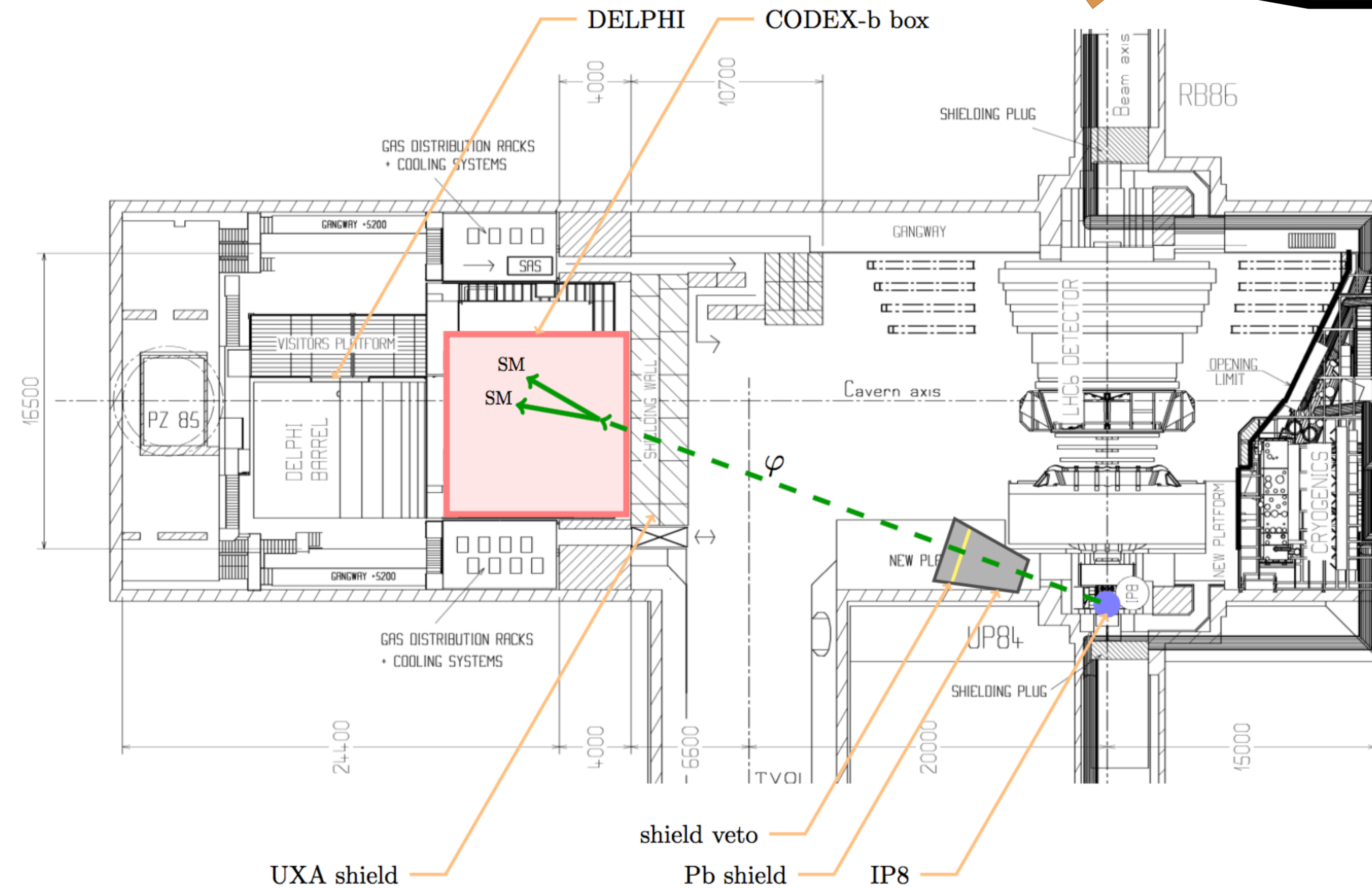


# Status and prospects of CODEX-b



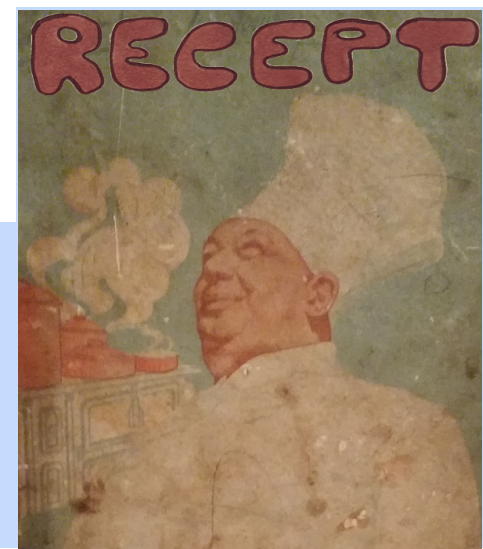
**Vladimir V. Gligorov (LPNHE/CNRS)**  
**New Physics at the Intensity Frontier Workshop**  
**Cyberspace 08.06.2021**



European Research Council  
Established by the European Commission



LPNHE  
PARIS



# Why LLPs?

Long lived particles are **generic consequence** of theories with:

- Small couplings
- Scale (or loop) hierarchies
- Phase space suppression

$$\Gamma \sim \varepsilon^2 \left( \frac{m}{M} \right)^n \text{PS}$$

broken sym  
weak mixing/ marginal operator  
technically natural

$m \ll M$ , typically  $n \geq 4$   
loop factors

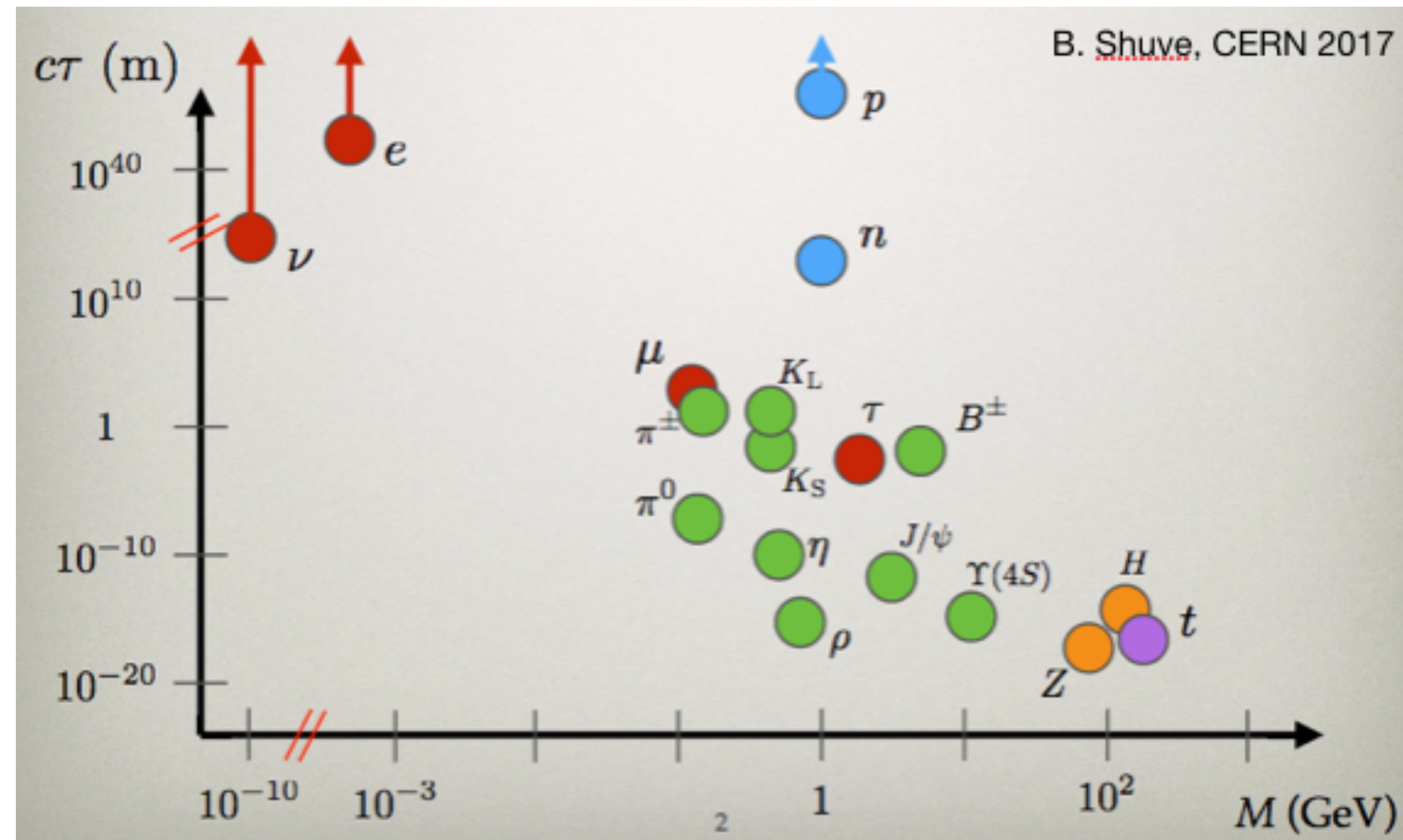
squeezed spectra  
approx sym  
multibody decays

SM provides a **template** in weak decays of  $n$  or  $K_L^0$ :

Multiple scales ( $\Lambda_{\text{qcd}}$ ,  $G_F^{-1/2}$ )

