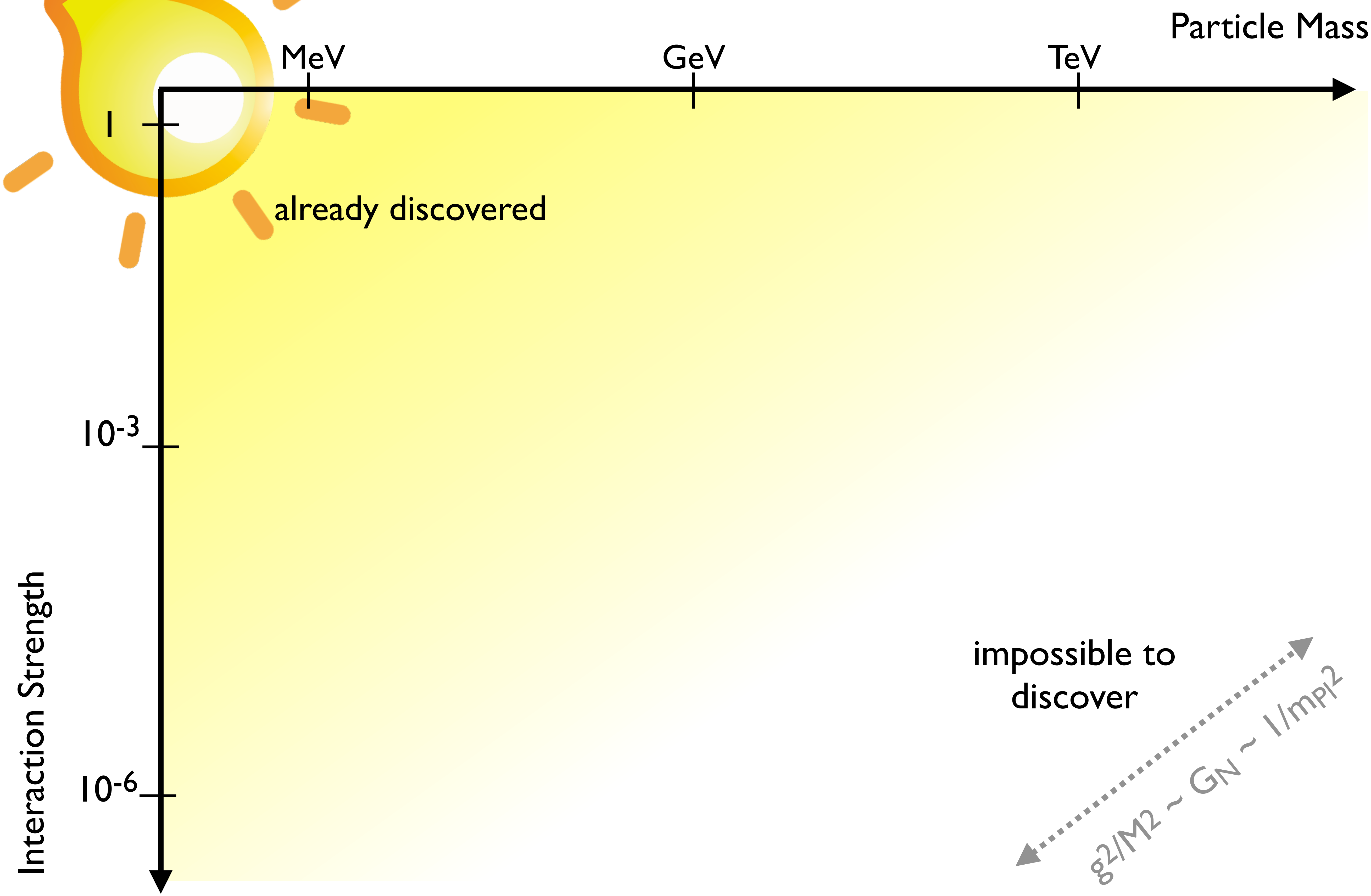
Testing the Dark Sector in the Laboratory

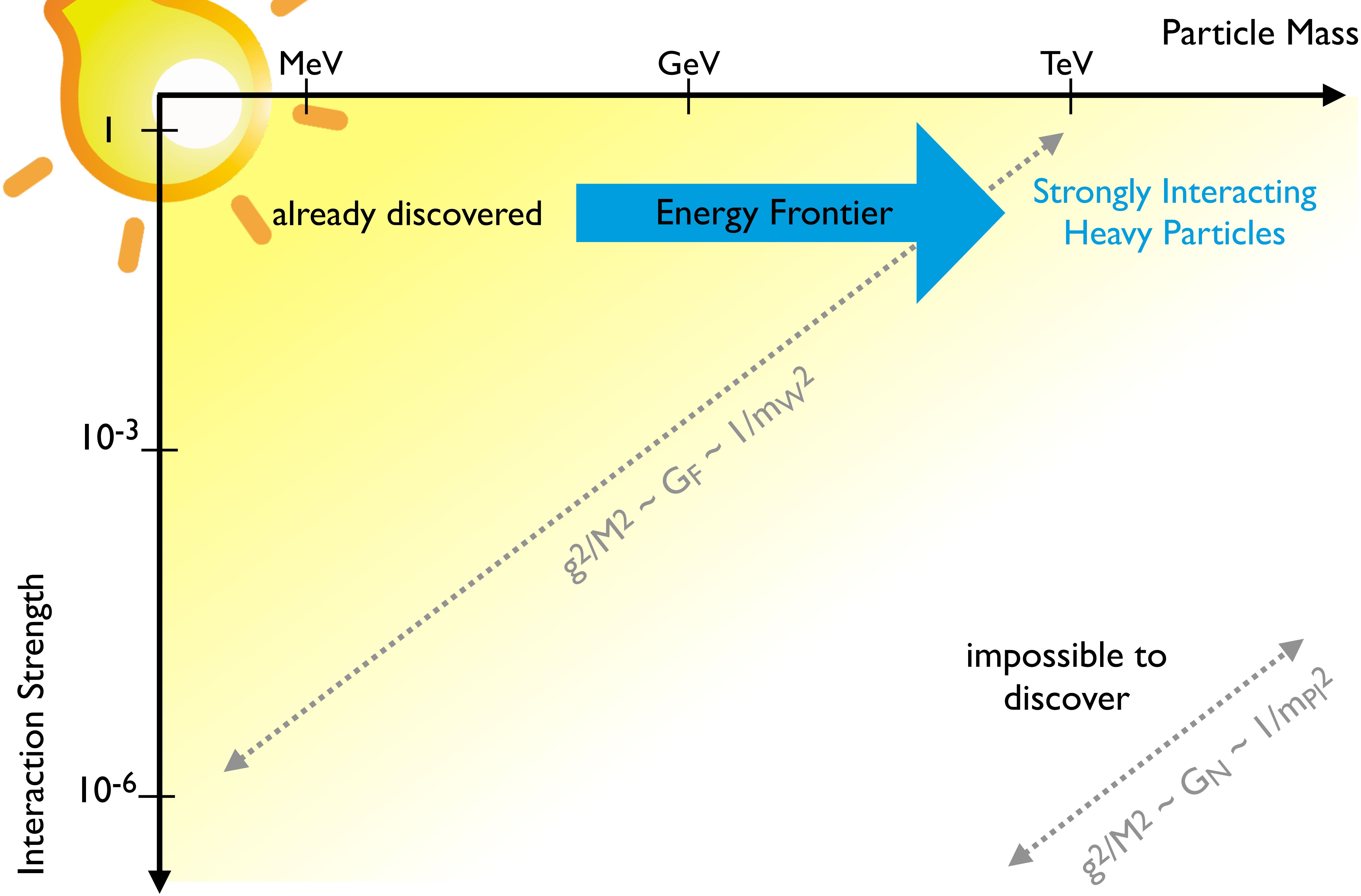
PASCOS 2022
July 29th 2022
Felix Kling

What is a dark sector?

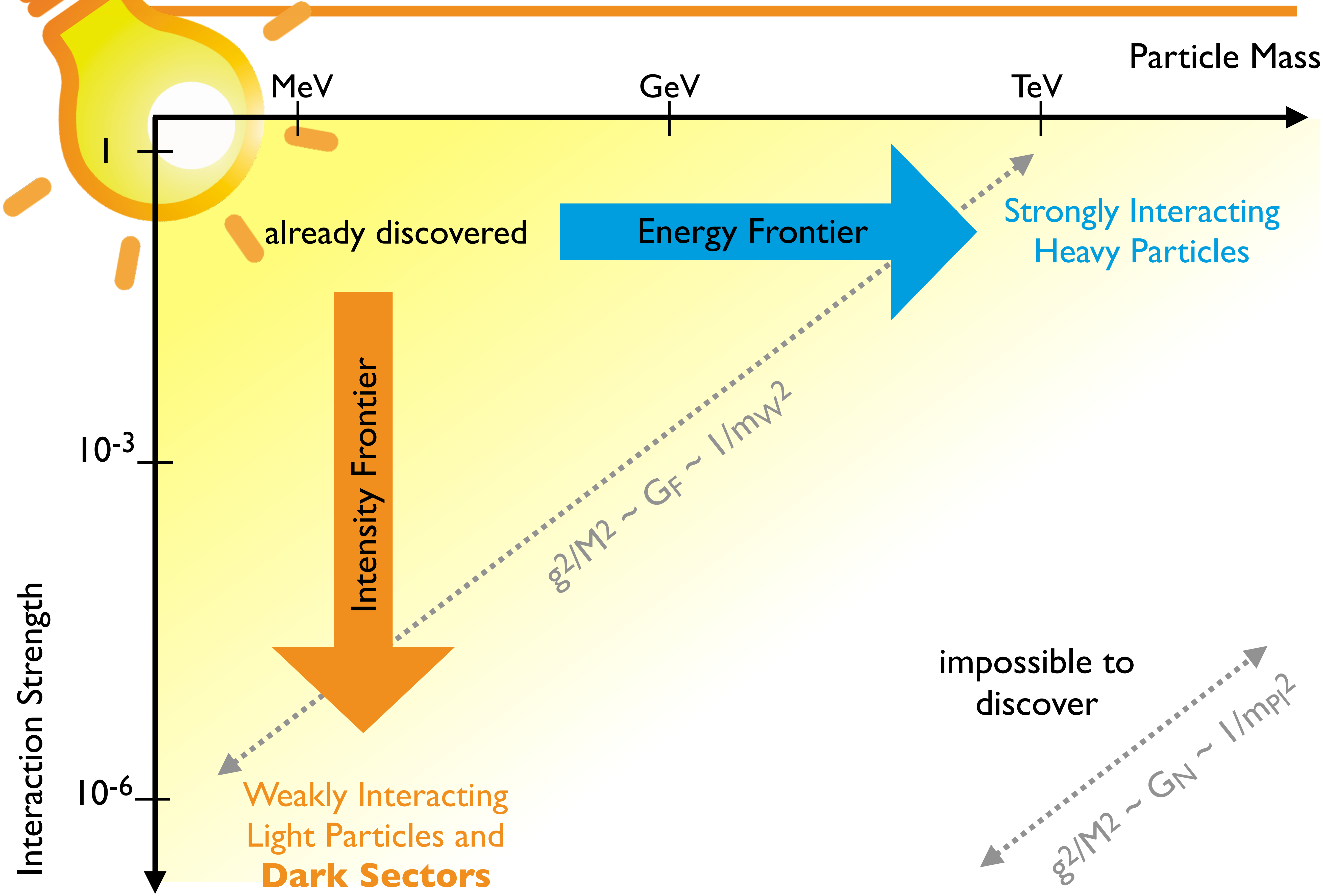
Where could new physics be?



Where could new physics be?



Where could new physics be?

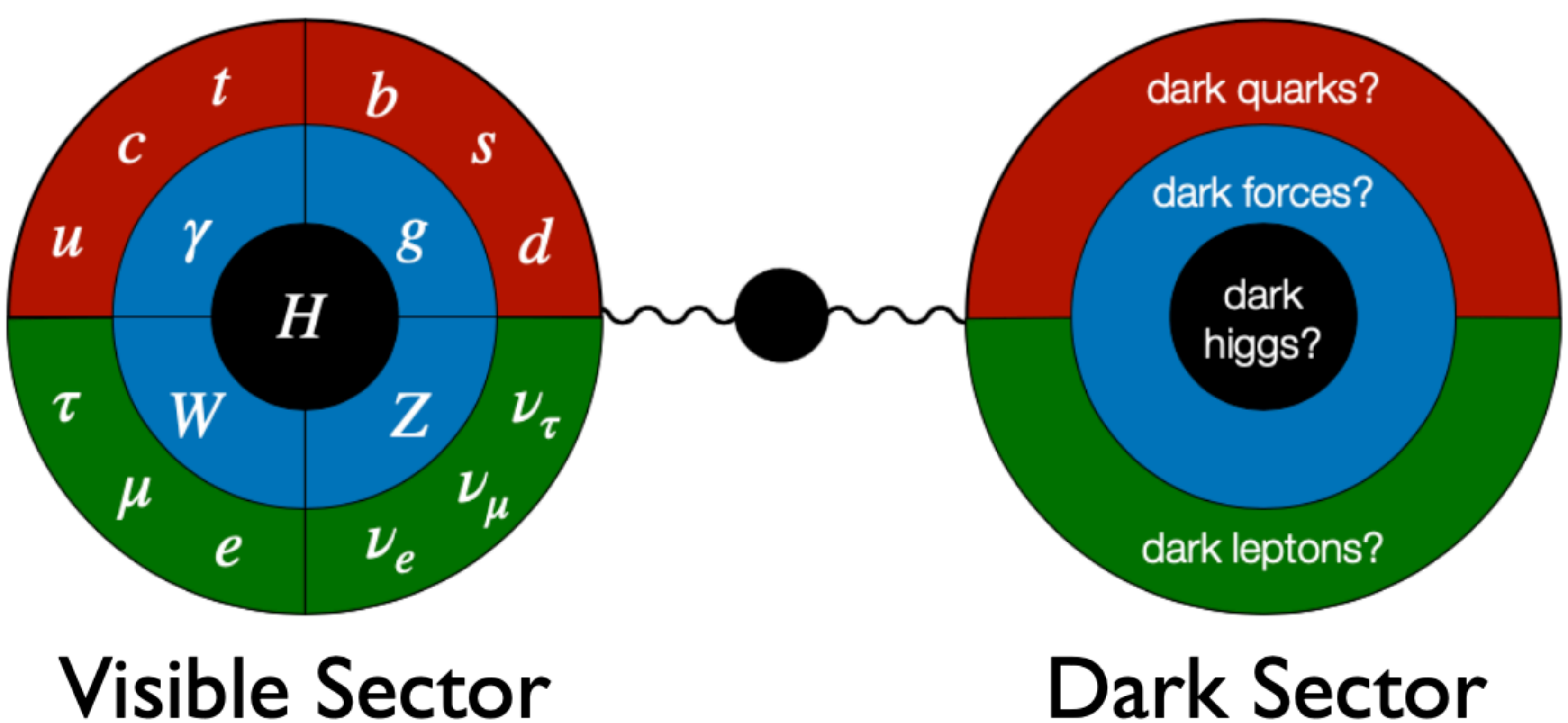


What is a dark sector?

Definition from Snowmass RF6 group: *Dark Sector Studies at High Intensities*
see Brian Batell's talk at Seattle Snowmass Summer Meeting 2022

set of new particles, which do not experience known forces

weakly coupled to visible sector through a mediator or "portal"

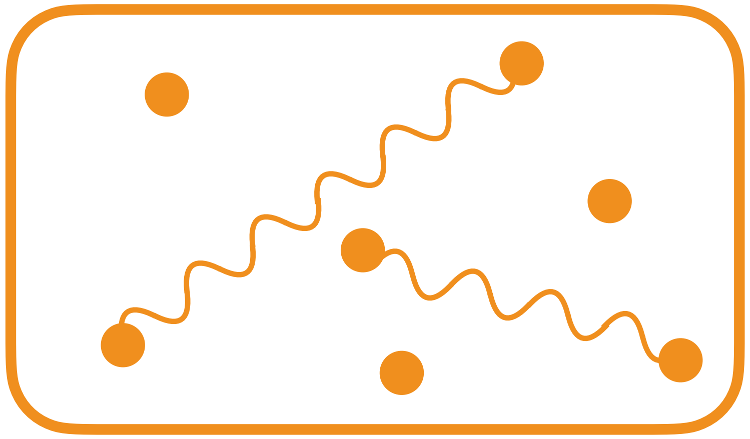


Example: dark photon portal.

