Search for dark matter candidates produced in $Z(\ell\ell)+E_{\mathrm{T}}^{\mathrm{miss}}$ events with the ATLAS detector at the LHC

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Puzzle of Dark Matter Conference
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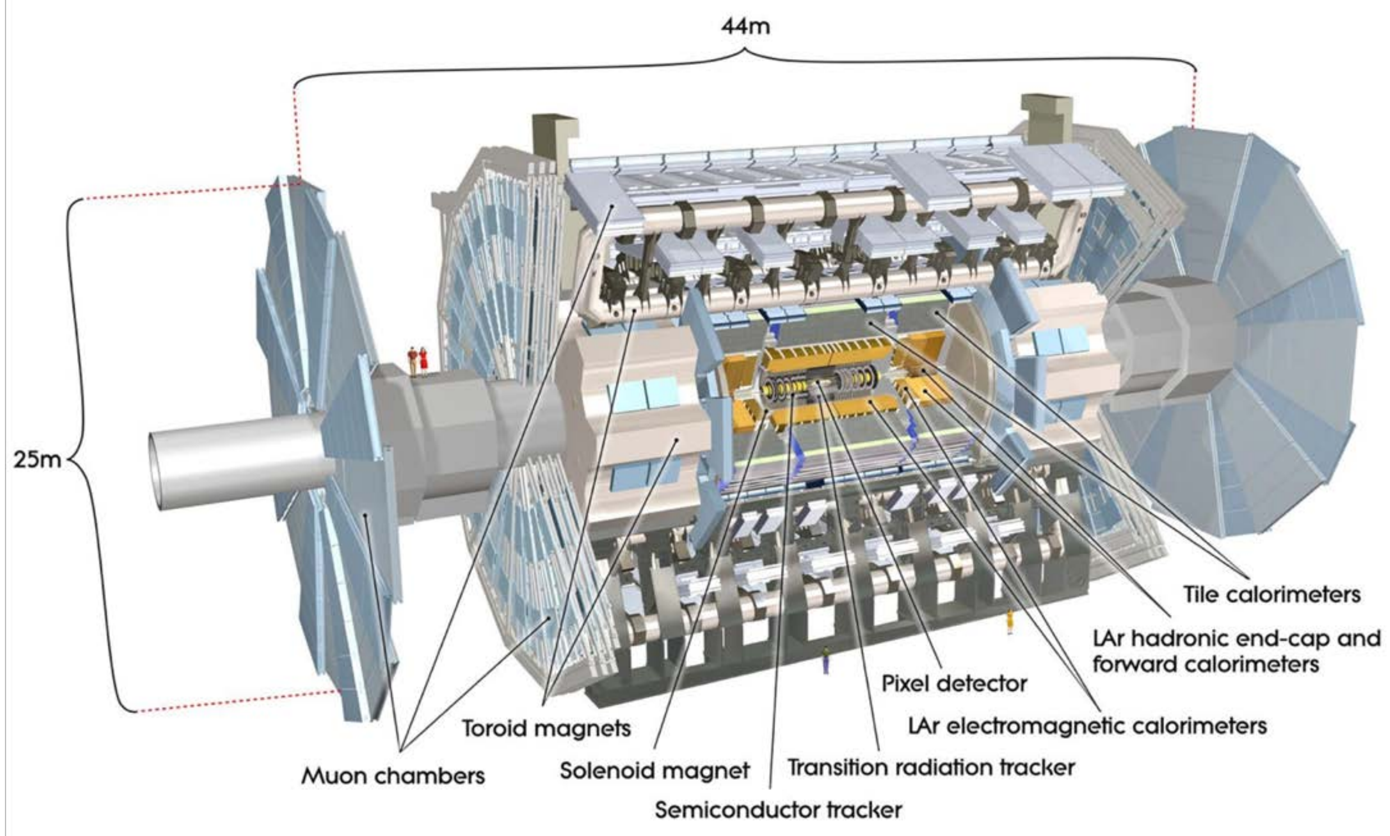
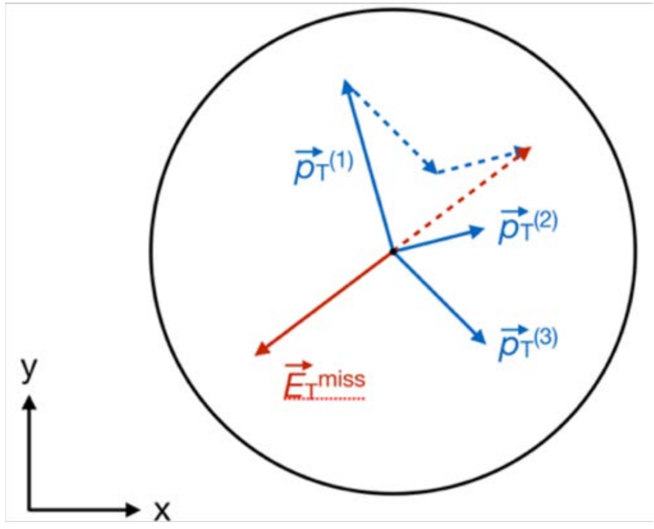
ATLAS EXPERIMENT

Searching for dark matter in the ATLAS detector

- The LHC has been delivering 13 TeV proton-proton collisions to the **ATLAS detector** since 2015
  - Analysis of the full 2015-2018 Run 2 dataset (**149 fb^{-1}**) has started and is **ongoing**
  - This talk will cover **results with the 2015+2016 dataset** with integrated luminosity = **36.1 fb^{-1}**

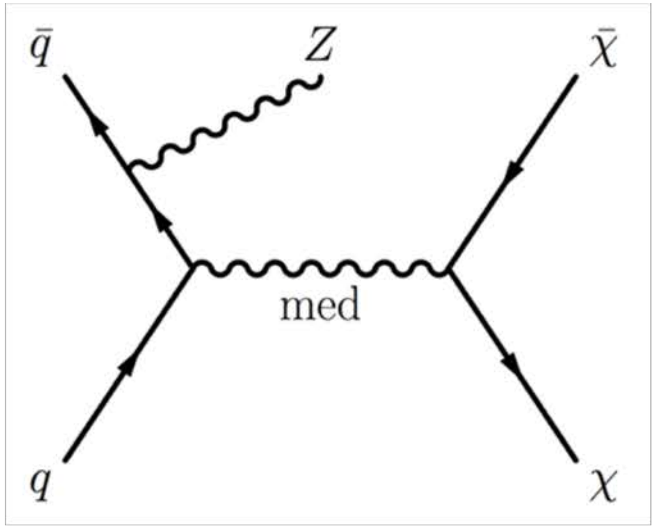




Invisible dark matter will manifest in the **missing transverse momentum, $\vec{E}_T^{miss}$**

