Results from ATLAS on searches for dark matter and Long-Lived Particles

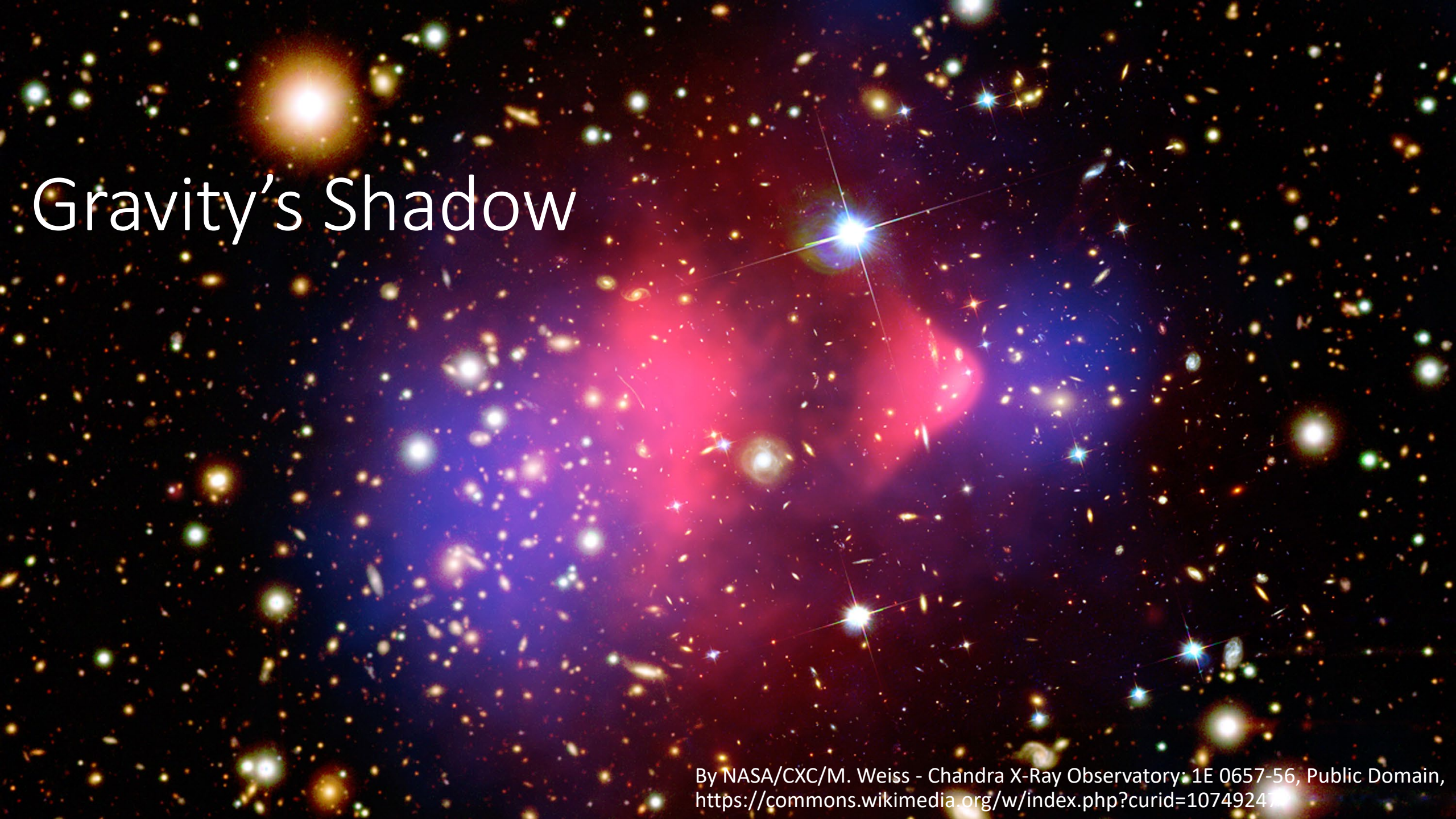
JESSE HEILMAN

ON BEHALF OF THE ATLAS COLLABORATION

Carleton University

ATLAS EXPERIMENT

Gravity's Shadow



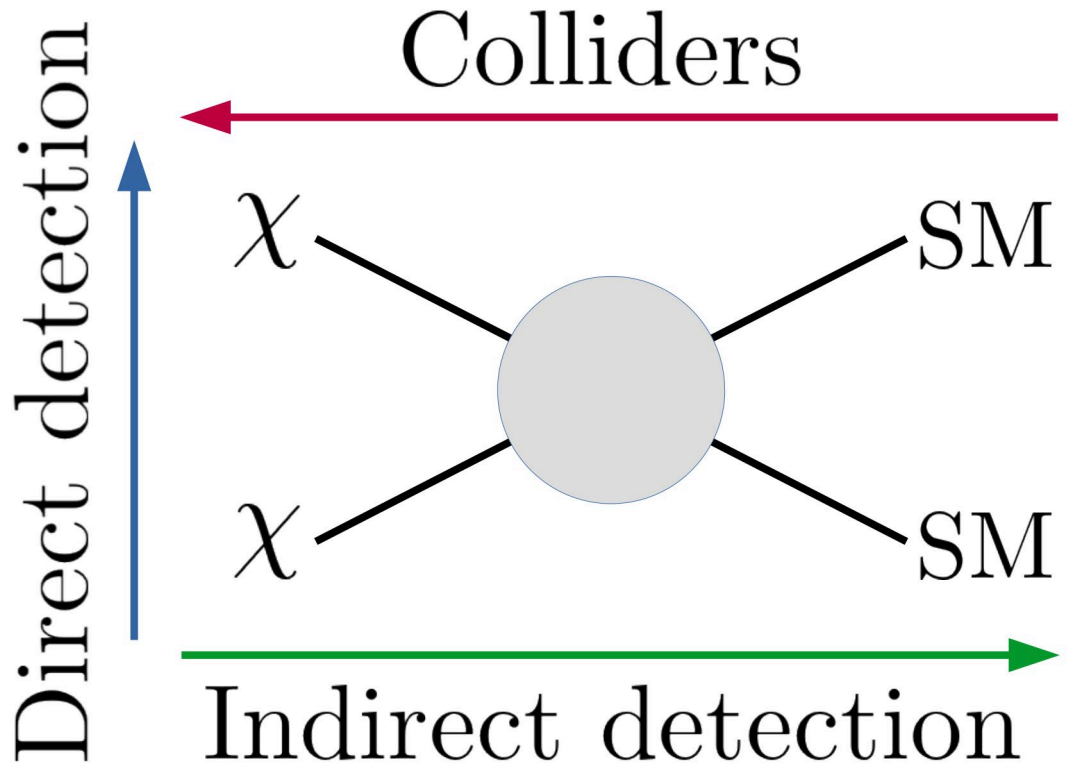
A Universe of Shadows

Normal matter is pulled into the gravity well of the dark matter structure

SIMULATION OF THE DARK-MATTER DISTRIBUTION IN THE UNIVERSE. (V. SPRINGEL ET AL. 2005)

Many Paths to the same Goal

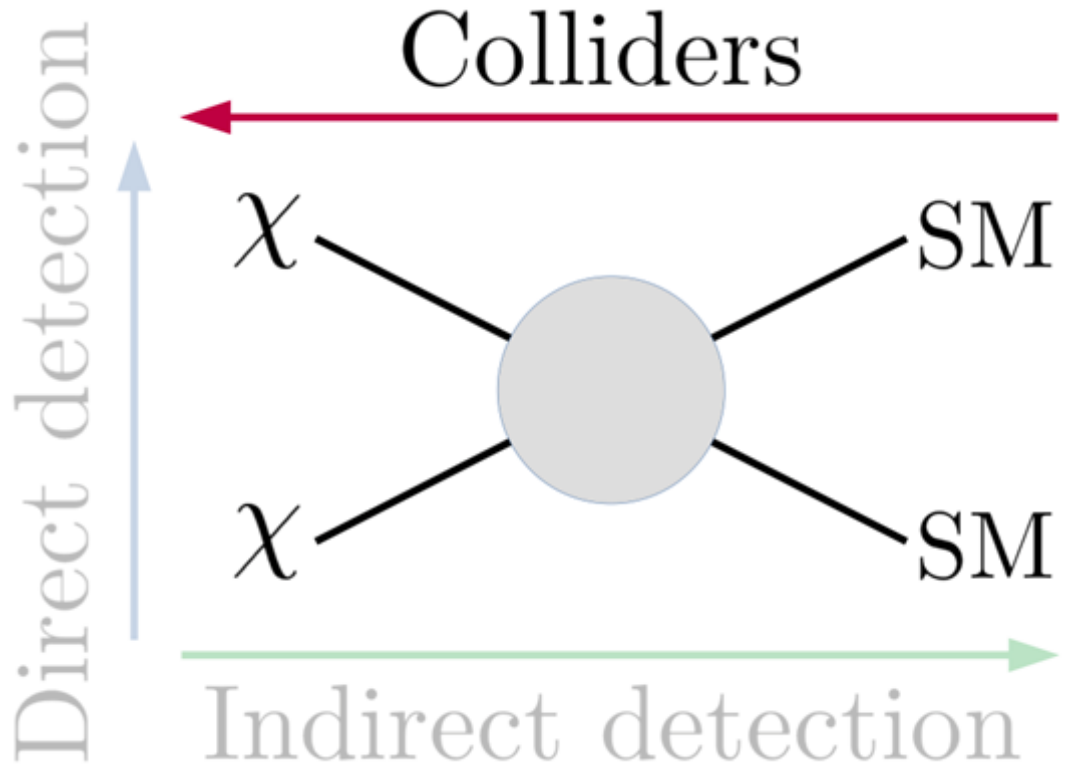
Different experiments are sensitive to different dark matter interactions.



