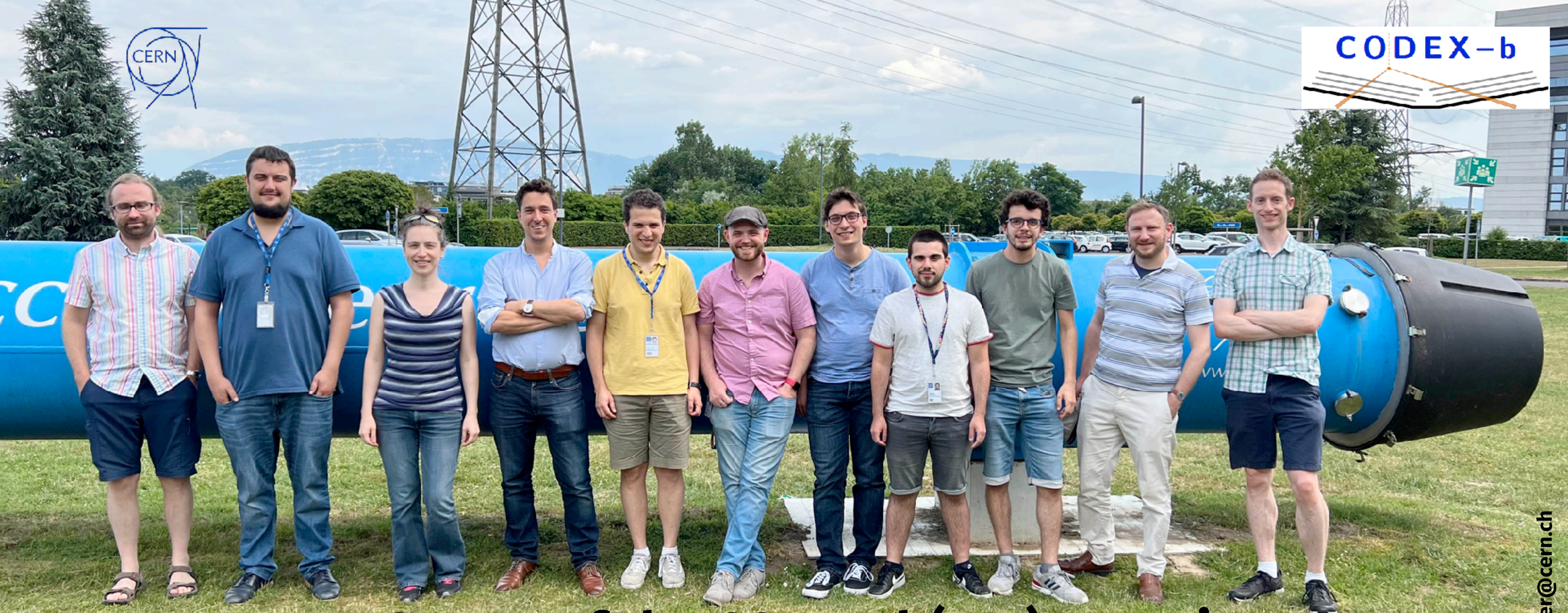


Status of the CODEX-b(eta) experiment

Titus Mombächer (CERN)

on behalf of the CODEX-b team

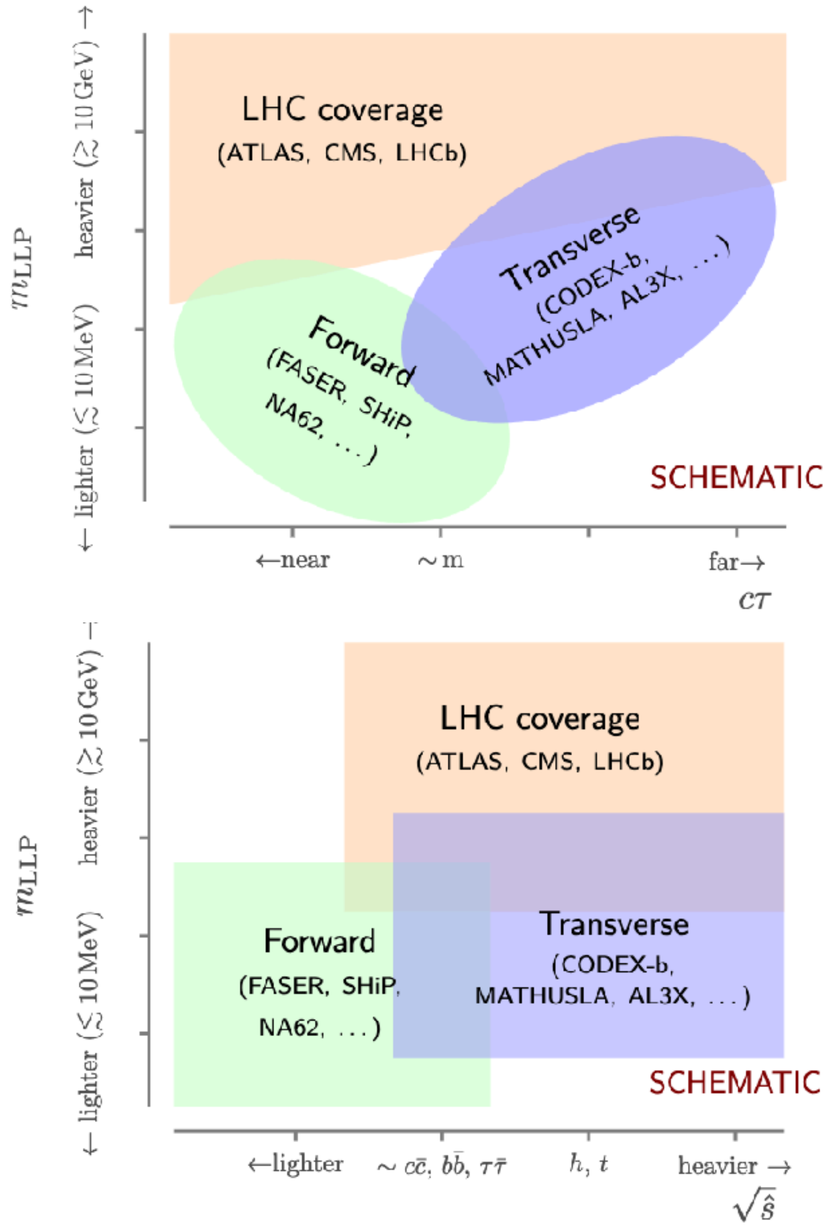
LLP13 workshop

21.06.2023

titus.mombacher@cern.ch

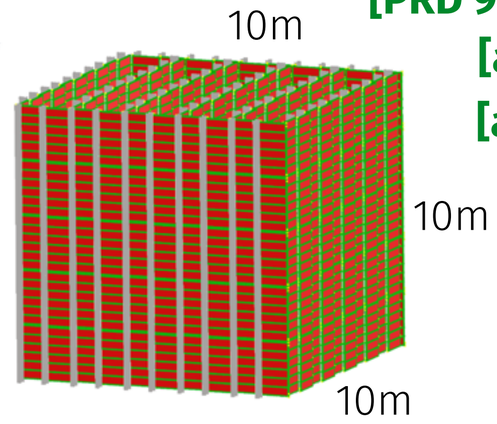
Why shielded new experiment?

