DMUK Meeting December 2025 - University of Birmingham

December 1, 2025
University of Birmingham

Democratizing Dark-Matter Constraints through Reinterpretation and Re-normalisation

https://darkmatter.web.cern.ch

Brij Kishor Jashal
Particle Physics Department,
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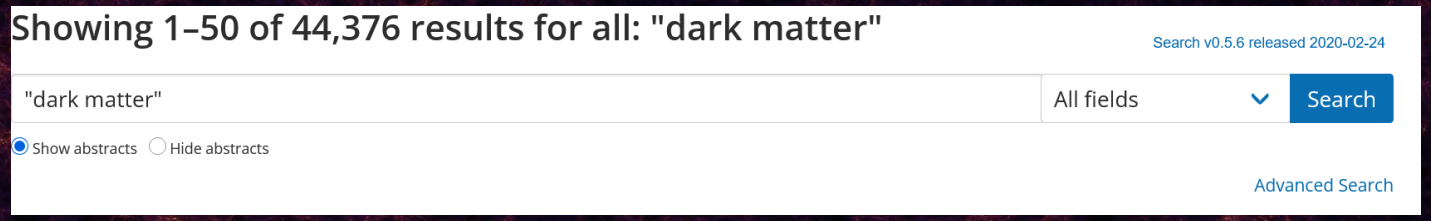
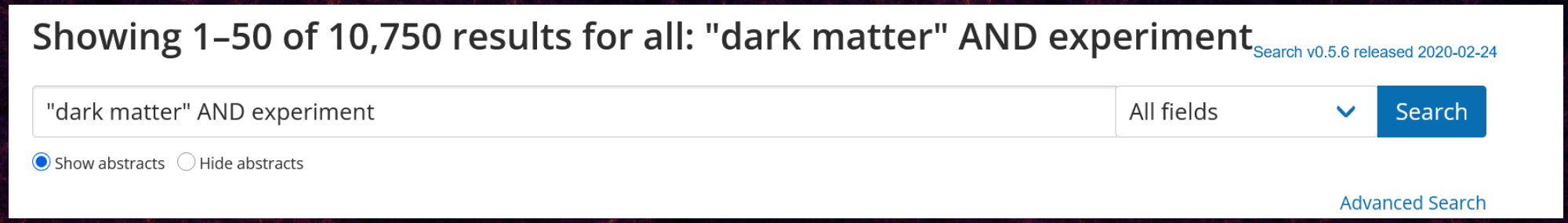
Dark matter community is huge



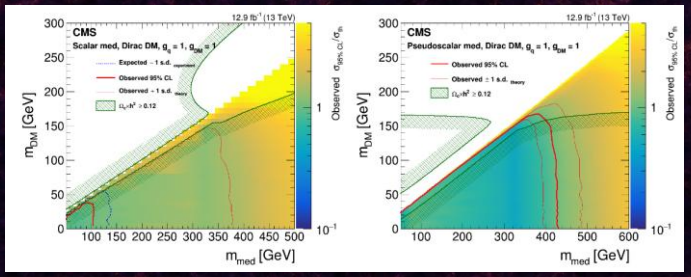
Number of papers on the arXiv that mention "dark matter", which represents 1.7% of the entire arXiv database.



If you count all distinct collaborations, major phases of existing facilities, and dedicated smaller experiments (current, operational, and funded future projects), the total number of searches is easily **over 80**, and possibly **well over 100**, depending on how granular you are with distinguishing sub-experiments within a larger umbrella

Dark matter community is huge

How do we build our collective understanding ?



Experiment (Data Analysis & Results)
Designs, builds, and operates experiments, Performs data analysis and publishes results, setting exclusion limits across the targeted parameter spaces.
Output: Published Exclusion Limits (Experiment-Specific)

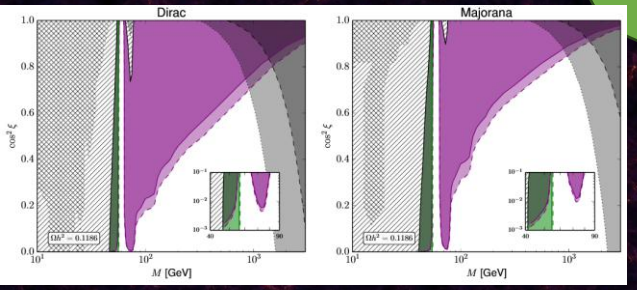
Search for dark matter with an energetic jet or a hadronically decaying W or Z boson at s =13 TeV" (CMS Collaboration, arXiv:1703.01651 2017)

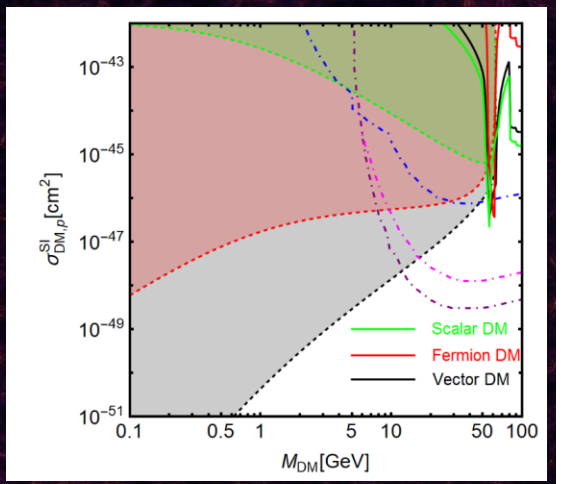
Model Builders (Theoreticians)
Develop specific models and define the parameter space (e.g mass vs. cross-section) that experiments should target.
Output: Phase Space Maps, Target Constraints

"The Higgs-portal for Dark Matter: effective field theories versus concrete realizations" (arXiv:2101.02507 2022)

Phenomenology (Global Synthesis)
Take published experimental results, re-interprets them and re-normalizes them across diverse theoretical models, synthesizing the data into combined Global Exclusion Plot
Output: Global Parameter Limits, Model Testing Results

"The Fermionic Dark Matter Higgs Portal: an effective field theory approach" (arXiv:1404.2283) (2014)



