European Strategy
for Particle Physics

PPG BSM: WIMPs

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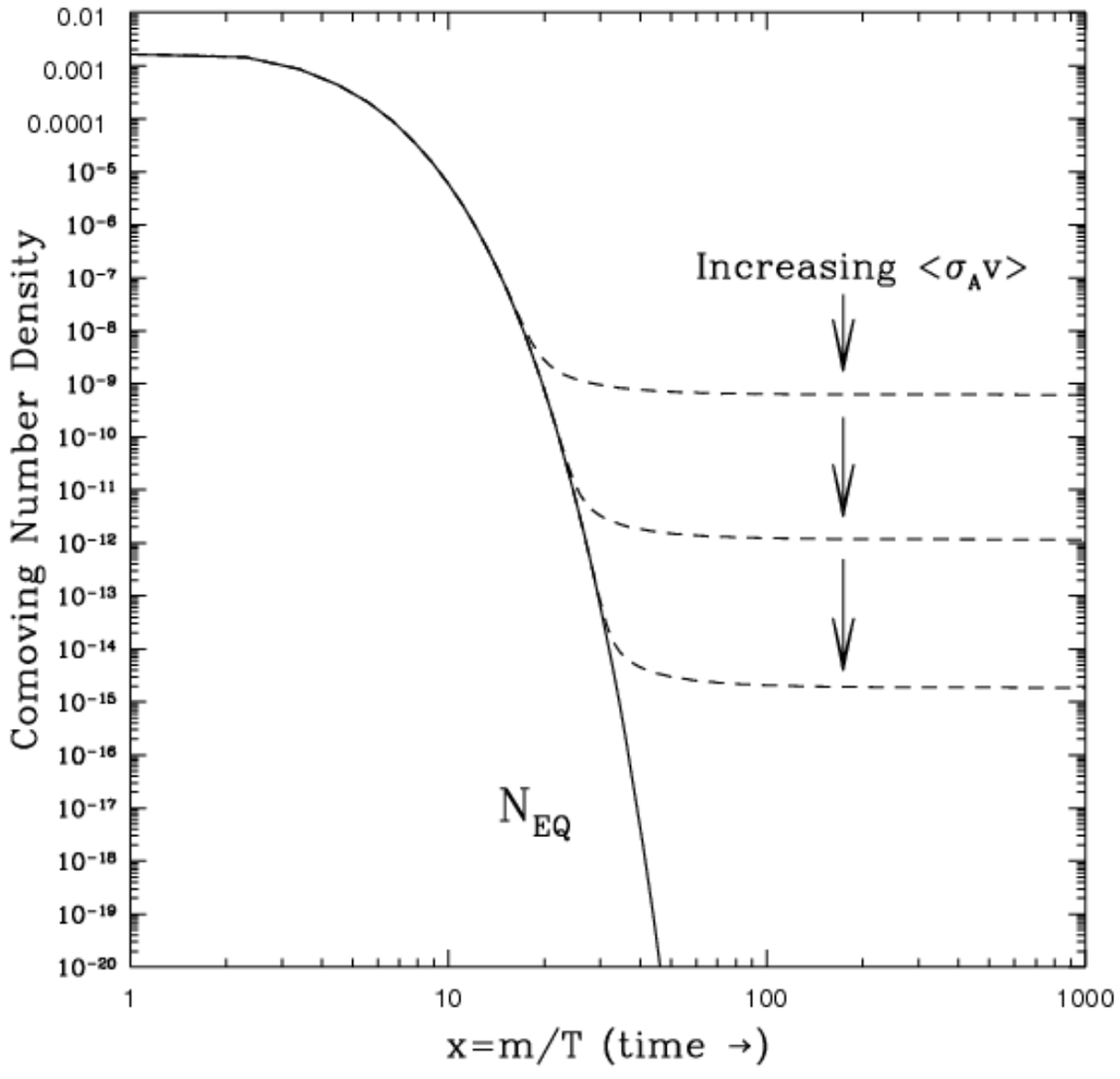
WIMP "Miracle"



Dark matter exists!

Assuming:

- Simple cosmology
- Interactions with the SM

  DM DM ⟷ SM SM

Freeze-out predicts

$$m_{\rm DM} \sim \alpha_{\rm ann} \left(T_{\rm eq} M_{\rm Pl} \right)^{1/2} \sim {\rm TeV}$$

Minimal Dark Matter

The simplest version of WIMP DM is to simply add one Electroweak multiplet to the SM

