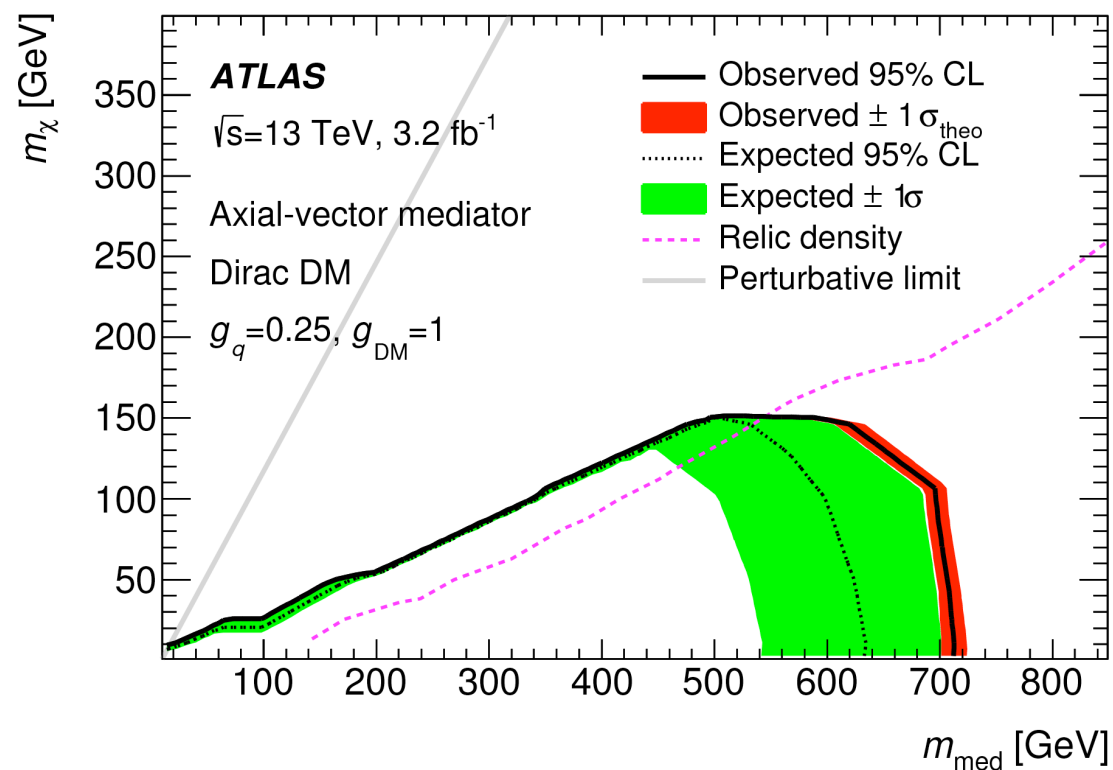
dominant backgrounds:

$Z(\nu\nu)+\gamma$, $W(l\nu)+\gamma$

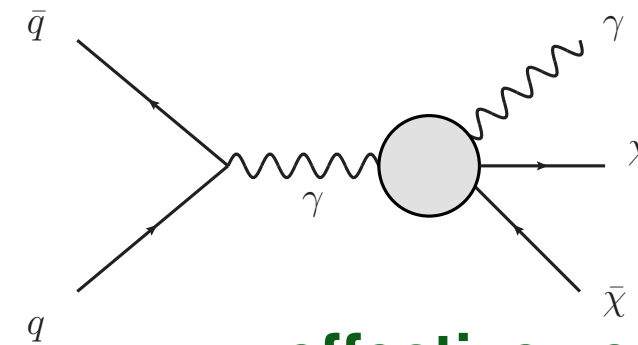
- ▶ $W\gamma/Z\gamma$ CRs:
leptons selected, mass cuts
- ▶ γ jet CR:
 $85 < E_T^{\text{miss}} < 110$ GeV, $\Delta\phi(E_T^{\text{miss}}, \gamma) < 3$
- ▶ SR: muon and electron veto
- ▶ statistically limited
 - ▶ 9% stat. uncertainty from CRs (total: 11%)

Simplified Model

$(g_q=0.25, g_\chi=1)$

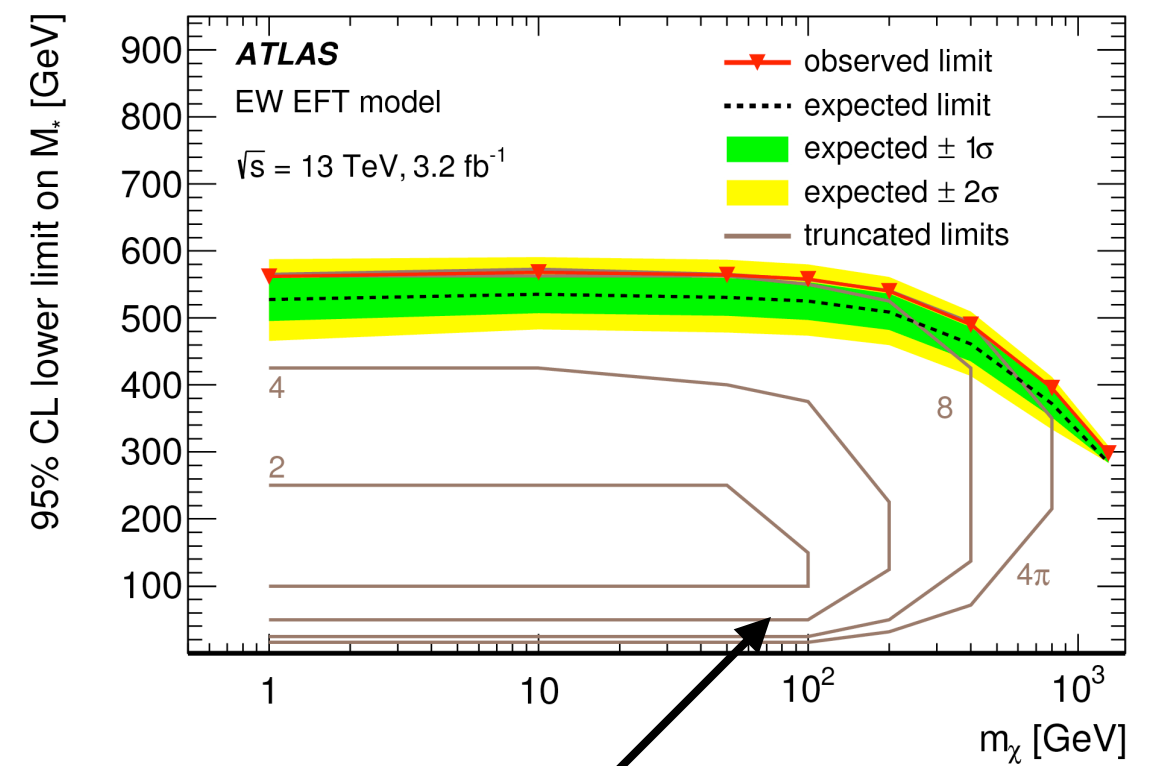


Effective Operator



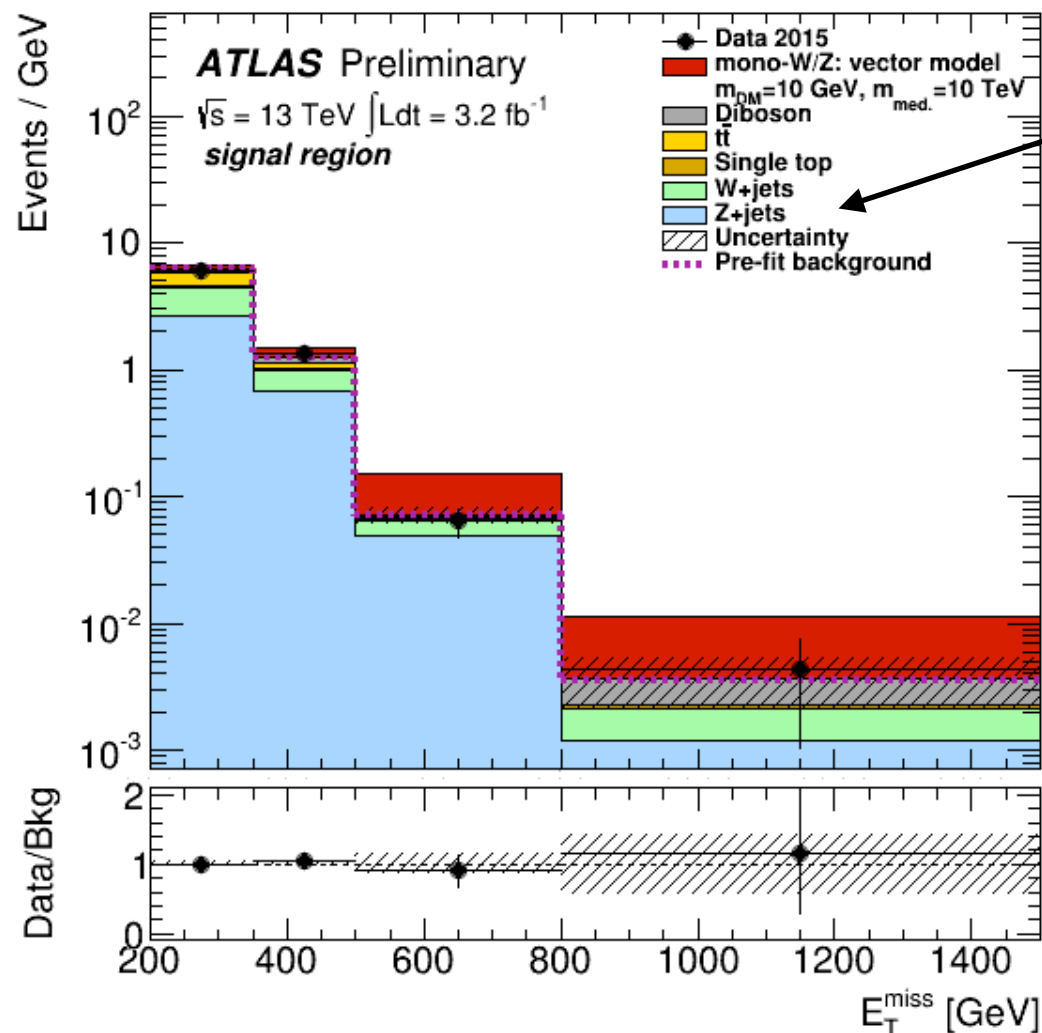
no ISR!

