Dark matter searches with displaced dimuons at the CMS experiment

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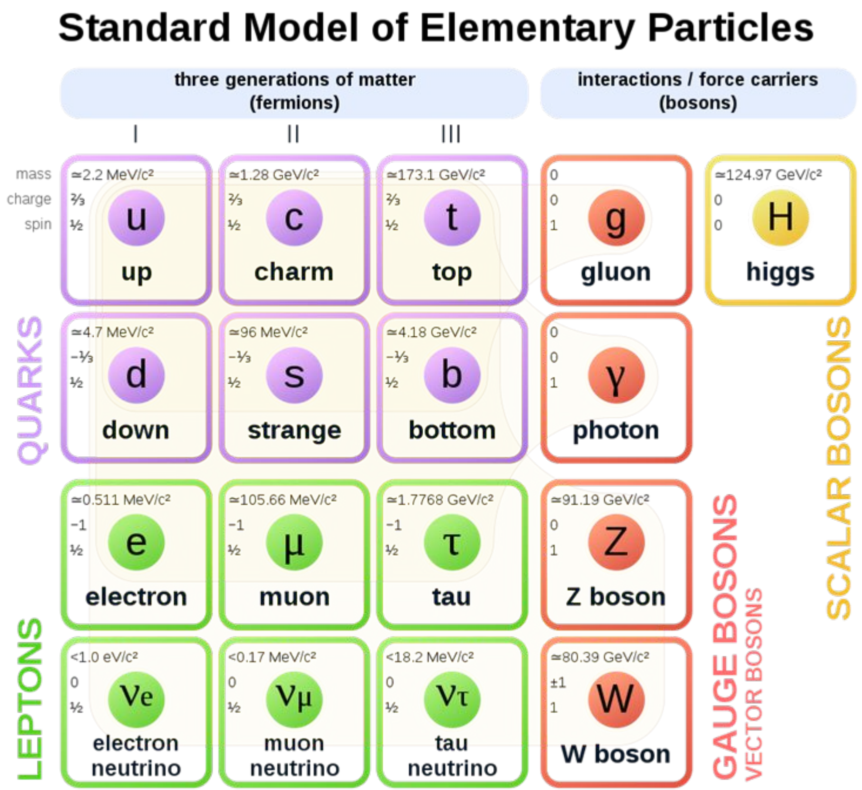
The Standard Model

- The theory that describes the interactions between elementary particles and fundamental forces.
- The SM does not offer an explanation for :
    - Matter and antimatter asymmetry
    - Dark energy
    - **Dark matter**

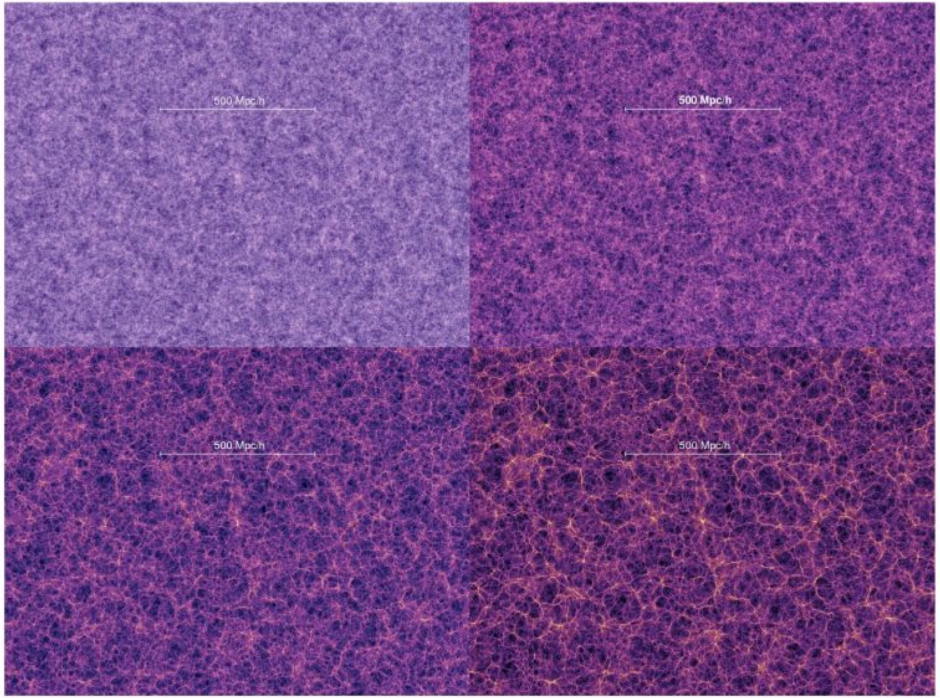
  among others.

