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Search for new physics at the multi-TeV scale, direct searches and dark matter

Venice Open Symposium
Physics Summary II

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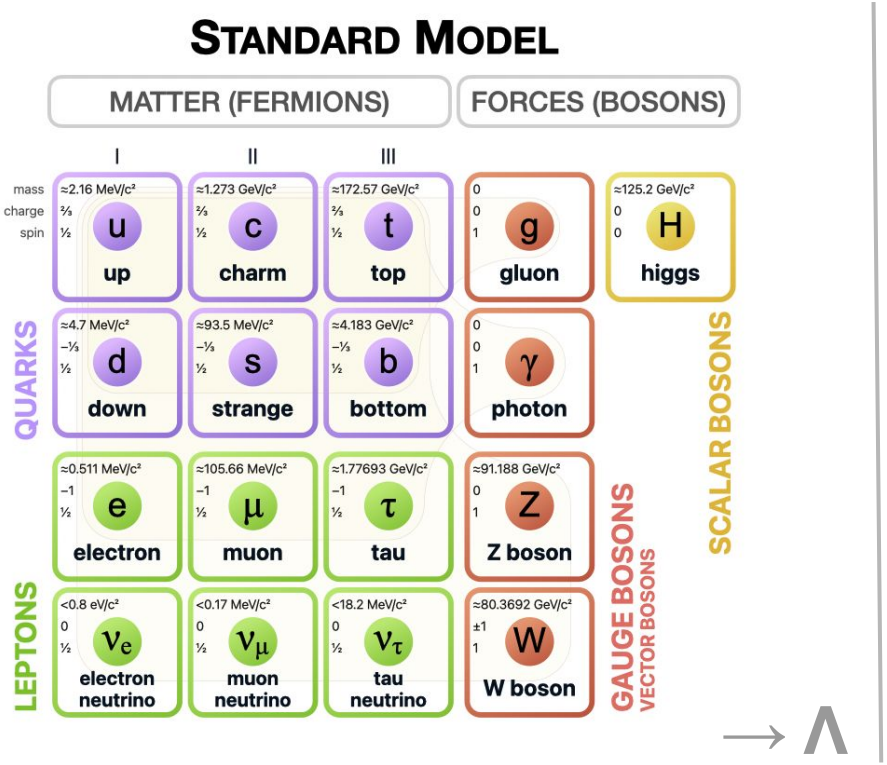
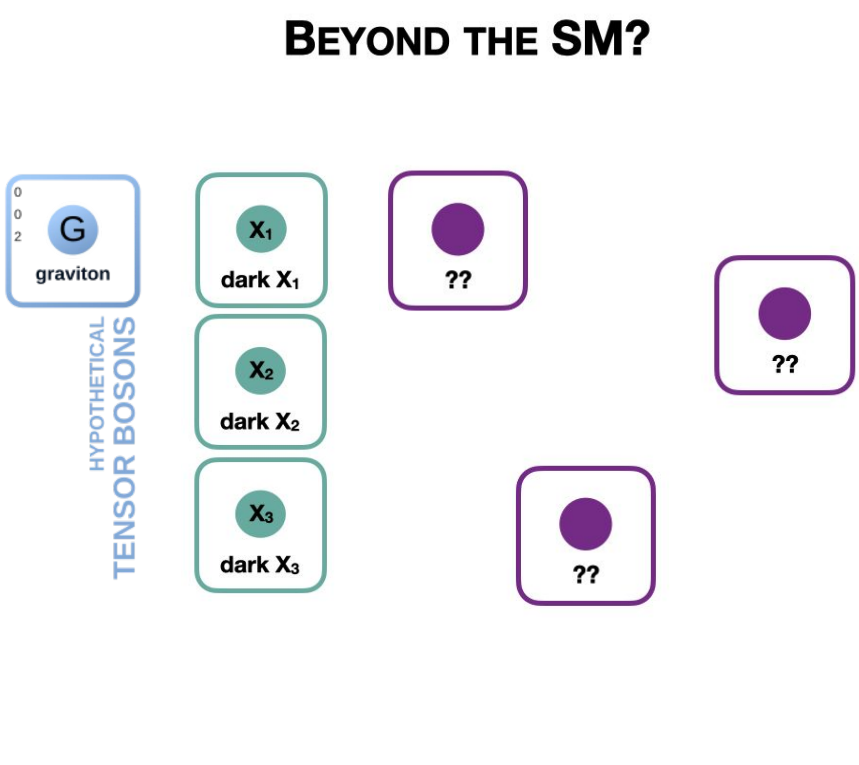
The Standard Model and its incompleteness

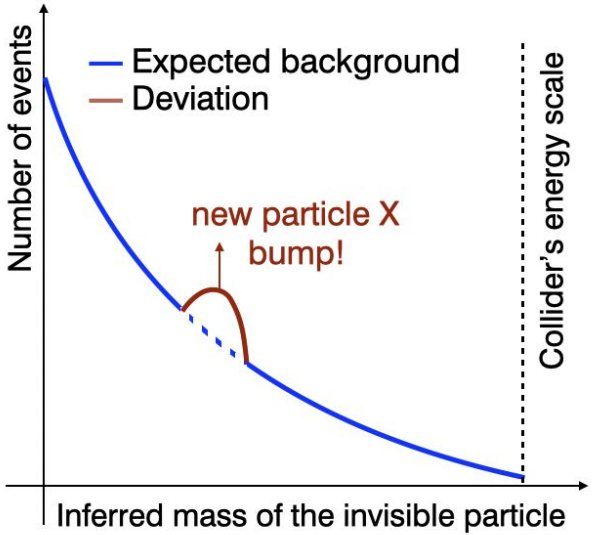




Where is the new physics?

Λ < √s

Direct searches



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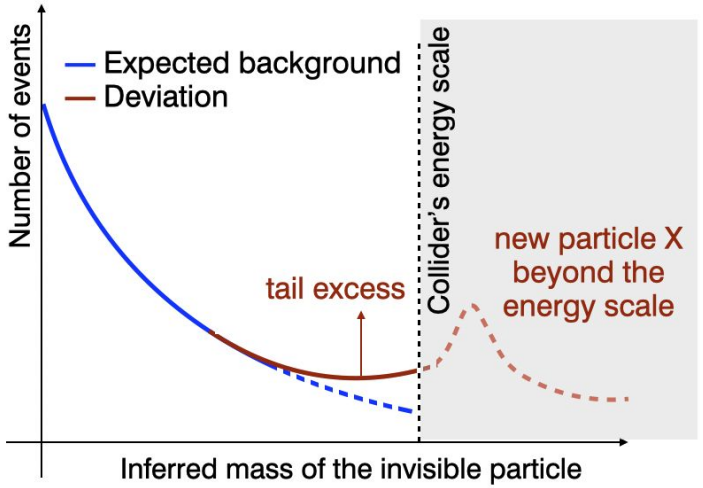
Indirect Searches



