Dark Matter Searches at ATLAS

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on behalf of the ATLAS collaboration

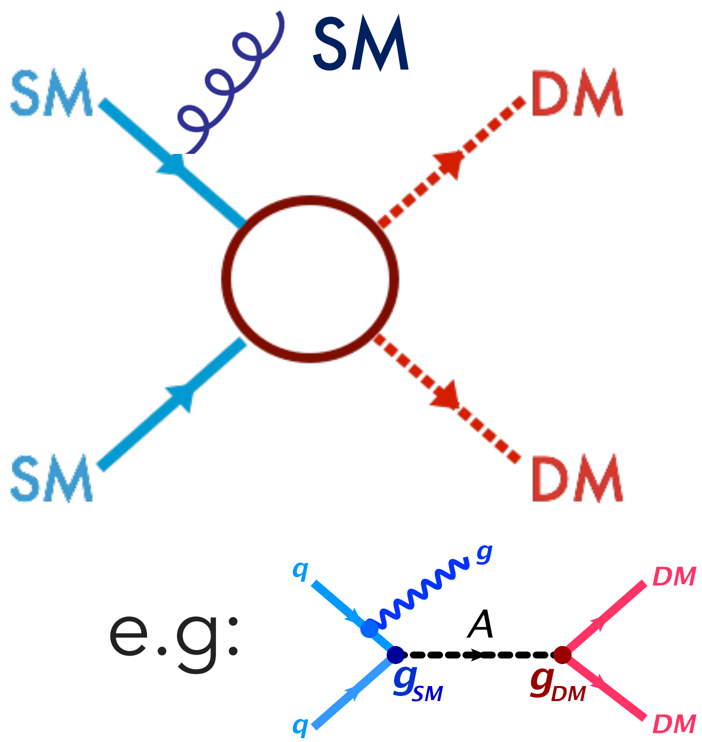
SUSY 2017 - Mumbai

Dark Matter Searches at the LHC

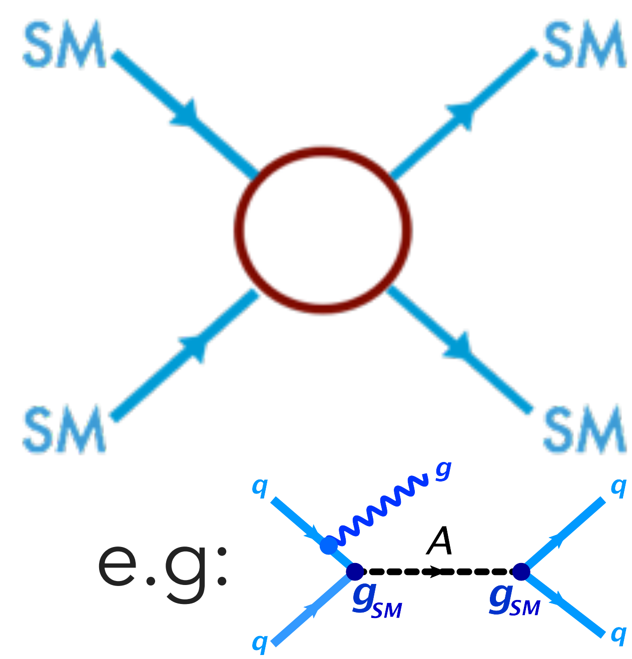
The DM problem connects with particle physics by assuming some kind of interaction other than gravitational between DM and SM particles.

Essentially two ways to search for DM production at the LHC

Mono-X



Di-X



Search for DM pairs

- Missing transverse momentum (MET) recoiling against a "visible" X=jet,ɣ,W,Z,h from ISR
- SUSY searches involving MET

Assume the same particle DM model and search for mediator decays into SM

- resonant searches, such as di-jet, di-lepton, ttbar final states

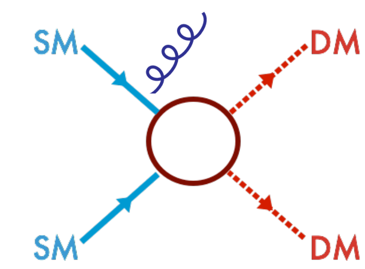
PARTICLE DM MODELS

ATLAS-CMS DM forum (1507.00966) ⇨ **LHC DM Working group** (link)

Completeness

EFT

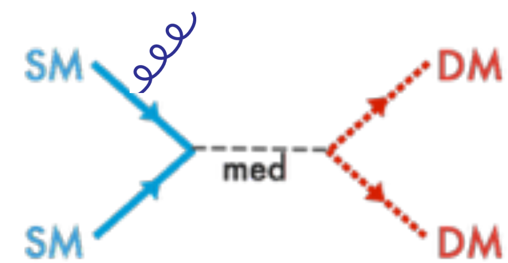
contact interaction assumed between DM and SM
parametrization based on spin and parity of the interaction
invalid at high Q^2



EFT contact interaction

Simplified Models

renormalizable minimal extension of SM
involving ***DM candidate*** + ***Mediator***
not covered by SUSY
usually neglect mass generation



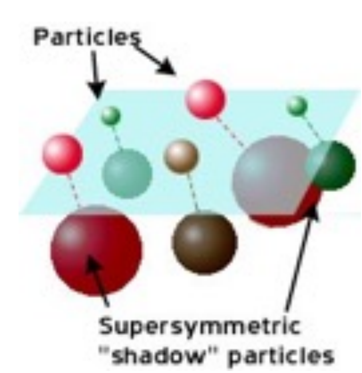
spin-1 s-channel mediator

Complete Theories

LED

MSSM

born to explain the hierarchy problem
naturally provide DM candidate
dark sector is usually more expanded



The Market of the Models

Mono-Jet & Xsec Ratio

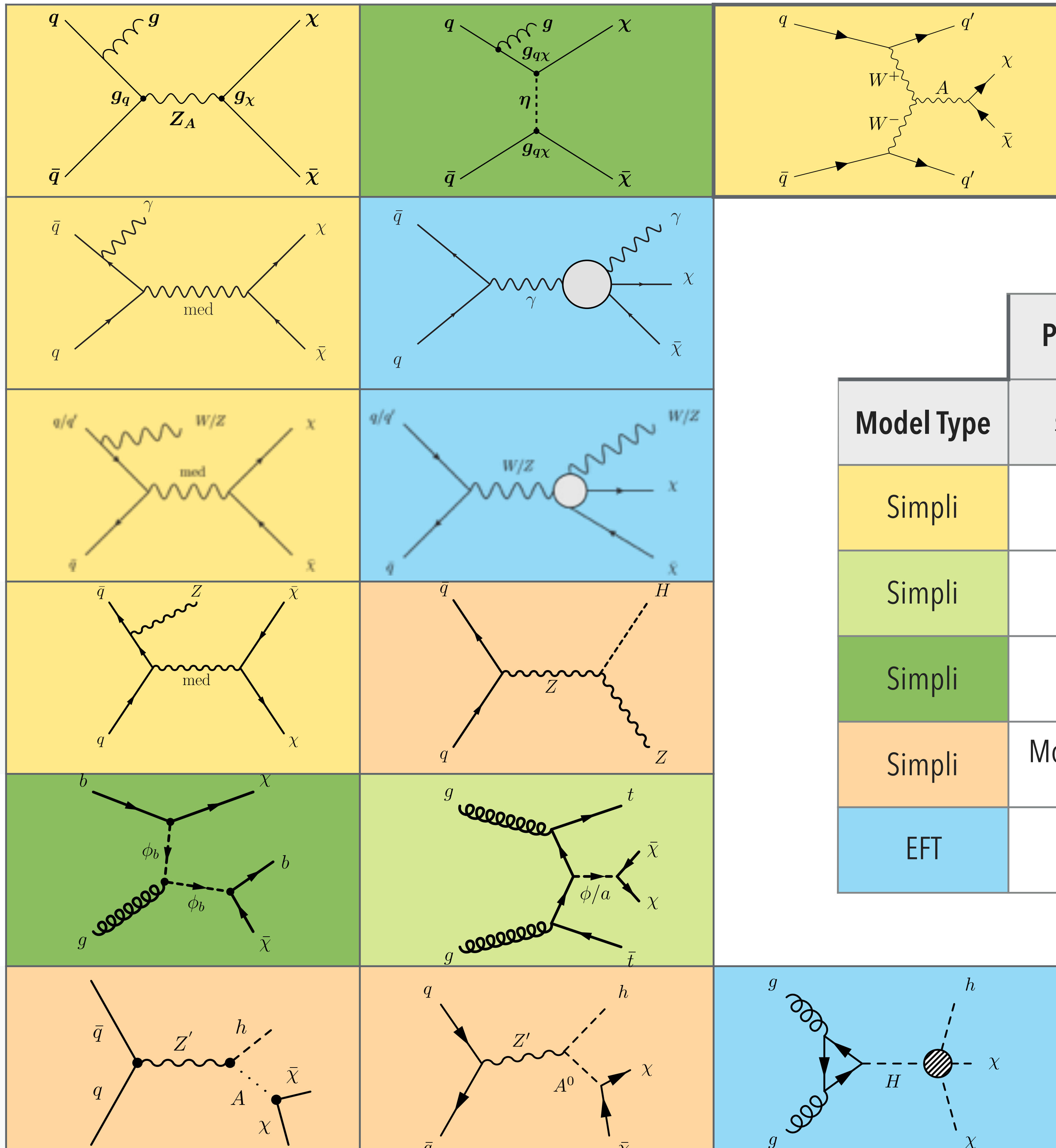
Mono-Photon

Mono-W/Z hadronic

Mono-Z(ll)

Mono-HF

Mono-H

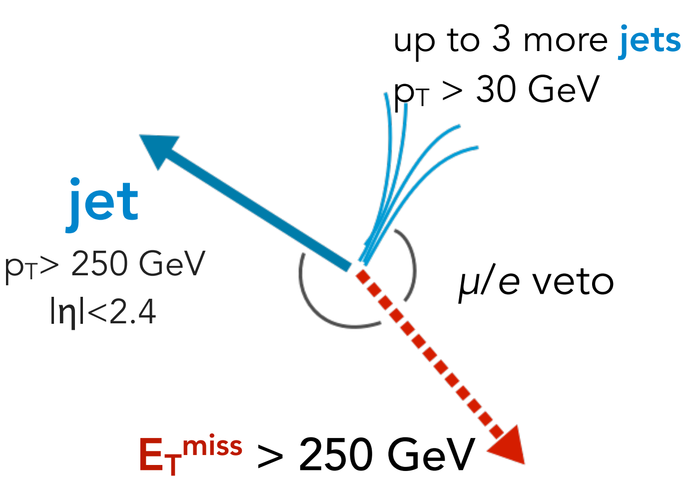


	Properties of the new Mediator		
Model Type	**spin**	**parity**	**color**
Simpli	1	+1, -1	neutral
Simpli	0	+1, -1	neutral
Simpli	0	+1	charged
Simpli	Models involving Higgs boson and/ or additional Higgs bosons		
EFT	Higher-dimension operators, involving EW bosons		

MONO-JET

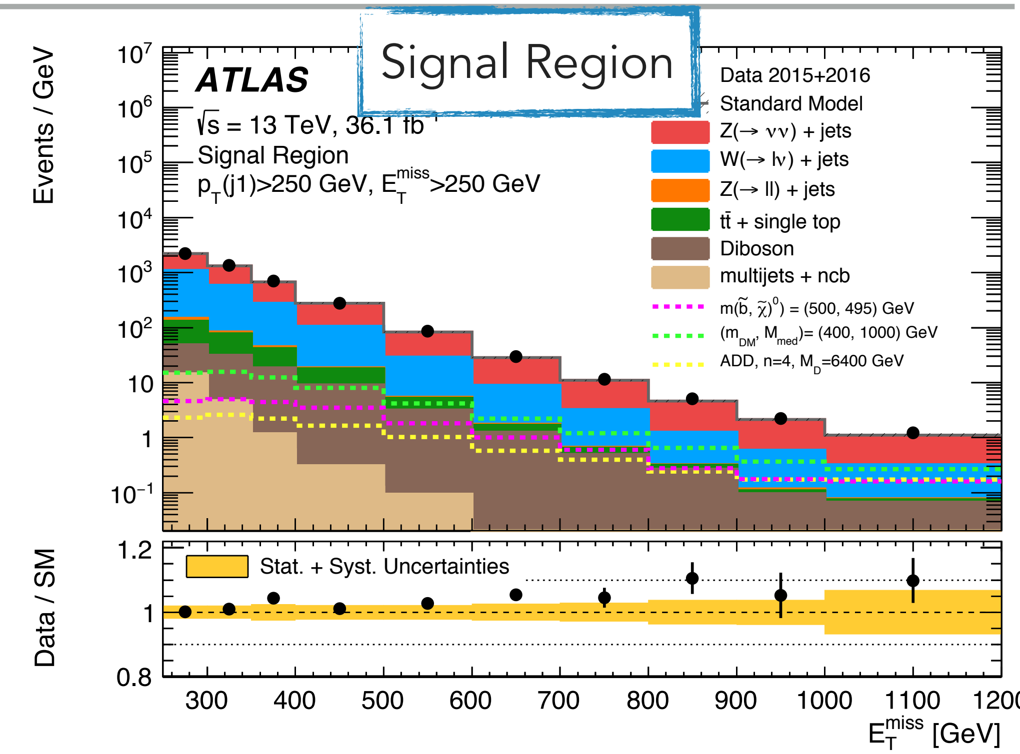
PAPER is OUT!