- Some Theories Beyond the SM (BSM) predict the existence of dark matter particles



Dark Matter

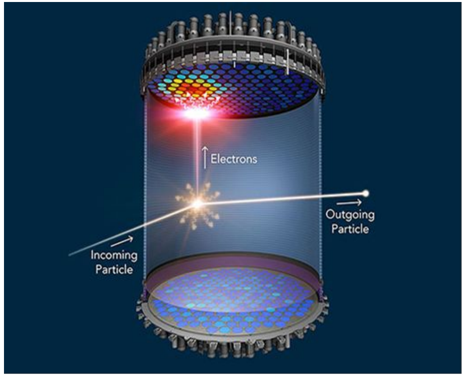
- Dark matter (DM) exists and makes up about 26% of the universe's mass-energy.
- Evidence comes from its gravitational effects on large scales.
- Some BSM theories can shed some light on the composition and behaviour of DM

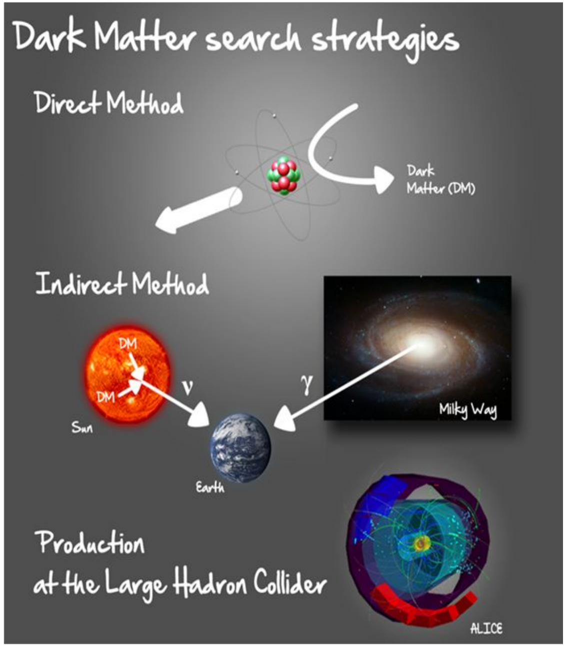


Dark matter distribution in the Millennium simulation

The search for Dark matter

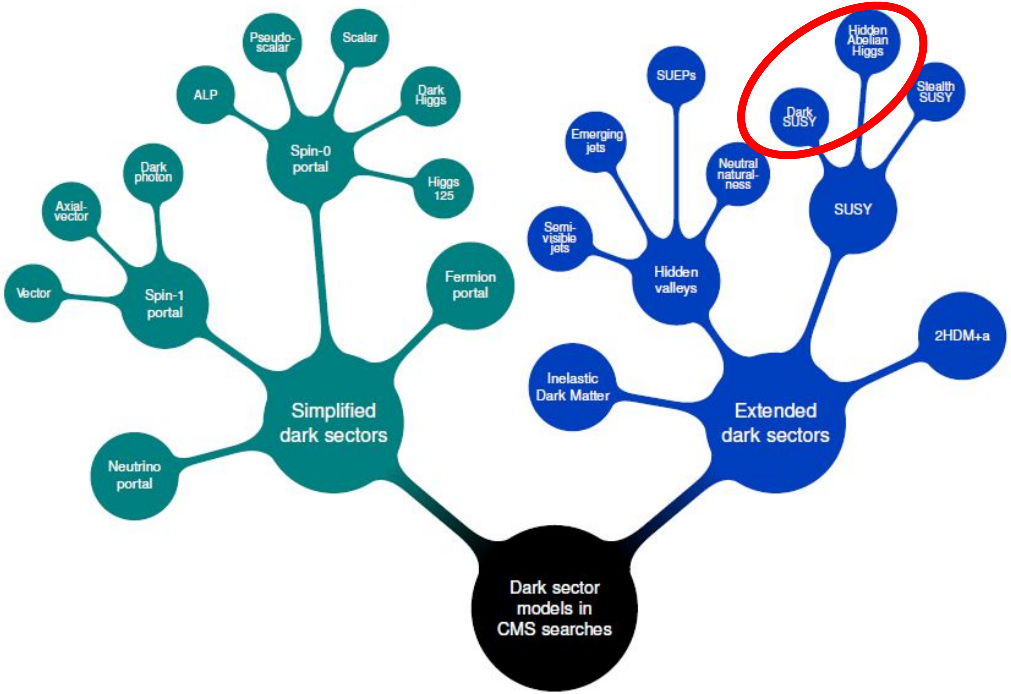
- Direct detection
  - Experiments: LUX-ZEPLIN, XENON, PandaX and PADME
- Indirect detection
