Multicomponent dark matter and the dark photon portal

By: Amalia Betancur Rodríguez

In collaboration with Andrés Fernando Castillo, Guillermo Palacio and Juan Guillermo Suárez.

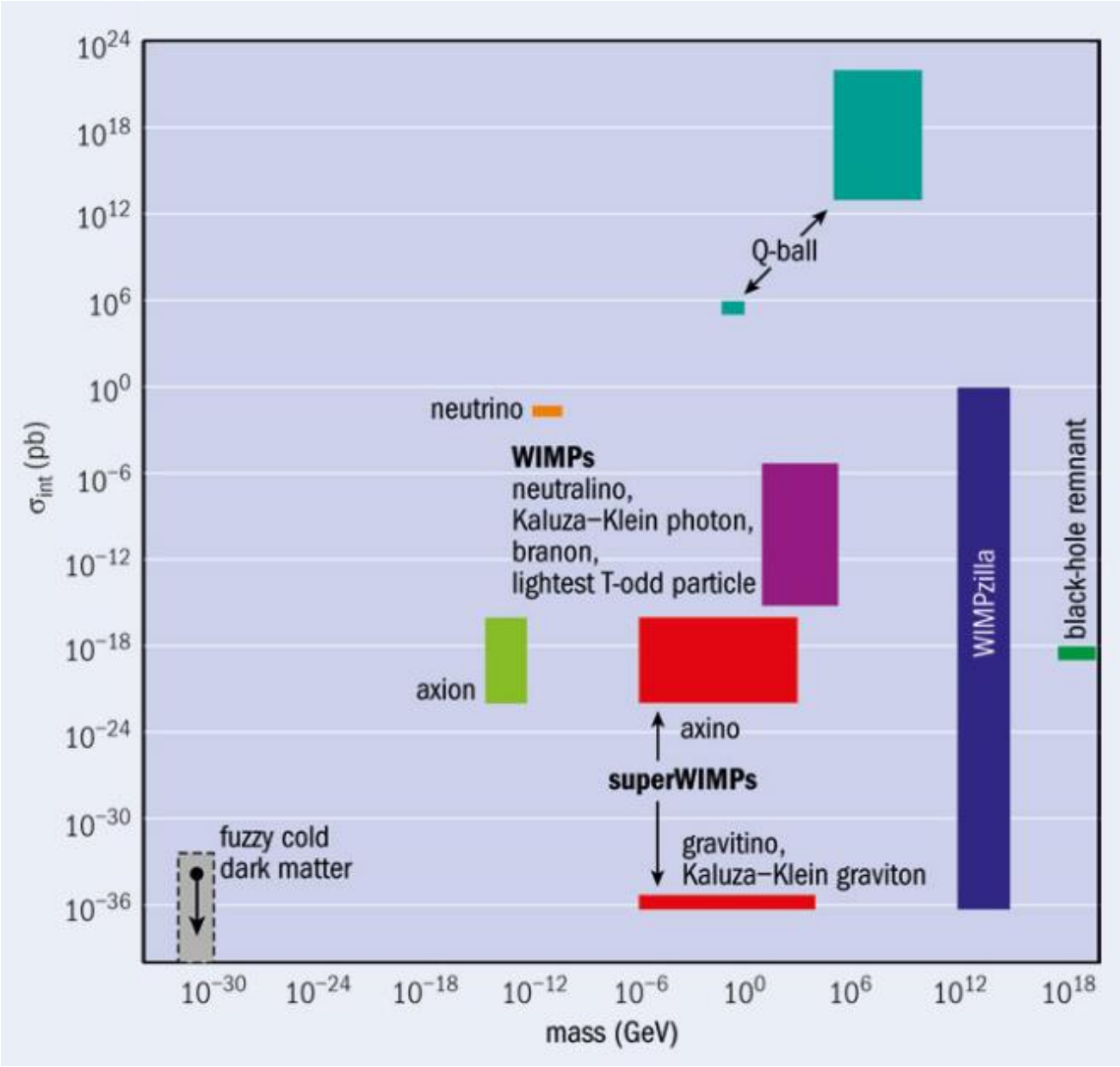
UNIVERSIDAD EIA
Ser, Saber y Servir

UNIVERSIDAD SERGIO ARBOLEDA

Outline:

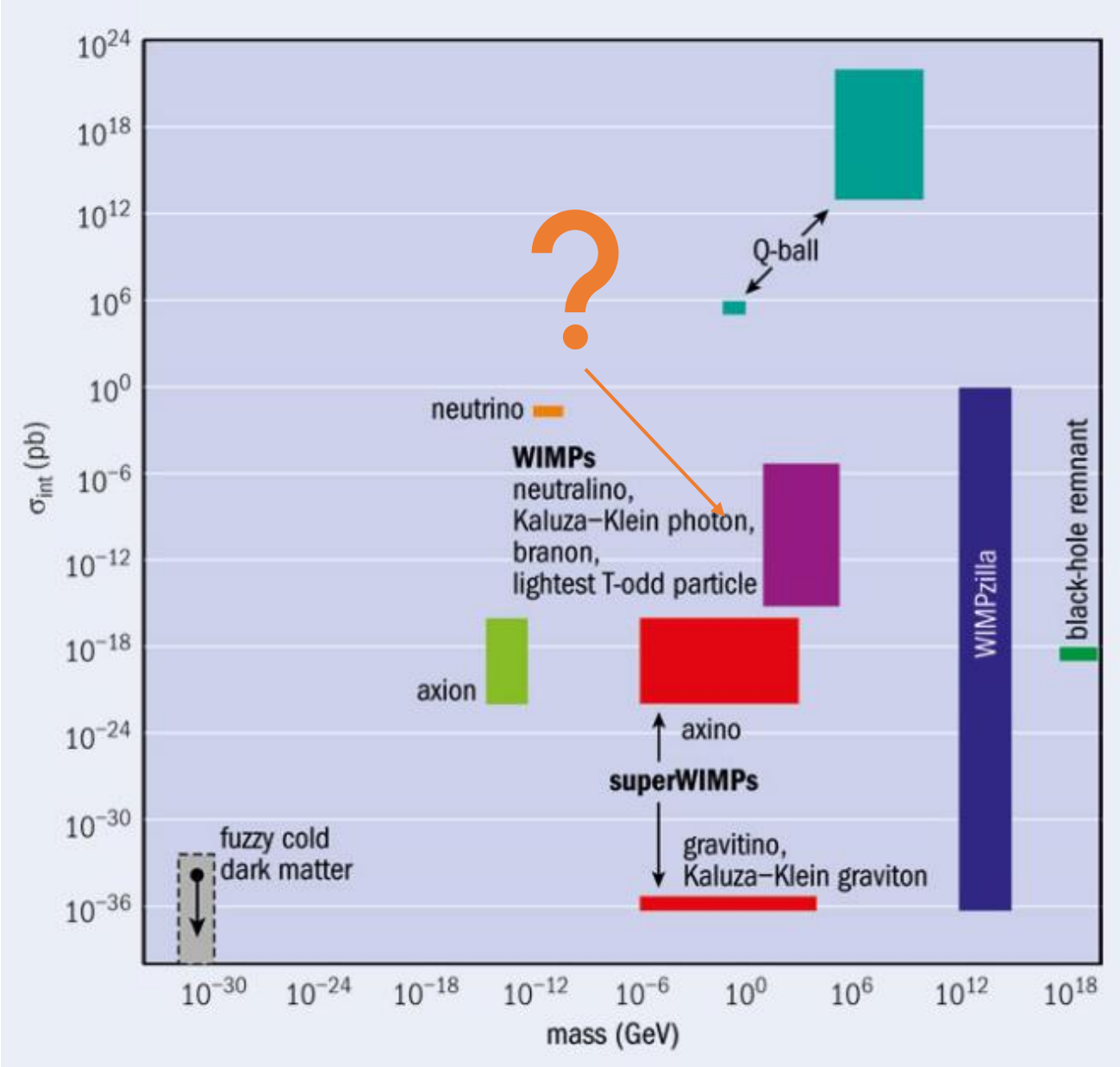
- Motivation
- The model.
- Relic density phenomenology.
- Probing the model.

