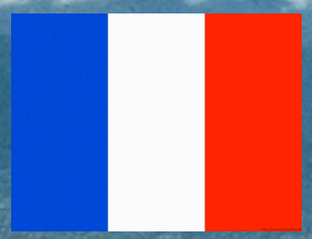
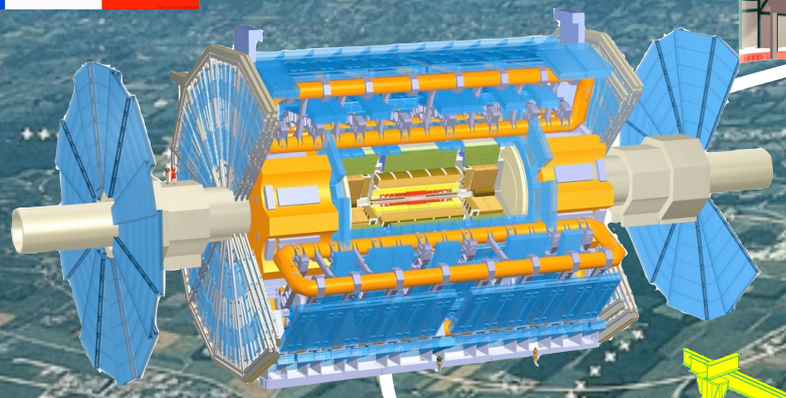
Dark Sectors @ LHCb

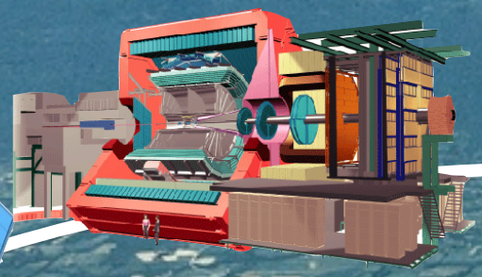
Mike Williams

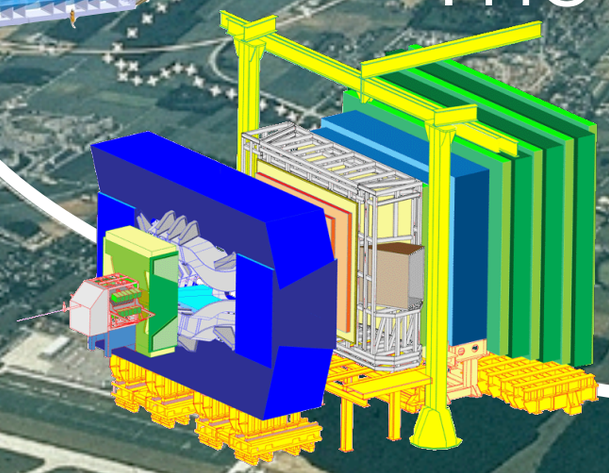
Department of Physics & Laboratory for Nuclear Science
Massachusetts Institute of Technology

April 11, 2018









The Large Hadron Collider

LHCb

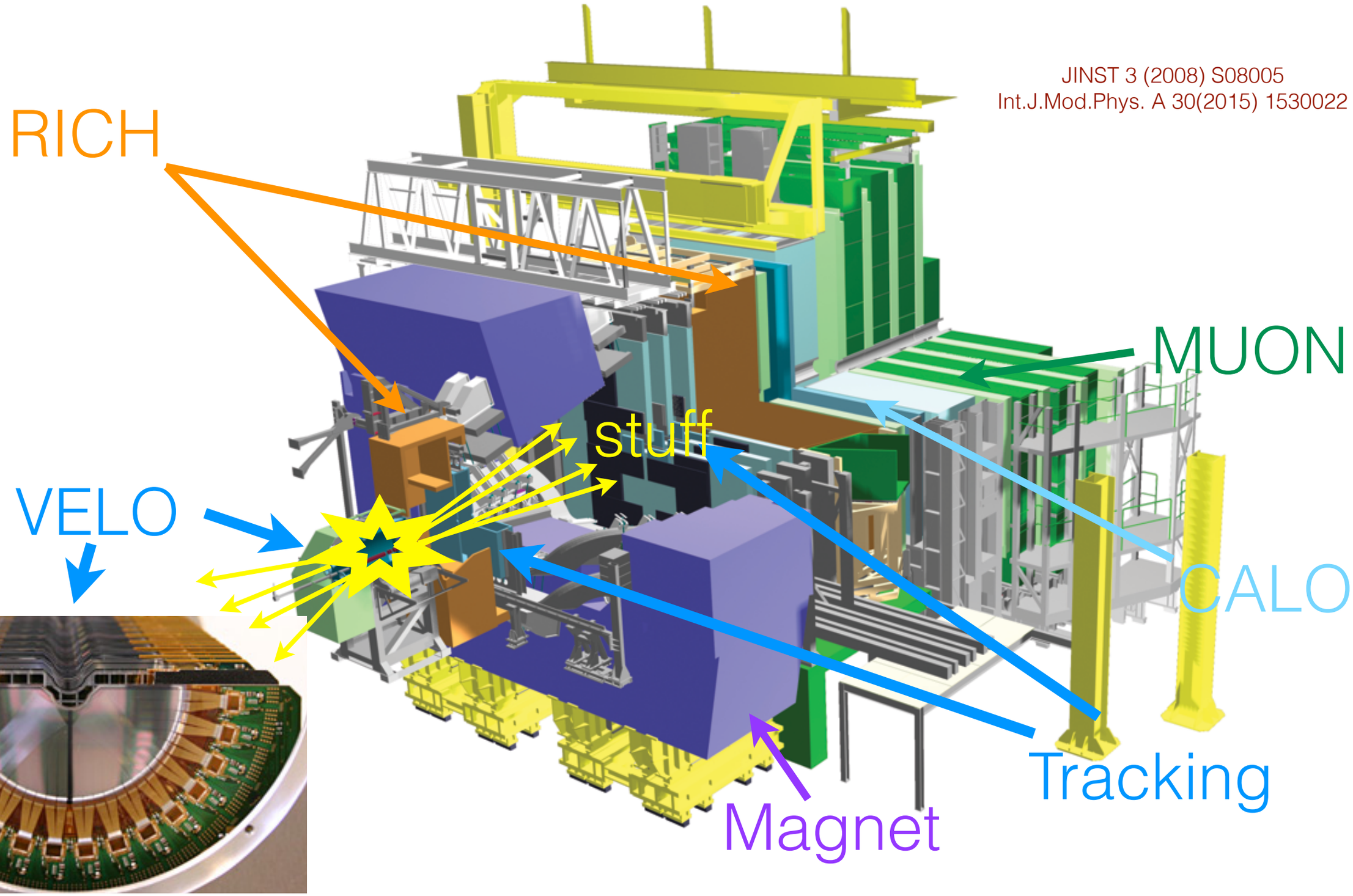
- 70 institutes
- 16 countries
- 700 physicists
- 400 papers

LHCb Detector

LHCb is a forward Spectrometer ($2 < \eta < 5$)

(roughly 1-15^{o})

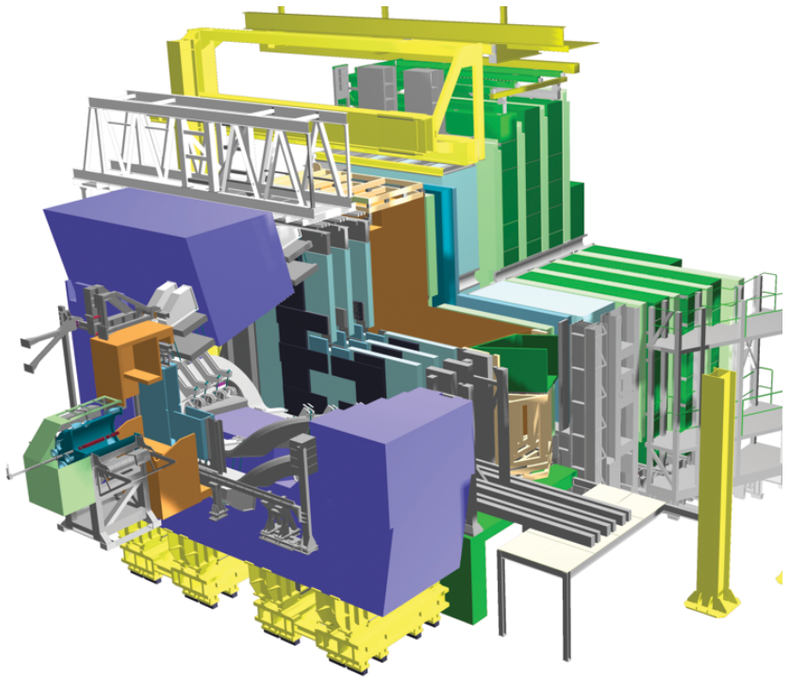
JINST 3 (2008) S08005
Int.J.Mod.Phys. A 30(2015) 1530022



JINST 8 (2013) P04022

Real-Time Processing

Comp. Phys. Commun. 208 (2016) 35



Simple feature-building, e.g. in FPGAs, required to reduce the data rate.*

1 TB/s
post zero suppression

50 GB/s

1 MHz

Heavy use of machine learning:
V.Gligorov, MW, JINST 8 (2012) P02013
T.Likhomanenko et al [1510.00572]

Real-time reconstruction for all charged particles with $p_T > 0.5$GeV.

6 GB/s

Data buffered on 10 PB of disk.

Full real-time reconstruction for all particles available to select events.

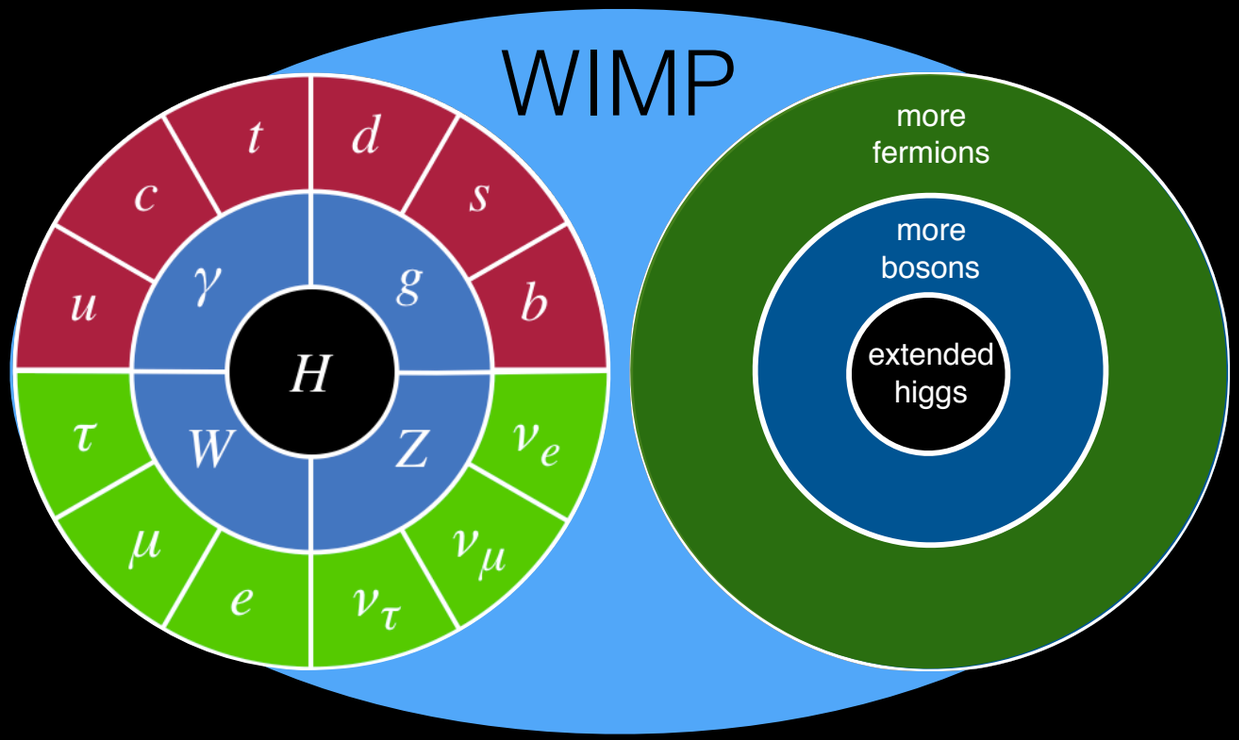
0.7 GB/s (mix of full + partial events)

Real-time calibration & alignment.

