Searches for dark matter and extra dimensions with the ATLAS detector

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On behalf of the ATLAS Collaboration

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Overview

Motivation: *Dark Matter and Extra Dimensions*

ATLAS Strategy & Results: *Signature-based searches*

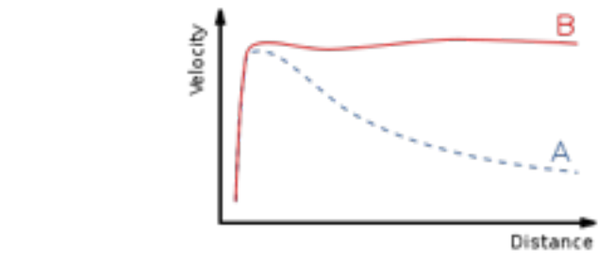
- **Mono-X**
- **Displaced Vertex**
- **Non-resonant multi-body decays**

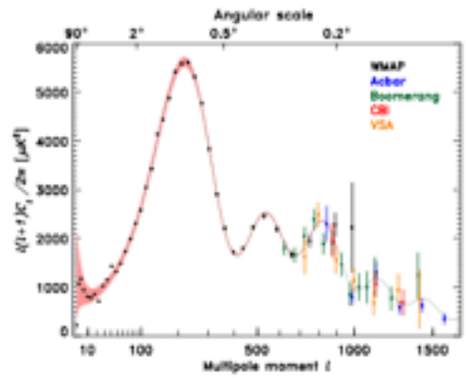
Conclusion

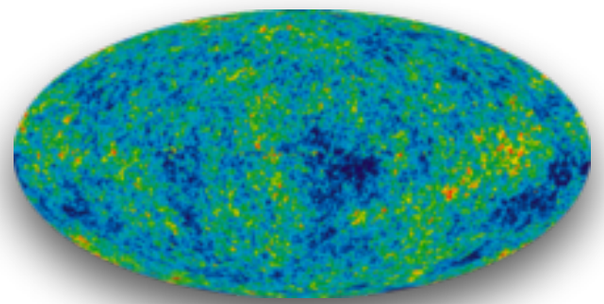
Motivation: Dark Matter

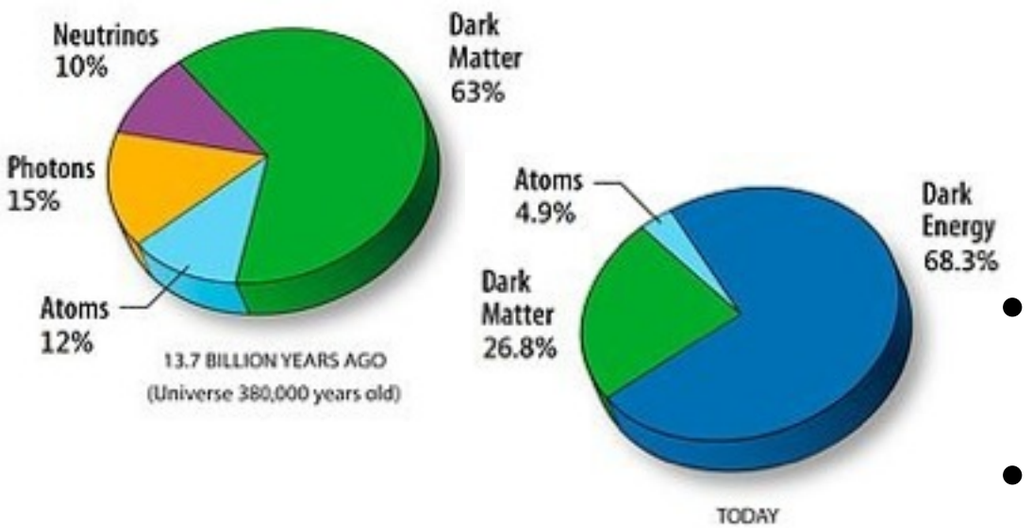
Astrophysical observations strongly suggest existence of DM

- Galactic rotation curves
- Gravitational lensing
- CMB, BAO, …









- In fact, there's more DM than regular matter
- **But:** we know *nothing* about its *particle nature*

Motivation: Dark Matter

WIMPs: popular candidate for dark matter

- Large-scale structure favors cold DM
- Interacts with the SM at some level (*relic density*)
- SUSY LSP can naturally provide a WIMP

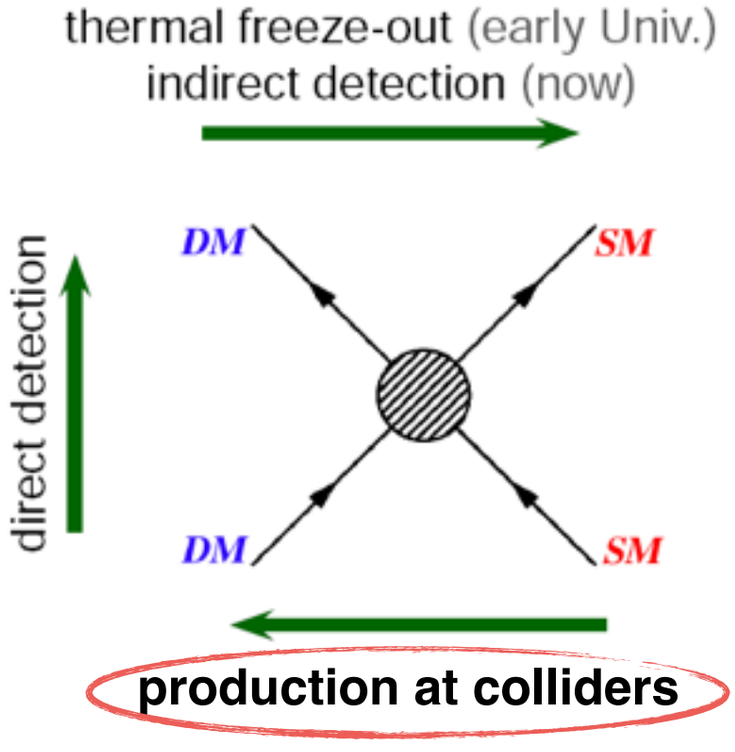
Many experiments looking for **SM↔DM** interaction;
so far no conclusive answers