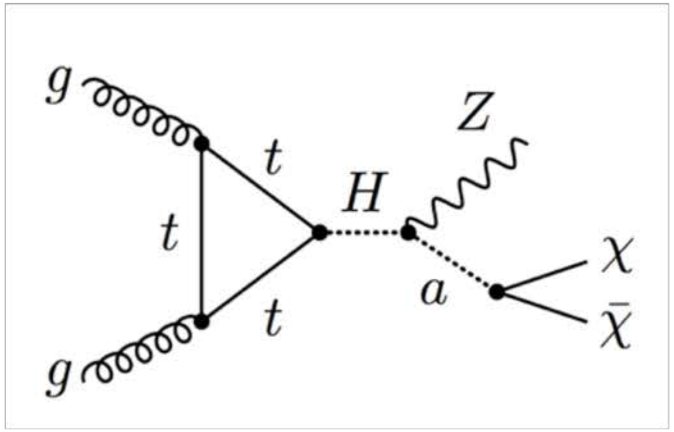
Signal models

- The **dark matter models** studied are coordinated by the LHC Dark Matter Working Group
- For this particular analysis we study "**mono-*Z***" events with $\boldsymbol{Z(\ell\ell)+E_T^{miss}}$ final states ($\boldsymbol{\ell\ell}$ **= *ee* or *μμ***)



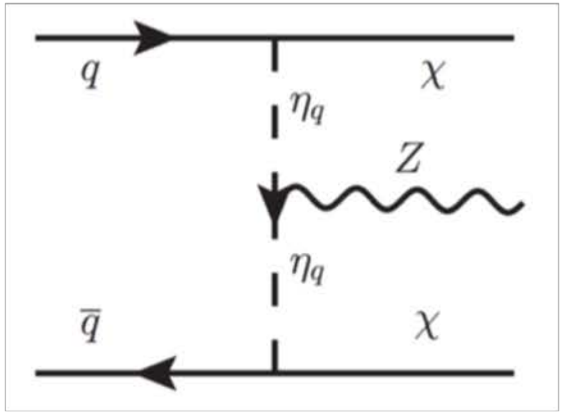
***s*-channel simplified models**

"Standard" benchmark DM model in Run 2



Two-Higgs-doublet + pseudoscalar model

Newer benchmark, more theoretically complete



***t*-channel simplified models**

To be studied

Event selection

- Event selection criteria are optimized to isolate potential signal events with **large E_T^{miss} recoiling against $Z \rightarrow ee$ or $Z \rightarrow \mu\mu$**, while also **reducing backgrounds**

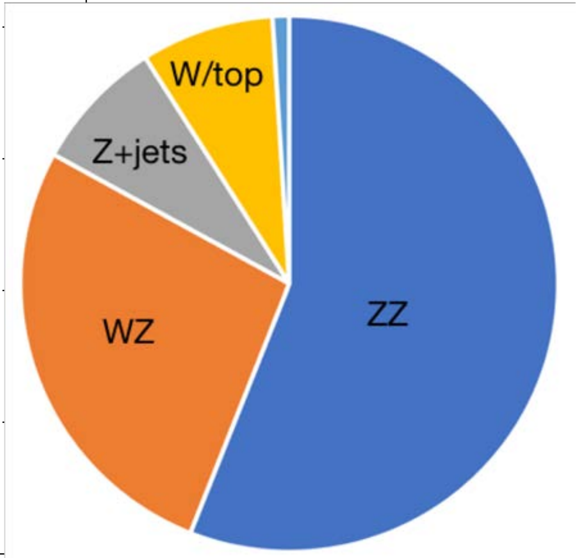
Selection criteria	Background reduced
Exactly one $\ell\ell$ (= ee or μμ) pair with opposite charge	
Veto events with 3rd lepton (e or μ) with $p_T > 7$ GeV	WZ
Z mass window: $76 < m_{\ell\ell} < 106$ GeV	WW/Wt/tt/Z(ττ)
$E_T^{miss} > 90$ GeV	Z+jets
$\Delta R(\ell\ell) < 1.8$	Z+jets, WW/Wt/tt/Z(ττ)
$\Delta\phi(Z, E_T^{miss}) > 2.7$	Z+jets, WW/Wt/tt/Z(ττ)
$\lvert p_T(\ell\ell) - \lvert \vec{E}_T^{miss} + \vec{p}_T(jets)\rvert \rvert / p_T(\ell\ell) < 0.2$	Z+jets
$E_T^{miss}/H_T > 0.6$ ($H_T = p_T(jets) + p_T(\ell_1) + p_T(\ell_2)$)	Z+jets
b-jet veto	tt

Backgrounds

- Standard Model **background processes** also produce $Z(\ell\ell)+E_T^{miss}$, mimicking the DM signal of interest

