

CODEX-b and the Quest for Longevity

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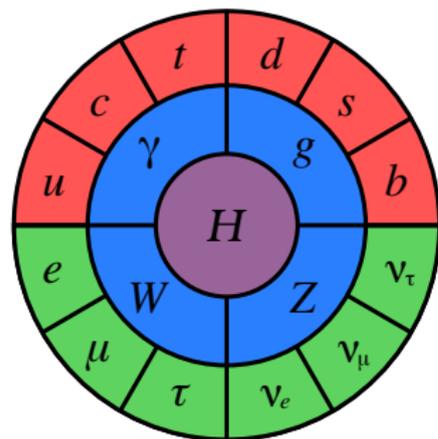
May 13, 2020



IMPERIAL SEMINAR

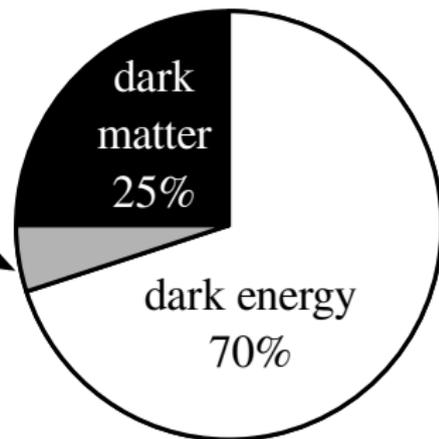


Dark Matter



SM matter
5%

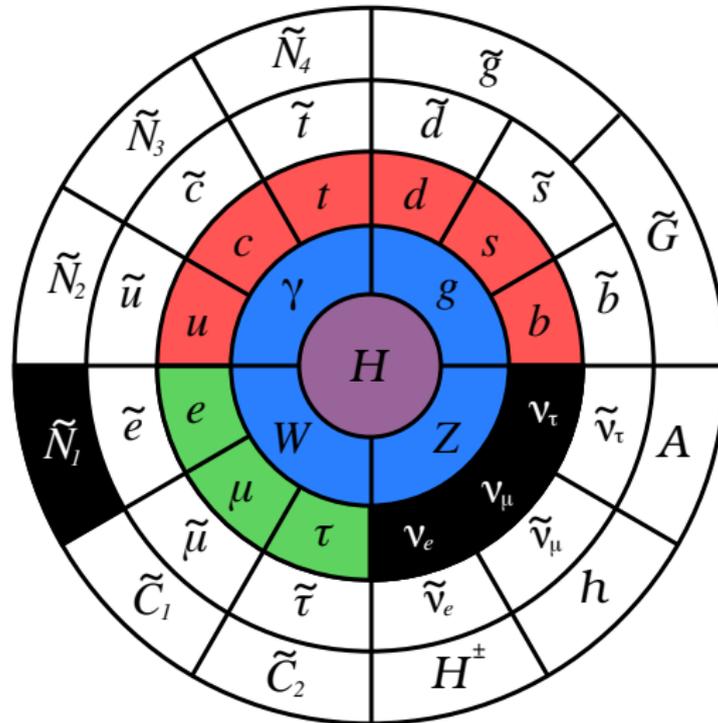
quarks
leptons
force carriers



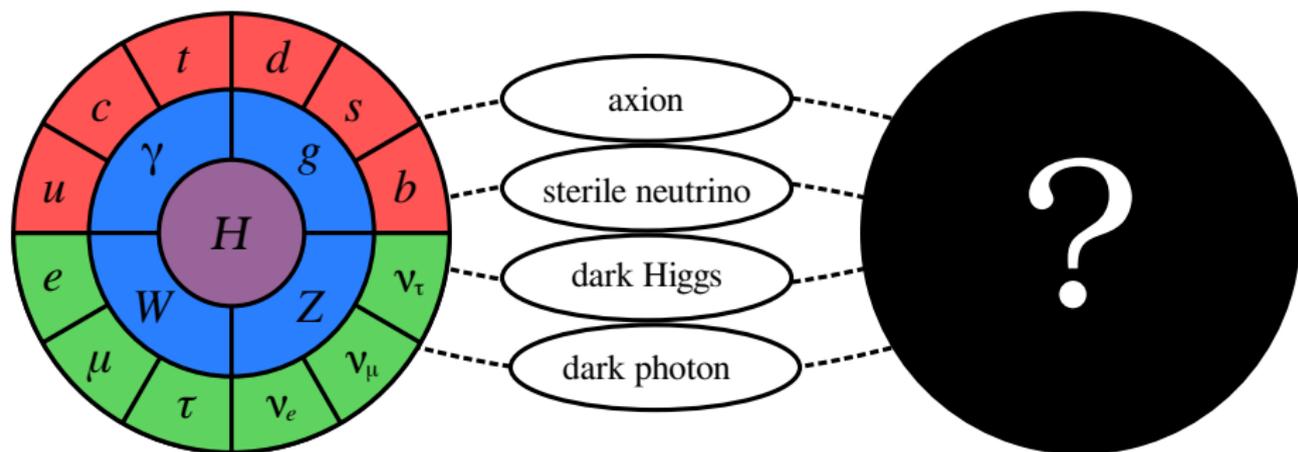
- ① interacts through gravity
- ② does not interact through the electromagnetic or strong forces
- ③ interacts weakly (or not at all) with itself



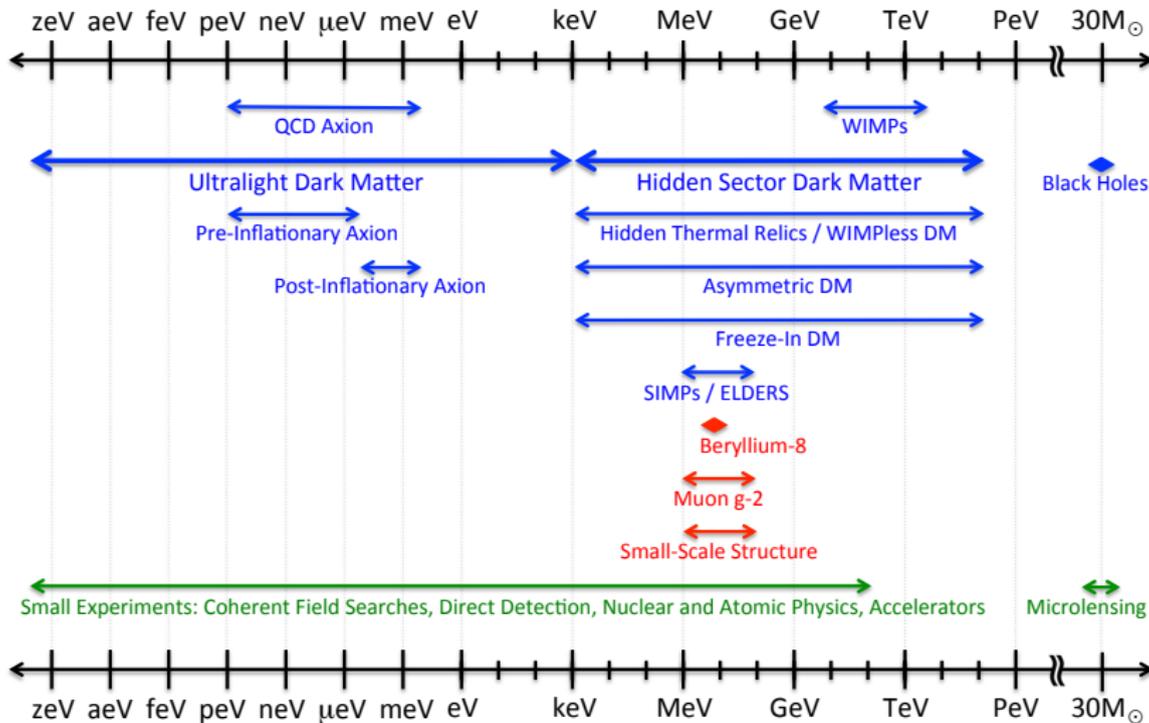
SM or Embedded Theory

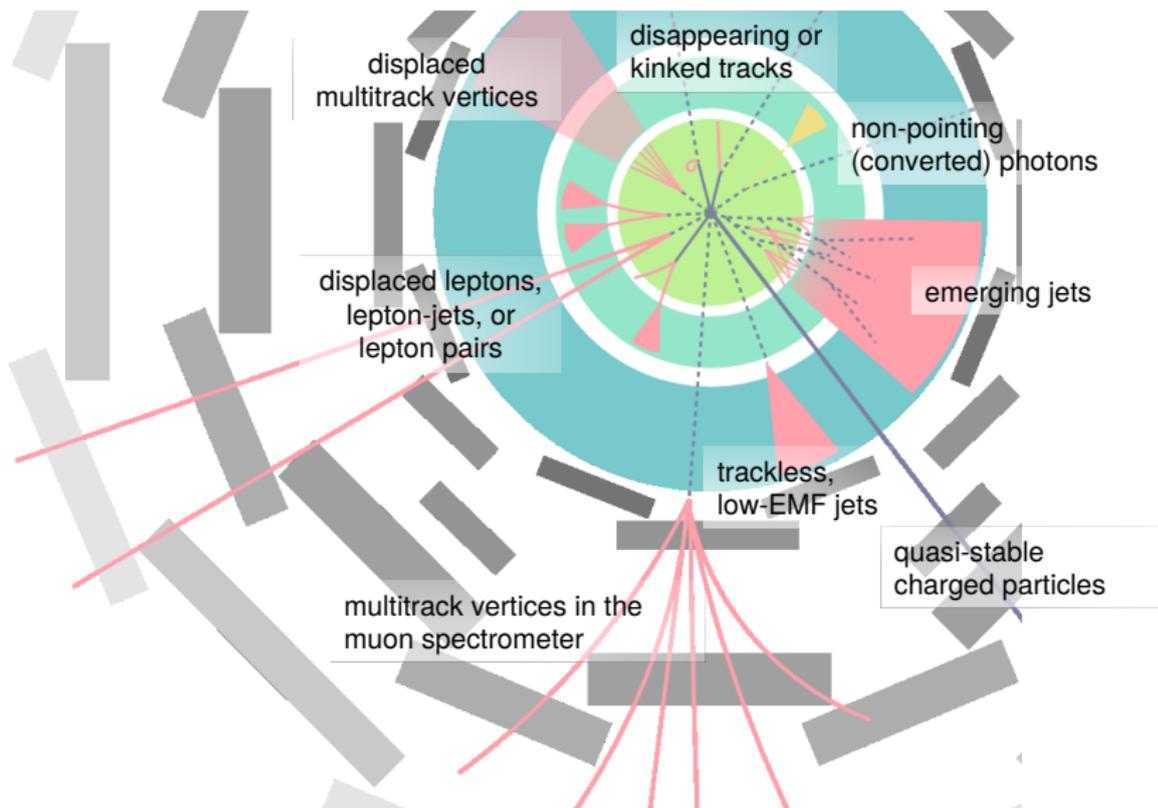


Hidden Sector

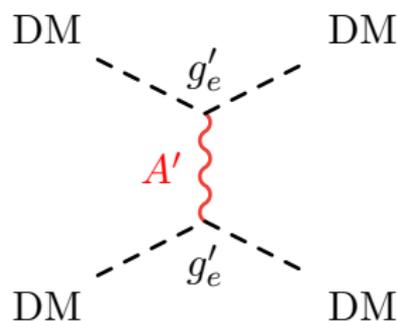
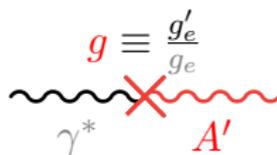
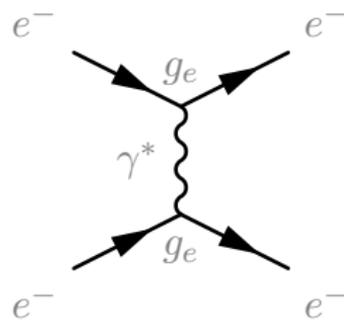