ARBEY, A. ET AL - ARXIV:2104.11488CERN-TH-2021-066

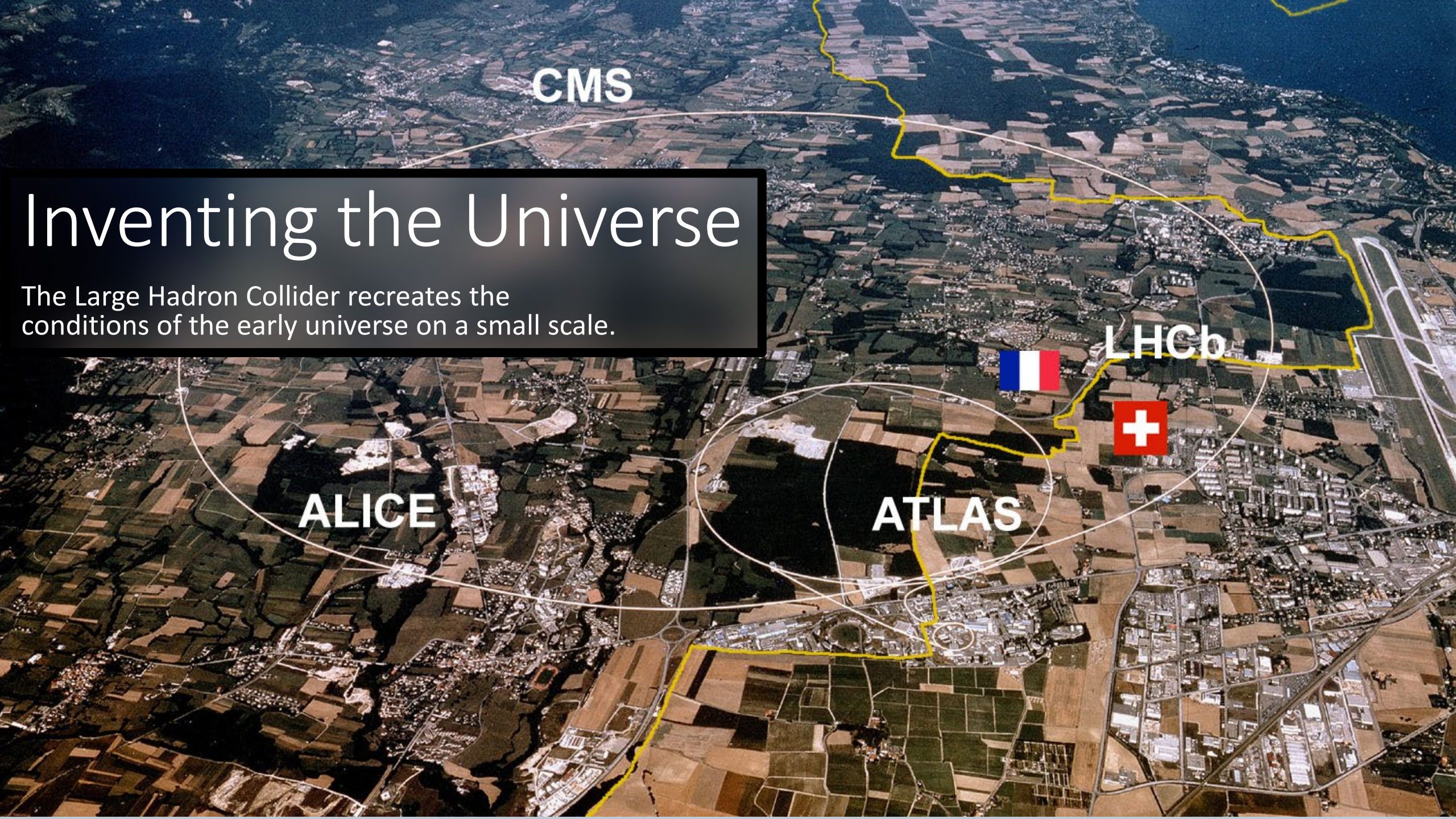
Many Paths to the same Goal

Different experiments are sensitive to different dark matter interactions.



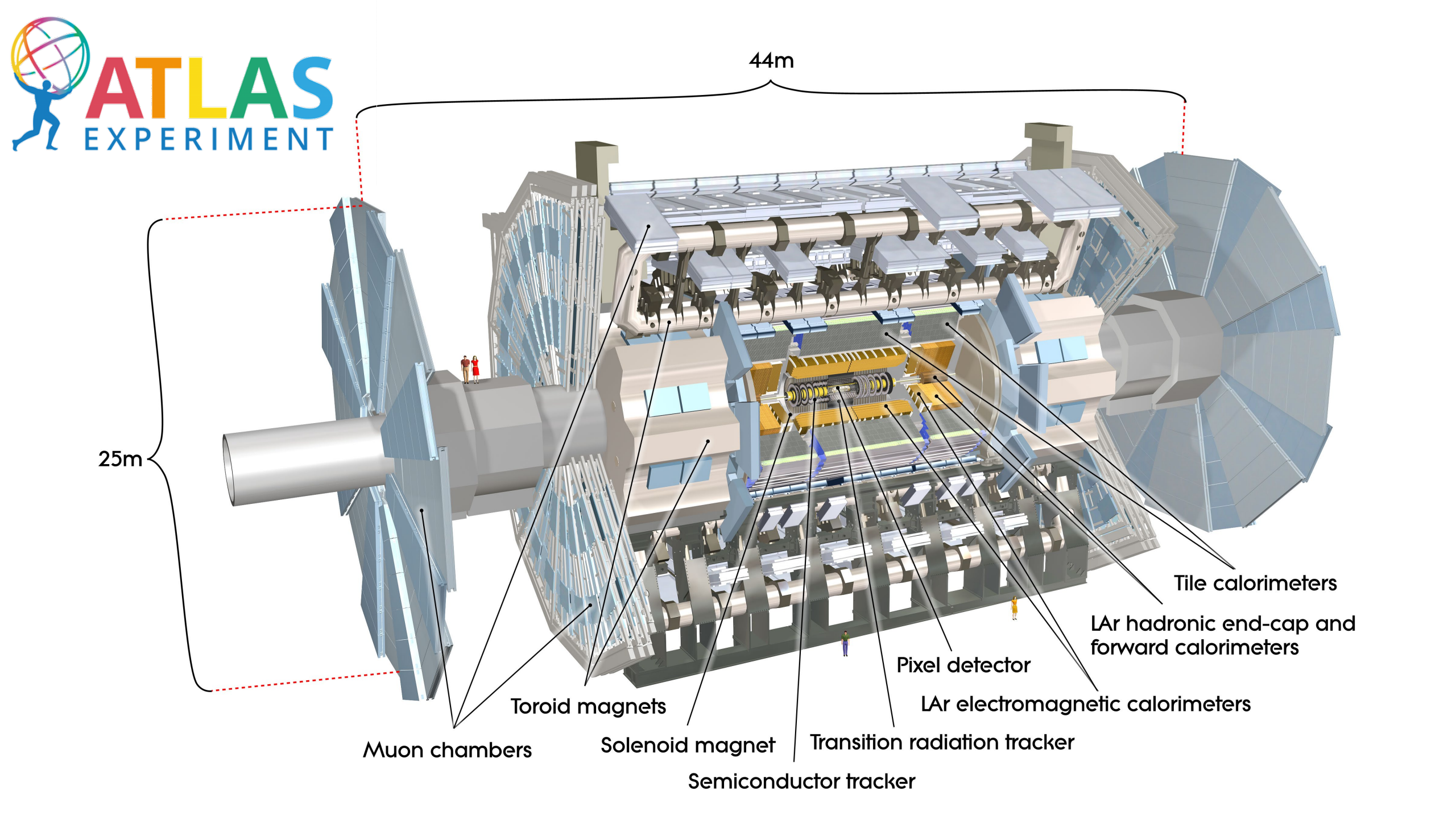
ARBEY, A. ET AL - ARXIV:2104.11488CERN-TH-2021-066

“If you wish to make an apple pie from scratch, you must first invent the universe.”
–Carl Sagan



Inventing the Universe

The Large Hadron Collider recreates the conditions of the early universe on a small scale.


ATLAS
EXPERIMENT
44m
25m
Muon chambers
Toroid magnets
Solenoid magnet
Semiconductor tracker
Transition radiation tracker
Pixel detector
LAr electromagnetic calorimeters
LAr hadronic end-cap and
forward calorimeters
Tile calorimeters

Constraints on production of WIMP DM

- SM and DM interact through mediator boson
  - Spin-0 or Spin-1
- Semi-visible final states with DM produced
- Visible final states with SM particles produced to constrain mediator

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: EPJC

CERN-EP-2024-102
25th April 2024

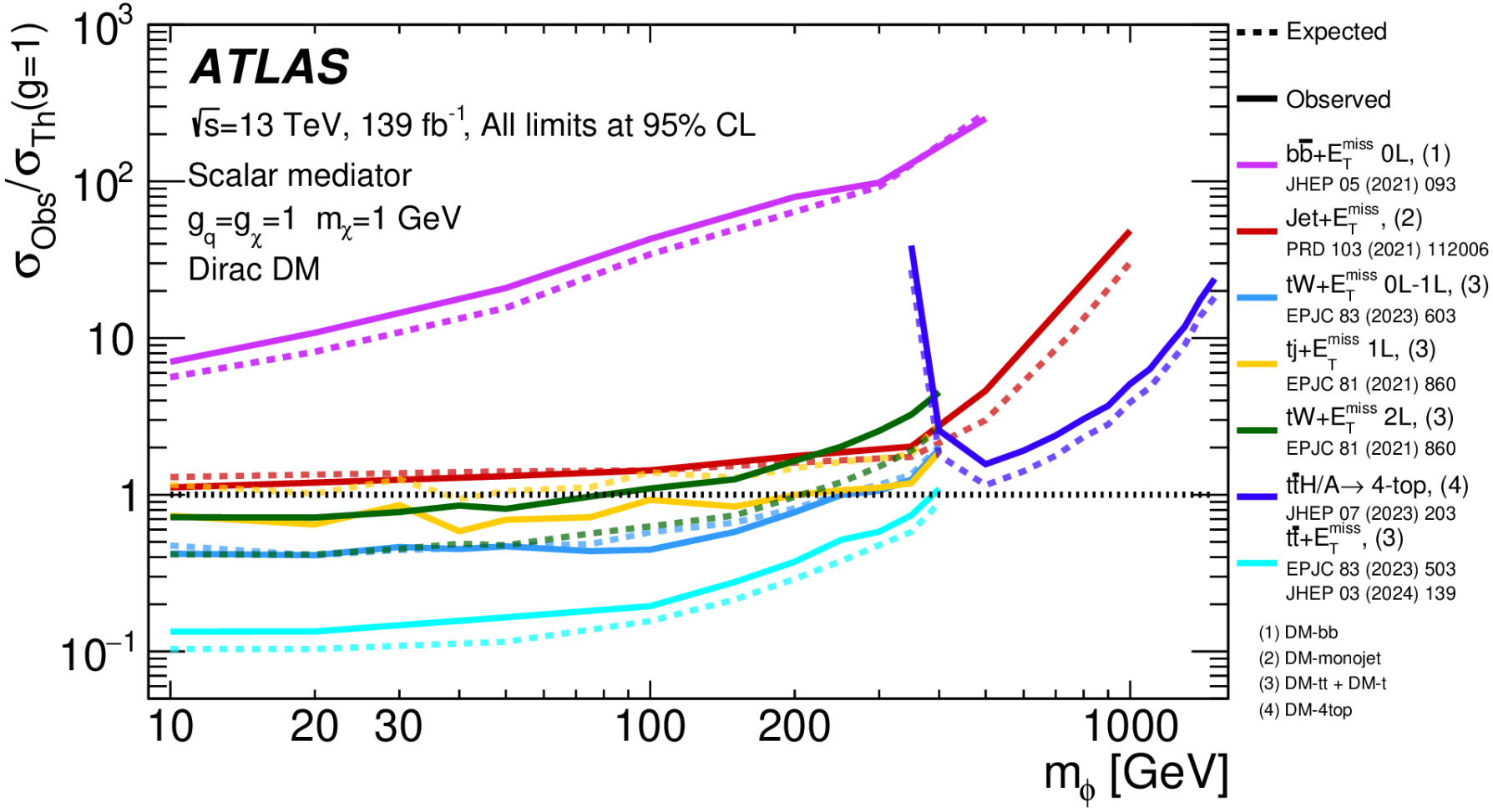
Constraints on dark matter models involving an s-channel mediator with the ATLAS detector in pp collisions at $\sqrt{s} = 13$ TeV

The ATLAS Collaboration

This paper reports a summary of searches for a fermionic dark matter candidate in the context of theoretical models characterised by a mediator particle exchange in the s-channel. The data sample considered consists of pp collisions delivered by the Large Hadron Collider during its Run 2 at a centre-of-mass energy of $\sqrt{s} = 13$ TeV and recorded by the ATLAS detector, corresponding to up to 140 fb^{-1}. The interpretations of the results are based on simplified models where the new mediator particles can be spin-0, with scalar or pseudo-scalar couplings to fermions, or spin-1, with vector or axial-vector couplings to fermions. Exclusion limits are obtained from various searches characterised by final states with resonant production of Standard Model particles, or production of Standard Model particles in association with large missing transverse momentum.