Motivation

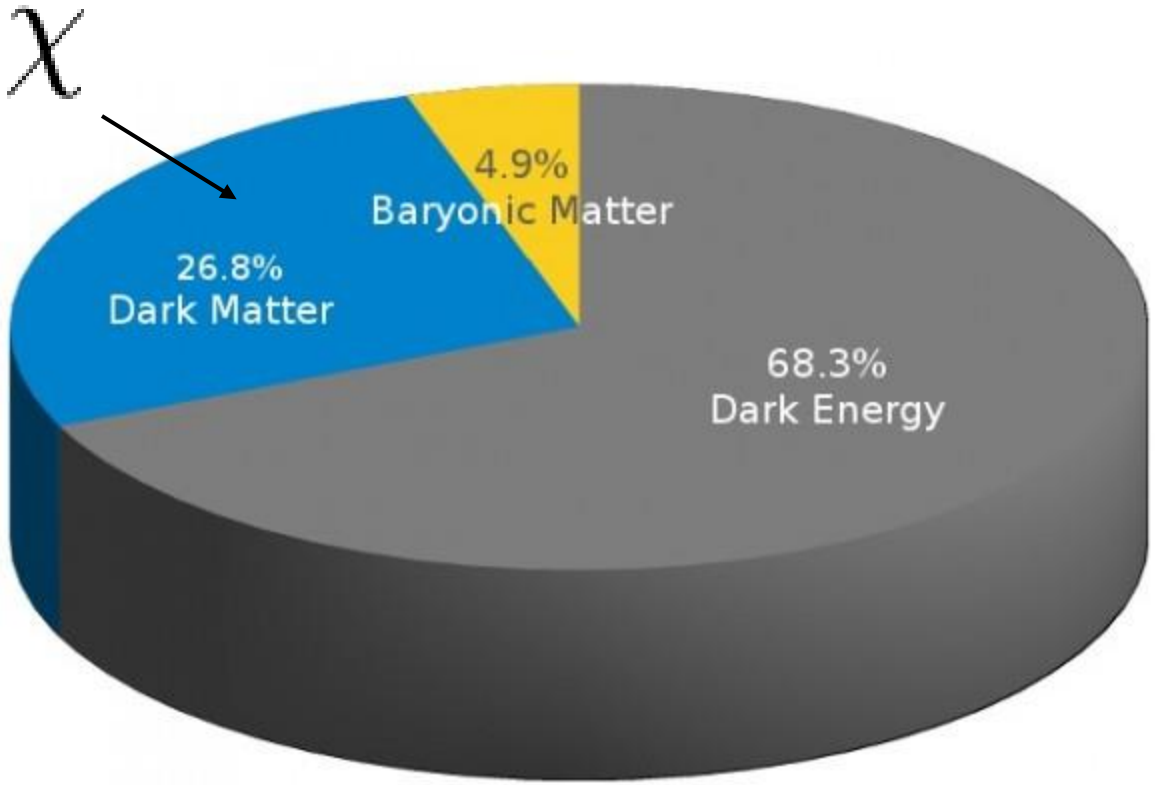

10^{24}
10^{18}
10^{12}
10^{6}
10^{0}
10^{-6}
10^{-12}
10^{-18}
10^{-24}
10^{-30}
10^{-36}
σ_{int} (pb)
Q-ball
neutrino
WIMPs
neutralino,
Kaluza–Klein photon,
branon,
lightest T-odd particle
axion
axino
superWIMPs
gravitino,
Kaluza–Klein graviton
fuzzy cold
dark matter
WIMPzilla
black-hole remnant
10^{-30}
10^{-24}
10^{-18}
10^{-12}
10^{-6}
10^{0}
10^{6}
10^{12}
10^{18}
mass (GeV)

Motivation

WIMP Dark matter candidates could be below the usual mass scales, but a new annihilation channel is needed.

