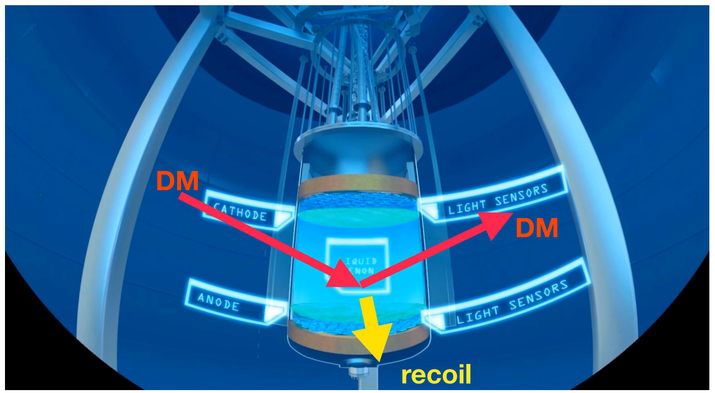
Search for dark matter with a signature of Higgs plus missing transverse energy in ATLAS

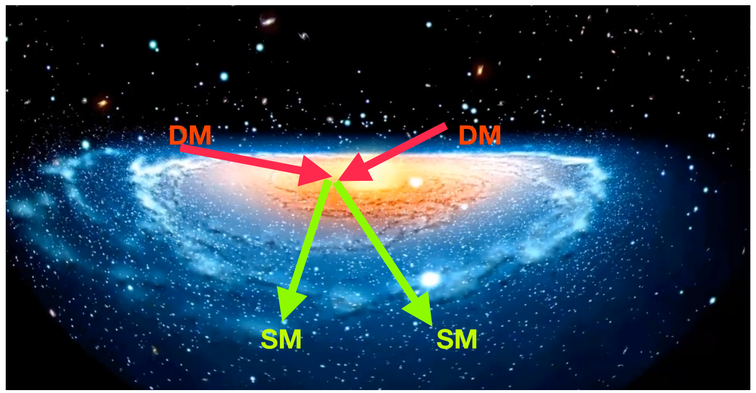
Ren-Jie Wang
LPNHE, Institute Lagrange de Paris
on behalf of ATLAS collaboration

Motivation and Detection of Dark Matter

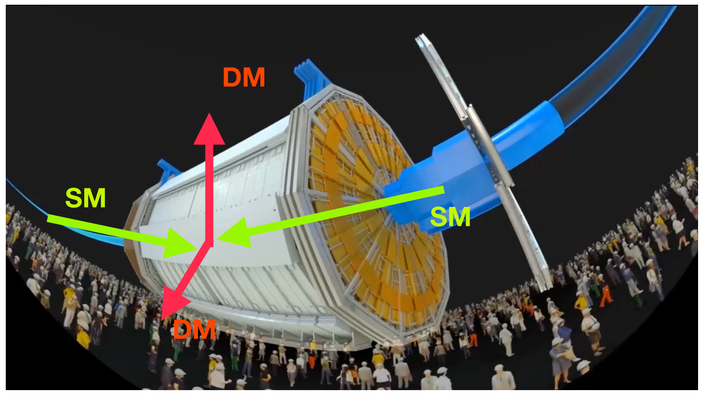
Direct Method



Indirect Method



Collider Method

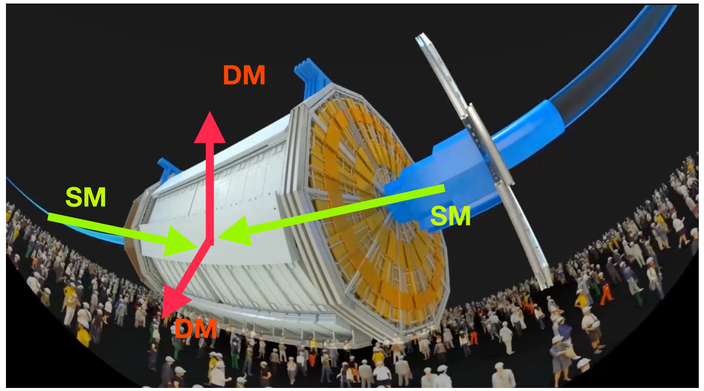


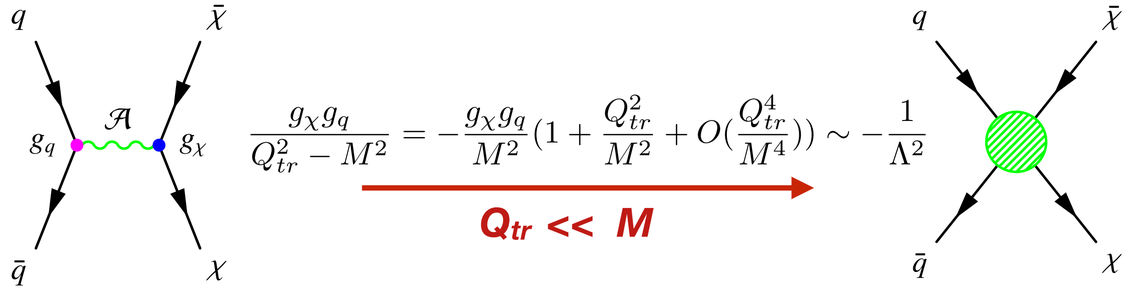
- Dark Matter (DM) has been one of the major unsolved problems in physics nowadays
  - What is the identity of DM? Is it a particle or not?
  - Much evidence from astrophysical measurements, but **no evidence** yet for **non-gravitational** interactions between DM and SM particles

- Three detection ways:
  - Direct method: DM-nucleon elastic scattering, results in a recoil (with energy ~ 50 keV)
  - Indirect method: DM pair-annihilation, decay to various observable particles: $\chi\chi \rightarrow$ tt, bb, WW, ZZ, $\gamma\gamma$, ……
  - Collider method: *main topic of this talk*