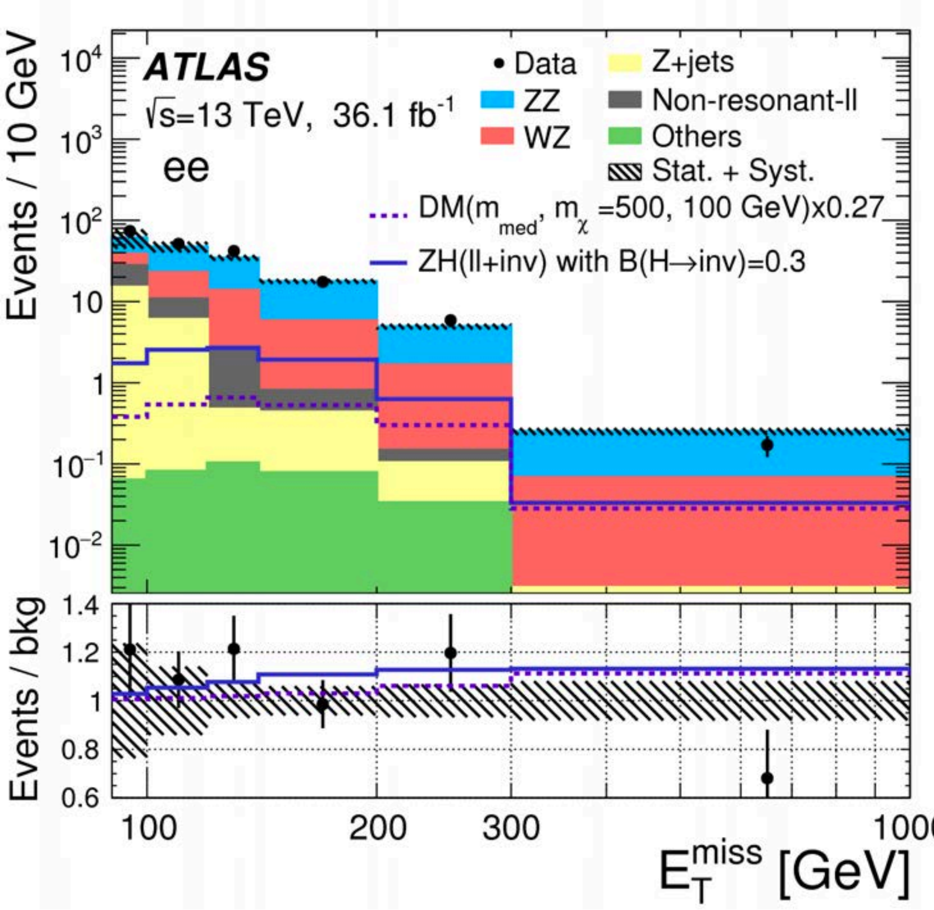
Background	Source	Estimation
ZZ	$ZZ \rightarrow \ell\ell\nu\nu$, irreducible	MC
WZ	$WZ \rightarrow \ell\nu\ell^+\ell^-$ ℓ from W not reconstructed	Data (yield), MC (shape)
Z+jets	Z(ee) / Z(μμ) + jets jets mis-measured as fake E_T^{miss}	Data (yield), MC (shape)
W/top	WW / Wt / tt / Z(ττ) → $\ell^+\nu\ell^-\nu$ $\ell\ell$ do not come from a Z	Data
W+jets	$W(\ell\nu)$ + jets ℓ mis-identified from a jet	Data
ttV/ttVV/VVV (V=Z,W)	e.g. ttW → $(\ell^+\nu b)(q_1q_2b)(\ell^-\nu)$	MC

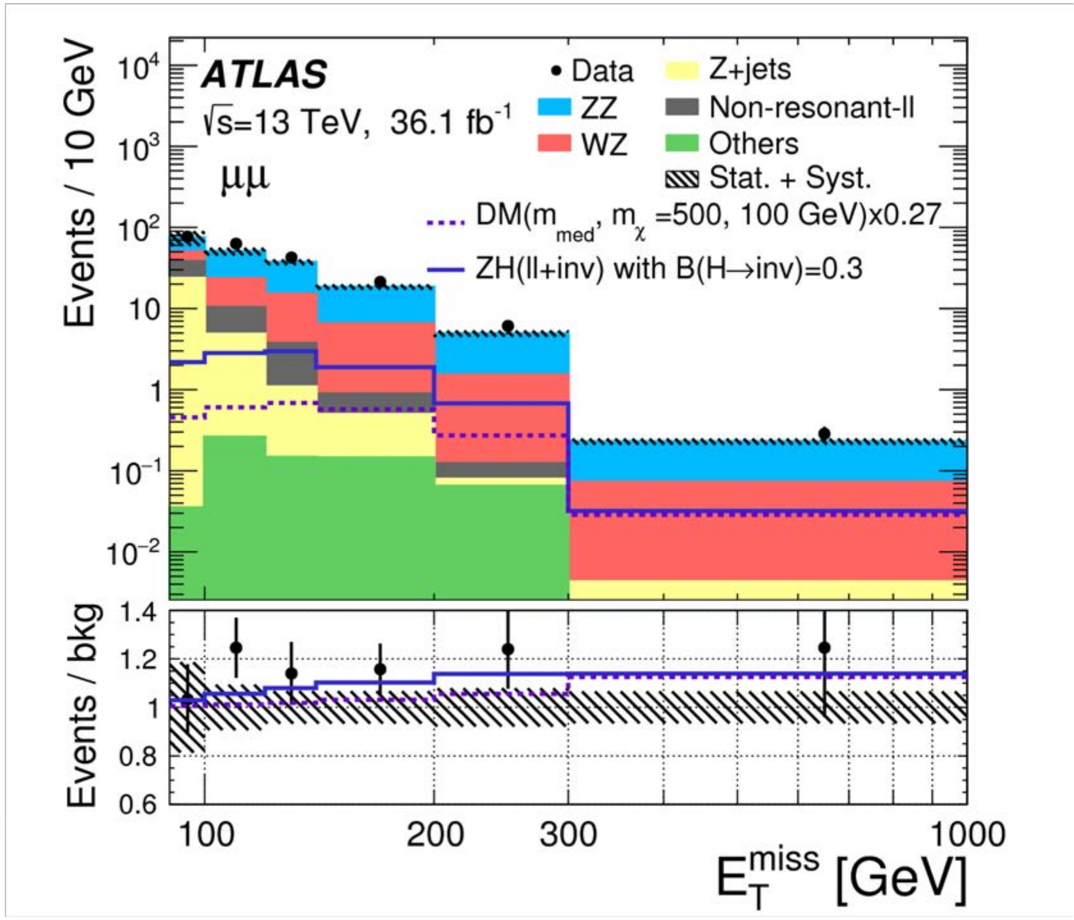
% in signal region



E_T^{miss} in signal region

- Perform **statistical analysis** on signal region
- Inputs: observed data, background estimates, all sources of systematic errors
- Small overall excess in μμ channel => **worse observed limits** compared to expected





- Since **no significant excess** is observed, we set **limits** using the CL_s method