Interpret with Effective Field Theories

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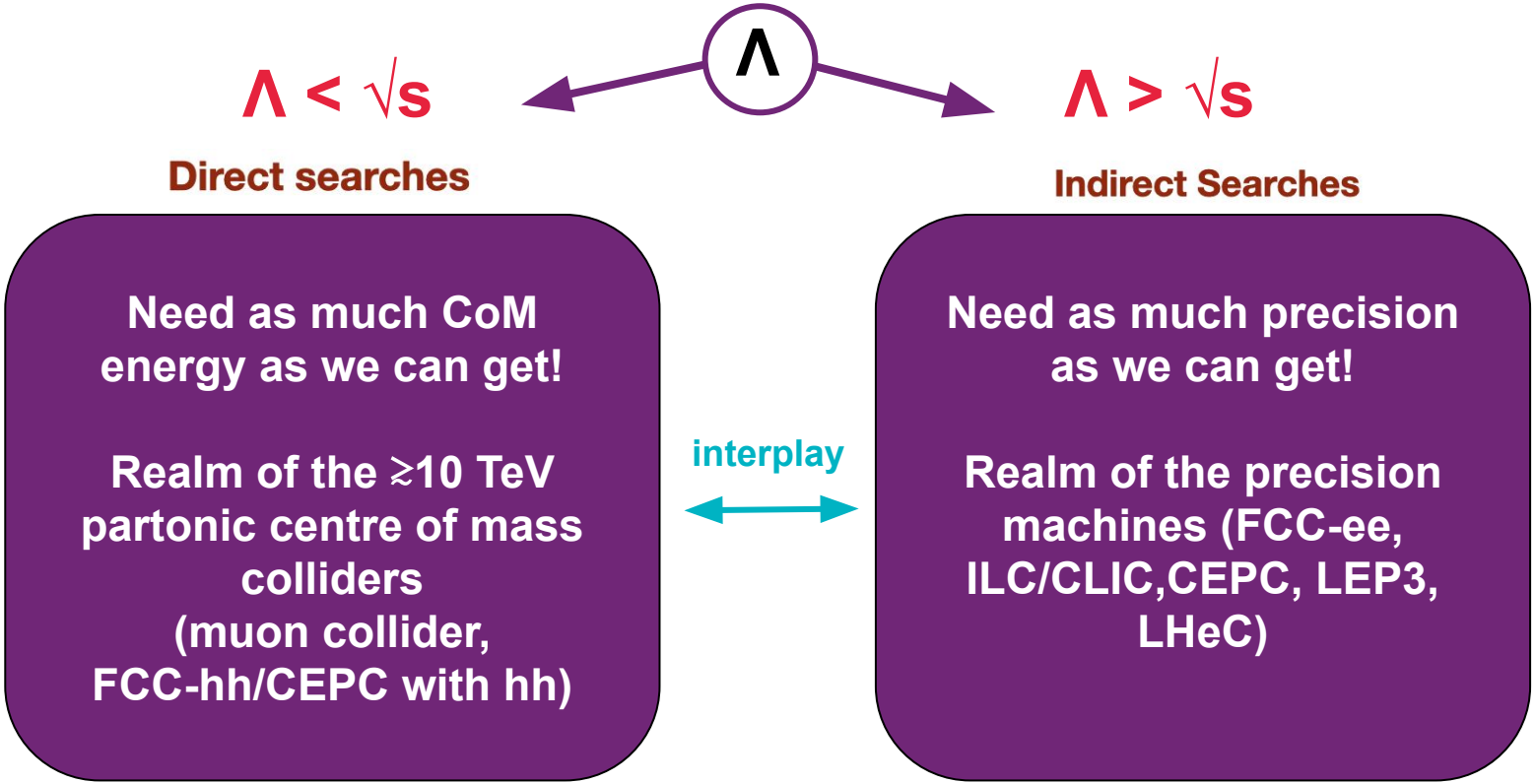
Where is the new physics?



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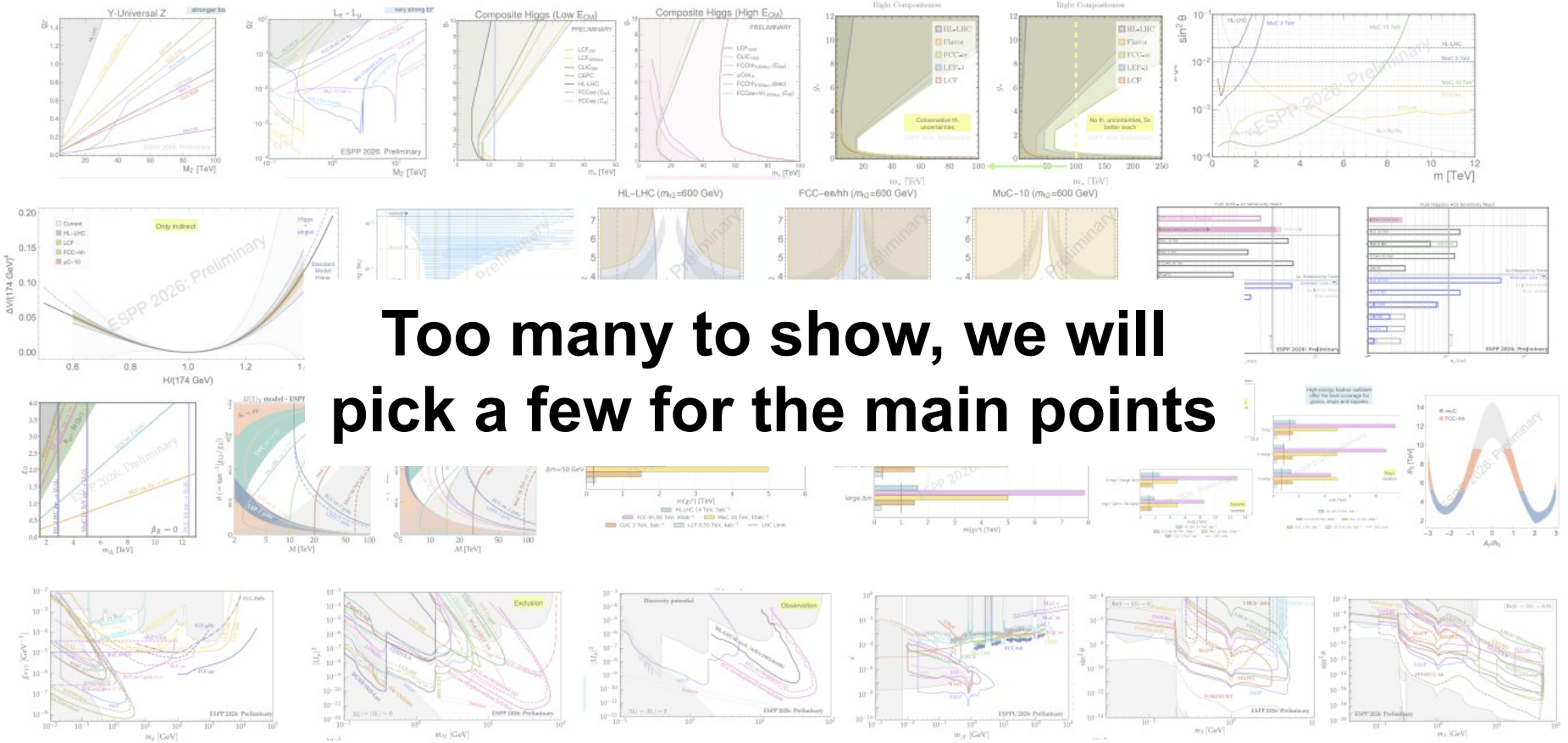
Beyond the Standard Model WG: Benchmarks

#	Question	Model	Method
1	Are there new gauge forces?	Z'	Direct and indirect
2	Are the heaviest particles of the SM elementary?	SILH	Indirect
3	Can we understand the EW phase transition?	Singlet and simplified models	Direct and indirect
4	Can we discover a WIMP?	Minimal DM	Direct and indirect
5	Are solutions to the flavour problem visible at high-Q2?	Leptoquarks, top FCNC	Direct and indirect
6	Do symmetries exist that protect the Higgs?	SUSY	Direct
7	Is the SM alone in the Universe?	Simplified model	Energy and Intensity