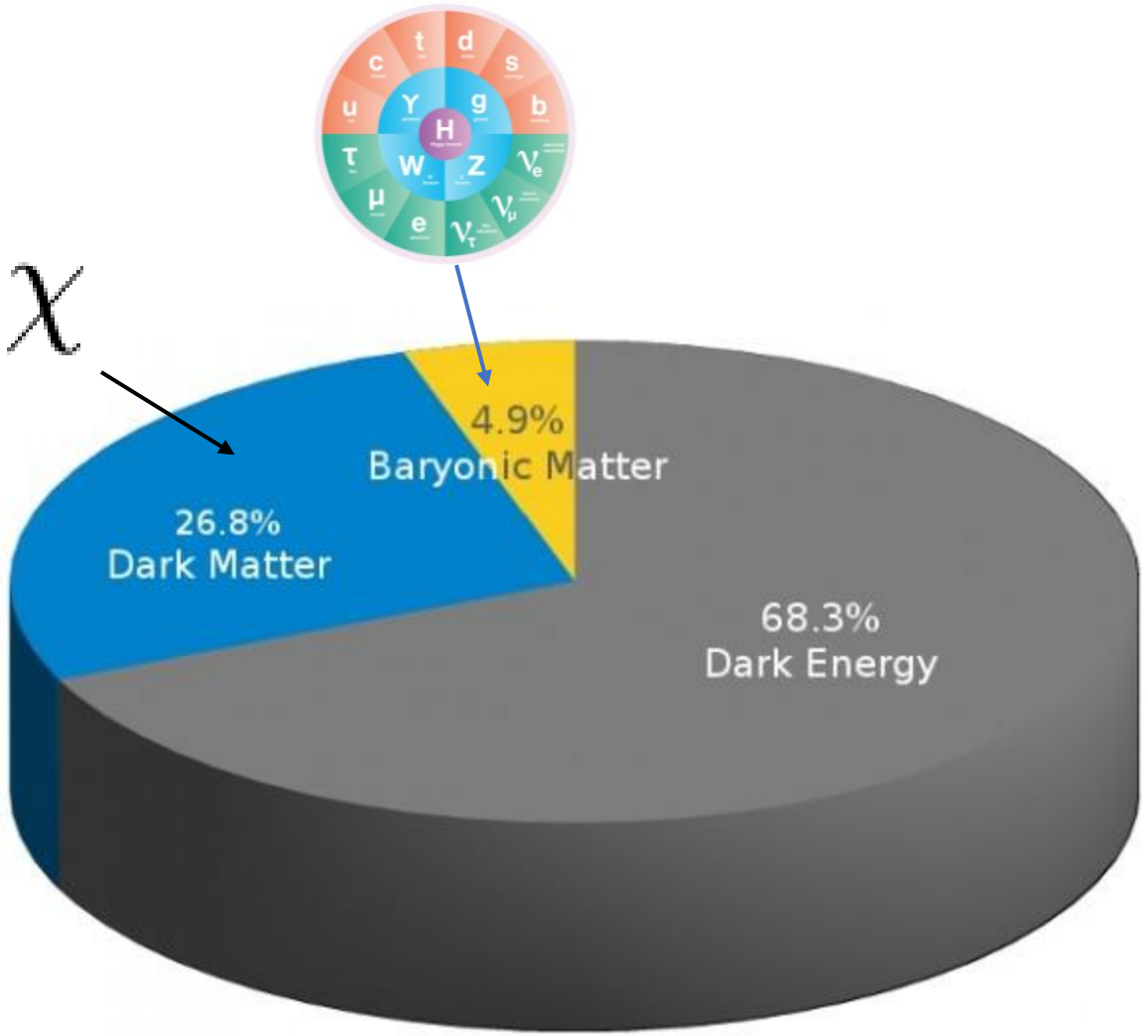


Motivation



Motivation

Many models focus on one DM candidate, but there could be several, just as the baryonic matter is made of a myriad of particles.



The Model:

To address the two issues mentioned, we focus on a multicomponent DM model with lighter WIMP particles (SubGeV). The model includes:

Added particle	Symmetries	Spin
ϕ_1	$U(1)_D \times Z_2$	0
ϕ_2	$U(1)_D \times Z_2'$	0

The gauge Lagrangian associated to the U(1) symmetries:

$$\mathcal{L}_{gauge} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\varepsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$

This part of the model based on Pospelov et al 2008, and Pospelov 2009

The Model:

To address the two issues mentioned, we focus on a multicomponent DM model with lighter WIMP particles (SubGeV). The model includes:

Added particle	Symmetries	Spin
ϕ_1	$U(1)_D \times Z_2$	0
ϕ_2	$U(1)_D \times Z_2'$	0

The gauge Lagrangian associated to the U(1) symmetries:

$$\mathcal{L}_{gauge} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\varepsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$

The dark U(1) symmetry is broken, thus there is a massive gauge boson, the dark photon.

The Model:

To address the two issues mentioned, we focus on a multicomponent DM model with lighter WIMP particles (SubGeV). The model includes:

Added particle	Symmetries	Spin
ϕ_1	$U(1)_D \times Z_2$	0
ϕ_2	$U(1)_D \times Z_2'$	0

The gauge Lagrangian associated to the U(1) symmetries:

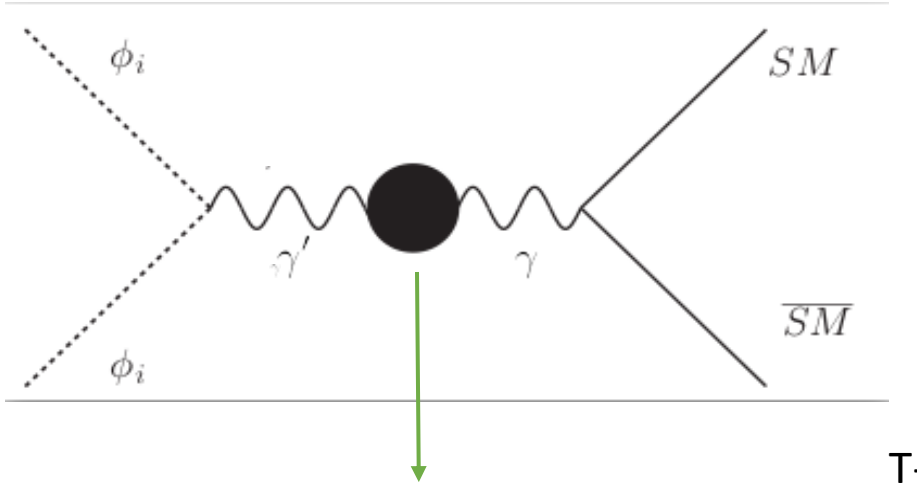
$$\mathcal{L}_{gauge} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\varepsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$

The dark U(1) symmetry is broken, thus there is a massive gauge boson, the dark photon.

There is a kinetic mixing between the photon and the dark photon

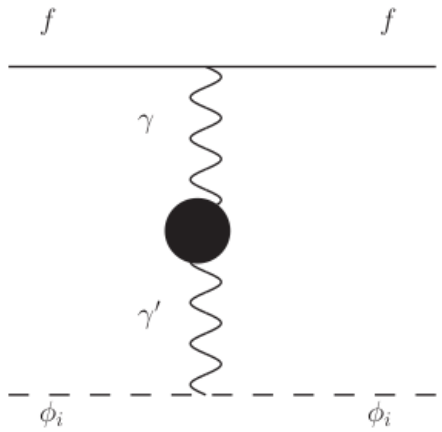
The Model: Feynman diagrams

DM annihilation into SM

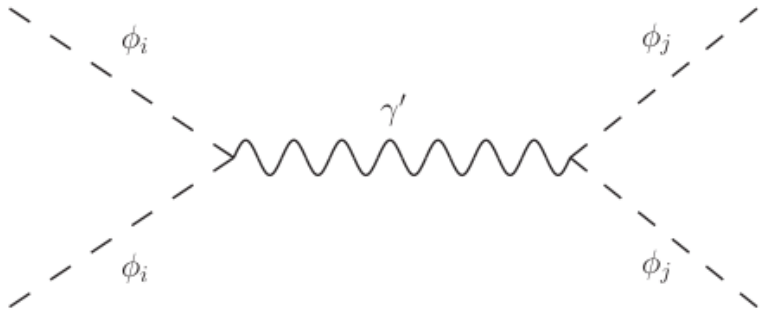


Kinetic Mixing

T-channel interaction with SM



DM conversion



To study the interactions we use SARAH, based on the model of D. Aristizabal et al. 2015

Relic density phenomenology

Free parameters:

ϵ , α_D, $m_{\gamma'}$, m_{ϕ_1}, and m_{ϕ_2}

Choose:

α_D=0.1, $m_{\gamma'}$=3m_{ϕ_1}, $m_{\phi_2} > m_{\phi_1}$

To calculate the relic density, we use micrOmegas.