- Dark sectors interaction with the Standard Model (SM) represented via mediators/portals
- Feebly interacting → long-lived
- Only LHC can produce potential LLP's from heavy SM particles
- **Missing out on zero-background transverse detector**

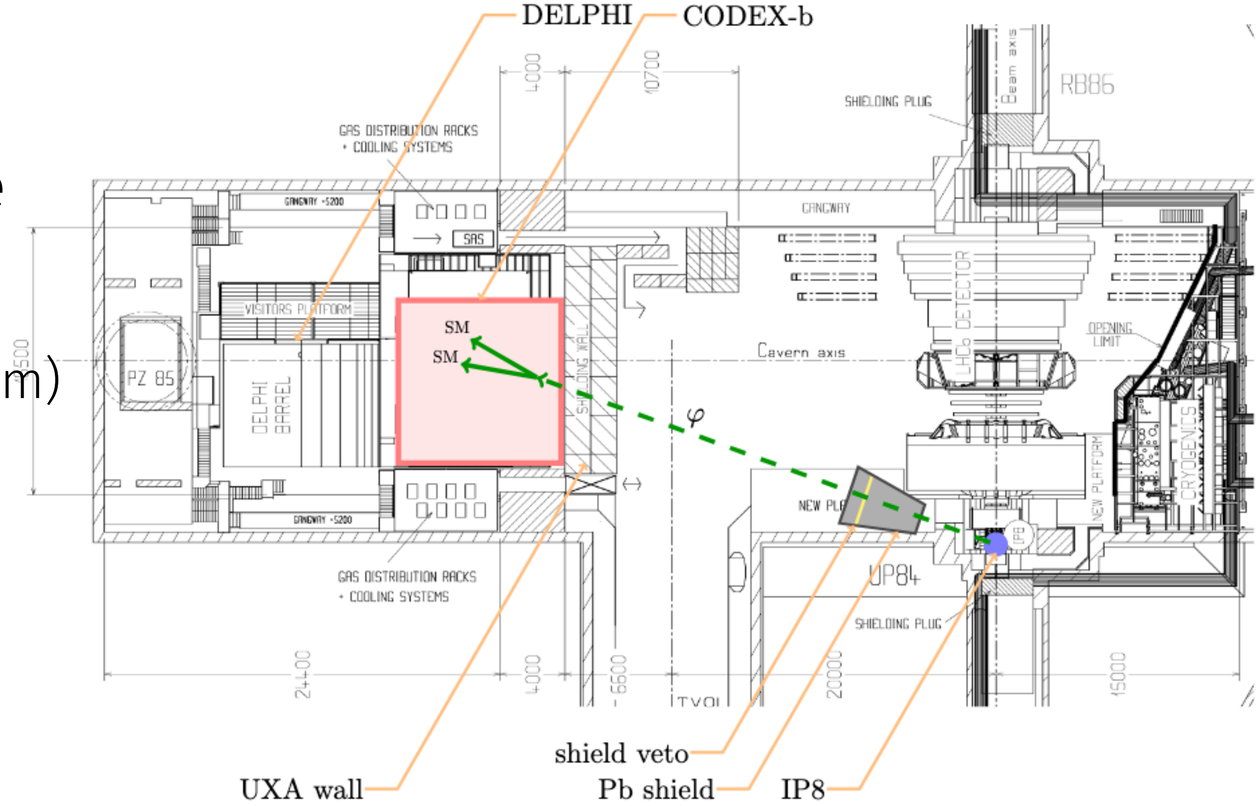


COmpact **D**etector for **EX**otics at LHC**b**

[PRD 97, 015023 (2018)]
[arXiv:1911.00481]
[arXiv:2203.07316]

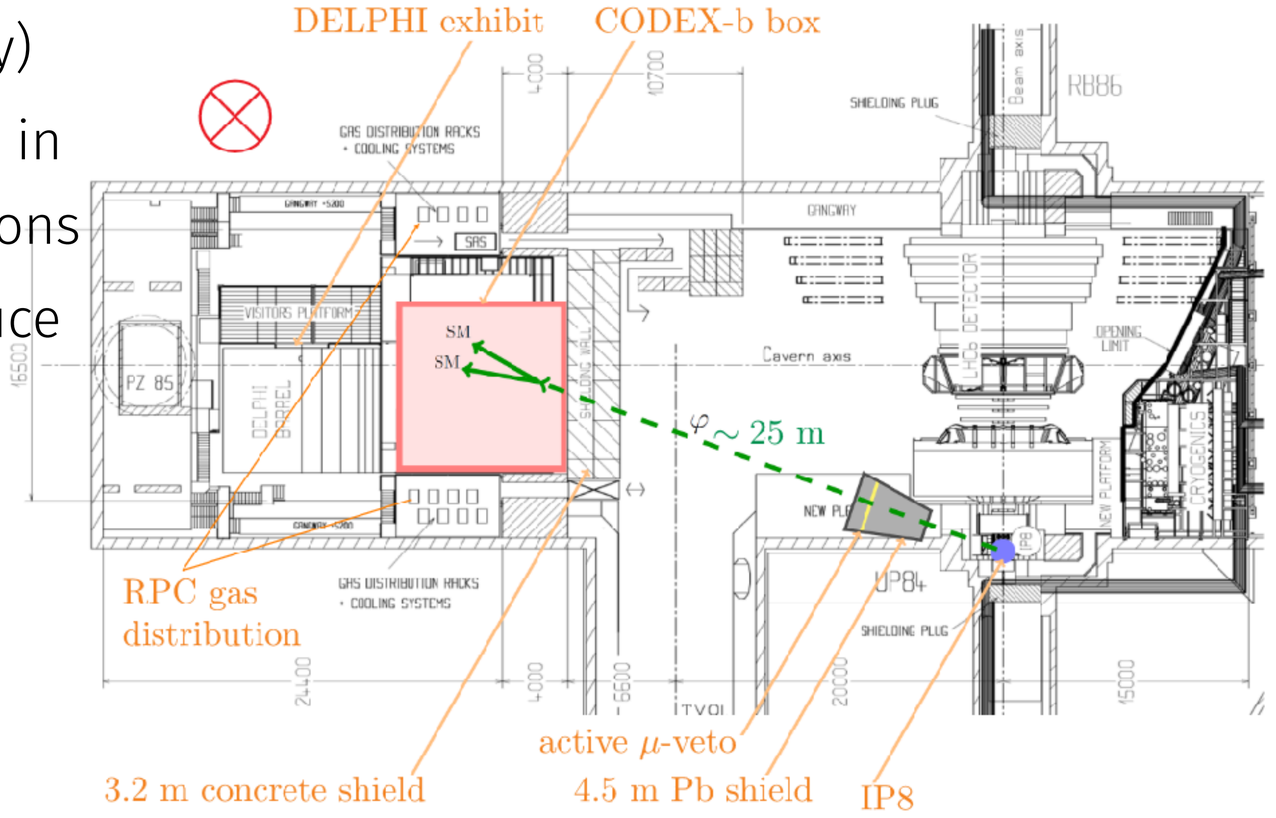


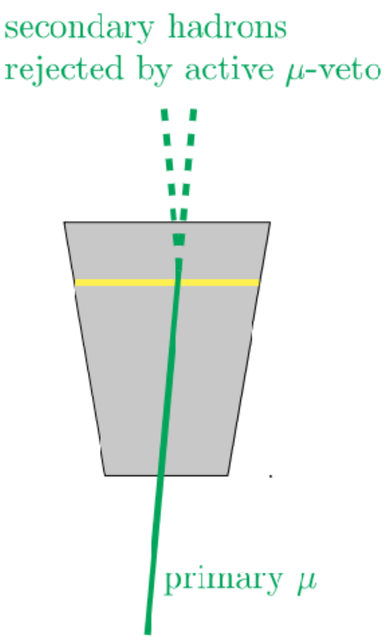
- Medium-scale transverse LLP detector
  - Proposed ~25m from IP8
  - From Run 4
- Cube instrumented with Resistive Plate Chambers (RPC)
  - Well known technology (ATLAS Upgrade system)
  - Medium size - low cost
- Zero background experiment
  - Shield + 3.2m concrete wall crucial
- Can integrate into LHCb trigger