Dark Sector Candidates, Anomalies, and Search Techniques





An Example

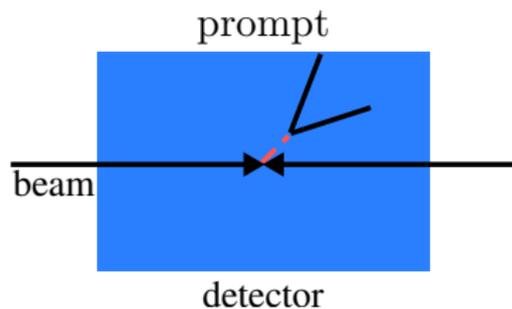
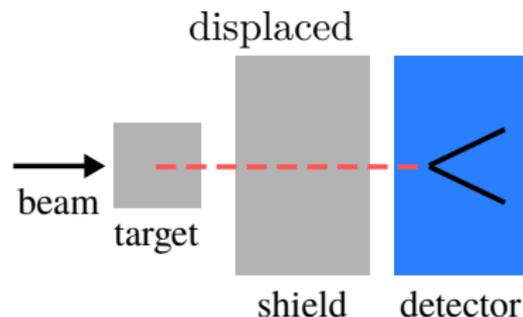


- ① broken $U(1)$ gauge symmetry in dark sector
- ② allow mixing between dark and SM hypercharge fields

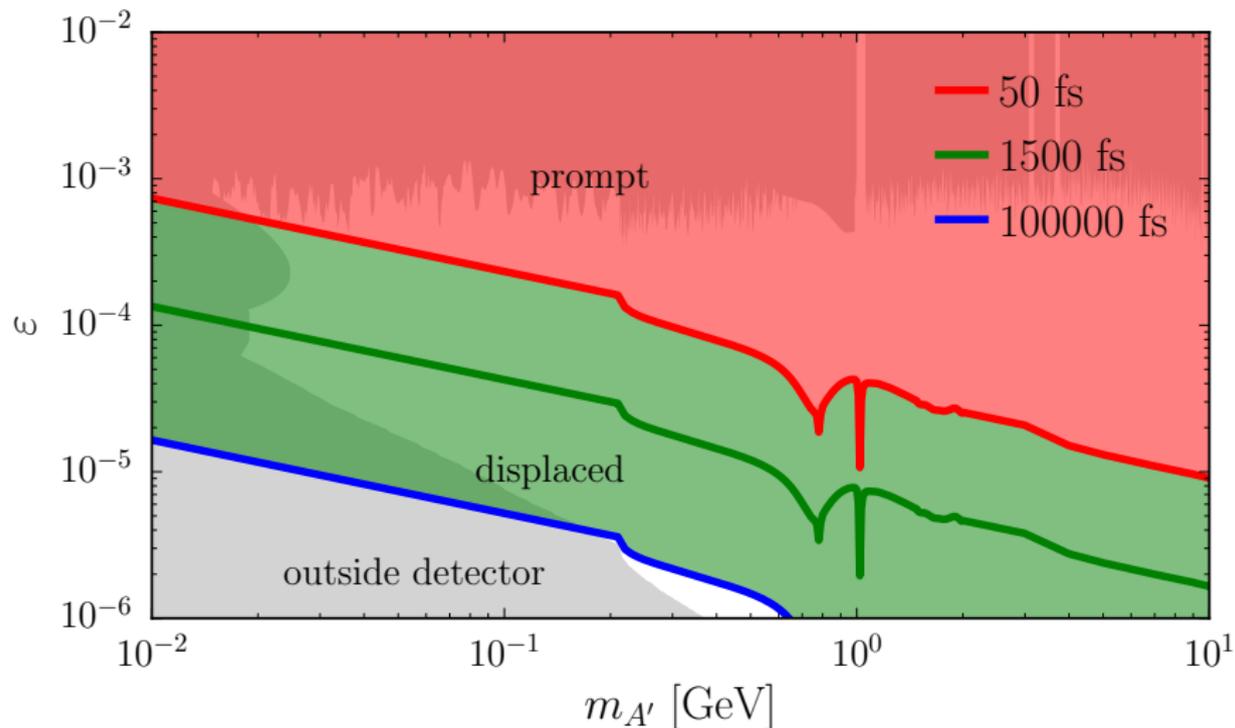
$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m_{A'}^2}{2}A'_\mu A'^\mu + g_e J^\mu A_\mu + \varepsilon g_e J^\mu A'_\mu$$



Search Strategies



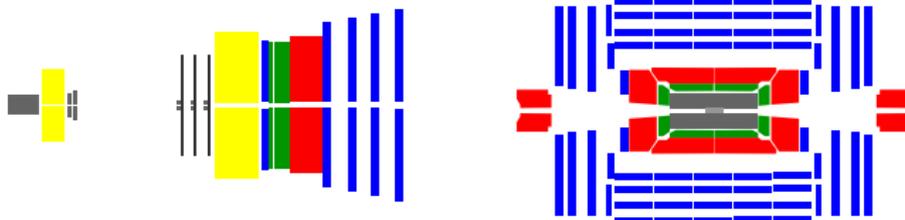
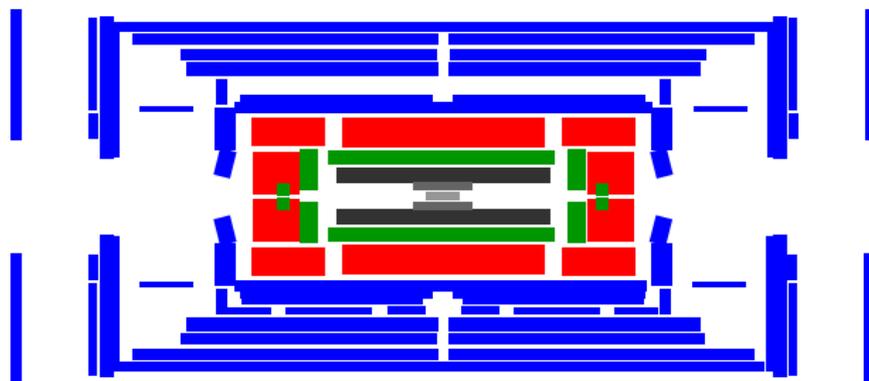
- sensitive to long lifetimes
- EM background free
- difficult to normalise
- do both simultaneously for best of both worlds
- sensitive to shorter lifetimes
- bump hunt on large EM background
- normalised from sidebands



