ATLAS EXPERIMENT

Université Mohammed V
Faculté des Sciences
Rabat

First Pan-African Astro-Particle and Collider Physics Workshop

Dark photon searches with the ATLAS detector at the LHC

Parallel Session V

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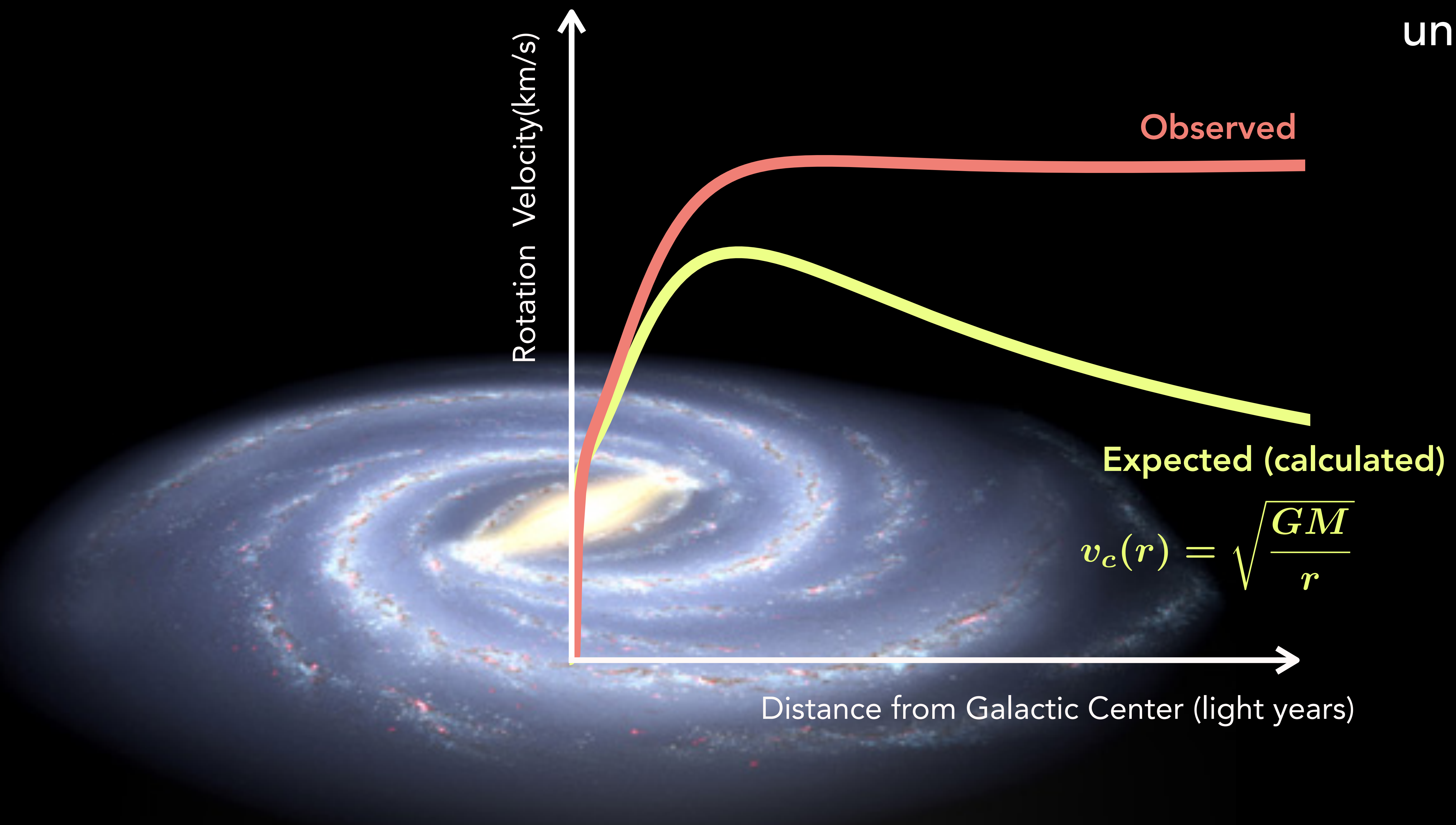
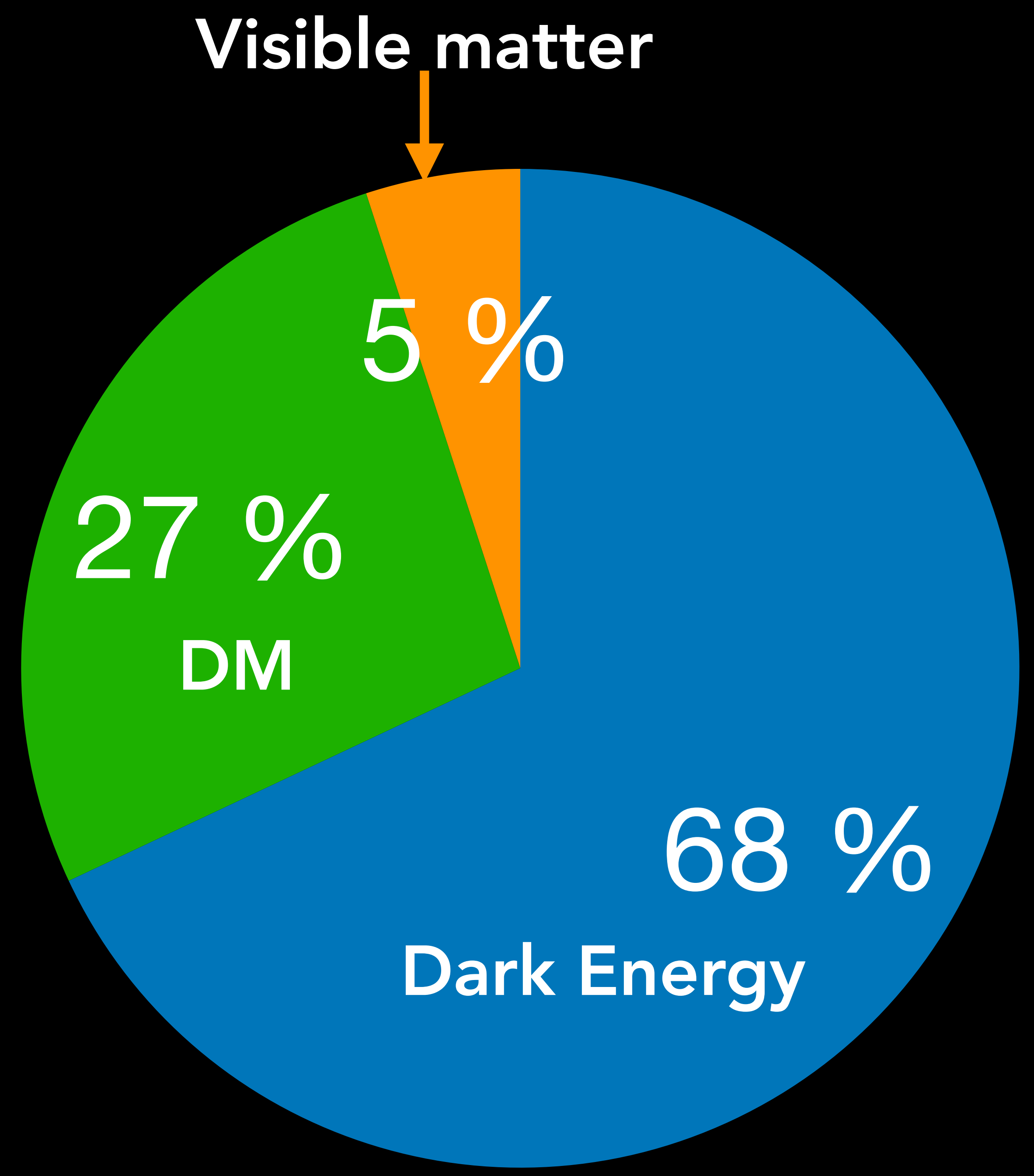
March 23rd, 2022

Galactic Rotation



Rubin and Ford (1970); Roberts and Whitehurst (1975); Rubin, Thonnard and Ford (1980); Bosma (1981)

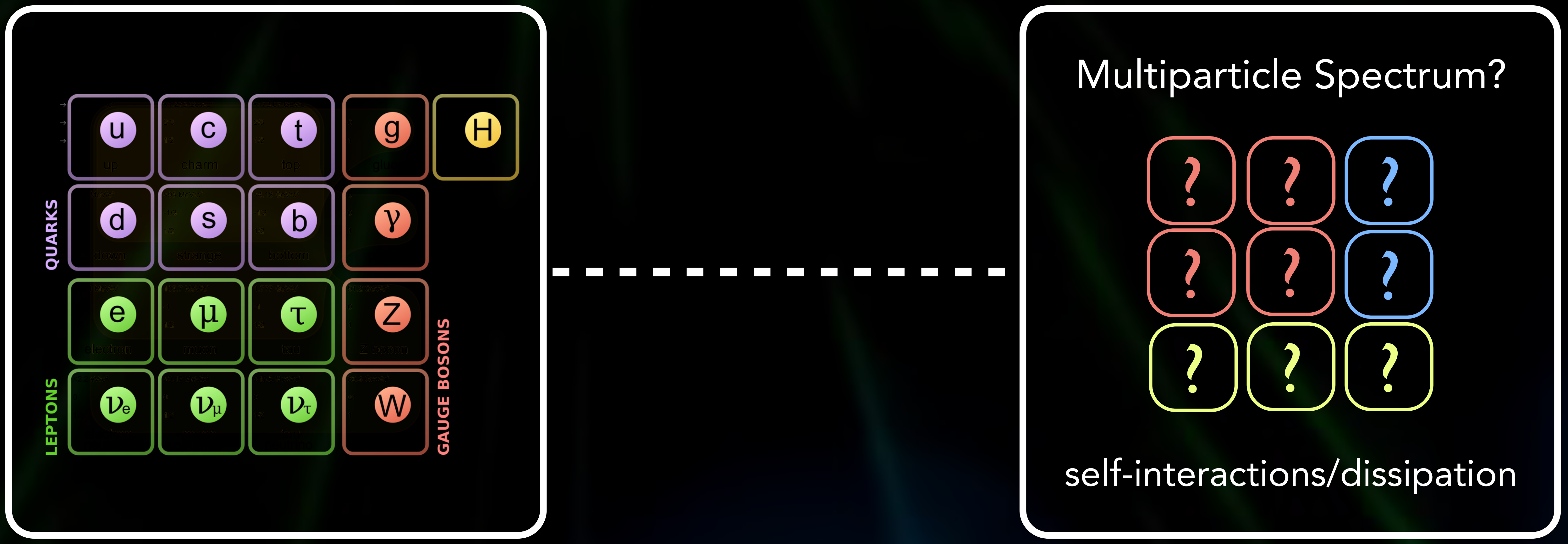
By fitting a theoretical model of the composition of the universe to the combined set of cosmological observations:

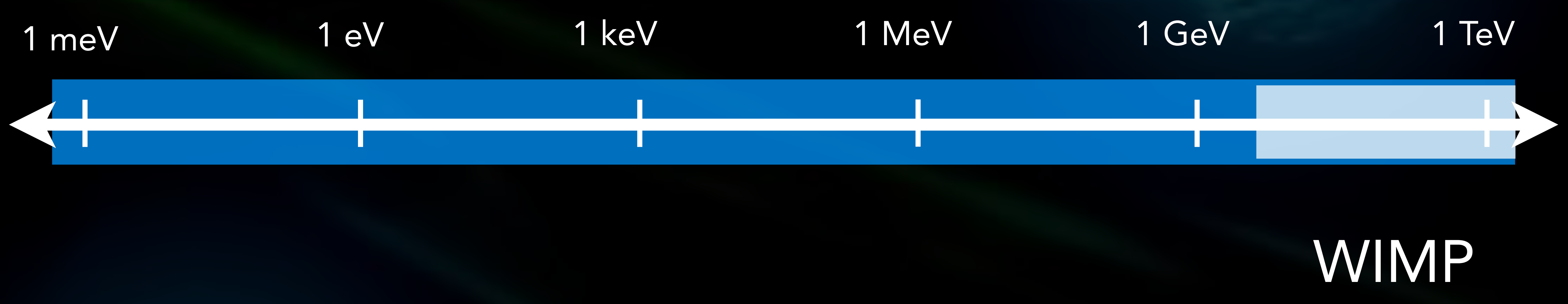


Hidden Dark Sectors

- Hypothetical collection of fields and particles predicted as possible Standard Model extensions.
- No direct interactions with the particles of the Standard Model (SM).
- Couples extremely weakly to SM particles through mediating particles such as dark photons, axions, or sterile neutrinos.

Visible Sector **Mediator(s)** **Hidden Sector**





Many viable hidden-sector DM models for meV-to-GeV masses

freeze-out, freeze-in, axion like particles, **dark photons**, scalars…

How to search for Dark Sectors

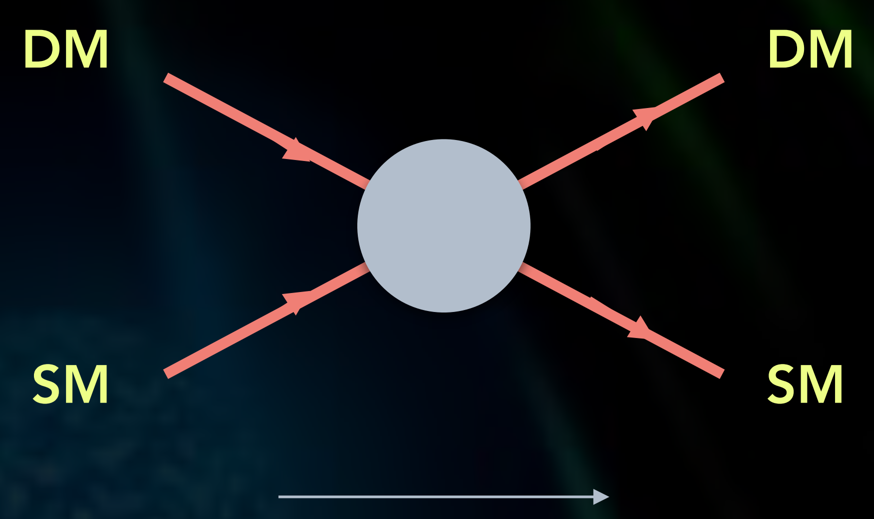
Gravitational Interactions

non-trivial DM interactions can affect small-scale structure

Galactic-Scale Observables

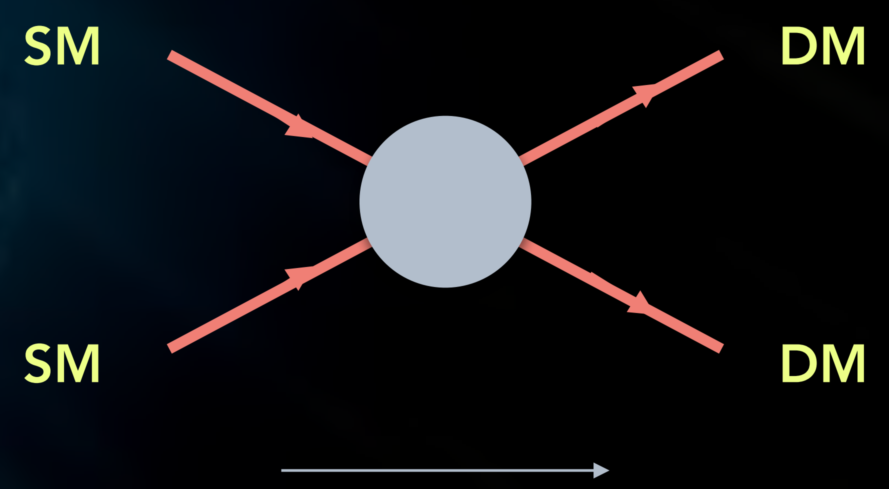
self-interactions can occur near centers of galaxies

Scattering or Absorption



recoil energies typically smaller than WIMPs

Production

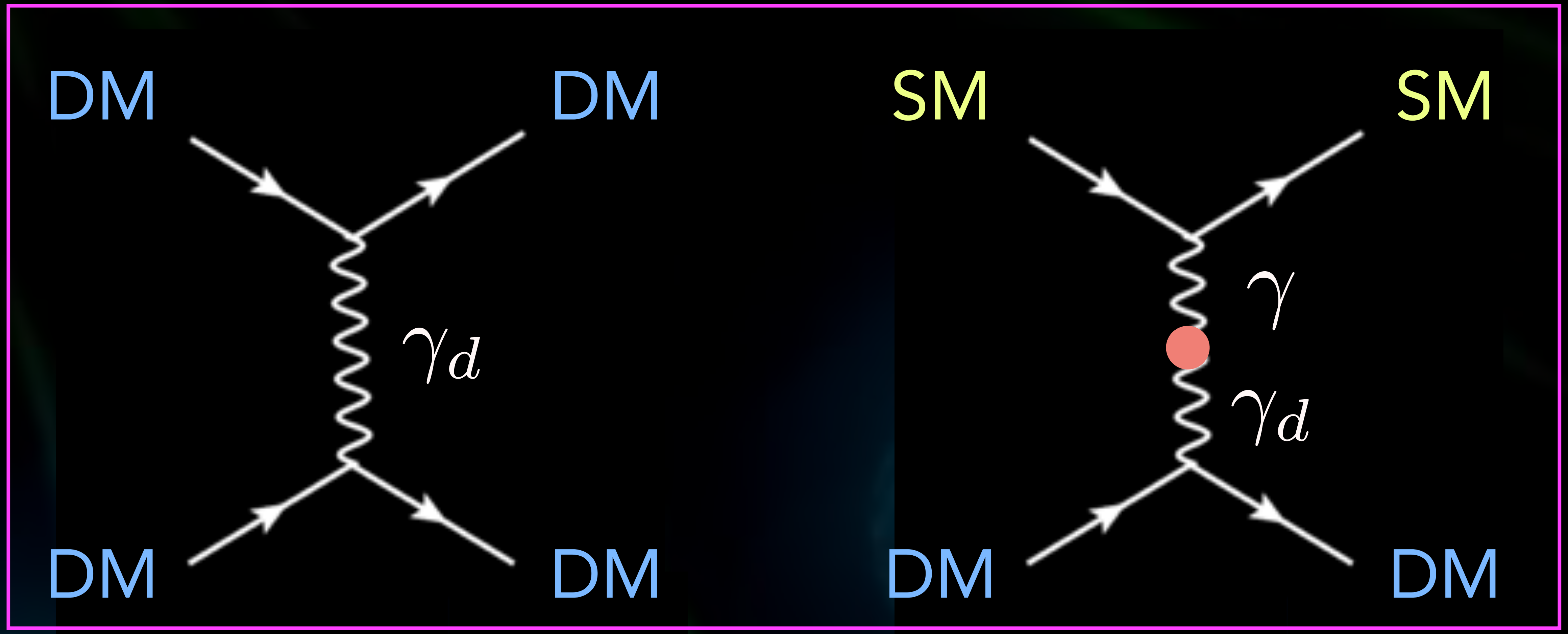


Either in colliders or beam-dump experiments

What is Dark Photon?

- New $U(1)_{Dark}$ gauge field under which the SM is not charged.
- Dark photons (γ_D ,Z_D or $A^{'}$) are neutral light vector gauge bosons which kinetically mix with the SM photon with a mixing strength.

A dark sector mediator.



connect to dark sector.

How is it produced ?

