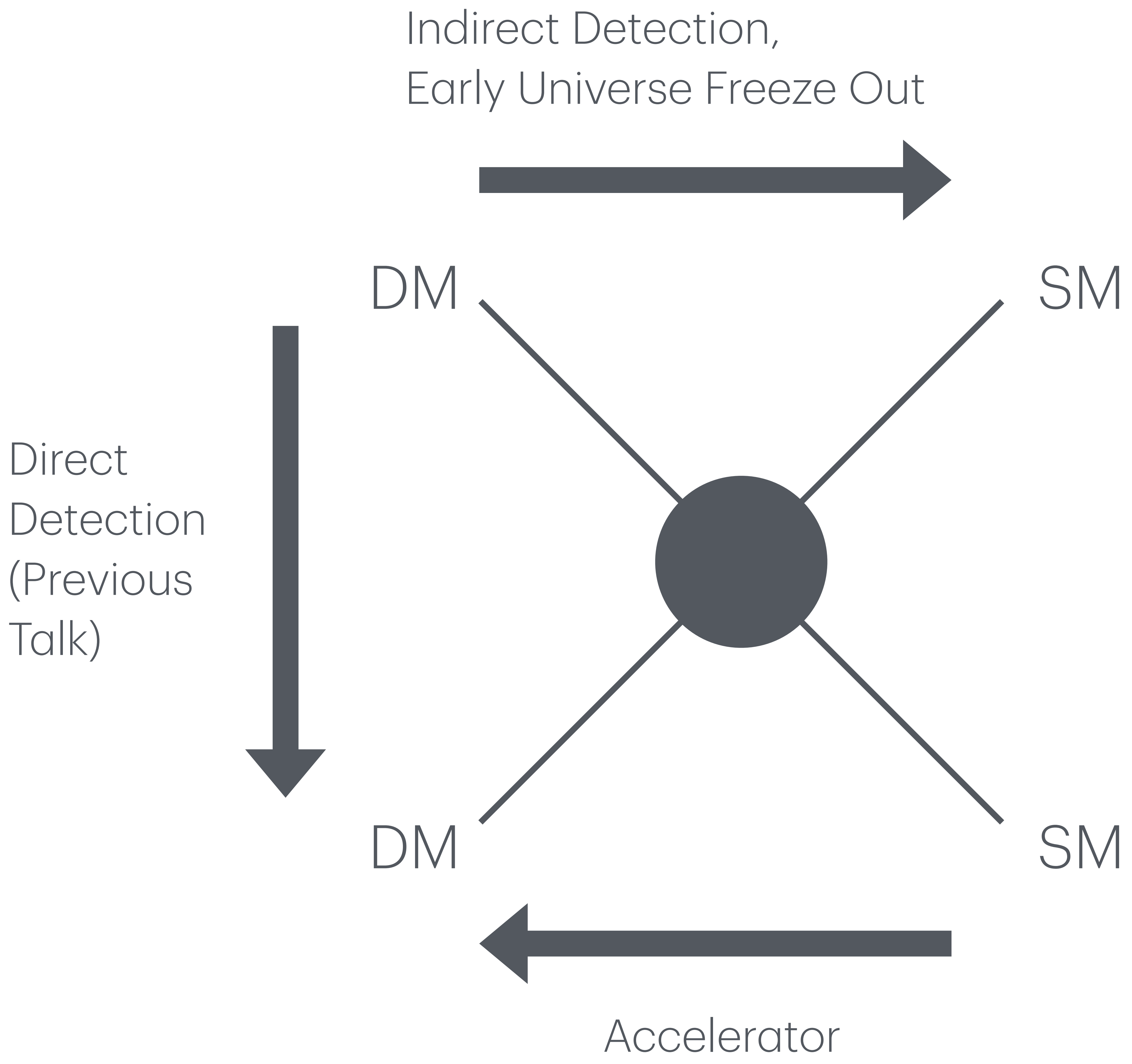
Non-direct Detection Dark Matter

Accelerators and Indirect Detection

Elliot Lipeles, University of Pennsylvania, DPF/Pheno 2024

Outline



A Little Bit about Models

- WIMPs are alive and well (WIMP=Weakly interacting massive particle)
- Beyond WIMPS

Minimal Dark Matter Targets

Simplified Models

Not so simplified model example

Disclaimer: I've sampled experiments/results to represent the range of methods based on public documents. I am not an expert on each experiment and I apologize in advance for errors/over simplifications.

WIMPs are Alive and Well

≈ Simplest Model

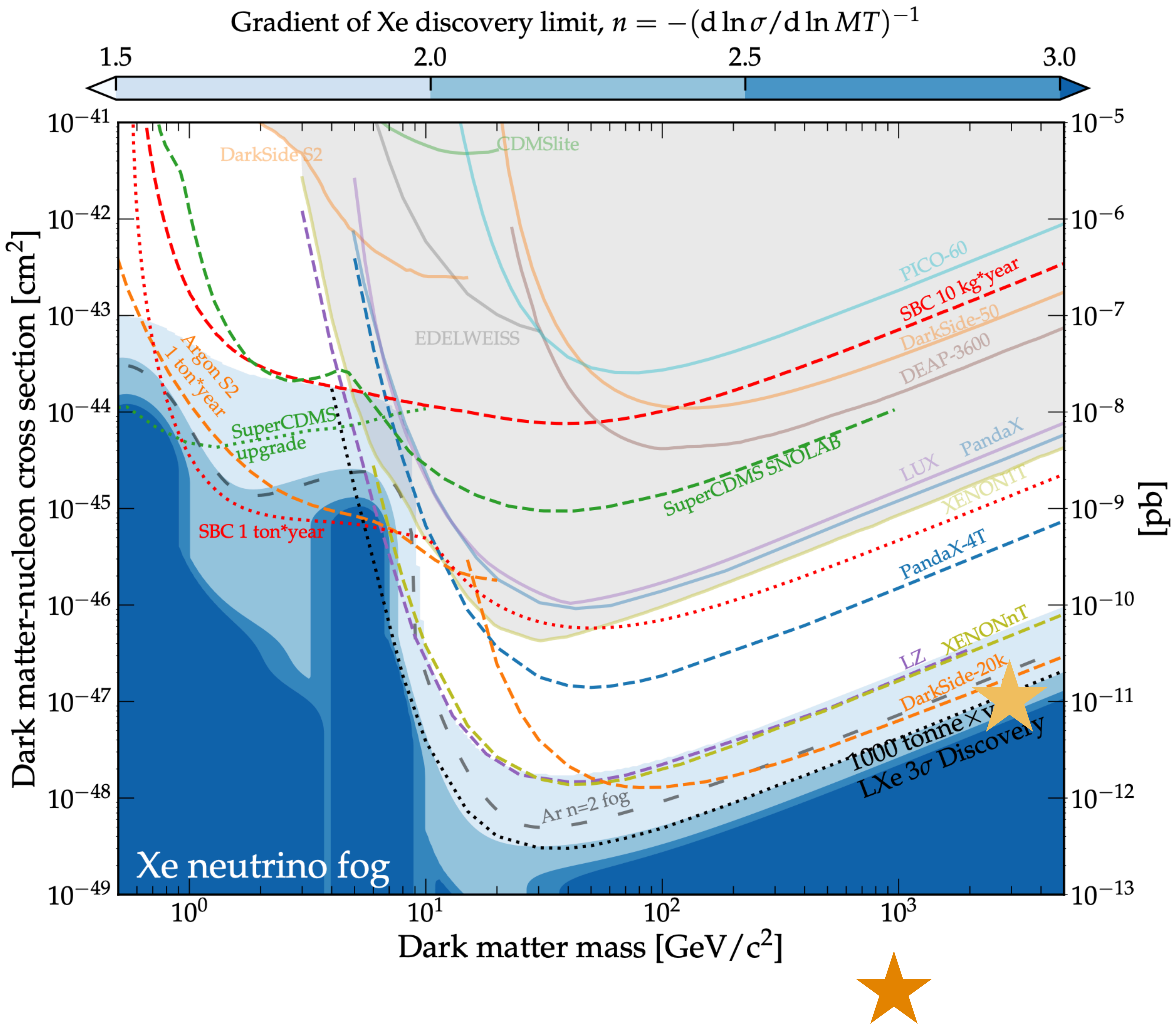
(=Minimal Dark Matter Nucl.Phys.B 753 (2006) 178)

Add a new electroweak multiplet and couple to SM with by weak interactions

- This is not quite the simplest models because it needs mass generation other than the Higgs

For each representation the mass is then fixed by requiring saturation of the DM relic abundance

$SU(2)_L$ Multiplet	Mass	SUSY analogy	Cross-sections
Doublet	1.1 TeV	Higgsino	★
Triplet	2.8 TeV	Wino	★



DM Cross-sections from Phys.Rev.D 108 (2023) 11, 116023

Beyond WIMPs

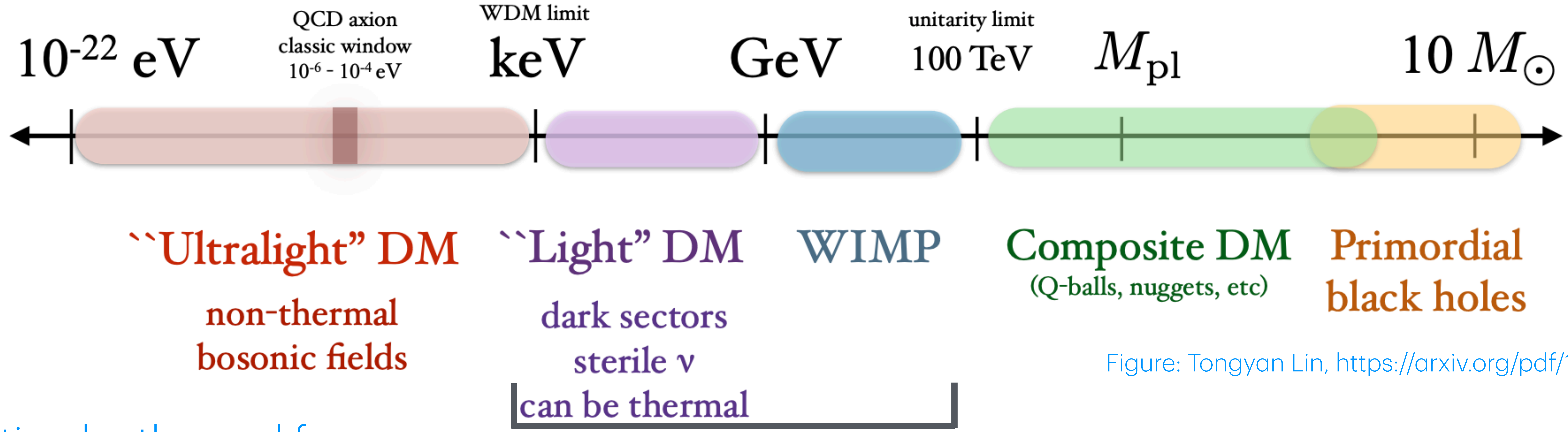


Figure: Tongyan Lin, https://arxiv.org/pdf/1904.07915

Production by thermal freeze-out gives

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4} \,,$$

WIMP miracle

g_X ~ weak → m_X ~ weak

Accelerators and Indirect are mostly focussed on this range

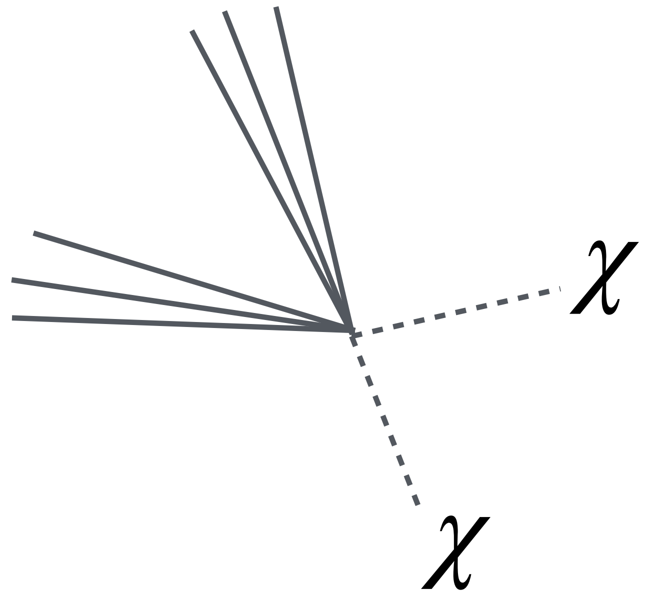
WIMP-less Miracle = still have thermal production without g_X ~ weak → bigger mass range

(Phys.Rev.Lett. 101 (2008) 231301)

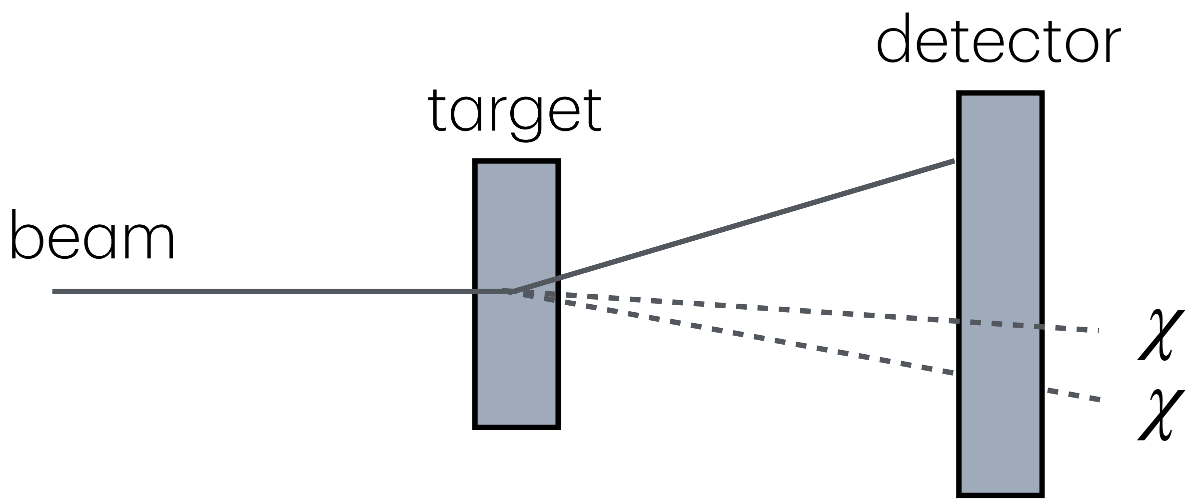
Accelerator/Collider Methods

Missing Energy/Momentum

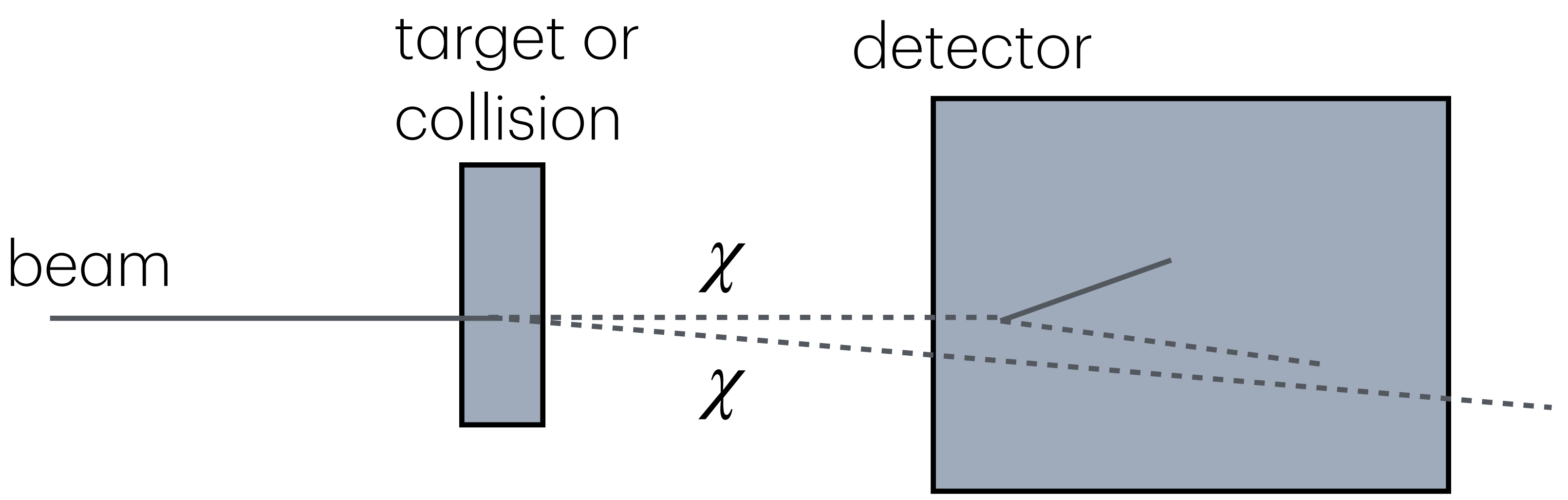
— Collider: Monojets, Mono-X, Higgs to Invisible



— Fixed Target: Scattering



DM production + Scattering



Mediator Searches

if this can happen...

then this can happen...

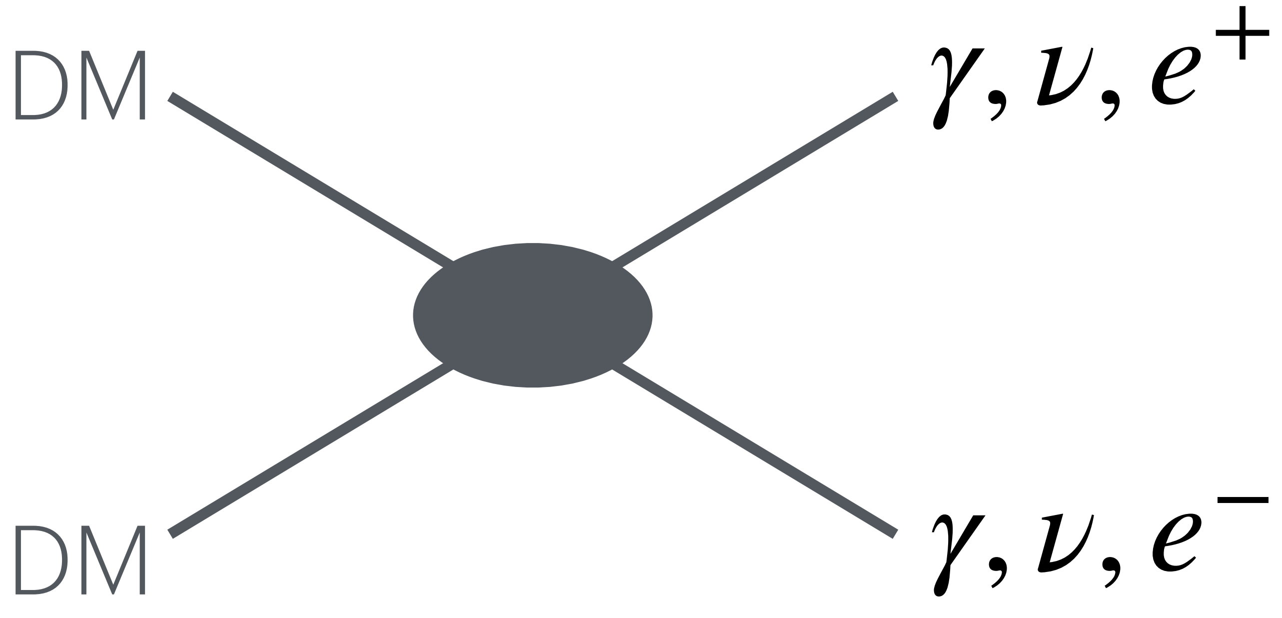
— Simplified Models

— Dark Photons

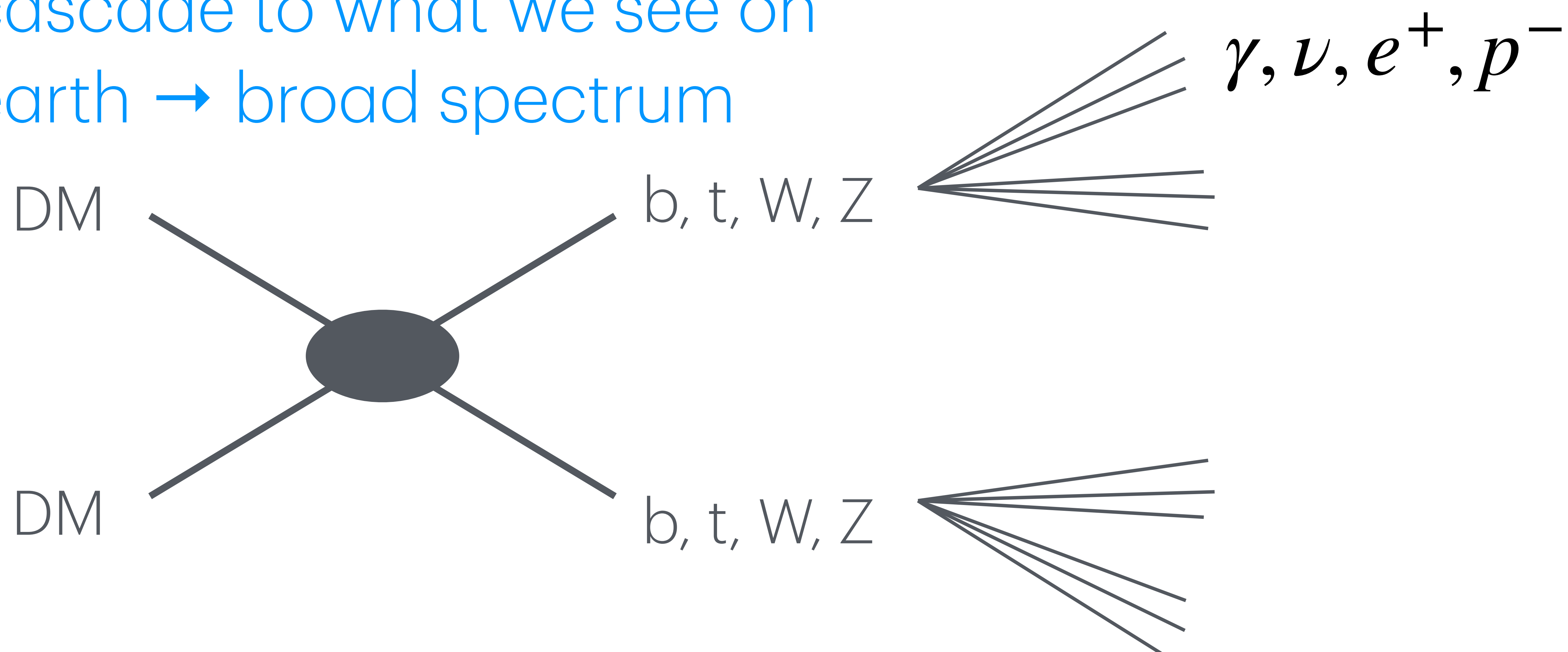
Indirect Detection

Dark Matter in galactic core or near-by dwarf galaxy annihilates to X (or in earth or in Sun)