Collider Method — DM searches at the LHC

Collider Method



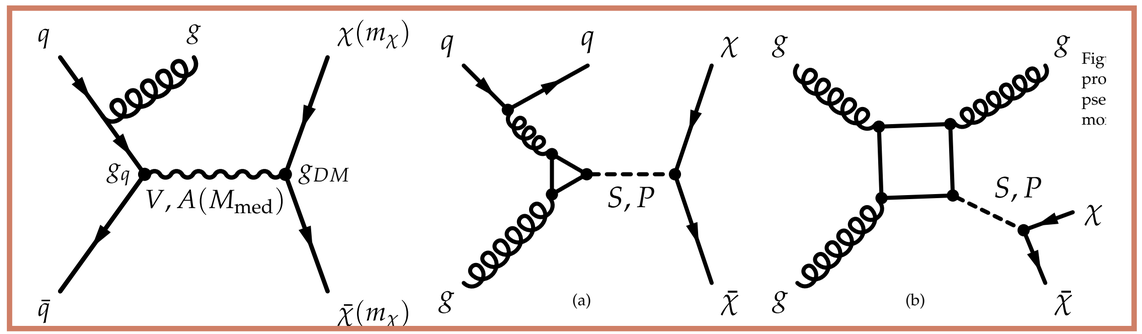


Run2 Run1

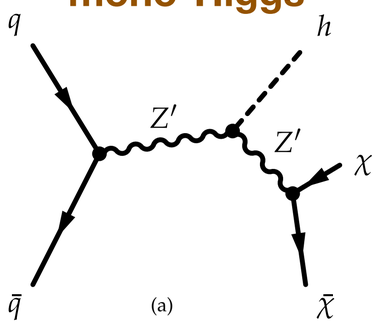
- Two different paths:
  - Effective field theory (EFT) approach: several nonrenormalizable operators without the UV physics specified
    - largely model-independent
    - but cannot be reliable when parton energies in the events are comparable to the effective mass scale
    - don’t account the constraints on the UV physics generating these operators (e.g. contains from recent dijet/dilepton searches)
  - Simplified models: UV particles are kept as degrees of freedom, but more model-dependent

Collider Method — DM searches at the LHC (Mono-X)

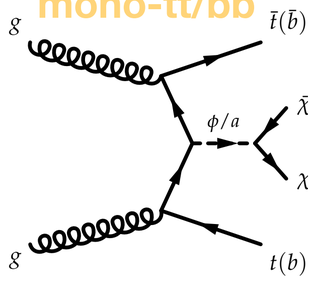
mono-Jet/photon/W/Z



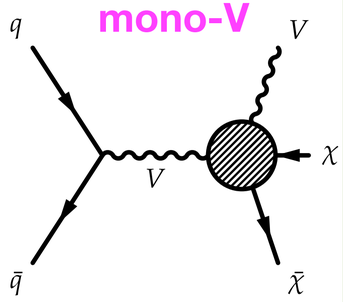
mono-Higgs

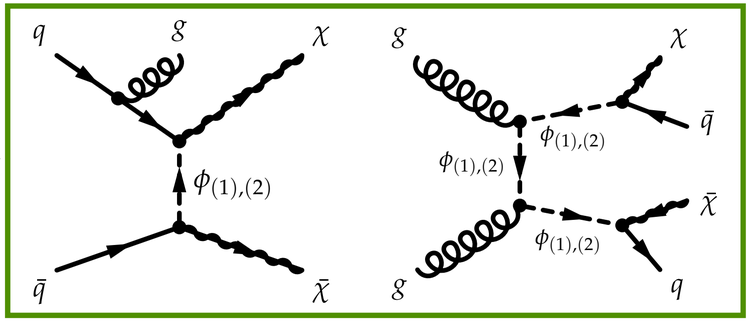


mono-tt/bb

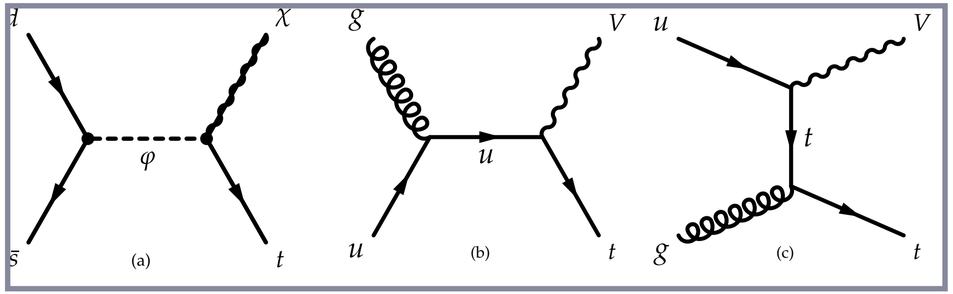


mono-V





t-channel mono-jet/dijet

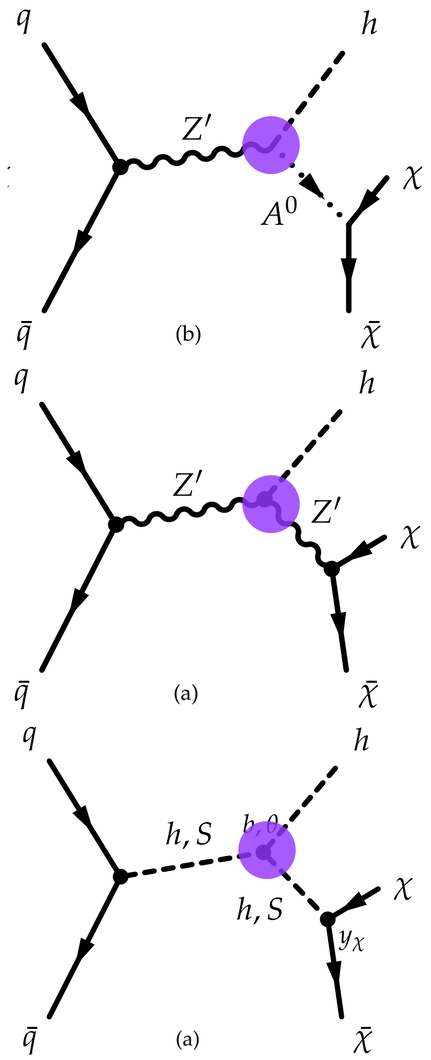


mono-t

- Mono-X: a final state of MET + Jet(s), photon, W, Z, Higgs, top/b quark
- X can be emitted
  - either directly from ISR through SM gauge interactions
  - or from a BSM vertex coupling