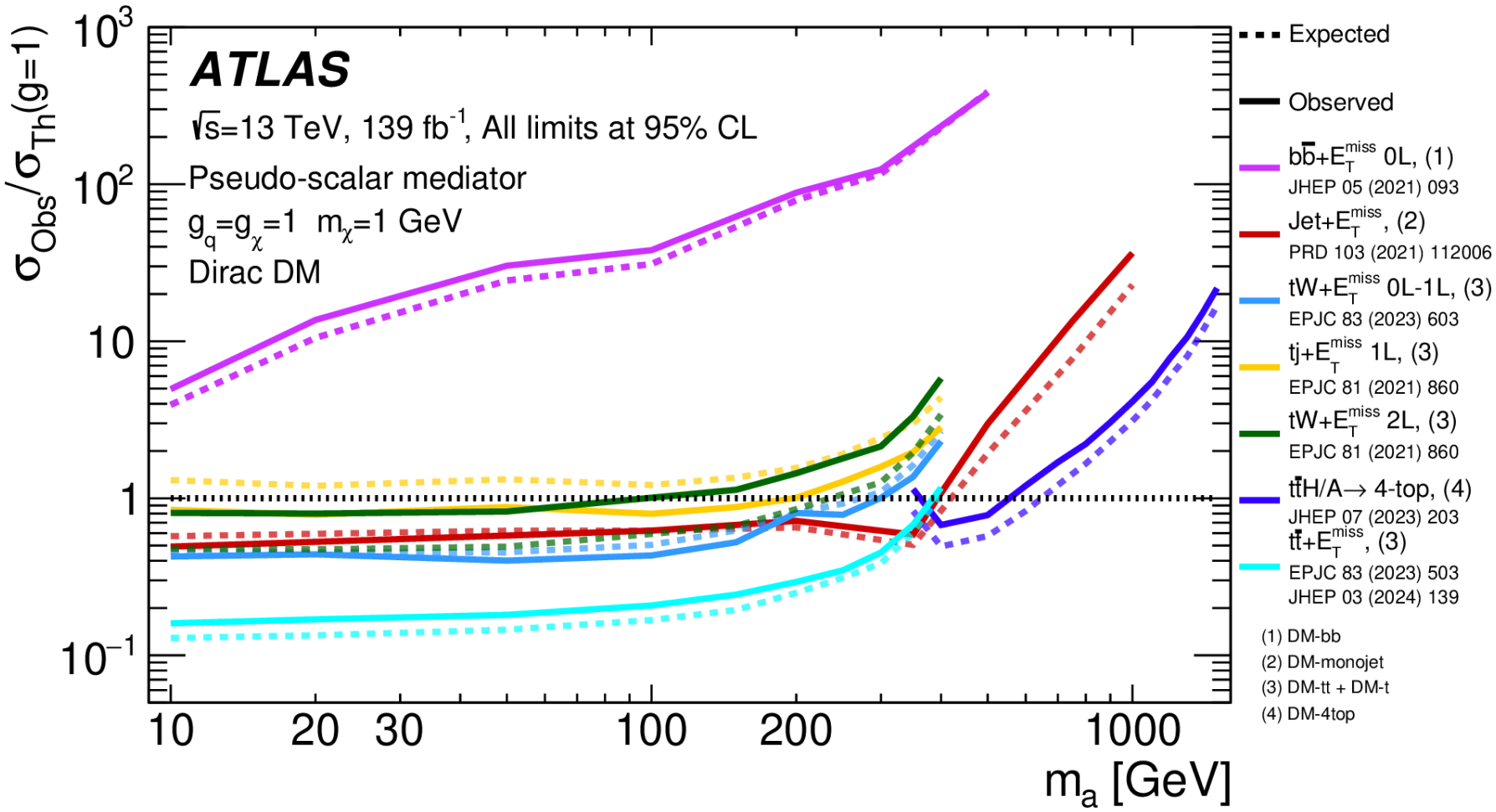
Benchmark Model Summary

Mediator	Acronym	Symbol	J^P	Couplings			Signatures
Spin-0				g_q		g_χ	
Scalar	S	ϕ	0^+	1.0		1.0	Jet + $E_{\mathrm{T}}^{\mathrm{miss}}$, $t\bar{t}$ + $E_{\mathrm{T}}^{\mathrm{miss}}$, $b\bar{b}$ + $E_{\mathrm{T}}^{\mathrm{miss}}$, $t(W/j)$ + $E_{\mathrm{T}}^{\mathrm{miss}}$, $t\bar{t}t\bar{t}$
Pseudo-Scalar	PS	a	0^-	1.0		1.0	
Spin-1				g_q	g_l	g_χ	
Vector	V1	Z'_V	1^-	0.25	0.0	1.0	Jet/γ/W/Z +$E_{\mathrm{T}}^{\mathrm{miss}}$, Dilepton resonances, Dijet resonances
	V2			0.1	0.01	1.0	
	V3			0.07	0.0	1.0	
	V4			0.15	0.03	1.0	
Axial-Vector	A1	Z'_A	1^+	0.25	0.0	1.0	
	A2			0.1	0.1	1.0	
	A3			0.07	0.0	1.0	
	A4			0.2	0.05	1.0	



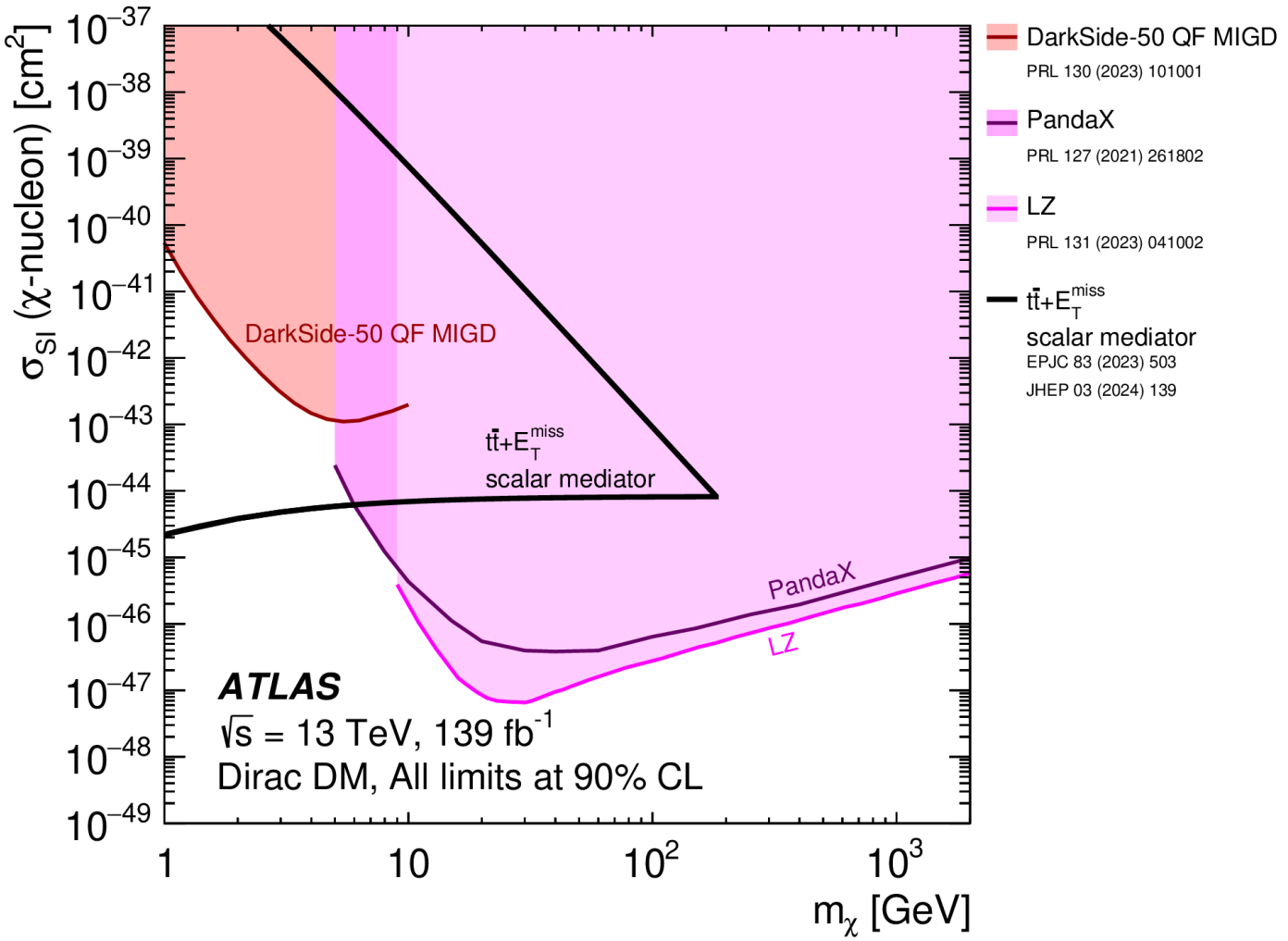
Scalar Mediator Exclusion Limits

Exclusion limits for colour-neutral **scalar** mediator models as a function of the mediator mass for a dark matter mass m_χ of 1 GeV.