Annihilates to particles we see on earth → lines

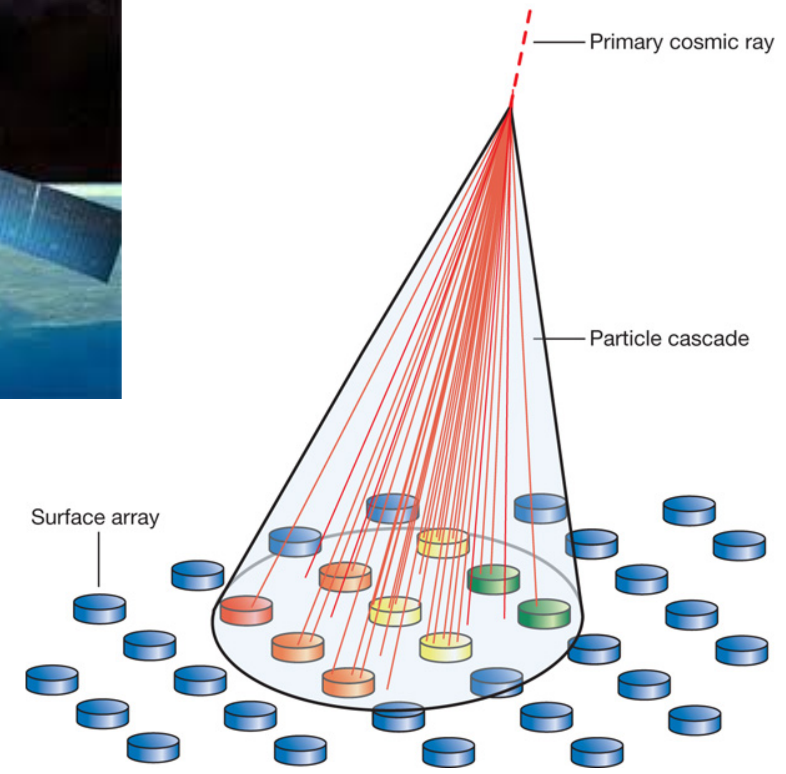


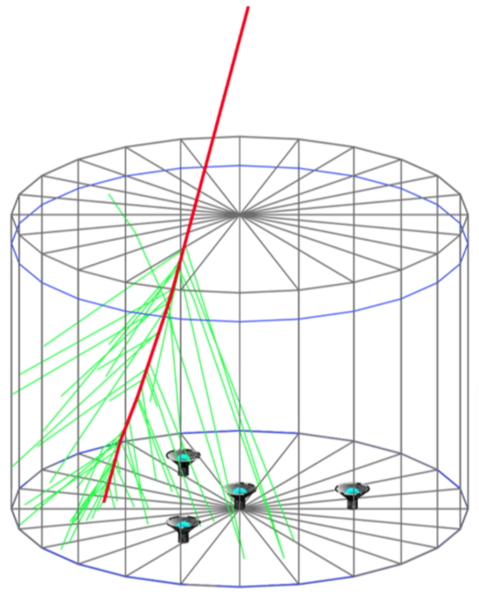
Annihilates to particles that cascade to what we see on earth → broad spectrum

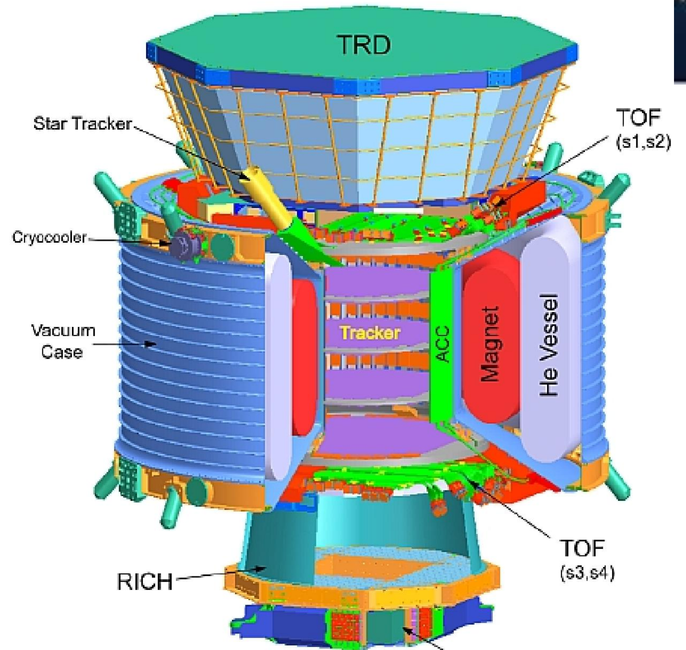


Detection

- Gamma rays:
  - Space-based
  - Water Cherenkov
  - Air Shower Cherenkov
- Neutrinos:
  - Ice: light and radio
  - Underground (water, scintillator)
- Antimatter cosmic rays:
  - Balloon
  - Space-station







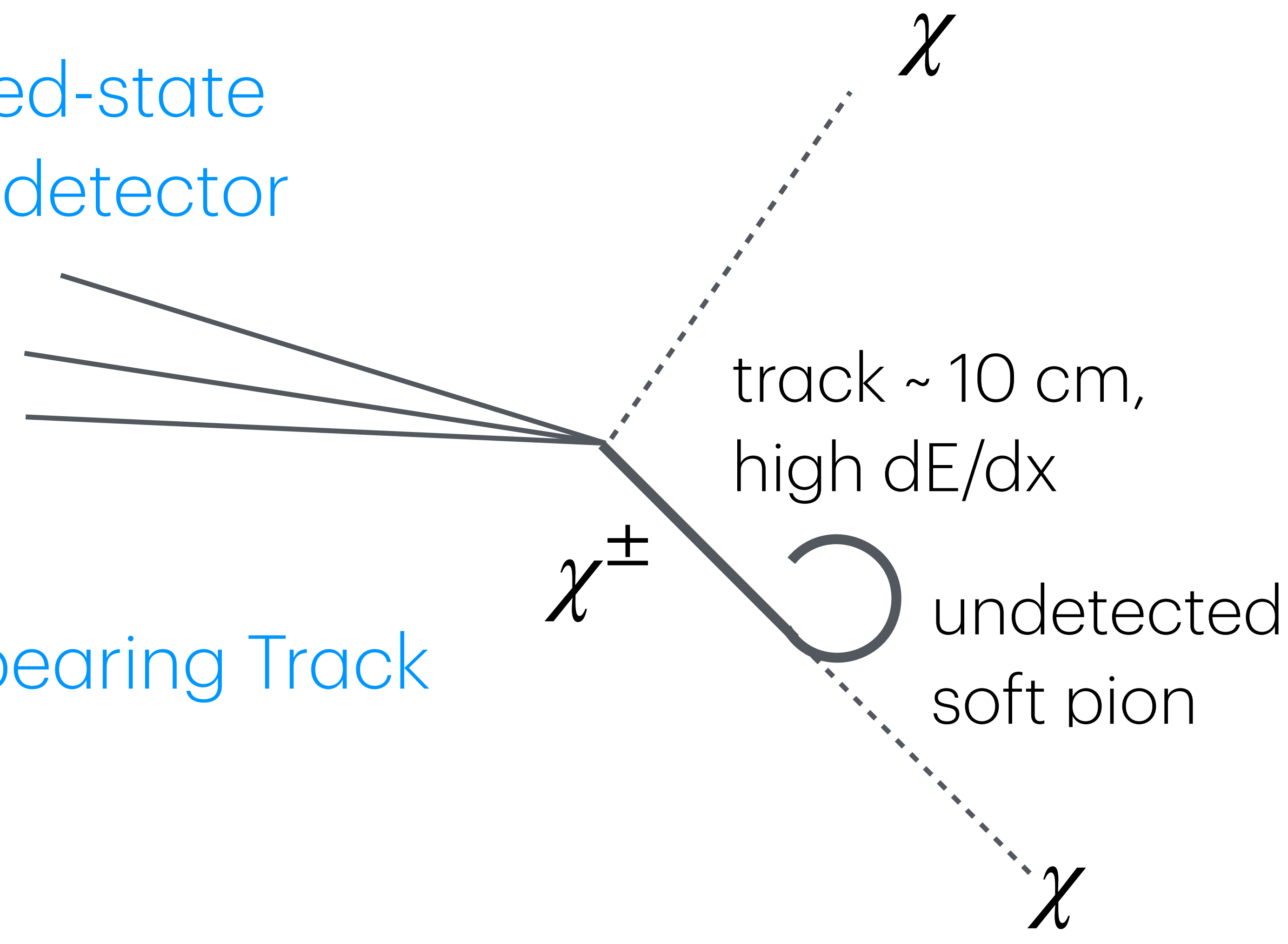
Minimal Dark Matter

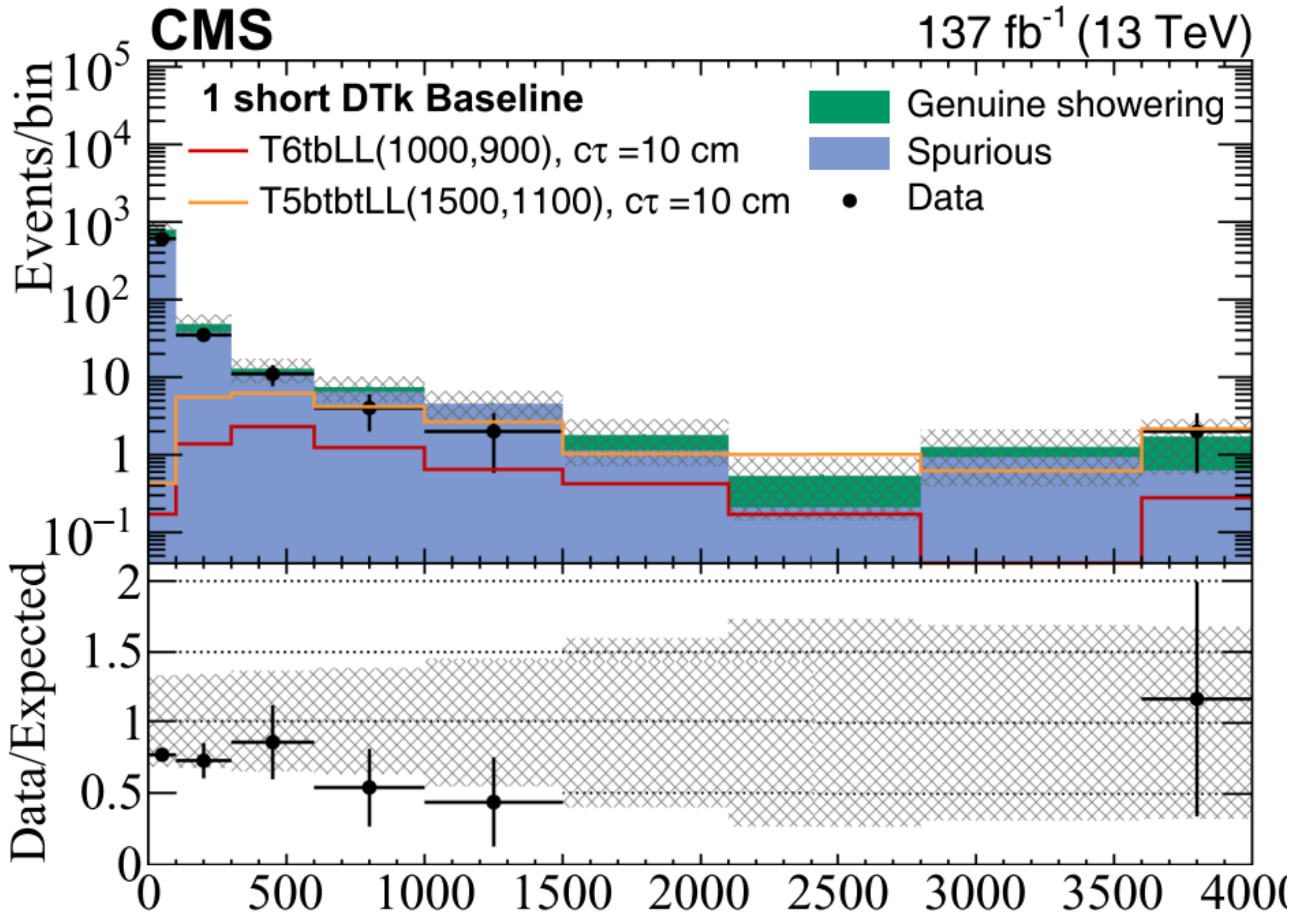
Minimal: Just at an SU(2) Multiplet at LHC