effective vertex: $\gamma\gamma\chi\chi$



to address question of EFT validity:
 truncation, i.e. remove events with
 $\sqrt{s} > gM^*$ for various values of g

- $E_T^{\text{miss}} > 250 \text{ GeV}$
- ≥ 1 large-R ($=1.0$) jet, $p_T > 200 \text{ GeV}$,
boson-tagged (boson mass, substructure)
- anti-multijet selections

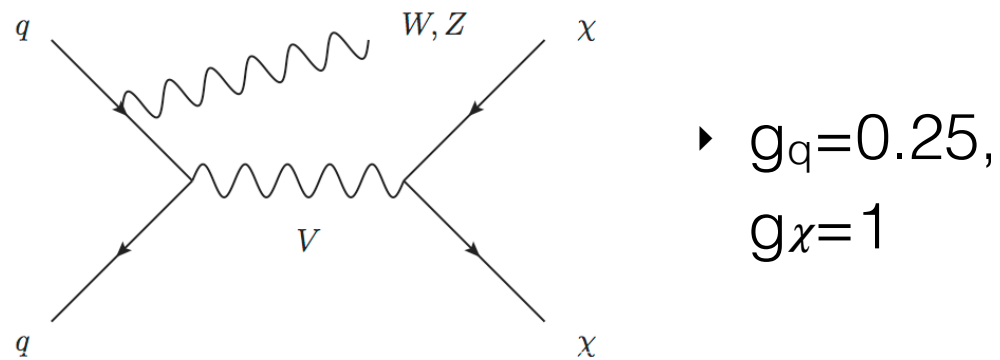


dominant backgrounds:

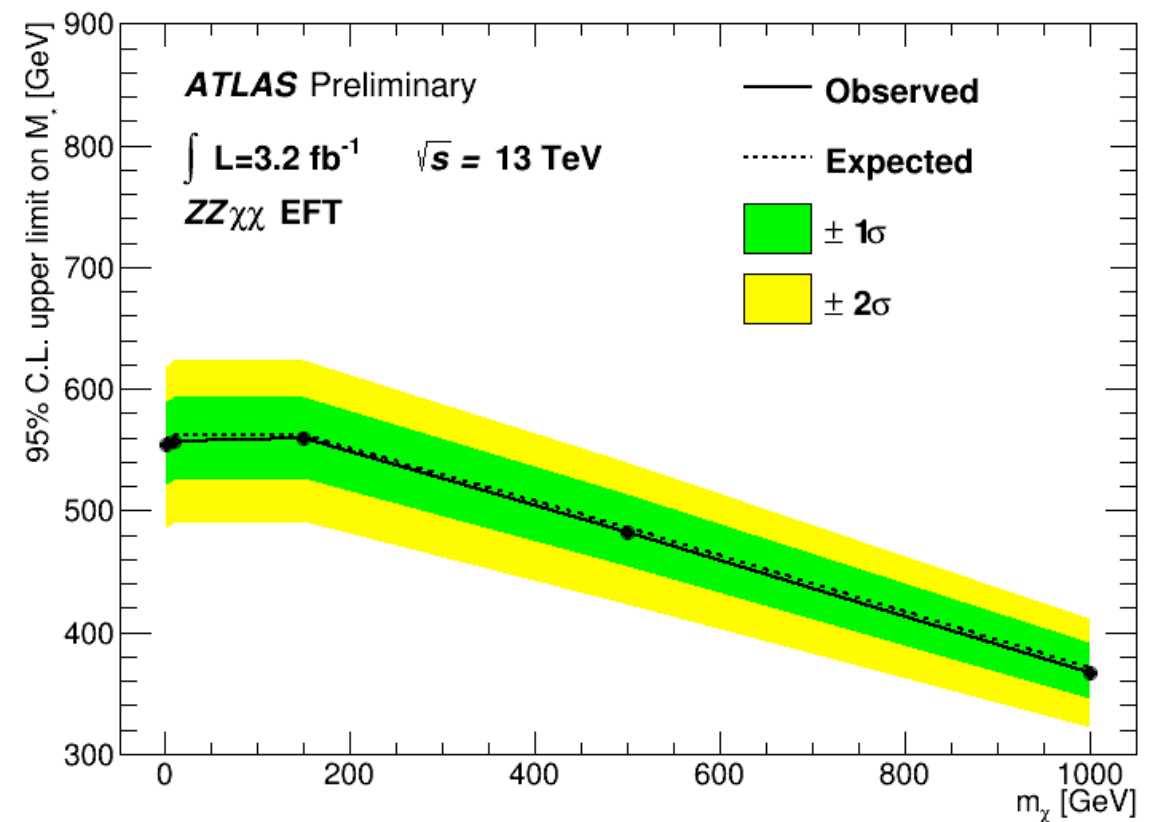
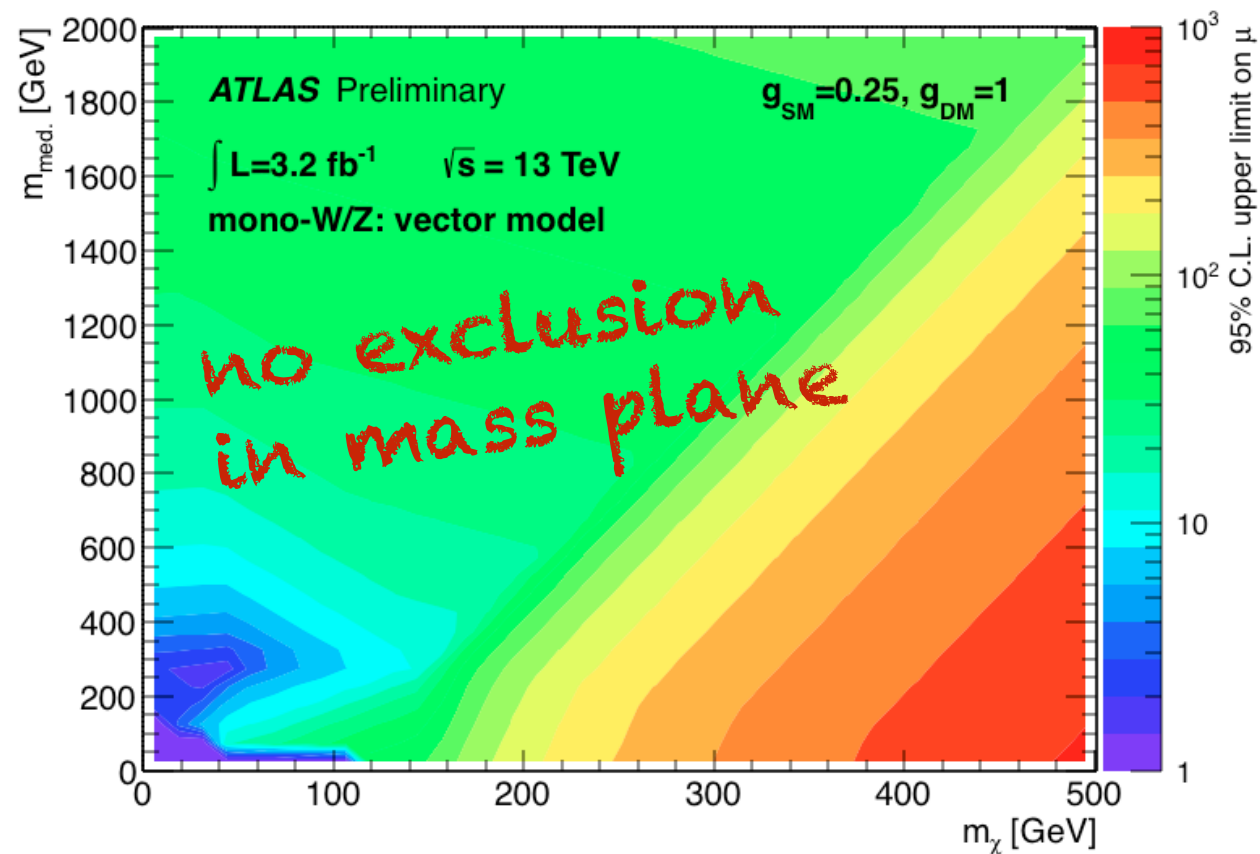
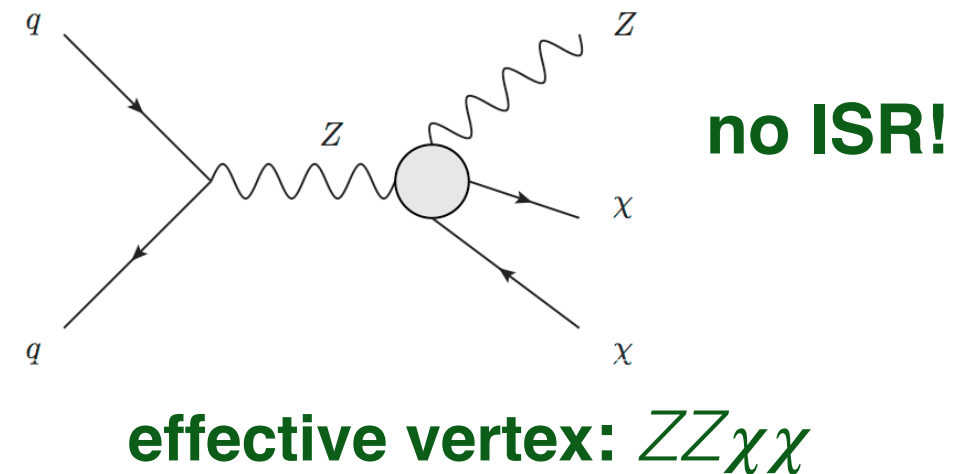
Z+jets , **W+jets**