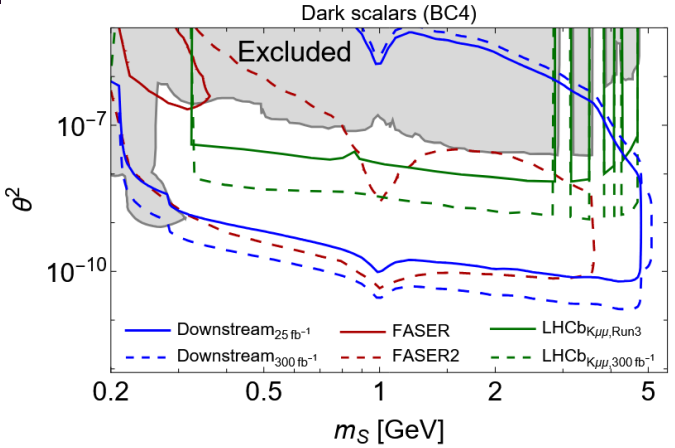


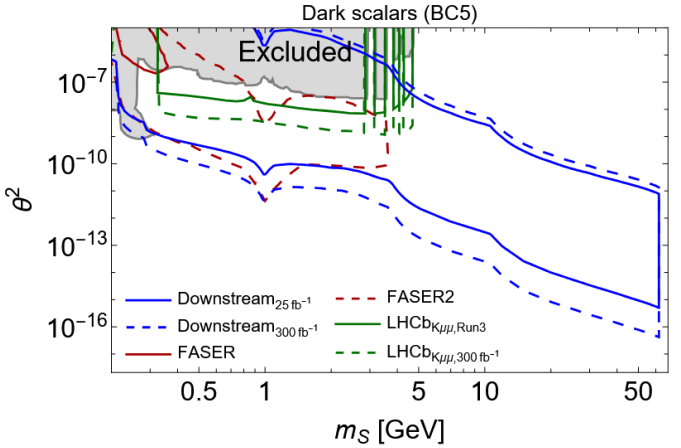
https://arxiv.org/pdf/2510.05257

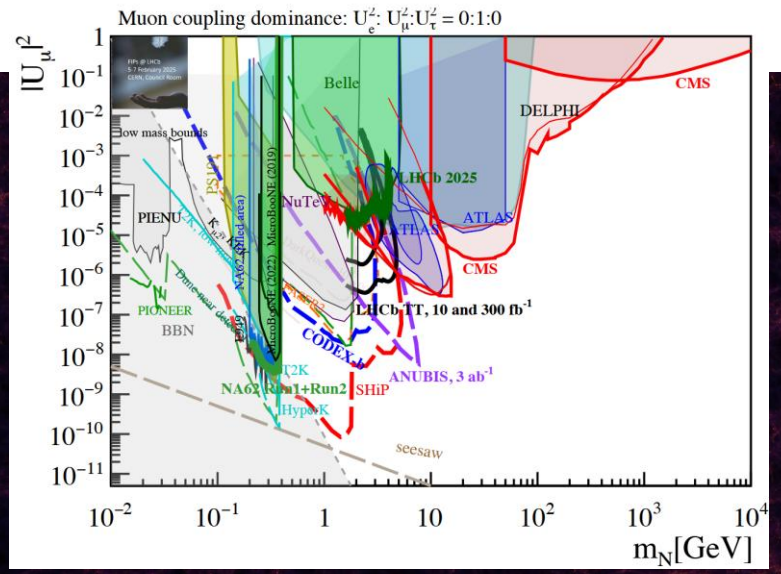
[hep-ph] 20 Nov 2025

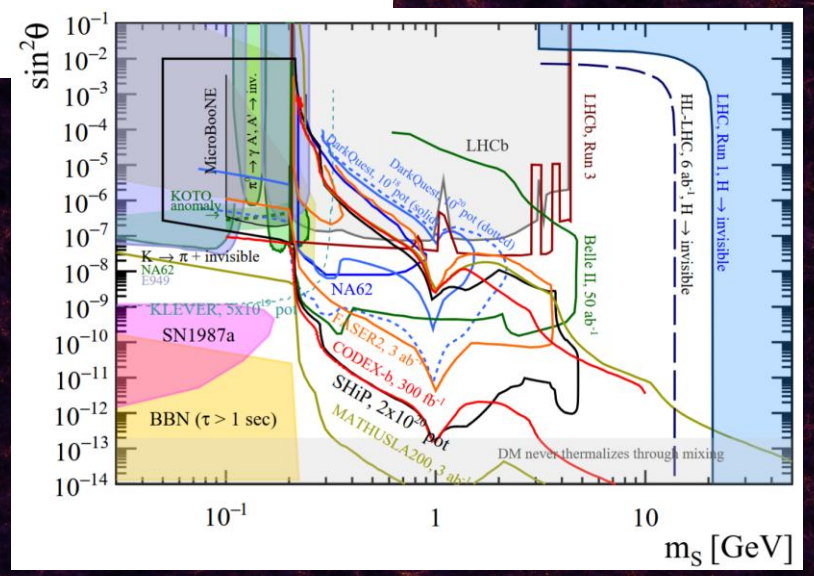
Feebly-Interacting Particles: FIPs at LHCb — Workshop Report 2025 Edition

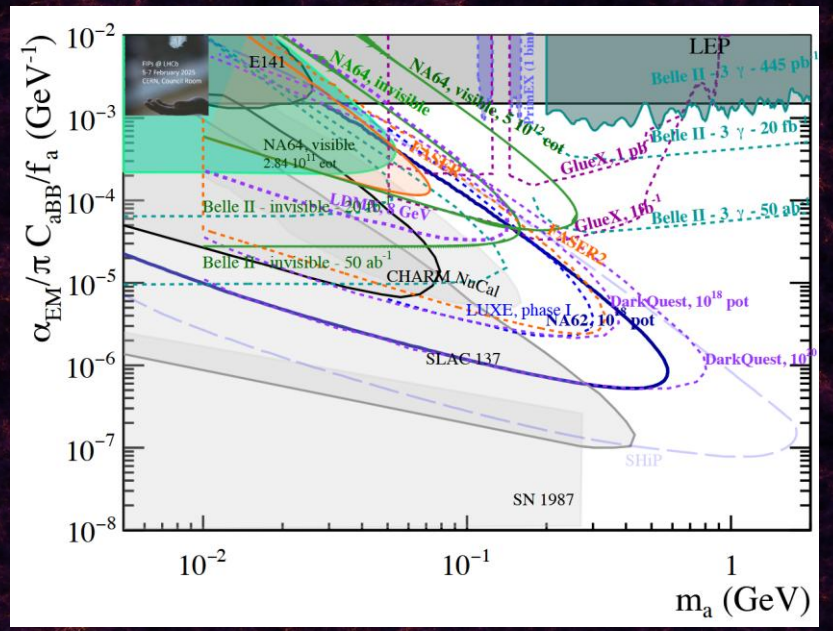
J. Alimena[1], J. Boyd[2], G. Cacciapaglia[3], A. Casais Vidal[4,*], X. Cid Vidal[5], S. Collaviti[6], A. De Oyanguren Campos[7], G. Dalla Valle Garcia[8], G. Elor[9], G. Ferretti[10], D. Gorbunov[11], E. Goudzovski[12], J. Hajer[13], J. Jerhot[14], B. Kishor Jashal[7], V. Kholoimov[7], J. Klaric[15], F. Kling[1,27], E. Kriukova[11,29], Y. Kyselov[16], G. Lanfranchi[17,*], C. Langenbruch[18], S. Libralon[7], F. Martinez Vidal[7], A. Merli[6], M. Ovchynnikov[2], J. Pfaller[19], G. Perez[20], P. Reimitz[21,28], I. Sanderswood[7], L. Shchutska[6], V. Svintozelskyi[7], E. Torro Pastor[22], Y. Tsai[23] A. Usachov[24,*], L. Vale Silva[25], C. Vázquez Sierra[26,*], F. Volle[12], J. Zhuo[7], J. Zurita[7]