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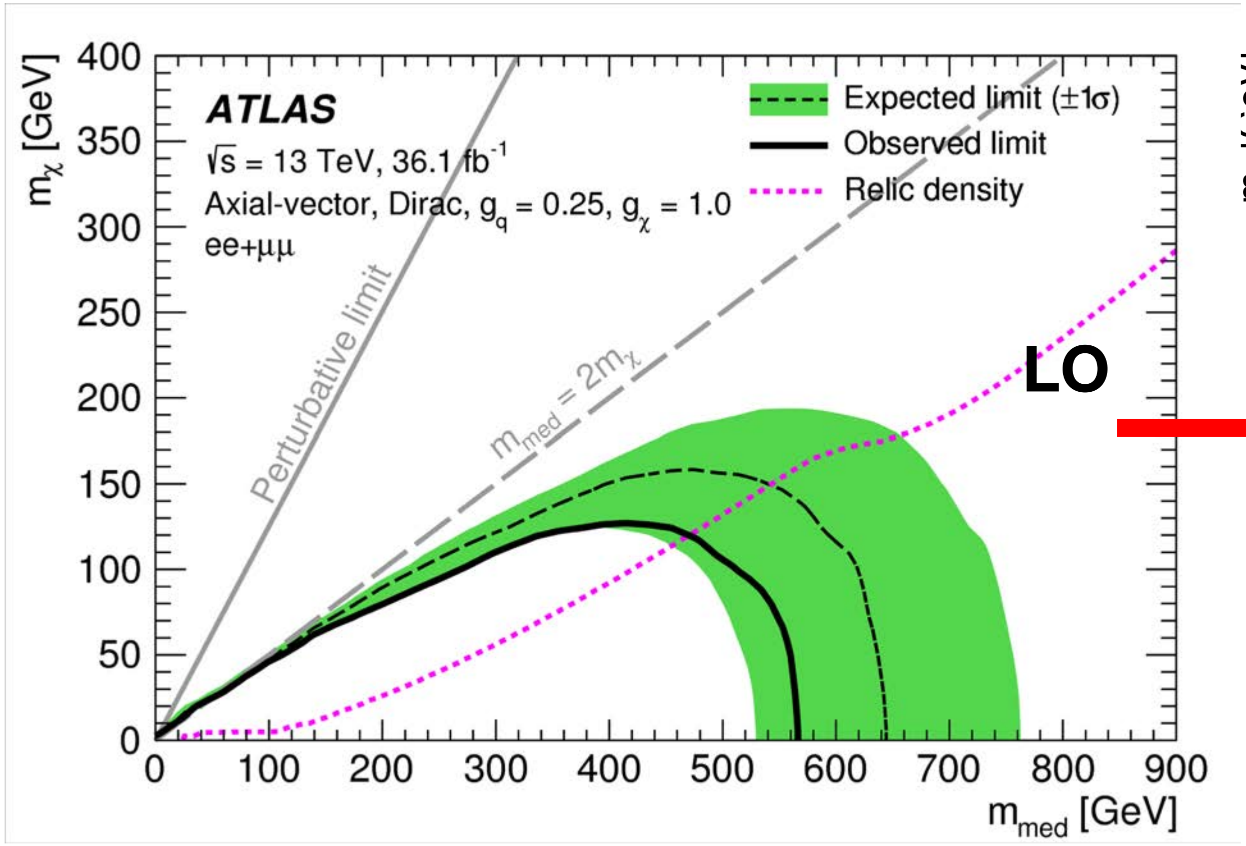
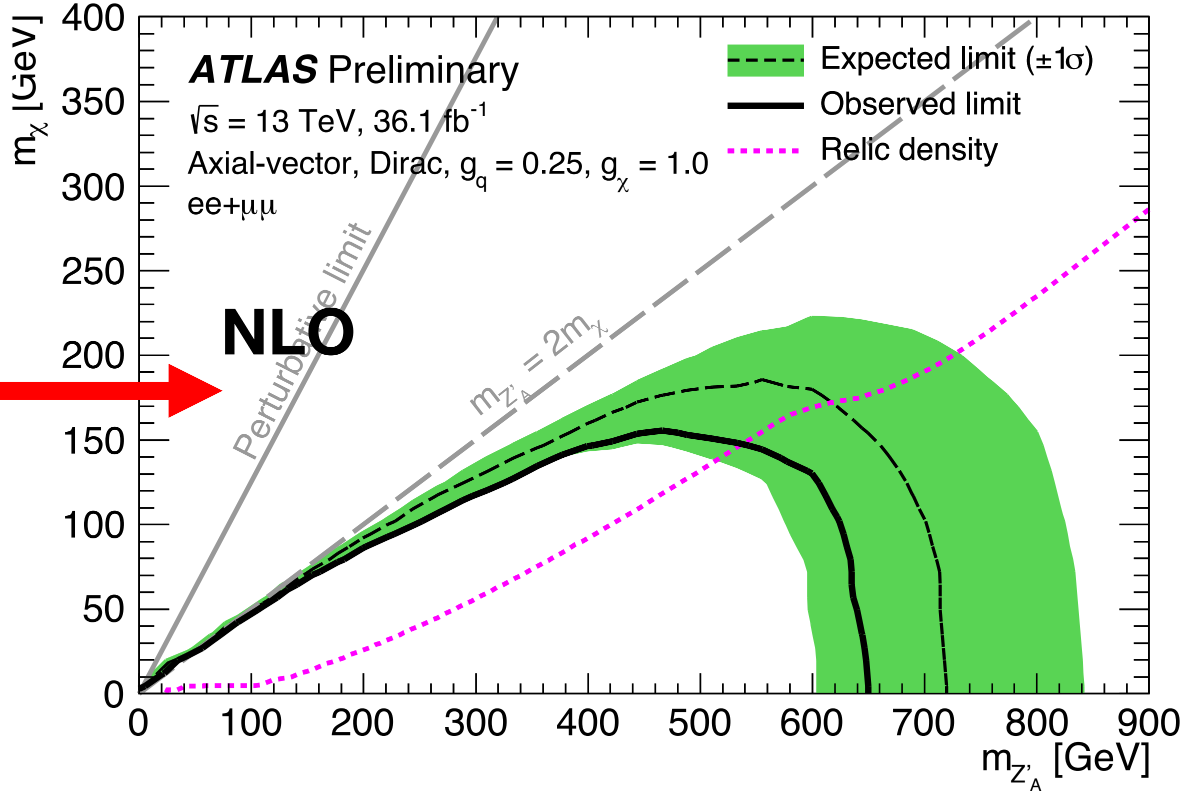
Simplified model mass exclusion limits (axial-vector)