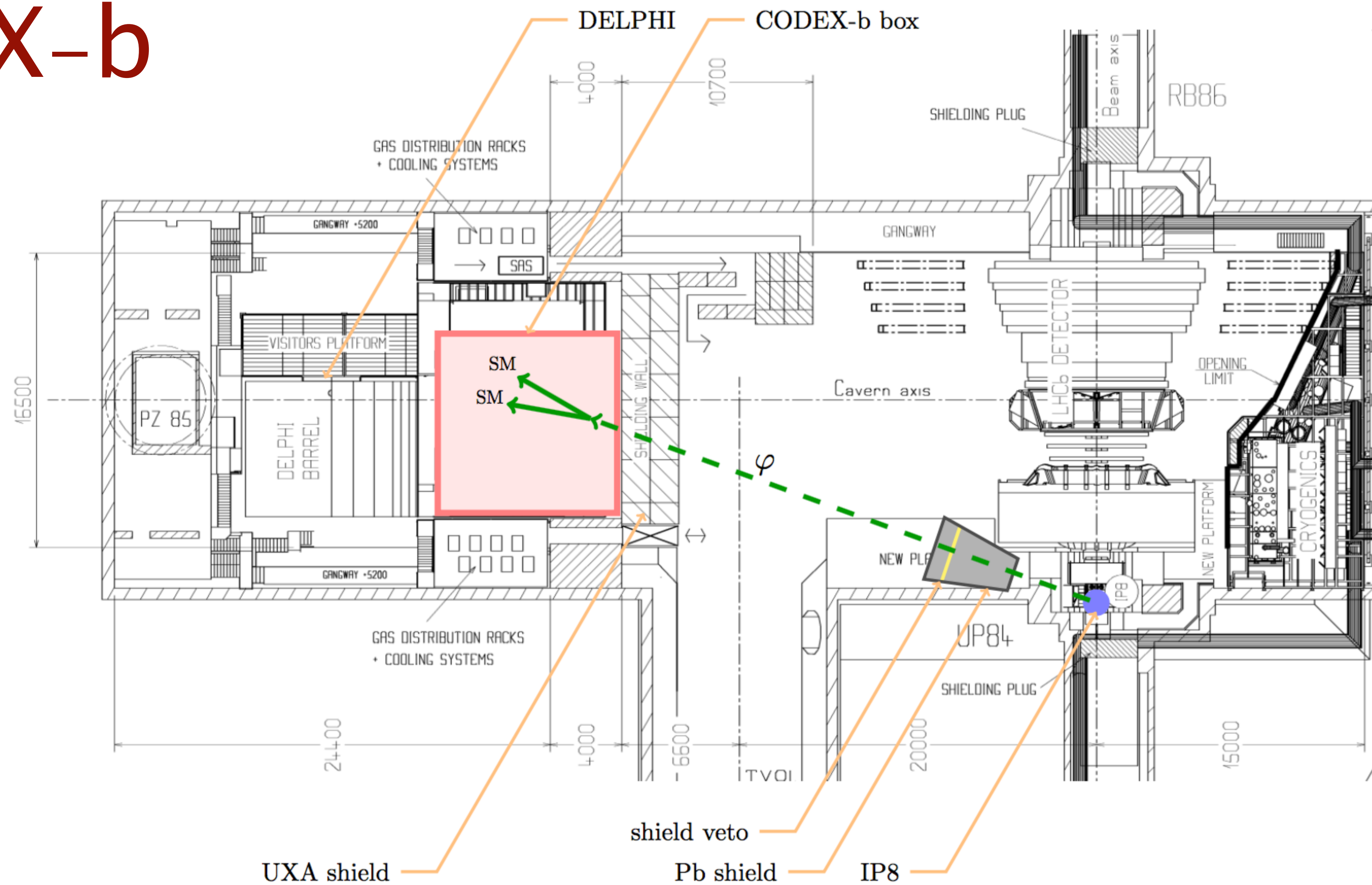
Approx symmetries (e.g. isospin)

3-body final states



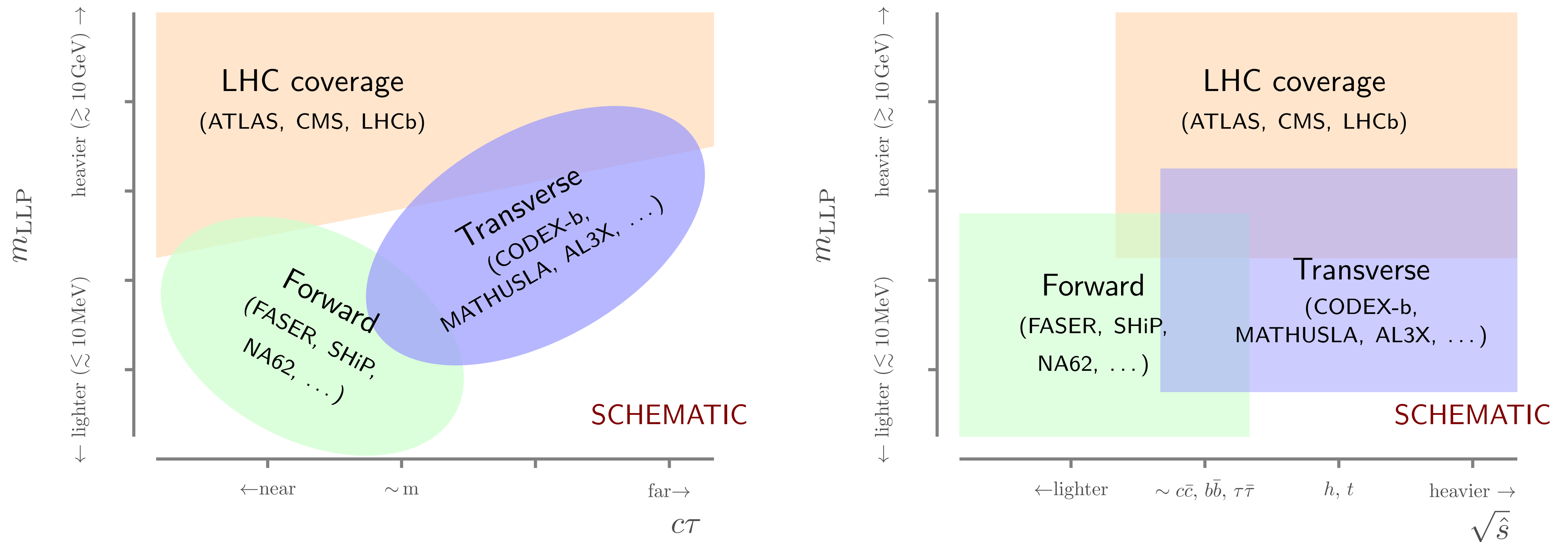
Mass & lifetime are correlated, small masses often come with longer lifetimes...

# CODEx-b



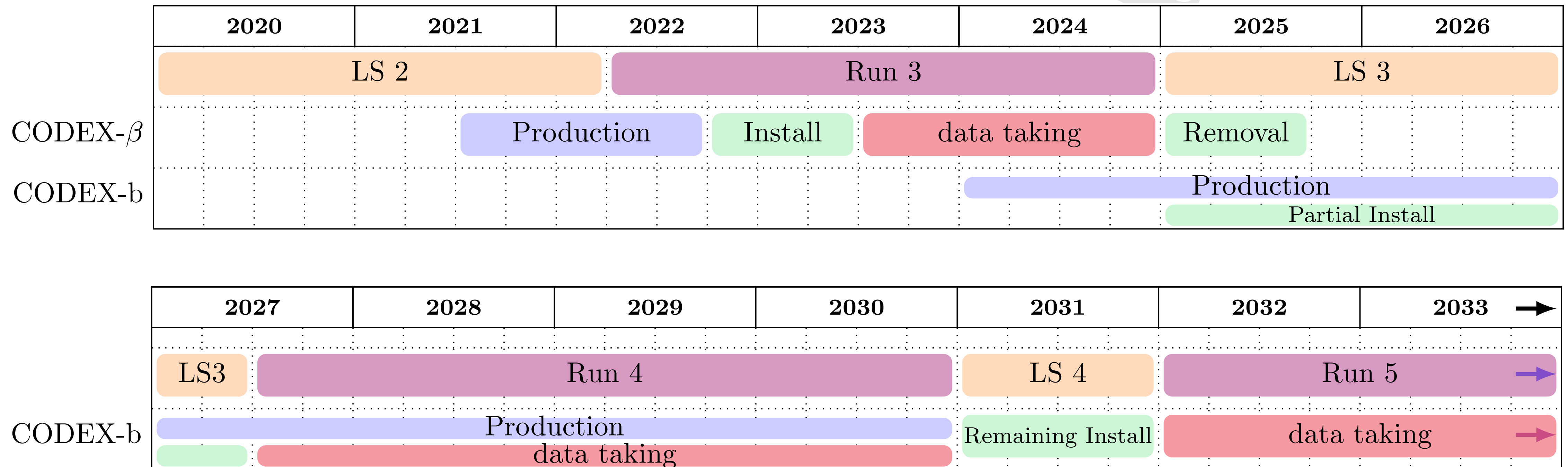
**KEY DRIVER OF DESIGN: LHCb Upgrade II aims to collect  $300 \text{ fb}^{-1}$  at IP8!**  
**No longer a low pileup/low luminosity interaction point.**