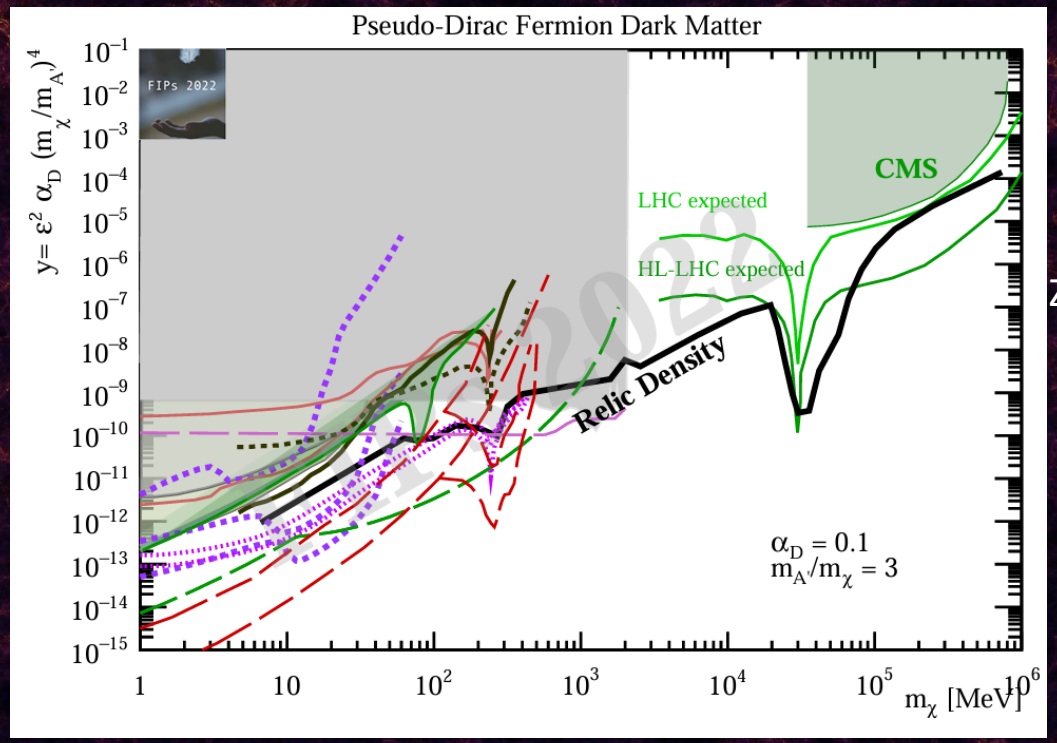




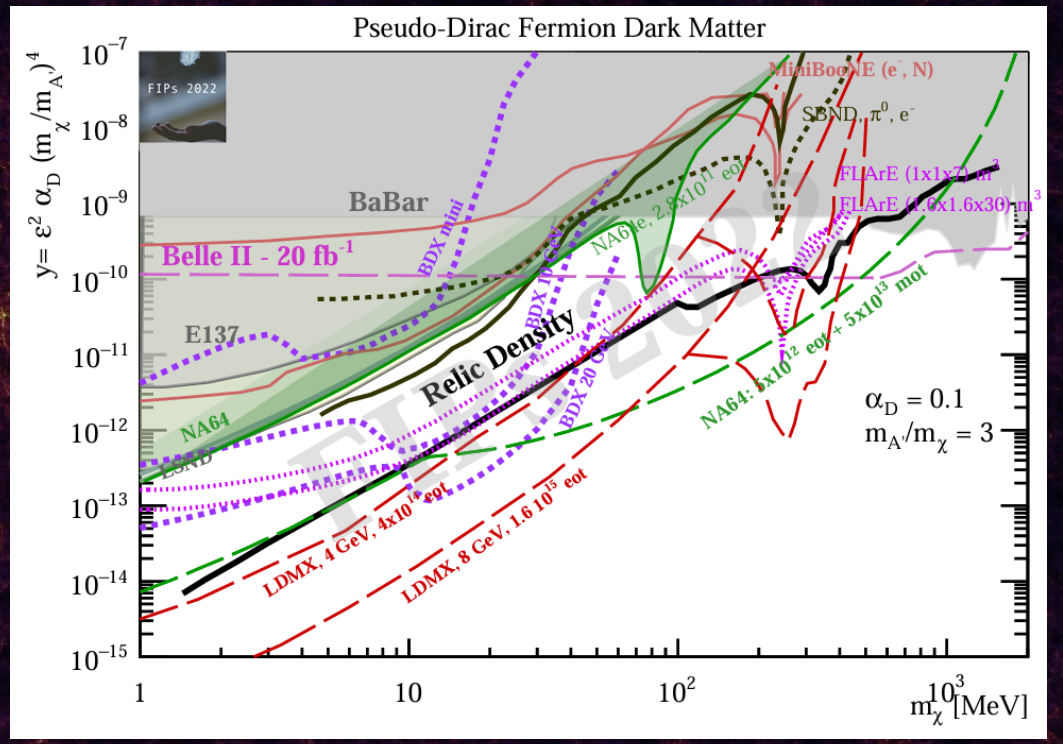


Scaling problem with global limit plots

Source



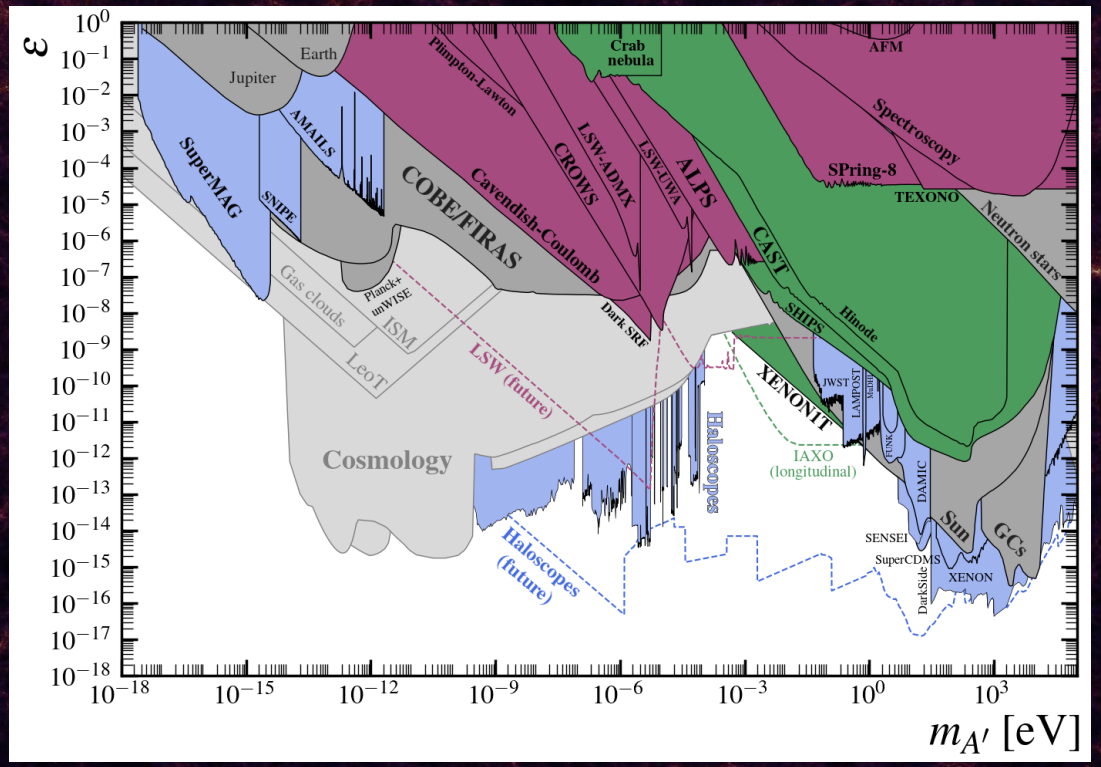
Zoom in



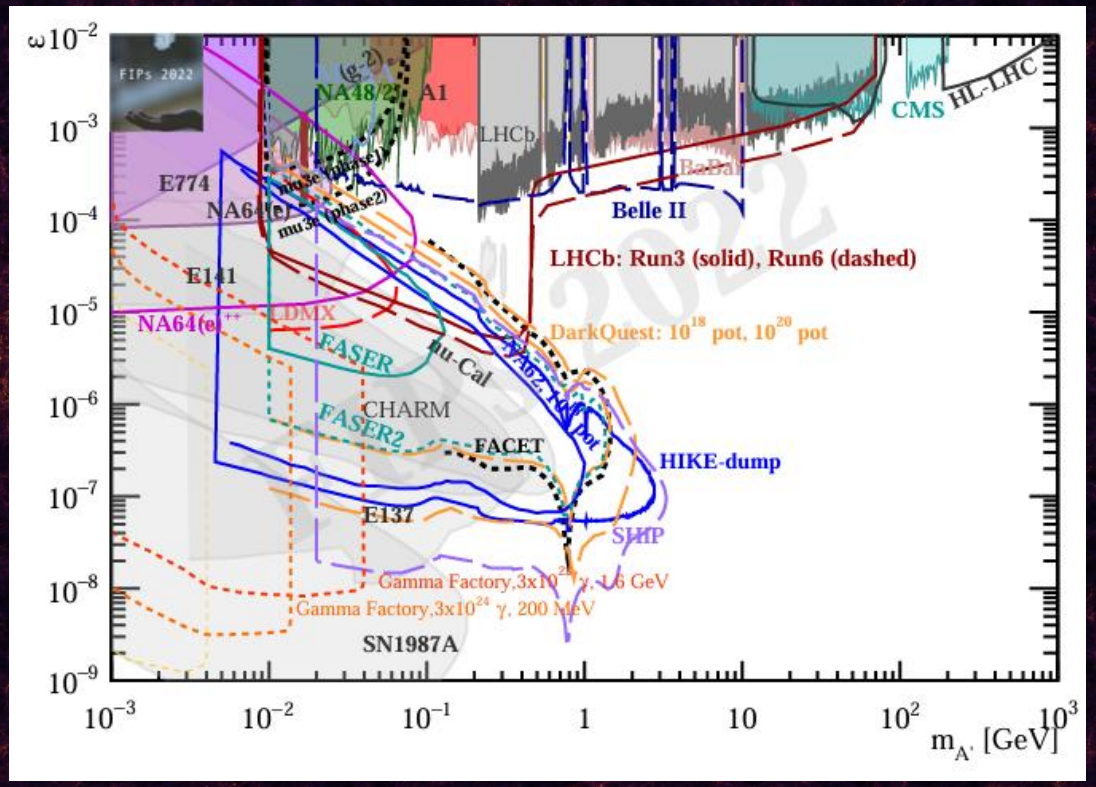
For plots with a lot of data, you often must to zoom the plot to understand what's going on