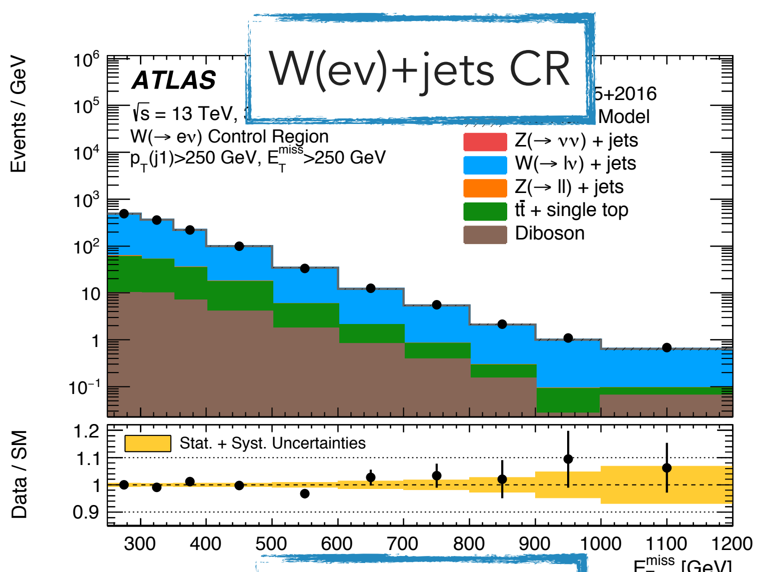
→ [EXOT-2016-27]

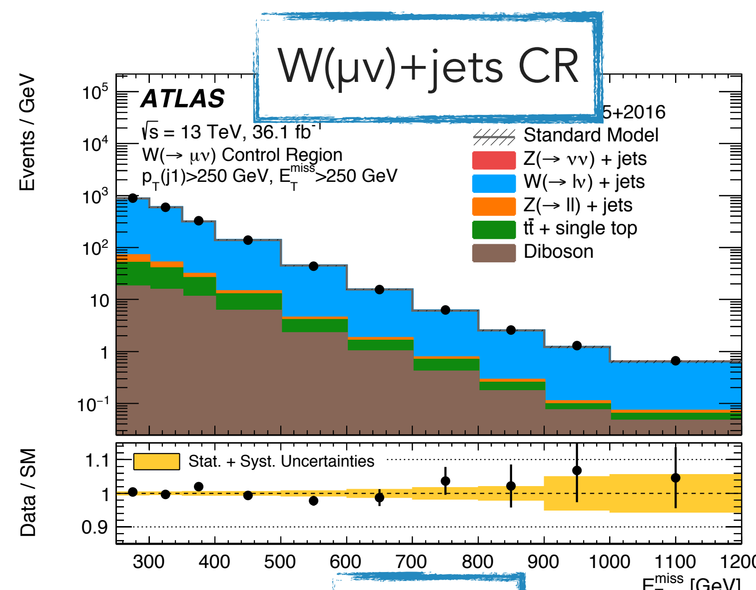


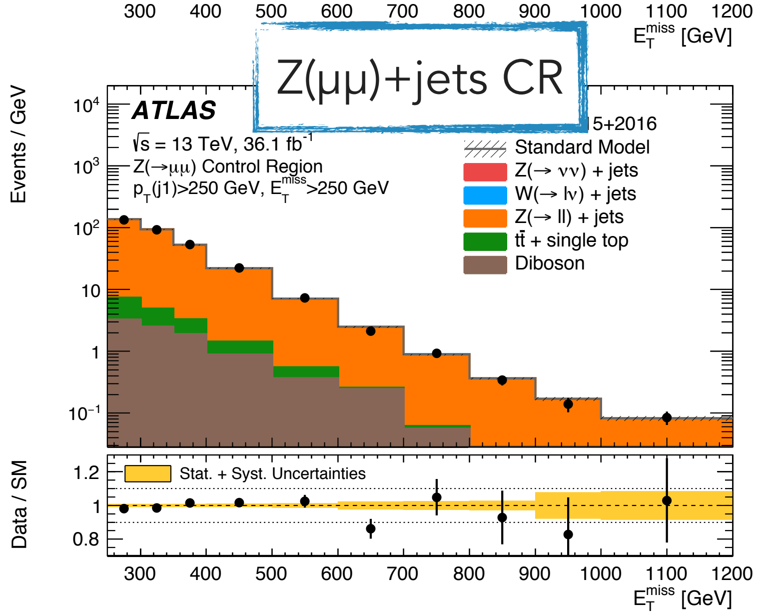
Most abundant mono-X reaction

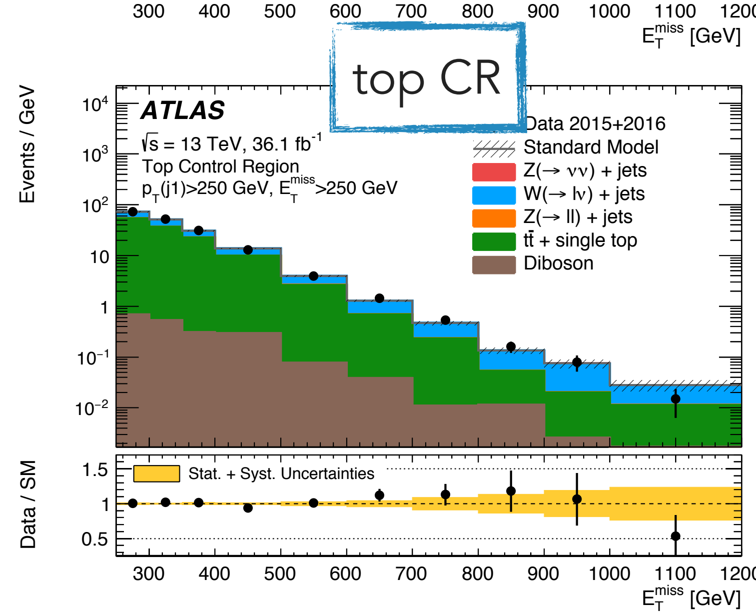
- MET trigger
- Z(νν)+jets irreducible background O(55-70%)
- W(lν)+jets O(35-20%)
- top O(4%)











V+jets backgrounds reweighted to perturbative calculations at NLO QCD + nNNLO EW (arXiv:1705.04664)

Simultaneous fit in CRs on the shape of the **MET ~ $p_T(V)$**:

- Same normalization factor for all V+jets processes
- One normalization factor for top

Precision on the background estimation: **2-7%**

Residual uncertainties: lepton veto efficiencies

→ For cross-section ratio analysis, see EXOT-2016-03

MONO-JET

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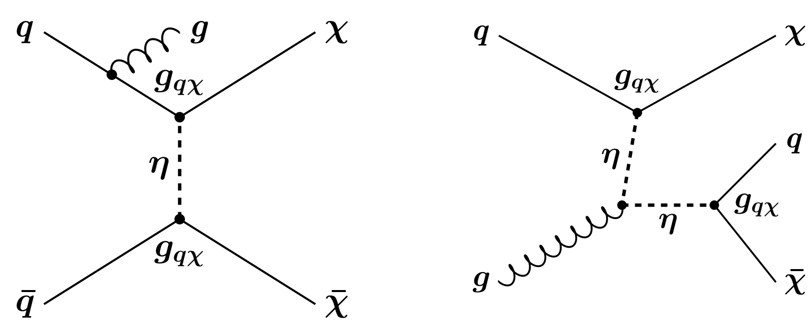
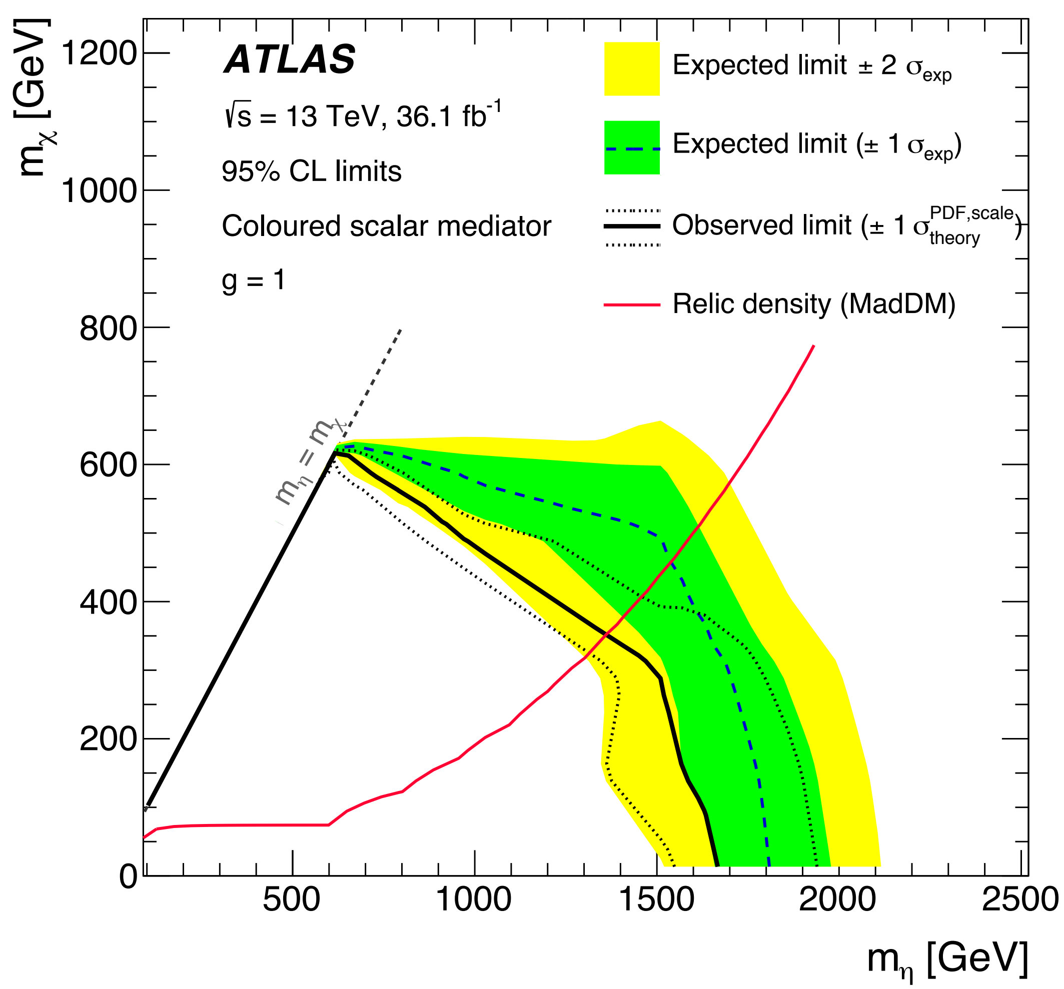
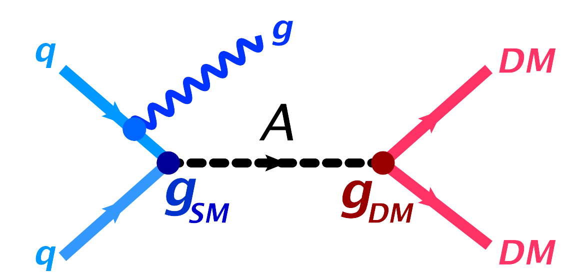
EXOT-2016-27