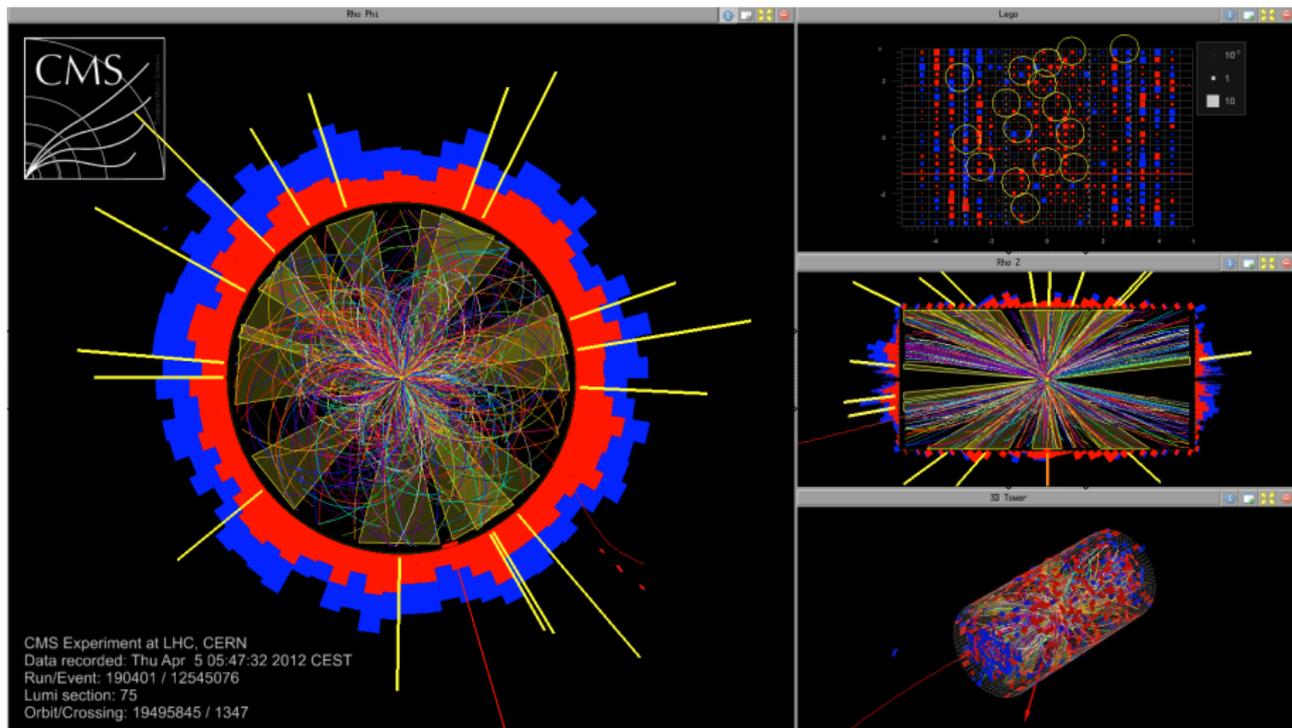
Experimental Landscape

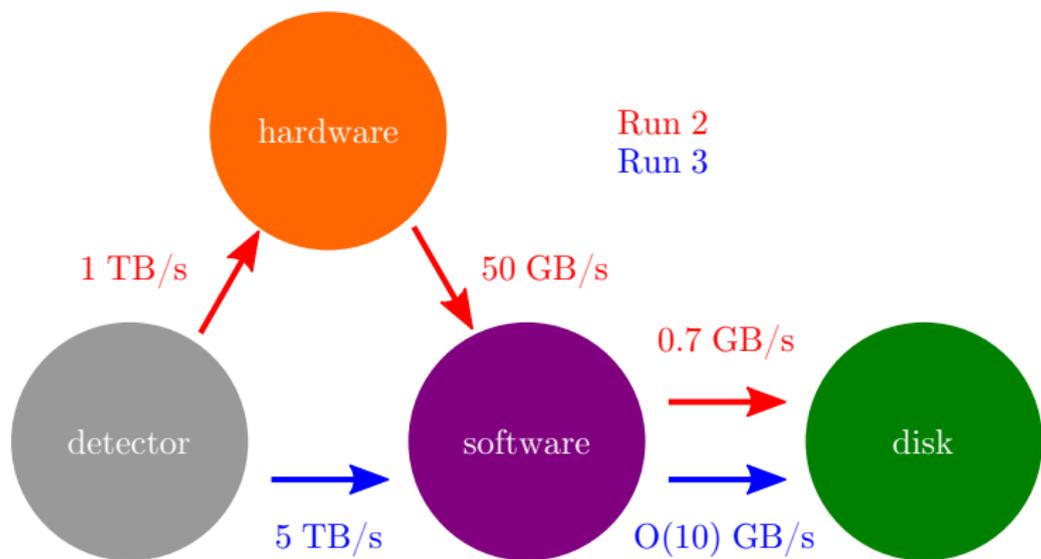


LHC Detectors

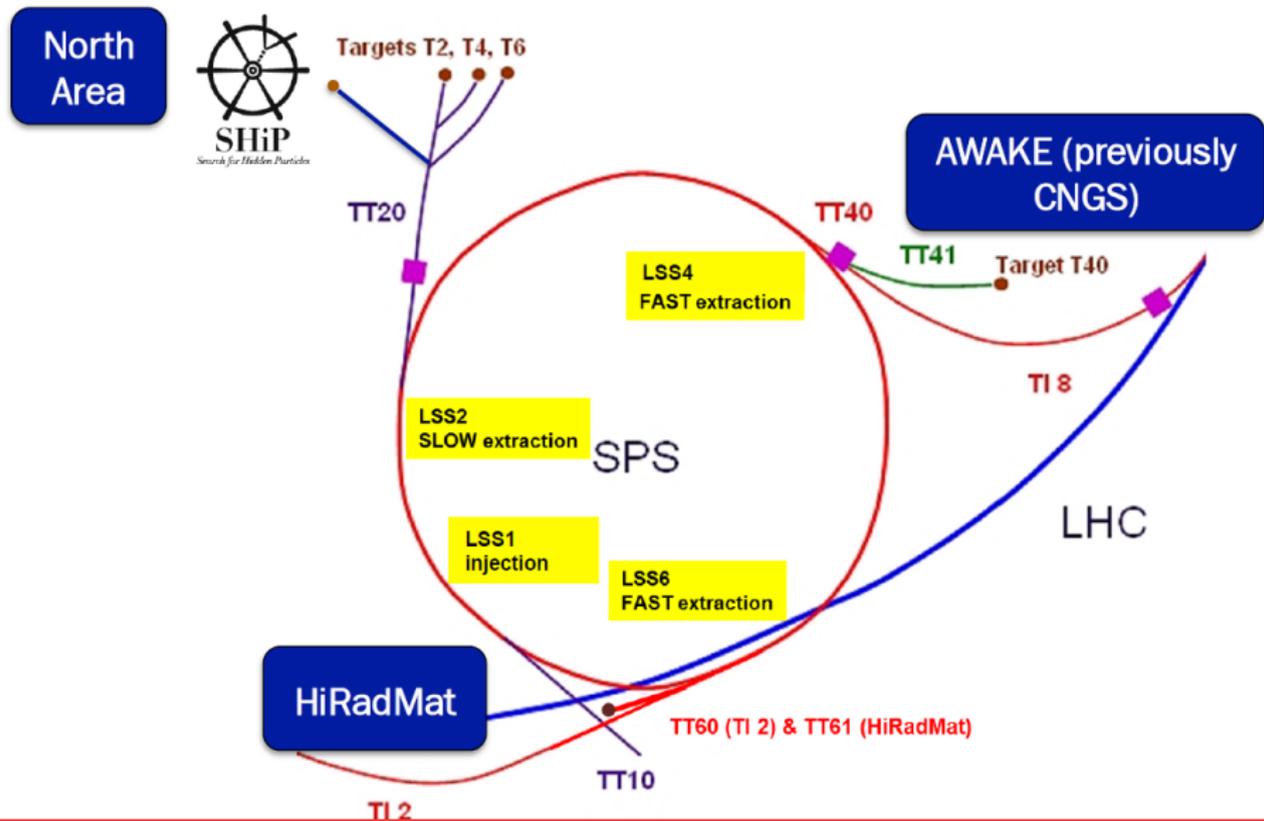


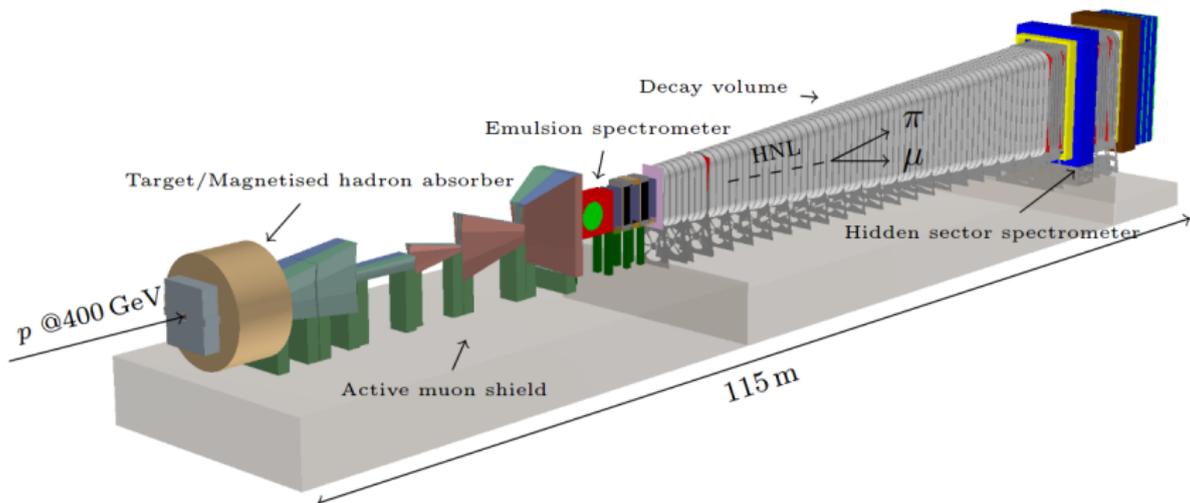
Seeing a Signal

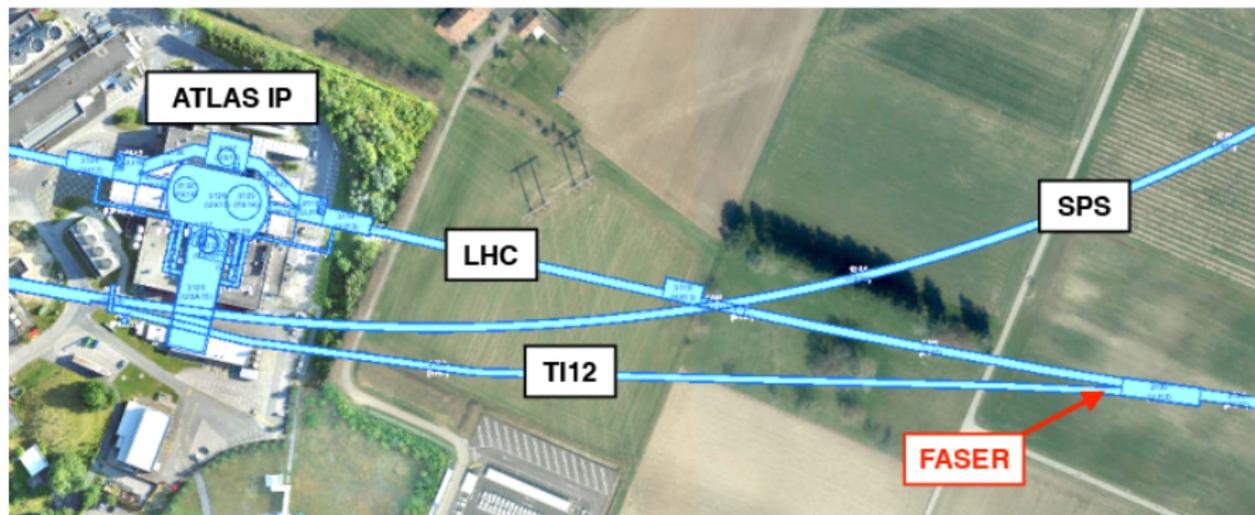


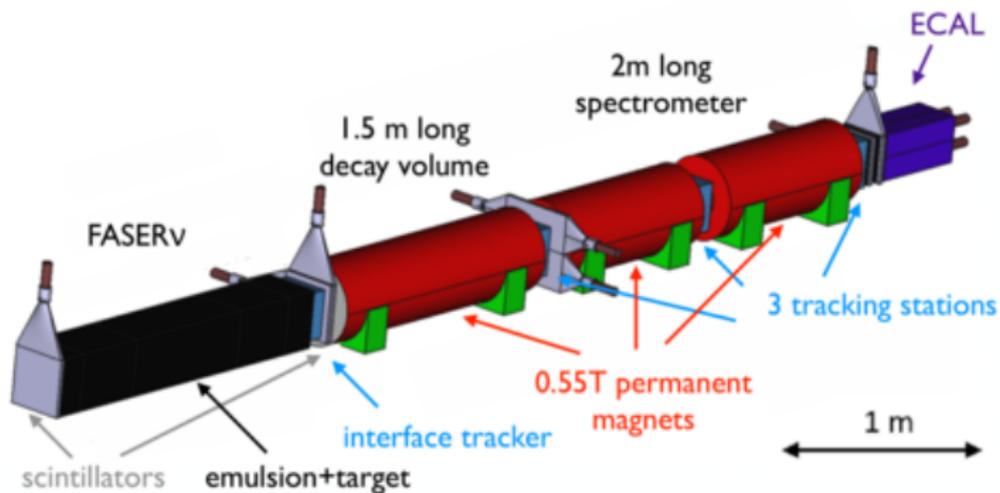


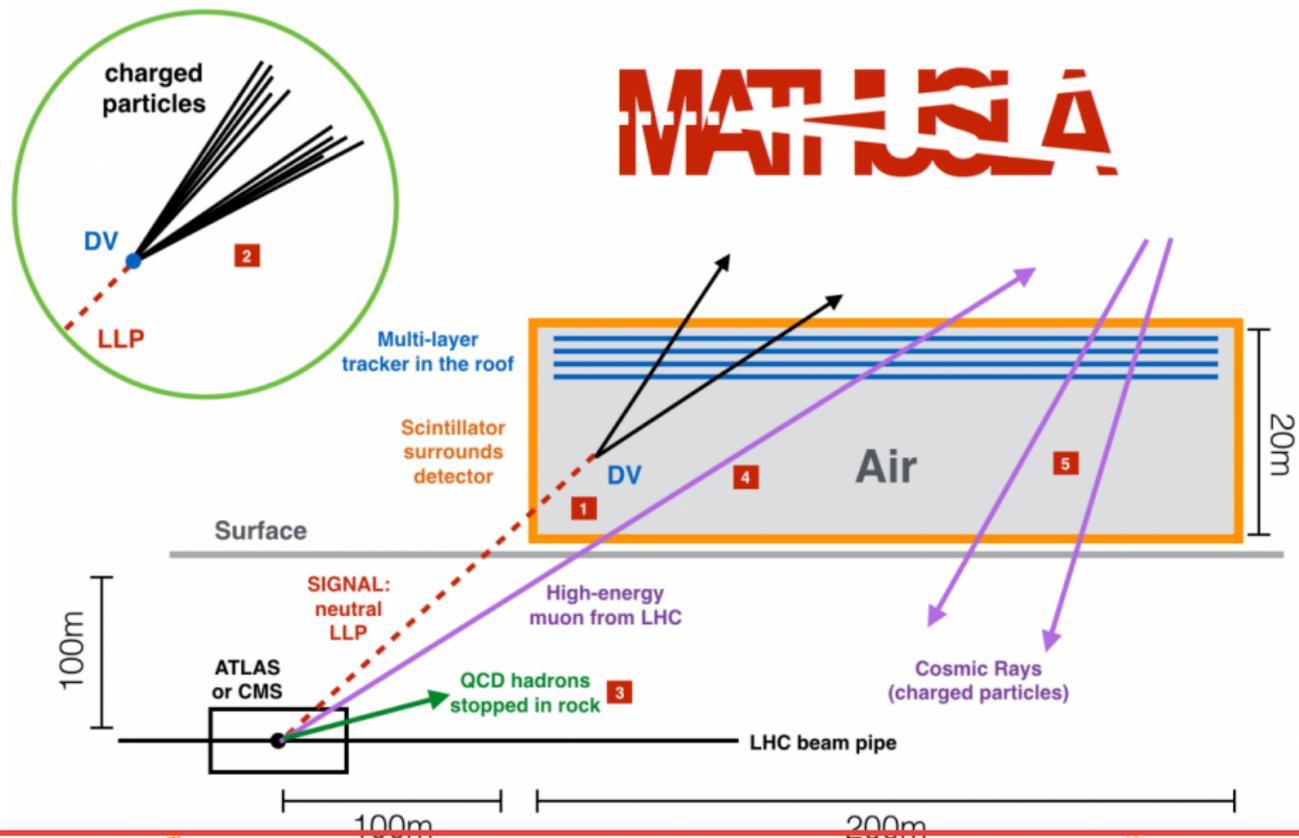
- real-time calibration and full event reconstruction in Run 2
- inclusive dimuon from threshold and jet triggers in Run 2
- full detector readout in Run 3

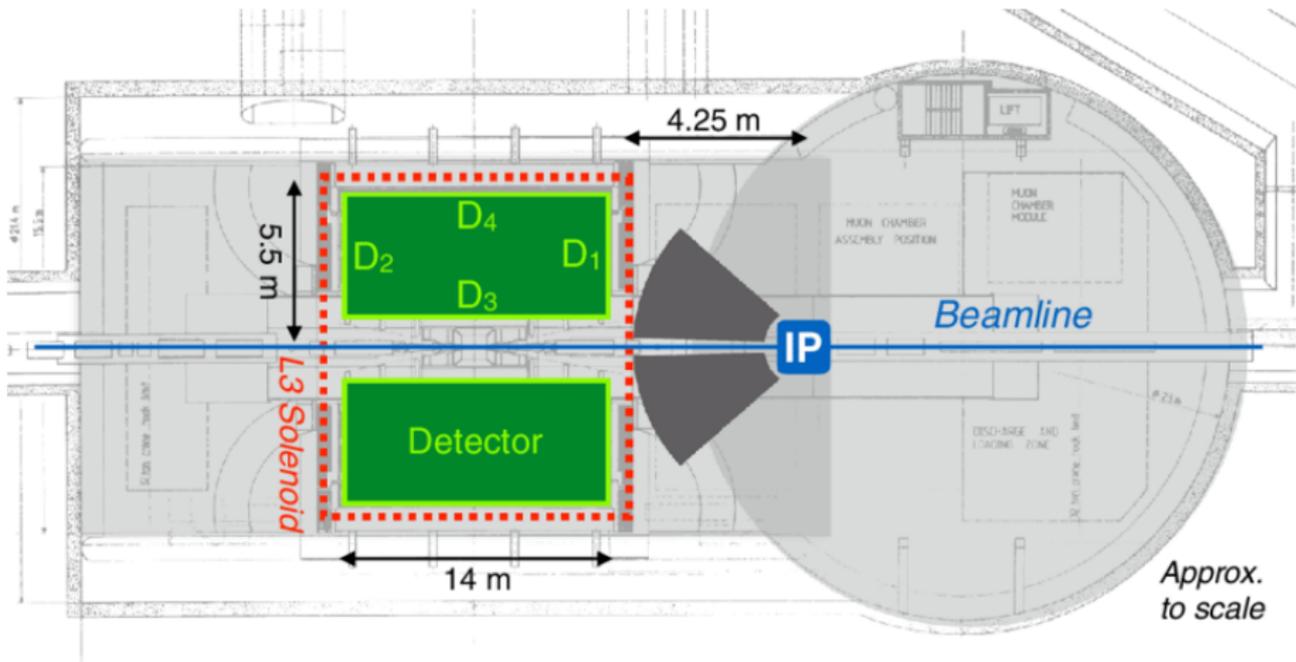












CODEX-b



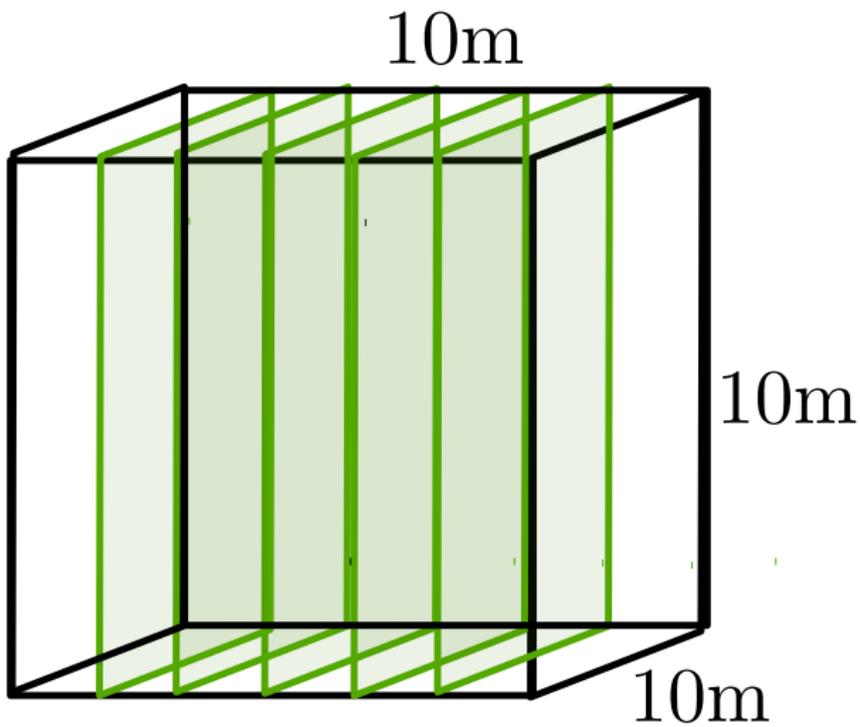
Expression of Interest for the CODEX-b Detector

