Hidden Sectors @ LHCb

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on behalf of the LHCb collaboration

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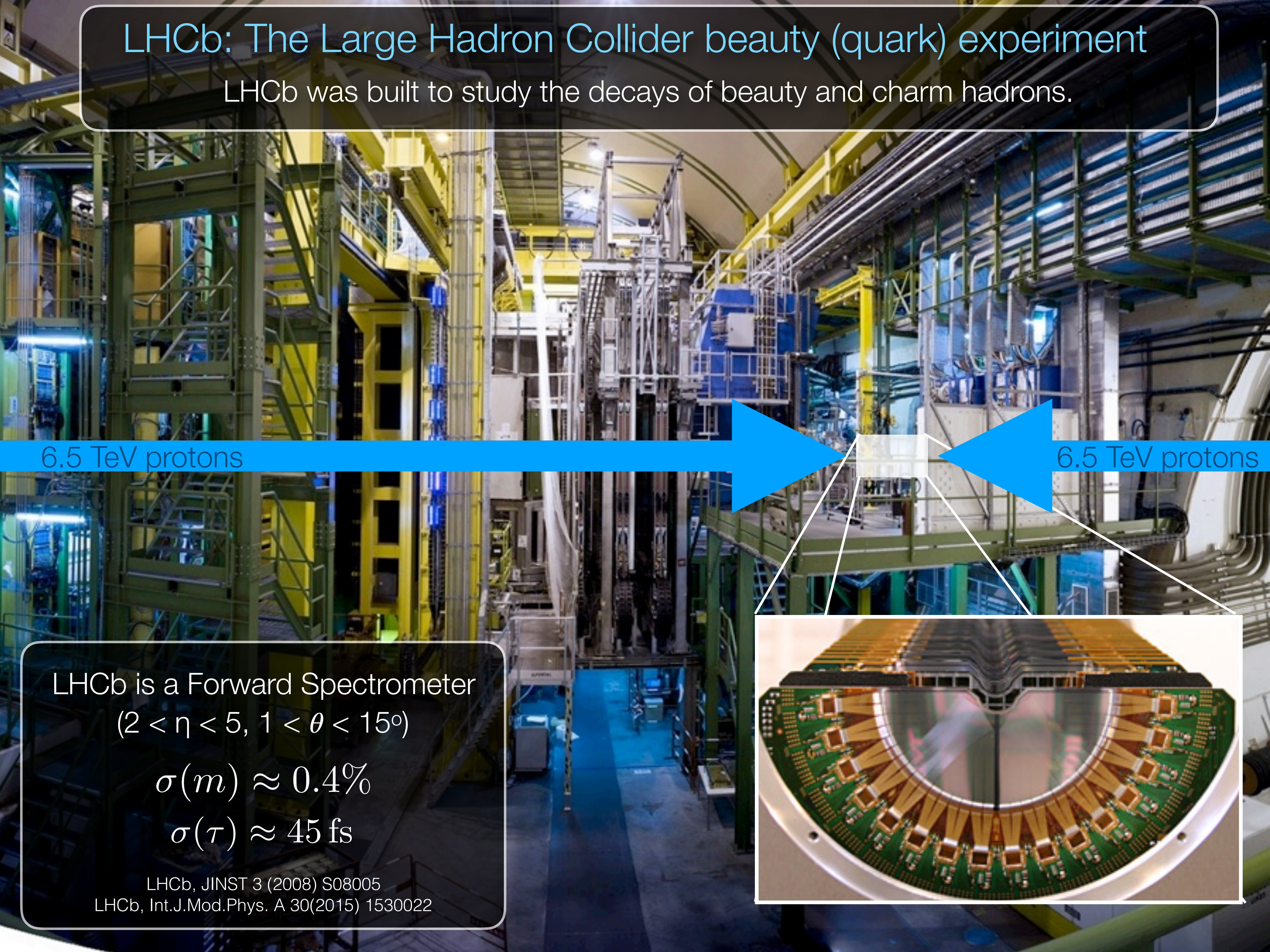
LHCb if painted by Van Gogh according to a Deep Neural Network.
https://github.com/jcjohnson/neural-style

LHCb: The Large Hadron Collider beauty (quark) experiment

LHCb was built to study the decays of beauty and charm hadrons.



LHCb is a Forward Spectrometer
($2 < \eta < 5$, $1 < \theta < 15^{\circ}$)