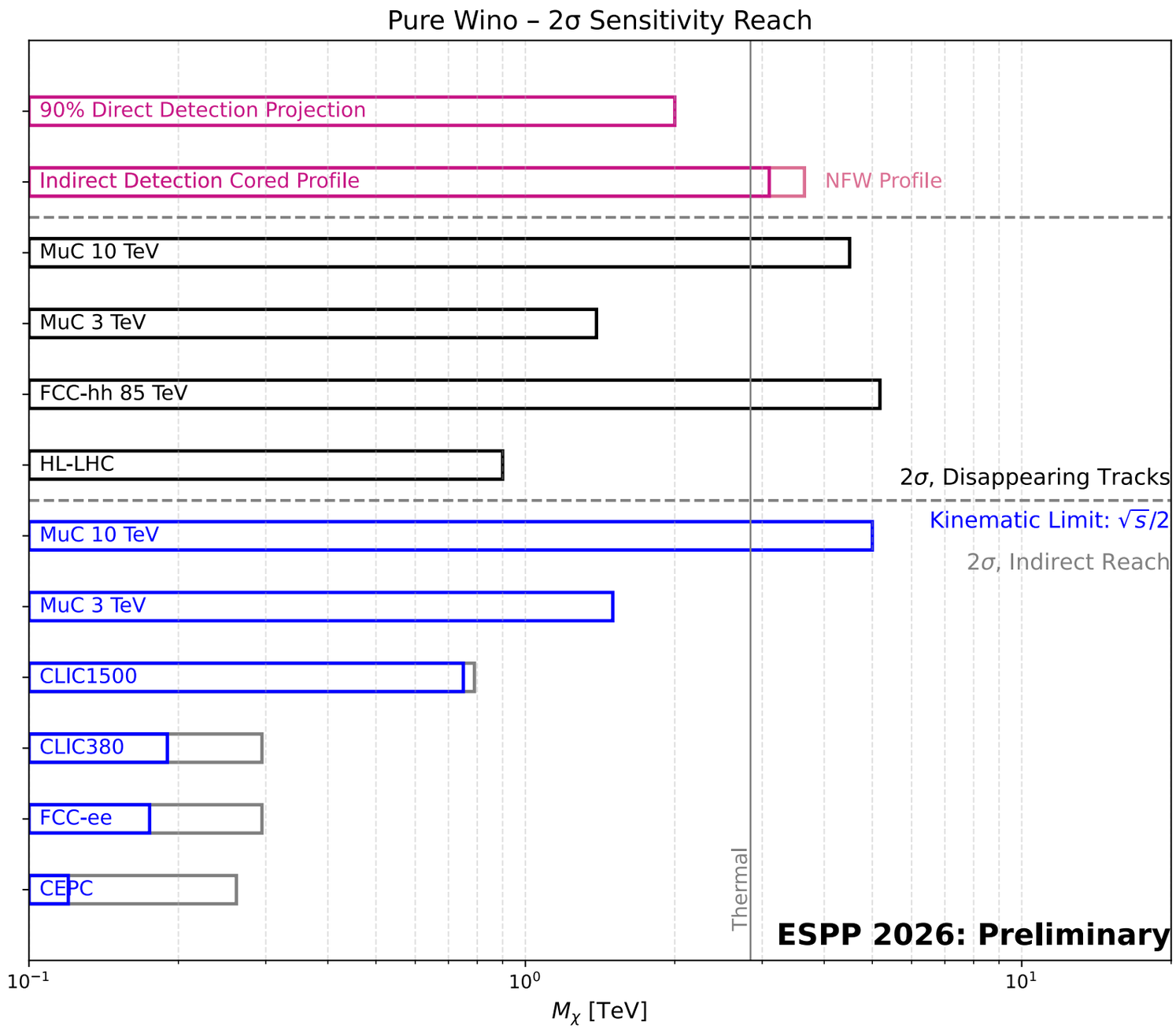
The model is then fully specified by choosing the mass of the multiplet