Multiplet of states means nearby (small ΔM) to another state

Charged-state enters detector

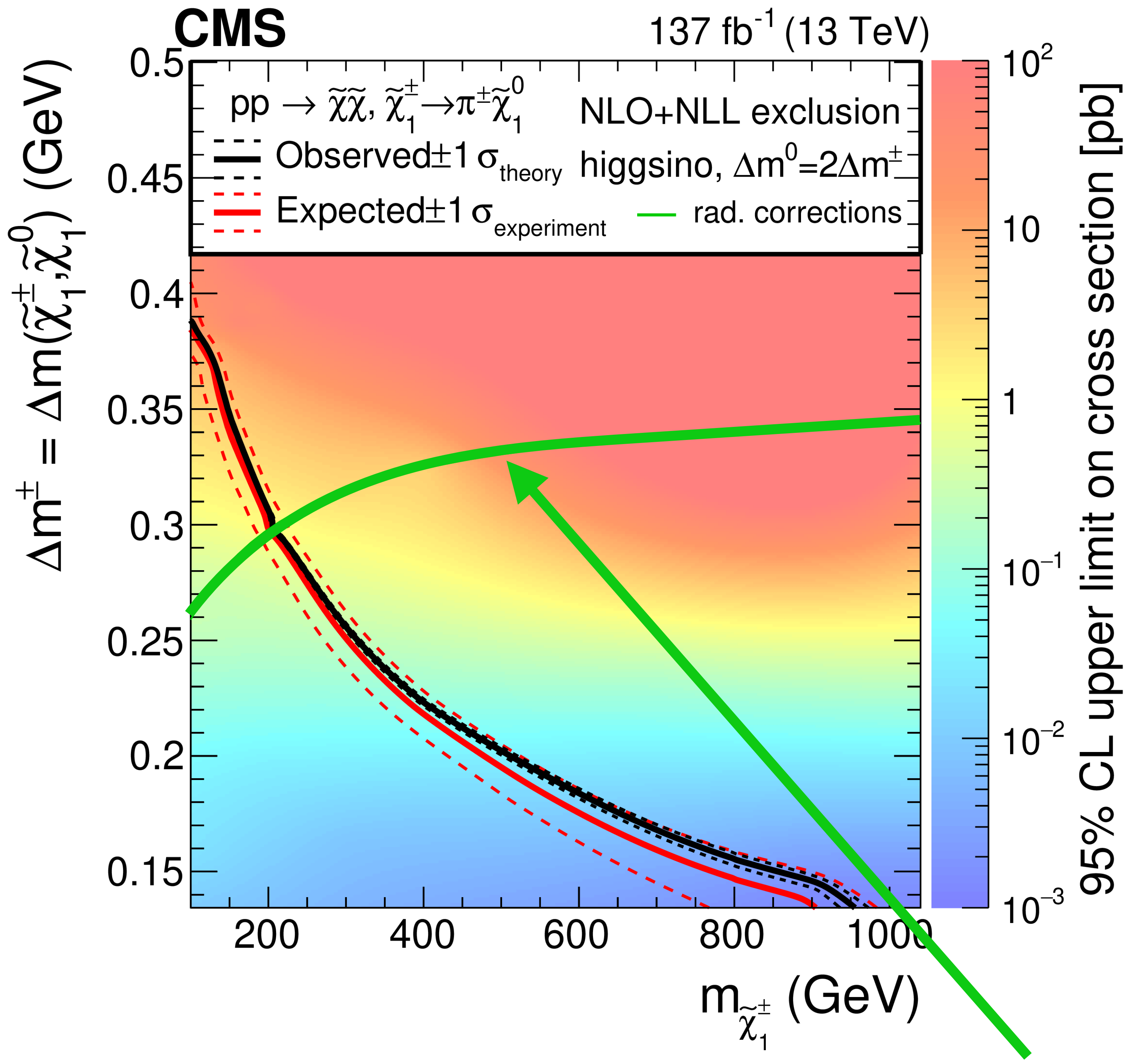
Disappearing Track



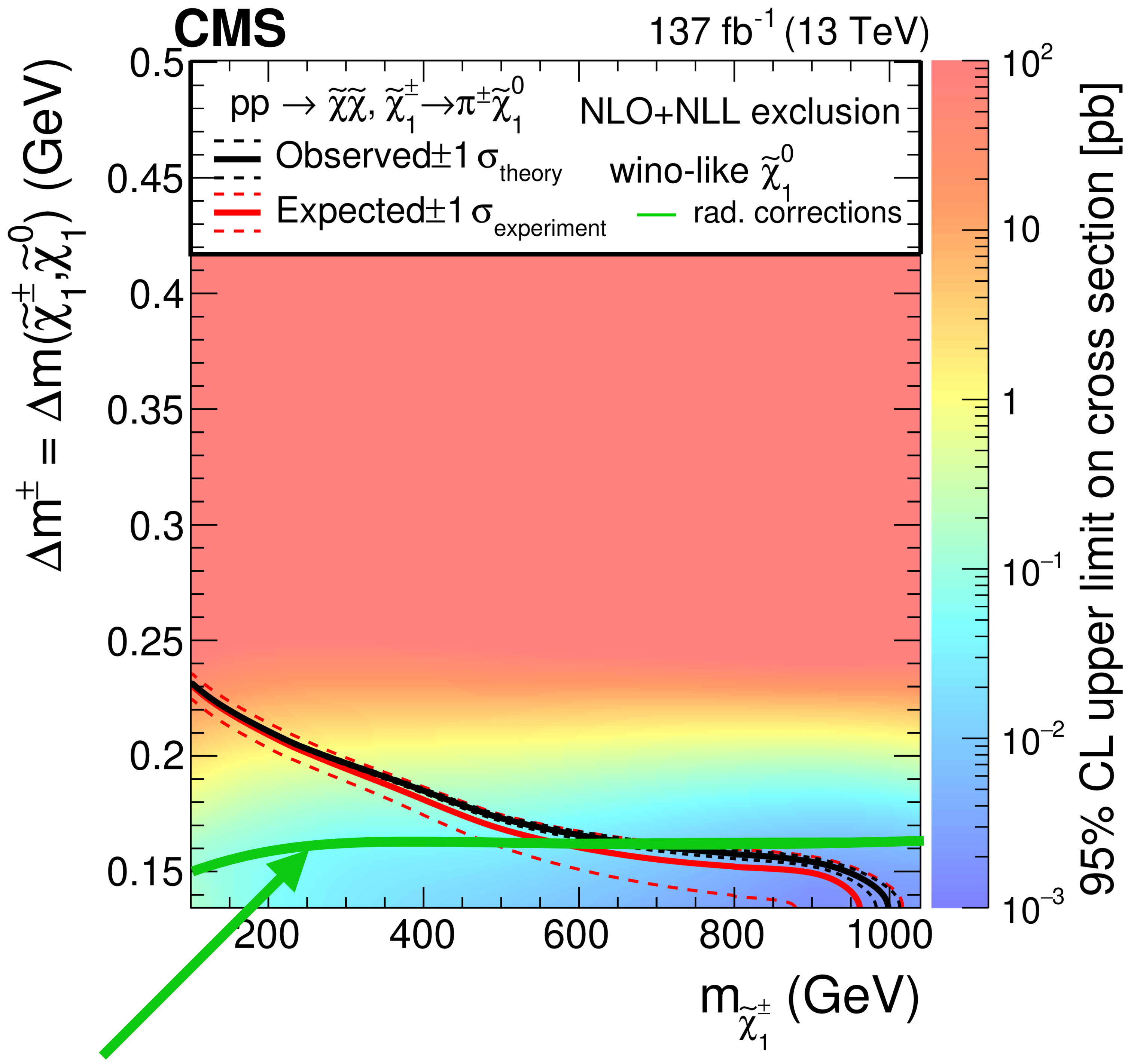


Mass from dE/dx + momentum

Doublet = Higgsino



Triplet = Wino



No other states means ΔM is fixed by radiative corrections

Full SUSY (more states) huge range of ΔM is allowed

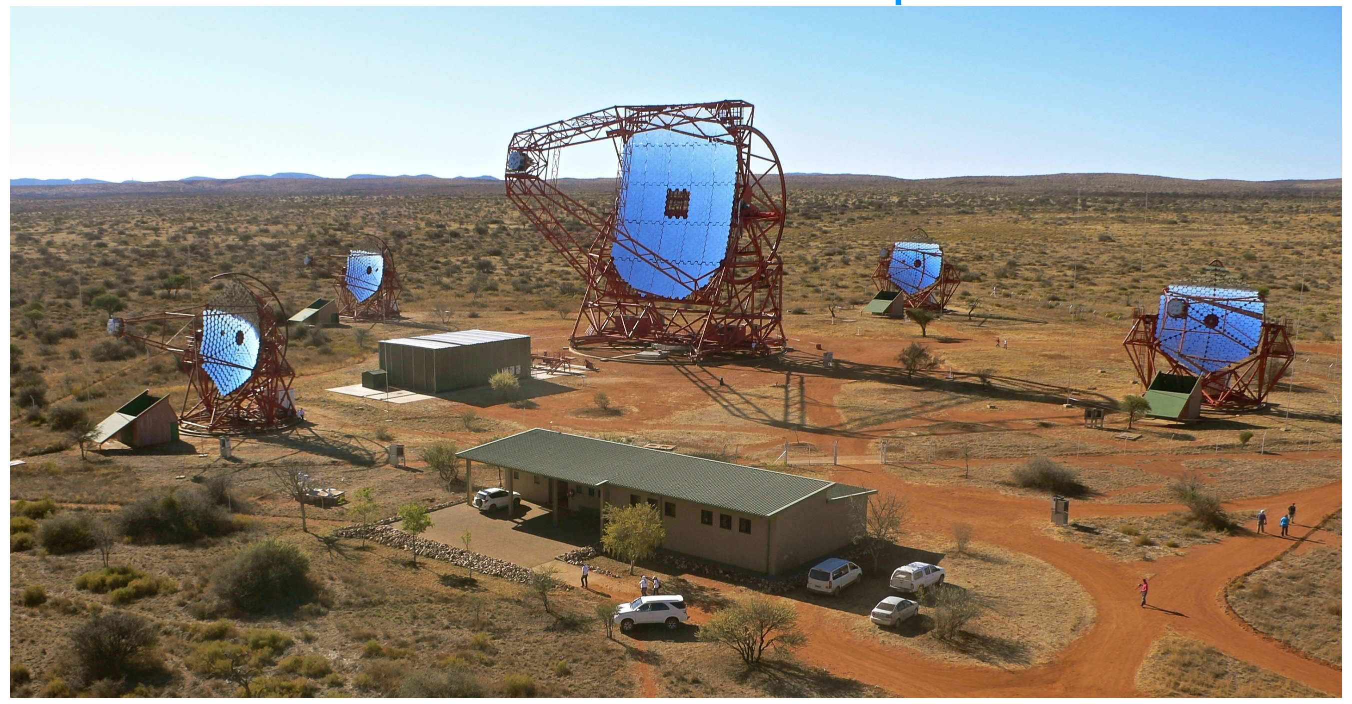
Phys.Rev.D 109 (2024) 7, 072007

Indirect Detection

H.E.S.S results

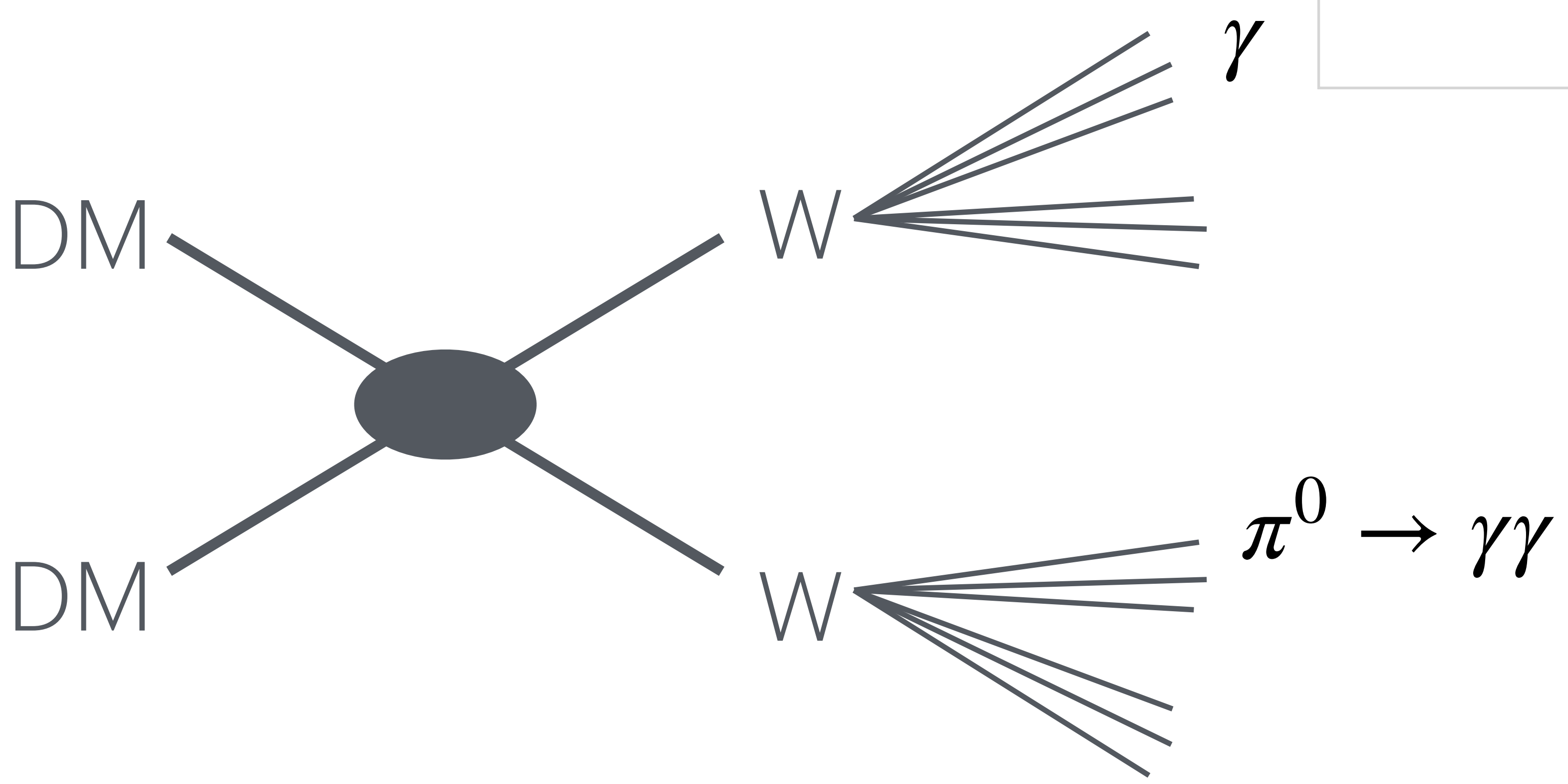
Air shower from gamma makes Cherenkov Radiation

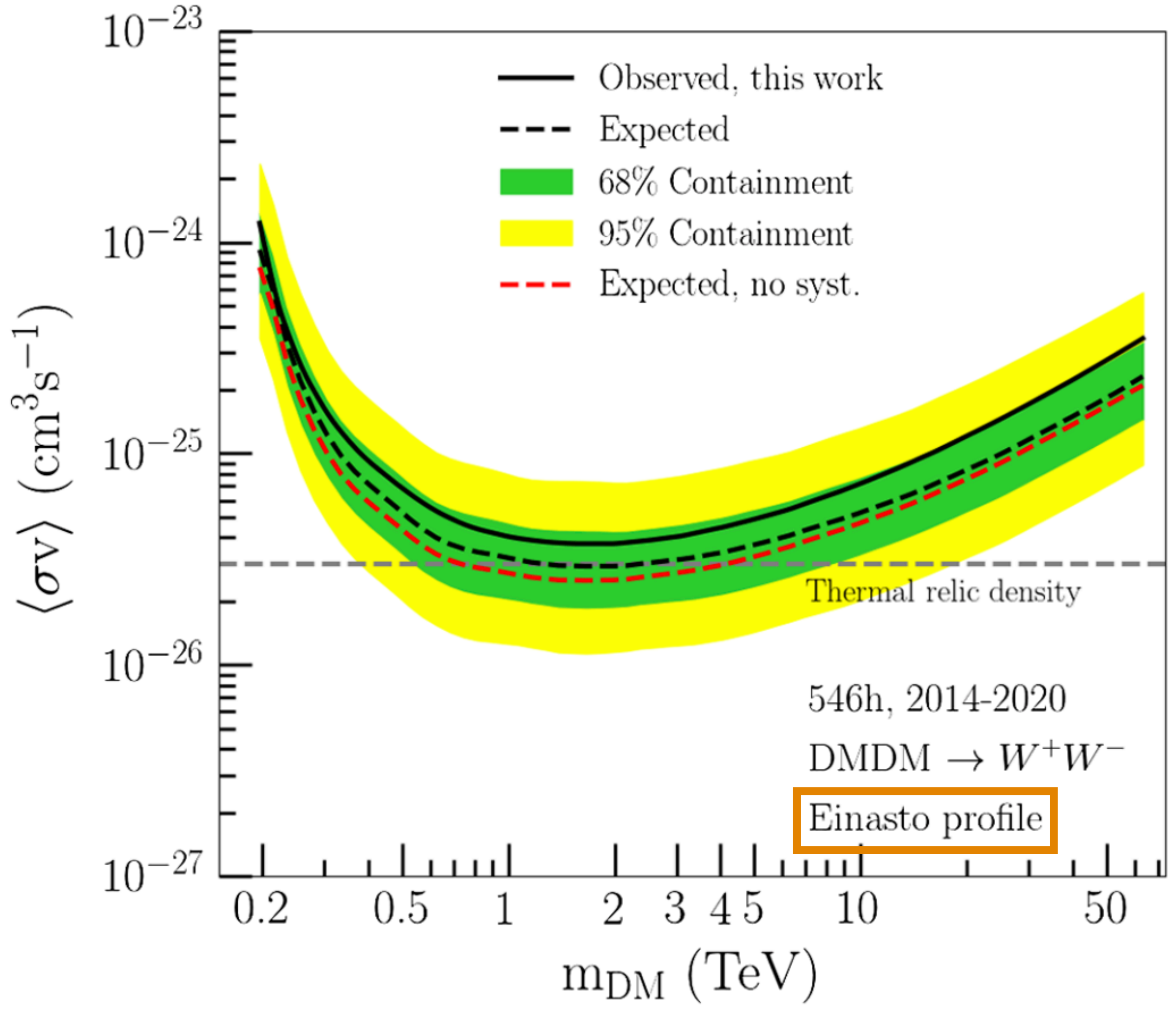
Array of five ground-based Cherenkov telescopes

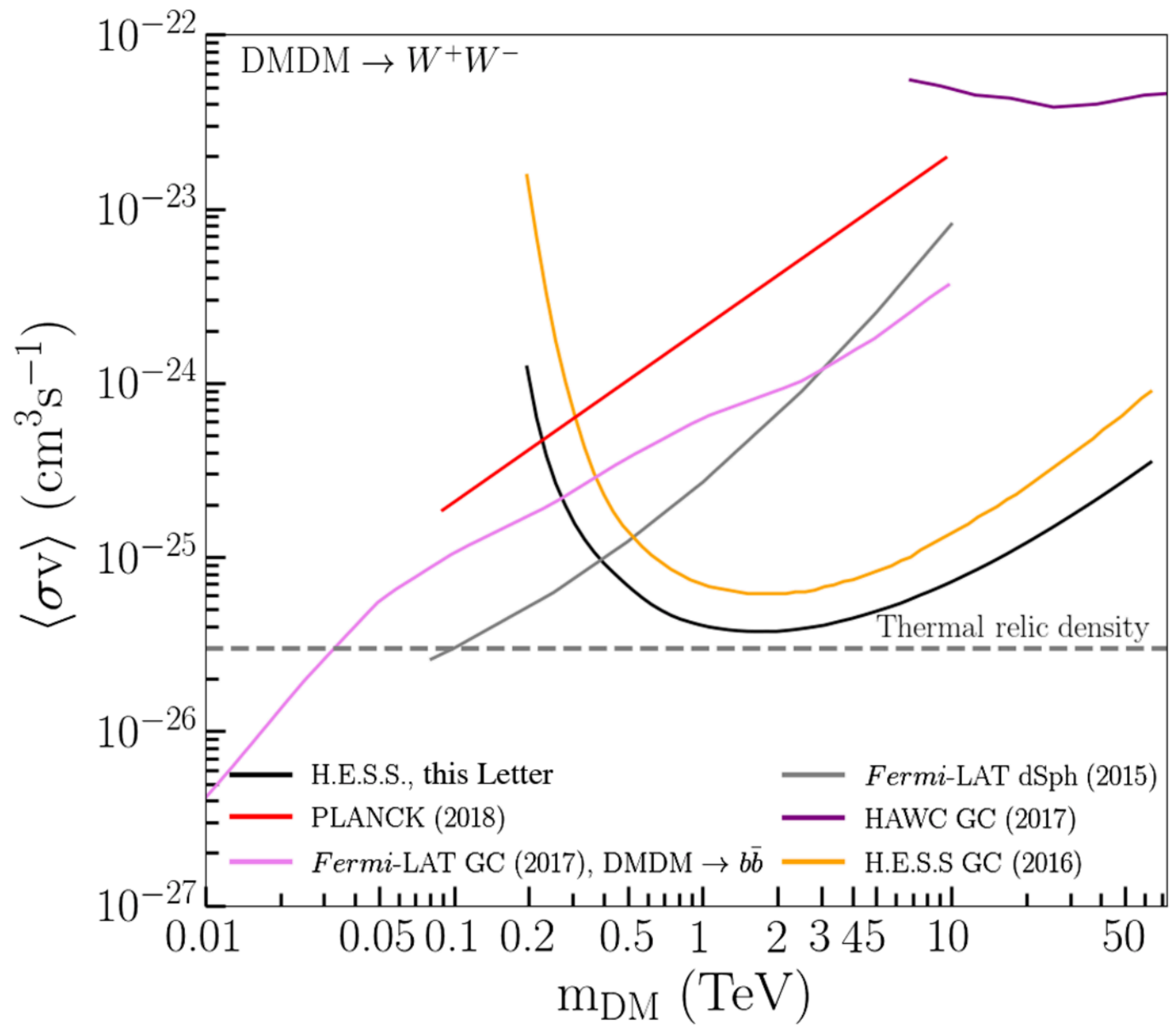


DM DM → WW applies

(… more general)





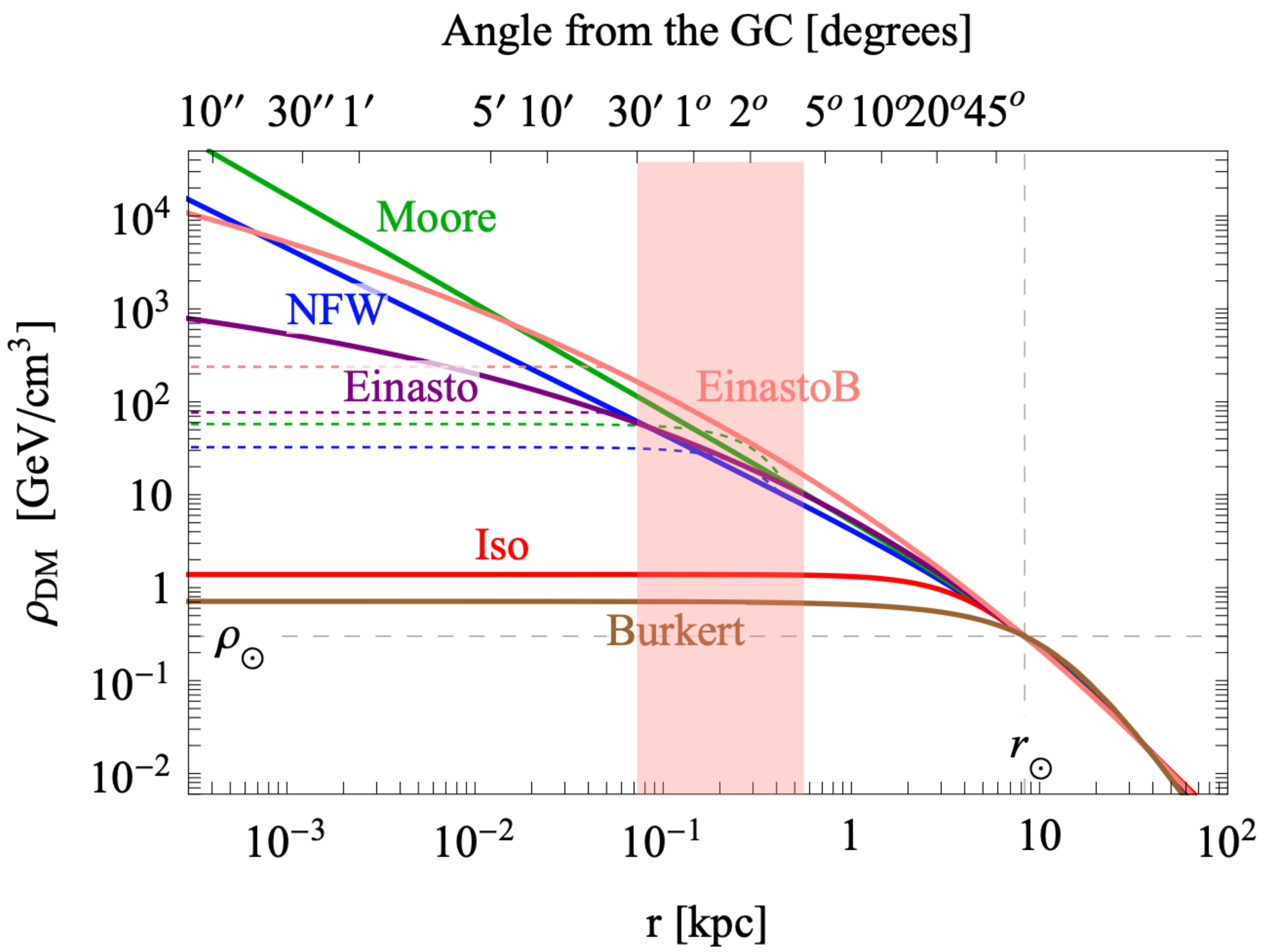


Phys.Rev.Lett. 129 (2022) 11, 111101

Dark Matter Galactic Profile

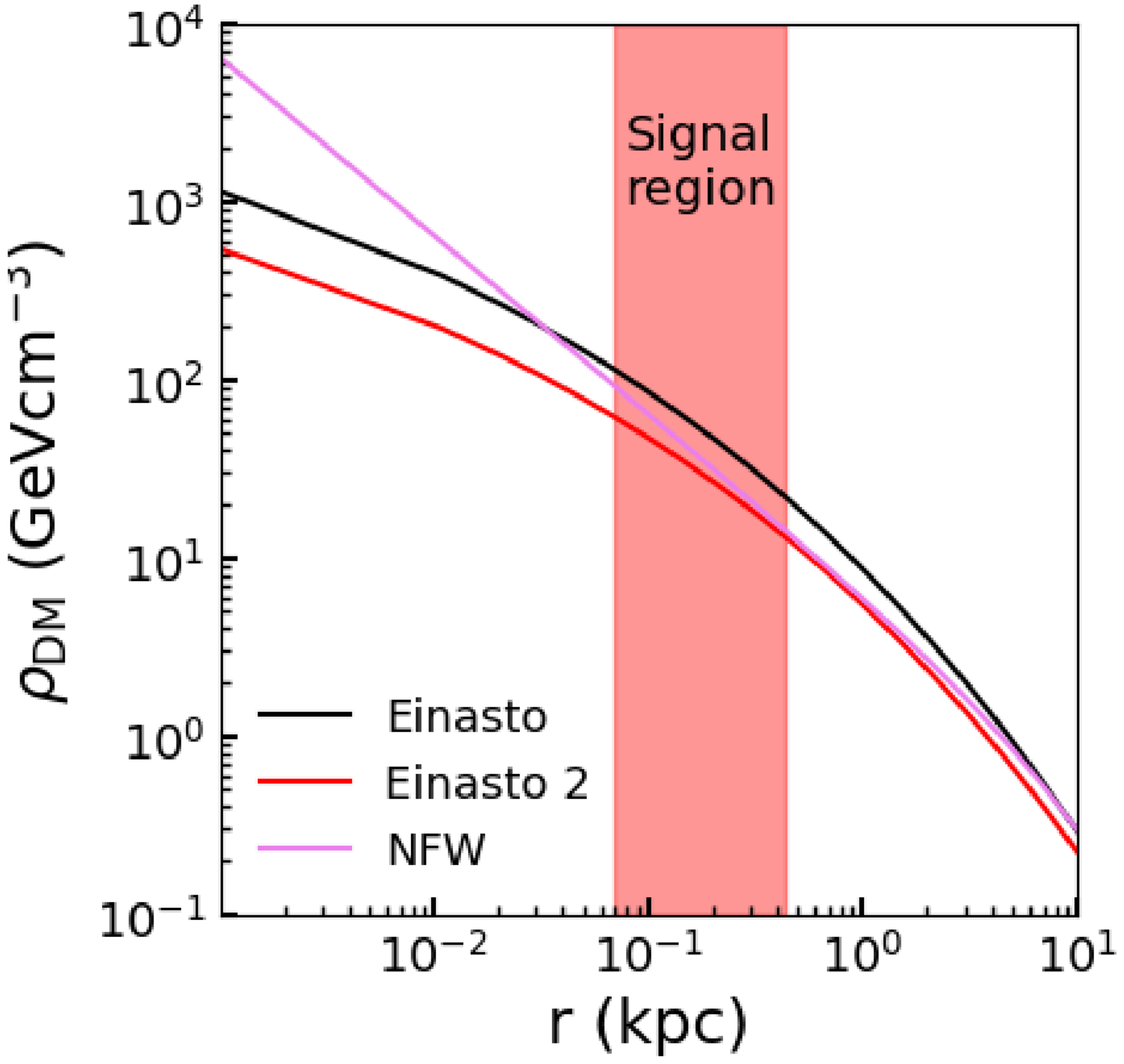
We don't actually know the galactic dark matter density very well

