Dark Sectors at LHCb

Constantin Weisser, MIT

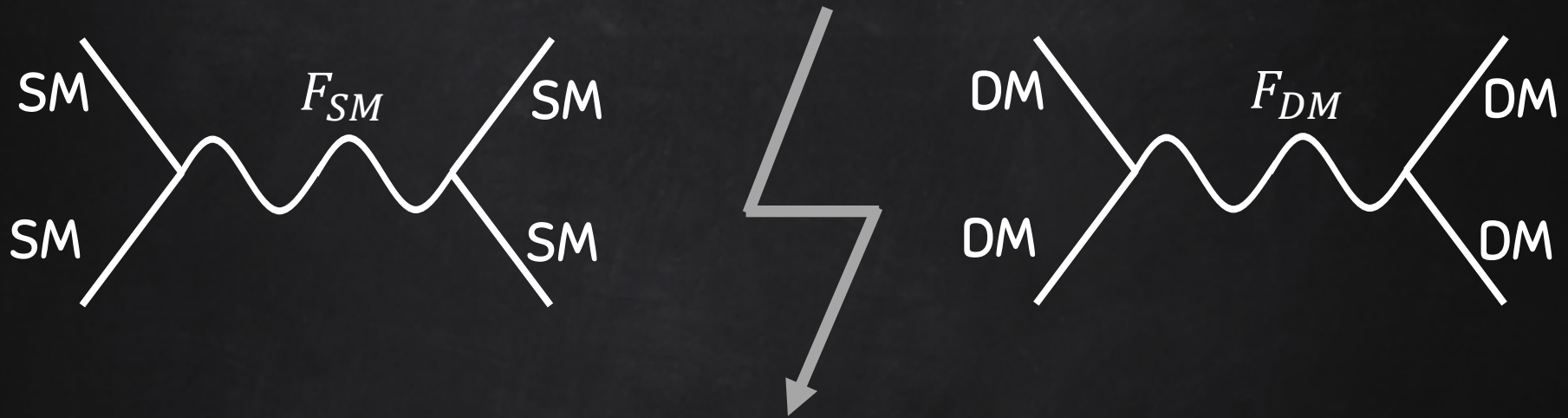on behalf of the LHCb collaboration

DPF, July 29 2019

The Chasm

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

What if there is no connection between the SM and
Dark Sector up to the Planck scale?

The Chasm

SM — F_{SM} — SM

SM — SM

DM — F_{DM} — DM

DM — DM

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

What if there is no connection between the SM and
Dark Sector up to the Planck scale?

Portals

The force carriers of the two sectors can couple if the sectors are somehow connected (even at a large mass scale).

PORTALS

SM $\qquad$ F_{SM} $\qquad$ F_{DM} $\qquad$ DM
SM $\qquad$ DM

> See: Natalia Toro, DPF Tue 8.50am
> Models of Dark Matter & Dark Sectors

The force carriers of the two sectors can couple if the sectors are somehow connected (even at a large mass scale).

Vector (Dark Photon) Portal
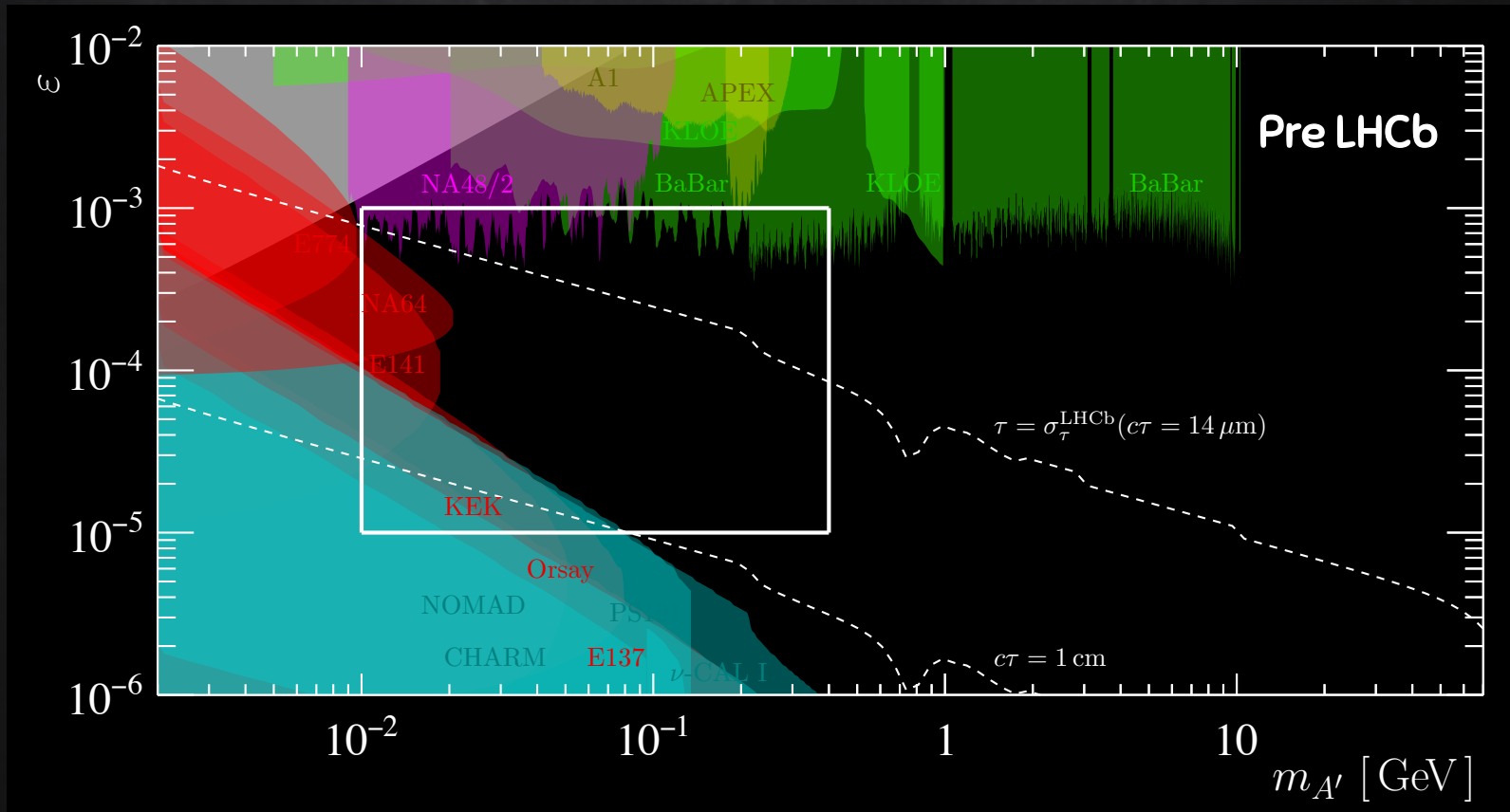
SM

SM

γ

A'