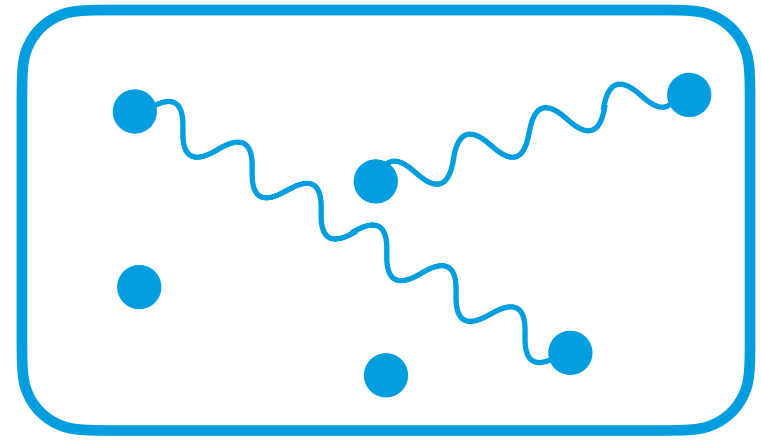
$$\mathcal{L} = i\bar{\psi}\gamma^\mu\partial_\mu\psi - m\bar{\psi}\psi \quad + i\bar{\chi}\gamma^\mu\partial_\mu\chi - m\bar{\chi}\chi$$

Example: dark photon portal.

visible sector



dark sector



$$\mathcal{L} = i\bar{\psi}\gamma^{\mu}\partial_{\mu}\psi - m\bar{\psi}\psi \qquad + i\bar{\chi}\gamma^{\mu}\partial_{\mu}\chi - m\bar{\chi}\chi$$

$$-\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + e\gamma^{\mu}\bar{\psi}A_{\mu}\psi \qquad -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + e_{D}\gamma^{\mu}\bar{\chi}A'_{\mu}\chi$$

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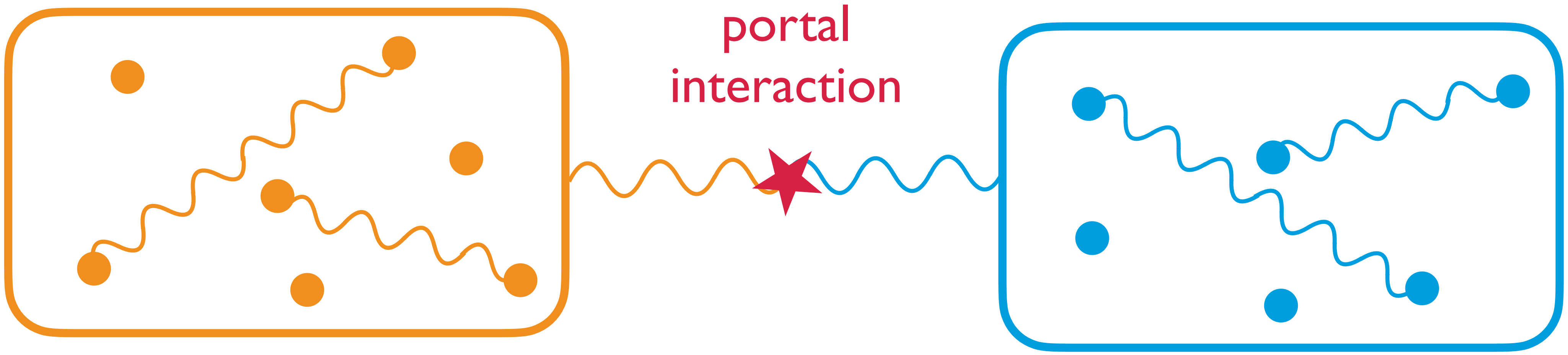
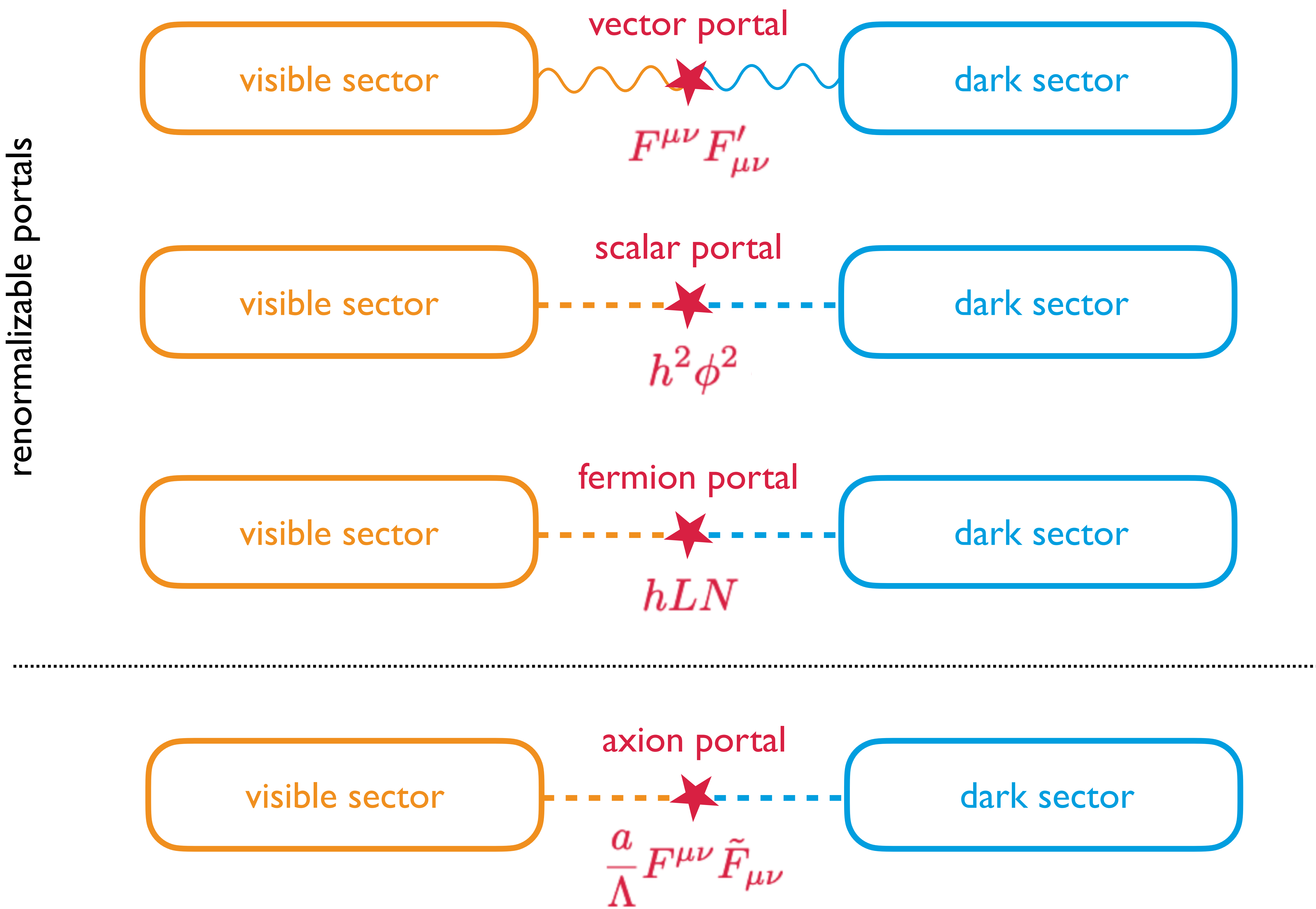


$$\mathcal{L} = i\bar{\psi}\gamma^\mu\partial_\mu\psi - m\bar{\psi}\psi \quad + i\bar{\chi}\gamma^\mu\partial_\mu\chi - m\bar{\chi}\chi$$

$$- \frac{1}{4}F^{\mu\nu}F_{\mu\nu} + e\gamma^\mu\bar{\psi}A_\mu\psi \quad - \frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + e_D\gamma^\mu\bar{\chi}A'_\mu\chi$$

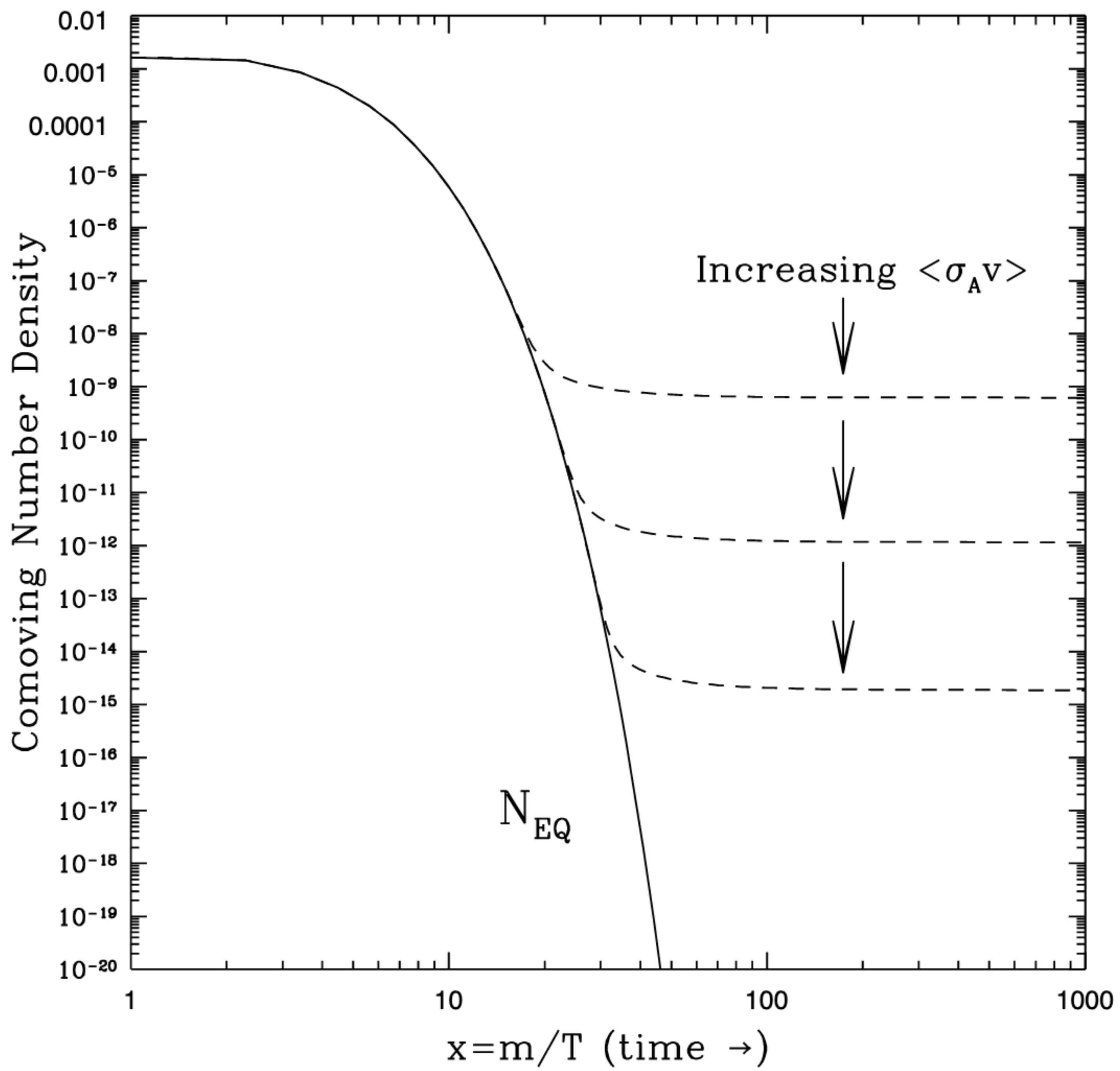
$$+\epsilon\frac{1}{4}F^{\mu\nu}F'_{\mu\nu}$$

Other popular portals.



What do we care about dark sectors?

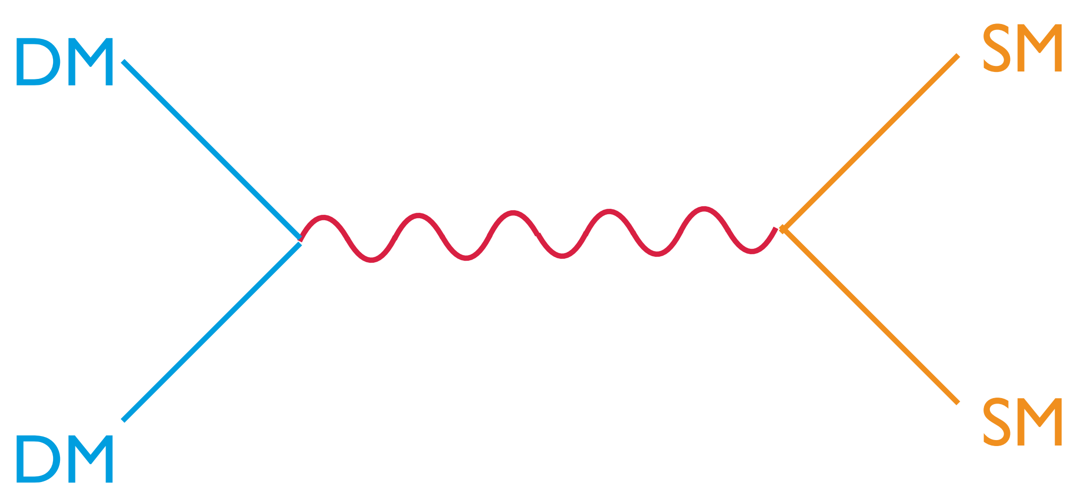
Motivation: dark matter.