Two canonical models are

- Wino: Majorana fermion triplet
- Higgsino: Dirac fermion doublet

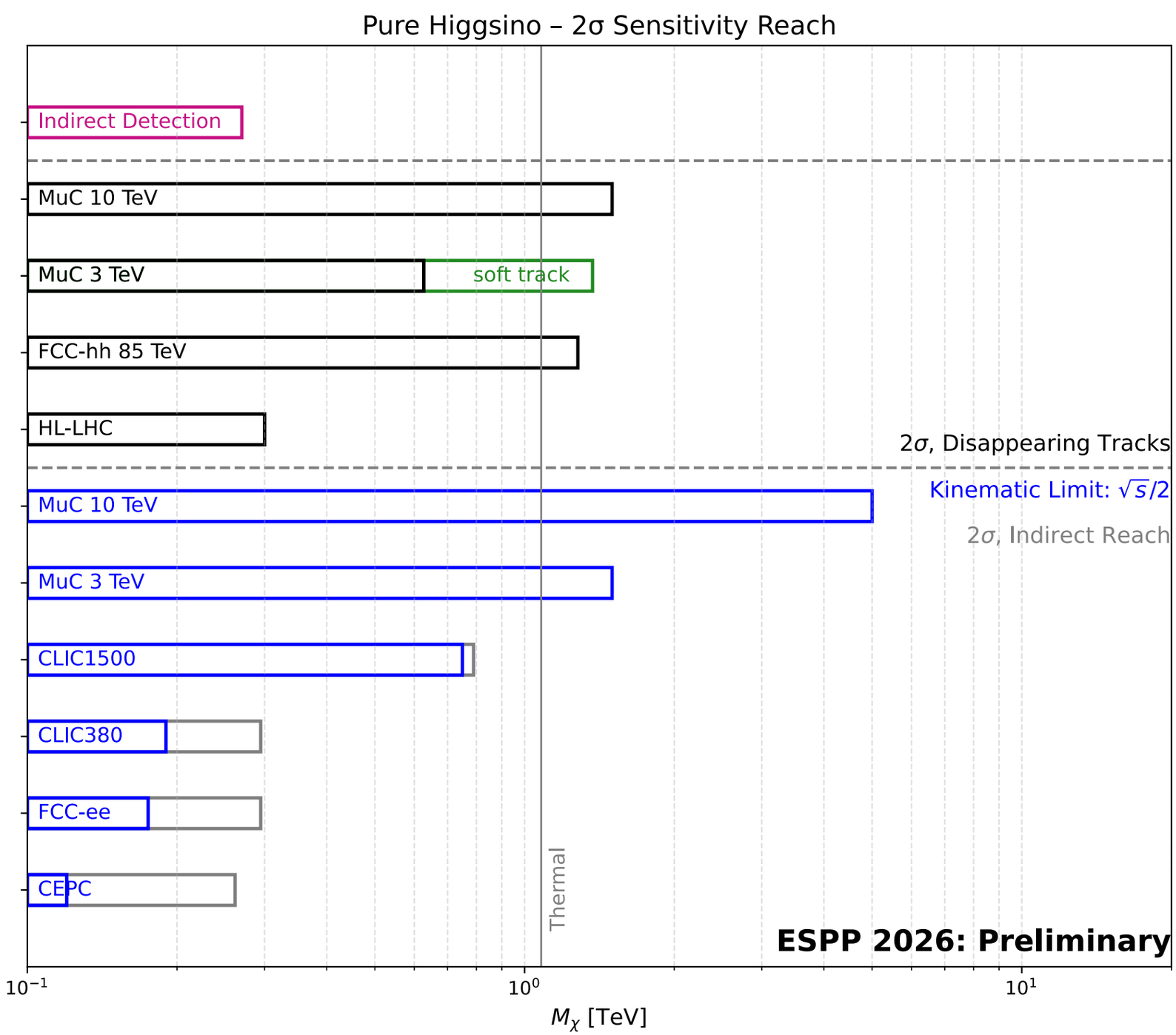
Note: for the Higgsino, must additionally split the neutral states to avoid direct detection

Wino



Note: thermal wino as dark matter is ruled out by indirect detection

Higgsino


Pure Higgsino – 2σ Sensitivity Reach
Indirect Detection
MuC 10 TeV
MuC 3 TeV
soft track
FCC-hh 85 TeV
HL-LHC
2σ, Disappearing Tracks
Kinematic Limit: √s/2
MuC 10 TeV
2σ, Indirect Reach
MuC 3 TeV
CLIC1500
CLIC380
FCC-ee
CEPC
Thermal
ESPP 2026: Preliminary
10^−1
10^0
10^1
M_χ [TeV]

Inputs for Wino and Higgsino

Collider inputs unchanged from the briefing book 2019 (fig 8.14 and 8.15 in https://arxiv.org/abs/1910.11775v2), or Snowmass 2021, except for:

- Muon Collider have been updated based on inputs from Federico Meloni based on Fig. 20.0.1 in https://arxiv.org/abs/2504.21417. A more sophisticated analysis based on soft tracks allows for a more stringent limit, and is overlayed to the 1DT result. (Note that the soft tracks limit is only dominates for Higgsinos, so it is not included in the wino plot.)
- FCC-hh from Fig 5 in https://www.arxiv.org/pdf/1901.02987, rescaled to 80 TeV by the authors. Scenario considered: Alternative Layout, optimistic pileup = 200 with time information (which assumes background reduction rate to be the same for optimistic and pessimistic pileup scenarios.

Inputs for Wino and Higgsino

Relic abundance lines:

- Wino relic density with NLO Sommerfeld https://arxiv.org/pdf/2009.00640

This paper derives the thermal line at 2.842 TeV. The also provide an LO value that 2.886 TeV.

- Higgsino relic density: https://arxiv.org/pdf/2205.04486

The relevant value is the 2_{1/2} entry in Table 1: 1.08 TeV

Indirect detection:

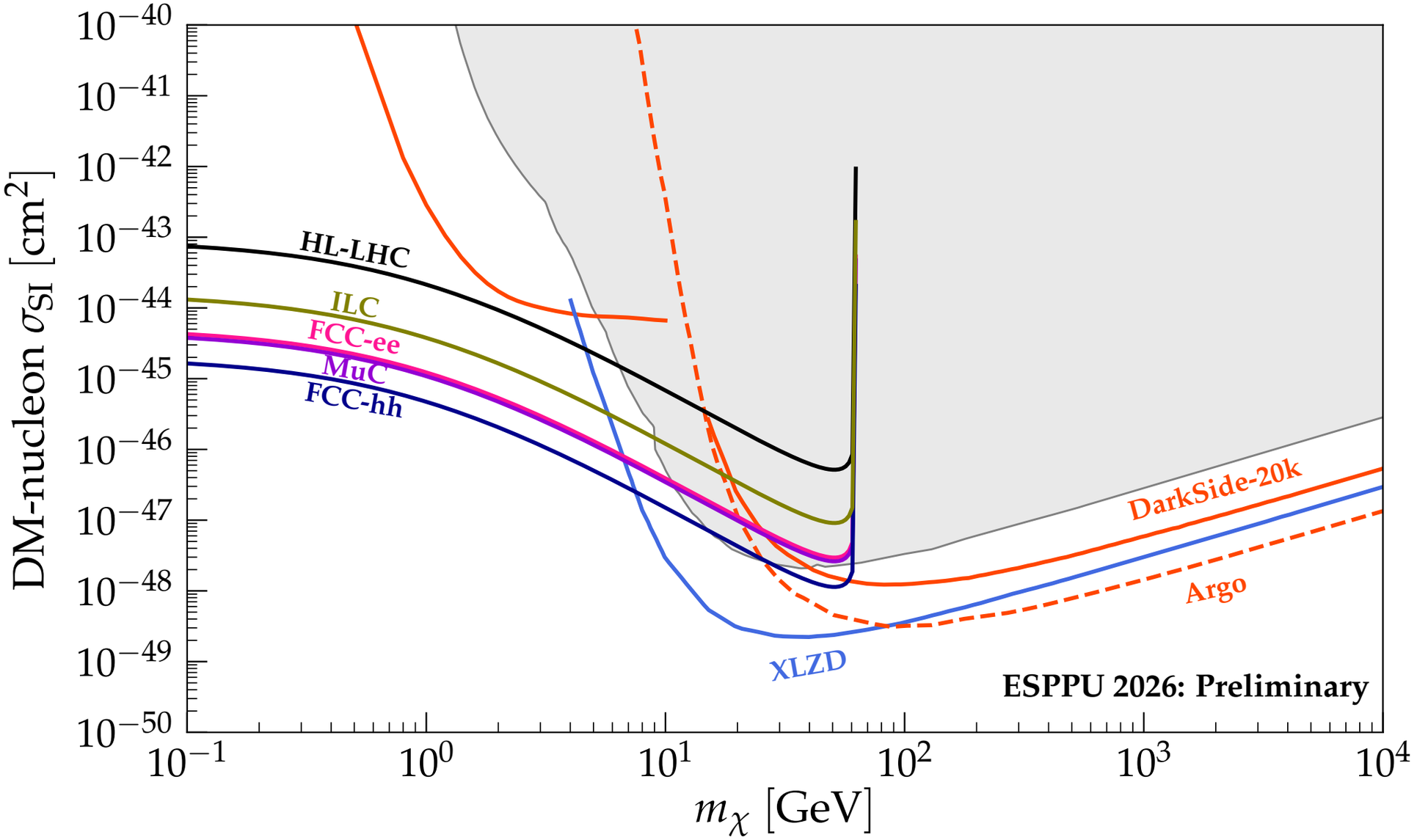
Wino limits from an analysis of the Fermi data looking for annihilation to WW:
NFW profile 2 sigma exclusion is 3.65 TeV; cored profile 3.1 TeV (private communication)

Higgsino limits from line search using Fermi data:
NFW profiled 2 sigma exclusion is 270 GeV https://arxiv.org/pdf/2207.10090

Credit: Joshua W. Foster, Yujin Park, Benjamin R. Safdi, Yotam Soreq, Weishuang Linda Xu, Nick Rodd, Christopher Dessert