Introduction — mono-Higgs

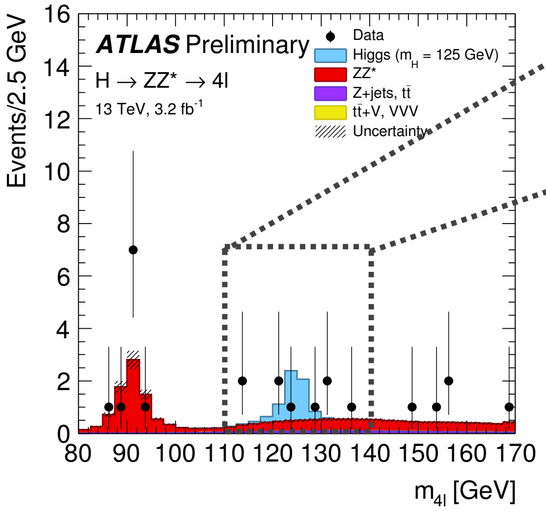
- Difference between mono-Higgs and other mono-X searches
  - ISR Higgs boson is Yukawa suppressed, a mono-Higgs signal can only be through BSM vertex
- This talk will focus on Higgs decaying to ZZ*→4ℓ, $\gamma\gamma$, and bb
- Three simplified models:
  - Z'-2HDM: vector mediator (Z'), two-Higgs-doublet: h; H (CP-even); A_0(CP-odd); H±;
    - DM only coupling to pseudo-scalar A_0, Z'→A_0 + h
    - free parameters: g_q , g_X , $M_{Z'}$,M_{A0}, M_X, mixing angles h-H, A_0-H
  - Z'$_B$: a vector boson Z' with baryon number coupling with Higgs,
    - free parameters: g_q , g_X , $g_{Z'}$, $M_{Z'}$,M_X , mixing angle h-h_B
  - Scalar model: a massive scalar S
    - free parameters: g_q, y_x, M_S, M_X, coupling S and h, mixing angle S-h

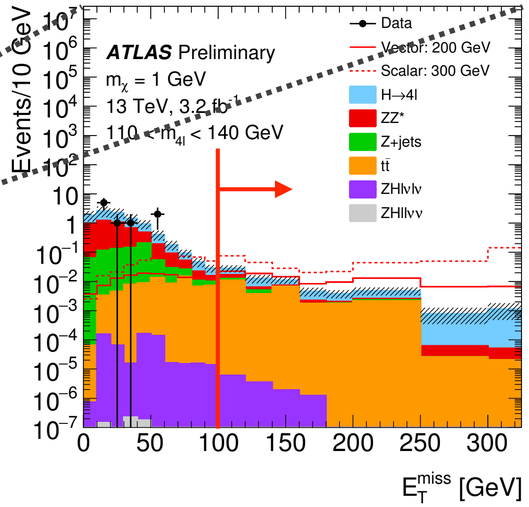


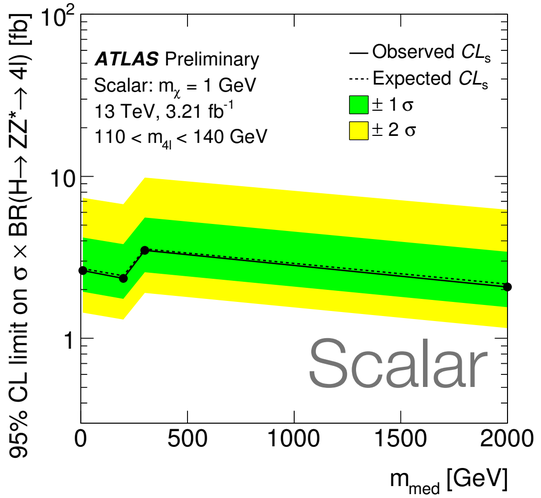
https://arxiv.org/abs/1507.00966

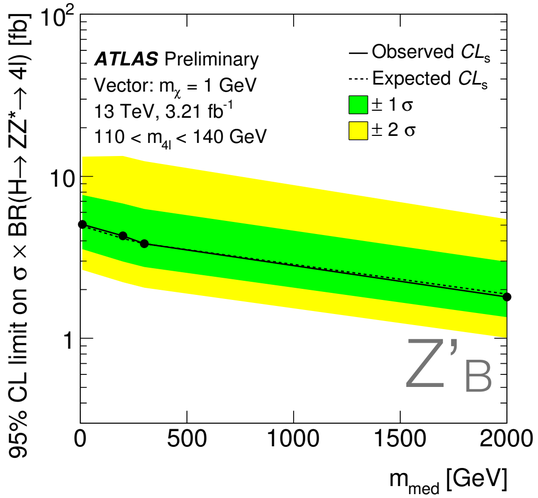
Mono-Higgs(→ZZ*→4ℓ)