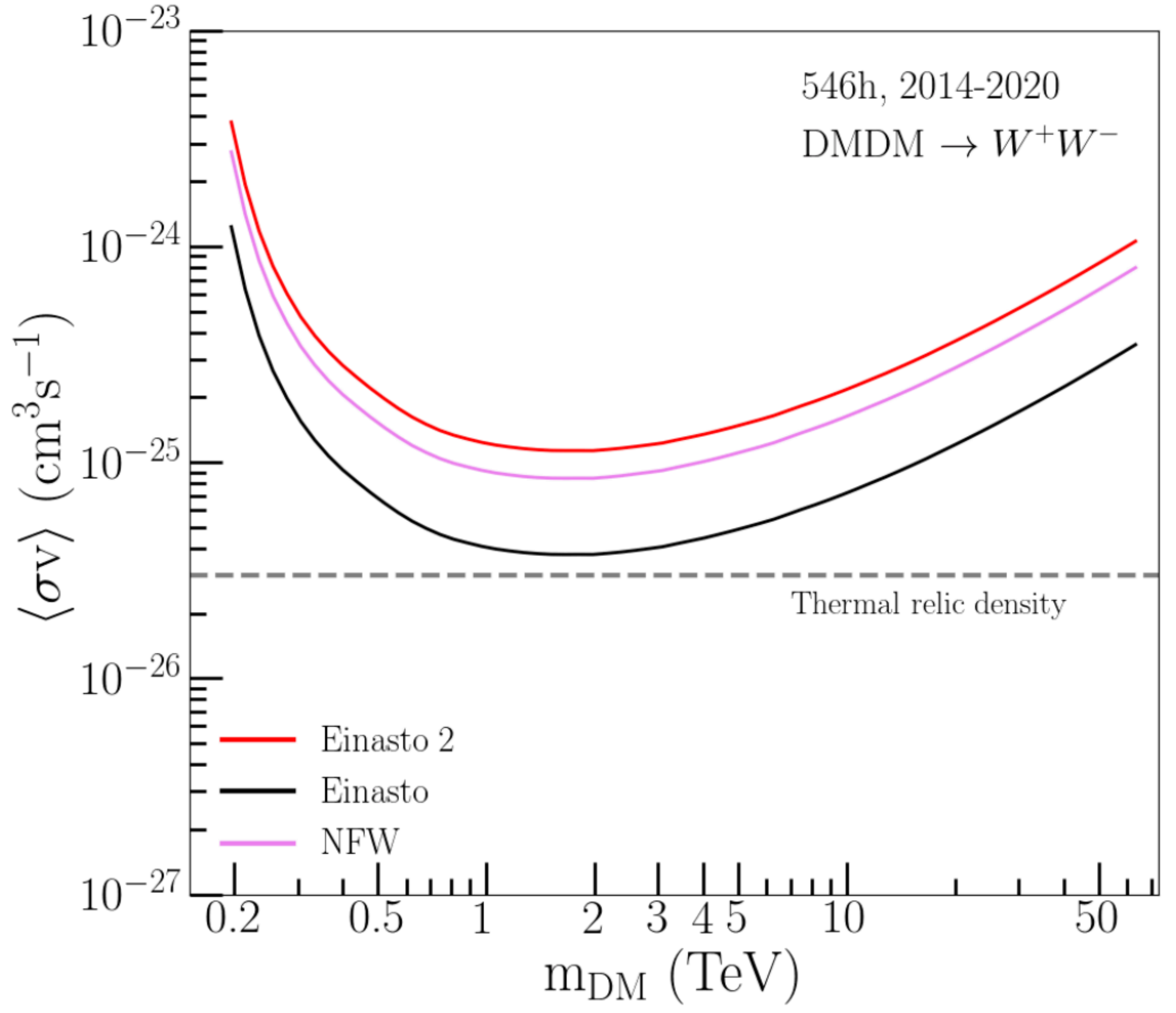
Plausible Dark Matter Densities



https://arxiv.org/pdf/1012.4515.pdf

H.E.S.S. Results Sensitivity to Profile

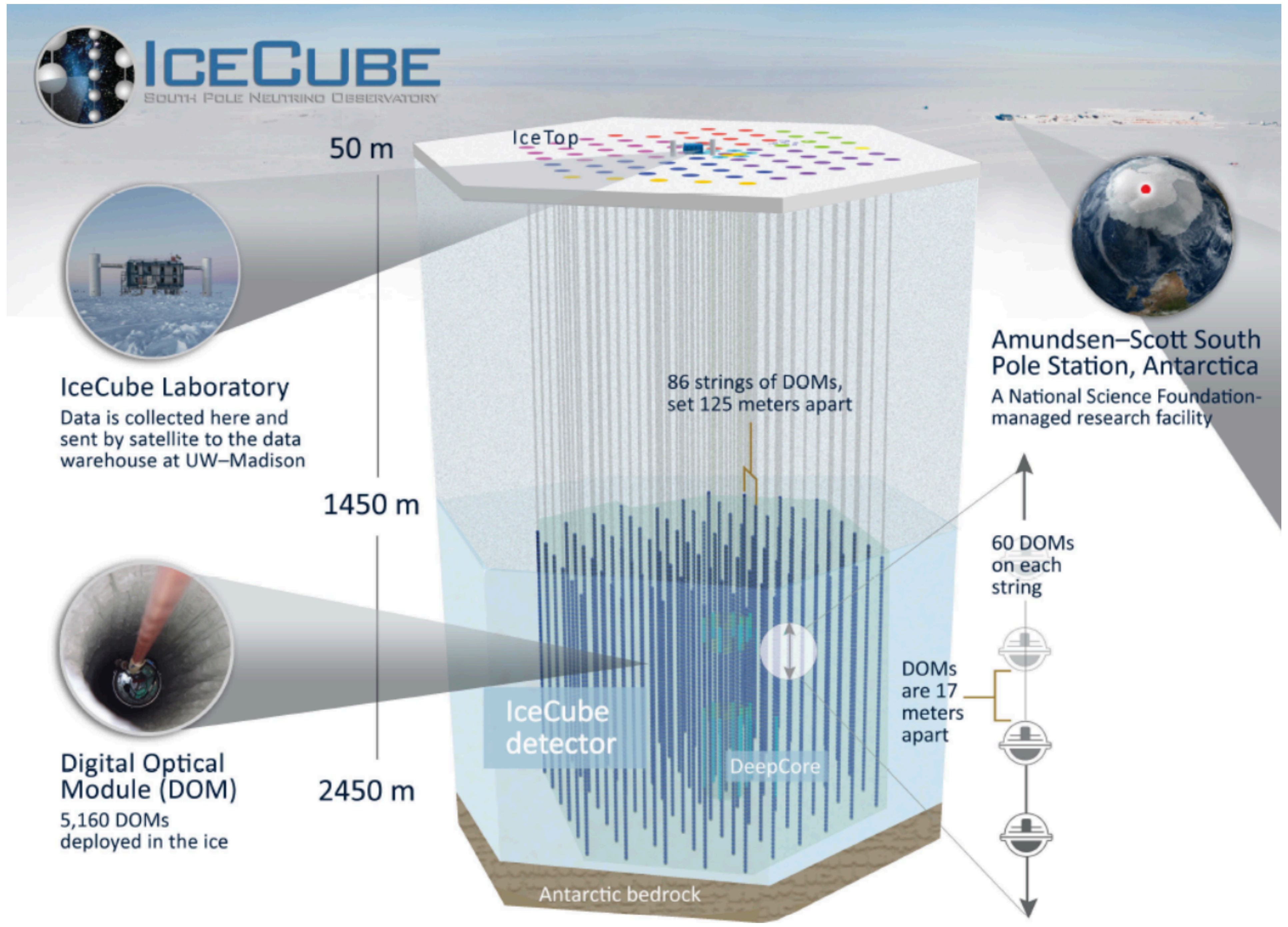




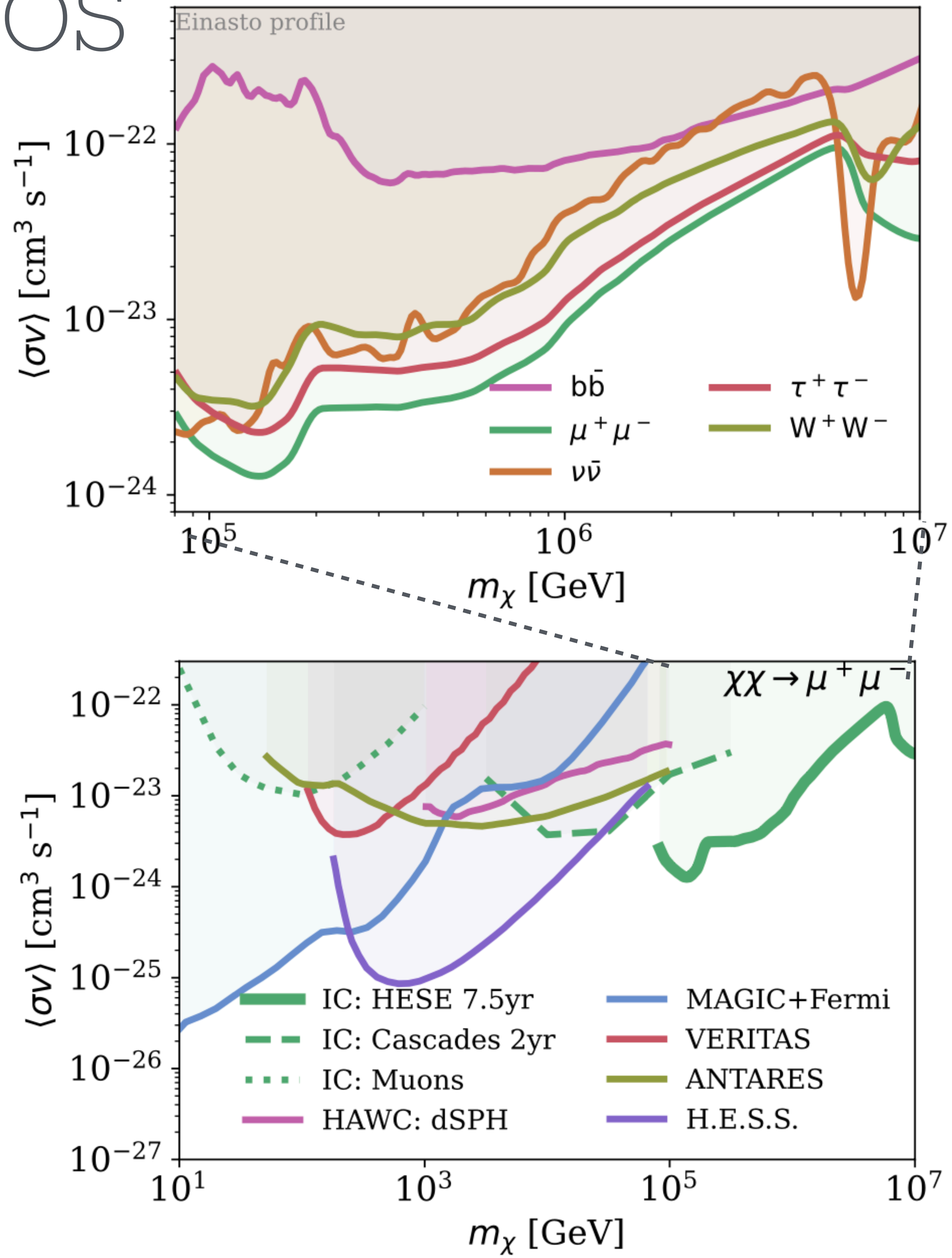
From HESS paper: "cored profiles such as the Burkert one are not studied here, since they need dedicated observations and analysis procedure" Phys.Rev.Lett. 129 (2022) 11, 111101

Indirect Neutrinos

Ice Cube Results



JCAP 10 (2023) 003



Also results from annihilation in earth and the sun

And lots of other models…

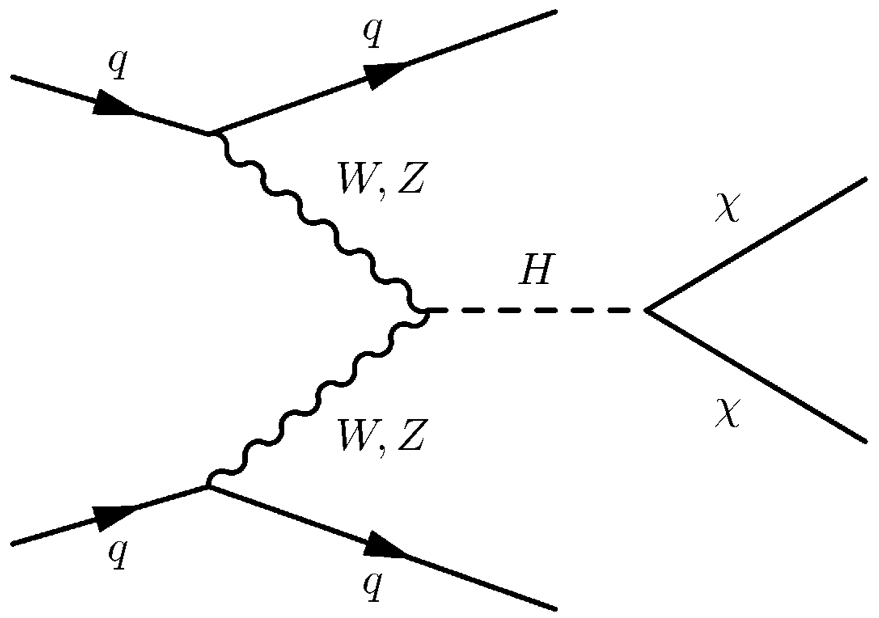
— decaying DM

— light DM scattering in detector

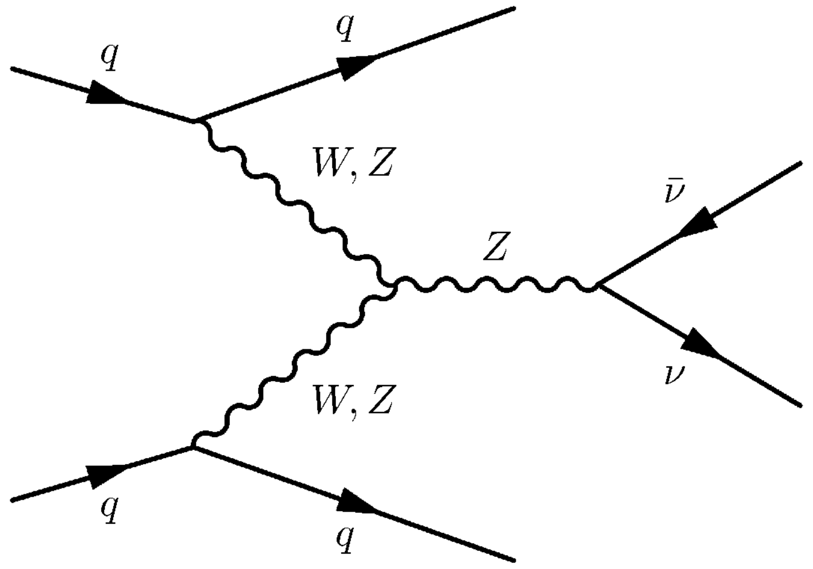
Minimal: Higgs to Invisible at LHC

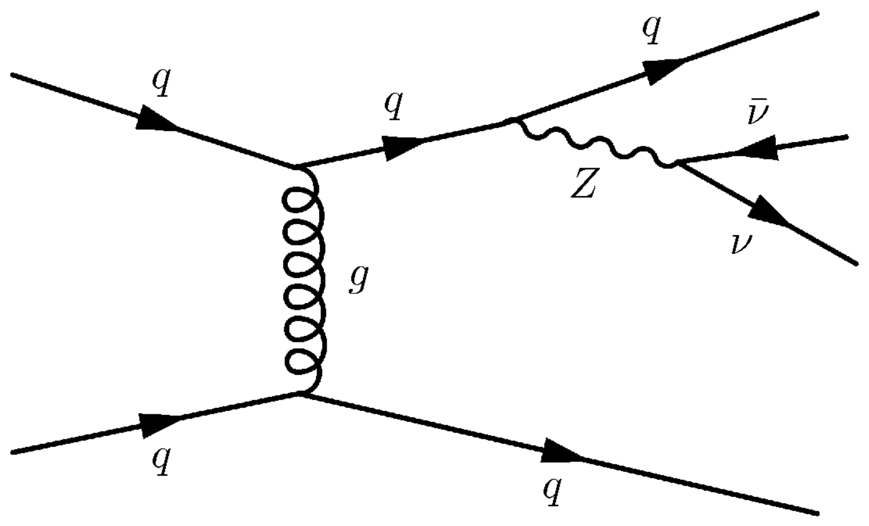
Aka “the Higgs Portal”

signal



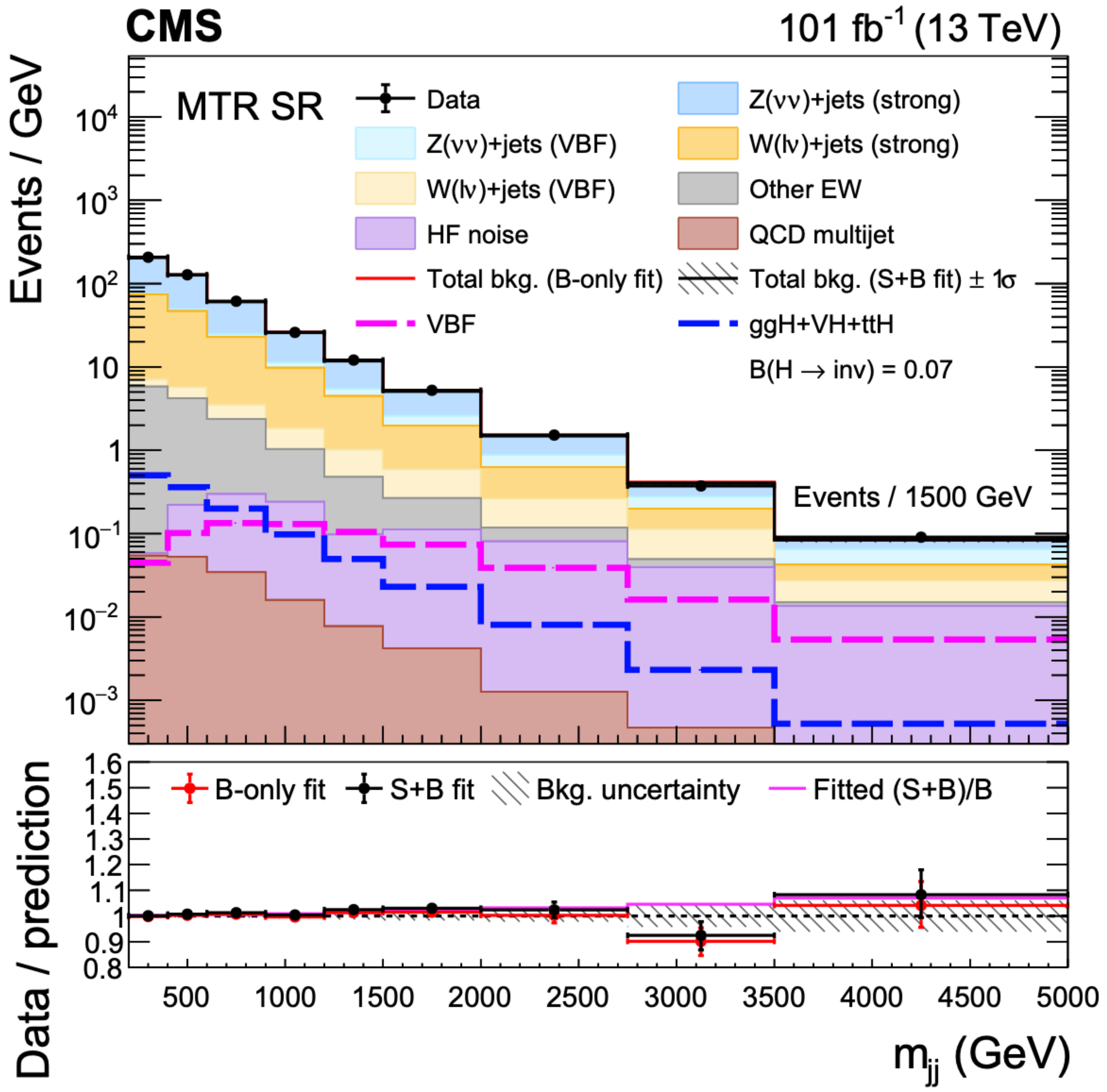
irreducible backgrounds





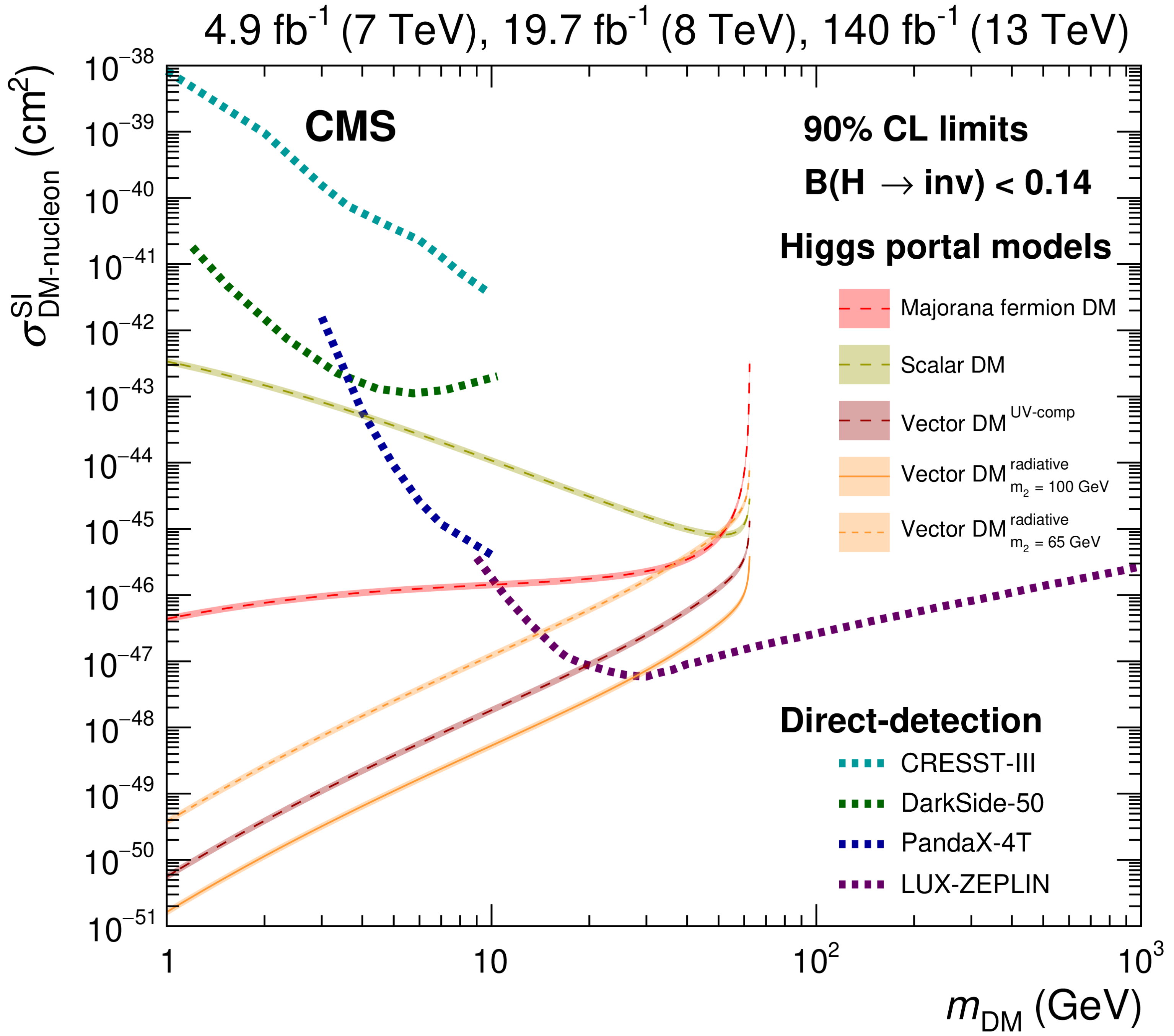
Have to tell invisible (H→χχ) from invisible (Z→νν)