Too many to show, we will pick a few for the main points

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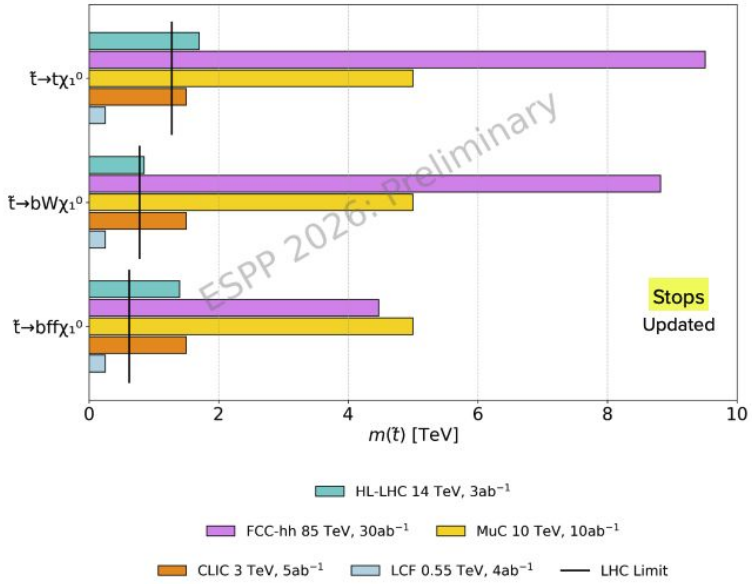
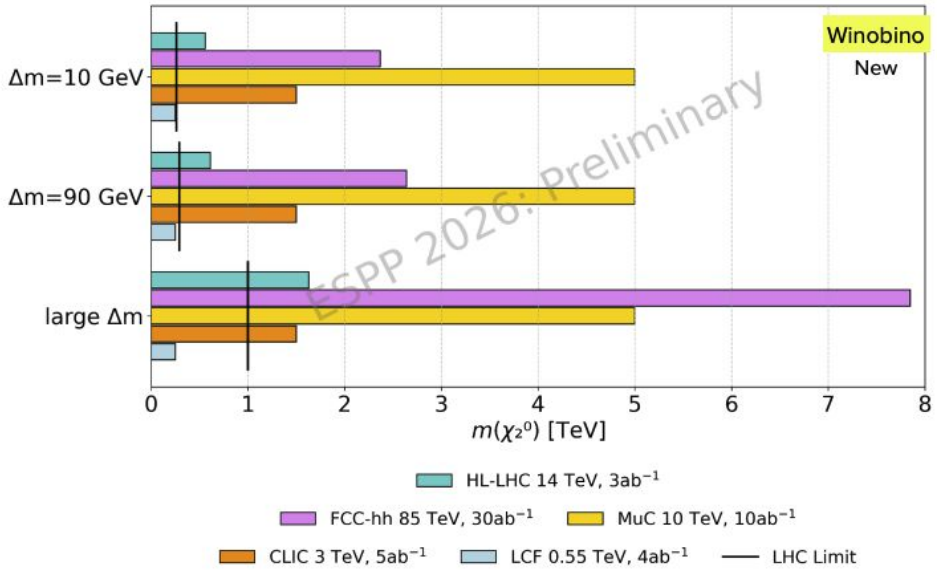
Λ is low: Direct Searches

High energy hadron colliders offer the best coverage for gluino, stops and squarks



Q6: Supersymmetry

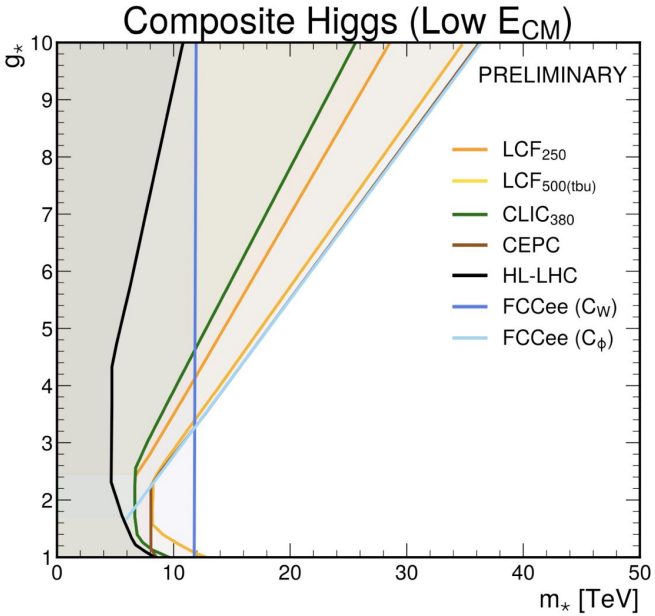
Dramatic improvement in sensitivity wrt HL-LHC, complementarity between high-energy hadron and lepton colliders