DM

DM

$$\alpha' = \epsilon^2 \alpha_{EM}$$

The dark photon mixes with the SM photon.
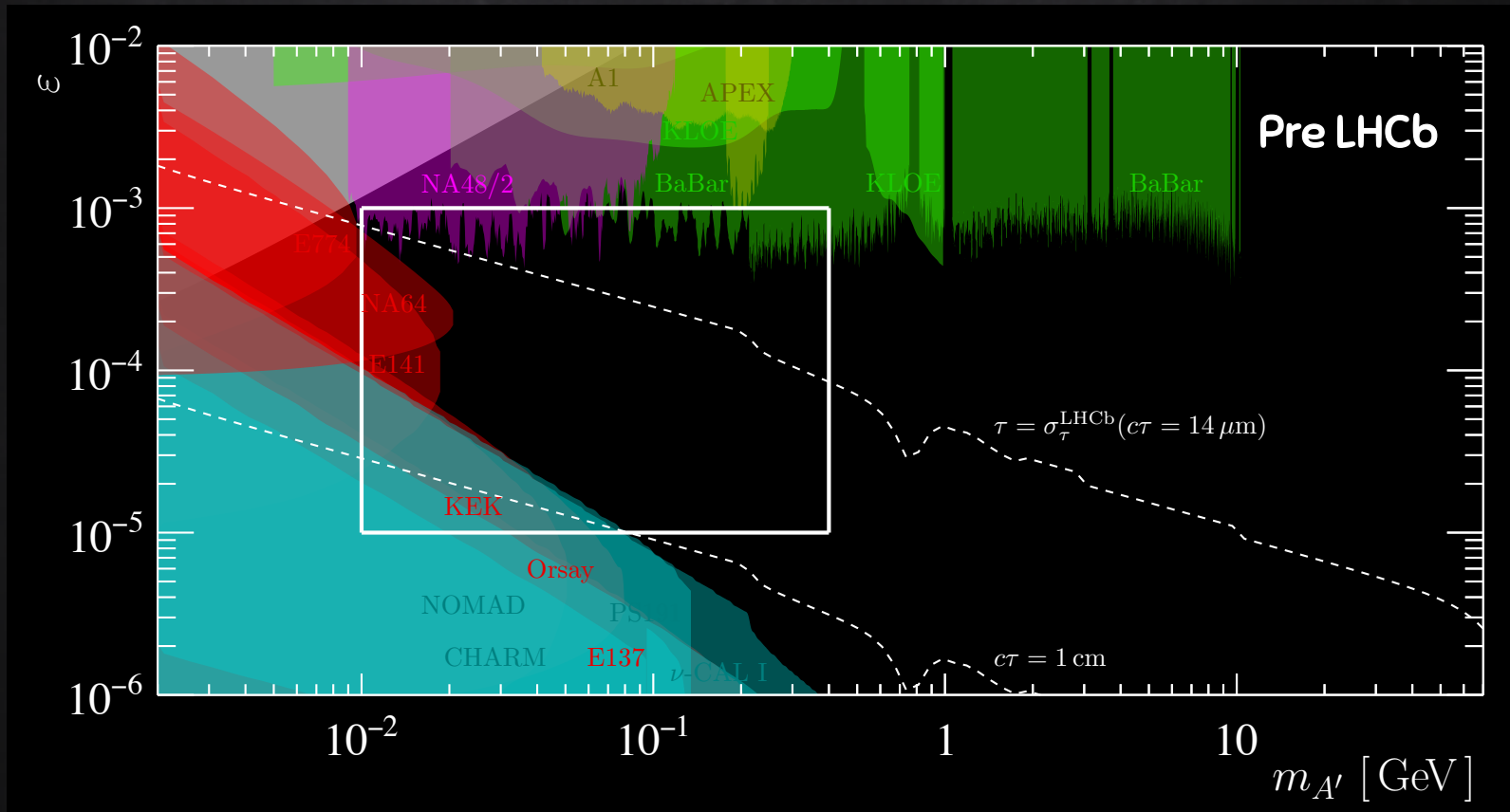The coupling to SM particles is proportional to electric charge.

1 or 2 loops: roughly $10^{-3} \lesssim \epsilon \lesssim 10^{-5}$

Visible A' decays

DM–DM self interactions and 1 or 2 loop regime
bound a naively interesting region.

Plot from Ilten, Soreq, Thaler, Williams, Xue [1801.04847]

Visible A' decays

Plot showing visible A' decay constraints in the ε vs $m_{A'}$ [GeV] plane, labeled "Pre LHCb". Regions labeled: A1, APEX, KLOE, BaBar, NA48/2, NA64, E141, KEK, Orsay, NOMAD, CHARM, E137, ν-CAL I, PS. Dashed contours: $\tau = \sigma_\tau^{\mathrm{LHCb}}(c\tau = 14\,\mu\mathrm{m})$ and $c\tau = 1\,\mathrm{cm}$.

See: Anika Peter, DPF Tue 11.30am
Astrophysical Evidence on Heavy & Light Dark Species