- **Direct Detection** → (CDMS, DaMa, LUX, XENON,…)
- **Indirect Detection** → (LAT, AMS, AMANDA, IceCube,…)
- **Production** → **LHC!**

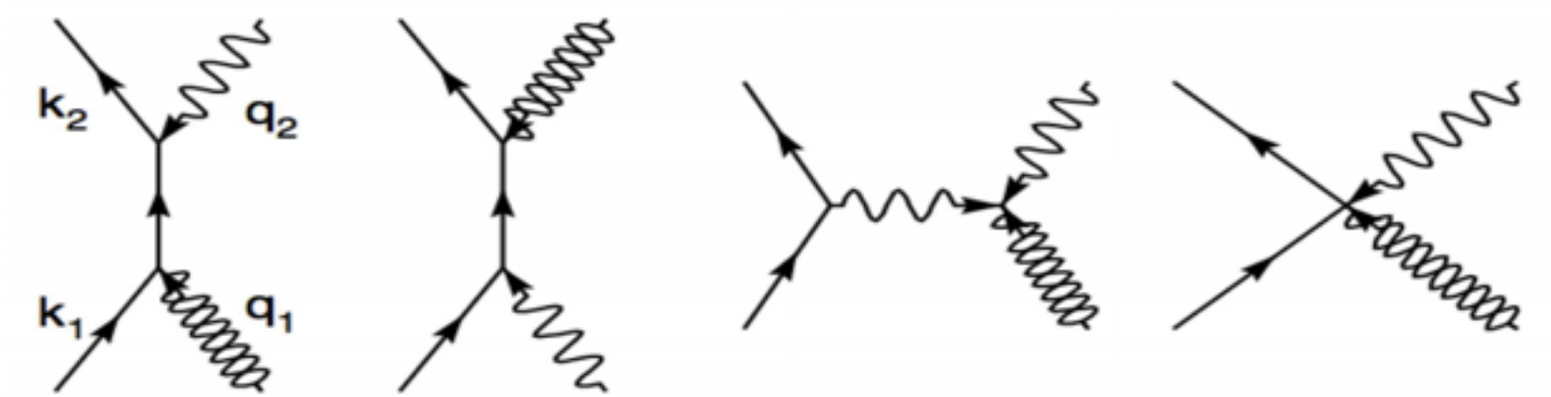
*Collider searches are complimentary to DD for low-mass!

Hidden Valley / Dark Sector:

- 25% of the universe is dark matter… why shouldn't it have complex physics as well?
- e.g. Models with DM charged under "dark" non-abelian gauge structure
- Requires a common coupling at unknown higher scale (TeV?)



Motivation: Extra Dimensions



- Proposed to solve hierarchy problem (weak gravity) by introducing Large Extra Dimensions (LED)

Arkani-Hamed, Dimopoulos, Dvali (ADD) Model:

- Given n extra dimensions of size R, the "true" Planck scale M_D can be related to observed Planck scale M_{Pl}

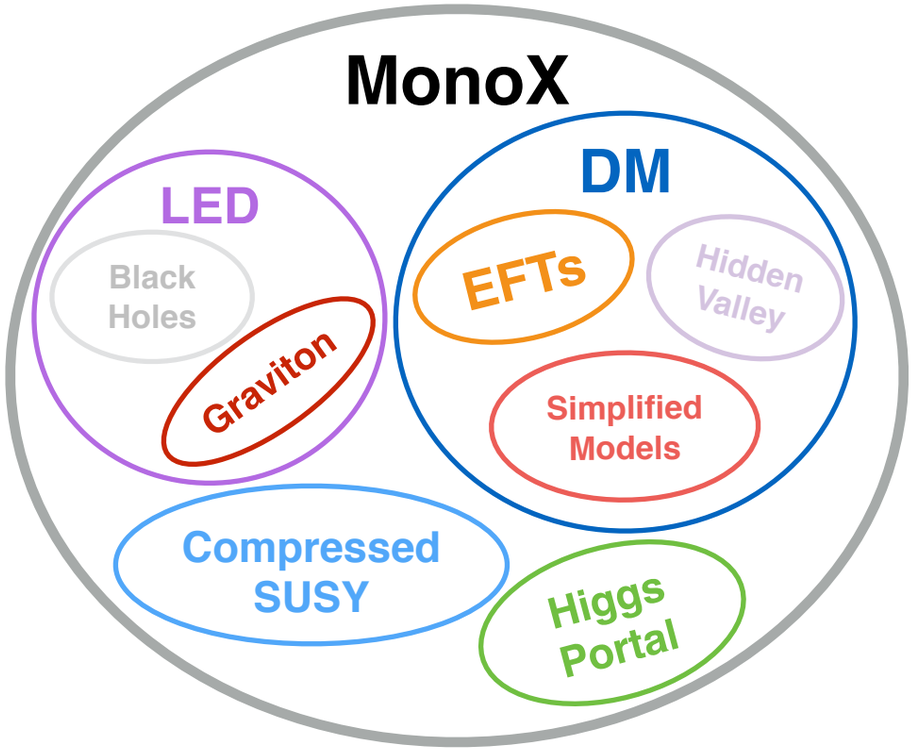
$$M_{Pl}^2 = 8\pi M_D^{2+n} R^n$$

- May allow us to *probe strong gravity* at the collider!