Giulio Aielli,¹ Roberto Cardarelli,² Matthew John Charles,³ Xabier Cid Vidal,⁴ Victor Coco,⁵ Biplab Dey,⁶ Raphael Dumps,⁵ Jared A. Evans,⁷ George Gibbons,⁸ Olivier Le Dortz,³ Vladimir V. Gligorov,³ Eli Ben Haim,³ Philip Ilten,⁸ Simon Knapen,⁹ Jongho Lee,^{5,10} Saul López Soliño,⁴ Benjamin Nachman,¹¹ Michele Papucci,^{11,12} Francesco Polci,³ Robin Quessard,¹³ Harikrishnan Ramani,^{11,14} Dean J. Robinson,¹¹ Heinrich Schindler,⁵ Michael D. Sokoloff,⁷ Paul Swallow,⁸ Riccardo Vari,¹⁵ Nigel Watson,⁸ and Mike Williams¹⁶

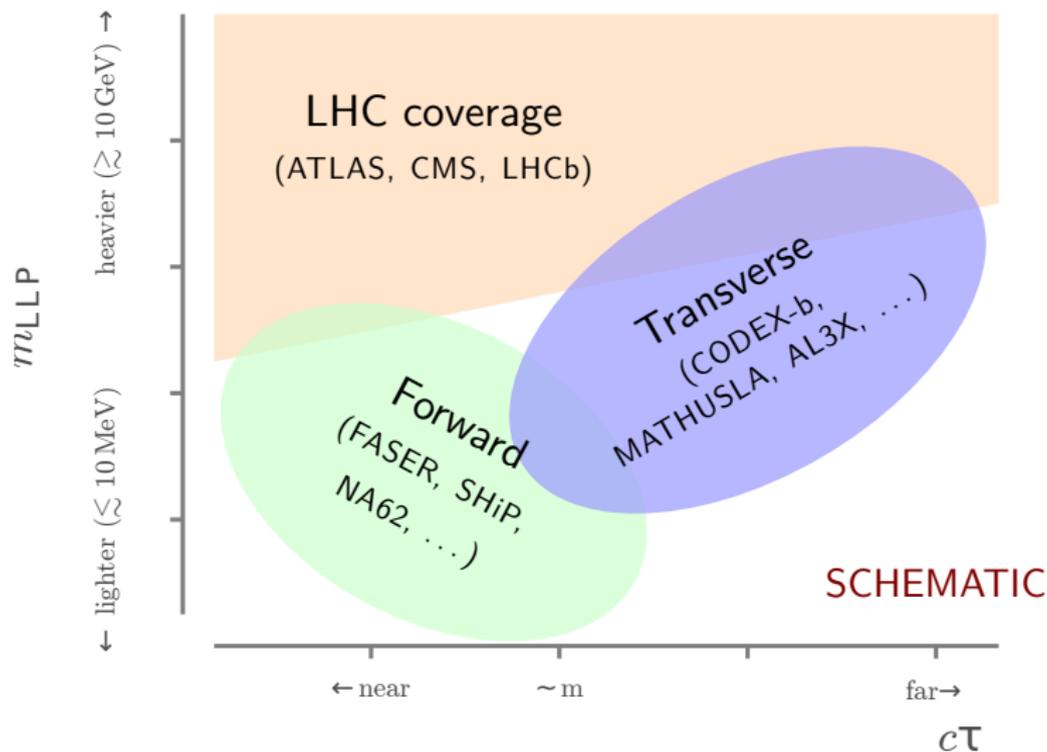
- A **C**ompact **D**etector for **E**xotics at **LHCb**
- letter of interest released last November, [arXiv:1911.00481](https://arxiv.org/abs/1911.00481) [hep-ex]
- letter of intent submitted
- collaboration growing: 28 contributors and 16 institutes