Plot from Ilten, Soreq, Thaler, Williams, Xue [1801.04847]
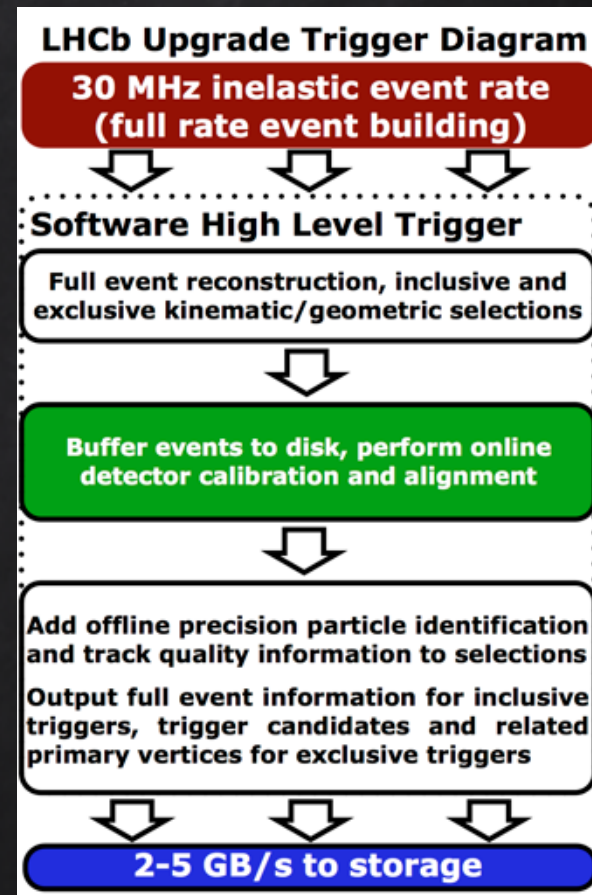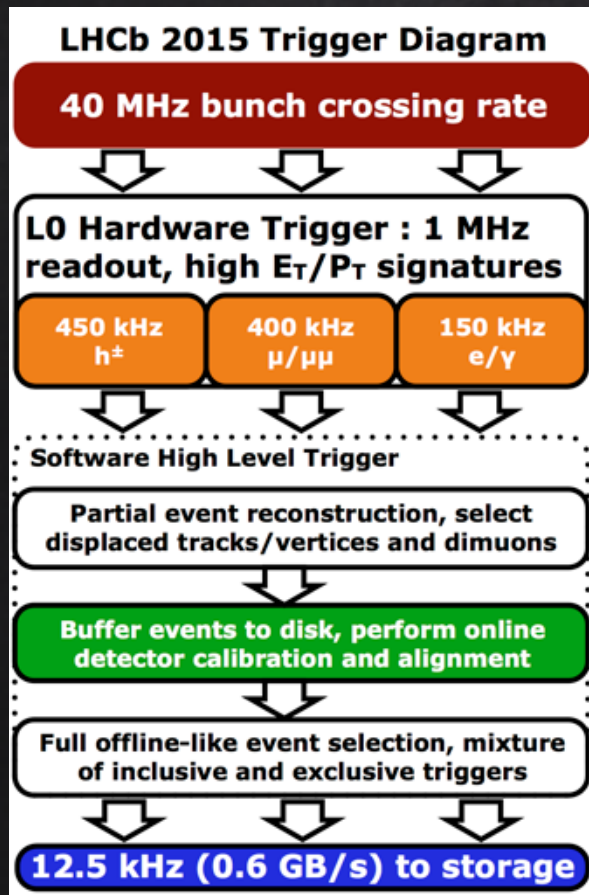
LHCʙ
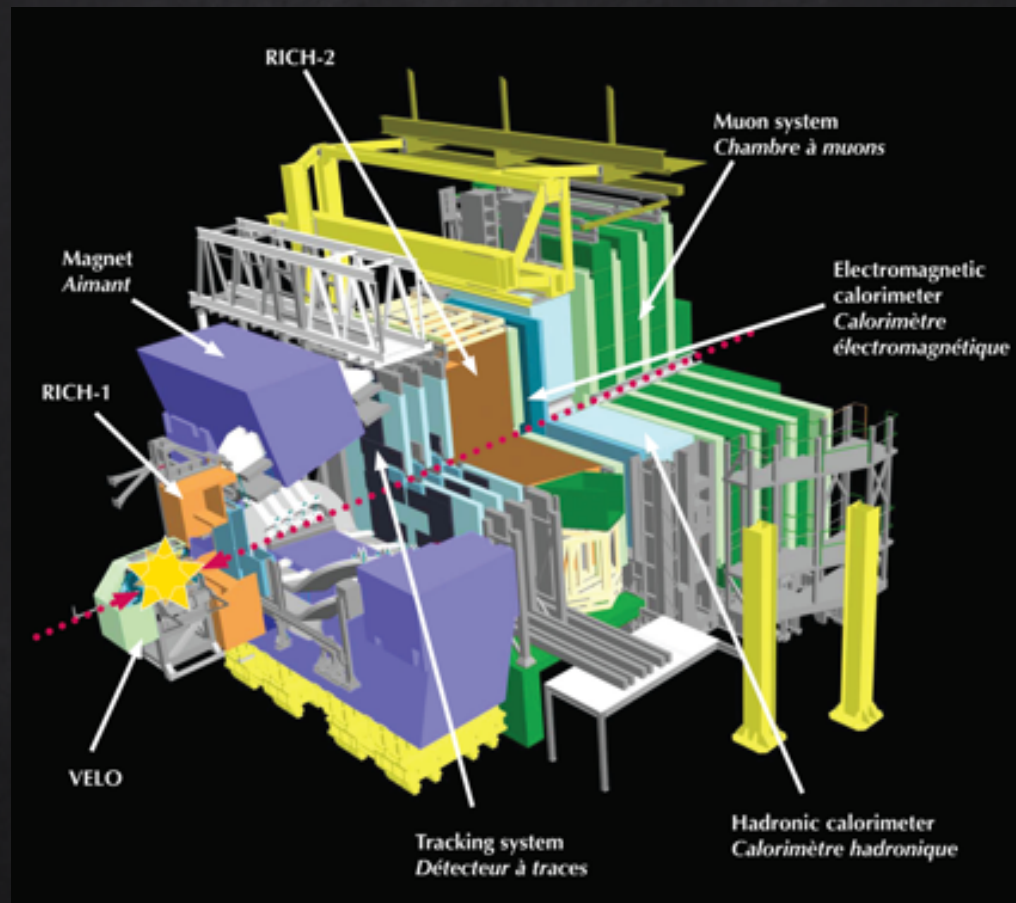
- Single-arm forward spectrometer ($2 < \eta < 5$; $1 < \theta < 15°$)
- Excellent lifetime ($\sigma_\tau = 45 fs$) and mass ($\sigma_m = 0.4\%$) resolution
- Unique particle ID

LHCʙ Trigger

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

↓ ↓ ↓

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

| 450 kHz $h^\pm$ | 400 kHz $\mu/\mu\mu$ | 150 kHz e/γ |

↓ ↓ ↓

Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

↓

Buffer events to disk, perform online detector calibration and alignment

↓

Full offline-like event selection, mixture of inclusive and exclusive triggers

↓ ↓ ↓

12.5 kHz (0.6 GB/s) to storage

LHCb Upgrade Trigger Diagram

30 MHz inelastic event rate (full rate event building)

↓ ↓ ↓

Software High Level Trigger

Full event reconstruction, inclusive and exclusive kinematic/geometric selections

↓

Buffer events to disk, perform online detector calibration and alignment

↓

Add offline precision particle identification and track quality information to selections

Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

↓ ↓ ↓

2-5 GB/s to storage

Flexible triggering scheme needed to select even low energy candidates.

