COmpact Detector for EXotics at LHCb: CODEX-b

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On behalf of the CODEX-b collaboration

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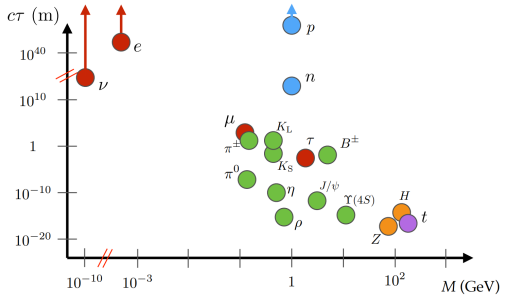
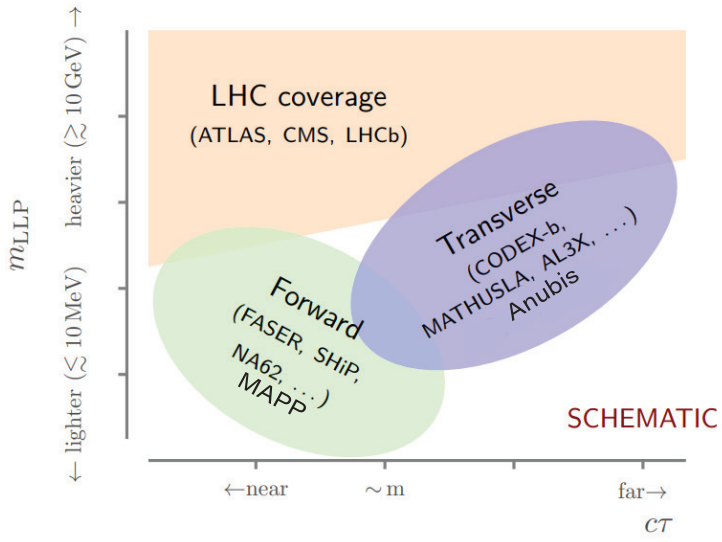
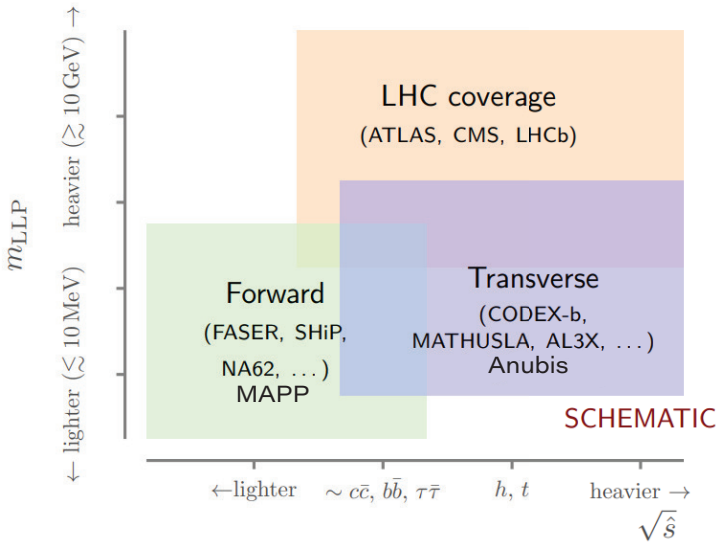
Long-Lived Particles

- Conventional LHC searches focus on a small range of $c\tau$
- SM backgrounds make LLP searches at current LHC detectors very difficult
- A transverse detector would have access to higher $c\tau$ and higher $\sqrt{s}$ than forward detectors



arXiv:1903.04497

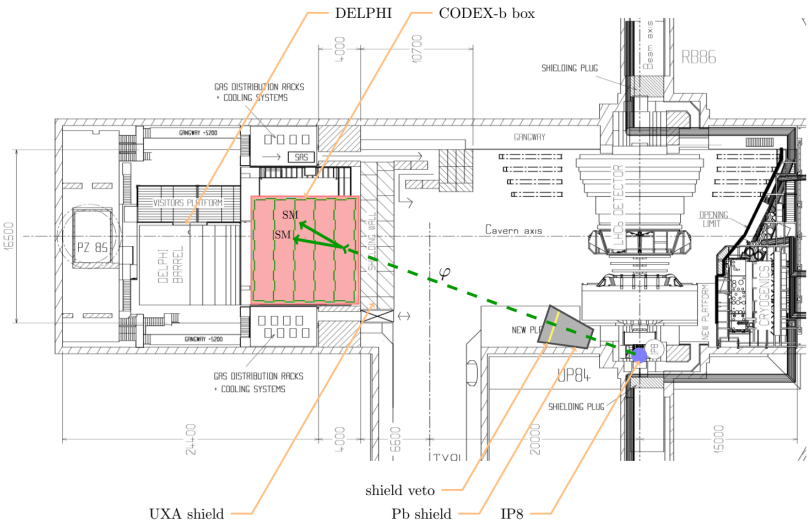




arXiv:1911.00481

CODEX-b: COmpact Detector for EXotics at LHCb

- Transverse long-lived particle detector.
- Located at LHC interaction point 8, next to the LHCb detector.
- 10m cube of resistive plate chambers (RPCs).
- Near zero-background experiment, achievable with a combination of active and passive shielding.