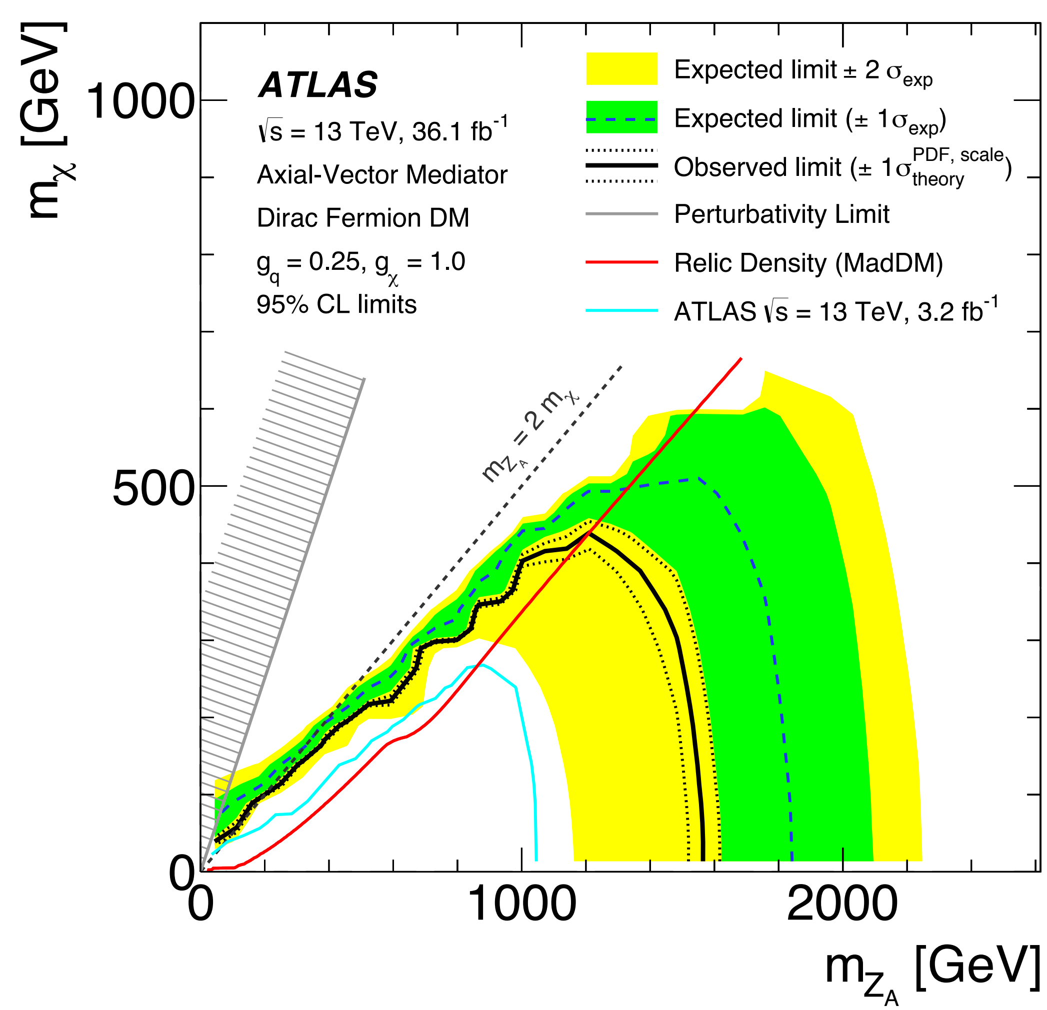
Scalar colored 't-channel'





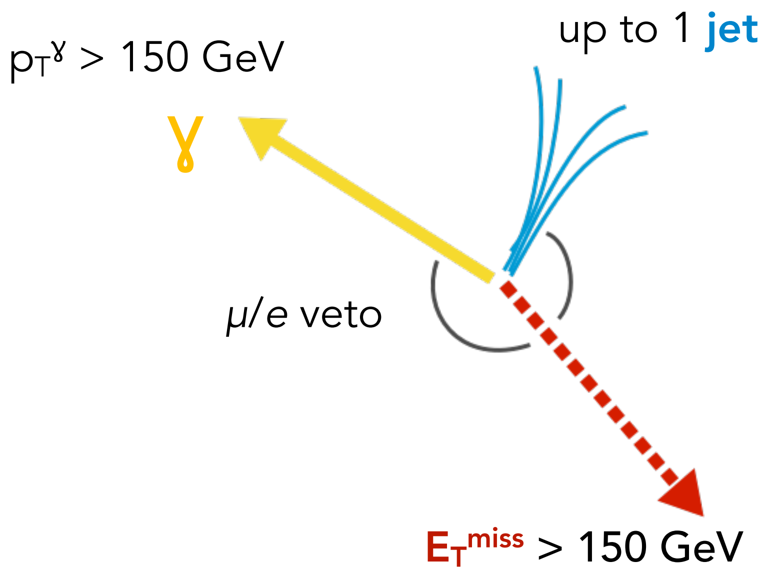
Spin-1 axial-vector s-channel





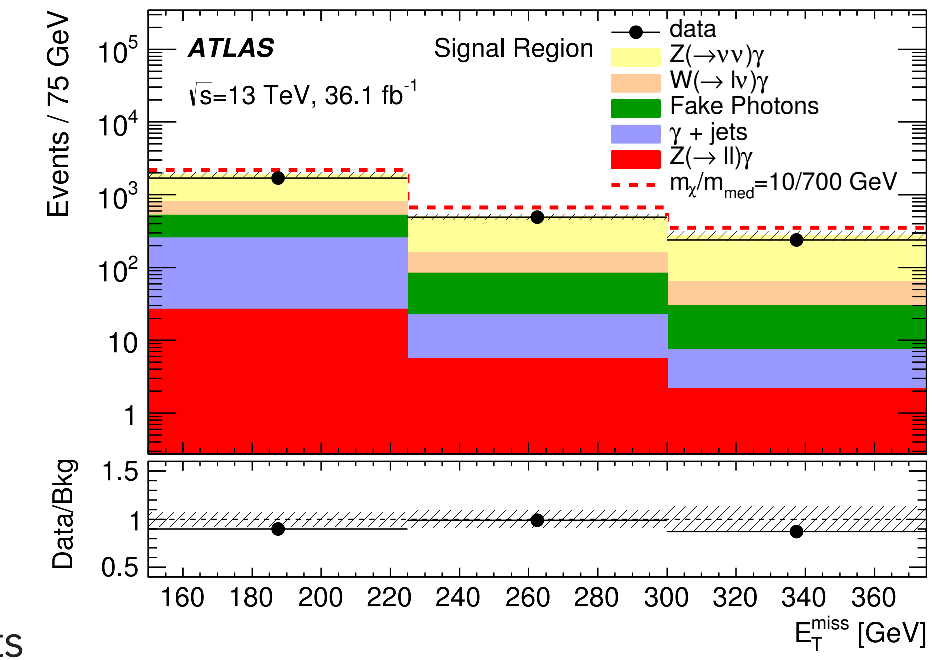
Mono-γ

EXOT-2016-32



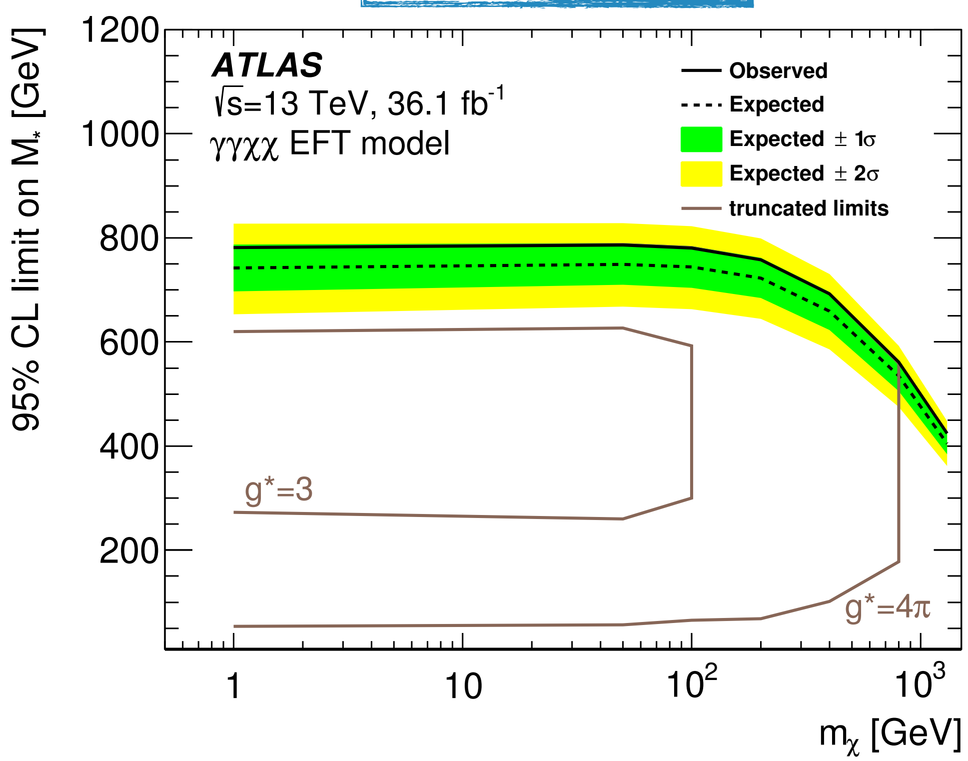
Clean signature

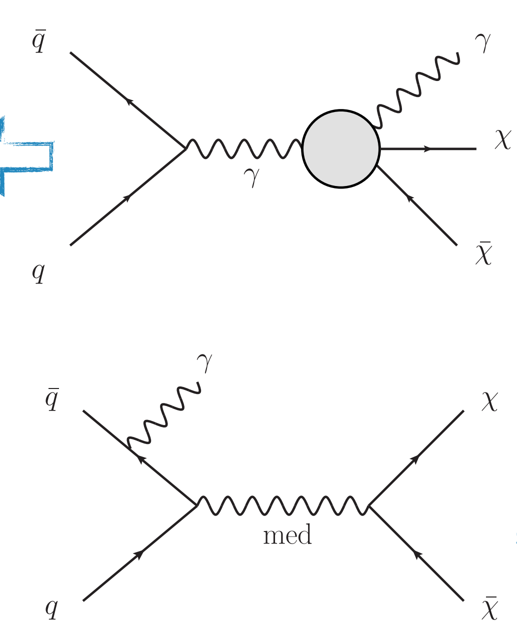
- triggering on photons -> go to lower MET
- Z(νν)γ irreducible background, estimated through Z(ll)γ control regions
- W(lν)γ estimated through W(lν)γ control region
- Backgrounds from fake photons (jets and electrons) entirely data-driven



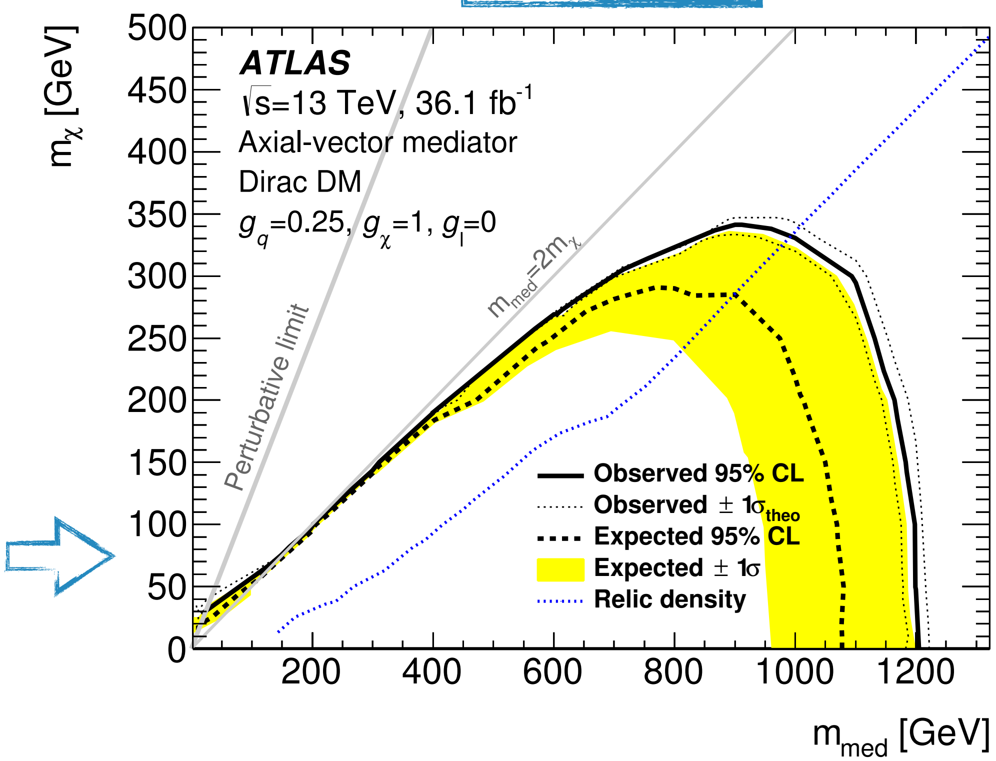
- Uncertainties: stat 4-10%, jet fake syst 1-5%