LHCB INCLUSIVE A' → $\mu^+ \mu^-$

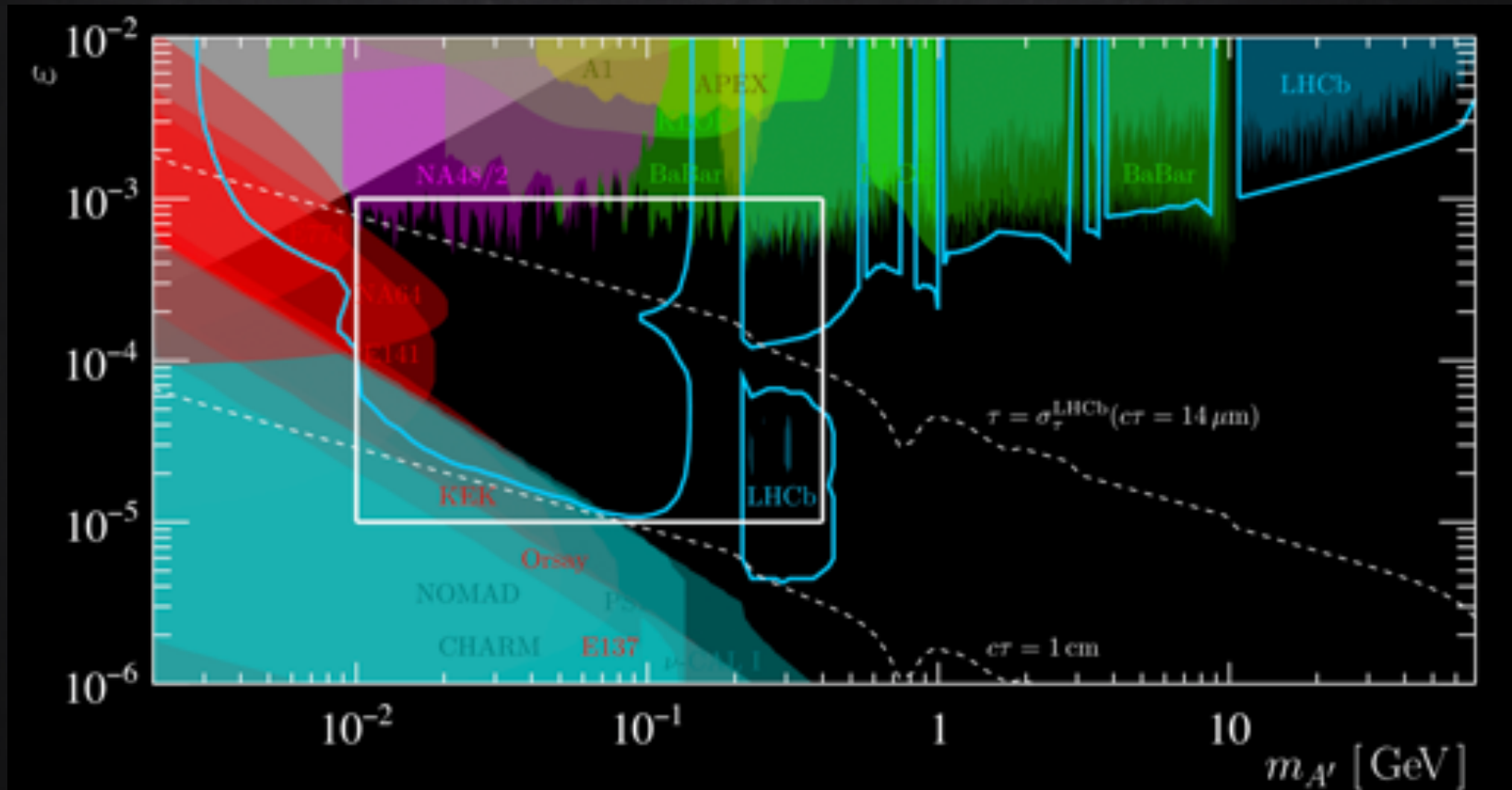Production: Pseudoscalar Meson Decay, Drell Yan, ...
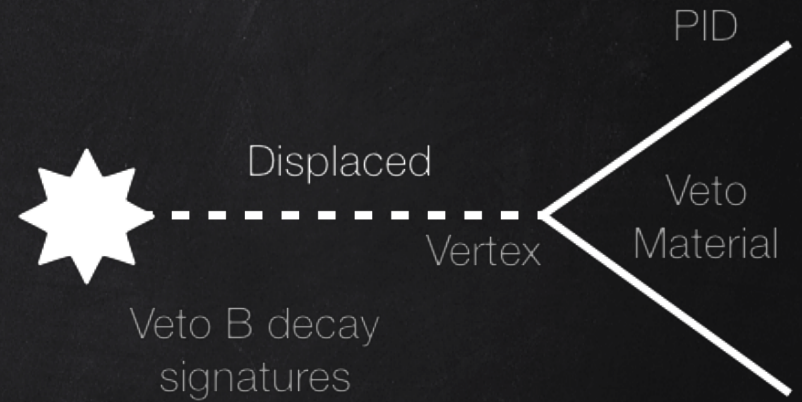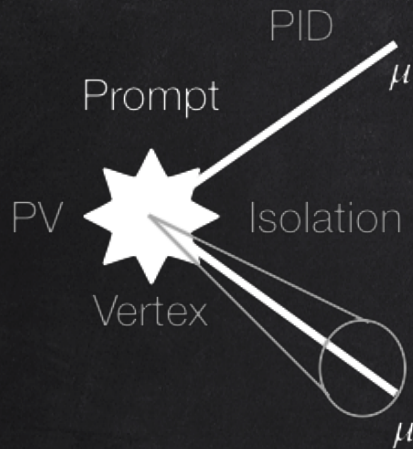
1. Count A' Candidates
2. Compare to prompt γ^*
3. Set Limits / Claim Discovery

⇒ Fully data-driven search

LHCb Limits: 2016 data

Run 2 sensitivity: prompt: 1.5 –2.5x gain; displ: much bigger region covered

Can recast as searches for other vector models (B, B–L, protophobic, …)
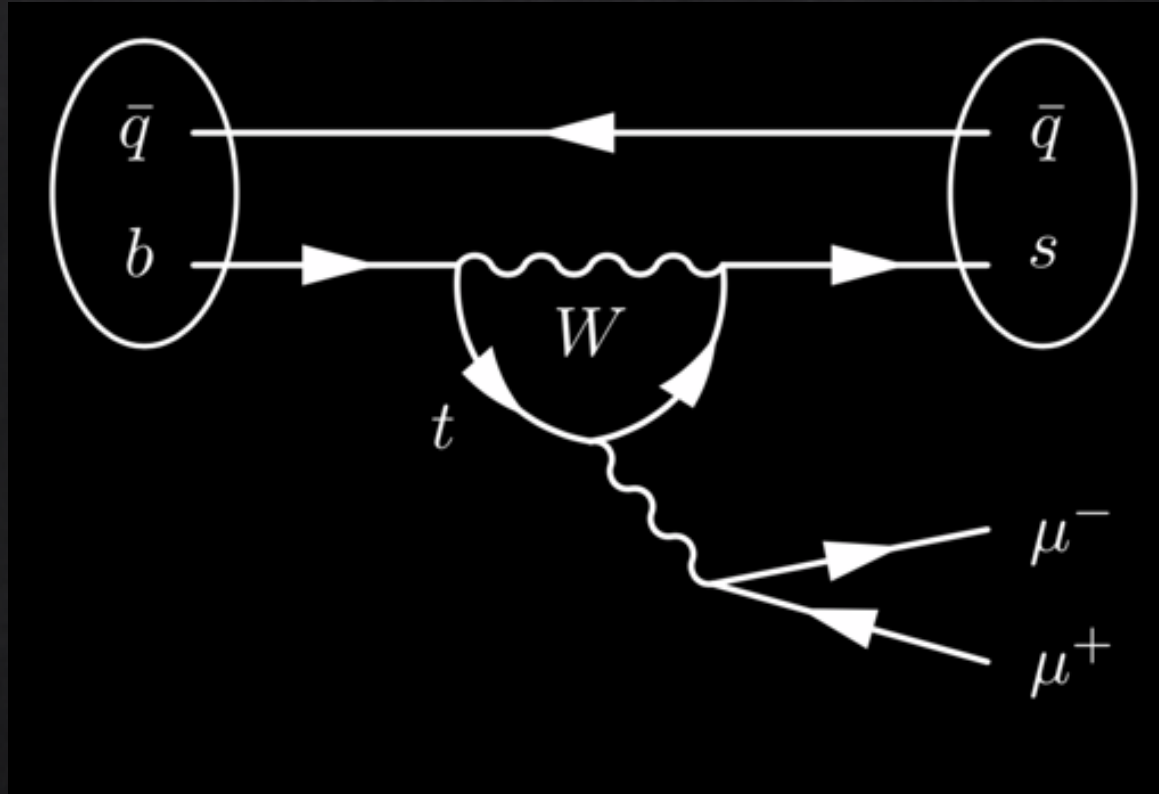
Run 2 Extensions