Visualisation problem of these increasingly busy global limit plots

Exclusion plot in range of 10^{-18} to 10^{5} eV



Exclusion plot in range of 10^{6} to 10^{12} eV



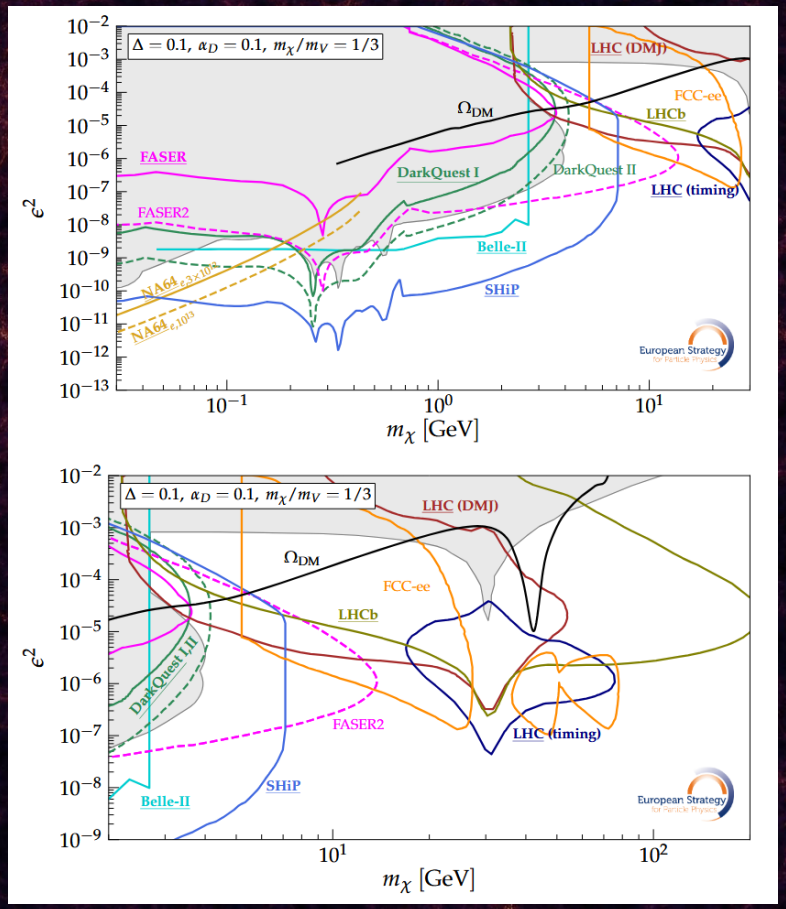
How can we properly unite these regions?