EFT γγχχ vertex

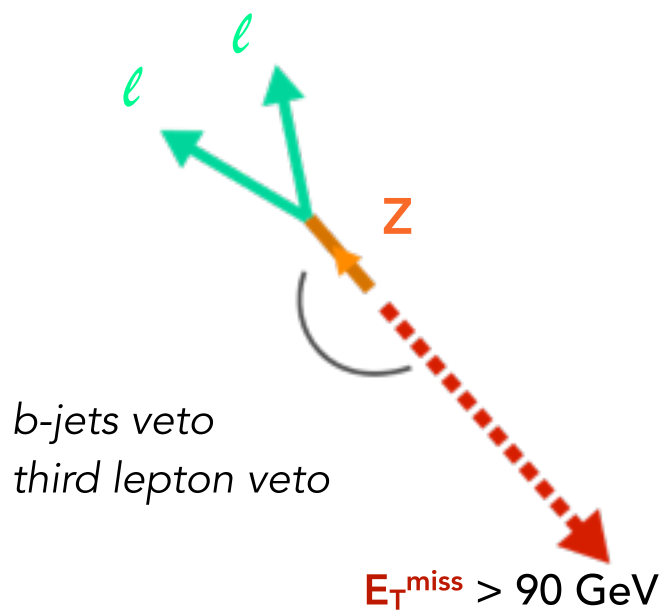




Axial-vector

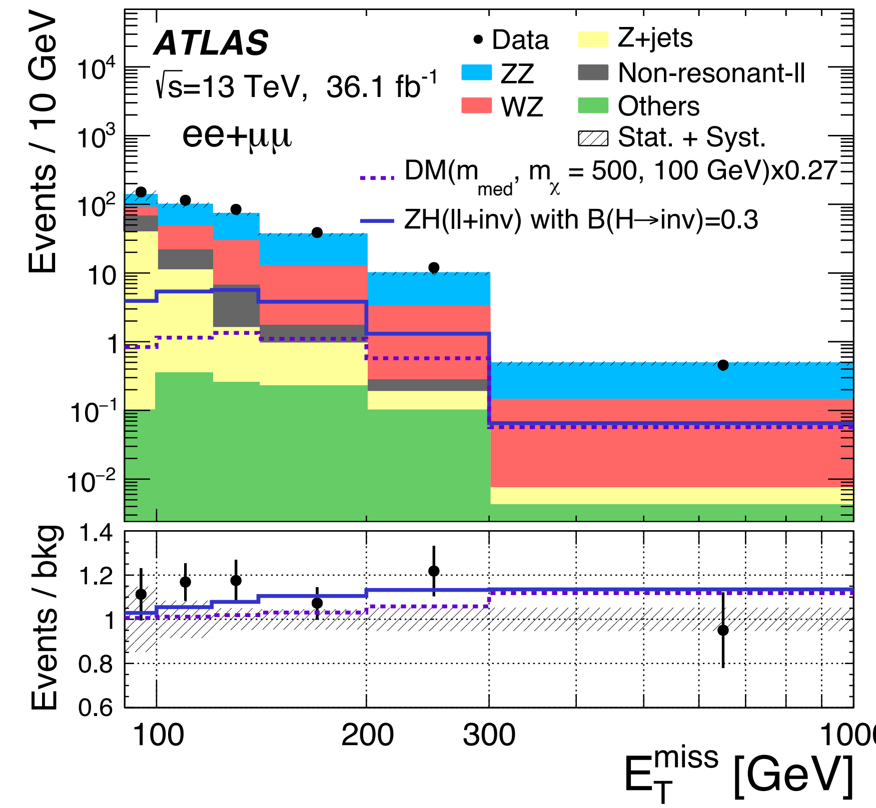


Mono-Z(ll)

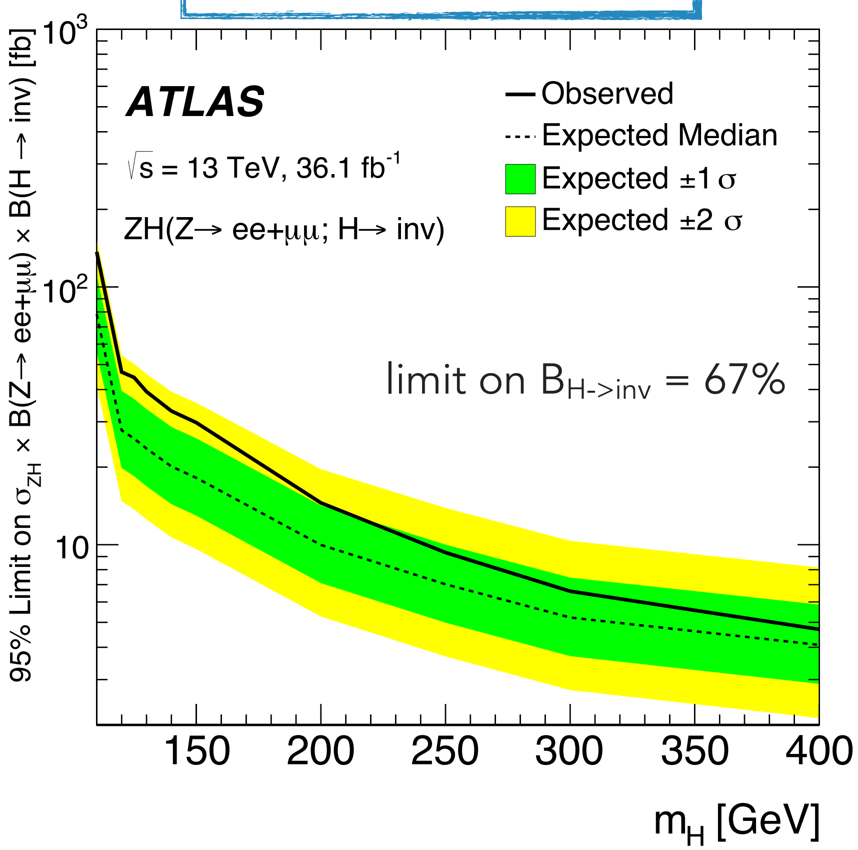


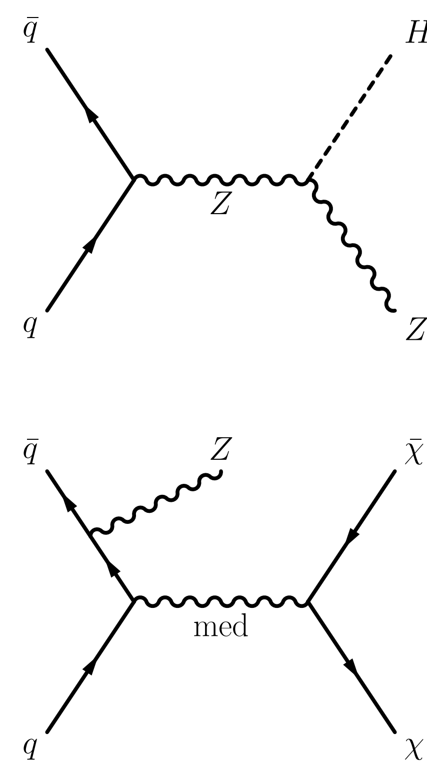
Another clean signature

- triggering on leptons -> go to even lower MET
- ZZ dominant background, estimated from simulation
- WZ normalized from control region
- Z+jets estimated through ABCD method
- largest uncertainties from lepton and jet scale, lepton efficiency

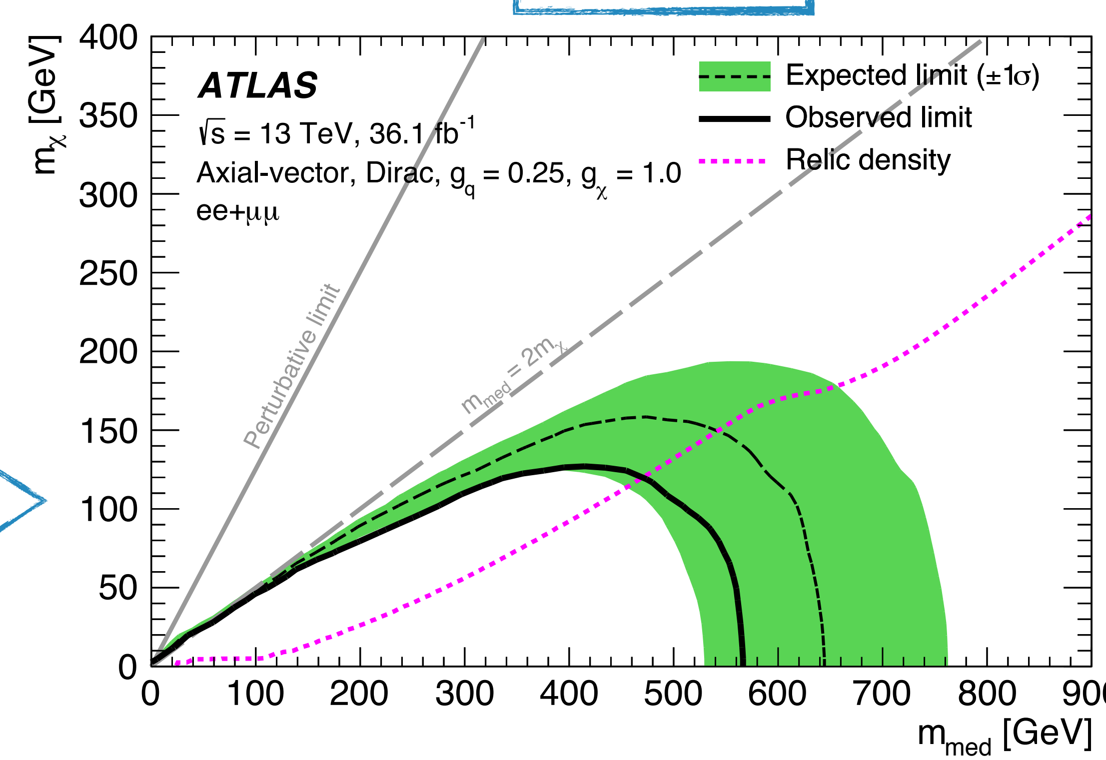


Invisible Higgs decays



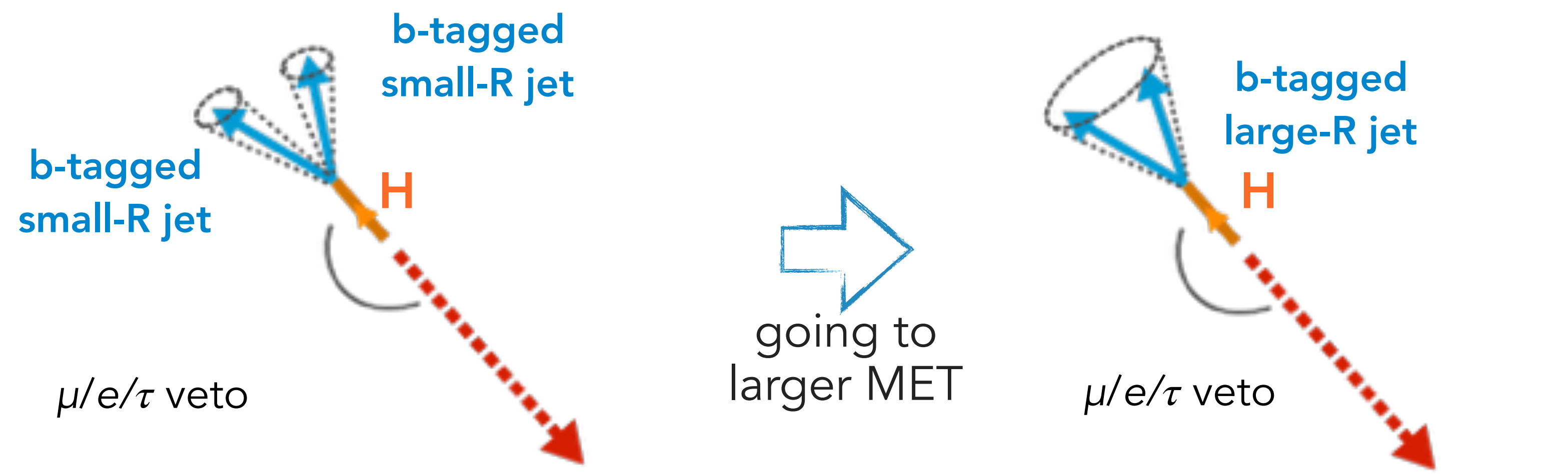


Axial-vector



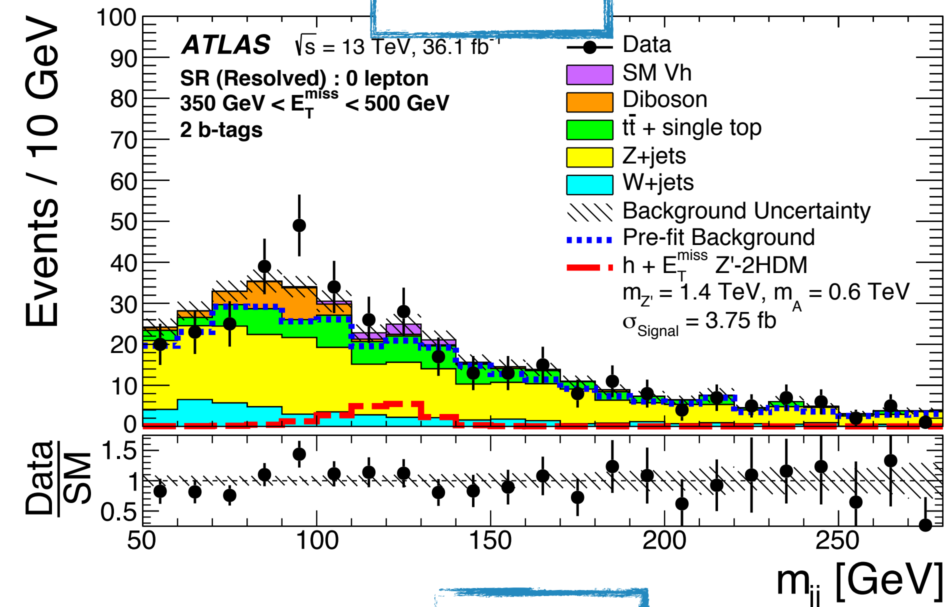
Mono-H(bb)