- W/Z/tt CRs:
leptons selected, relaxed mass cuts,
(anti-)b-tagging, $E_T^{\text{miss}} > 200 \text{ GeV}$
- SR: muon and electron veto
- largest uncertainty:
 - large-R jet parameter modelling: $\sim 10\%$
- **shape** fit

Simplified Model

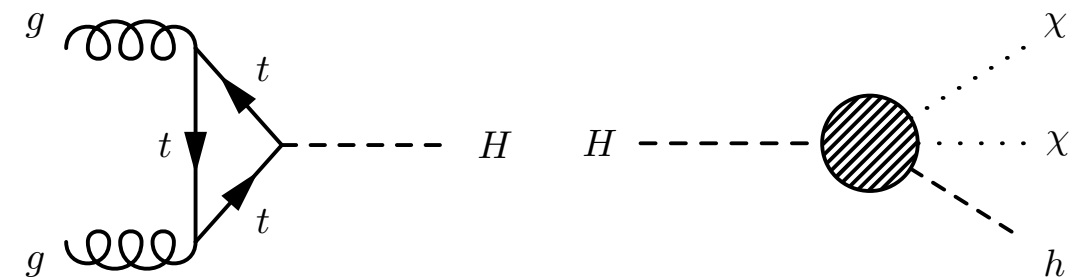
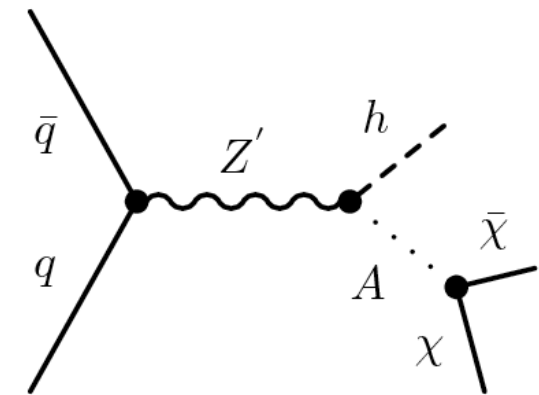
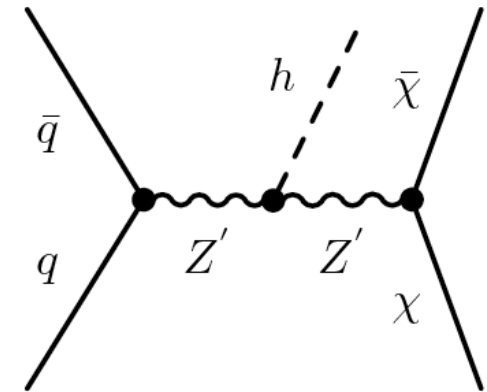


Effective Operator



Mono-Higgs

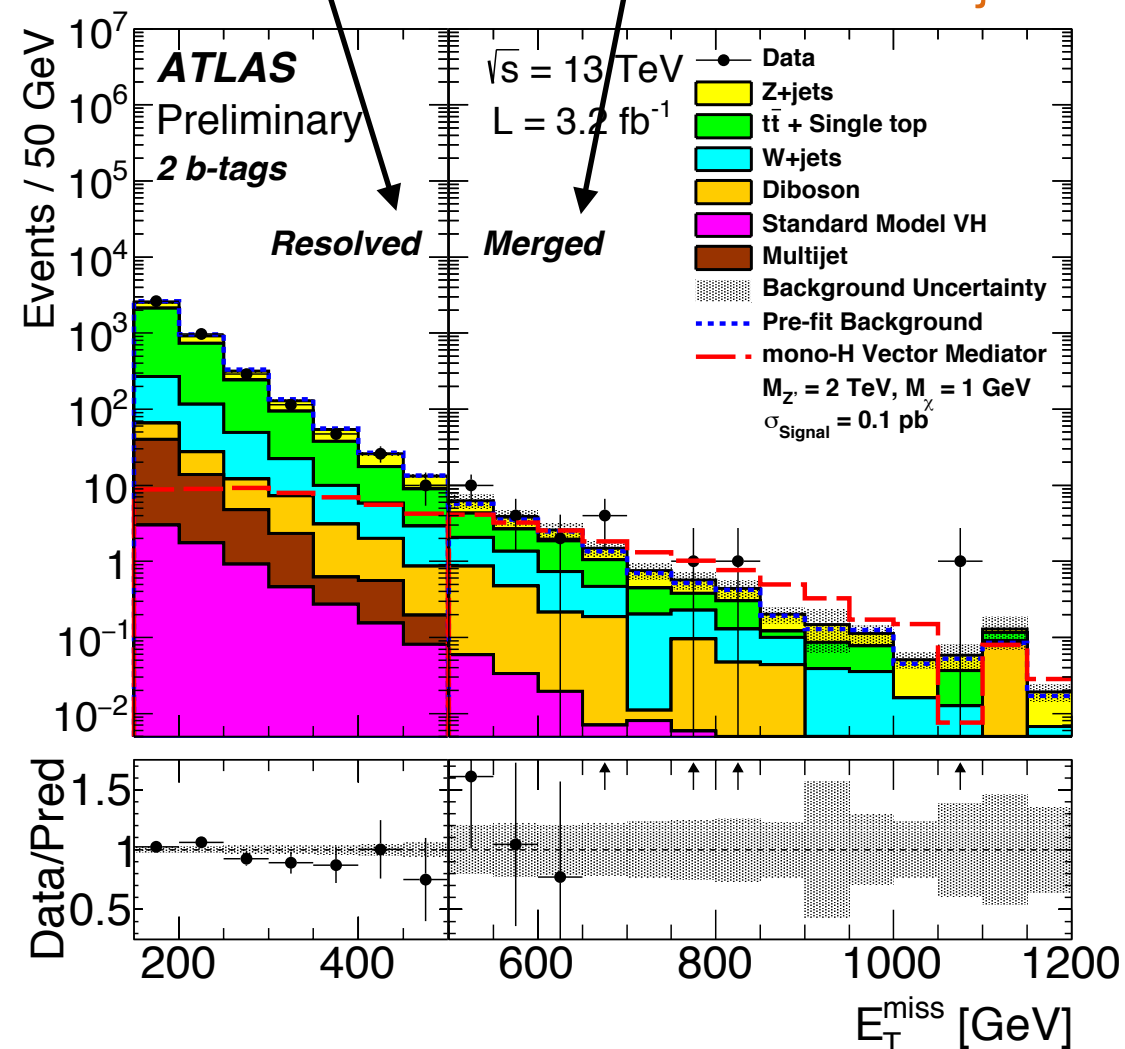
- ▶ new in run-2
- ▶ **no ISR!** (small coupling)
- ▶ widely used simplified model:
s-channel vector mediator radiating Higgs
- ▶ other models considered in some analyses:
 - ▶ s-channel scalar mediator radiating Higgs
 - ▶ Z' -2HD simplified model
 - ▶ scalar 2HD simplified model
- ▶ additional parameters, e.g. $g_{Z'Z'h}$, mixing angle...



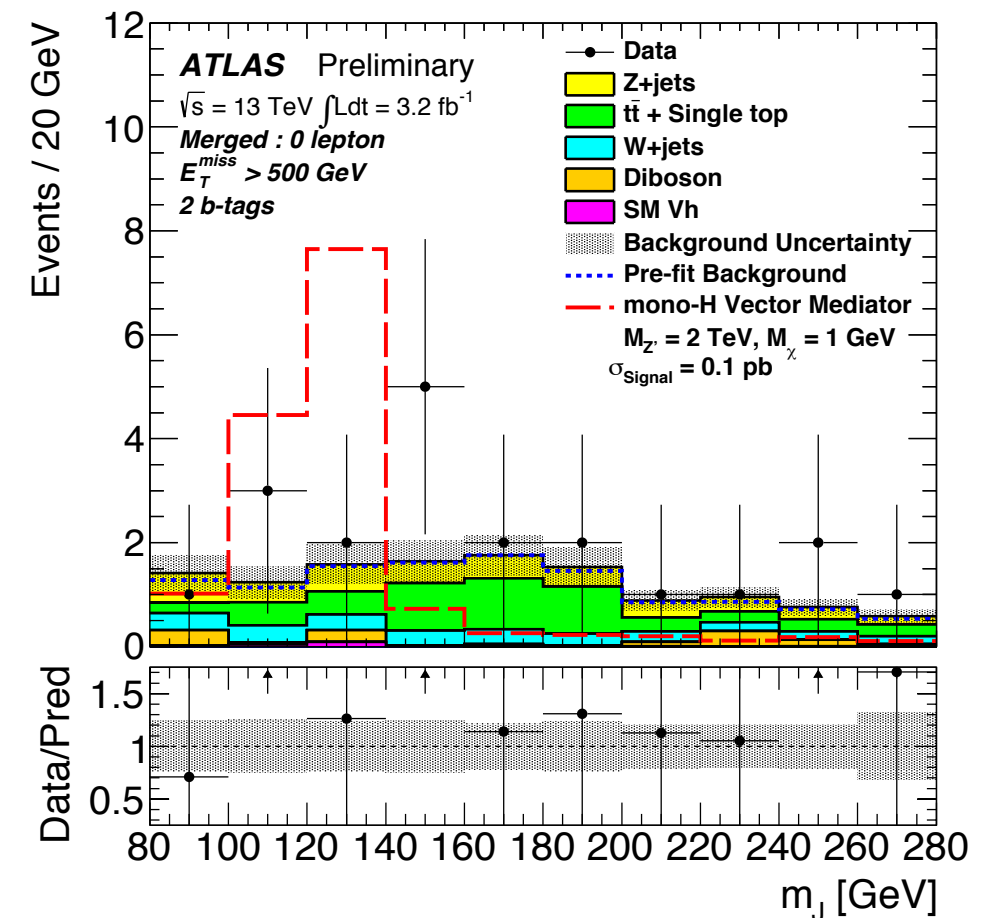
- ▶ $E_T^{\text{miss}} > 150 \text{ GeV}$, $p_T^{\text{miss}} > 30 \text{ GeV}$
- ▶ anti-multijet selections