Relic density phenomenology

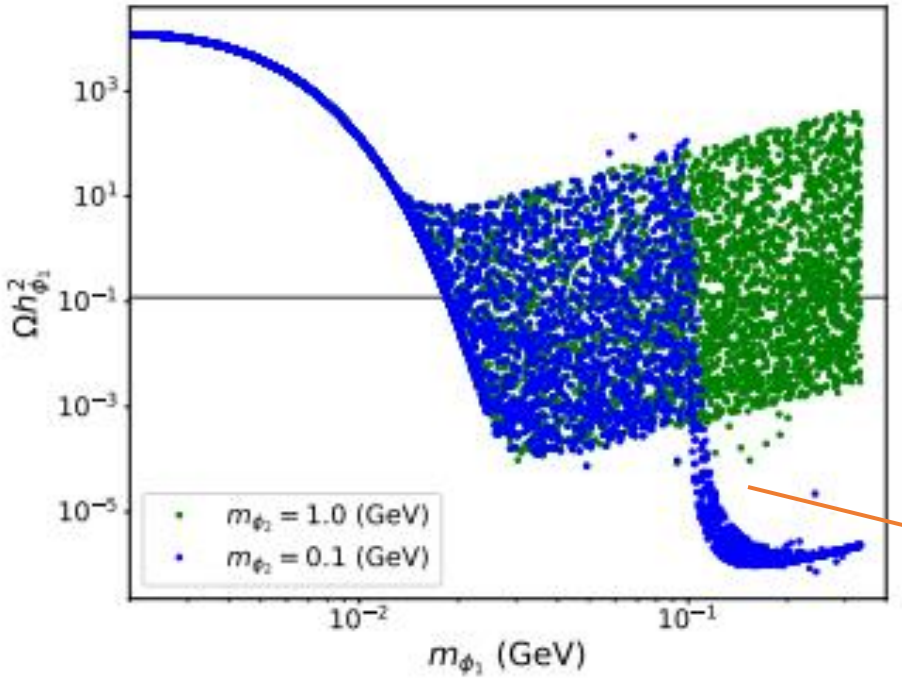
Free parameters:

ϵ , α_D, $m_{\gamma'}$, m_{ϕ_1}, and m_{ϕ_2}

Choose:

α_D=0.1, $m_{\gamma'}$=3m_{ϕ_1}, $m_{\phi_2} > m_{\phi_1}$

Benchmark similar to D.Romeri et al, 2019 and M. Breitbach et al 2021.

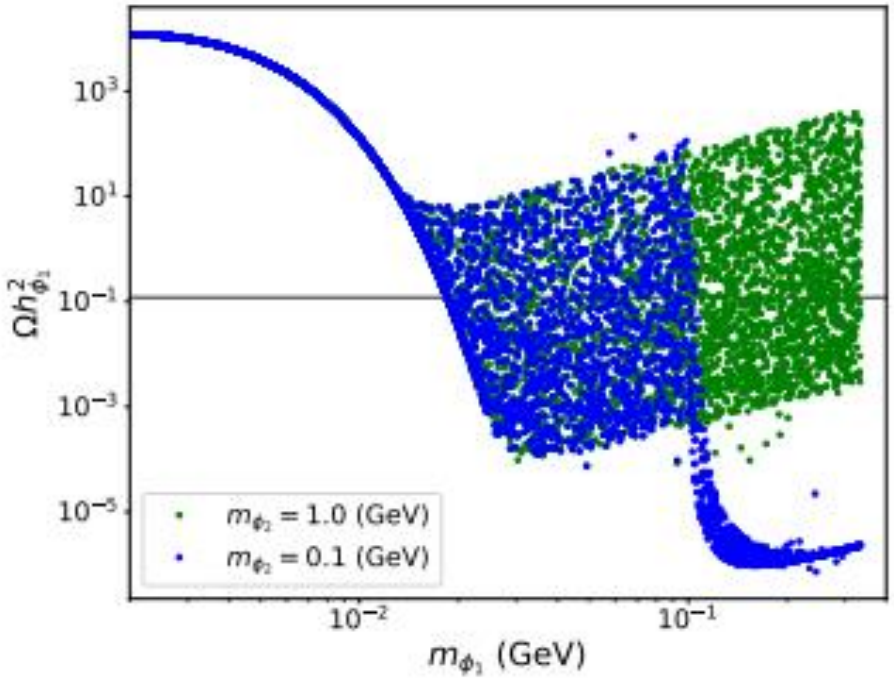


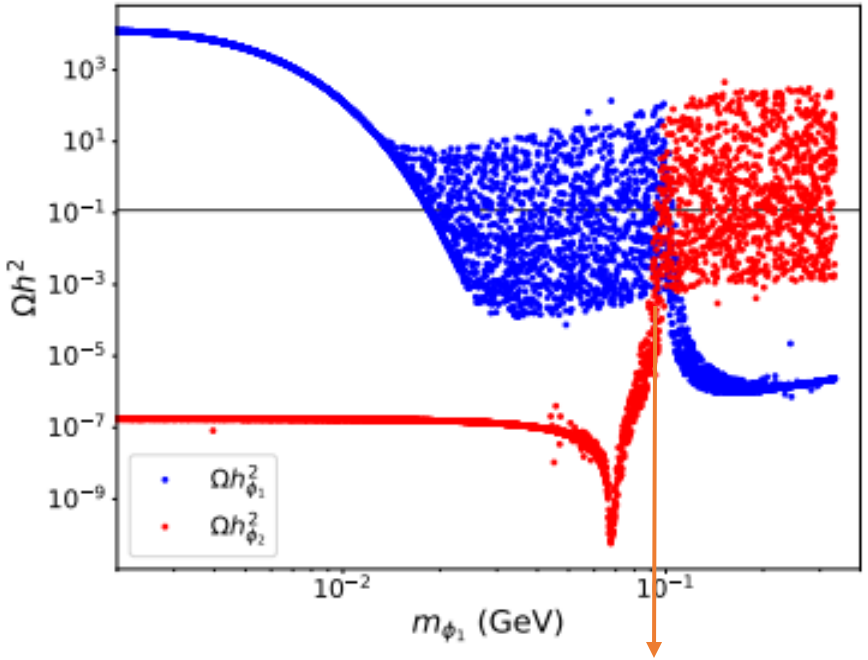
Heavier DM gets depleted!

Relic density phenomenology

Choose:

$\alpha_D = 0.1,\ m_{\gamma'} = 3m_{\phi_1},\ m_{\phi_2} > m_{\phi_1}$



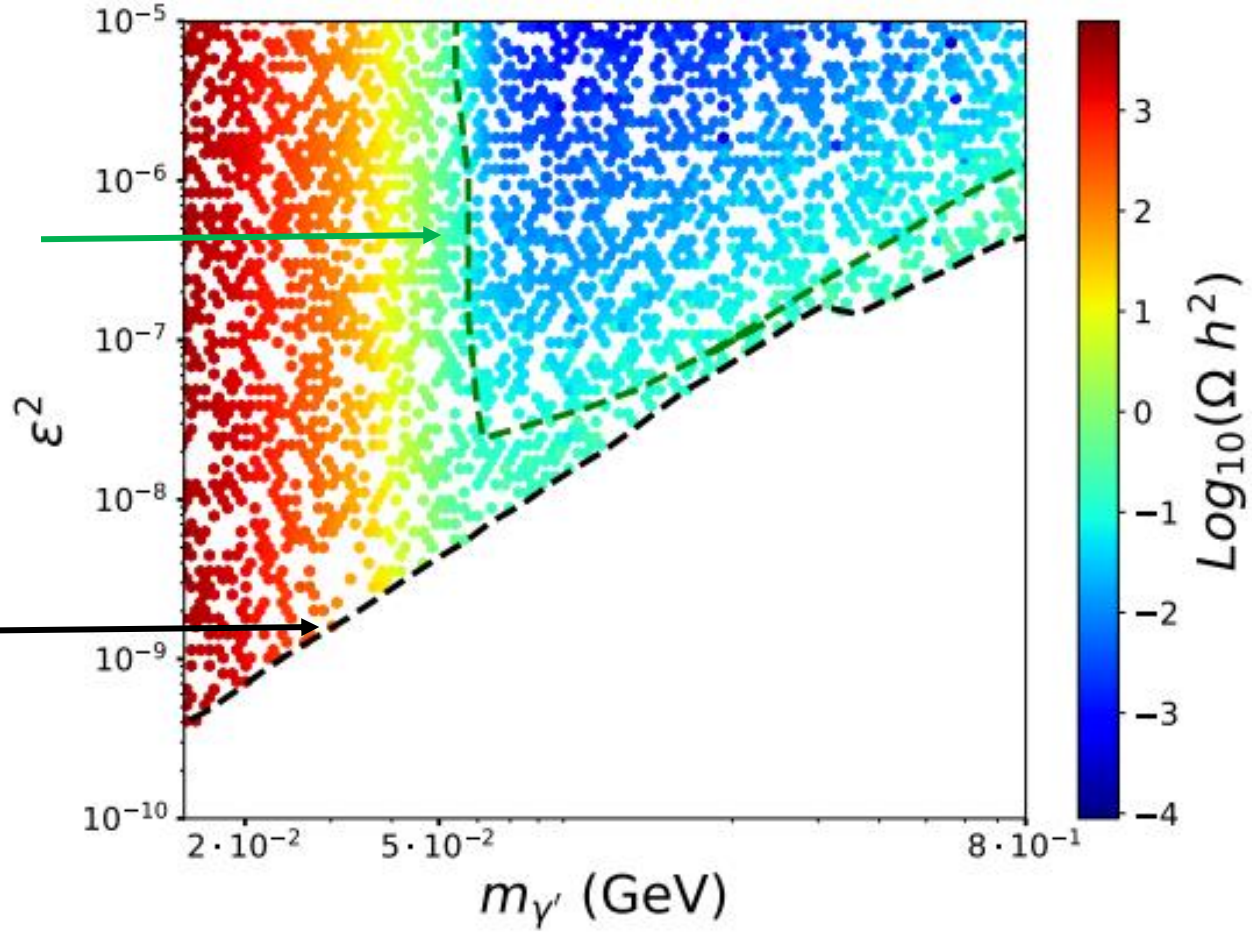


DM particles switch roles, only one DM particle remain, the heaviest

Relic density phenomenology

Relic abundance for the multicomponent model.

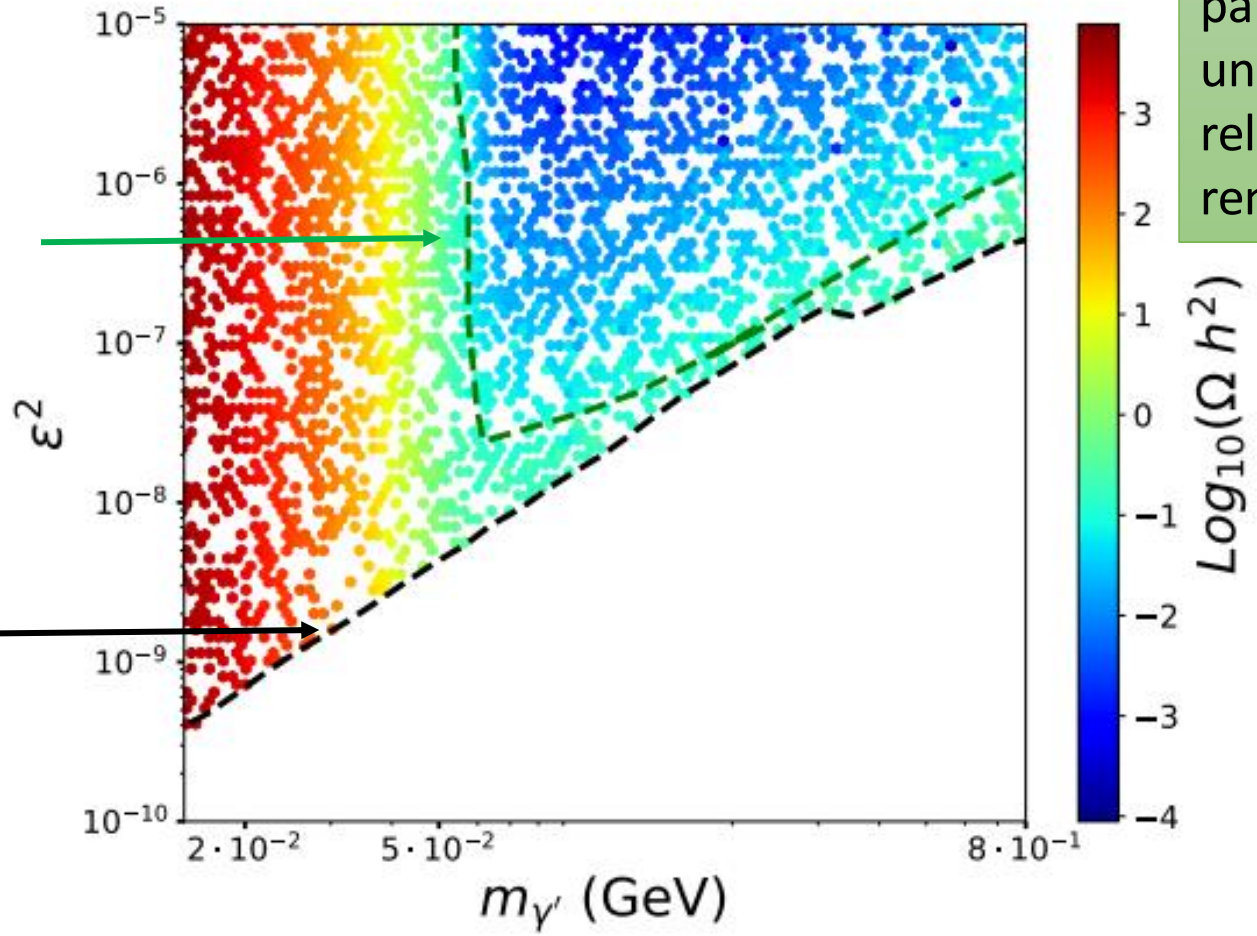
Correct relic abundance for one DM particle, such as the model studied in D. Romeri et al 2019.



Relic density phenomenology

Relic abundance for the multicomponent model.