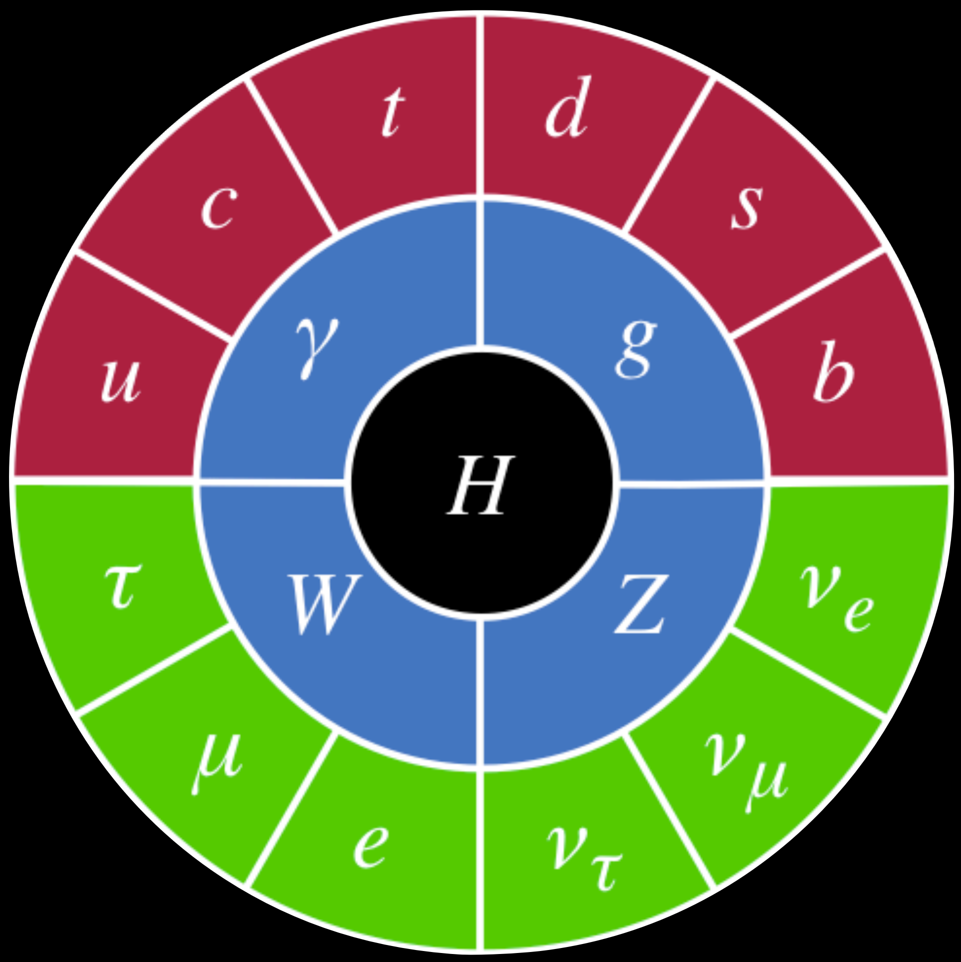
$$\sigma(m) \approx 0.4\%$$

$$\sigma(\tau) \approx 45\,\mathrm{fs}$$

LHCb, JINST 3 (2008) S08005
LHCb, Int.J.Mod.Phys. A 30(2015) 1530022

Hidden (Dark) Sectors

What if there is no connection between ordinary and dark matter up to the Planck scale?
(Hidden sectors can result from a Grand Unified Theory (GUT) of nature, and are generic in string theory constructions.)

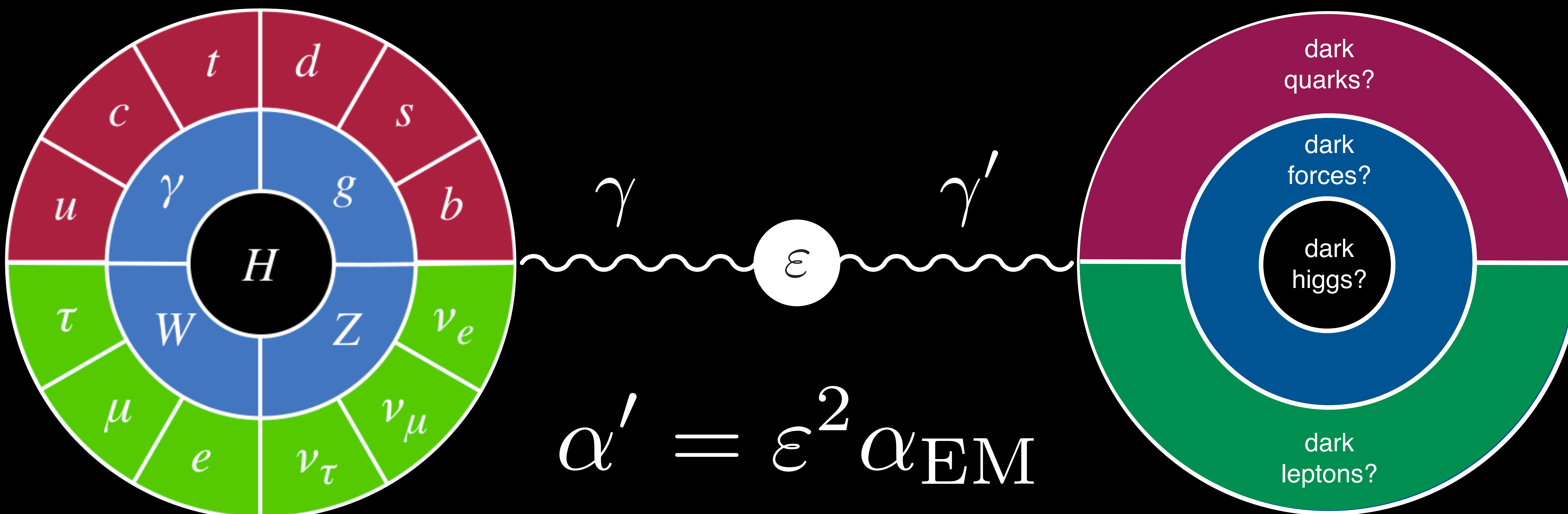


lightest DM particle could be stable because it's (dark) charged

When things are at their blackest, I say to myself "Cheer up, things could get worse." And sure enough, they get worse. —Robert Asprin

Dark Photons

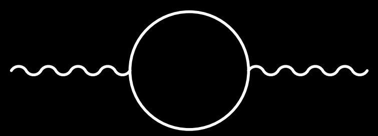
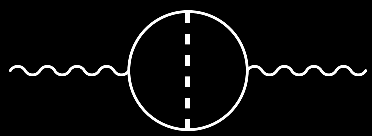
As long as our sector and the dark sector are connected at some scale (e.g. if they are both part of a GUT), then there is some path to get from a photon to a dark photon.