  - Experiments: AMS, EGRET, Fermi-LAT and IceCube.
- Search for dark matter in particle collider
  - The CMS experiment at The LHC
  - BSM model predict a Dark sector (DS) that can be probed with proton-proton collision.





Dark Sector Models at CMS

- DS models feature a **"portal"** connecting SM particles to DM.
- The CMS search strategy divides models into:
  - Simplified dark sectors
    - Involve a single mediator particle and DM.
  - **Extended dark sectors**
    - More complex DM dynamics.



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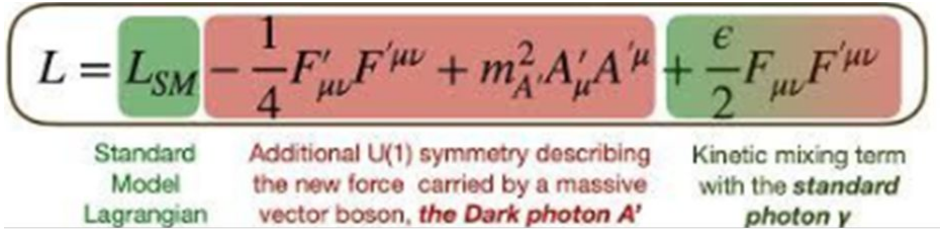
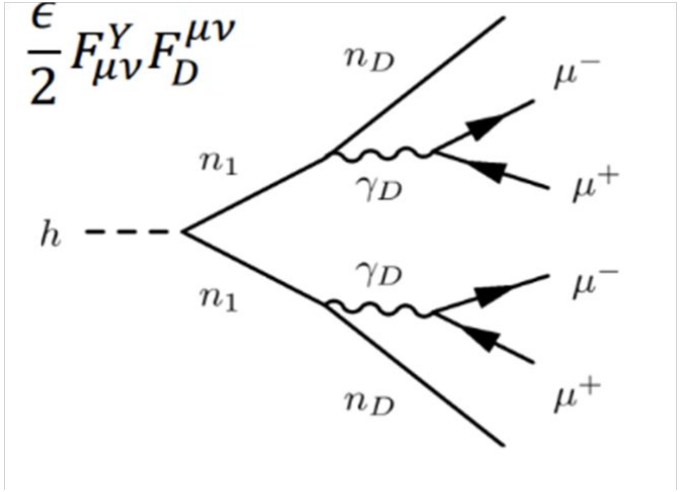
Dark-SUSY