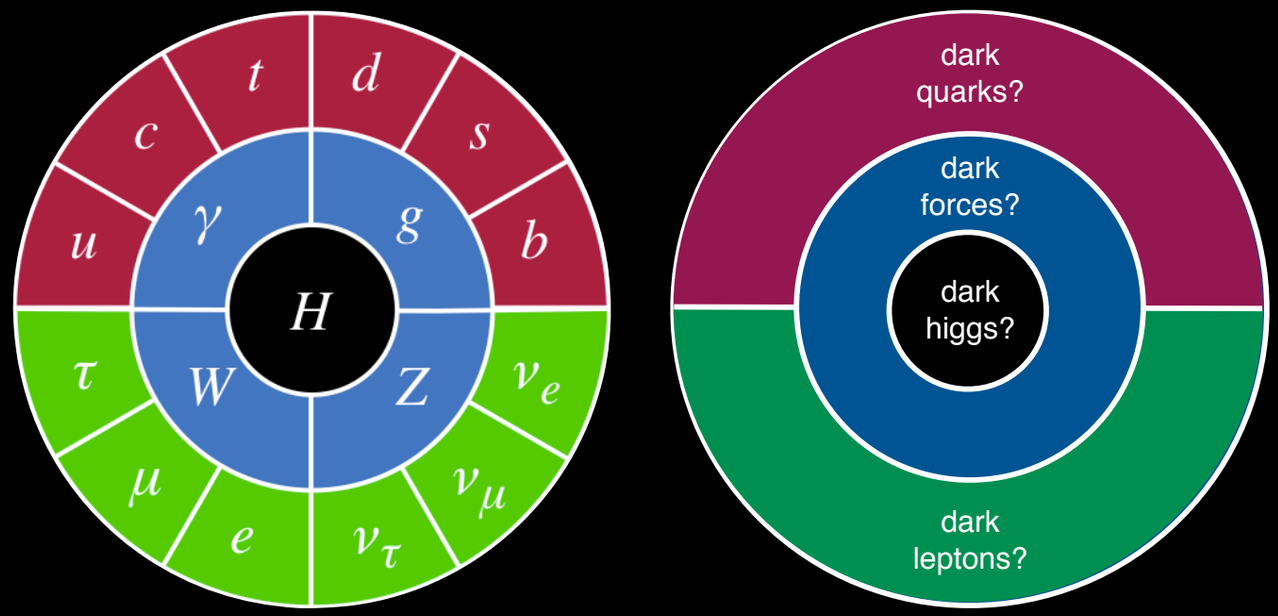
*LHCb will move to a triggerless-readout system for LHC Run 3 (2021-2023), and process 5 TB/s in real time on the CPU farm.

Dark Matter Paradigms

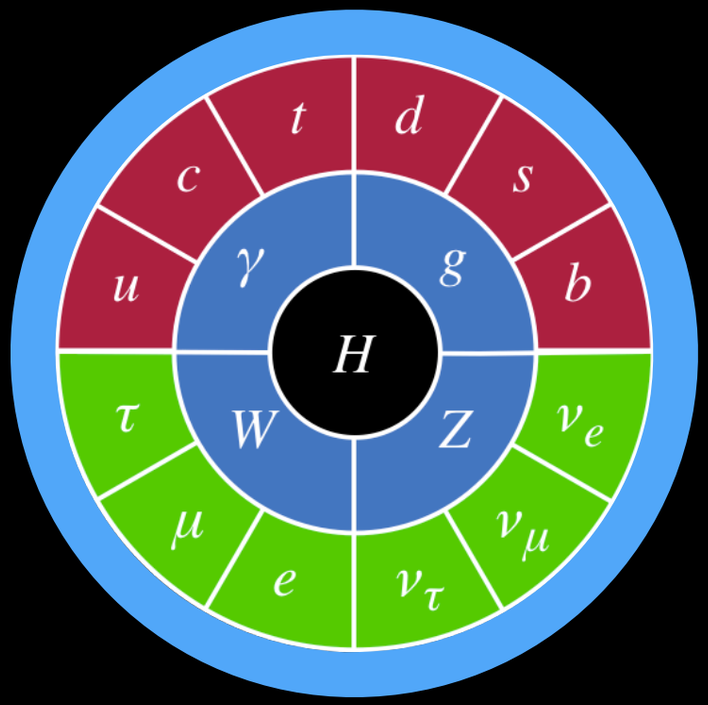
WIMP



Hidden Sector(s)