ATLAS-CONF-2015-059









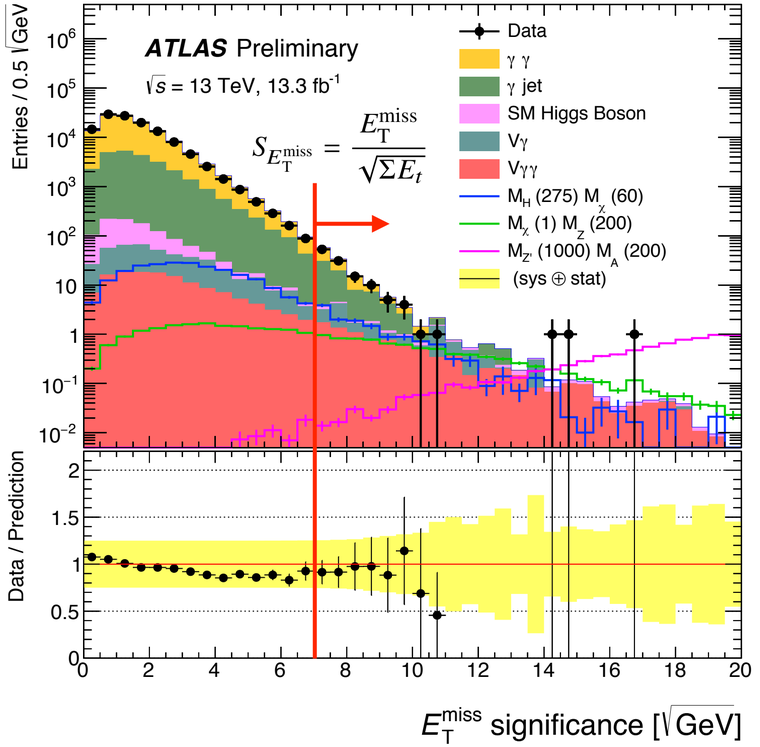
- H→ZZ*→4ℓ has low BR, but this channel is very clean
- Multi-leptons triggers (Efficiency > 99%)
- Event selection: at least four well-identified, isolated leptons, same flavor-opposite-charge lepton pair match to Z mass
- Background:
  - ZZ* (irreducible): from simulation with NNLO@QCD, NLO@EWK correction
  - ttV/VVV: from simulation
  - Z+jets, ttbar: Data driven estimated shape and normalization
- Signal region: $M_{4\ell}$ [110,140] GeV, MET>100 GeV
- No significant BSM excess is observed! Upper limit is set on the production cross section times BR as a function of mediator mass in both Z'_B and Scalar scenarios

Mono-Higgs($\rightarrow\gamma\gamma$)

ATLAS-CONF-2016-087

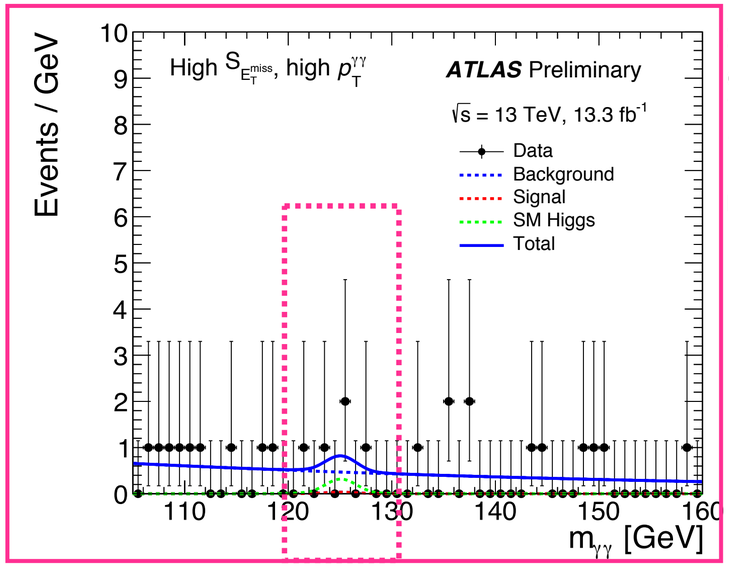
- Diphoton trigger (Efficiency > 99%)
- Two well-defined photons with $p_T > 35(25)$ GeV, and relative cut $p_T/m_{\gamma\gamma} > 0.35$ (0.25)
- MET is calculated w.r.t. the diphoton vertex including track-based soft term
- Non-resonant background
  - $\gamma\gamma$: dominant, need large METSig cut to reject
  - γ+jets: second dominant, similar to $\gamma\gamma$ when the jet is mis-identified as a photon
  - Vγ, V$\gamma\gamma$: visible contribution at High METSig, where a lepton is misidentified a a photon or not well-reconstructed (induce fake MET)
- Resonant background: SM Higgs, ZH is irreducible

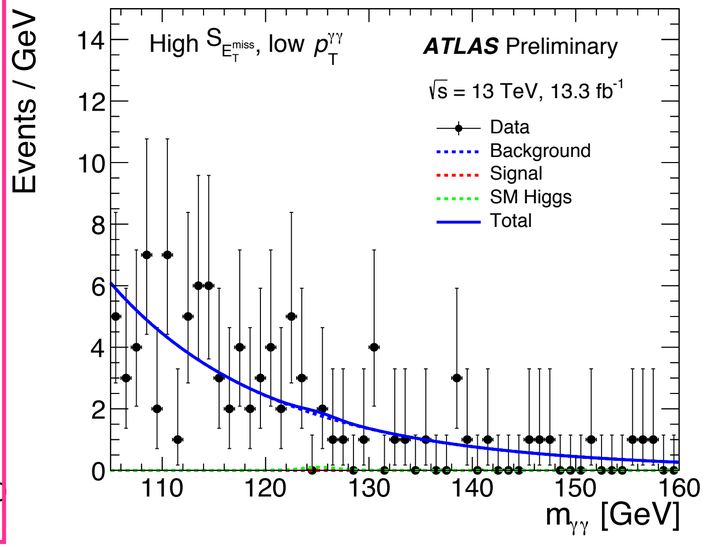
Category	$S_{E_T^{miss}}$ [$\sqrt{\text{GeV}}$]	$p_T^{\gamma\gamma}$ [GeV]
High $S_{E_T^{miss}}$, high $p_T^{\gamma\gamma}$	> 7	> 90
High $S_{E_T^{miss}}$, low $p_T^{\gamma\gamma}$	> 7	≤ 90
Intermediate $S_{E_T^{miss}}$	> 4 and ≤ 7	> 25
Rest	-	> 15

