



OSCAR

Open Science Clusters' Action
for Research & Society

ESPPU DM working group tools

DM Summary plots and the Virtual Research Environment

Léo Chazallet, 12th November 2025

LHC BSM Working Group General meeting:

Inputs from Giovanni Guerrieri, Caterina Doglioni, Yohei Ema, Maximilian Amerl



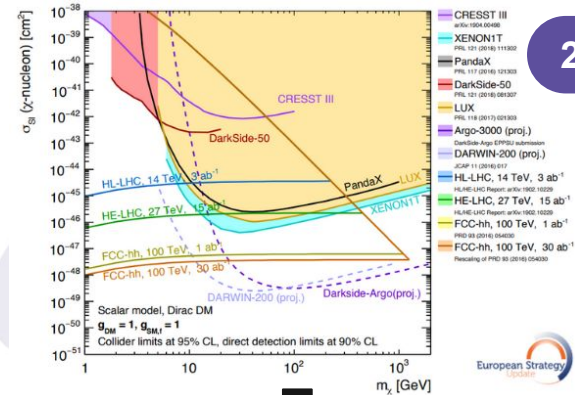
Funded by
the European Union

Difficulties with reproducing and updating summary plots from 2019 to 2025 ESPPU:

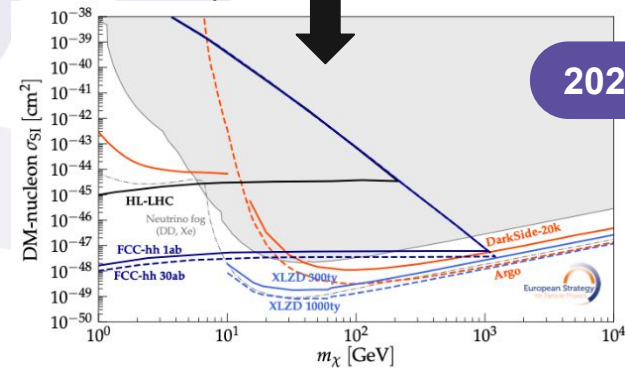
- **Git** repository to make the final plot available, but **private** (by student who worked on the plots in 2019)
- **Software** to translate HL-LHC results **only shared privately** via e-mail
- **References** on where to find the curves only available in figure caption, and **not descriptive enough** (HL-LHC report: 1418 pages, many plots...)
- **No README** or documentation

→ not an uncommon situation in the sciences

Portraying the complementarity of colliders and direct detection for heavy dark matter (s-channel simplified model with scalar mediator, WIMP-like Dirac DM)



Contains input for



Think of an optimistic situation: if **one (or more) experiments discover hints of dark matter**, the community will want to **compare** and **scrutinise**:

- Experimental techniques
- Assumptions and uncertainties
- Datasets
- Data analysis software

Our solutions:

- Develop **notebooks** following **code quality / FAIR guidelines**
- Execute them on a **dedicated computing cluster that helps reproducibility**, the **ESCAPE Virtual Research Environment**
→ more on this in the next slides, and in J. Wurzinger's talk!

Aligns perfectly with the goals of the **OSCARS** project
and with the **ESCAPE** Open Collaboration



OSCARS
Open Science Clusters' Action
for Research & Society



ESCAPE and related initiatives have supported and **funded services** that are used in HEP and beyond (e.g. **REANA**, **RUCIO/data lake**, **authentication services**, a Zenodo **software catalogue**, the **VRE**, ...)