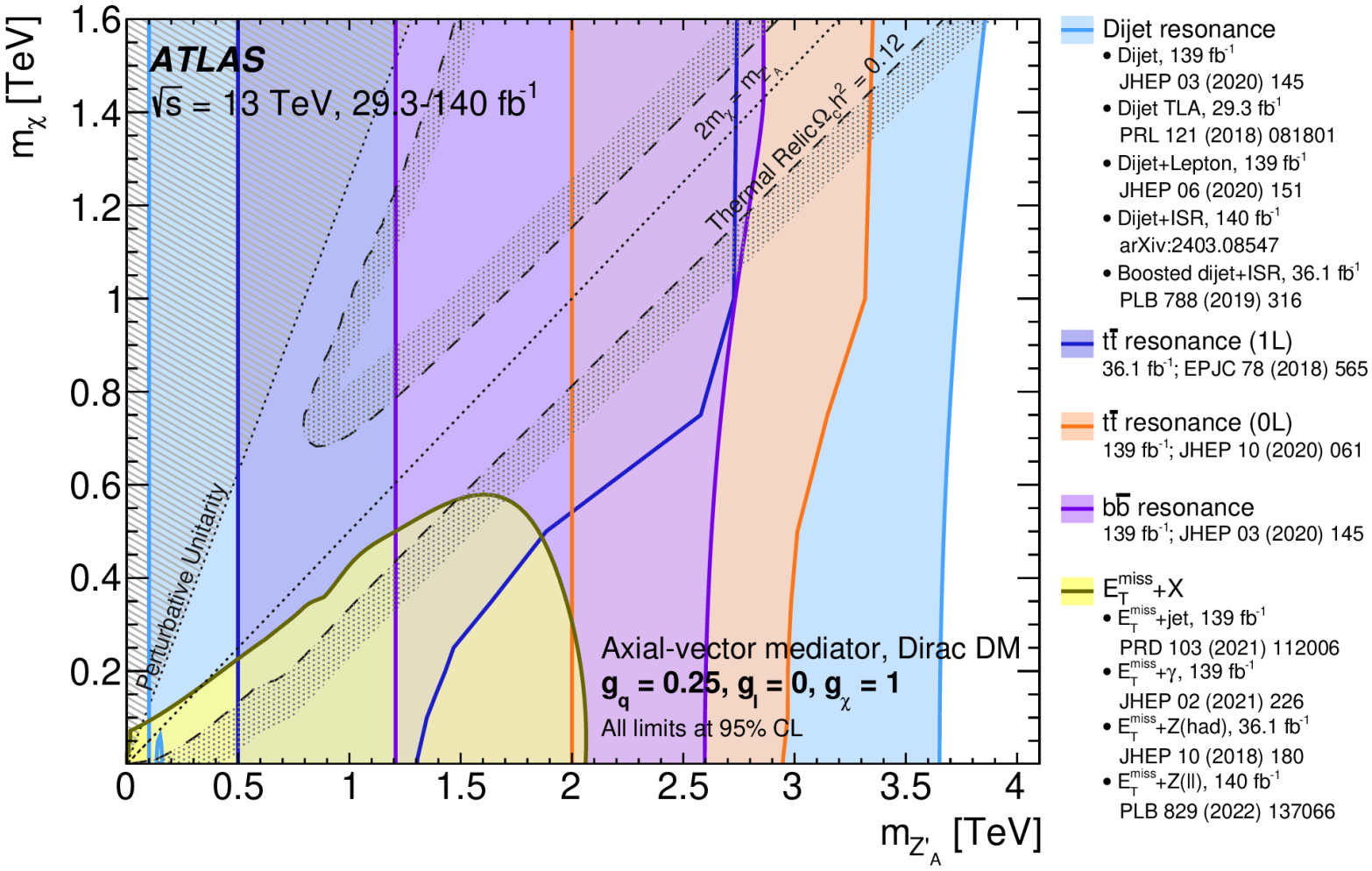
Pseudo-scalar Exclusion Limits

Exclusion limits for colour-neutral **pseudo-scalar** mediator models as a function of the mediator mass for a dark matter mass m_χ of 1 GeV.



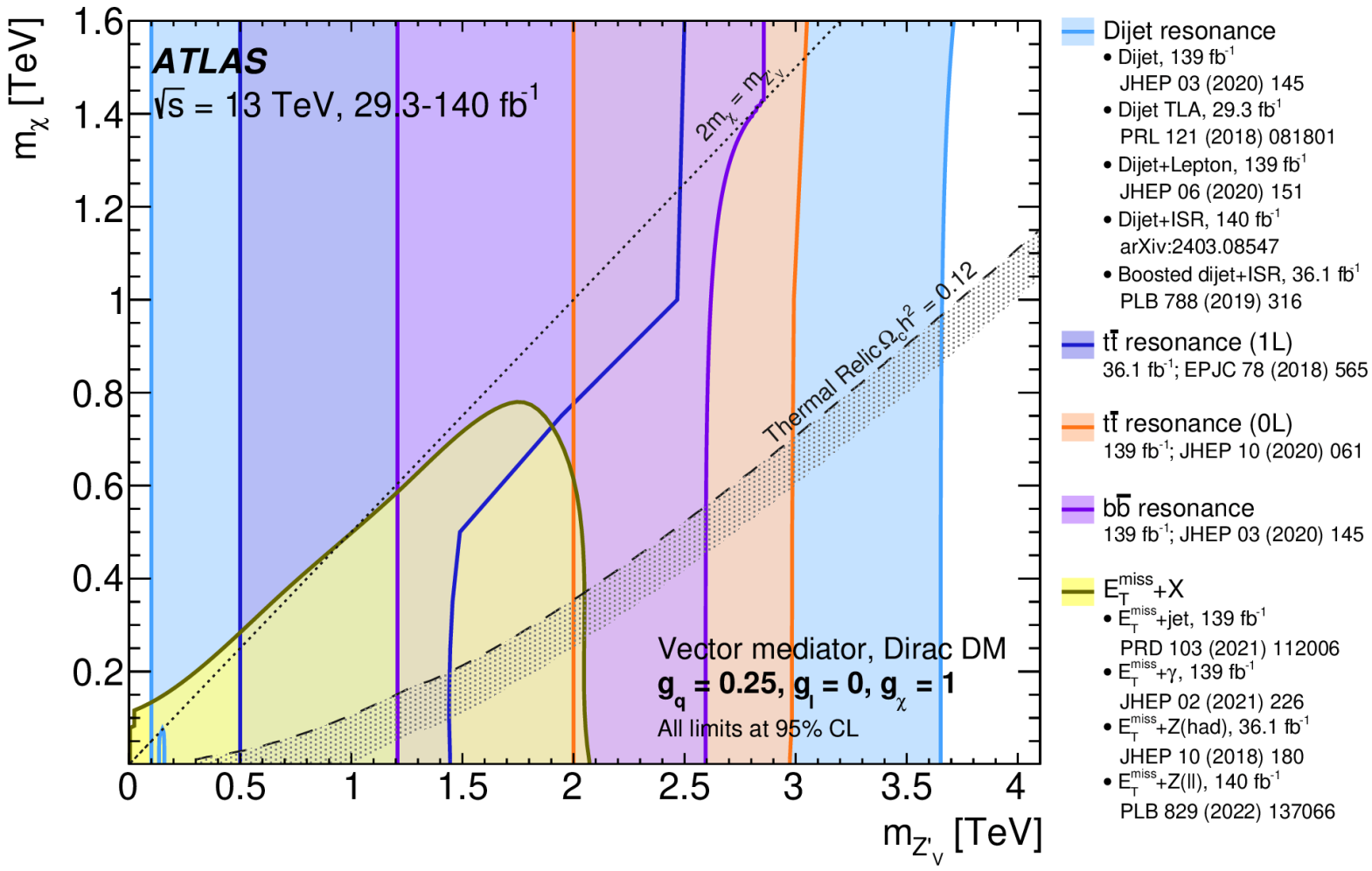
Comparison to Direct Detection Experiments

Comparison of the 90% CL limits on the spin-independent DM-nucleon cross-section as a function of the DM mass in the context of the colour-neutral simplified model with a scalar mediator. The lower horizontal line of the DM-nucleon scattering cross-section for the $tt+E_T^{miss}$ scalar mediator contour corresponds to the value of the cross-section for m_ϕ=366 GeV.