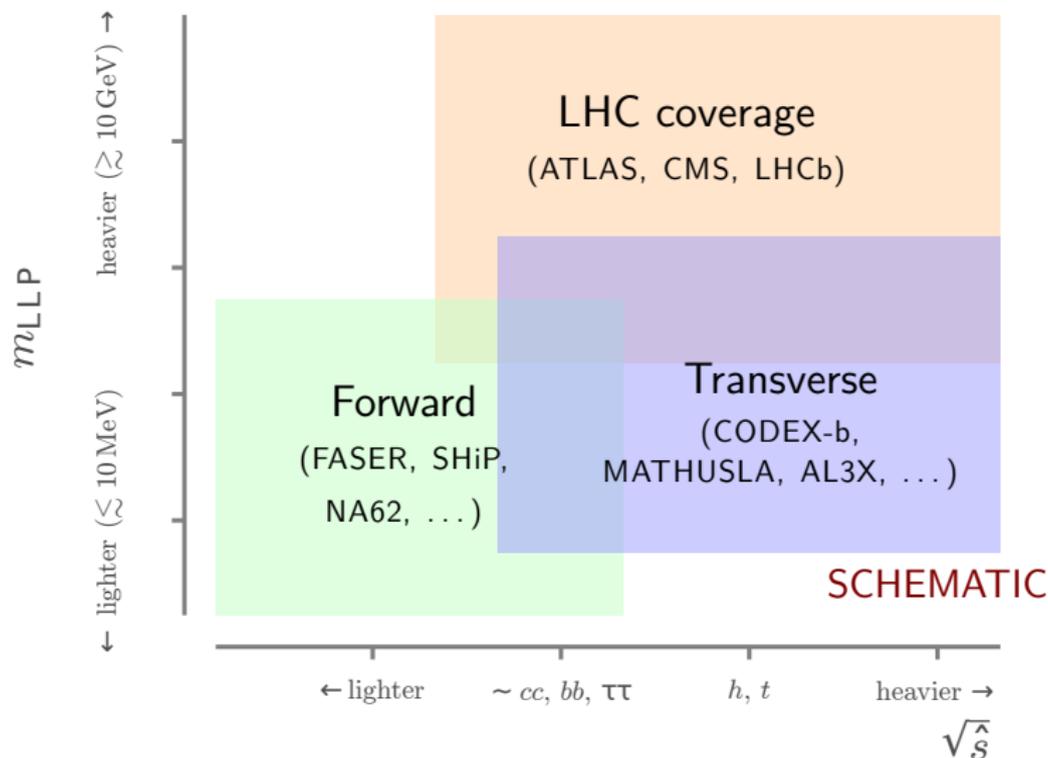
Zooming In



A Picture is Worth ...



A Picture is Worth ...

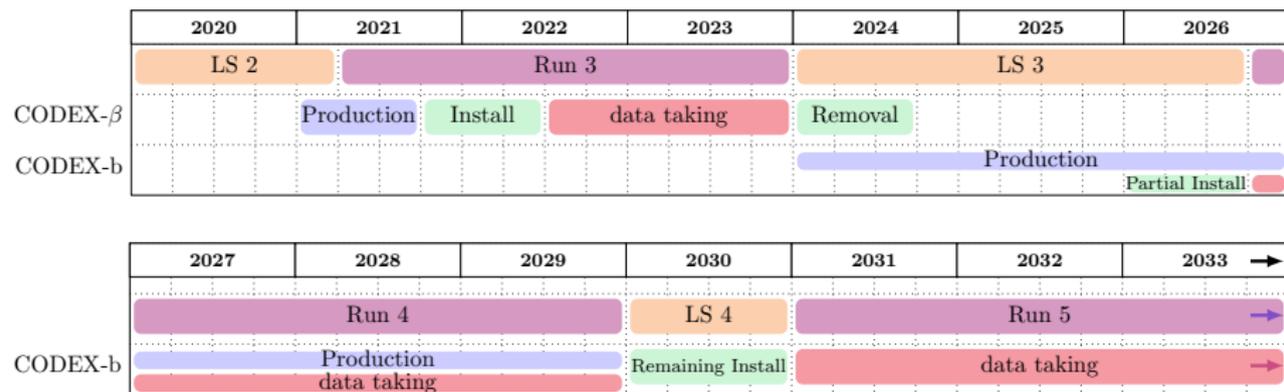


Why CODEX-b?

- ① we need a transverse detector at the LHC
- ② probes a wide range of LLP models; complementary or competitive with existing/proposed detectors
- ③ accessible zero background location with necessary services, DELPHI/UXA cavern
- ④ integration with LHCb trigger-less readout
- ⑤ compact size and modest cost with ability to extend



Timing is Key (pre COVID-19)



- significant progress has been made
- priority is finalising CODEX- β design and plans
- Birmingham working on technical drawings
- more detailed design informed from CODEX- β



Minimal Models



Model Overview

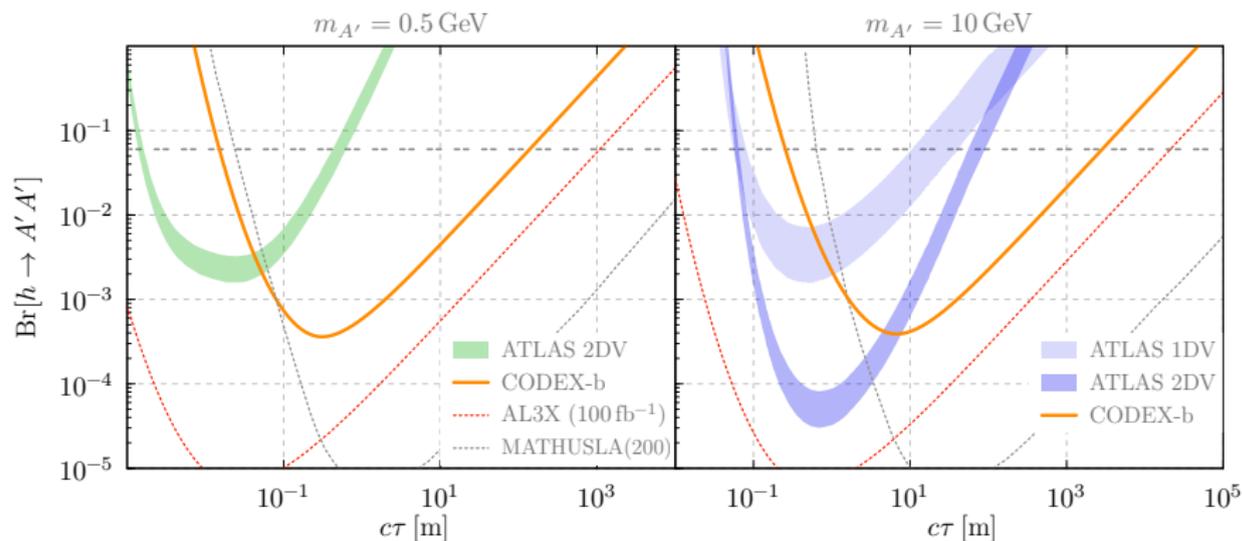
Vector (A')	$hA'A'$	$F'F$						
$F'F$	yes	no reach						
	Scalar (S)	$SH^\dagger H$	$S^2H^\dagger H$					
	$SH^\dagger H$	yes	yes					
		HNL (N)	HLN					
		HLN	yes					
		ALP (a)	$\partial_\mu a \bar{q} \gamma^\mu \gamma^5 q$	$a \tilde{G}G$	$a \tilde{F}F$	$a(W\tilde{W} - B\tilde{B})$		
			yes	yes	pending	pending		

Production portal
 Decay portal
 UV operator

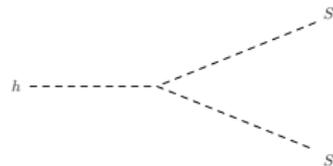
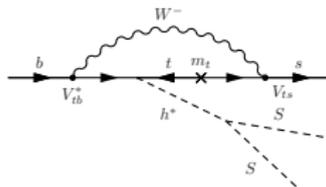
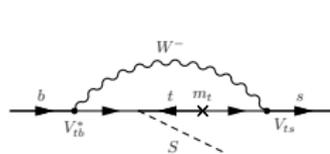
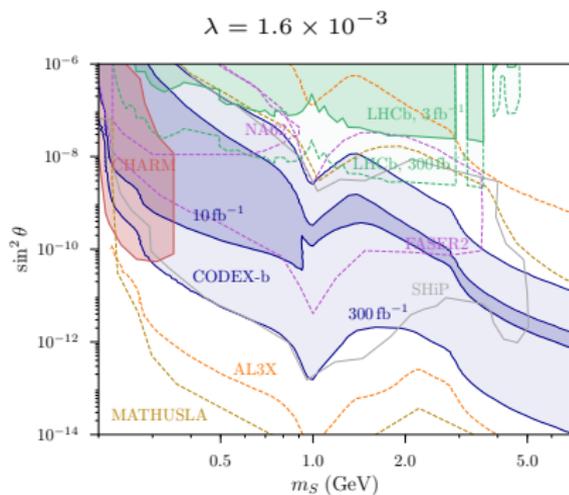
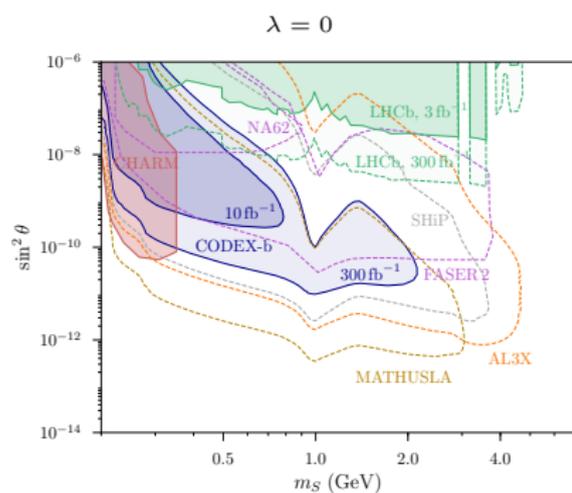