- Vector portal: Kinetic mixing of γ_D with the SM photon (ϵ) by adding a U(1)'
- Higgs portal: Add dark scalar singlet (S) that spontaneously breaks U(1) and mixes with SM Higgs.
- More exotic portals: hidden valley sectors, neutrinos, dark SUSY, ….

$$L \supset -\frac{\epsilon}{2}B^{\mu\nu}A'_{\mu\nu} - H^{+}H(AS+\lambda S^2) - Y_N^{ij}L_iHN + \frac{1}{f_a}(tr(G\tilde{G}) + c_F F\tilde{F})a + o(dim \geq 5)$$

Vector portal — [Okun; Galison & Manohar; Holdom; Foot et al]

Higgs portal — [Patt & Wilczek]

Neutrino portal — [Patt & Wilczek]

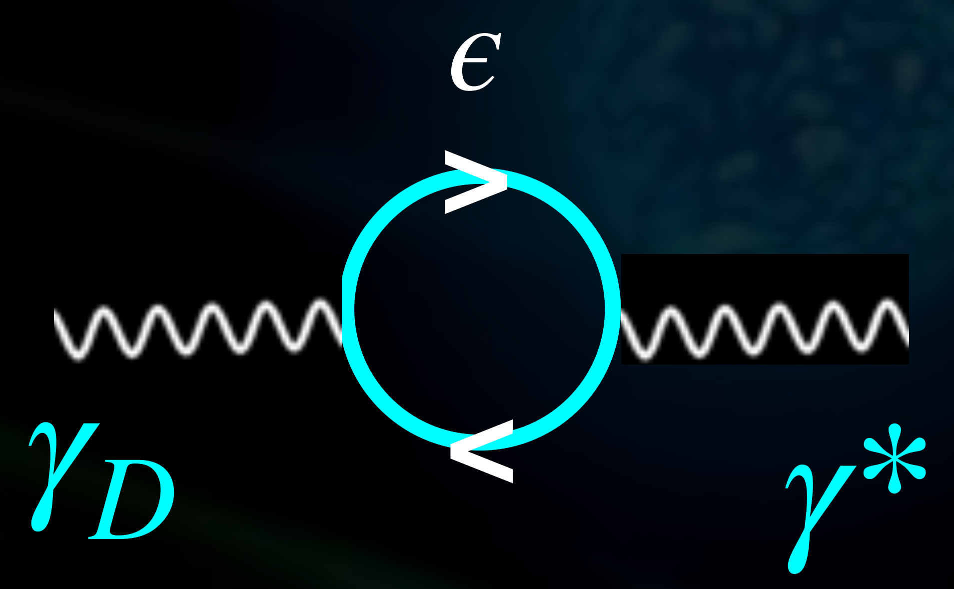
Axion portal — [Weinberg; Wilczek; KSVS; DFSZ]

How does it decay ?

- Visible: decays to SM particles
- Invisible: decays can include dark matter particles

Kinetic mixing

- If generated by 1 loop corrections, $\epsilon \sim 10^{-3} - 10^{-1}$
- If generated by 2 loop corrections, $\epsilon \sim 10^{-7} - 10^{-3}$

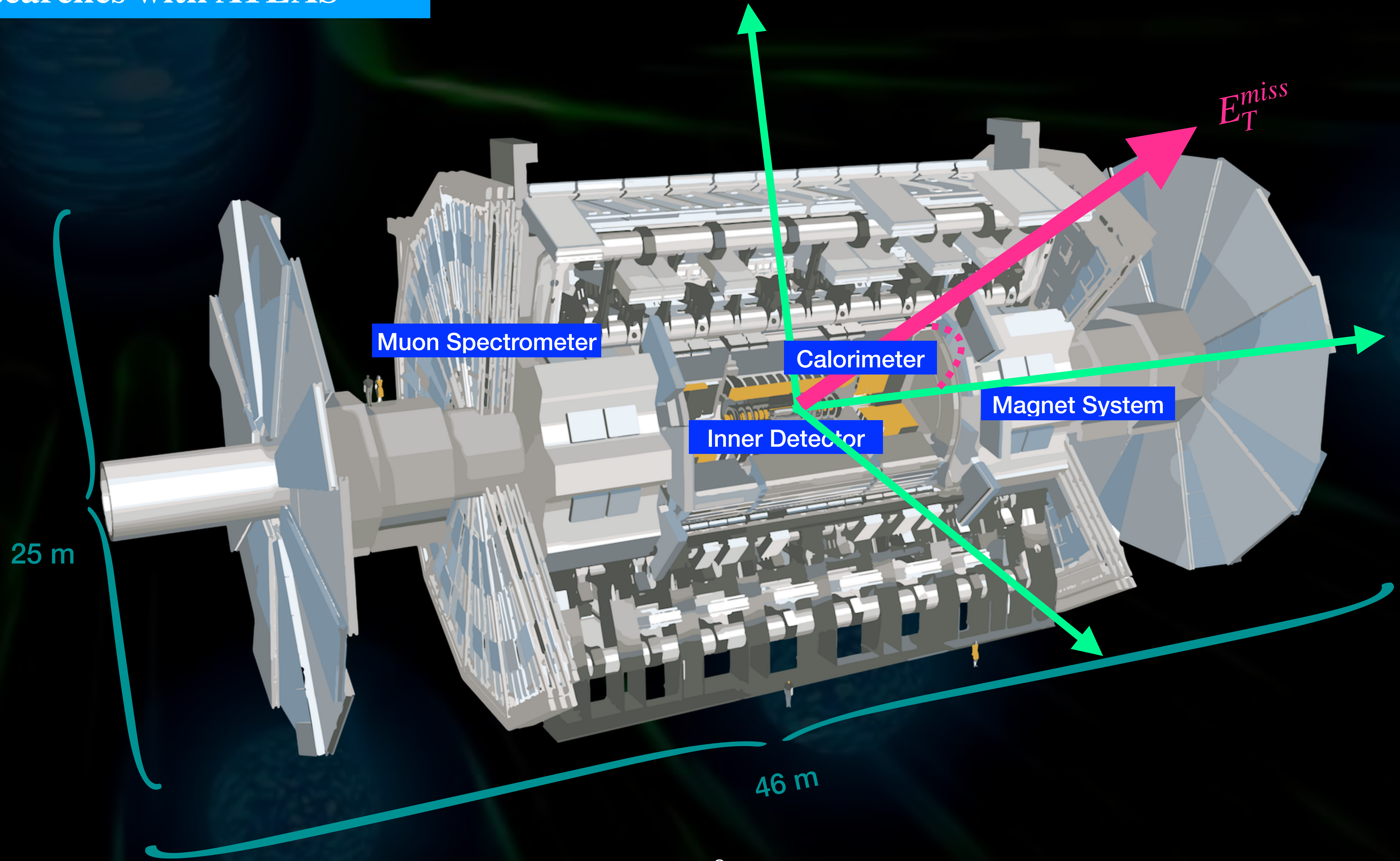


Lifetime

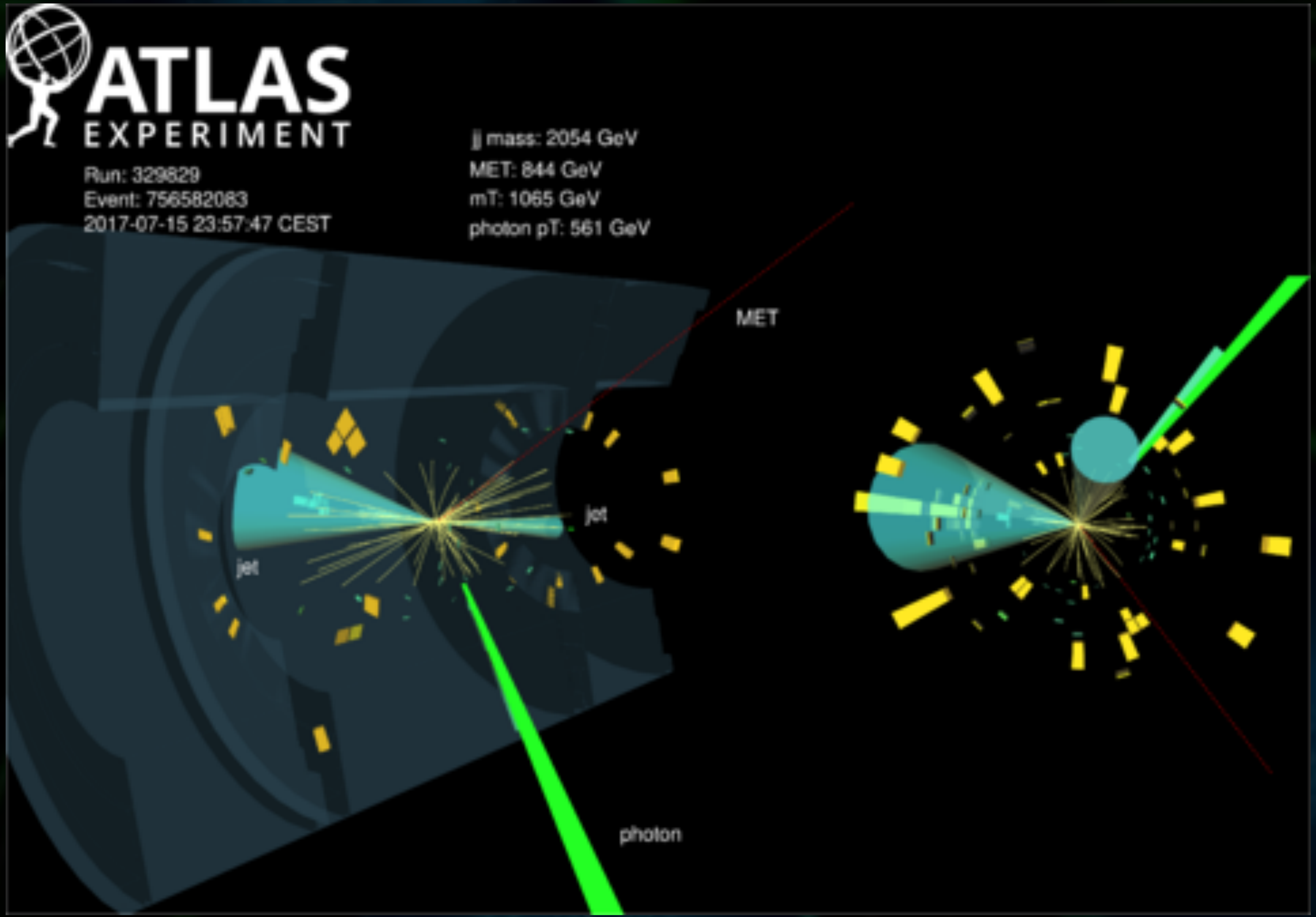
- Small ϵ value => long γ_D lifetime: γ_D decays at a macroscopic distance from its production point