# One slide physics motivation



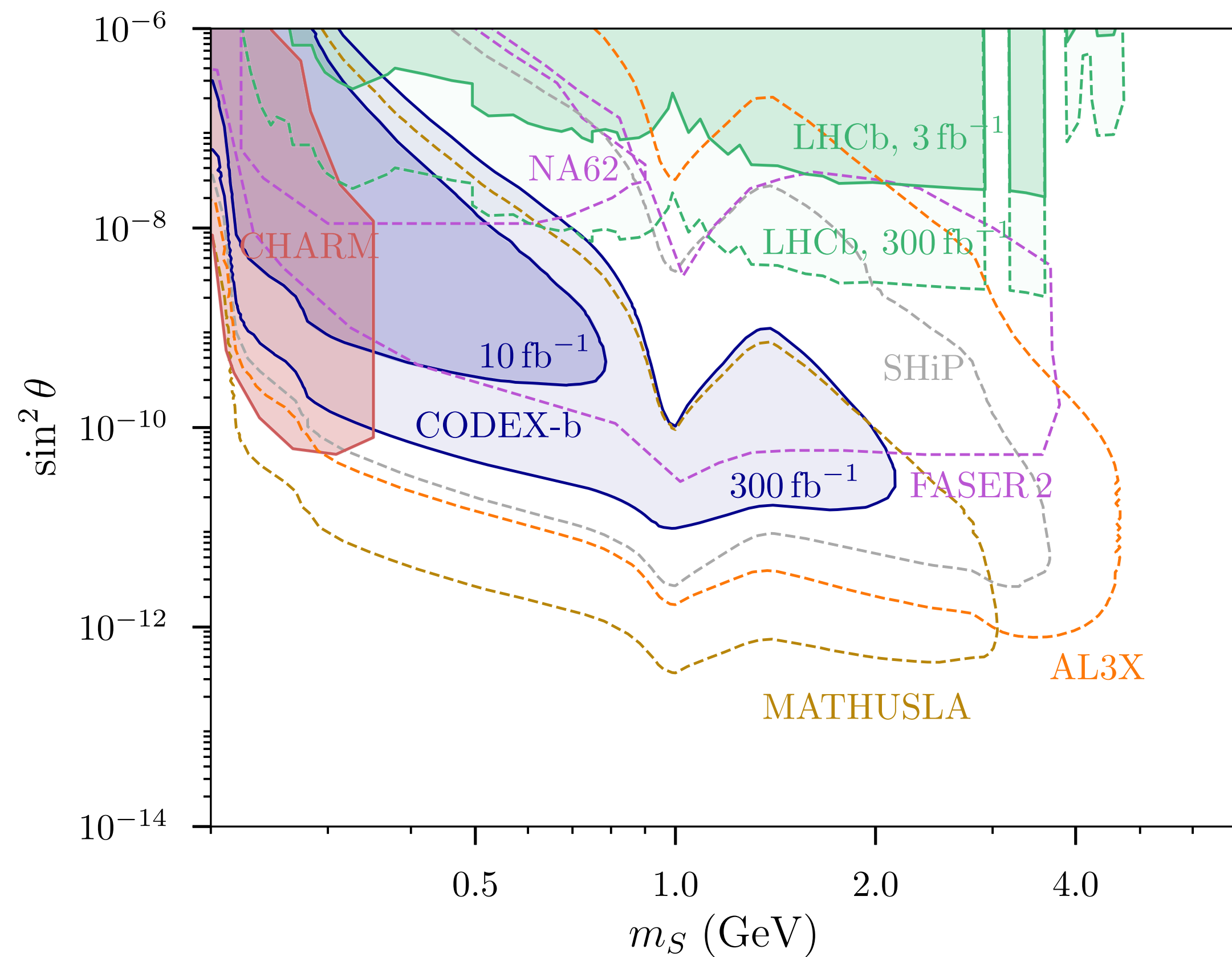
Complementary to other LLP experiments (existing or proposed)  
Easy integration into LHCb's triggerless readout gives additional  
information in case we see any interesting signals!

# Timeline

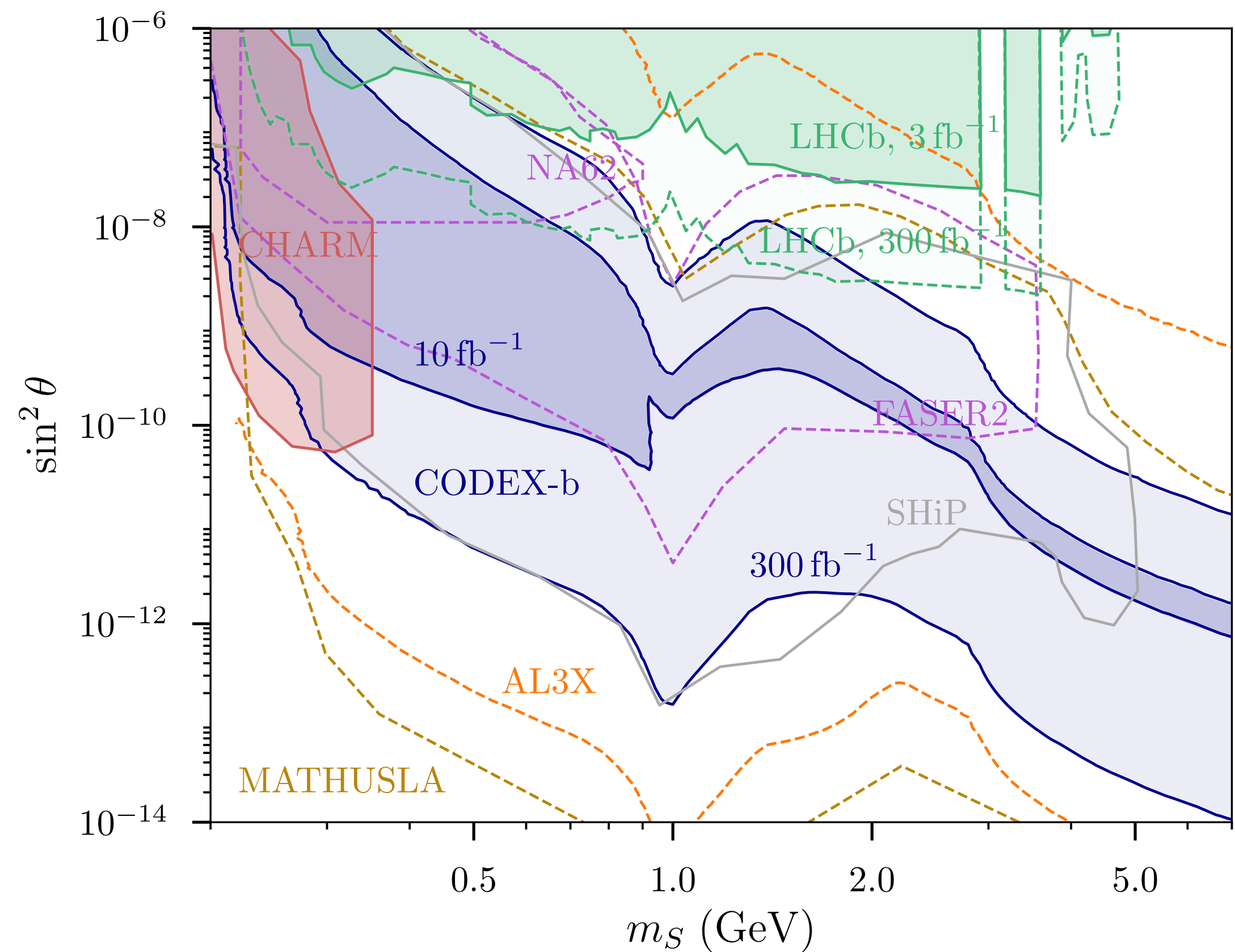


Begin with a demonstrator to validate backgrounds & tech, then scale up.