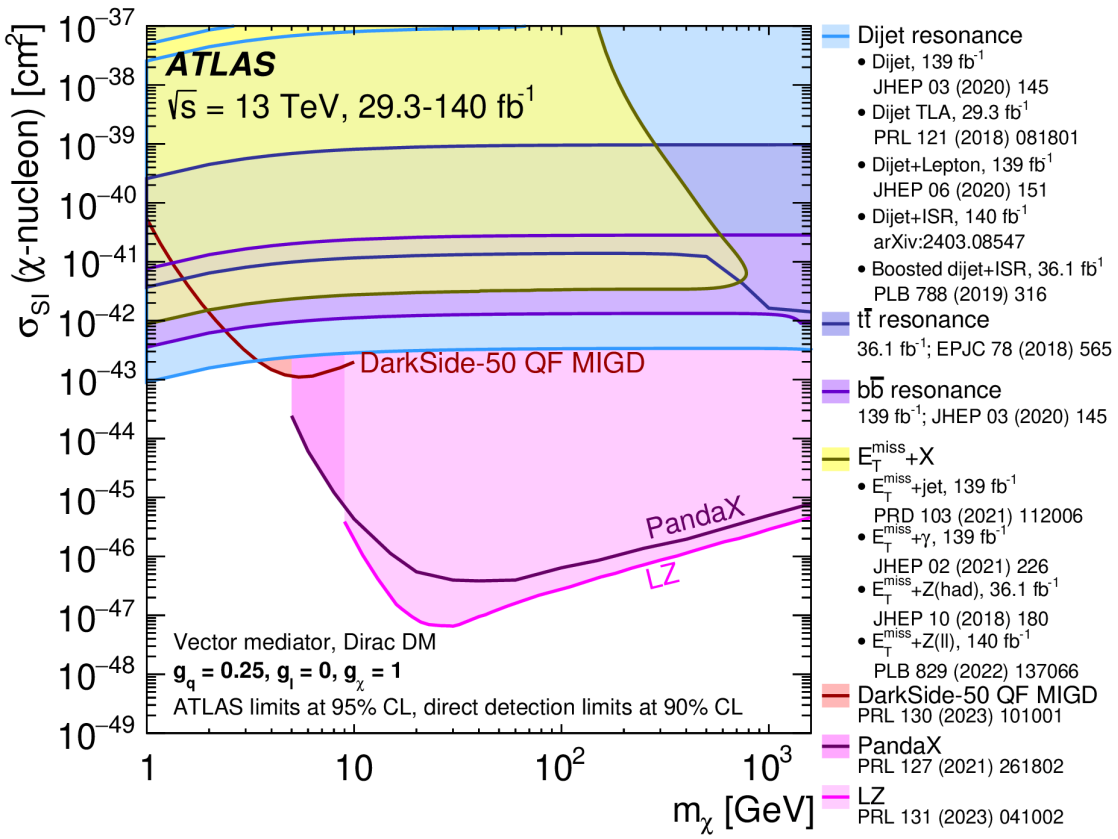
Axial Vector Exclusion Limits

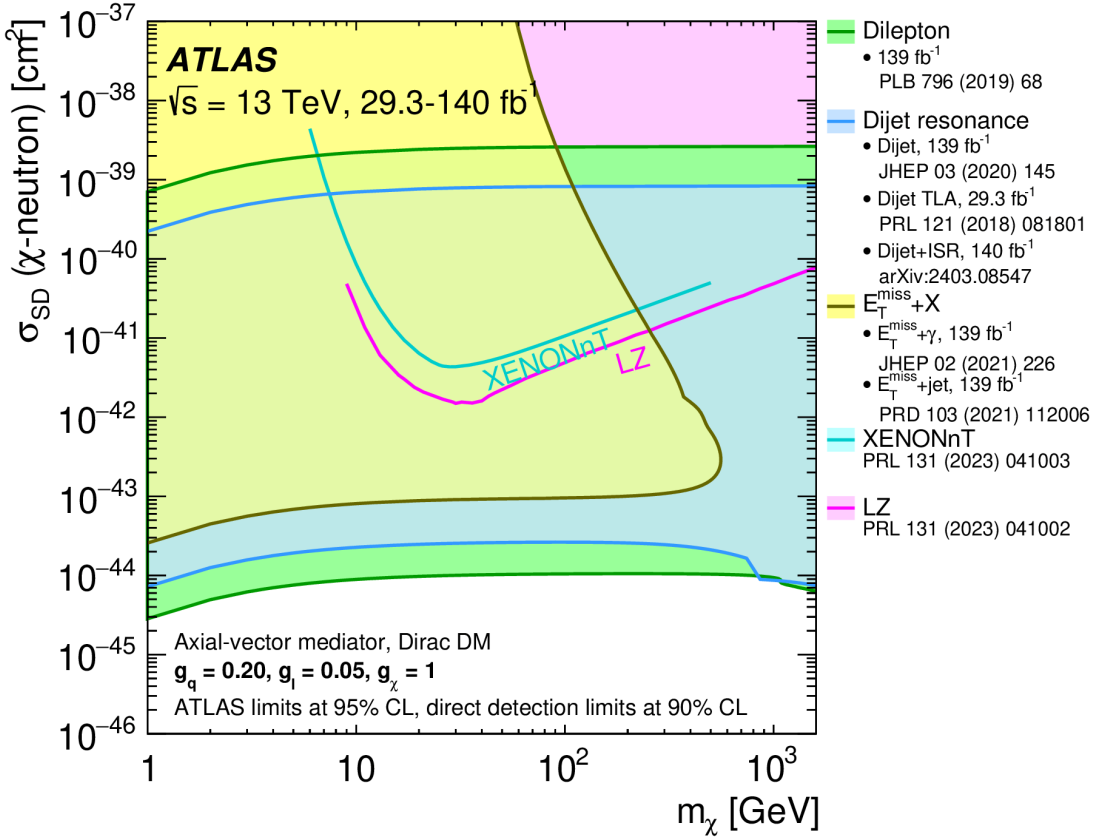
Exclusions in the (m_χ, m_{Med}) for benchmark model A1. Dashed curve indicates points consistent with a thermal relic density of $\Omega h^2 = 0.12$ with the overdense side shaded.



Vector Exclusion Limits

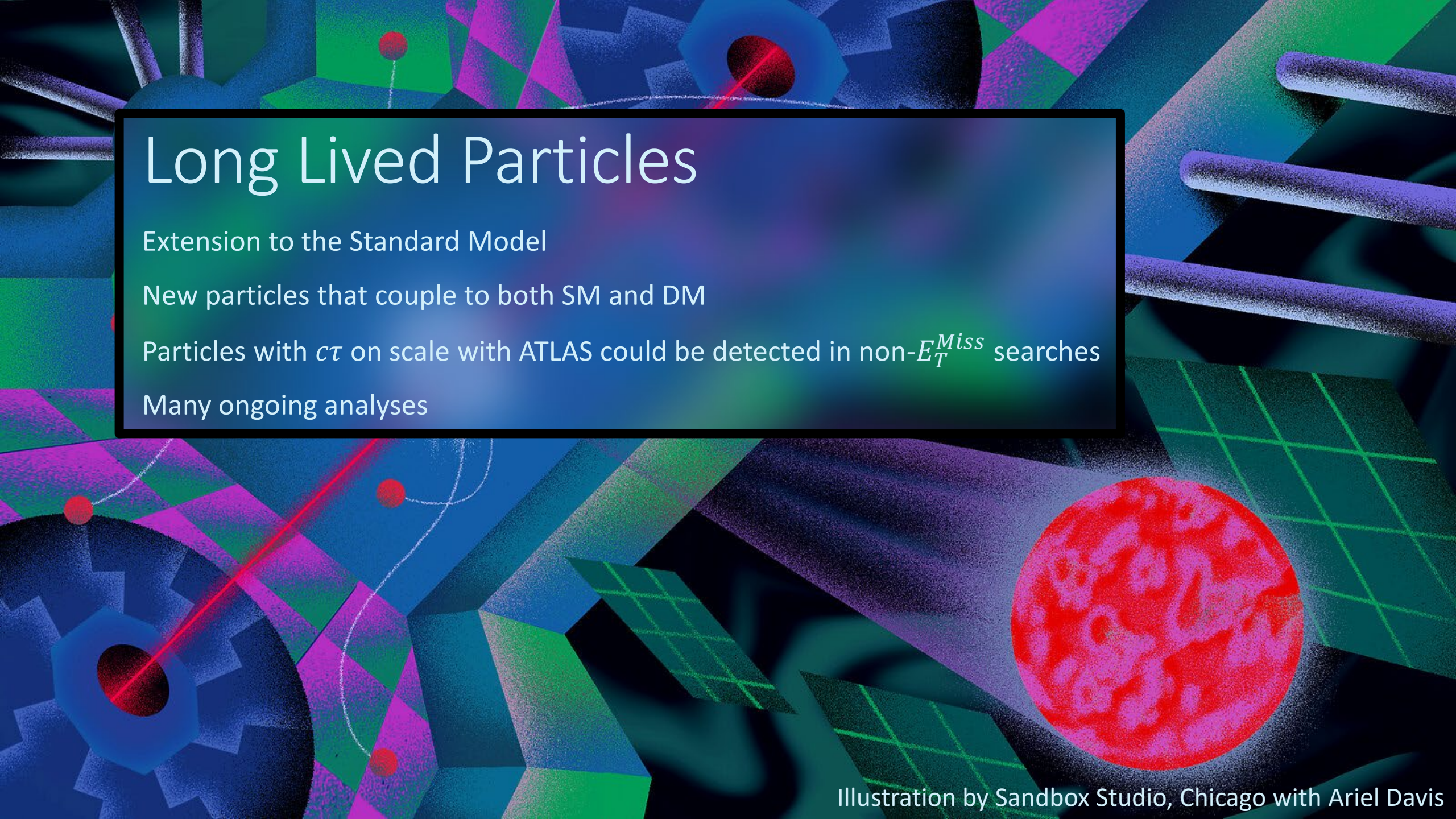
Exclusions in the (m_χ, m_{Med}) for benchmark model V1. Dashed curve indicates points consistent with a thermal relic density of $\Omega h^2 = 0.12$ with the overdense side shaded.





Comparison to Direct Detection Experiments

Benchmark V1 (left) comparison with spin-independent χ-nucleon cross-sections and A2 (right) comparison with spin-dependent χ-proton cross-sections.


Long Lived Particles
Extension to the Standard Model
New particles that couple to both SM and DM
Particles with $c\tau$ on scale with ATLAS could be detected in non-E_T^{Miss} searches
Many ongoing analyses
Illustration by Sandbox Studio, Chicago with Ariel Davis

LLPs with Displaced Vertices

Targets ‘displaced jets’ from Dark Sector particles that decay hadronically to SM particles with macroscopic decay lengths.

Uses per-jet BDT classifier and performs a Maximum Likelihood fit on the product of the BDT scores of the two highest scored jets.

Signal regions require the presence of highly scored jets as well as displaced vertices which are filtered to reject DVs from SM processes.

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Phys. Rev. Lett.

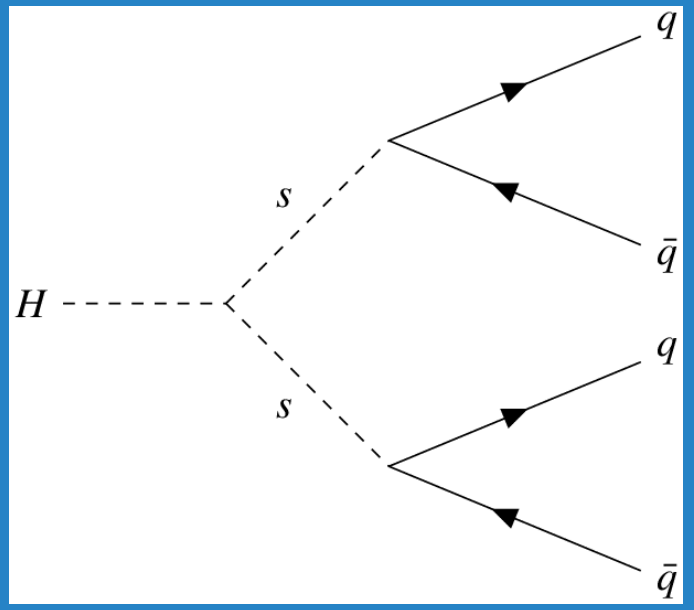
CERN-EP-2024-086
25th March 2024

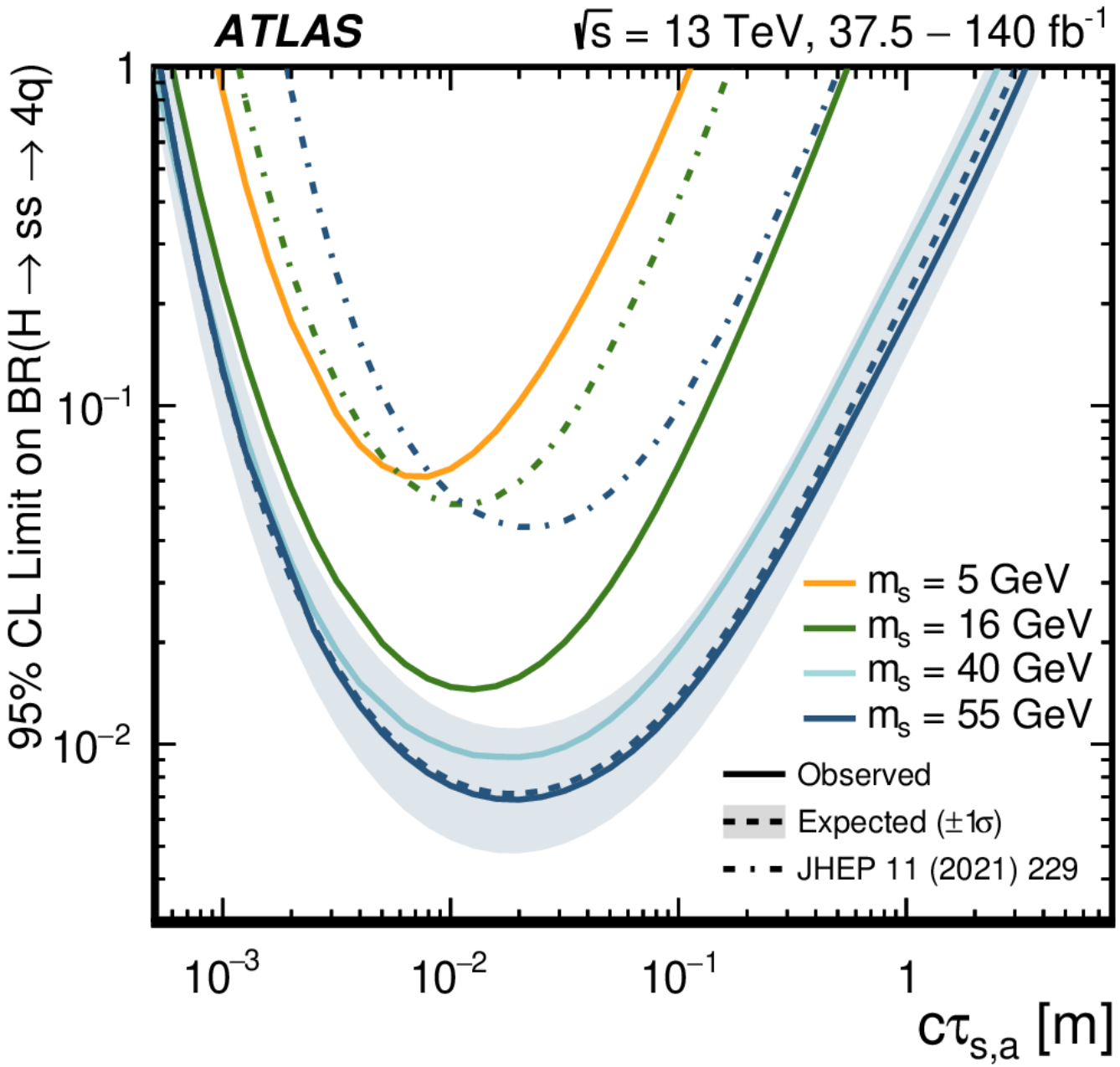
Search for light long-lived particles in pp collisions at $\sqrt{s}$ = 13 TeV using displaced vertices in the ATLAS inner detector