- ▶ SR: lepton veto, 2 **b-tagged** jets

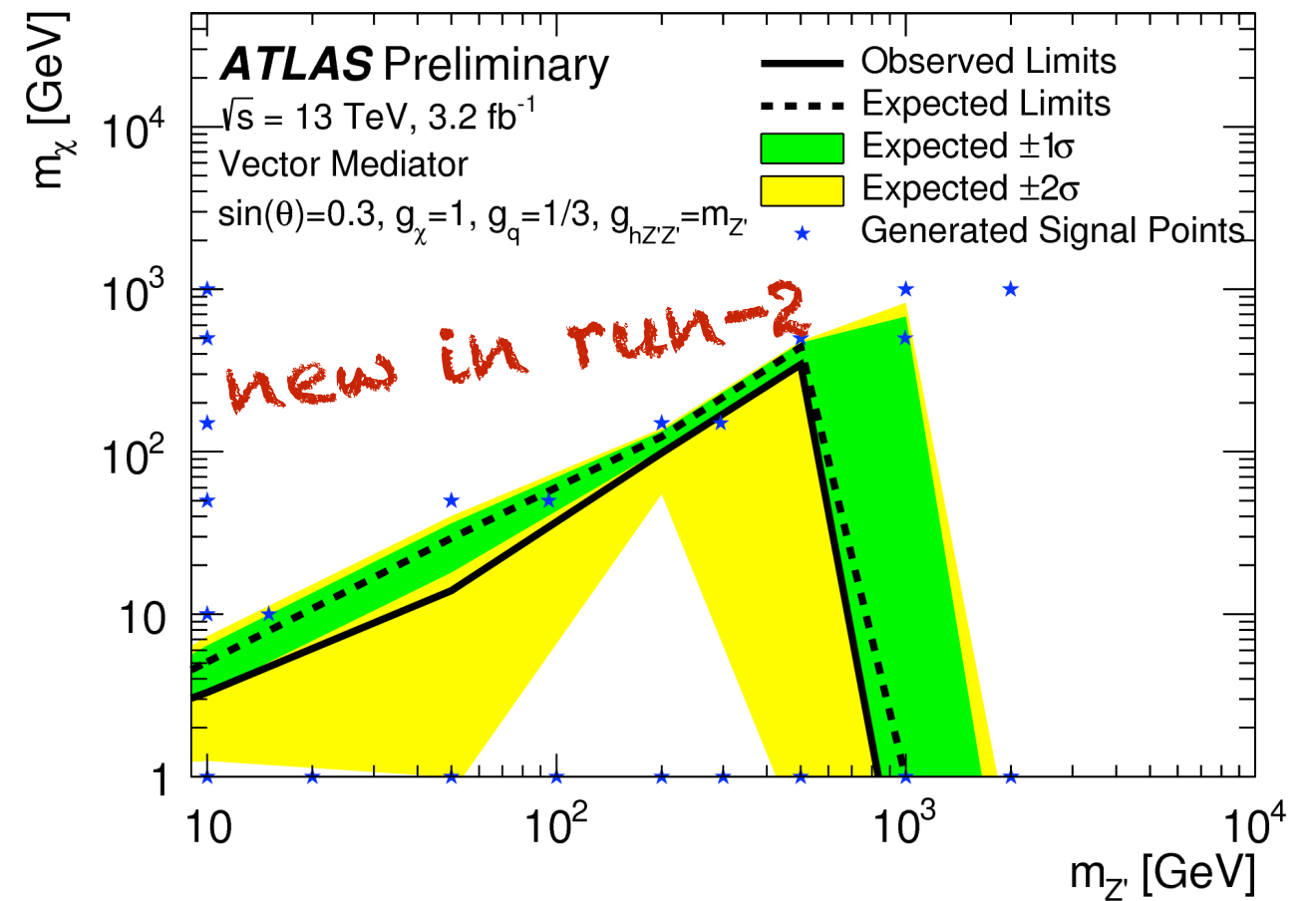
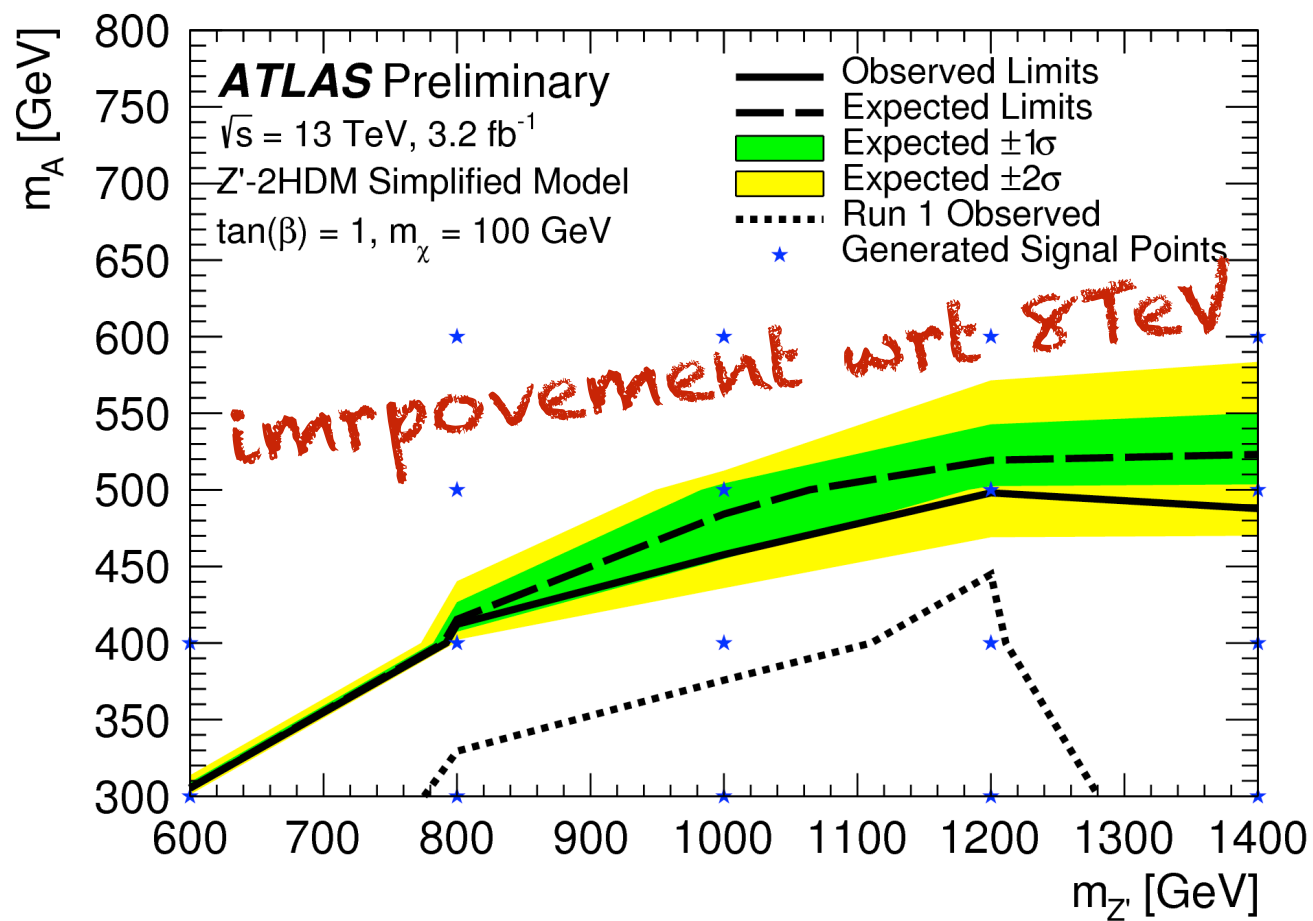
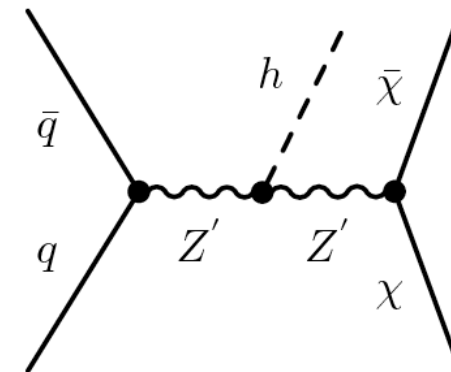
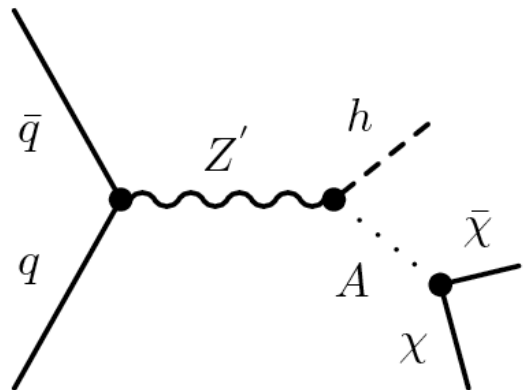
- ▶ resolved:
2 **small-R** jets
- ▶ merged:
1 large-R jet
+ 2 **track** jets