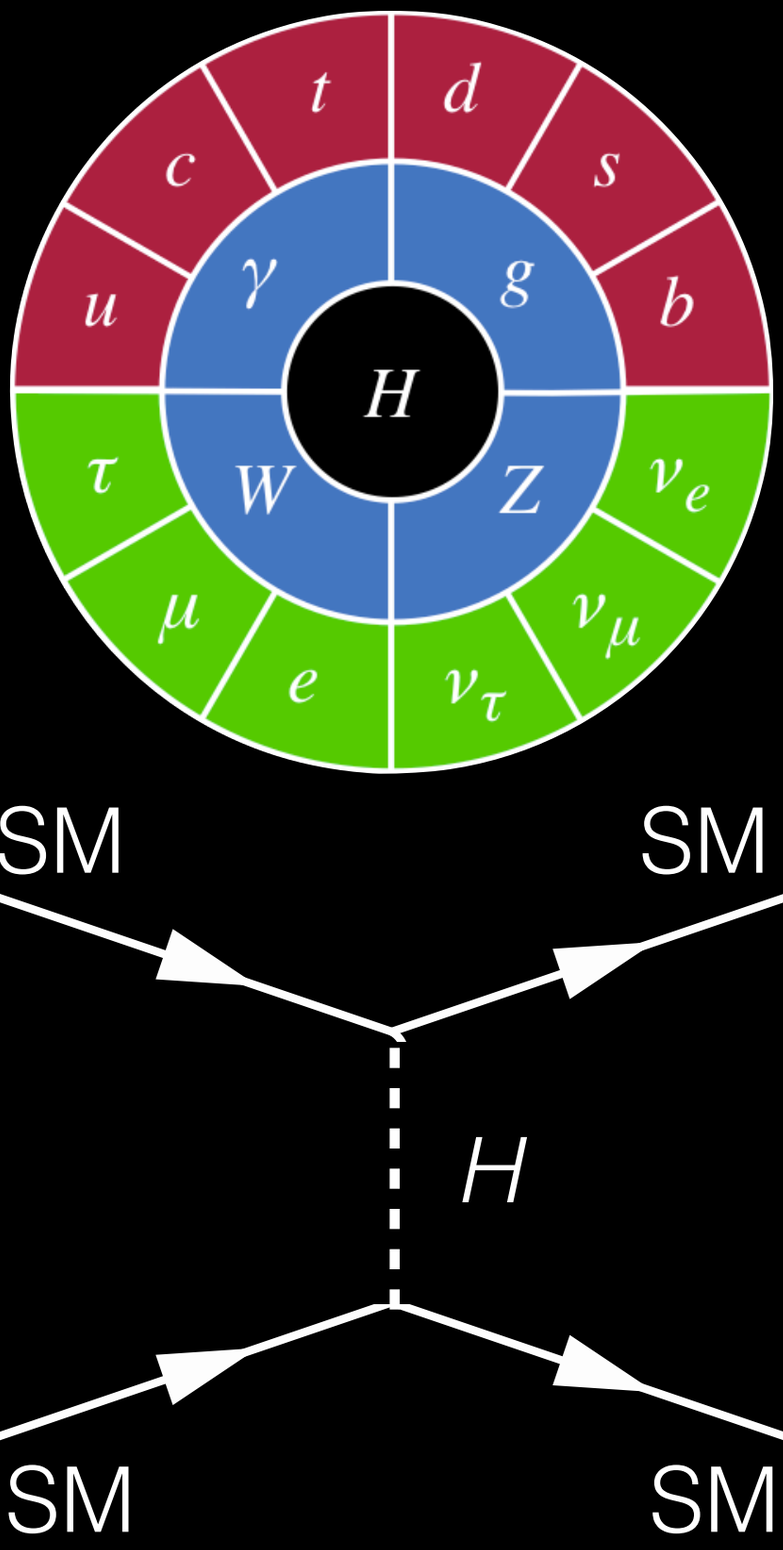


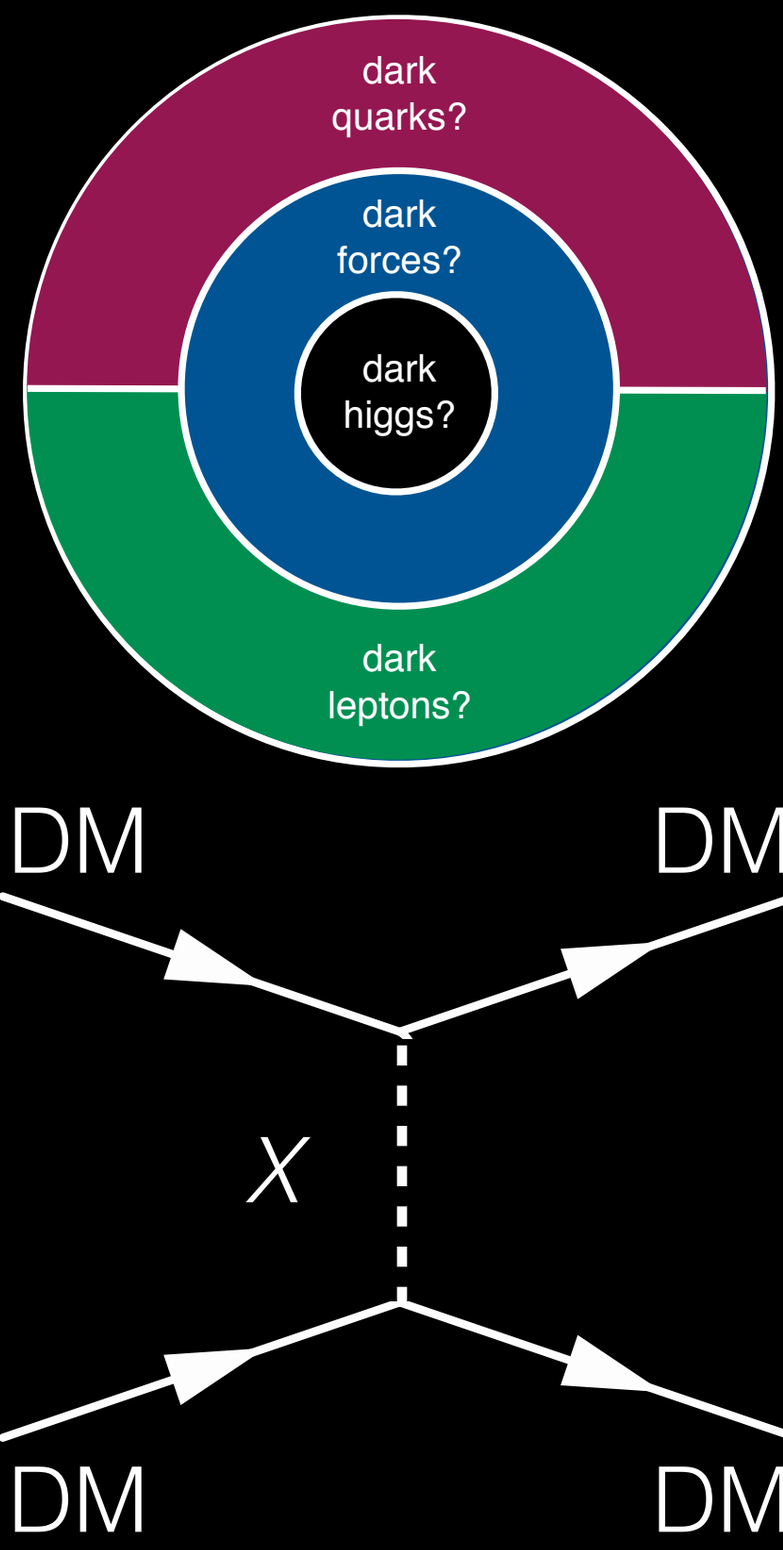
Minimal SM Extensions



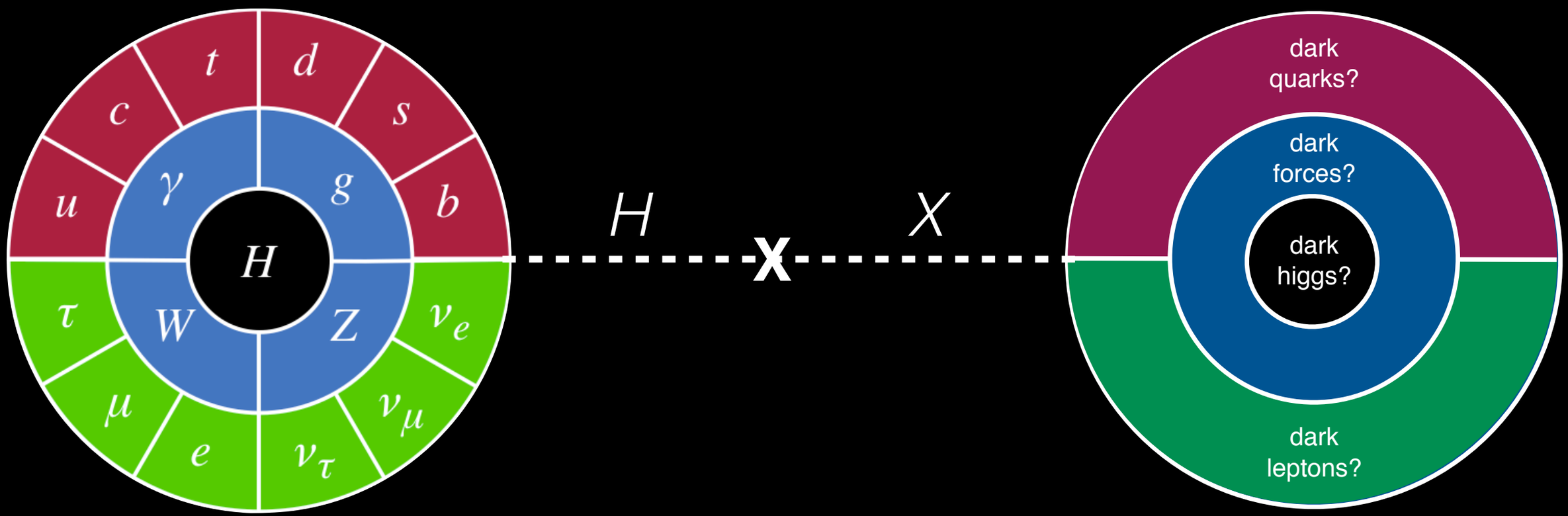
Primordial Black Holes

Higgs Portal





Higgs Portal



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

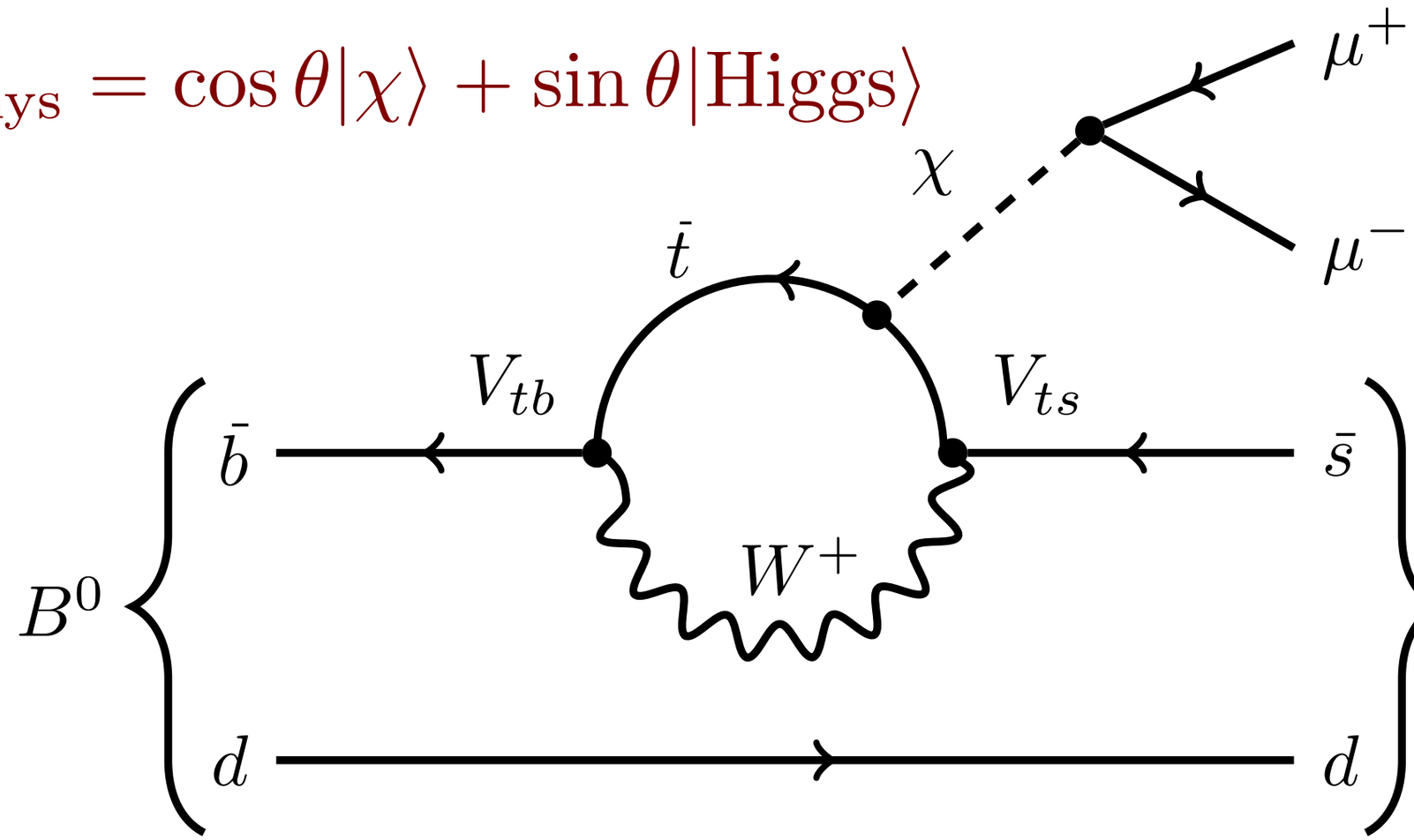
The X particle picks up couplings to SM particles proportional to mass, just like the Higgs. N.b., many non-DM theories also predict X fields.

Higgs Portal

b→s penguin decays are an excellent place to search for low-mass hidden-sector particles (e.g., anything that mixes with the Higgs sector).

$$|\mathrm{Higgs}\rangle_{\mathrm{phys}} = -\sin\theta|\chi\rangle + \cos\theta|\mathrm{Higgs}\rangle$$

$$|\chi\rangle_{\mathrm{phys}} = \cos\theta|\chi\rangle + \sin\theta|\mathrm{Higgs}\rangle$$



PRL 115 (2015) 161802
LHCb-PAPER-2015-036

PRD 95 (2017) 071101
LHCb-PAPER-2016-052

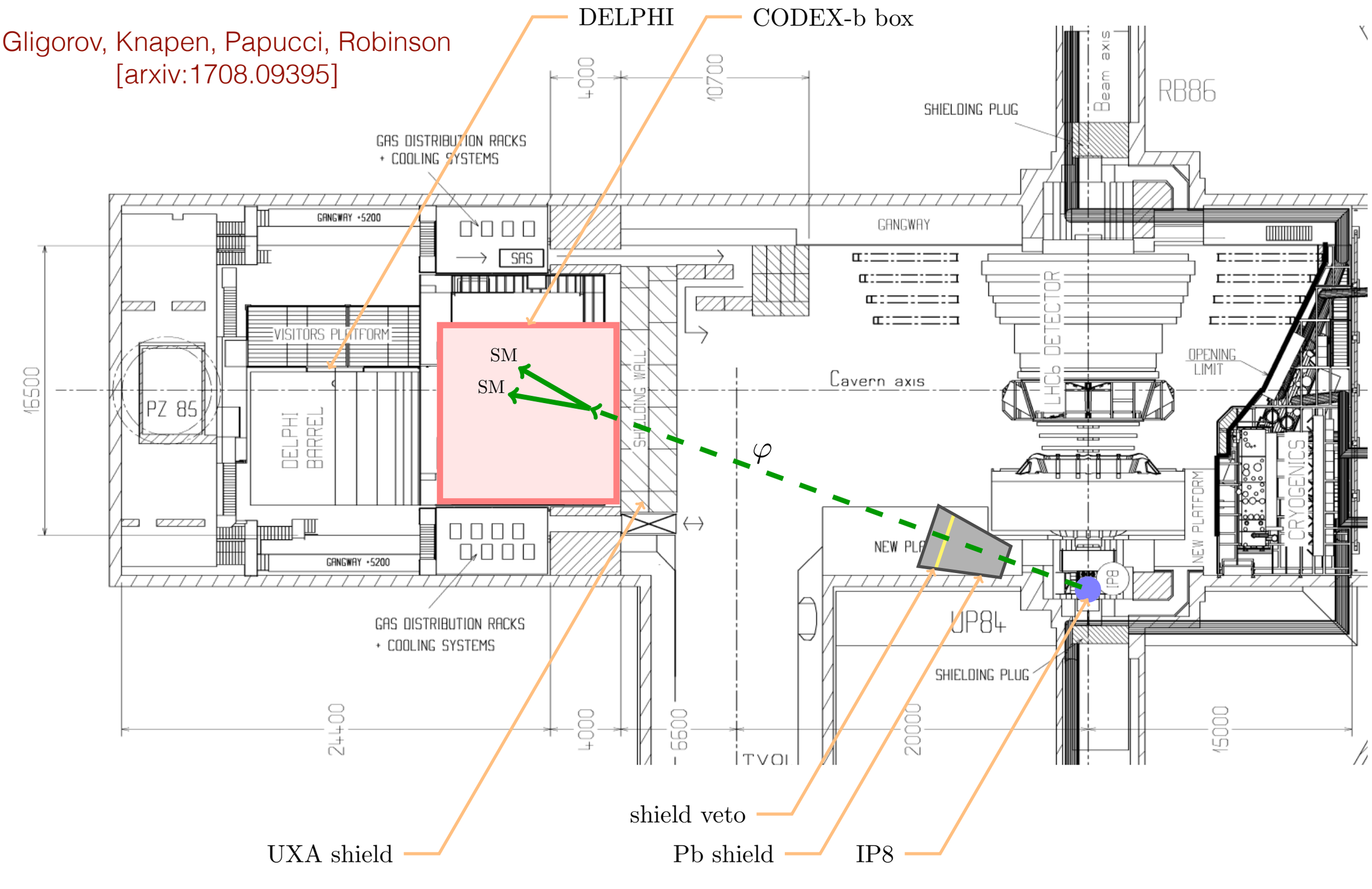
Model-independent limits set on B(B→K*X)B(X→μμ) translate into model-dependent constraints on the H-X mixing angle of O(**mrad**) (rules out nominal inflaton here), and O(**PeV**) on ALP decay constants.

See also MW [1503.04767]; J.Stevens, MW [1305.7248]; Freytsis,Ligeti,Thaler [0911.5355]; Batell, Lange, McKeen, Pospelov, Ritz [1606.04943].

CODEX-b

Proposed new detector element at LHCb to search for long-lived particles.