Backgrounds

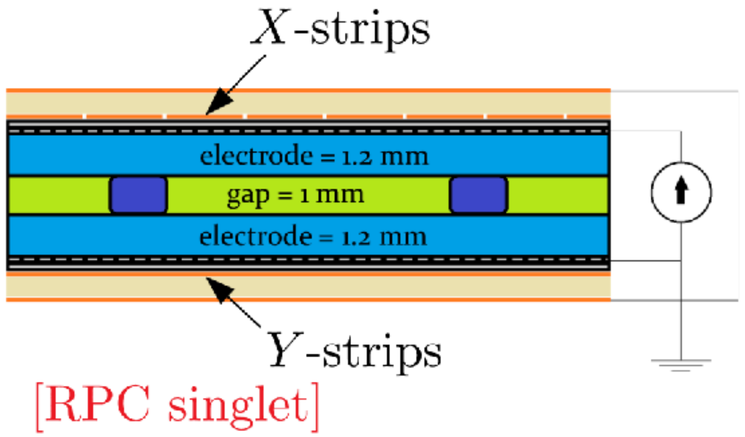
- Muons (primary/secondary)
- Neutrons, Kaons produced in passive shielding from Muons
- Decay in detector or produce particles from scattering
- ~25λ shield (conservative) with active veto to veto primary muons
- Expect to go down to $\lesssim 1$ background over $300\,\mathrm{fb}^{-1}$

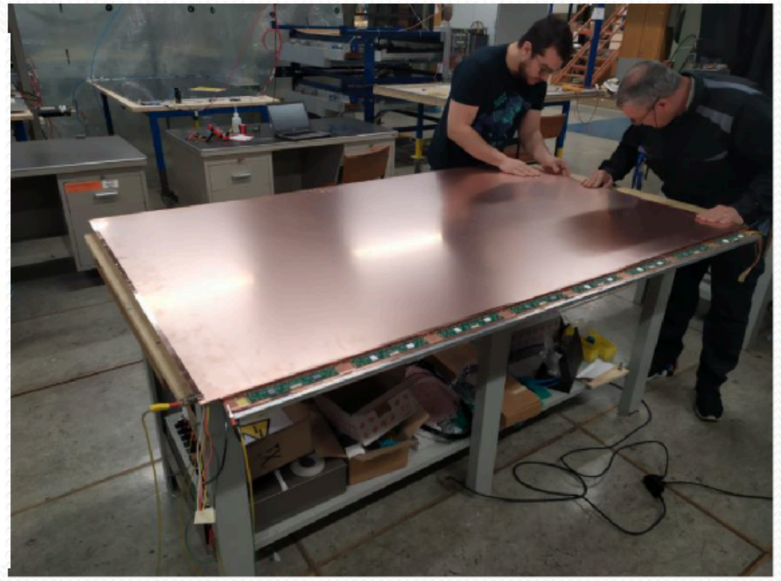




Detector technology

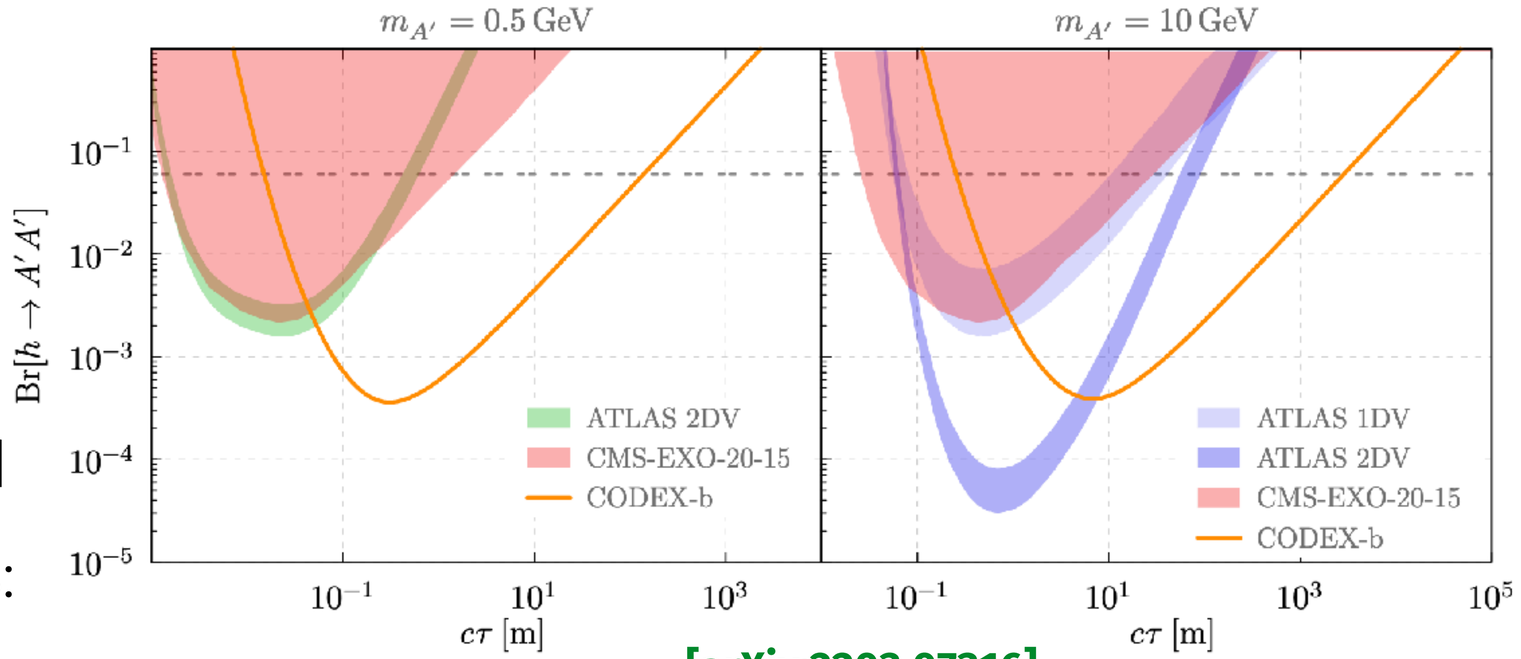
- RPC's designed for Upgrade 1 of ATLAS Muon system „BIS78“
- Triplet of RPC’s, $\mathcal{O}(1\,\text{mm})$ spatial resolution in X-Y; timing resolution $\mathcal{O}(100\,\text{ps})$
- Cost-effective for large-area tracker like CODEX-b
- Well established procedures from ATLAS productions



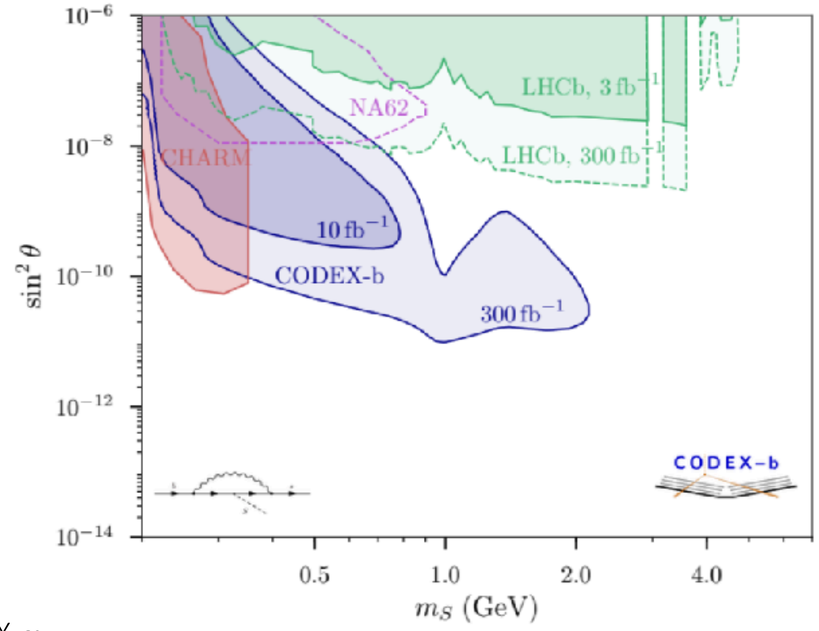


Physics reach

- Many UV complete and minimal benchmarks studied
- Two representative examples:
  - $h \to A'A' \to 2e2e$
  - $b \to sS \to s\ell\ell$
- Unique reach from CODEX-b wrt existing experiments
- Find many more scenarios in the EoI **[arXiv:1911.00481]**