[*TASI 2008 Lectures on Dark Matter*
By Dan Hooper: 0901.4090]

thermal freeze out:

$$\Omega_{DM} \sim 1/\langle \sigma v \rangle \sim m^2/g^4$$



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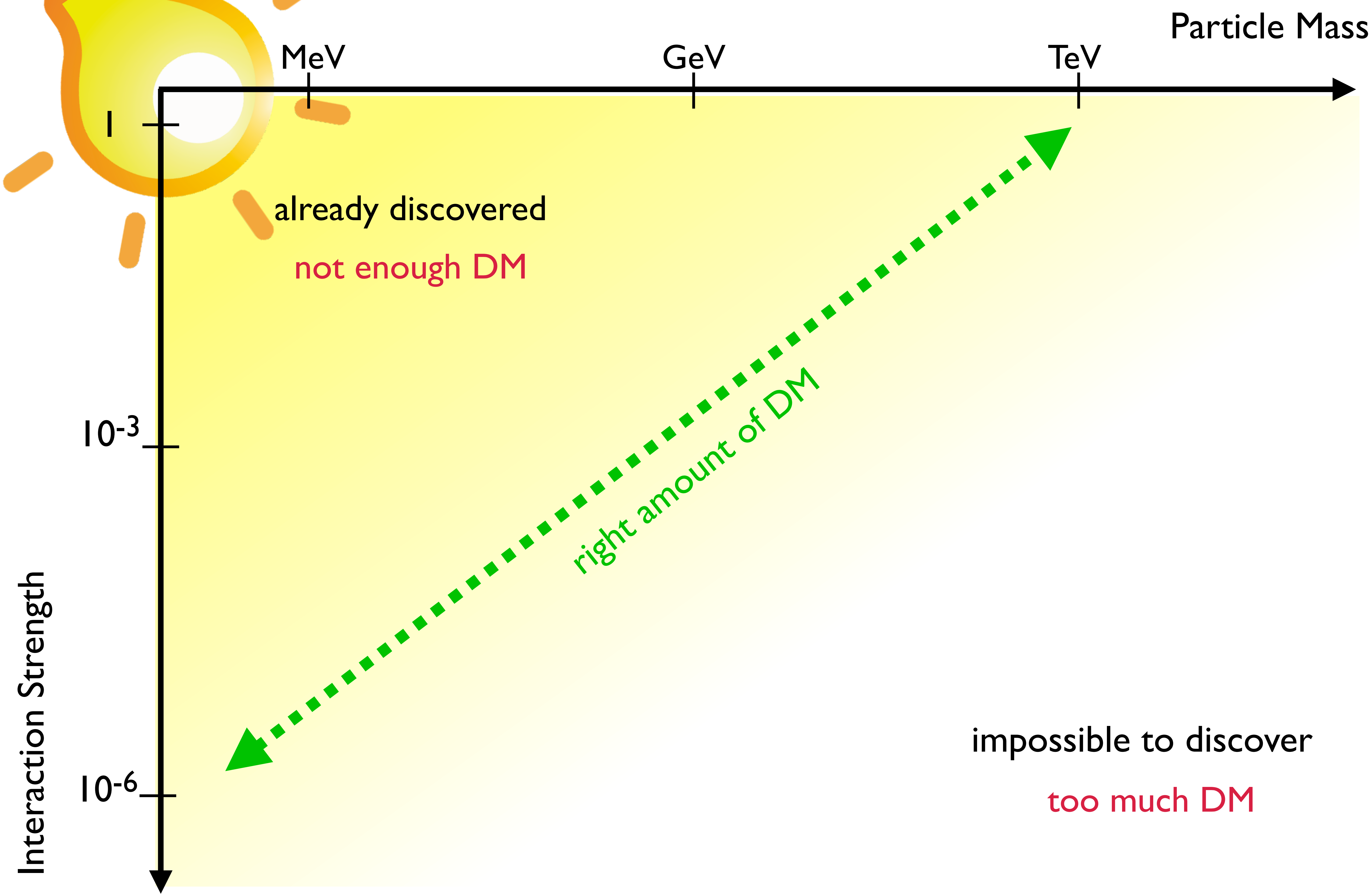

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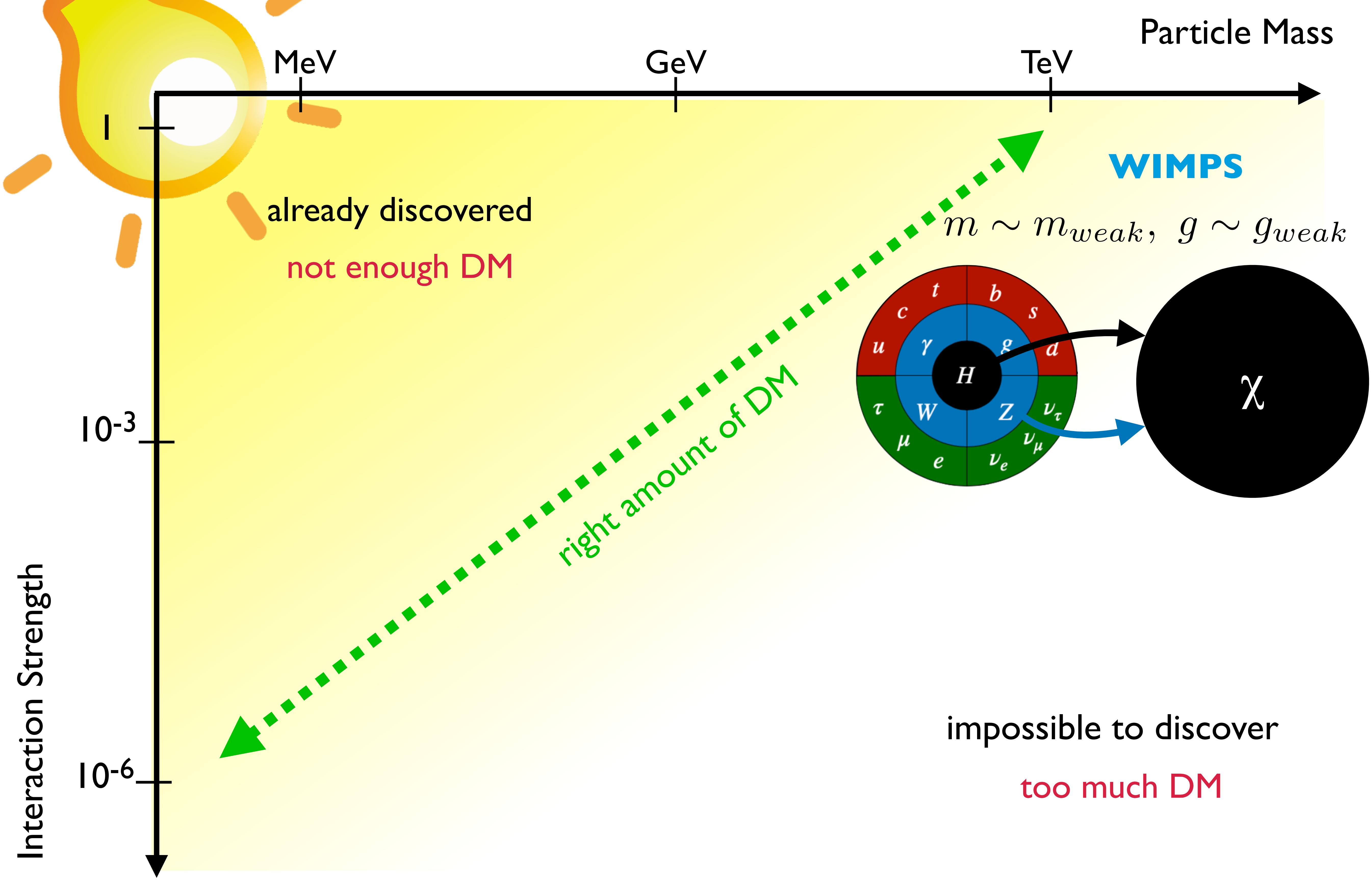

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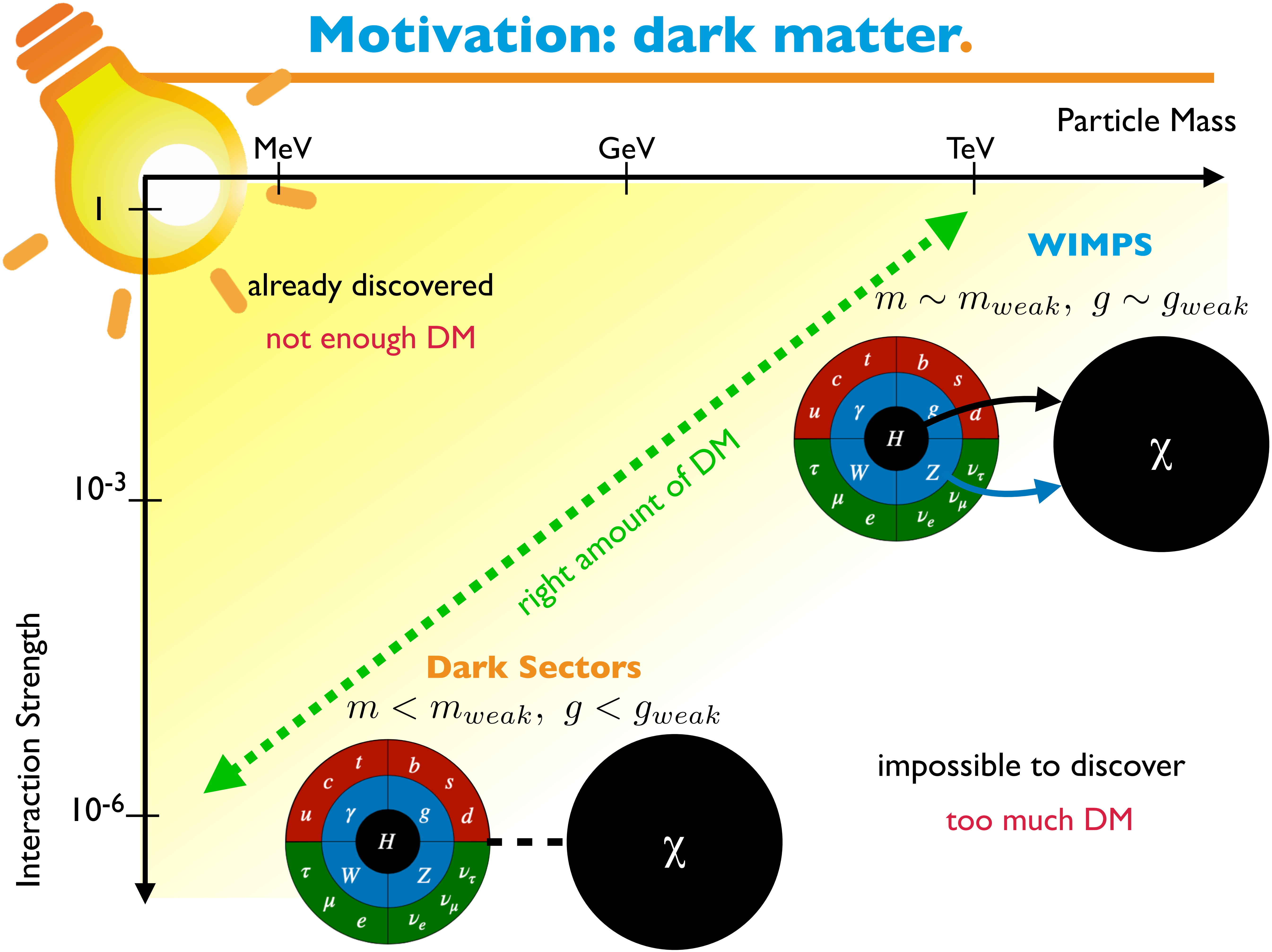
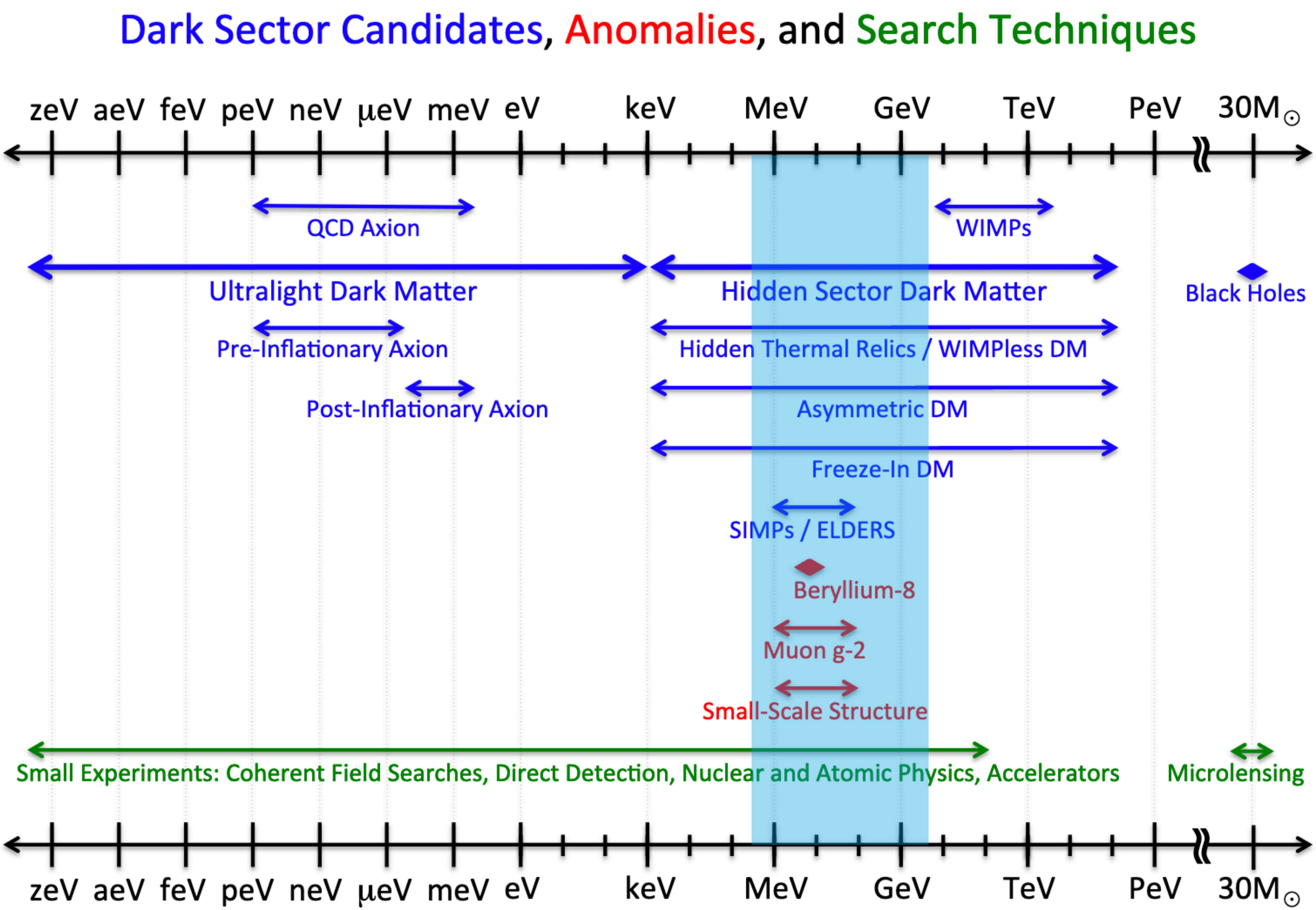
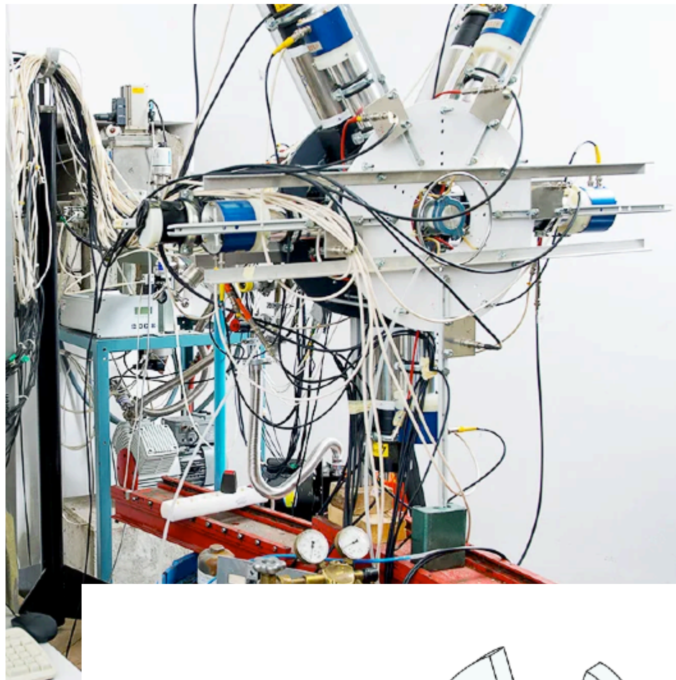


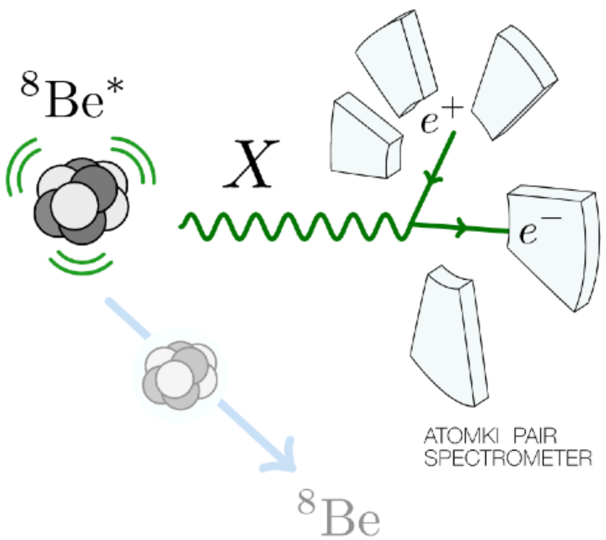
Motivation: anomalies.