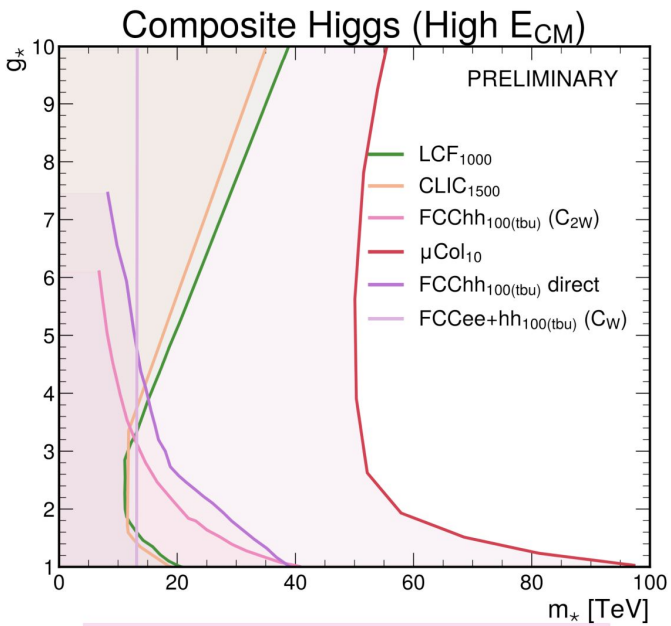
Λ is high: Indirect Searches

Q2: Compositeness

Composite Higgs models: m* compositeness scale; g* effective coupling



Exclusion reach on the composite Higgs model parameters



Exclusion reach on the composite Higgs model parameters

Direct vs Indirect Interplay

Q5: Flavour

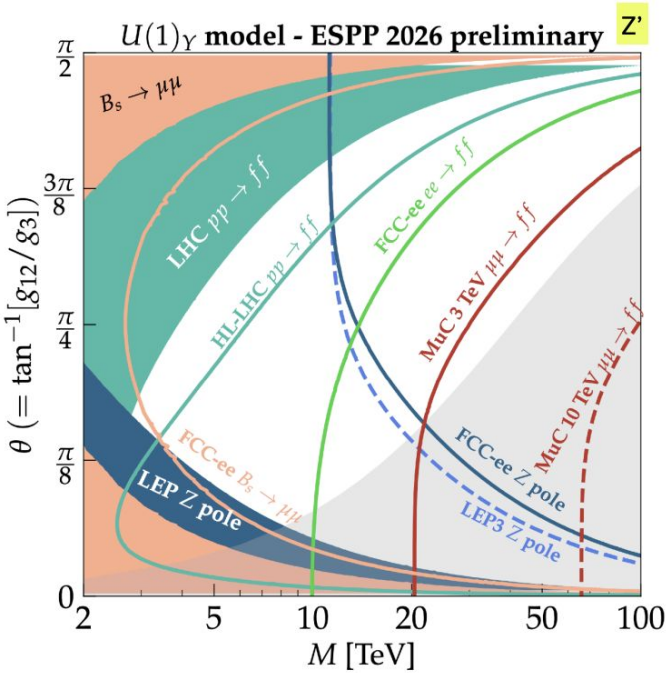
Flavour deconstructed gauge models

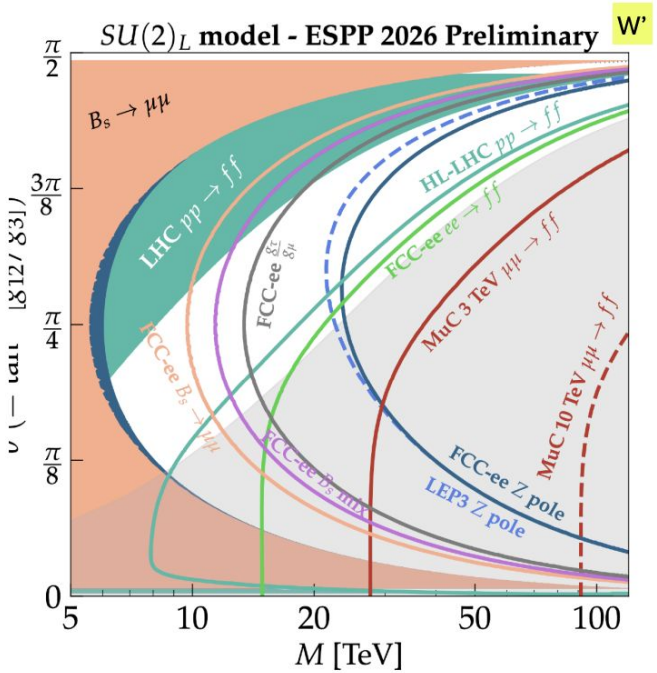
- Heavy Z' and W' with flavour-dependant couplings

Tanθ: ratio of couplings to light (1st,2nd gen) to heavy (3rd gen) fermions

Large indirect effects from electroweak precision FCC-ee (+MuC) exclude most of natural region

Gray: disfavoured for a natural Higgs mass



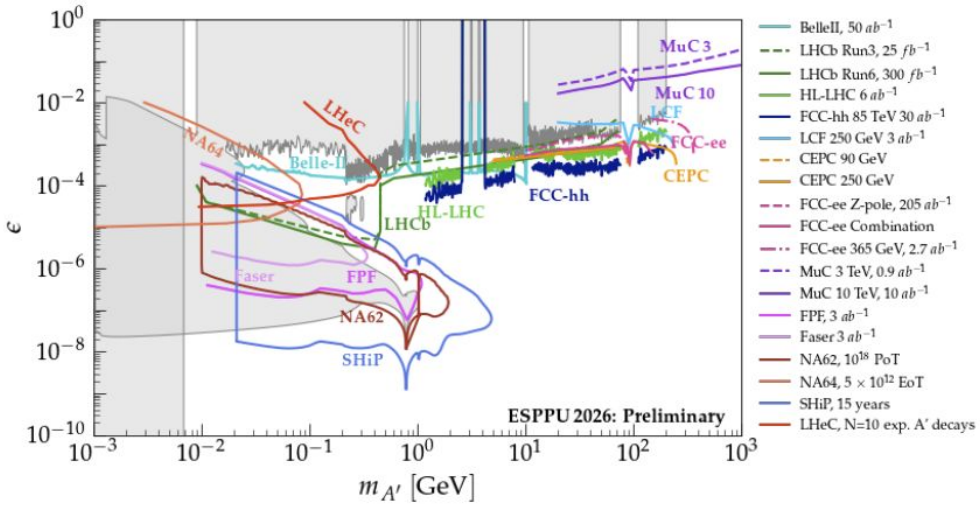


Direct vs Indirect Interplay

Dark Photon: vector particles A' from dark U(1)

- ε dark photon mixing parameter

Very low to medium mass and low mixing: beam dump/fixed target; Intermediate to high-mass/large couplings: colliders.

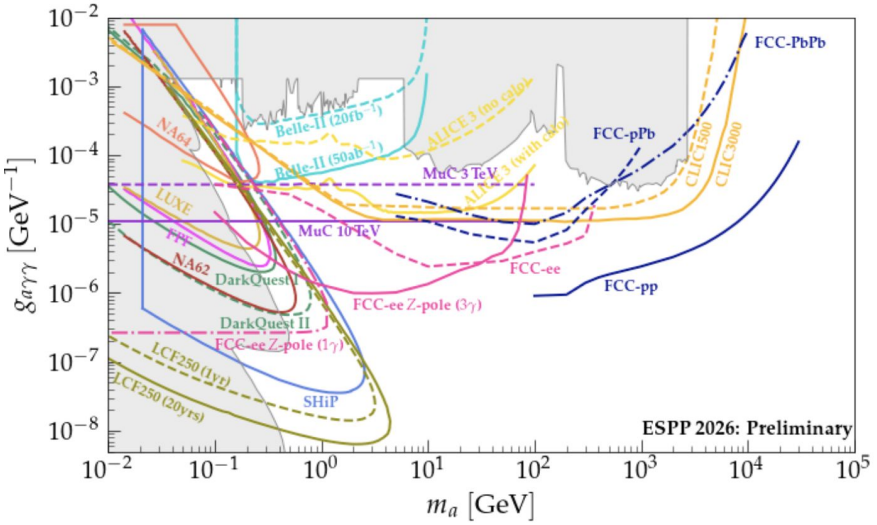


Q7: Dark sector portals

Axion-Like particles: pseudo-scalar portal *a*

- $g_{a\gamma\gamma}$: axion coupling to photons

Low couplings (long-lived): beam dump; Intermediate masses: FCC-ee; Above 90 GeV: high energy (linear and hadron colliders)



Dark Matter

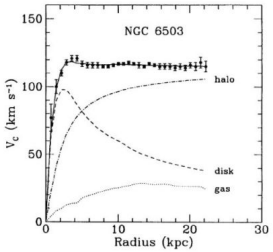
Image: JWST: NASA, ESA, CSA, STScI, CXC

Dark Matter

$$\mathcal{L}_{\rm SM} + \text{ Gravity} \neq \text{Cosmos}$$

A consistent need of a gravitating non-relativistic, non-interacting matter component across scales

@Galaxy



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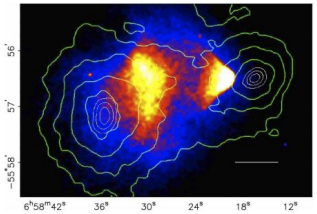

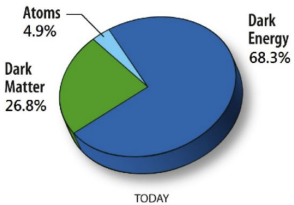

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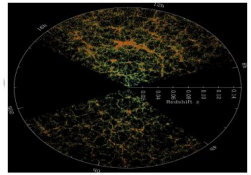

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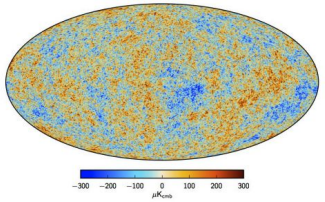

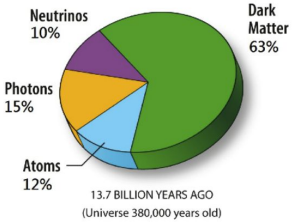

Dark Matter

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A consistent need of a gravitating non-relativistic, non-interacting matter component across scales