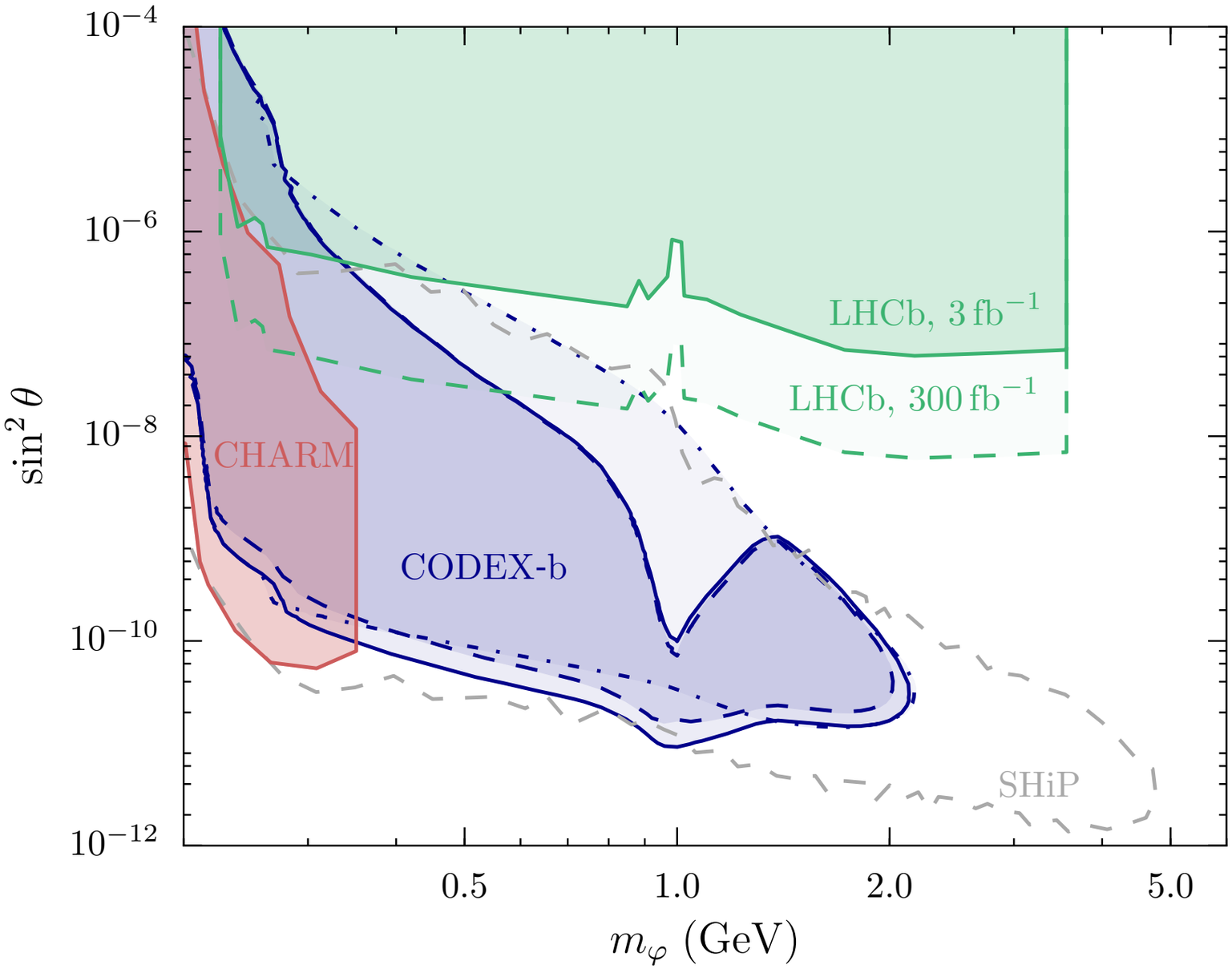
Gligorov, Knapen, Papucci, Robinson
[arxiv:1708.09395]



Gligorov, Knapen, Papucci, Robinson
[arxiv:1708.09395]

CODEX-b

Excellent sensitivity to inclusive Higgs portal production.

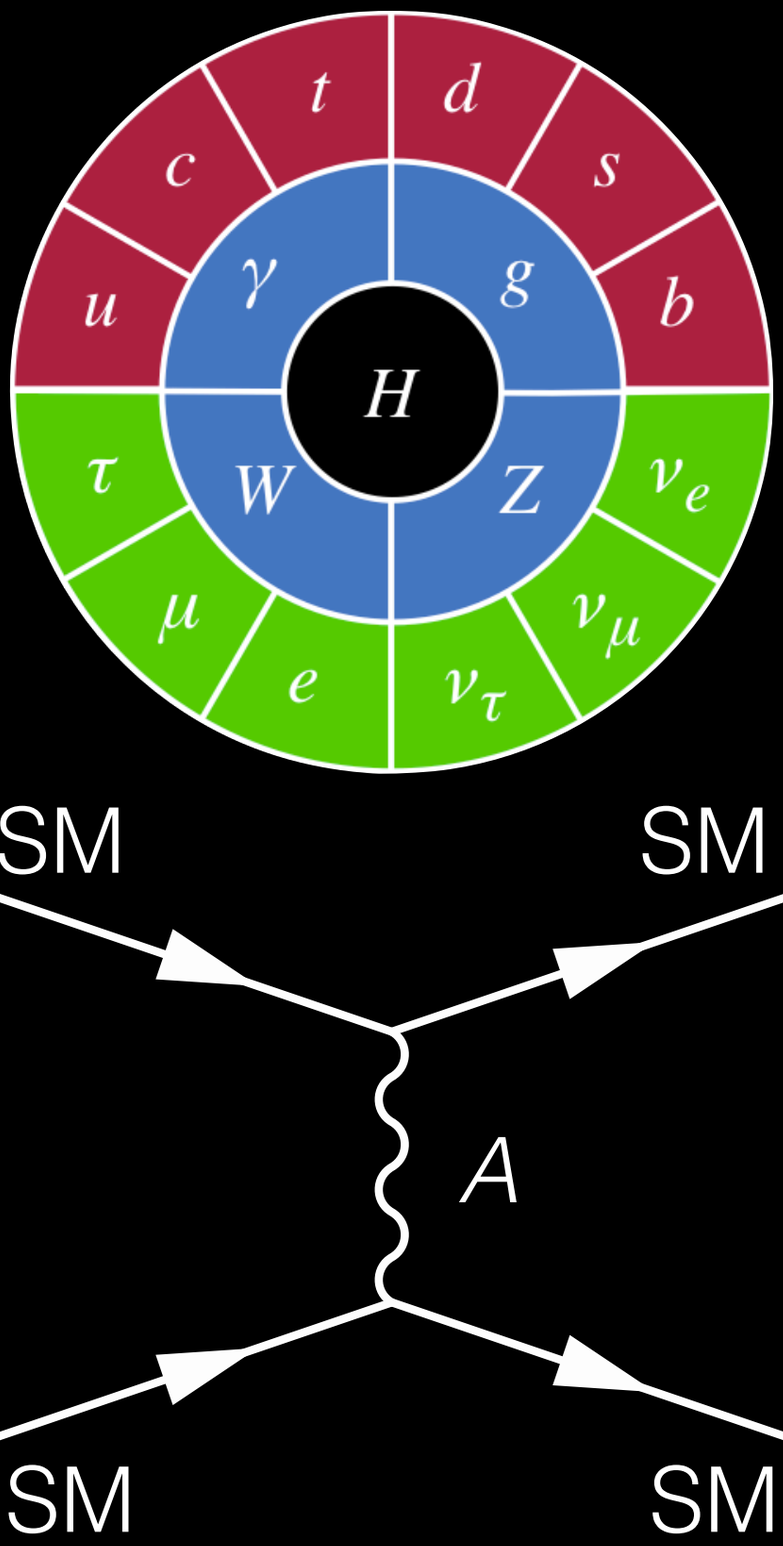


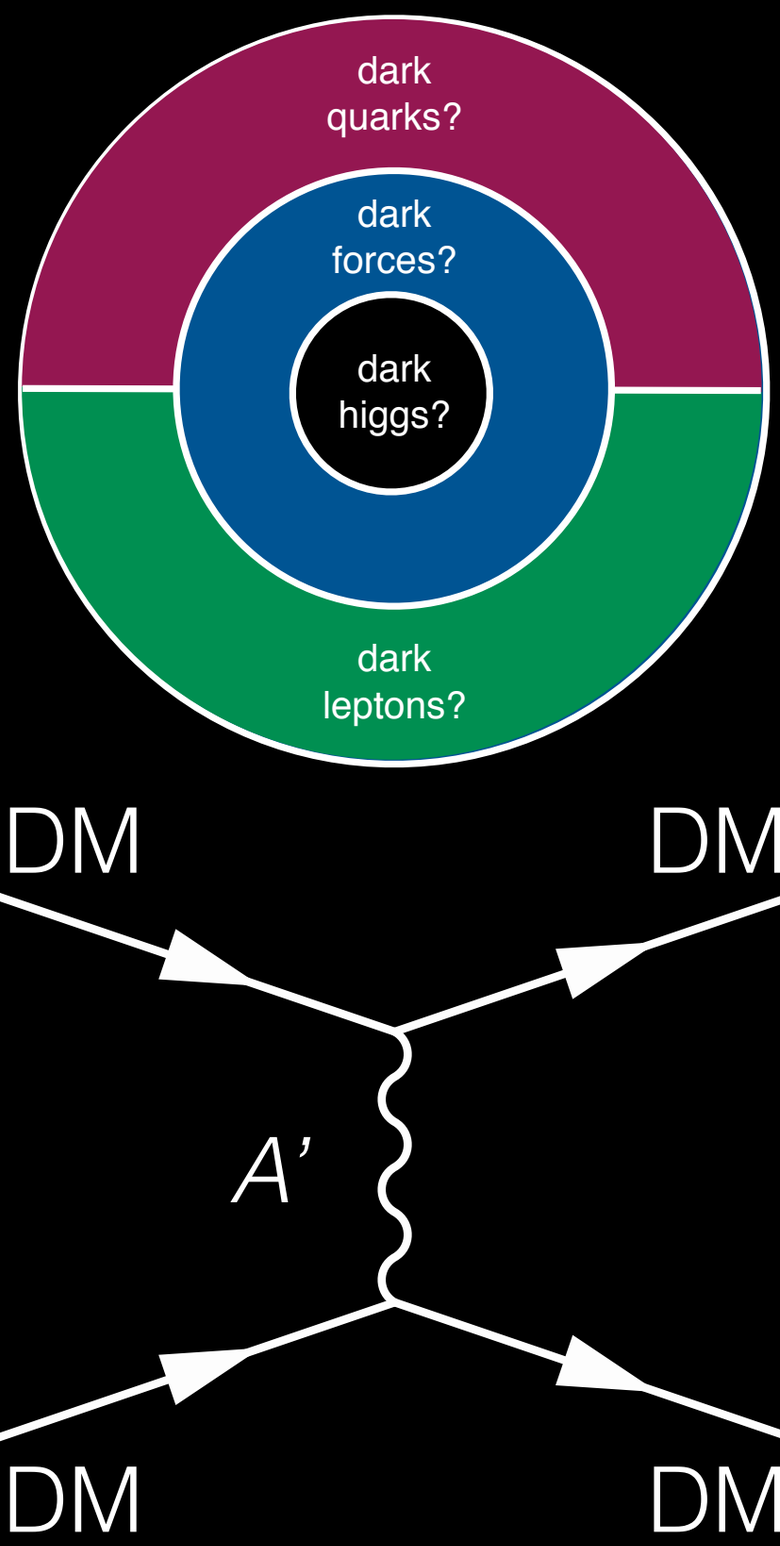
LHCb projections assume only decays in the VELO are used. Studies ongoing that would extend the fiducial decay volume within LHCb itself.

Sensitivity studies for other models, e.g. Higgs decays to dark photons, are provided in 1708.09395. Additionally, studies on boost/mass resolution are provided.

Sensitivity also demonstrated for Higgs decays to dark photons. Should have excellent sensitivity to most hypothetical long-lived particles.