... model backgrounds very carefully



Phys.Rev.D 105 (2022) 9, 092007

If DM couples to nucleon via Higgs, directly comparable to direct detection



Eur.Phys.J.C 83 (2023) 10, 933

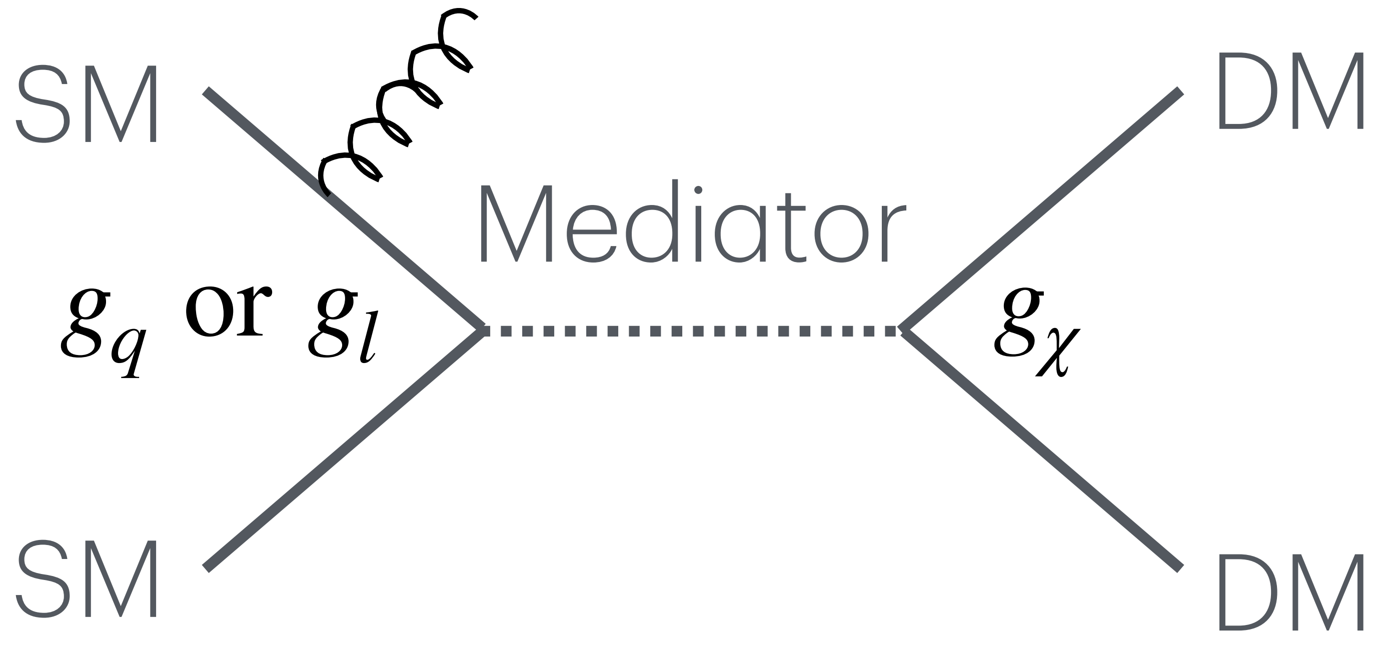
Simplified Models

Simplified Models

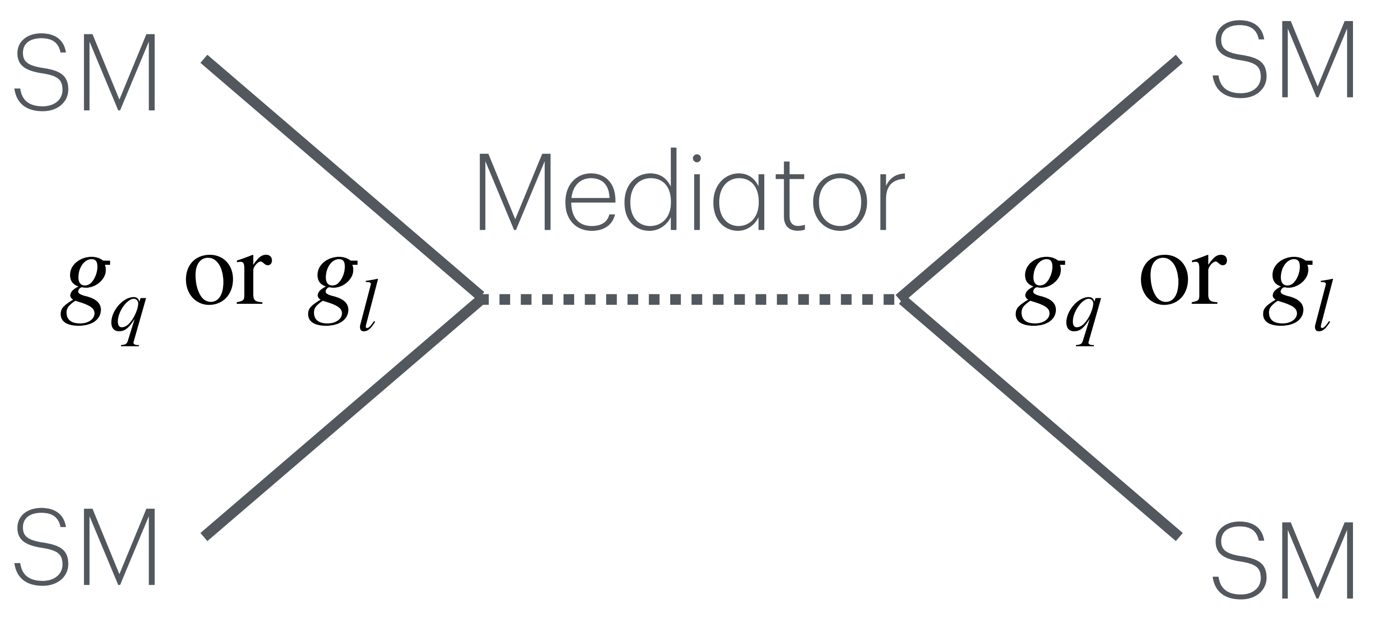
Just add DM and one Mediator (e.g. Axial Vector)

https://arxiv.org/pdf/2404.15930

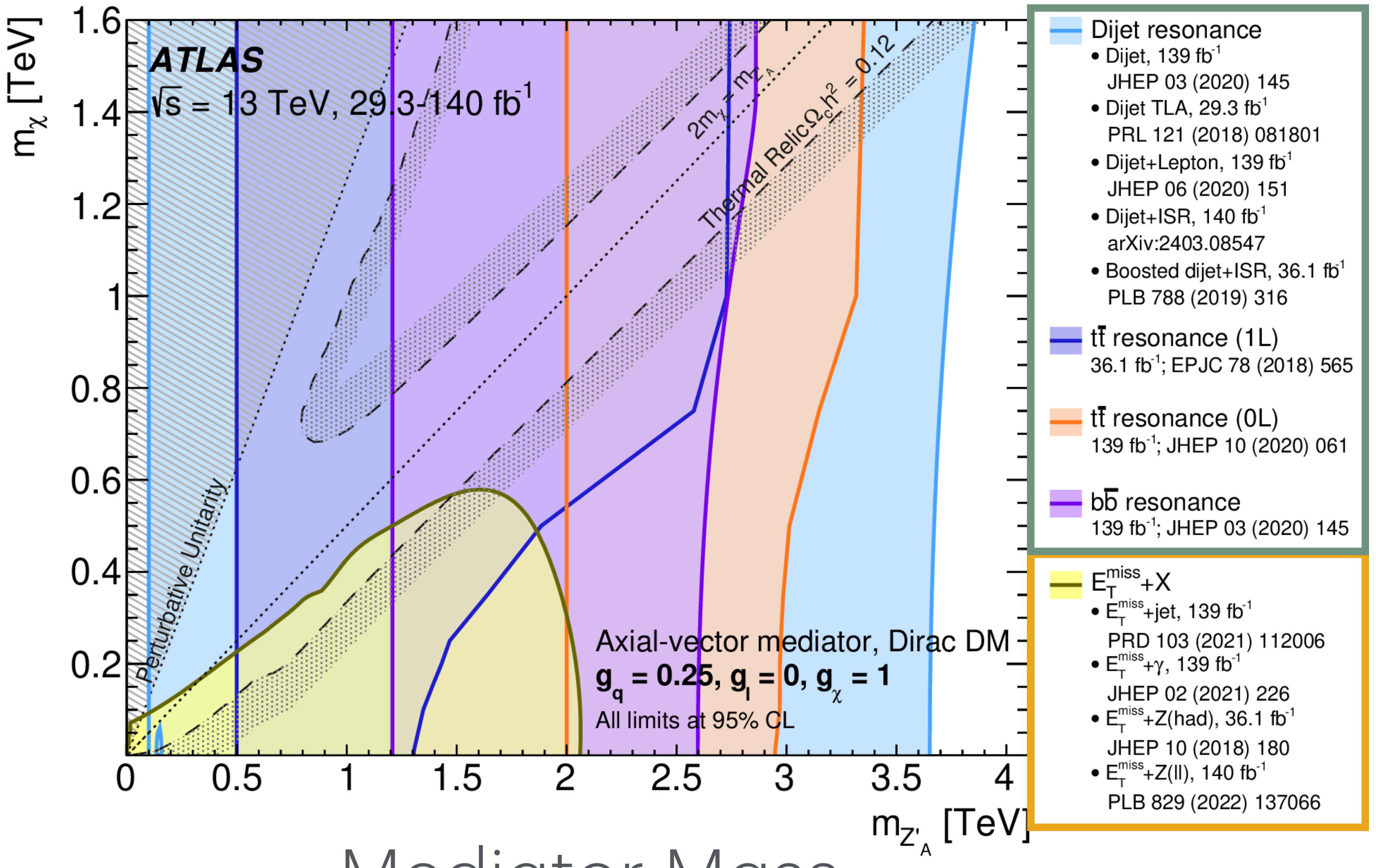
probe with this... =monojet



or with this... =diobject resonances



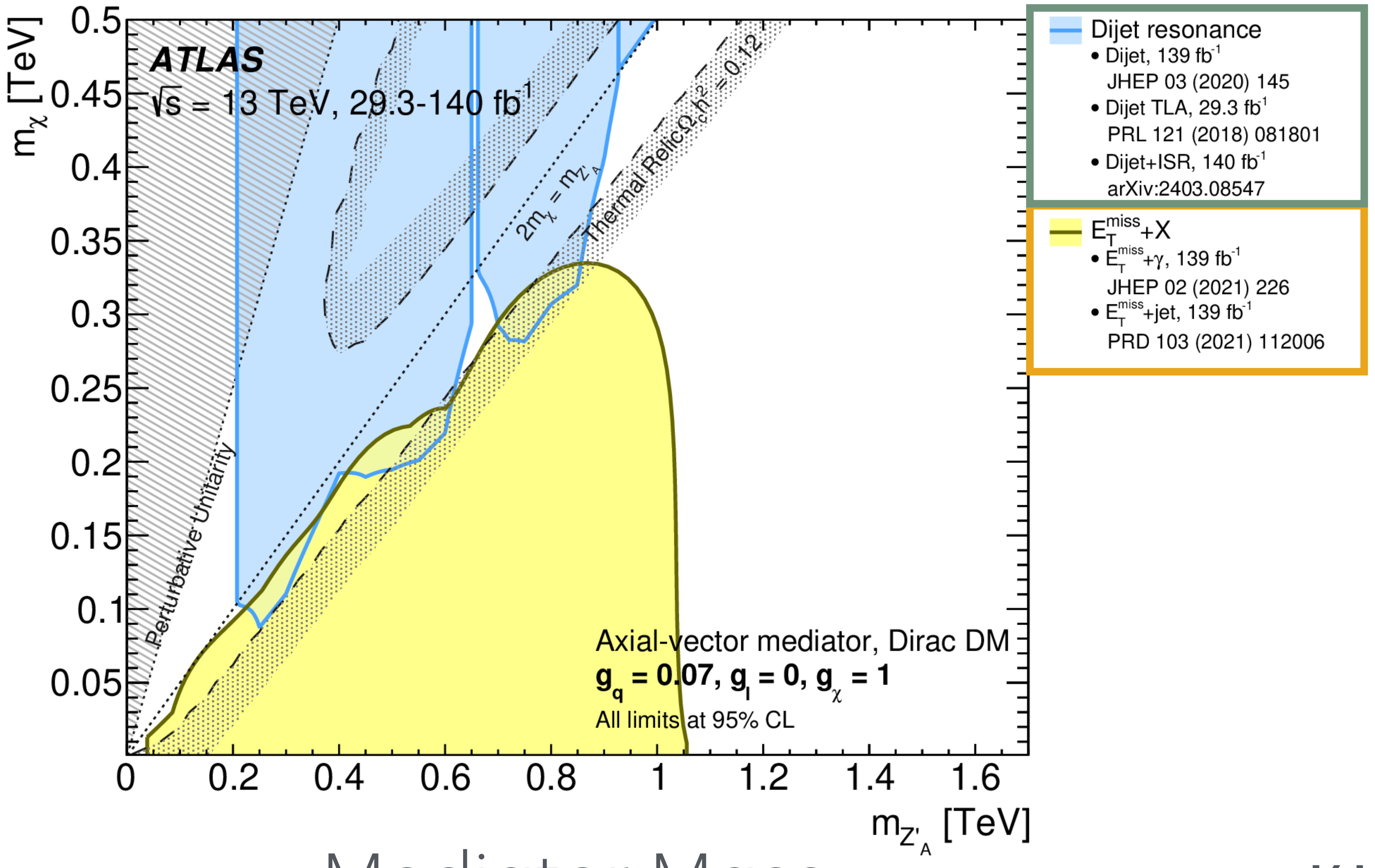
DM Mass



Mediator Mass

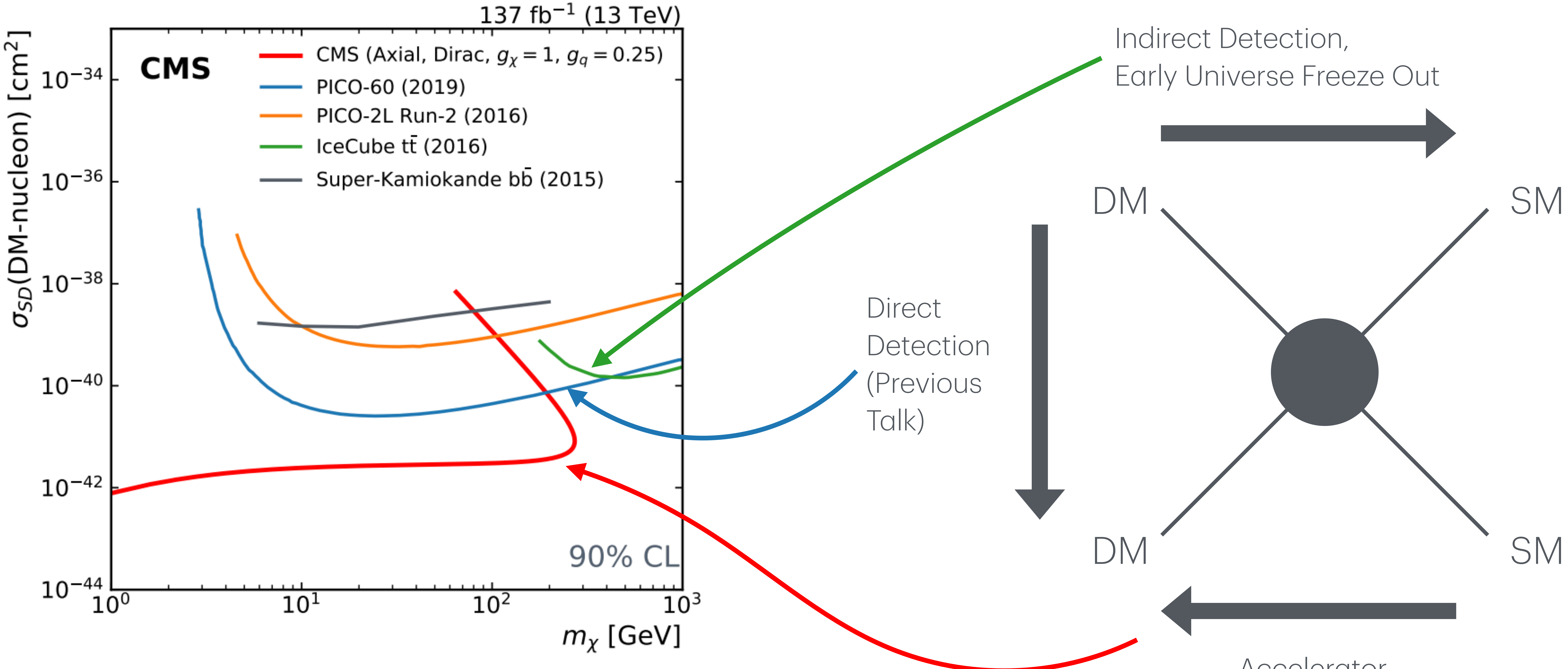
Dial down SM coupling

DM Mass



Mediator Mass

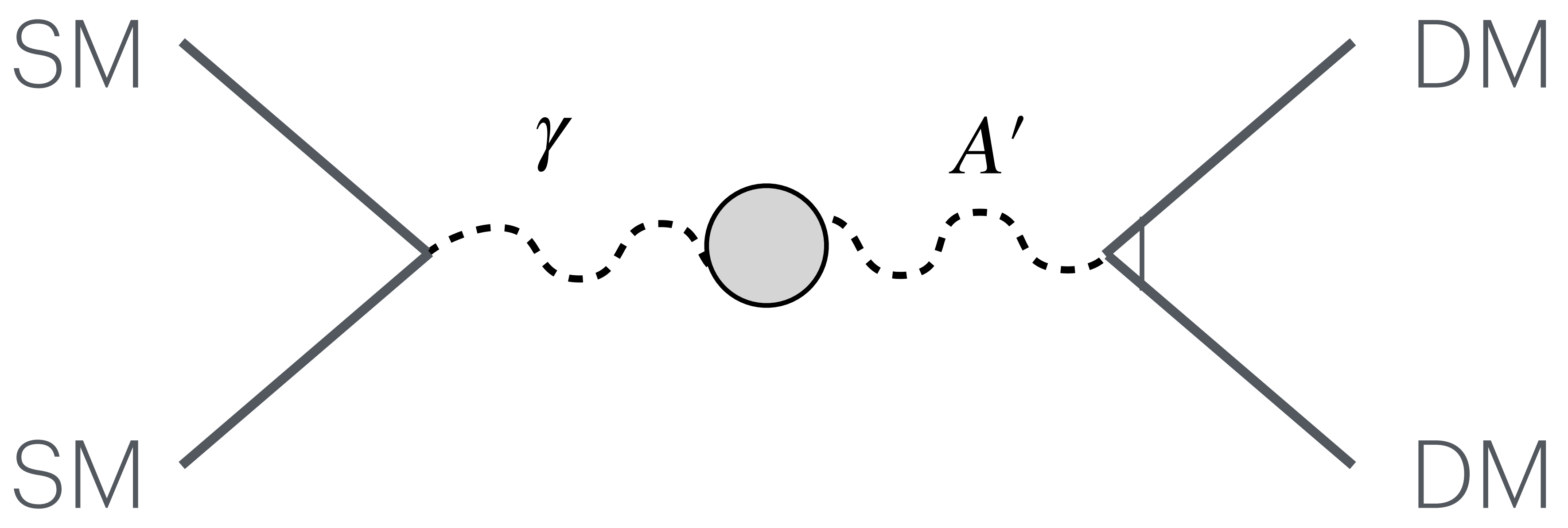
Complementarity

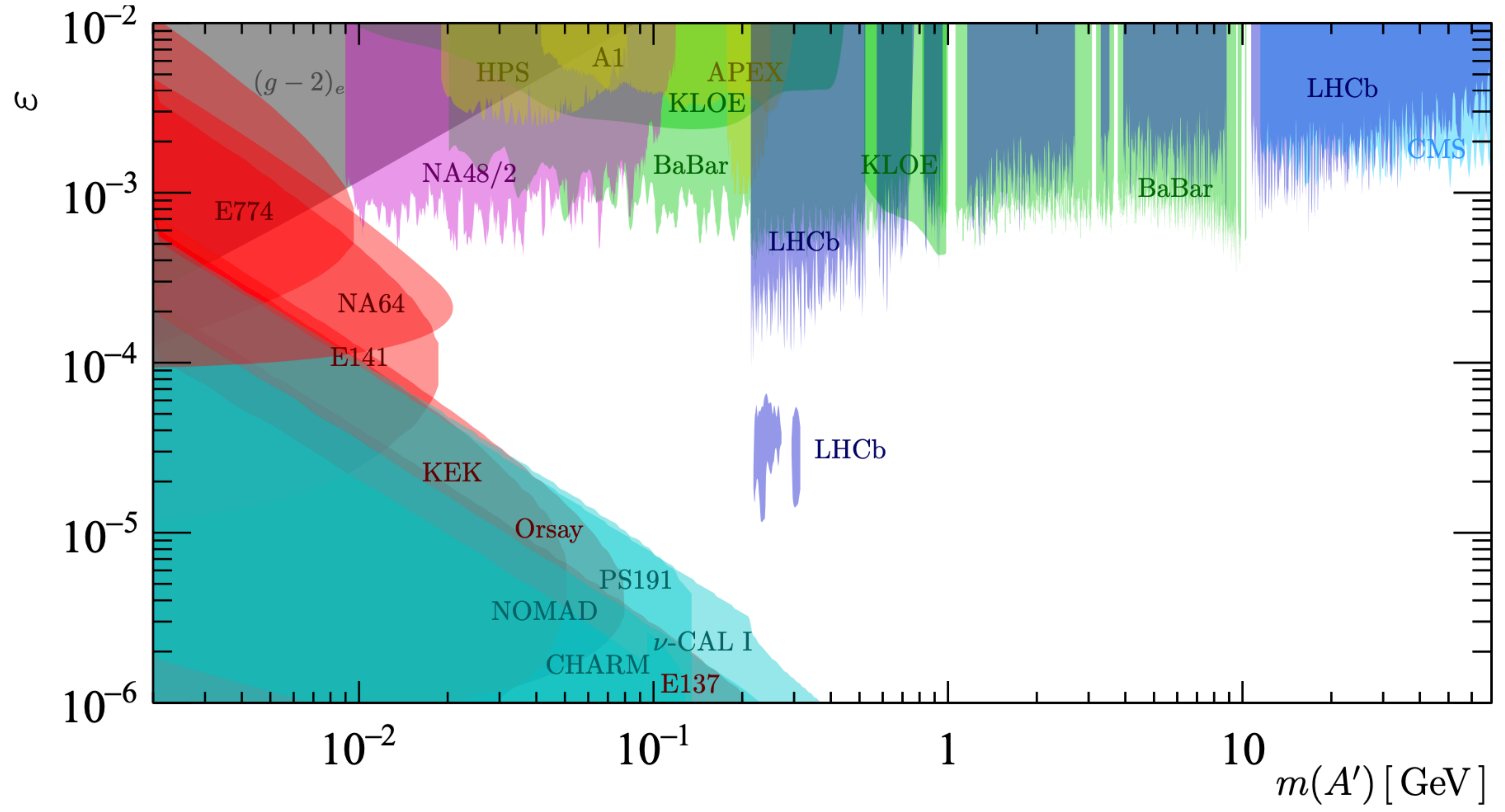


Eur.Phys.J.C 81 (2021) 1, 13

Another simplified model

Dark Photon as dark matter or mediator





Dark Photon Mixes with SM Photon

— Small coupling (ε)