An **open collaboration** that aims to **address the Open Science challenges** shared by **ESFRI facilities** (e.g. HL-LHC) and pan-European **research infrastructures** (e.g. CERN) in astronomy and particle physics



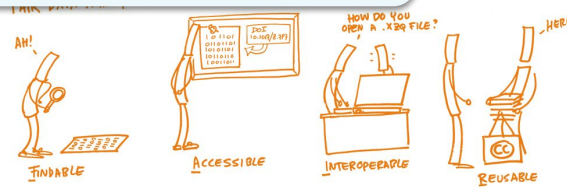
SCIENTIFIC DATA MANAGEMENT



RUCIO

Fostering the uptake of Open Science in Europe

EU grant that aims to enhance adoption of
Open Science and supporting
interdisciplinary **FAIR data services**
and **practices**



€ 16 MILLIONS

IN OPEN CALLS FOR
OPEN SCIENCE
PROJECTS AND SERVICES

OBJECTIVES



Setup and implementation of
**Clusters' Open Science
Competence Centres (CLOCCs)**



Identify and provide
**Composable Open Data and
Analysis Services (CODAS)**



Contribute to a
**Data space for science,
research and innovation**

The 2025 summary plots are now made using a **Jupyter notebook** with:

- tracking of **imported package** versions (using the uv package manager)
- installation **instructions** and **commented** code blocks
- light-touch **explanations** of model and parameters, with citations
- **Metadata tables** with provenance for the curves (location of digitized curves, citation with figure location)
- An **Open Source license** for conditions of reuse

The notebook is available on **Zenodo**:
DOI [10.5281/zenodo.16544850](https://doi.org/10.5281/zenodo.16544850)

(1) Higgs portals

Models (scalar and Majorana DM)

The models are defined in [Djouadi,2011] as:

$$\mathcal{L} = -\frac{1}{2}m_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{hSS} H^2 S^2, \quad (1)$$

$$\mathcal{L} = -\frac{1}{2}m_\chi \bar{\chi}\chi - \frac{1}{4\Lambda} |H|^2 \bar{\chi}\chi, \quad (2)$$

for the scalar and Majorana cases, respectively.

It is worth noting that the Majorana model has an EFT cut-off scale, Λ , set at 1 TeV. However, the current LHC bound is set at $\Lambda=10$ TeV so the validity of the current plot is not compromised.

In the Majorana case, the formula in this notebook absorbs the coupling constant into Λ .

Methods

The 95% constraints on the Higgs to invisible branching ratios are translated into limits on the DM-nucleon cross-section using the procedures in [Fox, 2017][Hoferichter, 2017].

The conversion formulas used are in the cell below:

```
In [15]: ## The conversion formula depends on the spin of the DM particle, either scalar or fermion
## The inputs are mass [GeV] and Branching ratio BR(H->inv), and the output is the spin-independent cross section

WidthSM = 0.00407 # SM Higgs width
vev = 174 # Higgs VEV
mH = 125 # Higgs mass
mn = 0.93895 # nucleon mass
fn = 0.326 # Nuclear constant
CV = 1e-36 # Conversion factor

def BRinv2sigmaScalar(mass, BRinv Notebook to create the Heavy Dark Matter plots for the European Strategy Briefing Book 2025
beta = sqrt(abs(1-4*pow(mass,2)
c = 4*(WidthSM*BRinv)/(1.-BR
c ./= vev*vev*pow(mH,3)*
return heaviside(mH-2, *mass,

def BRinv2sigmaFermion(mass, BRin
beta = sqrt(abs(1-4*pow(mass,2)
c = (WidthSM*BRinv)/(1.-BRin
c ./= vev*vev*pow(beta,3)*pow
return heaviside(mH-2, *mass,

zenodo
```

Where does this Jupyter notebook run?