# Example model 1 — $b \rightarrow sX$



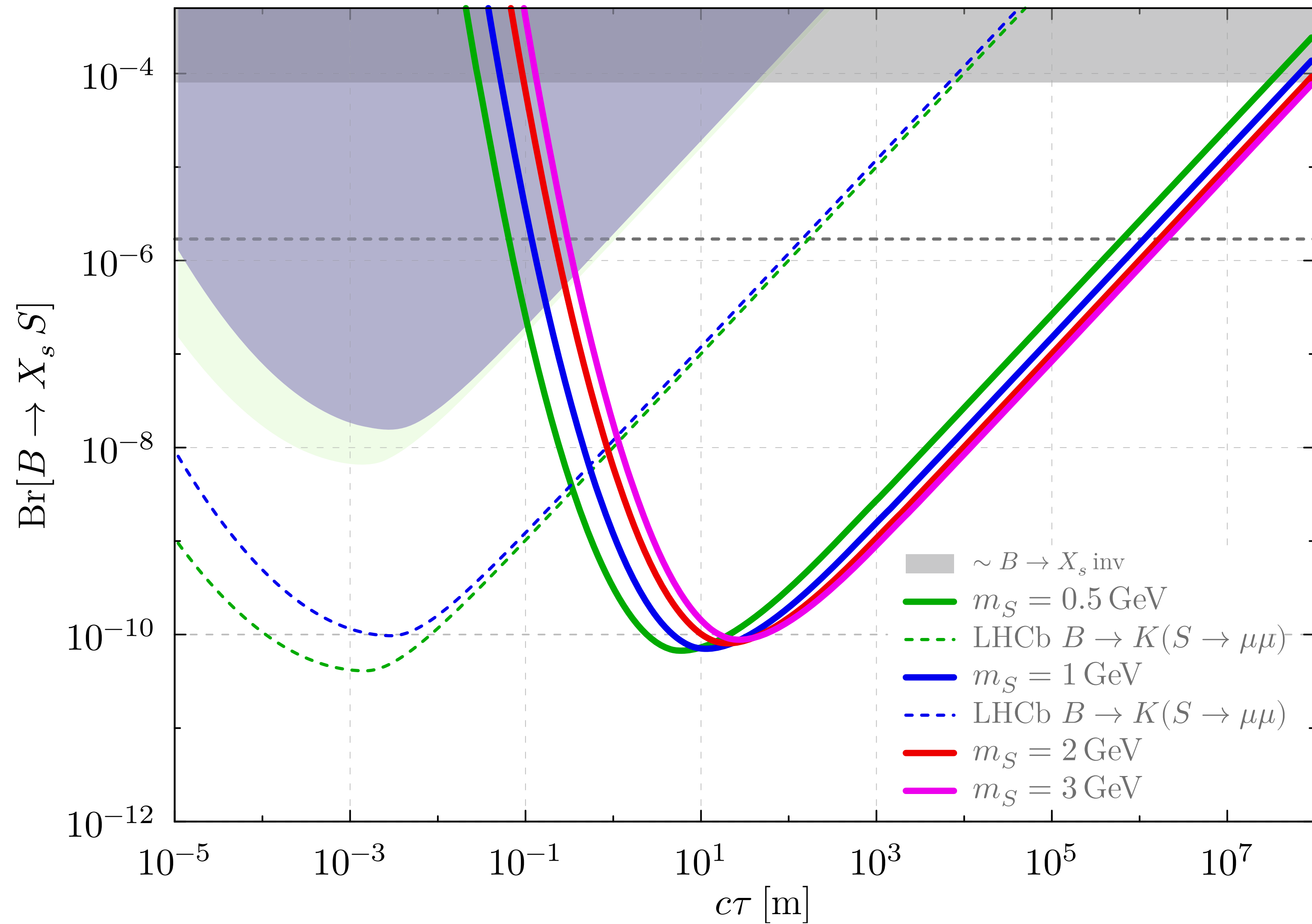
(a)  $\lambda = 0$



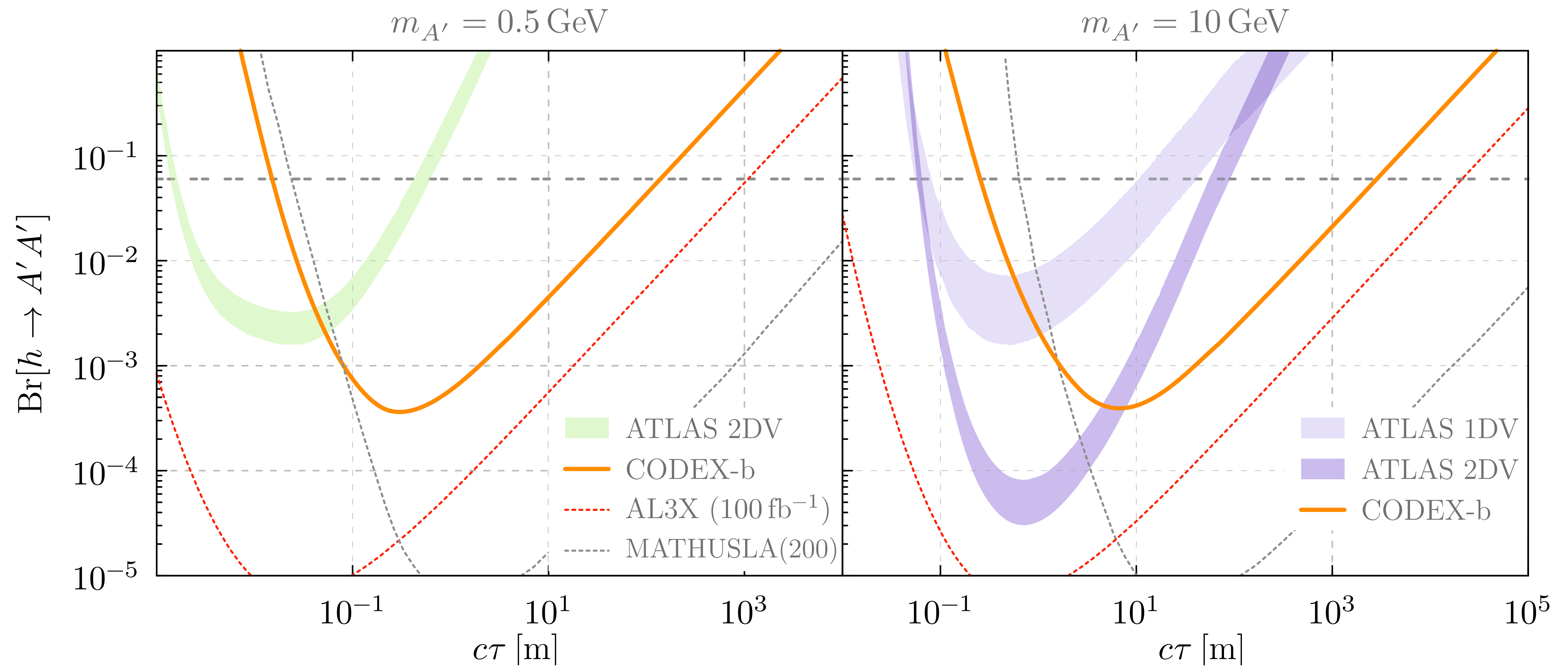
(b)  $\lambda = 1.6 \times 10^{-3}$

$\lambda$  parameterizes the off-shell Higgs boson contribution to the decay rate

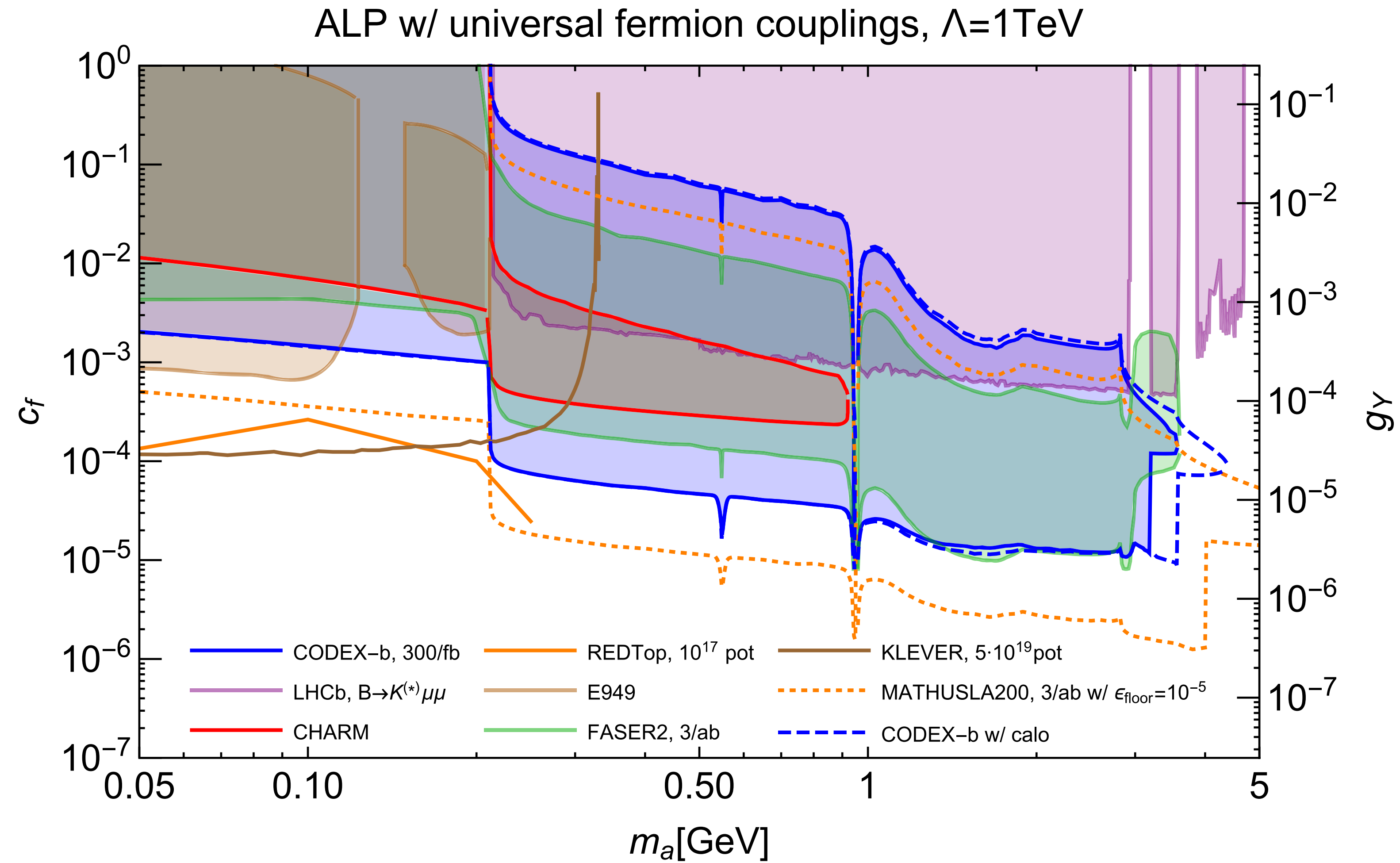
# $b \rightarrow sX$ complementarity with LHCb



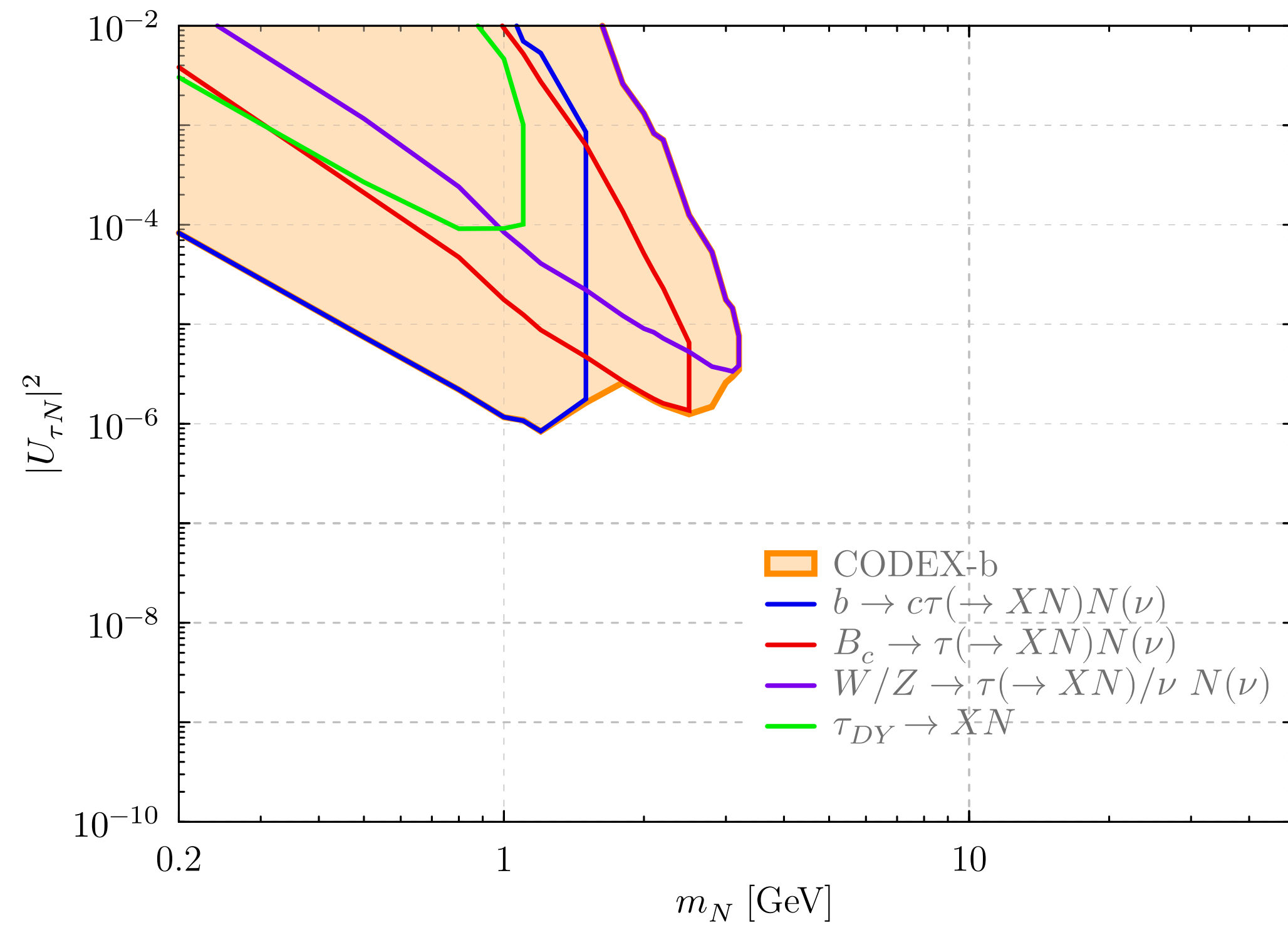
# Example model 2 — $H \rightarrow A' A'$