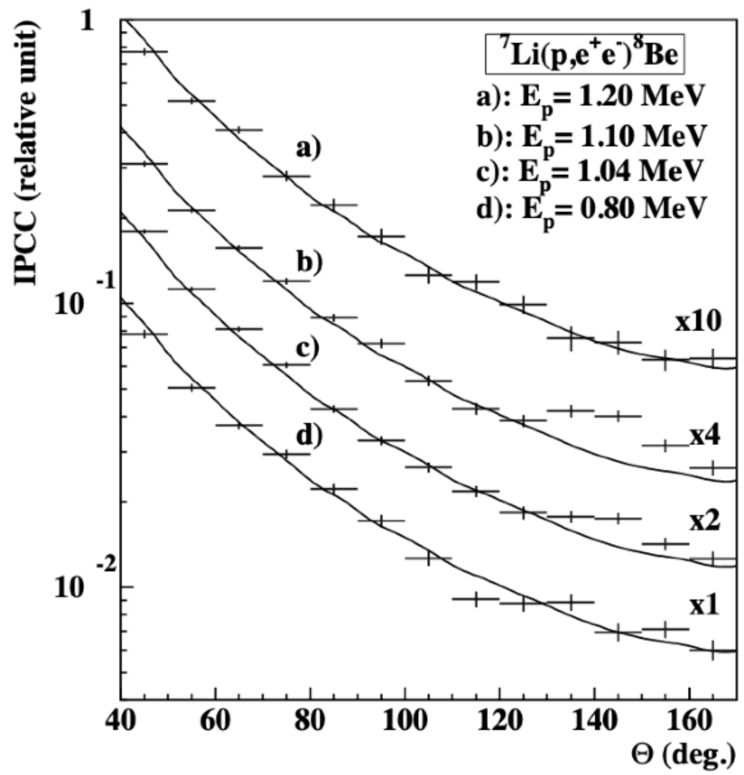


[US Cosmic Visions report: 1707.04591]

Motivation: Be8 and He4 anomalies.







2015: ATOMKI group reported a 7σ excess in rare Be decays

[ATOMKI, 1504.01527]

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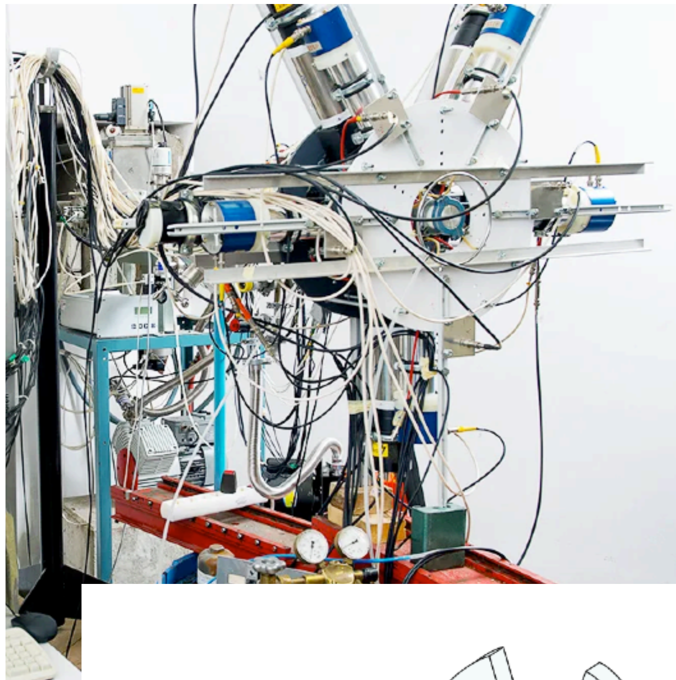

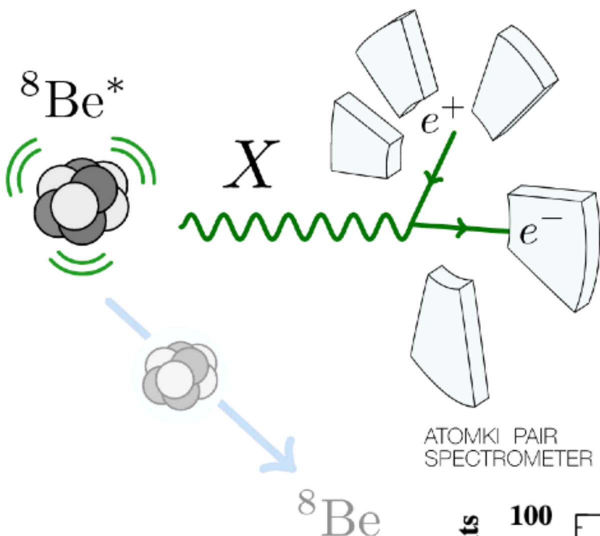

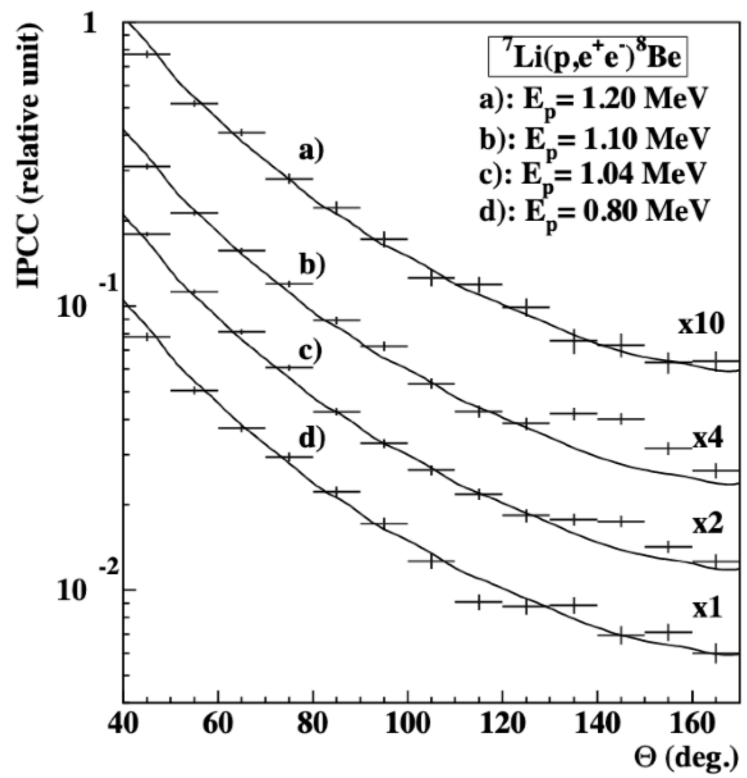

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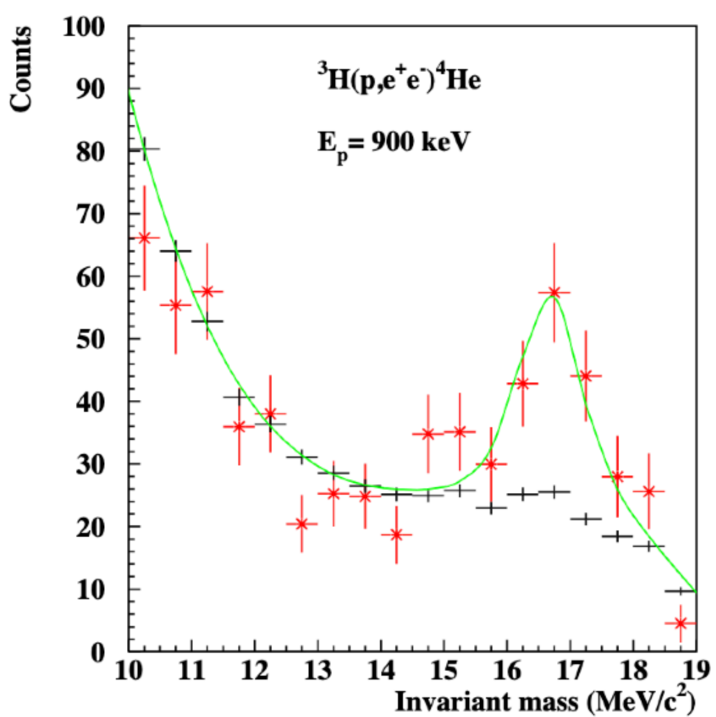
2019: also excess in He decays

[ATOMKI, 1910.10459]



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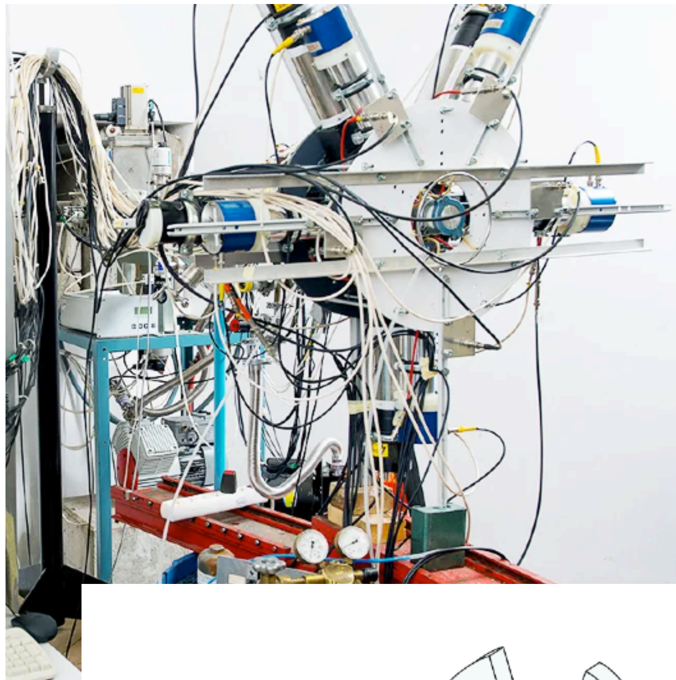

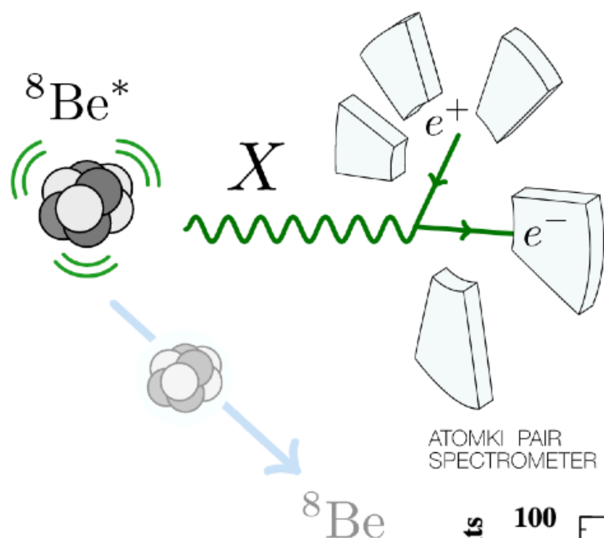

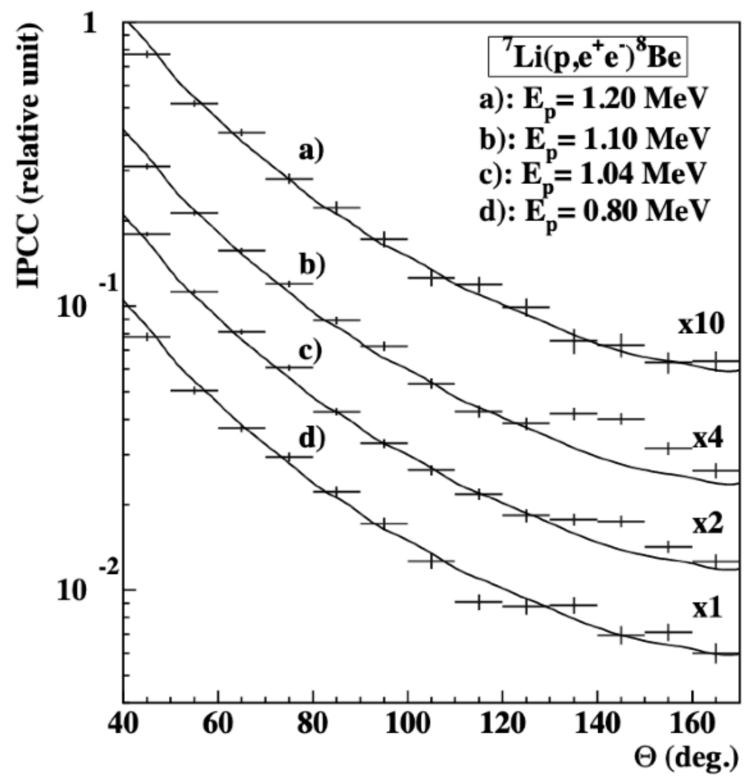

2015: ATOMKI group reported a 7σ excess in rare Be decays

[ATOMKI, 1504.01527]

Possible solution: new photophobic vector boson with 17 MeV mass

[Feng et al, 1608.03591]
[Feng et al, 2006.01151]

2019: also excess in He decays

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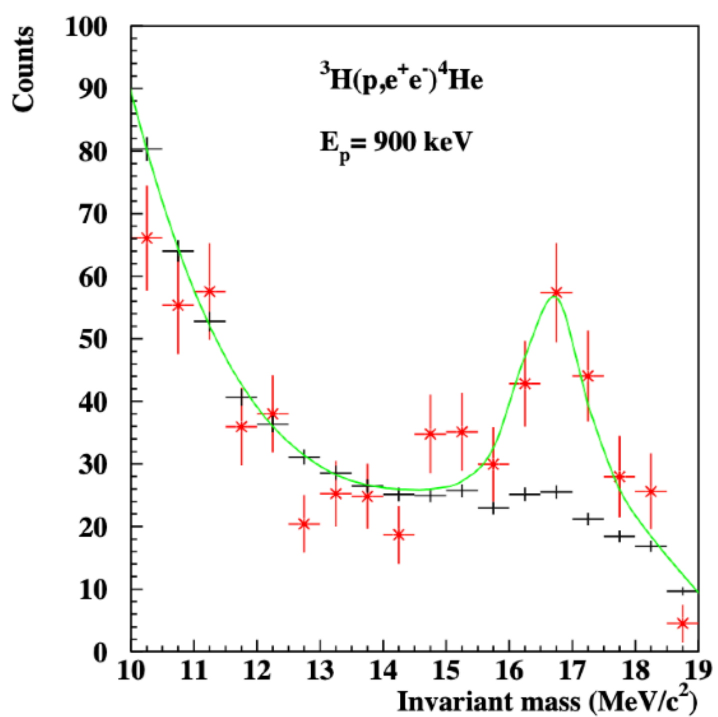
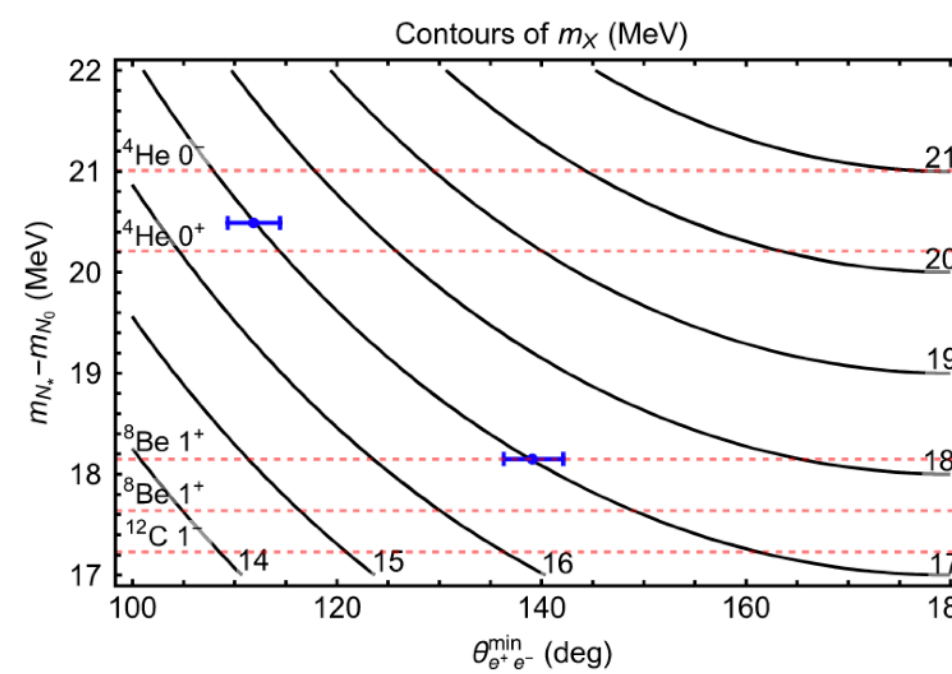




How can we look for them in the lab?