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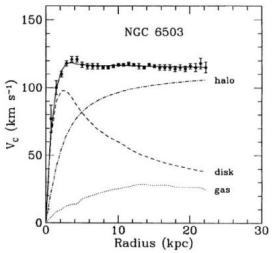

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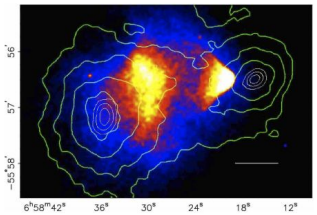

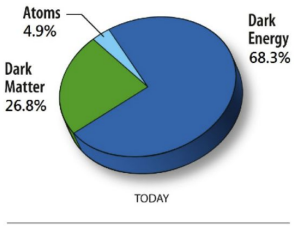

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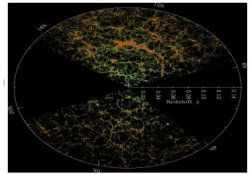

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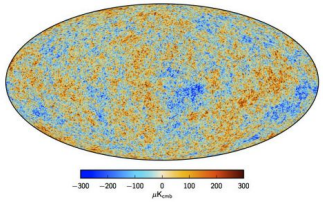
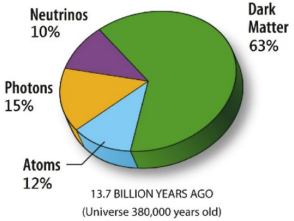
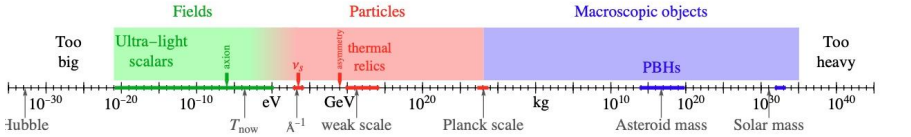




Searches span over 70 orders of magnitude: require a range of experiments

Models of DM has been proposed at widely different scales



Cirelli et al, 2406.01705

Most relevant for particle physics are those below Planck scale:

1. Ultralight mass range $m_\chi \lesssim$ eV.
2. Light mass range keV $\lesssim m_\chi \lesssim$ GeV.
3. Heavy mass range GeV $\lesssim m_\chi \lesssim 10$ TeV.
4. Ultraheavy mass range TeV $\ll m_\chi$

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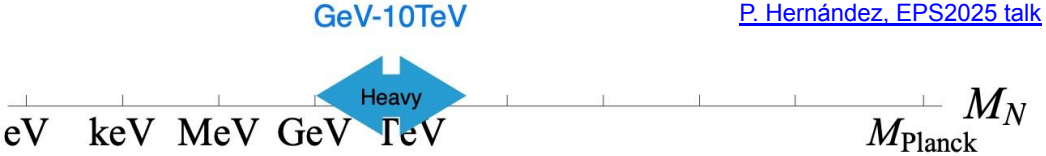
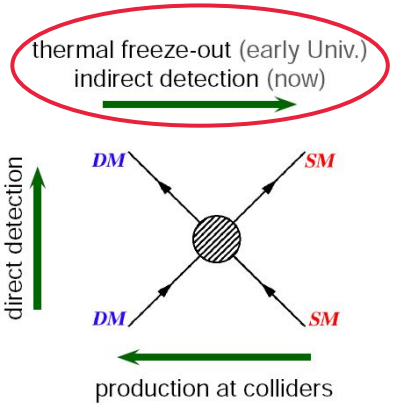
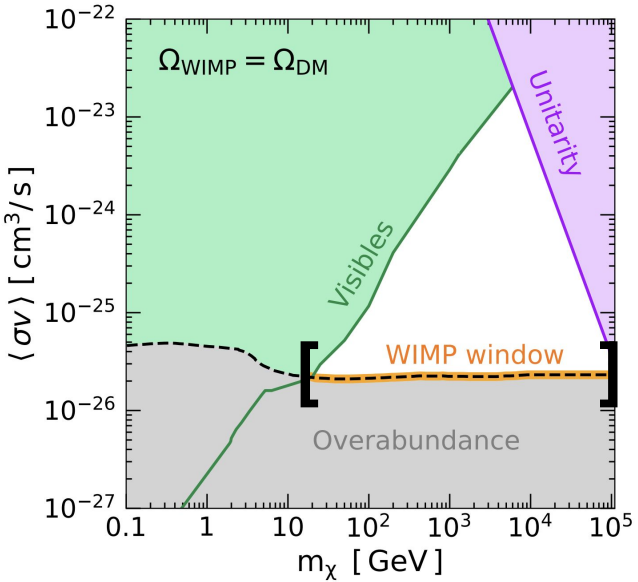
DM WIMP benchmark

Indirect detection



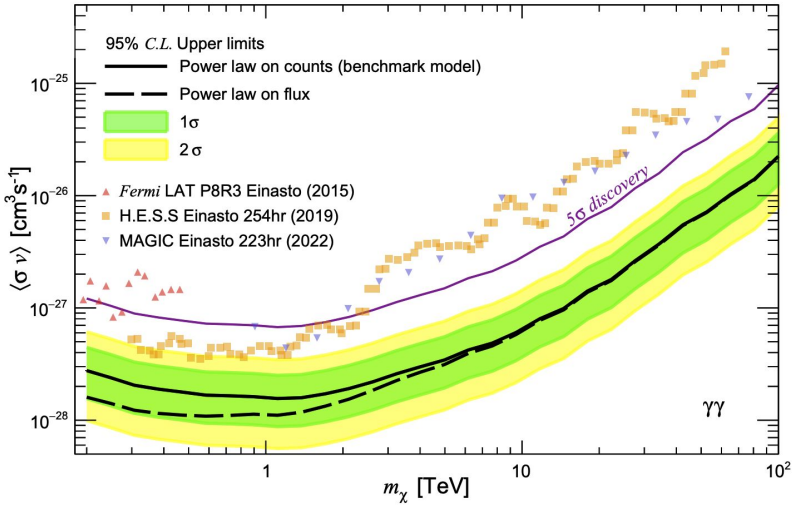
P. Hernández, EPS2025 talk





R. Leane et al
Phys. Rev. D 98, 023016 (2018)

CTA Collaboration expected limits JCAP 07 (2024)



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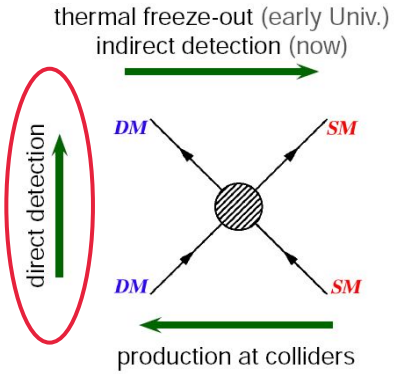
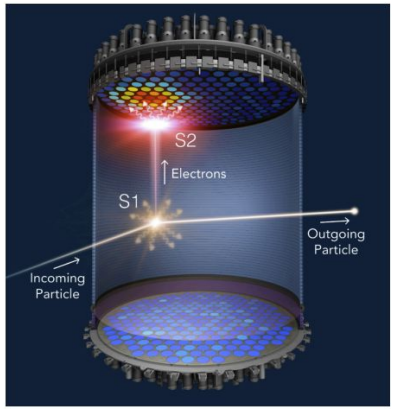
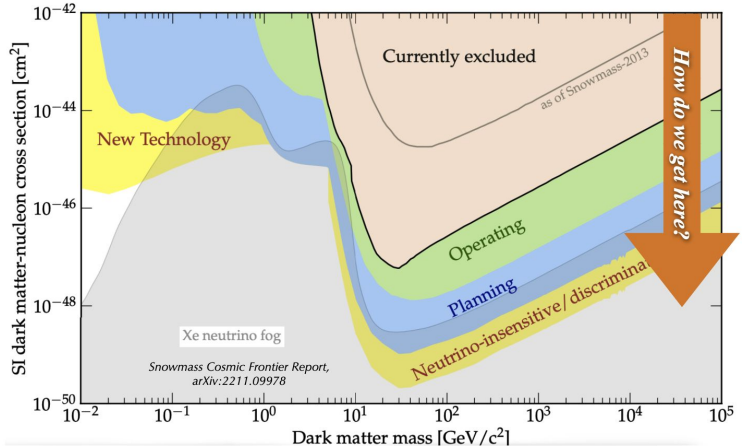
DM WIMP benchmark