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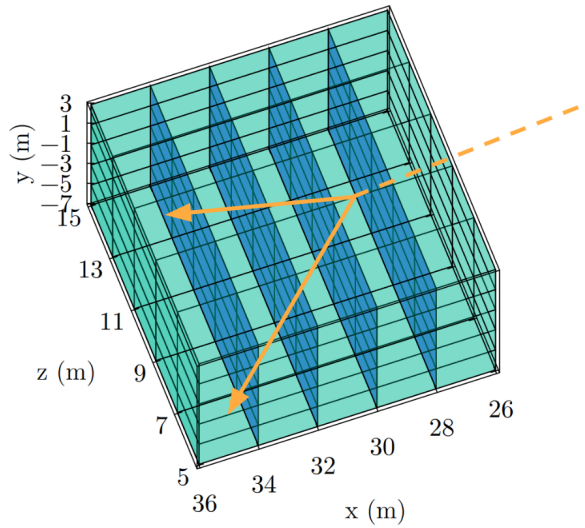
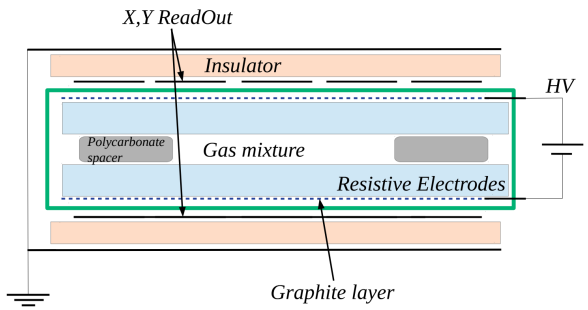
Detector Design

- Composed of 500 RPC triplet modules
- Arranged into a 10 meter cube with 4 internal faces
- Potential BSM particle would pass through the shielding unimpeded
- Would decay into charged SM tracks
- Vertex would be reconstructed within the detector volume

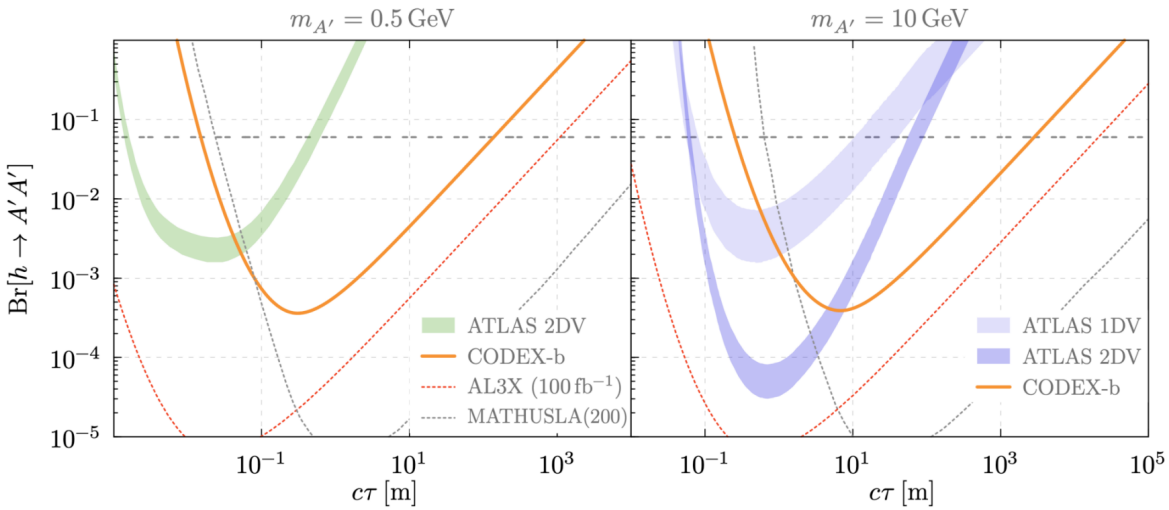




Sensitivity

CODEX-b offers a competitive sensitivity to a number of BSM models at a relatively low cost $\mathcal{O}(\$10\,\mathrm{M})$:

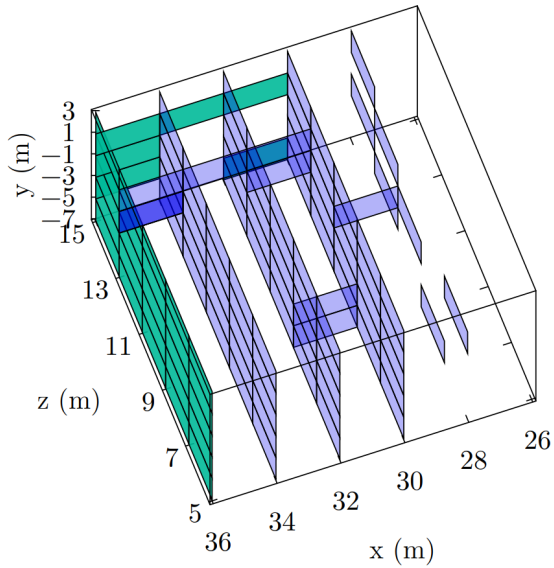
- Abelian hidden sector
- Dark Higgs
- Axion-like particles
- Heavy neutral leptons
- R-parity violating supersymmetry
- Relaxation models
- Neutral naturalness
- Inelastic dark matter
- Dark matter coscattering
- Dark matter from sterile coannihilation
- Asymmetric dark matter
- Baryogenesis
- Hidden valleys
- And many more!



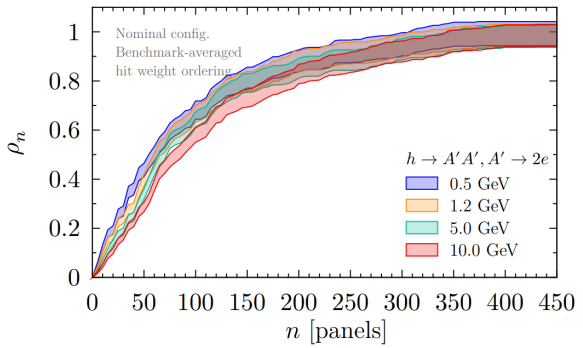
Lower limit on the branching ratio of Higgs decay to two dark photons, where the dark photons decay to leptons.