How to test dark sectors in the lab?

Simple Model: dark matter charged under U(1)$_D$

$$\mathcal{L} \supset \frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu} - \frac{1}{2} m_{A'}^2 A'^2 - m_\chi^2 \chi^2 + e_D \bar{\chi} \not{A}' \chi$$

phenomenology depends on masses

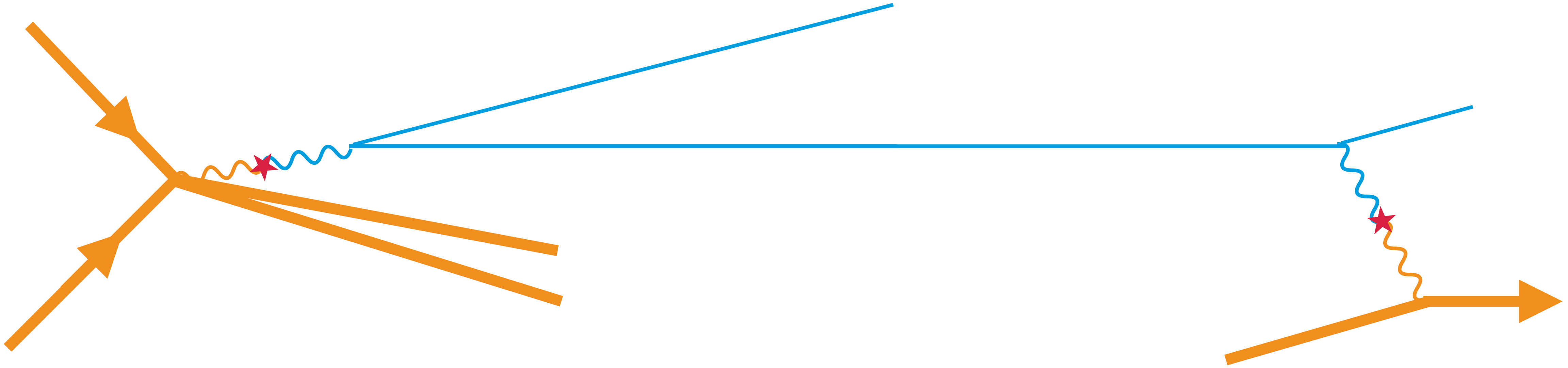
mA’ > 2mX:
A’ → XX

mA’ < 2mX:
A’ → SM SM

mA’ = 0:
milli-charged X

many possible signatures

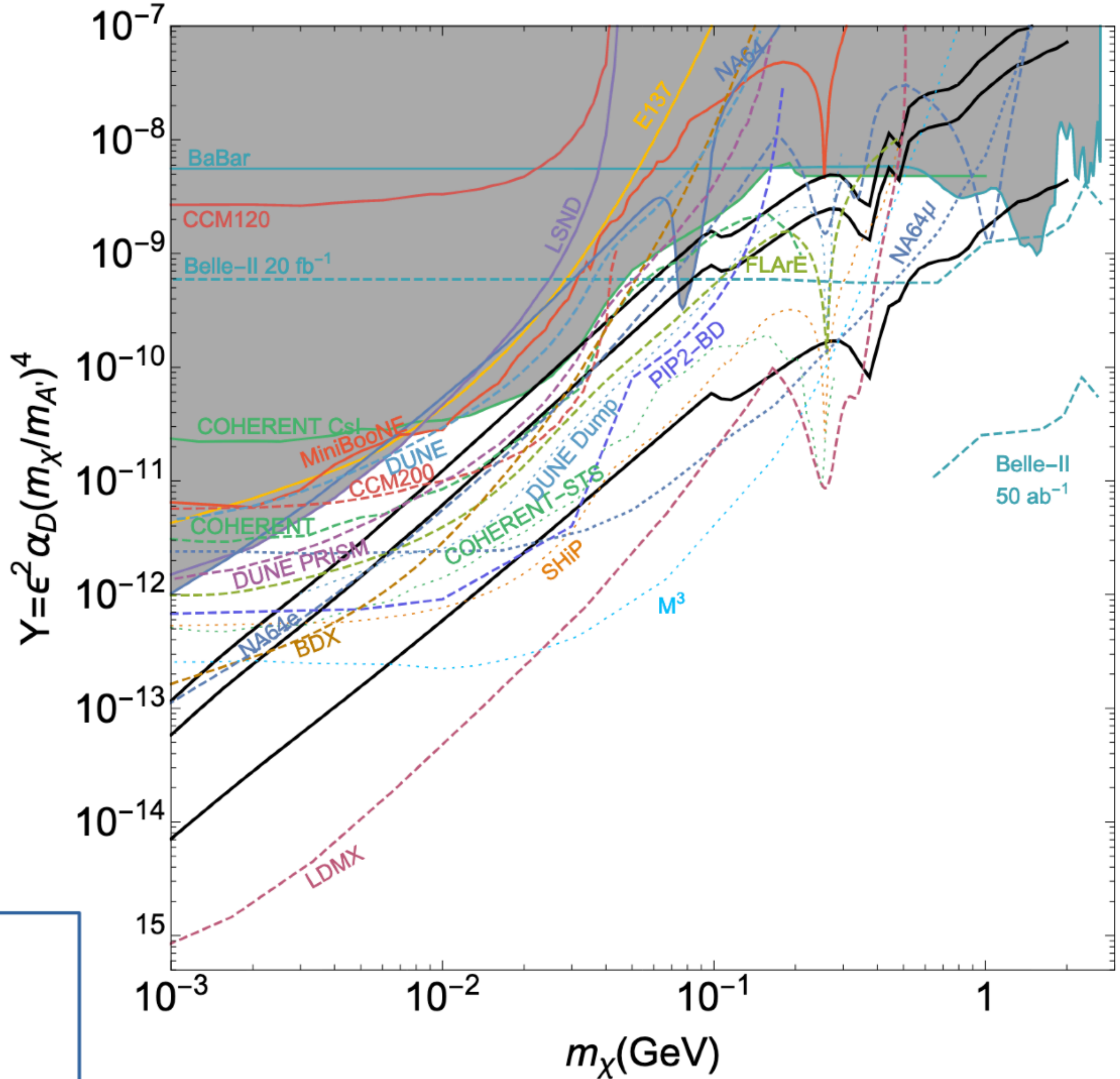
Signature with invisible decays.

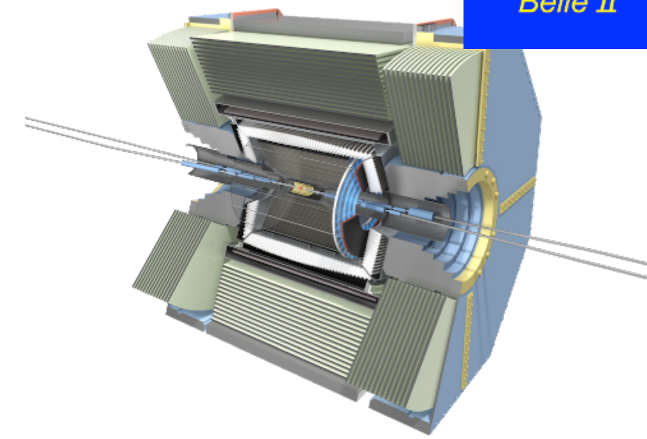


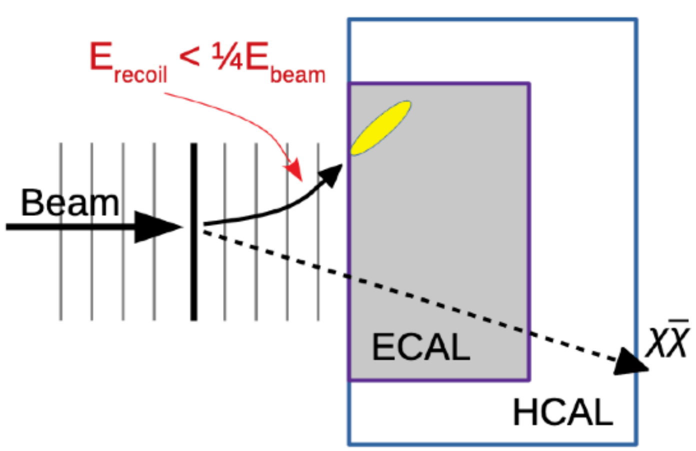
missing energy

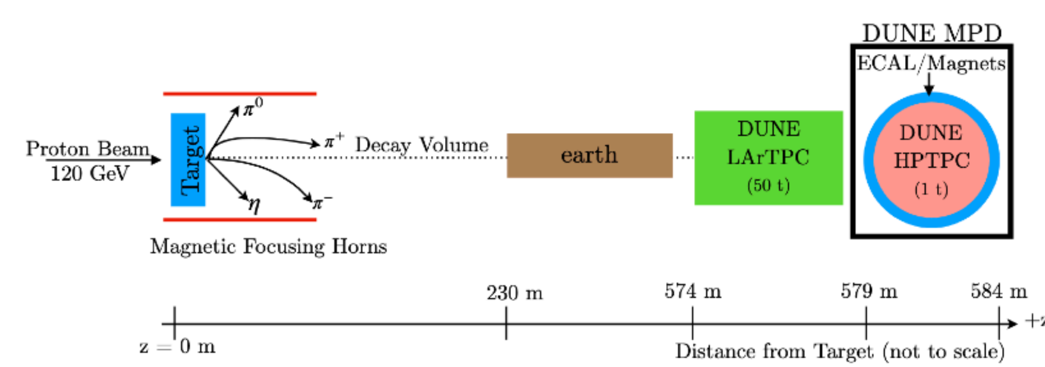
scattering

Signature with invisible decays.



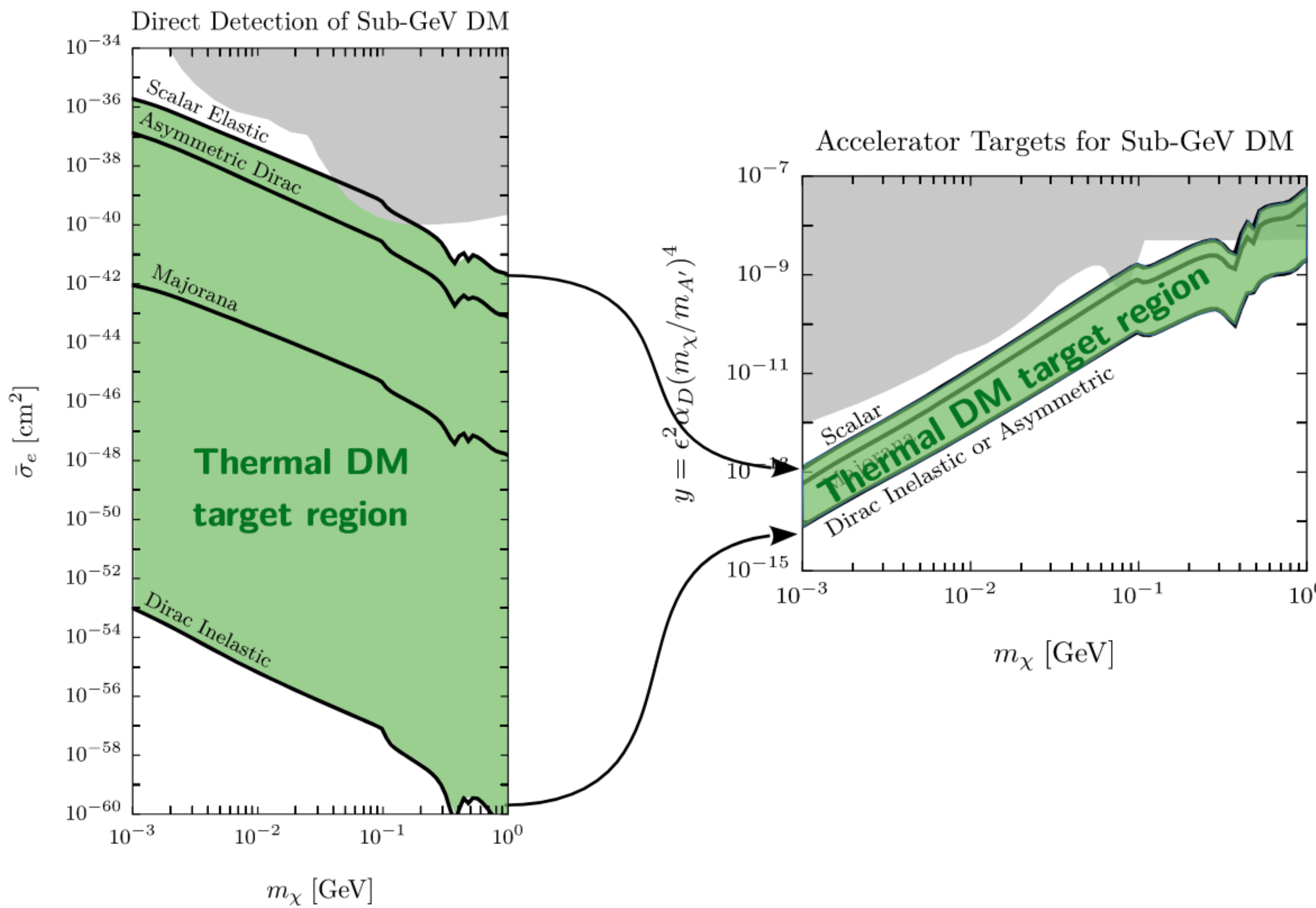






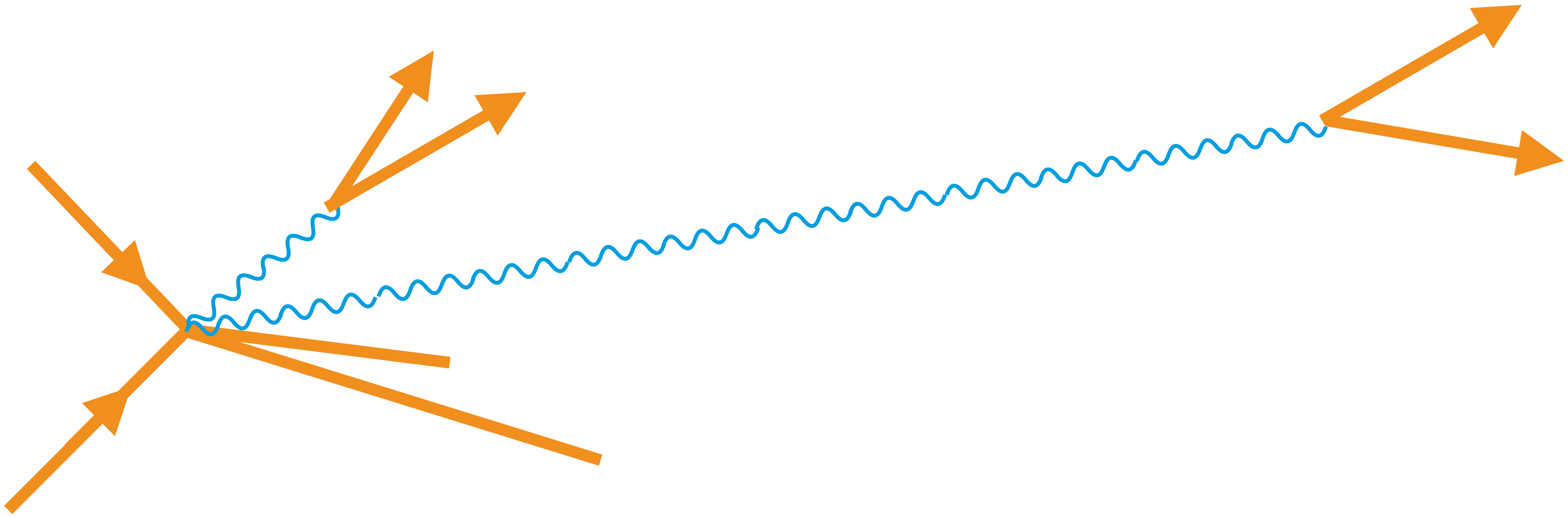
[Snowmass RF6, *Dark Matter Production at Intensity-Frontier Experiments*: 2207.00597]

Complementarity to Direct Detection.