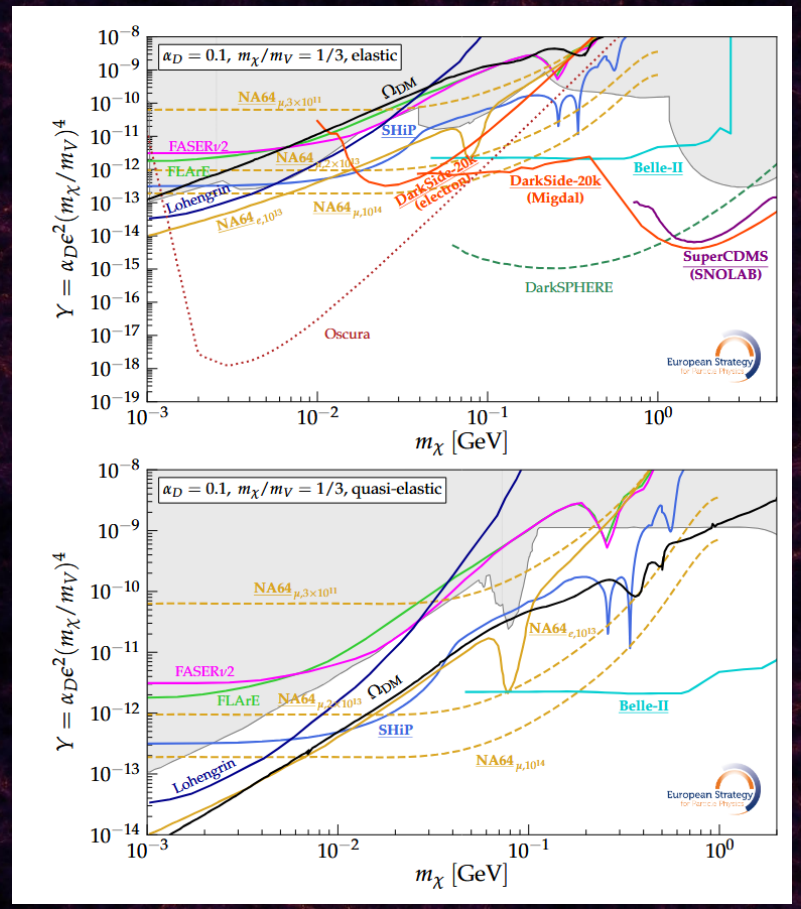
https://arxiv.org/pdf/2511.03883

CERN-ESU-2025-001
4 November 2025

Physics Briefing Book

Input for the 2026 update of the European Strategy for Particle Physics





https://arxiv.org/pdf/2511.03883

Chapter 9

Dark Matter and Dark Sector

- 333 direct references in chapter 9
https://arxiv.org/pdf/2511.03883

- Hundreds of individual LHC data analysis results behind each curve.

Challenges in the Dark-Matter Interpretation Process:

- Requires **deep specialized knowledge** of physics and of each model.
- **Software, tools, and scripts** used for re-interpretation and global-limit production are **hard to access, track, or reproduce**.
- Only a **small number of experts** produce global re-interpretation plots — often in narrow sub-domains — resulting in **significant, often unacknowledged effort**.
- A **sociological challenge** emerges as a highly diverse community tries to collaborate toward a shared goal.

Dark Matter live

Choose dark matter model

Cosmic Velocity Classes	Interaction Portals	Model Frameworks	Candidate Spectrum (BC F
Cold Dark Matter (CDM) — non-relativistic	Higgs Portal: $L \approx \lambda \chi^2 \lvert H \rvert^2$	Simplified: Spin-0 (φ) Higgs portal	**BC1 Dark Photon Min**
Warm Dark Matter (WDM) — semi-relativistic	Higgs-mixed scalar (BC4)	Simplified: Spin-1/2 (ψ) Higgs / Vector	BC2 Light DM + Dark P
Hot Dark Matter (HDM) — ultra-relativistic (ruled out)	Higgs-mixed scalar (pair) (BC5)	Simplified: Spin-1 (V_μ) kinetic mixing	BC3 Millicharged Pa
Free-streaming length sets structure hierarchy	Vector Portal: −(ε/2) F_{μν}F'^{μν}	EFT: heavy mediator integrated out	BC4 Higgs-Mixed
	Minimal dark photon (BC1)	Extended Higgs (2HDM, pseudoscalars)	BC5 Higgs-Mixed Sc
	Light DM + dark photon (BC2)	Dark Higgs + Dark Photon sector	BC6 Sterile Neu
	Millicharged particles (BC3)	Axion-Like Particles (ALPs)	BC7 Sterile Ne
	Axion Portal: g_{aγγ} a F_{μν} \u007eF^{μν}		BC8 Sterile N
	ALP photon dominance (BC9)		BC9 ALP

About Dark Matter live

Dark-Matter-Live is a static website project that provides interactive visualisations of experimental and observational constraints on dark-matter models. The site collects published limits and renders them as exclusion and projection curves so researchers and the public can compare results across experiments.

Goals

- Make published constraints discoverable and comparable in a single place.
- Provide an easy-to-use format for submitting new data via pull requests.
- Maintain a transparent and reproducible dataset with references to original p

Data formats, notation and normalisation

Results published by experimental, collider and cosmological communities are frequ conventions, units and parameterisations. Limits may appear as bounds on cross-se fractions, effective couplings or model-specific parameters (for example kinetic mixin or axion-photon couplings), and different communities sometimes adopt different sh choices. This heterogeneity makes direct, side-by-side comparison difficult without ca

One of the objectives of Dark Matter live is to renormalise and map incoming results o parameter space so they can be compared coherently. Where possible we re-express p coupling and mass variables used by the broader community (following widely-adopte in the Beyond Collider classification of dark-matter scenarios and related literature). Th the assumptions made in any translation, and any additional caveats so users can trace derived.

How to contribute

To add a new result, follow the instructions on the How to add your results page. It explai fields, and validation steps. Contributions via pull request are welcome; maintainers will re submissions.

Repository

The source code and data are available on GitHub and on the CERN GitLab mirror: GitLab.

Contact

For questions or to discuss contributions, contact Brij Kishor Jashal at brij@cern.ch

How to add your results

Contributing

Thank you for contributing to **Dark-Matter-Live**. This page explains how to add new constraint curves and how to validate your data before open- ing a Pull Request.

Basic rules

- Only add published results. Include at least one link to the published paper (arXiv, DOI, or official experiment note).
- Add one CSV and one JSON metadata file per curve.
- Keep file names clear and lowercase (use hyphens or underscores).

Folder layout

Place files under `data/<model>/` — each model or model family gets its own folder. Put CSV and JSON pairs there.

File formats

- CSV must be a numeric two-column file with header `x,y`.
- JSON must include at least the following keys:
  - `labelName` (string)
  - `id` (string)
  - `url` (string) — relative path to the CSV file
  - `paperUrls` (array) — at least one URL to the published result

Validation

Run the validator included in `scripts/validate_data.py` before opening a PR. It checks that JSON files parse, required fields exist, the CSV file exists, and the CSV contains a header `x,y` and numeric rows.

Run (PowerShell):

Dark Matter Explorer

Classifying the invisible 27% of our Universe. Explore models based on cosmic velocity, particle interactions, and theoretical frameworks.