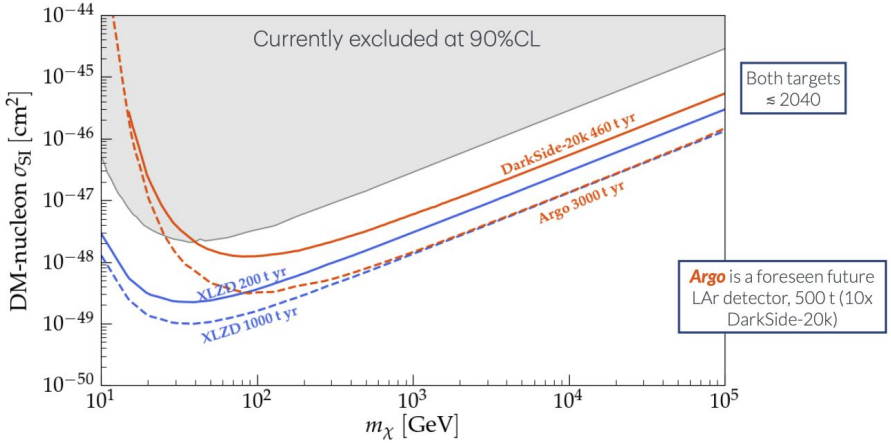
Direct detection



Noble Liquids (Xe, Ar)

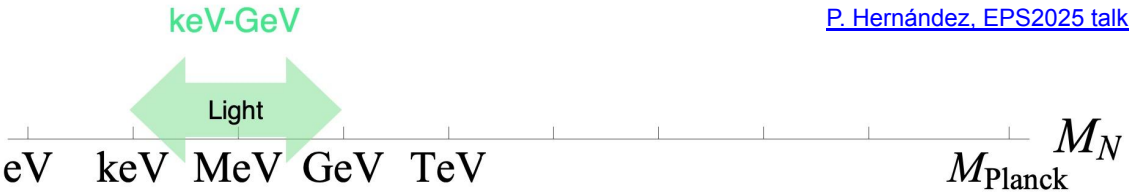






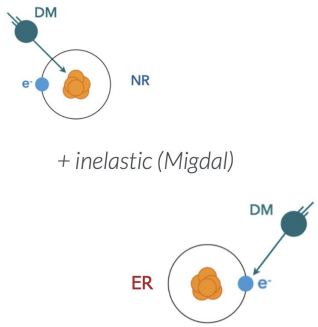
Light DM benchmark

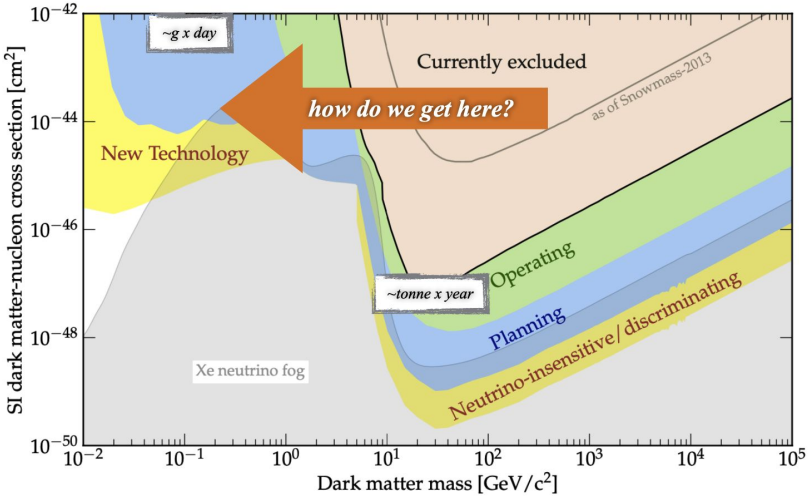
Direct detection



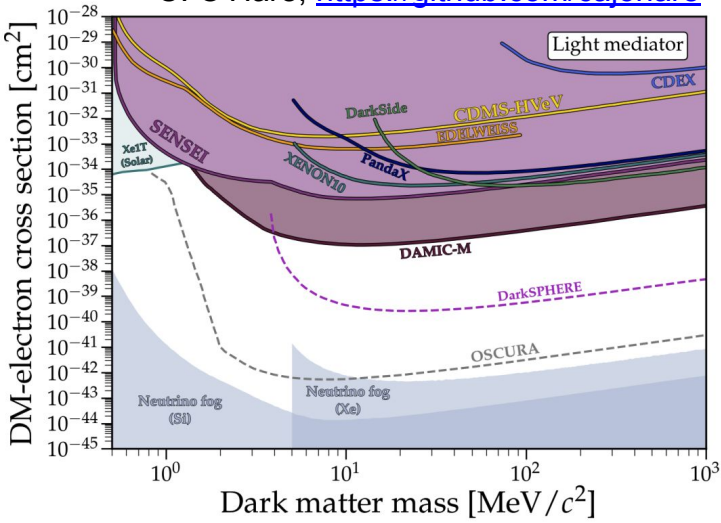
P. Hernández, EPS2025 talk

Lighter and feebly-coupled DM require alternative production mechanisms and detector technologies





C. O'Hare, https://github.com/cajohare



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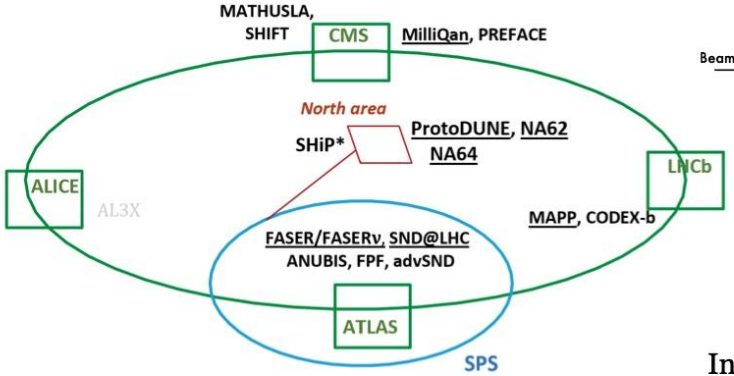
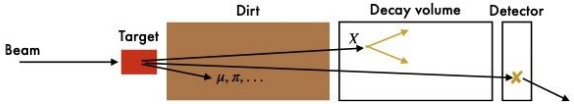
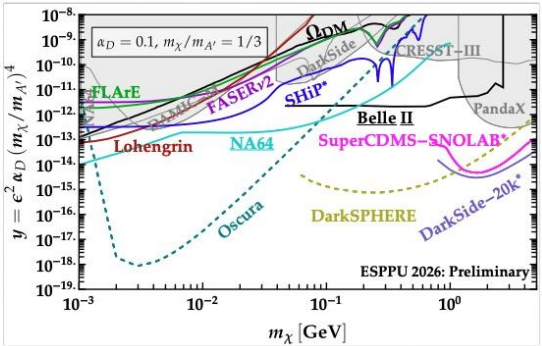
Venice DM parallel session
P. Hernández, EPS2025 talk