[Snowmass RF6, *Dark Matter Production at Intensity-Frontier Experiments*: 2207.00597]

Signature with visible decays.



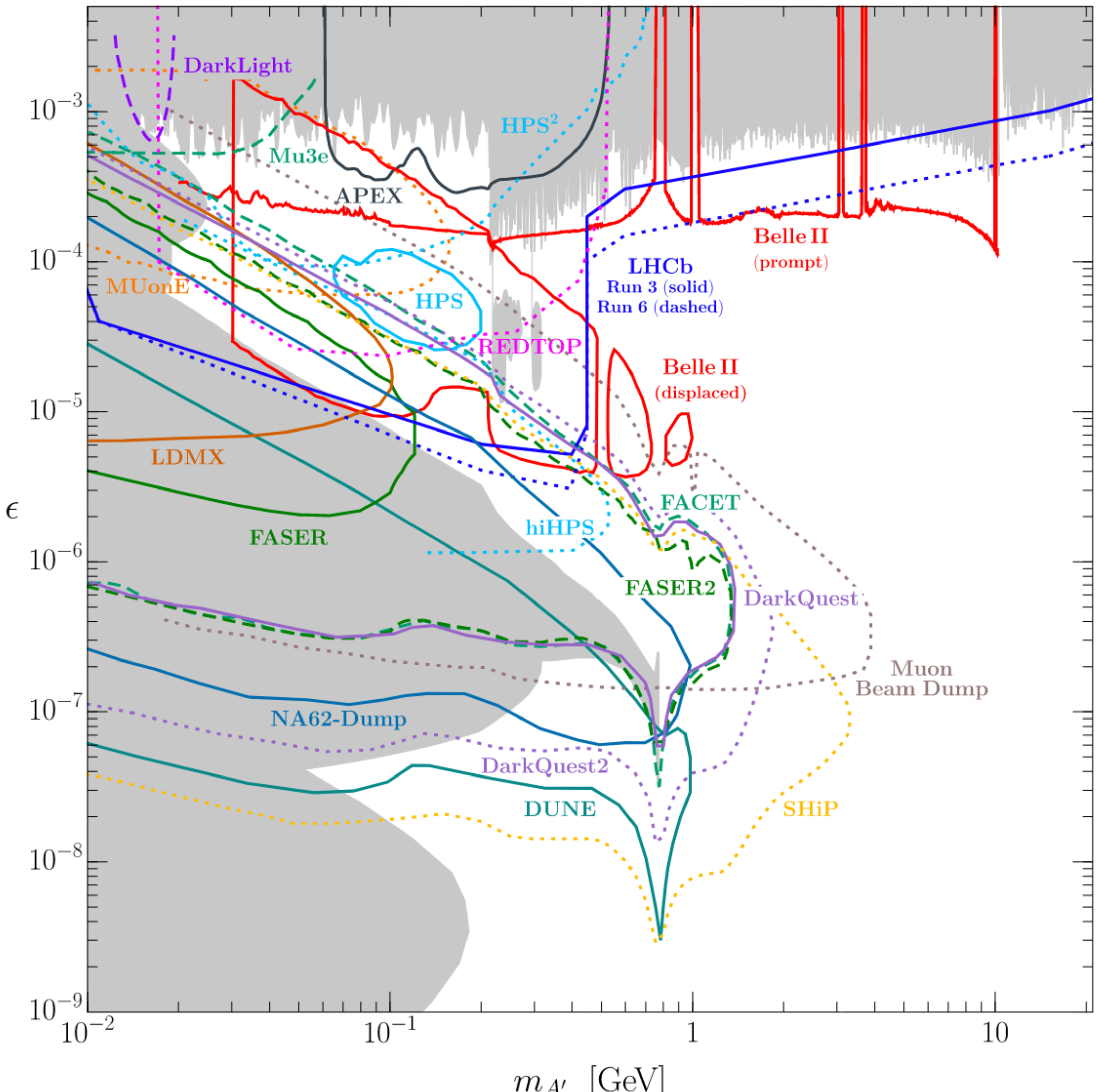
prompt resonances

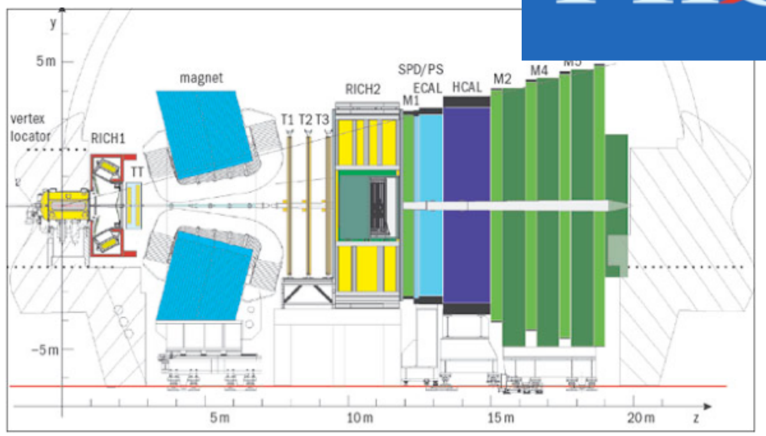
cτ << m

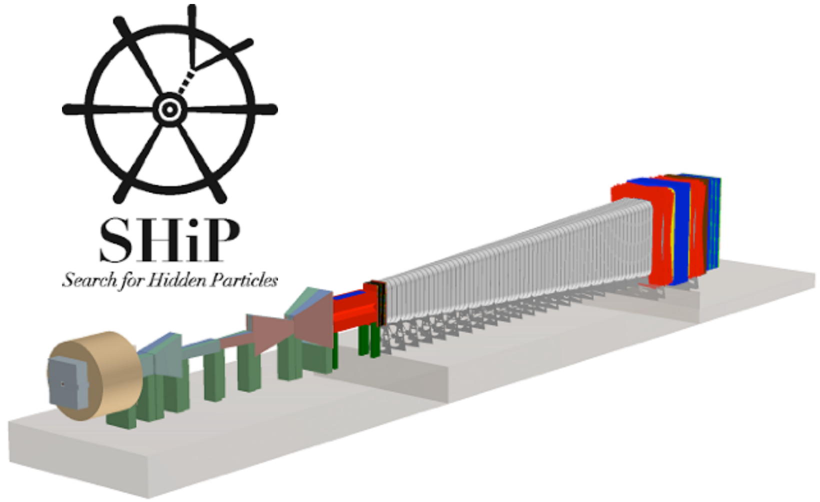
long-lived particle

cτ >> m

Signature with visible decays.

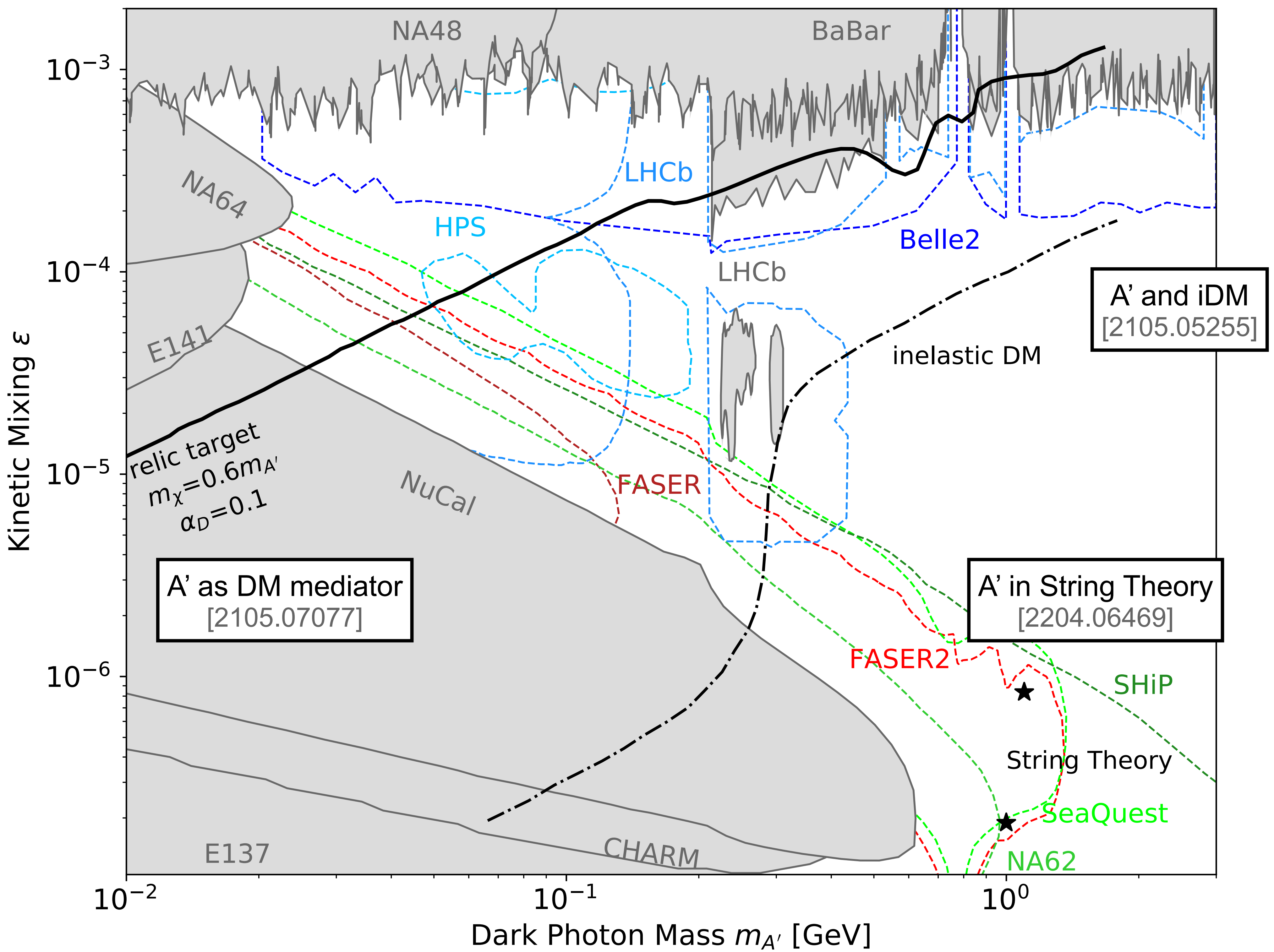






[Snowmass RF6, *Exploring Dark Sector Portals with High Intensity Experiments:* 2207.06905]

Signature with visible decays.

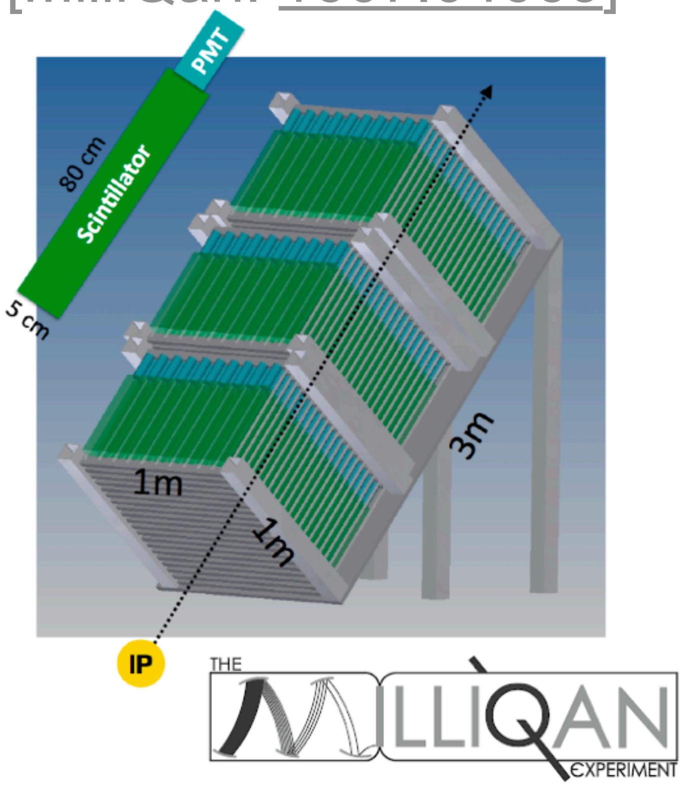


[FPF Whitepaper: 2203.05090]

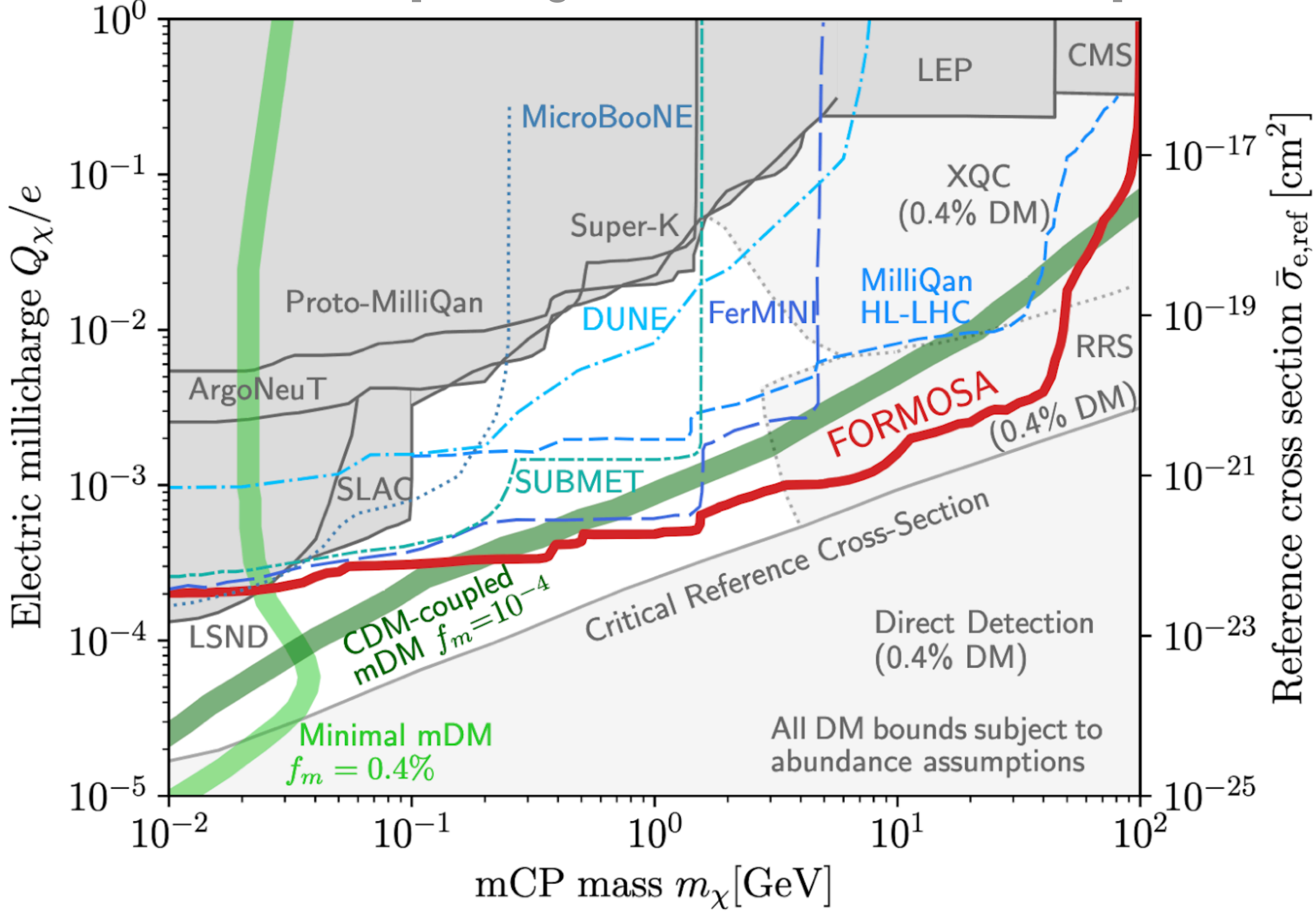
Signatures of Millichared Particles.