Alternative Designs

- LHCb to start using underground servers for run 4
- Original detector design can't fully be used
- Simulations show partial installations still yield similar reconstruction efficiencies
- Details on new design still need to be ironed out



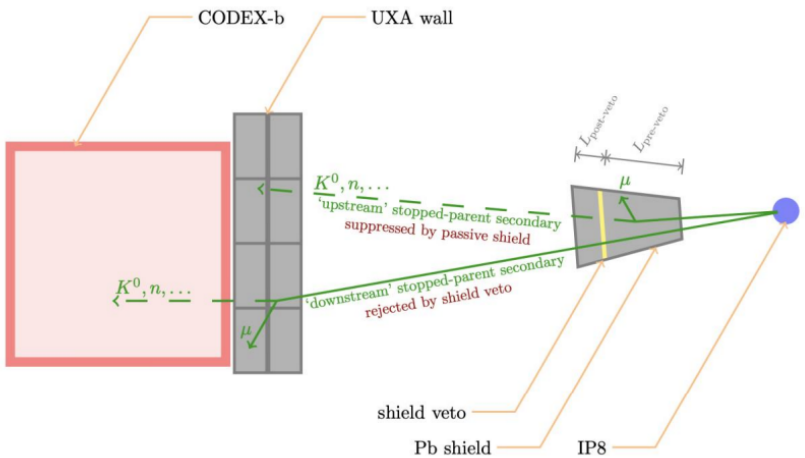
arXiv:2203.07316



arXiv:2203.07316

Backgrounds

- LLP signal should be a displaced vertex
- Neutrons and K_L^0 produced at the interaction point can mimic the signal
- Secondary interactions in the shielding layers can produce neutrons and K_s^0, mimicking signal
- Active veto embedded in the shield to remove most primary-produced backgrounds
- CODEX-β demonstrator to validate background estimates



Backgrounds

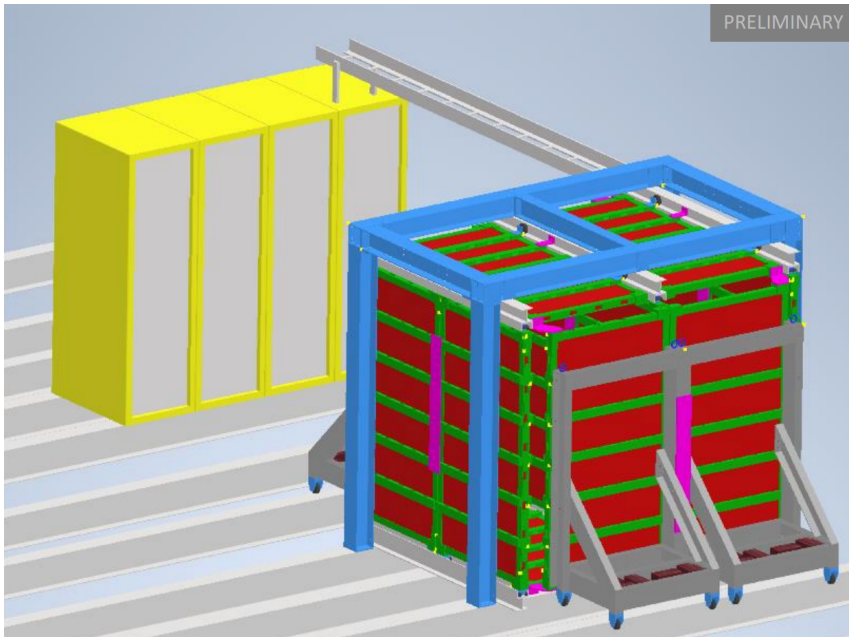
BG species	Particle yields			Net yield
	Net ($E_{\text{kin}}^{\text{neutral}} > 0.4\,\text{GeV}$)	Shield veto rejection (total)	Shield veto rejection ($\pm/0$ correlation)	
γ	0.54 ± 0.12	$(8.06 \pm 0.60) \times 10^4$	$(2.62 \pm 1.03) \times 10^3$	–
n	58.10 ± 4.63	$(4.59 \pm 0.15) \times 10^5$	$(3.44 \pm 0.51) \times 10^4$	–
n ($> 0.8\,\text{GeV}$)	2.78 ± 0.25	$(1.03 \pm 0.06) \times 10^5$	$(7.45 \pm 1.92) \times 10^3$	$\lesssim 1$
$\bar{n}$ (no cut)	$(3.24 \pm 0.72) \times 10^{-3}$	34.40 ± 25.80	$(7.12 \pm 2.19) \times 10^{-2}$	$\ll 1$
K_L^0	0.49 ± 0.05	$(1.94 \pm 0.74) \times 10^3$	54.40 ± 19.20	$\lesssim 0.1$
K_S^0	$(6.33 \pm 1.39) \times 10^{-3}$	93.90 ± 45.80	0.74 ± 0.19	$\ll 1$
$\nu + \bar{\nu}$	$(5.69 \pm 0.00) \times 10^{13}$	$(7.35 \pm 0.12) \times 10^6$	$(7.31 \pm 0.11) \times 10^6$	–
$p^{\pm}$	$(2.07 \pm 0.26) \times 10^2$	$(9.24 \pm 0.36) \times 10^5$	$(9.24 \pm 0.36) \times 10^5$	–
$e^{\pm}$	$(4.53 \pm 0.02) \times 10^3$	$(4.38 \pm 0.02) \times 10^7$	$(4.38 \pm 0.02) \times 10^7$	–
π^+	34.70 ± 2.27	$(2.96 \pm 0.20) \times 10^5$	$(2.96 \pm 0.20) \times 10^5$	–
π^-	31.40 ± 2.12	$(2.68 \pm 0.19) \times 10^5$	$(2.68 \pm 0.19) \times 10^5$	–
K^+	0.83 ± 0.30	$(3.08 \pm 1.24) \times 10^3$	$(3.08 \pm 1.24) \times 10^3$	–
K^-	0.23 ± 0.12	$(1.12 \pm 0.63) \times 10^3$	$(1.12 \pm 0.63) \times 10^3$	–
μ^+	$(1.04 \pm 0.00) \times 10^6$	$(1.04 \pm 0.00) \times 10^{10}$	$(1.04 \pm 0.00) \times 10^{10}$	–
μ^-	$(8.07 \pm 0.01) \times 10^5$	$(8.07 \pm 0.01) \times 10^9$	$(8.07 \pm 0.01) \times 10^9$	–

arXiv:1911.00481

Background simulation done using Pythia + Geant4 for $(20 + 5)\lambda$ shielding, active veto after $20\,\lambda$ shield. $\mathcal{L} = 300\,\text{fb}^{-1}$.