Dark Photon

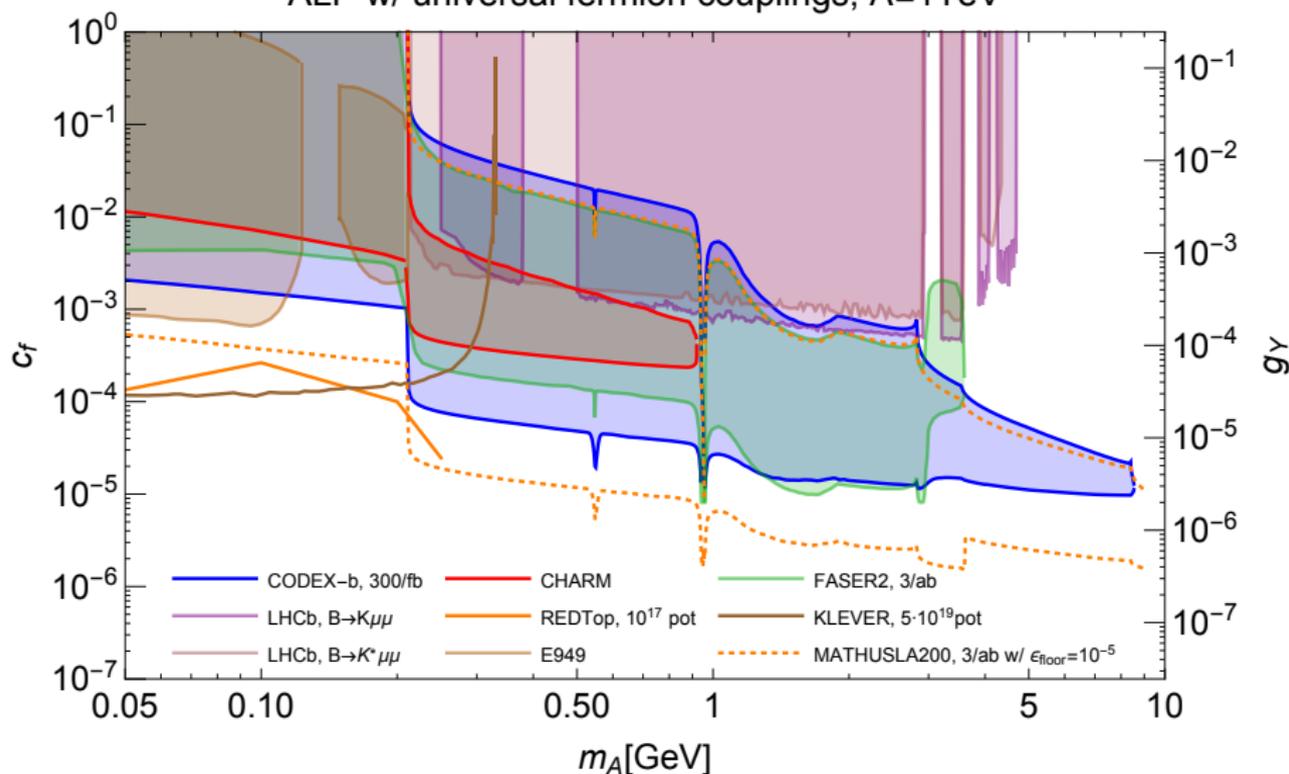
- no sensitivity to inclusive production from EM currents
- sensitive to production from $H \rightarrow A'A'$ decays



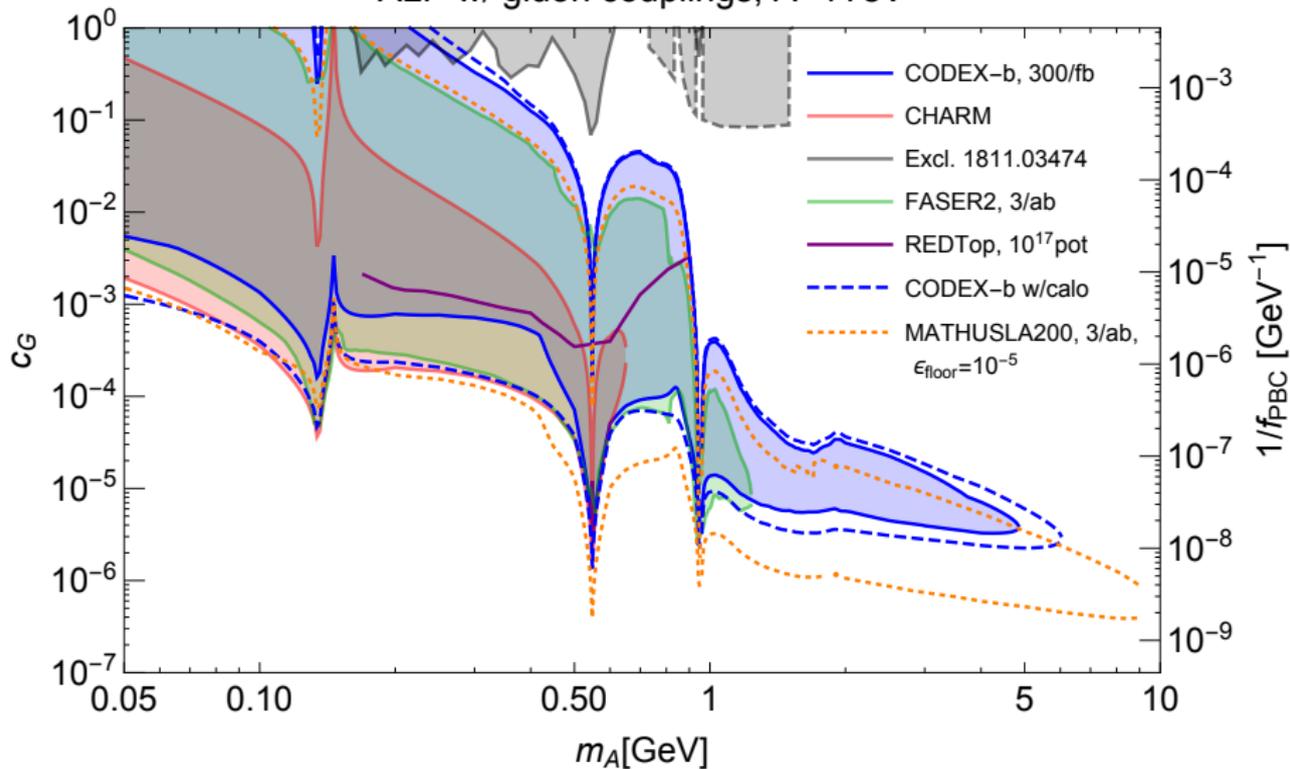
Higgs Portal



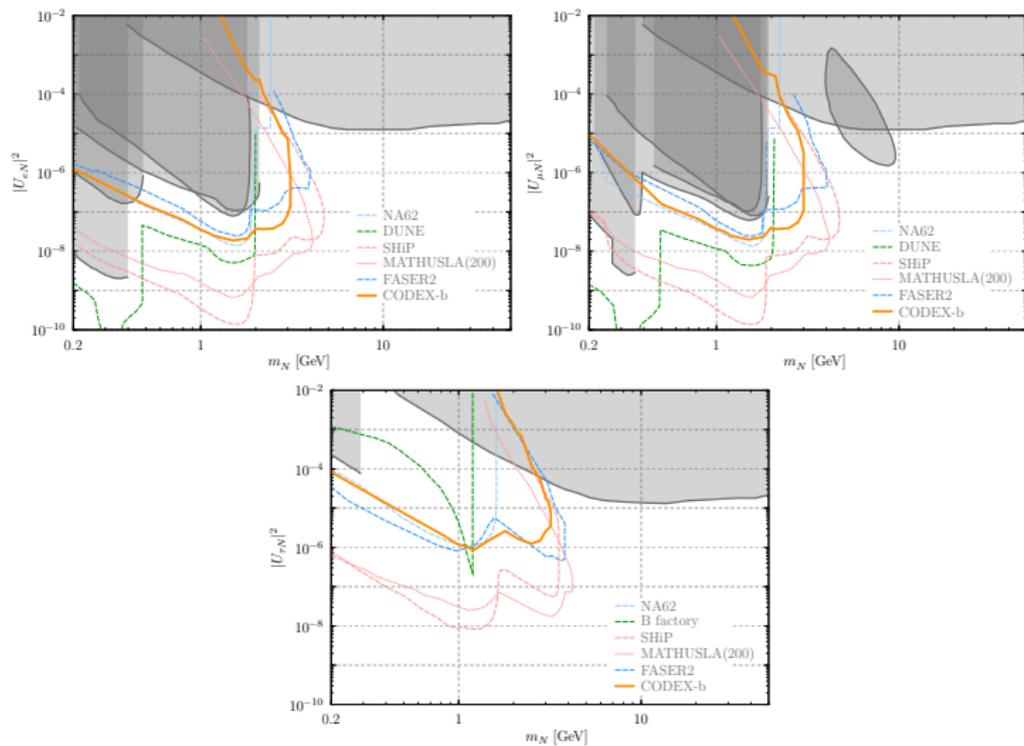
Fermion Coupled ALPs

ALP w/ universal fermion couplings, $\Lambda=1\text{TeV}$ 

Gluon Coupled ALPs

ALP w/ gluon couplings, $\Lambda=1\text{TeV}$ 

Heavy Neutral Leptons



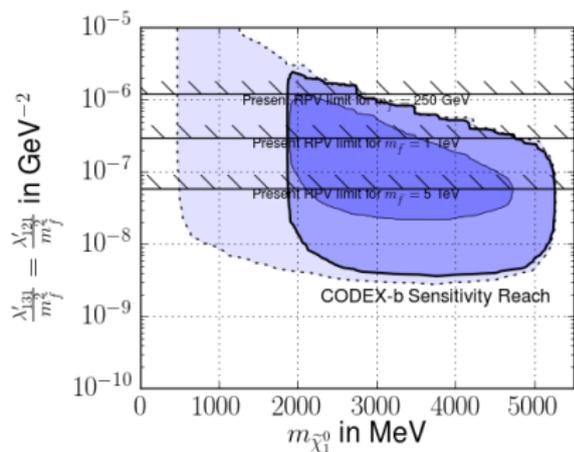
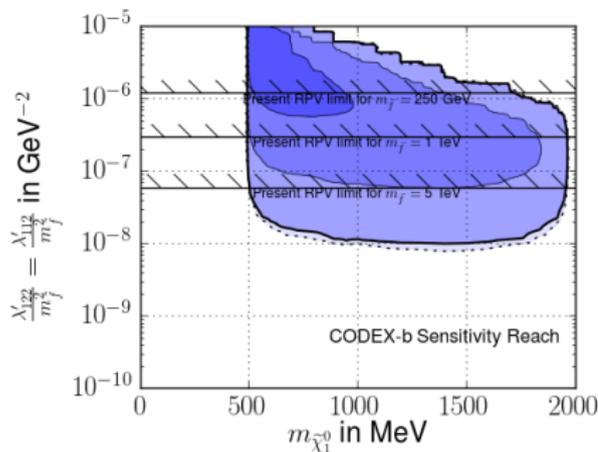
Complete Models