⇨ EXOT-2016-25



150 GeV< E_T^{miss} < 500 GeV E_T^{miss} > 500 GeV

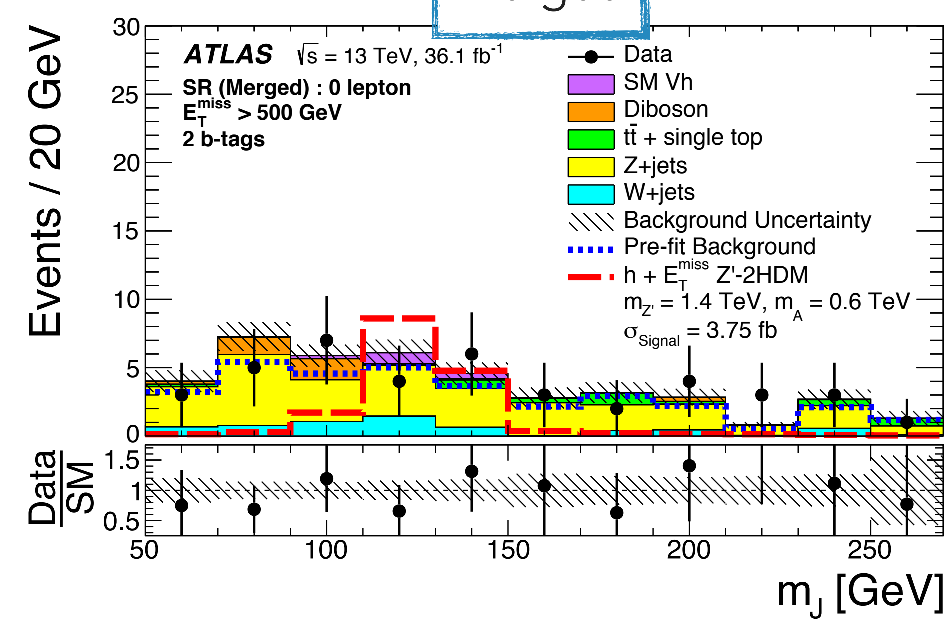
Resolved

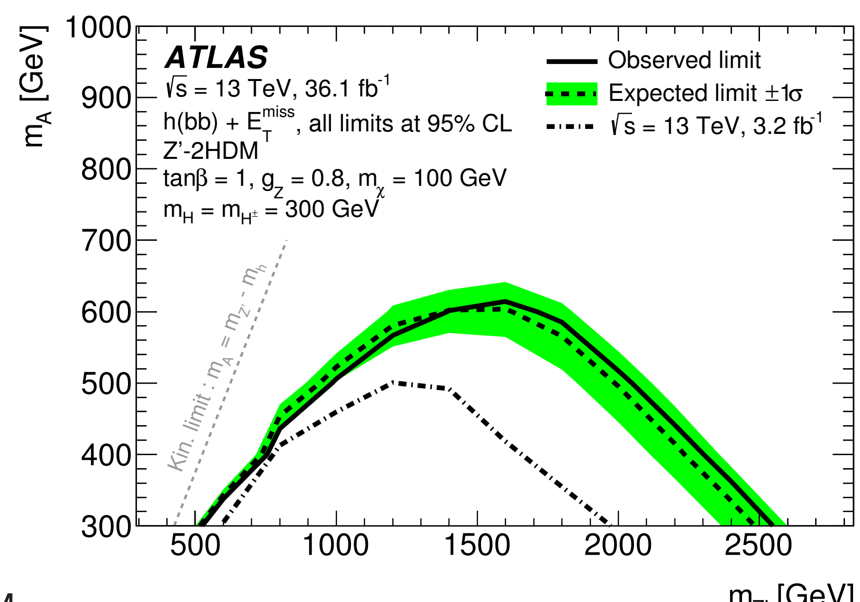


Higgs boson as event tagger

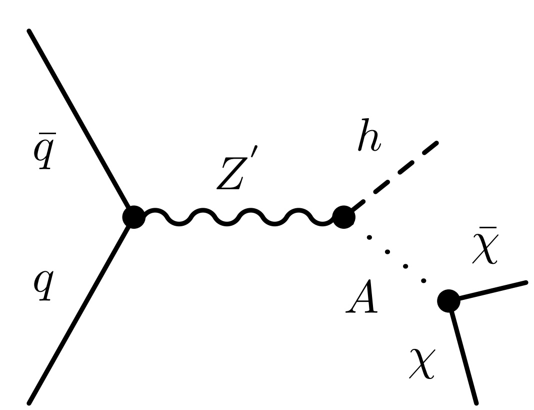
- trigger on MET
- top and Z+jets dominant backgrounds, W+jets smaller, normalization taken from lepton control regions
- other backgrounds (O(10%)) from MC, multi-jet data-driven
- shape fit on m_{jj} / m_J

Merged





Z′-2HDM

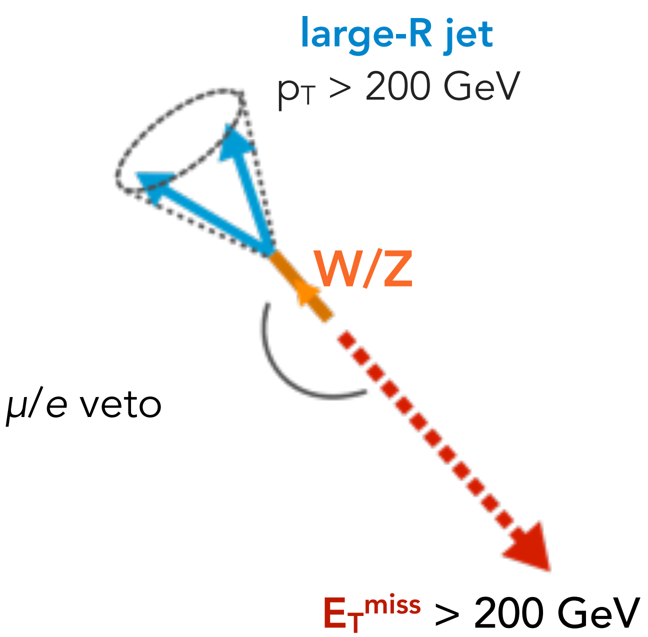


- Largest experimental uncertainties: b-tagging efficiency, jet energy scale and resolution, jet mass, MC statistics

⇨ for mono-H(γγ) see EXOT-2016-25

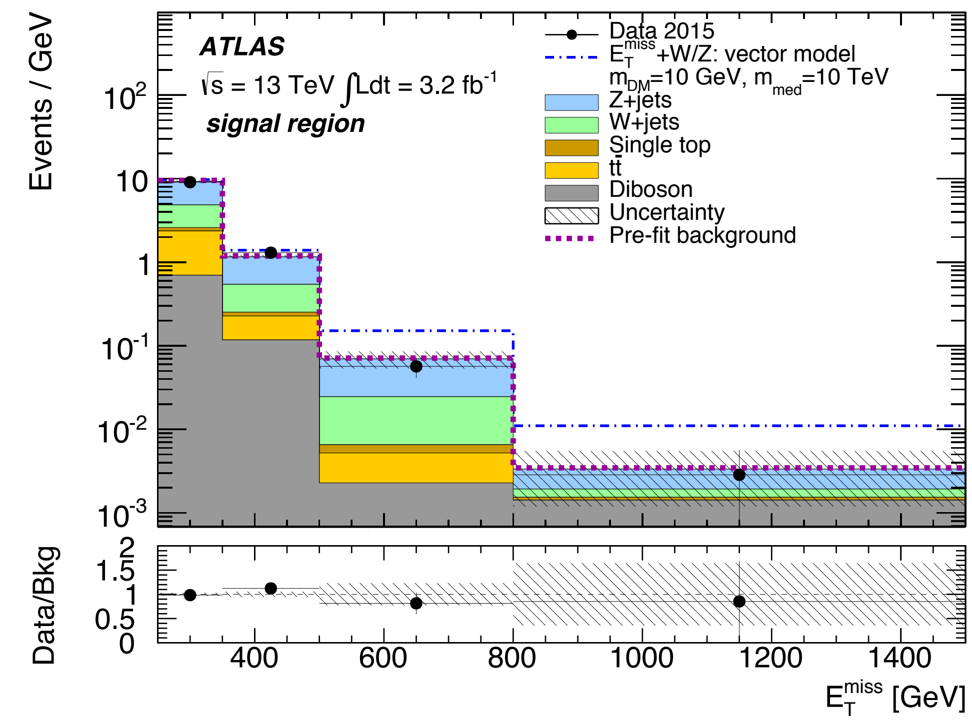
MONO-W/Z (HADRONIC)

EXOT-2015-08

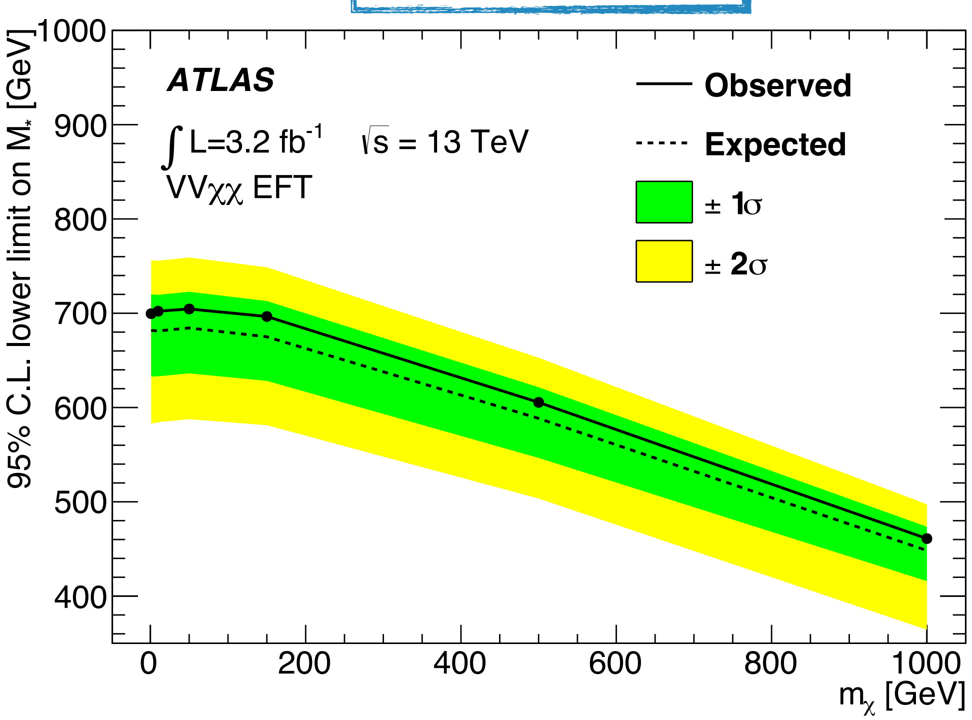


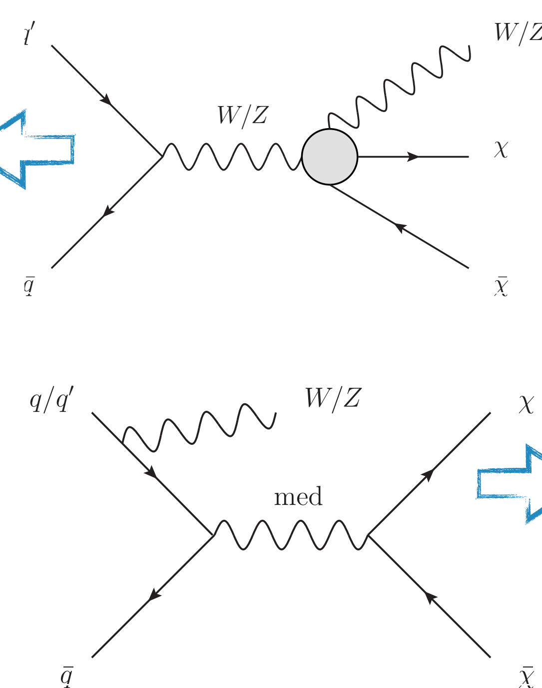
Large R-jets to capture W/Z hadronic decays

- anti-kT R=1.0
- trigger on MET
- Z(vv)/W(lv)+jets dominant background
- Z/W/top normalized in the CRs
- main uncertainty from modeling of the large-R jet observables