The ATLAS Collaboration

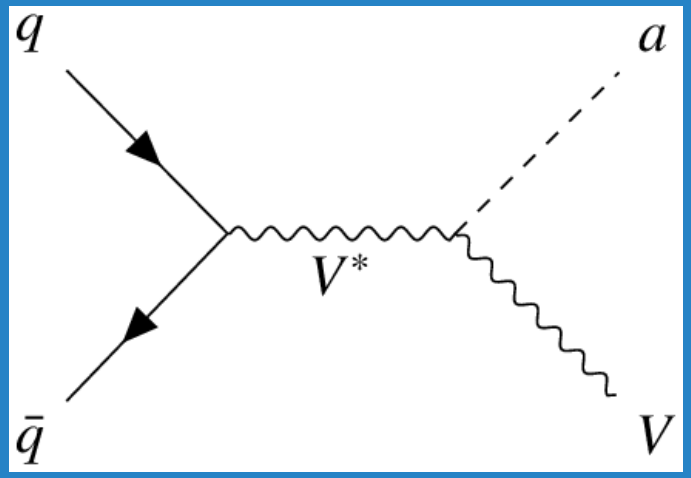
A search for long-lived particles (LLPs) using 140 fb^{-1} of pp collision data with $\sqrt{s}$ = 13 TeV recorded by the ATLAS experiment at the LHC is presented. The search targets LLPs with masses between 5 and 55 GeV that decay hadronically in the ATLAS inner detector. Benchmark models with LLP pair production from exotic decays of the Higgs boson and models featuring long-lived axion-like particles (ALPs) are considered. No significant excess above the expected background is observed. Upper limits are placed on the branching ratio of the Higgs boson to pairs of LLPs, the cross-section for ALPs produced in association with a vector boson, and, for the first time, on the branching ratio of the top quark to an ALP and a u/c quark.

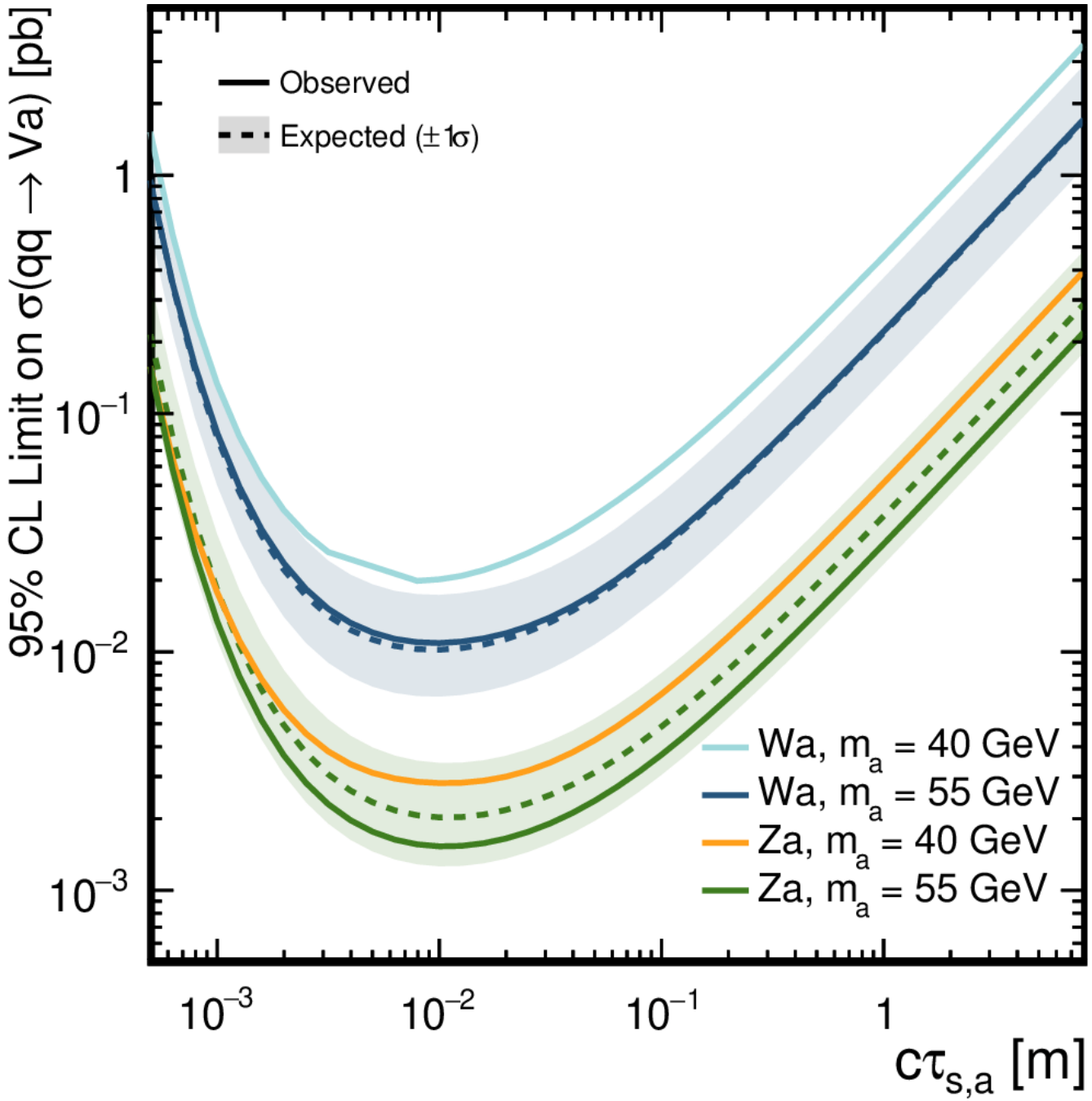
Higgs Portal Confidence Limits



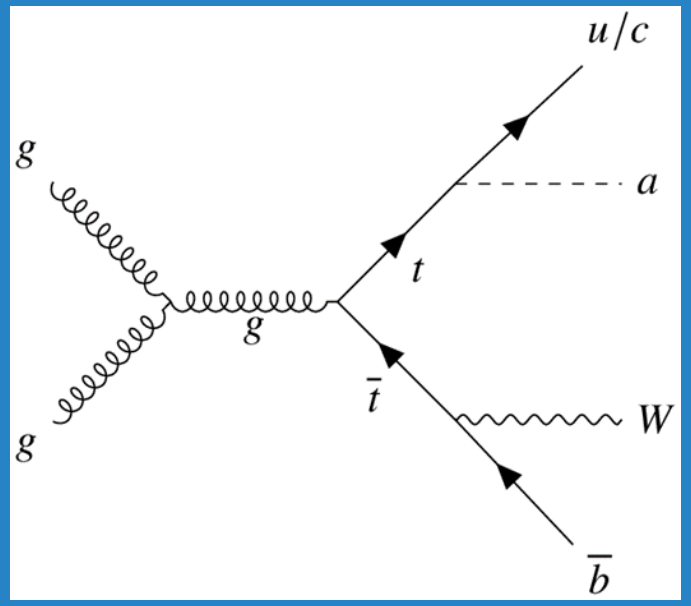


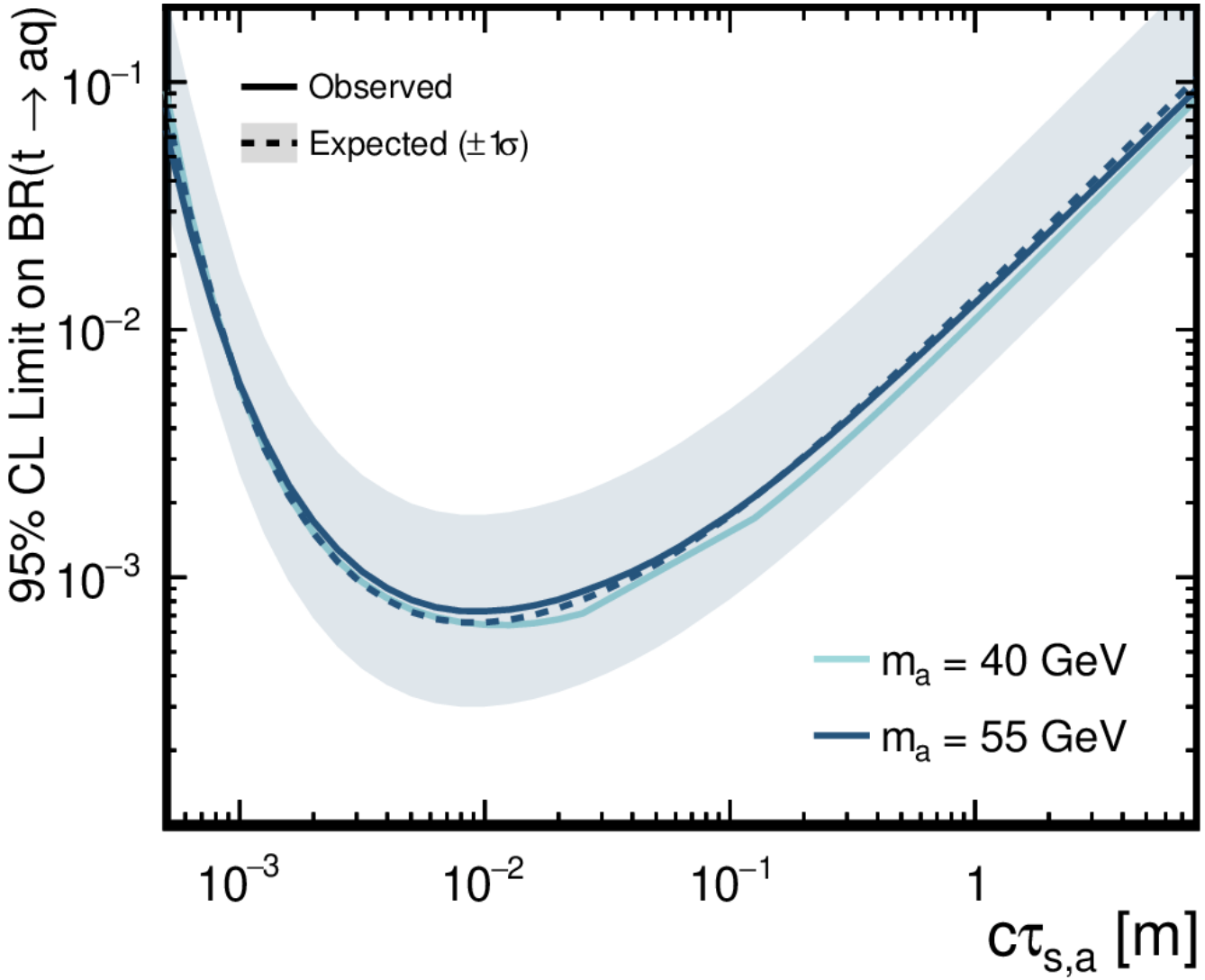
Associated Production Confidence Limits





Associated Production Confidence Limits





Dark Photons

γ_d mediates a broken U(1) gauge interaction in a dark sector

Can be produced in exotic decays of the SM Higgs

Subsequent decay into SM leptons or light quarks

LHC measurements of Higgs do not rule out decays to undetected states up to a BR of 12%