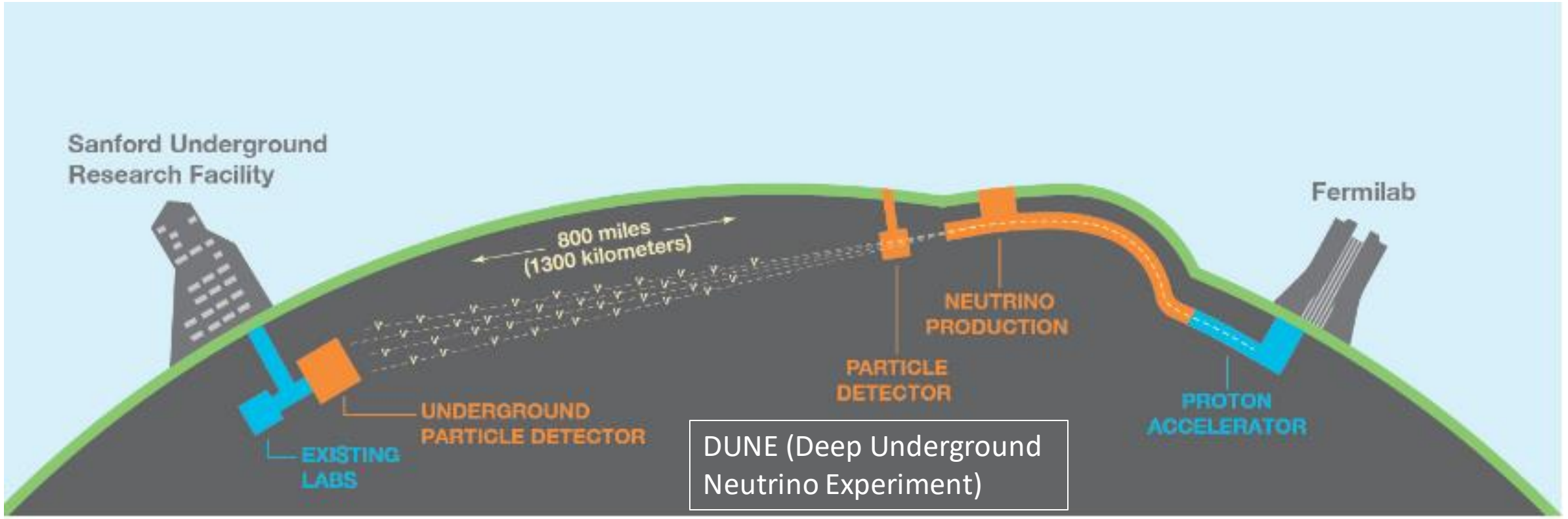
Correct relic abundance for one DM particle, such as the model studied in D. Romeri et al 2019.



Even though only one DM remains, the existence of the other particle in the early universe, affects the relic density of the remaining particle

Probing the model: DUNE

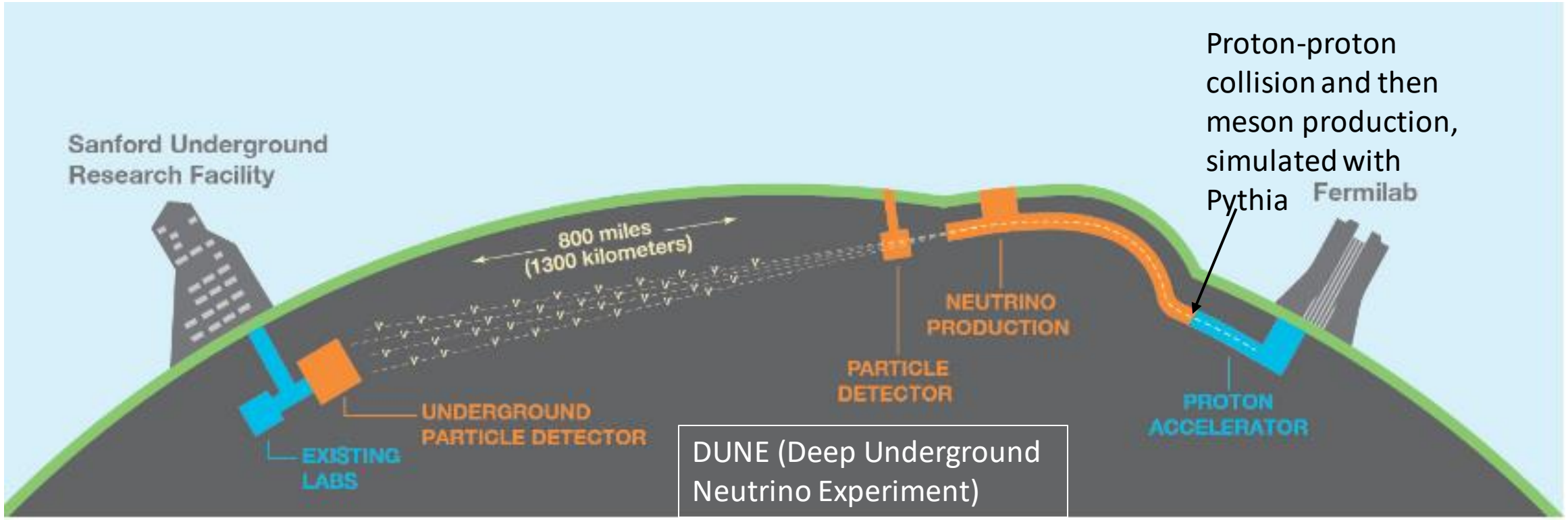
- High intensity proton beams present an opportunity to produce and observe the interactions of these DM particles.



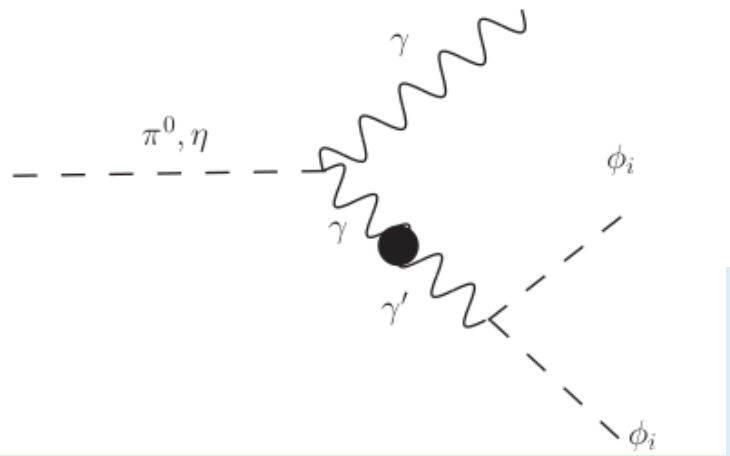
DUNE (Deep Underground Neutrino Experiment)