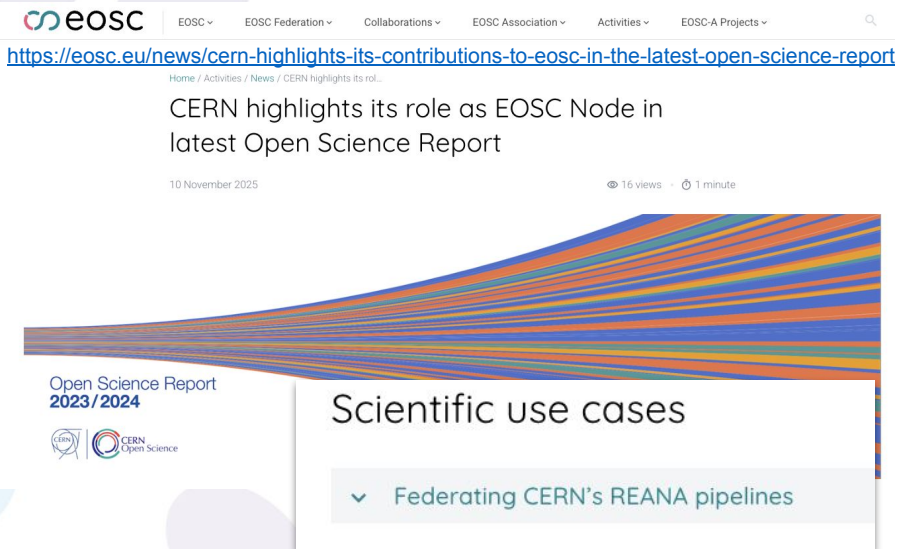
Anyone's laptop! Start from Zenodo [10.5281/zenodo.16544850](https://zenodo.org/record/10.5281/zenodo.16544850), install uv, and you're ready to go

But what if I wanted an even **easier** way to **rerun** my workflow (especially applies for more **complex** ones, e.g. full reinterpretation, REANA-based...)

It would be nice to have a platform where *everything is already installed* and I can just *log in and run!*

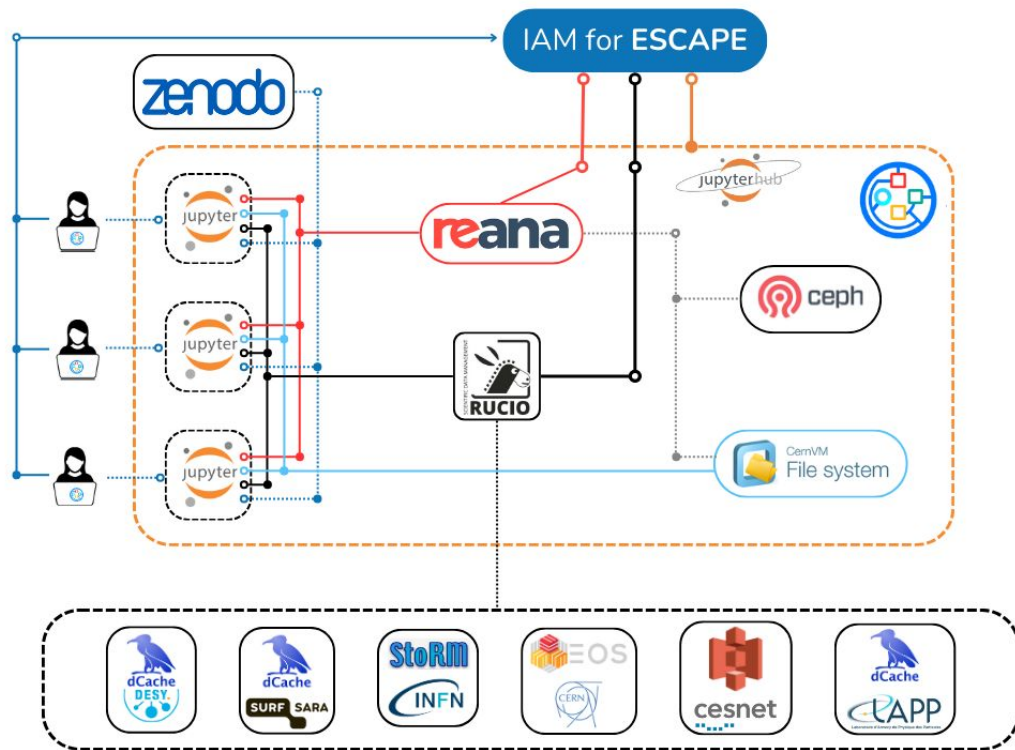
This is where the **Virtual Research Environment** comes in!