R-parity Violating Supersymmetry

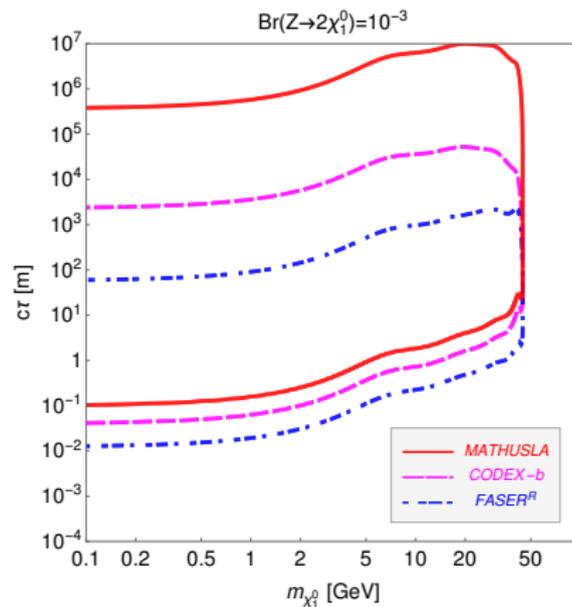
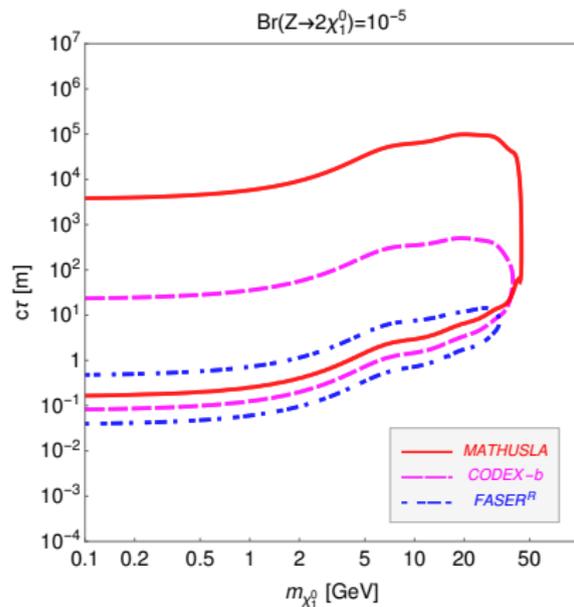
- study from Dercks, Vries, Dreiner, and Wang in [PRD 99 055039 \(2019\)](#)

benchmark	coupling	production	decay products
1	$\lambda'_{122}, \lambda'_{112}$	$D_s^\pm \rightarrow \tilde{\chi}_1^0 + e^\pm$	$\eta, \eta', \phi, K^{0,\pm} + \nu_e, e^\mp$
4	$\lambda'_{131}, \lambda'_{121}$	$B^{0,\pm} \rightarrow \tilde{\chi}_1^0 + X^{0,\pm}$	$D^\pm, D^{*\pm} + e^\mp$



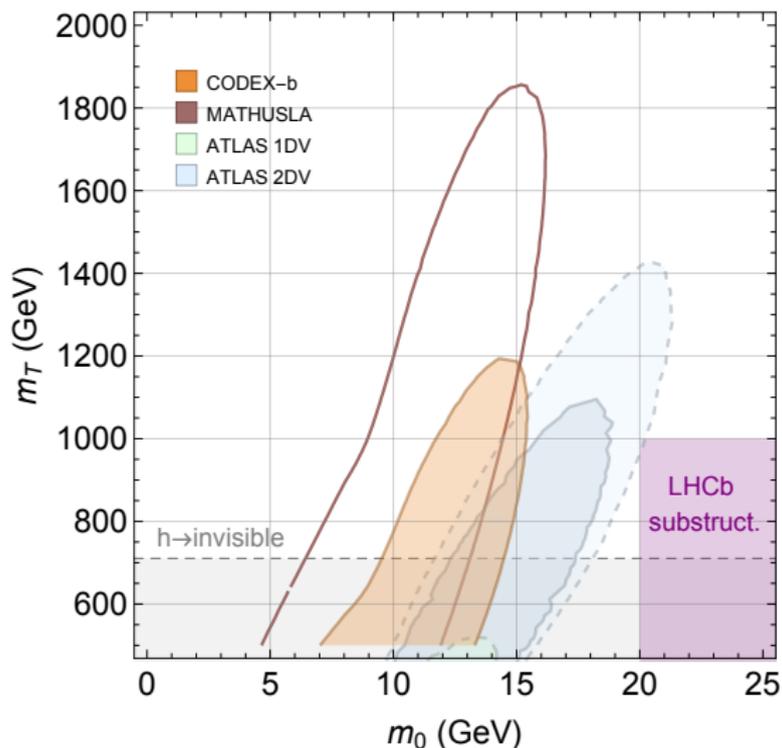
R-parity Violating Supersymmetry

- study from Helo, Hirsch, and Wang in [JHEP 07 056 \(2018\)](#)



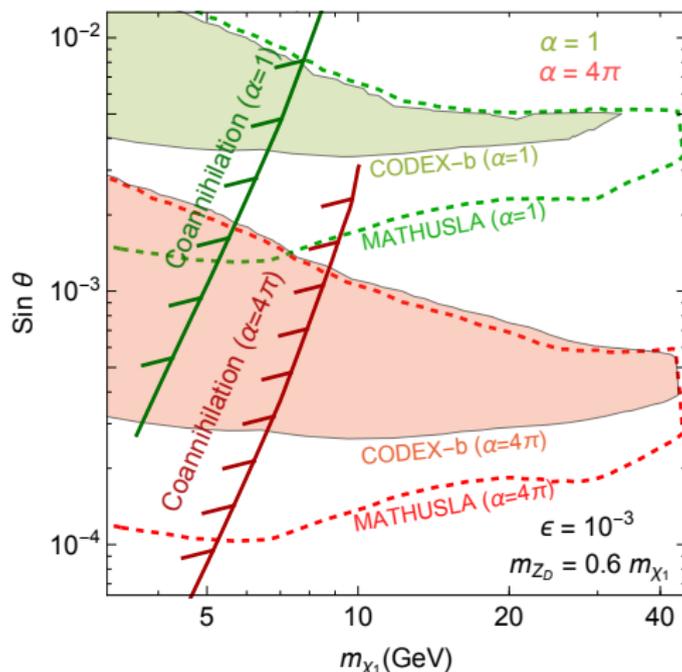
Neutral Naturalness

- consider fraternal twin Higgs model and search for glueball



Dark Matter Models

- a number of models considered including inelastic, co-scattering, co-annihilation, *etc.*



Building CODEX-b

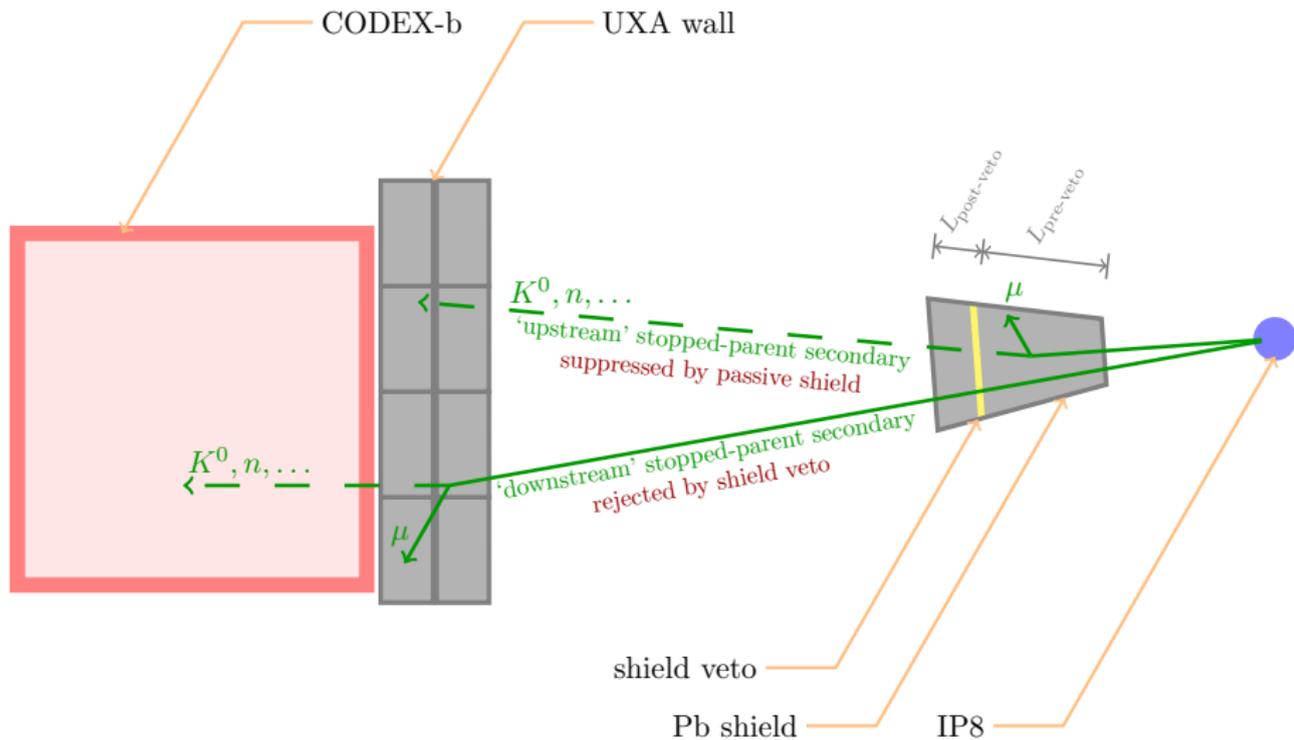


Backgrounds

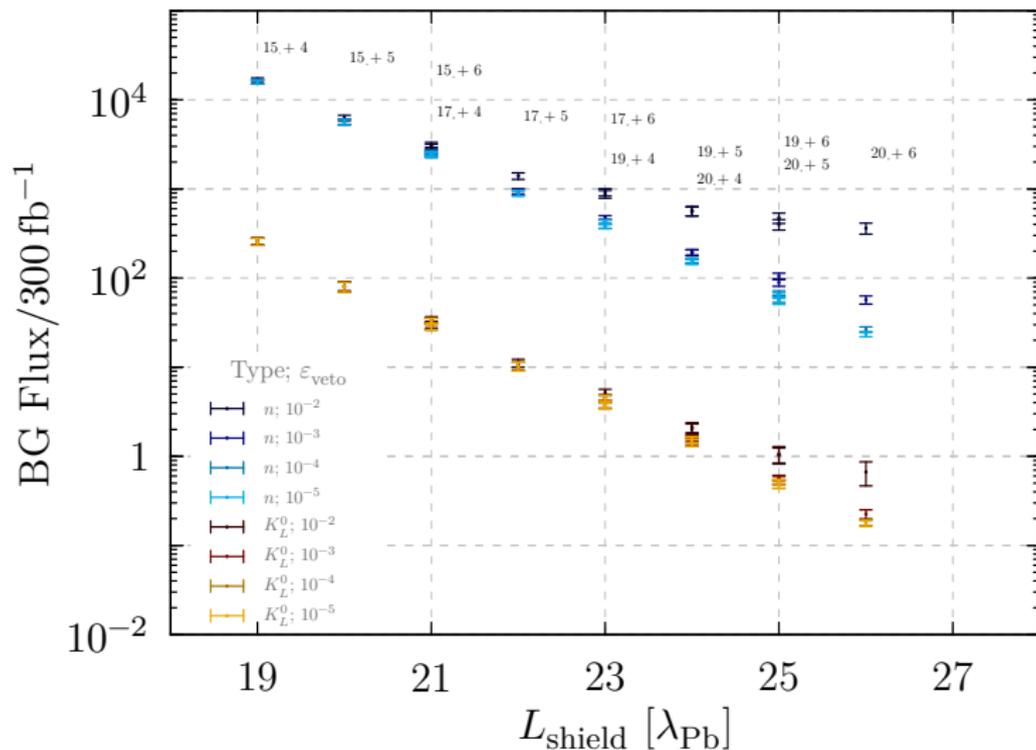
- 10^{14} neutrons and K_L^0 per 300 fb^{-1}
- this requires 32λ of shielding
- 7λ from UXA wall, 25λ from lead shield
- expect $\approx 10^9$ muons per 300 fb^{-1} which can produce secondaries
- $10^3 K_L^0$ per 300 fb^{-1} pass through the shield
- need active layer in shield for vetoing
- update of previous studies with detailed GEANT4 study