Probing the model: Meson production

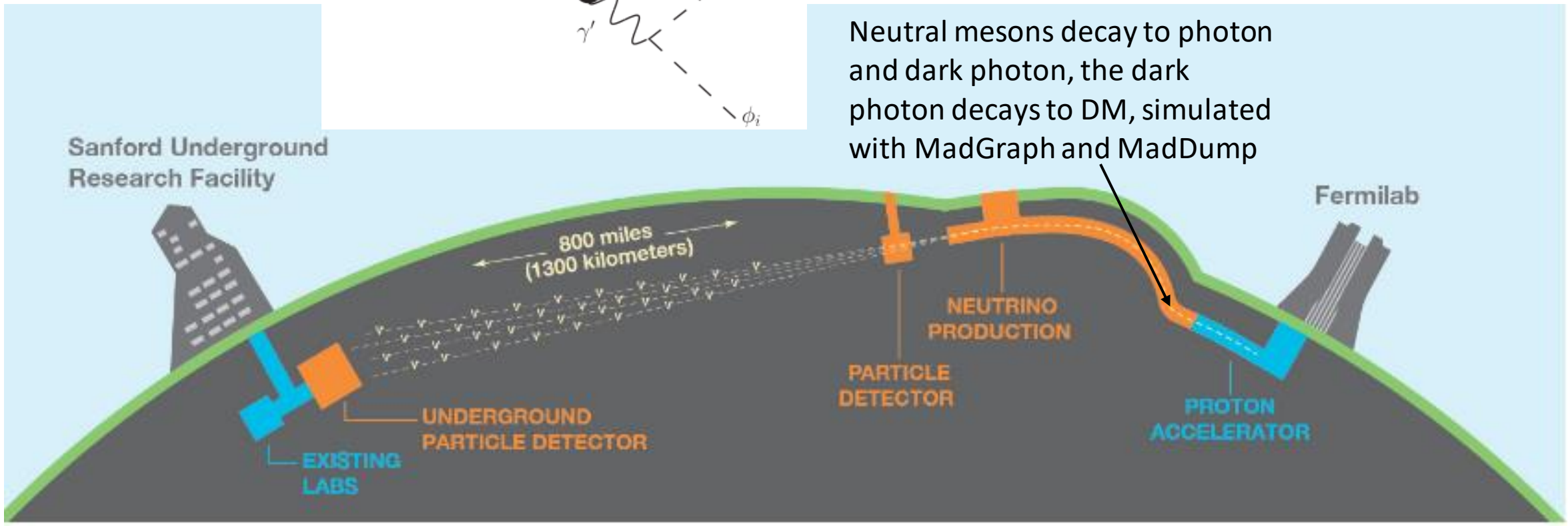
- High intensity proton beams present an opportunity to produce and observe the interactions of these DM particles.



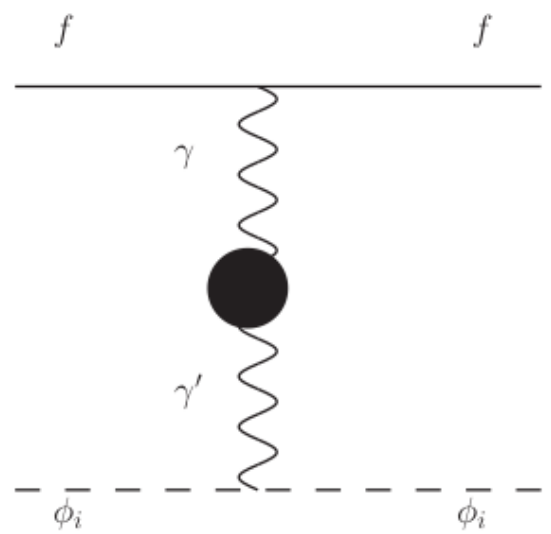
Probing the model: Meson decay, DM production



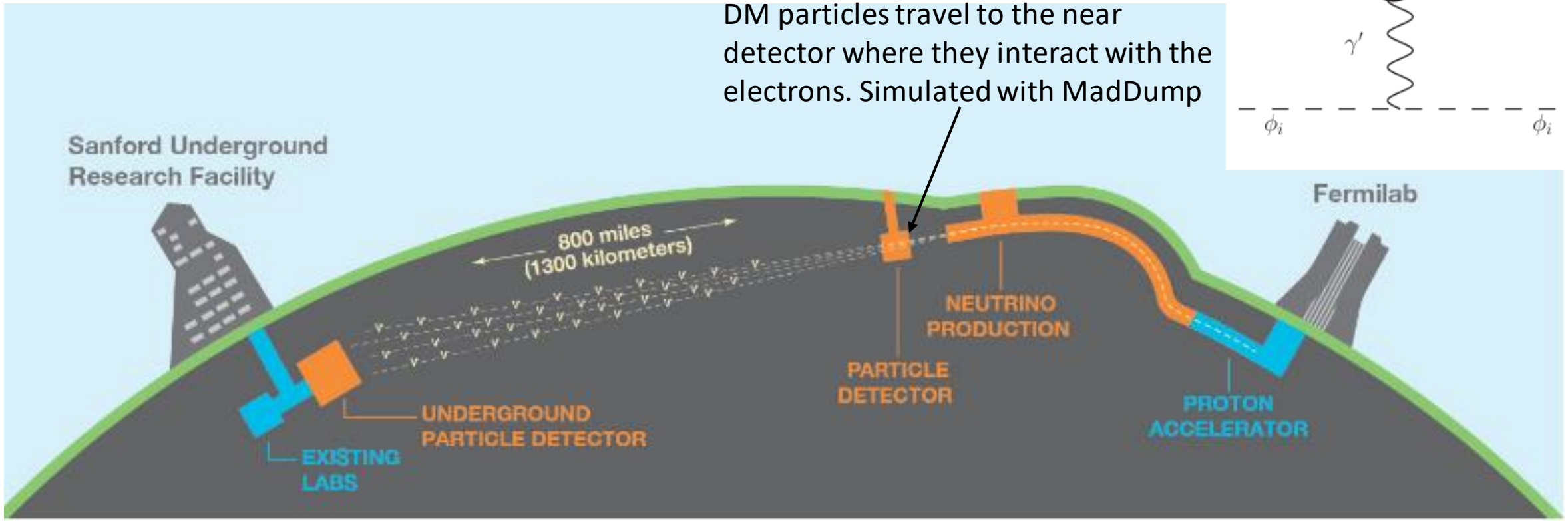
Neutral mesons decay to photon and dark photon, the dark photon decays to DM, simulated with MadGraph and MadDump



Probing the model: DM interaction



DM particles travel to the near detector where they interact with the electrons. Simulated with MadDump