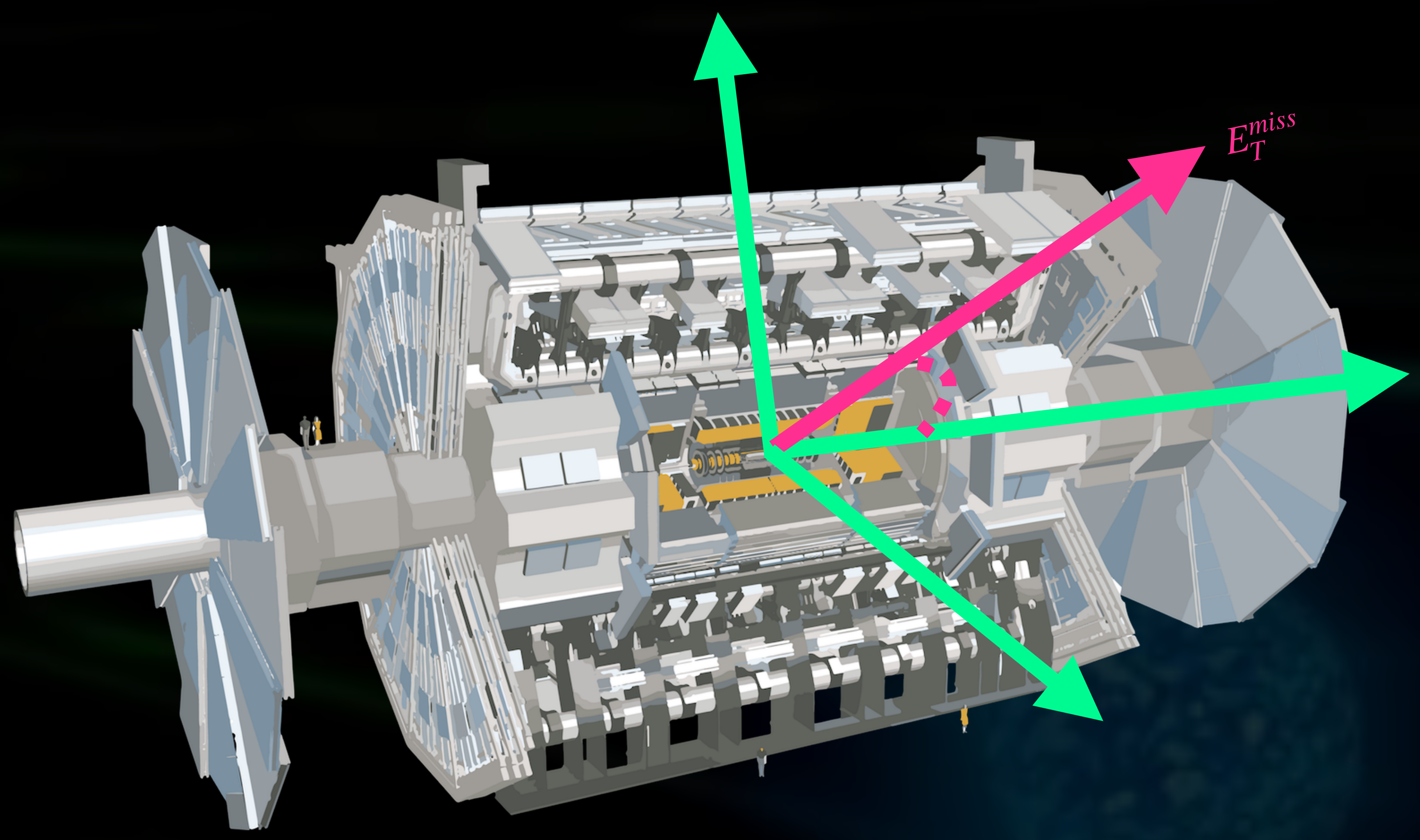
$$\tau(\gamma_D) \propto \frac{1}{m(\gamma_D)\epsilon^2}$$

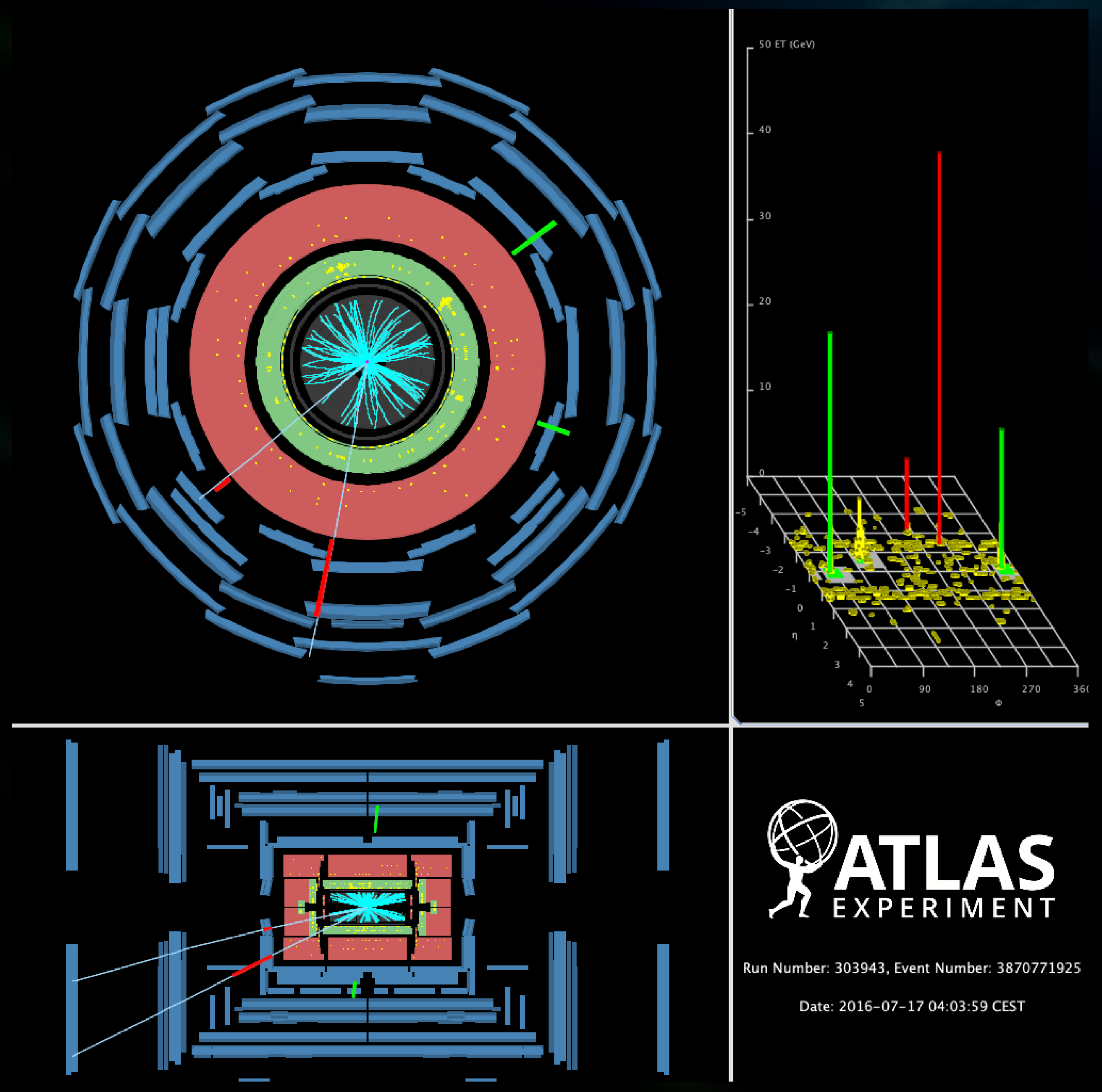
BSM searches with ATLAS



BSM searches with ATLAS



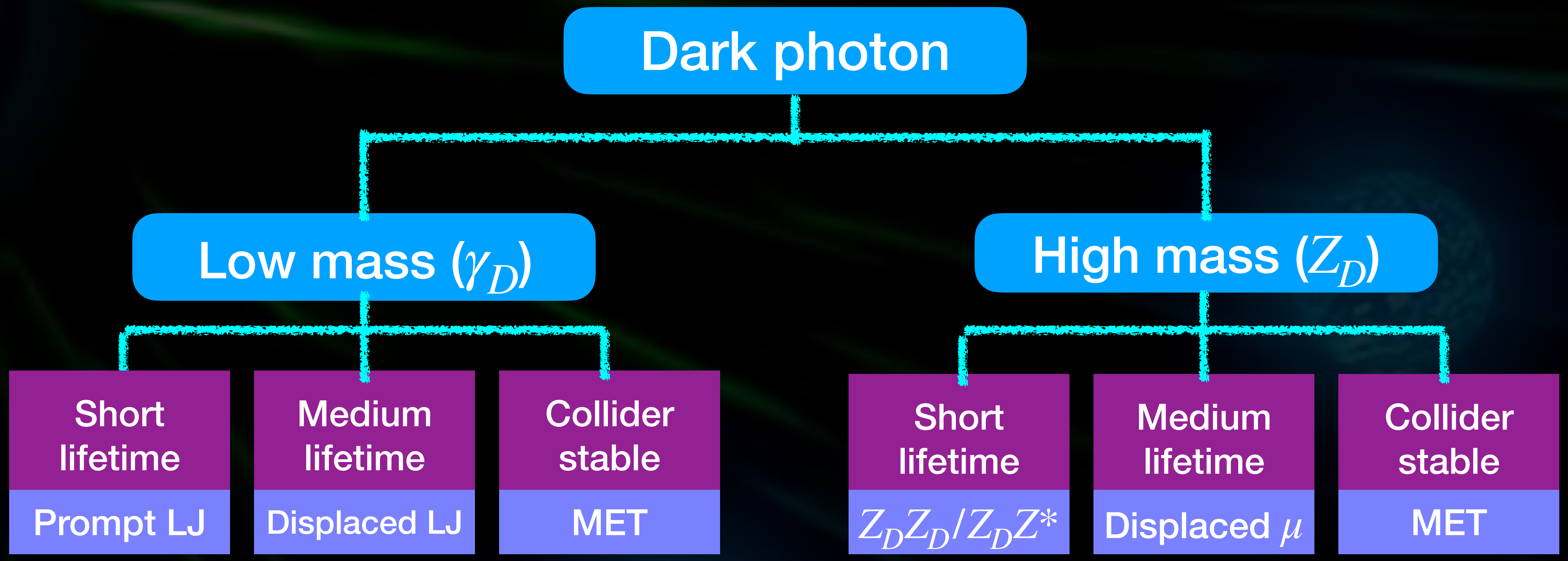




- Dark photon either kinetically mixes with the SM photon or couples to the Higgs sector via some mediator.