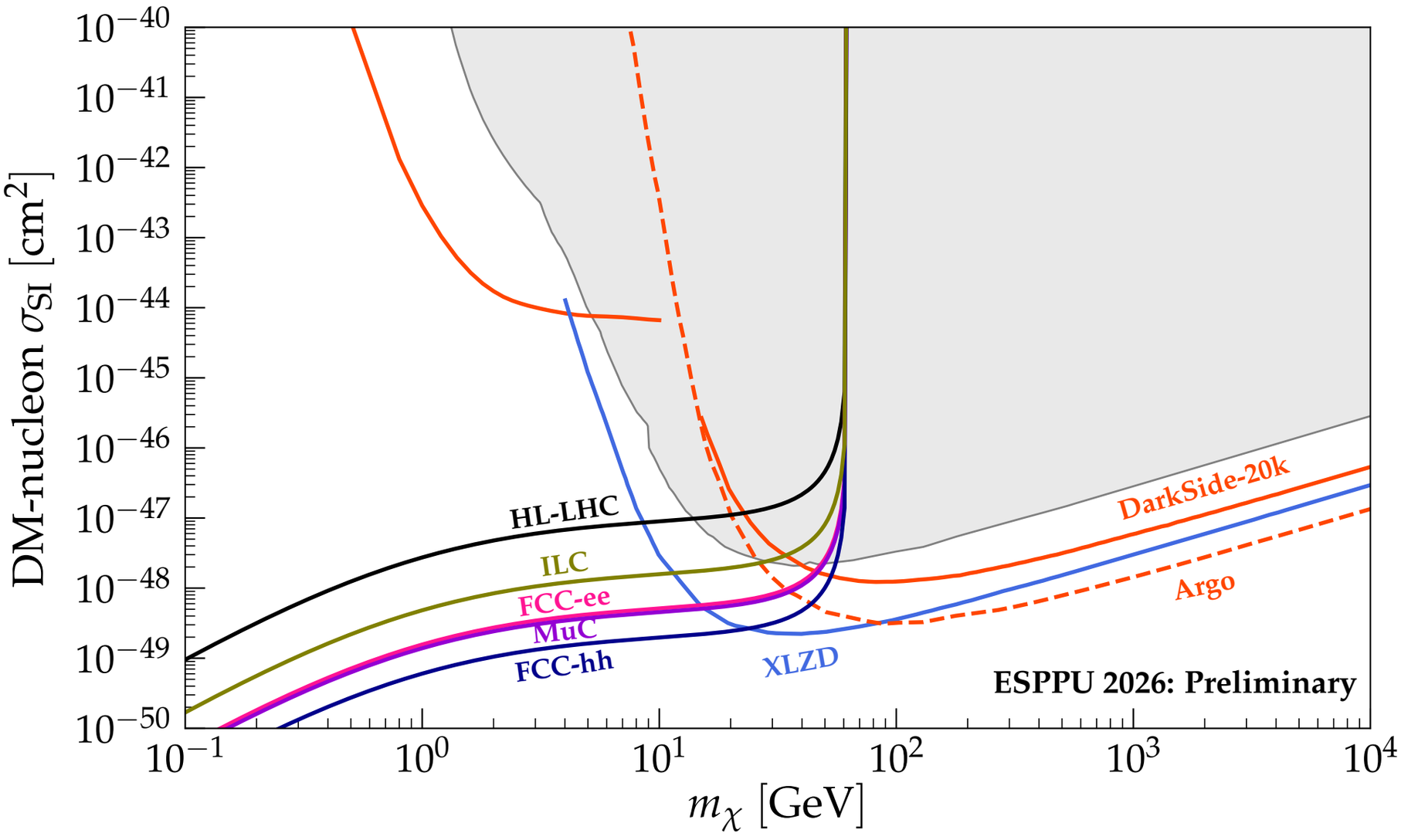
Higgs Portal DM: Scalar

$$\mathcal{L}_{\text{int}} \sim |H|^2 S^2$$



Higgs Portal DM: Fermion

$$\mathcal{L}_{\text{int}} \sim |H|^2 \bar{\Psi}\Psi$$



Non-renormalizable coupling implies need to be careful of EFT validity

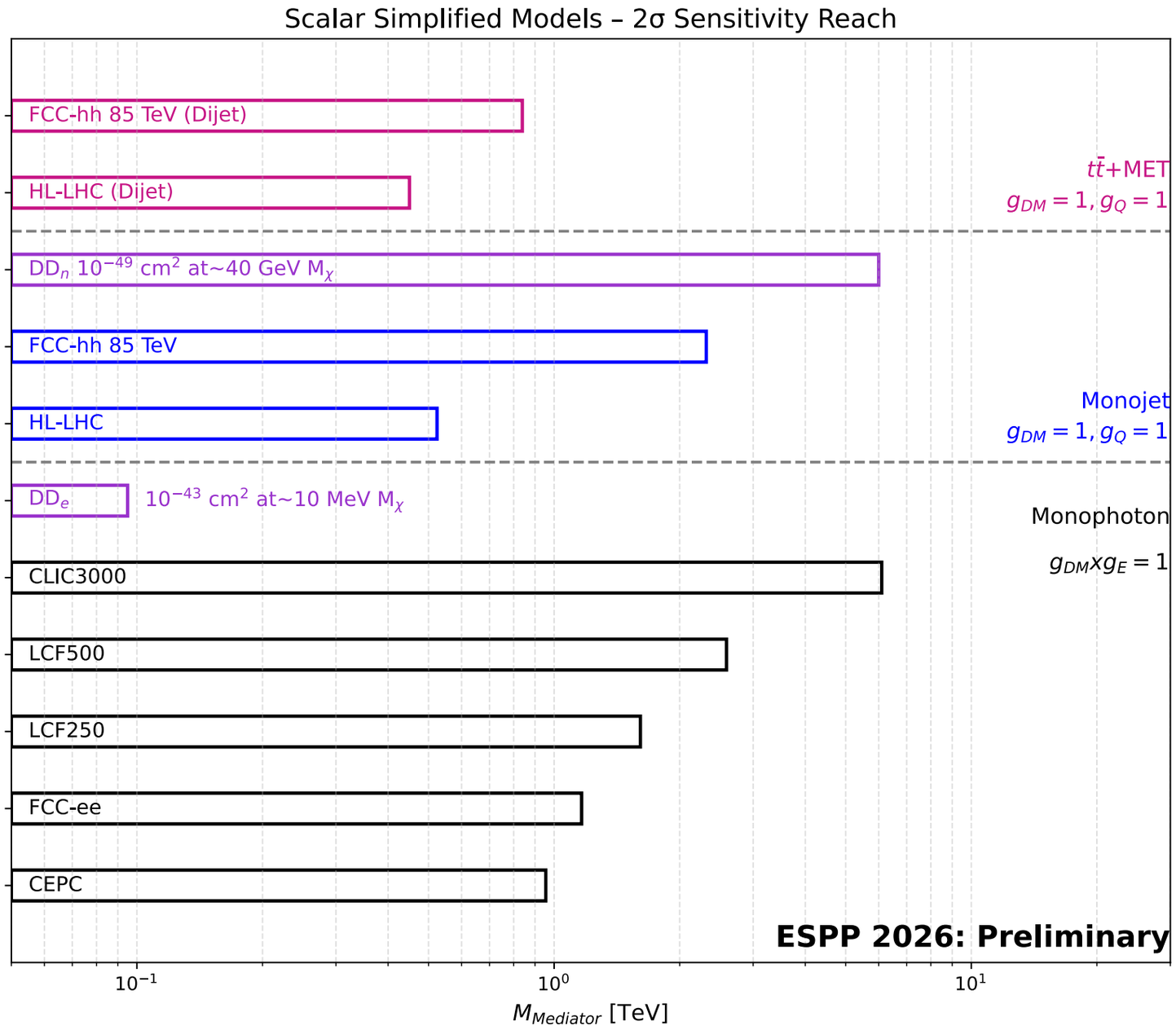
Higgs portal model: Collider Inputs

Direct constraints on Higgs to invisible

- HL-LHC: 2.5% as taken from https://e-publishing.cern.ch/index.php/CYRM/article/view/952/769 N.B: There is an additional study from Phil Harris that indicates 0.9% at 6 ab-1. Need to follow up after Venice.
- FCC-hh: 2 x 10-4 numbers from Phil Harris at sqrt(s) = 100 TeV
- ILC: 0.16% combining 900 fb-1 per each polarization at sqrt(s) = 250 GeV. Number from Table 8 in https://arxiv.org/pdf/2203.08330