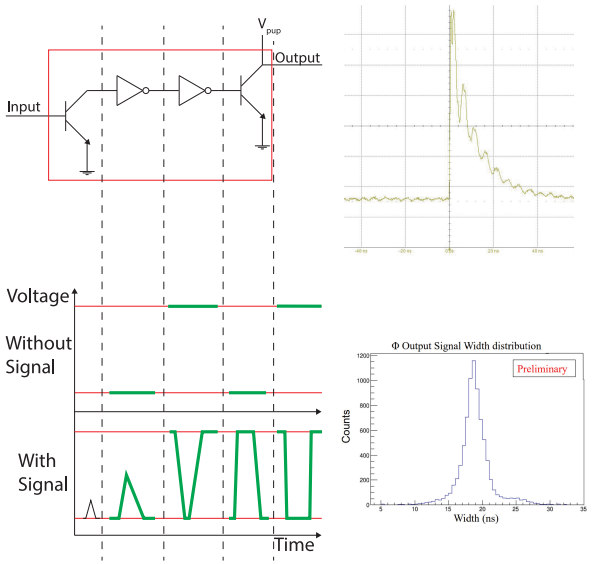
Time-limited LHCb R&D project (approved!), with opportunity for non-LHCb members to collaborate.

- Scaled-down version of CODEX-b
- 2 meter cube, 14 RPC triplet modules
- Goals include:
  - Validate background estimates
  - Integrate with LHCb DAQ
  - Test the suitability of RPCs
  - Validate the mechanical support structure of the modules and detector

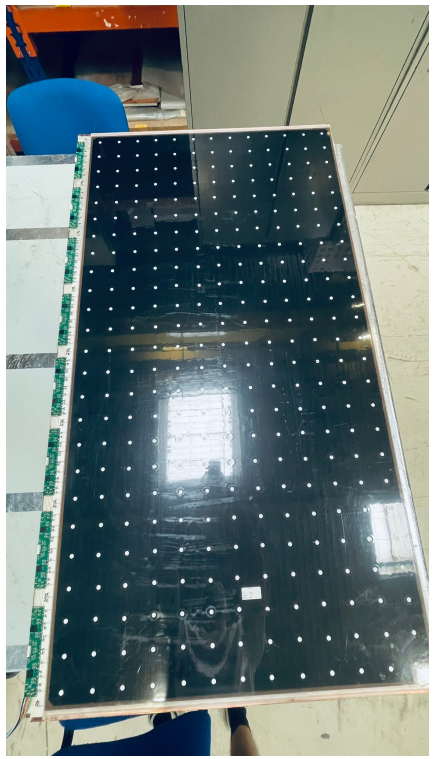


Resistive Plate Chambers

- BIS7 model for the HL-LHC upgrade of the ATLAS muon spectrometer
- 1mm gas gap
- Electronics include a custom SiGe discriminator, sensitive to signals $\mathcal{O}(\text{fC})$
- Timing resolution $\mathcal{O}(100\,\text{ps})$
- Spacial resolution $\mathcal{O}(1\,\text{mm})$

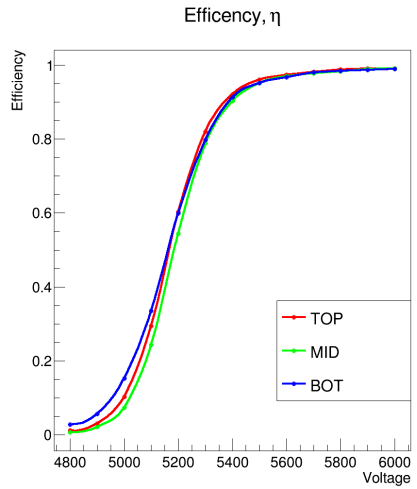


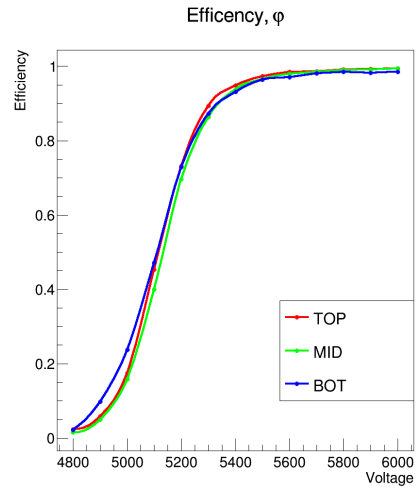
arXiv:1806.04113

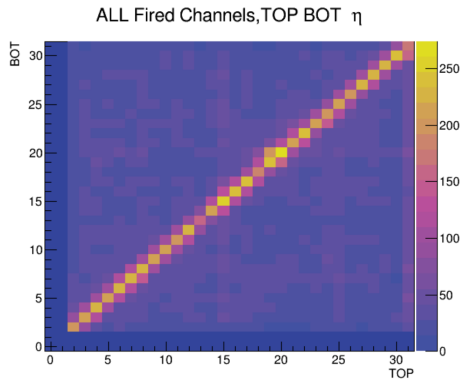


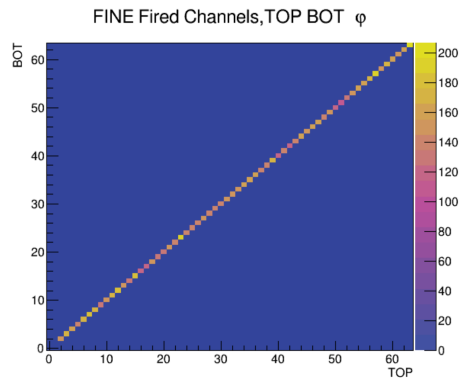
Commissioning

- Initial commissioning tests done with cosmic muons
- No need for commissioning in a high-radiation environment
- Test for:
  - Noise rates
  - False triggers
  - False muons
  - Hit correlations
  - Efficiency