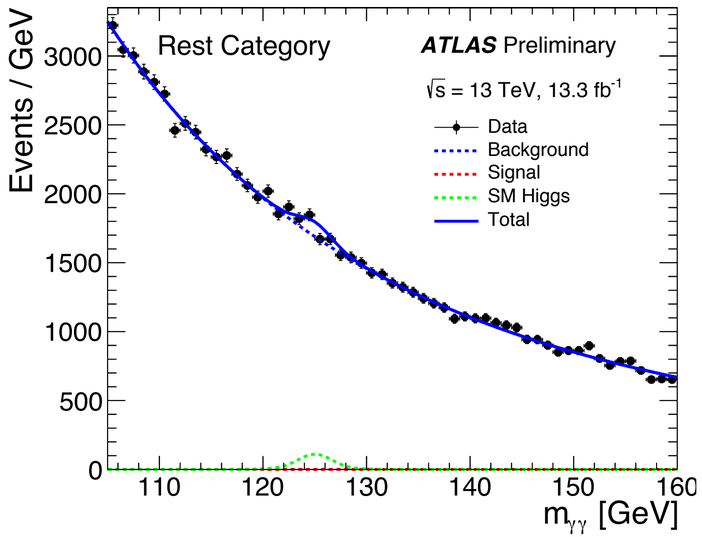


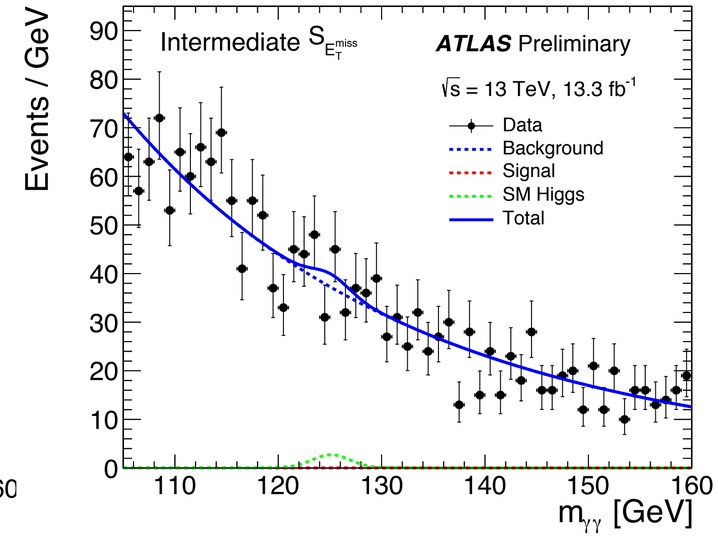
Mono-Higgs($\rightarrow\gamma\gamma$)

ATLAS-CONF-2016-087







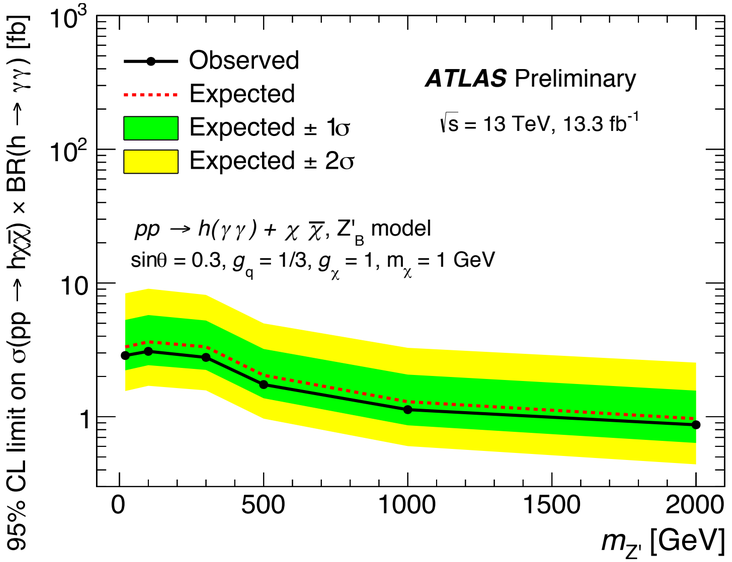


- Double-sided Crystal Ball function is used to model the signal shape as well the SM Higgs
- Data-driven non-resonant background:
  - High METSig category: simple exponential
  - Intermediate and rest categories: exponential of 2nd order polynomial.
- No significant BSM excess is observed!

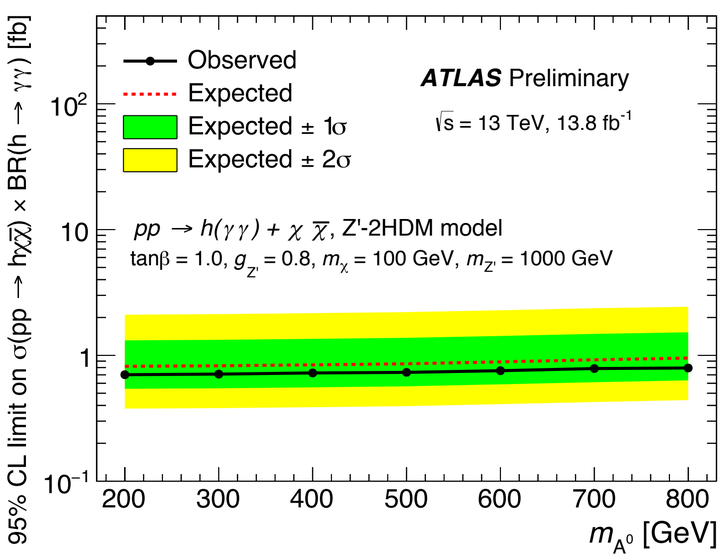
Mono-Higgs($\rightarrow\gamma\gamma$)

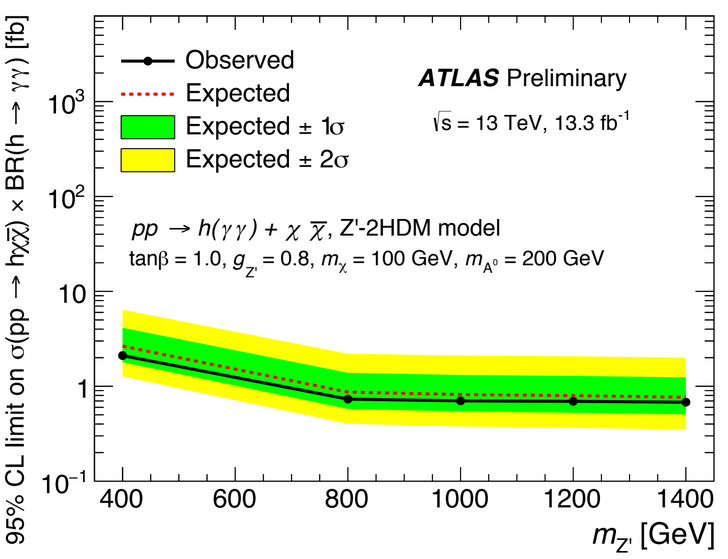
ATLAS-CONF-2016-087

- Upper limit is set on the production cross section times BR as a function of mediator mass in both Z'_B and Z'-2HDM scenarios