- FCC-ee: 0.052% from https://repository.cern/records/9b128-qqc43
- Muon Collider: 4.6 x 10 e-4 with 1% relative uncertainty on resolution from https://arxiv.org/pdf/2411.00096, which is referenced in the Muon Collider Input ID 207

For direct detection details, see dark sectors session

Scalar Portal Model



DD lines are for best a direct detection experiment could do (details on following slide)

Scalar Portal Model: Inputs

DDe and DDn show the “maximal” direct detection reach plausibly feasible in proposed experiments.

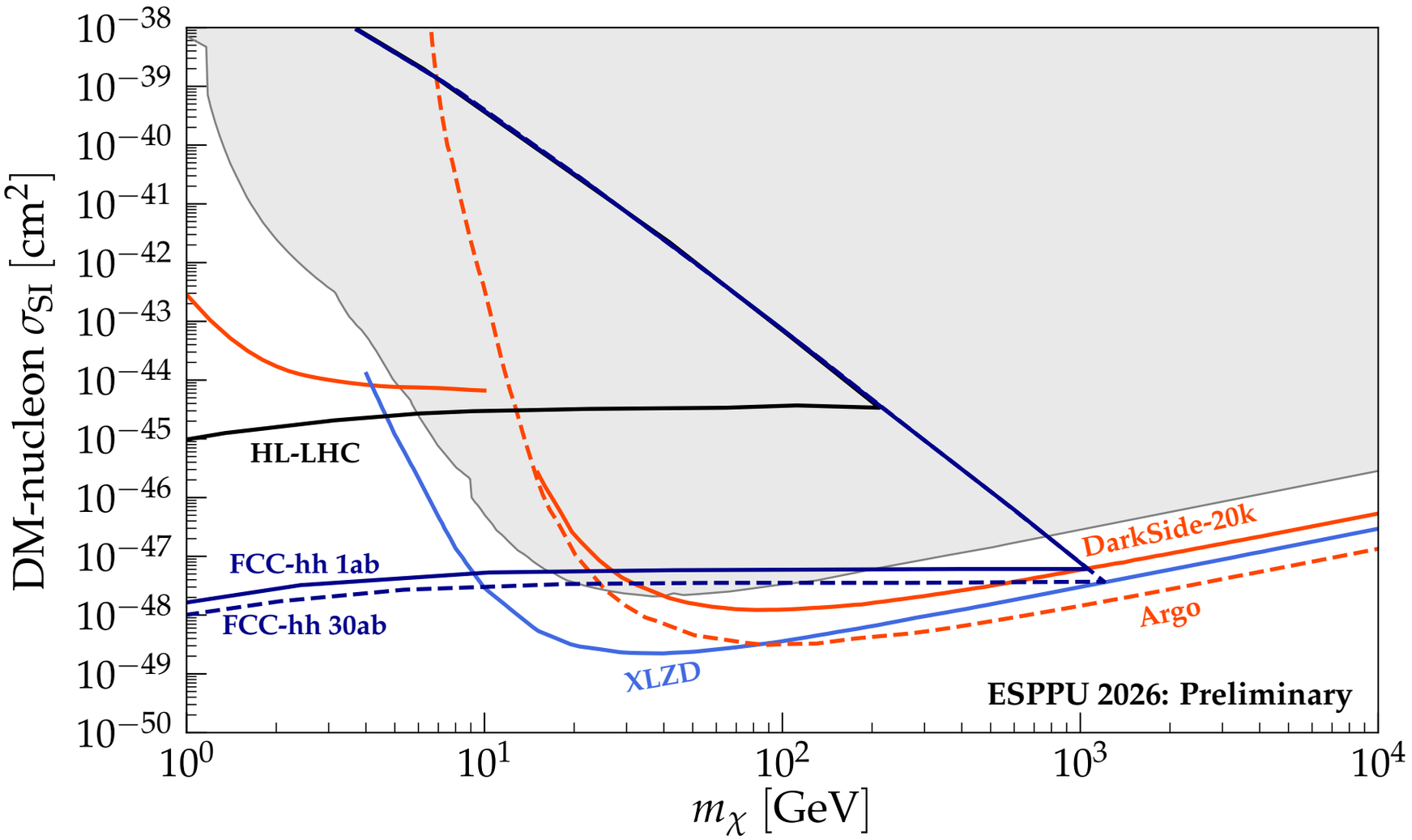
- XLZD 1000 t yr for nucleons (DM mass ~ 40 GeV)
- OSCURA for electrons (DM mass ~ 10 MeV)