1. Cosmic Velocity | 2. The Portals | 3. Model Frameworks | 4. Candidate Spectrum

Classification by Velocity & Structure Formation

Speed in the early universe sets the free-streaming length shaping hierarchical structure. Concordance cosmology is $\Lambda\mathrm{CDM}$.

Cold Dark Matter — Consensus
Non-Relativistic
Bottom-up halo formation; matches observations at all scales.

Warm Dark Matter — Contender
Semi-Relativistic
Suppresses smallest halos; addresses some small-scale tensions.

Hot Dark Matter — Ruled Out
Ultra-Relativistic
Erases small-scale structure; incompatible as dominant DM.

Cold Dark Matter (CDM)

Structure Formation Impact

Non-relativistic; bottom-up halo assembly matches observations.

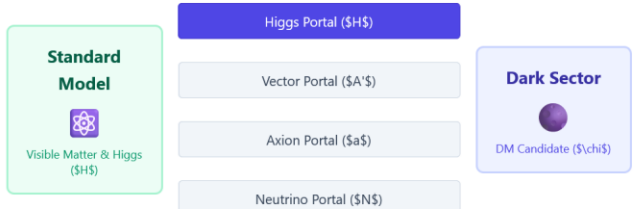
Key Candidates

- WIMPs
- Axions/ALPs
- Primordial Black Holes

1. Cosmic Velocity | 2. The Portals | 3. Model Frameworks | 4. Candidate Spectrum

The Portals: Interaction Mechanisms

Mediators enable Standard Model ↔ Dark Sector communication; they appear in interaction terms of the Lagrangian.



SELECTED PORTAL

Higgs Portal

Coupling to Higgs field: $\mathcal{L} \sim \lambda \chi^2 |H|^2$. Natural for scalar & fermionic DM.

Mediator

Higgs (H)

Key Candidate & Type

Scalar/Fermion WIMPs

Related Frameworks

Simplified (Spin-0,1/2) & Extended Higgs

Light DM coupled to dark photon (BC1)

Dark Matter Classification Context

Velocity Class:
Cold Dark Matter (CDM) — non-relativistic; supports bottom-up structure formation.

Portal Relation:
Vector Portal: kinetic mixing term $-(\epsilon/2) F_{\mu\nu}F'^{\mu\nu}$ linking dark photon A' to SM.

Framework Mapping:
Fits Simplified (Spin-1 mediator) & Dark Higgs + Dark Photon extended sector.

Key Parameters:
Mass $m_{A'}$, kinetic mixing ε; optionally dark gauge coupling g_D.

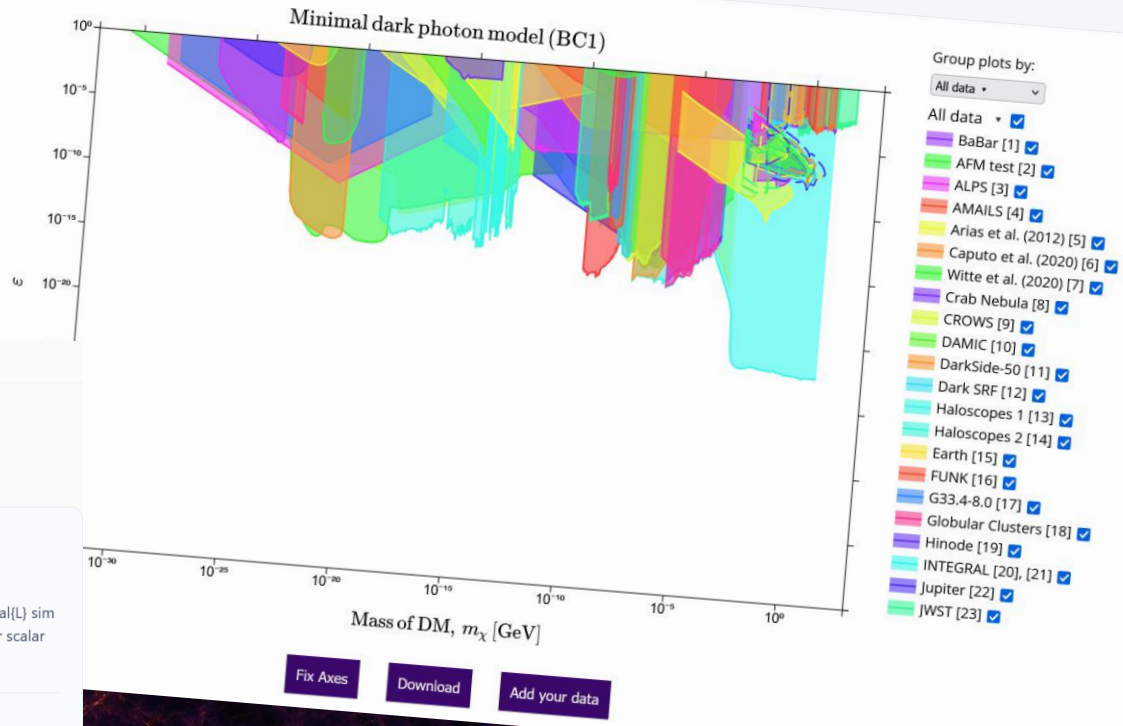
Related BC Pages:

- BC2 Light DM + Dark Photon
- BC3 Millicharged Particles
- BC4 Higgs-Mixed Scalar
- BC5 Higgs-Mixed Scalar (Pair)
- BC6 Sterile Neutrino (e)
- BC7 Sterile Neutrino (μ)
- BC8 Sterile Neutrino (τ)
- BC9 ALP Photon Dominance
- BC10 ALP Fermion Dominance
- BC11 ALP Gluon Dominance

Explorer:
See full taxonomy & formulas on the Dark Matter Explorer.

Formula Snippet:

$$\mathcal{L} \supset -\tfrac{1}{4} F'_{\mu\nu}F'^{\mu\nu} + \tfrac{1}{2} m_{A'}^2 A'_\mu A'^\mu + \varepsilon e A'^\mu J^{EM}_\mu$$