- We may choose n, R so that $M_D \sim 1$ TeV
  ↳expect new phenomena at LHC: **KK gravitons**, **black holes**

ATLAS Exotics Strategy

- Many interesting models out there describing DM, Extra Dimensions, other new physics
- Our job as **experimentalists**: Make *measurements* that translate to theoretical *constraints*
- Some models, such as SUSY, have many correlated signal channels → benefit from *concerted analysis efforts*
- **Exotics approach**: *signature-based searches*
  - Define general, orthogonal searches based on *final state*
  - Interpret results in *multiple models*
- **Goal of this talk:**
  - Where is ATLAS looking
  - What phenomenology is on our radar
  - 8 TeV results so far

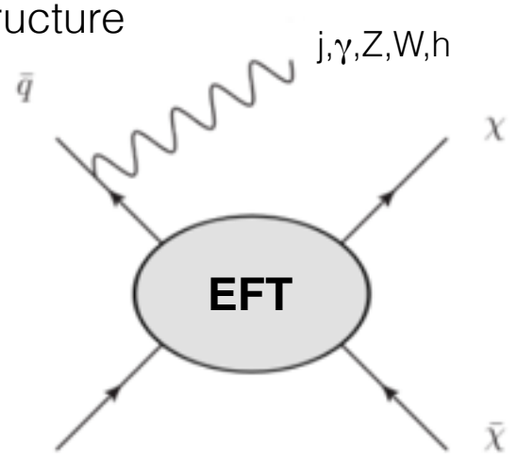


Mono-X: Models

Look for: events with high Missing Transverse Momentum (MET)
+ visible jet, γ, W, Z, Higgs…

DM EFTs:

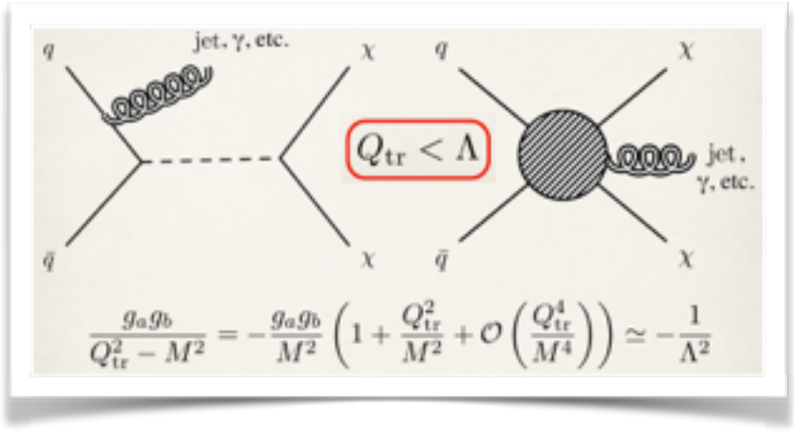
- Effective contact interaction e.g. qq↔χχ via *Heavy Mediator*
- Observable produced as **ISR** or via effective vertex
- Assumptions: DM mass, interaction scale, Lorentz structure



D1	scalar	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
D5	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D9	tensor	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
C1	scalar	$\frac{m_q}{M_*^2}\chi^\dagger\chi\bar{q}q$

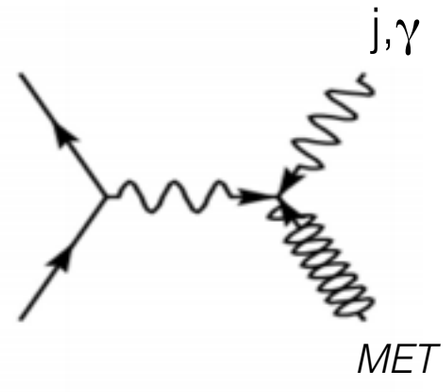
DM Simplified Models:

- EFTs have limited validity unless mediator mass >> $\sqrt{s}$
- UV-theories are valid everywhere
- Invoke ad-hoc fields, interactions to model possible DM nature



LED Gravitons:

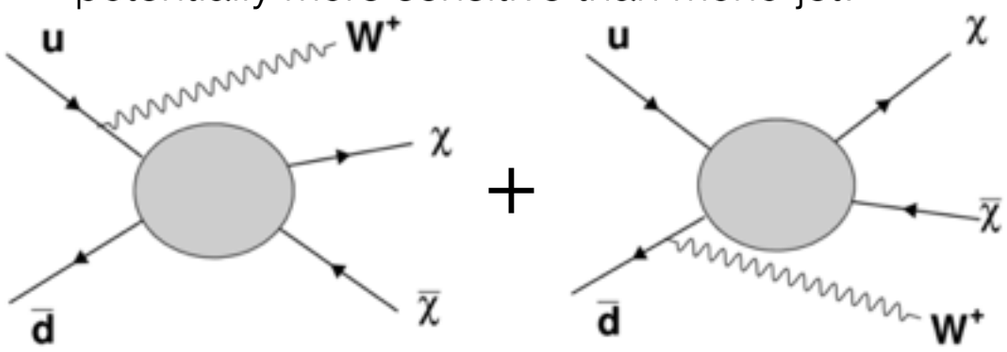
- If M_D << $\sqrt{s}$, particles may interact via gravity
- Additional dimensions create a tower of KK graviton states
- Produced gravitons escape undetected