Collider input changes wrt previous briefing book:

- FCC-hh scaled to 85 TeV
- ILC updates via private communication with Jenny List. Mass scale limits come from mono-photon analysis and are based on Eur.Phys.J.C 81 (2021) 10, 955 (arXiv:2107.11194) including systematic uncertainties.

Scalar Portal Model: DDn

Scalar particle with unit couplings mediates the interaction between SM fermions and Dirac fermion DM



Collider inputs unchanged from previous briefing book

Conclusions

Discovering dark matter requires a multi-pronged strategy

Input from colliders, direct detection, astrophysical probes, cosmology, and theory

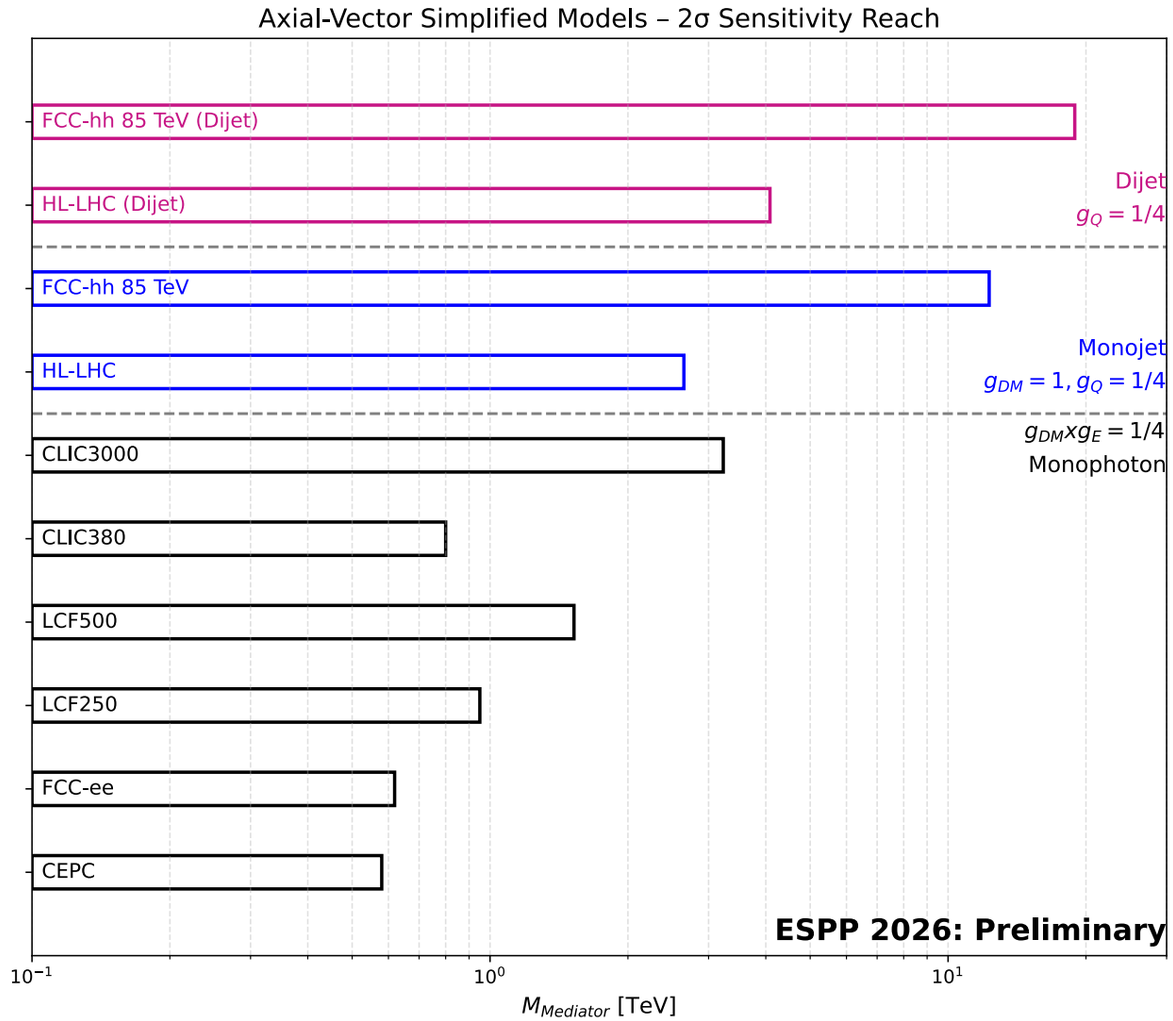
Dream scenario of discovering the Higgsino at CTA by around mid 2027 and then directly measuring at future colliders is still possible!