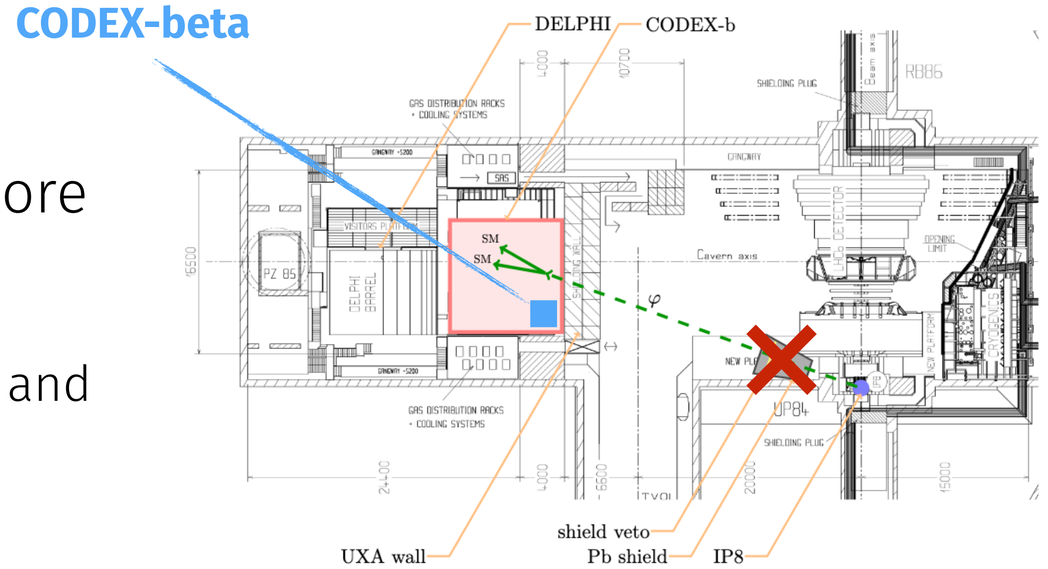


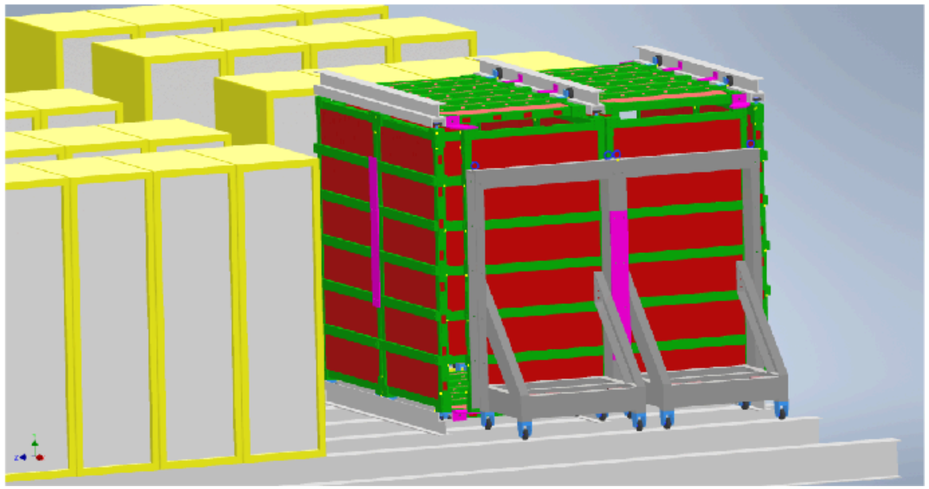
[arXiv:2203.07316]



CODEX-beta - a demonstrator

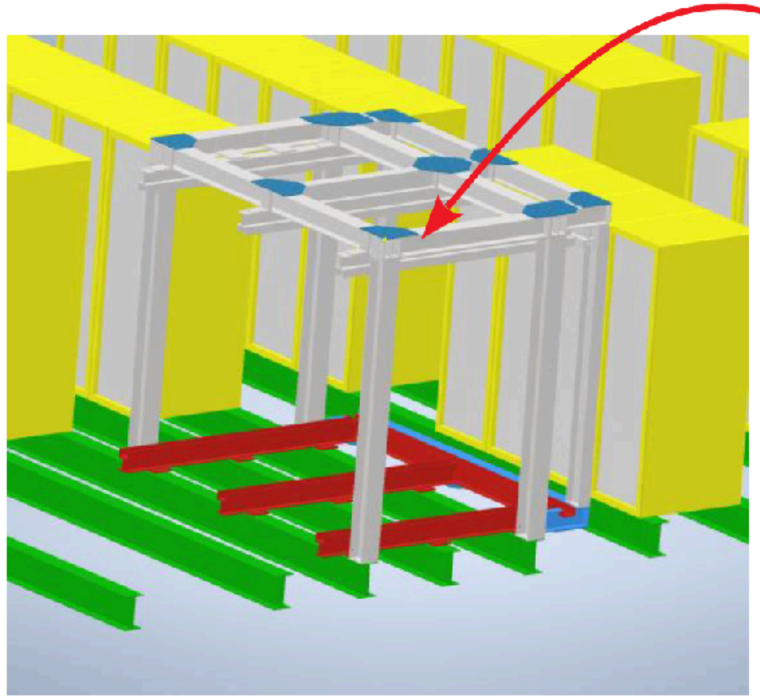
- Small $(2 \times 2 \times 2)$ m^3 detector to demonstrate core principles:
  - Demonstrate the ability to reconstruct SM backgrounds and validate simulation
  - Guarantee zero-background, optimise active veto
  - Demonstrate seamless integration into LHCb trigger
  - Demonstrate RPC as suitable baseline tracking technology for CODEX-b
  - Demonstrate suitability of mechanical support for RPC's and scalability for CODEX-b
- Build expertise within collaboration