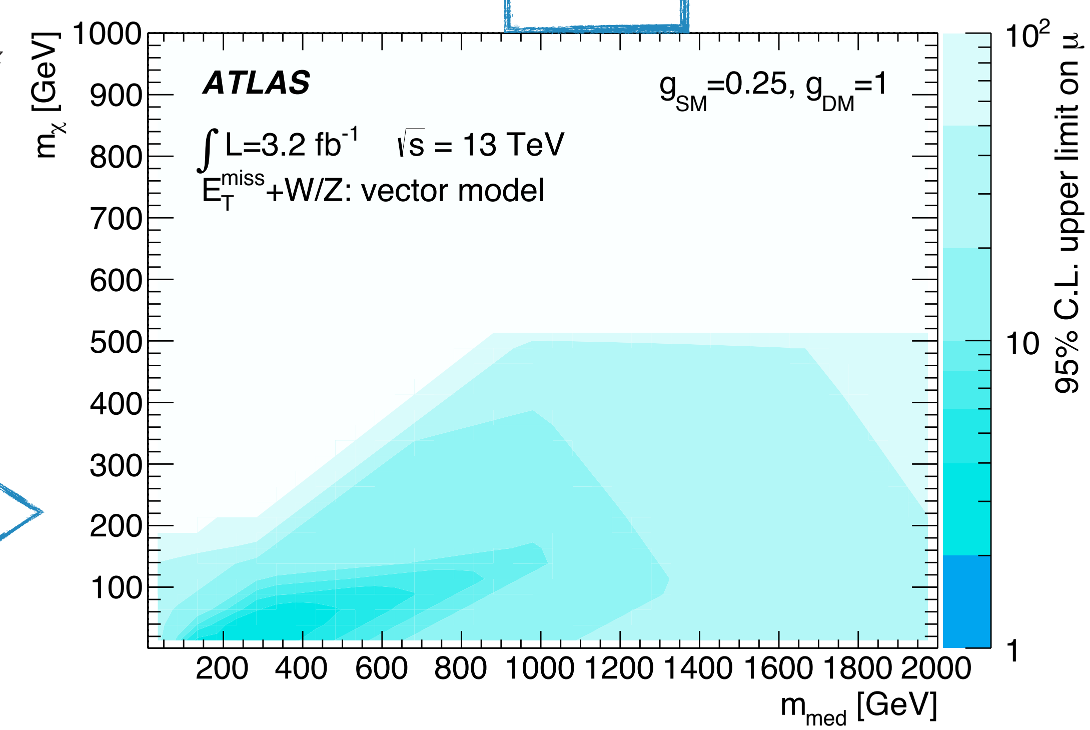


EFT VVχχ vertex





Vector

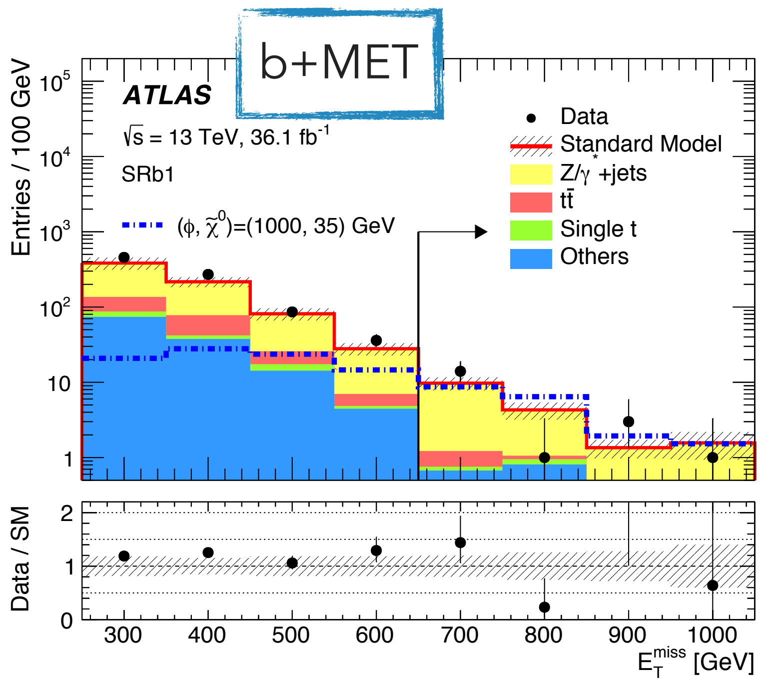


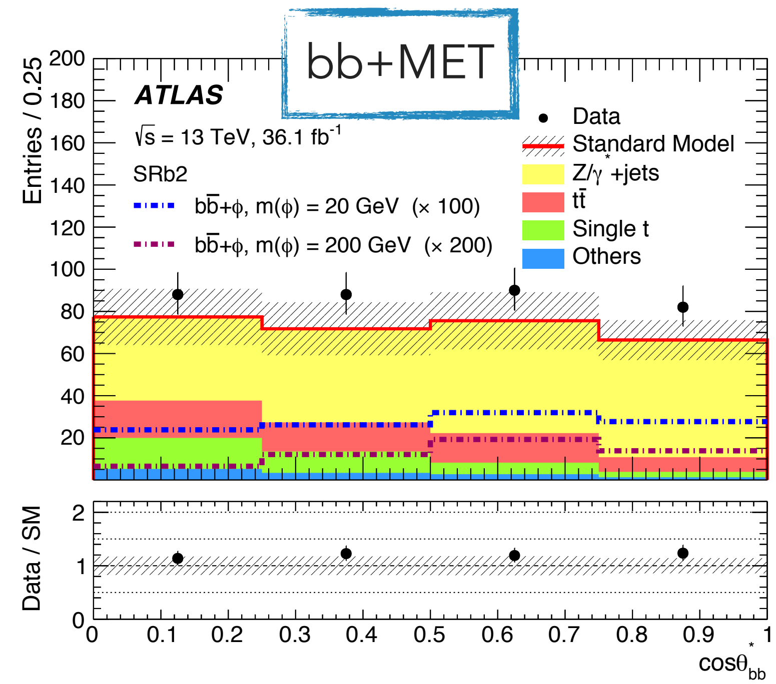
MONO-HF

NEW RESULT!

SUSY-2016-18

(Pseudo-)scalar mediators couple preferentially to heavy quarks ⇨ MET + heavy flavor quarks



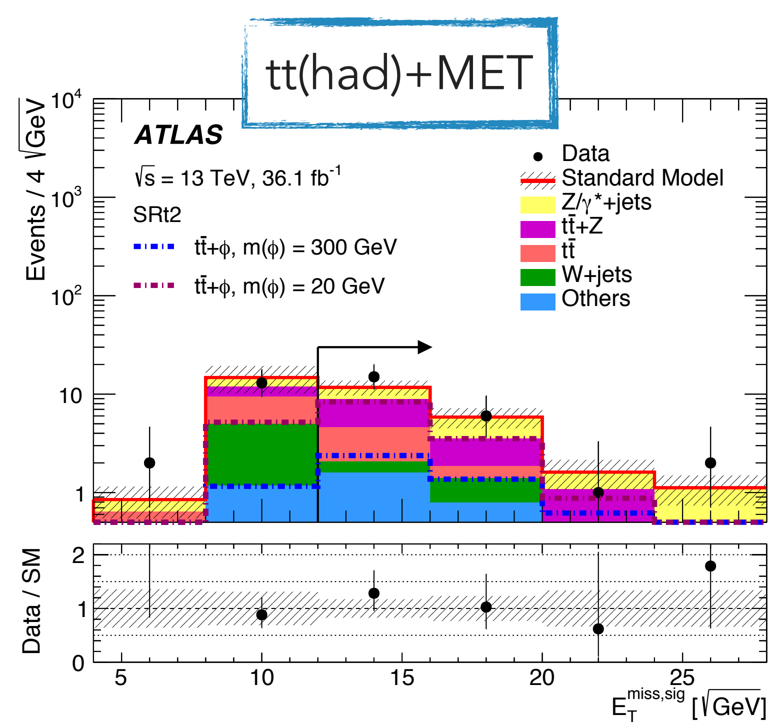


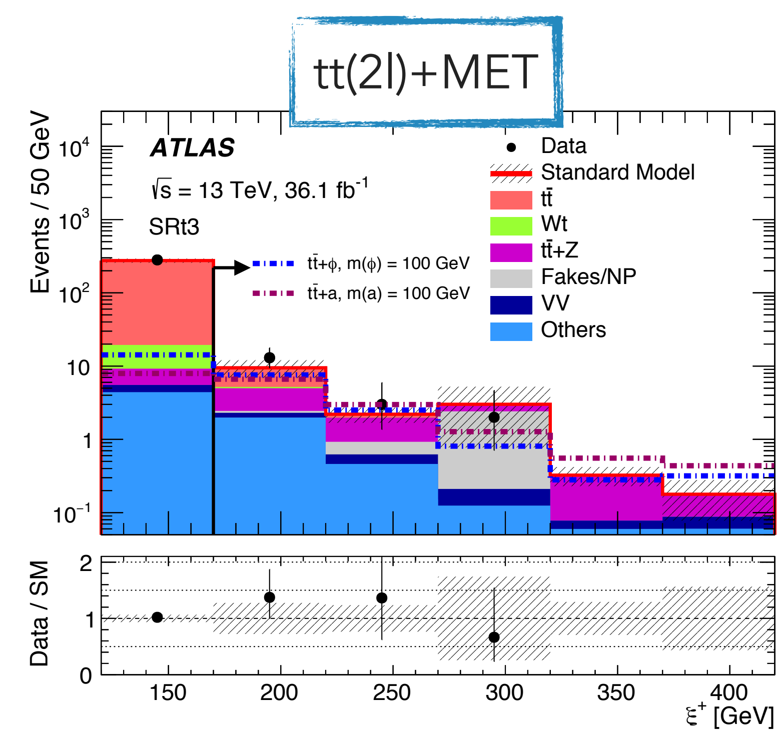
Target final states with bottom quarks:

- low jet multiplicities
- one or two b-tags
- large MET
- Z(νν)+jets dominant background

Target final states with top quarks:

- higher jet multiplicities for hadronic final states
- two OS leptons for dileptonic ttbar decays
- ttbar major background





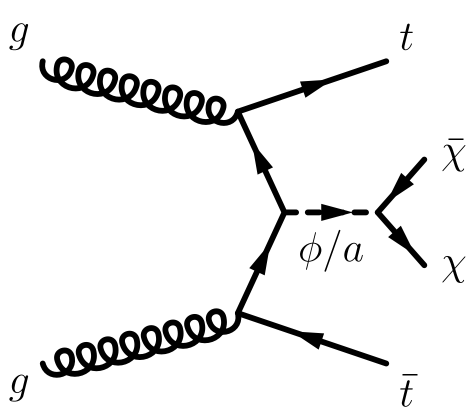
For semi-leptonic decay, see SUSY-2016-16