More collider complementarity: Forward Facilities

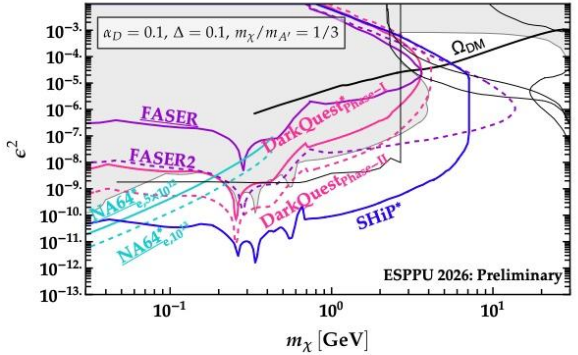




Elastic DM Vector Portal

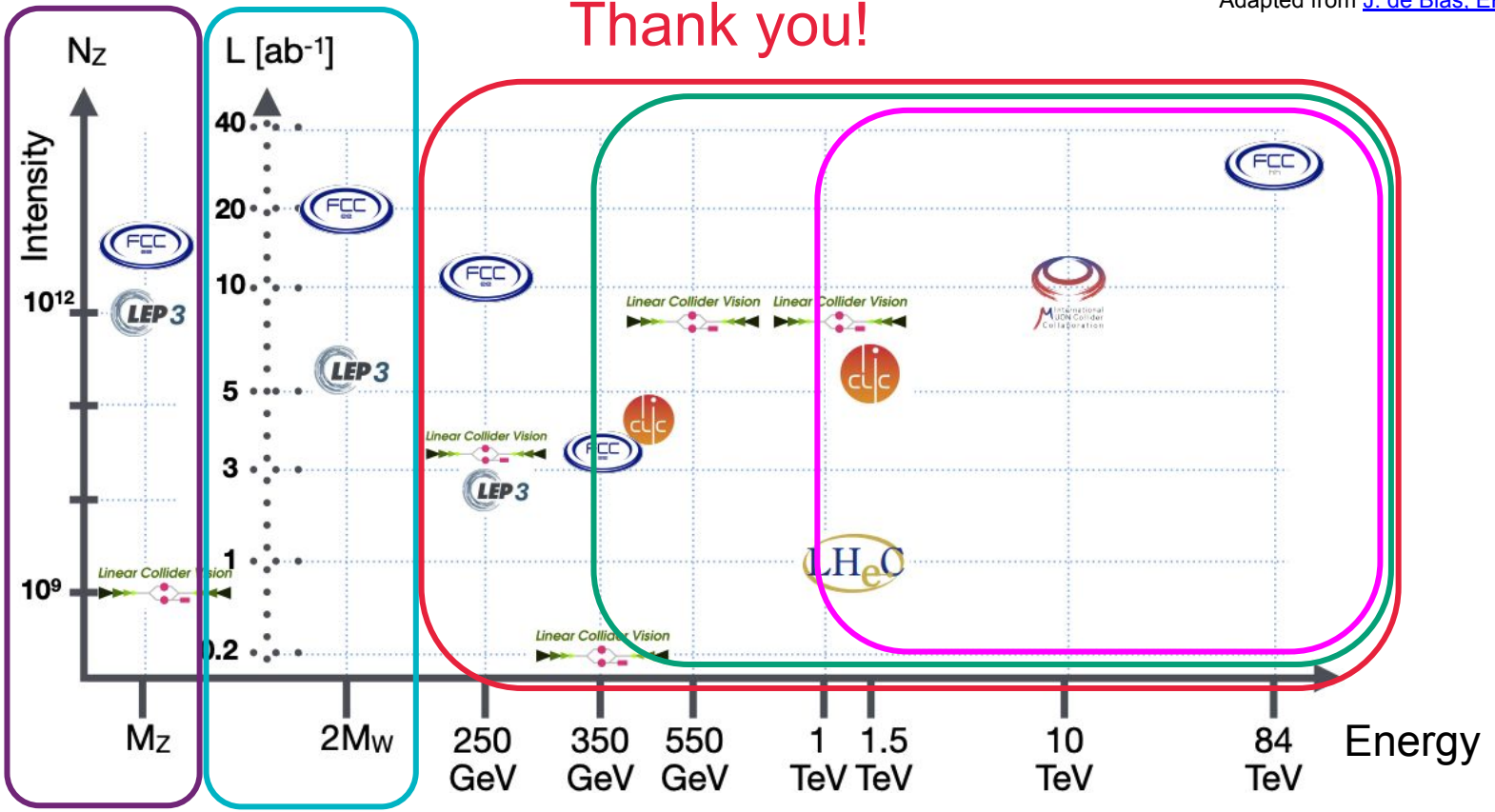


Inelastic DM Vector Portal



Adapted from J. de Blas, EPS2025 talk

Thank you!



Z pole: EWPO/Flavour/QCD
WW threshold: EWPO/Flavour/QCD

Precision Higgs
Precision top

High-E frontier: direct searches, precision from energy

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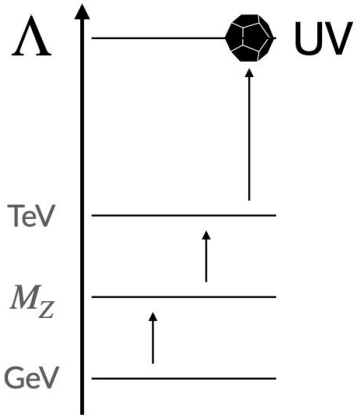
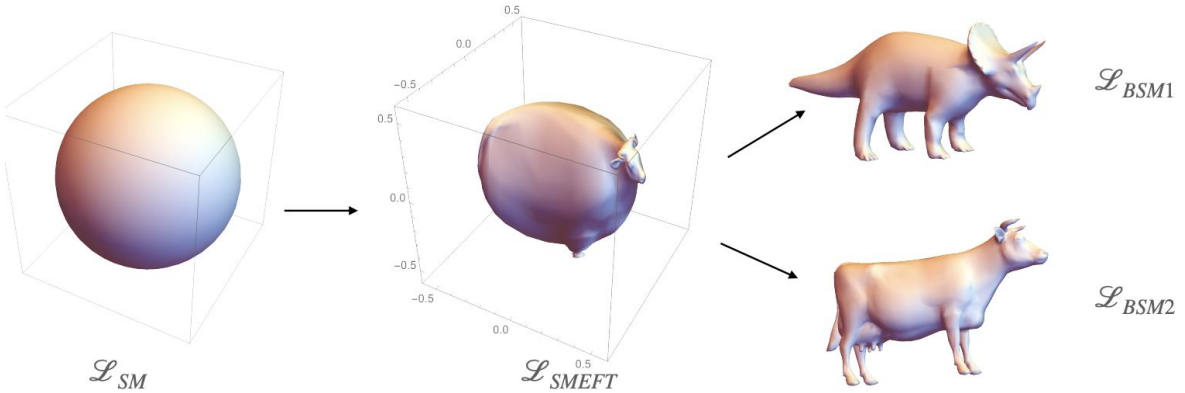
Back-up