$$\alpha' = \varepsilon^2 \alpha_{\mathrm{EM}}$$

e.g, particle carrying both EM and dark-EM charge

e.g, GUT near the Planck scale

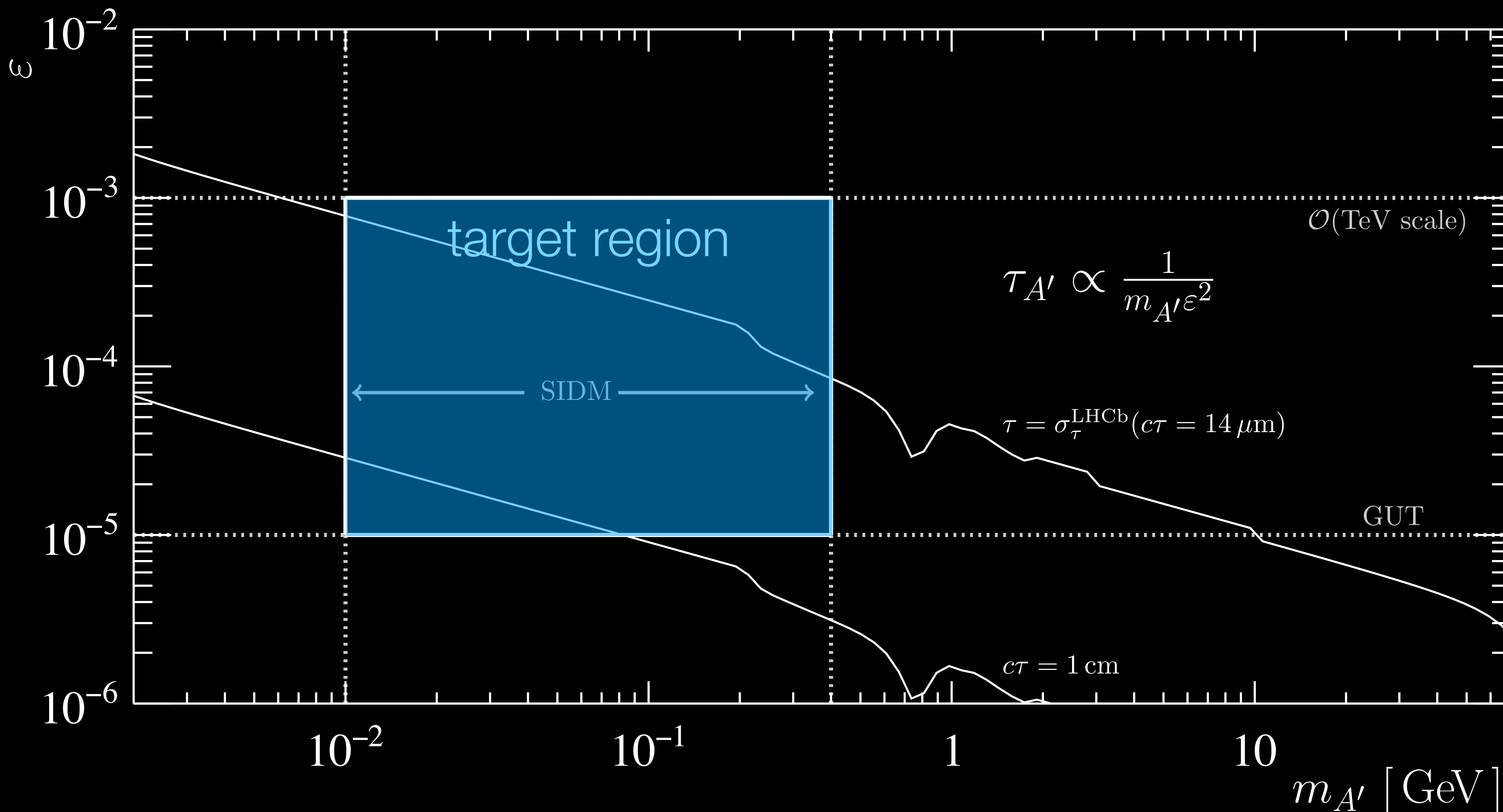
$\varepsilon \equiv \langle\gamma'|\gamma\rangle = \langle\gamma'|$  $|\gamma\rangle + \langle\gamma'|$  $|\gamma\rangle + \ldots$

$\varepsilon \sim \mathcal{O}(10^{-3})$ $\qquad$ $\varepsilon \sim \mathcal{O}(10^{-5})$

At low energy, we don't need to know the details. The bottom line is that the A' picks up a suppressed coupling to charged SM particles. We can make it in the lab, and it can decay into SM particles that we can detect.