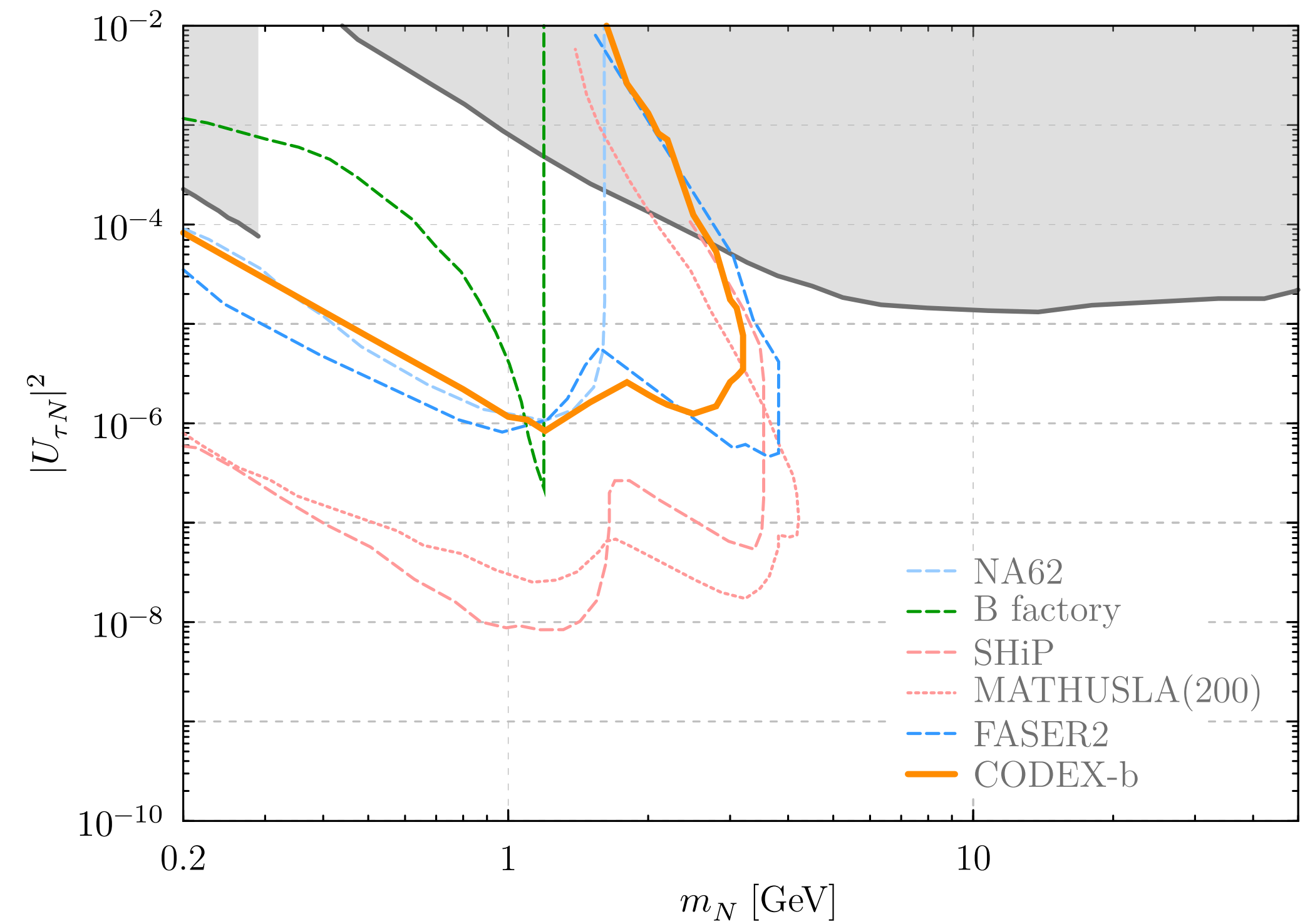
# Example model 3 — ALP



# Example model 4 — HNL

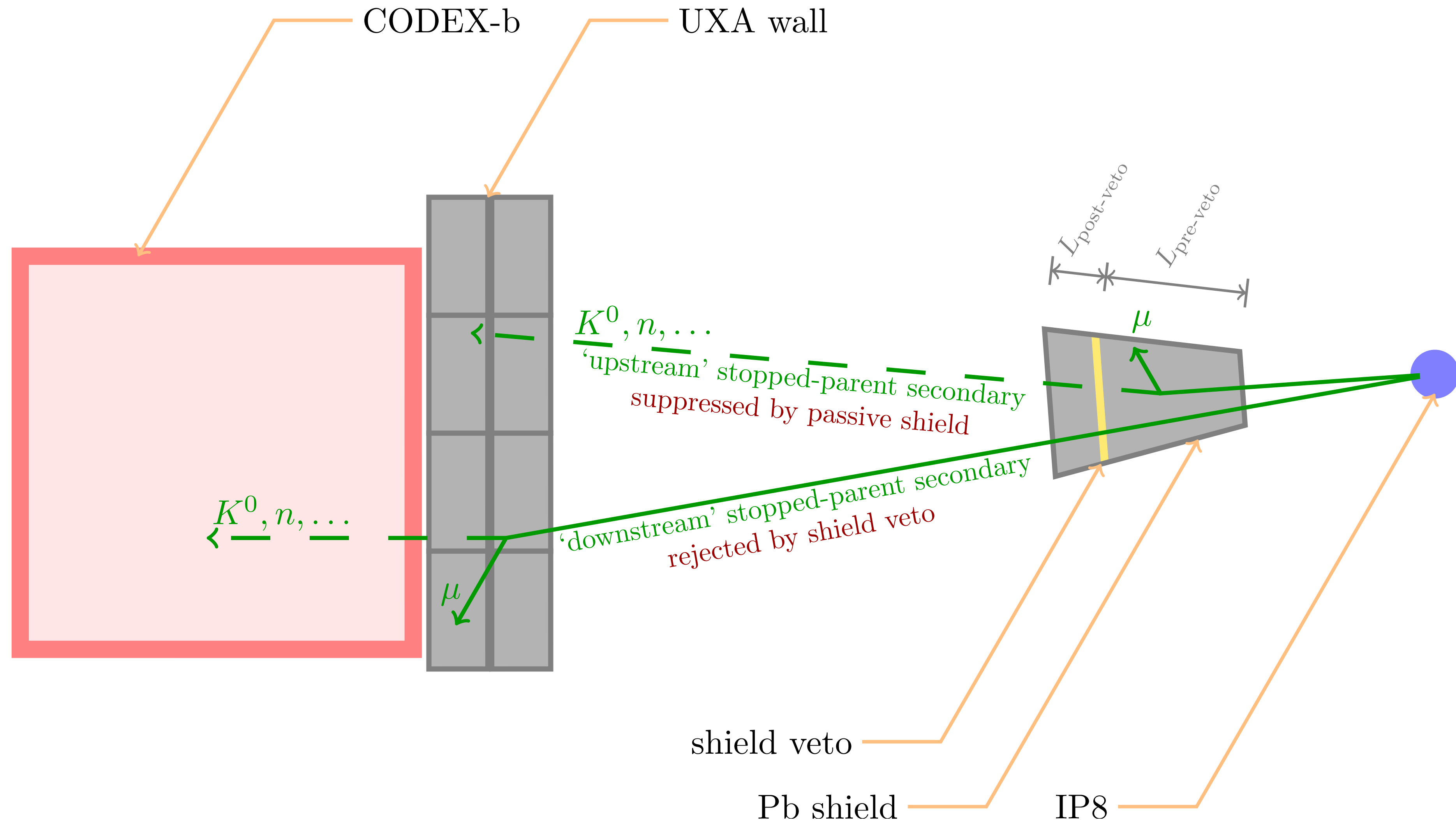


**(e)**  $U_{\tau N} \gg U_{eN}, U_{\mu N}$  (Channels)



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

# CODEx-b backgrounds

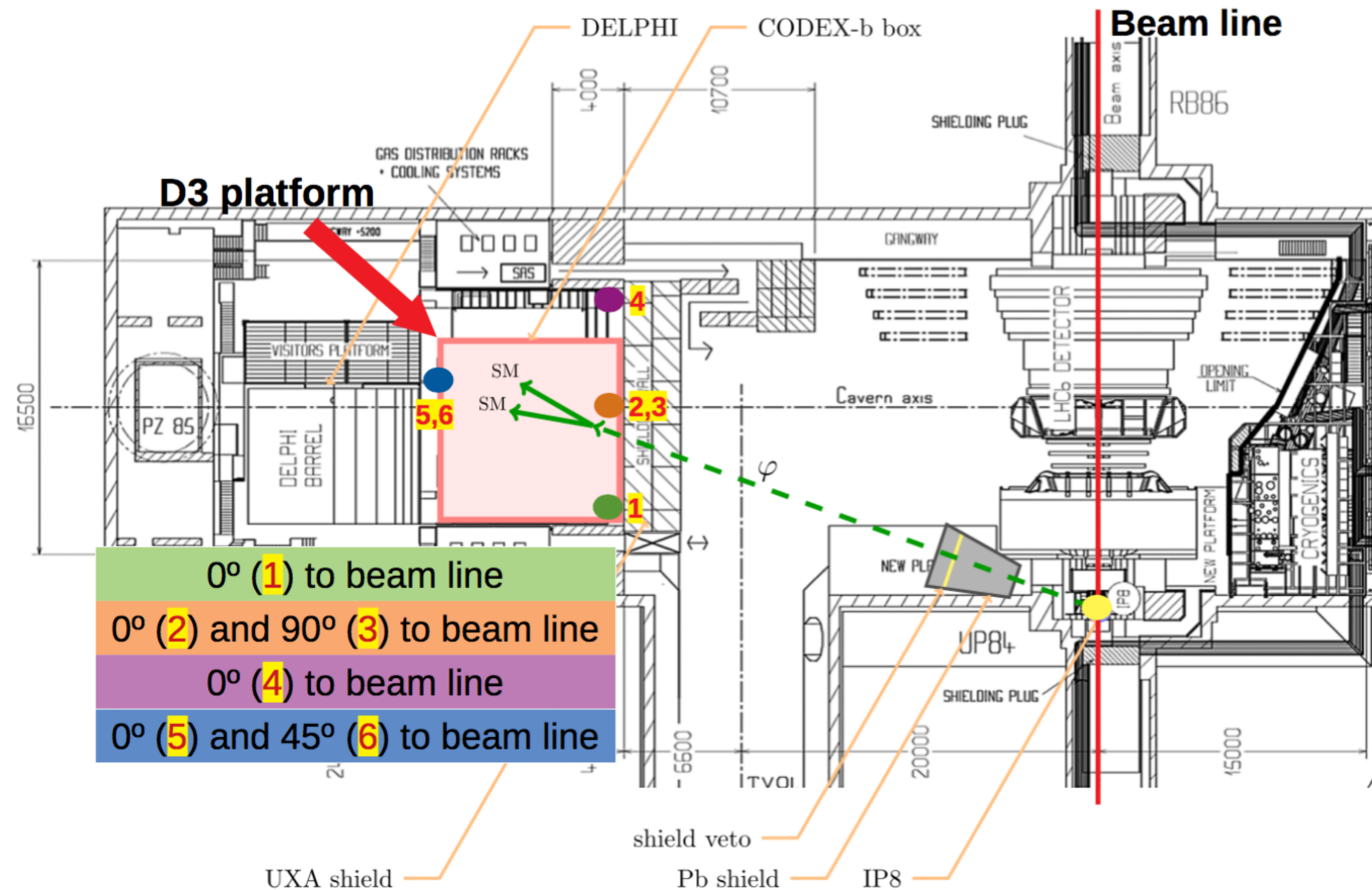


# Background estimates from simulation

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