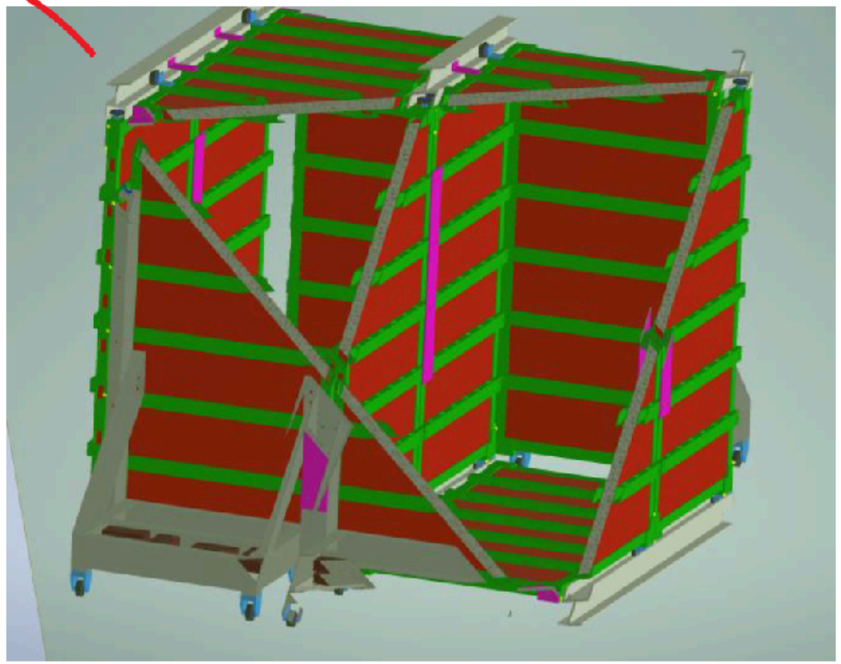


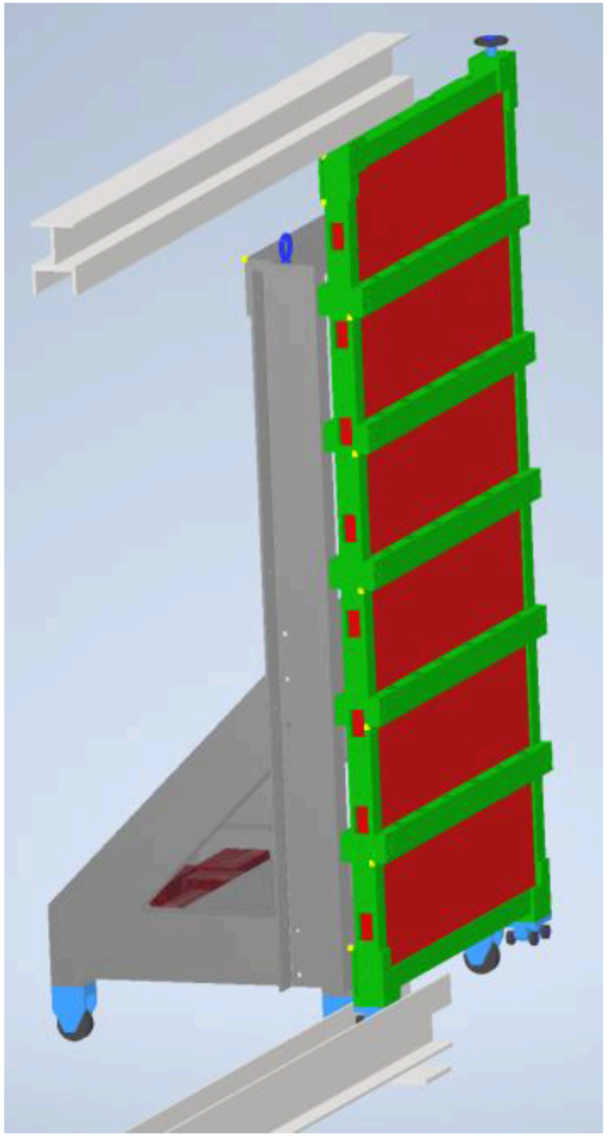


CODEX-beta design

- 2 RPC triplets per face, one central layer: 42 RPC’s
- Tight space constraints, chambers rolled in with carts







CODEX-beta construction

- Funding secured
- Installation plans reviewed by LHCb
- Procurement done/ongoing
- Preparing the RPC production at CERN
  - Front-end boards tested
  - Setting up the assembly site
  - **THANKS!** to ANUBIS and ATLAS for collaboration on RPC's (hardware and expertise)

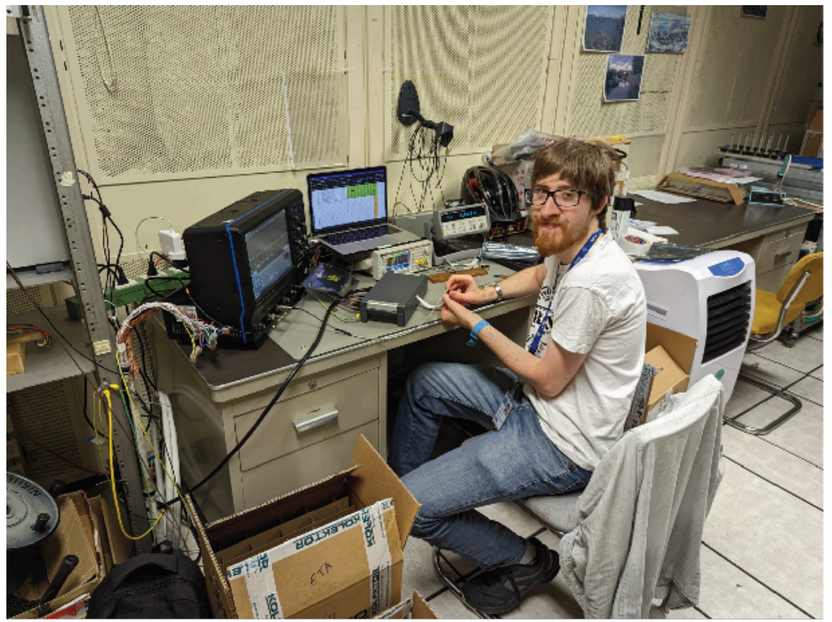
RPC assembly to commence next month

CODEX-β Installation Plan

The CODEX-b team

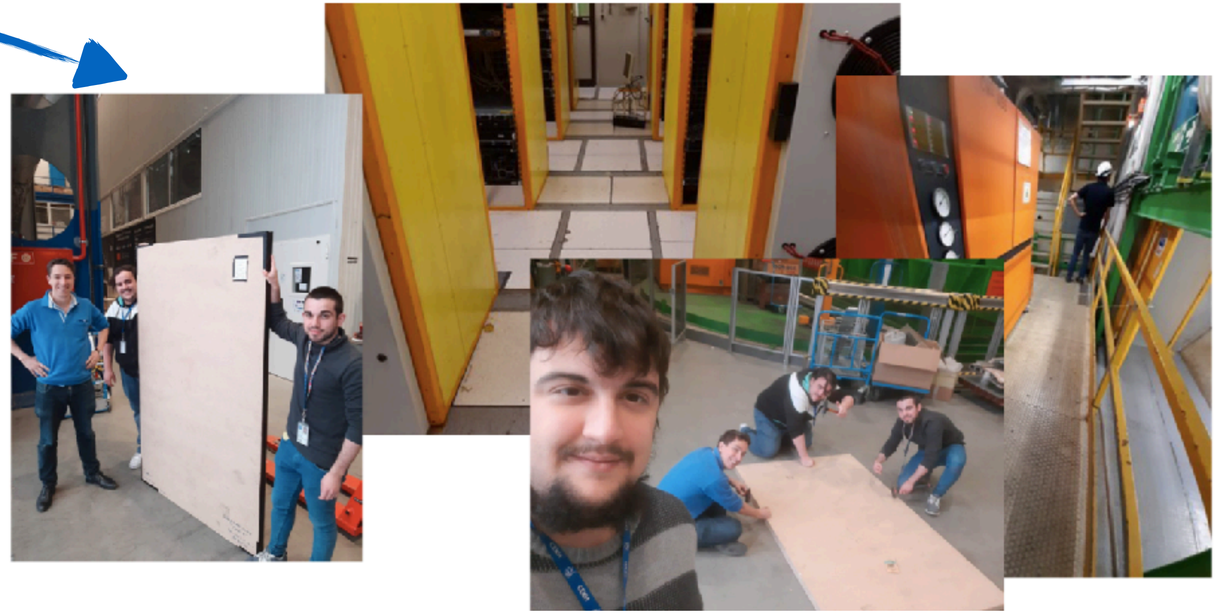
(Dated: April 2023)

67p document in iteration with LHCb



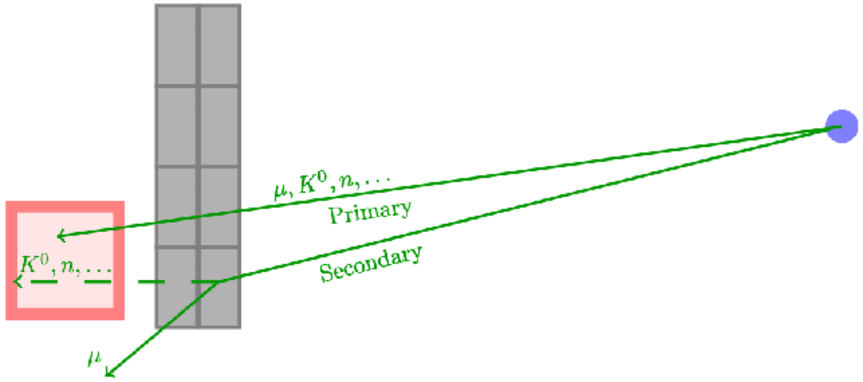
CODEX-beta construction

- Mechanical frame design ready
  - Frame prototype to hold RPC triplets
- Mockup to test transportation to the location
- Ongoing software development:
  - Checked RPC alignment tolerances
  - Setting up full simulation
  - First studies to prepare CODEX-beta analyses