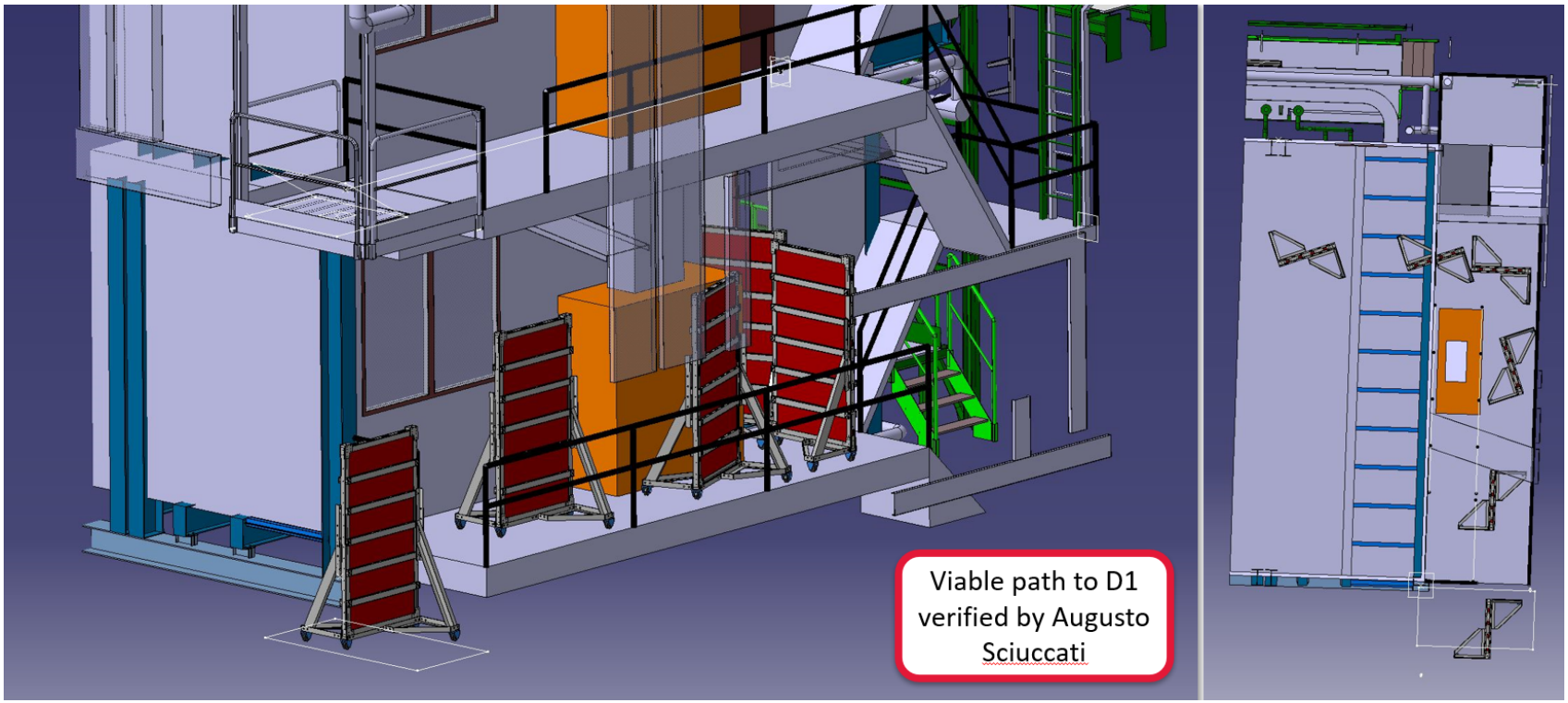




Mechanics

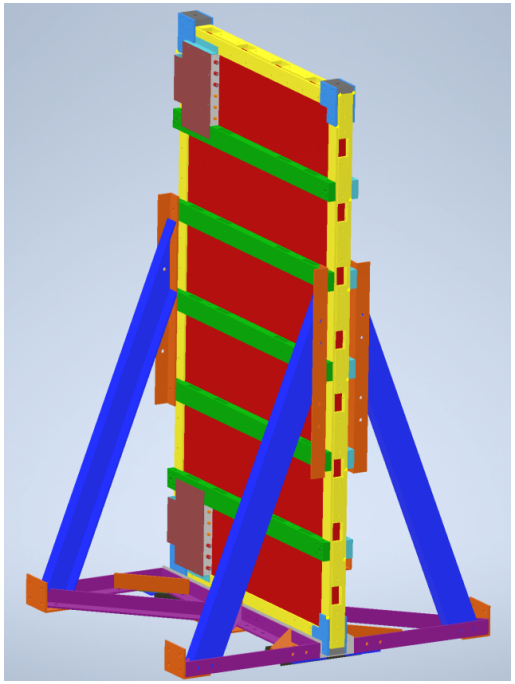
- Module frame and detector superstructure machined at the University of Cincinnati (US), shipped to CERN
- Frame is based on the BIS7 frame design, modified for our structural and rigidity needs
- Uses aluminum shims and skins to provide uniform pressure across the surface of the RPCs
- Interior components position the RPCs within the frame
- 3 frames currrently at CERN, remaining frames being produced