Zero background environment achievable with active veto!

# Data driven background studies

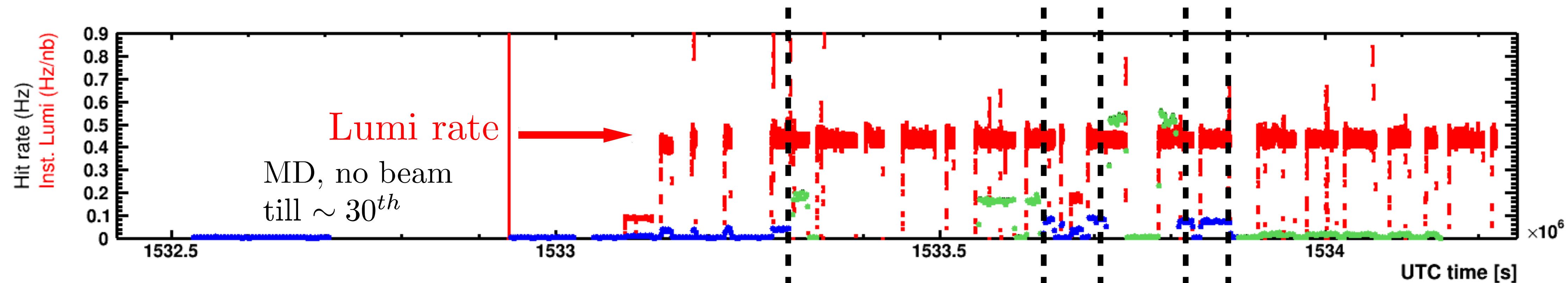


Use setup with two scintillators to measure backgrounds in 2018

# Data driven backgrounds, results

25<sup>th</sup> July

10<sup>th</sup> Aug



detector  
positions



1

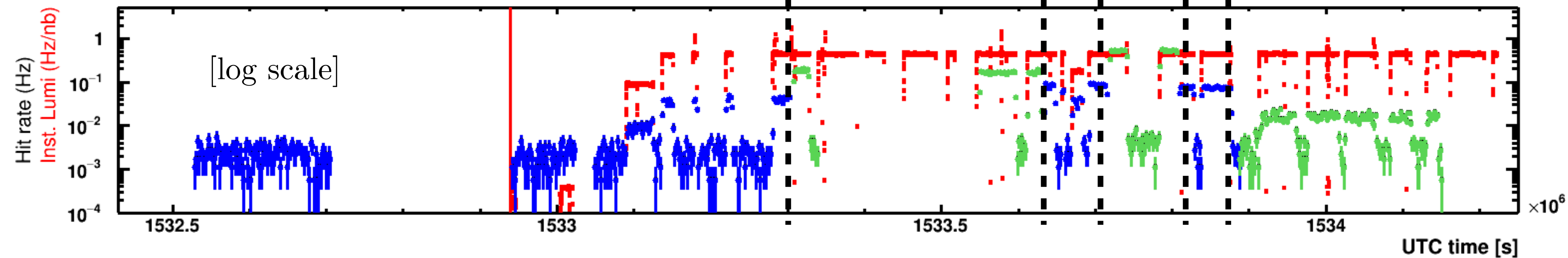
2

3

4

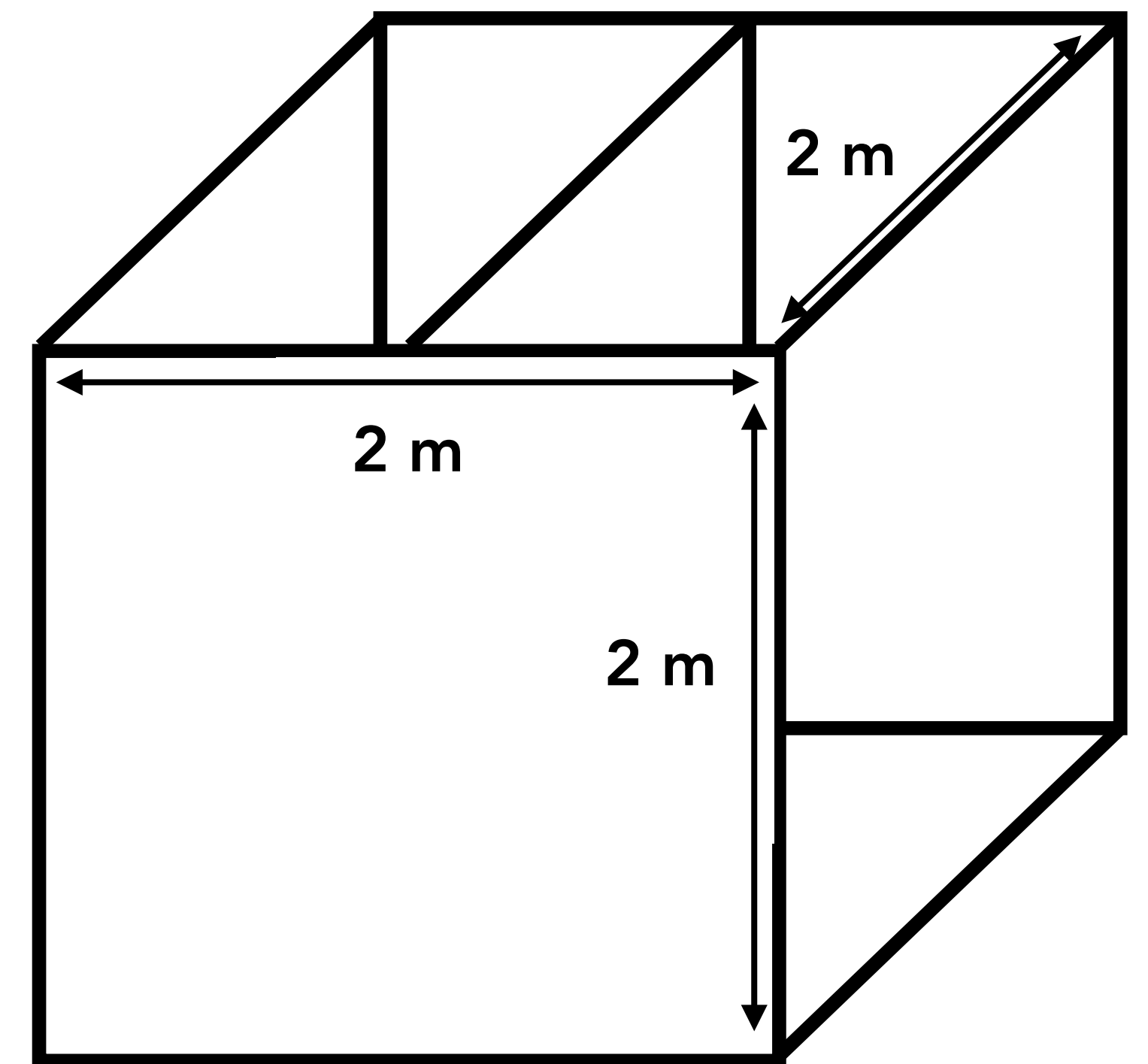
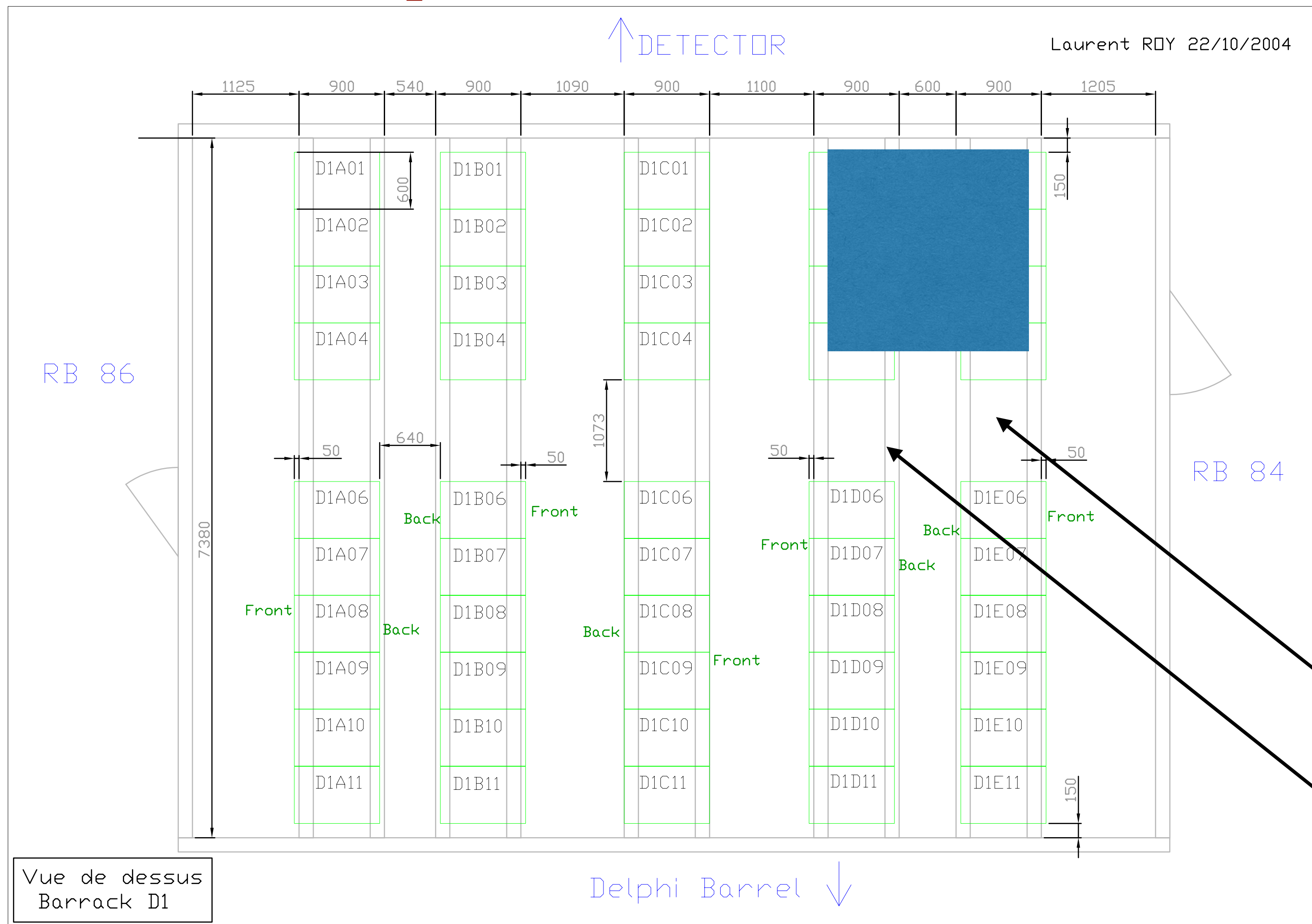
5