— A′ can be massive

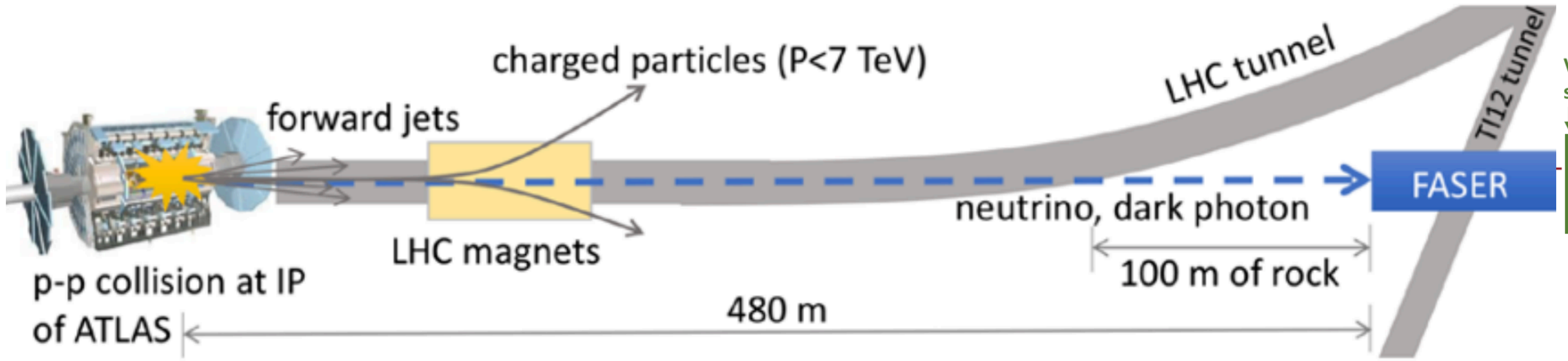
— A′ can be dark matter if $m_{A'} < 2\, m_e$ (cosmologically stable)

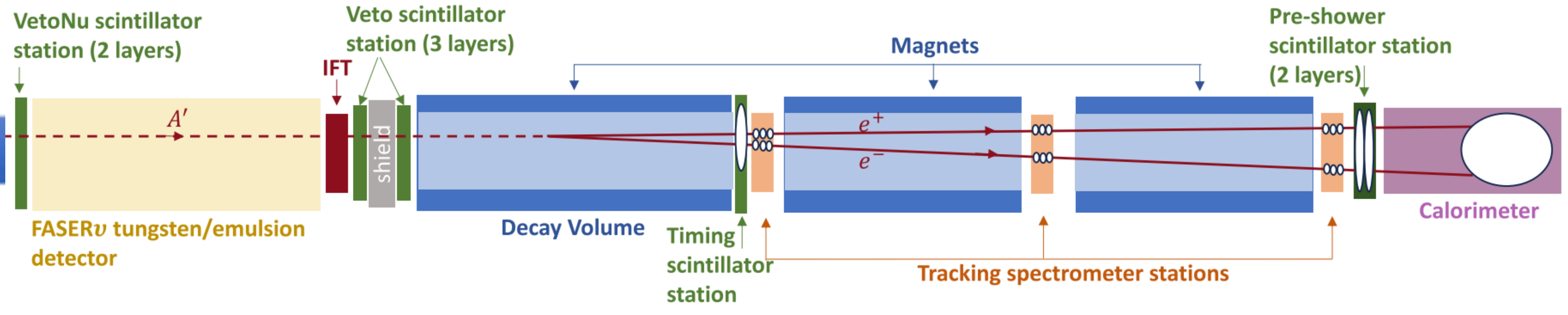
— A′ can also decay → many experiments

PoS EPS-HEP2021 (2022) 185

FASER dark photons

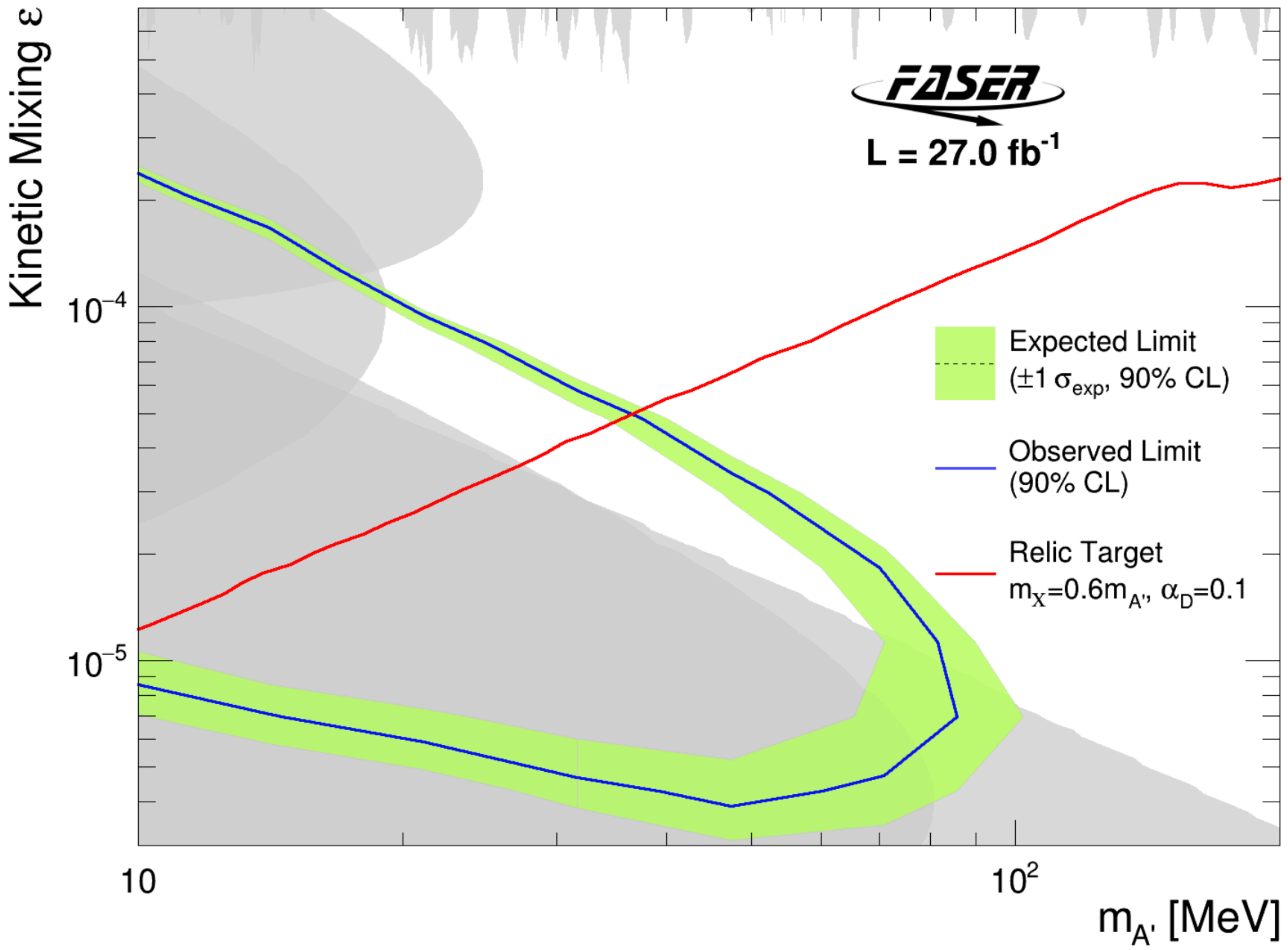
looking for A' to decay





Probing new phase space,
much more data to come

Phys.Lett.B 848 (2024)



See DPF talks:

[New Physics Results from the FASER Experiment]

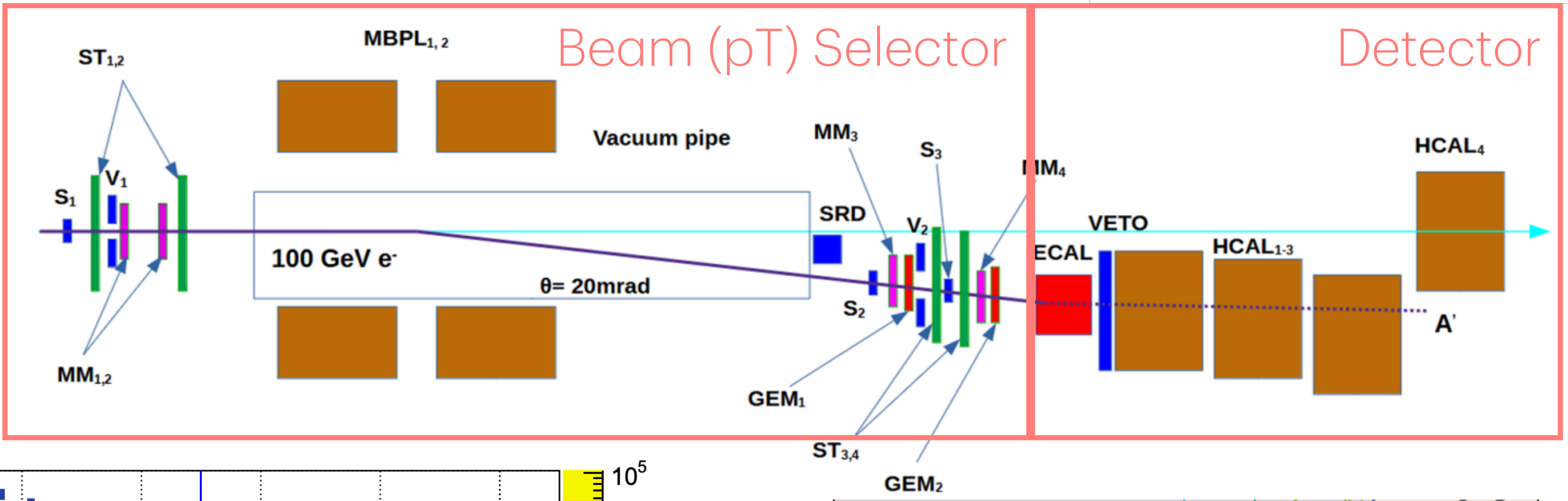
[Results From TeV Neutrinos at the FASER Experiment]

[FASER \nu a non-unitarity of the leptonic mixing matrix]

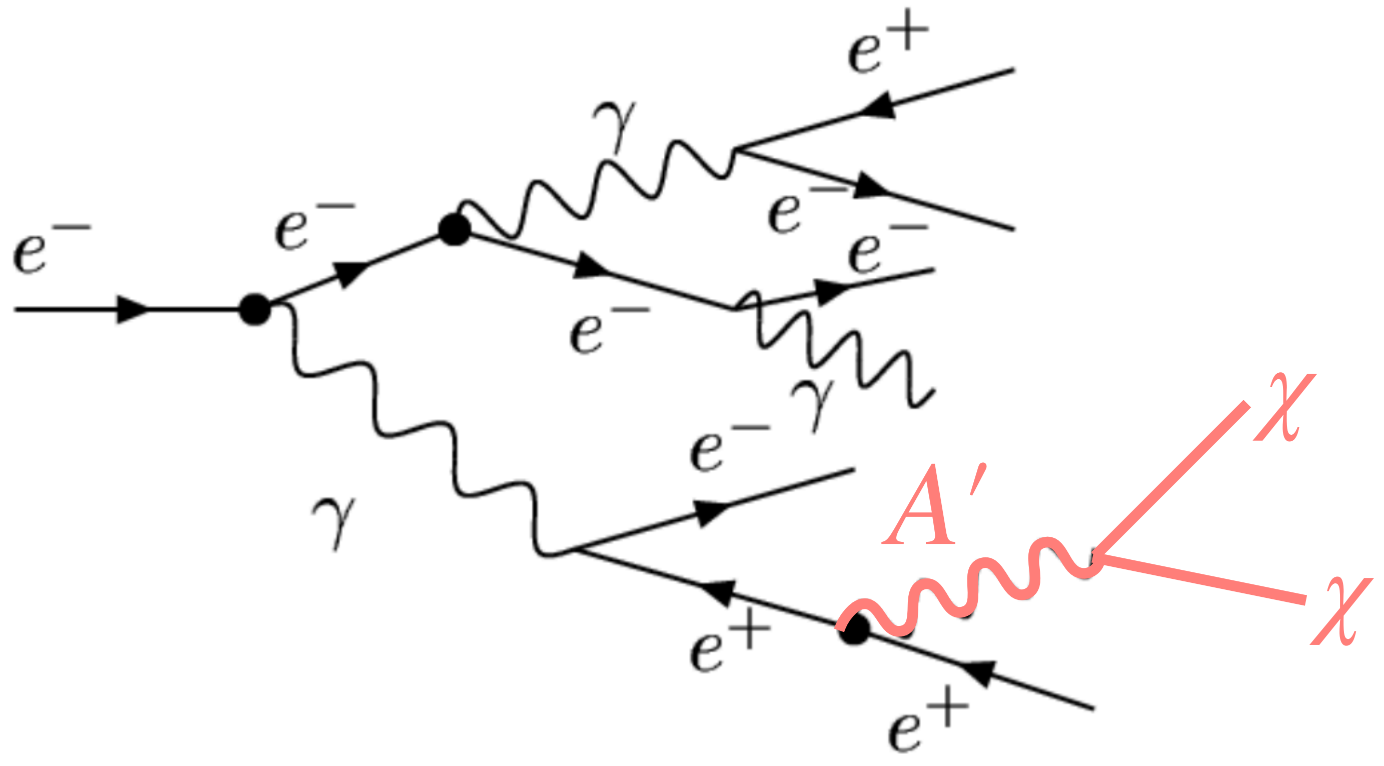
[FASER: recent results and perspectives]

NAA64 “Invisible Mode”

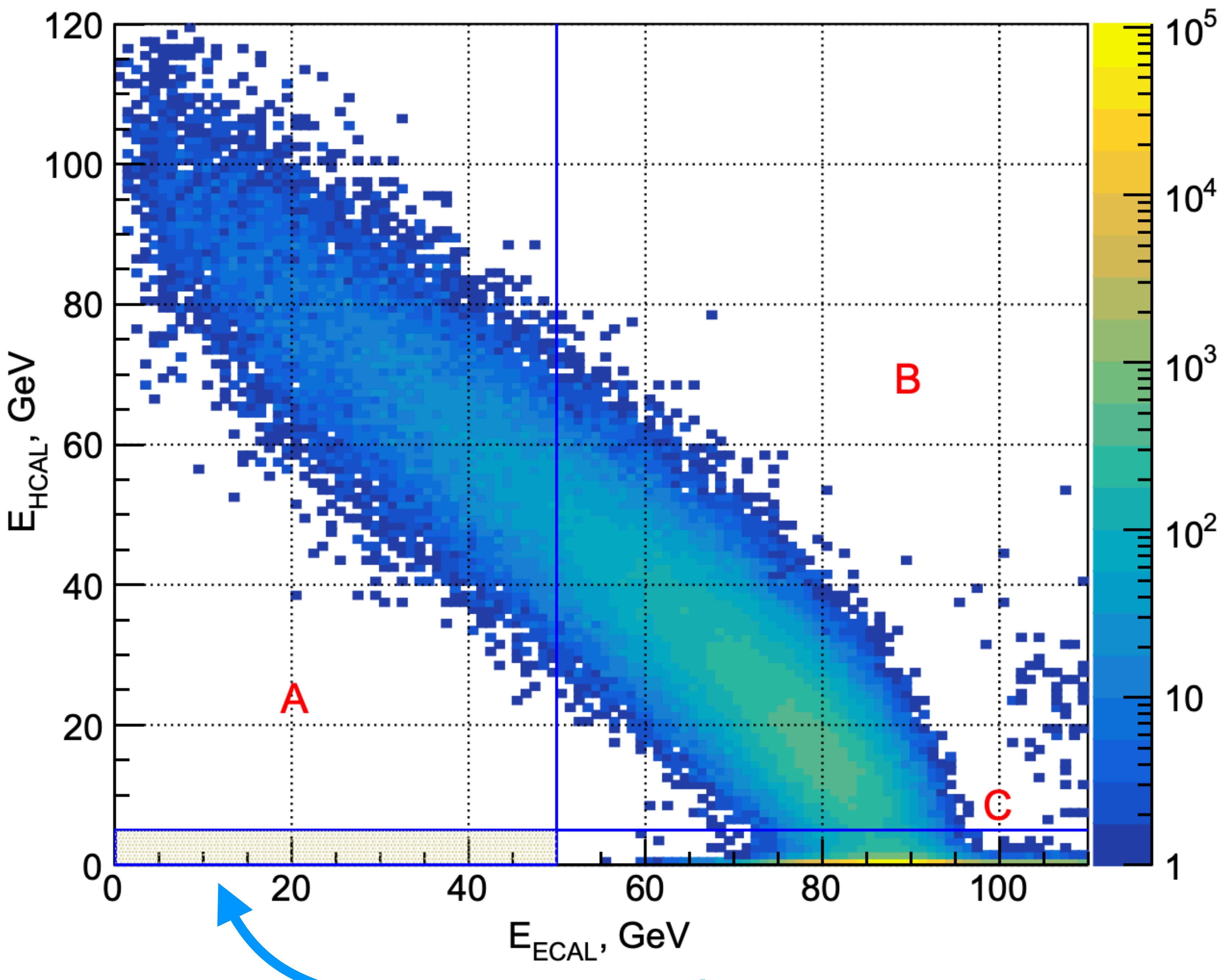
Phys.Rev.Lett. 131 (2023) 16, 161801



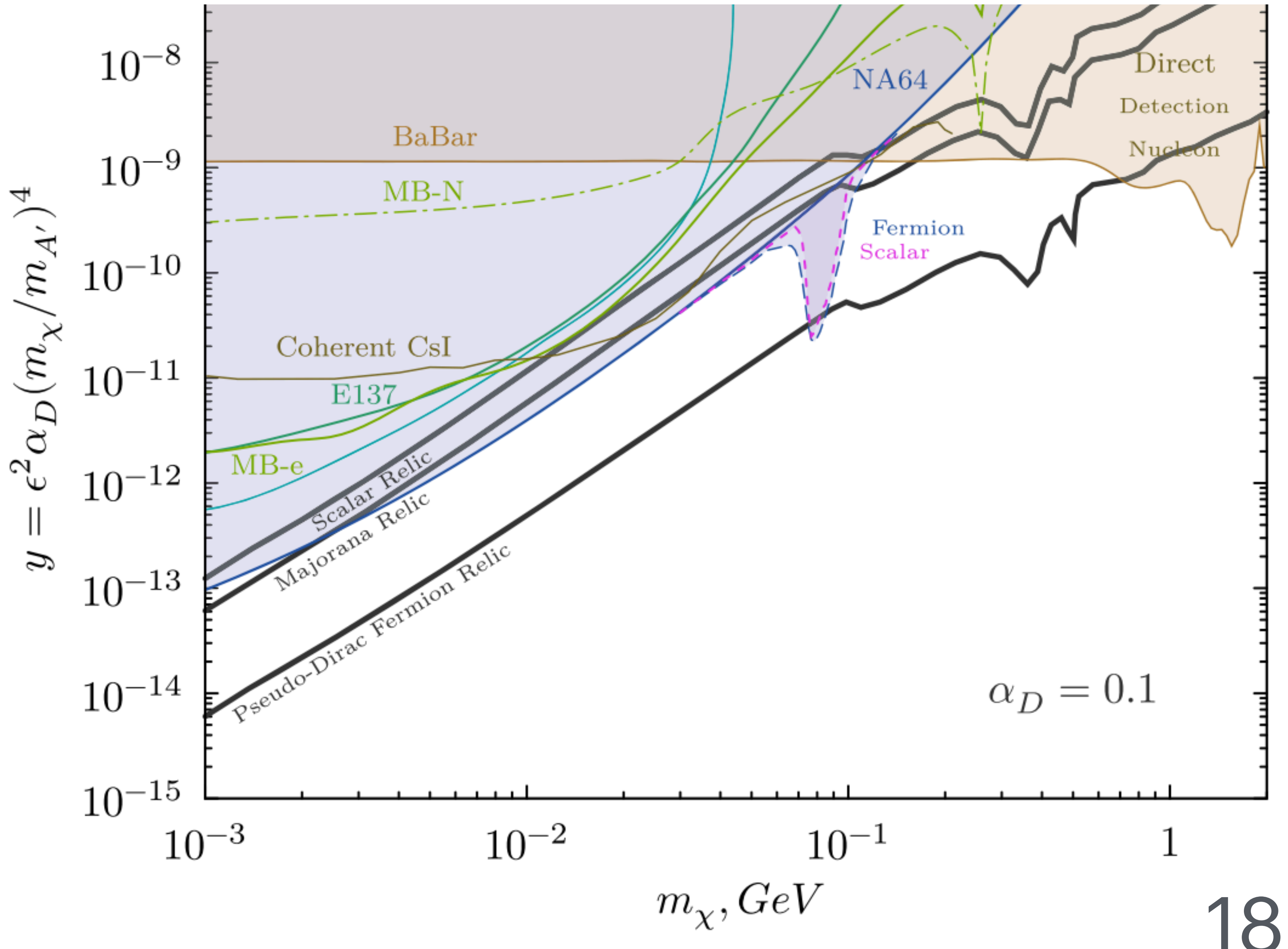
Look for Electron losing too much energy in calorimeter because to dark bremsstrahlung