Related: CERN and the European Open Science Cloud (EOSC)

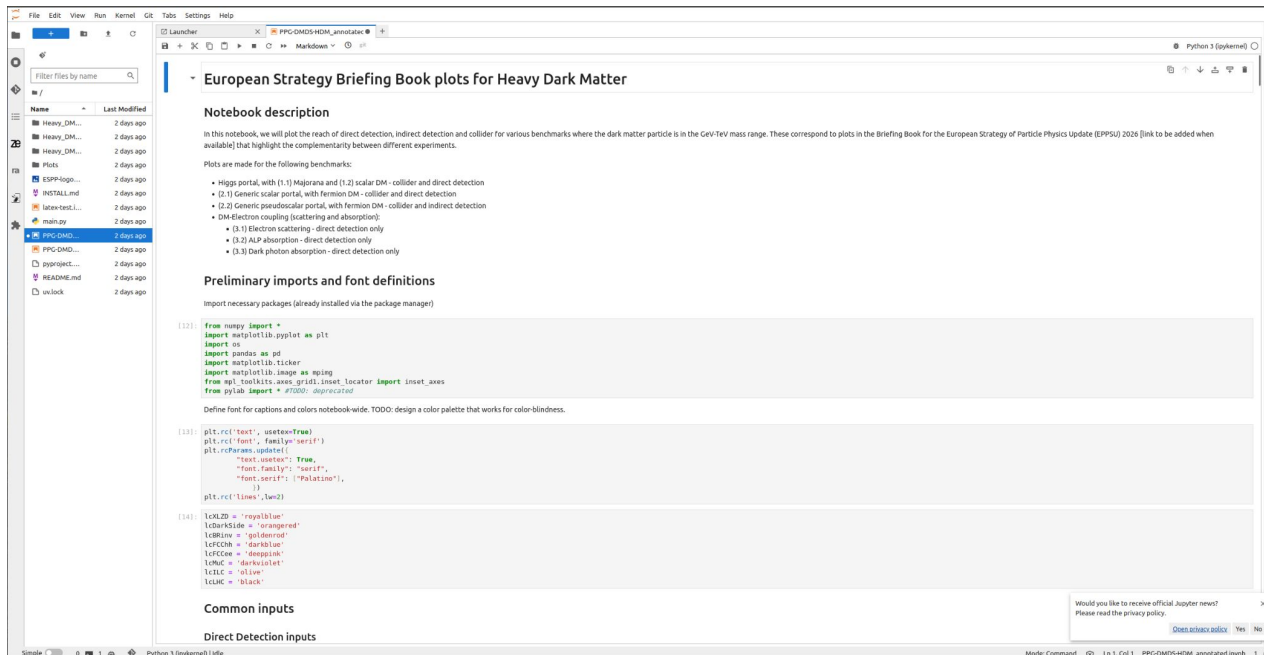


The screenshot shows the EOSC website with a navigation menu and a news article. The article title is "CERN highlights its role as EOSC Node in latest Open Science Report" and it is dated 10 November 2025. Below the article, there is a section titled "Open Science Report 2023/2024" with logos for CERN and CERN Open Science. To the right, a box titled "Scientific use cases" lists "Federating CERN's REANA pipelines".

1. [AAI](#): A federated and reliable **Authentication and Authorization** layer for **logging in** and **protecting access** to private data
2. [The Rucio Data Lake](#): A **federated distributed storage** solution, providing functionalities for **data injection and replication** through a Data Management framework (**Rucio**)
3. [REANA](#): A **computing** cluster supplying the processing power to **run full analyses** with REANA, a re-analysis service (supports RECAST as well)
4. [CVMFS](#): A **read-only file system** designed to **distribute software**, and more.
5. [JupyterHub](#): A **notebook interface** with containerised environments to hide the infrastructure's complexity from the user.