6



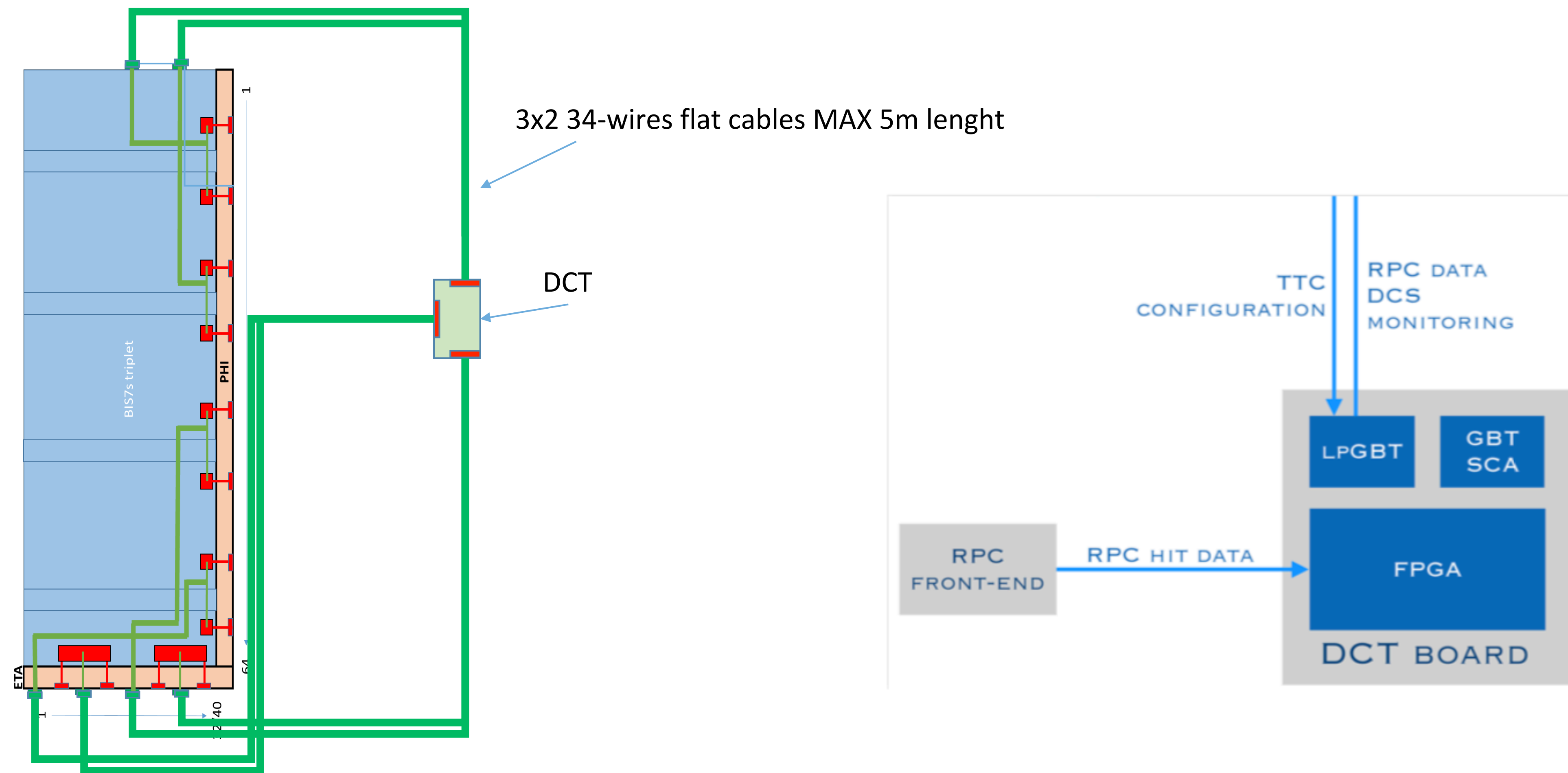
Lower than expected from simulation!

# CODEx- $\beta$ demonstrator



To be installed in the old LHCb HLT server room, 2x2x2 metre cube  
Use RPCs designed for the ATLAS upgrade (NSW) 14 triplets in total

# Integration with LHCb readout



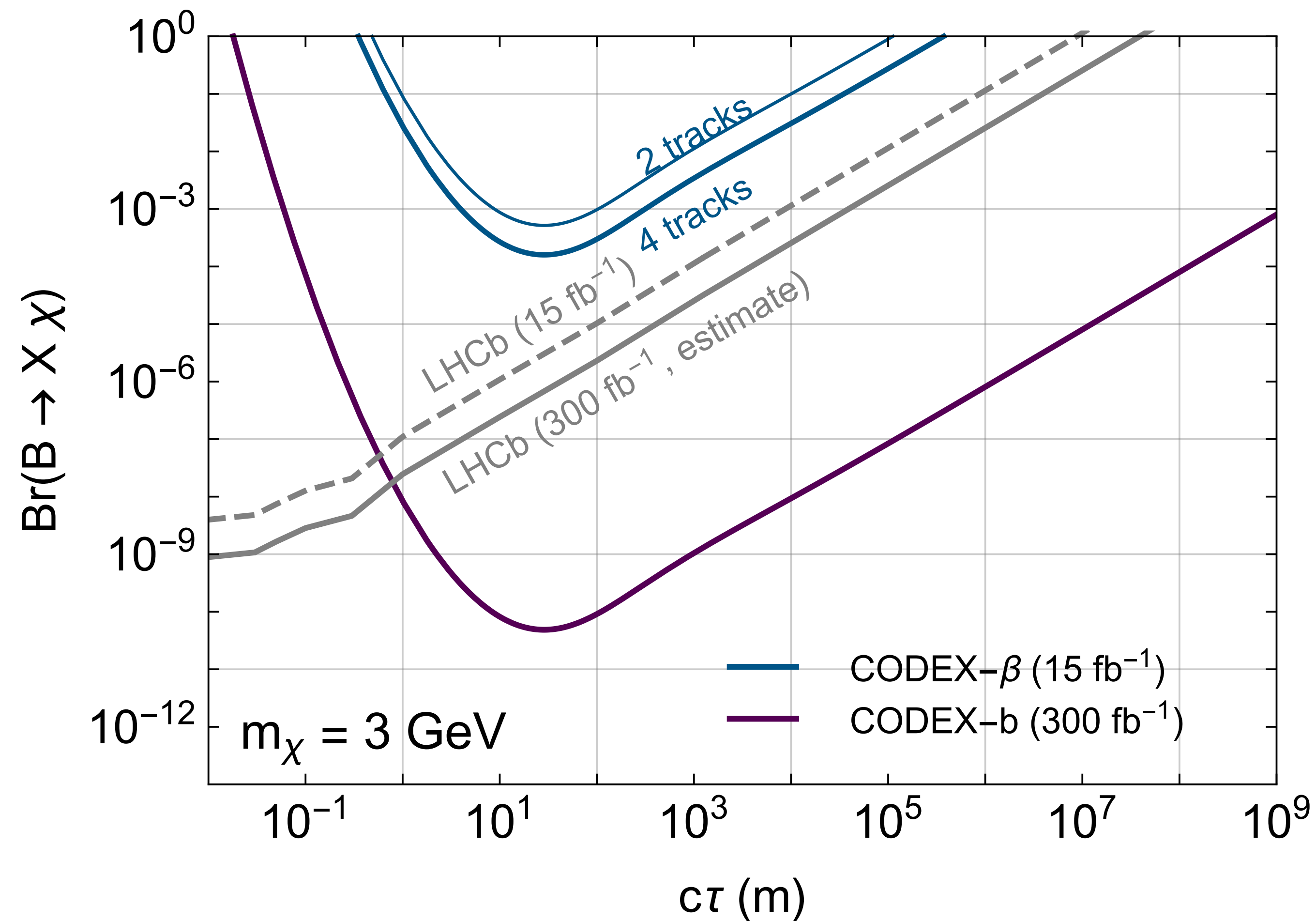
Old server room naturally contains required space for readout+power  
One single backend FPGA card is sufficient to read out the whole detector