- ▶ CRs: orthogonal cuts on $N_{b\text{-jet}}$ & N_{lep}
- ▶ fit to shape of (di)jet mass

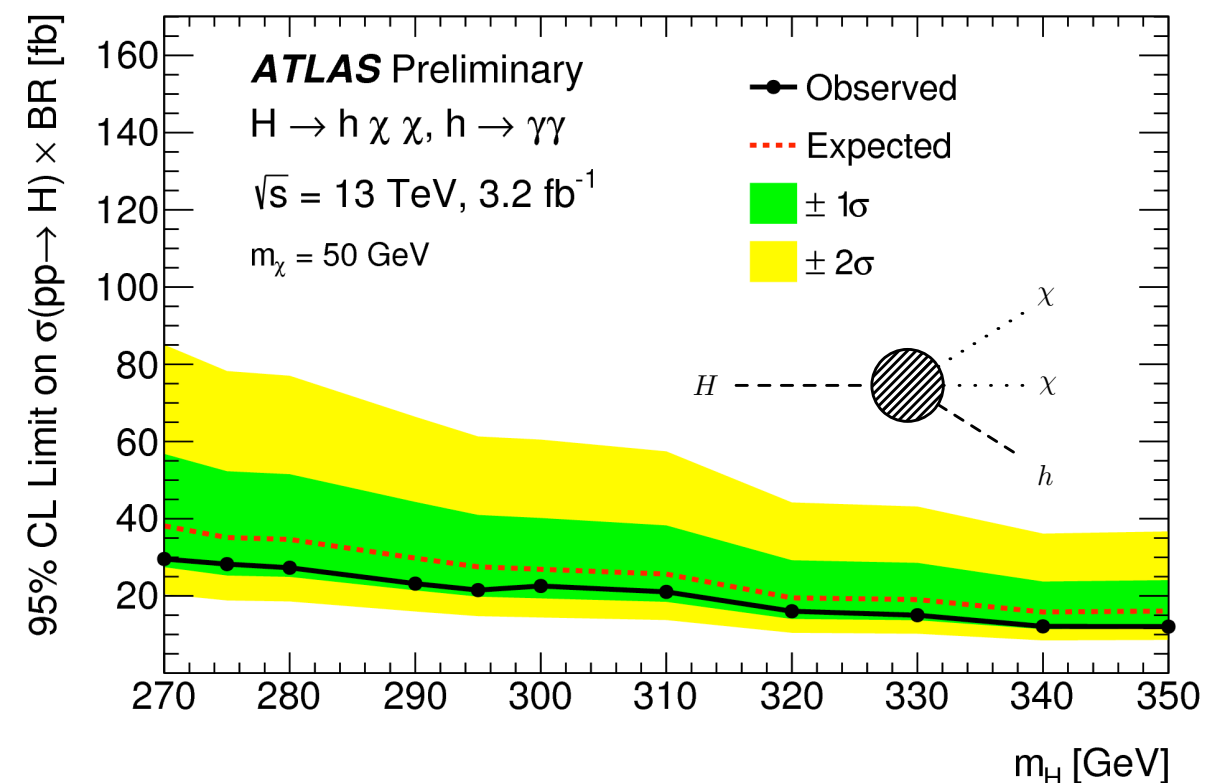
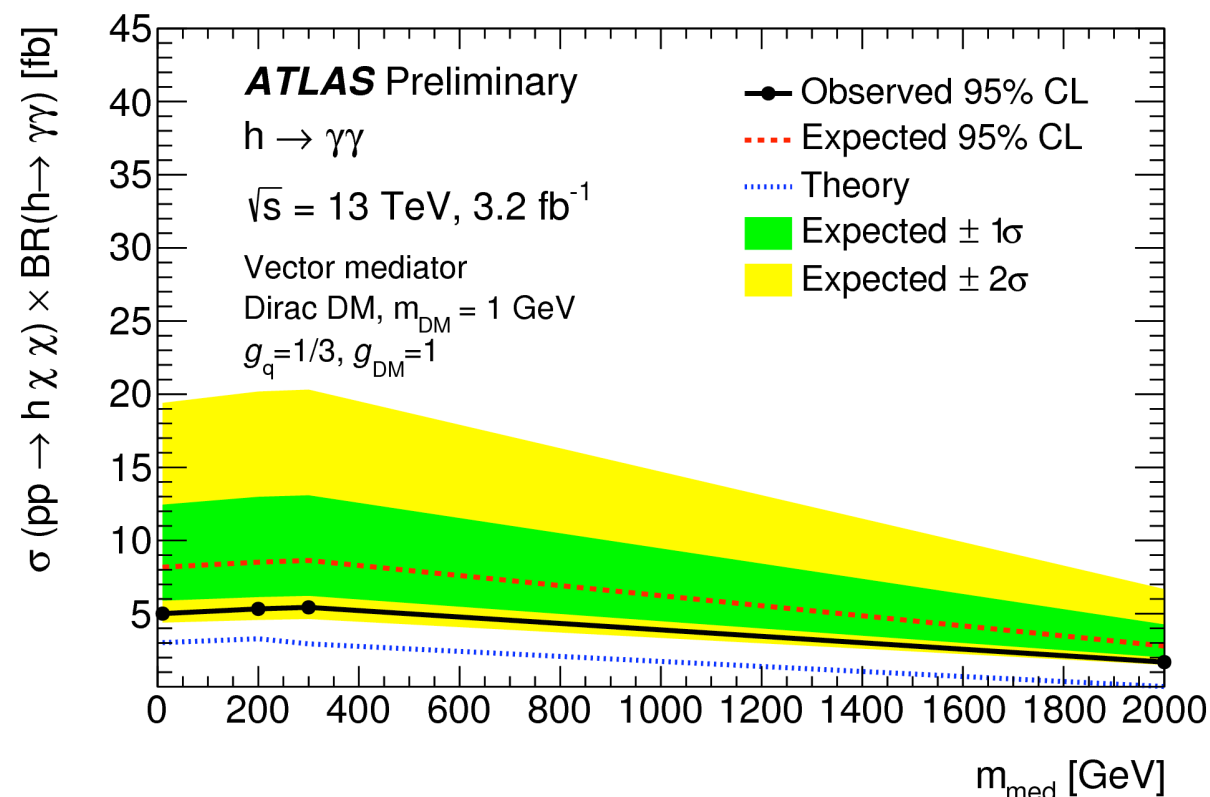
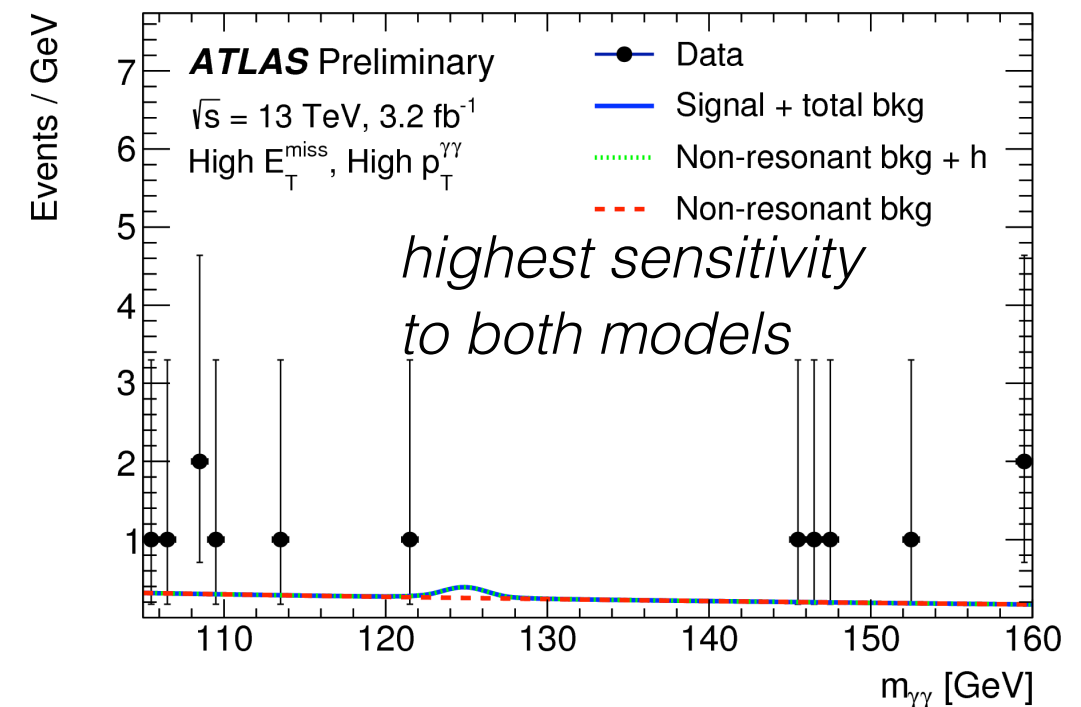


- ▶ largest uncertainties:
 - ▶ b-tagging
 - ▶ background normalisation (theo.)
 - ▶ total: few %