Implementation: LAPP VRE



European Strategy Briefing Book plots for Heavy Dark Matter

Notebook description

In this notebook, we will plot the reach of direct detection, indirect detection and collider for various benchmarks where the dark matter particle is in the GeV-TeV mass range. These correspond to plots in the Briefing Book for the European Strategy of Particle Physics Update (EPSU) 2026 [link to be added when available] that highlight the complementarity between different experiments.

Plots are made for the following benchmarks:

- Higgs portal, with (1,1) Majorana and (1,2) scalar DM - collider and direct detection
- (2,1) Generic scalar portal, with fermion DM - collider and direct detection
- (2,2) Generic pseudoscalar portal, with fermion DM - collider and indirect detection
- DM-Electron coupling (scattering and absorption):
 - (1,1) Electron scattering - direct detection only
 - (1,2) ALP absorption - direct detection only
 - (1,3) Dark photon absorption - direct detection only

Preliminary imports and font definitions

Import necessary packages (already installed via the package manager)

```
112: from numpy import *
import matplotlib.pyplot as plt
import os
import pandas as pd
import matplotlib
import matplotlib.ticker
import matplotlib.image as mimg
from mpl_toolkits.axes.view1D import locator
import inset_axes
from pylab import * #TODO: deprecated

Define font for captions and colors notebook-wide. TODO: design a color palette that works for color-blindness.

123: plt.rc('text', usetex=True)
plt.rc('font', family='serif')
plt.rcParams.update({
    "text.usetex": True,
    "font.family": "serif",
    "font.serif": "Palatino",
})
plt.rc('lines', lw=3)

124: ICLZD = "royalblue"
ICLZSD = "orange"
ICLRD = "gold"
ICFCD = "gray"
ICFCD = "darkgray"
ICLC = "red"
ICLRC = "black"
```

Common inputs

Direct Detection inputs



By executing the notebooks / our workflows on the VRE, we ensure that we have a **suitable computing infrastructure** that others can use

For examples of other workflows (including an **ATLAS analysis using RECAST**), see the [ESCAPE Dark Matter Science Project](#)

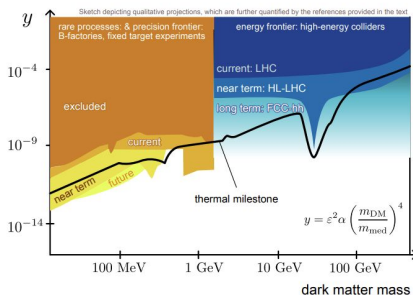
Solved the problem of “not being able to reproduce the European Strategy DM plots”, at least for the next Strategy!

- New plots use a **Jupyter notebook** following FAIR guidelines, on Zenodo
- **Execution is enabled** on the ESCAPE Virtual Research Environment (VRE)
- The VRE provides an easy-to-use platform for rerunning workflows - and for **reinterpretation?** TBD!

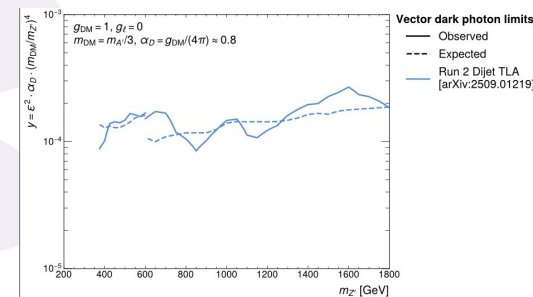


Note: this is even worse when the author of the plot is the same person as the one trying to remake the plot source: one of the authors of the poster

Coming soon: other DMWG interpretations (e.g. dark photon)

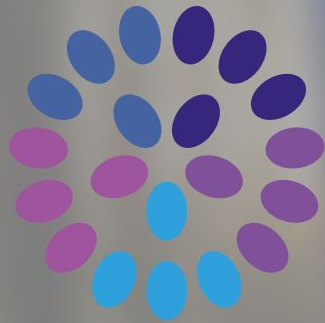


<https://github.com/mamerl/DMWG-dark-photon-tools>,
soon to be moved to the DMWG repository after cross-checks



(expert feedback welcome!)