No Iso

Non-Standard Topology

B Tag

$A' \rightarrow E^+ E^-$

Scalar (Higgs) Portal

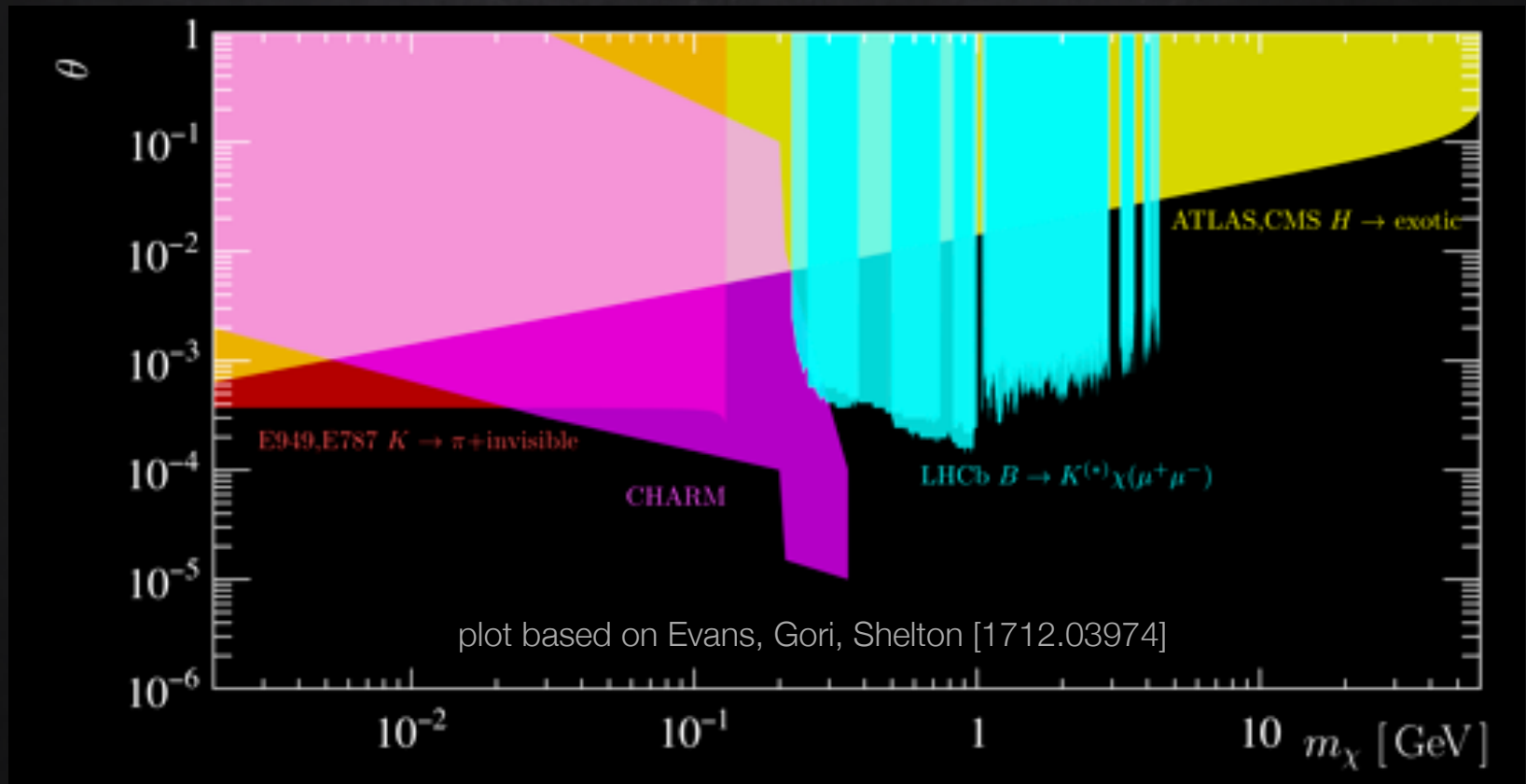e.g. χ responsible for an inflationary
period in the early universe

$B \rightarrow K^{(*)} \mu^+ \mu^-$

Penguin diagrams are sensitive to many BSM scenarios.
Dark higgs will have sizable coupling to the top
and a large decay rate to muons.

Dark Higgs Limits

LHCb sensitivity is limited by size of VELO

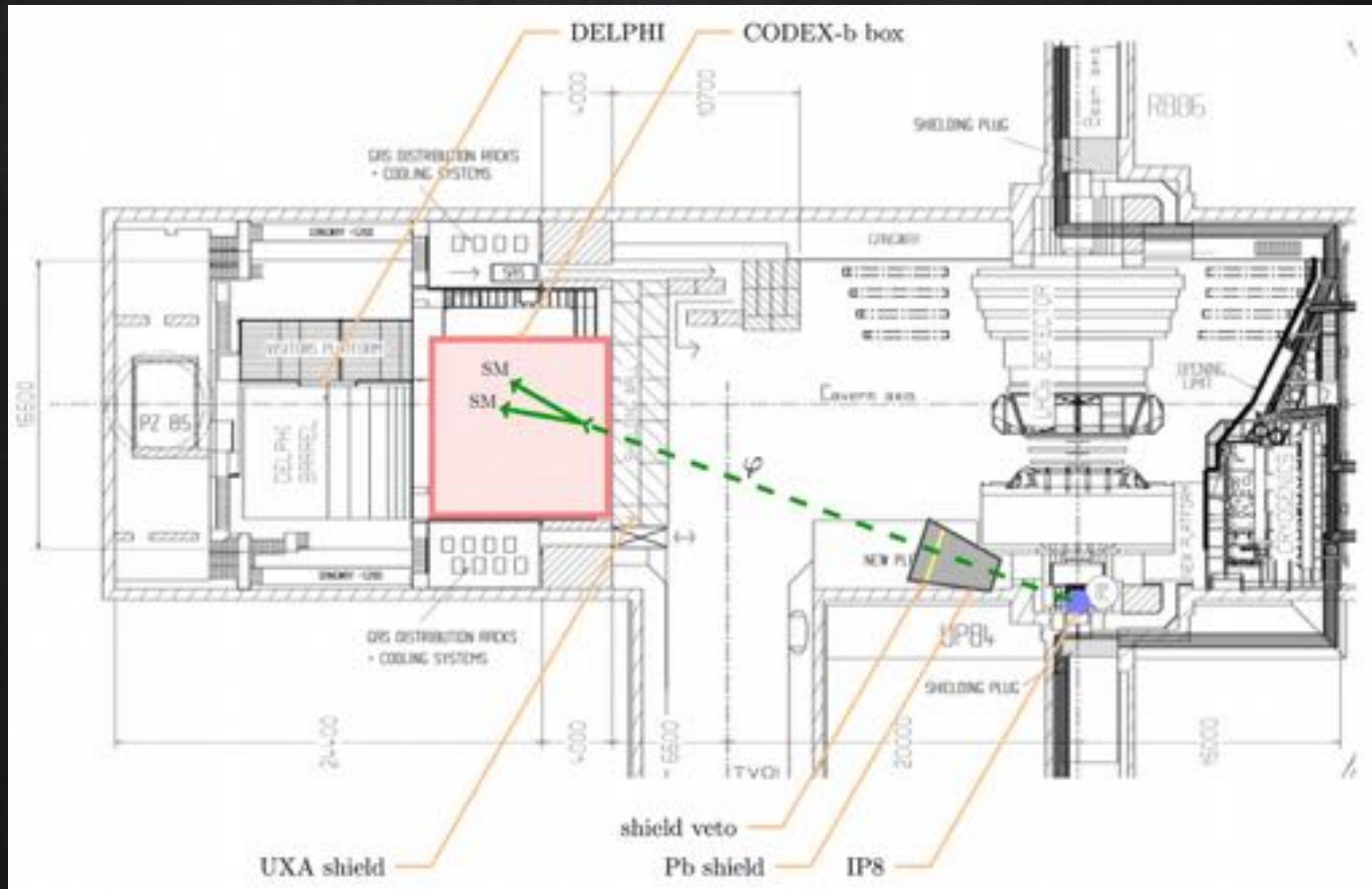plot based on Evans, Gori, Shelton [1712.03974]

Bonus: Run 1+2 LHCb data has world leading sensitivity to ALPs with dominant gluon coupling