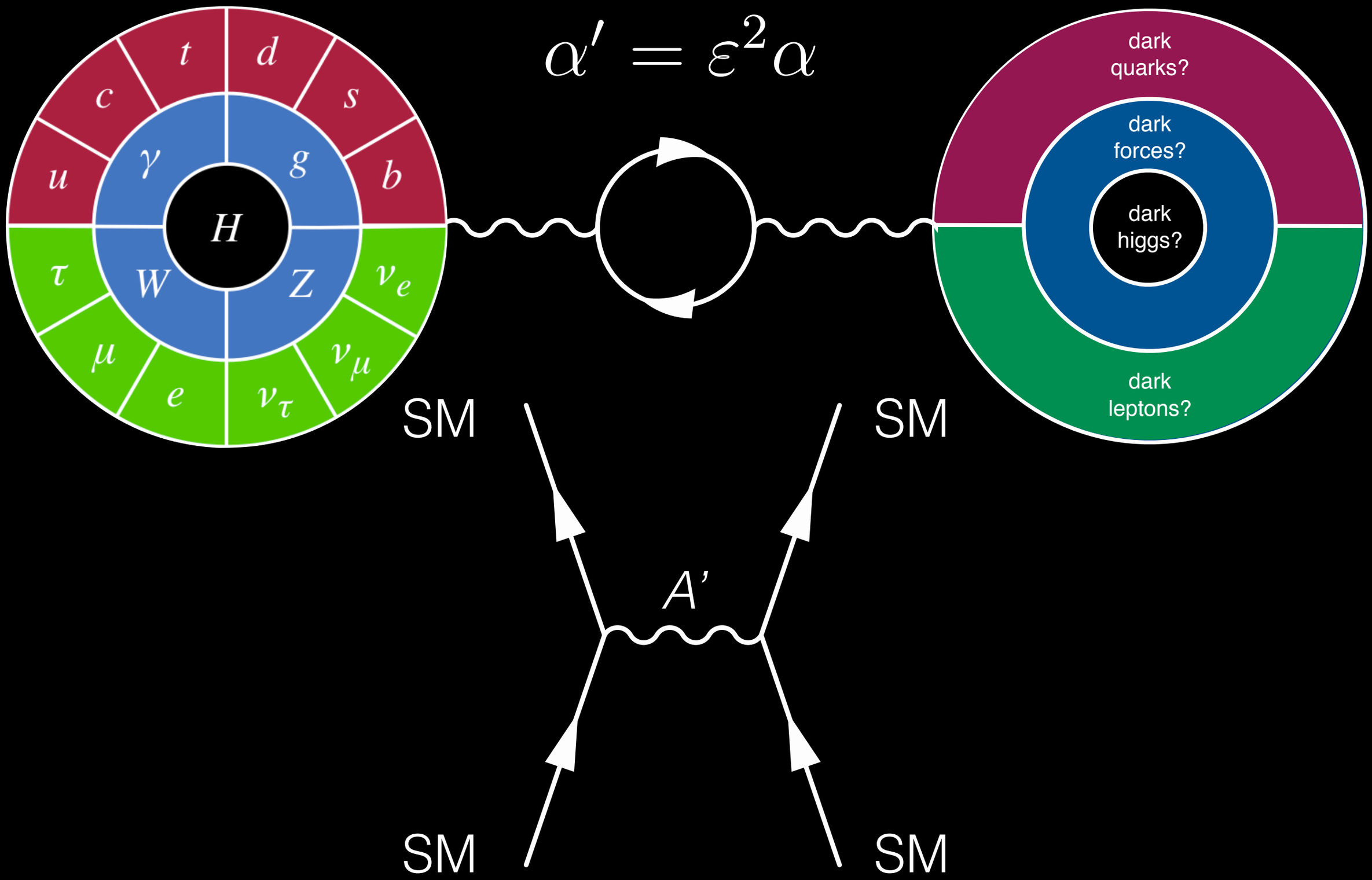
Dark Photons





Dark Photons

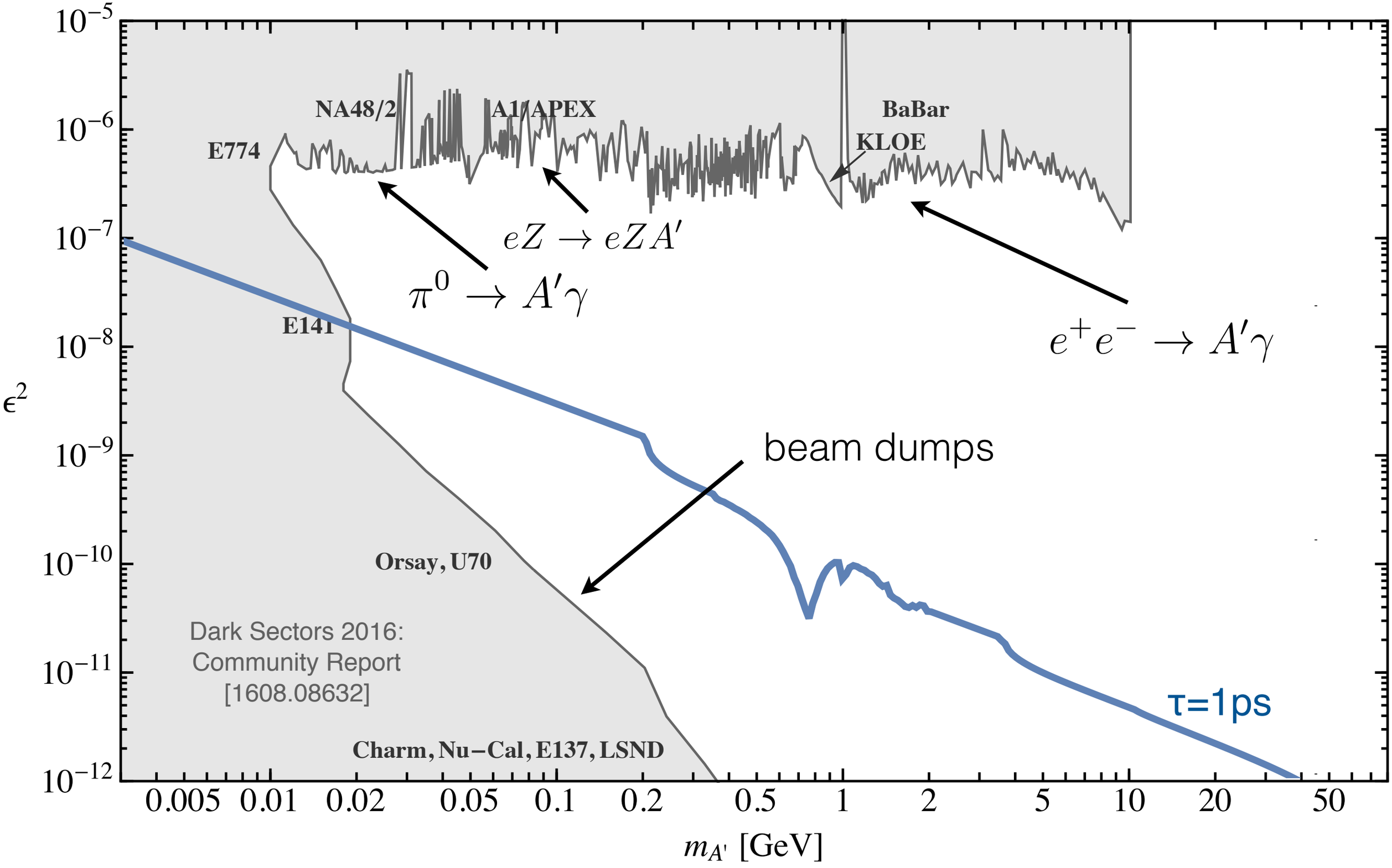
$$\alpha' = \varepsilon^2 \alpha$$



See Okun, 1982; Galison, Manohar, 1984; Holdom, 1986; etc.; Arkani-Hamed, Finkbeiner, Slatyer, Weiner, 2008; Pospelov, Ritz, 2008; etc.

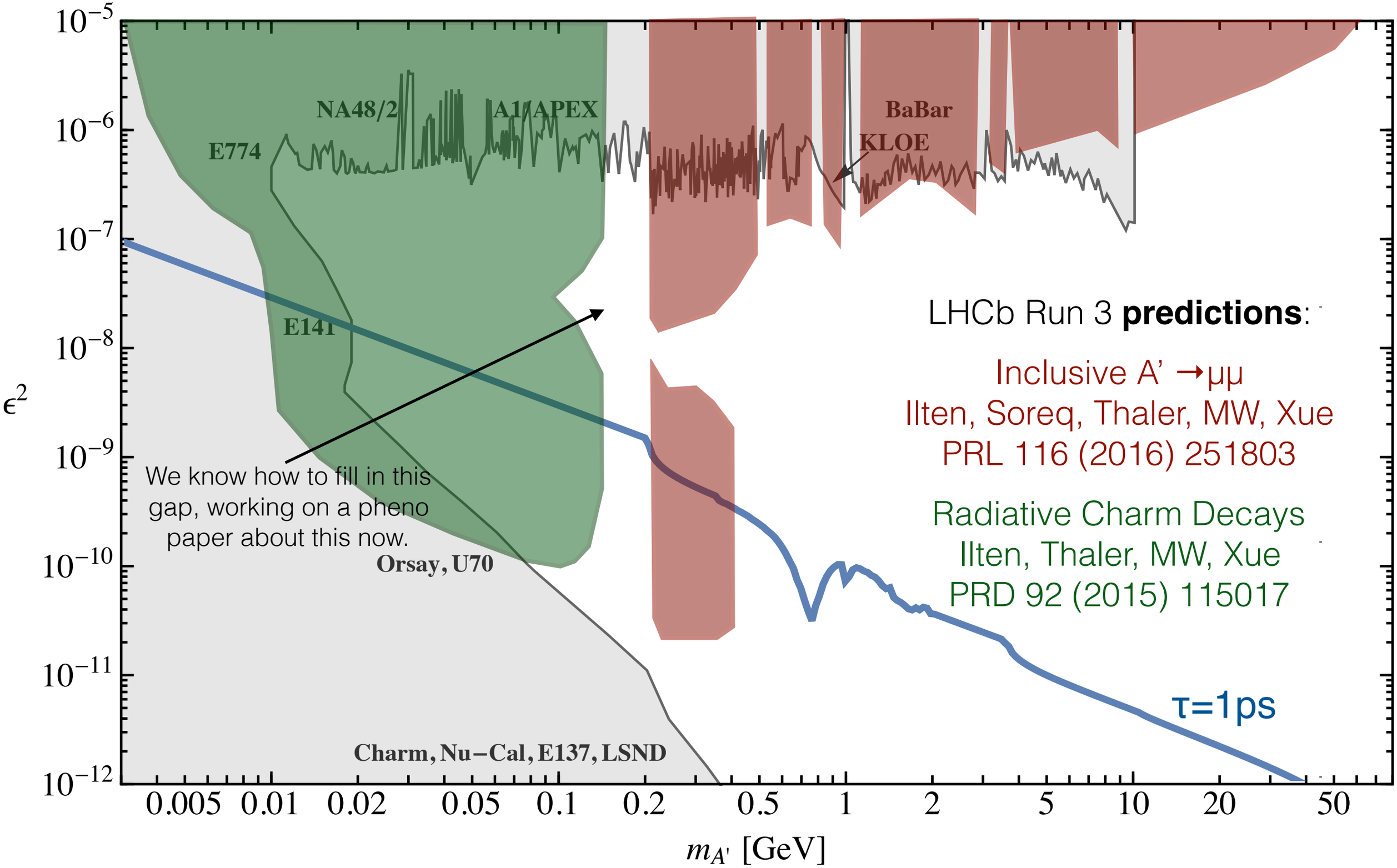
Visible A' Decays

Existing bounds on visible A' decays.



Visible A' Decays

Leverage LHCb's world-leading τ resolution and planned move to a triggerless readout.