Installation



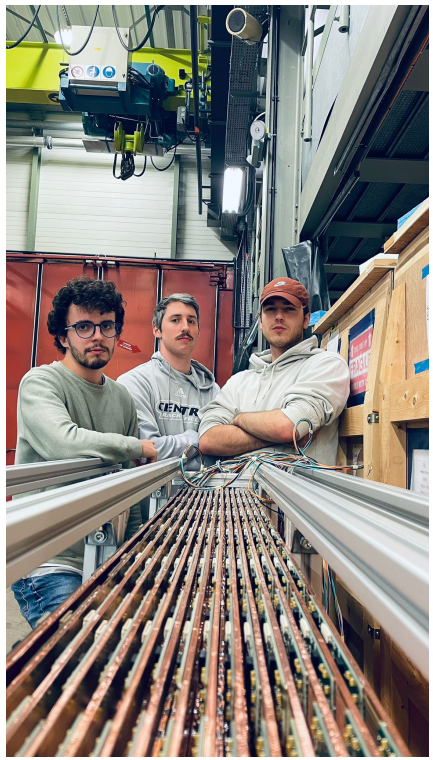
Installation

- Modules can be brought underground via personnel elevator
- Rather tricky path to get from the elevator to the server room
- Specialized cart has been designed to transport our modules
- Partial installation targeted for October technical stop
- Full installation to take place in the coming YETS (December 2024 - March 2025)
- Data will be taken for the remainder of run 3

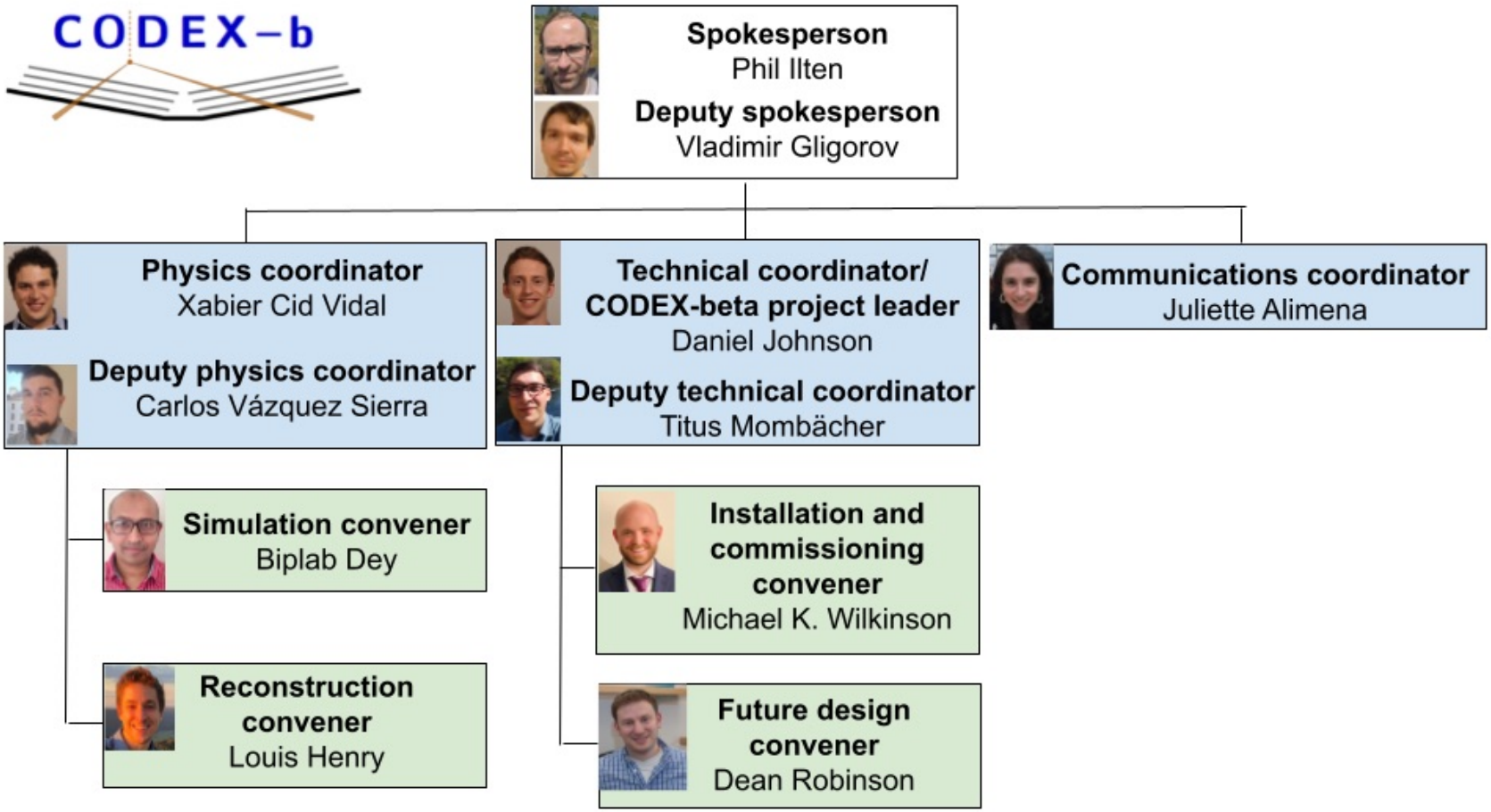


Summary

- LHC needs a zero-background transverse LLP detector
- CODEX-b offers a competetive sensitivity to a number of minimal models at a relatively low cost
- Relative easy of construction and installation compared to other proposed LLP detectors
- CODEX-β is the demonstrator detector for run 3
- Will validate background estimates and integration with LHCb
- Construction is full-steam ahead!