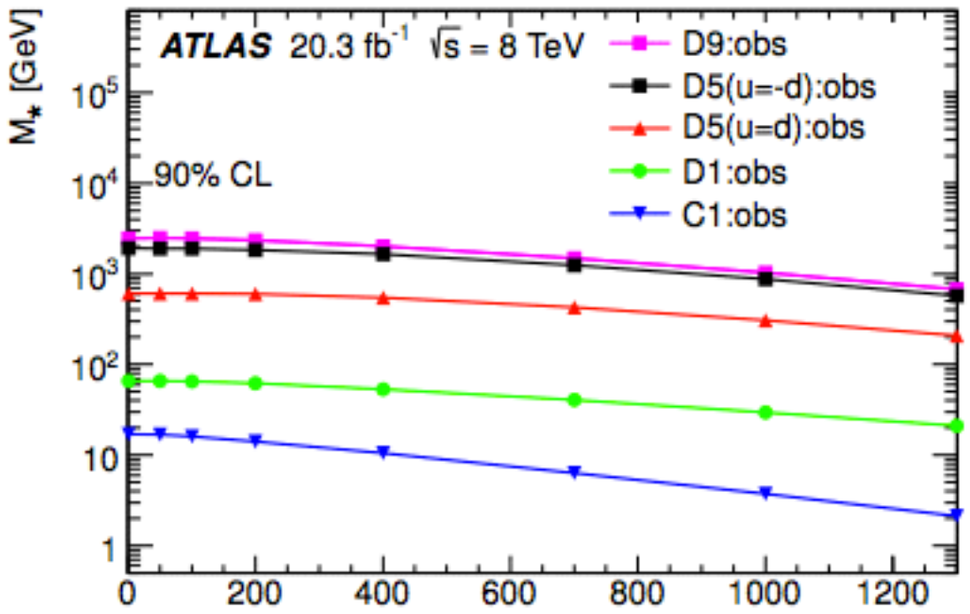


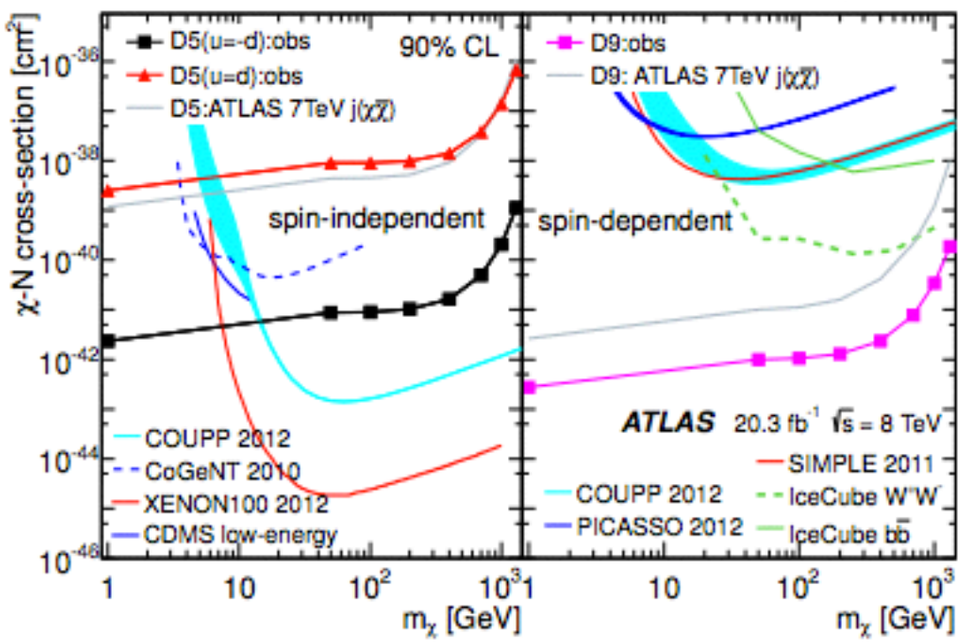
Mono-X: W/Z Hadronic

PRL 112, 041802 (2014), arXiv:1309.4017

- Limits on 4 dark-matter EFT operators (D1, D5, D9, C1)
  - With comparison to other experiments in WIMP-nucleon xs
- Select large radius jet (R=1.2) with p_T > 250 GeV, |η|<1.2, and mass between [50, 120] GeV
  - "Fat jet" assumed to contain *both quarks* from boosted decay of boson
- Two Signal Regions, optimized for different signal operators:
  - **SR1**: MET > 350 GeV
  - **SR2**: MET > 500 GeV
- **Interference effects:**
  - If DM couples equally to (u, d), ISR W's interfere *destructively*
  - If coupling has opposite sign for (u, d), interference is *constructive*
    ↳ potentially more sensitive than mono-jet!