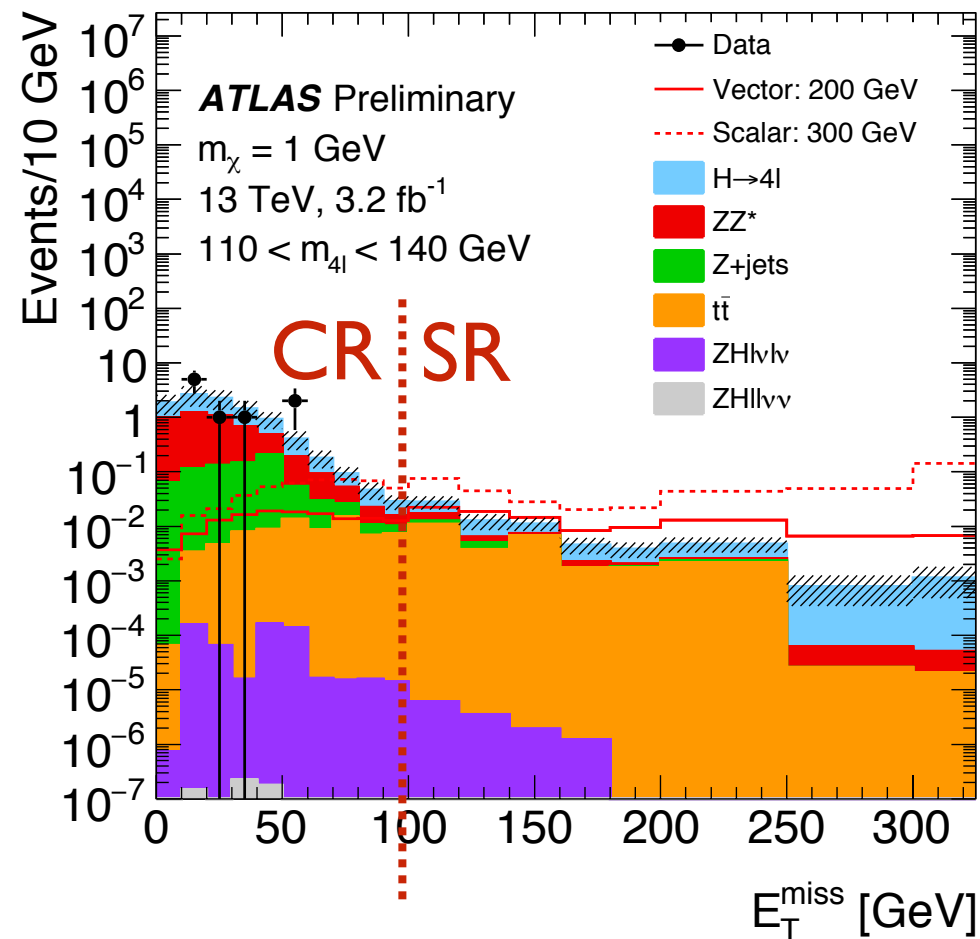


- diphoton trigger
- ≥ 2 photons with $m_{\gamma\gamma}$ in $[105, 160]$ GeV
- 4 event categories
 - cuts on E_T^{miss} , $p_T^{\gamma\gamma}$, p_T sum of γ 's & jets
- largest uncertainties:
 - $\gamma\gamma$ -vertex selection, E_T^{miss}
- simultaneous fit to all regions

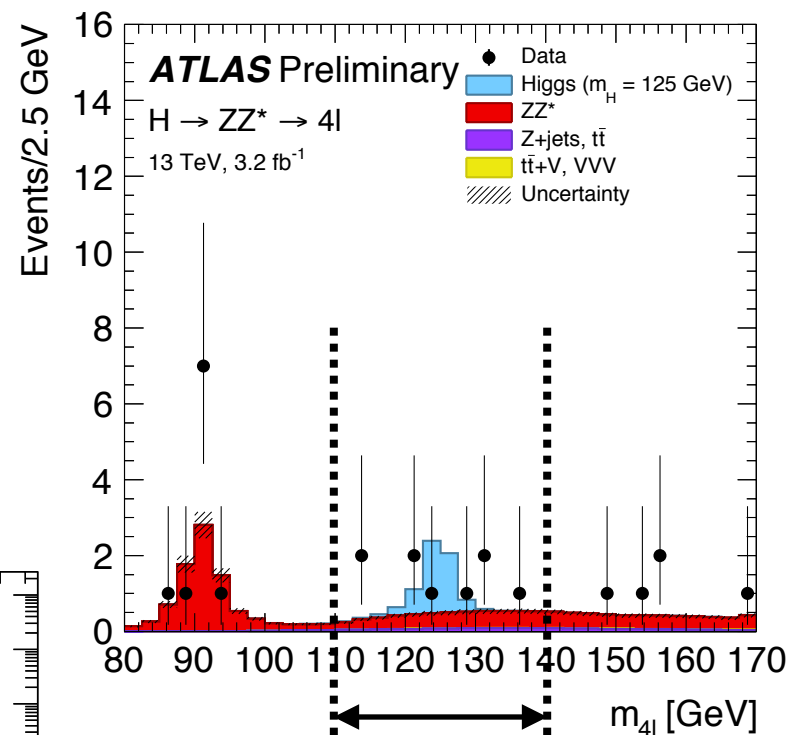
$E_T^{\text{miss}} > 100$ GeV , $p_T^{\gamma\gamma} > 100$ GeV



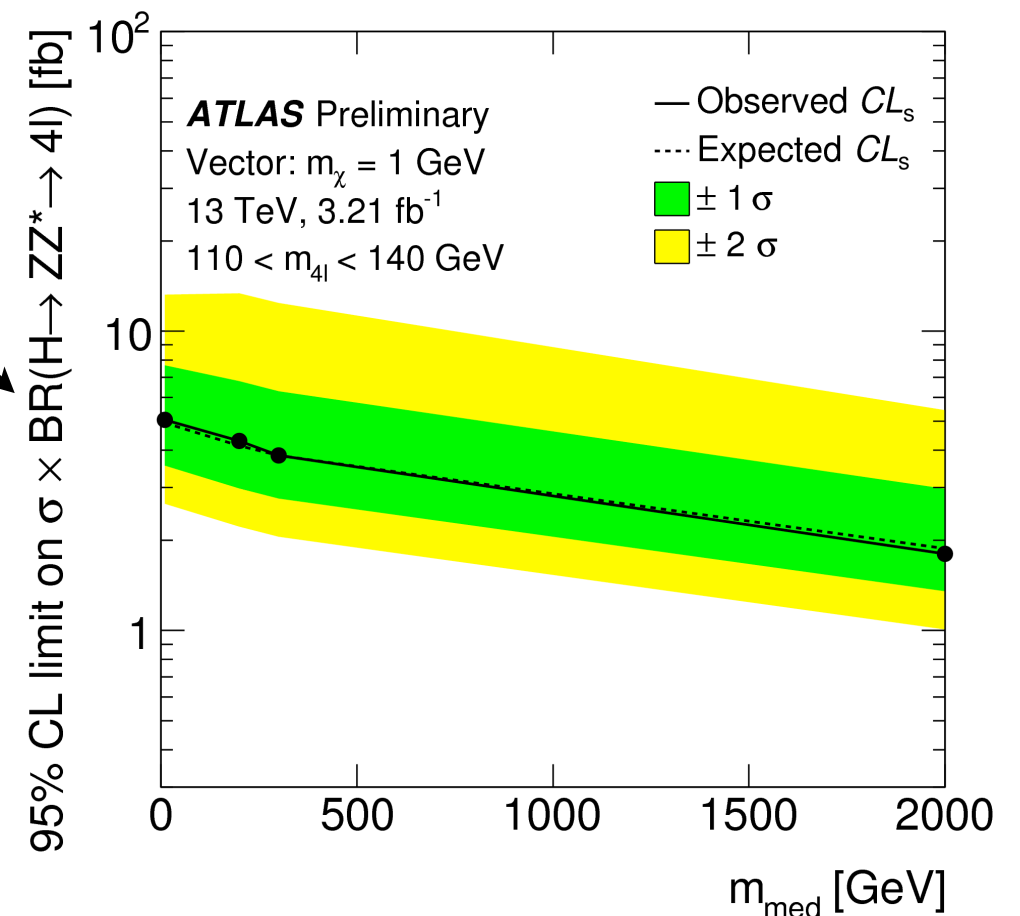
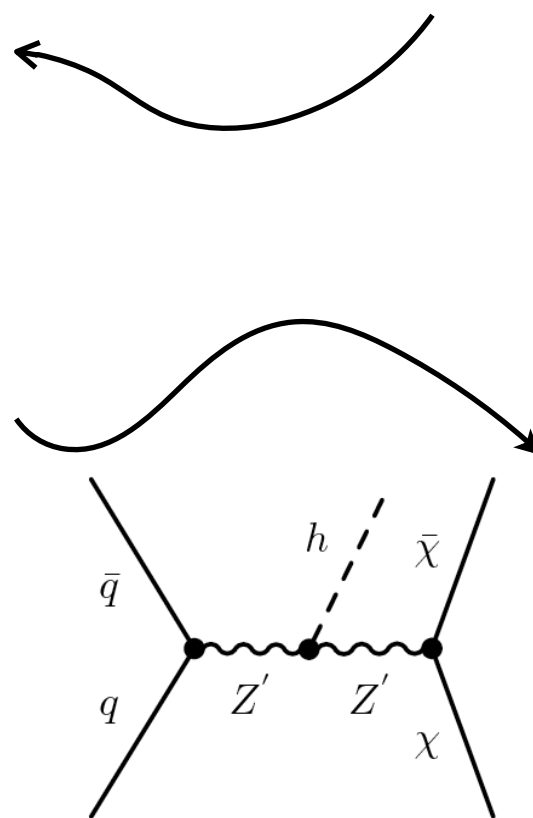
- various lepton triggers
- form lepton quadruplets
- m_{4l} in [110, 140] GeV