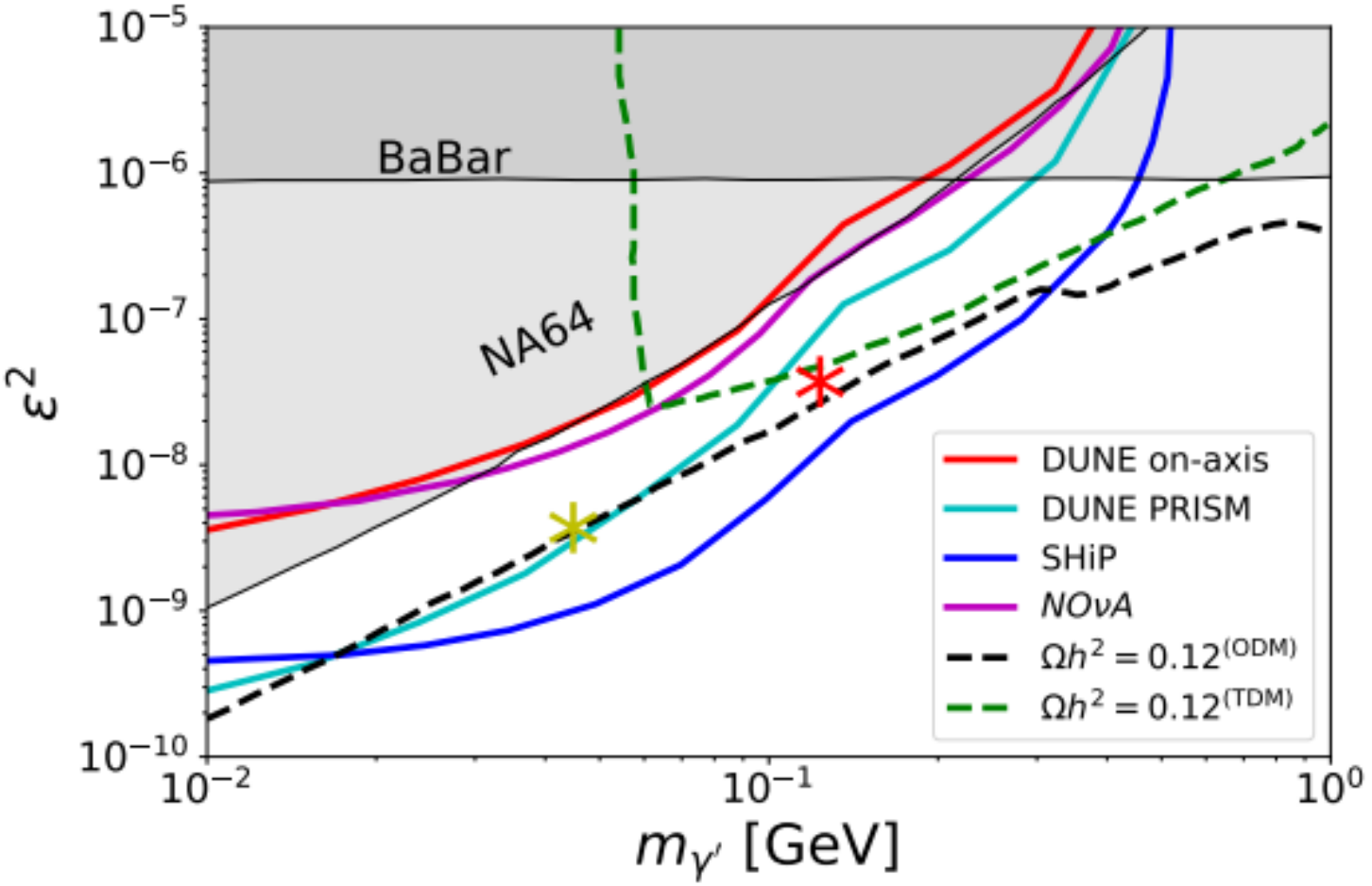


Probing the model:

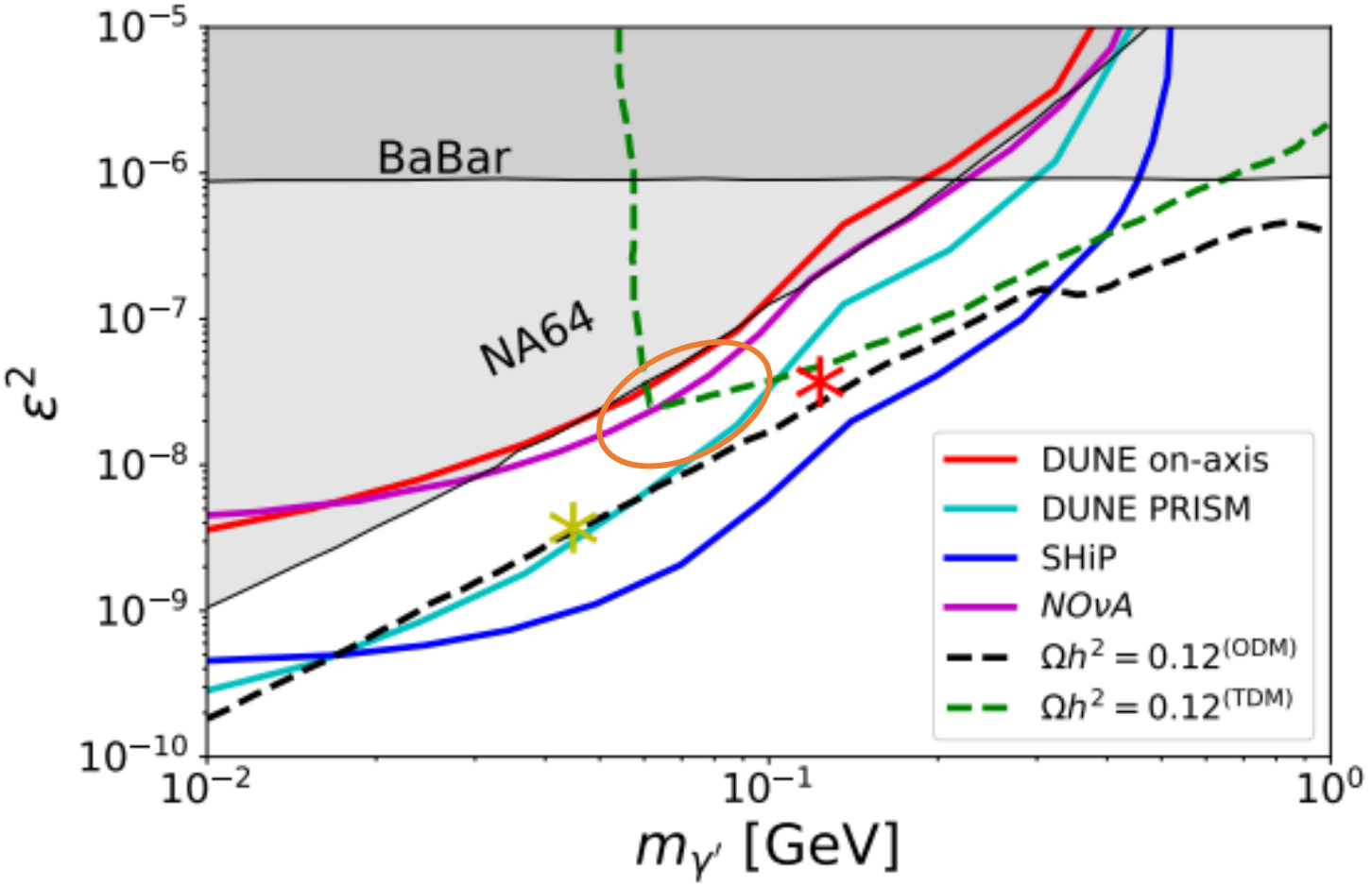
- Through this process (proton-proton collision and meson decay) neutrinos are also produced, huge background! To simulate it, we used NuWro (more at NuCo).

- To estimate the parameter space that DUNE may probe, we analyze the kinematic shape of both: background and DM+background. For this we used a Poisson likelihood, following a procedure similar to D.Romeri et al, 2019 and M. Breitbach et al 2021.

Probing the model: Results



Probing the model: Results



Conclusion:

- In the multicomponent subGeV DM model, the dark photon portal plays a very important role.
- It allows for DM conversion, which is important in setting the relic abundances.
- The model may be probed at DUNE (and also SHIP) with a better exclusion of the parameter space by using the near detector off-axis configuration.

References:

- M. Pospelov, A. Ritz, and M. B. Voloshin, Phys. Lett. B 662, 53 (2008), arXiv:0711.4866.
- M. Pospelov, Phys. Rev. D 80, 095002 (2009), arXiv:0811.1030.
- D. Aristizabal,F. Staub, A. Vicente, Phys. Rev. D92, 015001 (2015), arXiv:1503.06077.
- V. De Romeri, K. J. Kelly, and P. A. N. Machado, Phys. Rev. D 100, 095010 (2019), arXiv:1903.10505.
- M. Breitbach, L. Buonocore, C. Frugiuele, J. Kopp, and L. Mittnacht, (2021), arXiv:2102.03383.