Z'_B



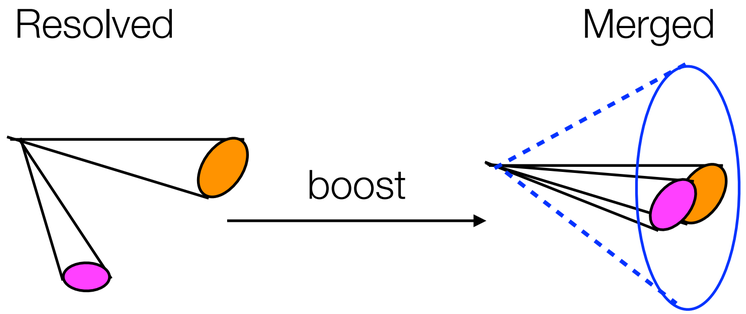


Z'-2HDM

Mono-Higgs(→*bb*)

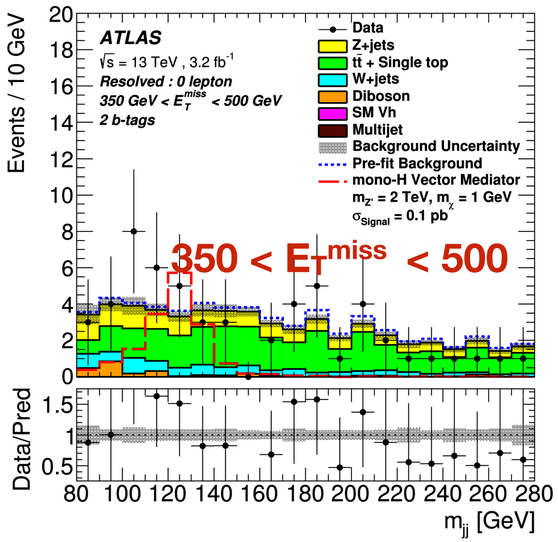
EXOT-2015-23

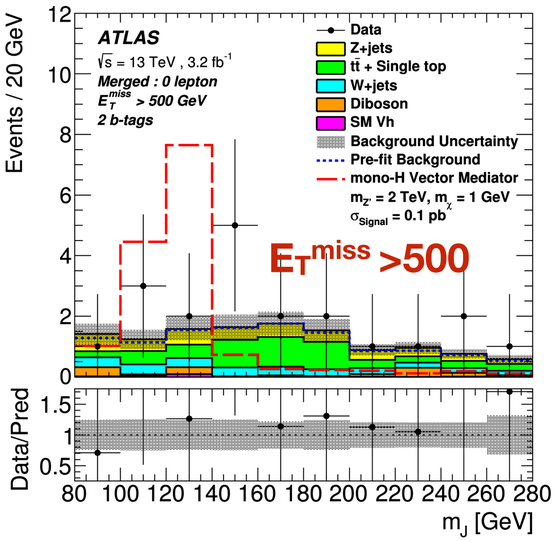
- MET Trigger (Efficiency: ~100%@200GeV)
- Signal region:

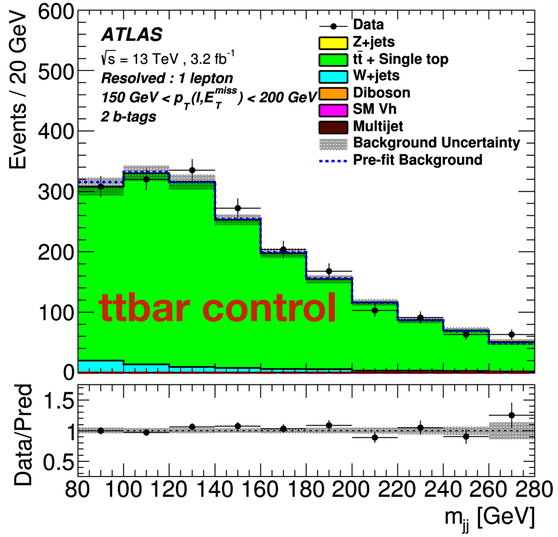


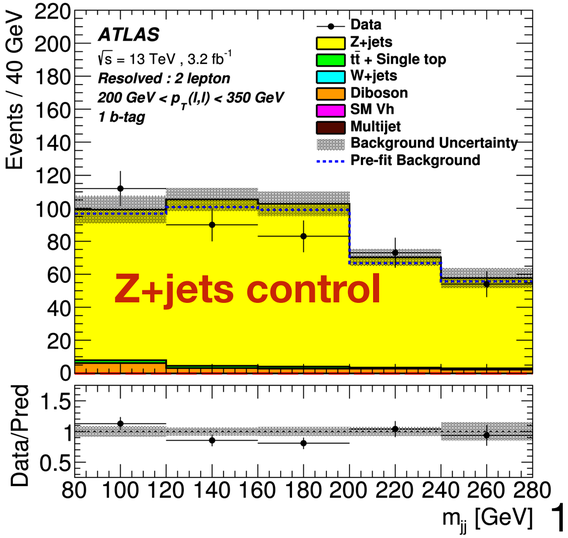
  - Resolved: two b-tagged jets + intermediate MET
  - Merged: one large-R jet with two b-tagged tracks + large MET

- Background:
  - two main backgrounds: W/Z+jets (15~65%); ttbar(45~80%)
  - control regions are defined with 1-/2-lepton events