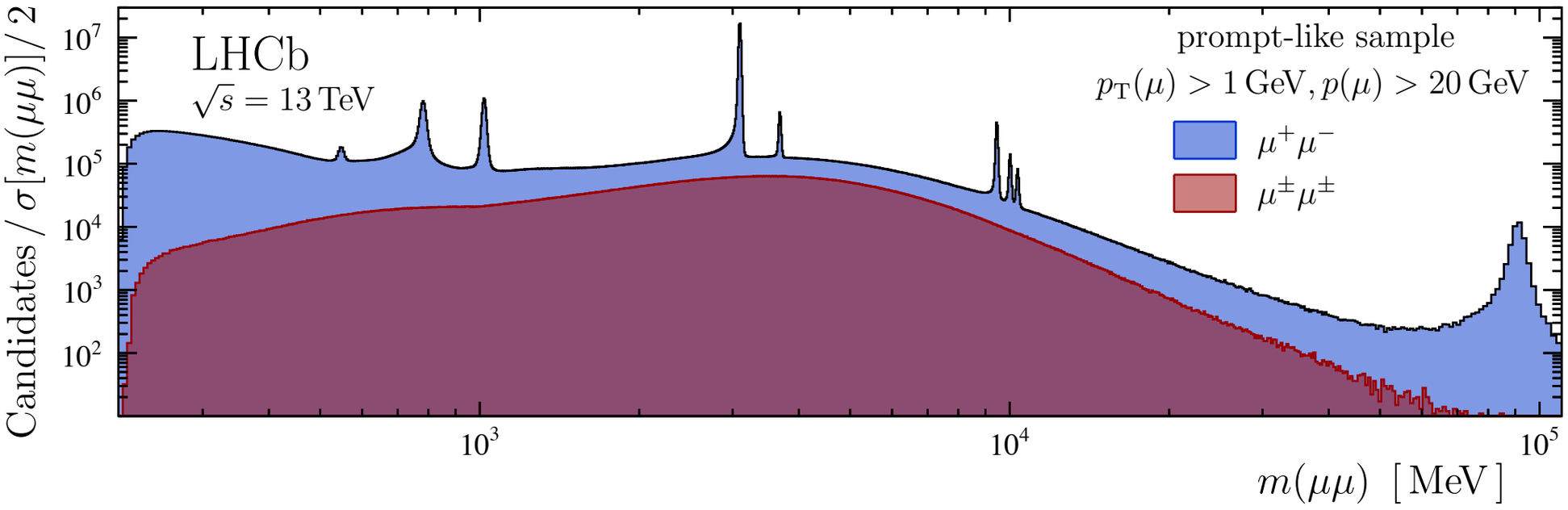


Prompt A’

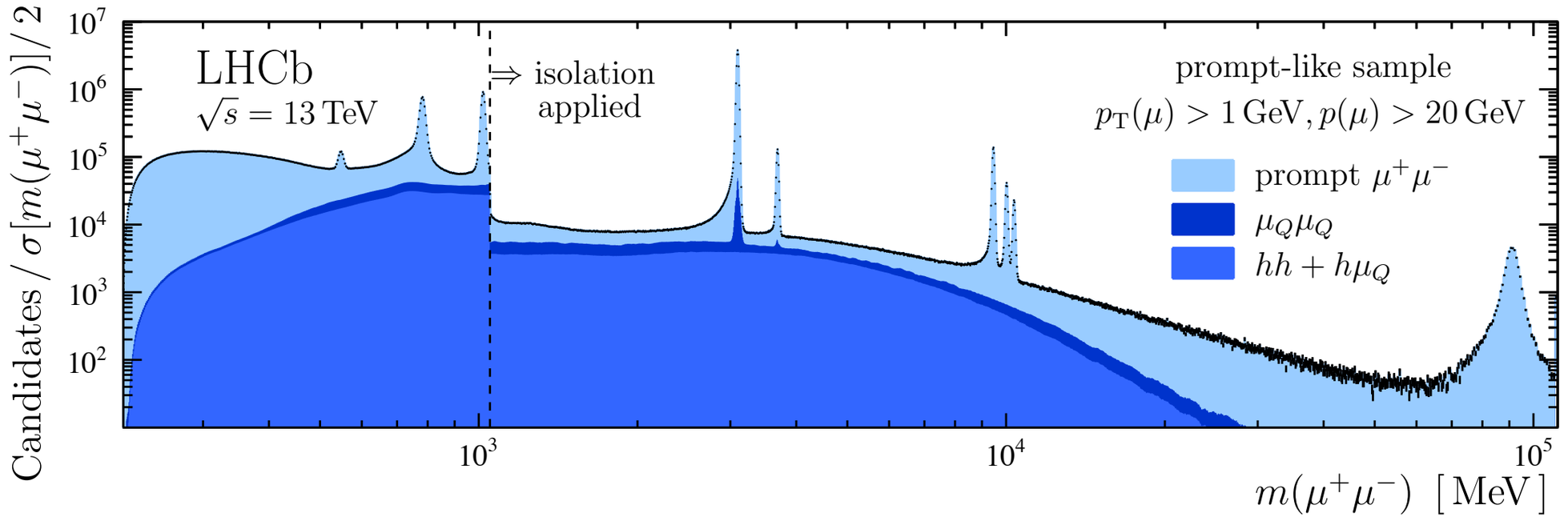
LHCb-PAPER-2017-038

Major hurdles: suppressing misidentified (non-muon) backgrounds and reducing the event size enough to record the prompt-dimuon sample. Accomplished these by moving to real-time calibration in Run 2—but hardware trigger is still there, and ~10% efficient.

trigger output



final prompt A’ sample (isolation applied above 1.1 GeV, backgrounds determined)

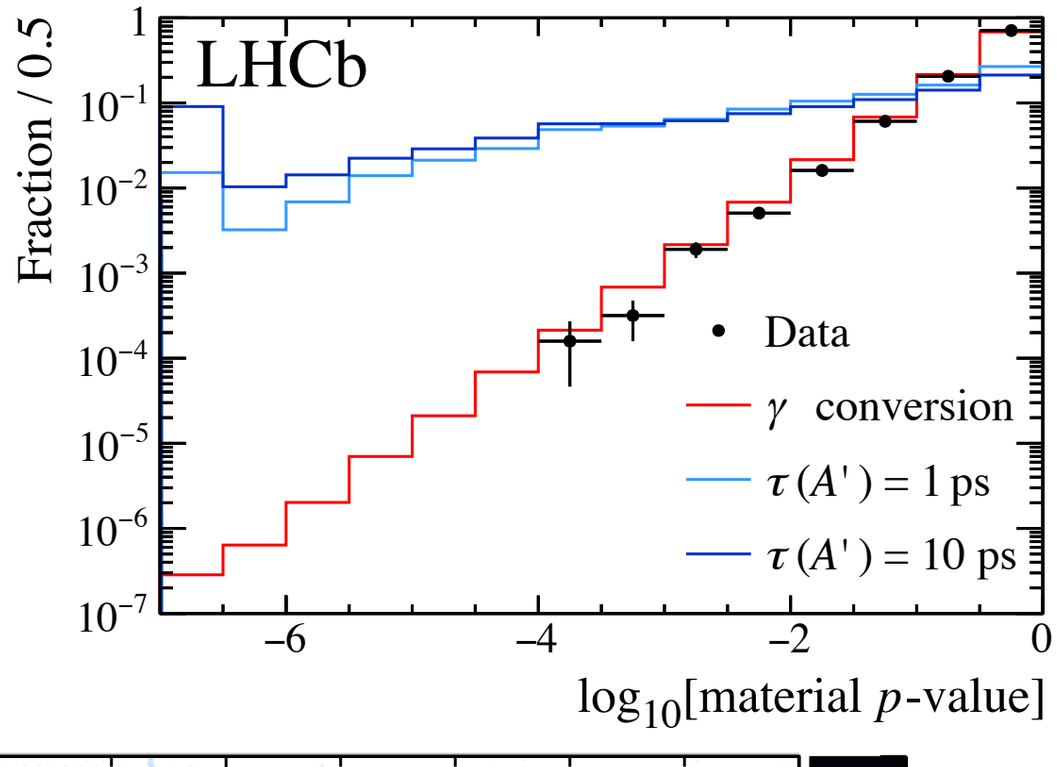


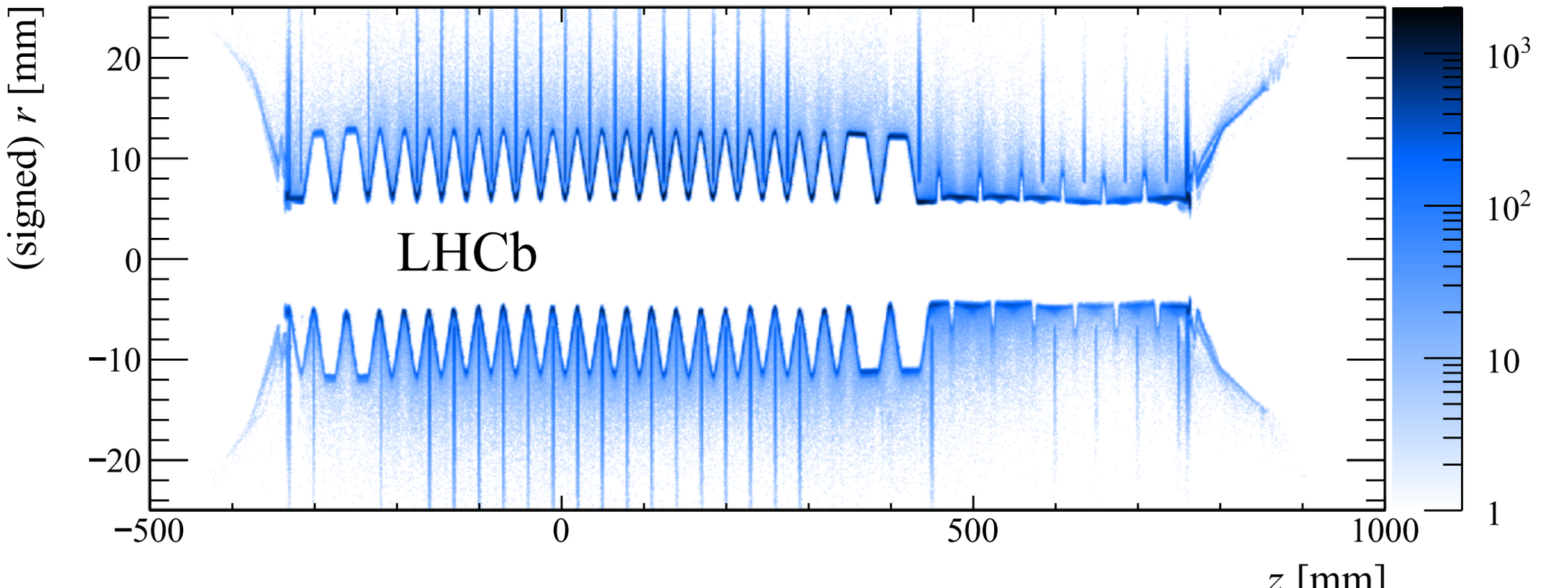
N.b., bump hunt follows MW, 1705.03587.

Long-Lived A’

LHCb-DP-2018-002
[1803.07466]

Major hurdle: building a high-precision map of the VELO material.