A wide range of dark photon masses, from 0 to 200 GeV:

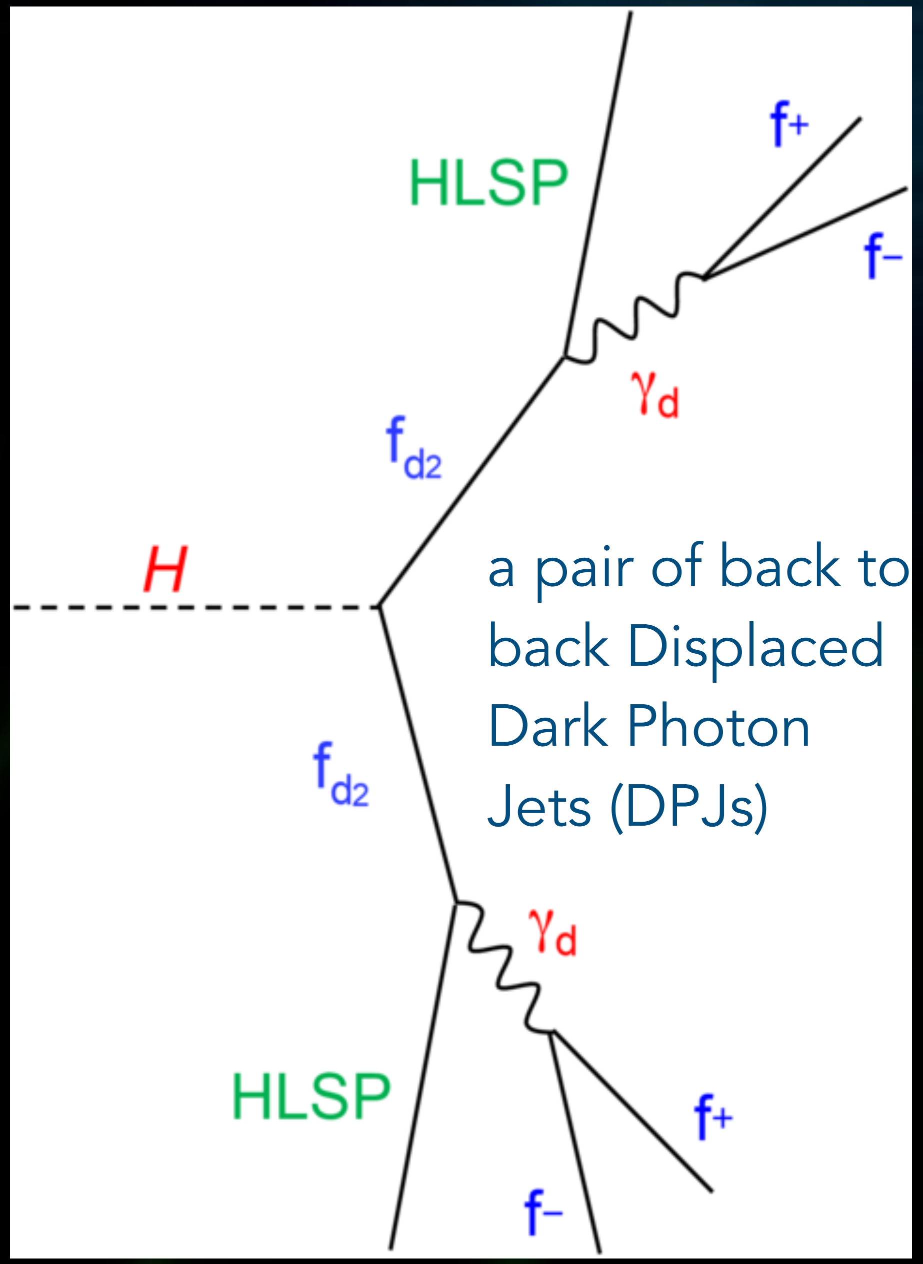
Variety of experimental signatures:



- Three main channels are presented:
  - Light long-lived neutral particles decaying into displaced collimated leptons or light hadrons. ($36.1\ fb^{-1}$) *Eur. Phys. J. C 80 (2020) 450*
  - Higgs boson decay into new spin-0 or spin-1 particles in four-lepton states. (Full LHC Run 2: $139\ fb^{-1}$) **arXiv:2110.13673**
  - Higgs boson decay to a photon and a dark photon (Full LHC Run 2: $139\ fb^{-1}$) *Eur. Phys. J. C 82 (2022) 105*