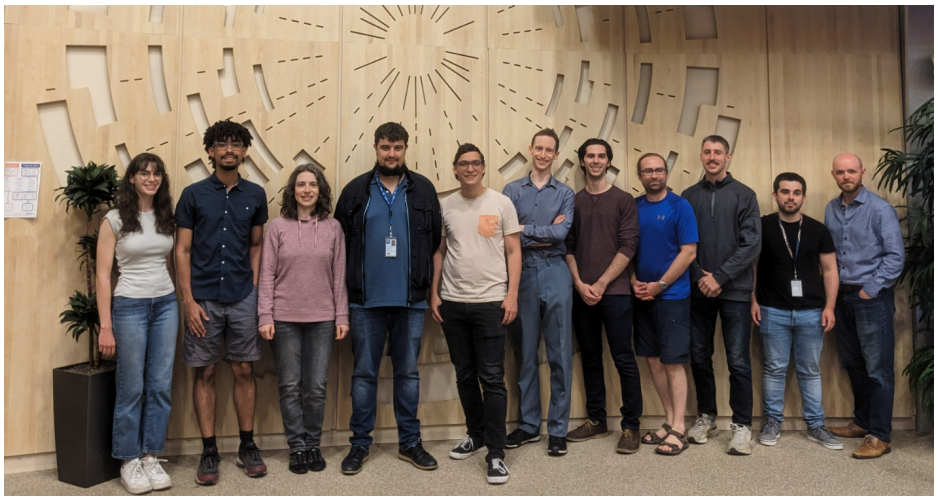
Collaboration



Technical Design Report recently uploaded to the arXiv:2406.12880, submitted to JINST. Constitution and physics paper coming soon!

Paid Advertisement

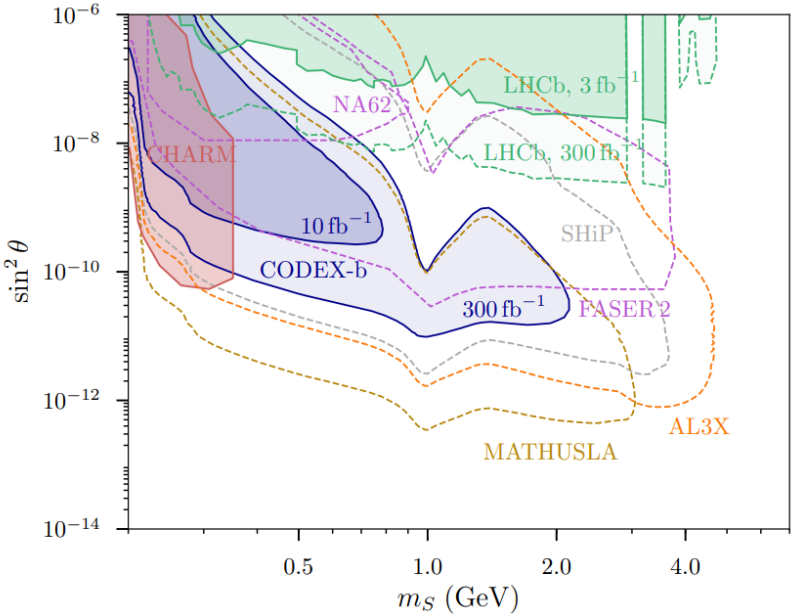
We are welcoming new collaborators, come join us!



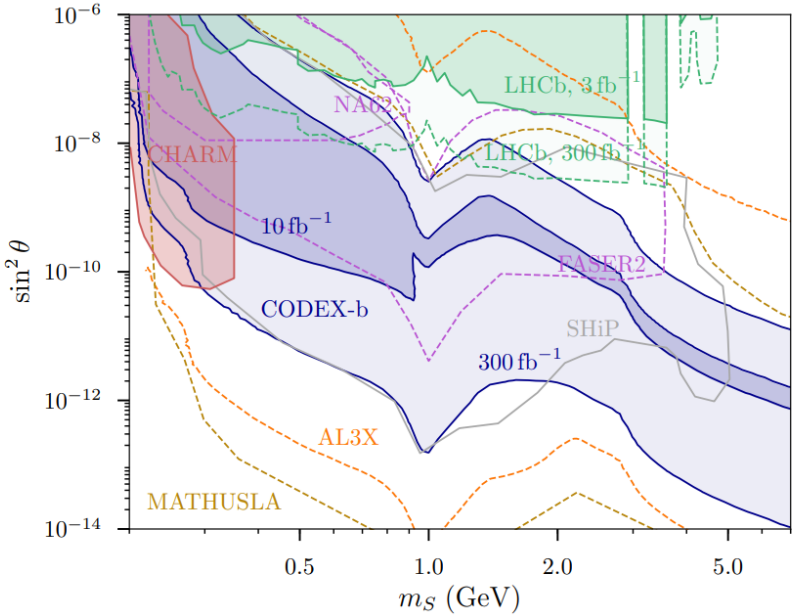
Thank you!

Backup

Decay of $b \to sS$ via penguin diagram. Mixes with SM Higgs as $sin^2\theta$.