CODEX-b

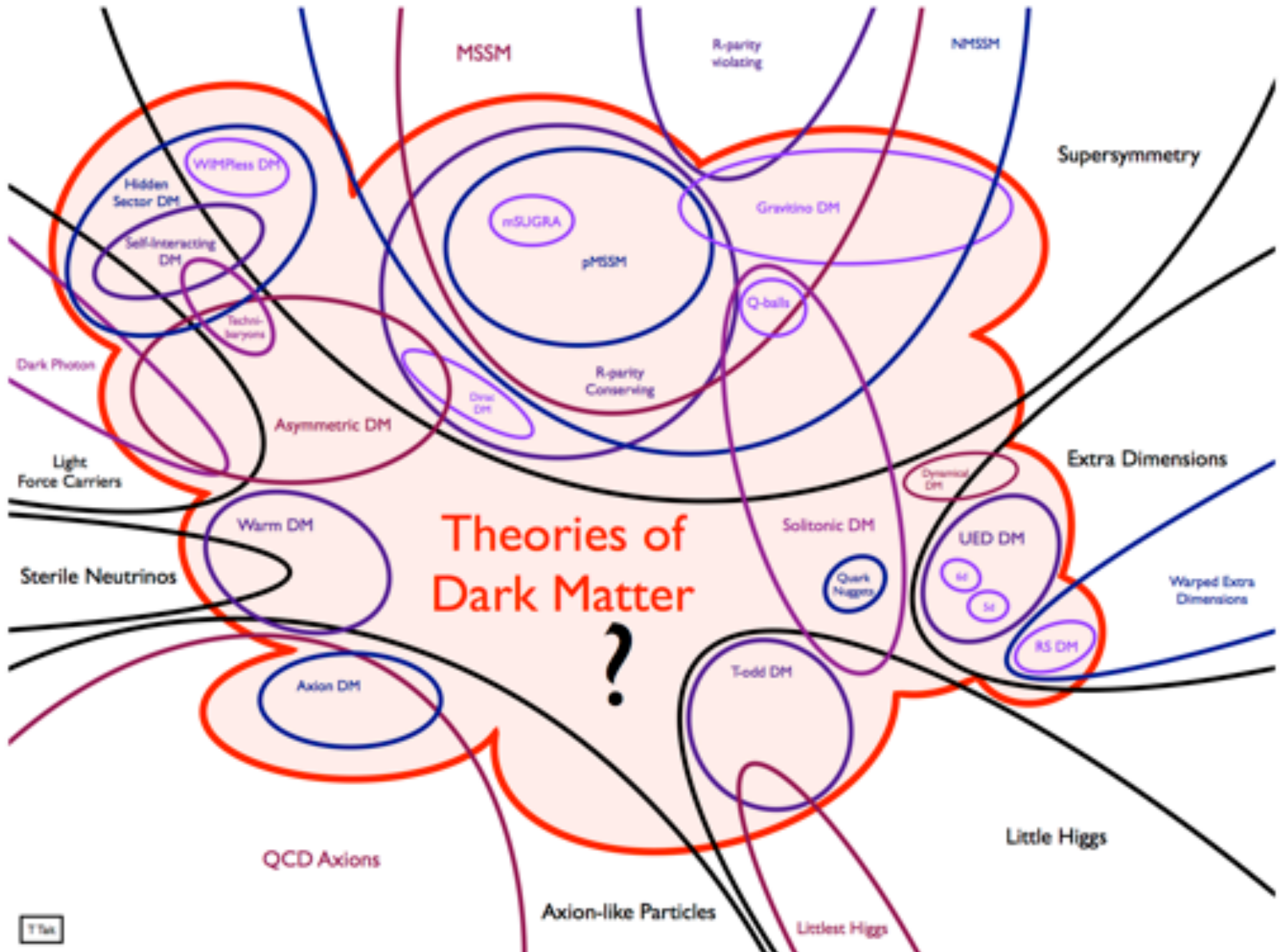A proposed COmpact Detector for EXotics at LHCb

Complimentary due to lifetime acceptance
Excellent sensitivity to most long-lived particle models
Including dark Higgs.

Gligorov, Knapen, Papucci, Robinson [1708.09395]

Dark Sectors are dark
matter scenarios worth exploring

LHCb has world leading
sensitivity to different models

Theories of
Dark Matter

?

MSSM

R-parity violating

NMSSM

Supersymmetry

Hidden Sector DM

WIMPless DM

Self-Interacting DM

Techni-baryons

mSUGRA

pMSSM

Gravitino DM

Q-balls

R-parity Conserving

Dark Photon

Asymmetric DM

Dark DM

Light Force Carriers

Warm DM

Sterile Neutrinos

Axion DM

Solitonic DM

Dynamical DM

Quark Nuggets

UED DM

M

M

RS DM

Extra Dimensions

Warped Extra Dimensions

T-odd DM

Little Higgs

QCD Axions

Axion-like Particles

Littlest Higgs

T Tait

Invisible A' decays

Recasting A' as any Vector

|	l	nu	u type	d type
A'	$-g_e$	0	$\dfrac{2g_e}{3}$	$-\dfrac{g_e}{3}$
B	$-\left(\dfrac{g_e}{4\pi}\right)^2$	0	$\dfrac{1}{3}$	$\dfrac{1}{3}$
B-L	-1	-1	$\dfrac{1}{3}$	$\dfrac{1}{3}$
Proto phobic	-1	0	$-\dfrac{1}{3}$	$\dfrac{2}{3}$