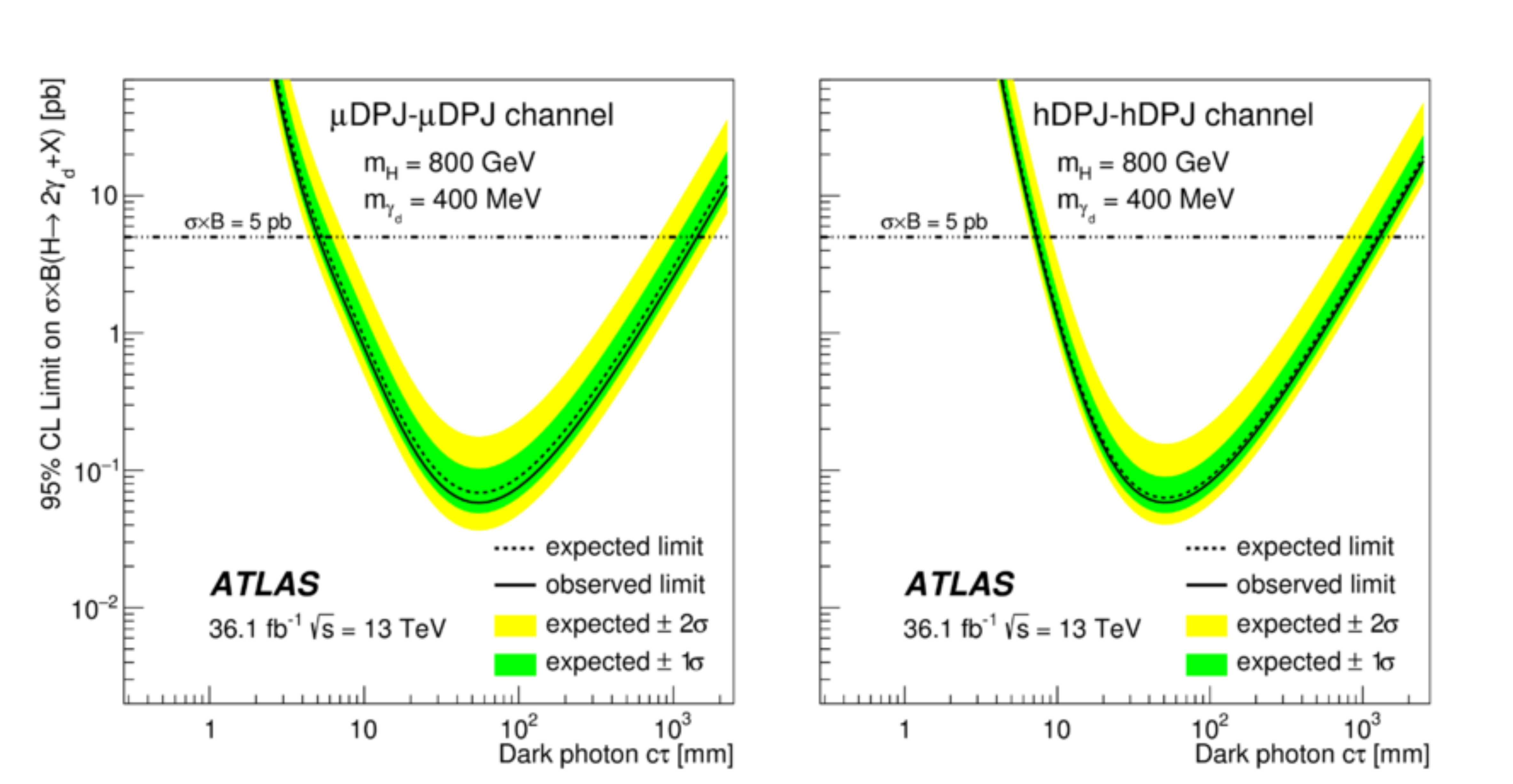
Higgs to long-lived dark photons

DS and SM couple via a vector portal



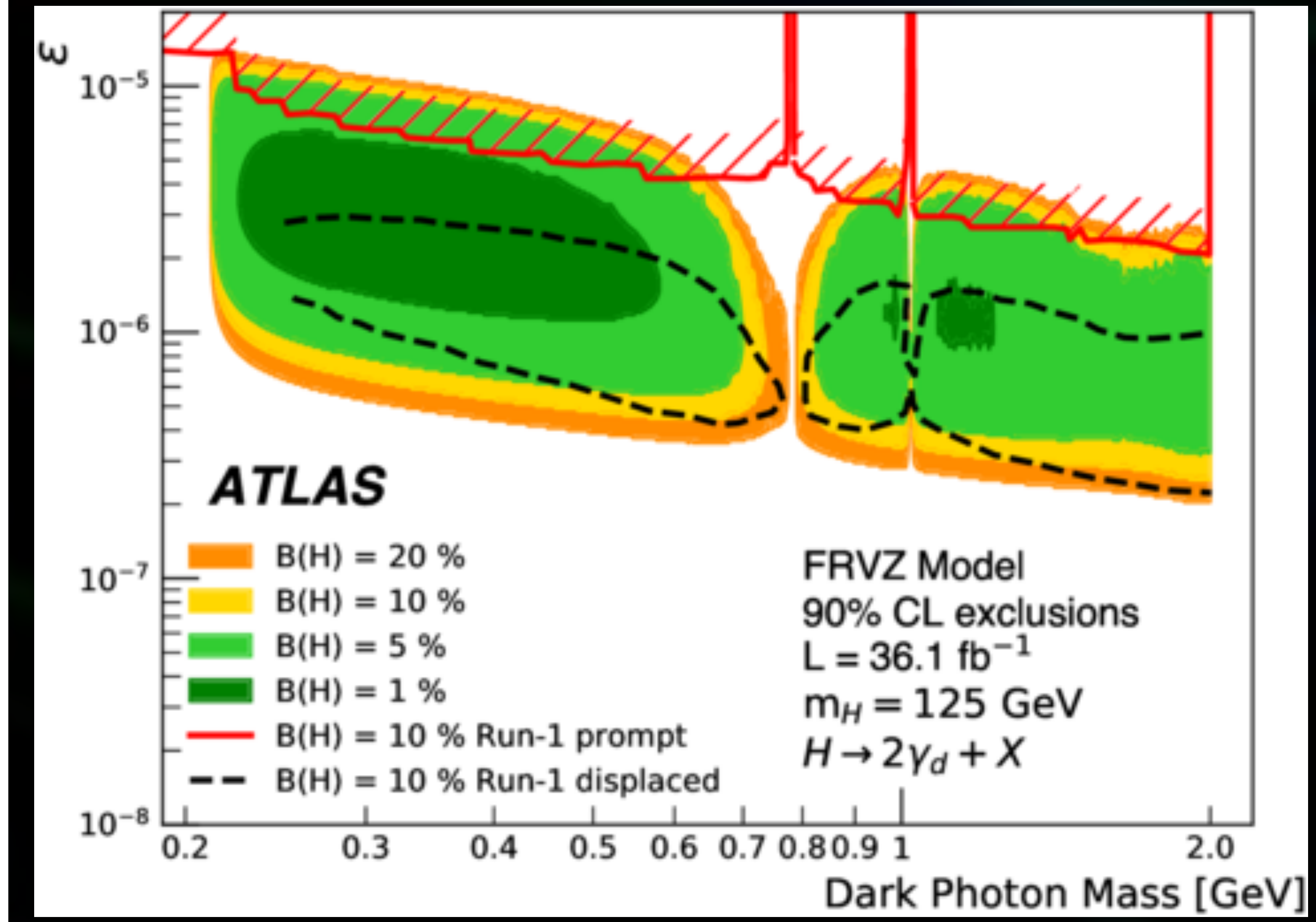
FRVZ model used as benchmarks

adding an extra U(1) symmetry and scalar, introduces two dark fermions, a dark photon and a hidden scalar (Hidden lightest stable particle)



μDPJ–μDPJ
Background: cosmic rays muons

hDPJ–hDPJ
Background: multi-jet production

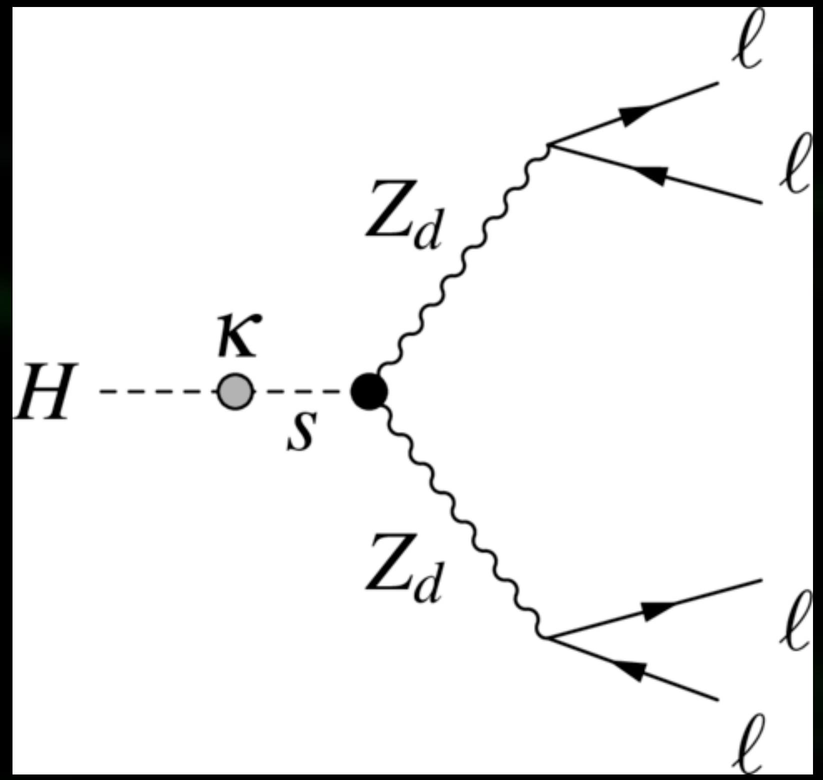


Run 1 and partial Run 2 combined results assuming branching ratios from 1% to 20%

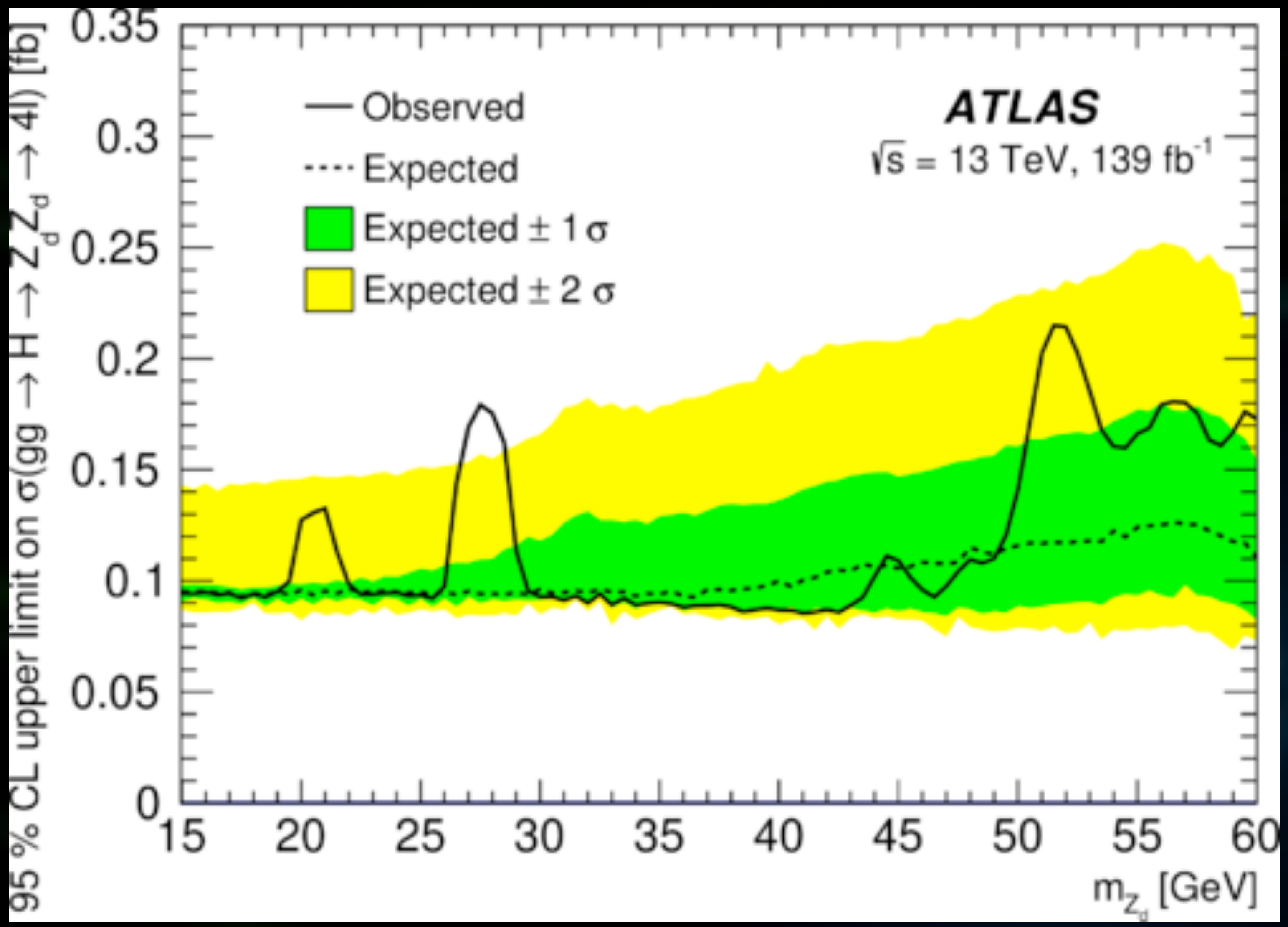
- This search resulted in an exclusion region at 90% CL as a function of the γD mass and of the kinetic mixing parameter ε