Dark Photon Searches

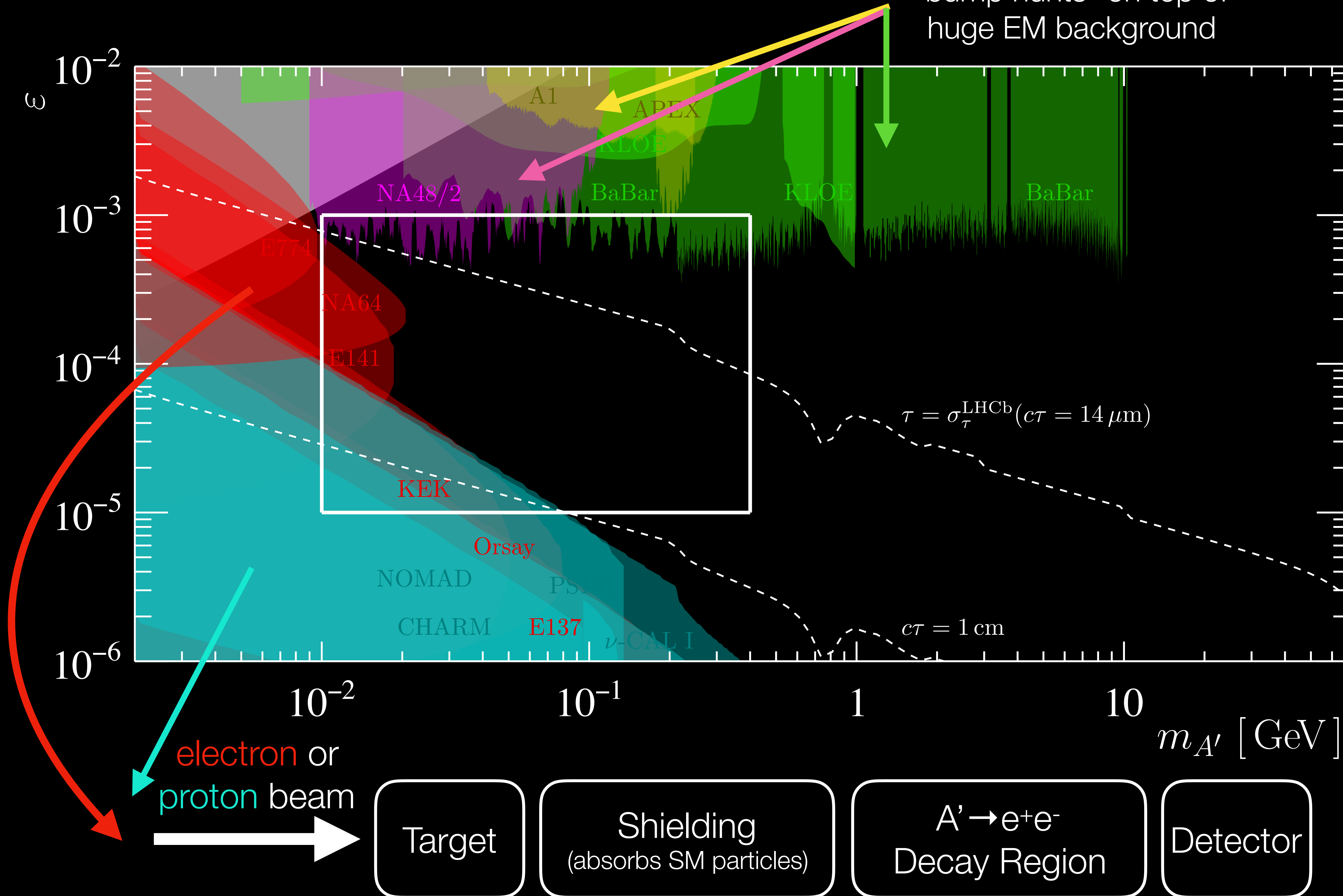
Well defined target region to search, e.g., assuming a SIDM-sized cross section and connection between sectors at the few-loop level (*cum grano salis*).



Additional constraints from BBN, tests of Coulomb's Law, etc. also motivate focusing (very roughly) on this target region (within a few orders of magnitude of it).