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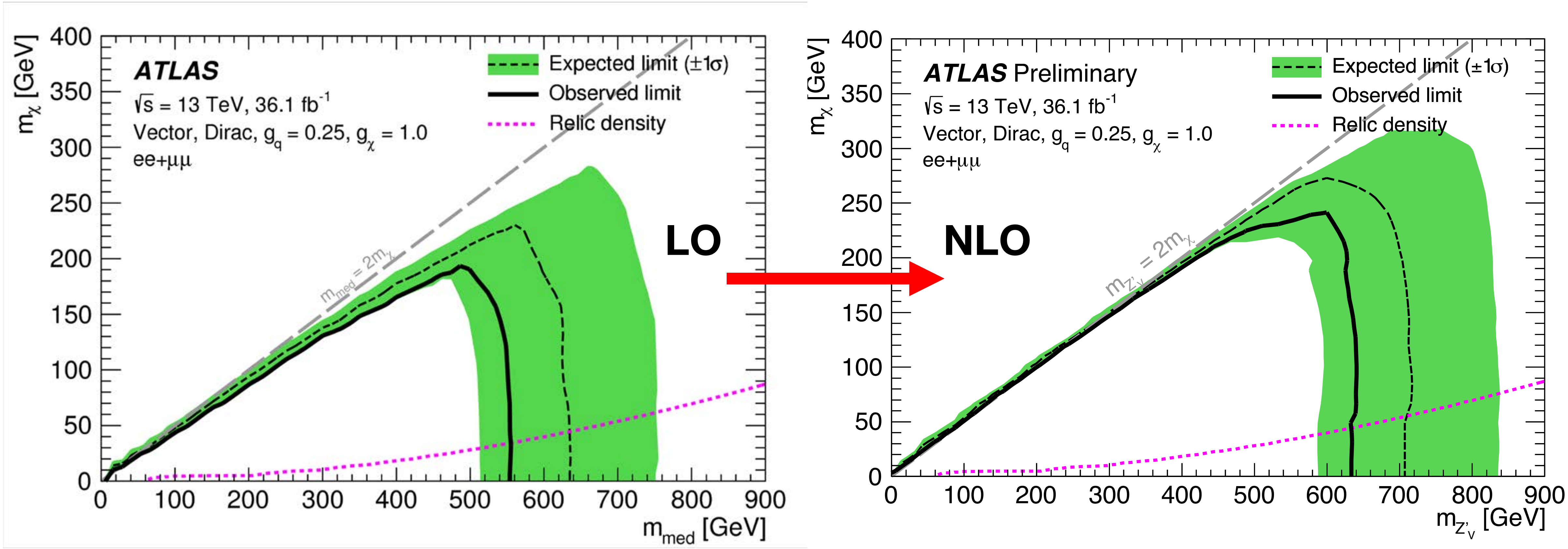
Simplified model mass exclusion limits (vector)



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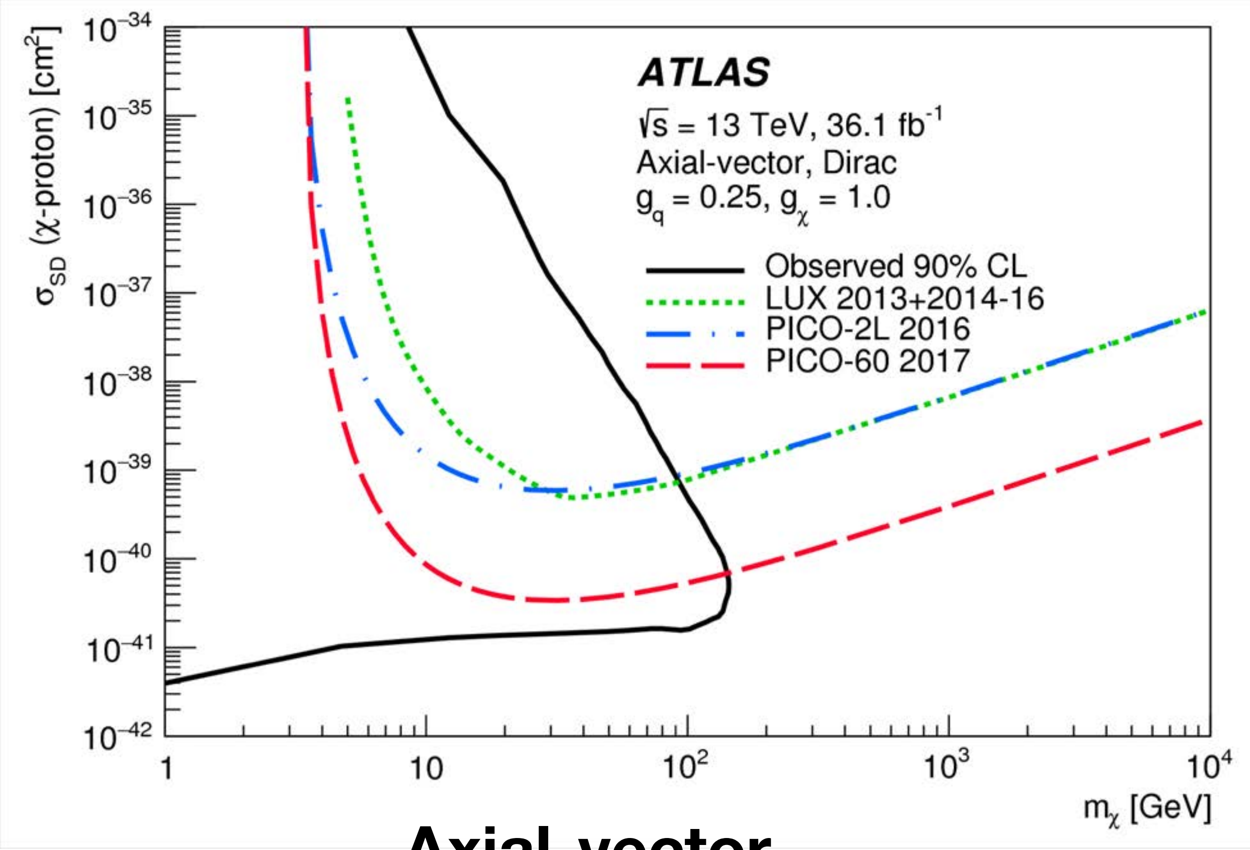
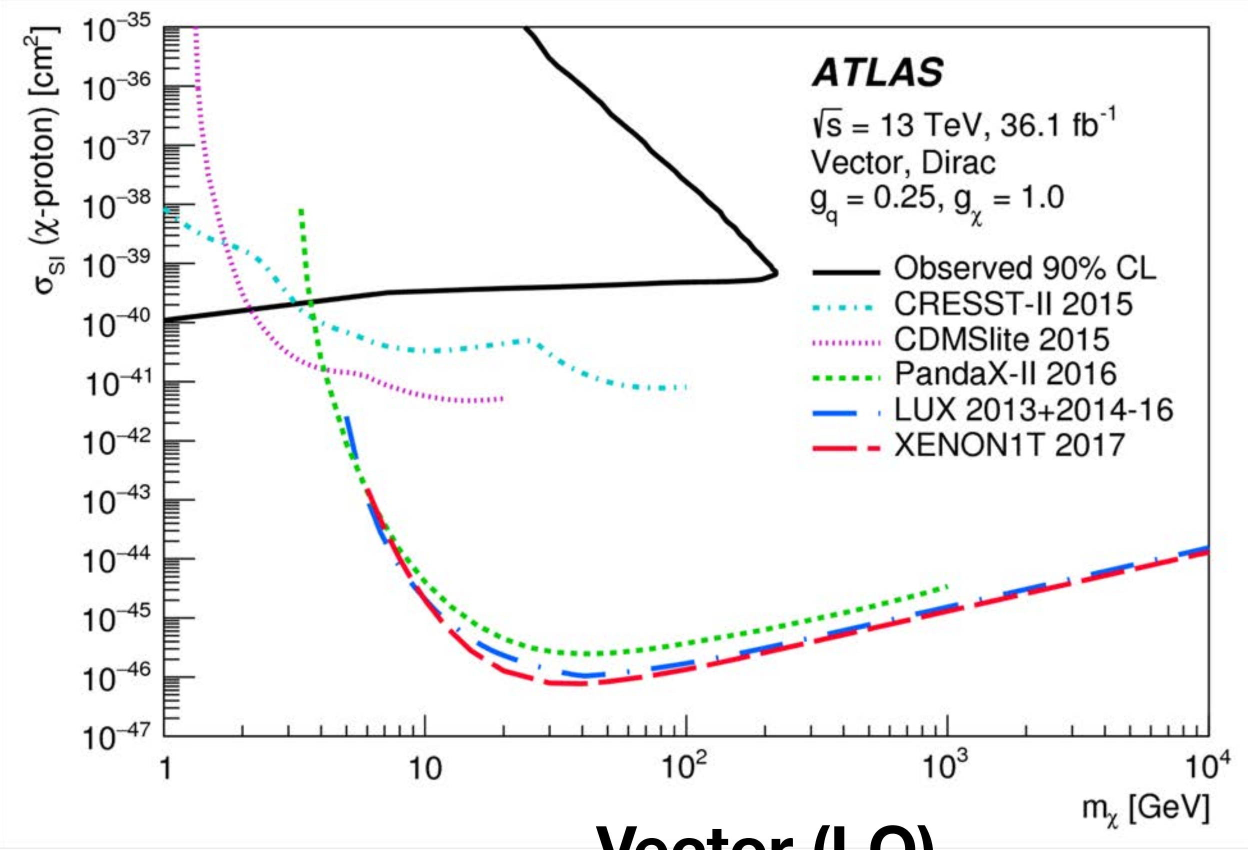
Mono-$Z(\ell\ell)$ limits compared to direct detection expts