# Demonstrator backgrounds

Tracks	$(20 + 5)\lambda$ Pb shield $1 - \varepsilon_{\text{veto}} = 10^{-4}$	Run 3 (CODEX- $\beta$ )	Run 3 (CODEX- $\beta$ ) $K_L^0$ contribution
1	$53.90 \pm 5.51$	$(3.87 \pm 0.11) \times 10^8$	$(2.94 \pm 0.07) \times 10^8$
2	$0.21 \pm 0.02$	$(4.09 \pm 0.13) \times 10^7$	$(3.74 \pm 0.13) \times 10^7$
3	$(1.36 \pm 0.34) \times 10^{-2}$	$(5.96 \pm 1.01) \times 10^5$	$(2.92 \pm 0.45) \times 10^5$
4	$(1.51 \pm 0.30) \times 10^{-3}$	$(6.78 \pm 1.22) \times 10^4$	$(5.12 \pm 1.19) \times 10^4$
5	$(3.80 \pm 0.87) \times 10^{-4}$	$(1.69 \pm 0.50) \times 10^4$	$(1.42 \pm 0.50) \times 10^4$
6	$(1.09 \pm 0.27) \times 10^{-4}$	$(3.23 \pm 0.79) \times 10^3$	$(2.21 \pm 0.79) \times 10^3$
7	$(1.84 \pm 1.41) \times 10^{-4}$	$(4.23 \pm 2.30) \times 10^3$	$(1.75 \pm 0.77) \times 10^3$
8	$(2.98 \pm 1.31) \times 10^{-5}$	$(1.04 \pm 0.63) \times 10^3$	$(8.45 \pm 6.11) \times 10^2$
9	$(1.07 \pm 0.33) \times 10^{-5}$	$(2.41 \pm 0.43) \times 10^2$	$(1.37 \pm 0.35) \times 10^2$

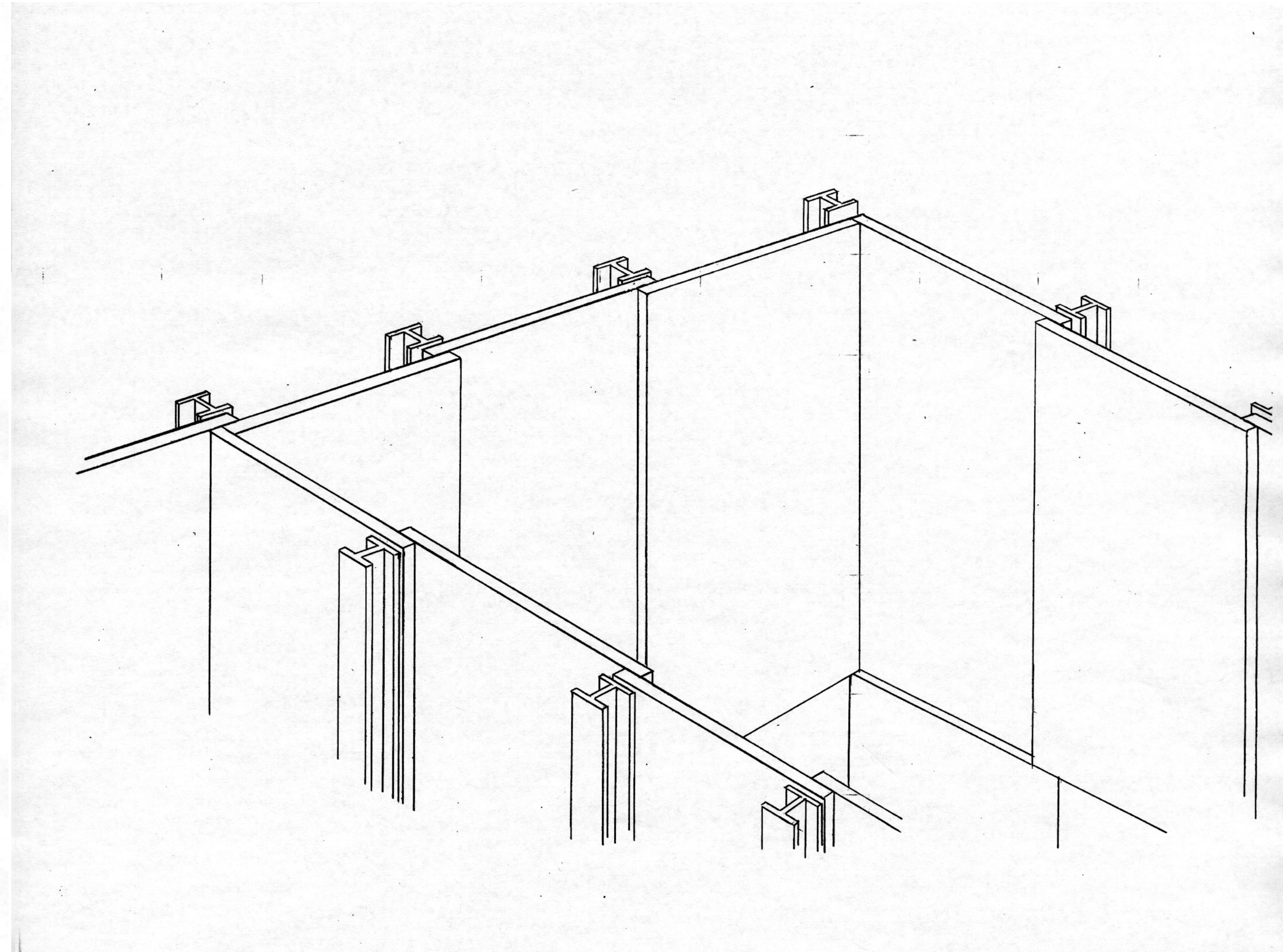
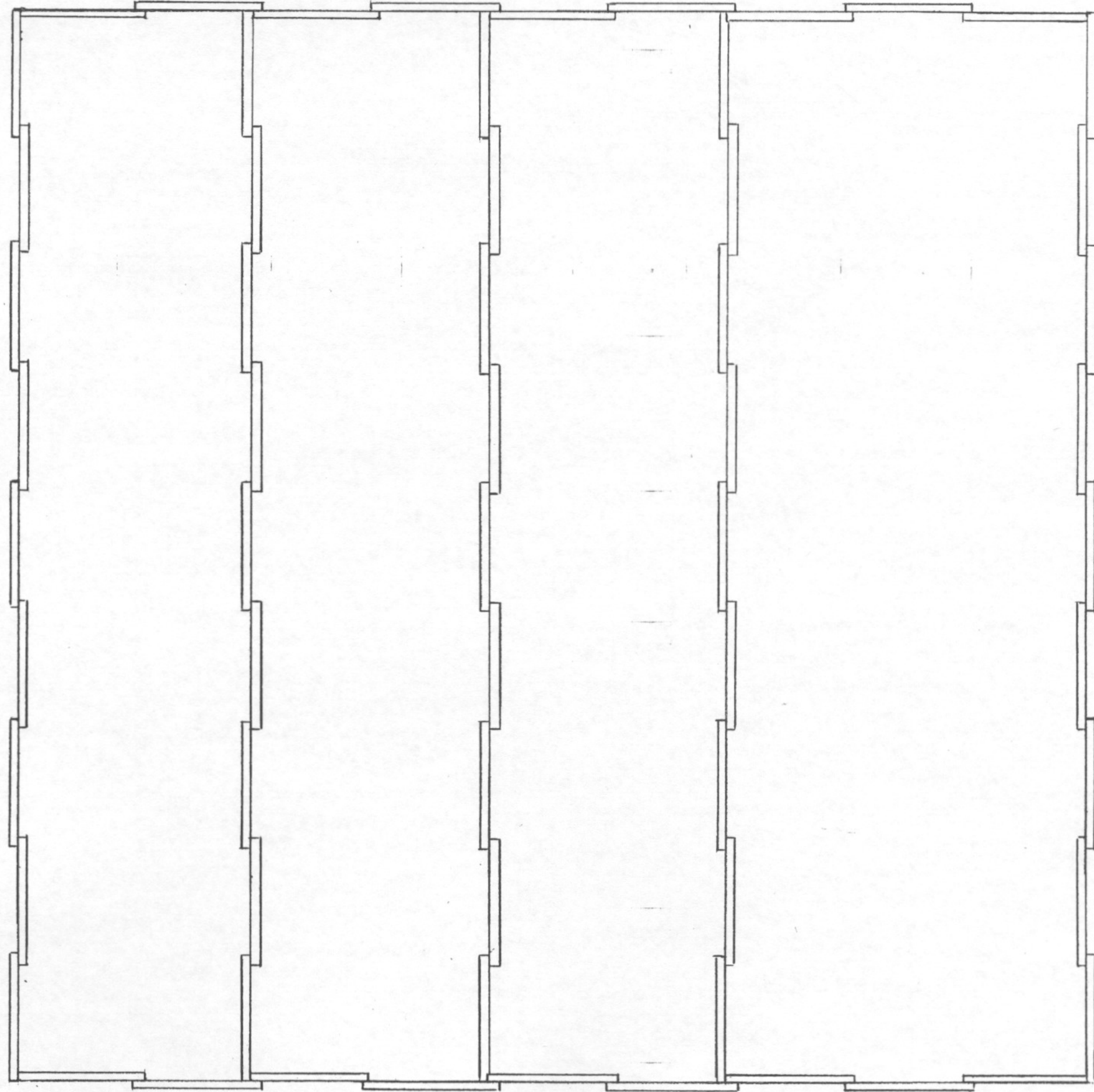
No active shield so substantial backgrounds dominated by  $K_L^0$  decays  
Use this data to precisely optimise the active shield design!

# Obligatory reach plot



Expect the demonstrator to nevertheless have some limited sensitivity

# Progress on detector mechanics



For the full-size CODEX-b mechanics are the biggest challenge!  
Detailed design study ongoing to see how to fit it into the available space.

# Conclusion and plans

**CODEX-b is an affordable detector which complements LHCb's reach for LLPs in the transverse direction, as well as that of other proposed LLP detectors.**

**We have not been immune to COVID, but work is progressing towards the construction and installation of the CODEX- $\beta$  demonstrator such that it can take data during Run 3.**

**We have made significant progress on the mechanics since the EOI, and are discussing with LHCb about the possible ways CODEX-b could realistically fit into the available space in UX85A.**

**The data collected from the demonstrator will be of crucial importance to optimize the active shield and ultimately detector design. Stay tuned!**

BACKUP