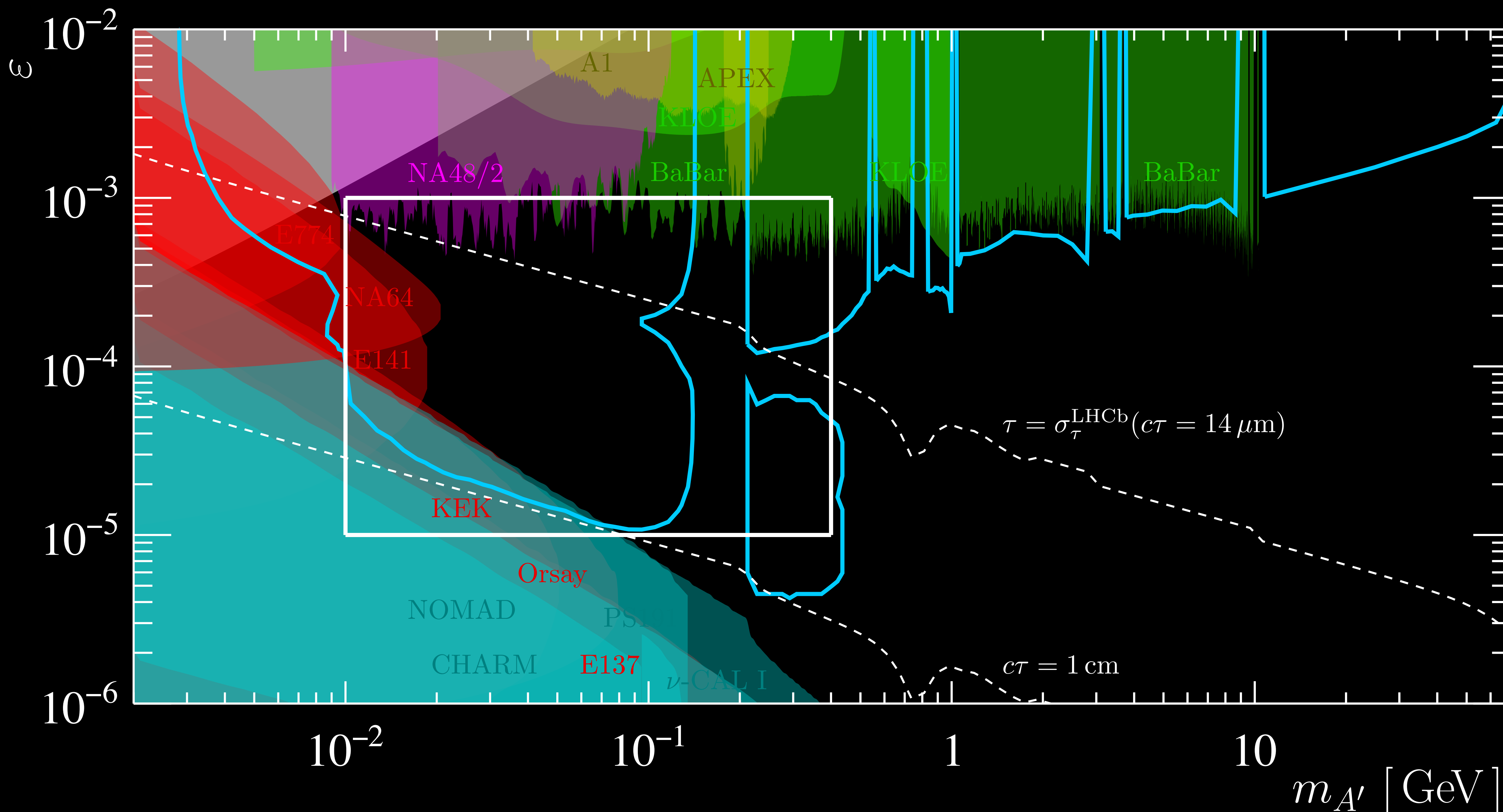
Dark Photon Constraints

Existing constraints leave the target region largely unexplored, i.e. no laboratory experiment would’ve seen the dark photon if it exists.



Dark Photons @ LHCb

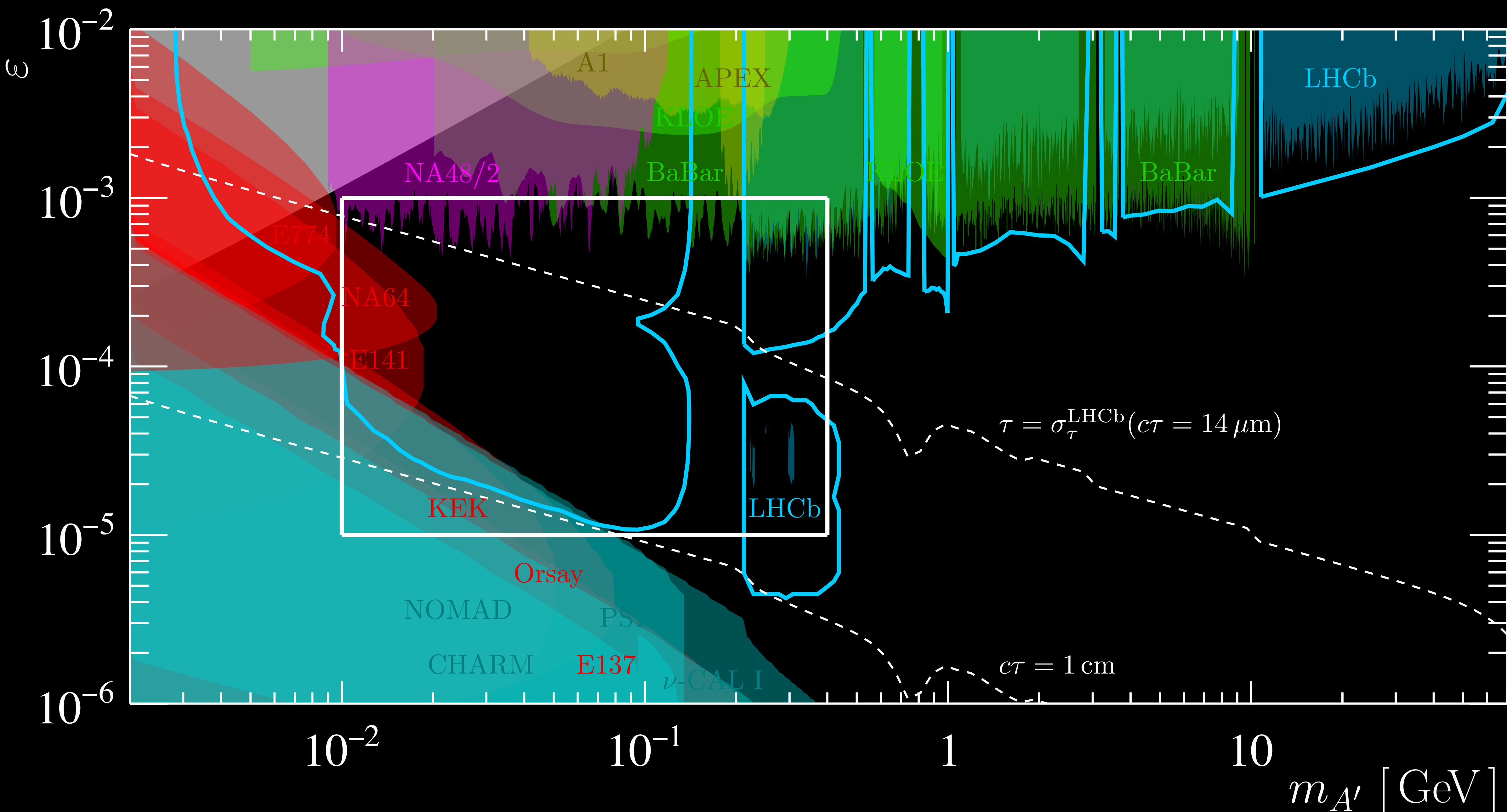
We proposed leveraging LHCb's excellent lifetime and mass resolution—and the planned move to triggerless readout in Run 3 — to probe all of the unexplored dark photon space.[1,2,3]



[1] Ilten, Soreq, Thaler, MW, Xue, PRL 116 (2016) 251803—proposed inclusive search for $A' \to \mu^+\mu^-$.
[2] Ilten, Thaler, MW, Xue, PRD 92 (2015) 115017—proposed search using radiative charm decays and $A' \to e^+e^-$.
[3] The gap between [1] and [2] is accessible in $\eta \to \gamma A'$ decays.