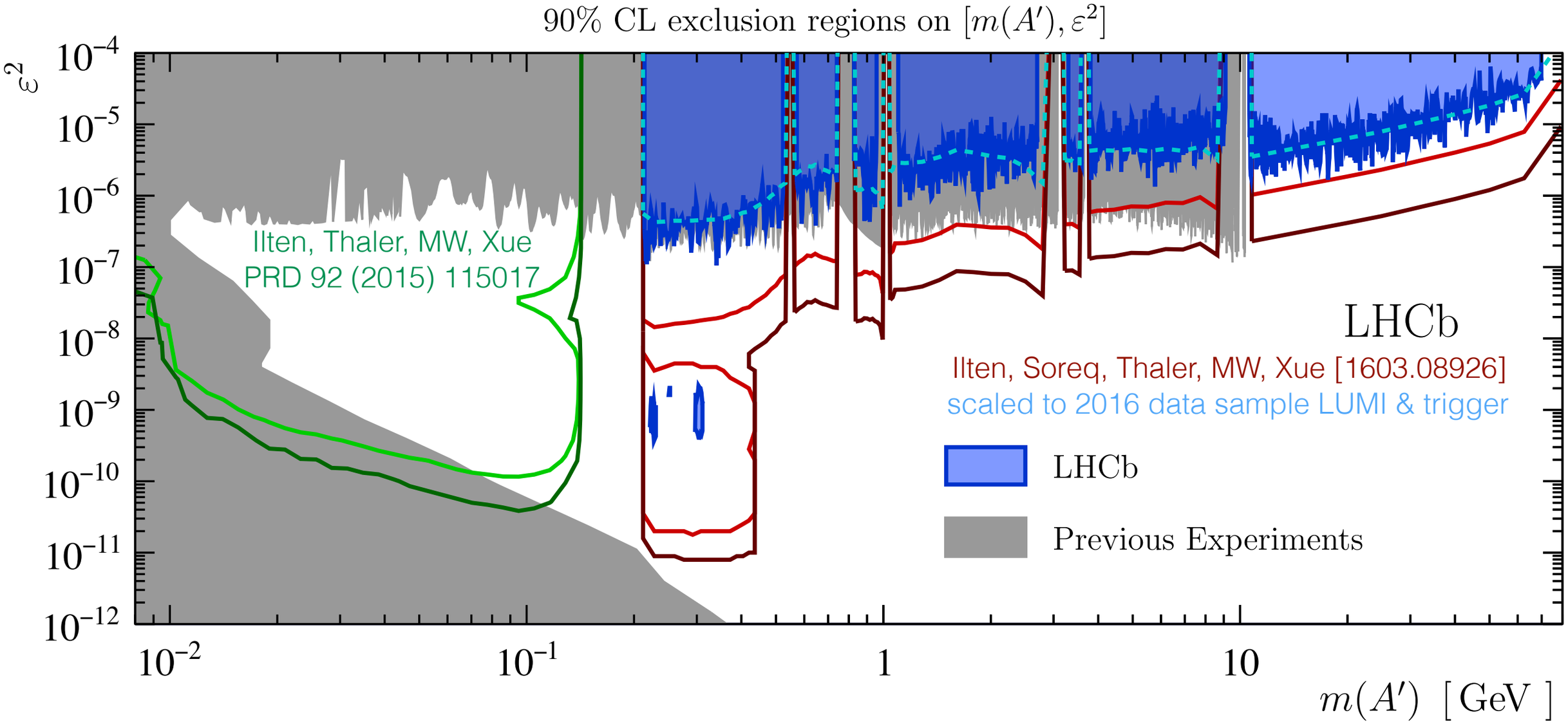




Dark Photons

LHCb-PAPER-2017-038
PRL 120 (2018) 061801

The 2016 dimuon results are consistent with (better than) our predictions for prompt (long-lived) dark photons. We implemented huge improvements in the 2017 triggers for low masses, so plan quick turn around on 2017 dimuon search — then onto electrons.



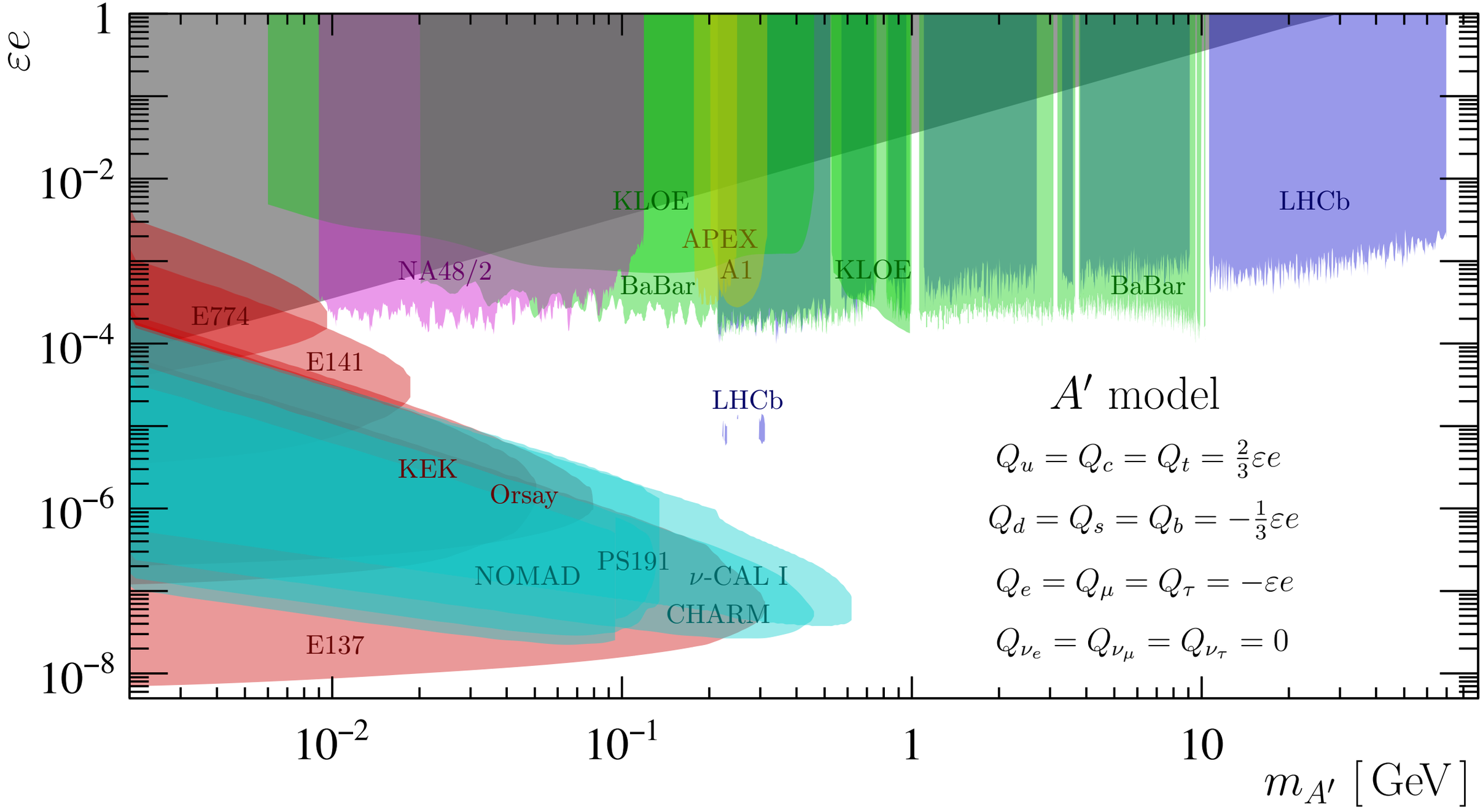
Proves LHCb has unique potential to search for A' using muons. Assuming we can make electrons work, we can cover all of the remaining low-mass parameter space (eventually).

See LHCb-PAPER-2018-008 for a search that fills in most of the gaps near the Upsilons.

Recasting for other Models

Dark photon searches provide sensitivity to (many) other models.

Ilten, Soreq, MW, Xue [1801.04847]

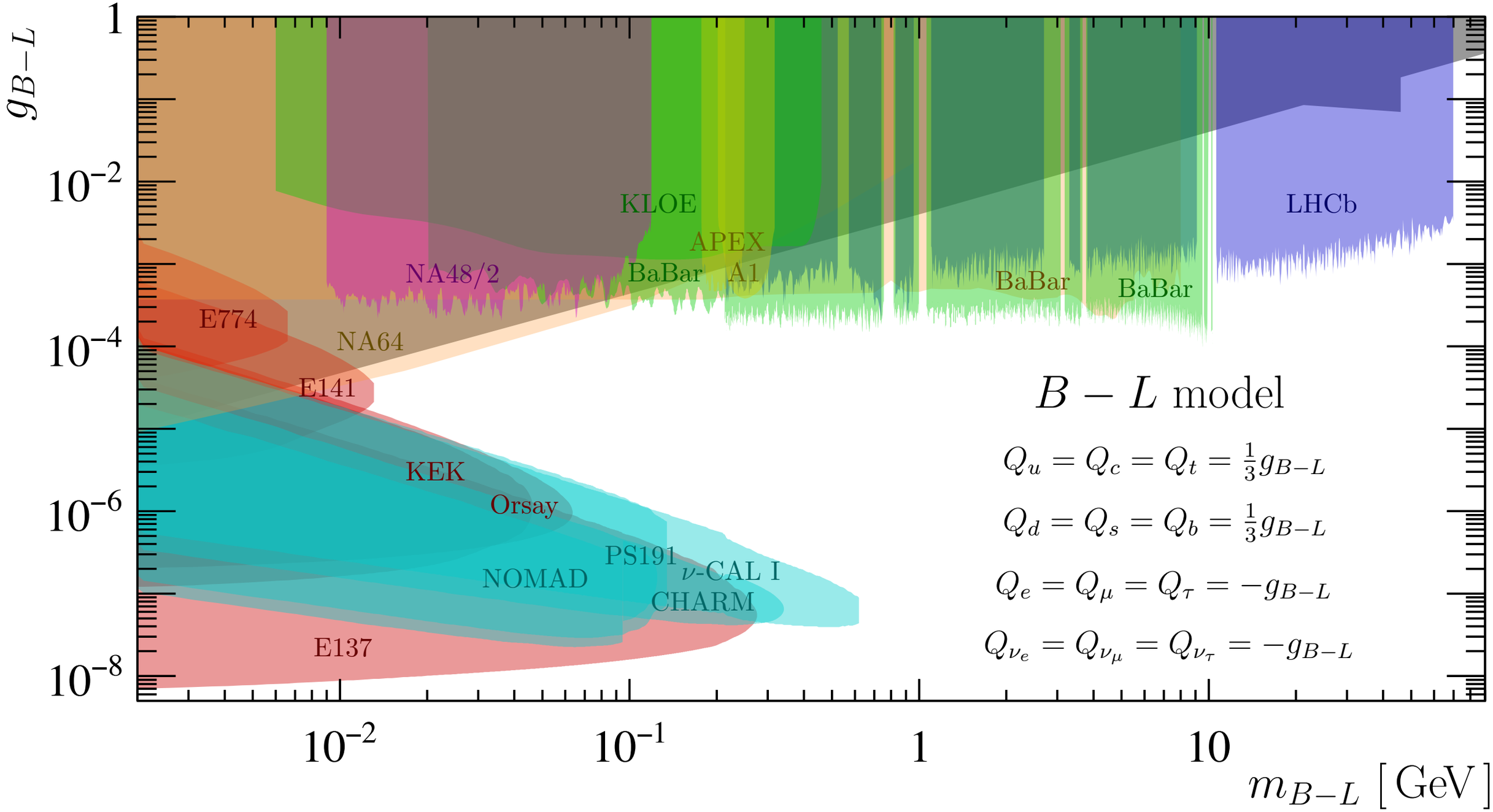


We developed a data-driven way to easily recast any dark photon search to obtain limits on any other vector model (auto-calculates hadronic decay rates for all masses).

Recasting for other Models

Dark photon searches provide sensitivity to (many) other models.