Fix Axes | Download | Add your data

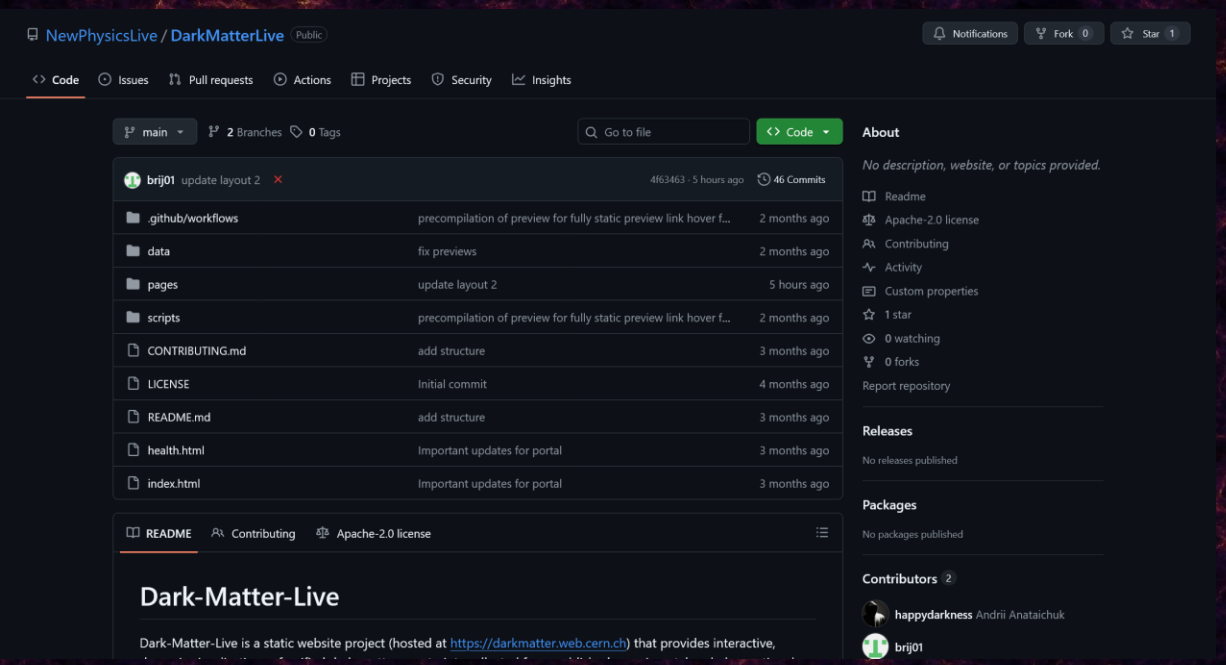
So how can we have a Open, Transparent, and Collaborative Global-Limit Framework

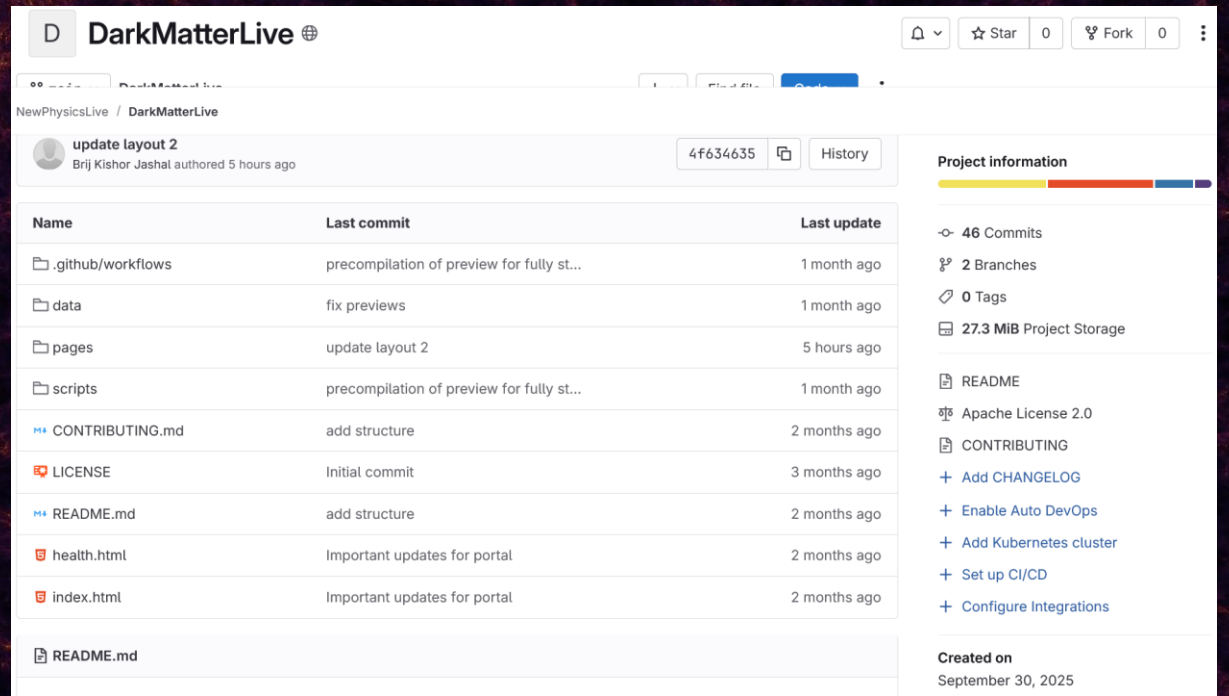
Motivation: Lessons from Software Development

- Linus Torvalds created **Git** to manage the growing Linux kernel, enabling **distributed collaboration**, **transparent history**,
and **community-driven review**.

Public and Open Repositories:

- The source code and data are available on GitHub and on the CERN GitLab mirror: **CERN** GitLab.
- Designed to ensure **collaboration**, **reproducibility**, and **shared ownership**.





Transparent Contribution Workflow

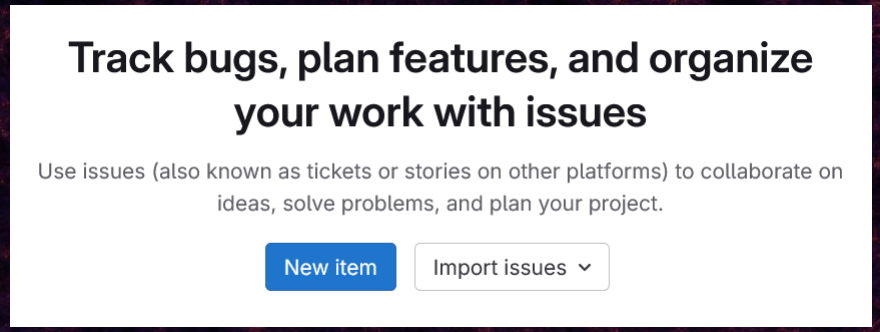
- New data points enter the global-limit framework via **Pull Requests (PRs)** or **Merge Requests (MRs)**.
- Expert review happens in the open, with discussions **publicly documented**.
- Use GIT raise issue feature to track requests for new features, bug fixes or corrections

Open Tools and Automated Pipelines

- Interpretation scripts and global-exclusion-plot algorithms become part of the repo as CI/CD code.
- A **CI/CD pipeline** automates processing when new PRs/MRs update results (for e.g., coupling vs mass for a particular model), ensuring consistent and reproducible outputs.