Axial-vector (LO)



Vector (LO)

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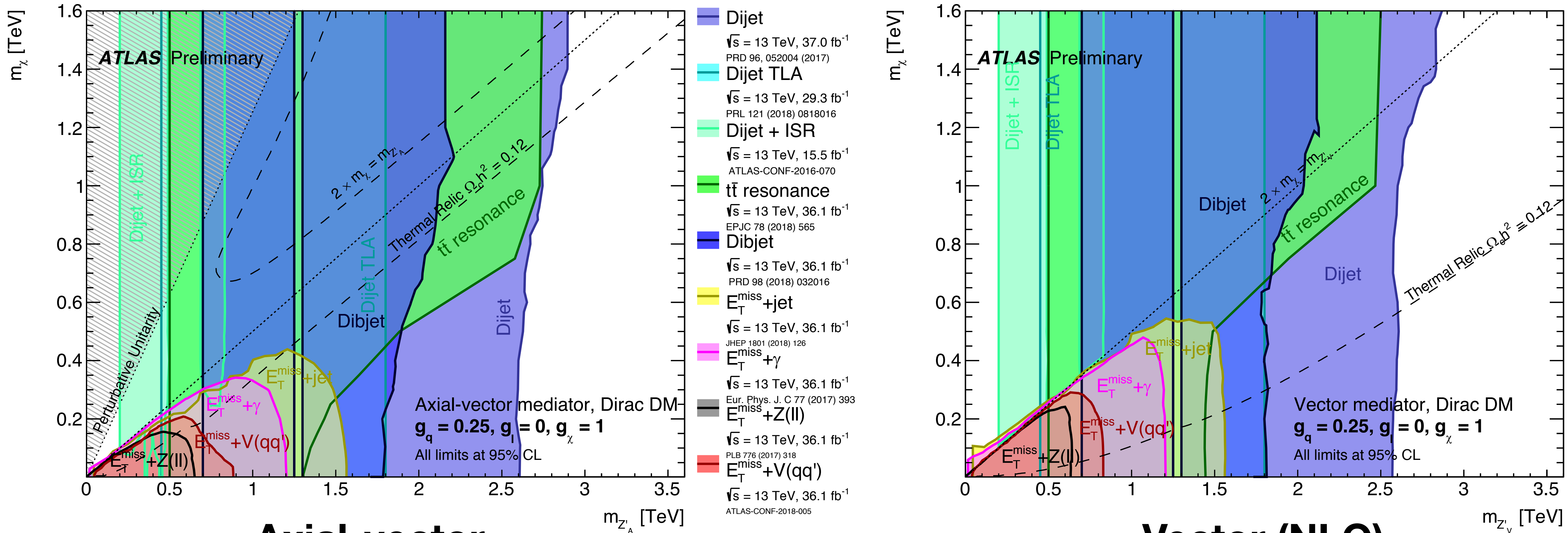
Mono-$Z(\ell\ell)$ limits compared to other ATLAS searches



Axial-vector (NLO)

Vector (NLO)