Dark Photons @ LHCb

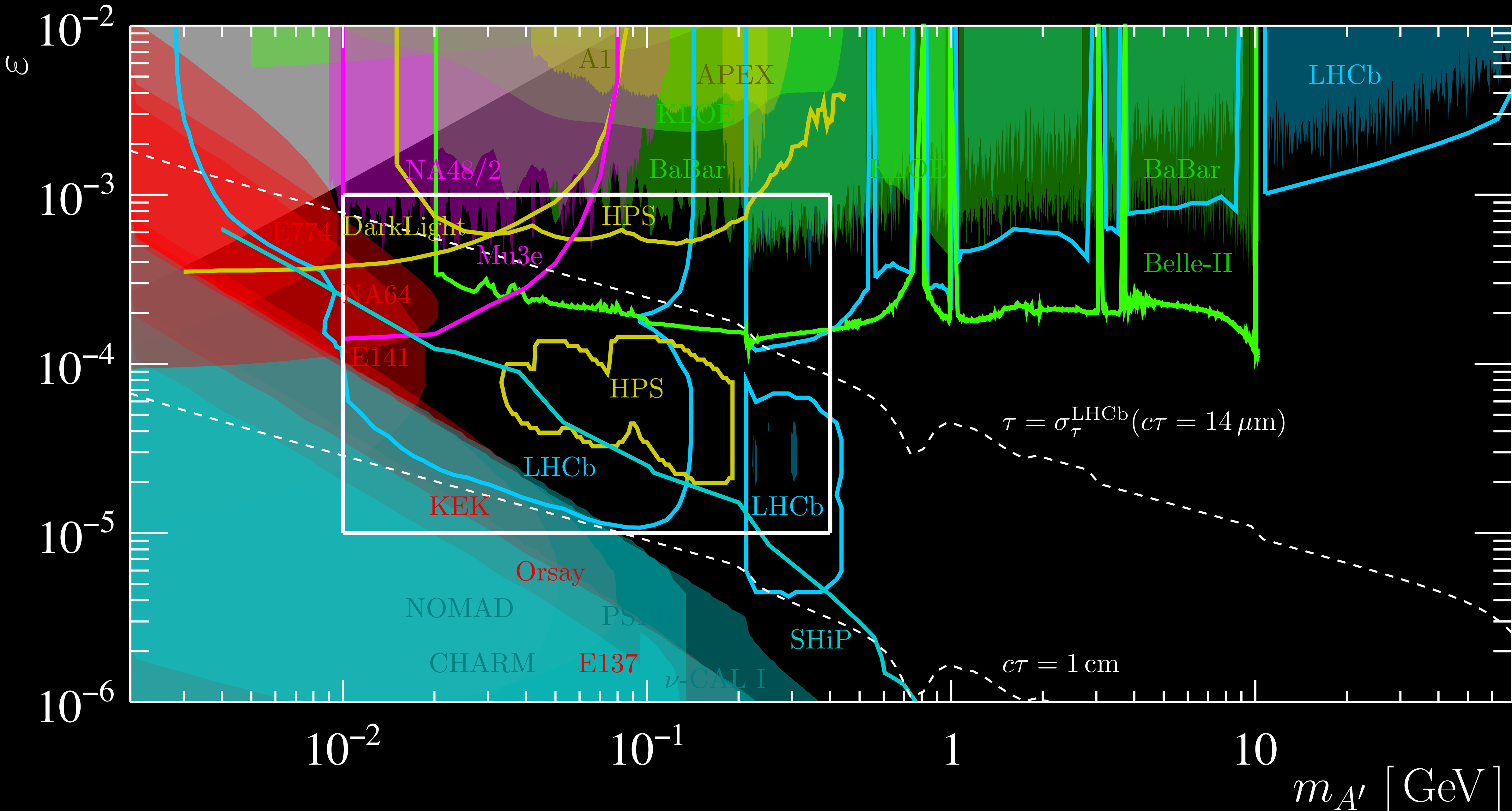
Using a 2016 data sample O(100) times smaller than expected in Run 3, LHCb showed[1] that our predictions are accurate[2]—and achieved the first ever sensitivity using a displaced vertex. LHCb will be able to fully explore the A' space in the next 5 years (much of it by 2019).



[1] LHCb-PAPER-2017-038, PRL 120 (2018) 061801 [1710.02867]
Technical support papers: LHCb, JINST 13 (2018) P06008; MW, JINST 12 (2017) P09034.
[2] LHCb achieves slightly better sensitivity than expected by rescaling our predictions for Run 3 to this data sample.
See also LHCb-PAPER-2018-008 JHEP 8 (2018) 147 for dimuon results near the Upsilon peaks.