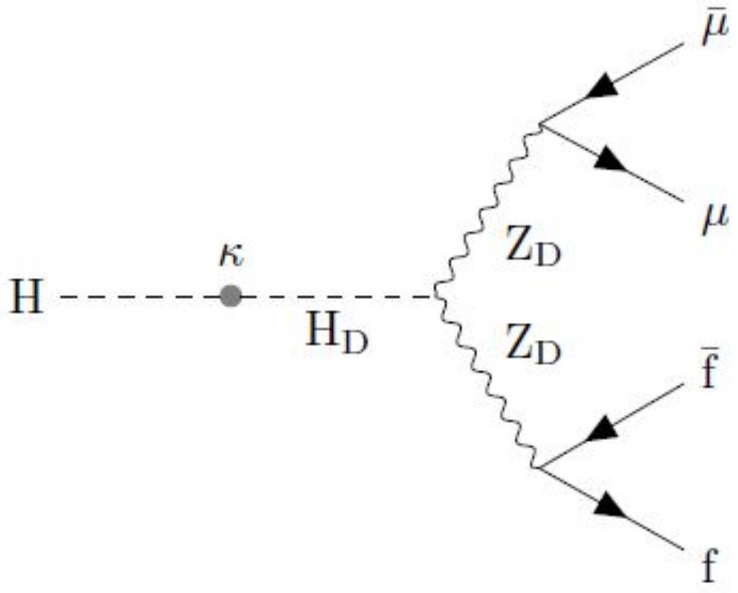
- Exotic decay of the Higgs characterized by the production of SUSY and DS particles
- Dark photon produced by the decay of the neutralino
- The **dark photon** couples to the SM photon through a kinetic mixing term (ε)
- ε is connected to the lifetime of the dark photon
- Final state characterized by the production of four muons





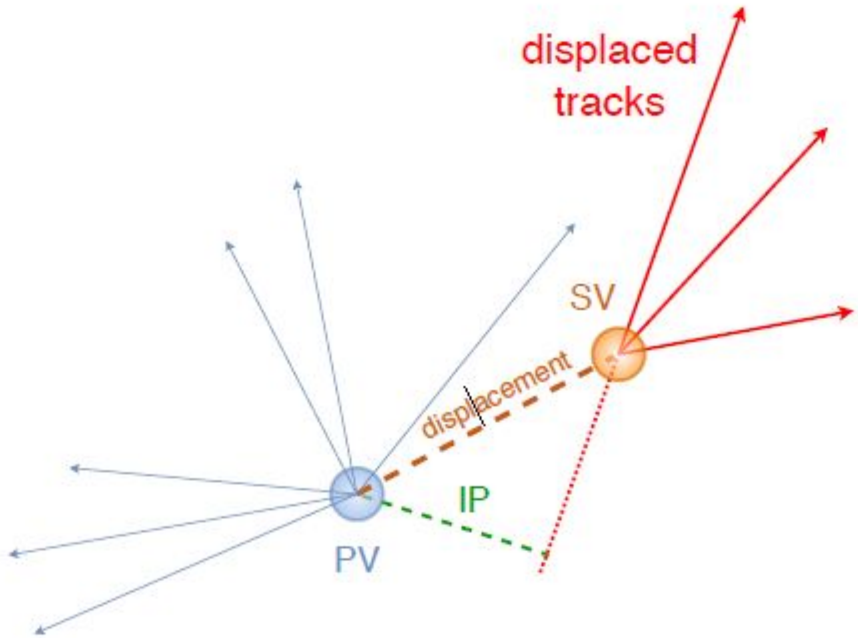
Hidden Abelian Higgs model

- HAHM extends the Standard Model (SM) with an additional U(1)χ gauge group.
- The new gauge sector couples to the SM via kinetic mixing with the hypercharge boson.
- There is mixing between the SM Higgs and a hidden (dark) Higgs via a parameter κ.
- This leads to production of **long-lived** dark photons, which decay to SM particles via the vector portal.