Search for new physics at the multi-TeV scale

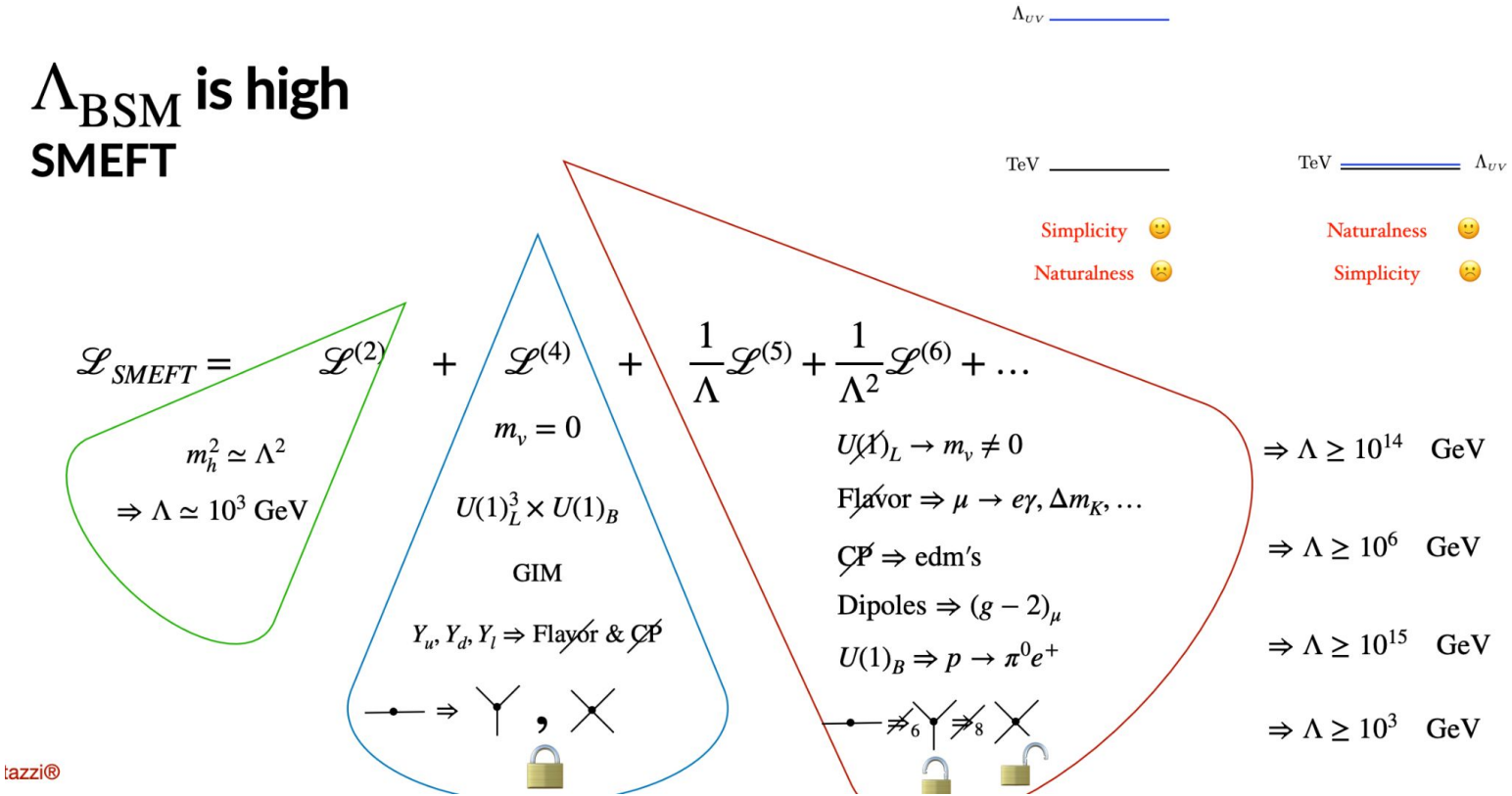
SMEFT: An EFT allows to connect measurements at different scales without needing to know the UV.

Linking observables at different scales



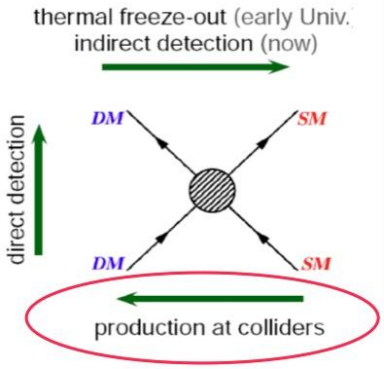


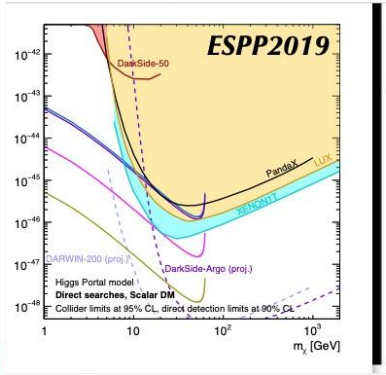
Search for new physics at the multi-TeV scale

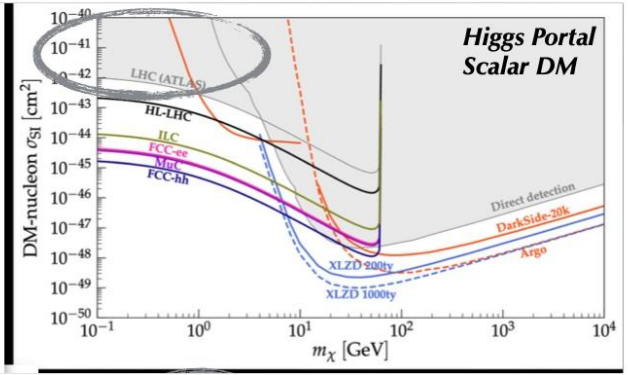


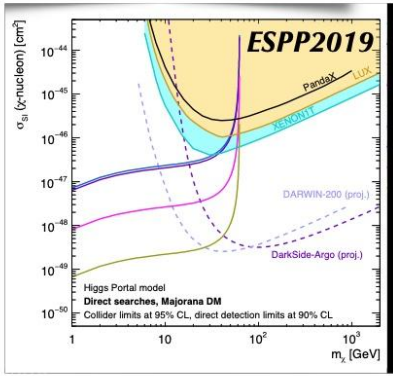
Light DM benchmark

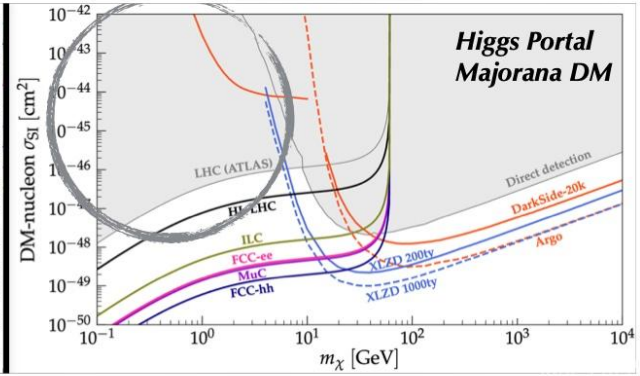
Collider complementarity











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Dark Matter Searches

- Dark Matter is an important feature of particle physics;
  Both non-accelerator and accelerator searches are needed in any scenario

- **Key messages:**
  - Flexibility should be kept on the experimental side to be able to respond to new developments in phenomenology

  - No one facility or approach can do it all. Important progress will continue to be made by relatively small / rapid projects

  - A convincing discovery will require **confirmation by multiple experiments and techniques** with independent systematics

- A mix of small and large projects is required

  - Major initiatives in the "traditional" dark matter thrusts in liquid nobles and axion haloscopes

  - A plethora of small scale approaches are a strong technology incubator and relatively small/rapid searches

  - Complemented by searches at colliders