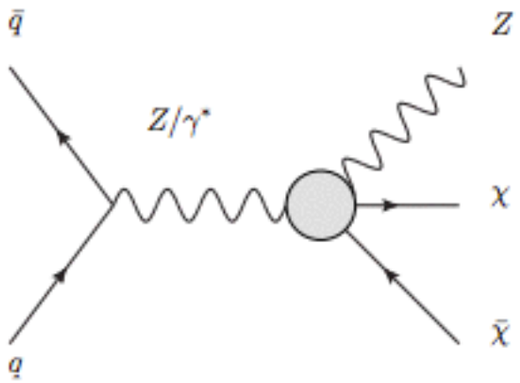


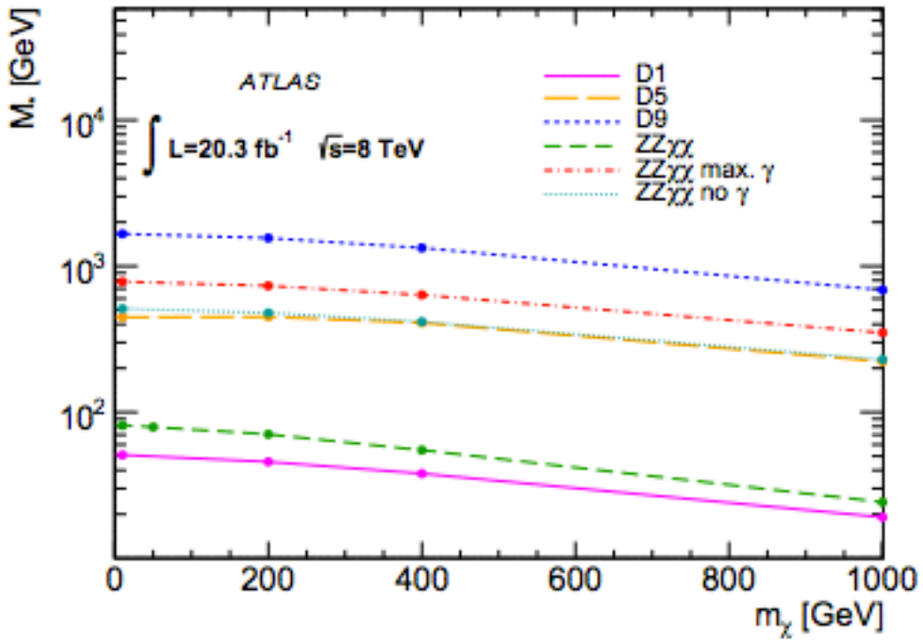


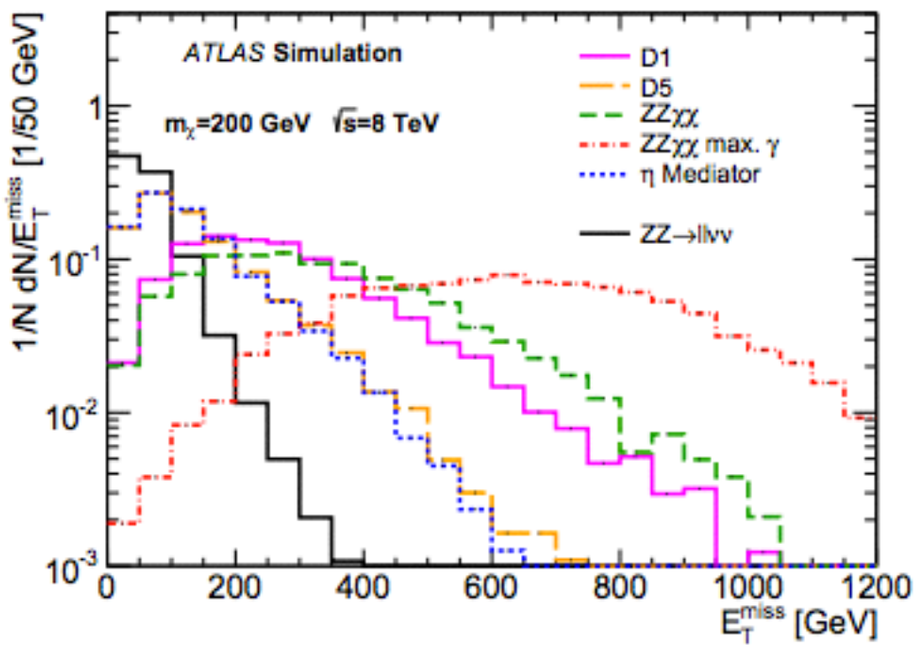
Mono-X: Z leptonic

(submitted to PRD) arXiv:1404.0051

- Z(ll)+MET is a *weak probe of ISR* + χχ production, compared to mono-jet
- However, if DM **interacts directly with EWK** bosons, this channel may be uniquely sensitive
- Limits on:
  - First limits on higher-dimensional ZZχχ EFT operators
  - qqχχ EFTs (w/ ISR Z)
  - Simplified light scalar η mediator model
- Select events with two SF, OS leptons (ee, μμ), near Z mass pole
- Four optimized Signal Regions: MET > 150,250,350,450 GeV