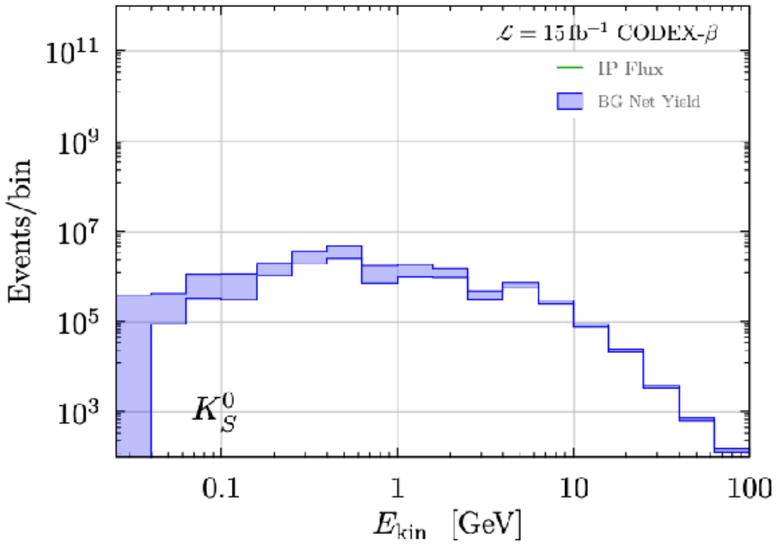


Towards measurements with CODEX-beta

- Crucial to understand and properly simulate background
- Measure fluxes and compare to simulation
  - Exploit decay vertex distribution and opening angles to test energy spectrum, acceptance and path length effects
  - Calibrate background simulation
  - Optimisation of shielding design
- Closure test with K^0_S lifetime:
  - Many boosted K^0_S produced in UXA wall
  - Fit K^0_S lifetime from vertex and opening angle distribution of $K^0_S \to \pi^+\pi^-$



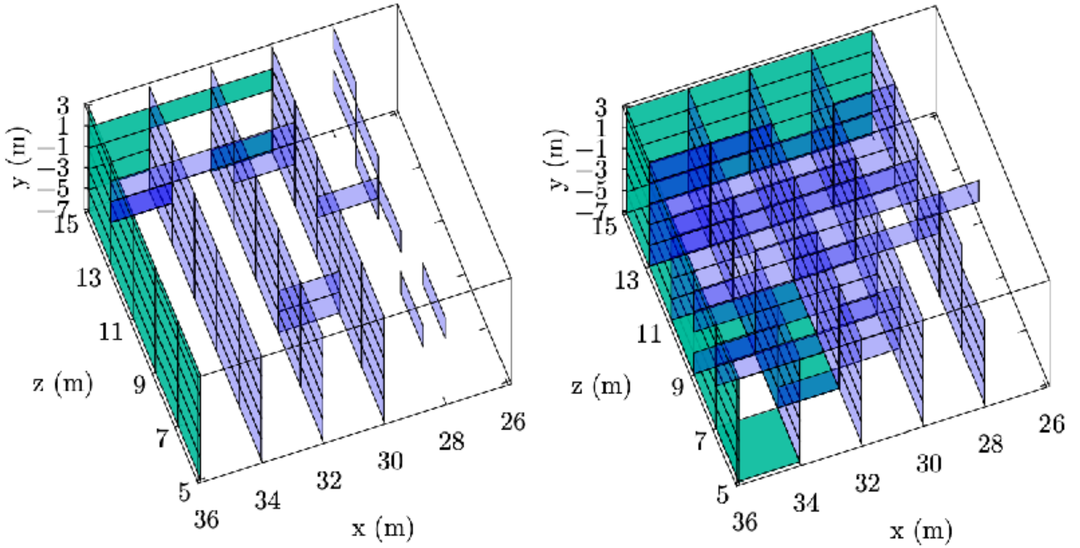
GEANT4-based simulation



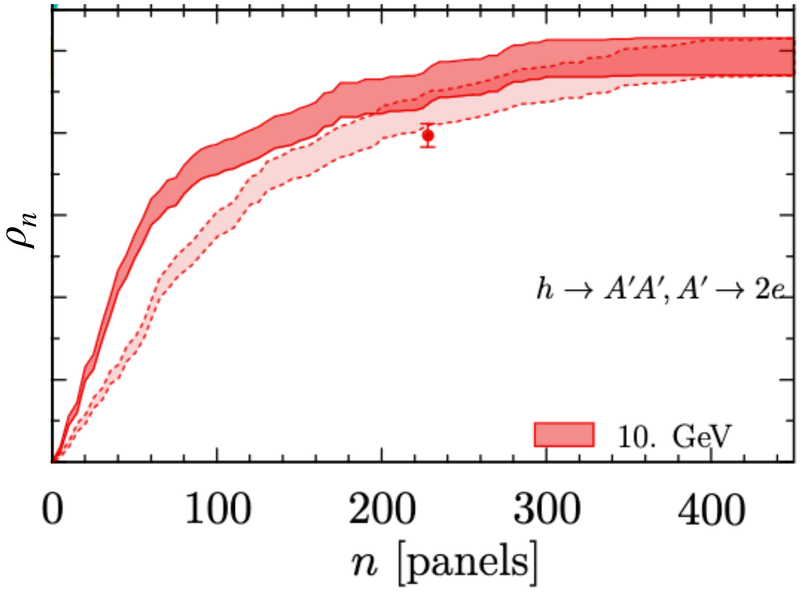
Detector optimisation

- Study by LBL group **[arXiv:2211.08450]**
- Fast simulation framework to study
  - Different detector geometries and locations
  - Different tracking configurations
- Divided CODEX-b geometry into 450 2×2 m^2 panels
  - Study optimal amount and location with benchmarks

    $h \to A'A' \to 2e2e$ and $b \to sS \to s2e(4\pi)$
  - Informs detector coverage
  - Can substantially reduce number of panels without significant efficiency drop
- Use the tool for finding best location given cavern constraints