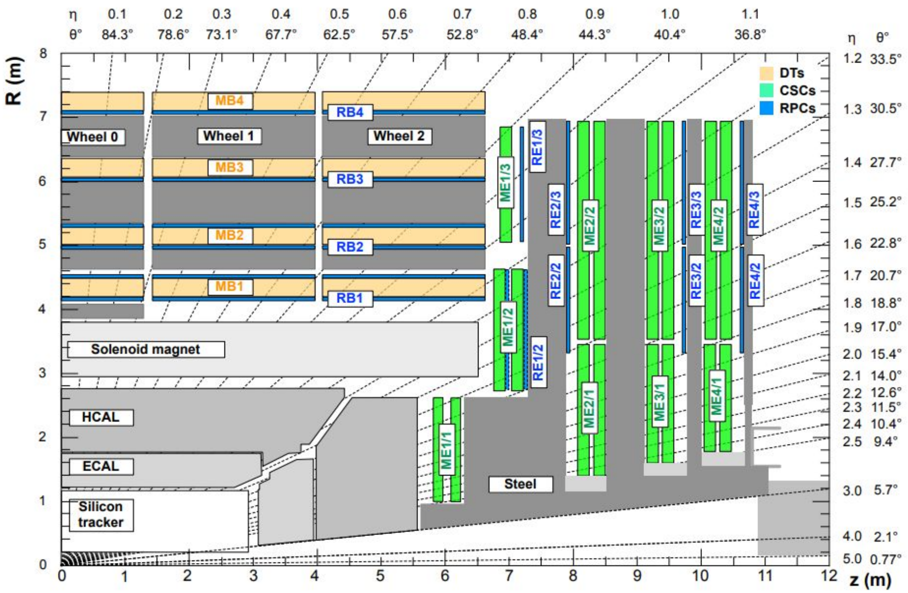
Long Lived particles

- CMS was designed to identify and reconstruct prompt signals
- The dark photon could belong to the category of long-lived particles (LLP)
- LLP can decay away from the primary vertex (PV), creating a secondary vertex.
- These decays result in charged-particle tracks with large impact parameters (IP).



The CMS Detector

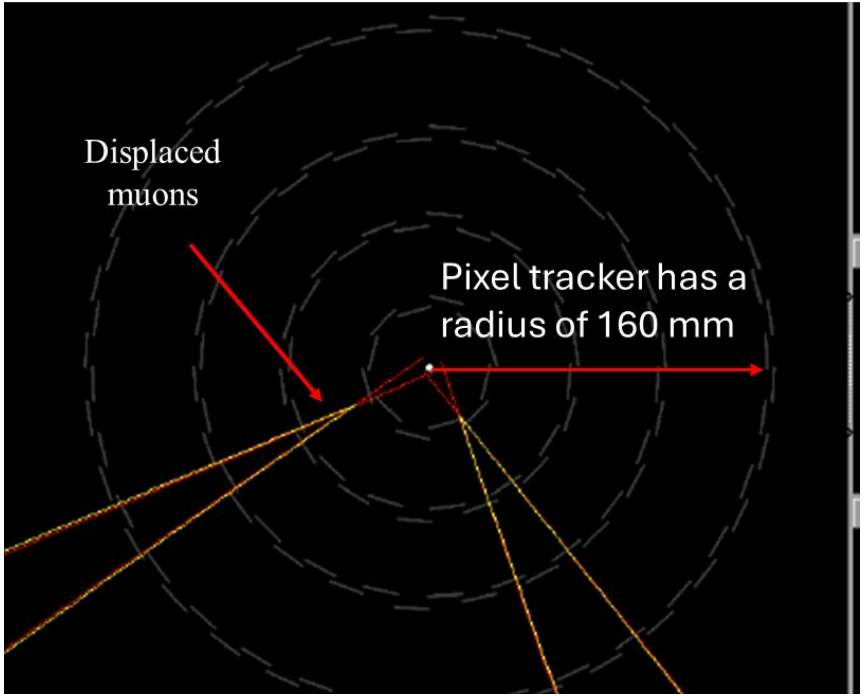
- The CMS detector is a general purpose detector highly sensitive to muons signals.
- A robust Muon systems make use of 3 different types of detector technologies
- Several algorithms are dedicated to muon identification and reconstructions.
    - Tracker muon (TMS)
    - Stand-alone muons (STA)
    - Global Muons
- Particle Flow algorithm