Special GEANT Simulation of Showers: Comput.Phys.Commun. 269 (2021) 108129

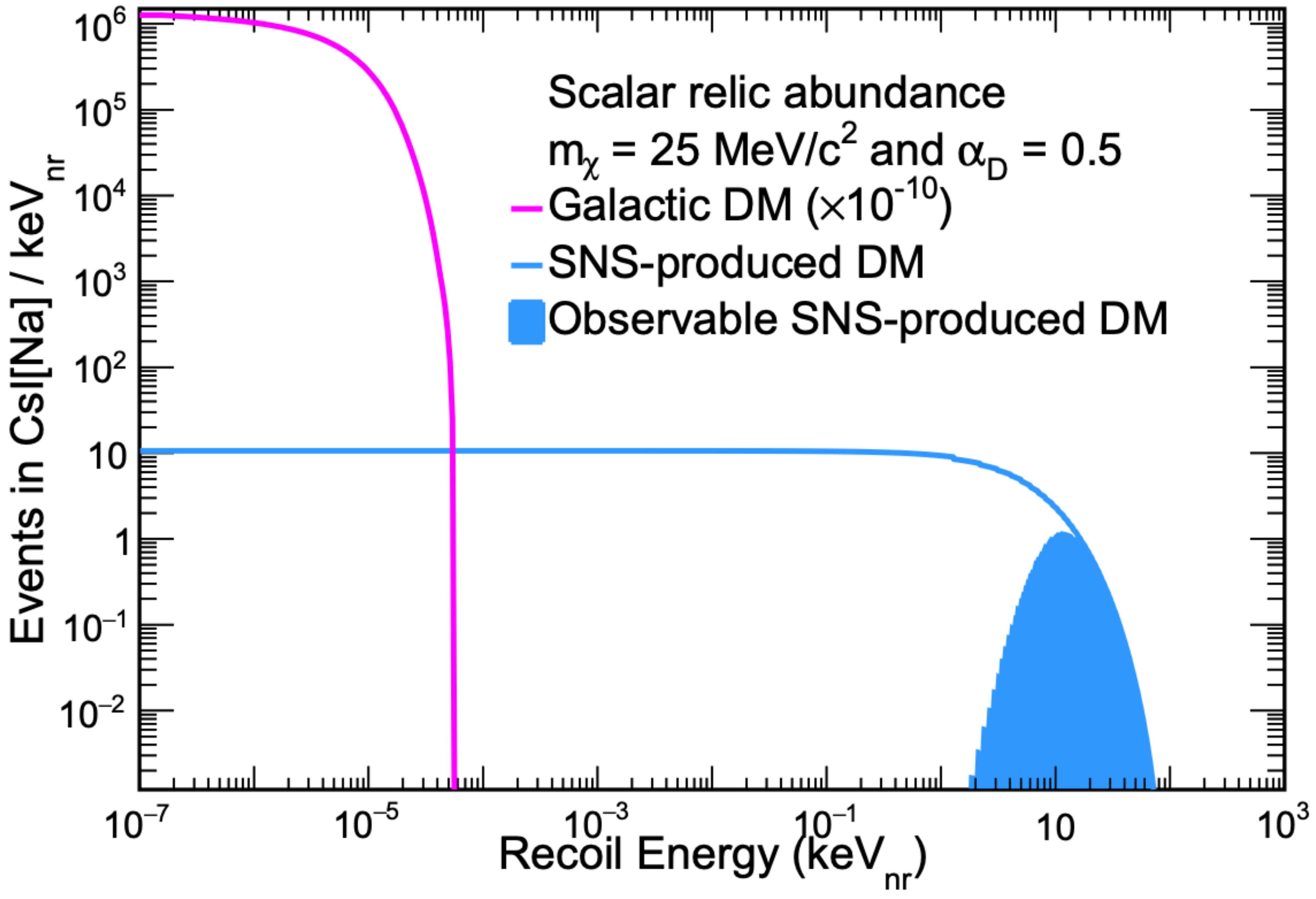


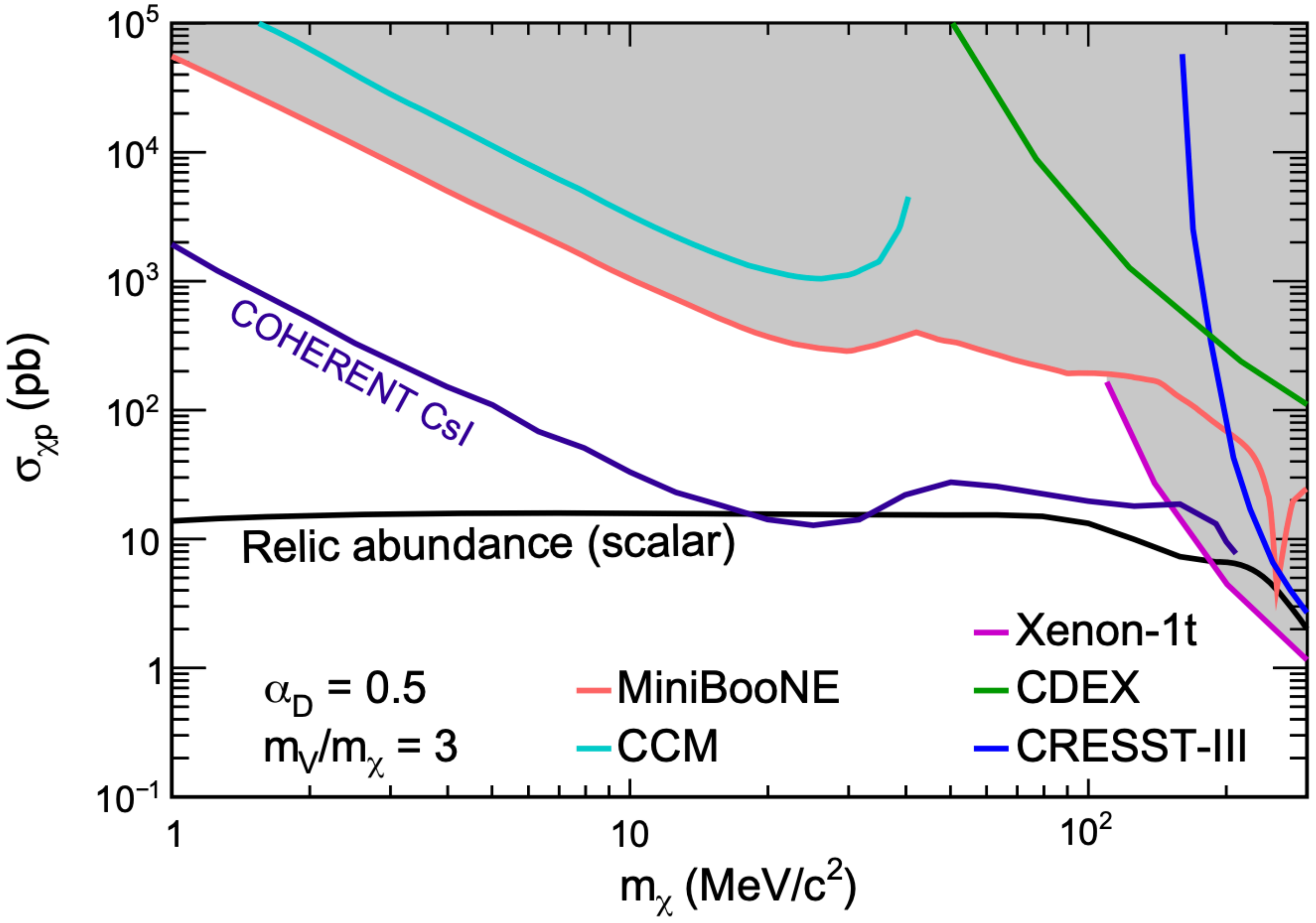
Signal Box = Lost Energy



COHERENT CsI Experiment

Benchmark model of scalar DM particle χ, mediated by a vector portal particle V

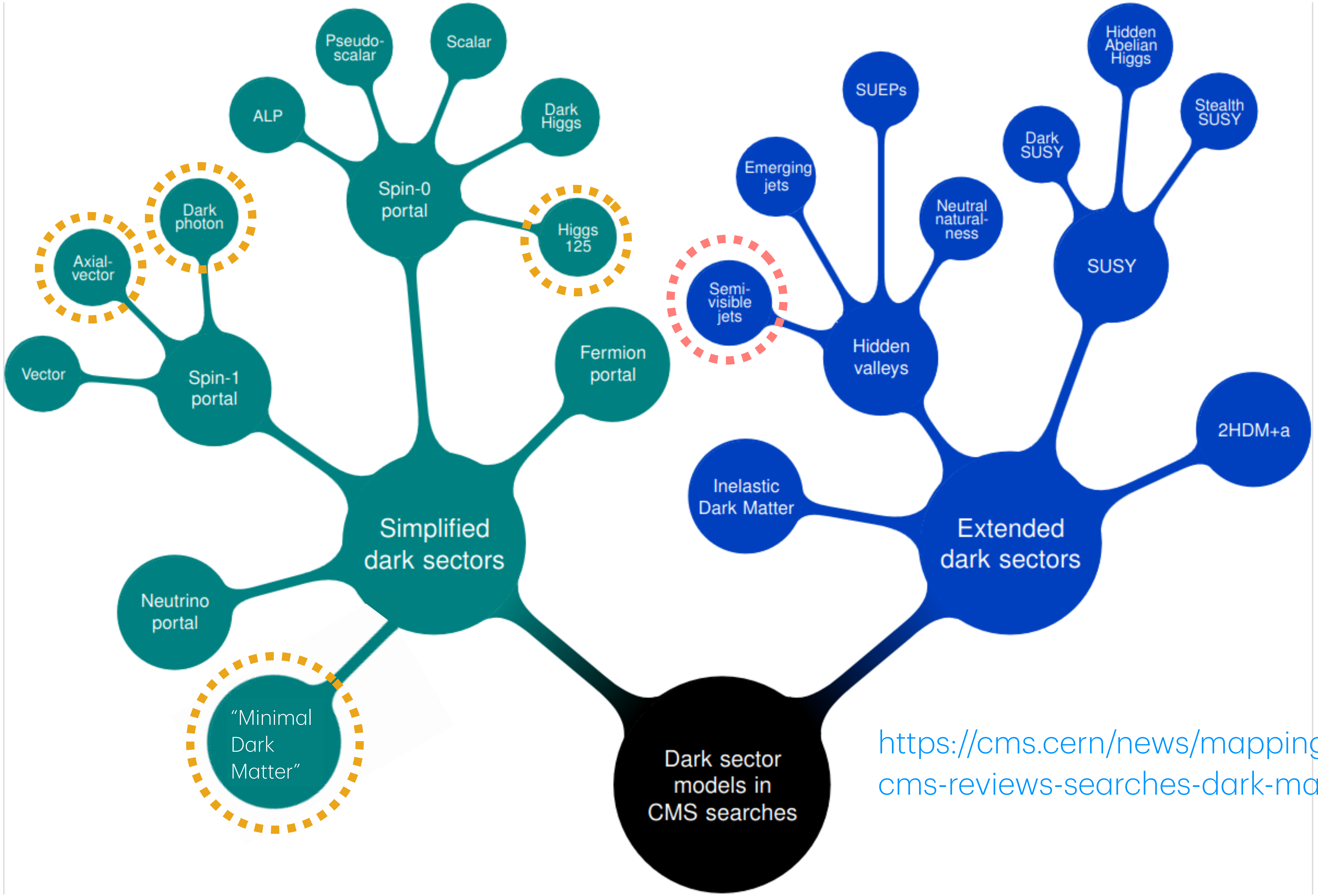




Phys.Rev.Lett. 130 (2023) 5, 051803

Models can be more complex

Discussed

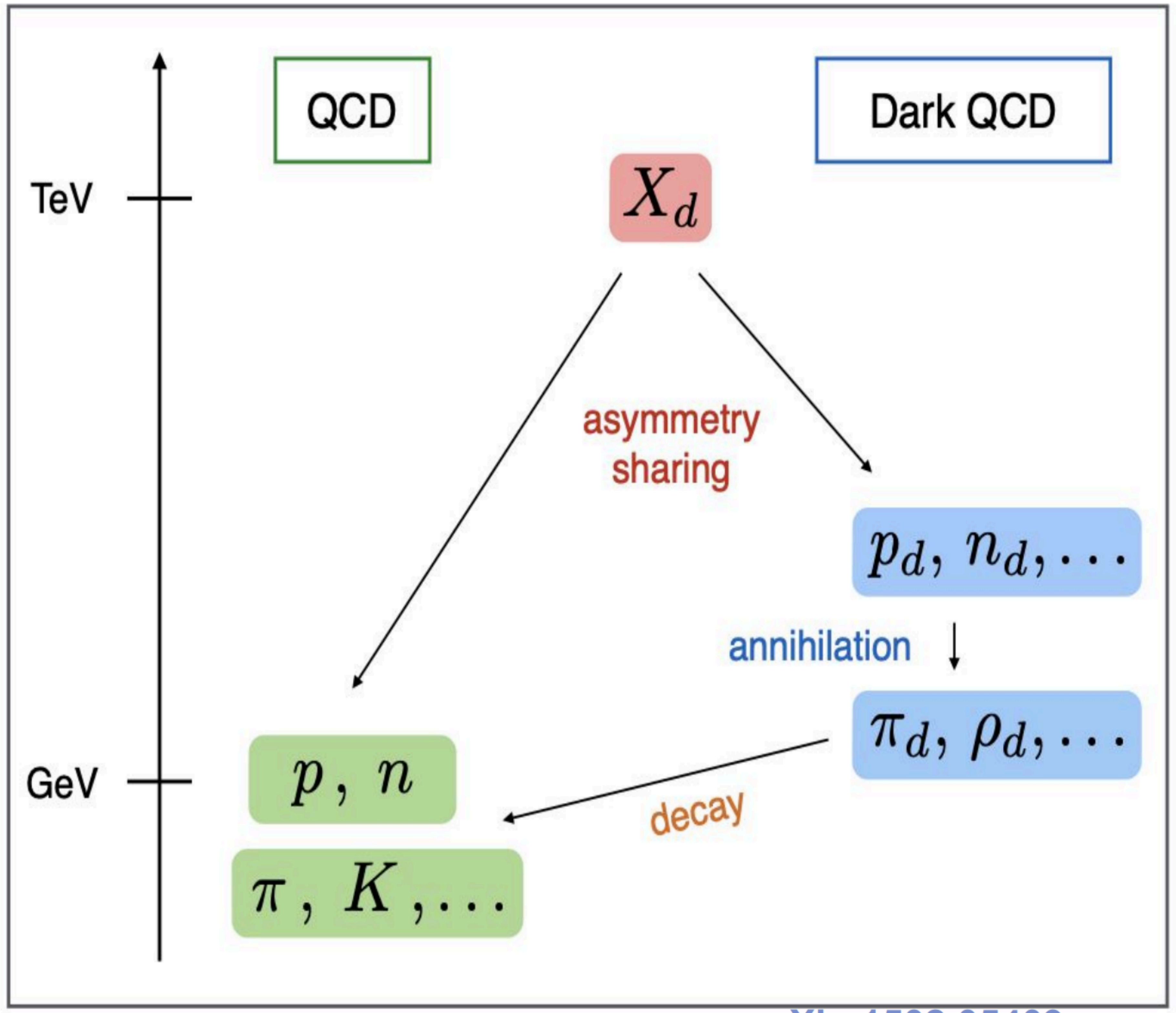


Complexity Example (next…)

https://cms.cern/news/mapping-uncharted-territory-cms-reviews-searches-dark-matter