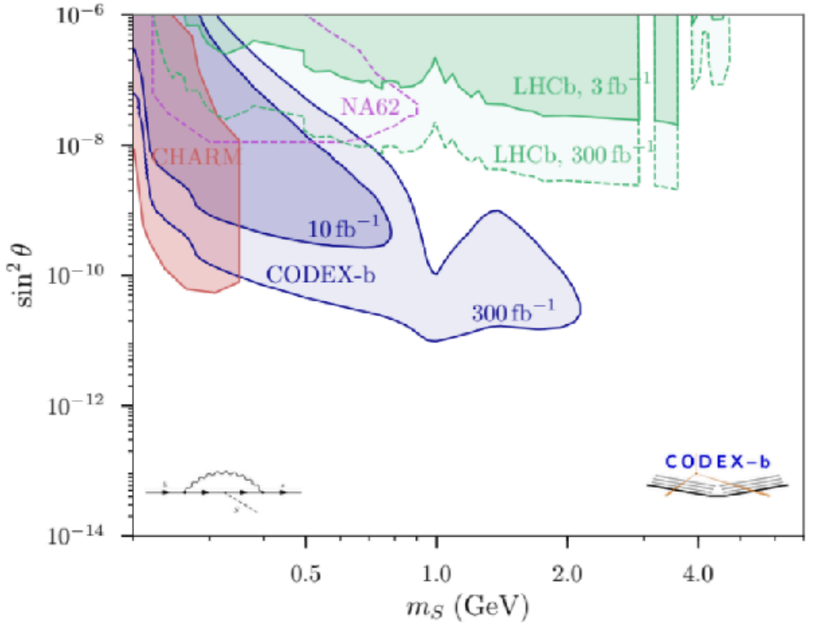
150 panels 250 panels



ρ_n relative vertex reconstruction efficiency

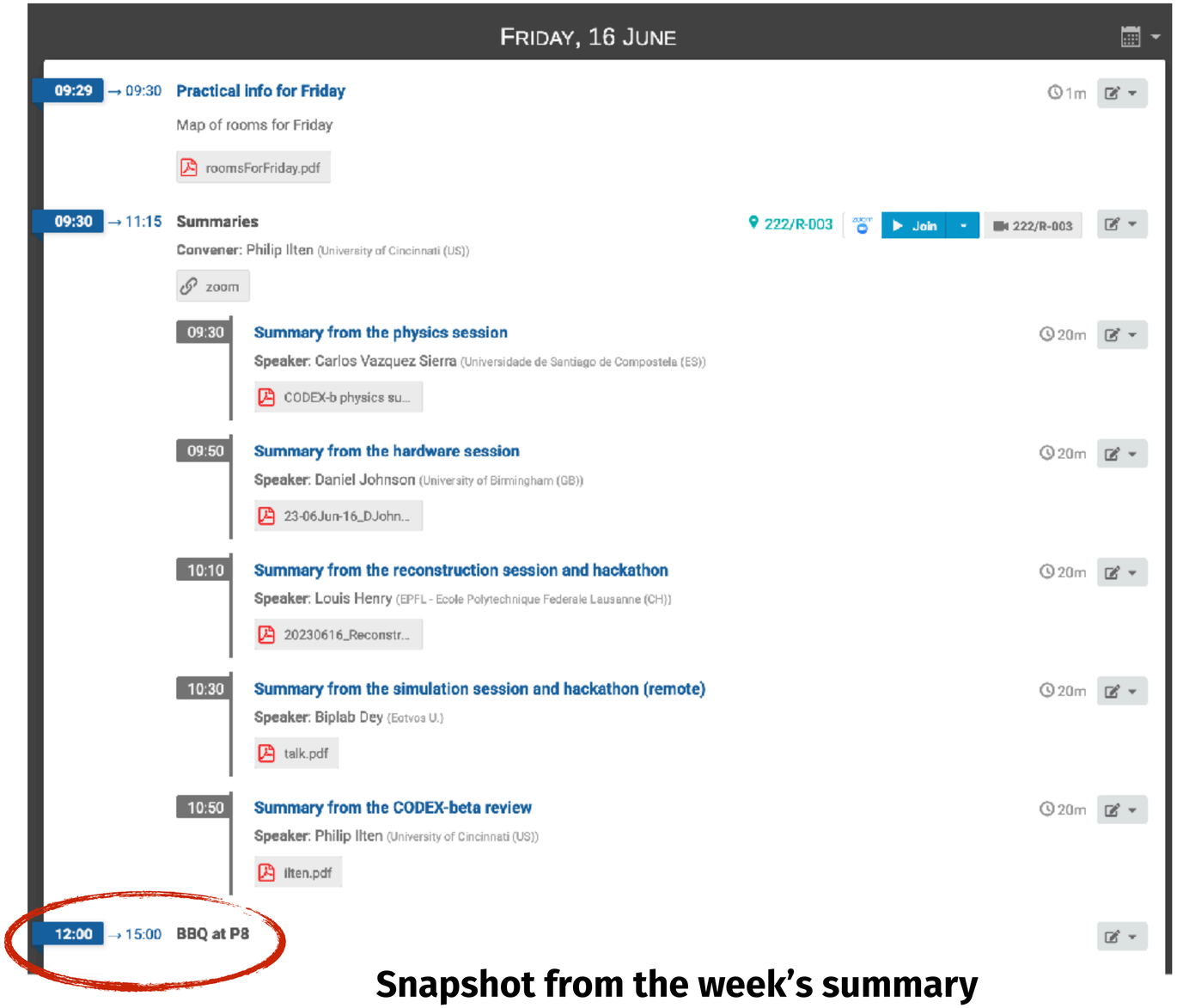
Fast simulation framework to project efficiencies

- Take HepMC simulation as input
- Build detector geometry and tracking faces
- Perform several optimisations to reduce CPU usage:
  - Flip in z
  - Rotation in phi according to detector geometry
  - Sample for long lifetime according to detector displacement
  - Keep track with overall event weight
- Join decay vertex with arbitrary (phase space) decay
- Filter sample according to which events survived in the detector volume
- Add track hits to the particles
- **Will become public to be used for reinterpretation!**



1st collaboration week!

- CODEX-beta installation
- Physics perspectives
- Input from LHCb on CODEX-b
- Hackathons on Simulation and Reconstruction
- Invited expertise from other (LLP) experiments (LHCb, ANUBIS, SHiP, MATHUSLA, R2E, CMS, …)
- … and end with a nice BBQ!