Test rescaling with public Run-2 TLA (dijet scouting) vector mediator results 10

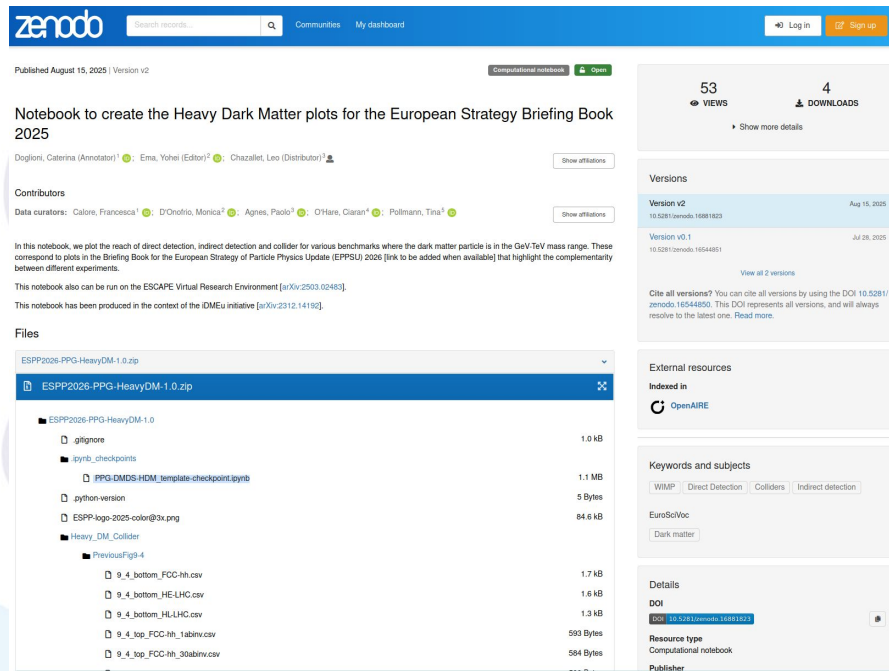


OSCARS

Thank you

Notebooks are available on [Zenodo](#)

- Open-access research data repository operated by **CERN**
- Supports sharing of **datasets, papers, software, and more**
- Each upload gets a **DOI** for permanent citation
- Promotes **open science** and **data preservation**
- Compliant with **FAIR principles** (Findable, Accessible, Interoperable, Reusable)
- Ensures **long-term storage** and **global accessibility**



The screenshot shows a Zenodo page for a computational notebook. The title is "Notebook to create the Heavy Dark Matter plots for the European Strategy Briefing Book 2025", published on August 15, 2025. It has 53 views and 4 downloads. The notebook is authored by Daniela, Caterina, Ema, Yohei, Chazaliet, and Leo. It includes a list of contributors and data curators. The file list shows a zip file "ESPP2026-PPG-HeavyDM-1.0.zip" containing a directory "ESPP2026-PPG-HeavyDM-1.0" with sub-directories like "gfigignore", "pyrb_checkpoints", "PPG-DMSD-HCM_template-checkpoint.pyrb", "python-version", "ESPP-logs-2025-color@3x.png", and "Heavy_DM_Collider". The "PreviousFig3-4" directory contains several CSV files. The page also features a sidebar with statistics, versions (v2 and v1), external resources (Indexed in OpenAIRE), keywords (WIMP, Direct Detection, Colliders, Indirect detection), and details (DOI: 10.5281/zenodo.16544851, Resource type: Computational notebook, Publisher).