Higgs to dark photons in four-lepton final state

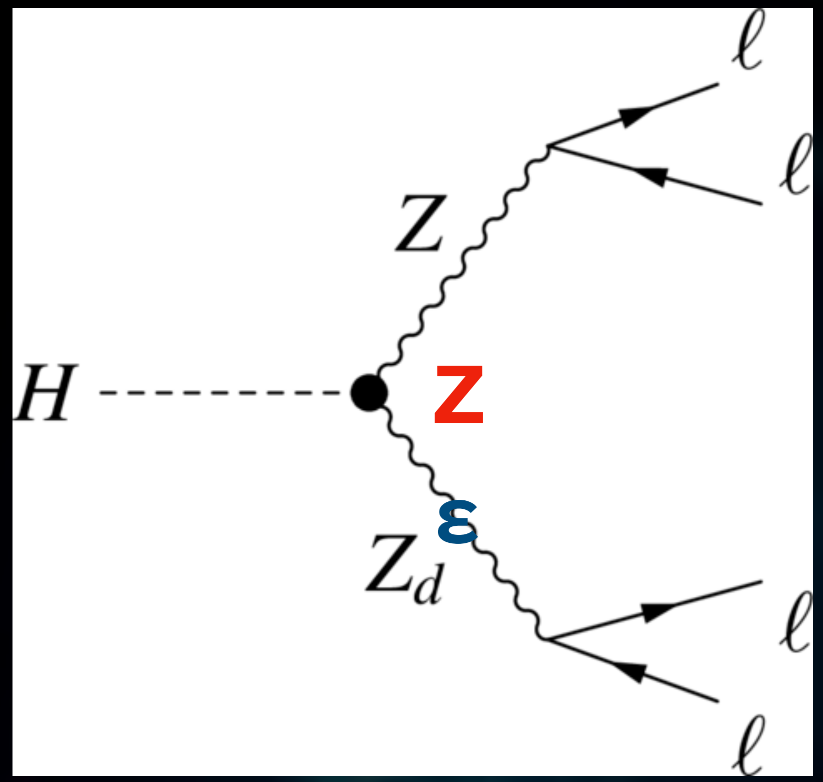
- Search strategy:
  - Look for higgs production of dark photons
    - photon portal: Z mixing with Z_D
    - higgs portal: mixing of SM H with dark H (S) via mixing parameter κ
  - 4 lepton signature, require (m_{4L} consistent with 125 GeV)
    - photon portal: require m_{12} consistent with Z, look for di-lepton resonance above H—> ZZ* background
    - higgs portal: require consistent mass for two di-lepton pairs



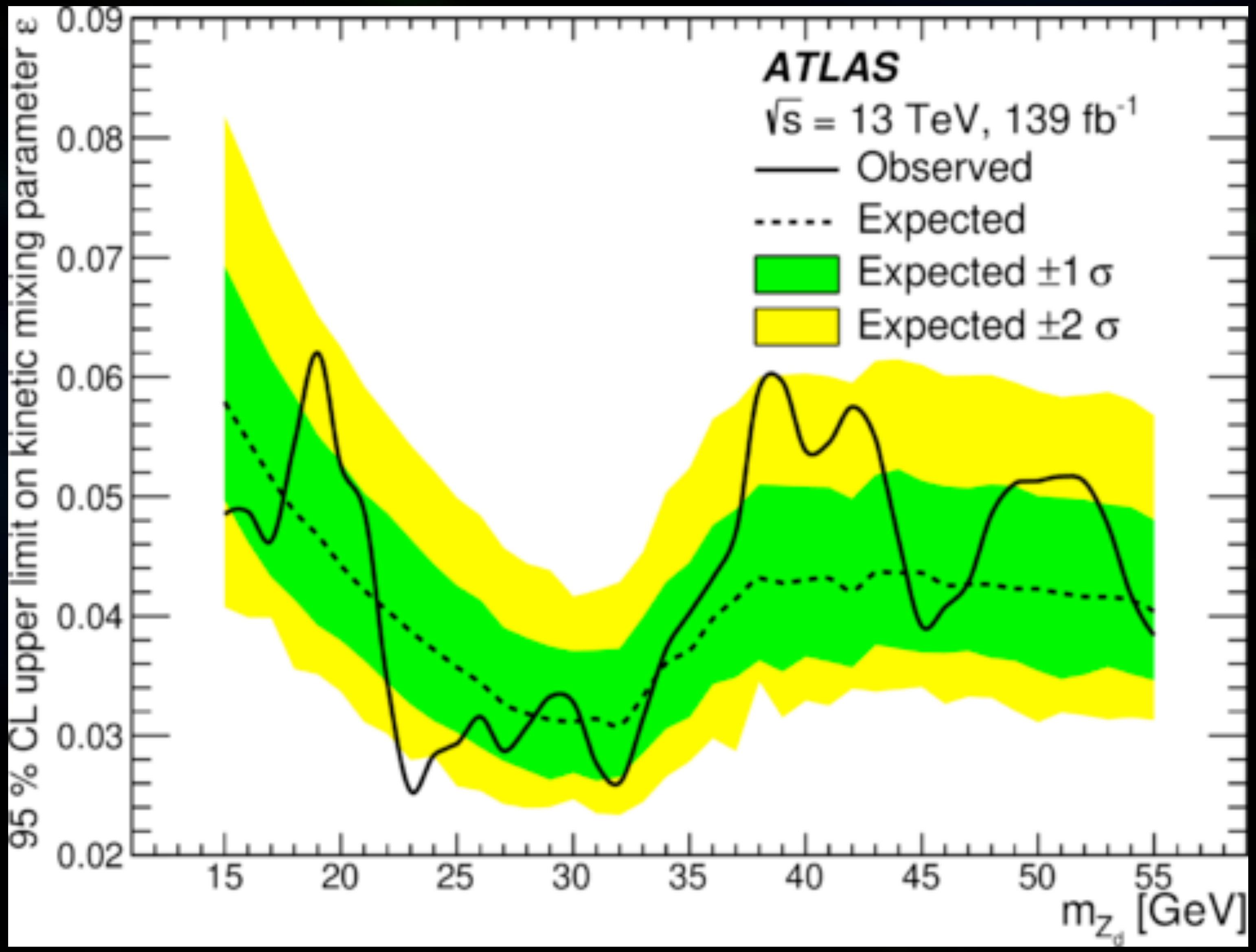
Higgs portal through k (HM, LM)



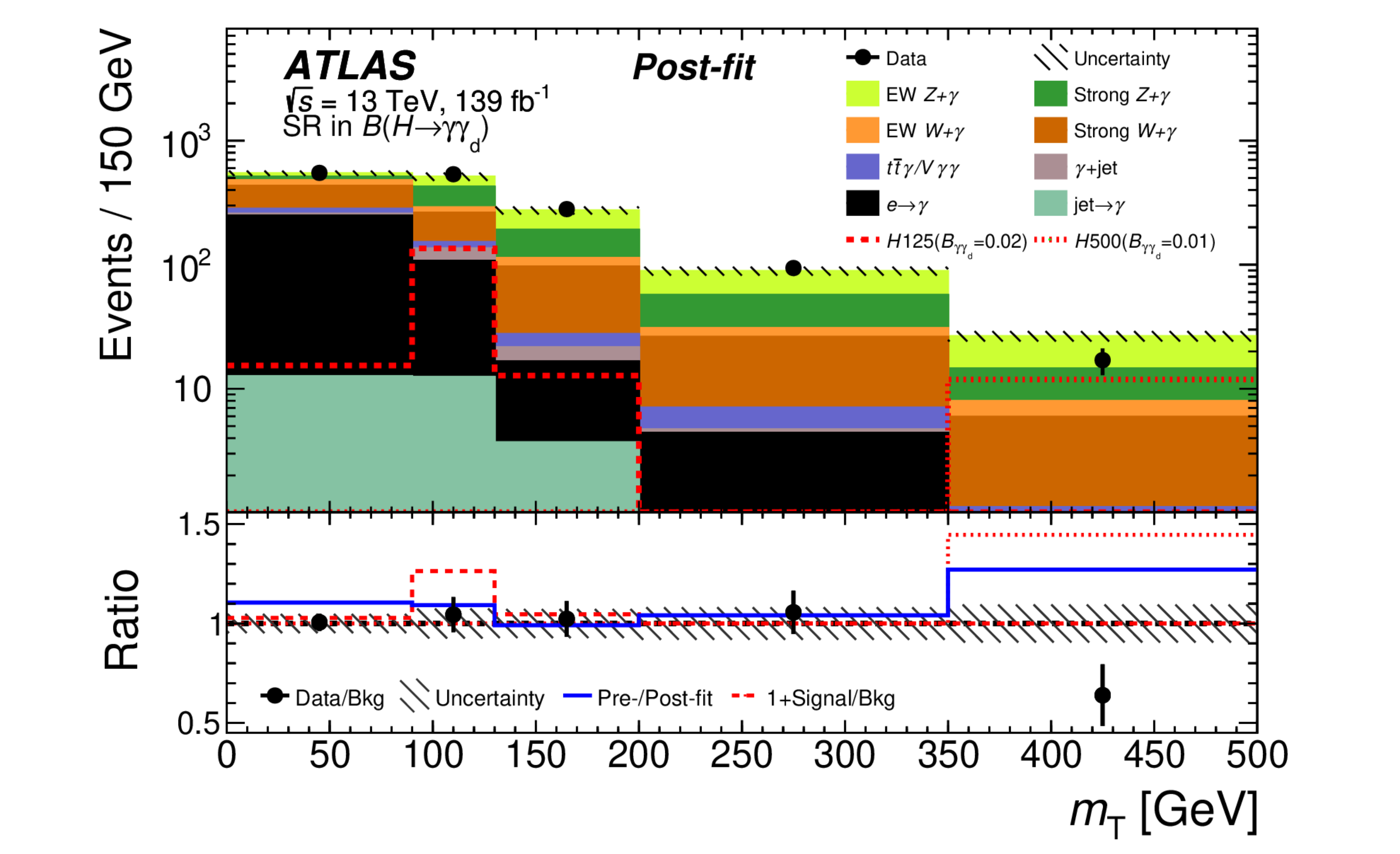
- Results presented in terms of BR of Higgs to new sates, assuming SM production of H