Search considers γ_d mass $\mathcal{O}$(MeV-GeV)

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: EPJC

CERN-EP-2023-226
1st December 2023

Search for light long-lived neutral particles from Higgs boson decays via vector-boson-fusion production from pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

A search is reported for long-lived dark photons with masses between 0.1 GeV and 15 GeV, from exotic decays of Higgs bosons produced via vector-boson-fusion. Events that contain displaced collimated Standard Model fermions reconstructed in the calorimeter or muon spectrometer are probed. This search uses the full LHC Run 2 (2015–2018) data sample collected in proton–proton collisions at $\sqrt{s}$ = 13 TeV, corresponding to an integrated luminosity of 139 fb^{-1}. Dominant backgrounds from Standard Model processes and non-collision sources are estimated by using data-driven techniques. The observed event yields in the signal regions are consistent with the expected background. Upper limits on the Higgs boson to dark photon branching fraction are reported as a function of the dark-photon mean proper decay length or of the dark-photon mass and the coupling between the Standard Model and the potential dark sector. This search is combined with previous ATLAS searches obtained in the gluon–gluon fusion and WH production modes. A branching fraction above 10% is excluded at 95% CL for a 125 GeV Higgs boson decaying into two dark photons for dark-photon mean proper decay lengths between 173 and 1296 mm and mass of 10 GeV.

Dark Photon Search Strategy

Higgs produced through VBF

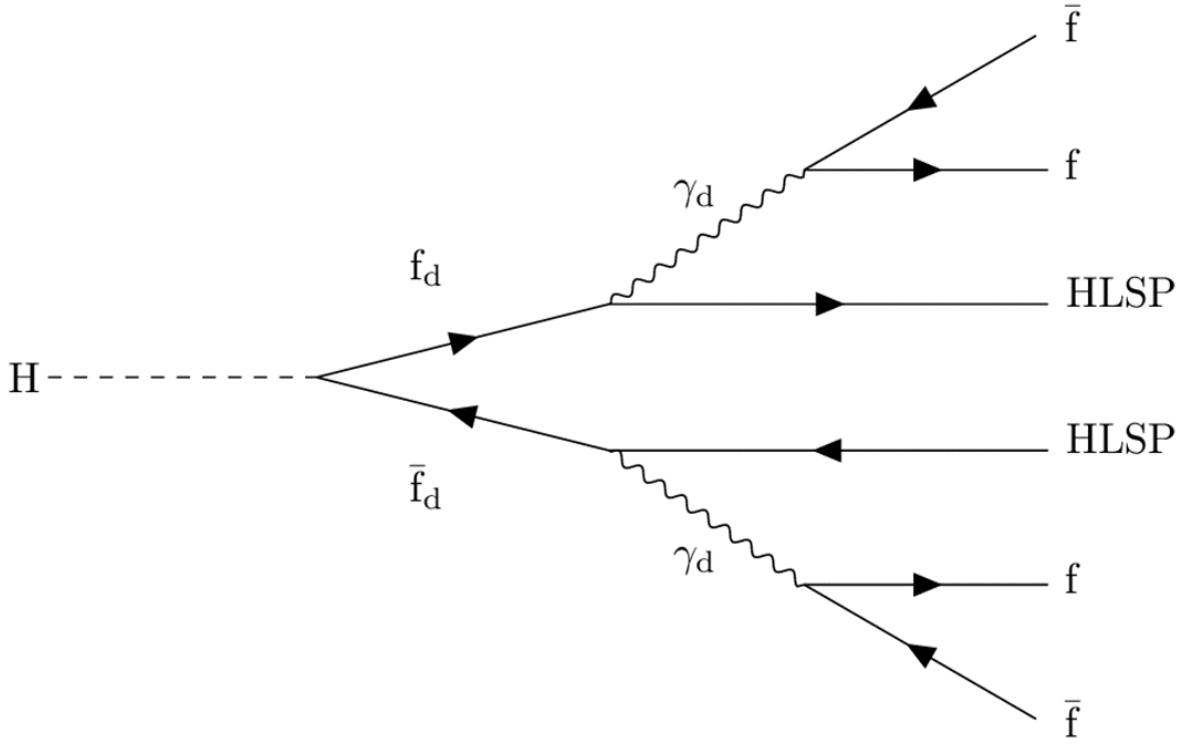
VBF remnant jets significantly reduce SM backgrounds

HLSP – Hidden Lightest Stable Particle

Analysis considers muonic decays of γ_d outside the Inner Detector and decays to electrons or quarks in the Hadronic Calorimeter

Low EM fraction jets

ABCD data driven background estimation



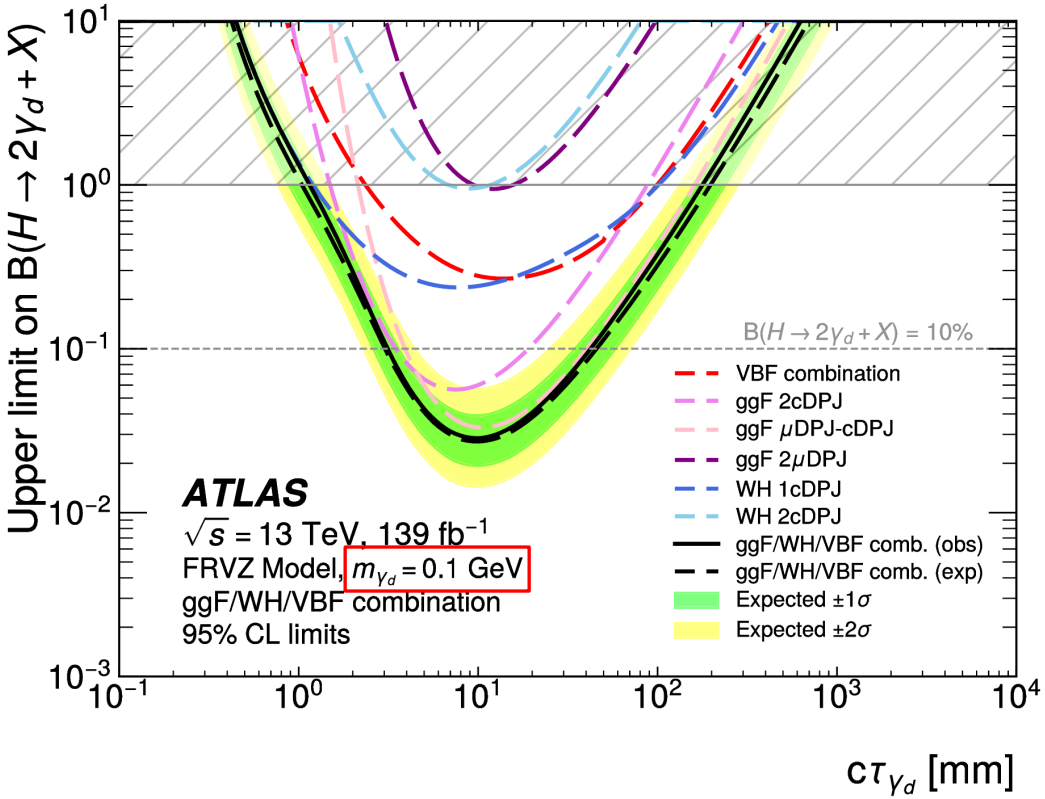
Observed Counts

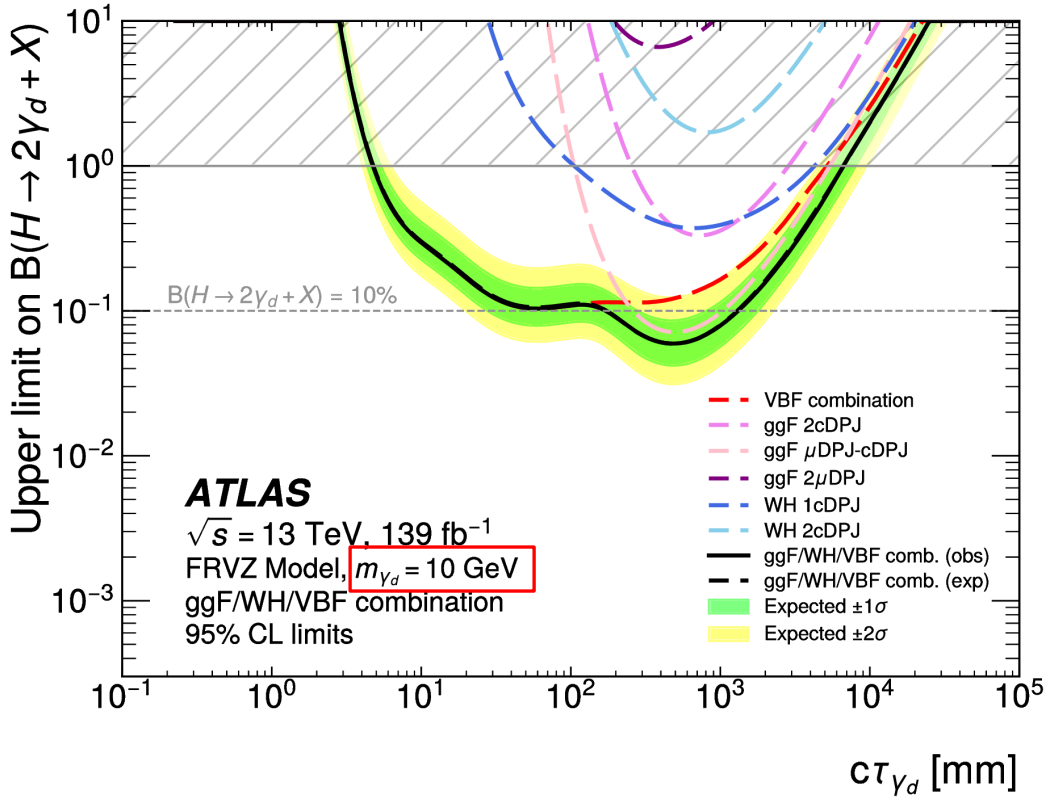
SR_c^L has $E_T^{miss} \in [100, 255]$ GeV

SR_c^H has $E_T^{miss} > 255$ GeV

Selection	CRB	CRC	CRD	SR expected	SR observed
SR_μ	44	22	21	42 ± 14	41
SR_c^L	224	256	1123	983 ± 95	923
SR_c^H	9	11	35	29 ± 14	46

Upper Limits





Dark Jets

Z' resonance decaying to dark quarks

Dark quarks hadronized in dark sector

Dark hadrons decay promptly to SM particles

Negligible fraction of stable dark hadrons

Expect wider jets from two layers of hadronization

Expect high charged track multiplicity

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Search for resonant production of dark quarks in the dijet final state with the ATLAS detector

ATLAS EXPERIMENT

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

Abstract: This paper presents a search for a new Z' resonance decaying into a pair of dark quarks which hadronise into dark hadrons before promptly decaying back as Standard Model particles. This analysis is based on proton-proton collision data recorded at $\sqrt{s} = 13\,\text{TeV}$ with the ATLAS detector at the Large Hadron Collider between 2015 and 2018, corresponding to an integrated luminosity of $139\,\text{fb}^{-1}$. After selecting events containing large-radius jets with high track multiplicity, the invariant mass distribution of the two highest-transverse-momentum jets is scanned to look for an excess above a data-driven estimate of the Standard Model multijet background. No significant excess of events is observed and the results are thus used to set 95% confidence-level upper limits on the production cross-section times branching ratio of the Z' to dark quarks as a function of the Z' mass for various dark-quark scenarios.