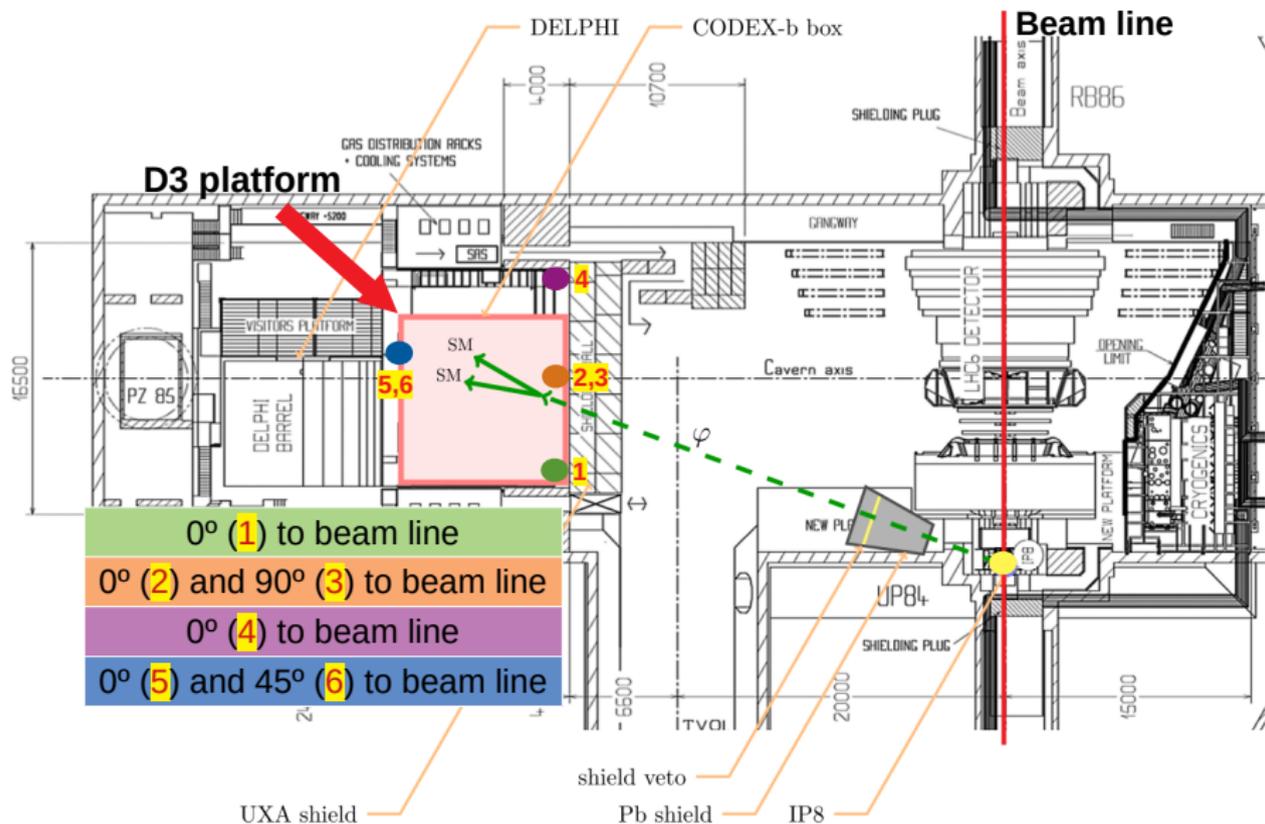
Shielding



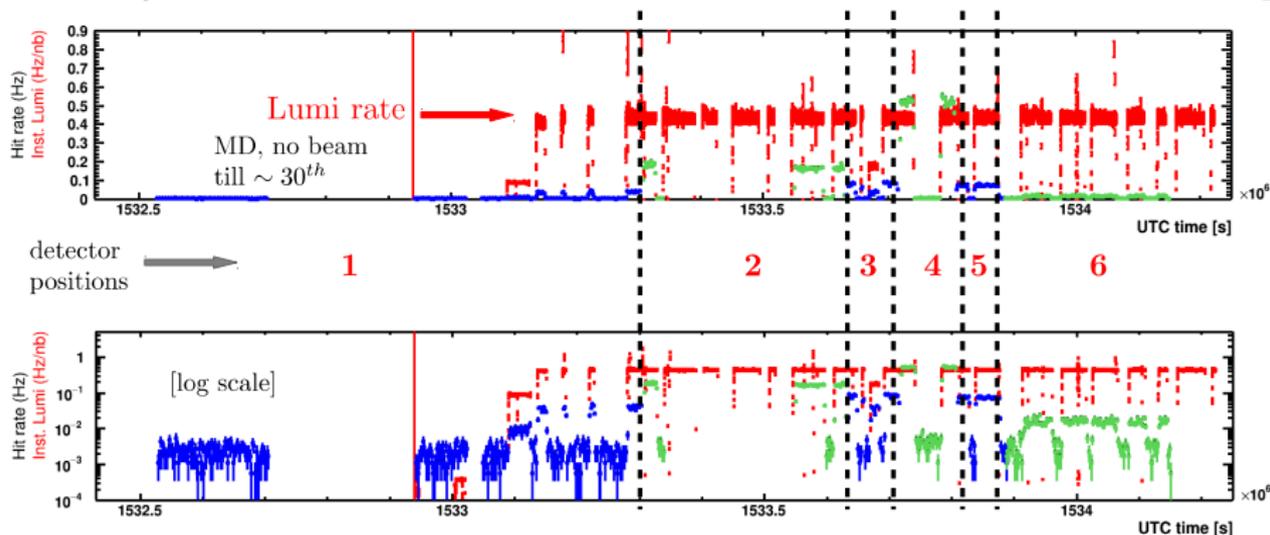
Background Simulation



Background Measurement



Background Measurement

25th July10th Aug

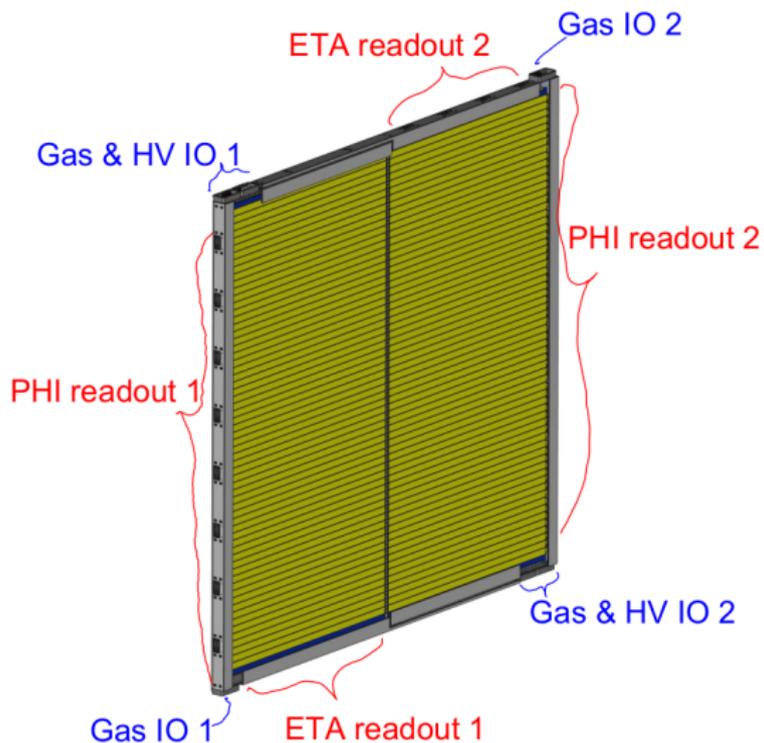
- 0.2 Hz hit rate at point 2 indicates GEANT4 prediction of 10 Hz is conservative

CODEX- β

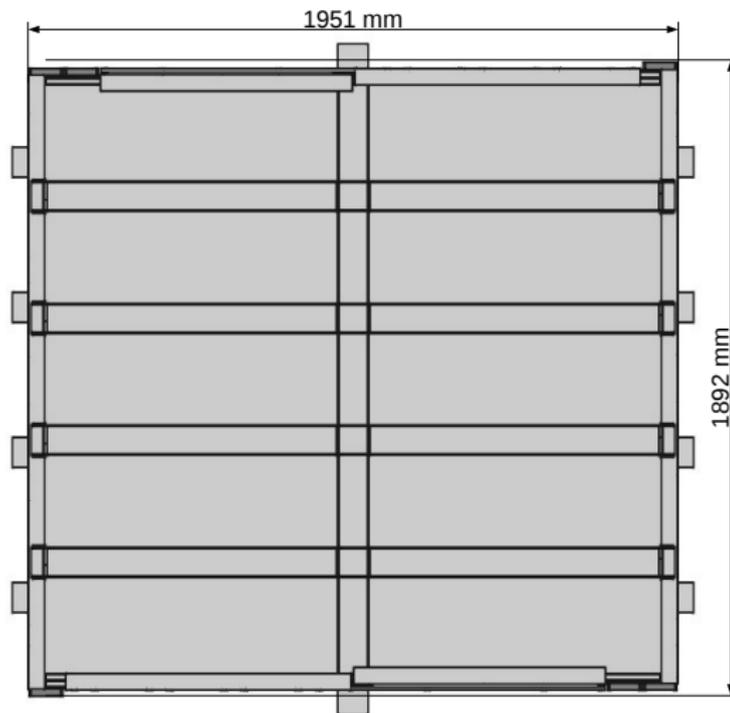
- $2 \times 2 \times 2 \text{ m}^3$ with central layer, each layer with triplet of RPCs
 - each layer made of $2 \times 1 \text{ m}^2$ RPC block, 42 such layers
 - expected hardware cost of 150k EUR
-
- ① *Demonstrate the ability to detect and reconstruct charged particles which penetrate into the DELPHI cavern as well as the decay products of neutral particles decaying within the DELPHI cavern.*
 - ② *Detect and reconstruct a reasonable rate of neutral particles decaying inside the hermetic detector volume.*
 - ③ *Show that CODEX-b can be integrated into the LHCb DAQ and demonstrate an ability to give a trigger to LHCb to retain an event that looks interesting in CODEX-b.*



Triplet Support



Outside Support



Outlook



Some Thoughts

- forward/beam-dump experiments give us light LLPs with medium/long lifetimes and low $\sqrt{\hat{s}}$
- LHC detectors give us heavy LLPs with long lifetimes
- transverse detectors give us light LLPs with long lifetimes and high
- *we need a transverse detector at LHC*

- CODEX-b covers does not have world-leading reach ...
- covers significant portions of parameter space
- low cost in comparison to other proposals

- clear plan forward for building CODEX-b
- first steps taken, CODEX- β plans underway

Looking for new collaborators!