If mA'=0: X is effectively milli-charged with Q=εe
search for minimum ionizing particle with very small dE/dx

[MilliQan: 1607.04669]

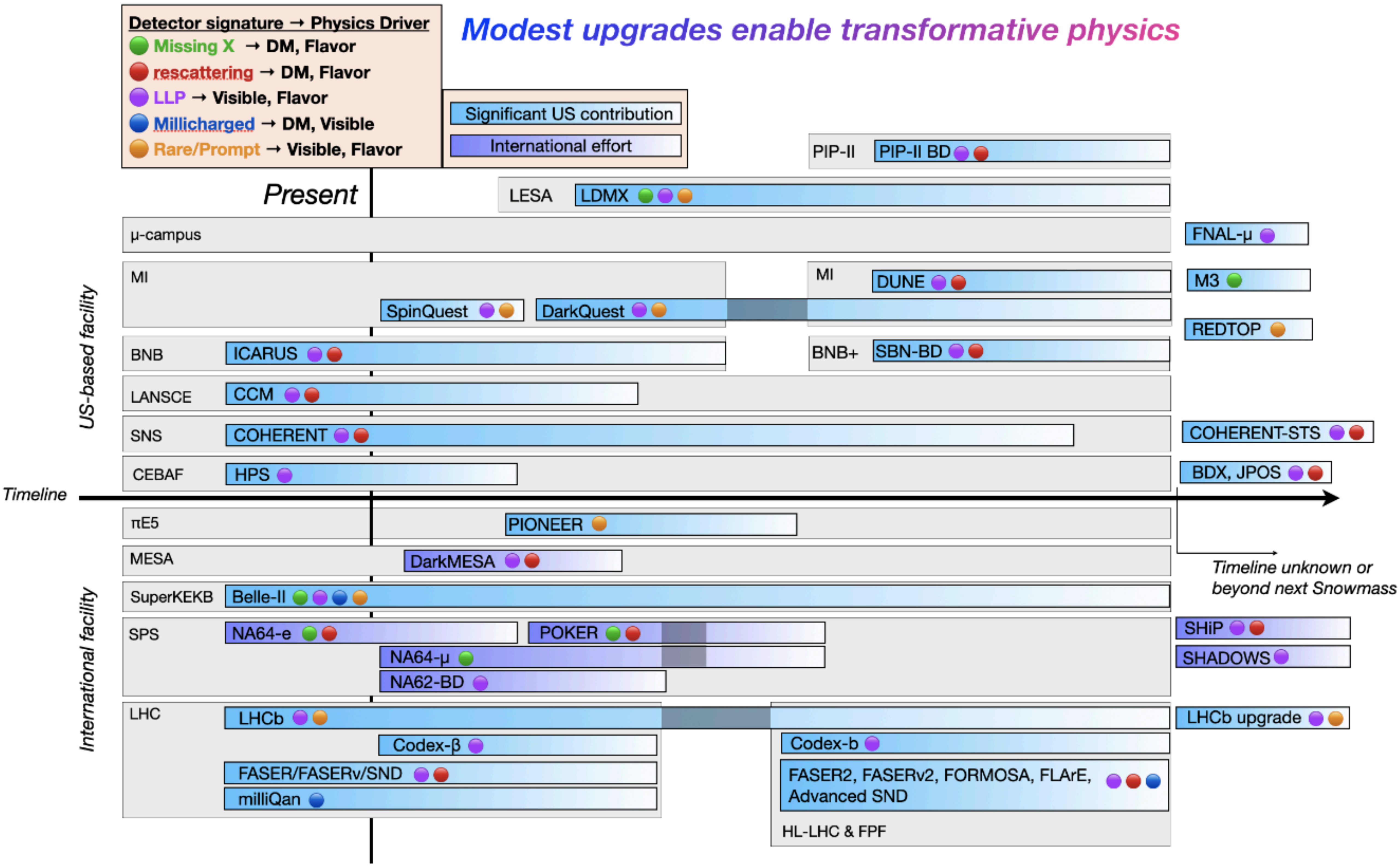


[Foroughi-Abari et al, 2010.07941]



Who is looking?

Experiments and Facilities



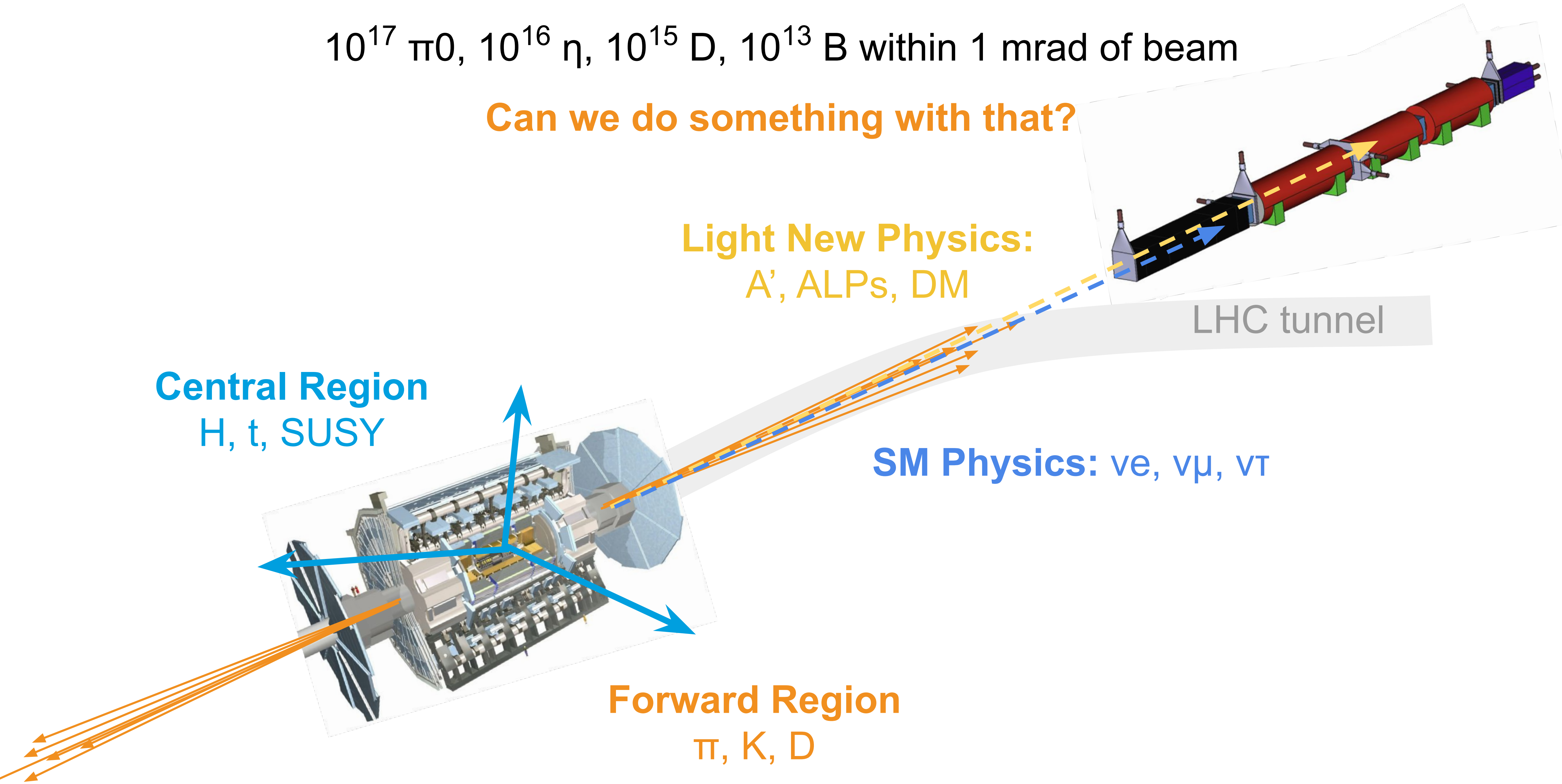
[Snowmass RF6, *Experiments and Facilities for Accelerator-Based Dark Sector Searches*: 2206.04220]

FASER: Idea.

The LHC produces an intense and strongly collimated beam of highly energetic particles in the forward direction.

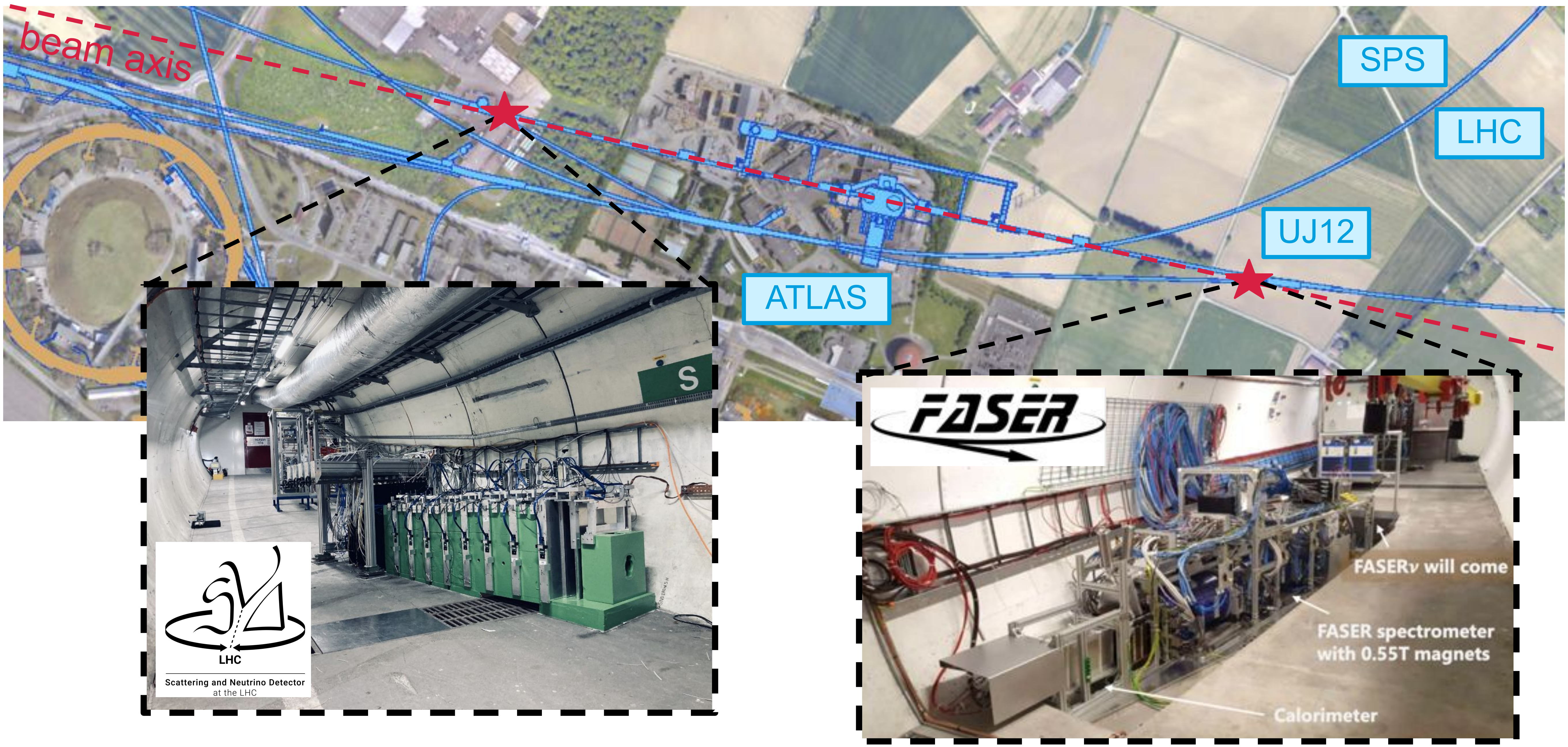
10^{17} π0, 10^{16} η, 10^{15} D, 10^{13} B within 1 mrad of beam

Can we do something with that?

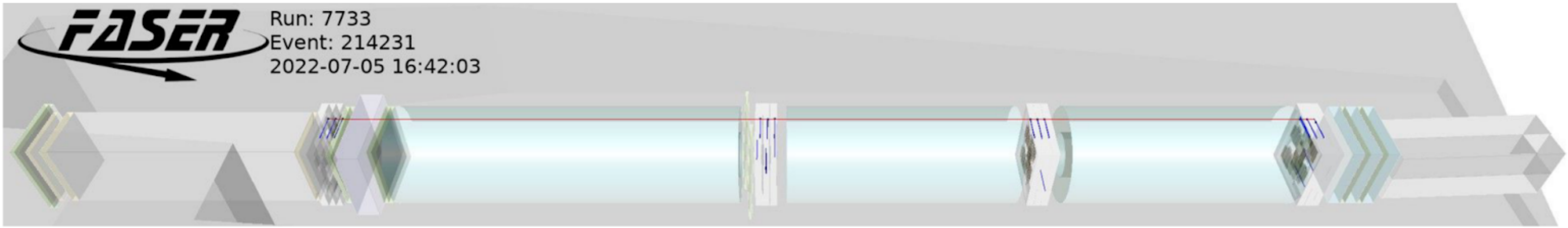


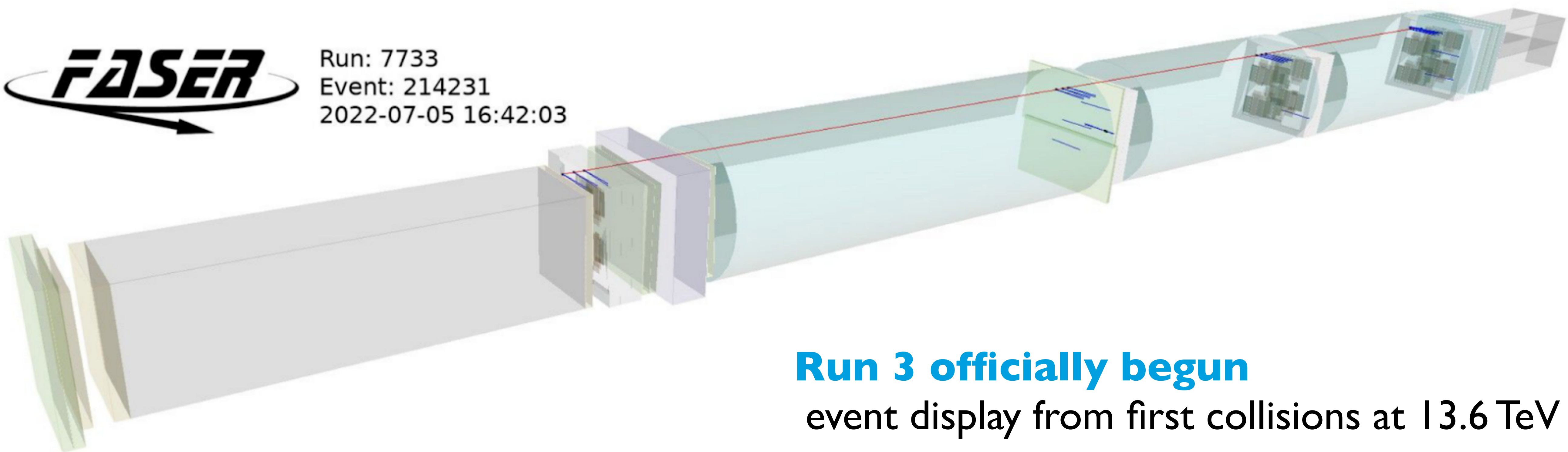
FASER: Location.

Two new experiments will exploit this potential during run 3 of the LHC:
SND@LHC and FASER.



FASER: First Events.