Ilten, Soreq, MW, Xue [1801.04847]

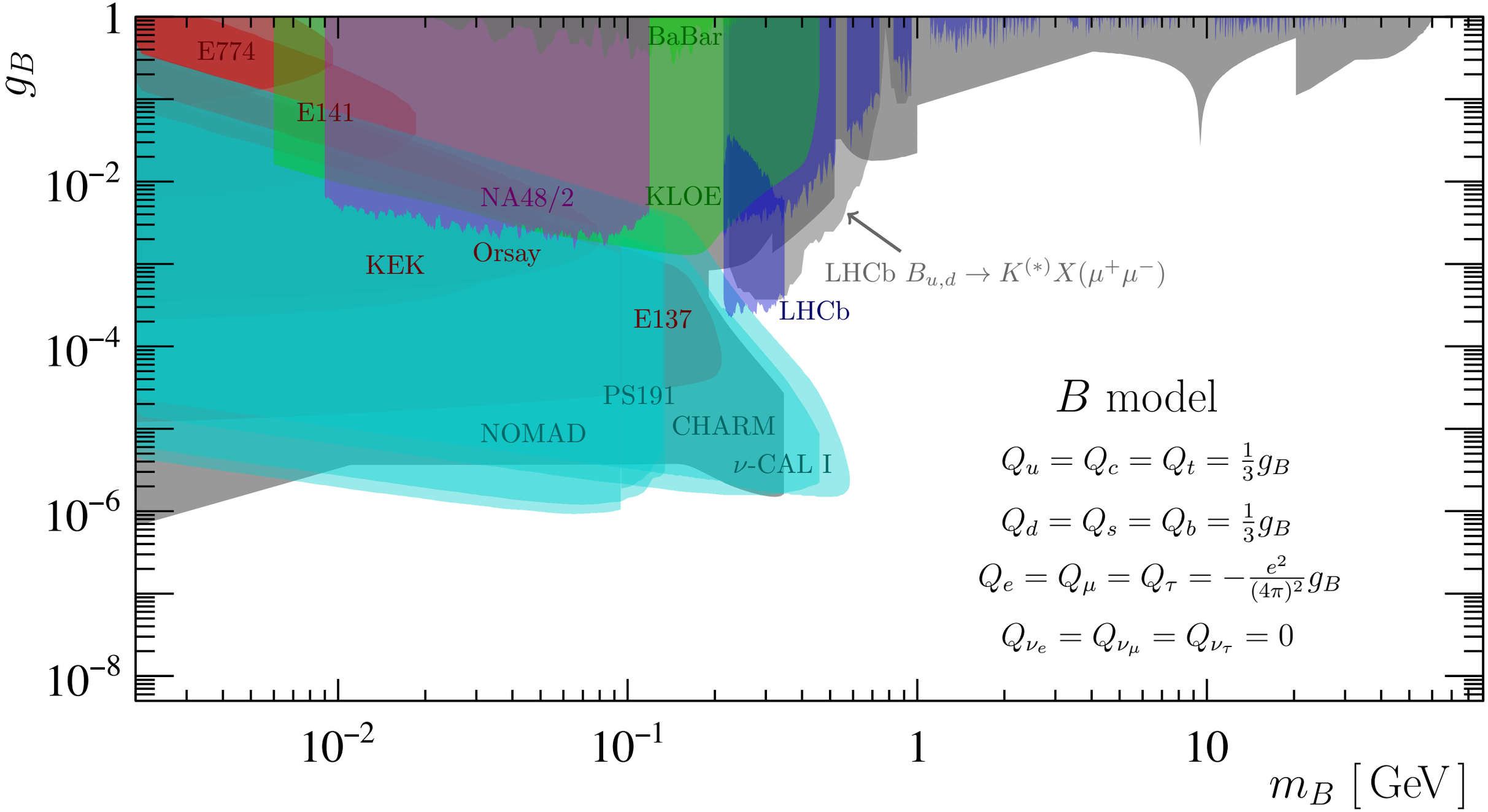


We developed a data-driven way to easily recast any dark photon search to obtain limits on any other vector model (auto-calculates hadronic decay rates for all masses).

Recasting for other Models

Dark photon searches provide sensitivity to (many) other models.

Ilten, Soreq, MW, Xue [1801.04847]



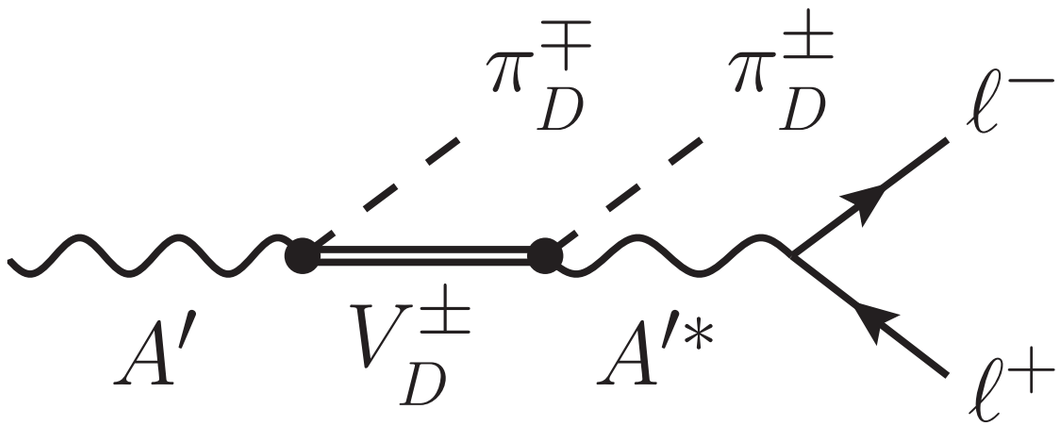
N.b., this search also provided the best limits on pseudo-scalars above ~ 7 GeV, etc.

Haisch, Kamenik, Malinauskas, Spira [1802.02156]

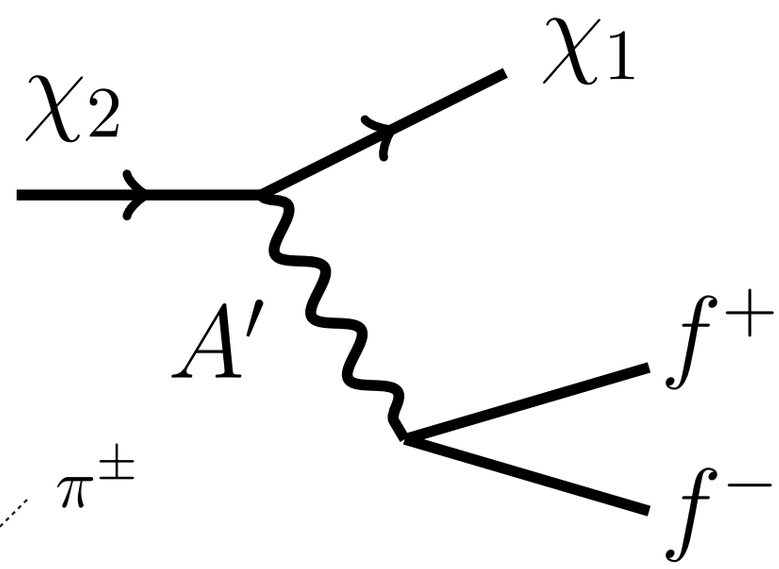
Coming Soon

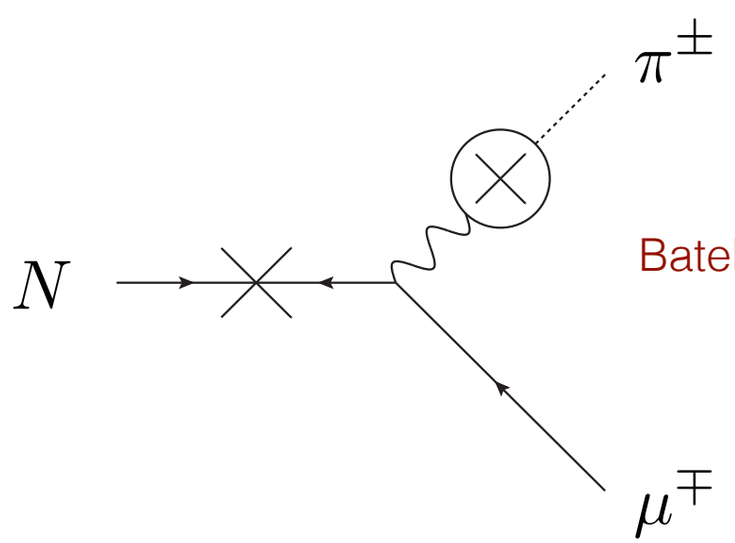
Triggers produced for non-standard decay topologies, RH neutrinos, etc., in 2016. Plan to produce these searches using 2016-2018 data. New triggers for A'→ee in 2018.

Berlin, Blinov, Gori, Schuster, Toro
[1801.05805]



Izaguirre, Kahn, Krnjaic, Moschella
[1703.06881]





Batell, Pospelov, Shuve
[1604.06099]

The future of dark-sector searches at LHCb is bright (dark?).

Long Term Plans

Run 1
2010-2012

7-8 TeV
3/fb

LS1

Run 2
2015-2018

13 TeV
+5/fb

Phase 1
Upgrade

LS2

Run 3
2021-2023

14 TeV
+15/fb

Consolidation

LS3

Run 4
2026-2029

14 TeV
+25/fb

Phase 2
Upgrade

LS4

Run 5
2031-2033

14 TeV
+100/fb

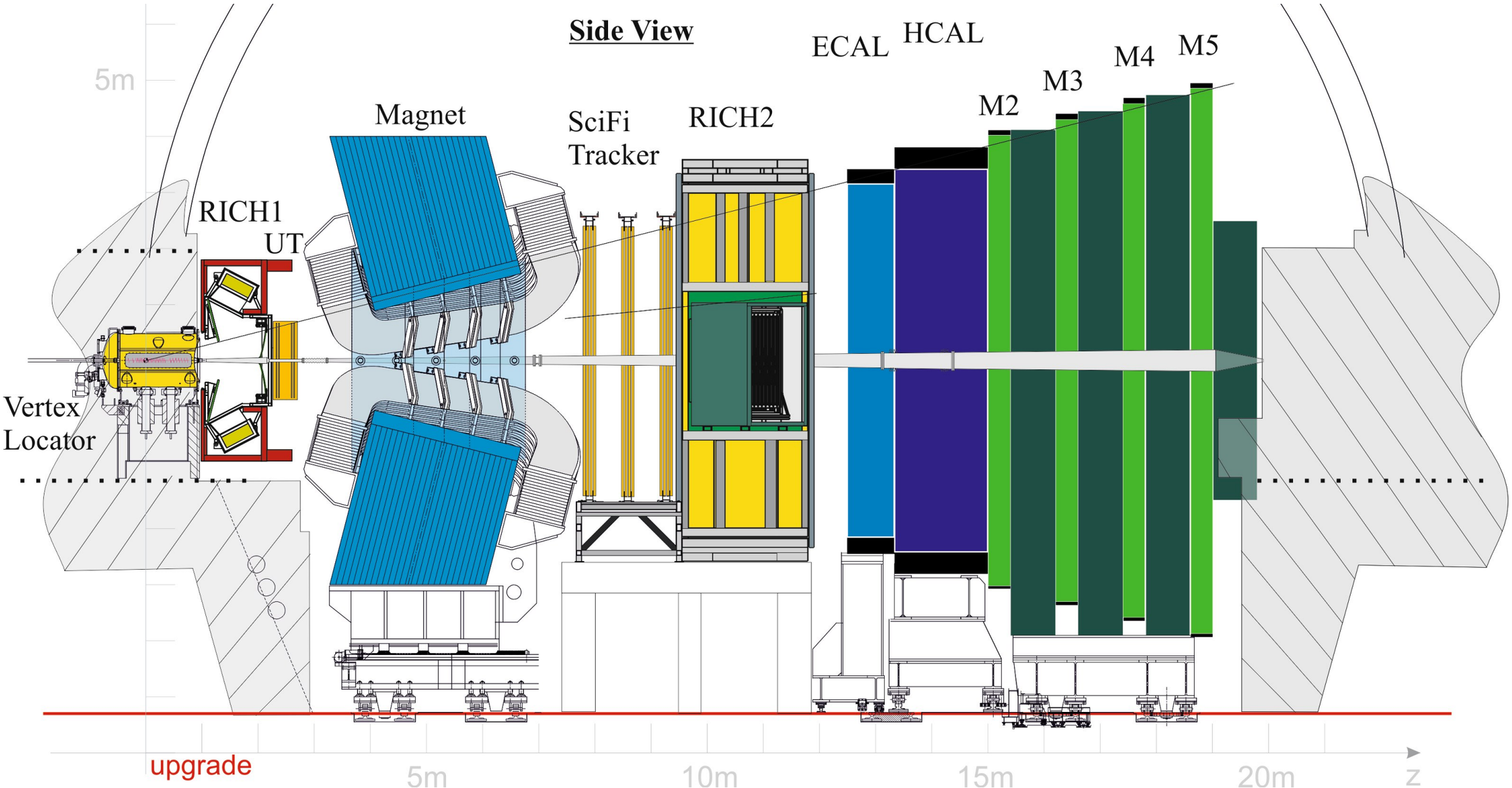
LS4

2035-???

Total:
300/fb

LHCb 2.0

Phase I upgrade for Run 3 (2021). Increase luminosity by a factor of 5, redesign tracking systems to handle this (also move VELO sensors to 5mm).



Removal of the hardware trigger, all 5 TB/s of data will be processed in near real time in the trigger (plan to keep real-time calibration) — huge gains for dark-sector physics!

Summary

LHCb is a general-purpose detector in the forward region.