Serendipity in A' Searches
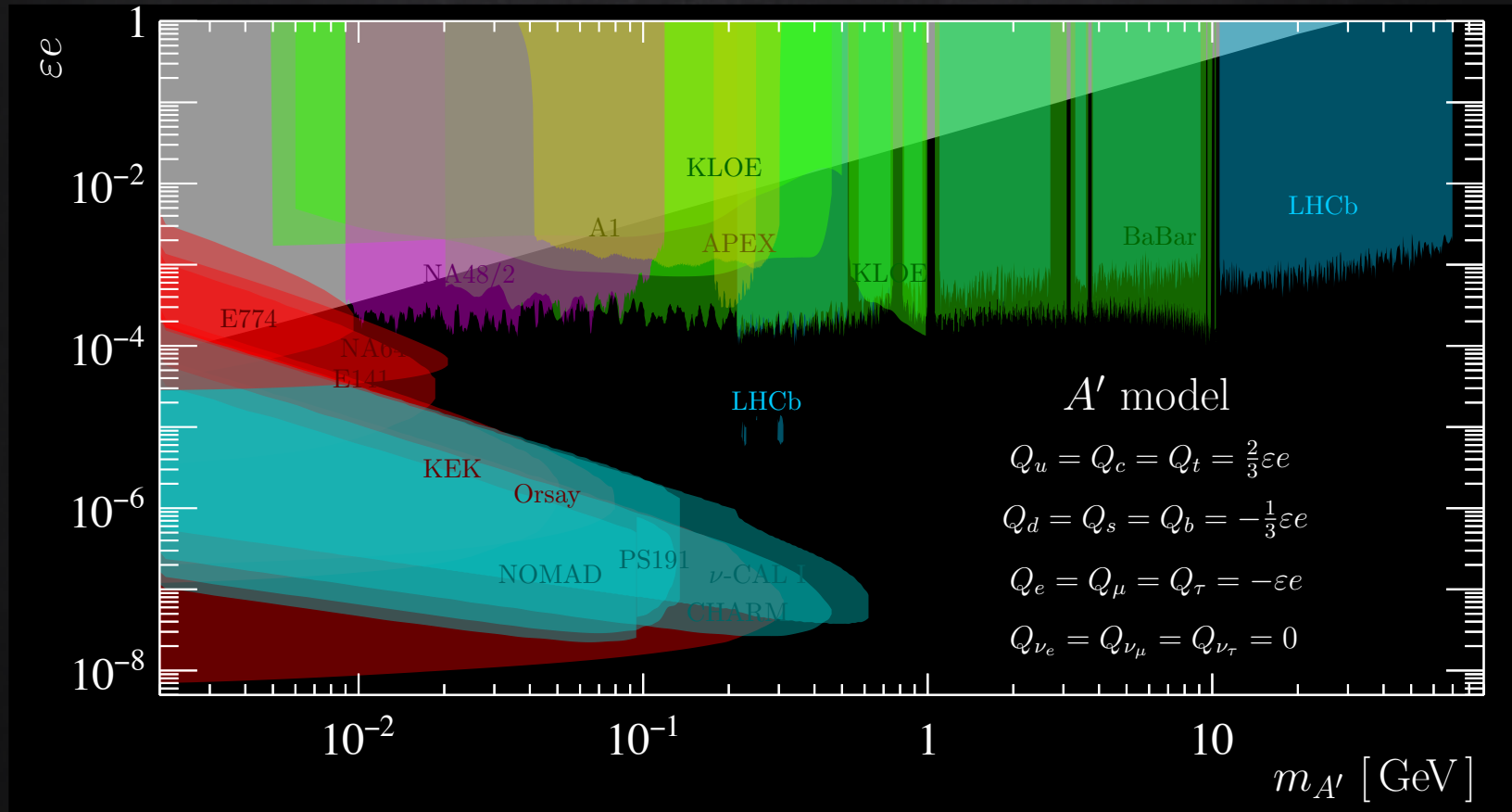
Accounting for production, branching ratio and detection efficiency, existing and future searches can be recast to any vector model.