Dark Photon Searches

Other future proposed experiments (including purpose-built ones) can each cover some of the target parameter space, though only LHCb can cover all of it.[1]



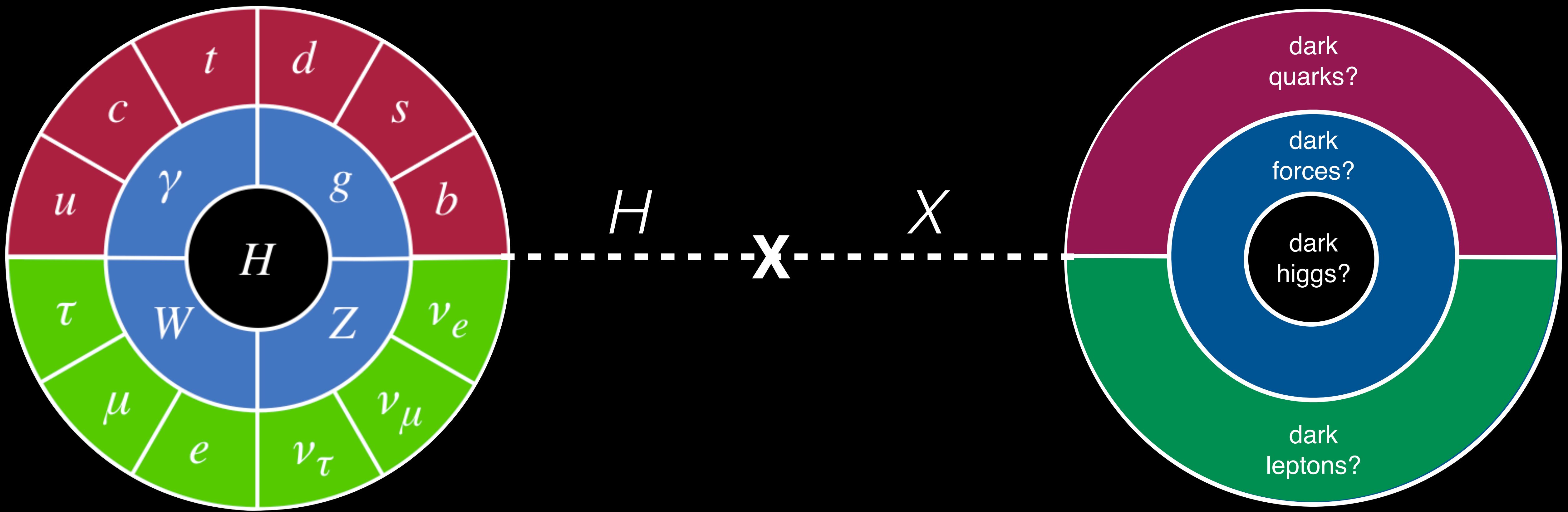
Of course, dark matter is not the only motivation for looking for new forces of nature.

See Ilten, Soreq, MW, Xue JHEP 6 (2018) for recasting to any other vector force model.

[1] Note that here and throughout this discussion I've assumed that $m_{A'} < 2m_X$.

Higgs Portal

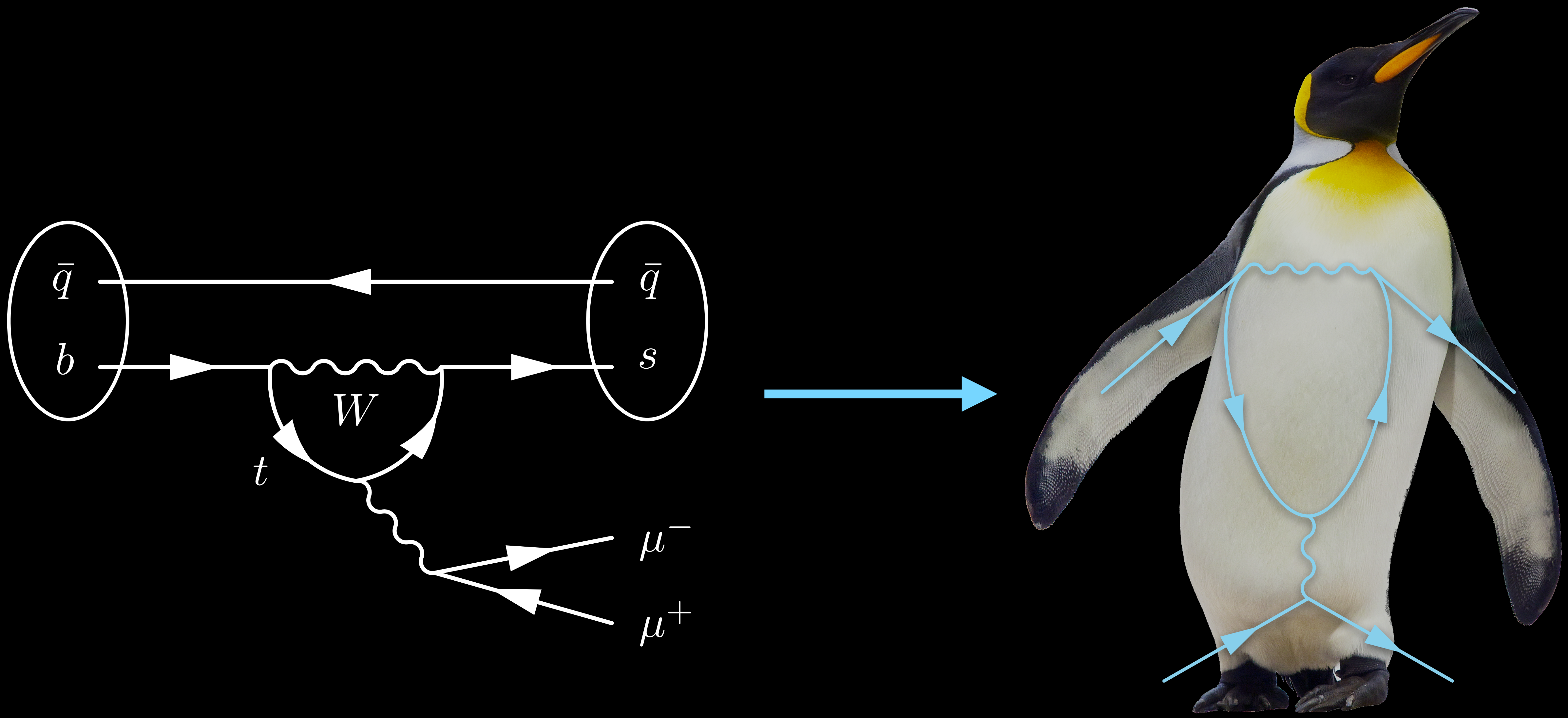
We can play a similar game with the Higgs this time, where now couplings to SM particles will be proportional to mass (not electric charge).



$$\begin{pmatrix} H \\ \chi \end{pmatrix}_{\text{physical}} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} H \\ \chi \end{pmatrix}_{\text{ideal}}$$

Penguin Decays

b➞s "penguin" decays are highly sensitive to many possible extensions to the SM, e.g., anything with a sizable coupling to the top quark.