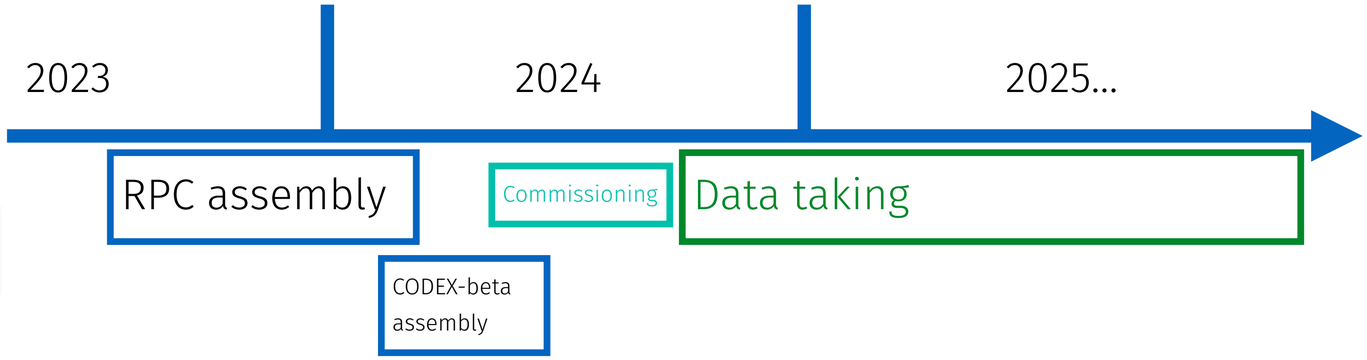


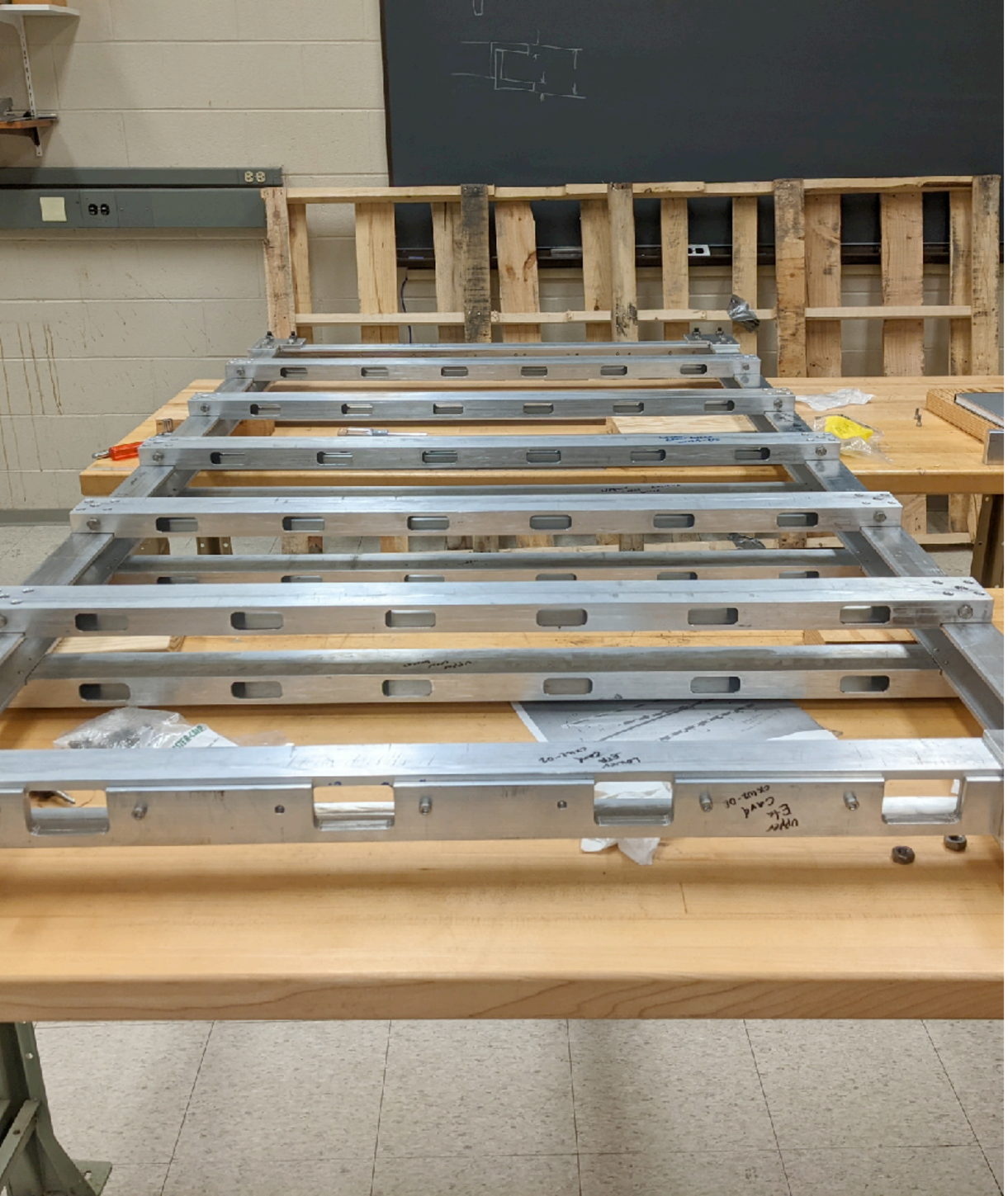
Snapshot from the week's summary

Summary

- Significant phase space for LLP's cannot be covered without a dedicated shielded transverse detector at the LHC
- CODEX-b will offer excellent physics reach for small cost (total ~10M€)
- CODEX-beta for Run 3 progressing steadily
  - Ramping up hardware production and software activities
  - RPC assembly to begin next month
  - Investigating first toy data analyses
- Collaboration is growing

More collaborators welcome!

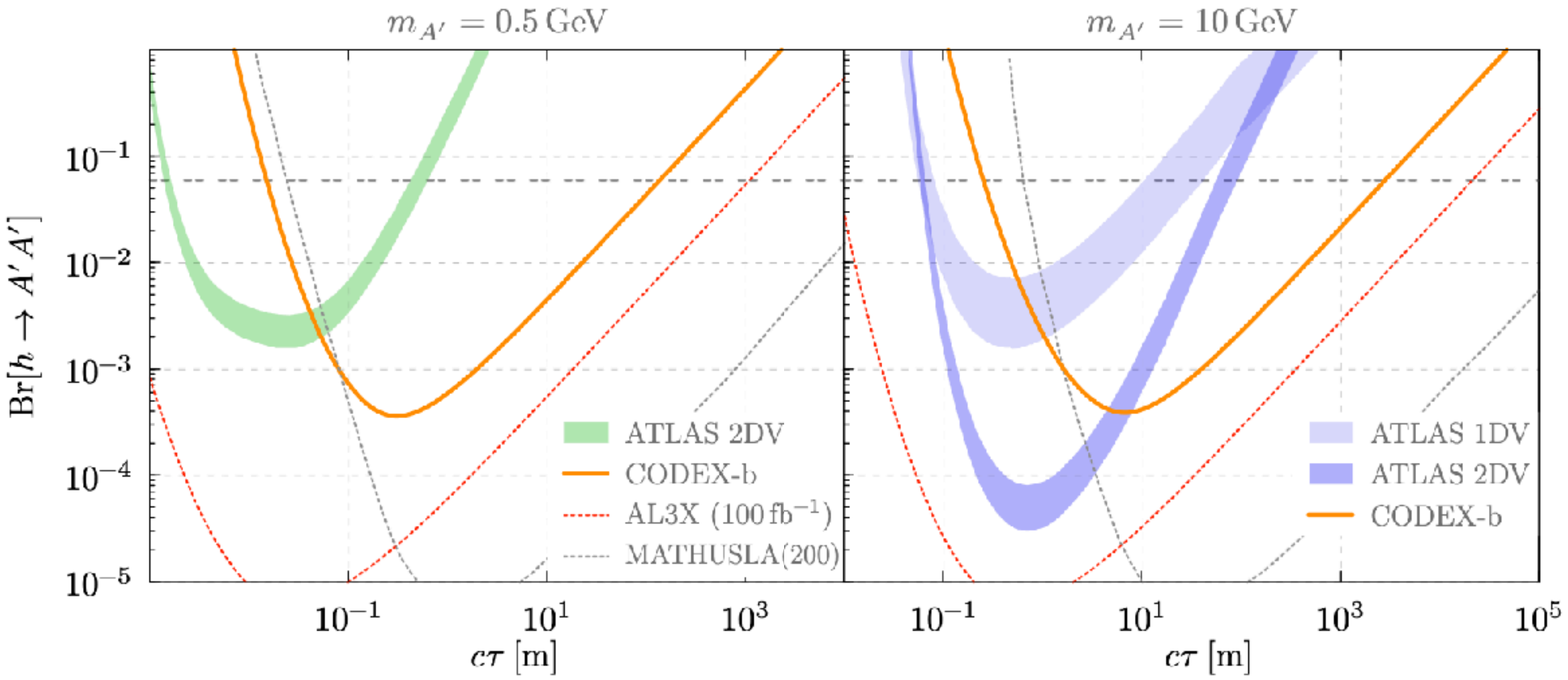


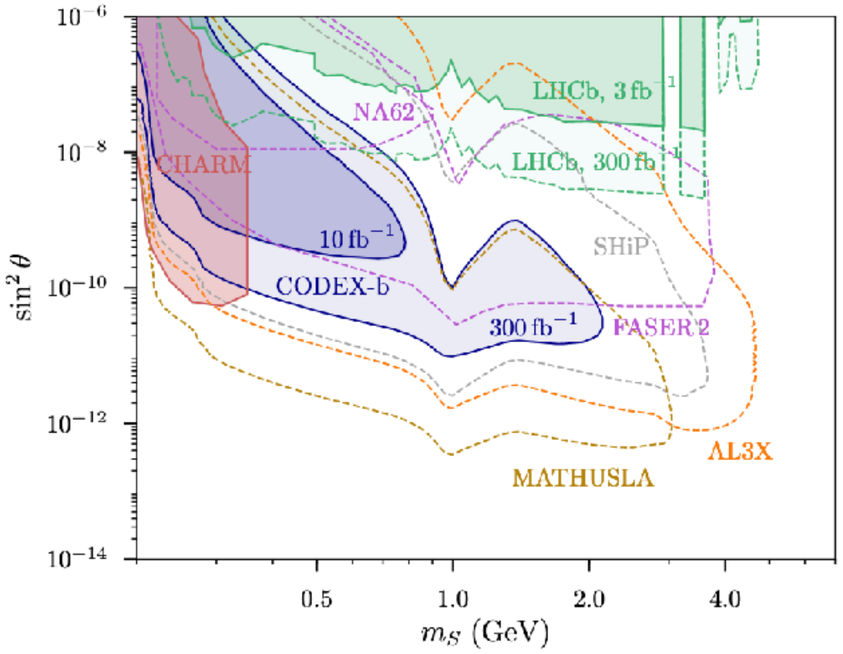


Backup

[arXiv:1911.00481]

Comparison to other proposals





[arXiv:1911.00481]

Backgrounds with that scenario

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^-	$(8.07 \pm 0.01) \times 10^5$	$(8.07 \pm 0.01) \times 10^9$	$(8.07 \pm 0.01) \times 10^9$	–

Nothing remains