Serendipity in A' Searches

$B - L$ model

$Q_u = Q_c = Q_t = \frac{1}{3} g_{B-L}$

$Q_d = Q_s = Q_b = \frac{1}{3} g_{B-L}$

$Q_e = Q_\mu = Q_\tau = -g_{B-L}$

$Q_{\nu_e} = Q_{\nu_\mu} = Q_{\nu_\tau} = -g_{B-L}$

Accounting for production, branching ratio and detection efficiency,
existing and future searches can be recast to any vector model.
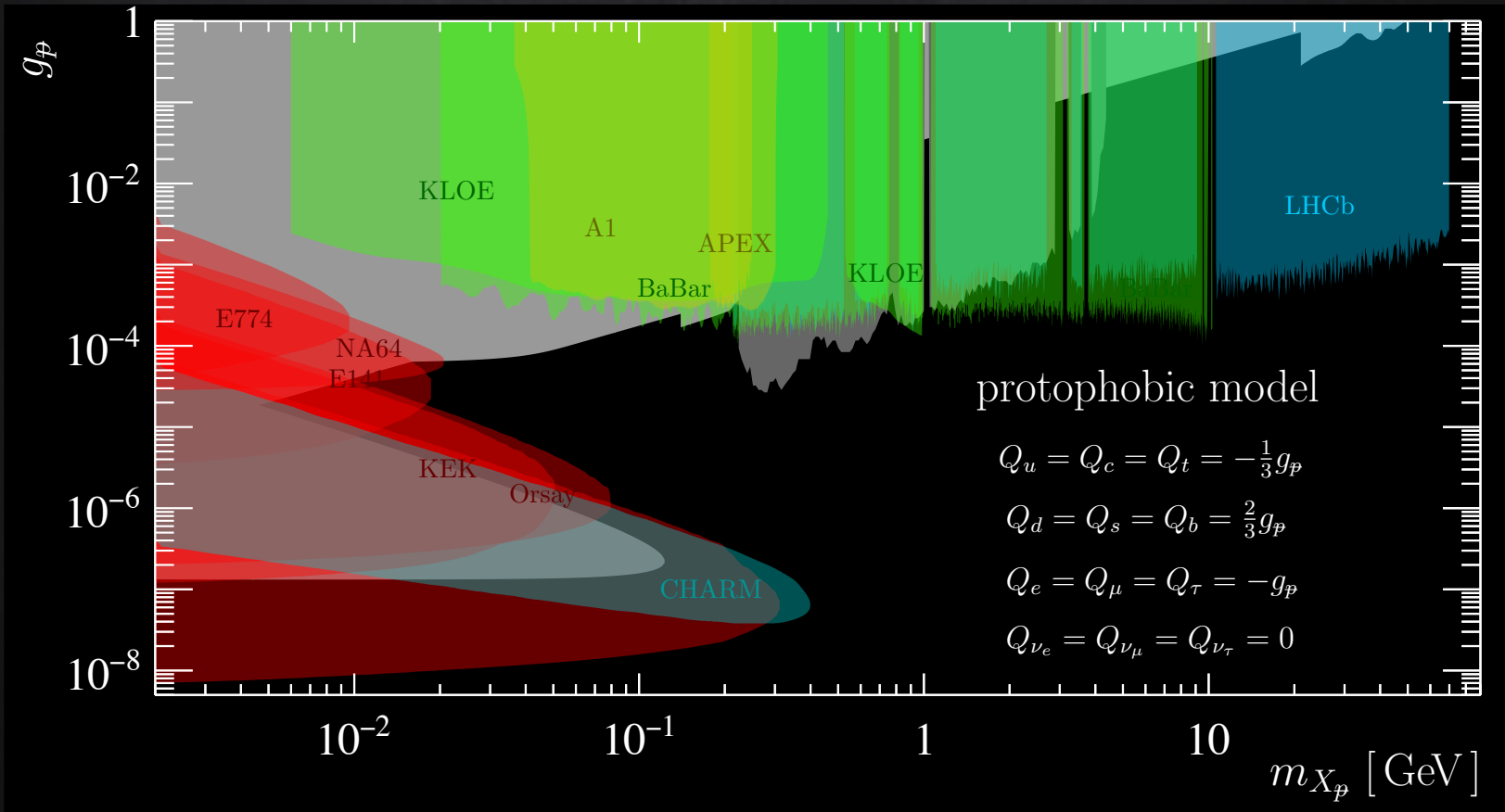
SERENDIPITY IN A' SEARCHES
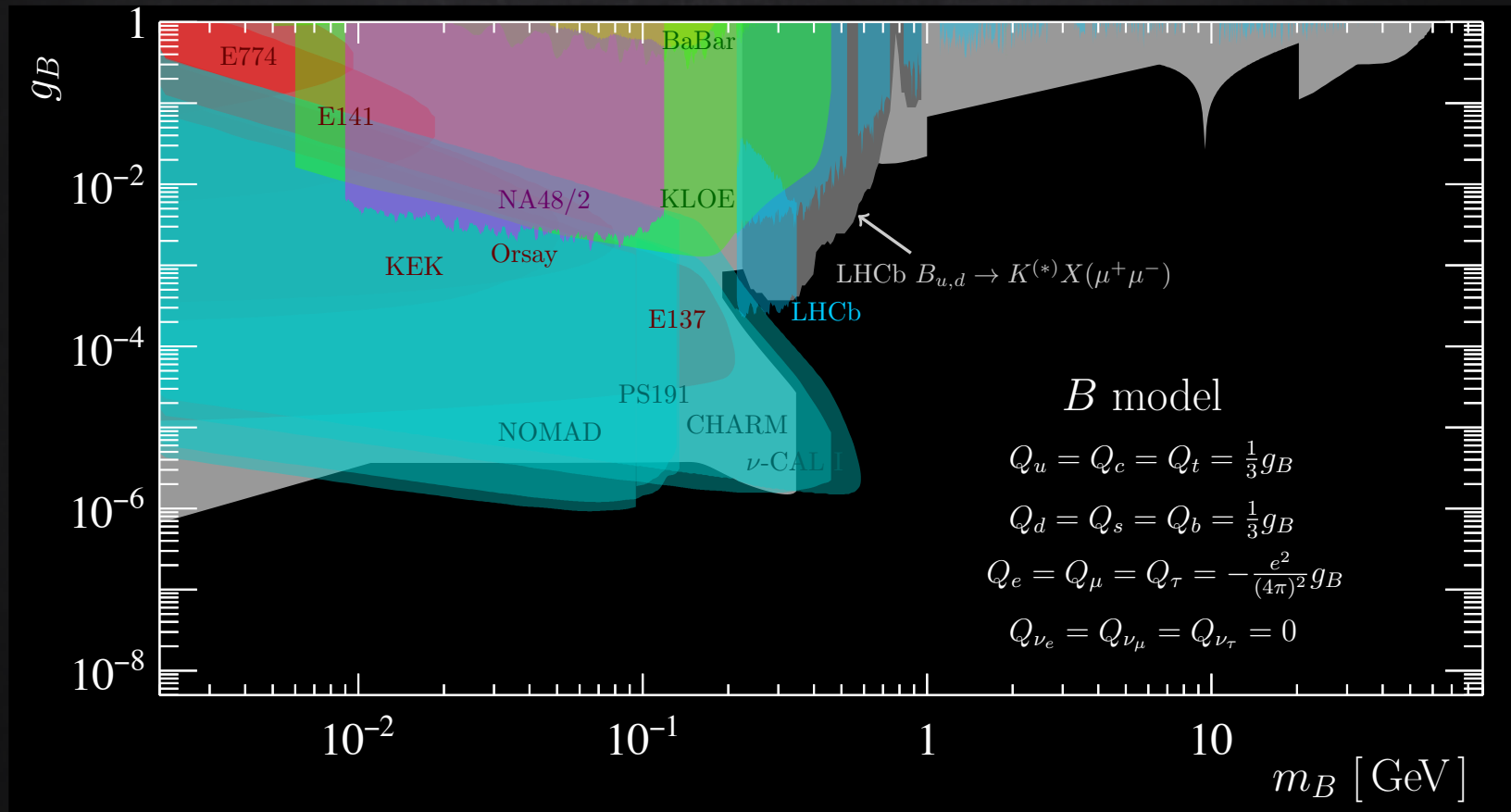
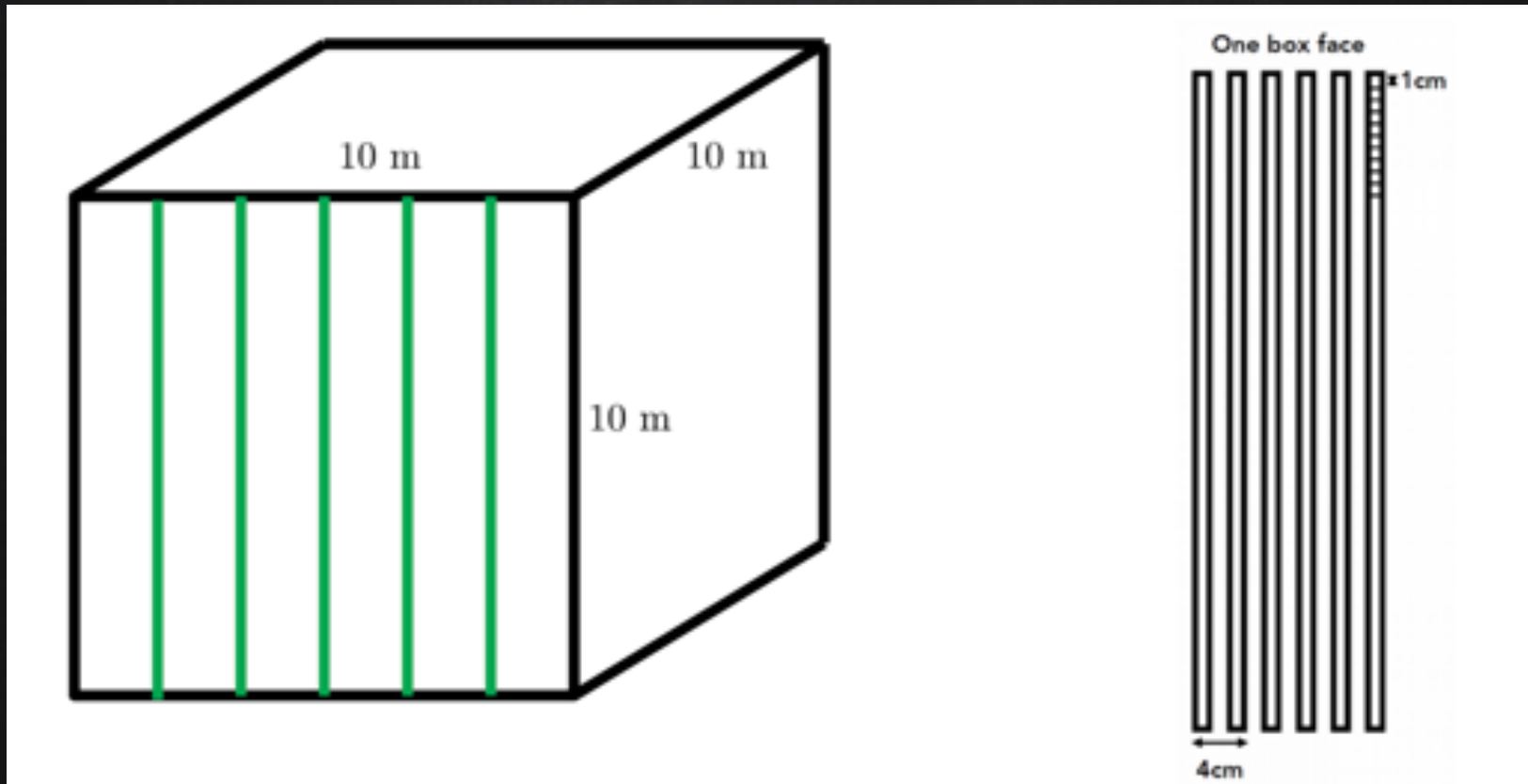

Accounting for production, branching ratio and detection efficiency, existing and future searches can be recast to any vector model.

SERENDIPITY IN A' SEARCHES

Accounting for production, branching ratio and detection efficiency, existing and future searches can be recast to any vector model.

CODEX-b

- 6 RPC layers at 4 cm intervals on each box face with 1 cm granularity
- 5 equally spaced triplets along the depth to minimize distance between reconstructed vertex and 1st measurement. $\epsilon_{tracking}$ ~ O(1).
- 50–100 ps timing from RPC's foreseen for mass reconstruction

Can the portals help us
discover dark matter?