Many simple well-motivated candidates exist and searching for them can lead to a discovery!

Note a few plots are provided in the backup that we are unsure if they will appear in the briefing book

Backup

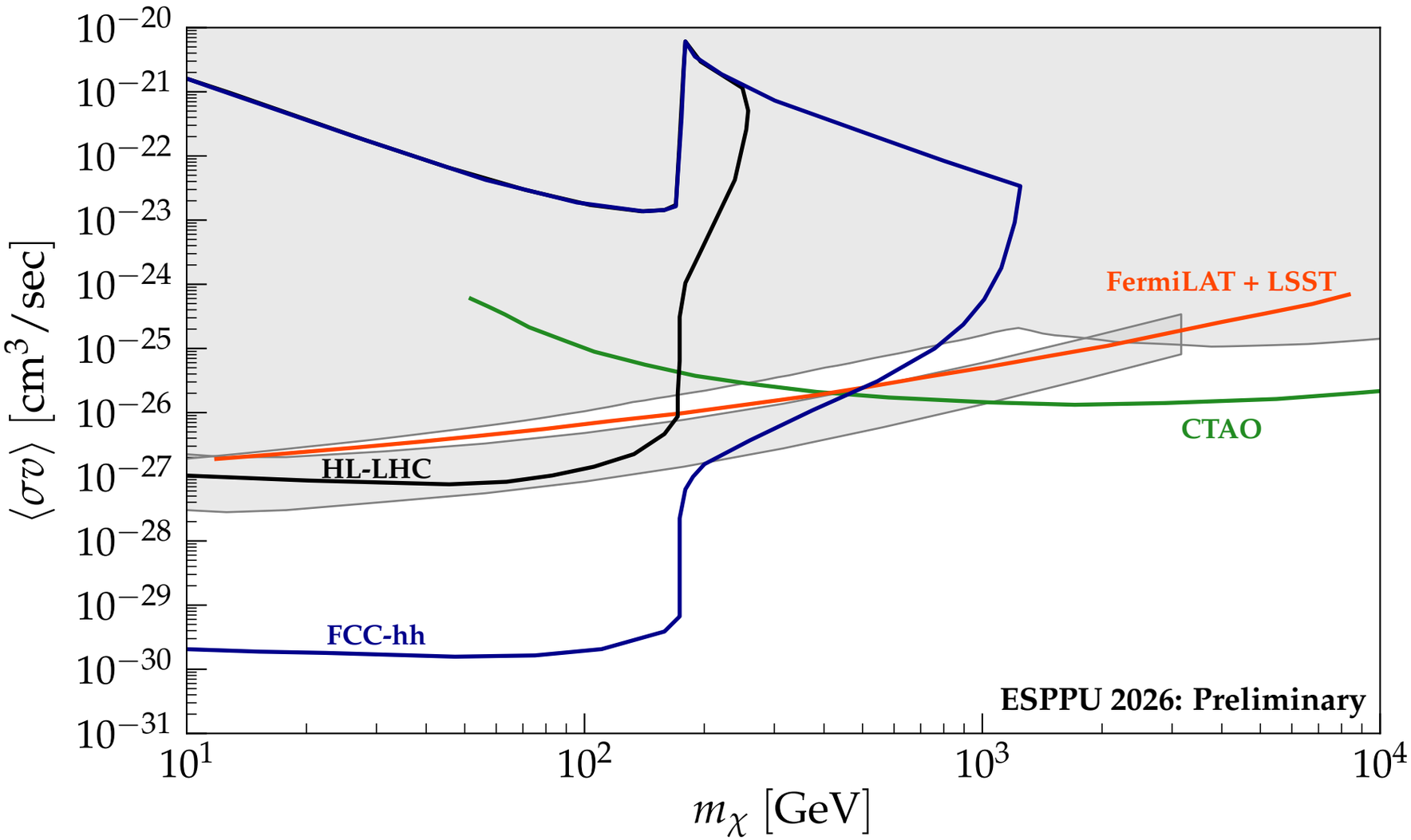
Axial-vector Mediator Models



- FCC-hh scaled to 84 TeV
- ILC updates results provided via private communication with Jenny List. Mass scale limits come from mono-photon analysis and are based on Eur.Phys.J.C 81 (2021) 10, 955 (arXiv:2107.11194) including systematic uncertainties.

Pseudo-scalar Portal

pseudoscalar particle with unit couplings mediates the interaction between SM fermions and Dirac fermionic DM



Collider inputs unchanged from previous briefing book