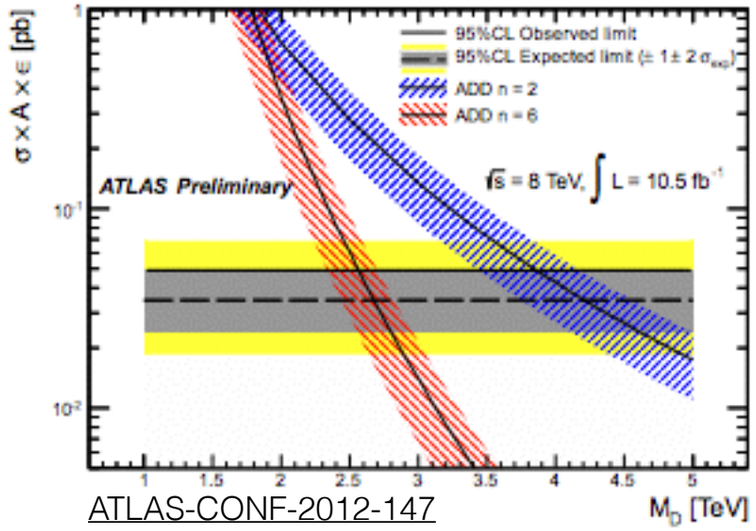




Mono-X: Jet, W leptonic

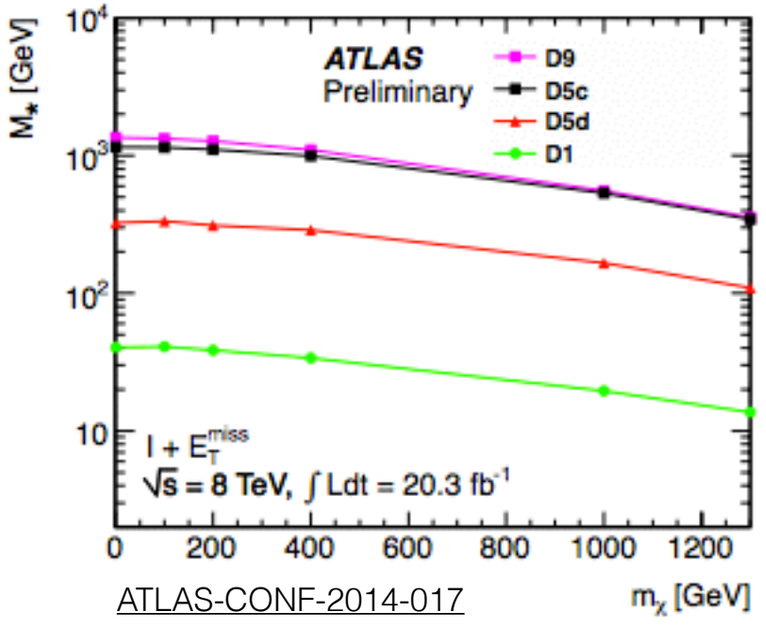
- **Mono-jet (8TeV)** [ATLAS-CONF-2012-147]
  - Limits on: DM EFTs, ADD, Gravitino production
  - Event selection:
    - 1 jet, p_T >120 GeV, $|\eta|$<2
    - veto electrons, muons, 2nd jet if $\Delta\varphi$(jet,MET)<0.5
    - Signal Regions: MET > [120, 220, 350, 500] GeV
- **Mono-W leptonic (8TeV)** [ATLAS-CONF-2014-017]
  - Limits on: W', excited chiral bosons (W*), DM EFTs
  - Event selection:
    - exactly 1 electron / muon candidate
    - MET > 125 GeV (electron channel), MET > 45 GeV (muon channel)
    - Variable m_T threshold, optimized per signal operator (252 - 1888 GeV)

ADD limits (mono-jet)



ATLAS-CONF-2012-147

EFT limits (mono-W leptonic)



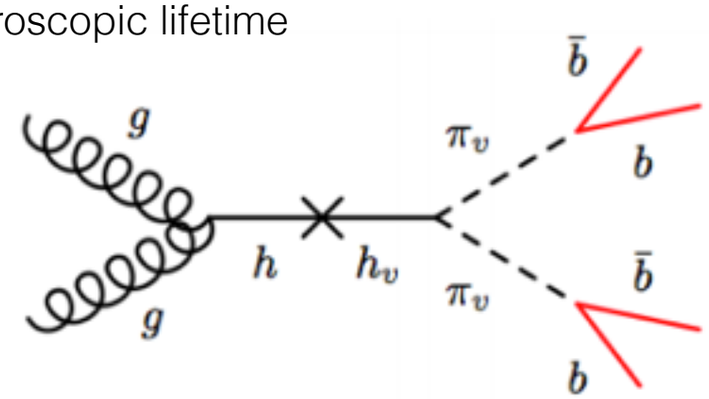
ATLAS-CONF-2014-017

Displaced Vertex: Models

Look for: events with various final-state topologies at highly displaced vertices

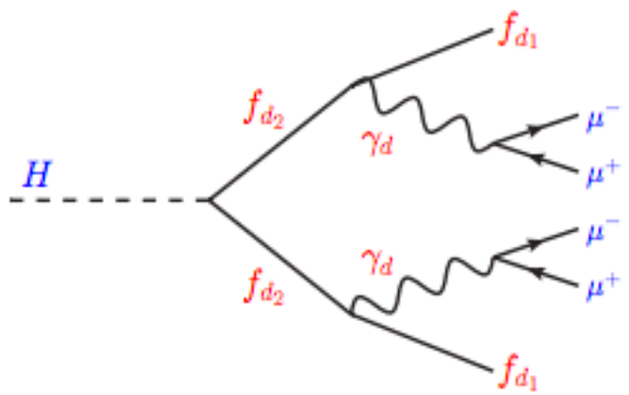
QCD-like Hidden Valley

- Particles in the hidden sector neutral under SM gauges
- Suppose they have a QCD-like gauge structure, which SM is neutral
- Weak interactions between sectors via a common "communicator" group
  - May arise at TeV as higher-dimensional operator / kinetic mixing
- v-particle production hadronizes to v-pions (π_v)
- v-pions predicted to **decay to heavy SM quarks** with macroscopic lifetime