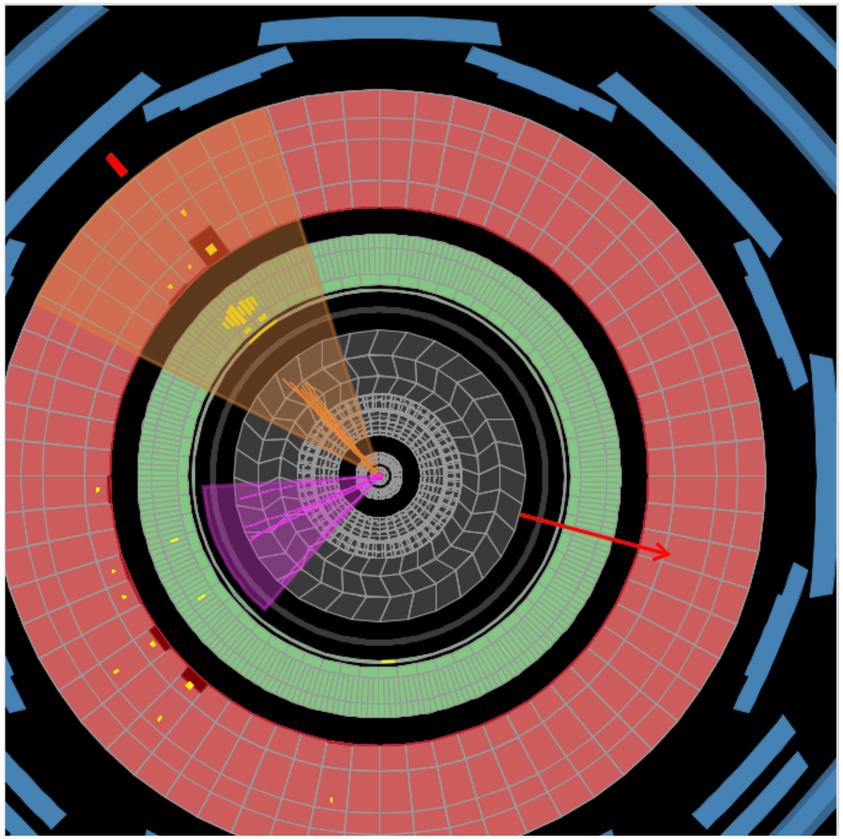




Mono-Higgs(→*bb*)

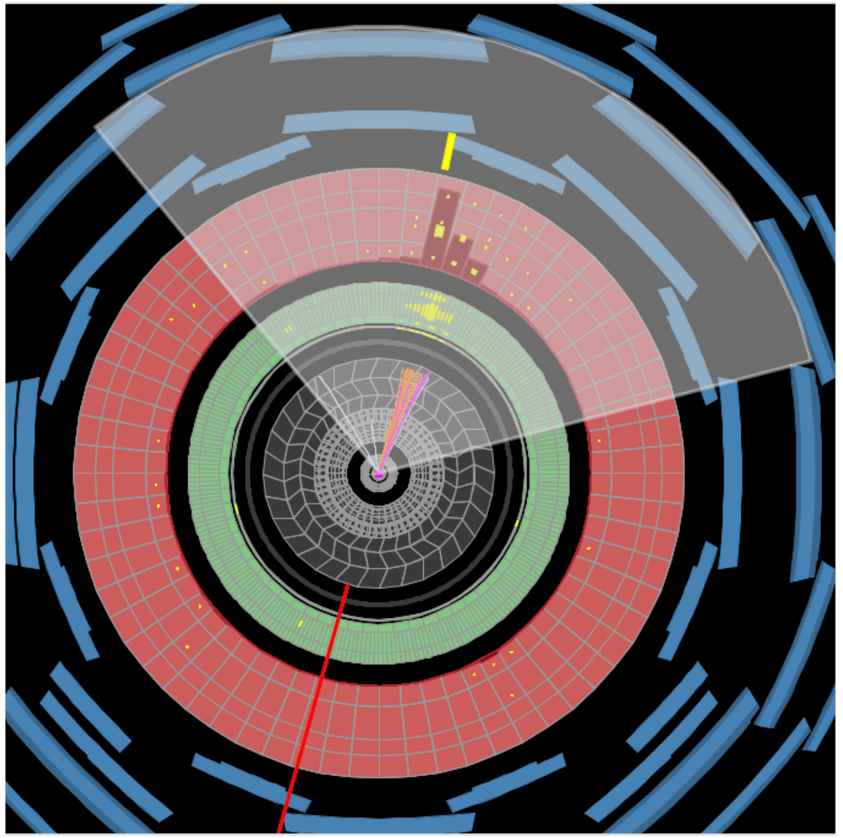
EXOT-2015-23

Resolved Region (E_T^{miss} < 500 GeV)
small radius jets



MET = 213 GeV, Mjj = 120 GeV

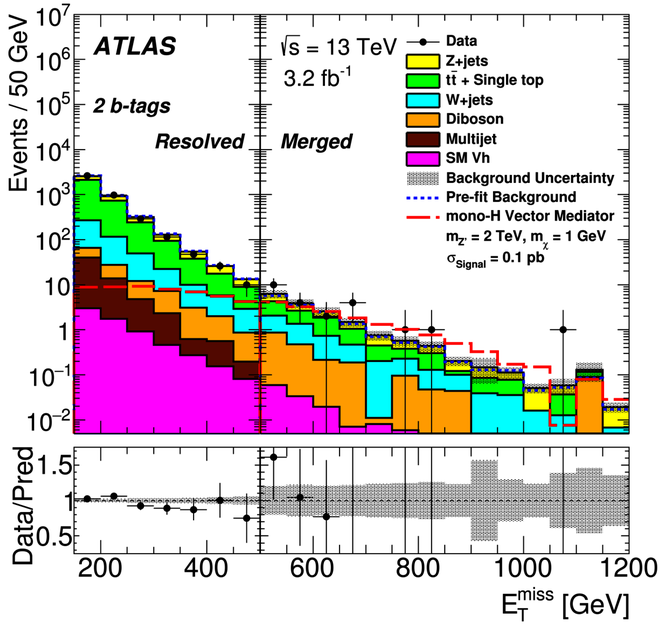
Merged Region (E_T^{miss} > 500 GeV)
large radius jet