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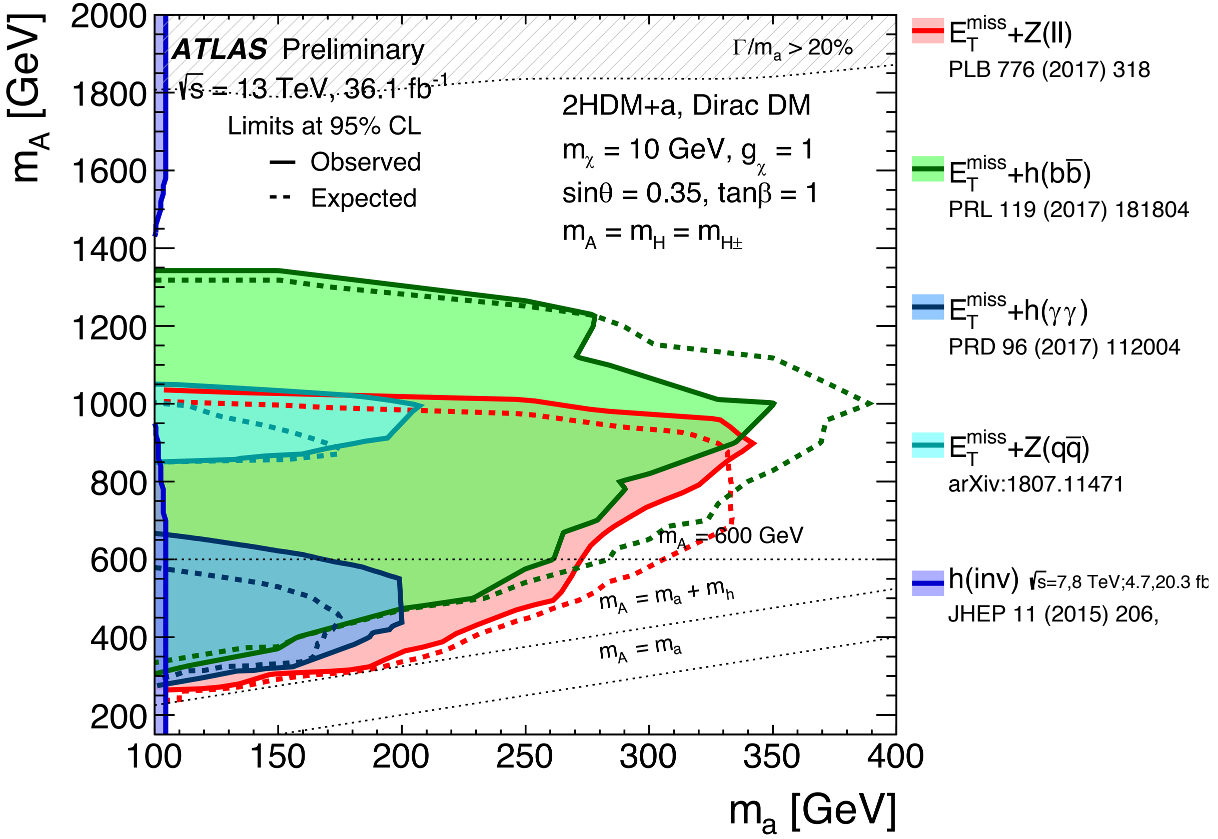
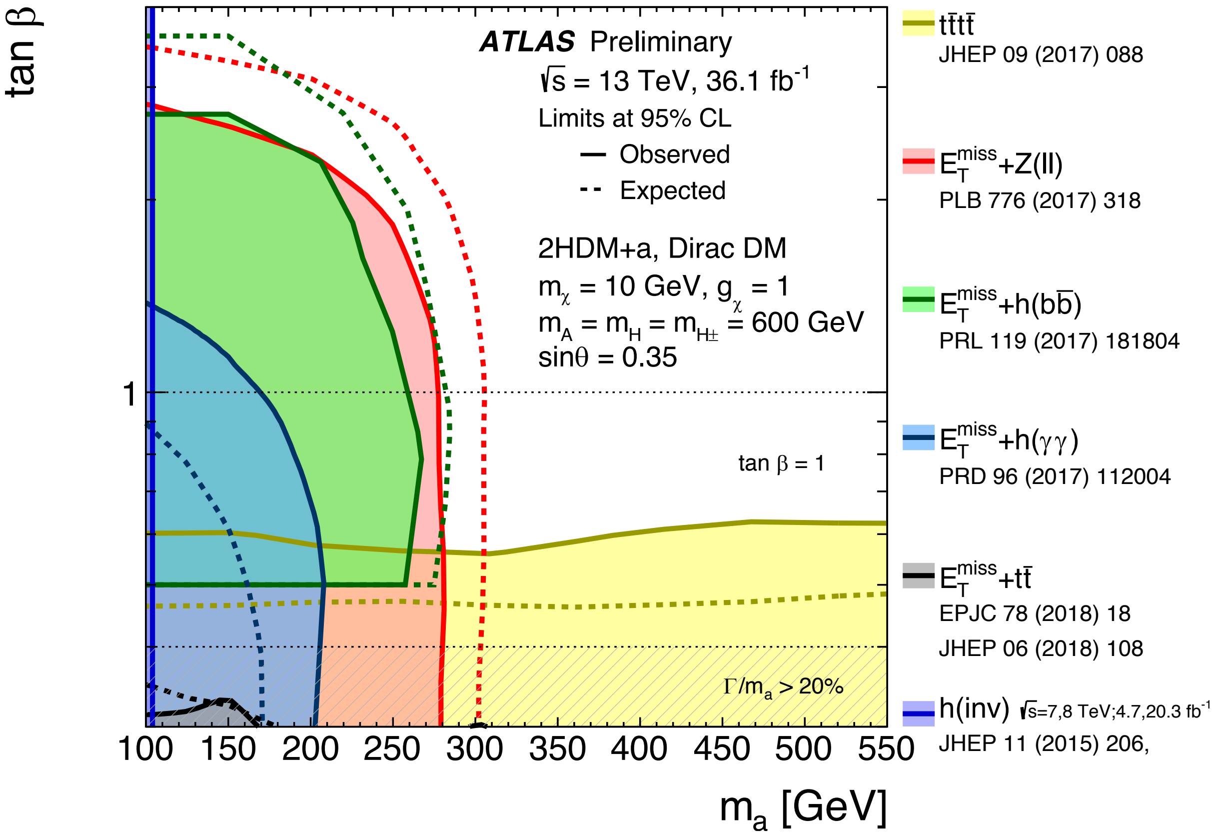
2HDM+a model limits