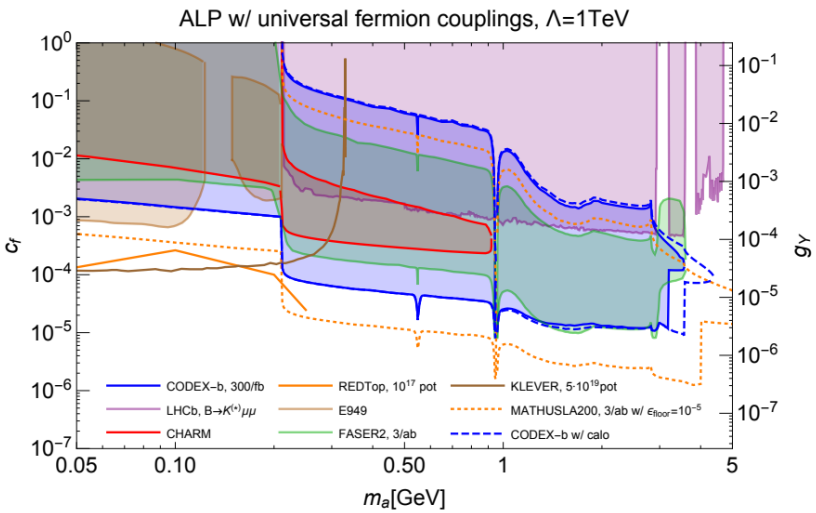


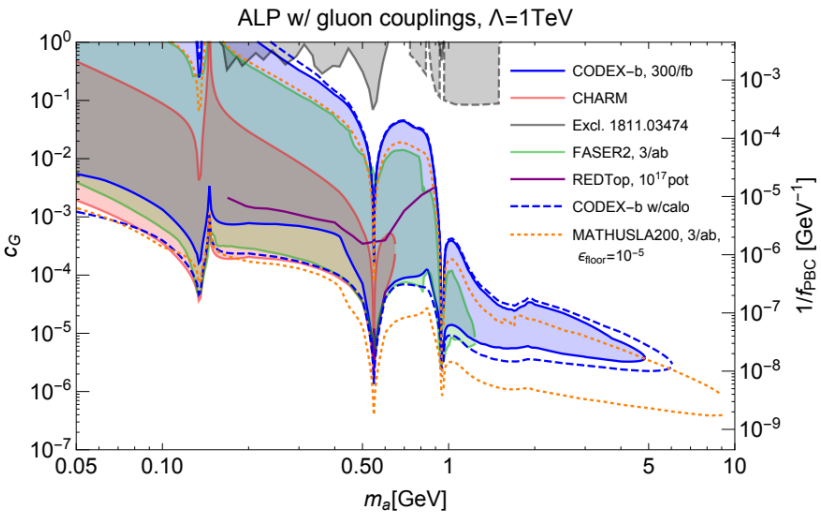
(a) $\lambda = 0$



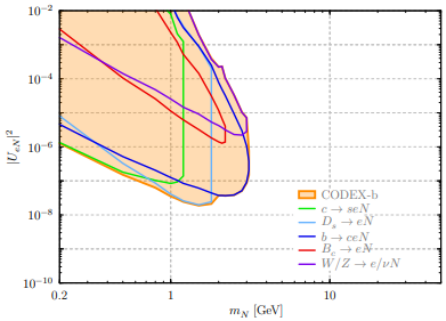
(b) $\lambda = 1.6 \times 10^{-3}$

Axion-like Particles

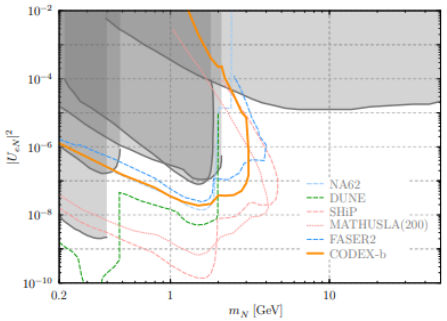




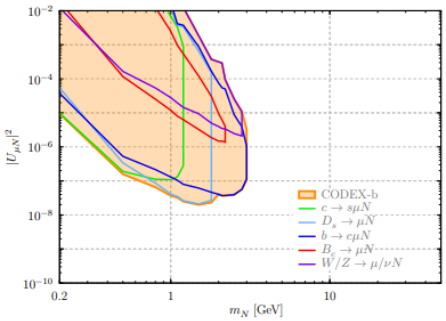
Heavy Neutral Leptons



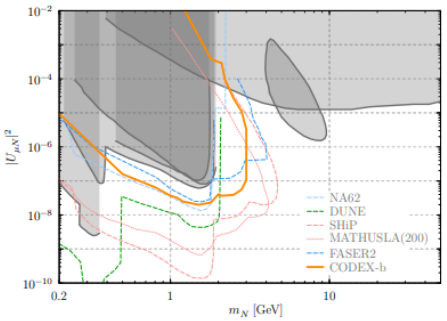
(a) $U_{eN} \gg U_{\mu N}, U_{\tau N}$ (Channels)



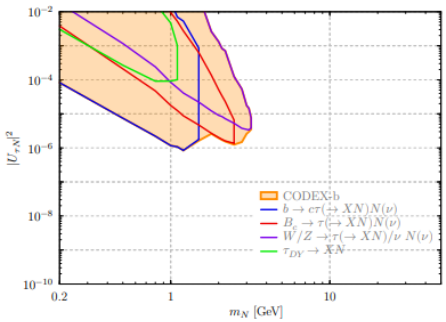
(b) $U_{eN} \gg U_{\mu N}, U_{\tau N}$ (Combined)



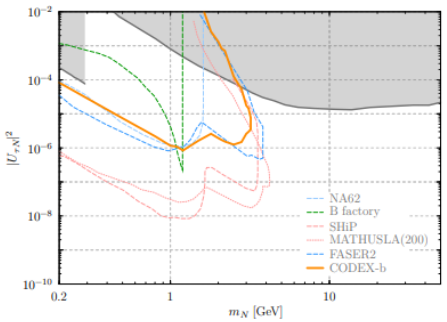
(c) $U_{\mu N} \gg U_{eN}, U_{\tau N}$ (Channels)



(d) $U_{\mu N} \gg U_{eN}, U_{\tau N}$ (Combined)



(e) $U_{\tau N} \gg U_{eN}, U_{\mu N}$ (Channels)



(f) $U_{\tau N} \gg U_{eN}, U_{\mu N}$ (Combined)