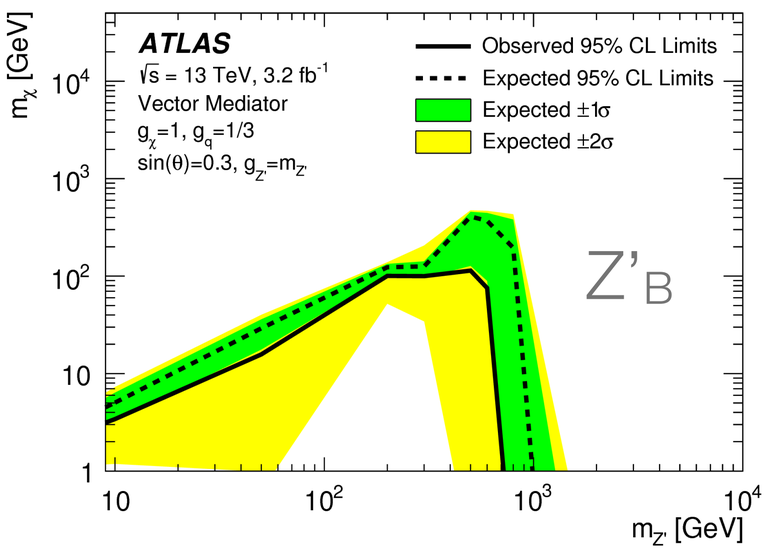


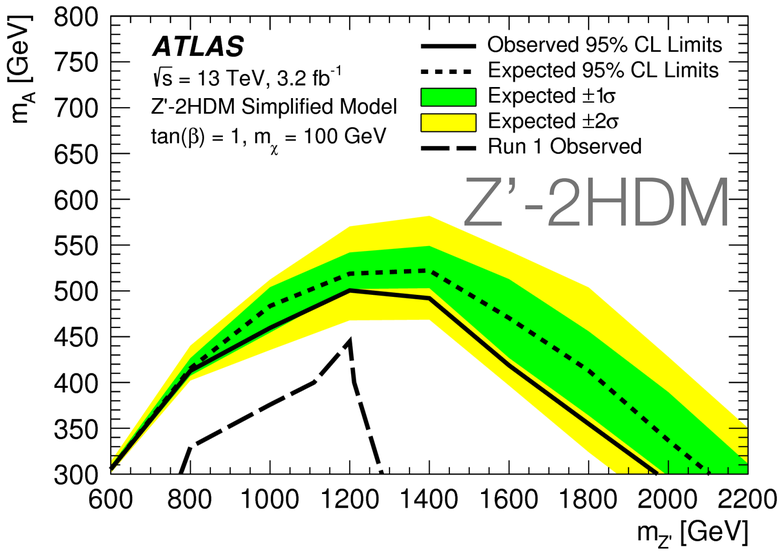
MET = 694 GeV, mJ = 106 GeV,
and two b-tagged track jets

Mono-Higgs(→*bb*)

EXOT-2015-23



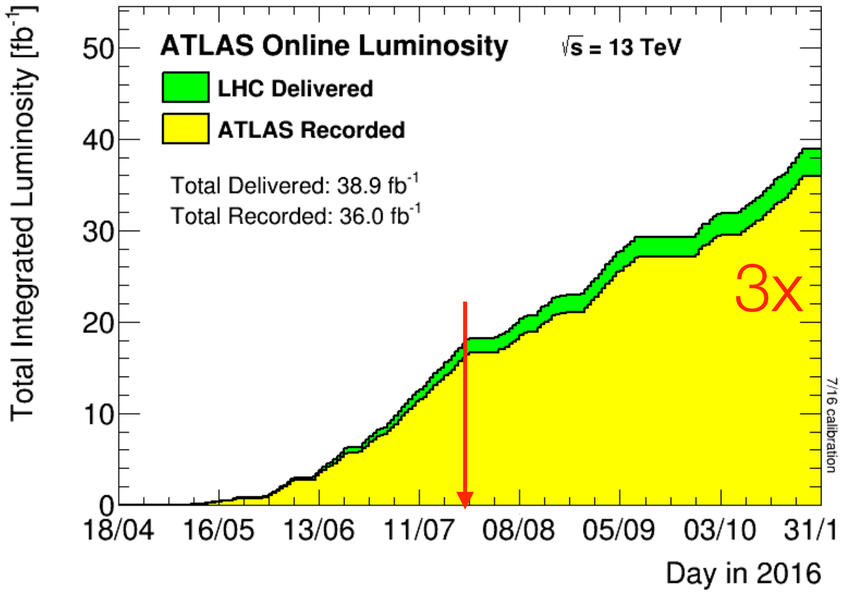


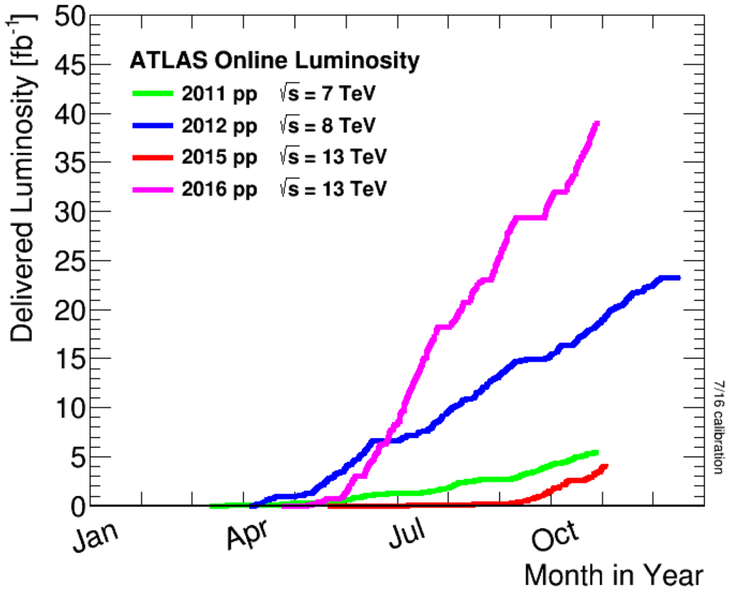


- No significant BSM excess is observed!
- Shape-based limit is obtained from dijet/single-large-R-jet mass simultaneously in all SRs and CRs.
- 2D Limit contour (m_{DM}, $m_{Z'}$) are set for both Z'_B and Z'-2HDM scenarios

Summary

- The dark matter searches with a signature of Higgs plus missing transverse energy in ATLAS are presented using 2015/2016 data
- Spirit: using the recent discovered Higgs boson as a tool for new possible discovery
- No significant BSM excess is observed yet, but looking forward to results using full 2015+2016 dataset.





Thank you!