no significant excess



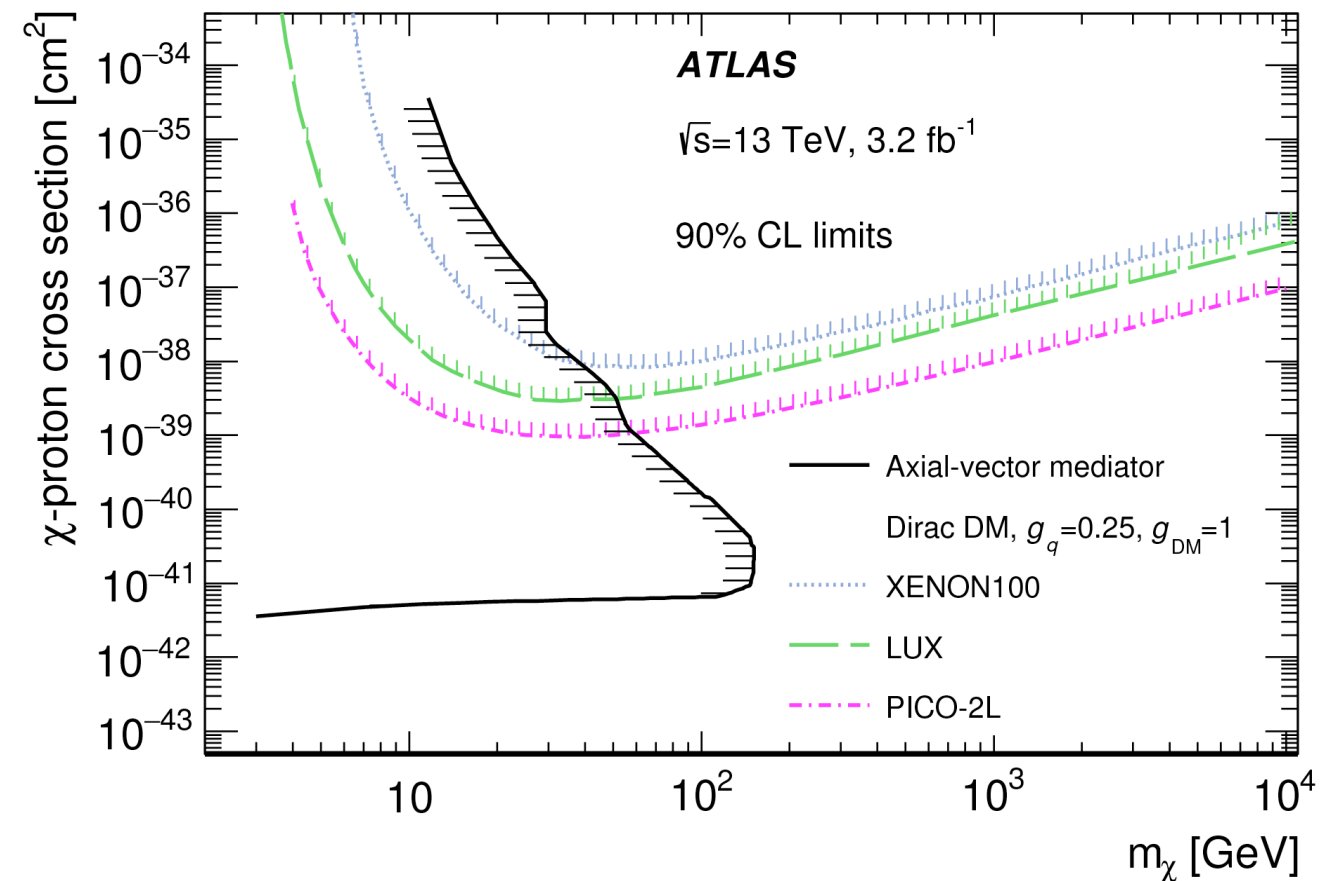
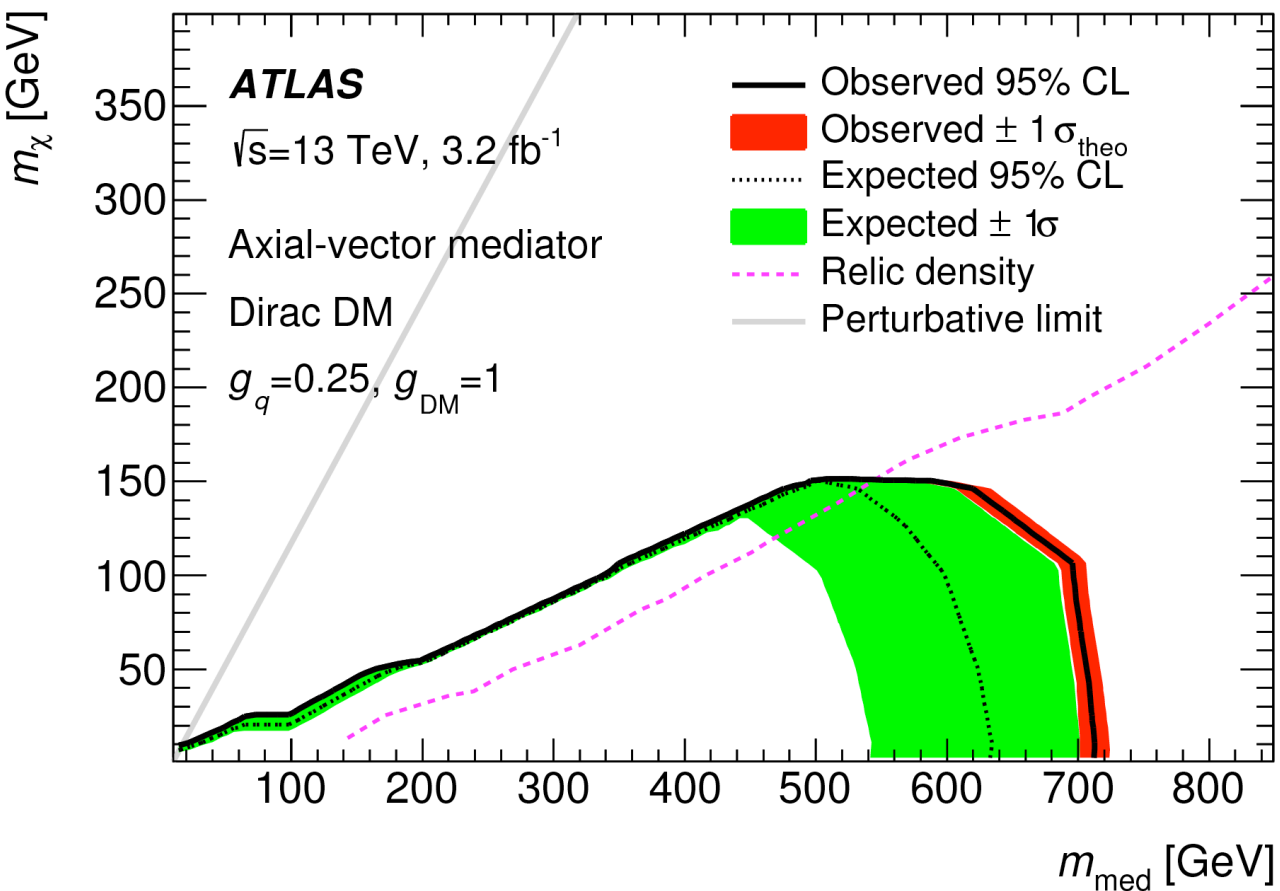
- largest uncertainties:
 - jet energy scale ~50-60%
 - E_T^{miss} soft term ~10%



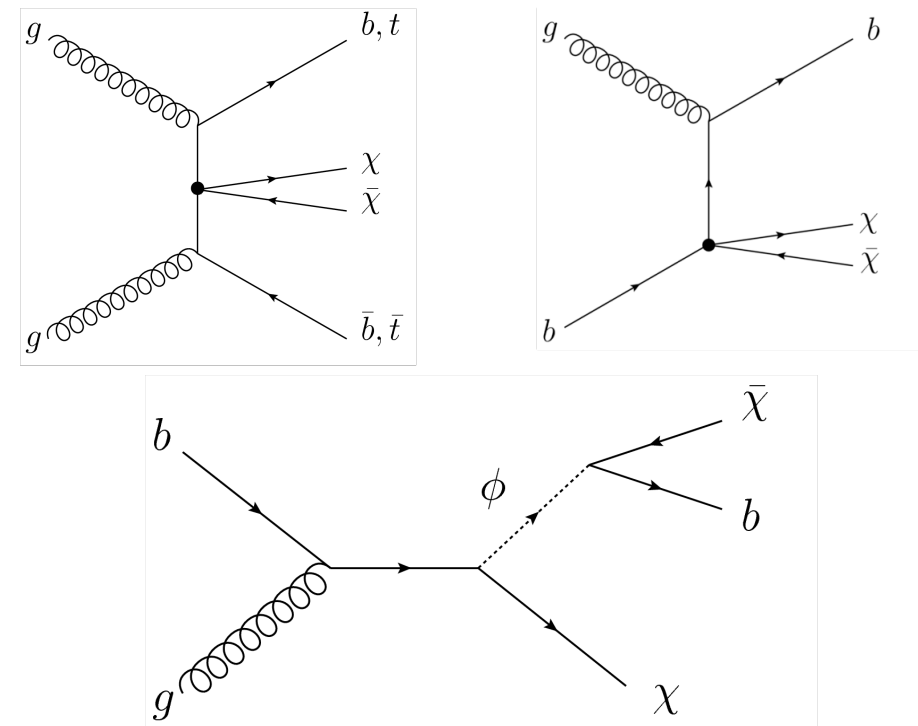
- ▶ already large suite of mono-X searches @13TeV at ATLAS
 - ▶ from “work horse” monojet to new mono-H searches
- ▶ transition EFT \rightarrow simplified models where possible
- ▶ no significant excess \rightarrow exclusion bounds on various models
- ▶ more data is coming!