Candidate signal event

- A candidate for signal event is shown in the image (2018 data)
- The event is characterized by the production of two LLPs each one decaying to a pair of muons
- This event could correspond to the decay of SM particles to muons (that decayed near by the first layer of the pixel tracker)

Candidate signal event



Analysis strategy

Dark-SUSY model

- Events must contain at least 4 PF muons
- At least 2 high pT muons
- Dimuon pairing:
  - Opposite charge
  - Invariant dimuon mass <9 GeV
  - exactly two dimuon per event
  - Consistent dimuon mass
- Main Background sources:
  - QCD processes: $b\bar{b}$, J/ψ
  - Electroweak processes: negligible at masses <8.5 GeV

HAHM model

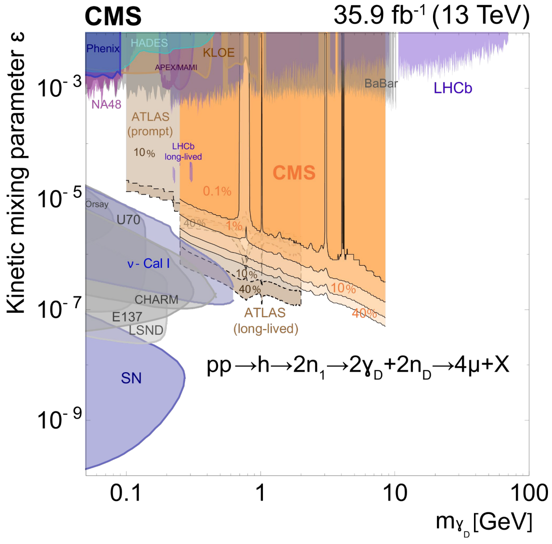
Both analysis search for events with final states that contain 2μ+2f.

- Scouting analysis
  - Use of a dedicated dimuon trigger
  - High data rate allows study of low-mass dimuons with displacement
  - The main sources of Background include: cosmic rays, pileup, QCD processes and prompt signals.
- LLP Analysis
  - The analysis focuses on exploring a wide lifetime range from μm to several meters.
  - The main sources of Background are: QCD and Electroweak processes, cosmic rays.

Result interpretation

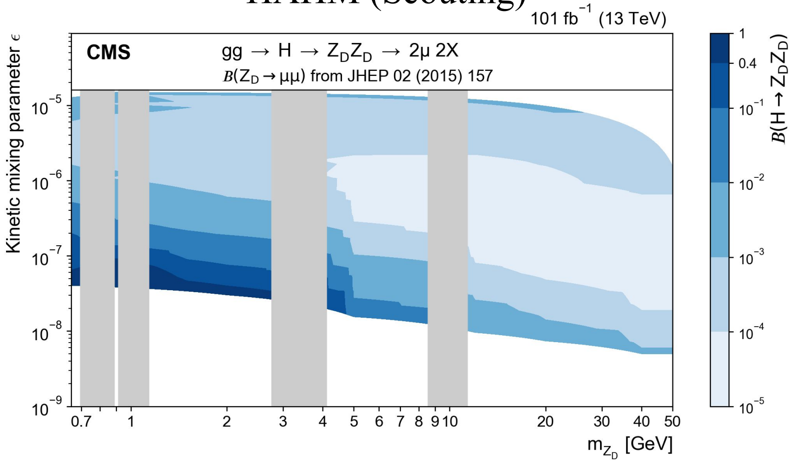
The results are interpreted in the context of each model and new limits are set on sensitive parameter of the models: the mass of the new dark boson ($m_{\gamma D}/m_{ZD}$) and the kinetic mixing parameter (ε)