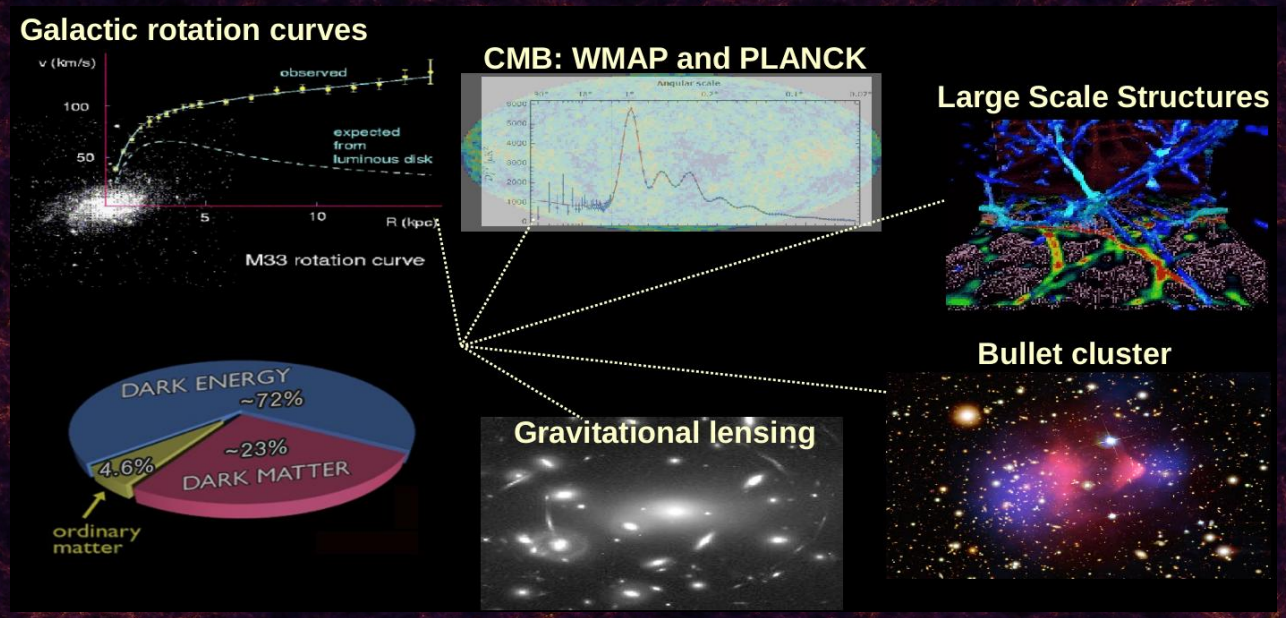
Versioning and Citation

- Each **tagged version** of the project is archived on **Zenodo**, generating a **DOI** for long-term preservation and citation.
  Contributors of the project automatically become part of author list.



Demo

https://darkmatter.web.cern.ch



PAPER • OPEN ACCESS

Exploring Milky Way rotation curves with Gaia DR3: a comparison between ΛCDM, MOND, and general relativistic approaches

William Beordo, Mariateresa Crosta and Mario Gilberto Lattanzi

Published 11 December 2024 • © 2024 The Author(s)

Journal of Cosmology and Astroparticle Physics, Volume 2024, December 2024

Citation William Beordo *et al* JCAP12(2024)024

DOI 10.1088/1475-7516/2024/12/024

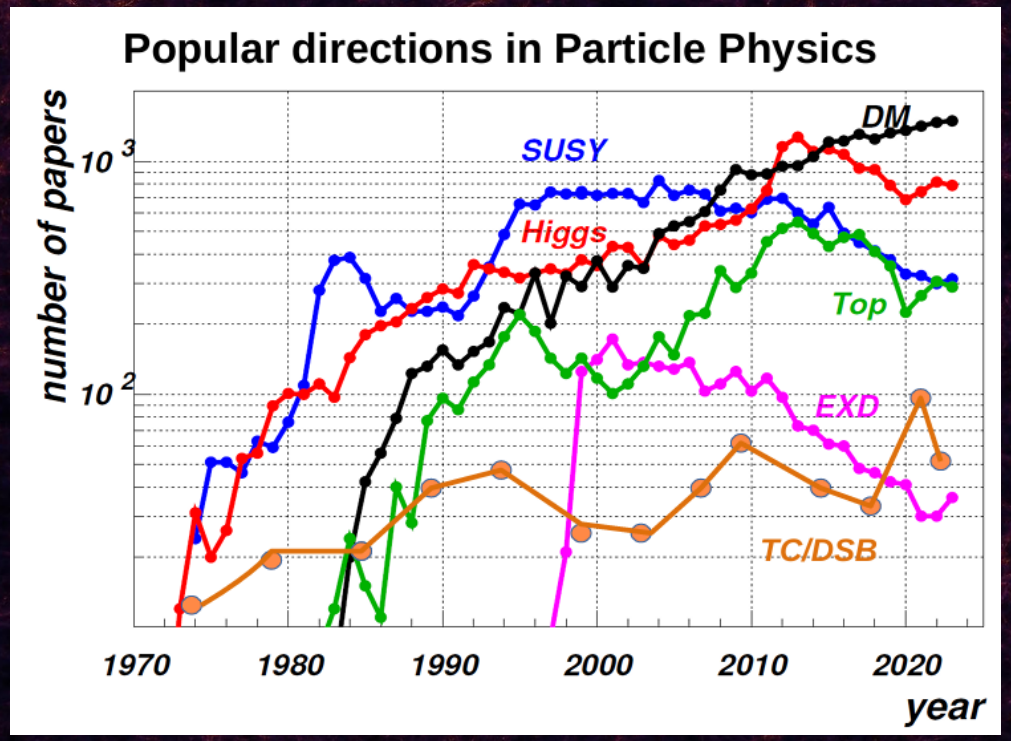
JOURNAL ARTICLE

On testing CDM and geometry-driven Milky Way rotation curve models with *Gaia* DR2

Mariateresa Crosta ✉, Marco Giammaria, Mario G Lattanzi, Eloisa Poggio

Monthly Notices of the Royal Astronomical Society, Volume 496, Issue 2, August 2020, Pages 2107–2122, https://doi.org/10.1093/mnras/staa1511

Published: 02 June 2020 **Article history** ▾



ABSTRACT

Flat rotation curves (RCs) in disc galaxies provide the main observational support to the hypothesis of surrounding dark matter (DM). Despite of the difficulty in identifying the DM contribution to the total mass density in our Galaxy, stellar kinematics, as tracer of gravitational potential, is the most reliable observable for gauging different matter components. From the *Gaia* second data release catalogue, we extracted parallaxes, proper motions, and line-of-sight velocities of unprecedented accuracy for a carefully selected sample of disc stars. This is the angular momentum supported population of the Milky Way (MW) that better traces its observed RC. We fitted such data to both a classical, i.e. including a DM halo, velocity profile model, and a general relativistic one derived from a stationary axisymmetric galaxy-scale metric. The general relativistic MW RC results statistically indistinguishable from its state-of-the-art DM analogue. This supports the ansatz that a weak gravitational contribution due to the off-diagonal term of the metric, by explaining the observed flatness of MW's RC, could fill the gap in a baryons-only MW, thus rendering the Newtonian-origin DM a general relativity-like effect. In the context of Local Cosmology, our findings are suggestive of the Galaxy's phase space as the exterior gravitational field in equilibrium far from a Kerr-like inner source, possibly with no need for extra matter to account for the disc kinematics.

Thank you