Additional Material

Simplified Model ($g_q=0.25, g_x=1$)



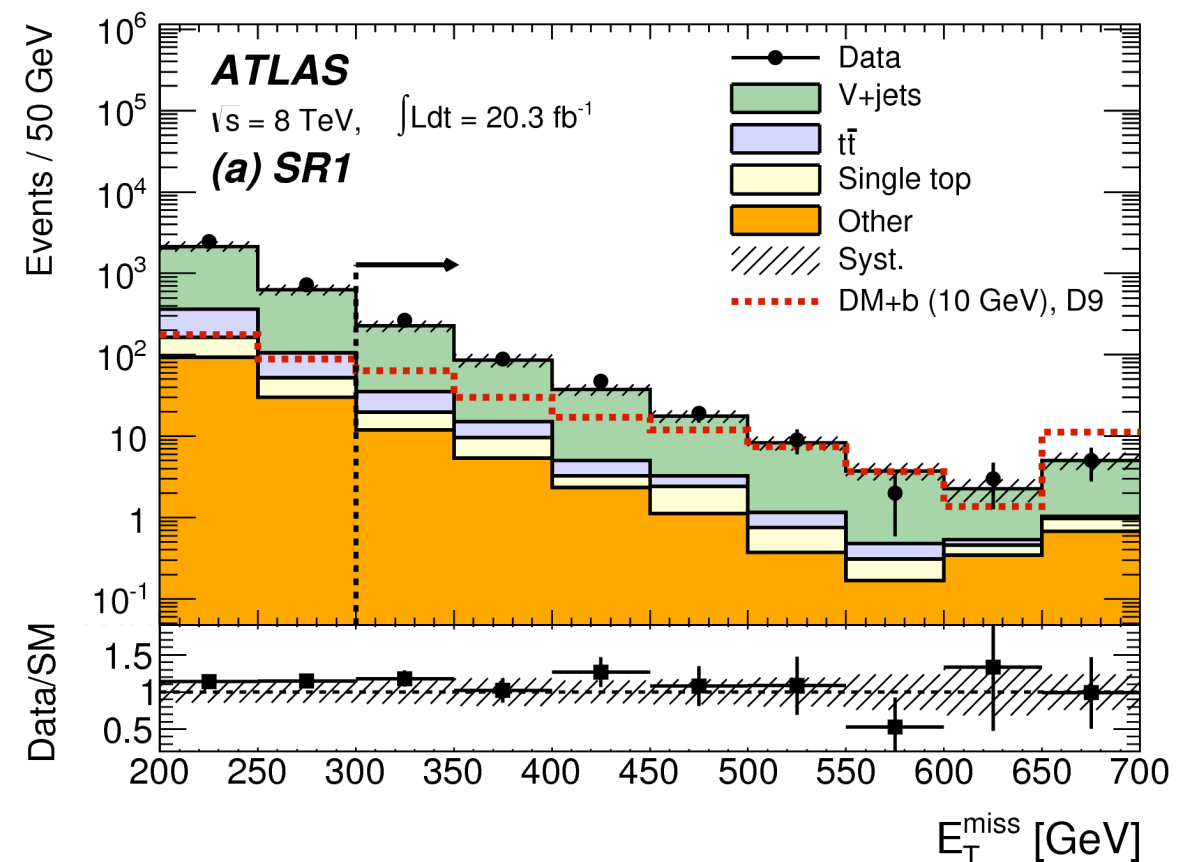
- ▶ 20.3/fb @ 8 TeV
- ▶ increased sensitivity to effective operators that contain quark mass
- ▶ in addition: b-flavoured DM model (b-FDM), preferred by FERMI gamma-ray excess



▶ 4 signal regions

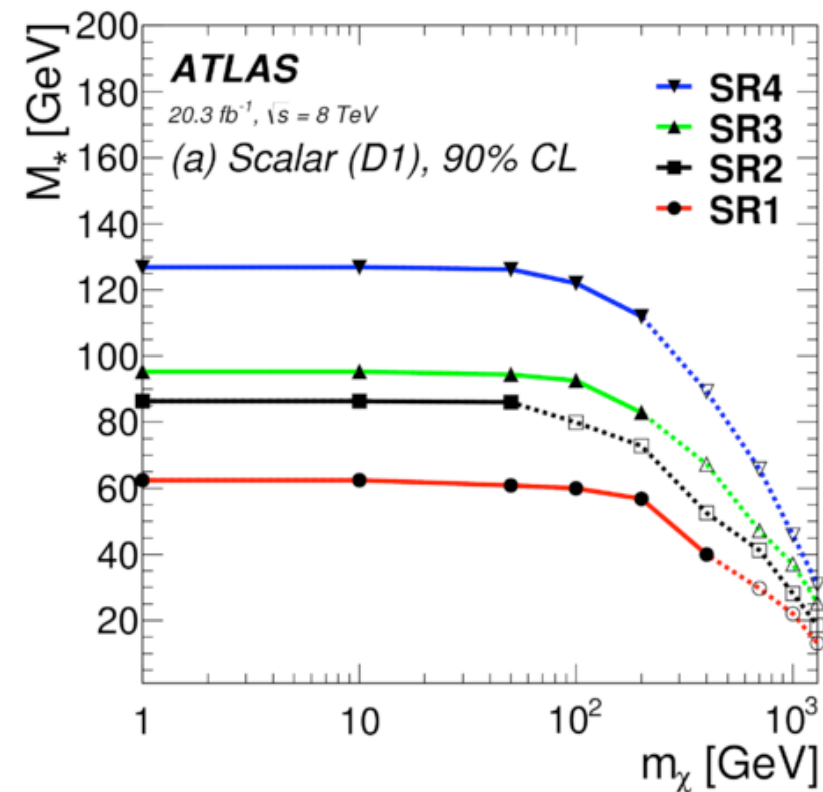
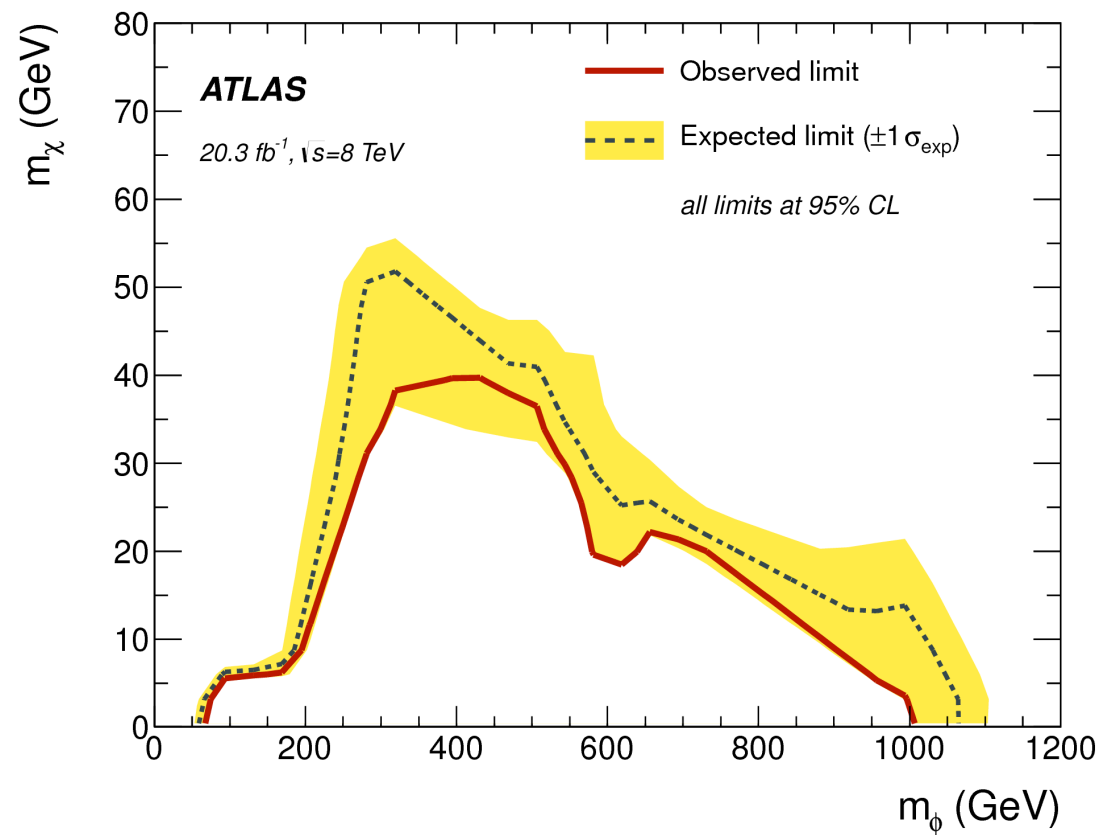
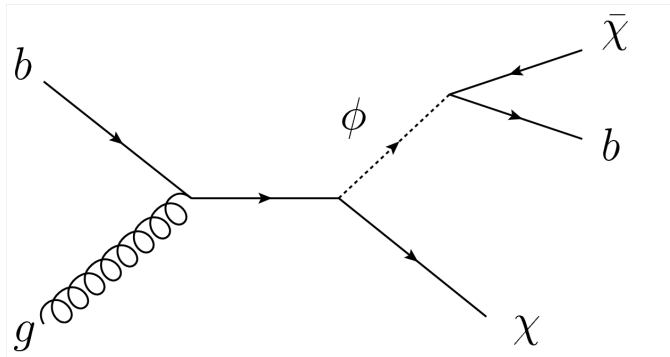
defined by various variables:
 $E_T^{\text{miss}} > 200\text{-}300\text{ GeV}$,
 many or high- p_T (b-)jets,
 small lepton multiplicity...

no significant excess



Effective Operator (example)

Simplified Model (b-FDM)



**much stronger
bounds on scalar
models than e.g.
mono-jet**