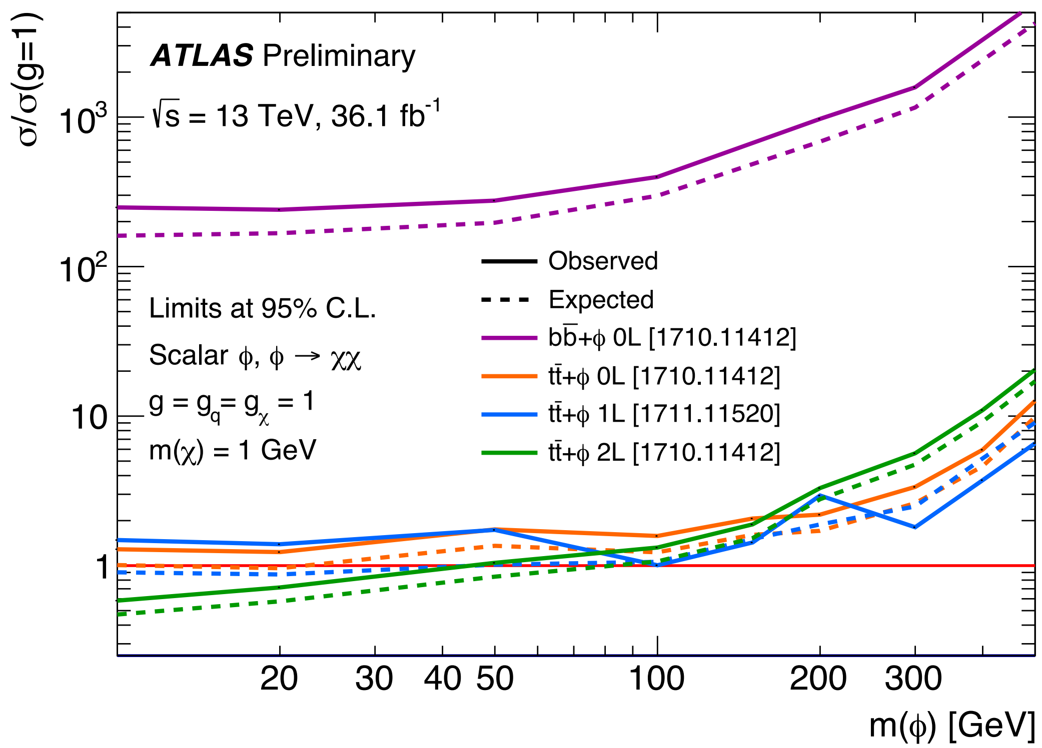
Mono-HF

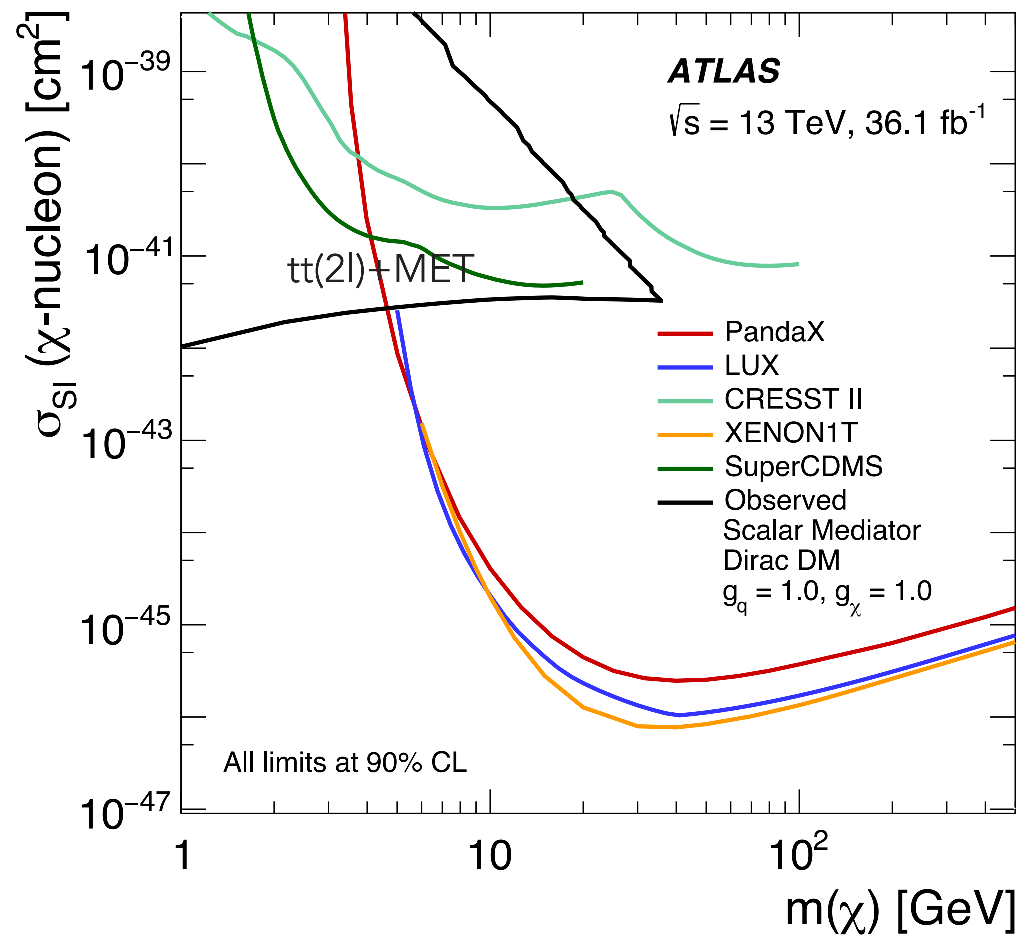
NEW RESULT!

⇨ SUSY-2016-18

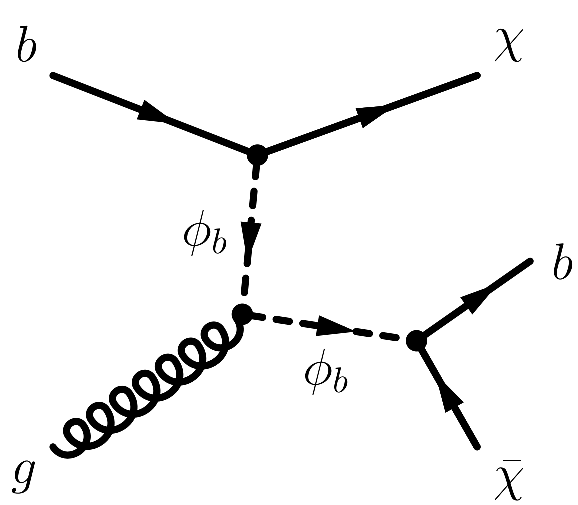
Scalar

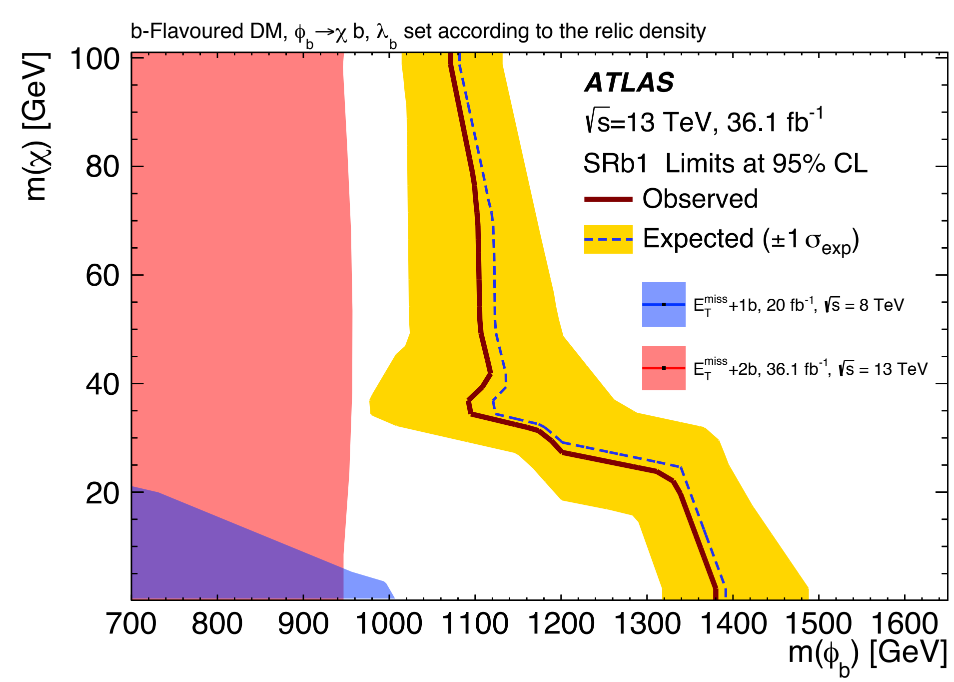






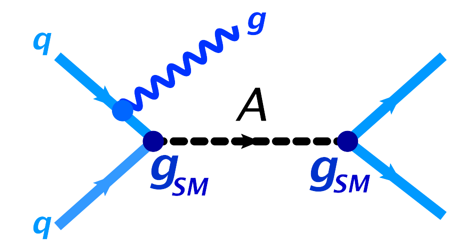
b-flavored DM





Di-Jet Searches

Searches for SM decays of mediator in s-channel spin-1 models



Bump in m_{jj} distribution ~ mass of the mediator
Can reach low couplings

Di-jet	Di-jet + ISR	Di-jet at Trigger Level
EXOT-2016-21	ATLAS-CONF-2016-070	ATLAS-CONF-2016-030

Di-jet (EXOT-2016-21)

Classic di-jet search

Rely on single jet triggers

Sensitive to resonance masses in the between 1TeV-2.6 TeV

Di-jet + ISR (ATLAS-CONF-2016-070)

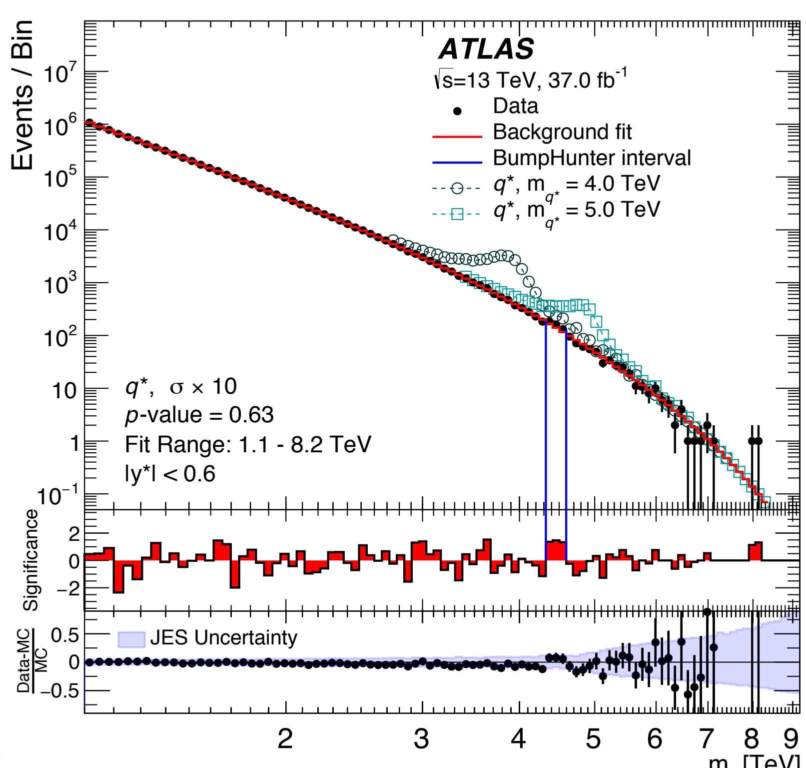
Trigger on ISR object to reach lower resonance masses

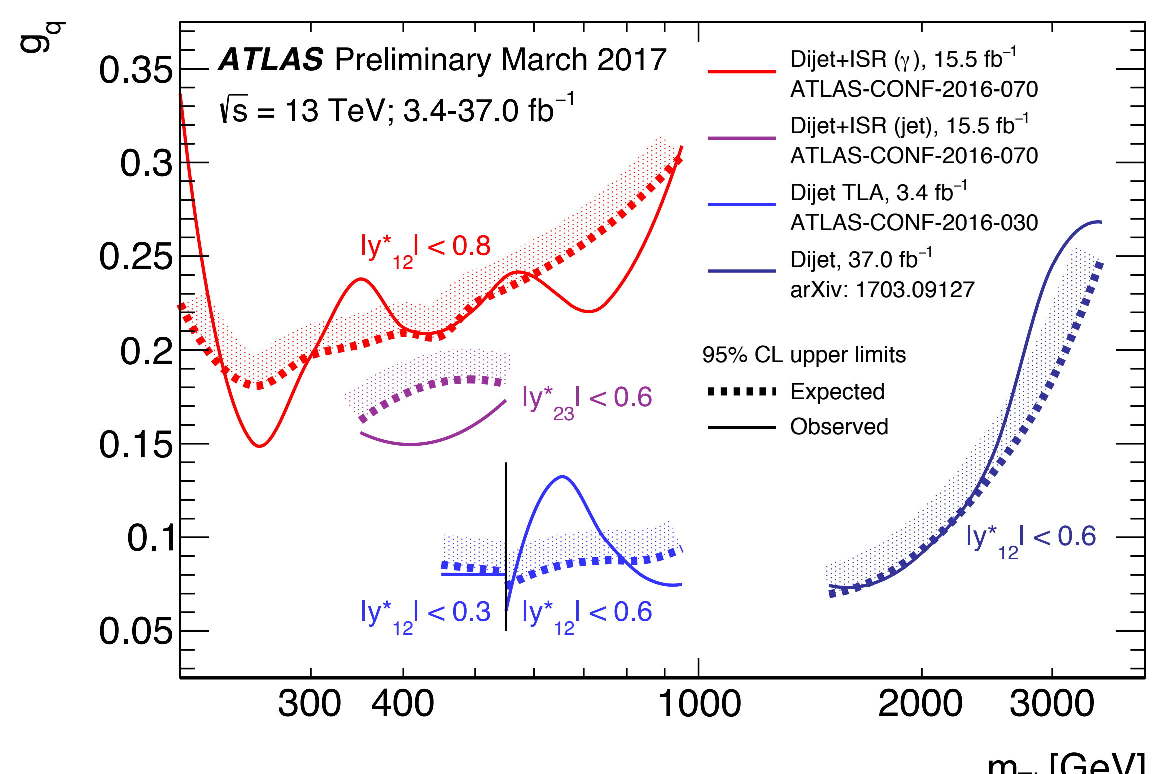
Sensitive to masses 200GeV-1TeV

Di-jet at Trigger Level (ATLAS-CONF-2016-030)

Overcome single jet trigger prescale limitations by reducing amount of stored information