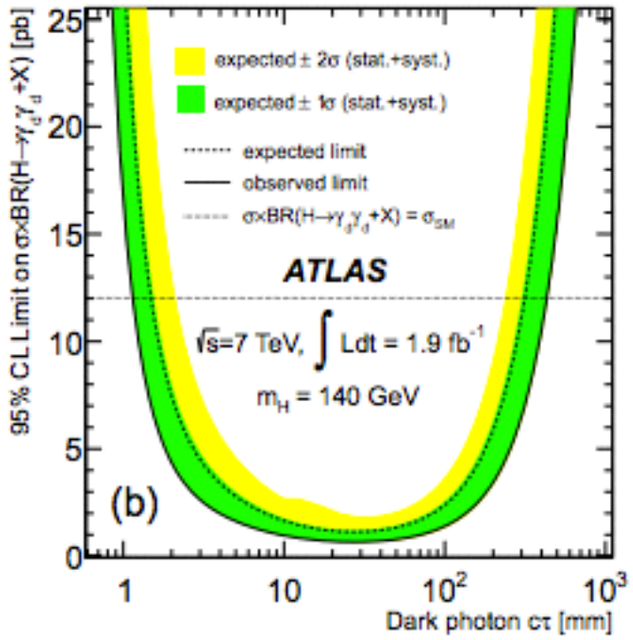
Lepton-jets

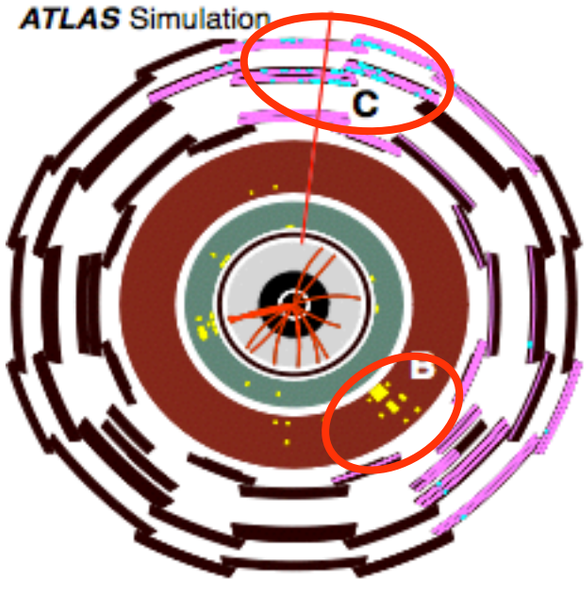
- Lepton-jets are **highly collimated clusters** of electrons, muon, pions
- Signature of *light unstable* hidden-sector particles
  - E.g.: **dark photon** γ_d between MeV~GeV
  - γ_d is light relative to v-particles → long-lived, eventually decaying to SM
- **Example**: Higgs decay to hidden leptons, which radiate dark photons



Displaced Vertex: Results

- **Displaced (e, μ) lepton-jets**
  - 7 TeV results for muonic LJ [PLB 721 (2013) 32]
- **Displaced b-jets in Muon Spectrometer and Hadronic Calorimeter**
  - Requires unique trigger strategies; studies at 8TeV: [JINST 8 (2013) P07015]
  - And dedicated vertex reconstruction in the MS [JINST 9 (2014) P02001]
  - 7 TeV results: Higgs → long-lived neutral particles (MS only) [PRL 108 (2012) 251801]





π_v decays in HCal and MS

JINST 8 (2013) P07015

Non-Resonant Multi-Body: Models

Look for: events with many high-p_T objects

Microscopic Black Holes in ADD extra dimensions

- Schwarzschild radius in 4+n dimensions of size >> R_S:

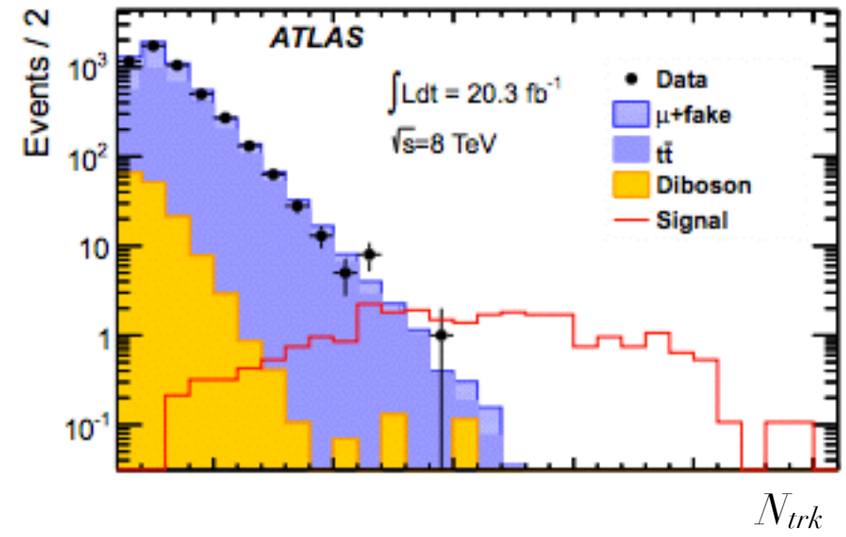
$$R_S = \frac{1}{\sqrt{\pi} M_P} \left[\frac{M_{\mathrm{BH}}}{M_P} \left(\frac{8\Gamma\left(\frac{n+3}{2}\right)}{n+2} \right) \right]^{\frac{1}{n+1}}$$