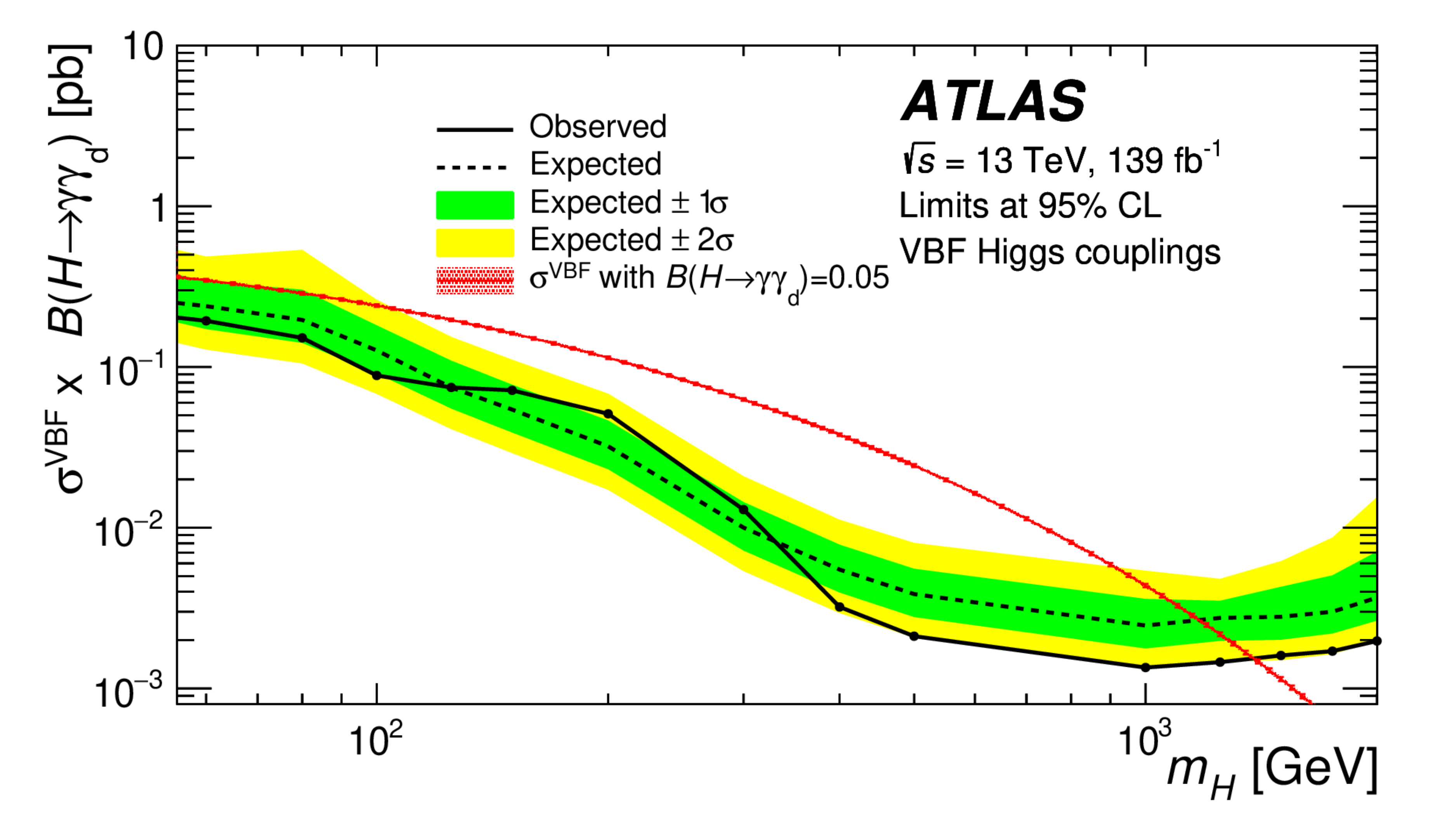


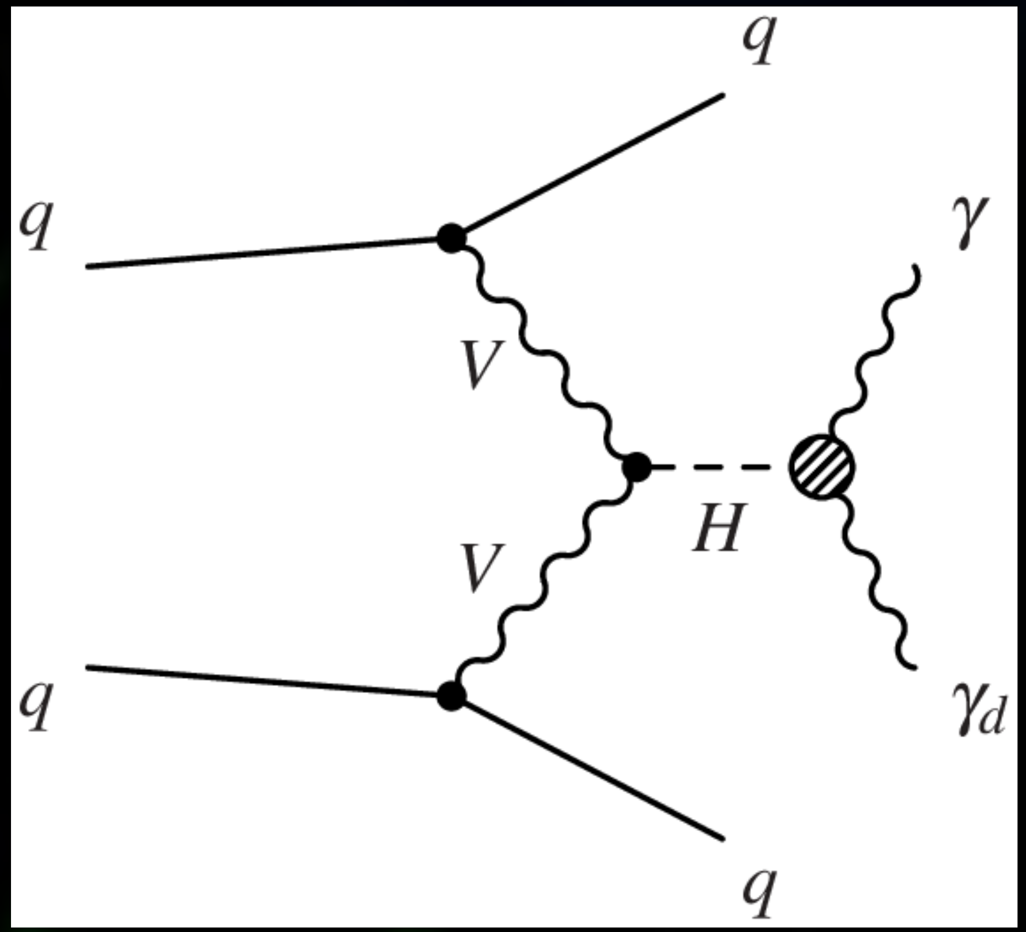
hypercharge portal through ϵ



Higgs to a photon and a dark photon | VBF mode



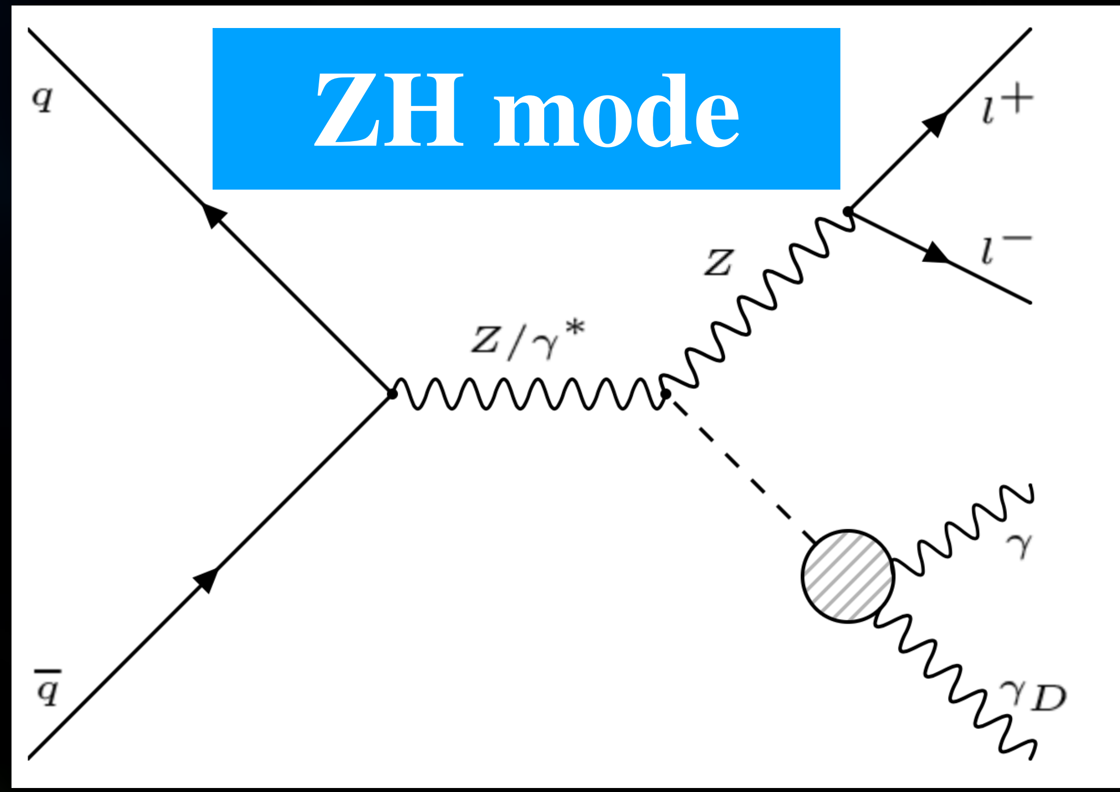




- **An observed (expected) 95% CL upper limit on the branching ratio for this decay is set at 0.018 ($0.017_{+0.007-0.005}$), assuming the Standard Model production cross-section for a 125 GeV Higgs boson.**

- The most powerful discriminating variable:

$$m_T(\gamma, E_T^{miss}) = \sqrt{2\, p_T\, E_T^{miss}\, [1 - \cos(\phi_\gamma - \phi_{E_T^{miss}})]}$$



New results expected in 2022

- Both astrophysical and terrestrial searches needed to uncover complete dark matter model.
- No significant excess of events above SM background prediction with the current LHC Run 2 data.
- Upper limits at 95% CL are set on model-independent fiducial cross-sections and on the Higgs boson decay branching ratios to vector and pseudoscalar bosons.
- Limits on the production cross-section times branching fraction as a function of the proper decay length of γ_D

Thank you