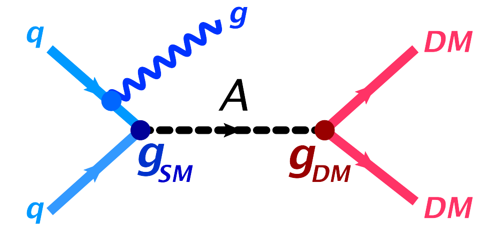
Sensitive to masses 450GeV-1TeV

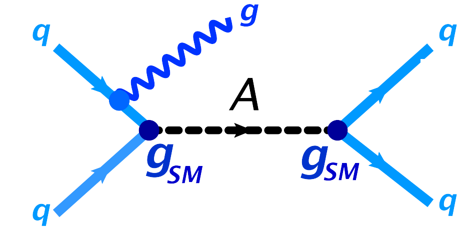




Mono-X vs Di-X

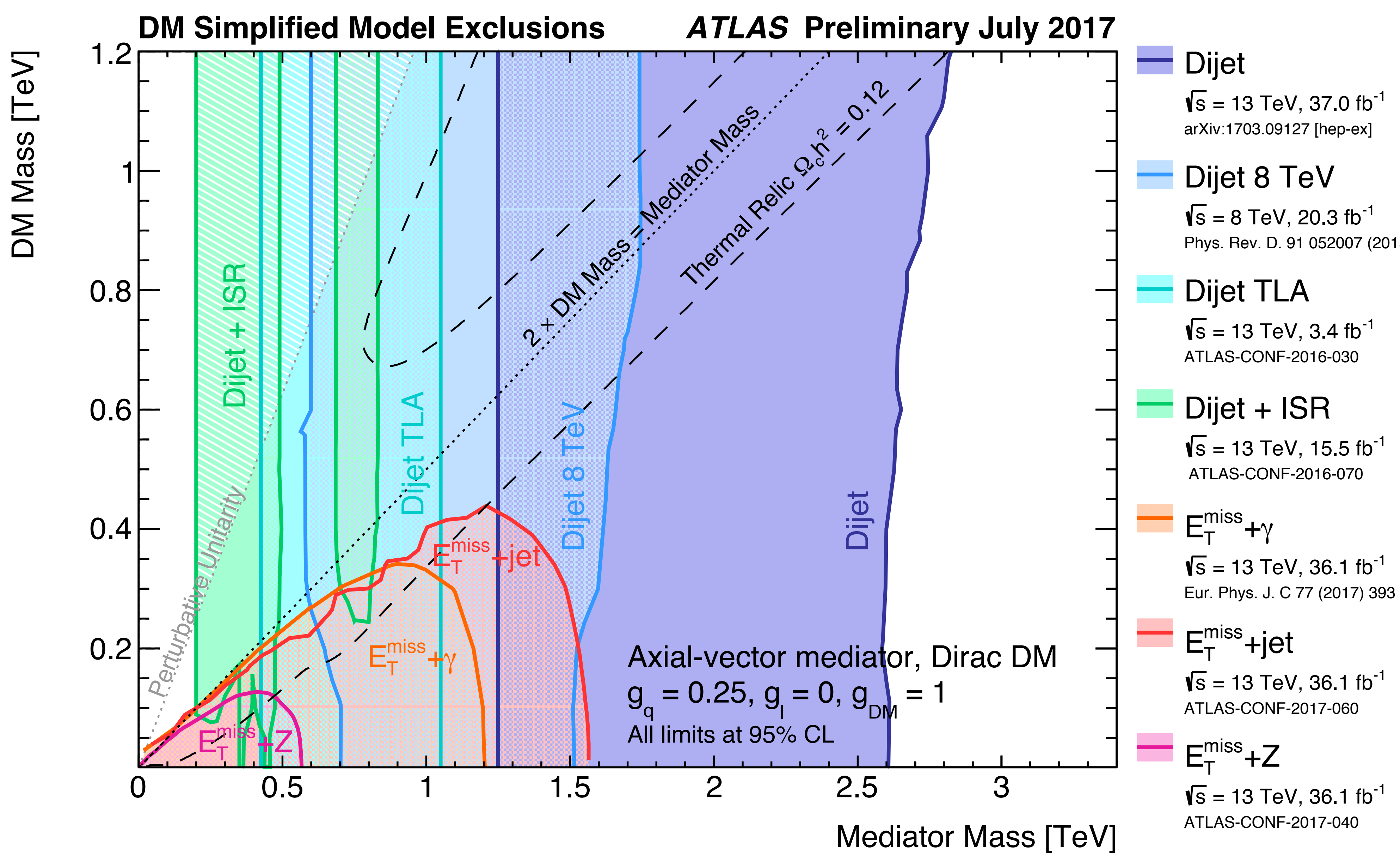
Mono-X





Di-X

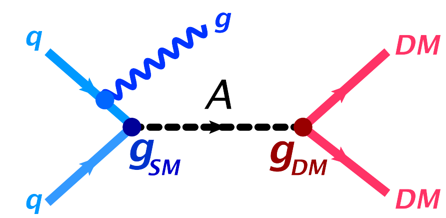
Summary-Plots

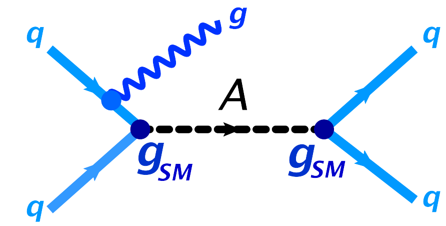


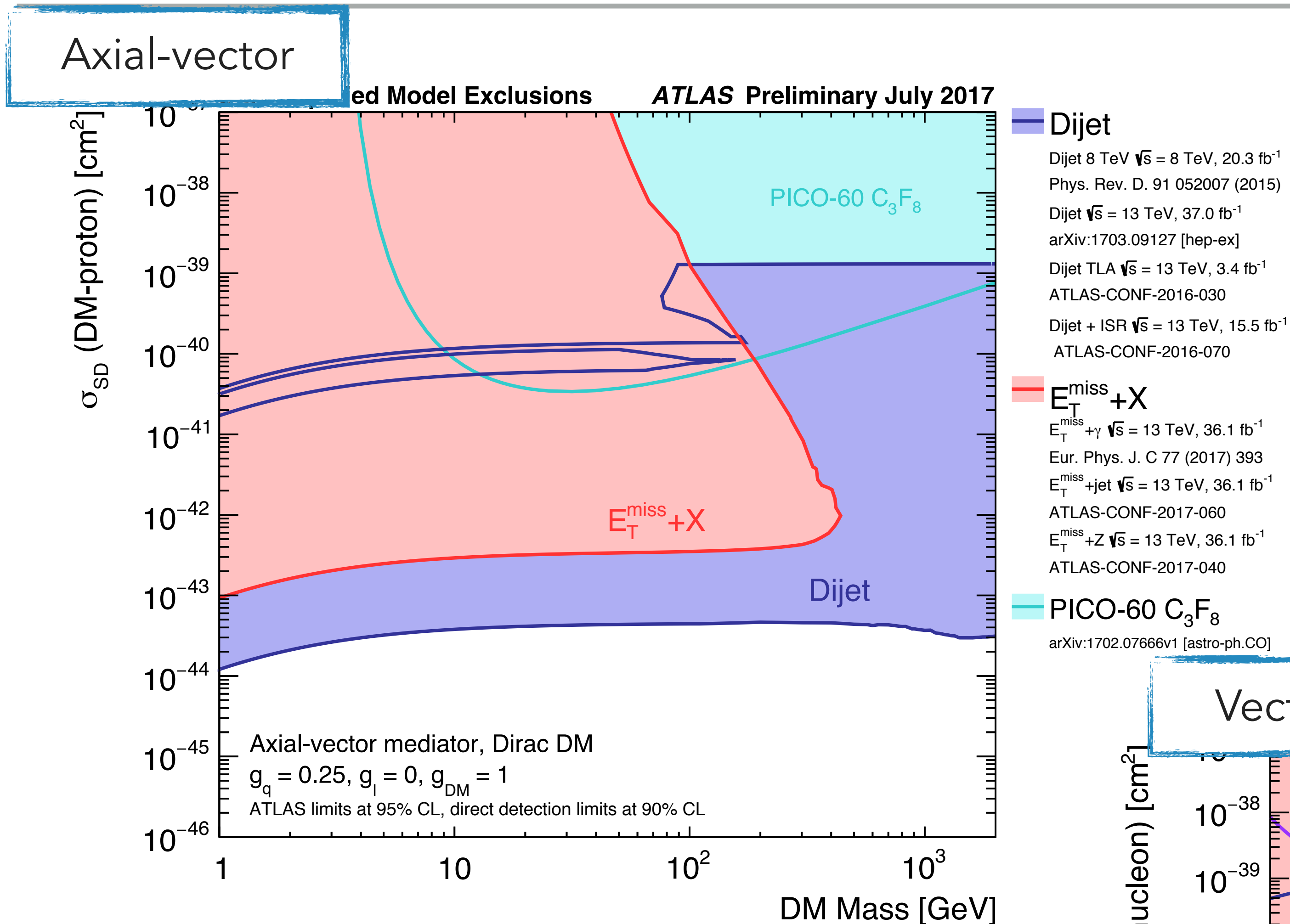
$$g_{DM} = 1.0\,, \quad g_{SM} = 0.25$$

Different coupling choices determine different interplay between Mono-X and Di-X

ATLAS VS DIRECT DETECTION

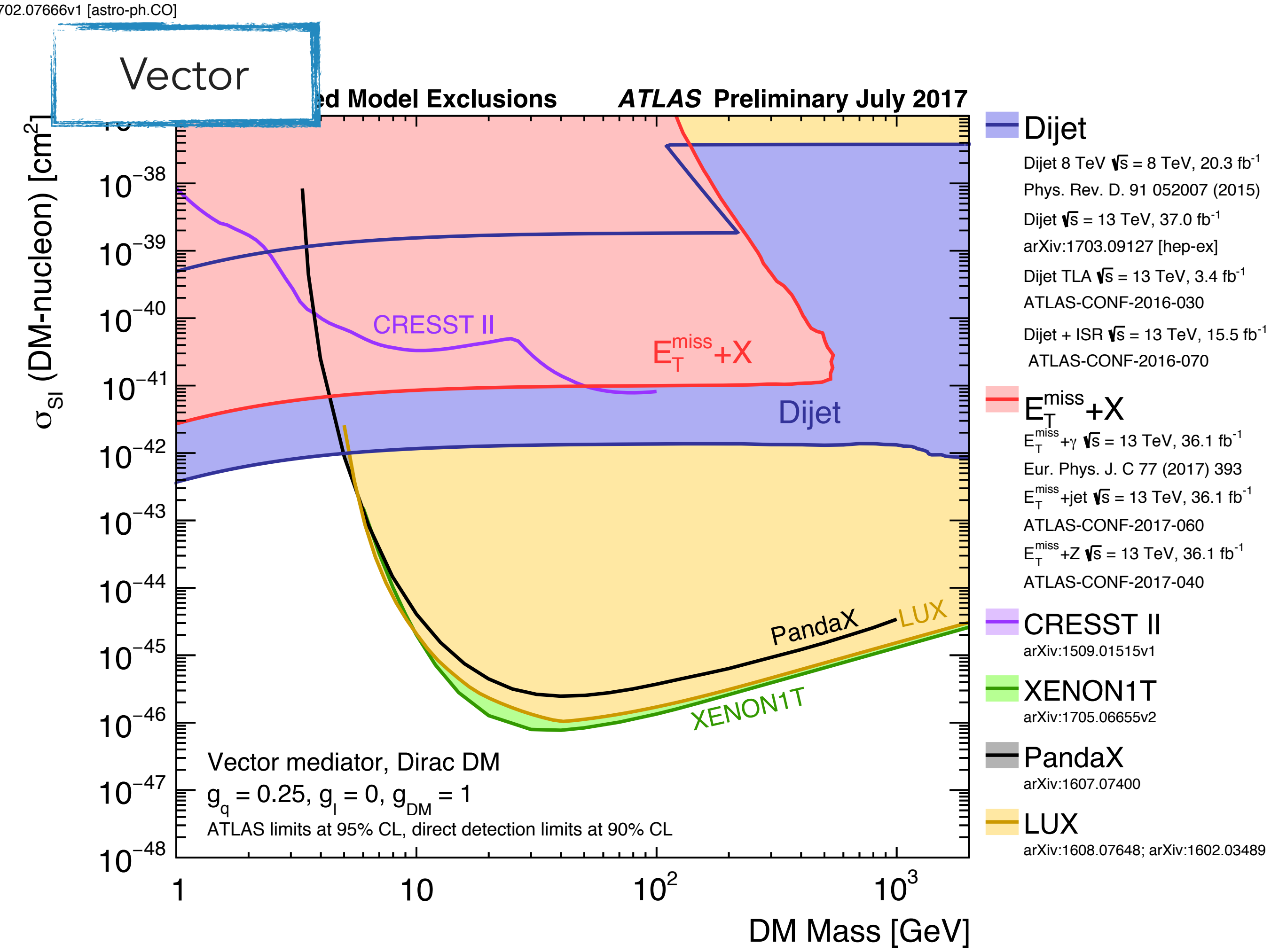






ATLAS results translated to direct detection plane (arXiv:1603.04156)

Nice complementarity between ATLAS and direct detection experiments



ATLAS results limited to model and coupling assumptions

Can exploit complementarity between channels (MET+X, di-jet) to cover coupling parameter space

Conclusions

- Extensive program of DM searches at the LHC
  - Many searches and a variety of DM models
  - A summary paper of ATLAS DM searches to come soon…
- New developments in view of full Run-2 dataset and beyond
  - interpretation with multi-signature models, such as 2HDM+Pseudo-Scalar
  - optimization of search techniques

CONCLUSIONS

Is  *the*  *to* *discovery*  *?*

BACK-UP

MONO-JET

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EXOT-2016-27