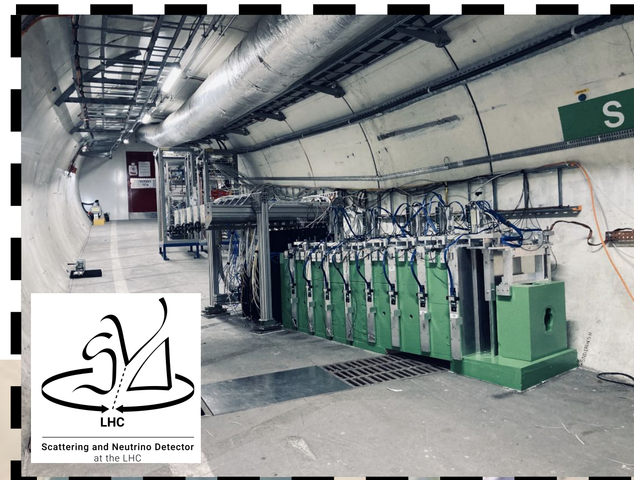


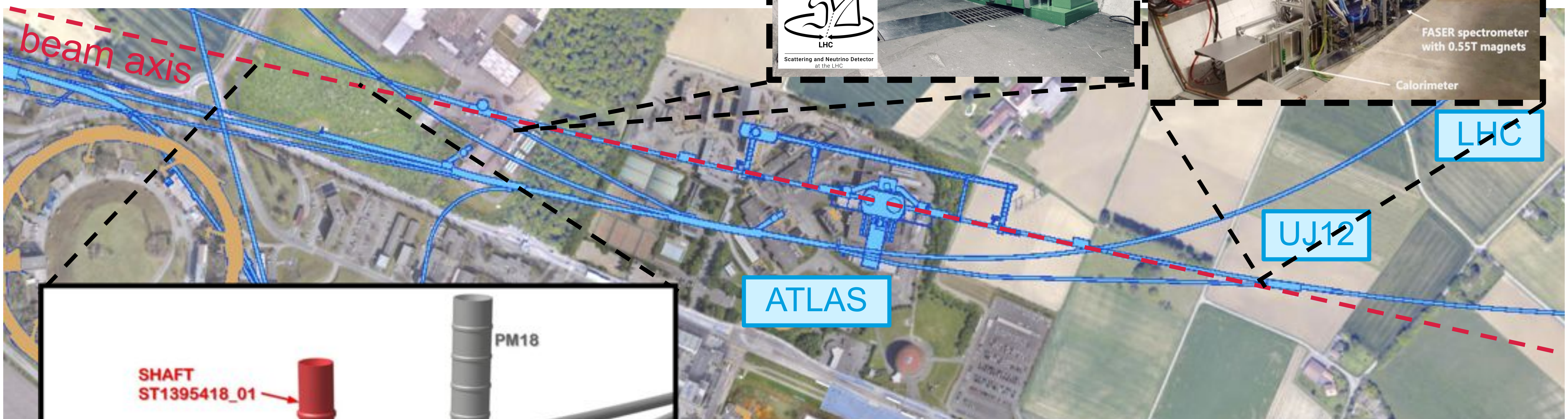
Run 3 officially begun
event display from first collisions at 13.6 TeV

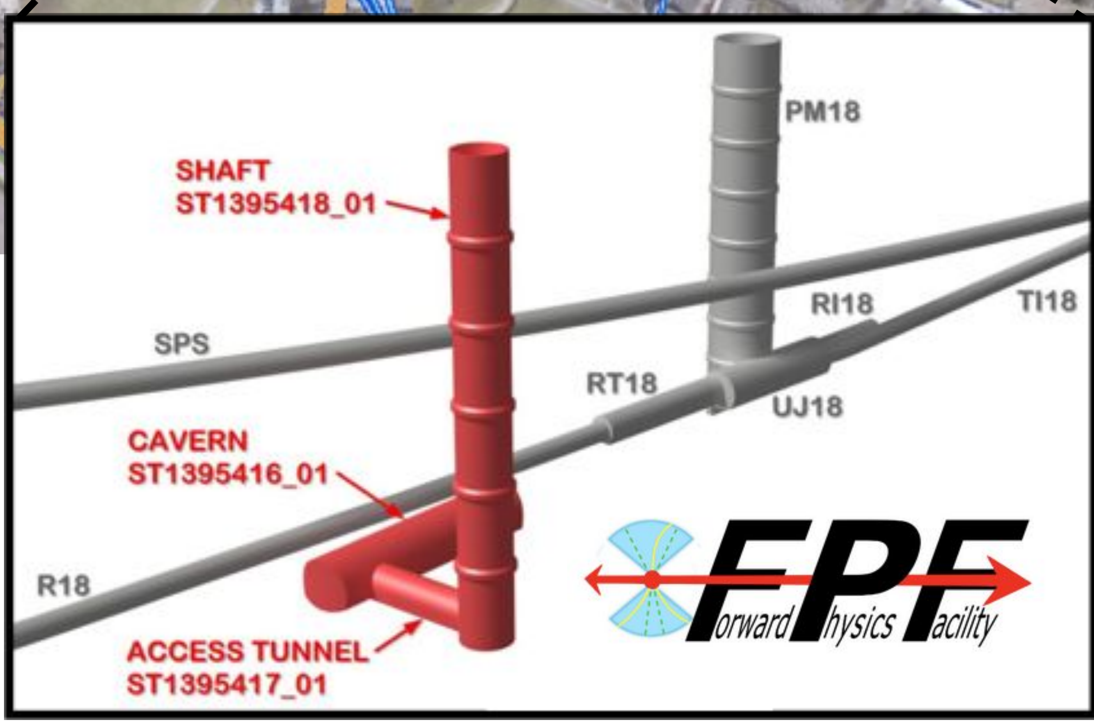
T. Böckh, D. Casper 2022

The Forward Physics Facility.

FASER and SND@LHC are highly constrained by 1980's infrastructure that was never intended to support experiments







The proposal: create a dedicated Forward Physics Facility (FPF) for the HL-LHC.

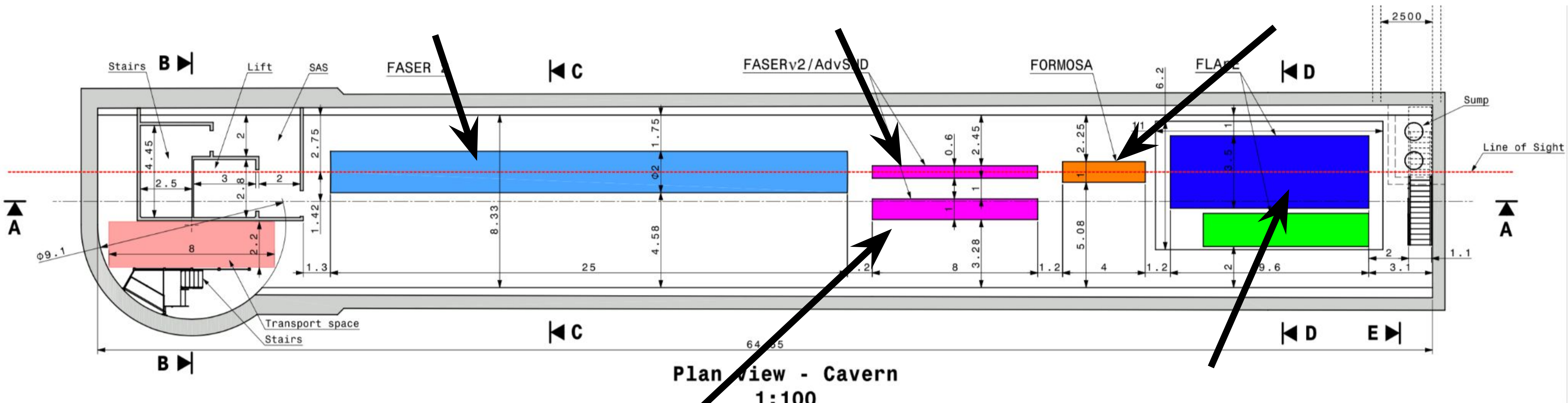
The Forward Physics Facility.

The FPF would house a suite of experiments that will greatly enhance the LHC's physics potential for BSM physics searches, neutrino physics and QCD.

FASER2
magnetized spectrometer
for BSM searches

FASERν2
emulsion-based
neutrino detector

FORMOSA
plastic scintillator array
for BSM searches



AdvSND
electronic
neutrino detector

FLArE
LAr based
neutrino detector

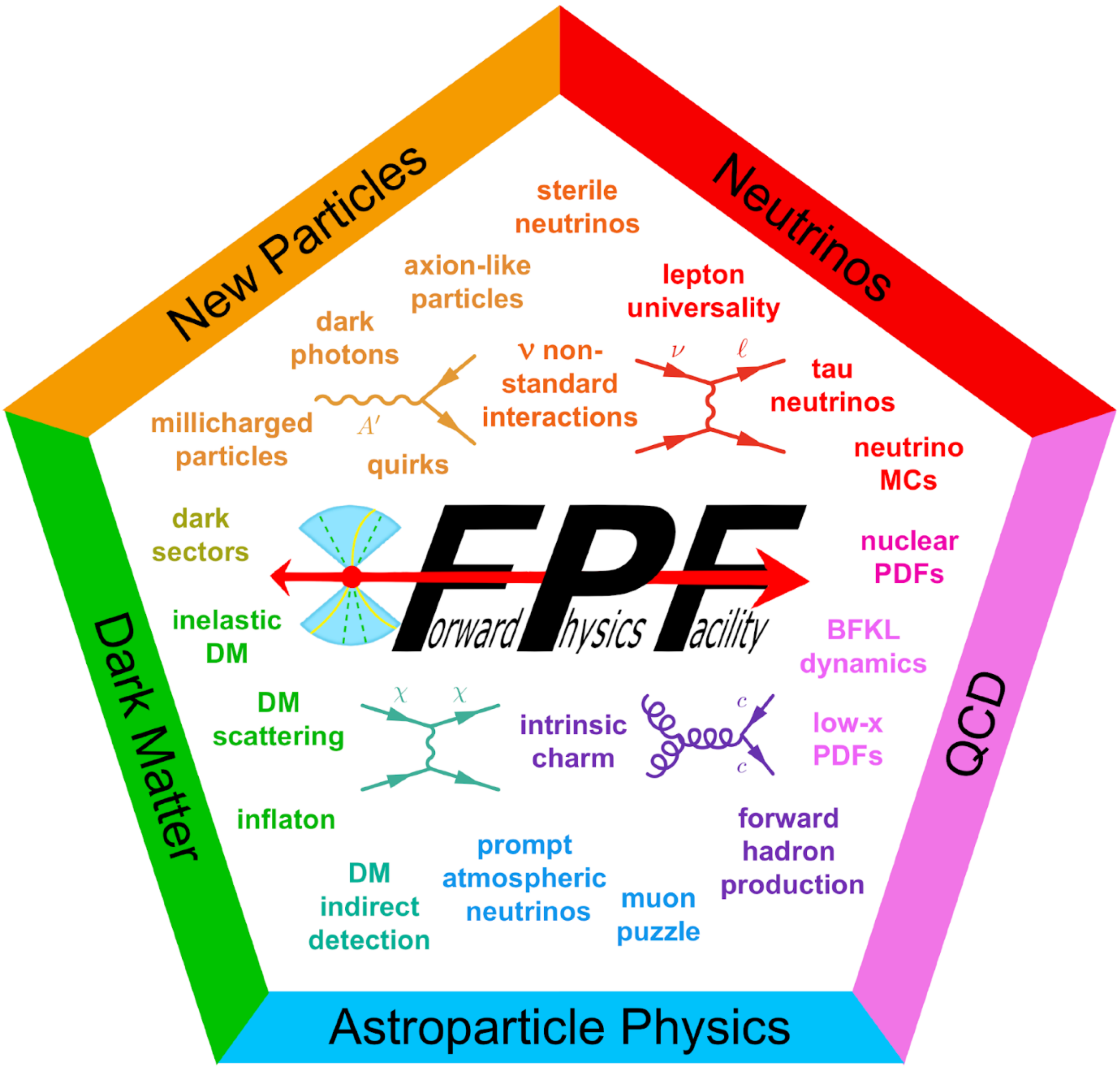
The Forward Physics Facility.

FPF workshop series:
FPF1, FPF2, FPF3, FPF4

FPF Paper:
2109.10905
~75 pages, ~80 authors

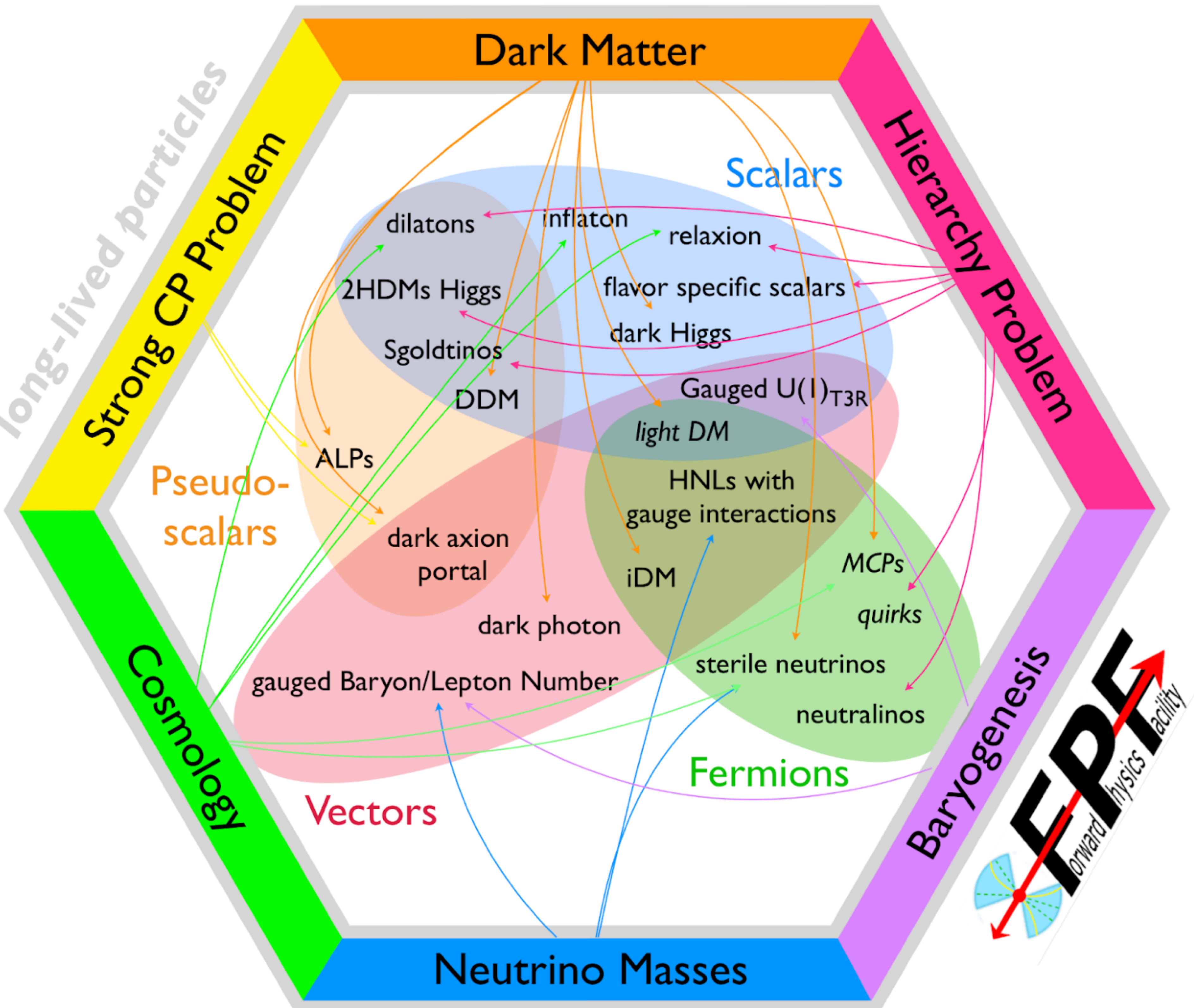
Snowmass Whitepaper:
2203.05090
~450 pages, ~250 authors

The Forward Physics Facility.



[FPF Whitepaper: 2203.05090]

The Forward Physics Facility.



[FPF Whitepaper: 2203.05090]

Summary.

What is a dark sector?

- set of new particles, which do not experience known forces
- weakly coupled to visible sector through a mediator or "portal"

Why are we interested in dark sector?

- dark matter, other theoretical puzzles, experimental anomalies

What can laboratory experiments do?

- intensity frontier experiments probe small portal couplings
- upcoming experiments have great potential to discover dark sectors

→ Next decade will be exciting