- Mono-$Z(\ell\ell)$ one of the most sensitive channels in the 2HDM+a model studied

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Conclusions

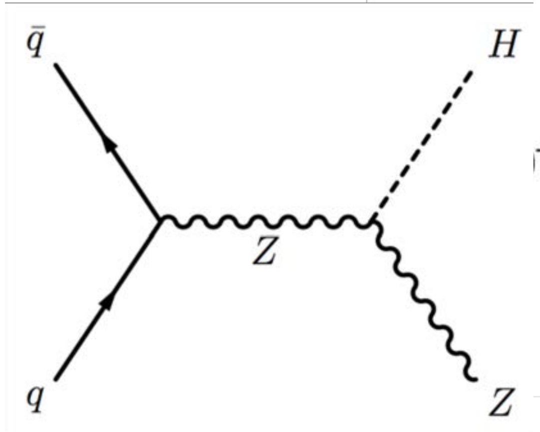
- Overview of the analysis and results with **36.1 fb^{-1}** (2015+16) has been presented
- Work is ongoing in the mono-*Z*($\ell\ell$) analysis towards unblinding the **full dataset = 149 fb^{-1}**
  - **More DM models** to be studied
    - In addition to simplified models, pursue models with diagrams unique to mono-*Z* (2HDM+a, *t*-channel, …)
  - **Signal region optimization**
    - New object-based E_T^{miss} significance – better discriminating power for events with fake E_T^{miss} (see Dilia's mono-*H(bb)* talk later today)
  - New **background estimation** techniques being studied
    - ***Zγ*** data-driven estimate of ***ZZ*** background
    - ***γ*+jet** data-driven estimate of ***Z*+jet** background
  - More potential for discovery than ever before!

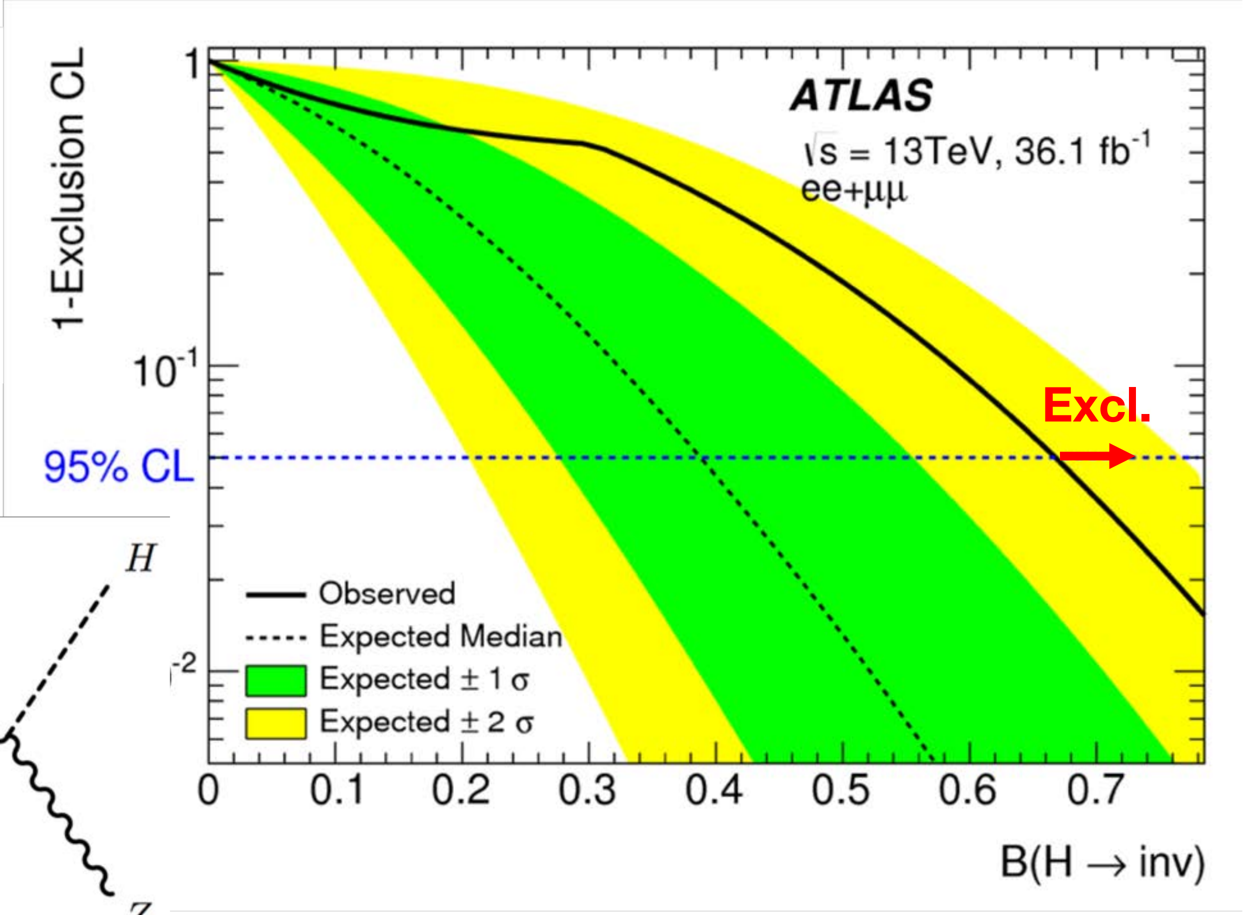
Backup

Invisible Higgs limits

	Obs. $B_{H\to\text{inv}}$ Limit	Exp. $B_{H\to\text{inv}}$ Limit $\pm1\sigma\pm2\sigma$
ee	59%	$(51\ ^{+21}_{-15}\ ^{+49}_{-24})$ %
$\mu\mu$	97%	$(48\ ^{+20}_{-14}\ ^{+46}_{-22})$ %
$ee+\mu\mu$	67%	$(39\ ^{+17}_{-11}\ ^{+38}_{-18})$ %

- Look for deviations in SM BR($H\to ZZ\to 4\nu$) = 1.06×10^{-3} = 0.1%
- **At most** the branching ratio is 67% or else we would have seen something… at the 95% confidence level
- Small data excess in μμ channel => **worse observed** upper limits compared to expected





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