Dark-SUSY



Physics Letters B, Volume 796, Pages 131-154,

HAHM (Scouting)



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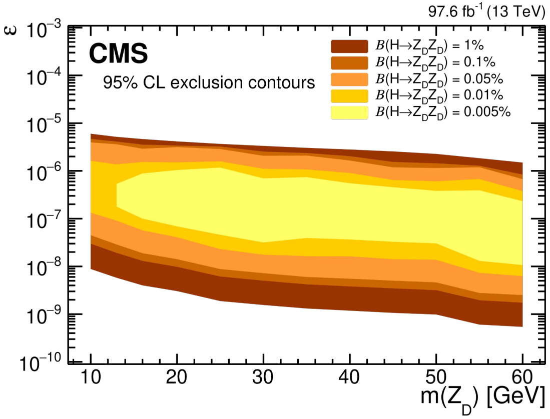
HAHM (LLP)



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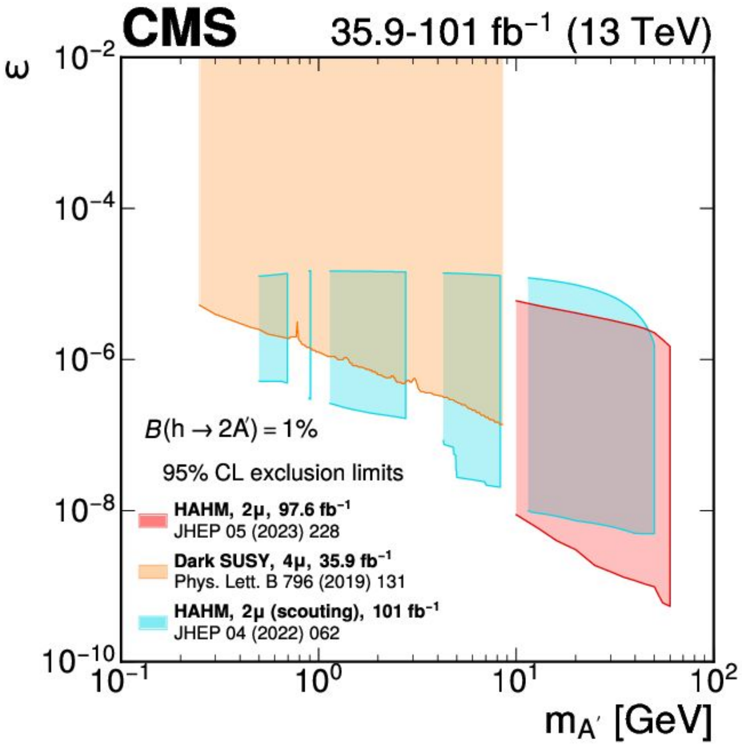
Result interpretation

- The plot shows the observed 95% Confidence level exclusion contours for all 3 previous mentioned nanalysis .
- For all 3 searches, the scenario where B(h→2A)=1% is assumed.



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Conclusions

- The results from previous searches for a new light boson at the CMS detectors was presented.
- Results from the three analysis are consistent with SM predictions.
- The results are interpreted in the context of extended dark sector models: the Dark-SUSY and HAHM models.
- Limits where set on the sensitive parameters of each model.
- Recent upgrades to the CMS detectors hardware and reconstruction algorithms, could let us prove new mass and lifetime ranges of the dark photon.