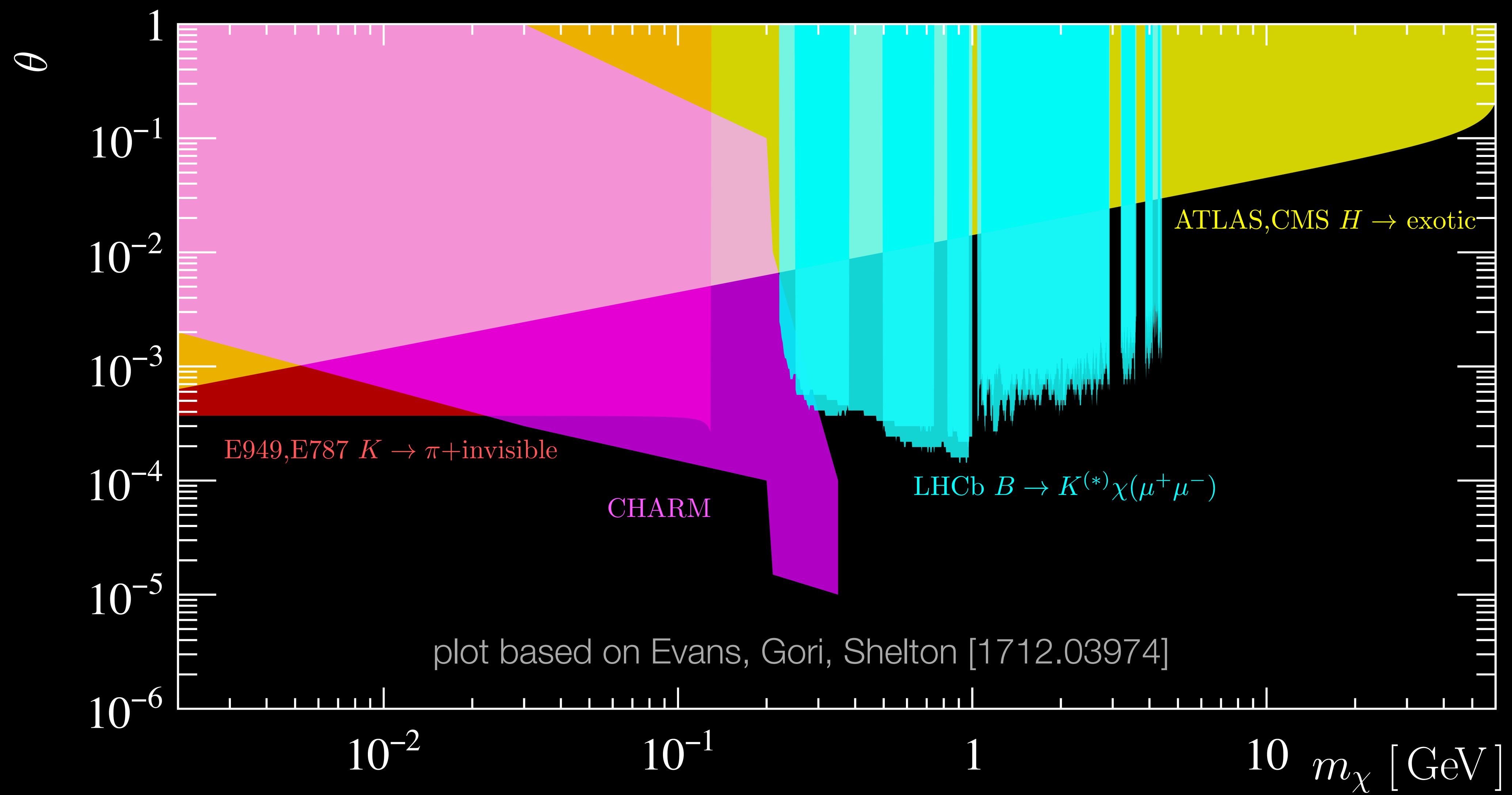
If you're in the right state of mind, the Feynman diagram may (sort of) look like a penguin.
(see https://en.wikipedia.org/wiki/Penguin_diagram)

Higgs Portal

Strongest constraints are from beam dumps, kaon decays, b→s penguin decays @ LHCb, the upper limit on exotic Higgs decays from ATLAS/CMS, and heavy Higgs searches at ATLAS/CMS (these are O(0.1), not shown on the plot).

LHCb-PAPER-2015-036, PRL 115 (2015) 161802 [1508.04094]
LHCb-PAPER-2016-052, PRD (2017) 071101 [1612.07818]

both LHCb searches only use Run 1 data



See Batell, Pospelov, Ritz [0911.4938], Izaguirre, Lin, Shuve [1611.09355], Aloni, Soreq, MW [1811.03474] for ALP production in penguin decays. LHCb is working on these searches now.

Thanks!
Questions?

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