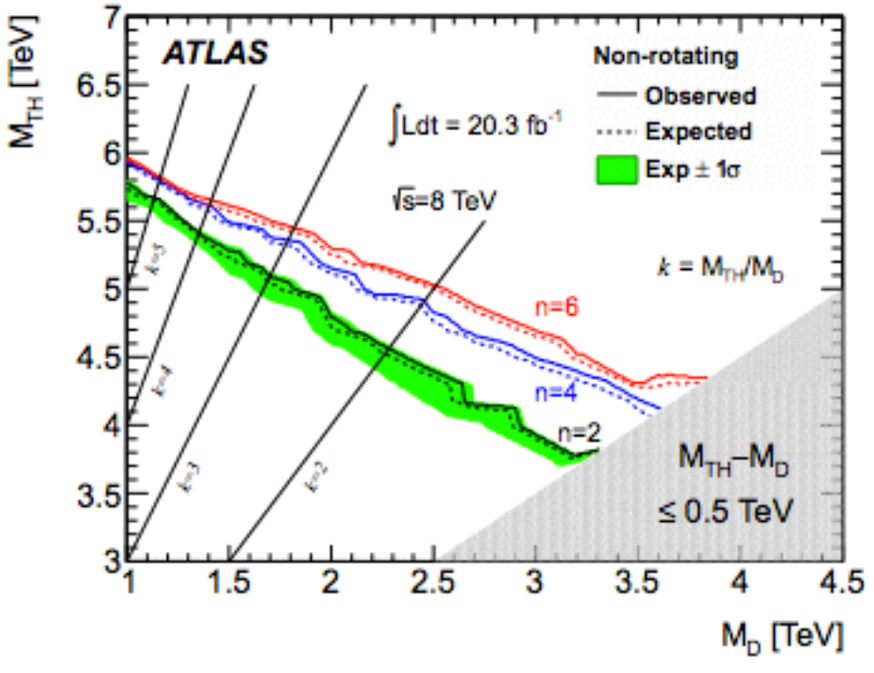
- **Hoop Conjecture**: BH forms when object of mass M_{BH} is contained within a radius R_S
  ↳ Cross section for BH formation: $\sigma(M_{\mathrm{BH}}) \approx \pi R_S^2$
- In pp collision, take M_{BH} = c.o.m energy of patrons → probe M_P at ~ 1 TeV
  - Semiclassical production only valid for mass >> M_P; parameterize threshold with M_{TH}
- BH undergoes high-multiplicity decay via **Hawking Radiation**

Non-Resonant Multi-Body: Like-sign Dimuons

PRD 88, 072001 (2013), arXiv:1308.4075

- Limits on ADD + semiclassical BH model with n=2,4,6
  - Free parameters: M_D, M_{TH}
- Event Selection:
  - Primary vertex with at least five tracks of p_T>400 GeV
  - Overall track multiplicity $N_{trk} \geq 30$
  - ≥ 2 muons
  - Leading muon p_T>100 GeV
  - Leading, subleading muons have the same charge

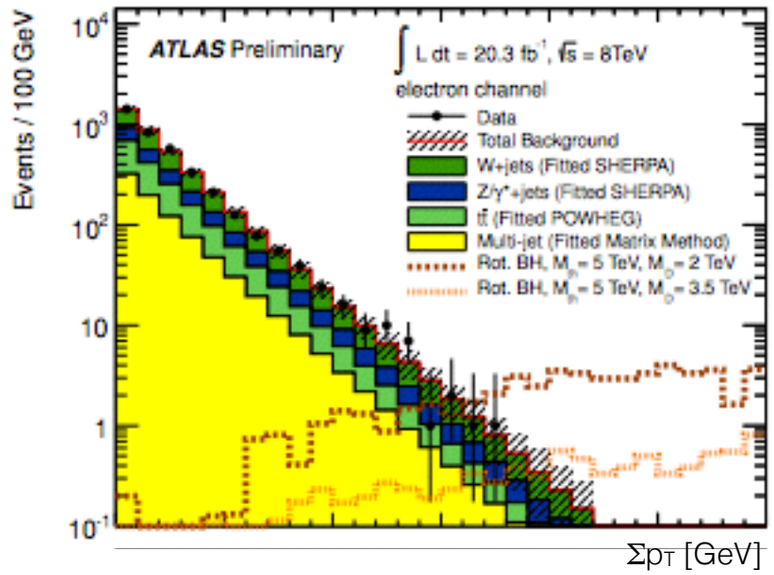


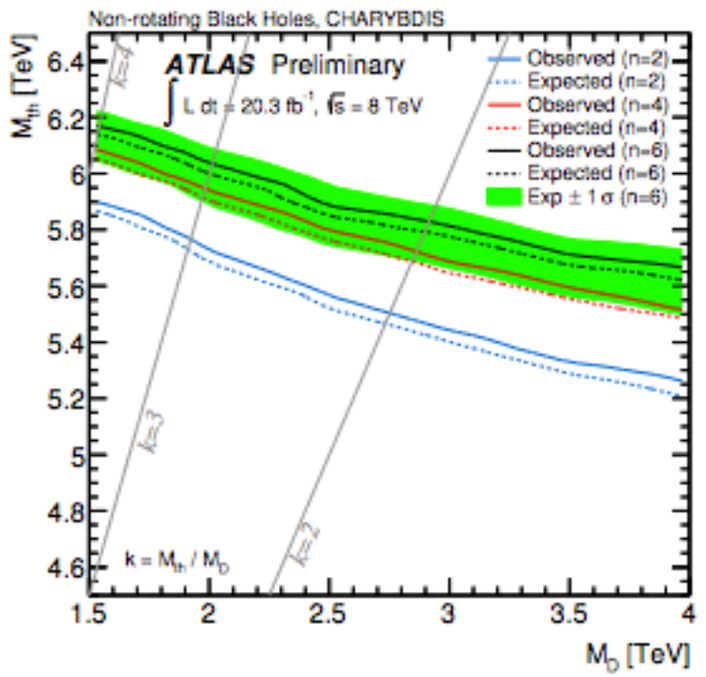


Non-Resonant Multi-Body: Leptons and Jets

ATLAS-CONF-2014-016

- Limits on ADD + semiclassical BH model with n=2,4,6
  - Free parameters: M_D, M_{TH}
- Select events with 1 lepton + at least two additional leptons/ jets (all with p_T>100 GeV)
- (Binned) Signal Region: events with Σp_T > 2000 GeV





Conclusion

- ATLAS is looking in a wide range of exotic signatures to pursue diverse phenomenological models
- 8TeV data yields **new limits**, pushed existing limits further
- Run-1 analyses are wrapping up; many papers on the horizon
- We look forward to energy and luminosity frontiers starting in 2015!
  - Lumi → tighter limits across the board
  - Energy → probe further into parameter spaces (e.g. M_{TH})