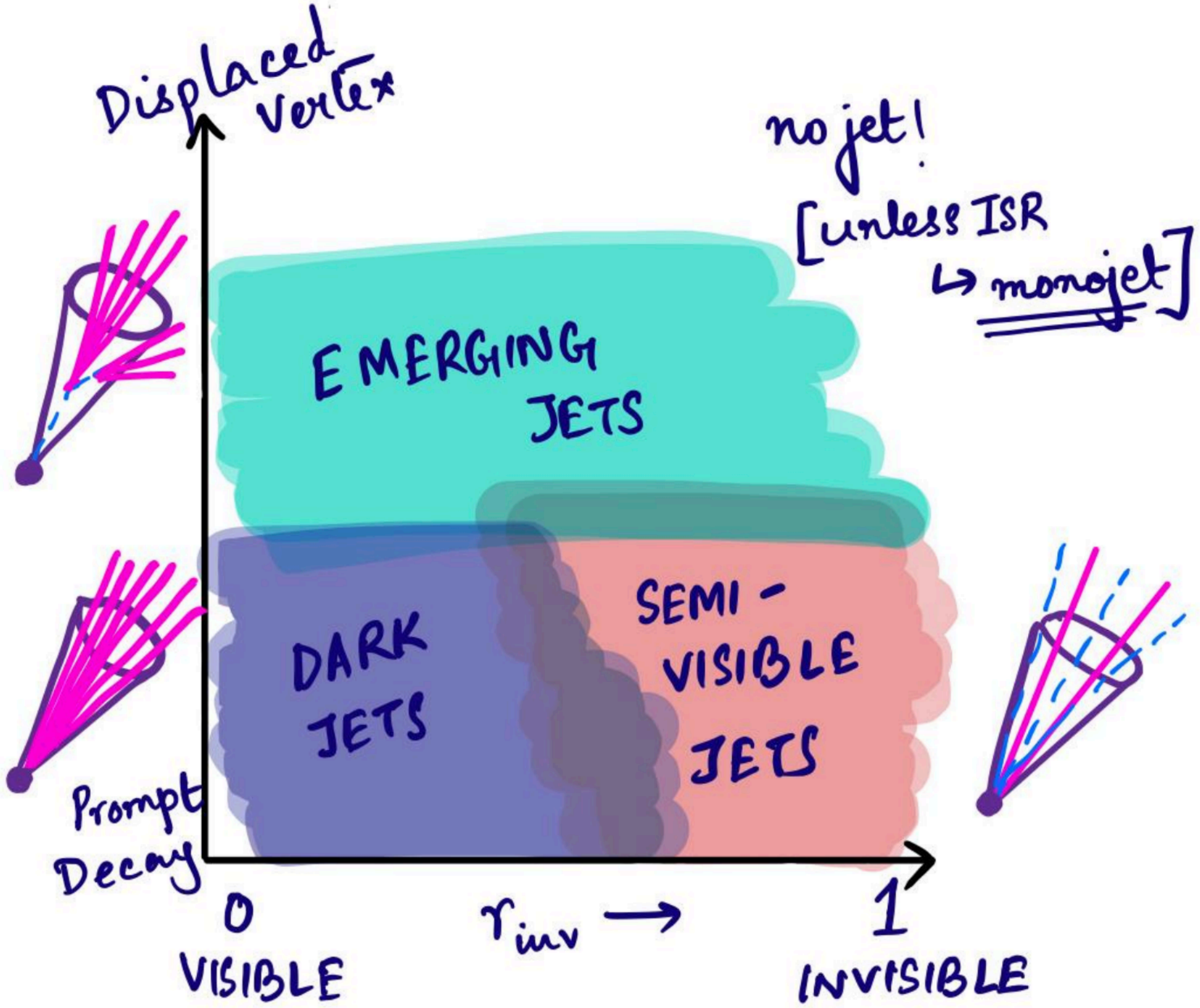
Dark matter to semi-visible jets: CMS

Hidden Valley with strong physics in the dark sector



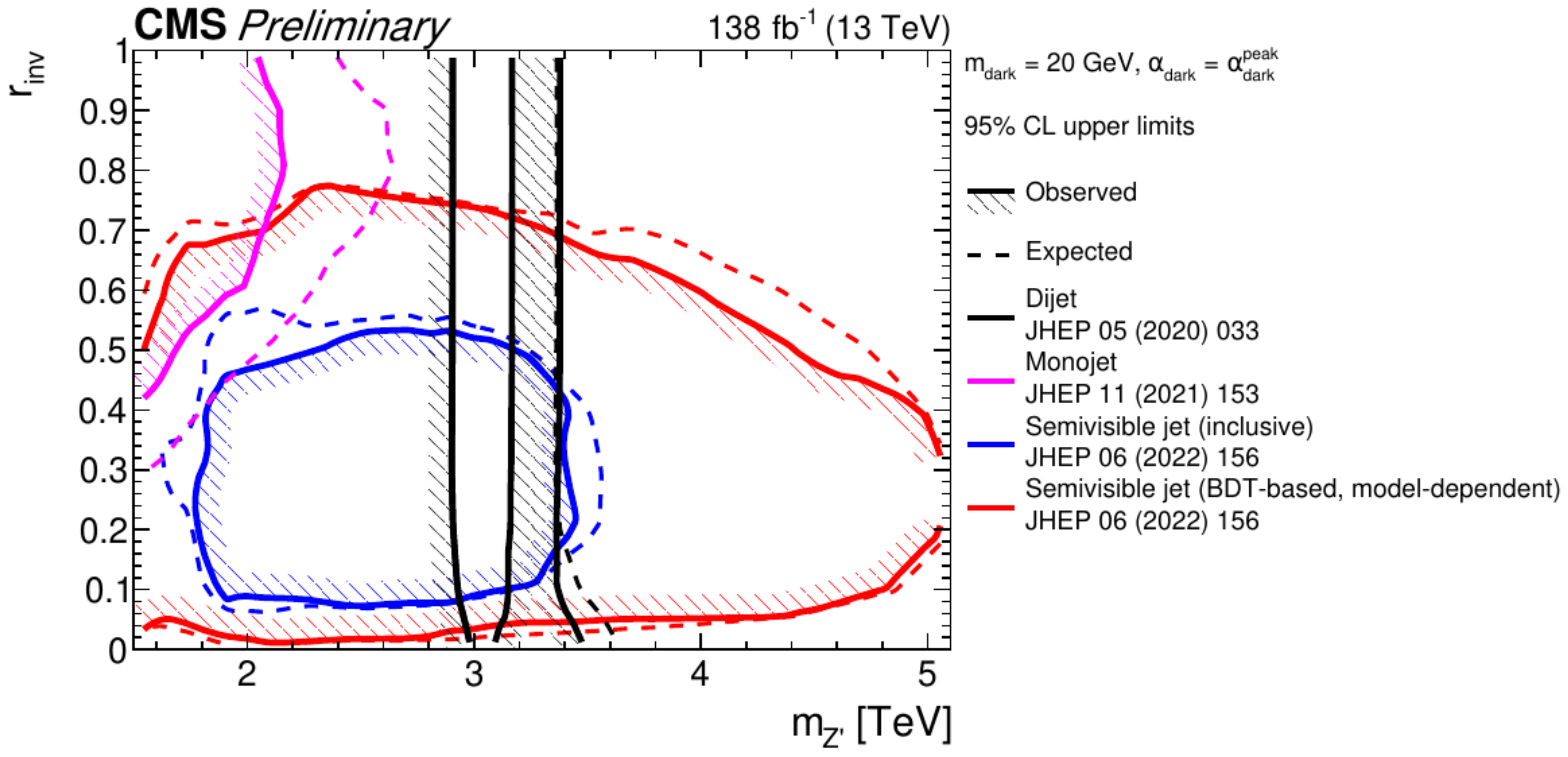
arXiv:1502.05409

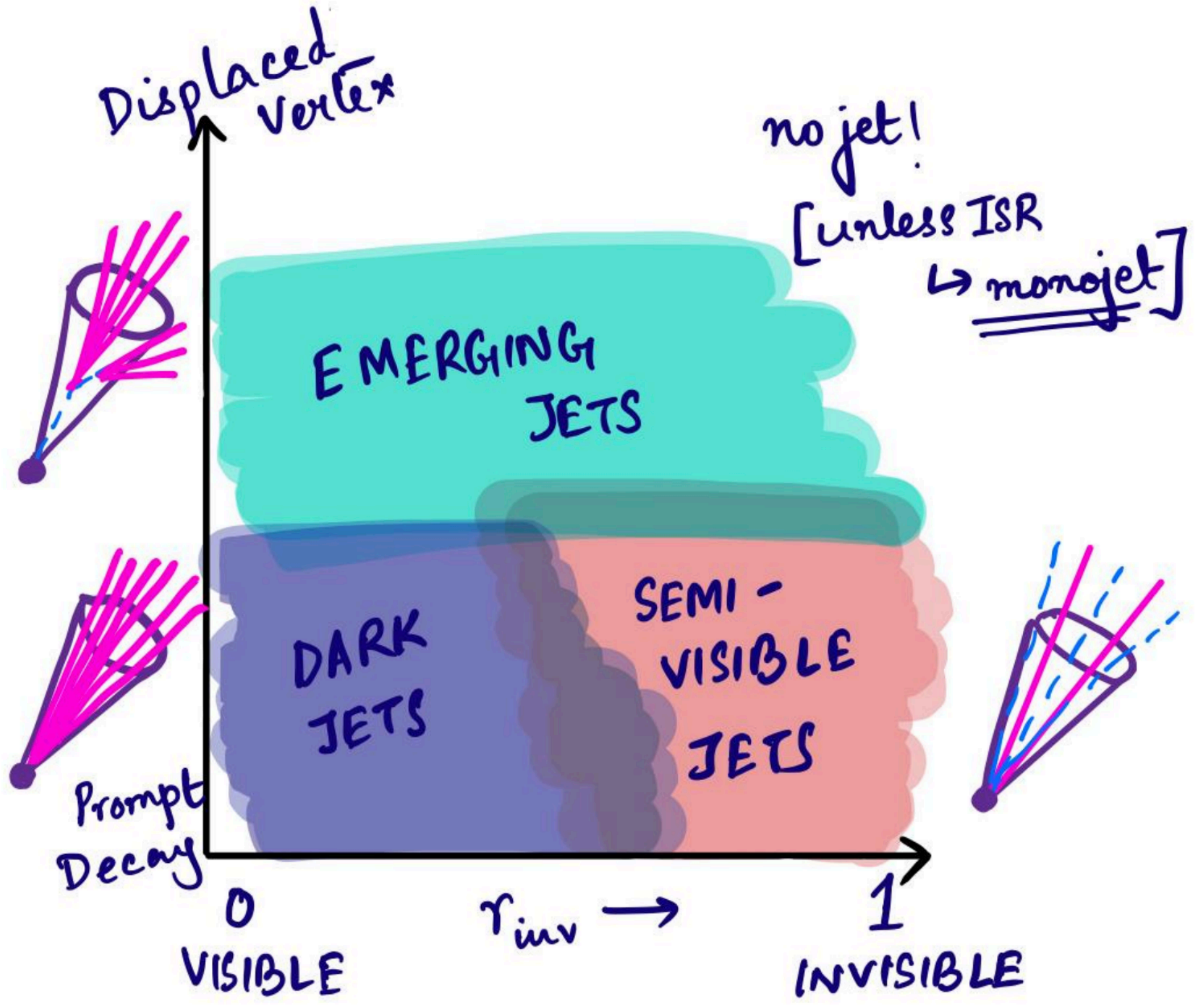
Complicated Collider Signatures



https://cds.cern.ch/record/2855831

Dark matter to semi-visible jets at CMS





https://cds.cern.ch/record/2855831

Conclusions

Wide variety of methods to cover large mass range and model space

— Complementarity

Many future experiments approved and proposed

— Report of the Topical Group on Particle Dark Matter for Snowmass

— Snowmass 2021 Cross Frontier Report: Dark Matter Complementarity (Extended Version)

— Dark Matter Production at Intensity-Frontier Experiments

Many excesses have been observed but not conclusively dark matter

— Nice snowmass summary of all the excesses indirect detection

Back-up/Spares

Backup: CMS disappearing track signals

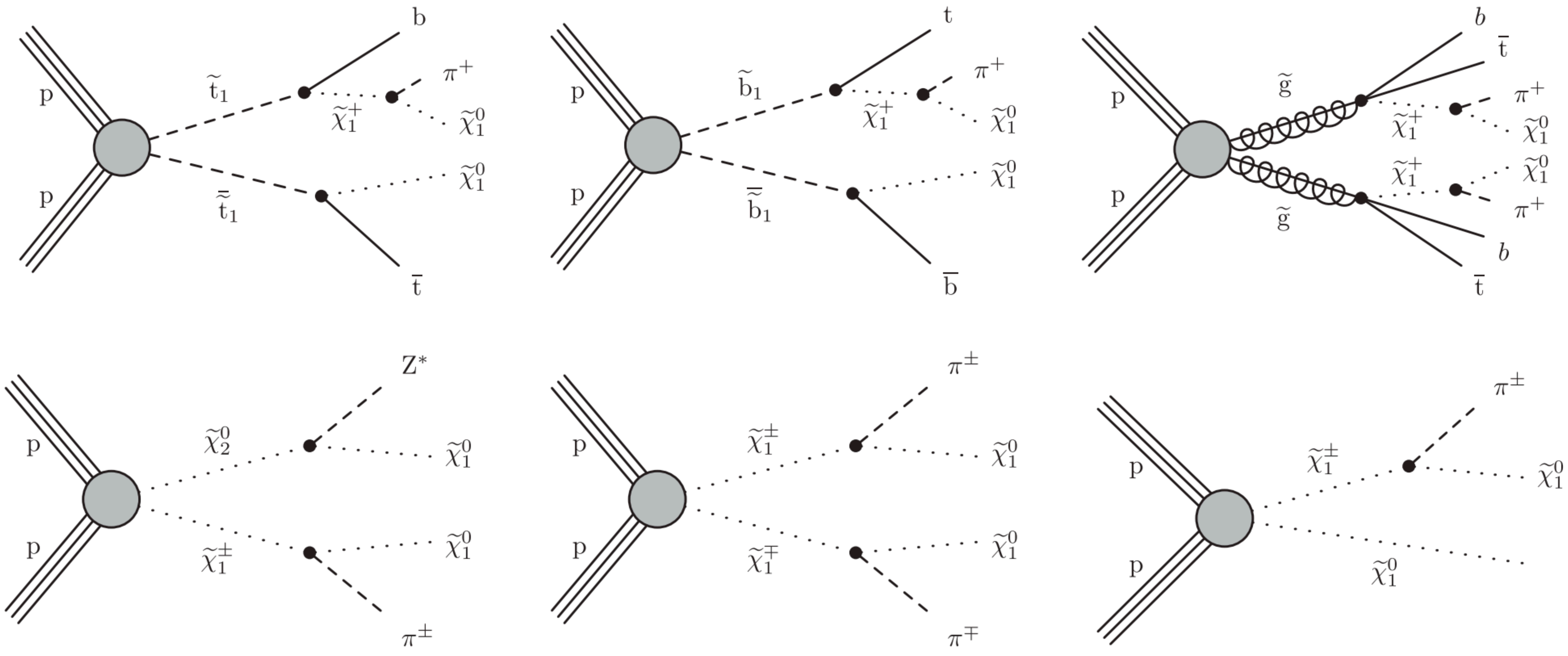
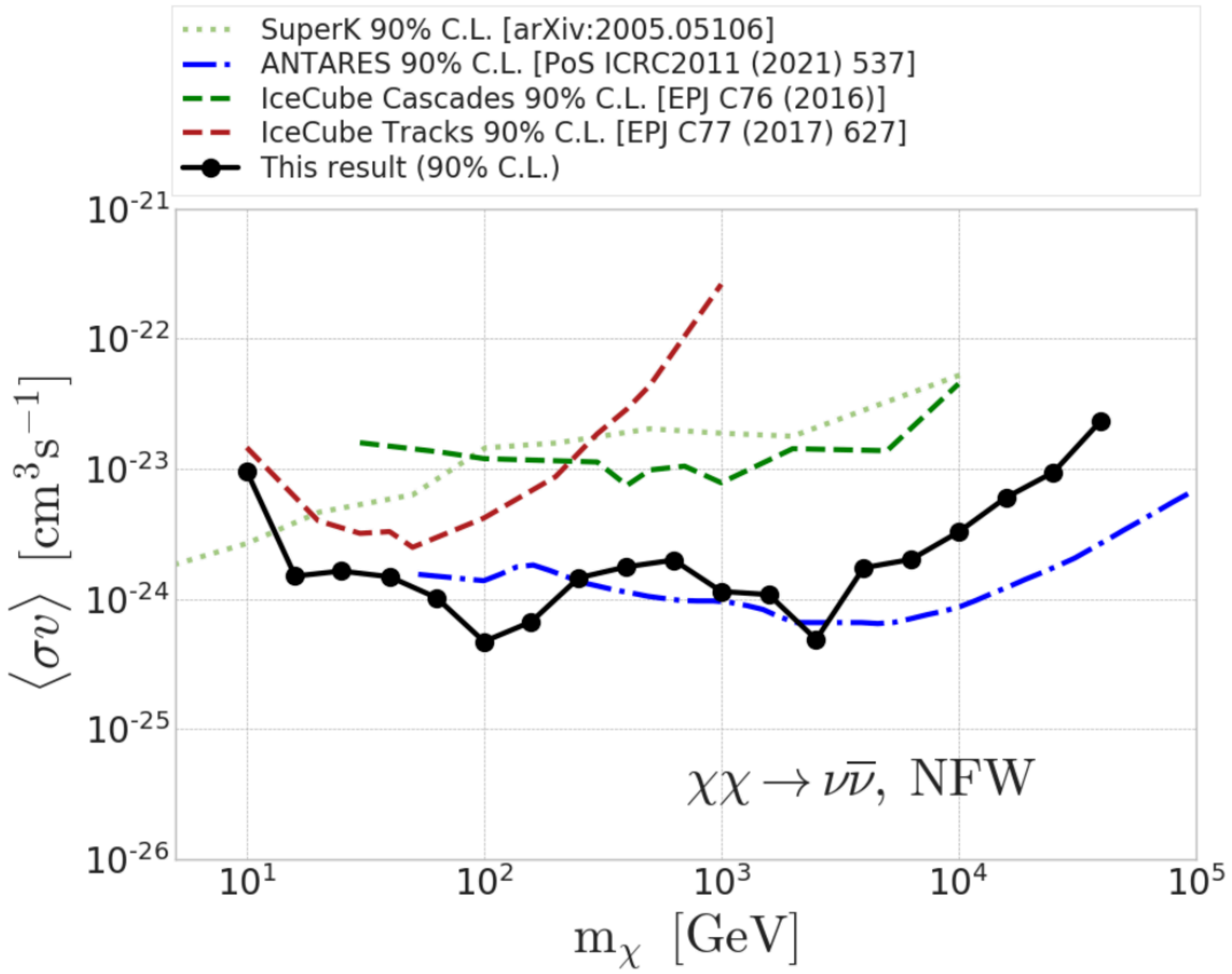


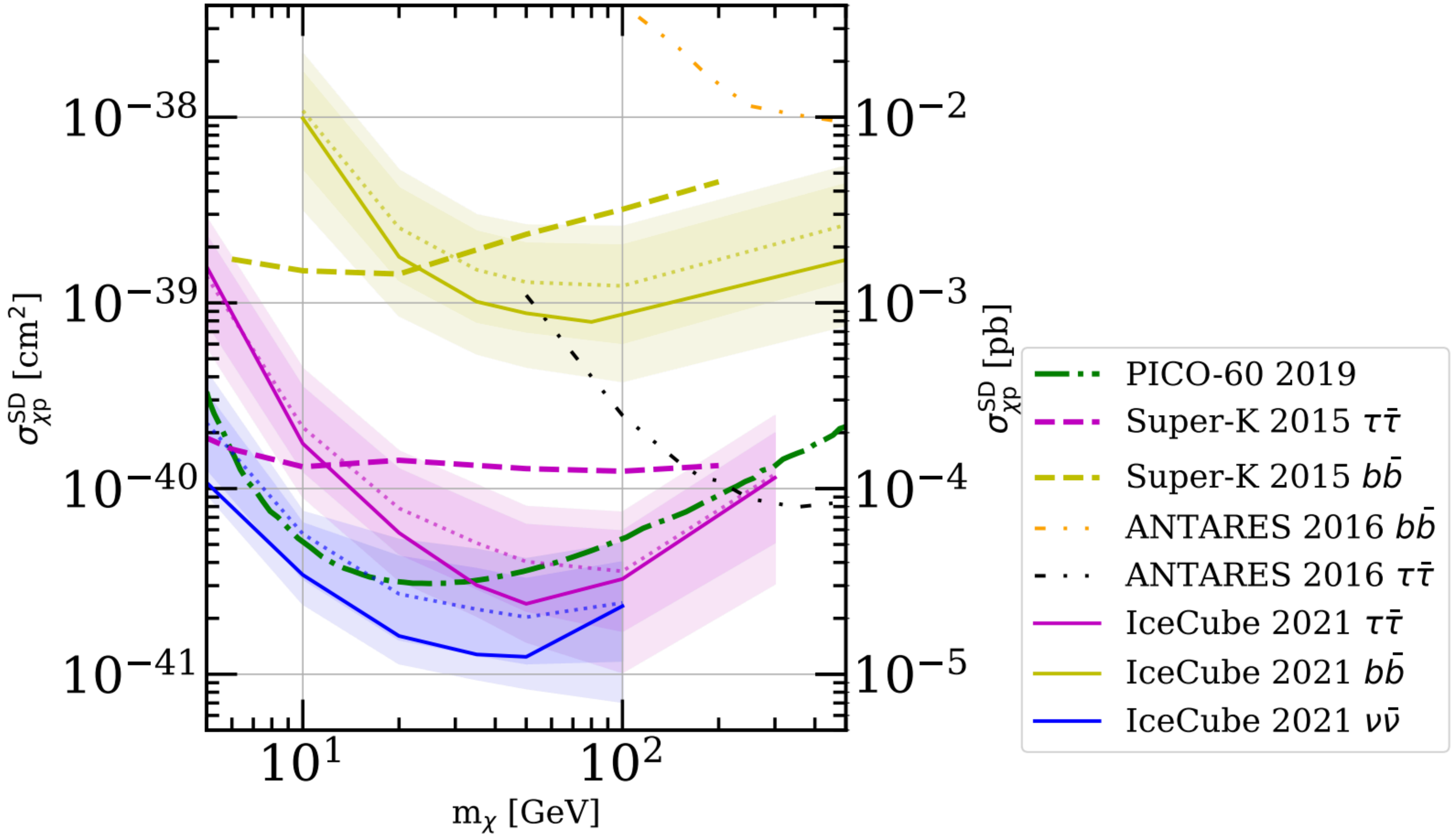
FIG. 1. Representative diagrams for the simplified models considered in this analysis. From left to right: T6btLL, T6tbLL, and T5btbtLL (upper); and TChiWZ, TChiWW, and TChiW (lower). The shaded circles at the production vertices represent a sum over perturbative terms.

Ice Cube

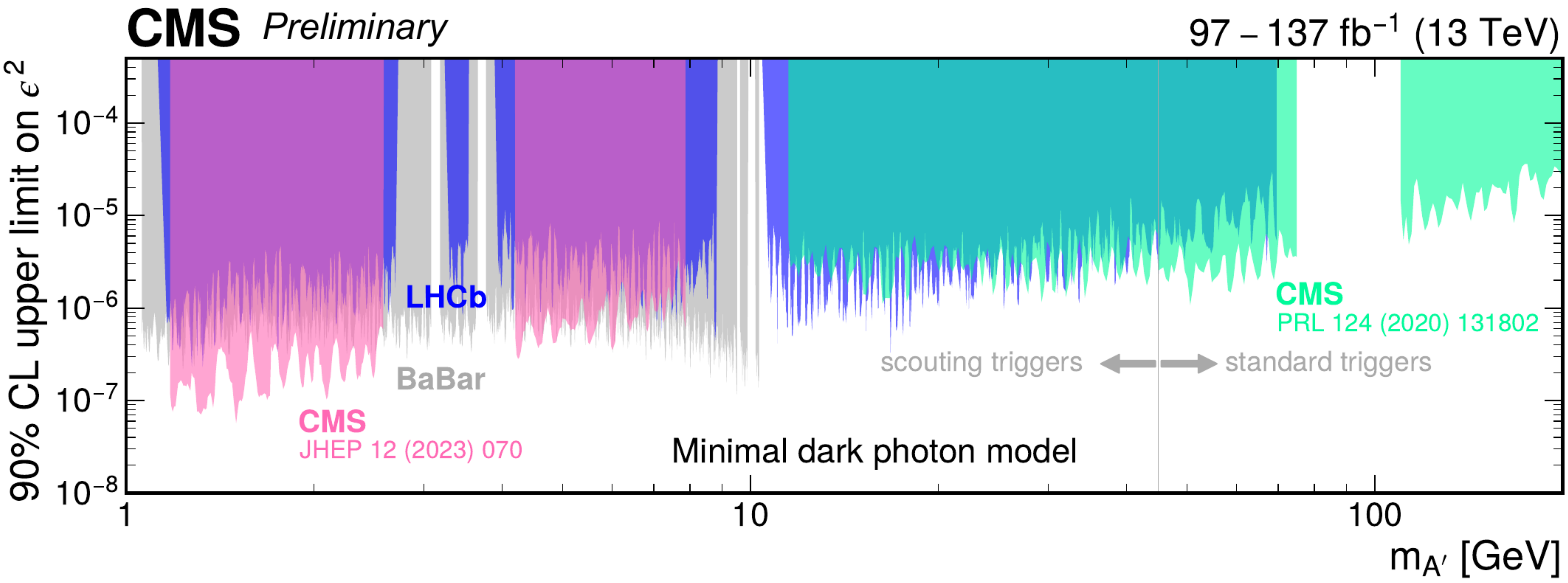
Neutrino lines



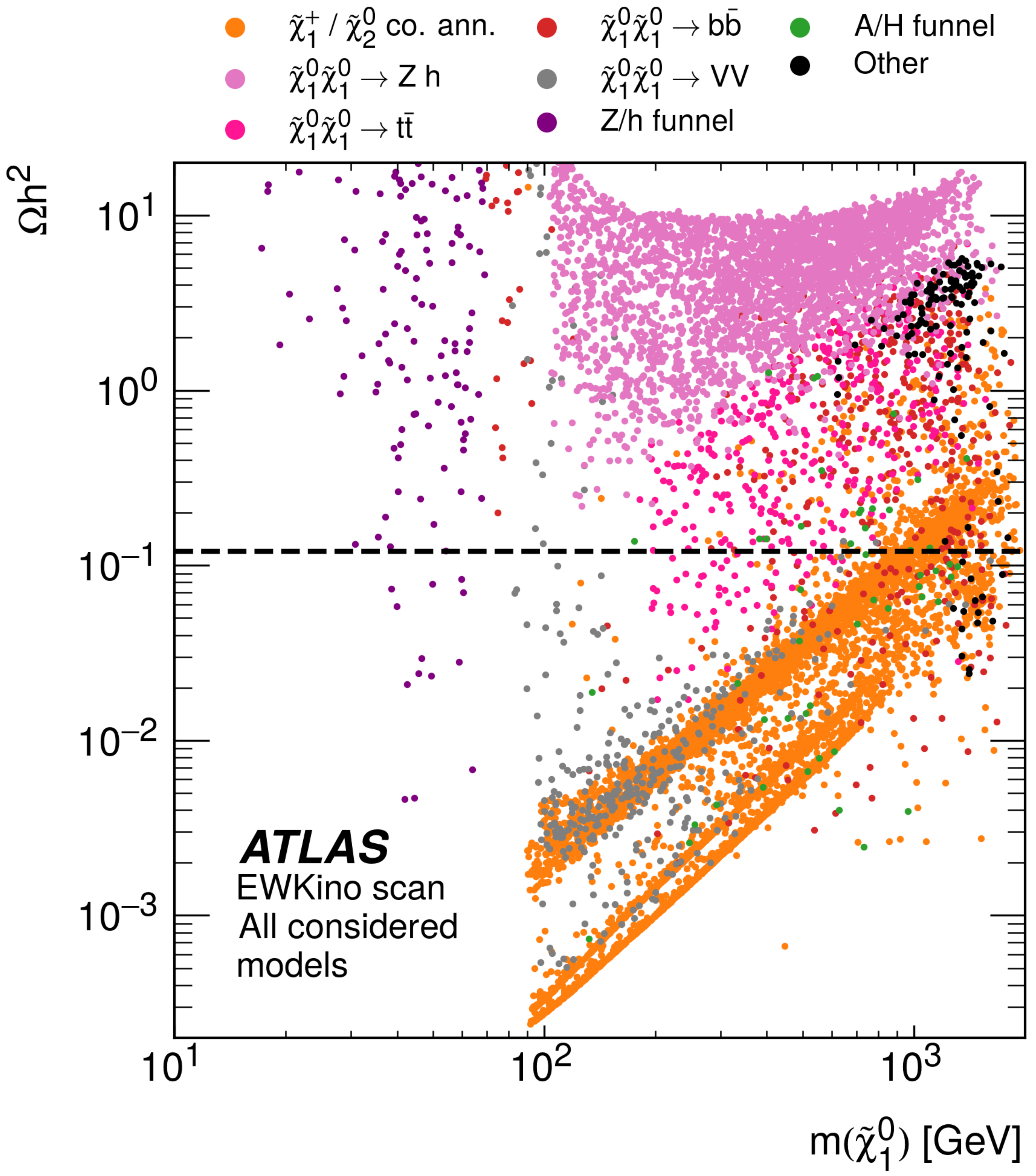
Dark Matter Neutrinos from Sun



LHC Dark Photons



SUSY and relic abundance



Same points labelled by LSP type

https://cds.cern.ch/record/2888303/