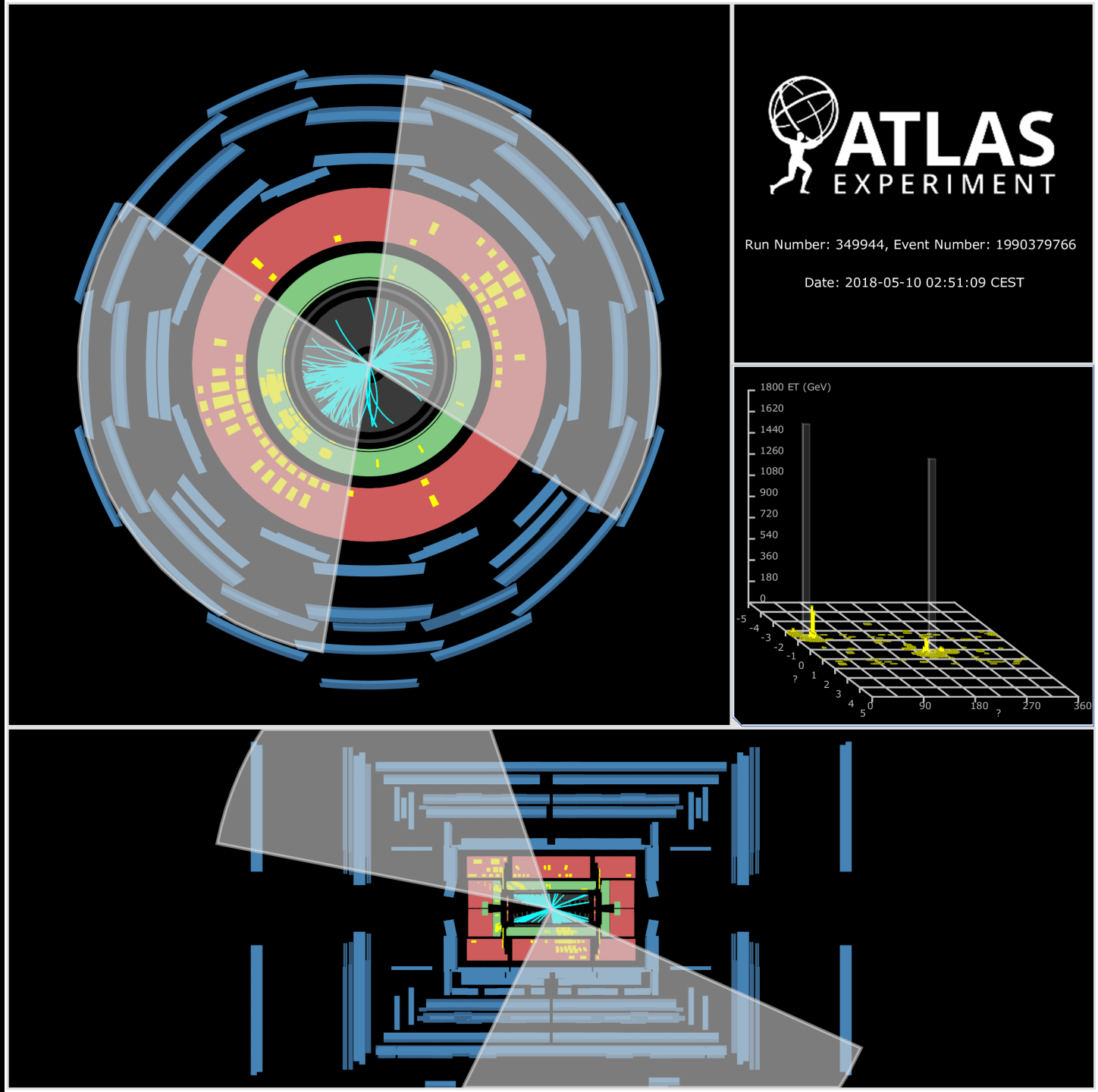
Keywords: Beyond Standard Model, Hadron-Hadron Scattering, Dark Matter, Exotics

ArXiv ePrint: 2311.03944

JHEP02(2024)128

Candidate Event

m_{jj} of 4.82 TeV



Dark Jet Benchmark Models

Model	n_f	Λ_d (GeV)	$\tilde{m}_{q'}$ (GeV)	m_{π_d} (GeV)	m_{ρ_d} (GeV)	π_d decay mode
A	2	15	20	10	50	$\pi_d \to c\bar{c}$
B	6	2	2	2	4.67	$\pi_d \to s\bar{s}$
C	2	15	20	10	50	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 4.0$ GeV
D	6	2	2	2	4.67	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 0.7$ GeV

Analysis Strategy

Trimmed Large R Jets

- $R = 1.0$ anti-k_t clustering
- Trim subjets of $R = 0.2$ and $< 5\%\ p_T$

Two high p_T, high mass jets

- Leading jet $500 < p_T < 3000$ GeV
- Subleading jet $400 < p_T < 3000$ GeV
- Jet mass $50 < p_T < 600$ GeV

Dijet invariant mass above 1300 GeV

Reject events with typical numbers of charged tracks associated with background processes

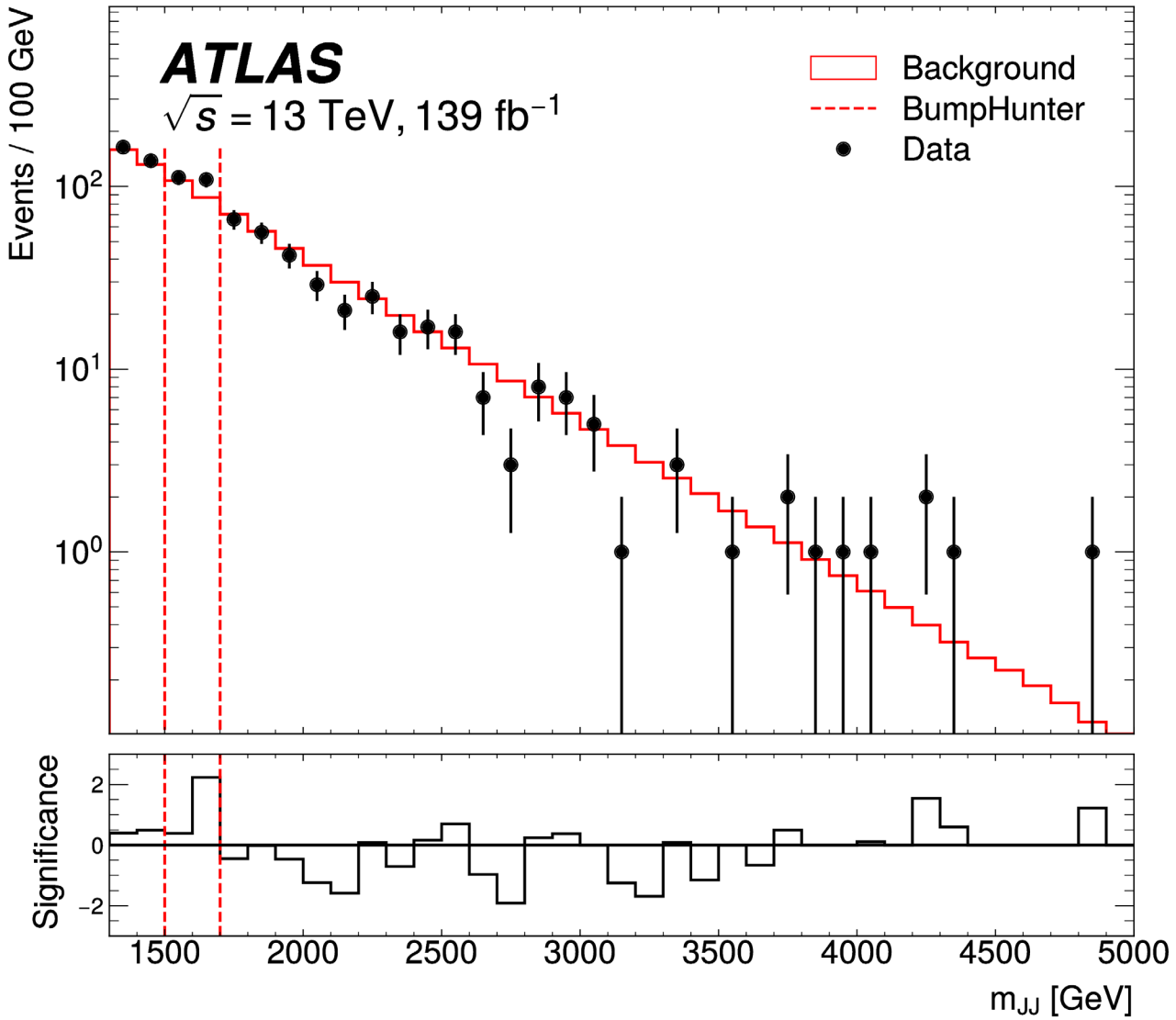
Maximum likelihood fit to m_{jj}

Signal Selection Efficiencies

Selection / Model	A	B	C	D
$m_{JJ} > 1.3$ TeV	92.9	94.8	80.9	91.8
Jet trigger	93.0	93.2	92.5	92.3
$m_{J_{1,2}} > 50$ GeV, $p_{T,J_1} > 500$ GeV, $p_{T,J_2} > 400$ GeV	88.5	60.0	81.3	56.1
$\lvert\eta_{J_{1,2}}\rvert < 2$	99.9	99.9	100	100
$m_{J_{1,2}} < 600$ GeV, $p_{T,J_{1,2}} < 3000$ GeV	99.8	99.7	99.9	99.8
Signal Region ($n^{\epsilon}_{\text{track},1} > 0$ and $n^{\epsilon}_{\text{track},2} > 0$)	37.0	2.7	11.6	55.5

Results

Bump Hunter discrepancy between 1500 and 1700 GeV with p_0-value of 0.63



Thank you!

ATLAS HAS AN ACTIVE GROUP OF ANALYZERS WORKING ON MORE DARK MATTER AND LLP SEARCHES. STAY TUNED!